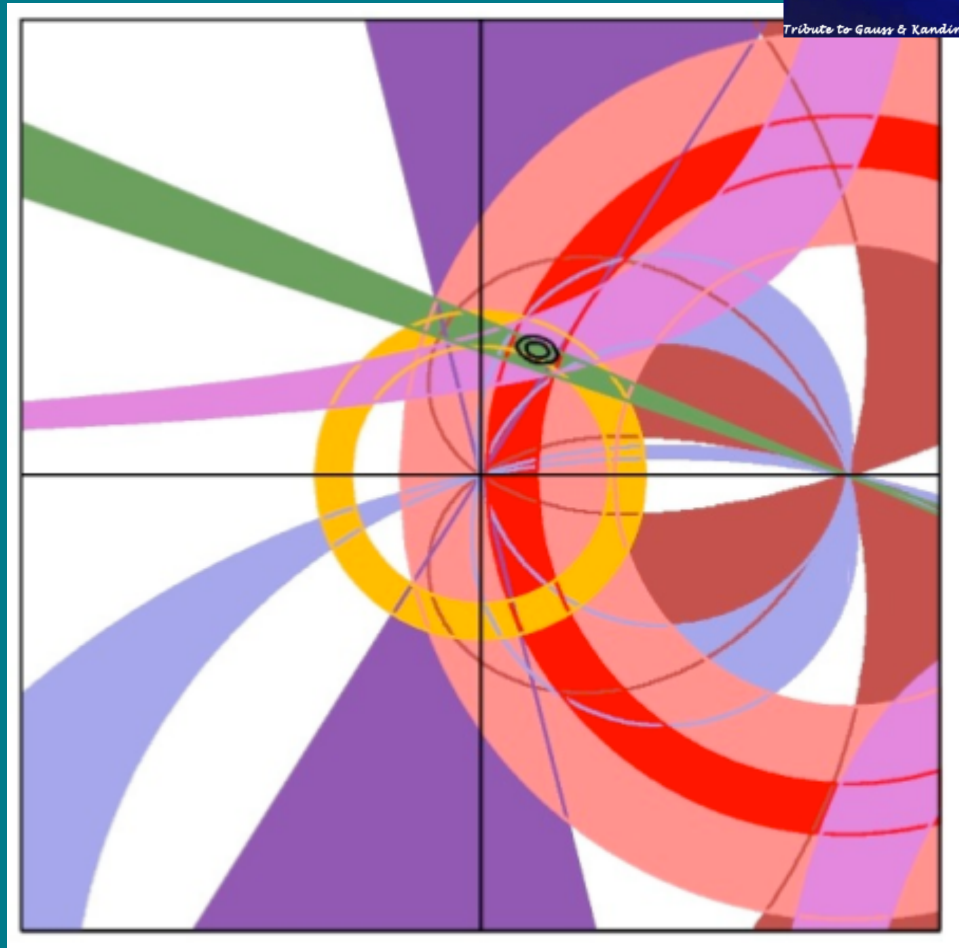
From the Standard Model to Dark Matter and beyond: Symmetries, Masses and Misteries

Guido Martinelli
SISSA & INFN



Pavia 27/01/2012

Something new and special happened (?)

Closing in on God Particle

SCIENTISTS say they are on the verge of finding the most elusive particle in science...but not just yet.

Experts at the Large Hadron Collider, based in Geneva, announced yesterday that they expect to prove the existence of the Higgs boson – dubbed the God Particle – early next year.

According to scientific theory the particle is a basic building block of the universe but has never been observed.

It would explain how everything in the universe gets its mass.

Scientists have been using the Large Hadron Collider, a 16-mile circular tunnel 300ft below Geneva, to fire two beams of protons in opposite directions at up to 99.99 per cent of the speed of light. They then study what happens when they collide.

Physicist Professor Tony Doyle, of the University of Glasgow, said: "It's fair to say that strong hints are what we're getting right now ...this is our Apollo 10 moment."

Professor Themis Bowcock, head of particle physics at the University of Liverpool, said if confirmed, ...

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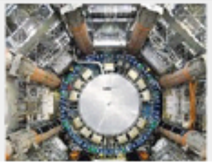
News

Missing particle 'confirmed soon'

14 Dec 2011



Confirmation that scientists have found the Higgs boson, the greatest trop... in particle physics, coul... in the New Ye... claimed.

We're so close to finding the God Particle, say scientists

SCOTTISH ACADEMIC INSISTS THE LARGE HADRON COLLIDER WILL DISCOVER IT

BY JOHN VON RADOWITZ

Confirmation that scientists have found the Higgs boson, the greatest trophy in particle physics, could come "very soon" in the new year, it was claimed yesterday.

Latest results from the Large Hadron Collider show "strong hints" of the sub-atomic particle which is believed to explain the mystery of mass.

Dubbed the "God Particle", the Higgs boson is the last missing piece in the leading theory – known as the Standard Model – that describes how particles and forces ...

The £4billion particle accelerator, which weighs more than 38,000 tonnes and straddles the Swiss-French border, fills a 16-mile circular tunnel sunk 100 yards into the ground.

Four huge detectors have been constructed along the tunnel to take "snapshots" of what happens during the proton collisions.

... mounted yes... ...ntists prepared ... data from two ...las and CMS, ...nducting inde... ...rches for the

Their findings add up to a "tantalising" indication that the Higgs is out there – while still falling short of the statistical proof necessary to confirm its existence.

Professor Tony Doyle, one of the LHC physicists from Glasgow University, who is part of the Atlas team, said: "It's fair to say that strong hints are what we're getting right now. My perspective is that this is our Apollo 10 moment.

"We've shown we've done everything needed to land on the Moon, or in our case, find the Higgs boson.

"Confirmation should be very soon in the new year. I absolutely think we'll find the Higgs boson next year."

SPEED

Press in December

TEAM DISCOVER ELUSIVE HIGGS BOSON

THE MAN WHO FOUND 'GOD'

Scientists set to confirm Scottish prof's theory on universe's building blocks

By Kevan Christie
k.christie@dailyrecord.co.uk

THE genius behind the "God particle" theory had his work vindicated yesterday after scientists claimed to be on the verge of a huge discovery.

Retired Edinburgh University professor Peter Higgs proposed in 1964 that one particle – later named the Higgs boson – was the basic building block of the universe.

It's thought the boson is what gives every particle mass – and stops everything breaking apart at the speed of light.

Finding the Higgs boson would be one of the biggest scientific advances of the last 60 years and is crucial in helping us make sense of the universe.

REFUSING

The LHC is a massive atom-smashing machine that has been used by scientists to recreate the Big Bang theory of how the universe evolved.

The teams – Atlas and CMS – said their data showed "spikes" at roughly the same mass – 124 to 125 gigaelectronvolts. Fabiola Gianotti, the spokeswoman for Atlas's 3000 physicists, said they were close to having enough data to solve the puzzle.

She said: "We cannot conclude anything at this stage.

"Given the outstanding performance of the LHC this year, we will not need to wait long for enough data and can look forward to resolving this puzzle in 2012."

Glasgow University professor Tony Doyle is part of the Atlas team.

He said: "It's fair to say that strong hints are what we're getting right now ... in the new year. I absolutely think we'll find the Higgs boson next year."

The God particle was named by Nobel Prize-winning physicist Leon Lederman in his book The God Particle: If The Universe Is The Answer, What Is The Question?

He originally wanted to call it the Goddamn particle because no one could find it but his editor convinced him The God Particle would sell more copies.

EMERITUS

Higgs was born in Wallsend, Newcastle-upon-Tyne, in 1929.

He was made personal chair of theoretical physics at Edinburgh in 1980 and became a fellow of the Royal Society in 1983.

He was awarded the Rutherford Medal and Prize in 1984 and became a fellow of the Institute of Physics in 1991.

Higgs retired in 1996 and was made emeritus professor at Edinburgh

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Scientists see signs of 'God particle'

SCIENTISTS say they have found signs of the Higgs boson, an elementary sub-atomic particle believed to have played a vital role in the creation of the universe after the Big Bang.

The leaders of two experiments, Atlas and CMS, revealed their findings to a packed seminar at the CERN physics research centre near Geneva, where they have tr... of the elu... smashing p... at near lig... Large Hadr...

The experiments generated such excitement by independently reaching very similar conclusions. But the scientists were quick to warn their results have not yet reached the level of certainty needed to claim a discovery.

Professor Tony Doyle, one of the physicists from the University of Glasgow, who is part of the Atlas ...

... thing needed to land on the Moon, or in our case, find the Higgs boson.

"Confirmation should be very soon, in the New Year. I absolutely think we'll find the Higgs boson next year."

Under what is known as the Standard Model of Physics, the boson is posited to have been the agent that gave mass and energy to matter after the creation of ...

... icist who first proposed the existence of the particle in 1964 as the missing link of a grand theory of matter and energy, was watching the announcement on a webcast with colleagues at Edinburgh University, where he is an emeritus professor.

"I won't be going home to open a bottle of whisky to drown my sorrows, but on the other hand I won't be ... open a bottle ... either," his ...lan Walker ... saying after ...nent.

What is all this fuzz about?
More about that later

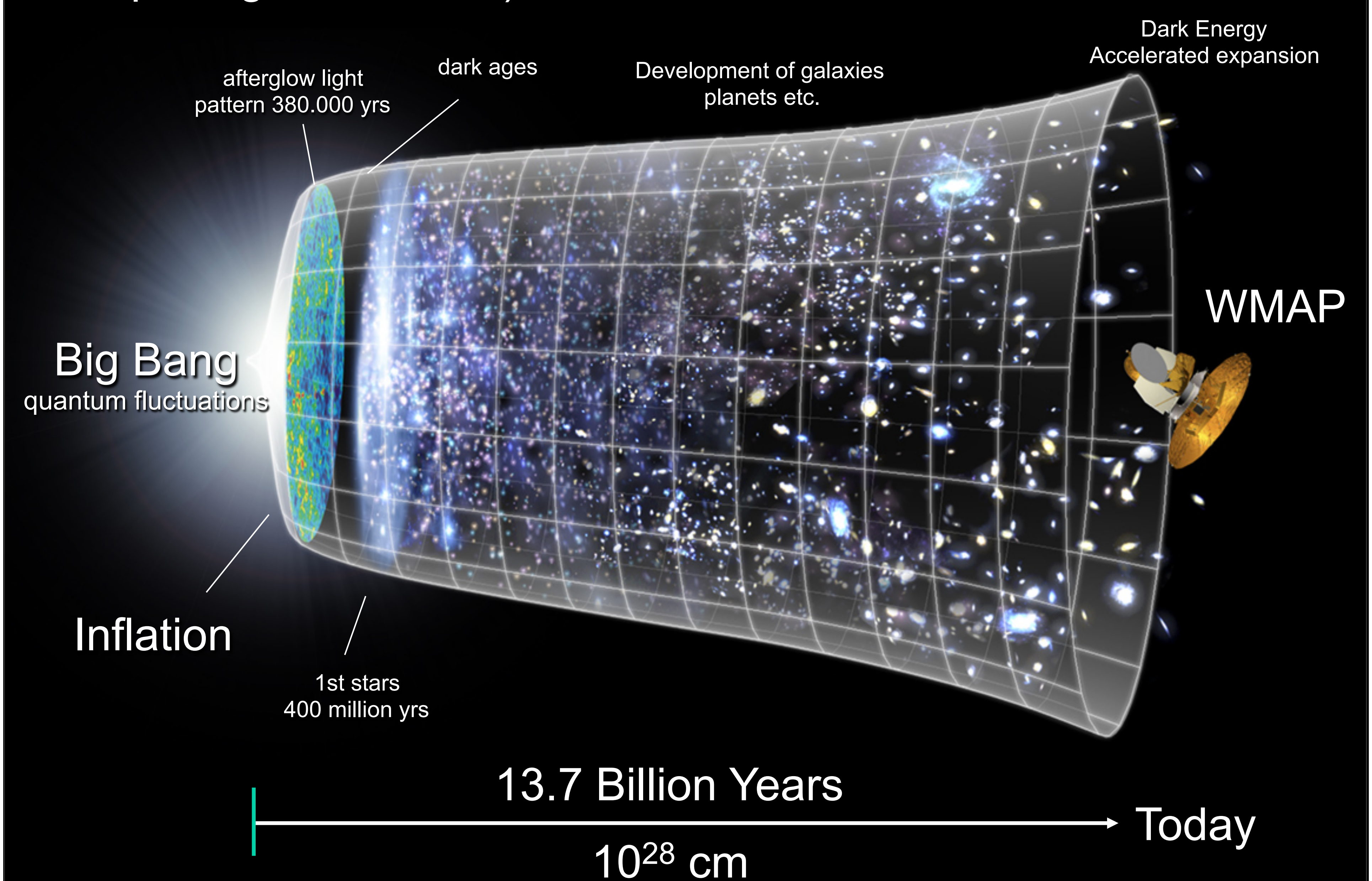
Un Modello Standard ?

No almeno due !!

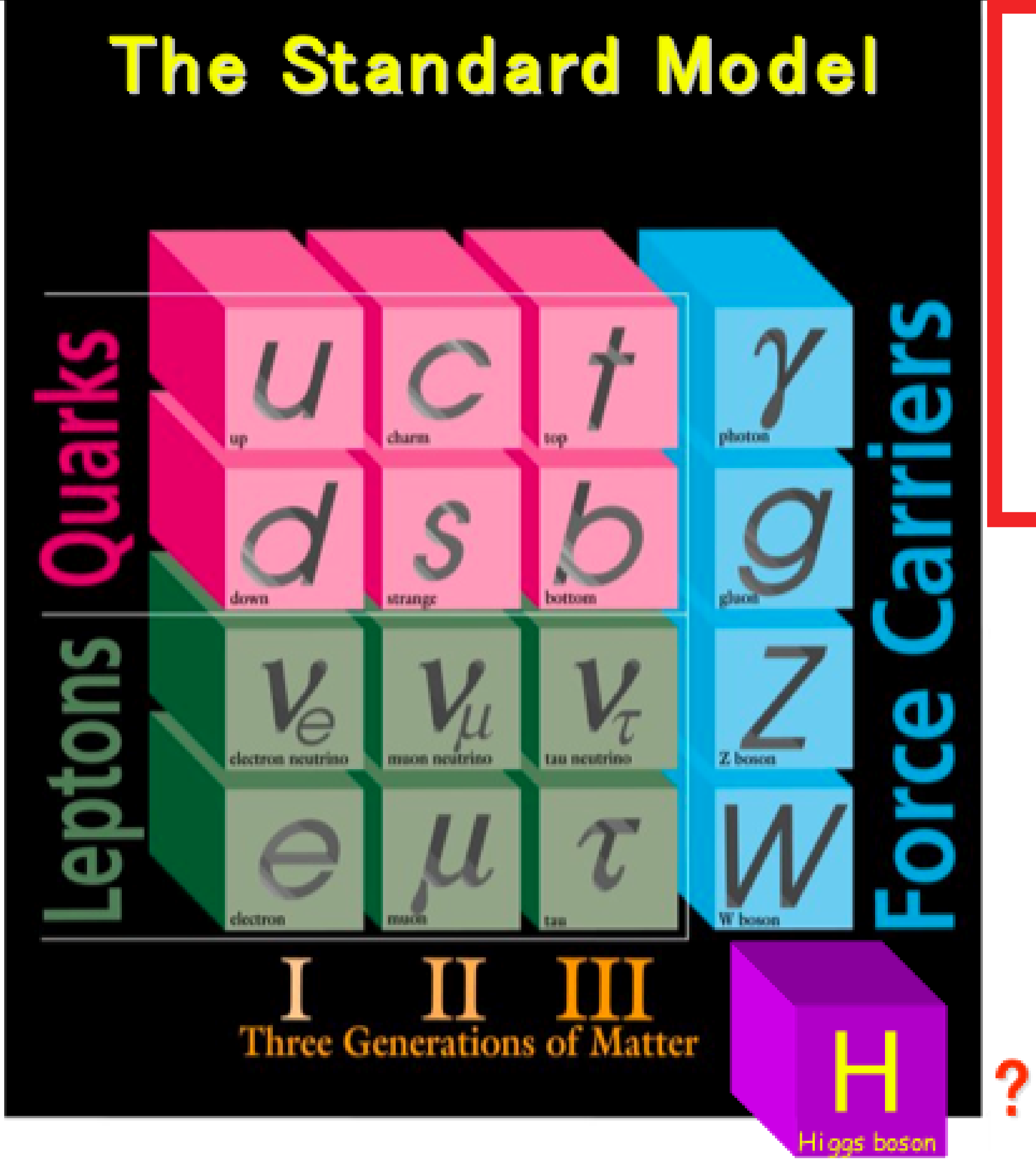
Il Modello Standard delle Particelle Elementari

Il modello Standard della Cosmologia

Principal ingredients : 1) Universe evolution



Principal ingredients: 2) Particles and Interactions (Force carriers and antiparticles)



$$q_L \equiv \begin{pmatrix} u_L \\ d_L \end{pmatrix} \qquad B=1/3 \qquad L=0$$

$$u^c_L \qquad B=-1/3 \qquad L=0$$

$$d^c_L \qquad B=-1/3 \qquad L=0$$

$$l_L \equiv \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \qquad B=0 \qquad L=1$$

$$e^c_L \qquad B=0 \qquad L=-1$$

$$\nu_R$$

16 degrees of freedom

×

3 generations

WHY 3 ???

Le ragioni per andare oltre i Modelli Standard:

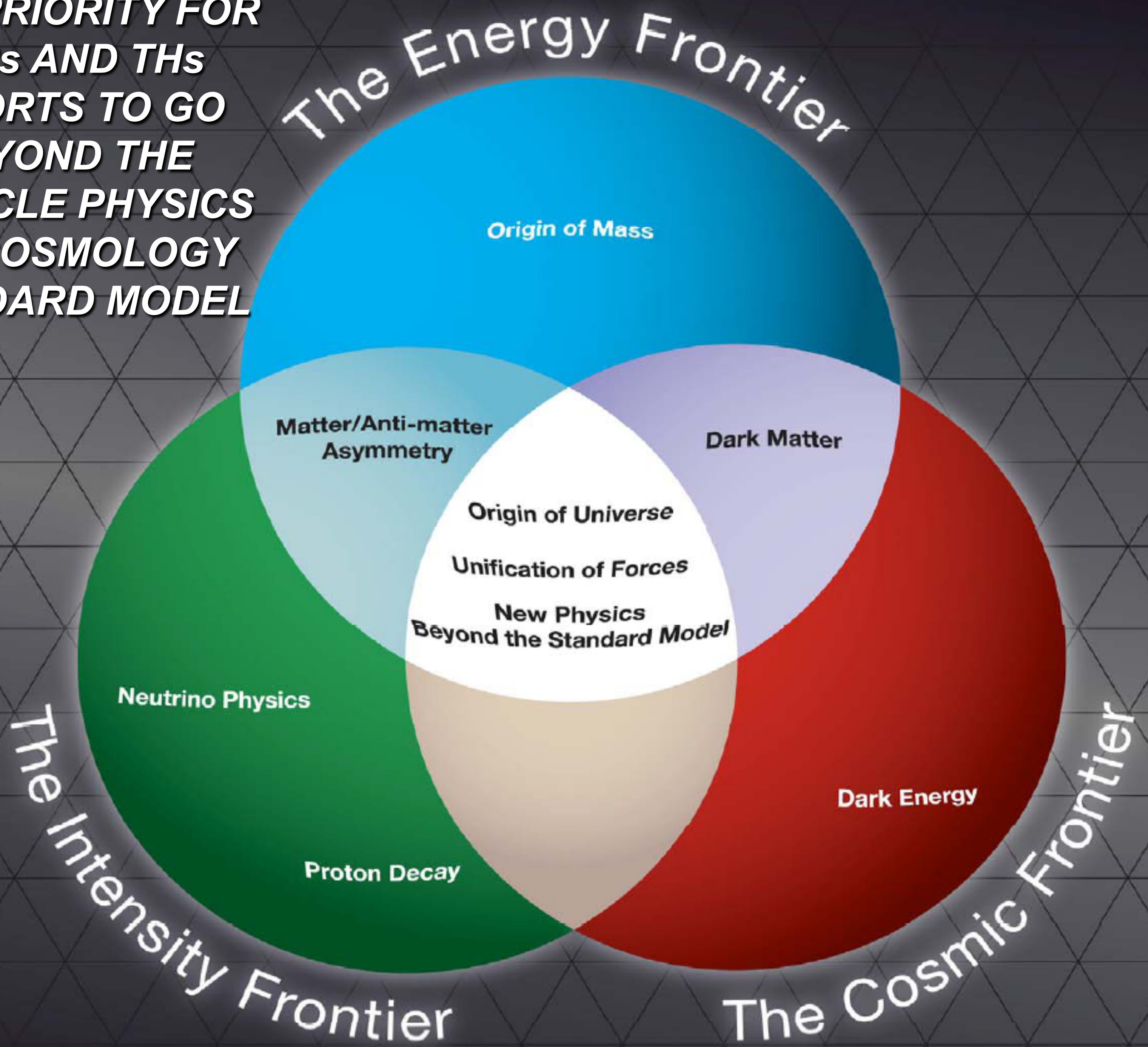
EVIDENZA ``SPERIMENTALE"

1. Le masse dei Neutrini
2. La Materia Oscura (DM), Energia Oscura (DE), Inflazione
3. L'Asimmetria Materia-Antimateria

EVIDENZA ``TEORICA"

1. Instabilita` dello SM (delle particelle)
2. Incapacita` di rispondere a questioni ``fondamentali" come gerarchia e unificazione
3. La fisica del sapore (sia quark che leptoni)

HIGH PRIORITY FOR EXPs AND THs EFFORTS TO GO BEYOND THE PARTICLE PHYSICS and COSMOLOGY STANDARD MODEL



Nel seguito la discussione sara` Incentrata su:

La Rottura della Simmetria Elettrodebole
(The Energy Frontier)

La fisica del Sapore e la Violazione di CP
(The Intensity Frontier)

La natura della Materia Oscura
(The Cosmic Frontier)

L'evidenza sperimentale suggerisce l'esistenza di nuovi gradi di liberta` (particelle) alla scala del TeV

A LHC osserveremo qualcosa oltre l'Higgs? Sett'10

Quello che troveremo potra` indicarci soluzioni di problemi fondamentali come la materia oscura, le generazioni dei fermioni e le loro proprieta` , la violazione di CP e l'asimmetria materia-antimateria?

O saranno gli esperimenti di fisica del sapore e di astrofisica a chiarire la natura delle particelle scoperte a LHC?

LO STANDARD ``STANDARD MODEL"

$$\mathcal{L}_{SM} = -F^A_{\mu\nu}F^{\mu\nu}_A + Y_{ij}\,\psi_i\psi_j H + h.c. + N_i M_{ij} N_j + |D_\mu H|^2 - V(H)$$

Settore di Gauge SU(3)×SU(2)×U(1)

Sapore

Masse dei Neutrini (Majorana)

Settore della Rottura della Simmetria Elettrodebole

1. Quasi un secolo per svilupparlo
2. Verificato a livelli di precisione senza precedenti
3. In accordo (anche troppo) con tutti i dati disponibili

La Particella di HIGGS, definita la ``ruota di scorta del Modello Standard" da Guido Altarelli e` l'unico elemento mancante ovverosia
Il meccanismo della rottura della simmetria elettrodebole (EW) e` il portale per il settori ancora ignoti della nuova fisica

Qualche relazione utile

Il valore di aspettazione sul vuoto (vev) del campo di Higgs e` misurato dalla costante di Fermi (Barbieri 4π v ≈ 3 TeV)

$$v = \frac{1}{(\sqrt{2}G_F)^{1/2}}$$

$$m_b = \frac{Y_{bb}\, v}{\sqrt{2}} \rightarrow g_{Hbb} = \frac{m_b}{v}$$

L' accoppiamento dell' Higgs alle particelle e` determinato dalla loro massa

$$g_{HVV} = -\frac{2\, M_V^2}{v} \qquad g_{HHVV} = -\frac{2\, M_V^2}{v^2}$$

Dato che v e` noto, l'unico parametro libero e` la massa dell'Higgs M_H oppure l'auto-accoppiamento λ
LA MASSA DELL'HIGGS NON DERIVA DALLA ROTTURA DI ALCUNA SIMMETRIA

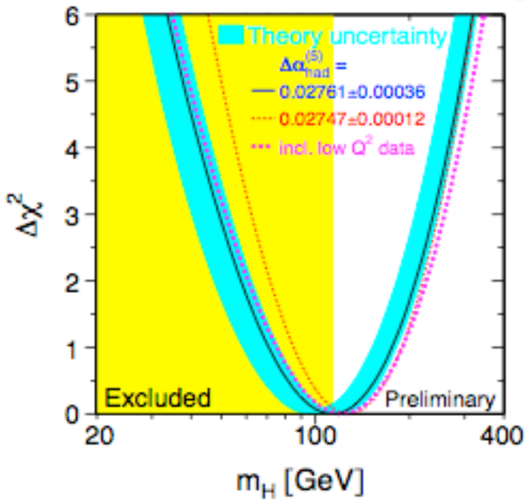
2. Constraints on M_H

Indirect Higgs searches:

H contributes to RC to W/Z masses:

Fit the EW precision data → Hollik:

one obtains $M_H = 87^{+35}_{-26}$ GeV, or

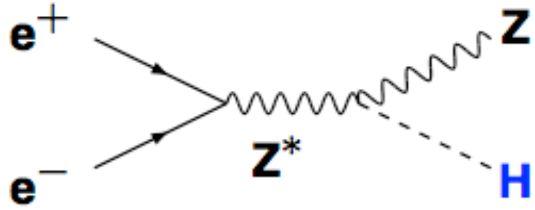


$M_H \lesssim 157$ GeV at 95% CL

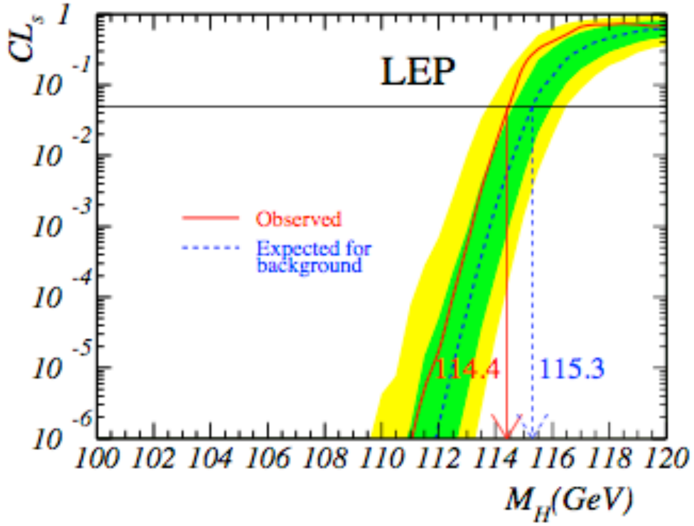
Beware: which m_t value? → Hoang

Direct searches at colliders:

H looked for in $e^+e^- \to ZH$



$M_H > 114.4$ GeV @95%CL

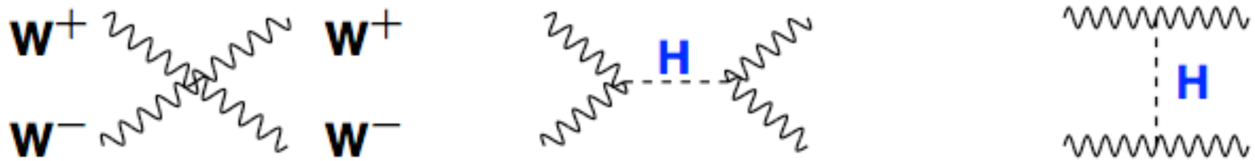


Tevatron $M_H \neq 158-175$ GeV

(to be discussed in details later on)

2. Constraints on M_H perturbative unitarity

Scattering of massive gauge bosons $V_L V_L \to V_L V_L$ at high-energy



Because w interactions increase with energy (q^μ terms in V propagator),

$s \gg M_W^2 \Rightarrow \sigma(w^+w^- \to w^+w^-) \propto s$: $\Rightarrow$ unitarity violation possible!

Decomposition into partial waves and choose J=0 for $s \gg M_W^2$:

$$a_0 = -\frac{M_H^2}{8\pi v^2}\left[1 + \frac{M_H^2}{s-M_H^2} + \frac{M_H^2}{s}\log\left(1+\frac{s}{M_H^2}\right)\right]$$

For unitarity to be fullfiled, we need the condition $|\mathrm{Re}(a_0)| < 1/2$.

- At high energies, $s \gg M_H^2, M_W^2$, we have: $a_0 \stackrel{s \gg M_H^2}{\longrightarrow} -\frac{M_H^2}{8\pi v^2}$

$$\text{unitarity} \Rightarrow M_H \lesssim 870\ \text{GeV}\ \ (M_H \lesssim 710\ \text{GeV})$$

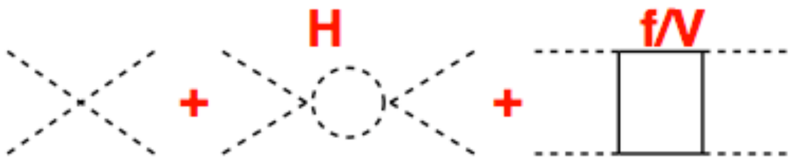
- For a very heavy or no Higgs boson, we have: $a_0 \stackrel{s \ll M_H^2}{\longrightarrow} -\frac{s}{32\pi v^2}$

$$\text{unitarity} \Rightarrow \sqrt{s} \lesssim 1.7\ \text{TeV}\ \ (\sqrt{s} \lesssim 1.2\ \text{TeV})$$

Otherwise (strong?) New Physics should appear to restore unitarity.

2. Constraints on M_H: triviality+stability

$\lambda \propto M_H^2$ increases with energy



Heavy H: H contributions dominant

RGE: $\frac{d\lambda(Q^2)}{dQ^2} = \frac{3}{4\pi^2}\lambda^2(Q^2) \Rightarrow$

$\lambda(Q^2) = \lambda(v^2)/[1 - \frac{3}{4\pi^2}\log\frac{Q^2}{v^2}]$

- $Q^2 \ll v^2$; $\lambda \to 0_+$: triviality
- $Q^2 \gg v^2$: $\lambda \to \infty$: Landau pole

SM only valid before $\lambda \lesssim 4\pi \ll \infty$

$\Lambda_C = M_H \Rightarrow M_H \lesssim 650$ GeV

(Comparable to results on lattice!)

$\Lambda_C = M_P \Rightarrow M_H \lesssim 180$ GeV

Light H: t/W/Z contributions dominant

$\frac{\lambda(Q^2)}{\lambda(v^2)} = 1 + 3\frac{2M_W^4 + M_Z^4 - 4m_t^4}{16\pi^2 v^4}\log\frac{Q^2}{v^2}$

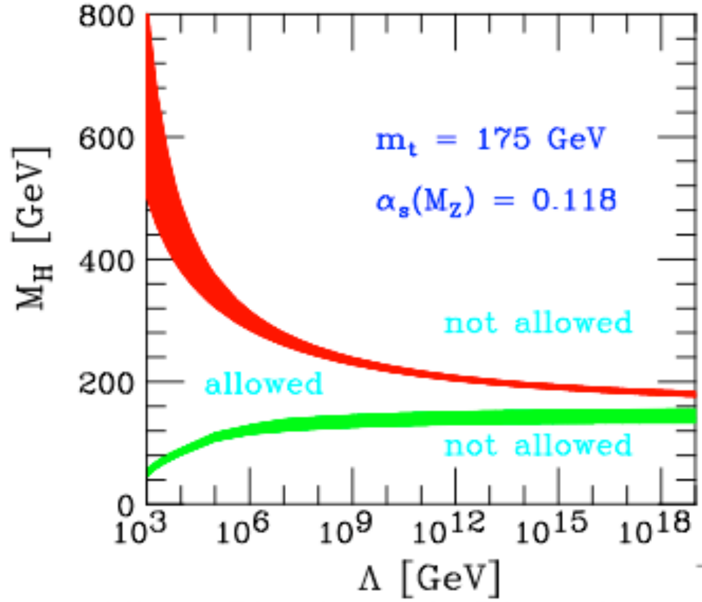
top loops might lead to $\lambda(0) < \lambda(v)$:

v not minimum / EW vacuum unstable

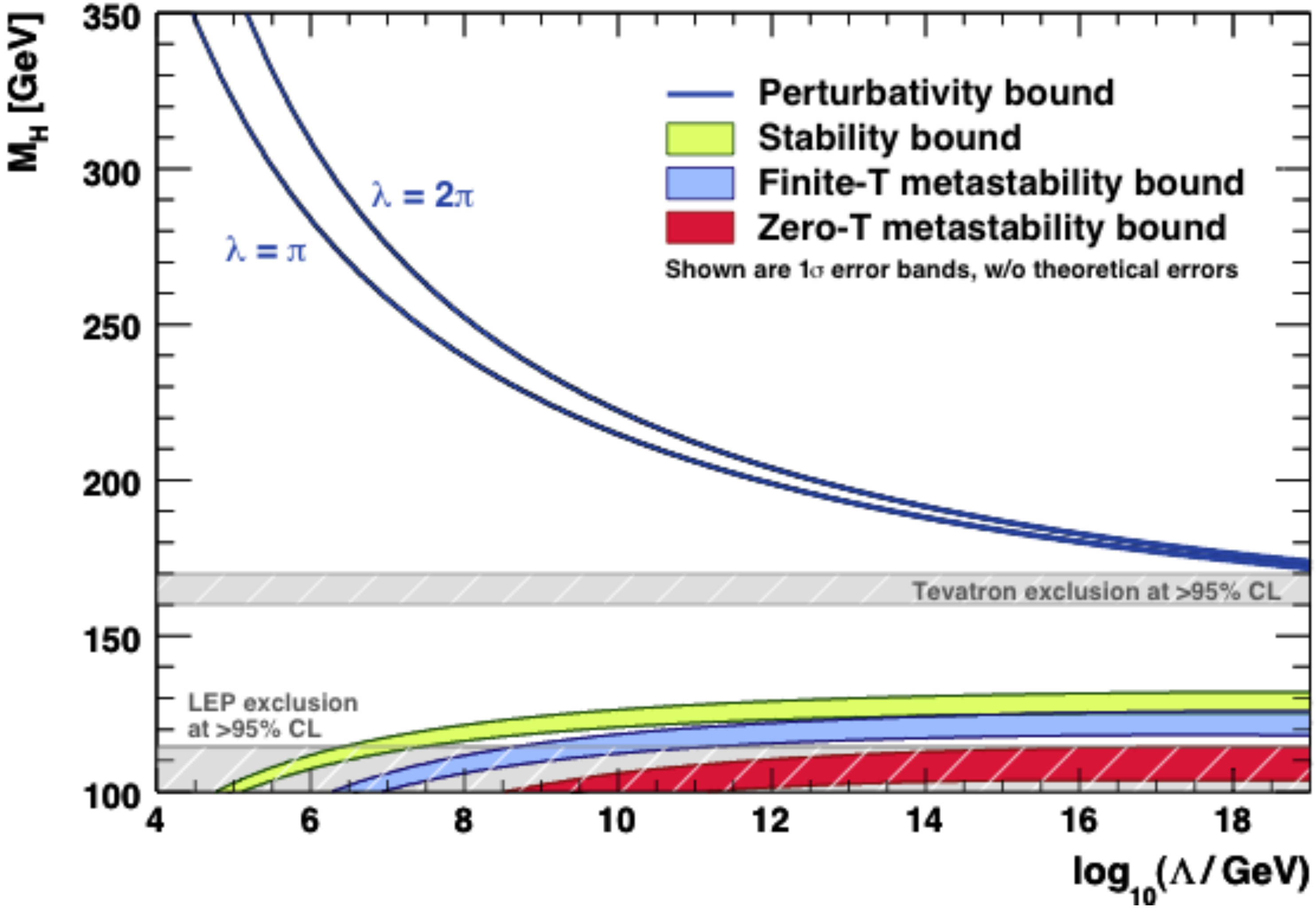
The SM is valid only if $\lambda(Q^2) > 0$

$\Lambda_C \sim 1$ TeV $\Rightarrow M_H \gtrsim 70$ GeV

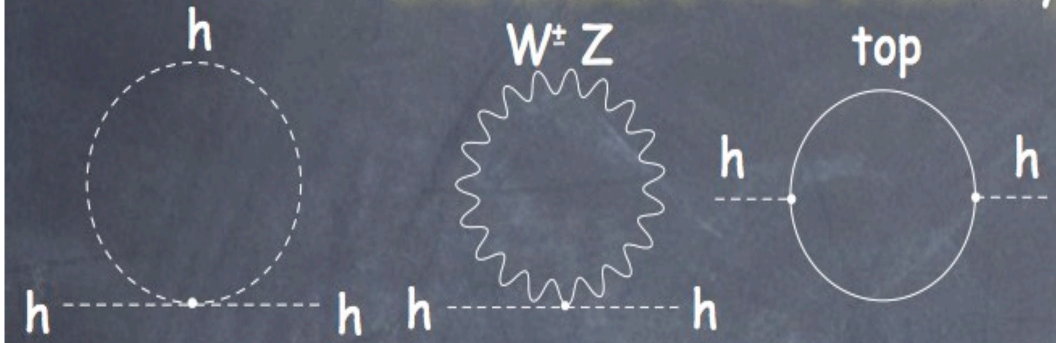
$\Lambda_C \sim M_P \Rightarrow M_H \gtrsim 130$ GeV



By J. Ellis and Collaborators (via A. Djouadi)



need new degrees of freedom to cancel Λ^2 divergences
and ensure the stability of the weak scale



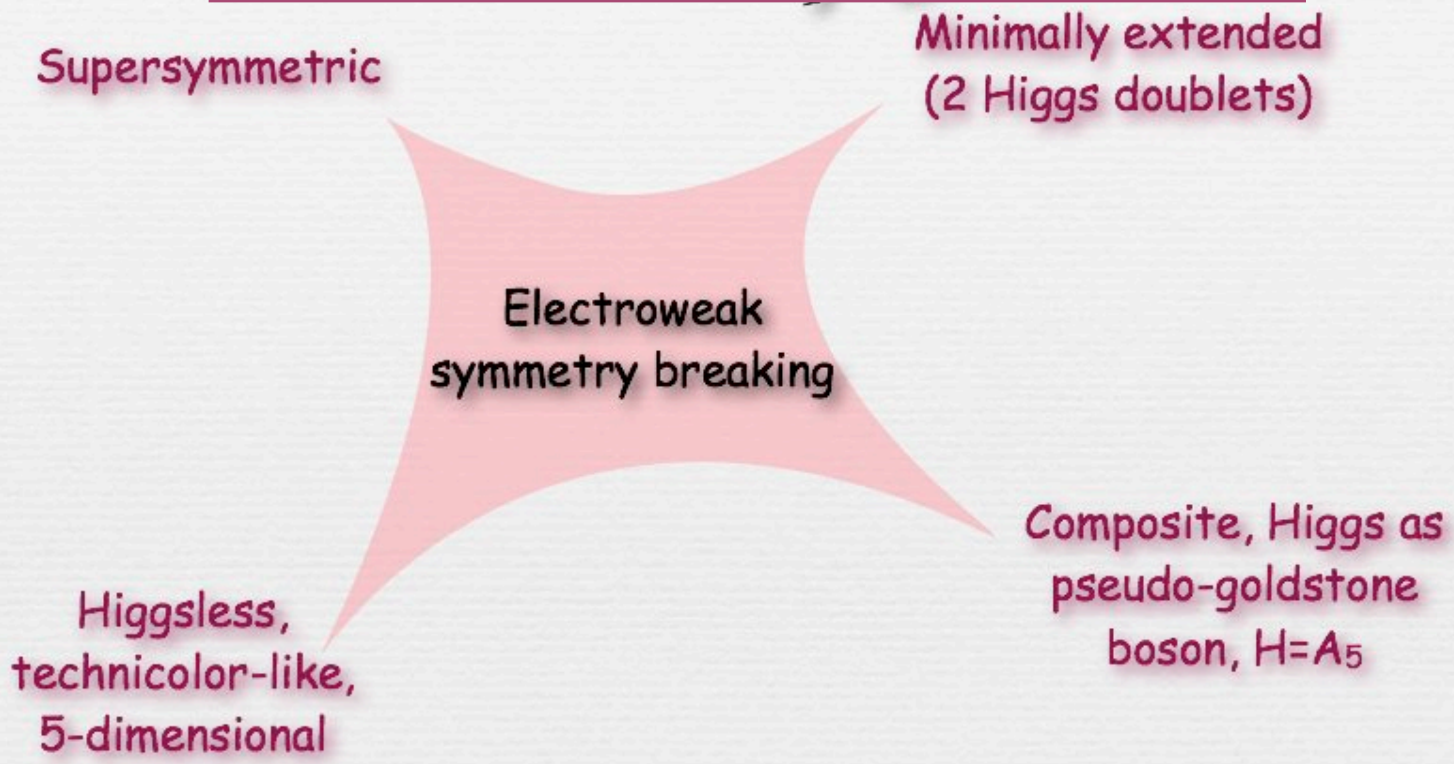
$$m_H^2 \sim m_0^2 - (115\ \text{GeV})^2 \left(\frac{\Lambda}{400\ \text{GeV}}\right)^2$$

R. Godbole + S. Pokorski's lectures

1. add a sym. such that a Higgs mass is forbidden until this sym. is broken
   - supersymmetry [Witten, '81] t'Hooft, Maiani
   - gauge-Higgs unification [Manton, '79, Hosotani '83]
   - Higgs as a pseudo Nambu-Goldstone boson [Georgi-Kaplan, '84]
2. lower the UV scale
   - large extra-dimension [Arkani-Hamed-Dimopoulos-Dvali, '98]
   - 10^{32} species [Dvali '07]
3. remove the Higgs
   - technicolor [Weinberg '79, Susskind '79]

C. Grojean 2010

Quale Fisica Nuova??

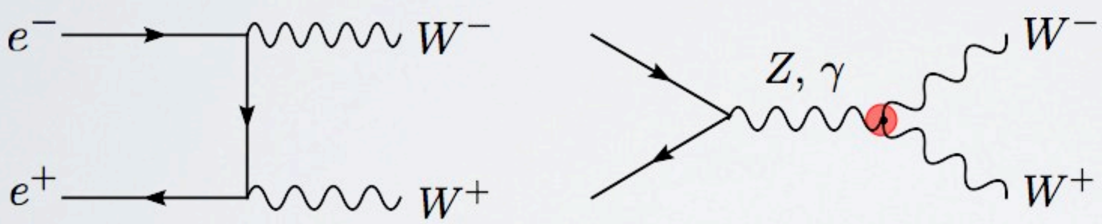


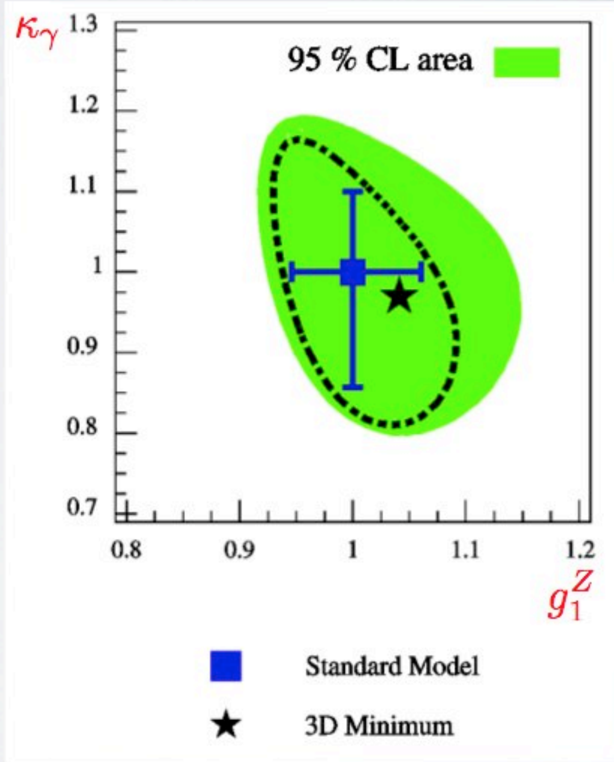
In tutti gli esempi espliciti, a meno di cancellazioni casuali, nuovi fenomeni devono avvenire a scale dell'ordine di $\Lambda \sim 3\text{-}5\ M_{higgs}$

Cosa sappiamo veramente dello SM? Che le interazioni elettrodeboli sono governate da una simmetria locale di gauge

$$\mathcal{L}_0 = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W^a_{\mu\nu}W^{a\,\mu\nu} - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + \sum_{j=1}^{3}\left(\bar{\Psi}_L^{(j)} i\not{D}\Psi_L^{(j)} + \bar{\Psi}_R^{(j)} i\not{D}\Psi_R^{(j)}\right)$$

Ex: Triple gauge couplings tested at LEP

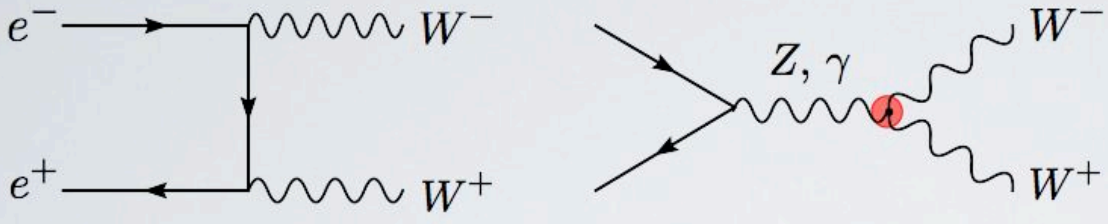


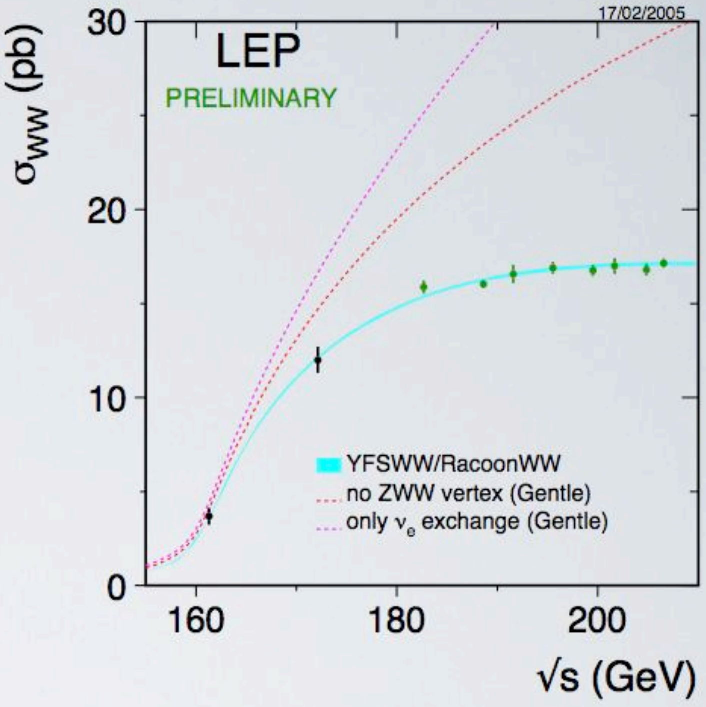


$$i\mathcal{L} = e\cot\theta_W\left[g_1^Z\, Z^\mu(W^-_{\mu\nu}W^{+\,\nu} - W^+_{\mu\nu}W^{-\,\nu}) + \kappa_Z\, W^+_\mu W^-_\nu Z^{\mu\nu}\right.$$
$$\left. + \lambda_Z\, W^{+\,\rho}_\nu W^-_{\rho\mu} Z^{\mu\nu}\right] + e\left[\kappa_\gamma\, W^+_\mu W^-_\nu \gamma^{\mu\nu} + \lambda_\gamma\, W^{+\,\rho}_\nu W^-_{\rho\mu}\gamma^{\mu\nu}\right]$$

R. Contino

Ex: Triple gauge couplings tested at LEP





$$i\mathcal{L} = e\cot\theta_W \left[g_1^Z\, Z^\mu (W^-_{\mu\nu} W^{+\,\nu} - W^+_{\mu\nu} W^{-\,\nu}) + \kappa_Z\, W^+_\mu W^-_\nu Z^{\mu\nu} + \lambda_Z\, W^{+\,\rho}_\nu W^-_{\rho\mu} Z^{\mu\nu} \right] + e\left[\kappa_\gamma\, W^+_\mu W^-_\nu \gamma^{\mu\nu} + \lambda_\gamma\, W^{+\,\rho}_\nu W^-_{\rho\mu} \gamma^{\mu\nu} \right]$$

	Real			Imaginary	
Parameter	SM value	Fit result ± (stat ⊕ syst)	95% confidence level interval	Fit result ± (stat ⊕ syst)	95% confidence level interval
κ_γ	1	1.071 ± 0.061	[0.956, 1.193]	0.070 ± 0.087	[−0.103, 0.236]
λ_γ	0	0.096 ± 0.066	[−0.028, 0.229]	0.002 ± 0.071	[−0.137, 0.142]
g_1^γ	1	1.123 ± 0.082	[0.967, 1.289]	0.030 ± 0.104	[−0.173, 0.231]
κ_Z	1	1.065 ± 0.060	[0.949, 1.182]	0.053 ± 0.058	[−0.062, 0.165]
λ_Z	0	0.019 ± 0.054	[−0.086, 0.125]	0.003 ± 0.045	[−0.086, 0.092]
g_1^Z	1	1.066 ± 0.076	[0.920, 1.214]	0.023 ± 0.068	[−0.110, 0.156]

Cosa sappiamo veramente dello SM? Che la simmetria e` rotta spontaneamente - il meccanismo di Higgs e` all'opera-

Interactions invariant under $SU(2)_L \times U(1)_Y$

$$\mathcal{L}_0 = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}W^a_{\mu\nu}W^{a\,\mu\nu} - \frac{1}{4}G_{\mu\nu}G^{\mu\nu} + \sum_{j=1}^{3}\left(\bar{\Psi}^{(j)}_L i\not{D}\Psi^{(j)}_L + \bar{\Psi}^{(j)}_R i\not{D}\Psi^{(j)}_R\right)$$

$$\mathcal{L}_{mass} = M_W^2\, W^+_\mu W^{-\,\mu} + \frac{1}{2}M_Z^2\, Z^\mu Z_\mu - \sum_{i,j}\left\{\bar{u}^{(i)}_L M^u_{ij} u^{(j)}_R + \bar{d}^{(i)}_L M^d_{ij} d^{(j)}_R + \bar{e}^{(i)}_L M^e_{ij} e^{(j)}_R + \bar{\nu}^{(i)}_L M^\nu_{ij} \nu^{(j)}_R + h.c.\right\}$$

lo spettro di massa corrisponde a una ridotta simmetria residua -> U(1)em, ma

L'esistenza del meccanismo di Higgs

NON IMPLICA L'ESISTENZA DELL'HIGGS

Possiamo rendere esplicita la rottura della simmetria introducendo dei bosoni di Nambu-Goldstone che corrispondono alle polarizzazioni longitudinali dei mesoni massicci W w Z

$$\Sigma = \exp\left(i\sigma^a \chi^a / v\right) \qquad D_\mu \Sigma = \partial_\mu \Sigma - i g_2 \frac{\sigma^a}{2} W_\mu^a \Sigma + i g_1 \Sigma \frac{\sigma_3}{2} B_\mu$$

$$\Sigma \to U_L \, \Sigma \, U_Y^\dagger \qquad U_L(x) = \exp(i\,\alpha_L^a(x)\sigma^a/2) \quad U_Y(x) = \exp(i\,\alpha_Y(x)\sigma^3/2)$$

$$\mathcal{L}_{mass} = \frac{v^2}{4} \mathrm{Tr}\left[(D_\mu\Sigma)^\dagger (D^\mu \Sigma)\right] - \frac{v}{\sqrt{2}} \sum_{i,j} (\bar{u}_L^{(i)}\ \bar{d}_L^{(i)}) \Sigma \begin{pmatrix} \lambda_{ij}^u u_R^{(j)} \\ \lambda_{ij}^d d_R^{(j)} \end{pmatrix} + h.c.$$
$$+ \frac{a_T}{8} v^2 \, \mathrm{Tr}\left[\Sigma^\dagger D_\mu \Sigma \, \sigma^3\right]^2$$

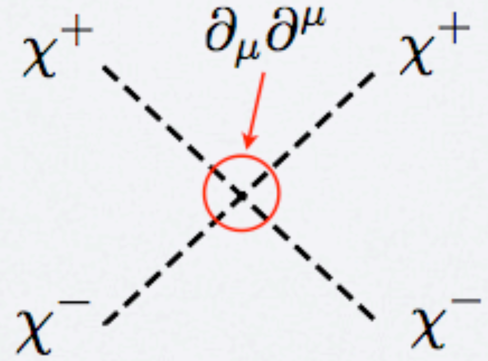
$$M_W^2 = \frac{v^2}{4} g_2^2$$

$$M_Z^2 = \frac{v^2}{4}(g_1^2 + g_2^2)(1 + a_T)$$

$$|\rho - 1| \le 2 \times 10^{-3}$$

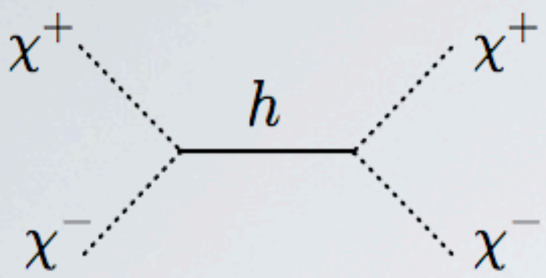
$$a_T = 0 \quad \to \quad \rho \equiv \frac{M_W^2}{M_Z^2 \cos^2\theta_W} = 1$$

La teoria con solo i bosoni di Nambu-Goldstone ha bisogno di altri gradi di liberta` che ne garantisca l'unitarieta` (perturbativa) un po` come la teoria di Fermi ha bisogno dell'introduzione dei bosoni vettoriali



$$A(\chi^+\chi^- \to \chi^+\chi^-) = \frac{1}{v^2}(s+t)$$

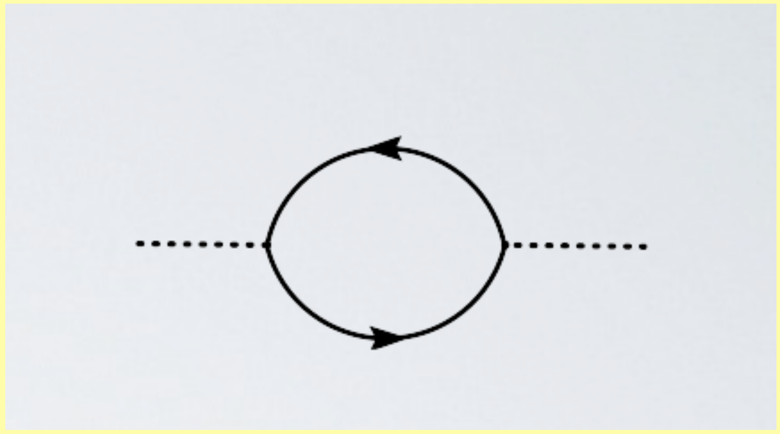
A scalar h can restore perturbative unitarity:



$$\mathcal{A}(\chi^+\chi^- \to \chi^+\chi^-) \simeq \frac{1}{v^2}\left[s - \frac{a^2 s^2}{s - m_h^2} + (s \leftrightarrow t)\right]$$

unitarity for: a=1

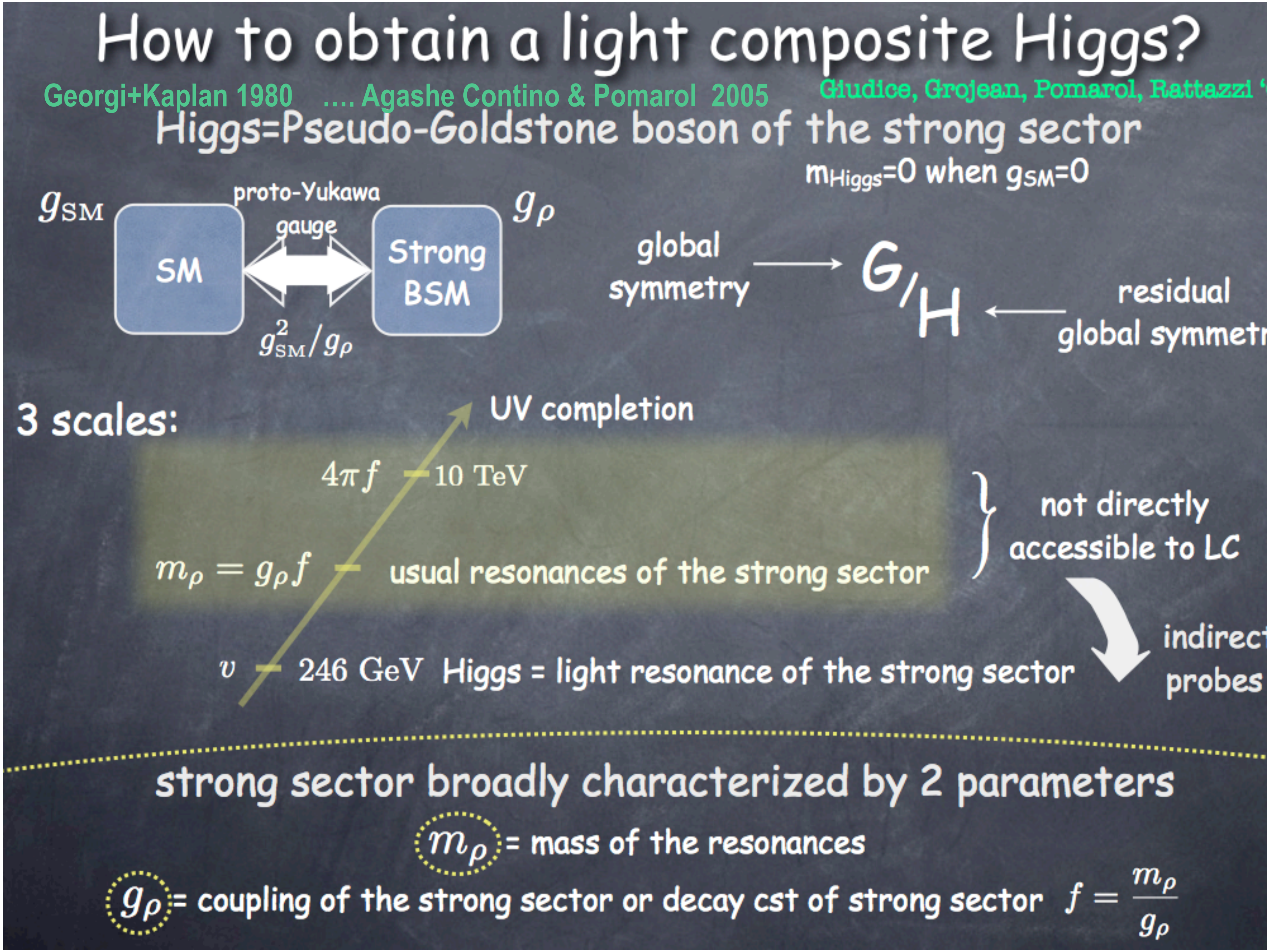
Elementare, Watson !!
uno scalare elementare e`
innaturale in assenza di una
simmetria che protegga
la sua massa



$$\Delta m_h^2 = \left[6Y_t^2 - \frac{3}{4}(3g_2^2 + g_1^2) - 6\lambda\right] \frac{\Lambda_{UV}^2}{8\pi^2}$$

In the limit g_1=0

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$


How to obtain a light composite Higgs?
Georgi+Kaplan 1980 .... Agashe Contino & Pomarol 2005
Giudice, Grojean, Pomarol, Rattazzi '
Higgs=Pseudo-Goldstone boson of the strong sector
m_{Higgs}=0 when g_{SM}=0
g_{SM}
proto-Yukawa
gauge
SM
Strong BSM
g_ρ
g_{SM}^2/g_ρ
global symmetry
G/H
residual global symmetr
3 scales:
UV completion
$4\pi f$
10 TeV
$m_\rho = g_\rho f$
usual resonances of the strong sector
not directly accessible to LC
v
246 GeV
Higgs = light resonance of the strong sector
indirect probes
strong sector broadly characterized by 2 parameters
m_ρ = mass of the resonances
g_ρ = coupling of the strong sector or decay cst of strong sector $f = \frac{m_\rho}{g_\rho}$

Continuous interpolation between SM and TC

$$\xi = \frac{v^2}{f^2} = \frac{(\text{weak scale})^2}{(\text{strong coupling scale})^2}$$

$\xi = 0$

SM limit

all resonances of strong sector, except the Higgs, decouple

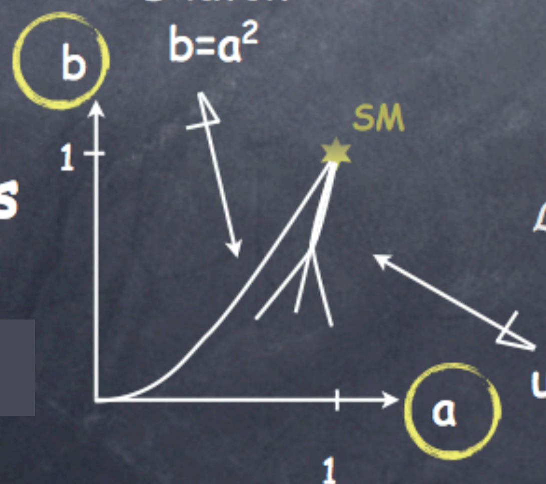
$\xi = 1$

Technicolor limit

Higgs decouple from SM; vector resonances like in TC

Dilaton
$b=a^2$

Composite Higgs
vs.
SM Higgs



$$\mathcal{L}_{\rm EWSB} = \left(a\,\frac{v}{2}\,h\ + b\,\frac{1}{4}\,h^2 \right) \mathrm{Tr}\left(D_\mu \Sigma^\dagger D_\mu \Sigma\right)$$

Composite Higgs
universal behavior for large f
a=1-v/2f b=1-2v/f

What is the SM Higgs?

A single scalar degree of freedom with no charge under $SU(2)_L \times SU(2)_R / SU(2)_V$

$$\mathcal{L}_{\rm EWSB} = \frac{v^2}{4} {\rm Tr}\left(D_\mu \Sigma^\dagger D_\mu \Sigma\right)\left(1 + 2a\frac{h}{v} + b\frac{h^2}{v^2}\right) - \lambda \bar\psi_L \Sigma \psi_R \left(1 + c\frac{h}{v}\right)$$

'a', 'b' and 'c' are arbitrary free couplings

For a=1: perturbative unitarity in elastic channels WW → WW

For b = a^2: perturbative unitarity in inelastic channels WW → hh

For ac=1: perturbative unitarity in inelastic WW → $\psi\,\psi$

'a=1', 'b=1' & 'c=1' define the SM Higgs

$\mathcal{L}_{\rm mass} + \mathcal{L}_{\rm EWSB}$ can be rewritten as $D_\mu H^\dagger D_\mu H$

$$H = \frac{1}{\sqrt{2}} e^{i\sigma^a \pi^a / v} \begin{pmatrix} 0 \\ v + h \end{pmatrix}$$

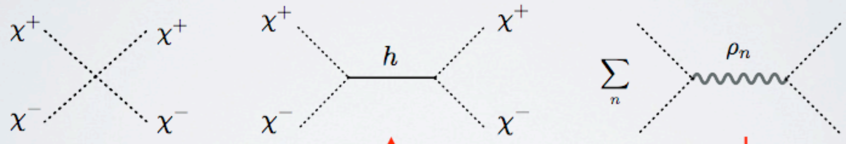
h and π^a (ie W_L and Z_L) combine to form a linear representation of $SU(2)_L \times U(1)_Y$

Higgs properties depend on a single unknown parameter (m_H)

Given the σ-model Lagrangian a, b are predicted in terms of ξ :

Ex: SO(5) → SO(4)

$$a = \sqrt{1-\xi}\,, \qquad b = (1-2\xi)$$



composite Higgs partially unitarizes WW scattering

other resonances can be heavier

- The parameter a controls the size of the IR contribution to the LEP precision observables $\epsilon_{1,3}$

$$\epsilon_{1,3} = c_{1,3}\,\log\left(\frac{M_Z^2}{\mu^2}\right) - c_{1,3}\,a^2\log\left(\frac{m_h^2}{\mu^2}\right) - c_{1,3}\,(1-a^2)\log\left(\frac{m_\rho^2}{\mu^2}\right) + \text{finite terms}$$

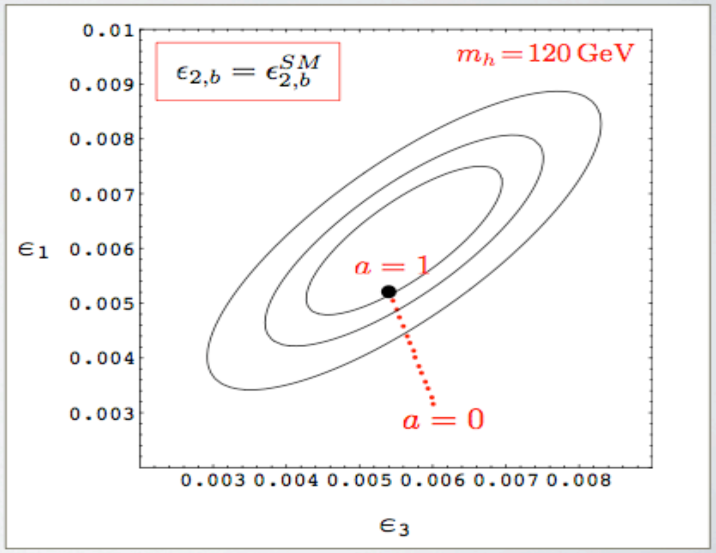
$$c_1 = +\frac{3}{16\pi^2}\frac{\alpha(M_Z)}{\cos^2\theta_W}$$

$$c_3 = -\frac{1}{12\pi}\frac{\alpha(M_Z)}{4\sin^2\theta_W}$$

$$\Delta\epsilon_{1,3} = -c_{1,3}\,(1-a^2)\log\left(\frac{m_\rho^2}{m_h^2}\right)$$

$$0.8 \lesssim a^2 \lesssim 1.6 \qquad @\ 99\%\ \text{CL}$$

see: Barbieri et al. PRD 76 (2007) 115008



SILH Effective Lagrangian
(strongly-interacting light Higgs)

Giudice, Grojean, Pomarol, Rattazzi '07

- extra Higgs leg: H/f
- extra derivative: ∂/m_ρ

Genuine strong operators (sensitive to the scale f)

$$\frac{c_H}{2f^2}\left(\partial_\mu\left(|H|^2\right)\right)^2 \qquad \frac{c_T}{2f^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)^2 \qquad \frac{c_y y_f}{f^2}|H|^2 \bar{f}_L H f_R + \text{h.c.} \qquad \frac{c_6\lambda}{f^2}|H|^6$$

custodial breaking

Form factor operators (sensitive to the scale m_ρ)

$$\frac{ic_W}{2m_\rho^2}\left(H^\dagger\sigma^i \overleftrightarrow{D^\mu} H\right)(D^\nu W_{\mu\nu})^i \qquad \frac{ic_B}{2m_\rho^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)(\partial^\nu B_{\mu\nu})$$

$$\frac{ic_{HW}}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}(D^\mu H)^\dagger\sigma^i(D^\nu H)W^i_{\mu\nu} \qquad \frac{ic_{HB}}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu}$$

minimal coupling: $h \to \gamma Z$

loop-suppressed strong dynamics

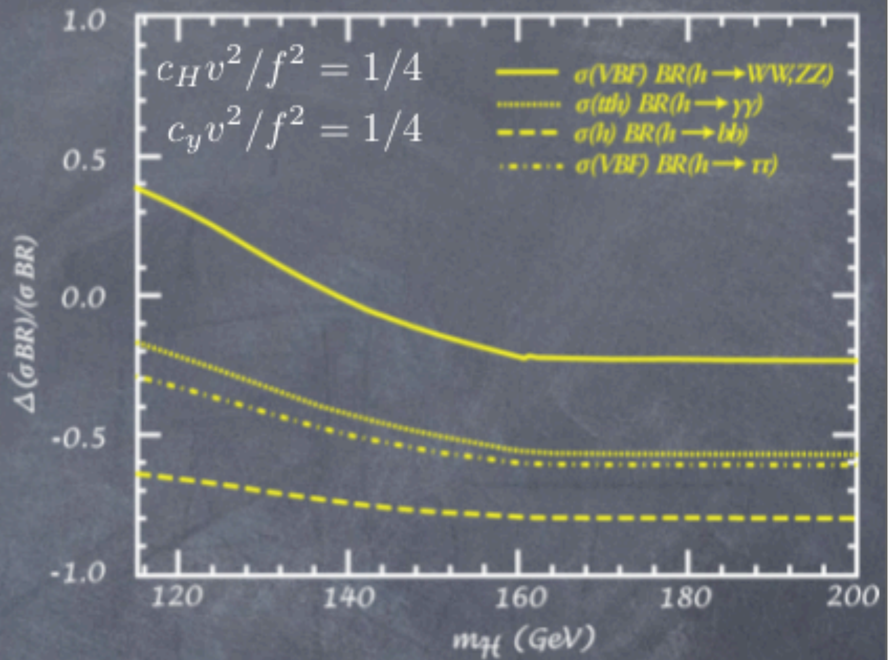
$$\frac{c_\gamma}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}\frac{g^2}{g_\rho^2}H^\dagger H B_{\mu\nu}B^{\mu\nu} \qquad \frac{c_g}{m_\rho^2}\frac{g_\rho^2}{16\pi^2}\frac{y_t^2}{g_\rho^2}H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}$$

Goldstone sym.

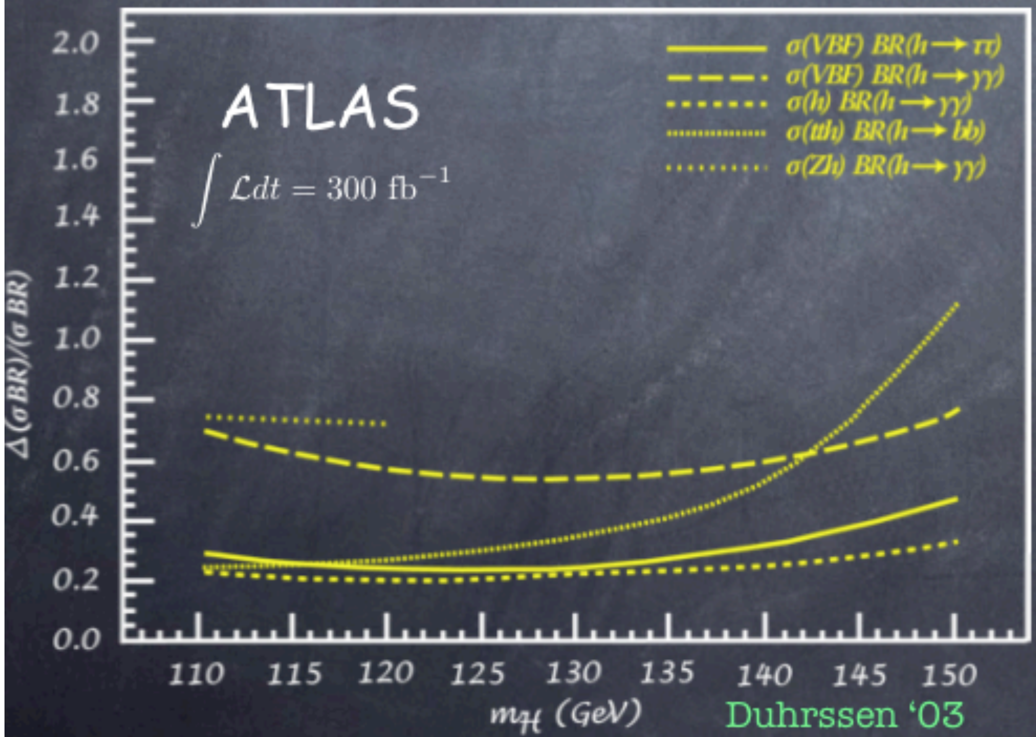
Higgs anomalous couplings @ LHC

$$\Gamma\left(h \to f\bar{f}\right)_{\rm SILH} = \Gamma\left(h \to f\bar{f}\right)_{\rm SM}\left[1 - (2c_y + c_H)\, v^2/f^2\right]$$

$$\Gamma\left(h \to gg\right)_{\rm SILH} = \Gamma\left(h \to gg\right)_{\rm SM}\left[1 - (2c_y + c_H)\, v^2/f^2\right]$$



observable @ LHC?



Duhrssen '03

LHC can measure

$c_H \dfrac{v^2}{f^2},\ c_y \dfrac{v^2}{f^2}$

up to 0.2-0.4

i.e. $4\pi f \sim 5-7$ TeV

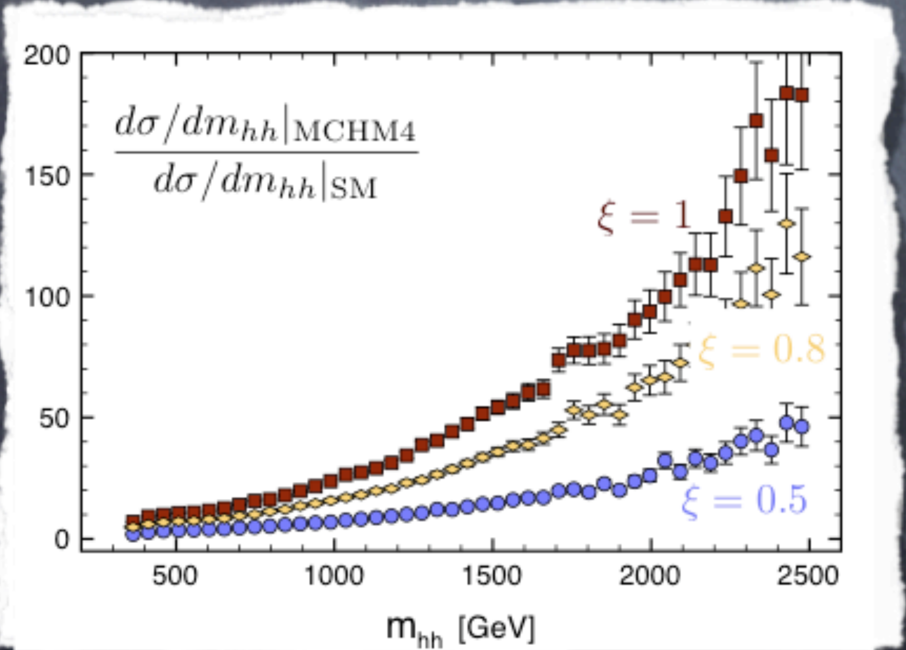
(ILC could go to few % ie
test composite Higgs up to $4\pi f \sim 30$ TeV)

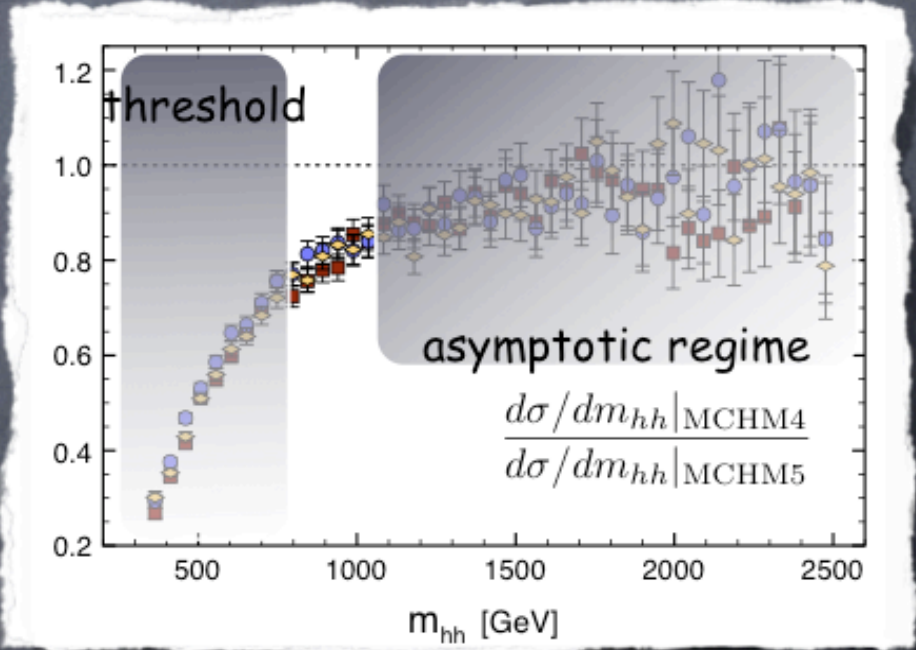
Isolating Hard Scattering

isolate events with large m_{hh}

luminosity factor drops out in ratios: extract the growth with m_{hh}

measure H^3 measure $b-a^2$





THE LITTLE HIERARCHY PROBLEM

SUSY CASE

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{stop}^2}{m_t^2}$$

$$m_h > 115 \text{ GeV} \quad \Rightarrow \quad m_{stop} \geq O(1 \text{ TeV})$$

$$\frac{1}{2} M_Z^2 \approx -(m_{H_u}^2 + \mu^2)|_{tree} + 0.1 M_{SUSY}^2 \ln \frac{\Lambda_{MSSM}}{M_{SUSY}}$$

$$10^{-2}\text{TeV} \quad \text{vs} \quad O(1)\text{TeV}|_{tree} + O(1)\text{TeV}$$

FINE TUNING IS FINE TUNING !

SM Higgs: fine tuning dei parametri per evitare che la sua massa sia dell'ordine della scala piu` alta (GUT o PLANCK)

MSSM Higgs: fine tuning per evitare i limiti di LEP e Tevatron sulle masse delle particelle supersimmetriche

Fine tuning per evitare i limiti imposti dalle misure di precisione in modelli tipo little Higgs o composite Higgs

(inclusi quelli in extra-dimensions)

Lessons from model building

G. Altarelli , LP09

In all the new physics models we mentioned

there is a light Higgs (< 200 GeV)

[except in Higgsless models (if any) but new light new vector bosons exist in this case]

there is at least a % fine tuning

Fine tuning appears to be imposed on us by the data

Is it possible that the Higgs is not found at the LHC?

Here "Higgs" means the "the EW symmetry breaking mechanism"

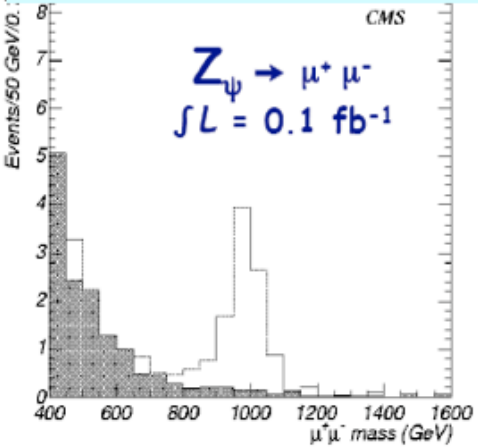
Looks pretty unlikely!!

The LHC discovery range is large enough: $m_H < \sim 1$ TeV
the Higgs should be really heavy!

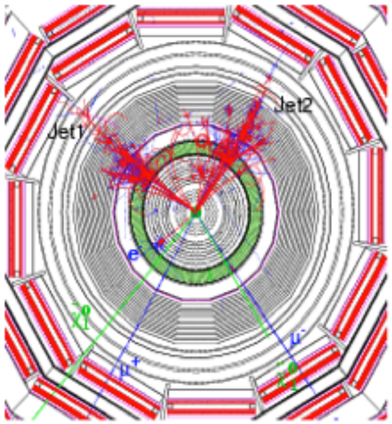
Rad. corr's indicate a light Higgs (whatever its nature)

New Physics at High Energies?

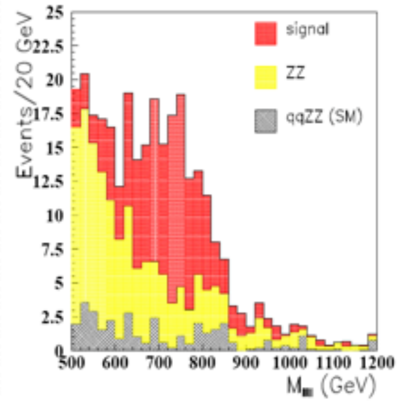
New Gauge Bosons?



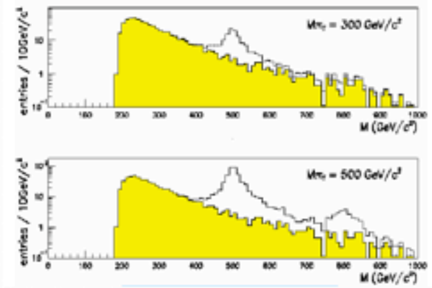
Supersymmetry



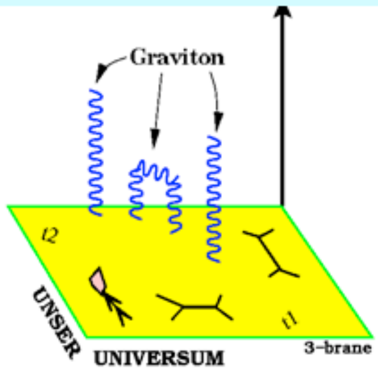
ZZ/WW resonances?



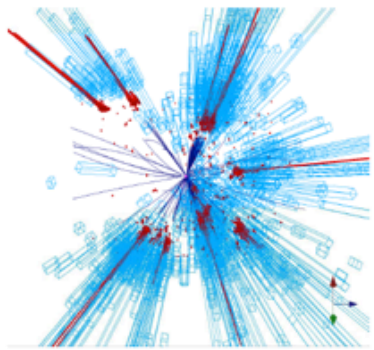
Technicolor?



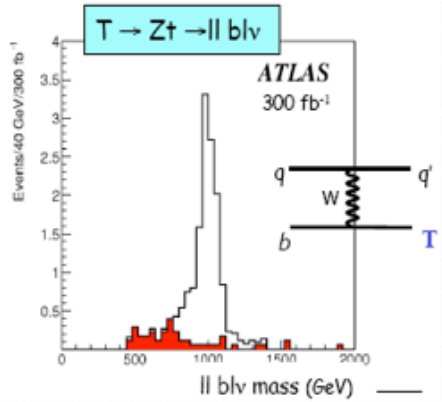
Extra Dimensions?



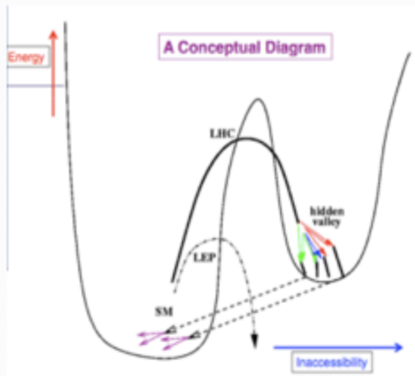
Black Holes???



Little Higgs?



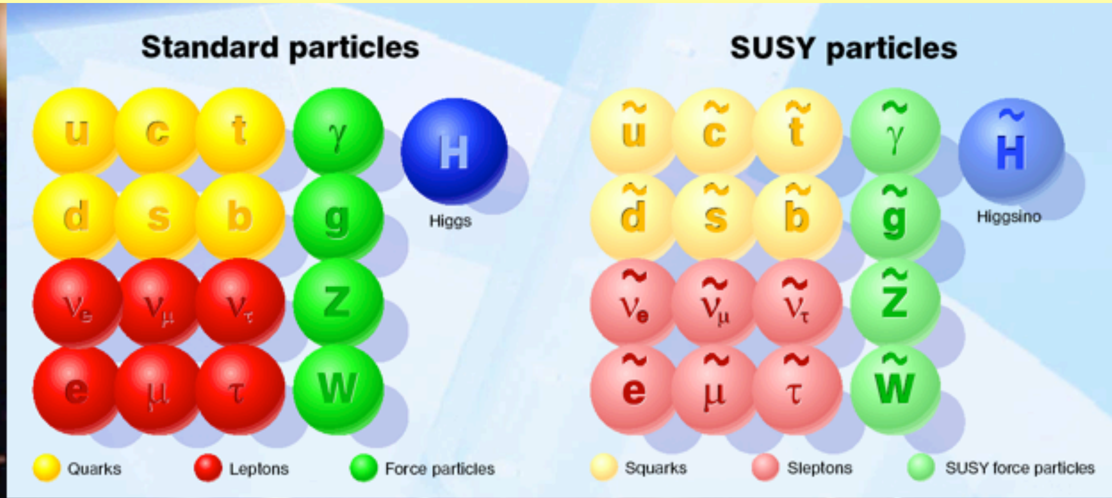
Hidden Valleys?



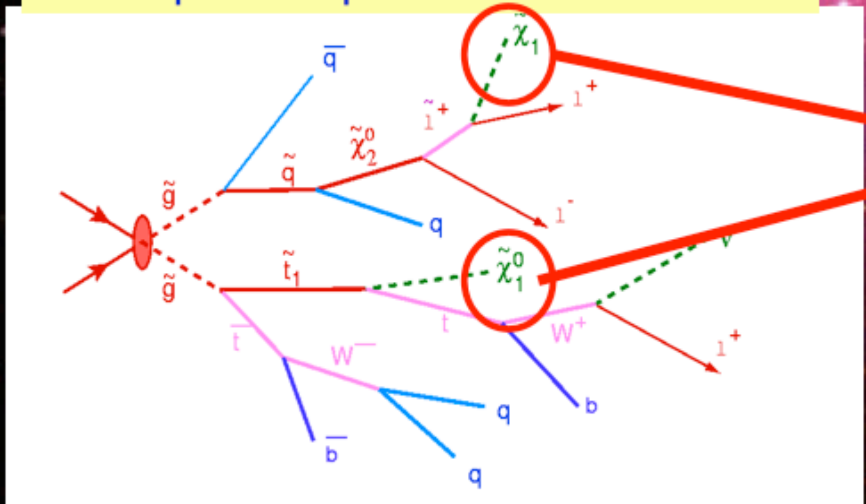
We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

A Popular Choice:

SUPERSYMMETRY

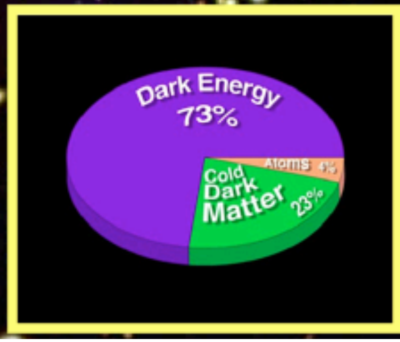


SUSY particle production at the LHC



Candidate particles for Dark Matter

⇒ Produce Dark Matter in the lab



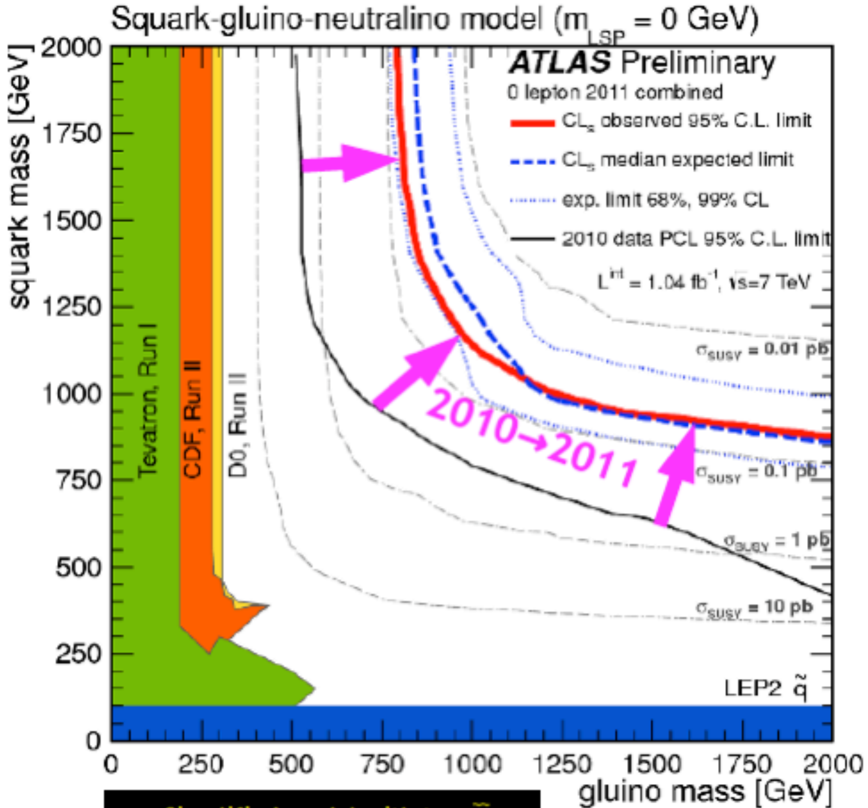
Assume “R-Parity” Conservation

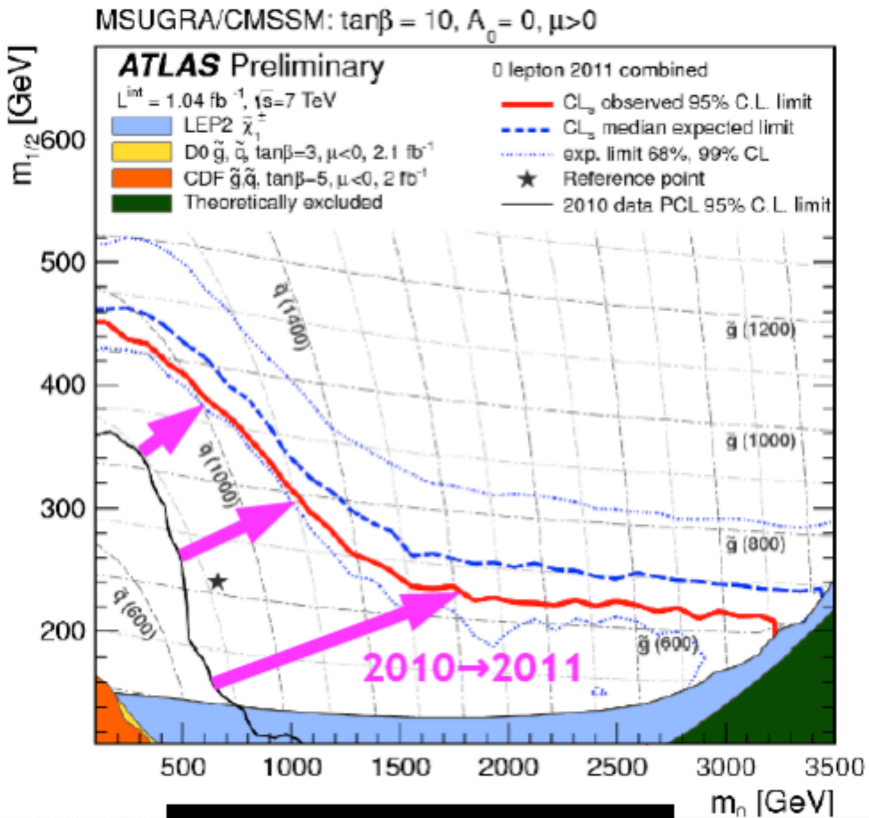
SUSY Search: Jets + Missing E_T Channel

Limits in a simplified model

Using 1 fb^{-1}

Limits in CMSSM





Simplified model with two $\tilde{q}$ generations, $m(\tilde{\chi}_1^0)$~0

$m_{\tilde{g}}$>800 GeV $m_{\tilde{q}}$>850 GeV

Equal mass case: $m_{\tilde{g}}=m_{\tilde{q}}$>1.075 TeV

MSUGRA/CMSSM: tanβ=10, A_0=0, μ>0

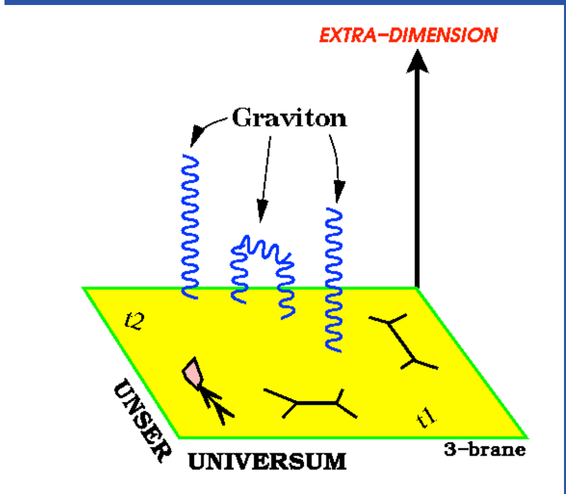
Equal mass case: $m_{\tilde{q}}=m_{\tilde{g}}$ > 980 GeV

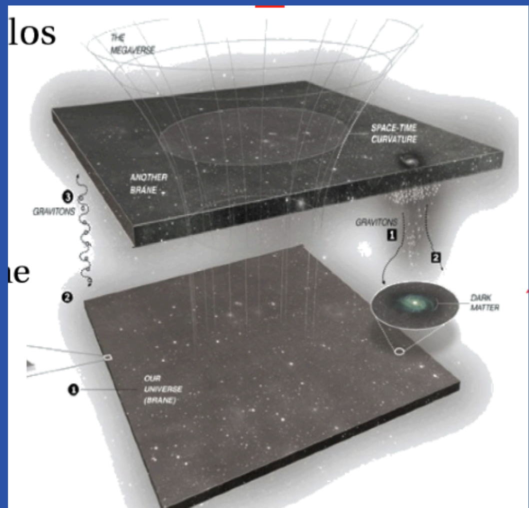
Up to masses of 1 TeV excluded for equal gluino-squark masses
Extends the 2010 data limits by ~ 250 GeV

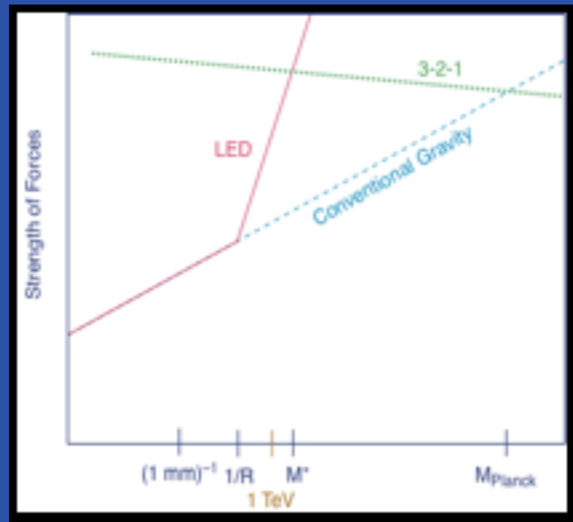
Extra Space Dimensions (trying to solve the Hierarchy Problem):

$$m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246 \text{ GeV}$$

$$M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19} \text{ GeV}$$

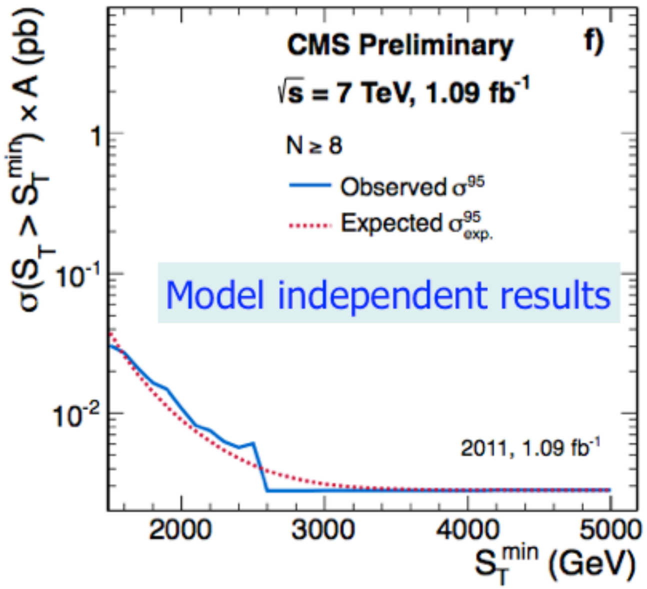


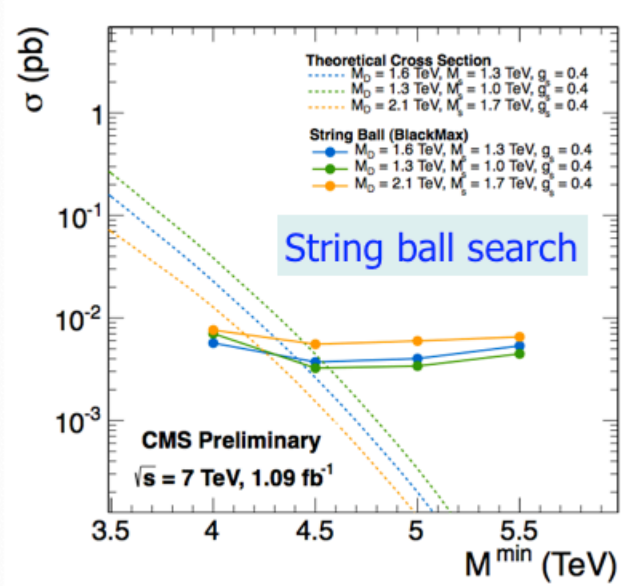




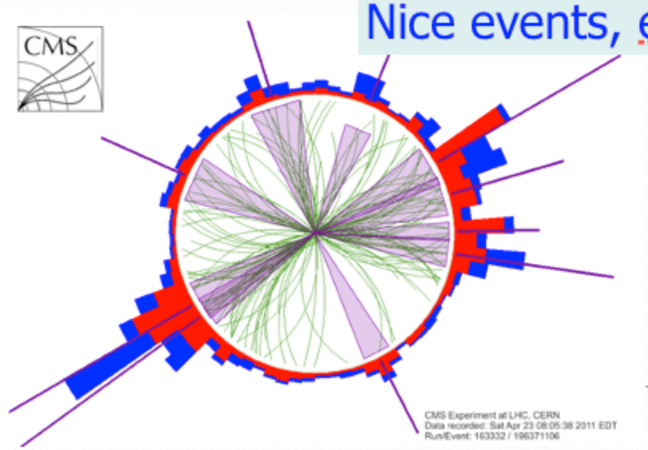
GRAVITY BECOMES STRONG @ TeV Scale !!

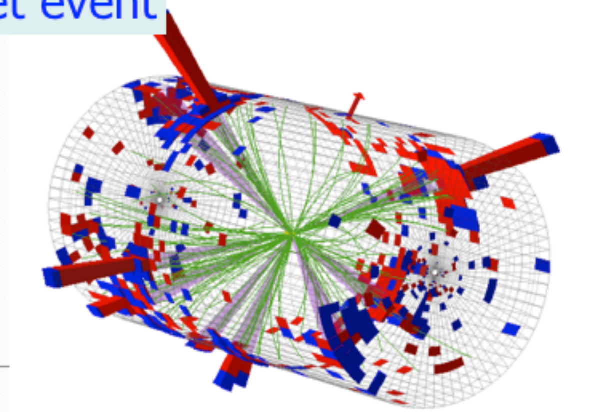
Search for Micro Black Holes





Nice events, eg this 10 jet event





Nel seguito la discussione sara` Incentrata su:

La Rottura della Simmetria Elettrodebole
(The Energy Frontier)

La fisica del Sapore e la Violazione di CP
(The Intensity Frontier)

La natura della Materia Oscura
(The Cosmic Frontier)

MASSE DEI FERMIONI

$$m_{top} \sim 170\ GeV = 1.7 \times 10^{11}\ eV$$

$10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$

$$m_s \sim 100\ MeV = 1.0 \times 10^{8}\ eV$$

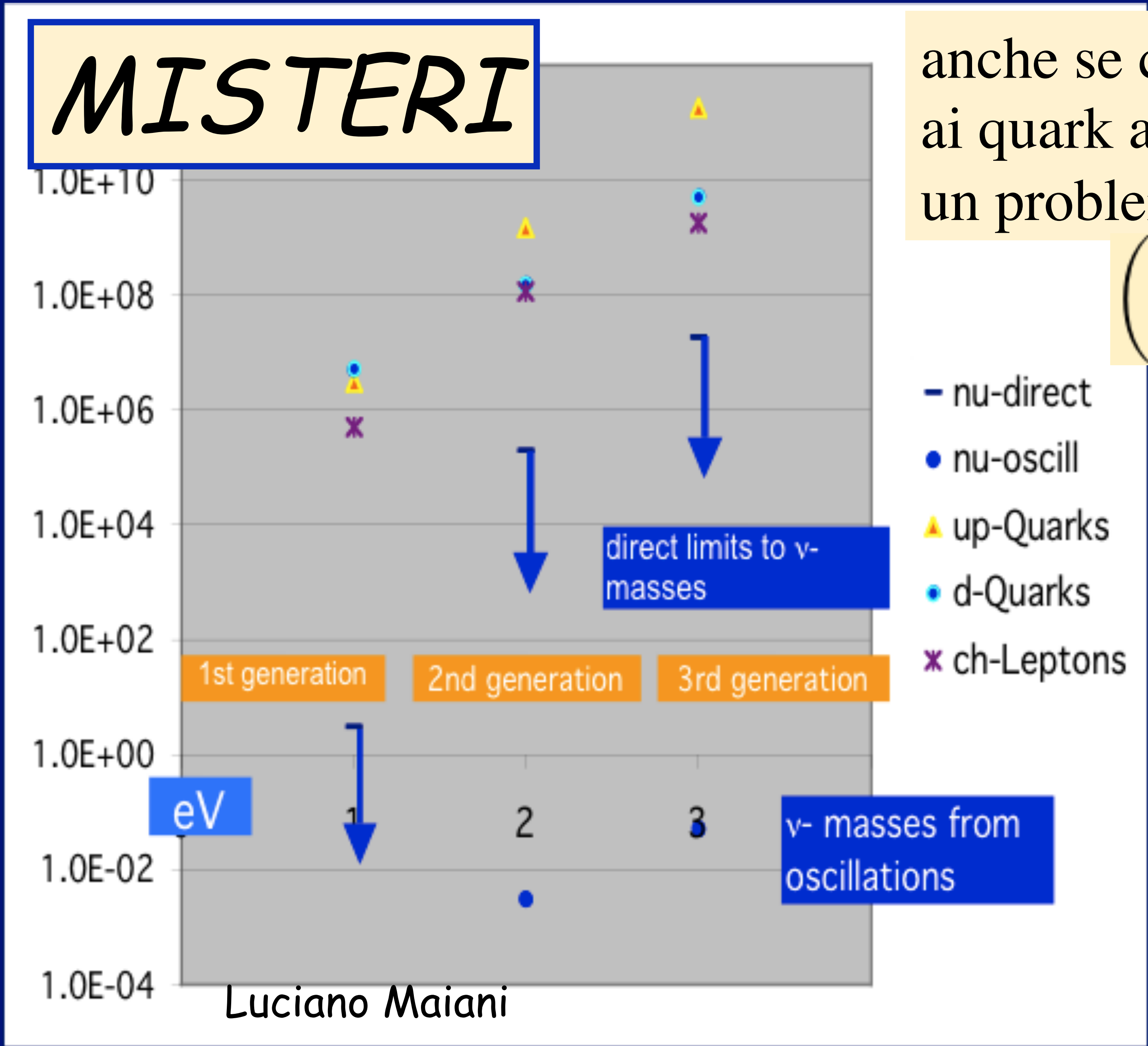
$$m_{u,d} \sim 4 - 10\ MeV = 4 - 10 \times 10^{6}\ eV$$

$$m_e \sim 0.5\ MeV = 5. \times 10^{5}\ eV$$

$$m_\nu < 1.0\ eV$$

le masse dei fermioni variano per più di 10 ordini di grandezza !!

MISTERI



Luciano Maiani

anche se ci limitiamo ai quark abbiamo un problema

$$\left(\frac{m_{top}}{m_{up}}\right) \simeq 10^4$$

m_{top}/m_e = 3×10^5 ->

y_{top}/y_e ~ 10^5

Nel Modello Standard, la matrice di massa dei quark, dalla quale originano la matrice di CKM e la violazione di CP̸, e` determinata dall'accoppiamento del bosone di Higgs ai fermioni.

$$\mathcal{L}^{\text{quarks}} = \mathcal{L}^{\text{kinetic}} + \mathcal{L}^{\text{gauge}} + \mathcal{L}^{Yukawa}$$

CP invariante (riferito a $\mathcal{L}^{\text{kinetic}}$ e $\mathcal{L}^{\text{gauge}}$)

CP̸ e rottura della simmetria sono strettamente correlati (riferito a $\mathcal{L}^{Yukawa}$)

$$\mathcal{L}(\Lambda_{Fermi}) = \mathcal{L}(\Lambda, H, H^\dagger) + \mathcal{L}^{kin} + \mathcal{L}^{gauge}_{SM} + \mathcal{L}^{Yukawa}_{SM} + \frac{\mathcal{L}_5}{\Lambda} + \frac{\mathcal{L}_6}{\Lambda^2} + \dots$$

EWSB

ha simmetrie accidentali

Viola le simmetrie accidentali

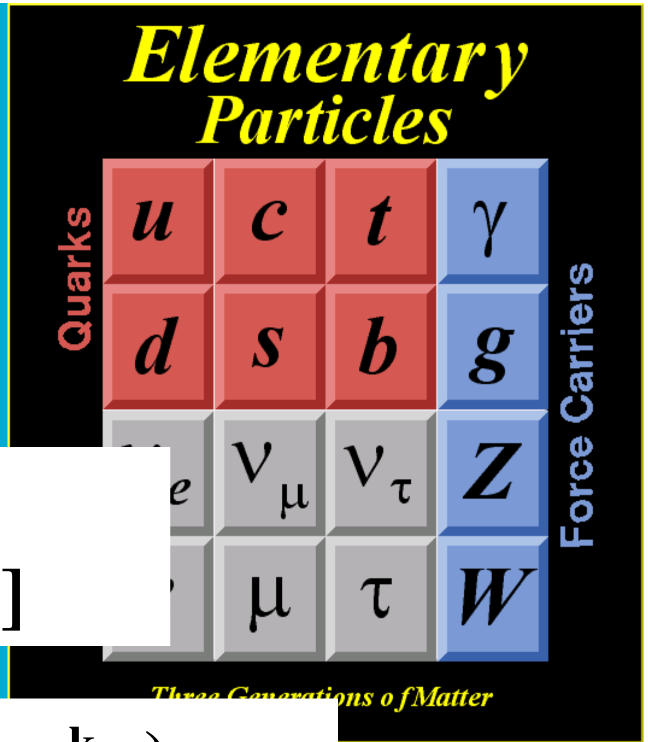
2 Simmetrie Accidentali:

Assenza di FCNC a livello albero (soppressione di GIM delle FCNC negli effetti quantistici @loops)

Nessuna violazione di CP @livello albero

LA FISICA DEL SAPORE E`
ESTREMAMENTE
SENSIBILE ALLA NUOVA FISICA

Le masse dei quark sono generate dalla rottura della simmetria



Charge +2/3

$$\mathcal{L}^{yukawa} \equiv \sum_{i,k=1,N} [\, Y_{i,k} (\overline{q}^{i}_{L} H^{C}) U^{k}_{R} + X_{i,k} (\overline{q}^{i}_{L} H) D^{k}_{R} + h.c. \,]$$

Charge -1/3

$$\sum_{i,k=1,N} [\, m^{u}_{i,k} (\overline{u}^{i}_{L} u^{k}_{R}) + m^{d}_{i,k} (\overline{d}^{i}_{L} d^{k}_{R}) + h.c. \,]$$

Diagonalizatione della Matrice di Massa

$$\mathcal{L}^{mass} \equiv m_{up} (u_L u_R + u_R u_L) + m_{ch} (c_L c_R + c_R c_L) + m_{top} (t_L t_R + t_R t_L)$$

$$L^{weak\,int}_{CC} = \frac{g_W}{\sqrt{2}} (J^{-}_{\mu} W^{+}_{\mu} + h.c.)$$

$$\rightarrow \frac{g_W}{\sqrt{2}} (\bar{u}_L \mathbf{V}^{CKM} \gamma_\mu d_L W^{+}_{\mu} + \ldots)$$

N(N-1)/2 angles and (N-1)(N-2) /2 phases

N=3 3 angles + 1 phase KM

the phase generates complex couplings i.e. CP violation;

6 masses +3 angles +1 phase = 10 parameters

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{tb}	V_{ts}	V_{tb}

NO Flavour Changing Neutral Currents (FCNC) at Tree Level
(FCNC processes are good candidates for observing NEW PHYSICS)

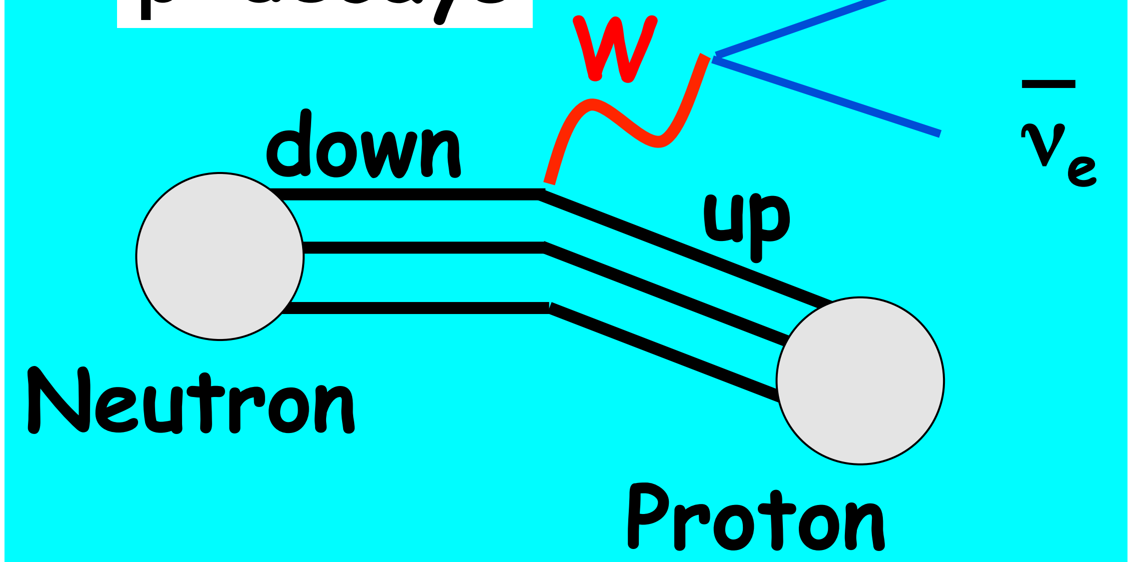
CP Violation is natural with three quark generations (Kobayashi-Maskawa)

With three generations all CP phenomena are related to the same unique parameter (δ)

Quark masses & Generation Mixing

V_{ud}	V_{us}	V_{ub}
V_{cd}	V_{cs}	V_{cb}
V_{td}	V_{ts}	V_{tb}

β-decays



$|V_{ud}|$

$|V_{ud}| = 0.9735(8)$

$|V_{us}| = 0.2196(23)$

$|V_{cd}| = 0.224(16)$

$|V_{cs}| = 0.970(9)(70)$

$|V_{cb}| = 0.0406(8)$

$|V_{ub}| = 0.00409(25)$

$|V_{tb}| = 0.99(29)$

(0.999)

The Wolfenstein Parametrization

$1 - 1/2\ \lambda^2$	λ	$A\ \lambda^3(\rho - i\ \eta)$
$-\ \lambda$	$1 - 1/2\ \lambda^2$	$A\ \lambda^2$
$A\ \lambda^3 \times (1 - \rho - i\ \eta)$	$-A\ \lambda^2$	1

V_{ub}

$+\ O(\lambda^4)$

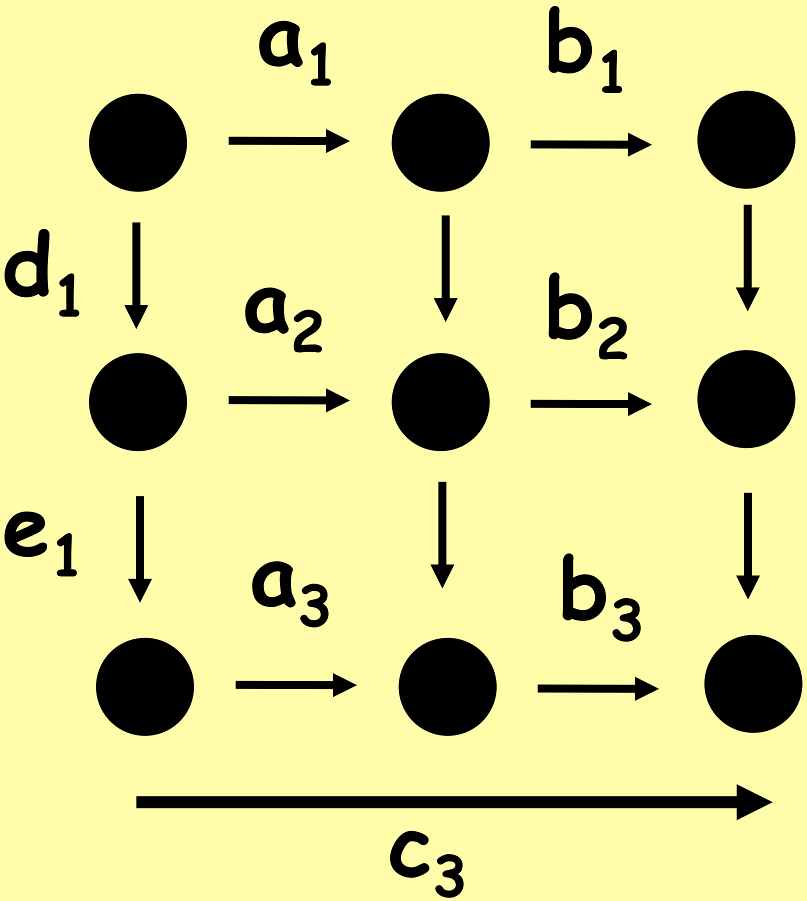
V_{td}

$\sin\theta_{12} = \lambda$
$\sin\theta_{23} = A\ \lambda^2$
$\sin\theta_{13} = A\ \lambda^3(\rho - i\ \eta)$

$\lambda \sim 0.2 \quad A \sim 0.8$

$\eta \sim 0.2 \quad \rho \sim 0.3$

The Bjorken-Jarlskog Unitarity Triangle



$| V_{ij} |$ is invariant under phase rotations

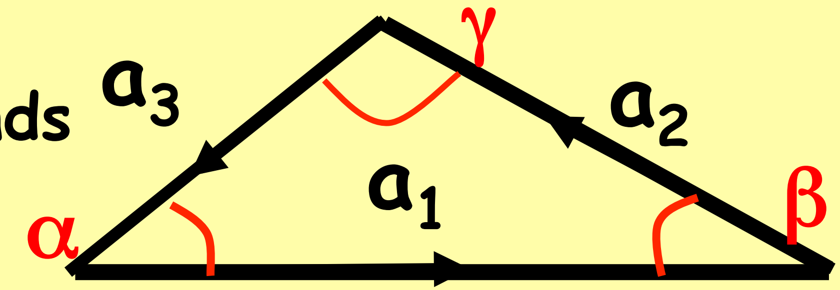
$a_1 = V_{11} V_{12}^* = V_{ud} V_{us}^*$

$a_2 = V_{21} V_{22}^* \quad a_3 = V_{31} V_{32}^*$

$a_1 + a_2 + a_3 = 0$

$(b_1 + b_2 + b_3 = 0$ etc.)

Only the orientation depends on the phase convention



STRONG CP VIOLATION

$$\mathcal{L}_\theta = \theta\, \tilde{G}^{\mu\nu a} G^a_{\mu\nu} \qquad \tilde{G}^a_{\mu\nu} = \varepsilon_{\mu\nu\rho\sigma} G^a_{\rho\sigma}$$

$$\mathcal{L}_\theta \sim \theta\, \vec{E}^a \cdot \vec{B}^a$$

This term violates CP and gives a contribution to the electric dipole moment of the neutron

$$e_n < 6.3\ 10^{-26}\ \mathrm{e\ cm}$$

$\theta < 10^{-9}$ which is quite unnatural !!

Asimmetria Materia-Antimateria e ~~CP~~

In 1967 Andrei Sakharov sottolineo` che bisognava soddisfare quattro condizioni per ottenere un universo dotato di asimmetria materia-antimateria da uno stato iniziale simmetrico (dominato dalla radiazione):

1) Baryon number violation $\Delta B \neq 0$ (GUT ??)

$$e^+ + d \rightarrow X \rightarrow u + u \qquad (\Delta(B-L) = 0)$$

Lepton number violation is possible but not necessary and could be zero because of the presence of a large number of antineutrinos

2) Charge symmetry violation ~~C~~

$$\Gamma(e^+ + \bar{d} \rightarrow X \rightarrow u + u) \neq \Gamma(e^- + d \rightarrow X \rightarrow \bar{u} + \bar{u})$$

3) ~~CP~~ violation: the number of left handed up quarks produced by X must be different from the number of right handed up antiquarks

da riprendere nel seguito se il tempo lo permette

4) The universe was not in equilibrium when this happened, otherwise if

$$\Gamma(e^+ + d \to u + u) > \Gamma(e^- + d \to \bar{u} + \bar{u})$$ then

$$\Gamma(u + u \to e^+ + d) > \Gamma(\bar{u} + \bar{u} \to e^- + d)$$

$$\langle B \rangle = Tr[e^{-\beta H} B] = Tr[(CPT)(CPT)^{-1} e^{-\beta H} B]$$

$$= Tr[e^{-\beta H} (CPT)^{-1} B (CPT)] = -\langle B \rangle$$

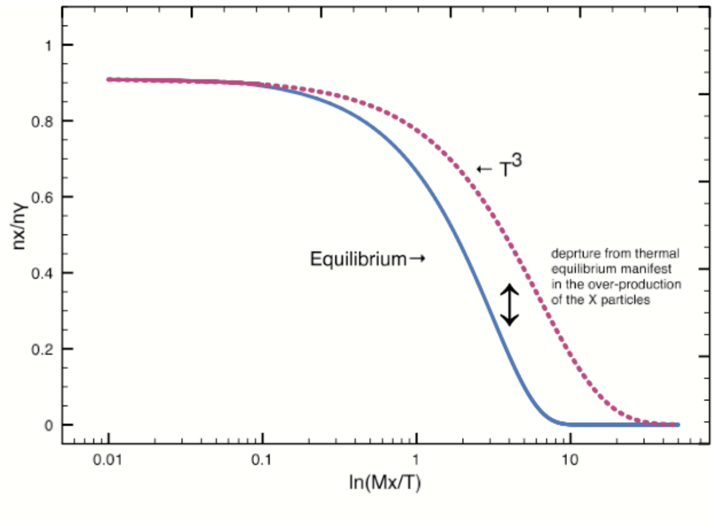


Fig. 1.6. The distribution of the X particles in thermal equilibrium (blue curve) follows Eq. 1.38 and 1.39. When departure from the thermal equilibrium occurs, the distribution of the X particles remains the same as the thermal distribution (red dashed curve).

Le ragioni per andare oltre lo SM:

1) **Trovare la ragione per lo *spettro di massa della ``materia” fermionica* (spiegare la correlazione tra masse e accoppiamenti deboli)**
2) **Risolvere il problema della *Strong CP violation***
3) **Nel Modello Standard non c’e` abbastanza $\not{CP}$ per spiegare quantitativamente *l’Asimmetria materia-antimateria* e abbiamo bisogno di nuove sorgenti di $\not{CP}$**

un intrigante possibilita` per risolvere questi problemi:

l’intera materia dell’universo (e dunque la violazione di CP) ha origine dallo stesso meccanismo responsabile per la piccolezza della massa dei neutrini

Fisica del Sapore e CP nello SM

Measure	V_{CKM}	Other NP parameters
$\Gamma(b \to u)/\Gamma(b \to c)$	$\bar{\rho}^2 + \bar{\eta}^2$	$\bar{\Lambda}, \lambda_1, F(1), \ldots$
ε_K	$\eta\,[(1-\bar{\rho}) + \ldots]$	B_K
Δm_d	$(1-\bar{\rho})^2 + \bar{\eta}^2$	$f_{B_d}^2 B_{B_d}$
$\Delta m_d/\Delta m_1$	$(1-\bar{\rho})^2 + \bar{\eta}^2$	ξ
$A_{CP}(B_d \to J/\psi\, K_s)$	$\sin 2\beta$	–

$$Q^{EXP} = V_{CKM} \times \langle H_F|\hat{O}|H_I\rangle$$

For details see:
UTfit Collaboration
http://www.utfit.org

classical UT analysis

sin 2β is measured directly from $B \rightarrow J/\psi K_s$ decays at Babar & Belle

$$\mathcal{A}_{J/\psi K_S} = \frac{\Gamma(B_d^0 \rightarrow J/\psi K_s, t) - \Gamma(\bar{B}_d^0 \rightarrow J/\psi K_s, t)}{\Gamma(B_d^0 \rightarrow J/\psi K_s, t) + \Gamma(\bar{B}_d^0 \rightarrow J/\psi K_s, t)}$$

$$\mathcal{A}_{J/\psi K_S} = \sin 2\beta \quad \sin(\Delta m_d t)$$

DIFFERENT LEVELS OF THEORETICAL UNCERTAINTIES (STRONG INTERACTIONS)

1) First class quantities, with reduced or negligible theor. uncertainties

$A_{CP}(B \to J/\psi K_s)$ $\quad \gamma$ *from* $B \to DK$

$K^0 \to \pi^0 \nu \bar{\nu}$

2) Second class quantities, with theoretical errors of O(10%) or less that can be reliably estimated

$\varepsilon_K \quad \Delta M_{d,s}$

$\Gamma(B \to c, u)\,, \quad K^+ \to \pi^+ \nu \bar{\nu}$

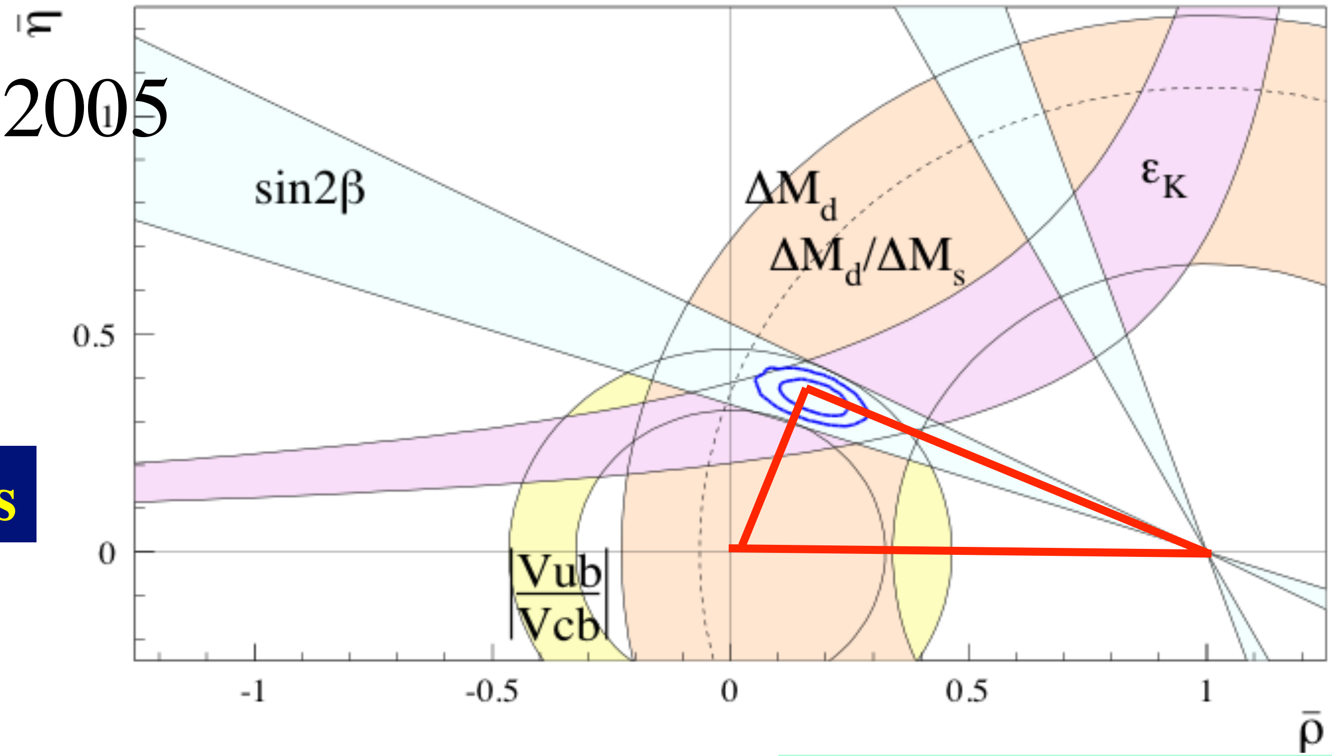
3) Third class quantities, for which theoretical predictions are model dependent (BBNS, charming, etc.)

In case of discrepacies we cannot tell whether is *new physics or we must blame the model*

$B \to K\pi \quad B \to \pi^0 \pi^0$

$B \to \phi K_s$

Unitary Triangle SM



semileptonic decays

Experimental coı

Meas.	$V_{CKM} \times$ other	$(\bar\rho, \bar\eta)$
$\frac{b \to u}{b \to c}$	$\lvert V_{ub}/V_{cb}\rvert^2$	$\bar\rho^2 + \bar\eta^2$
Δm_d	$\lvert V_{td}\rvert^2 f^2_{B_d} B_{B_d}$	$(1-\bar\rho)^2 + \bar\eta^2$
$\frac{\Delta m_d}{\Delta m_s}$	$\left\lvert \frac{V_{td}}{V_{ts}} \right\rvert^2 \xi^2$	$(1-\bar\rho)^2 + \bar\eta^2$
ϵ_K	$f(A, \bar\eta, \bar\rho, B_K)$	$\propto \bar\eta(1-\bar\rho)$
$A(J/\psi K^0)$	$sin 2\beta$	$\frac{2\bar\eta(1-\bar\rho)}{\sqrt{\bar\eta^2+(1-\bar\rho)^2}}$

K^0 - $\overline{K}^0$ mixing

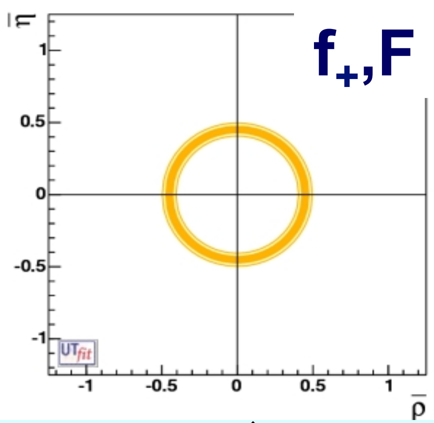
B_d Asymmetry

$B^0_{d,s}$ - $\overline{B}^0_{d,s}$ mixing

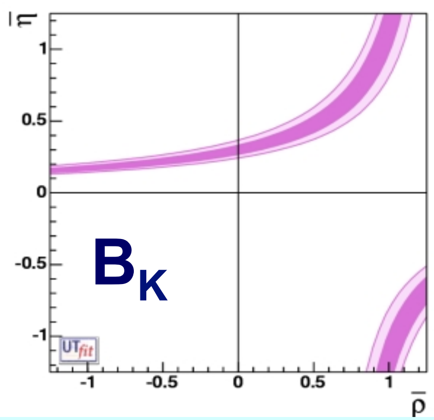
Classical Quantities used in the Standard UT Analysis

levels @
68% (95%) CL

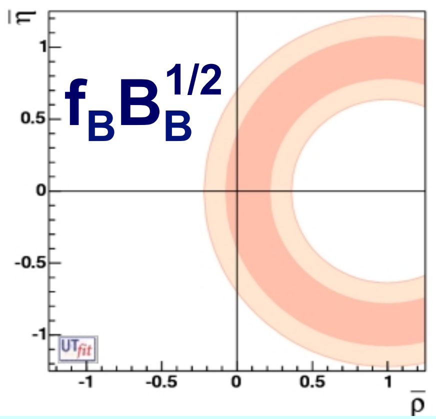
V_{ub}/V_{cb}



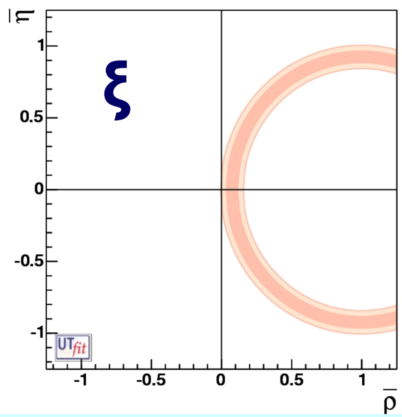
ε_K



Δm_d



$\Delta m_d/\Delta m_s$



UT-LATTICE

Inclusive vs Exclusive
Opportunity for lattice QCD
see later

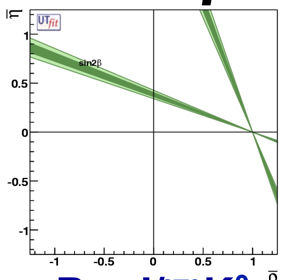
before
only a lower bound

New Quantities used in the UT Analysis

UT-ANGLES

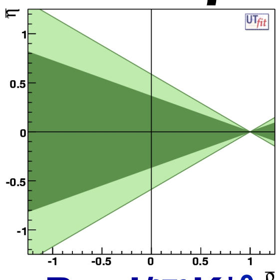
Several new determinations of UT angles are now available, thanks to the results coming from the B-Factory experiments

$\sin 2\beta$



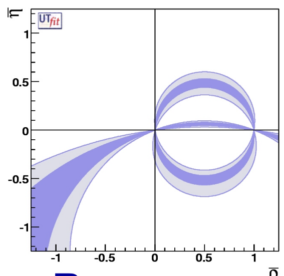
$B \to J/\Psi K^0$

$\cos 2\beta$



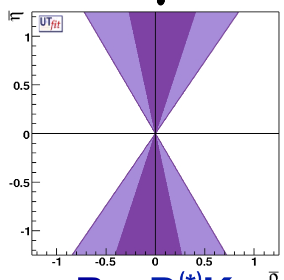
$B \to J/\Psi K^{*0}$

α



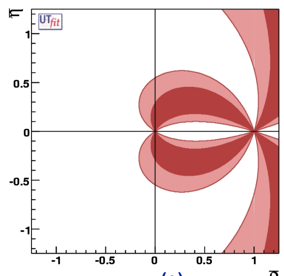
$B \to \pi\pi, \rho\rho$

γ



$B \to D^{(*)}K$

$\sin(2\beta+\gamma)$

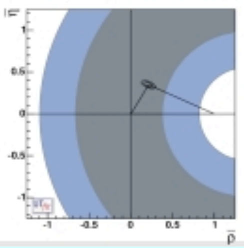


$B \to D^{(*)}\pi, D\rho$

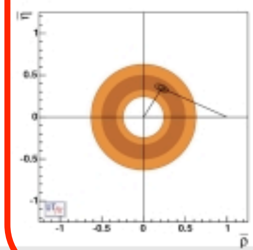
New Constraints from B and K rare decays (not used yet)

New bounds are available from rare B and K decays. They do not still have a strong impact on the global fit and they are not used at present.

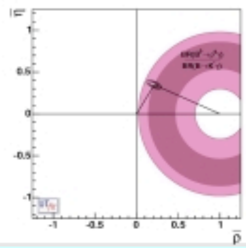
$K \to \pi \nu \bar{\nu}$

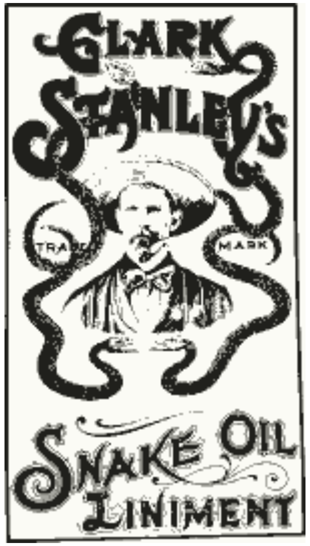


$B \to \tau \nu$



$(B \to \rho/\omega\, \gamma)/(B \to K^*\gamma)$





UTfit

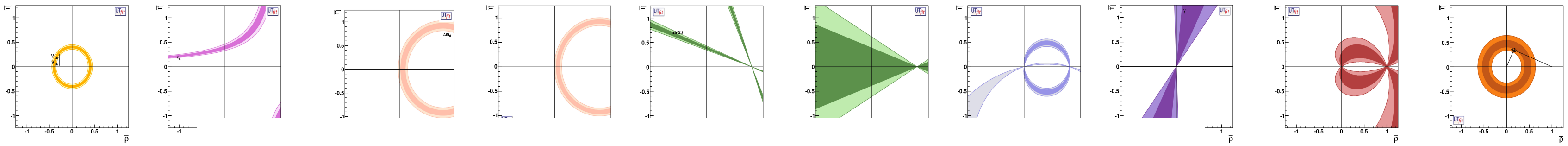
M.Bona *et al.*, UTfit
JHEP0507:028, 2005

www.utfit.org

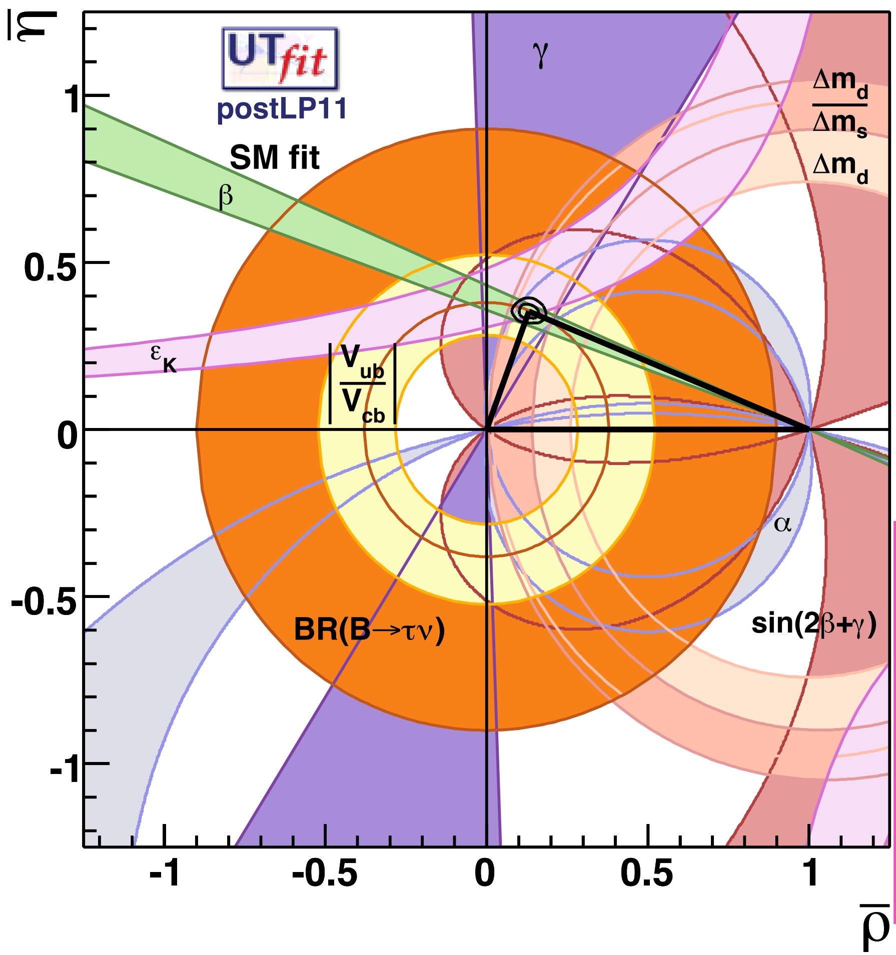
A. Bevan, M. Bona, M. Ciuchini,
D. Derkach, E. Franco, V. Lubicz,
G. Martinelli, F. Parodi, M. Pierini,
C. Schiavi, L. Silvestrini, A. Stocchi,
V. Sordini, C. Tarantino and V. Vagnoni

Global Fit within the SM

SM Fit



In the hadronic sector, the SM CKM pattern represents the principal part of the flavour structure and of CP violation



Consistence on an over constrained fit of the CKM parameters

$\rho = 0.132 \pm 0.020$

$\eta = 0.353 \pm 0.014$

$\alpha = (88 \pm 3)^0$

$\sin 2\beta = 0.695 \pm 0.025$

$\beta = (22 \pm 1)^0$

$\gamma = (69 \pm 3)^0$

CKM matrix is the dominant source of flavour mixing and CP violation

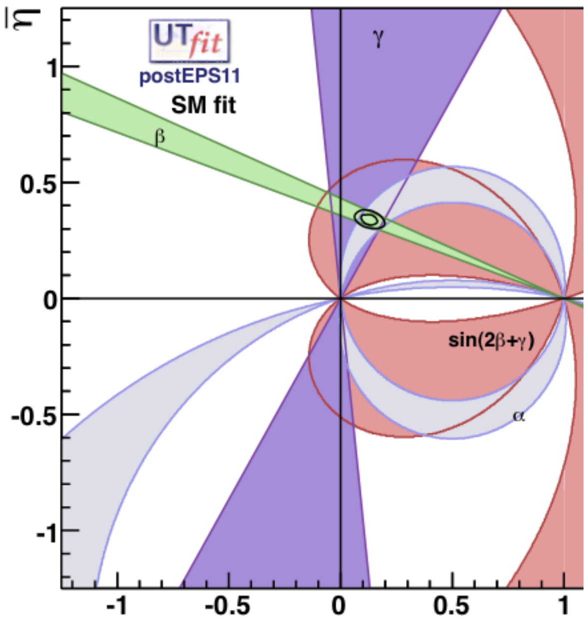
The UT-angles fit does not depend on theoretical calculations (treatement of errors is not an issue)

Comparable accuracy due to the precise sin2β value and substantial improvement due to the new Δm_s measurement

<u>Crucial to improve measurements of the angles, in particular γ</u> (tree level NP-free determination)

Still imperfect agreement in $\bar{\eta}$ due to sin2β and V_{ub} tension

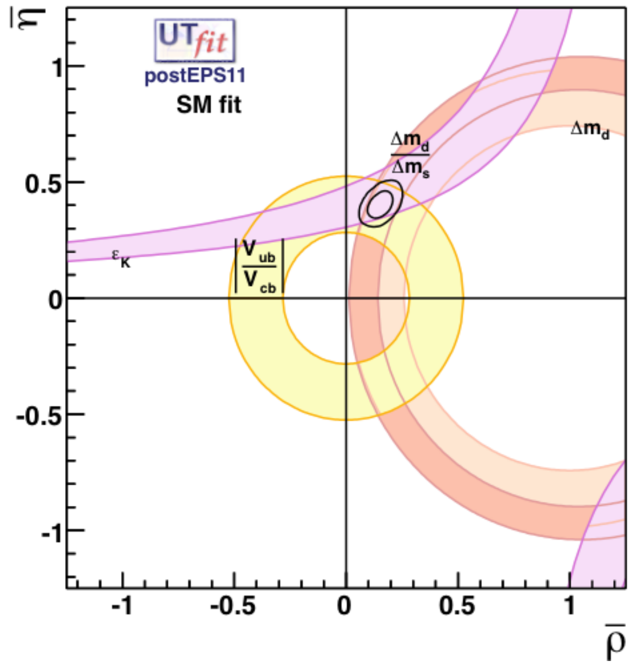
UT-angles



$\rho = 0.129 \pm 0.027$

$\eta = 0.340 \pm 0.016$

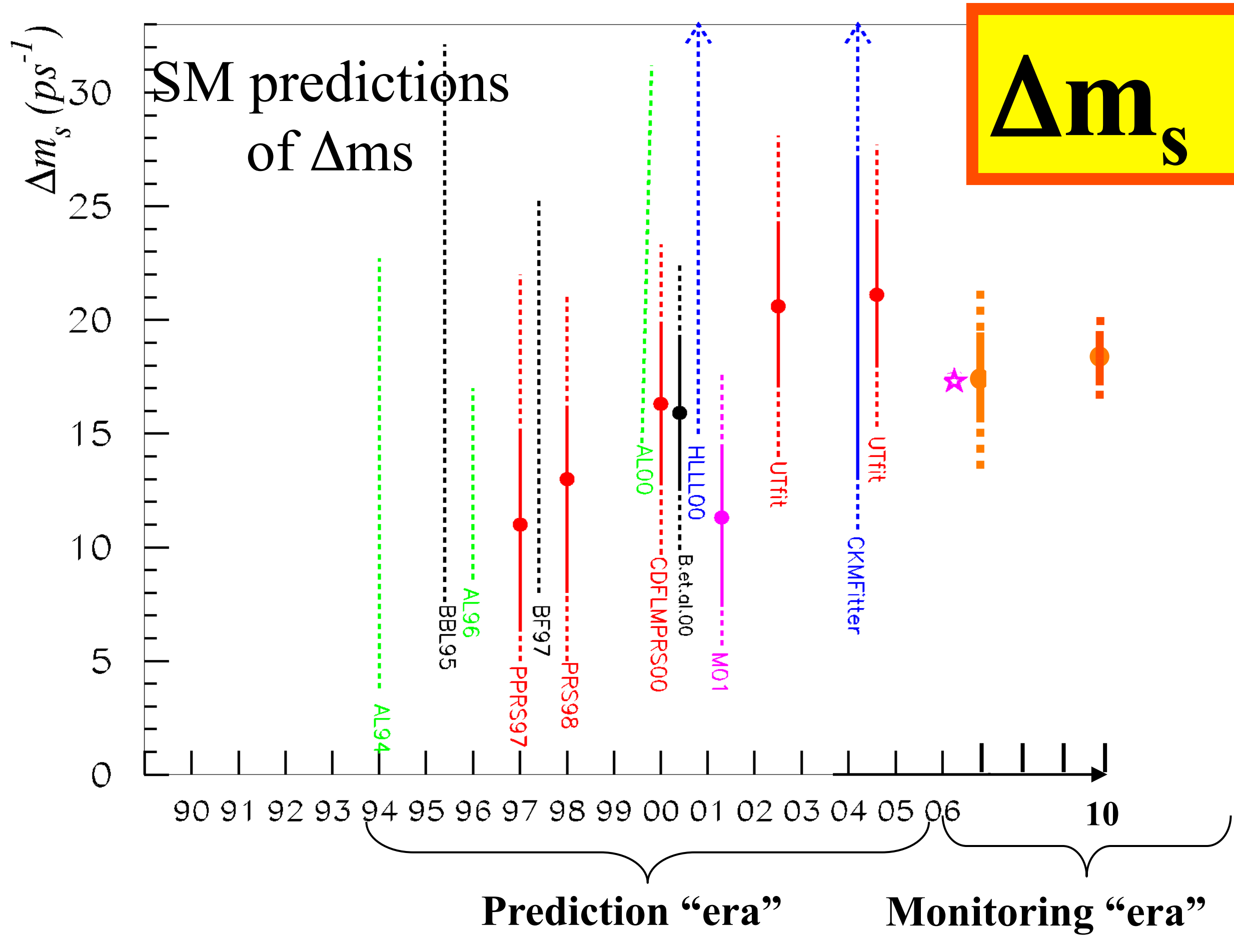
UT-lattice



$\rho = 0.155 \pm 0.038$

$\eta = 0.404 \pm 0.039$

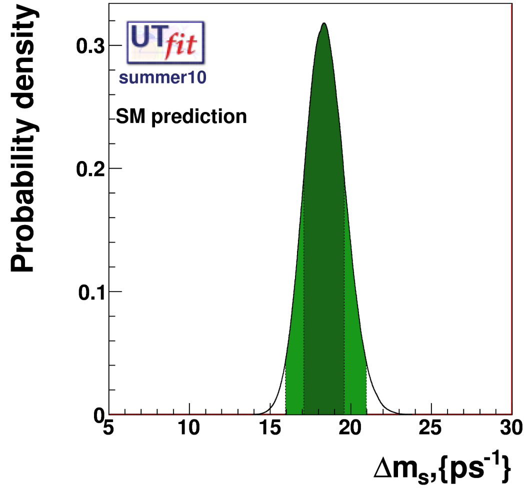
ANGLES VS LATTICE 2011



Δm_s

SM expectation

$\Delta m_s = (18.3 \pm 1.3\ )\ ps^{-1}$



Exp

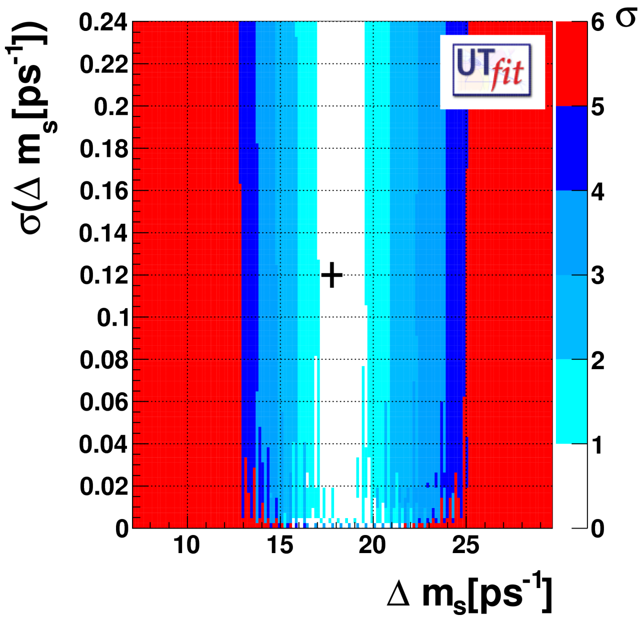
$\Delta m_s = (17.77 \pm 0.12\ )\ ps^{-1}$

Legenda

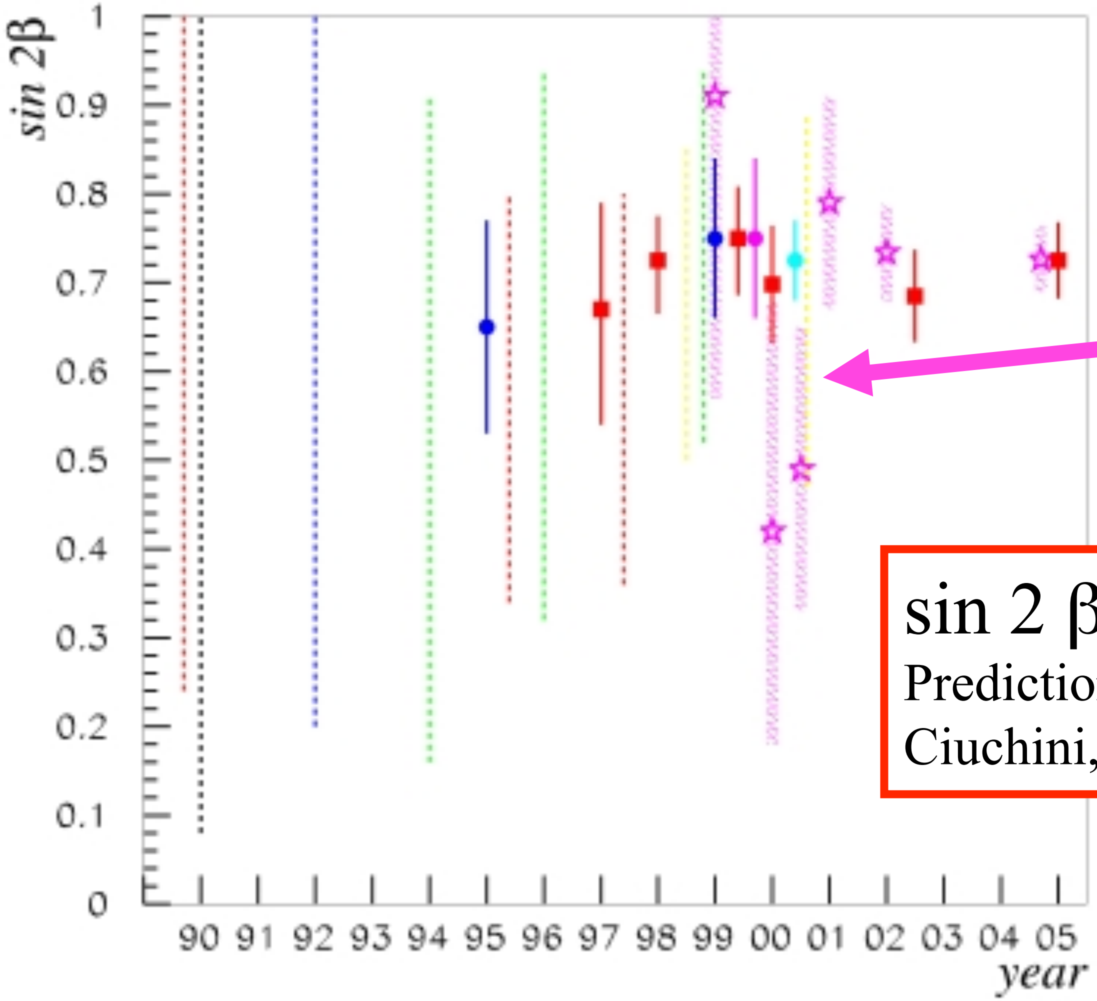
agreement between the predicted values and the measurements at better than :

1σ 3σ 5σ

2σ 4σ 6σ



Theoretical predictions of Sin 2 β in the years



predictions exist since '95

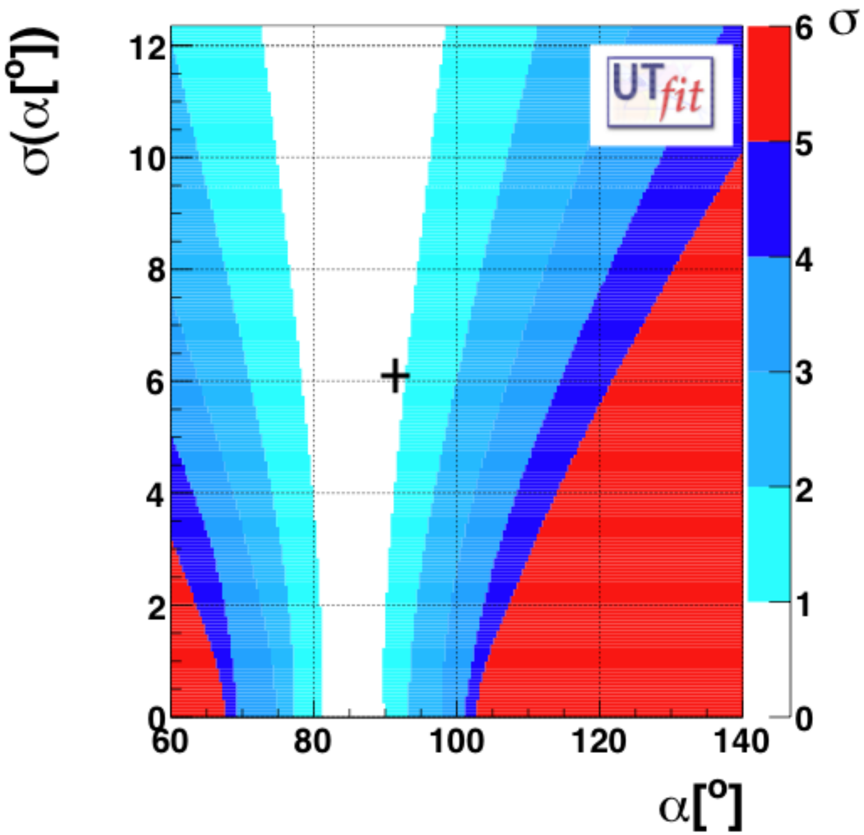
experiments

$\sin 2\beta_{UTA} = 0.65 \pm 0.12$

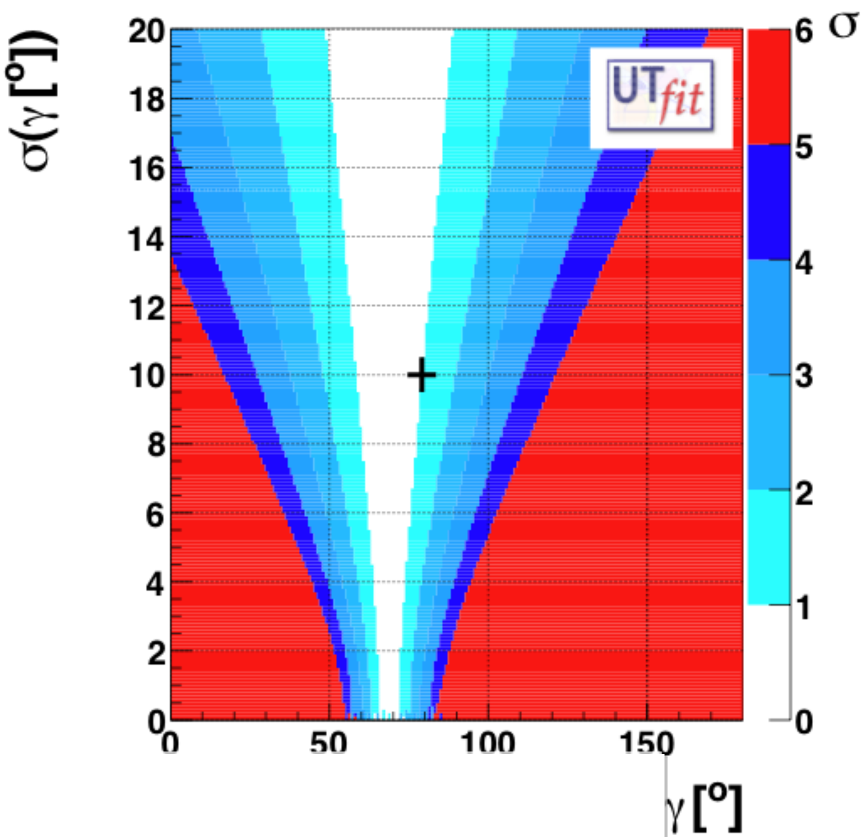
Prediction 1995 from Ciuchini,Franco,G.M.,Reina,Silvestrini

Compatibility plots

They are a procedure to ``measure'' the agreement of a single measurement with the indirect determination from the fit

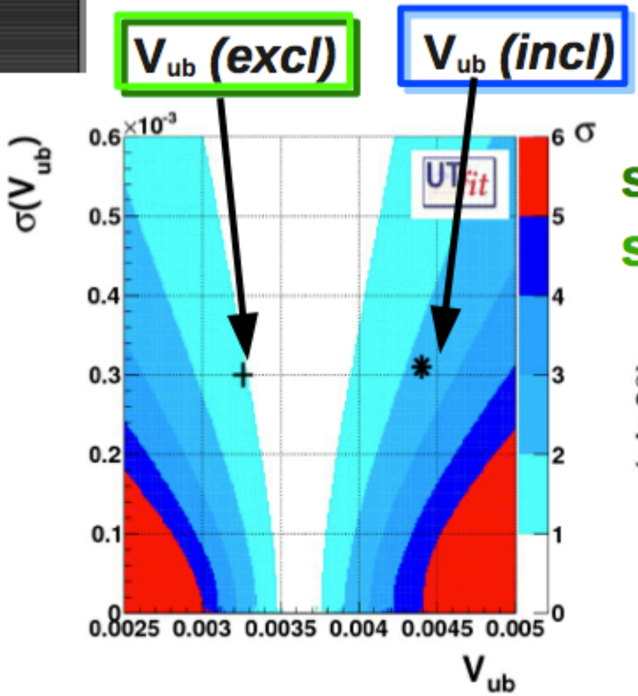


$\alpha_{exp} = (91 \pm 6)^0$



$\gamma_{exp} = (76 \pm 11)^0$

tensions



<1σ

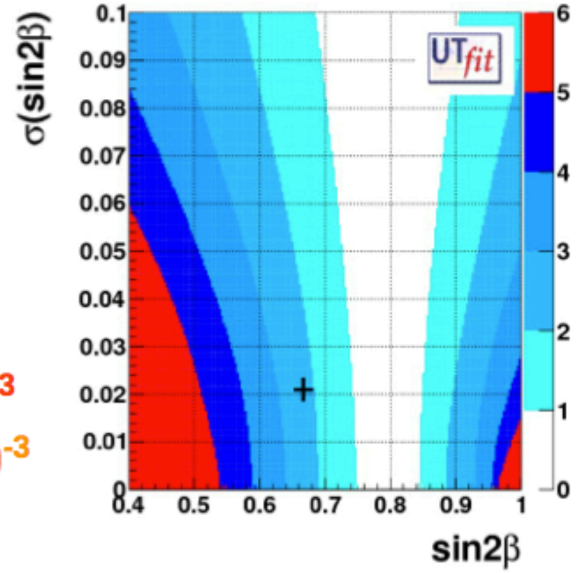
$Vub_{exp} = (3.83 \pm 0.57) \cdot 10^{-3}$

$Vub_{UTfit} = (3.63 \pm 0.15) \cdot 10^{-3}$

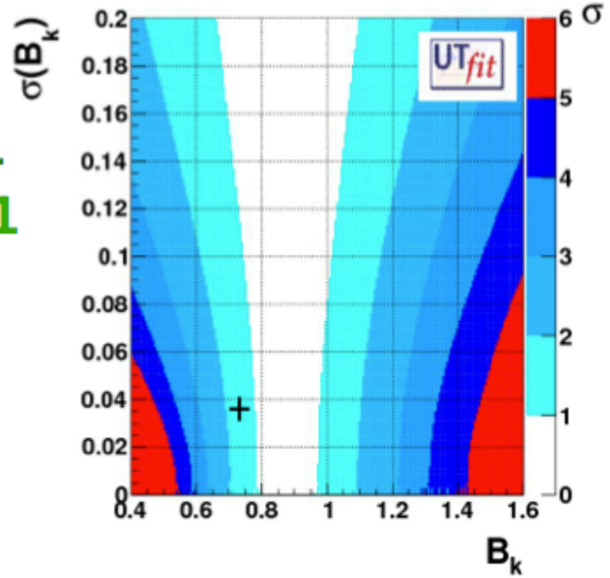
~2.3σ

$\sin 2\beta_{exp} = 0.667 \pm 0.021$

$\sin 2\beta_{UTfit} = 0.795 \pm 0.051$



~1.4σ



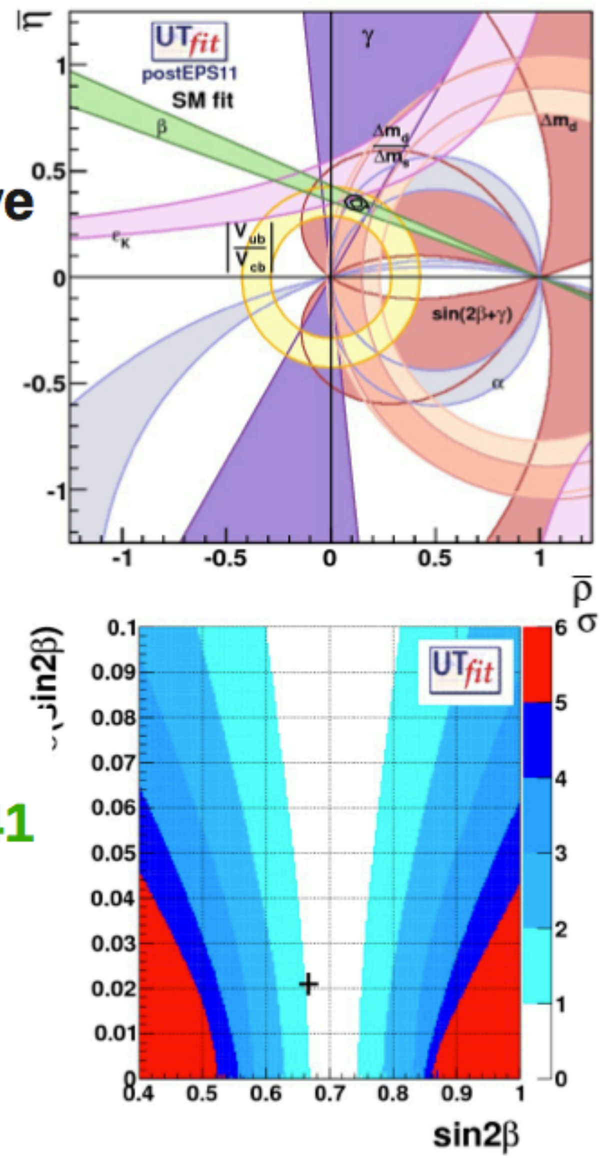
$BK_{exp} = 0.731 \pm 0.036$

$BK_{UTfit} = 0.88 \pm 0.09$

Vub incl = 4.40± 0.31 10^{-3}
Vub excl = 3.26± 0.30 10^{-3}

Vcb incl = 41.7± 0.7 10^{-3}
Vcb excl = 39.5± 1.0 10^{-3}

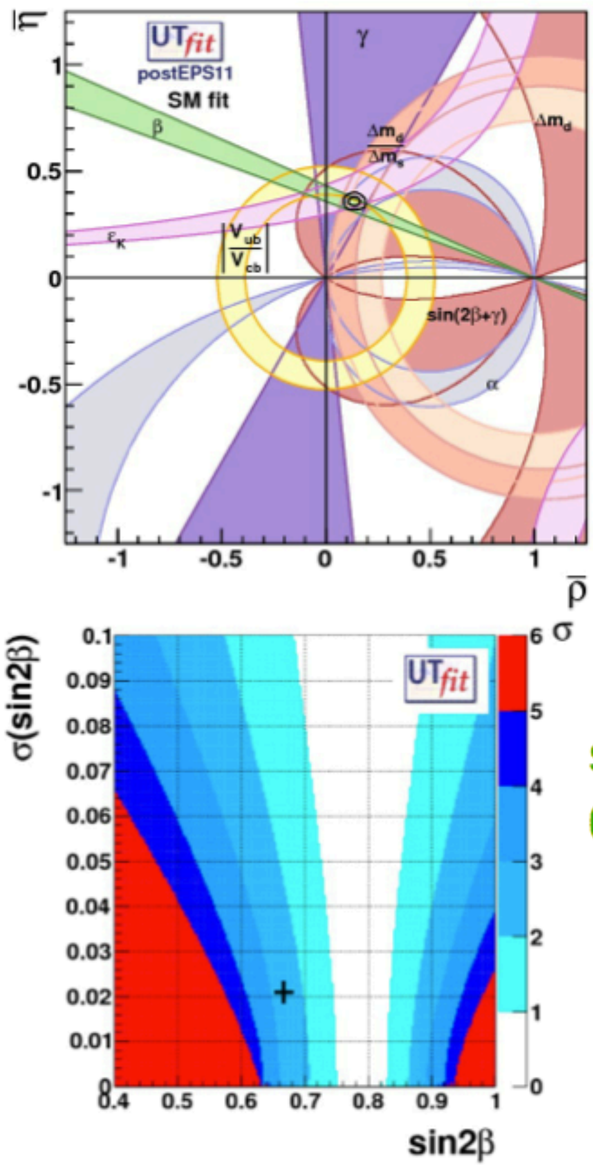
only exclusive values



$\sin2\beta_{UTfit} = 0.706 \pm 0.041$

~0.8σ

only inclusive values



$\sin2\beta_{UTfit} = 0.791 \pm 0.041$

~2.6σ

$\sin2\beta_{UTfit} = 0.76 \pm 0.10$ ¬ ***no semileptonic***

~0.9σ

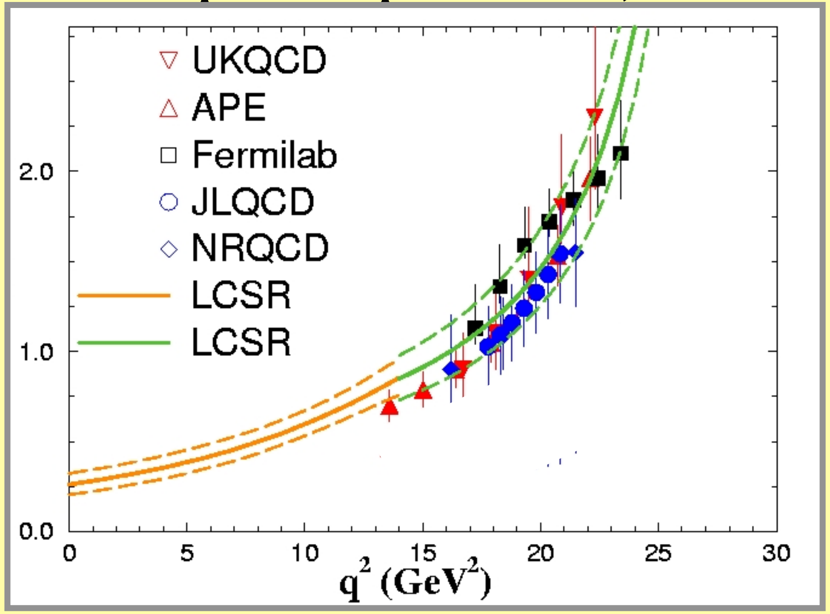
V_{UB} PUZZLE

Inclusive: uses non perturbative parameters most **not** from lattice QCD (fitted from the lepton spectrum)

$$\bar{\Lambda} \quad \lambda_1 \sim \frac{\bar{b}\vec{D}^2 b}{2m_b} \quad \lambda_2 \sim \frac{\bar{b}\sigma_{\mu\nu}G^{\mu\nu}b}{2m_b}$$

Exclusive: uses non perturbative form factors from LQCD and QCDSR

$$f^+(q^2) \quad V(q^2) \quad A_{1,2}(q^2)$$



V_{cb} & V_{ub}

AFTER EPS-HEP2011

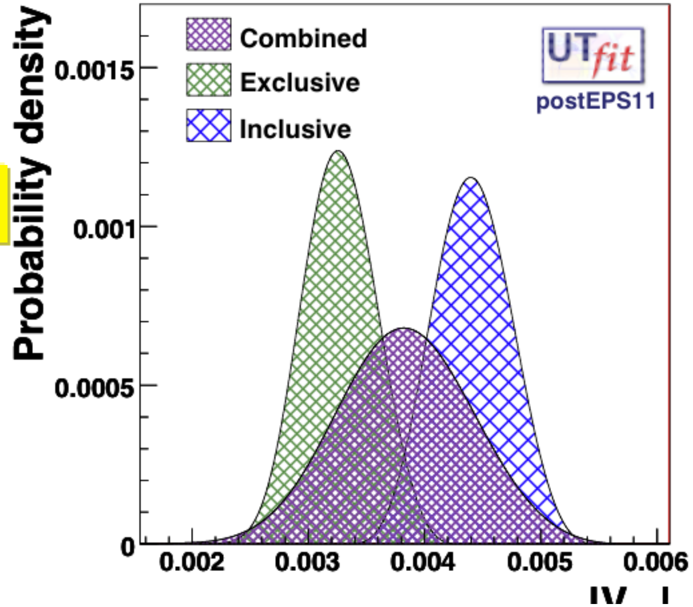
V_{ub} (excl) = $(3.26 \pm 0.30)\ 10^{-3}$

~2σ difference

V_{ub} (inc) = $(4.40 \pm 0.31)\ 10^{-3}$

V_{ub} (com) = $(3.83 \pm 0.57)\ 10^{-3}$

15% uncertainty

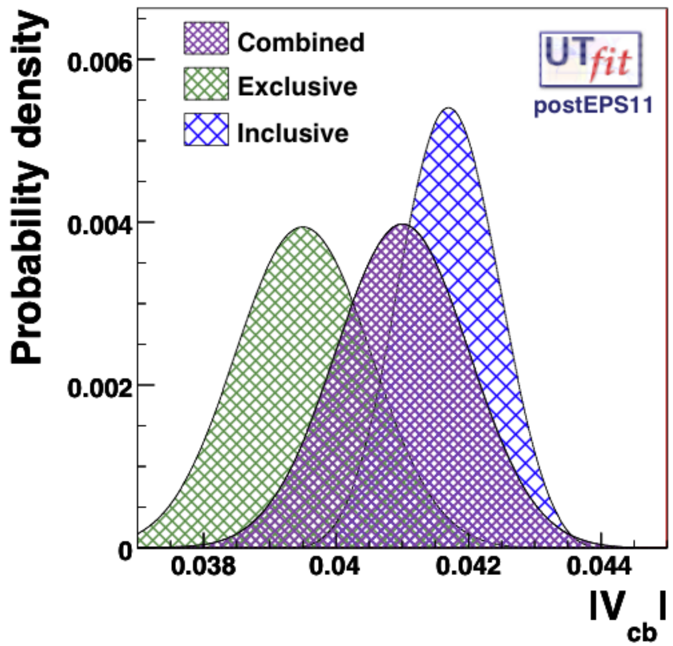


V_{cb} (excl) = $(39.5 \pm 1.0)\ 10^{-3}$

V_{cb} (inc) = $(41.7 \pm 0.7)\ 10^{-3}$

V_{cb} (com) = $(41.0 \pm 1.0)\ 10^{-3}$

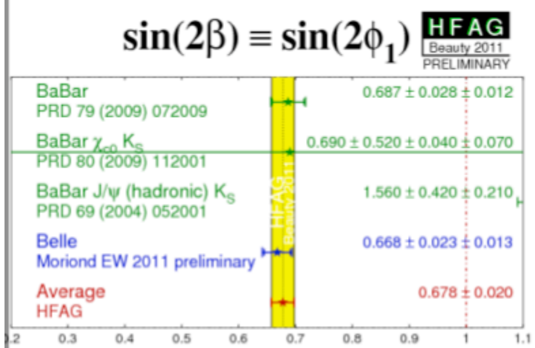
2.4% uncertainty



sin2β(excl) = 0.706 ± 0.041
0.8 σ from direct measurement

sin2β(incl) = 0.791 ± 0.041
2.6 σ from direct measurement

Latest sin2β results:



BABAR Collaboration
Physical Review D 79:072009, 2009

BaBar with 465 10^6 $B\bar{B}$ pairs
sin2β = 0.666 ± 0.031 ± 0.013

Belle with 772 10^6 $B\bar{B}$ pairs
sin2β = 0.663 ± 0.025 ± *0.013*

Belle Collaboration
Moriond EW 2011, preliminary

UTfit input value

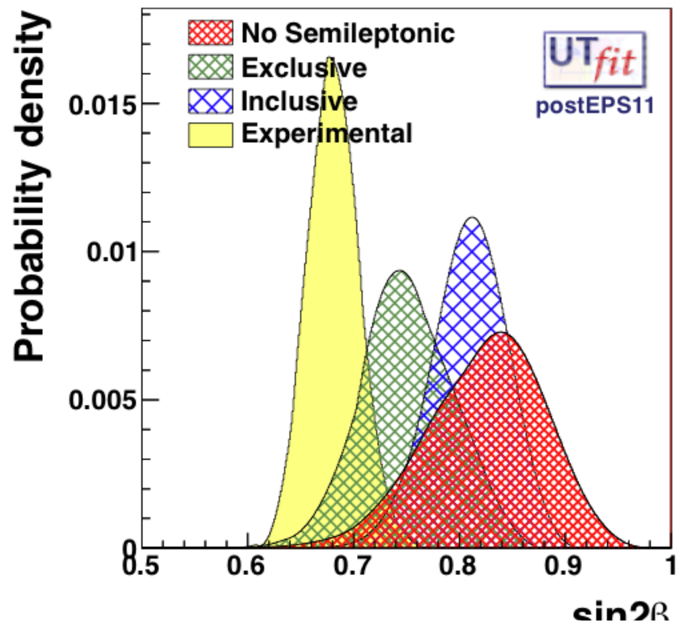
sin2β(J/ψK⁰) = 0.664 ± 0.022

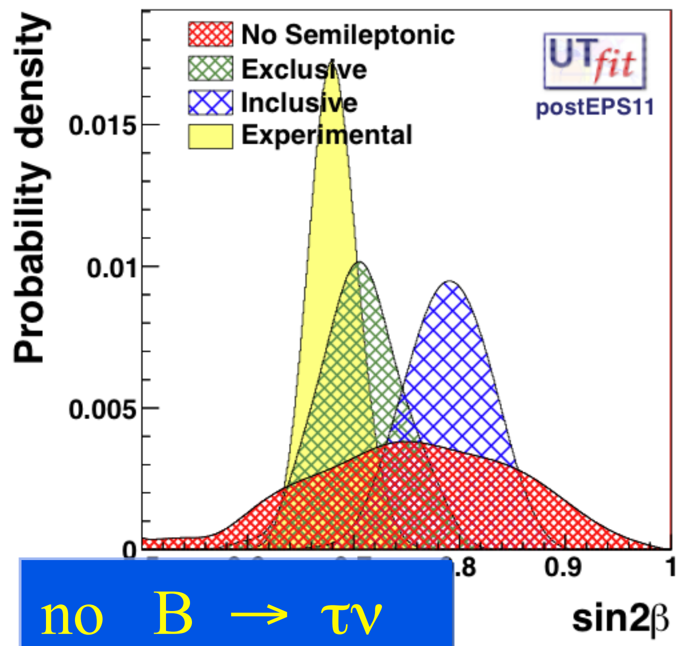
EPS2011 update from Belle:
sin2β(J/ψK⁰) = 0.668 ± 0.026
so new average should be
sin2β(J/ψK⁰) = 0.667 ± 0.021

data-driven theoretical uncertainty

ΔS = 0.000 ± 0.012

M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)





no $B \to \tau\nu$

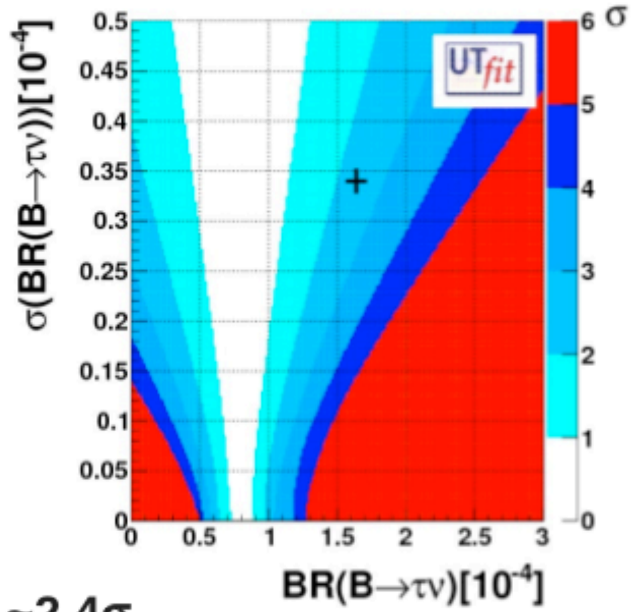
more standard model predictions:

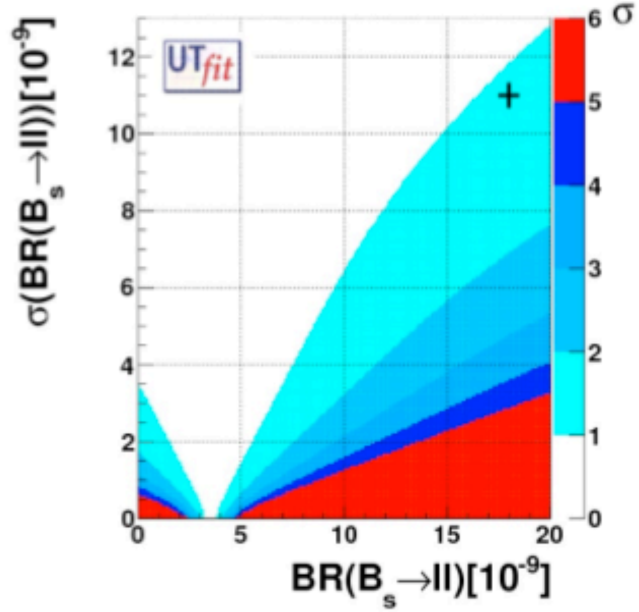
current HFAG world average

$BR(B \to \tau\nu) = (1.64 \pm 0.34)\ 10^{-4}$

latest CDF result

$BR(B_s \to \mu\mu) = (18^{+11}_{-9})\ 10^{-9}$





~2.4σ

indirect determinations from UT

$BR(B \to \tau\nu) = (0.79 \pm 0.08)\ 10^{-4}$

$BR(B_s \to ll) = (3.54 \pm 0.29)\ 10^{-9}$

M.Bona et al
0908.3470 [hep-ph]

Summary Table of the Pulls

	Prediction	Measurement	σ
γ	$(69 \pm 3)°$	$(79 \pm 10)°$	0.9
α	$(85 \pm 4)°$	$(91 \pm 6)°$	0.7
$\sin 2\beta$	0.795±0.051	0.667±0.021	2.3
V_{ub} $[10^3]$	3.63±0.15	3.83 ±0.57	0.3
$Br(B \to ll)$ 10^{-9}	3.55 ±0.28	18 ±11	+1.3
B_K $[10^3]$	0.88 ±0.09	0.731 ±0.036	1.4
$Br(B \to \tau \nu)$ 10^{-4}	0.83±0.08	1.64±0.34	2.3
Δm_s (ps^{-1})	19.1±1.5	17.70±0.08	1.0

What for a ``standardissimo" CKM which agrees so well with the experimental observations?

New Physics at the EW scale is "flavor blind" -> MINIMAL FLAVOR VIOLATION, namely flavour originates only from the Yukawa couplings of the SM

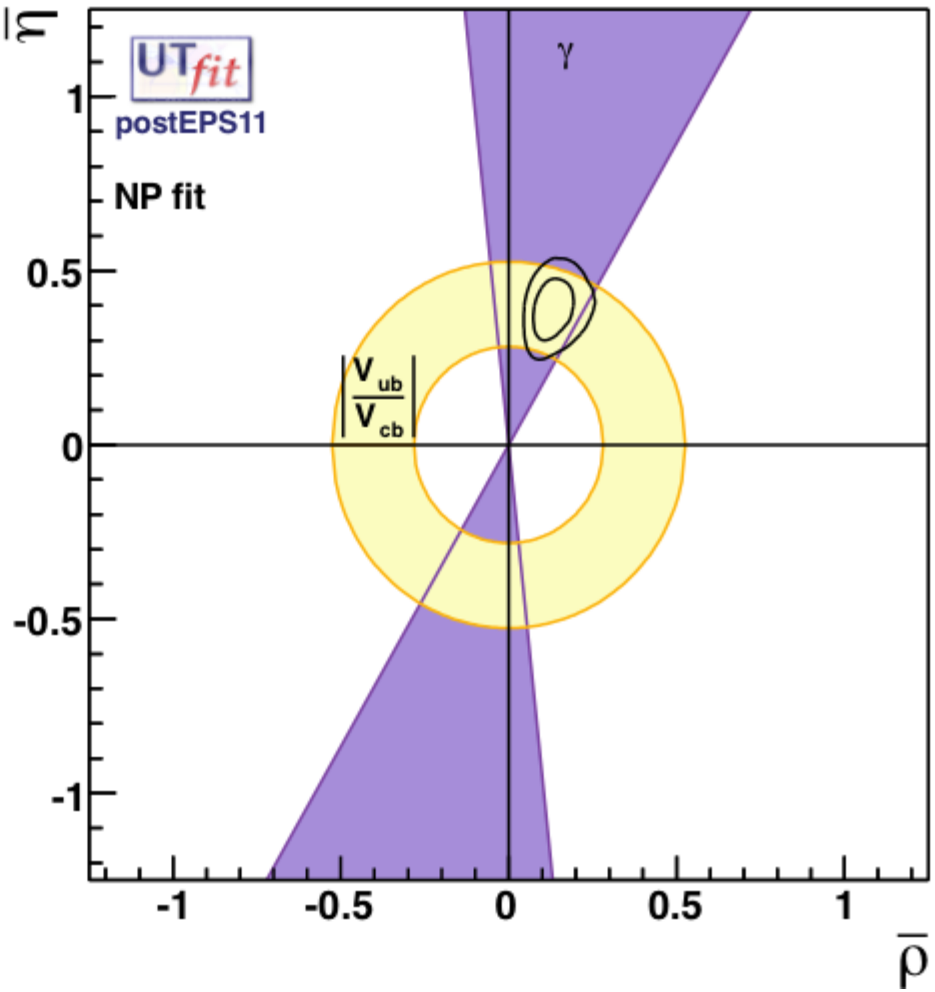
New Physics introduces new sources of flavour, the contribution of which, at most < 20 % , should be found in the present data, e.g. in the asymmetries of Bs decays

…. beyond the Standard Model

Only tree level processes Vub/Vcb and B-> DK$^{(*)}$

CP VIOLATION PROVEN IN THE SM !!

degeneracy of γ broken by A_{SL}



$$A^s_{SL} = \frac{\Gamma(\bar{B}_s \to l^+X) - \Gamma(B_s \to l^-X)}{\Gamma(\bar{B}_s \to l^+X) + \Gamma(B_s \to l^-X)} = Im\left(\frac{\Gamma^s_{12}}{A_s}\right)$$

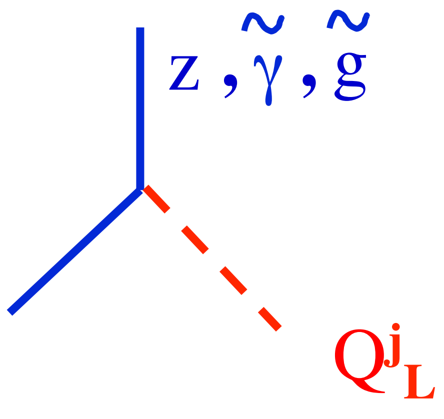
$$Q^{EXP} = V_{CKM}\langle F|\hat{O}|I\rangle$$

$$Q^{EXP} = \sum_i C^i_{SM}(M_W, m_t, \alpha_s)\langle F|\hat{O}_i|I\rangle + \sum_{i'} C^{i'}_{Beyond}(\tilde{m}_\beta, \alpha_s)\langle F|\hat{O}_{i'}|I\rangle$$

In general the mixing mass matrix of the SQuarks (SMM) is not diagonal in flavour space analogously to the quark case We may either

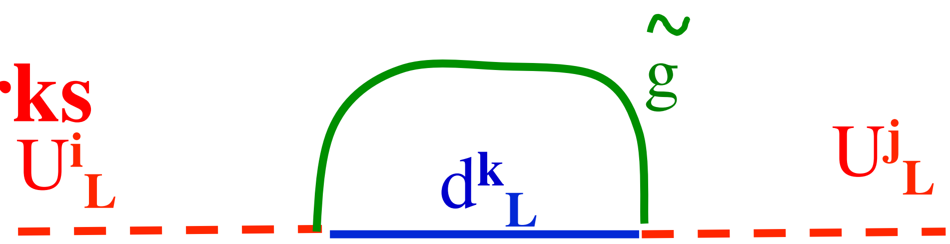
Diagonalize the SMM

FCNC

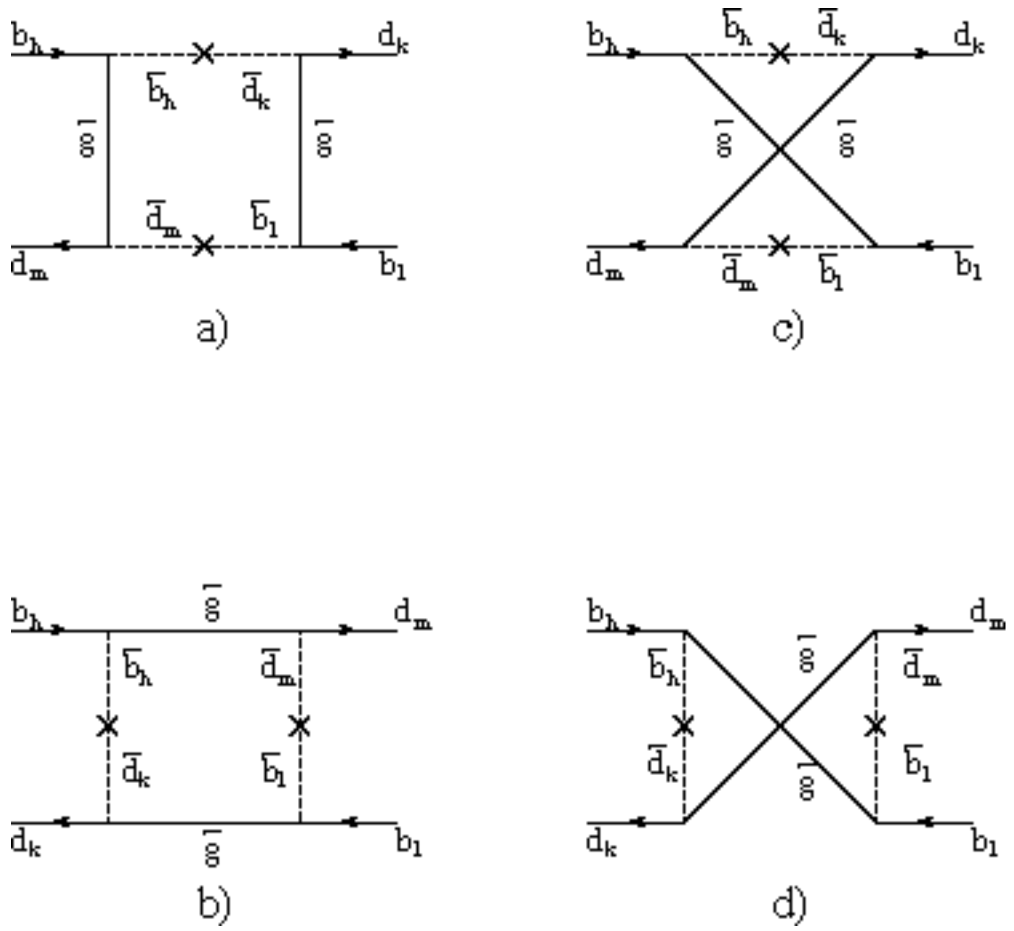


or Rotate by the same matrices the SUSY partners of the u- and d- like quarks

$(Q^j_L)' = U^{ij}_L \, Q^j_L$



In the latter case the Squark Mass Matrix is not diagonal



$$(\tilde{m}^2{}_Q)_{ij} = m^2{}_{average}\, 1_{ij} + \Delta m_{ij}{}^2 \qquad \delta_{ij} = \Delta m_{ij}{}^2 / m^2{}_{average}$$

New local four-fermion operators are generated

$Q_1 = (\bar{b}_L{}^A \gamma_\mu d_L{}^A)\,(\bar{b}_L{}^B \gamma_\mu d_L{}^B)$ SM

$Q_2 = (\bar{b}_R{}^A d_L{}^A)\,(\bar{b}_R{}^B d_L{}^B)$

$Q_3 = (\bar{b}_R{}^A d_L{}^B)\,(\bar{b}_R{}^B d_L{}^A)$

$Q_4 = (\bar{b}_R{}^A d_L{}^A)\,(\bar{b}_L{}^B d_R{}^B)$

$Q_5 = (\bar{b}_R{}^A d_L{}^B)\,(\bar{b}_L{}^B d_R{}^A)$

+ those obtained by L $\leftrightarrow$ R

Neutral Kaon Mixing Beyond the SM from $N_f = 2$ tmQCD

V. Bertone[(a)], N. Carrasco-Vela[(b)], P. Dimopoulos[(c)], R. Frezzotti[(c,d)], V. Gimenez[(b)], V. Lubicz[(e,f)], G. Martinelli[(g,h)], F. Mescia[(i)], M. Papinutto[(j)], G.C. Rossi[(c,d)], S. Simula[(f)], A. Vladikas[(d)]

$$\langle \bar{K}^0 | O_1(\mu) | K^0 \rangle = \frac{8}{3} M_K^2 f_K^2 \, B_1(\mu) \,,$$

$$\langle \bar{K}^0 | O_2(\mu) | K^0 \rangle = -\frac{5}{3} \left(\frac{M_K}{m_s(\mu) + m_d(\mu)} \right)^2 M_K^2 f_K^2 \, B_2(\mu) \,,$$

$$\langle \bar{K}^0 | O_3(\mu) | K^0 \rangle = \frac{1}{3} \left(\frac{M_K}{m_s(\mu) + m_d(\mu)} \right)^2 M_K^2 f_K^2 \, B_3(\mu) \,,$$

$$\langle \bar{K}^0 | O_4(\mu) | K^0 \rangle = 2 \left(\frac{M_K}{m_s(\mu) + m_d(\mu)} \right)^2 M_K^2 f_K^2 \, B_4(\mu) \,,$$

$$\langle \bar{K}^0 | O_5(\mu) | K^0 \rangle = \frac{2}{3} \left(\frac{M_K}{m_s(\mu) + m_d(\mu)} \right)^2 M_K^2 f_K^2 \, B_5(\mu) \,,$$

Similarly for the s quark e.g.

$(\bar{s}_R{}^A d_L{}^A)\,(\bar{s}_R{}^B d_L{}^B)$

B_s mixing , a road to New Physics (NP) ?

The Standard Model contribution to CP violation in B_s mixing is well predicted and rather small

2009

- Sin $2\beta_s$= 0.037 ± 0.002 (SM or MFV)

The phase of the mixing amplitudes can be extracted from $B_s \to J/\Psi\ \varphi$ with a relatively small th. uncertainty. A phase very different from 0.04 implies **NP in B_s mixing**

Main Ingredients and General Parametrizations

Fit simultaneously CKM and NP parameters (generalized Utfit)

$$H^{\Delta F=2} = \hat{m} - \frac{i}{2}\hat{\Gamma} \quad A = \hat{m}_{12} = \langle \bar{M}|\hat{m}|M\rangle \quad \Gamma_{12} = \langle \bar{M}|\hat{\Gamma}|M\rangle$$

Neutral Kaon Mixing

$$Re A_K = C_{\Delta m_K} Re A_K^{SM} \qquad Im A_K = C_\varepsilon Im A_K^{SM}$$

B_d and B_s mixing

$$A_q e^{2i\phi_q} \equiv C_{B_q} e^{2i\phi_{B_q}} \times A_q^{SM} e^{2i\phi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP} - \phi_q^{SM})}\right) \times A_q^{SM} e^{2i\phi_q^{SM}}$$

$$C_{B_s} e^{2i\phi_{B_s}} = \frac{A_s^{SM} e^{-2i\beta_s} + A_s^{NP} e^{2i(\phi_s^{NP} - \beta_s)}}{A_s^{SM} e^{-2i\beta_s}} = \frac{\langle \bar{B}_s | H_{eff}^{full} | B_s \rangle}{\langle \bar{B}_s | H_{eff}^{SM} | B_s \rangle}$$

$$\frac{\Gamma_{12}^q}{A_q} = -2\frac{\kappa}{C_{B_q}} \left\{ e^{i2\phi_{B_q}} \left(n_1 + \frac{n_6 B_2 + n_{11}}{B_1}\right) - \frac{e^{i(\phi_q^{SM} + 2\phi_{B_q})}}{R_t^q} \left(n_2 + \frac{n_7 B_2 + n_{12}}{B_1}\right) \right.$$
$$+ \frac{e^{i2(\phi_q^{SM} + \phi_{B_q})}}{R_t^{q^2}} \left(n_3 + \frac{n_8 B_2 + n_{13}}{B_1}\right) + e^{i(\phi_q^{Pen} + 2\phi_{B_q})} C_q^{Pen} \left(n_4 + n_9 \frac{B_2}{B_1}\right)$$
$$\left. - e^{i(\phi_q^{SM} + \phi_q^{Pen} + 2\phi_{B_q})} \frac{C_q^{Pen}}{R_t^q} \left(n_5 + n_{10} \frac{B_2}{B_1}\right) \right\}$$

C_q^{Pen} and ϕ_q^{Pen} parametrize possible NP contributions to Γ^q_{12} from b -> s penguins

Physical observables

$$\Delta m_s = |A_s| = C_{B_s} \Delta m_s^{SM}$$

$$2\phi_s = -\arg A_s = 2\,(\beta_s - \phi_{B_s})$$

$$A_{SL}^s = \frac{\Gamma(\bar{B}_s \to l^+ X) - \Gamma(B_s \to l^- X)}{\Gamma(\bar{B}_s \to l^+ X) + \Gamma(B_s \to l^- X)} = Im\left(\frac{\Gamma_{12}^s}{A_s}\right)$$

$$A_{SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{SL}^d + f_s \chi_{s0} A_{SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$$

$$\frac{\Delta\Gamma_s}{\Delta m_s} = Re\left(\frac{\Gamma_{12}^s}{A_s}\right) \qquad \tau_{B_s}^{FS} = \frac{1}{\Gamma_S} \frac{1 + (\Delta\Gamma_s/2\Gamma_s)^2}{1 - (\Delta\Gamma_s/2\Gamma_s)^2}$$

Experimental measurements

new-physics-specific constraints

semileptonic asymmetry:
sensitive to NP effects in both size and phase

D0
Phys.Rev.D82:012003,2010

$$A_{SL}^{s} \times 10^{2} = -0.17 \pm 0.91$$

same-side dilepton charge asymmetry:
admixture of B_s and B_d so sensitive to NP effects in both systems

$$A_{SL}^{\mu\mu} \times 10^{3} = -7.9 \pm 2.0$$

D0 arXiv:1106.6308

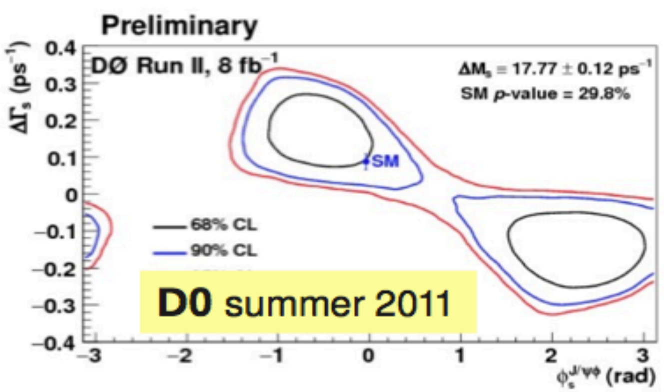
lifetime τ^{FS} in flavour-specific final states:
average lifetime is a function to the width and the width difference (independent data sample)

HFAG

$$\tau_{B_s}^{FS}\ [\mathrm{ps}] = 1.417 \pm 0.042$$

$\phi_s = 2\beta_s$ vs $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$

angular analysis as a function of proper time and b-tagging
additional sensitivity from the $\Delta\Gamma_s$ terms



D0 summer 2011

ϕ_s and $\Delta\Gamma_s$:
2D experimental likelihood from D0

SM	→	SM+NP
$(V_{ub}/V_{cb})^{SM}$ γ^{SM}	**tree level**	$(V_{ub}/V_{cb})^{SM}$ γ^{SM}
β^{SM} α^{SM} Δm_d	***Bd Mixing***	$\beta^{SM}+\phi_{Bd}$ $\alpha^{SM}-\phi_{Bd}$ $C_{Bd}\Delta m_d$
Δm_s^{SM} $-\beta_s^{SM}$	***Bs Mixing***	$C_{Bs}\Delta m_s^{SM}$ $-\beta_s^{SM}+\phi_{Bs}$
ε_K^{SM} Δm_K^{SM}	***K Mixing***	$C_{\varepsilon_K}\varepsilon_K^{SM}$ $C_{\Delta mK}\Delta m_K^{SM}$

NP model independent Fit $\Delta F=2$

Parametrizing NP physics in ΔF=2 processes

$$C_{Bq} e^{2i\phi_{Bq}} = \frac{A^{NP}_{\Delta B=2} + A^{SM}_{\Delta B=2}}{A^{SM}_{\Delta B=2}}$$

$\Delta m_d^{EXP} = C_{B_d} \Delta m_d^{SM}$	$f(\rho,\eta,C_{B_d},QCD..)$
$A_{CP}(J/\Psi,K^0) = \sin(2\beta + 2\phi_{B_d})$	$f(\rho,\eta,\phi_{B_d})$
$\alpha^{EXP} = \alpha^{SM} - \phi_{B_d}$	$f(\rho,\eta,\phi_{B_d})$
$\lvert\varepsilon_K\rvert^{EXP} = C_\varepsilon \lvert\varepsilon_K\rvert^{SM}$	$f(\rho,\eta,C_\varepsilon,QCD..)$
$\Delta m_s^{EXP} = C_{B_s} \Delta m_s^{SM}$	$f(\rho,\eta,C_{Bs},QCD..)$
$A_{CP}(J/\Psi,\phi) = \sin(2\beta_s - 2\phi_{B_s})$	$f(\rho,\eta,\phi_{B_s})$
...	

Soares, Wolfenstein PRD47;
Deshpande,Dutta, Oh PRL77;
Silva, Wolfenstein PRD55;
Cohen et al. PRL78;
Grossman, Nir, Worah PLB407;
Ciuchini et al. @ CKM Durham

		ρ , η	C_d	φ_d	C_s	φ_s	$C_{\varepsilon K}$
Tree processes	γ (DK)	X					
	V_{ub}/V_{cb}	X					
1↔3 family	Δm_d	X	X				
	ACP (J/Ψ K)	X		X			
	ACP (Dπ(ρ),DKπ)	X		X			
	A_{SL}		X	X			
	α (ρρ,ρπ,ππ)	X		X			
	A_{CH}		X	X	X	X	
2↔3 family	τ(Bs), $\Delta\Gamma_s/\Gamma_s$				X	X	
	Δm_s				X		
	ASL(Bs)				X	X	
	ACP (J/Ψ φ)	~X				X	
1↔2 familiy	ε_K	X					X

5 new free parameters	
C_s,φ_s	B_s mixing
C_d,φ_d	B_d mixing
$C_{\varepsilon K}$	K mixing

Today :

fit is overcontrained

Possible to fit 7 free parameters

(ρ, η, C_d,φ_d, C_s,φ_s, $C_{\varepsilon K}$)

SM analysis → **NP-ΔF=2 analysis**

$\rho = 0.132 \pm 0.020$ → $\rho = 0.129 \pm 0.040$

$\eta = 0.353 \pm 0.014$ → $\eta = 0.392 \pm 0.054$

ρ,η fit quite precisely in NP-ΔF=2 analysis and consistent with the one obtained on the SM analysis [error increases]

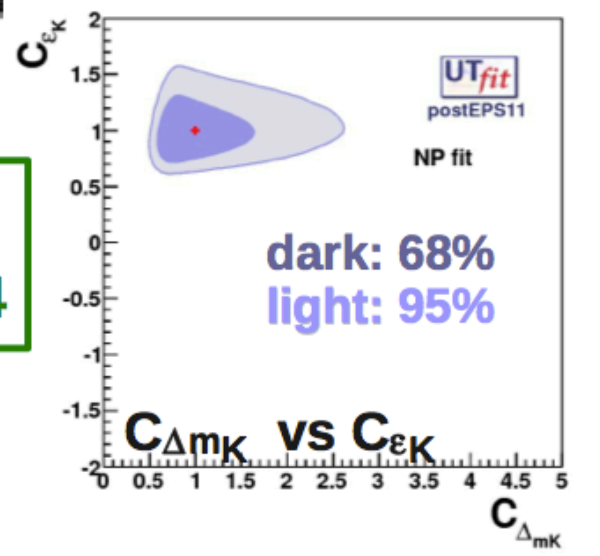
(main contributors tree-level γ and V_{ub})

Please consider these numbers when you want to get CKM parameters in the

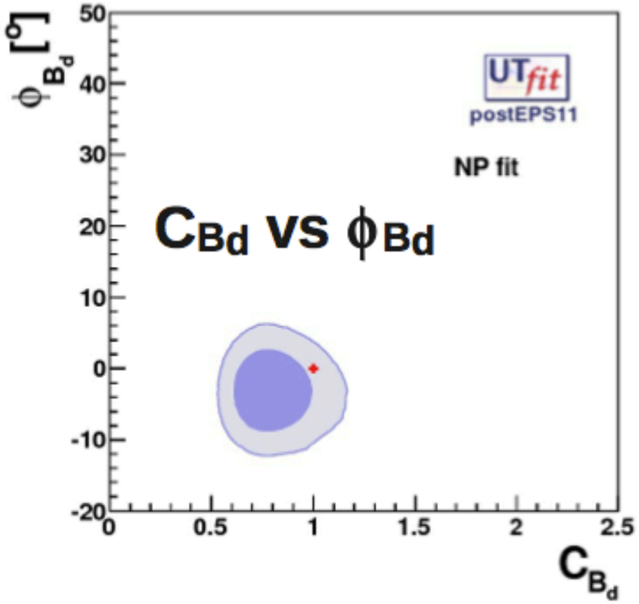
NP parameter results

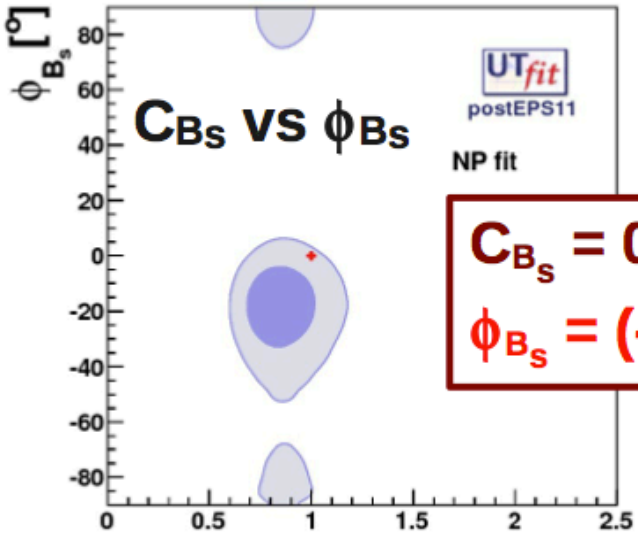
$C_{B_d} = 0.79 \pm 0.12$
$\phi_{B_d} = (-3.2 \pm 3.7)°$

$C_{\varepsilon_K} = 0.98 \pm 0.17$
$C_{\Delta mK} = 0.97 \pm 0.34$



X SM expectation





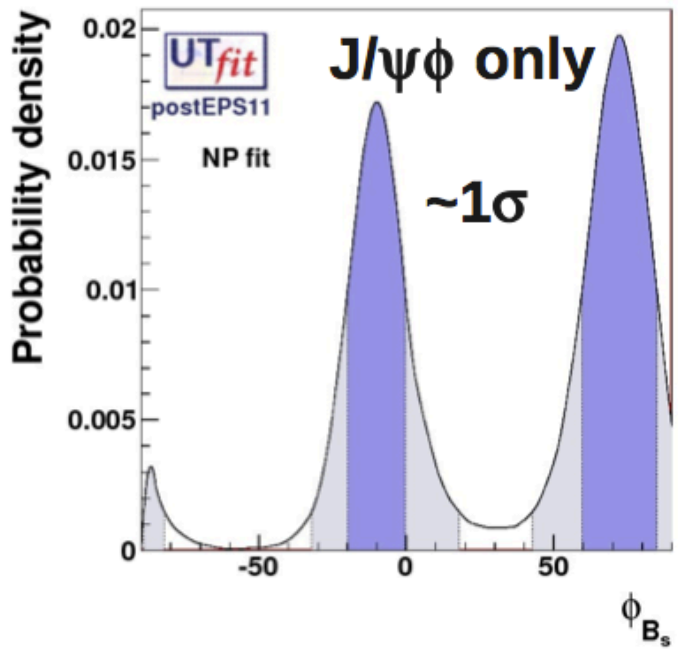
SM at ~1.6σ

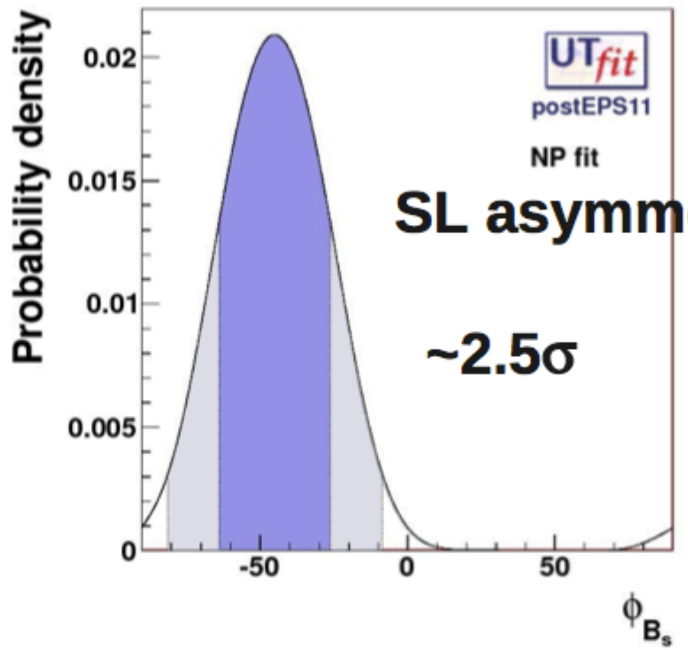
$C_{B_s} = 0.84 \pm 0.10$
$\phi_{B_s} = (-18 \pm 10)°$

post EPS 2011

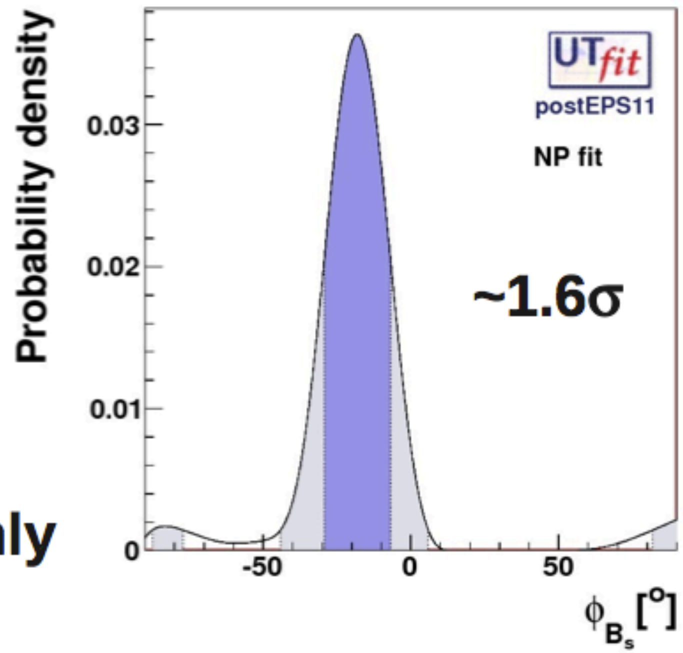
one ambiguity missing as D0 uses the sign of $B_d \rightarrow J/\psi K^*$ strong phase to eliminate it

B_s NP phase





all constraints



Effective Theory Analysis ΔF=2

Effective Hamiltonian in the mixing amplitudes

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \bar{q}_L^\alpha \gamma_\mu b_L^\alpha \, \bar{q}_L^\beta \gamma^\mu b_L^\beta \quad \text{(SM/MFV)}$$

$$Q_2 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_R^\beta b_L^\beta \qquad Q_3 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_R^\beta b_L^\alpha$$

$$Q_4 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad Q_5 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_L^\beta b_R^\alpha$$

$$\tilde{Q}_1 = \bar{q}_R^\alpha \gamma_\mu b_R^\alpha \, \bar{q}_R^\beta \gamma^\mu b_R^\beta$$

$$\tilde{Q}_2 = \bar{q}_L^\alpha b_R^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad \tilde{Q}_3 = \bar{q}_L^\alpha b_R^\beta \, \bar{q}_L^\beta b_R^\alpha$$

$$C_j(\Lambda) = \frac{LF_j}{\Lambda^2} \Rightarrow \Lambda = \sqrt{\frac{LF_j}{C_j(\Lambda)}}$$

C(Λ) coefficients are extracted from data

L is loop factor and should be :
L=1 tree/strong int. NP
$L=\alpha^2_s$ or α^2_W for stron/weak perturb. NP

$F_1=F_{SM}=(V_{tq}V_{tb}^*)^2$ $F_{j=1}=0$	**MFV**
$\lvert F_j \rvert = F_{SM}$ arbitrary phases	**NMFV**
$\lvert F_j \rvert = 1$ arbitrary phases	**Flavour generic**

Main contribution to present lower bound on NP scale come from $\Delta\Phi=2$ chirality-flipping operators (Q_4) which are RG enhanced

From Kaon sector @ 95% [TeV]			
Scenario	Strong/tree	α_s loop	α_W loop
MFV			
NMFV	107	11	3.2
Generic	~470000	~47000	~14000

From Bd&Bs sector @ 95% [TeV]			
Scenario	Strong/tree	α_s loop	α_W loop
MFV			
NMFV	8	0.8	0.25
Generic	3300	330	100

CONCLUSIONS

1) CKM matrix is the dominant source of flavour mixing and CP violation $\sigma(\rho)$~15% & $\sigma(\eta)$ ~4%

2) There are tensions that should be understood : sin2β, ε_K , Br(B→τ ν)

3) Estraction of SM predictions with different possibilities: inclusive vs exclusive, tensions pull Vub in opposite directions; better if we give up B -> τ ν

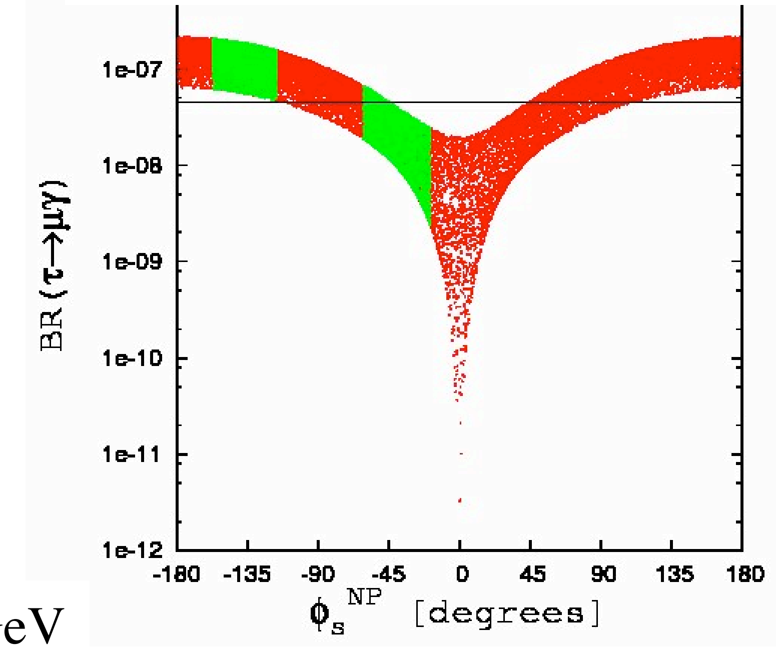
4) The suggestion of a large Bs mixing phase has not survived to LHCb measurements.

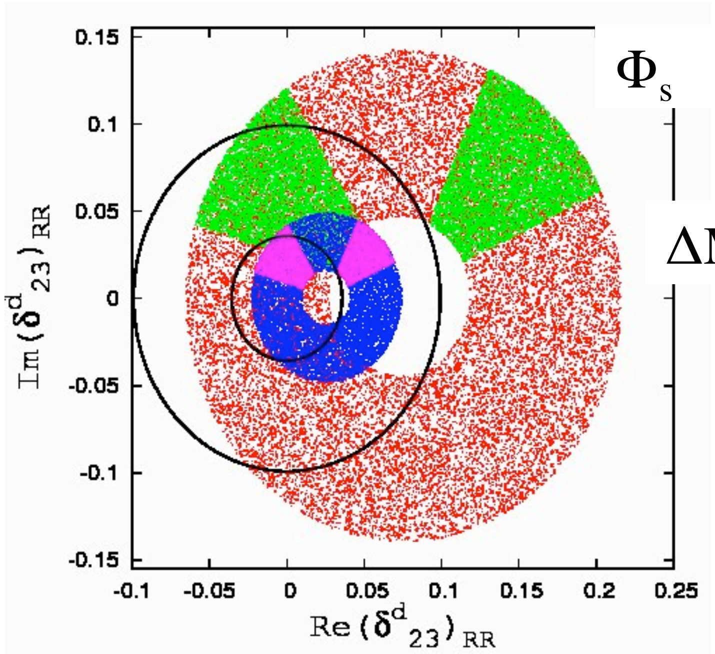
b → s & τ →μγ in SUSY GUTS

mass insertion analysis in a SUSY-GUT scheme

* RG-induced $(\delta_{23})_{LL}$
* explicit $(\delta_{23})_{RR}$

Limits from Belle and Babar < 4.5 & 6.8 10^{-8}





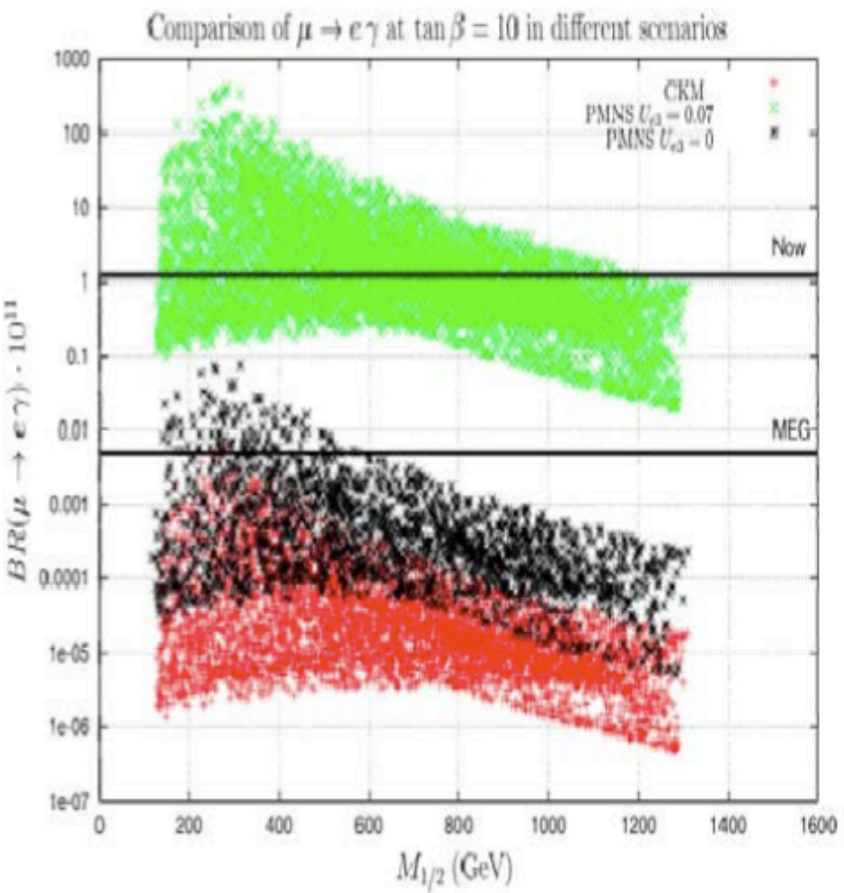
m_{sq}=500 GeV

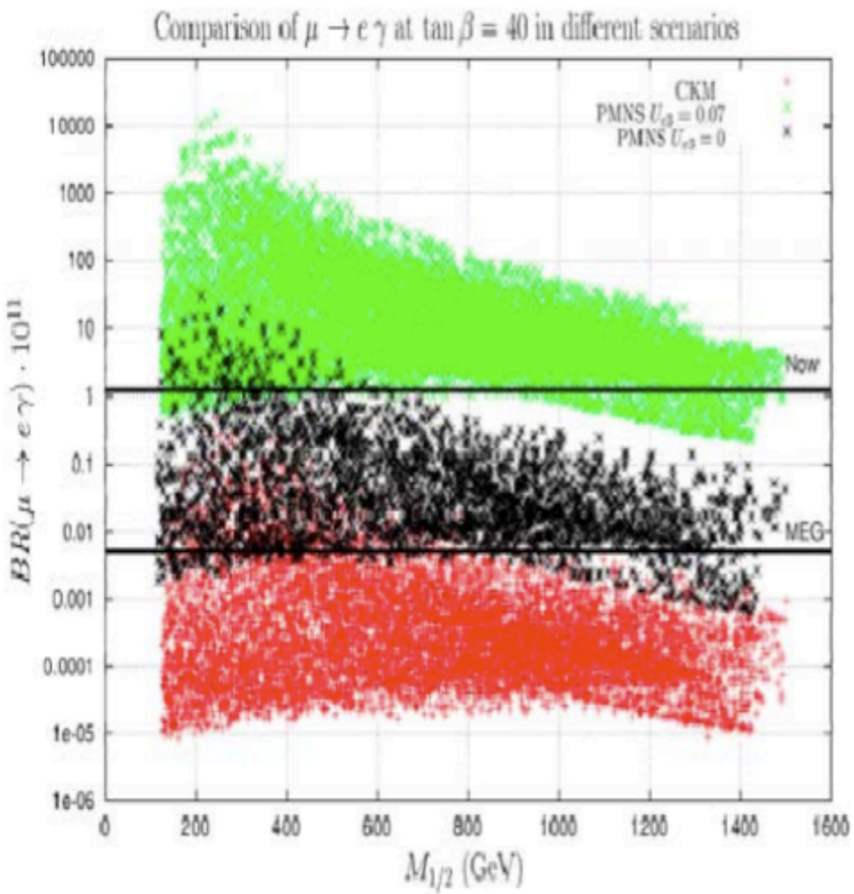
In the UTfit range for the B_s mixing phase:

$BR(\tau \to \mu\gamma) > 3 \times 10^{-9}$!!

μ ➞ e+γ in SUSYGUT: past and future

$\mu \to e\gamma$ in the $U_{e3} = 0$ PMNS case





Catena, Faccia, A.M., Vempati

We can consider simultaneously LFV, g-2 e EDM, e.g. Isidori, Mescia, Paradisi, Temes in MSSM

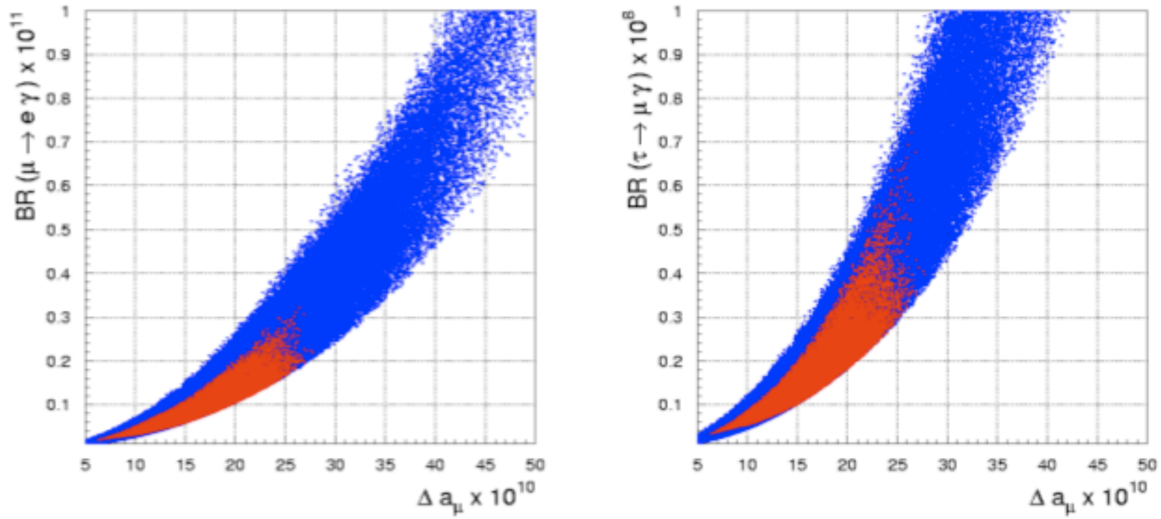
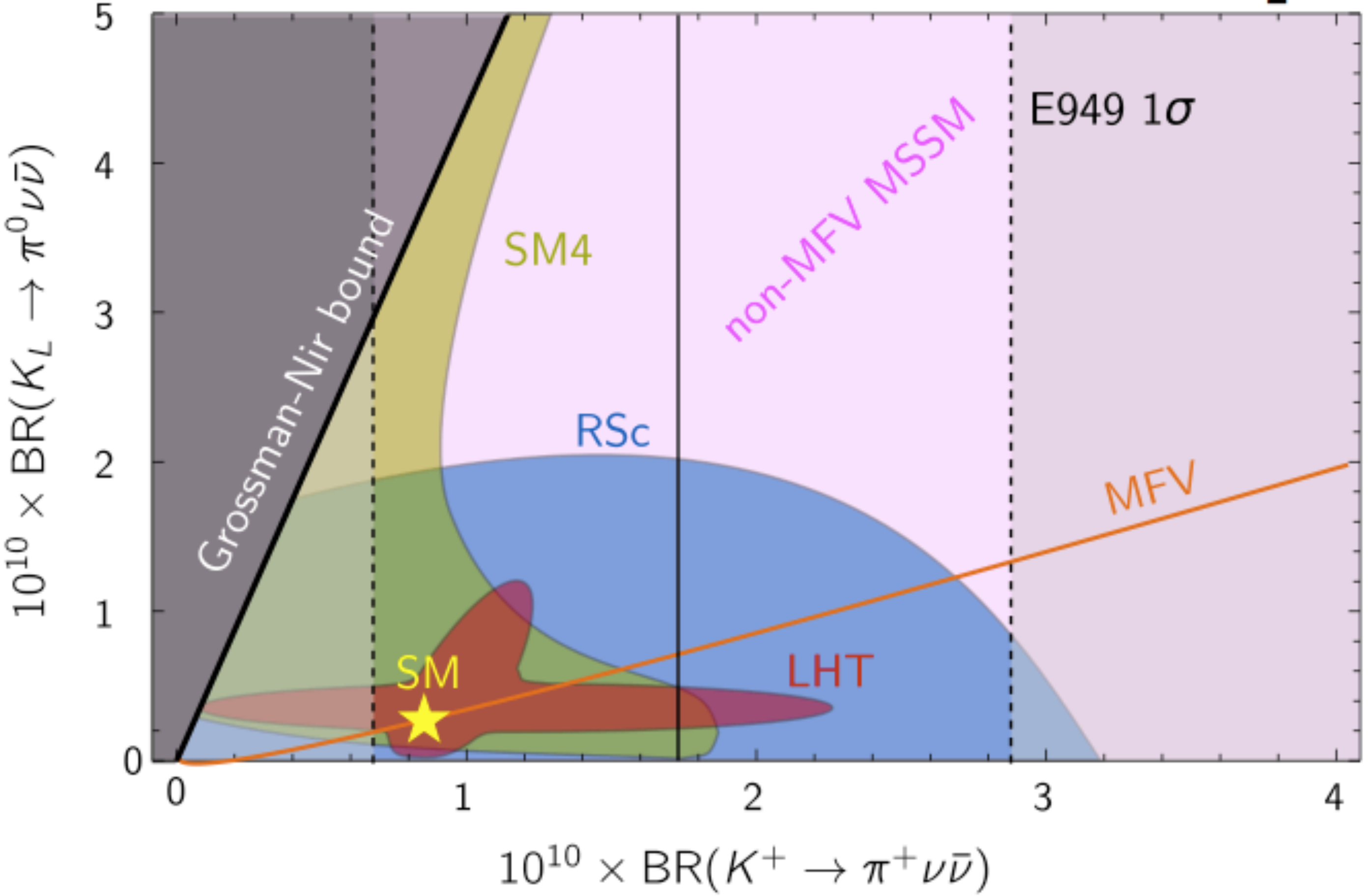


Figure 6: Expectations for $\mathcal{B}(\mu \to e\gamma)$ and $\mathcal{B}(\tau \to \mu\gamma)$ vs. $\Delta a_\mu = (g_\mu - g_\mu^{\rm SM})/2$, assuming $|\delta_{LL}^{12}| = 10^{-4}$ and $|\delta_{LL}^{23}| = 10^{-2}$. The plots have been obtained employing the following ranges: 300 GeV $\leq M_{\tilde{\ell}} \leq$ 600 GeV, 200 GeV $\leq M_2 \leq$ 1000 GeV, 500 GeV $\leq \mu \leq$ 1000 GeV, $10 \leq \tan\beta \leq 50$, and setting $A_U = -1$ TeV, $M_{\tilde{q}} = 1.5$ TeV. Moreover, the GUT relations $M_2 \approx 2M_1$ and $M_3 \approx 6M_1$ are assumed. The red areas correspond to points within the funnel region which satisfy the B-physics constraints listed in Section 3.2 [$\mathcal{B}(B_s \to \mu^+\mu^-) < 8 \times 10^{-8}$, $1.01 < R_{Bs\gamma} < 1.24$, $0.8 < R_{B\tau\nu} < 0.9$, $\Delta M_{B_s} = 17.35 \pm 0.25$ ps^{-1}].

Rare Decays as Probes of NP models

FCNC in rare K decays

[Straub]



- While only a schematic picture :
  - Correlation between different measurements a powerful probe of NP models
  - Large number of potential channels ... will talk only about a few
  - RD have a bright future: final data sets from B-factories, LHCb, Super Flavour Factories, Kaon experiments...

Nel seguito la discussione sara` Incentrata su:

La Rottura della Simmetria Elettrodebole
(The Energy Frontier)

La fisica del Sapore e la Violazione di CP
(The Intensity Frontier)

La natura della Materia Oscura
(The Cosmic Frontier)

2 osservazioni speimentali rimangono non spiegate nello SM e nello SM cosmologico

- the Dark Matter of the Universe

Some invisible transparent matter (that does not interact with photons) which presence is deduced through its gravitational effects

15% baryonic matter (1% in stars, 14% in gas)

85% dark unknown matter

- the (quasi) absence of antimatter in the universe

baryon asymmetry: $\frac{n_B - n_{\bar{B}}}{n_B + n_{\bar{B}}} \sim 10^{-10}$

→ observational need for new physics

→ what does this have to do with the electroweak scale?

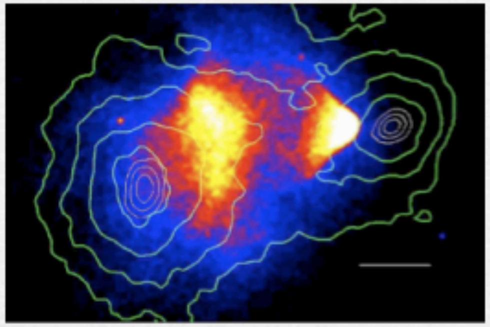
In termini di energia, lo straordinario progresso osservazionale ha individuato solo il 4% del contenuto dell'universo

La Materia Oscura (Dark Matter-DM) stabilita a 10 deviazioni standard

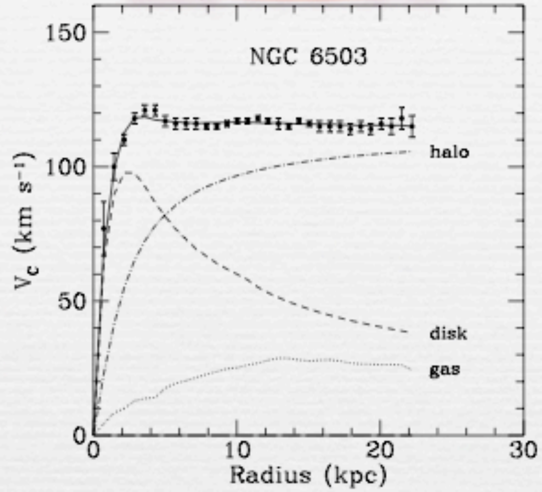
The existence of (Cold) Dark Matter has been established by a host of different methods; it is needed on all scales

Gravitational lensing

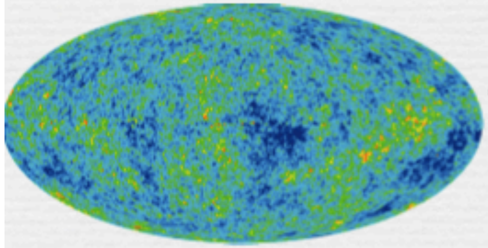
The "Bullet cluster": lensing map versus X-ray image

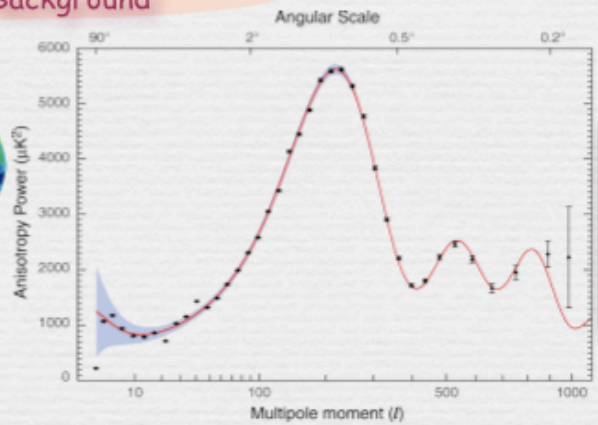


Galaxy rotation curves



Cosmic Microwave Background





... etc

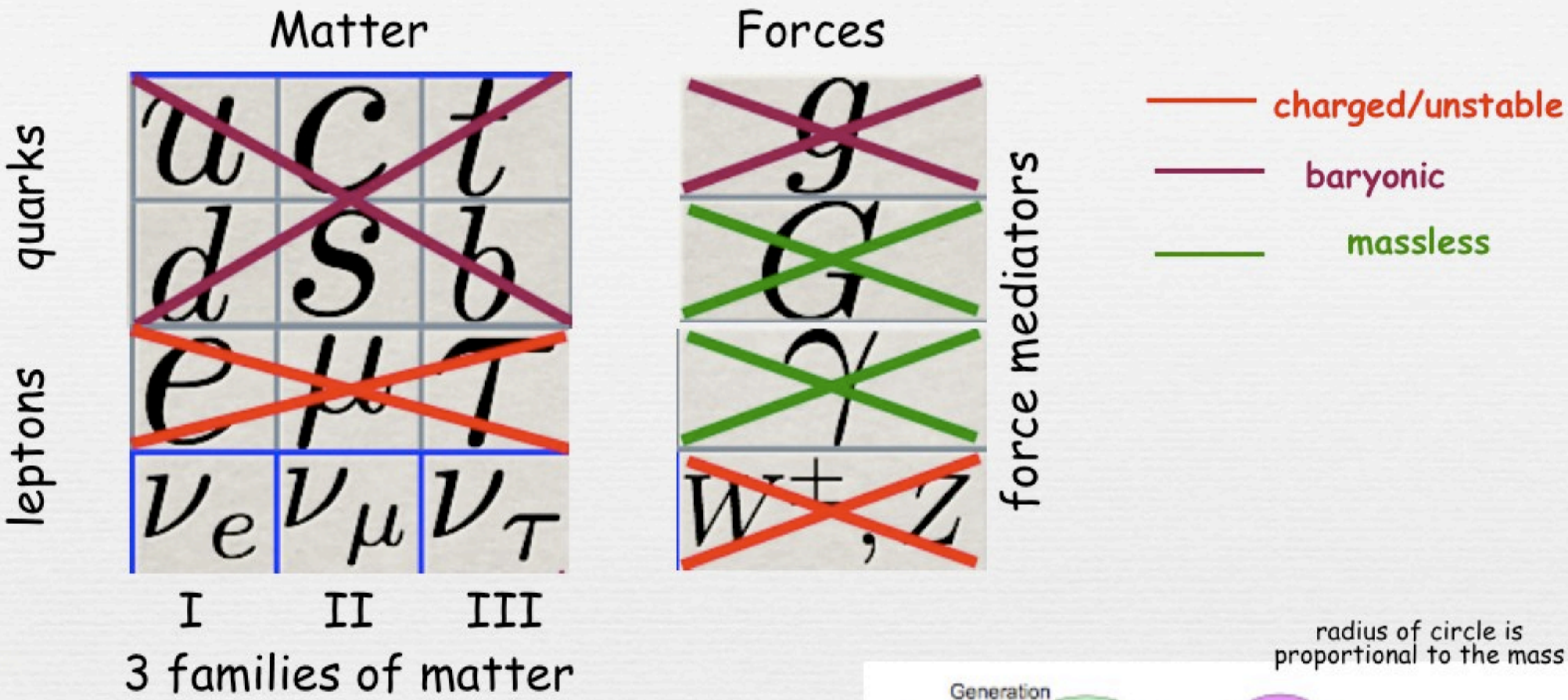
-> Fraction of the universe's energy density stored in dark matter :

$\Omega_{DM} \approx 0.22$

The picture from astrophysical and cosmological observations is getting more and more focussed

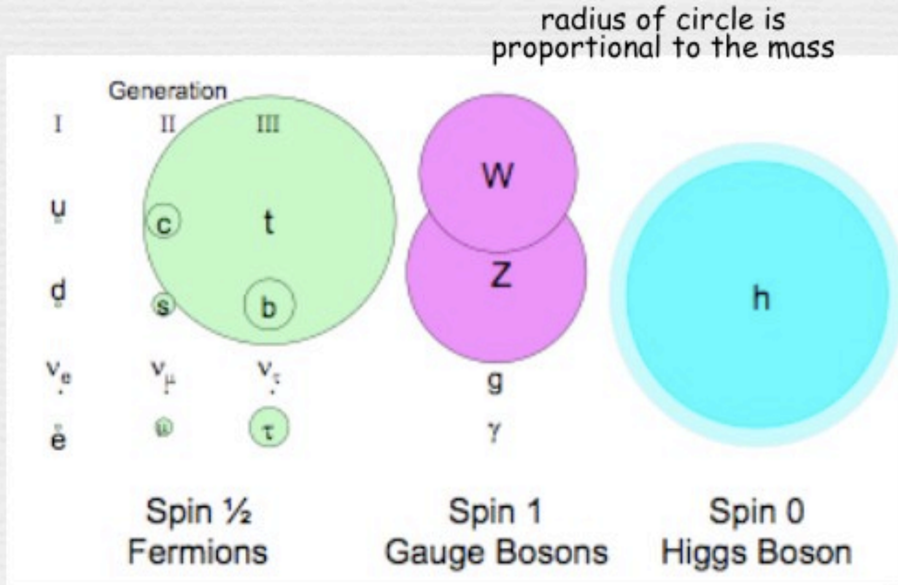
DM properties are well-constrained (gravitationally interacting, long-lived, not hot, not baryonic) but its identity remains a mystery

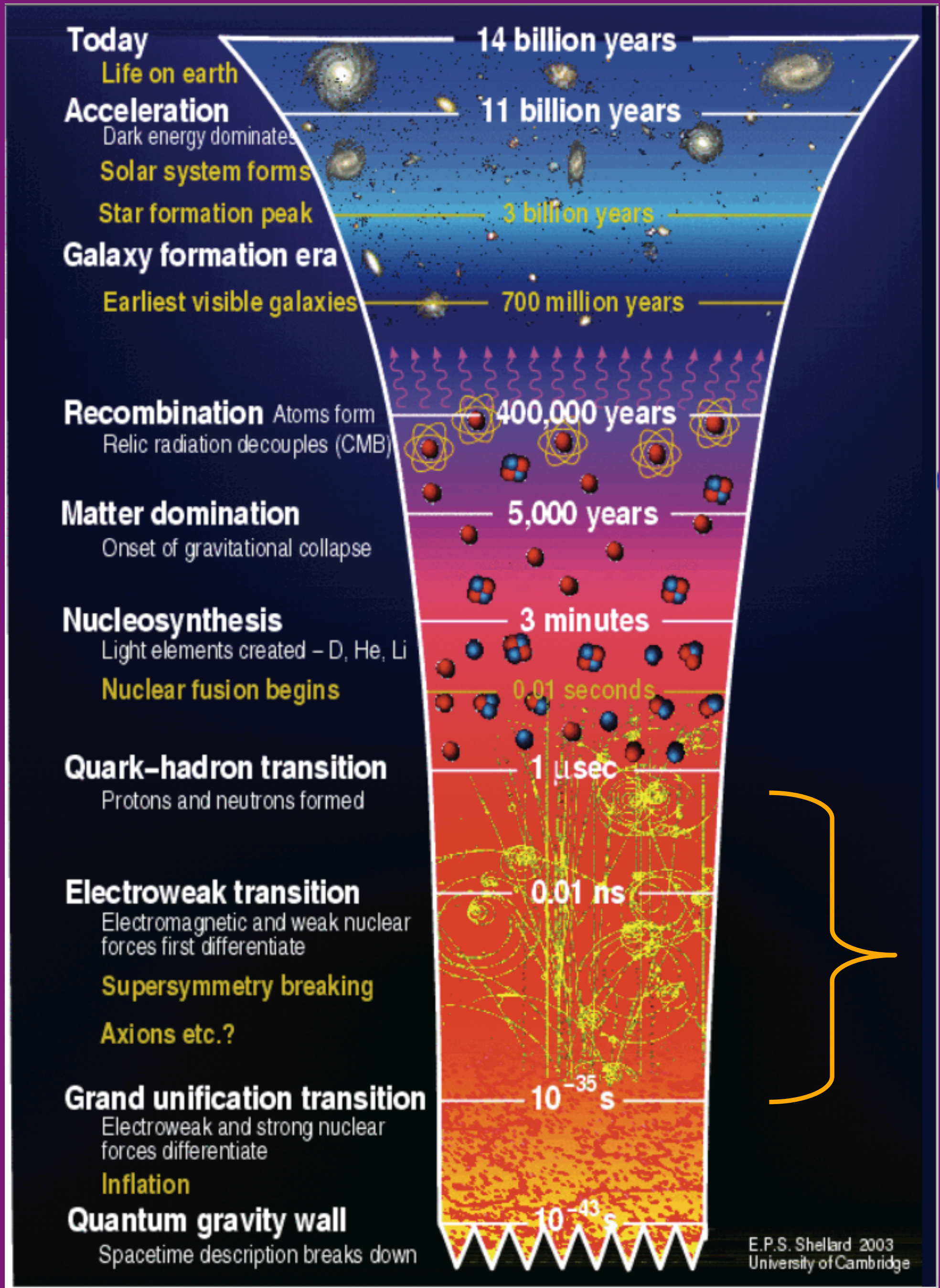
Why can't dark matter be explained by the Standard Model?



contribution to the energy budget of the universe

Particle	Ω	type
Baryons	4 - 5 %	cold
Neutrinos	< 2 %	hot
Dark matter	20 - 26 %	cold





NOW:

$$n_\gamma = 400\, cm^{-3}$$

$$\frac{n_b}{n_\gamma} = 6.1 \times 10^{-10}$$

$$\frac{\Omega_b}{\Omega_m} = 0.17$$

$$\Omega_\Lambda = 0.73$$

E` la DM una particella della Nuova Fisica (NP) che ci aspettiamo alla scala della rottura della simmetria elettrodebole?

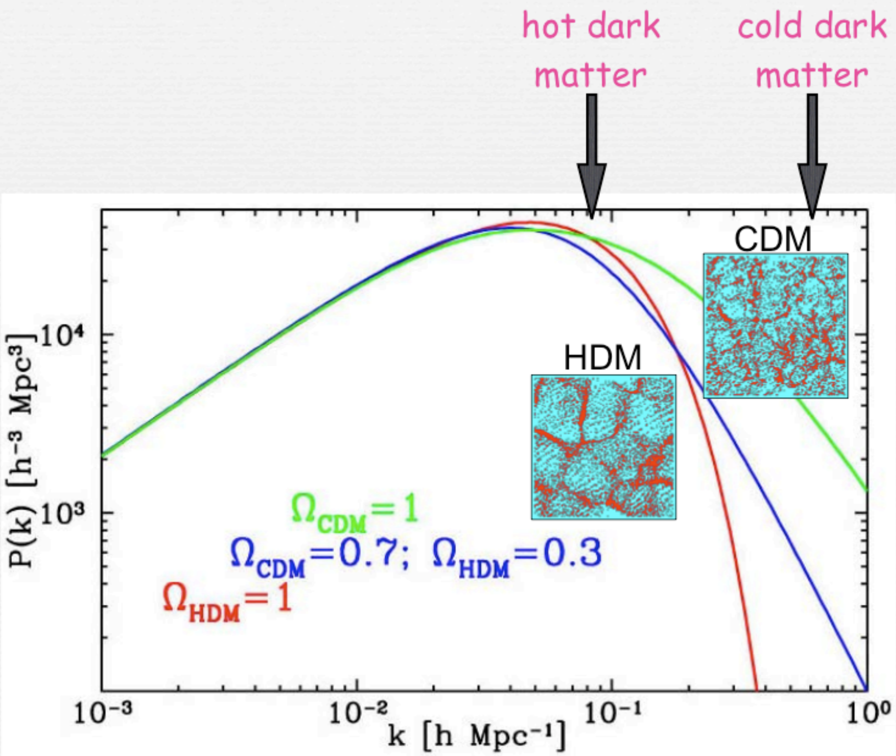
WIMP (weakly interacting massive particles)
E` questa la soluzione ?
Alcune delle proposte avanzate:

Tipo	*Spin*	*Scala di Massa (appr.)*
Assione	0	μeV-meV
Higgs doub. inerte	0	50 GeV
Neutrino Sterile	1/2	keV
Neutralino	1/2	10 GeV-10TeV
Kaluza-Klein	1	TeV

G.Fogli et al., Phys. Rev. Phys.Rev.D75:053001,2007.

TABLE II: Input cosmological data sets for seven representative cases considered in this work, together with their 2σ (95% C.L.) constraints on the sum of neutrino masses Σ.

Case	Cosmological data set	Σ bound (2σ)
1	WMAP	< 2.3 eV
2	WMAP + SDSS	< 1.2 eV
3	WMAP + SDSS + SN_{Riess} + HST + BBN	< 0.78 eV
4	CMB + LSS + SN_{Astier}	< 0.75 eV
5	CMB + LSS + SN_{Astier} + BAO	< 0.58 eV
6	CMB + LSS + SN_{Astier} + Ly-α	< 0.21 eV
7	CMB + LSS + SN_{Astier} + BAO + Ly-α	< 0.17 eV



I neutrini massicci sono gli unici candidati possibili per spiegare la DM nello SM

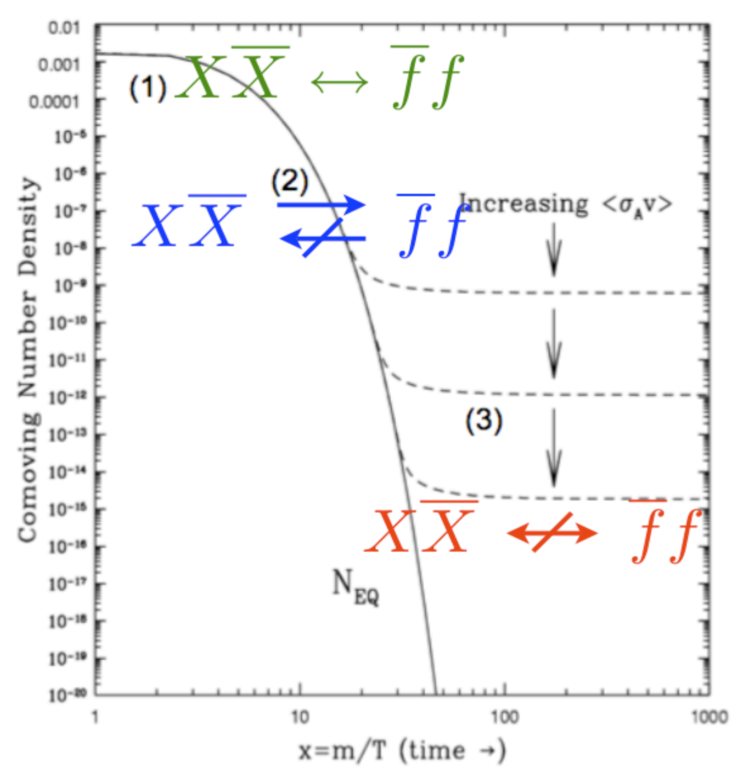
Tuttavia, essendo molto leggeri, e disaccopiandosi a un'energia di circa 1 MeV , continuano a diffondersi come particelle ultrarelativistiche nell'universo influenzando le fluttuazioni della densita` e limitando la formazione di protostrutture

Candidati per la DM: due possibilita` principali

Molto leggeri & con accoppiamenti (quasi-) solo gravitazionali, stabili su scala cosmologica

Meccanismo di produzione dipende dalla cosmologia dell'universo primordiale
e.g. scalare com massa
m ~ meV con accoppiamenti
~ 1/Mpl

Candidati per la DM: due possibilita` principali



accoppiamenti apprezzabili alle particelle dello SM + una simmetria per garantirne la stabilita`

$\Omega h^2 \propto 1 / \langle\sigma_{ann} v\rangle$

$\langle\sigma_{ann} v\rangle \sim$ 0.1 pb

$\sigma \sim \alpha^2 / m^2$

m ~ 100 GeV

Una coincidenza davvero speciale: **i parametri della fisica delle particelle e quelli della cosmologia cospirano per fornirci possibili candidati di DM alla scala EW**; molto generale non dipende dai dettagli dell'evoluzione iniziale dell'universo ma solo $T_{rh} > m/25$

Nuove simmerie alla scala del TeV e Materia oscura

per risolvere i problemi della rottura della simmetria EW con un Higgs elementare

E` necessario introdurre nuovi gradi di liberta` (nuova fisica) alla scala del TeV

Tensione con le misure di precisione dello SM & con la fisica del sapore (little hierarchy)

Indroduciamo dunque una simmetria (R-parita`, KK parita` etc.

A causa di questa nuova simmetria la particella piu` leggera prevista dai nuovi gradi di liberta` e` stabile

Ecco dunque un candidato naturale per la DM !!

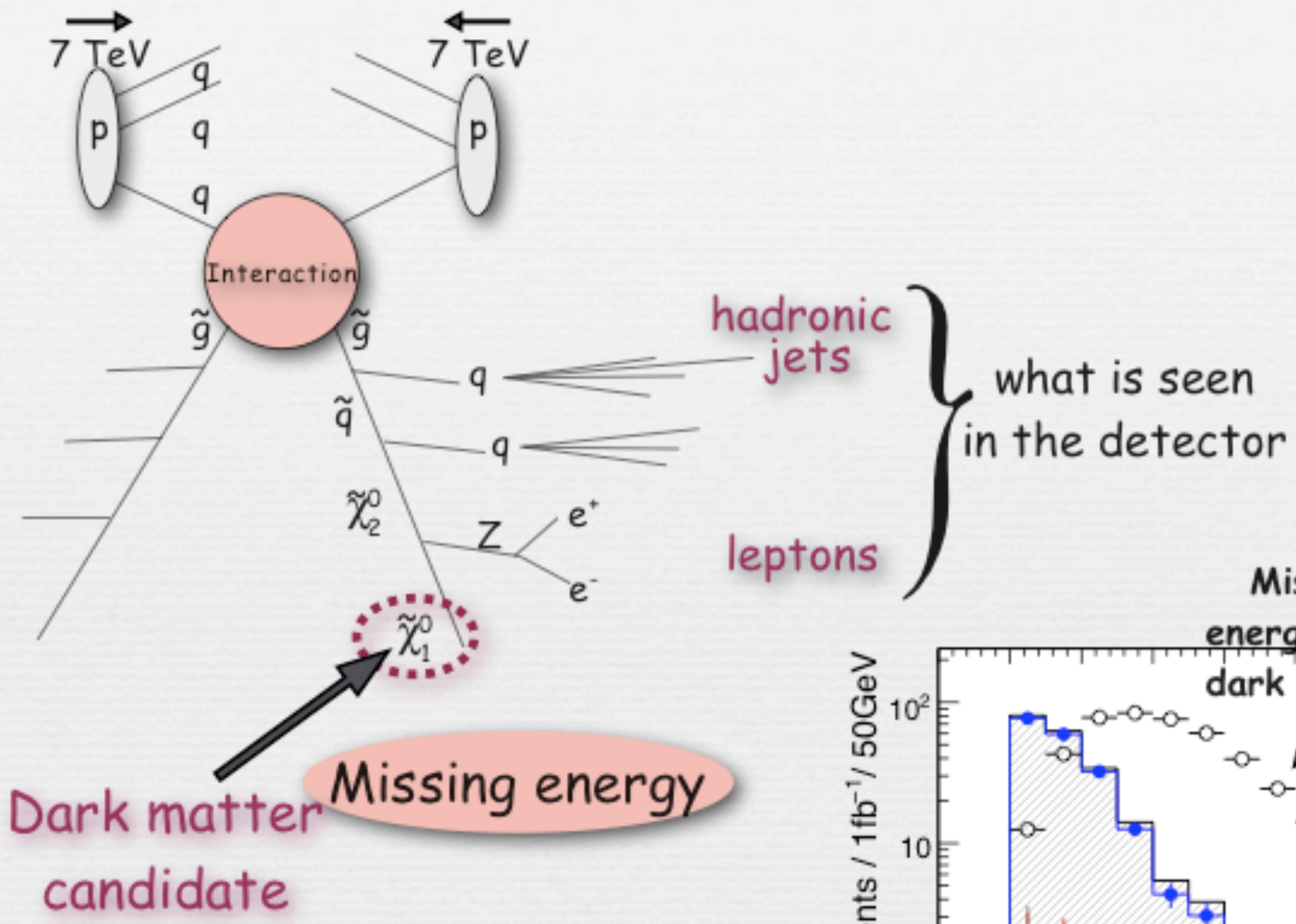
STABLE ELW. SCALE WIMPs from PARTICLE PHYSICS

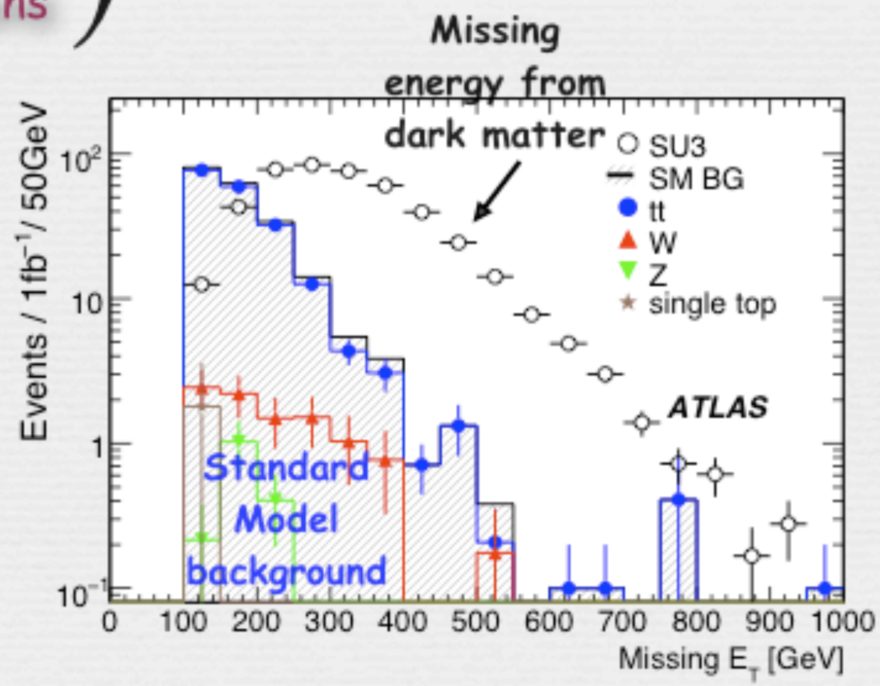
	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) **ENLARGEMENT OF THE SM**	(x^μ, θ)	(x^μ, j^i)	SM part + new part
	Anticomm. Coord.	New bosonic Coord.	to cancel Λ^2 at 1-Loop
2) **SELECTION RULE**	**R-PARITY LSP**	**KK-PARITY LKP**	**T-PARITY LTP**
→ **DISCRETE SYMM.** → **STABLE NEW PART.**	Neutralino spin 1/2 ↓	spin1 ↓	spin0 ↓
3) FIND REGION (S) PARAM. SPACE WHERE THE "L" NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	m_{LSP} ~100 - 200 GeV *	m_{LKP} ~600 - 800 GeV	m_{LTP} ~400 - 800 GeV

* But abandoning gaugino-masss unif. → Possible to have m_{LSP} down to 7 GeV

Bottino, Donato, Fornengo, Scopel

Producing Dark Matter at LHC = "Missing Energy" events





LHC non fornira` tutte le risposte per risolvere il problema della DM. E` necessario:

1) combinare la misura delle proprieta` delle nuove particelle in laboratorio con la rivelazione della DM nella galassia (dai suoi prodotti di annichilazione)

2) riuscire a fare la connessione con le particelle scoperte a LHC

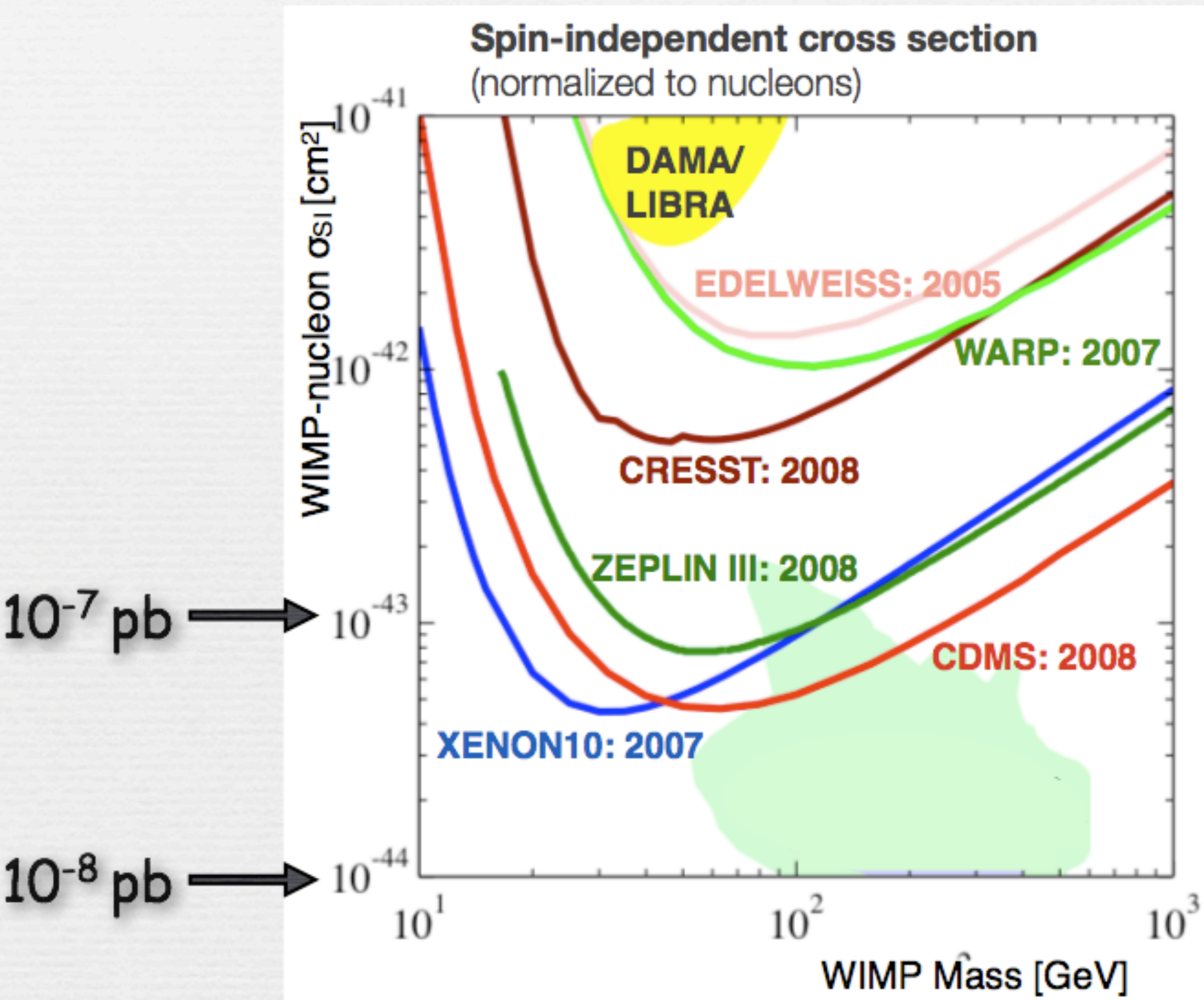
Interagendo cosi` debolmente,la maggior parte dei wimps passano attraverso la terra. I pochissimi che collidono con i nuclei, perdono una parte di energia cinetica che possiamo osservare misurando il rinculo dei nuclei colpiti

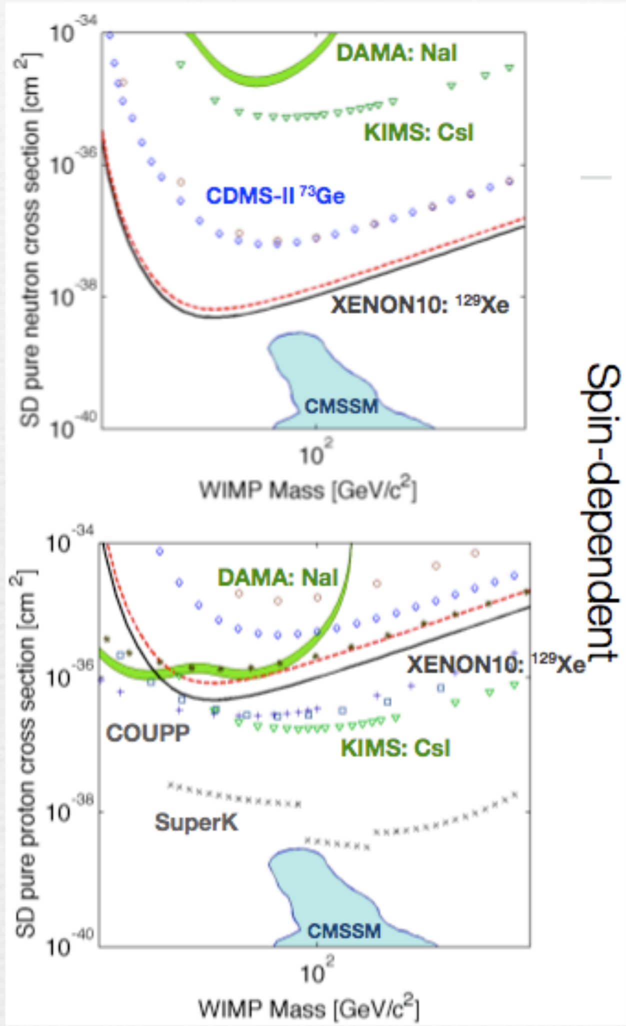
$$E_{kin} \sim M_{nucl}\, v^2 \sim 1 - 100 \quad \text{KeV}$$

Per una densita` di DM di ρ =0.3 GeV cm^{-3}

ci aspettiamo <1 evento/100Kg/giorno se la sezione d'urto e` 10^{-7}pb

Experimental results

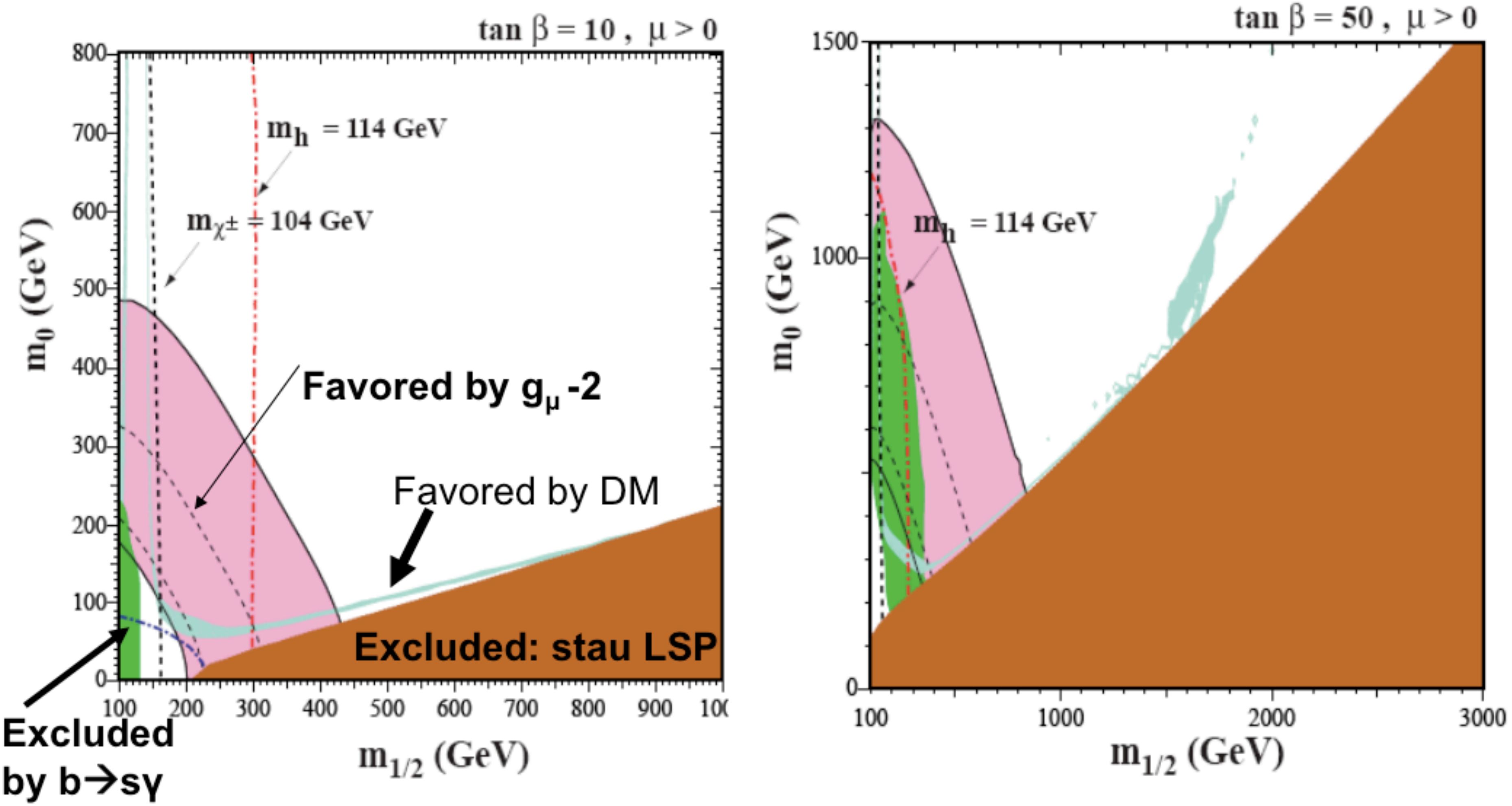




$\sigma_0^{SI} \sim A^2$, benefits from coherent scattering

$\sigma_0^{SD} \sim J(J+1)$

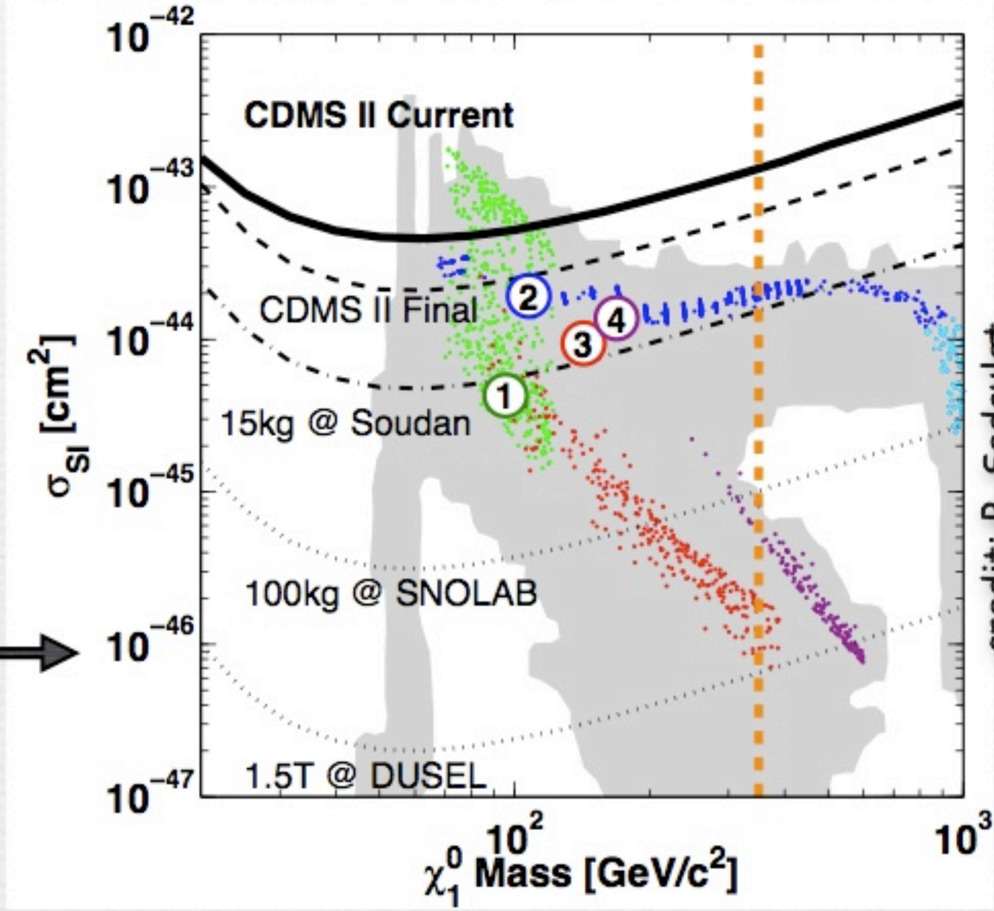
NEUTRALINO LSP IN THE CONSTRAINED MSSSM: A VERY SPECIAL SELECTION IN THE PARAMETER SPACE?



Ellis, Olive, Santoso, Spanos

Future prospects

10^{-10} pb

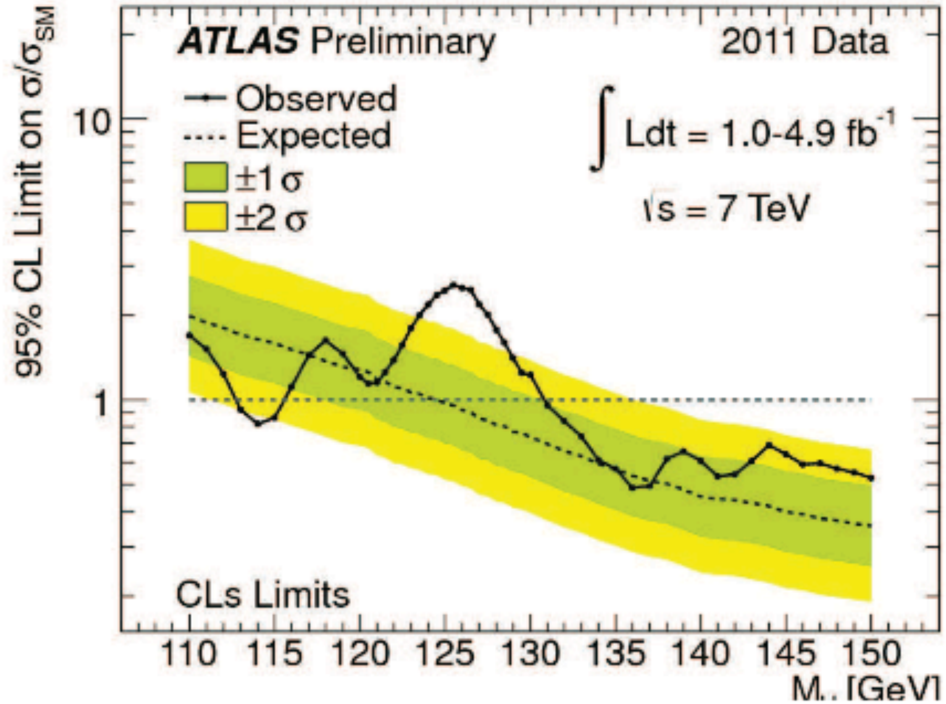


credit: B. Sadoulet

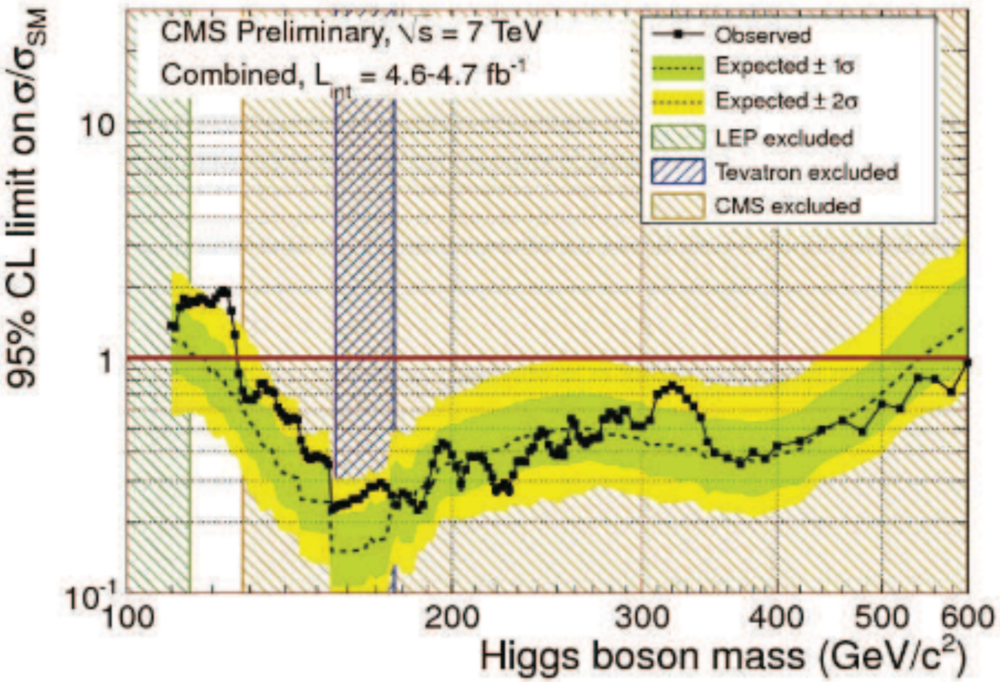
Short Summary of Searches

New signatures for new physics yet
→ Simple Summary (LP11: H. Bachacou)

	Lower Limit (95% C.L.)
SUSY ($m_{\tilde{q}} = m_{\tilde{g}}$)	1 TeV
Gauge bosons (SSM)	2 TeV
Excited quark	3 TeV



$116 < m_H < 130$



$115 < m_H < 127$

The LHC has entered new territory

The CMS and ATLAS experiment are searching for new physics. No clear sign of new physics yet in the first 1-2 fb-1 at 7 TeV

Exclusion at 95% CL for Higgs masses above 130 GeV. Some tantalizing excesses seen at lower mass, to be studied/confirmed with more data in 2012

8 TeV collision CM energy in 2012,which would settle the the SM Higg

Is the present picture showing a
Model Standardissimo ?

An evidence, an evidence, my kingdom for an evidence

From Shakespeare's *Richard III*

3 roads to New Physics