INVISIBLES.....
.....Visibles and Barely Visibles
Paris, 19.07.2014

L. Maiani, Roma Sapienza and IFT, Madrid

Closing Remarks

Part 1:
INVISIBLES

- no Dark Matter nor Supersymmetry are considered here. Sorry.

Wonderful, continuing progress in neutrino oscillations

- reported by M. Zito and T. Schwetz:
  - -Tau appearence in GranSasso
  - -Day-Night effect
  - -Propspects to determine the order of neutrino levels (Hierarchy)
- Tantalizing evidence for large δ_{CP} : comparing "θ_{13}" from reactor and from accelerator experiments

Not sensitive to δ_{CP}

$\bar{\nu}_e \rightarrow \bar{\nu}_e$ Reactor experiments

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13}\left(\cos^2\theta_{12}\sin^2\frac{\Delta m^2_{31} L}{4E} + \sin^2\theta_{12}\sin^2\frac{\Delta m^2_{32} L}{4E}\right) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\frac{\Delta m^2_{21} L}{4E}$$

$\sin^2\frac{\Delta m^2_{ee} L}{4E}$

$\nu_\mu \rightarrow \nu_\mu$

$$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \left(\cos^4\theta_{13}\sin^2 2\theta_{23} - \sin^2 2\theta_{13}\sin^2\theta_{23}\right)\sin^2\left(\frac{\Delta m^2_{32} L}{4E}\right)$$

Accelerator experiments

$\nu_\mu \rightarrow \nu_e$

$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2 2\theta_{13}\sin^2\theta_{23}\sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) - \frac{\sin 2\theta_{12}\sin 2\theta_{23}}{2\sin\theta_{13}}\sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right)\sin\delta_{CP}$$

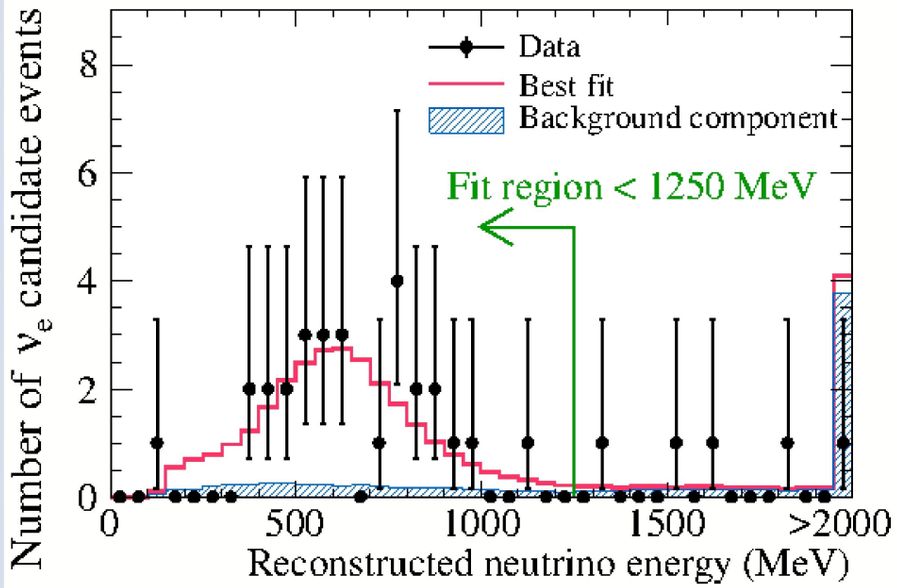
Modulated by $\sin\delta_{CP}$

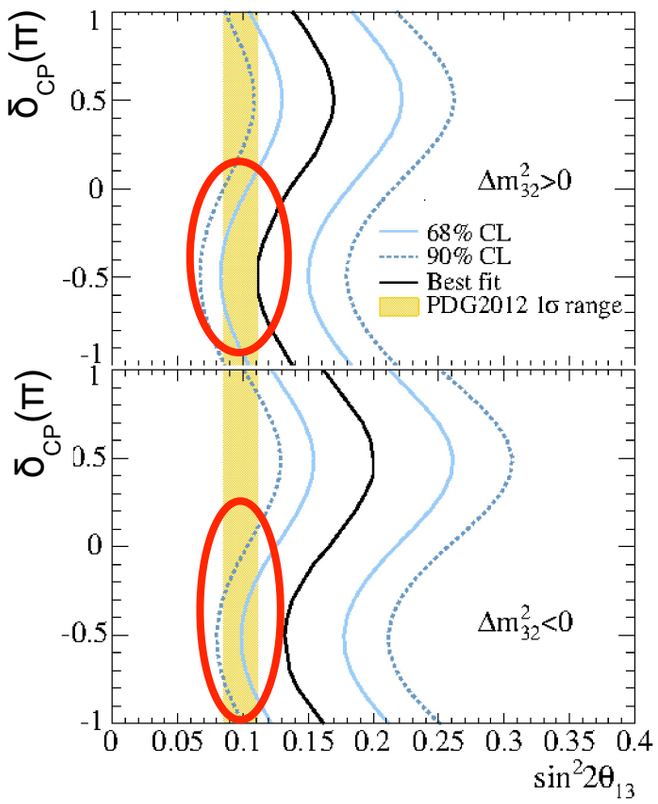
- Comparison is sensitive to normal or inverted hierarchy

$\nu_\mu \rightarrow \nu_e$

Phys. Rev. Lett. 112, 061802 (2014)

T2K observation of $\nu_\mu \rightarrow \nu_e$ appearance





- N_{obs} = 28
- N_{exp} (bck. only) = 4.9±0.6(syst.)
- N_{exp} ($\sin^2 2\theta_{13}$=0.1) = 21.6
- 7.3 σ evidence of non-zero θ_{13}
- First direct observation of a new flavor appearance
- Opens the way to the determination of the CP violation parameter δ

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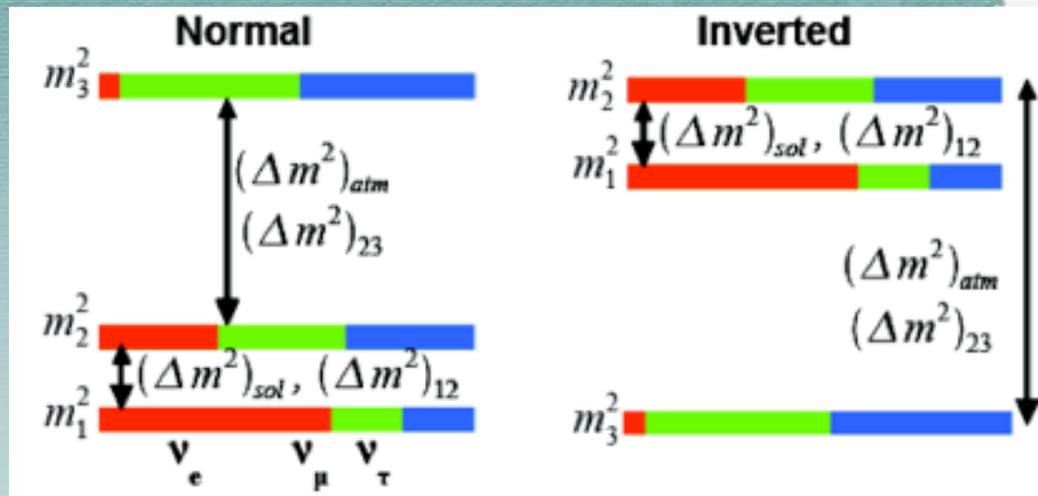
Marco Zito-Invisibles, Paris July 2014

- the two determinations of θ_{13} agree better for $\delta_{CP} \sim -0.5\pi$, in both cases
- very encouraging
- still a good margin for improvement!!

Mass Hierarchy

We know $m_2 > m_1$, from the oscillations in the solar atmsphere
But what about m_3 vs. m_2 ?



How to determine the mass ordering?

- *Matter effect in the 1-3 sector*
  - *long-baseline accelerator experiments NOvA, LBNE, LBNO, ESS-SB, NuFact*
  - *atmospheric neutrinos INO, PINGU, ORCA, HyperK*
- *Interference of oscillations with Δm^2_{21} and Δm^2_{31}*
  - *Reactor experiment at ~60 km JUNO, RENO50*

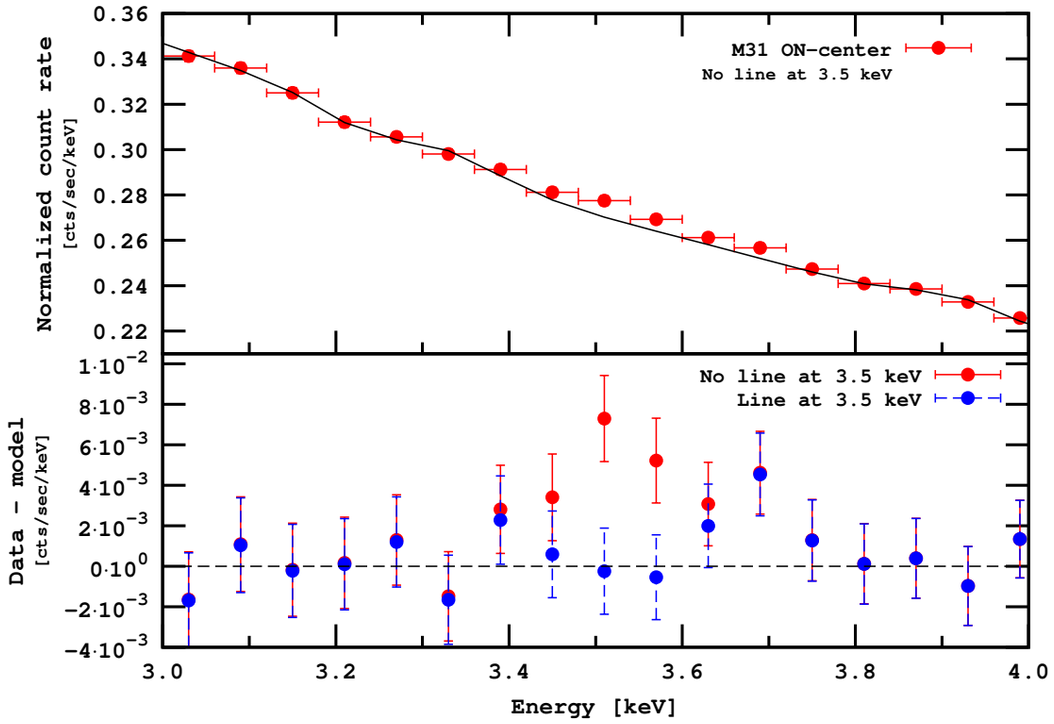
A big challenge
Technologies available
Worth trying!!

T. Schwetz 8

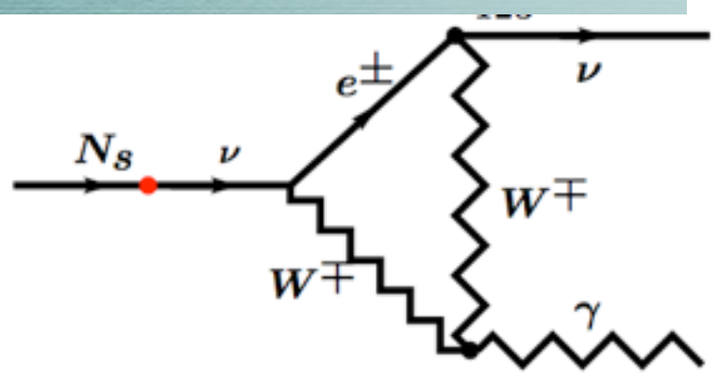
The unexpected 3.5 KeV line in Andromeda

Andromeda galaxy (zoom 3–4 keV)

[1402.4119]

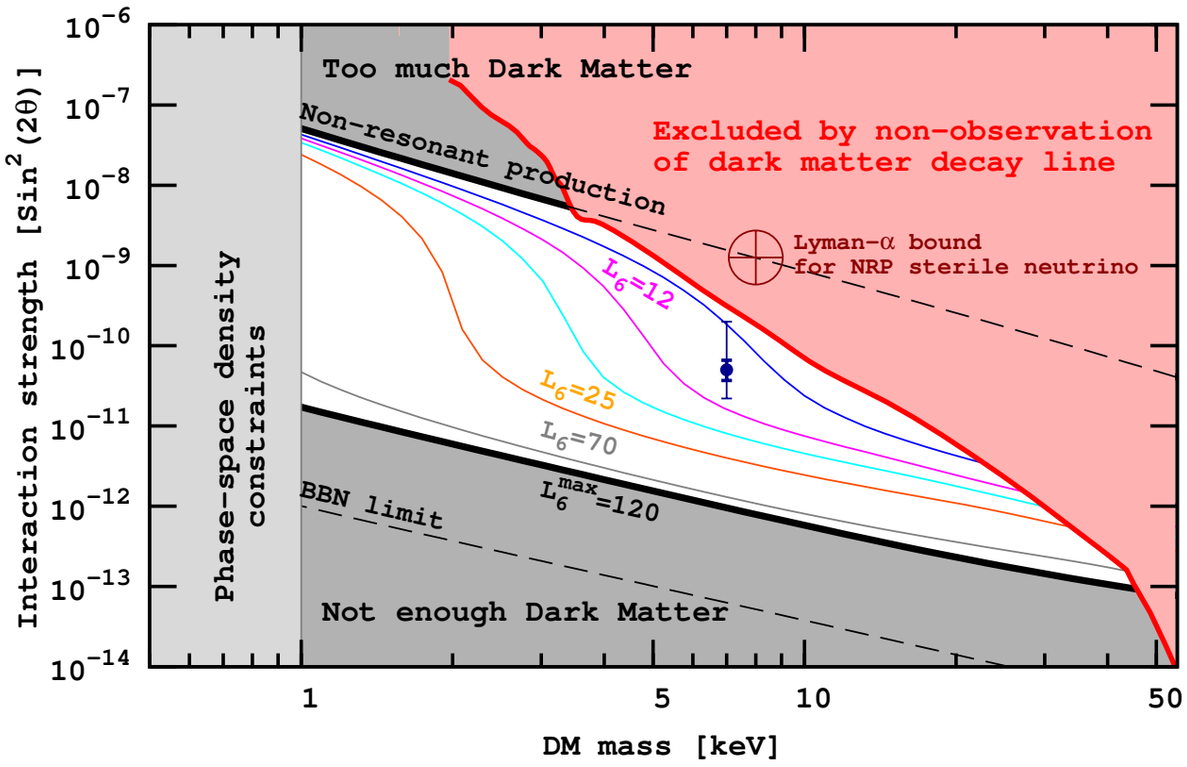


$$\theta^2 \approx 10^{-11}$$



Paris, July 18, 2014 L. Ma

Sterile neutrino and 3.5 keV line



Sterile neutrino DM with such parameters is not completely cold and would leave its imprints in the formations of structures

SHIP proposal @ CERN

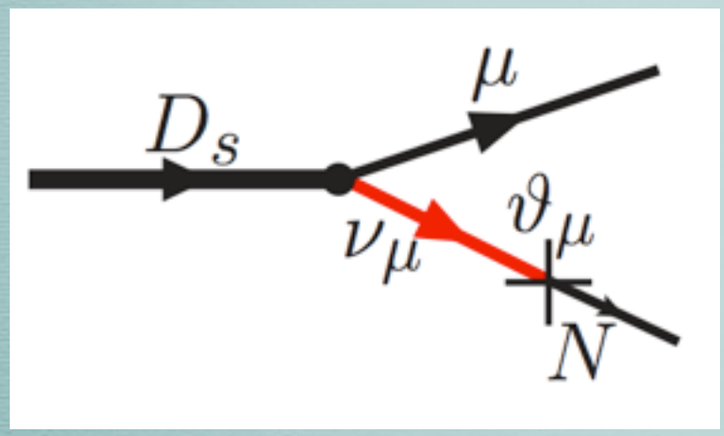
•LHC Beam dump experiment:

-proton beam dumped into a very thick target;

-negative pions and kaons absorbed, positive pions release ν s within nanosec. delay;

-charmed and heavier particles release "prompt" neutrinos, with picosec. delay or shorter:

-prompt ν s transform into N;



-N→ ν + γ in the tube;

-gamma revealed.

A high risk experiment even if line exists:
N only one of several possibilities

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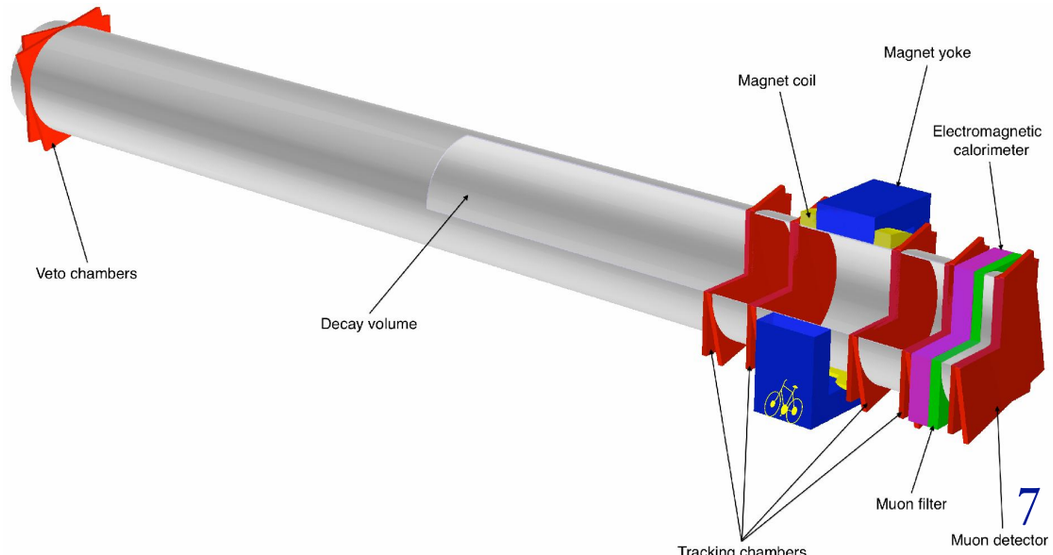
A dedicated experiment

[ar

W. Bonivento, A. Boyarsky, H. Dijkstra, U. Egede, M. Ferro-Luzzi, B. Goddard, A. Golutvin, D. Gorbunov, R. Jacobsson, J. Panman, M. Patel, **O. Ruchayskiy**, T. Ruf, N. Serra, M. Shaposhnikov, D. Treille

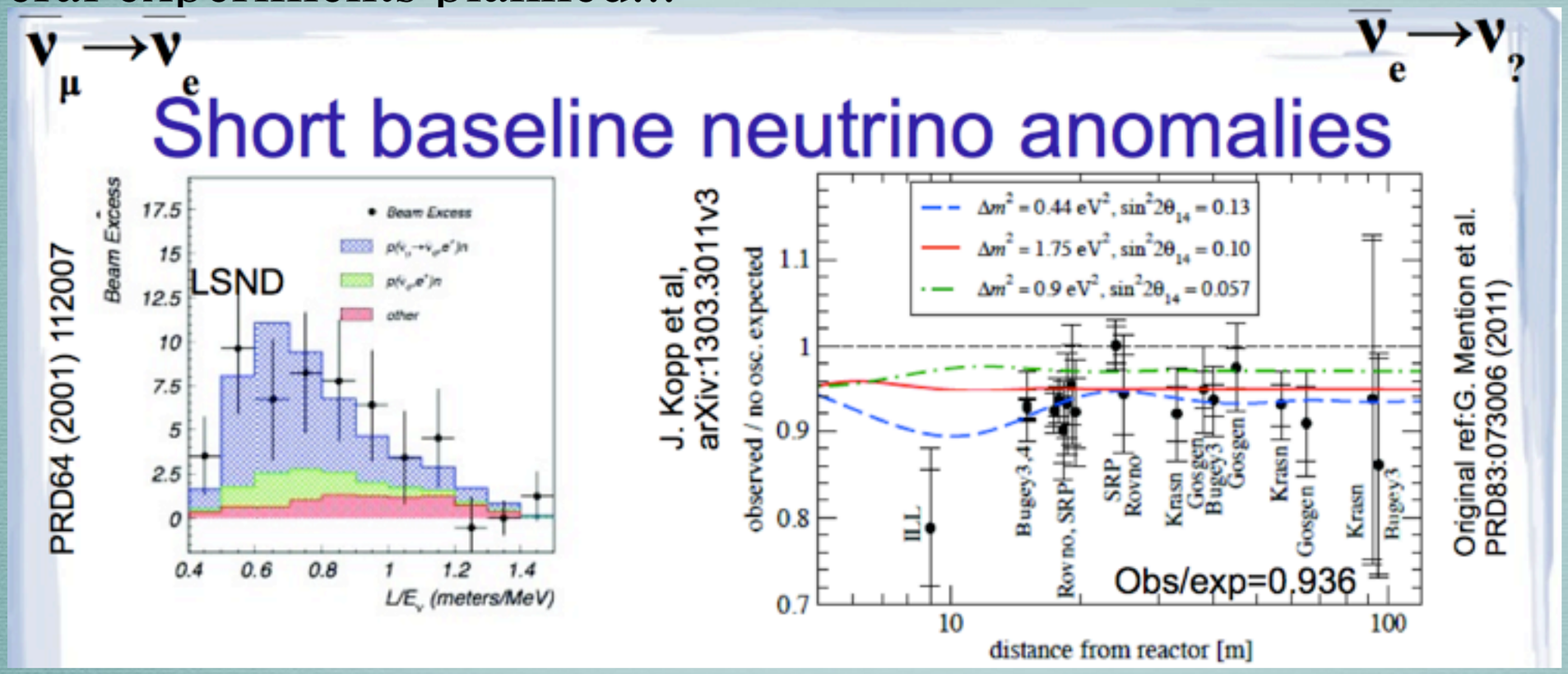
Proposal to Search for Heavy Neutral Leptons at the SPS

Expression of Interest. Endorsed by the CERN SPS council



Sterile Neutrinos

- Paradoxically, ortodoxy is that there are sterile, right-handed neutrinos endowed with a Majorana mass of order of $10^{10\text{-}14}$ GeV (see-saw)
- but there are unconfirmed indications of oscillations with eV mass scale...and several experiments planned...



- Short baseline experiments (LSND, MiniBooNE, reactors, Ga source) have revealed anomalies that could be interpreted as oscillations with $\Delta m \sim eV$
- No global satisfactory interpretation due to tensions within the data

Neutrinoless Double Beta Decay

- Large experimental effort going on;
- problem attacked with different technologies;
- an important activity of Underground Laboratories around the world
- status presented by C. Cattadori

0νββ rate and the effective neutrino mass

DBD can address, although in a Nuclear Model Dependent way

1. **Absolute mass scale: i.e. mass of the lightest ν**
2. **Hierarchy ($m_1 \ll m_2 < m_3$ or $m_3 \ll m_1 < m_2$) or degeneracy ($m_1 \approx m_2 \approx m_3$)**

0νββ rate ~ (effective Majorana neutrino mass)^2

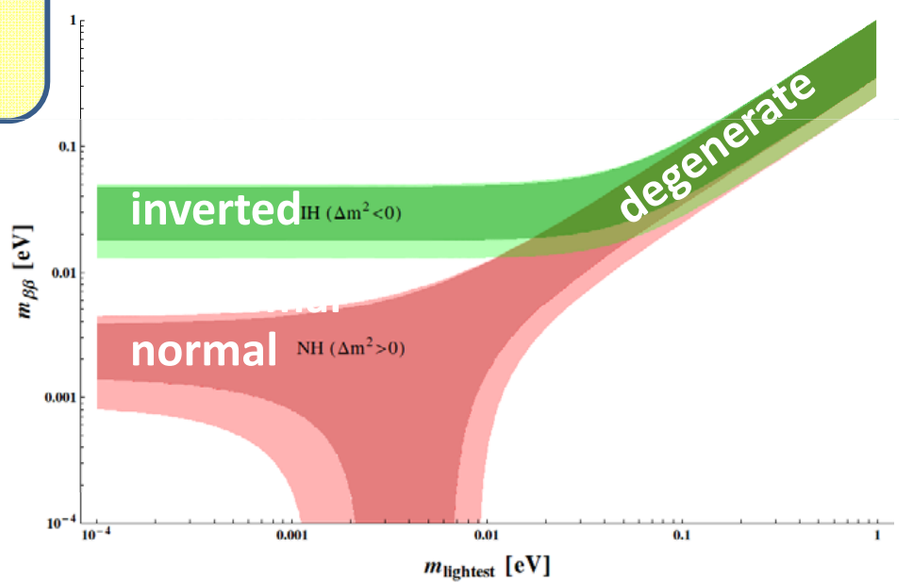
0νββ half-life $(T_{1/2}^{0\nu})^{-1} \sim F_{0\nu}(Q,Z)\,|M_{0\nu}|^2 \langle m_{ee}\rangle^2 / m_e^2$

Phase space… Nuclear Matrix Elements

$$\langle m_{ee} \rangle = \left| \sum_k m_k |U^2_{ek}| e^{i\alpha_i} \right|$$
$$= c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 e^{i\alpha} m_2 + s_{13}^2 e^{i\beta} m_3$$

N.B. m_{ee} could be < any m_i due to possible Majorana Phases cancellation

- Plotting m_{ee} vs. the lightest neutrino eigenstates & constraining by oscillation experiments data, one gets 3 allowed bands



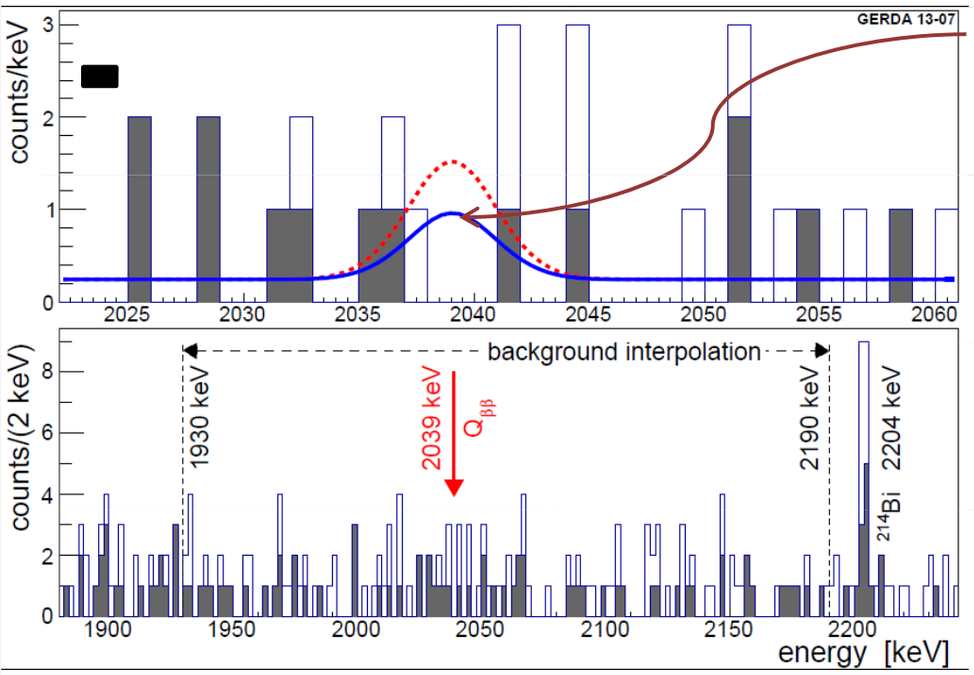
From Dell'Oro, Marcocci, Vissani, hep-ph/1404.2

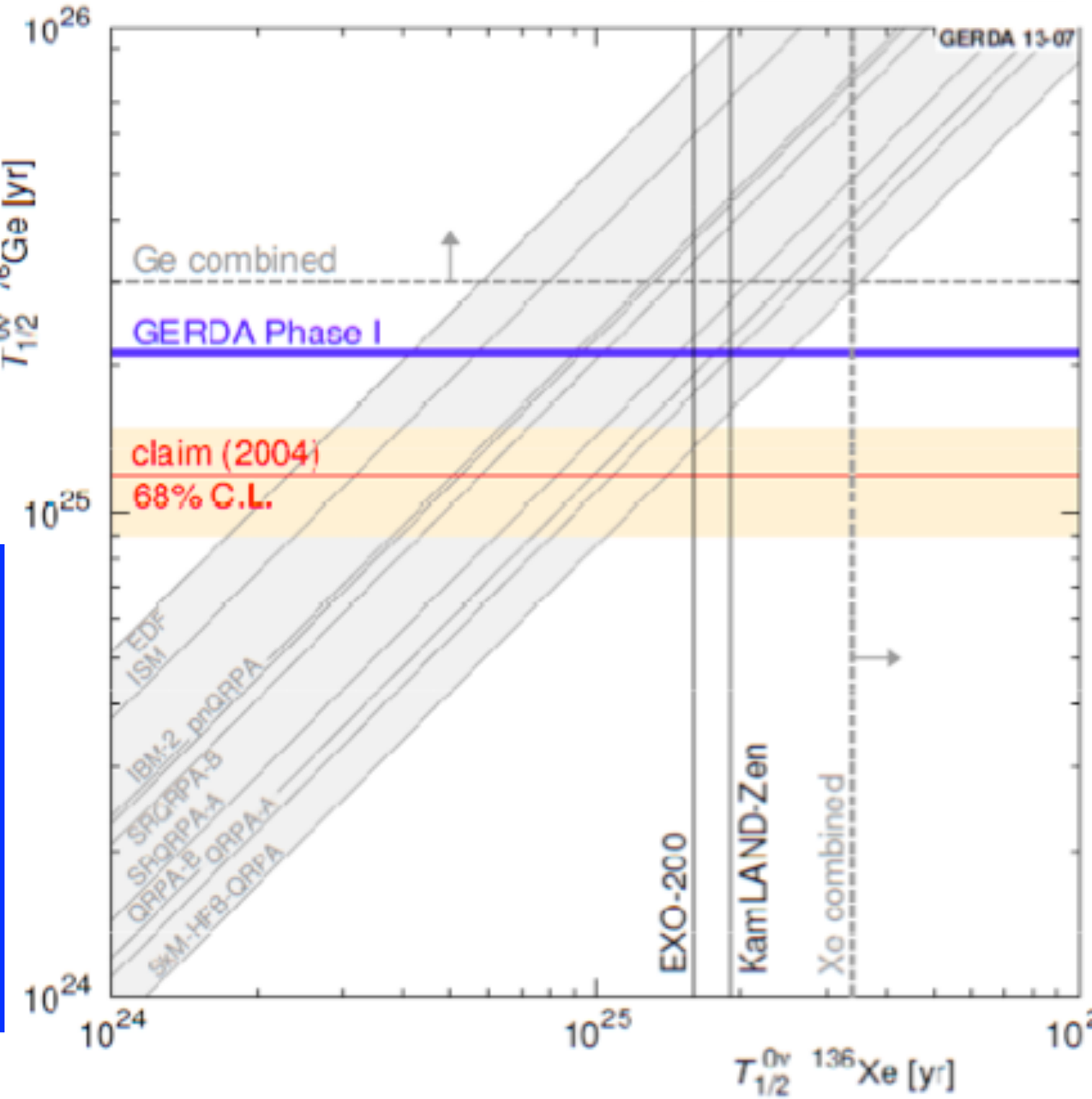
$T_{1/2}^{0\nu}$ from GERDA data sets

PRL111(2013)122503

Performed Profile Likelihood fit of the 3 data sets

- B+S: described by constant term + Gaus($Q_{\beta\beta}$,σ_E)
- 4 free parameters in the fit B_{gold}, B_{silv},B_{BEGe},$1/T_{1/2}^{0\nu}$
- Systematics folded in



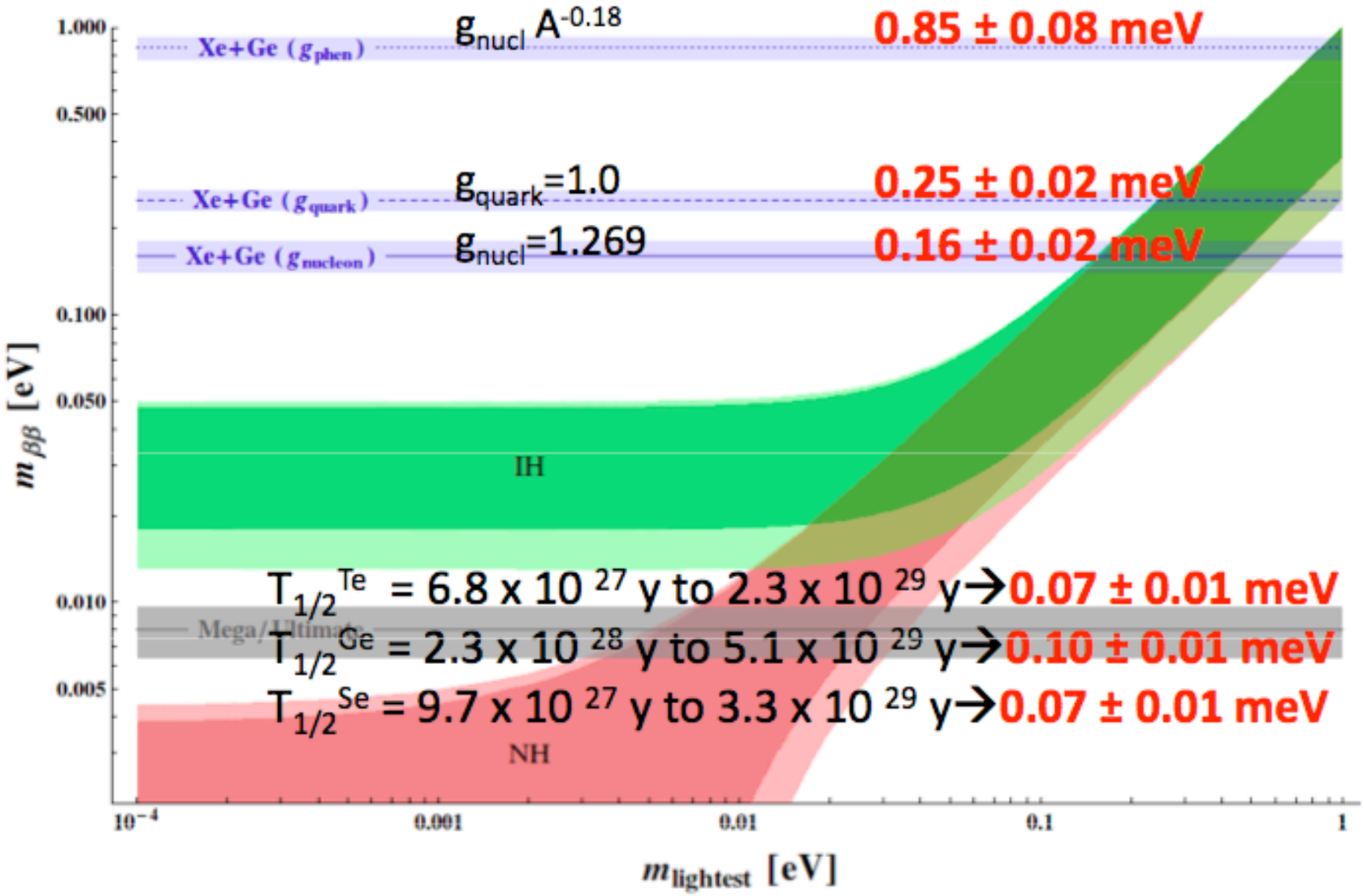


- Results for Ge and Xe are consistent
- Positive claim by Heidelberg-Moscow Collaboration not supported

Conclusion on Ge+Xe

C. Cattadori

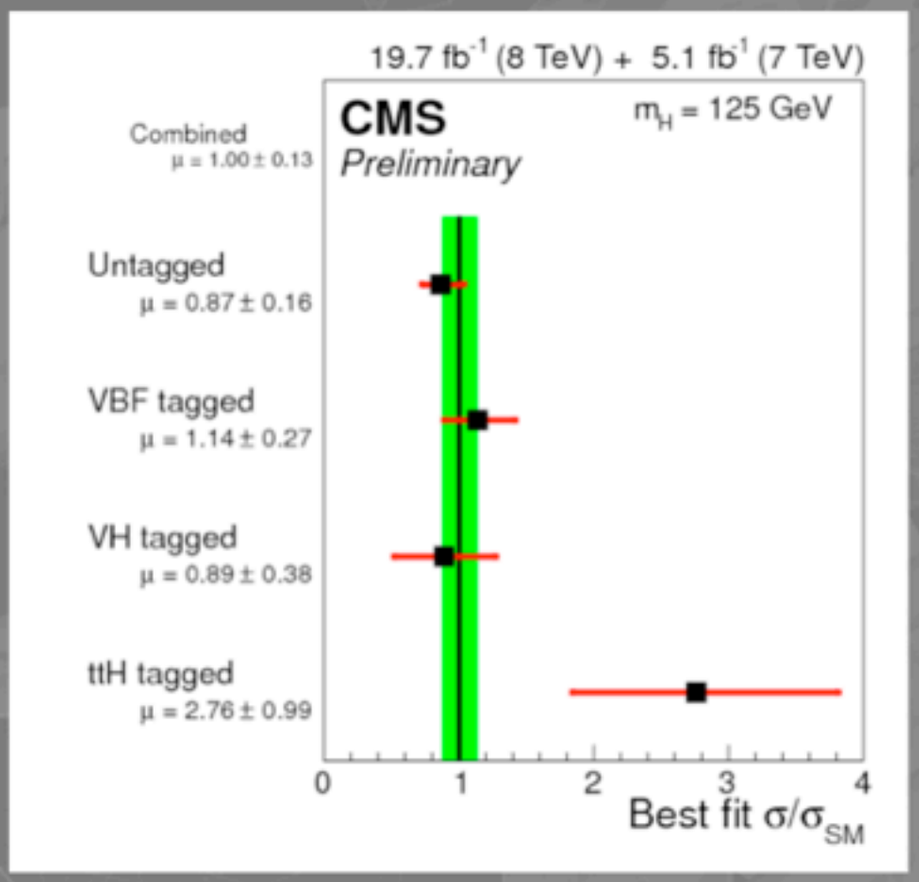
- Present Sensitivity on m_{ee} according to the Ge+Xe combined limit for
  - different quenching scenarios for g_A)
  - NME from QRPA. No error on relative ratio of NME_{Xe}/NME_{Ge}
- Bands from phase space & NME uncertainties

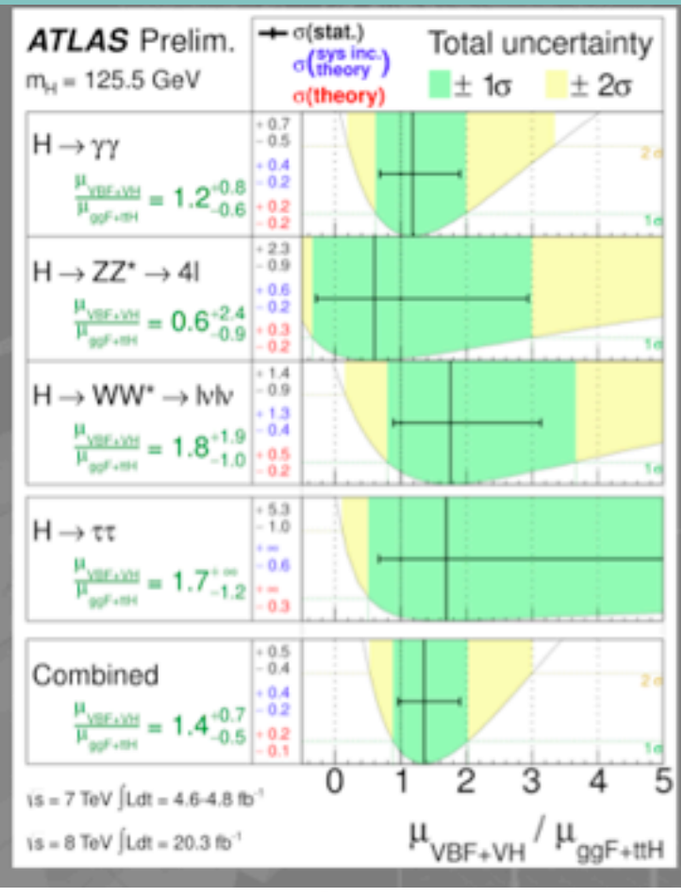


From Dell'Oro, Marcocci,Vissani, hep-ph/1404.2616v1

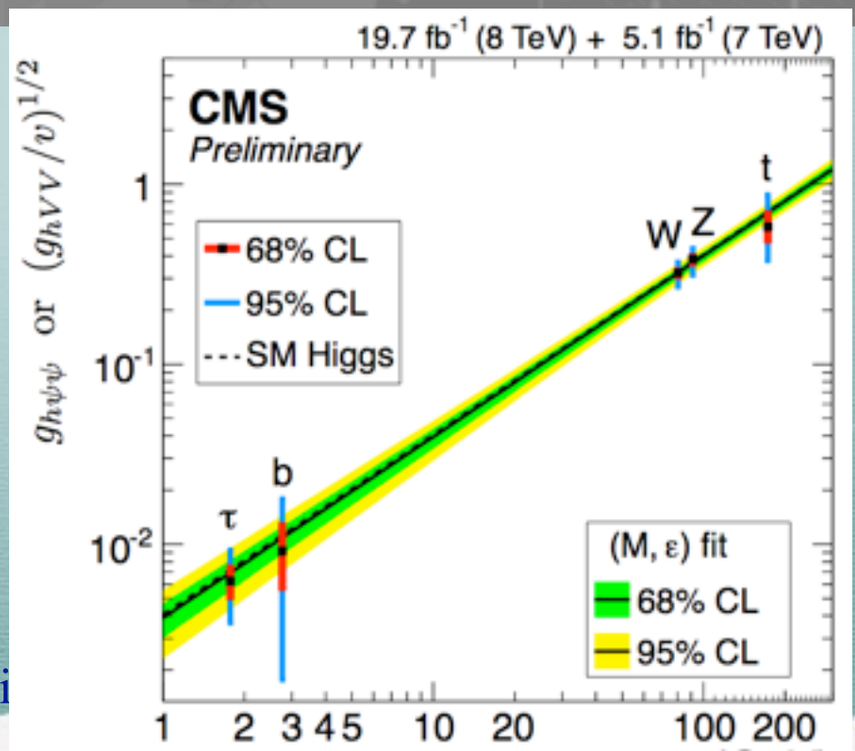
Part 2:
VISIBLES

Higgs Boson Summary (J. Ocariz)





- after all, this is the most important message: mass vs. coupling correlation for all known particles



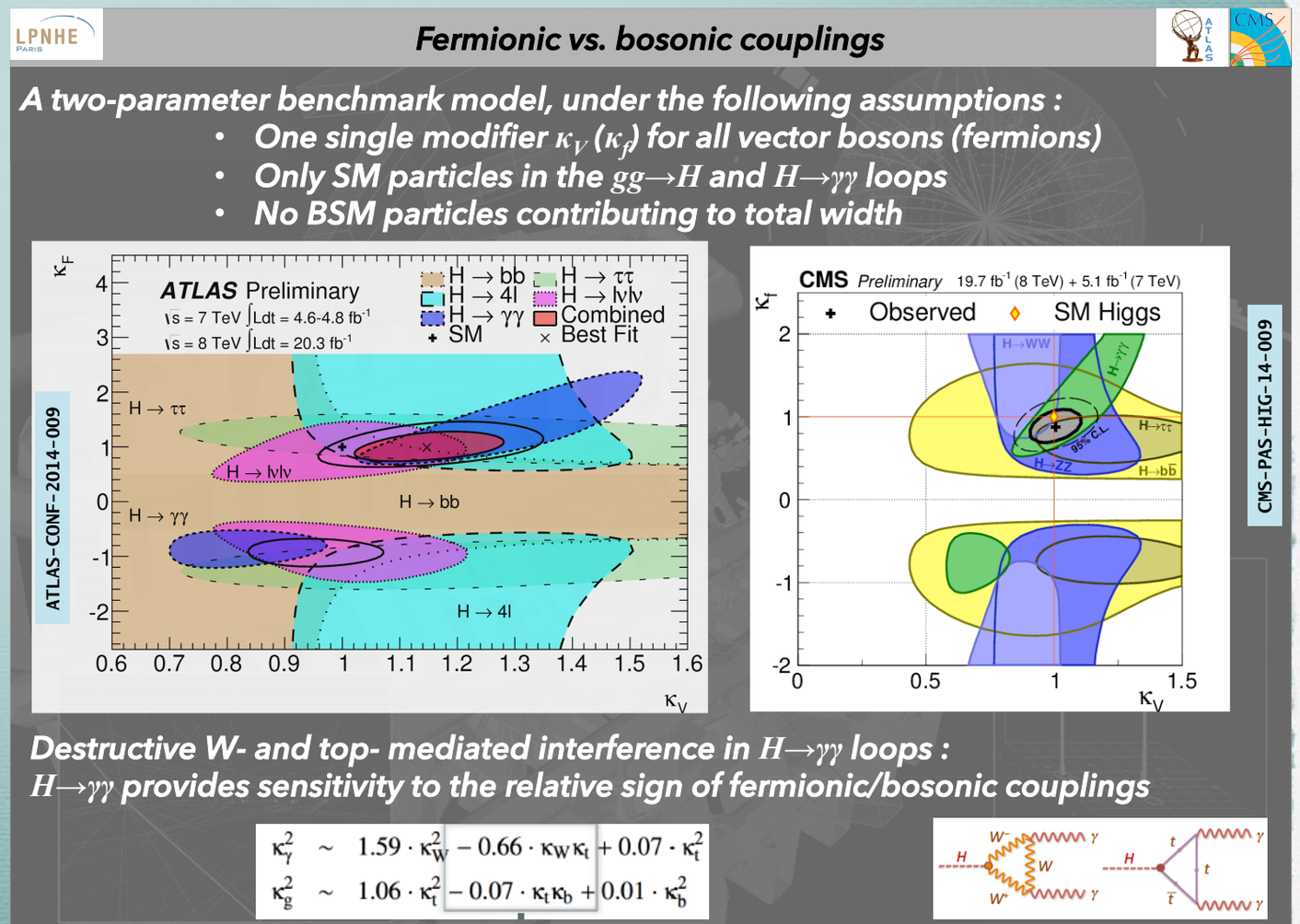
7. Higgs particle = Would Be Goldstone boson ?

R. Contino's talk

•Before finding the particles implied by extra strong interactions at high energy, one should detect ***anomalous couplings*** of the Higgs particle to vectors and fermions;

•the pattern of couplings implied by the composite, Would-Be Goldstone boson higgs is remarkably complicated, but in principle, deviations at few percent levels could be seen;

present status is somewhat represented here:



Higgs particle = would be goldstone boson ?

Luca Merlo@Moriond 2014

- A **strong dynamics** at the scale $\Lambda_s \sim \mathcal{O}(\mathrm{TeV})$ can provide a solution to the Hierarchy problem: in Composite Higgs models, the Higgs arises as a NGB, with an induced mass protected from large quantum corrections.
- In CH models, the resonance corresponds to a composite object, singlet under SM symmetries: **light CP-even singlet scalar *h***
- The Lagrangian can be written in terms of these building blocks:

$$\mathbf{U}(x) = e^{i\sigma_a \pi^a(x)/v} \qquad\qquad h$$

$\mathbf{U}(x)$ is a 2x2 **adimensional** matrix. This leads to a fundamental difference between the linear and chiral Lagrangians:

Linear Lagrangian

- The GBs are in the Higgs doublet Φ
- Φ has dimension 1 in mass
- d=4+n operators are suppressed by Λ_{NP}^n

Chiral Lagrangian

- The $\mathbf{U}(x)$ matrix is adimensional and any its extra insertions do not lead to any suppression

31 parameters

Luca Merlo@Moriond 2014

$$\mathcal{P}_B(h) = -\frac{g'^2}{4} B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$

$$\mathcal{P}_W(h) = -\frac{g^2}{4} W^a_{\mu\nu}W^{a\mu\nu}\mathcal{F}_W(h)$$

$$\mathcal{P}_G(h) = -\frac{g_s^2}{4} G^a_{\mu\nu}G^{a\mu\nu}\mathcal{F}_G(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4}\mathrm{Tr}(\mathbf{V}^\mu\mathbf{V}_\mu)\mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$

$$\mathcal{P}_1(h) = gg' B_{\mu\nu}\mathrm{Tr}(\mathbf{T}W^{\mu\nu})\mathcal{F}_1(h)$$

$$\mathcal{P}_2(h) = ig' B_{\mu\nu}\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_2(h)$$

$$\mathcal{P}_3(h) = ig\mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = ig' B_{\mu\nu}\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = ig\mathrm{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_5(h)$$

$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu))^2\mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\partial^\nu\mathcal{F}_7(h)$$

$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\partial^\mu\mathcal{F}_8(h)\partial^\nu\mathcal{F}'_8(h)$$

$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu\mathbf{V}^\mu)^2)\mathcal{F}_9(h)$$

$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu\mathcal{D}_\mu\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{10}(h)$$

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu))^2\mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2(\mathrm{Tr}(\mathbf{T}W_{\mu\nu}))^2\mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu\mathbf{V}^\nu)\mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T},\mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$

$$\mathcal{P}_{17}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu,\mathbf{V}_\nu])\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{18}(h)$$

$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu\mathcal{F}_{19}(h)$$

$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\mathcal{F}_{20}(h)\partial^\nu\mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$

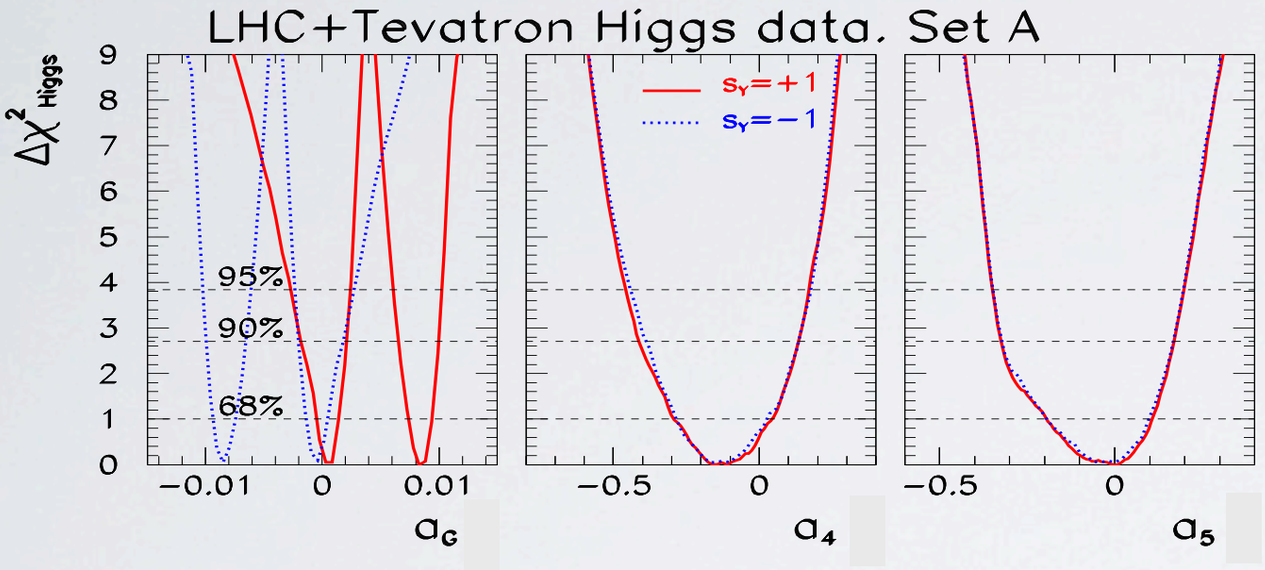
RED

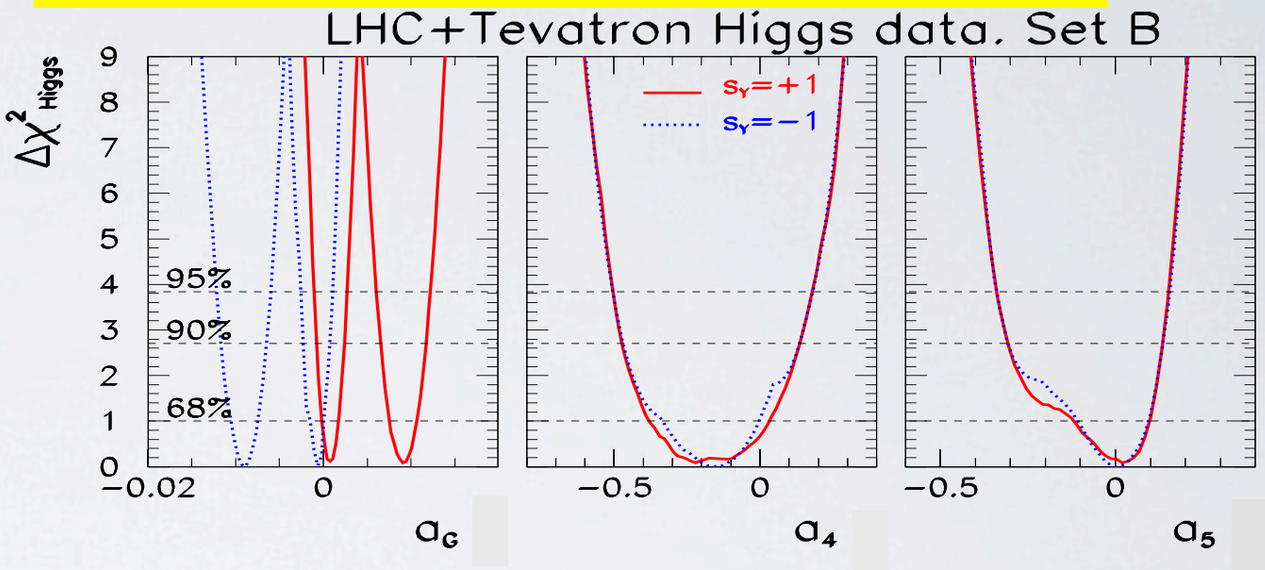
new Higgs couplings in the AL basis, and new operators with derivatives of *h*

Set A : $a_G\ ,\ a_4\ ,\ a_5\ ,a_B\ ,\ a_W\ ,\ c_H\ ,\ 2a_C - c_C = 0$ HVV = Hff

Set B : $a_G\ ,\ a_4\ ,\ a_5\ ,a_B\ ,\ a_W\ ,\ c_H = 2a_C - c_C$ HVV ≠ Hff

Fit by B. Gavela and coll.; Luca Merlo@Moriond 2014





$|\chi^2_{min,A} - \chi^2_{min,B}| < 0.5$

Data: Tevatron D0 and CDF Collaborations and LHC, CMS, and ATLAS Collaborations at 7 TeV and 8 TeV for final states $\gamma\gamma$, W^+W^-, ZZ, $Z\gamma$, $b\bar{b}$, and $\tau\bar{\tau}$

Conventional and less conventional Quarkonia

- The accuracy with which the spectra of Q Qbar states (Q=c, b) are predicted and measured makes it possible to discover new states "by difference"

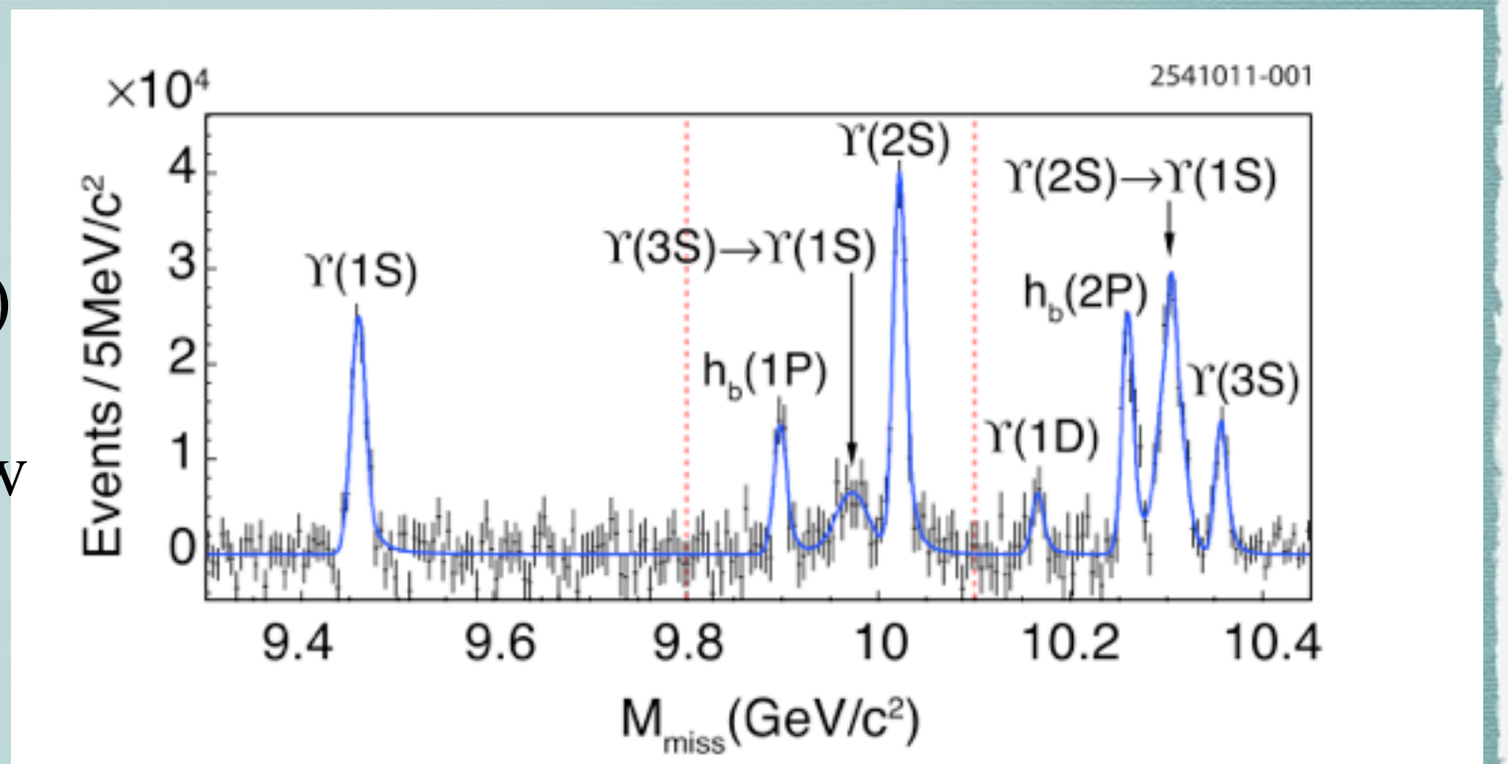


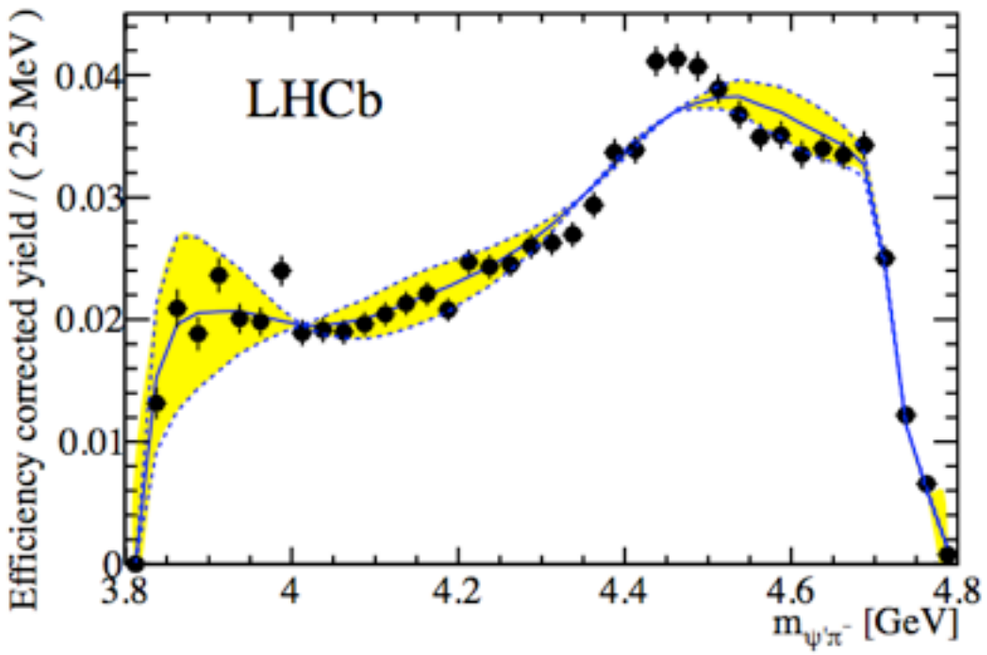
Figure 1: From Belle [31], the mass recoiling against $\pi^+\pi^-$ pairs, $M_{\rm miss}$, in e^+e^- collision

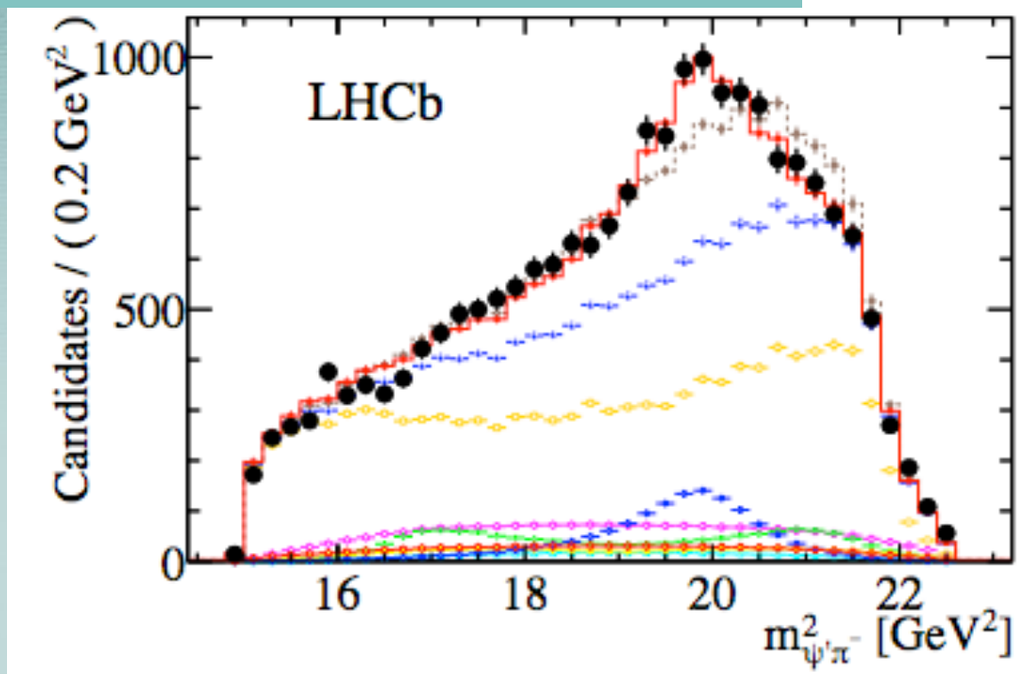
Particle Data Group:
S. Eidelman et al., *Developments in Heavy Quarkonium Spectroscopy*, 2012;
Quarkonium Working Group:
N. Brambilla et al., arXiv:1404.3723v1 [hep-ph] 14 Apr 2014

PDG: Unanticipated "Quarkonia"

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment ($\#\sigma$)	Year	Status
$X(3872)$	3871.68 ± 0.17	< 1.2	$1^{++}/2^{-+}$	$B \to K\,(\pi^+\pi^- J/\psi)$	Belle [36,37] (12.8), BABAR [38] (8.6)	2003	OK
				$p\bar{p} \to (\pi^+\pi^- J/\psi) + ...$	CDF [39–41] (np), D0 [42] (5.2)		
				$B \to K\,(\omega J/\psi)$	Belle [43] (4.3), BABAR [23] (4.0)		
				$B \to K\,(D^{*0}\overline{D}^0)$	Belle [44,45] (6.4), BABAR [46] (4.9)		
				$B \to K\,(\gamma J/\psi)$	Belle [47] (4.0), BABAR [48,49] (3.6)		
				$B \to K\,(\gamma\psi(2S))$	BABAR [49] (3.5), Belle [47] (0.4)		
				$p\bar{p} \to (\pi^+\pi^- J/\psi) + ...$	LHCb [50] (np)		
$X(3915)$	3917.4 ± 2.7	28^{+10}_{-9}	$0/2^{?+}$	$B \to K\,(\omega J/\psi)$	Belle [51] (8.1), BABAR [52] (19)	2004	OK
				$e^+e^- \to e^+e^-\,(\omega J/\psi)$	Belle [53] (7.7), BABAR [28] (np)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi\,(D\overline{D}^*)$	Belle [54] (6.0)	2007	NC!
				$e^+e^- \to J/\psi\,(...)$	Belle [20] (5.0)		
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^- \to \gamma\,(D\overline{D})$	BABAR [55] (np), Belle [56] (np)	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	Belle [57] (7.4)	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K\,(\pi^+\chi_{c1}(1P))$	Belle [58] (5.0), BABAR [59] (1.1)	2008	NC!
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B \to K\,(\phi J/\psi)$	CDF [60,61] (5.0)	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi\,(D\overline{D}^*)$	Belle [54] (5.5)	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B \to K\,(\pi^+\chi_{c1}(1P))$	Belle [58] (5.0), BABAR [59] (2.0)	2008	NC!
$Y(4260)$	4263^{+8}_{-9}	95 ± 14	1^{--}	$e^+e^- \to \gamma\,(\pi^+\pi^- J/\psi)$	BABAR [62,63] (8.0)	2005	OK
					CLEO [64] (5.4), Belle [57] (15)		
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	CLEO [65] (11)		
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO [65] (5.1)		
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B \to K\,(\phi J/\psi)$	CDF [61] (3.1)	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0/2^{++}$	$e^+e^- \to e^+e^-\,(\phi J/\psi)$	Belle [66] (3.2)	2009	NC!
$Y(4360)$	4361 ± 13	74 ± 18	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^-\psi(2S))$	BABAR [67] (np), Belle [68] (8.0)	2007	OK
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B \to K\,(\pi^+\psi(2S))$	Belle [69,70] (6.4), BABAR [71] (2.4)	2007	NC!
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma\,(\Lambda_c^+\Lambda_c^-)$	Belle [72] (8.2)	2007	NC!
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^- \to \gamma\,(\pi^+\pi^-\psi(2S))$	Belle [68] (5.8)	2007	NC!
$Z_b(10610)^+$	10607.2 ± 2.0	18.4 ± 2.4	1^+	$\Upsilon(5S) \to \pi^-(\pi^+[b\bar{b}])$	Belle [73,74] (16)	2011	NC!
$Z_b(10650)^+$	10652.2 ± 1.5	11.5 ± 2.2	1^+	$\Upsilon(5S) \to \pi^-(\pi^+[b\bar{b}])$	Belle [73,74] (16)	2011	NC!
$Y_b(10888)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\pi^+\pi^-\Upsilon(nS))$	Belle [75,76] (2.0)	2010	NC!

Z(4430) SAGA: LHCB, X10 STATISTICS





K0∗(800), K0∗(1430), J = 0;
K∗(892), K∗(1410) and K∗(1680), J = 1;
K2∗(1430), J = 2;
K3∗(1780), J = 3.....NO $Z^{\pm}$ ALLOWED

same K* , WITH $Z^{\pm}$:
$M_{Z^{\pm}}$= 4475 ± 7 MeV, $\Gamma_{Z^{\pm}}$= 172 ± 13 MeV, $J^P=1^+$

$$Z^{\pm} \to J/\Psi + \pi^{\pm}$$
$$\to c\bar{c}u\bar{d}$$

A schematic Model of Baryons and Mesons, M. Gell- Mann, 1964
We then refer to the members $u^{2/3}$, $d^{-1/3}$, and $s^{-1/3}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks, qbar. Baryons can now be constructed from quarks by using the combinations (q q q), (q q q q qbar), etc., while mesons are made out of (q qbar), (q q qbar qbar), etc.

A New Picture for the Formation and Decay of the Exotic XYZ Mesons, S. J. Brodsky et al., 2014
This first verification of the existence of exotic hadrons, which possess neither meson (q qbar) nor baryon (qqq) valence structure, is an exciting advance for QCD; a key challenge is to uncover the dynamical structure of these states….In this paper, we have been inspired by a well- known hypothesis for the XYZ states—that of a diquark- antidiquark (δ-δ bar) pair, [q_1 q_2][q_3 bar q_4 bar].

do we understand QCD ??

Part 3:
...to BARELY VISIBLES

Flavor Symmetry and (Minimal) Flavor Symmetry Breaking

•The symmetry group commuting with the ST gauge group, for three generations, is:

$$SU(3)_{Q_L} \otimes SU(3)_{U_R} \otimes SU(3)_{D_R} \otimes SU(3)_{\ell_L} \otimes SU(3)_{E_R}$$

Chivukula& Georgi, no right-handed neutrinos, or:

$$SU(3)_{Q_L} \otimes SU(3)_{U_R} \otimes SU(3)_{D_R} \otimes SU(3)_{\ell_L} \otimes SU(3)_{E_R} \otimes \mathcal{O}(3)$$

to trigger see-saw. O(3) is the maximal symmetry with three generations of right-handed neutrinos, N, endowed with a degenerate, Majorana mass, M.

•a set of Yukawa couplings break the symmetry, providing masses to all particles:

$$m_a = Y_a < H >, \; a = U, D, E$$

$$m_\nu =< H >^2 \frac{Y_\nu^T Y_\nu}{M}$$

•Y_ν are not particularly suppressed for very small ν masses (thanks to Feruglio for explaining):

$$|Y_\nu| \sim \sqrt{\frac{m_\nu M}{< H >^2}} \sim \text{normal coupling}$$

Minimal Flavor Violation for quarks

- Ys must appear in all Flavor Violating effective lagrangians arising from the heavy particles from New Physics (Technicolor or SUSY), in such a way as to make the effect. lag. to be symmetric under the Flavor Group (see G. Isidori's talk);
- MFV is very effective in reducing the lower bounds to the scale of New Physics, obtained from the non observed deviations from ST in flavor changing neutral current effects:

$$\mathcal{L}_{eff} = \frac{1}{\Lambda^2}(\bar{s}_L\gamma_\mu d_L)^2 \to \frac{1}{\Lambda^2}\left(\bar{Q}_L Y_U Y_U^\dagger \gamma_\mu Q_L\right)^2$$

Operator	Bounds on Λ in TeV Re	Im	Observables
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	Δm_K; ϵ_K
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	Δm_K; ϵ_K
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	Δm_D; $\lvert q/p\rvert, \phi_D$
$(b_L\gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	Δm_{B_d}; $S_{\psi K_S}$
$(b_L\gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	Δm_{B_s}; $S_{\psi\phi}$
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	Δm_{B_s}; $S_{\psi\phi}$

Table 1:

Operator	Bound on Λ	Observables
$H^\dagger\left(\bar{D}_R Y_d^\dagger Y_u Y_u^\dagger \sigma_{\mu\nu} Q_L\right)(eF_{\mu\nu})$	6.1 TeV	$B\to X_s\gamma$, $B\to X_s\ell^+\ell^-$
$\frac{1}{2}(\bar{Q}_L Y_u Y_u^\dagger \gamma_\mu Q_L)^2$	5.9 TeV	ϵ_K, Δm_{B_d}, Δm_{B_s}
$H_D^\dagger\left(\bar{D}_R Y_d^\dagger Y_u Y_u^\dagger \sigma_{\mu\nu} T^a Q_L\right)(g_s G^a_{\mu\nu})$	3.4 TeV	$B\to X_s\gamma$, $B\to X_s\ell^+\ell^-$
$(\bar{Q}_L Y_u Y_u^\dagger \gamma_\mu Q_L)(\bar{E}_R\gamma_\mu E_R)$	2.7 TeV	$B_s\to\mu^+\mu^-$, $B\to X_s\ell^+\ell^-$
$i(\bar{Q}_L Y_u Y_u^\dagger \gamma_\mu Q_L) H_U^\dagger D_\mu H_U$	2.3 TeV	$B_s\to\mu^+\mu^-$, $B\to X_s\ell^+\ell^-$
$(\bar{Q}_L Y_u Y_u^\dagger \gamma_\mu Q_L)(\bar{L}_L\gamma_\mu L_L)$	1.5 TeV	$B_s\to\mu^+\mu^-$, $B\to X_s\ell^+\ell^-$
$(\bar{Q}_L Y_u Y_u^\dagger \gamma_\mu Q_L)(eD_\mu F_{\mu\nu})$	1.7 TeV	$B\to X_s\ell^+\ell^-$

Table 1:

- a further reduction in Λ if effects come from 1-loop diagrams

The scale of the Flavor Symmetry Breaking

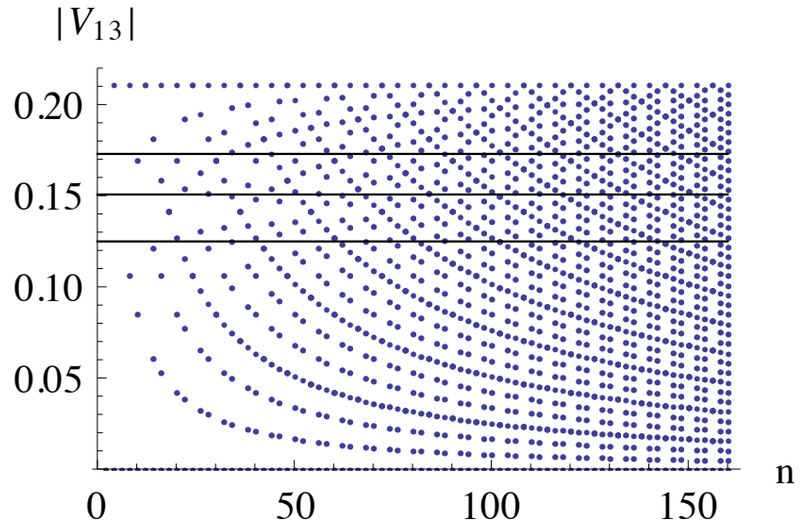
- For the particles of the ST, but neutrinos, the scale of symmetry breaking is given by Y<H> ;
- Y may be "universal", but I find it unlikely that the same <H> will convert Y into GeV;
- the more so if Y=<S> with S a completely new field: this is indicated as ***dynamical Yukawa couplings***.
- In Technicolor (Chivukula and Georgi), Y ∝ preon masses/V, V some new scale;
- if so in SUSY, and the scale of FSB is of the order of M_{SUSY}, s-quarks and s-leptons of different flavor could be ***not so degerate*** as normally expected.

Discrete symmetries for neutrinos?

- If Y_ν are dynamical, it may well be that the solution of the minimum principle admits some of the discrete symmetries like those investigated recently
- one possible criterion could be that the discrete symmetry be a subgroup of SU(3)xO(3), that admit a rep imbedded into the $(3,3_V)$ rep.
- can you identify the candidates in the plot below?
- (the symmetry of strong interactions was identified in the sisties choosing among rank 2 groups, corresponding to I_3 and Y conservation).

Mixing Results (contd.)

One can plot the possible values of $|V_{13}|$, the lines denote the present approximate 3σ range of $|V_{13}|$ (from Fogli et al,1205.5254):



Ex.: $|V_{13}| = 0.211, 0.170, 0.160, 0.154$ for $n = 4, 10, 16, 22$

Part 3:
... barely VISIBLES ?

A new "light" vector boson?

- In *Alonso et al.* (see Isidori) we have assumed that Yukawa couplings are VEV's of scalar fields, determined by a minumum principle (Alonso et al., see Isidori)
- a natural solution is found for neutrinos, with ***large mixing angles and degenerate masses***
- the solution, including diagonal masses for charged leptons, admits a conserved charge of the form (with respect to the full lepton flavor group)

$$Q_{cons} = \lambda'_3 \oplus \mathbf{1} \oplus \mathbf{1} + \mathbf{1} \oplus \lambda'_3 \oplus \mathbf{1} + \mathbf{1} \oplus \mathbf{1} \oplus \lambda_7$$
$$\lambda'_3 = \mathrm{diag}(0, 1, -1)$$

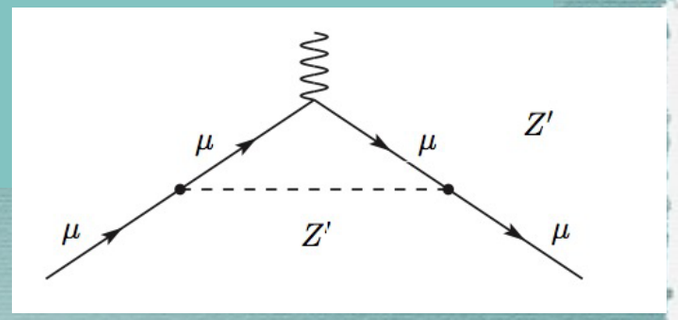
- gauging the flavor symmetry we would be left with one massless vector boson, Z', coupled to the conserved current

$$J_\lambda = \left[\bar{\ell}_L^{(\mu)} \gamma_\lambda \ell_L^{(\mu)} + \bar{\mu}_R \gamma_\lambda \mu_R\right] - [\mu \to \tau] + N^T \gamma^0 \gamma_\lambda \lambda_7 N$$

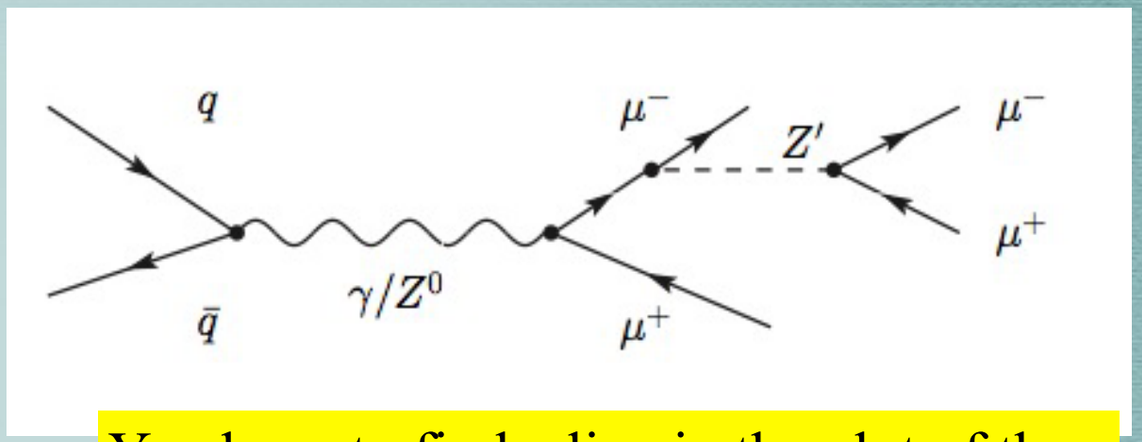
- One may assume that small perturbations to remove the neutrino degeneracies, will be able to give the Z' a mass, which may be much smaller than the general mass scale of flavons.
- A "light" Z' coupled to Lμ-Lτ, was proposed, on different grounds, by several authors, see J. Heeck and W. Rodejohann, 2011.

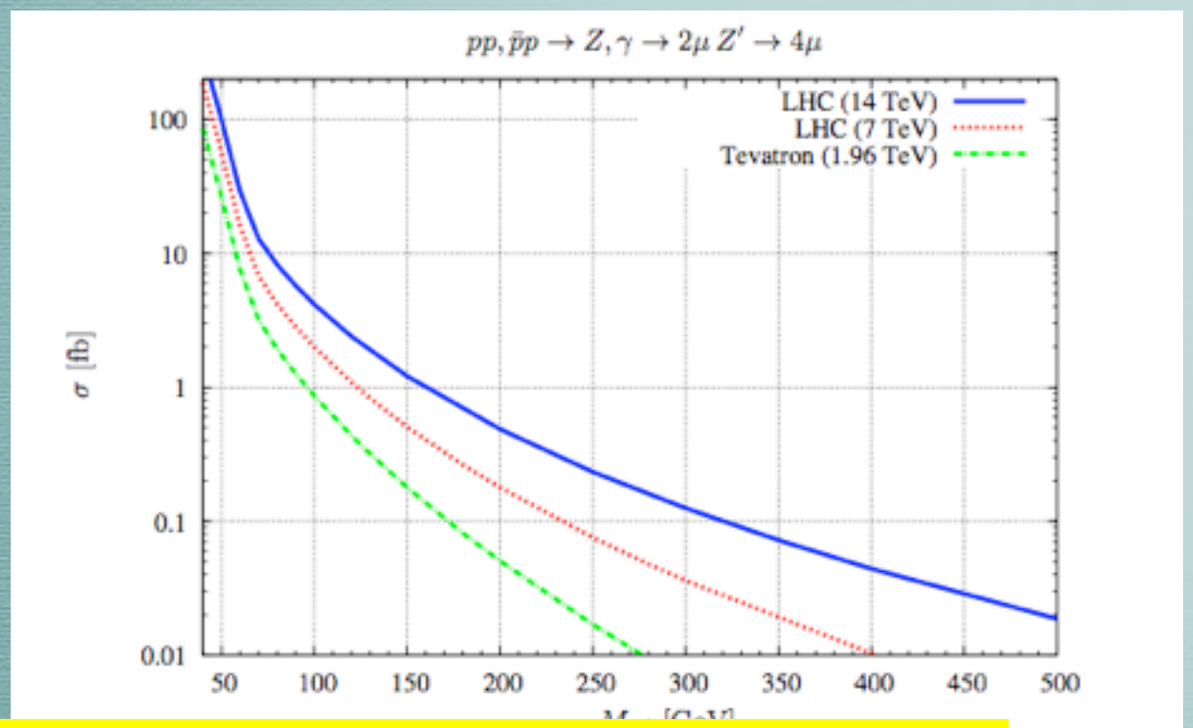
J. Heeck and W. Rodejohann, Phys. Rev. D **84** (2011) 075007 [arXiv:1107.5238].

Z' coupled to Lμ-Lτ



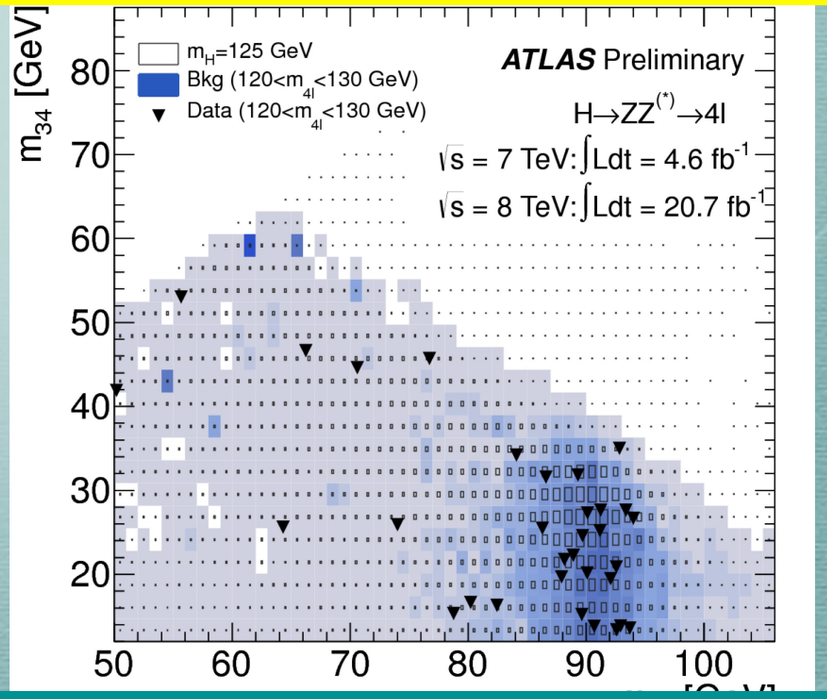
- explains discrepancy in the muon g-2 if: M/g ~ 200 GeV
- not directly coupled to electron or quarks, would be produced by final state muons at LEP and LHC:
- limits from LEP, M>50 GeV
- cross section at LHC:





Computed with g=1, scales like g^2
$\sigma \sim (1\text{-}10) \times g^2$ fb
(from Heeck and W. Rodejohann, 2011)

You have to find a line in the plot of the dimuon masses: low vs. high, and fight against the Z background



Yesterday sensation is the signal of today and the background of tomorrow

Conclusions

- Neutrino experiments: great progress, great perspectives.
- Theory: based on the Flavor Group $SU(3)^5$ or $SU(3)^5 \times O(3)$, broken by Yukawa couplings
- To get to a Theory of flavor we have to overcome the ST paradigm that Yukawa couplings are "just renormalized couplings"
- steps in this direction:
  - Minimal Flavor Violation (at least "universal constants", like quark masses)
  - Dynamical Yukawa: they are <S>, determined by a minimum principle on some potential
  - the old Cabibbo's dream o "compute the Cabibbo angle".
- O(3) marks a difference between quarks and leptons;
- intriguing result obtained recently relates O(3) to large mixing angles and degenerate neutrinos;
- double beta decay and cosmological measurements may get to test degenerate Majorana neutrinos in few years;
- if so, the road is open to bolder attempts: gauge theory of Flavor? a light flavon coupled to L_μ-L_τ ??

Enough for an INVISIBLES2 Network !!