PLANCK 2013, FROM THE PLANCK SCALE TO THE ELECTROWEAK SCALE, BONN UNIV., MAY 20 – 24, 2013

CRITICAL ISSUES IN FLAVOR PHYSICS

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IS THERE A "FLAVOR PROBLEM"?

The flavor problem in the SM

- Why 3 fermion families ("who ordered the muon?")
- How to account for the vast spread in the values of fermion masses and mixings ("I cannot believe that I've a final theory as long as it does not tell me why the muon is 200 heavier than the electron")

The flavor problem in TeV New Physics BSM

How to suppress the new FCNC contributions (with or without CPV) arising from the exchange of the virtual TeV new physics particles

THE SM AND BSM FLAVOR PUZZLES

SM

- The apparent randomness of fermion masses and mixings → it's one the three major **"esthetical" deficiencies of the SM** together with the lack of a true **UNIFICATION** of fundamental forces and the **NATURALNESS** issue of the **GAUGE HIERARCHY**

BSM

- TeV new Physics could be **FLAVOR BLIND** (i.e. only sources of flavor remain the SM Yukawa couplings) **MINIMAL FLAVOR VIOLATION**

- **If no MFV**, the new physics FCNC contribution can be suppressed by specific (like the GIM mechanism) or accidental (like the smallness of the mixing angles, or the largeness of the ~TeV masses) reasons (**with effects <10% of the leading SM contributions for some relevant flavor quantities**)

BOTH THE SM AND BSM FLAVOR PUZZLES CAN FIND A SOLUTION IN THE EXISTENCE OF **A NEW (GAUGE OR GLOBAL OR DISCRETE) FLAVOR SYMMETRY**

THE FLAVOUR PROBLEMS

FERMION MASSES

What is the rationale hiding behind the spectrum of fermion masses and mixing angles (our "**Balmer lines**" problem)

→ **LACK OF A FLAVOUR "THEORY"**

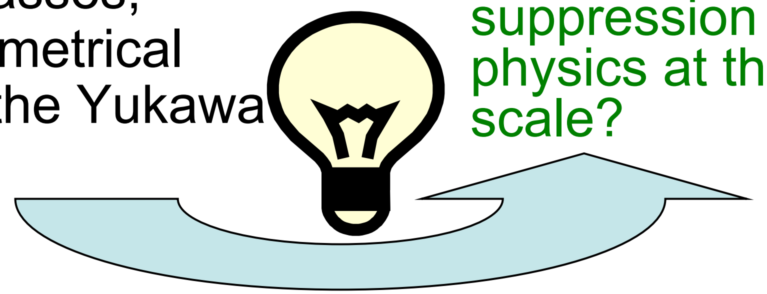
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

FCNC

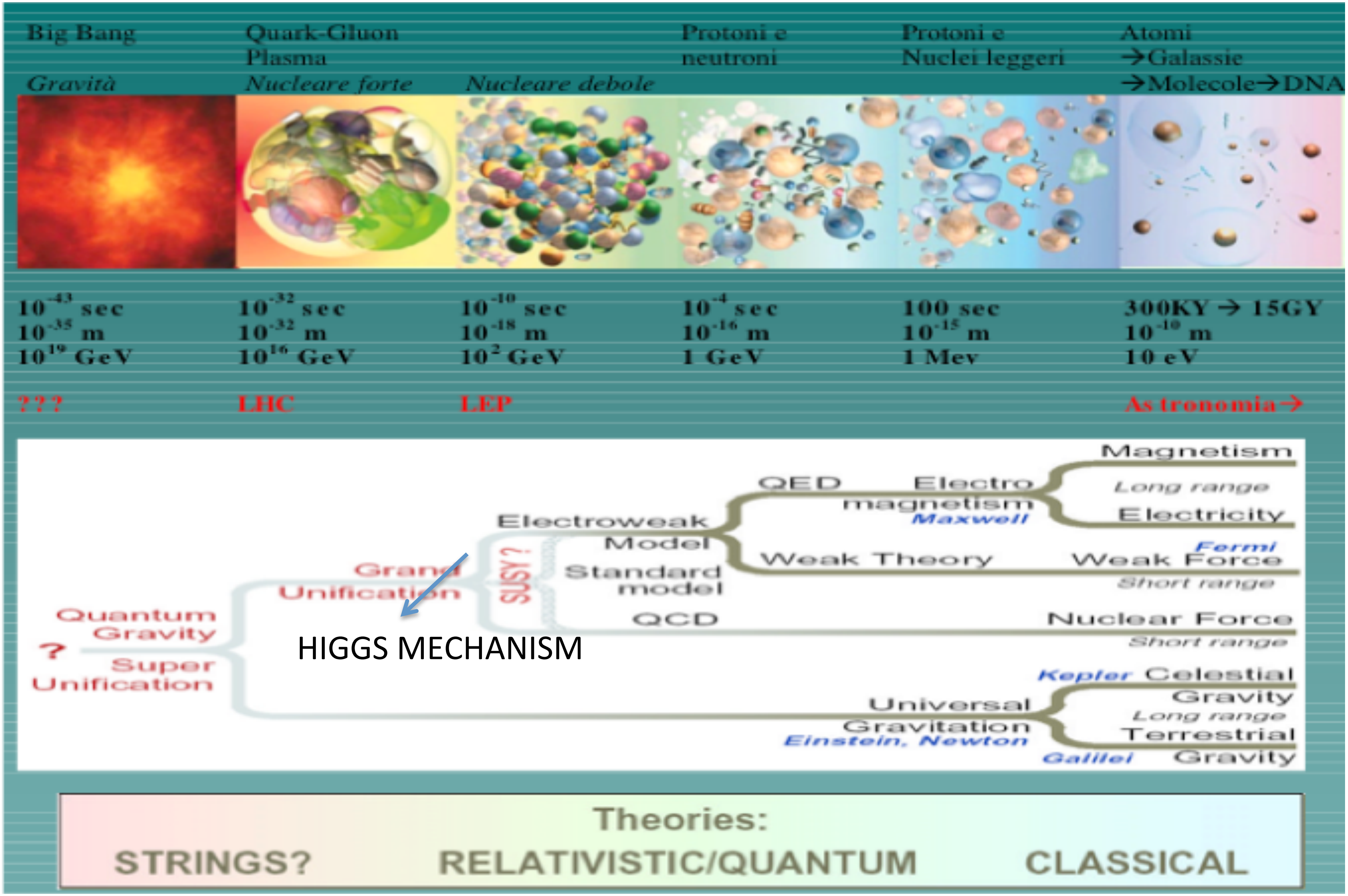
Flavour changing neutral current (FCNC) processes are suppressed.

In the SM two nice mechanisms are at work: the **GIM mechanism** and the structure of the **CKM mixing matrix.**

How to cope with such delicate suppression if the there is new physics at the electroweak scale?



A role for flavor in the Universe evolution?



MICRO

PARTICLE PHYSICS

GWS STANDARD MODEL

MACRO

COSMOLOGY

HOT BIG BANG
STANDARD MODEL

HAPPY MARRIAGE
Ex: NUCLEOSYNTHESIS

CRUCIAL THAT THERE
ARE **3 NEUTRINO SPECIES**
→**3 FERMION FAMILIES**

BUT ALSO

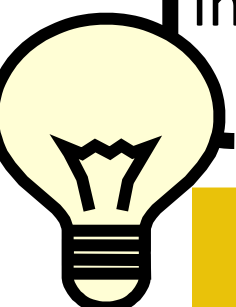
POINTS OF
FRICTION

- -COSMIC MATTER-ANTIMATTER ASYMMETRY
- -INFLATION
- - DARK MATTER + DARK ENERGY

"OBSERVATIONAL" EVIDENCE FOR NEW PHYSICS BEYOND THE **(PARTICLE PHYSICS)** STANDARD MODEL

The Energy Scale from the "Observational" New Physics

- neutrino masses
- dark matter
- baryogenesis
- inflation



→ NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE

The Energy Scale from the "Theoretical" New Physics

★ ★ ★ **Stabilization of the electroweak symmetry breaking at M_W calls for an ULTRAVIOLET COMPLETION of the SM already at the TeV scale**

+

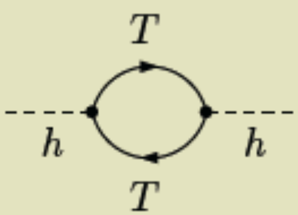
★ **CORRECT GRAND UNIFICATION "CALLS" FOR NEW PARTICLES AT THE ELW. SCALE**

Higgs and flavor physics as indirect BSM probes

NEUBERT SUSY2012

$$\mathcal{L}_{\rm EFT} = \Lambda_{\rm UV}^2\,\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{\mathcal{L}^{(5)}}{\Lambda_{\rm UV}} + \frac{\mathcal{L}^{(6)}}{\Lambda_{\rm UV}^2} + \dots$$

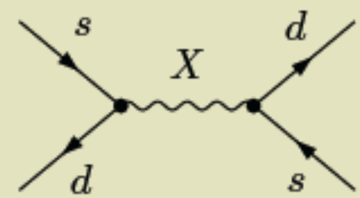
electroweak symmetry breaking $\Downarrow$ Higgs mass



$$\sim \frac{g_T^2}{16\pi^2}\Lambda_{\rm UV}^2$$

no fine-tuning $\Downarrow$

$$\Downarrow$$



$$\sim \frac{g_X^2}{\Lambda_{\rm UV}^2}$$

bounds on flavor mixing $\Downarrow$ assuming *generic* flavor structure

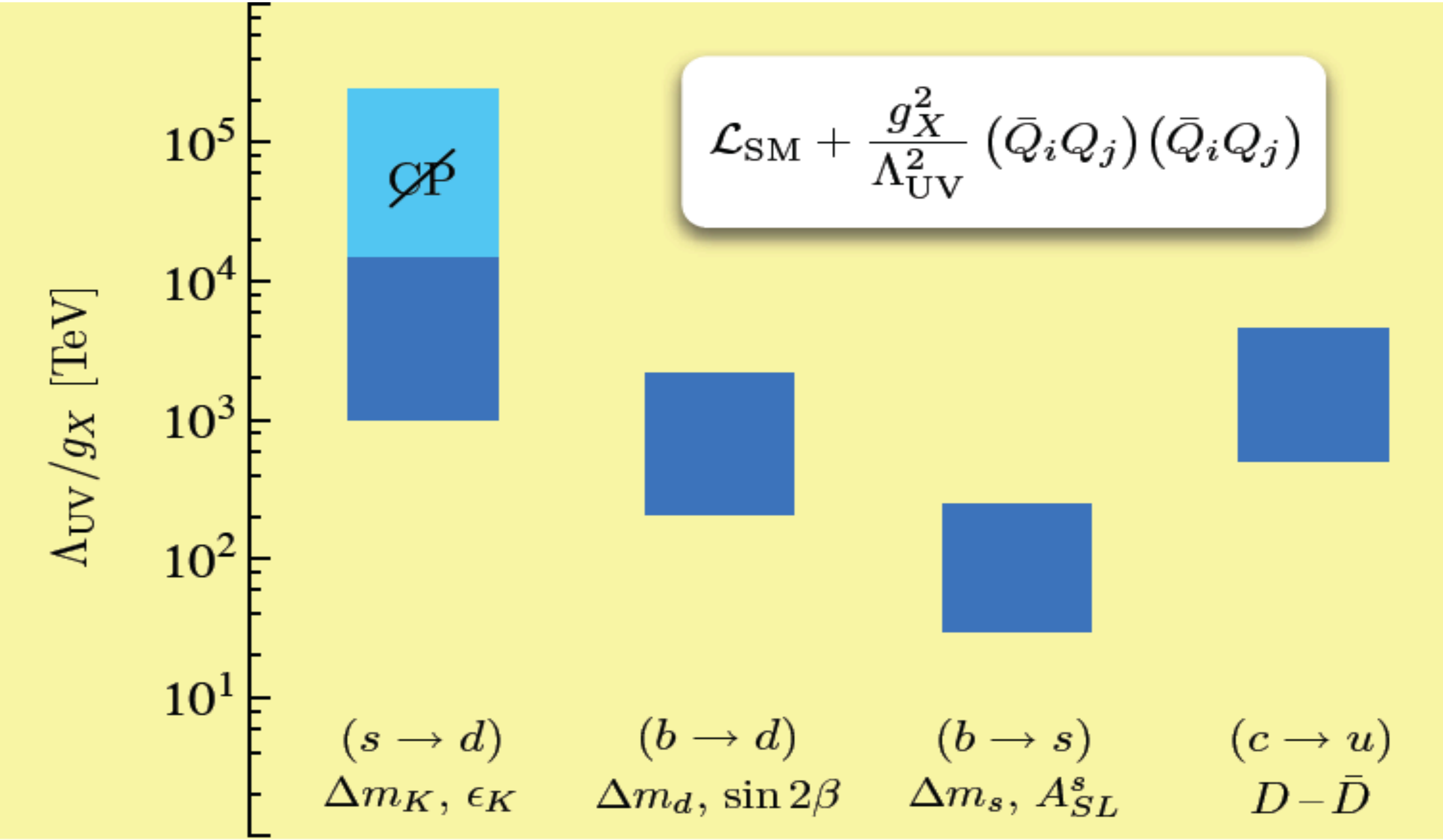
$\Lambda_{\rm Higgs} \lesssim 1$ TeV $\Lambda_{\rm flavor} \gtrsim 10^3$ TeV

Possible solutions to flavor problem explaining $\Lambda_{\rm Higgs} << \Lambda_{\rm flavor}$:

(i) $\Lambda_{\rm UV} >> 1$ TeV: **Higgs fine tuned**, new particles too heavy for LHC

(ii) $\Lambda_{\rm UV} \approx 1$ TeV: quark flavor-mixing protected by a **flavor symmetry**

FCNC and GENERIC FLAVOURED NEW PHYSICS



Generic bounds on New Physics scale (for $g_X \sim 1$)

Isidori, Nir, Perez

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \mathcal{L}_{eff}^{NP}$$

$$\mathcal{L}_{eff}^{NP} = \Sigma_i \frac{c_i}{\Lambda_{NP}^2} O_i$$

Operator	Bounds on Λ in TeV ($c_{ij} = 1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	$\Delta m_K; \epsilon_K$
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	$\Delta m_K; \epsilon_K$
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	$\Delta m_D; \lvert q/p \rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	$\Delta m_D; \lvert q/p \rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	2.3×10^{-6}	1.1×10^{-6}	$\Delta m_{B_d}; S_{\psi K_S}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	3.9×10^{-7}	1.9×10^{-7}	$\Delta m_{B_d}; S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	5.0×10^{-5}	1.7×10^{-5}	$\Delta m_{B_s}; S_{\psi\phi}$
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	8.8×10^{-6}	2.9×10^{-6}	$\Delta m_{B_s}; S_{\psi\phi}$

theoretical (esthetical) SM problems

New physics at the TeV scale

GAUGE HIERARCHY ★★★★★

UNIFICATION ★★★

FLAVOR ???

FLAVOR AND THE OBSERVATIONAL REASONS TO GO BEYOND THE SM

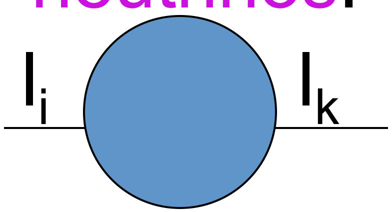
- **MASSIVE NEUTRINOS**: new Yukawa couplings related to the appearance of neutrino masses ("Dirac couplings" $\nu_L - \nu_R$, "Majorana couplings" $\nu_L - \nu_L$ or $\nu_R - \nu_R$)
- **COSMIC MATTER - ANTIMTTER ASYMMETRY**: i) **new source of CP violation** ; ii) in leptogenesis need **more than one fermion generation**
- **DARK MATTER** and **INFLATION**: no necessary link with the flavor issue.

LFV and NEW PHYSICS

- Flavor in the HADRONIC SECTOR:

  CKM paradigm
- Flavor in the LEPTONIC SECTOR:

  - Neutrino masses and (large) mixings
  - Extreme smallness of LFV in the charged lepton sector of the SM with massive neutrinos:



suppressed by $(m_{\nu_i}^2 - m_{\nu_k}^2) / M_W^2$

LFV IN SUSY SEE-SAW

SEE- SAW (type 1)

New source of (leptonic) flavor:

YUKAWA COUPLINGS OF THE NEUTRINO DIRAC MASS CONTRIBUTIONS, i.e. **THE YUKAWAs** of the **HIGGS couplings to the LETF- and RIGHT – HANDED NEUTRINOS**

LOW-ENERGY SUSY

The scalar lepton masses through their running bring memory of those new sources of leptonic flavor at the TeV scale, i.e. at energies much below the (Majorana) mass of the RH neutrinos

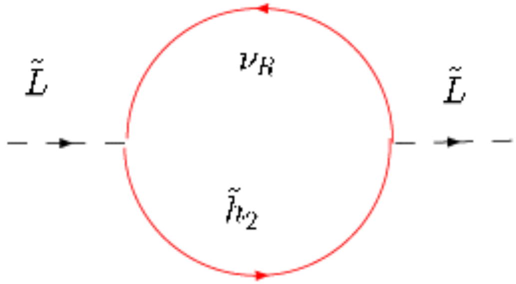
THE STRONG ENHANCEMENT OF LFV IN SUSY SEESAW MODELS CAN OCCUR

EVEN IF THE MECHANISM RESPONSIBLE FOR SUSY BREAKING IS ABSOLUTELY FLAVOR BLIND

SUSY SEESAW: *Flavor universal SUSY breaking and yet* ***large lepton flavor violation***

Borzumati, A. M. 1986 (after discussions with W. Marciano and A. Sanda)

$$L = f_l \, \overline{e}_R L h_1 + f_\nu \, \overline{\nu}_R L h_2 + M \, \nu_R \nu_R$$



$$\left(m_{\tilde{L}}^2\right)_{ij} \simeq \frac{1}{8\pi^2}\left(3m_0^2 + A_0^2\right)\left(f_\nu^\dagger f_\nu\right)_{ij} \log\frac{M}{M_G}$$

Non-diagonality of the slepton mass matrix in the basis of diagonal lepton mass matrix depends on the **unitary matrix U which diagonalizes ($f_\nu^+ f_\nu$)**

How Large LFV in SUSY SEESAW?

- 1) Size of the **Dirac neutrino couplings f_ν**
- 2) Size of the **diagonalizing matrix U**

In **MSSM seesaw** or in **SUSY SU(5)** (Moroi): not possible to correlate the neutrino Yukawa couplings to know Yukawas;

In **SUSY SO(10)** (A.M., Vempati, Vives) at least one neutrino Dirac Yukawa coupling has to be of the **order of the top Yukawa coupling** one large of O(1) f_ν

U → two "extreme" cases:

a) **U with "small" entries** → ***U = CKM***;
b) **U with "large" entries** with the exception of the 13 entry
→ ***U = PMNS*** matrix responsible for the diagonalization of the neutrino mass matrix

LFV in SUSYGUTs with SEESAW

Scale of appearance of the SUSY soft breaking terms resulting from the spontaneous breaking of supergravity

Low-energy SUSY has "memory" of all the multi-step RG occurring from such superlarge scale down to M_W

→ **potentially large LFV**

Barbieri, Hall; Barbieri, Hall, Strumia; Hisano, Nomura, Yanagida; Hisano, Moroi, Tobe Yamaguchi; Moroi;A.M.,, Vempati, Vives; Carvalho, Ellis, Gomez, Lola; Calibbi, Faccia, A.M, Vempati

LFV in MSSMseesaw: $\mu \to e\gamma$ Borzumati, A.M.

$\tau \to \mu\gamma$ Blazek, King;

General analysis: Casas Ibarra; Lavignac, Masina,Savoy; Hisano, Moroi, Tobe, Yamaguchi; Ellis, Hisano, Raidal, Shimizu; Fukuyama, Kikuchi, Okada; Petcov, Rodejohann, Shindou, Takanishi; Arganda, Herrero; Deppish, Pas, Redelbach, Rueckl; Petcov, Shindou

LFV in SUSY seesaw

L. Calibbi, NuFact 2012

In SUSY, new fields interacting with the MSSM fields enter the radiative corrections of the sfermion masses

Hall Kostelecky Raby '86

⇨ This applies to the new seesaw interactions: generically induce LFV in the slepton mass matrix!

Type I $(\tilde{m}^2_L)_{ij} \propto m_0^2 \sum_k (\mathbf{Y}_N^*)_{ki} (\mathbf{Y}_N)_{kj} \ln\left(\frac{M_X}{M_{R_K}}\right)$ Borzumati Masiero '86

Type II $(\tilde{m}^2_L)_{ij} \propto m_0^2 (\mathbf{Y}_\Delta{}^\dagger \mathbf{Y}_\Delta)_{ij} \ln\left(\frac{M_X}{M_\Delta}\right) \propto m_0^2 (\mathbf{m}_\nu{}^\dagger \mathbf{m}_\nu)_{ij} \ln\left(\frac{M_X}{M_\Delta}\right)$

$U \hat{\mathbf{m}}^2_\nu U^\dagger$

A. Rossi '02; Rossi Joaquim '06

Type III Similar to type I

Biggio LC '10; Esteves et al. '10

Thorough analysis of LFV in these 3 kinds of Seesaw in the SUSY context

M. HIRSCH, F. JOAQUIM, A. VICENTE arXiv: 1207.6635 [hep-ph]

IMPACT OF

HIGGS $124.5 \text{ GeV} \lesssim m_h \lesssim 126.5 \text{ GeV}$

LFV LIMITS $\text{BR}(\mu \to e + \gamma) < 2.4 \times 10^{-12}$ (90% CL).

θ_{13}

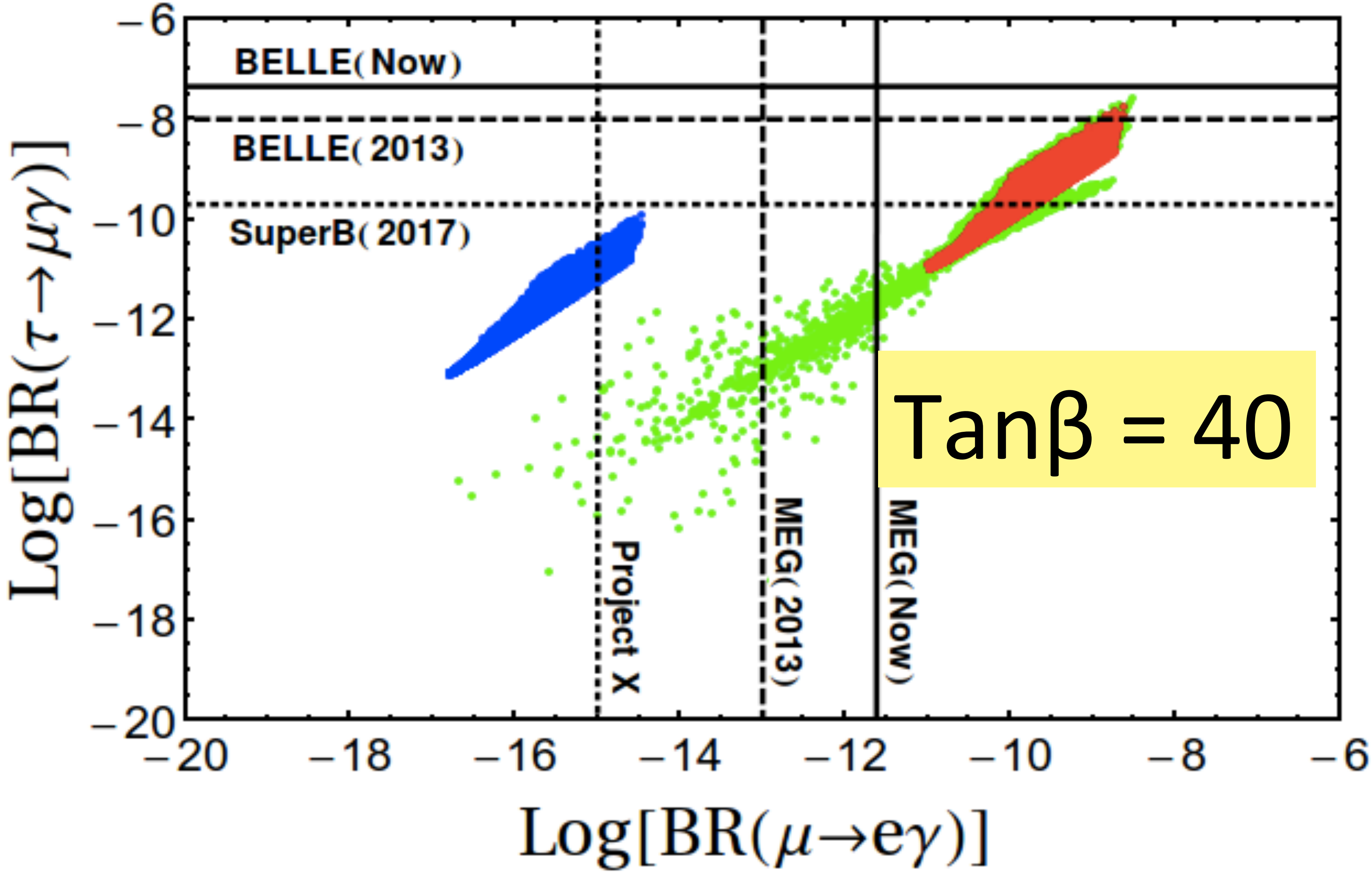
$$\sin^2 2\theta_{13} = 0.092 \pm 0.016(\text{stat.}) \pm 0.005(\text{syst.})$$

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(\text{stat.}) \pm 0.019(\text{syst.})$$

on SUSY GUTs where neutrinos get mass through the SEE-SAW MECHANISM

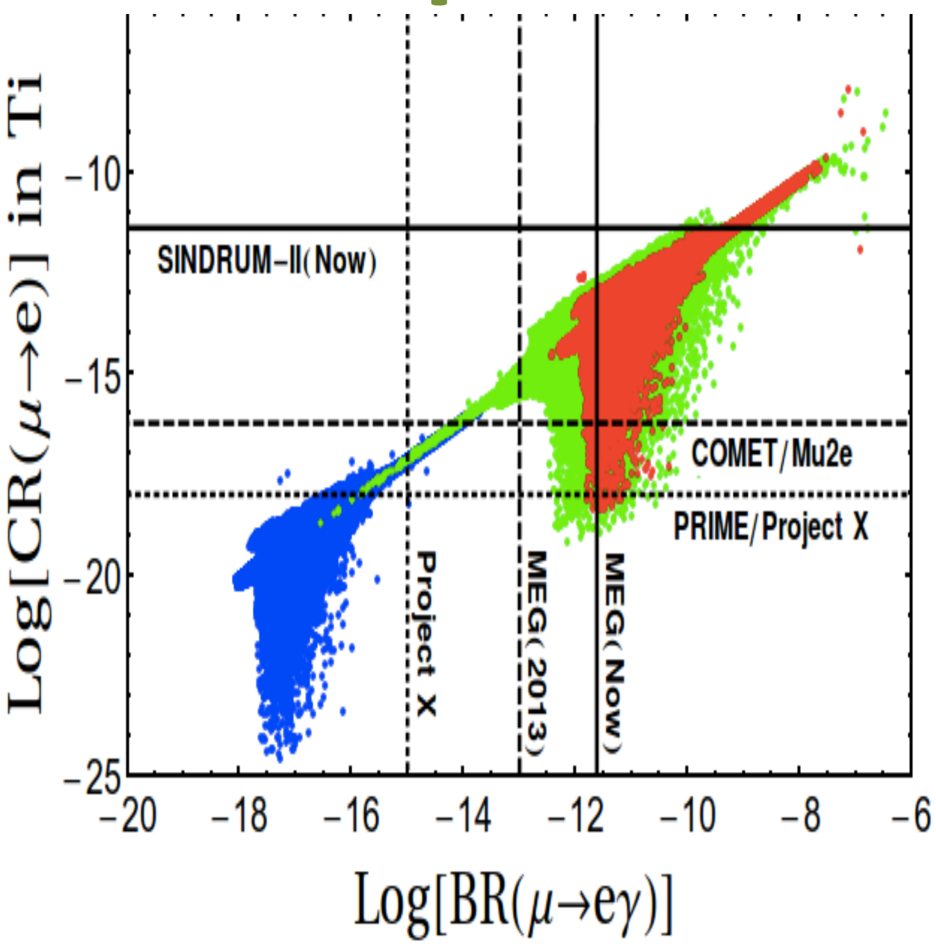
L. Calibbi, D. Chowdhury,A.M., K.M. Patel and S.K. Vempati arXiv:1207.7227v1 [hep-ph]

τ → μγ vs. μ → eγ sensitivities

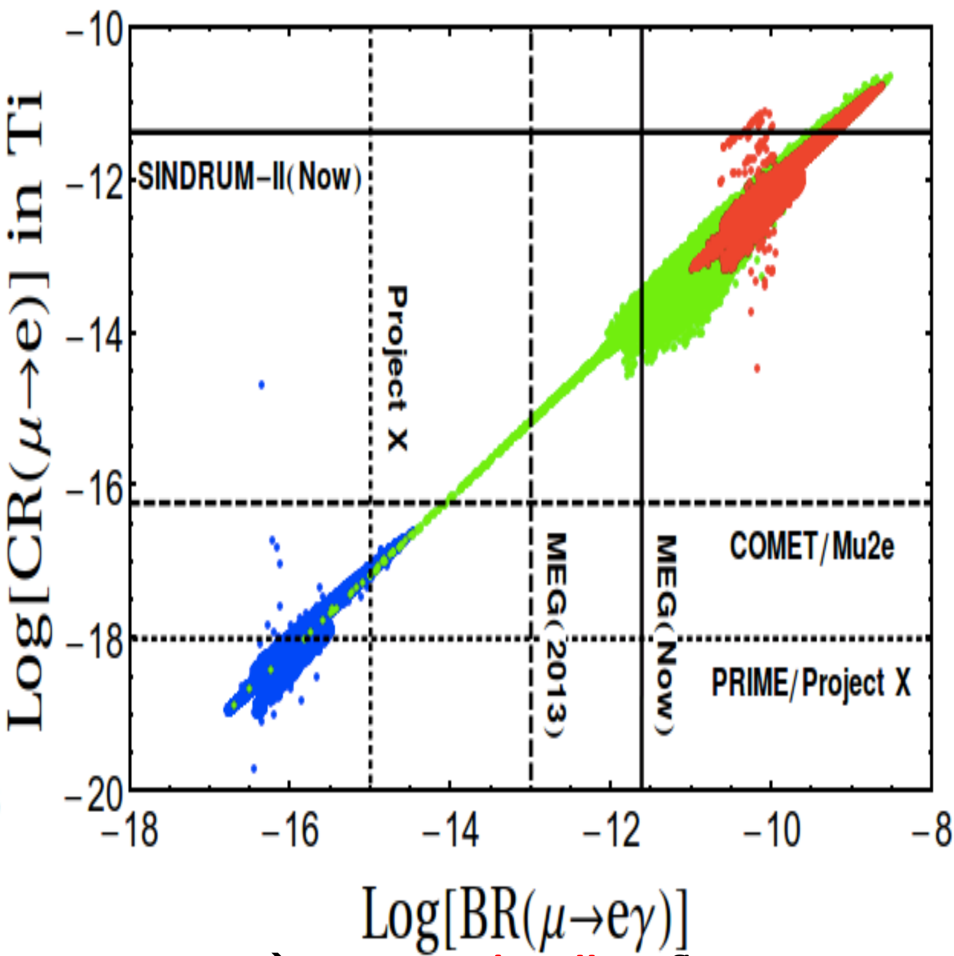


μ – e conversion vs μ → eγ

Tanβ = 10

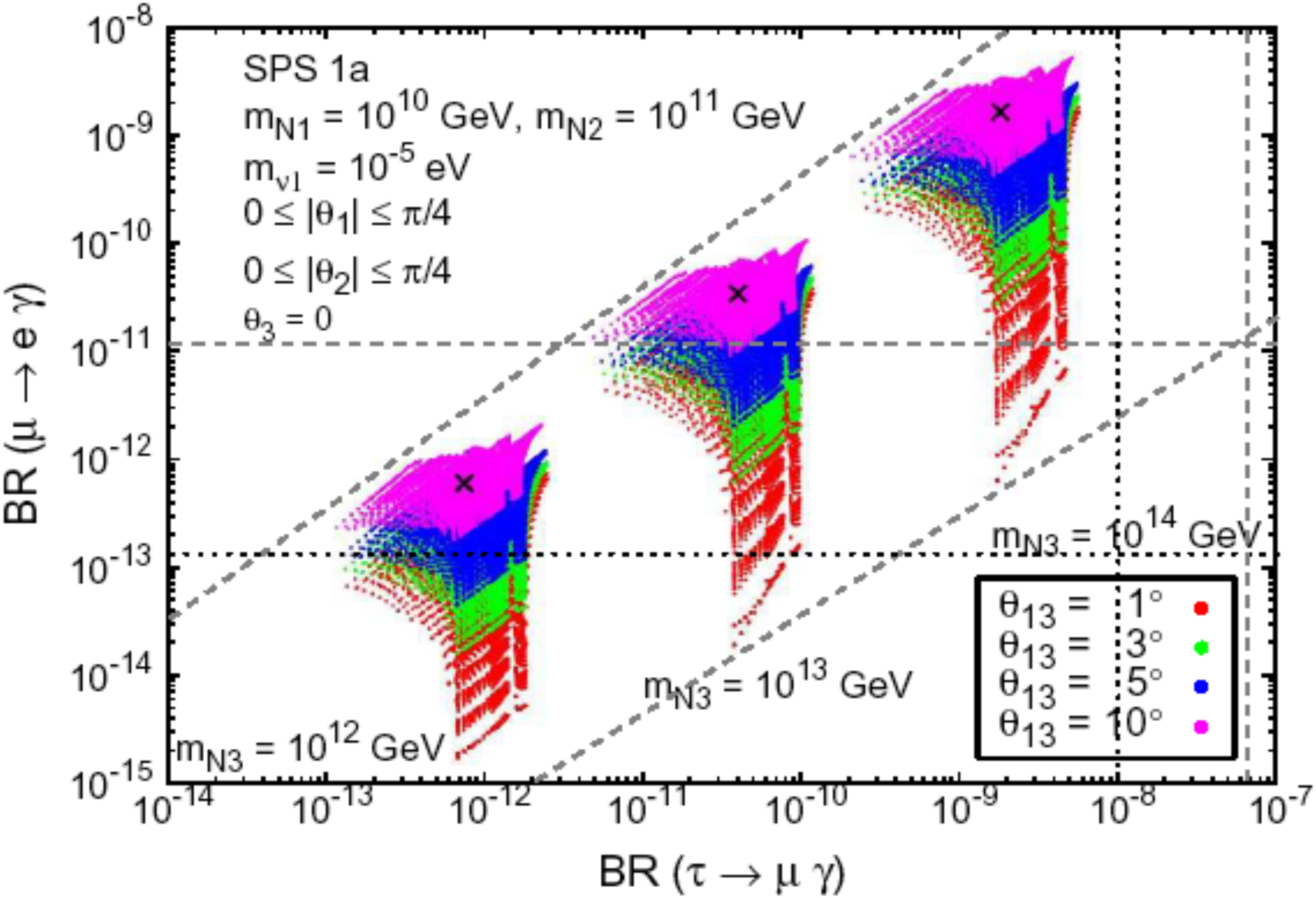


Tanβ = 40



FOR AN UPDATE ON MU-E CONVERSION IN TYPE-I SEASAW → **M. DHEN's talk** in flavor parallel session

Antusch, Arganda, Herrero, Teixeira



DEVIATION from μ - e UNIVERSALITY

A.M., Paradisi, Petronzio

- Denoting by $\Delta r_{NP}^{e-\mu}$ the deviation from $\mu - e$ universality in $R_{K,\pi}$ due to new physics, i.e.:

$$R_{K,\pi} = R_{K,\pi}^{SM}\left(1 + \Delta r_{K,\pi\,NP}^{e-\mu}\right),$$

- we get at the 2σ level:

$$-0.063 \leq \Delta r_{K\,NP}^{e-\mu} \leq 0.017 \quad \mathrm{NA48/2}$$

$$-0.0107 \leq \Delta r_{\pi\,NP}^{e-\mu} \leq 0.0022 \quad \mathrm{PDG}$$

Presently: error on R_K down to the **1% level** (KLOE (09) and NA48 (07 data);using 40% of the data collected in 08, NA62 is now decreasing the uncertainty at the **0.7% level** **Prospects**: Summer conf. we'll have the result concerning the 40% data analysis by NA62 and when the analysis of the whole sample of data is accomplished **the stat. uncertainty will be < 0.3%**

HIGGS-MEDIATED LFV COUPLINGS

- When non-holomorphic terms are generated by loop effects (HRS corrections)
- And a source of LFV among the sleptons is present
- → Higgs-mediated (radiatively induced) H-lepton-lepton LFV couplings arise

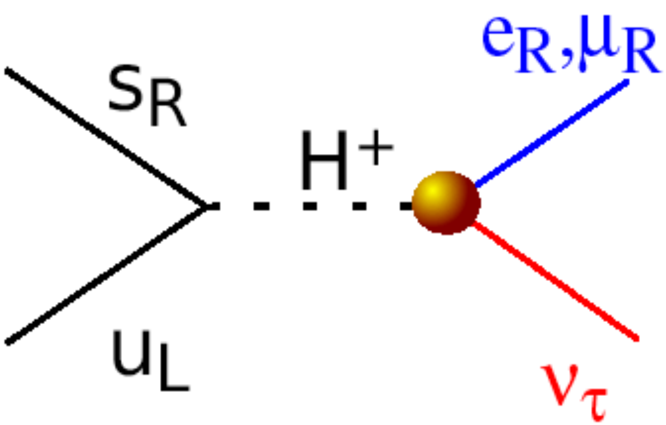
Babu, Kolda; Sher; Kitano,Koike,Komine, Okada; Dedes, Ellis, Raidal; Brignole,Rossi; Arganda,Curiel,Herrero,Temes; Paradisi; Brignole,Rossi

DEVIATION from μ - e UNIVERSALITY

A.M., Paradisi, Petronzio

H mediated LFV SUSY contributions to R_K

$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}\ , \quad i = e, \mu, \tau$$



$$eH^\pm \nu_\tau \to \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{31} \tan^2\beta$$

$$\Delta_R^{31} \sim \frac{\alpha_2}{4\pi} \delta_{RR}^{31}$$

$$\Delta_R^{31} \sim 5 \cdot 10^{-4} \quad t_\beta = 40 \quad M_{H^\pm} = 500\text{GeV}$$

Analysis in various SUSY models: see R. Fonseca's talk in yesterday Flavor parallel Session

$$\Downarrow$$

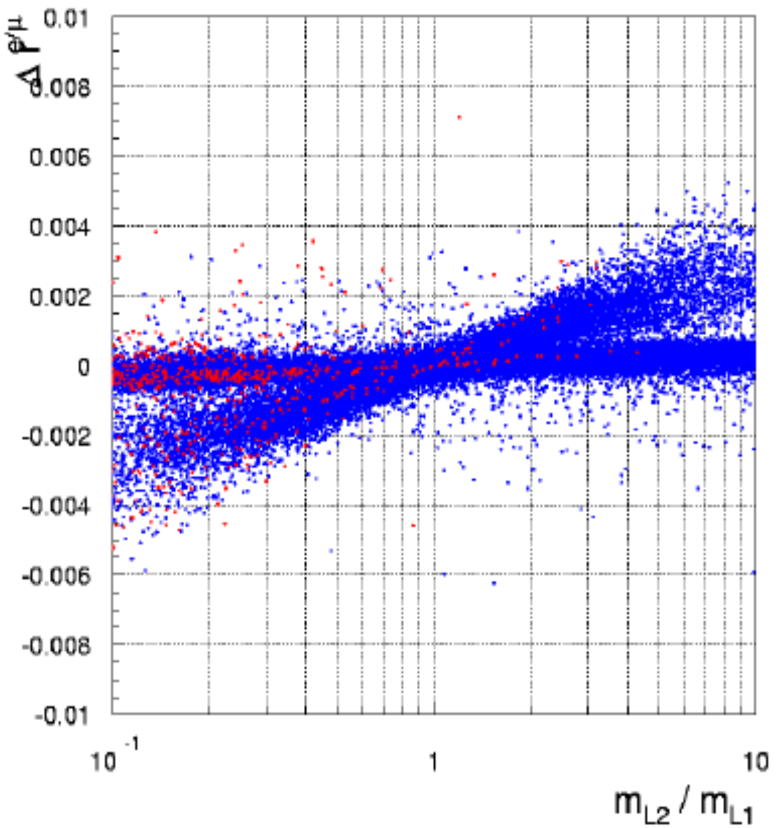
$$\Delta r_{K\ SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right) |\Delta_R^{31}|^2 \tan^6\beta \approx 10^{-2}$$

Extension to B ⟶ lν deviation from universality Isidori, Paradisi

LFU breaking occurs in a **LF conserving** case because of the splitting in slepton masses

A.M., PARADISI. PETRONZIO

LFU breaking occurs with LFV



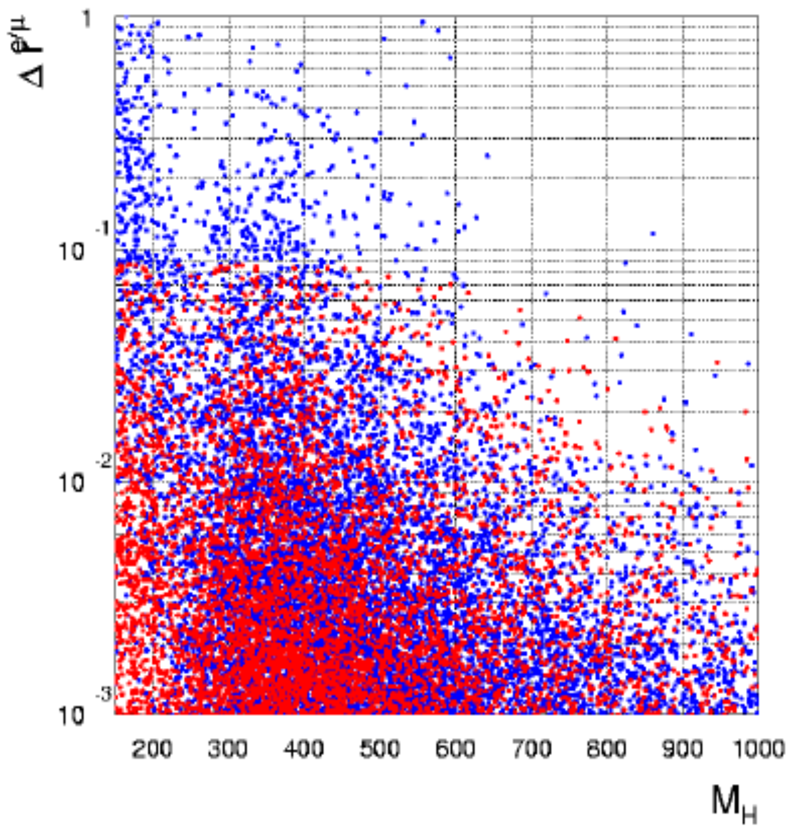


Figure 2: Left:$\Delta r_K^{e/\mu}$ as a function of the mass splitting between the second and the first (left-handed) slepton generations. Red dots can saturate the $(g-2)_\mu$ discrepancy at the 95% C.L., i.e. $1 \times 10^{-9} < (g-2)_\mu < 5 \times 10^{-9}$. Right: $\Delta r_K^{e/\mu}$ as a function of M_{H+}.

ν : WHERE WE STAND AND WHERE WE'RE HEADING TO

δm^2_{12} ✓ SOLARS+KAMLAND $\delta m^2_{12} = (7.9 +/- 0.7)\ 10^{-5} eV^2$

θ_{12} ✓ SOLARS+KAMLAND $\sin^2(2\theta_{12}) = 0.82 +/- 0.055$

Addressed by accelerator neutrino experiments

δm^2_{23} ✓ ATMOSPHERICS $\delta m^2_{23} = (2.4 +/- 0.4)\ 10^{-3}\ eV^2$

θ_{23} ✓ ATMOSPHERICS $\sin^2(2\theta_{23}) > 0.95$

θ_{13} ✓ $\sin^2 2\theta_{13} = 0.1$

LSND/Steriles ? ★

δ_{CP} ★★

Mass hierarchy ★★

Σm_ν BETA DECAY END POINT $\Sigma m_\nu < 6.6$ eV ★★★

Dirac/Majorana ★★★★ ★

ACCORDING TO MY PERSONAL TASTE

CKM matrix and Unitarity Triangle

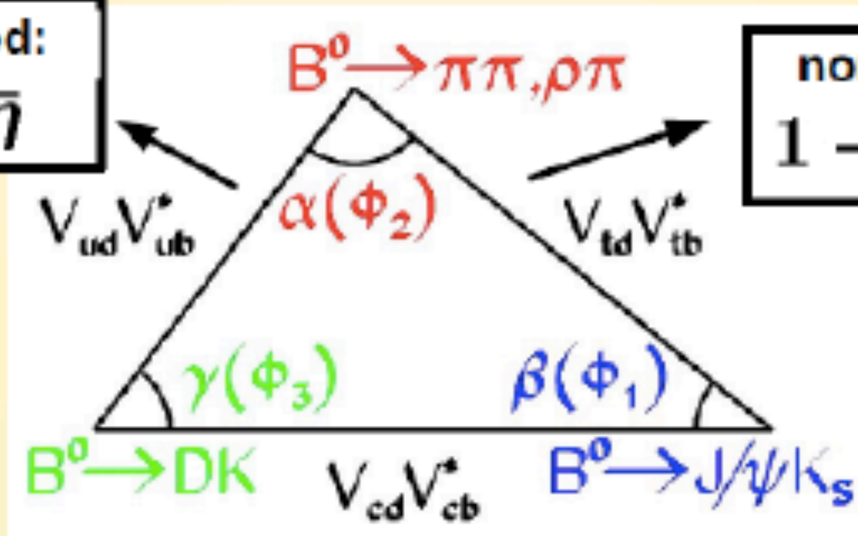
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

many observables functions of $\bar{\rho}$ and $\bar{\eta}$: overconstraining

$$\alpha = \pi - \beta - \gamma$$

normalized: $\bar{\rho} + i\bar{\eta}$

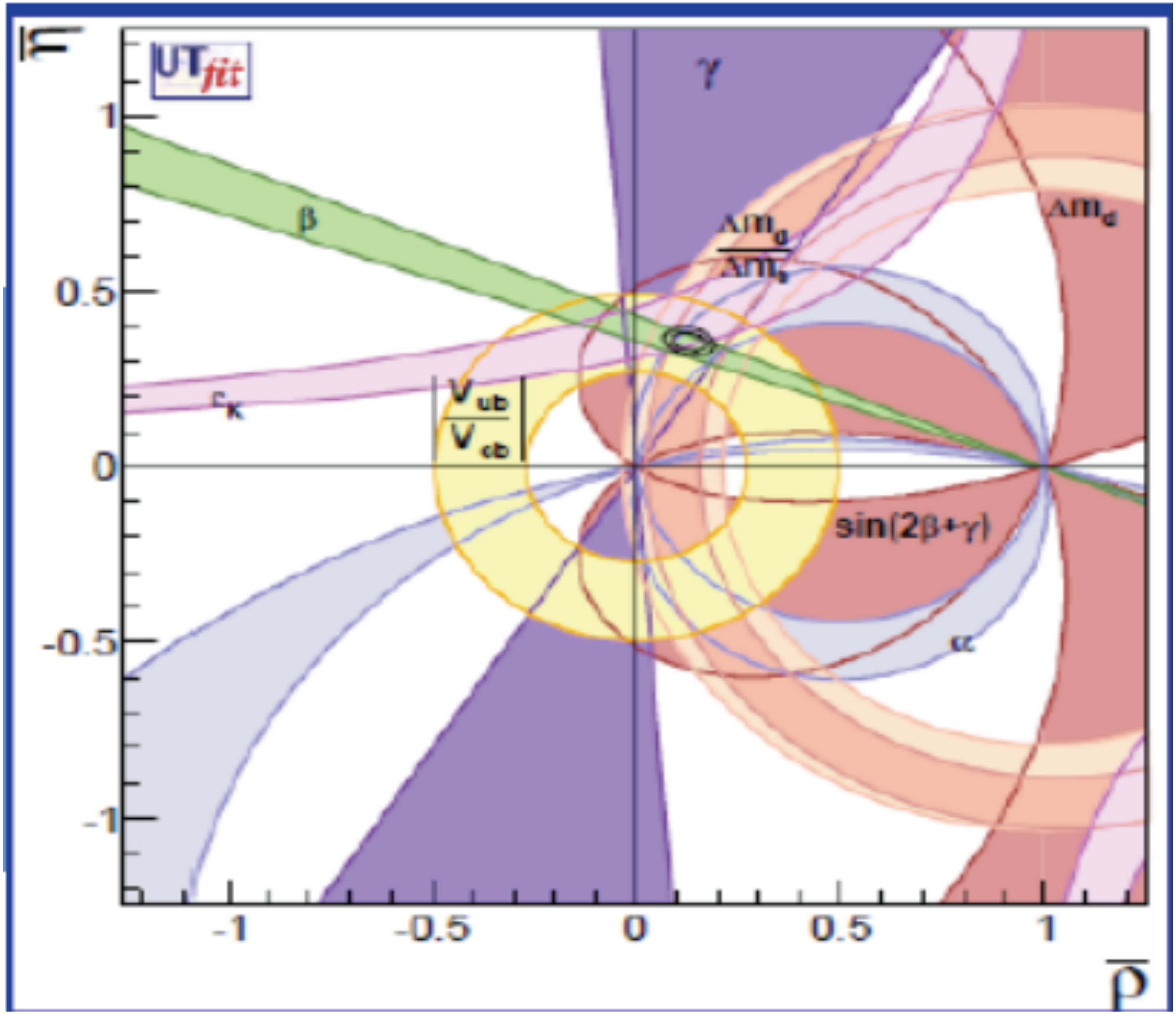
normalized: $1 - \bar{\rho} - i\bar{\eta}$



$$\gamma = atan\left(\frac{\bar{\eta}}{\bar{\rho}}\right)$$

$$\beta = atan\left(\frac{\bar{\eta}}{(1-\bar{\rho})}\right)$$

the (almost complete) CKM triumph



What to make of this triumph of the CKM pattern in hadronic **flavor tests**?

New Physics at the Elw. Scale is Flavor Blind CKM exhausts the flavor changing pattern at the elw. Scale

MINIMAL FLAVOR → VIOLATION

MFV : Flavor originates only from the SM Yukawa coupl.

New Physics introduces

NEW FLAVOR SOURCES in addition to the CKM pattern. They give rise to contributions which are <10% in the "flavor observables" which have already been observed!

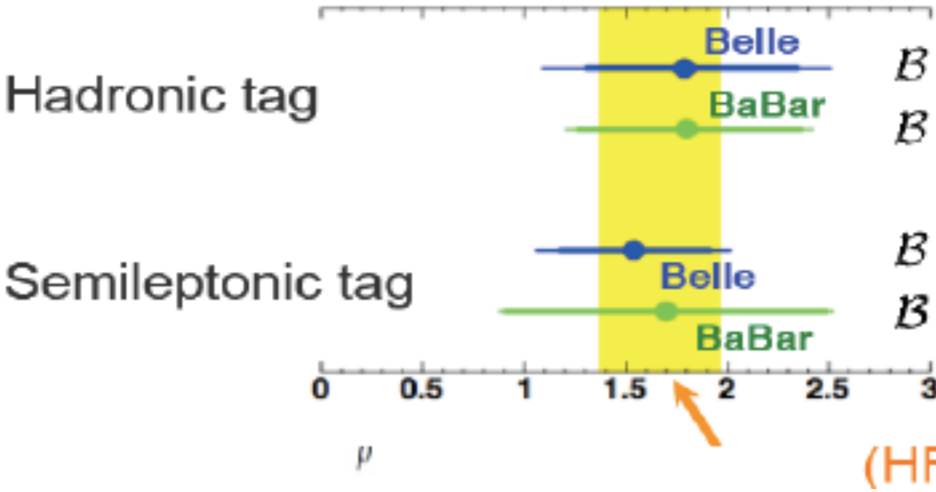
From a closer look

From the UTA (excluding its exp. constraint)

	Prediction	Measurement	Pull
$\sin 2\beta$	0.81 ± 0.05	0.680 ± 0.023	2.4 ←
γ	$68° \pm 3°$	$76° \pm 11°$	<1
α	$88° \pm 4°$	$91° \pm 6°$	<1
$\|V_{cb}\| \cdot 10^3$	42.3 ± 0.9	41.0 ± 1.0	<1
$\|V_{ub}\| \cdot 10^3$	3.62 ± 0.14	3.82 ± 0.56	<1
$\varepsilon_K \cdot 10^3$	1.96 ± 0.20	2.23 ± 0.01	1.4 ←
$BR(B \to \tau\nu) \cdot 10^4$	0.82 ± 0.08	1.67 ± 0.30	-2.7 ←

TARANTINO ICHEP2012

Status for B→ τ ν before ICHEP 2012



$\mathcal{B} = [1.79^{+0.56}_{-0.49}(\text{stat})^{+0.46}_{-0.51}(\text{syst})] \times 10^{-4}$

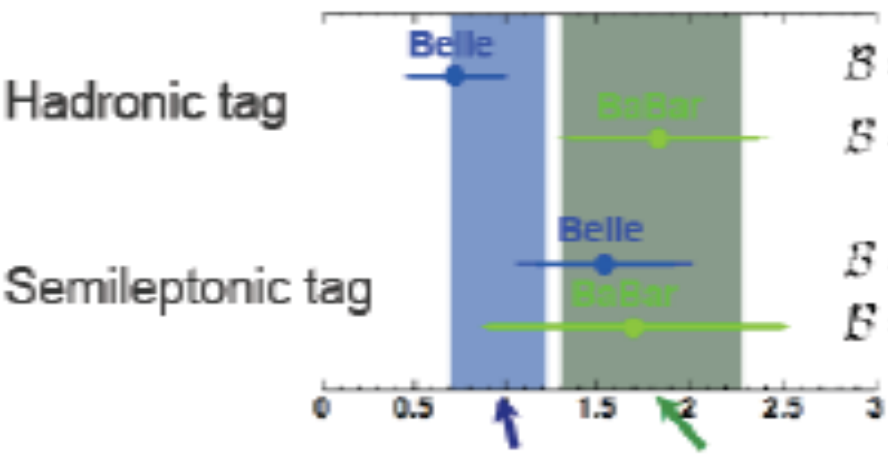
$\mathcal{B} = [1.80^{+0.57}_{-0.54}(\text{stat}) \pm 0.26(\text{syst})] \times 10^{-4}$

$\mathcal{B} = [1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4}$

$\mathcal{B} = [1.7 \pm 0.8(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-4}$

(HFAG): $\mathcal{B} = (1.67 \pm 0.30) \times 10^{-4}$

Status for B→ τ ν after ICHEP 2012



$\mathcal{B} = [0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}$

$\mathcal{B} = [1.83^{+0.53}_{-0.49}(\text{stat}) \pm 0.24(\text{syst})] \times 10^{-4}$

$\mathcal{B} = [1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})] \times 10^{-4}$

$\mathcal{B} = [1.7 \pm 0.8(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-4}$

Belle combined: $\mathcal{B}=(0.96\pm0.26)\times10^{-4}$ BaBar combined: $\mathcal{B}=(1.79\pm0.48)\times10^{-4}$

Unitarity Triangle analysis in the SM:

obtained excluding the given constraint from the fit

Observables	Measurement	Prediction	Pull (#σ)
sin2β	0.665 ± 0.024	0.757 ± 0.045	~ 1.7
γ	71.1 ± 7.6	68.6 ± 3.3	< 1
α	91.1 ± 6.7	87.4 ± 3.6	< 1
$\lvert V_{ub}\rvert \cdot 10^3$	3.82 ± 0.56	3.60 ± 0.14	< 1
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	4.40 ± 0.31	–	~ 2.2
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	3.28 ± 0.30	–	~ 1.1
$\lvert V_{cb}\rvert \cdot 10^3$	41.0 ± 1.0	42.8 ± 0.79	~ 1.3
B_K	0.730 ± 0.30	0.866 ± 0.086	< 1
BR($B \to \tau\nu$)	0.99 ± 0.25	0.826 ± 0.077	< 1
BR($B \to \tau\nu$)(old)	1.67 ± 0.30	–	~ 2.6

From a closer look

UTfit

From the UTA (excluding its exp. constraint) → Prediction

	Prediction	Measurement	Pull
$\sin 2\beta$	0.81±0.05	0.680±0.023	2.4 ←
γ	68°±3°	76°±11°	<1
α	88°±4°	91°±6°	<1
$\lvert V_{cb}\rvert \cdot 10^3$	42.3±0.9	41.0±1.0	<1
$\lvert V_{ub}\rvert \cdot 10^3$	3.62±0.14	3.82±0.56	<1
$\varepsilon_K \cdot 10^3$	1.96±0.20	2.23±0.01	1.4 ←
$BR(B \to \tau\nu) \cdot 10^4$	0.82±0.08	1.67±0.30	-2.7 ←

Observables	Measurement	Prediction	Pull (#σ)
$\sin 2\beta$	0.665 ± 0.024	0.757 ± 0.045	~ 1.7 ←
γ	71.1 ± 7.6	68.6 ± 3.3	< 1
α	91.1 ± 6.7	87.4 ± 3.6	< 1
$\lvert V_{ub}\rvert \cdot 10^3$	3.82 ± 0.56	3.60 ± 0.14	< 1
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$\lvert V_{cb}\rvert \cdot 10^3$	41.0 ± 1.0	42.8 ± 0.79	~ 1.3 ←
B_K	0.730 ± 0.30	0.866 ± 0.086	< 1
$BR(B \to \tau\nu)$	0.99 ± 0.25	0.826 ± 0.077	< 1
$BR(B \to \tau\nu)$(old)	1.67 ± 0.30	–	~ 2.6 ←

$B \to D^{(*)} \tau \nu$ from BaBar and SM

$$\mathcal{R}(D)_{\rm exp} = 0.440 \pm 0.072 \quad \mathcal{R}(D^*)_{\rm exp} = 0.332 \pm 0.030$$

$\updownarrow$ 2.0σ $\qquad\qquad$ $\updownarrow$ 2.7σ

$$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017 \quad \mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$$

SM expectations in S. Fajfer, J. Kamenik, I. Nisandzic, PRD 85, 094025 (2012).

$B \to D^{(*)} \tau \nu$ from Belle

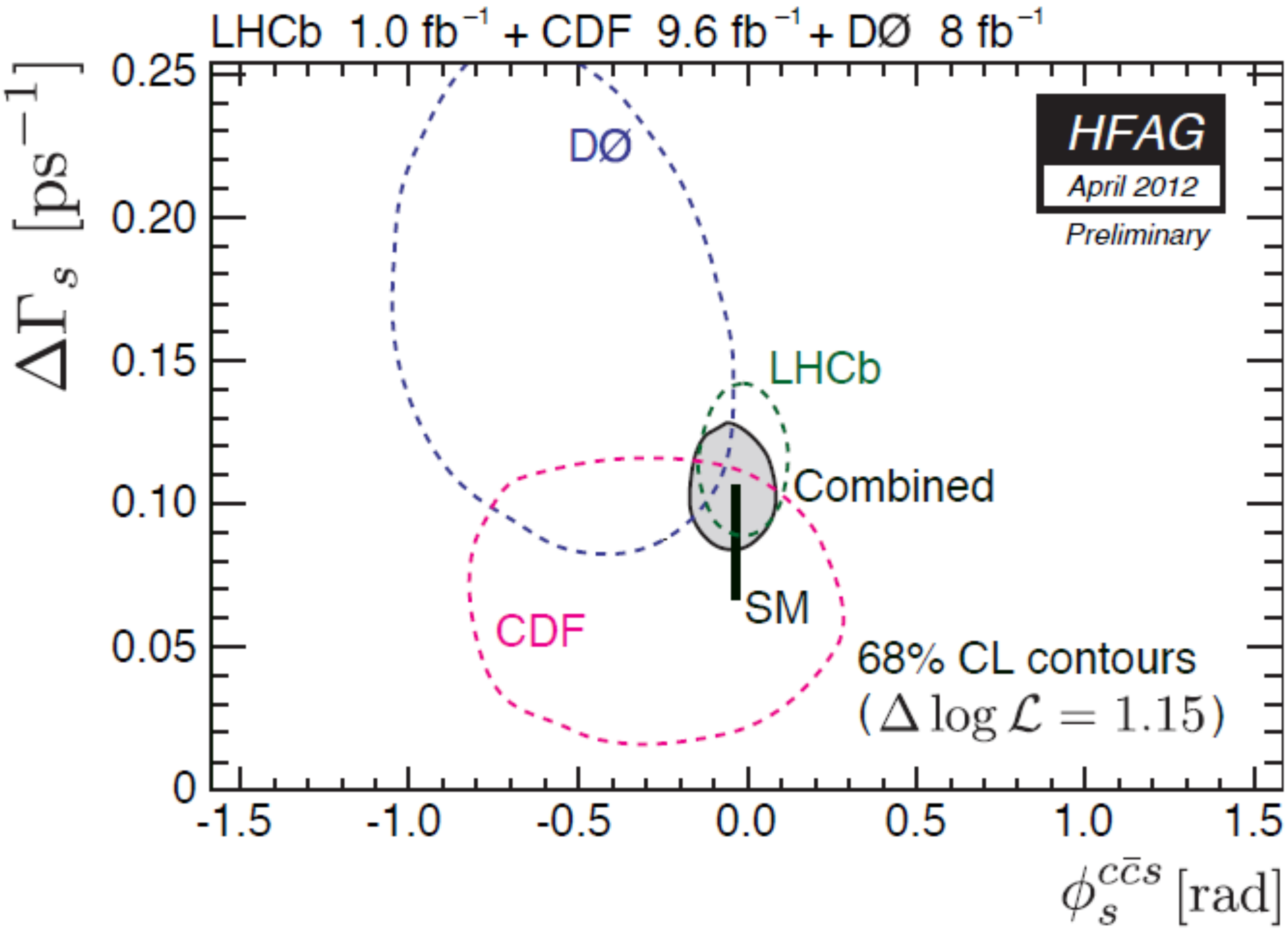
A. Bozek's averages (KEK-FF 2013):

(naive averages for inclusive and exclusive hadronic tags)

	Deviation from SM
R(D) = 0.430 ± 0.091	1.4 σ
R(D*) = 0.405 ± 0.047	3.0 σ
Combined	3.3 σ

Correlation btw R(D) and R(D*) neglected conservatively.

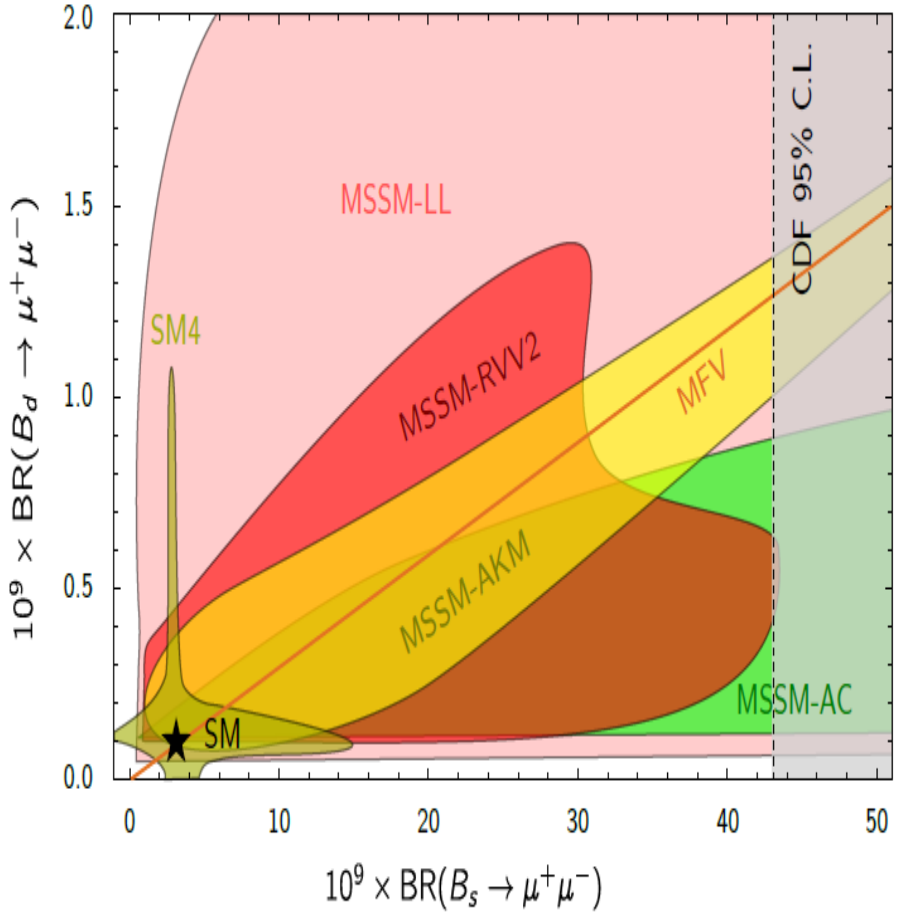
LHCb and CPV in the B_s decays



Ref.	Mode	$\phi_s=\phi_s^{ccs}$	$\Delta\Gamma_s$ (ps^{-1})
CDF Note 10778 (2012)	$J/\psi\phi$	$[-0.60,\ 0.12]$, 68% CL	$0.068 \pm 0.026 \pm 0.007$
DØ, PRD D85 032006 (2012)	$J/\psi\phi$	$-0.55^{+0.38}_{-0.36}$	$0.163^{+0.065}_{-0.064}$
LHCb-CONF-2012-002	$J/\psi\phi$	$-0.001 \pm 0.101 \pm 0.027$	$0.116 \pm 0.018 \pm 0.006$
LHCb, arXiv:1204.5675	$J/\psi\pi\pi$	$-0.019^{+0.173+0.004}_{-0.174-0.003}$	—
Combined [HFAG'2012]		$-0.044^{+0.090}_{-0.085}$	$+0.105 \pm 0.015$

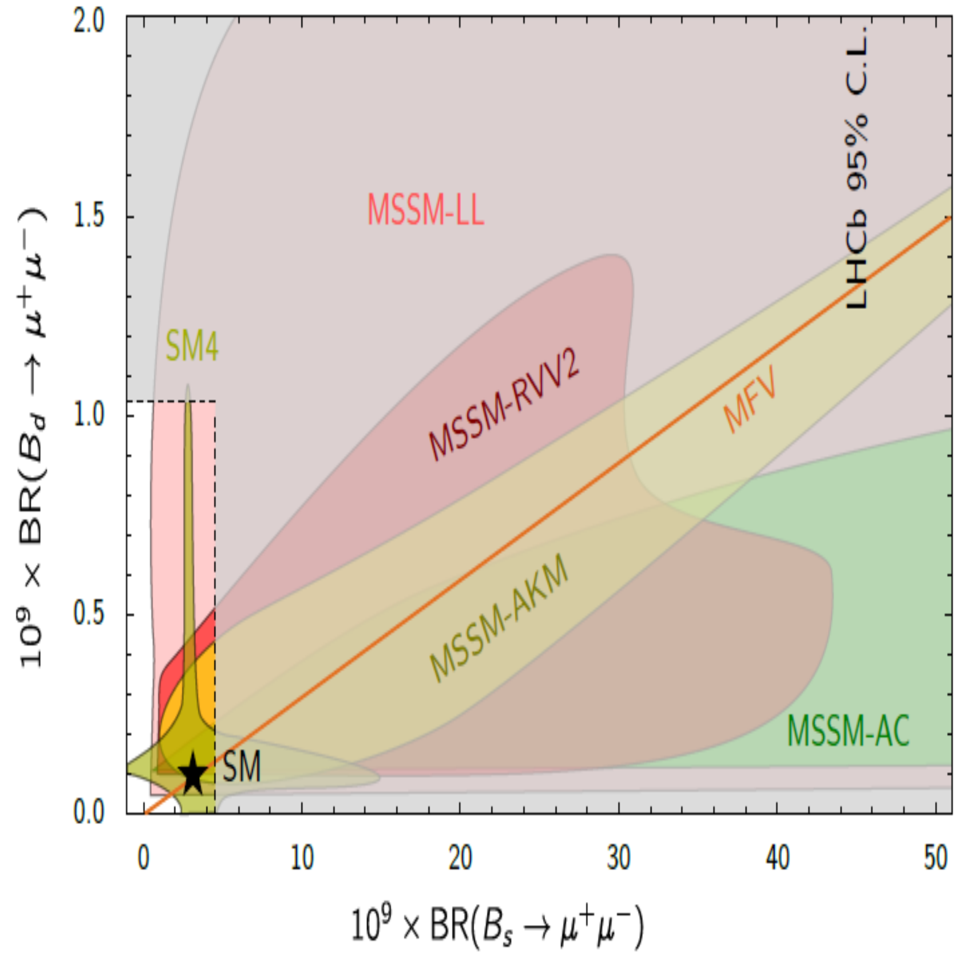
David Straub: arXiv:1205.6094

2011



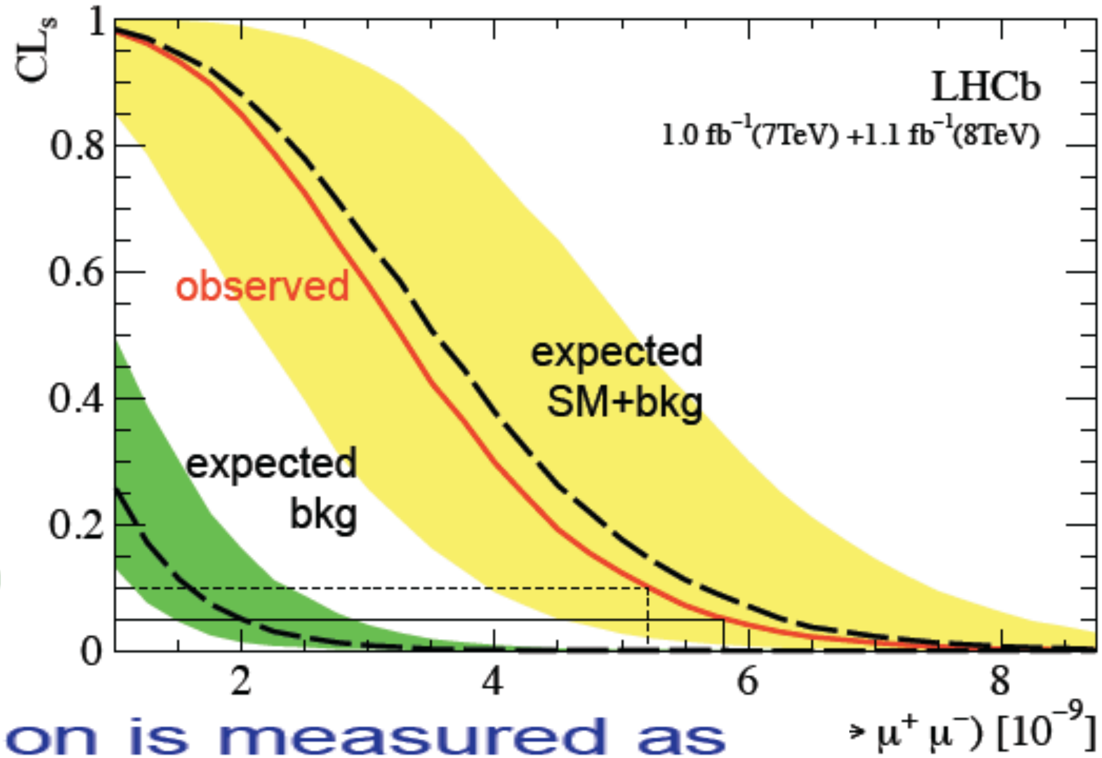
2012

ATLAS, CMS and **LHCb** results combined:
BPH-12-009, ATLAS-CONF-2012-061, LHCb-CONF-2012-017



Results for $B_s \rightarrow \mu^+\mu^-$: Limits and significance

- Evaluate compatibility with background only and background+signal hypotheses (CLs method)
  - 2011+2012: bkg only p-value: 5×10^{-4} (corresponds to 3.5σ)
  - 2012 alone bkg only p-value: 9×10^{-4} (corresponds to $3.3\ \sigma$)



The branching fraction is measured as

$$BR(B_s \rightarrow \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

- **This is the first evidence of the decay $B_s \rightarrow \mu^+\mu^-$!**

DIRECT CPV IN $D^0 \rightarrow \pi^+\pi^-, K^+K^-$

2011: LHCb, 620 pb^{-1} first evidence (3.5 σ) of CPV in charm

$$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.82 \pm 0.21 \pm 0.11)\%$$

2012: fom CDF, 9.6 fb^{-1}, + LHCb + BELLE

$$\Delta A_{CP} \equiv A_{CP}\left(K^+K^-\right) - A_{CP}\left(\pi^+\pi^-\right) = \left(-0.74 \pm 0.15\right)\%$$

This result demands an enhancement of the suppressed CKM amplitudes of the SM of a factor approx. 5 – 10 Isidori, Kamenik, Ligeti, Perez 2011

But the charm quark is ***TOO HEAVY*** to apply the ChPT, while, at the same time, it is ***TOO LIGHT*** to trust the Heavy Quark Effective approach : ***HENCE IT IS NOT IMPOSSIBLE THAT THE SM IS ONCE AGAIN FINDING A WAYOUT TO SURVIVE!*** Golden, Grinstein 1989; Brod, Kagan, Zupan 2011

ON THE OTHER IT REMAINS POSSIBLE THAT NEW PHYSICS IS SHOWING UP… Giudice, Isidori, Paradisi 2012; Barbieri, Buttazzo, Sala e Straub 2012

POSSIBLE SURPRISES FROM THE KAON TOO → NA62 ?

Experimental update including latest LHCb results

$$\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$$
$$= -0.00656 \pm 0.00154.$$

HILLER, HOCHBERG, NIR

$$\Delta A_{CP}^{\rm SUSY} \sim 0.006 \, \frac{\mathcal{I}m(\delta_{LR})}{0.001} \, \frac{1 \text{ TeV}}{\tilde{m}}$$

TYPICAL RESULT IN SUSY MODELS WITH FLAVOR SYMMETRIES AND ACCOUNTING FOR M_H = 125 GeV → Δ_{CP} ~ 0.001 but there could be some accidental enhancement of O(1)

TARANTINO ICHEP2012

On the Lattice side: Ten Years Ago → Today

Hadronic parameter	L.Lellouch ICHEP 2002 [hep-ph/0211359]		UTA Lattice inputs 2012 [www.utfit.org]	
$\hat{B}_K$	0.86(15)	[17%]	0.75(2)	[3%]
f_{Bs}	238(31) MeV	[13%]	233(10) MeV	[4%]
f_{Bs}/f_B	1.24(7)	[6%]	1.20(2)	[1.5%]
$\hat{B}_{Bs}$	1.34(12)	[9%]	1.33(6)	[5%]
B_{Bs}/B_B	1.00(3) (quenched, $\mu_l > m_s/2$, …)	[3%]	1.05(7)	[7%]
$F_{D^*}(1)$	0.91(3)	[3%]	0.92(2)	[2%]
$F_+^{B\to\pi}$	--	[20%]	--	[11%]

- The last 10 years teach us that Lattice QCD has made important progresses (quenched->unquenched , higher computational power, better algorithms)
- More recently further improvements are being realized: simulations at the physical point, discretization effects well under control (in the light and heavy sectors), N_f=2+1+1, …

Expected Progress

	NOW	$\lesssim$ 5 years
δB_K	~ 3%	1%
$\delta \xi$	~ 4%	1%
δV_{ub} excl	~ 9%	3%
δV_{cb} excl	~ 3.5%	1.5%

EXPECTATIONS OF USQCD Collab

SUSY GUTs

- UV COMPLETION OF THE SM TO STABILIZE THE ELW. SCALE:

LOW-ENERGY

SUSY

TREND OF UNIFICATION OF THE SM GAUGE COUPLINGS AT HIGH SCALE:

GUTs

GUT -RELATED SUSY SOFT BREAKING TERMS

$$m_Q^2 = m_{\tilde{e}^c}^2 = m_{\tilde{u}^c}^2 = m_{\mathbf{10}}^2$$

$$m_{\tilde{d}^c}^2 = m_L^2 = m_{\bar{\mathbf{5}}}^2$$

$$A_{ij}^e = A_{ji}^d \, .$$

SU(5) RELATIONS

	Relations at weak-scale	Relationss at M_{GUT}
(1)	$(\delta_{ij}^u)_{\mathrm{RR}} \approx (m_{e^c}^2/m_{u^c}^2)\ (\delta_{ij}^l)_{\mathrm{RR}}$	$m_{u^c}^2{}_0 = m_{e^c}^2{}_0$
(2)	$(\delta_{ij}^q)_{\mathrm{LL}} \approx (m_{e^c}^2/m_Q^2)\ (\delta_{ij}^l)_{\mathrm{RR}}$	$m_{Q_0}^2 = m_{e^c}^2{}_0$
(3)	$(\delta_{ij}^d)_{\mathrm{RR}} \approx (m_L^2/m_{d^c}^2)\ (\delta_{ij}^l)_{\mathrm{LL}}$	$m_{d^c}^2{}_0 = m_{L_0}^2$
(4)	$(\delta_{ij}^d)_{\mathrm{LR}} \approx (m_{L_{avg}}^2/m_{Q_{avg}}^2)\ (m_b/m_\tau)\ (\delta_{ij}^l)_{\mathrm{LR}}^\star$	$A_{ij_0}^e = A_{ji_0}^d$

FCNC HADRON-LEPTON CONNECTION IN SUSYGUT

If

M_{Pl} **M_{GUT}** **M_W**

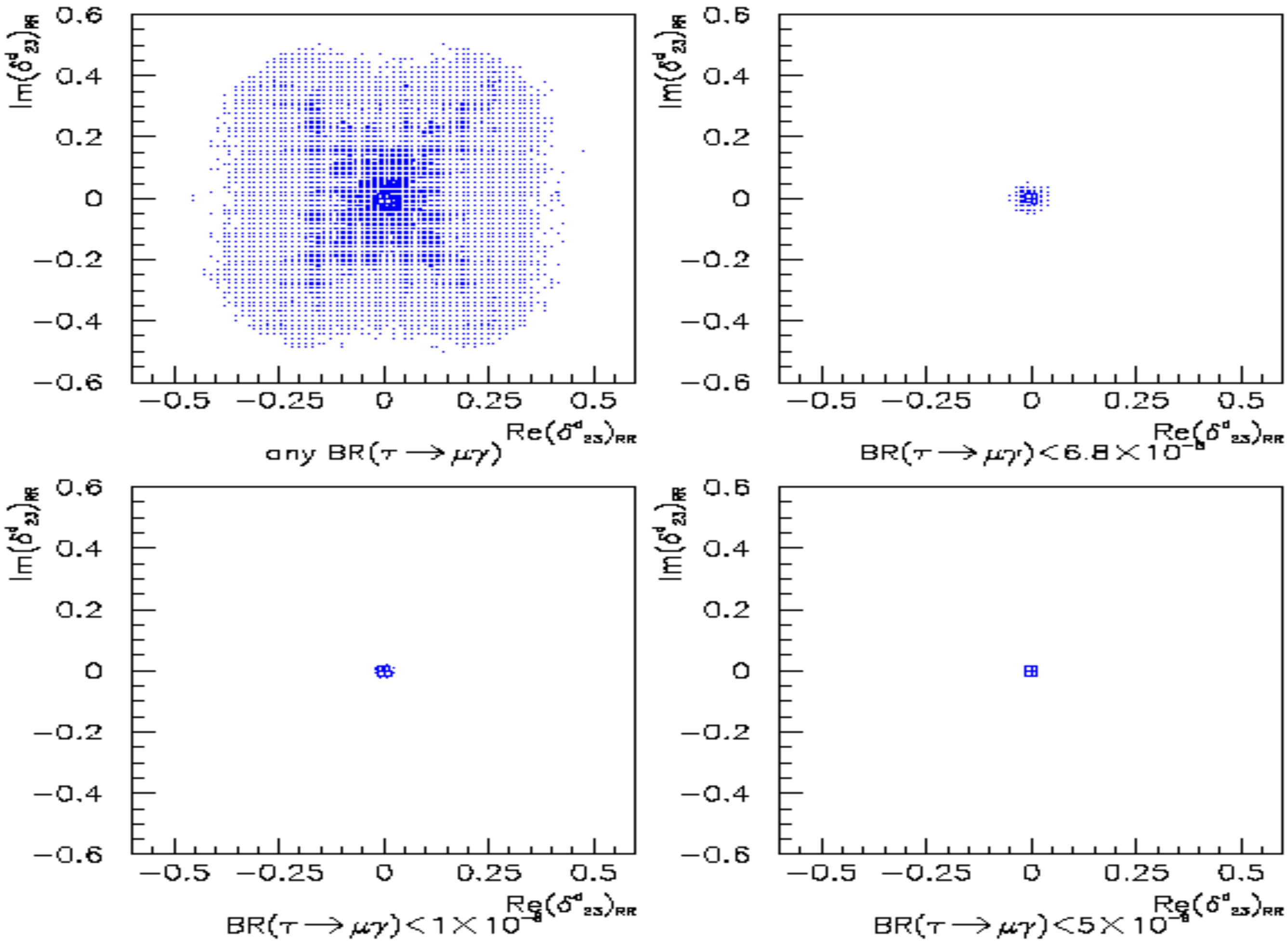
soft **SUSY breaking terms** arise
at a scale > M_{GUT}, they have to **respect the underlying quark-lepton GU symmetry**

constraints on δ^{quark} **from LFV** and
constraints on δ^{lepton} **from hadronic FCNC**

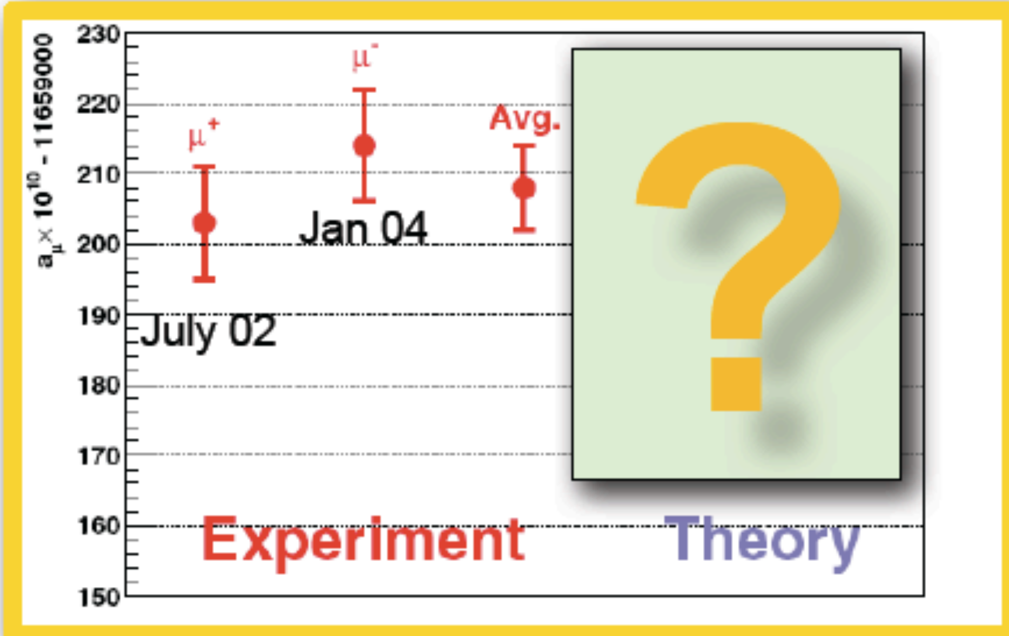
Ciuchini, A.M., Silvestrini, Vempati, Vives PRL
general analysis **Ciuchini, A.M., Paradisi, Silvestrini, Vempati, Vives**

Bounds on the hadronic $(\delta_{23})_{RR}$ as modified by the inclusion of the LFV correlated bound

CMPSVV



The muon g-2: the experimental result



- Today: $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys})x10^{-11}$ [0.5ppm].
- Future: new muon g-2 experiments proposed at:
  - Fermilab (E989), aiming at 0.14ppm → Sep 2012: CD0 approval! Data in 2016?
  - J-PARC aiming at 0.1 ppm

  See B. Lee Roberts & T. Mibe @ Tau2012, September 2012
- Are theorists ready for this (amazing) precision? No(t yet)

The muon g-2: SM vs. Experiment

Adding up all contributions, we get the following SM predictions and comparisons with the measured value:

$a_\mu^{EXP} = 116592089\ (63) \times 10^{-11}$

E821 – Final Report: PRD73 (2006) 072 with latest value of $\lambda=\mu_\mu/\mu_p$ from CODATA'06

$a_\mu^{\mathrm{SM}} \times 10^{11}$	$\Delta a_\mu = a_\mu^{\mathrm{EXP}} - a_\mu^{\mathrm{SM}}$	σ
116 591 794 (66)	$295\ (91) \times 10^{-11}$	3.2 [1]
116 591 814 (57)	$275\ (85) \times 10^{-11}$	3.2 [2]
116 591 840 (58)	$249\ (86) \times 10^{-11}$	2.9 [3]

with the "conservative" $a_\mu^{HHO}(lbl)$ = 116 (39) x 10^{-11} and the LO hadronic from:

[1] Jegerlehner & Nyffeler, Phys. Rept. 477 (2009) 1
[2] Davier et al, EPJ C71 (2011) 1515 (includes BaBar & KLOE10 2π)
[3] Hagiwara et al, JPG38 (2011) 085003 (includes BaBar & KLOE10 2π)

Note that the th. error is now about the same as the exp. one

THE EDM CHALLENGE

FOR **ANY NEW PHYSICS AT THE TEV SCALE** WITH **NEW SOURCES OF CP VIOLATION** → NEED FOR **FINE-TUNING** TO PASS THE EDM TESTS OR SOME **DYNAMICS TO SUPPRESS THE CPV** IN FLAVOR CONSERVING EDMS

$$
\begin{aligned}
|d_{\rm n}| &< \ 2.9 \times 10^{-26} e \ {\rm cm} \ (90\%{\rm C.L.}), \\
|d_{\rm Tl}| &< \ 9.0 \times 10^{-25} e \ {\rm cm} \ (90\%{\rm C.L.}), \\
|d_{\rm Hg}| &< \ 3.1 \times 10^{-29} e \ {\rm cm} \ (95\%{\rm C.L.}).
\end{aligned}
$$

Some thoughts on the "flavor path" to TeV New Physics

- Out of the **3 traditional theoretical shortcomings of the SM:** i) lack of true unification; ii) gauge hierarchy; iii) no explanation for the fermion masses and mixings (flavor question within the SM) , this latter issue is the one with the **least progress in the last decades** (we still completely lack a flavor theory – unfortunately the (very) good knowledge of the CKM structure has not helped us much in this direction
- Today question: with all the existing constraints, how can it be that NP shows up only in very specific "corners" that we have not experimentally probed yet? The **lack of a flavor theory tells us that what we consider unlikely "coincidences" may be just a fruit of such ignorance** (think of finding $\rho = 1$ without knowing the ELW gauge theory)
- In my view, in this moment of relevance of the "virtuality" as a gate to access NP, the flavor path remains imporatnt: **SLOW DECOUPLING OF NEW PHYSICS IN VIRTUAL EFFECTS W.R.T. PHYSICAL PRODUCTS**

A FUTURE FOR FLAVOR PHYSICS IN OUR SEARCH BEYOND THE SM?

- **COMPLEMENTARITY** between direct and indirect searches for New Physics is the key-word

- Twofold meaning of such complementarity:

i) **synergy in "reconstructing" the "fundamental theory"** staying behind the signatures of NP;

ii) **coverage of complementary areas of the NP parameter space** (ex.: multi-TeV SUSY physics)

SLOWER DECOUPLING OF NEW PHYSICS IN VIRTUAL EFFECTS W.R.T. PHYSICAL EFFECTS → FCNC SENSITIVITY TO NEW PARTICLE MASSES IN THE TENS OF TEV

SOME FINAL THOUGHTS … (in particular dedicated to the young researchers present here)

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

1964: BF= 2×10^{-3} Christenson, Cronin, Fitch, Turlay BNL '64

Early '80s … "neutrinos should have a mass <few eV ; this would be ridiculously small even compared to the lightest fermion mass – that of the electron –→ neutrinos have to be massless and a symmetry should guarantee it" ….

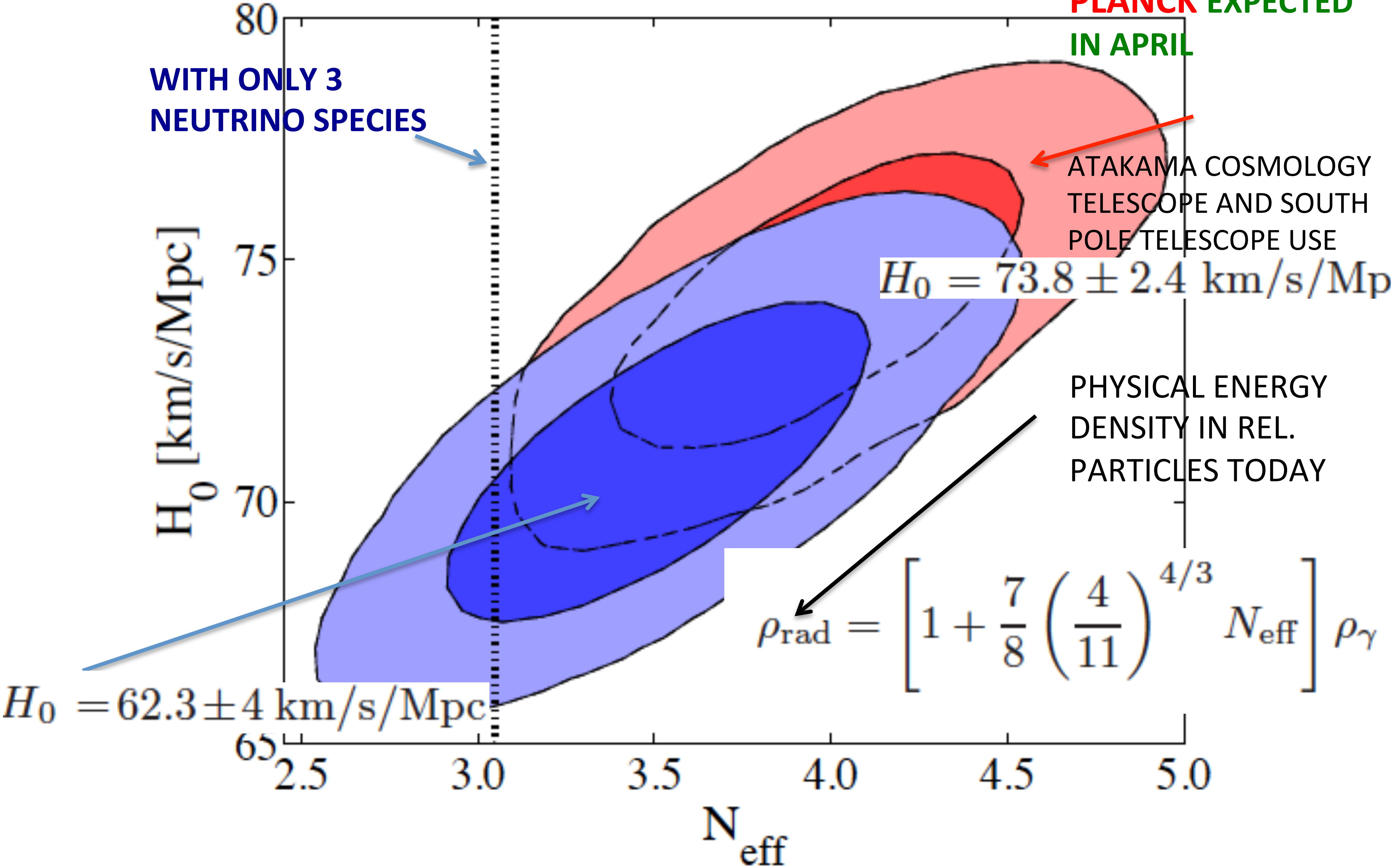
I'm convinced that FLAVOR PHYSICS CAN STILL RESERVE IMPORTANT SURPRISES…

BACKUP SLIDES

HINTS FROM COSMOLOGY IN FAVOR OF > 3 ν SPECIES?

"DARK RADIATION"

NEW RELEVANT DATA FROM **PLANCK** EXPECTED IN APRIL



CALABRESE, ARCHIDIACONA, MELCHIORRI, RATRA 2012

Limit on the SUM of the ν masses from COSMOLOGY

- WMAP 7yr
- SDSS III 8th data release
- Hubble space telescope H

R. De Putter et al, arXiv: 1201.1909 [astro-ph.CO]

$\Sigma m < 0.26$ eV (95 % CL)

Conservative bias

$\Sigma m < 0.36$ eV (95 % CL)

Bounds presented at ICHEP 2012

- WMAP 7yr
- Observable Hubble parameter data (OHD)
- H_0 (in correlation with σ_8)

M. Moresco, et al., arXiv:1201.6658 [astro-ph.CO]

$\Sigma m < 0.24$ eV (68 % CL)

Future: $\Sigma m < 0.08$ eV

Double beta decay: status

GIULIANI IFAE2012

In 1998, when neutrino flavour oscillations were discovered, the « old-generation » **Heidelberg-Moscow** experiment (^{76}Ge, Ge diodes) was leading in terms of sensitivity.

Today, it is still the most sensitive experiment in 0ν-DBD → **Difficult subject, slow progresses**

Klapdor's claim → $T^0_{1/2} = (2.23^{+0.44}_{-0.31}) \times 10^{25}$ y - $\langle M_{\beta\beta} \rangle = (0.30^{+0.02}_{-0.03})$ eV

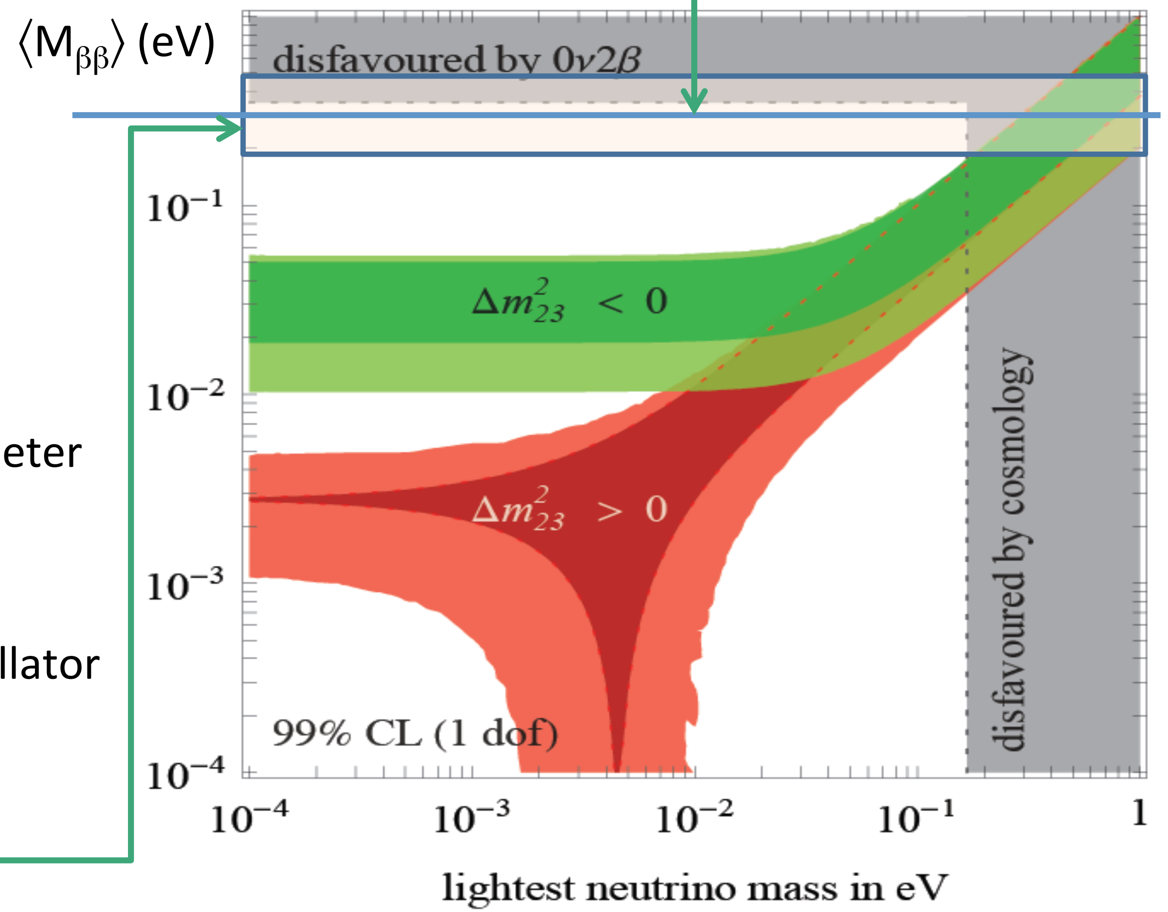
New searches, with different techniques, have similar sensitivities

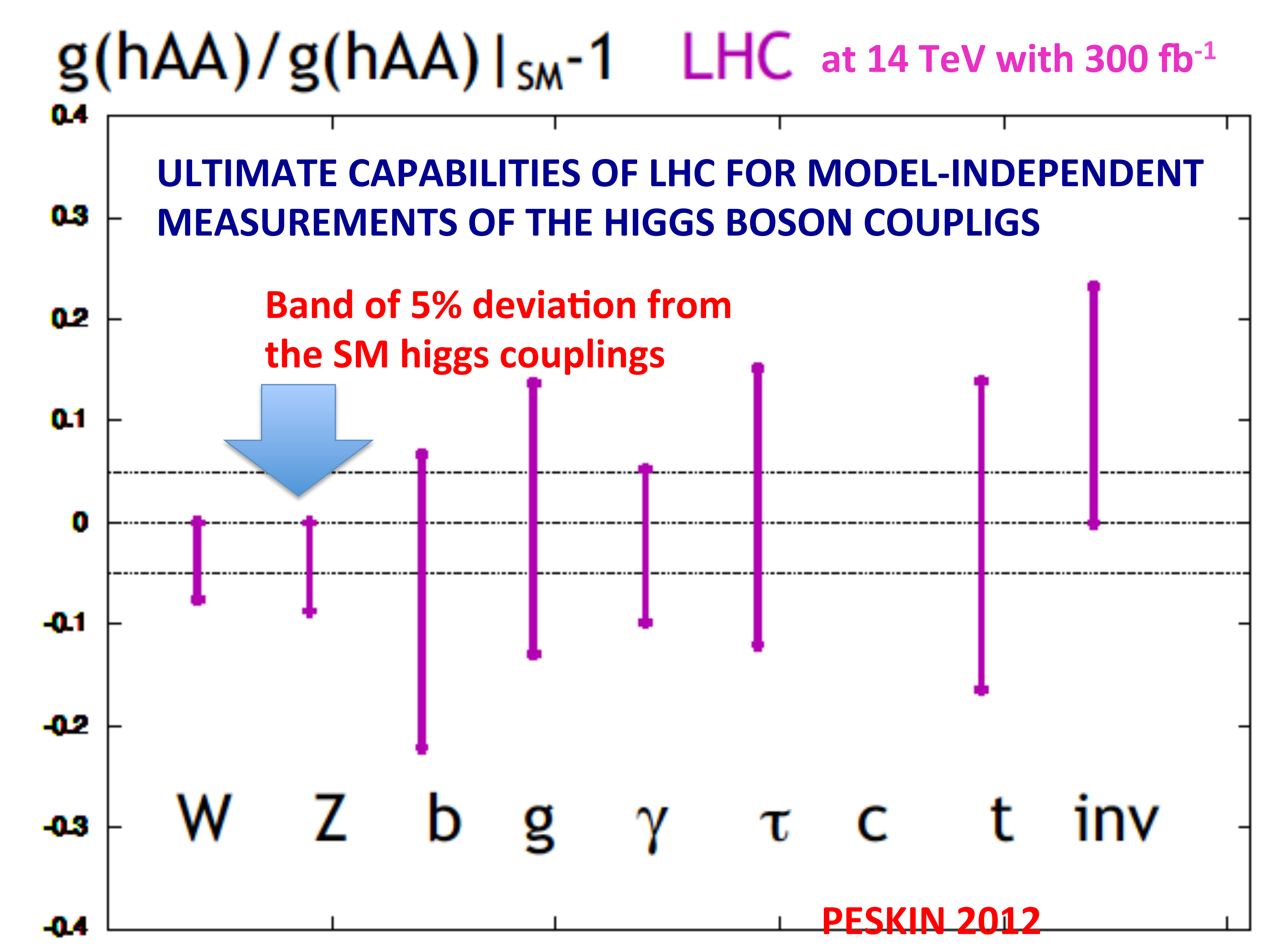
« Medium Generation »
- **CUORICINO** bolometers
- **NEMO3** Tracking+calorimeter

« New Generation »
- **KamLAND-Zen** Large mass scintillator

Similar sensitivity

$\langle M_{\beta\beta} \rangle < 0.3 – 0.6$ eV




g(hAA)/g(hAA)|SM-1
LHC
at 14 TeV with 300 fb-1
ULTIMATE CAPABILITIES OF LHC FOR MODEL-INDEPENDENT MEASUREMENTS OF THE HIGGS BOSON COUPLIGS
Band of 5% deviation from the SM higgs couplings
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
W
Z
b
g
γ
τ
c
t
inv
PESKIN 2012

LC at $\sqrt{s}$ = 250 GeV: a HIGGS FACTORY

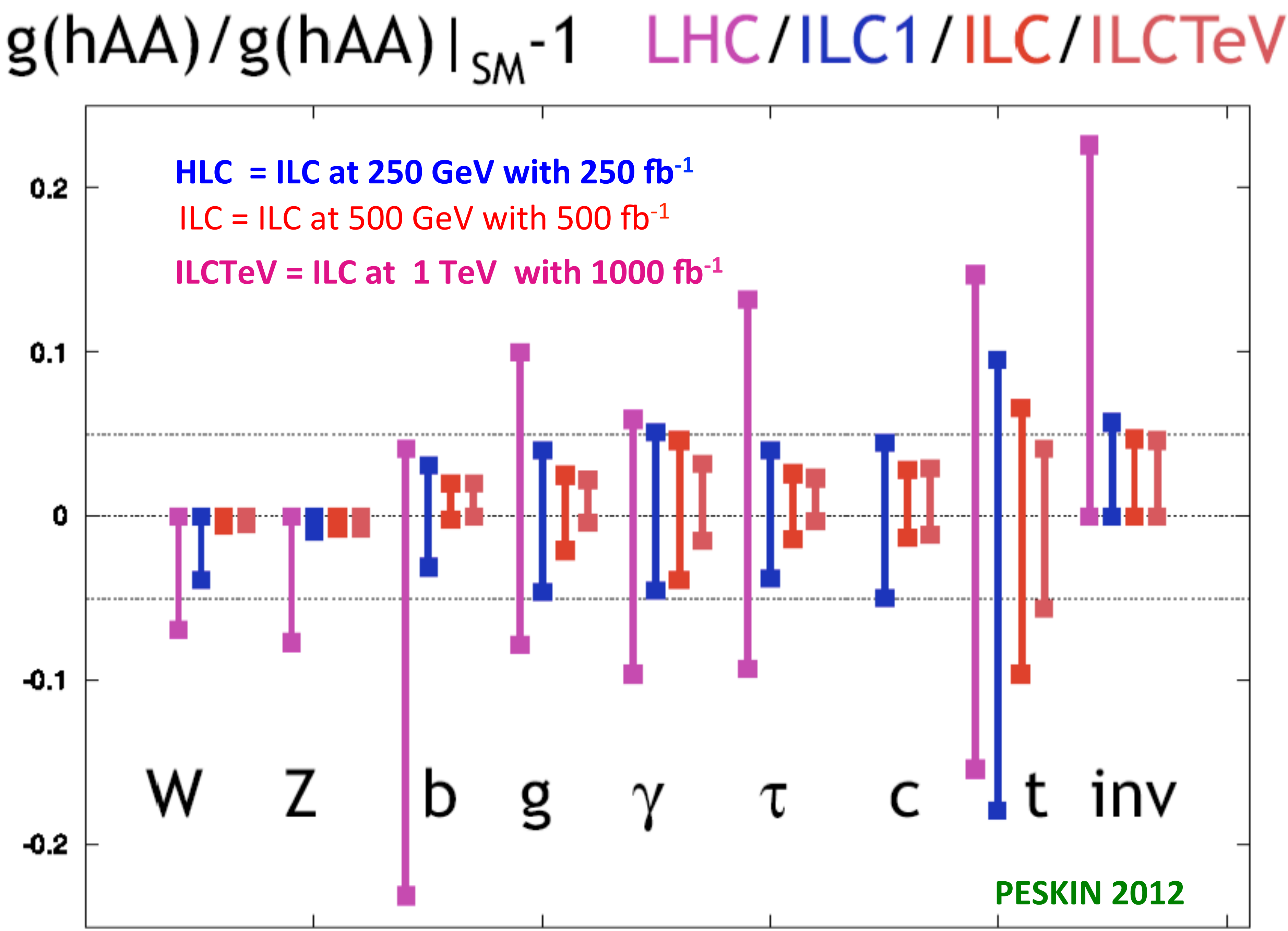
- Expected **O(10^5) Higgs bosons for ~ 250 fb^{-1}**
- Accuracies on **Higgs couplings** for M_H = 125 GeV (on individual couplings and not only on products of production cross section × BR)

g / BR	g_{HWW}	g_{HZZ}	g_{Hbb}	g_{Hcc}	$g_{H\tau\tau}$	g_{Htt}	g_{HHH}	BR($\gamma\gamma$)	BR(gg)	BR(invis.)
Precision	1.4 %	1.4 %	1.4 %	2.0 %	2.5 %	15 %	40 %	15 %	5 %	0.5 %

Baer et al., ILC Detailed Baseline Design report 2012

PRECISION ON THE MEASUREMENT OF M_H : 0.03%

Probing additional non-SM-like Higgs bosons: the 125 GeV Higgs could be the second lightest Higgs in the spectrum → lighter Higgs (maybe below the LEP limit for a SM-like Higgs) with reduced couplings to gauge bosons



g(hAA)/g(hAA)|SM-1
LHC/ILC1/ILC/ILCTeV
HLC = ILC at 250 GeV with 250 fb-1
ILC = ILC at 500 GeV with 500 fb-1
ILCTeV = ILC at 1 TeV with 1000 fb-1
0.2
0.1
0
-0.1
-0.2
W
Z
b
g
γ
τ
c
t
inv
PESKIN 2012

e^+e^- Collider Summary

Accelerator →Physical quantity ↓	LHC 300fb^{-1} /exp	HL-LHC 3000fb^{-1} /exp	ILC (250) 250 fb^{-1}	ILC (250+350+1000)	LEP3 240 4 IP	TLEP 240 +350 4 IP
Approx. date	2021	2030	2035	2045	2035	2035
N_H	1.7 x 10^7	1.7 x 10^8	5 10^4 ZH	(10^5 ZH) (1.4 10^5 Hvv)	4 10^5ZH	2 10^6 ZH
m_H (MeV)	100	50	35	35	26	7
$\Delta\Gamma_{H}/\Gamma_H$	--	--	10%	3%	4%	1.3%
$\Delta\Gamma_{inv}/\Gamma_H$	Indirect (30%?)	Indirect (10% ?)	1.5%	1.0%	0.35%	0.15%
$\Delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$	6.5 – 5.1%	5.4 – 1.5%	--	5%	3.4%	1.4%
$\Delta g_{Hgg}/g_{Hgg}$	11 – 5.7%	7.5 – 2.7%	4.5%	2.5%	2.2%	0.7%
$\Delta g_{Hww}/g_{Hww}$	5.7 – 2.7%	4.5 – 1.0%	4.3%	1%	1.5%	0.25%
$\Delta g_{HZZ}/g_{HZZ}$	5.7 – 2.7%	4.5 – 1.0%	1.3%	1.5%	0.65%	0.2%
$\Delta g_{HHH}/g_{HHH}$	--	< 30% (2 exp.)	--	~30%	--	--
$\Delta g_{H\mu\mu}/g_{H\mu\mu}$	<30	<10	--	--	14%	7%

ICFA Higgs Factory Workshop
Fermilab, Nov. 2012

HOW MUCH PRECISION IS NEEDED?

Examples: (references in arXiv:1208.5152)

M. Peskin, Theoretical Summary Lecture for Higgs Hunting 2012

Supersymmetry:

$$g(\tau)/SM = 1 + 10\% \left(\frac{400 \text{ GeV}}{m_A}\right)^2$$

$$g(b)/SM = g(\tau)/SM + (1-3)\%$$

Little Higgs:

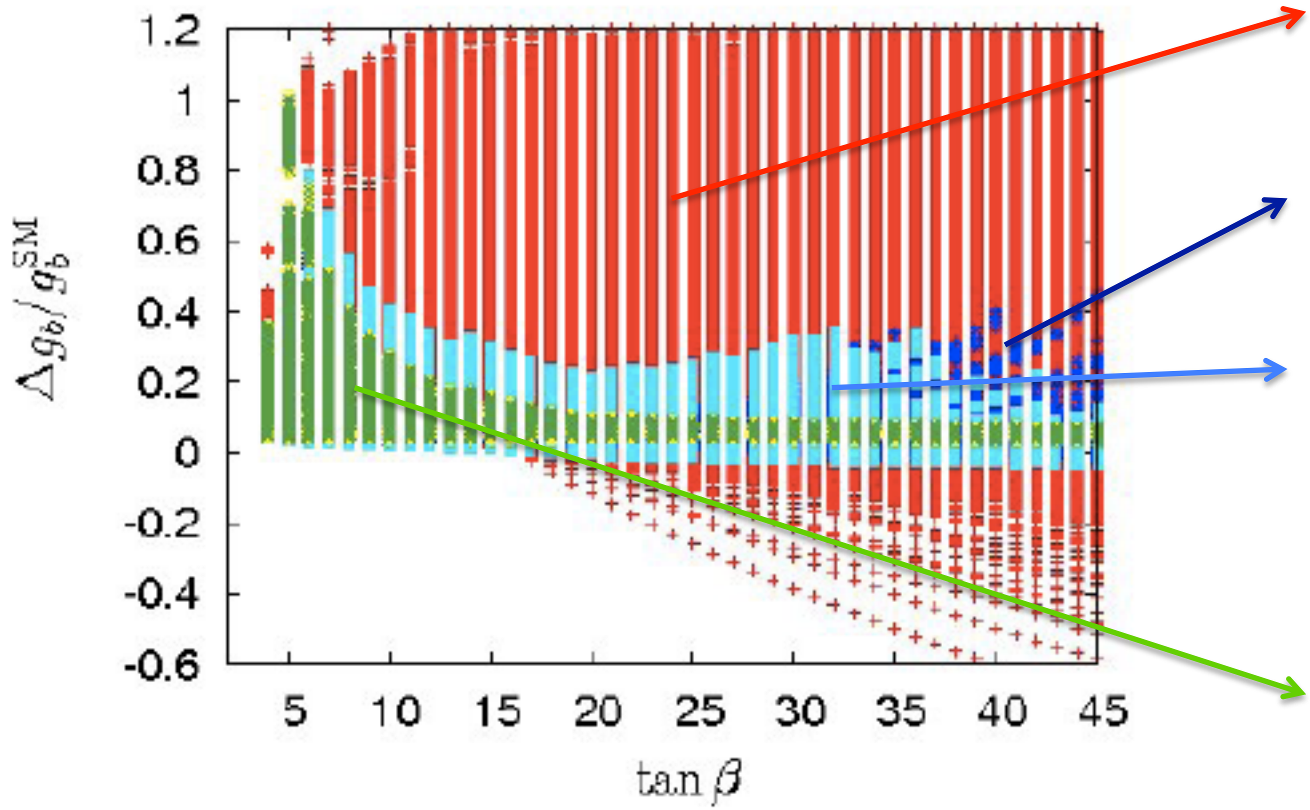
$$g(g)/SM = 1 + (5-9)\%$$

$$g(\gamma)/SM = 1 + (5-6)\%$$

Composite Higgs:

$$g(f)/SM = 1 + (3-9)\% \cdot \left(\frac{1 \text{ TeV}}{f}\right)^2$$

reach: roughly 3 TeV in new particle masses for the most sensitive deviations.



RED: several Higgses are discovered at LHC

DARKBLUE: excluded by BR ($b \rightarrow s\gamma$) constraint

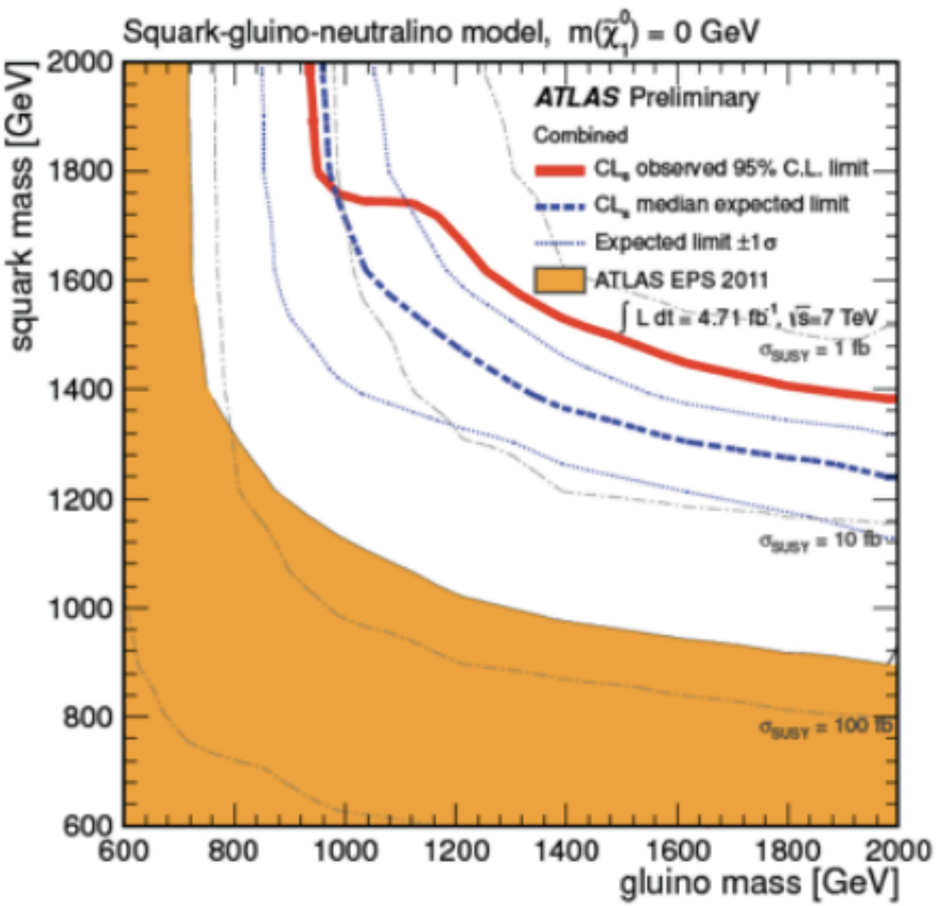
LIGHTBLUE: at least one stop has mass < 1 TeV

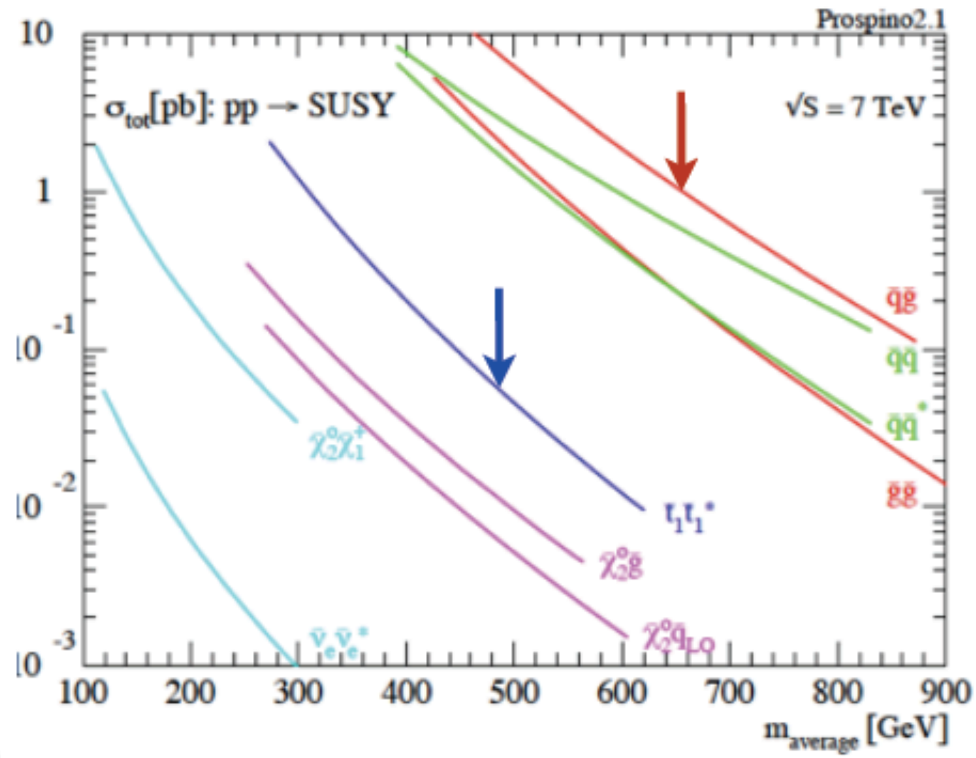
GREEN: both top squarks are heavier than 1.5 TeV

	ΔhVV	$\Delta h\bar{t}t$	Δhbb
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	10%[a], 100%[b]
LHC 14 TeV, 3 ab^{-1}	8%	10%	15%

GUPTA, RZEHAK, WELLS 2012

IS LOW-ENERGY SUSY STILL ALIVE?





$$g\ q \rightarrow \tilde{g}\ \tilde{q}$$
$$q\ q \rightarrow \tilde{q}\ \tilde{q}$$
$$q\ \bar{q} \rightarrow \tilde{q}\ \tilde{q}^*$$

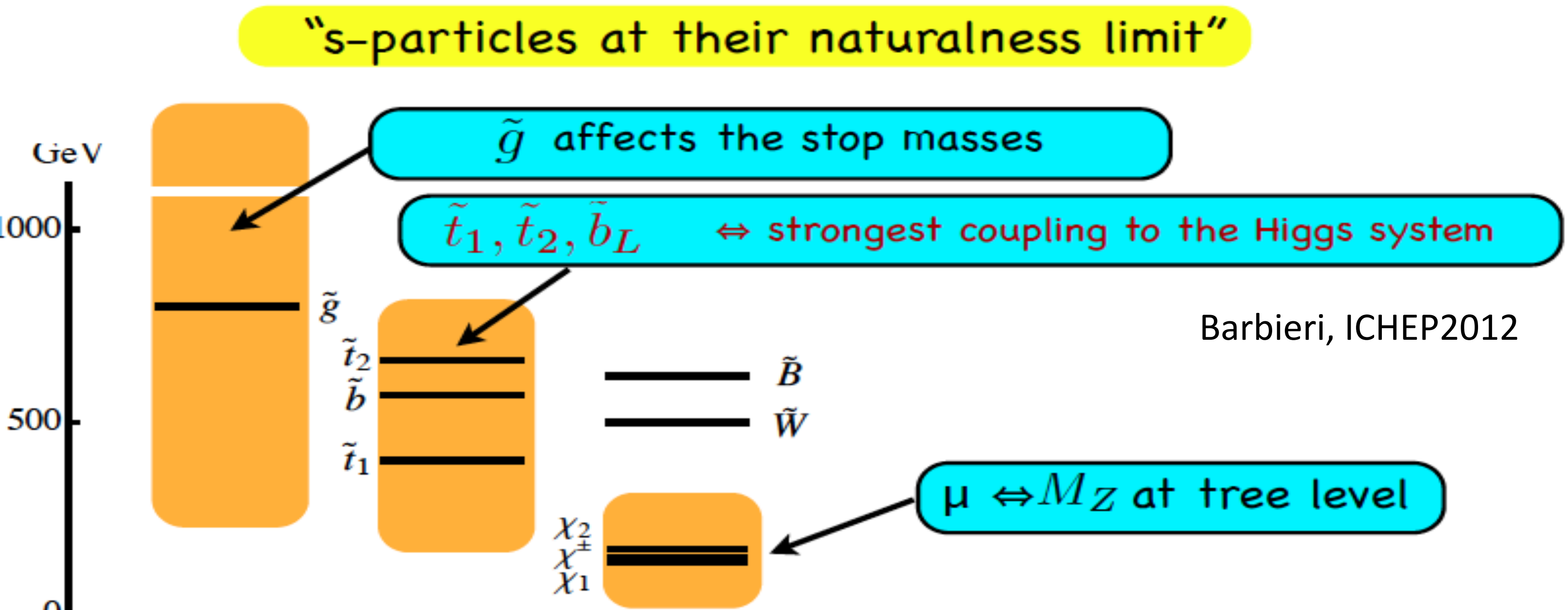
$$\Rightarrow m_{\tilde{g}}, m_{\tilde{q}_{1,2}} > 1 \div 1.5\ TeV$$

Stop and **sbottom**

not so stringently constrained

NATURAL SUSY

LOW-ENERGY SUSY to cope with the gauge hierarchy problem: only the SUSY particles involved in the cancellation of the quadratic div. to the Higgs mass have to remain "light"



Barbieri, ICHEP2012

orange areas indicative and dependent on how the Higgs boson gets its mass

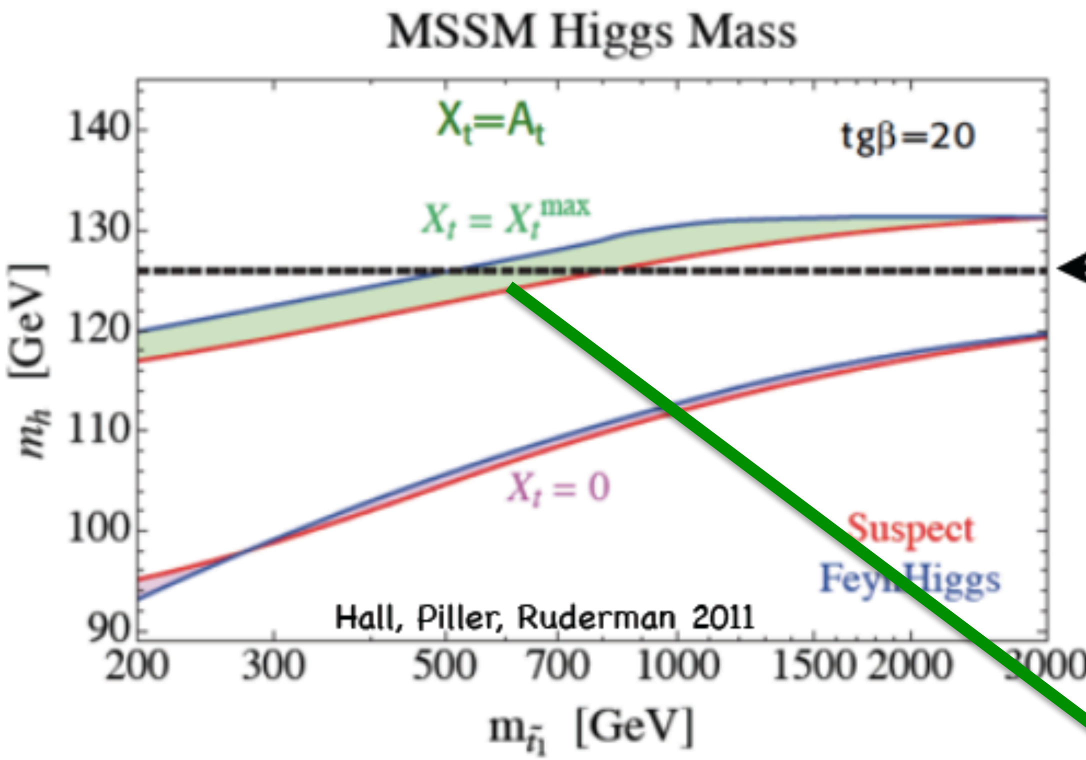
$\tilde{B}, \tilde{W}$ not much constrained but expected below $m_{\tilde{g}}$

MSSM

COPING WITH A HIGGS MASS OF 125 GEV?

the two players to raise the Higgs mass

$$m_h^2 \approx m_Z^2 \cos^2 2\beta + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$



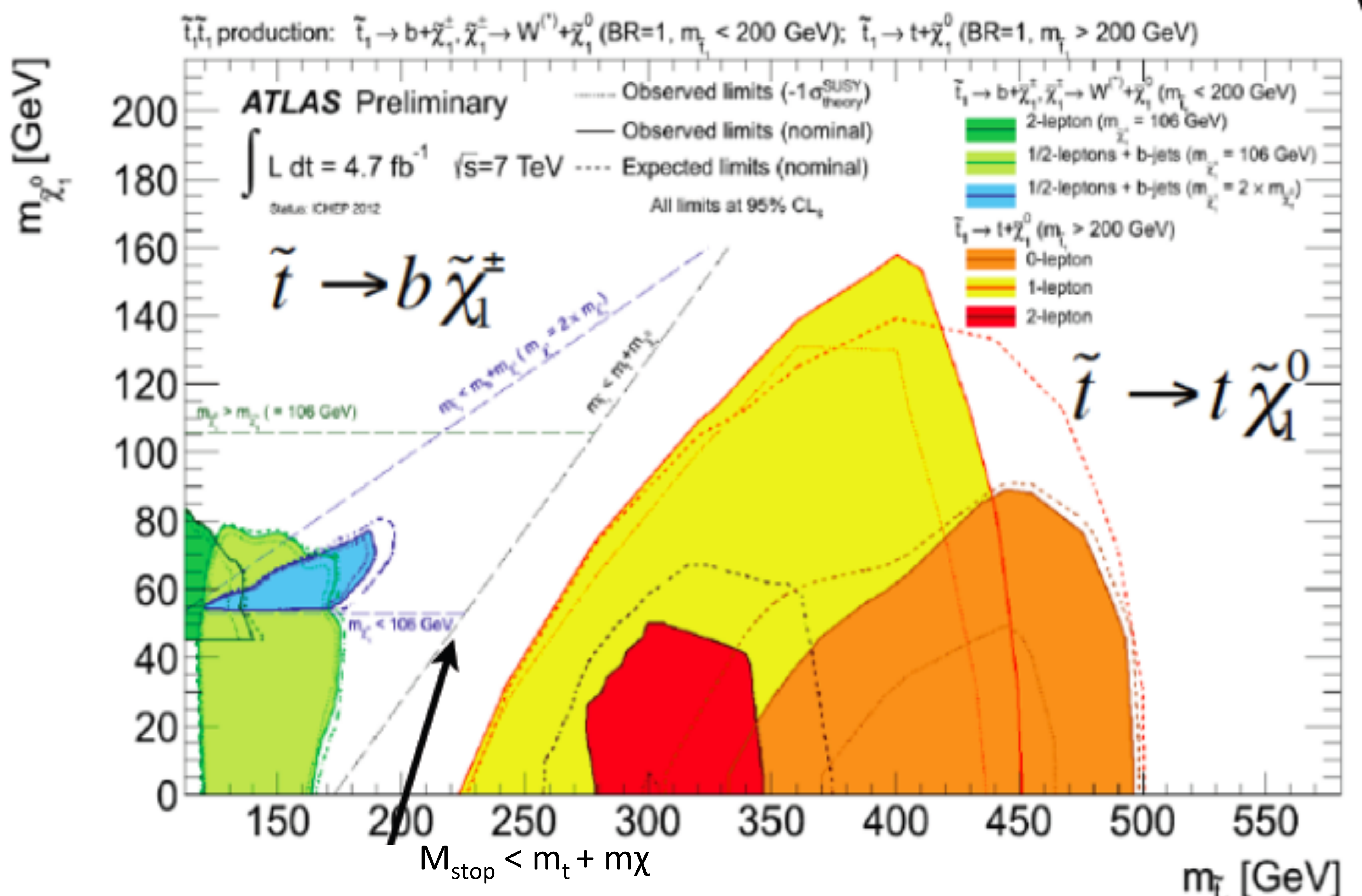
POSSIBLE TO HAVE A LIGHT STOP IF ONE MOVES FROM THE MSSM TO THE

NMSSM

WITH ONE ADDITIONAL SINGLET

Possible for the MSSM to have a light Higgs of mass=125 GeV, but need for **not so light stop**

Hunting for a light s-top



FORWARD-BACKWARD Top Asy

SM e NNLO+
$0.072^{+.011}_{-.007}$

~2

Observable	Values	Experiment
$\mathcal{A}^{t}_{FB}$	0.19 ± 0.065	DØ Collaboration [1]
	0.158 ± 0.074	CDF Collaboration [2]
	0.176 ± 0.05	Combined
$\mathcal{A}^{t,low}_{FB}$	0.078 ± 0.048	DØ Collaboration [1]
	-0.022 ± 0.043	CDF Collaboration [2]
	0.023 ± 0.032	Combined
$\mathcal{A}^{t,high}_{FB}$	0.115 ± 0.060	DØ Collaboration [1]
	0.266 ± 0.062	CDF Collaboration [2]
	0.188 ± 0.043	Combined
$\sigma^{Tevatron}_{t\bar{t}}$	$8.18^{+0.98}_{-0.87}$ pb	DØ Collaboration [8]
$\sigma^{LHC}_{l^{\pm}l^{\pm}}$	< 1 fb	ATLAS & CMS Collaborations [9]

Table 1: Measured values of various observables used in our analysis; combined here mea weighted averages.

+ V. Ahrens, A. Ferroglia, M. Neubert, B. D. Pecjak and L. L. Yang, JHEP **1009**, 097 (2010) [arxiv:1003.5827 [hep-ph]].

powerful discriminator SST

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Berger et al 1101.5625
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