Int. Symposium on Neutrino Physics and Beyond,
Sept. 23 -26, Shenzhen, China

HIGHLIGHTS on the EUROPEAN STRATEGY for PARTICLE PHYSICS

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Preparation of the EU Strategy in an **exciting and crucial moment in our field**

- **High-energy physics**: Discovery of a Higgs-like boson at the LHC, new important lower bounds on the mass of new physics particles
- **Neutrino physics**: large θ_{13} + (in a few months) new Planck result on the number of ν species
- **Flavor Physics**: new impressive bounds on FCNC ($B_S \to \mu^+\mu^-$; $\mu \to e\gamma$) and some puzzling results ($B \to \tau\nu$, CPV in D decays, …)
- **Dark Matter**: new bounds on WIMP DM (touching the 10^{-7} pb sensitivity), puzzling results for few GeV wimps, interplay with LHC wimp searches
- **Astroparticle frontier**: new results from Planck coming soon

MICRO

PARTICLE PHYSICS

GWS STANDARD MODEL

LHC

MACRO

COSMOLOGY

HOT BIG BANG STANDARD MODEL

PLANCK

HAPPY MARRIAGE

Ex: NUCLEOSYNTHESIS

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

3 WAYS TO IMPLEMENT THE HIGGS MECHANISM

- **NO HIGGS PARTICLE**: **HIGGSLESS** MODEL (almost) killed by LHC (unlikely the observed scalar is an "impostor", however not impossible – ex. dilaton, radion. Possibility of mixing of an "authentic" Higgs with the "impostor"…)

- **COMPOSITE HIGGS**: PSEUDO-GOLDSTONE BOSON

- **ELEMENTARY HIGGS**

  A) FINE-TUNED (unnatural Higgs – anthropic road, high-scale fundamental theory taking care of it, …)

  B) NATURAL (protection mechanism: low-energy SUSY; inexistence of the scale hierarchy problem: extra dimensions, warped space, …)

$J^{PC} = 0^{++}$?

- **SPIN**: it's a **BOSON** with spin either 0 or 2
- Disentangling 0 from 2: possible to separate the **scalar** option from the spin-2 state at the **4σ** level with the 8 TeV data
- **CP**: more difficult. Anyway, possible to distinguish between the **pure CP-even** and **pure CP-odd** possibilities at the **3.5σ** level by the end of the 8 TeV run

Contribution to the Open Symposium of the EU Strategy Prep. Group
eds. Heinemeyer, Kado, Mariotti, Weiglein, Weiler

ITS COUPLINGS: IMPOSTOR, A HIGGS OR THE (SM) HIGGS ?

- Strictly sticking to the data, we **cannot exclude** the logical possibility that the observed particle is **not connected to EWSB** (however, *Subtle* is the *Lord, but malicious* He is *not* ...)

- **The "a" vs. "the" dispute** decided by 5 numbers:

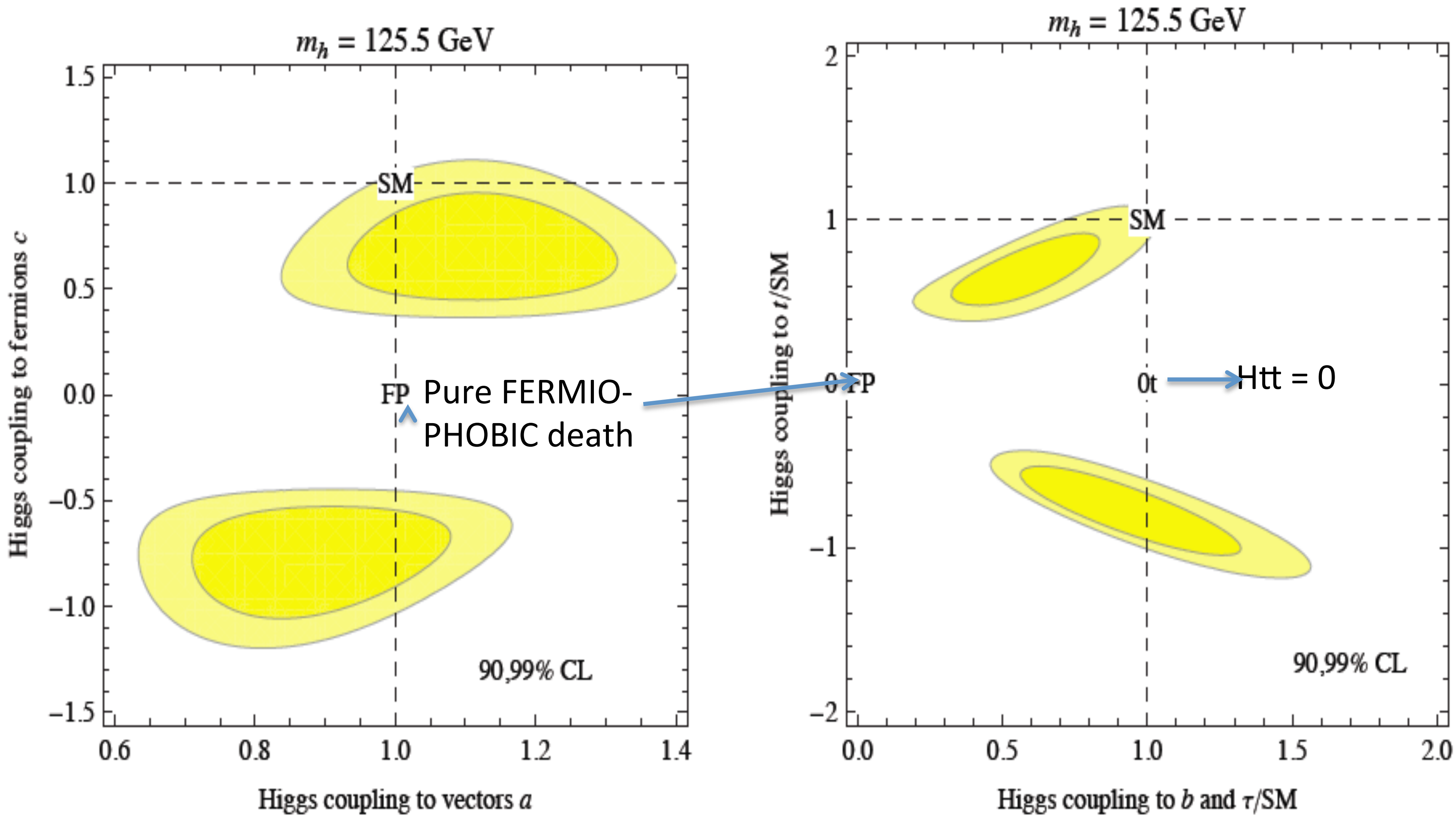
$$\mathcal{L}^{eff}_{<m_h} \approx c_V\left(\frac{2m_W^2}{v}W^+_\mu W^-_\mu + \frac{m_Z^2}{v}Z^2_\mu\right)h + c_b\frac{m_b}{v}\bar{b}bh + c_\tau\frac{m_\tau}{v}\bar{\tau}\tau h$$
$$+c^\gamma\frac{2\alpha}{9\pi v}F^2_{\mu\nu}h + c^g\frac{\alpha_S}{12\pi v}G^2_{\mu\nu}h$$
$$+\mathcal{L}(h \to inv)$$

$$c^\gamma = c_t + \frac{9}{2}\delta c^\gamma$$
$$c^g = c_t + \delta c^g$$

In the SM all 5 $c = 1$ and $\mathcal{L}(h \to inv) \approx 0$

BARBIERI, ICHEP2012

HIGGS: TO BE OR NOT TO BE STANDARD



Giardino, Kannike, Raidal, Strumia 2012

HOW TO GO NON-STANDARD

- **H MIXES WITH OTHER SCALARS** (e.g. 2HDM, MSSM, NMSSM, …) → all couplings possibly affected
- **H IS NOT AN ELEMENTARY PARTICLE** → all couplings possibly affected
- **H DECAYS INTO STATES THAT HAVE BEEN MISSED** (e.g., into invisible particles which do not interact or interact very weakly in the detector, into indiscernible particles which cannot be distinguished against the large background) ***H → inv***
- **LOOPS IN H PRODUCTION** (ex. g fusion) OR **IN H DECAYS** (ex. H→gg, H→ γγ) **ARE MODIFIED BECAUSE OF NEW VIRTUAL PARTICLES RUNNING INSIDE THEM** → **c^g and c^γ affected**

IF there is TeV NEW PHYSICS → not difficult to get variations of O(1) w.r.t. the SM expectations on the above 5 Higgs couplings

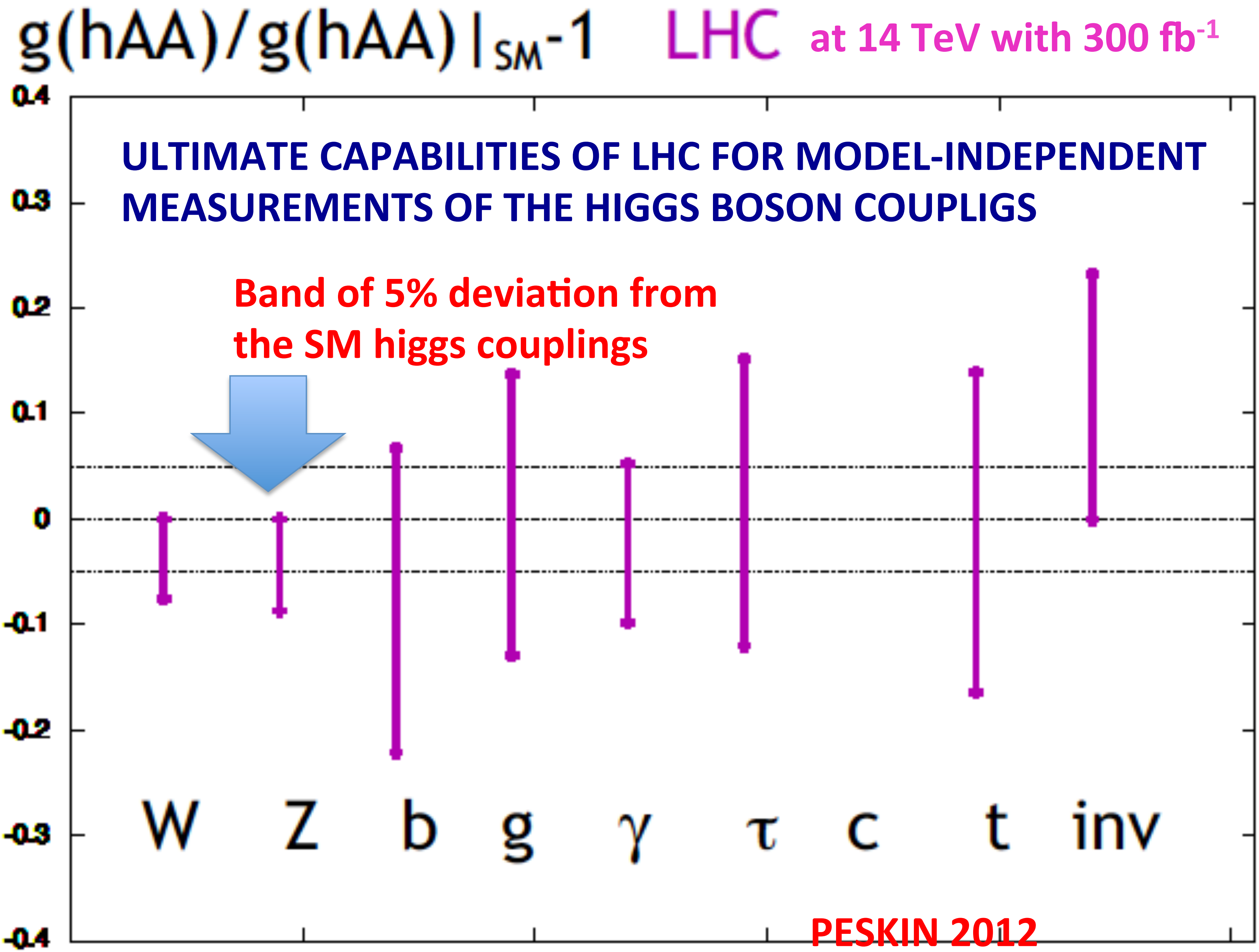
HOW PRECISE CAN WE BE ON AN SM-LIKE HIGGS PRODUCTION × BR at the LHC?

Decay	Prod	$10\,\mathrm{fb}^{-1}$ 7 - 8 TeV	$60\,\mathrm{fb}^{-1}$ 8 TeV	$300\,\mathrm{fb}^{-1}$ 14 TeV
$H \to b\bar{b}$	VH	70%	30%	10 %
$H \to b\bar{b}$	$t\bar{t}H$	-	60%	10 %
$H \to \tau\tau$	ggH	64%	40%	10 %
$H \to \tau\tau$	qqH		40%	10 %
$H \to \gamma\gamma$	ggH	38%	20%	6 %
$H \to \gamma\gamma$	qqH		40%	10 %
$H \to WW^*$	ggH	42%	16%	5 %
$H \to WW^*$	qqH	-	60%	16 %
$H \to ZZ^*$	ggH	40%	16%	5 %
c_V	-	10%	-	2%
c_F	-	25%	-	5%

M_H fixed at 125 GeV

Assuming that the **stat. errors scale with the luminosity**, whilst **the syst. and theor. errors remain the same**

WG Contribution to the Open Symposium of the EU Strategy
P. Anger et al.


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

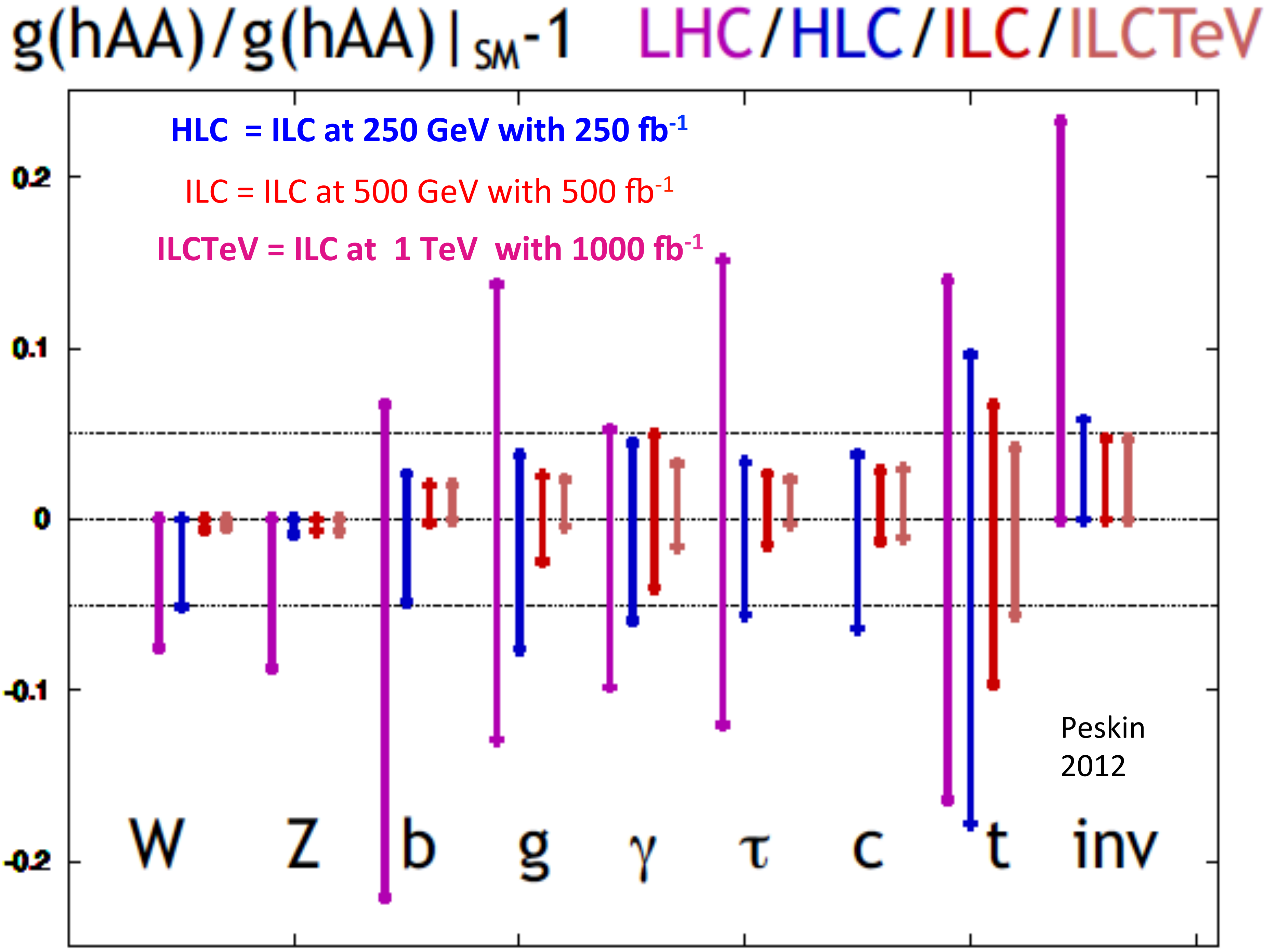
- Expected **O(10^5) Higgs bosons for ~ 250 fb^{-1}**
- Accuracies on **Higgs couplings** for M_H = 125 GeV (on individual couplings and not only on products of production cross section × BR)

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

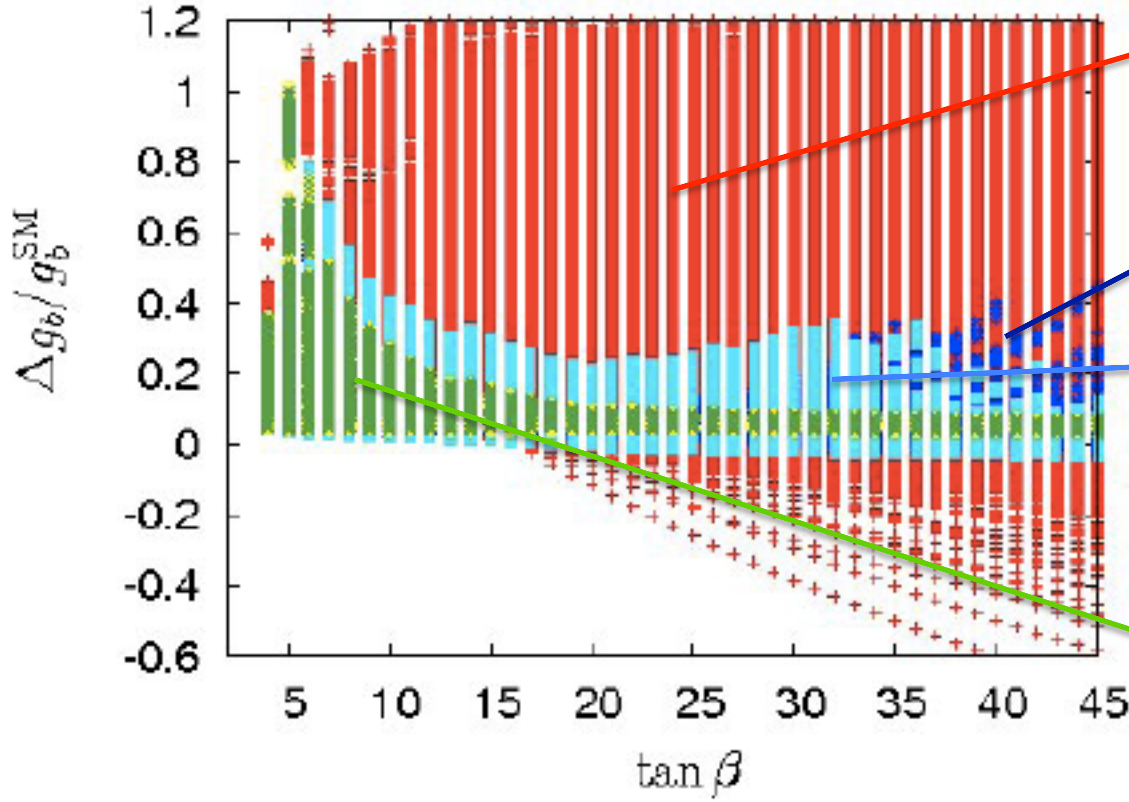


g(hAA)/g(hAA)|SM-1 LHC/HLC/ILC/ILCTeV
HLC = ILC at 250 GeV with 250 fb-1
ILC = ILC at 500 GeV with 500 fb-1
ILCTeV = ILC at 1 TeV with 1000 fb-1
0.2
0.1
0
-0.1
-0.2
W
Z
b
g
γ
τ
c
t
inv
Peskin
2012

but, **which precision should we aim at?**

- Possible (conservative) answer: push your precision up to the level **you cannot beat the theoretical errors** (ex. bottom Yukawa coupl. → its relation to the partial width known at the few percent level; useless to reach 1% precision on b partial width

- Ask how much H couplings can differ from the SM ones in a situation where **no other direct signal of new physics appear at the LHC** (ex.: in the decoupling limit of SUSY – with no SUSY particle detectable at the LHC, how large can the deviations in the H couplings be?)



RED: several Higgses are discovered at LHC

DARKBLUE: excluded by BR (b → sγ) constraint

LIGHTBLUE: at least one stop has mass < 1 TeV

GREEN: both top squarks are heavier than 1.5 TeV

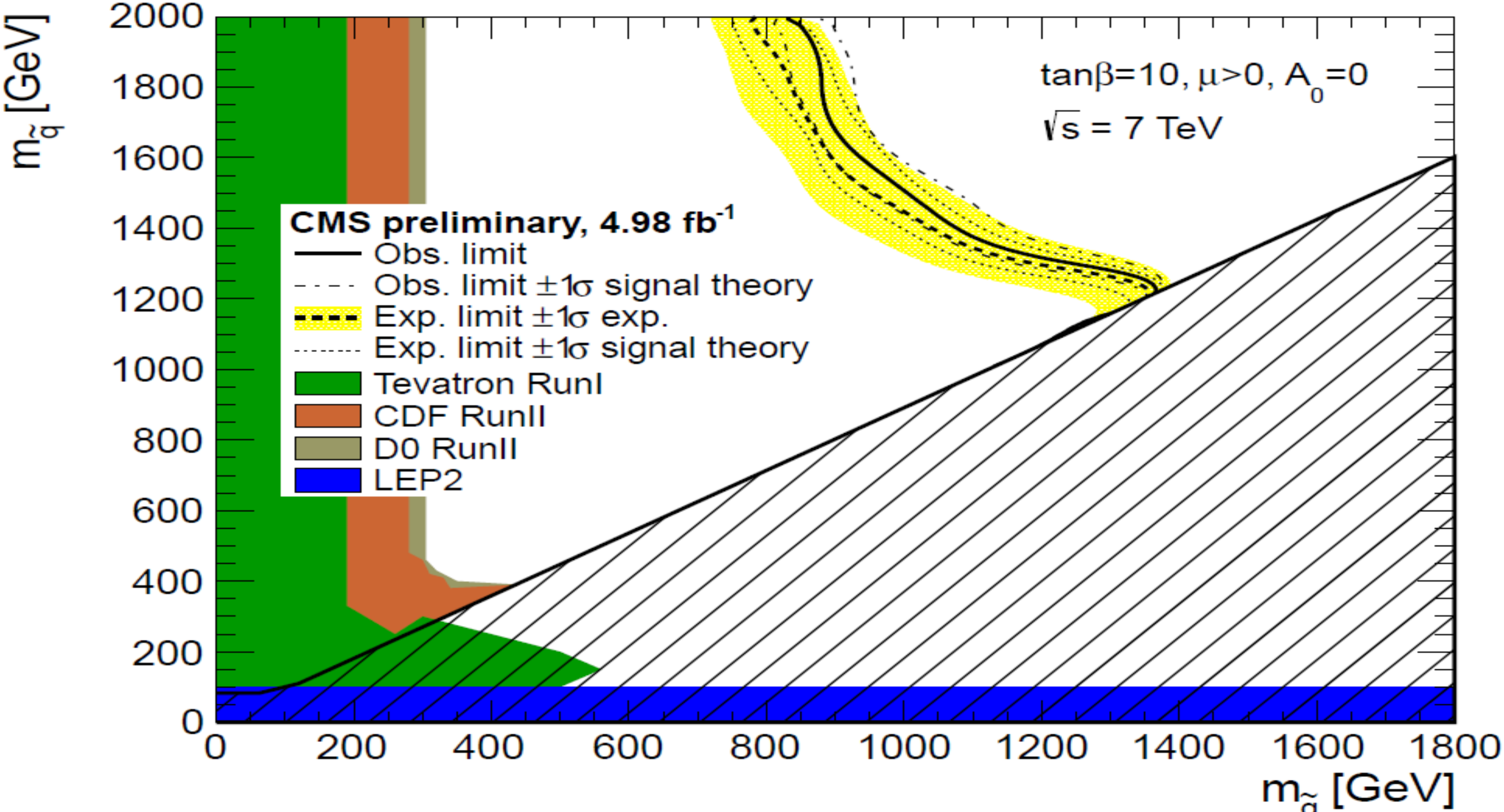
	ΔhVV	$\Delta h\bar{t}t$	Δhbb
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	10%[a], 100%[b]
LHC 14 TeV, 3 ab^{-1}	8%	10%	15%

GUPTA, RZEHAK, WELLS 2012

Is Supersymmetry Dead?

The grand scheme, a stepping-stone to string theory, is still high on physicists' wish lists. But if no solid evidence surfaces soon, it could begin to have a serious PR problem

By Davide Castelvecchi | April 25, 2012 | 32

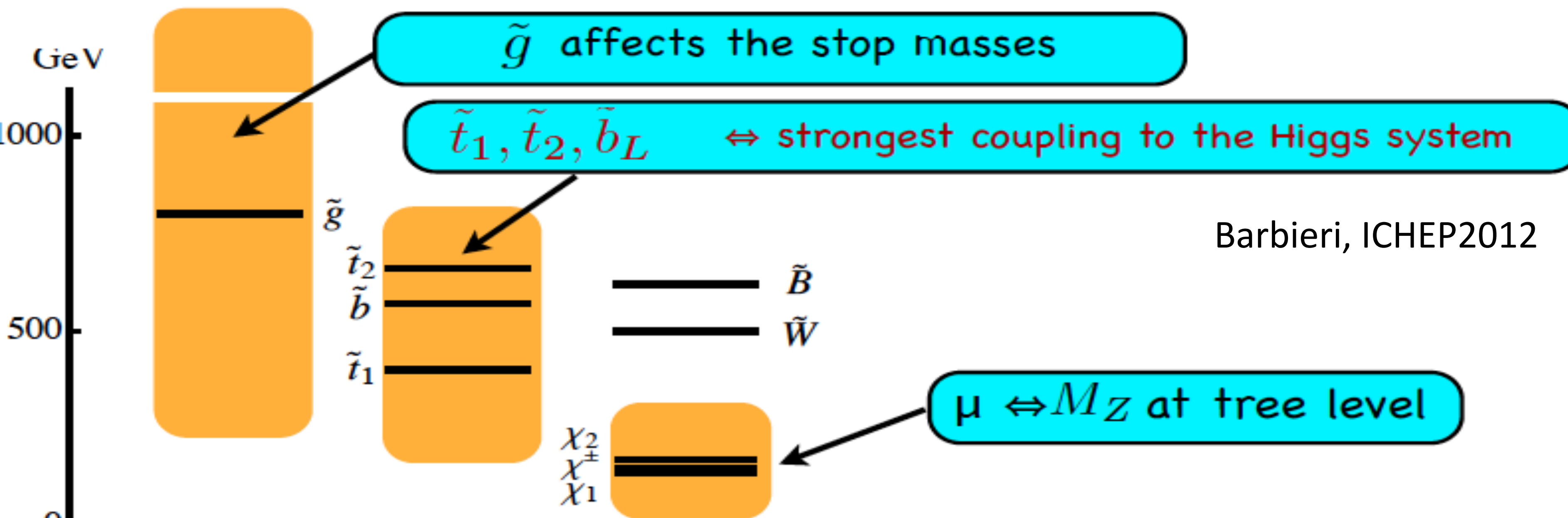


PLHC June 4-9, 2012 – Vancouver CMS 2011 data

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"

"s-particles at their naturalness limit"

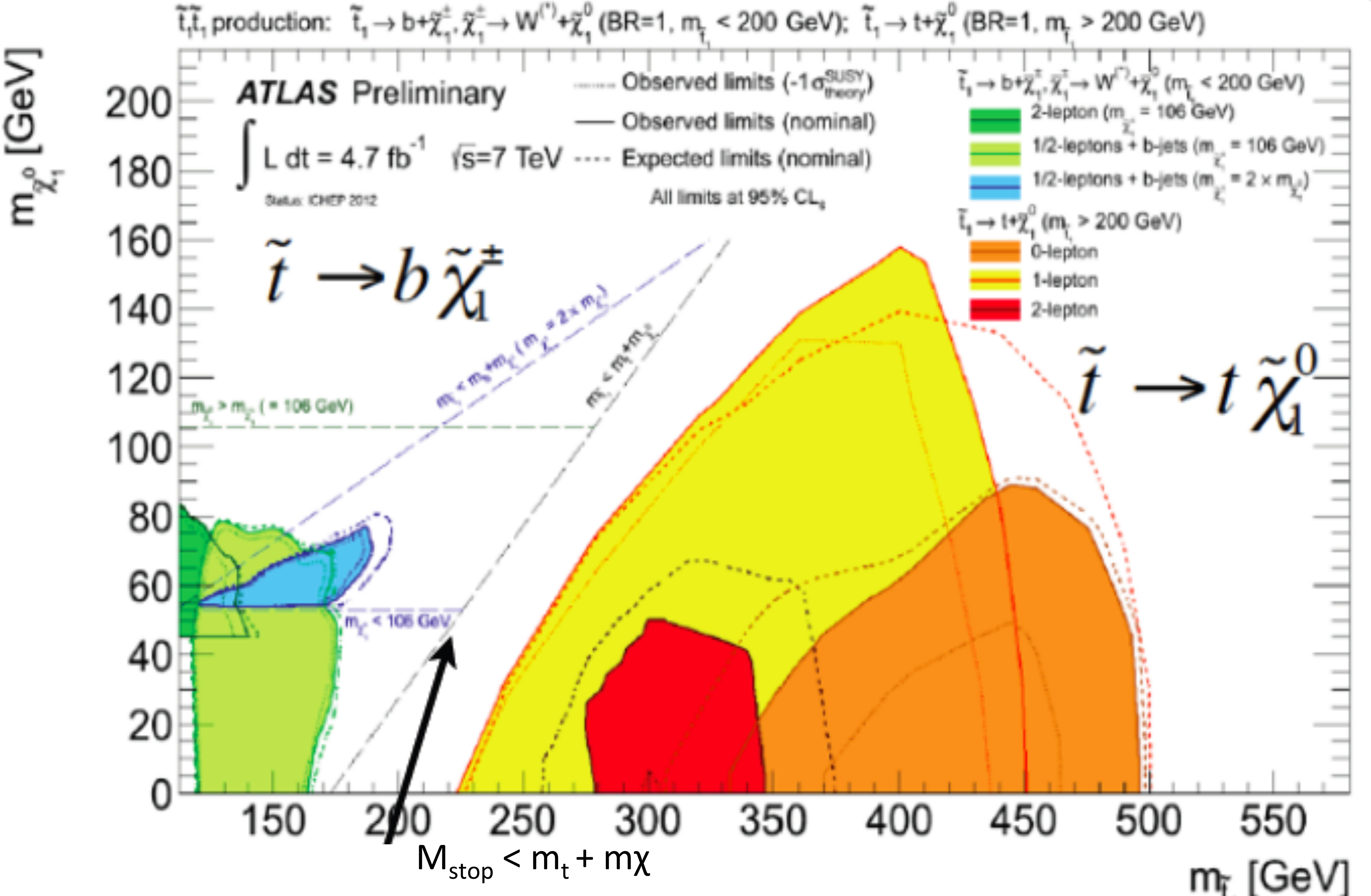


Barbieri, ICHEP2012

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

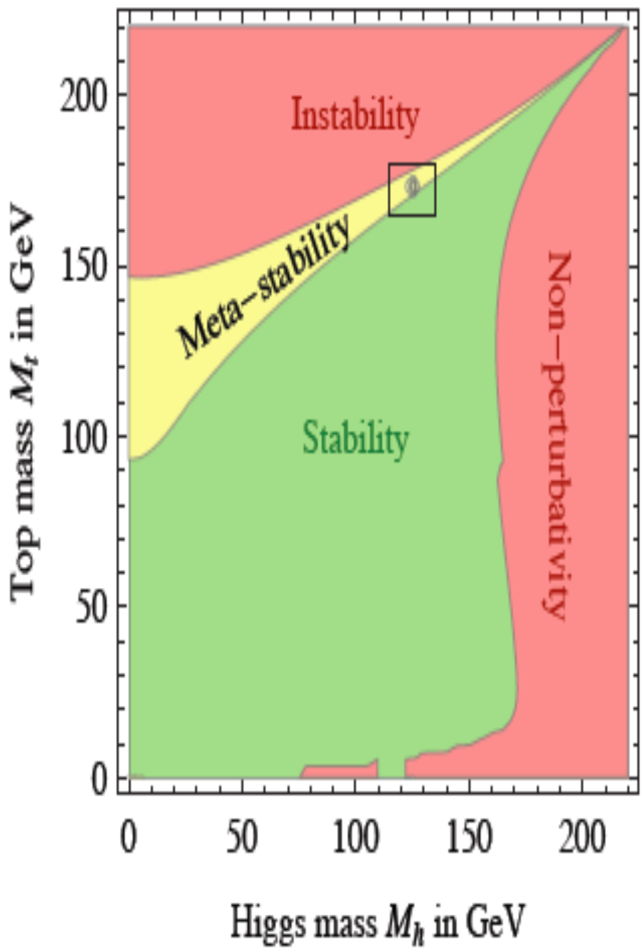
$\tilde{B}, \tilde{W}$ not much constrained but expected below $m_{\tilde{g}}$

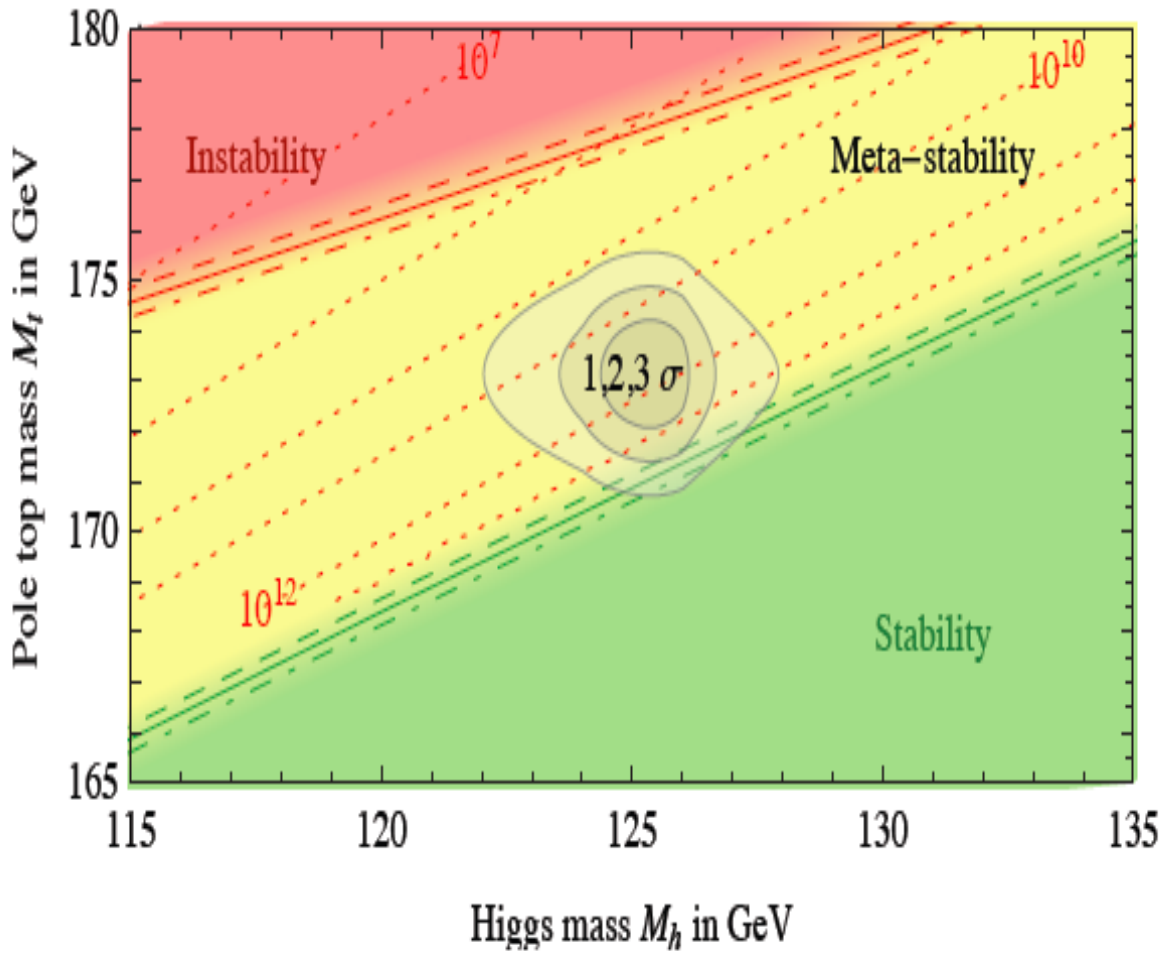
Hunting for a light s-top



$M_{stop} < m_t + m\chi$

LIVING DANGEREOUSLY IN A "PROBABLE" METASTABLE UNIVERSE





DEGRASSI, DI VITA, ELIAS-MIRO', ESPINOSA, GIUDICE, ISIDORI, STRUMIA 2012

FIRST COMPLETE ANALYSIS NNLO OF THE SM HIGGS POTENTIAL

ON THE IMPORTANCE OF PRECISELY MEASURING HIGGS and TOP MASSES

DEGRASSI ET AL

Type of error	Estimate of the error	Impact on M_h
M_t	experimental uncertainty in M_t	± 1.4 GeV
α_s	experimental uncertainty in α_s	± 0.5 GeV
Experiment	Total combined in quadrature	± 1.5 GeV
λ	scale variation in λ	± 0.7 GeV
y_t	$\mathcal{O}(\Lambda_{QCD})$ correction to M_t	± 0.6 GeV
y_t	QCD threshold at 4 loops	± 0.3 GeV
RGE	EW at 3 loops + QCD at 4 loops	± 0.2 GeV
Theory	Total combined in quadrature	± 1.0 GeV

INTRINSIC DIFFICULTY TO “DEFINE” WHAT THE TOP MASS IS AT A **HADRON COLLIDER** WITH UNCERTAINTY ≤ 1 GeV

High Energy Frontier

NAKADA's summary of the WG on HE Physics in Cracow

- Discovery of Higgs-like state is a landmark for the field (and a triumph for the LHC)
- Plethora of SM measurements with increasing precision (QCD,t,W,Z,VV,...)
- Searches for NP leading to o(TeV) limits on new particles

- Excellent prospects (much increased NP reach!) for 14 TeV LHC (300 fb^{-1})
- Higgs measurements & WW unitarity require HL-LHC 3000 fb^{-1} upgrade (detectors + machine)

- Excellent physics case for the study of „Higgs" state (+top, EW) in depth with high precision and complementary to LHC in e^+e^- (γγ?, ep??)
- Announcement from Japanese community to aim hosting ILC (250-500 GeV) as global project
- Assess which machine best suited for this program (linear vs. circular)
- Time matters – technical readiness also

- In absence of direct evidence for NP and strong theoretical guidance too early to decide on post-LHC facility for HEF (CLIC, HE-LHC(33), UHE-LHC(50+), μC, Plasma??, ...)
- Maintain critical R&D and feasibility studies

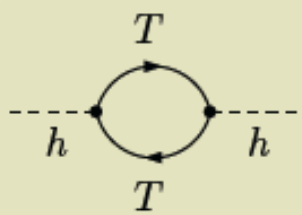
Higgs and flavor physics as indirect BSM probes

NEUBERT SUSY2012

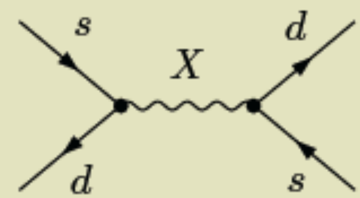
$$\mathcal{L}_{\rm EFT} = \Lambda_{\rm UV}^2\,\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{\mathcal{L}^{(5)}}{\Lambda_{\rm UV}} + \frac{\mathcal{L}^{(6)}}{\Lambda_{\rm UV}^2} + \dots$$

electroweak symmetry breaking $\Downarrow$ Higgs mass

$\Downarrow$



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



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

no fine-tuning $\Downarrow$

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**

From a closer look

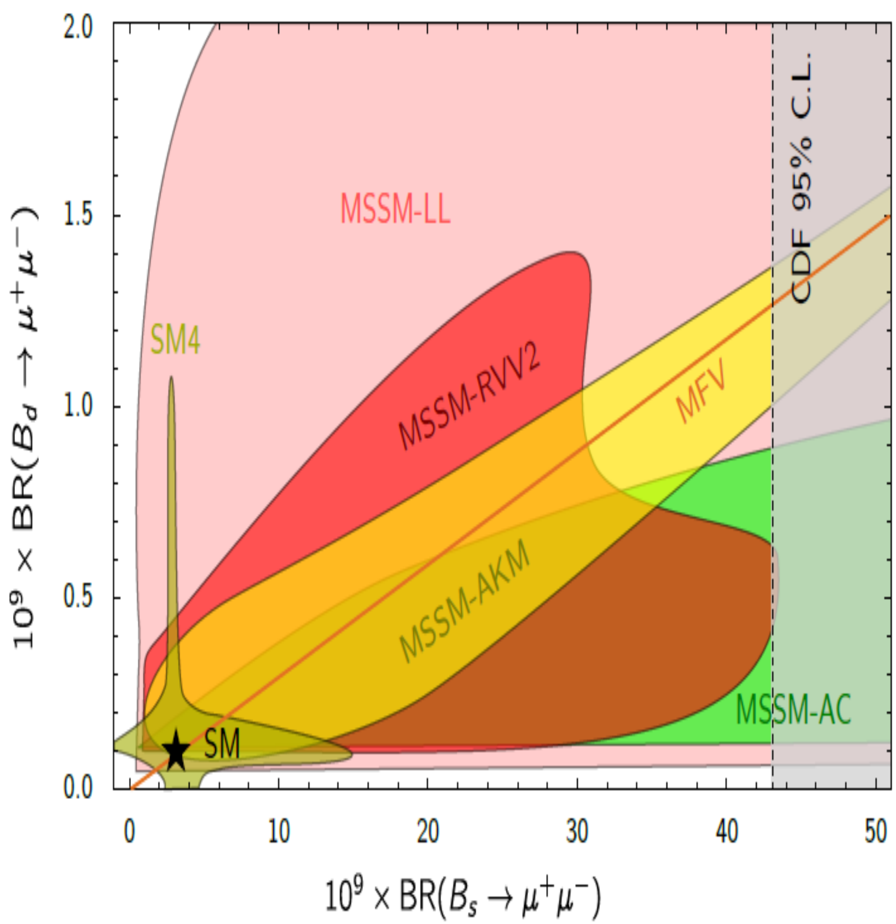
From the UTA
(excluding its exp. constraint)

	Prediction	Measurement	Pull
$\sin 2\beta$	0.81±0.05	0.680±0.023	2.4 ←
γ	68°±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 ←
$BR(B\rightarrow \tau\nu) \cdot 10^4$	0.82±0.08	1.67±0.30	-2.7 ←

TARANTINO 2012

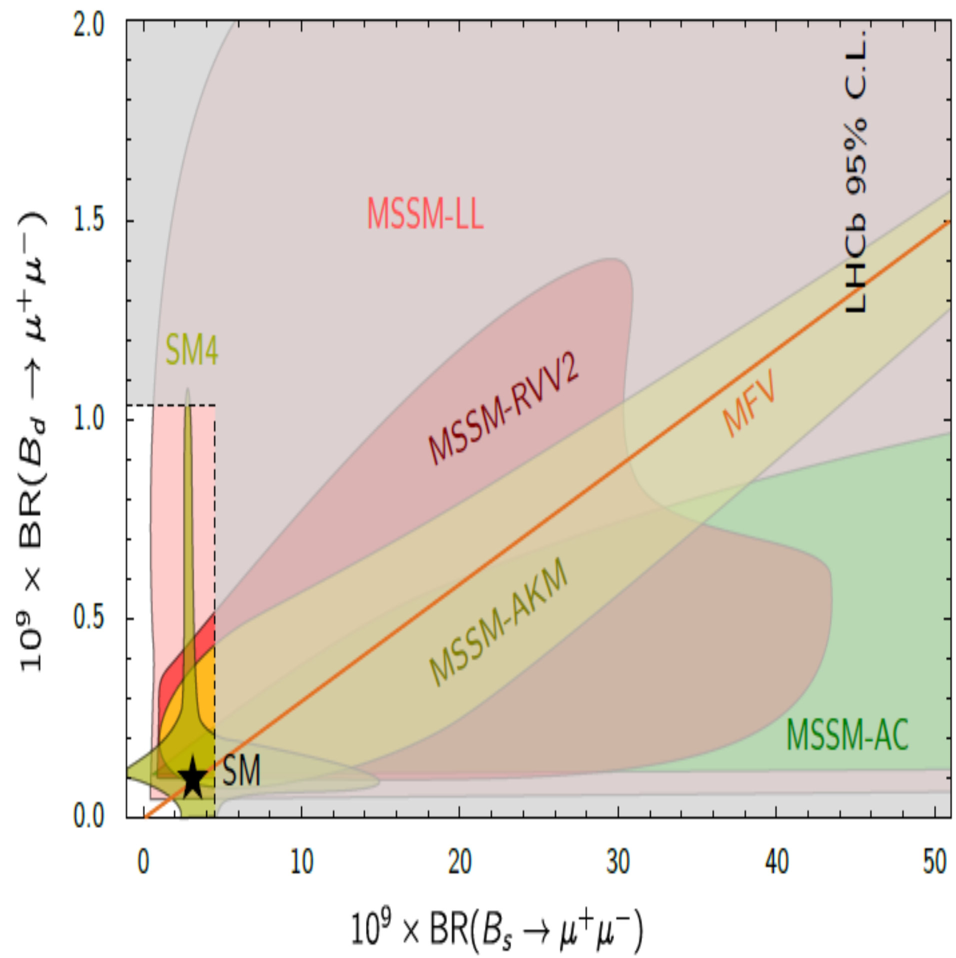
David Straub: arXiv:1205.6094

2011



2012

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



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 ?

BABAR DATA in TENSION WITH THE SM

- The *BABAR* collaboration recently reported on new measurements of decays of *B* mesons into final states containing tau lepton, τ. The decay branching fractions are higher than predicted by the Standard Model with a **3.4σ level** of significance.
- *BABAR* measures the ratios of branching fractions

  $R(D) = Br(B \to D\tau\nu_\tau)/B(B \to Dl\nu_l)$ and

  $R(D^*) = B(B \to D^*\tau\nu_\tau)/B(B \to D^*l\nu_l)$

	SM Theory	BaBar value	Diff.
R(D)	0.297±0.017	0.440±0.058±0.042	+2.0σ
R(D*)	0.252±0.003	0.332±0.024±0.018	+2.7σ

$B \to \tau\nu$

$BR(B \to \tau\nu)_{SM} = (0.82 \pm 0.08) \cdot 10^{-4}$

[UTfit, update of 0908.3470]

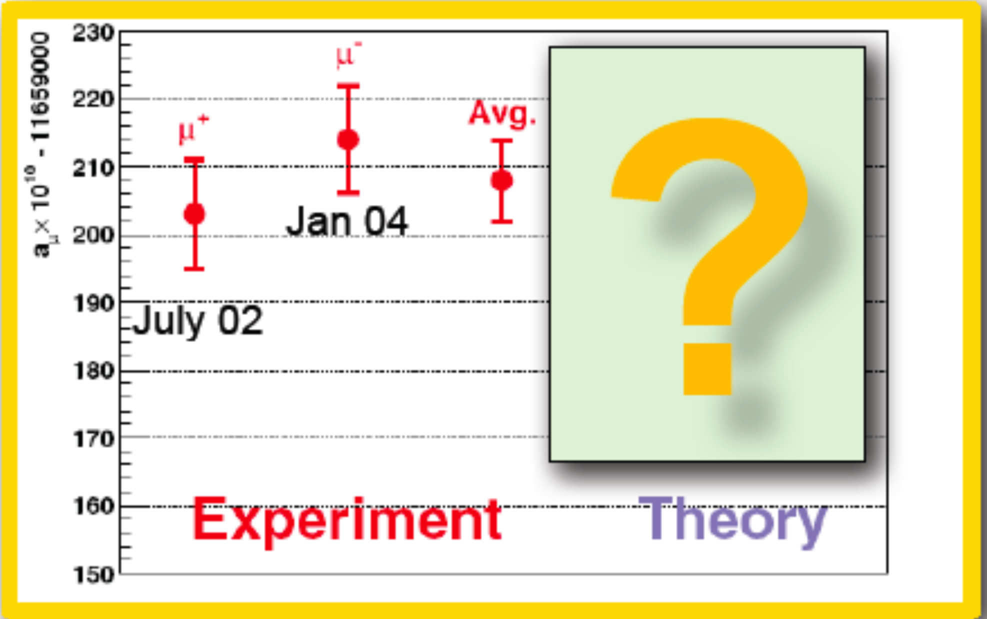
turns out to be smaller by ~2.7 σ than the experimental value

$BR(B \to \tau\nu)_{exp} = (1.67 \pm 0.30) \cdot 10^{-4}$

NEW 2012 BABAR and BELLE ANALYSES:

- BABAR CONFIRMS
- BELLE SOMEWHAT REDUCES THE DISCREPANCY

The muon g-2: the experimental result



- **Today:** $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys})\times 10^{-11}$ [0.5ppm].
- **Future:** new muon g-2 experiments proposed at:
  - Fermilab (E989), aiming at 0.14ppm → **Has now Stage 1 Approval!**
  - J-PARC aiming at 0.1 ppm

  [D. Hertzog & N. Saito, U.Paris, Feb 2010; B.Lee Roberts & T. Mibe, Tau2010]
- **Are theorists ready for this (amazing) precision?** No(t yet)

M. PASSERA 2012

The muon g-2: Standard Model 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 $\lambda = \mu_\mu/\mu_p$ (CODATA'06)

	$a_\mu^{SM} \times 10^{11}$	$(\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$	σ
[1]	116 591 782 (59)	307 (86)	3.6
[2]	116 591 802 (49)	287 (80)	3.6
[3]	116 591 828 (50)	261 (80)	3.2
[4]	116 591 894 (54)	195 (83)	2.4

M. PASSERA 2012

with $a_\mu^{HHO}(lbl) = 105\ (26) \times 10^{-11}$

[1] F. Jegerlehner, A. Nyffeler, Phys. Rept. 477 (2009) 1

[2] Davier et al, EPJ C71 (2011) 1515 (includes BaBar and KLOE10 2π)

[3] HLMNT11: Hagiwara et al, JPG38 (2011) 085003 (incl BaBar and KLOE10 2π)

[4] Davier et al, Eur.PJ C71 (2011) 1515, τ data.

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

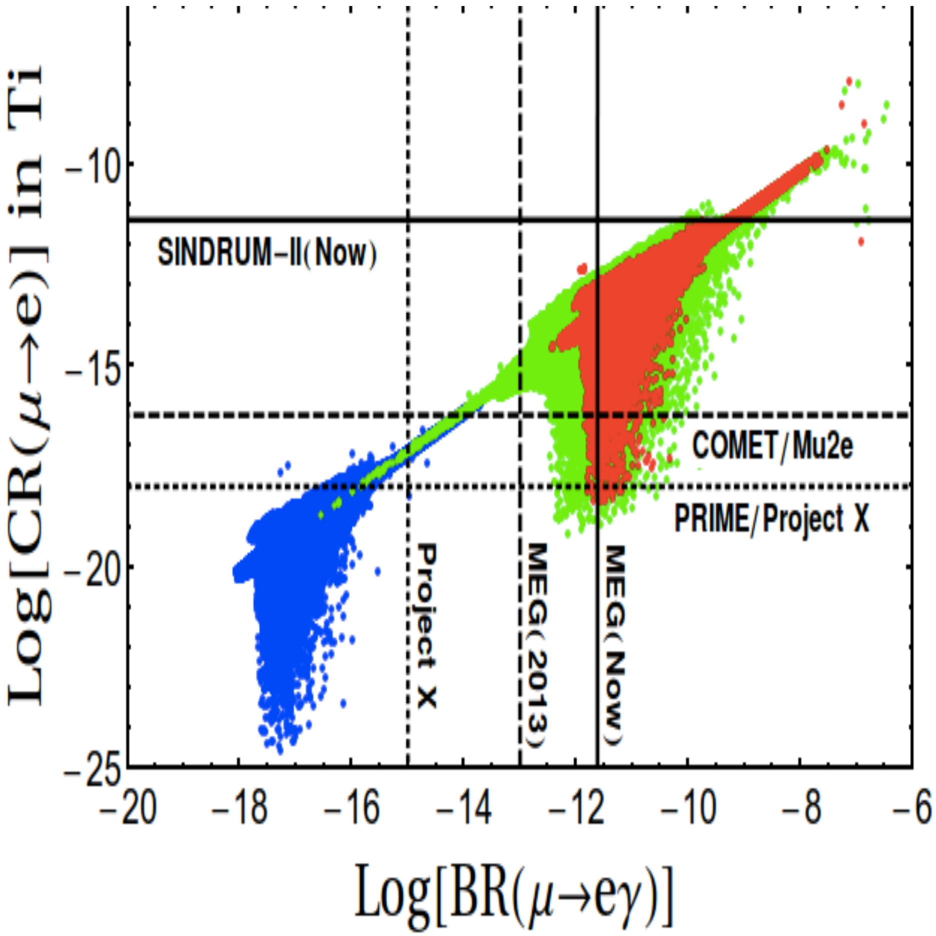
THE EDM CHALLENGE

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

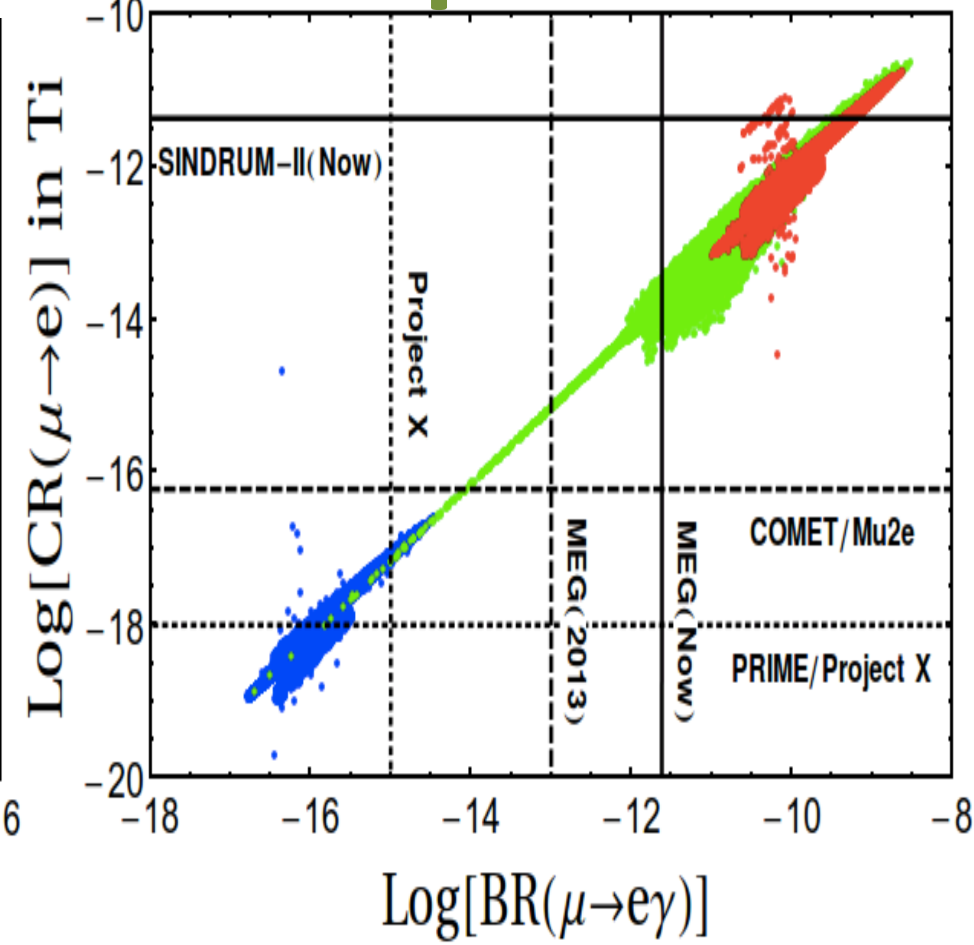
$$|d_{\rm n}| < 2.9 \times 10^{-26} e \text{ cm } (90\%\text{C.L.}),$$
$$|d_{\rm Tl}| < 9.0 \times 10^{-25} e \text{ cm } (90\%\text{C.L.}),$$
$$|d_{\rm Hg}| < 3.1 \times 10^{-29} e \text{ cm } (95\%\text{C.L.}).$$

μ – e conversion vs μ → eγ

Tanβ = 10



Tanβ = 40



Summary of Flavour Physics and Symmetry Session

at the CRACOW Symposium

- Recent Progress
  - B Factories (Belle and Barbar) have completed data taking and continue to provide wide range of interesting results, including CP violation and rare decays.
  - LHCb has demonstrated that precision flavour physics is possible at hadron collider
  - High-p_T experiments (CDF, D0, ATLAS, CMS) also doing excellent flavour physics
  - Detailed study made of CP violation and rare decays in B system (now including B_s)
  - NA62 is completing its preparation for precision kaon physics
  - MEG at PSI is improving a search for $\mu \to e\gamma$ at 2.4×10^{-12}
- Open Issues
  - No clear sign of physics beyond the Standard Model in flavour sector, and possible key measurements (a la G. Isidori) are as follows.
    - Φ_s, $|V_{ub}|$, CP angle gamma, B rare decays such as $B_s \to \mu\mu$ and $B \to \tau\nu$
    - CP violation in charm
    - K rare decays such as $K \to \pi\nu\nu$
    - Charged lepton flavor violation (CLFV) eg. $\mu \to e\gamma$, $\mu N \to eN$, $\mu \to eee$, $\tau \to \mu\gamma$, etc.
    - Muon g-2 and EDM (neutron, electron, muon, atom)
- Towards a Strategic Plan
  - Essential to maintain a diverse programme (B, D, K, charged leptons)
  - Flavour experiments typically on smaller scale than Higgs/neutrino, but crucial for search for/understanding of New Physics
  - LHCb and its upgrade form an important part of the exploitation of the LHC
  - An upgraded B Factory will give complementary physics coverage
  - CLFV (μ and τ) and EDM could provide a clean demonstration of new physics

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

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

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

Addressed by accelerator neutrino experiments

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

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 ☐

Debate on the perspectives quite unsettled

Summary of the ν session

- ν mass and mixings confirmed by many experiments and remain, with dark matter, the only present evidence of beyond the Standard Model physics.
- As the highest priority we should determine the unknown oscillation parameters and look for surprises. CP violation and the ν mass hierarchy could be keys to the matter/antimatter asymmetry of the Universe.
- A large and effective European community exists in this area.
- Long baselines are optimal for determining the mass hierarchy, real advantage of the CERN → Pyhäsalmi baseline and, to a lesser extent, LBNE.
- The CERN → Pyhäsalmi baseline is also near optimal for a Neutrino Factory.
- Shorter (~hundreds of kilometres) baselines with huge detectors would allow very high statistics measurements more helpful for CP violation, particularly if hierarchy is known. This is the case of T2HK (also European alternatives such as CERN → Frejus, CERN → Canfranc, or ESS-based ν beam)
- For best performance and synergy an experiment of each category is needed → Coherence with efforts in other regions. Coordination and cooperation with our international colleagues mandatory.
- Anomalies in a range of phenomena at lower energies perhaps point to sterile neutrinos, and a proposed experiment at CERN would be highly competitive.
- More sophisticated future projects, which EUROnu has concluded should be a Neutrino Factory, necessary to achieve the desired sensitivity to the CP phase and probe new physics.
- R&D including projects such as MICE and nuStorm (which may also offer a definitive test for sterile neutrinos) should be supported.
- Experiments in absolute neutrino mass, especially in neutrinoless double-beta decay, are also a top priority.
- Hadron production, neutrino cross-section, and other support measurements will be essential to reach the neutrino oscillation sensitivity goals.

Accelerator Science & Technology Session

Summary of the WG at the Cracow meeting

LHC & high-energy hadron collider

- LHC operating successfully (a huge technology success!)
- technology to go to 13-14 TeV and HL-LHC at hand with some development needed
- possibility to go to 26-33 TeV with 16-20 T magnets (HE-LHC), but substantial R&D needed ; higher energy requires a new tunnel (80 km → 80-100 TeV)

high-energy lepton collider

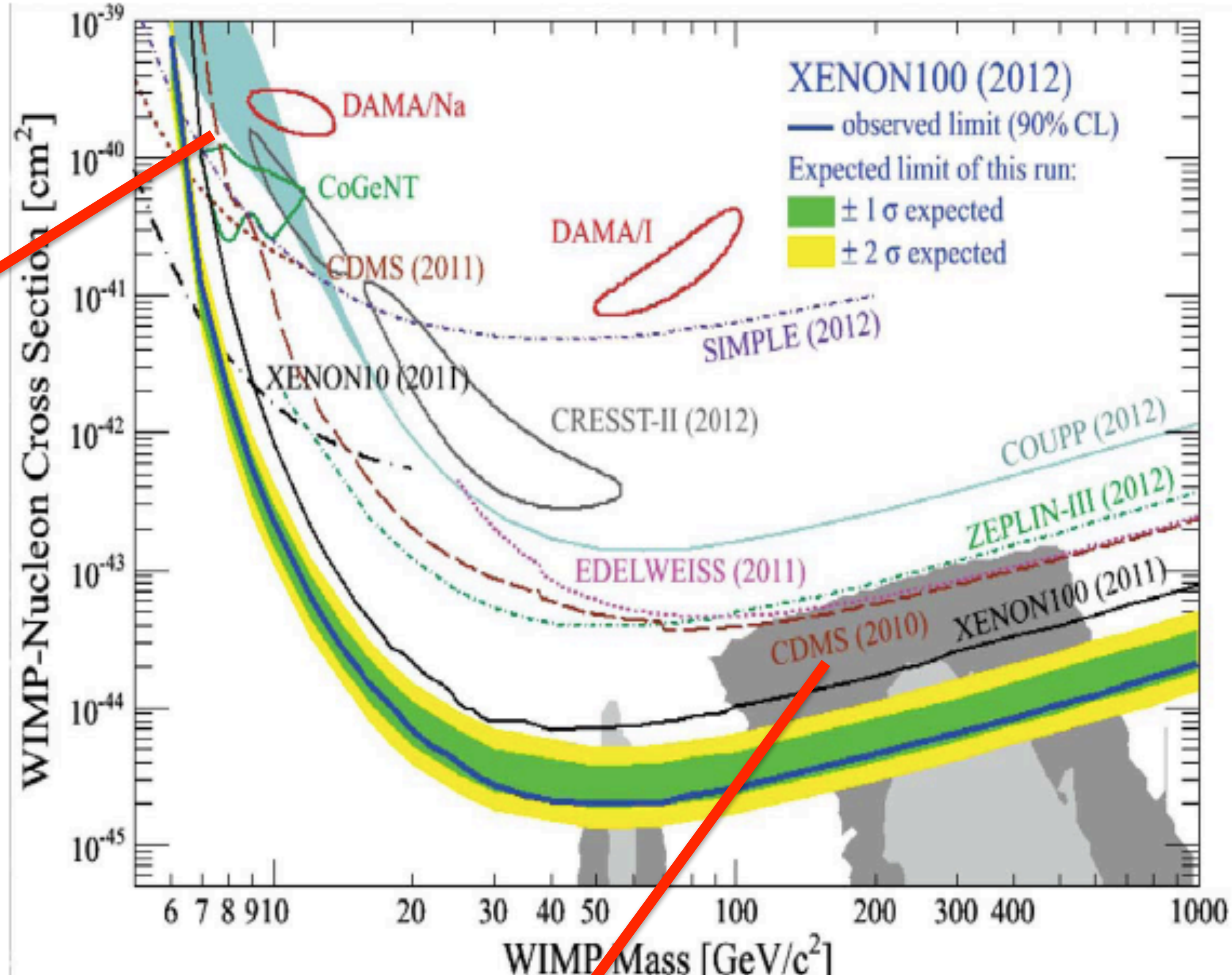
- great progress in SRF for ILC makes project possible ; very advanced proposal
- CLIC could be alternative, esp. if one wants to go to 3 TeV with still significant R&D
- new ideas for circular or $\gamma\gamma$ colliders; more studies needed on performance reach
- SRF ERL/RLA technology is attractive for many applications (LHeC, $\gamma\gamma$)
- to go to much higher energy using leptons requires muon collider, dielectric acceleration or plasma acceleration with increasing complexity and R&D needed

high intensity beams

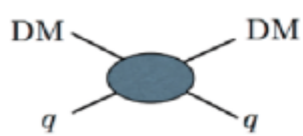
- high power linacs being constructed (ESS, IFMIF, Project-X?); technology in hand
- improving neutrino beams with optimized existing infrastructures is possible
- high-intensity ν beam requires ν factory, with intense R&D
- technology for very-high luminosity flavor factories exists

Low-mass region:
either unexplained backgrounds in DAMA, CoGeNT, and CRESST-II, …
or
… other experiments do not understand low recoil energy calibration, …
or
… can't compare different experiments

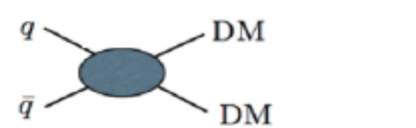
Kolb SUSY2012



Relevant to intensify the efforts here: ex. **asymmetric DM** with **DM particles of mass~ baryon mass given that ρ_{DM} not much different from ρ_B**



Direct Detection (t-channel)



Collider Searches (s-channel)

- This is indeed **an exciting moment in all the three frontiers of High Energy, High Intensity and Astroparticle physics**
- The celebrated dilemma: is there **new physics to stabilize the ELW symmetry breaking scale** (i.e. TeV NP) or is there **the big desert**? Becomes more articulated:

i) TeV NP physics (testable - along the “real” path, i.e. observing its new particles, or at least some of them) ;

ii) **more and more unnatural NP related to the ELW breaking (more chances in a near future for the “virtual path”);**

iii) **no need to stabilize the ELW scale, big desert or possibly some remnant at lower energies (tests of the validity of the SM up to very large scales, for instance its vacuum stability)?**

The GLOBAL CHALLENGE

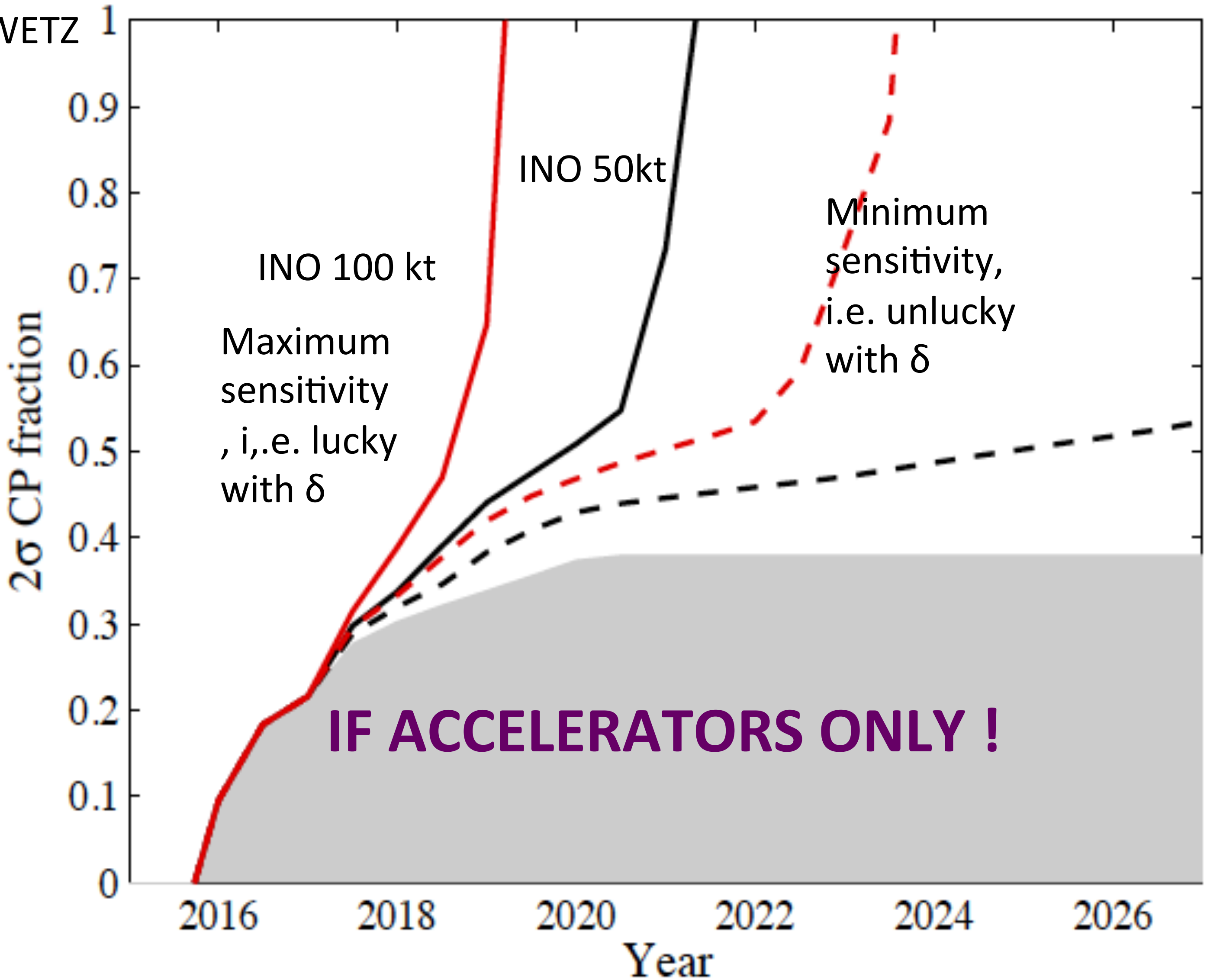
- This is also an important moment to take decisions of high impact for the future of our community at a **GLOBAL LEVEL**
- **HIGH-ENERGY**: ILC (250, 350, 500 GEV?)
- **NEUTRINO PHYSICS**: sterile ν exps? R&D for a (very) large underground facility
- **FLAVOR**: super B-factories; CLFV exps.; rare, theor. clean FCNC K decays; EDM exps?
- **DM:** 1-ton frontier; new exps. on low-mass wimps?

BACK-UP SLIDES

COMBINATION OF INO, NOvA AND T2K TO SOLVE THE ν MASS HIERARCHY PUZZLE

BLENNOW, SCHWETZ 2012

FRACTION OF VALUES OF δ for which INO +NOvA+T2K are sensitive to the **ν mass hierarchy at 2 σ**



ANSWER TO THE ν MASS HIERARCHY FROM ICE/DEEP WATER ?

IceCube → DeepCore → **PINGU**

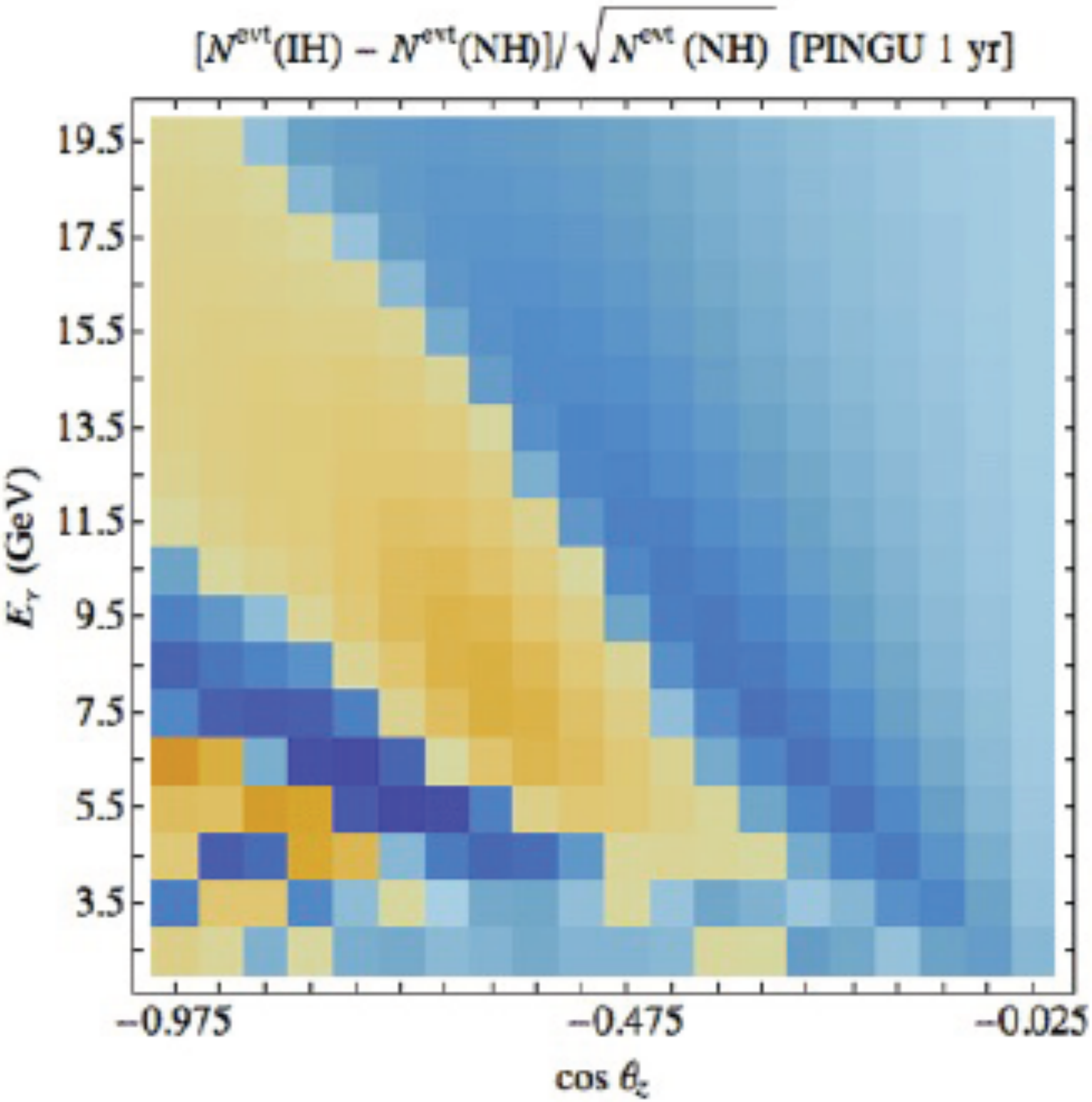
Addition of 18 – 20 strings into the DEEP CORE volume

- *~20 additional strings within DeepCore*
- *lower threshold to few GeV*
- *~10 Mt effective volume*
- *construction within 1 yr, ~$25 M*

Doug Cowen, NuSky, ICTP, June 2011

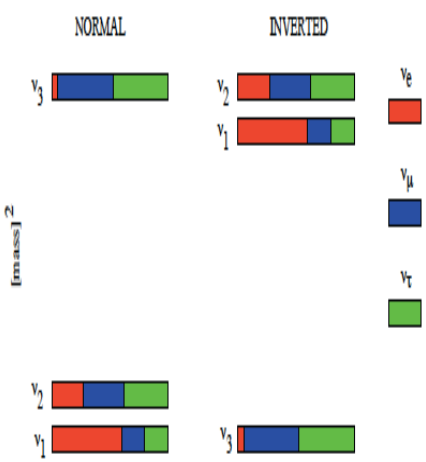
HIERARCHY CAN BE IDENTIFIED AT THE 4σ - 11σ (depending on the reconstruction accuracies) **AFTER 5 yrs. OF PINGU OPERATION**

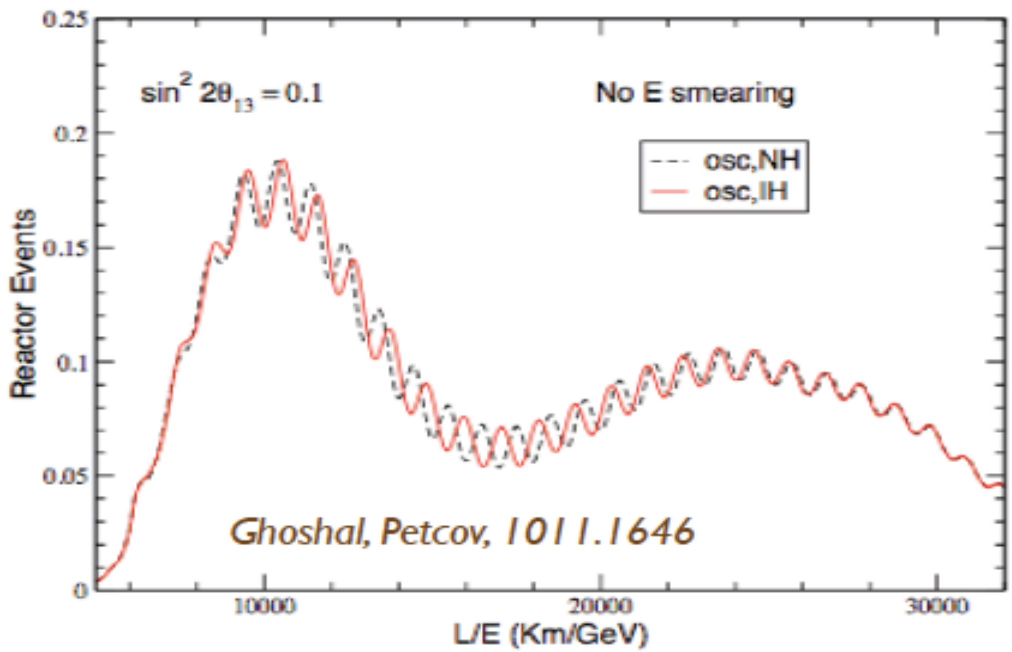
AKHMEDOV, RAZZAQUE AND SMIRNOV, 2012



Mass hierarchy from reactor experiments

$$\overline{P}(\overline{\nu}_e \to \overline{\nu}_e) = 1 - \frac{1}{2}\sin^2 2\theta_{13}\left[1 - \left(c_{12}^2 \cos 2\Delta_{31} + s_{12}^2 \cos 2\Delta_{32}\right)\right] - \sin^2 2\theta_{12} c_{13}^4 \sin^2 \Delta_{21}$$

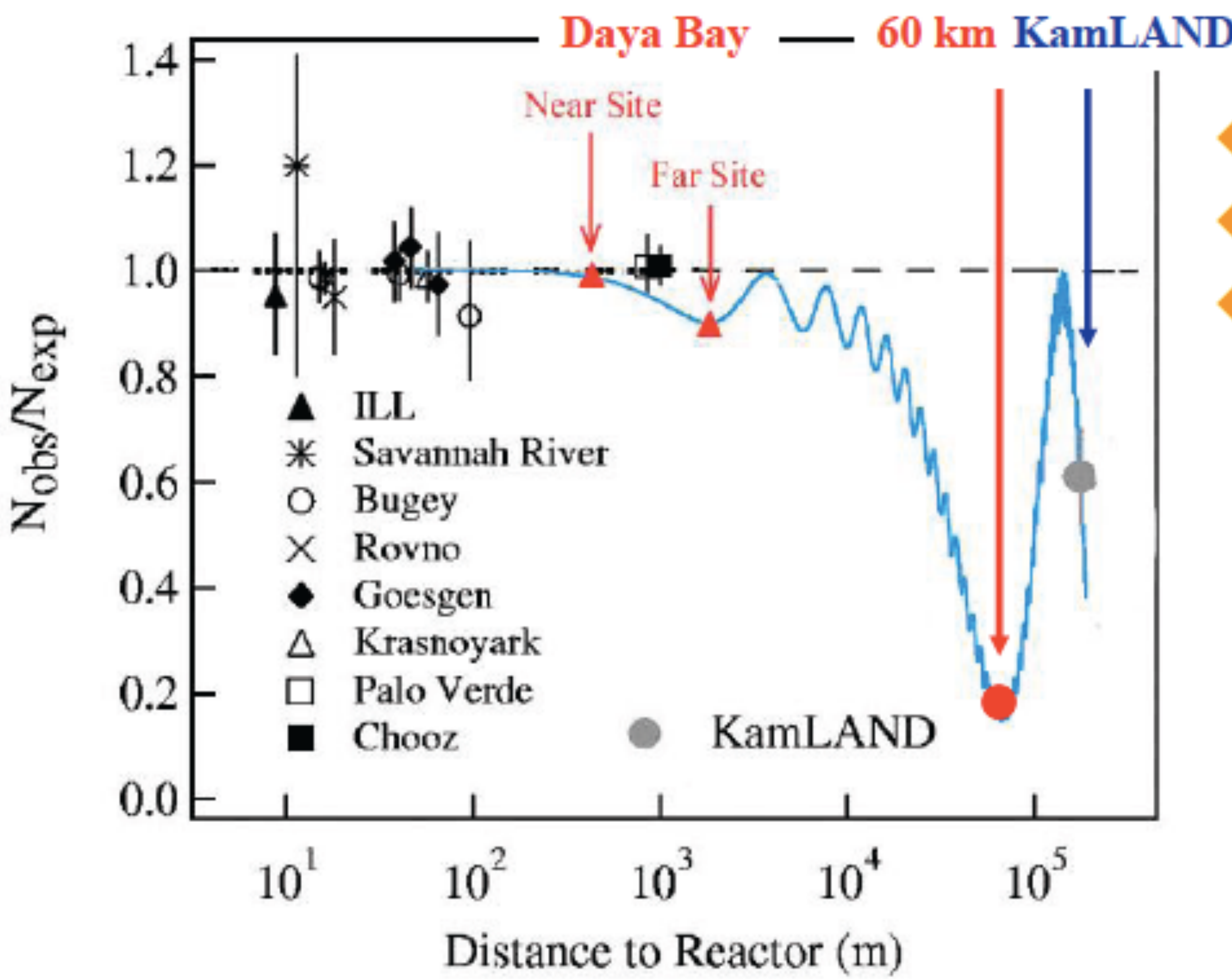




Δm^2_{31} and Δm^2_{32}

2 frequencies: **for NH (IH) the larger (smaller) frequency dominates**

After θ_{13} → DAYA BAY FOCUS ON THE MASS HIERACHY: the DAYA BAY-II EXP.



Main challenge

- 20 kton detector
- 3% energy resolution
- Rich physics possibilities

Apart from mass hierarchy, possible to look for **supernovae neutrinos**, **geoneutrinos**, **sterile neutrinos** and maybe **even CPV**

THE ν CPV CHALLENGE

The large θ_{13} opens the door to the (very) long path to observe LCPV

ν_μ-ν_e oscillations in a 3 ν scheme

$$p(\nu_\mu - \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1 - 2s_{13}^2)\right]$$ θ_{13} driven

$$+ 8c_{13}^2 s_{12} s_{13} s_{23}(c_{12} c_{23} \cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E}$$ CPeven

$$\mp 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E}$$ CPodd

$$+ 4s_{12}^2 c_{13}^2 \{ c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta\} \sin \frac{\Delta m_{12}^2 L}{4E}$$ solar driven

$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1 - 2s_{13}^2)$$ matter effect (CP odd)

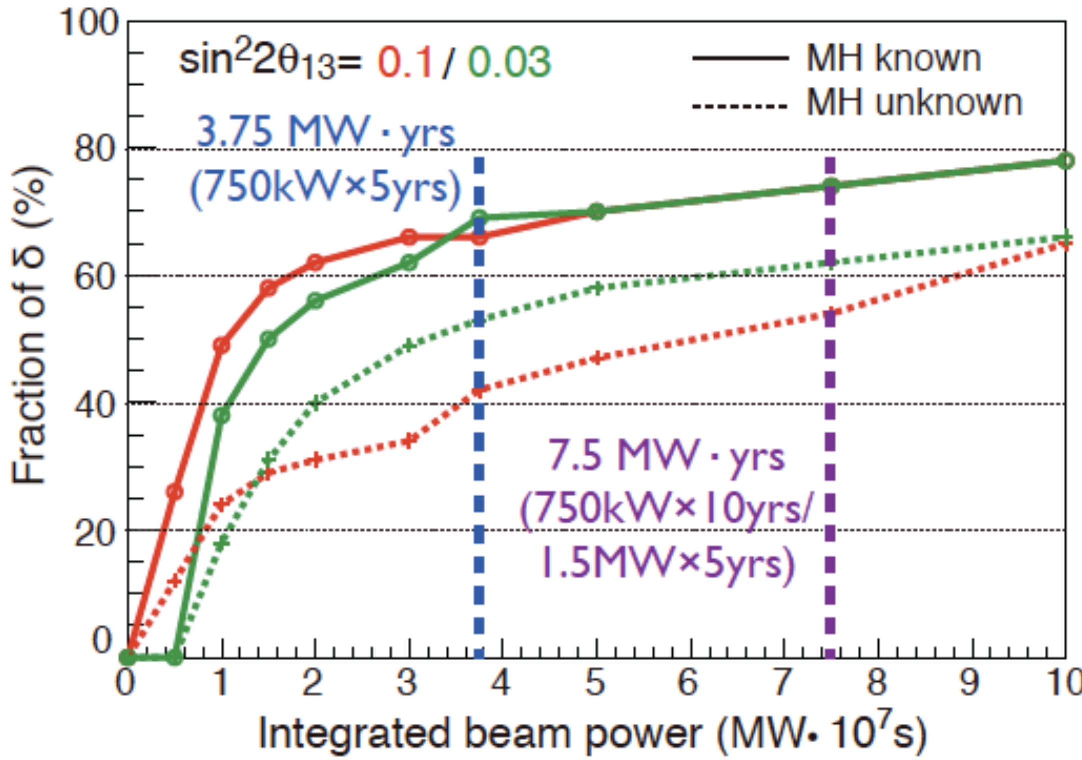
BUT

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\overline{\nu}_\mu \to \overline{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\overline{\nu}_\mu \to \overline{\nu}_e)} \propto \frac{1}{\sin\theta_{13}}$$

Signal statistics is maximum, but **asymmetry is minimum**

Fraction of δ (%) for CPV discovery

Fraction of δ in % for which expected CPV ($\sin\delta \neq 0$) significance is $>3\sigma$

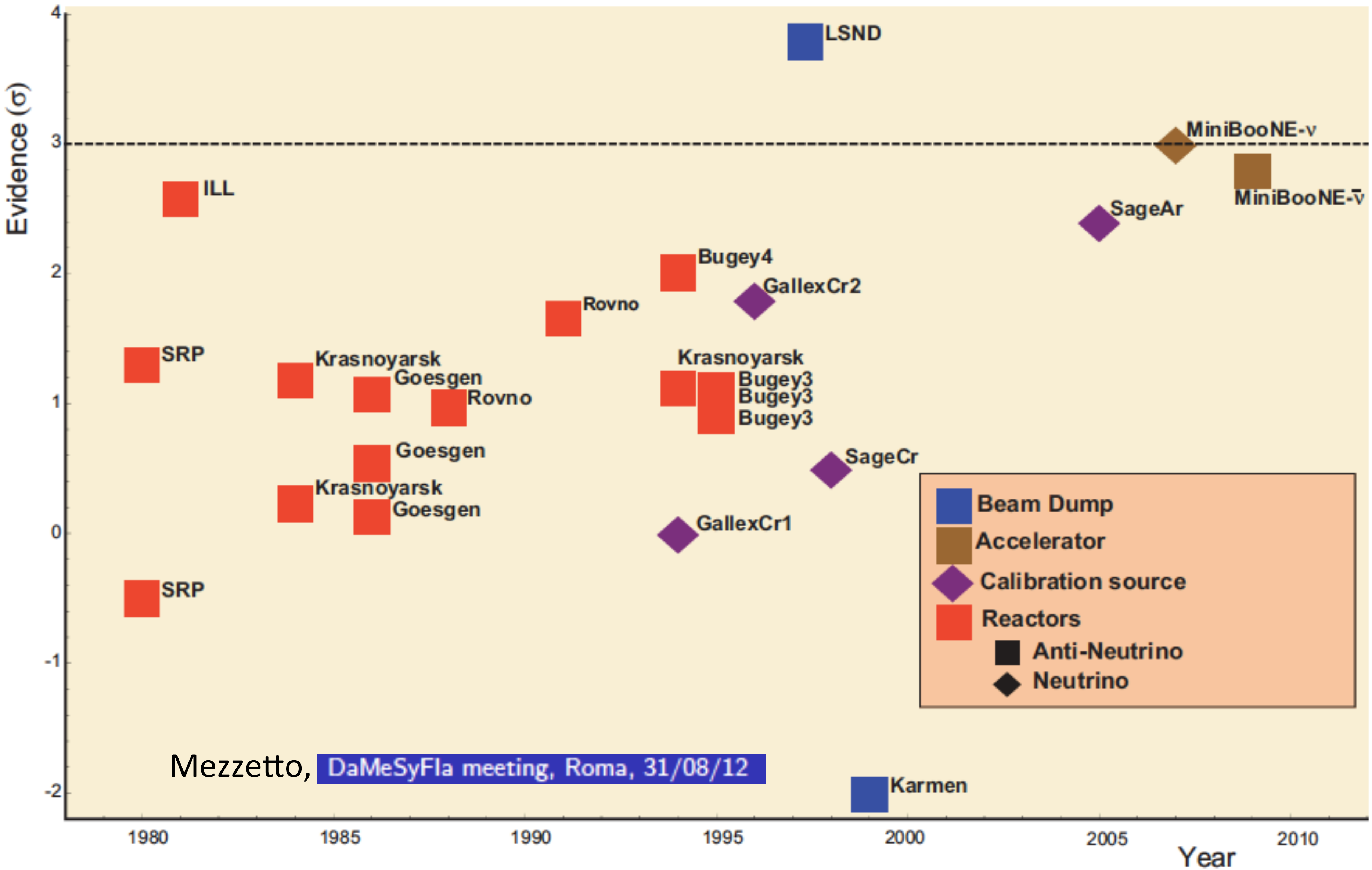


$\sin^2 2\theta_{13}=0.1$

(MW× yrs)	Mass hierarchy known	Mass hierarchy unknown
3.75	69%	42%
7.5	74%	54%

- Effect of unknown mass hierarchy is limited
  - Input from atm ν and other experiments also expected for MH

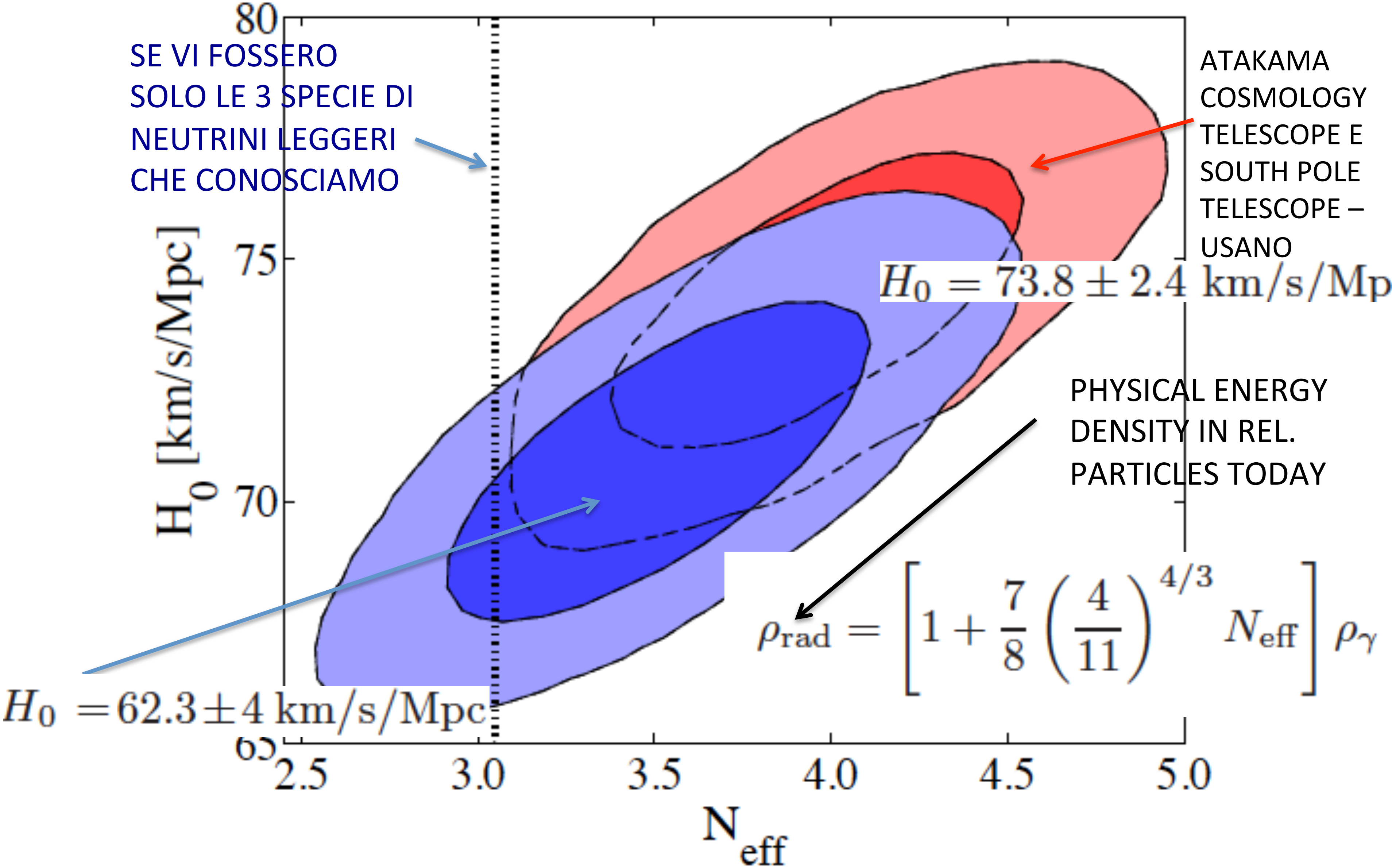
A long standing set of anomalies



Mezzetto, DaMeSyFla meeting, Roma, 31/08/12

INDICAZIONI DALLA COSMOLOGIA A FAVORE DI > 3 SPECIE DI NEUTRINI?

"DARK RADIATION"



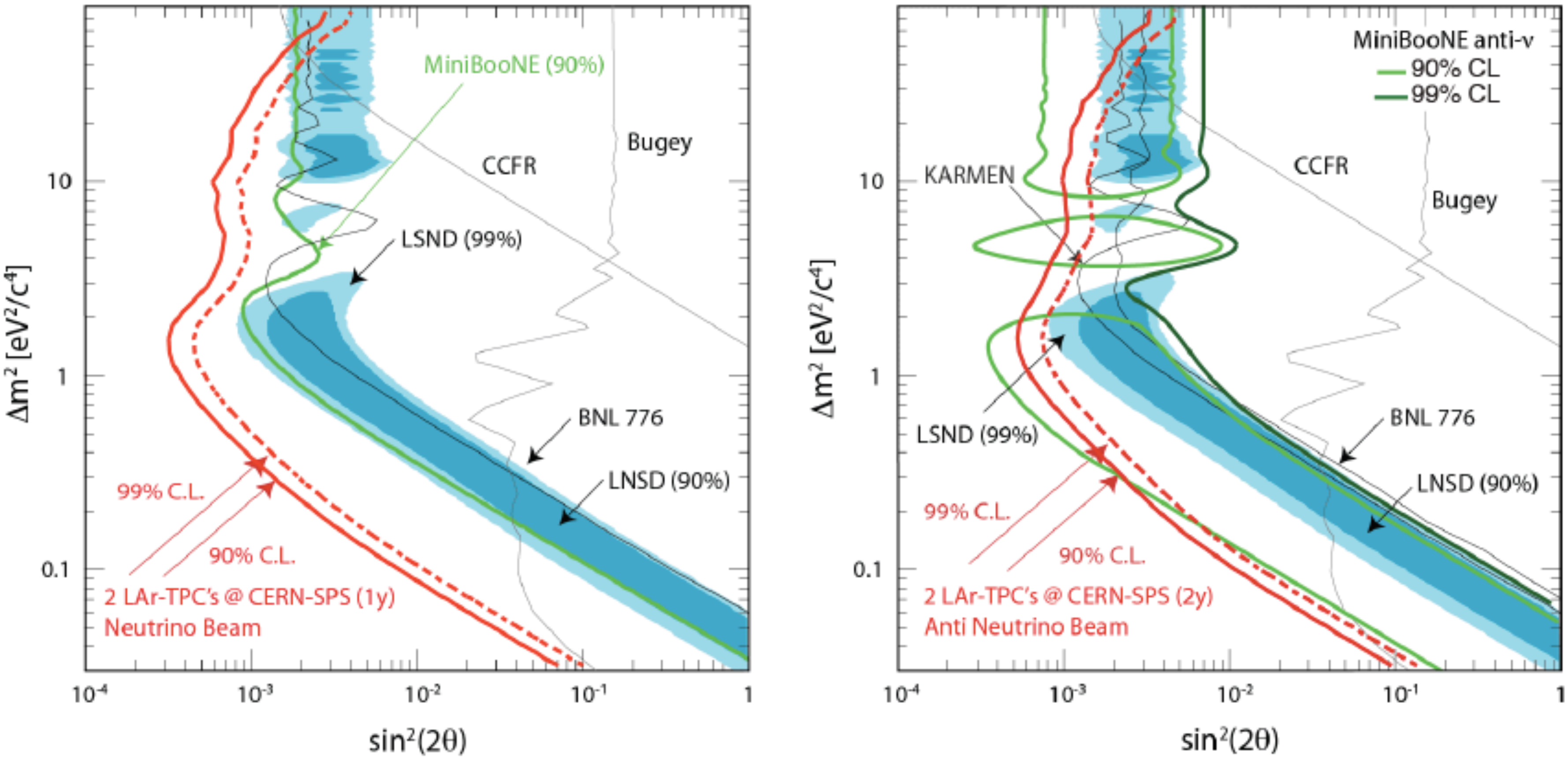
CALABRESE, ARCHIDIACONA, MELCHIORRI, RATRA 2012

Table III. A selection of recent constraints on N_{eff}, with 68% (95%) uncertainties. W-5 and W-7 stand for WMAP 5-year and 7-year data respectively, H_0 refers to the constraint $H_0 = 74.2 \pm 3.6$ km s^{-1} from [347], LRG the halo power spectrum determined from the luminous red galaxy sample of the SDSS data release 7 [348], while CMB denotes a combination of small-scale CMB experiments such as ACBAR, BICEP and QUaD.

From **STERILE NEUTRINOS WHITE PAPER**, arXiv: 1204.5479

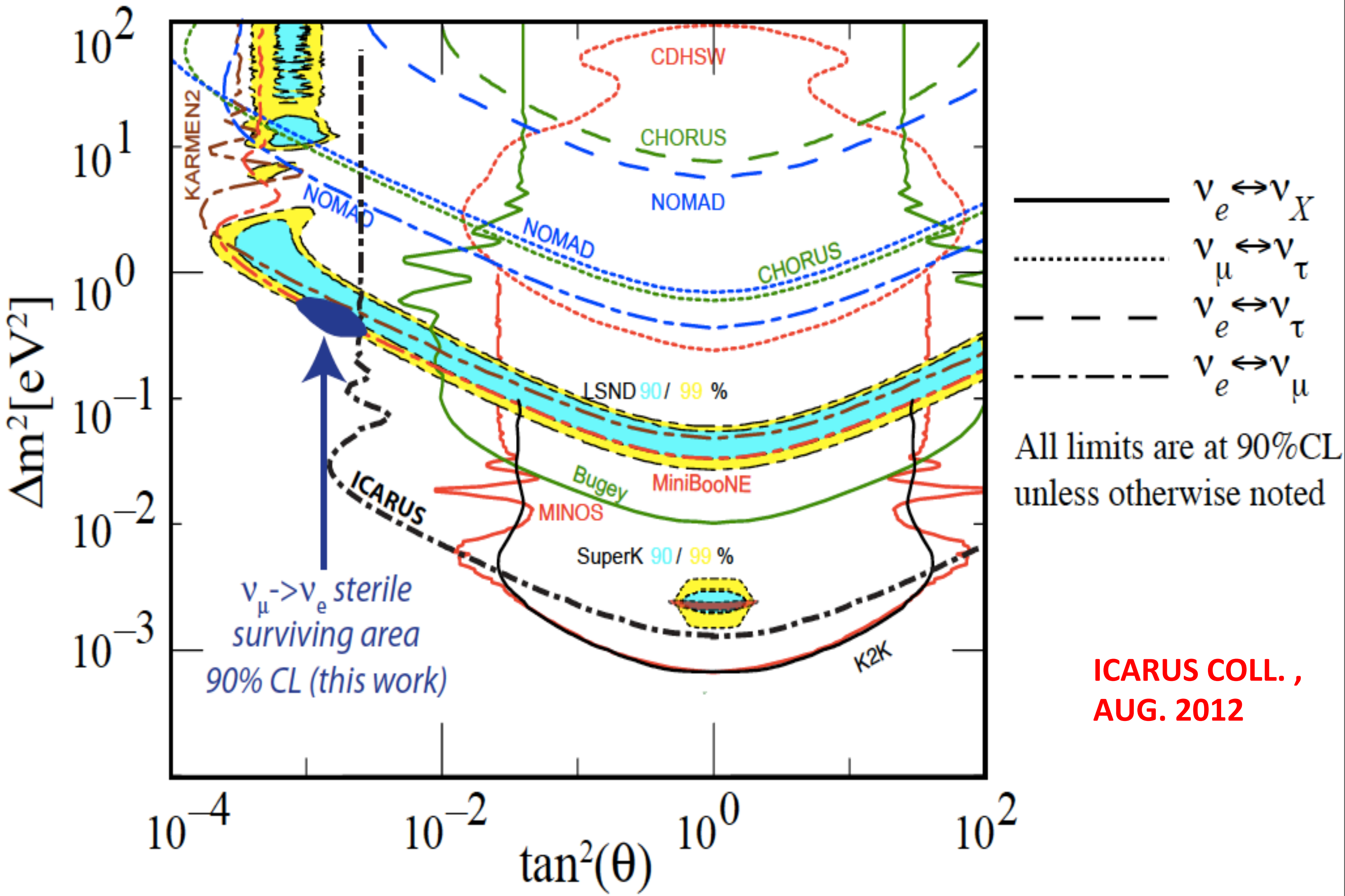
Model	Data	N_{eff}	Ref.
N_{eff}	W-5+BAO+SN+H_0	$4.13^{+0.87(+1.76)}_{-0.85(-1.63)}$	[346]
	W-5+LRG+H_0	$4.16^{+0.76(+1.60)}_{-0.77(-1.43)}$	[346]
	W-5+CMB+BAO+XLF+f_{gas}+H_0	$3.4^{+0.6}_{-0.5}$	[349]
	W-5+LRG+maxBCG+H_0	$3.77^{+0.67(+1.37)}_{-0.67(-1.24)}$	[346]
	W-7+BAO+H_0	$4.34^{+0.86}_{-0.88}$	[338]
	W-7+LRG+H_0	$4.25^{+0.76}_{-0.80}$	[338]
	W-7+ACT	5.3 ± 1.3	[343]
	W-7+ACT+BAO+H_0	4.56 ± 0.75	[343]
	W-7+SPT	3.85 ± 0.62	[344]
	W-7+SPT+BAO+H_0	3.85 ± 0.42	[344]
	W-7+ACT+SPT+LRG+H_0	$4.08^{(+0.71)}_{(-0.68)}$	[350]
	W-7+ACT+SPT+BAO+H_0	3.89 ± 0.41	[351]
$N_{eff}+f_\nu$	W-7+CMB+BAO+H_0	$4.47^{(+1.82)}_{(-1.74)}$	[352]
	W-7+CMB+LRG+H_0	$4.87^{(+1.86)}_{(-1.75)}$	[352]
$N_{eff}+\Omega_k$	W-7+BAO+H_0	4.61 ± 0.96	[351]
	W-7+ACT+SPT+BAO+H_0	4.03 ± 0.45	[352]
$N_{eff}+\Omega_k+f_\nu$	W-7+ACT+SPT+BAO+H_0	4.00 ± 0.43	[351]
$N_{eff}+f_\nu+w$	W-7+CMB+BAO+H_0	$3.68^{(+1.90)}_{(-1.84)}$	[352]
	W-7+CMB+LRG+H_0	$4.87^{(+2.02)}_{(-2.02)}$	[352]
$N_{eff}+\Omega_k+f_\nu+w$	W-7+CMB+BAO+SN+H_0	$4.2^{+1.10(+2.00)}_{-0.61(-1.14)}$	[353]
	W-7+CMB+LRG+SN+H_0	$4.3^{+1.40(+2.30)}_{-0.54(-1.09)}$	[353]

Comparing LSND sensitivities



Expected sensitivity for the proposed experiment: ν_μ beam (left) and anti-ν_μ (right) for 4.5 10^{19} pot (1 year) and 9.0 10^{19} pot (2 years) respectively. LSND allowed region is fully explored in both cases.

M. Mezzetto



$\Delta m^2 [eV^2]$
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^0
10^2
$\tan^2(\theta)$
CDHSW
CHORUS
NOMAD
KARMEN2
NOMAD
NOMAD
CHORUS
LSND 90 / 99 %
Bugey
MiniBooNE
MINOS
ICARUS
SuperK 90 / 99 %
K2K
$\nu_\mu \to \nu_e$ sterile surviving area 90% CL (this work)
$\nu_e \leftrightarrow \nu_X$
$\nu_\mu \leftrightarrow \nu_\tau$
$\nu_e \leftrightarrow \nu_\tau$
$\nu_e \leftrightarrow \nu_\mu$
All limits are at 90%CL unless otherwise noted
ICARUS COLL. ,
AUG. 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)

- 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

Bounds presented at ICHEP 2012

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

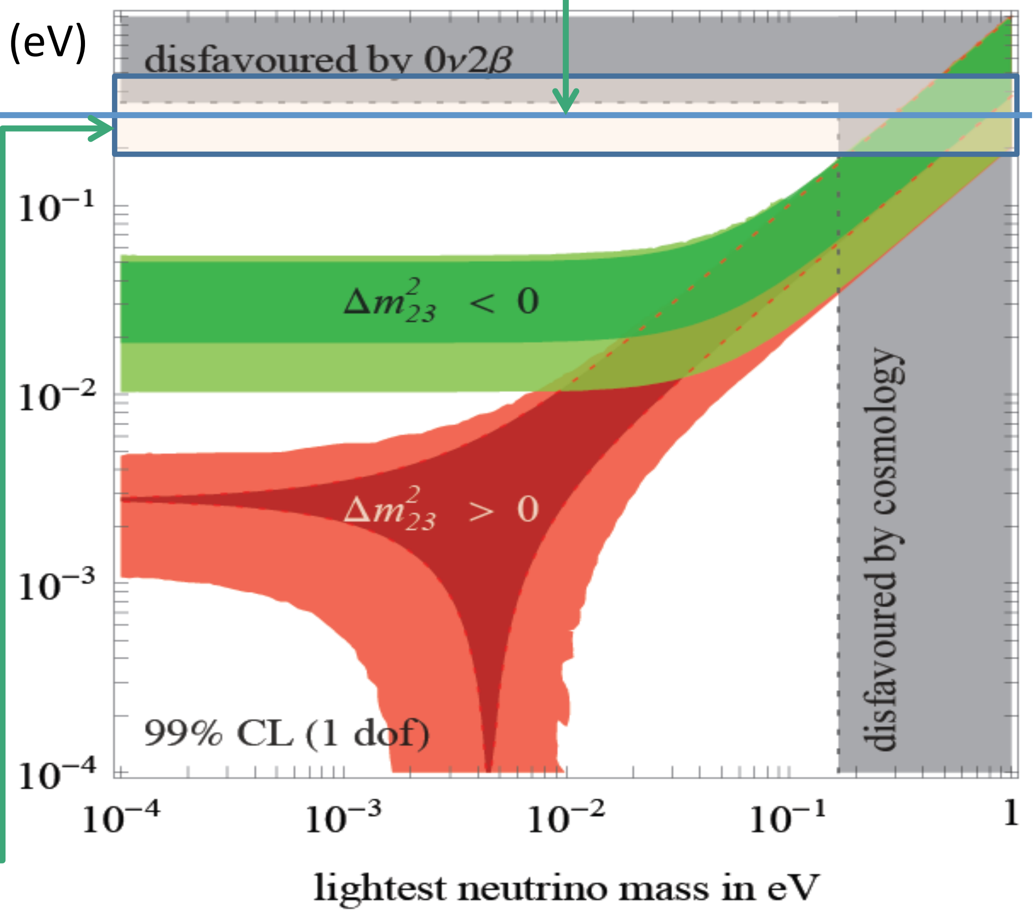
New searches, with different techniques, have similar sensitivities

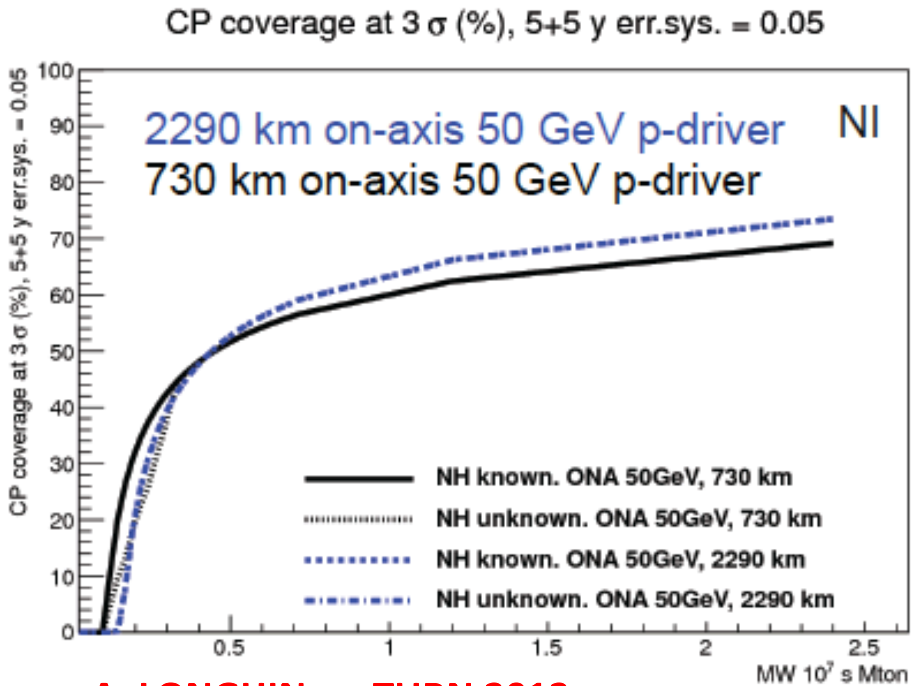
« Medium Generation »
- **CUORICINO** bolometers
- **NEMO3** Tracking+calorimeter

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

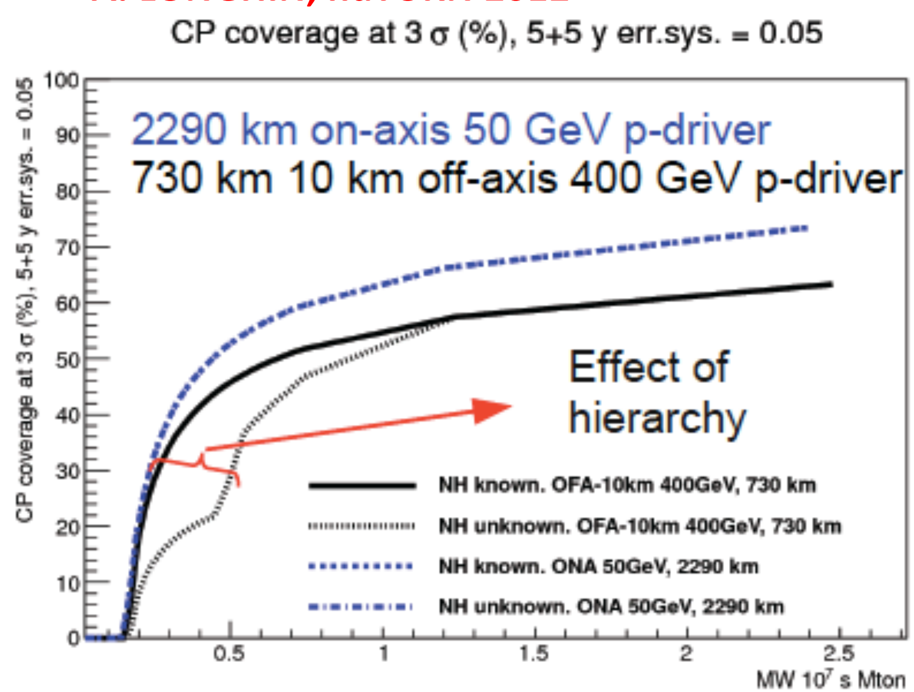
Similar sensitivity

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





A. LONGHIN, nuTURN 2012



LAGUNA-LBNO observatory at Pyhasalmi (-1400m.)

2x50 kton LAr + 50 kton LSc
879'000 m^3 excavation
Design to be finalized within LAGUNA-LBNO by ≈2014

- Nominal beam power scenarios (700kW).
- For $\sin^2 2\theta_{13}=0.1$, approximately (at 90%C.L.):
  - MH: 100% coverage at >5σ in a few years of running
  - CPV: ≈60% coverage and evidence for maximal CP (π/2, 3π/2) at 2.9σ in 10 years