LNGS beyond 2020, LNGS, April 28th, 2015

INFN:
Post-2020 glimpses

Antonio Masiero
INFN and Univ. of Padova

much depends on the next 5 years …

- **LHC14** (high energy: ATLAS, CMS; flavor: LHCb; quark-hadron phase transition: ALICE)
- **Flavor**: NA62; upgraded MEG, Mu-e; BELLEII; EDMs; g-2
- **DM** 1-ton exps. → $10^{-10} – 10^{-11}$ pb
- **Neutrinoless double β** → ν mass degenerate region; enter IH region
- **SBN** → sterile ν ?
- **Gravitational waves** → discovery
- **DE**: BOSS →DESI; DES → LSST
- **CMB**: final PLANCK; B-modes of the polariz.+ black-body spectrum : EU exps. QUBIC, LSPE, QIJOTE + many others on ground and balloons in US, Japan

if

- **Some signal** of physics beyond what the Standard Models of Fundamental Interactions and Cosmology predict → focus and converge on that "area" of New Physics

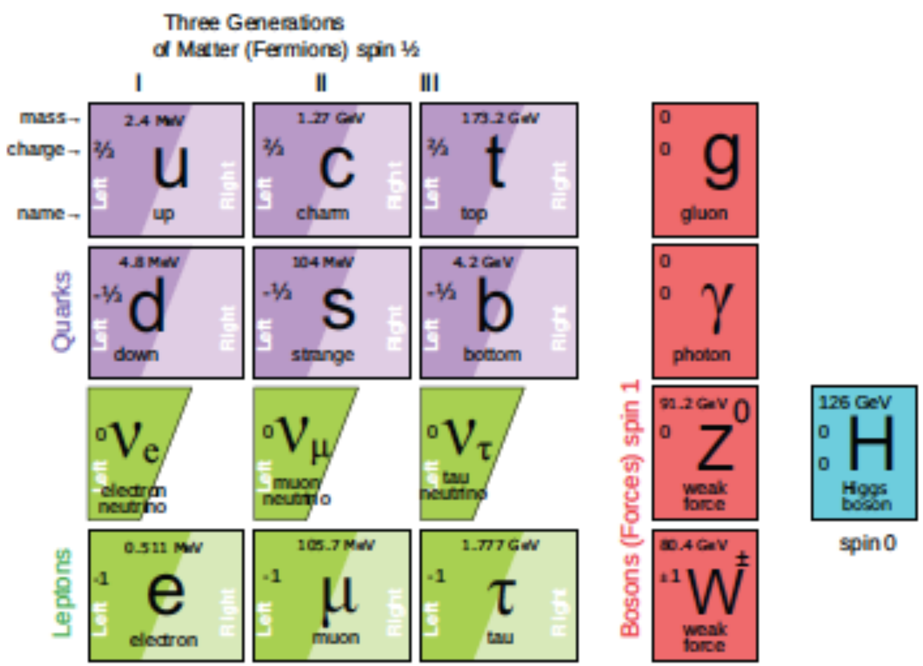
- **No signal** of BSM physics shows up whatsoever → i) go onand move the frontier of the existing exploration paths; ii) look for alternative, "non-ballistic" paths

- By the end of the 20th century … **we have a comprehensive, fundamental theory of all observed forces of nature which has been tested and might be valid from the Planck length scale [10^{-33} cm.] to the edge of the universe [10^{+28} cm.]**

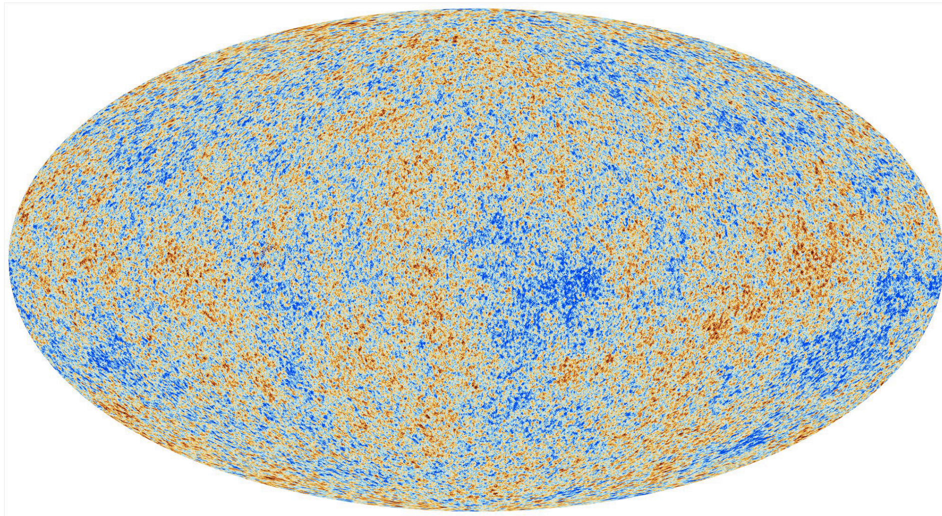
D. Gross 2007

2013: the thiumph of the **STANDARD**

- **PARTICLE STANDARD MODEL**



- **COSMOLOGY STANDARD MODEL**



ΛCDM + "SIMPLE" INFLATION

$\Omega_\Lambda = 0.686 \pm 0.020$

$\Omega_m = 0.314 \pm 0.020$

$\Omega_b h^2 = 0.02207 \pm 0.00033$

$h = 0.674 \pm 0.014$

WHY BSM

"**OBSERVATIONAL**" **REASONS**:

- **Dark Matter**
- **Neutrino Masses**
- **Cosmic Matter-Antimatter Asymmetry** (twofold problem: disappearance of primordial antimatter and extreme reduction of the number of baryons w.r.t the number of photons – initially ~ equal, today $n_{baryons}/n_{photons} \sim 10^{-9}$
- **Primordial Inflation**
- **Dark Energy**

WHY BSM

Theoretical reasons (of dissatisfaction towards the SM as a "final" theory rather than actual problems for the SM)

- Lack of the theory of **Flavor** (why three fermion families, why hierarchical mass spectrum, why mixing angles so different)
- **CPV in strong interactions**, i.e. the θ-problem
- **Unification** of the fundamental interactions (running the SM gauge couplings → clear trend for unificationof the interactions, but "pure SM" fails
- **Gauge hierarchy** – twofold puzzle: why M_{GUT} or M_{planck} >>> M_W; stabilization of the higgs mass at M_W at any order in perturbation theory *

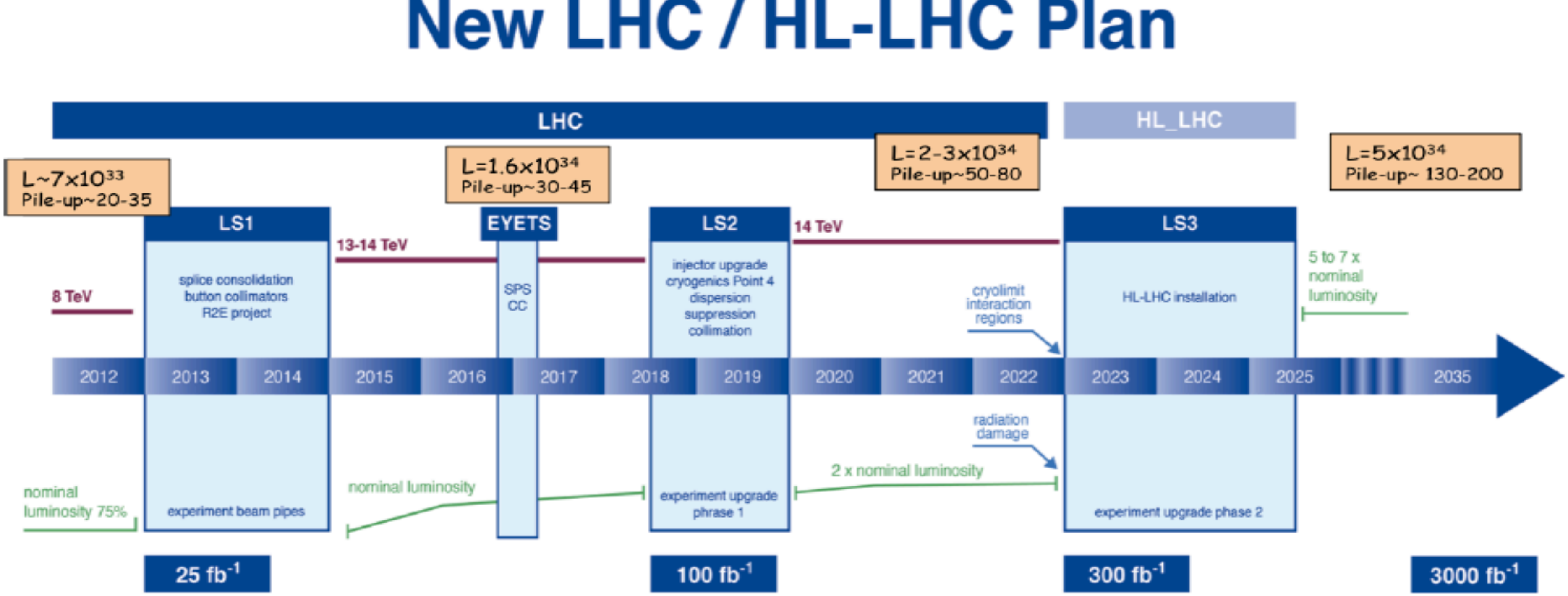
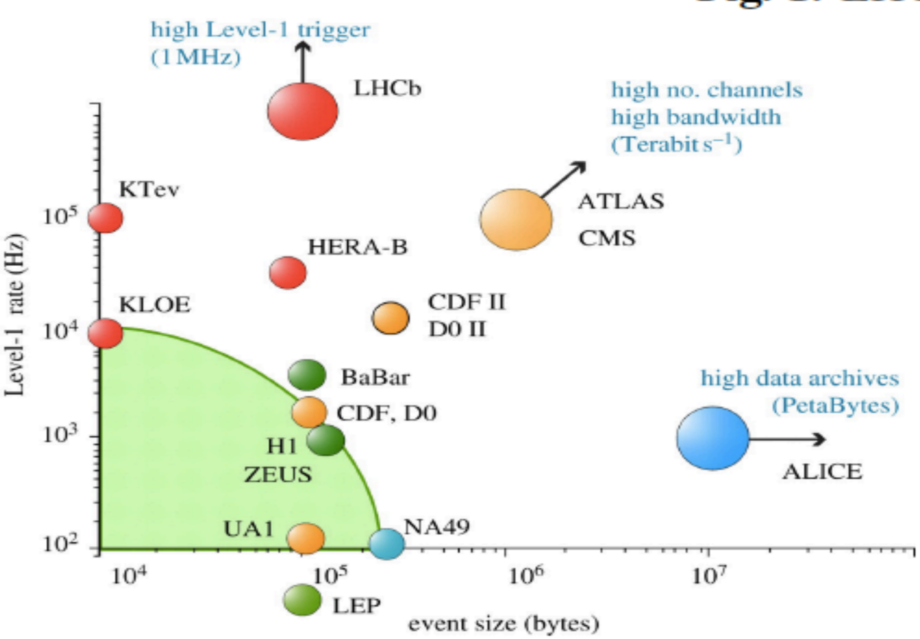


Fig. 1: LHC evolution plan



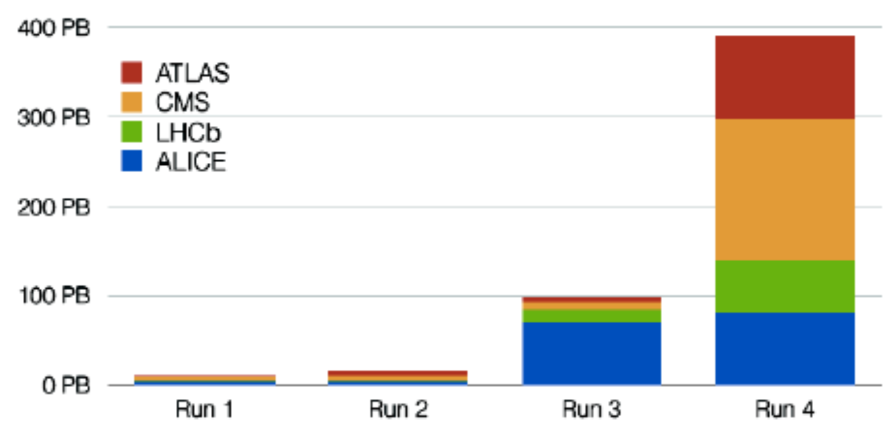
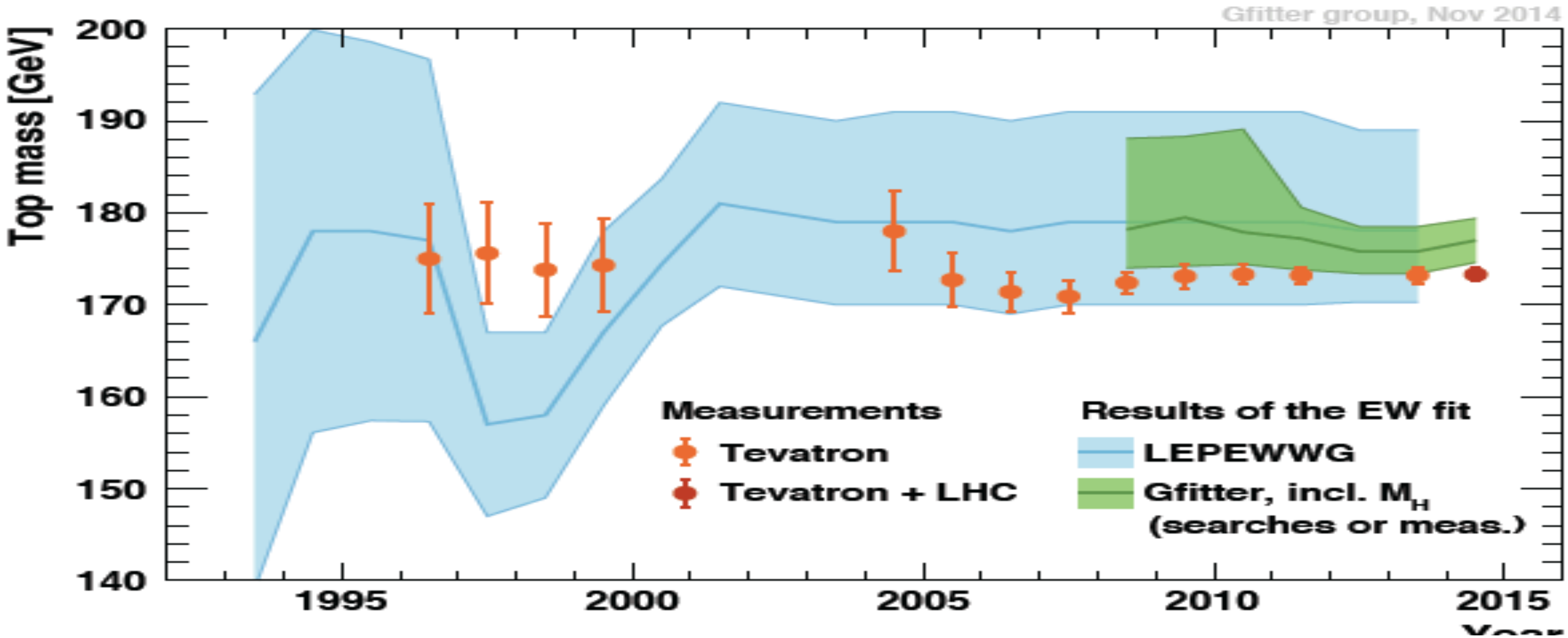
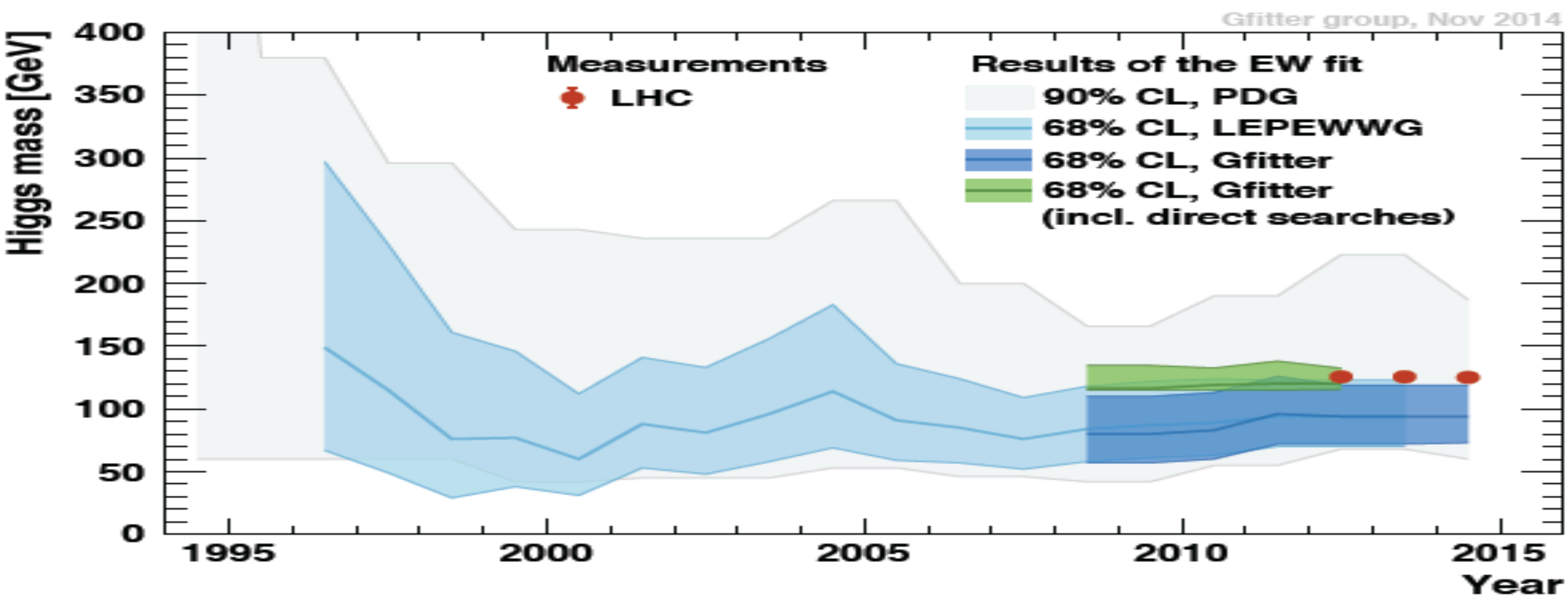


Fig. 5: Estimate of the disk space needed by the LHC experiments.


Gfitter group, Nov 2014
Top mass [GeV]
200
190
180
170
160
150
140
1995
2000
2005
2010
2015
Measurements
Tevatron
Tevatron + LHC
Results of the EW fit
LEPEWWG
Gfitter, incl. M_H
(searches or meas.)


Gfitter group, Nov 2014
Higgs mass [GeV]
400
350
300
250
200
150
100
50
0
1995
2000
2005
2010
2015
Year
Measurements
LHC
Results of the EW fit
90% CL, PDG
68% CL, LEPEWWG
68% CL, Gfitter
68% CL, Gfitter
(incl. direct searches)

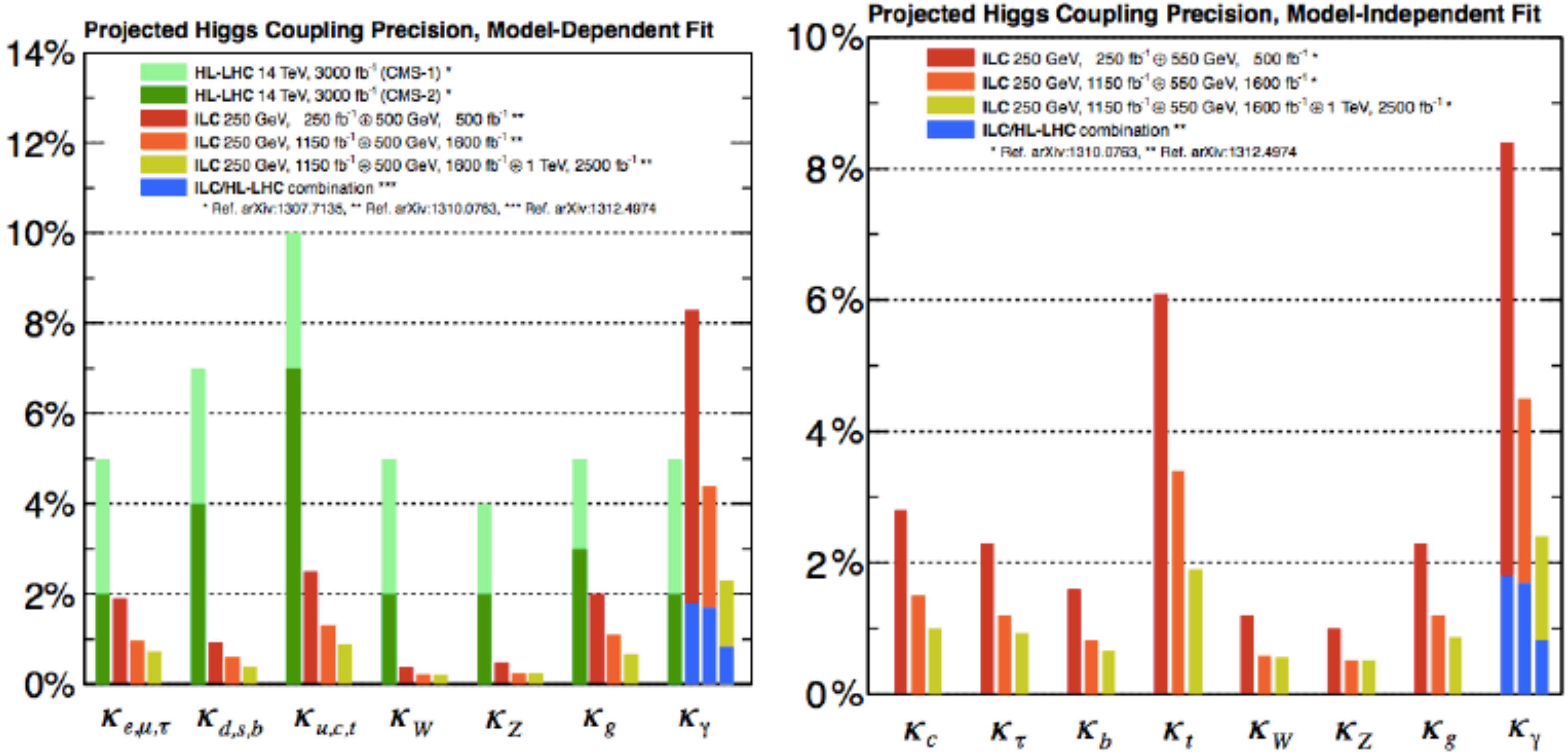
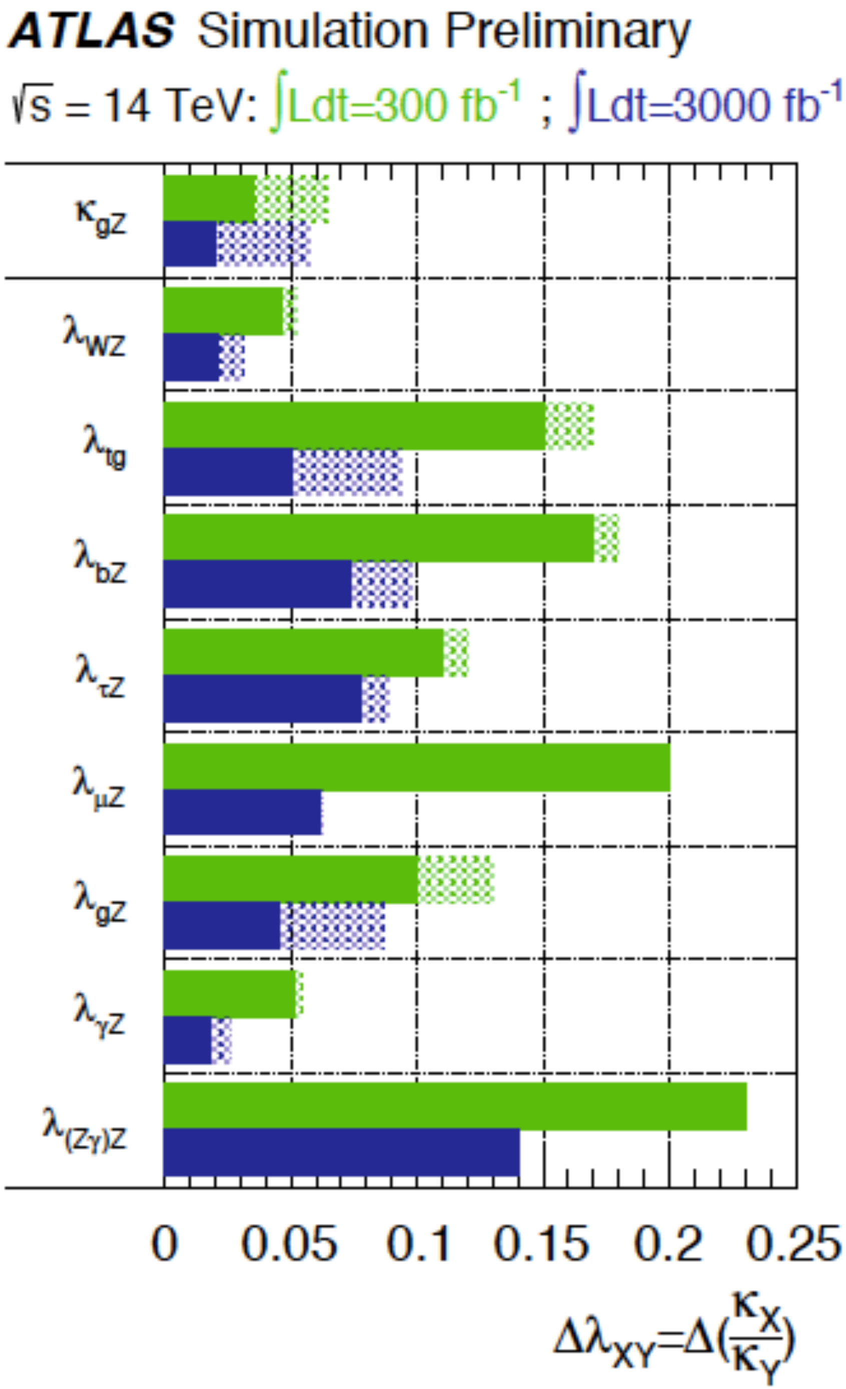
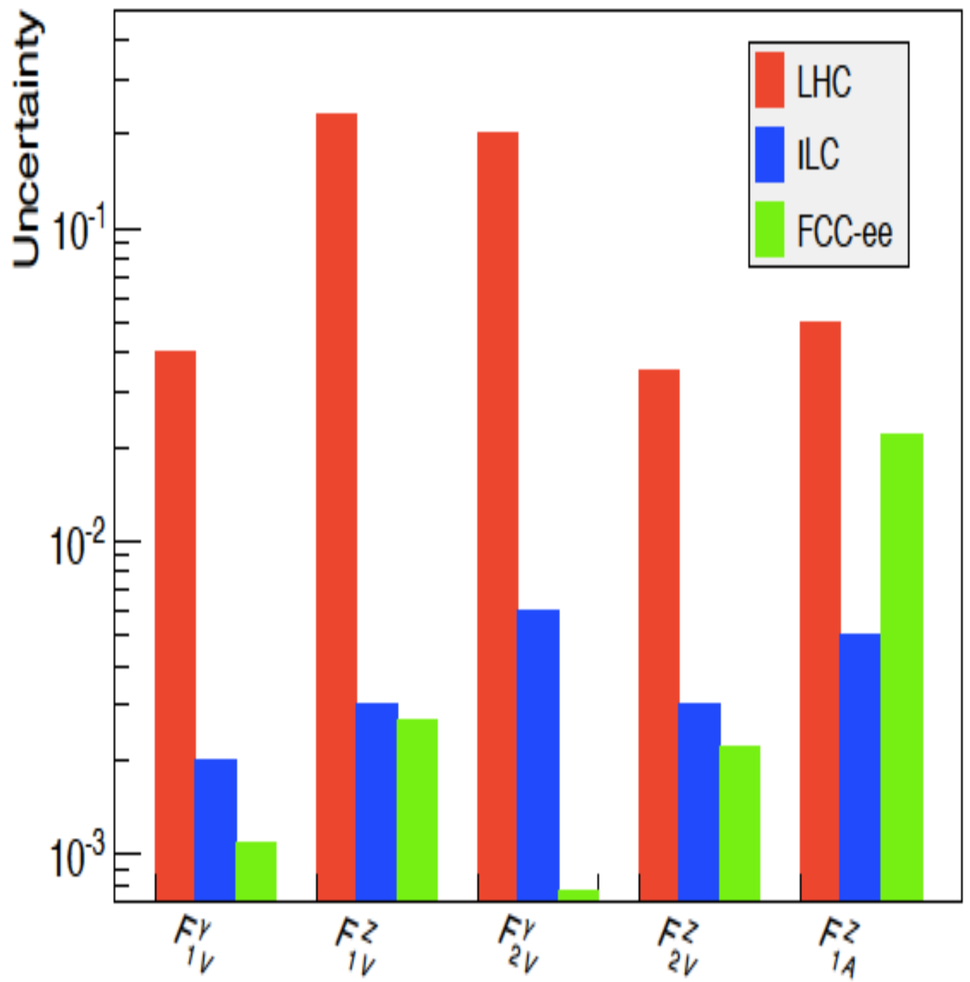
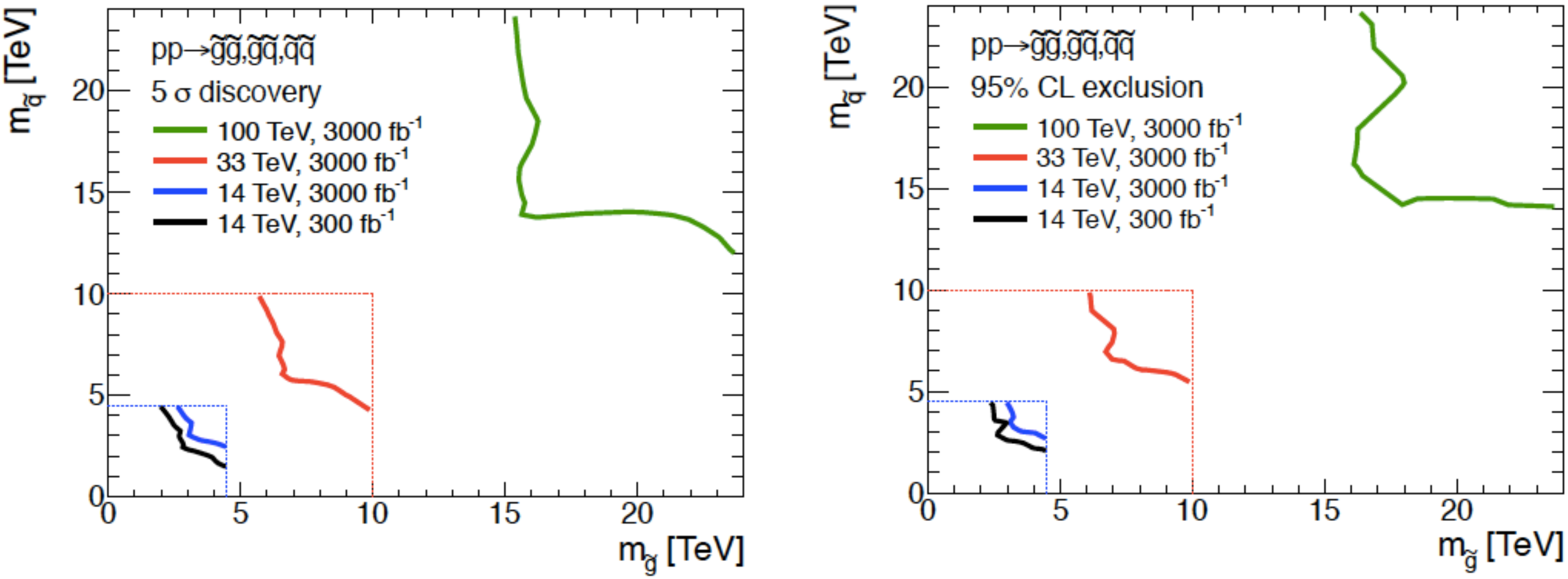


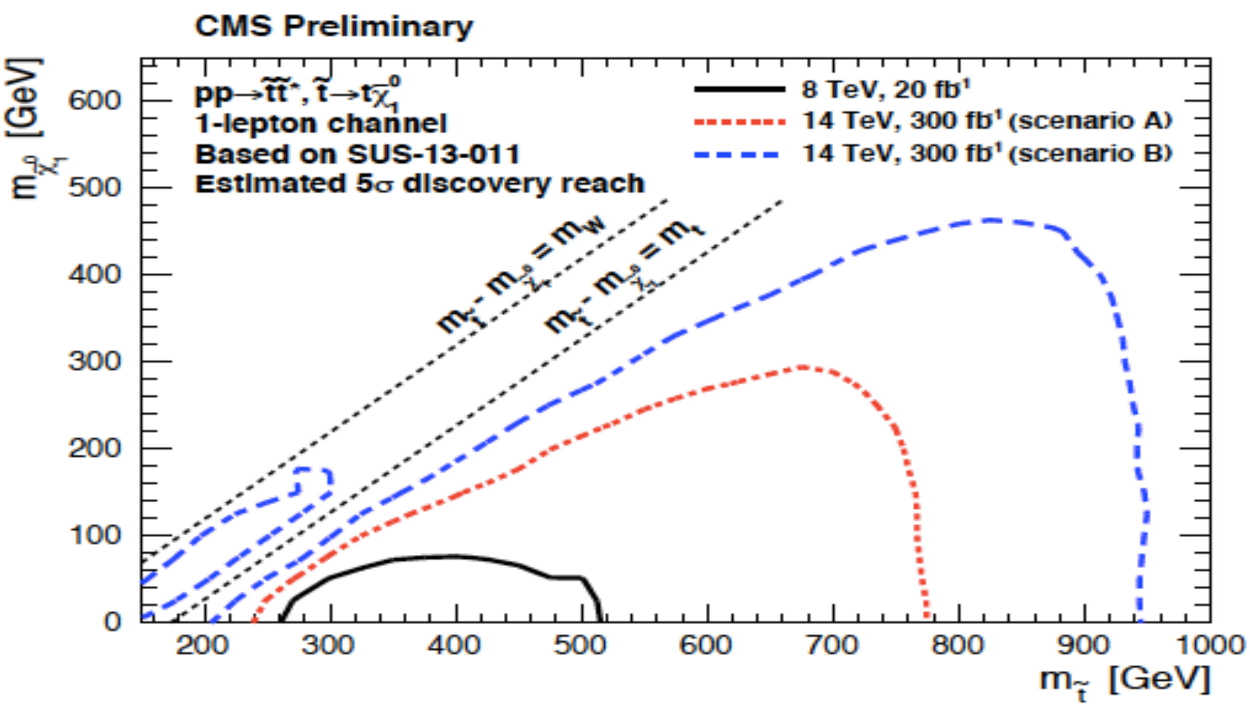
Fig. 11: *Model-Dependent (left) and Model-Independent (right) projected precision on Higgs-boson coupling scaling factors. Here* $\kappa_i \equiv g_{hii}/g_{hii}^{(SM)}$*. Green bands refer to HL-LHC projections; blue bands refer to combinations of ILC and HL-LHC outputs.*



Statistical precisions on vector and axial form factors at LHC with 300 fb^{-1}, at ILC500 with 500 fb^{-1}, at FCC-ee with 2.4 ab^{-1}




pp→g̃g̃,g̃q̃,q̃q̃
5 σ discovery
100 TeV, 3000 fb-1
33 TeV, 3000 fb-1
14 TeV, 3000 fb-1
14 TeV, 300 fb-1
m_q̃ [TeV]
m_g̃ [TeV]
pp→g̃g̃,g̃q̃,q̃q̃
95% CL exclusion
100 TeV, 3000 fb-1
33 TeV, 3000 fb-1
14 TeV, 3000 fb-1
14 TeV, 300 fb-1
m_q̃ [TeV]
m_g̃ [TeV]


CMS Preliminary
pp→t̃t̃*, t̃→tχ̃⁰₁
1-lepton channel
Based on SUS-13-011
Estimated 5σ discovery reach
8 TeV, 20 fb-1
14 TeV, 300 fb-1 (scenario A)
14 TeV, 300 fb-1 (scenario B)
m_t̃ - m_χ̃⁰₁ = m_W
m_t̃ - m_χ̃⁰₁ = m_t
m_χ̃⁰₁ [GeV]
m_t̃ [GeV]

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"**

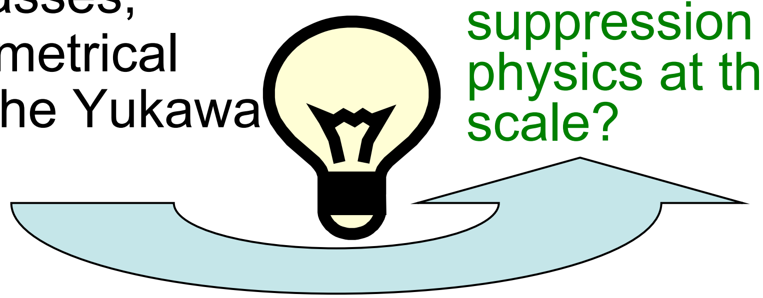
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

FCNC

Flavour changing neutral current (FCNC) processes are suppressed.

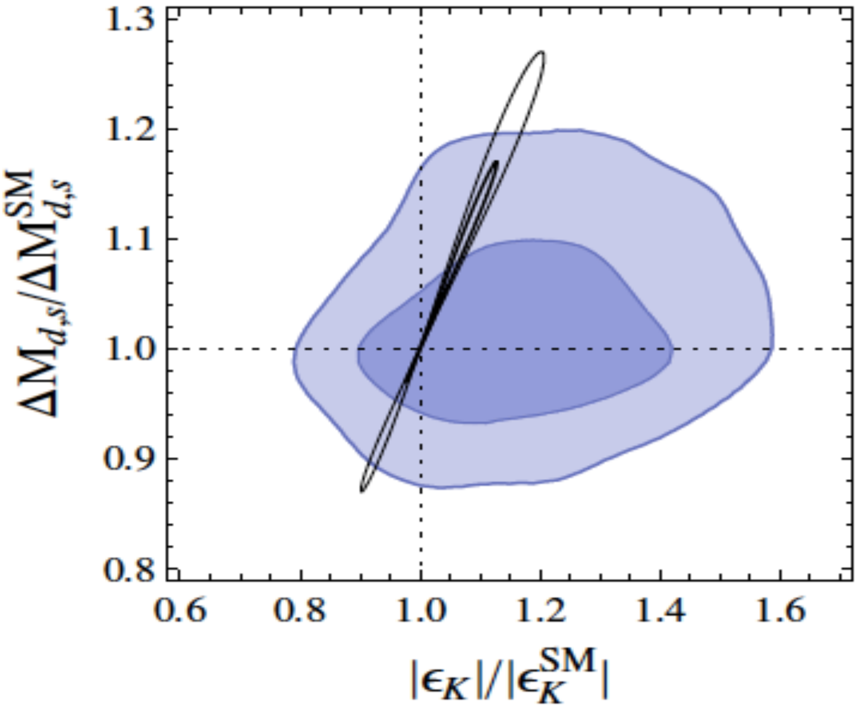
In the SM two nice mechanisms are at work: the **GIM mechanism** and the structure of the **CKM mixing matrix.**

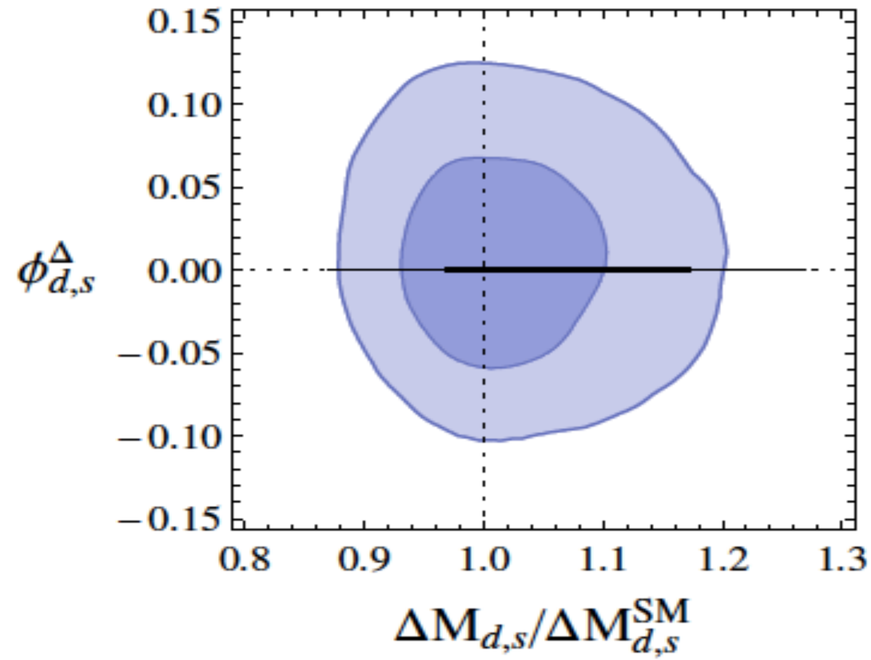
How to cope with such delicate suppression if the there is new physics at the electroweak scale?



IF SOME SYMMETRY – OR "DYNAMICAL" RATIONALE EXISTS FOR THE FLAVOR PUZZLE → POSSIBILITY OF VERY SELECTIVE PLACES WHERE DEVIATIONS FROM THE CKM PARADIGM APPEAR

EX.with U(3) or SU(2)^3 flavor symmetries **Barbieri et al**





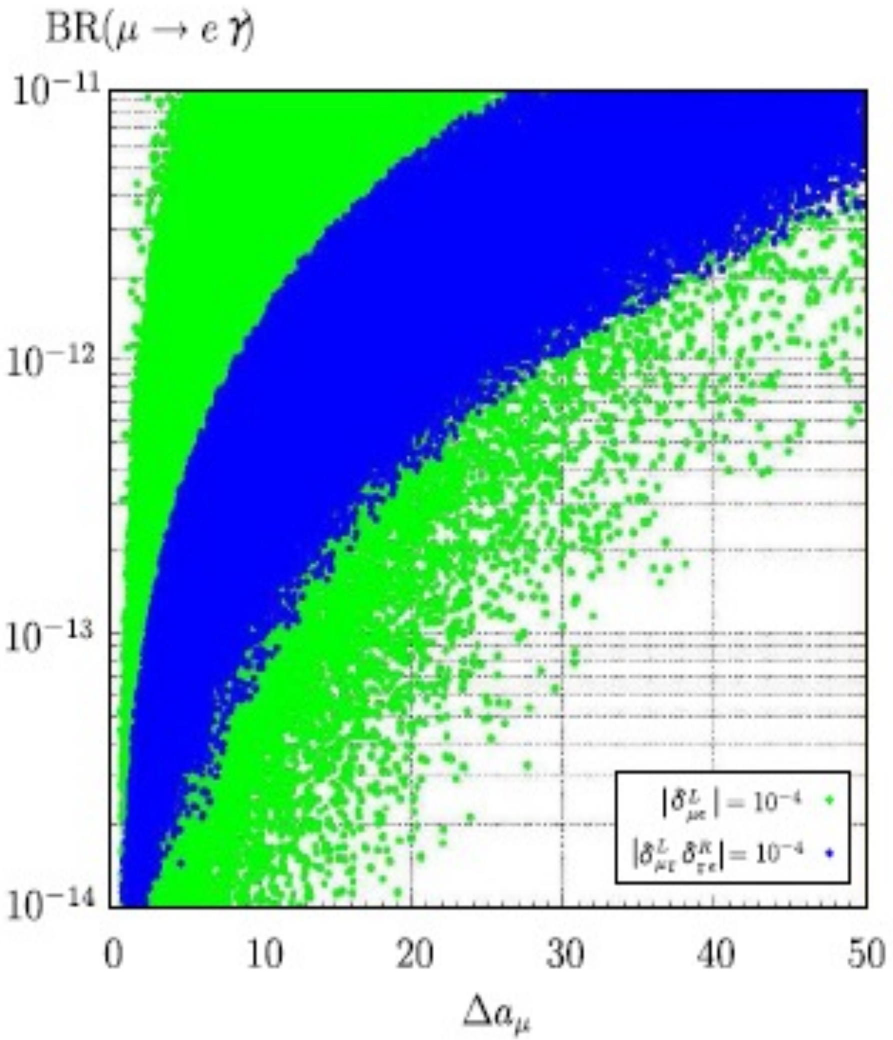
Theoretical-experimental CHALLENGE: can we reach the 1% accuracy in the determination of the CKM unitarity triangle? → the "extreme flavor" path: a dream? Punzi et al

Hadronic Parameter	2002 [1115]	2013 [1116]
$f_+^{K\pi}(0)$	-	0.4%
B_K	17%	1.3%
f_{B_s}	13%	2%
f_{B_s}/f_B	6%	1.7%
B_{B_s}	9%	7%
B_{B_s}/B_B	3%	10%
$F_{D^*}(1)$	3%	2%
$B \to \pi$	20%	10%

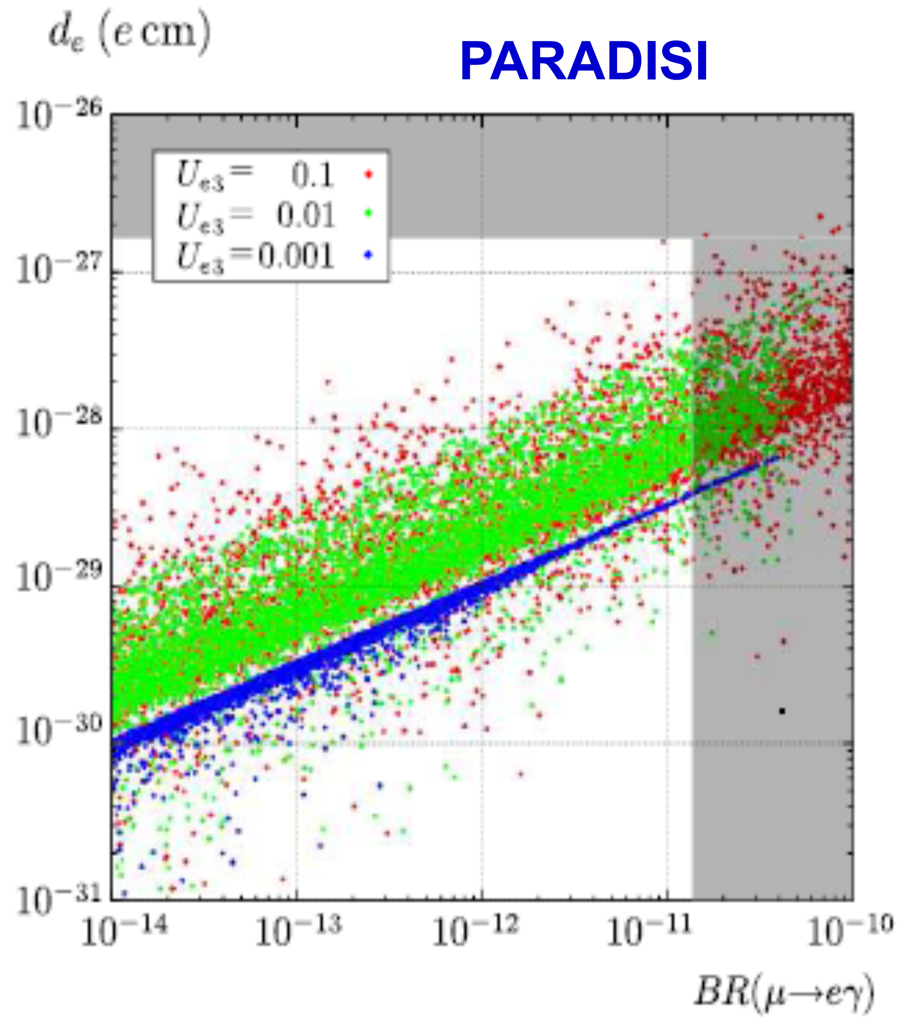
C. Tarantino et al

Hadronic Parameter	What Next Era (2025)
$f_+^{K\pi}(0)$	0.1%
B_K	$0.1-0.5\%$
f_{B_s}	0.5%
f_{B_s}/f_B	0.5%
B_{B_s}	$0.5-1\%$
B_{B_s}/B_B	$0.5-1\%$
$F_{D^*}(1)$	0.5%
$B \to \pi$	$\geq 1\%$

LFV, g – 2, EDM: a promising correlation in SUSY SEESAW



PARADISI



A) Multimessenger astronomy, B) neutrino properties, C) dark side of the Universe and CMB

- A) **Photon**, **cosmic ray**, **neutrino** , **gravitational** astronomies (some in their maturity, some in their youth, some just baby or even still to be born
- B) **neutrino mass** and its relation to the global symmetry of the SM, **Lepton number** (Dirac vs. Majorana natur of the neutrinos); measuring the full neutrino mass parameters (neutrino mass hierarchy, CP violation)
- C) **Dark Matter**; **Dark Energy** and **their role in the evolution of the Universe** (primordial inflation, elw. Ph ase transition, quark-hadron phase transition, nucleosynthesis, matter-antimatter cosmic asymmetry)

MAGNIFICENT NINE

What the combined BICEP2 +PLANCK analysis is telling us

- Only upper limit on r → **no hint for the presence of a large energy scale (related to primordial inflation)**
- Most **inflationary scalar potentials** still allowed
- Strong constraints on the **number of neutrino-like particles** present at the photon decoupling and on the **sum of the neutrino masses**

Info from Planck: Neutrino # and mass

$$\Sigma m_{\nu} < 0.23 \text{ eV (95\% CL)}$$

$$N_{eff} = 3.15 \pm 0.23$$

Planck + Lyman alpha

$$\Sigma m_{\nu} < 0.14 \text{ eV (C.L)}$$

Prospects for PLANCK + EUCLID

$$\Delta m_{\nu} \sim 0.03 \text{ eV} \ \& \ \Delta N_{\nu} \sim 0.08$$

Going beyond the SM:
the NEUTRINO MASS

A. GIULIANI, SAC APPEC 2013

Cosmology, **single** and **double β decay** measure different combinations of the neutrino mass eigenvalues, constraining the **neutrino mass scale**

In a standard three active neutrino scenario:

$$\Sigma \equiv \sum_{i=1}^{3} M_i$$

cosmology
simple sum
pure kinematical effect

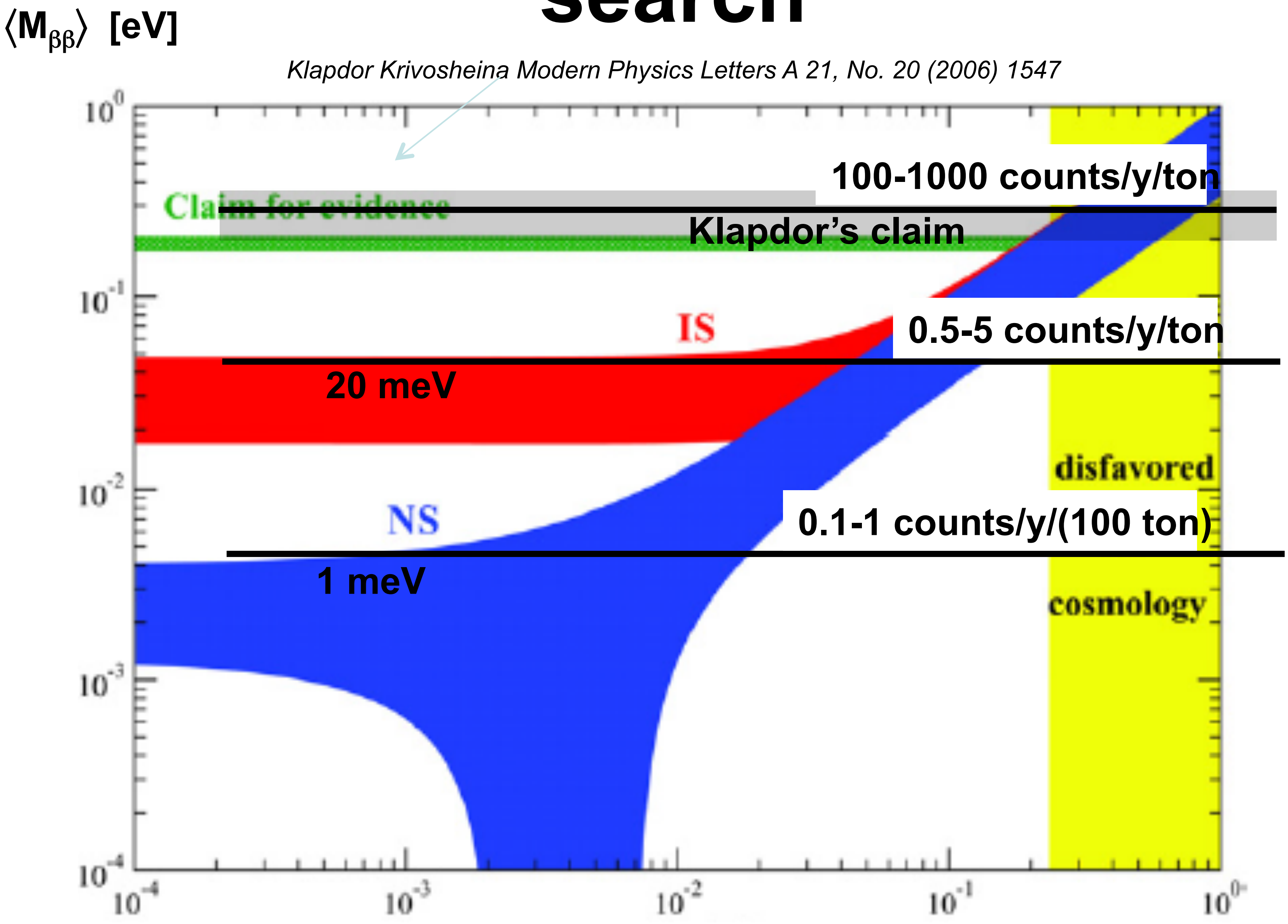
$$\langle M_\beta \rangle \equiv \left(\sum_{i=1}^{3} M_i^2 \, |U_{ei}|^2 \right)^{1/2}$$

β decay
incoherent sum
real neutrino

$$\langle M_{\beta\beta} \rangle \equiv \left| \sum_{i=1}^{3} M_i \, |U_{ei}|^2 e^{i\alpha_i} \right|$$

double β decay
coherent sum
virtual neutrino
Majorana phases

Three challenges for 0ν-DBD search



CONNECTION DM – ELW. SCALE

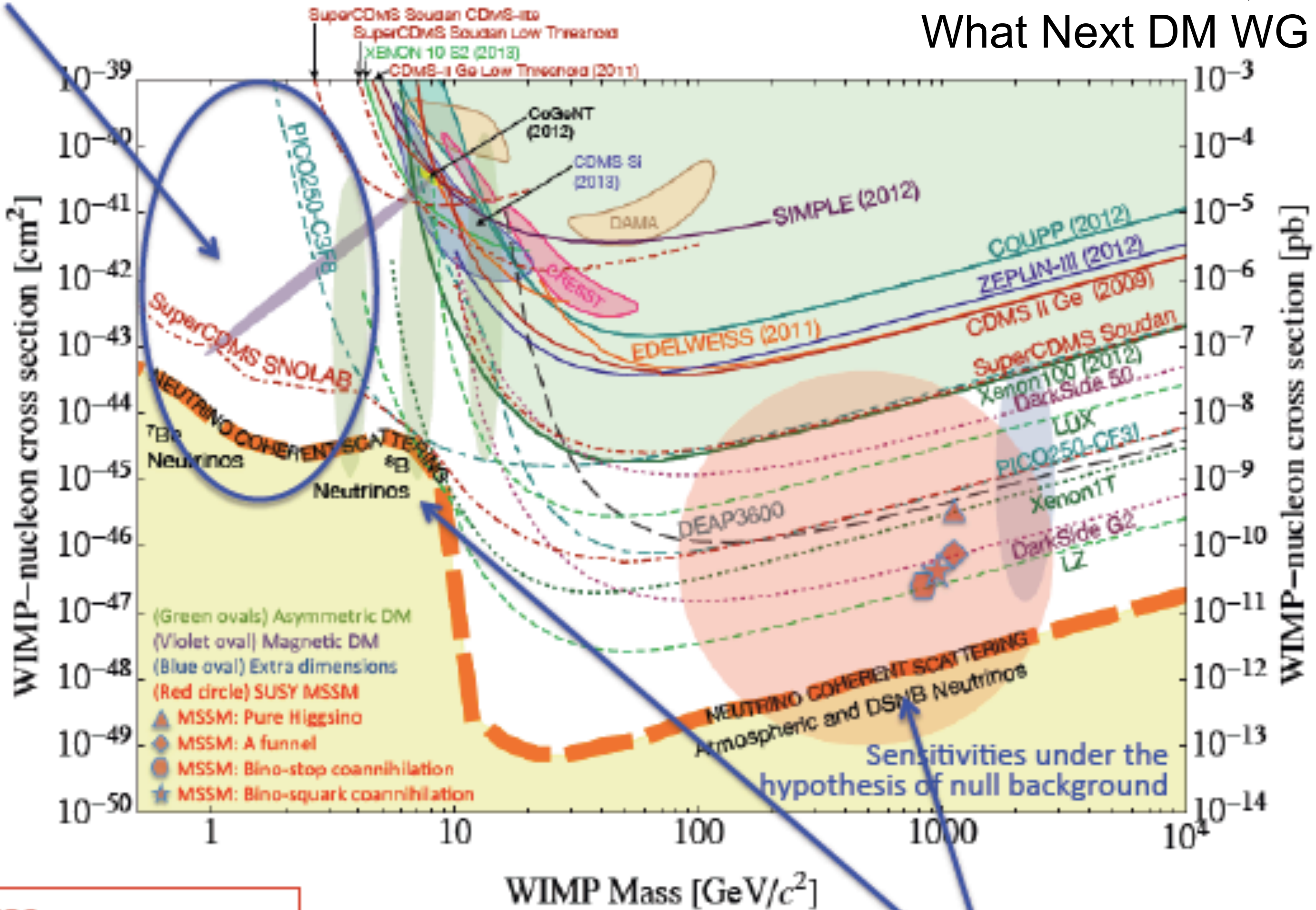
THE WIMP MIRACLE :STABLE ELW. SCALE WIMPs

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

Direct detection

Light WIMPs window

N. FORNENGO,
What Next DM WG 2015

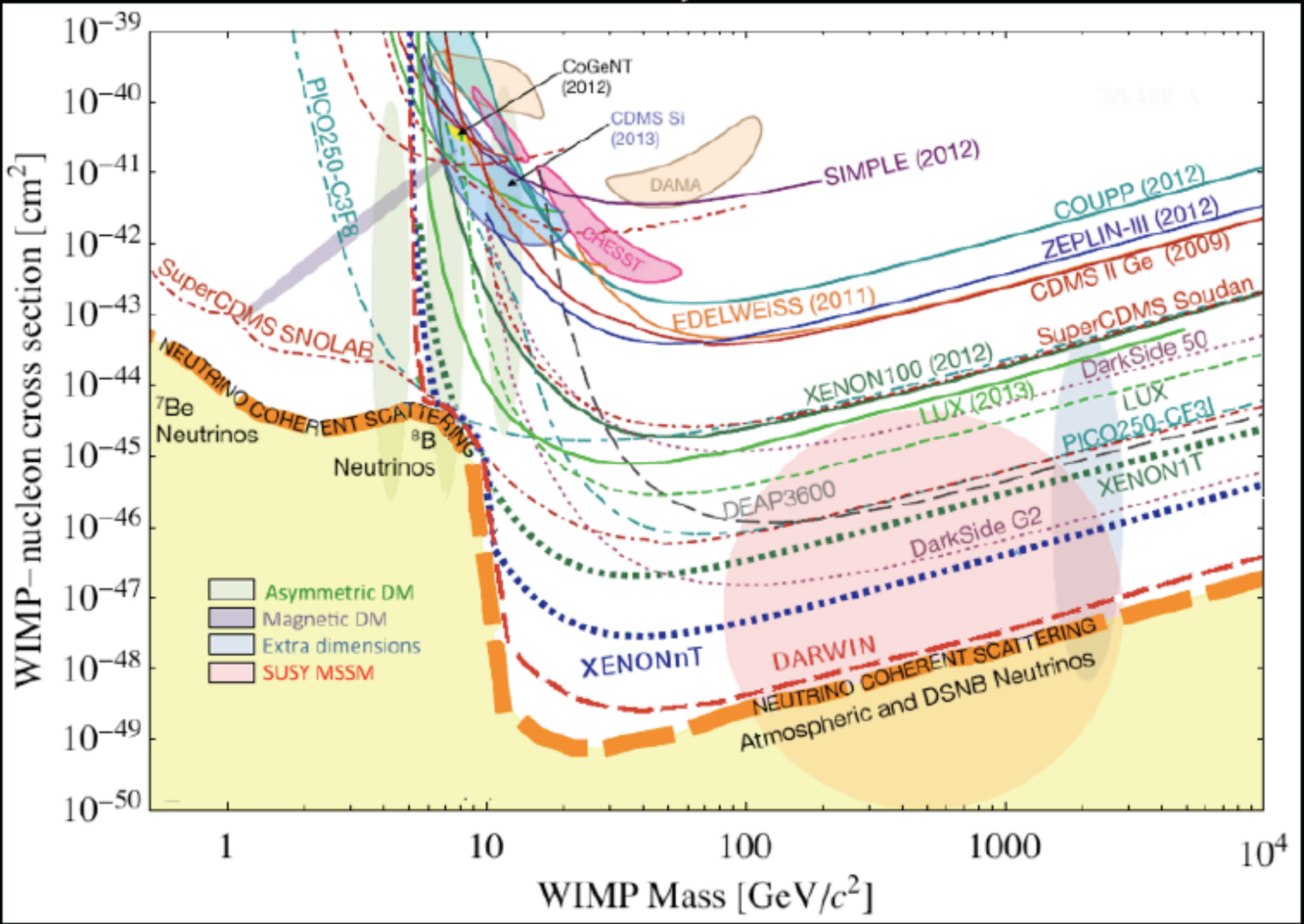


Signatures
- Annual modulation
- Diurnal modulation
- Directionality

Full set of effective operators (15)

"Neutrino floor"

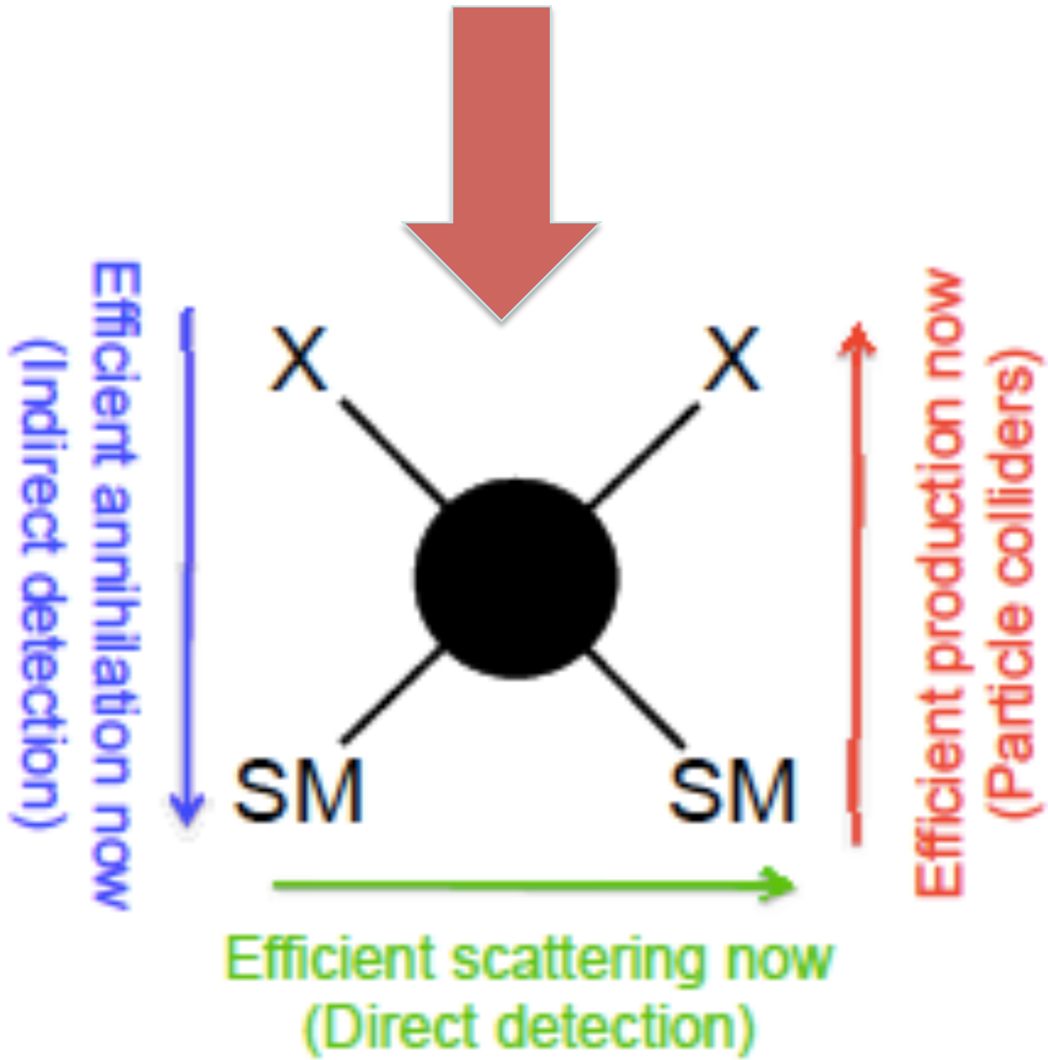
1) Science Goals: Dark Matter Projected Sensitivities



What if 2+ of these experiments observe strong candidate dark matter signals?

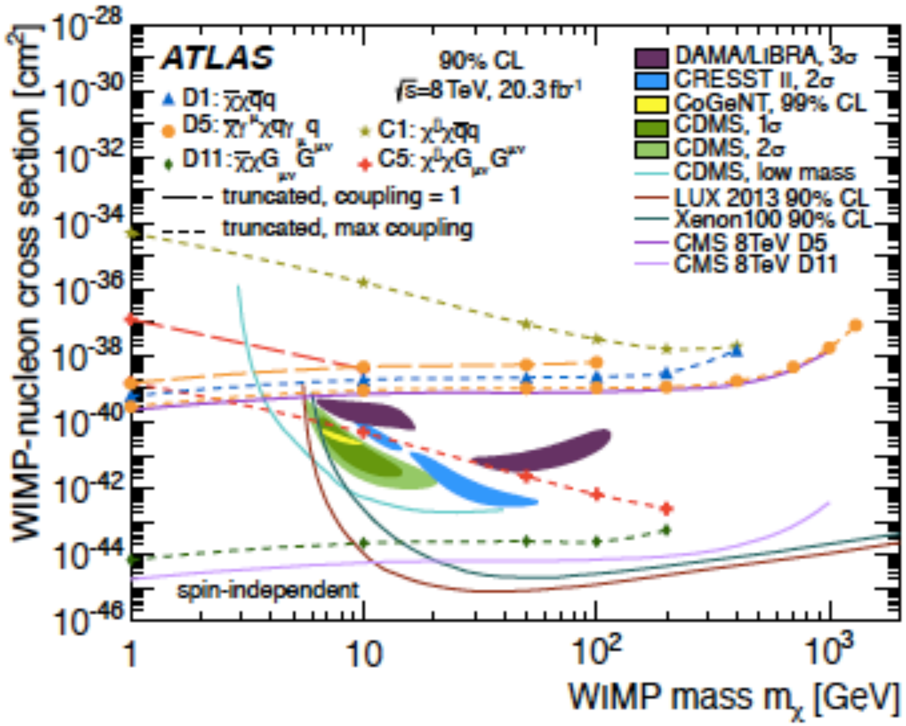
Build a directional detector to establish astrophysical origin.

DM COMPLEMENTARITY: efficient annihilation in the early Universe implies today

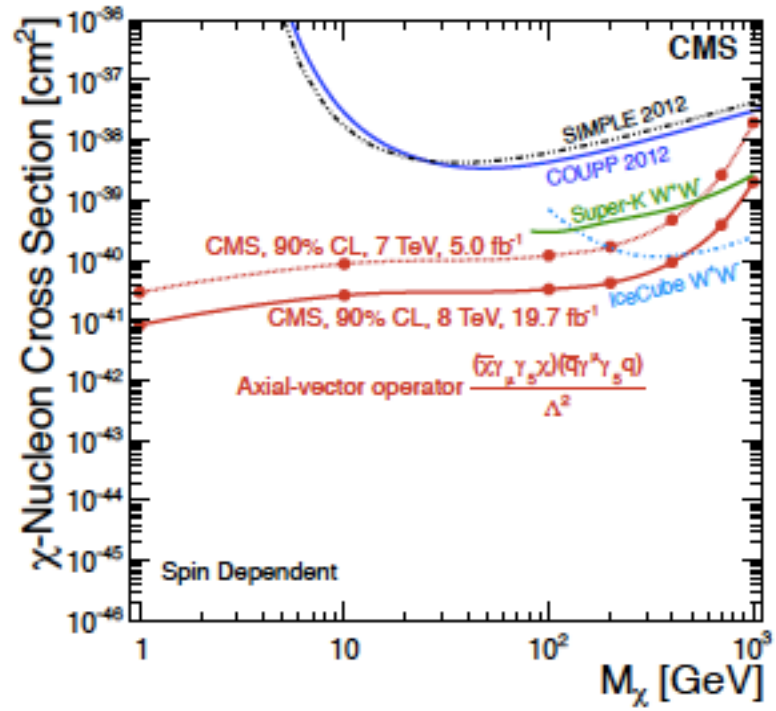


Mono-X searches

N. Fornengo, What Next DM WG 2015



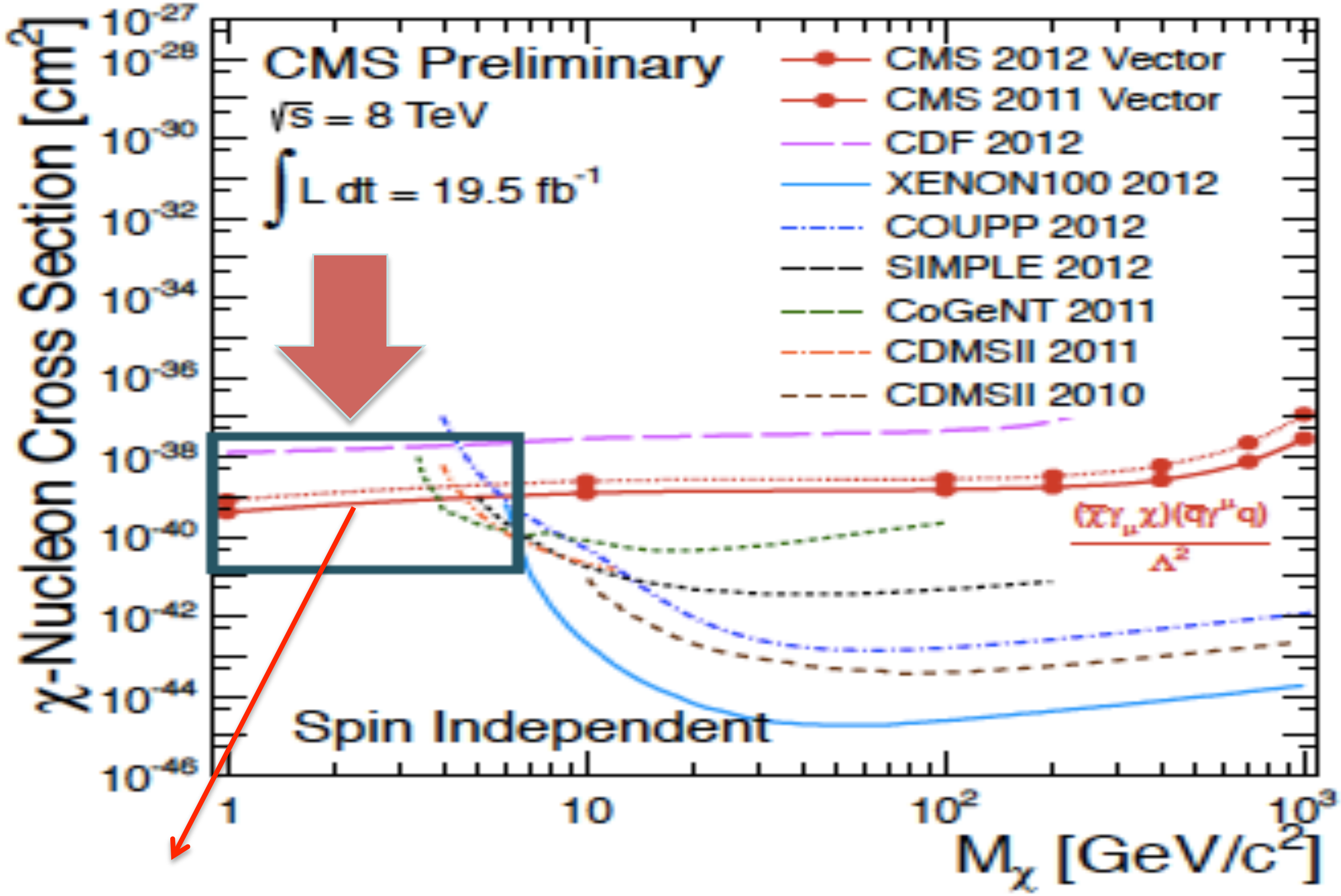
spin independent



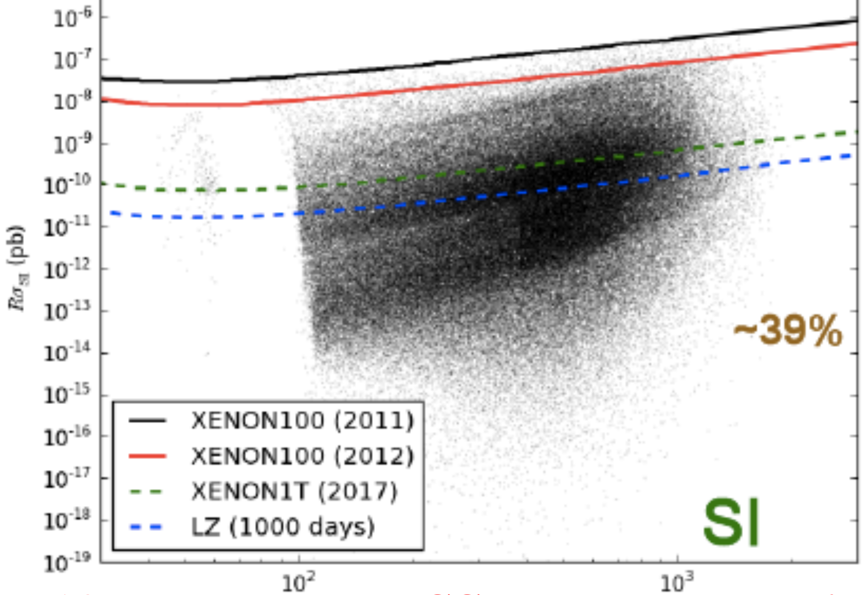
spin dependent

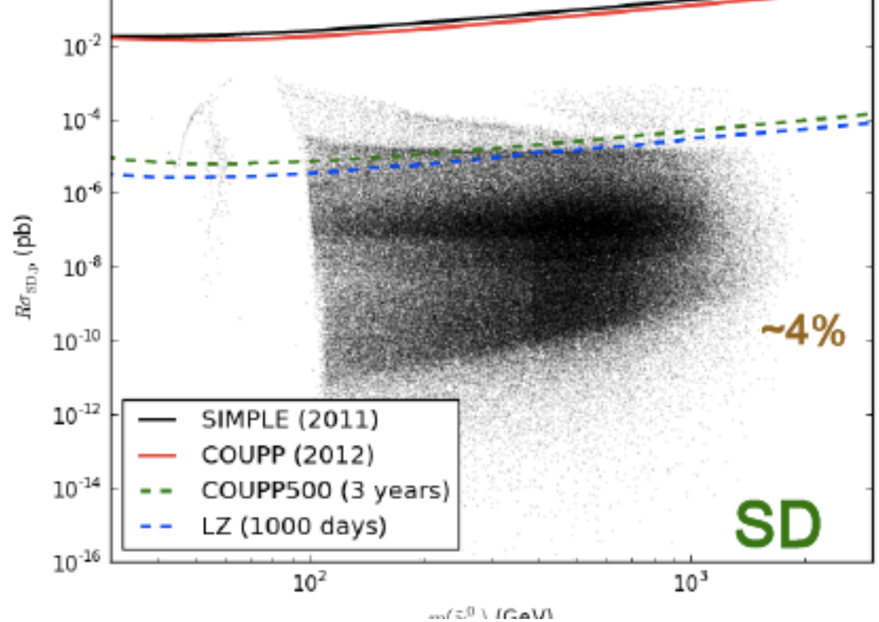
Inferred bounds on the direct detection scattering cross section
(subject to the validity range of EFT)

Romanino What Next BSM WG 2015



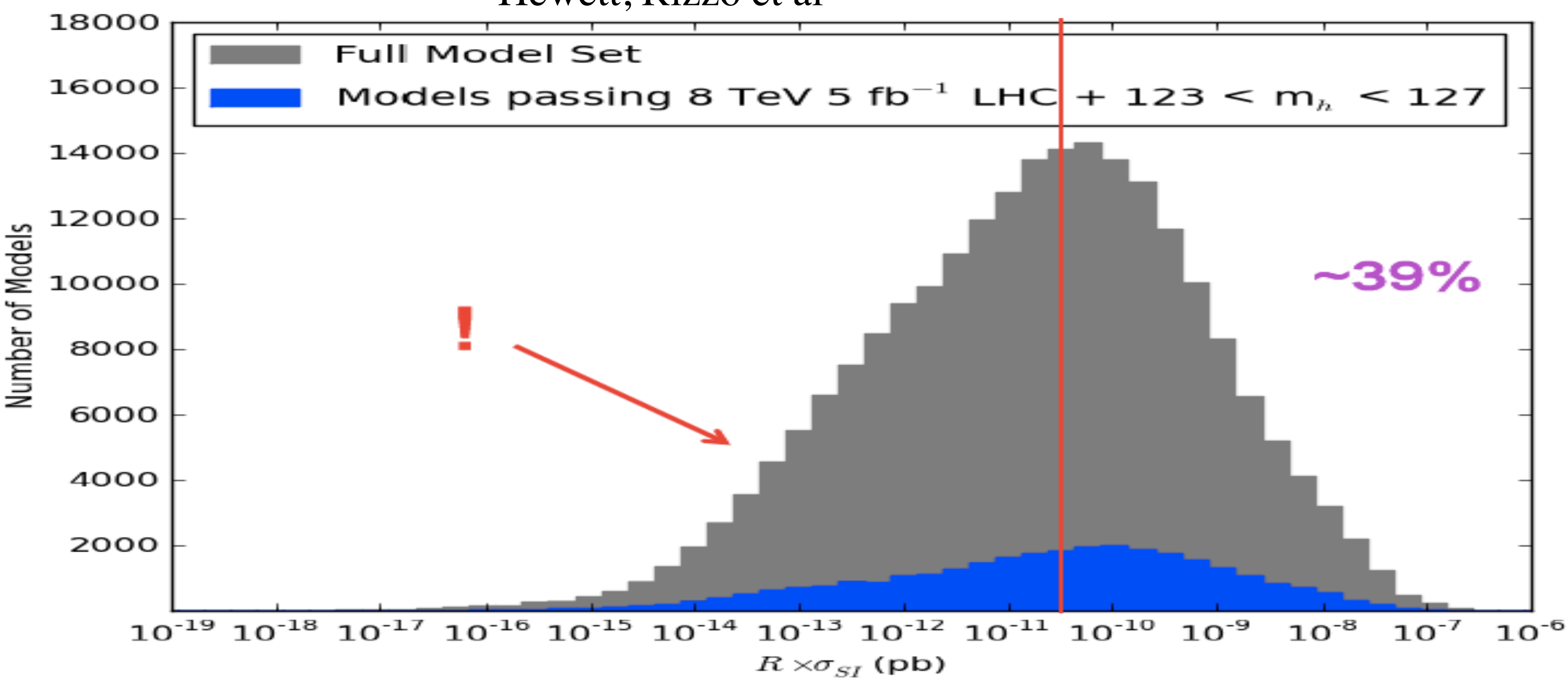
Relevant to intensify the efforts here: ex. **asymmetric DM** with **DM particles of mass~ baryon mass given that ρ_{DM} not much different from ρ_B**



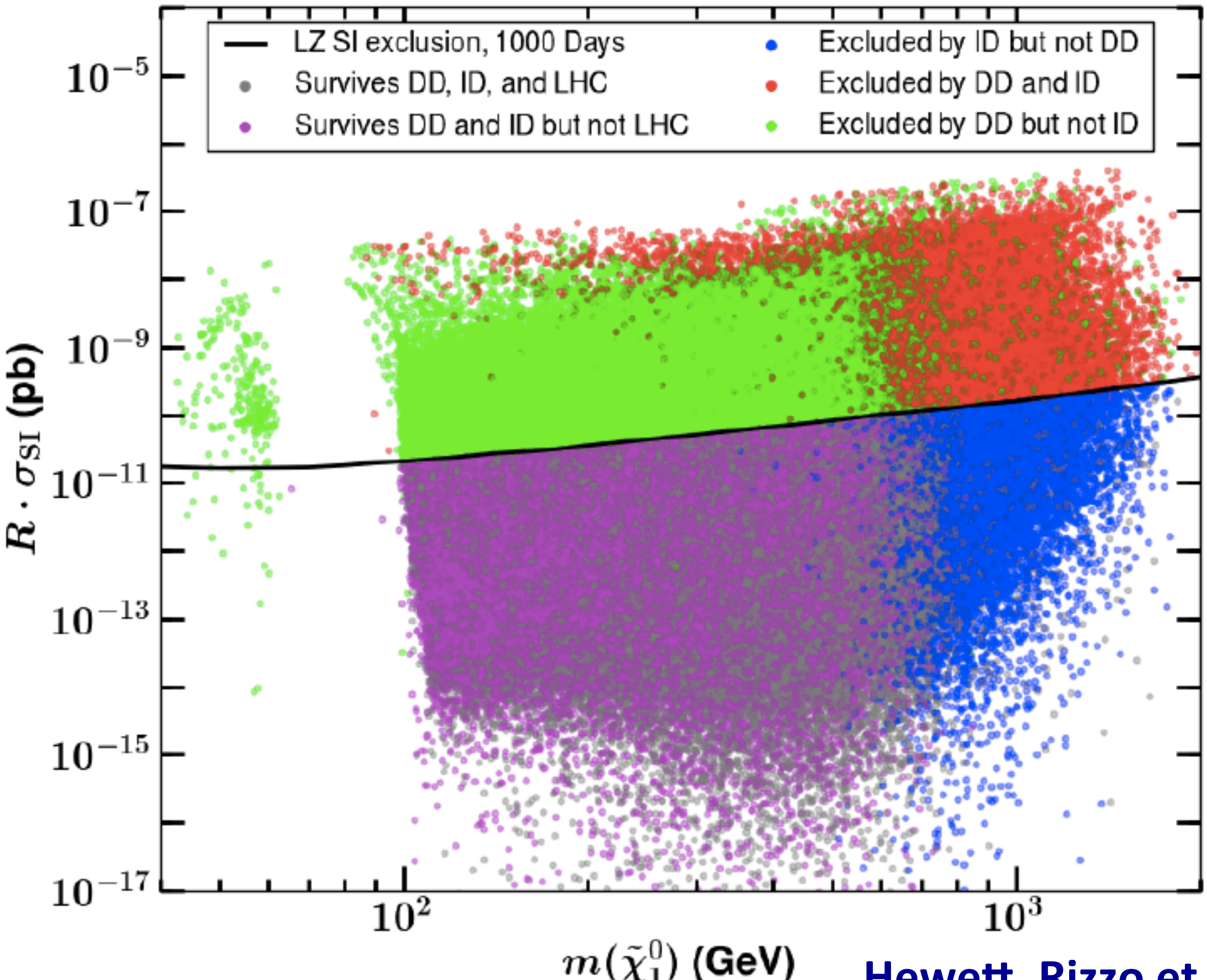


125k models pMSSM under scrutiny

Hewett, Rizzo et al



pMSSM models DD = LZ both SI + SD ID = FERMI + CTA



11.4%
29.2%
7.2%
27.5%
24.7%

Hewett, Rizzo et al. 2013

Challenges for next DM, ββ frontiers; Challenges for LNGS

- **Attack and cover the IH region → 1-ton neutrinoless ββ**
- **WIMPS DM : Reach the neutrino background → n-ton exps. n > 5**

LNGS → largest ultra low-background facility …

(see Terranova's talk)

LNGS at the next frontier: national lab or ERIC?

- To cope with the impressive future challenges → need for a truly international lab
- Possibility: European Research Infrastructure Consortium (ERIC)
- Possible partners: Netherland, Germany, Spain, Poland, … (UK?, Sweden?; later on, also France should join)

Overall, **in the next three years the APPEC agencies will need to take a decision on**

a) **the construction of the phase 1.5 of KM3Net,**

b) **a major investment as a contribution to a neutrino long baseline program in US or Japan,**

c) **a European-led dark matter multi-ton experiment**

d) **a ton-scale neutrino mass detector (double beta decay technique)**

e) **a major contribution on ground and/or space to the cosmology program probing the param. of inflation.**

The SAC recommends that APPEC prepares these decisions, in **coordination with its global partners, as well as with nearby fields,** e.g. particle physics national and international laboratories (CERN, FNAL, KEK and JPARC).

3 crucial ingredients for the success of the recipe:

- **Intense theoretical activity** with large integration of it with the experimental activities (PACT …)

- **INNOVATIVE R&D**

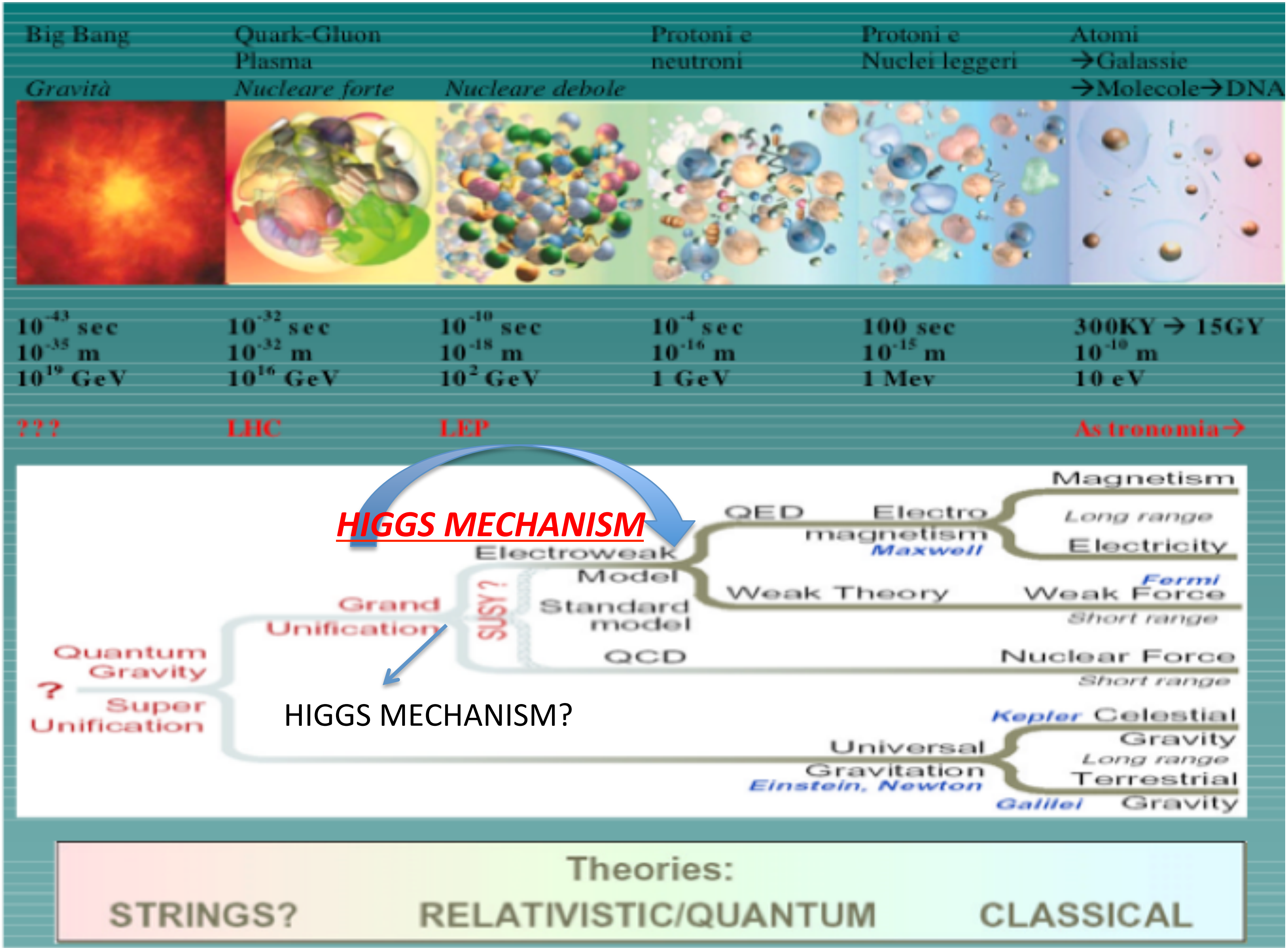
- **Modern Computing**

The importance of being **SMALL**

My recommendation: beware the temptation of going ONLY for LARGE enterprises

The protective shield of large, Big Science: too big to fail!

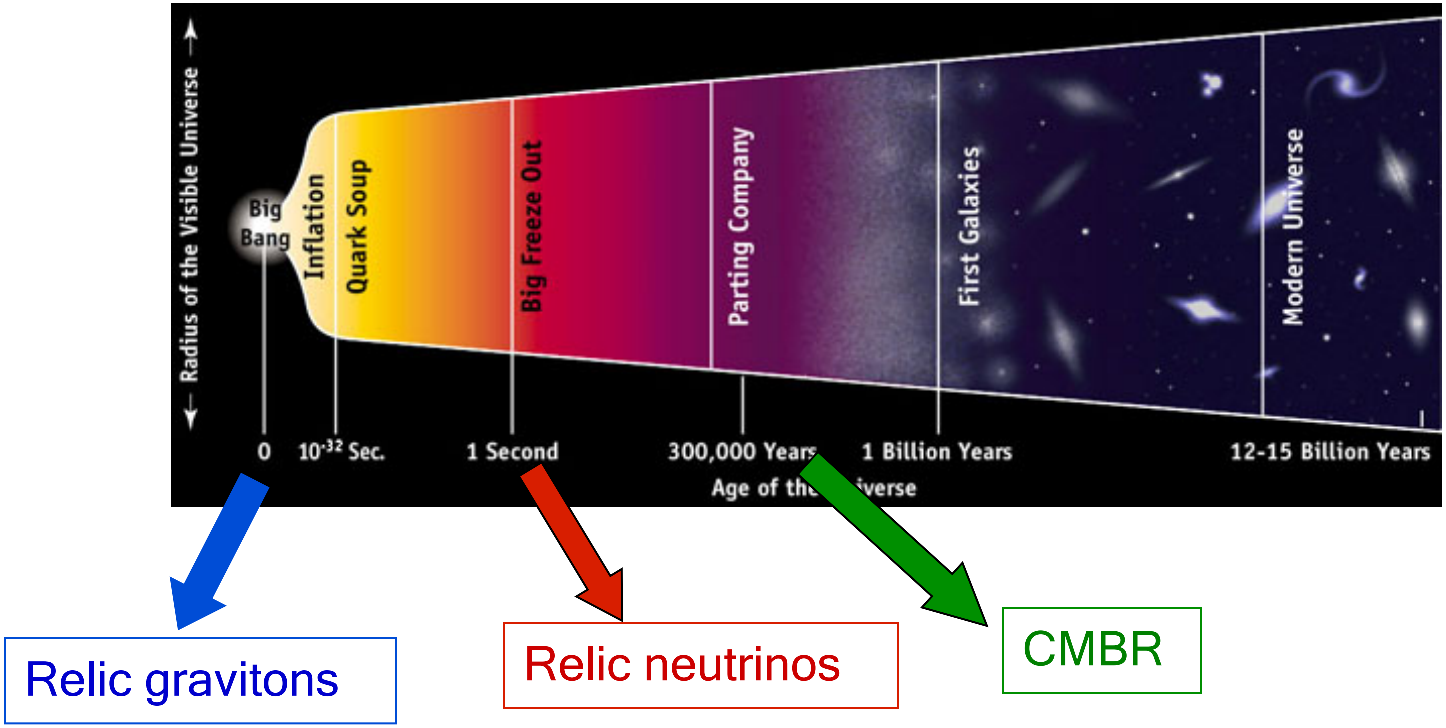
Richness of small, “unorthodox” projects based more on clever ideas than on muscular, managerial strength!



Big Bang
Gravità
Quark-Gluon Plasma
Nucleare forte
Nucleare debole
Protoni e neutroni
Protoni e Nuclei leggeri
Atomi →Galassie →Molecole→DNA
10^-43 sec 10^-35 m 10^19 GeV
10^-32 sec 10^-32 m 10^16 GeV
10^-10 sec 10^-18 m 10^2 GeV
10^-4 sec 10^-16 m 1 GeV
100 sec 10^-15 m 1 Mev
300KY → 15GY 10^-10 m 10 eV
???
LHC
LEP
As tronomia→
HIGGS MECHANISM
Magnetism
QED
Electro magnetism
Maxwell
Long range
Electricity
Electroweak Model
Fermi
Weak Theory
Weak Force
Short range
Grand Unification
SUSY ?
Standard model
QCD
Nuclear Force
Short range
Quantum Gravity
?
Super Unification
HIGGS MECHANISM?
Kepler
Celestial Gravity
Long range
Universal Gravitation
Einstein, Newton
Terrestrial Gravity
Galilei
Theories:
STRINGS?
RELATIVISTIC/QUANTUM
CLASSICAL

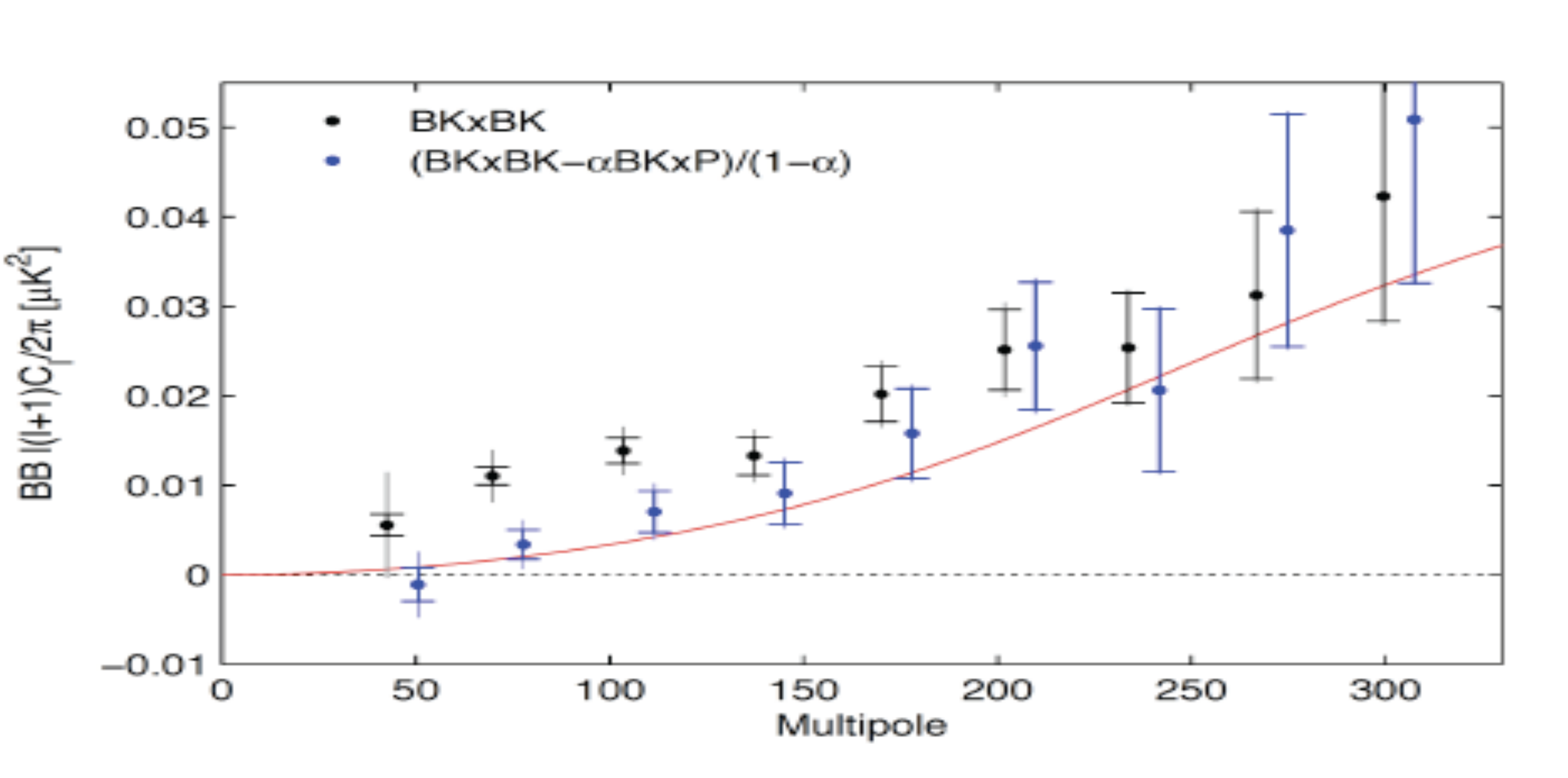
BACK-UP SLIDES

Relic Stochastic Background



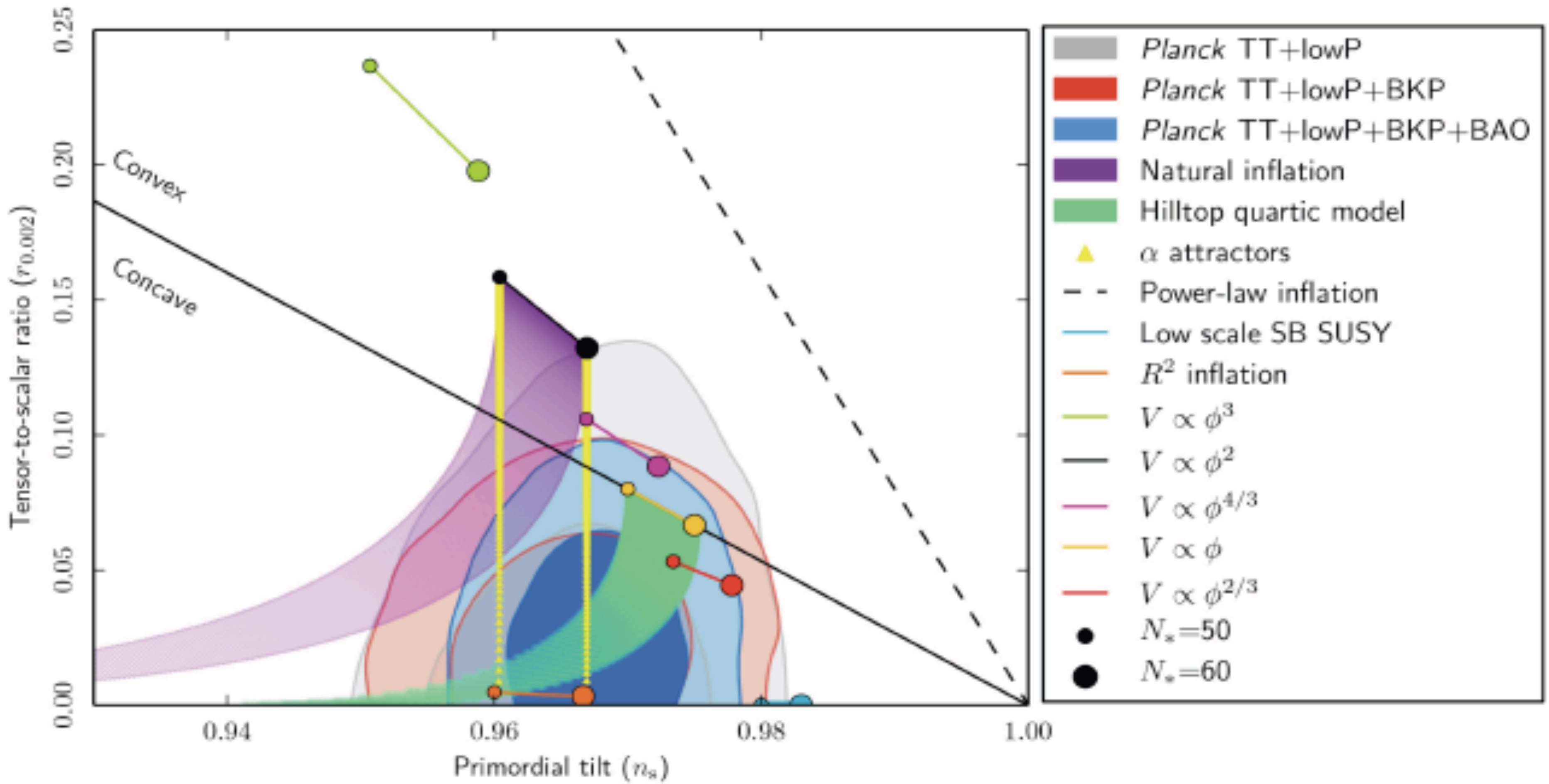
- Imprinting of the early expansion of the universe
- Correlation of at least two detectors needed

Subtracting PLANCK "dust" from BICEP2 results



r<0.12 @95% CL

THE INFLATON SCALAR POTENTIAL



0.94 0.96 0.98 1.00

Primordial tilt (n_s)

$$V^{1/4} = 1.94 \times 10^{16} \left(\frac{r}{0.12}\right)^{1/4} \text{GeV}$$

Is gauge hierarchy a "fictitious" problem?

- * Notice: gauge hierarchy is not a problem of the SM in itself; indeed, it arises when the **SM particles come in touch with much more massive particles** probably related to a new, large energy scale in physics

- But, how about having the SM as the final theory ("forever") of all the interactions, but for gravity whose quantization has its own story independently from the SM of electroweak+ strong interactions? – **softened gravity** (Giudice, Isidori, Salvio, Strumia 2014)

2012: the conquest of a new energy scale in physics

- ~1900 **ATOMIC SCALE** **10^{-8} cm.** $1/(\alpha m_e)$
- ~1970 **STRONG SCALE** **10^{-13} cm.** $M e^{-2\Pi/\alpha_s b}$
- ~2010 **WEAK SCALE** **10^{-17} cm.** TeV^{-1}

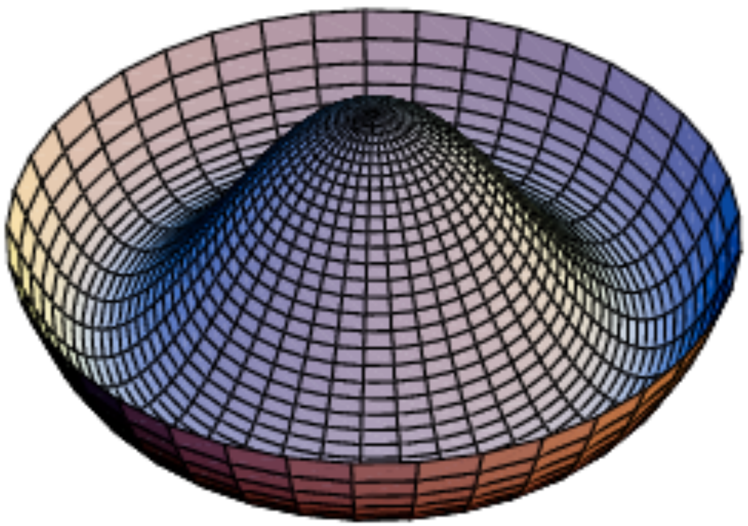
FUNDAMENTAL OR **DERIVED SCALE**?

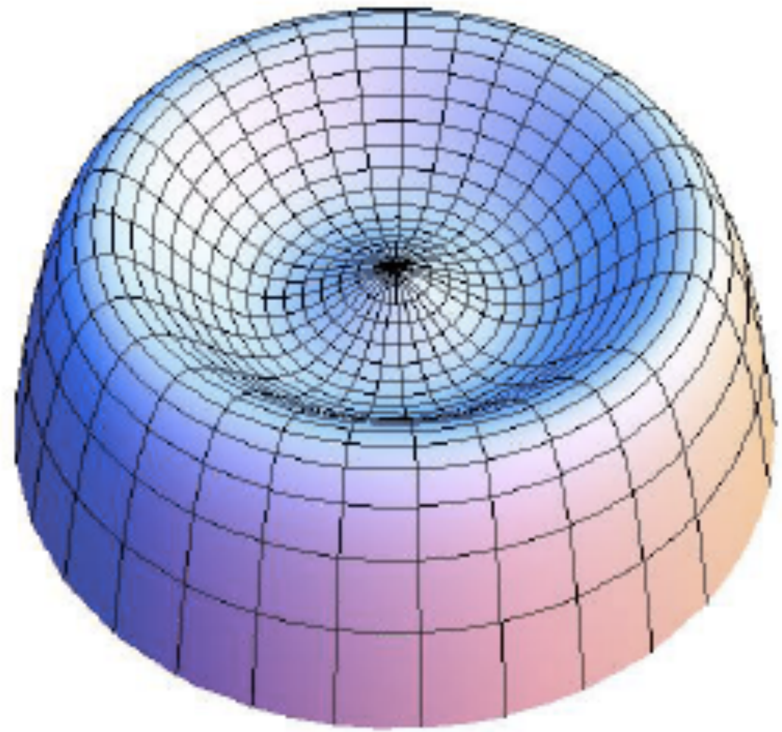
EX. **EXTRA-DIMENSIONS**
or
TeV STRING THEORY

EX.: **TECHNICOLOR** or
SUSY with ELW RAD. BREAKING

NEW PARTICLES AT THE TEV SCALE?

STABILITY ⟷ **INSTABILITY**





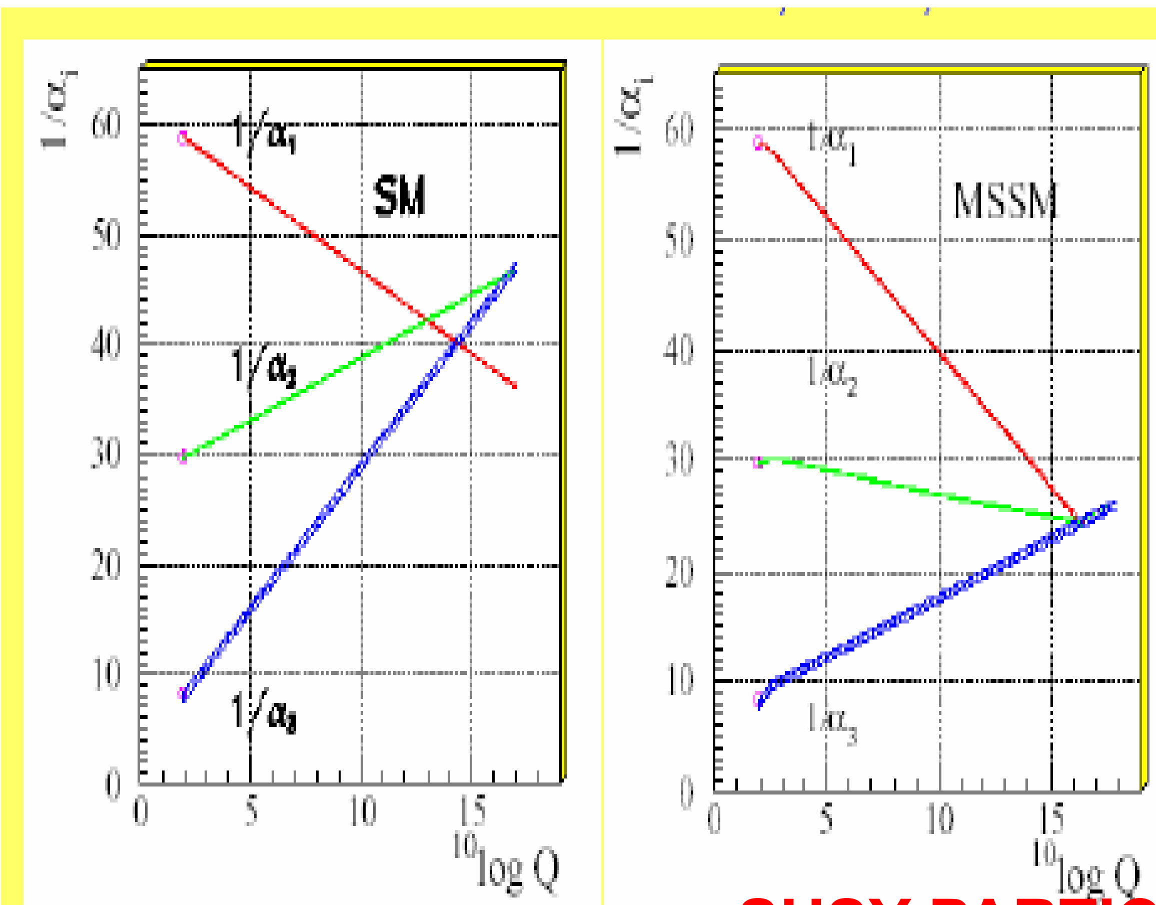
ON THE IMPORTANCE OF PRECISELY MEASURING HIGGS and TOP MASSES

The harvest of the recently opened high energy gamma ray astronomy and the opening of the new astronomies: gravitational waves, neutrinos and the high energy cosmic rays

The understanding of the neutrino sector and its cosmological role

Large theoretical and experimental progress in the dark matter quest, reaching close to the parameter limits of current theories; the precise study of the parameters of the equation of state of dark energy and, eventually, of those of the inflation potential.

LOW-ENERGY SUSY AND UNIFICATION



Input

$$\alpha^{-1}(M_Z) = 128.978 \pm 0.027$$

$$\sin^2 \theta_{\overline{MS}} = 0.23146 \pm 0.00017$$

$$\alpha_s(M_Z) = 0.1184 \pm 0.0031$$

Output

$$M_{SUSY} = 10^{3.4 \pm 0.9 \pm 0.4}\ \text{GeV}$$

$$M_{GUT} = 10^{15.8 \pm 0.3 \pm 0.1}\ \text{GeV}$$

$$\alpha_{GUT}^{-1} = 26.3 \pm 1.9 \pm 1.0$$

SUSY PARTICLES AT THE TEV SCALE !

The BIG and the SMALL- dim[m] ≠ 0

- $V = \mu^2|H|^2 + \lambda|H|^4$ what is the value of the energy of its vacuum, i.e. the SM **vacuum energy**?
  → $V_o = \mu^2 <H>^2 + \lambda <H>^4 \sim (100\ \text{GeV})^2$

observed vacuum energy, i.e. dark energy accelerating the expansion of the Universe $O(10^{-3}\ \text{eV})$

- V defined up to a constant → choose such constant to **cancel** the $O\ (100\ \text{GeV})^2$ contribution
- **10^{-3} eV 10^{2} GeV 10^{16} GeV 10^{19} GeV**

- **Why** so different mass scales ?

- **How** to guarantee their separation → symmetry vs. multiverse

The BIG and the SMALL – dim[m]=0

- $h_t - h_e$ **flavour** issue
- L_{SM} no symmetry prevents to add a term violating **CP in the strong interactions** whose size depends on a **dimensionless** parameter θ → the bound on the neutron EDM → $\theta < 10^{-10}$
- **The θ – problem** : the symmetry solution

Axion from breaking of global chiral symmetry; axion field acts as dynamical theta para-meter, [Peccei,Quinn 77; Weinberg 78; Wilczek 78]

$$\mathcal{L} \supset -\frac{\alpha_s}{8\pi} \underbrace{\frac{A}{f_A}}_{\bar\theta} G^a_{\mu\nu}\tilde{G}^{a,\mu\nu}$$

spontaneously relaxing to zero, $\langle A \rangle = 0$ (thus CP conserved)

- mass due to chiral symmetry breaking $m_A \sim m_\pi f_\pi / f_A$
- has universal coupling to photons, $\mathcal{L} \supset -\frac{\alpha}{8\pi} C_0 \frac{A}{f_A} F_{\mu\nu}\tilde{F}^{\mu\nu}$

Ringwald

LOW-ENERGY SIGNATURES OF UNIFICATION AT 10^{16} GeV

- **PROTON DECAY** mediated by new particles (scalars or gauge bosons) related to the unified physics at 10^{16} GeV which DOES NOT respect the BARYON and LEPTON NUMBER SYMMETRIES → for a mediator of mass ~ 10^{16} GeV we expect a proton lifetime in the ballpark of ~ 10^{34} years → exp. accessible

- **NEUTRON-ANTINEUTRON OSCILLATION** if the unified symmetry (ex. SO(10)) breaks down to an intermediate symmetry subsequently spontaneously broken at ~ 10^{6} GeV with the breaking of Baryon number of two units (ex. $SO(10) \to SU(4)_{PS} \times SU(2)_L \times SU(2)_R \to SU(3) \times SU(2)_L \times U(1)_Y$) → exp. accessible (for instance , at the ESS)

MATTER-ANTIMATTER ASYMMETRY ⟷ NEUTRINO MASSES CONNECTION: BARYOGENESIS THROUGH LEPTOGENESIS

- Key-ingredient of the SEE-SAW mechanism for neutrino masses: **large Majorana mass for RIGHT-HANDED neutrino**
- In the early Universe the heavy RH neutrino decays with Lepton Number violatiion; if these decays are accompanied by a new source of CP violation in the leptonic sector, then

VANILLA LEPTOGENESISIS !

→ it is possible to create a lepton-antilepton asymmetry at the moment RH neutrinos decay. Since SM interactions preserve Baryon and Lepton numbers at all orders in perturbation theory, but violate them at the quantum level, such **LEPTON ASYMMETRY** can be converted by these purely quantum effects into a BARYON-ANTIBARYON ASYMMETRY (**Fukugita-Yanagida mechanism for leptogenesis**)

LFV IN SUSY SEE-SAW

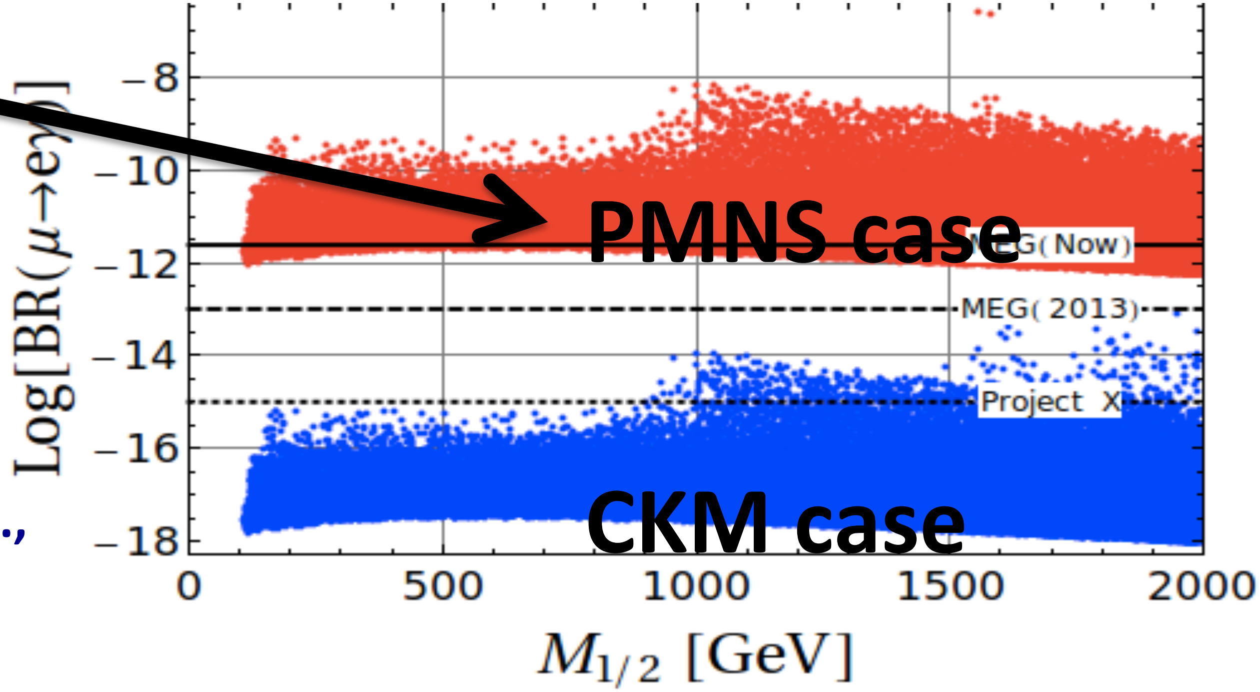
SEE- SAW (type 1) **LOW-ENERGY SUSY**

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**

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

PMNS case in mSUGRA with tanβ = 10



Calibbi, Chowdhuri, A. M., Patel, Vempati 2012