Status of Neutrino, Astro & Flavor Physics

Troels C. Petersen

Post ESPP Cracow Recount

2nd of November 2012

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* ...)

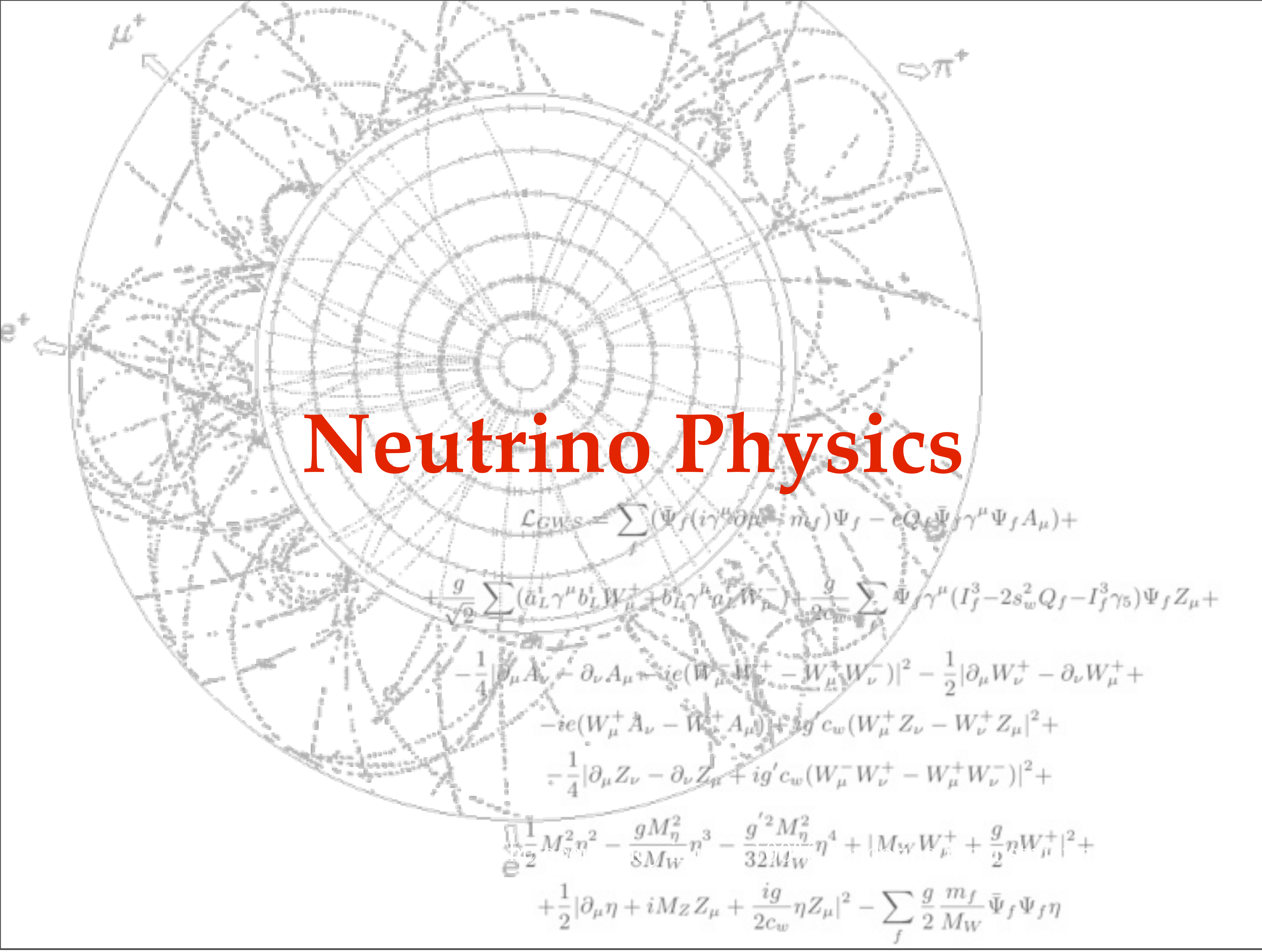
- The **"a" vs. "the"** dispute decided by 5 numbers:

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

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

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

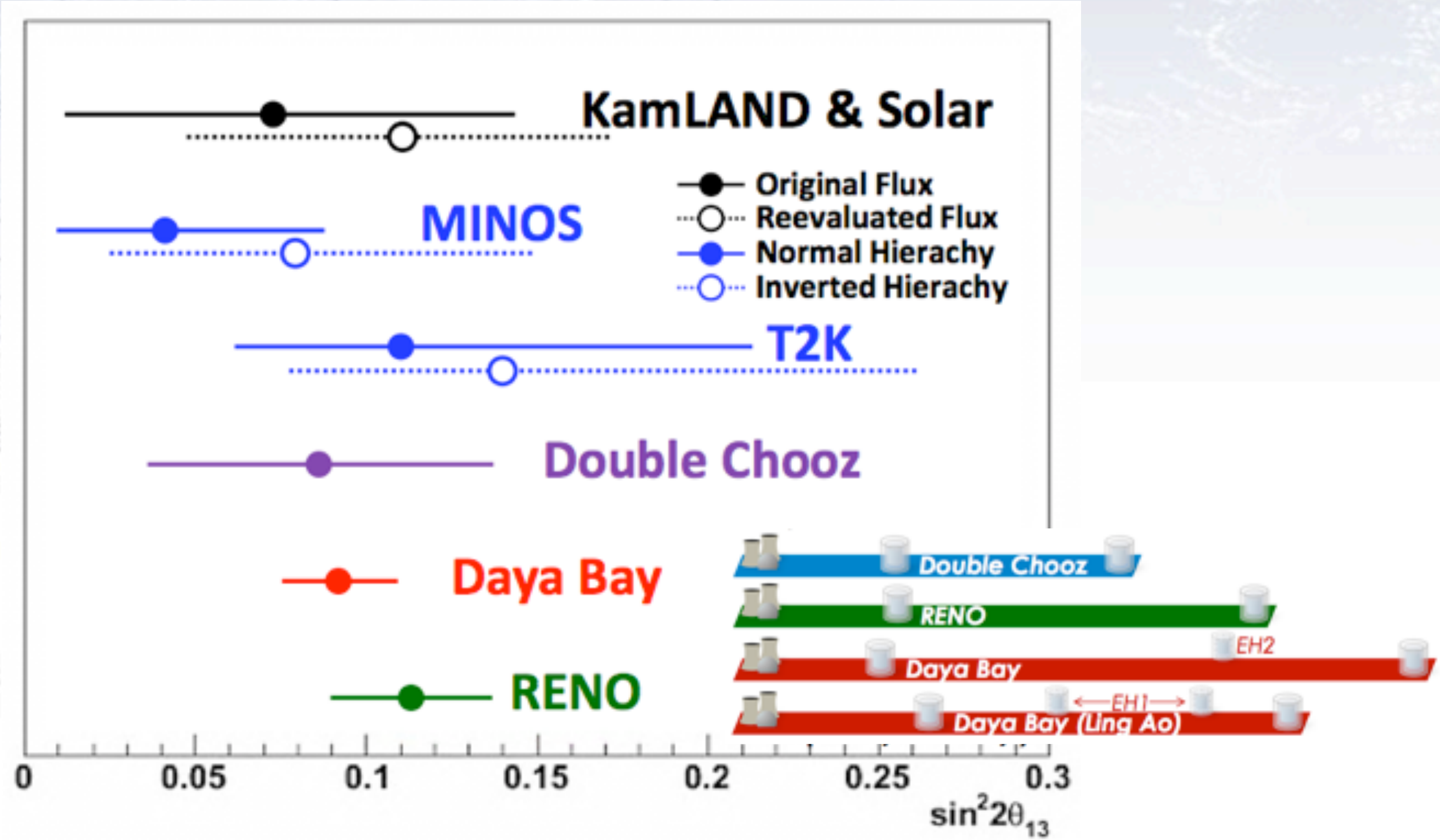
BARBIERI, ICHEP2012



Neutrino Physics

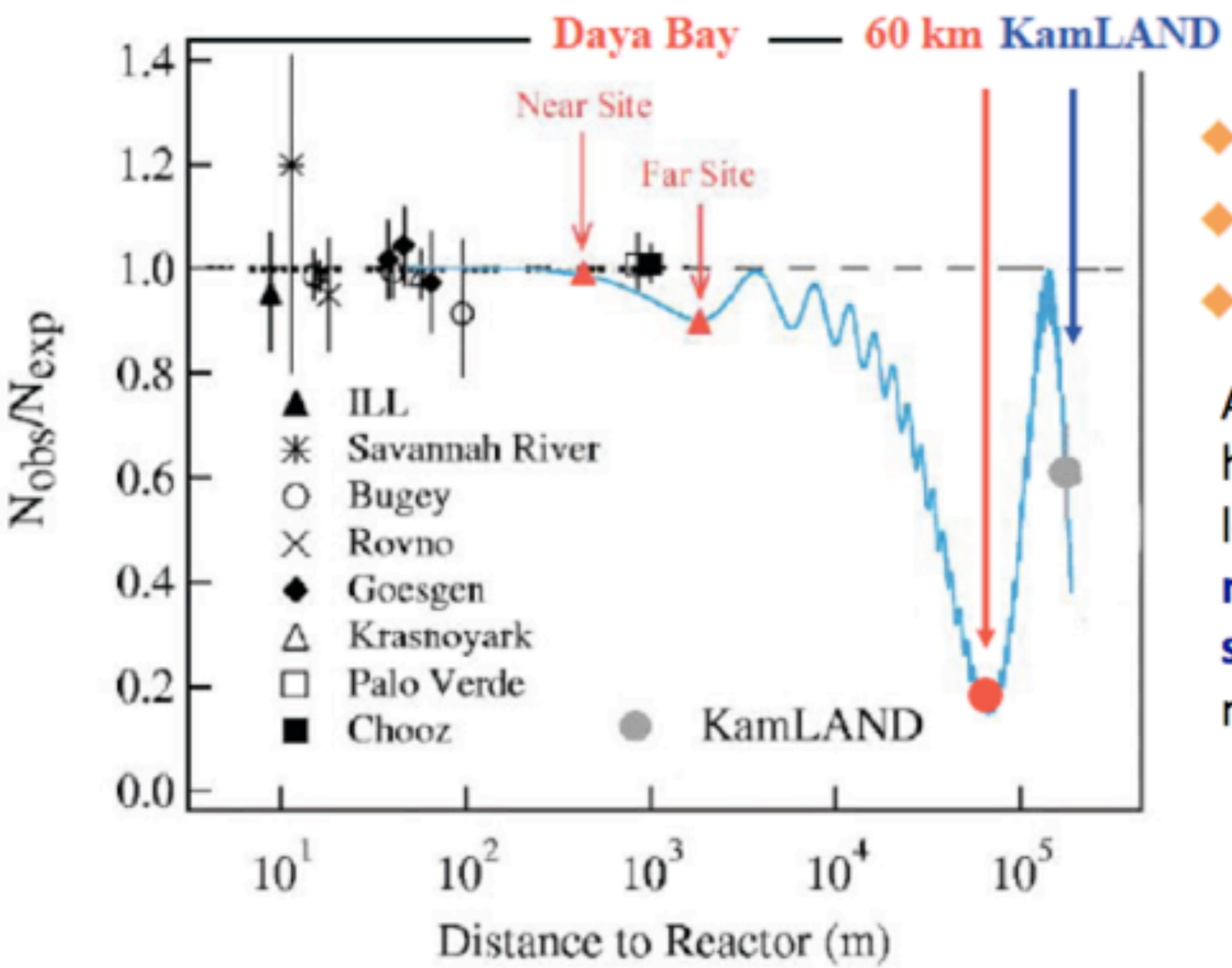
θ_{13} is large - thank you Nature!

In less than a year, θ_{13} went from being unknown to well measured!



Small / zero value ruins possibility of measuring leptonic CP violation.

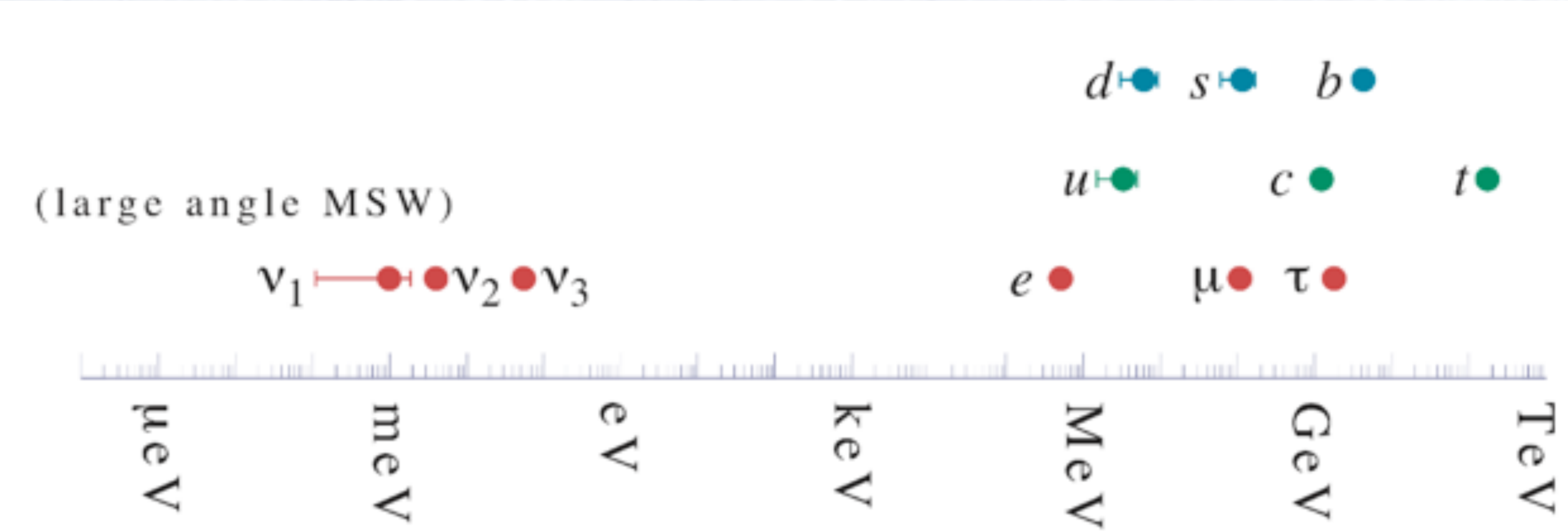
After θ_{13} → DAYA BAY FOCUS ON THE MASS HIERACHY: the DAYA BAY-II EXP.



- 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**

Why are neutrinos special?

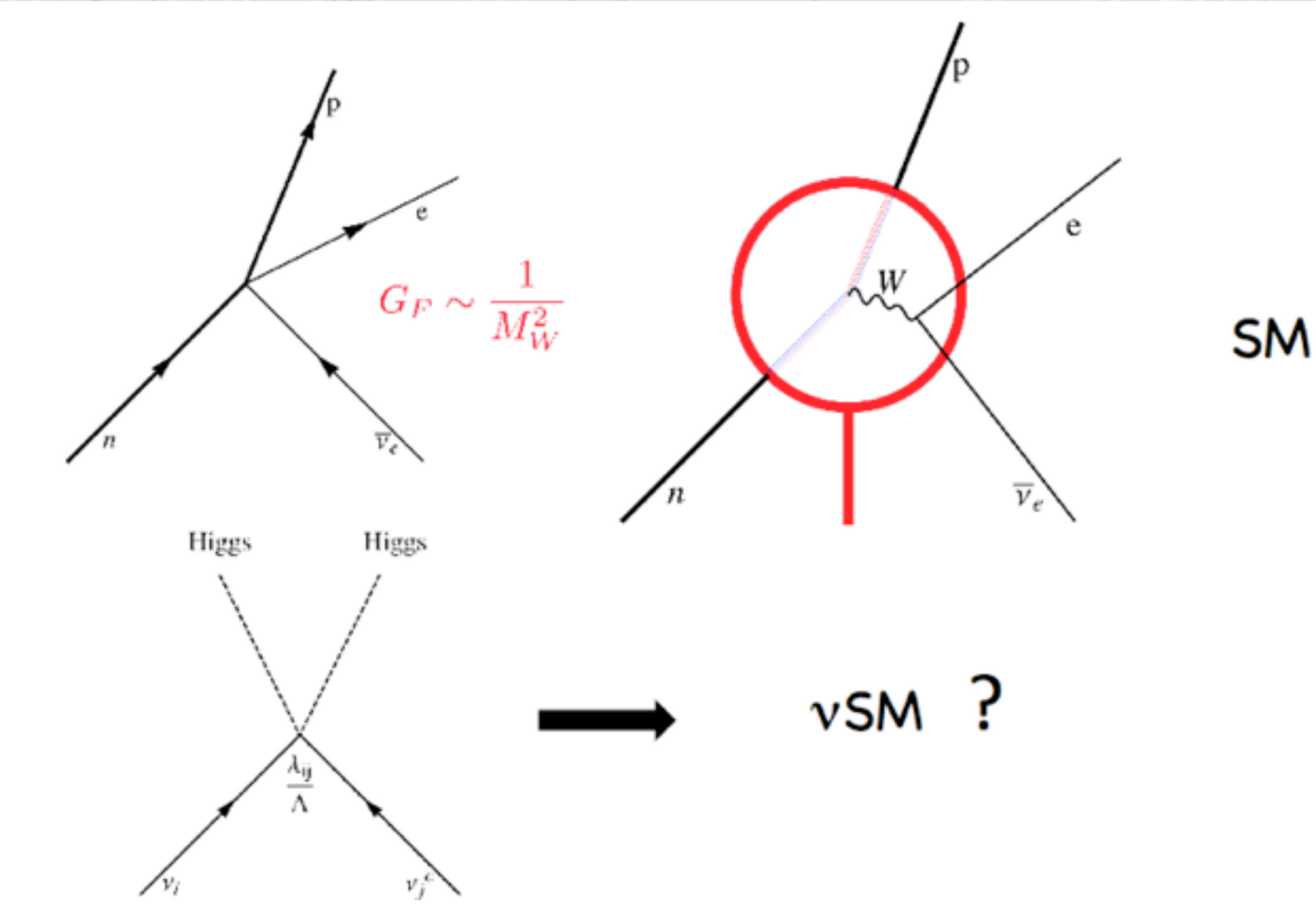


$m_f \sim \lambda$

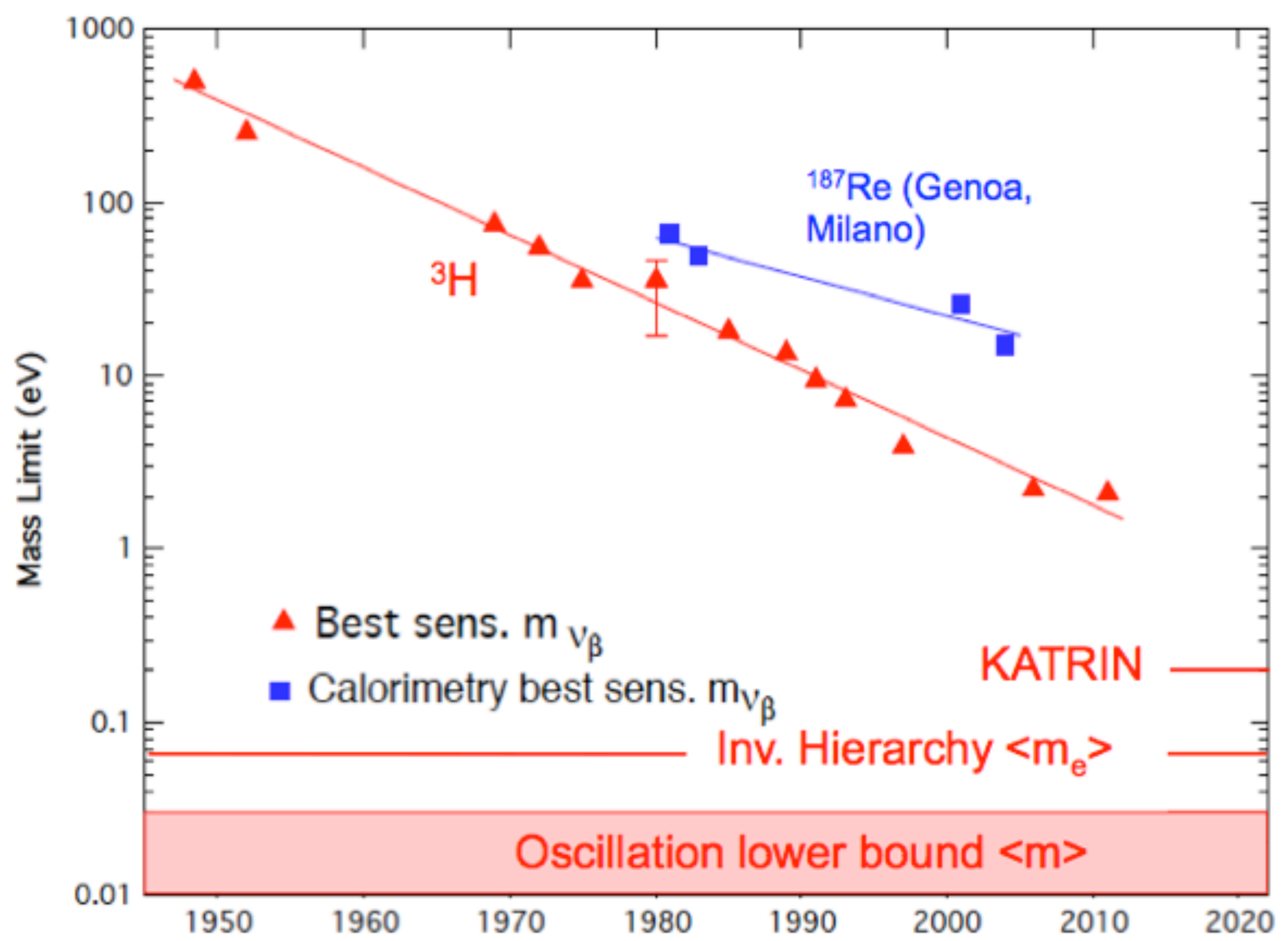
$$|V|_{\text{CKM}} = \begin{pmatrix} 0.97427 \pm 0.00015 & 0.22534 \pm 0.0065 & (3.51 \pm 0.15) \times 10^{-3} \\ 0.2252 \pm 0.00065 & 0.97344 \pm 0.00016 & (41.2^{+1.1}_{-5}) \times 10^{-3} \\ (8.67^{+0.29}_{-0.31}) \times 10^{-3} & (40.4^{+1.1}_{-0.5}) \times 10^{-3} & 0.999146^{+0.000021}_{-0.000046} \end{pmatrix}$$

$$|U|_{\text{LEP}(3\sigma)} = \begin{pmatrix} 0.795 \to 0.841 & 0.517 \to 0.584 & 0.141 \to 0.179 \\ 0.213 \to 0.543 & 0.425 \to 0.728 & 0.575 \to 0.802 \\ 0.213 \to 0.541 & 0.411 \to 0.720 & 0.576 \to 0.802 \end{pmatrix}$$

Neutrino underlying scale?



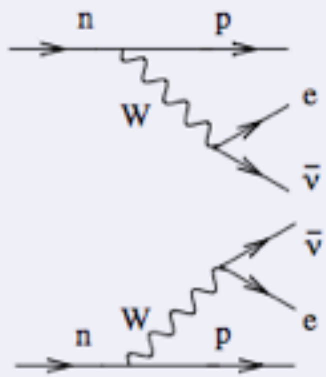
Neutrino masses from β decay



Double neutrinoless β decay

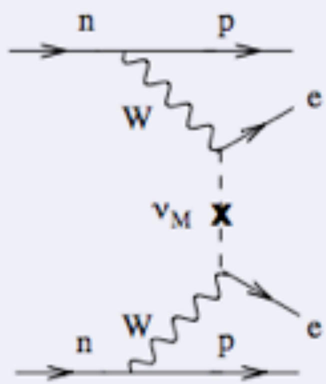
$2\nu\beta\beta$

- $(Z, A) \to (Z+2, A) + 2e^- + 2\bar{\nu}_e$
- $\Delta L = 0$
- $\left|T^{2\nu}_{1/2}\right|^{-1} = G^{2\nu}(Q_{\beta\beta}, Z)\,|M_{2\nu}|^2 \sim \left|10^{20}\ \mathrm{y}\right|^{-1}$



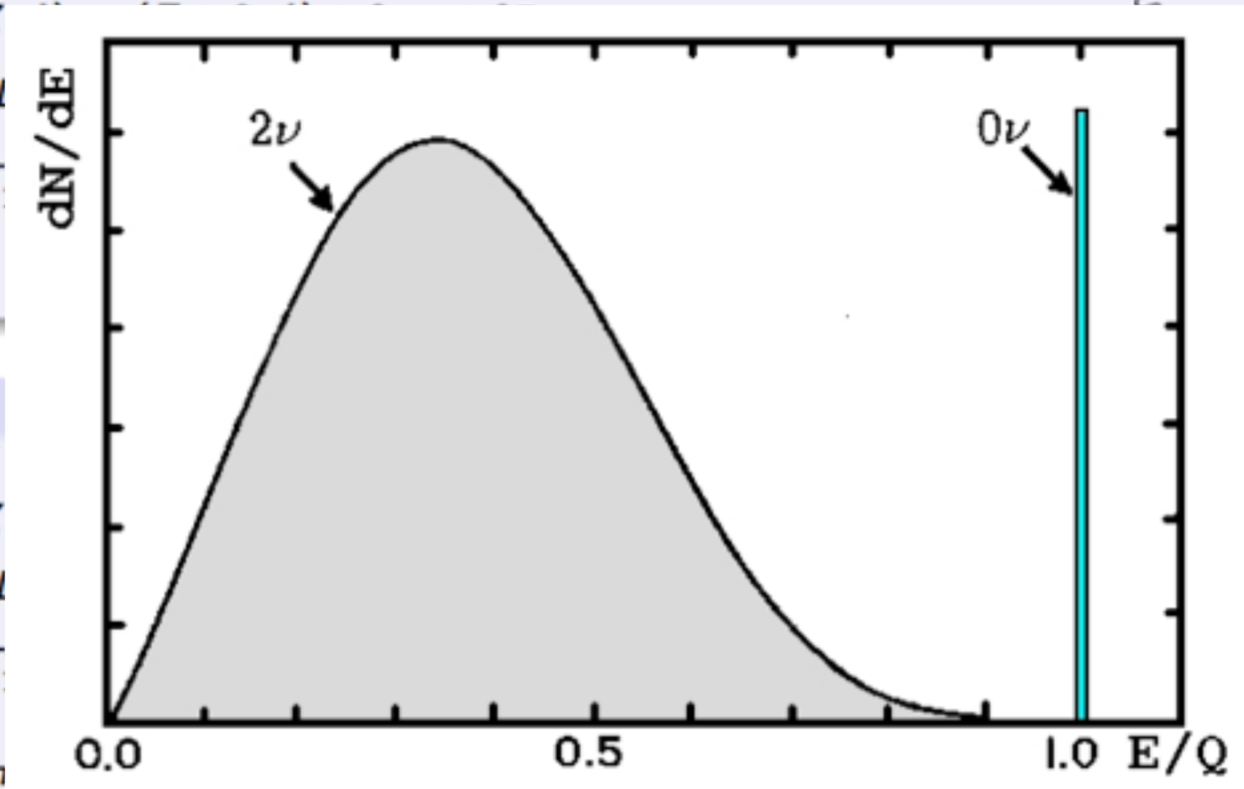
$0\nu\beta\beta$

- $(Z, A) \to (Z+2, A) + 2e^-$
- $\Delta L = 2$
- $\left|T^{0\nu}_{1/2}\right|^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2 \,\langle m^2_{\beta\beta}\rangle \sim \left|10^{25}\ \mathrm{y}\right|^{-1}$
- $\langle m_{\beta\beta}\rangle = \left|\sum_i U^2_{ei}\ m_i\right|$



Double neutrinoless β decay

$2\nu\beta\beta$

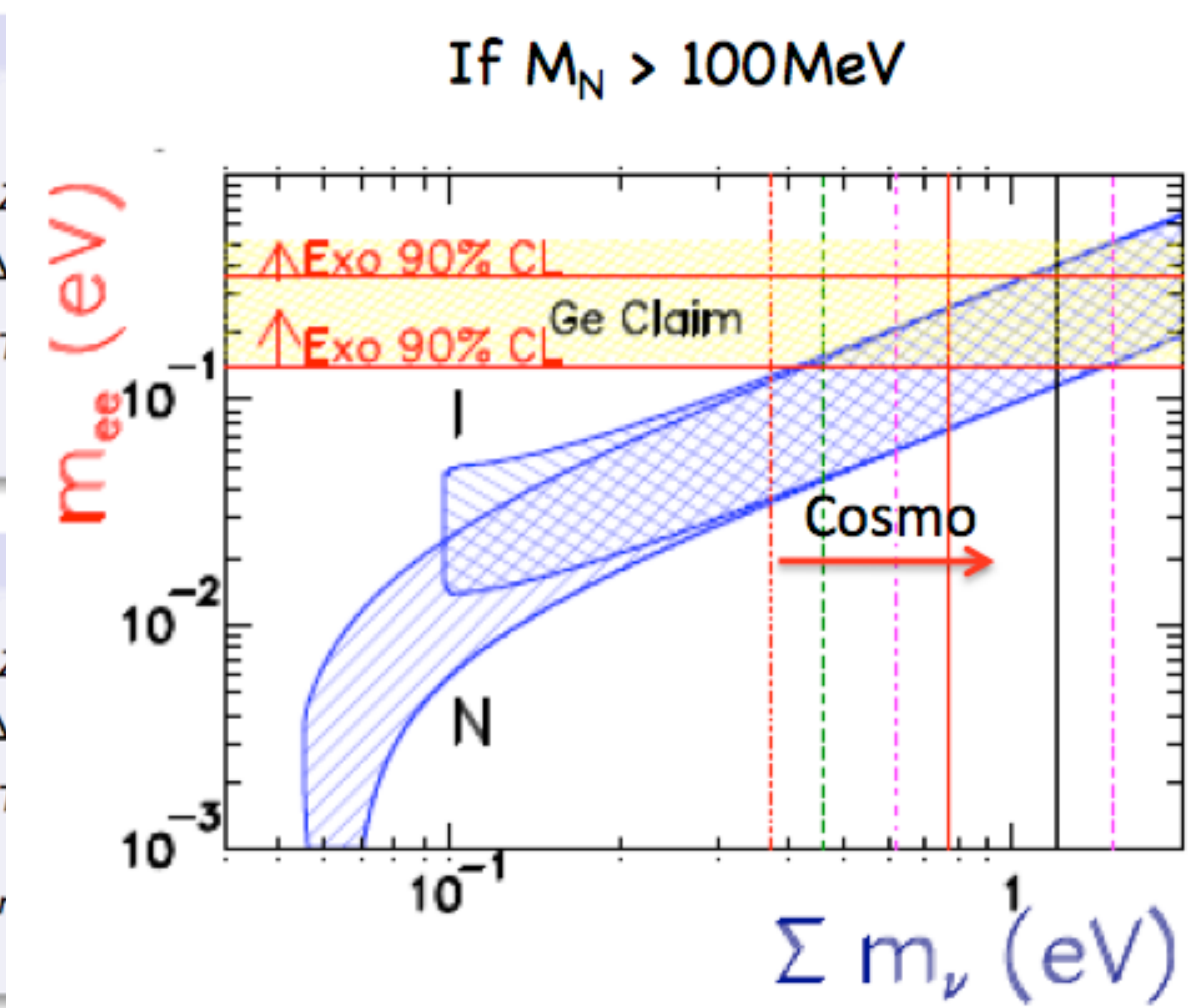


$0\nu\beta\beta$

Double neutrinoless β decay

$2\nu\beta\beta$

$0\nu\beta\beta$



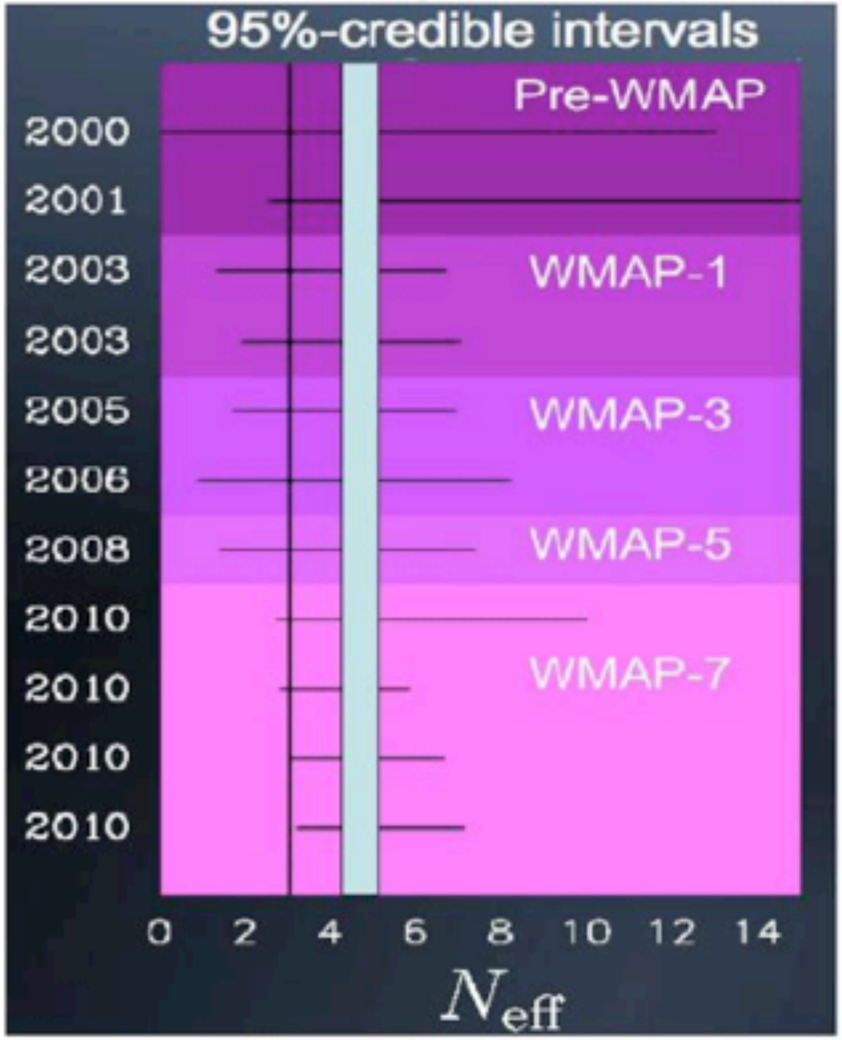
More than three neutrinos?

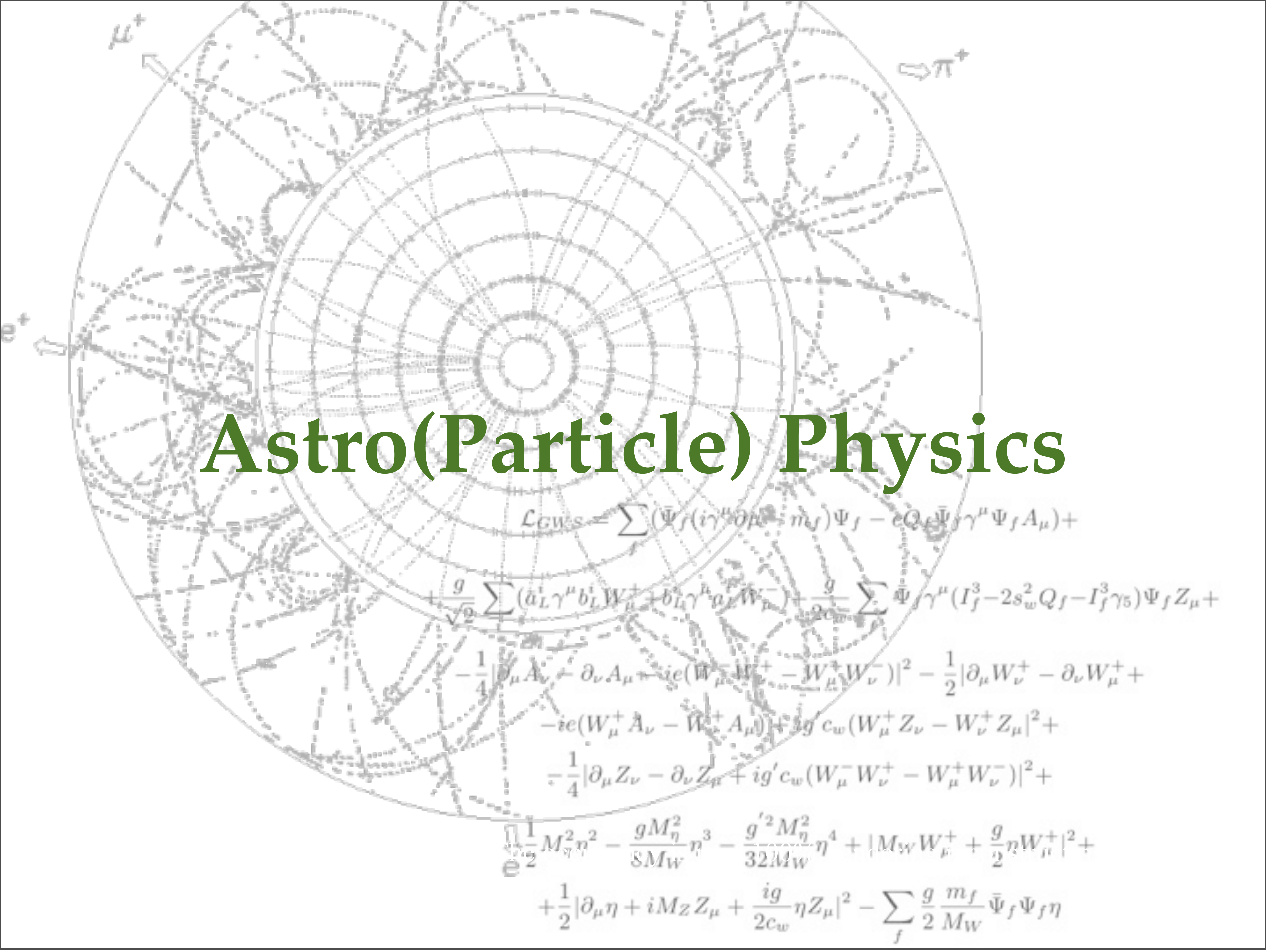
- Parameterise excess relativistic energy density in terms of extra species of massless neutrinos.

$$\rho_\nu + \rho_X = \underline{N_{\rm eff}} \left(\frac{7}{8} \frac{\pi^2}{15} T_\nu^4 \right)$$
$$= (3.046 + \Delta N_{\rm eff}) \left(\frac{7}{8} \frac{\pi^2}{15} T_\nu^4 \right)$$

- **Evidence for N_{eff} > 3:**
  - @ 98.4% (CMB+LSS)
    Hou et al. 2011
  - @ 99.5% (CMB+LSS+BBN)
    Hamann et al. 2011

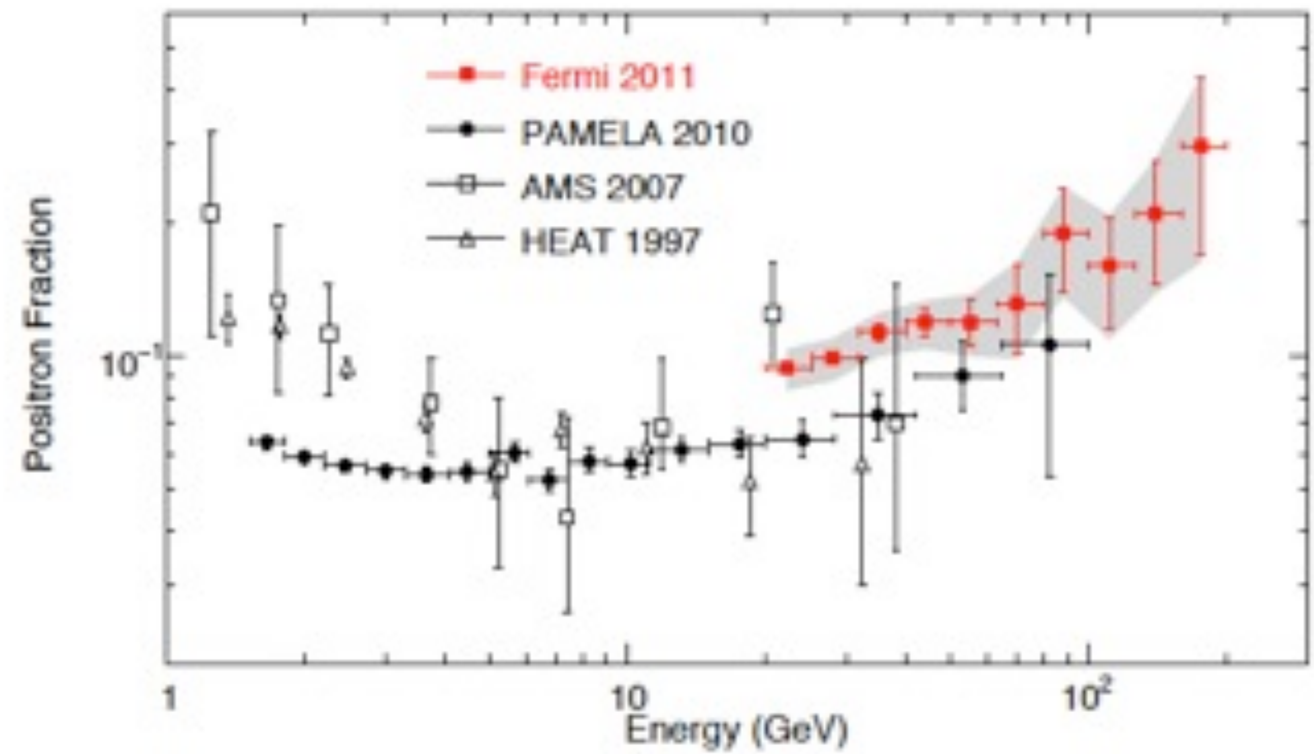
Adapted from S. Hannestad



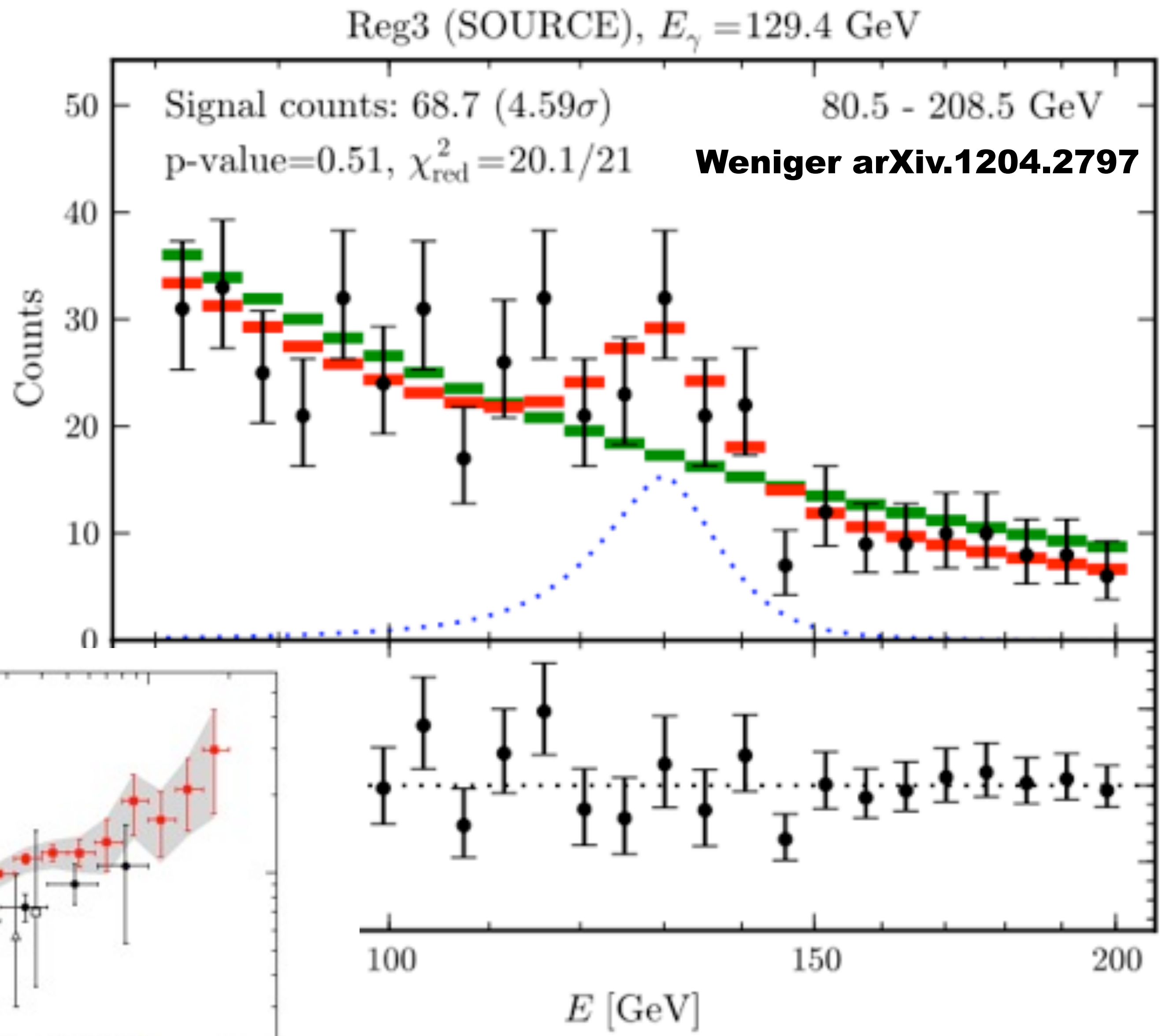


Astro(Particle) Physics

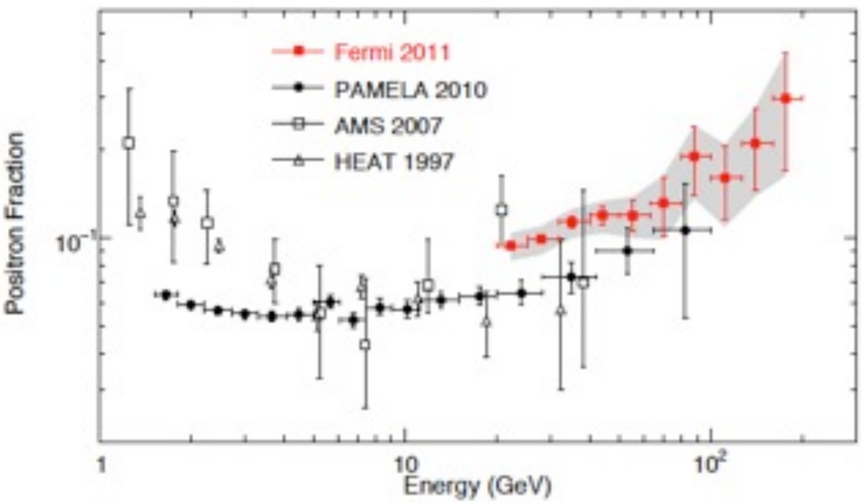
Fermi satellite



Fermi satellite

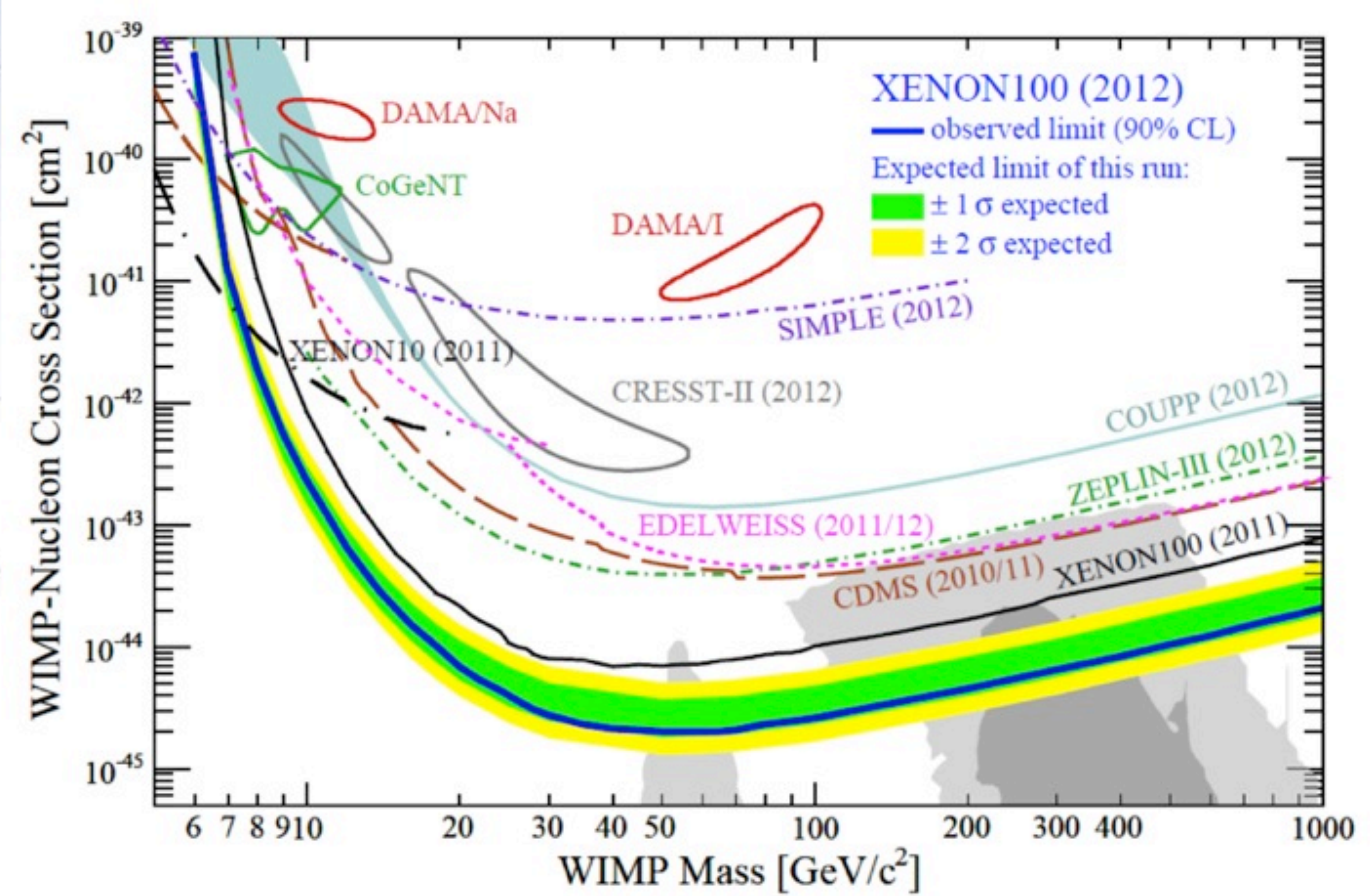


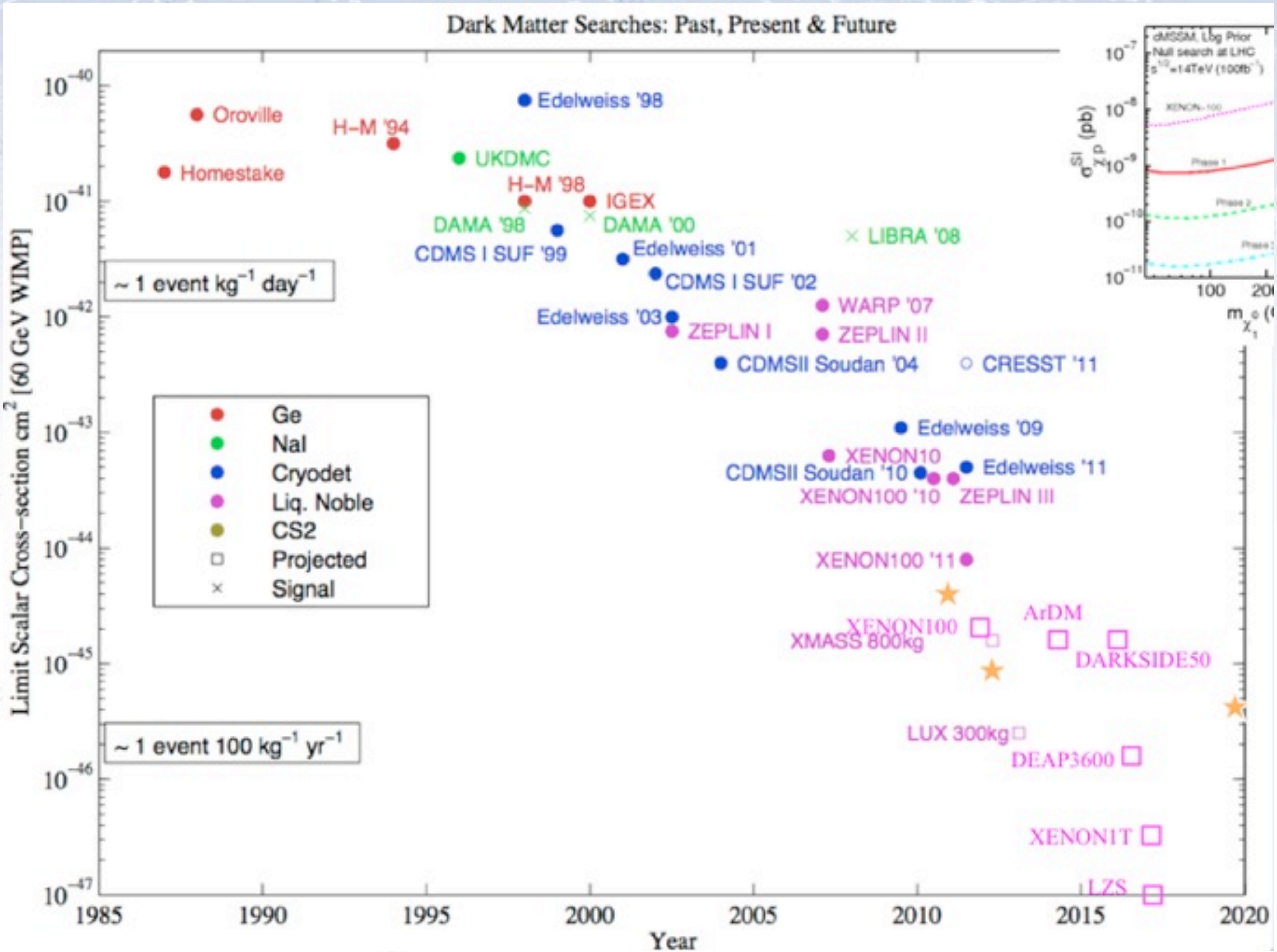
Waiting for AMS results!



However, such results tend to come and go in AstroParticle physics...

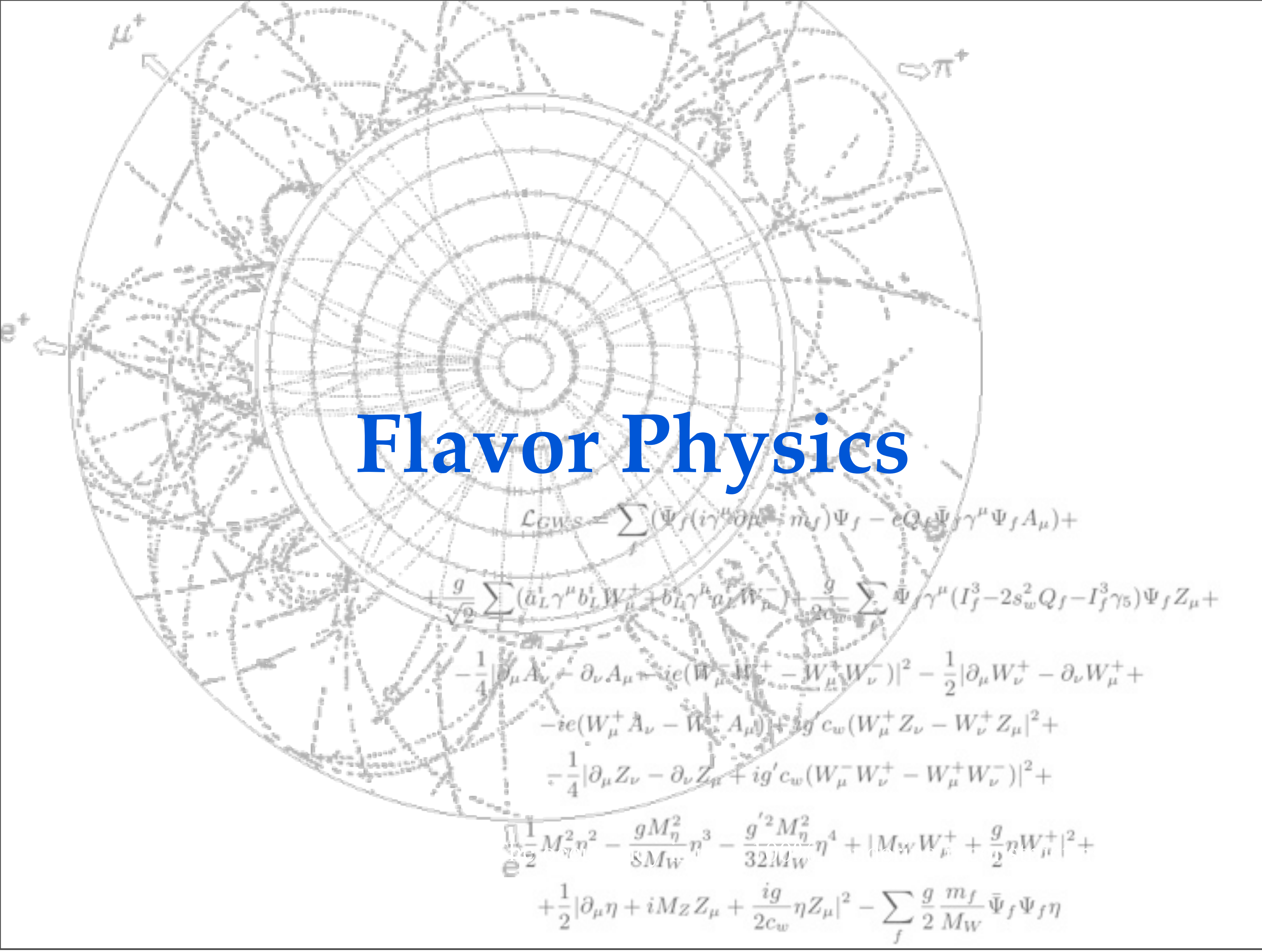
WIMP search - Xenon100




Dark Matter Searches: Past, Present & Future
Limit Scalar Cross−section cm^2 [60 GeV WIMP]
Year
~ 1 event kg^{-1} day^{-1}
~ 1 event 100 kg^{-1} yr^{-1}
Ge
NaI
Cryodet
Liq. Noble
CS2
Projected
Signal
Oroville
Homestake
H−M '94
Edelweiss '98
UKDMC
H−M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
CDMS I SUF '02
LIBRA '08
WARP '07
Edelweiss '03
ZEPLIN I
ZEPLIN II
CDMSII Soudan '04
CRESST '11
Edelweiss '09
XENON10
CDMSII Soudan '10
Edelweiss '11
XENON100 '10
ZEPLIN III
XENON100 '11
XENON100
XMASS 800kg
ArDM
DARKSIDE50
LUX 300kg
DEAP3600
XENON1T
LZS
cMSSM, Log Prior
Null search at LHC
XENON-100
Phase 1
Phase 2

X

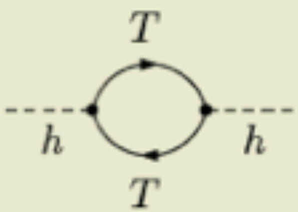
Flavor Physics



Higgs and Flavor sectors...

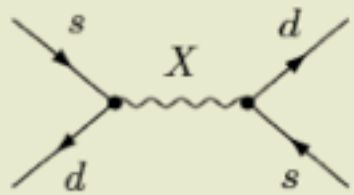
$$\mathcal{L}_{\rm EFT} = \Lambda_{\rm UV}^2\,\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{\mathcal{L}^{(5)}}{\Lambda_{\rm UV}} + \frac{\mathcal{L}^{(6)}}{\Lambda_{\rm UV}^2} + \ldots$$

electroweak symmetry breaking $\Downarrow$ Higgs mass



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

$\Downarrow$



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

no fine-tuning $\Downarrow$

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

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

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

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

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

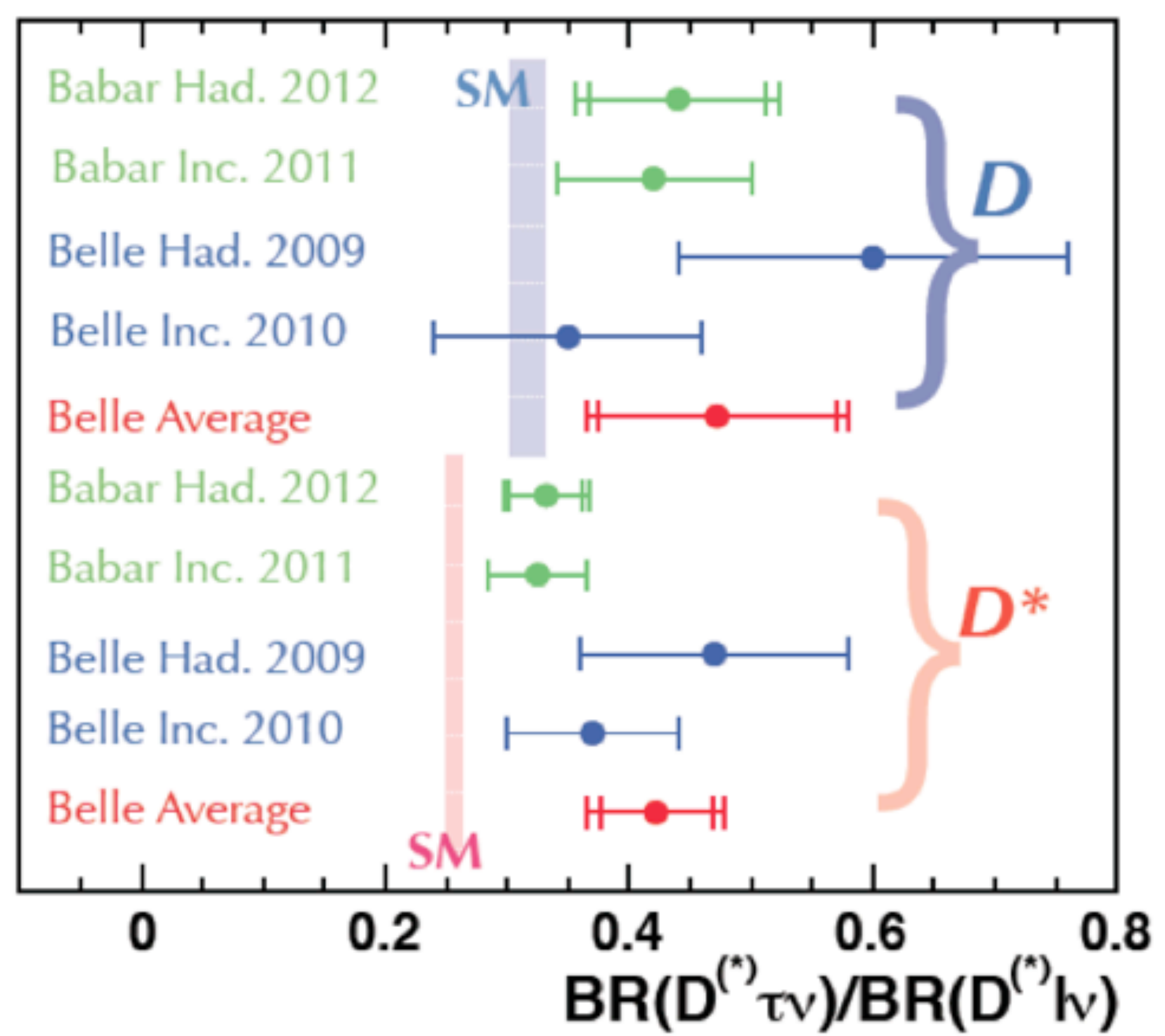
This result demands an enhancement of the suppressed CKM amplitudes of the SM of a factor approx. 5 – 10 Isidori, Kamenik, Ligeti, Perez 2011

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

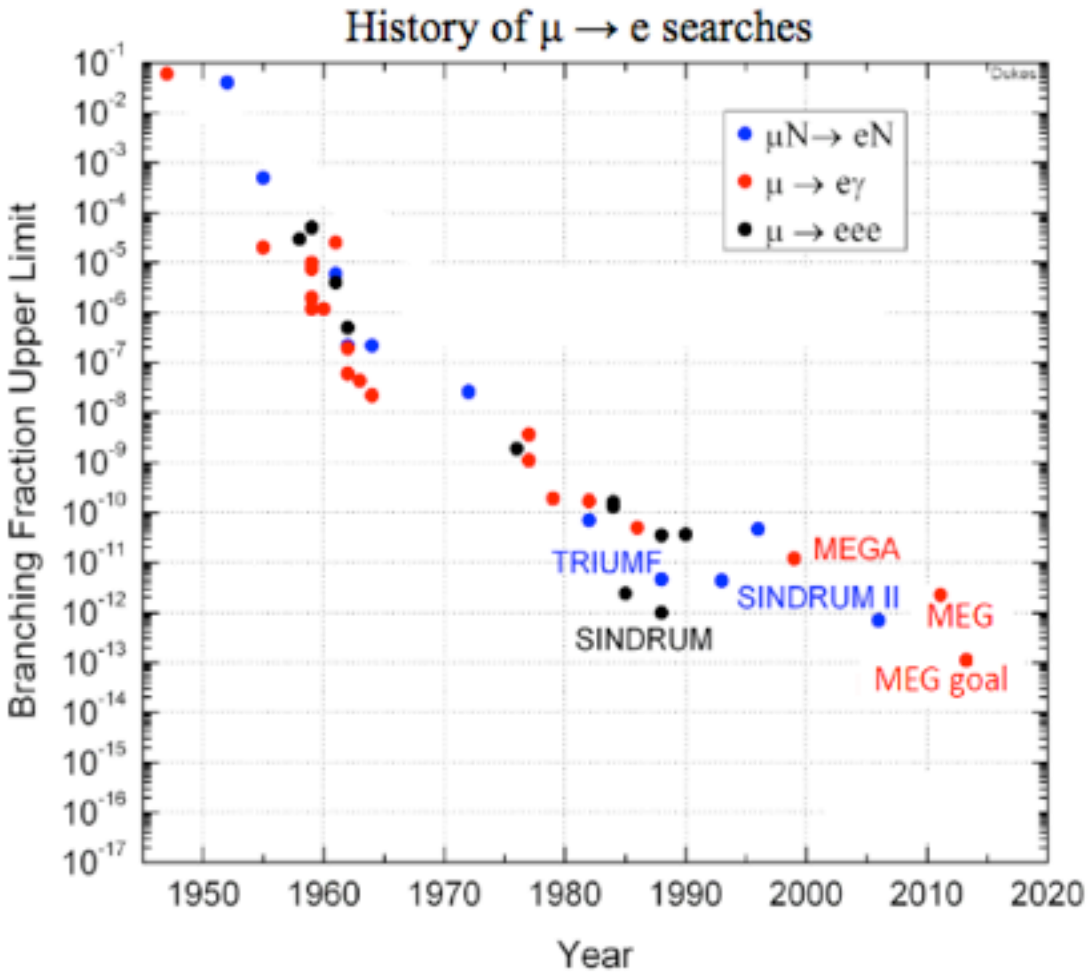
POSSIBLE SURPRISES FROM THE KAON TOO → NA62 ?

Another discrepancy



Lepton Flavor Violation

- Neutrino oscillations => Lepton Flavor Violation
- No problems of SM (and SM + ν) backgrounds
- LFV in charged leptons at "visible rates" if there are new particles carrying lepton flavor not too far from the TeV scale (*as in most realistic NP models*)



There was some focus on "smaller" experiments, which can extend the limits on LFV by 2-4 orders of magnitude... indirectly reaching into the TeV scale.

Lepton Flavor Violation

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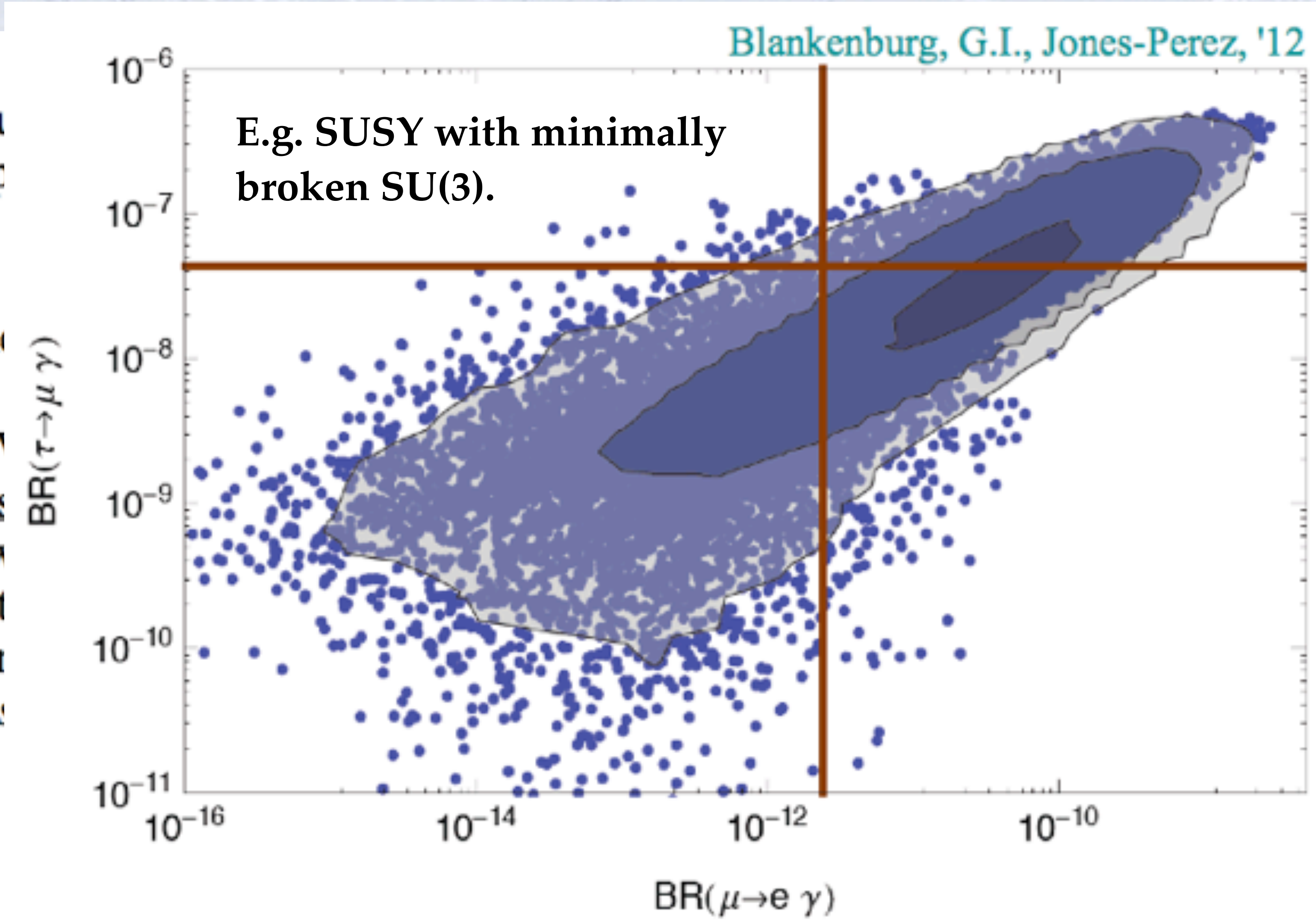


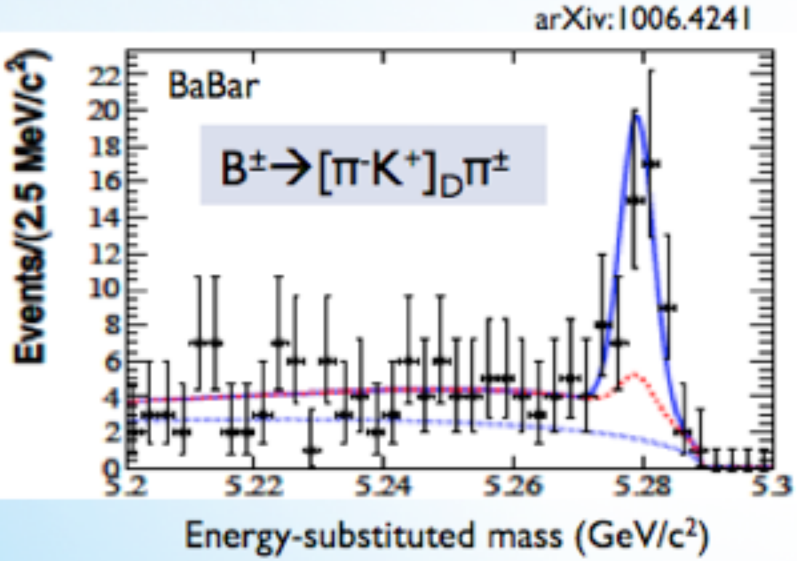
EG
goal
0 2020

There was some focus on "smaller" experiments, which can extend the limits on LFV by 2-4 orders of magnitude... indirectly reaching into the TeV scale.

The role of LHCb

Rule of thumb:

1/fb at 7TeV at LHCb is equivalent to (1-5)/ab at the B-factories before tagging.



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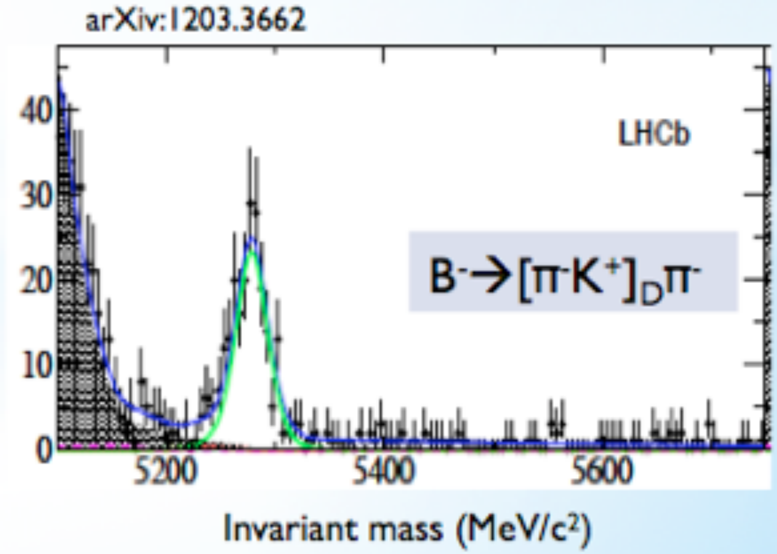


LHCb has "killed" essentially all minor discrepancies.
Theorists "complain" that in this light new theories are hard to make!
Underlying symmetry / mechanism protecting SUSY?!?

g-2 experiment and theory

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

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

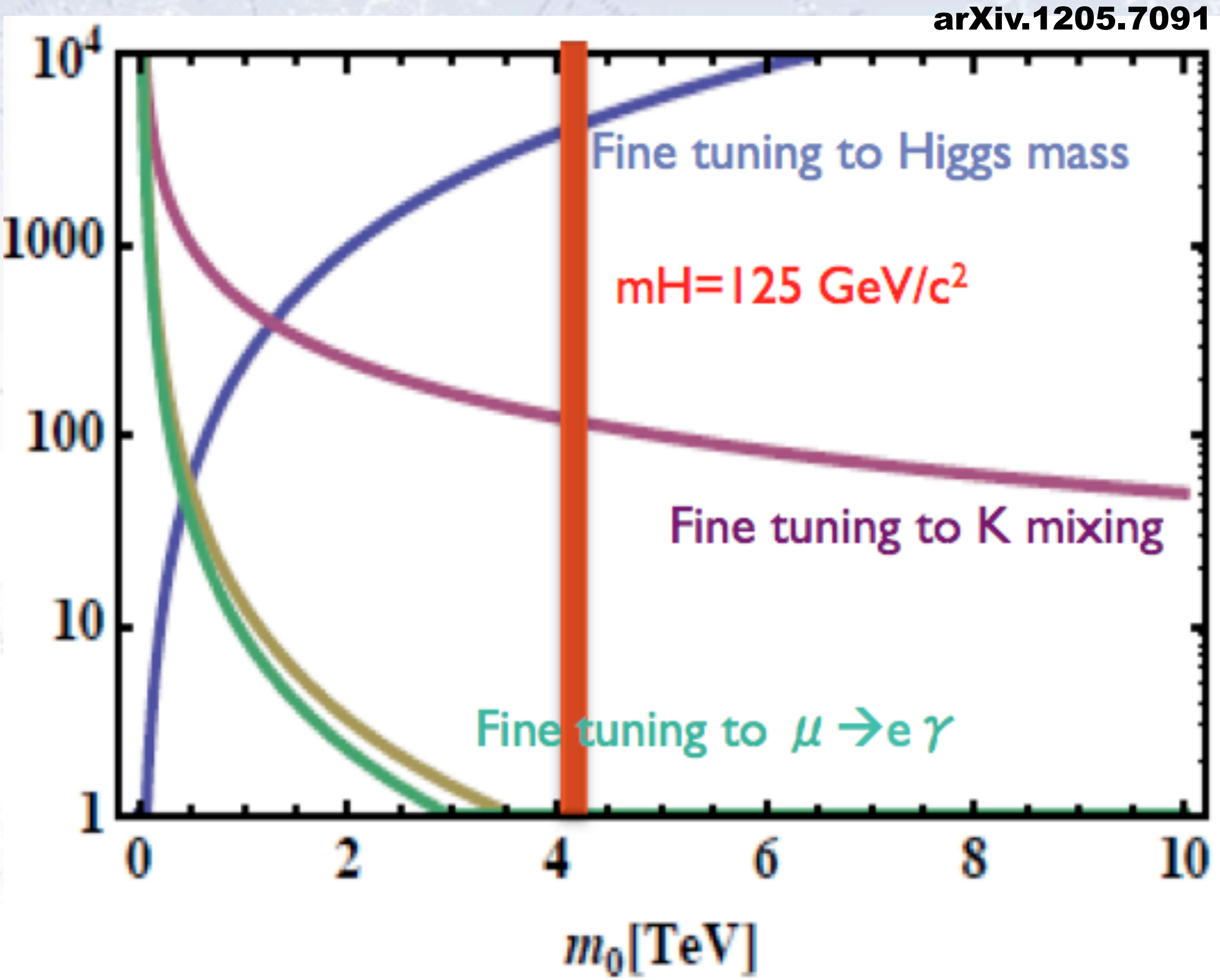
M. PASSERA 2012

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.

Unusual to see several "theories" try to match one measurement!!!

Comment on Fine Tuning…



What if...

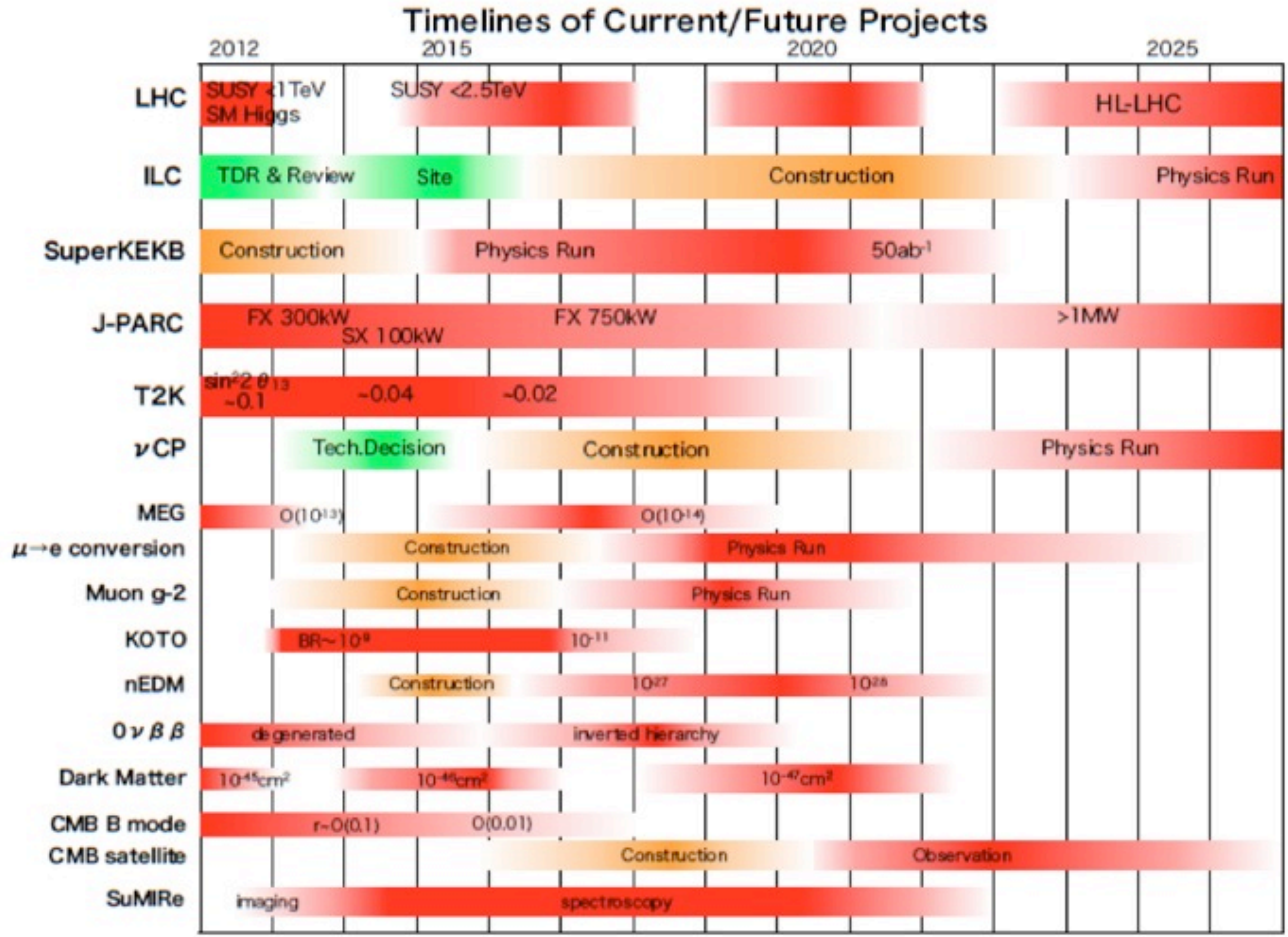
Picture courtesy of R. Rattazzi

What would have happened if in 1996 the CERN directorate had accepted the offer of the German company who was producing the LEP superconductive cavities and spent XX MCHF to buy 32 extra cavities?

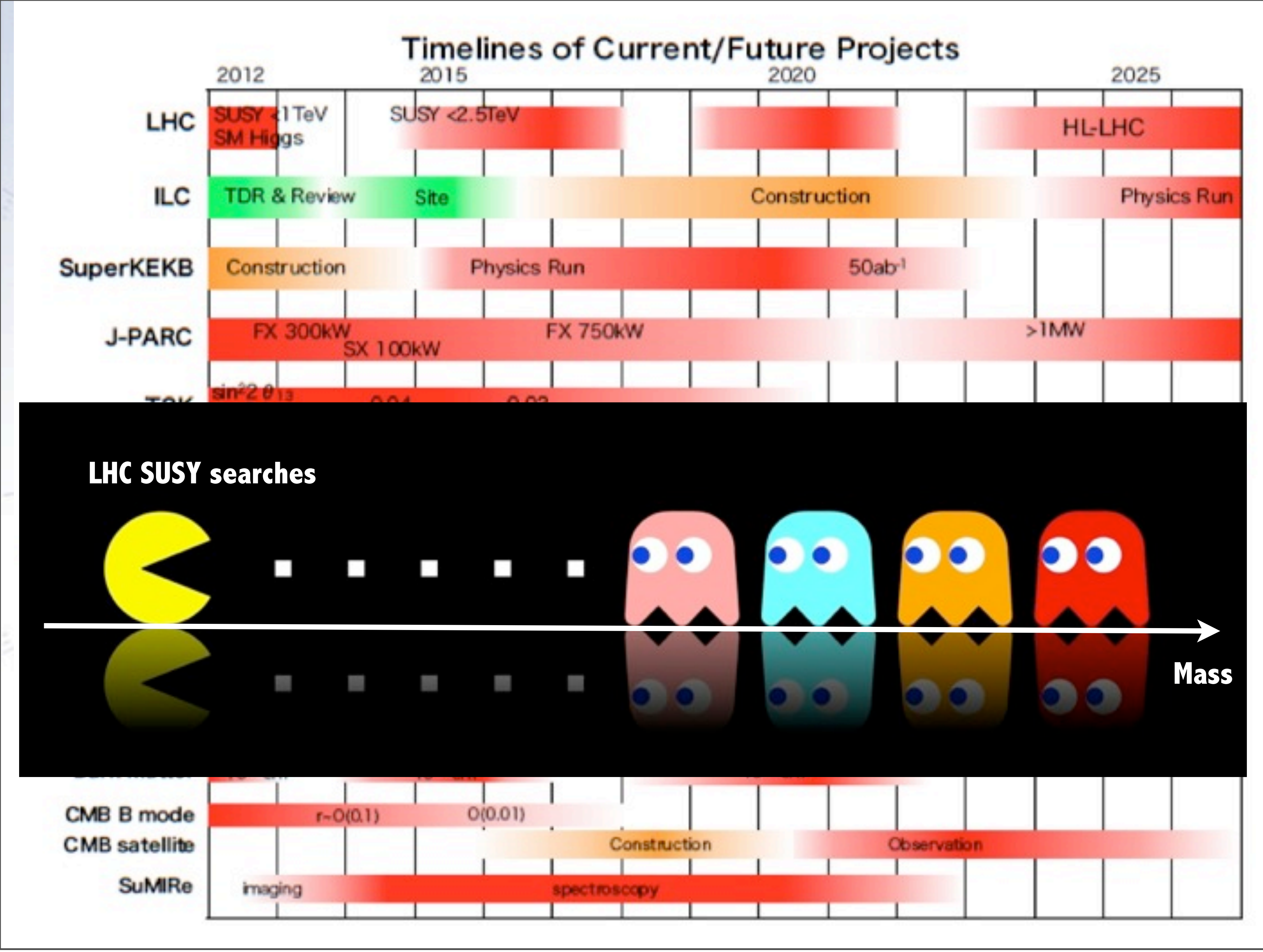
- the Higgs is discovered in the Spring of 2000
- the democrats understand that Clinton made a mistake in canceling the SSC and they decide to resume the project
- science becomes a major topic in the campaign and people understand that the results in Florida is not a statistical fluctuation but a fraud
- Al Gore becomes the 43rd US president
- no war in Afghanistan nor in Iraq
- no economical crisis
- Japan starts building an ILC in 2010, CLIC construction starts in 2011.
- LHC discovers SUSY in the fall of 2012... Etc, Etc...

We are only a few years behind schedule!

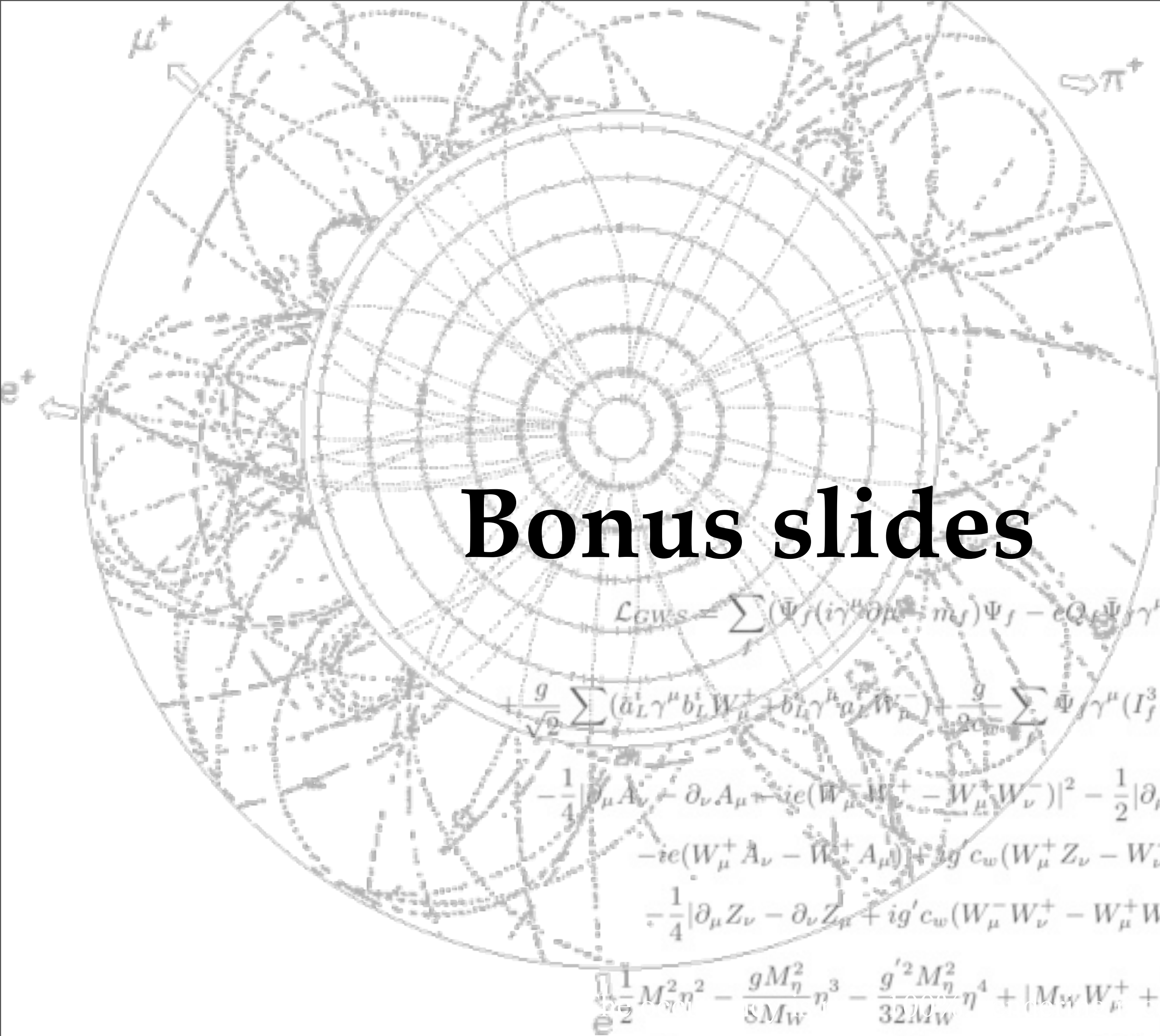
C. Grojean



Monday, November 12, 12



Timelines of Current/Future Projects
2012
2015
2020
2025
LHC
SUSY <1TeV
SM Higgs
SUSY <2.5TeV
HL-LHC
ILC
TDR & Review
Site
Construction
Physics Run
SuperKEKB
Construction
Physics Run
50ab-1
J-PARC
FX 300kW
SX 100kW
FX 750kW
>1MW
LHC SUSY searches
Mass
CMB B mode
r~O(0.1)
O(0.01)
CMB satellite
Construction
Observation
SuMIRe
imaging
spectroscopy



Bonus slides

$$
\begin{aligned}
\mathcal{L}_{GWS} = & \sum_f (\bar\Psi_f (i\gamma^\mu \partial_\mu - m_f)\Psi_f - eQ_f \bar\Psi_f \gamma^\mu \Psi_f A_\mu) + \\
& + \frac{g}{\sqrt{2}} \sum_i (\bar a^i_L \gamma^\mu b^i_L W^+_\mu + \bar b^i_L \gamma^\mu a^i_L W^-_\mu) + \frac{g}{2c_w} \sum_f \bar\Psi_f \gamma^\mu (I^3_f - 2s^2_w Q_f - I^3_f \gamma_5)\Psi_f Z_\mu + \\
& - \frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 - \frac{1}{2}|\partial_\mu W^+_\nu - \partial_\nu W^+_\mu + \\
& - ie(W^+_\mu A_\nu - W^+_\nu A_\mu) + ig' c_w (W^+_\mu Z_\nu - W^+_\nu Z_\mu|^2 + \\
& - \frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w (W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 + \\
& - \frac{1}{2} M^2_\eta \eta^2 - \frac{g M^2_\eta}{8 M_W} \eta^3 - \frac{g'^2 M^2_\eta}{32 M_W} \eta^4 + |M_W W^+_\mu + \frac{g}{2} \eta W^+_\mu|^2 + \\
& + \frac{1}{2}|\partial_\mu \eta + i M_Z Z_\mu + \frac{ig}{2c_w} \eta Z_\mu|^2 - \sum_f \frac{g}{2} \frac{m_f}{M_W} \bar\Psi_f \Psi_f \eta
\end{aligned}
$$