Outlook

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The flavour of new physics
Zurich, 7-9 January 2015

1. Around the hierarchy problem

2. And if the hierarchy problem were a dead end?

1. Around the hierarchy problem

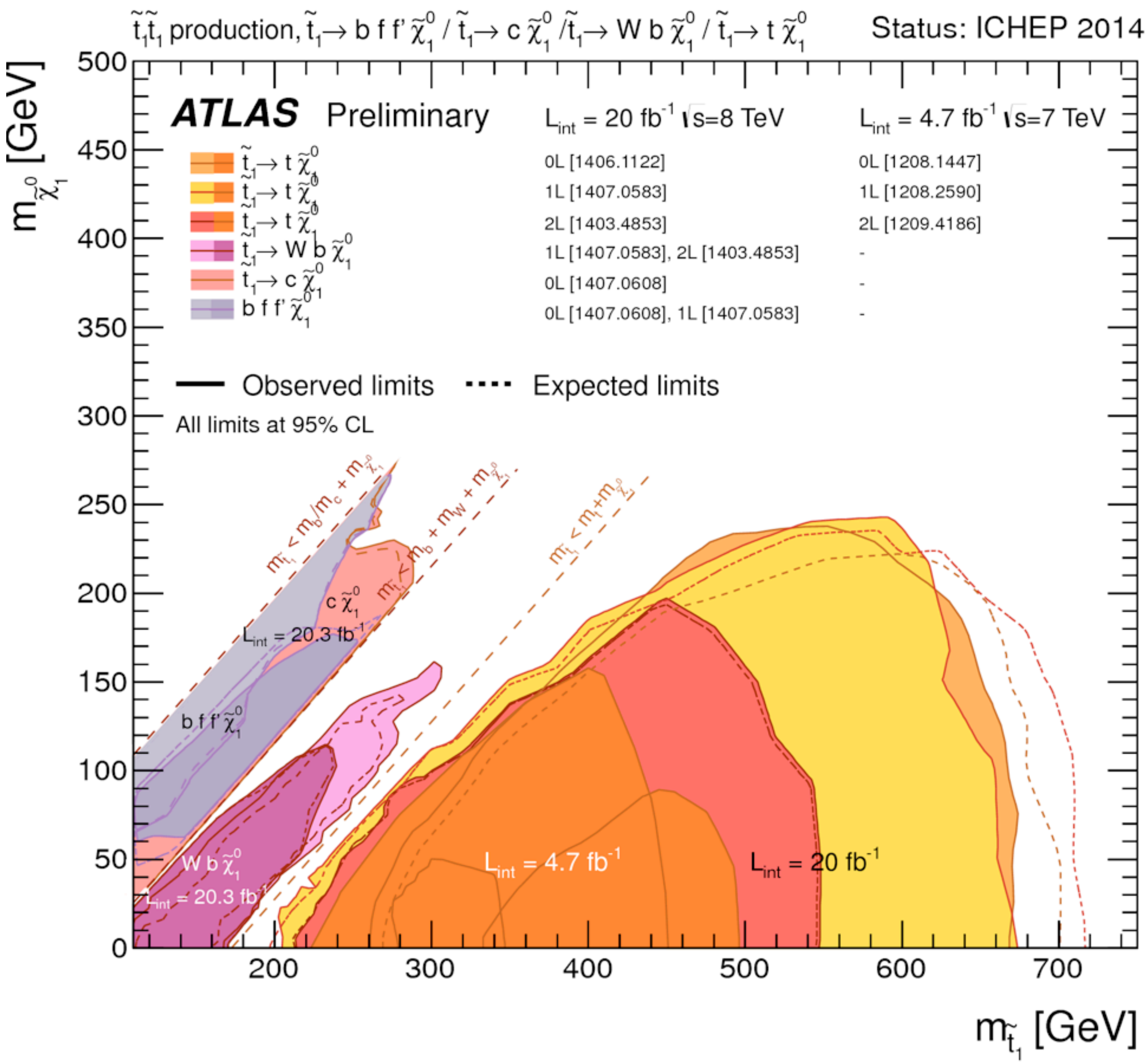
1. How solid are the "current" lower bounds on top-partner masses?

2. How dramatic is the "little hierarchy problem"?

3. Any strictly natural theory compatible with current data?

4. Can one formulate the hierarchy problem in a conceptually different way?

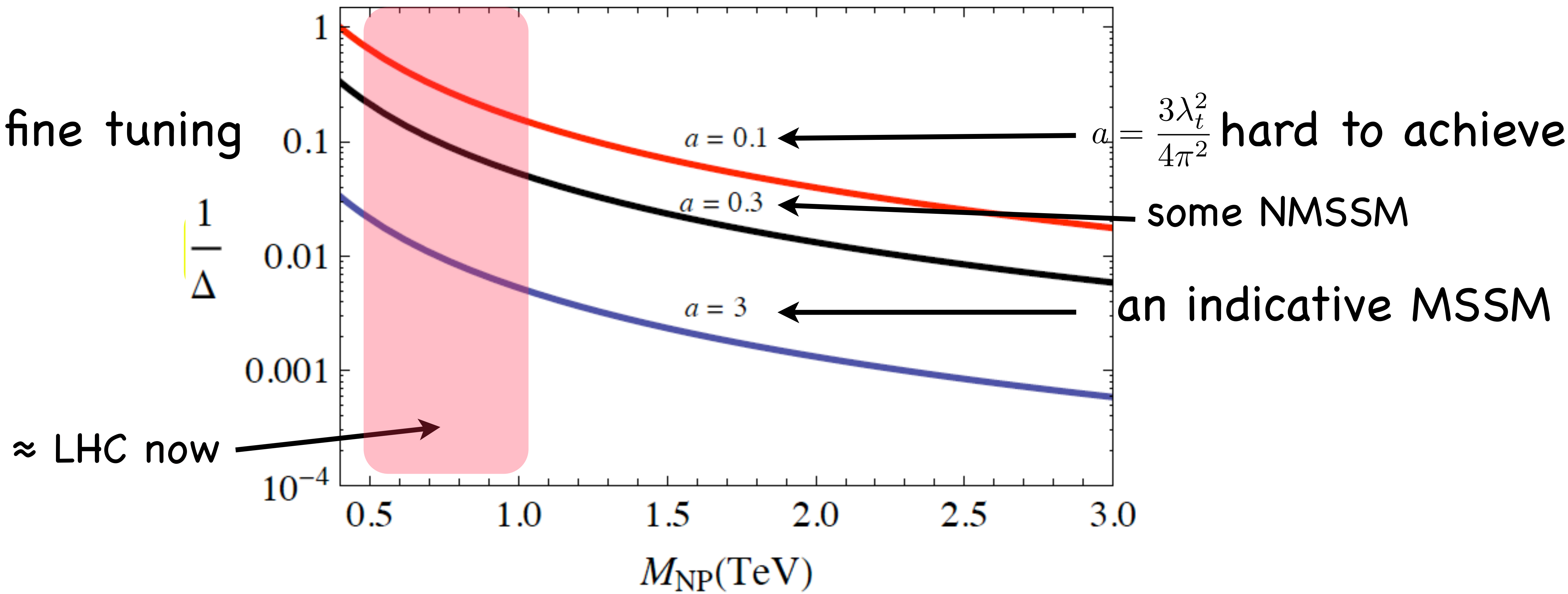
1. How solid are the "current" lower bounds on top-partner masses?



2. How dramatic is the "little hierarchy problem"?

$$\Delta \equiv \frac{\delta m_h^2}{m_h^2} \approx a \frac{M_{NP}^2}{m_h^2}$$

model dependent



- Things do not work the way they were originally thought
- Not a serious problem at a fundamental level: LHC-13 TeV
- A serious practical problem for the future: FCC, etc

3. Any strictly natural theory compatible with current data?

Not in my view. However

$$\lambda_t \bar{Q} t H + \lambda_t \bar{Q}_M t_M H_M + V(H) + V(H_M)$$

$$V(H) + V(H_M) : SO(4) \times SO(4)_M \times Z_2 \Rightarrow SO(8)$$

$$< H_M >= f \Rightarrow \ SO(8) \rightarrow SO(7)$$ ⇒ 7 PGBs

$$SU(2) \times U(1) \times (SU(2) \times U(1))_M \rightarrow SU(2) \times U(1) \times U(1)_M$$

⇒ 3(eaten by $SU(2)_M$) + 4(the standard H, not sensitive to $\lambda_t^2 \Lambda^2$)

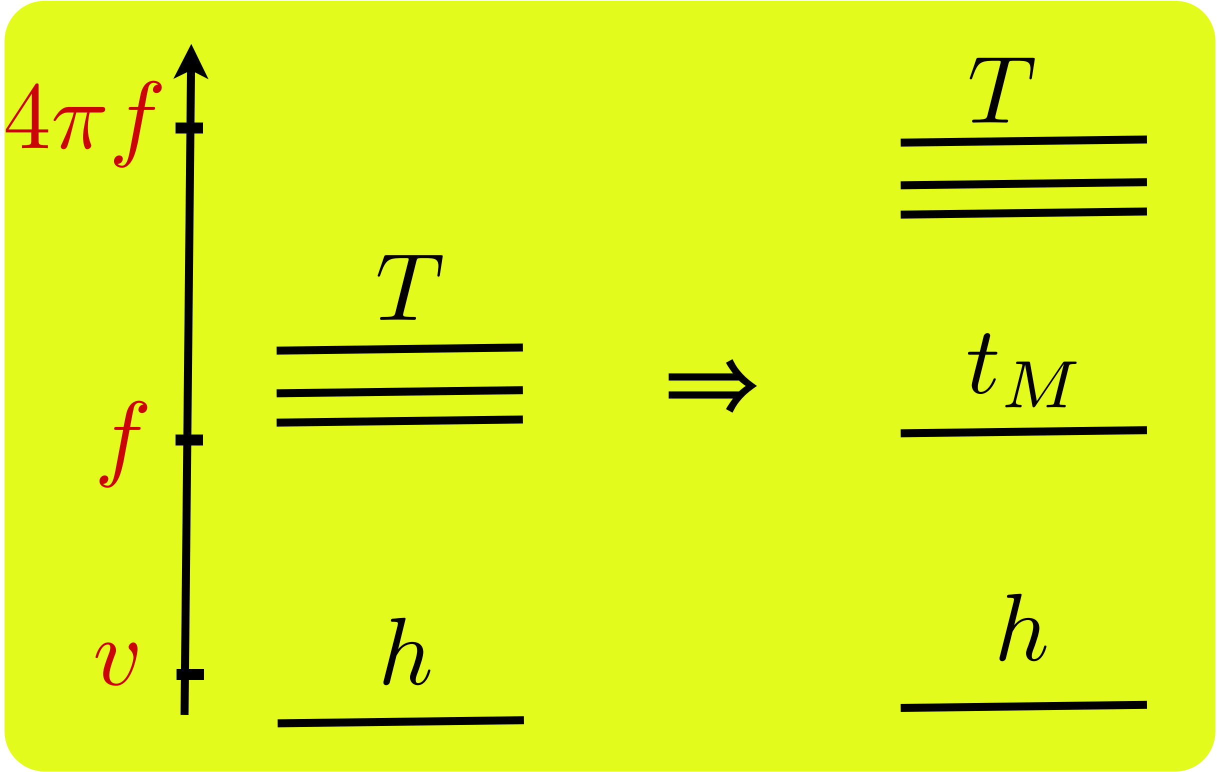
"Twin Higgs"

"Twin Higgs": an epicycle?

Greco, Rattazzi, Tesi, Wulzer

Which UV completion? Higgs composite

Z_2 breaking? Don't gauge $U(1)_M$



fine tuning: $O(v^2/f^2)$

4. Can one formulate the hierarchy problem in a conceptually different way?

Ways that do not work

Ways that leave us in the middle of nowhere

2. What if the hierarchy problem were a dead end?

1. Precision physics

2. The flavour puzzle

3. The astro-cosmo-particle connection

4. Dark Matter

Precision physics: 2 ways to go

"Micro-precision": Which possible deviations from the SM are less constrained?

effective operators and so on

"Macro-precision": How competitive with direct searches of NP?

Higgs couplings

LHC14 at $300\ fb^{-1}$
HighIntensity-LHC14
ILC
TLEP

versus

the EWPT
at a Z-factory

ILC
TLEP

1. "Composite" Higgs boson

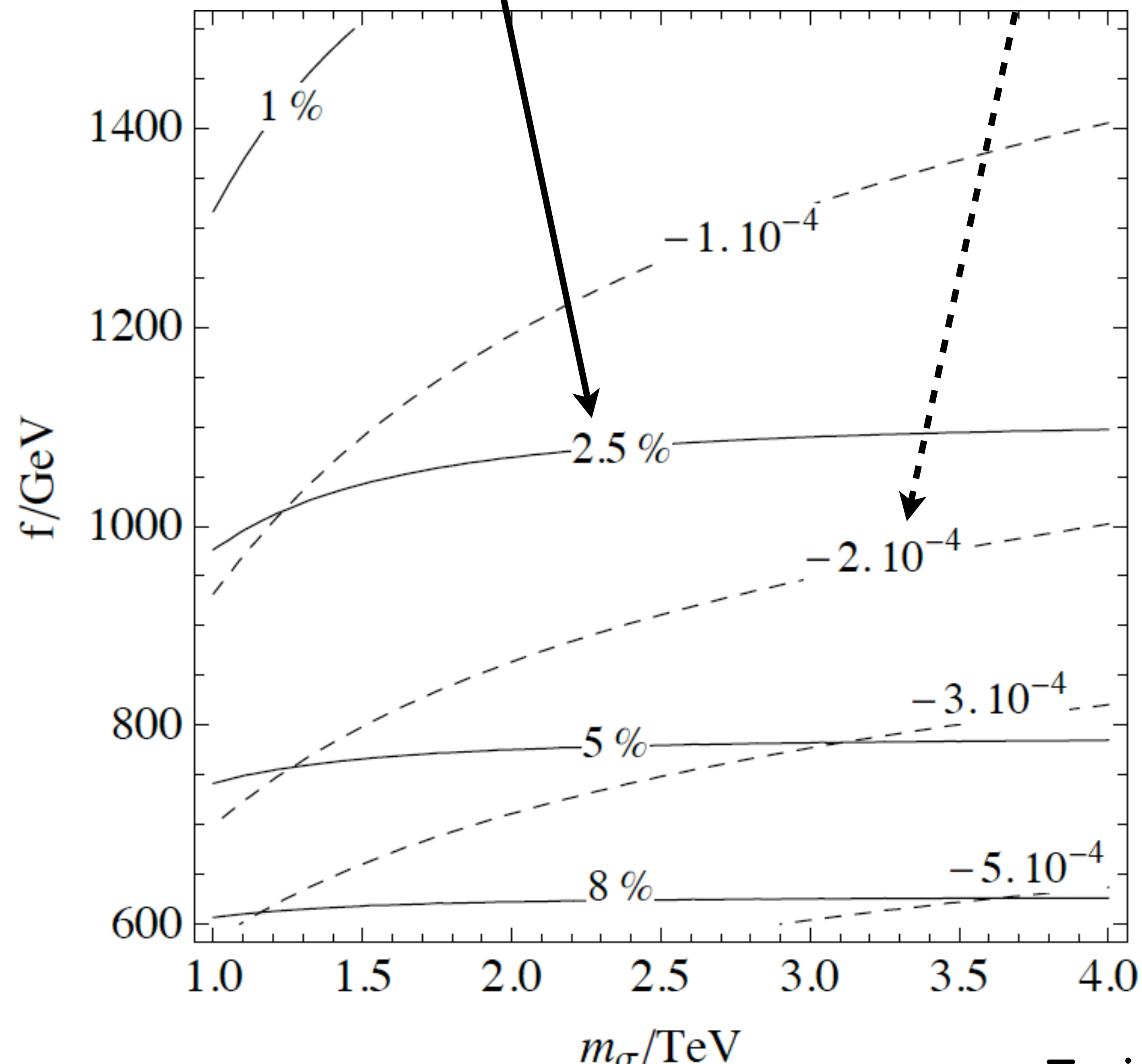
LHC14 after $300\ fb^{-1}$
$\delta g_{hVV} \approx 5\%$
(maybe down by a factor of 2 at HI-LHC if…)

At an e^+e^- h-factory
$\delta g_{hVV} < 1\%$

At TLEP
$\delta \varepsilon_i < 10^{-4}$

δg_{hVV}

$\Delta \varepsilon_i$



Tesi

Both types of precision tests highly motivated

2. NMSSM with s-particles and the second Higgs doublet "decoupled"

$$h = \cos\gamma H - \sin\gamma S$$

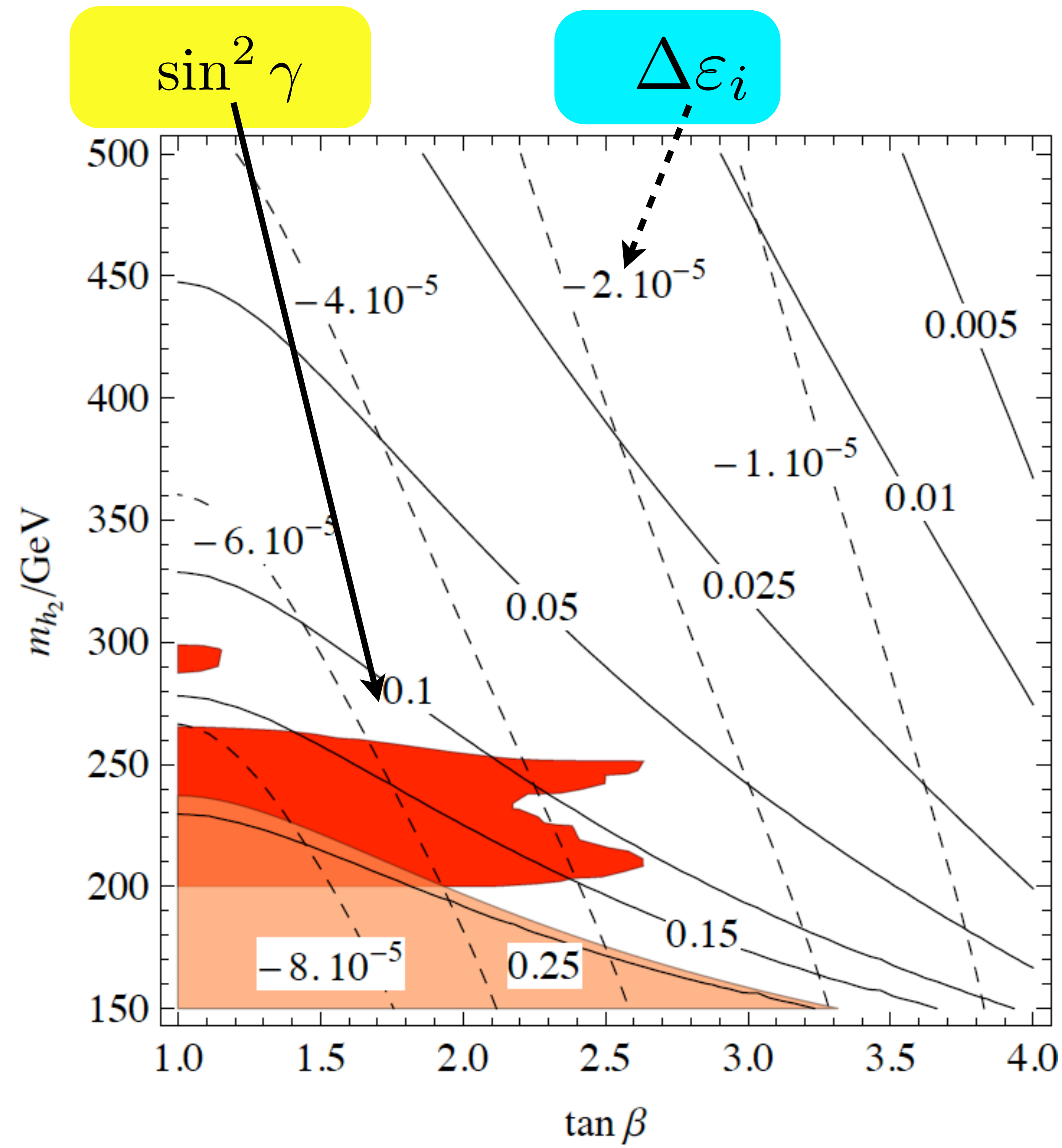
LHC14 after $300\ fb^{-1}$
$\sin^2\gamma \leq 0.15$ (95% CL)

HI-LHC $\sin^2\gamma \leq 0.05$

TLEP $\sin^2\gamma \leq 0.01$
(absolute σ_{Zh})

At TLEP
$\delta\varepsilon_i < 10^{-4}$

(Higgs precision dominant)



$\lambda = 0.8 \quad \Delta_t \leq 75\ GeV$

3. MSSM with s-particles "decoupled"

$$h = \cos\delta h_v - \sin\delta h_v^{\perp}$$

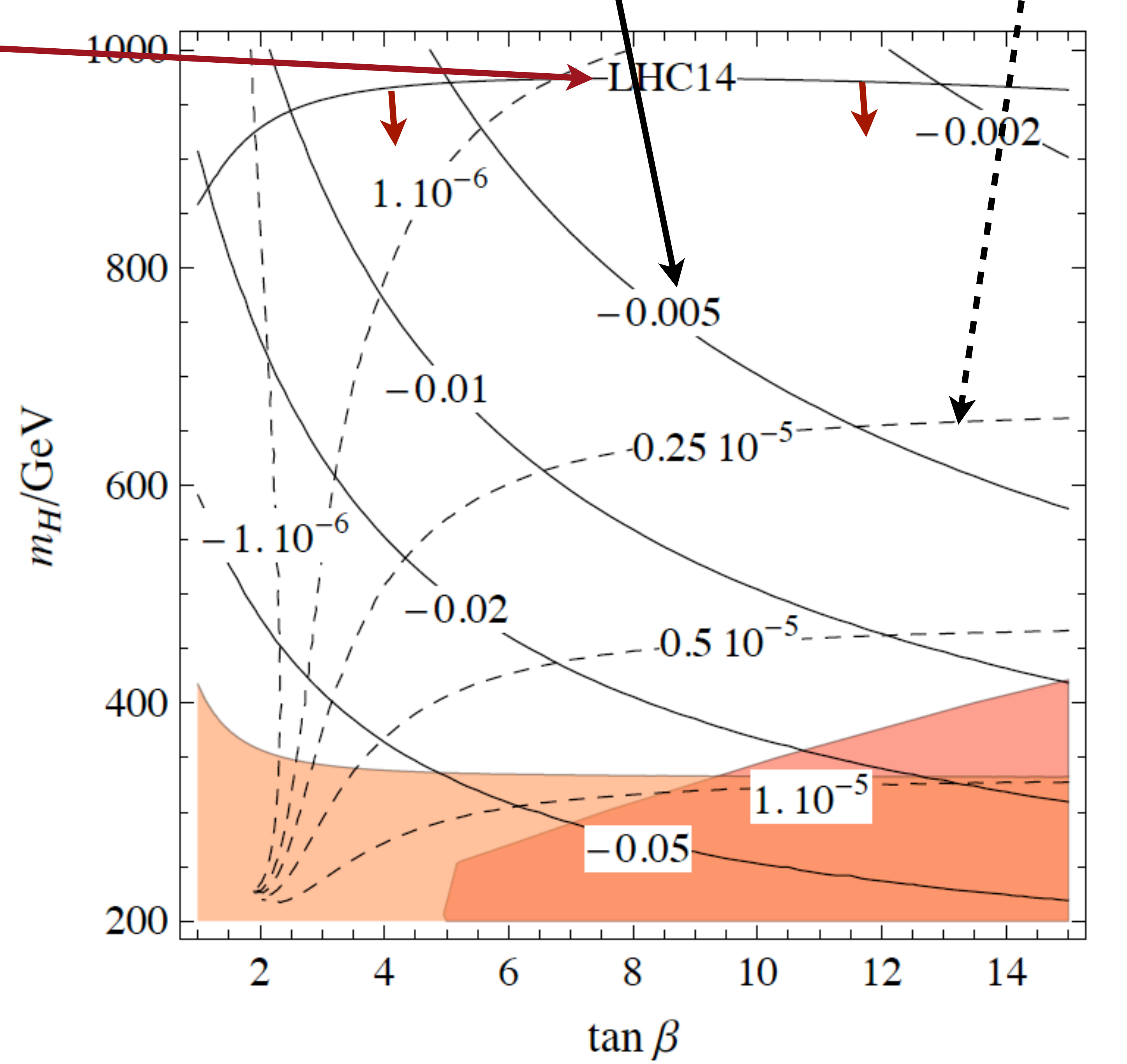
LHC14 after $300\ fb^{-1}$ (95% CL)

	ATLAS	CMS
$h \to \gamma\gamma$	0.16	0.15
$h \to ZZ$	0.15	0.11
$h \to WW$	0.30	0.14
$Vh \to Vb\bar{b}$	–	0.17
$h \to \tau\tau$	0.24	0.11
$h \to \mu\mu$	0.52	–

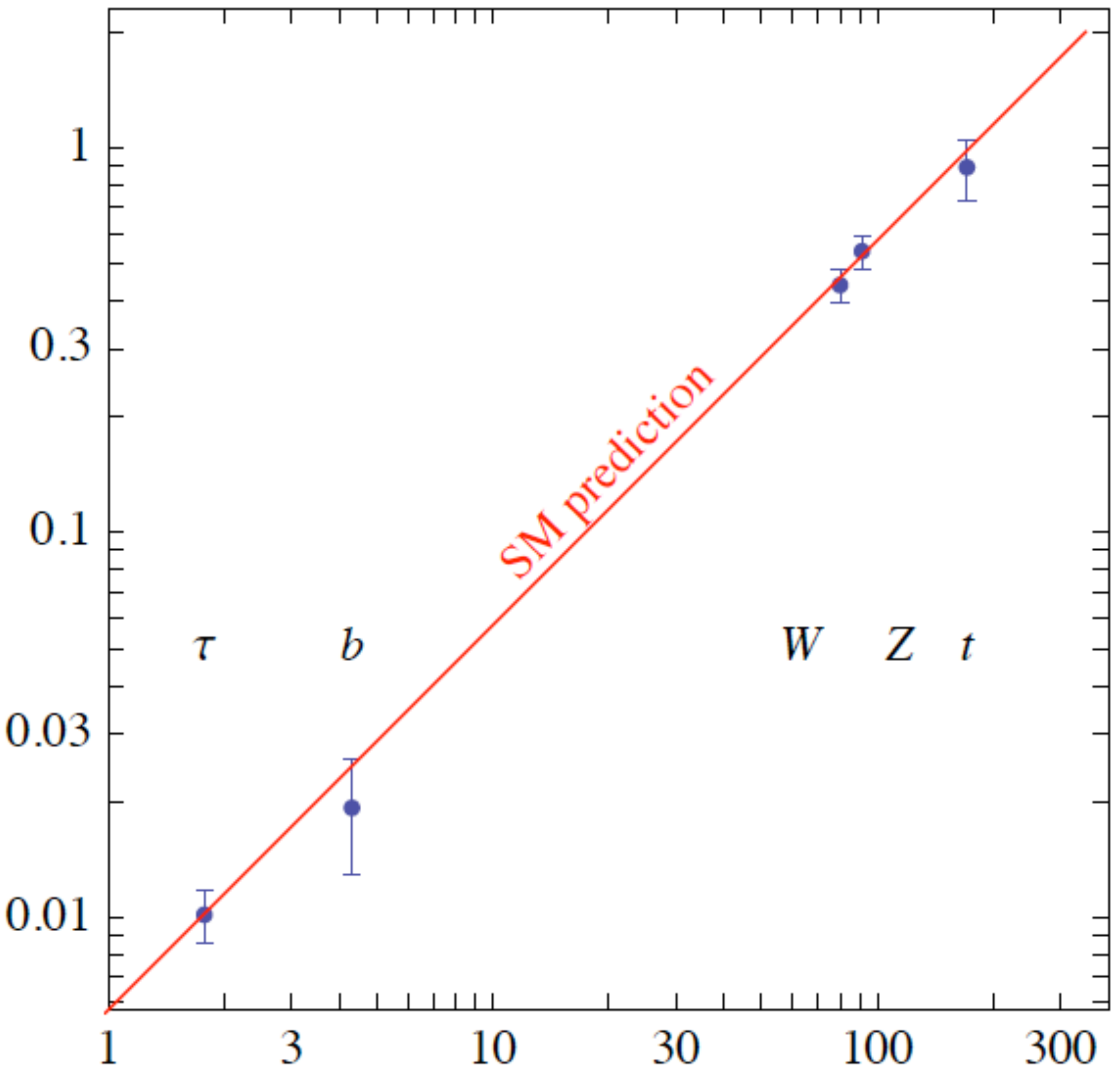
At TLEP

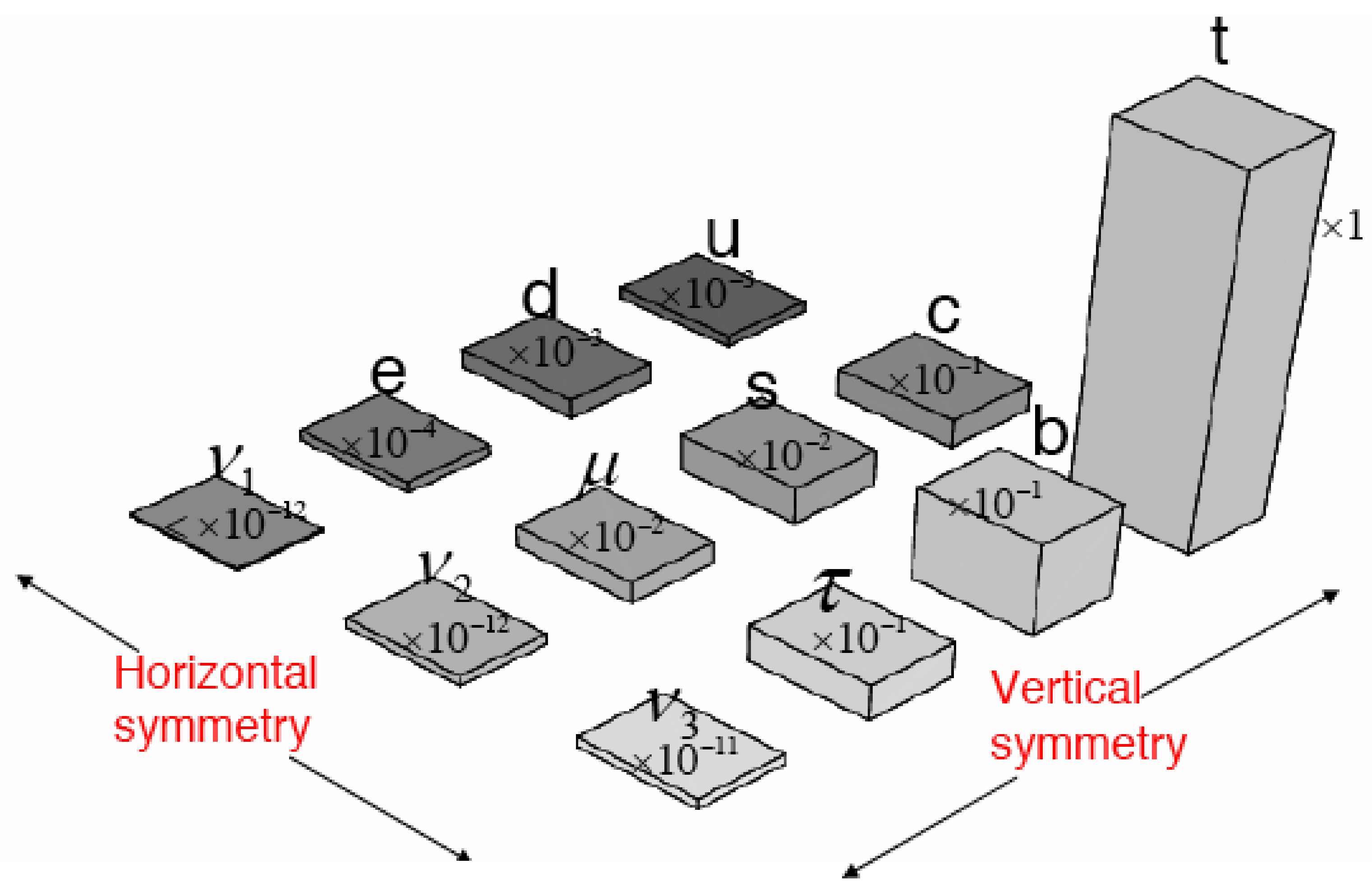
$\delta\varepsilon_i < 10^{-4}$

(Higgs precision dominant)



The flavour paradox





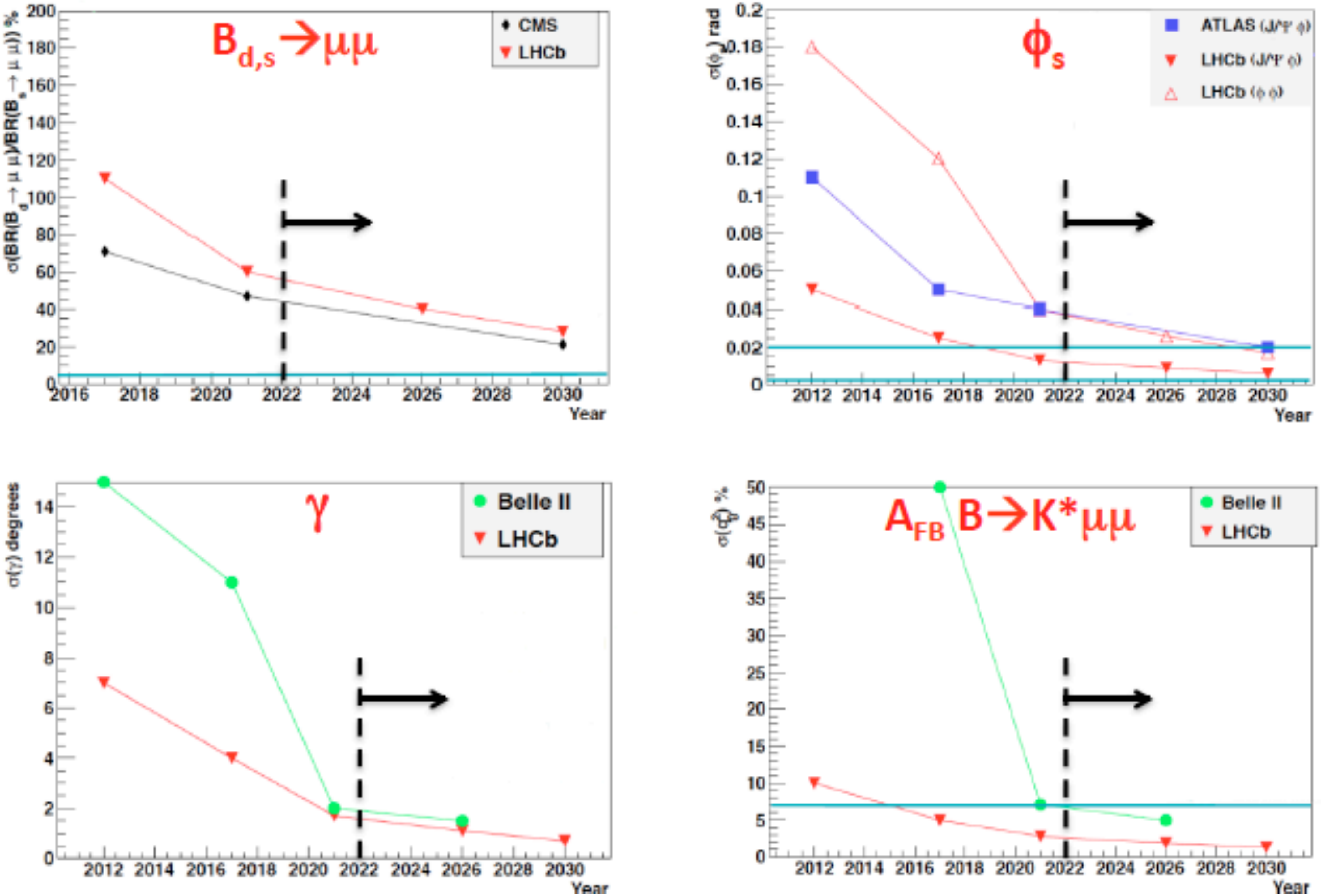
$$m_i = \lambda_i v$$

An "Extreme Flavour" experiment?

- Currently planned experiments at the HL-LHC will only exploit a small fraction of the huge rate of heavy-flavoured hadrons produced
  - ATLAS/CMS: full LHC integrated luminosity of 3000 fb^{-1}, but limited efficiency due to lepton high p_T requirements
  - LHCb: high efficiency, also on charm events and hadronic final states, but limited in luminosity, 50 fb^{-1} vs 3000 fb^{-1}
- Would an experiment capable of exploiting the full HL-LHC luminosity for flavour physics be conceivable?
  - Aiming at collecting O(100) times the LHCb upgrade luminosity → 10^{14} b and 10^{15} c hadrons in acceptance at $L=10^{35}\ cm^{-2}s^{-1}$

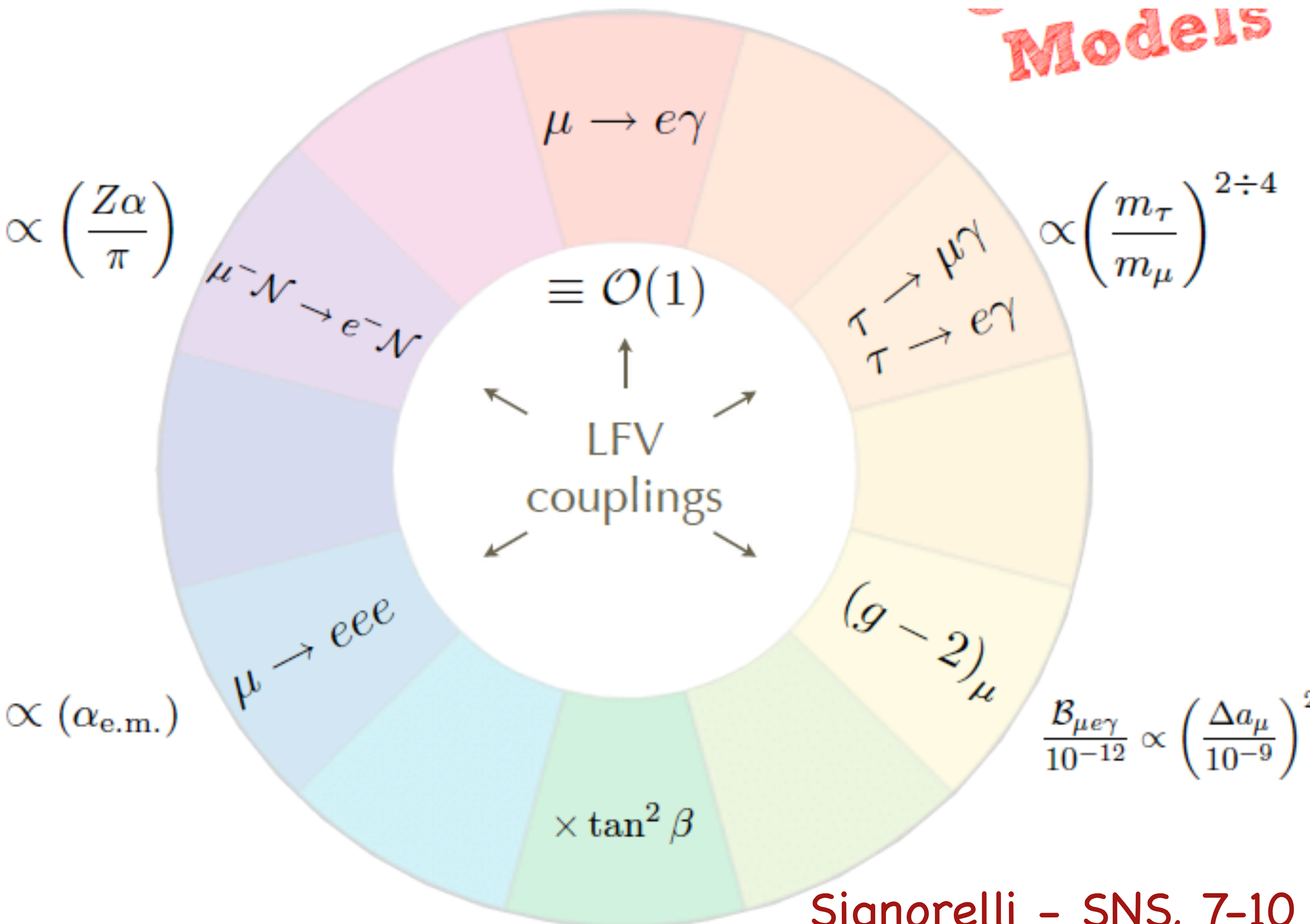
Motivation: test CKM from ≃ 20% to ≲ 1%

Nice prospects in the quark sector …



…but flattening out after ~2022

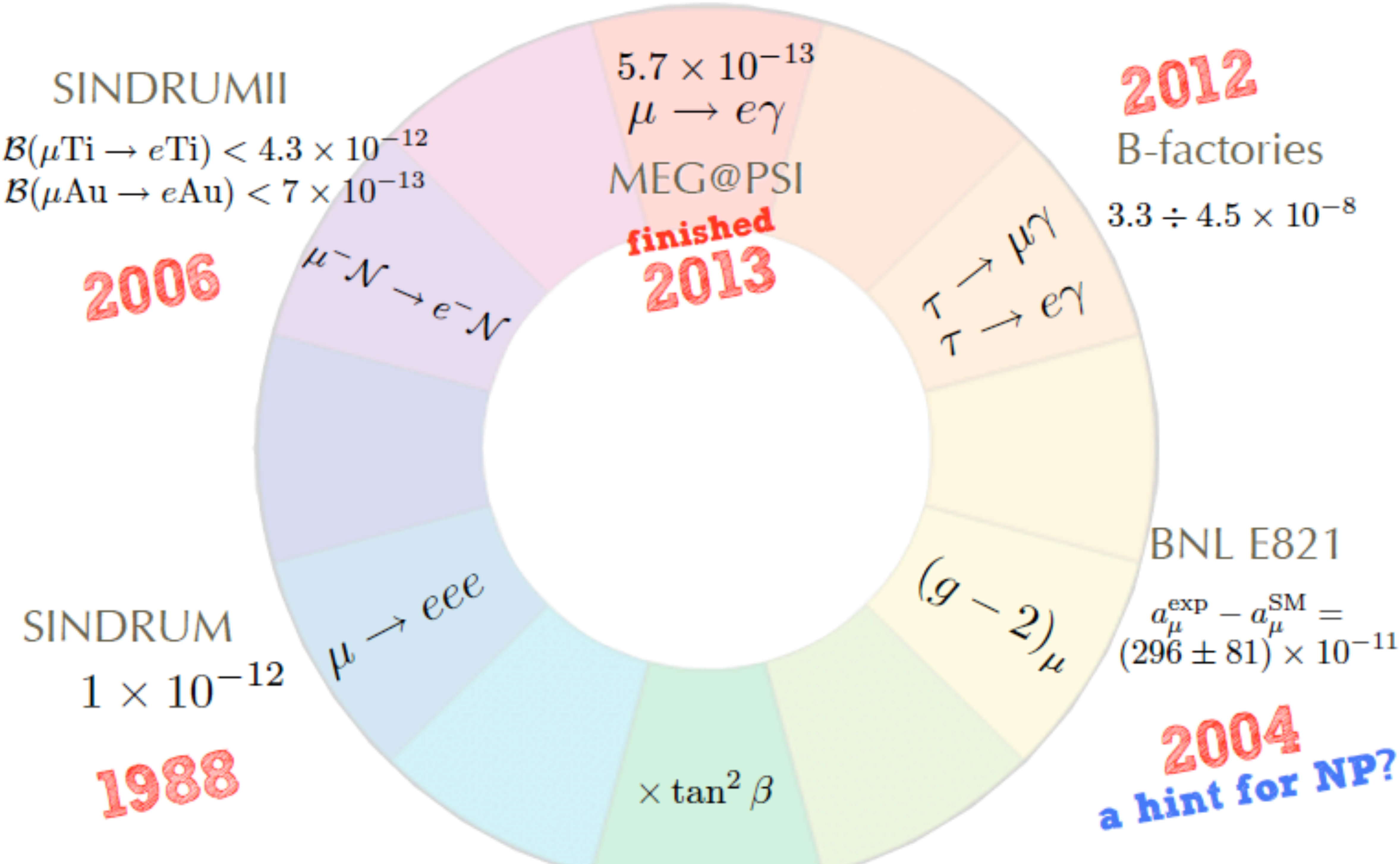
Lepton Flavour Violation



Signorelli - SNS, 7-10 Dec 2014

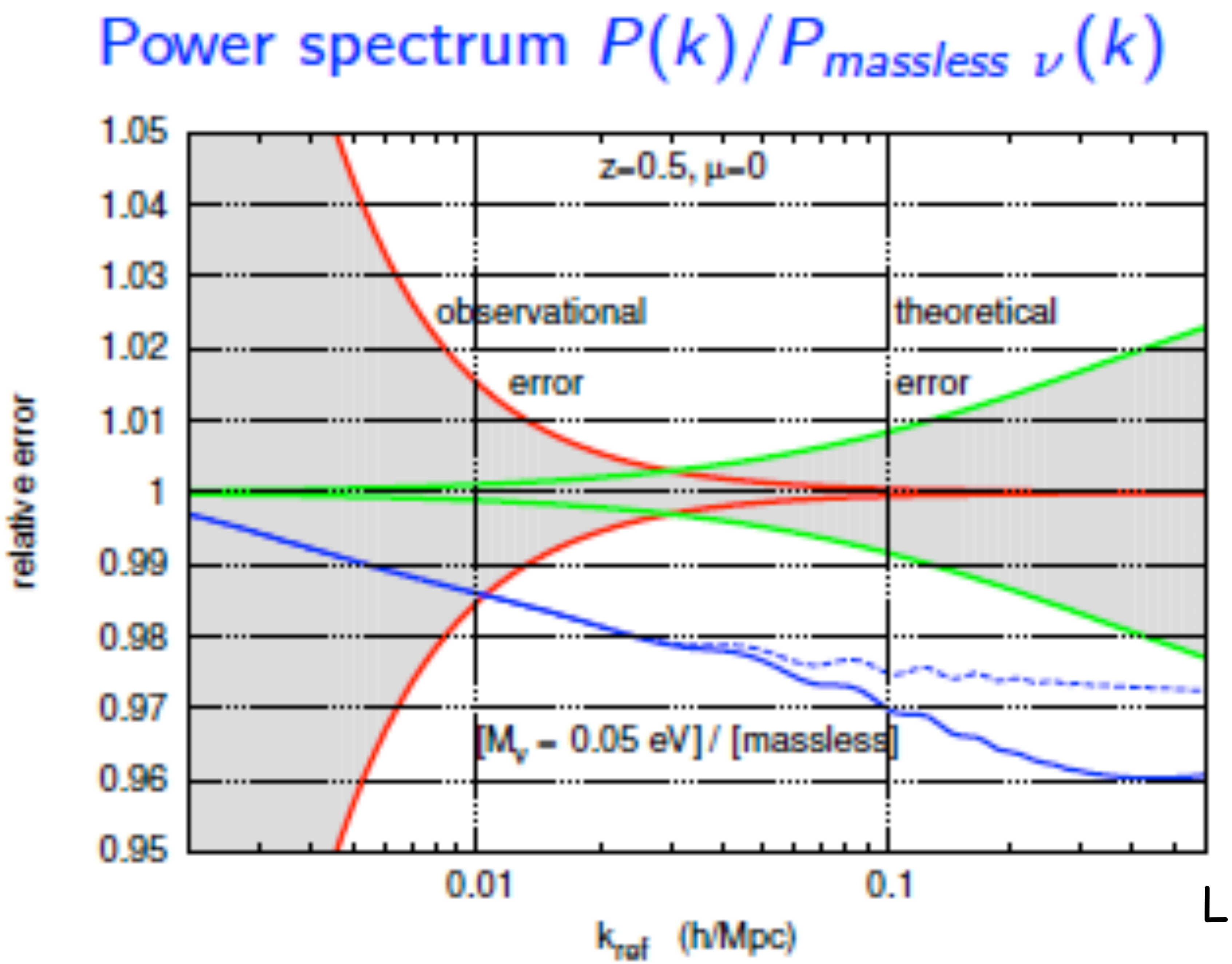
Motivation: extra degrees of freedom + unification

Current limits



time for improvement

The astro-cosmo-particle connection



Lesgourgues et al

- Determination with future large-scale structure observations (Euclid) at $2-5\sigma$ depending on control of (mildy) non-linear physics

  ▶ Not independent on "priors" but still highly significant

Key neutrino measurements

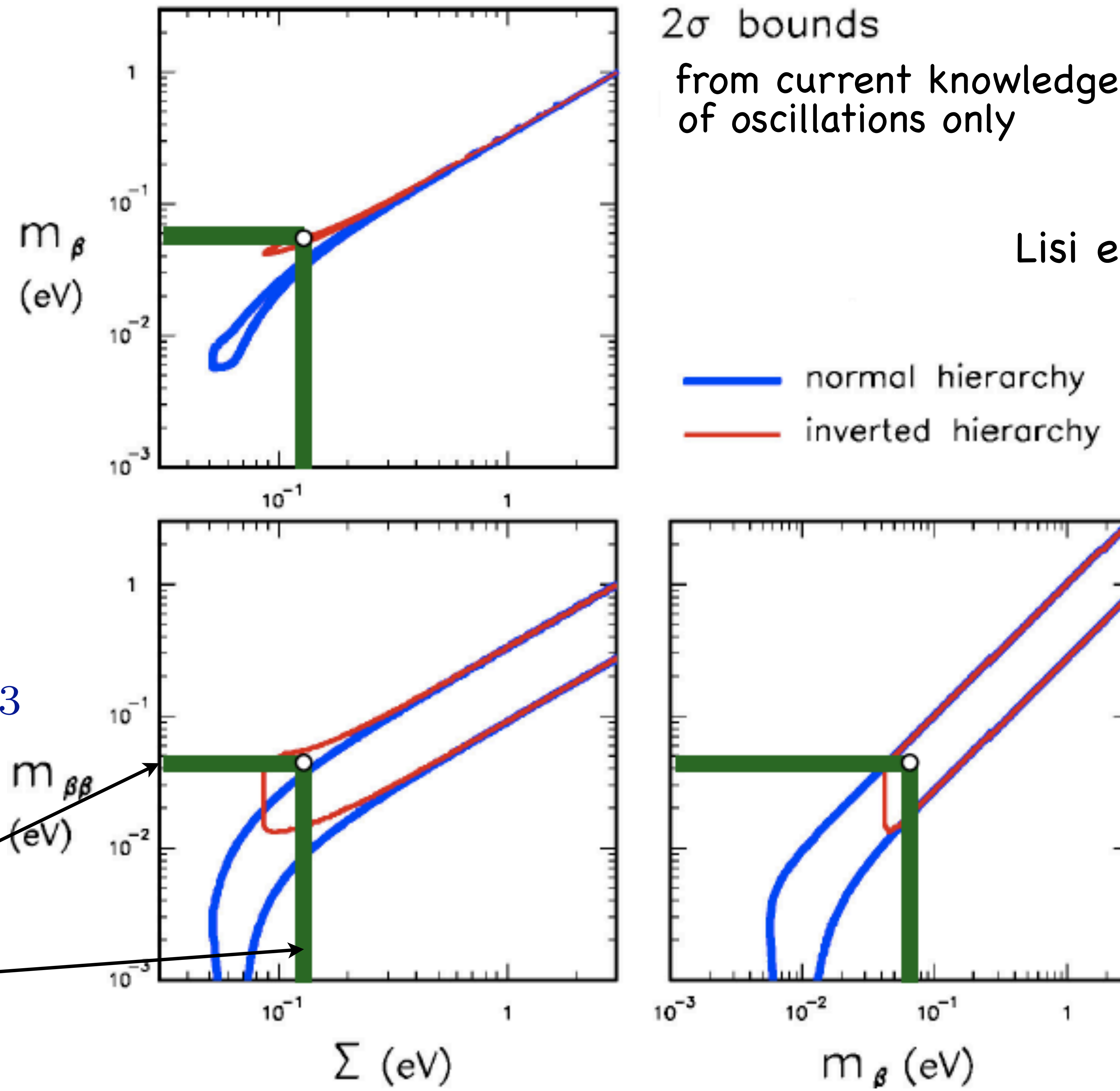
m_β
beta-decay endpoint

$m_{\beta\beta}$
neutrino-less $\beta\beta$ decay

$\Sigma = m_1 + m_2 + m_3$
large scale structures

2σ bounds
from current knowledge of oscillations only

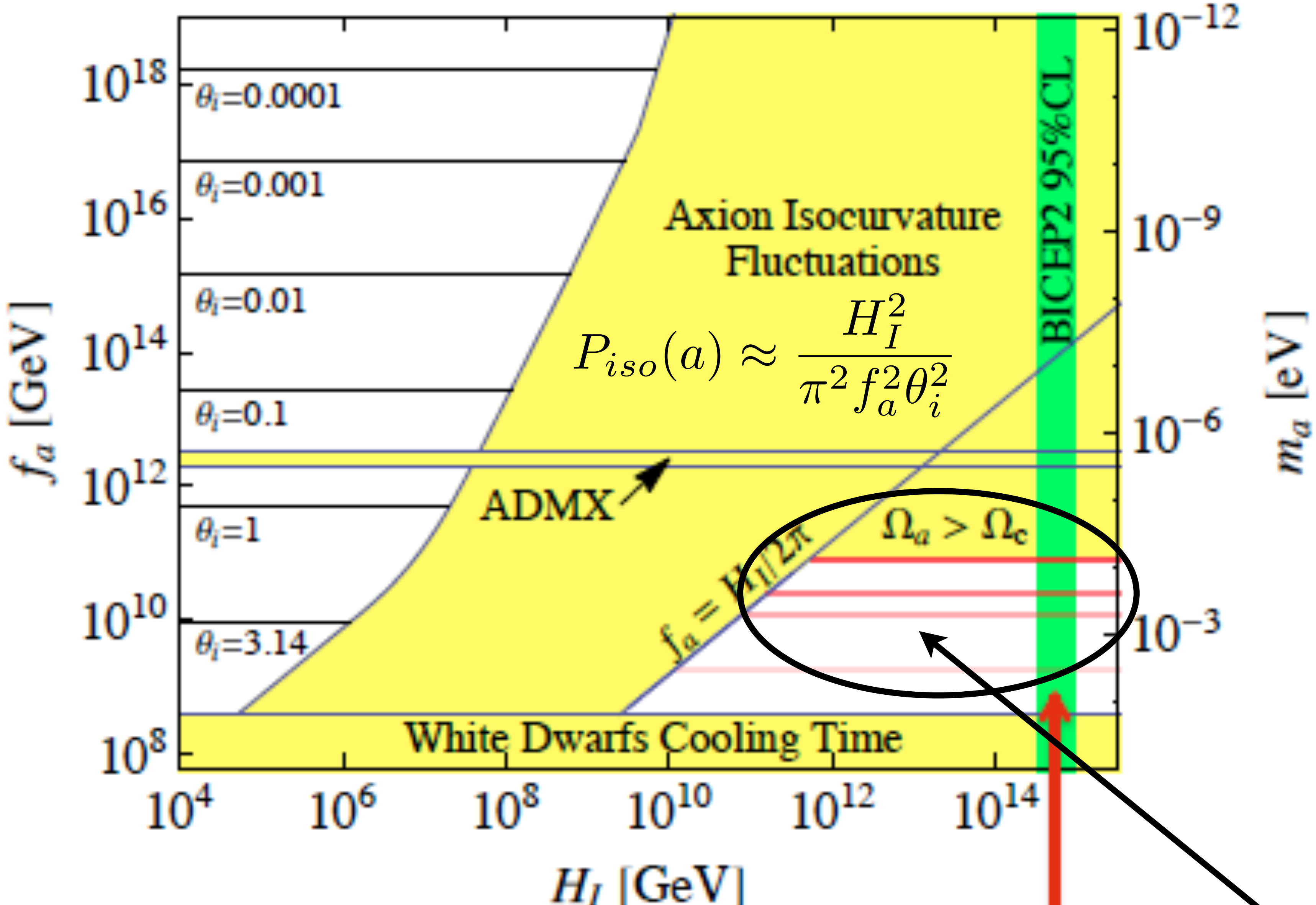
Lisi et al



hypothetical measurements

Dark Matter: QCD Axions

$m_a f_a \approx 10^{-4}\ eV \cdot 10^{11} GeV$

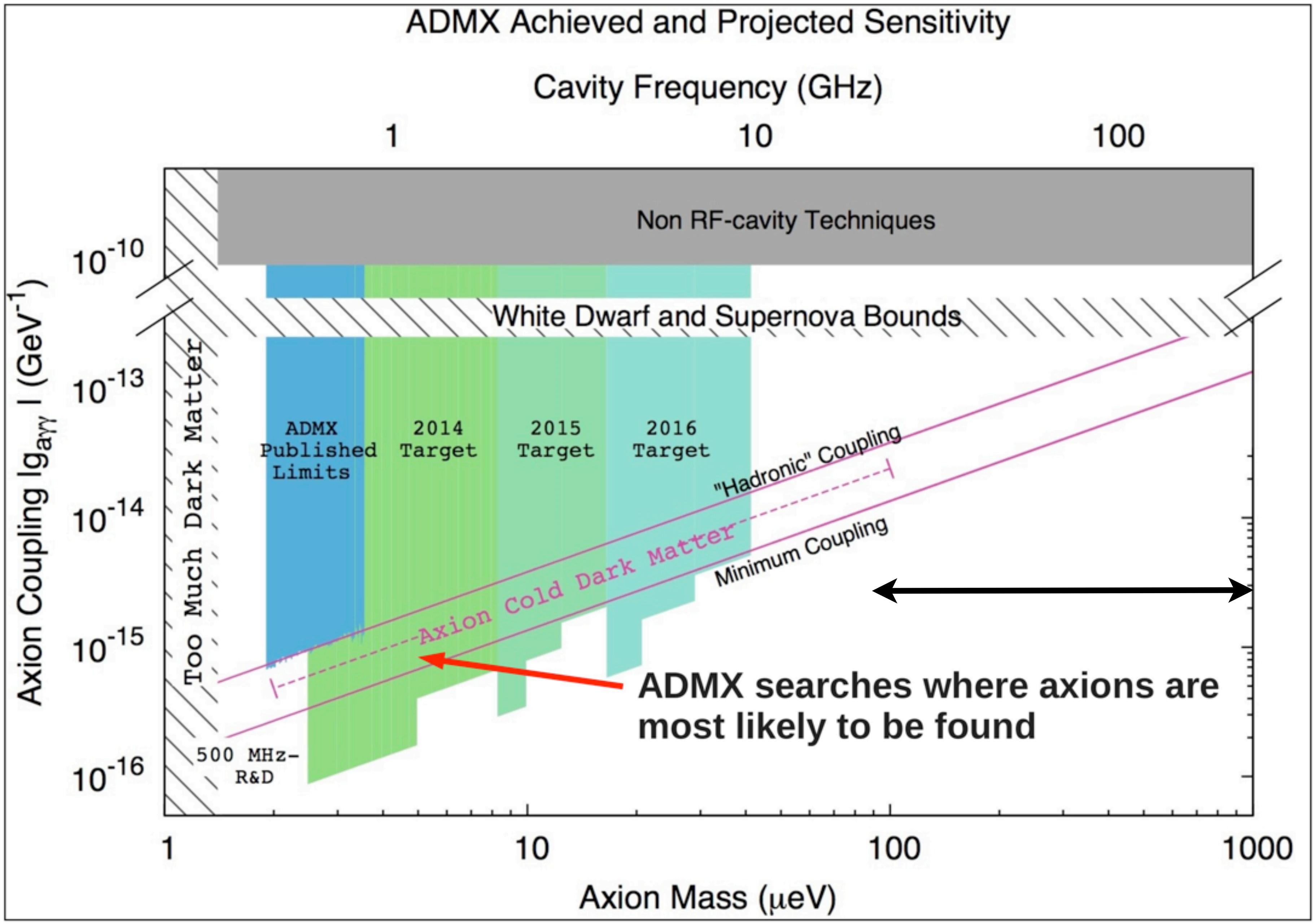


$$\Omega_a h^2 \approx 0.16\left(\frac{m_a}{10^{-5} eV}\right)^{-1.18} \theta_i^2 \qquad \theta_i = \frac{a_i}{f_a} \qquad \theta_i^2 = \frac{\pi^2}{3}$$

(Axion Like Particles: m and f unrelated)

The classic search

$$\mathcal{L}_{a\gamma\gamma} = -\left(\frac{\alpha}{\pi}\frac{g_\gamma}{f_a}\right) a\vec{E}\cdot\vec{B} = -g_{a\gamma\gamma} a\vec{E}\cdot\vec{B}$$



Not easy to explore the most relevant region

$10^{-4} \lesssim m_a/eV \lesssim 10^{-3}$

Rybka ADMX

The coupling to spin

$$L = \bar{\psi}(x)(i\hbar\partial\!\!\!/_x - mc)\psi(x) - a(x)\bar{\psi}(x)(g_s + ig_p\gamma_5)\psi(x)$$

$$g_p = A_\Psi \frac{m_\Psi}{f_a} \qquad (g_s = 10^{-(12\div17)} g_p \frac{GeV}{m_\Psi})$$

DFSZ
KSVZ

NRL: $$i\hbar\frac{\partial\varphi}{c\partial t} = \left[-\frac{\hbar^2\nabla^2}{2m} + g_s ca - i\frac{g_p}{2m}\vec{\sigma}\cdot(-i\hbar\vec{\nabla}a)\right]\varphi$$

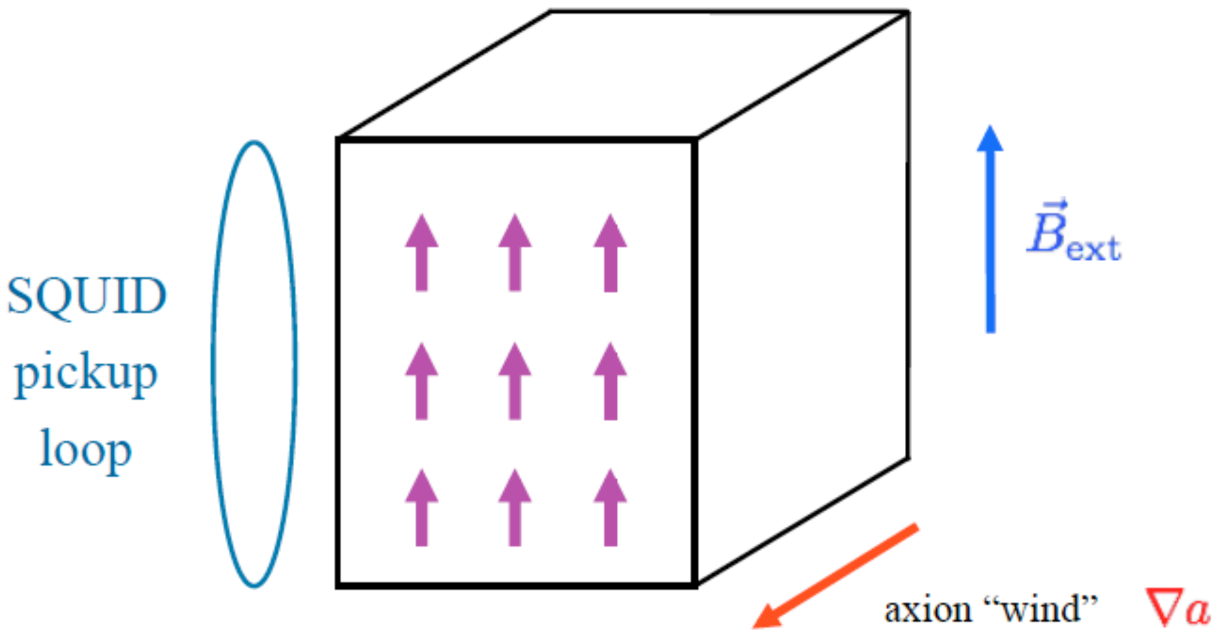
$$\gamma\vec{B}_{eff}\cdot\vec{\sigma} \qquad \gamma = \frac{e}{2m_\Psi}$$

A coupling to the spin and to the Electric field

$$L \approx \frac{\alpha_S}{4\pi}\frac{a}{f_a}G_{\mu\nu}\tilde{G}^{\mu\nu} \qquad \Rightarrow \quad d\,\vec{\sigma}\cdot\vec{E}$$

$$d \approx 10^{-16}\frac{a}{f_a}(e\cdot cm)$$

Proposal 1 (axion DM wind)



on electron spins
B, Cerdonio, Fiorentini, Vitale 1989

on nucleon spins
Graham, Rajendram 2010
CASPEr 2014

Solving Block eq.s, at resonance $m_a =$

- e: $2\gamma_e B^{ext} \approx 10^{-4}\ eV \frac{B^{ext}}{T}$
- N: $2\gamma_N B^{ext} \approx 10^{-7}\ eV \frac{B^{ext}}{T}$

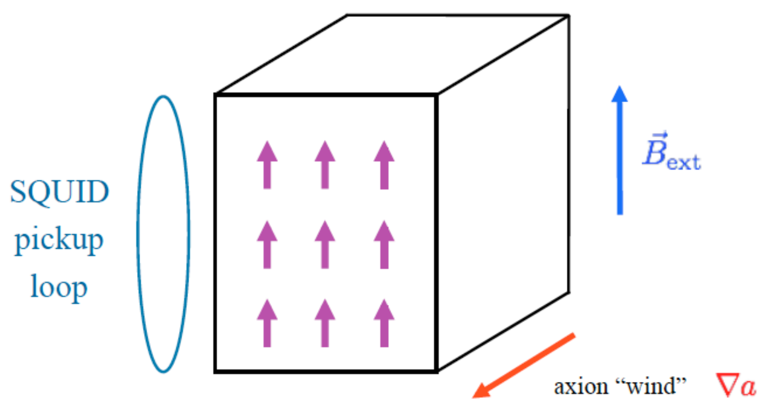
$$M_T = \gamma_{e,N}^2 B_{e,N}^{eff} n_S \tau \cos(m_a t)$$

- N: $10^{-19} T\ (m_a = 10^{-7}\ eV,\ \tau = 0.1\ sec)$
- e: $10^{-21} T\ (m_a = 10^{-4}\ eV,\ \tau = 10^{-6}\ sec)$

$$\tau = min(\tau_a, \tau_{rel}, \tau_R)$$

$$n_S = 10^{22}/cm^3$$

(partial) Summary on proposed exp.s

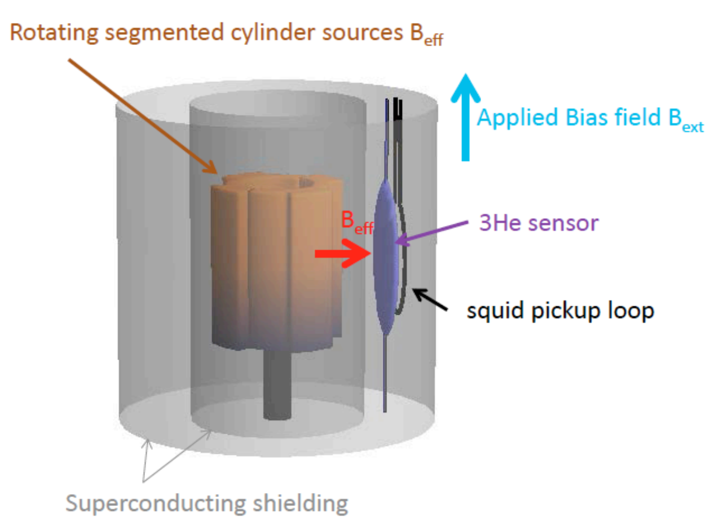


CASPEr axion wind/NMR

limited in frequency (mass)
but size of the effect OK

$$(m_a/eV = 10^{-7},\ \tau = 0.1 sec)$$

$$B_{eff}/T \approx 10^{-22} \qquad M_T/T \approx 10^{-19}$$

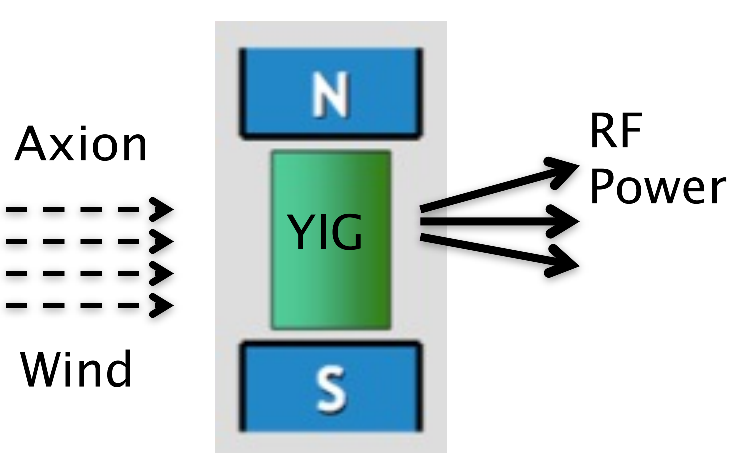


static source NMR

not limited in frequency
but size of the effect smaller

$$(m_a/eV = 10^{-4},\ \tau = 0.1 sec)$$

$$B_{eff}/T \lesssim 10^{-23} \qquad M_T/T \lesssim 10^{-20}$$



QUAX axion wind/EMR

frequency OK
detection method under scrutiny

$$(m_a/eV = 10^{-4},\ \tau = 10^{-6} sec)$$

$$B_{eff}/T \approx 10^{-22} \qquad M_T/T \approx 10^{-21}$$

Outlook of the Outlook

In the current confusing state of fundamental physics
useful/necessary to have a diversified program
(LHC, precision, flavour, astro-cosmo-particle, DM)

The exploration of the energy frontier still the
main task of particle physics
(FCC ee/hh)

(No contradiction, in spite of the appearances)