Guido Altarelli: eredità e prospettive, 10 anni dopo

Precision, precision
… and supersymmetry (sic!)
remembering Guido

(a story starting in the summer of 1990)

Riccardo Barbieri

Roma3, Dec 2025

The observables at the Z-pole

Assuming quark-lepton and flavour universality,

3 effective observables only

$$g_A^f = T_{3L}^f\left(1+\frac{\epsilon_1}{2}\right) \qquad \frac{g_V^f}{g_A^f} = 1-4|Q_f|s^2\left(1+\frac{\epsilon_3-c^2\epsilon_1}{c^2-s^2}\right)$$

$$\Delta r = \frac{1}{s^2}\left(-c^2\epsilon_1+(c^2-s^2)\epsilon_2+2s^2\epsilon_3\right) \qquad s^2c^2=\frac{\pi\alpha(M_Z)}{\sqrt{2}G_F M_Z^2}$$

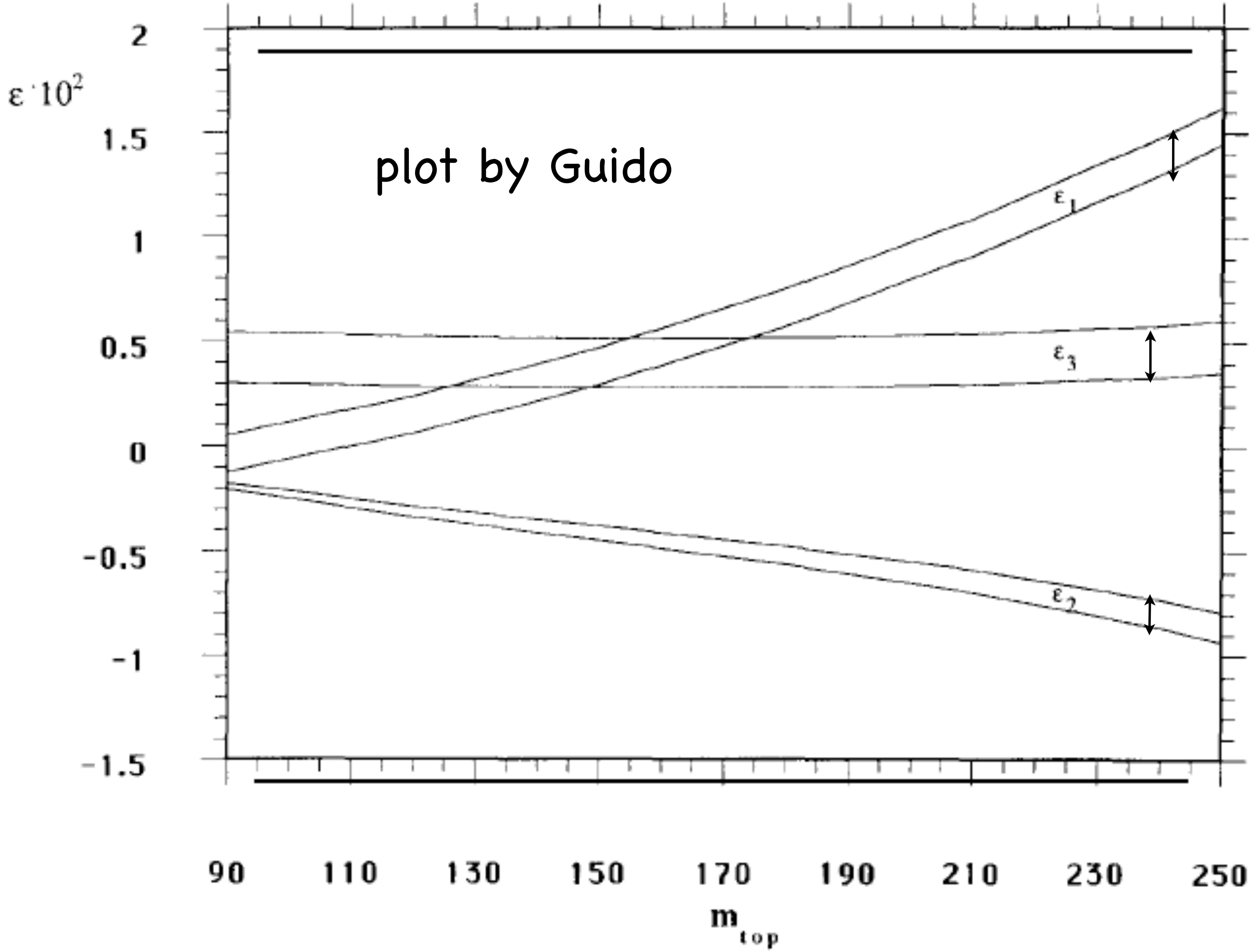
+1 including flavour breaking in $Z\to b\bar{b}$

$$g_A^b = -\frac{1}{2}\left(1+\frac{\epsilon_1}{2}\right)(1+\epsilon_b) \qquad \frac{g_V^b}{g_A^b} = \frac{1}{1+\epsilon_b}\left(1-\frac{4}{3}s^2\left(1+\frac{\epsilon_3-c^2\epsilon_1}{c^2-s^2}\right)+\epsilon_b\right)$$

(S,T,U = leading VP only)
(Peskin, Takeuchi 1990)

Altarelli, B 1990
Altarelli, B, Jadach 1991

$\epsilon_i(m_t, m_H)$ predicted in the SM

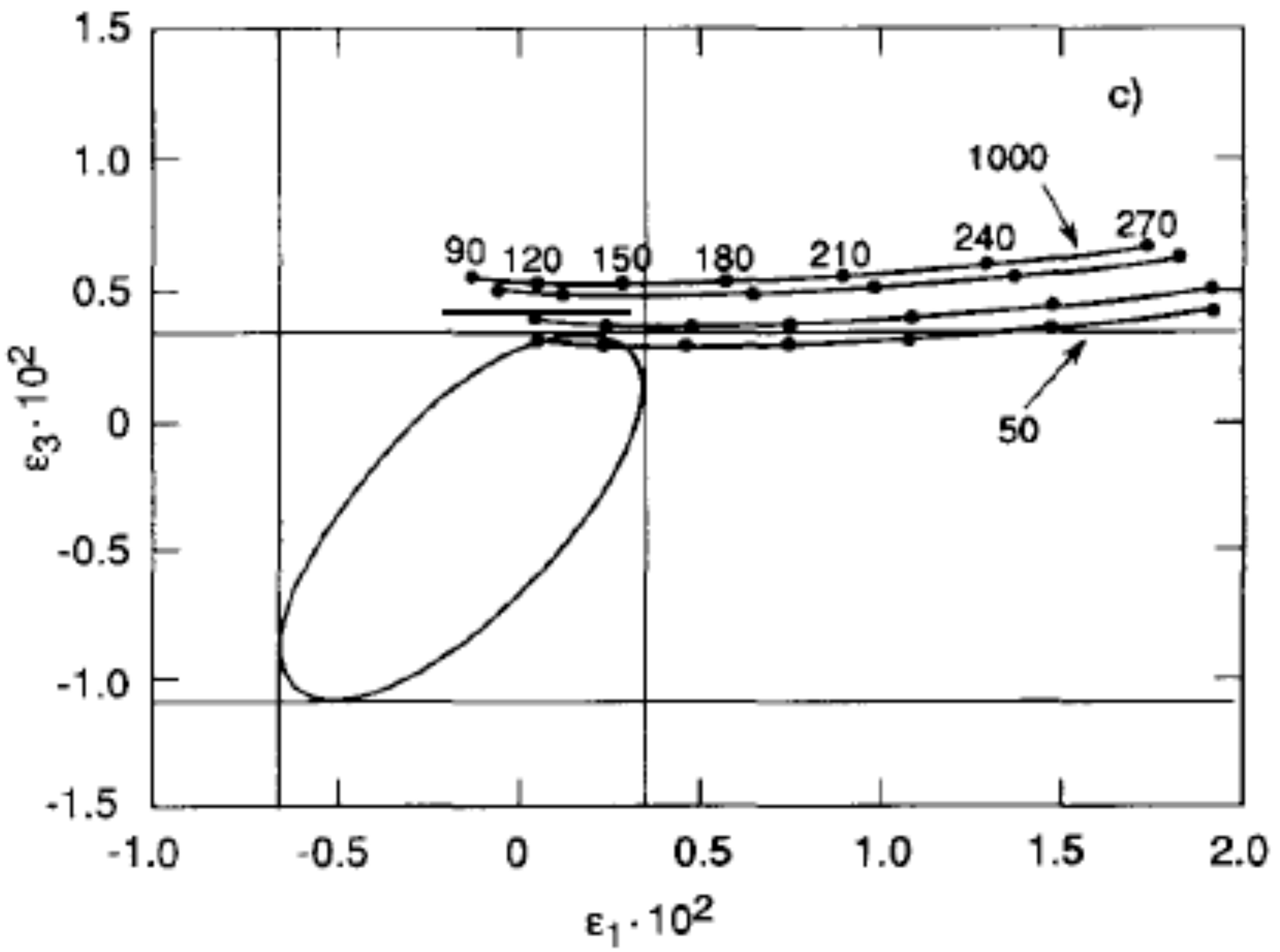


$m_H = 50 \div 1000\ GeV$

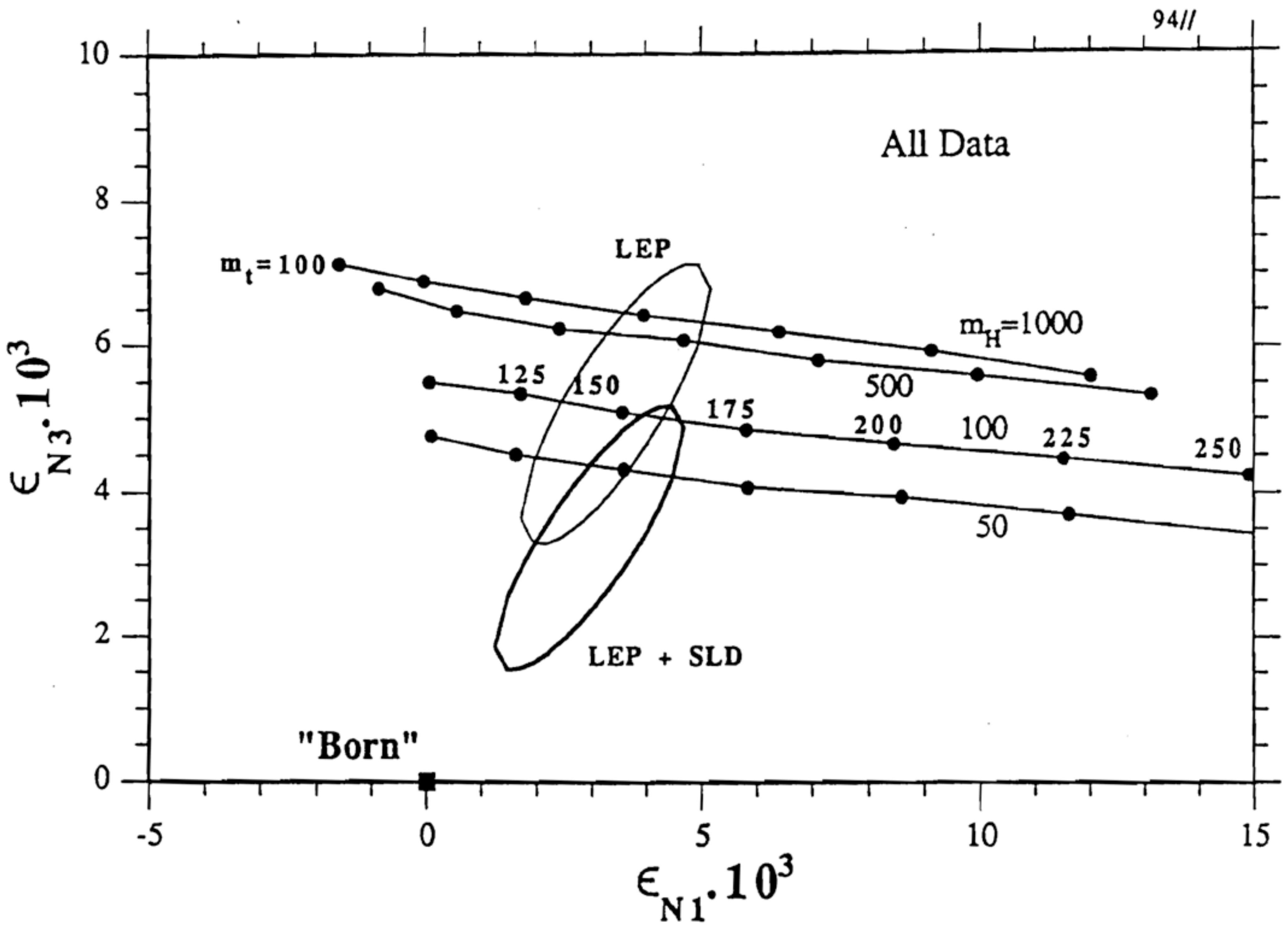
Altarelli, B, Jadach 1991

From LEP data in 1991-1994

plots by Guido



1991

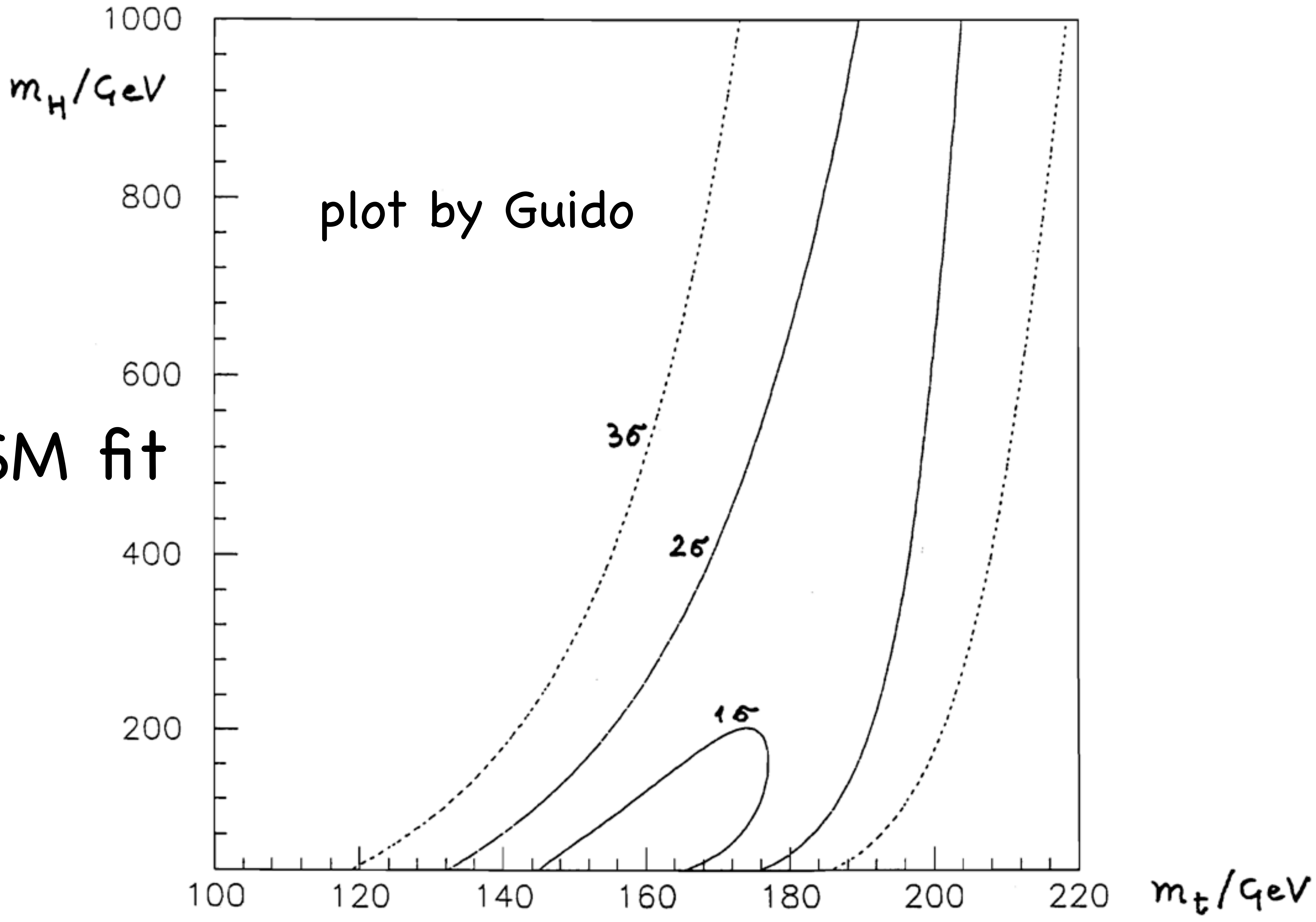


La Thuile, April 1994

Altarelli, B, Caravaglios

La Thuile, April 1994

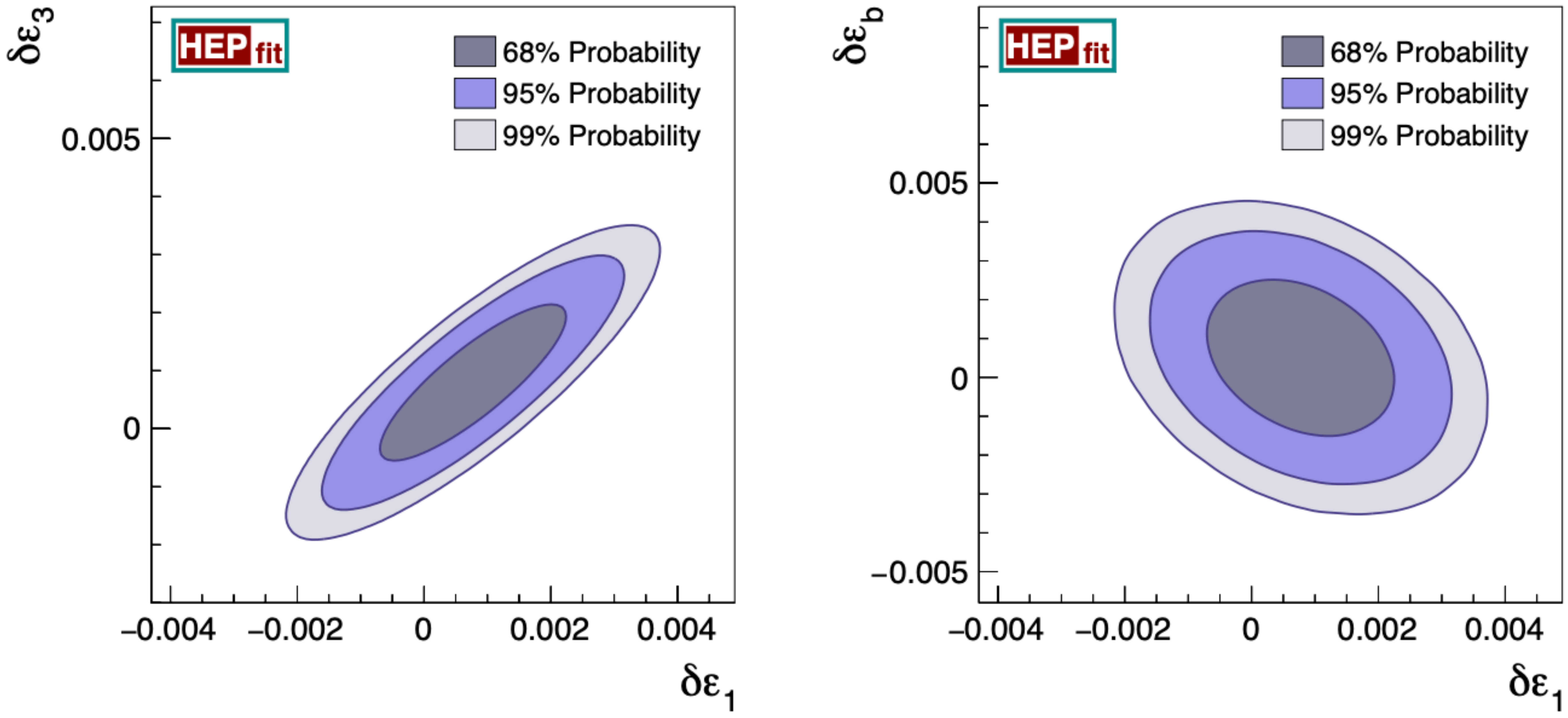
pure SM fit



compared with $m_t = 174 \pm 10^{+13}_{-12}\ GeV$ in the first CDF paper

that appeared in PRD in Sept 1994 (not statistically definitive)

The ϵ's today



SM = (0,0)

De Blas et al, 2025

A difference in the two sectors of the SM?

$$\mathcal{L}_{SM} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + i\bar{\Psi}\not{D}\Psi$$

The "gauge sector"

$$+|D_\mu\phi|^2 + M^2|\phi|^2 - \lambda|\phi|^4 + \Lambda + \lambda_{ij}\phi\bar{\Psi}_i\Psi_j$$

The "Higgs sector"

2. A different level of precision

(See specific models for precise comparisons)

De Blas et al, 2025

EWPT

	Result
$\delta\varepsilon_1$	0.0007 ± 0.0010
$\delta\varepsilon_2$	-0.0002 ± 0.0008
$\delta\varepsilon_3$	0.0007 ± 0.0009
$\delta\varepsilon_b$	0.0004 ± 0.0013

E.g. $M_W = M_W^{SM}(1 + a_i\delta\epsilon_i)$

$a_i = O(1)$ known

$\lesssim 1ppm$

Higgs couplings

	Result
κ_W	0.94 ± 0.10
κ_Z	1.03 ± 0.13
κ_ℓ	1.02 ± 0.15
κ_u	0.95 ± 0.13
κ_d	0.91 ± 0.22

$\mathcal{L}_Y = \frac{m}{v} k_f \bar{f}_L H f_R$ etc

$\gtrsim 10\%$

Flavour

see below

"Mid term" prospects in precision on BSM

(Under current update)

De Blas et al, 2025

EWPT

Not expected to improve significantly due to parametric uncertainties

$$\Delta\alpha_{had}(M_Z) \to \pm 3\cdot 10^{-3}, \quad \alpha_S(M_Z) \to \pm 1\cdot 10^{-3}$$

$$(FCC_{ee}: \quad \Delta\alpha_{had}(M_Z) \to \pm 5\cdot 10^{-5}, \quad \alpha_S(M_Z) \to \pm 2\cdot 10^{-4})$$

(See also Drell-Yan and top quark observables)

Higgs couplings

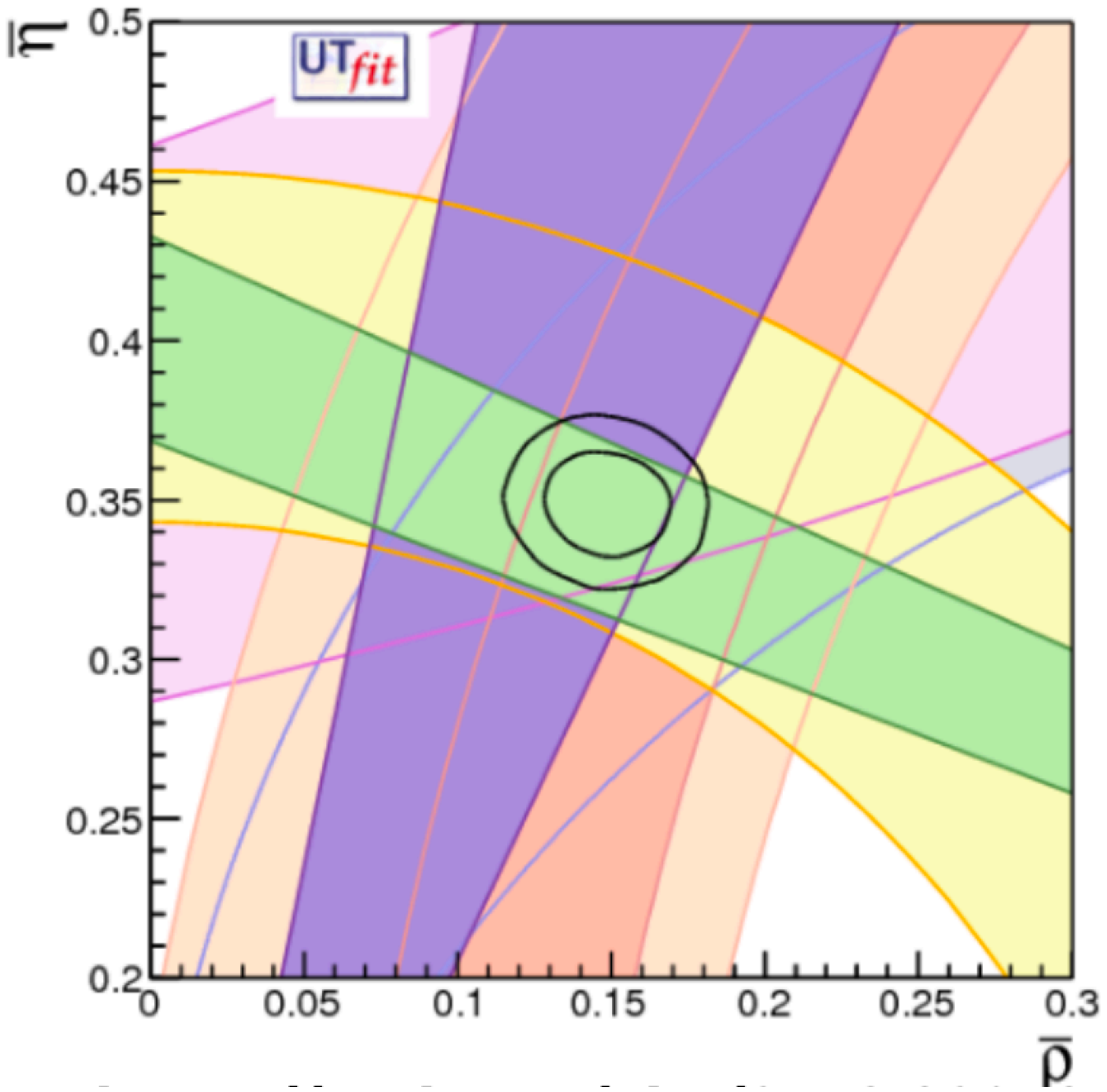
	$\approx 10\%$	$\Rightarrow$ $(1 \div 2)\%$
$\Delta\kappa_V\,[\times 10^{-4}]$	190	83
$\Delta\kappa_f\,[\times 10^{-4}]$	960	150
$\Delta\kappa_W[\times 10^{-4}]$	510	120
$\Delta\kappa_Z\,[\times 10^{-4}]$	1100	150
$\Delta\kappa_f\,[\times 10^{-4}]$	1100	160
$\Delta\kappa_V\,[\times 10^{-4}]$	210	120
$\Delta\kappa_u\,[\times 10^{-4}]$	1200	170
$\Delta\kappa_d\,[\times 10^{-4}]$	1400	230
$\Delta\kappa_\ell\,[\times 10^{-4}]$	1300	270

$$\approx \left(\frac{140 fb^{-1}}{3ab^{-1}}\right)^{1/2}$$

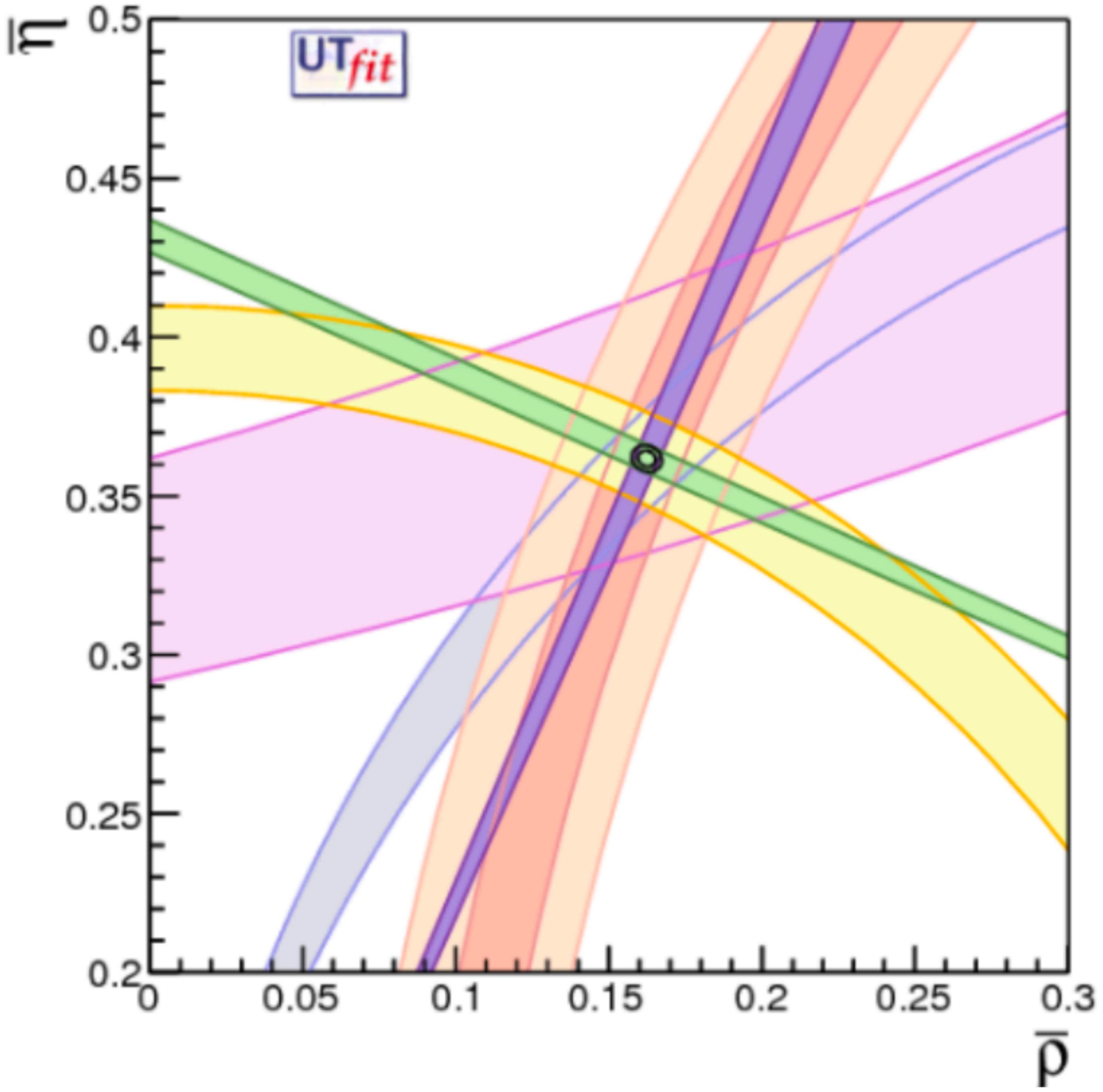
“Mid term” prospects in precision on BSM

Flavour

Unitarity triangle



$\Rightarrow$



A much too synthetic description!

A FlavourPT Table long awaited!

Conceivable progress in the "mid-term" of flavour

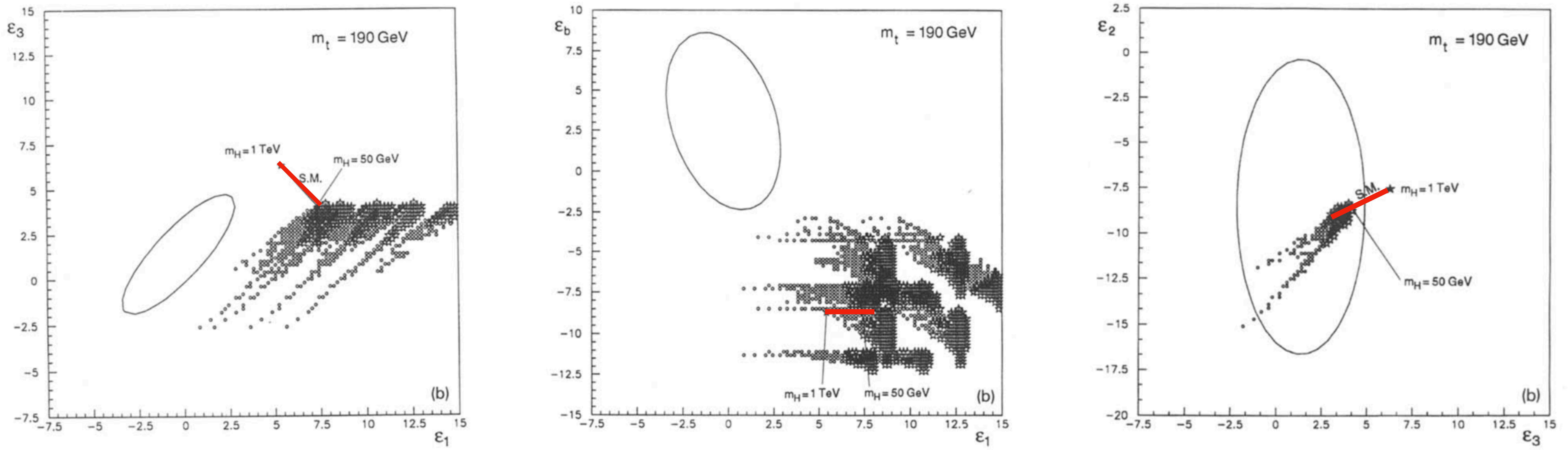
Input	Reference	Measurement	UTfit Prediction	Pull	current	mid-term
$\sin 2\beta$	[22], **UTfit**	0.688(20)	0.736(28)	−1.4	4%th/exp	0.6%
γ	[22]	66.1(3.5)	64.9(1.4)	+0.29	5%exp	0.8%
α	**UTfit**	94.9(4.7)	92.2(1.6)	+0.6	5%exp	0.4%
$\varepsilon \cdot 10^3$	[38]	2.228(1)	2.00(15)	+1.56	8%th	
$\lvert V_{ud}\rvert$	**UTfit**	0.97433(19)	0.9738(11)	+0.03	0.1%th	
$\lvert V_{ub}\rvert \cdot 10^3$ •	**UTfit**	3.77(24)	3.70(11)	+0.25	8%exp/th	1%
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	[39]	3.74(17)				
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	[22]	4.32(29)				
$\lvert V_{cb}\rvert \cdot 10^3$ •	**UTfit**	41.25(95)	42.22(51)	−0.59	2%exp/th	0.5%
$\lvert V_{cb}\rvert \cdot 10^3$ (excl)	**UTfit**	39.44(63)				
$\lvert V_{cb}\rvert \cdot 10^3$ (incl)	[40]	42.16(50)				
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	[39]	0.0844(56)				
$\Delta M_d \times 10^{12}\,\mathrm{s}^{-1}$	[38]	0.5065(19)	0.519(23)	−0.49	5%th/exp	2%
$\Delta M_s \times 10^{12}\,\mathrm{s}^{-1}$	[38]	17.741(20)	17.94(69)	−0.30	4%th	1.5%
$\mathrm{BR}(B_s \to \mu\mu) \times 10^9$	[38]	3.41(29)	3.47(14)	−0.14	9%exp	4%
$\mathrm{BR}(B \to \tau\nu) \times 10^4$	[38]	1.06(19)	0.869(47)	+0.96	20%exp	4%
$\mathrm{Re}\,(\varepsilon'/\varepsilon) \times 10^4$	[38]	16.6(3.3)	15.2(4.7)	+0.27	30%th	
$(\lvert q/p\rvert_D - 1) \times 10^2$		0.05(2.50)	0.8(4.0)	−0, 15	100%th*	30%*
$BR(B^+ \to K^+\nu\nu)10^6$		23(7)	5.58(37)	+2.5	35%exp	10%
$BR(K^+ \to \pi^+\nu\nu)10^{11}$		10.6(4.0)	9.31(76)	+0, 3	40%exp	20%
R_D		0.344(26)	0.298(4)	+1.7	8%exp	3%
R_{D^*}		0.285(12)	0.254(5)	+2.3	4%exp	2%

with strong correlations!

(No EDM's, $\mu \to e\gamma$, etc.)

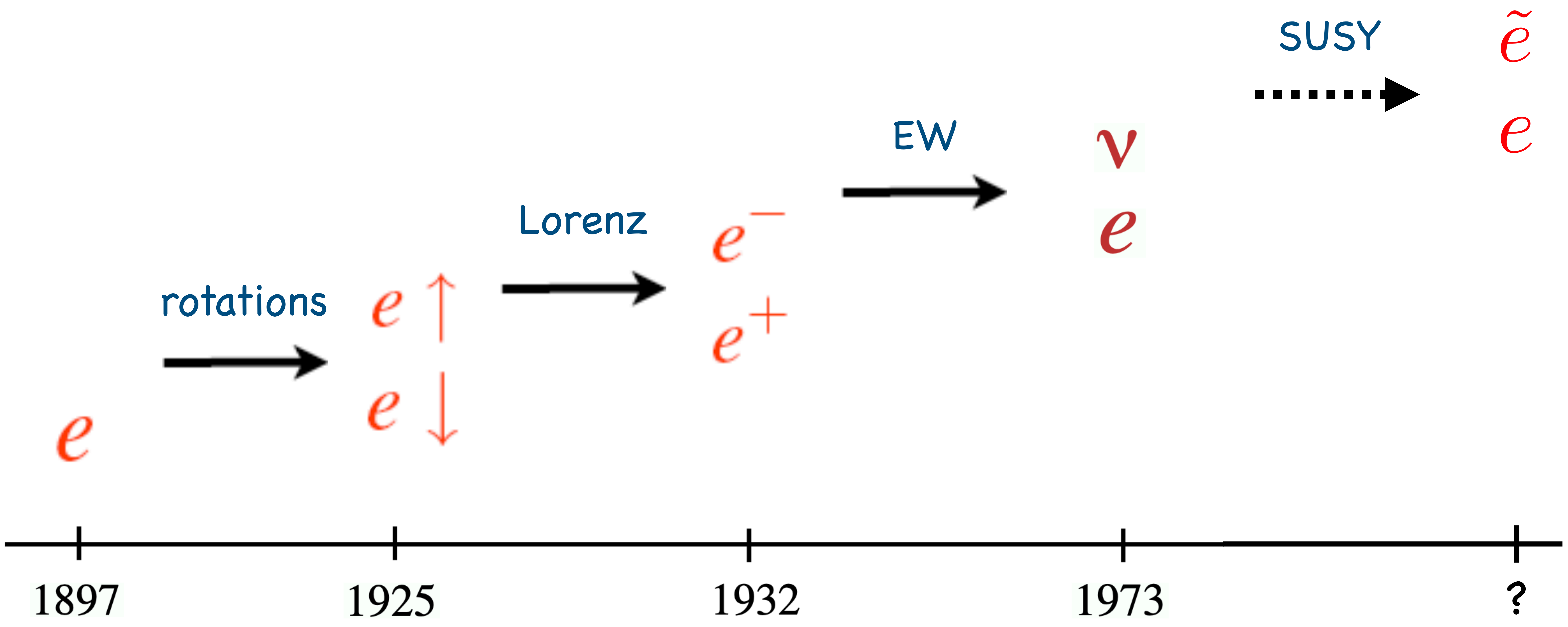
An early fit to the LEP EWPT, using the ϵ variables (1983)

(in units of 10^{-3})



SUSY with $m_\chi = 50 \div 100 GeV$ and $m_{\tilde{t}} = 150 \div 200 GeV$

Altarelli, B, Caravaglios



rotations
Lorenz
EW
SUSY
e
$e\uparrow$
$e\downarrow$
e^-
e^+
ν
e
$\tilde{e}$
e
1897
1925
1932
1973
?

A suspended conclusion on supersymmetry

- Indirect evidences for SUSY (Beyond “Naturalness”)

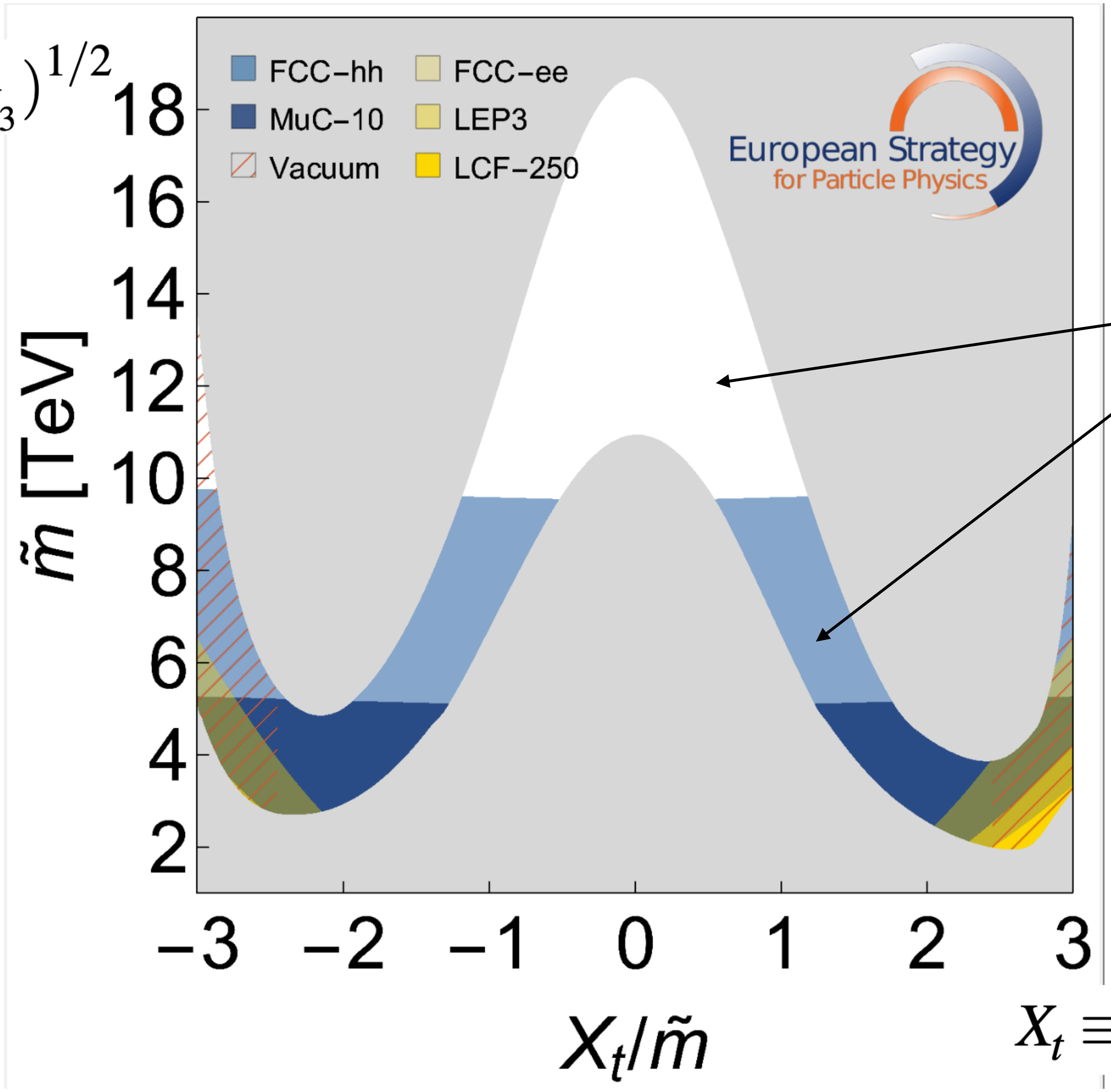
1. A source for a negative curvature of $V(H)$
2. LSP a candidate for DM
3. Gauge coupling unification

(None of which giving a “strong” upper bound on s-particle masses)

The strongest upper bound from $m_H = 125 GeV$

$$m_H^2 = m_Z^2 \cos(2\beta) + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}(\log\frac{\tilde{m}^2}{m_t^2} + \frac{X_t^2}{\tilde{m}^2}(1 - \frac{X_t^2}{12\tilde{m}^2})$$

$\tilde{m} \equiv (\tilde{m}_{Q_3}\tilde{m}_{U_3})^{1/2}$



allowed region

$\tan\beta = 20$

$X_t \equiv A_t - \mu\cot\beta$

A suspended conclusion on supersymmetry

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(None of which giving a "strong" upper bound on s-particle masses)

- Two pending questions for SUSY

1. What about the cosmological constant? In 1998 $\Lambda_{cc} \approx 10^{-3} eV$ (as anticipated by Weinberg)

In EFT the Λ_{cc} and the δm_H problems apparently related

2. No fundamental scalar particle in nature? (Dirac, Wilson,...)

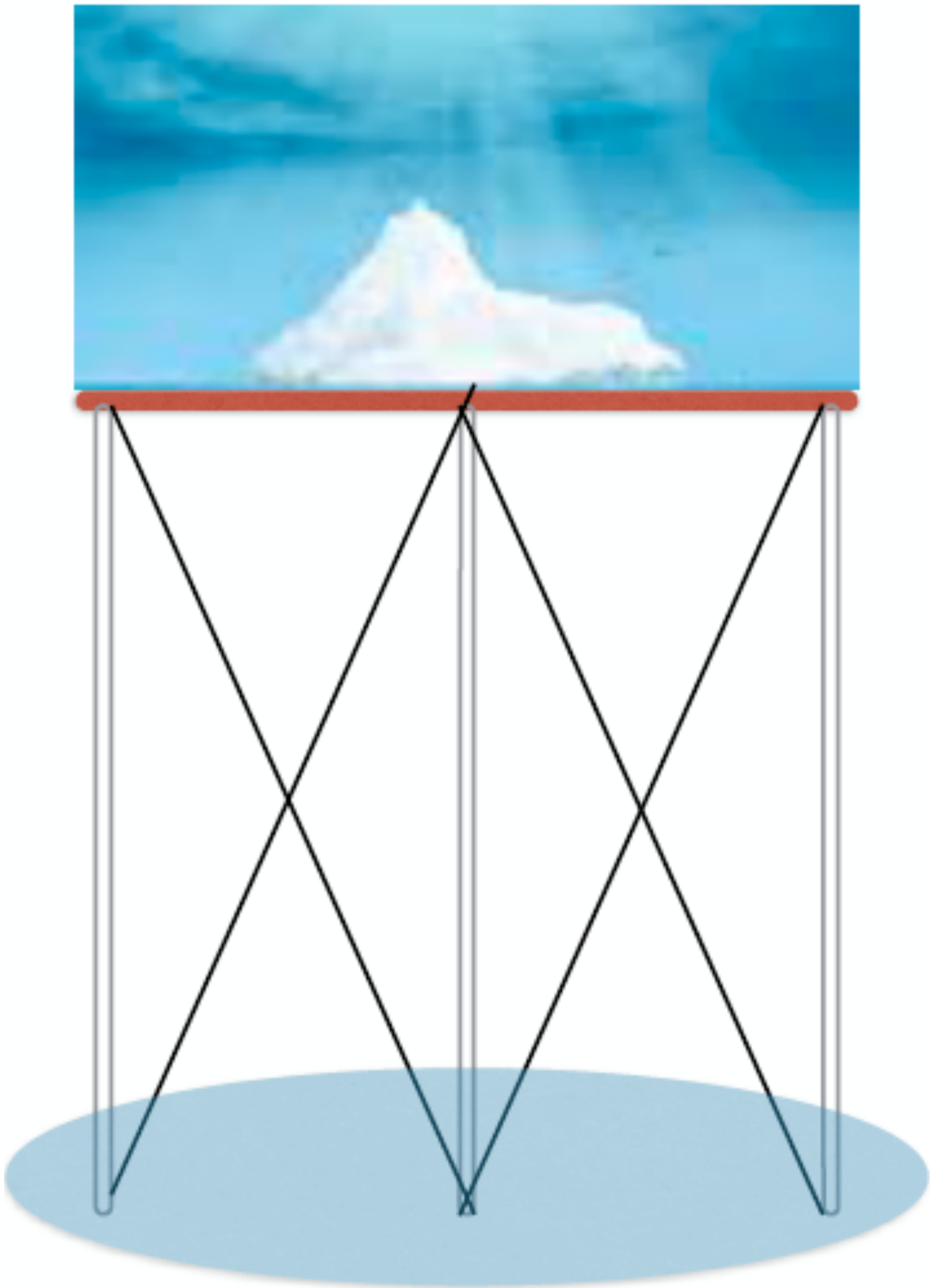
A statement that would exclude SUSY as relevant in nature

Still today: To test the nature of the Higgs boson is a main open task of PP

The SM as an emerging iceberg

What there is under the water?

BSM in the multi TeV region...



... or the SM extended up to E >> TeVs?

Where would Guido stand?

Guido was a wise man
who had a strong influence
on particle physics at large
and in particular at CERN and in Italy

A kind of “older brother” for me,
in spite of having about the same age