EWPO in the pMSSM

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1. Introduction
2. Our tool: MasterCode
3. Some pMSSM results
4. Conclusions

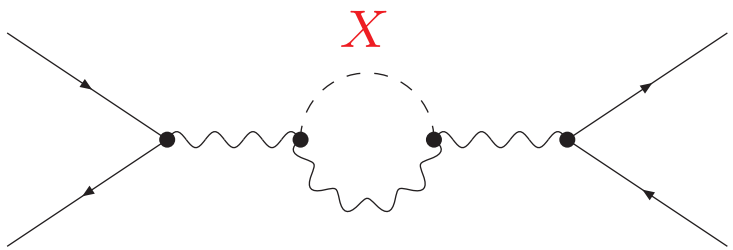
1. Introduction

Comparison of observables with theory:

Precision data:		Theory:
$M_W, \sin^2\theta_{\text{eff}}, a_\mu,\ M_h$	$\leftrightarrow$	SM, MSSM , . . .

$\Downarrow$

Test of theory at quantum level: Sensitivity to loop corrections, e.g. X



$\Downarrow$

BSM: limits on M_X

Very high accuracy of measurements and theoretical predictions needed

Precision observables in the SM and the MSSM

M_W, $\sin^2\theta_{\text{eff}}$, M_h, $(g-2)_\mu$, b physics, ...

A) Theoretical prediction for M_W in terms of $M_Z, \alpha, G_\mu, \Delta r$:

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\,\alpha}{\sqrt{2}\,G_\mu}(1+\Delta r)$$

$\Updownarrow$

loop corrections

Evaluate Δr from μ decay $\Rightarrow M_W$

One-loop result for M_W in the SM:

[*A. Sirlin '80*] , [*W. Marciano, A. Sirlin '80*]

$$\Delta r_{1-\text{loop}} = \Delta\alpha - \frac{c_W^2}{s_W^2}\Delta\rho + \Delta r_{\text{rem}}(M_H)$$

$$\sim \log\frac{M_Z}{m_f} \qquad \sim m_t^2 \qquad \log(M_H/M_W)$$

$$\sim 6\% \qquad \sim 3.3\% \qquad \sim 1\%$$

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loop corrections

B) Effective mixing angle:

$$\sin^2\theta_{\text{eff}}=\frac{1}{4\,|Q_f|}\left(1-\frac{\text{Re}\,g_V^f}{\text{Re}\,g_A^f}\right)$$

Higher order contributions:

$$g_V^f\to g_V^f+\Delta g_V^f,\quad g_A^f\to g_A^f+\Delta g_A^f$$

Corrections to M_W, $\sin^2\theta_{\text{eff}}$ → approximation via the ρ-parameter:

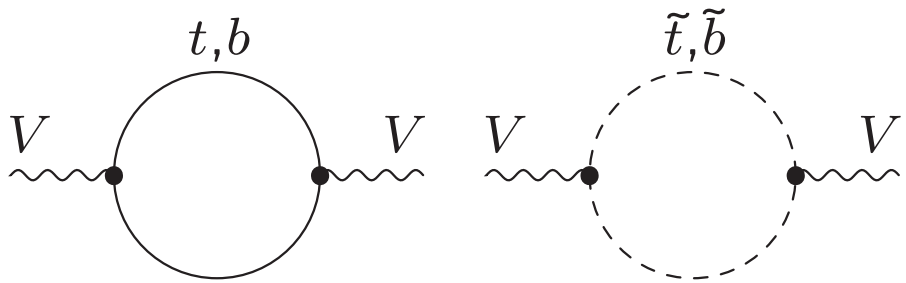
ρ measures the relative strength between
neutral current interaction and charged current interaction

$$\rho = \frac{1}{1-\Delta\rho} \qquad \Delta\rho = \frac{\Sigma_Z(0)}{M_Z^2} - \frac{\Sigma_W(0)}{M_W^2}$$

(leading, process independent terms)

$\Delta\rho$ gives the main contribution to EW observables:

$$\Delta M_W \approx \frac{M_W}{2}\frac{c_{\text{W}}^2}{c_{\text{W}}^2 - s_{\text{W}}^2}\Delta\rho, \qquad \Delta\sin^2\theta_W^{\text{eff}} \approx -\frac{c_{\text{W}}^2 s_{\text{W}}^2}{c_{\text{W}}^2 - s_{\text{W}}^2}\Delta\rho$$



$\Delta\rho^{\text{SUSY}}$ from $\tilde{t}/\tilde{b}$ loops > 0 $\Rightarrow M_W^{\text{SUSY}} \gtrsim M_W^{\text{SM}}$, $\sin^2\theta_{\text{eff}}^{\text{SUSY}} \lesssim \sin^2\theta_{\text{eff}}^{\text{SM}}$

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SM result for M_W and $\sin^2\theta_{\text{eff}}$:

- full one-loop
- full two-loop
- leading 3-loop via $\Delta\rho$
- leading 4-loop via $\Delta\rho$

Our MSSM result for M_W and $\sin^2\theta_{\text{eff}}$:

- full SM result (via fit formel)
- full MSSM one-loop (incl. complex phases)
- all existing two-loop $\Delta\rho$ contributions

$\Rightarrow$ non-$\Delta\rho$ one-loop and $\Delta\rho$ two-loop contributions sometimes non-negligible!

The W boson mass

Experimental accuracy:

Today: LEP2, Tevatron: $M_W^{\text{exp}} = 80.385 \pm 0.015$ GeV

ILC:

$$\delta M_W^{\text{exp,ILC}} = 5 - 6 \text{ MeV}$$

Theoretical accuracies: $\Rightarrow$ see my next talk!

Effective weak leptonic mixing angle: $\sin^2\theta_{\text{eff}}$

Experimental accuracy:

Today: LEP, SLD: $\sin^2\theta_{\text{eff}}^{\text{exp}} = 0.23153 \pm 0.00016$

ILC/GigaZ:

$$\delta \sin^2\theta_{\text{eff}}^{\text{exp,ILC}} = 0.000013$$

Theoretical accuracies: $\Rightarrow$ see my next talk!

What is the pMSSM?

Particle content of the MSSM:

$$\left[u, d, c, s, t, b\right]_{L,R} \quad \left[e, \mu, \tau\right]_{L,R} \quad \left[\nu_{e,\mu,\tau}\right]_{L} \qquad \text{Spin } \tfrac{1}{2}$$

$$\left[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\right]_{L,R} \quad \left[\tilde{e}, \tilde{\mu}, \tilde{\tau}\right]_{L,R} \quad \left[\tilde{\nu}_{e,\mu,\tau}\right]_{L} \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^{\pm}, H^{\pm}} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin } 1 \text{ / Spin } 0$$

$$\tilde{g} \quad \tilde{\chi}_{1,2}^{\pm} \quad \tilde{\chi}_{1,2,3,4}^{0} \qquad \text{Spin } \frac{1}{2}$$

most general case: $\Rightarrow$ 105 new parameters: masses, mixing angles, phases

How many free parameters do you want?

- what is relevant for (your) physics case?
- what can you handle reliably?
- is your set really representative?

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⇒ many options:

- pMSSM7, pMSSM8, . . .
- pMSSM19, pMSSM20, . . .
- pMSSM105

Further questions:

- do you scan? do you scatter?
  (How many points are reliable?)
- MCMC to find "best-fit" points? do you find them?
- do you pick "some benchmarks"?
- does your choice cover everything (relevant)?

Snowmass: 24 points with $\mathcal{O}(20)$ free parameters (real)

[*M. Cahill-Rowley, J. Hewett, A. Ismail, M. Peskin, T. Rizzo, arXiv:1305.2419 [hep-ph]*]

2. Our tool: Mastercode

⇒ collaborative effort of theorists and experimentalists

[*Buchmüller, Cavanaugh, De Roeck, Dolan, Ellis, Flächer, SH, Isidori, Marouche, Martinez Santos, Olive, Rogerson, Ronga, de Vries, Weiglein*]

Über-code for the combination of different tools:

- Über-code original in Fortran, now re-written in C++
- tools are included as subroutines
- compatibility ensured by collaboration of authors of "MasterCode" and authors of "sub tools" /SLHA(2)
- sub-codes in Fortran or C++

⇒ evaluate observables of one parameter point consistently with various tools

cern.ch/mastercode

Status of the "MasterCode":

- one model: (MFV) MSSM (see next section)

- tools included:
  - B-physics observables [*SuFla*]
  - more B-physics observables [*SuperIso*]
  - Higgs related observables, $(g-2)_\mu$ [*FeynHiggs*]
  - Electroweak precision observables [*FeynWZ*]
  - Dark Matter observables [*MicrOMEGAs, DarkSUSY*]
  - for GUT scale models: RGE running [*SoftSusy*]

$\Rightarrow$ all most-up-to-date codes on the market!

- added: χ^2 analysis code [*Minuit*]

- currently being implemented:
  - Higgs constraints (for χ^2 contributions . . .) [*HiggsBounds*]

- planned: inclusion of more tools / more models

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(Some) Electroweak precision observables in the MasterCode

($\rightarrow$ as for blue band analysis, except Γ_W)

1. M_W (LEP/Tevatron)
2. A^e_{LR} (SLD)
3. A^b_{FB} (LEP)
4. A^c_{FB} (LEP)
5. A^l_{FB}
6. A_b, A_c
7. R_b, R_c
8. σ^0_{had}

$\Rightarrow$ largest impact: (1), (2), (3)

(2), (3), (4), ... $\Rightarrow \sin^2\theta_{\mathrm{eff}}$

(Some) B/K physics observables in the MasterCode

1. BR($b \to s\gamma$) (MSSM/SM)
2. BR($B_s \to \mu^+\mu^-$)
3. ΔM_s
4. R($\Delta M_s/\Delta M_d$)
5. BR($B_u \to \tau\nu_\tau$) (MSSM/SM)
6. BR($B \to X_x\ell^+\ell^-$)
7. BR($K \to \ell\nu$) (MSSM/SM)
8. BR(ΔM_K) (MSSM/SM)

$\Rightarrow$ largest impact: (1) and (2)

Further low-energy observables

– anomalous magnetic moment of the muon: $(g-2)_\mu$

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– CDM density: $\Omega_\chi h^2$

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SM parameters

– top mass: m_t

– Z boson mass: M_Z

– hadronic contribution to fine structure constant: $\Delta\alpha_{\text{had}}$

3. Some pMSSM results

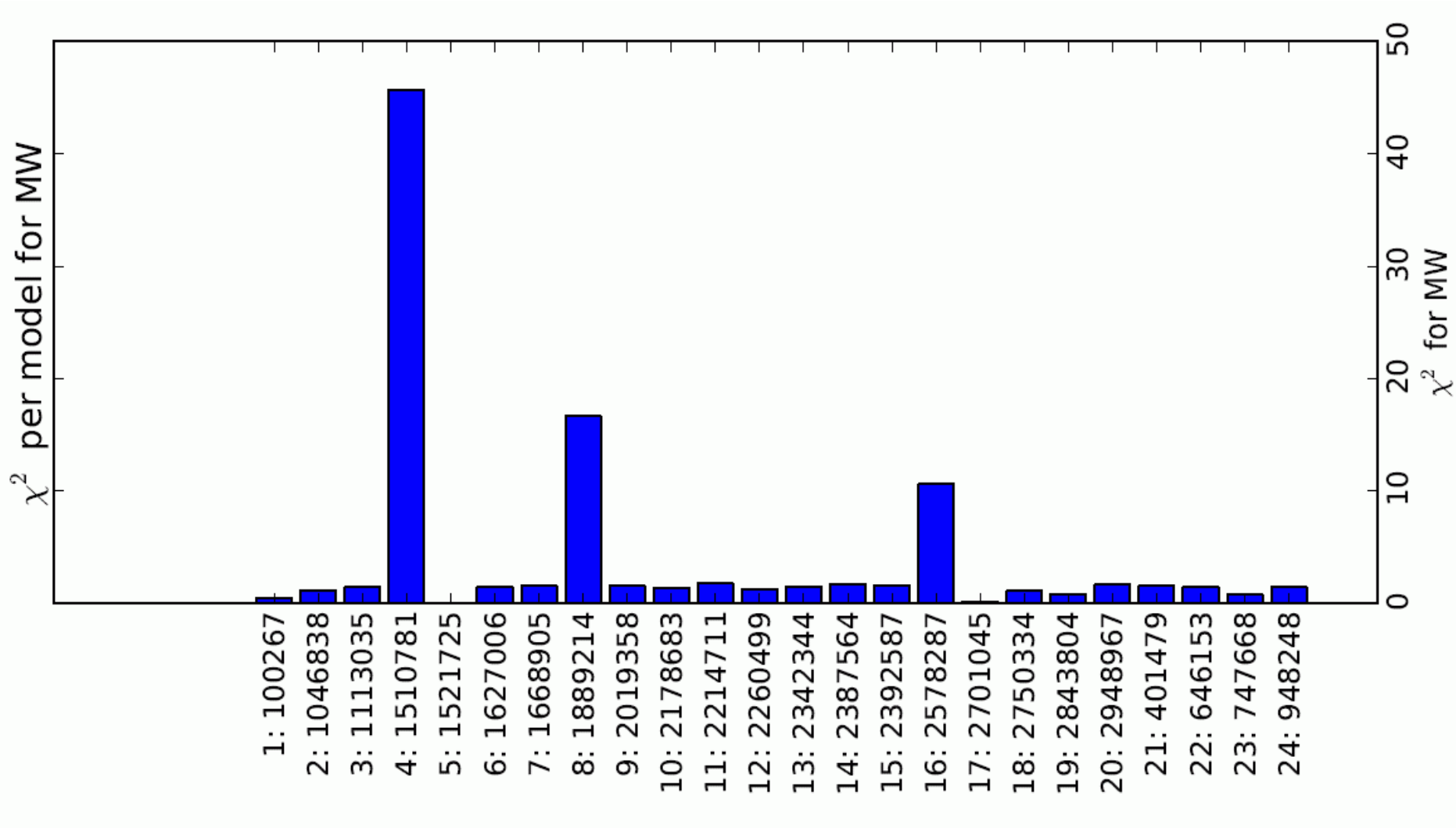
Simple strategy:

1. Take the 24 "Snowmass pMSSM-SLHA files"

2. Pipe them through MasterCode

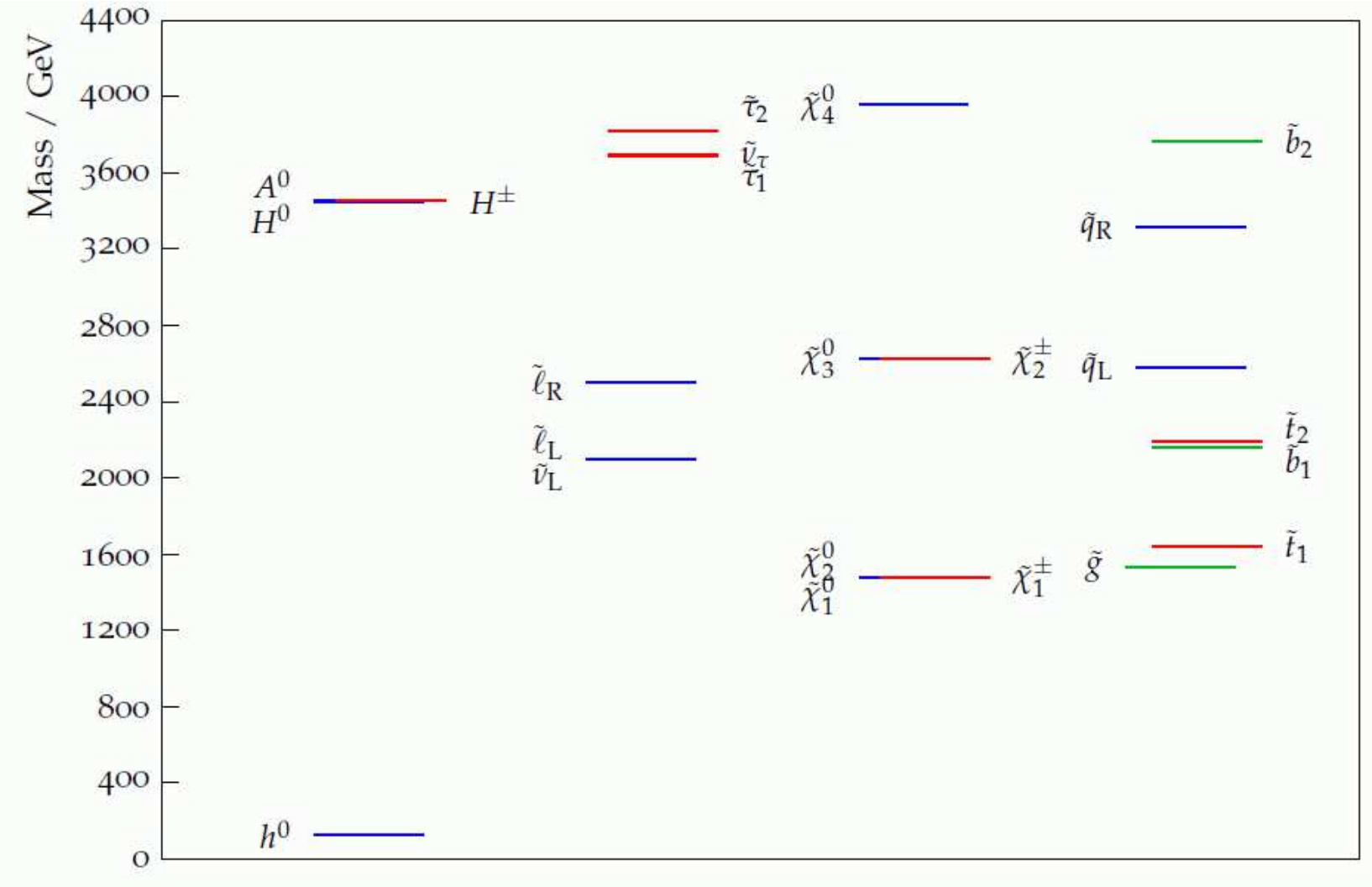
3. Check results! Do we learn anything?

Results for M_W:



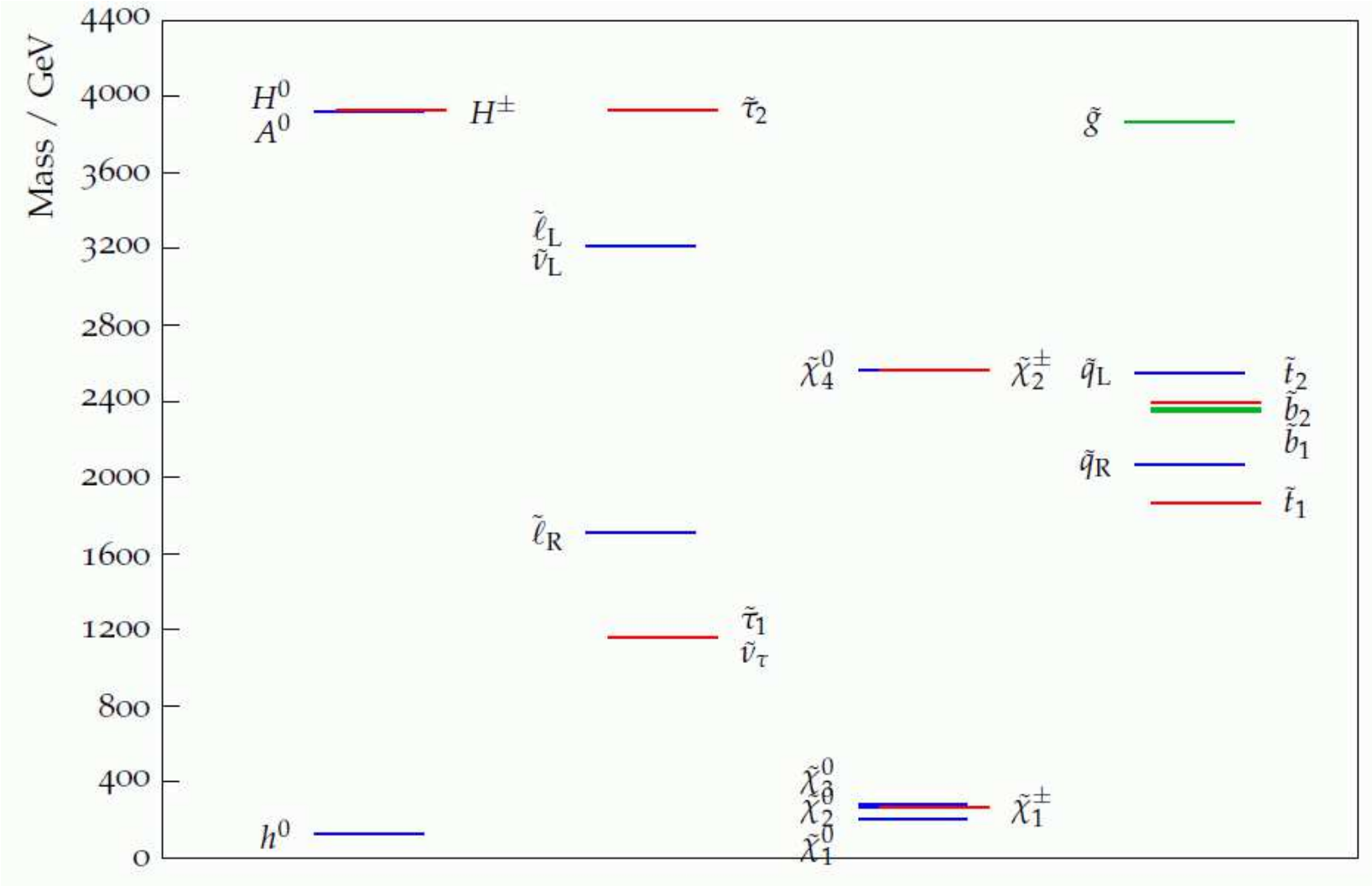
$\Rightarrow$ mostly ok, some not, some better, . . .

Spectrum point # 4:



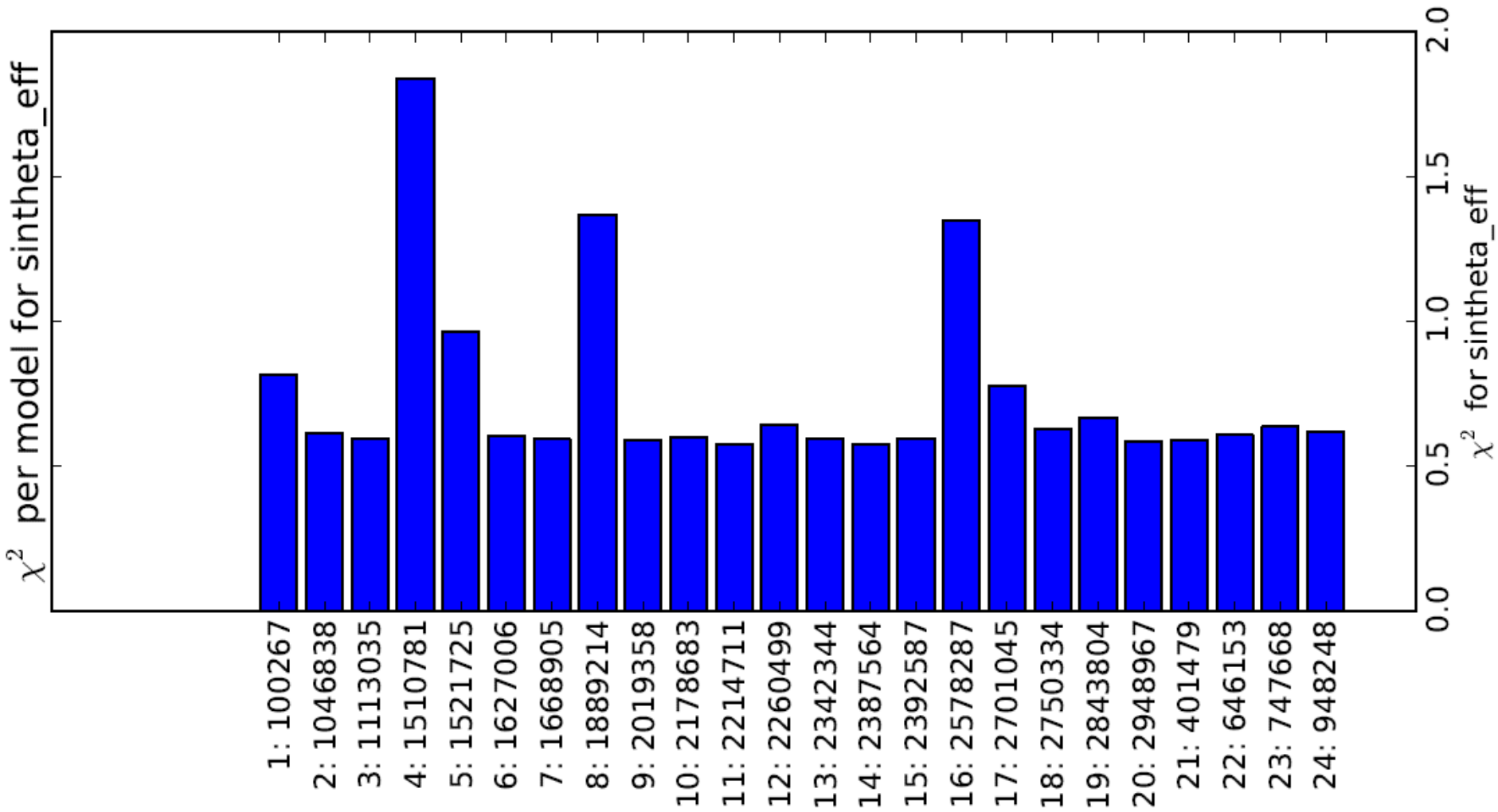
$\Rightarrow$ draw your own conclusions . . .

Spectrum point # 8:



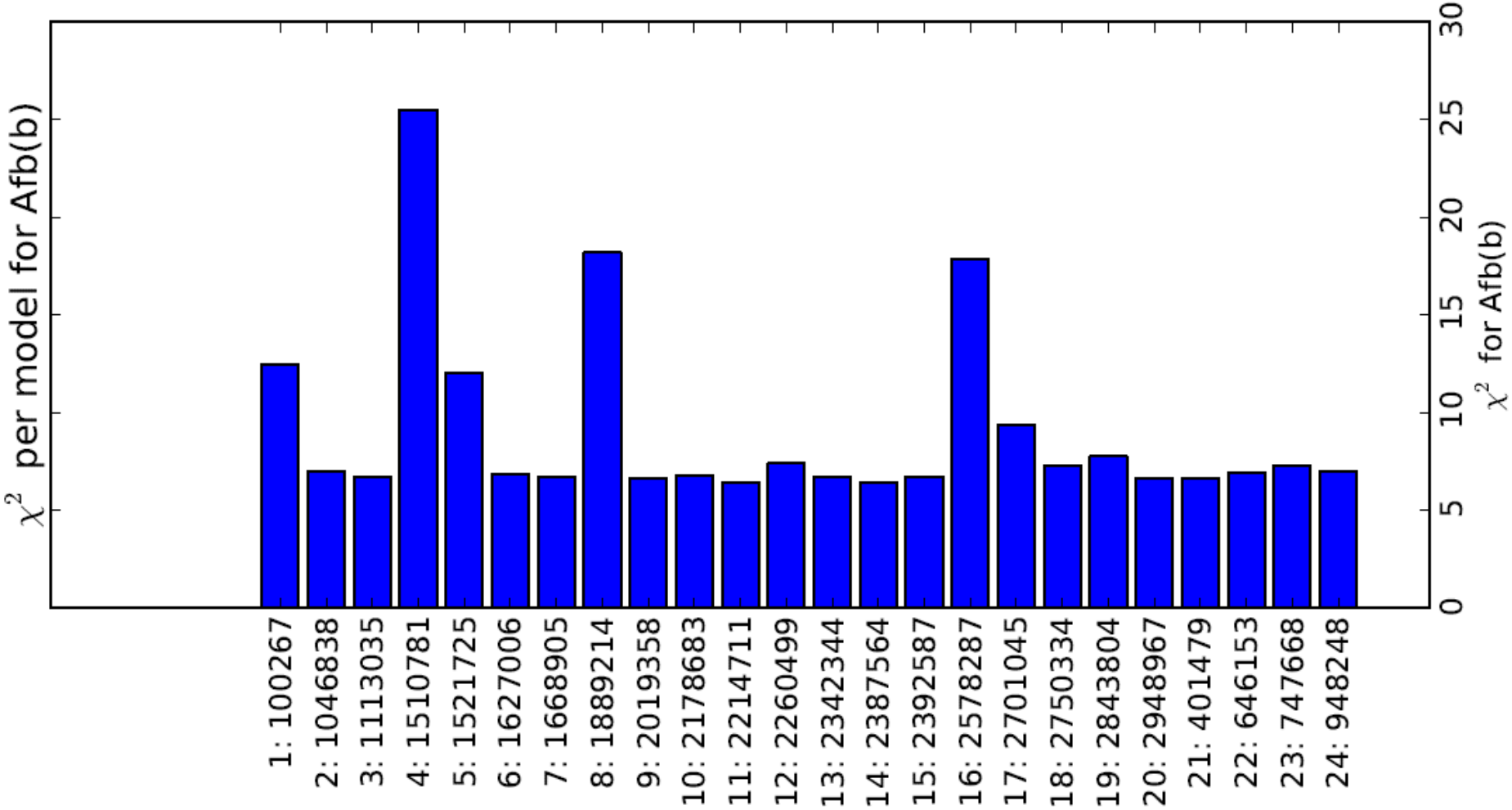
⇒ draw your own conclusions . . .

Results for $\sin^2\theta_{\text{eff}}$:



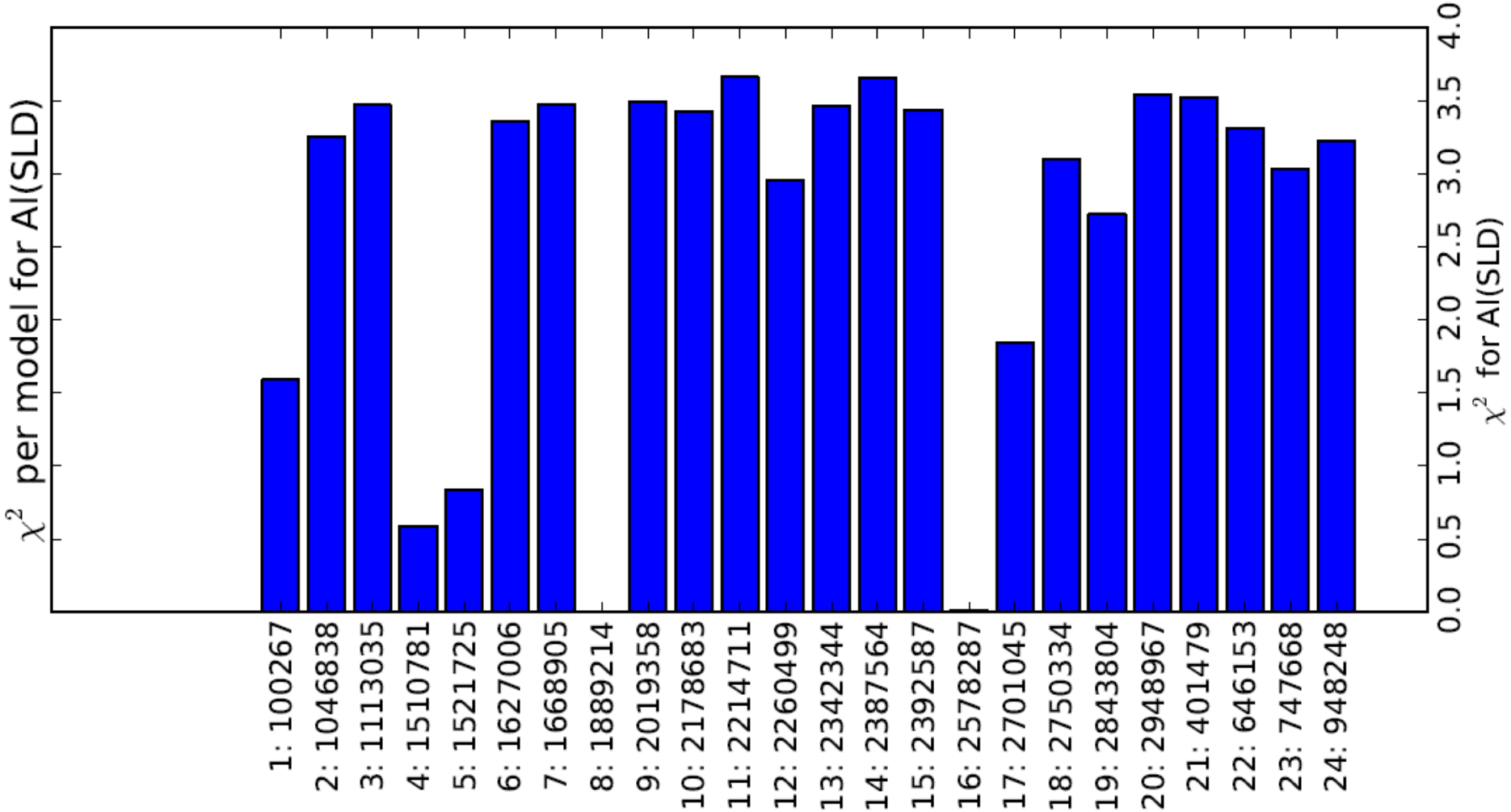
$\Rightarrow$ mostly ok, same "problematic" points

Results for $A^b_{\rm FB}$(LEP):



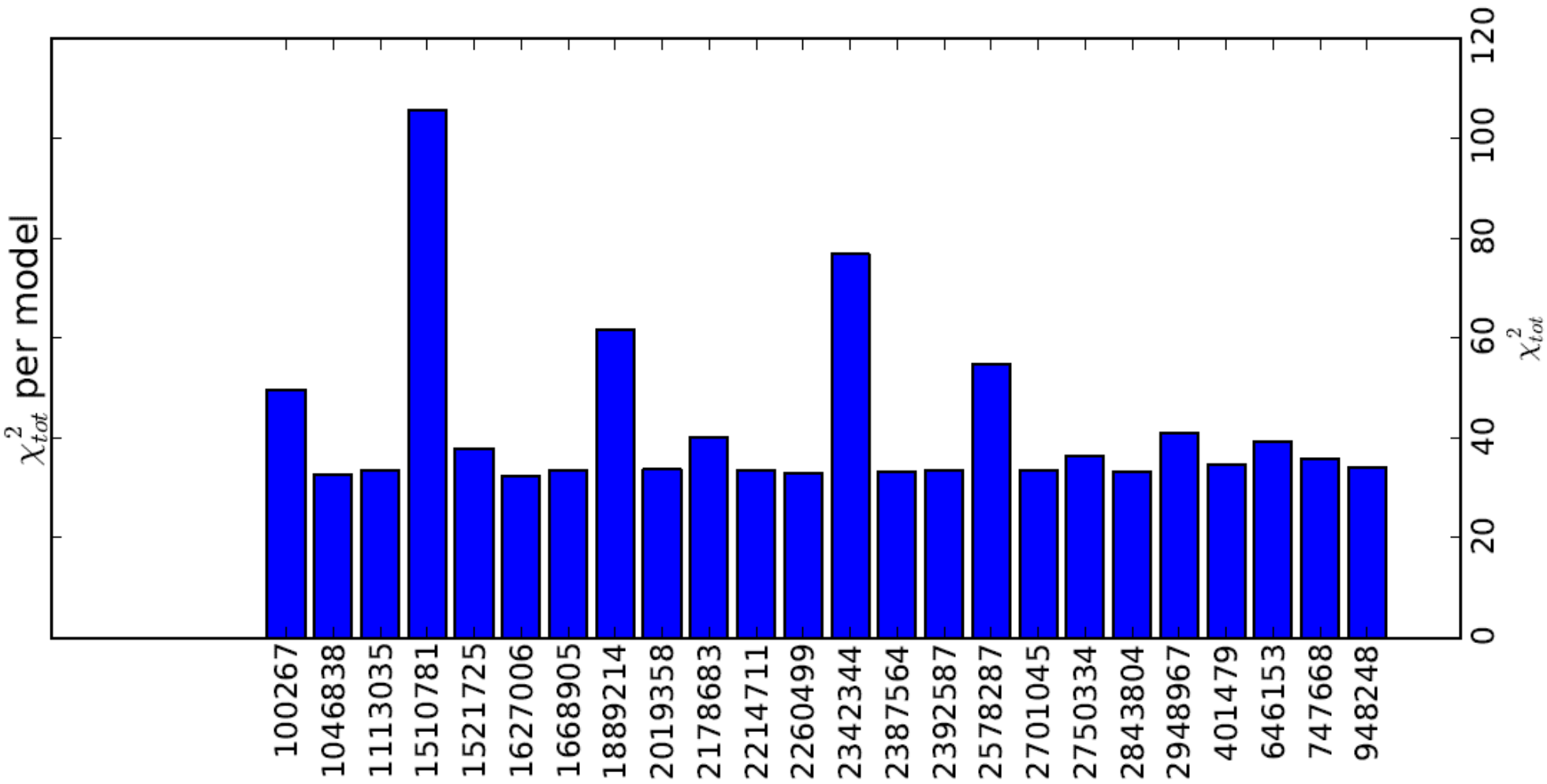
$\Rightarrow$ mostly ok, same "problematic" points

Results for A^e_{LR}(SLD):



$\Rightarrow$ different pattern

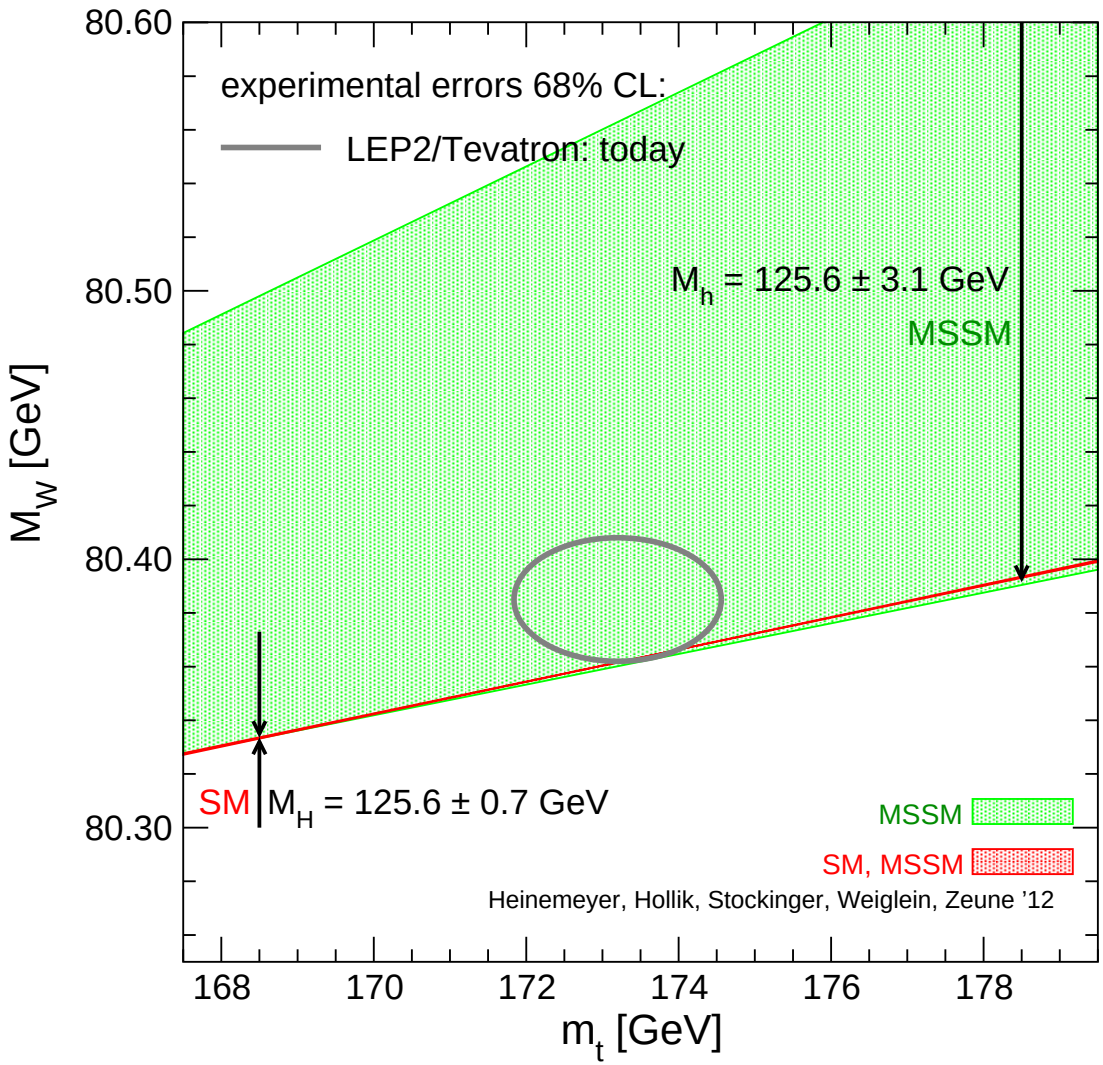
Total χ^2 values:



⇒ Some points clearly disfavored

Comparison to our scan:

[S.H., G. Weiglein, L. Zeune, PRELIMINARY]



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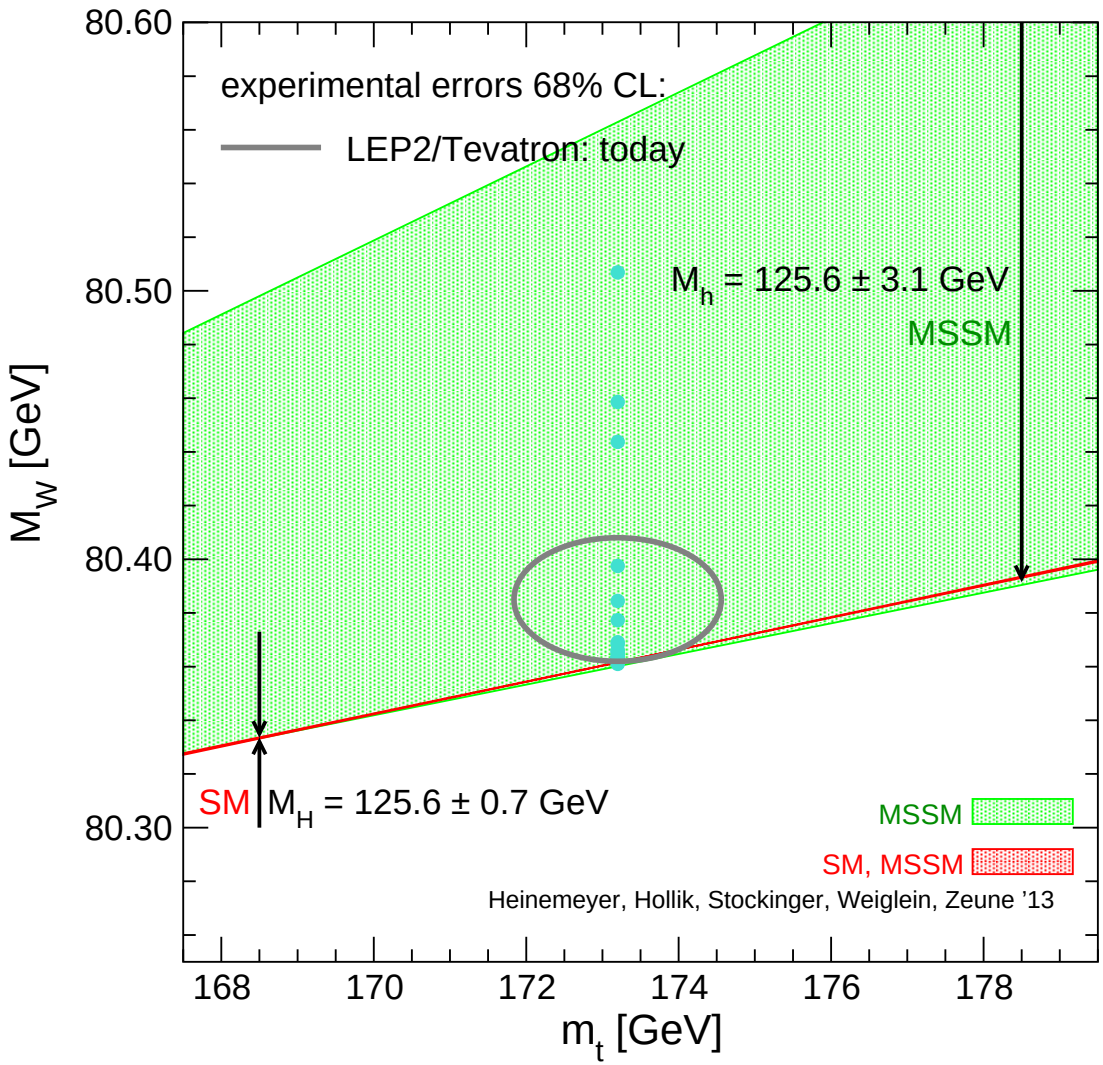

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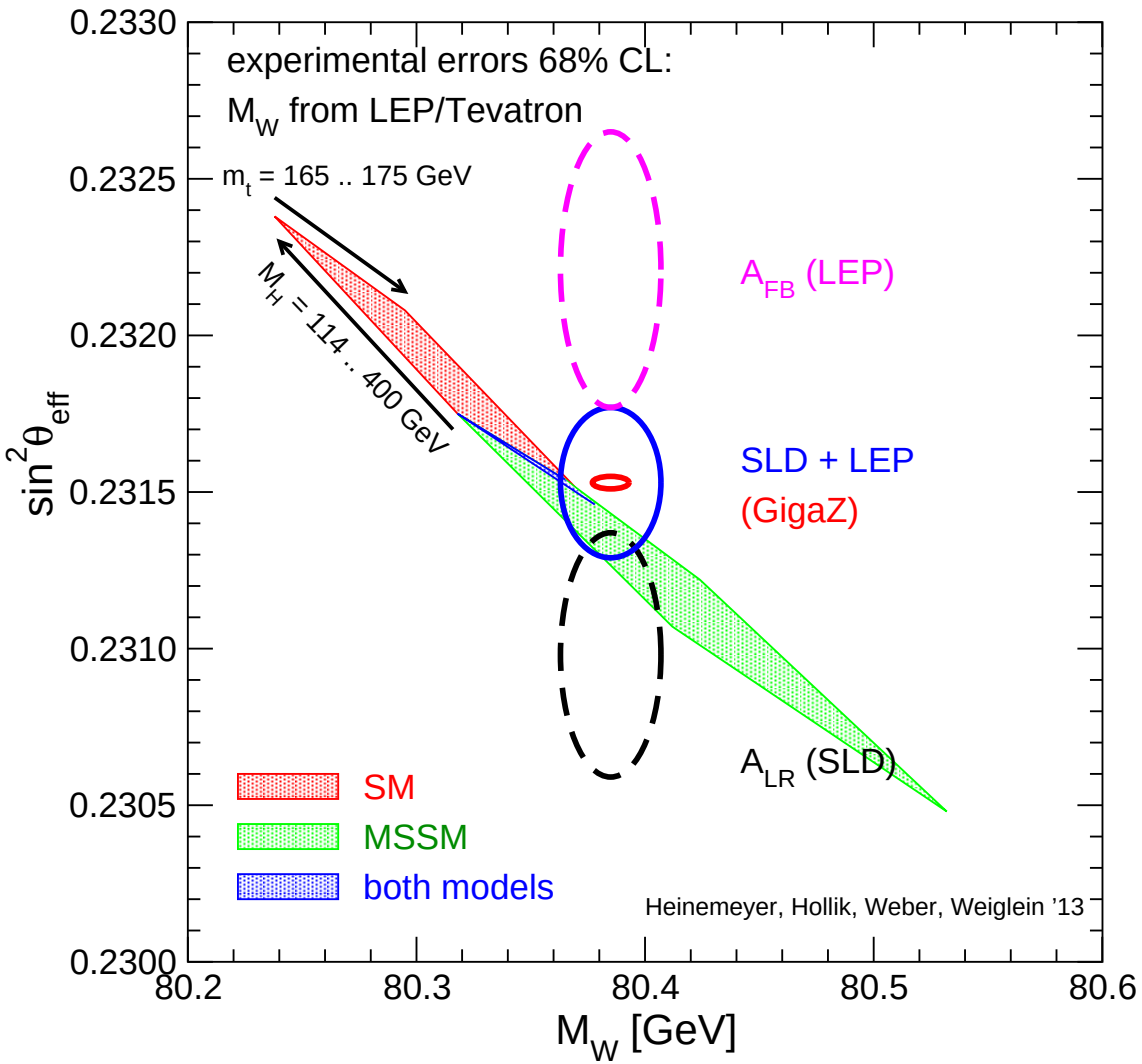

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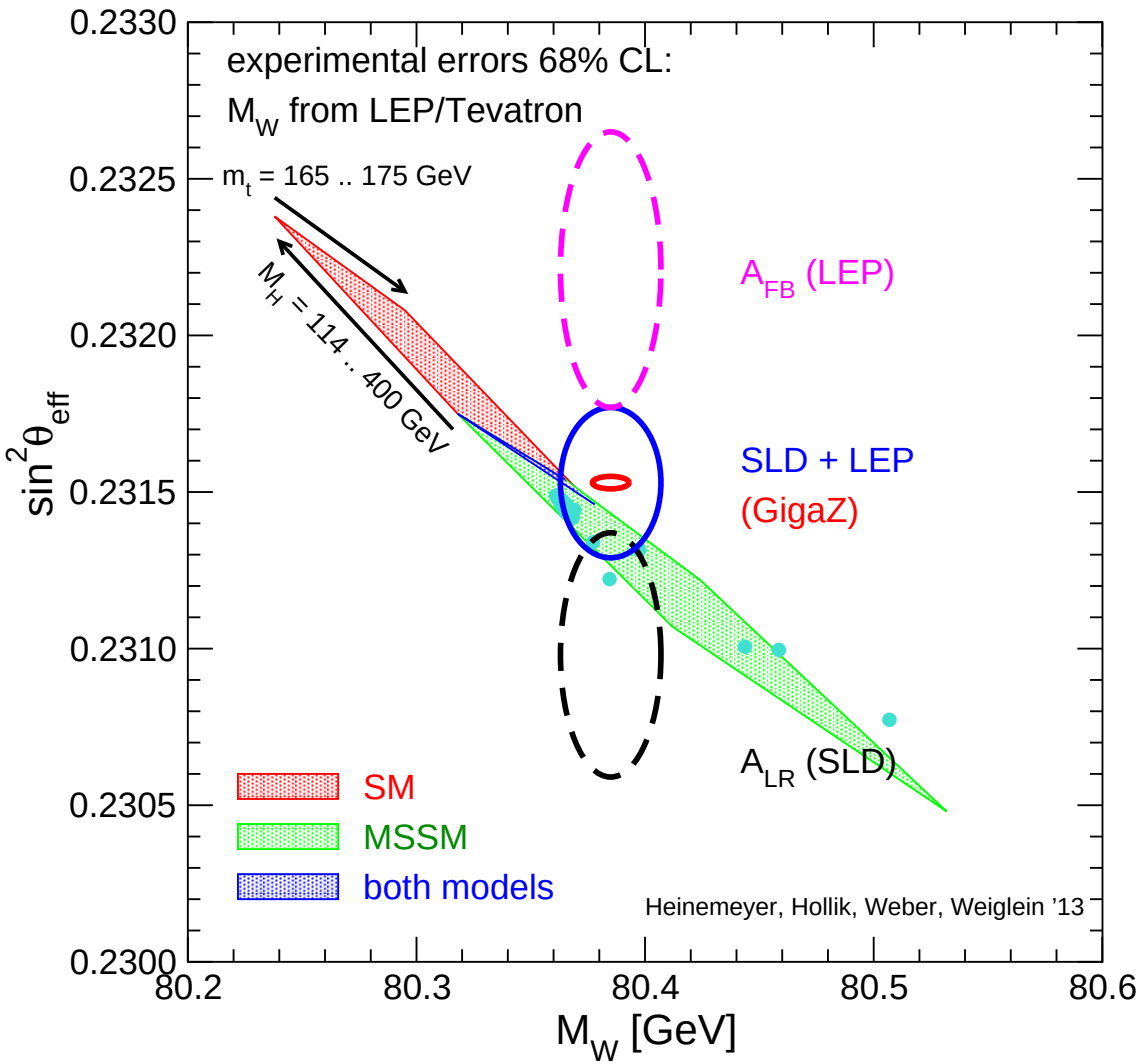

$\Rightarrow$ deviation from line can indicate non-$\Delta\rho$ contributions

4. Conclusinos

- EWPO can give valuable information about SM, BSM
  Best: M_W, $\sin^2\theta_{\text{eff}}$, $(g-2)_\mu$, ...

- SUSY corrections mainly via $\Delta\rho$
  But also non $\Delta\rho$ can be relevant

- Our tool: MasterCode
  Only code that contains the most precise EWPO evaluation in the MSSM

- pMSSM?
  Snowmass: 24 points with $\mathcal{O}(20)$ free parameters (real) [1305.2419 [hep-ph]]
  Sufficient? Representative?
  $\Rightarrow$ check (again) EWPO!

- Result: Most points ok, about 5 clearly disfavored
  Some more (non-negligible) variation among the rest
  Extreme spectra!?