Electroweak Precision Data

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The year of the Ox: Physics at the LHC

Aspen Center for Physics — February 8 – 14, 2009

Outline

- High Energy Data: where is the SM Higgs?
    - indirect constraints (precision measurements)
    - direct constraints (searches)
- Low Energy Data: the Intensity Frontier
    - parity violating electron scattering
    - APV and $g-2$
- Conclusions

High Energy Data:
where is the SM Higgs?

Top quark mass: projections

	fb^{-1} / exp.	value [GeV]	error / goal
Tevatron Run I	0.11	178.0	4.3
currently	2.8	172.4	1.2
Tevatron Run IIB	8		1.1
LHC low lumi	10		0.7
LHC high lumi	400		0.6
ILC	300		0.05

Top quark mass: interpretation

- Poor perturbative series between pole (M^t) & $\overline{MS}$ ($\bar{m}^t$) masses (IR renormalons) ⇒ $\Delta\bar{m}^t = \pm\, 0.6$ GeV

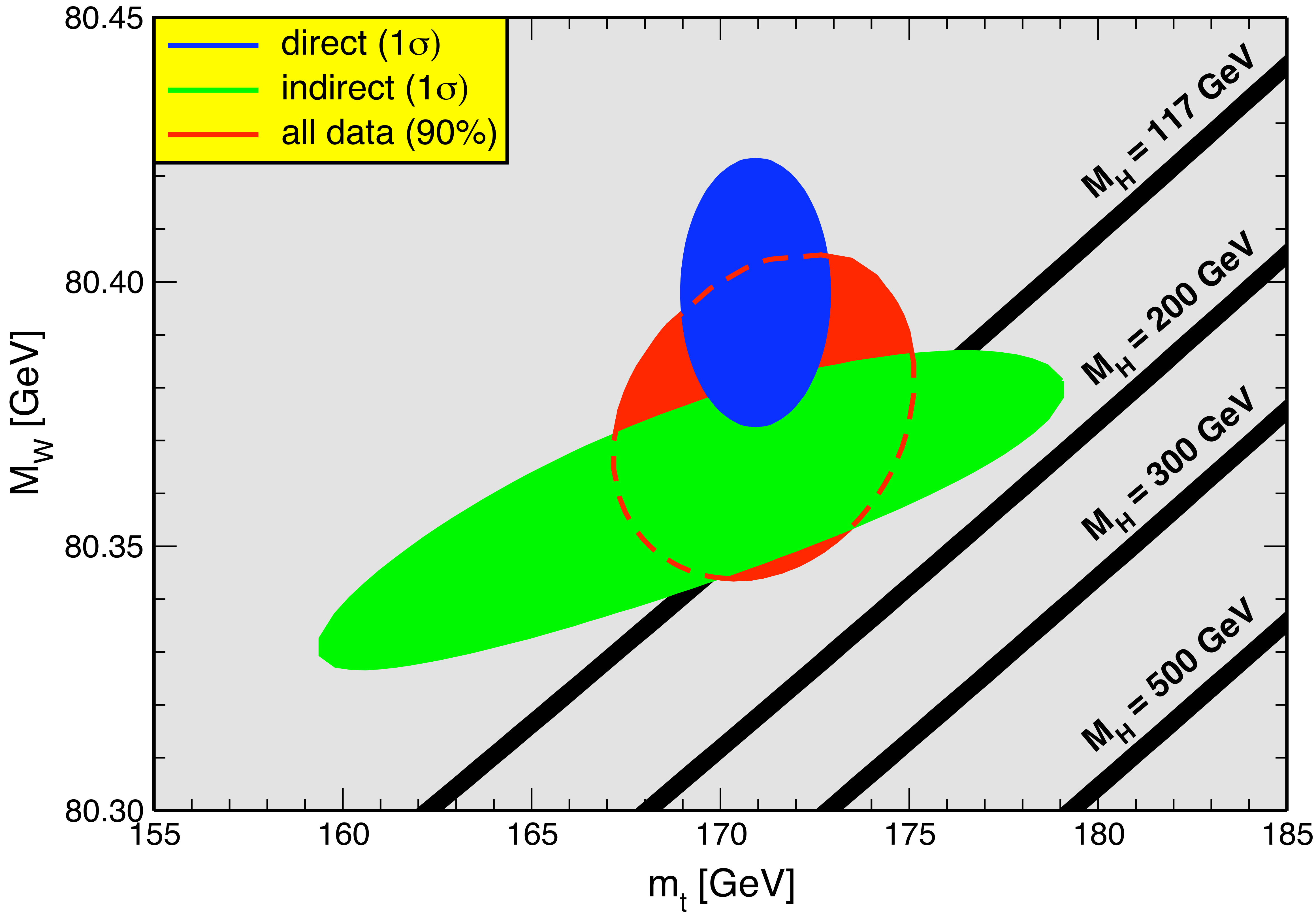
- Which top mass definition is measured in kinematic reconstruction ($p\bar{p}$, pp, e^+e^-)?

✓ $e^+e^- \to t\bar{t}$ (Fleming, Hoang, Mantry, Stewart, 2008): factorization theorem expressing $d^2\sigma / d\mathscr{M}^t d\bar{\mathscr{M}}^t$ (jet invariant masses) in terms of a top-resonance mass (m^t) with $|m^t - M^t| \lesssim \mathcal{O}(\Gamma^t)$ (ruling out $\bar{m}^t$).

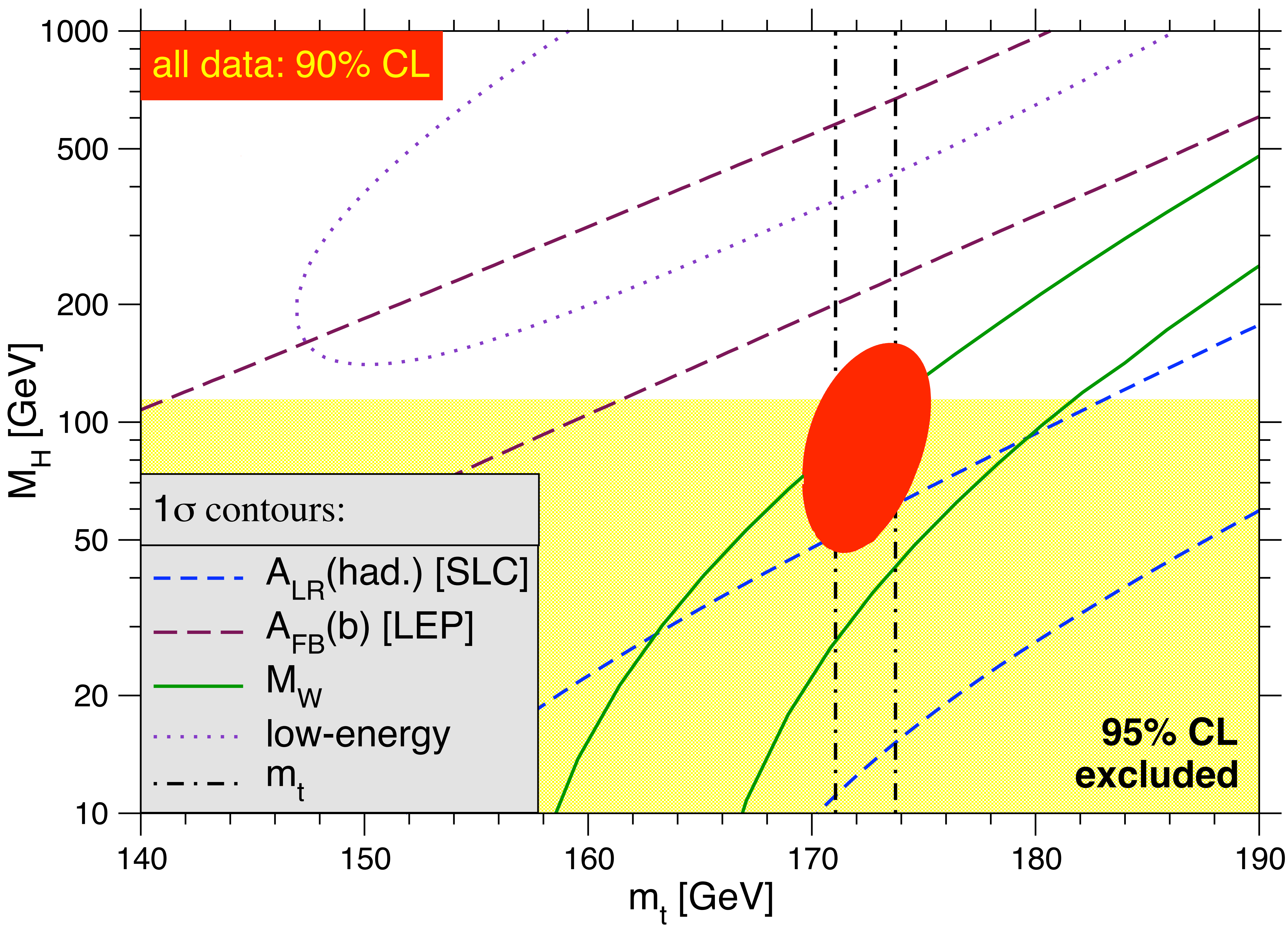
✓ LHC (Hoang, Stewart, 2008): $m^t \equiv \mathbb{M}^t$ (MSR mass), $\mathbb{M}^t(\mathbb{M}^t) = \bar{m}^t(\bar{m}^t)$; $\mathscr{M}^t = \mathbb{M}^t(3^{+6}{}_{-2}$ GeV) at large p^T.

W boson mass: projections

	fb^{-1} / exp.	value [GeV]	error / goal
Tevatron Run I	0.11	80.452	59
LEP 2	0.7	80.376	33
currently	1	80.398	25
Tevatron Run IIA	2		21 (e+μ)
Tevatron Run IIB	7		14 (e+μ)
LHC low lumi	10		23
LHC high lumi	400		7 (e), 6 (μ)
ILC	300		10
MegaW (ILC-160)	70		7



direct (1σ)
indirect (1σ)
all data (90%)
M_H = 117 GeV
M_H = 200 GeV
M_H = 300 GeV
M_H = 500 GeV
80.45
80.40
80.35
80.30
155
160
165
170
175
180
185
M_W [GeV]
m_t [GeV]



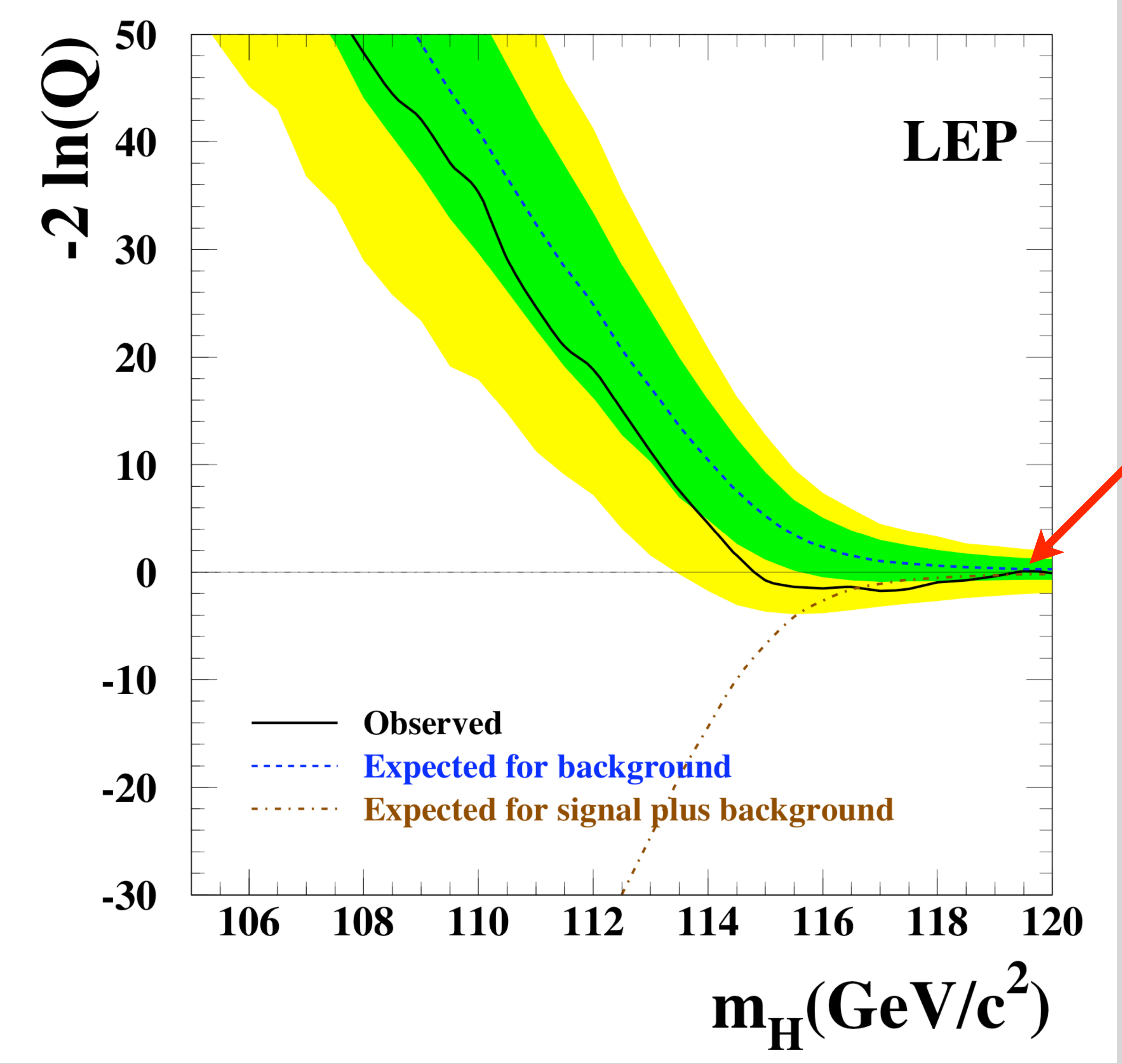
all data: 90% CL
1000
500
200
100
50
20
10
M_H [GeV]
140
150
160
170
180
190
m_t [GeV]
1σ contours:
A_LR(had.) [SLC]
A_FB(b) [LEP]
M_W
low-energy
m_t
95% CL
excluded

SM global fit results

	all data	indirect only
M_H [GeV]	91^{+28}_{-23}	117 (fixed)
M_t [GeV]	172.5 ± 1.3	175.6 ± 3.0
$\hat{\alpha}_s(M_Z)$	0.1185 ± 0.0016	0.1186 ± 0.0016
$\chi^2/\text{d.o.f.}$	48.1 / 45 (35%)	48.0 / 45 (24%)

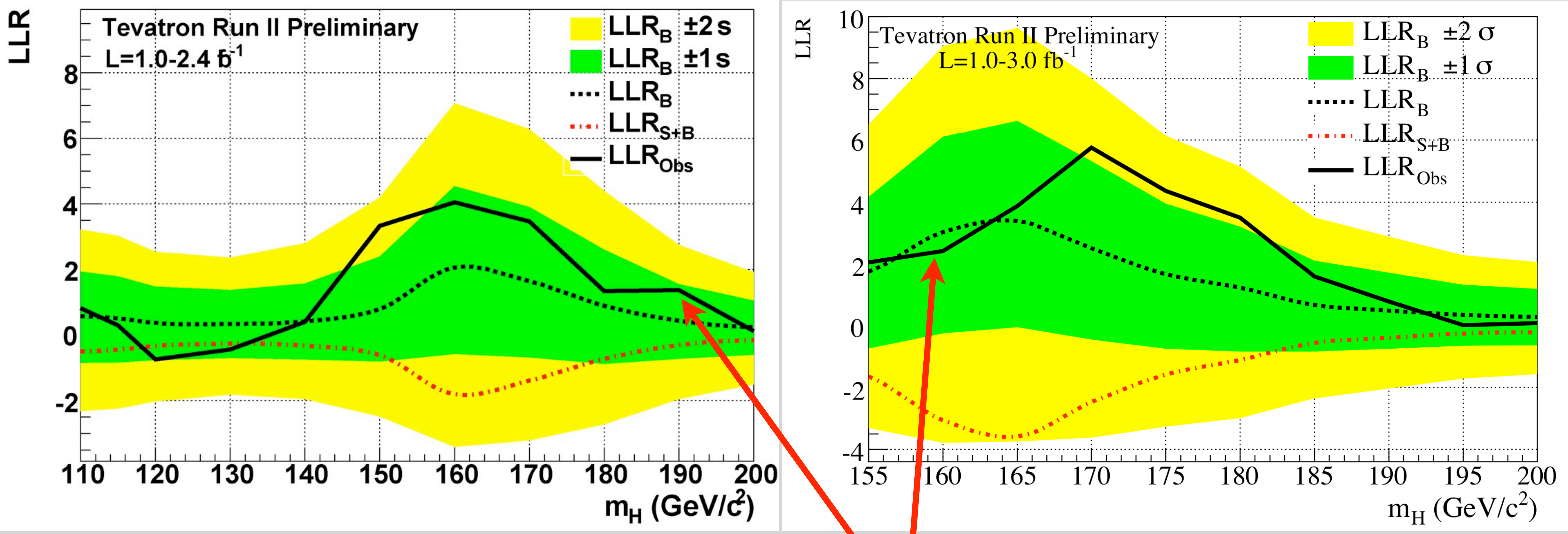
- α^s includes τ-lifetime and branching ratios;
  - Baikov, Chetyrkin, Kühn (2008): 4-loop PQCD
  - Maltman (2008): dimension 4, 6, 8 terms of OPE
  - Jamin, Beneke (2008): FOPT ↔ CIPT

LEP 2 Higgs searches

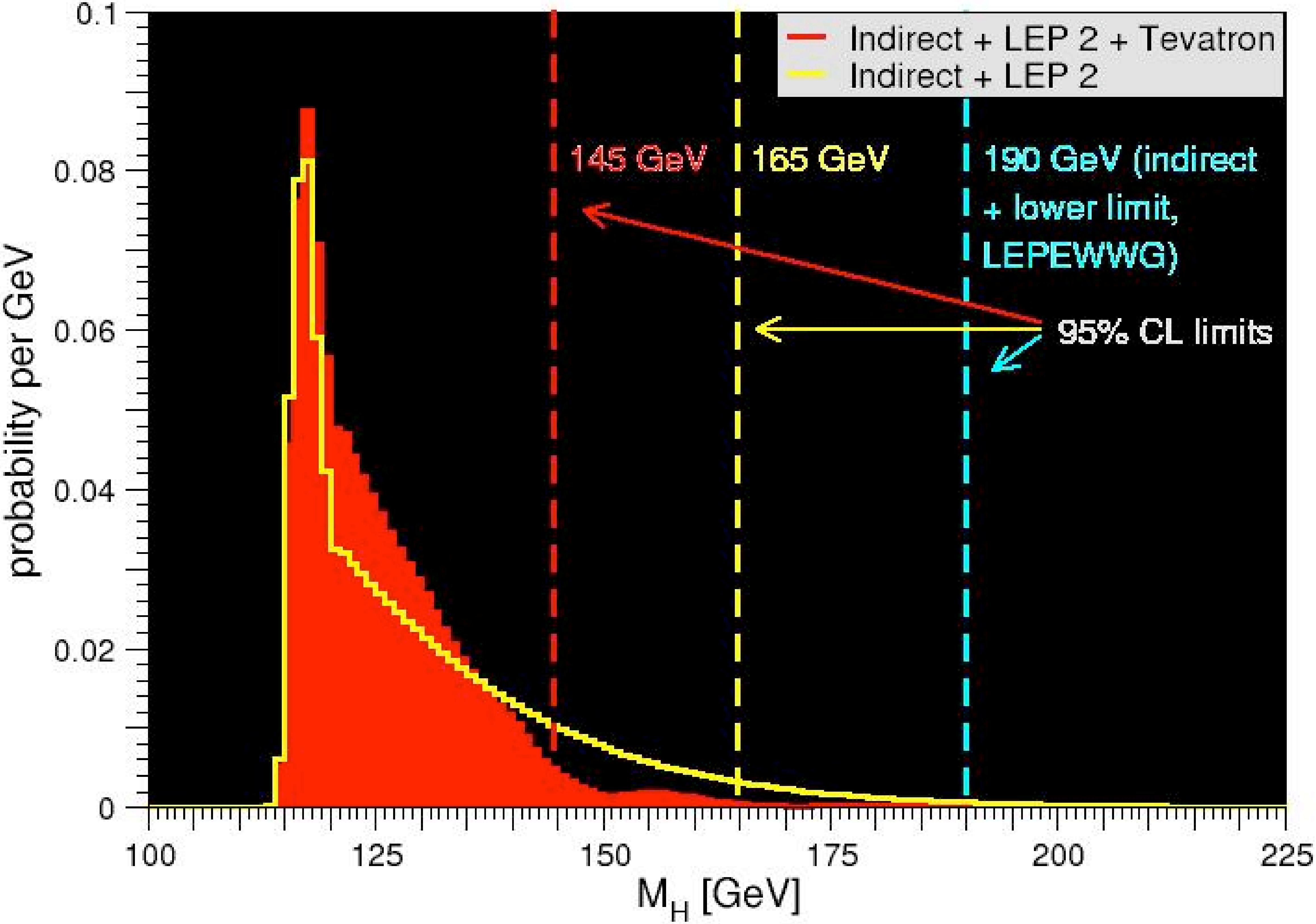


Contribution to likelihood

Tevatron Higgs searches



Contribution to likelihood


Indirect + LEP 2 + Tevatron
Indirect + LEP 2
145 GeV
165 GeV
190 GeV (indirect
+ lower limit,
LEPEWWG)
95% CL limits
probability per GeV
0.1
0.08
0.06
0.04
0.02
0
100
125
150
175
200
225
M_H [GeV]

Low Energy Data:
the Intensity Frontier

Møller asymmetry (SLAC)

$$A_{RL} \equiv \frac{d\sigma_R - d\sigma_L}{d\sigma_R + d\sigma_L} = \frac{\sqrt{2} G_F Q^2}{8\pi\alpha} F(\theta)(1+\Delta) Q_W^e$$

- E-158 Collaboration: Krishna Kumar et al. (2005)
- SLC e^--beam: E^e = 45 & 48 GeV, P^e = 89 ± 4 %
- $\Rightarrow$ $Q^2 \approx m^e E^e \approx 0.026$ GeV^2 (high energy, low Q^2)

$$Q_W^e \equiv g_R^2 - g_L^2 \approx -1 + 4\sin^2\hat{\theta}_W(Q^2) \approx -0.045$$

- $A^{RL} = -(1.31 \pm 0.14 \pm 0.10)\times 10^{-7}$

$$\Rightarrow Q_W^e = -0.0403 \pm 0.0053$$

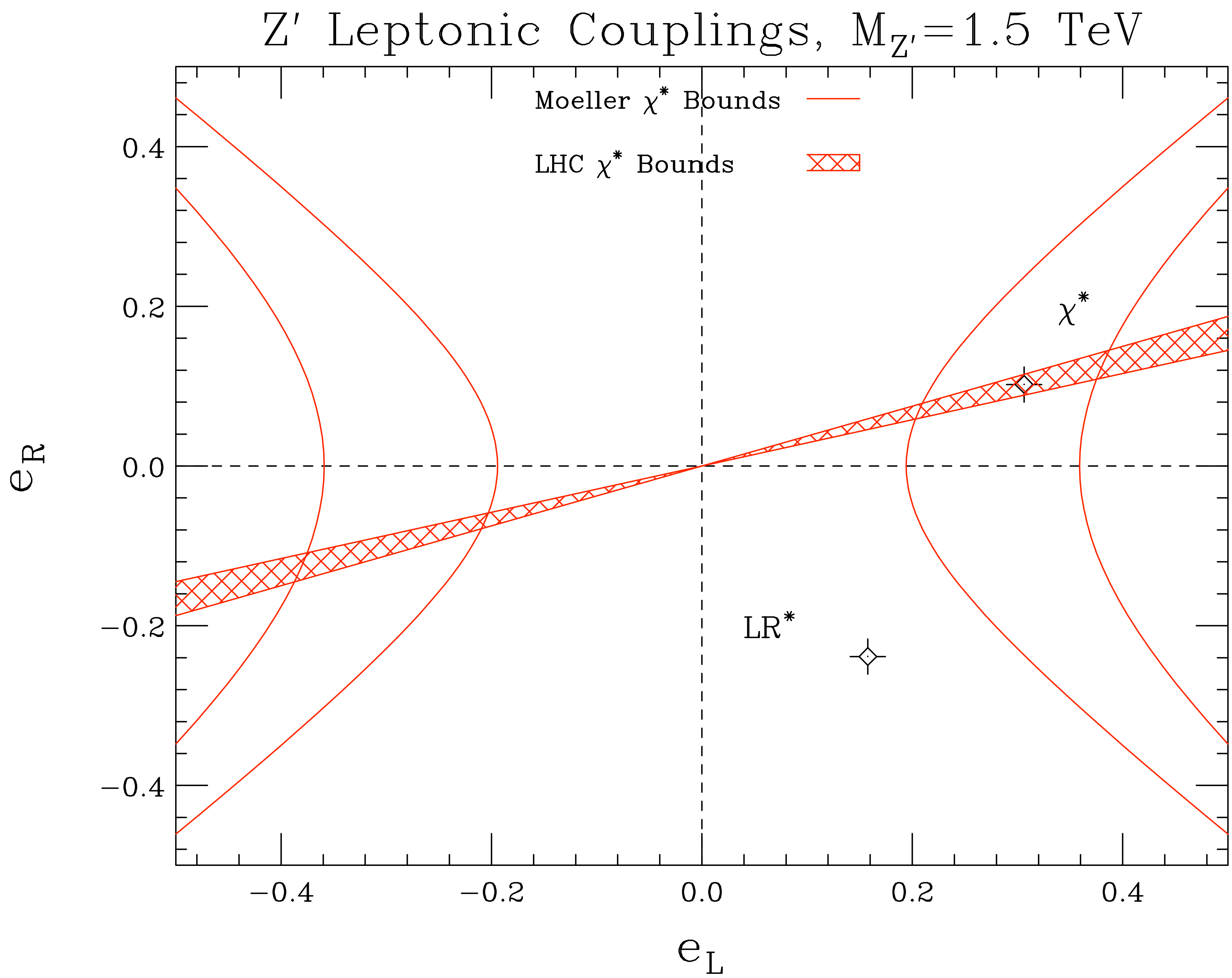
$$\Rightarrow \sin^2\hat{\theta}_W(M_Z) = 0.2330 \pm 0.0014$$

Møller asymmetry (JLab)

- Proposal accepted by JLab PAC (2 weeks ago)
- $Q^2 \simeq 0.0064$ GeV^2 (E = 11 GeV), P $\simeq 85 \pm 0.5$ %
- $A^{pv} \simeq -3.4\times10^{-8}\times(1 \pm 0.023) \Rightarrow \Delta Q^W \simeq \pm\, 0.0011$

  $\Rightarrow$ $\Delta \sin^2 \hat{\theta}_W(M_Z) \simeq \pm 0.00029$
- compare with SLD: ± 0.00029, best LEP: ± 0.00028
- complementary to Tevatron (eeqq-couplings), LEP 2 $(\, g_R^2 + g_L^2, g_{RL}^2\,)$ and electron EDM (⊄P)

$$\frac{\Lambda_{new}}{g_{new}} = \frac{1}{\sqrt{\sqrt{2} G_F \Delta Q_W^e}} > 7.5 \;\; \text{TeV}$$



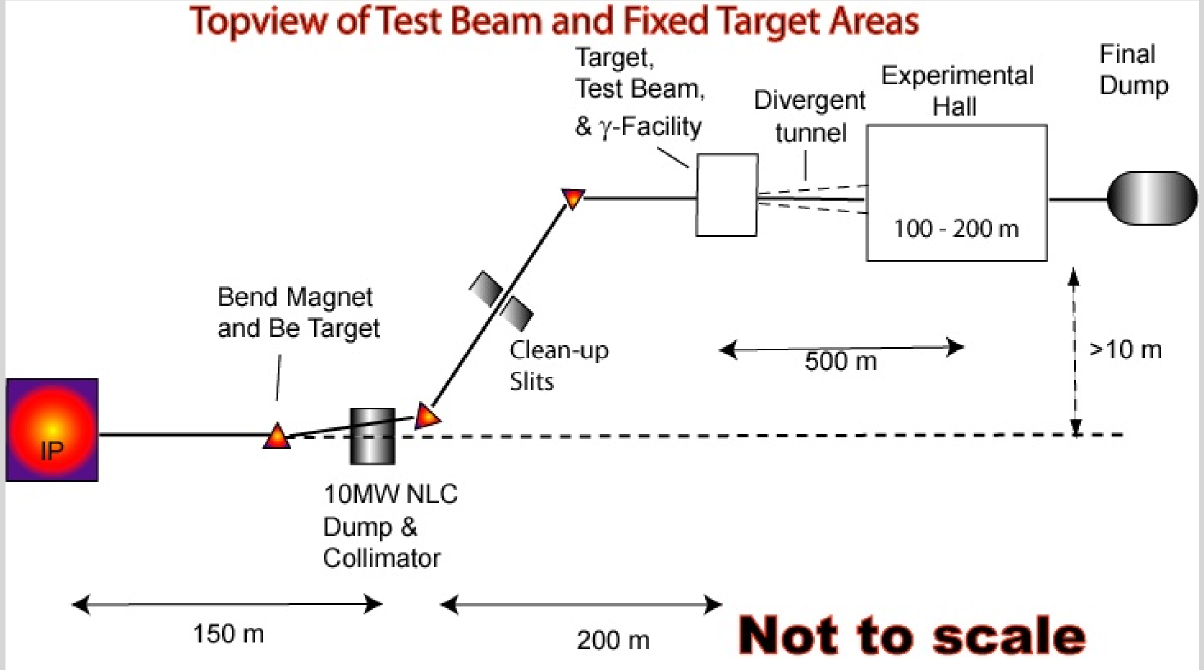
(Petriello, Quackenbush, 2008)

Møller asymmetry (ILC)

- E = 250 & 500 GeV, P $\simeq$ 90 ± 0.25 %
- statistics increase by factor of 200 over E-158 from beam intensity, figure of merit and run time
- $A^{pv} \simeq -10^{-6} \times (1 \pm 0.0076 \pm 0.0025)$
- $\Rightarrow \Delta Q^W \simeq \pm\, 0.00036 \Rightarrow$

$$\Delta \sin^2 \hat{\theta}_W(M_Z) \simeq \pm 9.5 \times 10^{-5}$$

$$\frac{\Lambda_{new}}{g_{new}} = \frac{1}{\sqrt{\sqrt{2} G_F \Delta Q_W^e}} > 13 \text{ TeV}$$



(plot by Krishna Kumar)

Elastic ep scattering (JLab)

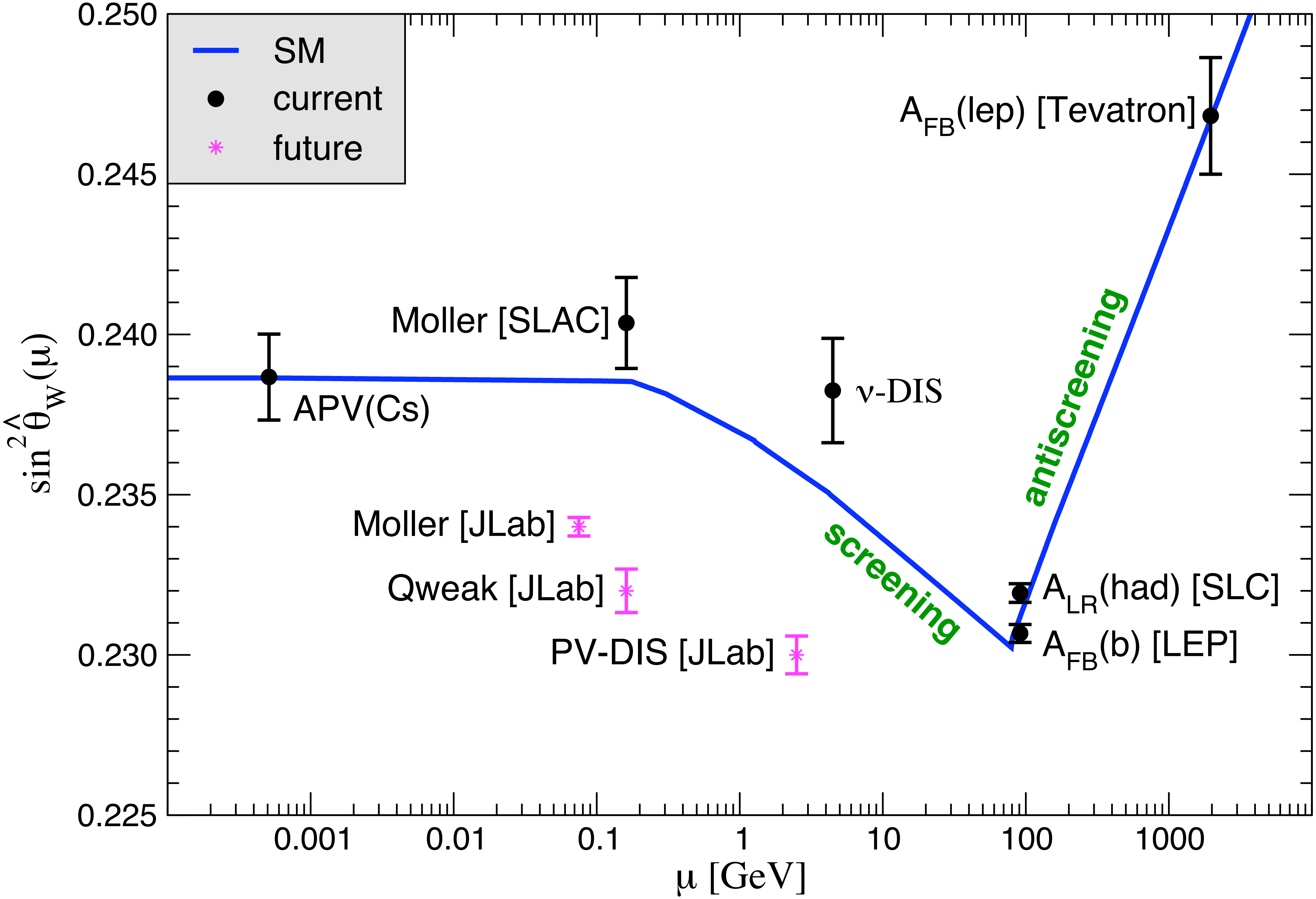
- Qweak experiment: Roger Carlini et al. (approved)
- begin installation: late October 2009 (6 months)
- end of data taking (6 months): May 14, 2012
- $Q^2 \simeq 0.026\ \mathrm{GeV}^2$ (E = 1.165 GeV), P ≃ 85 ± 1%

$$A_{RL} = \frac{\sqrt{2} G_F}{8\pi\alpha}\left(Q_W^p Q^2 + B_4 Q^4 + \ldots\right) \approx (2.68 \pm 0.07) 10^{-7}$$

- SM (WW & γZ-boxes!): Ramsey-Musolf, JE (2003)

$$\Delta Q_W^p \simeq \pm 0.0029 \Rightarrow \Delta \sin^2 \hat{\theta}_W(M_Z) \simeq 0.00072$$

- ⇒ Λ/g > 4.6 TeV (APV in Cs: Λ/g > 4.8 TeV)



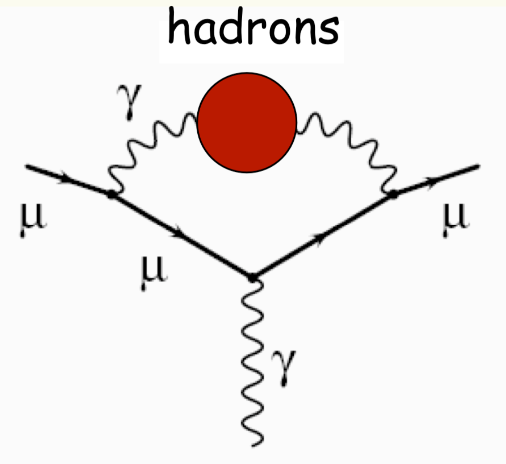
SM
current
future
0.250
0.245
0.240
0.235
0.230
0.225
$\sin^2\hat{\theta}_W(\mu)$
A_{FB}(lep) [Tevatron]
Moller [SLAC]
APV(Cs)
ν-DIS
antiscreening
screening
Moller [JLab]
Qweak [JLab]
PV-DIS [JLab]
A_{LR}(had) [SLC]
A_{FB}(b) [LEP]
0.001
0.01
0.1
1
10
100
1000
μ [GeV]

Weak mixing angle: projections

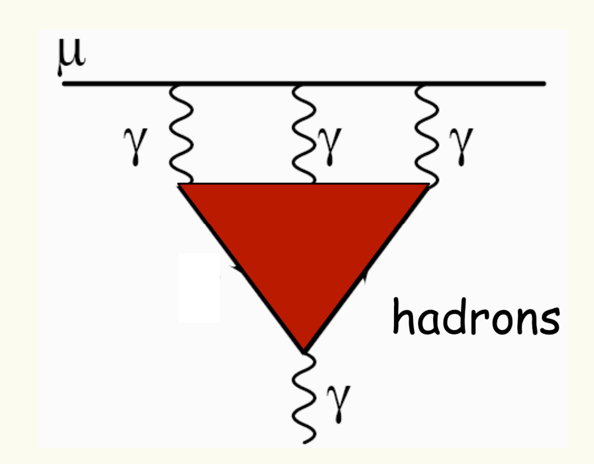
	fb^{-1} / exp.	value	error / goal
SLC	0.05	0.23098	0.00026
LEP I	0.20	0.23187	0.00021
DØ Run IIA	1.1	0.2327	0.0019
currently		0.23153	0.00016
Tevatron Run IIB	8		0.0003
JLab	Qweak, Møller		0.00027
LHC high lumi	400		0.00014
ILC	Møller		0.000095
GigaZ	70		0.000013

Atomic parity violation (APV)

- Nuclear spin (in)dependent PV sensitive to nuclear anapole moment & axial-vector couplings, C_2 (quark-vector electron-axial-vector couplings, C_1)
- most precise measurement (^{133}Cs): Wood et al. 1997; agrees with Bouchiat et al. 2004
- interpretation needs very good understanding of atomic structure
- most precise atomic theory calculation (^{133}Cs): Derevianko 2008
- $Q^W(Cs) = -73.17 \pm 0.29$ (exp.) ± 0.20 (theory)



Muon g−2 (BNL)



- E-821: 2.7-3.4 σ (3×10^{-9}) SM deviation (in flux)
- SUSY with tanβ ≫ 1, light superpartners, sign(μ)>0?
- 2-loop vacuum polarization (dispersion calculation)

  τ data inconsistent with e^+e^-: enhanced CVC?
  CMD 2, SND, KLOE inconsistent with BaBar (RR)
  & Belle (τ): 3.4 → 1.7 σ after BaBar result on R(s)
- 3-loop γ × γ (not first principles calculations!)

  π^0 + VMD: $(1.16 \pm 0.40)\times10^{-9}$ (Nyffeler 2009)
  free quarks: $< 1.59\times10^{-9}$ (Toledo, JE 2006)

Conclusions

Conclusions

- Assuming the SM (or decoupling new physics) $\Rightarrow M^H \simeq 130$ GeV give or (more likely) take 15 GeV.
- LHC may be fatal for the SM but not for low-energy precision measurements

The Year of the Earth Ox: recently seen in this zodiac

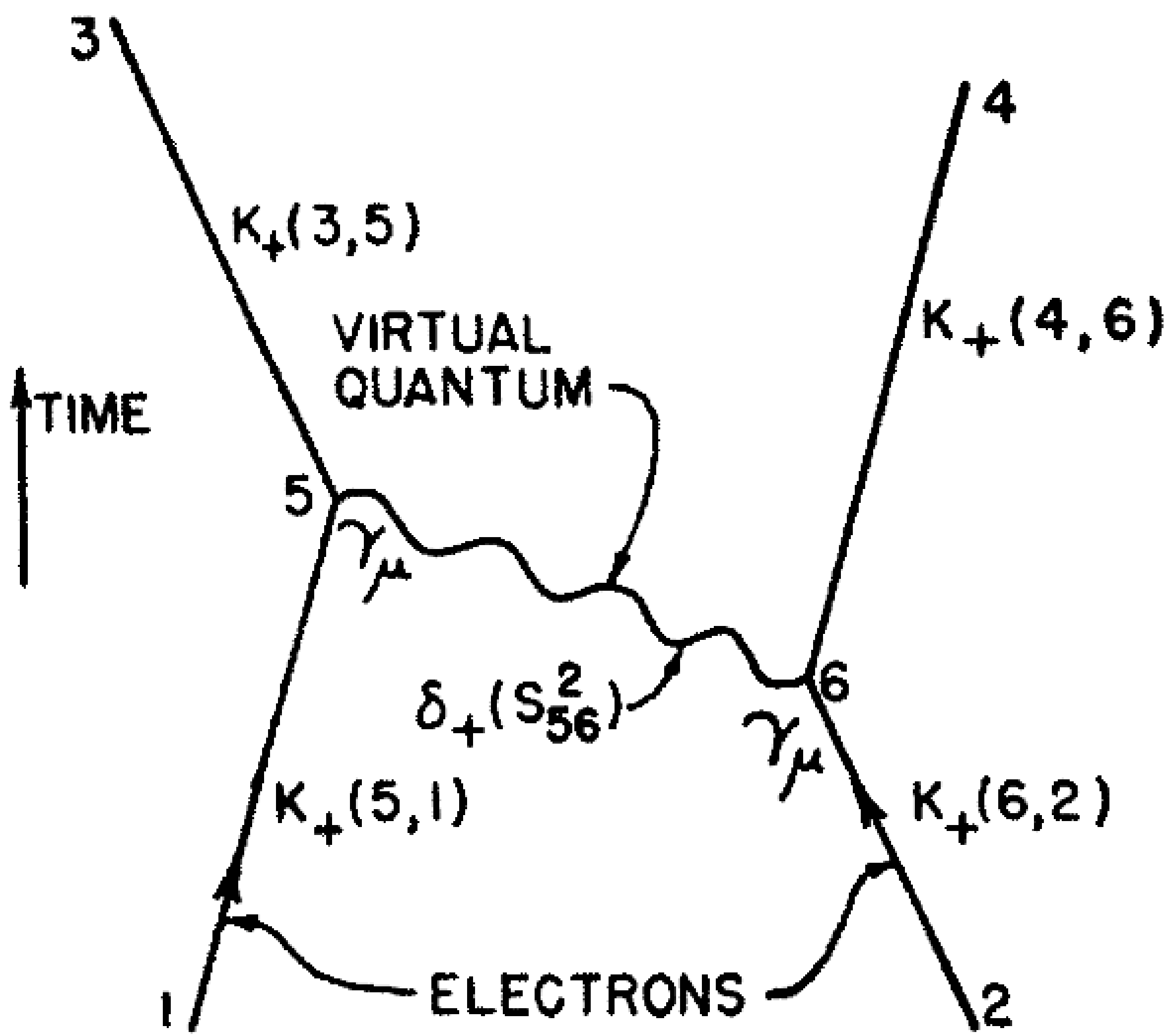


FIG. 1. The fundamental interaction Eq. (4). Exchange of one quantum between two electrons.