Electroweak Tests of the Standard Model

Jens Erler (IF-UNAM)

PASCOS 2012 — Mérida, Yuc. (Mexico) June 7, 2012

Electroweak Tests of the Standard Model

Jens Erler (IF-UNAM)

PASCOS 2012 — Mérida, Yuc. (Mexico)

June 7, 2012

Electroweak Tests of the Standard M

just the Higgs

Jens Erler (IF-UNAM)

PASCOS 2012 — Mérida, Yuc. (Mexico) June 7, 2012

Many Thanks

4

Many Thanks

- for invitation: organizers (especially Myriam Mondragon)

Many Thanks

- for invitation: organizers (especially Myriam Mondragon)
- for collaboration and plots:
  - Leo Bellantoni (FNAL)
  - Jon Heckman, Paul Langacker (IAS Princeton)
  - Krishna Kumar (Amherst, MA)
  - Sky Bauman, Michael Ramsey-Musolf (Madison, WI)
  - Eduardo Rojas (IF-UNAM, Mexico)

Table of the Elementary Particles

ν_τ s=½ ~ 0	τ^- s=½ 1.9075	τ^+ s=½ 1.9075	t s=½ 176	t s=½ 176	t s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	b s=½ 4.5	b s=½ 4.5	b s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5
ν_μ s=½ ~ 0	μ^- s=½ 0.11343	μ^+ s=½ 0.11343	c s=½ 1.4	c s=½ 1.4	c s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	s s=½ 0.1	s s=½ 0.1	s s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1
ν_e s=½ ~ 0	e^- s=½ 0.00055	e^+ s=½ 0.00055	u s=½ 0.003	u s=½ 0.003	u s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	d s=½ 0.005	d s=½ 0.005	d s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005
H s=0 134	$H^\pm$ s=0 86.3 ξ	Z s=1 97.9	W^- s=1 86.3	W^+ s=1 86.3	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	γ s=1 0	G s=2 0

Table of the Elementary Particles

ν_τ	τ^-	τ^+	t	t	t	$\bar{t}$	$\bar{t}$	$\bar{t}$	b	b	b	$\bar{b}$	$\bar{b}$	$\bar{b}$	
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	
~ 0	1.9075	1.9075	176	176	176	176	176	176	4.5	4.5	4.5	4.5	4.5	4.5	
ν_μ	μ^-	μ^+	c	c	c	$\bar{c}$	$\bar{c}$	$\bar{c}$	s	s	s	$\bar{s}$	$\bar{s}$	$\bar{s}$	
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	
~ 0	0.11343	0.11343	1.4	1.4	1.4	1.4	1.4	1.4	0.1	0.1	0.1	0.1	0.1	0.1	
ν_e	e^-	e^+	u	u	u	$\bar{u}$	$\bar{u}$	$\bar{u}$	d	d	d	$\bar{d}$	$\bar{d}$	$\bar{d}$	
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	
~ 0	0.00055	0.00055	0.003	0.003	0.003	0.003	0.003	0.003	0.005	0.005	0.005	0.005	0.005	0.005	
H	$H^\pm$	Z	W^-	W^+	g	g	g	g	g	g	g	g	γ	G	
s=0	s=0	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=2	
[illegible]	86.3 ξ	97.9	86.3	86.3	0	0	0	0	0	0	0	0	0	0	

6

Table of the Elementary Particles

ν_τ s=½ ~ 0	τ^- s=½ 1.9075	τ^+ s=½ 1.9075	t s=½ 176	t s=½ 176	t s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	b s=½ 4.5	b s=½ 4.5	b s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5
ν_μ s=½ ~ 0	μ^- s=½ 0.11343	μ^+ s=½ 0.11343	c s=½ 1.4	c s=½ 1.4	c s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	s s=½ 0.1	s s=½ 0.1	s s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1
ν_e s=½ ~ 0	e^- s=½ 0.00055	e^+ s=½ 0.00055	u s=½ 0.003	u s=½ 0.003	u s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	d s=½ 0.005	d s=½ 0.005	d s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005
H s=0 134	$H^\pm$ s=0 86.3 ξ	Z s=1 97.9	W^- s=1 86.3	W^+ s=1 86.3	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	γ s=1 0	G s=2 0

7

Table of the Elementary Particles

ν_τ s=½ ~ 0	τ^- s=½ 1.9075	τ^+ s=½ 1.9075	t s=½ 176	t s=½ 176	t s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	b s=½ 4.5	b s=½ 4.5	b s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5
ν_μ s=½ ~ 0	μ^- s=½ 0.11343	μ^+ s=½ 0.11343	c s=½ 1.4	c s=½ 1.4	c s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	s s=½ 0.1	s s=½ 0.1	s s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1
ν_e s=½ ~ 0	e^- s=½ 0.00055	e^+ s=½ 0.00055	u s=½ 0.003	u s=½ 0.003	u s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	d s=½ 0.005	d s=½ 0.005	d s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005
H s=0 134	$H^\pm$ s=0 86.3 ξ	Z s=1 97.9	W^- s=1 86.3	W^+ s=1 86.3	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	γ s=1 0	G s=2 0

Table of the Elementary Particles

ν_τ s=½ ~ 0	τ^- s=½ 1.9075	τ^+ s=½ 1.9075	t s=½ 176	t s=½ 176	t s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	b s=½ 4.5	b s=½ 4.5	b s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5
ν_μ s=½	μ^- s=½ 0.11343	μ^+ s=½ 0.11343	c s=½ 1.4	c s=½ 1.4	c s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	s s=½ 0.1	s s=½ 0.1	s s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1
ν_e s=½ ~ 0	e^- s=½ 0.00055	e^+ s=½ 0.00055	u s=½ 0.003	u s=½ 0.003	u s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	d s=½ 0.005	d s=½ 0.005	d s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005
H s=0 134	$H^\pm$ s=0 86.3 ξ	Z s=1 97.9	W^- s=1 86.3	W^+ s=1 86.3	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	γ s=1 0	G s=2 0

9

Table of the Elementary Particles

ν_τ	τ^-	τ^+	t	t	t	$\bar{t}$	$\bar{t}$	$\bar{t}$	b	b	b	$\bar{b}$	$\bar{b}$	$\bar{b}$
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½
~ 0	1.9075	1.9075	176	176	176	176	176	176	4.5	4.5	4.5	4.5	4.5	4.5
ν_μ	μ^-	μ^+	c	c	c	$\bar{c}$	$\bar{c}$	$\bar{c}$	s	s	s	$\bar{s}$	$\bar{s}$	$\bar{s}$
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½
~ 0	0.11343	0.11343	1.4	1.4	1.4	1.4	1.4	1.4	0.1	0.1	0.1	0.1	0.1	0.1
ν_e	e^-	e^+	u	u	u	$\bar{u}$	$\bar{u}$	$\bar{u}$	d	d	d	$\bar{d}$	$\bar{d}$	$\bar{d}$
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½
~ 0	0.00055	0.00055	0.003	0.003	0.003	0.003	0.003	0.003	0.005	0.005	0.005	0.005	0.005	0.005
H	$H^\pm$	Z	W^-	W^+	g	g	g	g	g	g	g	g	γ	G
s=0	s=0	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=2
134	86.3 ξ	97.9	86.3	86.3	0	0	0	0	0	0	0	0	0	0

10

Table of the Elementary Particles

ν_τ s=½ ~ 0	τ^- s=½ 1.9075	τ^+ s=½ 1.9075	t s=½ 176	t s=½ 176	t s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	$\bar{t}$ s=½ 176	b s=½ 4.5	b s=½ 4.5	b s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5	$\bar{b}$ s=½ 4.5
ν_μ s=½ ~ 0	μ^- s=½ 0.11343	μ^+ s=½ 0.11343	c s=½ 1.4	c s=½ 1.4	c s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	$\bar{c}$ s=½ 1.4	s s=½ 0.1	s s=½ 0.1	s s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1	$\bar{s}$ s=½ 0.1
ν_e s=½ ~ 0	e^- s=½ 0.00055	e^+ s=½ 0.00055	u s=½ 0.003	u s=½ 0.003	u s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	$\bar{u}$ s=½ 0.003	d s=½ 0.005	d s=½ 0.005	d s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005	$\bar{d}$ s=½ 0.005
H s=0 134	$H^\pm$ s=0 86.3 ξ	Z s=1 97.9	W^- s=1 86.3	W^+ s=1 86.3	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	g s=1 0	γ s=1 0	G s=2 0

11

Table of the Elementary Particles

ν_τ	τ^-	τ^+	t	t	t	$\bar{t}$	$\bar{t}$	$\bar{t}$	b	b	b	$\bar{b}$	$\bar{b}$	$\bar{b}$
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½
~ 0	1.9075	1.9075	176	176	176	176	176	176	4.5	4.5	4.5	4.5	4.5	4.5
ν_μ	μ^-	μ^+	c	c	c	$\bar{c}$	$\bar{c}$	$\bar{c}$	s	s	s	$\bar{s}$	$\bar{s}$	$\bar{s}$
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½
~ 0	0.11343	0.11343	1.4	1.4	1.4	1.4	1.4	1.4	0.1	0.1	0.1	0.1	0.1	0.1
ν_e	e^-	e^+	u	u	u	$\bar{u}$	$\bar{u}$	$\bar{u}$	d	d	d	$\bar{d}$	$\bar{d}$	$\bar{d}$
s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½	s=½
~ 0	0.00055	0.00055	0.003	0.003	0.003	0.003	0.003	0.003	0.005	0.005	0.005	0.005	0.005	0.005
H	$H^\pm$	Z	W^-	W^+	g	g	g	g	g	g	g	g	γ	G
s=0	s=[illegible]	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=1	s=2
134	86.3 ξ	[illegible]	86.3	86.3	0	0	0	0	0	0	0	0	0	0

History of Precision Tests

13

History of Precision Tests

- 1970s: discovery of key predictions of the SM (neutral currents, APV, polarized DIS)

History of Precision Tests

- 1970s: discovery of key predictions of the SM (neutral currents, APV, polarized DIS)
- 1980s: establishment of basic structure of the SM (mutually consistent values of $\sin^2\theta_W = g'^2/(g^2 + g'^2)$ from many different processes)

History of Precision Tests

- 1970s: discovery of key predictions of the SM (neutral currents, APV, polarized DIS)
- 1980s: establishment of basic structure of the SM (mutually consistent values of $\sin^2\theta_W = g'^2/(g^2 + g'^2)$ from many different processes)
- 1990s (LEP, SLC): confirmation of the SM at the loop level $\Rightarrow$ new physics at most a perturbation

13

History of Precision Tests

- 1970s: discovery of key predictions of the SM (neutral currents, APV, polarized DIS)
- 1980s: establishment of basic structure of the SM (mutually consistent values of $\sin^2\theta_W = g'^2/(g^2 + g'^2)$ from many different processes)
- 1990s (LEP, SLC): confirmation of the SM at the loop level $\Rightarrow$ new physics at most a perturbation
- 2000s (Tevatron): ultra-high precision in m_t (0.5%) and M_W (2×10^{-4}) $\Rightarrow$ (most of) new physics seperated by at least a little hierarchy (or else conspiracy)

13

History of Precision Tests

- 1970s: discovery of key predictions of the SM (neutral currents, APV, polarized DIS)
- 1980s: establishment of basic structure of the SM (mutually consistent values of $\sin^2\theta_W = g'^2/(g^2+g'^2)$ from many different processes)
- 1990s (LEP, SLC): confirmation of the SM at the loop level $\Rightarrow$ new physics at most a perturbation
- 2000s (Tevatron): ultra-high precision in m_t (0.5%) and M_W (2×10^{-4}) $\Rightarrow$ (most of) new physics seperated by at least a little hierarchy (or else conspiracy)
- 2010s (LHC, intensity frontier): electroweak symmetry breaking sector

Recent Developments

μ^--lifetime and G_F

15

μ^--lifetime and G_F

- $\tau_\mu = 2.1969803(2.2) \times 10^{-6}$ s ***MuLan 2011*** $\Longrightarrow$

μ^--lifetime and G_F

- $\tau_\mu = 2.1969803(2.2) \times 10^{-6}$ s ***MuLan 2011*** $\Longrightarrow$
- $G_F = 1.1663787(6) \times 10^{-5}\ \mathrm{GeV}^{-2}$

μ^--lifetime and G_F

- $\tau_\mu = 2.1969803(2.2) \times 10^{-6}$ s ***MuLan 2011*** $\Rightarrow$
- $G_F = 1.1663787(6) \times 10^{-5}\ \mathrm{GeV}^{-2}$
- so precise that error in atomic mass unit (u) can shift G_F

  (***MuLan*** quotes $G_F = 1.1663788(7) \times 10^{-5}\ \mathrm{GeV}^{-2}$)

μ^--lifetime and G_F

- $\tau_\mu = 2.1969803(2.2) \times 10^{-6}$ s ***MuLan 2011*** $\Rightarrow$
- $G_F = 1.1663787(6) \times 10^{-5}\ \mathrm{GeV}^{-2}$
- so precise that error in atomic mass unit (u) can shift G_F

  (***MuLan*** quotes $G_F = 1.1663788(7) \times 10^{-5}\ \mathrm{GeV}^{-2}$)
- finite M_W in the W-propagator no longer negligible:
  - correct for, i.e., absorb in Δq: $\tau_\mu^{-1} \sim G_F^2\,(1 + \Delta q)$
  - or not, i.e., absorb in Δr: $\sqrt{32}\, G_F \equiv g^2 / M_W^2\,(1 + \Delta r)$
  - latter convention motivated by effective Fermi theory point of view and used by ***MuLan***, and since this year also in ***PDG***

15

τ^{-}-lifetime and α_s

16

τ^{-}-lifetime and α_s

- at least one low-energy α_s-value needed to promote Z-width to a SM test (constraint on BSM physics).

16

τ^--lifetime and α_s

- at least one low-energy α_s-value needed to promote Z-width to a SM test (constraint on BSM physics).
- recent developments:
  - 4-loop PQCD coefficient ***Baikov, Chetyrkin, Kühn 2008***
  - FOPT vs. CIPT controversy ***Le Diberder, Pich 1992; Beneke, Jamin 2008***
  - fit to condensate terms ***Davier et al. 2008; Boito et al. 2012***

τ^--lifetime and α_s

- at least one low-energy α_s-value needed to promote Z-width to a SM test (constraint on BSM physics).
- recent developments:
  - 4-loop PQCD coefficient ***Baikov, Chetyrkin, Kühn 2008***
  - FOPT vs. CIPT controversy ***Le Diberder, Pich 1992; Beneke, Jamin 2008***
  - fit to condensate terms ***Davier et al. 2008; Boito et al. 2012***
- $\alpha_s[\tau] = 0.1193 \pm 0.0021$

τ^--lifetime and α_s

- at least one low-energy α_s-value needed to promote Z-width to a SM test (constraint on BSM physics).
- recent developments:
  - 4-loop PQCD coefficient ***Baikov, Chetyrkin, Kühn 2008***
  - FOPT vs. CIPT controversy ***Le Diberder, Pich 1992; Beneke, Jamin 2008***
  - fit to condensate terms ***Davier et al. 2008; Boito et al. 2012***
- $\alpha_s[\tau] = 0.1193 \pm 0.0021$
- $\alpha_s[\text{Z-pole}] = 0.1197 \pm 0.0028$ (perfect agreement)
  - only determination with very small theory uncertainty

NuTeV

17

NuTeV

- $\sin^2\theta_W^{\text{on-shell}} \equiv 1 - M_W^2/M_Z^2 = 0.2277 \pm 0.0016$

NuTeV

- $\sin^2\theta_W^{\text{on-shell}} \equiv 1 - M_W^2/M_Z^2 = 0.2277 \pm 0.0016$
- SM: $\sin^2\theta_W = 0.22296 \pm 0.00028$ (3.0 σ deviation)

NuTeV

- $\sin^2\theta_W^{\text{on-shell}} \equiv 1 - M_W^2 / M_Z^2 = 0.2277 \pm 0.0016$
- SM: $\sin^2\theta_W = 0.22296 \pm 0.00028$ (3.0 σ deviation)
  - deviation sits in g_L^2 (2.7 σ)

17

NuTeV

- $\sin^2\theta_W^{\text{on-shell}} \equiv 1 - M_W^2/M_Z^2 = 0.2277 \pm 0.0016$
- SM: $\sin^2\theta_W = 0.22296 \pm 0.00028$ (3.0 σ deviation)
  - deviation sits in g_L^2 (2.7 σ)
  - various SM effects have been suggested:

    asymmetric strange sea

    isospin violation (QED splitting effects ***Glück, Jimenez-Delgado, Reya 2005*** and PDFs ***Sather 1992; Rodionov, Thomas, Londergan 1994; Martin et al. 2004***)

    nuclear effects (e.g., isovector EMC effect ***Cloët, Bentz, Thomas 2009***)

    QED ***Arbuzov, Bardin, Kalinovskaya 2005; Park, Baur, Wackeroth 2009***, ***Diener, Dittmaier, Hollik 2004***
    QCD ***Dobrescu, Ellis 2004*** and EW ***Diener, Dittmaier, Hollik 2005*** radiative corrections

NuTeV

- $\sin^2\theta_W^{\text{on-shell}} \equiv 1 - M_W^2/M_Z^2 = 0.2277 \pm 0.0016$
- SM: $\sin^2\theta_W = 0.22296 \pm 0.00028$ (3.0 σ deviation)
  - deviation sits in g_L^2 (2.7 σ)
  - various SM effects have been suggested:

    asymmetric strange sea

    isospin violation (QED splitting effects ***Glück, Jimenez-Delgado, Reya 2005*** and PDFs ***Sather 1992; Rodionov, Thomas, Londergan 1994; Martin et al. 2004***)

    nuclear effects (e.g., isovector EMC effect ***Cloët, Bentz, Thomas 2009***)

    QED ***Arbuzov, Bardin, Kalinovskaya 2005; Park, Baur, Wackeroth 2009***, ***Diener, Dittmaier, Hollik 2004***
    QCD ***Dobrescu, Ellis 2004*** and EW ***Diener, Dittmaier, Hollik 2005*** radiative corrections
  - situation not conclusive; breaking news @CIPANP: Bob Bernstein confirms that NuTeV fitting functions were applied correctly by ***Cloët et al.***

M_W

M_W

- $M_W = 80.387 \pm 0.016$ GeV ***CDF & D0 2012*** (± 19 MeV ***CDF*** 2.2 fb^{-1})

M_W

- $M_W = 80.387 \pm 0.016$ GeV ***CDF & D0 2012*** (± 19 MeV ***CDF*** 2.2 fb^{-1})
- $M_W = 80.376 \pm 0.033$ GeV ***LEP 2***

$\Rightarrow \sin^2\theta_W^{\text{on-shell}} \equiv 1 - M_W^2/M_Z^2 = 0.22290 \pm 0.00028$

$\Rightarrow \sin^2\theta_W^{\text{eff}} = 0.23141 \pm 0.00013$ and $M_H = 96^{+29}_{-25}$ GeV

M_W

- $M_W = 80.387 \pm 0.016$ GeV ***CDF & D0 2012*** (± 19 MeV ***CDF*** 2.2 fb^{-1})
- $M_W = 80.376 \pm 0.033$ GeV ***LEP 2***

$\Rightarrow \sin^2\theta_W^{on\text{-}shell} \equiv 1 - M_W^2/M_Z^2 = 0.22290 \pm 0.00028$

$\Rightarrow \sin^2\theta_W^{eff} = 0.23141 \pm 0.00013$ and $M_H = 96^{+29}_{-25}$ GeV

- new global electroweak fit: $M_H = 102^{+24}_{-20}$ GeV ***JE 2012***

M_W

- $M_W = 80.387 \pm 0.016$ GeV ***CDF & D0 2012*** (± 19 MeV ***CDF*** 2.2 fb^{-1})
- $M_W = 80.376 \pm 0.033$ GeV ***LEP 2***

$\Rightarrow \sin^2\theta_W^{\text{on-shell}} \equiv 1 - M_W^2/M_Z^2 = 0.22290 \pm 0.00028$

$\Rightarrow \sin^2\theta_W^{\text{eff}} = 0.23141 \pm 0.00013$ and $M_H = 96^{+29}_{-25}$ GeV

- new global electroweak fit: $M_H = 102^{+24}_{-20}$ GeV ***JE 2012***
- prospects for 10 fb^{-1}:
  - no PDF (± 10 MeV) & QED (± 4 MeV) improvement $\Rightarrow \pm 13$ MeV ***CDF***
  - most optimistic scenario $\Rightarrow \pm 10$ MeV ***CDF***
  - cf. with ILC threshold scan: ± 6 MeV

m_t

19

m_t

- $m_t = 173.4 \pm 0.9_{exp} \pm 0.5_{th}$ GeV

m_t

- $m_t = 173.4 \pm 0.9_{exp} \pm 0.5_{th}$ GeV
- Question: What is the definition of m_t?

  Correct but useless answer: $m_t \equiv m_t^{Pythia}$ ("Pythia tuning parameter")

  We assume $m_t^{Pythia} = m_t^{pole} \pm \Lambda_{QCD}$ where

  $m_t^{pole} \equiv \overline{m}_t(\overline{m}_t)\,[1 + 4/3\;\alpha_s(\overline{m}_t)/\pi + \mathcal{O}(\alpha_s^2) + \mathcal{O}(\alpha_s^3)]$

  and $\Lambda_{QCD} \equiv$ the $\mathcal{O}(\alpha_s^3)$ term above (see also ***Skands, Wicke 2007***)

19

m_t

- $m_t = 173.4 \pm 0.9_{exp} \pm 0.5_{th}$ GeV
- Question: What is the definition of m_t?

  Correct but useless answer: $m_t \equiv m_t^{Pythia}$ ("Pythia tuning parameter")

  We assume $m_t^{Pythia} = m_t^{pole} \pm \Lambda_{QCD}$ where

  $m_t^{pole} \equiv \overline{m}_t(\overline{m}_t)\,[1 + 4/3\ \alpha_s(\overline{m}_t)/\pi + \mathcal{O}(\alpha_s^2) + \mathcal{O}(\alpha_s^3)]$

  and $\Lambda_{QCD} \equiv$ the $\mathcal{O}(\alpha_s^3)$ term above (see also ***Skands, Wicke 2007***)
- Alternative I: SCET + HQET → "jet mass" ***Fleming, Hoang, Mantry, Stewart 2008***

19

m_t

- $m_t = 173.4 \pm 0.9_{exp} \pm 0.5_{th}$ GeV
- Question: What is the definition of m_t?

  Correct but useless answer: $m_t \equiv m_t^{Pythia}$ ("Pythia tuning parameter")

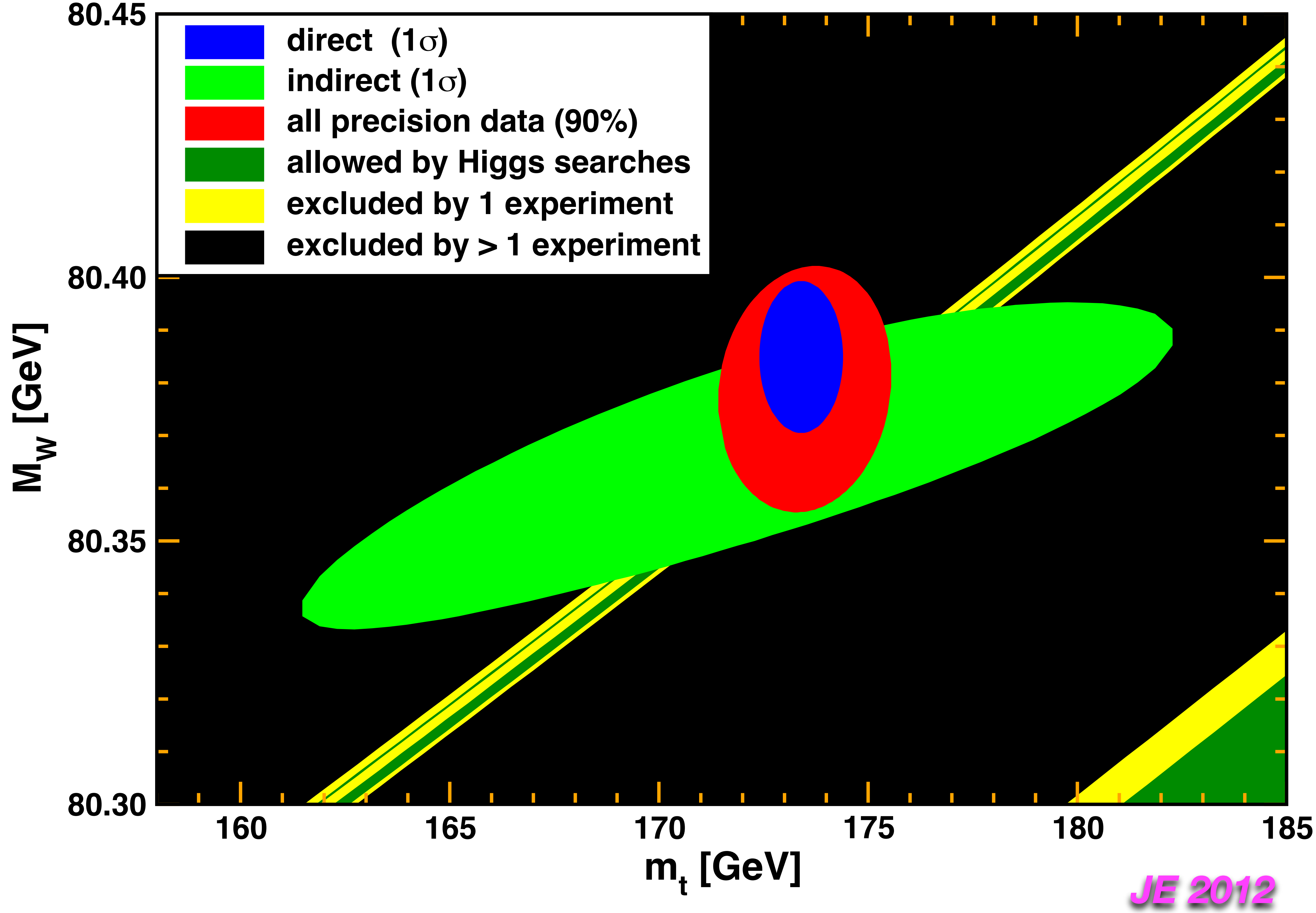
  We assume $m_t^{Pythia} = m_t^{pole} \pm \Lambda_{QCD}$ where

  $m_t^{pole} \equiv \overline{m}_t(\overline{m}_t)\,[1 + 4/3\,\alpha_s(\overline{m}_t)/\pi + \mathcal{O}(\alpha_s^2) + \mathcal{O}(\alpha_s^3)]$

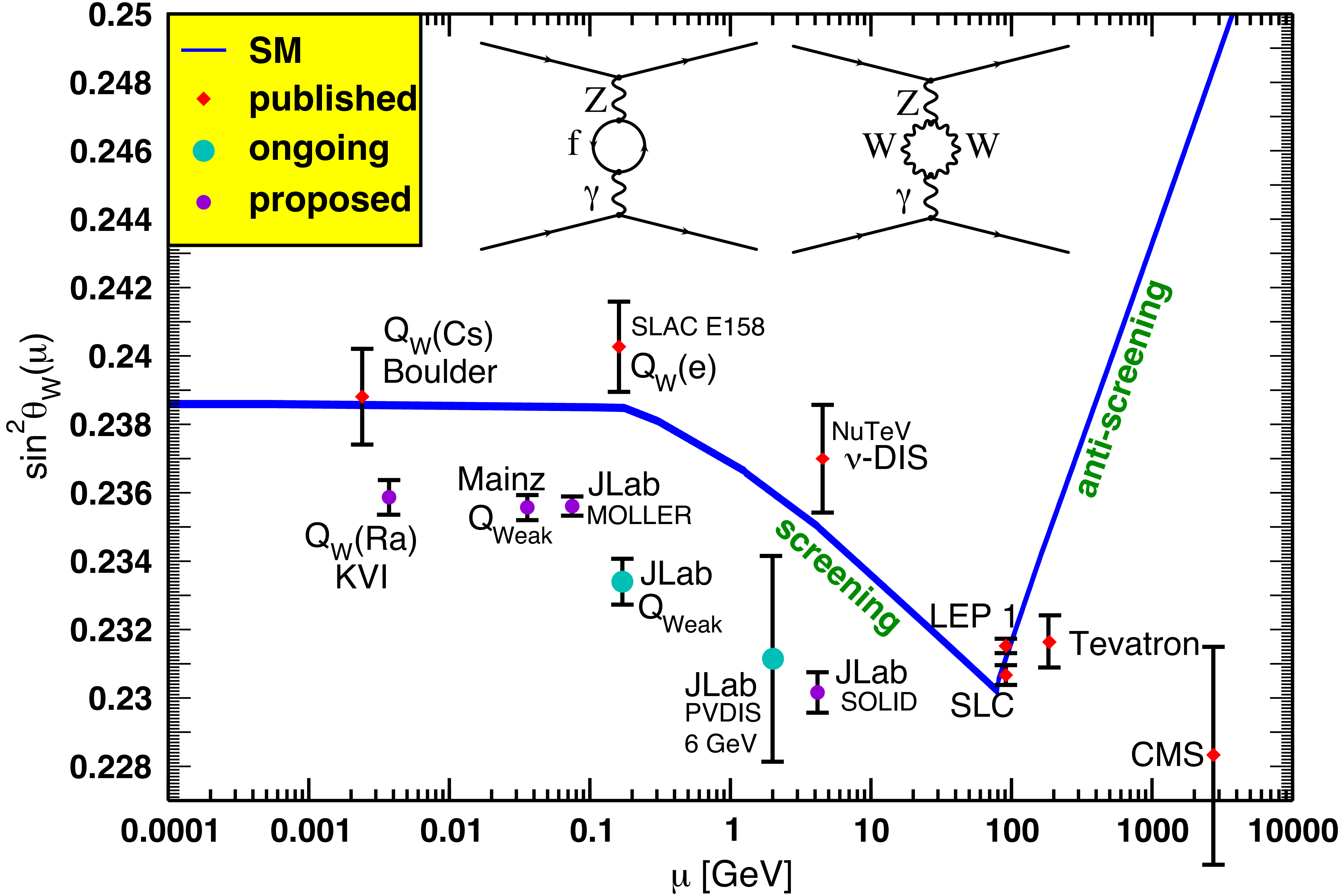
  and $\Lambda_{QCD} \equiv$ the $\mathcal{O}(\alpha_s^3)$ term above (see also ***Skands, Wicke 2007***)
- Alternative I: SCET + HQET → "jet mass" ***Fleming, Hoang, Mantry, Stewart 2008***
- Alternative II: get $\overline{m}_t(\overline{m}_t)$ directly from $t\,\overline{t}$ cross-section ⇒

  $\overline{m}_t(\overline{m}_t) = 160.0 \pm 3.3$ GeV ***Langenfeld, Moch, Uwer 2008***

  ⇒ $M_H = 81^{+32}_{-24}$ GeV ($m_t^{pole} = 169.6 \pm 3.5$ GeV)


direct (1σ)
indirect (1σ)
all precision data (90%)
allowed by Higgs searches
excluded by 1 experiment
excluded by > 1 experiment
80.45
80.40
80.35
80.30
M_W [GeV]
160
165
170
175
180
185
m_t [GeV]
JE 2012

20



SM
published
ongoing
proposed
Z
f
γ
Z
W
W
γ
Q_W(Cs)
Boulder
SLAC E158
Q_W(e)
NuTeV
ν-DIS
Q_W(Ra)
KVI
Mainz
Q_Weak
JLab
MOLLER
JLab
Q_Weak
JLab
PVDIS
6 GeV
JLab
SOLID
screening
anti-screening
LEP 1
SLC
Tevatron
CMS
$\sin^2\theta_W(\mu)$
μ [GeV]

Parity-violating electron scattering (PVES)

Parity-violating electron scattering (PVES)

- Qweak: measurement of $Q_W(p) \sim 1 - 4\sin^2\theta_W$ to 4% in elastic polarized $e^- p$ scattering
  - data taking completed
  - similar quantity as weak charges measured in APV, but different kinematics ⇒ re-enhancement of γ-Z box
  - also at MESA in Mainz? (if not then MAMI)

Parity-violating electron scattering (PVES)

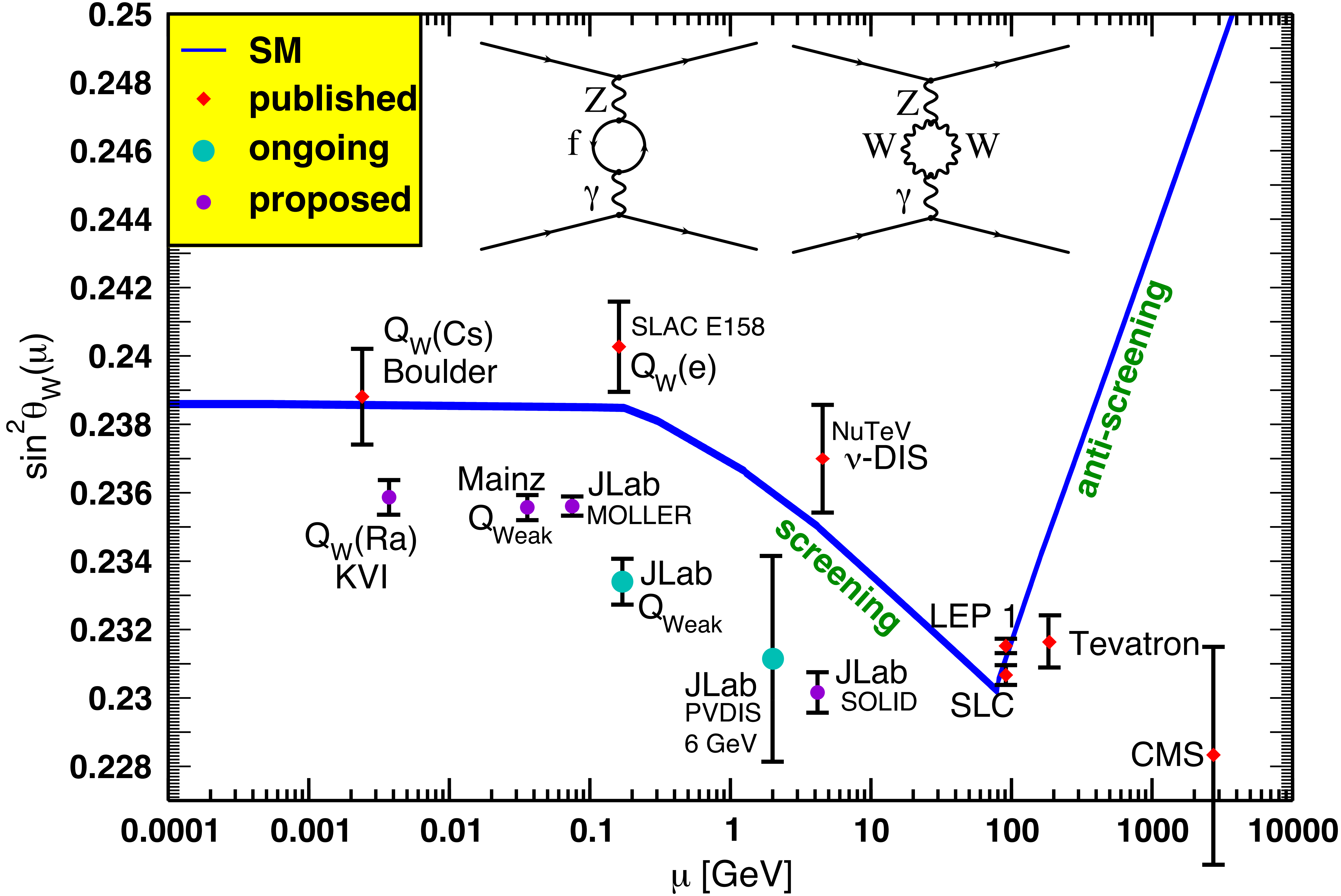
- Qweak: measurement of $Q_W(p) \sim 1 - 4 \sin^2\theta_W$ to 4% in elastic polarized $e^- p$ scattering
  - data taking completed
  - similar quantity as weak charges measured in APV, but different kinematics ⇒ re-enhancement of γ-Z box
  - also at MESA in Mainz? (if not then MAMI)
- MOLLER: ultra-high precision $\sin^2\theta_W$ measurement in polarized $e^- e^-$ scattering at 12 GeV CEBAF
  - improvement over ***SLAC-E158*** by factor of 5

Parity-violating electron scattering (PVES)

- Qweak: measurement of $Q_W(p) \sim 1 - 4 \sin^2\theta_W$ to 4% in elastic polarized $e^- p$ scattering
  - data taking completed
  - similar quantity as weak charges measured in APV, but different kinematics ⇒ re-enhancement of γ-Z box
  - also at MESA in Mainz? (if not then MAMI)
- MOLLER: ultra-high precision $\sin^2\theta_W$ measurement in polarized $e^- e^-$ scattering at 12 GeV CEBAF
  - improvement over ***SLAC-E158*** by factor of 5
- PVDIS and SOLID: array of kinematics points to test strong, EW & new physics

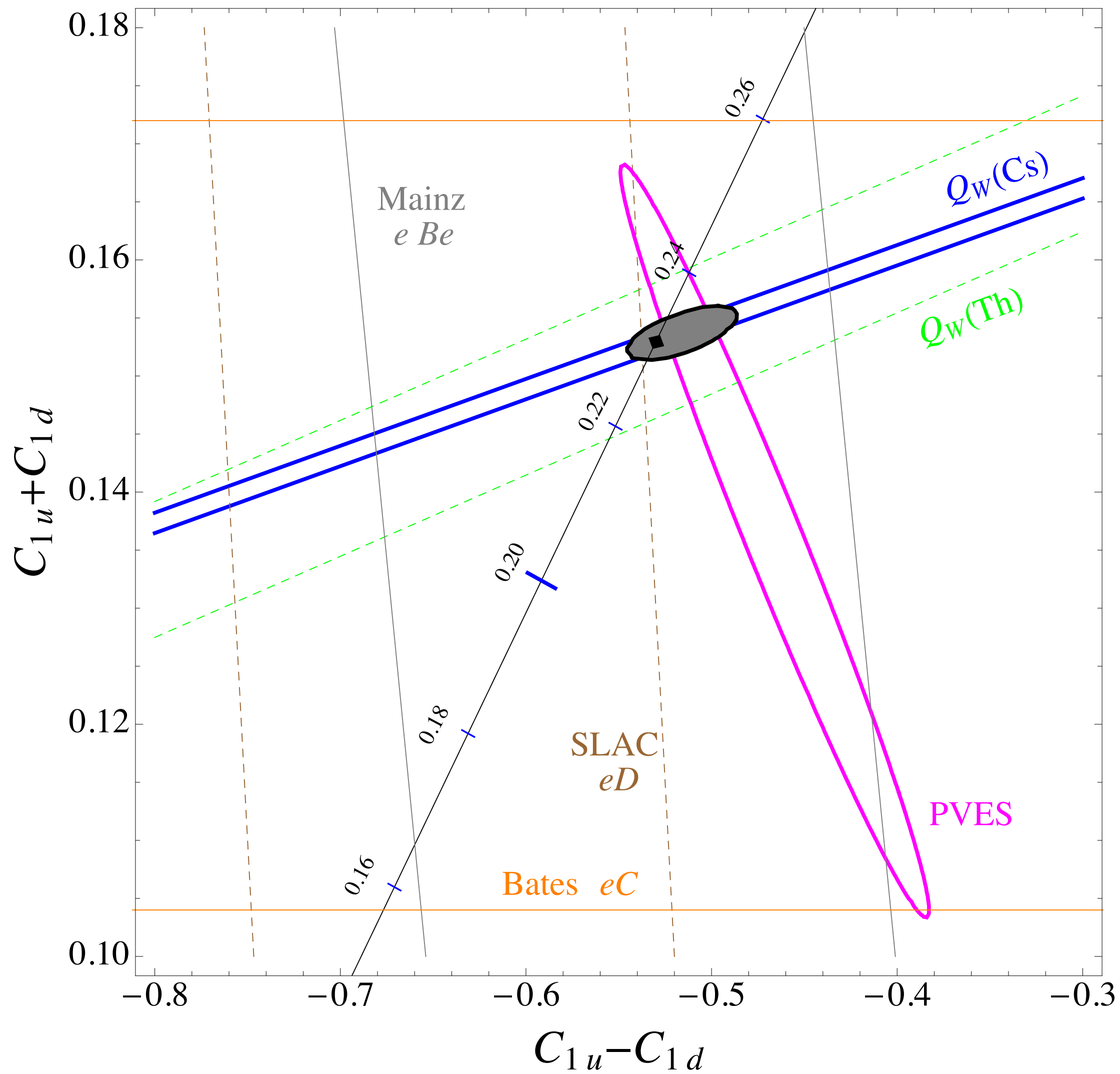
Parity-violating electron scattering (PVES)

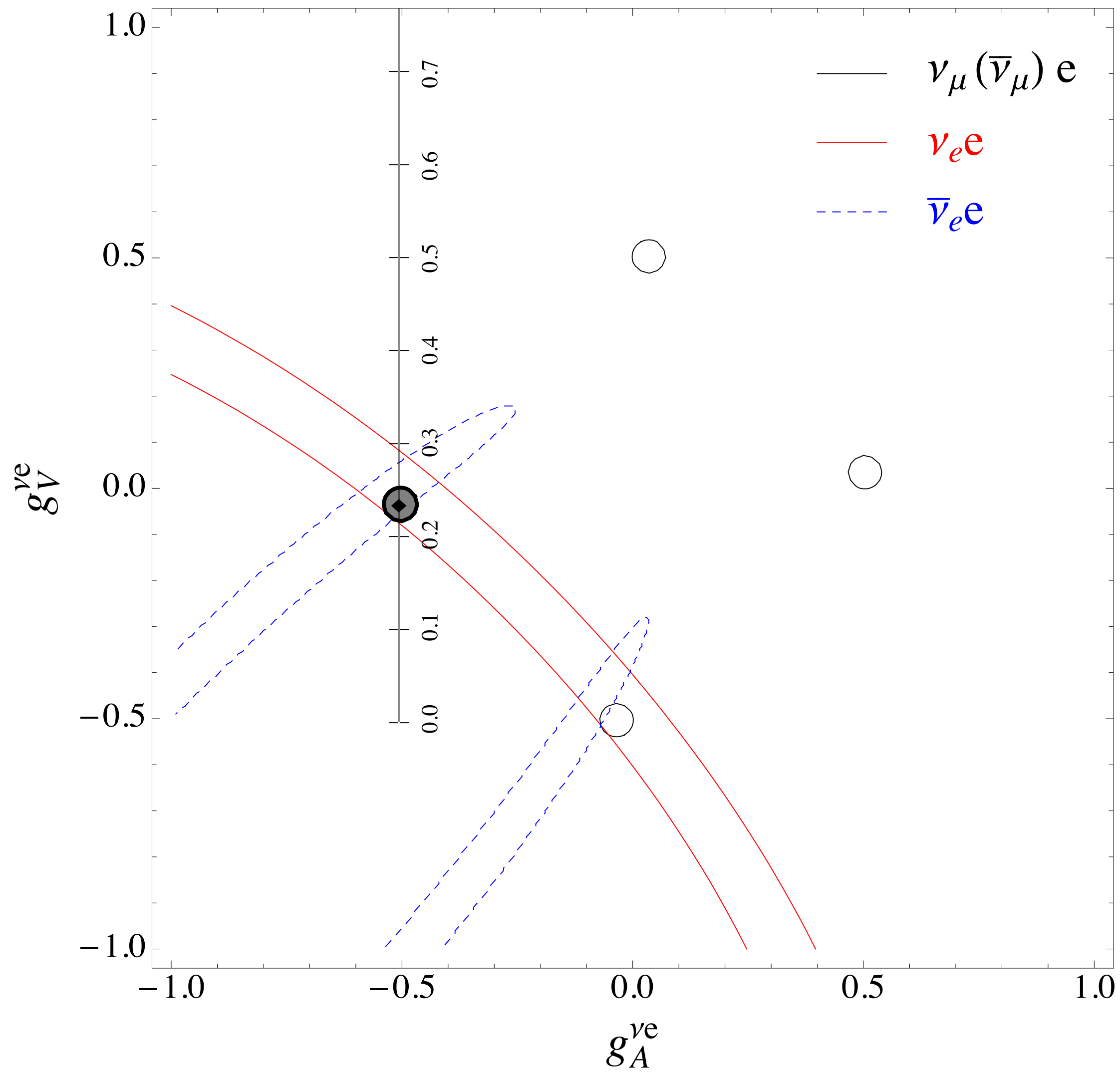
- Qweak: measurement of $Q_W(p) \sim 1 - 4\sin^2\theta_W$ to 4% in elastic polarized $e^- p$ scattering
  - data taking completed
  - similar quantity as weak charges measured in APV, but different kinematics ⇒ re-enhancement of γ-Z box
  - also at MESA in Mainz? (if not then MAMI)
- MOLLER: ultra-high precision $\sin^2\theta_W$ measurement in polarized $e^- e^-$ scattering at 12 GeV CEBAF
  - improvement over ***SLAC-E158*** by factor of 5
- PVDIS and SOLID: array of kinematics points to test strong, EW & new physics
- JLab 12 GeV upgrade



SM
published
ongoing
proposed
Z
f
γ
Z
W
W
γ
Q_W(Cs)
Boulder
SLAC E158
Q_W(e)
NuTeV
ν-DIS
Q_W(Ra)
KVI
Mainz
Q_Weak
JLab
MOLLER
JLab
Q_Weak
screening
anti-screening
LEP 1
SLC
Tevatron
JLab
PVDIS
6 GeV
JLab
SOLID
CMS
$\sin^2\theta_W(\mu)$
μ [GeV]
0.25
0.248
0.246
0.244
0.242
0.24
0.238
0.236
0.234
0.232
0.23
0.228
0.0001
0.001
0.01
0.1
1
10
100
1000
10000

Effective 4-Fermi interactions



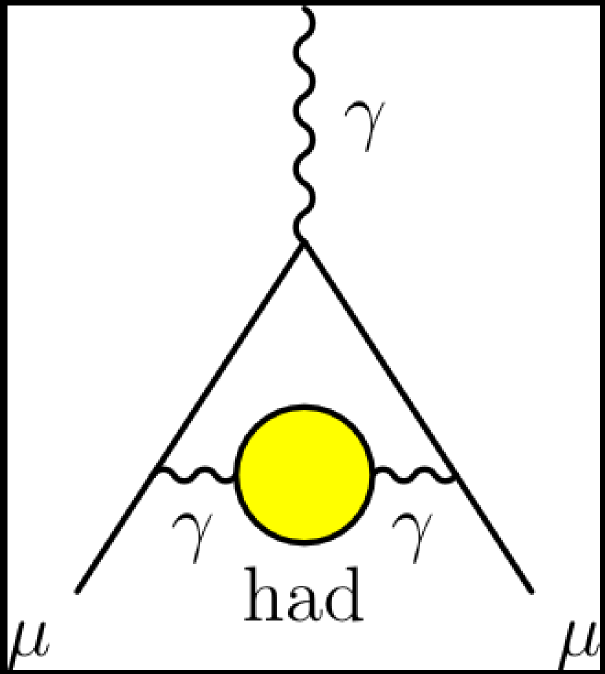


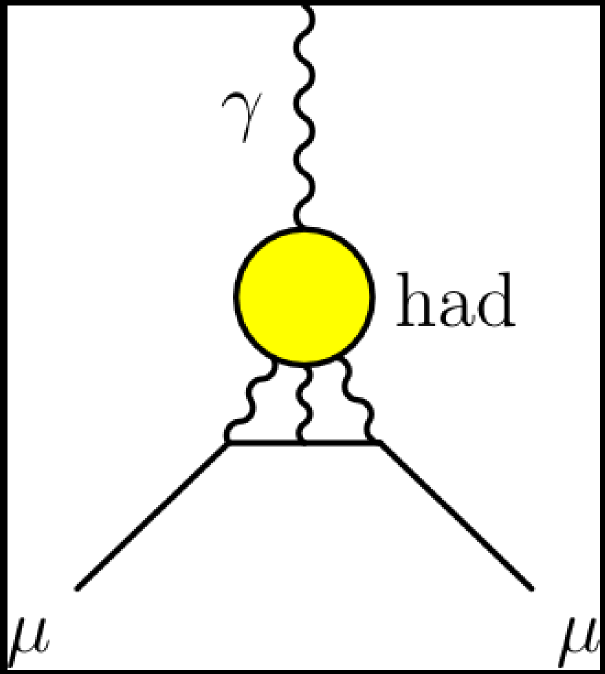
$\bar{q}q\bar{e}\gamma^5 e$ $\bar{e}e\bar{\nu}\gamma^5\nu$

☞ ***talk on LENA by Estela Garces tuesday***

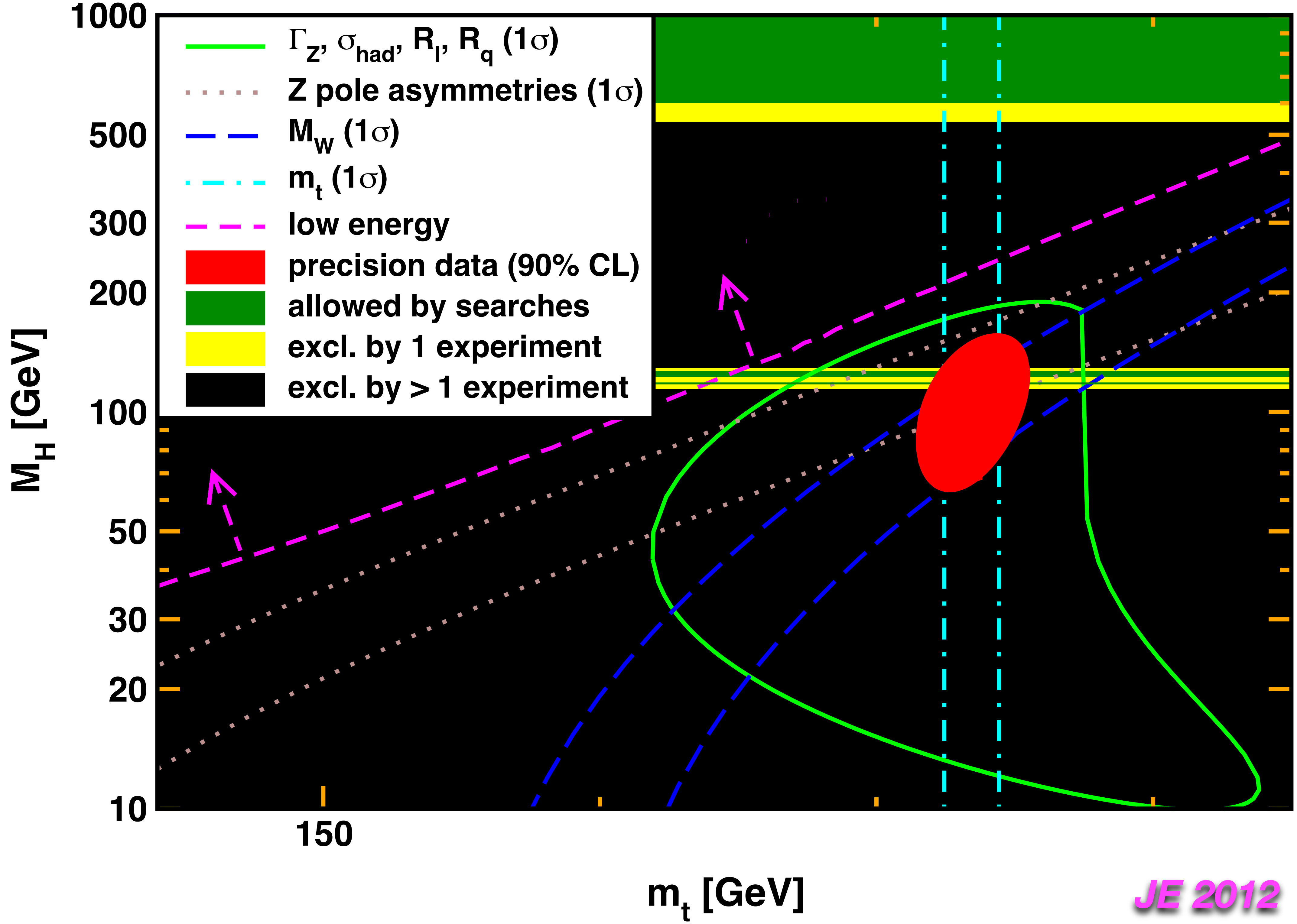
$g_\mu - 2$

- $a_\mu \equiv (1165920.80 \pm 0.63) \times 10^{-9}$ ***BNL-E821 2004***
- SM: $a_\mu \equiv (1165918.41 \pm 0.48) \times 10^{-9}$
  - 3.0 σ deviation (includes e^+e^- and τ-decay data)
  - e^+e^- based (annihilation and radiative return): 3.6 σ
  - τ based: 2.4 σ
  - 2.3 σ discrepancy between experimental $\mathcal{B}(\tau^- \to \nu\, \pi^0 \pi^-)$ and prediction from e^+e^- and CVC
  - but also 1.9 σ conflict between ***KLOE*** and ***BaBar*** (which is not inconsistent with τ-data)
- new physics (SUSY)? Personally, I am less concerned about the hadronic issues than the absence of BSM hints at the Tevatron/LHC

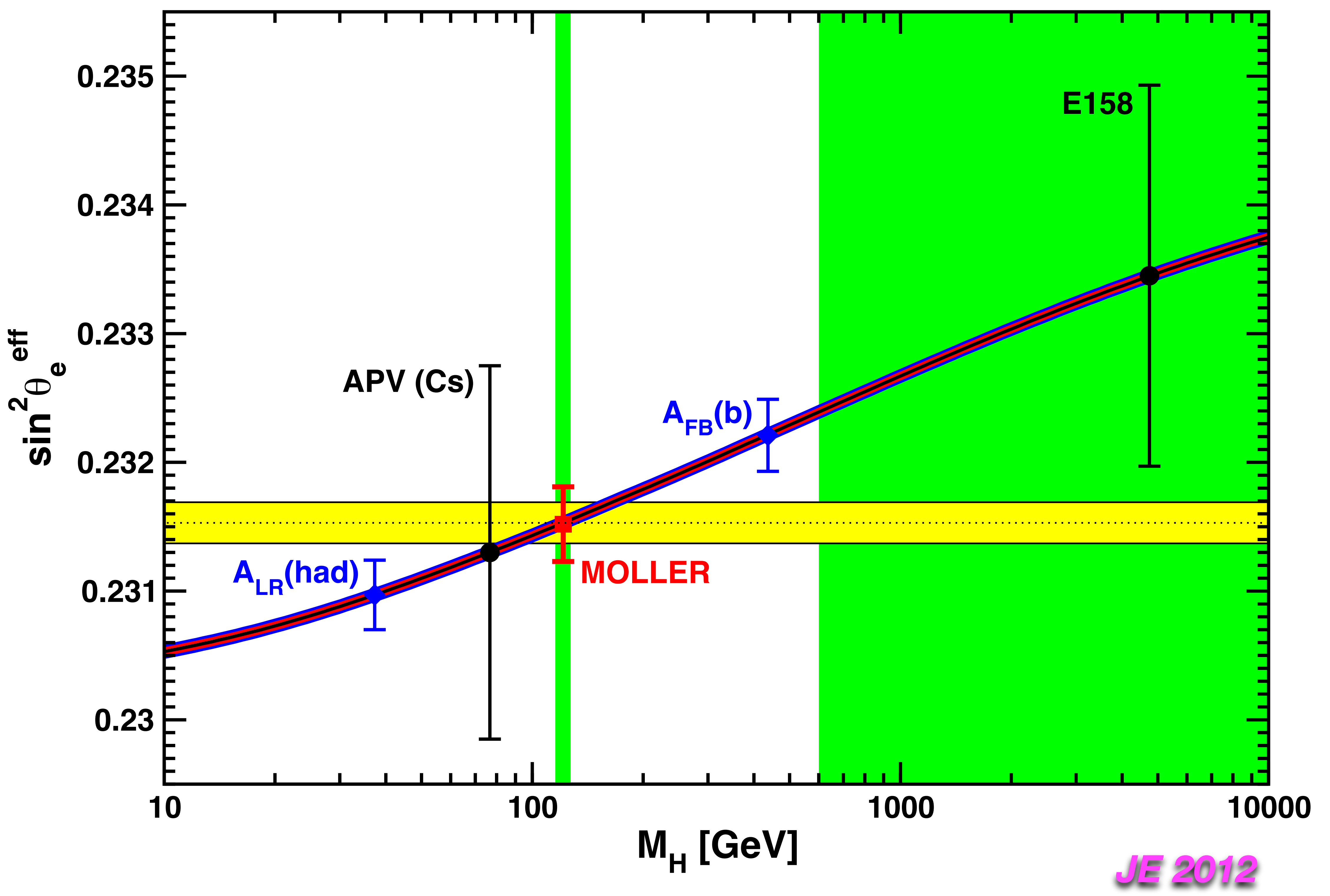




SM Interpretation: M_H

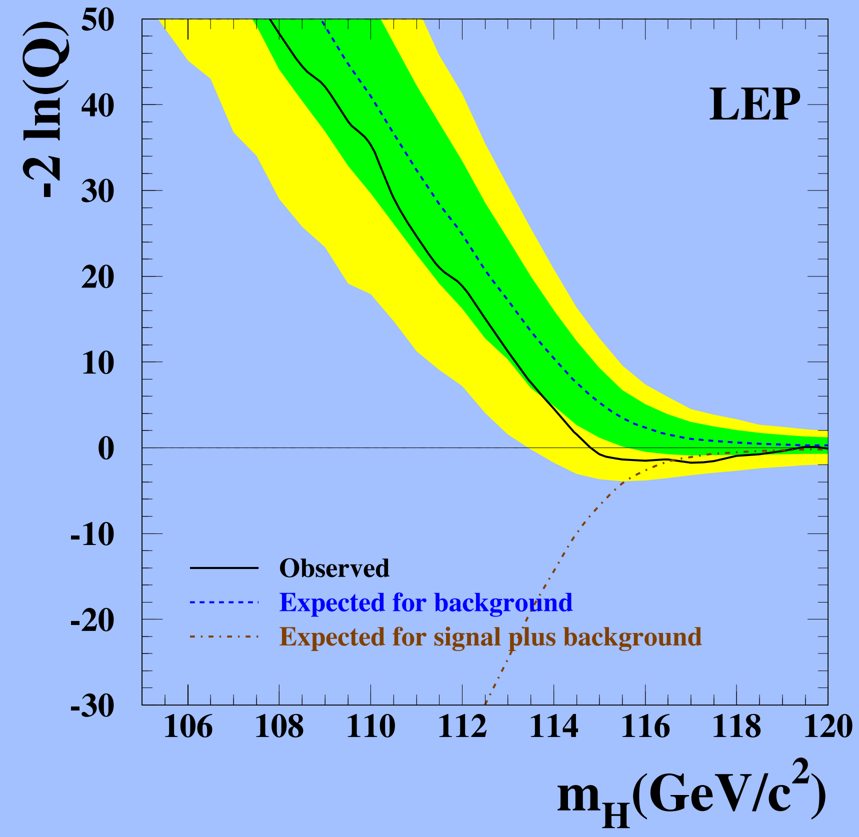


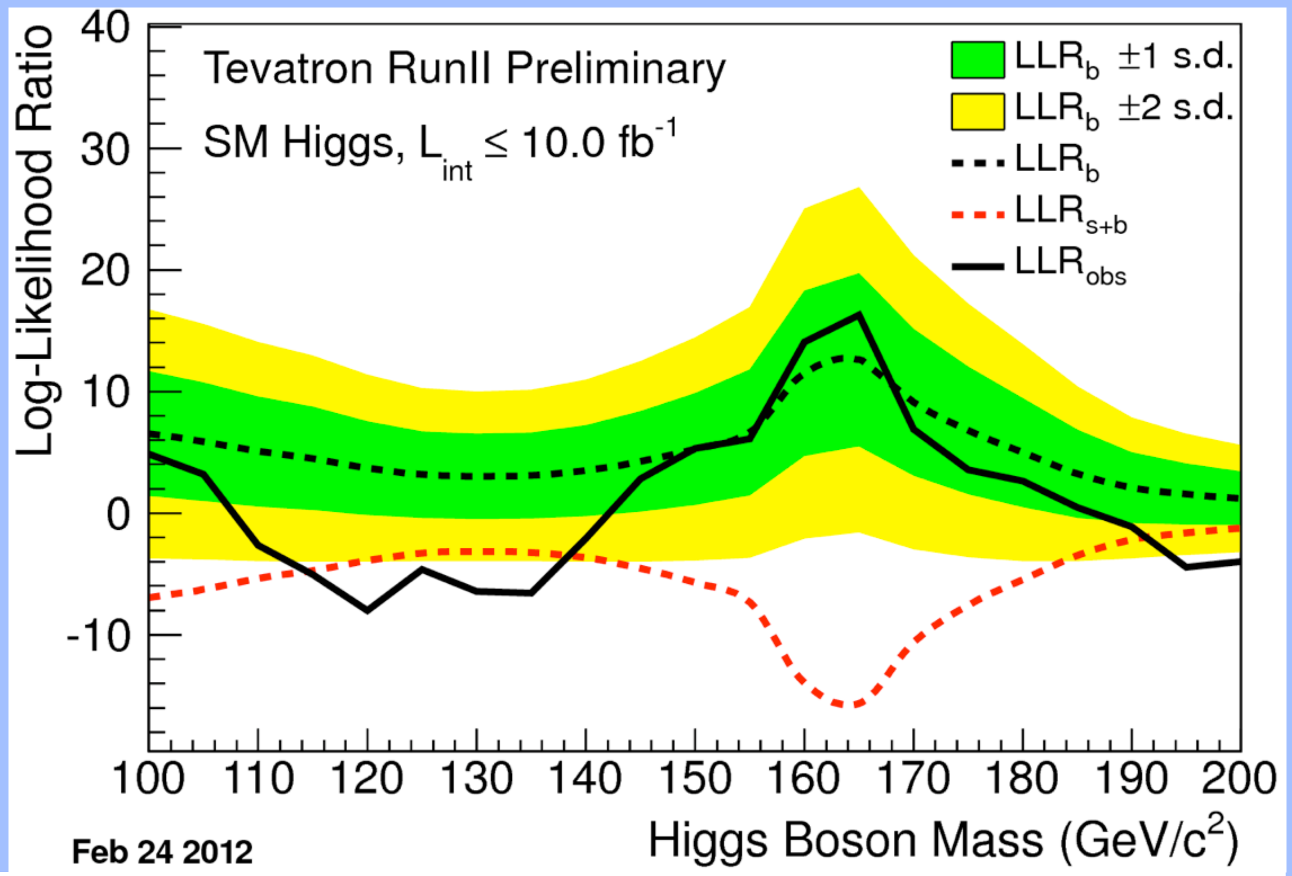
Γ_Z, σ_{had}, R_l, R_q (1σ)
Z pole asymmetries (1σ)
M_W (1σ)
m_t (1σ)
low energy
precision data (90% CL)
allowed by searches
excl. by 1 experiment
excl. by > 1 experiment
1000
500
300
200
100
50
30
20
10
150
M_H [GeV]
m_t [GeV]
JE 2012

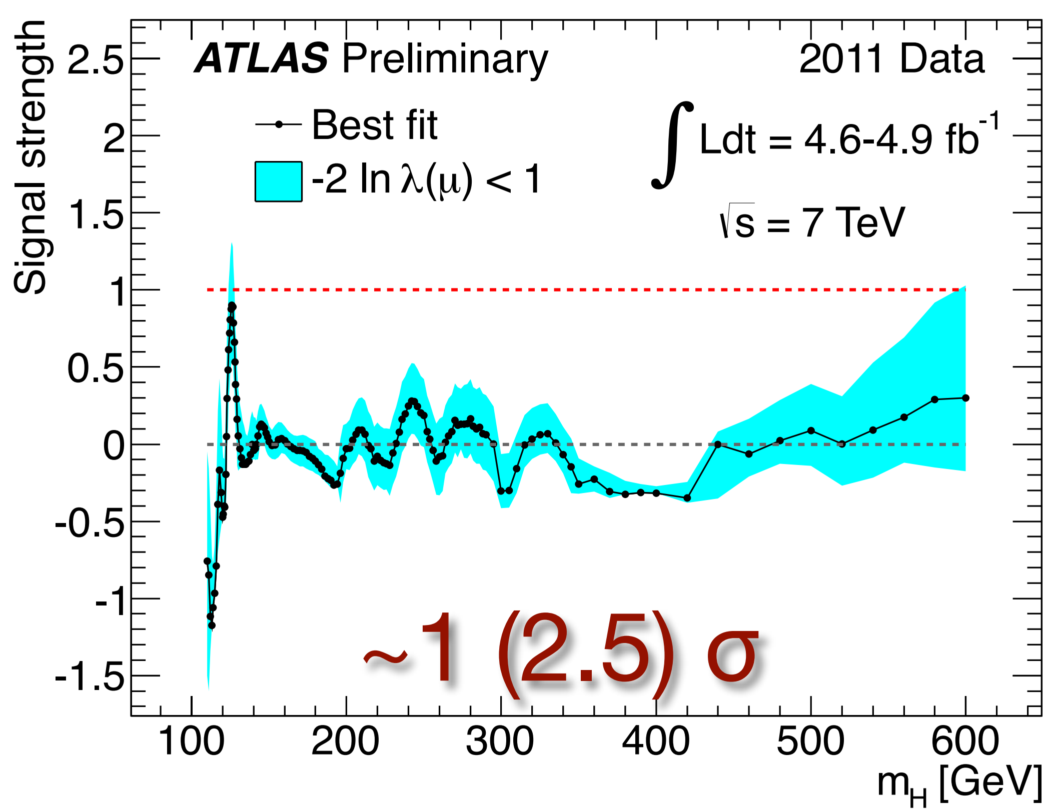


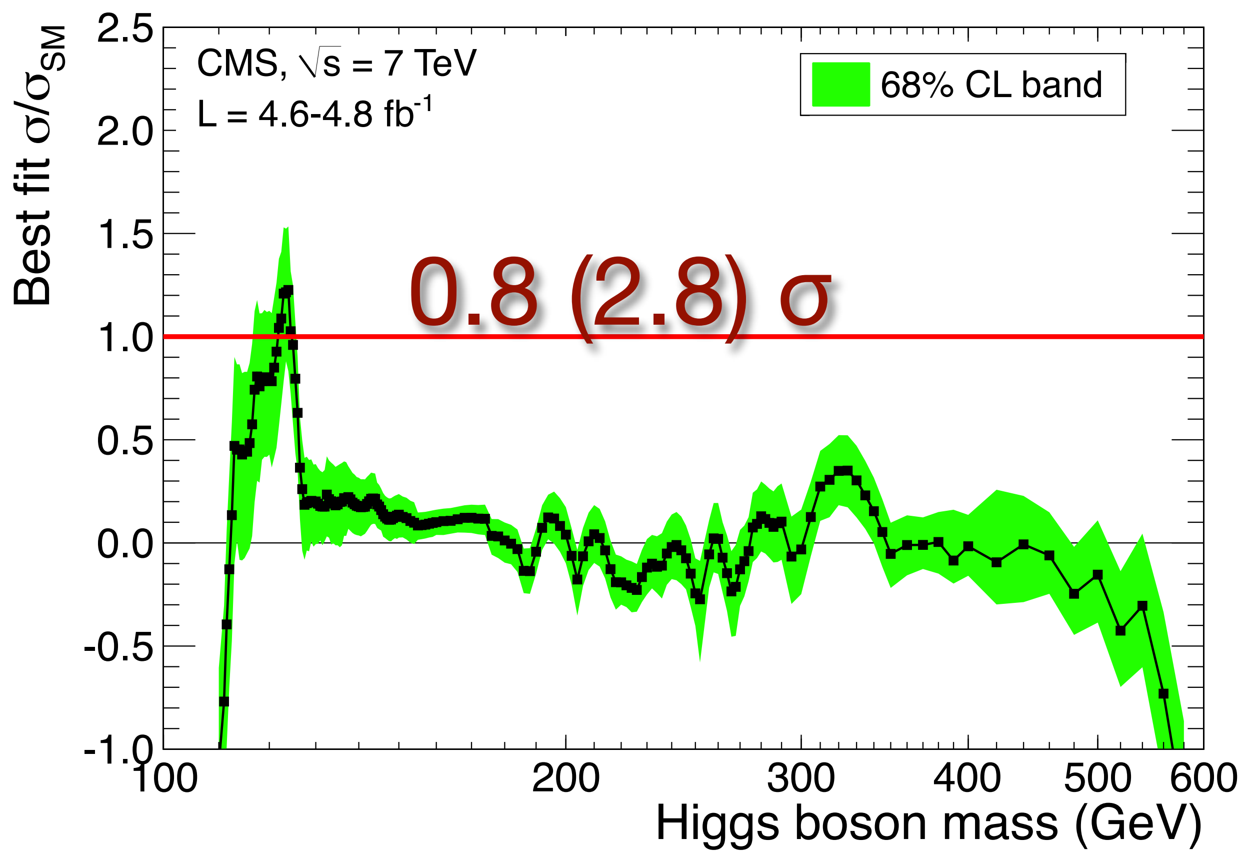
0.235
0.234
0.233
0.232
0.231
0.23
sin²θ_e^eff
E158
APV (Cs)
A_FB(b)
A_LR(had)
MOLLER
10
100
1000
10000
M_H [GeV]
JE 2012

28

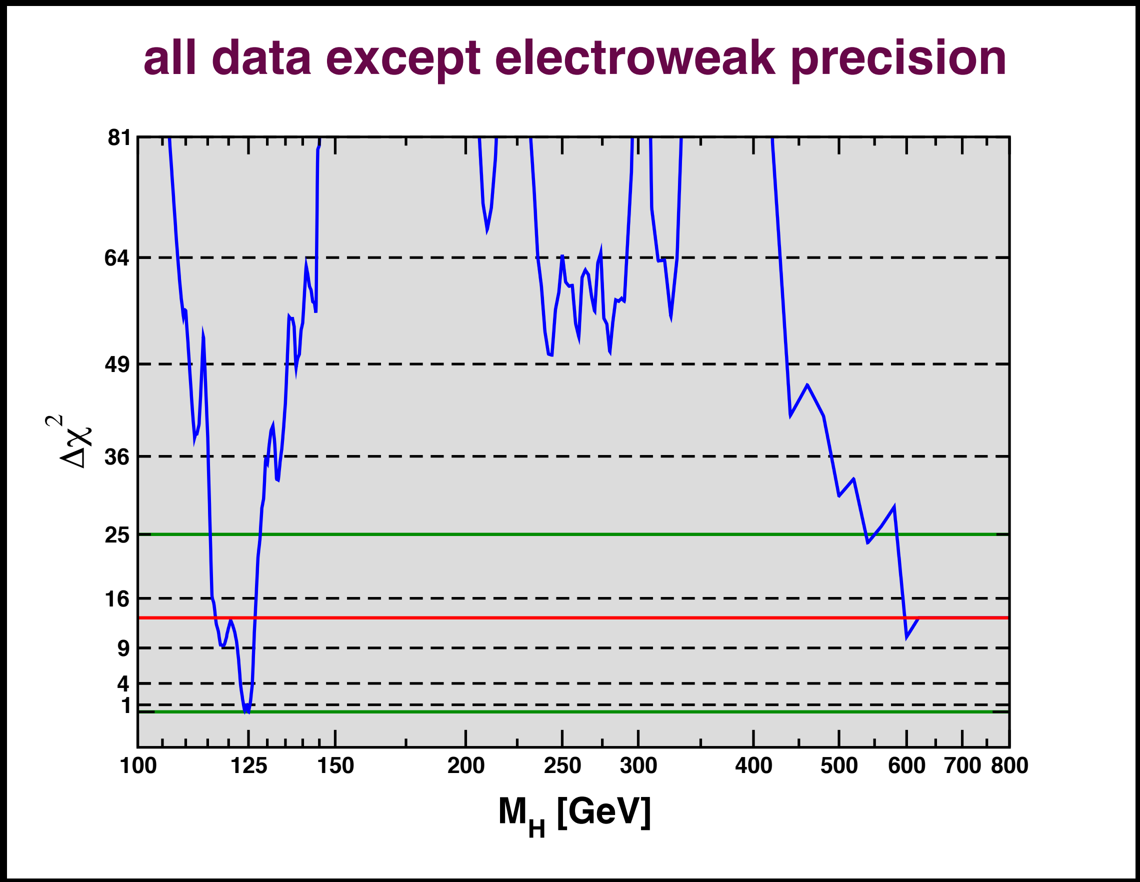

-2 ln(Q)
LEP
Observed
Expected for background
Expected for signal plus background
m_H(GeV/c^2)

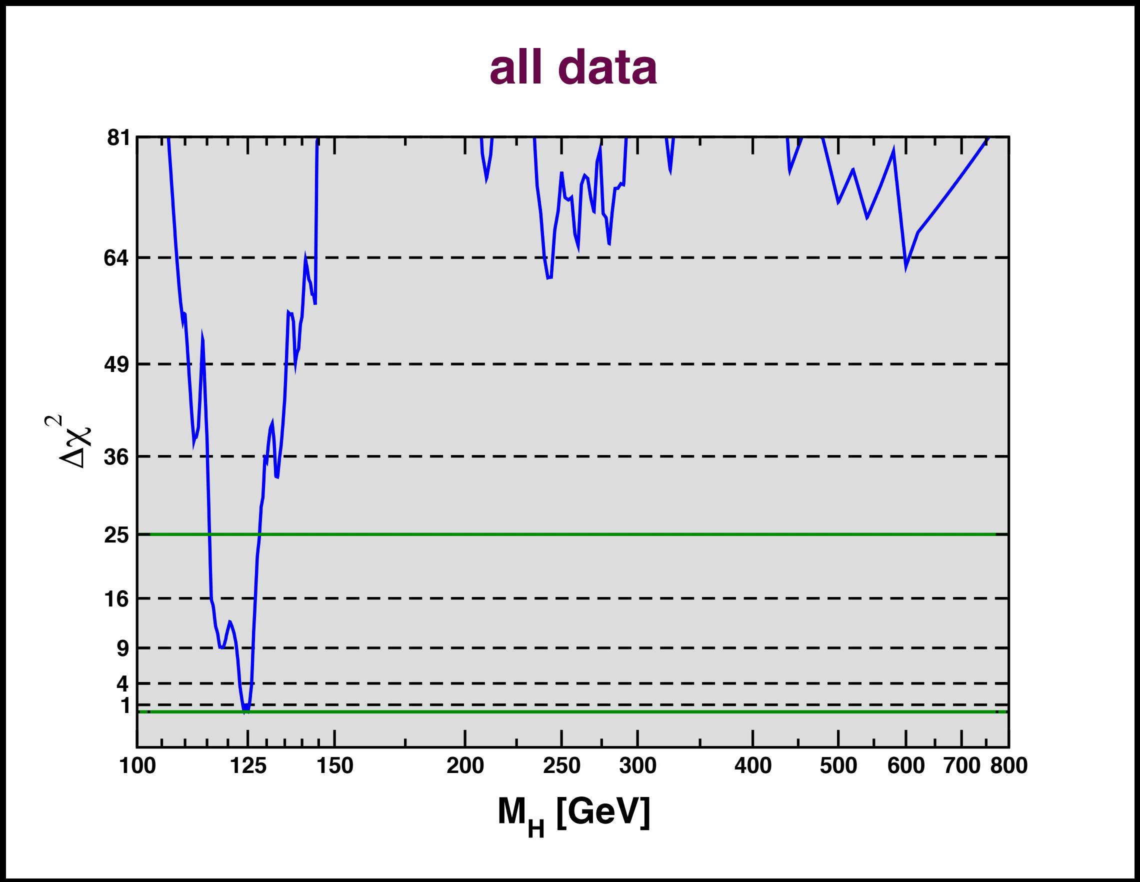

Tevatron RunII Preliminary
SM Higgs, $L_{int} \leq 10.0$ fb^{-1}
LLR_b ±1 s.d.
LLR_b ±2 s.d.
LLR_b
LLR_{s+b}
LLR_{obs}
Log-Likelihood Ratio
Feb 24 2012
Higgs Boson Mass (GeV/c^2)


ATLAS Preliminary
2011 Data
Best fit
-2 ln λ(μ) < 1
$\int$Ldt = 4.6-4.9 fb^{-1}
$\sqrt{s}$ = 7 TeV
Signal strength
m_H [GeV]
~1 (2.5) σ

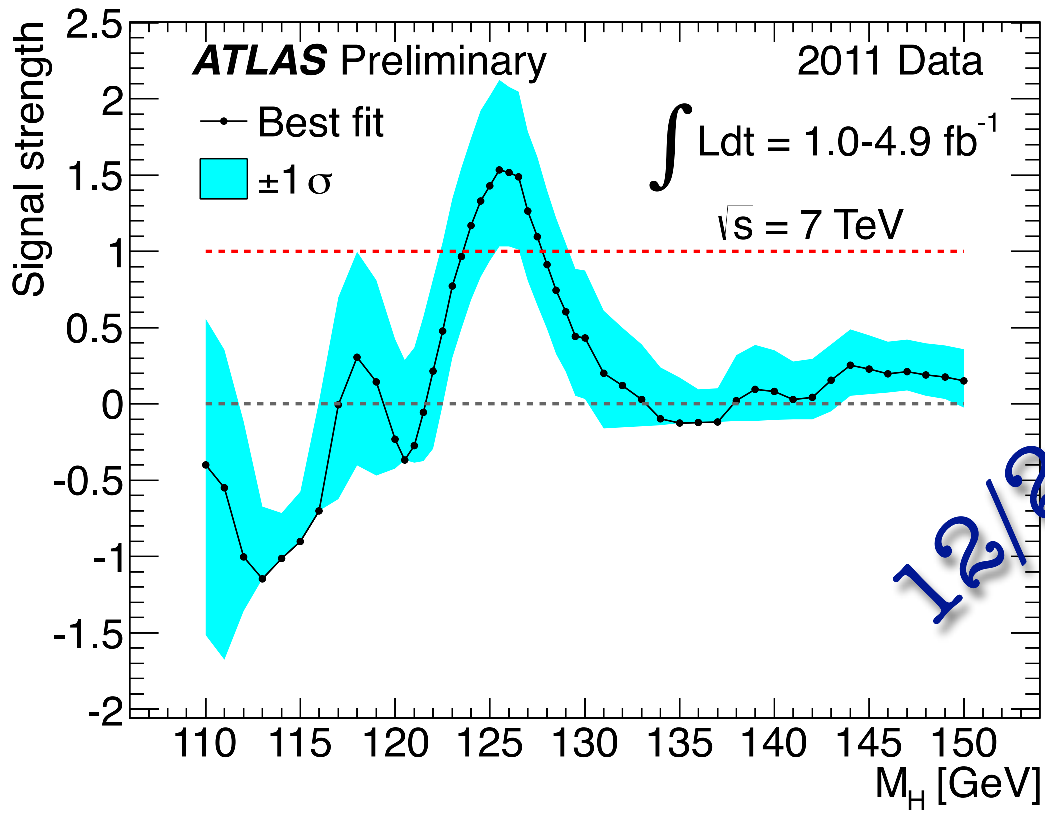

CMS, $\sqrt{s}$ = 7 TeV
L = 4.6-4.8 fb^{-1}
68% CL band
Best fit σ/σ_{SM}
0.8 (2.8) σ
Higgs boson mass (GeV)

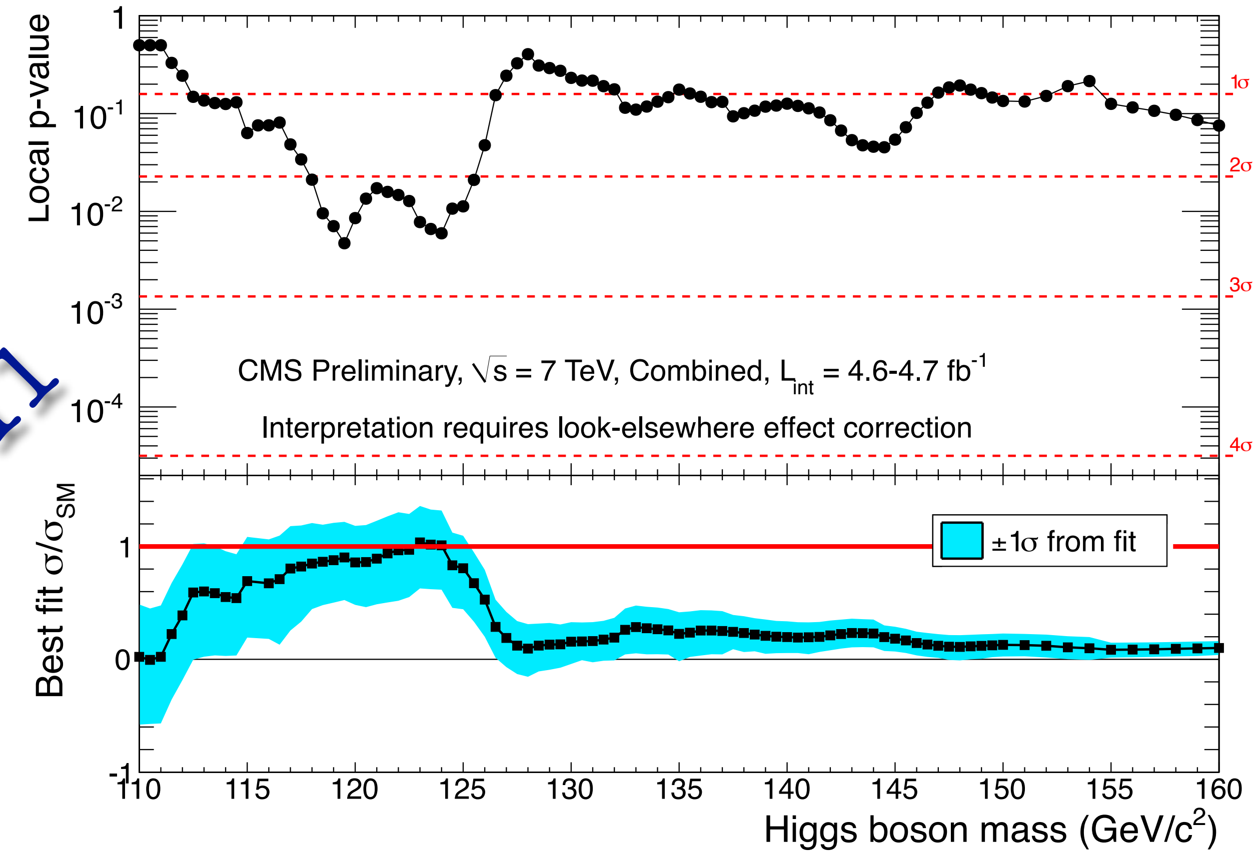
- LHC data require "look elsewhere effect correction"
- Can be avoided when combined with electroweak precision data ***JE 2012***



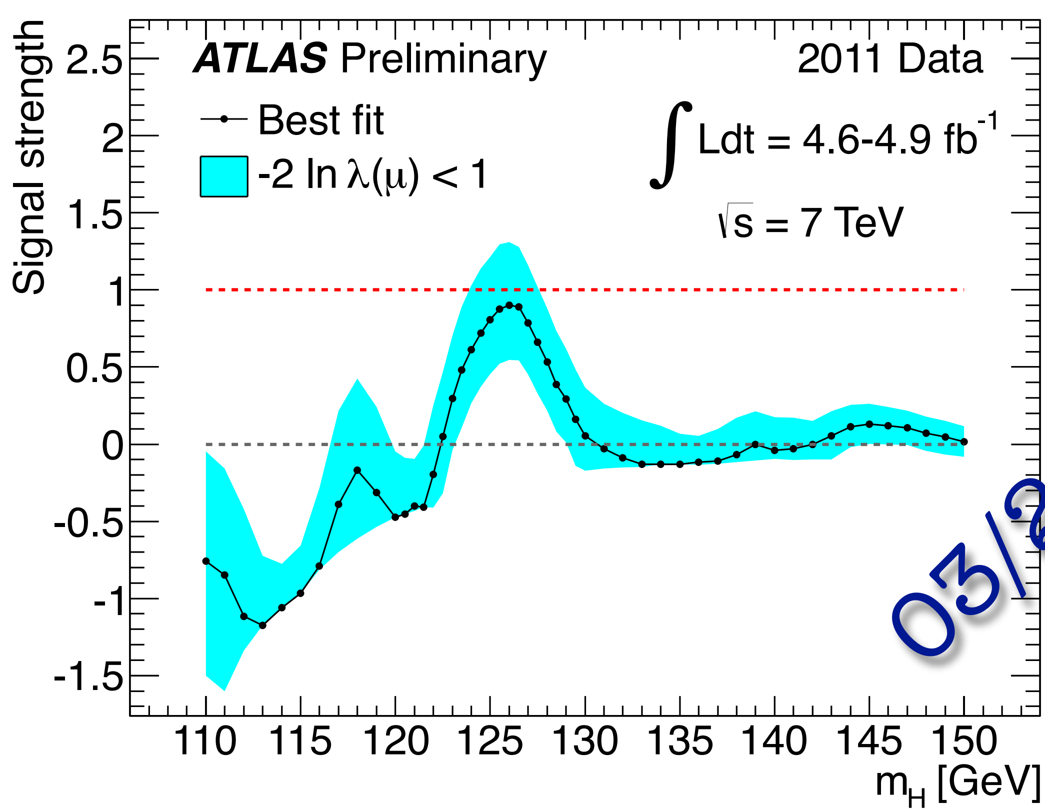


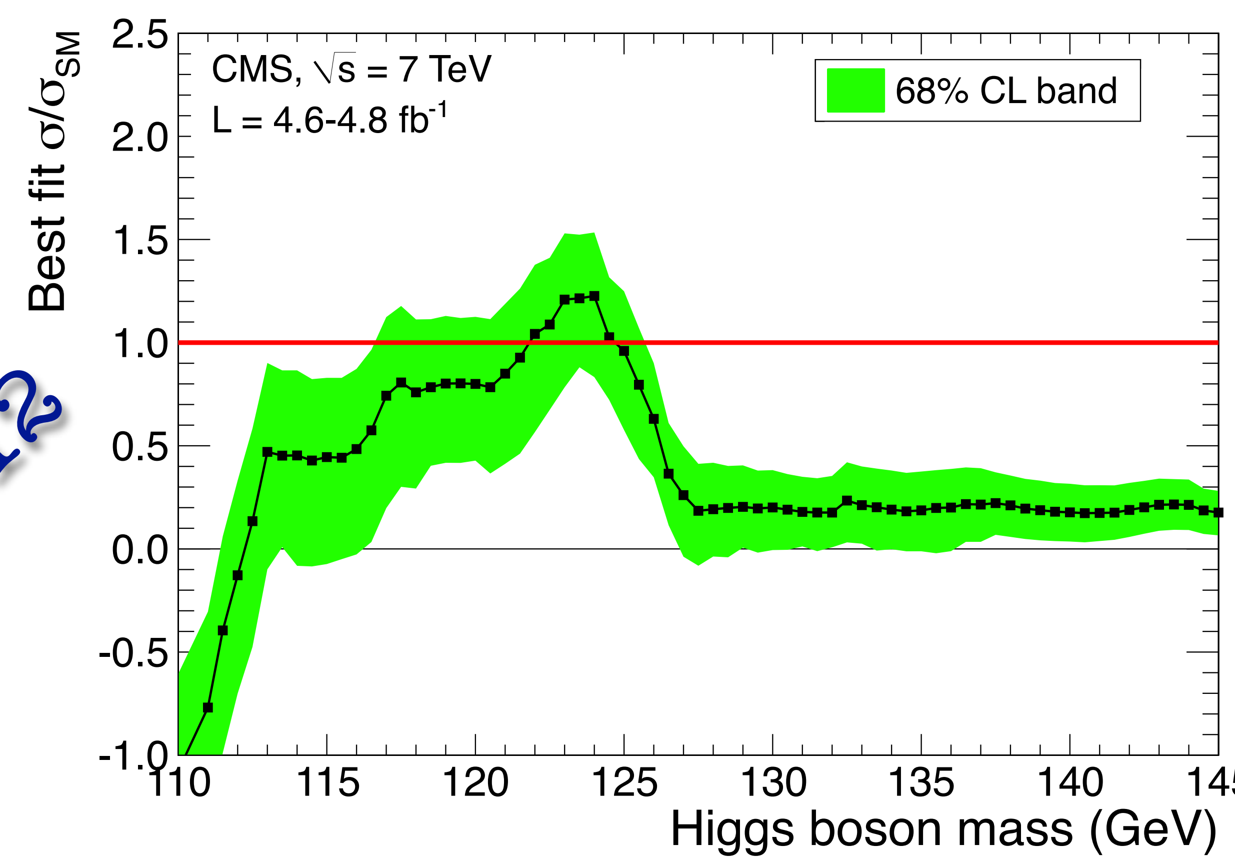
30





12/2011





03/2012

31

M_H probability density

32

M_H probability density

- $p(M_H) \equiv \exp[-\chi^2_{EW}(M_H)/2]\, Q_{LEP}\, Q_{Tevatron}\, Q_{LHC}\, M_H^{-1}$

  factorized form: neglect of correlations

M_H probability density

- $p(M_H) \equiv \exp[-\chi^2_{EW}(M_H)/2]\, Q_{LEP}\, Q_{Tevatron}\, Q_{LHC}\, M_H^{-1}$

  factorized form: neglect of correlations

- $Q_{LEP}(M_H)$, $Q_{Tevatron}(M_H)$: likelihood ratios H/H+B

M_H probability density

- $p(M_H) \equiv \exp[-\chi^2_{EW}(M_H)/2]\ Q_{LEP}\ Q_{Tevatron}\ Q_{LHC}\ M_H^{-1}$

  factorized form: neglect of correlations

- $Q_{LEP}(M_H)$, $Q_{Tevatron}(M_H)$: likelihood ratios H/H+B

- $Q_{LHC}(M_H) = Q_{ATLAS}(M_H)\ Q_{CMS}(M_H)$ (but not available)

  instead: $2 \ln Q \equiv \chi^2_{H+B}(M_H) - \chi^2_B(M_H) \equiv$

  $(1 - \bar{\sigma}_{obs})^2/\Delta\bar{\sigma}_+^2 - \bar{\sigma}_{obs}^2/\Delta\bar{\sigma}_-^2$

M_H probability density

- $p(M_H) \equiv \exp[-\chi^2_{EW}(M_H)/2]\; Q_{LEP}\; Q_{Tevatron}\; Q_{LHC}\; M_H^{-1}$

  factorized form: neglect of correlations

- $Q_{LEP}(M_H)$, $Q_{Tevatron}(M_H)$: likelihood ratios H/H+B
- $Q_{LHC}(M_H) = Q_{ATLAS}(M_H)\; Q_{CMS}(M_H)$ (but not available)

  instead: $2 \ln Q \equiv \chi^2_{H+B}(M_H) - \chi^2_B(M_H) \equiv$

  $(1 - \bar{\sigma}_{obs})^2/\Delta\bar{\sigma}_+^2 - \bar{\sigma}_{obs}^2/\Delta\bar{\sigma}_-^2$

- $\bar{\sigma}_{obs}$: eff. observed X-section (signal strength) combining all channels

M_H probability density

- $p(M_H) \equiv \exp[-\chi^2_{EW}(M_H)/2]\, Q_{LEP}\, Q_{Tevatron}\, Q_{LHC}\, M_H^{-1}$

  factorized form: neglect of correlations

- $Q_{LEP}(M_H)$, $Q_{Tevatron}(M_H)$: likelihood ratios H/H+B

- $Q_{LHC}(M_H) = Q_{ATLAS}(M_H)\, Q_{CMS}(M_H)$ (but not available)

  instead: $2 \ln Q \equiv \chi^2_{H+B}(M_H) - \chi^2_B(M_H) \equiv$

  $(1 - \bar{\sigma}_{obs})^2/\Delta\bar{\sigma}_+^2 - \bar{\sigma}_{obs}^2/\Delta\bar{\sigma}_-^2$

- $\bar{\sigma}_{obs}$: eff. observed X-section (signal strength) combining all channels

- $\Delta\bar{\sigma}_\pm$: error pointing in signal (+) and background (–) direction

M_H probability density

- $p(M_H) \equiv \exp[-\chi^2_{EW}(M_H)/2]\ Q_{LEP}\ Q_{Tevatron}\ Q_{LHC}\ M_H^{-1}$

  factorized form: neglect of correlations

- $Q_{LEP}(M_H)$, $Q_{Tevatron}(M_H)$: likelihood ratios H/H+B

- $Q_{LHC}(M_H) = Q_{ATLAS}(M_H)\ Q_{CMS}(M_H)$ (but not available)

  instead: $2 \ln Q \equiv \chi^2_{H+B}(M_H) - \chi^2_B(M_H) \equiv$

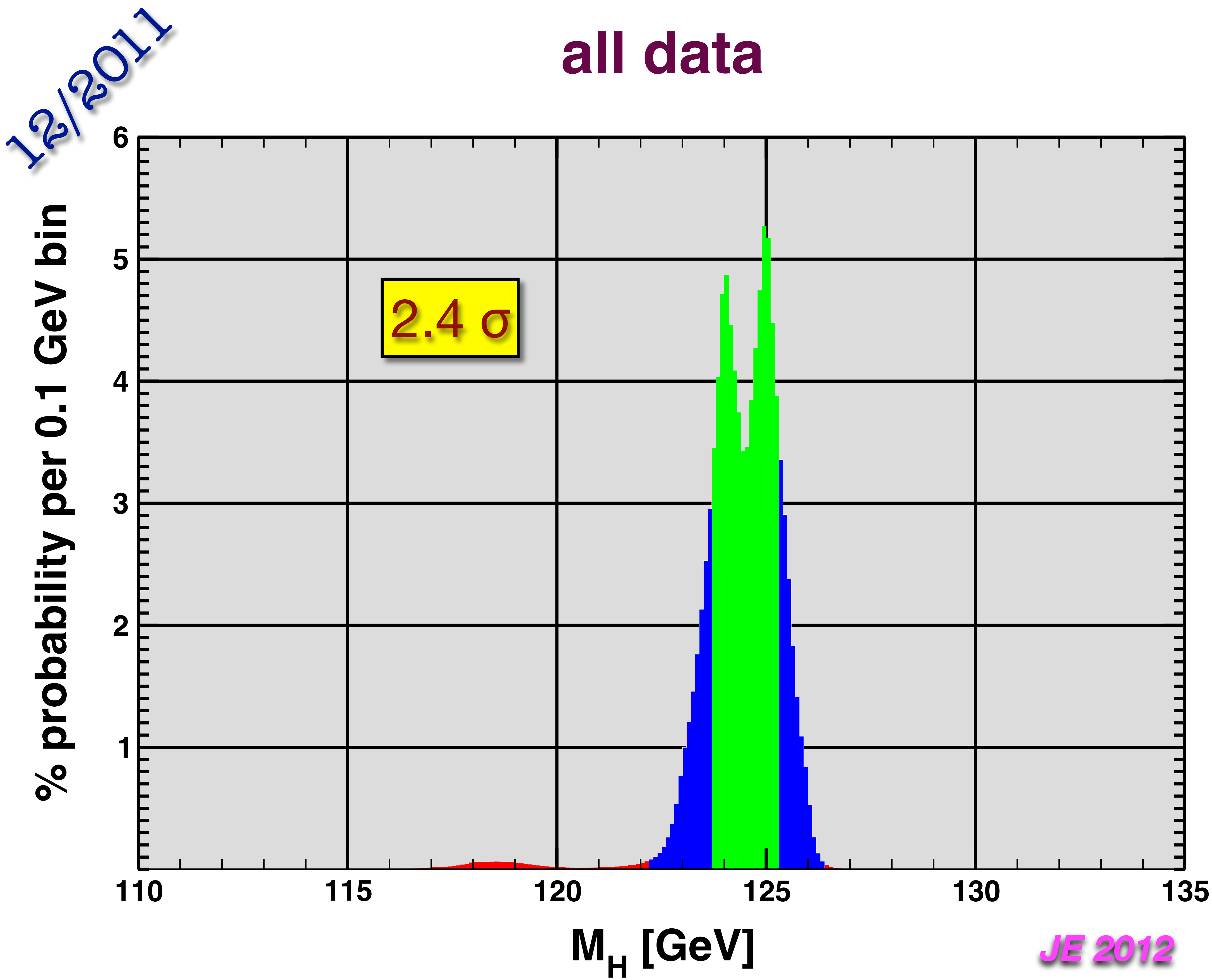
  $(1 - \bar{\sigma}_{obs})^2/\Delta\bar{\sigma}_+^{\,2} - \bar{\sigma}_{obs}^{\,2}/\Delta\bar{\sigma}_-^{\,2}$

- $\bar{\sigma}_{obs}$: eff. observed X-section (signal strength) combining all channels

- $\Delta\bar{\sigma}_\pm$: error pointing in signal (+) and background (–) direction

- Poisson statistics ⇒ $\Delta\bar{\sigma}_+ > \Delta\bar{\sigma}_-$ but often also $\Delta\bar{\sigma}_+ < \Delta\bar{\sigma}_-$

all data


12/2011
2.4 σ
% probability per 0.1 GeV bin
6
5
4
3
2
1
110
115
120
125
130
135
M_H [GeV]
JE 2012

33

Examples

34

Examples

- $2 \ln Q_{ATLAS}(126\ \text{GeV}) = 9.8 - 1.1 = -8.7$ ($H \to \gamma\gamma$, ZZ^*)

  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ

Examples

- $2 \ln Q_{ATLAS}(126 \text{ GeV}) = 9.8 - 1.1 = -8.7$ ($H \to \gamma\gamma, ZZ^*$)

  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ

- $2 \ln Q_{ATLAS}(244 \text{ GeV}) \approx 2 \ln Q_{ATLAS}(560 \text{ GeV}) \approx -3$ ($H \to ZZ$)

34

Examples

- $2 \ln Q_{ATLAS}(126\ \mathrm{GeV}) = 9.8 - 1.1 = -8.7$ ($H \rightarrow \gamma\gamma, ZZ^*$)

  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ

- $2 \ln Q_{ATLAS}(244\ \mathrm{GeV}) \approx 2 \ln Q_{ATLAS}(560\ \mathrm{GeV}) \approx -3$ ($H \rightarrow ZZ$)

- $2 \ln Q_{CMS}(119.5\ \mathrm{GeV}) = -5.6$ ($H \rightarrow ZZ^*, WW^*, b\,\bar{b}, \tau^+\,\tau^-$)

Examples

- $2 \ln Q_{ATLAS}(126\ \text{GeV}) = 9.8 - 1.1 = -8.7$ ($H \to \gamma\gamma$, ZZ^*)

  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ
- $2 \ln Q_{ATLAS}(244\ \text{GeV}) \approx 2 \ln Q_{ATLAS}(560\ \text{GeV}) \approx -3$ ($H \to ZZ$)
- $2 \ln Q_{CMS}(119.5\ \text{GeV}) = -5.6$ ($H \to ZZ^*$, WW^*, $b\,\bar{b}$, $\tau^+\,\tau^-$)
- $2 \ln Q_{CMS}(124\ \text{GeV}) = -6.6$ (mostly $H \to \gamma\gamma$)

Examples

- $2 \ln Q_{ATLAS}(126\ \text{GeV}) = 9.8 - 1.1 = -8.7$ ($H \to \gamma\gamma$, ZZ^*)

  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ
- $2 \ln Q_{ATLAS}(244\ \text{GeV}) \approx 2 \ln Q_{ATLAS}(560\ \text{GeV}) \approx -3$ ($H \to ZZ$)
- $2 \ln Q_{CMS}(119.5\ \text{GeV}) = -5.6$ ($H \to ZZ^*$, WW^*, $b\,\bar{b}$, $\tau^+\,\tau^-$)
- $2 \ln Q_{CMS}(124\ \text{GeV}) = -6.6$ (mostly $H \to \gamma\gamma$)
- $2 \ln Q_{\text{Tevatron 2012}}(120\ \text{GeV}) = -8.0$ (mostly $H \to b\,\bar{b}$)

Examples

- $2 \ln Q_{ATLAS}(126\ \text{GeV}) = 9.8 - 1.1 = -8.7$ ($H \rightarrow \gamma\gamma$, ZZ^*)

  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ
- $2 \ln Q_{ATLAS}(244\ \text{GeV}) \approx 2 \ln Q_{ATLAS}(560\ \text{GeV}) \approx -3$ ($H \rightarrow ZZ$)
- $2 \ln Q_{CMS}(119.5\ \text{GeV}) = -5.6$ ($H \rightarrow ZZ^*$, WW^*, $b\,\bar{b}$, $\tau^+\,\tau^-$)
- $2 \ln Q_{CMS}(124\ \text{GeV}) = -6.6$ (mostly $H \rightarrow \gamma\gamma$)
- $2 \ln Q_{Tevatron\ 2012}(120\ \text{GeV}) = -8.0$ (mostly $H \rightarrow b\,\bar{b}$)
- $2 \ln Q_{LEP}(117\ \text{GeV}) = -1.7$ ($H \rightarrow$ 4 jets ***ALEPH***)

Examples

- $2 \ln Q_{ATLAS}(126\ \text{GeV}) = 9.8 - 1.1 = -8.7$ (H → γγ, ZZ*)

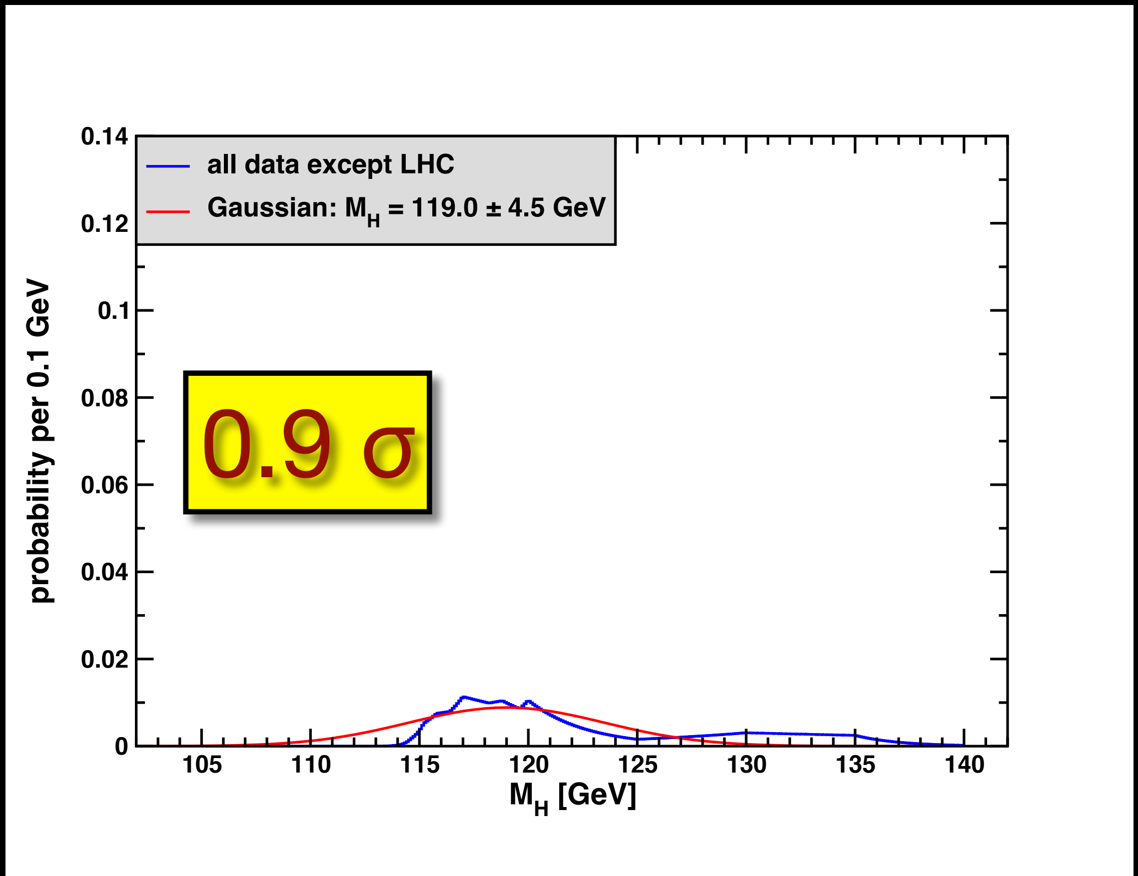
  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ
- $2 \ln Q_{ATLAS}(244\ \text{GeV}) \approx 2 \ln Q_{ATLAS}(560\ \text{GeV}) \approx -3$ (H → ZZ)
- $2 \ln Q_{CMS}(119.5\ \text{GeV}) = -5.6$ (H → ZZ*, WW*, $b\,\bar{b}$, $\tau^+\,\tau^-$)
- $2 \ln Q_{CMS}(124\ \text{GeV}) = -6.6$ (mostly H → γγ)
- $2 \ln Q_{\text{Tevatron 2012}}(120\ \text{GeV}) = -8.0$ (mostly H → $b\,\bar{b}$)
- $2 \ln Q_{LEP}(117\ \text{GeV}) = -1.7$ (H → 4 jets ***ALEPH***)
- $\chi^2_{EW}(127\ \text{GeV}) - \chi^2_{EW}(115.5\ \text{GeV}) = 0.63$

Examples

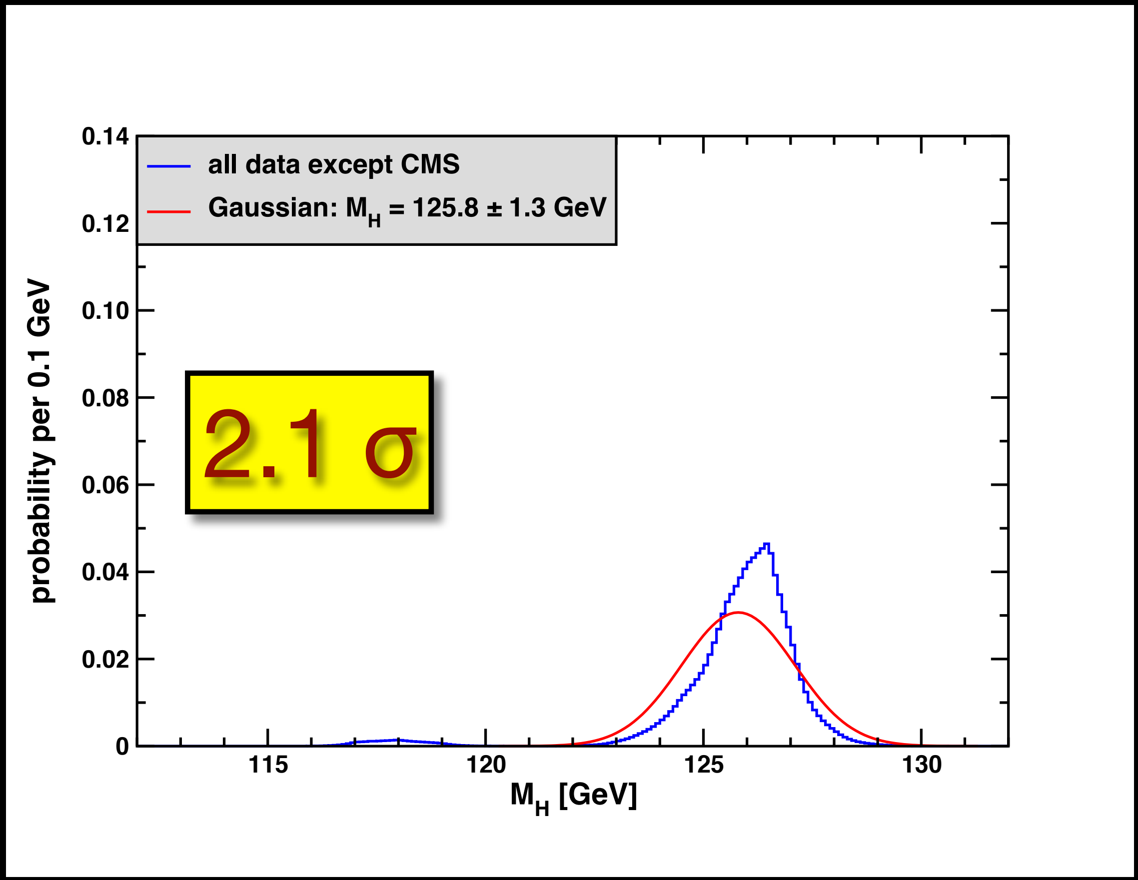
- $2 \ln Q_{ATLAS}(126\ \text{GeV}) = 9.8 - 1.1 = -8.7$ ($H \to \gamma\gamma$, ZZ^*)

  $\sqrt{8.7} = 2.9$ while quoted local significance of excess = 3.6 σ
- $2 \ln Q_{ATLAS}(244\ \text{GeV}) \approx 2 \ln Q_{ATLAS}(560\ \text{GeV}) \approx -3$ ($H \to ZZ$)
- $2 \ln Q_{CMS}(119.5\ \text{GeV}) = -5.6$ ($H \to ZZ^*$, WW^*, $b\,\bar{b}$, $\tau^+\,\tau^-$)
- $2 \ln Q_{CMS}(124\ \text{GeV}) = -6.6$ (mostly $H \to \gamma\gamma$)
- $2 \ln Q_{Tevatron\ 2012}(120\ \text{GeV}) = -8.0$ (mostly $H \to b\,\bar{b}$)
- $2 \ln Q_{LEP}(117\ \text{GeV}) = -1.7$ ($H \to$ 4 jets ***ALEPH***)
- $\chi^2_{EW}(127\ \text{GeV}) - \chi^2_{EW}(115.5\ \text{GeV}) = 0.63$
- $2 \ln p_{direct}(125\ \text{GeV}) = -13.2$

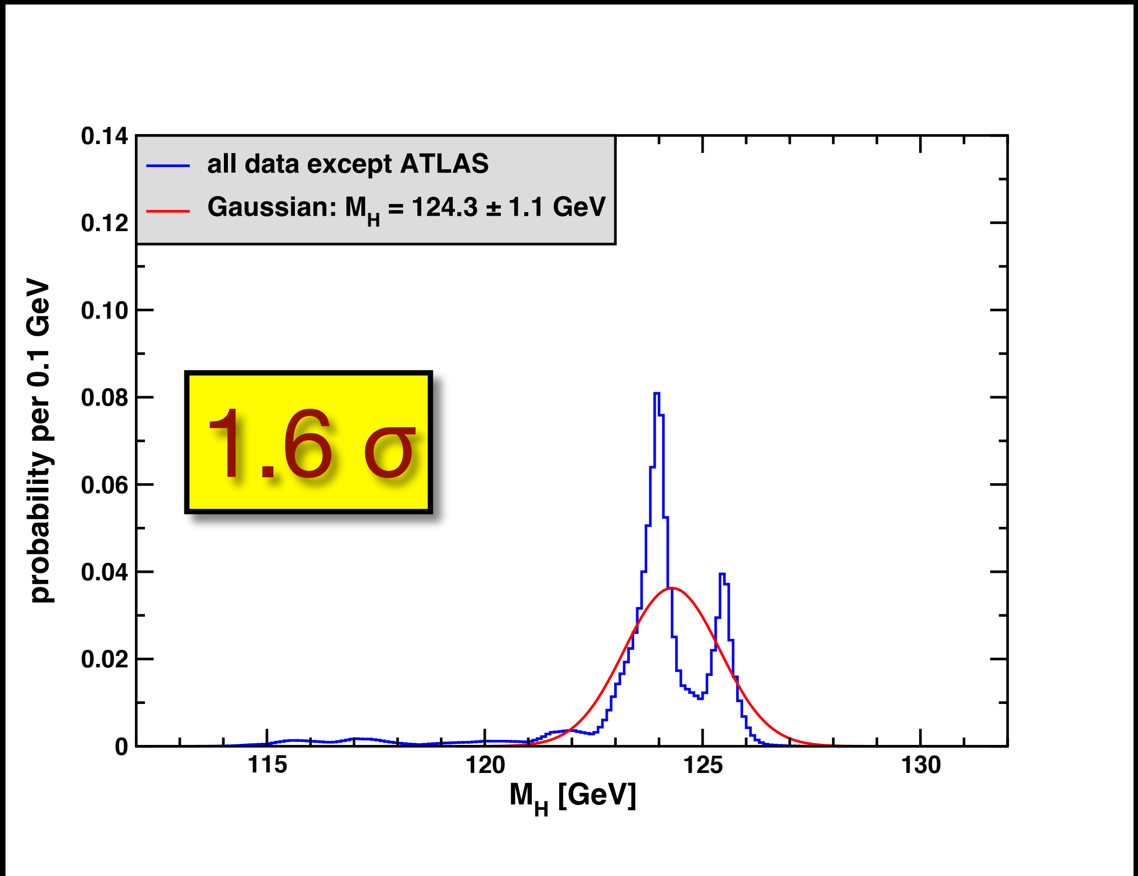
34



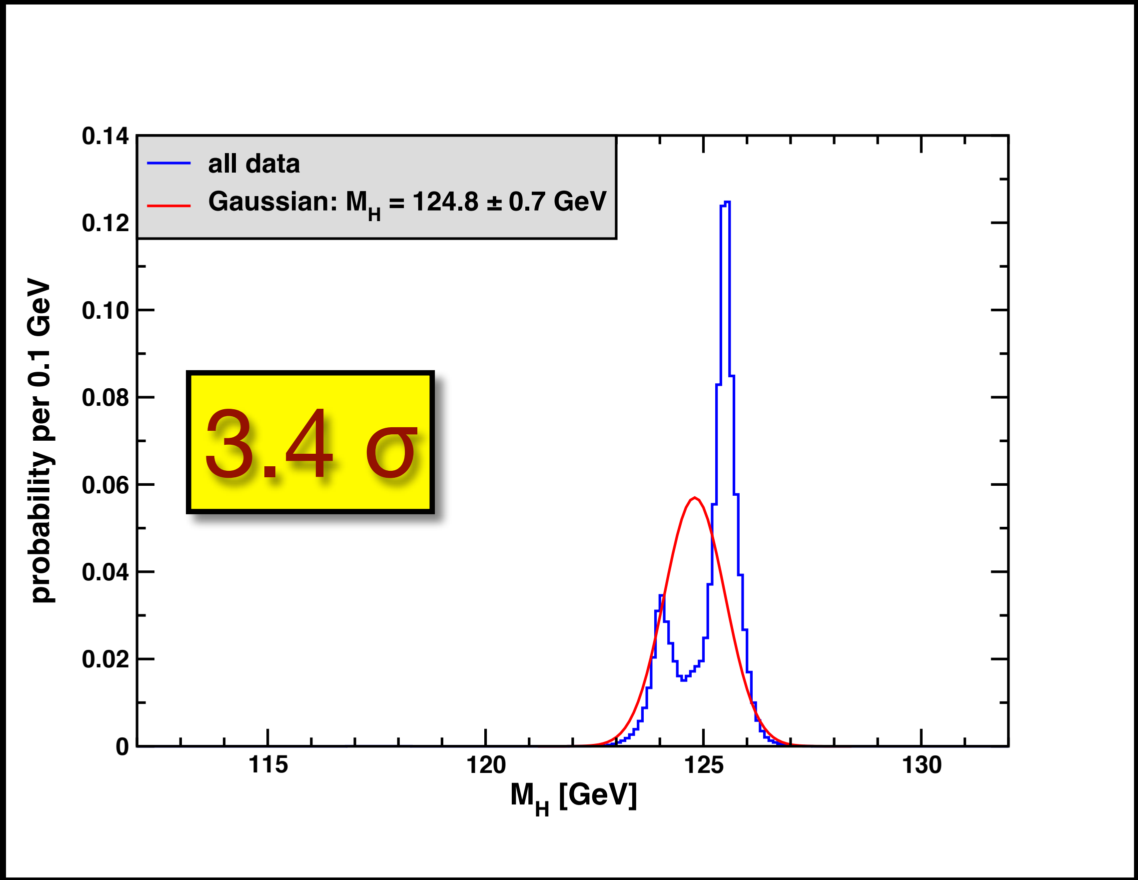
all data except LHC
Gaussian: M_H = 119.0 ± 4.5 GeV
0.9 σ
probability per 0.1 GeV
M_H [GeV]



all data except CMS
Gaussian: M_H = 125.8 ± 1.3 GeV
2.1 σ
probability per 0.1 GeV
M_H [GeV]

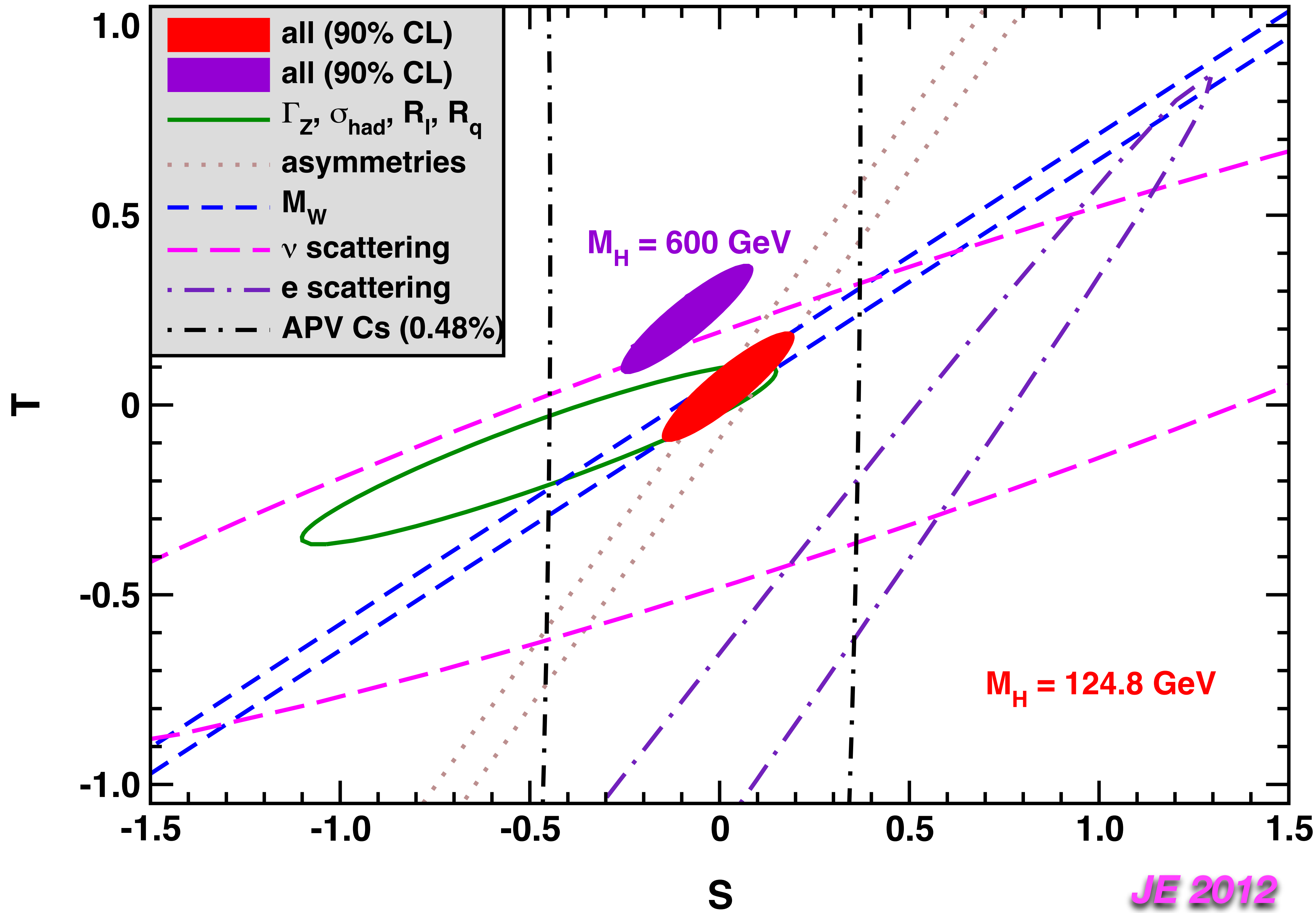


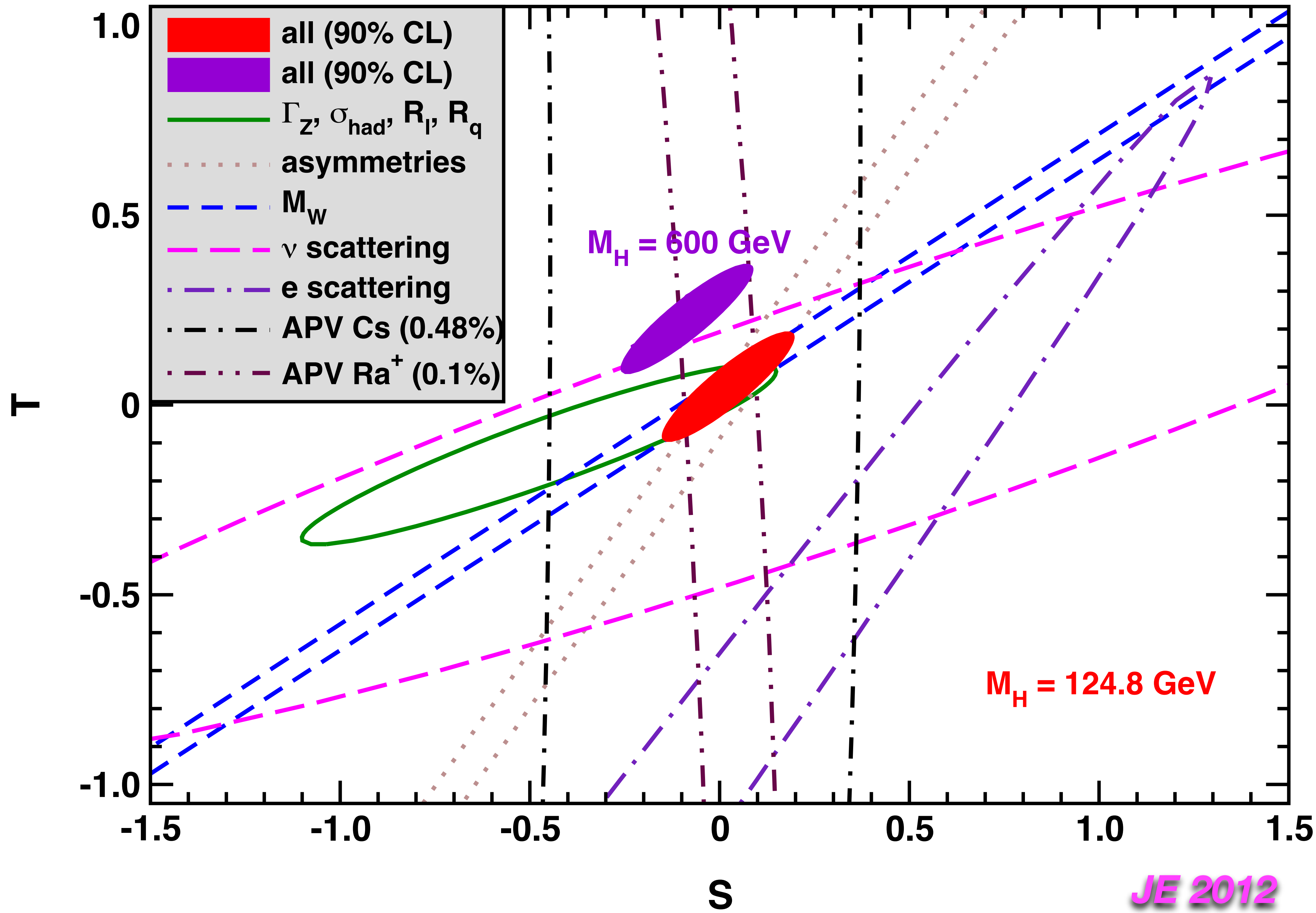
all data except ATLAS
Gaussian: M_H = 124.3 ± 1.1 GeV
1.6 σ
probability per 0.1 GeV
M_H [GeV]



all data
Gaussian: M_H = 124.8 ± 0.7 GeV
3.4 σ
probability per 0.1 GeV
M_H [GeV]

New Physics Interpretations

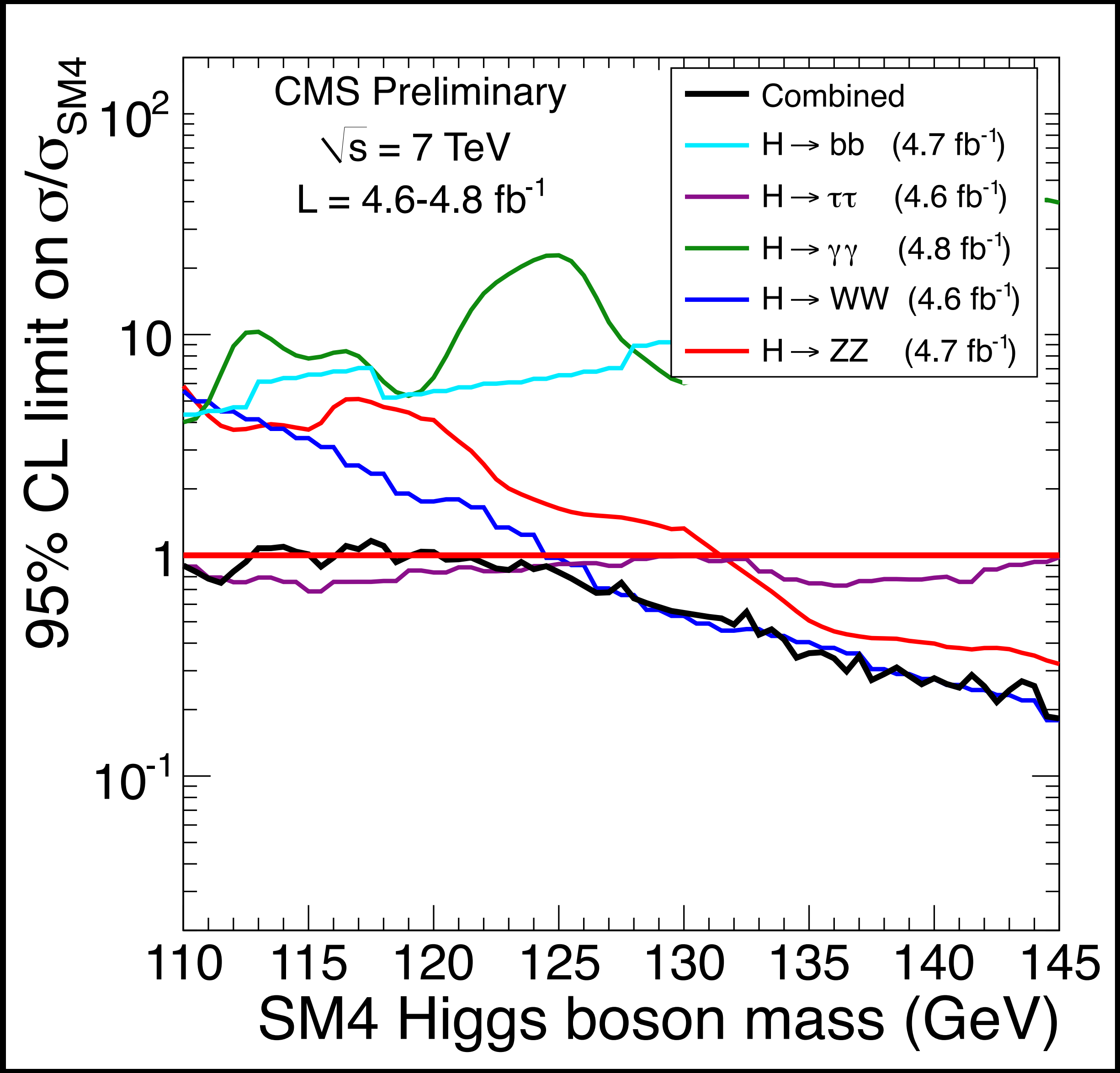

all (90% CL)
all (90% CL)
Γ_Z, σ_{had}, R_l, R_q
asymmetries
M_W
ν scattering
e scattering
APV Cs (0.48%)
M_H = 600 GeV
M_H = 124.8 GeV
T
S
1.0
0.5
0
-0.5
-1.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
JE 2012



all (90% CL)
all (90% CL)
Γ_Z, σ_{had}, R_l, R_q
asymmetries
M_W
ν scattering
e scattering
APV Cs (0.48%)
APV Ra^+ (0.1%)
M_H = 600 GeV
M_H = 124.8 GeV
T
S
1.0
0.5
0
-0.5
-1.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
JE 2012

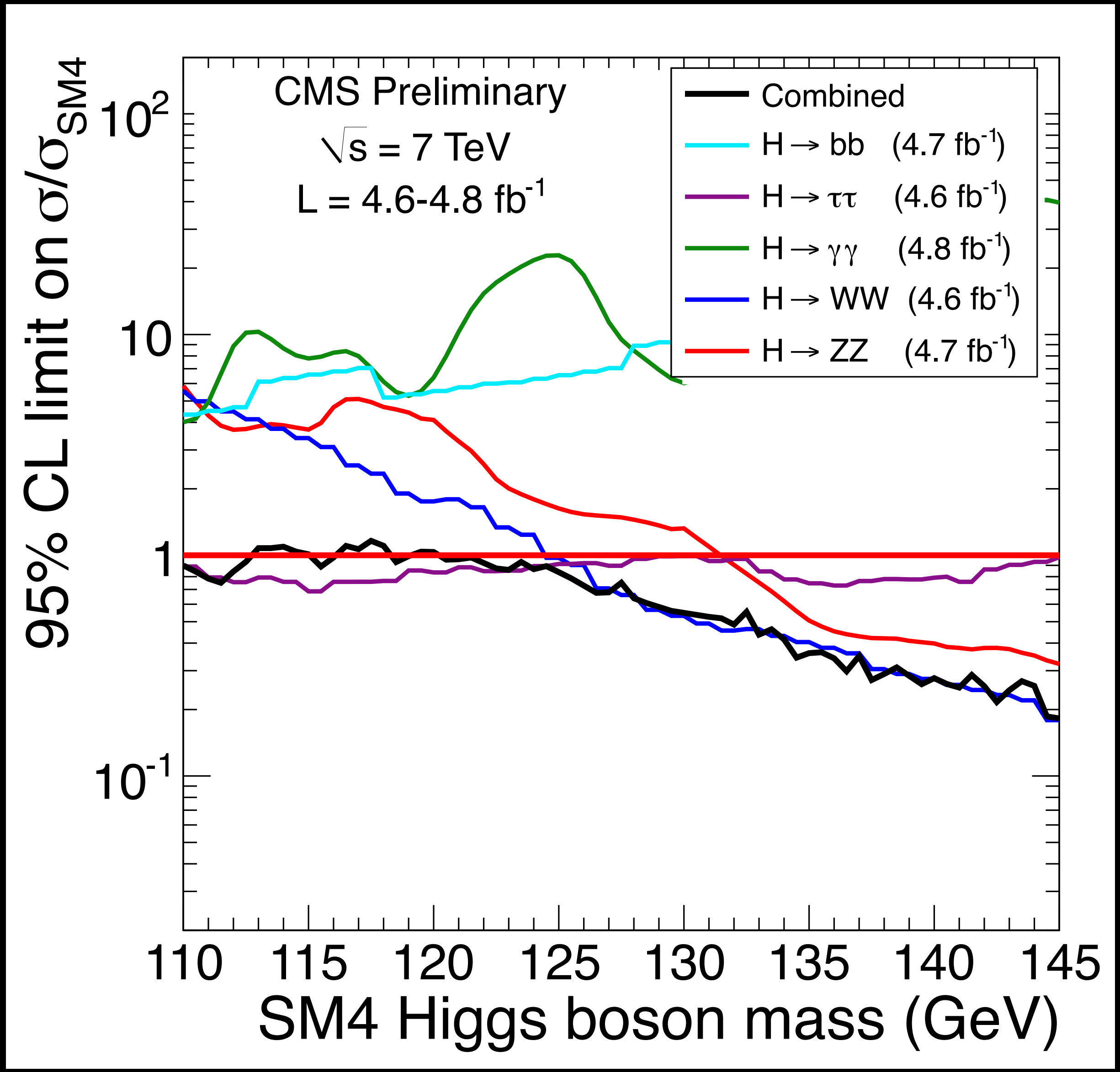
38

canonical examples: 4G & 2HD



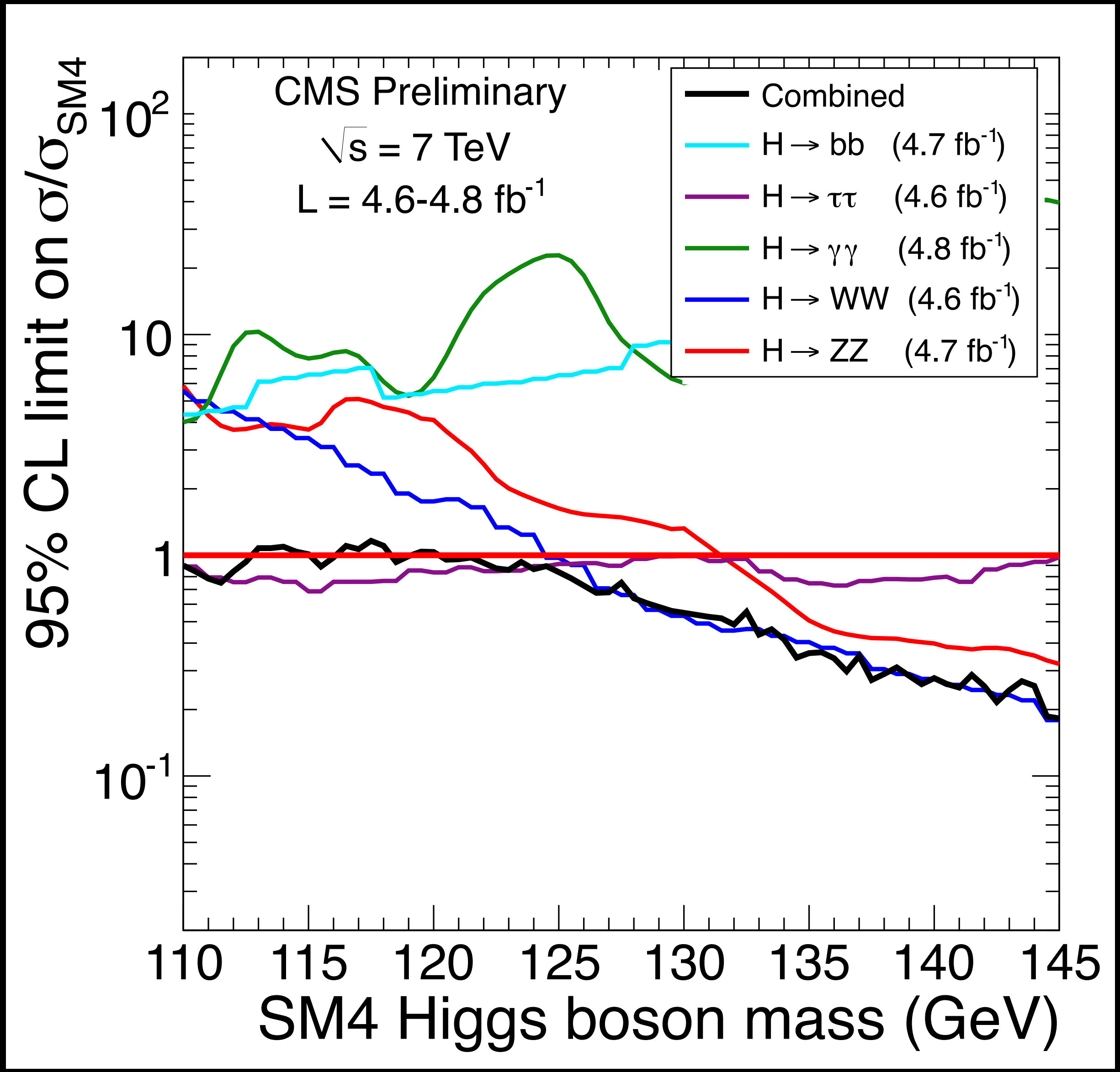
canonical examples: 4G & 2HD

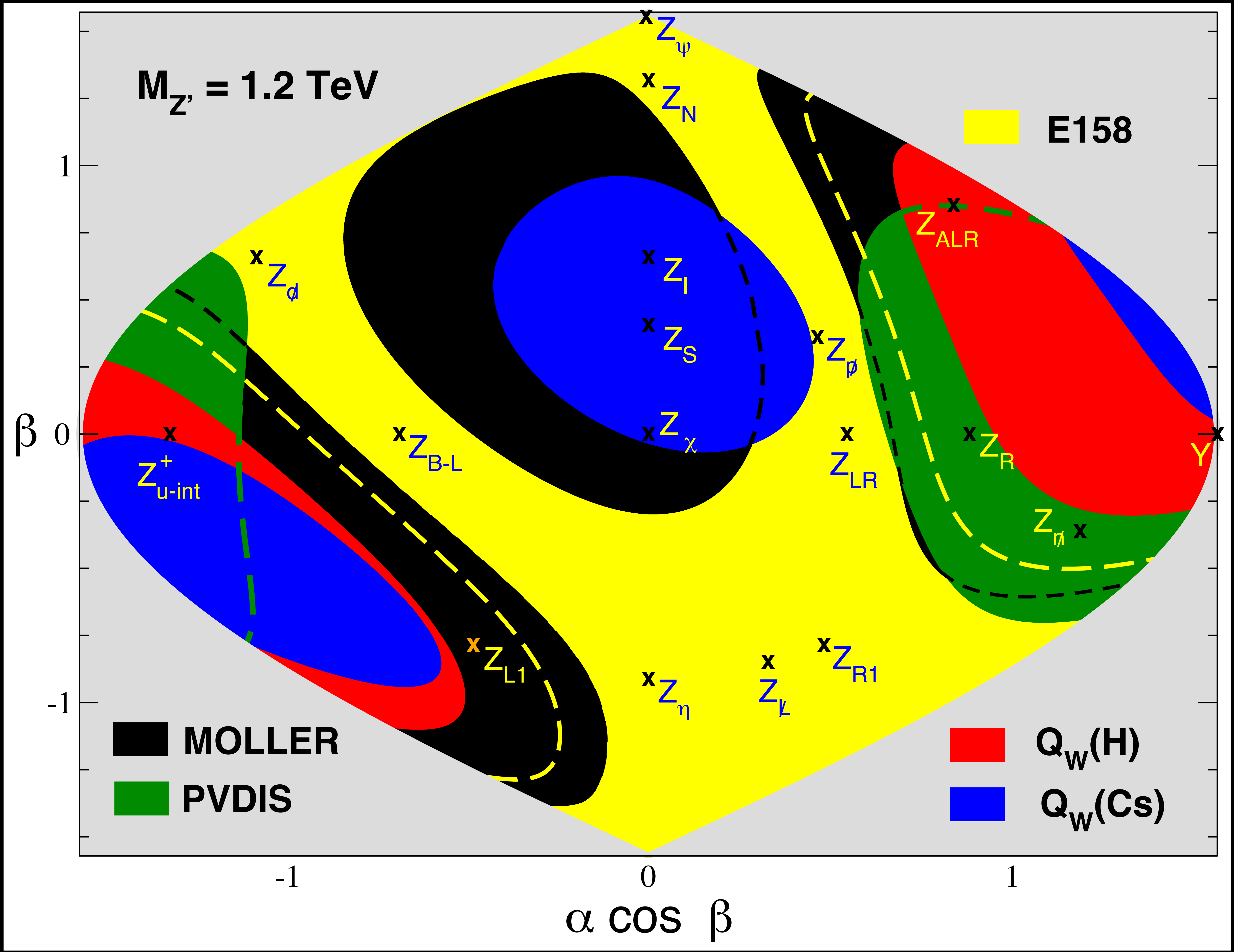
- if Higgs hint is real, an extra fermion generation is ruled out (99.6% CL) ***Kuflik, Nir, Volansky 2012***



canonical examples: 4G & 2HD

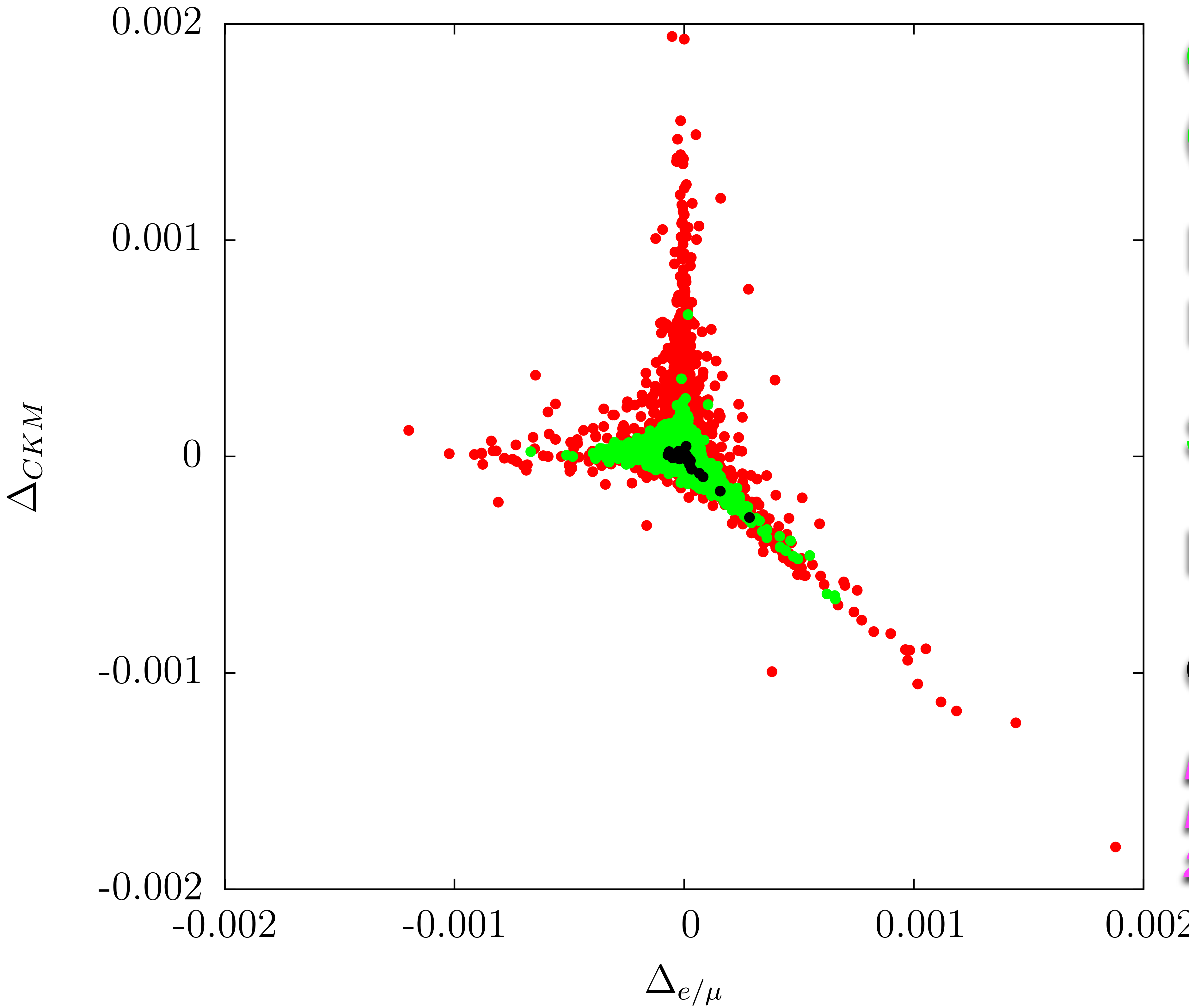
- if Higgs hint is real, an extra fermion generation is ruled out (99.6% CL) ***Kuflik, Nir, Volansky 2012***
- 3 scenarios (all need some tuning & faith; mass spectra generally similar)
  - $M_H \lesssim 120$ GeV ***e.g., Dighe, Ghosh, Godbole, Prasath 2012***
  - $M_H \gtrsim 450$ GeV ***Buchkremer, Gérard, Maltoni 2012***
  - $M_H \approx 125$ GeV + physics beyond 4G. Example: 2HD4G ***Bellantoni, Heckman, JE 2012***





$M_{Z'}$ = 1.2 TeV
E158
MOLLER
PVDIS
$Q_W(H)$
$Q_W(Cs)$
Z_ψ
Z_N
Z_I
Z_S
Z_χ
Z_d
Z_p
Z_{ALR}
Z_R
Z_{LR}
Z_{B-L}
Z^+_{u-int}
Z_{L1}
Z_η
Z_L
Z_{R1}
Z_n
Y
β
α cos β
1
0
-1

MSSM with R-parity



CKM unitarity (first row)

Γ[π→ν e (γ)] / Γ[π→ν μ (γ)]

STU

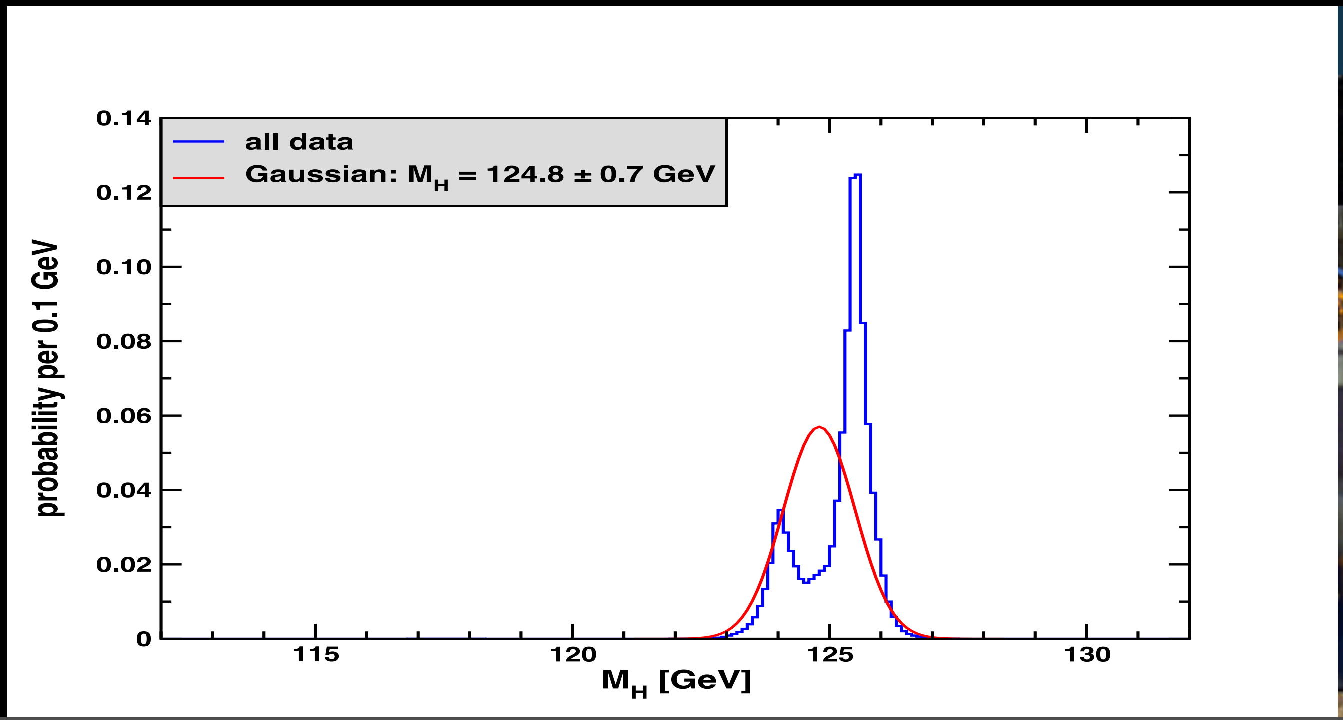
LHC bounds

combined

Bauman, JE, Ramsey-Musolf 2012

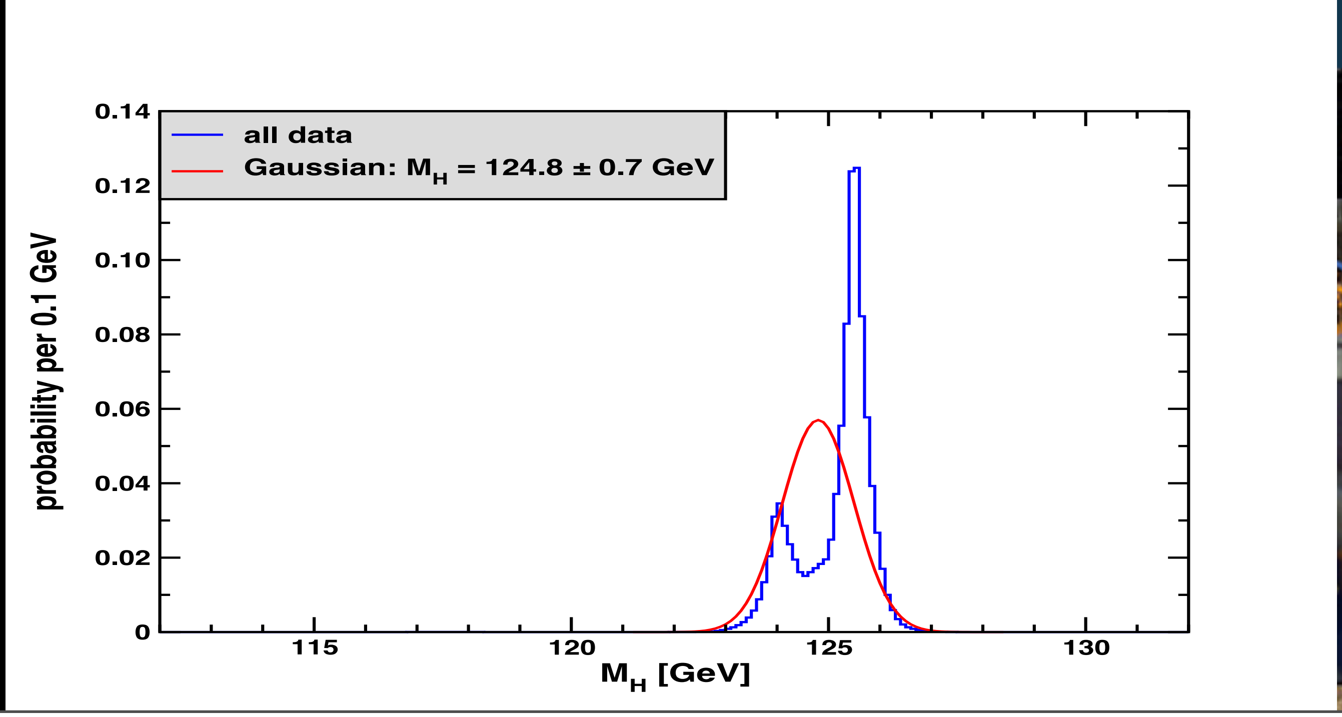
Conclusions

Conclusions



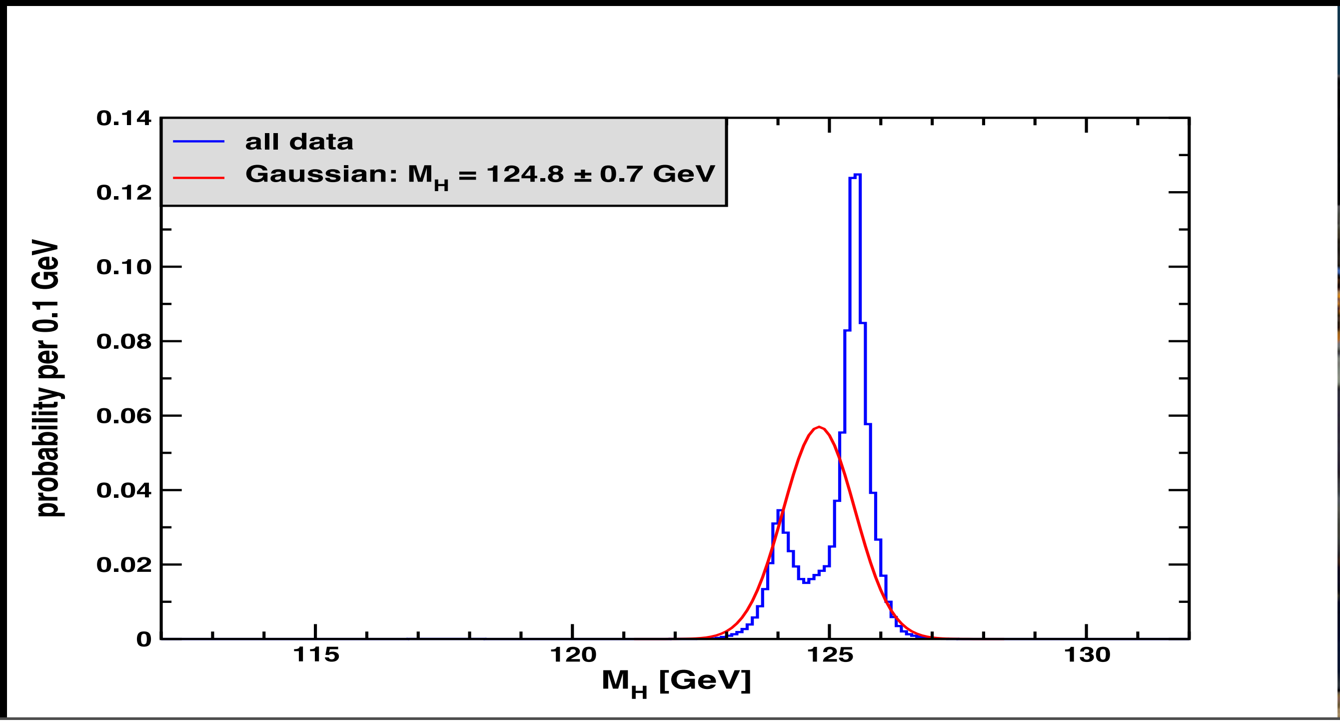
Conclusions

- Precision tests have reached per-mille and sub per-mille accuracy in derived quantities.



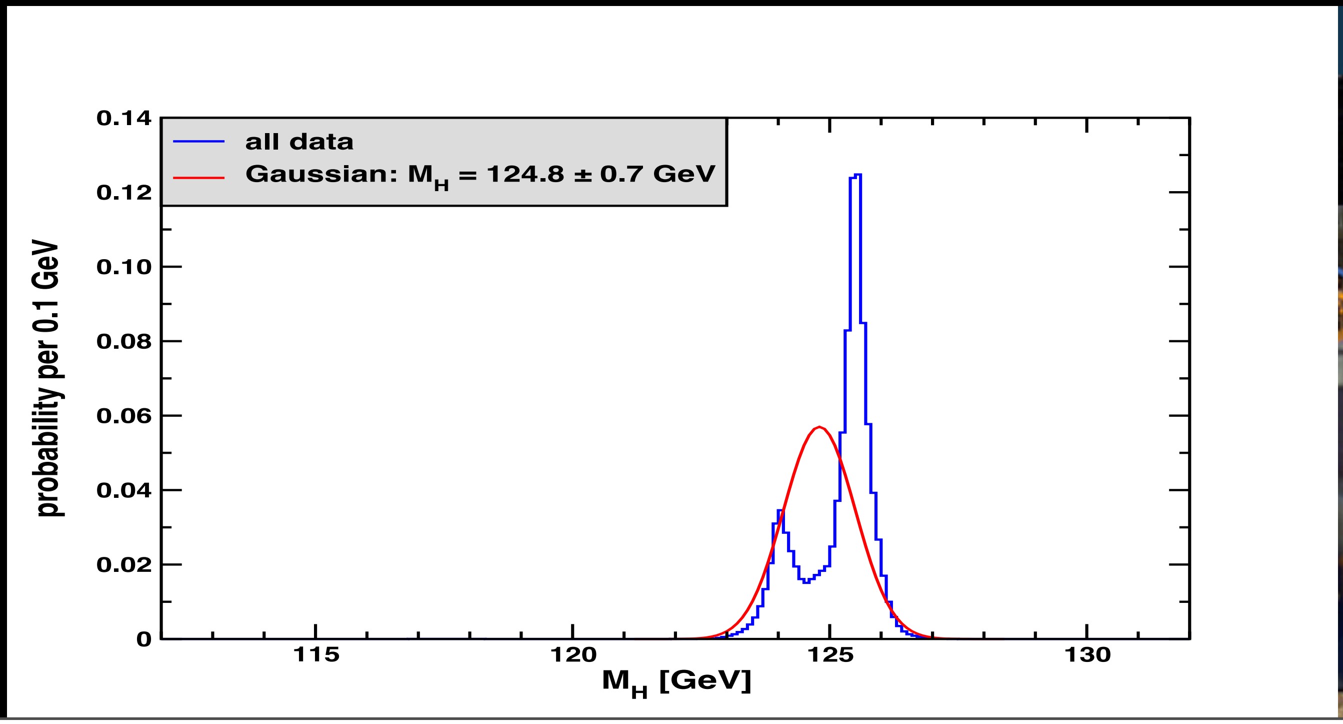
Conclusions

- Precision tests have reached per-mille and sub per-mille accuracy in derived quantities.
- Precision data in very good agreement with the SM $\Rightarrow$ tight constraints on new physics.



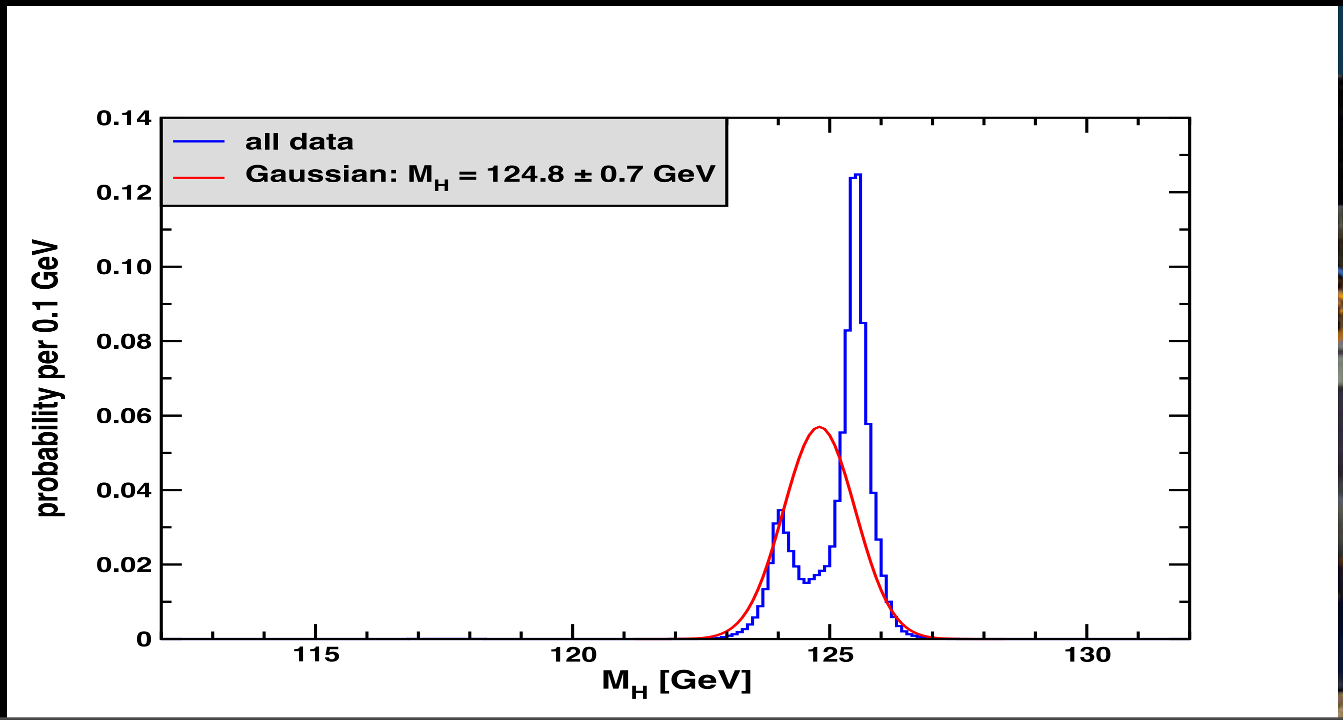
Conclusions

- Precision tests have reached per-mille and sub per-mille accuracy in derived quantities.
- Precision data in very good agreement with the SM ⇒ tight constraints on new physics.
- When combined with the absence of BSM signals at the LHC ⇒ more and more likely that new physics is separted from the SM by at least a little hierarchy.



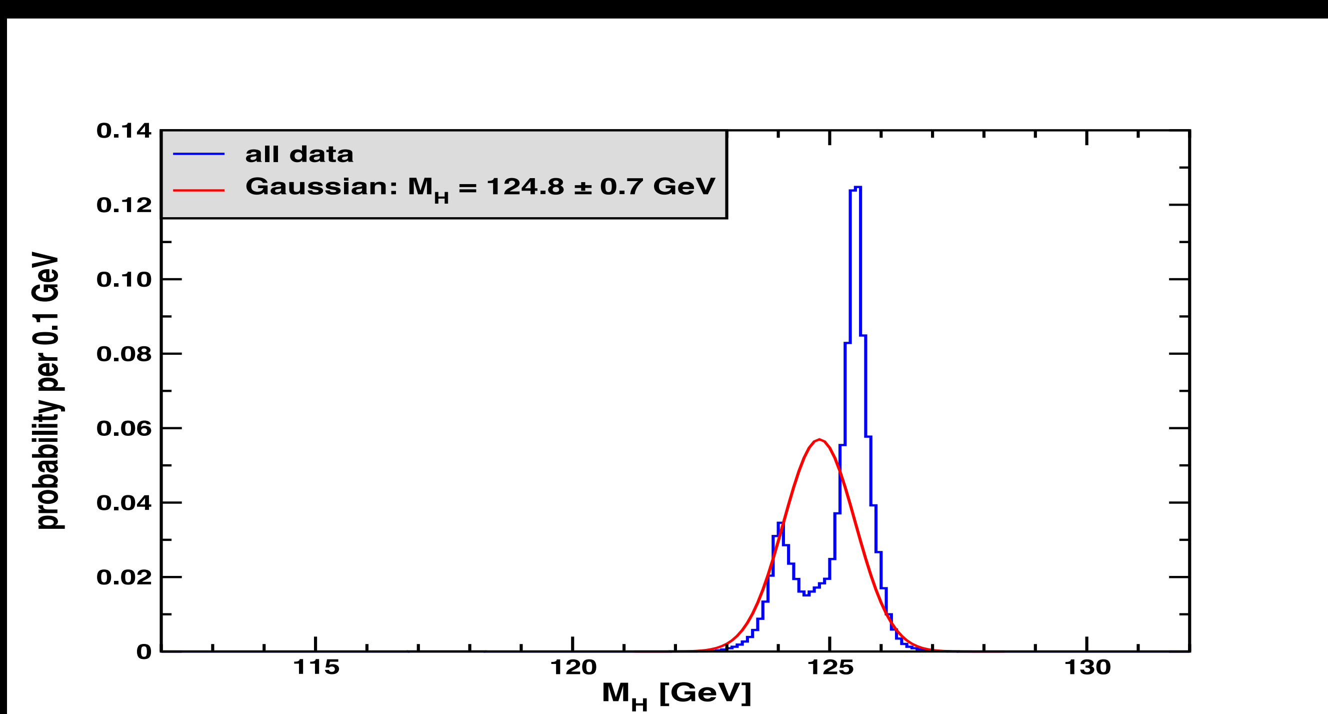
Conclusions

- Precision tests have reached per-mille and sub per-mille accuracy in derived quantities.
- Precision data in very good agreement with the SM ⇒ tight constraints on new physics.
- When combined with the absence of BSM signals at the LHC ⇒ more and more likely that new physics is separted from the SM by at least a little hierarchy.
- Only tantalizing deviation is in $g_\mu - 2$.



Conclusions

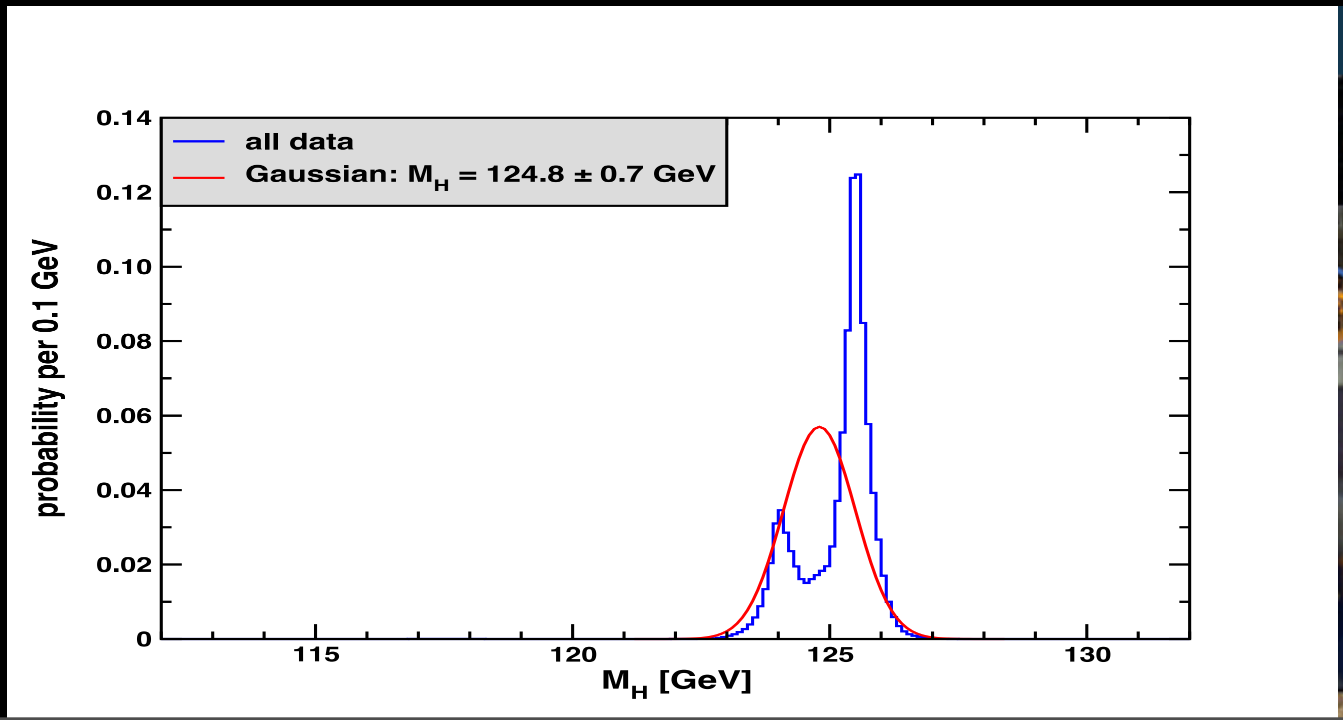
- Precision tests have reached per-mille and sub per-mille accuracy in derived quantities.
- Precision data in very good agreement with the SM ⇒ tight constraints on new physics.
- When combined with the absence of BSM signals at the LHC ⇒ more and more likely that new physics is separted from the SM by at least a little hierarchy.
- Only tantalizing deviation is in $g_\mu - 2$.
- Within SM, Higgs searches + EW precision data give the LHC/Tevatron Higgs hints a 3 ½ σ significance (no need for look-elsewhere effect correction).



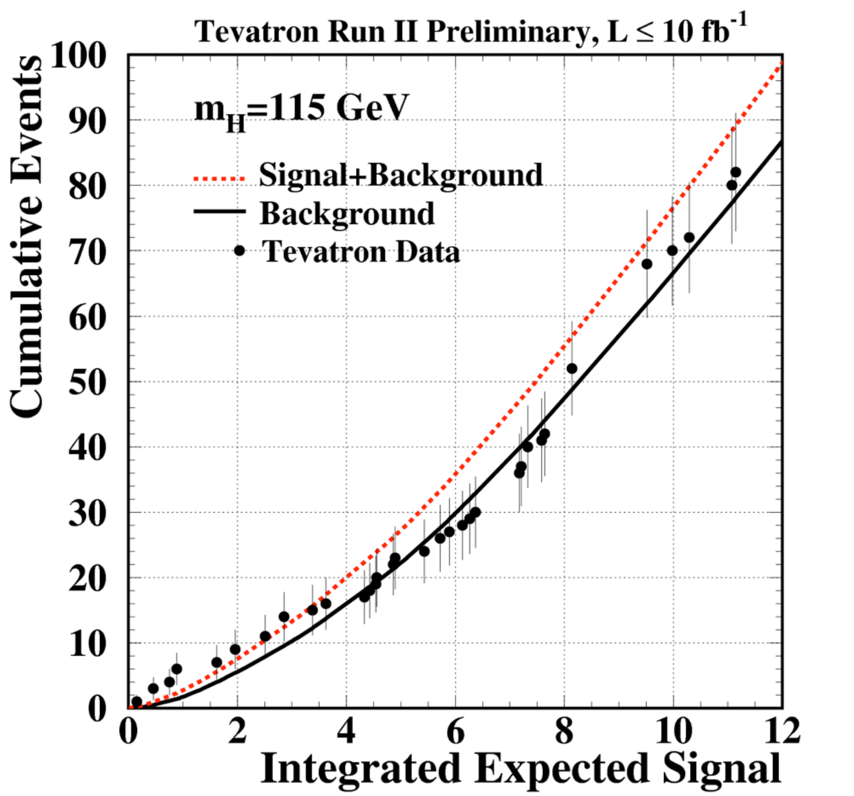
43

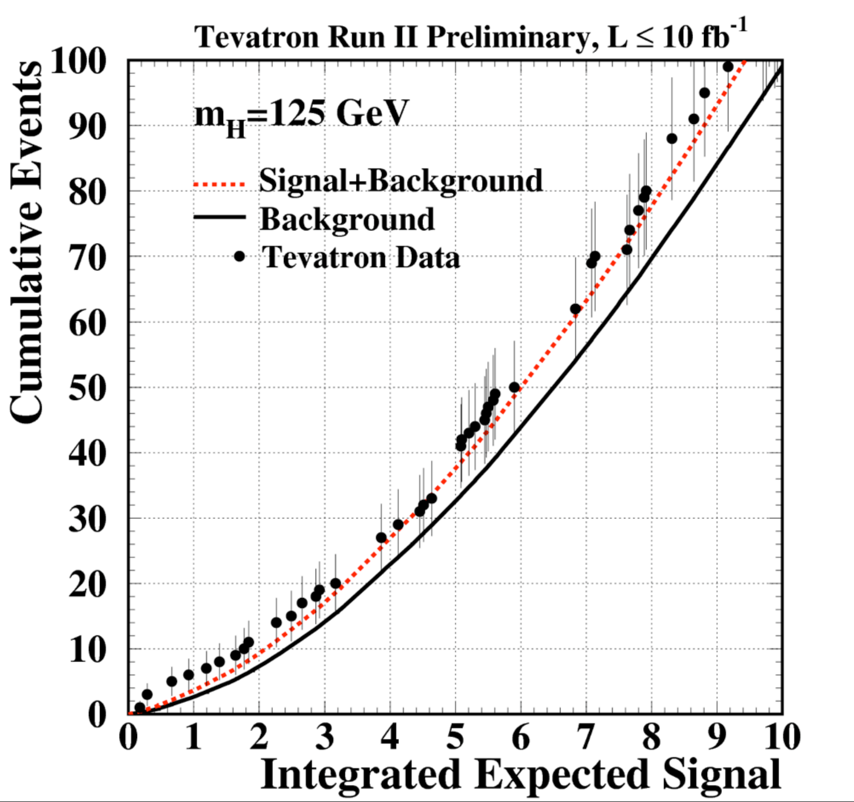
Conclusions

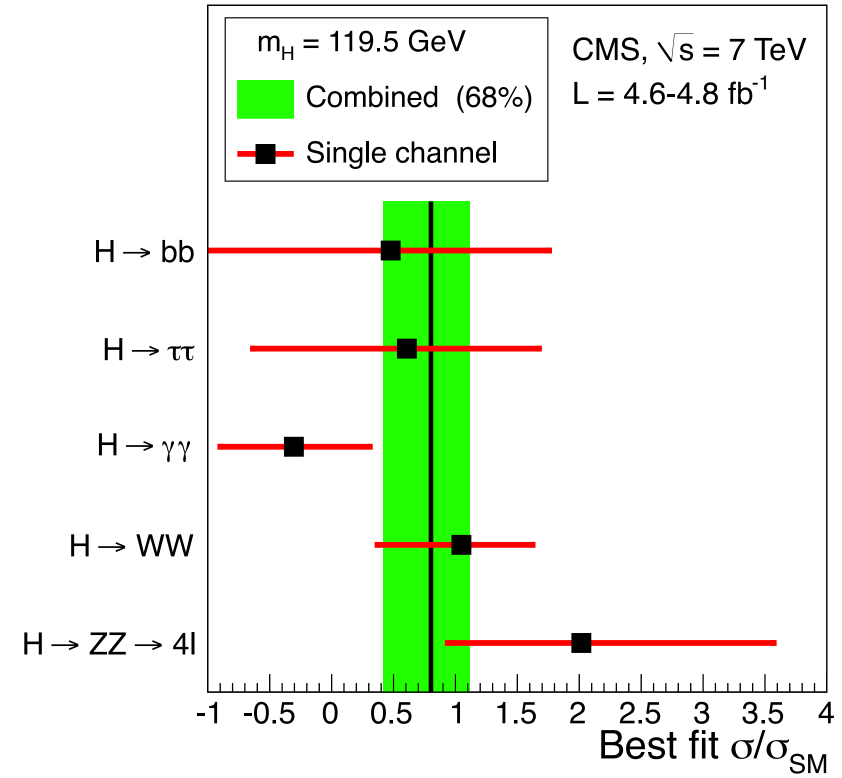
- Precision tests have reached per-mille and sub per-mille accuracy in derived quantities.
- Precision data in very good agreement with the SM ⇒ tight constraints on new physics.
- When combined with the absence of BSM signals at the LHC ⇒ more and more likely that new physics is separted from the SM by at least a little hierarchy.
- Only tantalizing deviation is in $g_\mu-2$.
- Within SM, Higgs searches + EW precision data give the LHC/Tevatron Higgs hints a 3 ½ σ significance (no need for look-elsewhere effect correction).
- ***Not*** confirming the LHC Higgs hint would be a much bigger deal than discovering it

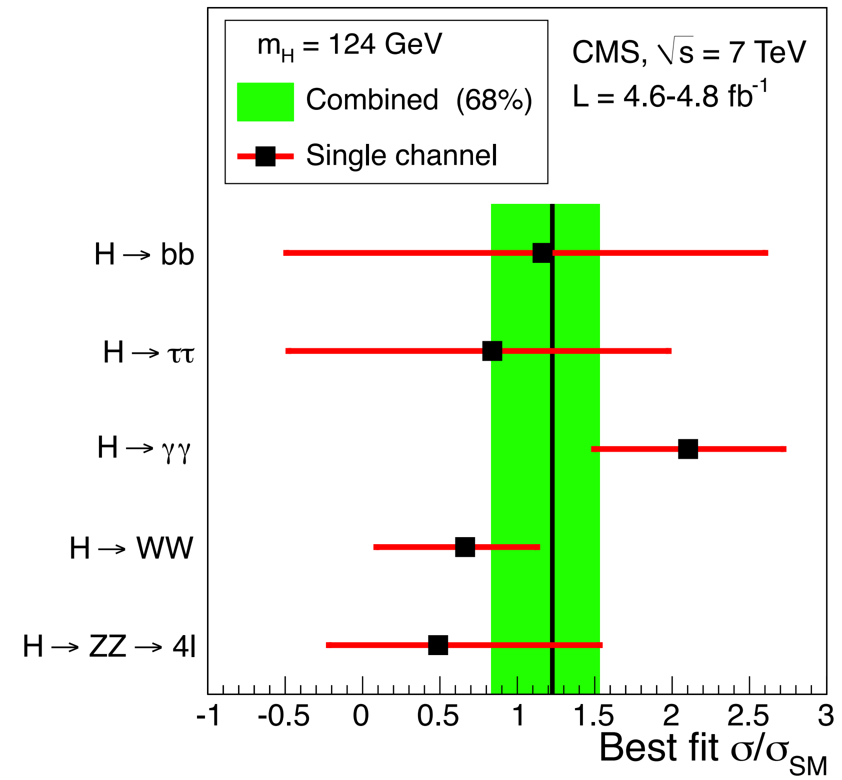


Back-ups


Tevatron Run II Preliminary, L ≤ 10 fb^{-1}
m_H=115 GeV
Signal+Background
Background
Tevatron Data
Cumulative Events
Integrated Expected Signal


Tevatron Run II Preliminary, L ≤ 10 fb^{-1}
m_H=125 GeV
Signal+Background
Background
Tevatron Data
Cumulative Events
Integrated Expected Signal


m_H = 119.5 GeV
Combined (68%)
Single channel
CMS, $\sqrt{s}$ = 7 TeV
L = 4.6-4.8 fb^{-1}
H → bb
H → ττ
H → γγ
H → WW
H → ZZ → 4l
Best fit σ/σ_{SM}


m_H = 124 GeV
Combined (68%)
Single channel
CMS, $\sqrt{s}$ = 7 TeV
L = 4.6-4.8 fb^{-1}
H → bb
H → ττ
H → γγ
H → WW
H → ZZ → 4l
Best fit σ/σ_{SM}