Status of Precision Extractions of α_s and Heavy Quark Masses

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Motivation

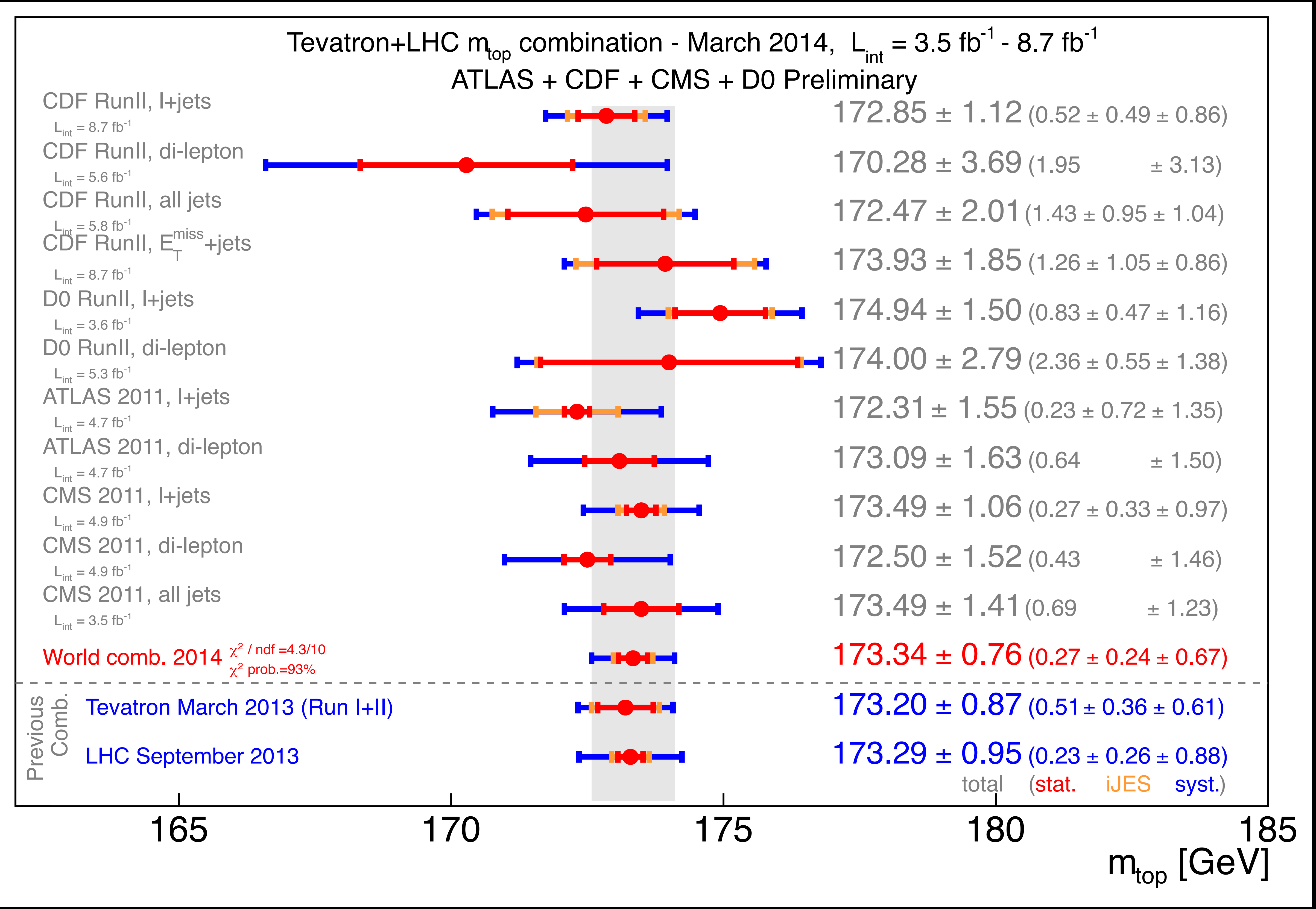
- Fundamental parameters of nature (the SM)
- α_s: gauge coupling unification
- heavy quark masses: Higgs decay BRs
- m_b: Yukawa coupling unification
- m_t: vacuum stability

Outline

- Top Quark Mass
  - Tevatron/LHC combination
  - very recent developments
  - indirect (electroweak) constraints
- Charm and Bottom Quark Masses
  - recent results
  - not covered: m_b/m_c
- Strong Coupling Constant
  - recent results
  - Z and tau decays
- Conclusions

Top quark mass

First Tevatron/LHC combination



ATLAS, CDF, CMS, D0 1403.4427

m_t combination uncertainty

$\pm\ 0.27_{stat}$

$\pm\ 0.33_{JES}$

$\pm\ 0.25_{bJES}$ strongly correlated

$\pm\ 0.54_{theory\ \&\ model}$ strongly correlated: MC, Rad, CR, PDF

$\pm\ 0.2_{other}$

$= \pm\ 0.76_{exp}$

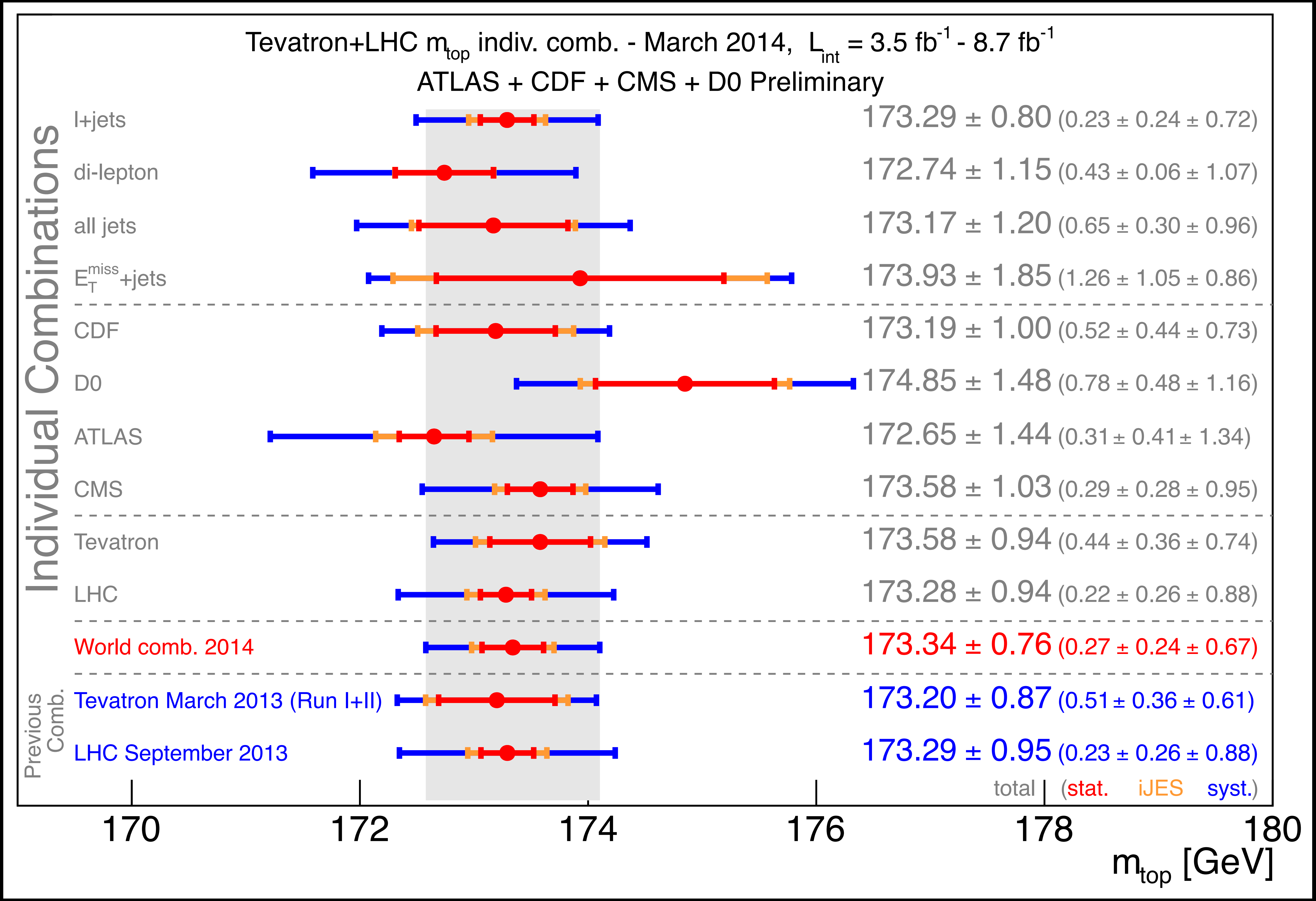
$\pm\ 0.5_{QCD}$ fully correlated: taken as $O(\alpha_s^3)$-term in conversion formula from m_{pole} to MS-bar mass $\overline{m}(\overline{m})$ (renormalon uncertainty)

and assuming $m^{MC} = m^{pole} = \overline{m}(\overline{m}) + 9.65 \pm 0.50$ GeV

alternative: $m^{MC} = m^{MSR}(3^{+6}_{-3}\ \mathrm{GeV}) = \overline{m}(\overline{m}) + 9.6^{+0.6}_{-0.3}$ GeV

A.H. Hoang, I.W. Stewart 0808.0222

First Tevatron/LHC combination



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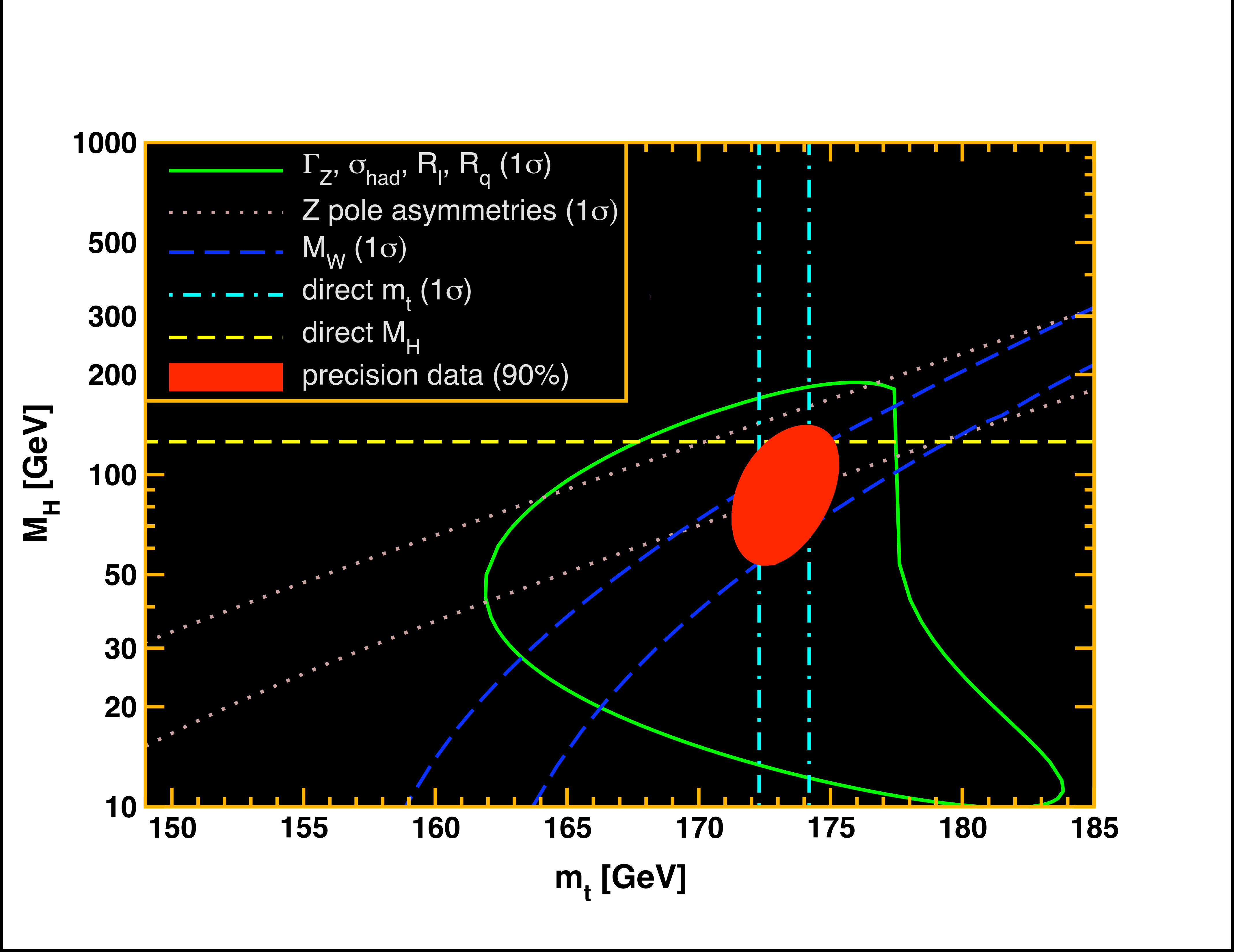
After m_t combination

- D0 l+jet: $m_t = 174.98 \pm 0.58_{stat + JSF} \pm 0.49_{syst}$ GeV *1405.1756*
  most precise single measurement (matches world average)
- Tevatron average: $m_t = 174.34 \pm 0.37 \pm 0.52$ GeV *1407.2682*
- ATLAS all jets: $m_t = 175.1 \pm 1.4 \pm 1.2$ GeV *1409.0832*
- CMS l+jets (8 TeV): $m_t = 172.04 \pm 0.19_{stat + JSF} \pm 0.75_{syst}$ GeV
  CMS average: $m_t = 172.22 \pm 0.73$ GeV *CMS-PAS-TOP-14-001*
  more precise than previous world average
- CMS all jets: $m_t = 172.08 \pm 0.36_{stat + JSF} \pm 0.83_{syst}$ GeV
  CMS-PAS-TOP-14-002
- 2.7 σ (or more including correlations)
  between D0 and CMS l+jets results
- 2.2 σ between Tevatron & CMS averages
  (not even including all jets channel)

m_t prospects

- m_t from inclusive $\overline{t}t$ X-section
  - m_t = 172.9 ± 2.6 GeV ***ATLAS***
  - but 1.7 σ tension between 7 and 8 TeV results
  - can extract $\overline{m}_t(\overline{m}_t)$ = 162.3±2.3 directly
    S. Alekhin, J. Blümlein, S. Moch 1310.3059
  - improvement to ±1 GeV conceivable ***CMS PAS FTR-13-017***
- differential distribution of $\overline{t}t$+1-jet X-section
  S. Alioli, P. Fernandez, J. Fuster, A. Irles, S. Moch 1303.6415
  - potential to reach ±1 GeV precision
- LHC projections ***CMS PAS FTR-13-017***
  - 13 TeV, 30 fb^{-1}: Δm_t = ± 0.15 ± 0.60 GeV = ± 0.62 GeV
  - 14 TeV, 300 fb^{-1}: Δm_t = ± 0.05 ± 0.44 GeV = ± 0.44 GeV
  - 14 TeV, 3000 fb^{-1}: Δm_t = ± 0.01 ± 0.20 GeV = ± 0.20 GeV
  - the conversion error may also improve with more data

m_t from electroweak precision data



JE, Freitas PDG 2014

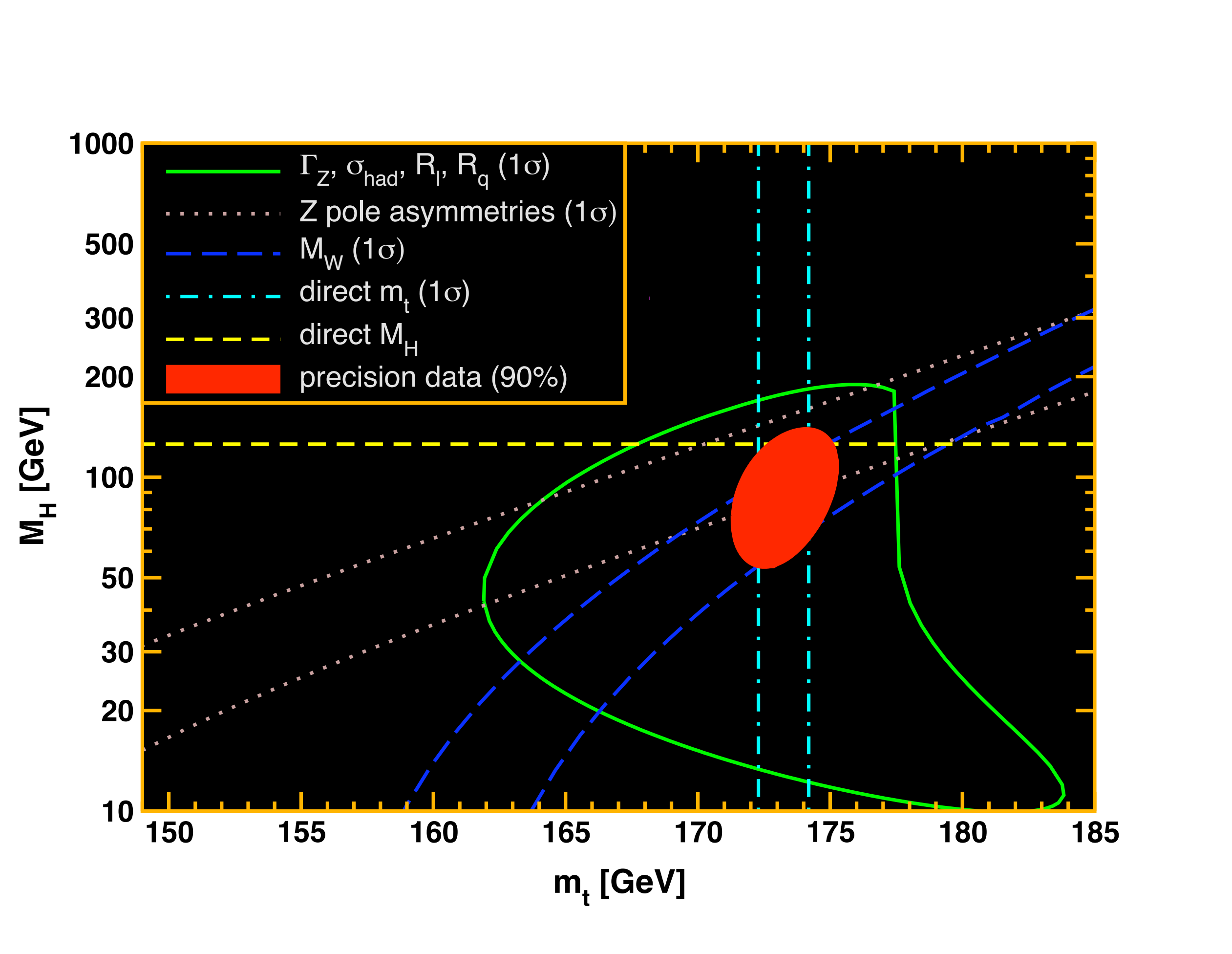
m_t from electroweak precision data

- global fit excluding m_t from hadron colliders:

  $m_t = 177.0 \pm 2.1$ GeV

  (1.5 σ high reflecting M_W measurement)

- fits were done before Tevatron/LHC average



$m_t = 173.34 \pm 0.76$ GeV

used our own average six months earlier (not identical data sets)

$m_t = 173.24 \pm 0.81$ GeV

JE, Freitas PDG 2014

Charm & Bottom Quark Masses

recent $\overline{m}_b(\overline{m}_b)$ determinations

$\overline{m}_b$ [MeV]	approach	observables	group	arXiv
4196 ± 23	lattice ($n_f = 4$)	$\Gamma(\Upsilon, \Upsilon' \to e^+e^-)$	*HPQCD*	*1408.5768*
4174 ± 24	lattice ($n_f = 4$)	PS current	*HPQCD*	*1408.4169*
4201 ± 43	N^3LO PQCD	M_Υ	*Ayala et al*	*1407.2128*
4169 ± 9	15th moment SR	Υ(1S-6S)	*Penin, Zerf*	*1401.7035*
4247 ± 34	Borel SR	f_B, f_{Bs}	*Lucha et al*	*1305.7099*
4166 ± 43	lattice + PQCD	M_Υ, M_{Bs}	*HPQCD*	*1302.3739*
4235 ± 55	10th moment SR	Υ(1S-4S), R	*Hoang et al*	*1209.0450*
4171 ± 9	optimized SR	Υ(1S-4S), R	*Bodenstein et al*	*1111.5742*
4177 ± 11	exponential SR	Υ(1S-6S)	*Narison*	*1105.5070*
4180^{+50}_{-40}	lattice + PQCD	static potential	*Laschka et al*	*1102.0945*
4163 ± 16	2nd moment SR	Υ(1S-4S), R	*Chetyrkin et al*	*1010.6157*

recent $\overline{m}_c(\overline{m}_c)$ determinations

$\overline{m}_c$ [MeV]	approach	observables	group	arXiv
1275.8 ± 5.8	lattice ($n_f = 4$)	PS current	*HPQCD*	*1408.4169*
1348 ± 46	lattice (2+1+1)	M_D, M_{Ds}	*ETM*	*1403.4504*
1274 ± 36	lattice ($n_f = 2$)	f_D, f_{Ds}	*ALPHA*	*1312.7693*
1240^{+50}_{-30}	PDF + HT fit	DIS	*Alekhin et al*	*1310.3059*
1260 ± 65	NLO fit	$c\bar{c}$ X-section	*H1 and ZEUS*	*1211.1182*
1262 ± 17	exponential SR	J/ψ, $\psi(2S\text{-}6S)$	*Narison*	*1105.5070*
1260 ± 36	lattice (2+1)	f_D, f_{Ds}	*PACS-CS*	*1104.4600*
1278 ± 9	optimized SR	J/ψ, ψ', R	*Bodenstein et al.*	*1102.3835*
1282 ± 24	1st moment SR	J/ψ, ψ', R	*Dehnadi et al*	*1102.2264*
1280^{+70}_{-60}	lattice + PQCD	static potential	*Laschka et al*	*1102.0945*
1279 ± 13	1st moment SR	J/ψ, ψ', R	*Chetyrkin et al*	*1010.6157*

Strong Coupling Constant

recent $\overline{\alpha}_s(M_Z)$ determinations

$\overline{\alpha}_s(M_Z)$	approach	observables	group	arXiv
0.11856(53)	lattice (n_f = 4)	PS current	*HPQCD*	*1408.4169*
0.1166(10)	lattice (2+1)	static potential	*Bazavov et al*	*1407.8437*
0.1165(39)	NLO fit	jet X-sections	*H1*	*1406.4709*
0.1192(27)	global fit	electroweak	*JE*	*1405.4781*
0.1196(11)	lattice (2+1+1)	ghost-gluon vertex	*ETM*	*1310.3763*
0.1132(11)	PDF + HT fit	DIS	*Alekhin et al*	*1310.3059*
0.1151(28)	NNPDF fit	$t\overline{t}$ X-section	*CMS*	*1307.1907*
0.1174(14)	RGOPT	f_π	*Kneur, Neveu*	*1305.6910*
0.1184(20)	BRGSPT	τ decays	*Abbas et al*	*1211.4316*
0.1131(25)	NNLO fit	e^+e^- thrust	*Gehrmann et al*	*1210.6945*
0.1140(15)	SCET	e^+e^- thrust	*Abbate et al*	*1204.5746*
0.1191(22)	FOPT	τ decays	*Boito et al*	*1203.3146*
0.1201(30)	NNLO fit	e^+e^- event shapes	*OPAL*	*1101.1470*

α_s from global electroweak fit

- determined by Γ_Z, σ_{had}, R_l, but other measurements, SM parameters, and new physics enter
- experimental correlations: small, known, included
- parametric uncertainties: non-Gaussian ($\sin^2\theta_W$), treated exactly in fits
- theory errors (PQCD) 100% correlated: $\Delta\alpha_s = \pm\ 9\times10^{-5}$ (dominated by $O(\alpha_s^4)$ axial-vector singlet piece)
- σ_{had} deviates from SM (1.7 σ) dragging down average
- allowing special new physics corrections to Zbb-vertex: $\alpha_s = 0.1167 \pm 0.0038$

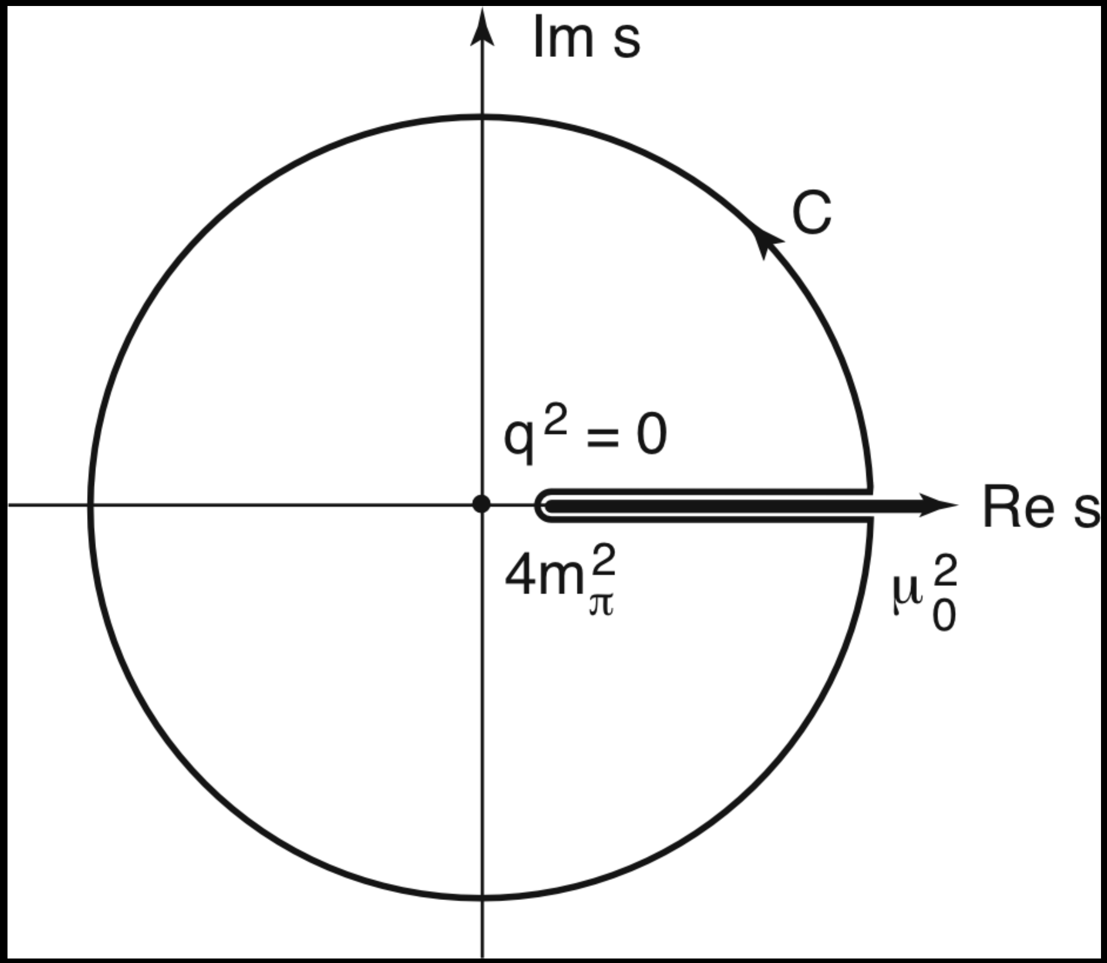
α_s from τ decays

- 4-loop PQCD coefficient
  Baikov, Chetyrkin, Kühn 2008

- FOPT vs. CIPT controversy
  Le Diberder, Pich 1992;
  Beneke, Jamin 2008

- CIPT: expansion coefficients identical to those in Adler-function

- fits to condensate terms
  Davier et al. 2008; Boito et al. 2012



- $\Gamma_{ud}^{theo} = G_F^2\, m_\tau^5\, |V_{ud}|^2 / 64\pi^3\, S(m_\tau, M_Z)\, (1 + 3/5\, m_\tau^2 / M_W^2)$
  $(1 + a + 5.202\, a^2 + 26.37\, a^3 + 127.1\, a^4 - 1.393\, \alpha/\pi + \delta_q)$

τ lifetime average

$\tau[B_e] = \hbar\, B_e^{expt} / \Gamma_e^{theo}$

B_e^{expt}: $0.1783 \pm 0.0004 \Rightarrow \tau[B_e^{expt}] = 291.15 \pm 0.65$ fs

B_μ^{expt}: $0.1741 \pm 0.0004 \Rightarrow \tau[B_\mu^{expt}] = 291.85 \pm 0.67$ fs

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$B_{e,\mu}^{expt}$ $(\rho_{e\mu} = 0.13)$ $\Rightarrow \tau[B_{e,\mu}^{expt}] = 291.49 \pm 0.50$ fs

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$\tau_{direct}^{expt} = 290.3 \pm 0.5$ fs (PDG incl. new Belle result)

$\tau^{expt} \equiv \tau[B_{e,\mu}^{expt}, \tau_{direct}^{expt}] = 290.90 \pm 0.35$ fs $\Rightarrow$

$R \equiv \Gamma_{ud} / \Gamma_e = 3.479 \pm 0.007 \Rightarrow \delta_{QCD} = 0.1977 \mp 0.0025 \Rightarrow$

$\alpha_s\, [\tau_\tau] = 0.1195^{+0.0022}_{-0.0020}$ (september 2014 using FOPT)

Summary

- m_t: new precise CMS (8 TeV) & D0 results in l+jets channel
  good agreement with respective previous results
  but > 2.7 σ conflict between them
- all (except for one) results consistent with
  $\overline{m}_b(\overline{m}_b)$ = 4175 ± 20 MeV (PDG: 4180 ± 30 MeV)
- all (except for one) results consistent with
  $\overline{m}_c(\overline{m}_c)$ = 1276 ± 6 MeV (PDG: 1275 ± 25 MeV)
- wide scatter of $\alpha_s(M_Z)$ but most values consistent with
  $\alpha_s(M_Z)$ = 0.1174 ± 0.0006 (PDG: 0.1185 ± 0.0006)
  (dragged down by PDF fits and thrust)

Backup

Update of heavy quark masses

charm mass

	$m_c(mc)$	λ_3	λ_3^{exp}	$\Delta\lambda_3$	Δres	Δth	$\Delta\lambda_1$	$\Delta\alpha_s(M_z)$	$\Delta cond$	final
old α_s^2	1.297	1.71	0.5	12	14	18	1	1	29	1.297(39)
new α_s^2	1.278	1.45	1.21(13)	2	5	15	1	1	2	1.278(16)
new α_s^3	1.277	1.24	1.24(13)	1	5	6	1	1	3	1.277(9)

$$m_c(m_c) = 1.277(9)\mathrm{GeV}$$

$m_c(m_c) = 1.279(13)\mathrm{GeV}$ [Kühn et al 2009]

preliminary *JE, P. Masjuan, H. Spiesberger*

bottom mass

	$m_b(mb)$	λ_3	λ_3^{exp}	$\Delta\lambda_3$	Δres	Δth	$\Delta\lambda_1$	$\Delta\alpha_s(M_z)$	$\Delta cond$	final
old α_s^2	4.207	1.91	0.5	12	4	23	0	1	2	4.207(26)
new α_s^2	4.198	1.85	1.2(1)	5	3	21	0	1	0	4.198(22)
new α_s^3	4.195	1.82	1.2(1)	5	3	5	0	1	0	4.195(8)

$$m_b(m_b) = 4.195(8)\mathrm{GeV}$$

$m_b(m_b) = 4.163(16)\mathrm{GeV}$ [Kühn et al 2009]

preliminary *JE, P. Masjuan, H. Spiesberger*