The program GAPP and α_s

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Outline

- GAPP
- α_s from Z decays
- α_s from τ decays
- α_s from the global EW fit
- M_H

GAPP features

- GAPP = Global Analysis of Particle Properties
- special purpose FORTRAN package to compute pseudo-observables and perform least-χ^2 fits
- SM parameters: $\overline{m}_t$, $\overline{m}_b$, $\overline{m}_c$, M_Z, M_H, $\alpha(m_\tau)$, α_s
- BSM parameters: STU, 4th family, Z′ physics, …
- full analytical expressions (expansions) when possible (not for non-enhanced 2-loop contributions to M_W and $\sin^2\theta_W$)
- $\overline{\text{MS}}$ scheme

GAPP observables

- Z pole: M_Z, Γ_Z, σ_{had}, R_l, R_q, A_{FB}, A_{LR}
- APV & lepton scattering: $\sin^2\theta_W$ ($\mu \ll M_Z$)
- low energy: $g_\mu-2$ and τ_τ (new physics)
- other: M_W, Γ_W, Higgs BRs, m_t^{pole}, sumrules for $\overline{m}_b$ & $\overline{m}_c$
- uncertainties: statistical, systematic, parametric and theoretical errors & correlations estimated and included

α_s from Z decays

- determined by Γ_Z, σ_{had}, R_l, but other measurements, SM parameters, and new physics enter indirectly
- experimental correlations: small, known, included
- parametric uncertainties: non-Gaussian ($\sin^2\theta_W$), treated exactly in fits
- theory errors (PQCD): 100% correlated (currently neglected), $\Delta_{theo}\alpha_s = \pm 0.00009$
- unknown unknowns?

α_s from Z decays: theory

- massless non-singlet QCD corrections known to $O(\alpha_s^4)$
  Baikov, Chetyrkin, Kühn 2008
- FOPT vs. CIPT: $\Delta\alpha_s = \pm 0.00005$ (opposite sign from τ_τ)
- $O(\alpha_s^4)$ vector singlet terms ***Baikov, Chetyrkin, Kühn 2010*** known up to singlet piece in *Crewther* relation $\Rightarrow \Delta\alpha_s \approx +10^{-5}$
- axial-vector singlet: $O(\alpha_s^2)$ ***Kniehl, Kühn 1990*** $\Delta\alpha_s = +0.0027$
  $O(\alpha_s^3)$ ***Larin, van Ritbergen, Vermaseren 1995*** $\Delta\alpha_s = +0.00043$
  $O(\alpha_s^4) \sim O(\alpha_s^3)^2/O(\alpha_s^2) \Rightarrow \Delta\alpha_s = \pm 0.00007$ (dominant)

α_s from Z decays: results

	α	$\Delta\alpha$
Γ	0.1188	±0.0076
LEP I	0.1213	±0.0028
LEP I + SLC	0.1198	±0.0028
Z pole +	0.1190	±0.0027
EW fit (excl.	0.1192	±0.0027
full EW fit	0.1192	±0.0016

α_s [Z pole]: new physics

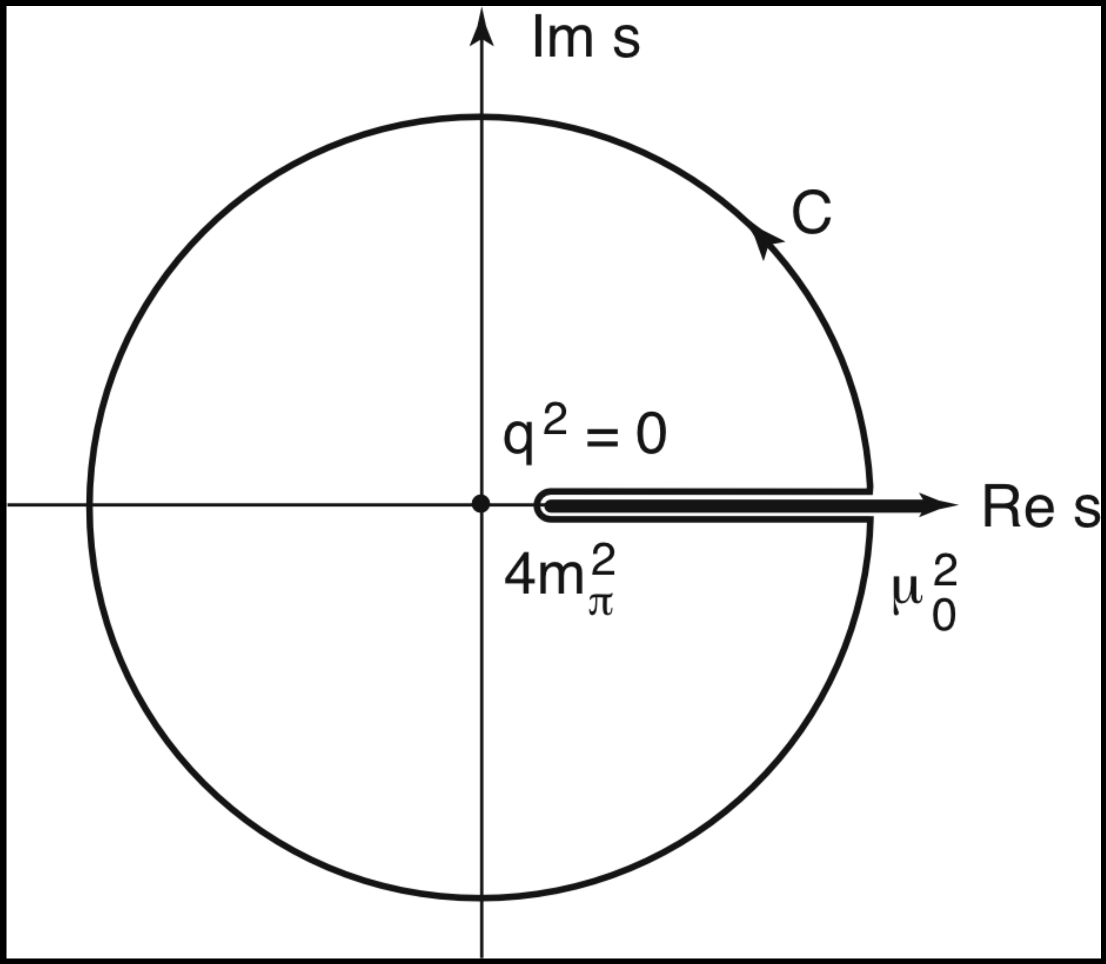
- expect Z pole value of α_s to be stronger affected by new physics than τ decay value
- Z pole (LEP 1 & SLC):
  $\alpha_s = 0.1198 \pm 0.0028$ ($\chi^2_{min} = 23.2/23$)
- allowing "oblique" (universal) parameters:
  $\alpha_s = 0.1199^{+0.0027}_{-0.0030}$ ($\chi^2_{min} = 23.0/20$)
- allowing special new physics corrections to Zbb-vertex:
  $\alpha_s = 0.1167 \pm 0.0038$ ($\chi^2_{min} = 16.3/21$)

α_s from τ decays

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

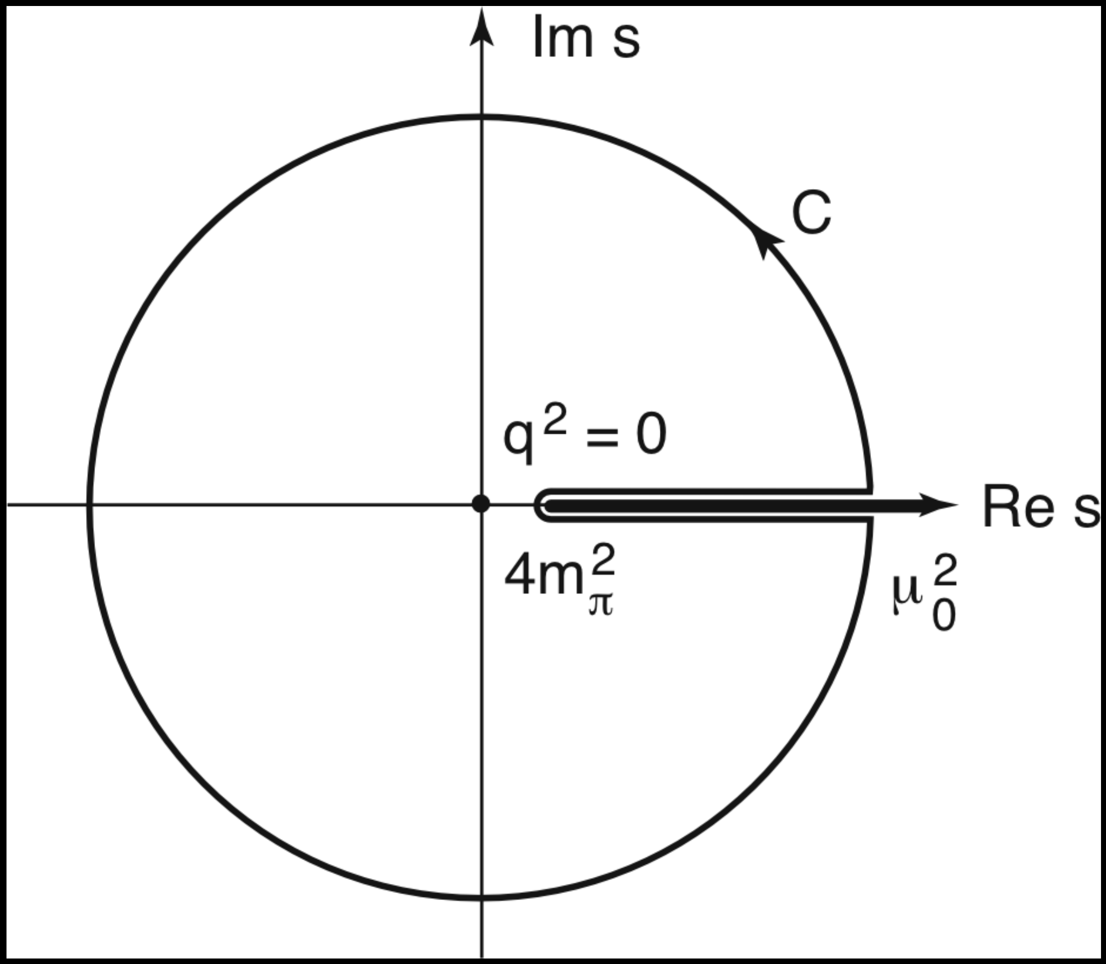
  $\Delta\alpha_s(M_Z) \sim [\alpha_s(M_Z)/\alpha_s(m_\tau)]^2 \, \Delta\alpha_s(m_\tau)$
- OPE can be applied and tested
- NNNLO ***Baikov, Chetyrkin, Kühn 2008***
- fully inclusive
- double zero near branch cut:

  $R_\tau = 6\pi i \oint ds/m_\tau^2 \, (1-s/m_\tau^2)^2 \, [(1 + 2\, s/m_\tau^2) \, \mathrm{Im}\Pi(s) + O(m_q^2/m_\tau^2)]$
- non-perturbative effects constrained from data



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



α_s from τ decays

- $\tau^{expt} = \hbar\,(1 - B_s^{expt}) / (\Gamma_e^{theo} + \Gamma_\mu^{theo} + \Gamma_{ud}^{theo})$ ***JE, Luo 2003***
- $\Gamma_{ud}^{theo} = G_F^2\, m_\tau^5\, |V_{ud}|^2 / 64\pi^3\, S(m_\tau, M_Z)\, (1 + 3/5\, m_\tau^2 / M_W^2)$
  $(1 + a + 5.202\, a^2 + 26.37\, a^3 + 127.1\, a^4 - 1.393\, \alpha / \pi + \delta_q)$
- $\Delta S=1$ decays: $B_s^{expt} = 0.0287 \pm 0.0007$ from data, since $\bar{m}_s(m_\tau)$ uncertain & QCD series $\propto \bar{m}_s^2$ poorly converging
- log enhanced EW: $S(m_\tau, M_Z) = 1.01907 \pm 0.0003$
  Marciano, Sirlin 1988; JE 2002
- δ_q: quark condensates ***Boito et al. 2012*** and finite m_c, m_b & m_s effects ***Chetyrkin 1993; Larin, van Ritbergen, Vermaseren 1995***

τ lifetime average

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

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

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

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

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τ_{direct}^{expt} = 290.6 ± 1.0 fs

$\tau^{expt} \equiv \tau[B_{e,\mu}^{expt}, \tau_{direct}^{expt}]$ = 291.31 ± 0.45 fs ⇒

$R \equiv \Gamma_{ud} / \Gamma_e$ = 3.471 ± 0.009 ⇒ δ_{QCD} = 0.1948 ± 0.0032

α_s [τ_τ]: experimental errors

source	uncertainty	$\Delta\tau$	$\Delta\alpha$
$\Delta\tau$	$\pm$ 0.45 fs	$\pm$ 0.45	$\mp$
Δ	$\pm$ 0.0007	$\mp$	$\mp$
Δ	$\pm$ 0.00015	$\mp$	$\mp$
Δ	$\pm$ 0.16 MeV	$\mp$	$\mp$
total		0.50	0.000 37

α_s [τ_τ]: theoretical errors

source	uncertainty	based on	$\Delta\alpha$
PQCD	$\mp$	α	$^{+0.00180}_{-0.00145}$
RGE	β	GAPP	0.0004
δ	0.012	*Boito et al. 2012*	0.0013
~~OPE~~	0.0008	*'t Hooft 1976, Davier et al. 2005*	0.00012
S(m	0.0003	*JE 2002*	0.00004
total			$^{+0.0022}_{-0.0020}$

Padé

- many Padé approximants, summations, or predictions (for the next term) can be defined. For illustration only:
- Padé [1/1]* $\equiv 1 + (a + 0.133\,a^2)/(1 - 5.069\,a) - 6.6\,a^4$

  higher order coefficients positive
- Padé [2/2] $\equiv (1 - 13.6\,a + 40\,a^2)/(1 - 14.6\,a + 49.5\,a^2)$

  $\Rightarrow \alpha_s(M_Z) = 0.11725$

  fails!

α_s [τ_τ]: summation schemes

	FOPT	CIPT	Padé [1/1]*
α	0.1192	0.1215	0.1177
Δδ	∓	∓	∓
Δ	+0.00180 −0.001	+0.00133 −0.00119	±0.00007
Δ	±0.0004	±0.0006	±0.0004

α_s from the global EW fit

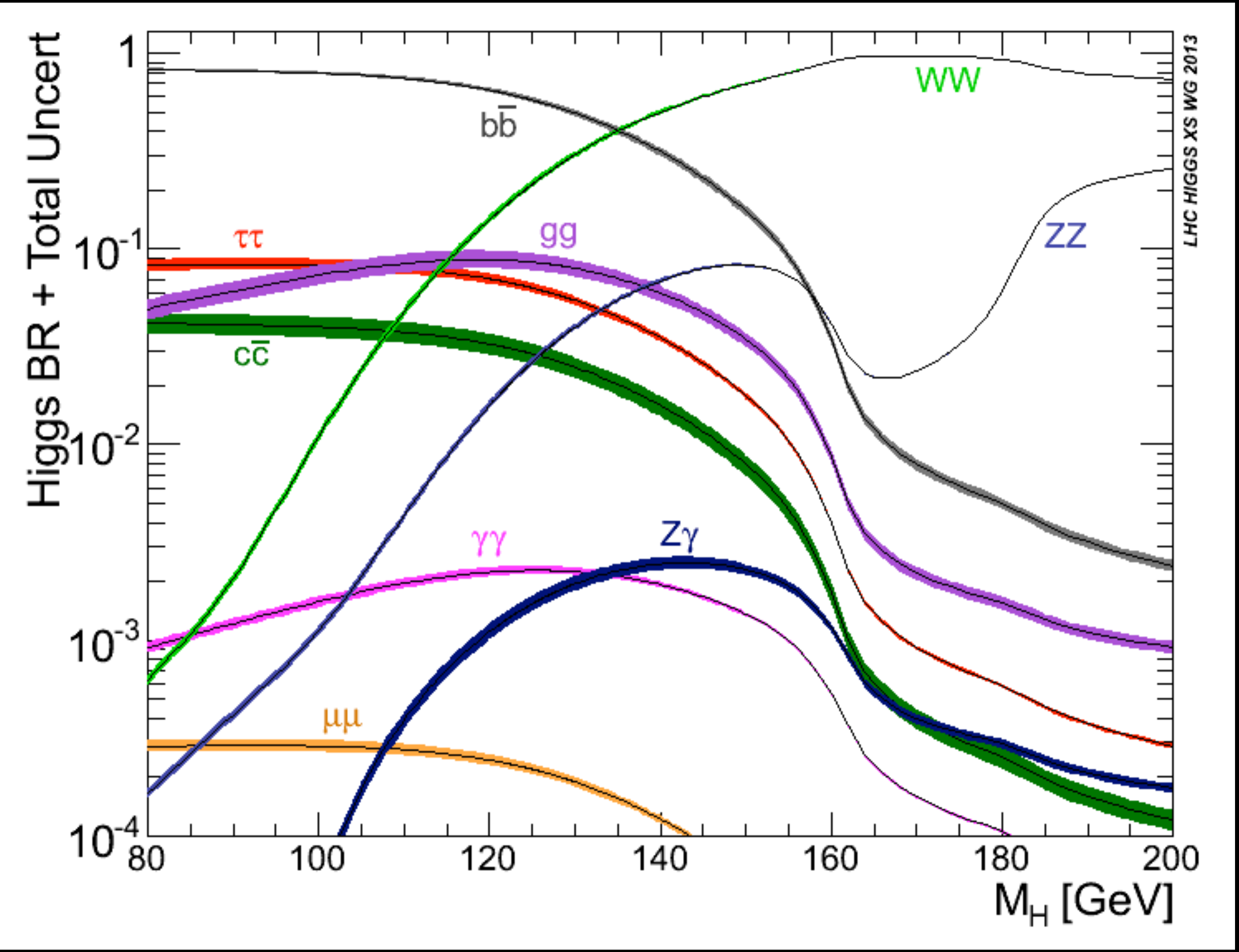
Z decays:	$\alpha_s = 0.1198 \pm 0.0028$
τ decays:	$\alpha_s = 0.1192^{+0.0022}_{-0.0020}$
Z & τ decays:	$\alpha_s = 0.1194 \pm 0.0017$
global fit:	$\alpha_s = 0.1192 \pm 0.0016$

M_H [GeV]

source	M	uncertainty
radiative corrections	89	+22
LHC	123.7	2.3
ATLAS	125.5	0.6
CMS	125.7	0.4
global fit	125.5	0.4

JE, Ayres 2013
PDG 2014

M_H from Higgs branching ratios?



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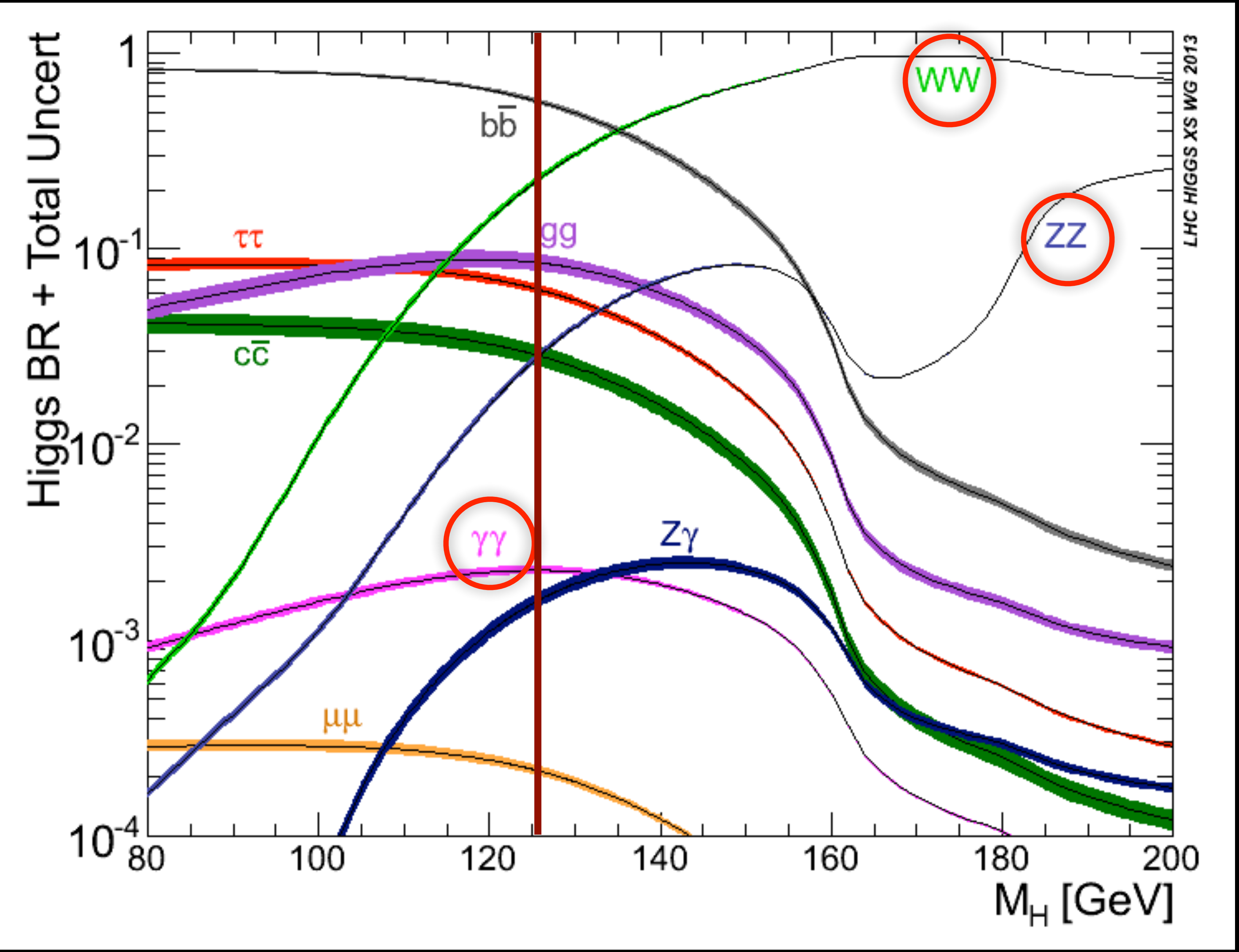

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Summary

- global EW fit: $\alpha_s = 0.1192 \pm 0.0016$
- new physics: negligible (significant) sensitivity of Z-pole value to (non-)universal corrections
- α_s [τ_τ]: theory uncertainty itself α_s dependent ⇒

  asymmetric error (re-calculated in each call in the fits)

  FOPT vs CIPT vs Padé (geometric progression)

  power corrections need improvement