Top at LHC

top constraints from LEP
single top and ttbar+X production

Dipartimento di Fisica

Sapienza
Università di Roma

Shahram Rahatlou

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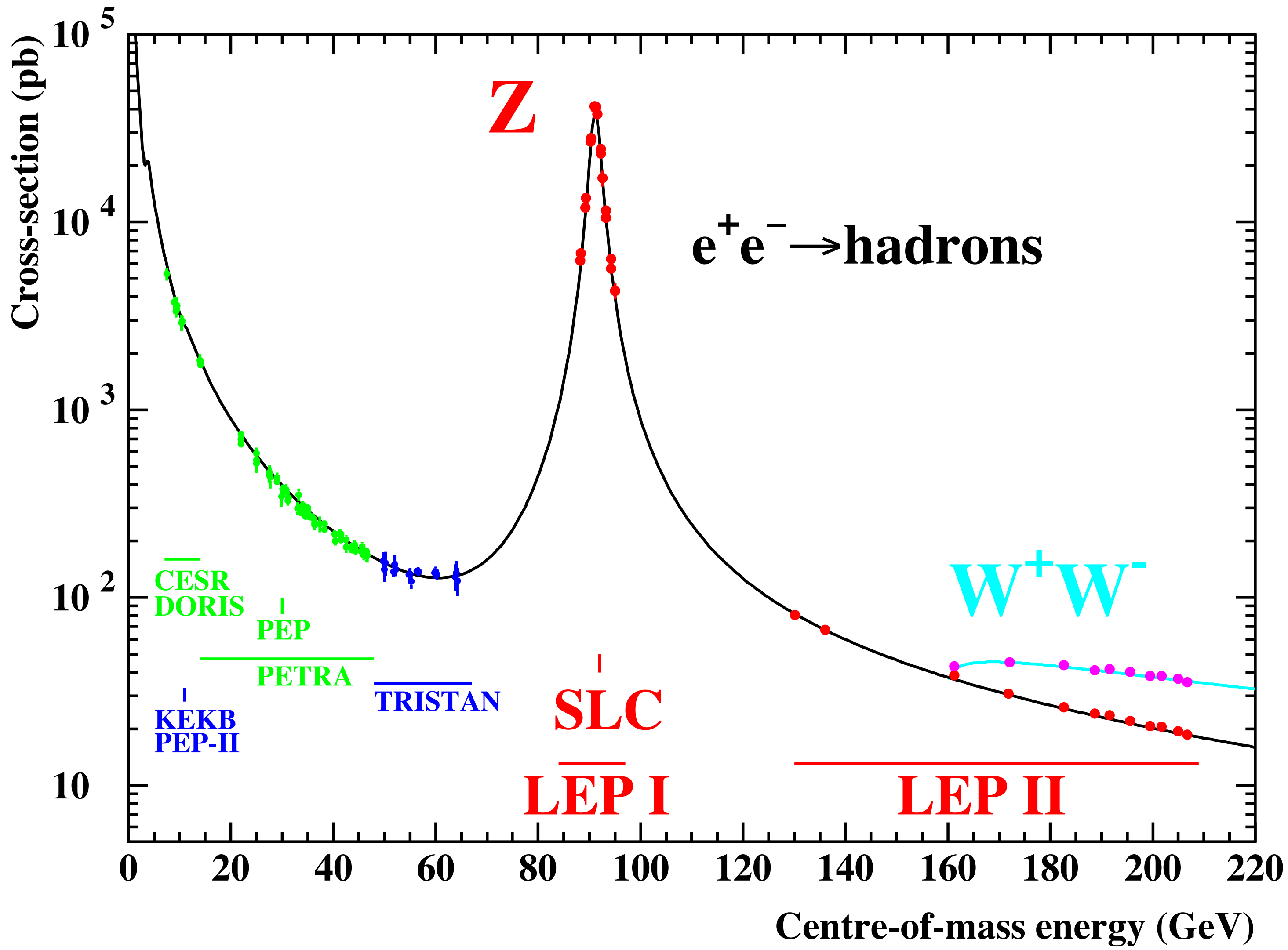
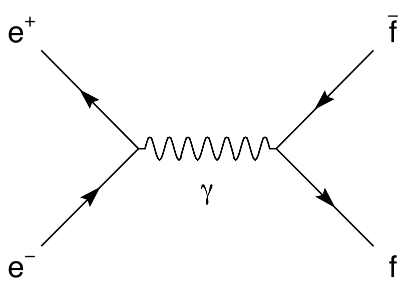
http://www.roma1.infn.it/people/rahatlou/particelle/

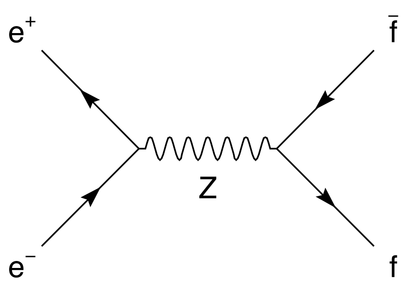
Top @ LEP

Z Resonance



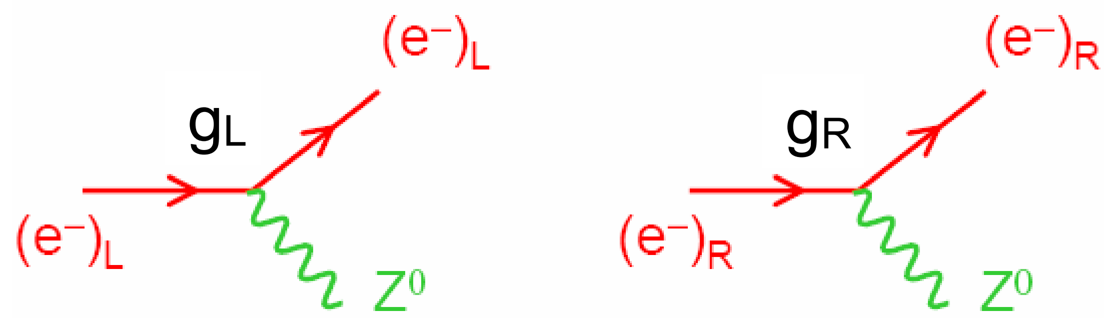
Cross section near the Z pole is commonly referred to as the Z lineshape





- LEP and SLC are Z factories providing copious sample of Z bosons in 1990s
- Dedicated detectors covering almost full solid angle to study Z decays
- Bhabha scattering cross section known very precisely allows very precise measurement of luminosity needed for normalization

NEUTRAL CURRENT IN SM



SM current: $$J_\mu^{NC} = j_\mu^3 - \sin^2\theta_W j_\mu^{em} = \bar{u}_f \gamma_\mu [\frac{1}{2}(1-\gamma^5)T_3^f - Q_f \sin^2\theta_W] u_f$$

phenomenological current: $$J_\mu^{NC} = \bar{u}_f \gamma_\mu \frac{1}{2}(g_V - g_A \gamma^5) u_f$$

$$\begin{aligned} g_{\mathrm{V}}^{\mathrm{tree}} &\equiv g_{\mathrm{L}}^{\mathrm{tree}} + g_{\mathrm{R}}^{\mathrm{tree}} = \sqrt{\rho_0}\,(T_3^{\mathrm{f}} - 2Q_{\mathrm{f}} \sin^2\theta_{\mathrm{W}}^{\mathrm{tree}}) \\ g_{\mathrm{A}}^{\mathrm{tree}} &\equiv g_{\mathrm{L}}^{\mathrm{tree}} - g_{\mathrm{R}}^{\mathrm{tree}} = \sqrt{\rho_0}\, T_3^{\mathrm{f}}\,. \end{aligned} \qquad \begin{aligned} g_{\mathrm{L}}^{\mathrm{tree}} &= \sqrt{\rho_0}\,(T_3^{\mathrm{f}} - Q_{\mathrm{f}} \sin^2\theta_{\mathrm{W}}^{\mathrm{tree}}) \\ g_{\mathrm{R}}^{\mathrm{tree}} &= -\sqrt{\rho_0}\, Q_{\mathrm{f}} \sin^2\theta_{\mathrm{W}}^{\mathrm{tree}}\,, \end{aligned}$$

- In SM with simple Higgs doublet
  - ρ =1 in minimal SM

$$\rho_0 = \frac{m_{\mathrm{W}}^2}{m_{\mathrm{Z}}^2 \cos^2\theta_{\mathrm{W}}^{\mathrm{tree}}}$$

ratio between charged and neutral currents determined by W and Z mass

- SM is renormalizable, such relation holds at all orders (on-shell scheme)
  - One needs to incorporate appropriate corrections for each order

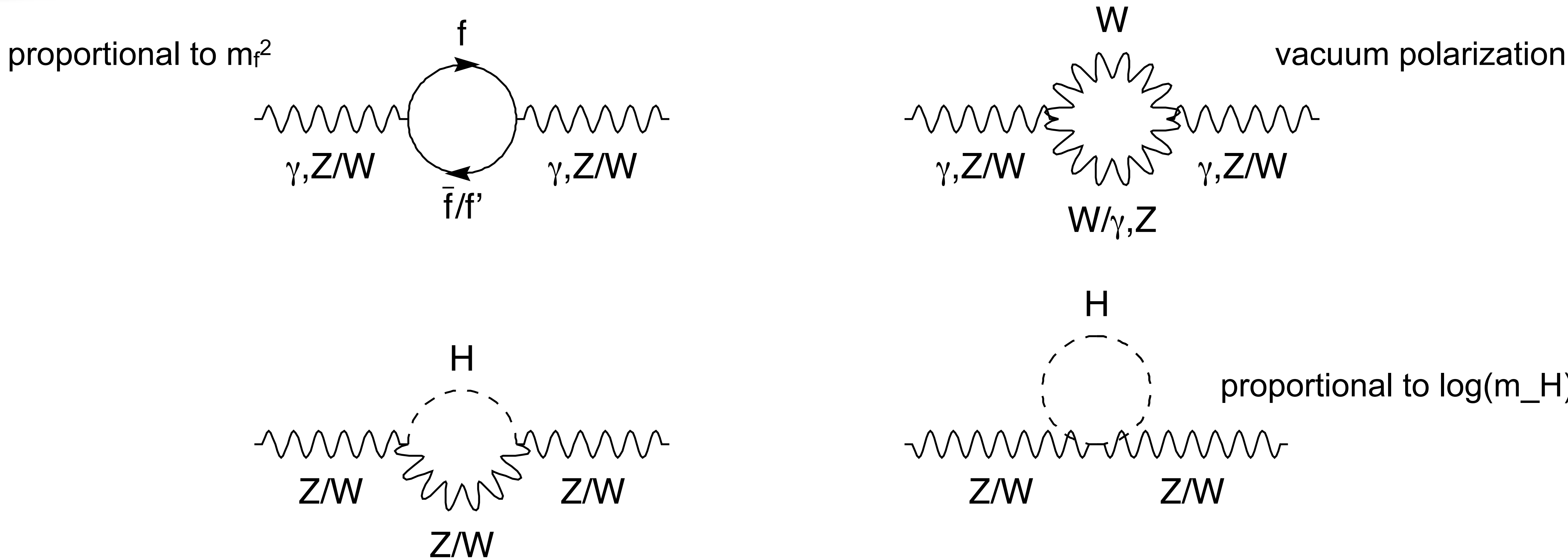
$$\begin{aligned} \sin^2\theta_{\mathrm{eff}}^{\mathrm{f}} &\equiv \kappa_{\mathrm{f}} \sin^2\theta_{\mathrm{W}} \\ g_{\mathrm{Vf}} &\equiv \sqrt{\rho_{\mathrm{f}}}\,(T_3^{\mathrm{f}} - 2Q_{\mathrm{f}} \sin^2\theta_{\mathrm{eff}}^{\mathrm{f}}) \\ g_{\mathrm{Af}} &\equiv \sqrt{\rho_{\mathrm{f}}}\, T_3^{\mathrm{f}}\,, \end{aligned}$$

$$\begin{aligned} \rho_{\mathrm{f}} &\equiv \Re(\mathcal{R}_{\mathrm{f}}) = 1 + \boxed{\Delta\rho_{\mathrm{se}}} + \boxed{\Delta\rho_{\mathrm{f}}} \\ \kappa_{\mathrm{f}} &\equiv \Re(\mathcal{K}_{\mathrm{f}}) = 1 + \boxed{\Delta\kappa_{\mathrm{se}}} + \boxed{\Delta\kappa_{\mathrm{f}}} \end{aligned}$$

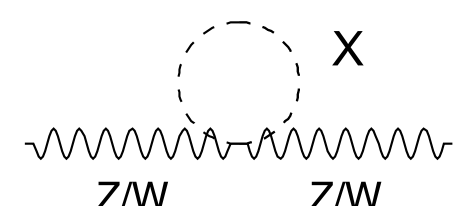
flavor specific

self-energy

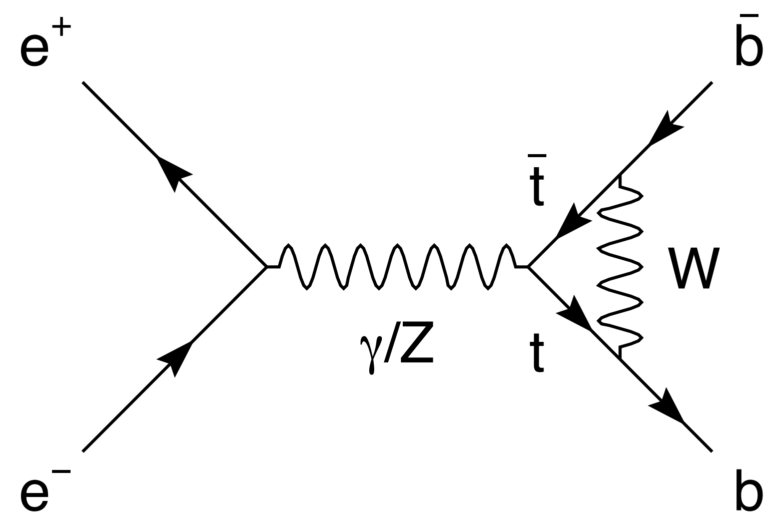
SELF-ENERGY CORRECTIONS

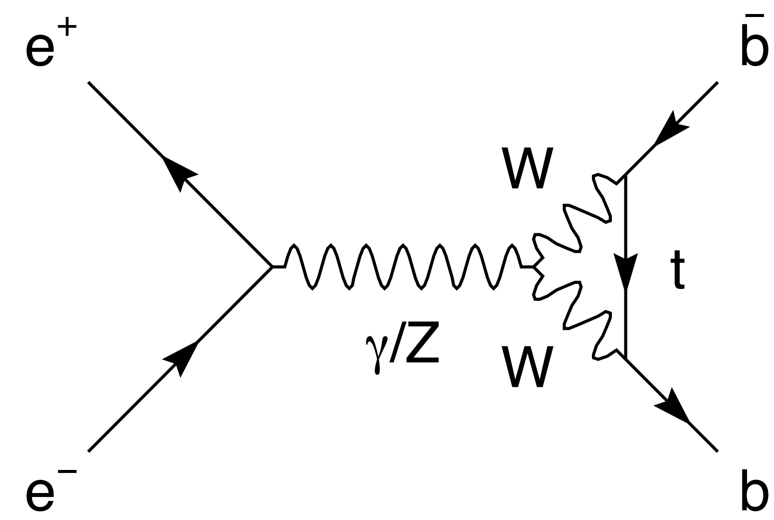


- precise measurement of 1-loop corrections to boson propagators
- Sensitive to new physics contribution
  - A new X particle could provide additional diagram
  - interference with SM diagrams could result in very different observed rate
  - Constraints on top and Higgs mass before either was discovered



FLAVOR-DEPENDENT VERTEX CORRECTIONS





- Same diagrams exist for all fermions (quarks + leptons)
- Magnitude very much dependent on specific fermion (flavor dependence)
  - Very small corrections for leptons
  - CKM elements V_{ij} large only for diagonal elements
  - contributions from light quarks suppressed due to their mass
  - $|V_{tb}| \sim 1$ makes the b diagrams the most significant contribution

SUMMARY OF CORRECTIONS

$$\rho_{\mathrm{f}} \equiv \Re(\mathcal{R}_{\mathrm{f}}) = 1 + \boxed{\Delta\rho_{\mathrm{se}}} + \boxed{\Delta\rho_{\mathrm{f}}}$$
$$\kappa_{\mathrm{f}} \equiv \Re(\mathcal{K}_{\mathrm{f}}) = 1 + \boxed{\Delta\kappa_{\mathrm{se}}} + \boxed{\Delta\kappa_{\mathrm{f}}}$$

flavor specific

self-energy

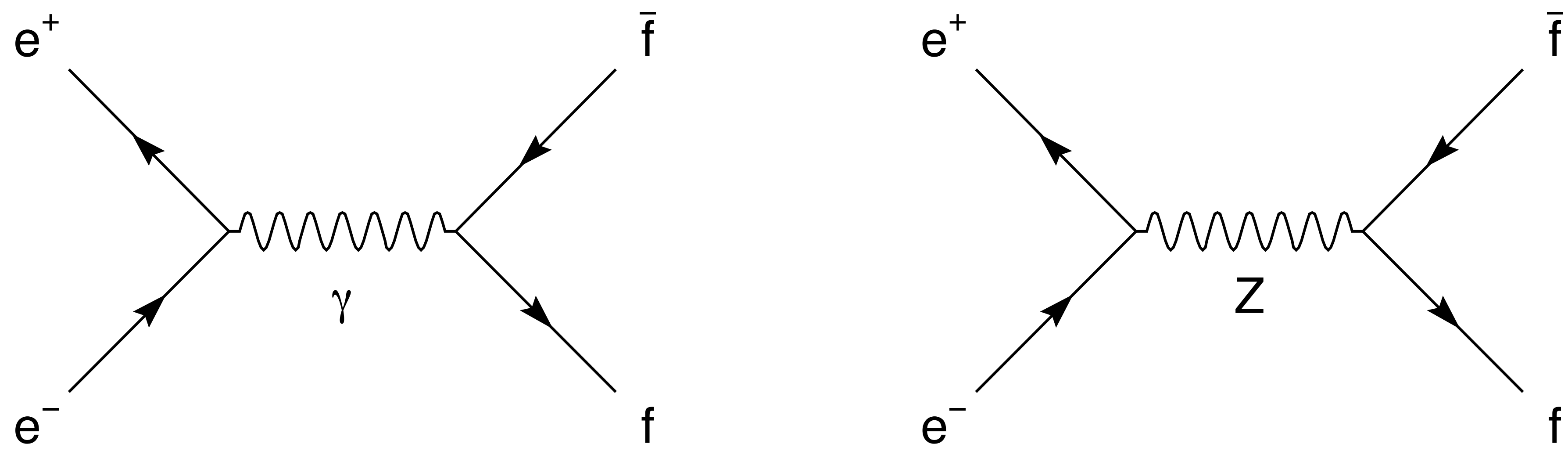
- Self-energy corrections for $m_H >> m_W$:
  - quadratic dependence on top mass
  - only logarithmic dependence on Higgs mass

$$\Delta\rho_{\mathrm{se}} = \frac{3G_{\mathrm{F}}m_{\mathrm{W}}^2}{8\sqrt{2}\pi^2}\left[\frac{m_{\mathrm{t}}^2}{m_{\mathrm{W}}^2} - \frac{\sin^2\theta_{\mathrm{W}}}{\cos^2\theta_{\mathrm{W}}}\left(\ln\frac{m_{\mathrm{H}}^2}{m_{\mathrm{W}}^2} - \frac{5}{6}\right) + \cdots\right]$$
$$\Delta\kappa_{\mathrm{se}} = \frac{3G_{\mathrm{F}}m_{\mathrm{W}}^2}{8\sqrt{2}\pi^2}\left[\frac{m_{\mathrm{t}}^2}{m_{\mathrm{W}}^2}\frac{\cos^2\theta_{\mathrm{W}}}{\sin^2\theta_{\mathrm{W}}} - \frac{10}{9}\left(\ln\frac{m_{\mathrm{H}}^2}{m_{\mathrm{W}}^2} - \frac{5}{6}\right) + \cdots\right]$$

- Vertex corrections: dominant contribution from b quark
- Exact calculation of such corrections provided strong limits on top mass
- Remember: top was yet to be discovered!

$$\Delta\kappa_{\mathrm{b}} = \frac{G_{\mathrm{F}}m_{\mathrm{t}}^2}{4\sqrt{2}\pi^2}$$
$$\Delta\rho_{\mathrm{b}} = -2\Delta\kappa_{\mathrm{b}}$$

TREE-LEVEL (BORN) DIAGRAMS

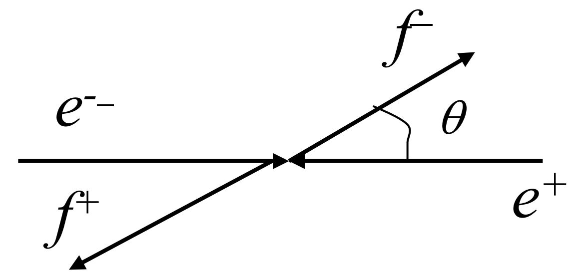


$$|\mathcal{M}|^2 = |\mathcal{M}_\gamma + \mathcal{M}_Z|^2 = |\mathcal{M}_\gamma|^2 + |\mathcal{M}_Z|^2 + 2\,\mathrm{Re}\,\mathcal{M}_Z\mathcal{M}_\gamma$$

- Two contributions to the cross section at leading order
  - Z and gamma intermediate states
  - interference between them very important and visible experimentally
  - Cross section depends on coupling constants of each fermion to Z boson
- Experimental observables

EW Cross Section near Z Pole

- Several experimental observables closely related to SM predictions
- cross section vs. energy
  - confirm interference of 2 diagrams
  - Absence of additional intermediate vector bosons
- Z mass position
  - fixed if m_W and θ_W known
- Z total and partial width
  - # of generations
- Charge asymmetry (parity violation) to test V-A structure



$$
\begin{aligned}
\mathcal{G}_{\mathrm{Vf}} &= \sqrt{\mathcal{R}_{\mathrm{f}}}\,(T_3^{\mathrm{f}} - 2Q_{\mathrm{f}}\mathcal{K}_{\mathrm{f}}\sin^2\theta_{\mathrm{W}}) \\
\mathcal{G}_{\mathrm{Af}} &= \sqrt{\mathcal{R}_{\mathrm{f}}}\,T_3^{\mathrm{f}}\,.
\end{aligned}
$$

$$
\frac{2s}{\pi}\frac{1}{N_c^{\mathrm{f}}}\frac{d\sigma_{\mathrm{ew}}}{d\cos\theta}(\mathrm{e^+e^-} \to \mathrm{f\bar{f}}) =
$$

$$
\underbrace{|\alpha(s)Q_{\mathrm{f}}|^2\,(1+\cos^2\theta)}_{\sigma^\gamma}
$$

$$
\underbrace{-8\Re\left\{\alpha^*(s)Q_{\mathrm{f}}\chi(s)\left[\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Vf}}(1+\cos^2\theta) + 2\mathcal{G}_{\mathrm{Ae}}\mathcal{G}_{\mathrm{Af}}\cos\theta\right]\right\}}_{\gamma\text{–Z interference}}
$$

$$
\underbrace{\begin{gathered}+16|\chi(s)|^2\left[(|\mathcal{G}_{\mathrm{Ve}}|^2 + |\mathcal{G}_{\mathrm{Ae}}|^2)(|\mathcal{G}_{\mathrm{Vf}}|^2 + |\mathcal{G}_{\mathrm{Af}}|^2)(1+\cos^2\theta)\right. \\ \left. +8\Re\left\{\mathcal{G}_{\mathrm{Ve}}\mathcal{G}_{\mathrm{Ae}}{}^*\right\}\Re\left\{\mathcal{G}_{\mathrm{Vf}}\mathcal{G}_{\mathrm{Af}}{}^*\right\}\cos\theta\right]\end{gathered}}_{\sigma^{\mathrm{Z}}}
$$

N_c = 1 for f = leptons
N_c = 3 for f = quarks

$$
\chi(s) = \frac{G_{\mathrm{F}} m_{\mathrm{Z}}^2}{8\pi\sqrt{2}}\frac{s}{s - m_{\mathrm{Z}}^2 + is\Gamma_{\mathrm{Z}}/m_{\mathrm{Z}}}
$$

Z Total Cross Section

- Integrating over θ total cross section

$$\sigma^{Z}_{f\bar{f}} = \sigma^{peak}_{f\bar{f}} \frac{\boxed{s\Gamma^2_Z}}{(s-m^2_Z)^2 + s^2\Gamma^2_Z\boxed{/m^2_Z}} \qquad \sigma^{peak}_{f\bar{f}} = \frac{1}{R_{QED}}\sigma^0_{f\bar{f}} \qquad \sigma^0_{f\bar{f}} = \frac{12\pi}{m^2_Z}\frac{\Gamma_{ee}\Gamma_{f\bar{f}}}{\Gamma^2_Z}$$

- Total width

$$\Gamma_Z = \Gamma_{ee} + \Gamma_{\mu\mu} + \Gamma_{\tau\tau} + \Gamma_{had} + \Gamma_{inv}$$

$$\Gamma_{inv} = N_\nu \Gamma_{\nu\bar{\nu}} \qquad \Gamma_{had} = \sum_{q\neq t}\Gamma_{q\bar{q}}$$

- Measurement of partial widths needed to prove universality of fermion coupling
- Simultaneous fit to data could determine partial widths + peak position + total width at once, BUT
  - partial widths highly correlated due to constraint on total sum
- Convenient to define different set of parameters to reduce correlation
  - ratio of similar quantities typically have reduced correlation since common factors could cancel out

$$\boxed{\sigma^0_{had}} \equiv \frac{12\pi}{m^2_Z}\frac{\Gamma_{ee}\Gamma_{had}}{\Gamma^2_Z} \qquad \boxed{R^0_e} \equiv \Gamma_{had}/\Gamma_{ee}, \ \boxed{R^0_\mu} \equiv \Gamma_{had}/\Gamma_{\mu\mu} \ \text{ and } \ \boxed{R^0_\tau} \equiv \Gamma_{had}/\Gamma_{\tau\tau}$$

SM Input to Z-Pole Measurements

- Precision measurements at LEP rely on parameters not known a-priori
  - coupling constants for weak, electromagnetic, and strong interaction
  - fermion masses
  - vector boson masses
    - Correlation between photon, W and Z mass
  - Higgs mass

$$\frac{G_F}{(\hbar c)^3} = \frac{\sqrt{2}}{8}\frac{g^2}{m_W^2} = 1.16637(1) \times 10^{-5}\text{GeV}^{-2}\,.$$

- Some parameters are well known, others can be constrained from precision measurements
  - Light fermion masses well known. Small and well calculated corrections at Z pole
  - Photon mass fixed to be zero from QED
  - Z mass: can be measured precisely at Z pole

From measurement of muon lifetime
Calculation at 2-loop level

$$\frac{G_F}{\hbar c} = \frac{\sqrt{2}}{8}\frac{g^2}{m_W^2} = 1.16637(1)\cdot 10^{-5}\,\text{GeV}^{-2}$$

- W mass: correlated to Z mass and Fermi Constant G_F
  - G_F known with very high precision far beyond reach for m_W measurements
    - Assume G_F to be fixed and treat m_W as function of m_Z to be constrained with data

$$m_W^2 = \frac{m_Z^2}{2}\left(1+\sqrt{1-4\frac{\pi\alpha}{\sqrt{2}G_F m_Z^2}\frac{1}{1-\Delta r}}\right)$$

Running of α

SM Parameters to be Extracted from Measurements

- QED coupling constant $\alpha(m_Z^2)$
  - more precisely the hadronic corrections to it $\alpha(m_Z^2) \rightarrow \Delta\alpha_{had}(m_Z^2)$
- QCD coupling constant $\alpha_S(m_Z^2)$
  - most precise measurement if EW sector well understood
- Z mass m_Z
- And more importantly two parameters not directly accessible at LEP
  - Higgs mass m_H
  - Top mass m_t

Source	δ	Γ_Z [MeV]	σ^0_{had} [nb]	R^0_ℓ	R^0_b	ρ_ℓ	$\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}}$	m_W [MeV]
$\Delta\alpha^{(5)}_{\mathrm{had}}(m_Z^2)$	0.00035	0.3	0.001	0.002	0.00001	—	0.00012	6
$\alpha_S(m_Z^2)$	0.003	1.6	0.015	0.020	—	—	0.00001	2
m_Z	2.1 MeV	0.2	0.002	—	—	—	0.00002	3
m_t	4.3 GeV	1.0	0.003	0.002	0.00016	0.0004	0.00014	26
$\log_{10}(m_H/\mathrm{GeV})$	0.2	1.3	0.001	0.004	0.00002	0.0003	0.00022	28
Theory		0.1	0.001	0.001	0.00002	—	0.00005	4
Experiment		2.3	0.037	0.025	0.00065	0.0010	0.00016	34

Choosing Best Pseudo-Observables

- Each experimental measurement has different sensitivity to SM parameters we want to constrain. Choose those with
  - highest sensitivity to m_t and m_H (through radiative corrections)
  - small dependency on QCD corrections
- Parameters most sensitive to radiative corrections will be most powerful

$$\rho_0 = \frac{m_W^2}{m_Z^2 \cos^2\theta_W^{\text{tree}}}$$

$$\begin{aligned} \rho_f &\equiv \Re(\mathcal{R}_f) = 1 + \underbrace{\boxed{\Delta\rho_{se}}}_{\text{self-energy}} + \underbrace{\boxed{\Delta\rho_f}}_{\text{flavor specific}} \\ \kappa_f &\equiv \Re(\mathcal{K}_f) = 1 + \boxed{\Delta\kappa_{se}} + \boxed{\Delta\kappa_f} \end{aligned}$$

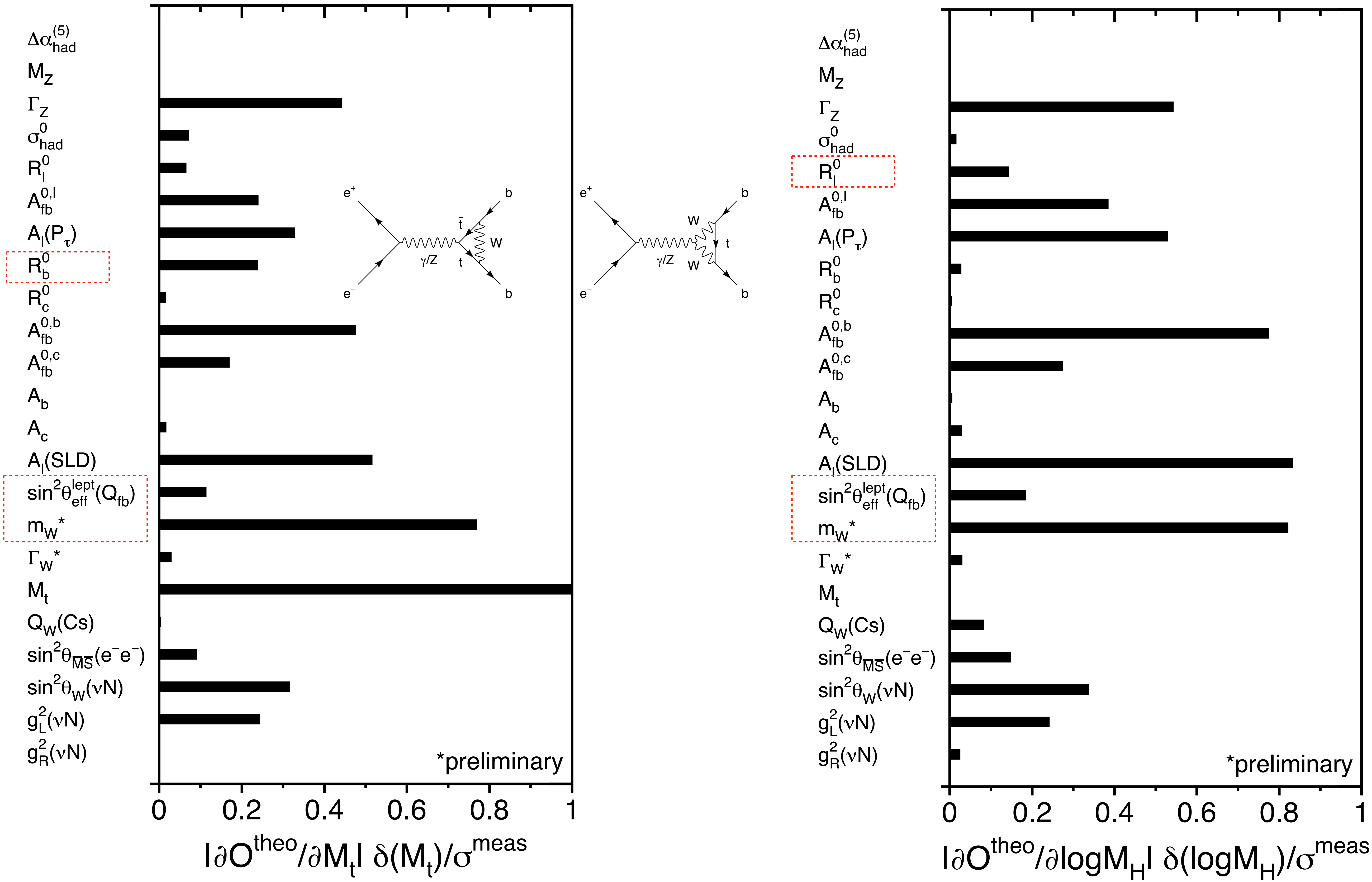
flavor specific

self-energy

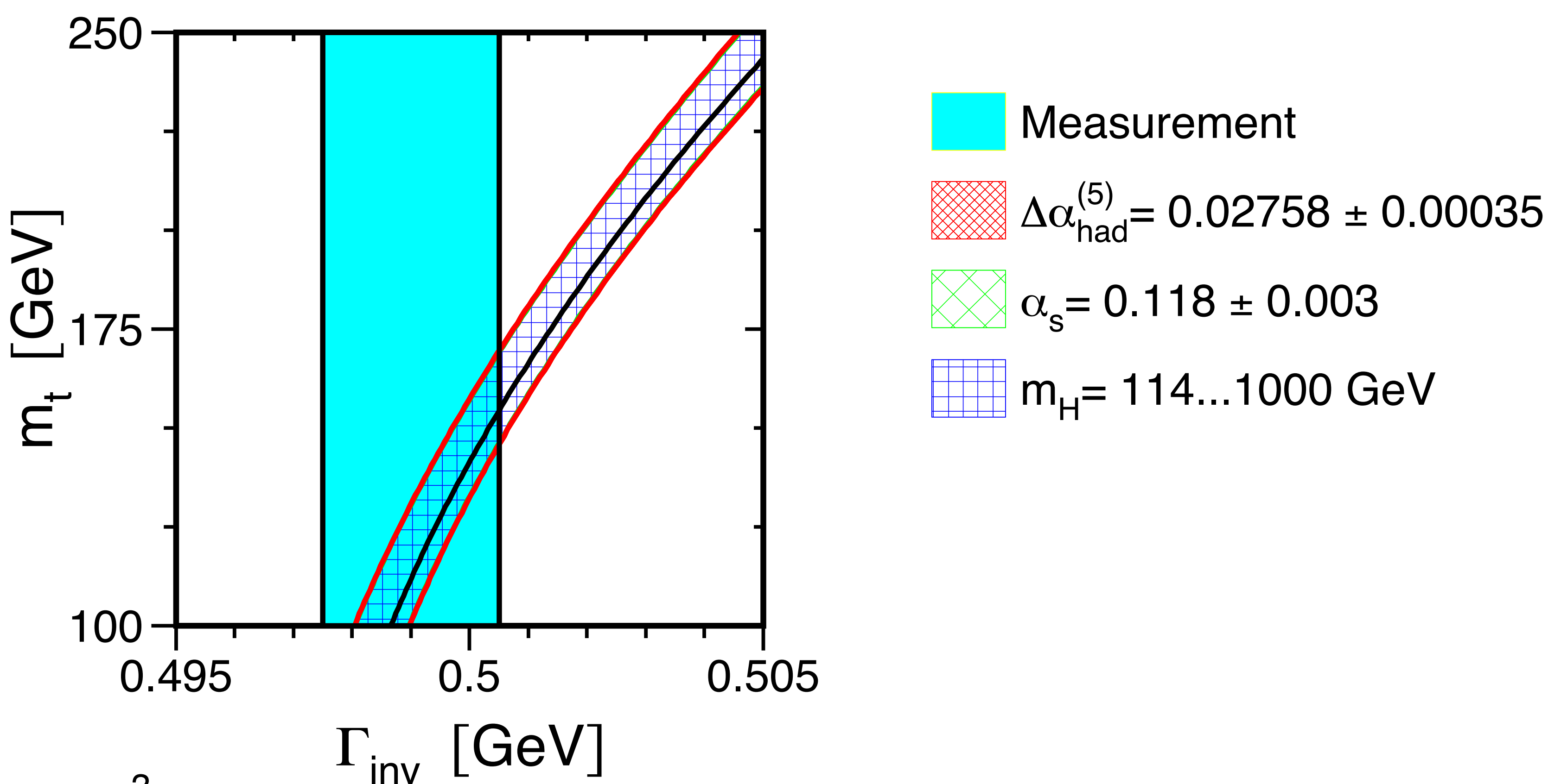
$$\begin{aligned} \sin^2\theta_{\text{eff}}^f &\equiv \kappa_f \sin^2\theta_W \\ g_{Vf} &\equiv \sqrt{\rho_f}\,(T_3^f - 2Q_f \sin^2\theta_{\text{eff}}^f) \\ g_{Af} &\equiv \sqrt{\rho_f}\,T_3^f\,, \end{aligned}$$

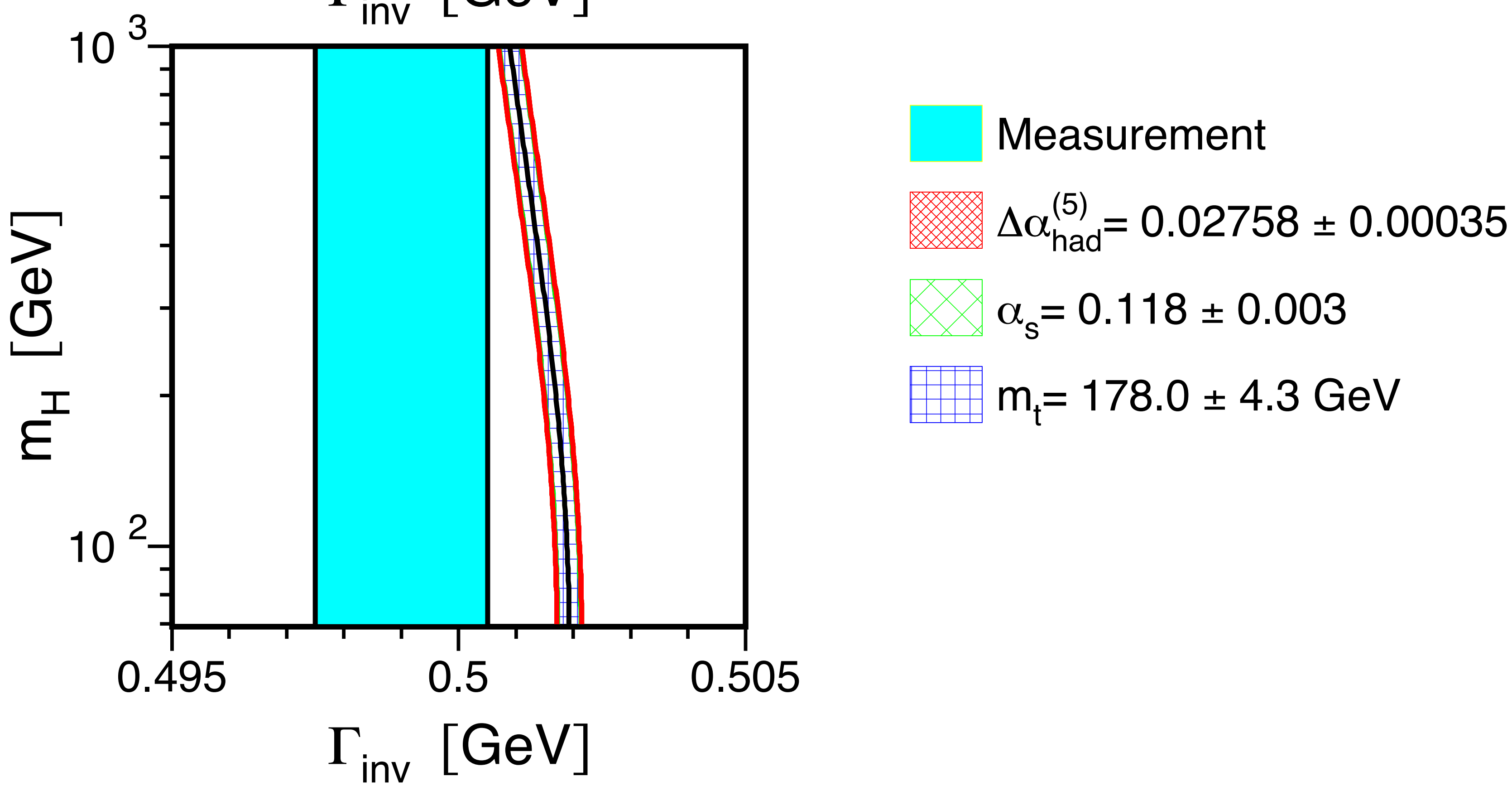
$$\begin{aligned} \Delta\rho_{se} &= \frac{3G_F m_W^2}{8\sqrt{2}\pi^2}\left[\frac{m_t^2}{m_W^2} - \frac{\sin^2\theta_W}{\cos^2\theta_W}\left(\ln\frac{m_H^2}{m_W^2} - \frac{5}{6}\right) + \cdots\right] \\ \Delta\kappa_{se} &= \frac{3G_F m_W^2}{8\sqrt{2}\pi^2}\left[\frac{m_t^2}{m_W^2}\frac{\cos^2\theta_W}{\sin^2\theta_W} - \frac{10}{9}\left(\ln\frac{m_H^2}{m_W^2} - \frac{5}{6}\right) + \cdots\right] \end{aligned}$$

SENSITIVITY TO M_t AND M_H

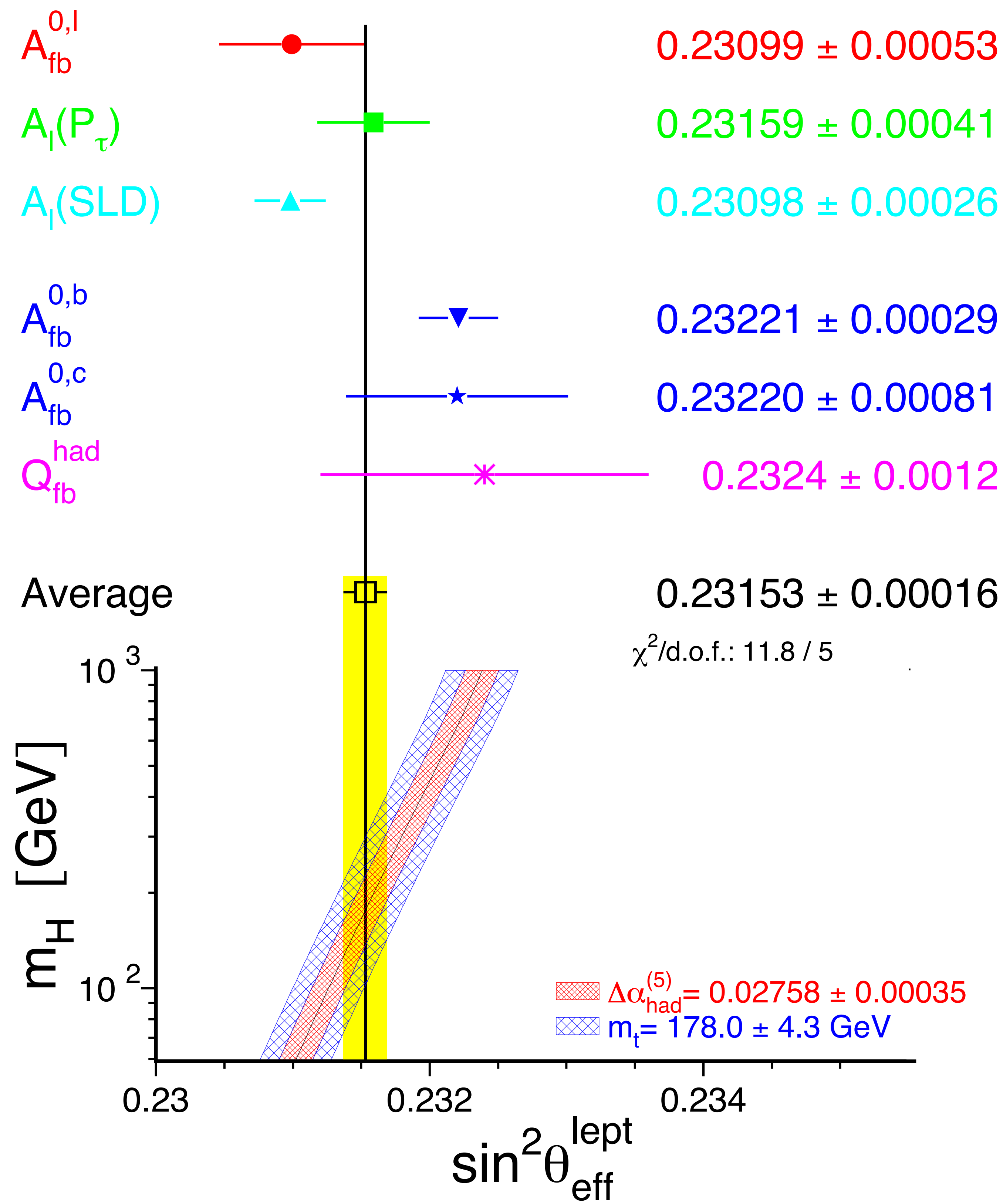


Γ_{INV} DEPENDENCY ON M_t AND M_H



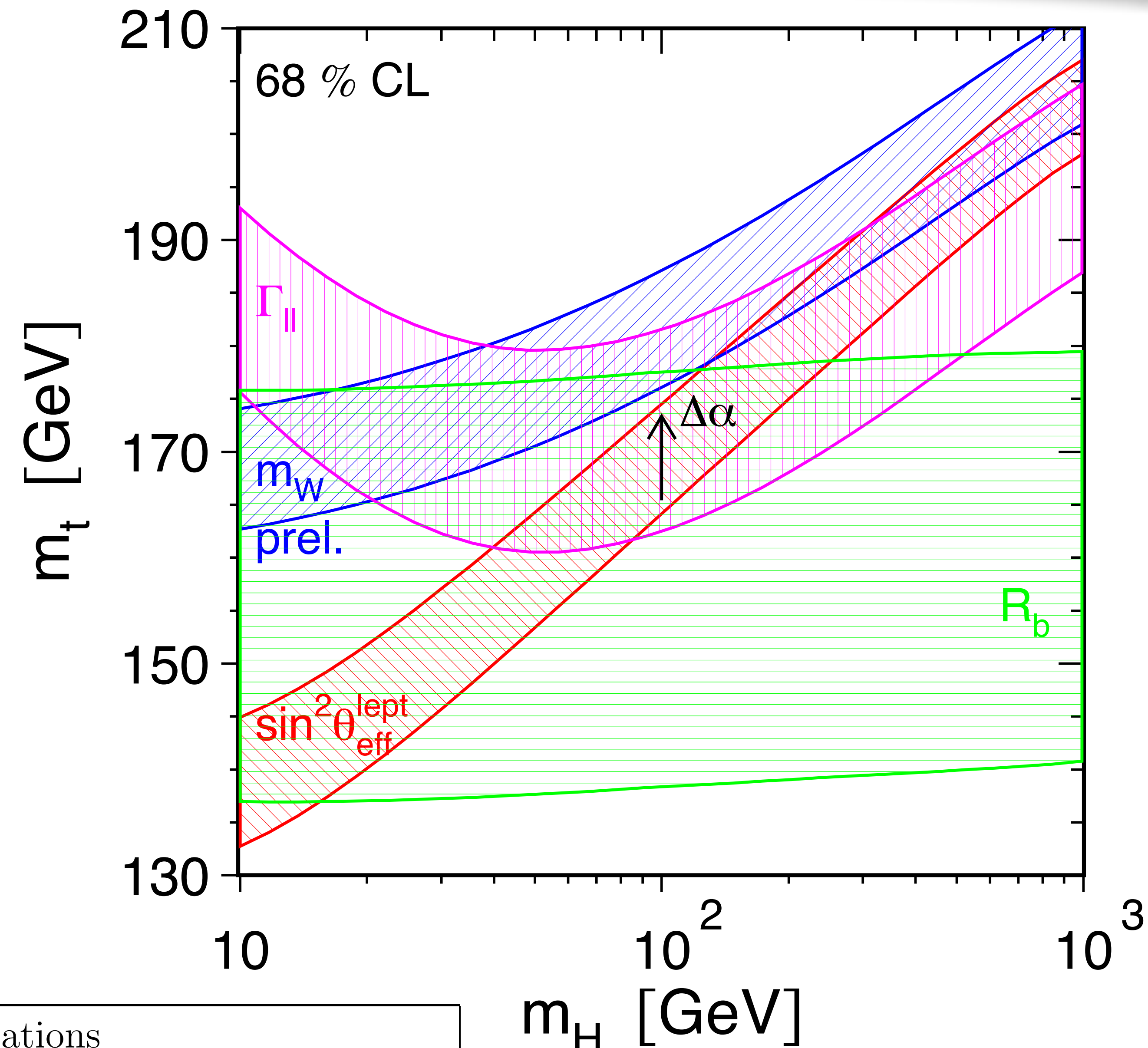


EFFECTIVE MIXING ANGLE



Z-Pole Results

- m_H very sensitive to $\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}}$
- $\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}}$ only parameter sensitive to $\Delta\alpha^{(5)}_{\mathrm{had}}(m_Z^2)$
- Source of sensitivity of Higgs mass to $\Delta\alpha^{(5)}_{\mathrm{had}}(m_Z^2)$



Parameter	Value	Correlations				
		$\Delta\alpha^{(5)}_{\mathrm{had}}(m_Z^2)$	$\alpha_S(m_Z^2)$	m_Z	m_t	$\log_{10}(m_H/\mathrm{GeV})$
$\Delta\alpha^{(5)}_{\mathrm{had}}(m_Z^2)$	0.02759 ± 0.00035	1.00				
$\alpha_S(m_Z^2)$	0.1190 ± 0.0027	-0.04	1.00			
m_Z [GeV]	91.1874 ± 0.0021	-0.01	-0.03	1.00		
m_t [GeV]	$173\pm^{13}_{10}$	-0.03	0.19	-0.07	1.00	
$\log_{10}(m_H/\mathrm{GeV})$	$2.05\pm^{0.43}_{0.34}$	-0.29	0.25	-0.02	0.89	1.00
m_H [GeV]	$111\pm^{190}_{60}$	-0.29	0.25	-0.02	0.89	1.00

Implication of Precision Measurements

$$\begin{aligned}\rho_\mathrm{f} &\equiv \Re(\mathcal{R}_\mathrm{f}) = 1 + \boxed{\Delta\rho_\mathrm{se}} + \boxed{\Delta\rho_\mathrm{f}} \\ \kappa_\mathrm{f} &\equiv \Re(\mathcal{K}_\mathrm{f}) = 1 + \boxed{\Delta\kappa_\mathrm{se}} + \boxed{\Delta\kappa_\mathrm{f}}\end{aligned}$$

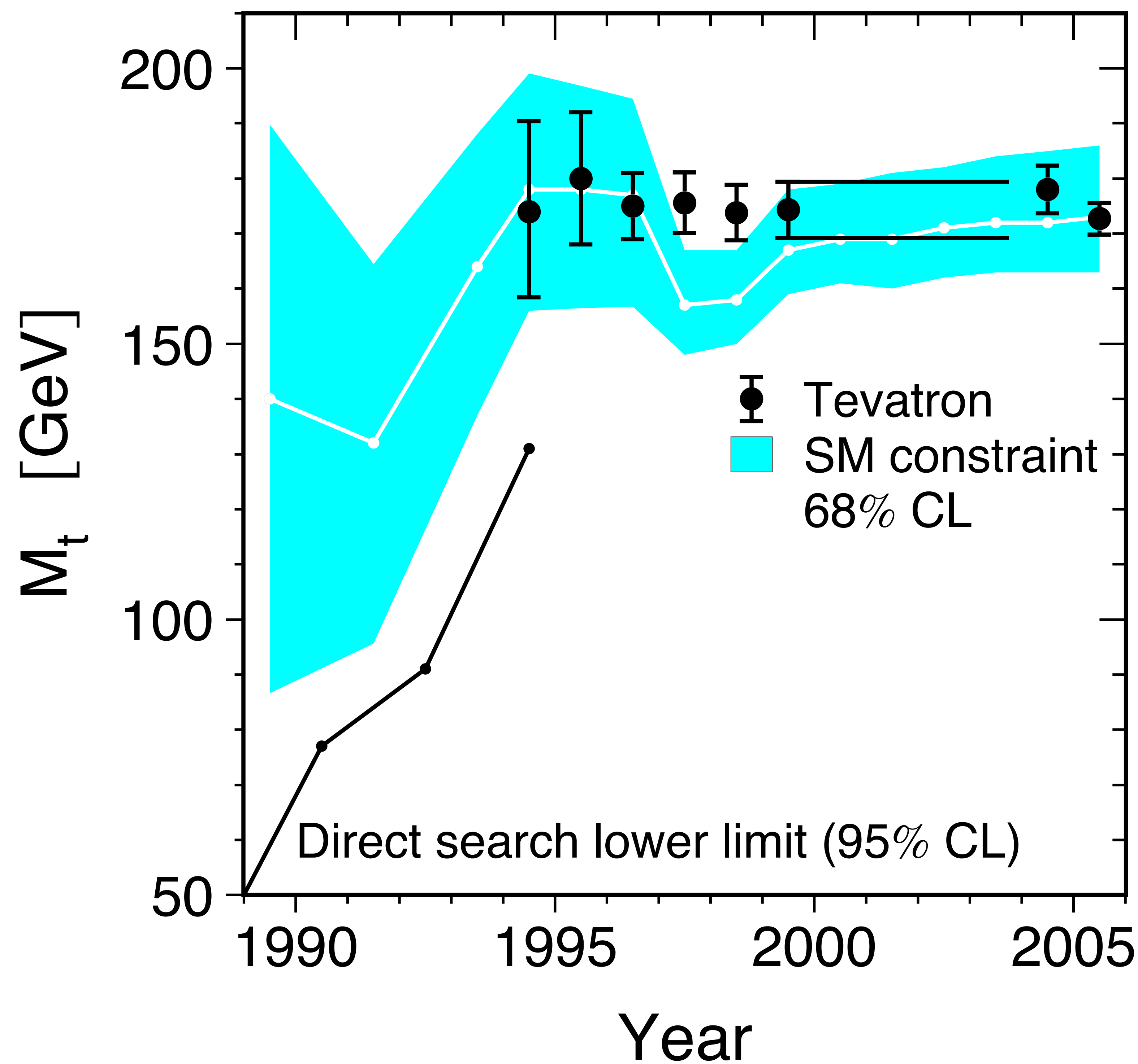
flavor specific

self-energy

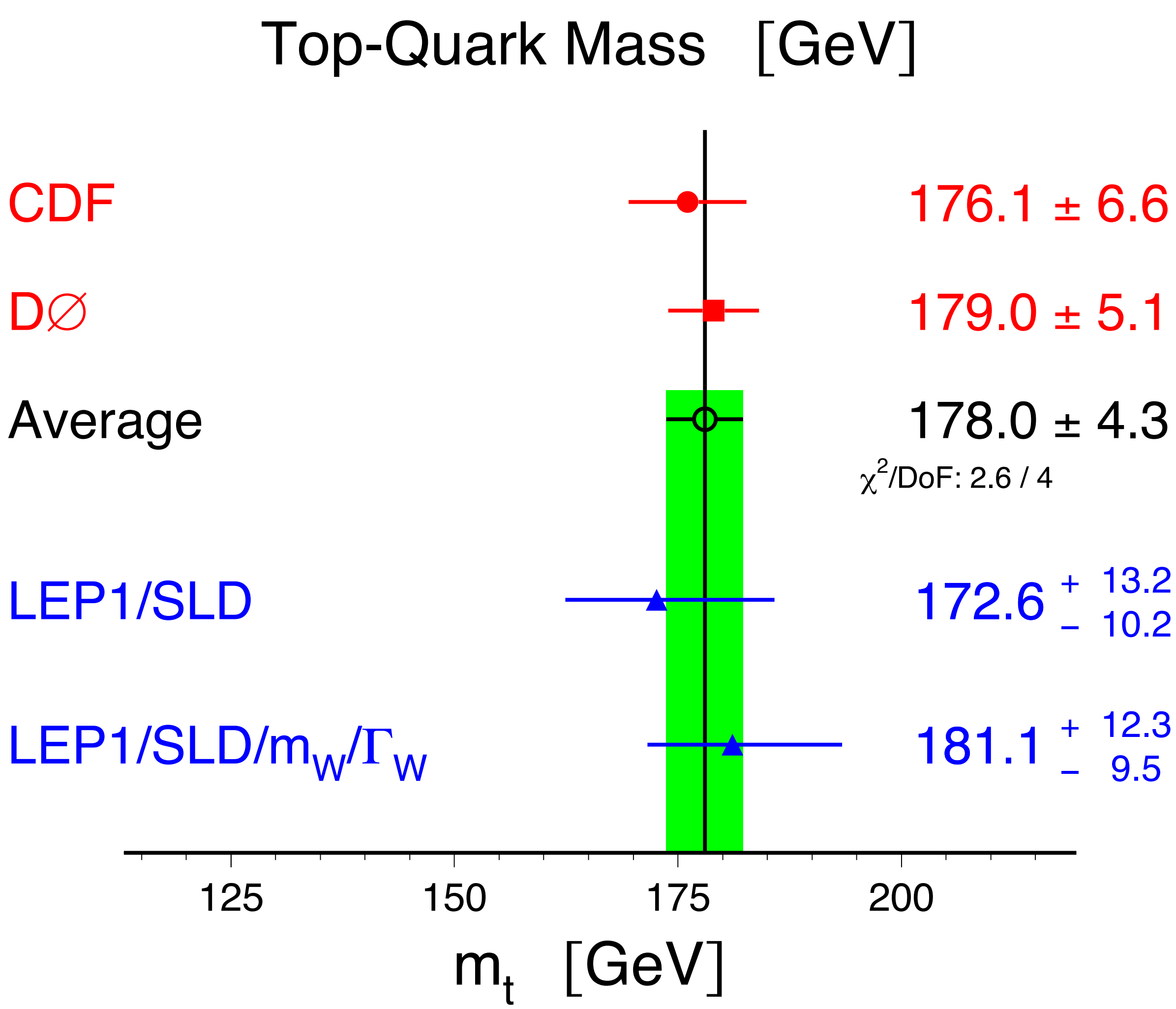
$$\begin{aligned}\sin^2\theta^\mathrm{f}_\mathrm{eff} &\equiv \kappa_\mathrm{f}\sin^2\theta_\mathrm{W} \\ g_{V\mathrm{f}} &\equiv \sqrt{\rho_\mathrm{f}}\,(T^\mathrm{f}_3 - 2Q_\mathrm{f}\sin^2\theta^\mathrm{f}_\mathrm{eff}) \\ g_{A\mathrm{f}} &\equiv \sqrt{\rho_\mathrm{f}}\,T^\mathrm{f}_3\,,\end{aligned}$$

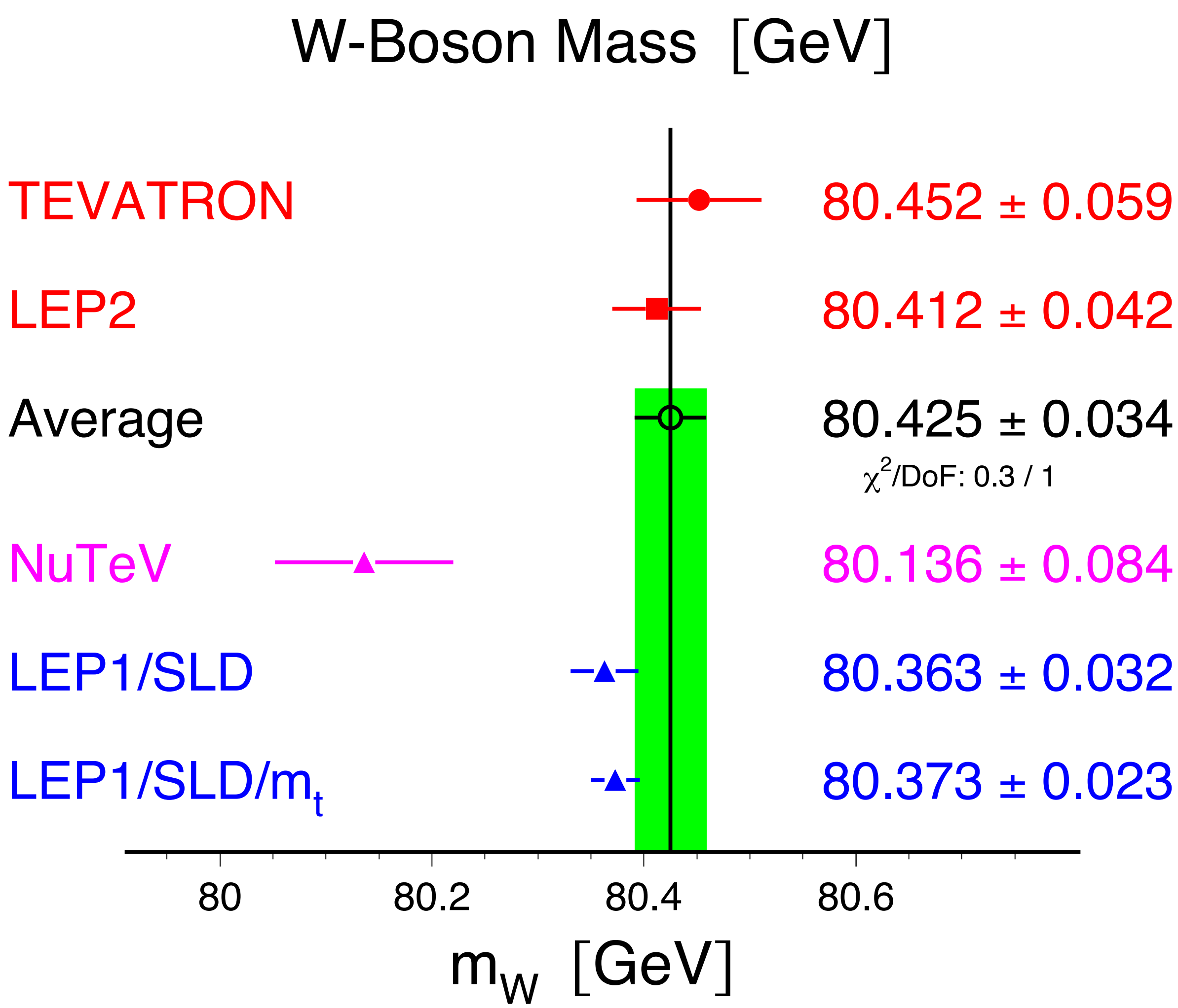
$$\begin{aligned}\sin^2\theta_\mathrm{W} &= 0.22331 \pm 0.00062 \\ \sin^2\theta^\mathrm{lept}_\mathrm{eff} &= 0.23149 \pm 0.00016 & \kappa_\ell &= 1.0366 \pm 0.0025 \\ \sin^2\theta^\mathrm{b}_\mathrm{eff} &= 0.23293\pm^{0.00031}_{0.00025} & \kappa_\mathrm{b} &= 1.0431 \pm 0.0036 \\ \rho_\ell &= 1.00509\pm^{0.00067}_{0.00081} & -\Delta r_\mathrm{w} &= 0.0242 \pm 0.0021 \\ \rho_\mathrm{b} &= 0.99426\pm^{0.00079}_{0.00164} & \Delta r &= 0.0363 \pm 0.0019\end{aligned}$$

CONSTRAINTS ON TOP MASS @ LEP

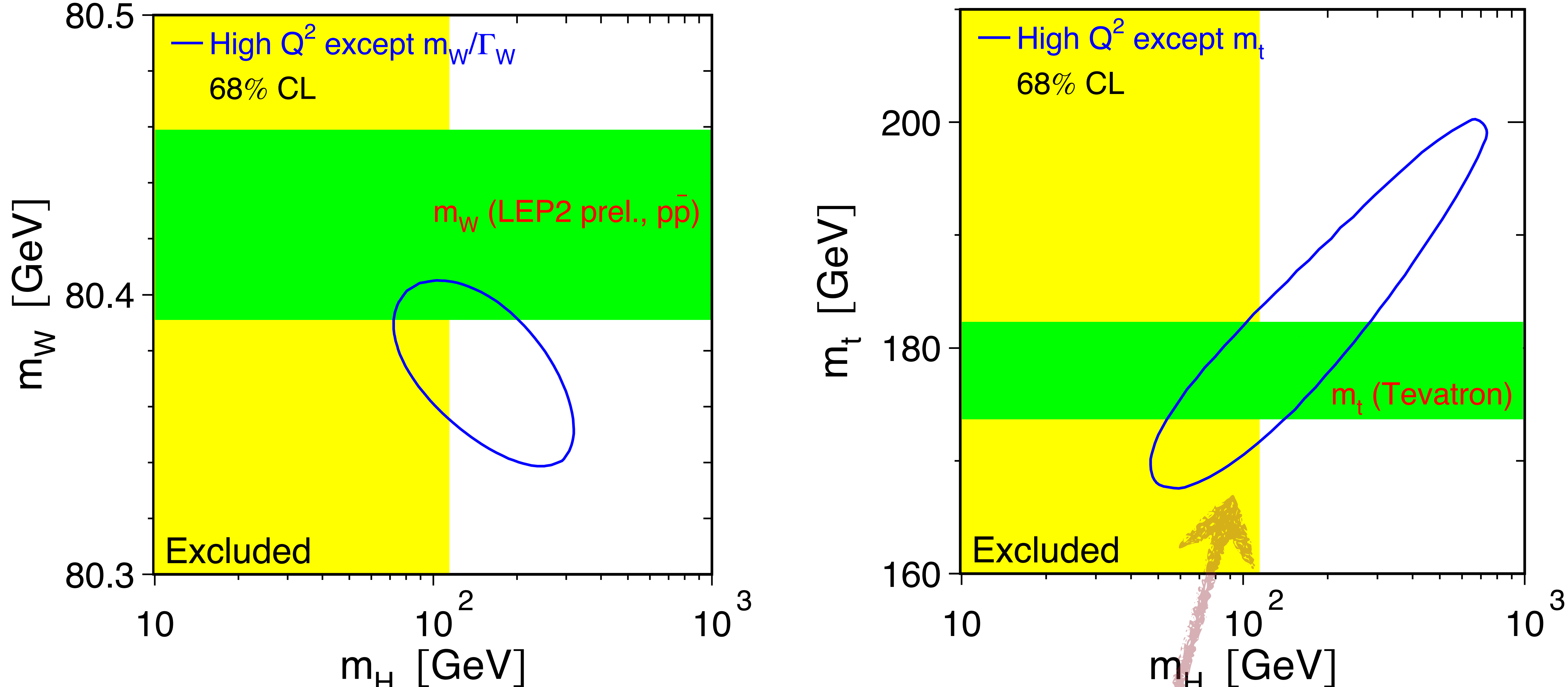


CONSTRAINTS ON TOP AND W MASS



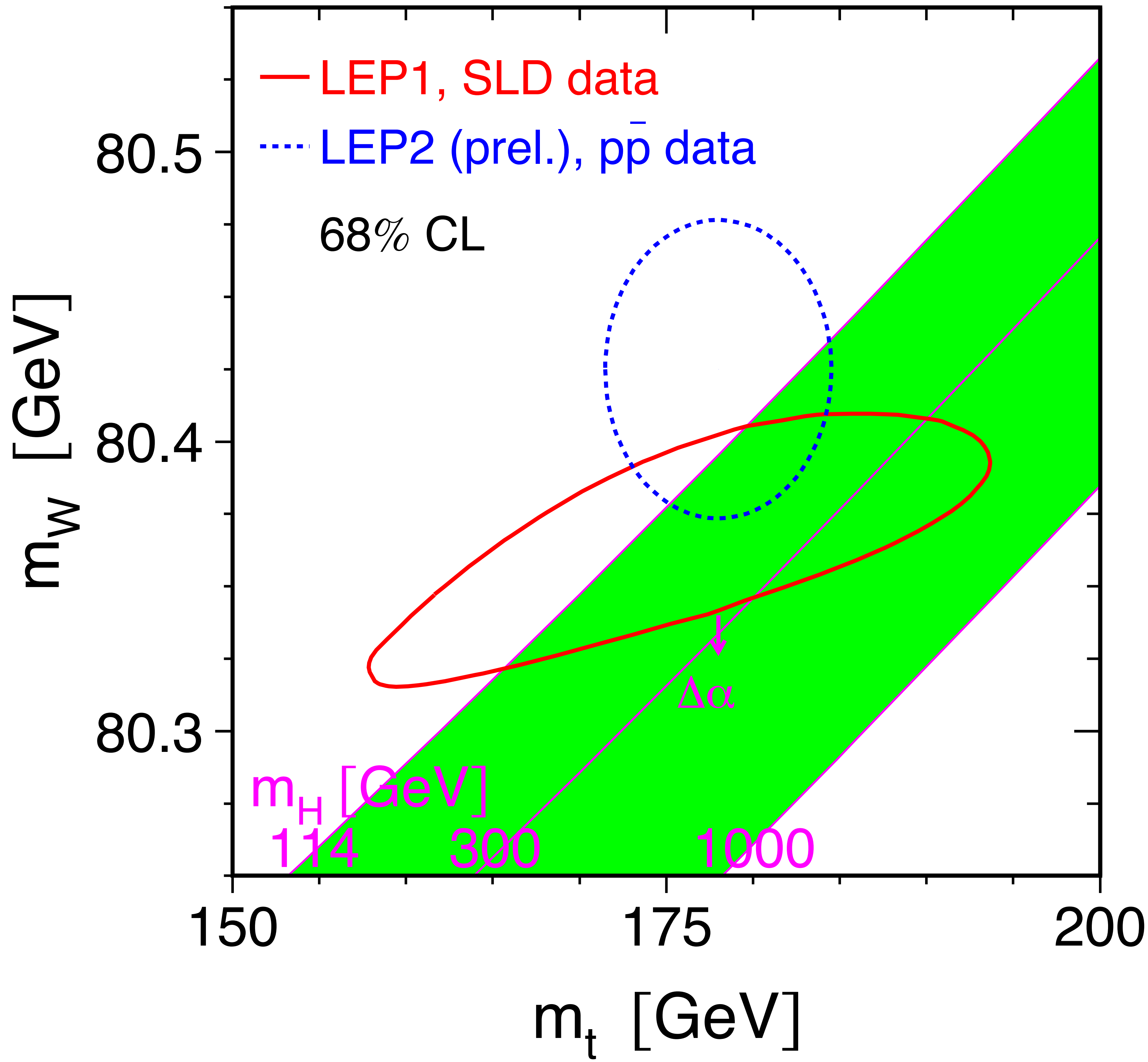


Importance of Direct W and Top Measurements

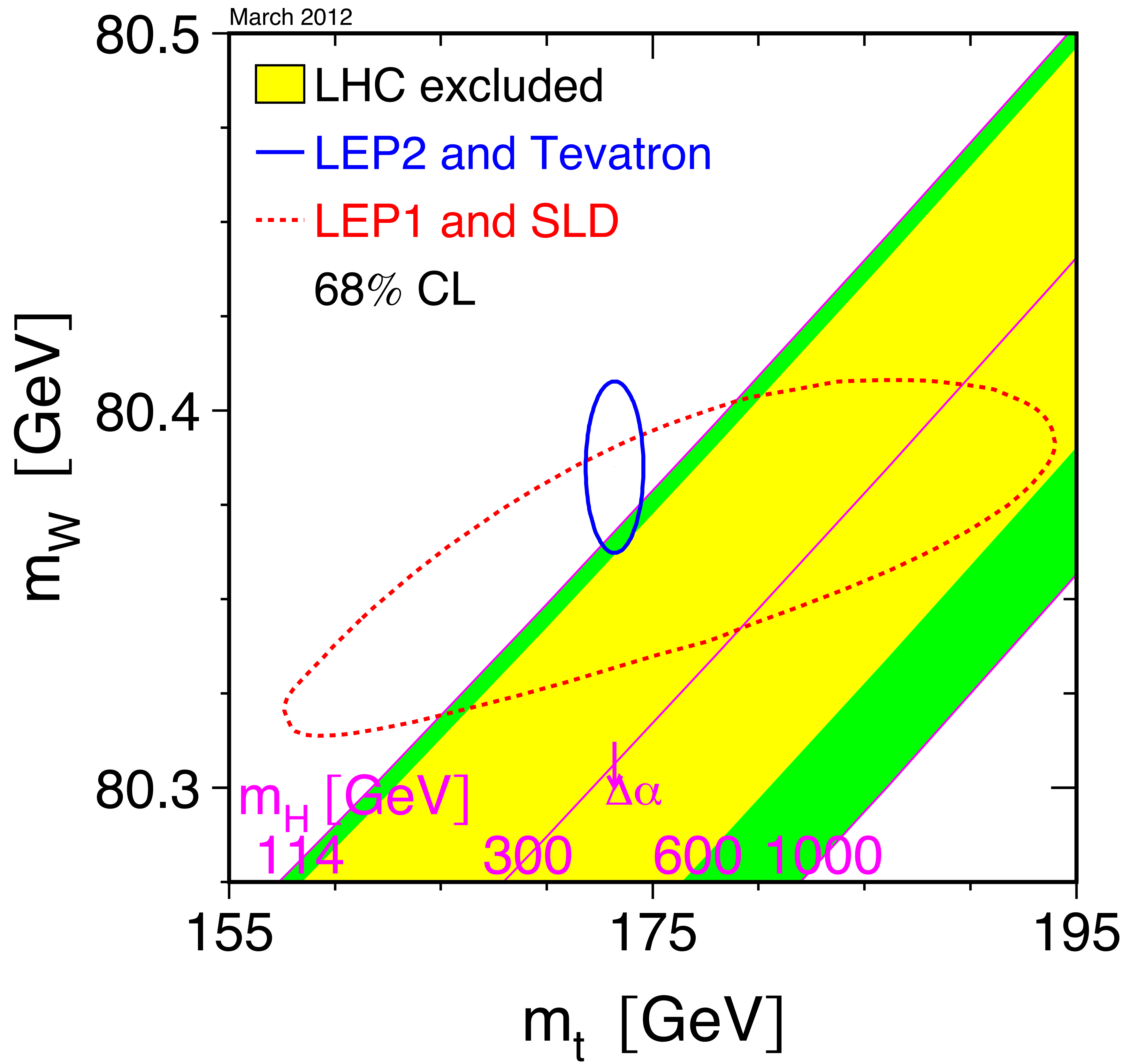


Parameter	Value	Correlations				
		$\Delta\alpha_{\mathrm{had}}^{(5)}(m_Z^2)$	$\alpha_S(m_Z^2)$	m_Z	m_t	$\log_{10}(m_H/\mathrm{GeV})$
$\Delta\alpha_{\mathrm{had}}^{(5)}(m_Z^2)$	0.02767 ± 0.00034	1.00				
$\alpha_S(m_Z^2)$	0.1188 ± 0.0027	−0.02	1.00			
m_Z [GeV]	91.1874 ± 0.0021	−0.01	−0.02	1.00		
m_t [GeV]	178.5 ± 3.9	−0.05	0.11	−0.03	1.00	
$\log_{10}(m_H/\mathrm{GeV})$	2.11 ± 0.20	−0.46	0.18	0.06	0.67	1.00
m_H [GeV]	129^{+74}_{-49}	−0.46	0.18	0.06	0.67	1.00

CONSTRAINTS ON HIGGS MASS



INCLUSION OF LHC



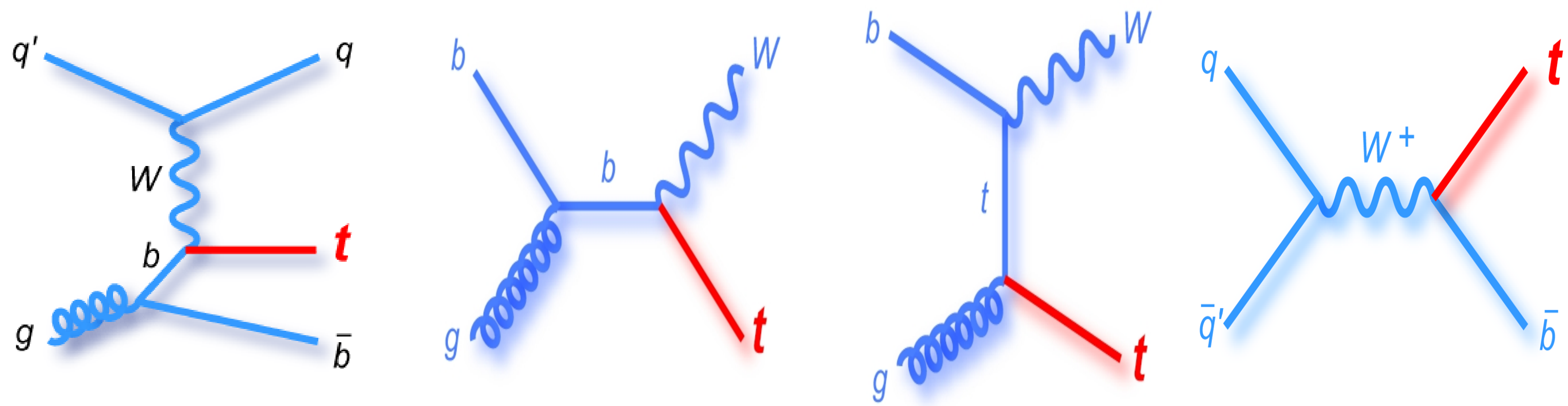
Single Top

SINGLE TOP

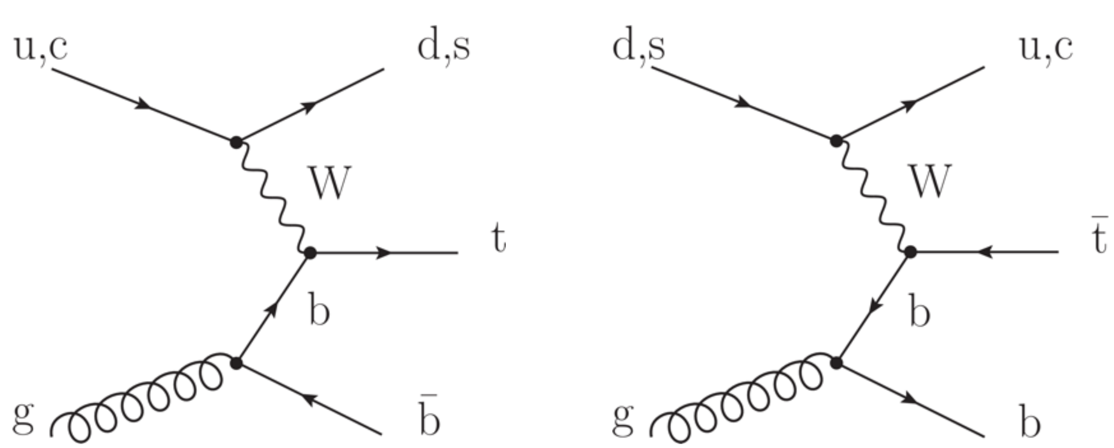
Electroweak top production

↓

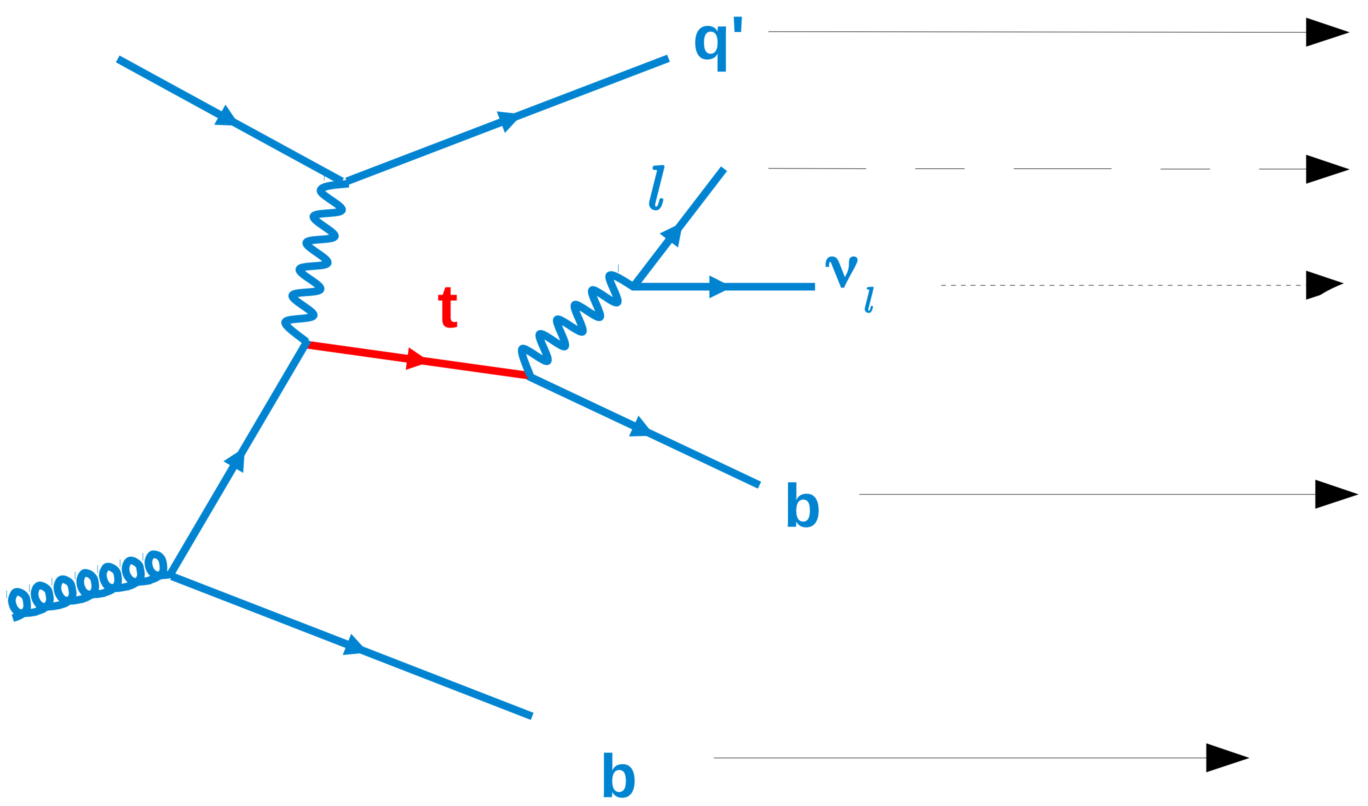
single-top



	t-channel	W-associated (tW)	*s*-channel
Tevatron: *pp* @1.96 TeV(N. KidonakisPhys. Rev. D 82, 054018 (2010) and arxiv:0909.0037	2.08±0.12 pb	0.22±0.08 pb	1.046±0.058 pb
LHC pp @7 TeV(N. Kidonakis Phys. arXiv:1205.3453)	64.6±2.1 pb	15.6±1.2 pb	4.59±0.19 pb
LHC pp @8 TeV(N. Kidonakis arXiv:1205.3453)	87.1±2.8 pb	22.2±1.5 pb	5.55±0.22 pb



Leptonic Single Top in tW



"Light" jet j' with high pseudorapidity $|\eta_{j'}|$

μ or e

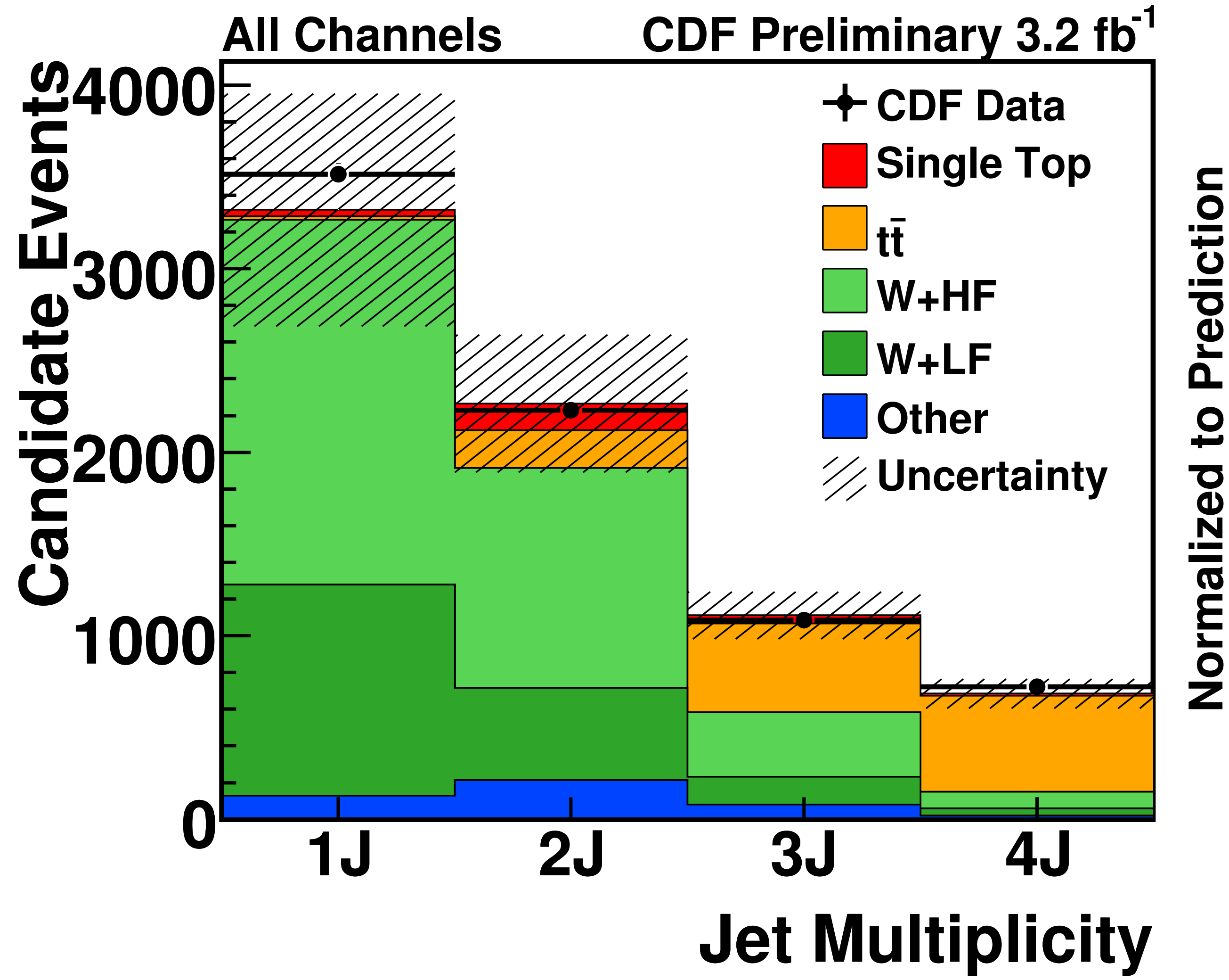
Missing energy

b-jet:
central, high p_T

2^{nd} b-jet:
broad $|\eta|$, low p_T

EXPERIMENTAL CHALLENGE

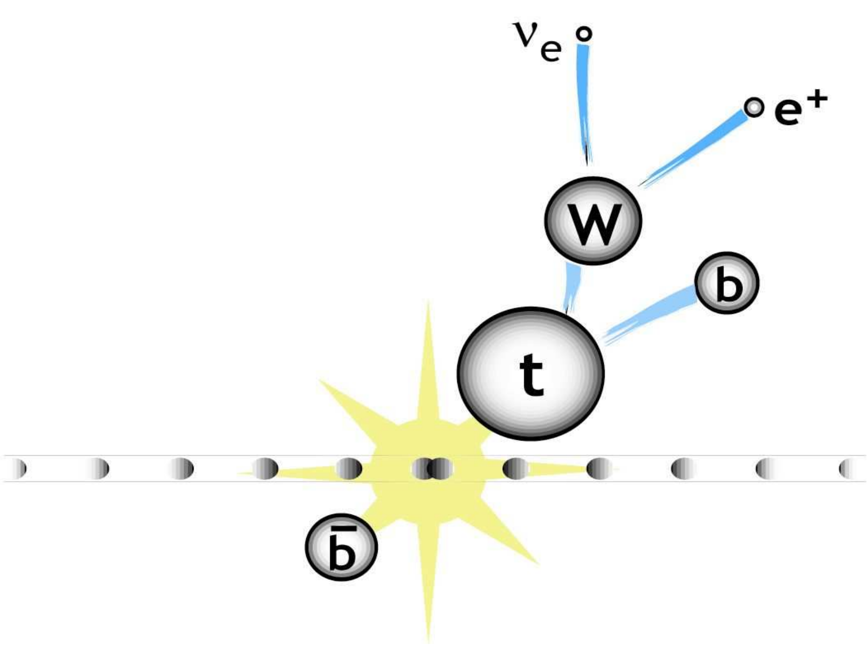
- Rare process at the Tevatron
  - $S : B \sim 1 : 10^9$ before trigger
- Not very distinct signature with many sources of background
  - $S : B \sim 1 : 20$ after final selection
  - No “golden” variable
- Large systematics uncertainties



- Sophisticated analysis methods needed
- Current approaches at CDF: Likelihood Function, Matrix Element, Neural Network, Boosted Decision Trees
  - $S : B > 1 : 1$ in most significant bins

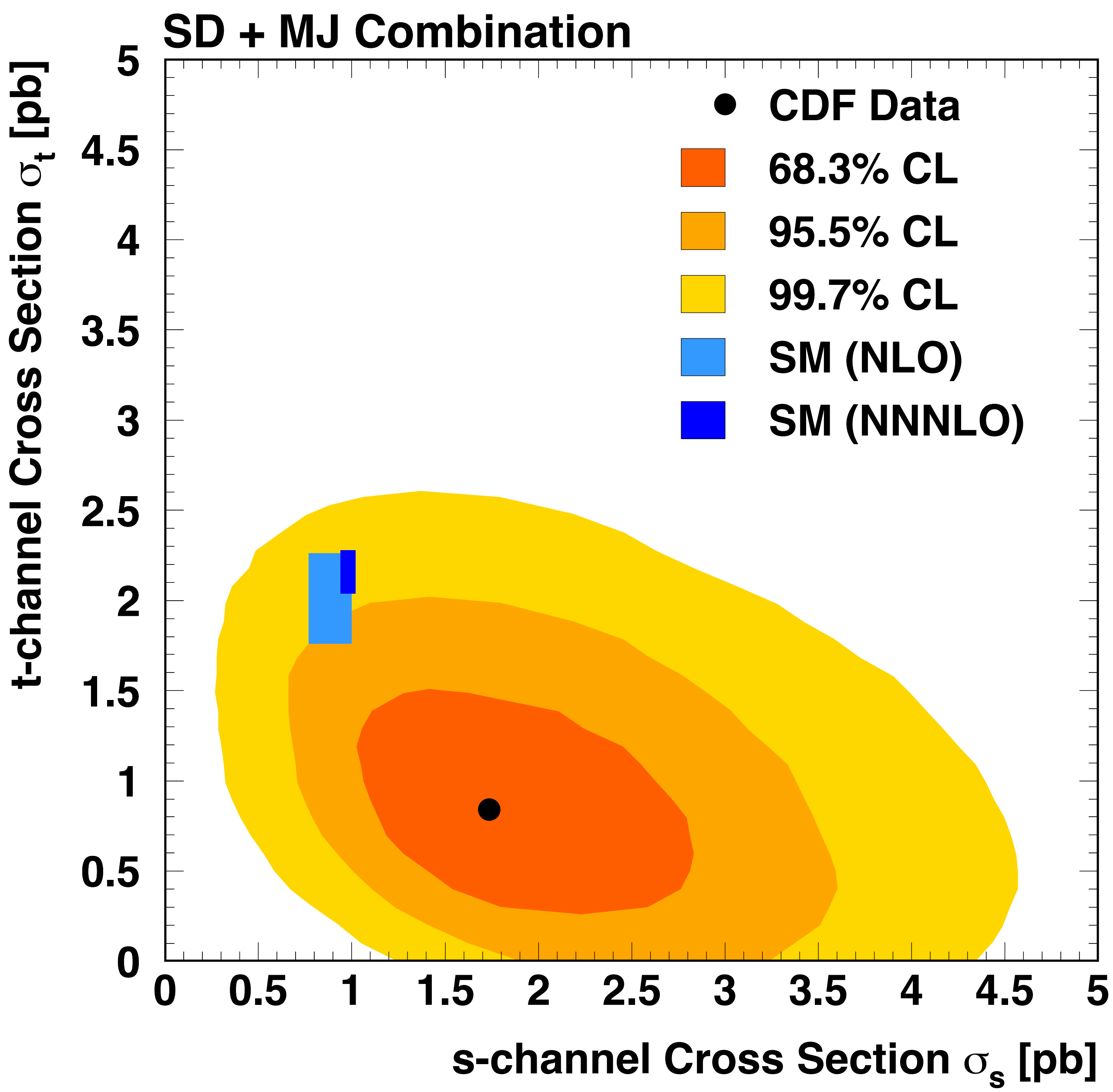
SINGLE TOP AT CDF

- Top decays most of the times to Wb
- W + 2 or 3 jets with $E_T > 20$ GeV
- One lepton (electron or muon) with $p_T > 20$ GeV
  - Mainly from standard high p_T lepton triggers
  - Extended muon coverage from missing E_T dedicated triggers (30% gain in signal acceptance)
- Missing transverse energy from neutrino, $\not{E}_T > 25$ GeV
- Veto "non-W", Z, dilepton, conversion, cosmics
- At least one b-tagged jet (displaced secondary vertex algorithm)
- Main backgrounds: W+Heavy Flavor, W+Mistags, $t\bar{t}$,...



Process	Number of Events in 3.2 fb^{-1}	
	W + 2 jets	W + 3 jets
s-channel	58.1 ± 8.4	19.2 ± 2.8
t-channel	87.6 ± 13.0	26.2 ± 3.9
$Wb\bar{b}$	656.9 ± 198.0	201.3 ± 60.8
$Wc\bar{c}$	292.2 ± 90.1	98.1 ± 30.2
Wcj	250.4 ± 77.2	52.1 ± 16.0
Mistags	501.3 ± 69.6	151.9 ± 21.4
non-W	89.6 ± 35.8	35.1 ± 14.0
WW	58.5 ± 6.6	21.2 ± 2.4
WZ	28.9 ± 2.4	8.5 ± 0.7
ZZ	0.9 ± 0.1	0.4 ± 0.0
$Z + jets$	36.5 ± 5.6	15.6 ± 2.4
$t\bar{t}$ dilepton	69.2 ± 10.0	60.2 ± 8.7
$t\bar{t}$ non-dilepton	134.9 ± 19.6	421.8 ± 61.1
Total signal	145.7 ± 21.4	45.4 ± 6.7
Total prediction	2265.0 ± 375.4	1111.5 ± 129.5
Observed in data	2229	1086

Observation at Tevatron



OBSERVATION OF SINGLE TOP @ CDF AND D0

- First Observation of Electroweak Single Top Quark Production (CDF)
  - http://arxiv.org/abs/0903.0885

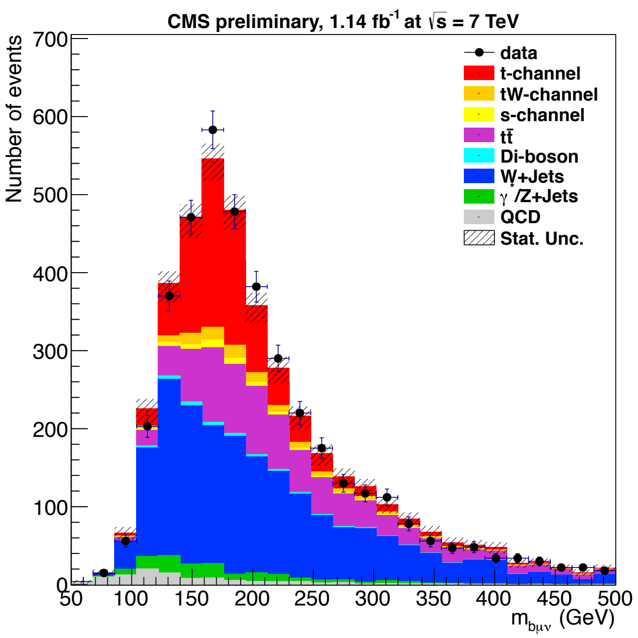
- Observation of Single Top-Quark Production (D0)
  - http://arxiv.org/abs/0903.0850

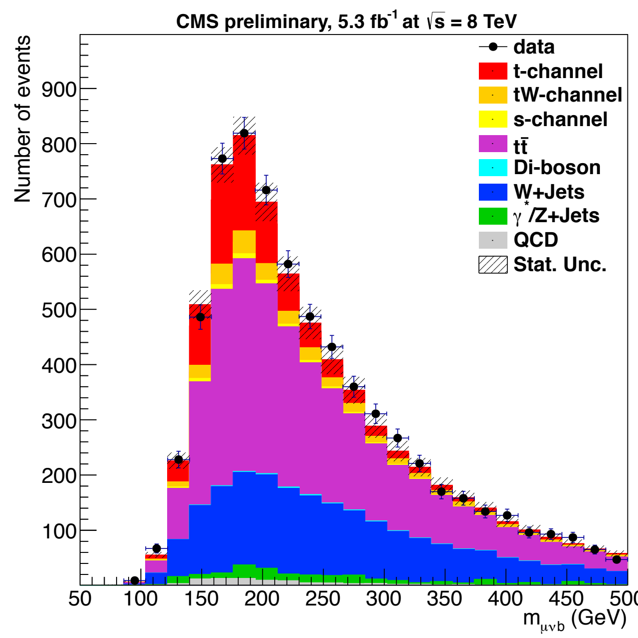
- Analysis underway at both ATLAS and CMS but will be a challenging measurement also at LHC
  - Expect measurement by end of 2011 with 1 fb^{-1} of accumulated data

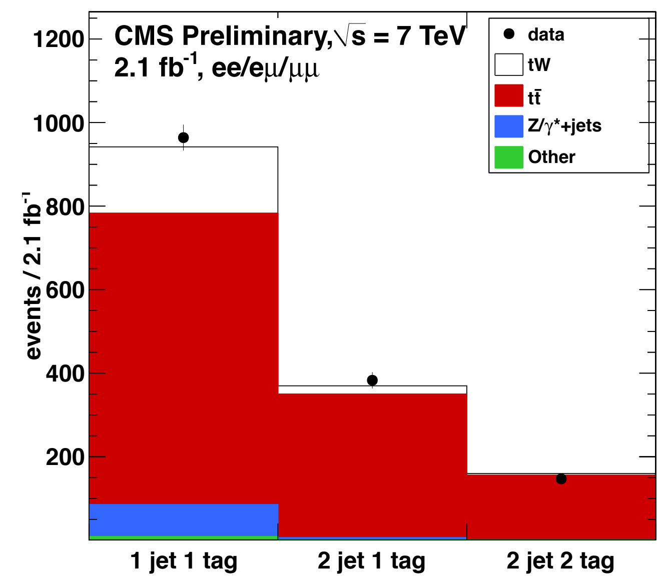
2010

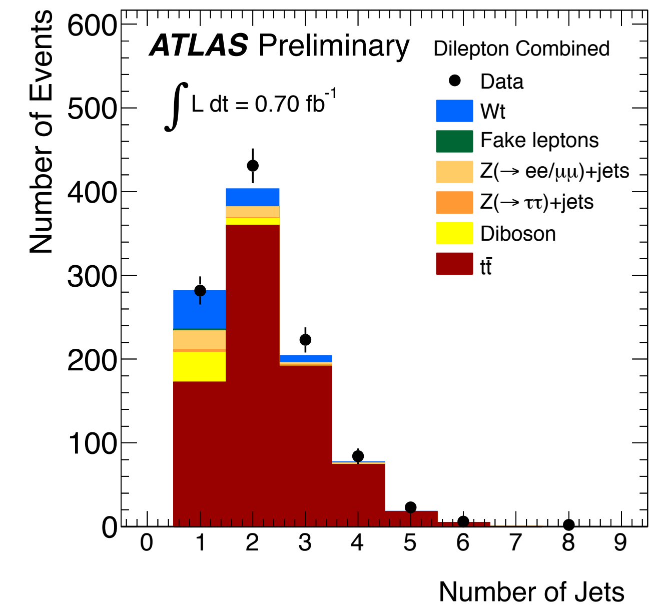
- Measurement of the t-channel single top quark at CMS
  - arXiv:1106.3052v1, published in Phys. Rev. Lett. 107 (2011) 091802
- Measurement of single top at ATLAS
  - W+t channel (ATLAS-CONF-2011-104), t-channel (ATLAS-CONF-2011-101), s-channel (ATLAS-CONF-2011-118)

Single Top at LHC

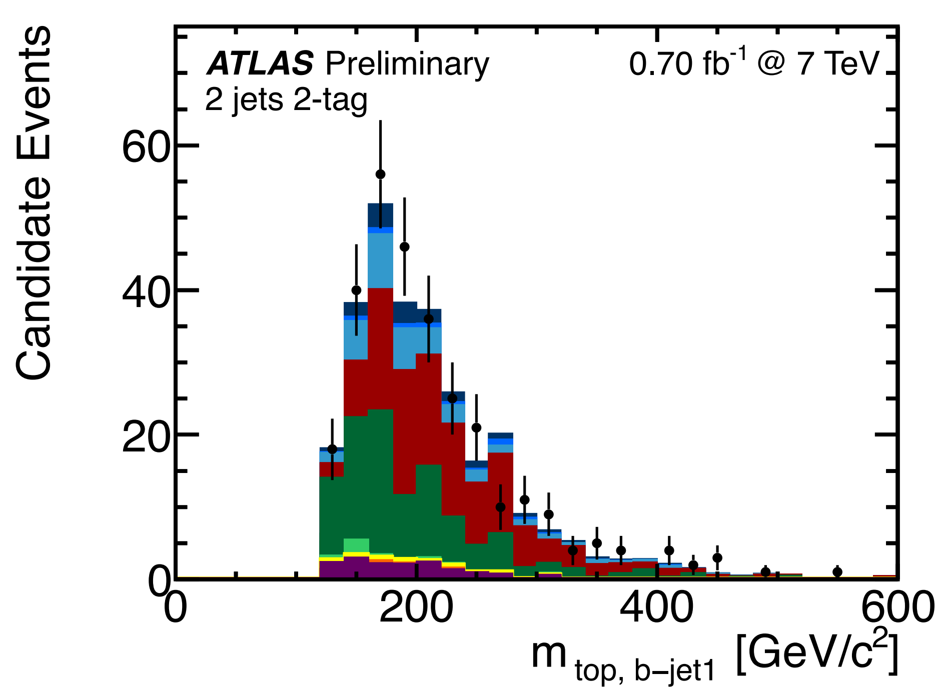


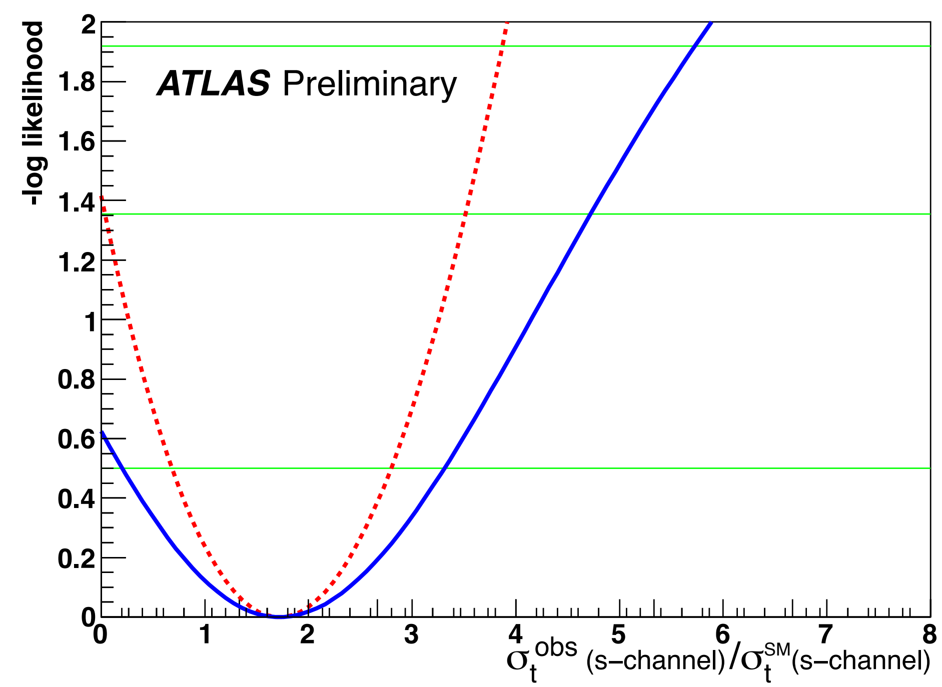




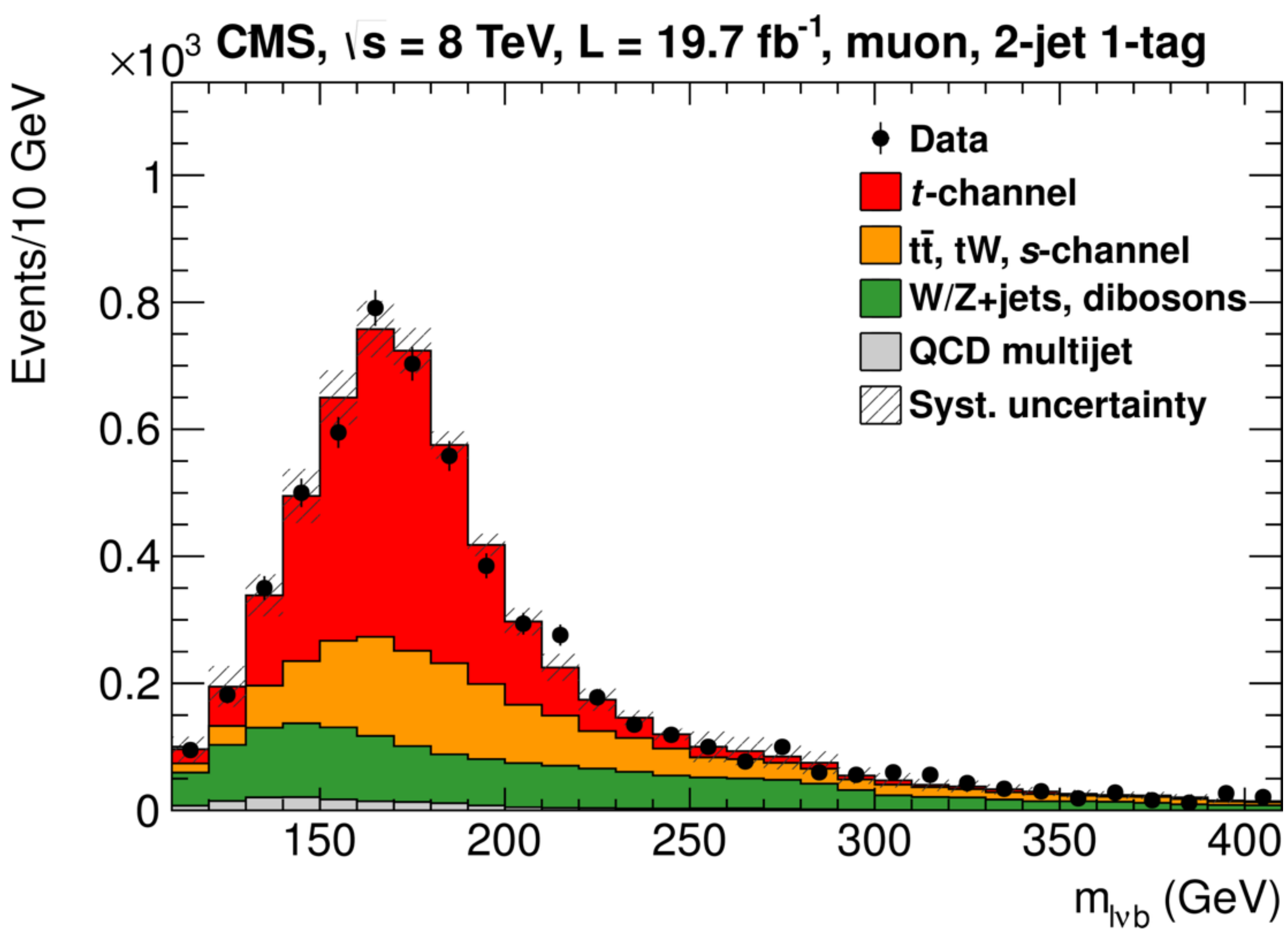


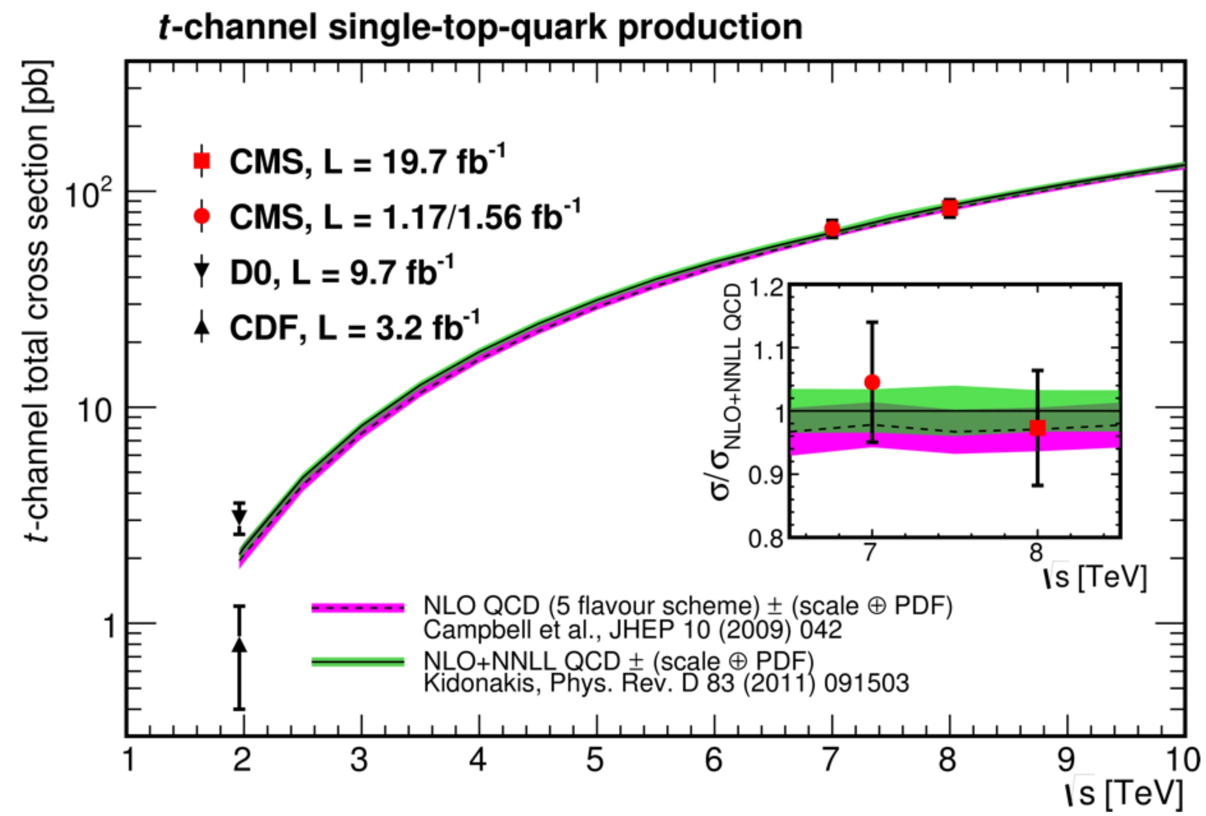
arXiv:1205.5764

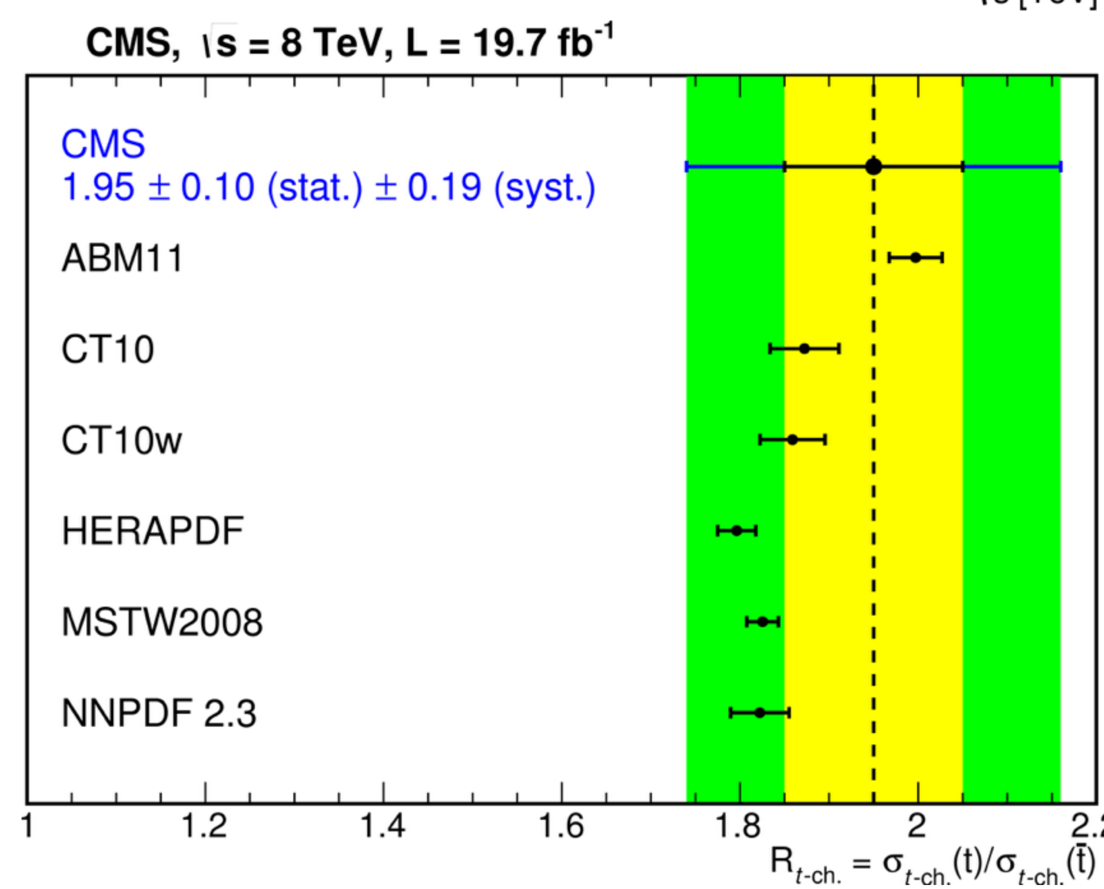




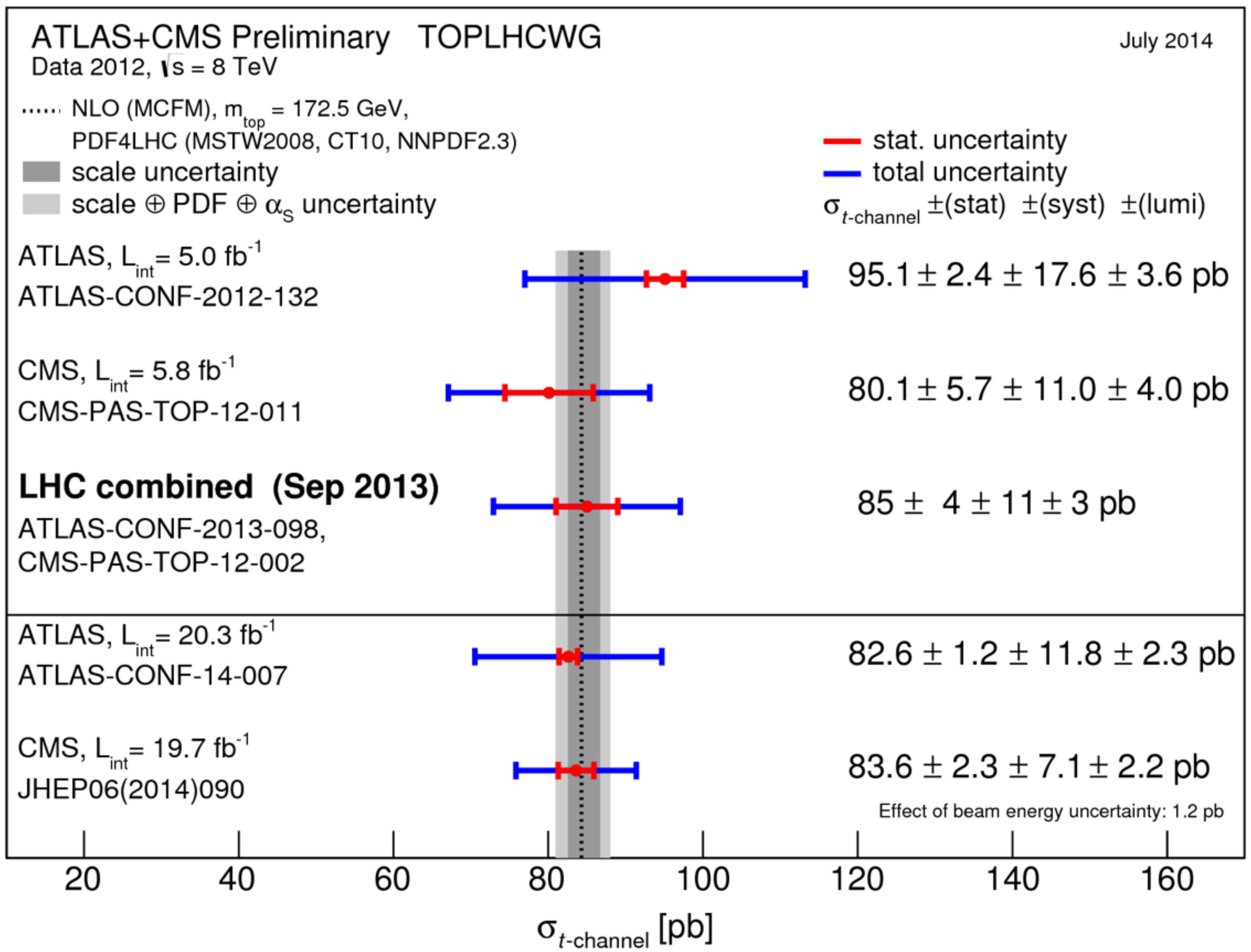
Single Top @ LHC

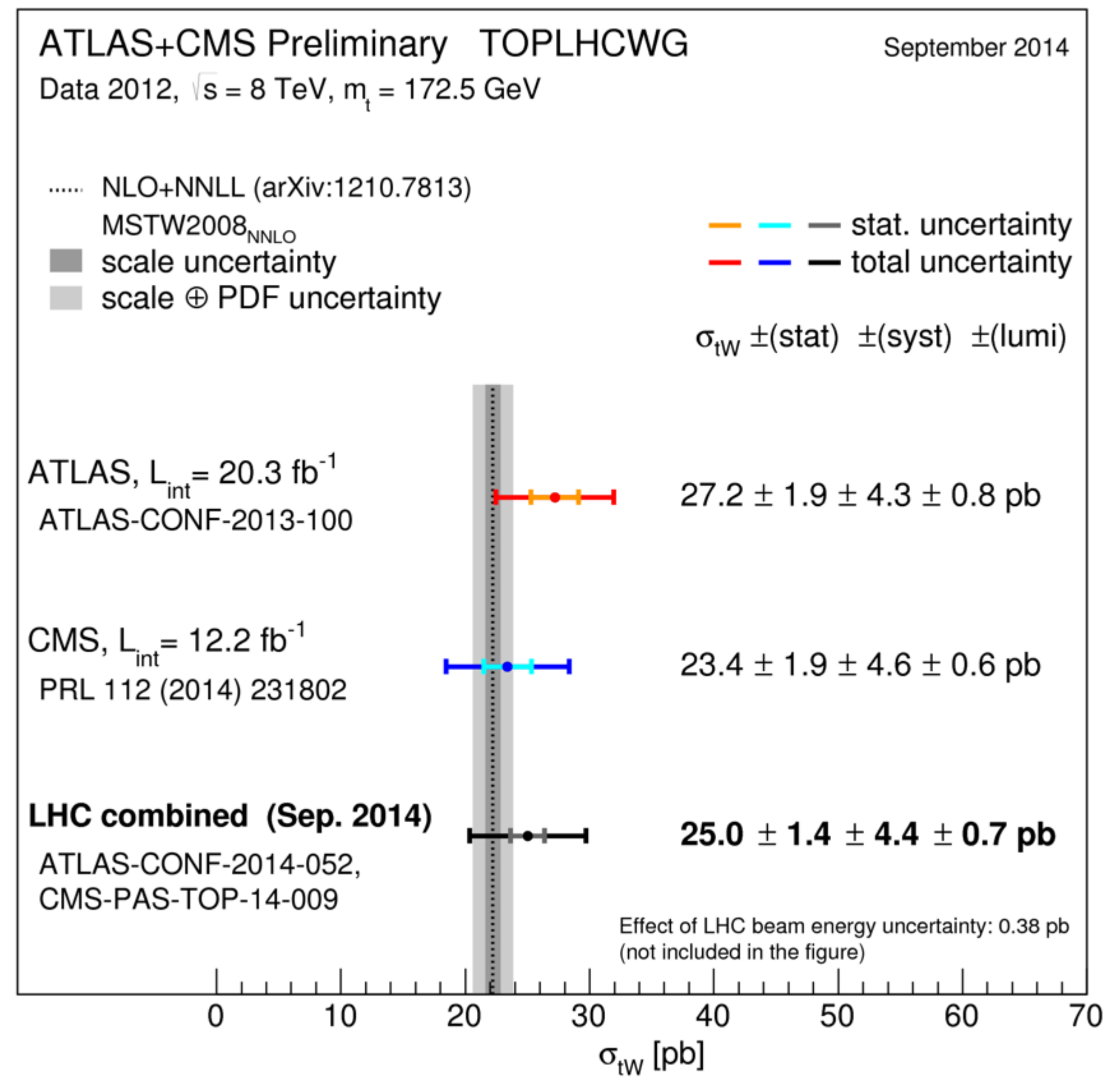




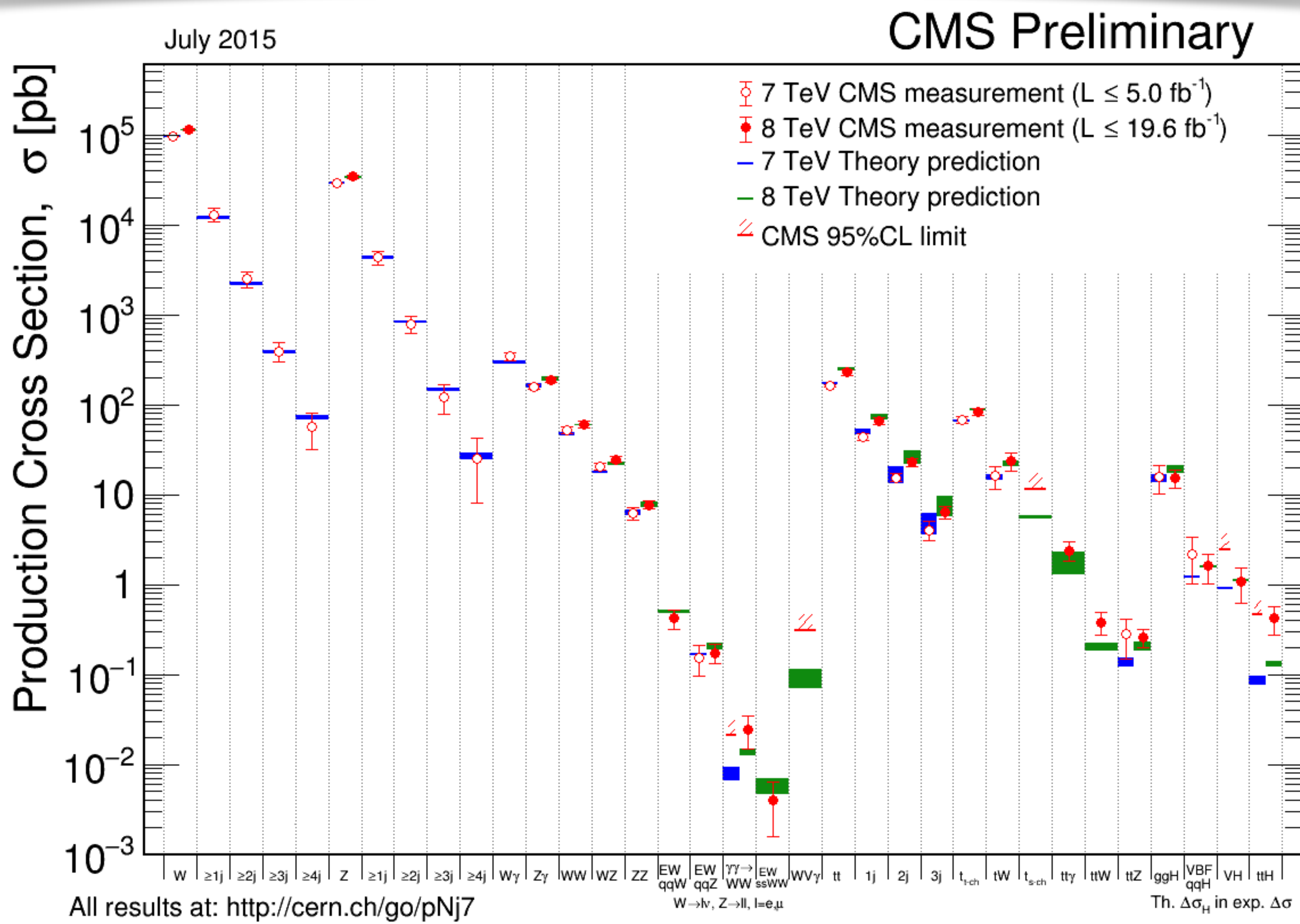


MEASUREMENT OF CROSS SECTION



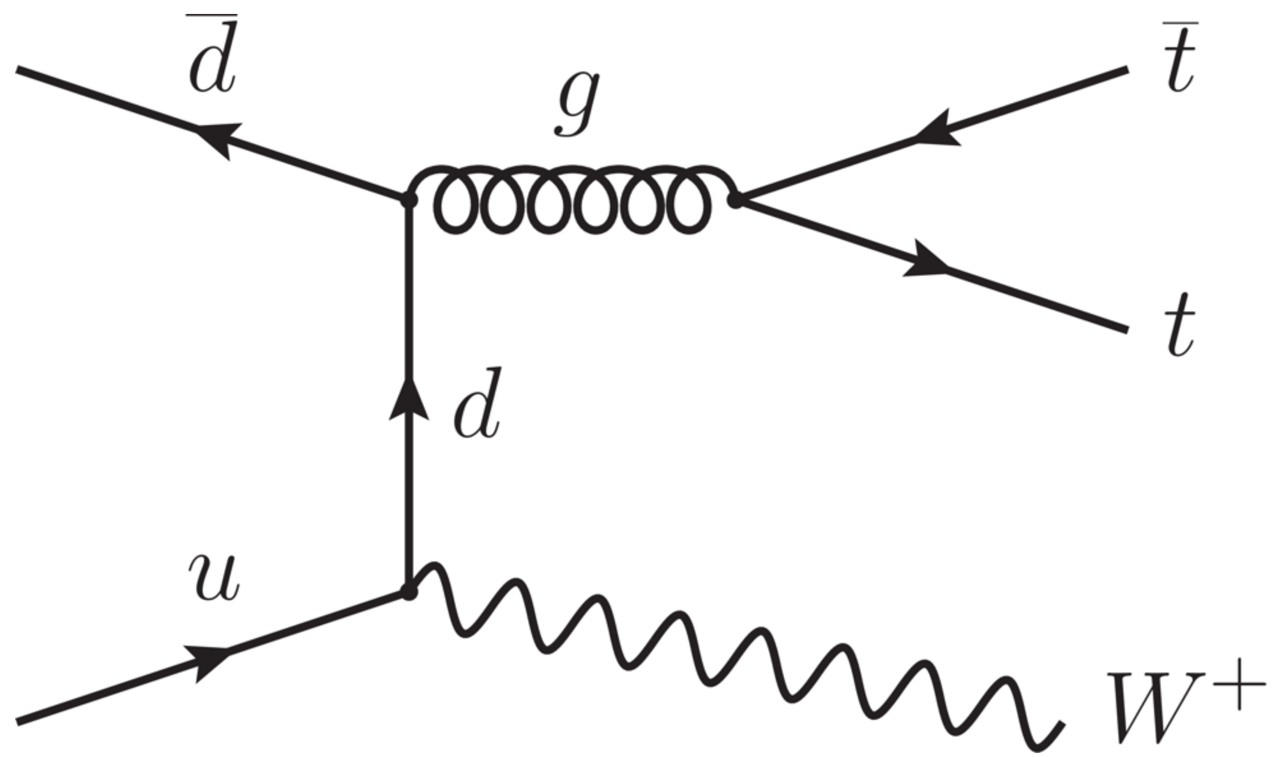


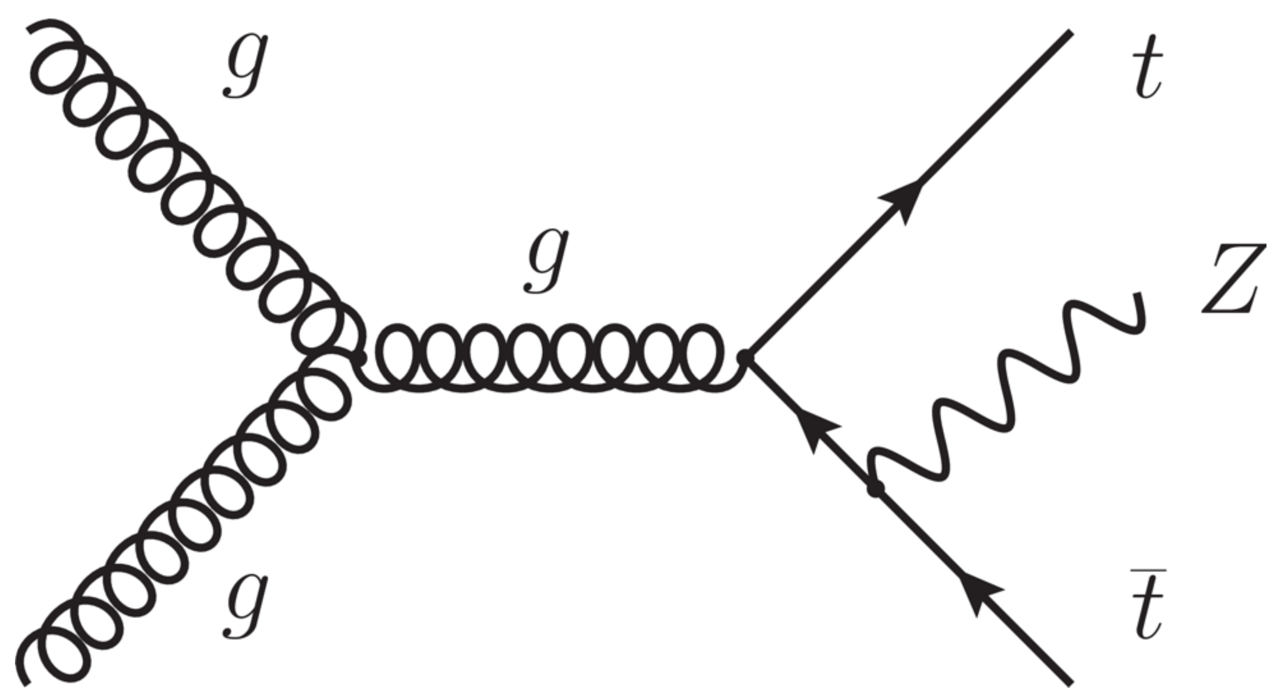
ttbar + X



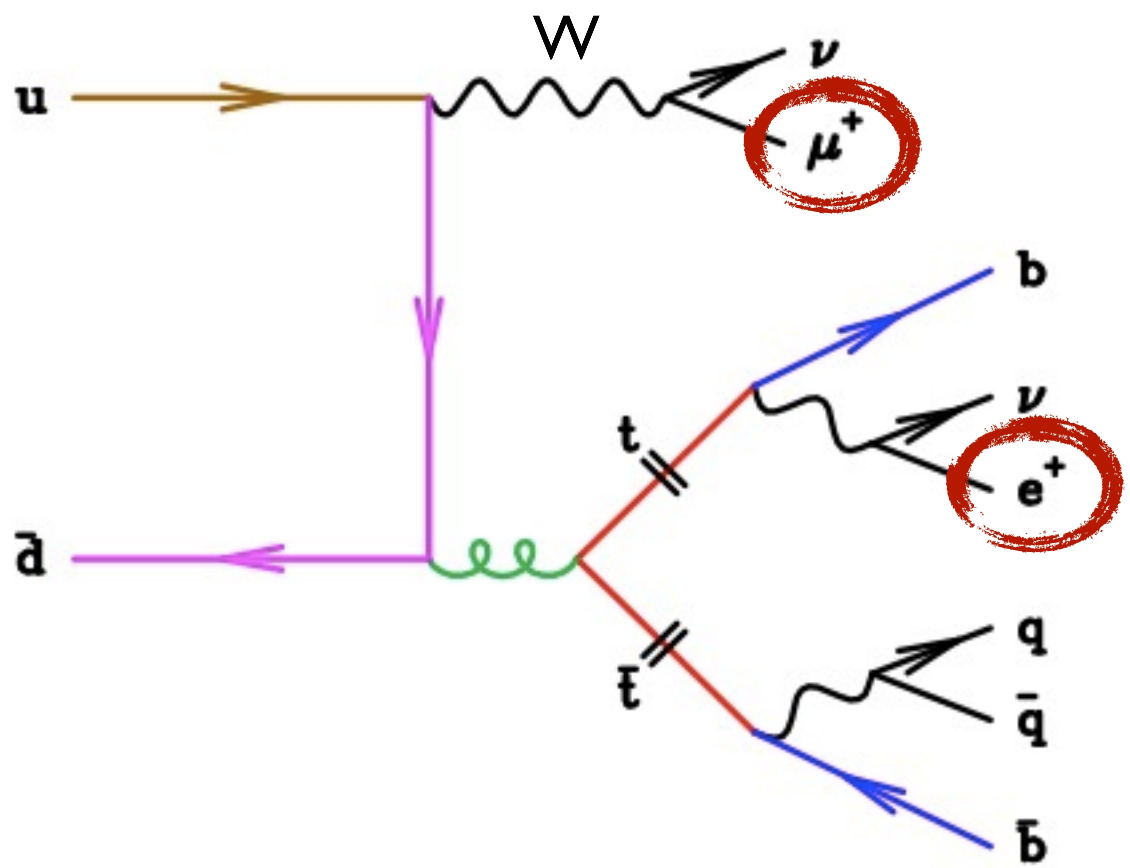
July 2015
CMS Preliminary
Production Cross Section, σ [pb]
7 TeV CMS measurement (L ≤ 5.0 fb^{-1})
8 TeV CMS measurement (L ≤ 19.6 fb^{-1})
7 TeV Theory prediction
8 TeV Theory prediction
CMS 95%CL limit
W ≥1j ≥2j ≥3j ≥4j Z ≥1j ≥2j ≥3j ≥4j Wγ Zγ WW WZ ZZ EW qqW EW qqZ γγ→WW EW ssWW WVγ tt 1j 2j 3j t$_{t\text{-}ch}$ tW t$_{s\text{-}ch}$ ttγ ttW ttZ ggH VBF qqH VH ttH
W→lν, Z→ll, l=e,μ
Th. Δσ$_H$ in exp. Δσ
All results at: http://cern.ch/go/pNj7

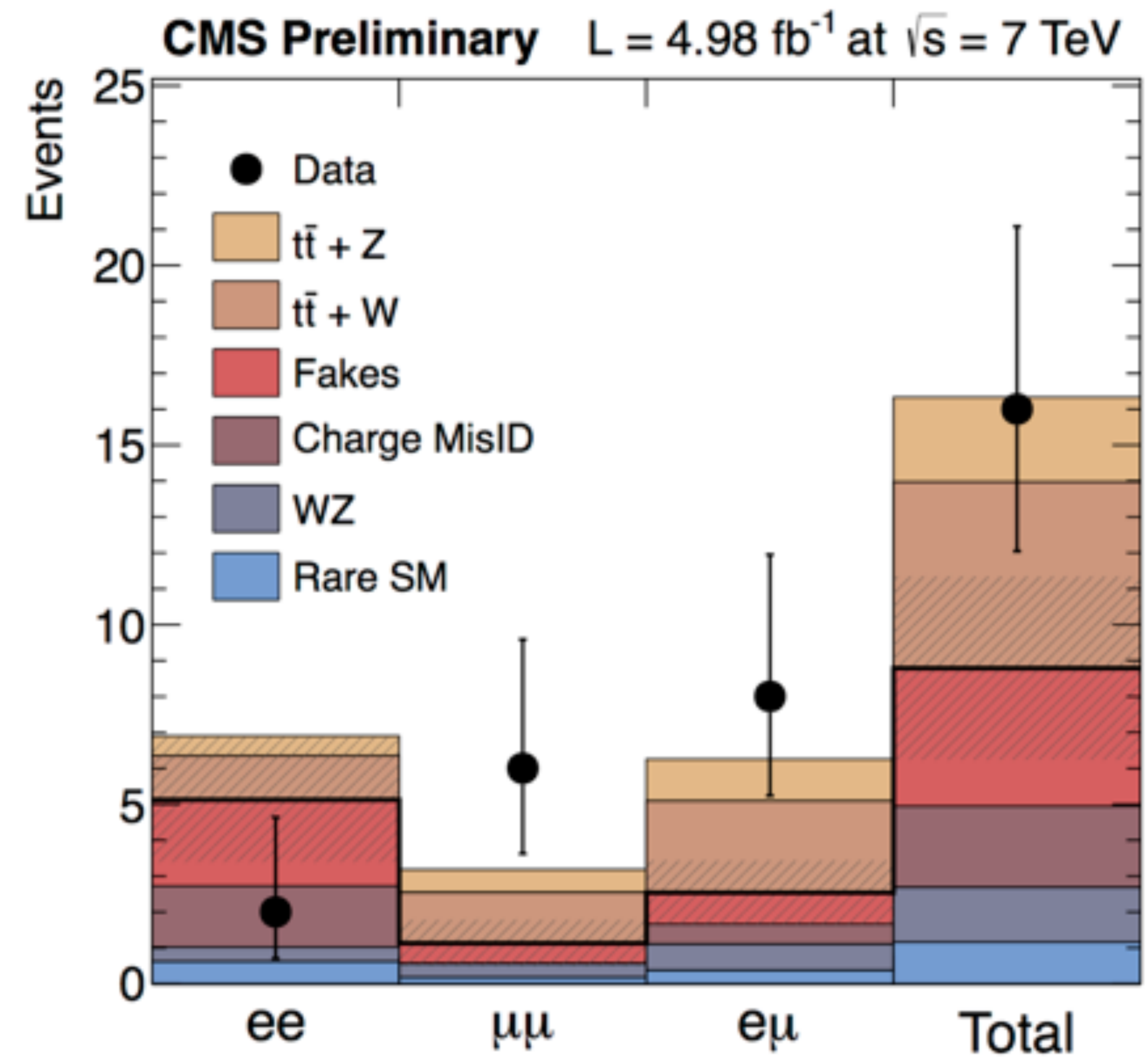
ttbar + W/Z





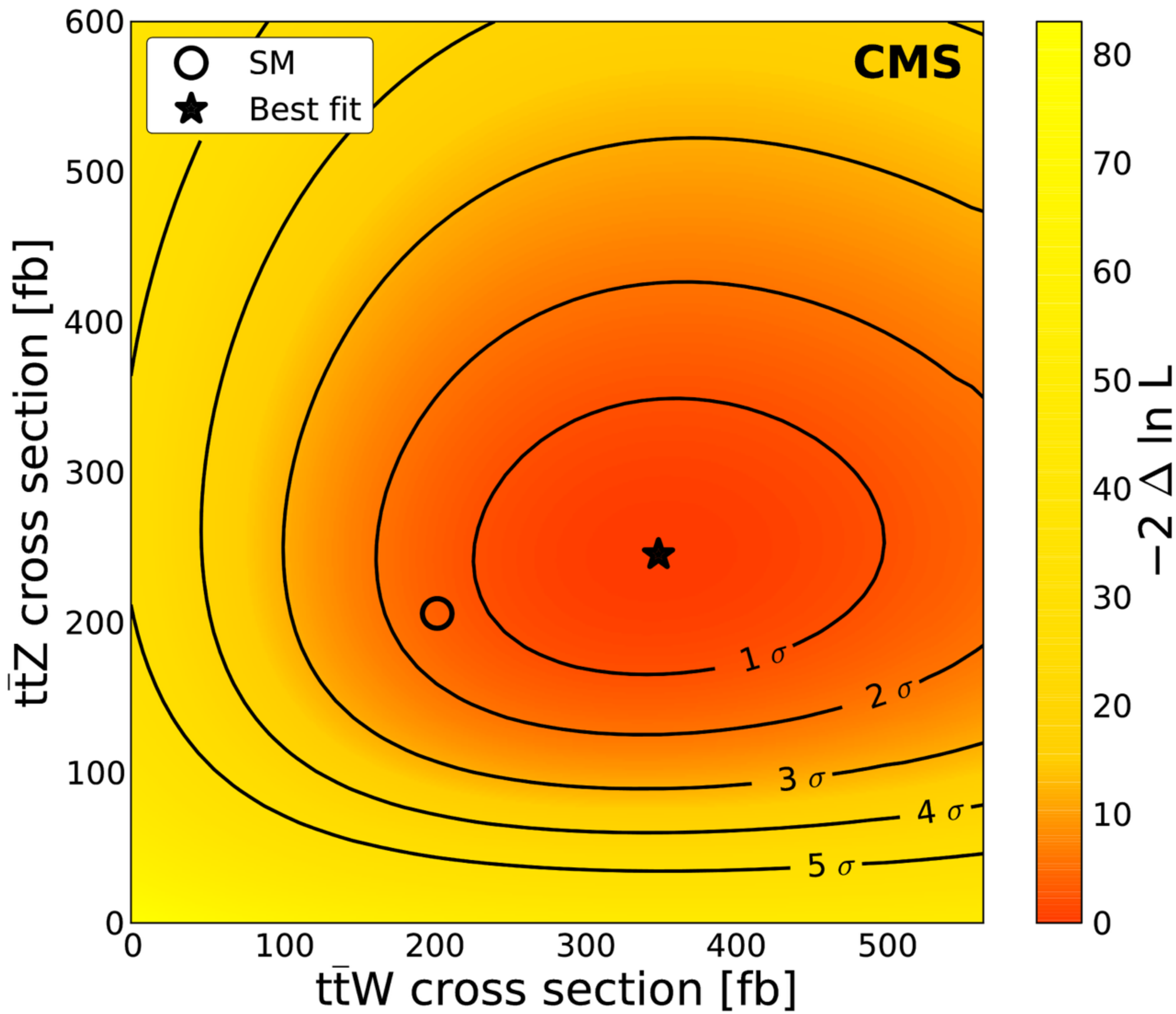
TTW



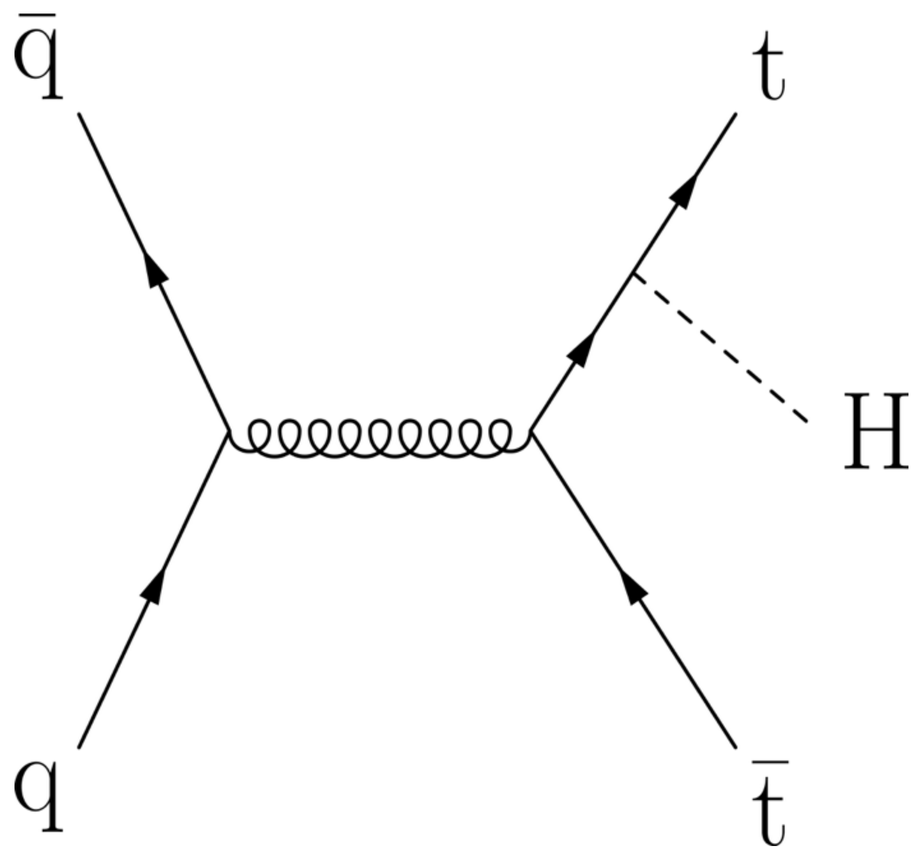


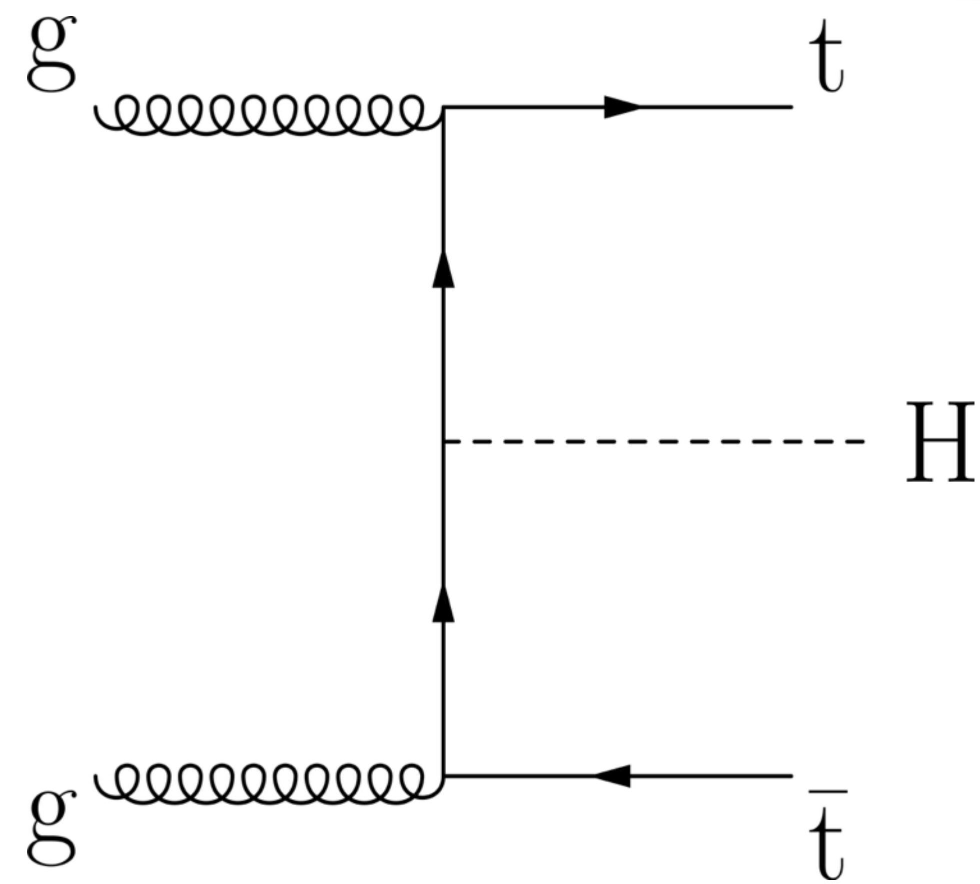
- rare SM process and background for new physics events

ttbar + W/Z Cross Section

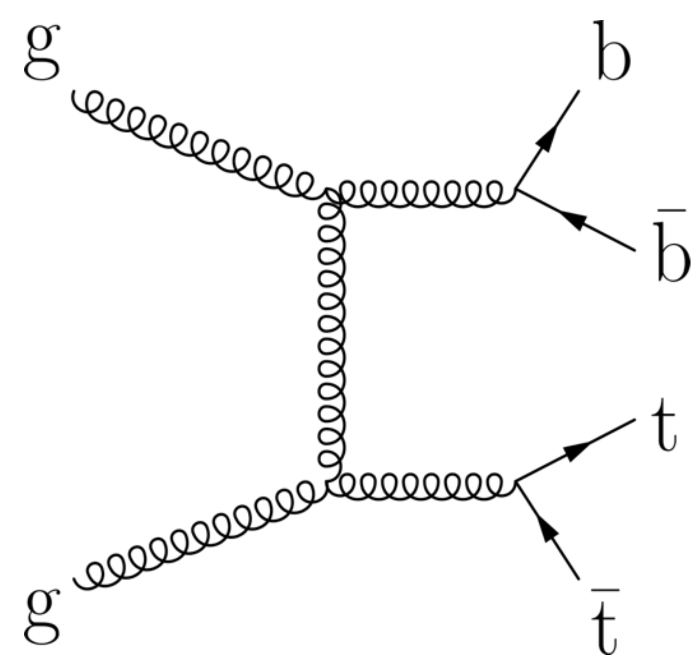


ttbar + Higgs

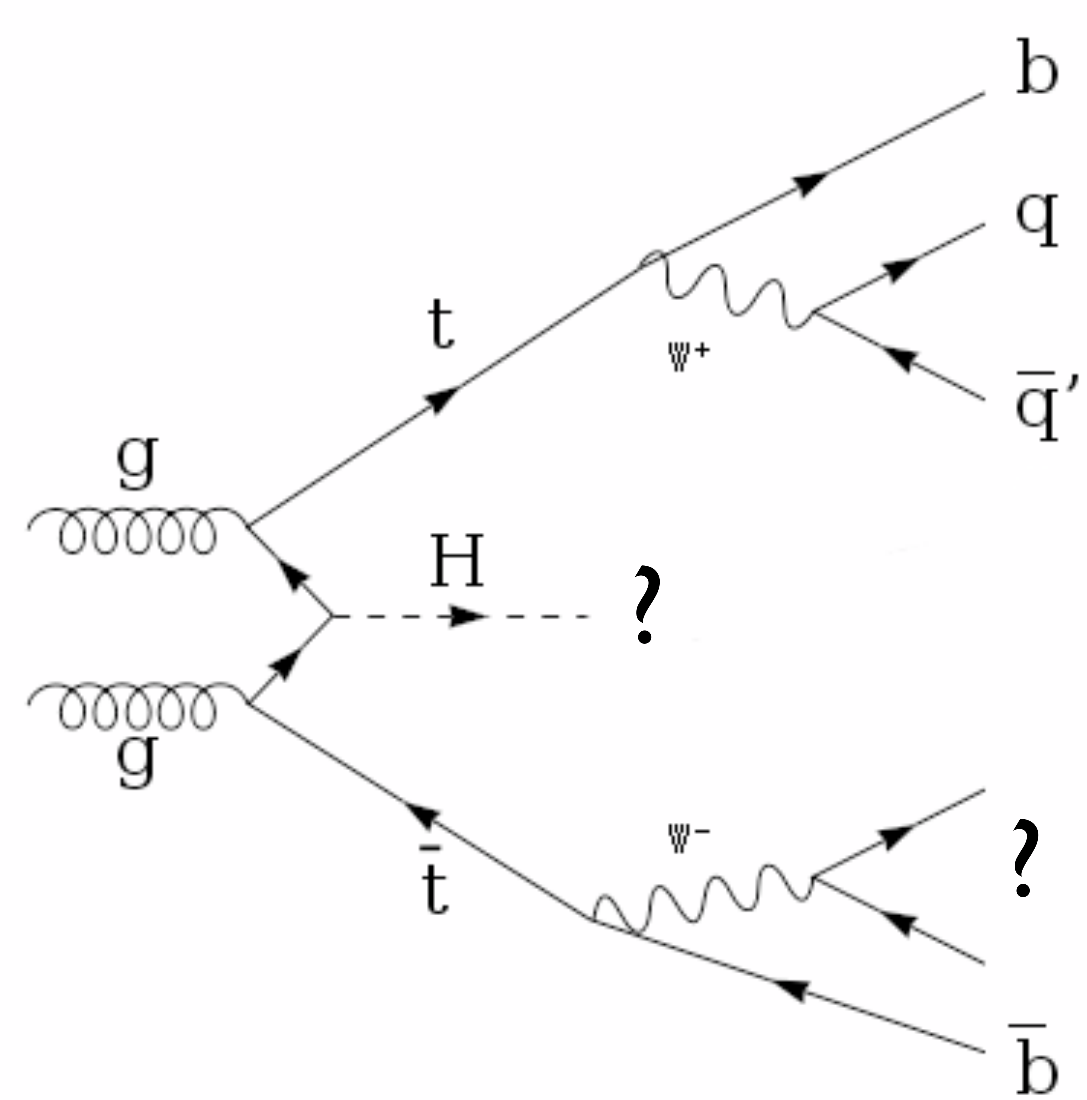


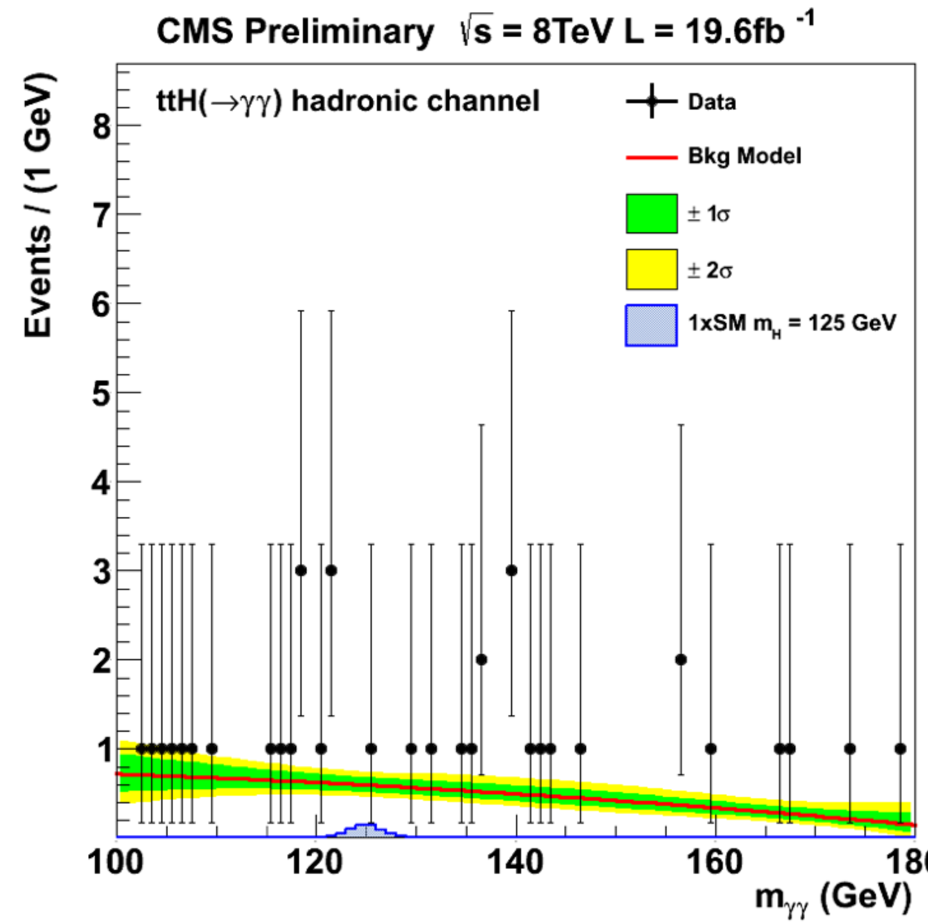


Dominant background
if H → bb



ttbar + H→γγ





- Rare but useful process to measure Higgs coupling constants
  - to be discussed in detail after Higgs
- Experimentally challenging due to very small cross section
  - 130±20 fb !