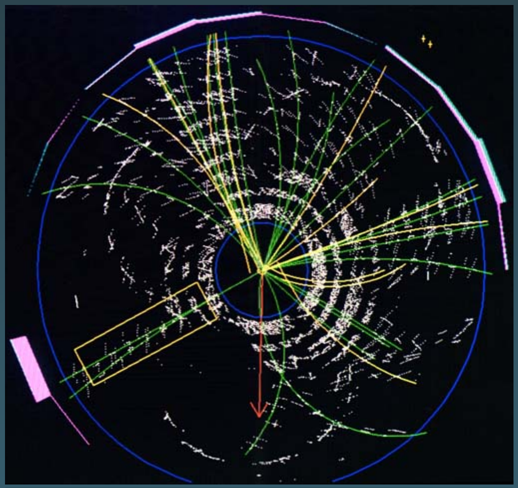
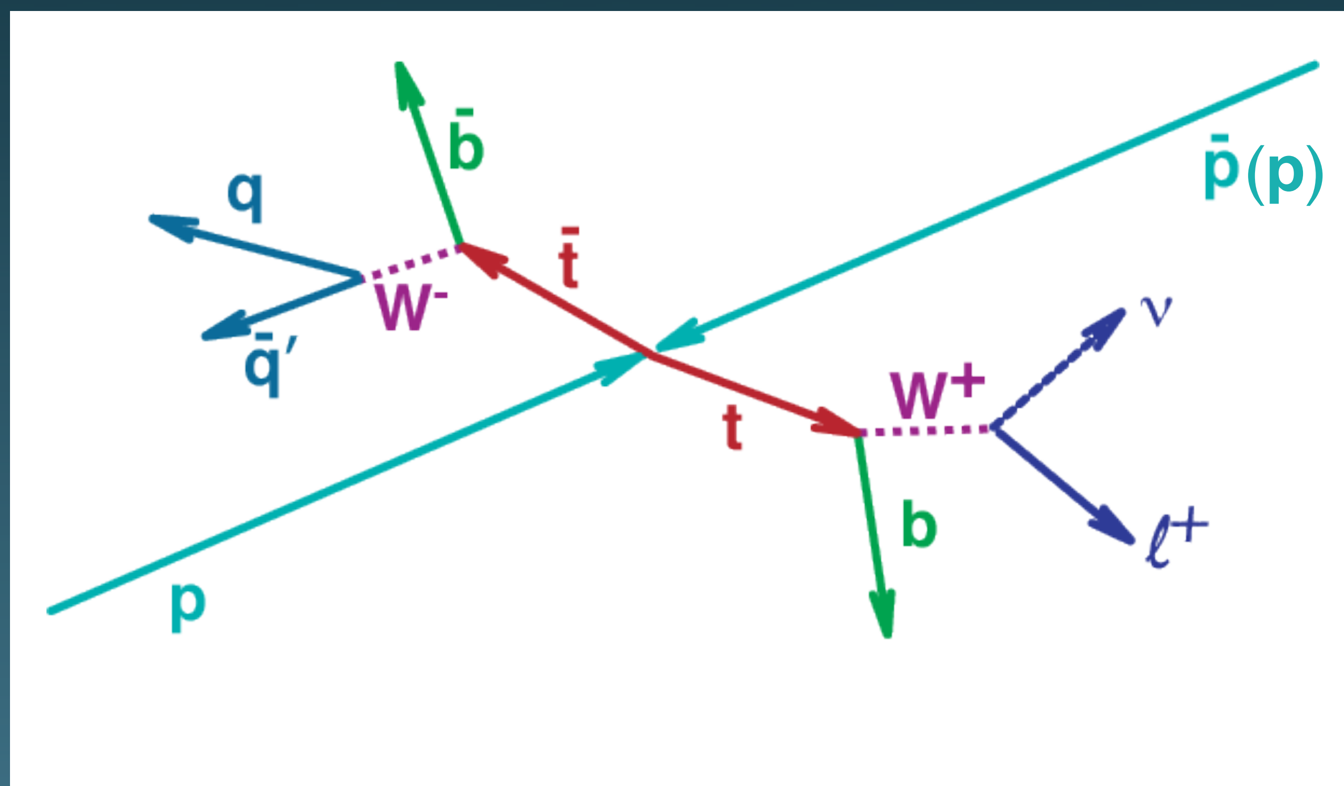
Top Quark and Electroweak Physics



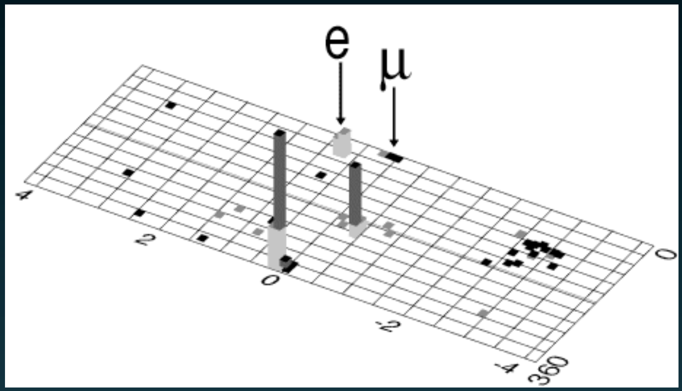
Robin Erbacher -- UC Davis

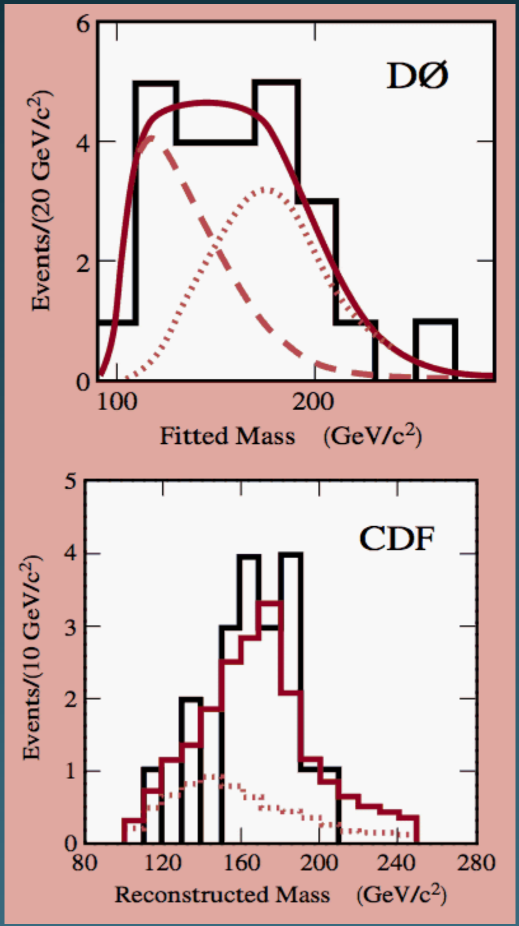
UC Santa Cruz APS DPF Meeting August 2013

Top Quark Physics

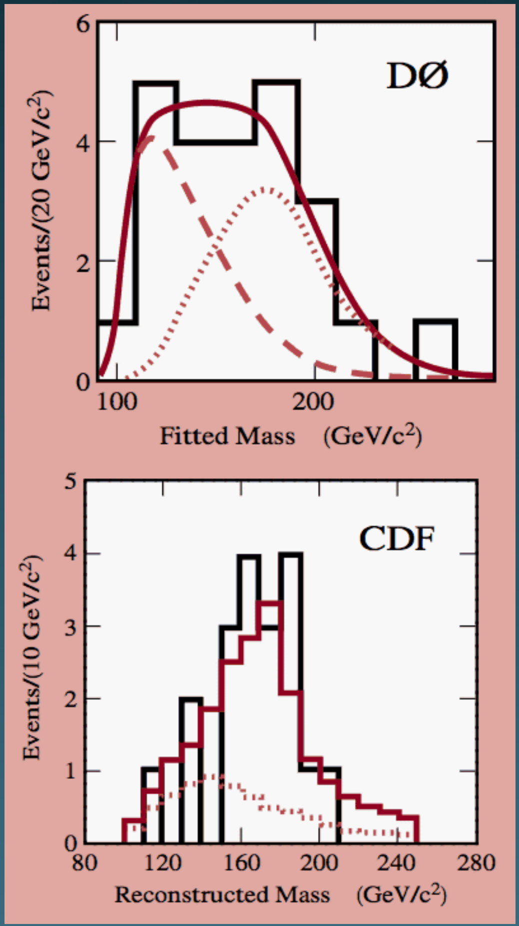


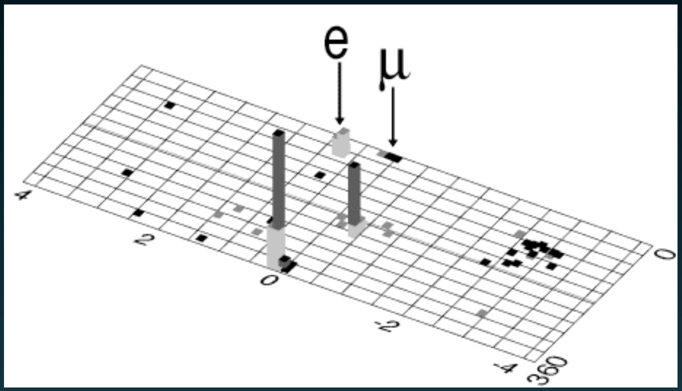
Top Discovery!
Tevatron Run 1
1994-5

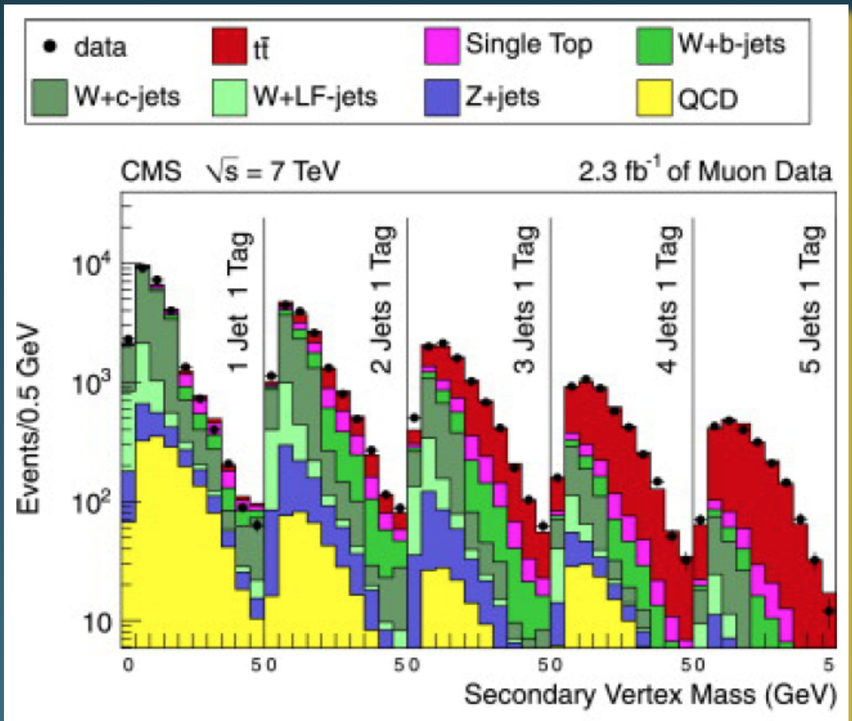




Top Discovery!
Tevatron Run 1
1994-5

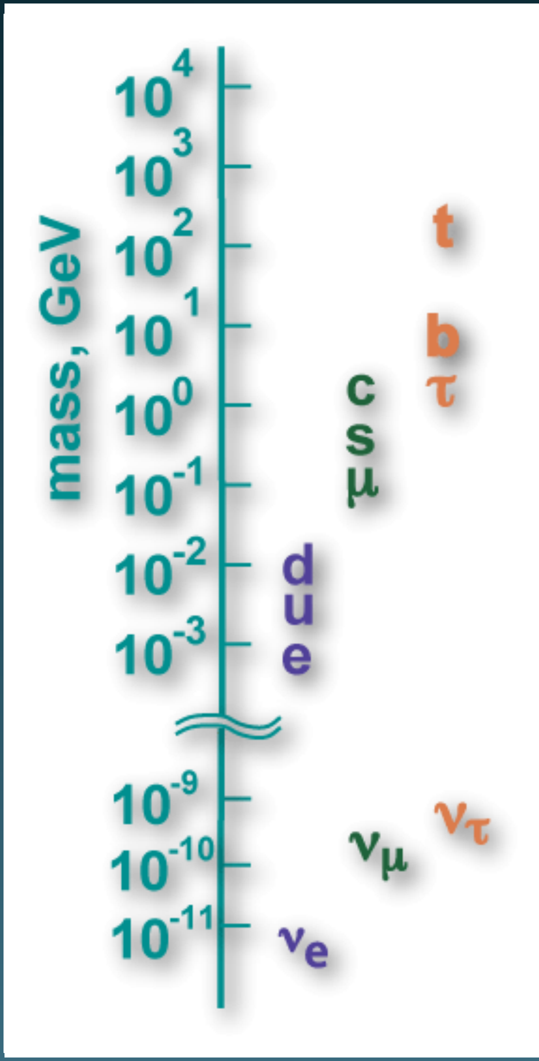


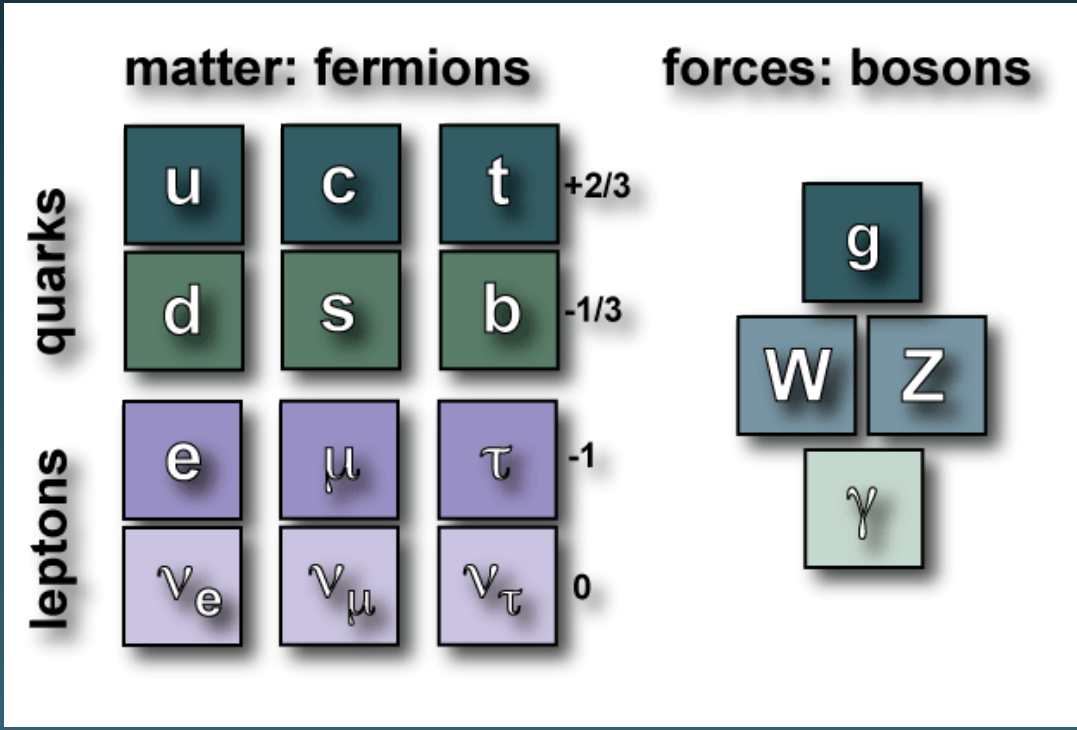




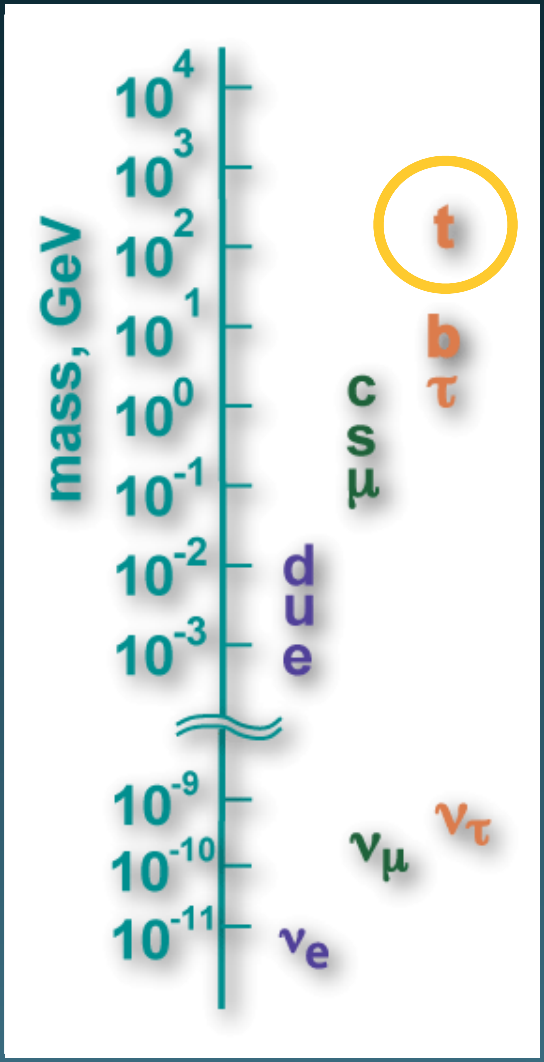
Now: Huge top sample sizes

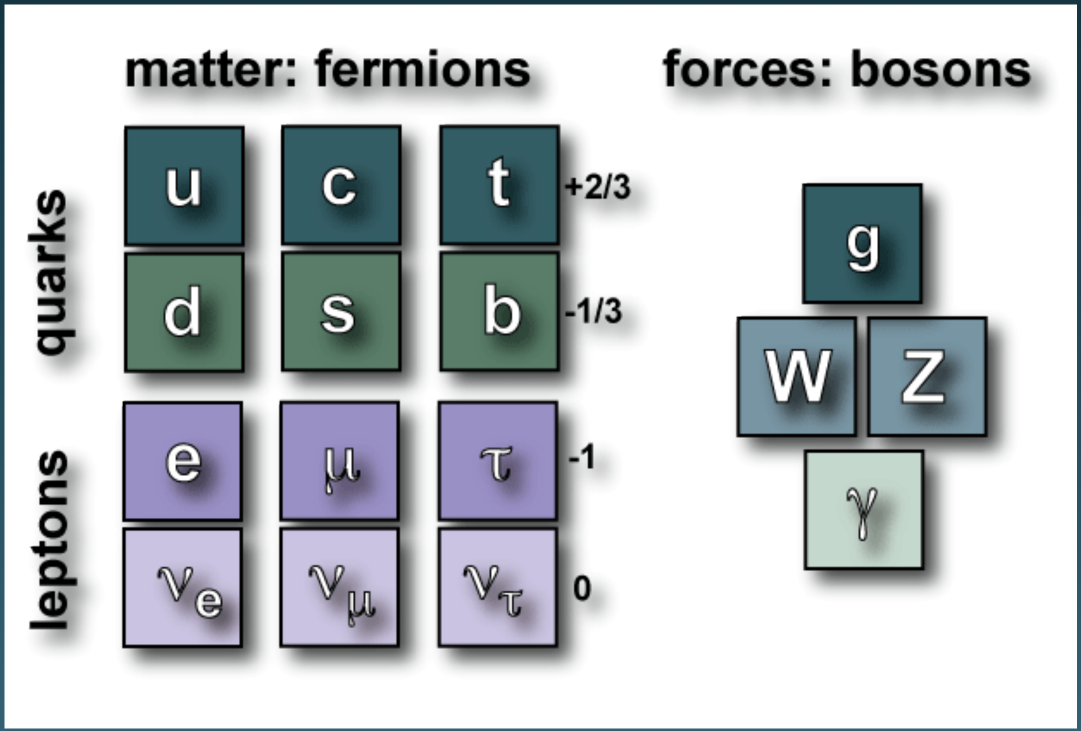
periodic table of the particles





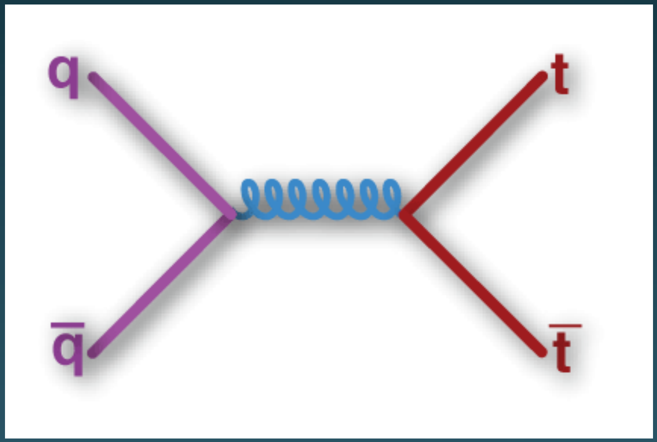
periodic table of the particles

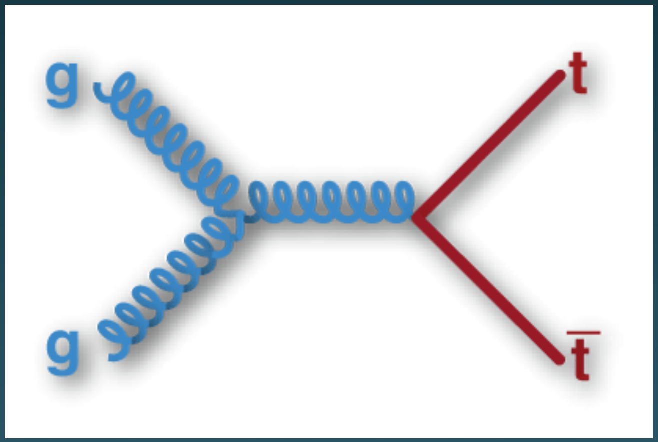




How is Top Produced?

~85% **Tevatron** ~15%

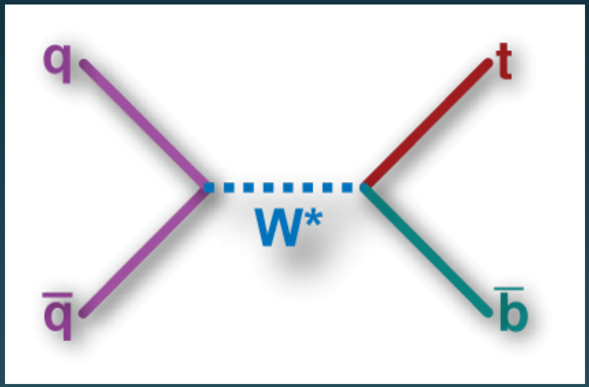




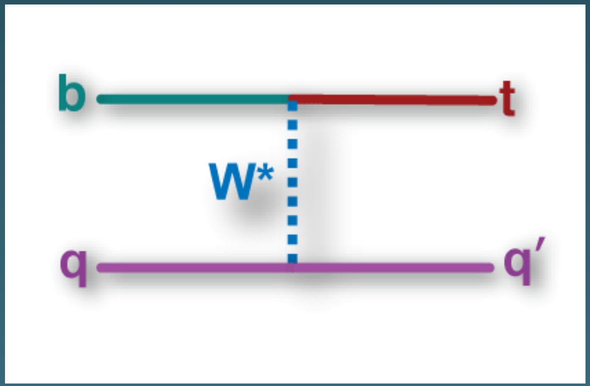
~15% **LHC** ~85%

How else is Top Produced?

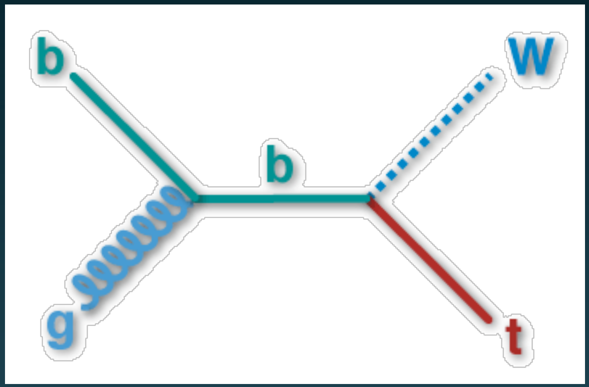
EWK (single top)



s-channel



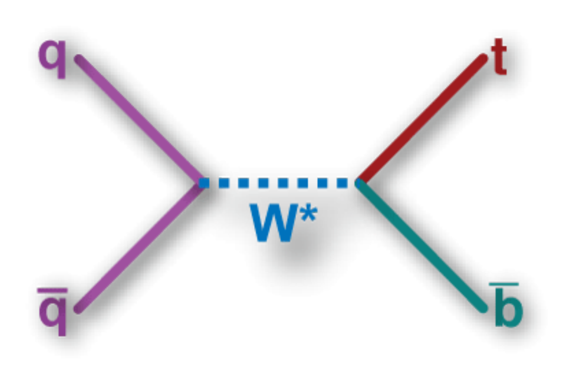
t-channel



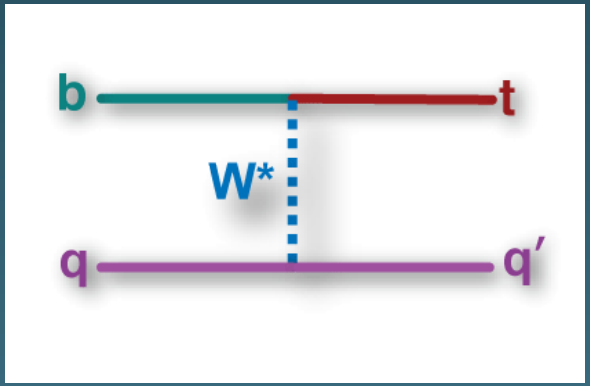
associated Wt

How else is Top Produced?

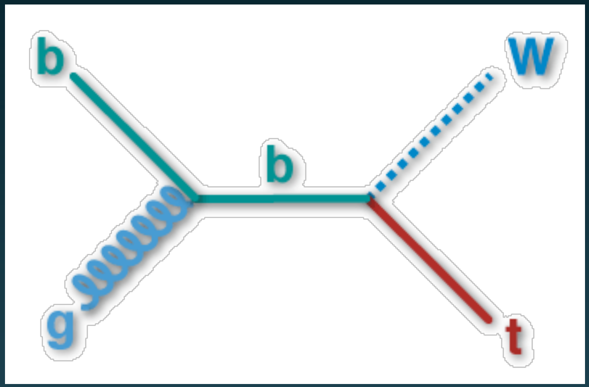
EWK (single top)



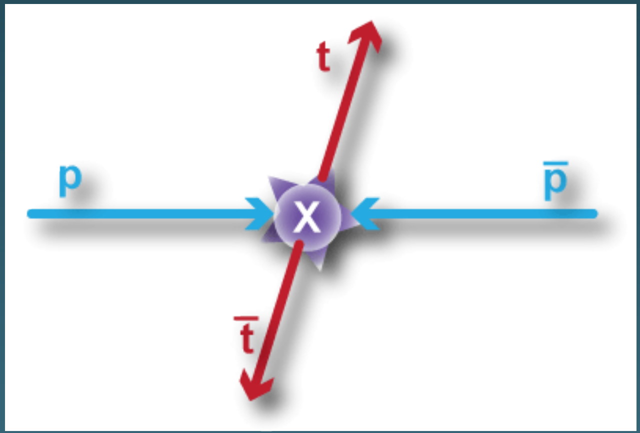
s-channel



t-channel

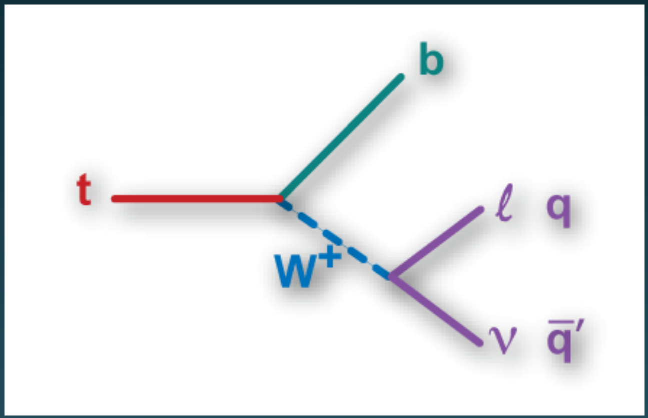


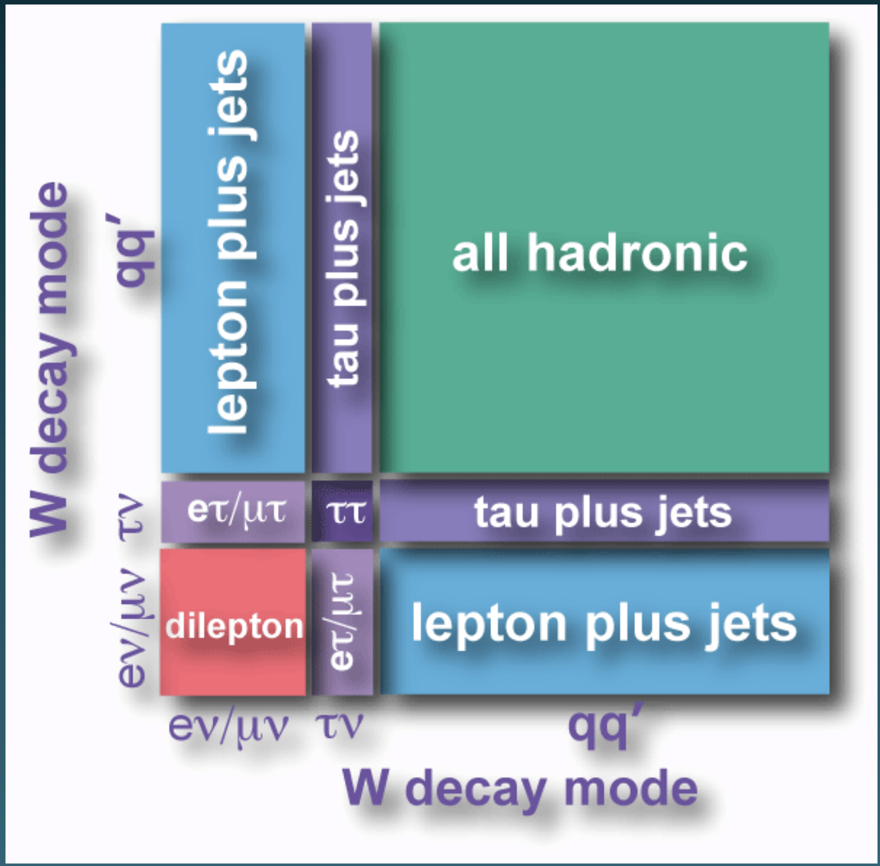
associated Wt



New production?

How does top decay?

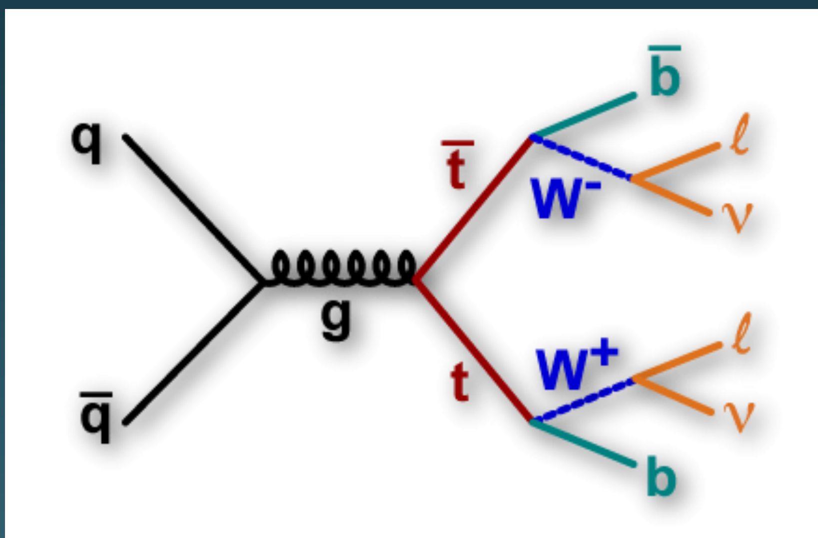


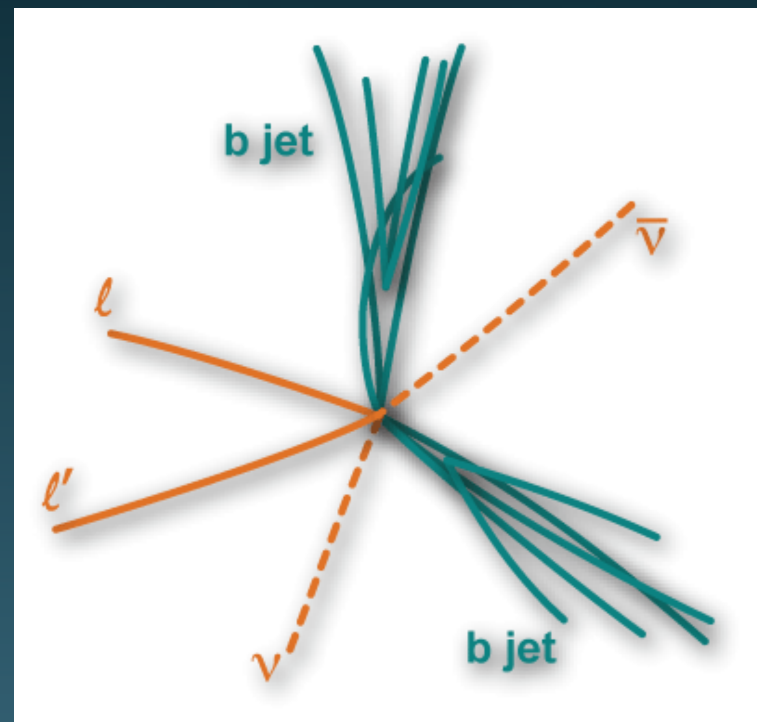


$t \to Wb \sim 100\%$


dilepton

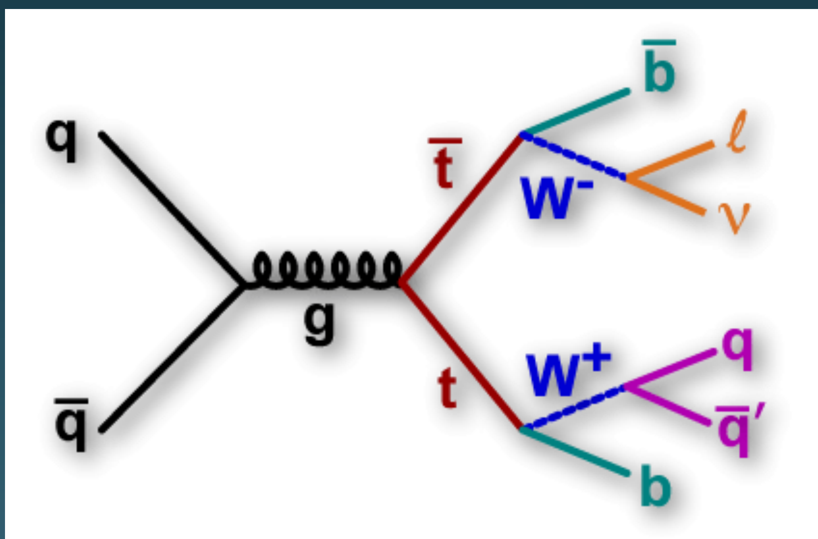
Dilepton

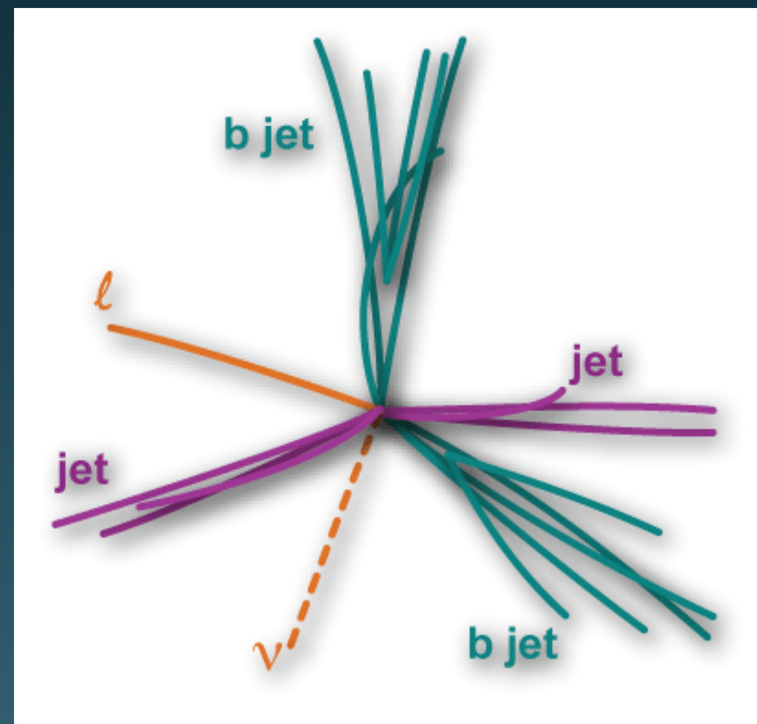

q
$\bar{q}$
g
$\bar{t}$
t
W^-
W^+
$\bar{b}$
b
ℓ
ν
ℓ
ν


b jet
$\bar{\nu}$
ℓ
ℓ'
ν
b jet

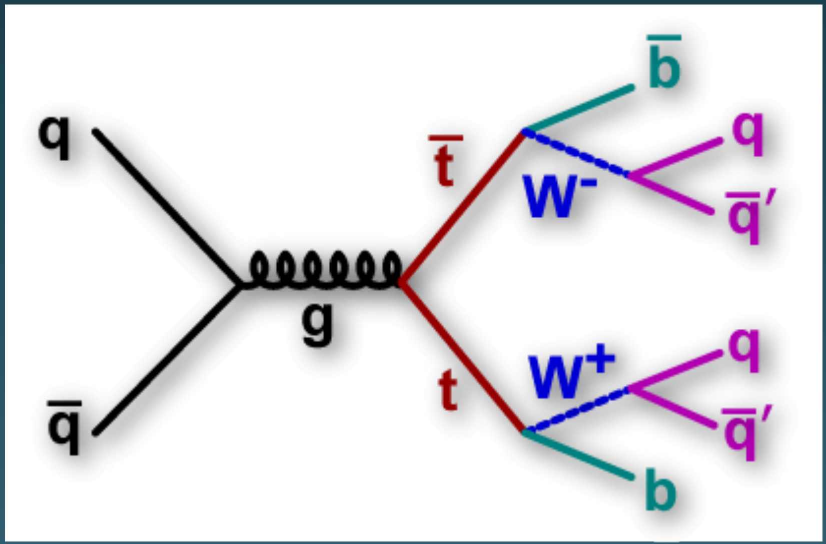
lepton plus jets

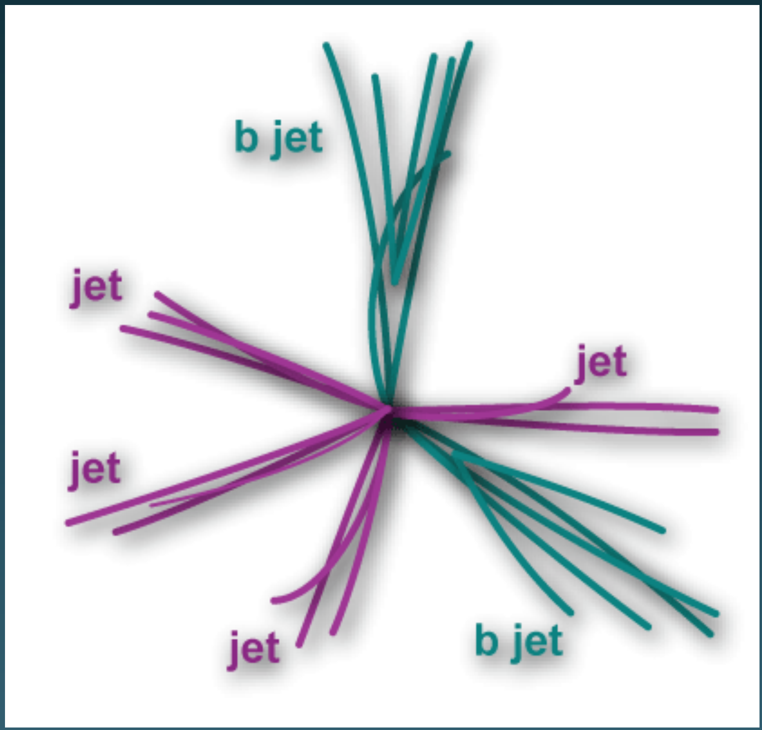
Lepton+Jets



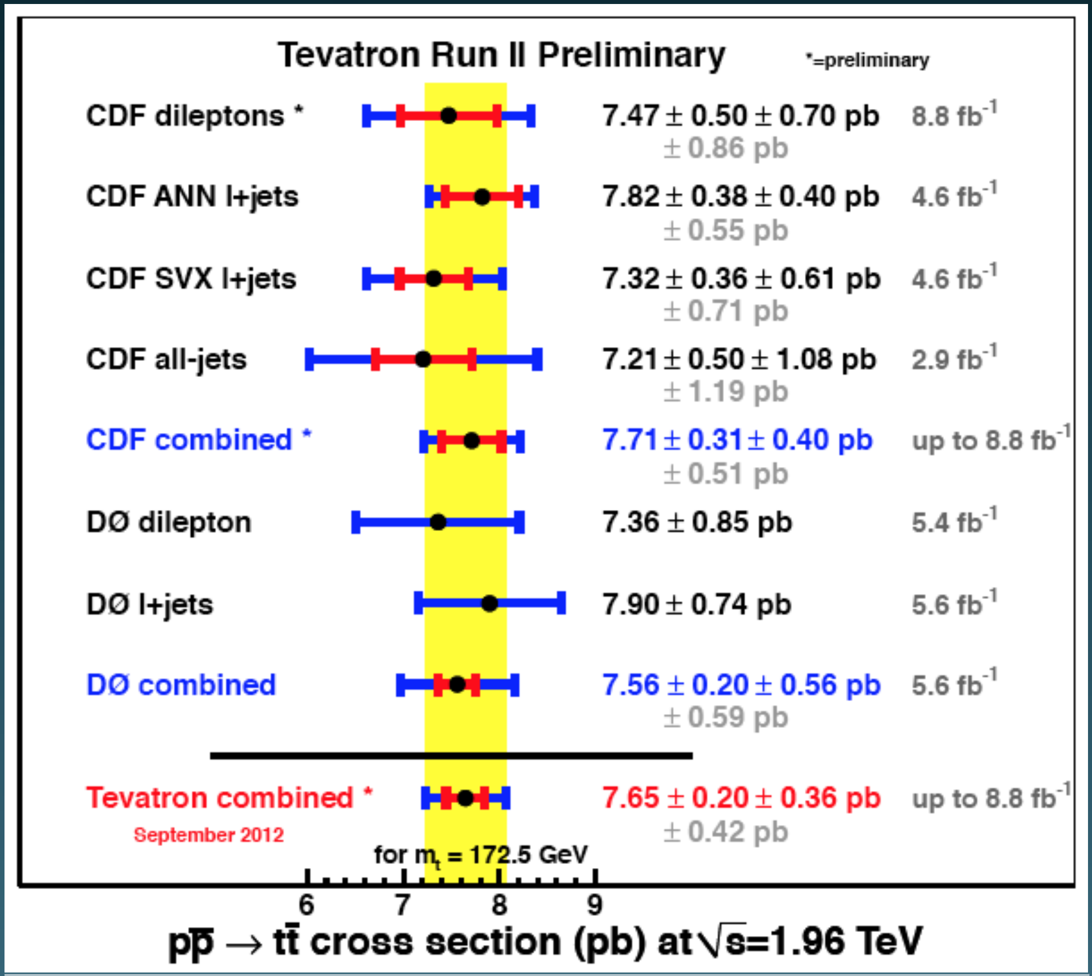


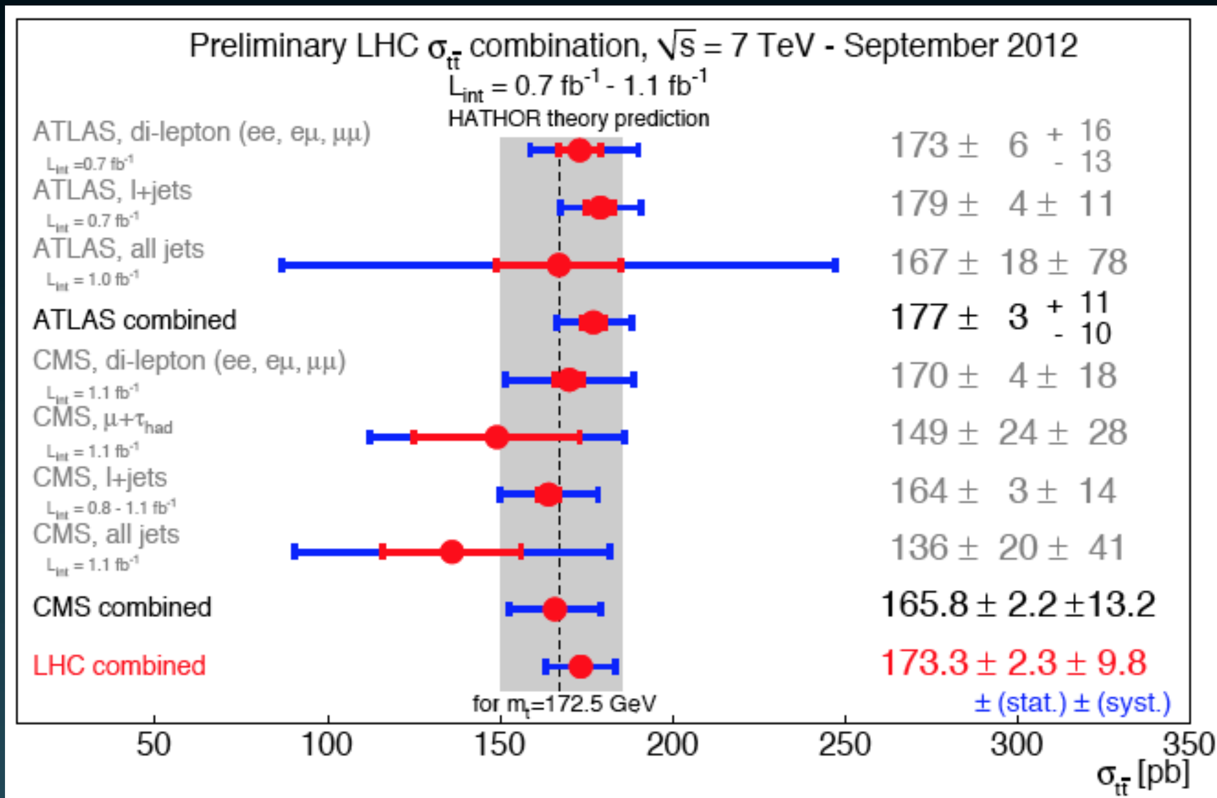
All-hadronic





Top Pair Production





8 TeV results:

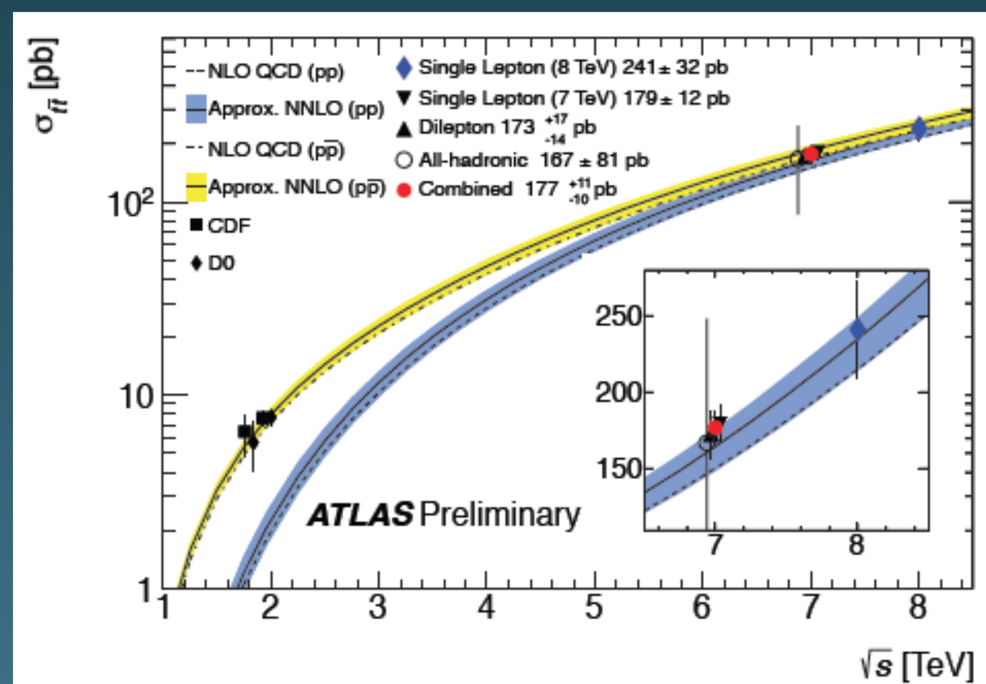
ATLAS ℓ+j: 232 ± 2(stat) ± 31(syst) ± 9(lumi) pb

CMS $\ell\ell$: 227 ± 3(stat) ± 10(syst) ± 10(lumi) pb

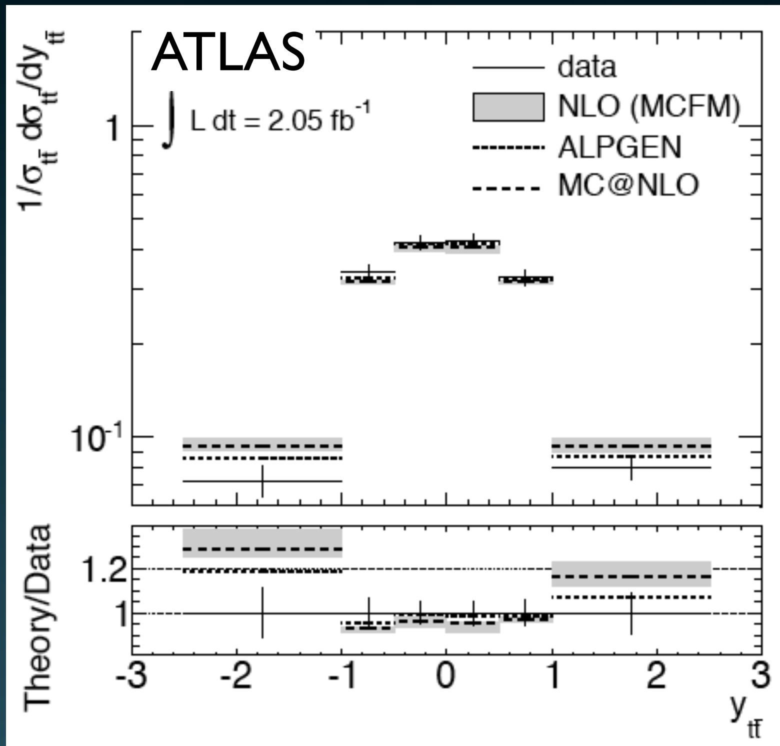
CMS ℓ+j: 228 ± 9(stat)$^{+29}_{-26}$(syst) ± 10(lumi) pb

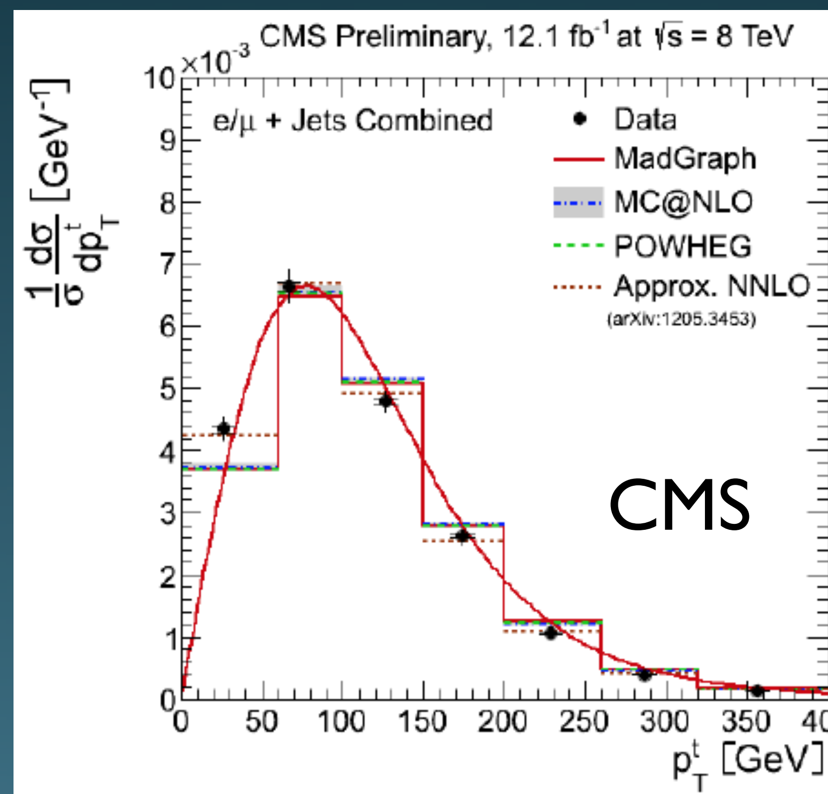
Total uncertainty (CMS $\ell\ell$): 6.3%

Top Pair Production



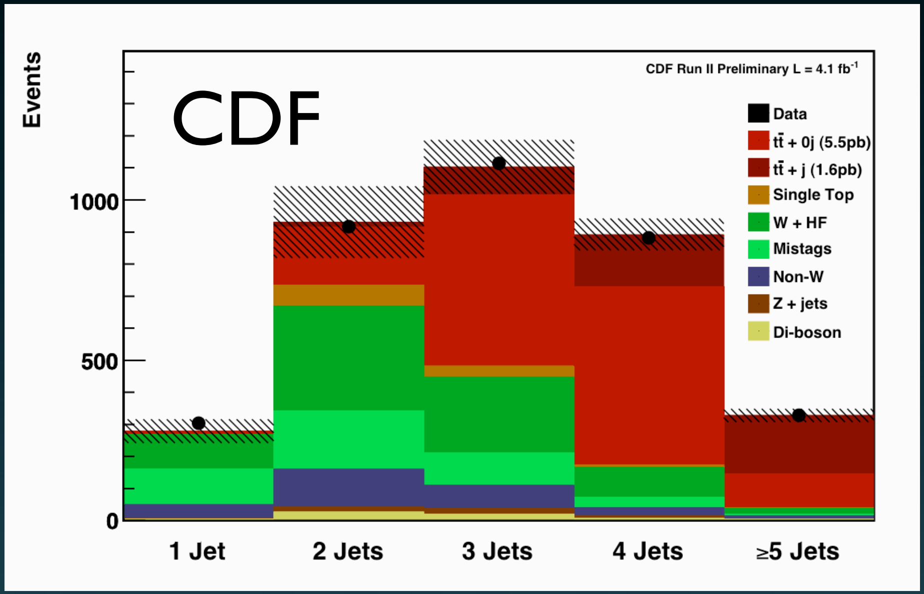
LHC is becoming a top factory

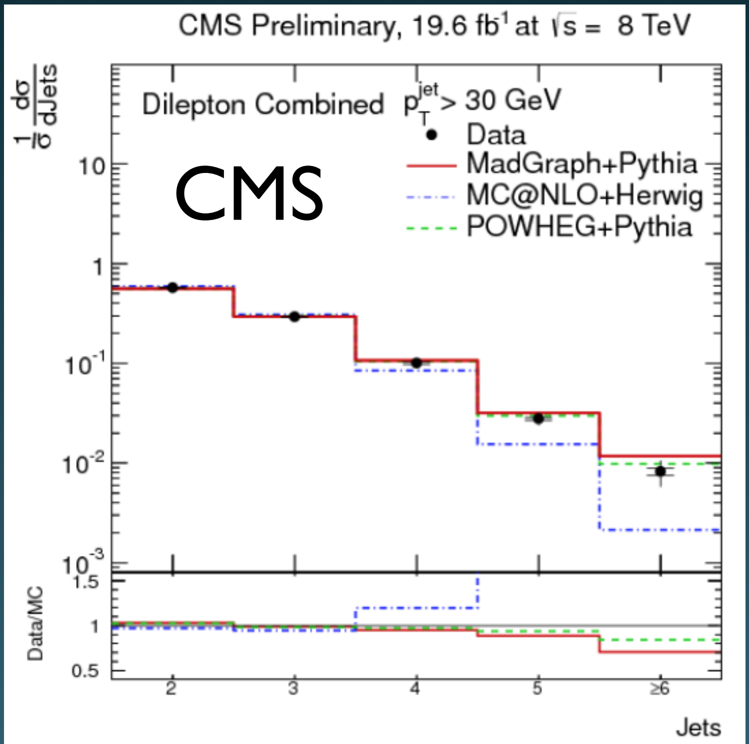


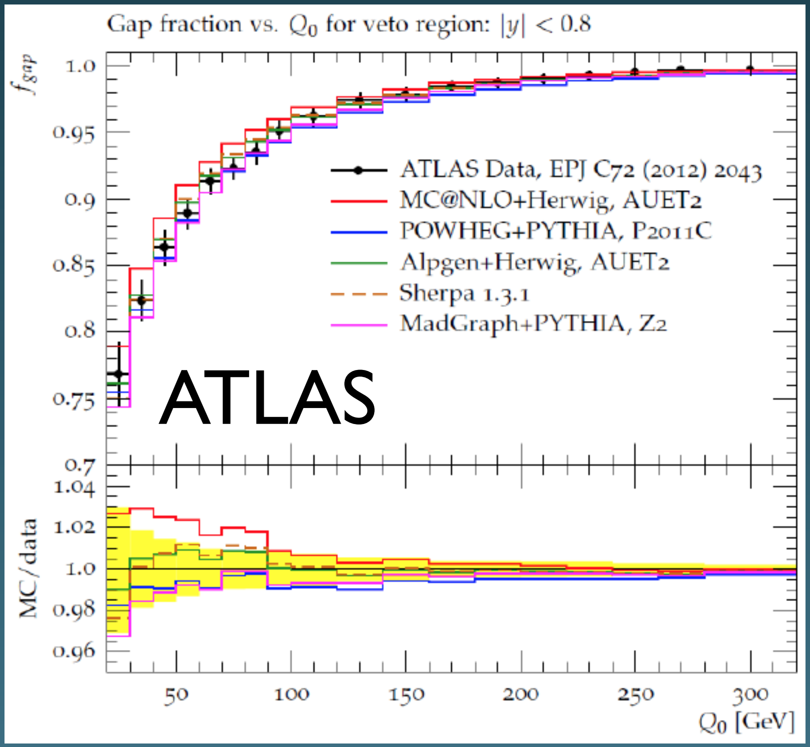


Top Differential Cross Section

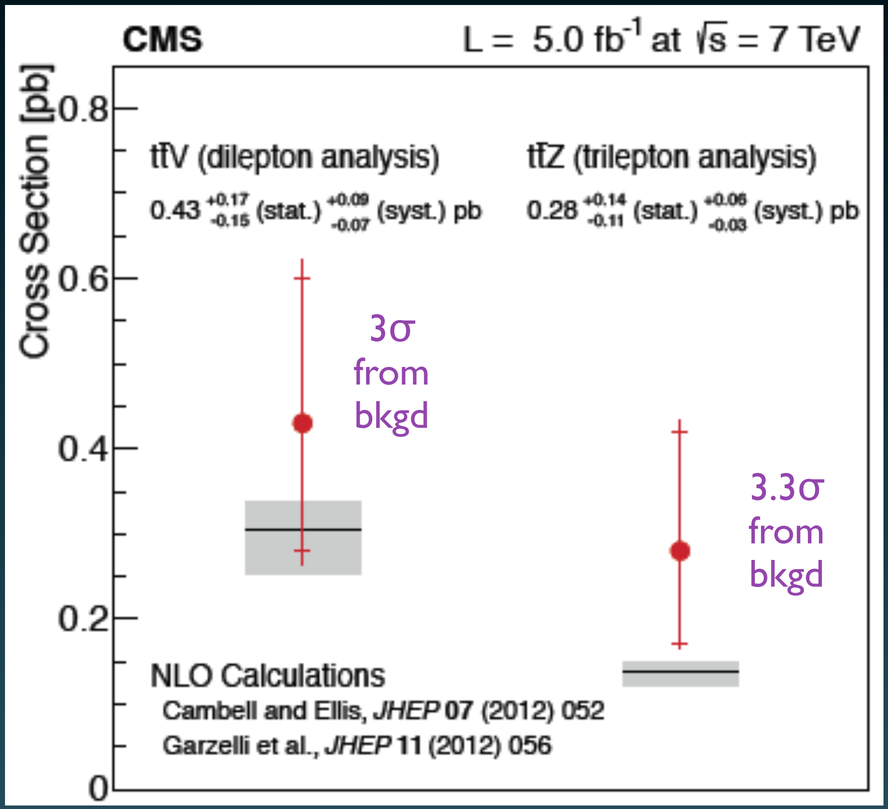
Top + Jets Production







Can use to reduce ISR/FSR uncertainty



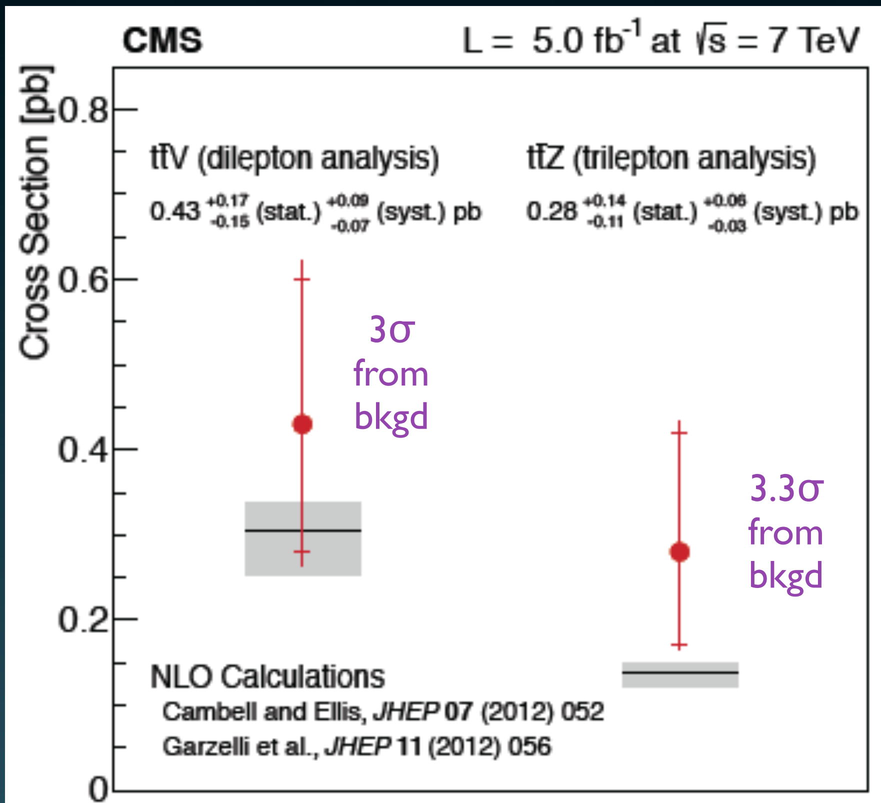
ttV (dileptons)

ttZ (trileptons)

ttW, ttZ, ttγ

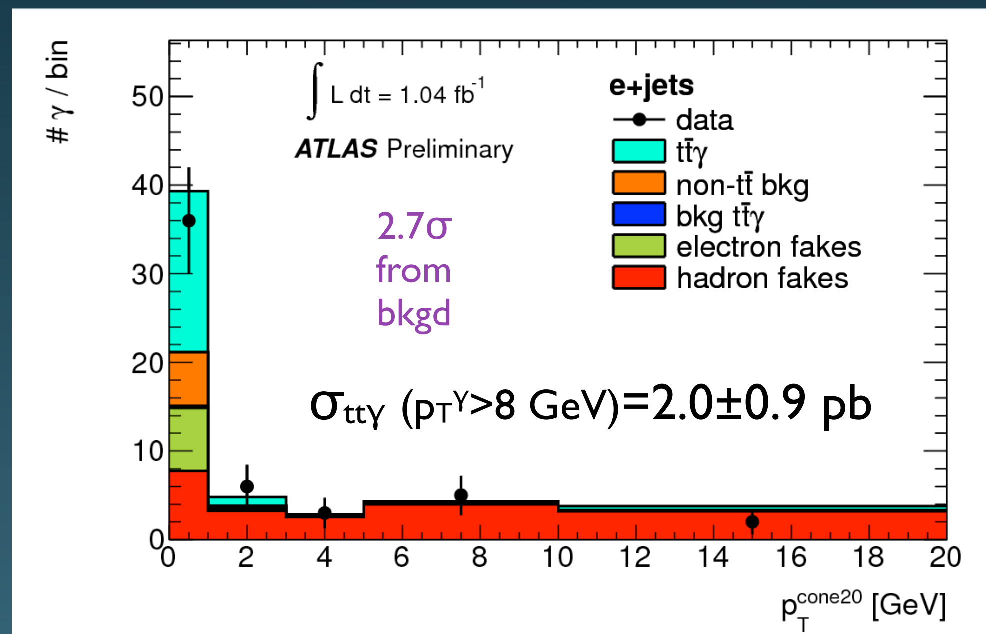
Evidence for ttV production

ttW, ttZ, ttγ



ttV (dileptons)

ttZ (trileptons)



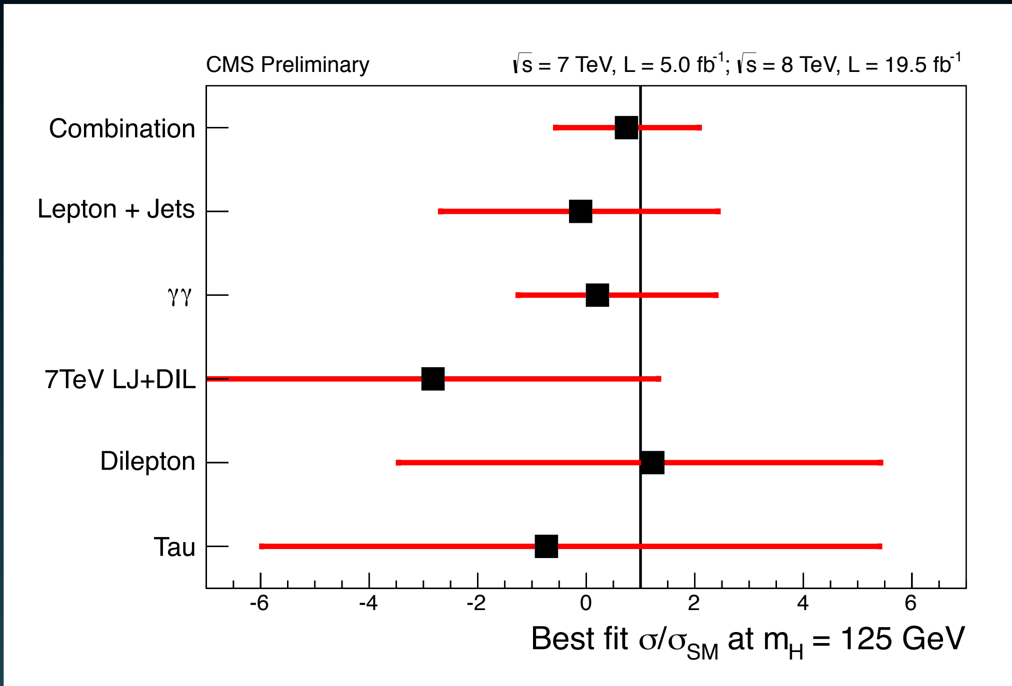
Evidence for ttV production

SM: $\sigma_{tt\gamma}$ (p_T^{γ}>8 GeV)=2.1±0.4 pb

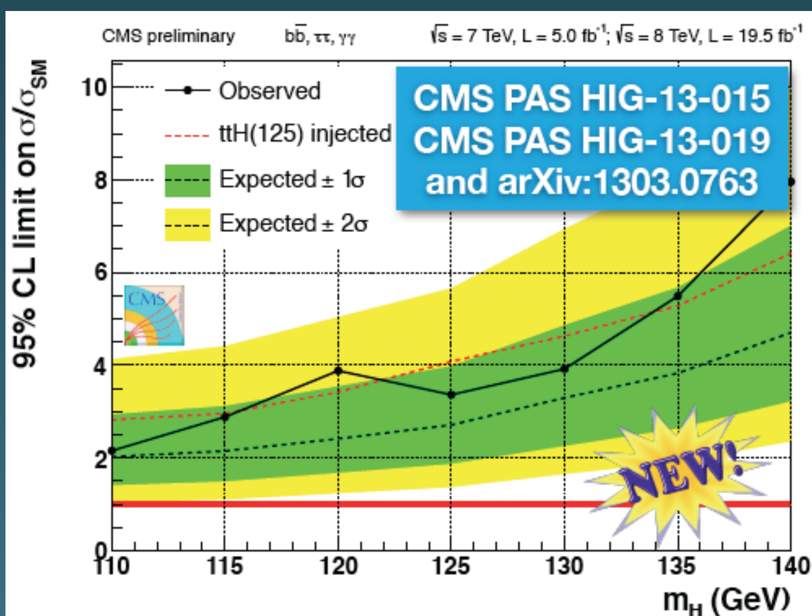
LO+NLO k-factor

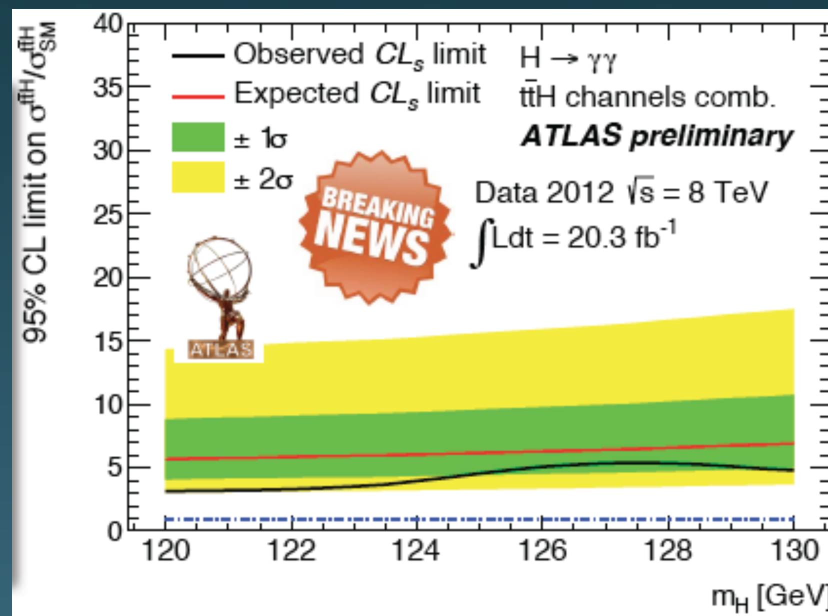
Top Yukawa

Latest on ttH production



CMS ttH combination

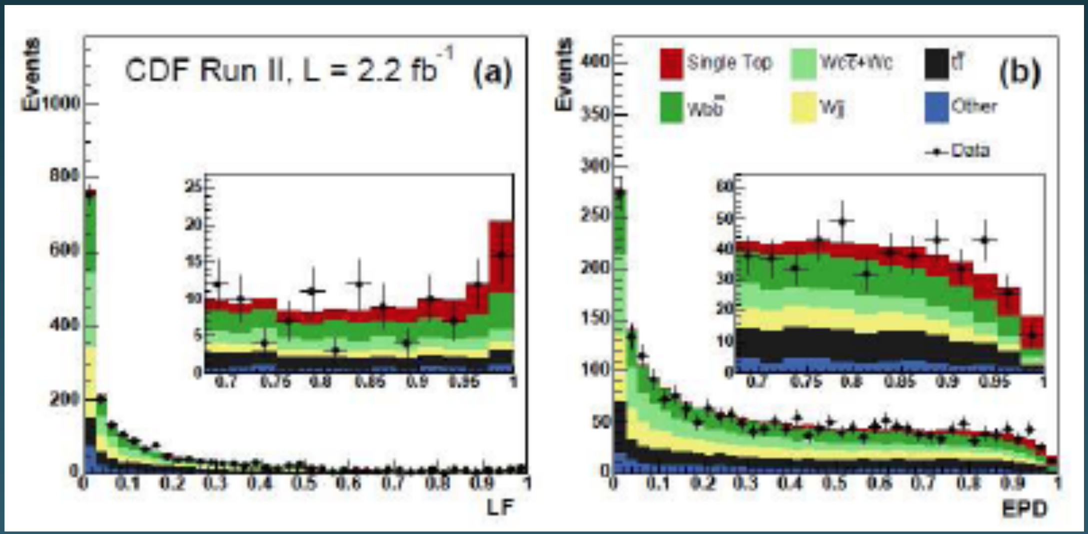




New ATLAS result, ttH, H→γγ

Electroweak Single Top Production

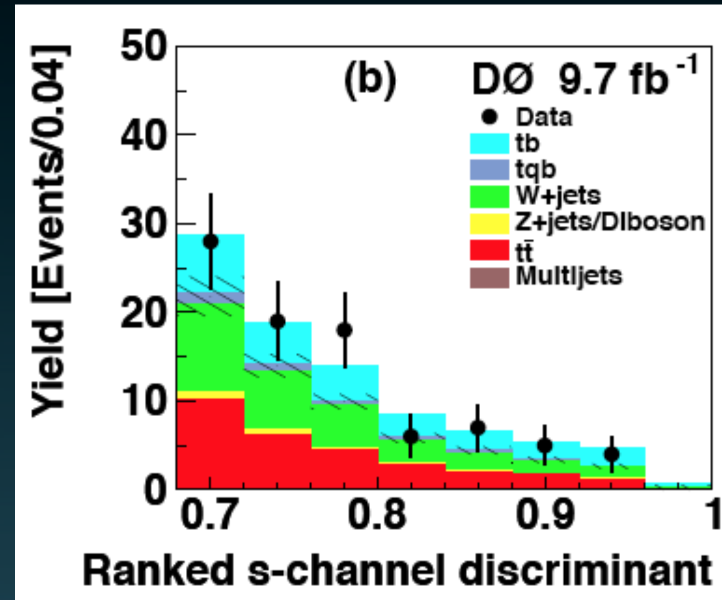
Large backgrounds, small signal: Need MVAs to find



2009 Tevatron observed s+t channels

See also parallel talks (H. Liu, M. Cremonessi - CDF)

Electroweak Single Top Production



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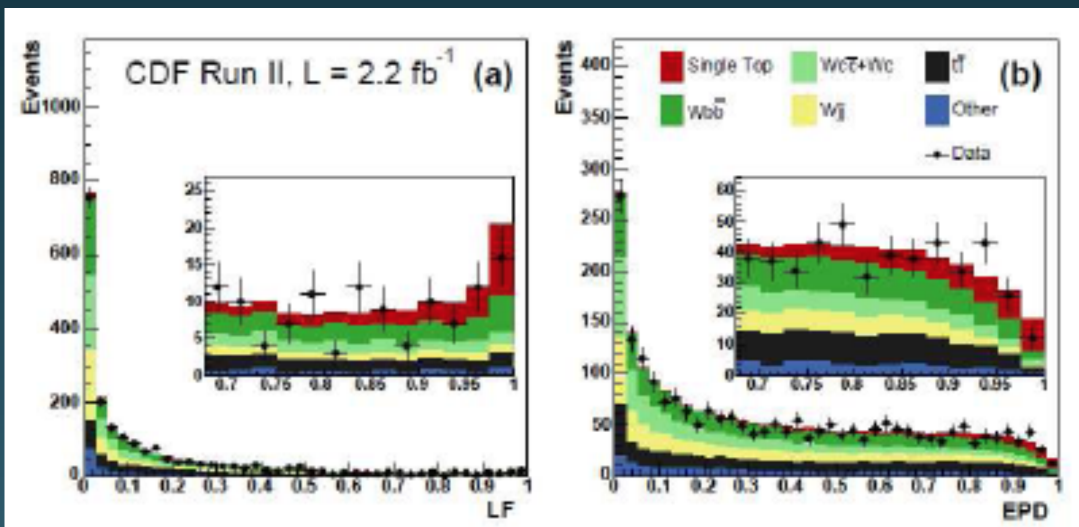
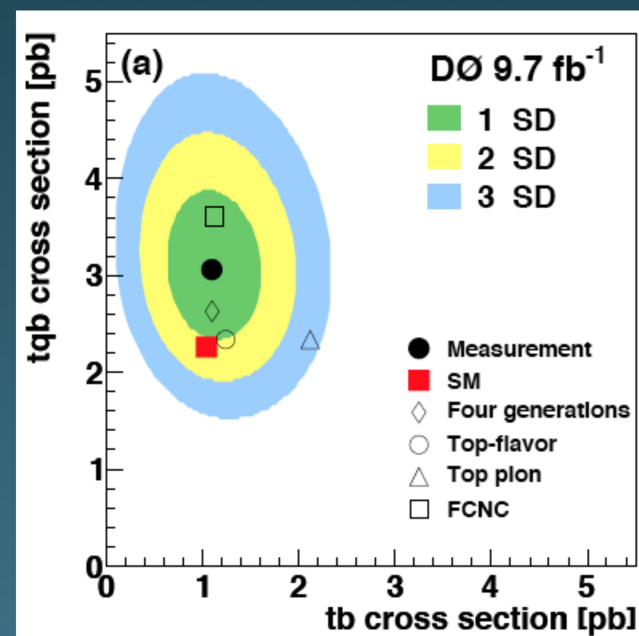


New: D0 first evidence for s-channel production



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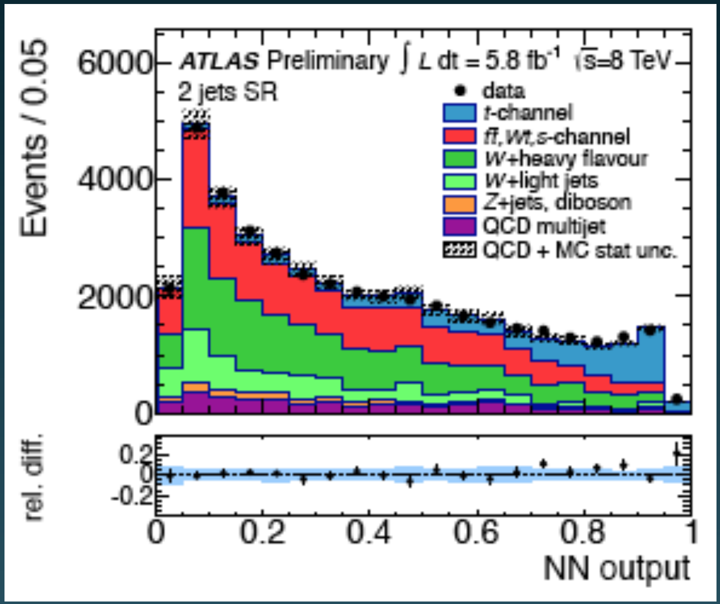
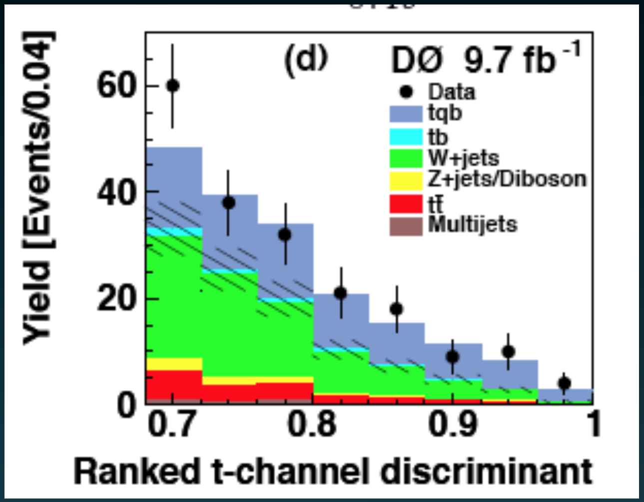
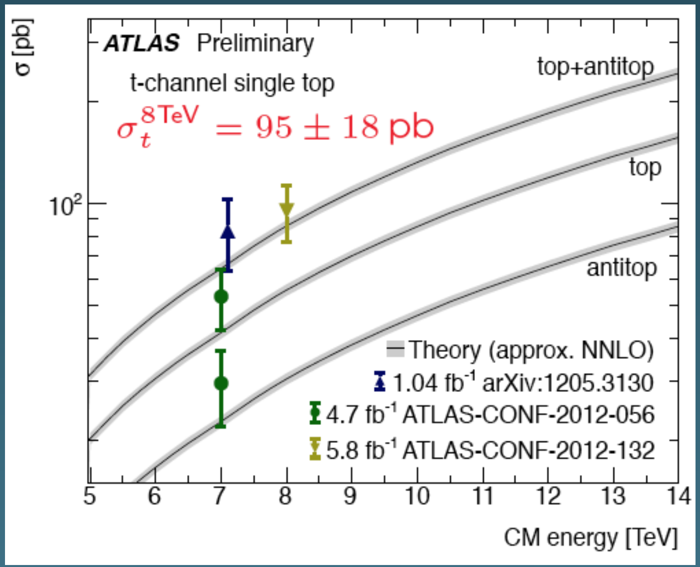
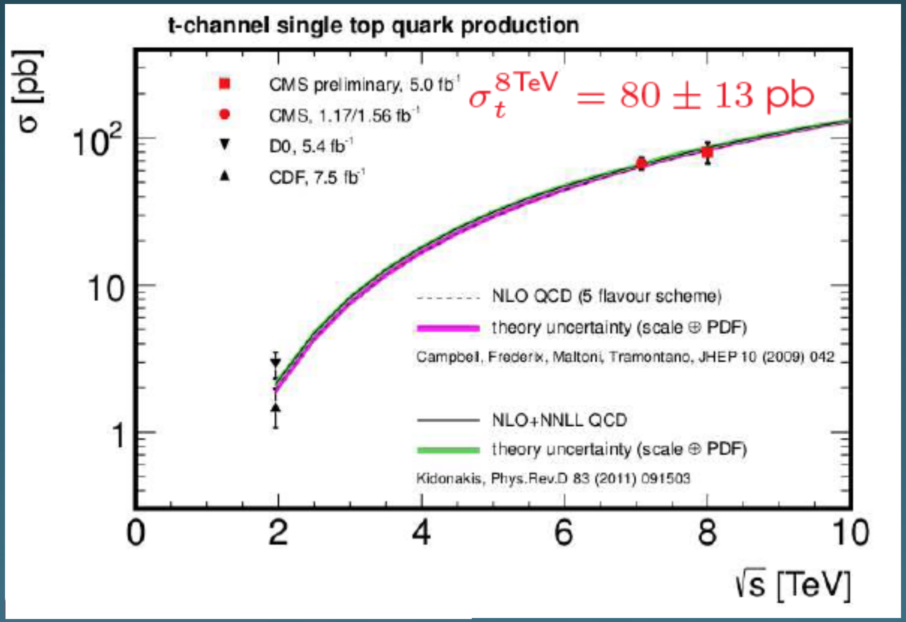
Electroweak
Single Top Production



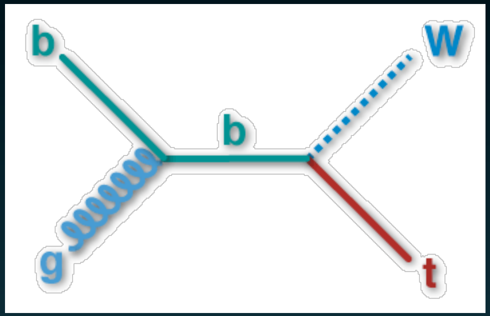


t-channel observed,
Tevatron & LHC





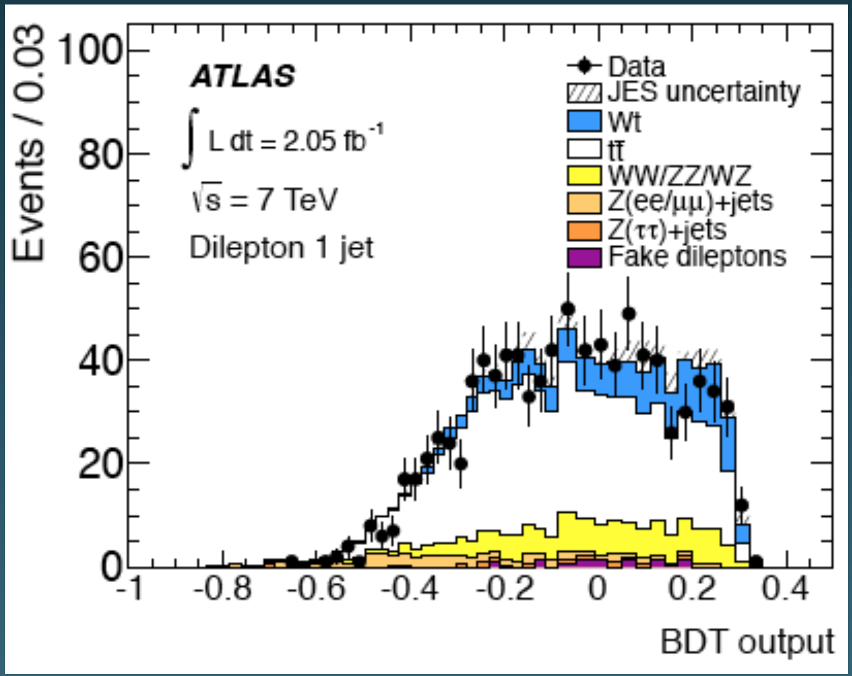
Electroweak Single Top Production



See also parallel talk by P. Baringer

Wt production

ATLAS Evidence 3.3σ

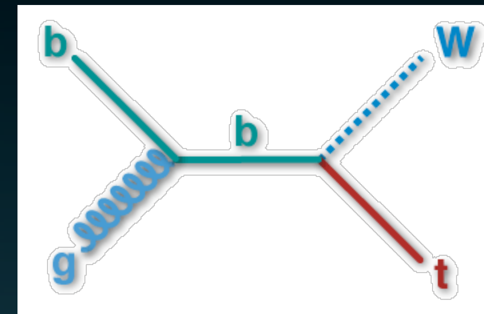


σ_t (7 TeV) = 16.8 ± 5.7 pb

SM σ_t (7 TeV) = 15.7 ± 1.2 pb

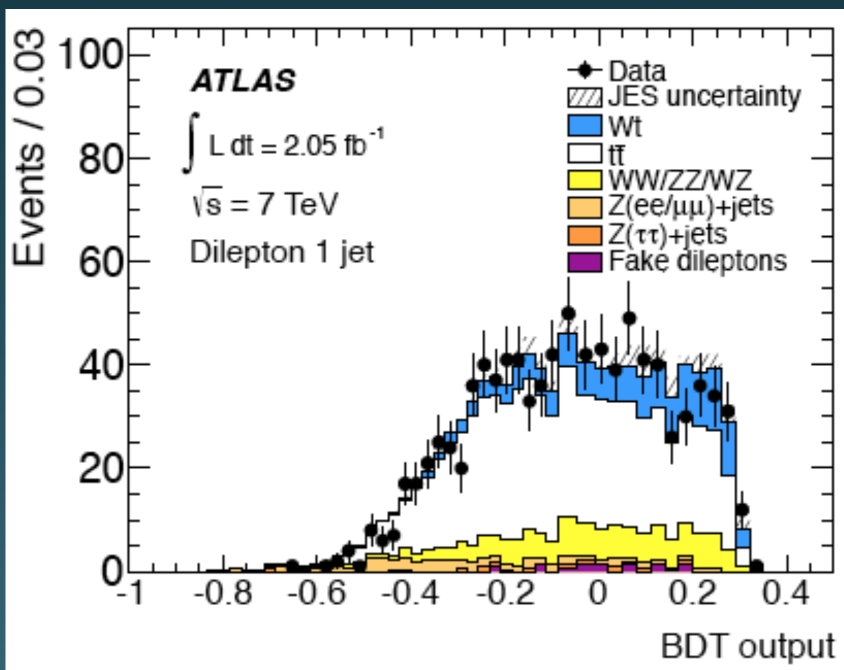
Electroweak
Single Top Production

See also parallel talk by P. Baringer



Wt production

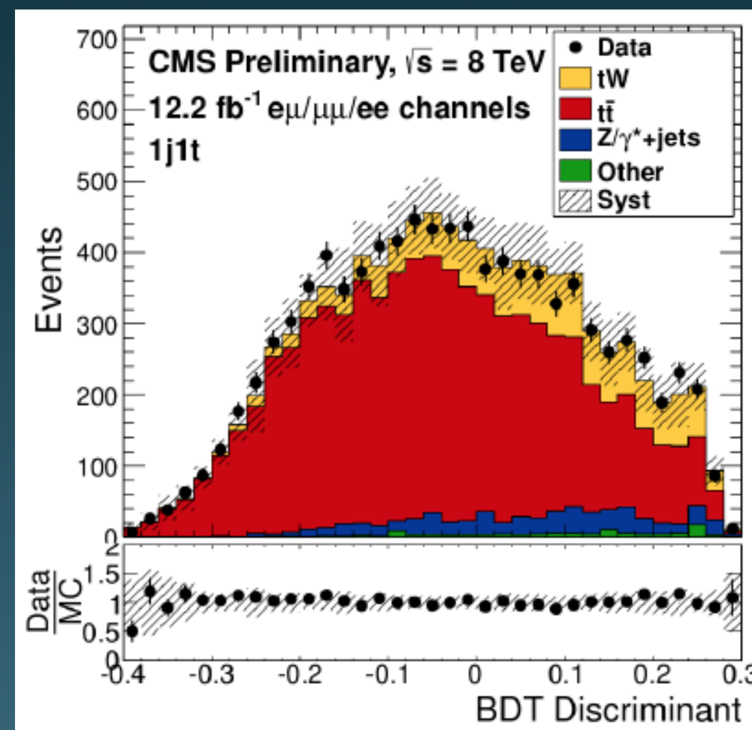
ATLAS Evidence 3.3σ



σ_t (7 TeV) = 16.8 ± 5.7 pb

SM σ_t (7 TeV) = 15.7 ± 1.2 pb

CMS Observation 6.0σ

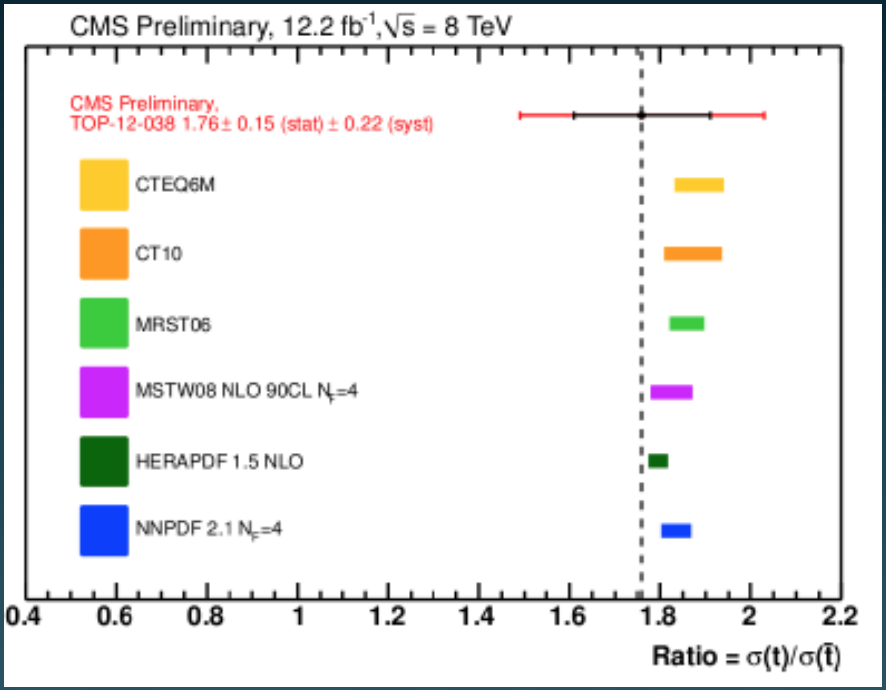


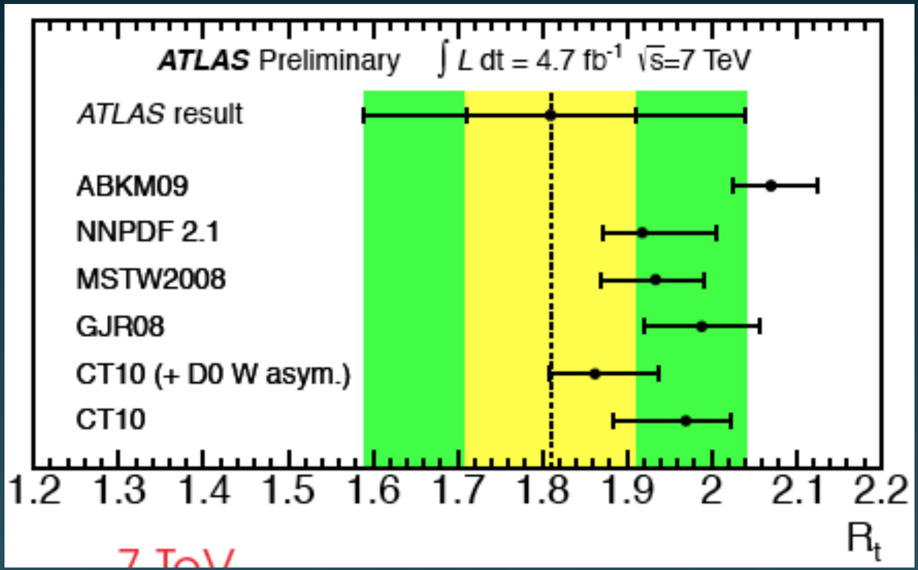
σ_t (8 TeV) = 23.4 ± 5.5 pb

SM σ_t (8 TeV) = 22.2 ± 1.5 pb

Ratio R_t and V_{tb}

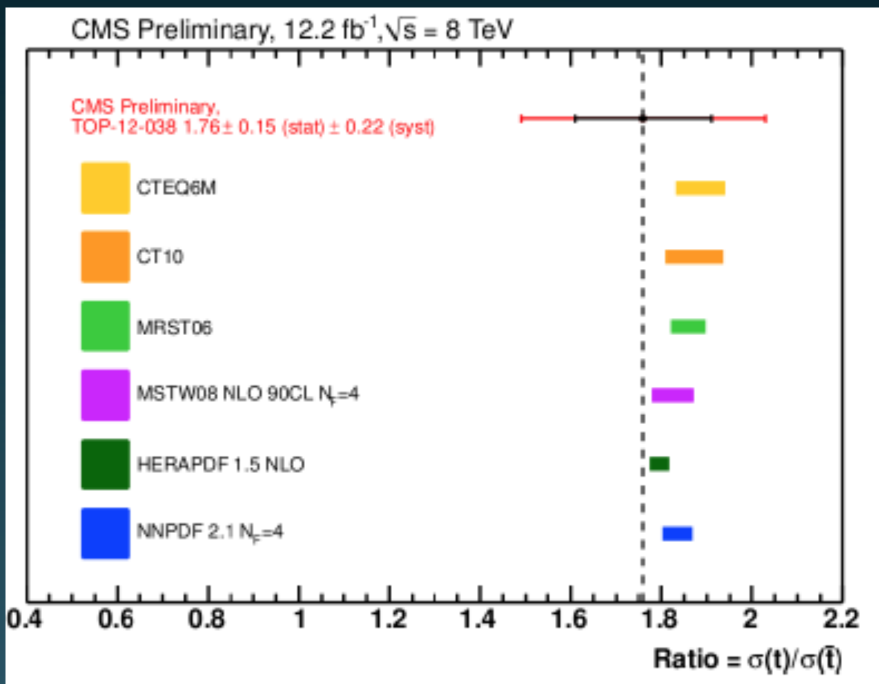
t-channel Ratio $R_t=\sigma_t/\sigma_{tbar}$ sensitive to u/d proton content

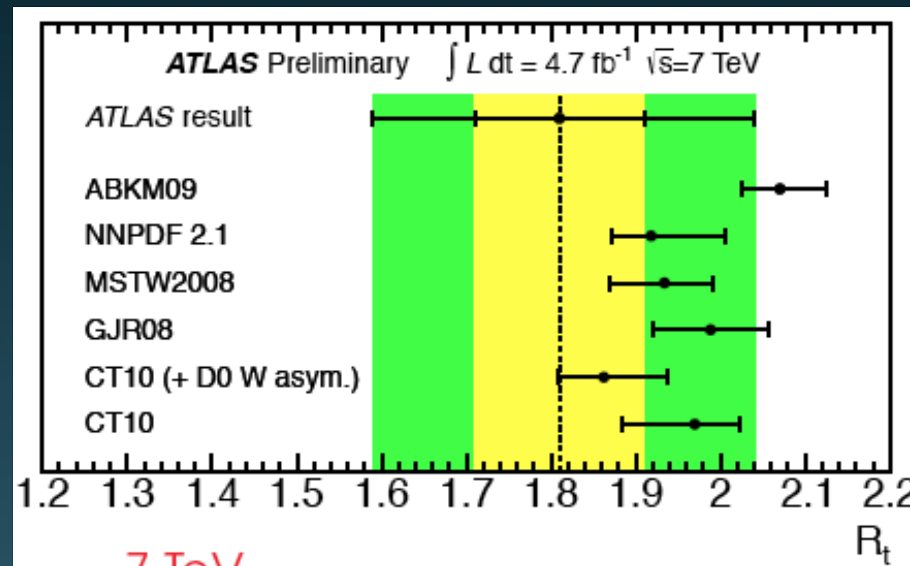




Ratio R_t and V_{tb}

t-channel Ratio $R_t = \sigma_t / \sigma_{tbar}$ sensitive to u/d proton content



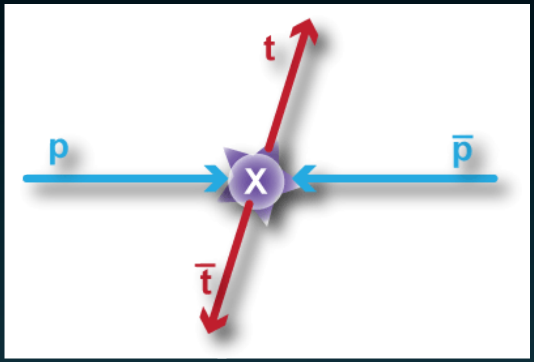


tWb coupling:

$|V_{tb} \cdot f|^2 \propto \sigma_t / \sigma_{SM}$

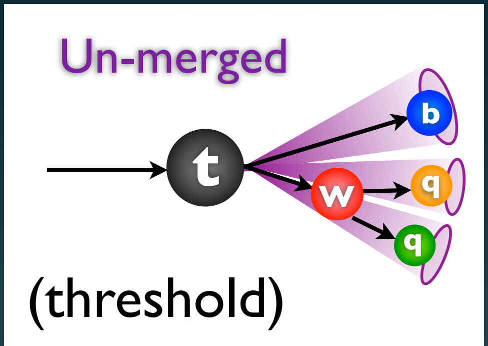
(f=1 in SM)

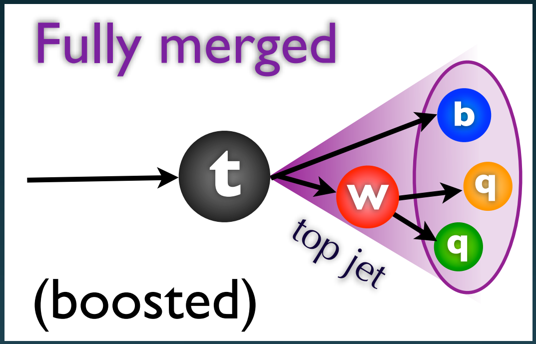
CMS 7 TeV:	$\|V_{tb}\| = 1.0 \pm 0.05$
CMS 8 TeV:	$\|V_{tb}\| = 0.96 \pm 0.08$
ATLAS 7 TeV:	$\|V_{tb}\| = 1.0 \pm 0.05$
ATLAS 8 TeV:	$\|V_{tb}\| = 1.0 \pm 0.1$ or
	$\|V_{tb}\| > 0.8$ @ 95% CL



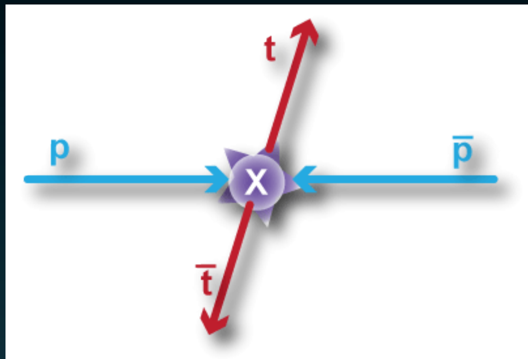
Resonant Production

See also parallel talks (P. Turner, R. Nayyar)





Resonant Production



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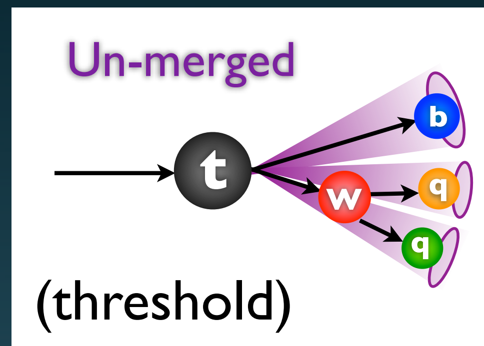
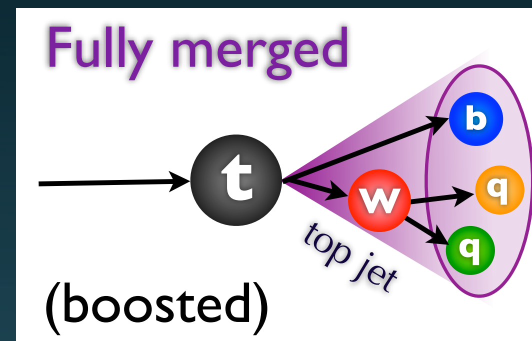
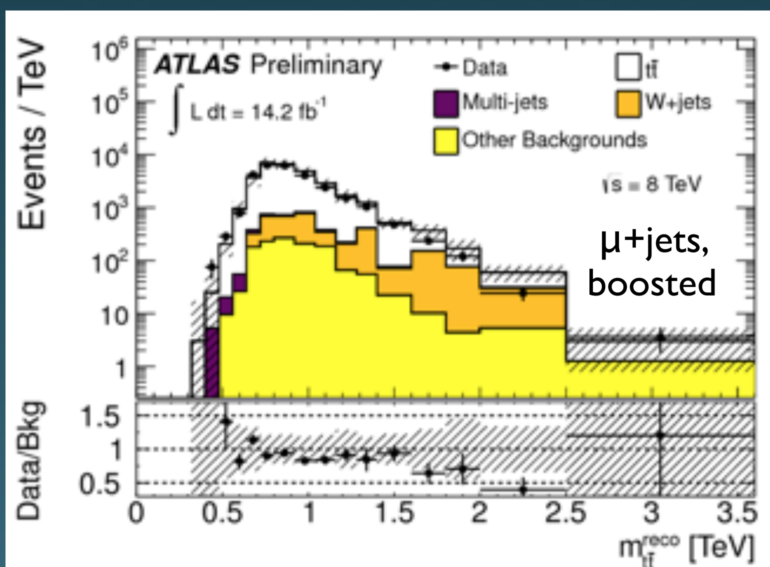
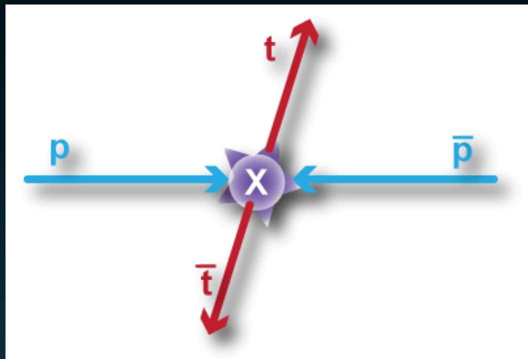


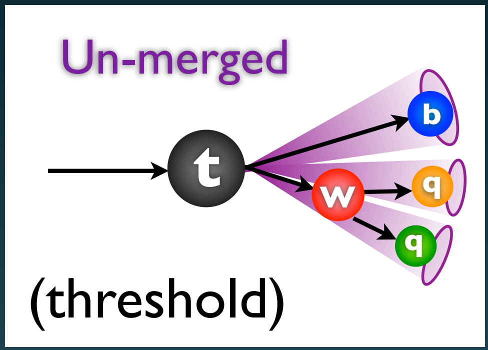


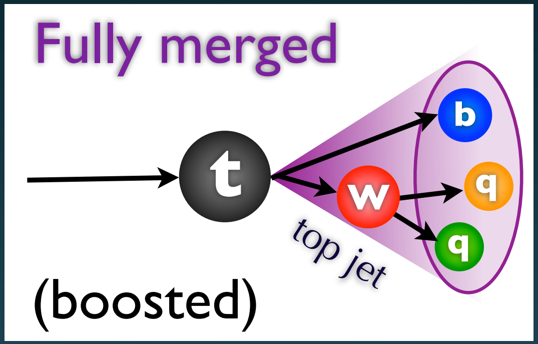


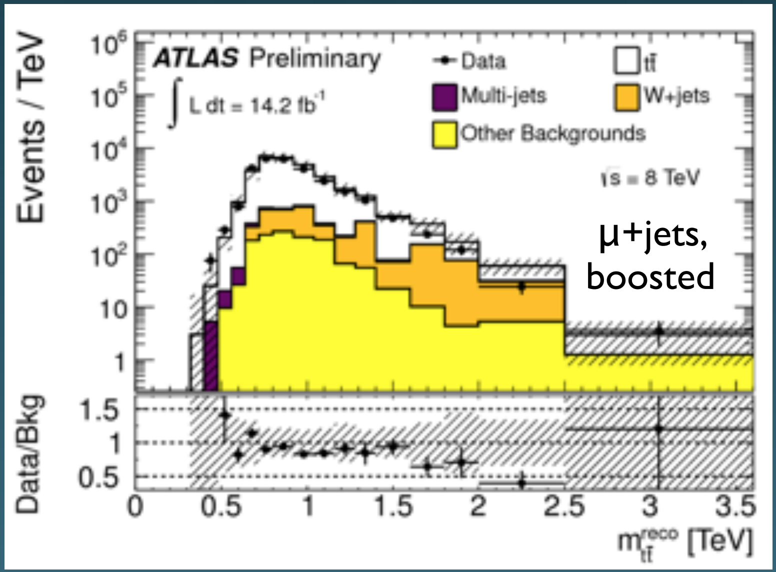
Resonant Production

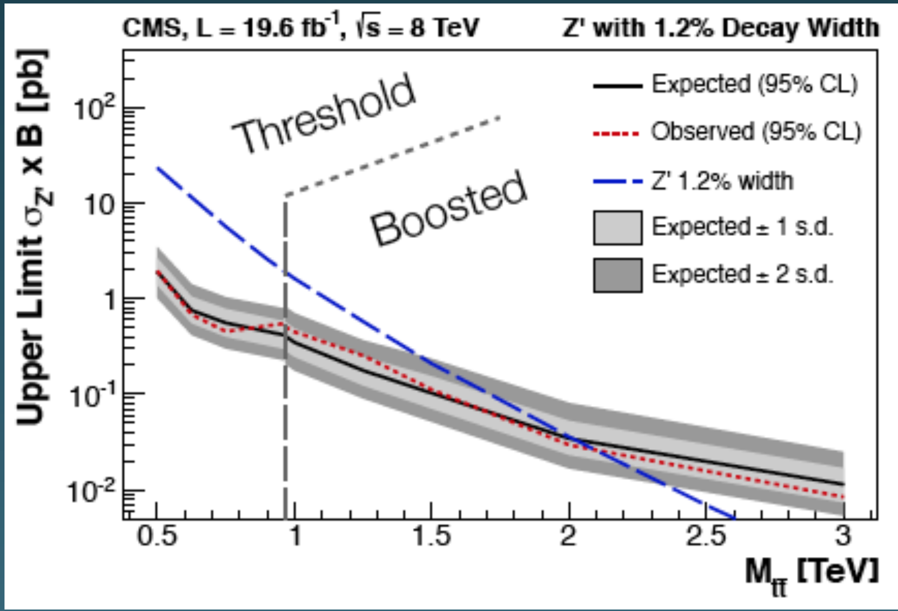


See also parallel talks (P. Turner, R. Nayyar)









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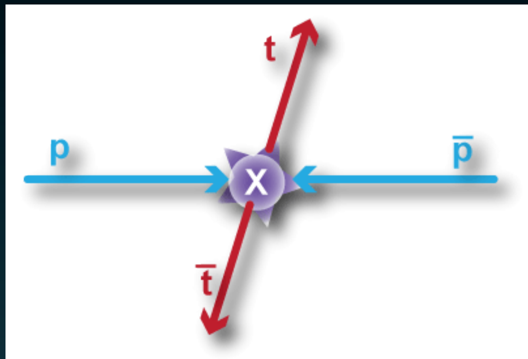

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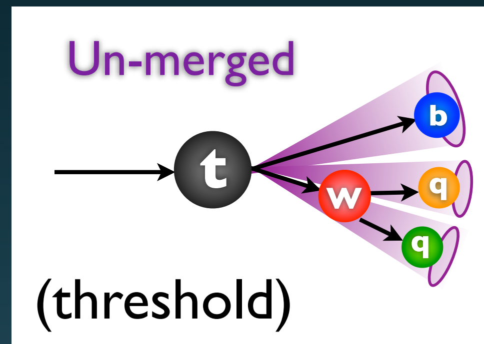
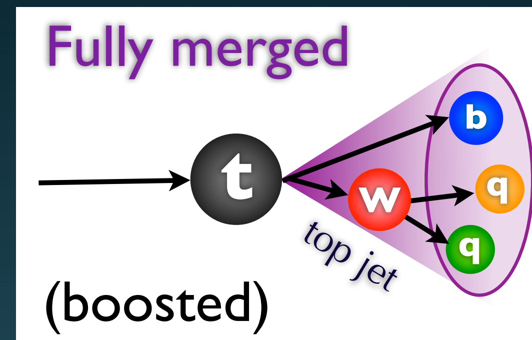
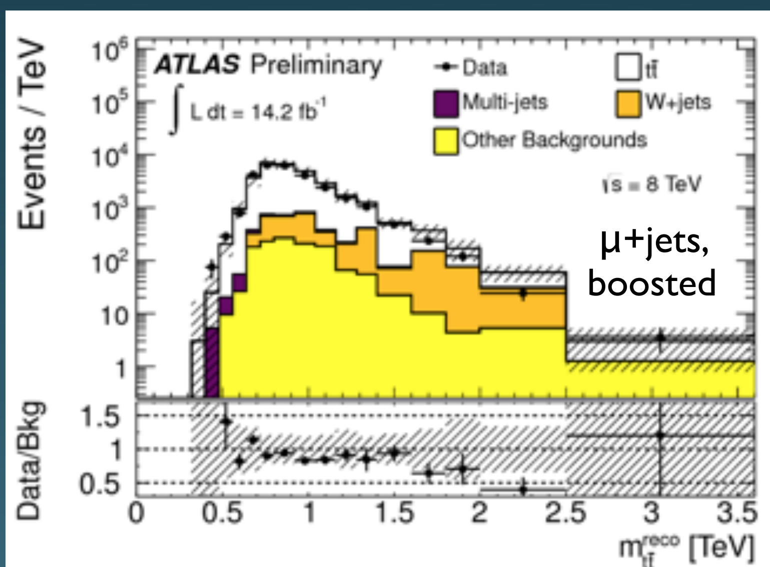
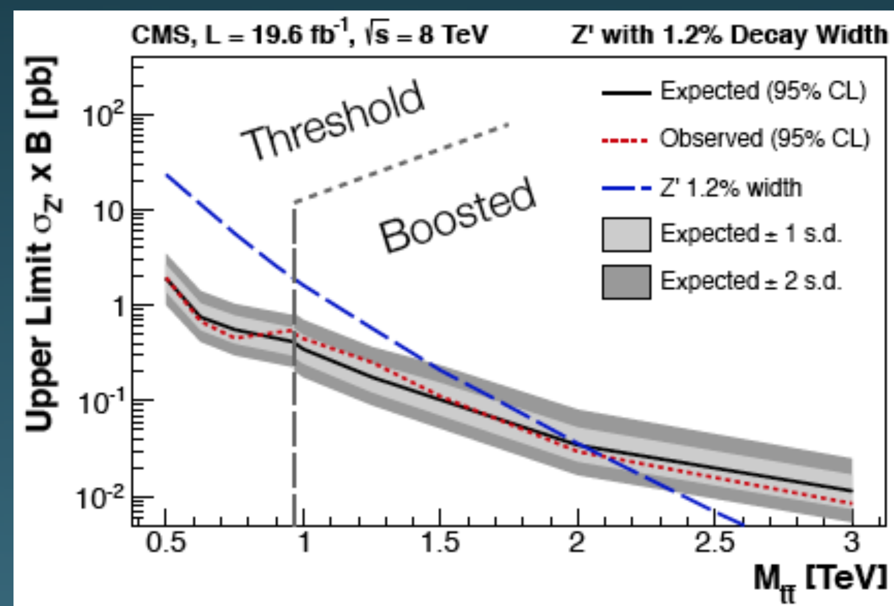
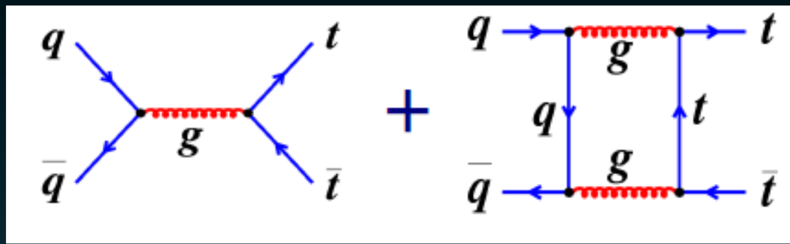


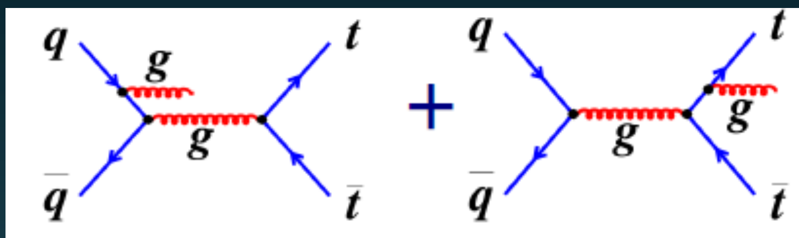






See also parallel talk (M. True) on resonant **W'→tb** *search*





Top Forward-Backward Asymmetry

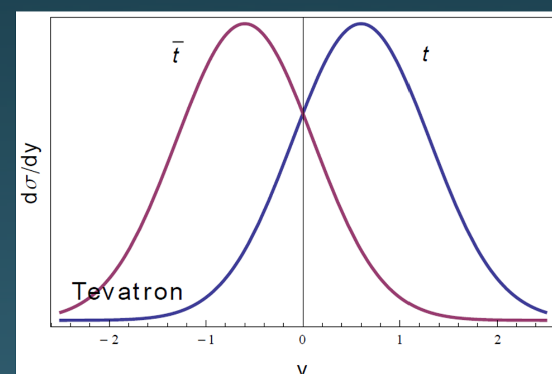
SM: NLO diagram interference in $q\bar{q}$.

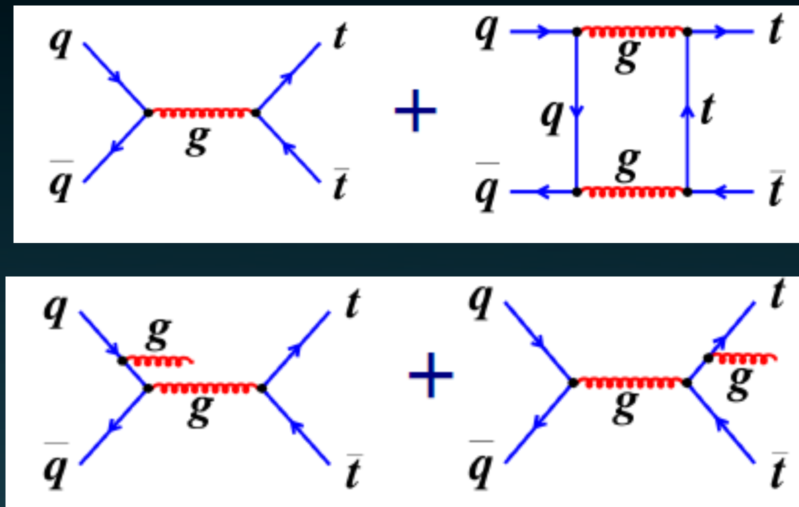
BSM: New physics could enhance asymmetry.

$$A^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$\Delta y = y_t - y_{\bar{t}} = q_l (y_{t,lep} - y_{t,had})$$

Tevatron A_{fb}





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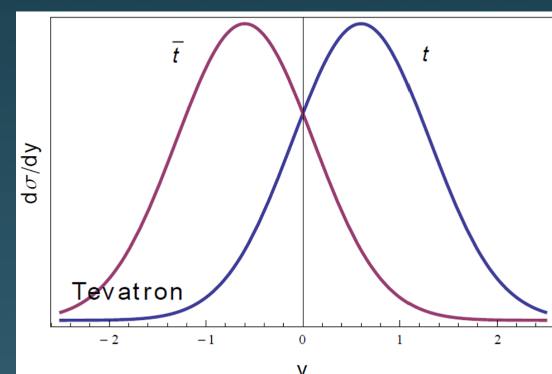
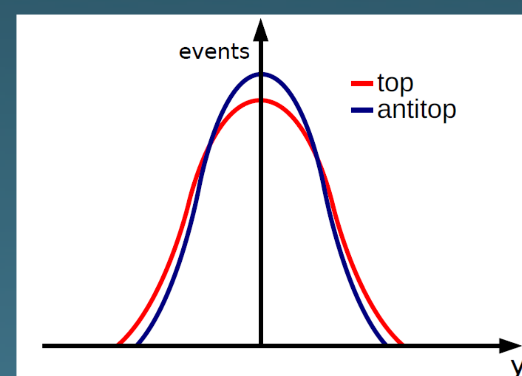
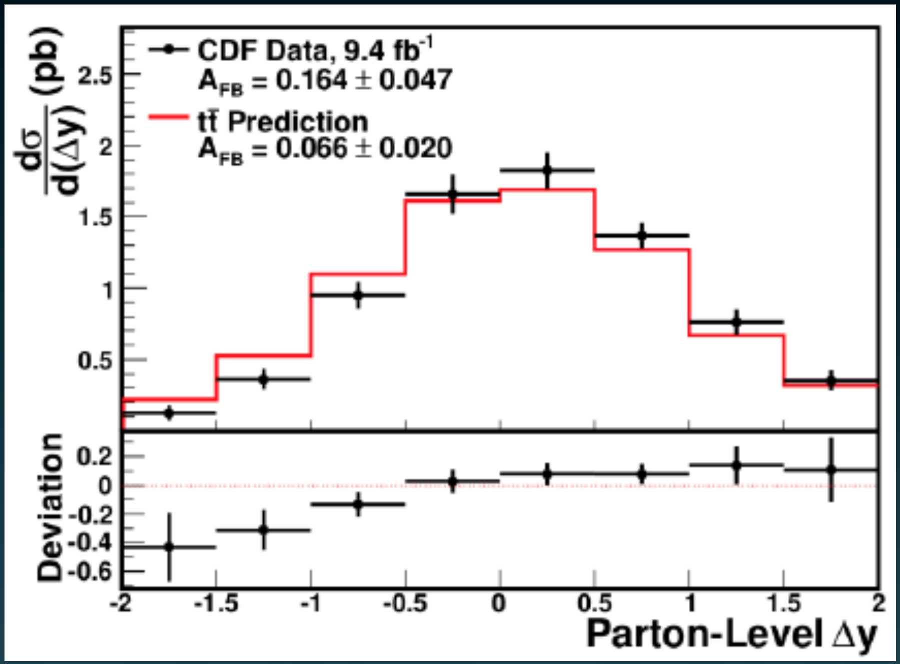


$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

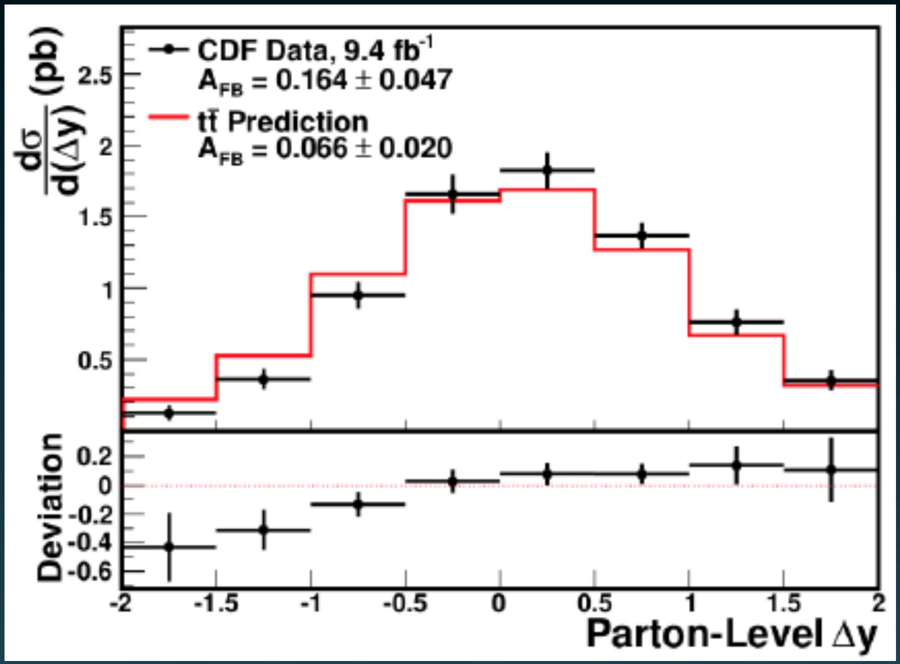
LHC A_c





Top Forward-Backward Asymmetry

Tevatron A_{FB} historically in tension with SM



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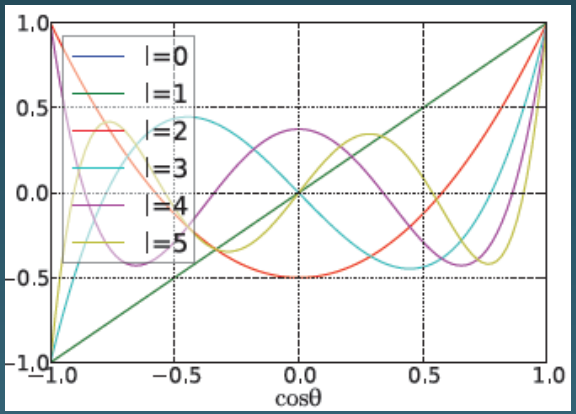
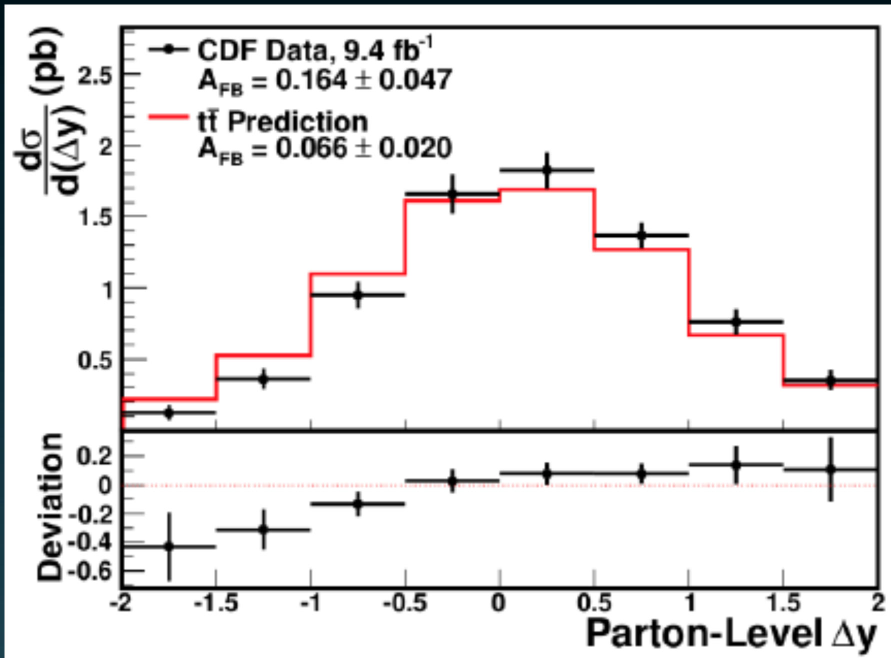
$$\frac{d\sigma(t\bar{t})}{d\cos\theta} = \sum a_l P_l(\cos\theta)$$

Recent CDF study: Legendre Polynomials



ℓ	$P_\ell(x)$
0	1
1	x
2	$\frac{1}{2}(3x^2-1)$
3	$\frac{1}{2}(5x^3-3x)$
4	$\frac{1}{8}(35x^4-30x^2+3)$
5	$\frac{1}{8}(63x^5-70x^3+15x)$



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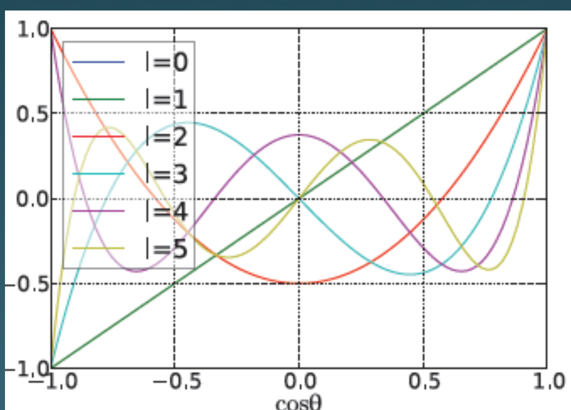

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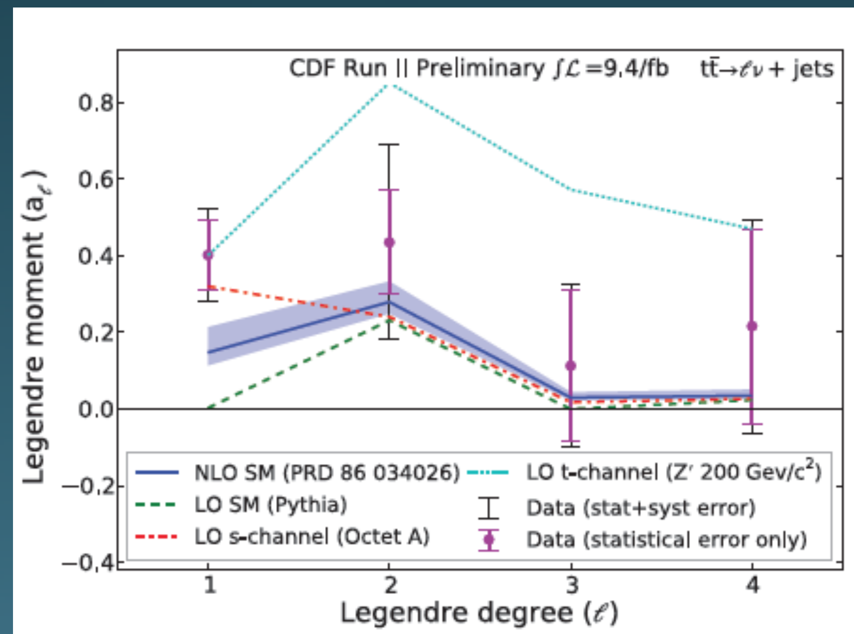

Legendre moments consistent with SM except 1st (2.1σ): s-channel exchange of s=1 particle (axigluon or Z')

Lepton A_{FB}

$$A_l = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

Top Forward-Backward Asymmetry

- A^{tt}_{FB} requires full top reconstruction.
- A_ℓ, use lepton η from W decay -clean.
- $A_\ell \sim (0.5) A^{tt}_{FB}$ if no t polarization.

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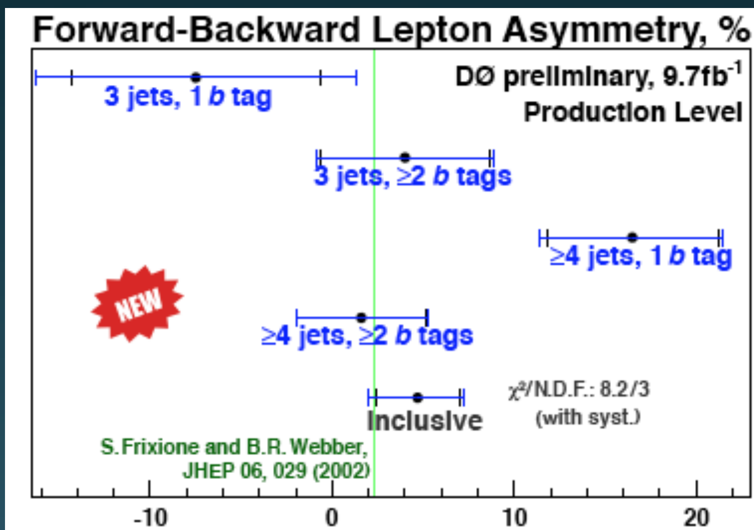

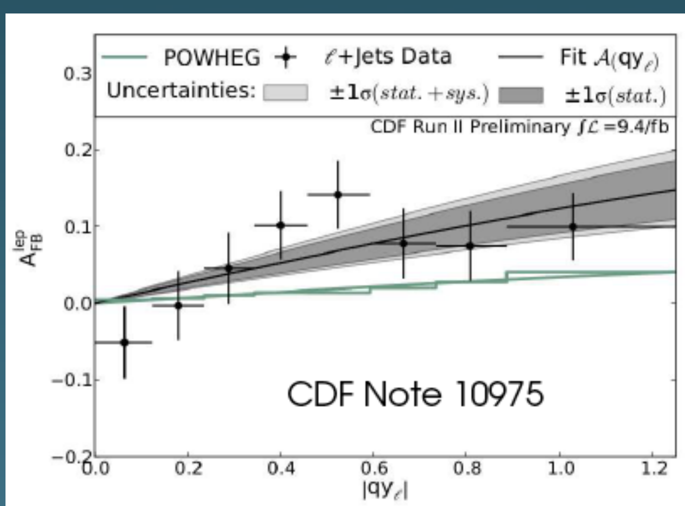

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CDF: $A^{\ell}_{FB} = 0.094^{+0.032}_{-0.029}$ (2σ from SM)

D0: $A^{\ell}_{FB} = 0.047 \pm 0.023(\text{stat})^{+0.011}_{-0.014}(\text{syst})$

SM (mc@NLO) = 0.023 ± 0.20

Lepton A_{FB}

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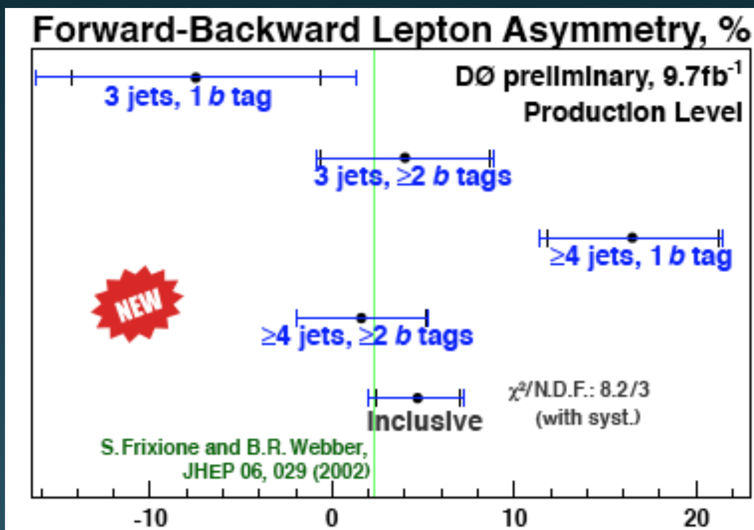

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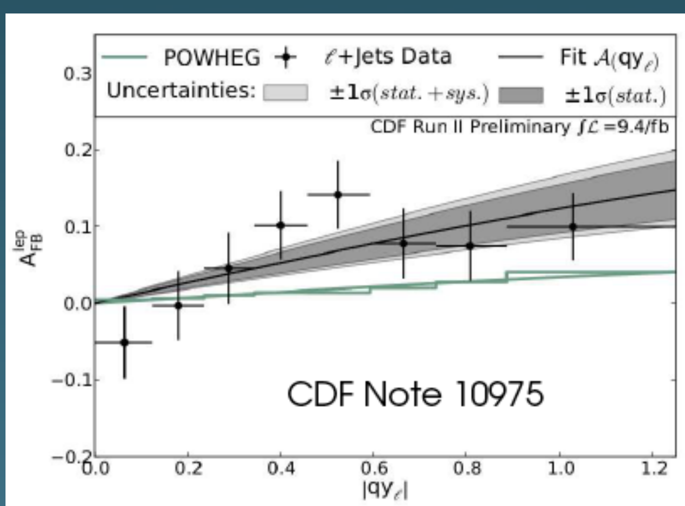
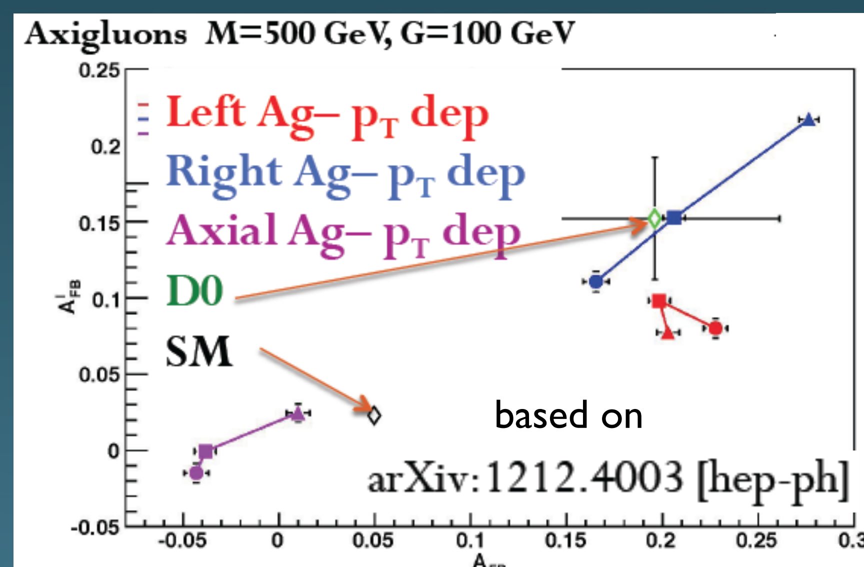
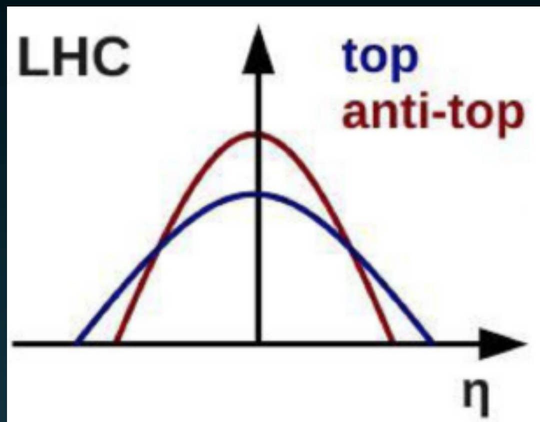




Top Forward-Backward Asymmetry

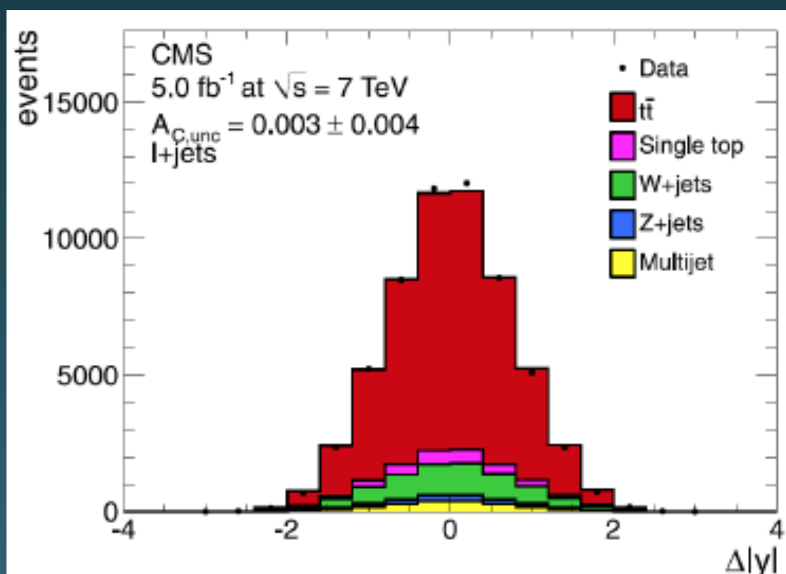


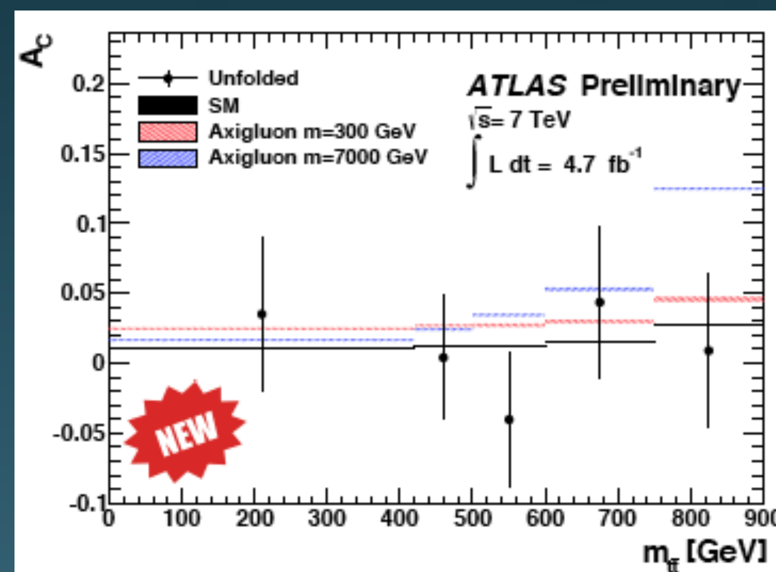
LHC A_c

$0.004 \pm 0.010\ (\text{stat.}) \pm 0.011\ (\text{syst.})$

0.0115 ± 0.0006

$A_c^{t\bar{t}} = 0.006 \pm 0.010(\text{ stat.} + \text{ syst.})$
SM: $A_c^{t\bar{t}} = 0.0123 \pm 0.0005$

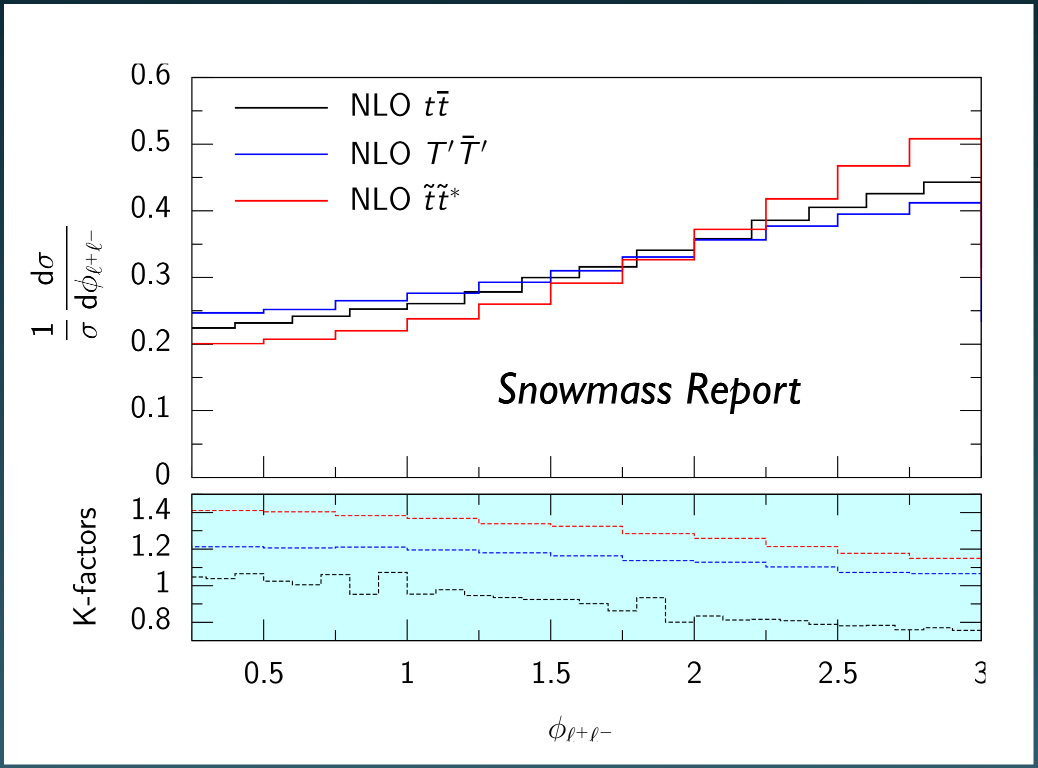


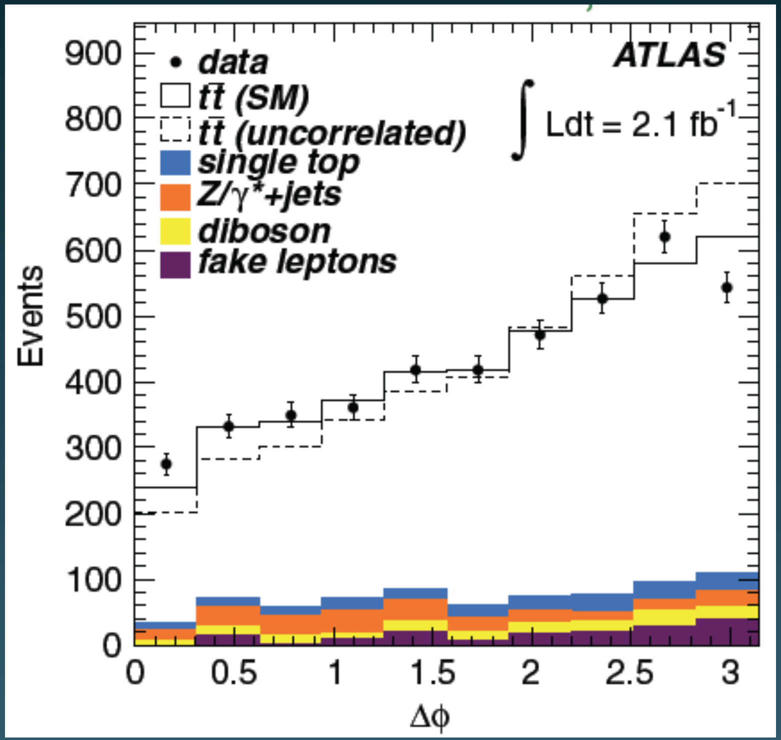


Effect smaller due to p-p collider. Consistent with SM, but little sensitivity: few statistics, large systematics. However...
Snowmass: If 50% of systematics scale w/ statistics, HL-LHC may help.

See also parallel talks (S.Youn - D0 analysis, N. Kidonakis- other distributions)

Other Top Kinematics

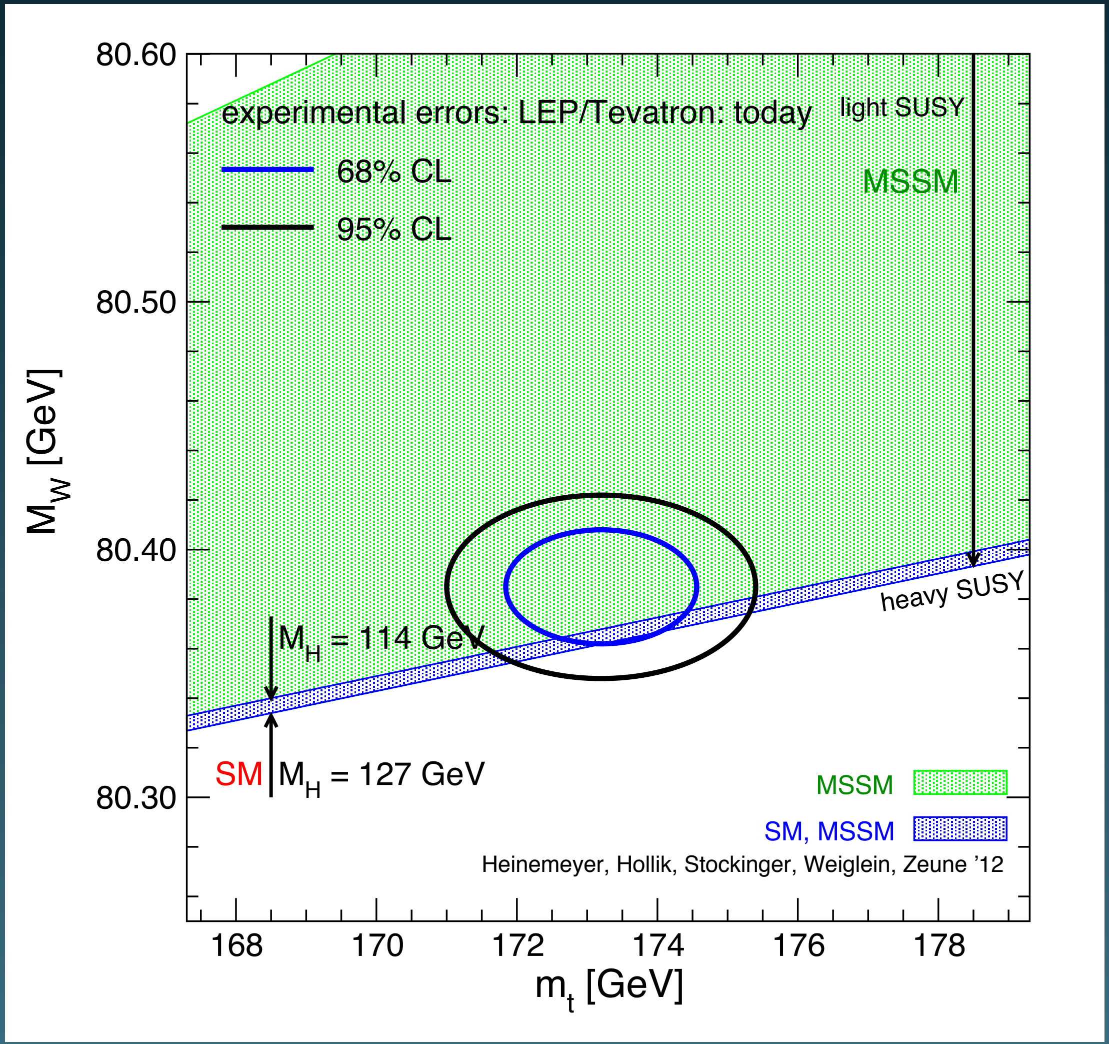




plus similar result from CMS

Eg: spin correlations

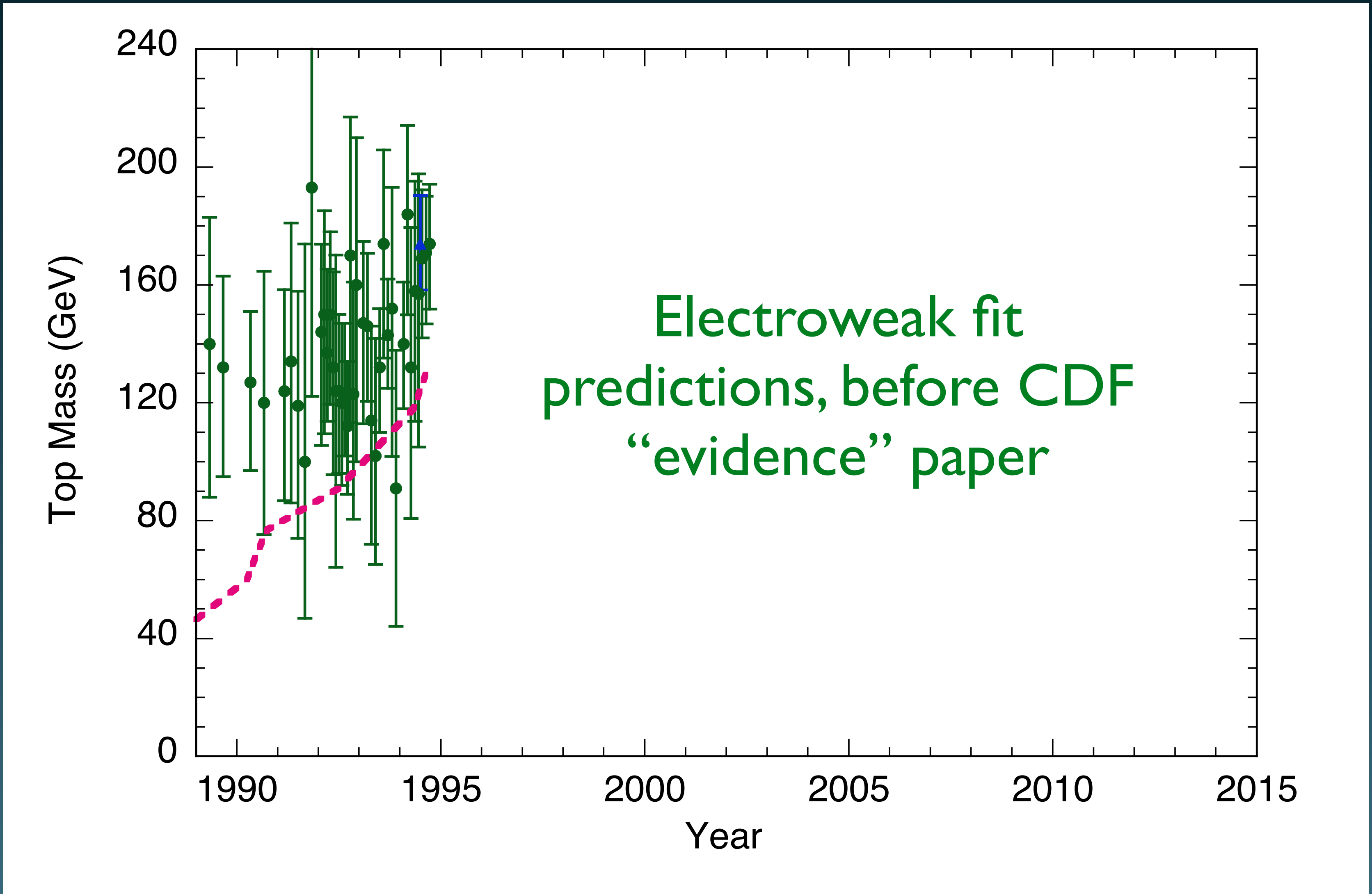
Top Quark Mass



Fundamental Standard Model Parameter

Top mass history

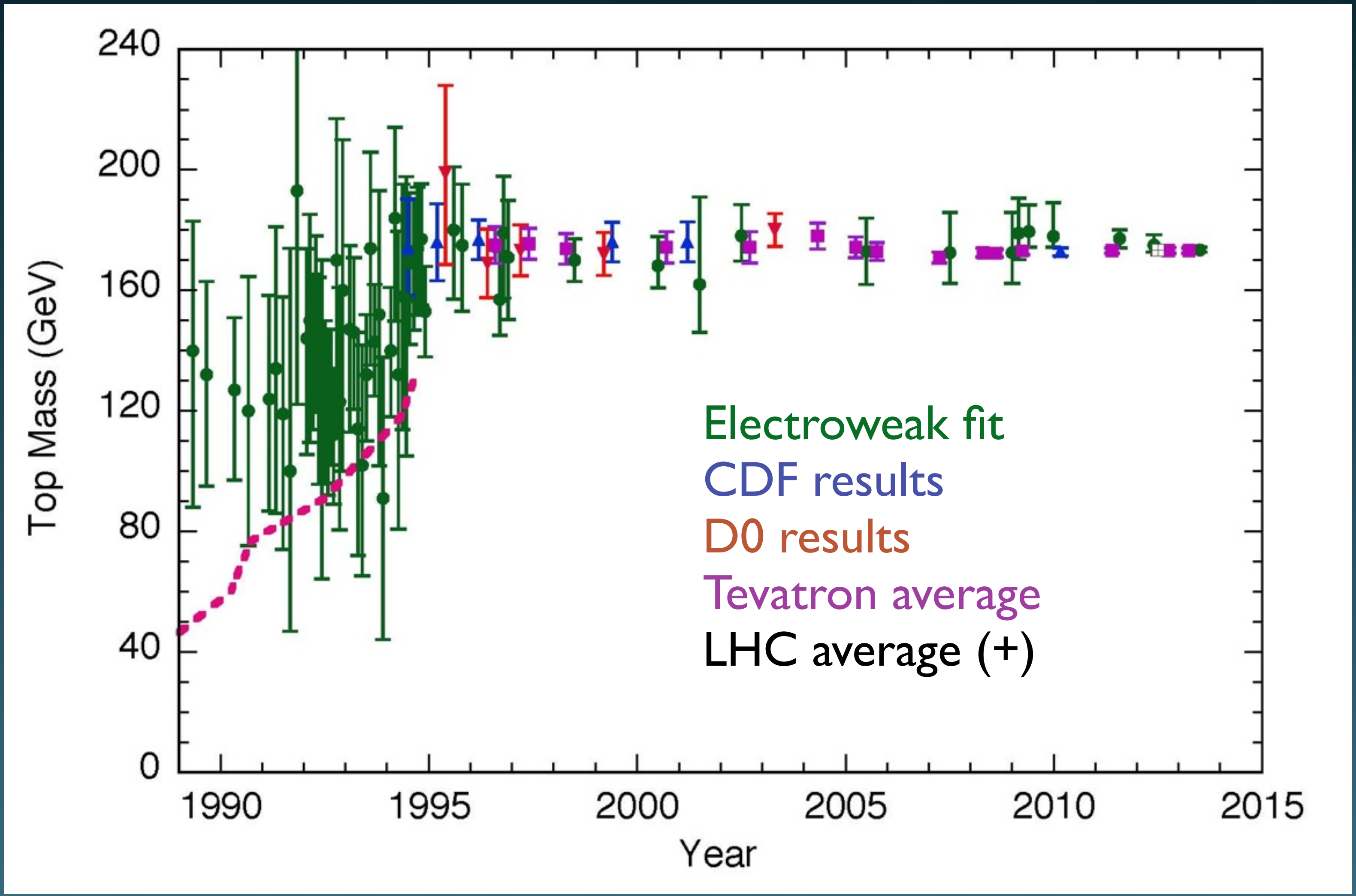
Top Quark Mass



C. Quigg, *Physics Today* **50**, 20 (May 2007), hep-ph/9704332, & update from private communication

Top mass history

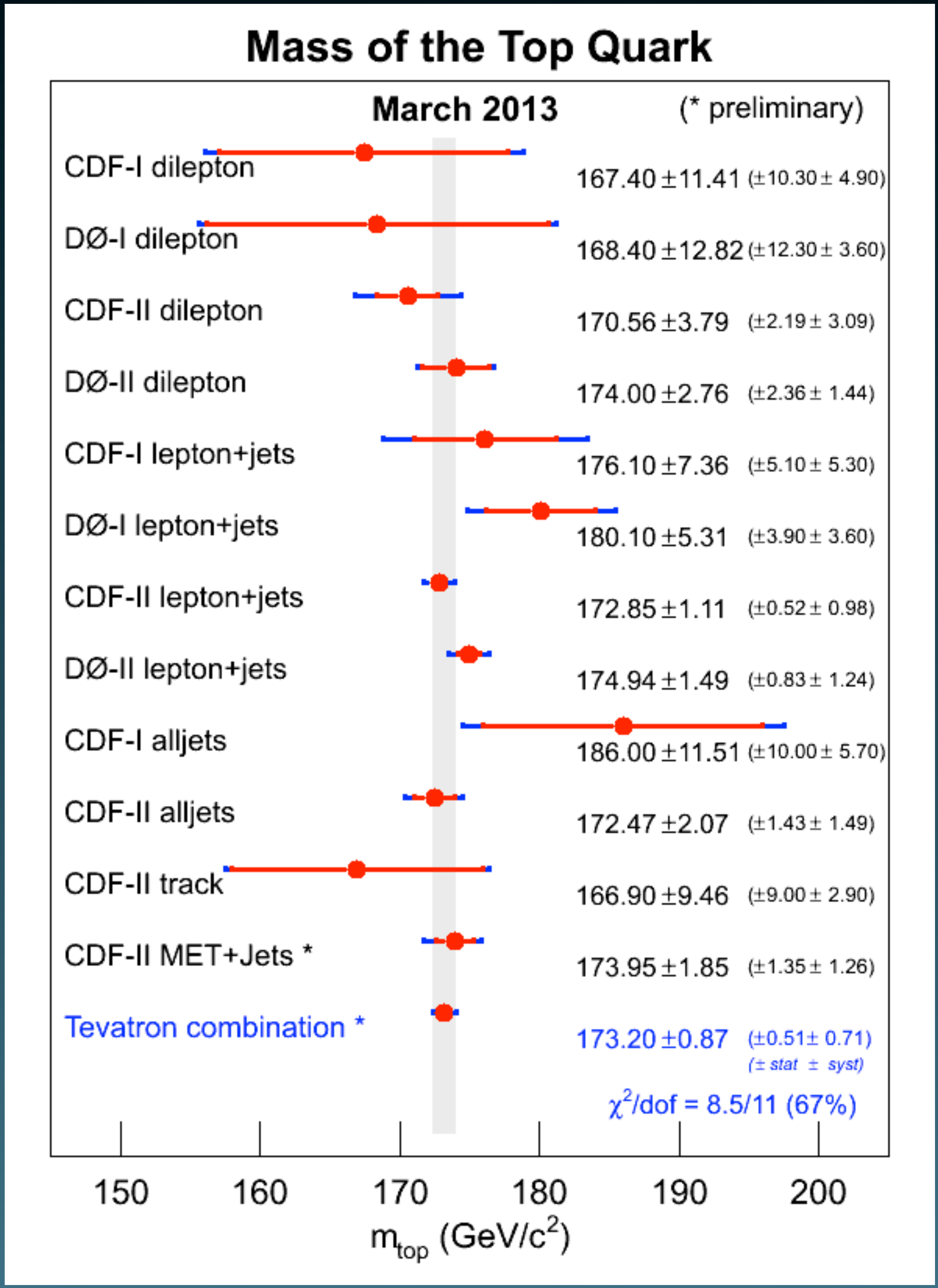
Top Quark Mass



C. Quigg, *Physics Today* **50**, 20 (May 2007), hep-ph/9704332, & update from private communication

Top Quark Mass

Tevatron 2013 Combo

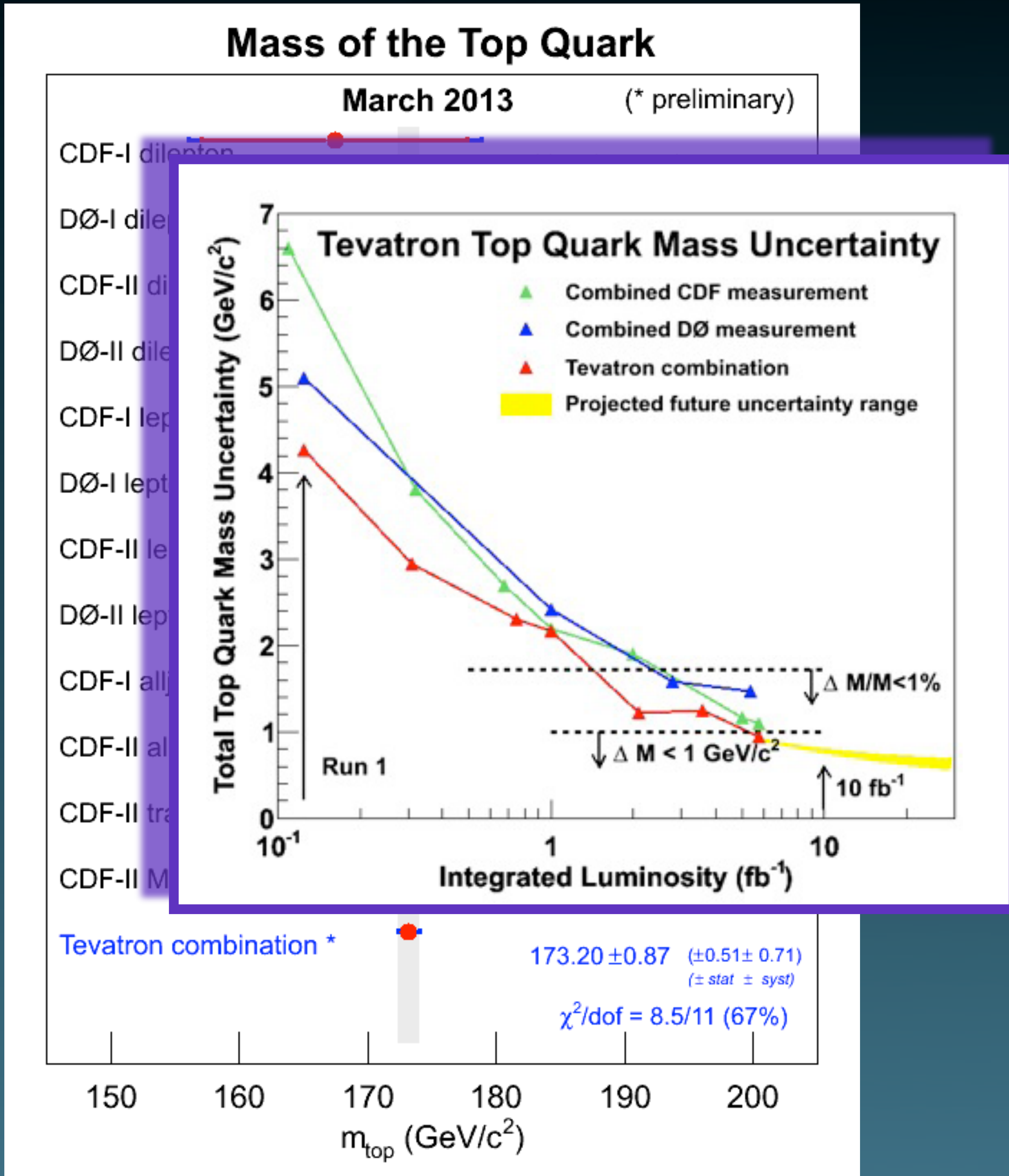


Tevatron still most precise: 0.5% relative uncertainty.

Top Quark Mass

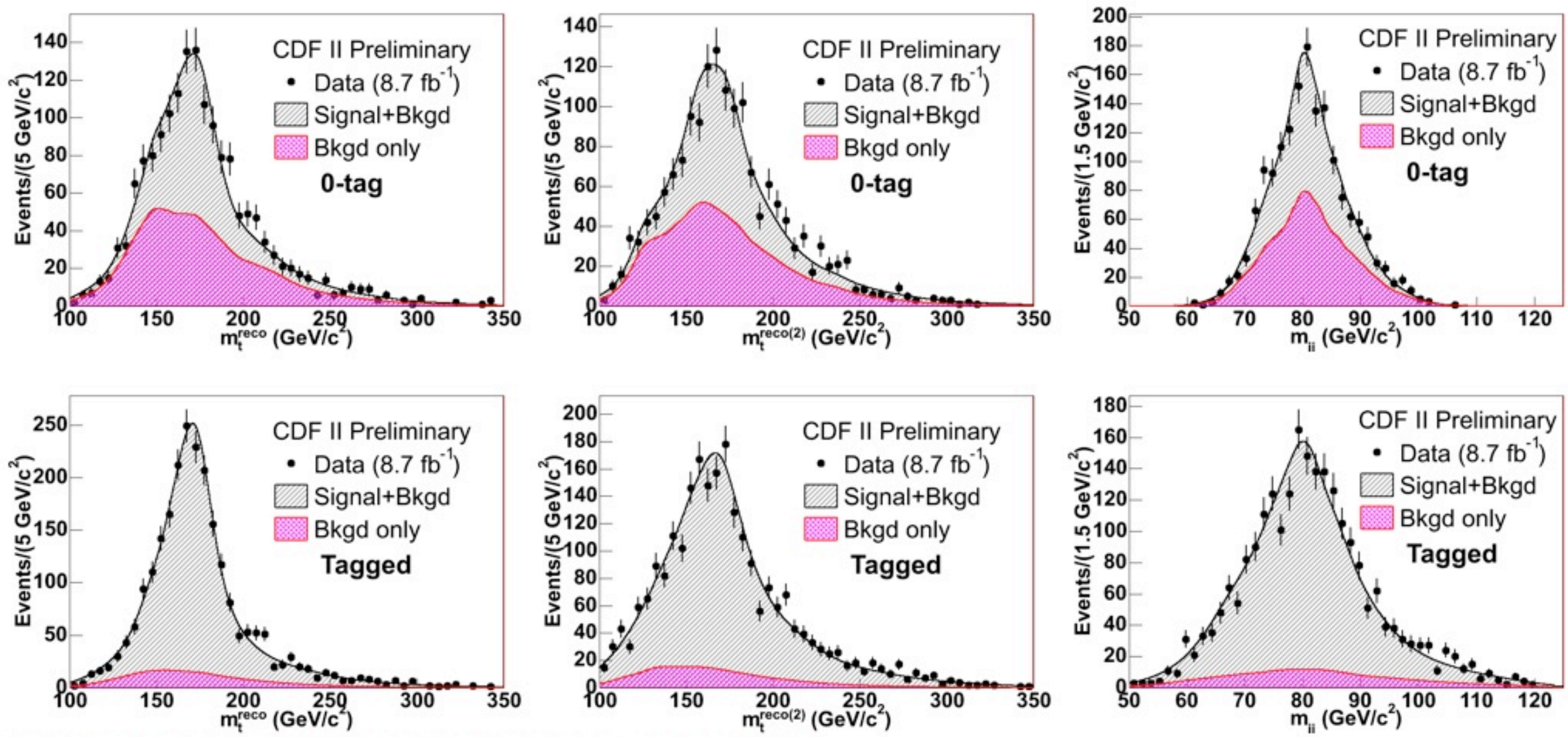
Tevatron 2013 Combo

Tevatron still most precise: 0.5% relative uncertainty.

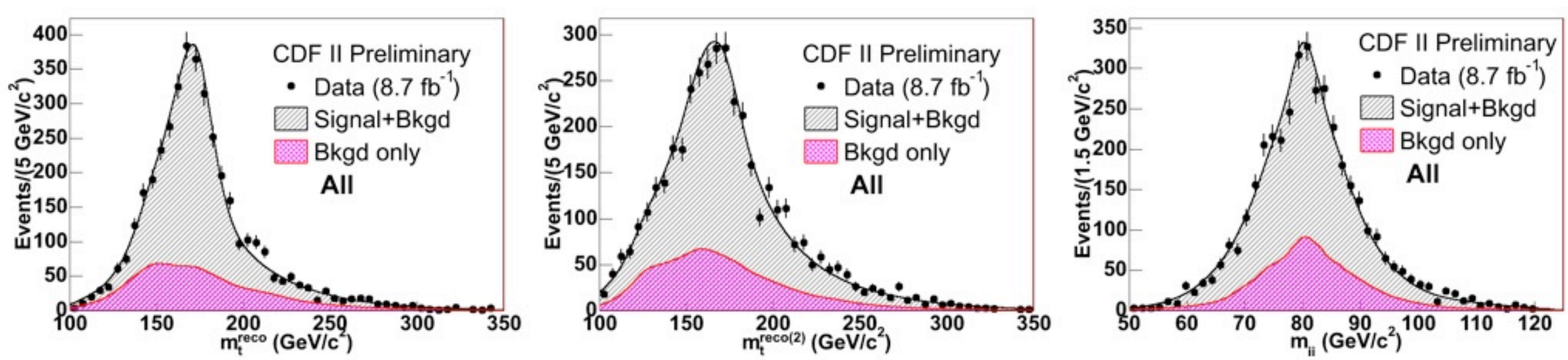


Most precise single result: 0.63% relative

Top Quark Mass



Similar plots with all events, combining 0-tag and tagged events, are shown below.



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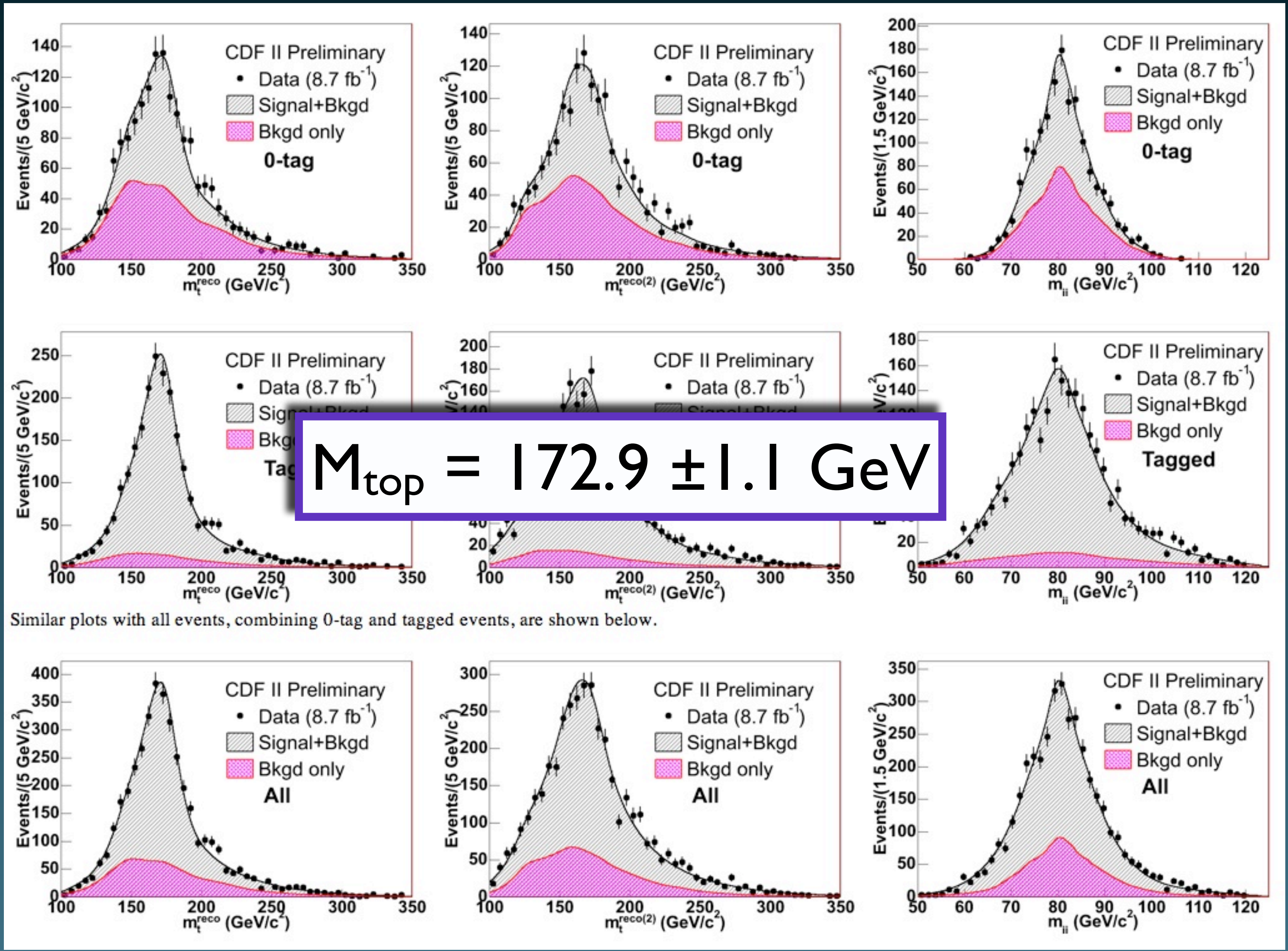
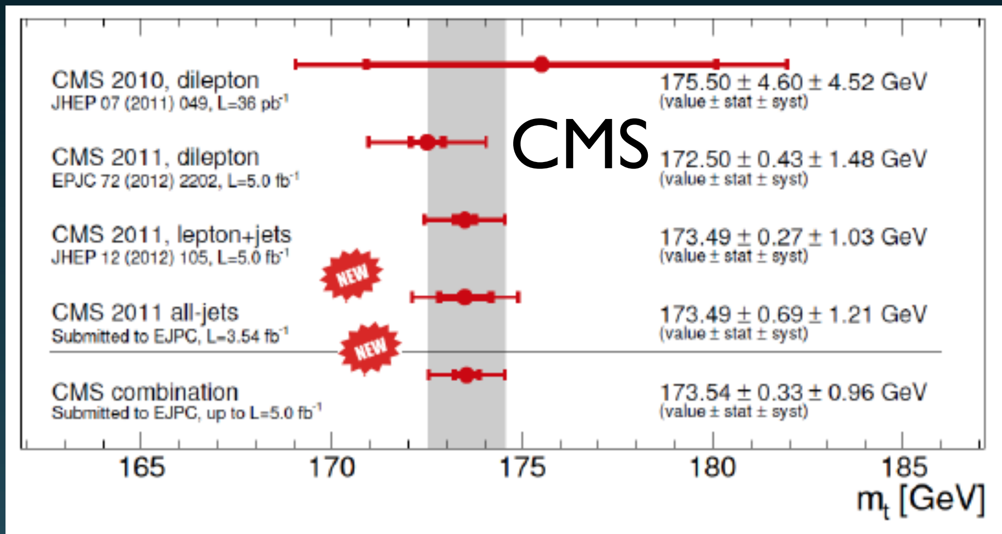


M_{top} = 172.9 ±1.1 GeV

Similar plots with all events, combining 0-tag and tagged events, are shown below.

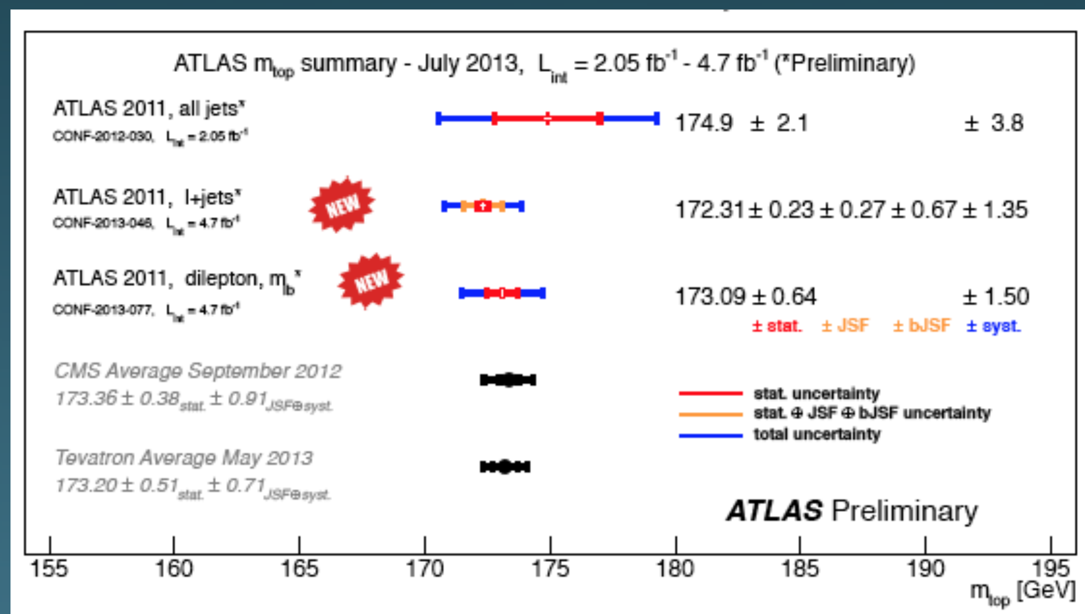
Most precise single-LHC: 0.65% relative

Top Quark Mass



LHC not far behind: precision close to Tevatron

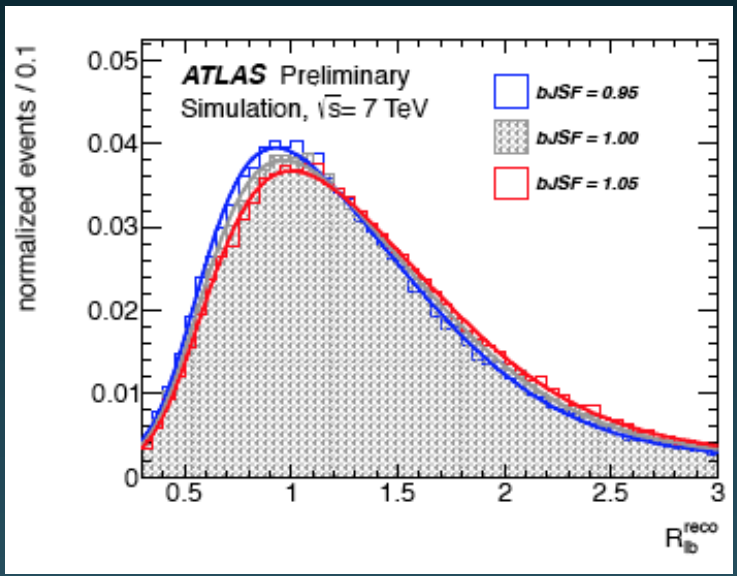
- New LHC combination coming soon.
- TopLHCWG... agreeing to common systematics.
- Tevatron/LHC combo coming soon, too.

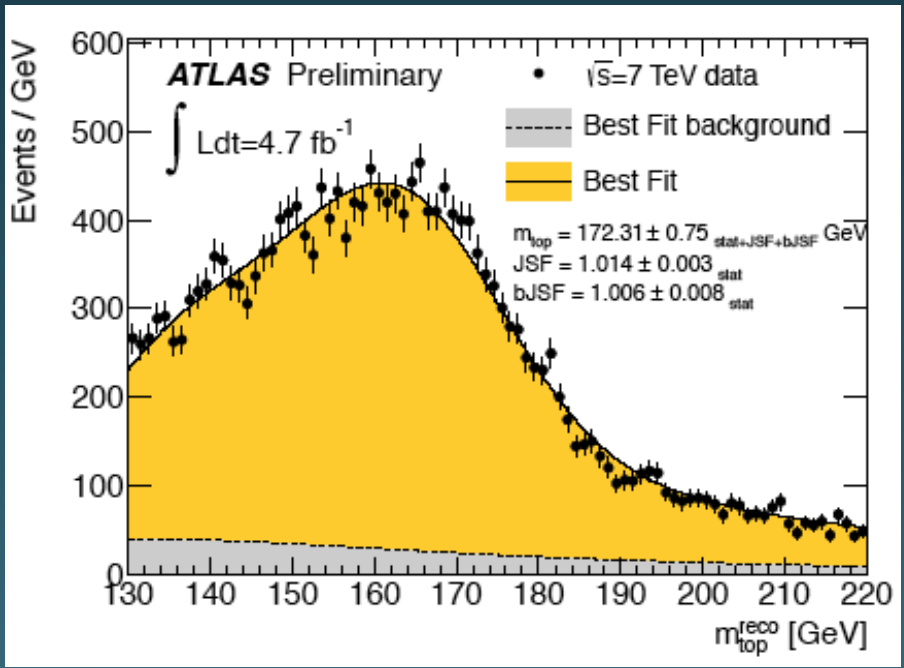


New Techniques: 3D fit by ATLAS

Top Quark Mass

Fit to top mass, W mass, and R_{lb}(ratio). In situ jet and b-jet energy scale calibration.





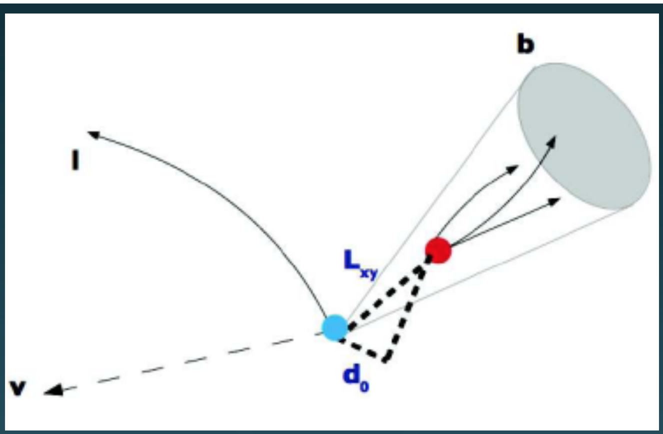
Reduces systematics by 40% over previous measurement.

M_{top} = 172.3 ± 0.23*(stat)* ± 0.27*(JSF)* ± 0.67*(bJSF)* ± 1.35*(syst)* GeV

Top Quark Mass

New Techniques: CMS b-Lifetime

$$L_{xy} = \gamma_b \beta_B \tau_B \approx 0.4 \cdot \frac{m_t}{m_B} \beta_B \tau_B$$



First used in CDF, systematics complementary (no jets).
Lxy distribution gives Mtop.

$M_t = 172.4 \pm 1.5_{(stat)} \pm 1.3_{(syst)} \pm 2.6_{(p_T t)}$ GeV

Top Quark Mass

New Techniques: CMS b-Lifetime

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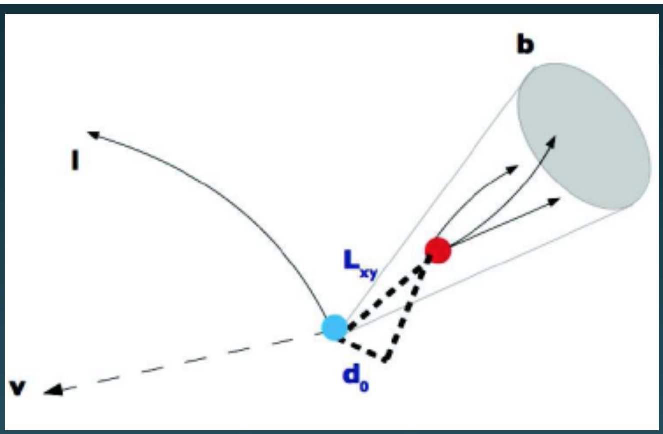
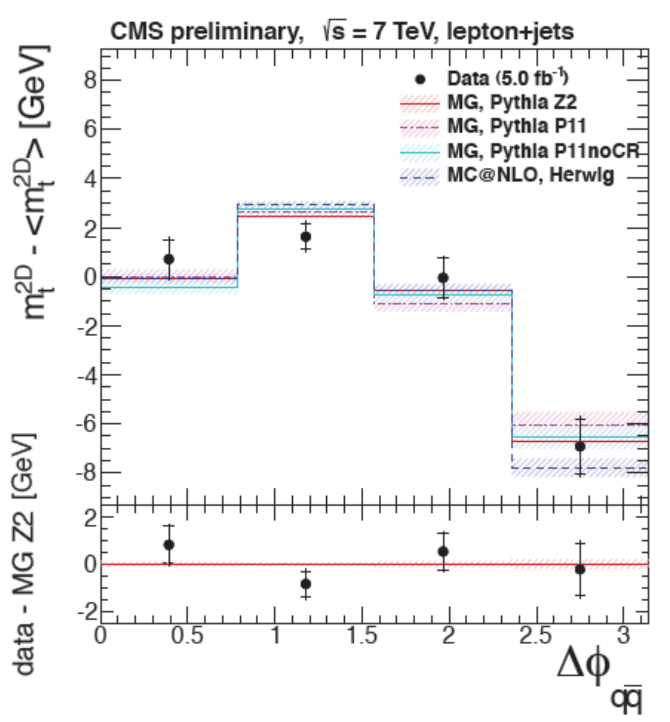


First used in CDF, systematics complementary (no jets). Lxy distribution gives Mtop.

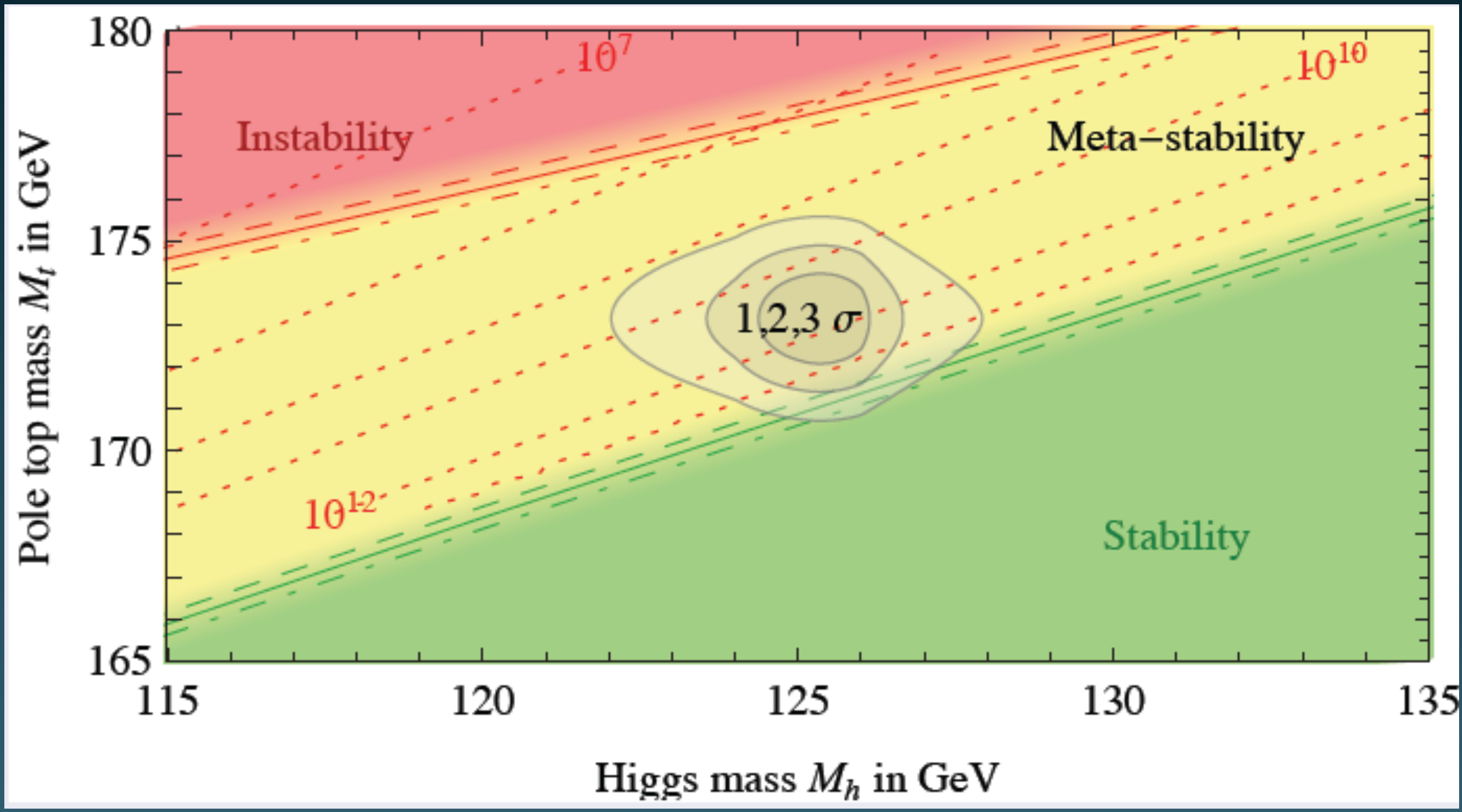
M_t=172.4±1.5*(stat)*±1.3*(syst)*±2.6*(p_Tt)*GeV

New Techniques: CMS Differential



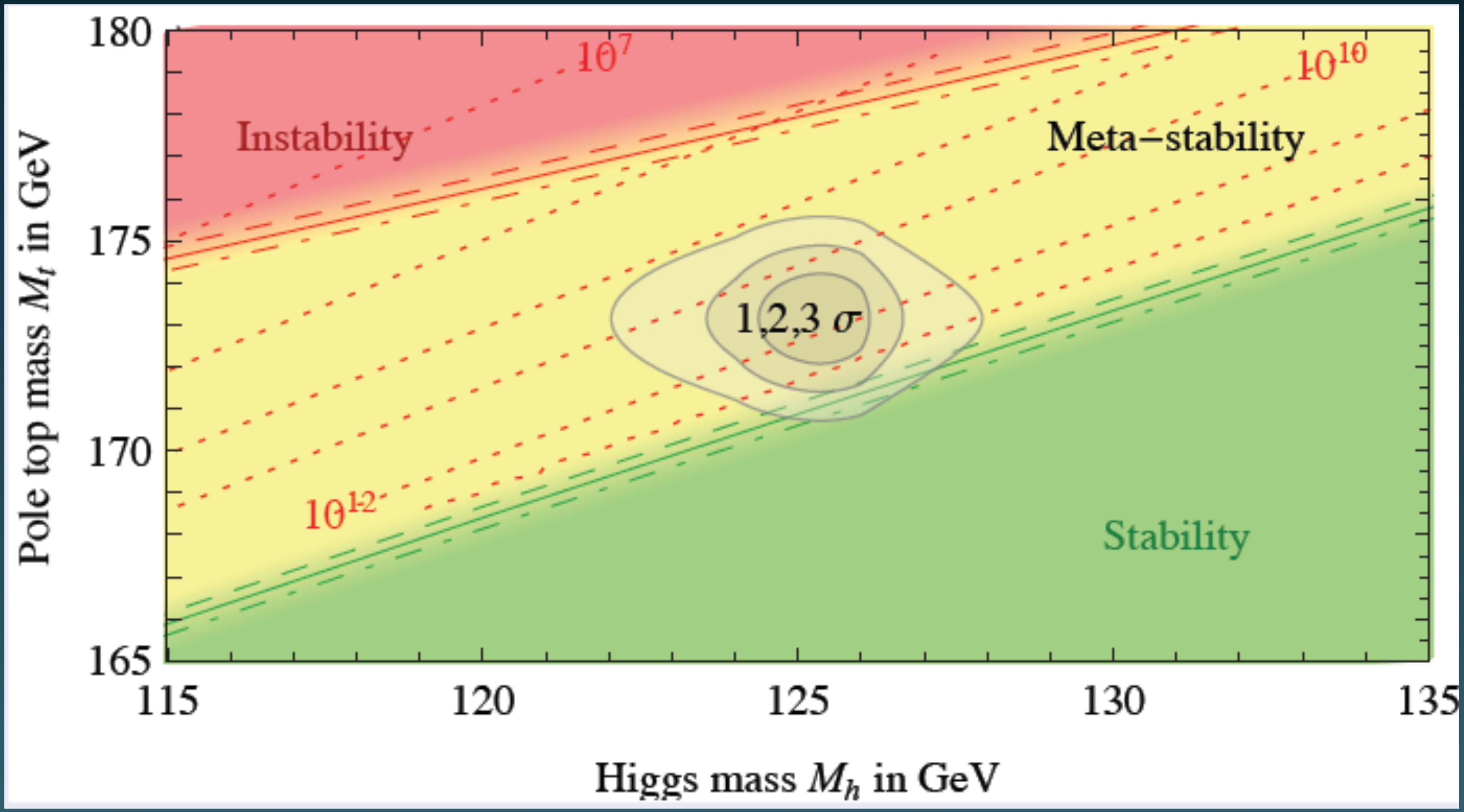
Probe color recon-nection, ISR/FSR

vacuum stability



150 MeV $\delta(M_H)$ ~ 100 MeV $\delta(M_t)$

vacuum stability

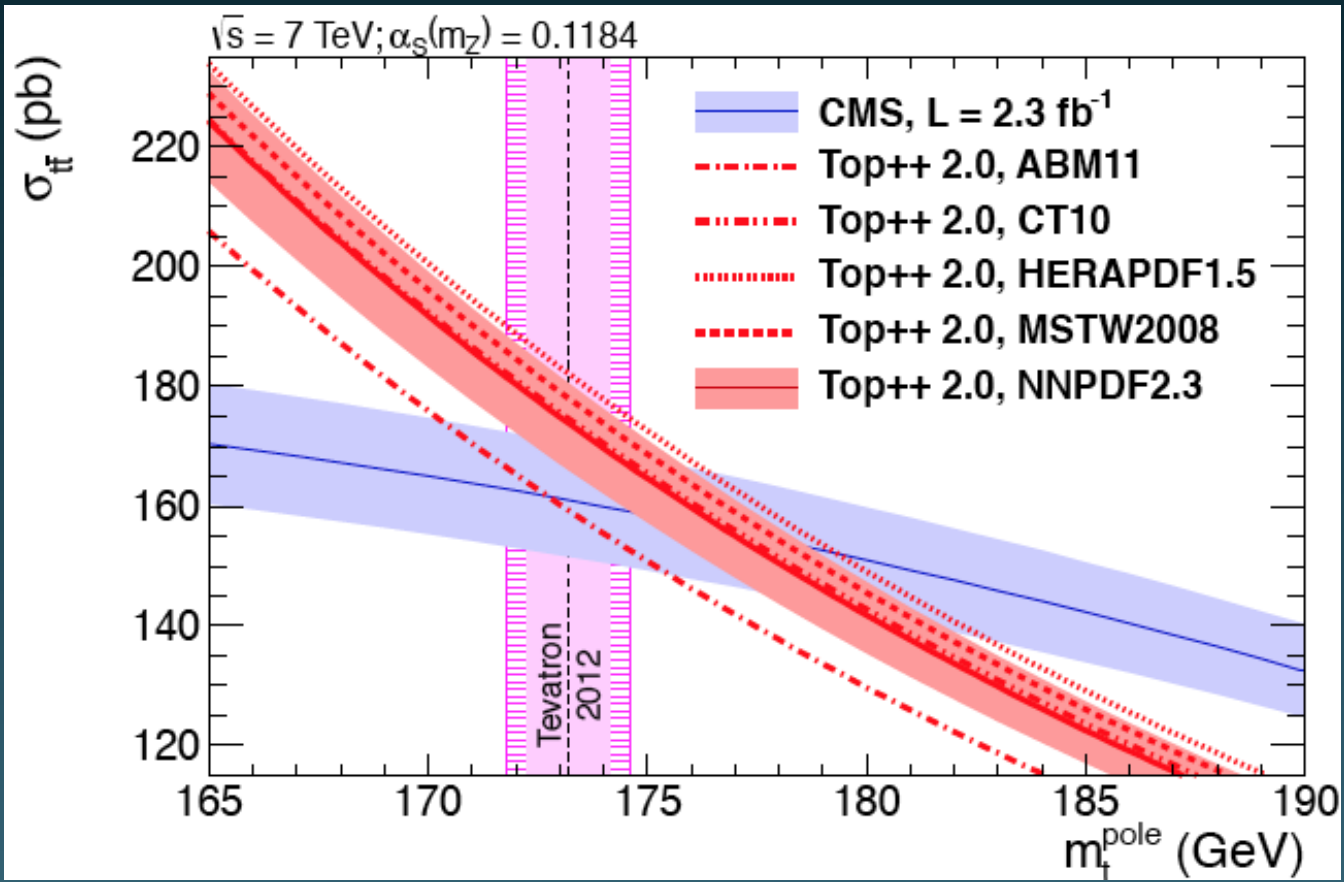


150 MeV $\delta(M_H)$ ~ 100 MeV $\delta(M_t)$

Are we measuring the pole mass?

Top Quark Mass

Top mass from σ_{tt}



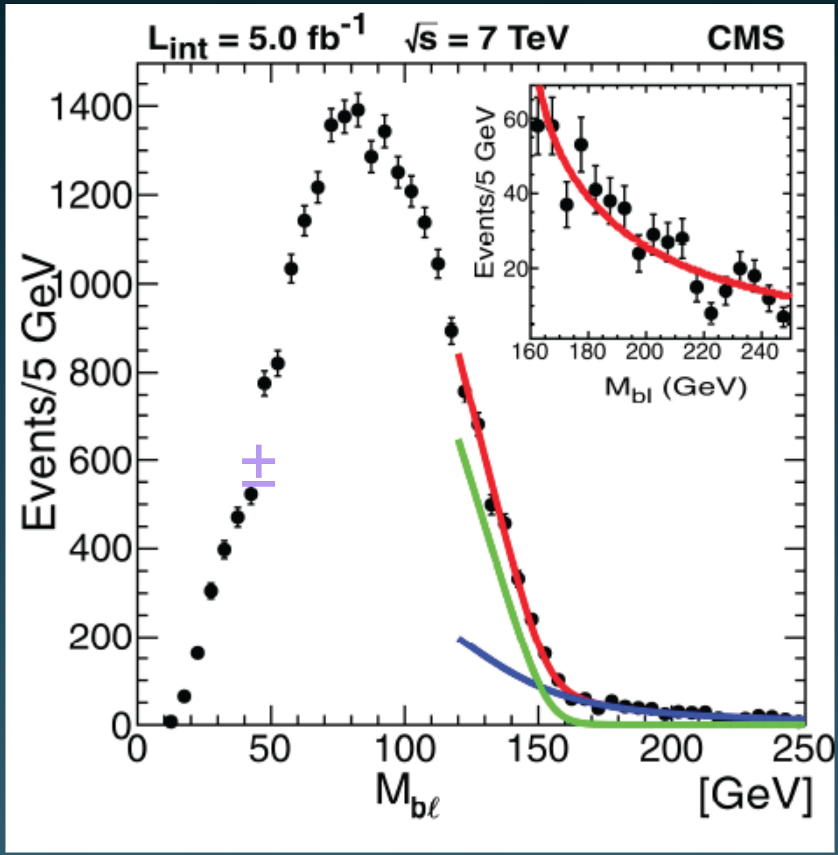
Compare precise σ_{tt} for different m_t to NNLO prediction ($\alpha_{s(PDG)}$).

$M_{t\ (pole)} = 176.7 \pm 3.6$ GeV

$M_t = 173.9 \pm 0.9 \pm 1.8$ GeV

Top Quark Mass

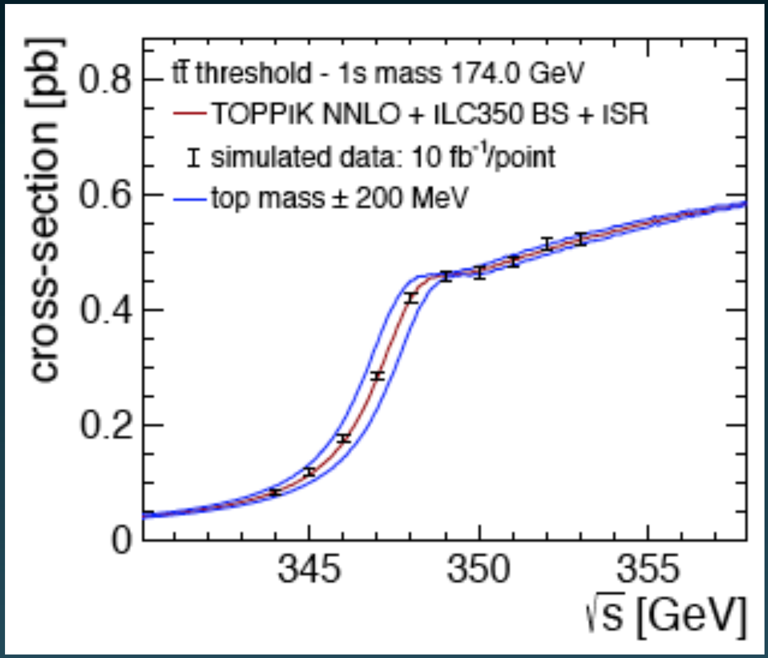
What M_t do we measure?

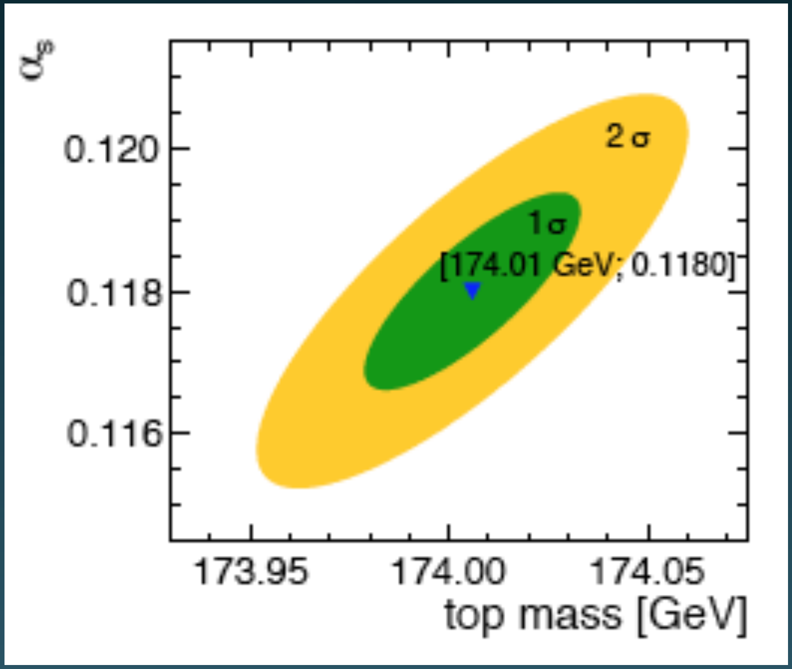


"Endpoints" of transverse distributions:

- Can fit to shapes independent of MC/theory
- Very sensitive to M_{top}
- CMS: fit to M_{T2}, M_{WT}, $M_{b\ell}$

Top Quark Mass





Linear collider threshold scans

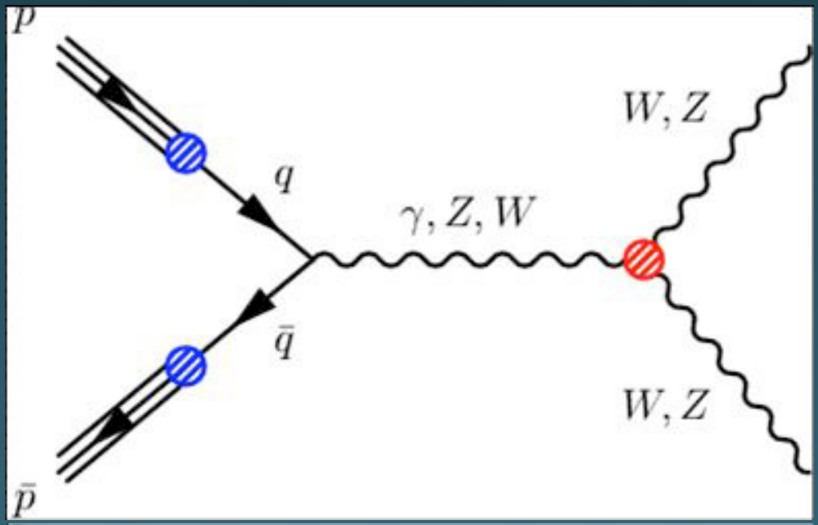
Analytical theory predictions.
Expected precision < 100 MeV.

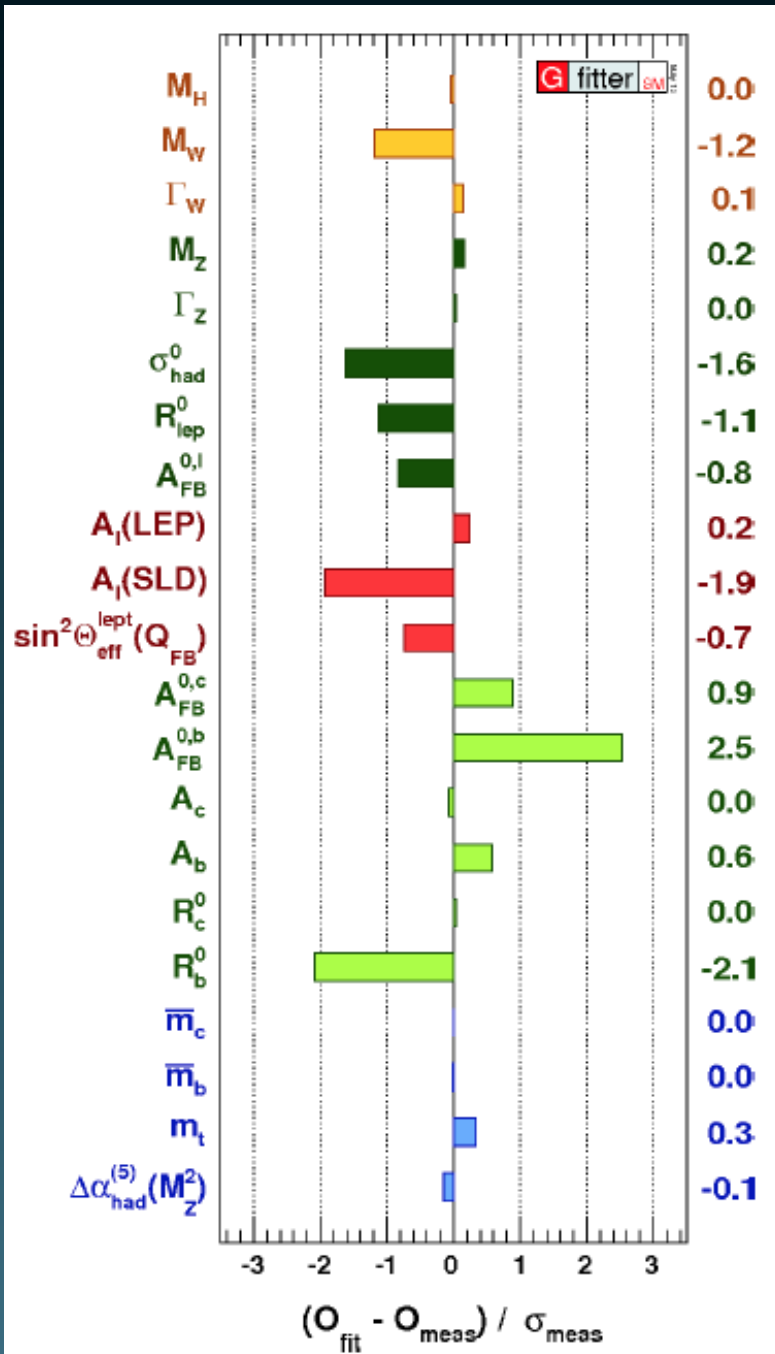
Snowmass top ILC white paper

“Top”-ics not covered...

- Top quark branching ratios
- W helicity in top decays: test of V-A
- Baryon number violating tops
- Studies of top kinematic distributions
- Flavor-changing neutral currents
- Rare top decays
- Top/ Anti-top mass difference
- Searches for top quark partners
- New techniques in reconstruction: boosted tops
- ... and more!

Electroweak Physics



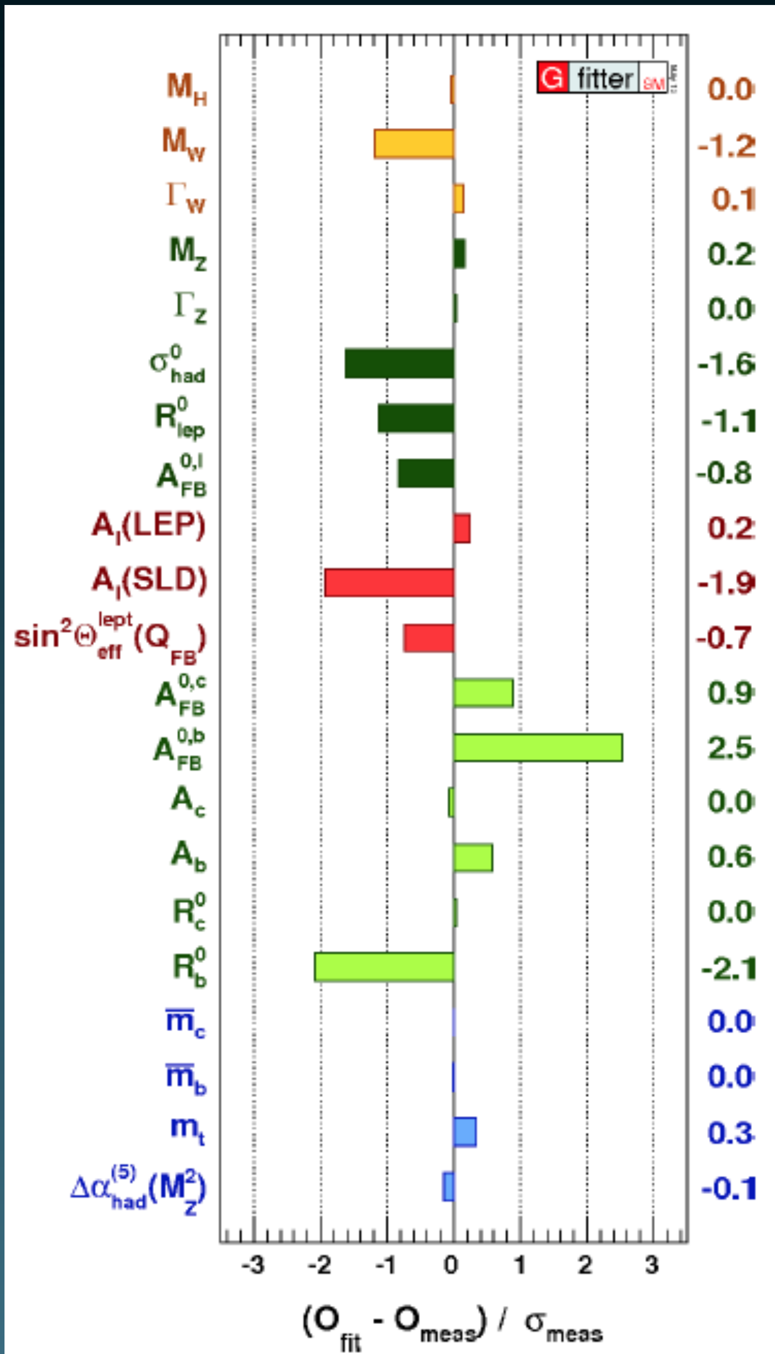


Global Electroweak Fits

- χ^2_{min} 20.7 per 14 degrees of freedom
- Pulls all within 2.5σ
- Higgs mass measured to 1 GeV

latest from Gfitter May 2013

We'll revisit this fit later...



Global Electroweak Fits

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What next?

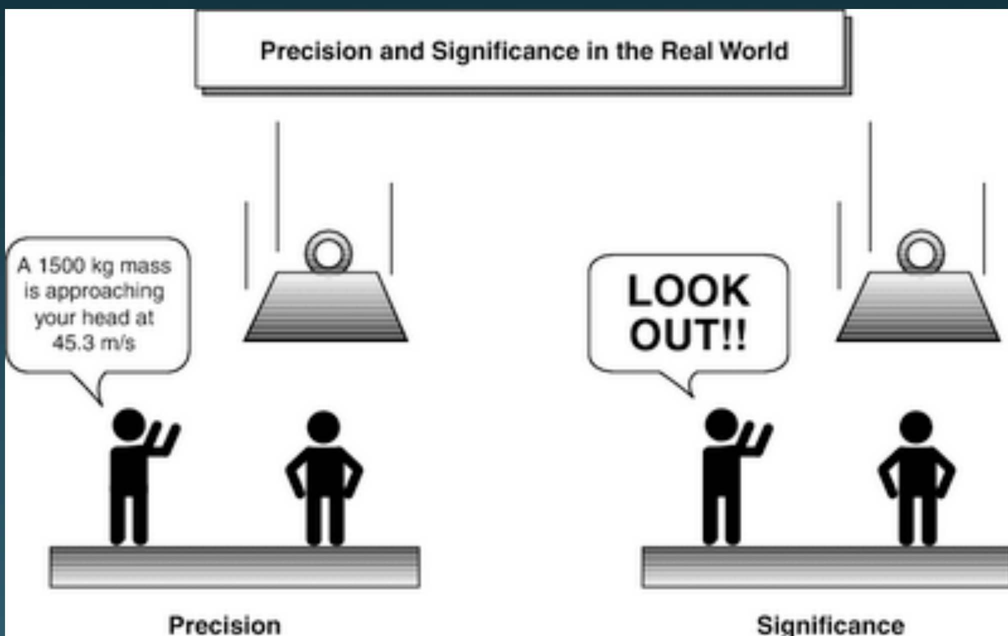
latest from Gfitter May 2013

We'll revisit this fit later...

What next?

Global Electroweak Fits

Precision!

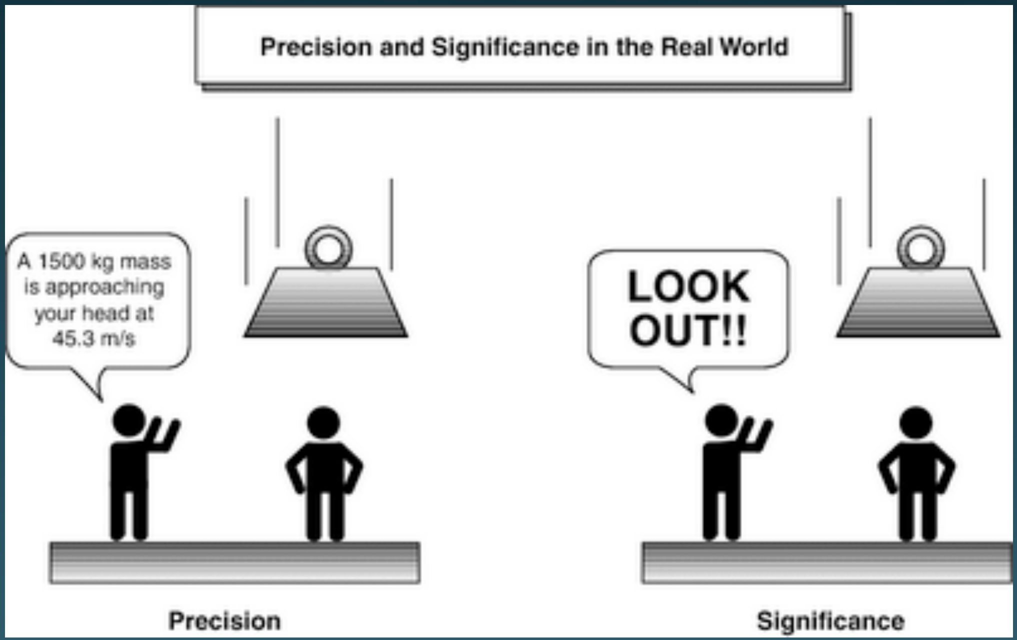


Electroweak physics remains very active

What next?

Global Electroweak Fits

Precision!



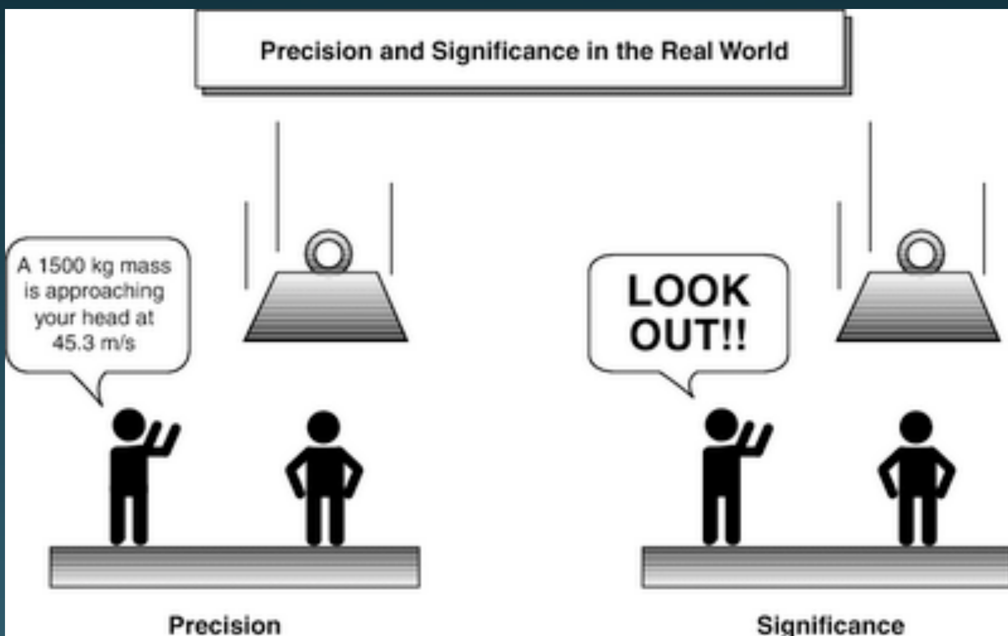
- Improve precision parameters: W mass, FB asymmetry (weak mixing angle)

Electroweak physics remains very active

What next?

Global Electroweak Fits

Precision!



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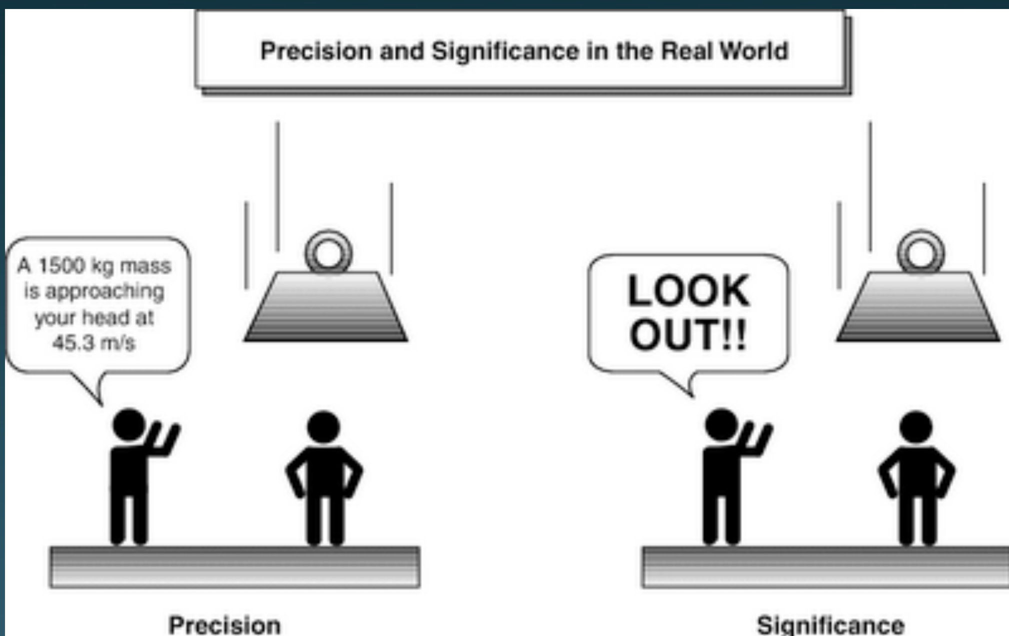
- Study W,Z thoroughly: differential distributions

Electroweak physics remains very active

What next?

Global Electroweak Fits

Precision!



- Improve precision parameters: W mass, FB asymmetry (weak mixing angle)
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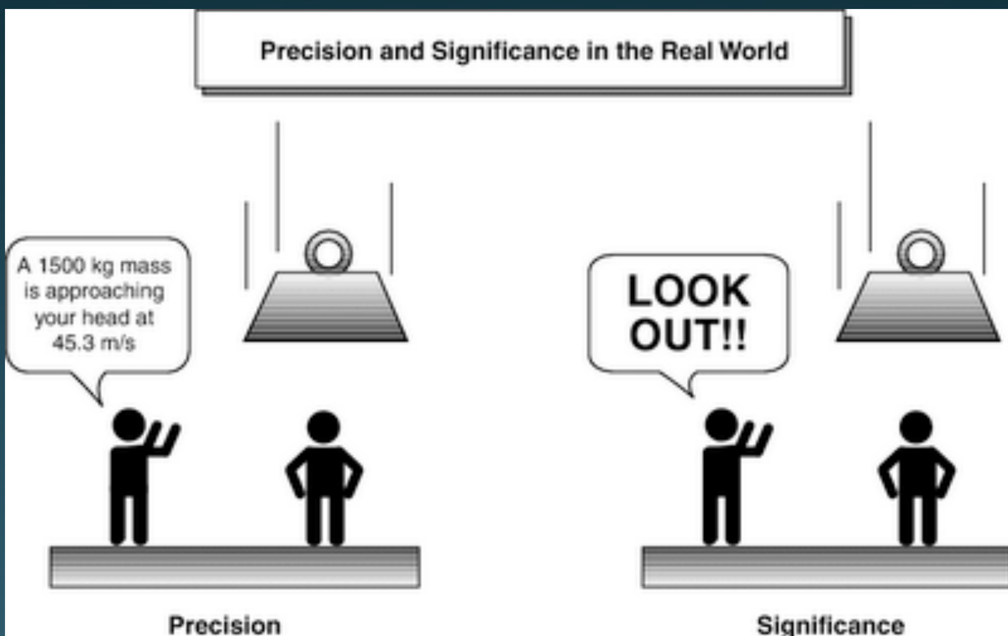
- Precision theory & PDF constraints

Electroweak physics remains very active

What next?

Global Electroweak Fits

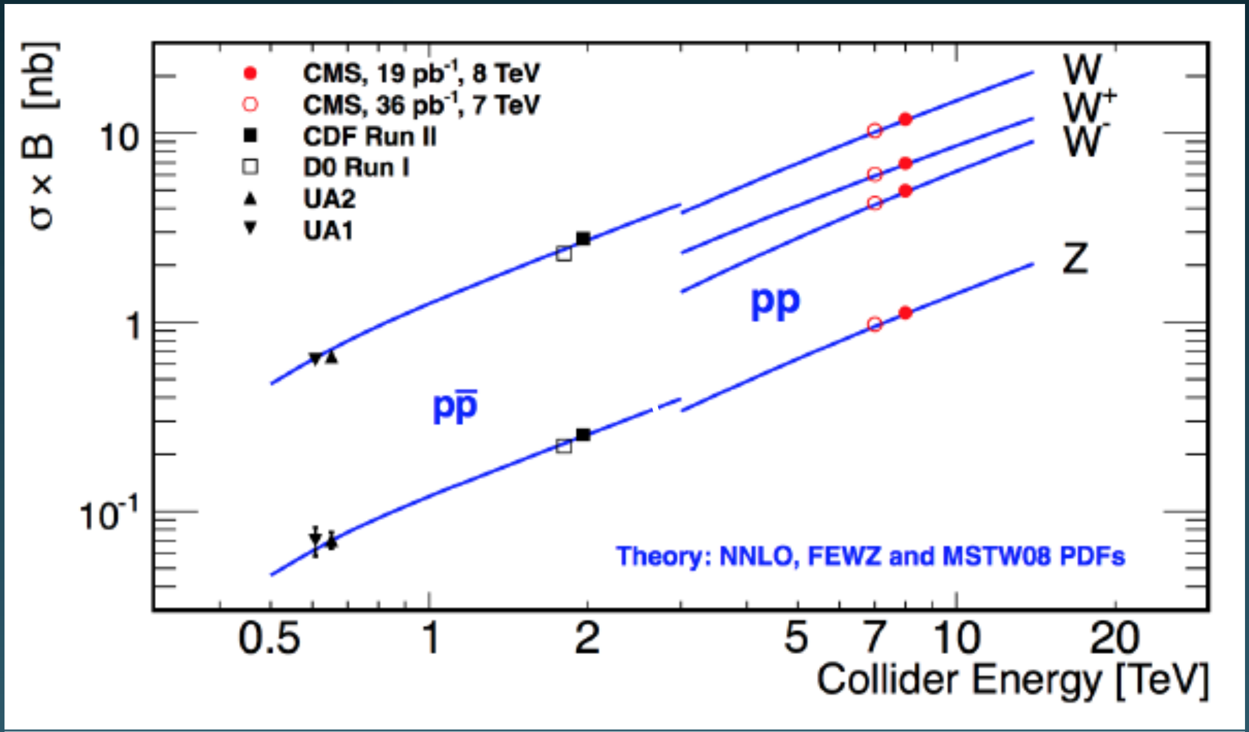
Precision!



Electroweak physics remains very active

- Improve precision parameters: W mass, FB asymmetry (weak mixing angle)
- Study W,Z thoroughly: differential distributions
- Precision theory & PDF constraints
- Look for new physics -- anomalous couplings

Vector Boson Production



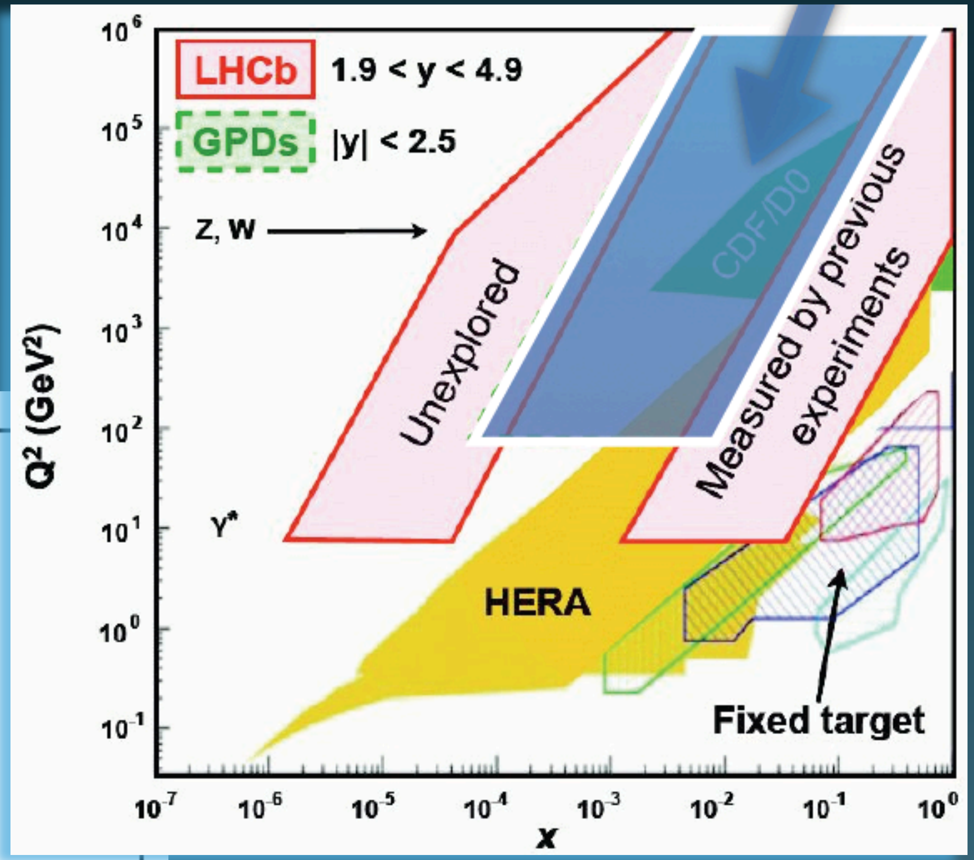
Low-pileup data only

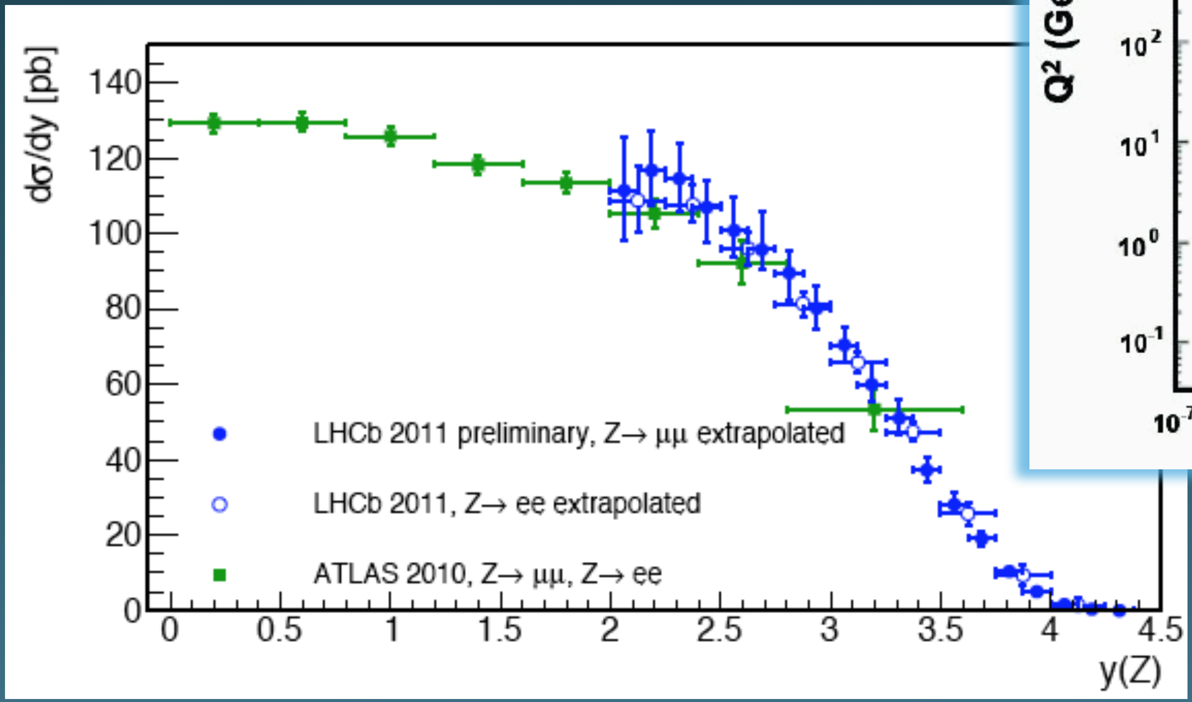
Vector Boson Production

LHCb

ATLAS & CMS

Measurements extended to $|\eta_l|$=4.9 important constraints on PDFs

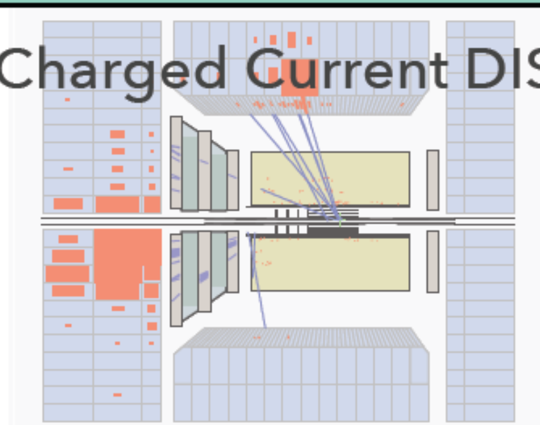
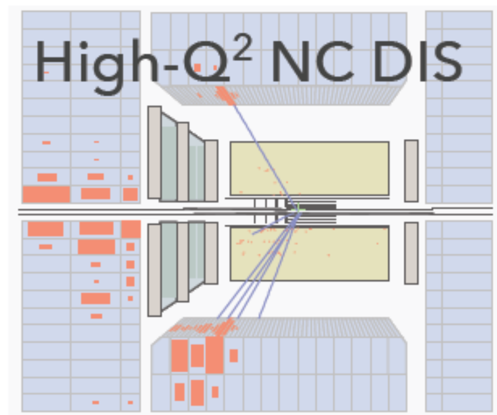
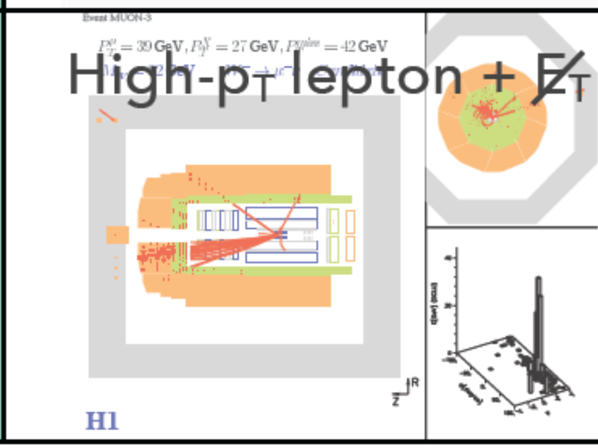




Electroweak Bosons at HERA

e-p Z^0 production

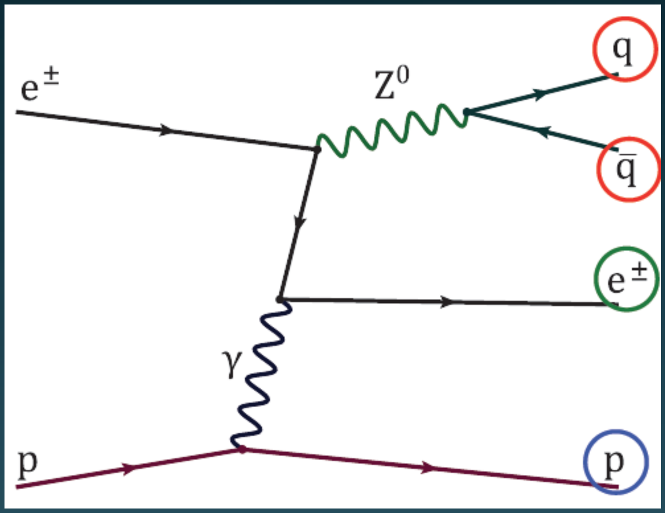
HERA finished data taking in 2007!

	W	Z
Virtual	 Charged Current DIS	 High-Q^2 NC DIS
Real	 High-p_T lepton + $\not{E}_T$	**Missing piece in HERA EW program?** Smallest cross section measured at HERA!

See EPS talk: Junipei Maeda

Electroweak Bosons at HERA

Z bosons: t-channel off-shell exchanges (small cross section)



Electroweak Bosons at HERA

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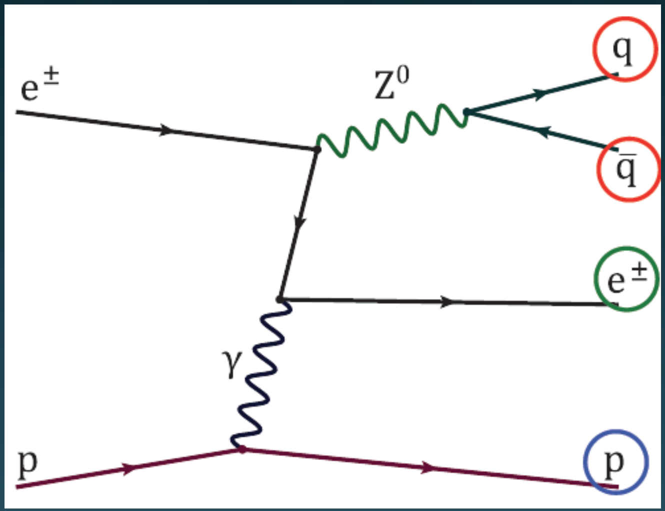

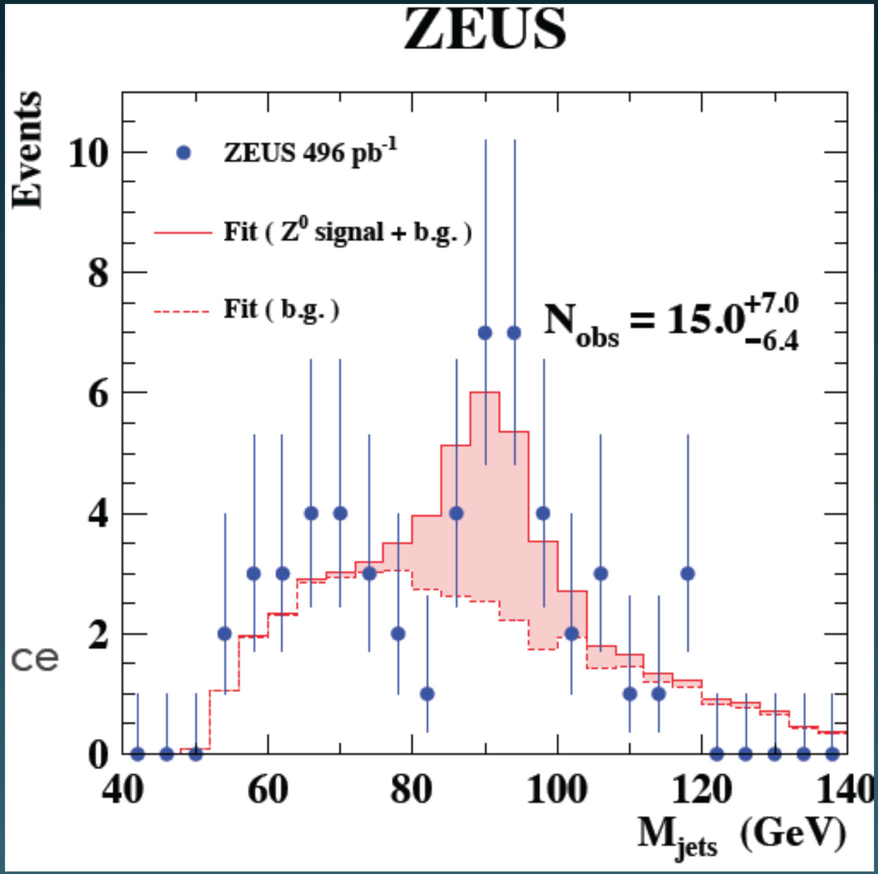

ce

15 ± 6.8 events observed: 2.3σ significance

Electroweak Bosons at HERA

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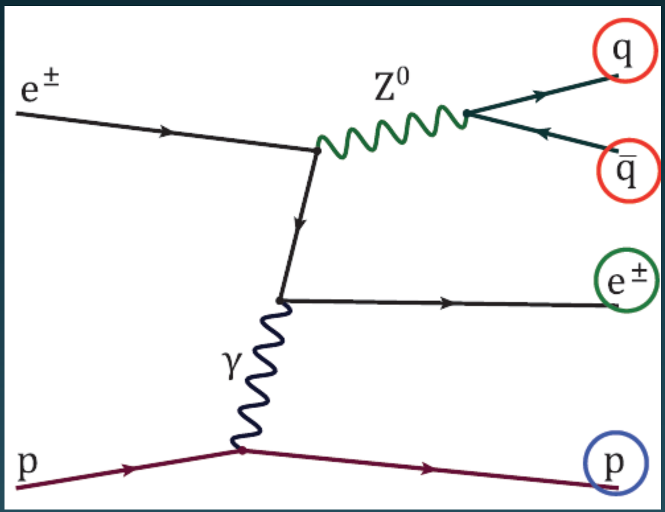
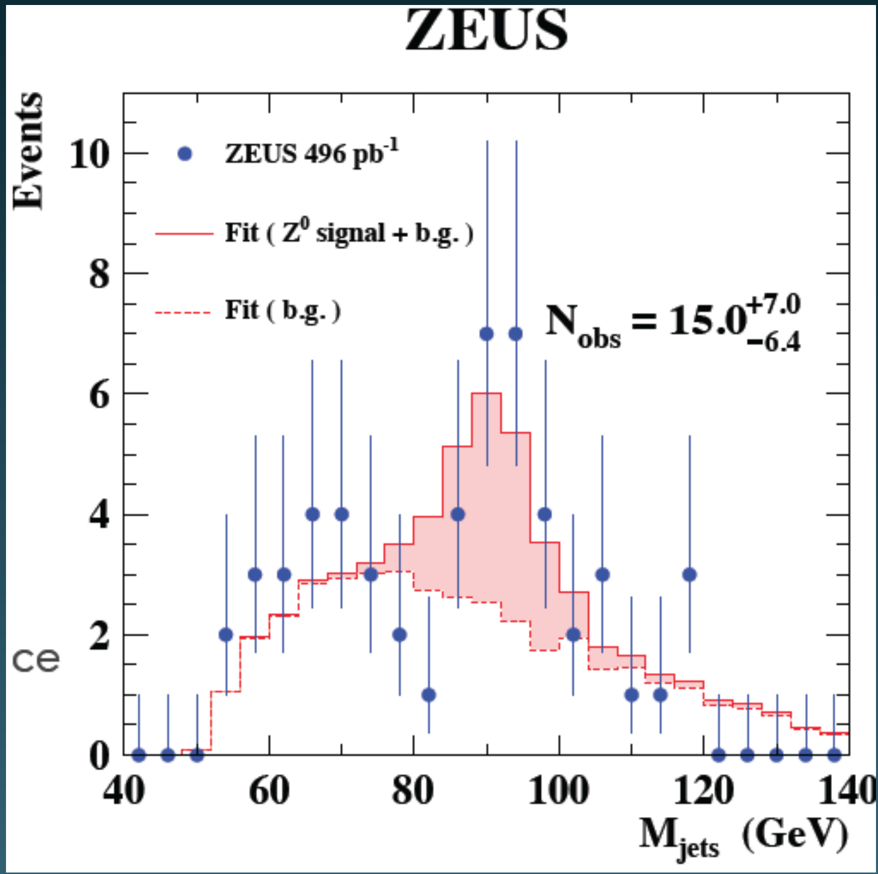


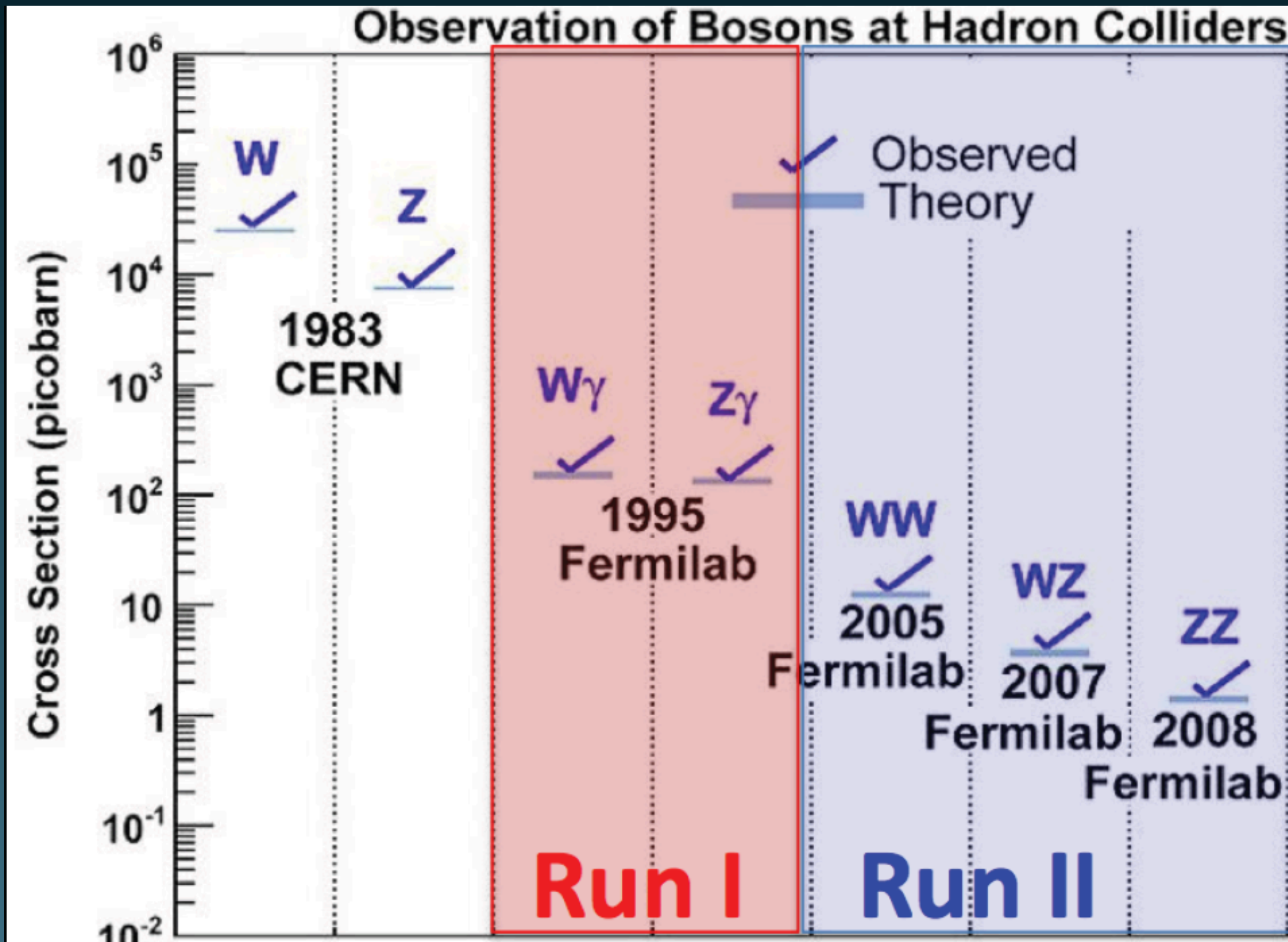


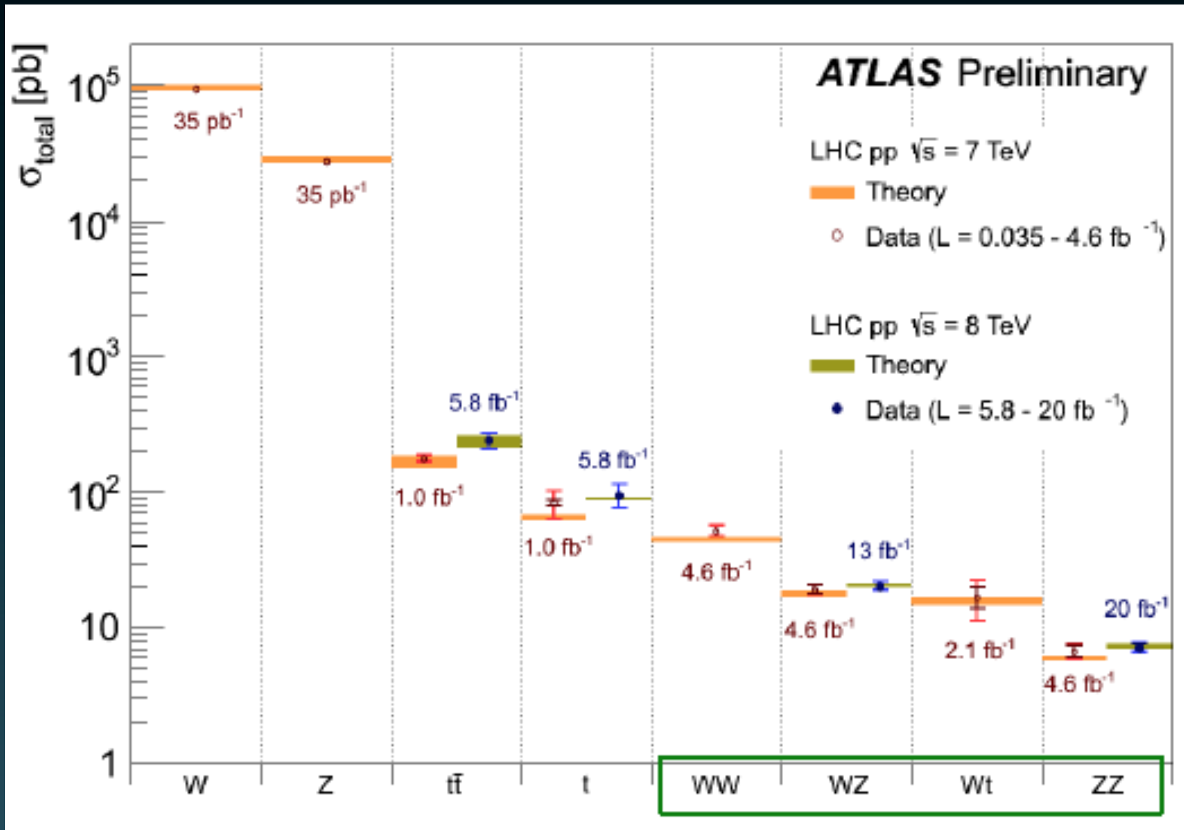
15 ± 6.8 events observed:
2.3σ significance

$\sigma(ep \rightarrow eZ^0 p^*) = 13.0 \pm 0.06$ pb

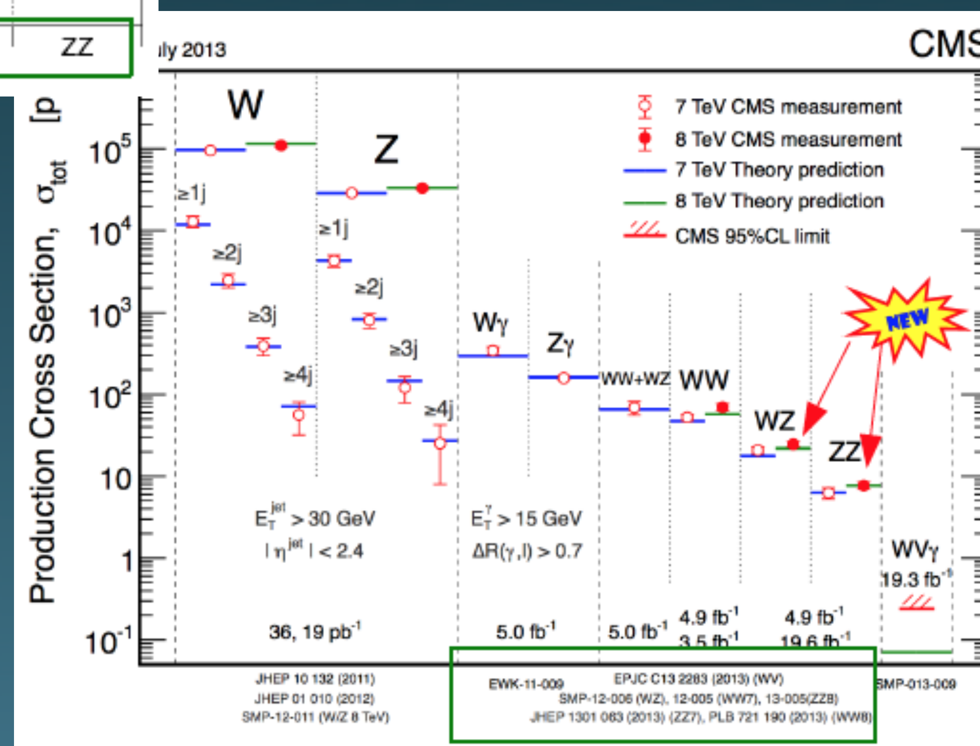
$\sigma(theory) = 16.0$ pb

Diboson Production



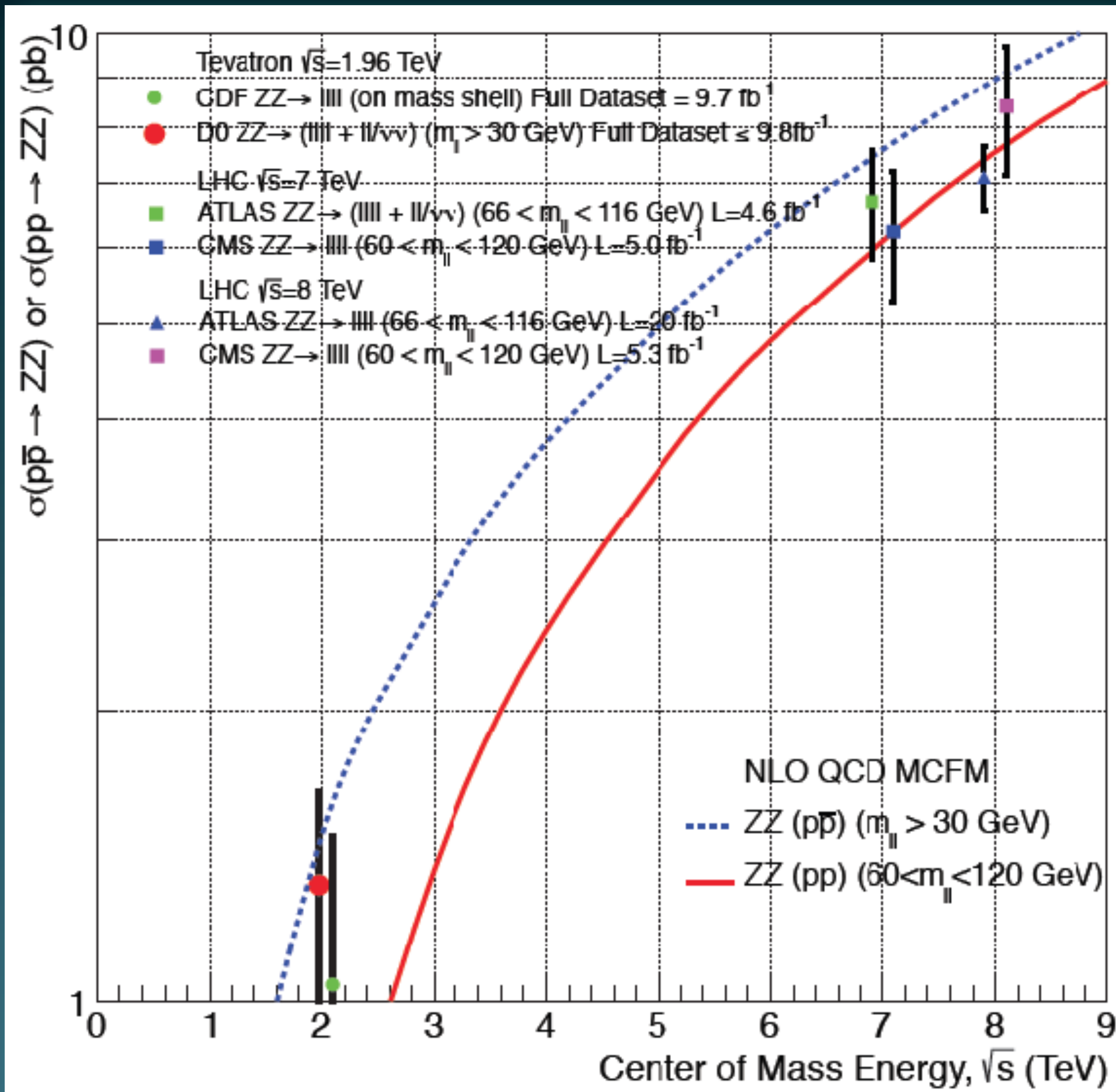


Diboson Production

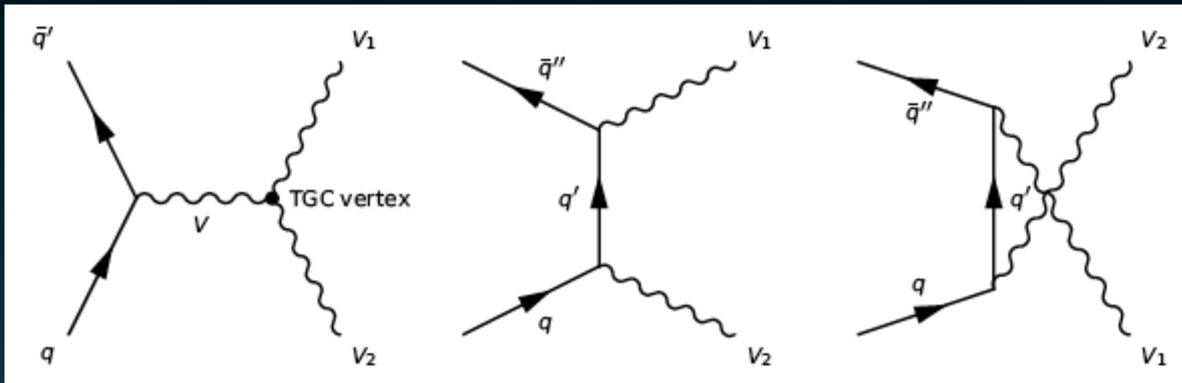


See also parallel talks (P. Rebello Teles - CMS, J. Moss- ATLAS, D. Nguyen- ATLAS, I. Osipenkov- CMS, D. Menenez- D0, G. Brandt- ATLAS)

Diboson Production



Example: ZZ Production

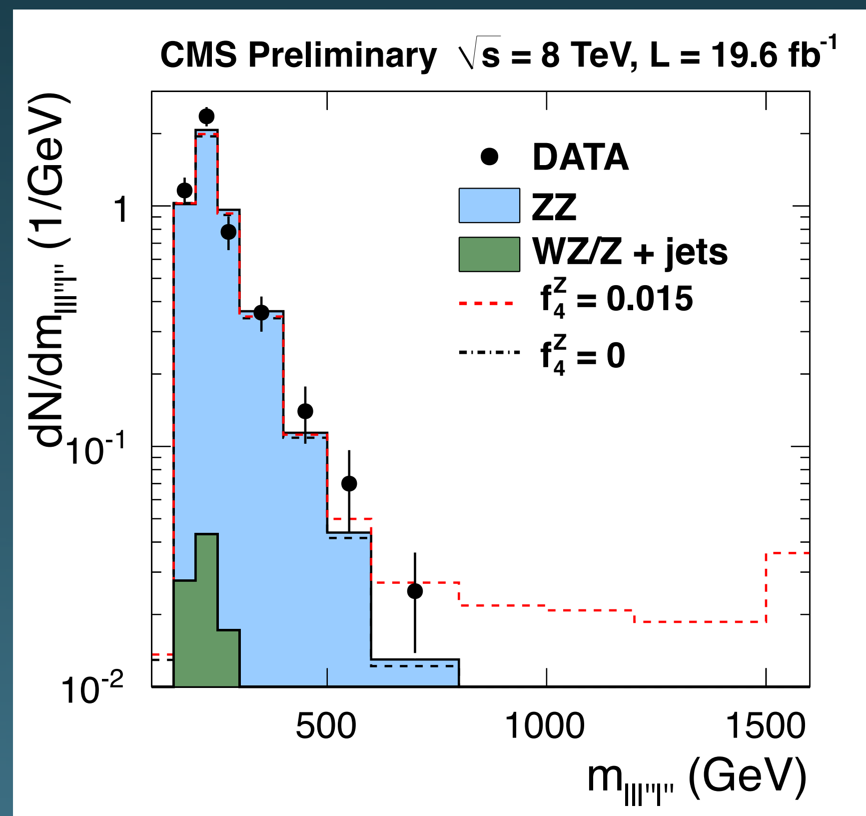


Anomalous Triple Gauge Boson Couplings

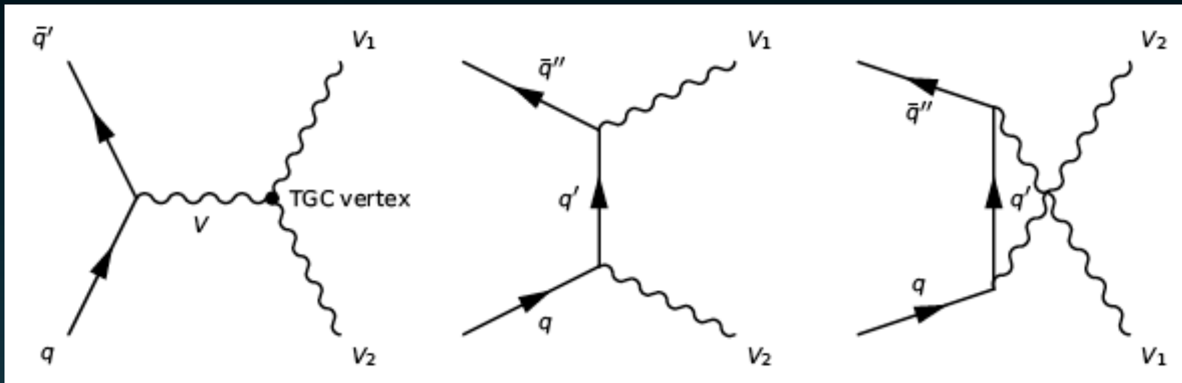
Precision test of the SM

ZZ Production

Coupling	Parameters	Channels
$WW\gamma$	$\lambda_\gamma, \Delta\kappa_\gamma$	WW
WWZ	$\lambda_Z, \Delta\kappa_Z, \Delta g_1^Z$	WW,WZ
$Z\gamma Z$	f_4^Z, f_5^Z	ZZ
ZZZ	f_4^γ, f_5^γ	ZZ



All parameters zero in SM



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Coupling	Parameters	Channels
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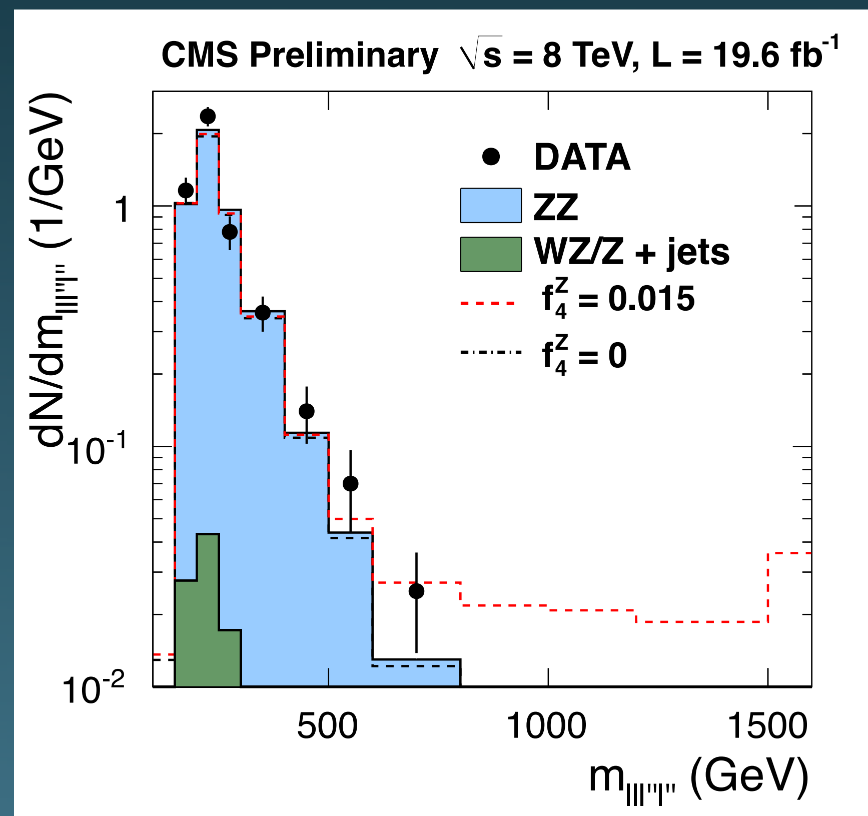
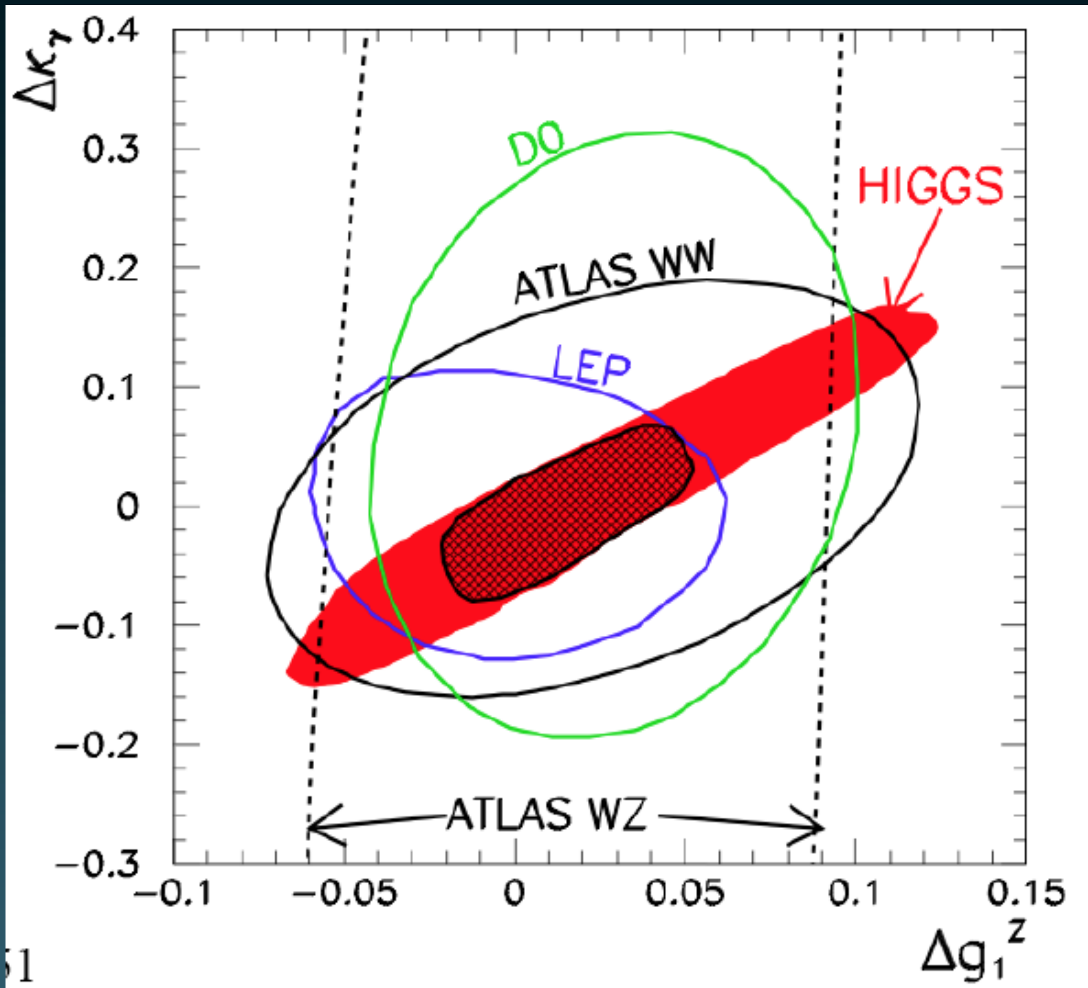


All parameters zero in SM

No evidence for aTGCs from any experiment so far



Anomalous Triple Gauge Boson Couplings

Corbett *et al* arXiv:1304.1151

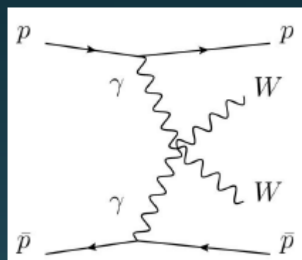
Complementary approaches to new physics using coupling deviations

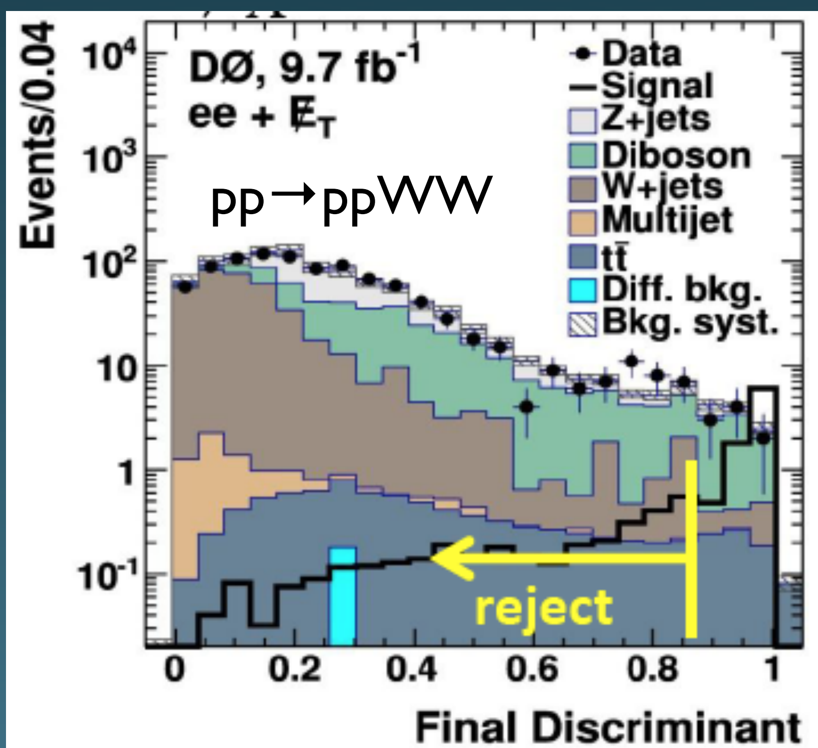
Anomalous Quartic Gauge Boson Couplings

BSM models (eg- extra dimensions):
10-100x cross section enhancement

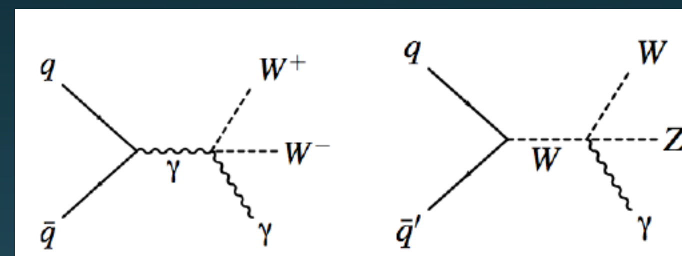
Limits set by Tevatron & LHC on anomalous terms in Lagrangian.

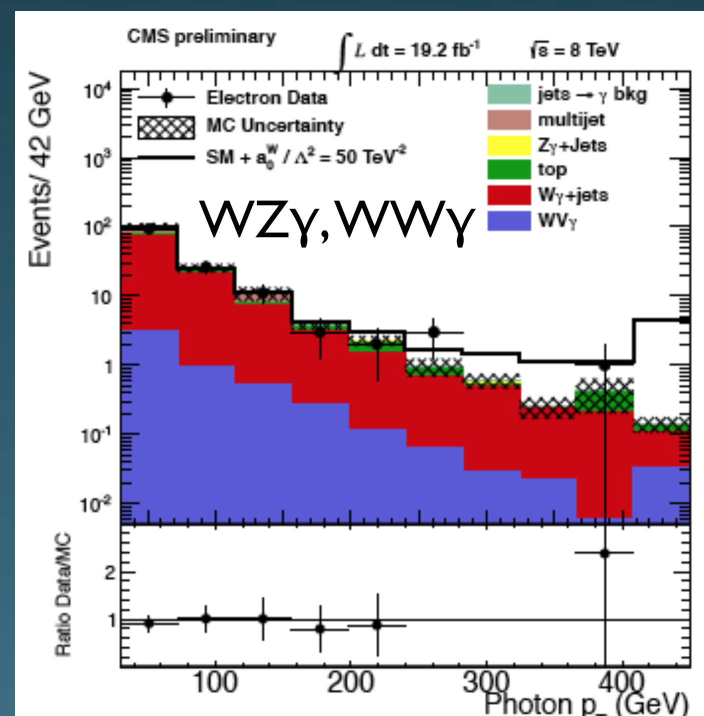
photon-initiated



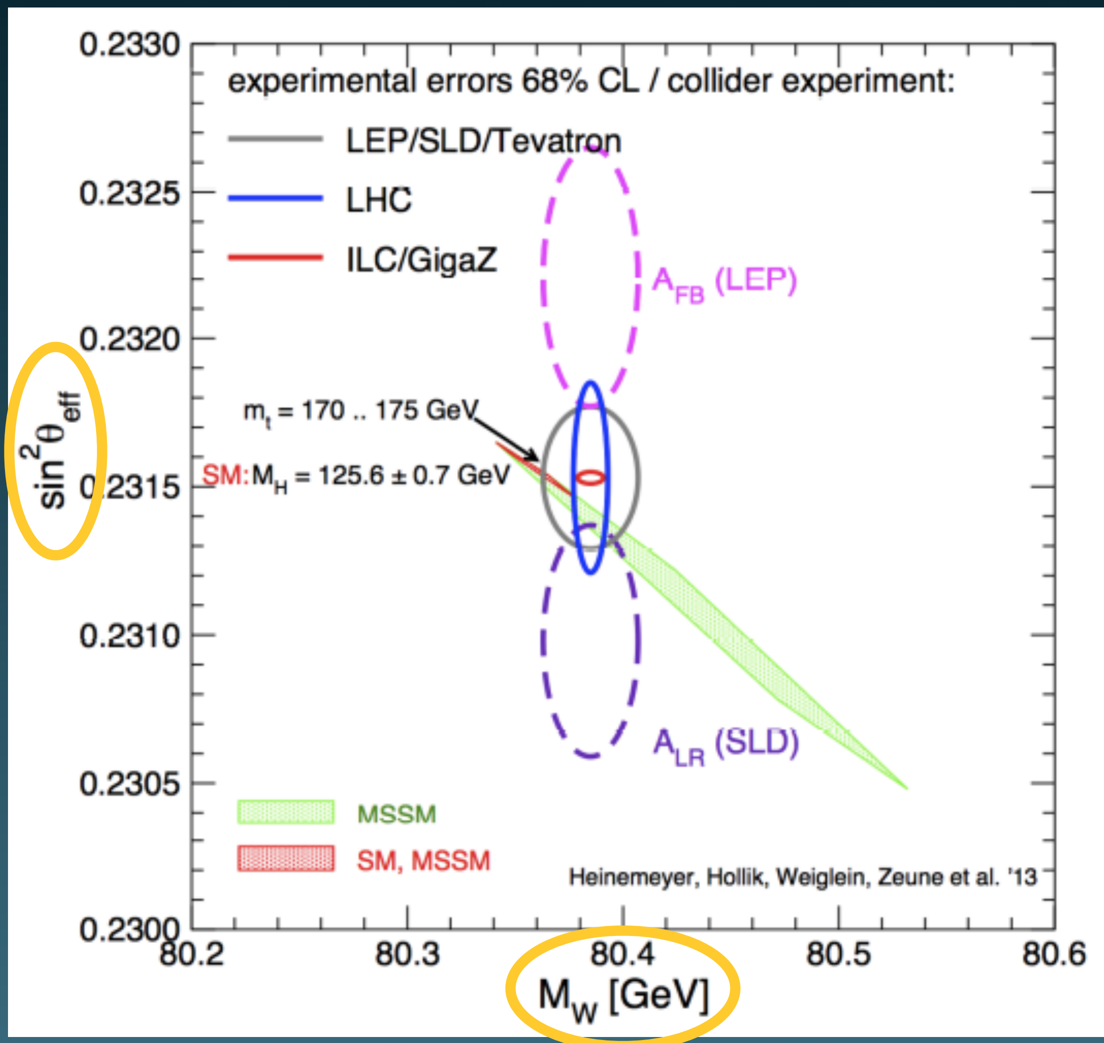


triple boson production





Electroweak Precision Observables



Nice discussion in Snowmass proceedings (Kotwal, Wackeroth, et al.)

Both predicted precisely in SM. BSM predictions, too.

$\sin^2\theta_{eff}$

$$\sin^2\theta^f_{\rm eff} = \sin^2\theta_{\rm W}(1+\Delta\kappa)$$

$$q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$$

$\sin^2\theta_{eff}$

V-A nature of EWK interaction:

$$\sin^2\theta^f_{\rm eff} = \sin^2\theta_{\rm W}(1+\Delta\kappa)$$

$$g_v^f = I_3^f - 2Q_f \sin^2\theta_W$$
$$g_a^f = I_3^f$$

$$\sin^2\theta_W = 1 - M_W^2 / M_Z^2$$

$$q\bar{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$$

$\sin^2\theta_{eff}$

V-A nature of EWK interaction:

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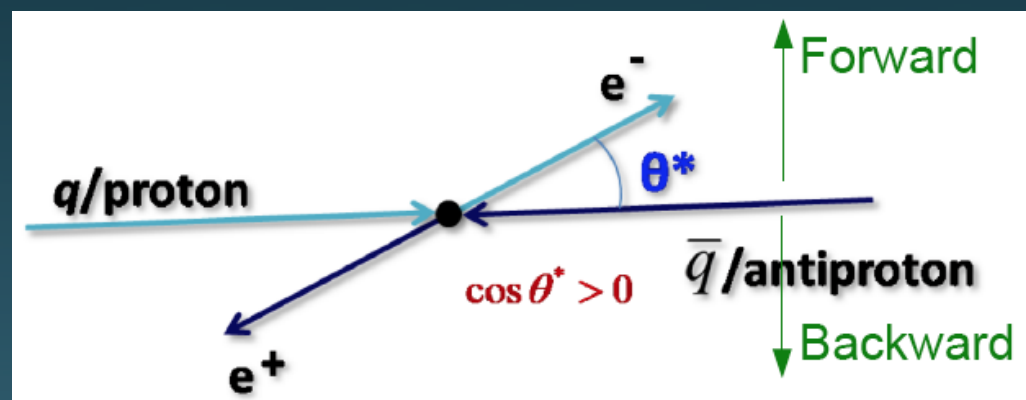
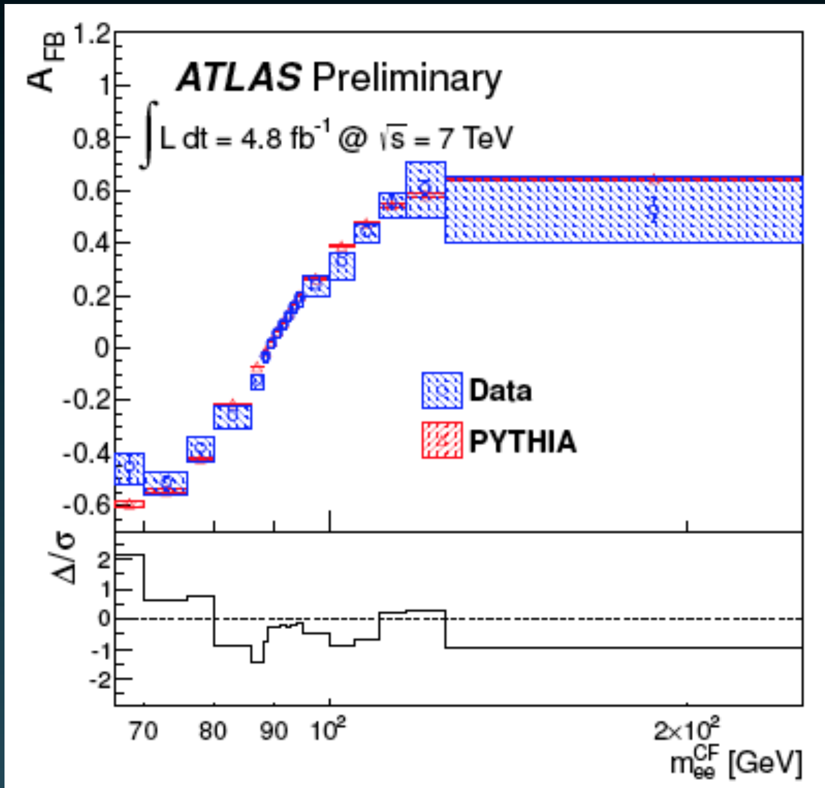


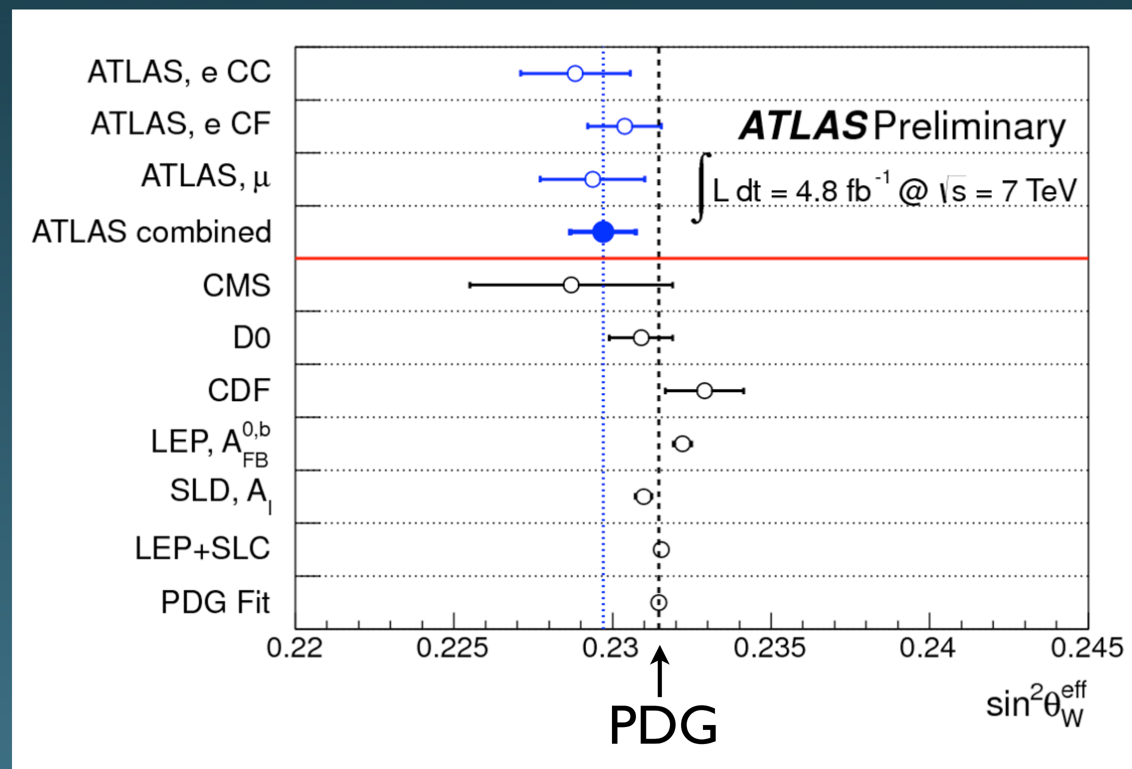
forward-backward asymmetry

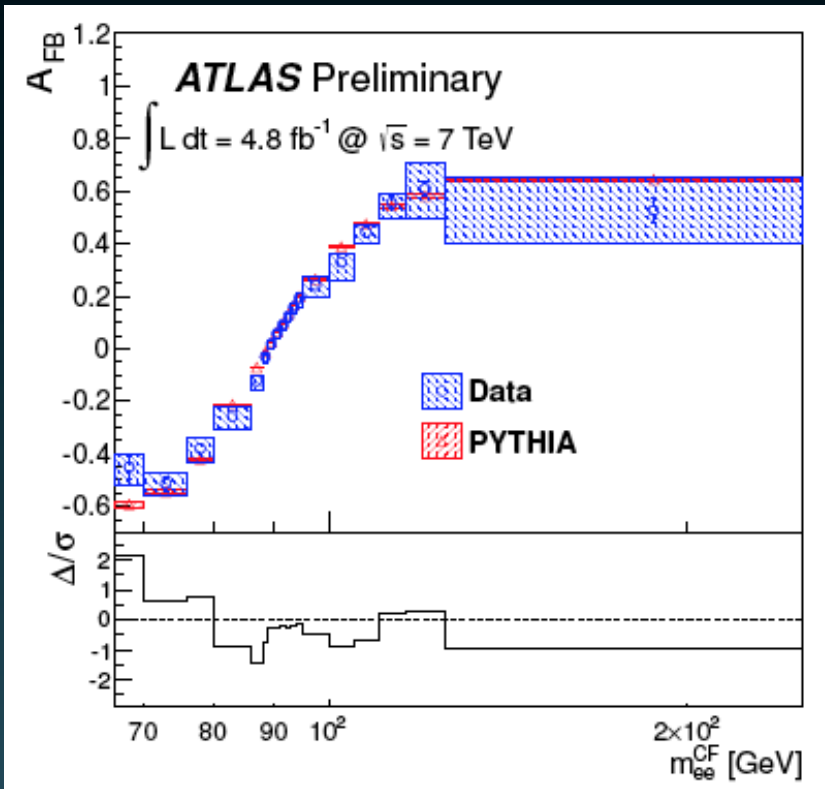
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$



$\sin^2\theta_{eff}$

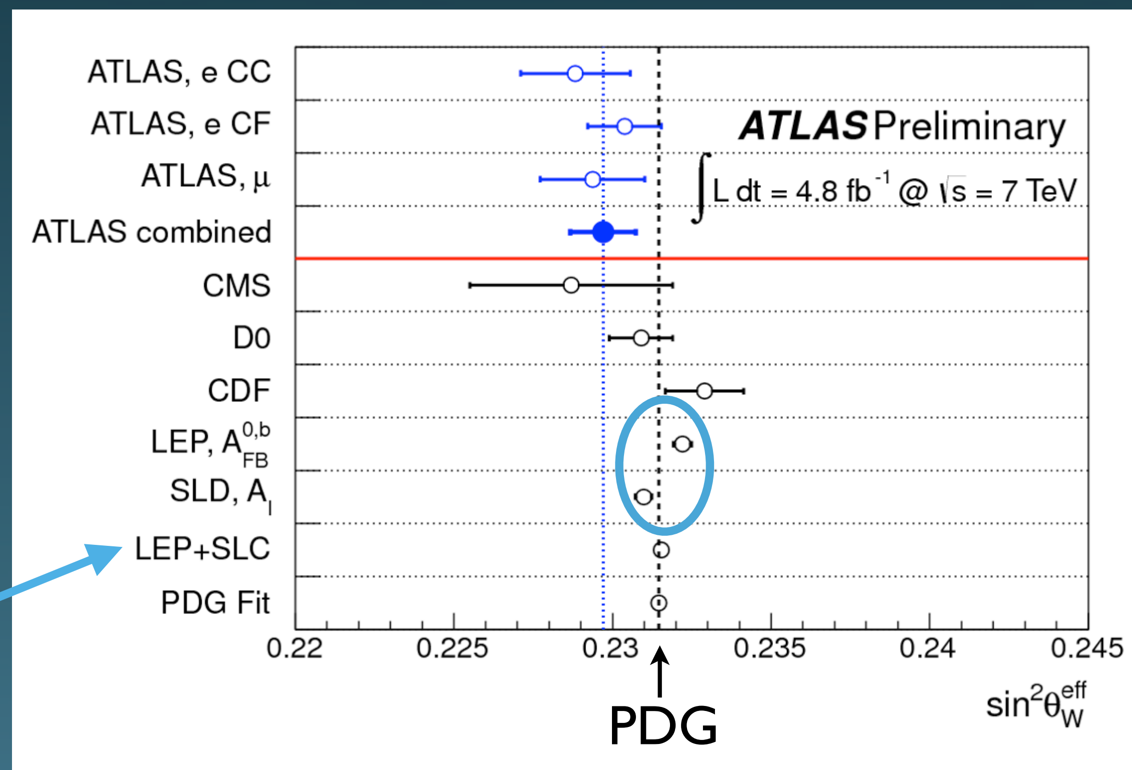
forward-backward asymmetry





$\sin^2\theta_{eff}$

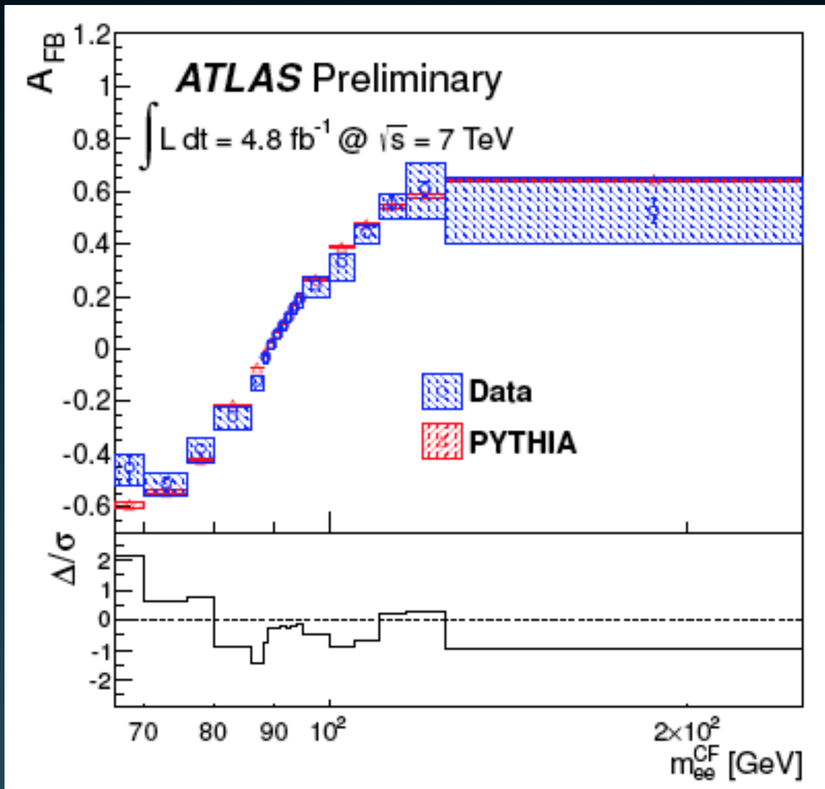
forward-backward asymmetry



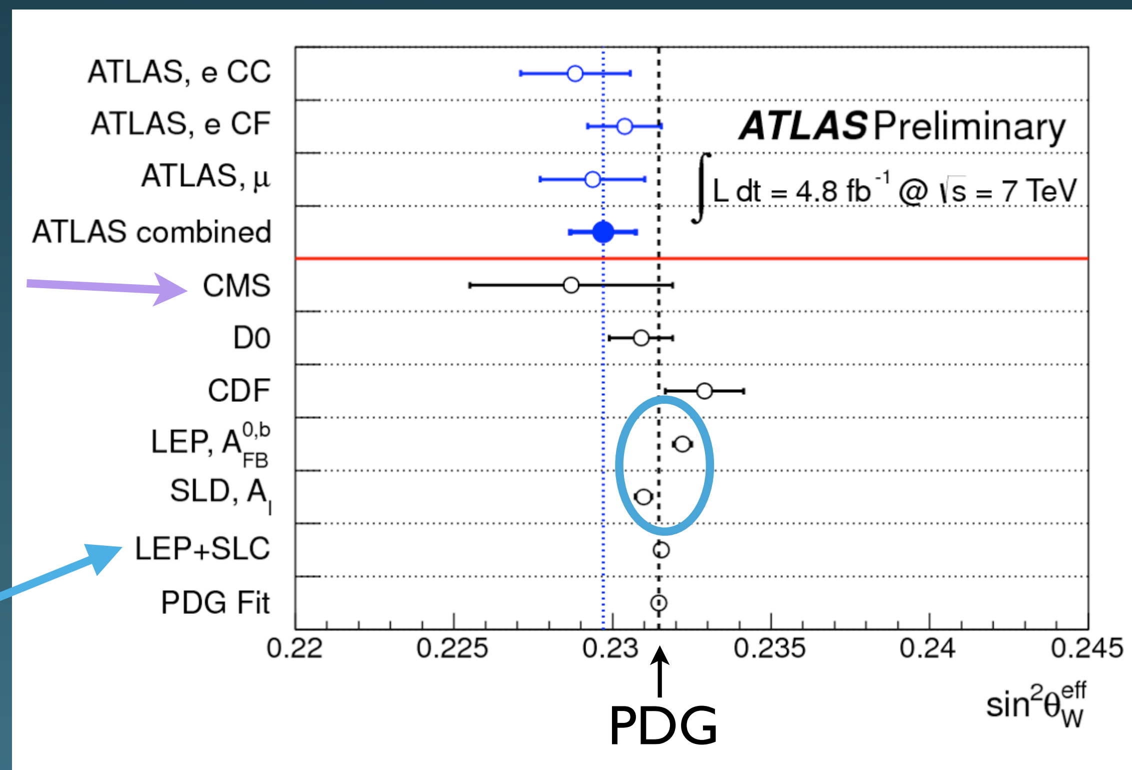
3σ tension

$\sin^2\theta_{eff}$

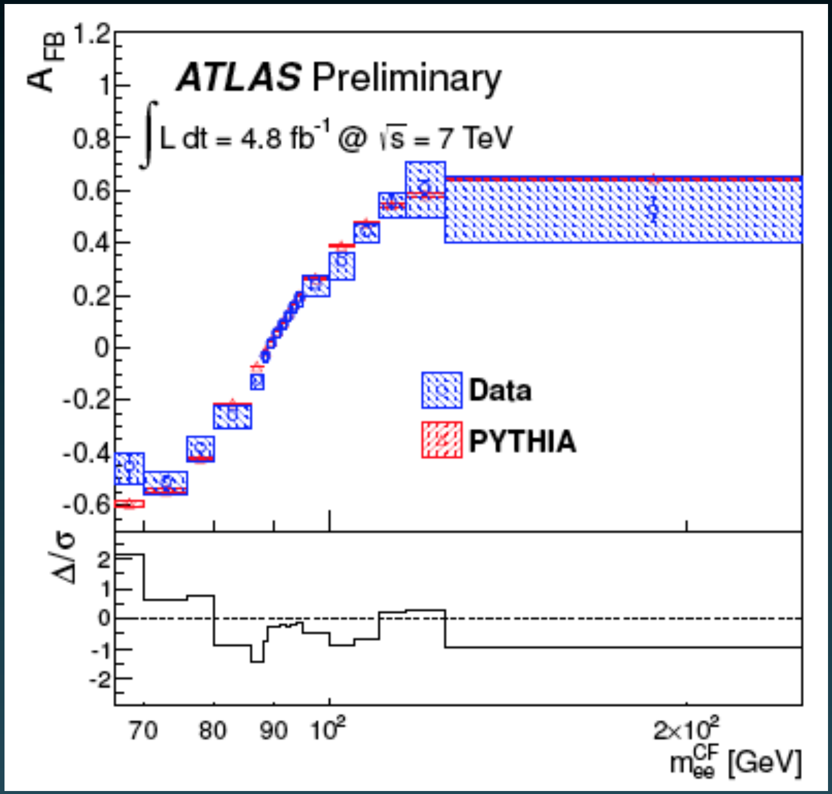
forward-backward asymmetry



CMS: First LHC, 1.1 fb^{-1}(2011)



3σ tension



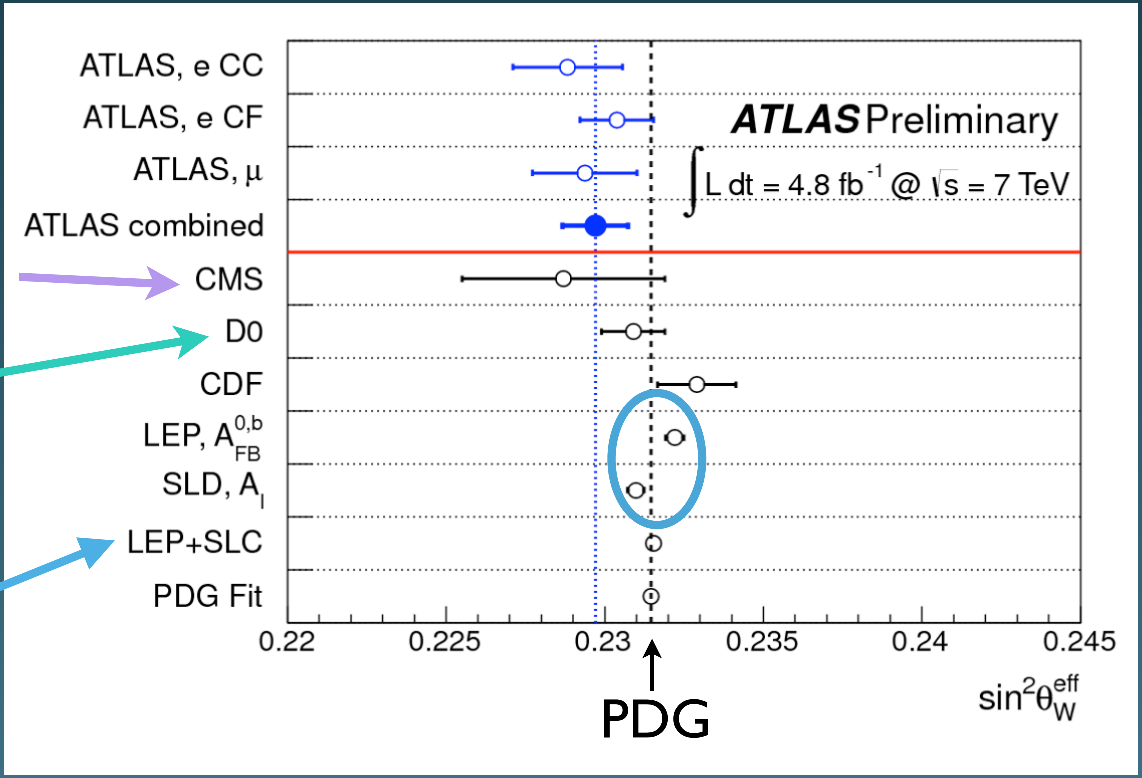
$sin^2\theta_{eff}$

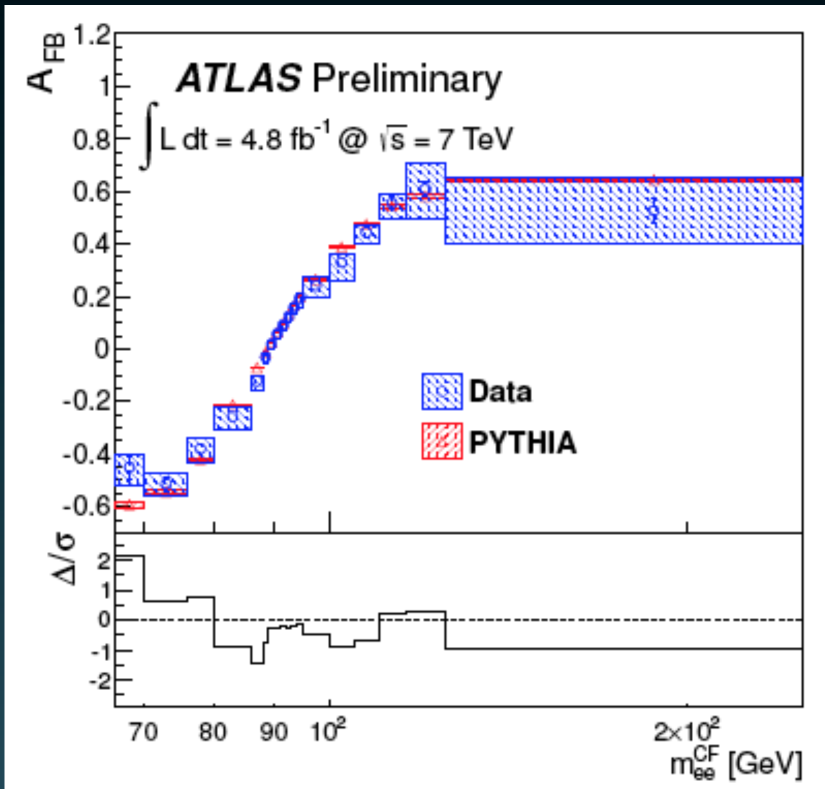
forward-backward asymmetry

CMS: First LHC, 1.1 fb^{-1}(2011)

D0: 5.0 fb^{-1} (2011)

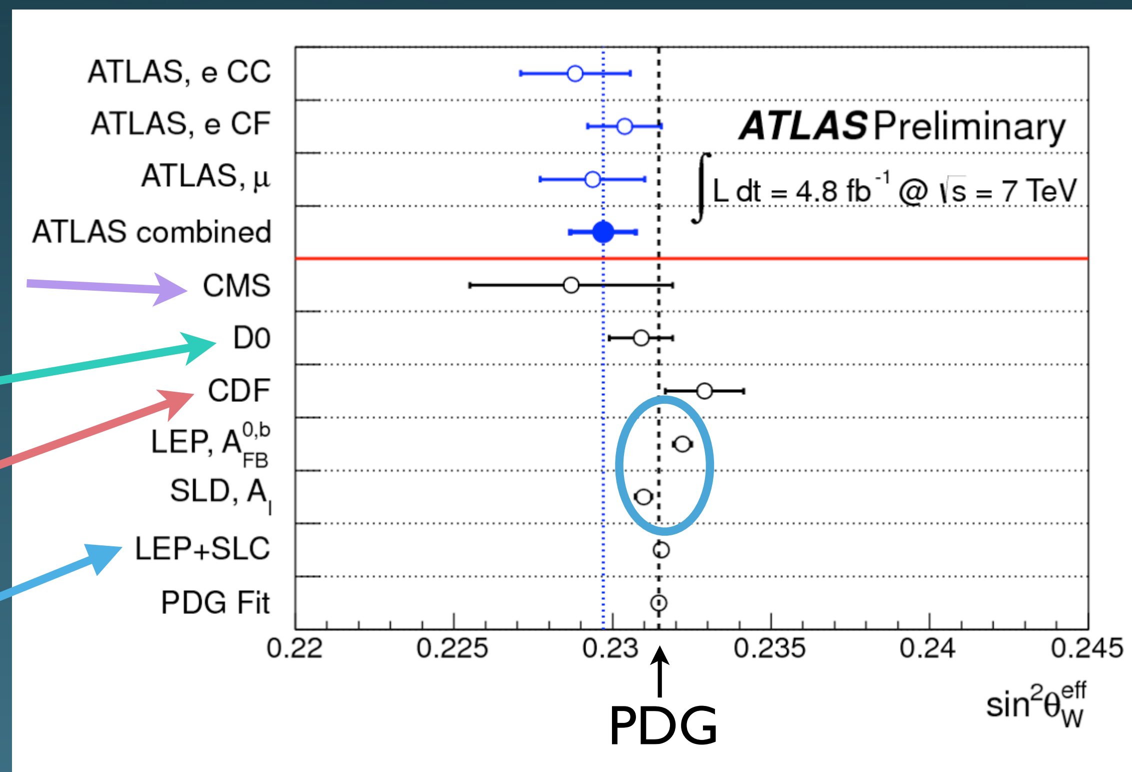
3σ tension





$\sin^2\theta_{eff}$

forward-backward asymmetry



CMS: First LHC, 1.1 fb^{-1}(2011)

D0: 5.0 fb^{-1} (2011)

CDF: 2.1 fb^{-1} (2013)
(boosted Z's)

3σ tension

Projections

$\sin^2\theta_{eff}$

$\Delta \sin^2 \theta^l_{\text{eff}}$ [10^{-5}] final state	CDF e^+e^-	D0 e^+e^-	final CDF $\mu^+\mu^-$	final CDF e^+e^-	final CDF combined
$\mathcal{L}[\text{fb}^{-1}]$	2.1	5.0	9.0	9.0	9.0 $\mu\mu + 9\ e^+e^-$
PDF	12	48	12	12	12
higher order corr.	13	8	13	13	13
other systematics	5	38	5	5	5
statistical	90	80	80	40	40
total $\Delta \sin^2 \theta^l_{\text{eff}}$	**92**	**101**	**82**	**44**	**41**

Tevatron (CDF)

A. Bodek

Snowmass proceedings (Kotwal, Wackeroth, et al.)

Projections

$\sin^2\theta_{\text{eff}}$

$\Delta \sin^2 \theta^l_{\text{eff}}$ [10^{-5}] final state	CDF e^+e^-	D0 e^+e^-	final CDF $\mu^+\mu^-$	final CDF e^+e^-	final CDF combined
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A. Bodek

$\Delta \sin^2 \theta^l_{\text{eff}}$ [10^{-5}]	ATLAS	CMS	LHC/per experiment		
$\sqrt{s}$ [TeV]	7	7	8	14	14
$\mathcal{L}$[fb^{-1}]	4.8	1.1	20	300	3000
PDF	70	130	35	25	10
higher order corr.	20	110	20	15	10
other systematics	70	181	60(35)	20	15
statistical	40	200	20	5	2
Total	108	319	75(57)	36	21

LHC conservative (optimistic)

R. Caputo

Snowmass proceedings (Kotwal, Wackeroth, et al.)

Projections

$\sin^2\theta_{eff}$

$\Delta \sin^2\theta^l_{eff}$ $[10^{-5}]$ final state	CDF e^+e^-	D0 e^+e^-	final CDF $\mu^+\mu^-$	final CDF e^+e^-	final CDF combined
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Tevatron (CDF)

A. Bodek

$\Delta \sin^2\theta^l_{eff}$ $[10^{-5}]$	ILC/GigaZ	TLEP(Z)
systematics	1.2	
statistical	0.5	0.2
total	1.3	

ILC/GigaZ

$\Delta \sin^2\theta^l_{eff}$ $[10^{-5}]$	ATLAS	CMS	LHC/per experiment		
$\sqrt{s}$ [TeV]	7	7	8	14	14
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Projections

$\sin^2\theta_{eff}$

$\Delta \sin^2 \theta^l_{\text{eff}}$ [10^{-5}] final state	CDF e^+e^-	D0 e^+e^-	final CDF $\mu^+\mu^-$	final CDF e^+e^-	final CDF combined
$\mathcal{L}$[fb^{-1}]	2.1	5.0	9.0	9.0	9.0 $\mu\mu$ + 9 e^+e^-
PDF	12	48	12	12	12
higher order corr.	13	8	13	13	13
other systematics	5	38	5	5	5
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A. Bodek

$\Delta \sin^2 \theta^l_{\text{eff}}$ [10^{-5}]	ILC/GigaZ	TLEP(Z)
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statistical	0.5	0.2
total	1.3	

ILC/GigaZ

>10x LEP/SLC precision

$\Delta \sin^2 \theta^l_{\text{eff}}$ [10^{-5}]	ATLAS	CMS	LHC/per experiment		
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Snowmass proceedings (Kotwal, Wackeroth, et al.)

W boson mass

precision EWK observable

At tree level, M_W observable related to important EWK parameters:

$$M_W^2 = \pi\alpha_{EM} / \sqrt{2}G_F \sin^2\vartheta_W$$

W boson mass

precision EWK observable

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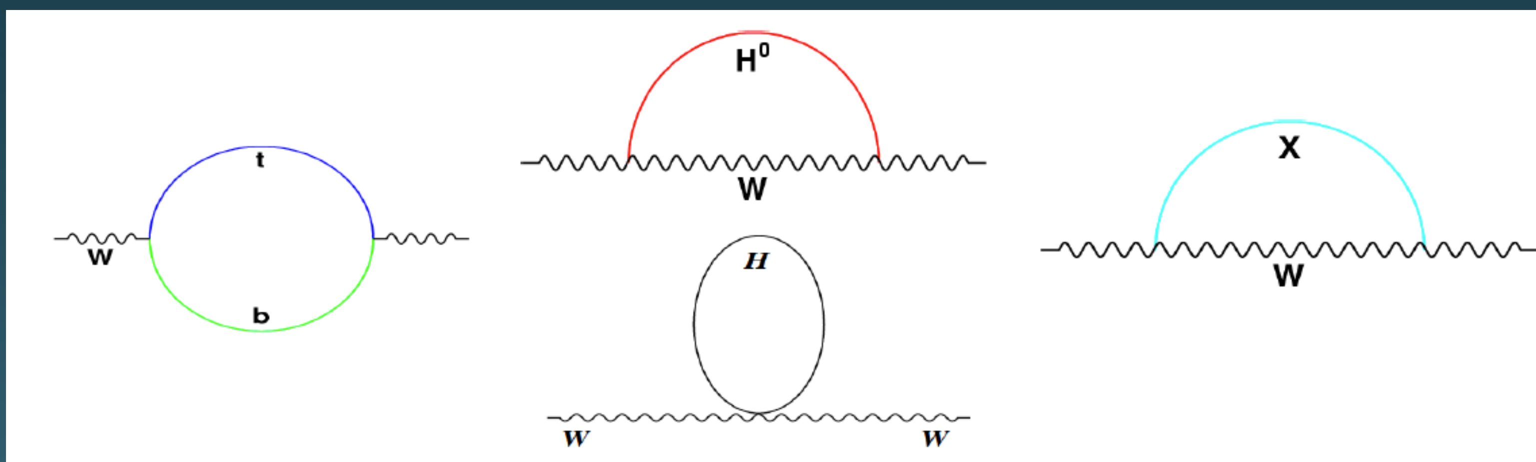
Radiative corrections due to quarks, Higgs loops, exotica make M_W important constraint on physics beyond the Standard Model:



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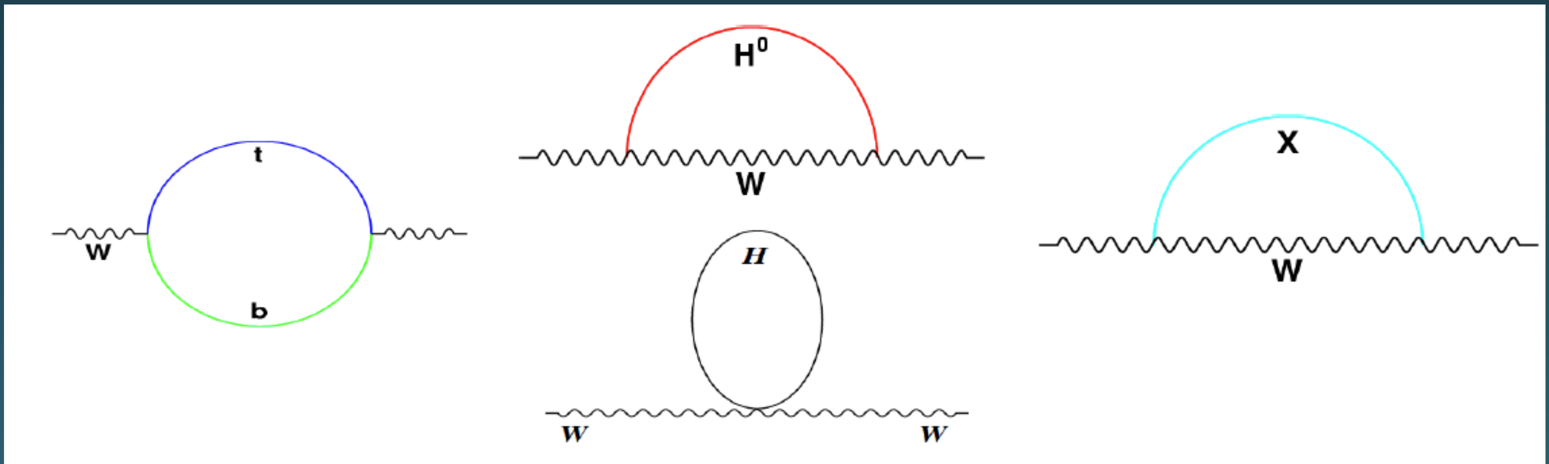
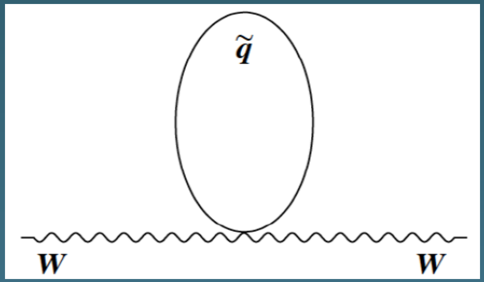
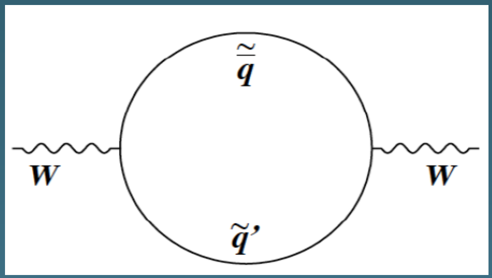
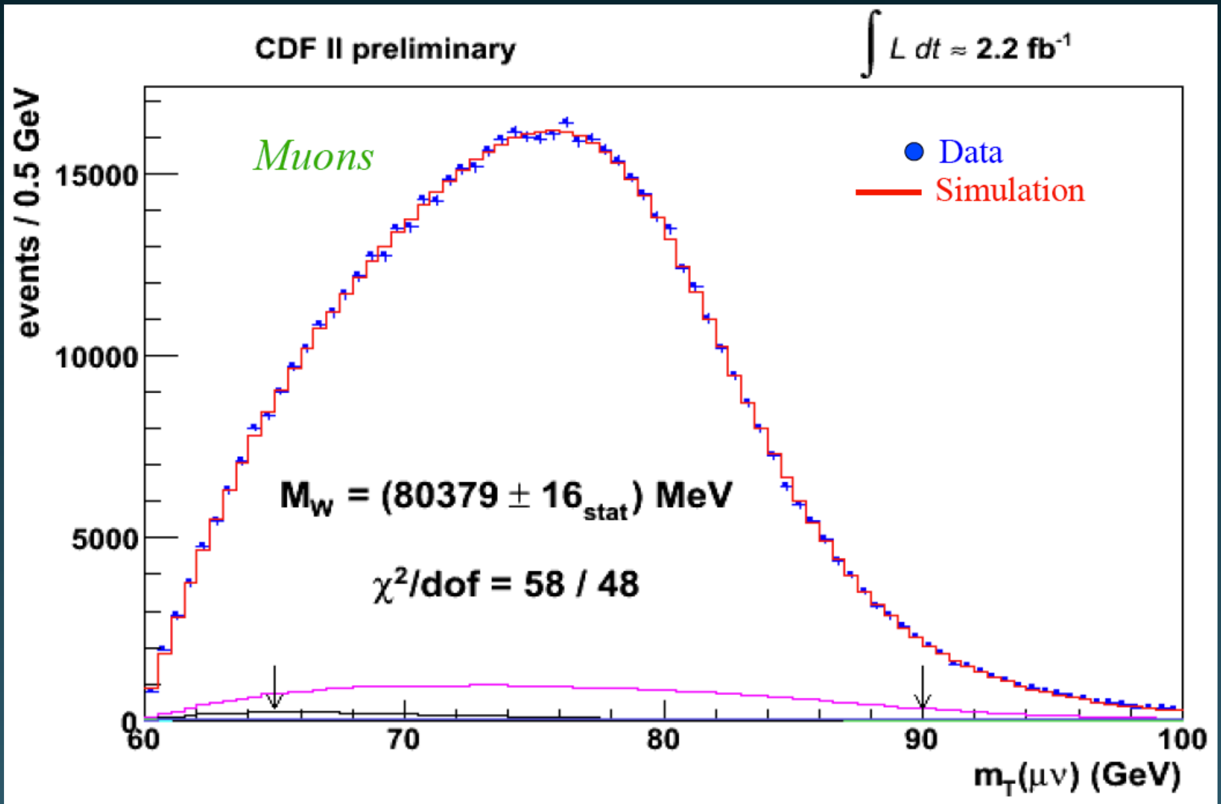


Example: folding in limits from direct searches, SUSY loops can contribute 100-200 MeV to M_W.



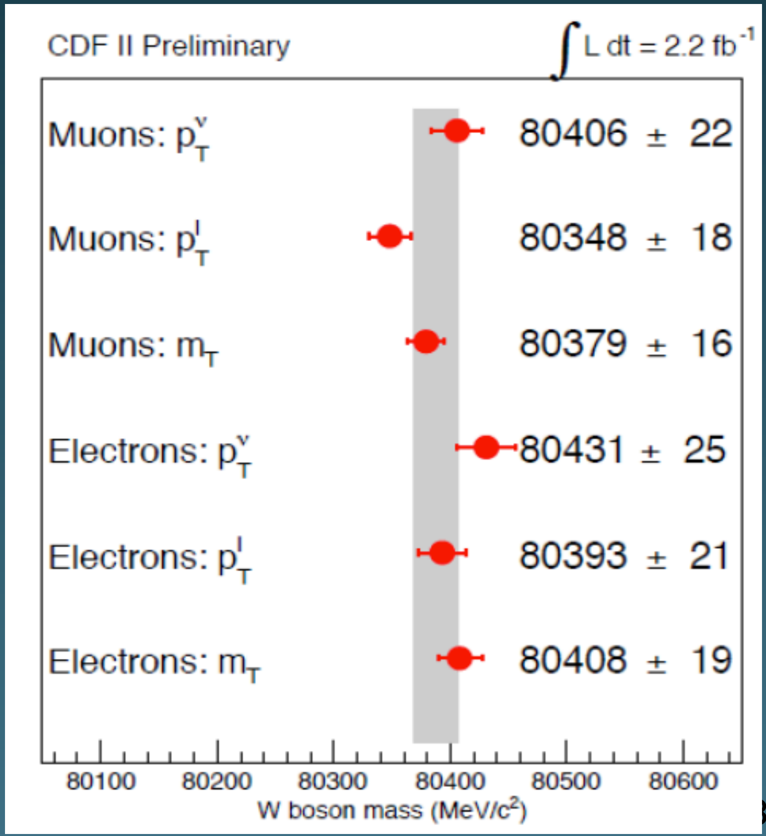


W boson mass



Used three observables from muon & electrons: lepton p_T, neutrino p_T, transverse mass m_T

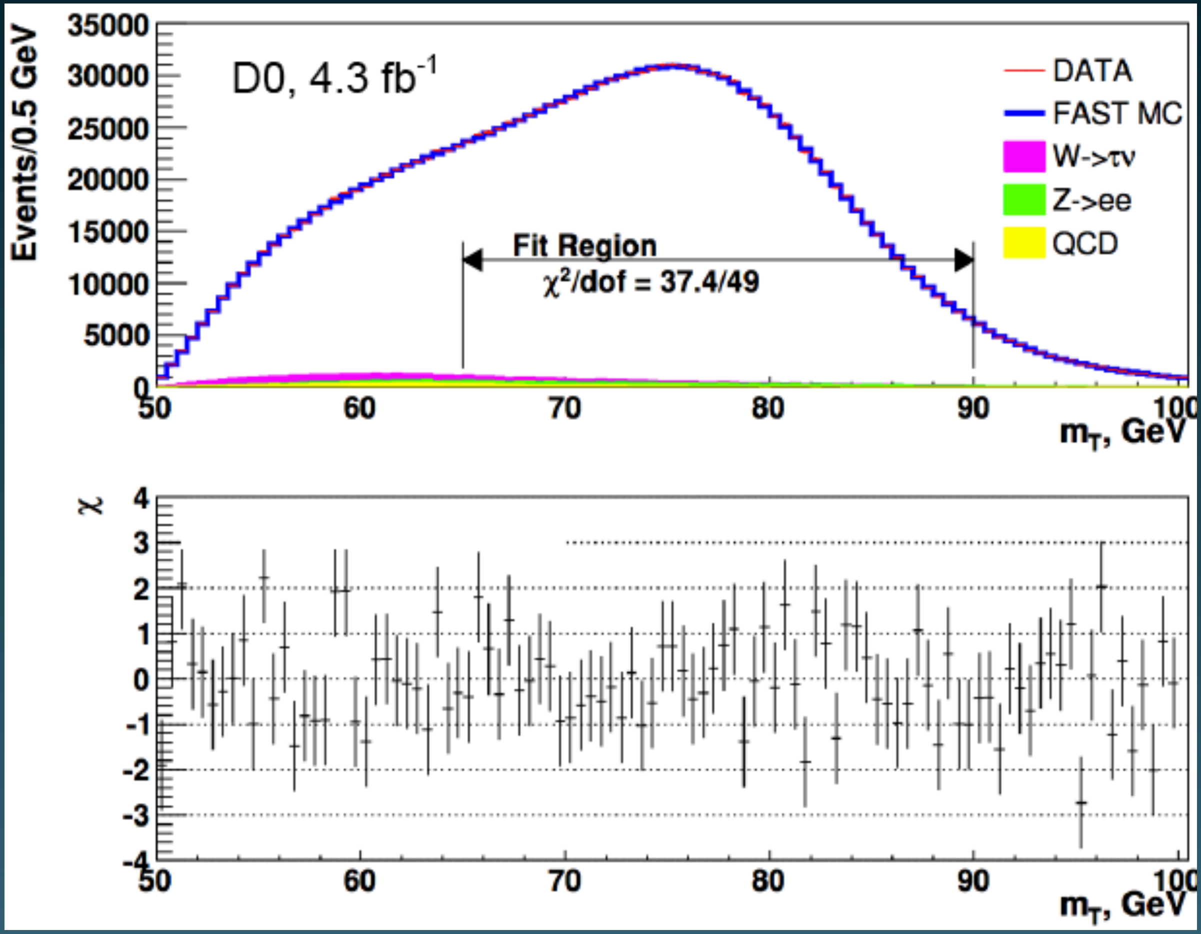
All combined (6 fits):
M_W=80387 ± 19 MeV
$P(\chi^2)$=25%



2012: CDF update last year

W boson mass

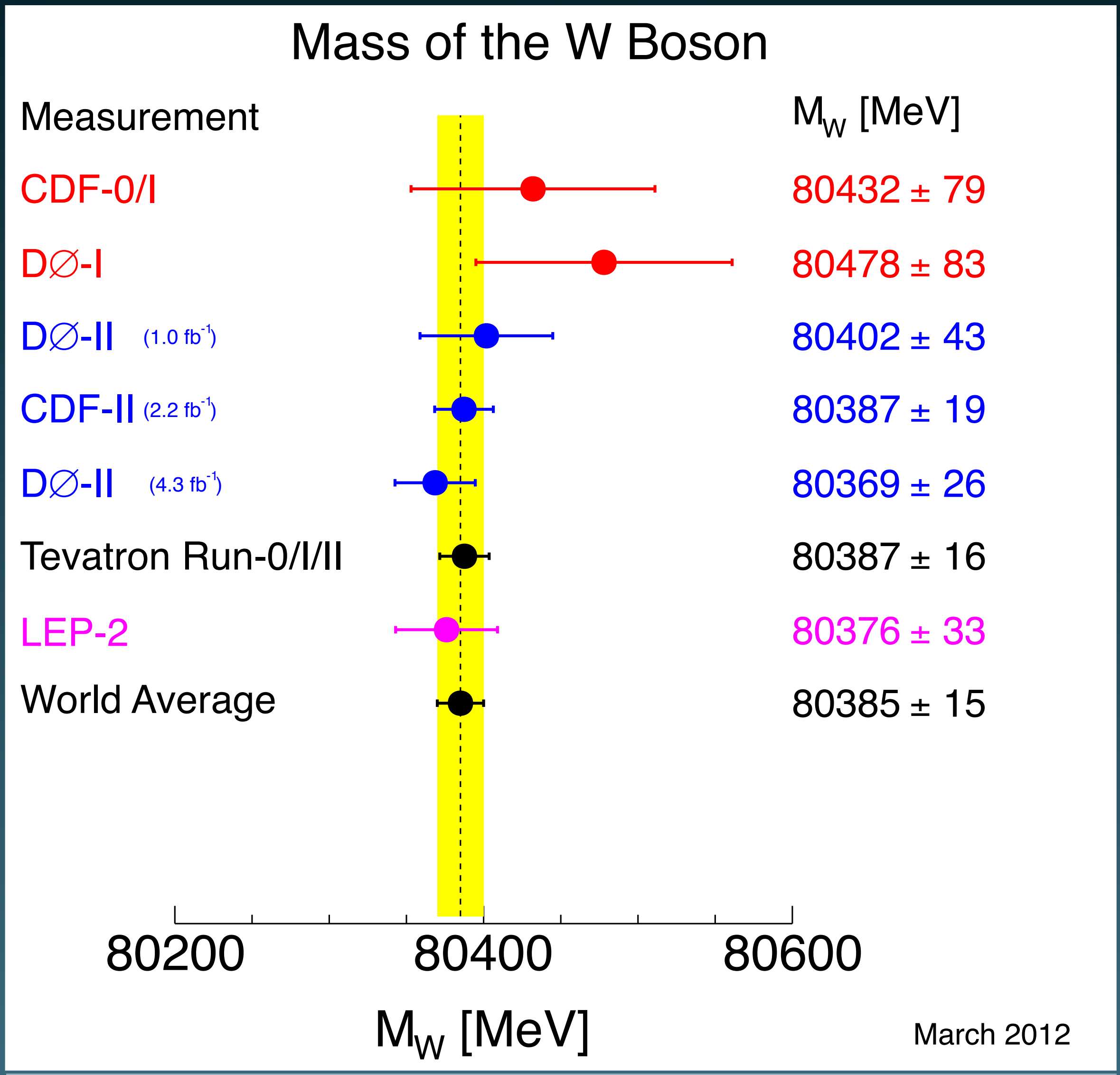
2012: D0 update last year



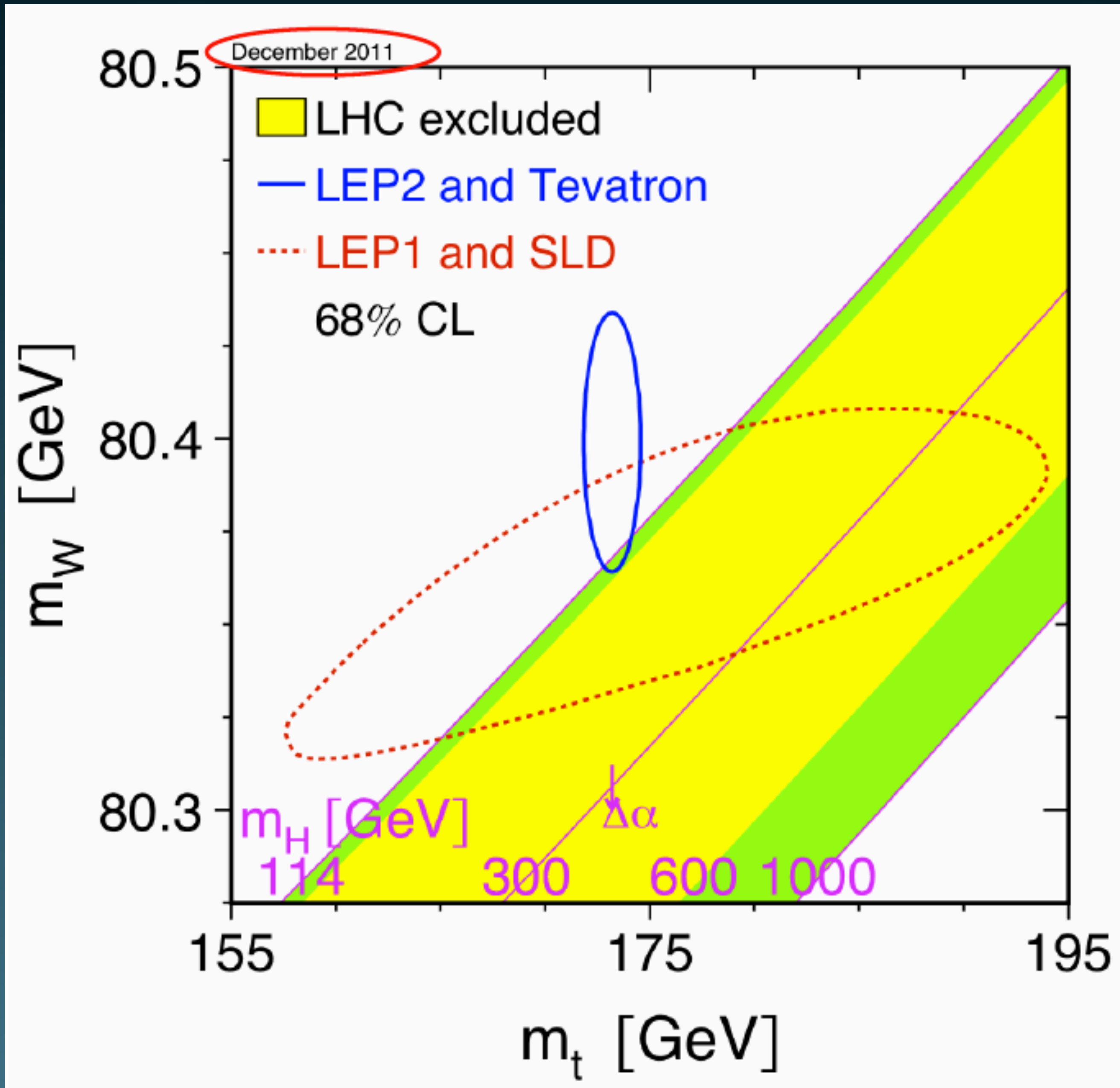
Again three observables: lepton p_T, ν p_T, transverse mass m_T

All 3 new fits (electron only), combined with earlier Run 2a:
M_W=80375 ± 23 MeV, $P(\chi^2)$=25%

W boson mass

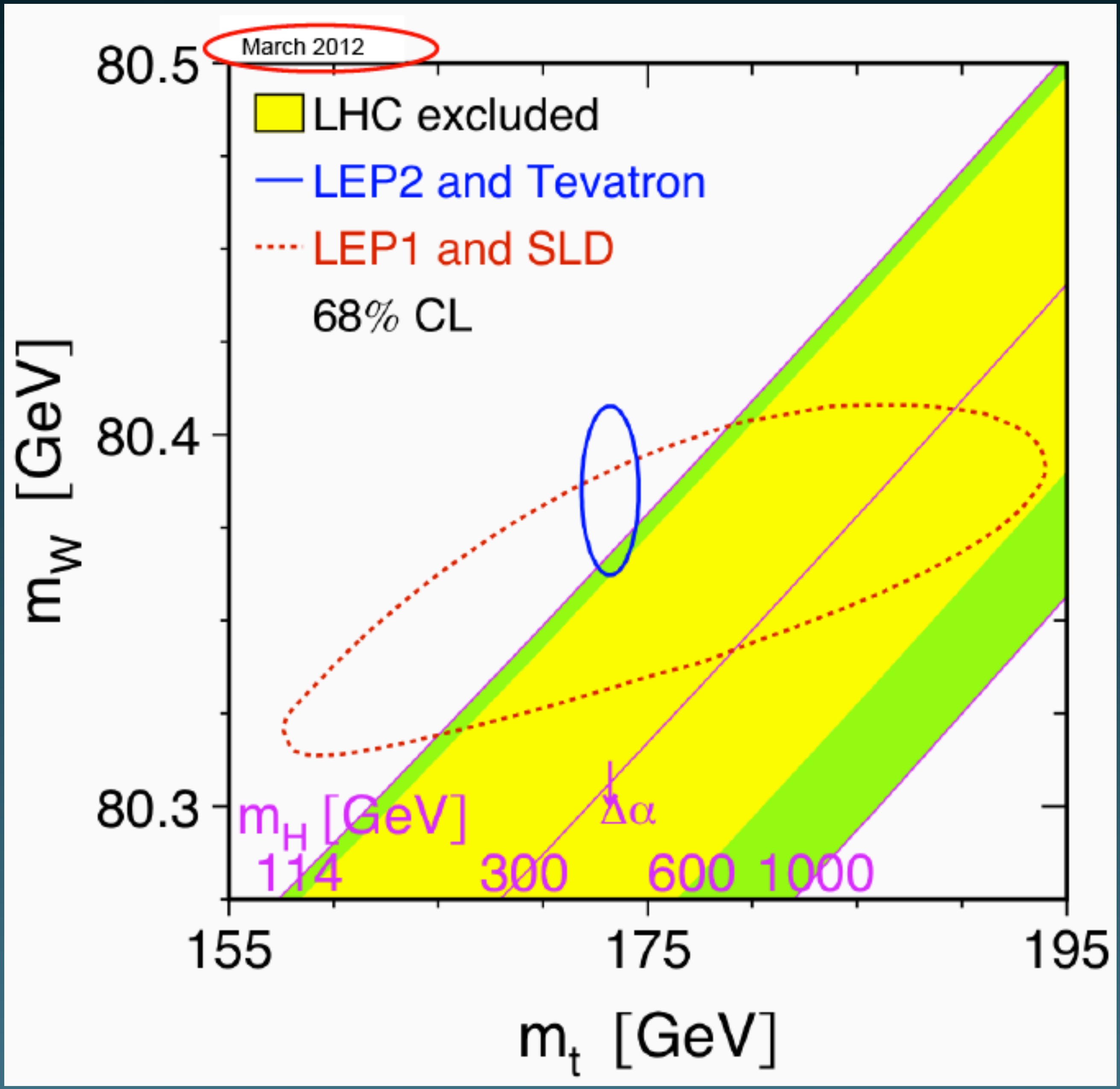

Mass of the W Boson
Measurement
M_W [MeV]
CDF-0/I
80432 ± 79
DØ-I
80478 ± 83
DØ-II (1.0 fb^{-1})
80402 ± 43
CDF-II (2.2 fb^{-1})
80387 ± 19
DØ-II (4.3 fb^{-1})
80369 ± 26
Tevatron Run-0/I/II
80387 ± 16
LEP-2
80376 ± 33
World Average
80385 ± 15
80200
80400
80600
M_W [MeV]
March 2012

W boson mass



December 2011
LHC excluded
LEP2 and Tevatron
LEP1 and SLD
68% CL
m_W [GeV]
80.5
80.4
80.3
m_H [GeV]
114
300
600
1000
$\Delta\alpha$
155
175
195
m_t [GeV]

W boson mass



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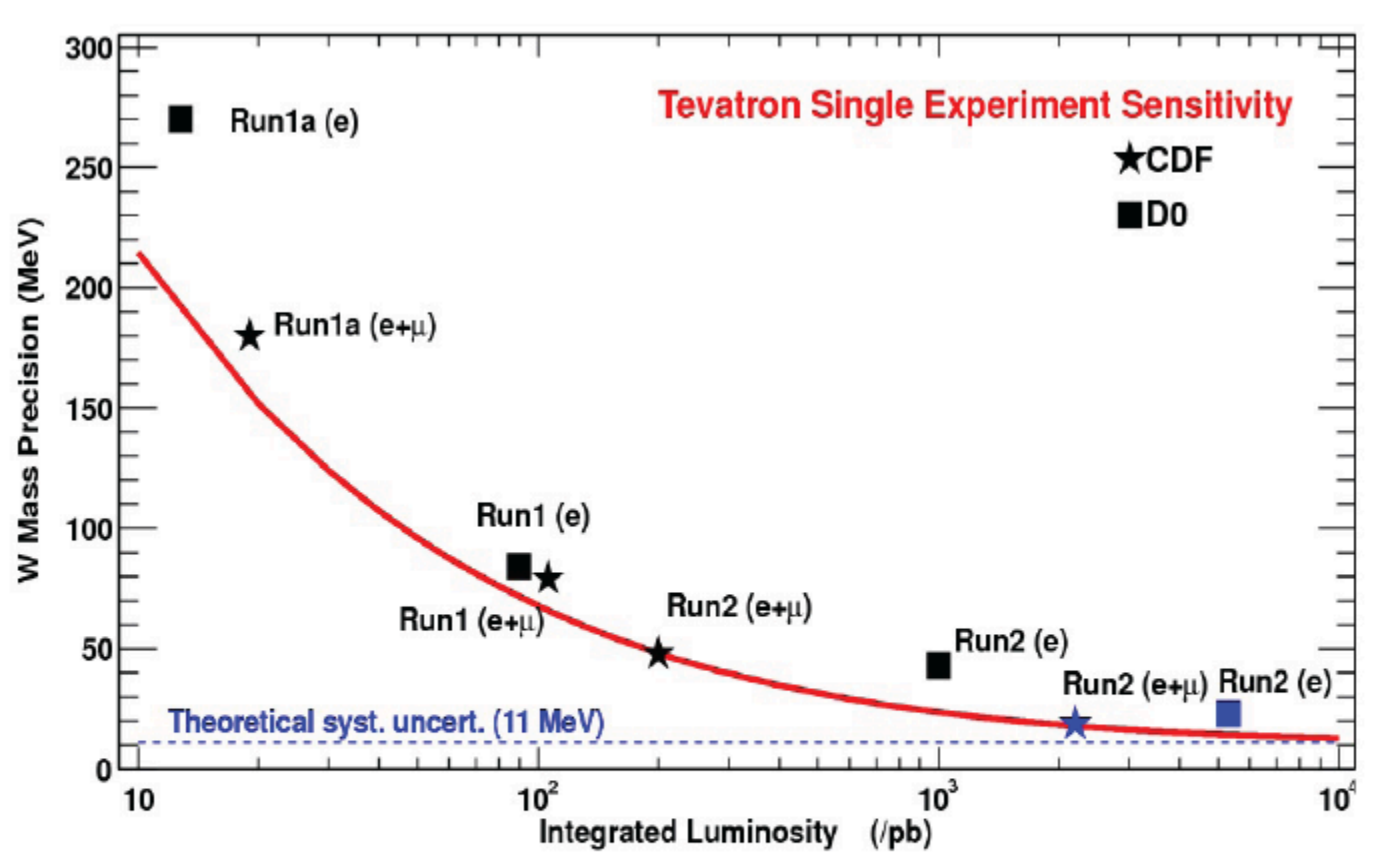

Projecting future precision

W boson mass

Final Tevatron uncertainty: 9-10 MeV

assuming factor 2 improvement to δPDF (helped by LHC)

ΔM_W [MeV]	CDF	D0	combined	final CDF	final D0	combined
$\mathcal{L}[\text{fb}^{-1}]$	2.2	4.3(+1.1)	7.6	10	10	20
PDF	10	11	10	5	5	5
QED rad.	4	7	4	4	3	3
$p_T(W)$ model	5	2	2	2	2	2
other systematics	10	18	9	4	11	4
W statistics	12	13	9	6	8	5
Total	19	26(23)	16	10	15	9

Table 1-4. *Current and projected uncertainties in the measurement of M_W at the Tevatron.*

Projecting future precision

W boson mass

ΔM_W [MeV]	LHC		
$\sqrt{s}$ [TeV]	8	14	14
$\mathcal{L}[\text{fb}^{-1}]$	20	300	3000
PDF	10	5	3
QED rad.	4	3	2
$p_T(W)$ model	2	1	1
other systematics	10	5	3
W statistics	1	0.2	0
Total	15	8	5

Targeted final precision for LHC:
δPDF factor 2 worse than Tevatron

Projecting future precision

W boson mass

ΔM_W [MeV]	LHC		
$\sqrt{s}$ [TeV]	8	14	14
$\mathcal{L}[\text{fb}^{-1}]$	20	300	3000
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other systematics	10	5	3
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Total	15	8	5

Targeted final precision for LHC:

δPDF factor 2 worse than Tevatron

ΔM_W [MeV]	LEP2	ILC	ILC	LEP3	TLEP
$\sqrt{s}$ [GeV]	161	161	161	161	161
$\mathcal{L}$ [fb^{-1}]	0.040	100	480	600	3000
$P(e^-)$ [%]	0	90	90	0	0
$P(e^+)$ [%]	0	60	60	0	0
systematics	70			?	?
statistics	200			2.3?	1.0?
experimental total	210	3.9	1.9	>2.3	>1.0
beam energy	13	0.8	0.8	0.8	0.1-0.8
theory	-	1.0	1.0	1.0	1.0
total	210	4.1	2.3	>2.6	>1.5

Current estimates for e+e-

using threshold scan, polarization (Snowmass).

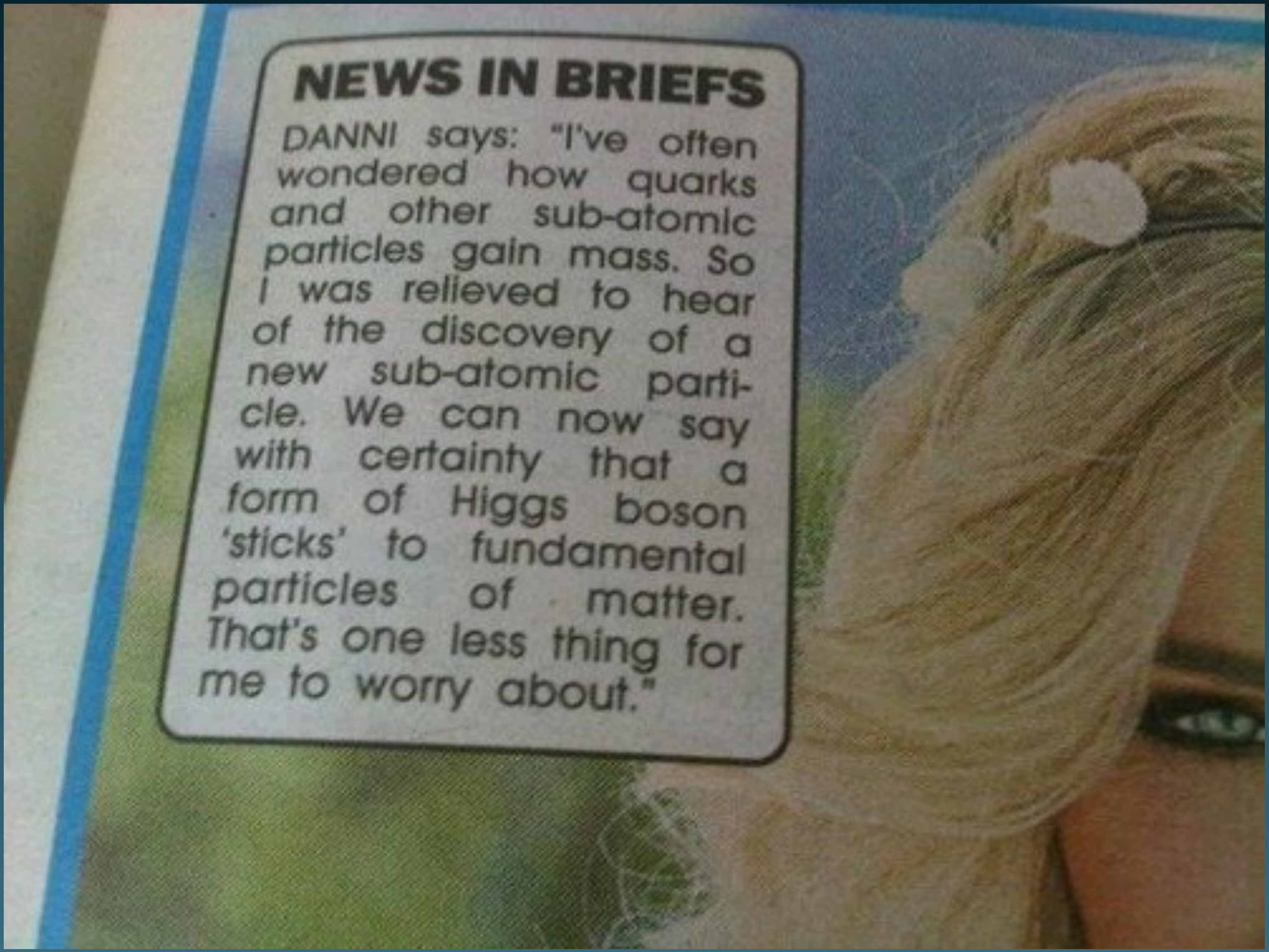
LEP3/TLEP studies: projections from ILC.

Projecting future precision

Global EWK Fits


Science
21 December 2012 | $10
BREAKTHROUGH
of the YEAR
The HIGGS
BOSON
AAAS

Higgs! Everyone is relieved...



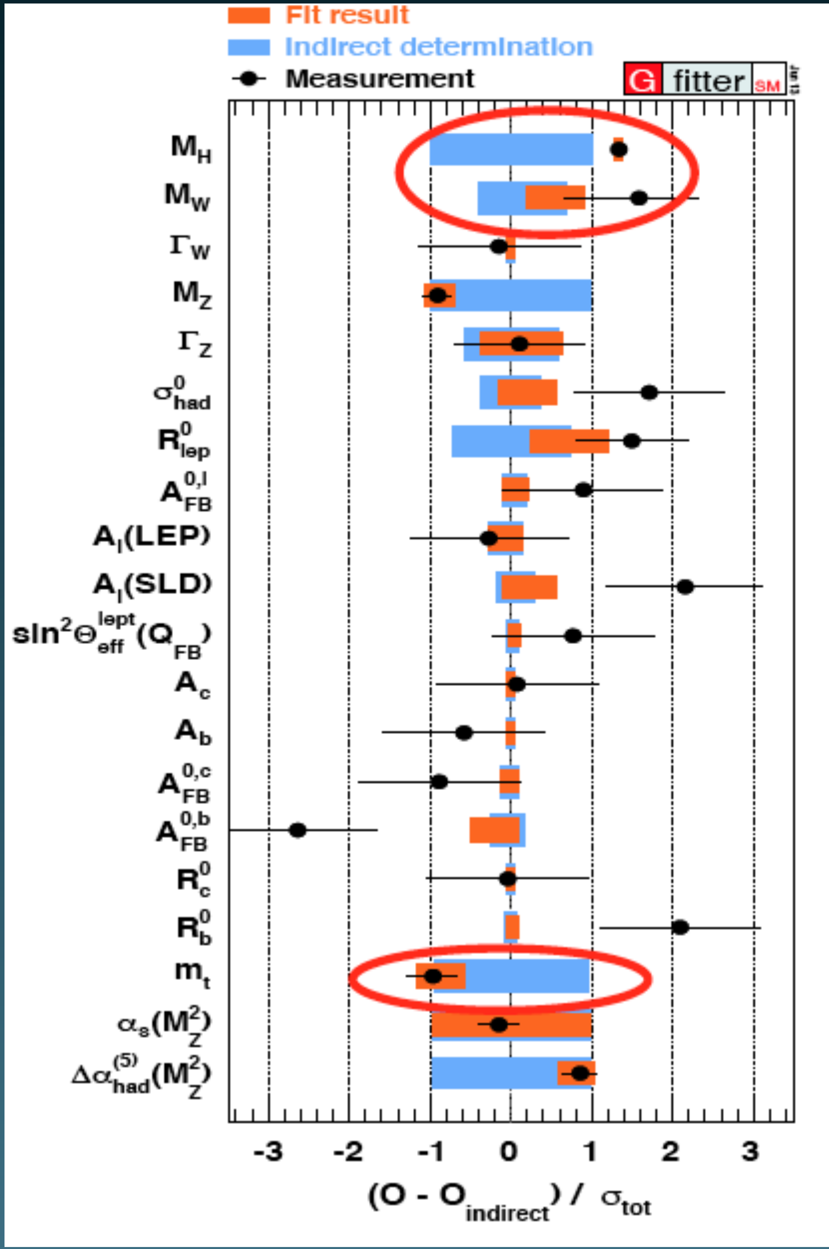
Precision EWK fits

http://cern.ch/Gfitter

EPJC 72, 2205 (2012), arXiv:1209.2716

Pulls from new fits: May 2013
(new Tevatron top mass)

Assume Standard Model Higgs:
$M_H = 125.7 \pm 0.4$ GeV



(see M. Baak EPS talk)

Precision EWK fits

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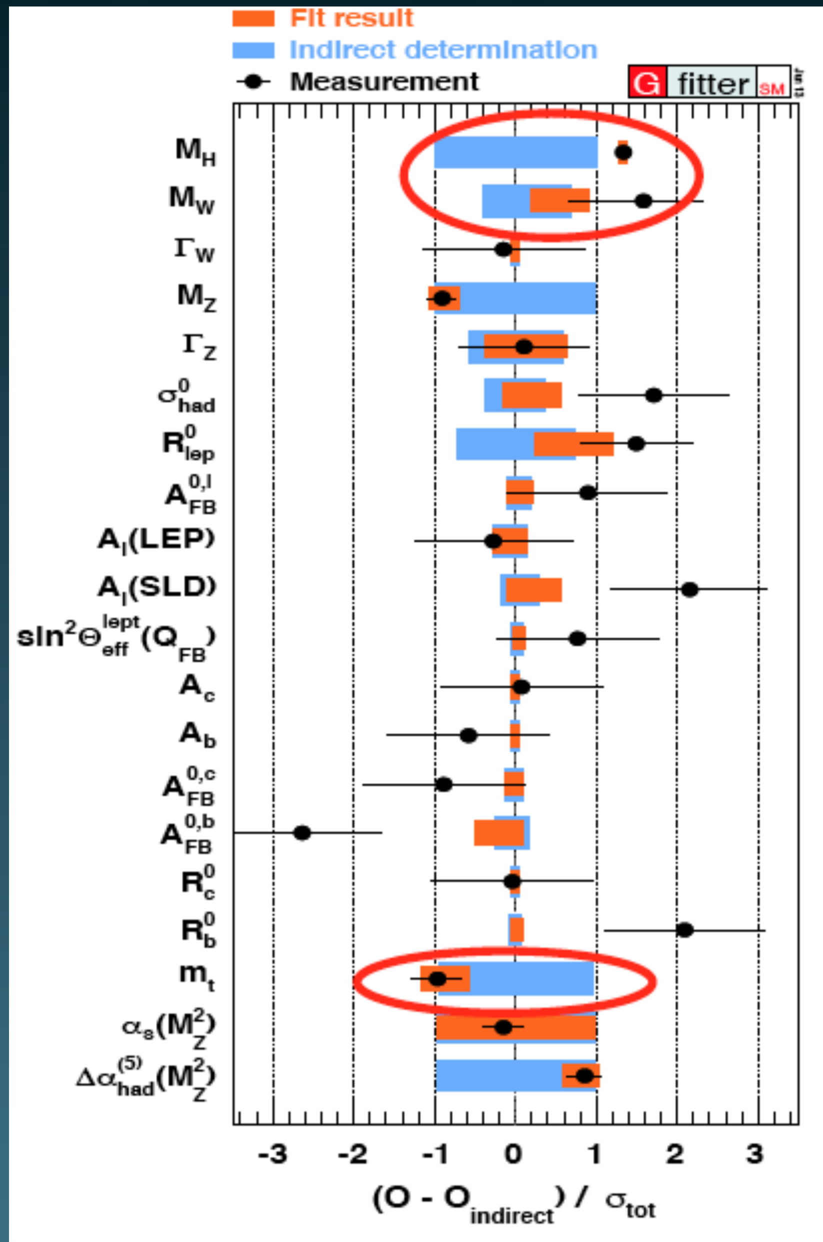
EPJC 72, 2205 (2012), arXiv:1209.2716

Pulls from new fits: May 2013
(new Tevatron top mass)

Assume Standard Model Higgs:
$M_H = 125.7 \pm 0.4$ GeV

Black: direct measurement (data)
Orange: full fit including M_H
Light-blue: fit including M_H, but excluding input from the row



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Global EWK fits

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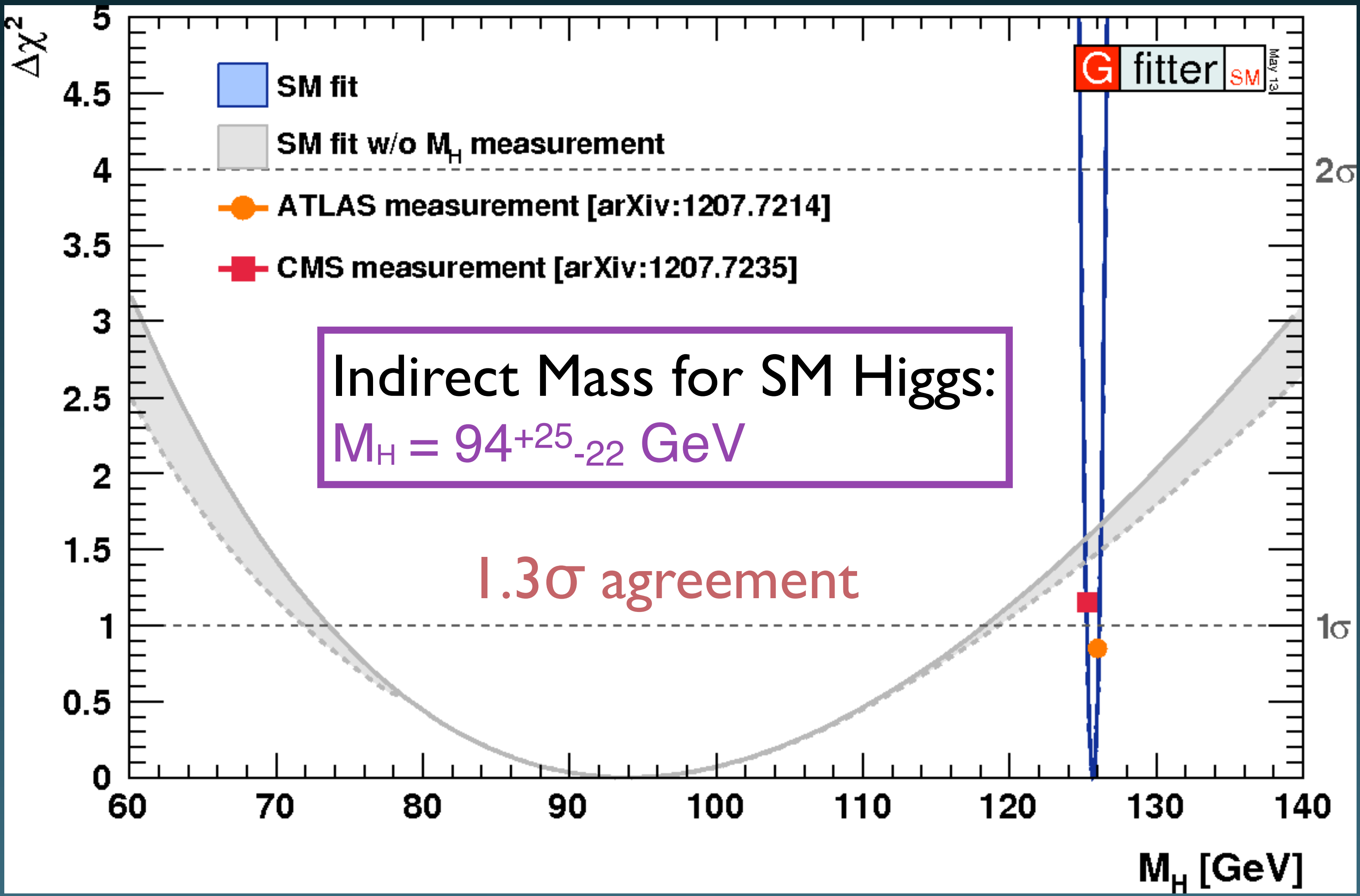


(see M. Baak EPS talk)

G fitter

http://cern.ch/Gfitter

EPJC 72, 2205 (2012), arXiv:1209.2716

Global EWK fits

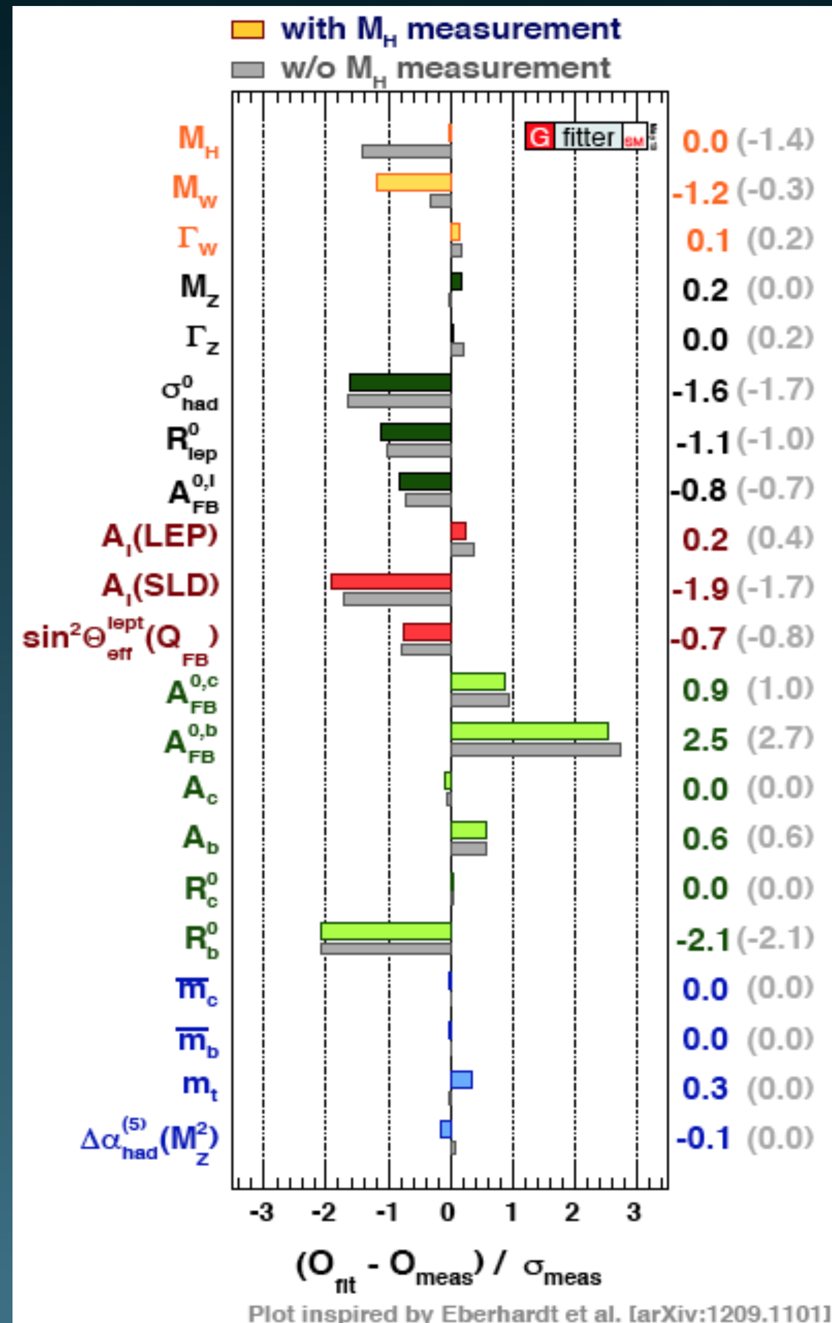
What does the Higgs do?

Pull values of full fit:

- No value exceeds 3
- Small pulls: accuracies exceed fit requirements.

Most affected by M_H:

- Shift in M_W by 13 MeV!



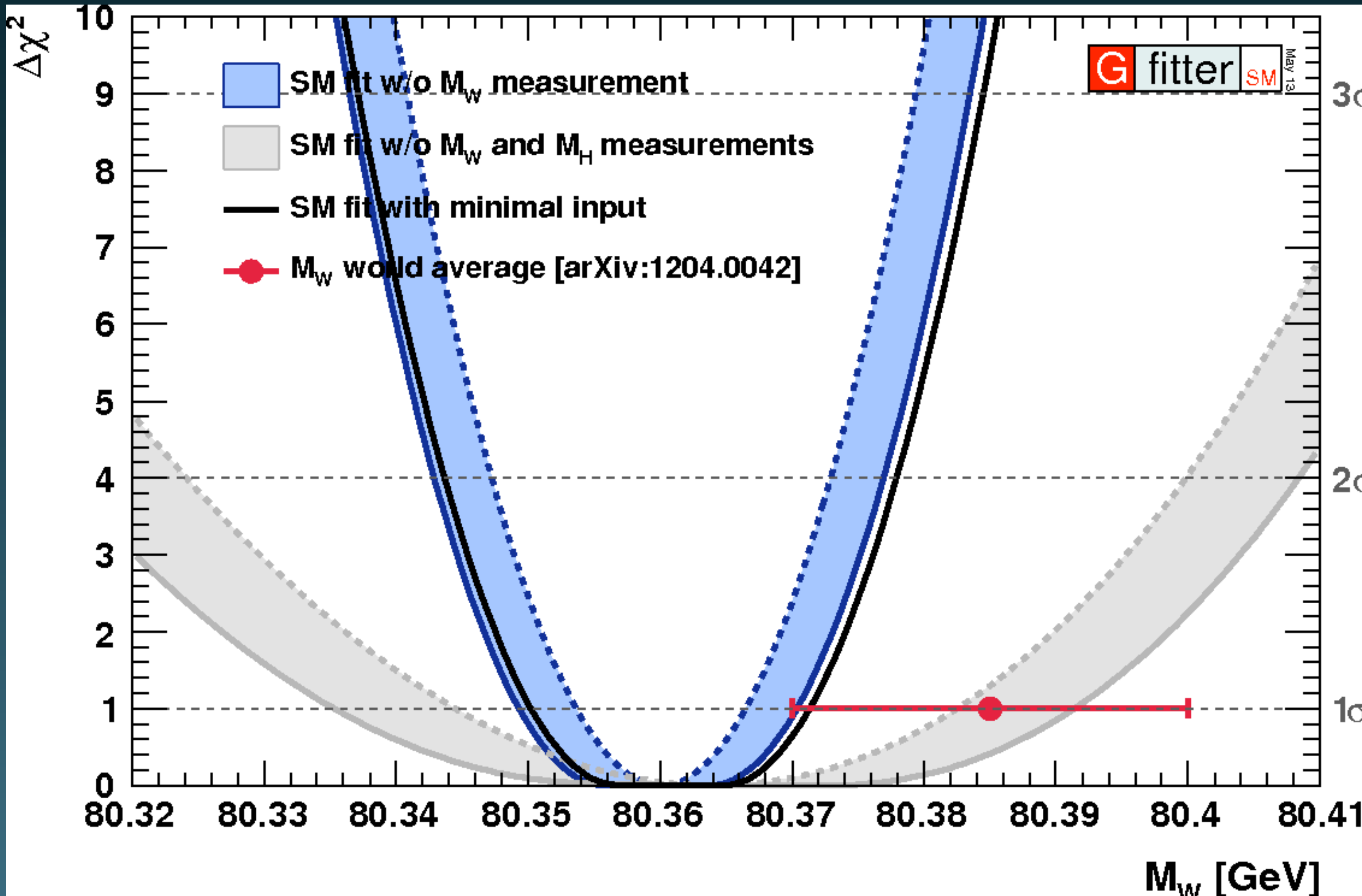
(see M. Baak EPS talk)

Global EWK fits

http://cern.ch/Gfitter

EPJC 72, 2205 (2012), arXiv:1209.2716

Indirect W mass determination from M_H:



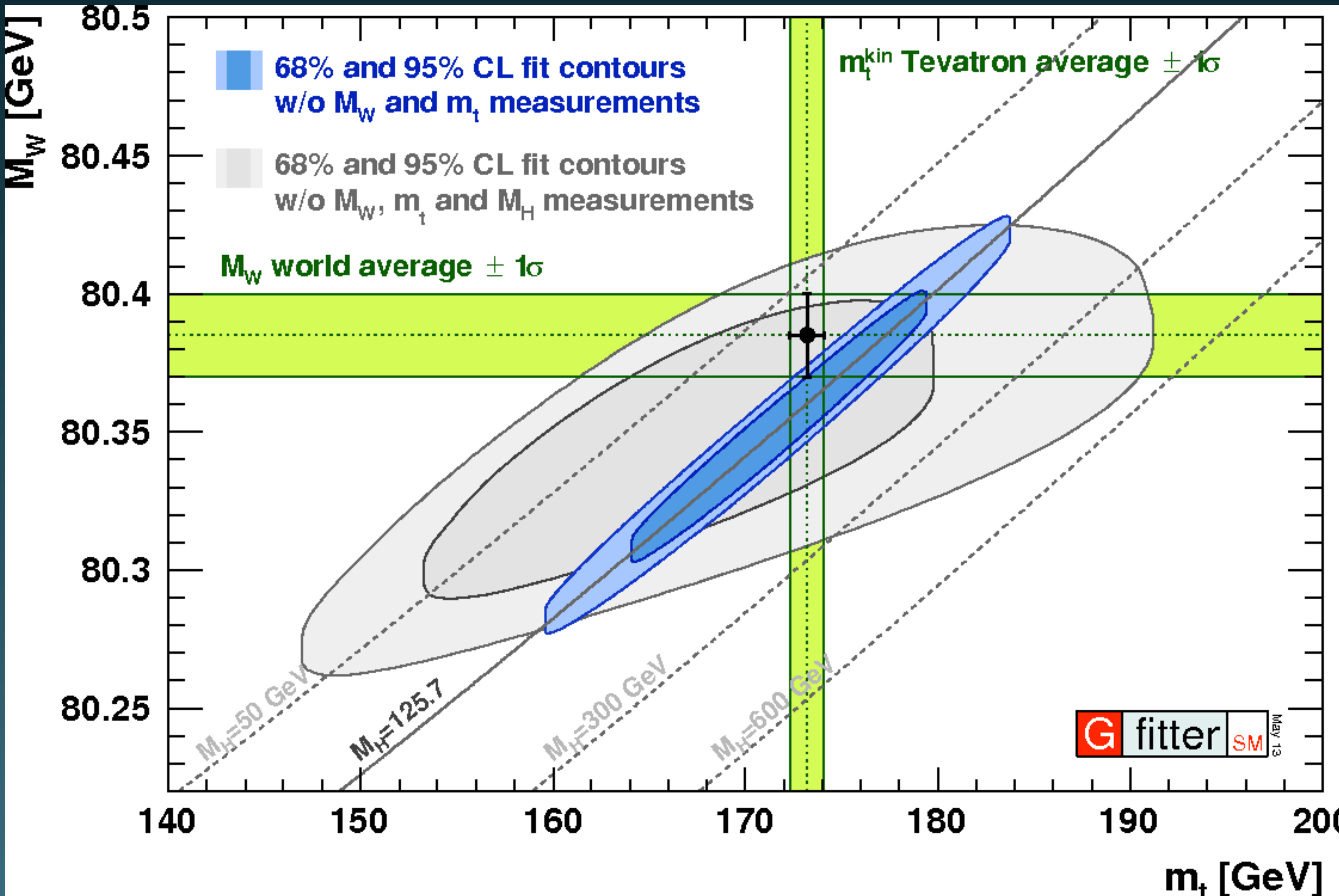
Agreement within 1.4σ

http://cern.ch/Gfitter

EPJC 72, 2205 (2012), arXiv:1209.2716

Global EWK fits

Higgs constrains the M_t/M_W parameter space:



Impressive agreement overall

Outlook

Top quark physics has entered the realm of precision studies, providing a probe for physics beyond the SM.

Many electroweak processes, particularly involving multi-boson production, are now within reach, and searches for anomalies in this sector are underway.

Fits to global EWK data with the Higgs, and with precise theory calculations, show the SM remains a consistent theory, in spite of some interesting tensions.

We can look forward to much greater precision for key electroweak observables, as well as the top mass, which may help point us toward physics beyond the SM.