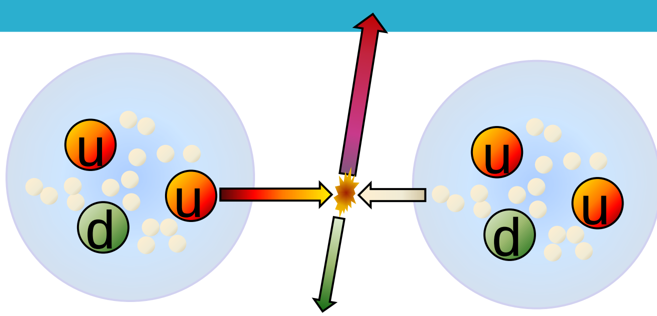
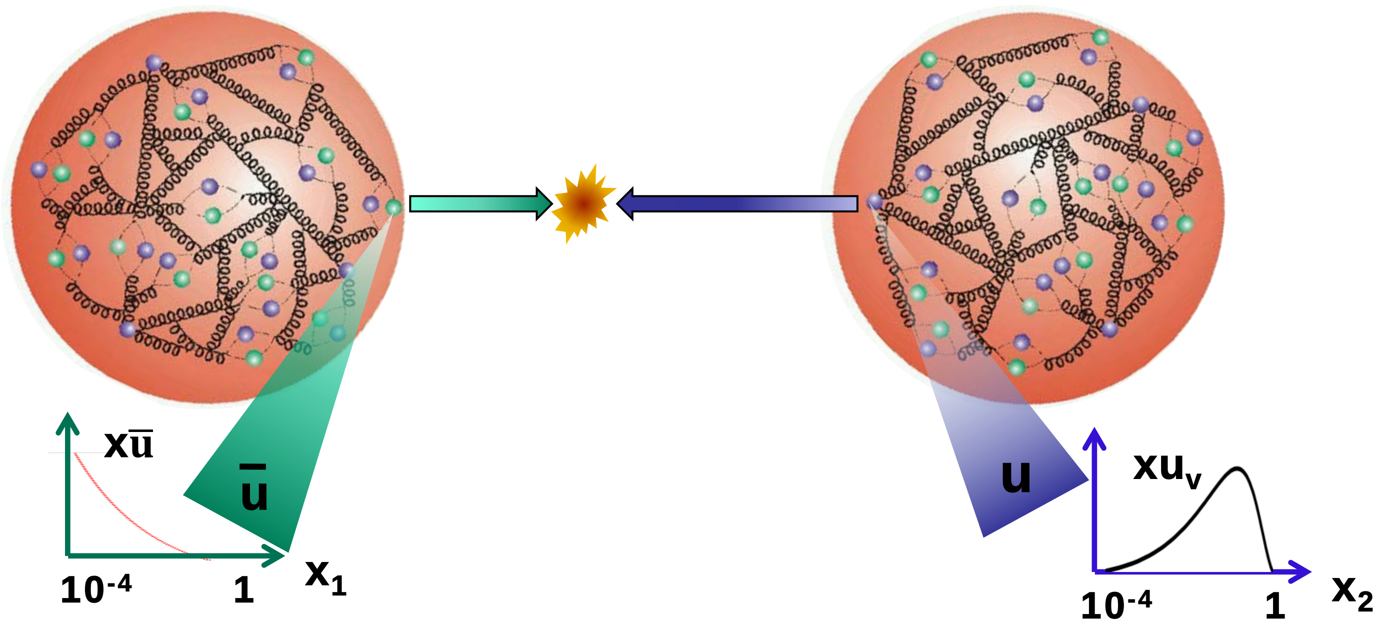


Electroweak interactions

Manuella G. Vincter
(Carleton University)

presenting results from ATLAS, CMS, LHCb, CDF, and D0

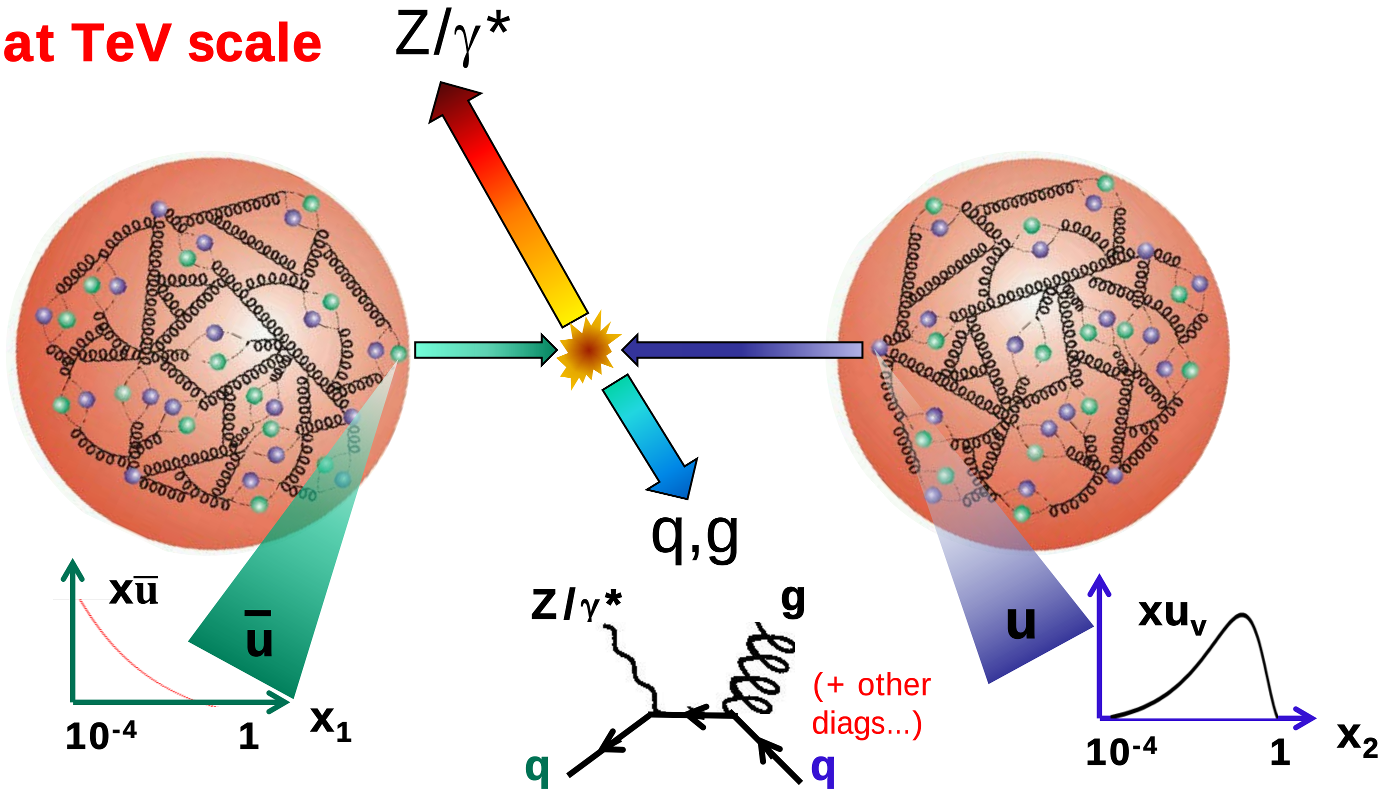


Parton distribution functions f of the proton (pdf)

x_1,x_2 = momentum fraction of partons

Thanks to:
desy.de, hepdata.cedar.ac.uk

SM Z, W, t production
EW interactions at TeV scale
pQCD



Parton distribution functions f of the proton (pdf)

x_1, x_2 = momentum fraction of partons

Hard scattering $\hat{\sigma}$ for k[th] sub-process between partons of flavour a and b

$$\sigma = \sum_{a,b,k} \int dx_1 dx_2 \; f_a(x_1, Q^2) \quad \hat{\sigma}_{a,b,k}(x_a, x_b) \quad f_b(x_1, Q^2)$$

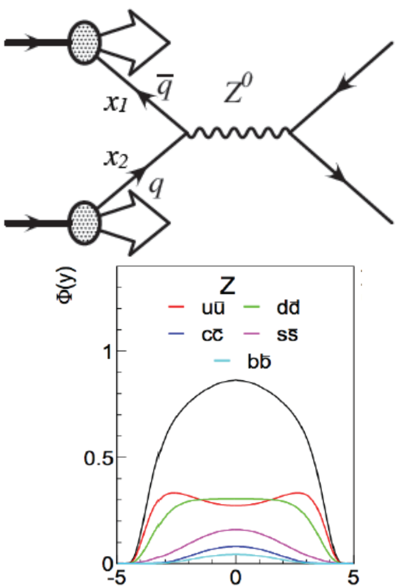
Via hard scatter, can produce massive EW states in $pp/p\bar{p}$ collisions

Thanks to:
desy.de, hepdata.cedar.ac.uk

Thanks to:
M. Sutton Moriond 2014, U. Klein DIS 2012

Global fits to extract PDFs

- Feed e.g. $W^{\pm}$, Z/γ^*, ... cross section information into global fits to extract PDFs
  - All data have differing sensitivity to different aspects of the proton's PDFs.
  - EW boson production sensitive to valence and sea quark distributions

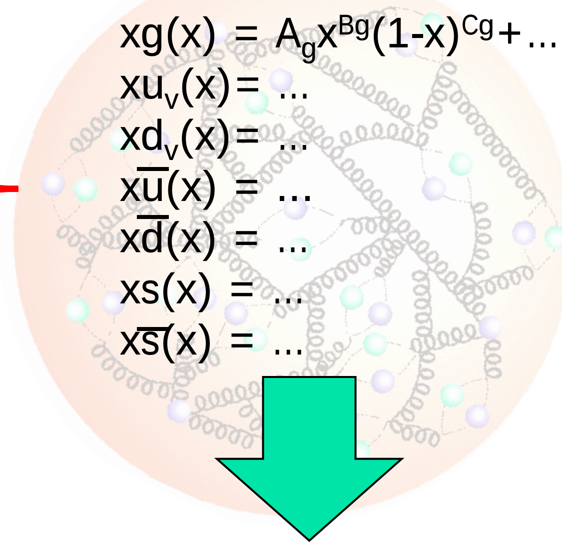


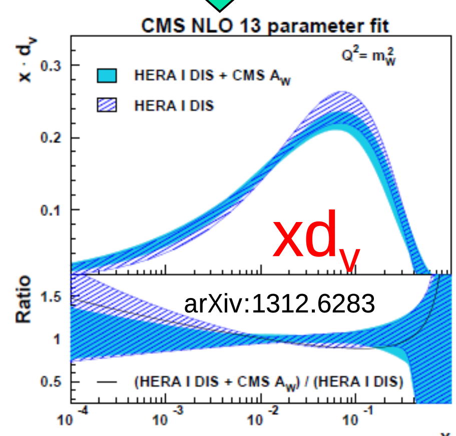
Rapidity y
(related at LO to momentum fraction x)

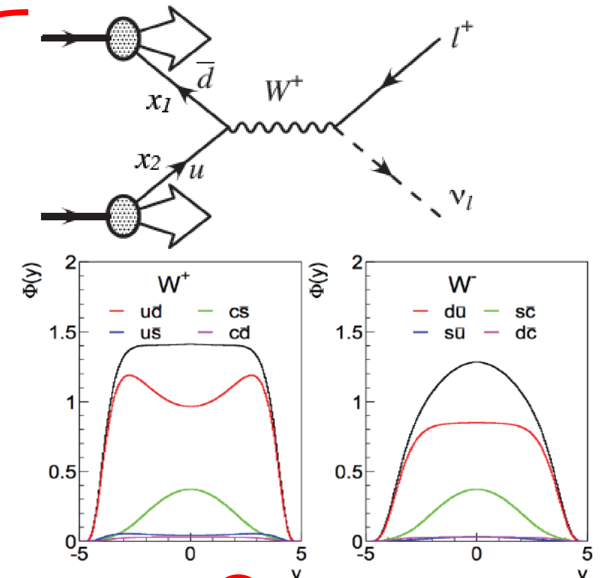
$Z \sim 0.29(u\bar{u} + c\bar{c}) + 0.37(d\bar{d} + s\bar{s} + b\bar{b})$

Parameterise PDFs:

$xg(x) = A_g x^{Bg}(1-x)^{Cg} + \ldots$
$xu_v(x) = \ldots$
$xd_v(x) = \ldots$
$x\bar{u}(x) = \ldots$
$x\bar{d}(x) = \ldots$
$xs(x) = \ldots$
$x\bar{s}(x) = \ldots$



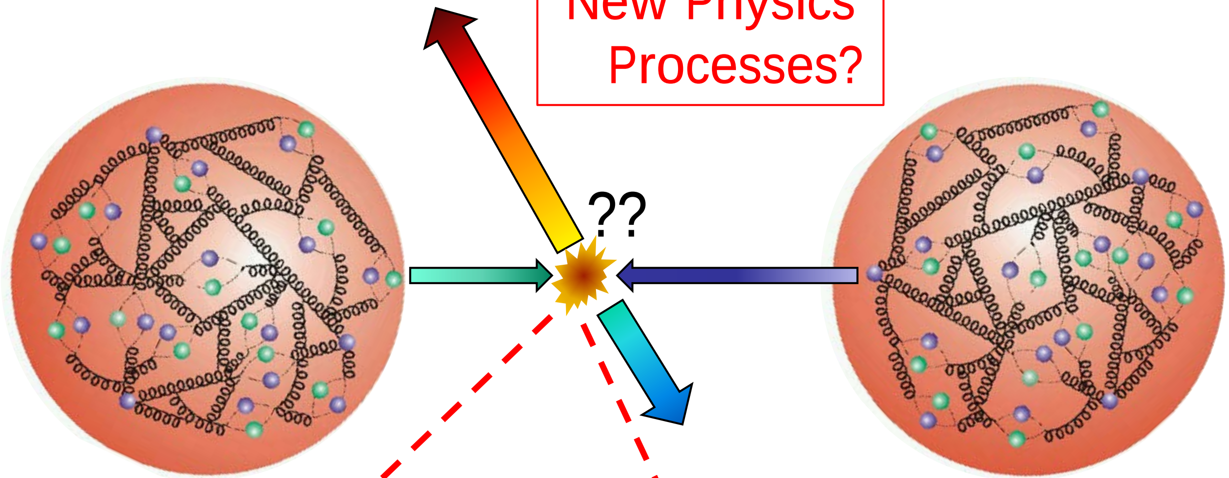


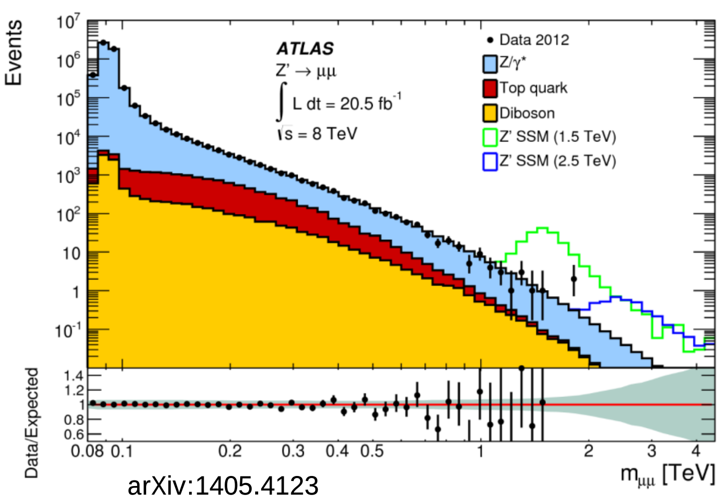


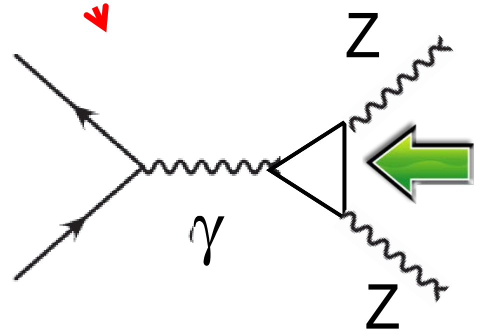
$W^+ \sim 0.95(u\bar{d} + c\bar{s}) + 0.05(u\bar{s} + c\bar{d})$
$W^- \sim 0.95(d\bar{u} + s\bar{c}) + 0.05(d\bar{c} + s\bar{u})$

Beyond the SM?

New Physics Processes?







New particles in this loop?

Searches for new dilepton resonances

Anomalous couplings of gauge bosons

Outline of presentation

- Single W, Z/γ^* production
  - Z/γ^*: $m_{\ell\ell}$, $y_{\ell\ell}$ dependence
  - Lepton and W charge asymmetry
  - m_W
- Multiple W, Z, γ production
  - Neutral and charged aTGC
  - VBS: $W^{\pm}W^{\pm}jj$ production
- Top physics
  - Quark pair, single-top cross sections, $|V_{tb}|$
  - Mass

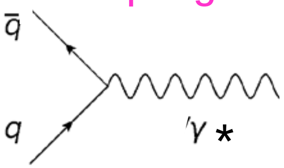
➡ Will show an illustrative experimental result per topic, but many of these measurements done at all experiments: D0, CDF, CMS, ATLAS (too many to show!)

SINGLE W, Z/γ^* PRODUCTION

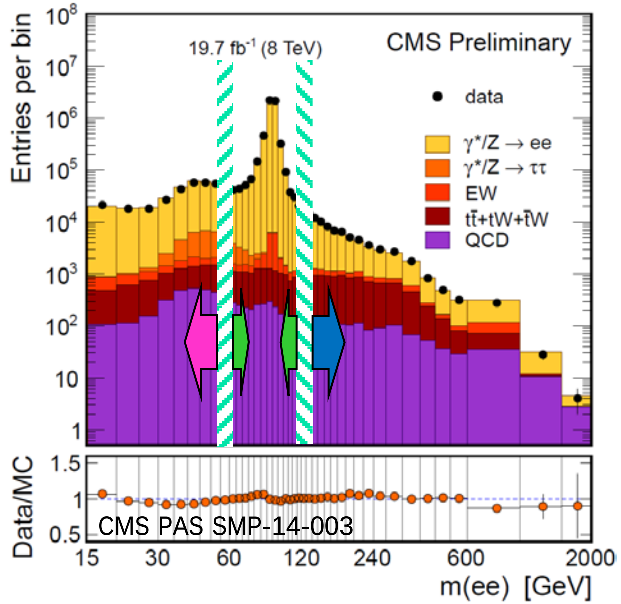
$m_{\ell\ell}$ dependence of Z/γ^* production

Very wide mass range measured at the LHC: $m_{\ell\ell}$~12-2000 GeV

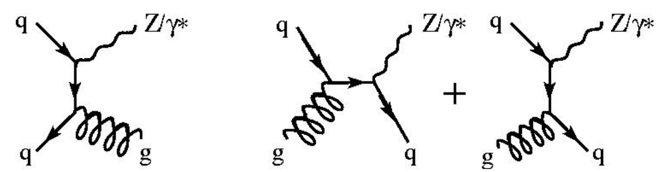
- $d\sigma/dm_{\ell\ell}$, $d^2\sigma/dm_{\ell\ell}d|y_{\ell\ell}|$
- Low-mass DY: dominated by EM coupling of γ^* to $q\bar{q}$



- Different sensitivity to u, d-type $q\bar{q}$ than on peak



- Peak region and above dominated by Z, γ^* coupling to $q\bar{q}$



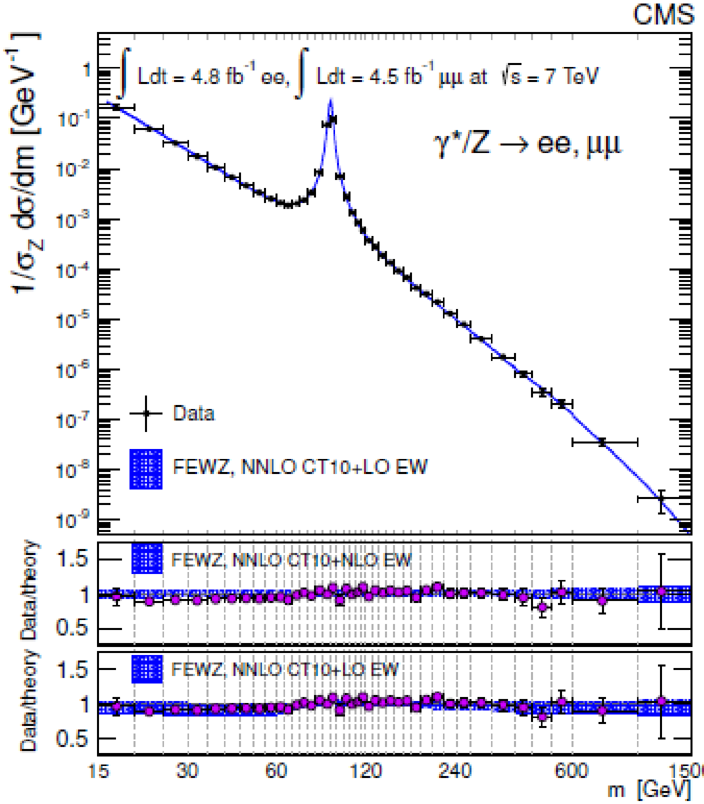
- High-mass DY shape can be modified by new physics

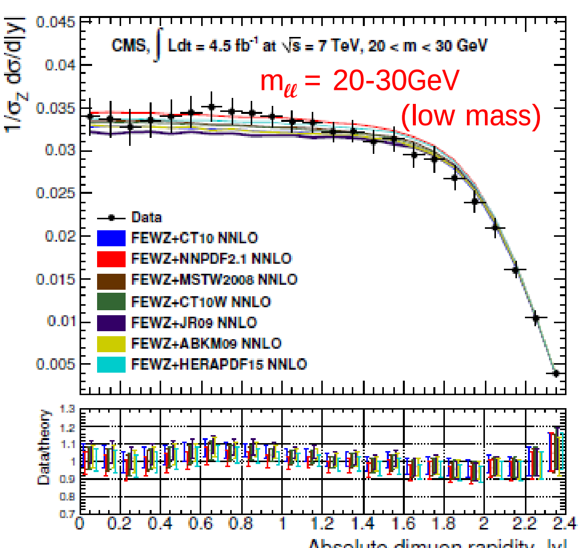
Measurements compared to fixed-order calculations like FEWZ, including higher-order EW corrections, and various PDFs

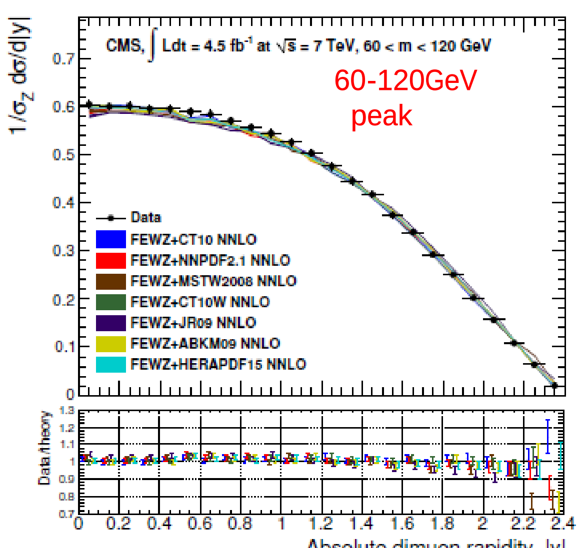
- PDFs: MSTW2008, HERADPDF1.5, CT10, CT10W,AMB11, NNPDF2.1,2.3, JR09, ABKM09, ...

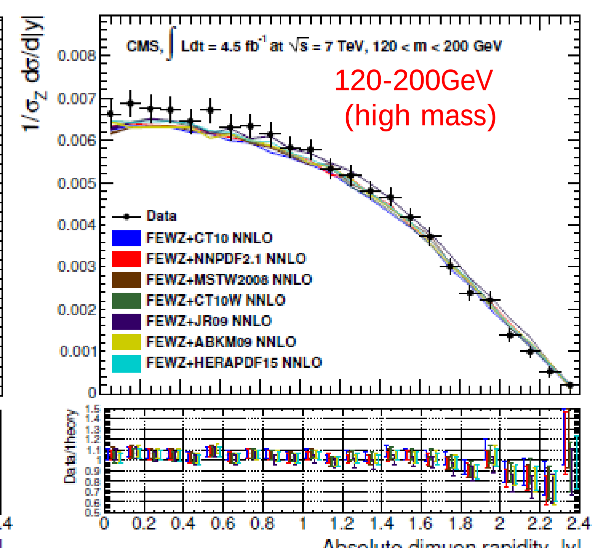
$y_{\ell\ell}$ and $m_{\ell\ell}$

- CMS 7TeV: $(1/\sigma_Z)\, d\sigma/dm_{\ell\ell}$: ee+μμ channel normalised to peak region
  - Comparisons including LO and NLO EW corrections
- Dimuon $(1/\sigma_Z)\, d\sigma/d|y_{\ell\ell}|$ normalised to peak region in $m_{\ell\ell}$ bins compared to FEWZ using various PDF sets
  - Test compatibility of PDFs with low-to-high-mass DY
- Also ratio of born-level $(1/\sigma_Z)\, d\sigma/dm_{\ell\ell}$ at 8TeV to 7TeV



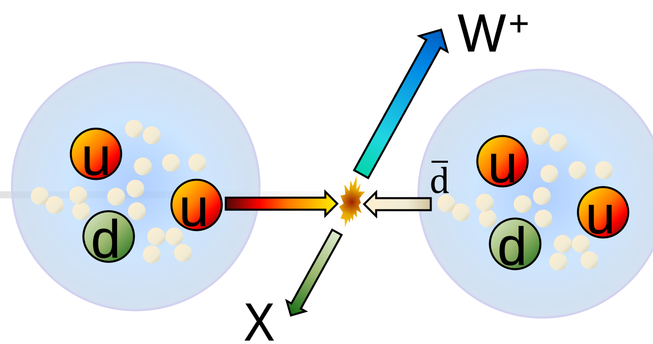






arXiv:1312.6283
PRL112(2014)191802
arXiv:1408.4354

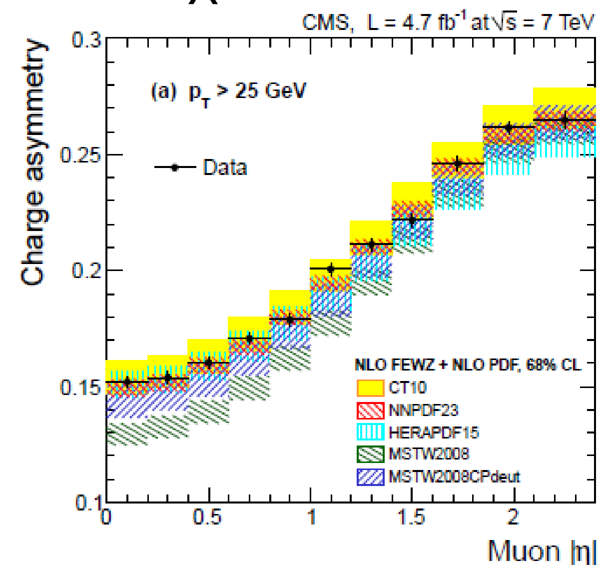
LHC lepton-charge asymmetry



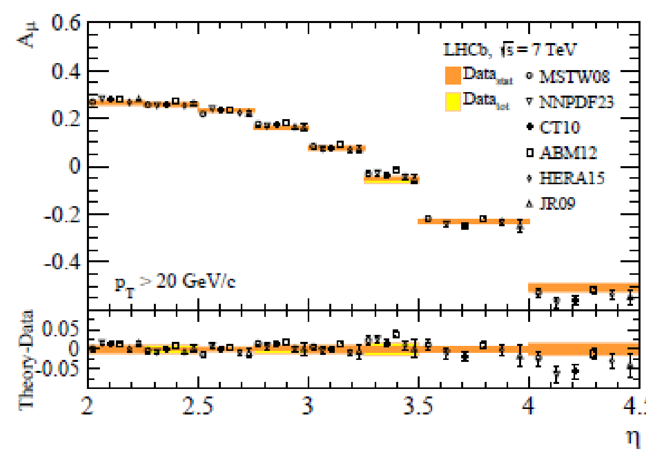
- Dominant W production mechanisms at LHC:
  - valence+sea antiquark: $d\bar{u} \rightarrow W^-$ and $u\bar{d} \rightarrow W^+$
  - W^+,W^- production asymmetry due to valence content
    - R_{W^+/W^-} $1.39 \pm 0.01(\mathrm{stat}) \pm 0.02(\mathrm{syst})$ (CMS at 8TeV)
- Lepton charge asymmetry vs. pseudorapidity η can provide information on PDFs:

$$\mathcal{A}(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \rightarrow \ell^+\nu) - \frac{d\sigma}{d\eta}(W^- \rightarrow \ell^-\overline{\nu})}{\frac{d\sigma}{d\eta}(W^+ \rightarrow \ell^+\nu) + \frac{d\sigma}{d\eta}(W^- \rightarrow \ell^-\overline{\nu})}$$

  - d/u ratio and sea antiquarks (including strangeness)

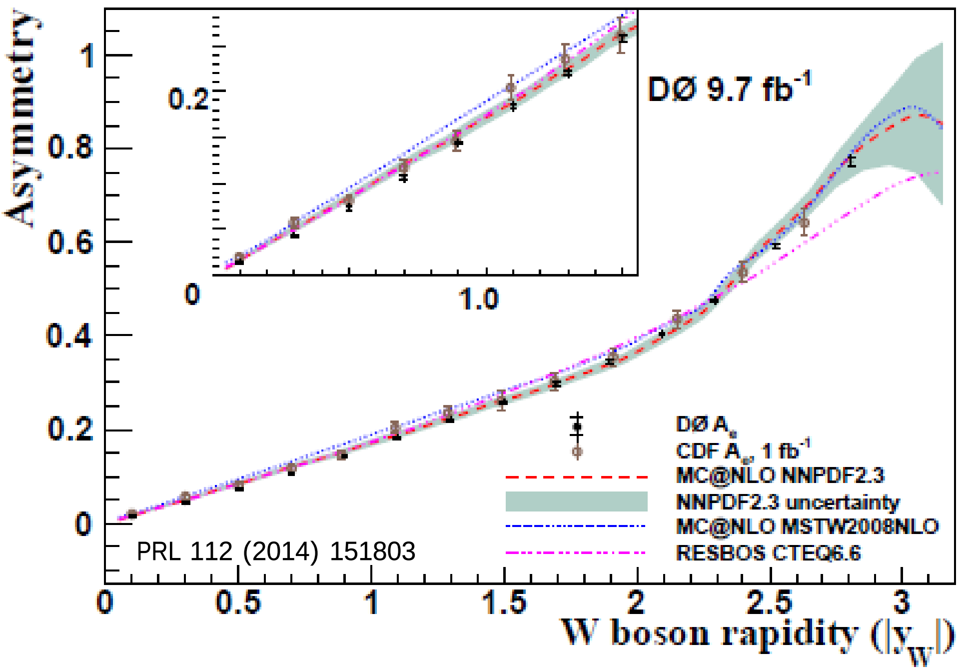


- CMS measurement at 8TeV with $W \rightarrow \mu\nu$ and p_T^{ℓ}>25GeV
  - Agreement with CT10, NNPDF2.3, HERAPDF1.5
  - Less so: MSTW2008 $|\eta|<1$ (MSTW2008CPdeut better)
- LHCb measurement at 7TeV with $W \rightarrow \mu\nu$ and p_T^{ℓ}>20GeV
  - Forward acceptance: unique rapidity coverage for PDFs
    - Excellent agreement with NNLO + different PDFs except at highest η where some predictions undershoot the data.



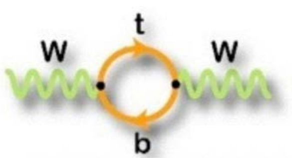
Tevatron W charge asymmetry

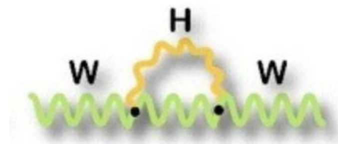
- Lepton charge asymmetry is convolution of W asymmetry and V-A structure of W decay
  - Leptons at given η originate from a range of W rapidity y_W and hence wide x range
- D0 at Tevatron: use ν weighting method to extract W charge asymmetry
  - Assuming m_W value gives two possible solutions to missing information on p^ν_z, which can be partially resolved on a statistical basis from known V-A decay distributions, assigning probabilities to p^ν_z solutions
- 9.7fb^{-1} at $\sqrt{s}$=1.96TeV
  - Comparison to MC@NLO +
    - NNPDF2.3, MSTW2008NLO
  - Good agreement except slight overshoot of predictions at low $|y_W|$
  - Expt uncert << NNPDF2.3 uncert
    - Results can significantly constrain PDF predictions



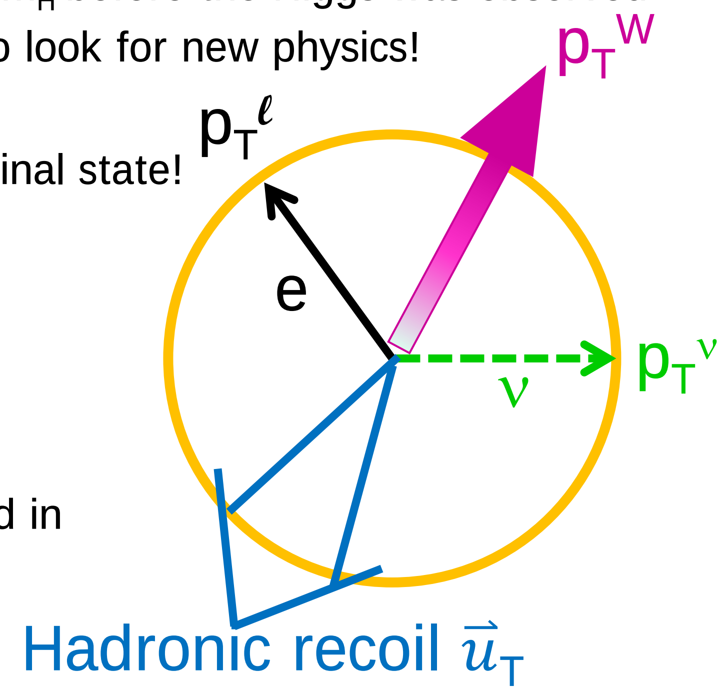
The mass of the W boson: m_W

- EW sector of SM relates important parameters such as m_W, α_{EM}, G_F and $\sin^2\theta_W$
- Quantum corrections to m_W dominated by contributions depending quadratically on the top mass m_t and logarithmically on the Higgs mass m_H





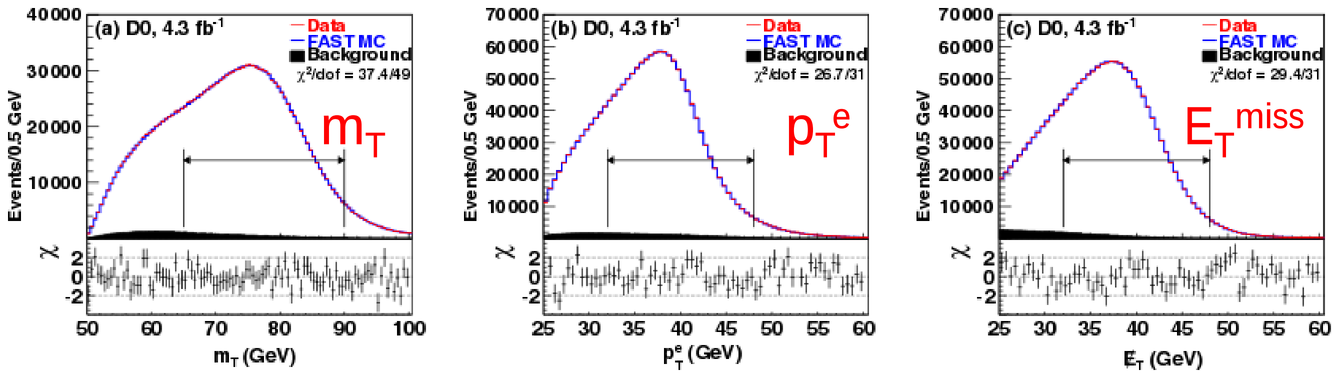
- Precision measurements of m_W were first used to predict m_H before the Higgs was observed
- Now use comparisons of predicted m_H to measured m_H to look for new physics!
- Extraction of m_W from hadron collisions
  - $u\bar{d} \rightarrow W^+(\rightarrow \ell^+\nu) + X$ $\rightarrow$ Can't fully reconstruct the final state!
  - Transverse plane balance: $\vec{p}_T^{\,\nu} = -\vec{p}_T^{\,\ell} - \vec{u}_T$
- Use variables sensitive to m_W :
  - p_T^ℓ, E_T^{miss}, $m_T = \sqrt{2\, p_T^\ell p_T^\nu \, [1 - \cos(\varphi_\ell - \varphi_\nu)]}$



- Simulate what these variables should look like as measured in the detector, scanning over a range of possible m_W values
- Perform a fit of these templates to data

Tevatron m_W

- Fermilab Tevatron measurements
  - D0: $W \to e\nu$, 4.3fb^{-1}, 1.68M evts (+earlier 1fb^{-1}) [PRD89 (2014) 012005, PRL108 (2012) 151804]
  - CDF: $W \to e,\mu\nu$, 2.2fb^{-1}, 1.10M evts [PRD89 (2014) 072003, PRL108 (2012) 151803]

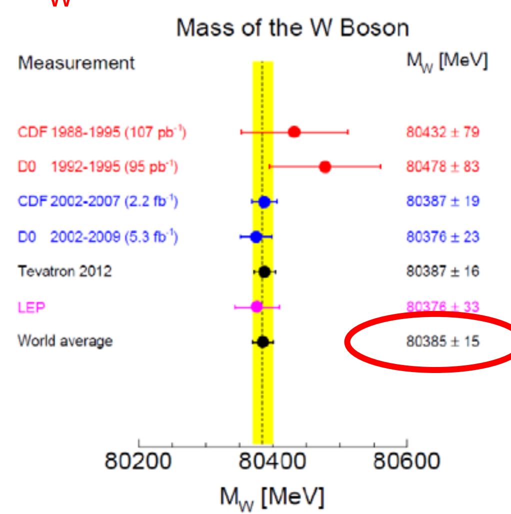


- Dominant expt sys: lepton E scale & hadronic recoil, dominant theo uncert: knowledge of PDF
  - δm_W^{D0} = 23MeV, δm_W^{CDF} = 19MeV
  - World avg: known to 15MeV!

$m_W^{Tevatron}$=80387±16MeV

TABLE II. Uncertainties for the final combined result on M_W.

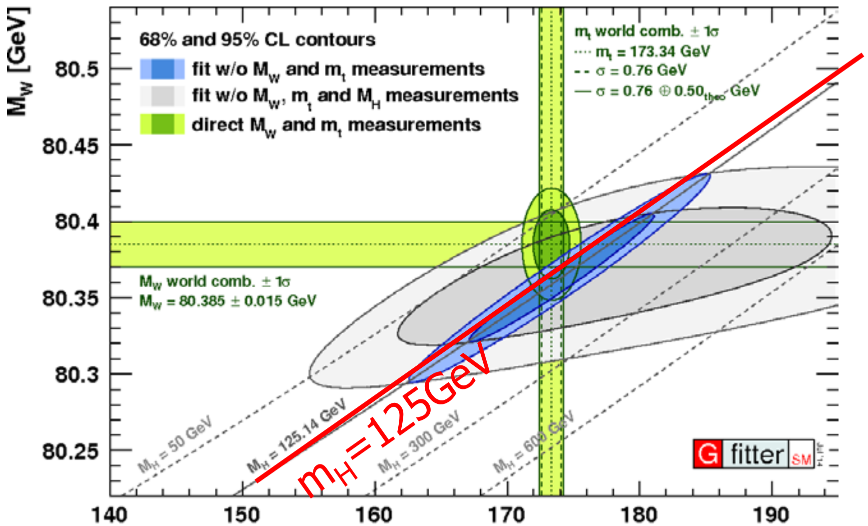
Source CDF	Uncertainty (MeV)
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
$p_T(W)$ model	5
Parton distributions	10
QED radiation	4
W-boson statistics	12
Total	19



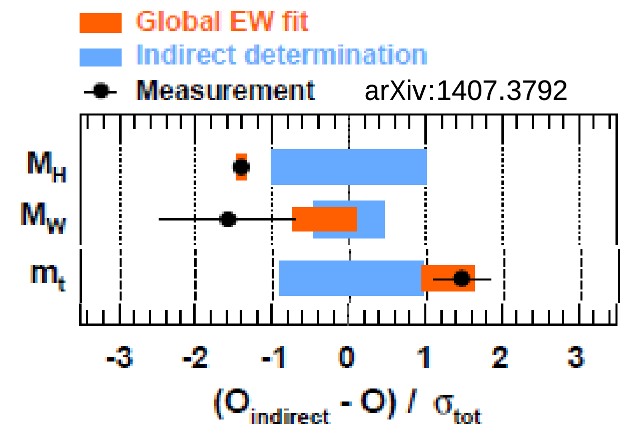
Updated from arXiv:1204.0042

Future prospects for m_W

- Use global fits of EW sector of the SM to compare measured and predicted masses
  - Incredible compatibility! m_W, m_t, m_H



http://project-gfitter.web.cern.ch/project-gfitter/



- Even with precision of δm_W = 15MeV,

indirect determination of m_W better by factor of ~2

  - ➡ Calls for better measurements

- Projected final Tevatron precision: δm_W ~ 9MeV?
- Can LHC do better? A real challenge!
  - Higher pileup environment
  - Momentum scale, recoil model, PDF
    - will need to be well known

Targets for LHC

arXiv:1310.6708

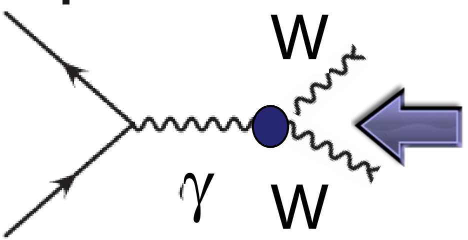
ΔM_W [MeV]	LHC		
$\sqrt{s}$ [TeV]	8	14	14
$\mathcal{L}[\text{fb}^{-1}]$	20	300	3000
PDF	10	5	3
QED rad.	4	3	2
$p_T(W)$ model	2	1	1
other systematics	10	5	3
W statistics	1	0.2	0
Total	15	8	5

Note on theo uncertainties on mass:

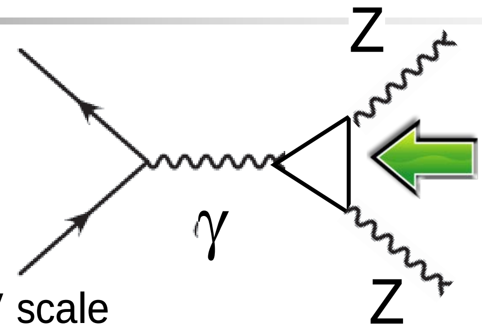
ATL-PHYS-PUB-2014-015

MULTIPLE W,Z,γ PRODUCTION

Multiple Gauge-Boson Couplings



SM?

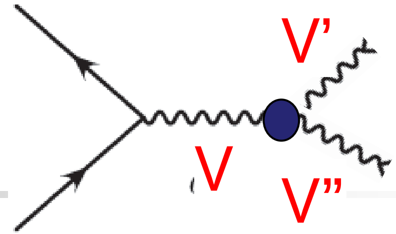


BSM?

New particles in this loop?

- Test predictions of EW sector of SM at TeV scale
  - Self interactions between gauge bosons
    - Will talk about anomalous Triple Gauge Couplings (aTGC)
      - Anomalous quartic gauge boson couplings aQGC also being measured
- SM diboson production is also a source of background for:
  - Higgs production (e.g. $H \to WW$, ZZ)
  - Searches for new physics
    - Deviations: new resonances decaying to gauge bosons, other non-SM processes?
- At tree level, some TGCs are non-zero in the SM
  - γWW, WWZ
- Other TGCs are zero at tree level but have non-zero contributions at the higher loop levels
  - e.g. γZZ $O(10^{-4})$ contributions at one-loop SM. Some BSM models are $O(10^{-3}\text{-}10^{-4})$
- Precision measurements could reveal new physics!
- Will review processes with ZZ, WW, WZ, Wγ, Zγ final states
  - leptonic decays of W,Z ($W \to \ell\nu$, $Z \to \ell\ell, \nu\nu$)

aTGC: nomenclature



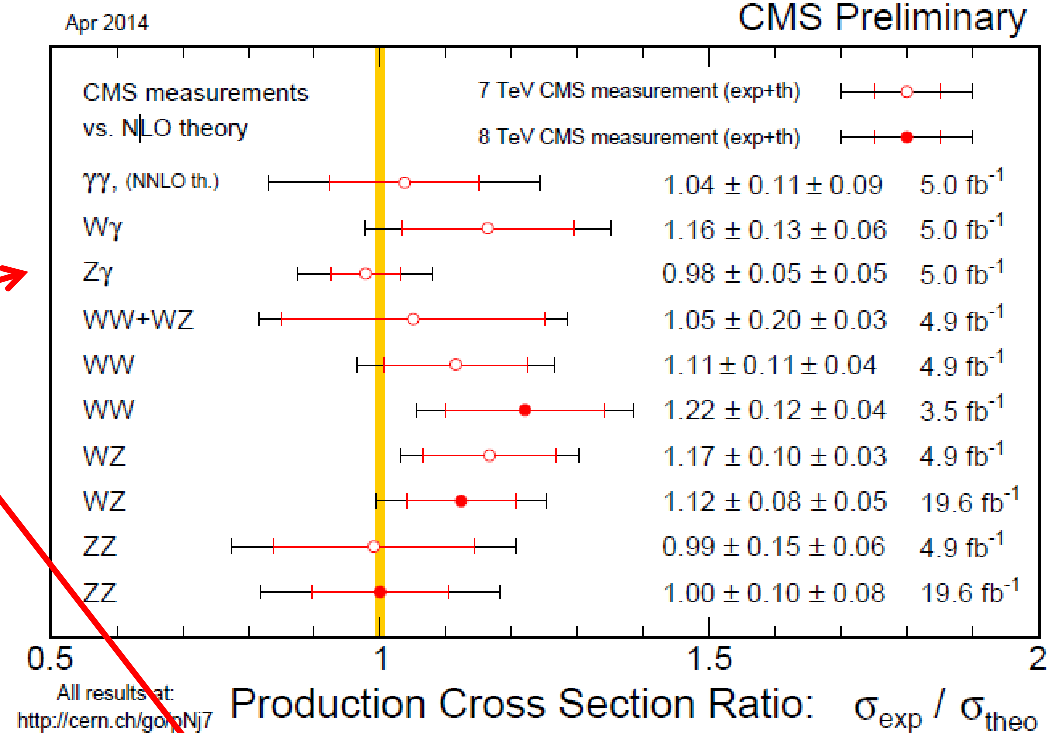
- Introduce a general V V' V" vertex
  - γWW, WWZ, $Z\gamma\gamma$, $ZZ\gamma$, ZZZ
- Coupling nomenclature:
  - Define couplings such that SM values are 0 or 1
    - For SM couplings that are 1: define deviation Δ from SM
  - Test for any aTGC
- Note: Many terms in Lagrangian would give cross sections as a function of $\sqrt{s}$ leading to unitarity violation. As this is not possible, new physics interactions at scale Λ needed to counter the effect
  - Use form factor parameterisation that leads to couplings that vanish at high $\sqrt{s}$

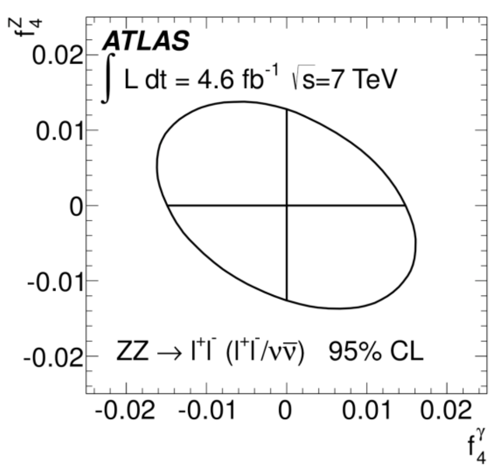
$$f_i^V = f_{i0}^V / (1 + \hat{s}/\Lambda^2)^n$$

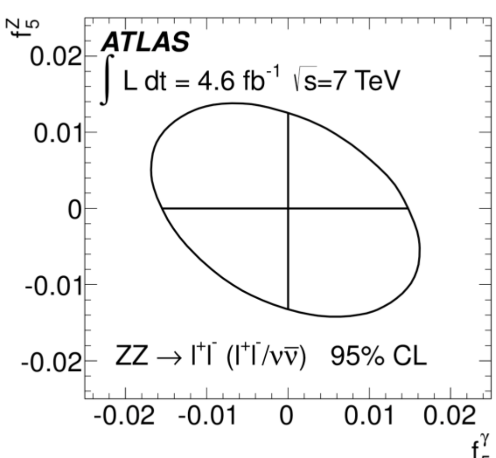
Charged	
Couplings	Vertex (Final state)
λ_γ, $\Delta\kappa_\gamma$	γWW (WW, Wγ)
λ_Z, $\Delta\kappa_Z$, Δg_1^Z	ZWW (WW, WZ)
Neutral	
Couplings	Vertex (Final state)
h_3^γ, h_4^γ	$\gamma\gamma Z$ (Zγ)
h_3^Z, h_4^Z	$ZZ\gamma$ (Zγ)
f_4^γ, f_5^γ	γZZ (ZZ)
f_4^Z, f_5^Z	ZZZ (ZZ)

aTGC: methodology

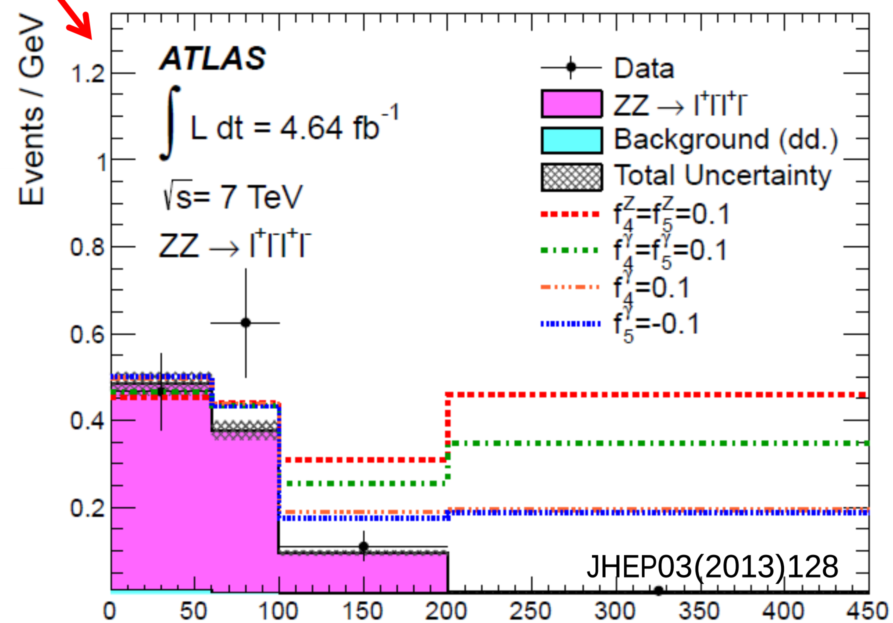
- Measure diboson production cross section vs. variables sensitive to aTGCs
  - $W \to \ell\nu$: p_T^{ℓ}
  - $Z \to \ell\ell$: $m_{4\ell}$ (ZZ) or $p_T^{\ell\ell}$ of leading Z
- Presence of aTGC would distort shape
- Use MC to reweight / interpolate to distributions with anomalous couplings
- Set limits on aTGCs on each coupling:
  - assuming others are zero or
  - on pairs assuming others are zero







JHEP03(2013)128

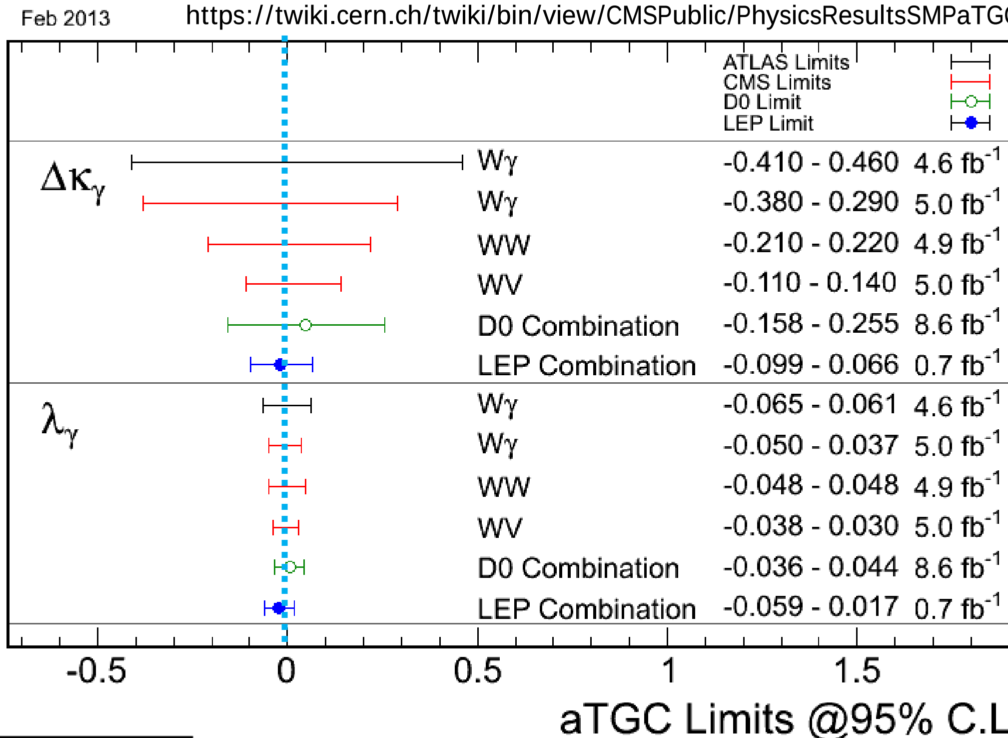


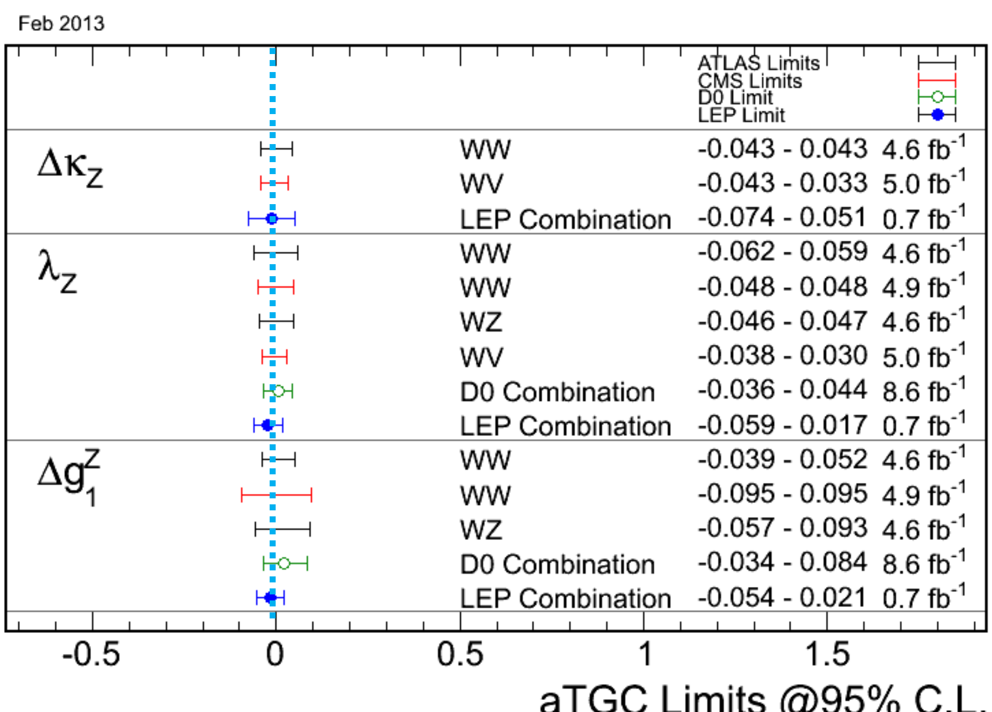
The leading Z boson transverse momentum

Charged aTGC limits

Snap shot of aTGCs: LHC 7TeV data + LEP + Tevatron

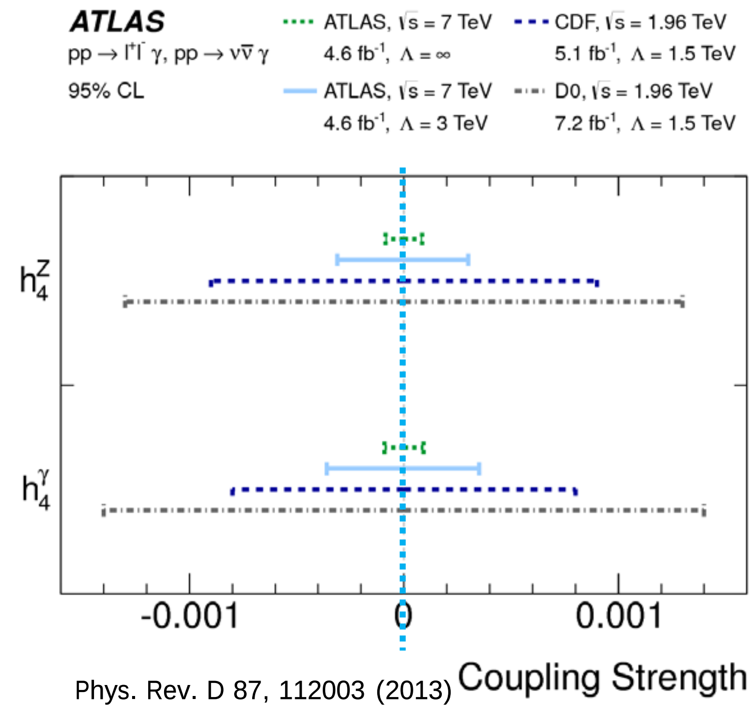
$WW\gamma$, WWZ





LEP still sets stringent limits in some cases, LHC limits comparable to Tevatron

Neutral aTGC limits

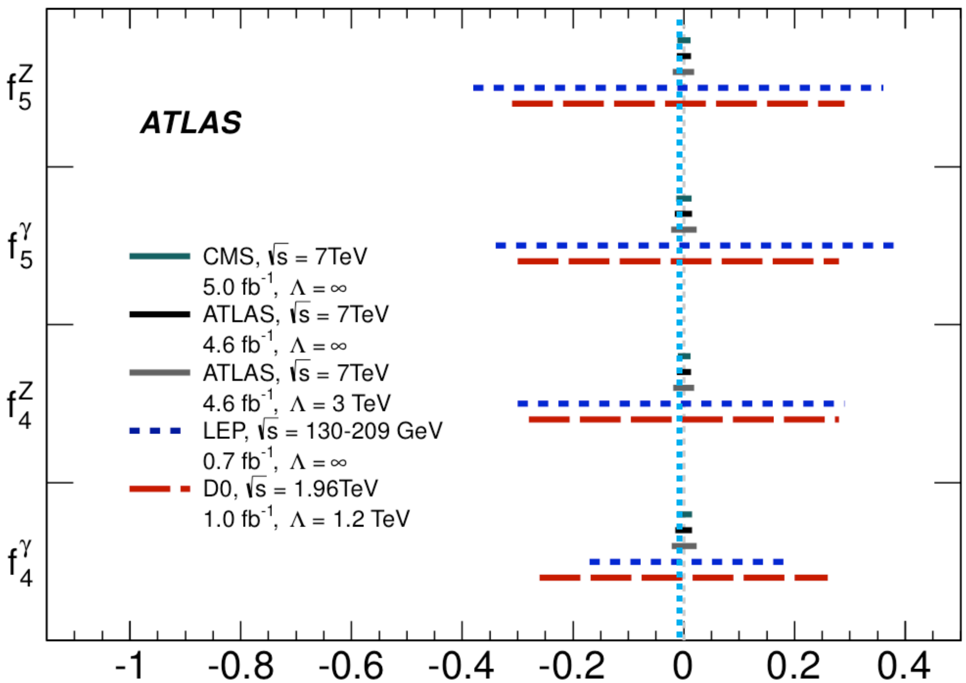


Phys. Rev. D 87, 112003 (2013)

LHC is now dominating this measurement

→ No evidence for aTGCs

Zγγ, ZZγ, ZZZ



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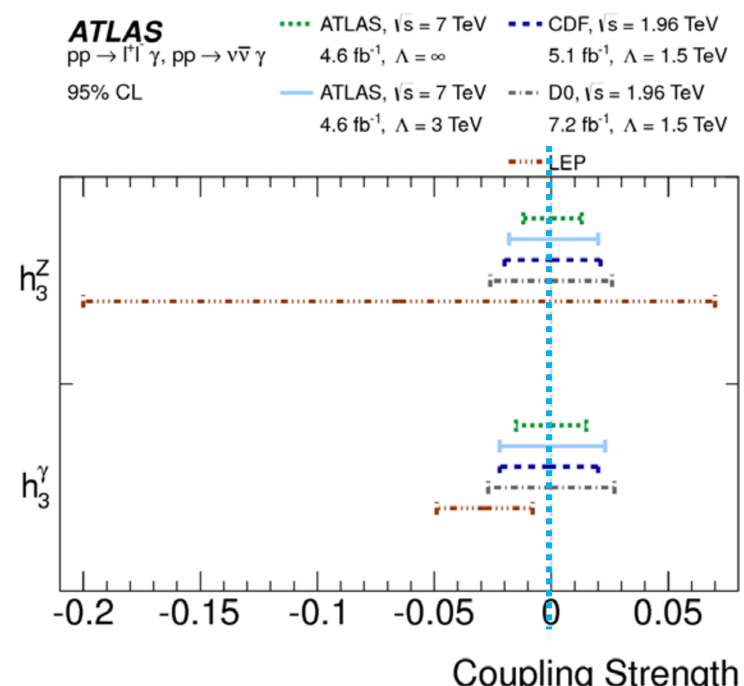
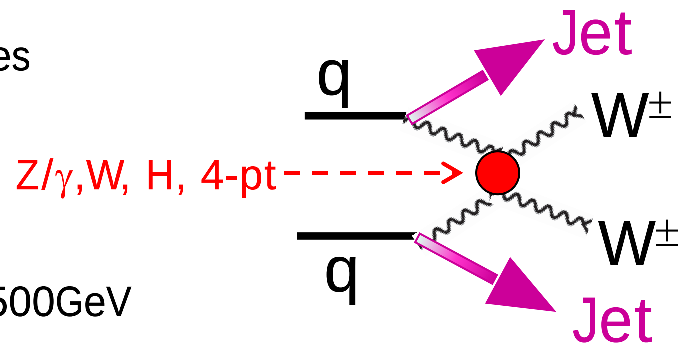
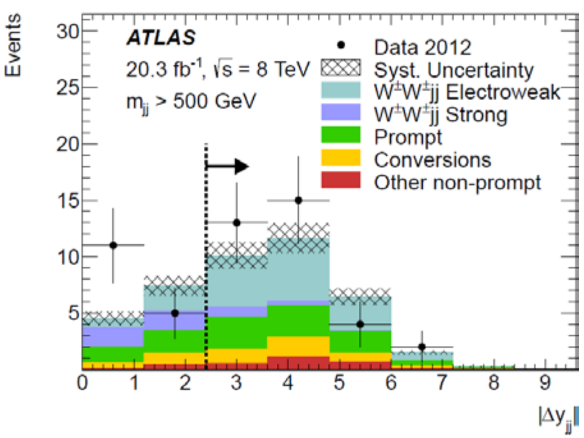


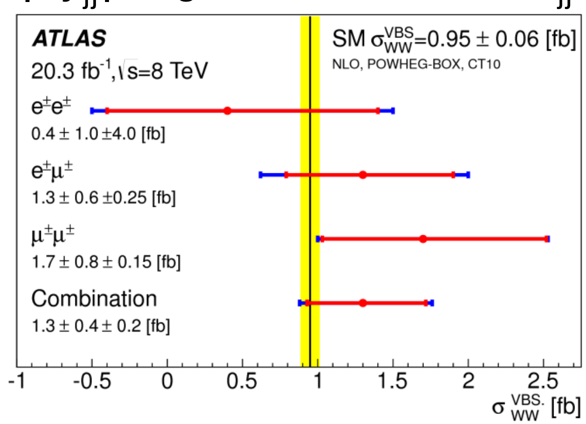
Vector boson scattering (VBS): $W^{\pm}W^{\pm}jj$

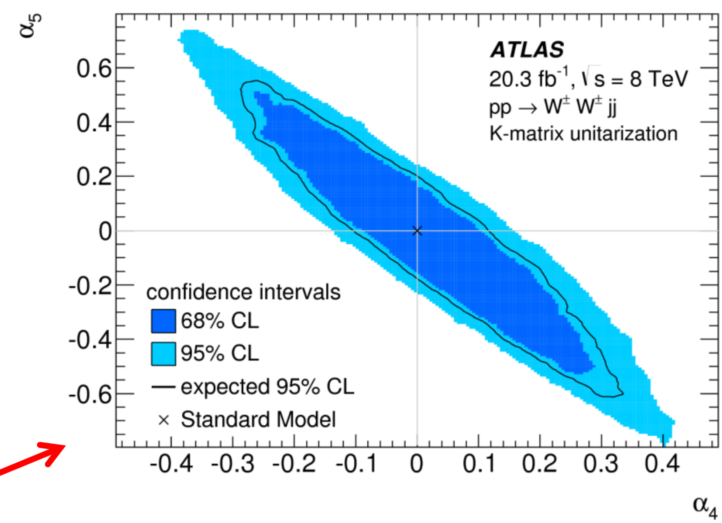
- VBS VV→VV where V=W or Z: key process to probe nature of EW symmetry breaking
  - Without a SM Higgs, longitudinally polarised VBS amplitude violates unitarity at ~1TeV!
  - Newly discovered Higgs boson could unitarise process
- V+V+jet+jet in final state → both EW and strong processes
  - Same sign WW: EW process dominates
- $W^{\pm}W^{\pm}jj$ production: ATLAS 20.3fb^{-1} at 8TeV
  - Enhanced VBS region: $e^{\pm}e^{\pm}$, $\mu^{\pm}\mu^{\pm}$,$\mu^{\pm}e^{\pm}$, +

  ≥2 well separated jets in $|\Delta y_{jj}|$, high invariant mass m_{jj}>500GeV





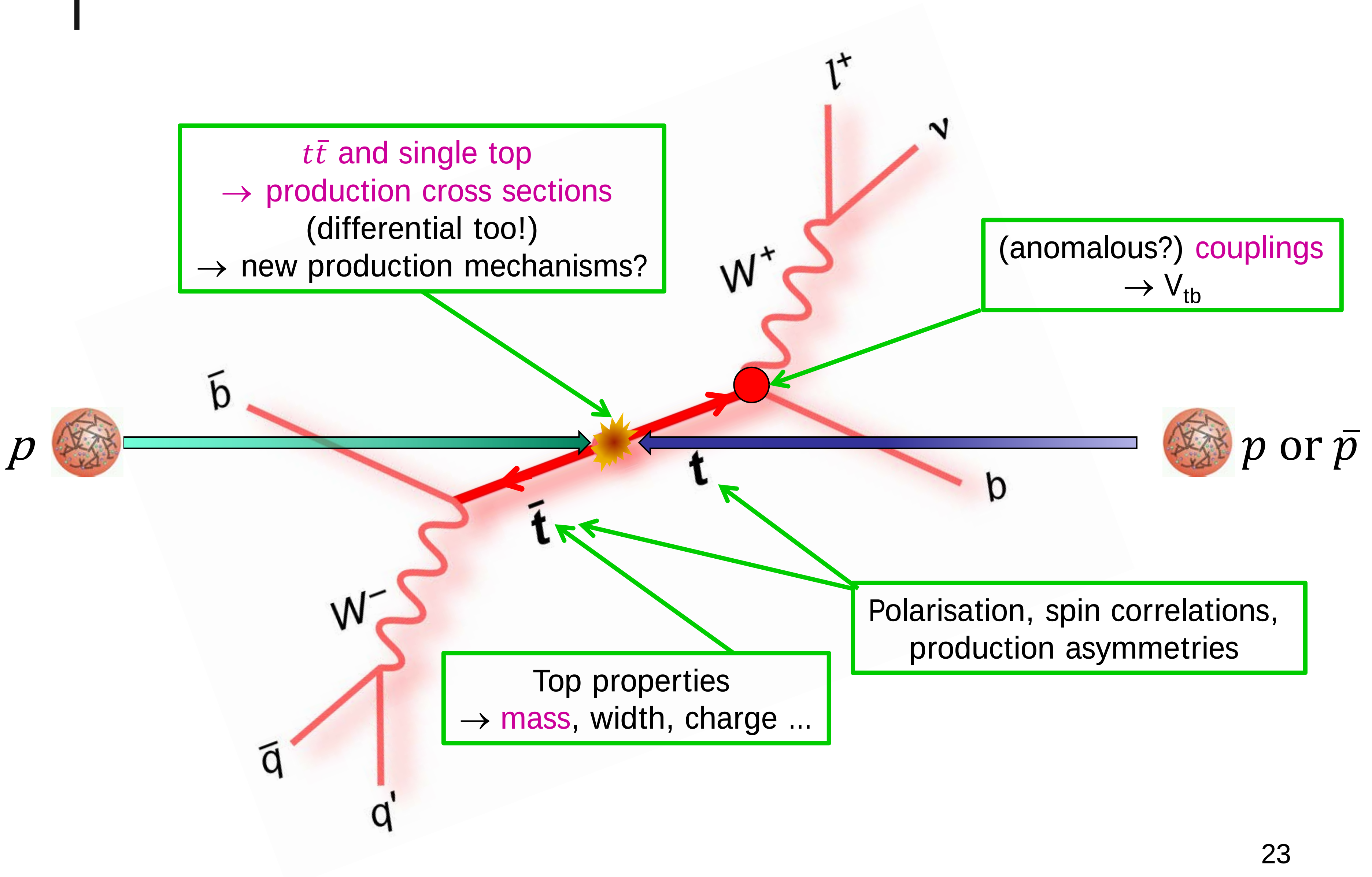




- 3.6σ significance of EW signal (σ_{WW}(VBS))
- Deviations from SM quartic gauge couplings:
  - Parameterised by α_4,α_5 : limits set

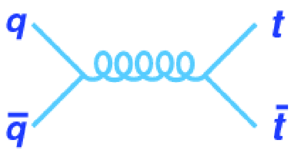
TOP PHYSICS

Top production and decay: the many properties



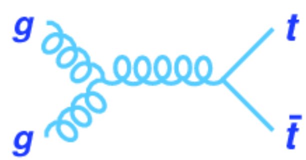
Top quark pair production and decay

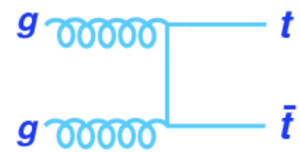
- Top quark pair ($t\bar{t}$) production is via the strong interaction



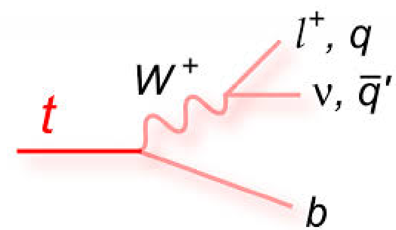
←85% Tevatron 15%→

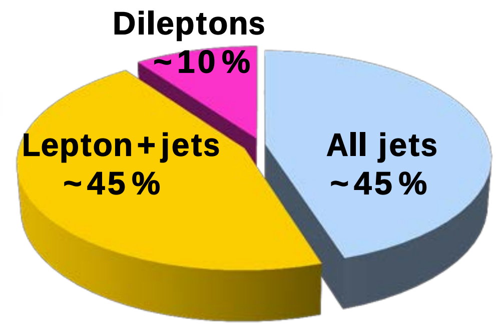
←15% LHC 85%→

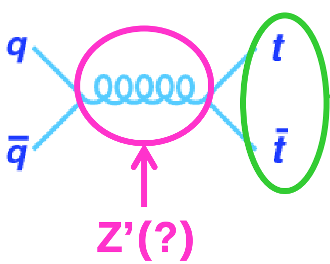




- Top quark subsequently decays ~100% to W + b: $t\bar{t} \to W^+W^-b\bar{b}$
  - W decays are hadronic or leptonic
- Dilepton channel: very clean but low rate
- Lepton+jets: clean and good rate
- Measure $t\bar{t}$ production cross section $\sigma(t\bar{t})$
  - Precise $\sigma(t\bar{t}) \to$ measurement of SM parameters: m_t and α_S
  - New physics could be hidden? New production modes or decays?





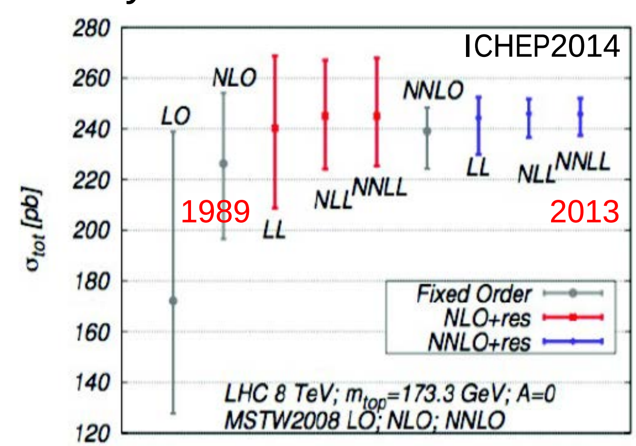


t' or $\tilde{t}$? New heavy quarks?
SUSY decays?

- SM predictions: →
- Will be a trade off:
  - stats vs. sys

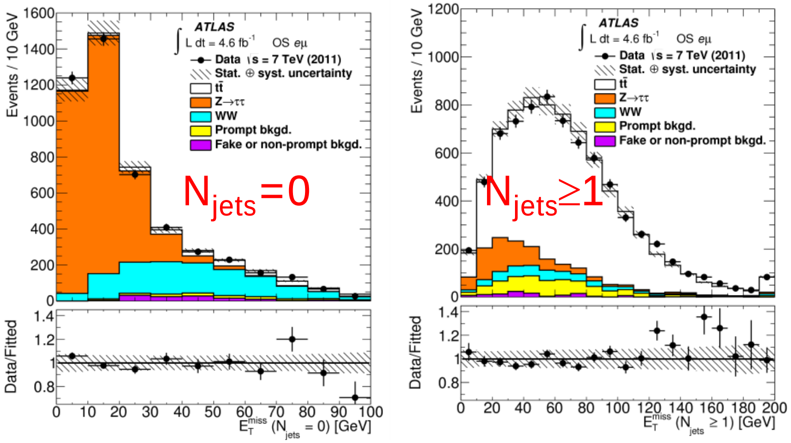
√s [TeV]	$\sigma(t\bar{t})$ (NNLO+NNLL) [pb] (m_t=172.5GeV)	Uncert. [%]
2	7.35	~4-6%
7	177.3	
8	252.8	
13	824.2	

x100

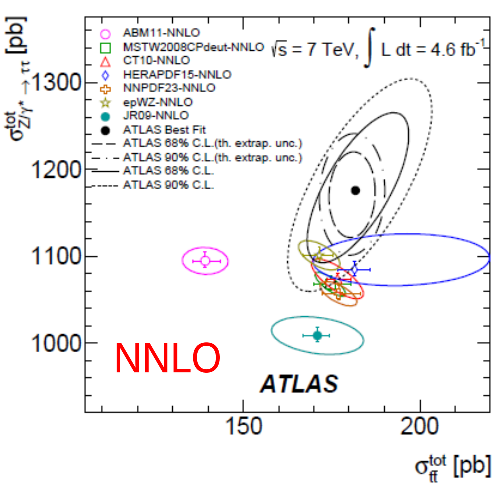


$t\bar{t}$: dilepton

- ATLAS simultaneous: $t\bar{t}$, WW, $Z/\gamma^*\to\tau\tau$
  - Dominant processes in eμ final state
- Template fit over E_T^{miss}, N_{jets}



- Normalisation $t\bar{t}$, WW, $Z/\gamma^*\to\tau\tau$ free pars



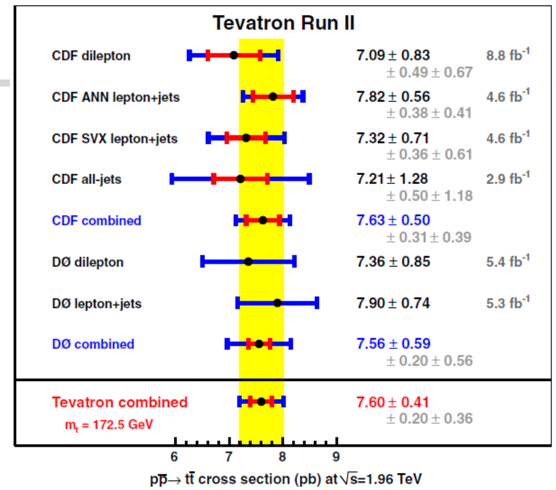
$\sigma(Z/\gamma^*\to\tau\tau)$ vs. $\sigma(t\bar{t})$

Comparisons with PDFs

arXiv:1407.0573

Combined results

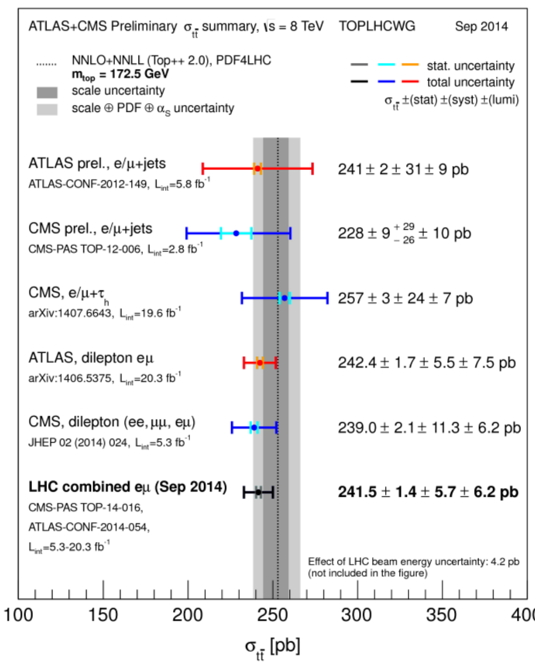
- Tevatron Run II combined results



PRD89 (2014) 072001

  - stat ≅ sys ≅ lumi → tot = 5.4%

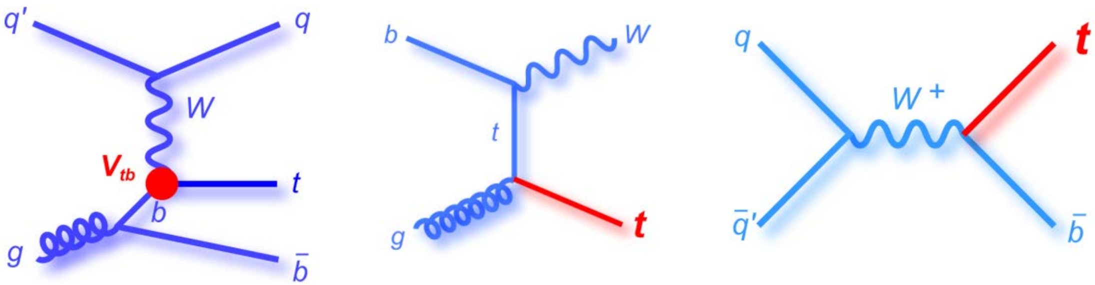
- LHC combination with first 8TeV results



  - stat << sys ≅ lumi → tot = 3.5%

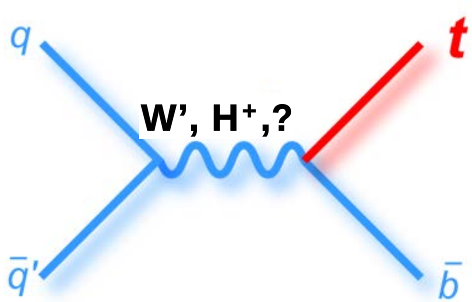
Single-top production

- Single-top production is via the EW interaction

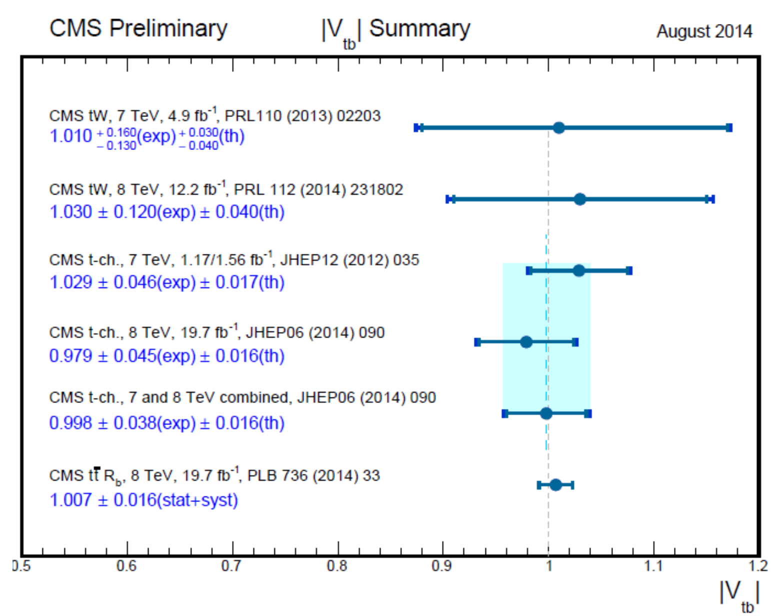


t-channel **Wt-channel** **s-channel**

- Measure fundamental parameters of SM
  - $\sigma_{single\text{-}top} \sim |V_{tb}|^2 \rightarrow$ CKM and unitarity
    - V_{tb} measured at LHC, Tevatron: ~2-10%
- Background in Higgs and SUSY searches
- Sensitive to new physics?

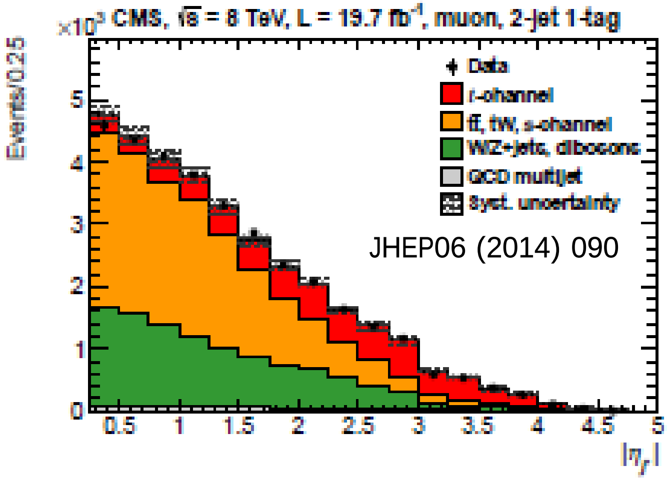


	SM prediction [pb] arXiv:1311.0283			
√s [TeV]	t	Wt	s	Tot.
2	2.08 (62%)	0.25 (7%)	1.05 (31%)	~3
8	87.8 (76%)	22.2 (19%)	5.55 (5%)	~115
14	248 (72%)	83.6 (24%)	11.86 (4%)	~343
Meas. precision	~10% LHC	~20% LHC	~20% Tevatron	



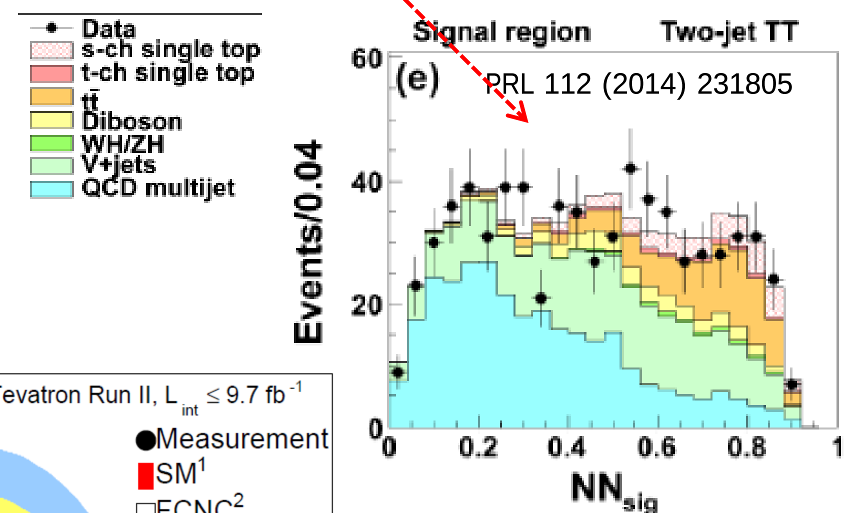
Single top: t and s channel

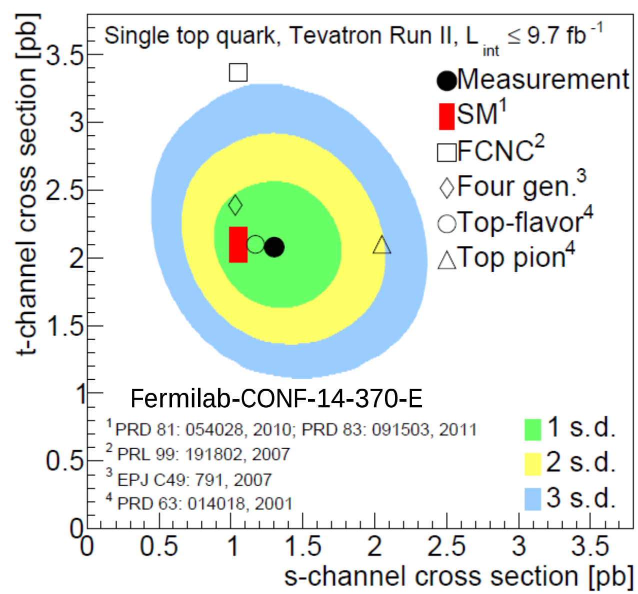
- t-channel: CMS @ 8TeV (19.7fb^{-1})
- Lepton + 2 jets (1 b jet)
- Template fit on the untagged jet



$$\sigma_{t\text{-ch.}}(\mathrm{t}) = 53.8 \pm 1.5\,(\mathrm{stat}) \pm 4.4\,(\mathrm{syst})\ \mathrm{pb}$$
$$\sigma_{t\text{-ch.}}(\bar{\mathrm{t}}) = 27.6 \pm 1.3\,(\mathrm{stat}) \pm 3.7\,(\mathrm{syst})\ \mathrm{pb}$$

- s-channel: CDF full run 2 9.5fb-1
- l+jet and E_T^{miss}+jet
- MVA discriminants sensitive to s-channel

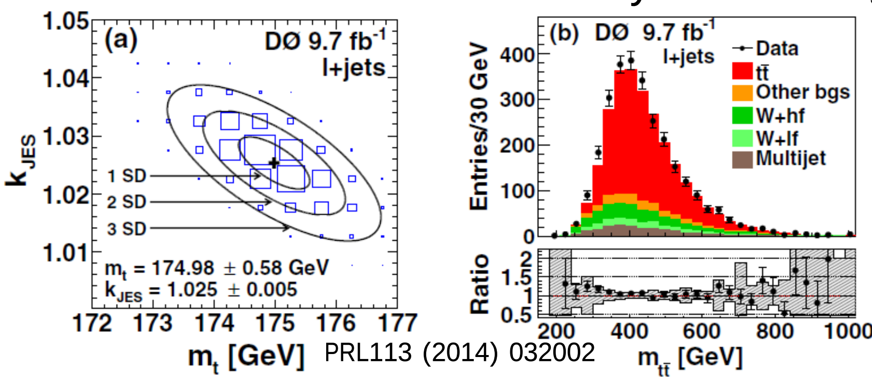




- Tevatron: t-channel vs. s-channel: summary
- BSM predictions: 4-quark generations, top-flavour model with new heavy bosons, top-pions, FCNC

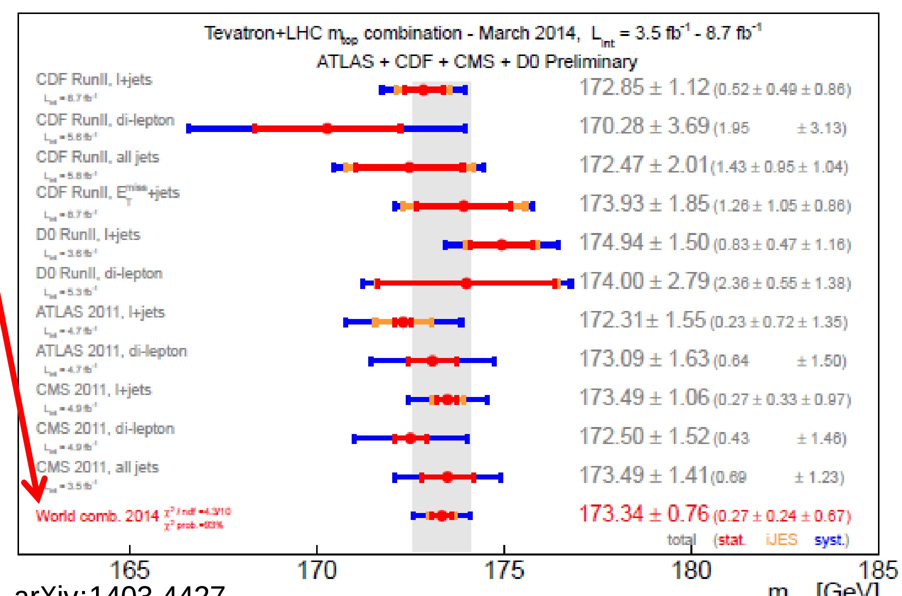
Top mass

- m_t is a fundamental parameter: m_W, m_t, m_H together test the consistency of the SM
- Many techniques to extract m_t
  - Decay kinematic fits or likelihood compatibility with top hypo, template fit to reco mass
- Matrix element technique: D0 l+jet (full run 2, 9.7fb^{-1})
  - From kinematic info in the event, use LH technique per-event probability densities
    - Calculate probability that each event results from a $t\bar{t}$ or bkg
  - Overall JES is calibrated by constraining in-situ mass of hadronically decaying W



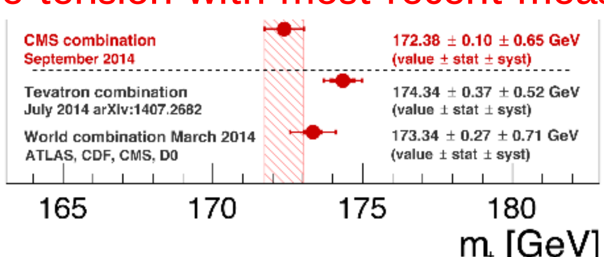
PRL113 (2014) 032002

$$m_t = 174.98 \pm 0.58(\text{stat+JES}) \pm 0.49(\text{syst})\ \text{GeV}$$
$$m_t = 174.98 \pm 0.76\ \text{GeV}\ \ [0.43\%]$$



arXiv:1403.4427

- World avg last March: same precision of <1GeV
- Some tension with most recent measurements



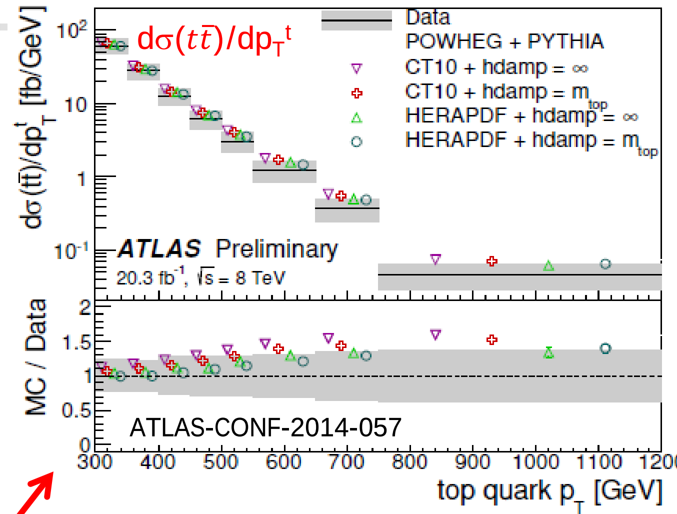
Conclusions

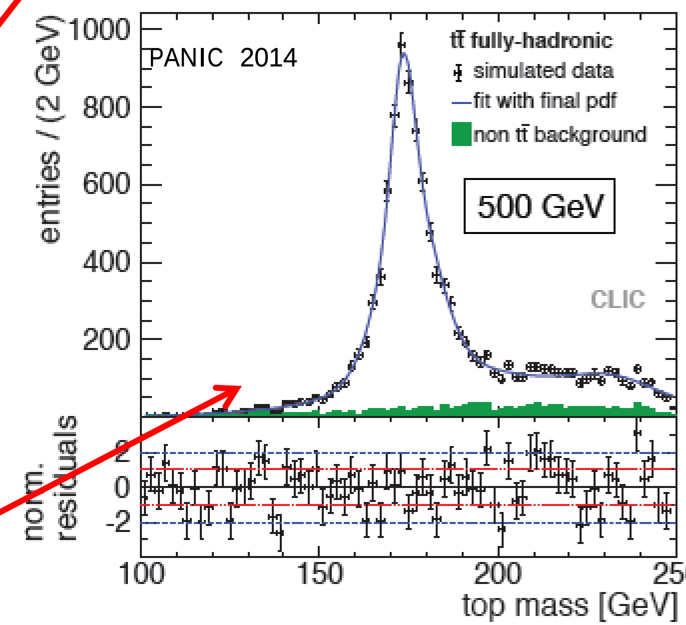
Single and diboson production is interesting on so many levels

- Probes of
  - pQCD, PDFs, consistency of the SM
  - $m_{\ell\ell}$, $|y_{\ell\ell}|$ dependence of Z/γ^* production, W charge asymmetry, m_W
- Underlying foundation of many new physics searches
  - e.g. critical to better understand backgrounds and PDFs for LHC at higher energy/luminosity
- Sensitive venues for new physics: aT/QGCs

Top quark physics

- Tevatron and LHC: top factories
  - Top mass known to better than 1GeV
  - Moving into realm of precision measurements of top (differential) properties, not limited by statistics
- Precision top physics will be taken to a new level at future colliders!





ADDITIONAL MATERIAL

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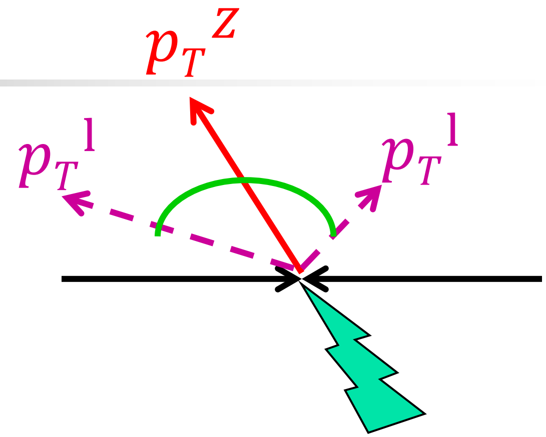
Z cross section vs. ϕ_η^*



- A better variable to probe low-p_T Z: ϕ_η^*

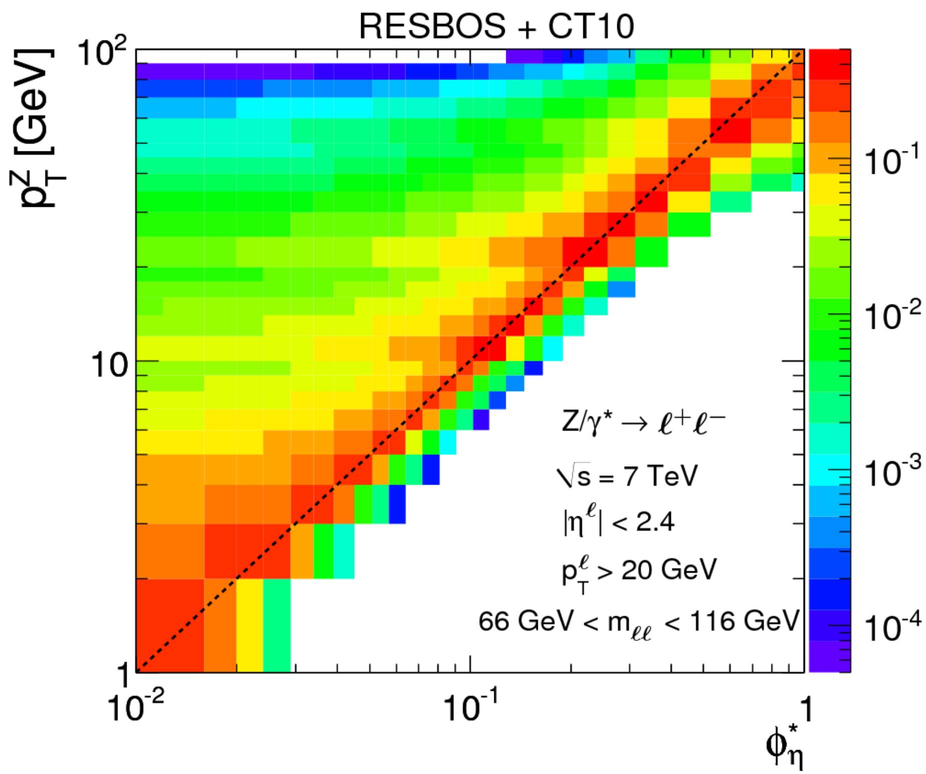
$$\phi_\eta^* \equiv \tan(\phi_{\rm acop}/2) \cdot \sin(\theta_\eta^*)$$

where $\phi_{\rm acop} \equiv \pi - \Delta\phi,$ (ϕ between 2 leptons)
and $\cos(\theta_\eta^*) \equiv \tanh[(\eta^- - \eta^+)/2]$ (η between 2 leptons)

- Probes same physics as Z p_T but with better precision

$$p_T^Z \approx m_Z \, \phi_\eta^*$$

- Depends uniquely on direction of lepton tracks (which is better measured than their momenta)
- Significant improvement in the understanding of electron track parameters in 2011/2012 really helped this analysis!

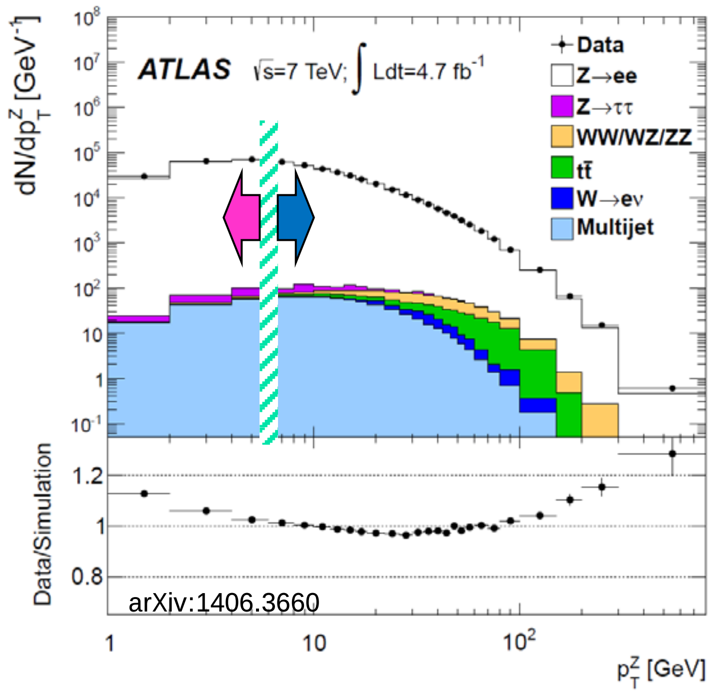


p_T dependence of Z/γ^* production

Near Z pole $m_{\ell\ell}$=≅ 90GeV within a mass window of ~±25GeV

- $d\sigma/dp_T^{\ell\ell}$, $d^2\sigma/dp_T^{\ell\ell}d|y_{\ell\ell}|$

- Low $p_T^{\ell\ell}$: region of ISR and intrinsic k_T of partons
- modeled through soft-gluon resummation or parton showers (PS)
  - e.g. ResBos (NLO,NNLO)+NNLL



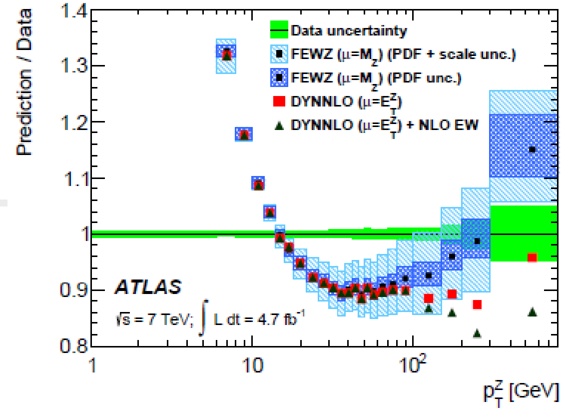
- High $p_T^{\ell\ell}$: region dominated by radiation of high p_T gluons/quarks
- Sensitive to gluon PDF
- Modeled with fixed-order calculations like FEWZ @NLO,NNLO & DYNNLO (with NLO,NNLO EW corrs)

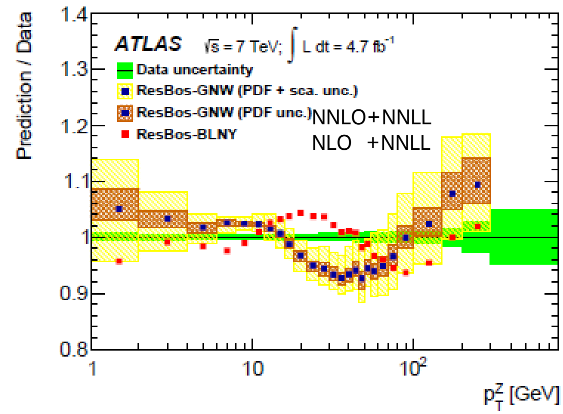
arXiv:1406.3660
Phys. Lett. B720 (2013) 32

A tool for tuning: $p_T^{\ell\ell}$

ATLAS 7TeV: $(1/\sigma^{fid})\, d\sigma^{fid}/dp_T^{\ell\ell}$, inclusively in $y_{\ell\ell}$ (ee and $\mu\mu$)

- FEWZ,DYNNLO (top), ResBos (bot)





Parton-shower tunes: determine sensitivity of $d\sigma/dp_T^{\ell\ell}$ to PS models

- Include measurement of ϕ_η*, highly correlated to p_T^Z but depends on direction of tracks (better measured than momenta)

$$p_T^Z \approx m_Z\, \phi_\eta^*$$

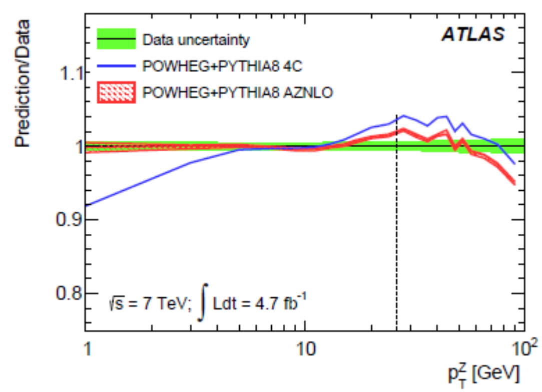
- e.g. compare POWHEG+PYTHIA8

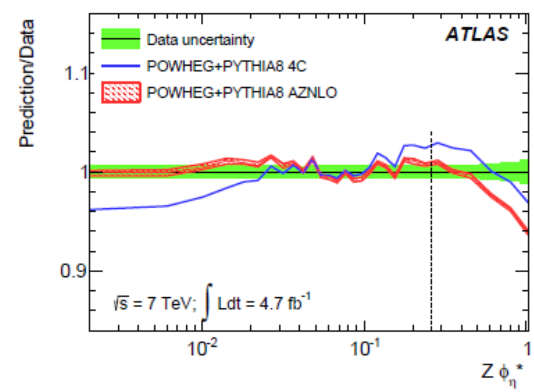
new tune AZNLO with base tune 4C

  - Primordial k_T and ISR cut-off

  have been tuned

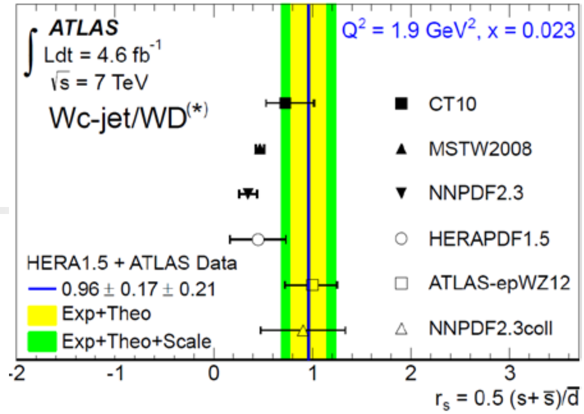
- Consistent tune with $p_T^{\ell\ell}$ and ϕ_η* in agreement within 2% with data for $p_T^{\ell\ell}$<50GeV





PDF extraction in the HERAFITTER framework

ATLAS: JHEP05 (2014) 068
CMS: arXiv:1312.6283



- Use HERA inclusive DIS data with LHC W data to better constrain PDFs, in particular valence and strange
- ATLAS: HERA + [W+charm]
  - Repeat HERAPDF1.5 fit making $f_s = \bar{s}/(\bar{d}+\bar{s})$ ~free while constraining other params to HERAPDF1.5 fit results
    - $r_s \equiv 0.5(s+\bar{s})/\bar{d}$ ~1 at starting scale Q^2=1.9GeV^2
- CMS: HERA + $\mathcal{A}(\eta)$ + [W+charm]
  - Adding $\mathcal{A}(\eta)$ improves valence precision, changes shape
  - Free-s fit where dbar and sbar parameterised separately
    - $R_S = (s+\bar{s})/(\bar{u}+\bar{d})$, just below 1
- Within framework, ATLAS&CMS strange fraction definition similar at starting scale… R_S & r_s can be directly compared: ~consistent