New Results on Z Boson Production with the ATLAS Detector

Peter Wagner
on behalf of the ATLAS Collaboration

QCD @ LHC, 30.8.2018

Overview

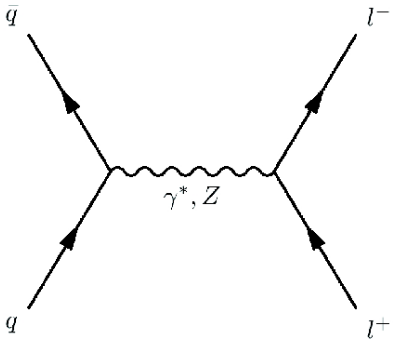
Increasing Precision on Z+jets production → better understanding of QCD, more precise modeling:

$\sqrt{S}$ = 8 TeV

L = 20 fb^{-1}

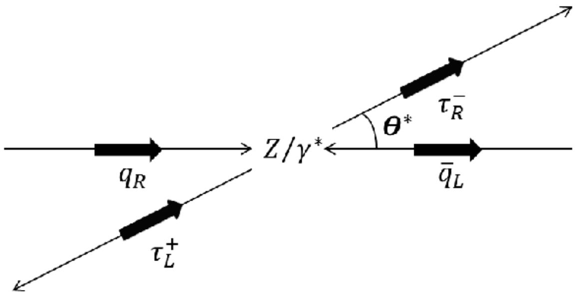
- Triple-differential measurement of $Z/\gamma^* \rightarrow ll$ cross section

  JHEP 12 (2017) 059



- τ polarization in $Z \rightarrow \tau\tau$ events

  EPJC 78 (2018) 163

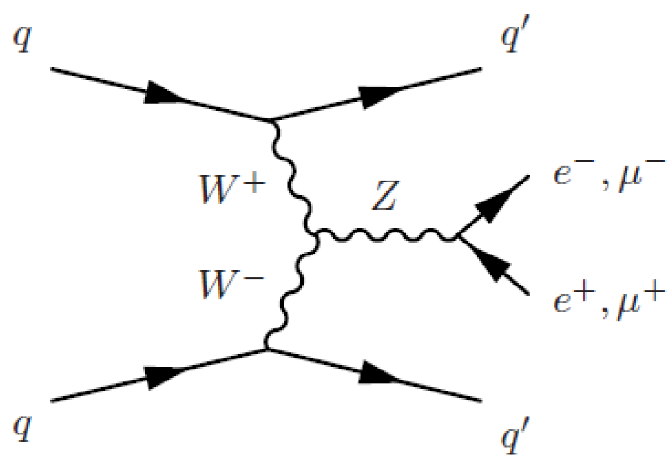


$\sqrt{S}$ = 13 TeV

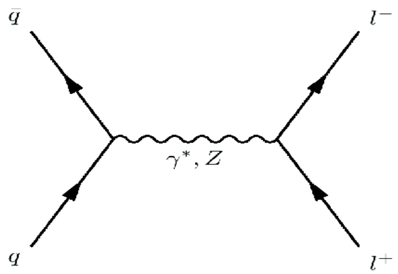
L = 3 fb^{-1}

- EW production of Z bosons

  Phys. Lett. B 775 (2017) 206



Triple-diff. σ of $Z/\gamma^* \rightarrow ll$

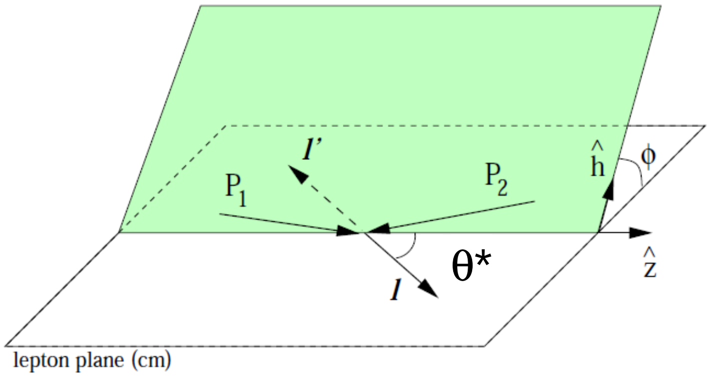


- Access to axialvector- and vector couplings via decay kinem.
- Measurement of $\sin^2\theta_W$

$$\frac{d^3\sigma}{dm_{\ell\ell}dy_{\ell\ell}d\cos\theta^*} = \frac{\pi\alpha^2}{3m_{\ell\ell}s}\sum_q P_q\left[f_q(x_1,Q^2)f_{\bar{q}}(x_2,Q^2) + (q \leftrightarrow \bar{q})\right]$$

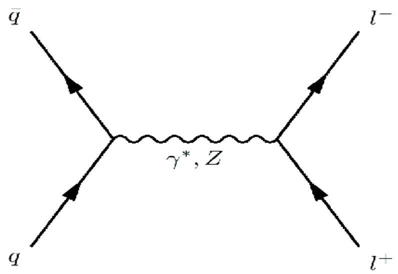
M_{ll}, y_{ll}: Dilepton mass, rapidity

$\cos\theta^*$: Decay angle



arxiv:1101.0909

Triple-diff. σ of Z/γ*→ll



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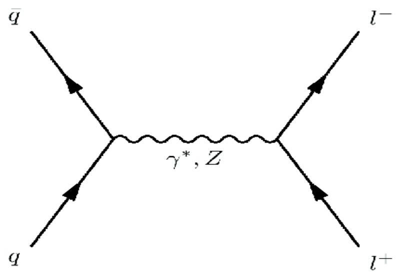
$m_{ll}^2 = Q^2$

$(m_{\ell\ell}/\sqrt{s})e^{\pm y_{\ell\ell}} = x_{1,2}$

- Sensitivity to quark PDFs via m_{ll} and y_{ll}
- Sensitivity to quark vs gluon PDF through $\cos\theta^*$

Triple-diff. σ of $Z/\gamma^* \to ll$



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Contains EW coupling constants ~ $\sin^2\theta_W$

Depends on $\cos\theta^*$

→ Observable:

$$A_{FB} = \frac{d^3\sigma(\cos\theta^* > 0) - d^3\sigma(\cos\theta^* < 0)}{d^3\sigma(\cos\theta^* > 0) + d^3\sigma(\cos\theta^* < 0)}$$

Measurement of σ unfolded to Born level

- Sensitivity to quark PDFs via m_{ll} and y_{ll}
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- Sensitivity to $\sin^2\theta_W$ through forward-backward asymmetry

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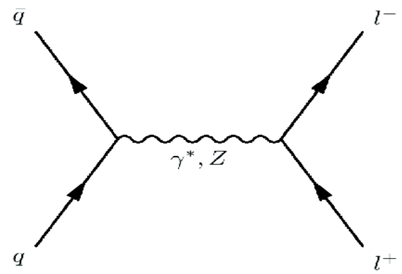

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- Large PDF uncertainty in $\sin^2\theta_W$ measurement @ 7 TeV

  → now constrain PDFs in $\sin^2\theta_W$ measurement

Signal & Backgrounds Estimation

$$\frac{d^3\sigma}{dm_{\ell\ell}\,d|y_{\ell\ell}|\,d\cos\theta^*}$$

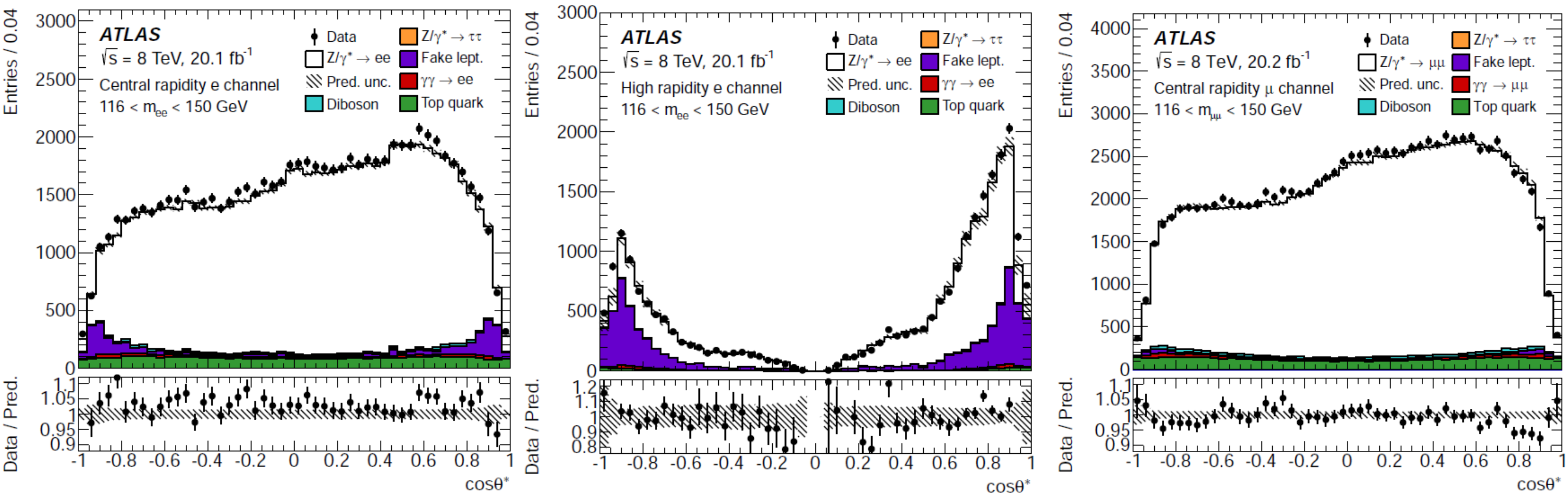
Simple high-purity selection of dilepton events

Three final states:

- Two central muons
- Two central electrons
- Central+forward electron

Signal simulation:

- NLO Powheg-Box + Pythia8 PS, CT10 PDF
- m_{ll}-dependent K-factor from NNLO pQCD
- NLO EW corrections using G_μ scheme
- Amplitude coefficient A_0 reweighted in bins of y_{ll} and $p_T(Z)$



Small $|y_{ll}|$ and m_{ll} near Z peak: higher purity, smaller asymmetry

Large $|y_{ll}|$ and m_{ll} off Z peak: more background, stronger asymmetry

Signal & Backgrounds Estimation

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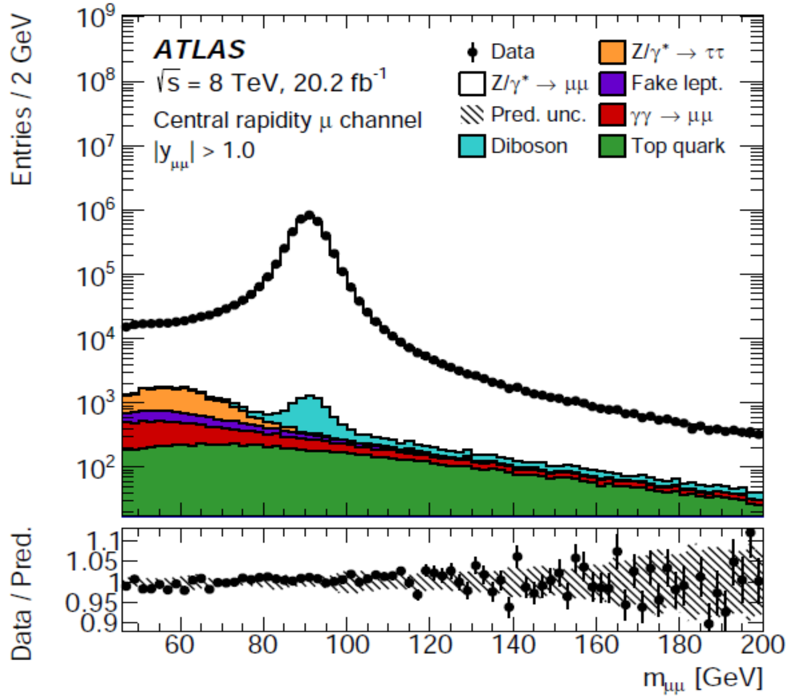
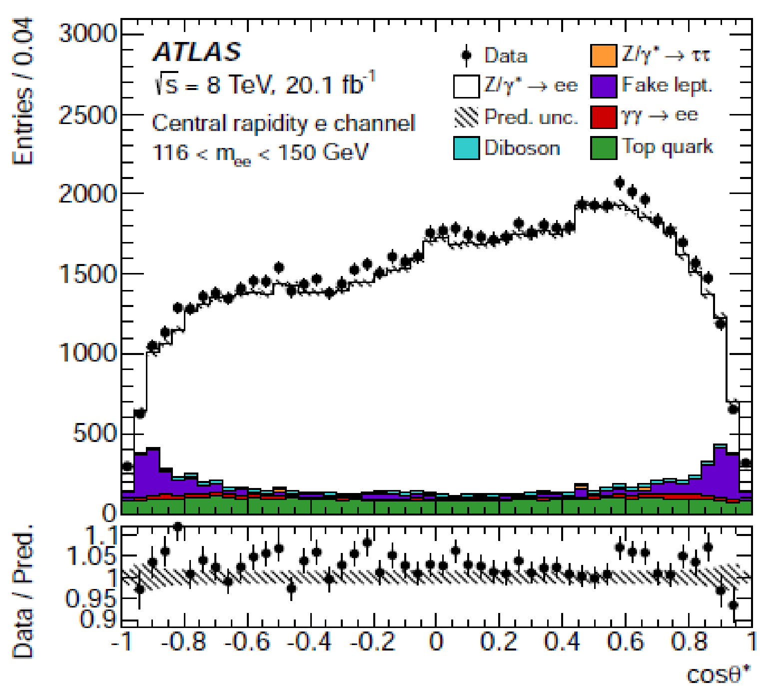


Simulated backgrounds:

- Top quarks
- Diboson
- $Z \to \tau\tau$
- $W \to l\nu$

All very small below 10%, a bit higher in some regions



Data-driven estimates of fake lepton ~ multijets background:

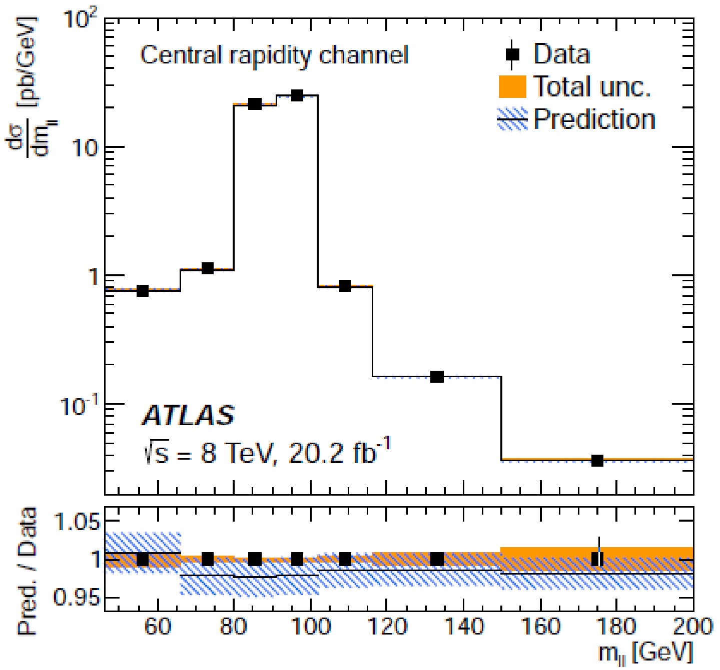
- Fake muons, typically very small, up to ~5%
- Fake electrons, typically small, up to ~30-60% at high |η|

Central e and μ channel results consistent →
Combination of σ's using χ^2 minimization technique

Results & Systematics

$$\frac{d^3\sigma}{dm_{\ell\ell}\, d|y_{\ell\ell}|\, d\cos\theta^*}$$

Integrated over y_{ll} and cosθ*



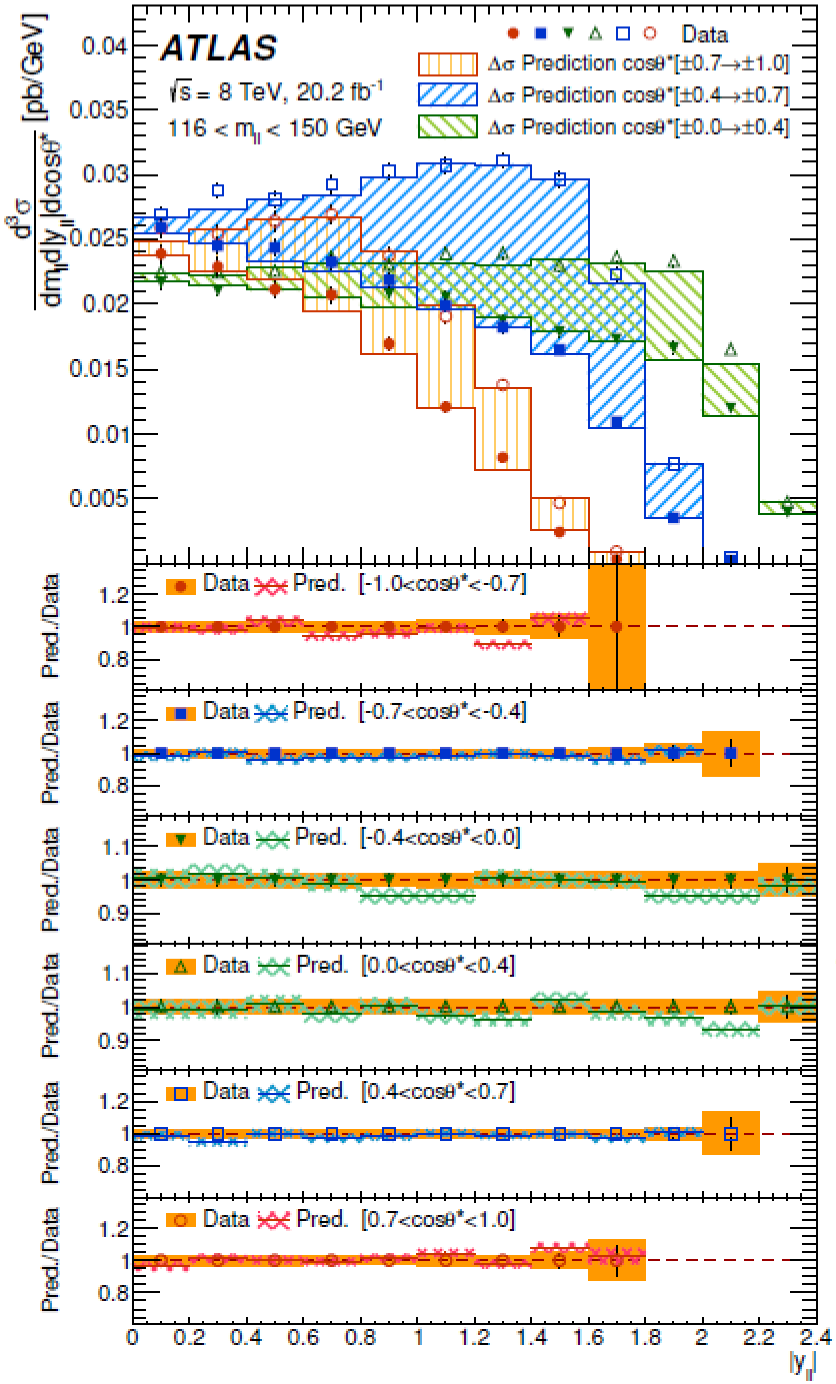
Impact of systematics on $\frac{d^3\sigma}{dm_{\ell\ell}\, d|y_{\ell\ell}|\, d\cos\theta^*}$ varies depending on m_{ll}:

- Off-Z peak: Background uncertainties, lepton reco/ID/isolation efficiency, MC signal statistics
  - For central electrons & muons: total below ~5% at low m_{ll} and up to 10% at high m_{ll}
  - Impacts from unc. larger by factor 2-3 for forward electrons
- On Z peak: lepton momentum scale
  - For electrons total impact ~2-3%
  - For muons total impact ~1%

Slight underestimation covered by lumi & PDF systematics

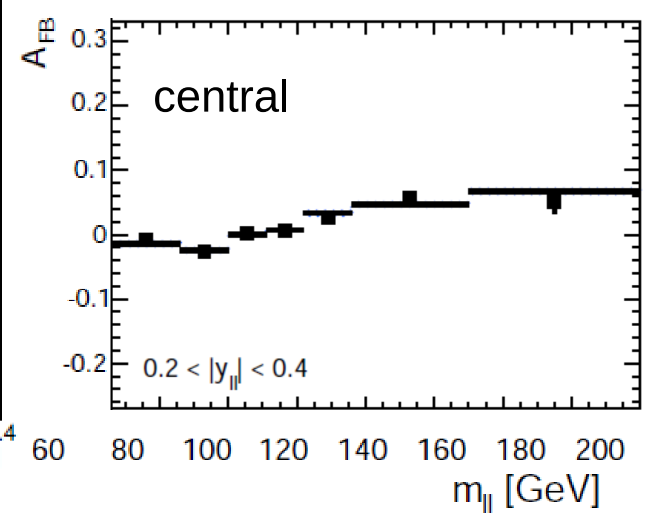
Results

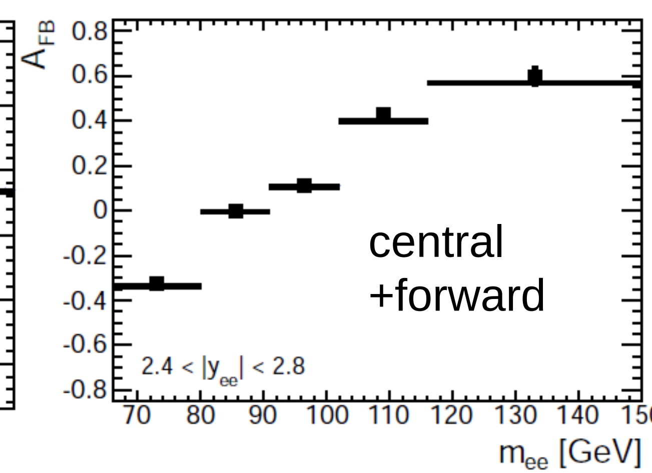
$$\frac{d^3\sigma}{dm_{\ell\ell}\, d|y_{\ell\ell}|\, d\cos\theta^*}$$



- A_{FB} switches sign at low vs. high m_{ll}
- A_{FB} ~ 0 at low y_{ll}: Determination of incident quark difficult
- Better determination of quark direction at larger y_{ll} → stronger A_{FB} variation
- Limited detector acceptance at highest $|y_{ll}|$ → smaller A_{FB}
- All distributions well described by MC simulation

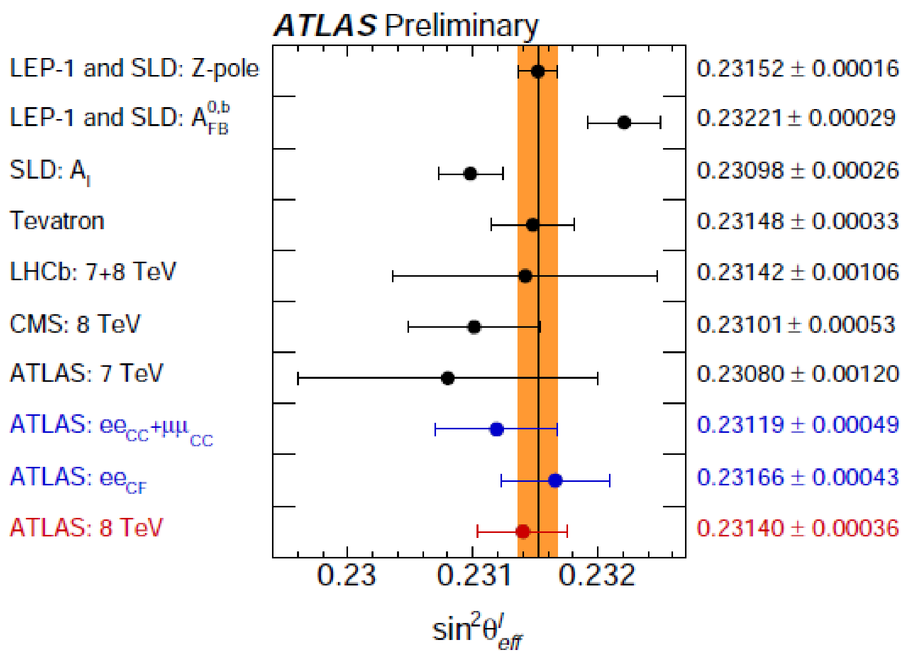
- Bars: stat unc.
- Solid: total exp. unc. (w/o lumi)
- Cross-hatched: stat+PDF unc.



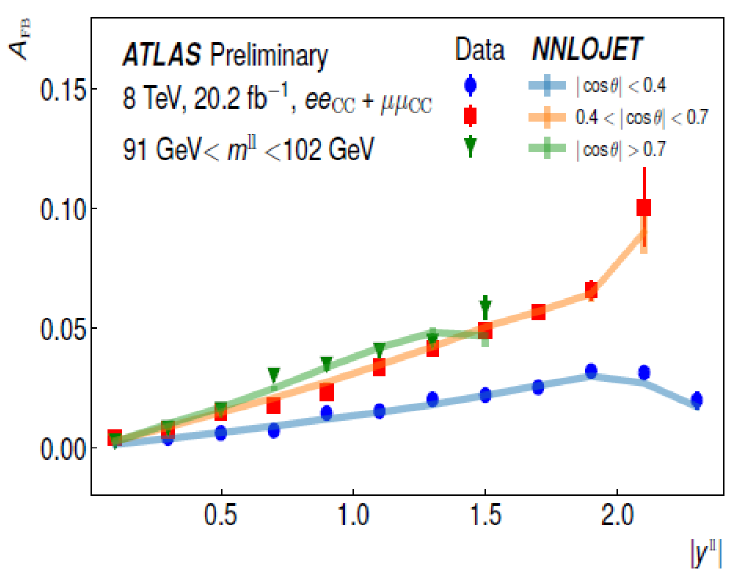


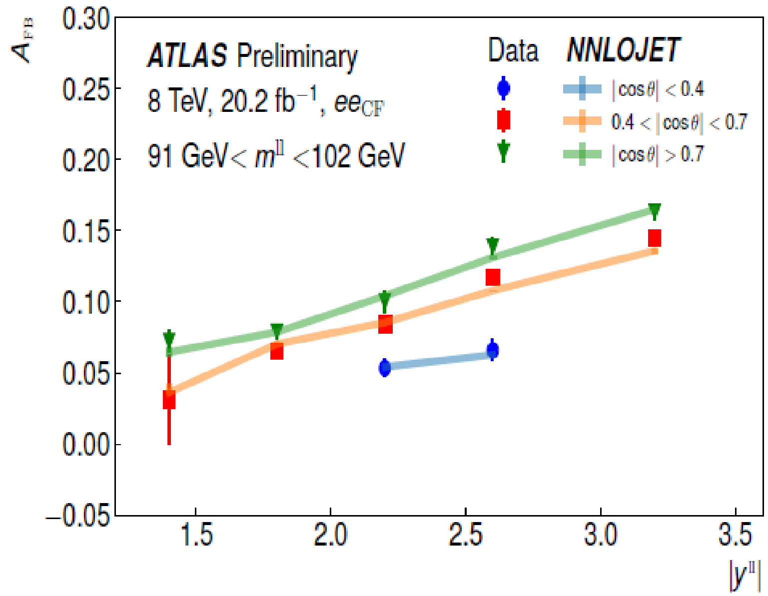
Alternative $\sin^2\theta^l_{eff}$ Measurement

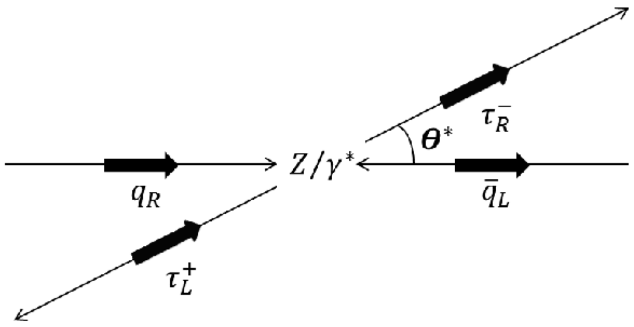
ATLAS-CONF-2018-037



- $\sin^2\theta^l_{eff}$ measured from angular coefficients in DY→ll (see J. Crane's talk)
- Used $\sin^2\theta^l_{eff}$= 0.23148 to evaluate modeling of A_{FB} → compatibility
- Possible sensitivity gain by combining A_{FB} and A_4 measurements







Tau polarization in Z→ττ events

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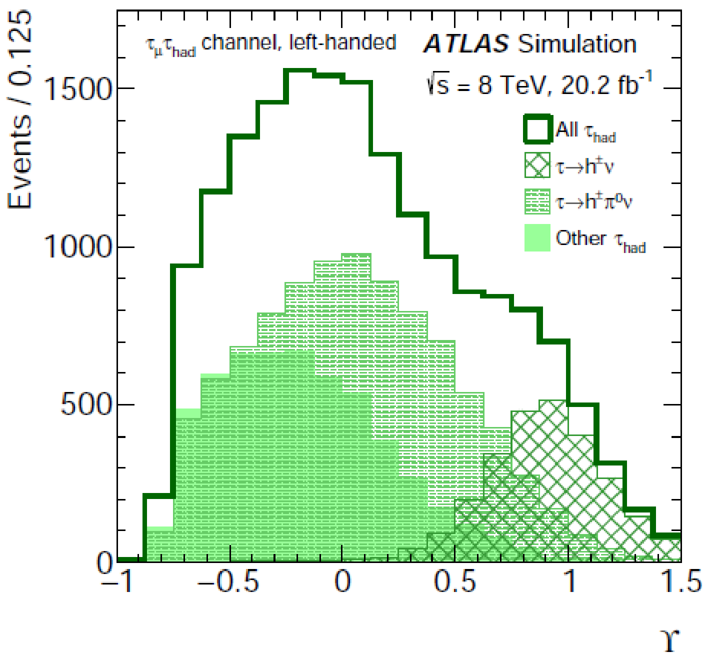
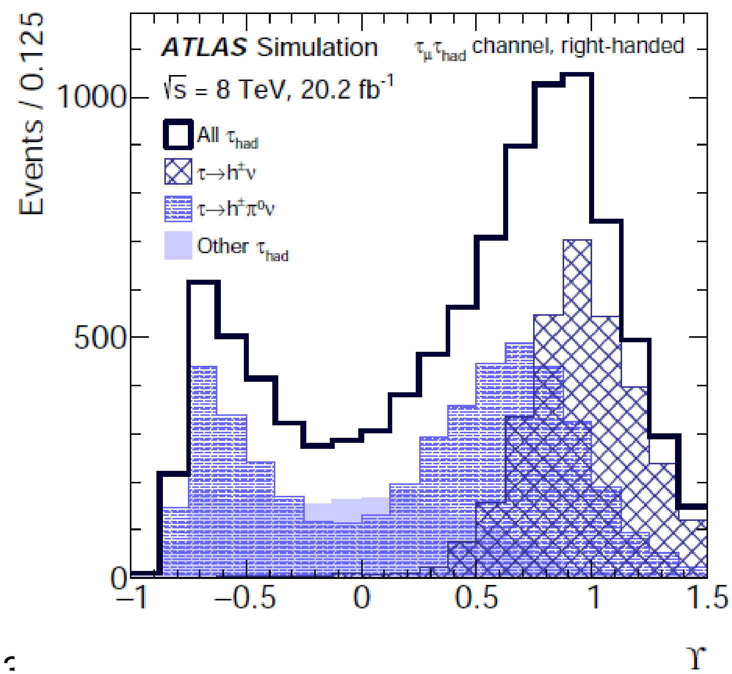
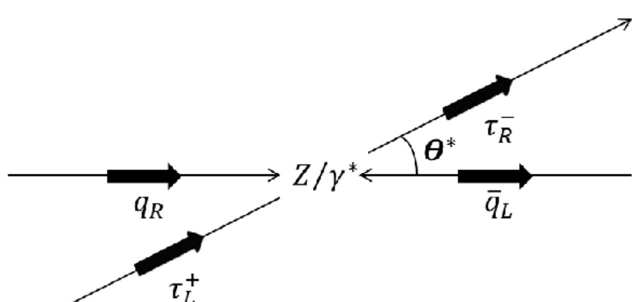




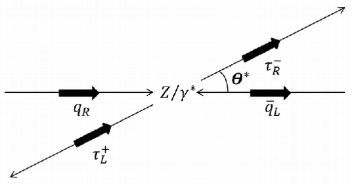
- Axialvector- and vector couplings cause asymmetry of average τ_{had} polarization P_τ in Z boson decays
- Affects $\tau\to\pi^{\pm}\pi^0\nu$ decay kinematics
- Observable: $$\Upsilon = \frac{E_T^{\pi^\pm} - E_T^{h^0}}{E_T^{\tau\text{had-vis}}} = 2\frac{p_T^{\text{track}}}{E_T^{\tau\text{had-vis}}} - 1$$
- Most precise O(1%) measurements of P_τ from LEP

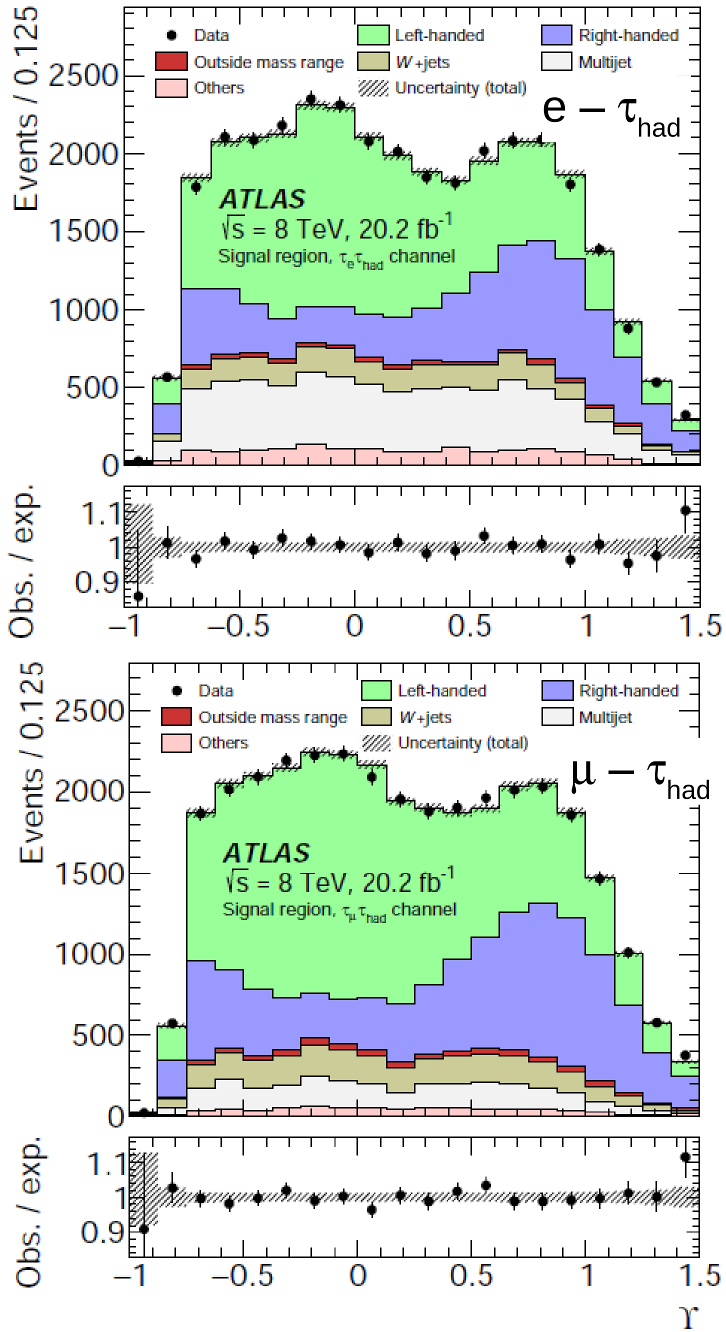
This analysis:

- Can measure P_τ in range of Z peak incl. non-Z contributions
- Pioneer new experimental techniques (τ pol. in H→ττ, Higgs CP, background suppression using Ψ)



Selection & Backgrounds

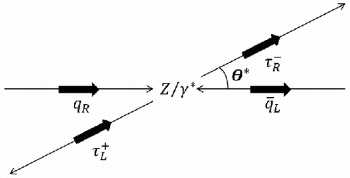


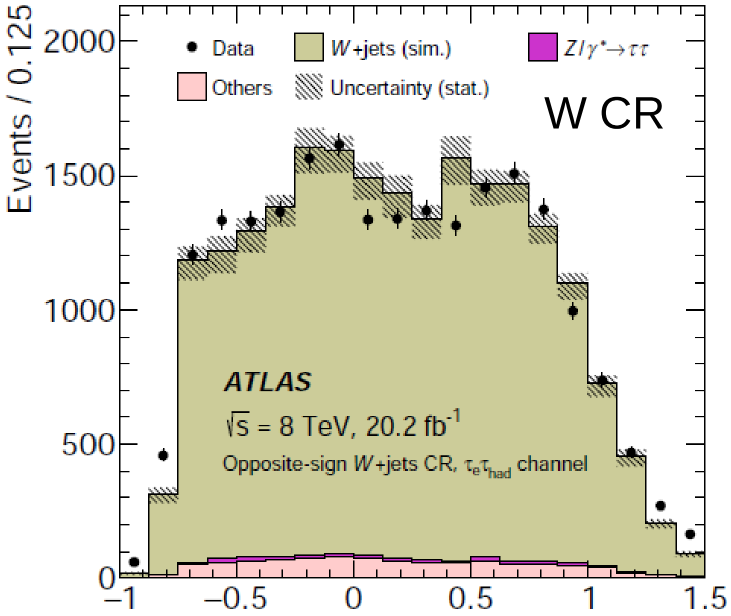


- Typical requirements to select Z decays with identified l and τ_{had}
- Opposite sign (OS) & visible mass 40 < m(l,τ) < 80 GeV
- Suppression of W+jets events: ΣΔϕ(l,τ,MET) < 3.5 and small m_T
- Selection eff. ~0.1%

- Z→ττ simulation Alpgen+Pythia6, τ decays from Tauola
- Sample splitting into left-/right-handed τ_{had} with TauSpinner

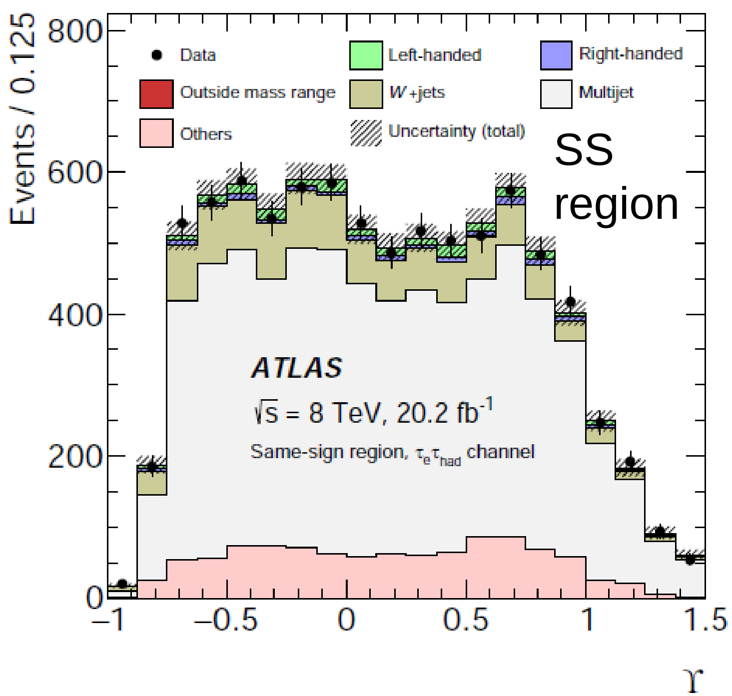
Selection & Backgrounds





W+jets estimate:

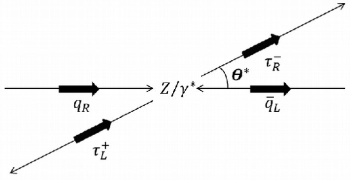
- Shape from data in control region (CR) → inv. m_T and $\Sigma\Delta\phi$ cuts
- Small O(%) shape correction from MC for CR-to-SR transfer
- Normalization from simulation



Multijets estimate:

- Shape from same-sign (SS) events
- Normalization transfer SS to OS from events with inverted lepton isolation

Systematic Uncertainties



Dominant uncertainties on shape

Theory

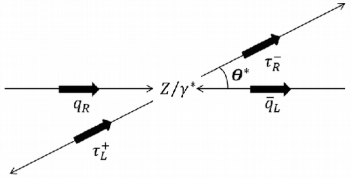
- Difference between Alpgen, Pythia8 and Powheg → uncertainty in Ψ distr. and η acceptance
- TauSpinner sample splitting → vary QCD parameters, $\sin^2\theta_{eff}$, …

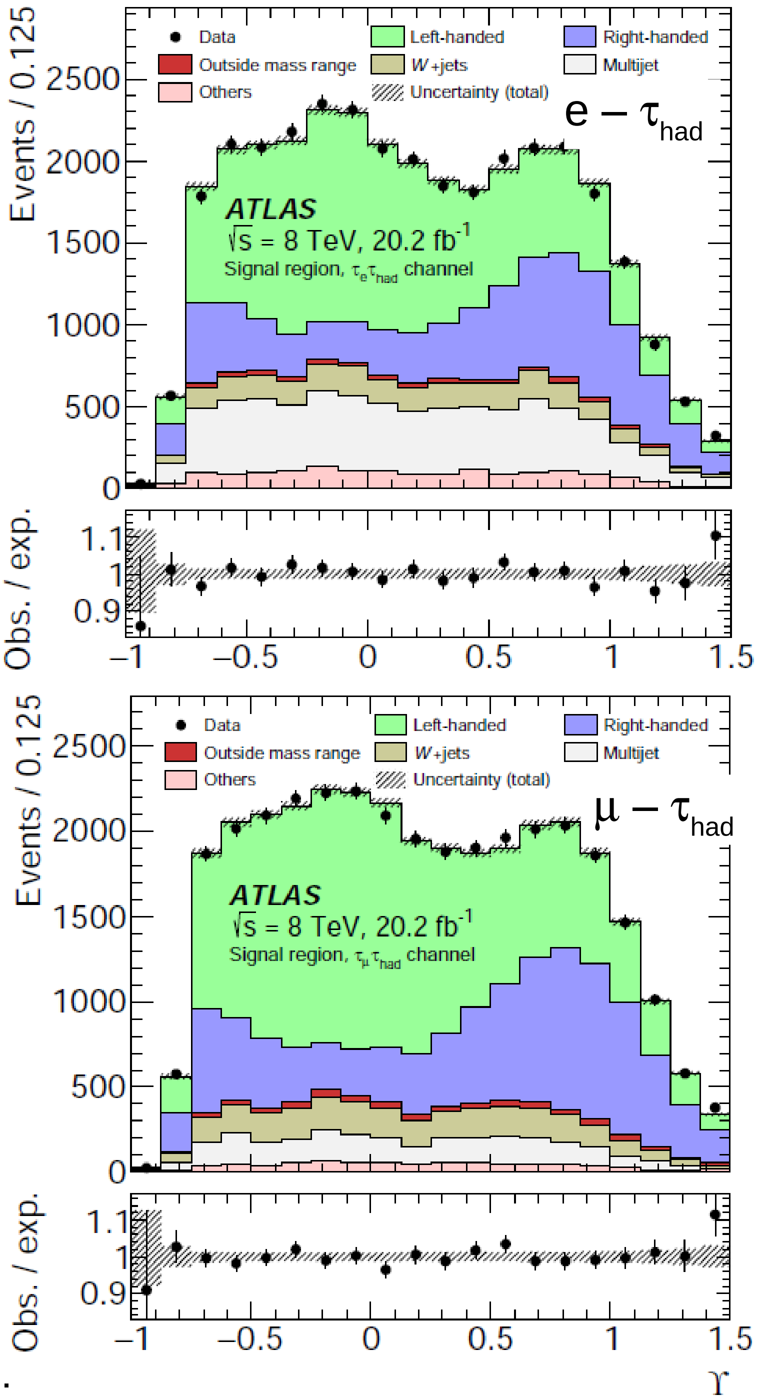
Experimental

- Mismodeling of τ ID input variables propagated to Ψ
- τ energy scale and resolution split into EM and hadr. contributions: measured in-situ

Source of uncertainty	σ_{P_τ} in mass-selected region
Modelling of signal process	±0.026
τ_{had} identification	±0.020
MC statistical	±0.016
Signal sample splitting	±0.015
TES and TER	±0.015
Multijet estimate	±0.013
PDF	±0.007
W+jets shape	±0.002
Other	±0.008
Total systematic uncertainty	±0.040
Statistical uncertainty	±0.015

Result



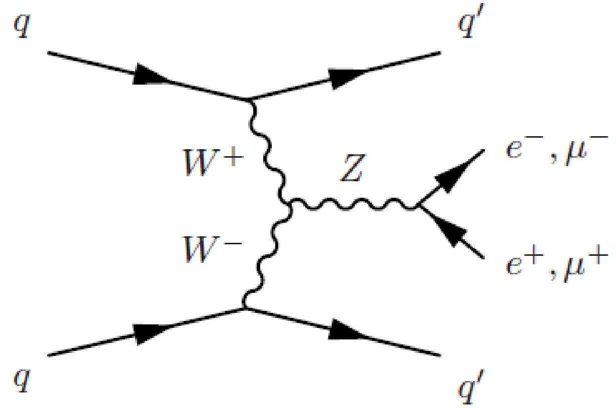


- Binned fit in signal and SS regions
- Fractional contributions from left- and right-handed $Z \to \tau\tau$ templates → P_τ

Channel	P_τ in mass-selected region
τ_e–τ_{had}	-0.20 ± 0.02 (stat) $\pm$ 0.05 (syst)
τ_μ–τ_{had}	-0.13 ± 0.02 (stat) $\pm$ 0.05 (syst)
Combination	-0.14 ± 0.02 (stat) $\pm$ 0.04 (syst)

→ Agreement with SM prediction: -0.1517 ± 0.0019

- Also measured: P_τ in fiducial region selected with truth information → less model dependent
- Result compatible



EW Zjj cross section

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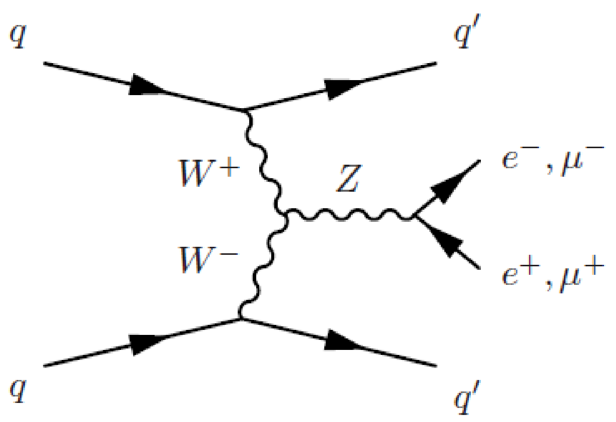
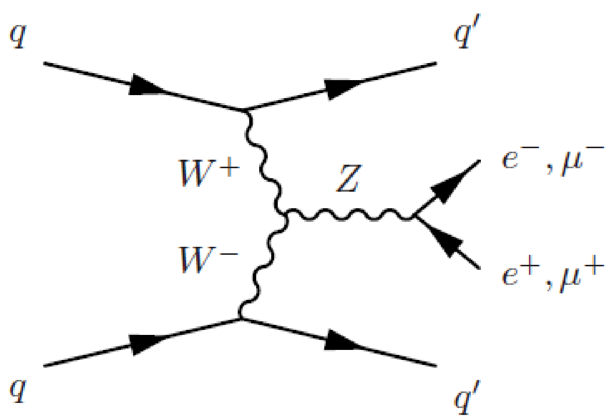


Motivation

- Sensitivity to inclusive σ of EW+QCD and of EW Zjj
- Sensitivity to triple gauge couplings
- Similar measurement of EW Zjj at sqrt(s) = 8 TeV
  → first observation JHEP 04 (2014) 31

EW Zjj cross section



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Measurement

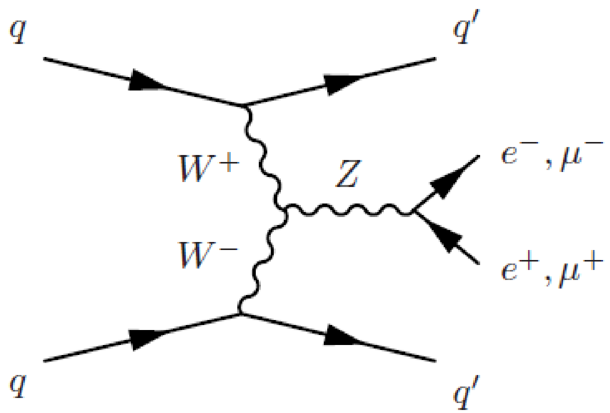
Particle level fiducial σ:

$$\sigma^f_{\mathrm{EW}} = \frac{N^f_{\mathrm{obs}} - N^f_{\mathrm{QCD-}Zjj} - N^f_{\mathrm{bkg}}}{L \cdot C^f_{\mathrm{EW}}}$$

with $C^f = \dfrac{N^f_{\mathrm{det}}}{N^f_{\mathrm{particle}}}$ ~ 0.6–0.8 (Zjj MC)

Also published (not shown):
Inclusive EW+QCD Zjj cross section

EW Zjj cross section



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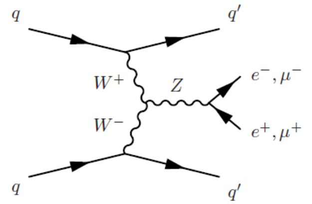
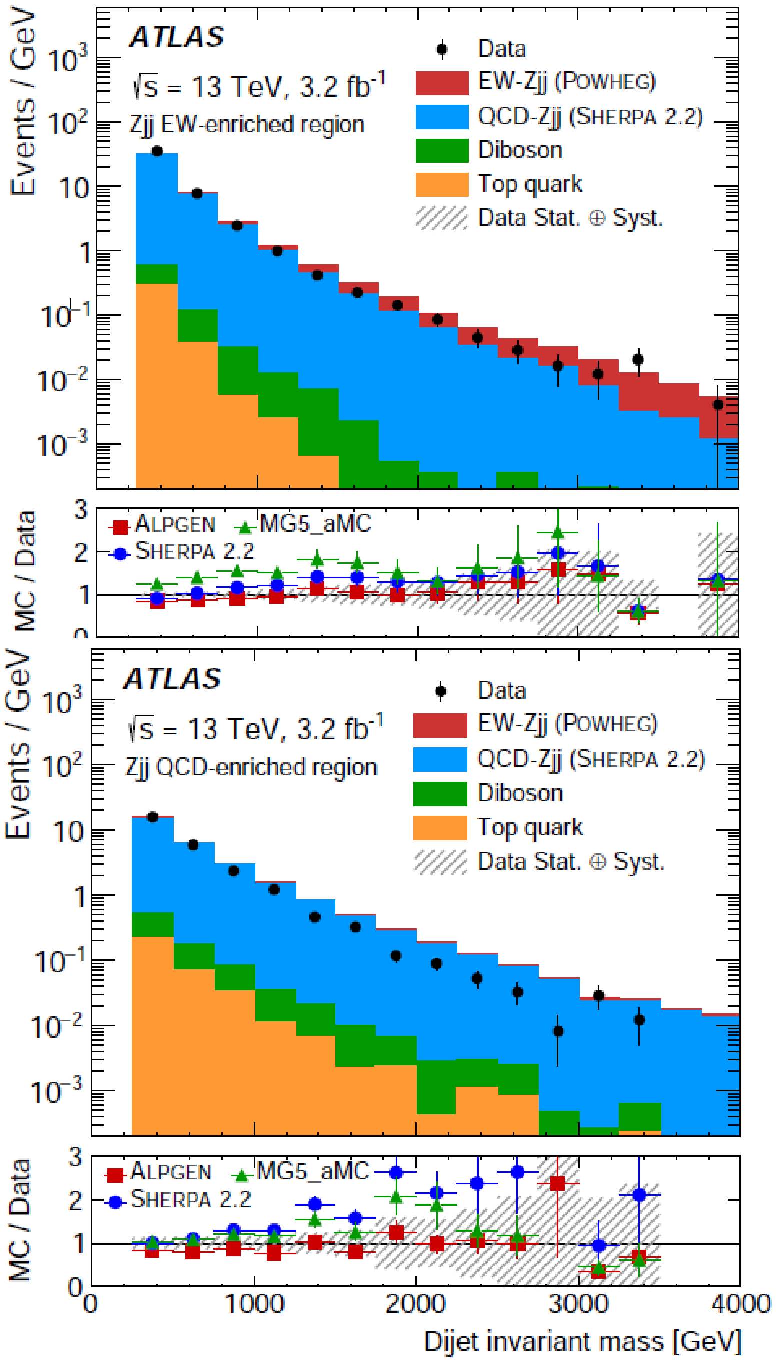
Inclusive EW+QCD Zjj cross section

Selection & Categorization

- Select dilepton evts in Z peak + 2 jets → mostly QCD Zjj
- 2 categories in phase space near EW Zjj:
  - High m_{jj} > 1 TeV
  - Large jet p_T
- 3 categories with varying EW/QCD fraction:
  - EW enriched: 0 jet with η between jets
  - EW enriched and m_{jj} > 1 TeV
  - QCD enriched: ≥1 jet with η between jets

Signal & Backgrounds





Signal EW Zjj simulation

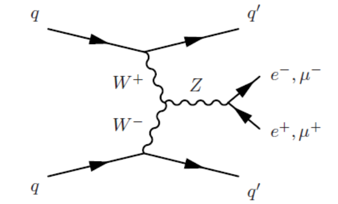
NLO Powheg-Box + Pythia8 PS, CT10 PDF

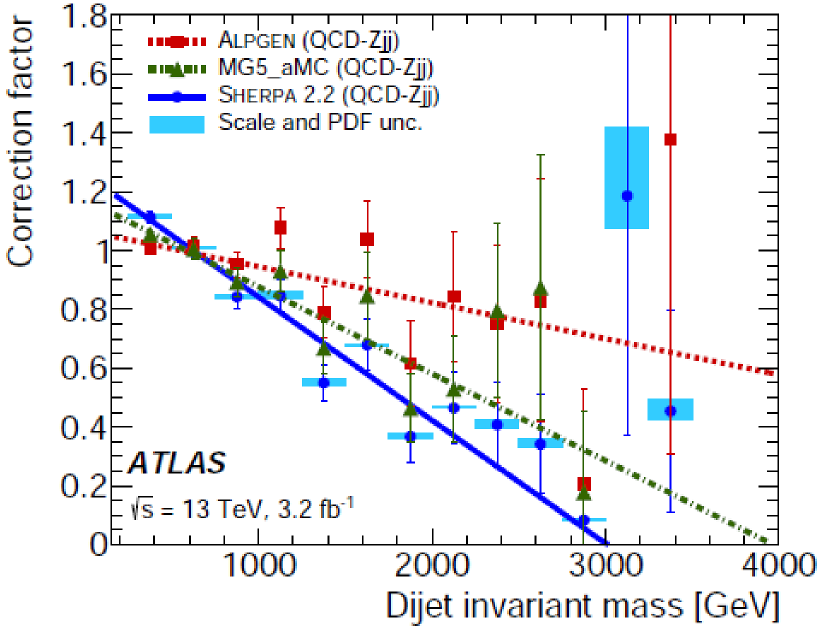
(same as previous analysis)

Backgrounds

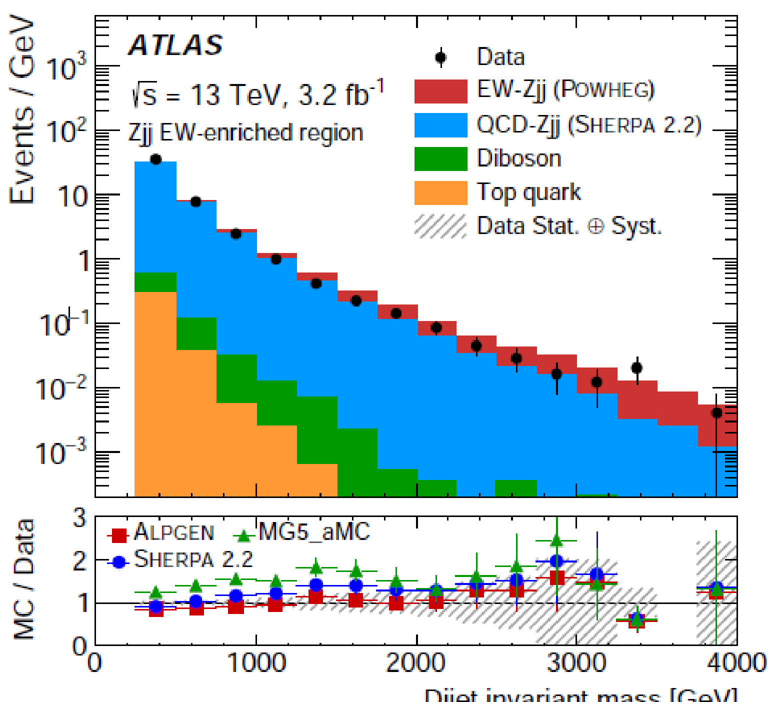
- QCD Zjj: Alpgen, MG5_aMC@NLO, Sherpa 2.2.1
- Other simulated: Dibosons, Top → both <5%
- Multijets & W+jets est'd data-driven:
  - Templates vs. m_{ll} from inverted lepton ID/isolation
  - Normalization from fit to m_{ll}
  - Both contribute <0.3%

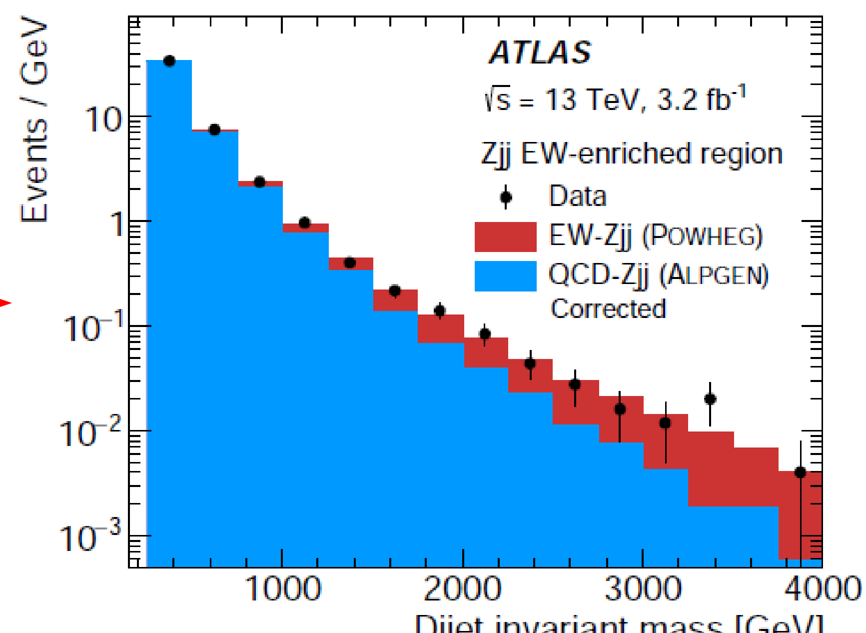
Correction of m_{jj}



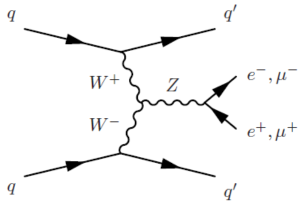


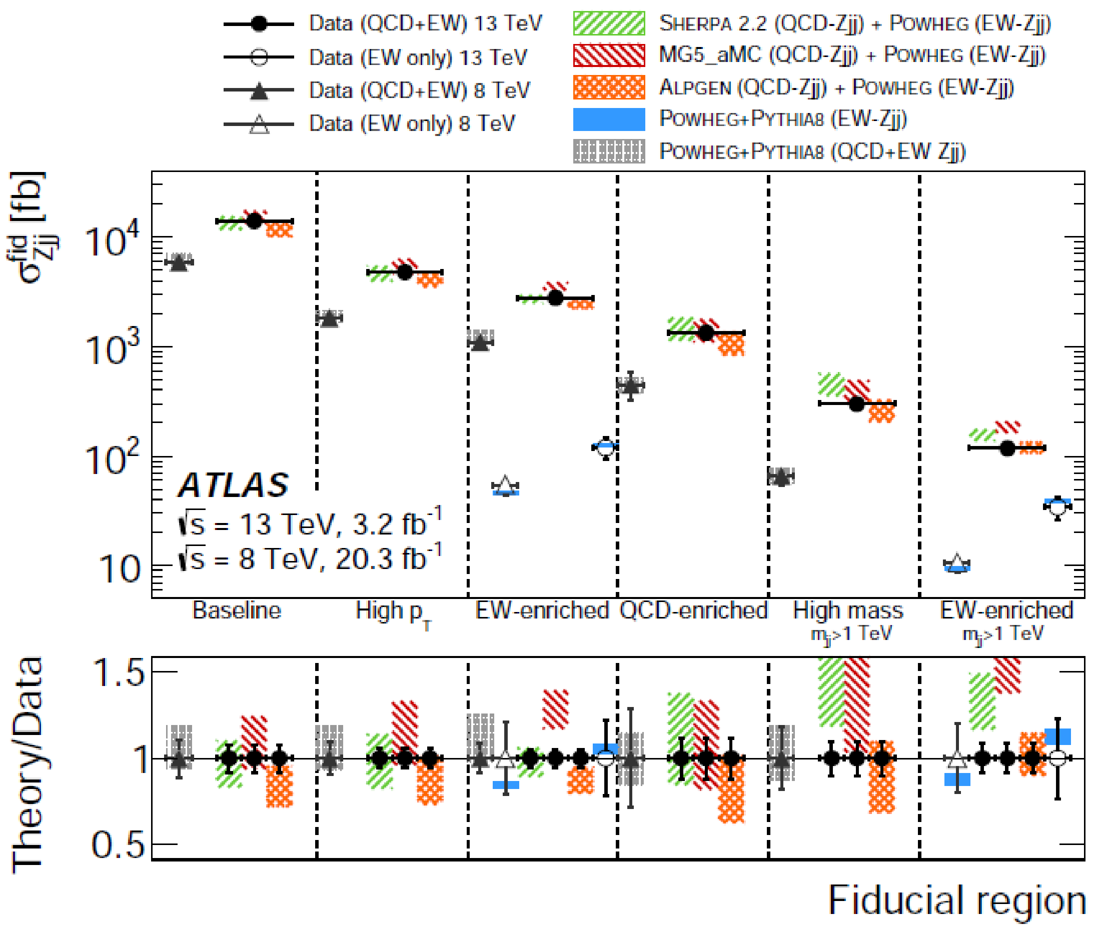
- Extract correction factors vs. m_{jj} in QCD-enriched region and apply to EW-enriched region
- Modeling of additional jet within η-interval of selected jets → largest uncertainty on measurement





Result





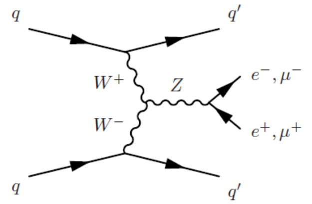
Measurement

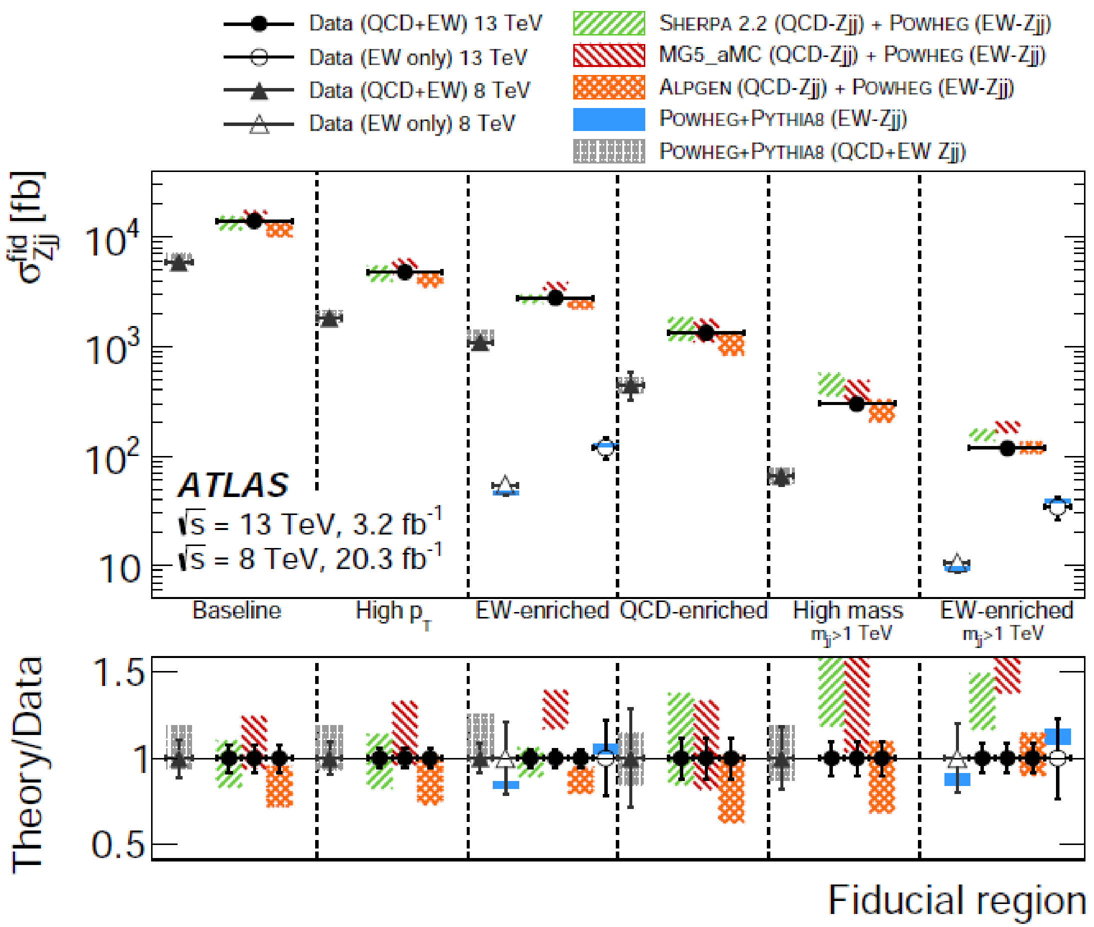
- Fit both QCD Zjj and EW Zjj normalization in EW-enriched region
- Repeat measurement for each QCD Zjj MC, take average

Uncertainties

- Jet modeling in QCD region
- EW Zjj signal modeling (scale, PDF)
- Jet energy scale

Result



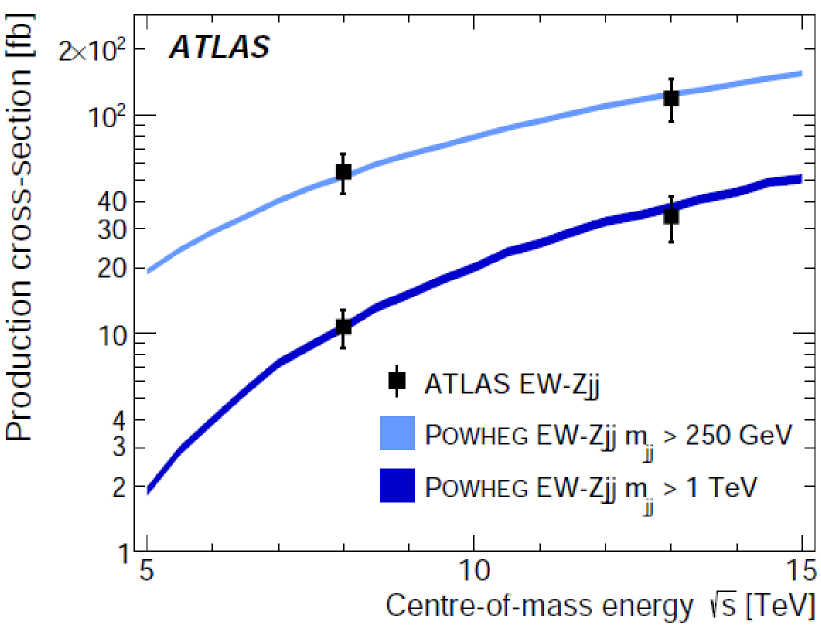


Measurement

- Fit both QCD Zjj and EW Zjj normalization in EW-enriched region
- Repeat measurement for each QCD Zjj MC, take average

Uncertainties

- Jet modeling in QCD region
- EW Zjj signal modeling (scale, PDF)
- Jet energy scale



⇒

- Results compatible with predictions
- Most constraining power of fit at m_{jj} ~ 900–1000 GeV

Summary

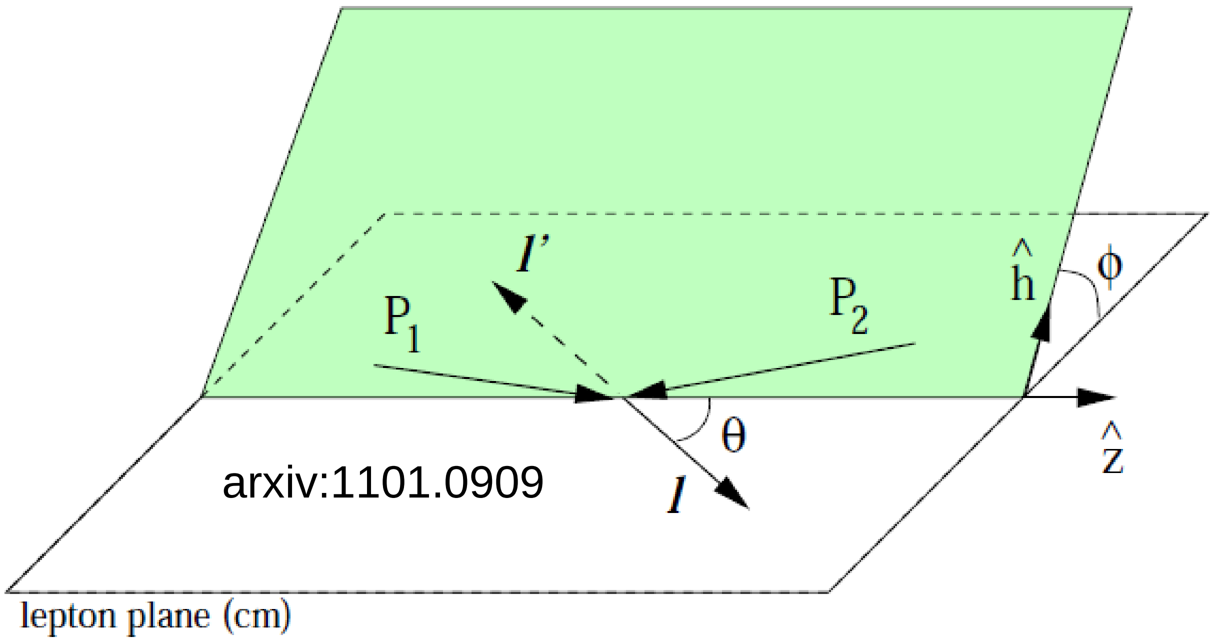
Various precision measurements in Z+jets

- Triple-differential cross section in $Z\rightarrow ll$
  - Asymmetry behavior as predicted by SM, compatible with $\sin^2\theta^{lep}_{eff}$ measurement
  - All distributions well modeled by Powheg+Pythia8 within PDF uncertainties

- Measurement of τ polarization in $Z\rightarrow\tau\tau$ events
  - Sensitive to New Physics contributions outside Z peak
  - Led to development of novel techniques useful for other analyses
  - Result compatible with SM prediction, ~10% precision

- EW Zjj cross section
  - Sensitive to triple gauge couplings
  - Mismodeling of m_{jj} corrected
  - Result compatible with SM prediction, ~20% precision

Collins Soper Frame



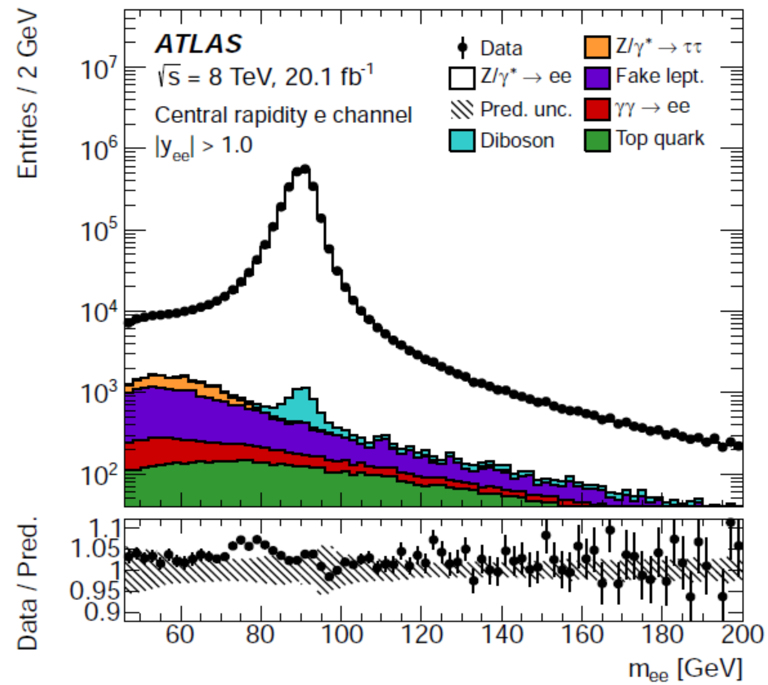
$$\cos\theta^* = \frac{p_{z,\ell\ell}}{m_{\ell\ell}|p_{z,\ell\ell}|} \frac{p_1^+ p_2^- - p_1^- p_2^+}{\sqrt{m_{\ell\ell}^2 + p_{T,\ell\ell}^2}}$$

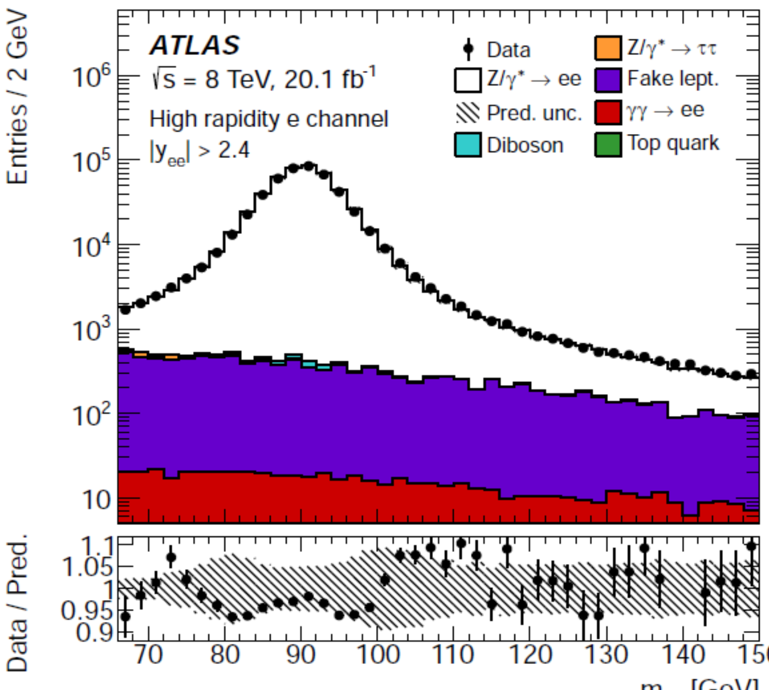
Binning and some plots

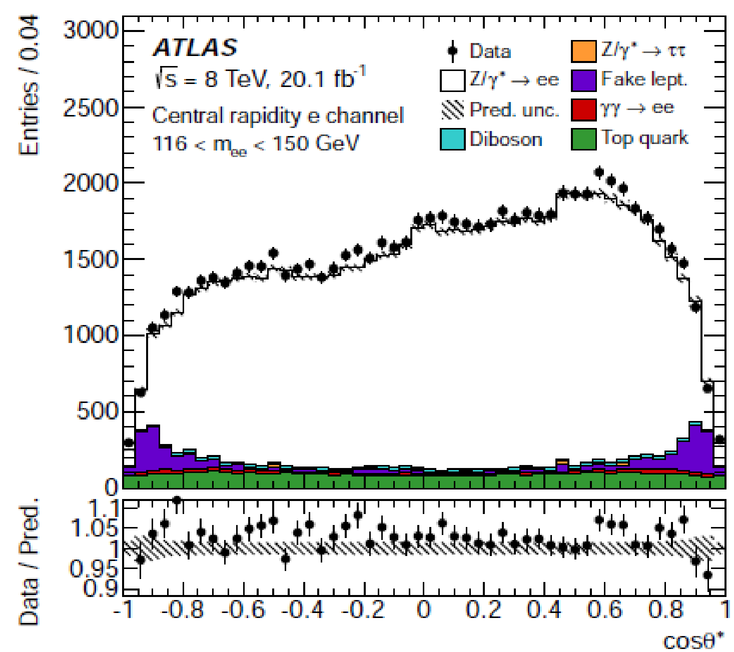
Three analyses with diff. binning in (m_{ll}, y_{ll}, cosθ*):

- Two central muons: Total 504
- Two central electrons: Total 504
- Central+forward electron: Total 150
- 12 bins within $|y_{ll}| < 2.4$ (muons) or $|y_{ll}| < 3.6$ (electrons)
- 7 bins within $46 < m_{ll} < 200$ GeV
- 6 bins within $-1 < \cos\theta^* < 1$

→ Central and forward leptons







Backgrounds

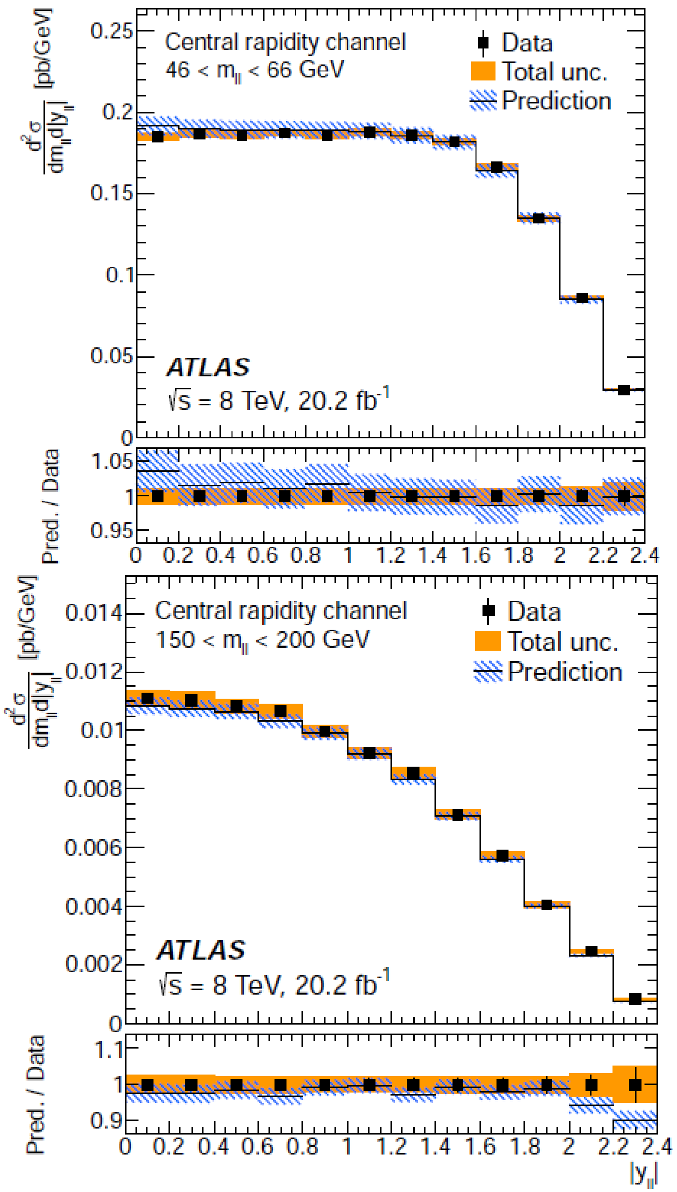
Data-driven estimates of fake lepton ~ multijets background:

- Fake muons (typically very small, up to ~5%):
  - Shape vs. cosθ* and $|y_{\mu\mu}|$ from inverted μ isolation
- Fake electrons (typically small, up to ~30-60% at high |η|):
  - Multijet fraction from template fits to energy isolation, shape template from inverted identification
  - In some regions: Template fits to E_T of forward electron

Results & Systematics

$$\frac{d^3\sigma}{dm_{\ell\ell}\, d|y_{\ell\ell}|\, d\cos\theta^*}$$

Integrated over cosθ*



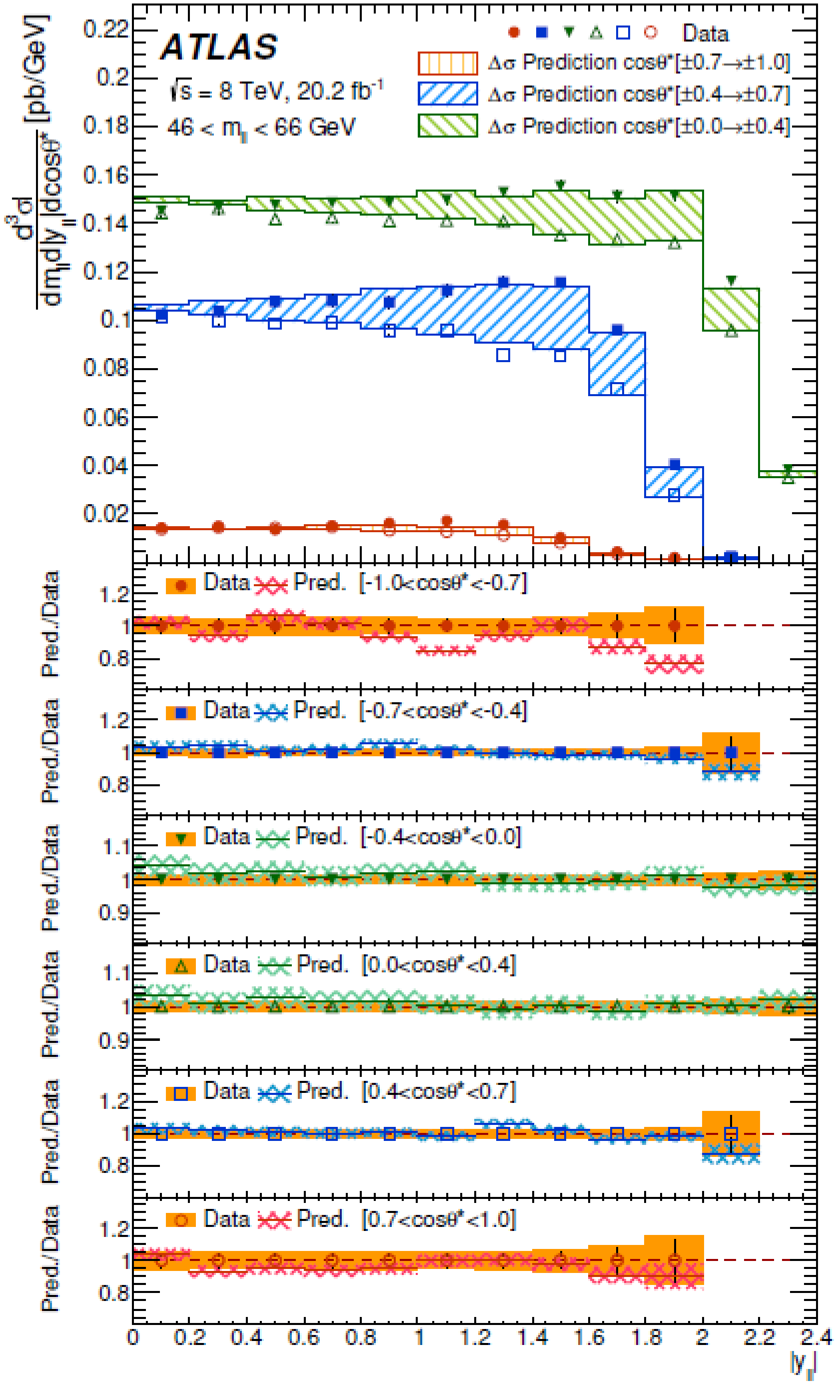
Impact of systematics varies depending on m_{ll}:

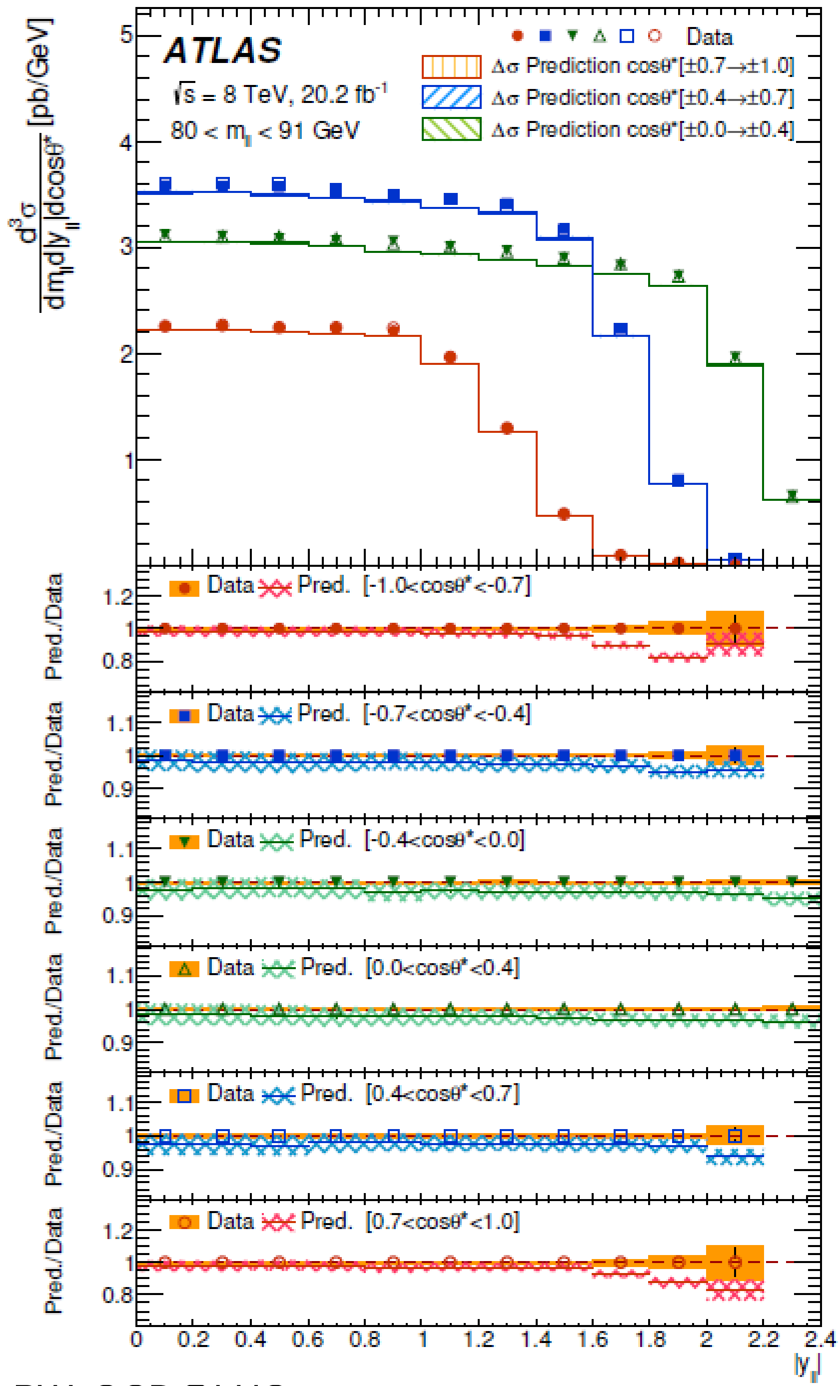
- Below and above Z peak: Background uncertainties, lepton reco/ID/isolation efficiency, MC signal statistics
  - For central electrons total below ~5% at low m_{ll} and up to 10% at high m_{ll}
  - Similar values for muons, MC stats dominant
  - By factor 2-3 larger uncertainties for forward electrons
- On Z peak: lepton momentum scale
  - For electrons total unc ~2-3%
  - For muons total unc ~1%

Central e and μ channel results consistent → Combination of σ's using χ^2 minimization technique

- As expected y_{ll} distribution narrower at higher m_{ll}
- Simulation slightly high in some high y_{ll} bins

Distributions





Signal & Backgrounds Estimation

$$\frac{d^3\sigma}{dm_{\ell\ell}\, d|y_{\ell\ell}|\, d\cos\theta^*}$$

Simple high-purity selection of dilepton events

Three final states:

- Two central muons
- Two central electrons
- Central+forward electron

Signal simulation:

- NLO Powheg-Box + Pythia8 PS, CT10 PDF
- m_{ll}-dependent K-factor from NNLO pQCD
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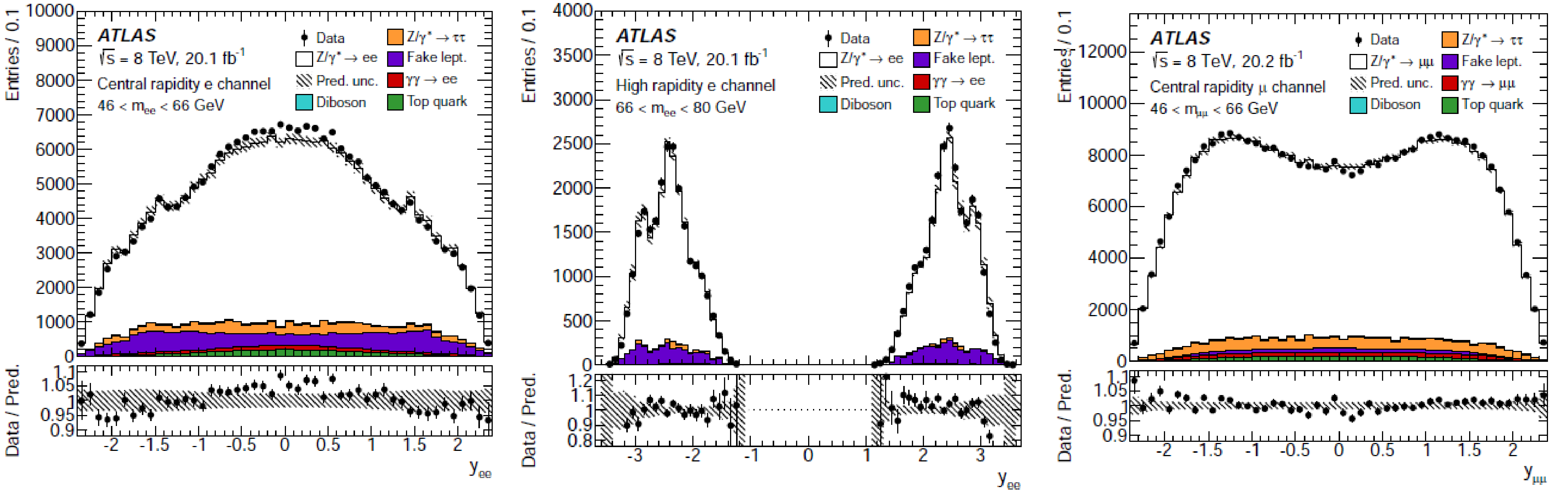
- Amplitude coefficient A_0 reweighted in bins of y_{ll} and $p_T(Z)$



Small $|y_{ll}|$ and m_{ll} near Z peak: higher purity, smaller asymmetry

Large $|y_{ll}|$ and m_{ll} off Z peak: more background, stronger asymmetry

Signal & Backgrounds Estimation

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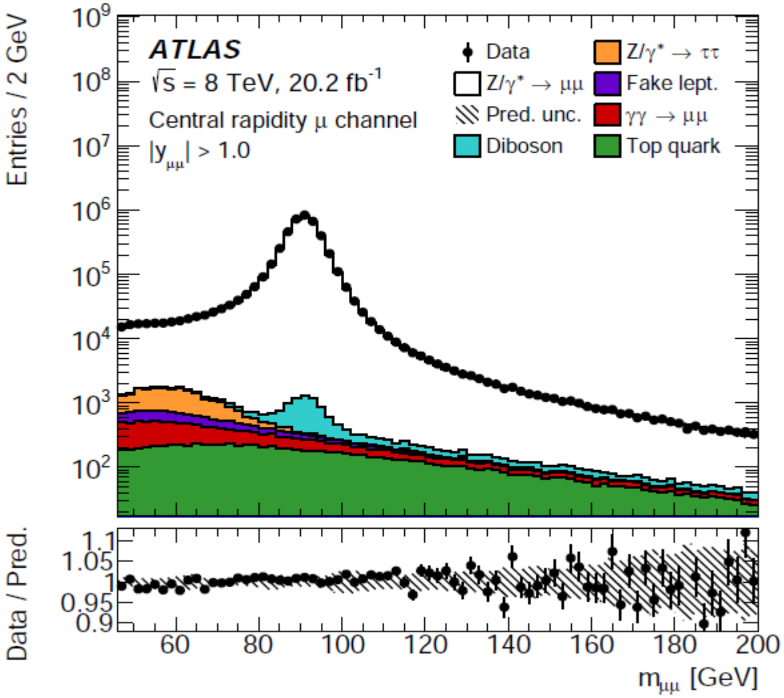

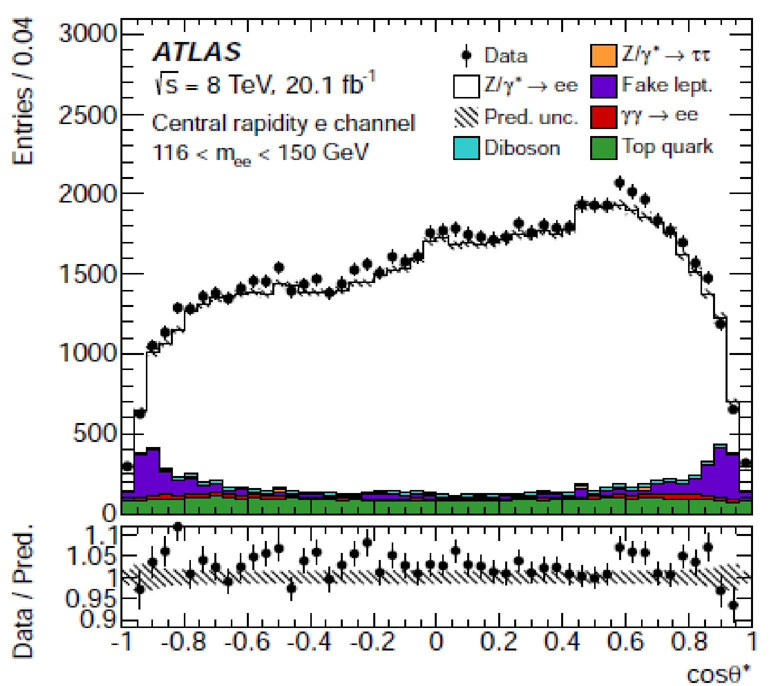

Simulated backgrounds:

- Top quarks
- Diboson
- $Z \rightarrow \tau\tau$
- $W \rightarrow l\nu$

All very small below 10%, a bit higher in some regions

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  - In some regions: Template fits to E_T of forward electron

EW Zjj – Event Categories

$$p_{\mathrm{T}}^{\mathrm{balance}} = \frac{\left|\vec{p}_{\mathrm{T}}^{\,\ell_1} + \vec{p}_{\mathrm{T}}^{\,\ell_2} + \vec{p}_{\mathrm{T}}^{\,j_1} + \vec{p}_{\mathrm{T}}^{\,j_2}\right|}{\left|\vec{p}_{\mathrm{T}}^{\,\ell_1}\right| + \left|\vec{p}_{\mathrm{T}}^{\,\ell_2}\right| + \left|\vec{p}_{\mathrm{T}}^{\,j_1}\right| + \left|\vec{p}_{\mathrm{T}}^{\,j_2}\right|},$$

	Fiducial region					
Object	Baseline	High-mass	High-p_{T}	EW-enriched	EW-enriched, $m_{jj} > 1$ TeV	QCD-enriched
Leptons	$\lvert\eta\rvert < 2.47$, $p_{\mathrm{T}} > 25$ GeV, $\Delta R_{j,\ell} > 0.4$					
Dilepton pair	$81 < m_{\ell\ell} < 101$ GeV					
	—			$p_{\mathrm{T}}^{\ell\ell} > 20$ GeV		
Jets	$\lvert y\rvert < 4.4$					
	$p_{\mathrm{T}}^{j_1} > 55$ GeV		$p_{\mathrm{T}}^{j_1} > 85$ GeV	$p_{\mathrm{T}}^{j_1} > 55$ GeV		
	$p_{\mathrm{T}}^{j_2} > 45$ GeV		$p_{\mathrm{T}}^{j_2} > 75$ GeV	$p_{\mathrm{T}}^{j_2} > 45$ GeV		
Dijet system	—	$m_{jj} > 1$ TeV	—	$m_{jj} > 250$ GeV	$m_{jj} > 1$ TeV	$m_{jj} > 250$ GeV
Interval jets	—			$N_{\mathrm{jet}\ (p_{\mathrm{T}}>25\ \mathrm{GeV})}^{\mathrm{interval}} = 0$		$N_{\mathrm{jet}\ (p_{\mathrm{T}}>25\ \mathrm{GeV})}^{\mathrm{interval}} \geq 1$
Zjj system	—			$p_{\mathrm{T}}^{\mathrm{balance}} < 0.15$		$p_{\mathrm{T}}^{\mathrm{balance,3}} < 0.15$

Table 1: Summary of the particle-level selection criteria defining the six fiducial regions (see text for details).

Inclusive Zjj fiducial σ measurement

Systematics on C_f and background estimates:

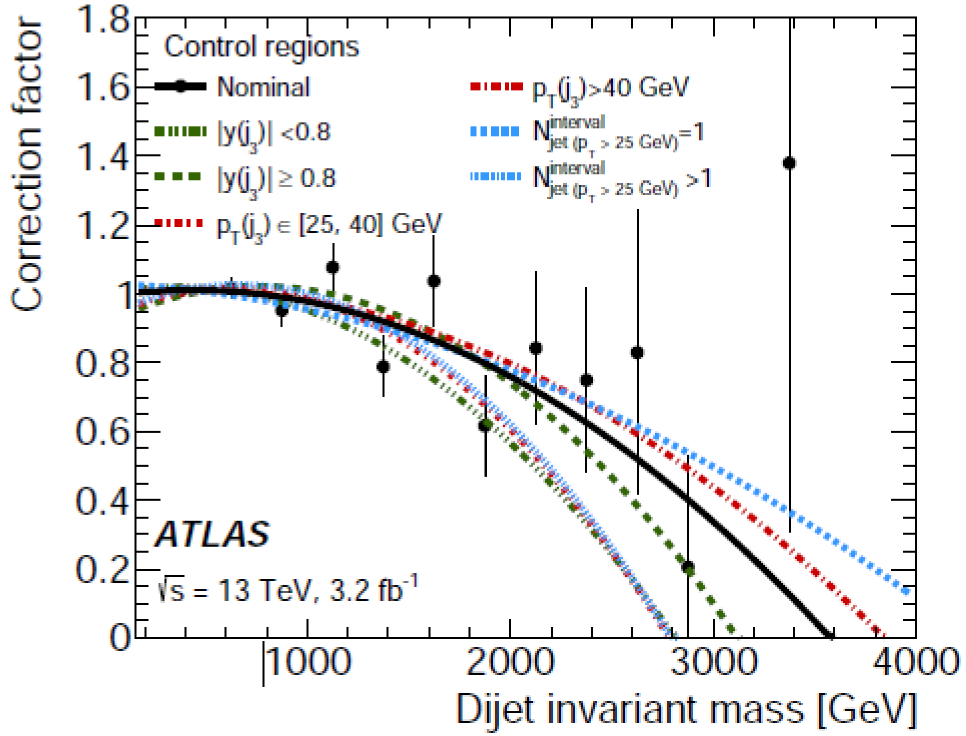
- Jet energy scale & resolution ~4-12%
- m_{jj} distribution modelling < 5%
- Luminosity: 2%

Result:

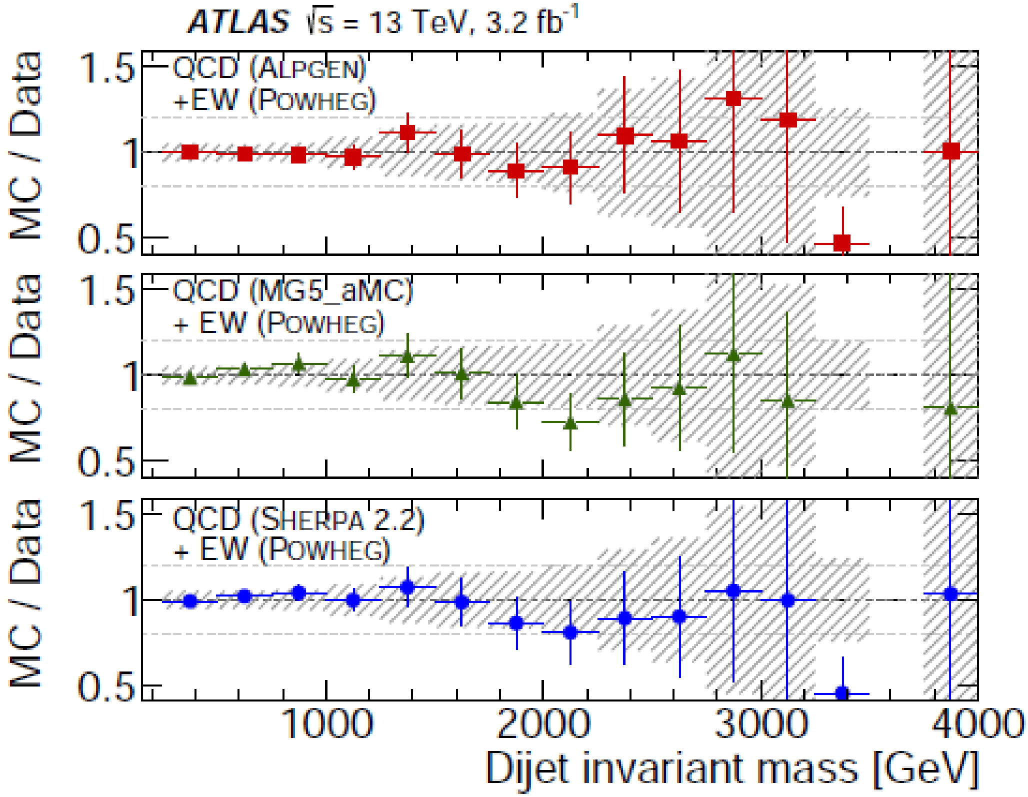
- Generally larger uncertainties on theory
- Mostly agreement
- Some disagreement in EW-enriched regions due to mismodeling of QCD Zjj

Fiducial region	Inclusive *Zjj* cross-sections [pb]			
	Measured	Prediction		
	value ± stat. ± syst. ± lumi.	SHERPA (QCD-*Zjj*) +POWHEG (EW-*Zjj*)	MG5_aMC (QCD-*Zjj*) +POWHEG (EW-*Zjj*)	ALPGEN (QCD-*Zjj*) +POWHEG (EW-*Zjj*)
Baseline	13.9 ± 0.1 ± 1.1 ± 0.3	13.5 ± 1.9	15.2 ± 2.2	11.7 ± 1.7
High-p_T	4.77 ± 0.05 ± 0.27 ± 0.10	4.7 ± 0.8	5.5 ± 0.9	4.2 ± 0.7
EW-enriched	2.77 ± 0.04 ± 0.13 ± 0.06	2.7 ± 0.2	3.6 ± 0.3	2.4 ± 0.2
QCD-enriched	1.34 ± 0.02 ± 0.17 ± 0.03	1.5 ± 0.4	1.4 ± 0.3	1.1 ± 0.3
High-mass	0.30 ± 0.01 ± 0.03 ± 0.01	0.46 ± 0.11	0.40 ± 0.09	0.27 ± 0.06
EW-enriched (m_{jj} > 1 TeV)	0.118 ± 0.008 ± 0.006 ± 0.002	0.156 ± 0.019	0.185 ± 0.023	0.120 ± 0.015

Uncertainty from additional jets



Results from other MCs



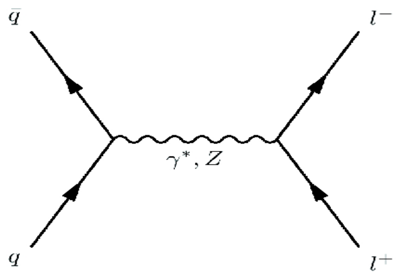
Other systematics on EW Zjj measurement

Source	Relative systematic uncertainty [%] $\sigma_{\mathrm{EW}}^{m_{jj}>250\ \mathrm{GeV}}$	$\sigma_{\mathrm{EW}}^{m_{jj}>1\ \mathrm{TeV}}$
EW-*Zjj* signal modelling (QCD scales, PDF and UEPS)	± 7.4	± 1.7
EW-*Zjj* template statistical uncertainty	± 0.5	± 0.04
EW-*Zjj* contamination in QCD-enriched region	−0.1	−0.2
QCD-*Zjj* modelling (m_{jj} shape constraint / third-jet veto)	± 11	± 11
Stat. uncertainty in QCD control region constraint	± 6.2	± 6.4
QCD-*Zjj* signal modelling (QCD scales, PDF and UEPS)	± 4.5	± 6.5
QCD-*Zjj* template statistical uncertainty	± 2.5	± 3.5
QCD–EW interference	± 1.3	± 1.5
$\bar{t}t$ and single-top background modelling	± 1.0	± 1.2
Diboson background modelling	± 0.1	± 0.1
Jet energy resolution	± 2.3	± 1.1
Jet energy scale	+5.3/–4.1	+3.5/–4.2
Lepton identification, momentum scale, trigger, pile-up	+1.3/–2.5	+3.2/–1.5
Luminosity	± 2.1	± 2.1
Total	± 17	± 16

EW Zjj result

Fiducial region	EW-*Zjj* cross-sections [fb]	
	Measured	Powheg+Pythia
EW-enriched, $m_{jj} > 250$ GeV	119 ± 16 ± 20 ± 2	125.2 ± 3.4
EW-enriched, $m_{jj} > 1$ TeV	34.2 ± 5.8 ± 5.5 ± 0.7	38.5 ± 1.5

$\sin^2\theta^{lep}_{eff}$ from $Z/\gamma^* \rightarrow ll$



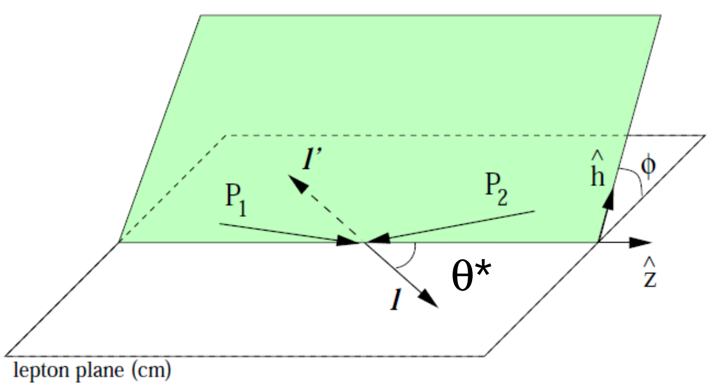
- Access to axialvector- and vector couplings via decay kinem.
- Consistency test with lepton collider results and global EW fits: precision ~$O(10^{-3})$
- Large PDF uncertainty in $\sin^2\theta_W$ measurement @ 7 TeV

$$\frac{d\sigma}{dp_T^{\ell\ell}\, dy^{\ell\ell}\, dm^{\ell\ell}\, d\cos\theta\, d\phi} = \frac{3}{16\pi} \frac{d\sigma^{U+L}}{dp_T^{\ell\ell}\, dy^{\ell\ell}\, dm^{\ell\ell}} \left\{ (1+\cos^2\theta) + \ldots + A_4(p_T^{ll}, y^{ll}, m^{ll}) \cos\theta + \ldots \right\}$$

m^{ll}, y^{ll}, p_T^{ll}: Dilepton mass, rapidity, p_T

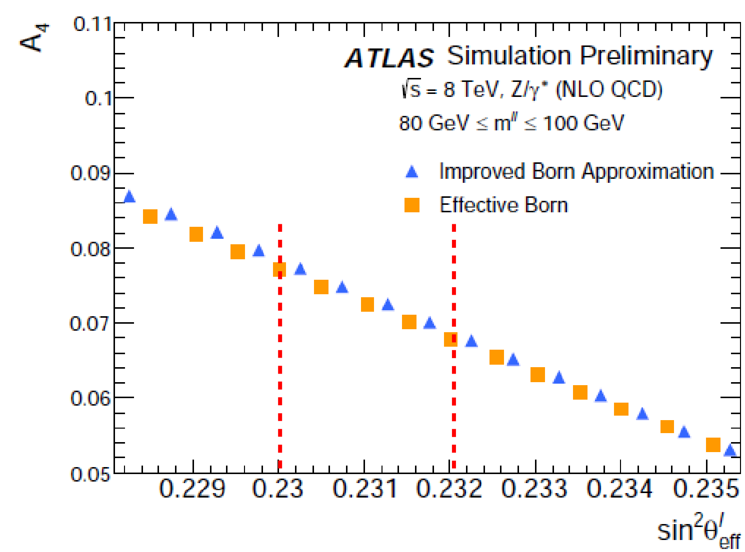
ϕ, θ: Decay angles

(p_T^{ll} is reweighted to data and integrated out)



arxiv:1101.0909

- Decomposition at LO EW theory into harmonic polynomials: A_4 sensitive to $\sin^2\theta^{lep}_{eff}$ → measurement binned in $\cos\theta$



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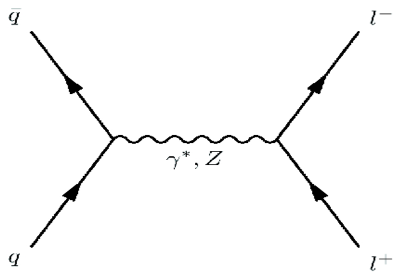

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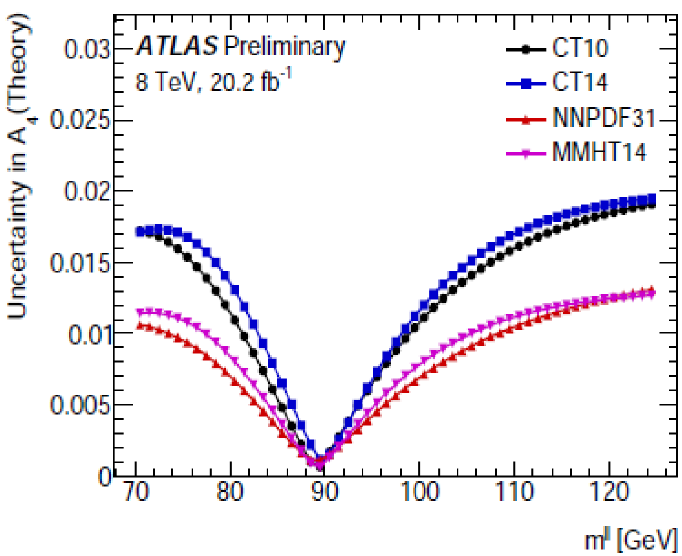
$m_{ll}^2 = Q^2$

$(m_{\ell\ell}/\sqrt{s})e^{\pm y_{\ell\ell}} = x_{1,2}$



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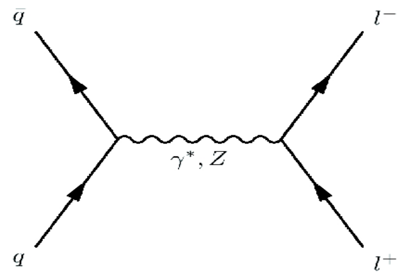

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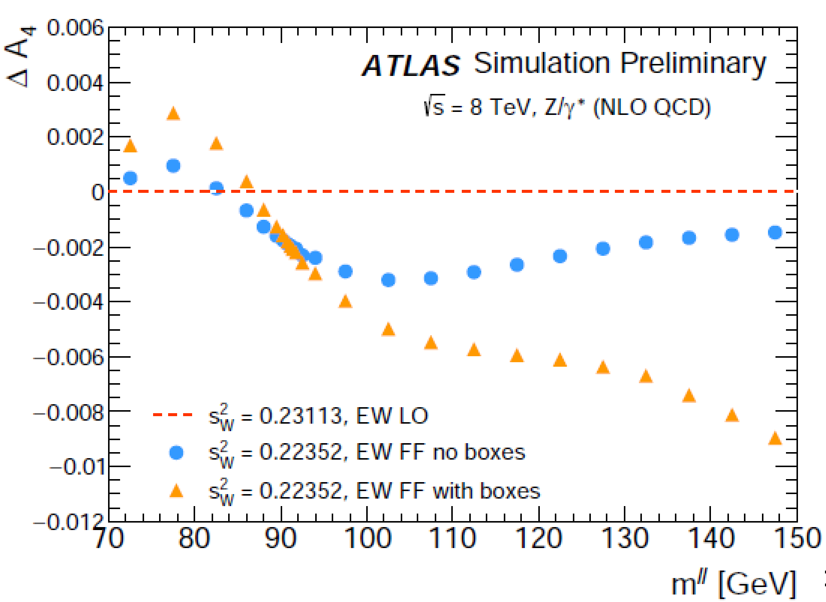
Measurement of σ unfolded to Born level
EW corrections are important
→ Improved Born Approximation



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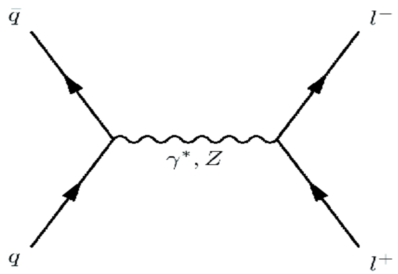

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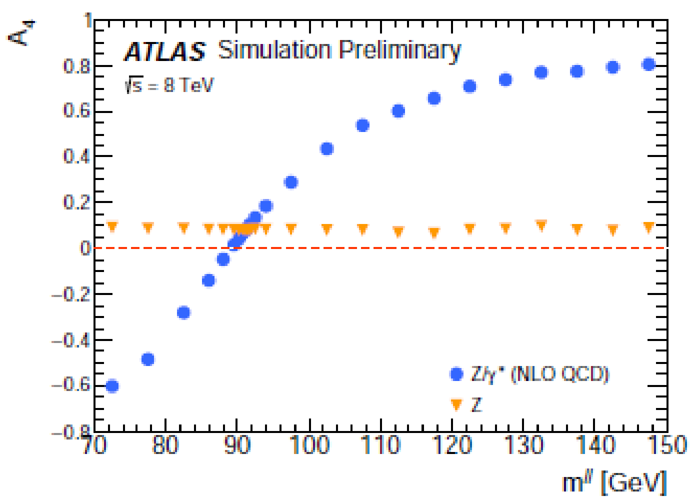
Constributions from Z, Z/γ* interference and γ*:



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Simple high-purity selection of dilepton events

Three final states:

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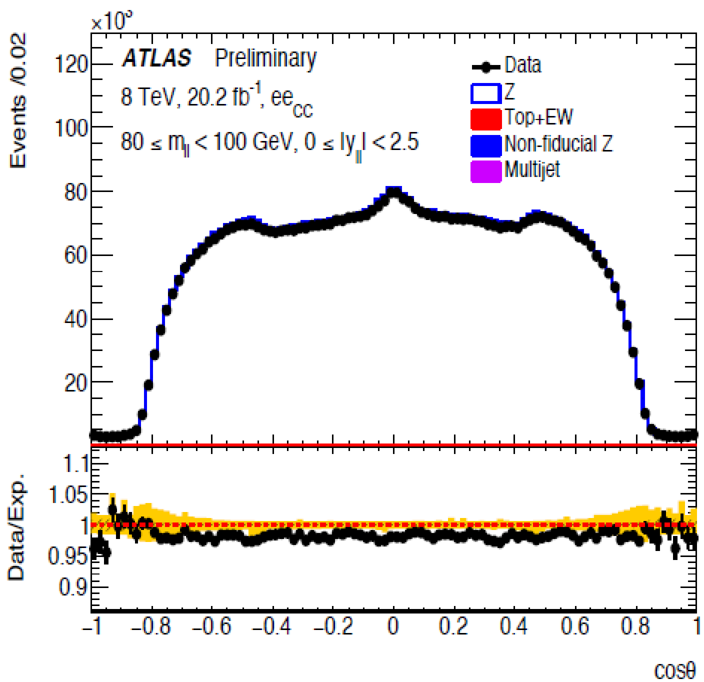

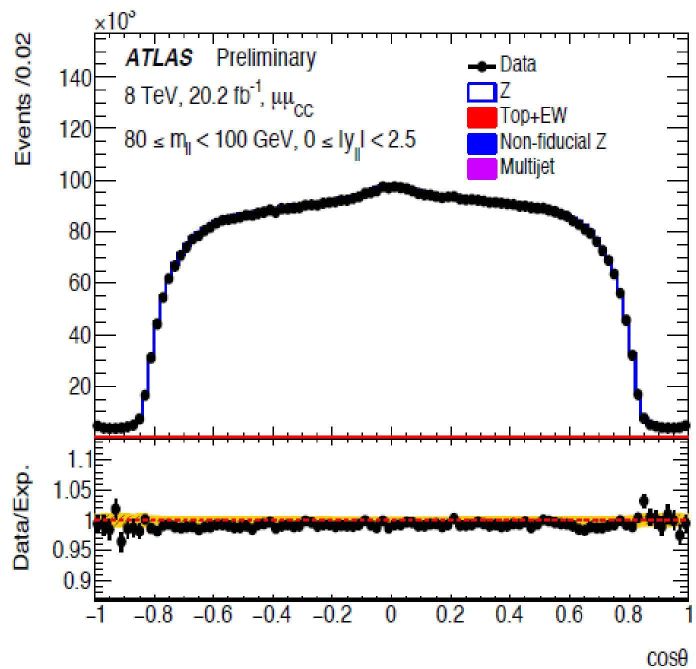

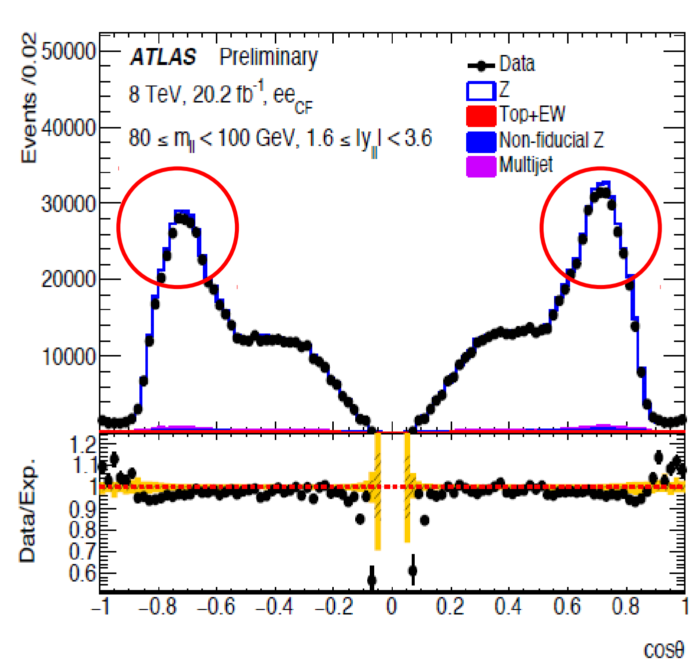

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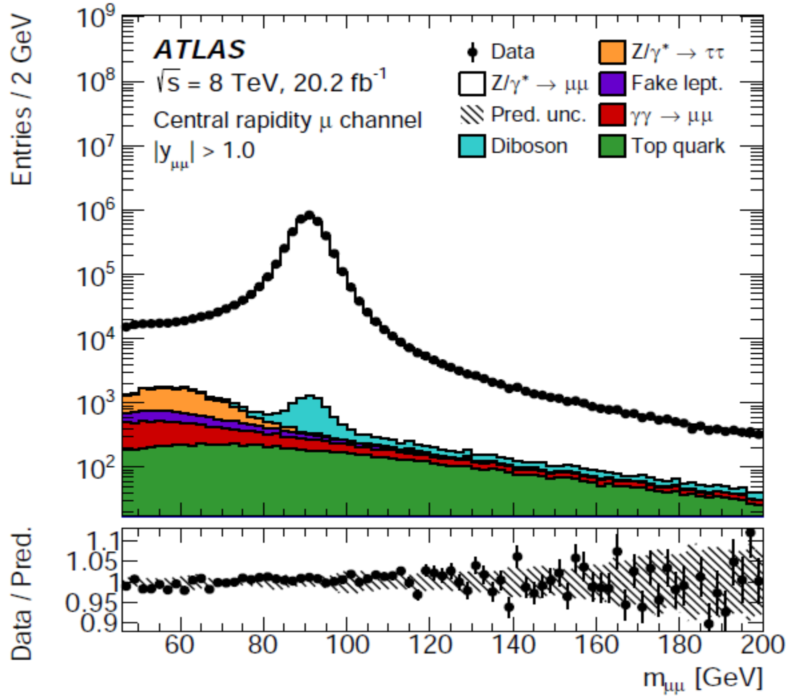

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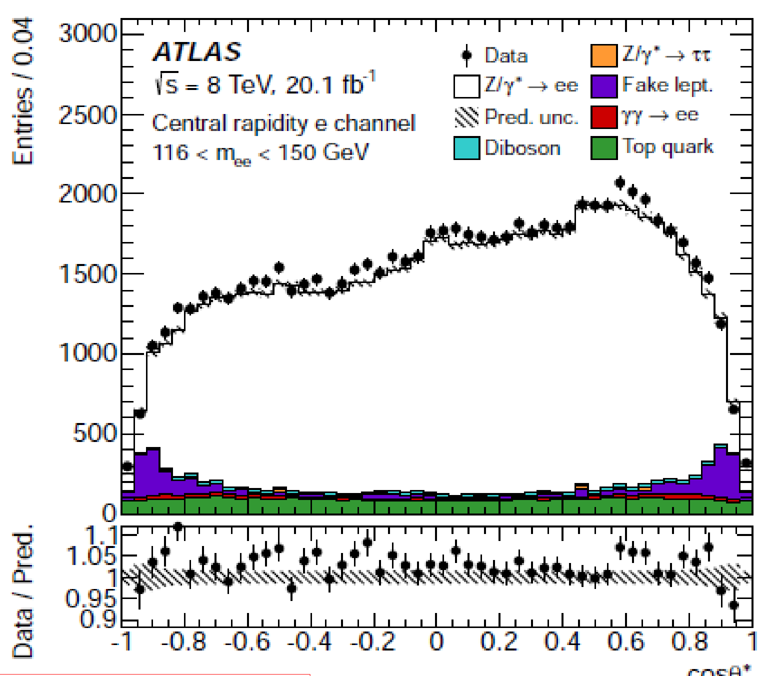

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Systematics

Channel	ee_{CC}	$\mu\mu_{CC}$	ee_{CF}	$ee_{CC} + \mu\mu_{CC}$	$ee_{CC} + \mu\mu_{CC} + ee_{CF}$
Central value	0.23148	0.23123	0.23166	0.23119	0.23140
	Uncertainties				
Total	68	59	43	49	36
Stat.	48	40	29	31	21
Syst.	48	44	32	38	29
	Uncertainties in measurements				
PDF (meas.)	8	9	7	6	4
p_T^Z modelling	0	0	7	0	5
Lepton scale	4	4	4	4	3
Lepton resolution	6	1	2	2	1
Lepton efficiency	11	3	3	2	4
Electron charge misidentification	2	0	1	1	< 1
Muon sagitta bias	0	5	0	1	2
Background	1	2	1	1	2
MC. stat.	25	22	18	16	12
	Uncertainties in predictions				
PDF (predictions)	37	35	22	33	24
QCD scales	6	8	9	5	6
EW corrections	3	3	3	3	3

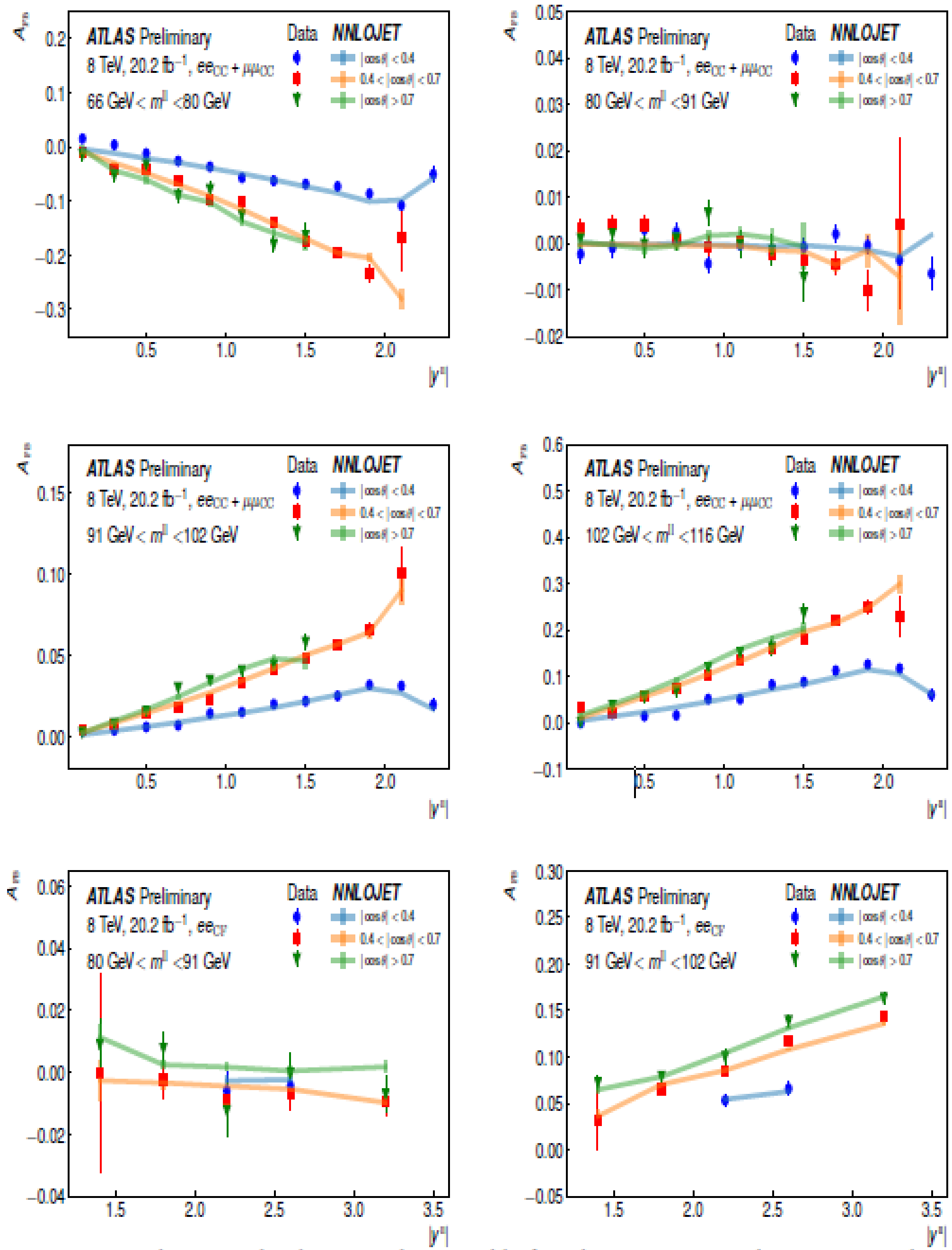
- CF final state competitive with combined CC final states

Dominant uncertainties:

- On A_4 measurement: Data & MC stat.
- On interpretation $A_4 \rightarrow \sin^2\theta^{lep}_{eff}$: PDF

Results

- Results for A_{FB}



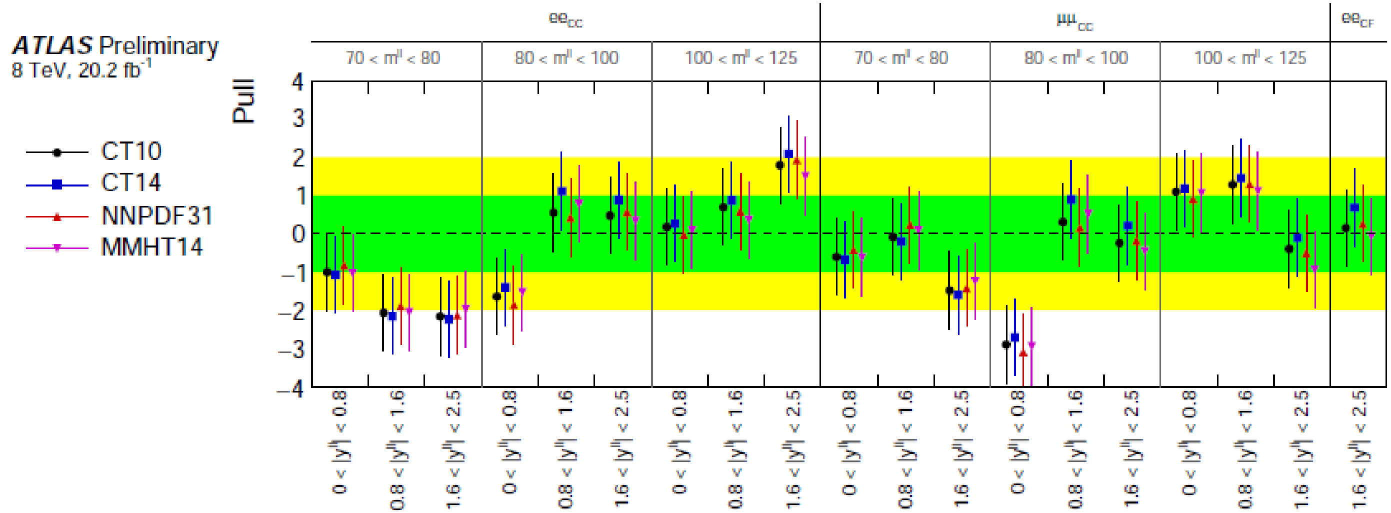
Tau pol. in Ztautau

- MC datasets

Sample	Event generator	PDF	UE tune
$(Z/\gamma^* \to \tau\tau)$ + jets	ALPGEN 2.14 [3] + PYTHIA6.427 [4]	CTEQ6L1 [10]	Perugia2011C [11]
$(Z/\gamma^* \to \tau\tau)$ + jets	PYTHIA 8.160 [19]	CTEQ6L1	AU2 [20]
$(Z/\gamma^* \to \tau\tau)$ + jets	POWHEG r1556 [21–23] + PYTHIA 8.160	CT10 [24]	AUET2 [28]
$(Z/\gamma^* \to \tau\tau)$ + jets	ALPGEN 2.14 + HERWIG 6.5/JIMMY 4.3 [25, 26]	CTEQ6L1	Perugia2011C
Top pairs + jets	POWHEG r2129 + PYTHIA 6.426	CT10	AUET2
$(W \to e\nu)$ + jets	ALPGEN 2.14 + PYTHIA 6.427	CTEQ6L1	Perugia2011C
$(W \to \mu\nu)$ + jets	ALPGEN 2.14 + PYTHIA 6.427	CTEQ6L1	Perugia2011C
$(W \to \tau\nu)$ + jets	ALPGEN 2.14 + PYTHIA 6.427	CTEQ6L1	Perugia2011C
$(Z/\gamma^* \to ee)$ + jets	ALPGEN 2.14 + PYTHIA 6.427	CTEQ6L1	Perugia2011C
$(Z/\gamma^* \to \mu\mu)$ + jets	ALPGEN 2.14 + PYTHIA 6.427	CTEQ6L1	Perugia2011C

Results

- Single measurements generally compatible between final states
- One $\mu\mu_{CC}$ bin slightly off compared to most sensitive ee_{CF} bin



Result: $\sin^2\theta^{lep}_{eff} = 0.23140 \pm 0.00021\ (\text{stat.}) \pm 0.00024\ (\text{PDF}) \pm 0.00016\ (\text{syst.})$

- Consistency with previous measurements
- Does not confirm the ~3σ deviation from A_{FB}