Electroweak Results from CMS

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Outline

I will cover in this talk most recent results on:

- W and Z inclusive production **- 8 TeV**
- Drell-Yan differential cross-section and forward-backward asymmetry
- W differential lepton charge asymmetry
- Diboson production (WW, WZ, Wγ and Zγ) **- 8 TeV**
- Limits on aTGC

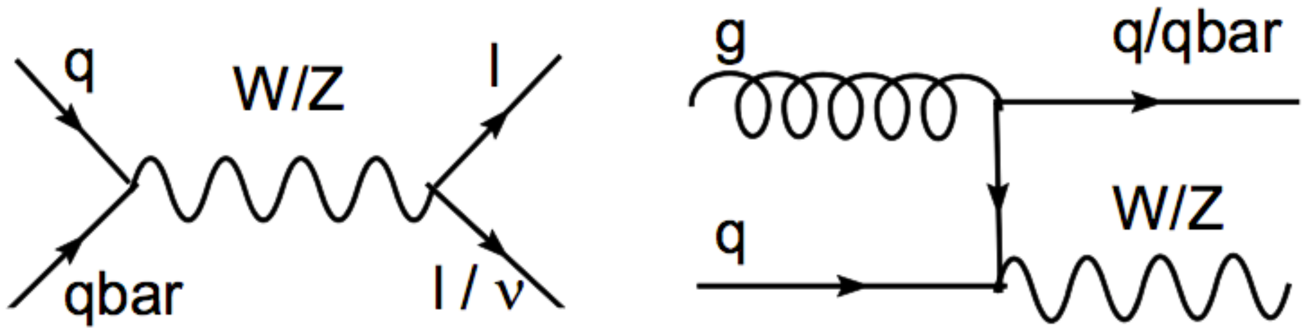
I will not cover

- Z/W + jets → talk by Tom Cornelis tomorrow

with two notable exceptions

- W+c
- dijet mass resonances in W+2 jets

W/Z production at the LHC



LO (Drell-Yan) + NLO

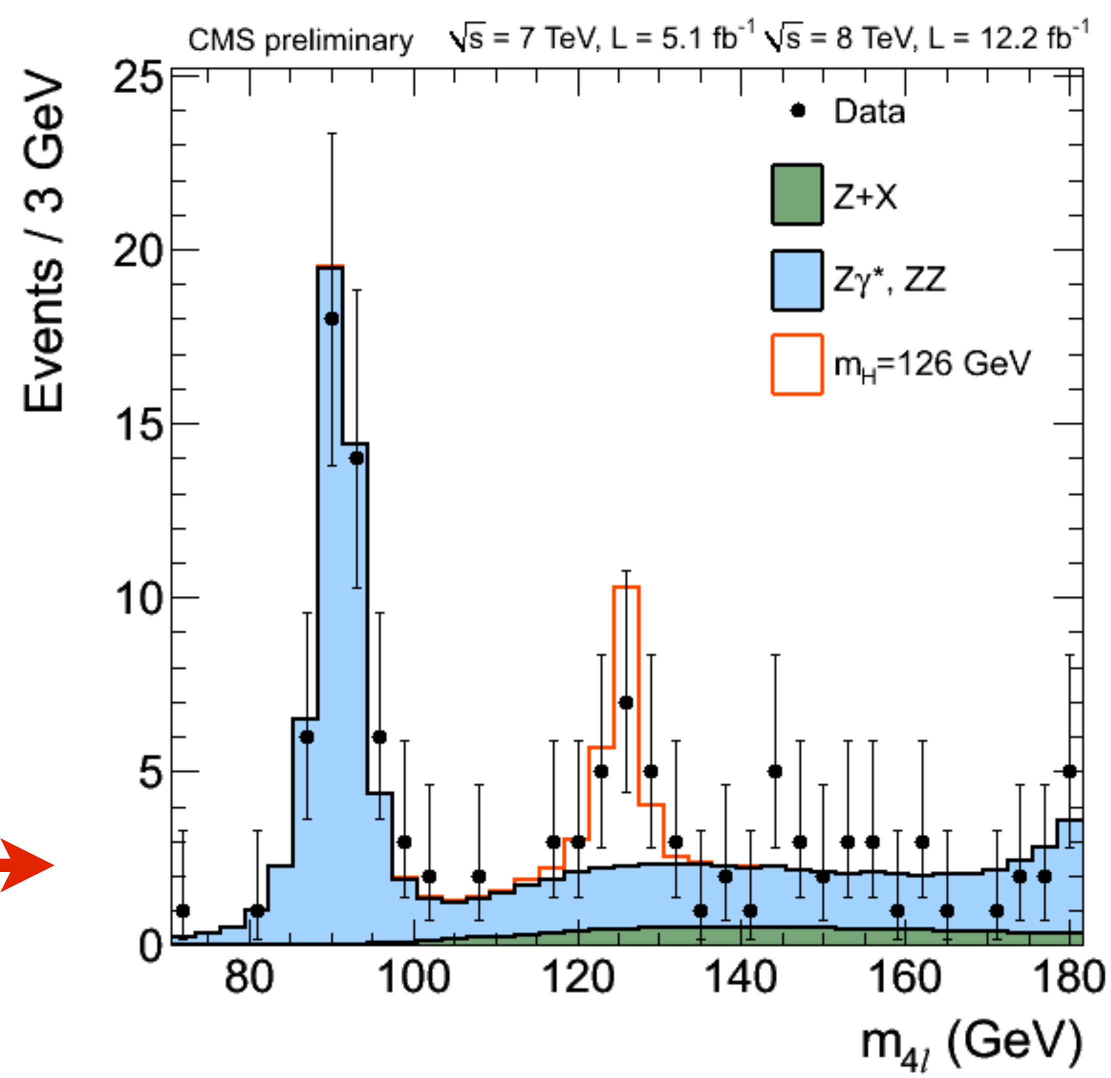
To first order at LHC, W and Z are generated by a valence quark and a sea anti-quark (Q~100 GeV)

Parton fractions are $10^{-3}<x<10^{-1}$, so sea-sea contributions also important

NLO (W/Z+jets) depends on gluon pdf

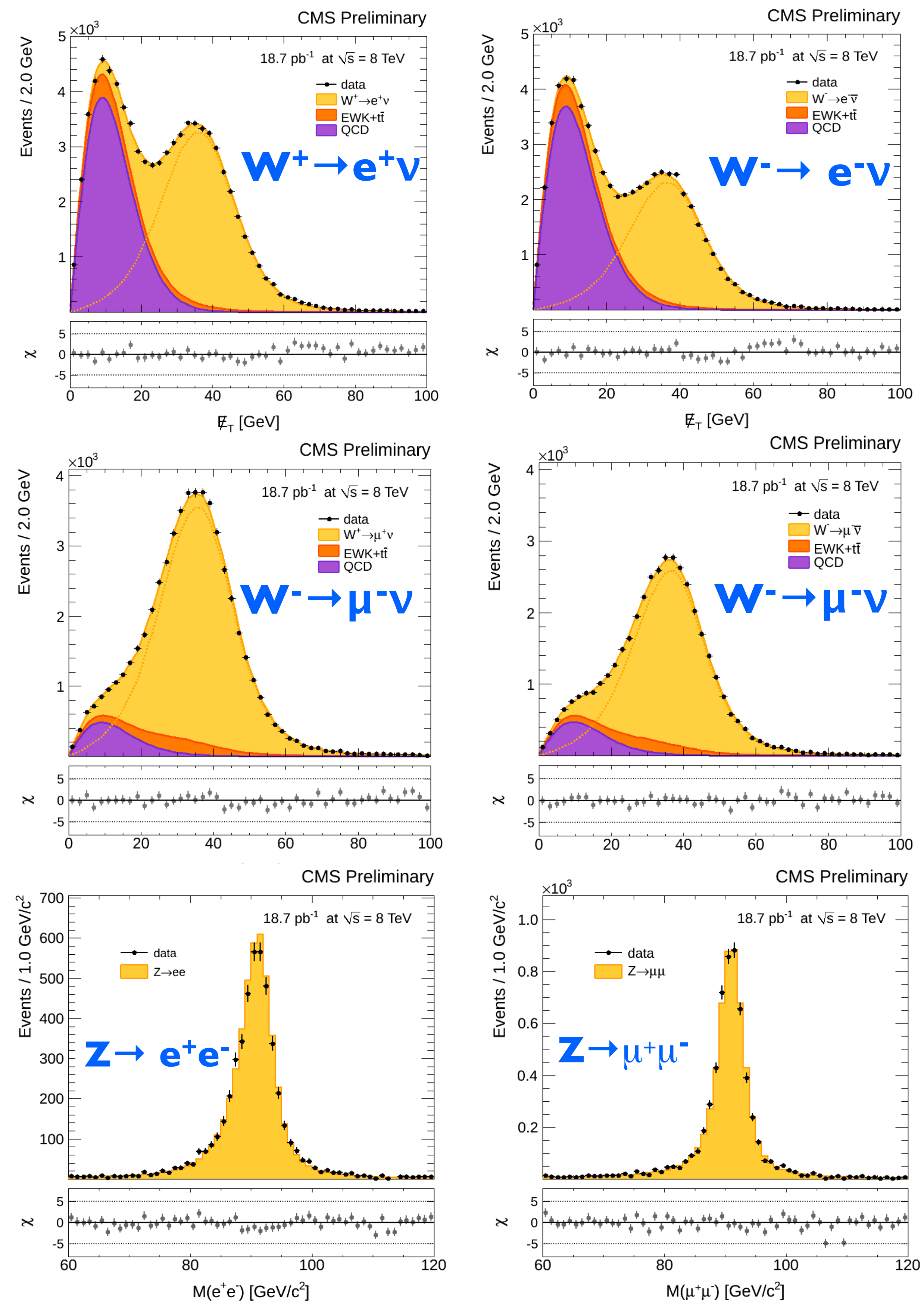
EWK processes allow both precision measurements of fundamental parameters (couplings) and PDFs constraints

W and Z are also the dominant signal and/or background in many searches



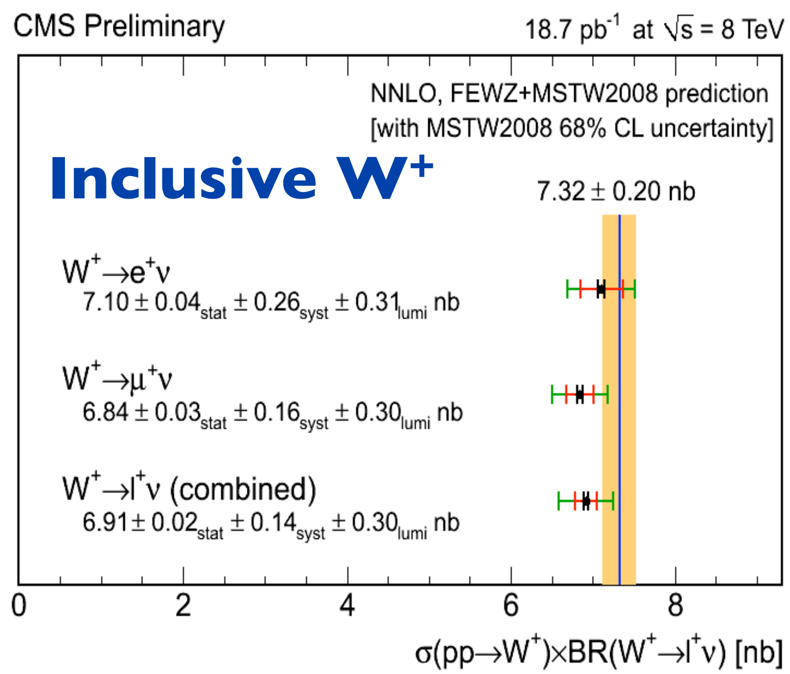
W and Z x-sec @ 8 TeV

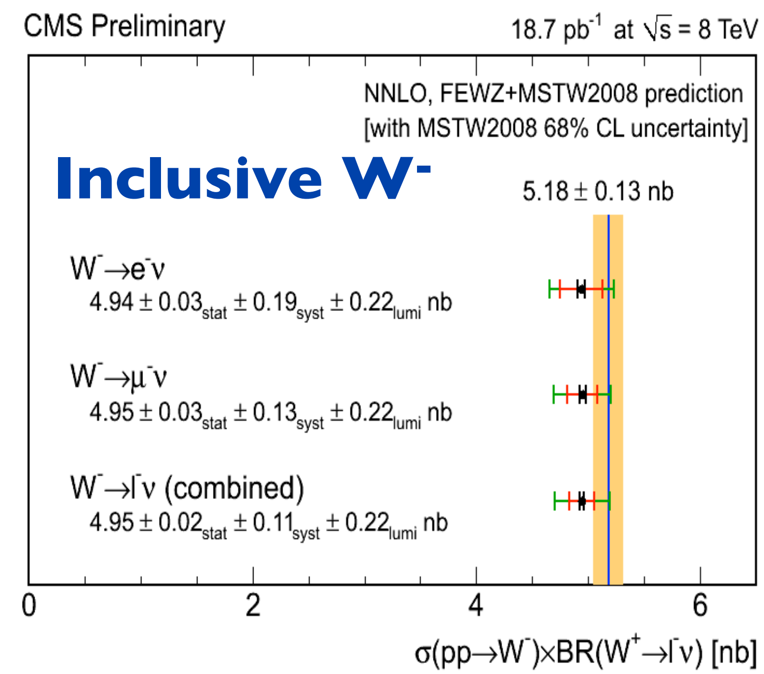
- Requested special low luminosity run @ 8 TeV:
  - Luminosity leveling at 3-6*10^{32} cm^{-2} s^{-1}, integrated 18.7±0.9 pb-1
  - Low pile-up (~5 events) for good MET resolution
  - Special HLT menu with low thresholds:
    - 22 GeV for e /15GeV for μ
- Same analysis strategy as in 2010
  - Fit MET distribution separately for W^+ and W^-
  - Z signal nearly background free: simple cut and count is used to extract the x-sec
  - Efficiencies, resolutions, signal and background shapes are extracted from data

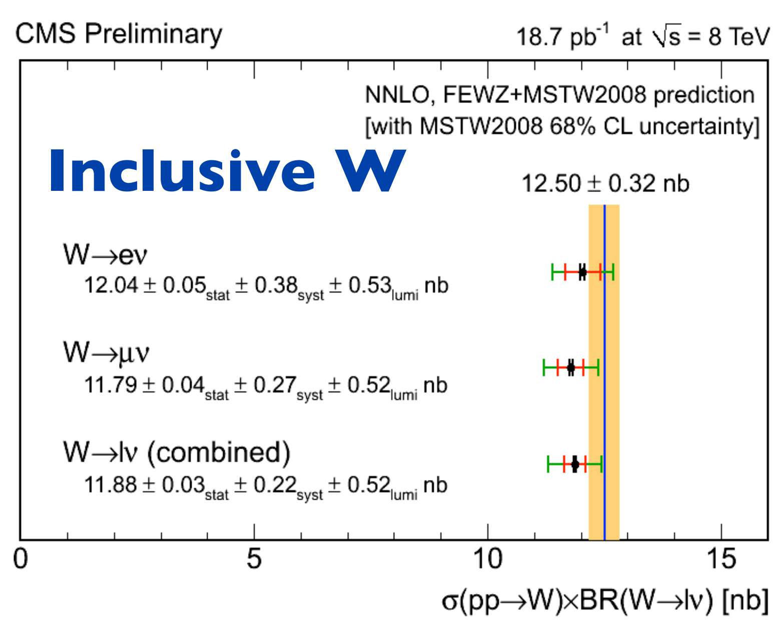


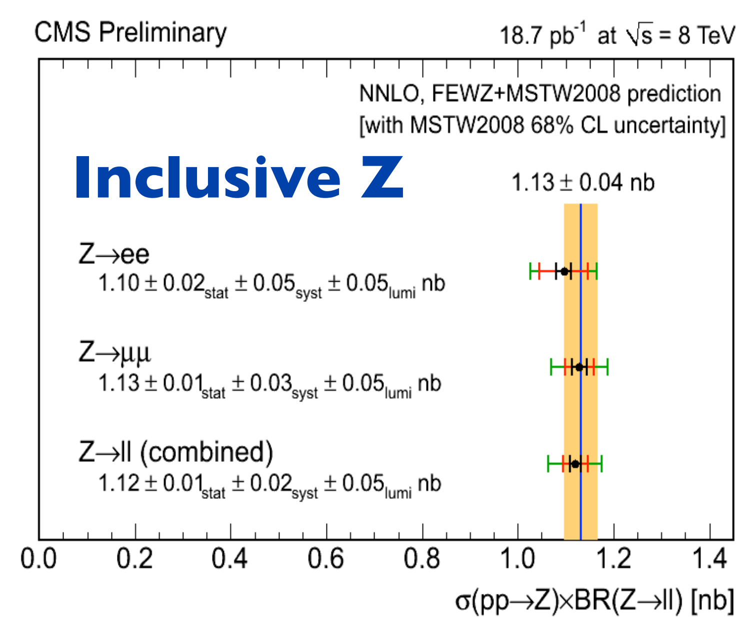
CMS-PAS-SMP-12-011

W and Z x-sec at 8 TeV





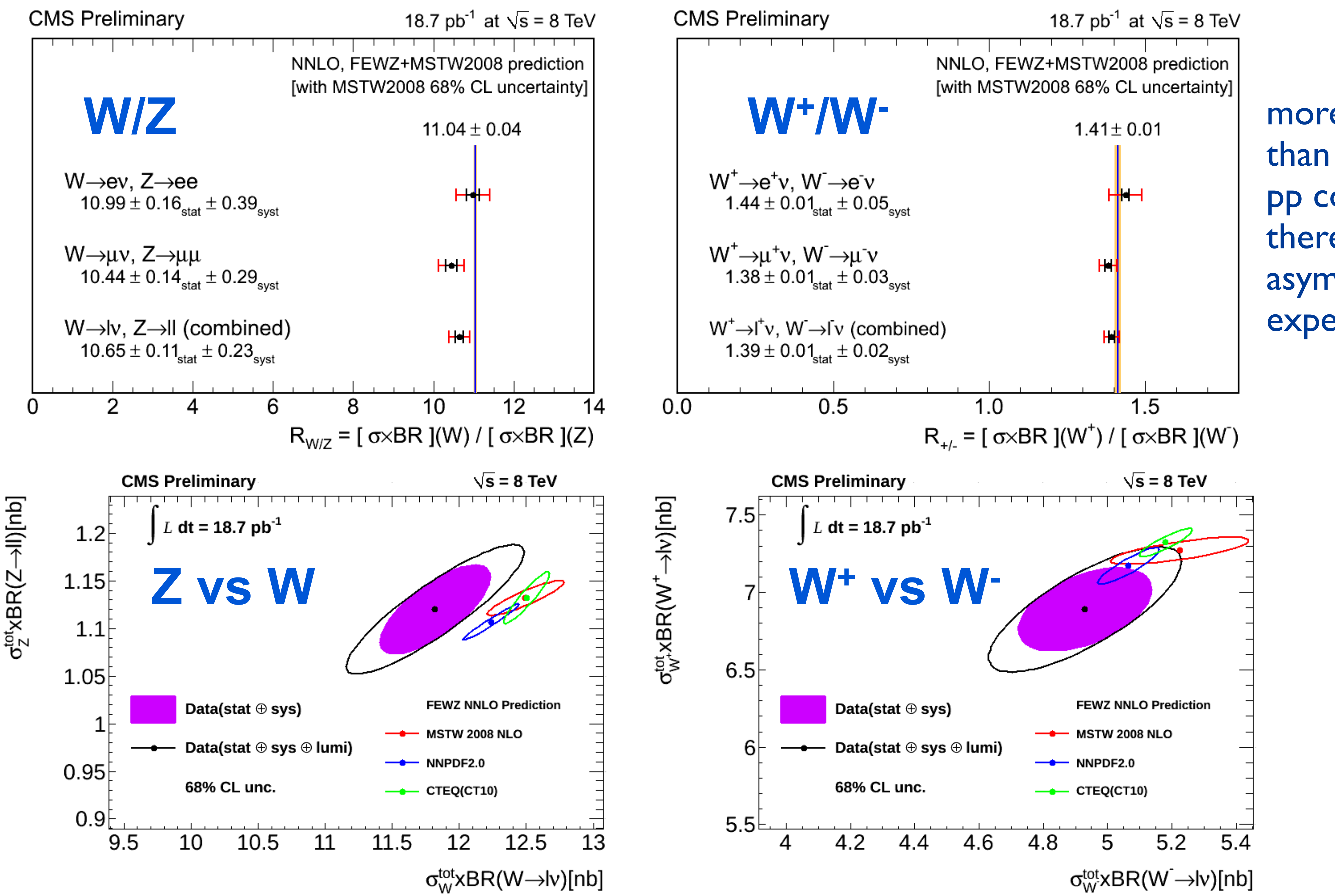




Results corrected to full acceptance (60 < M_{ll} < 120 GeV for Z events)

Good agreement with NNLO predictions

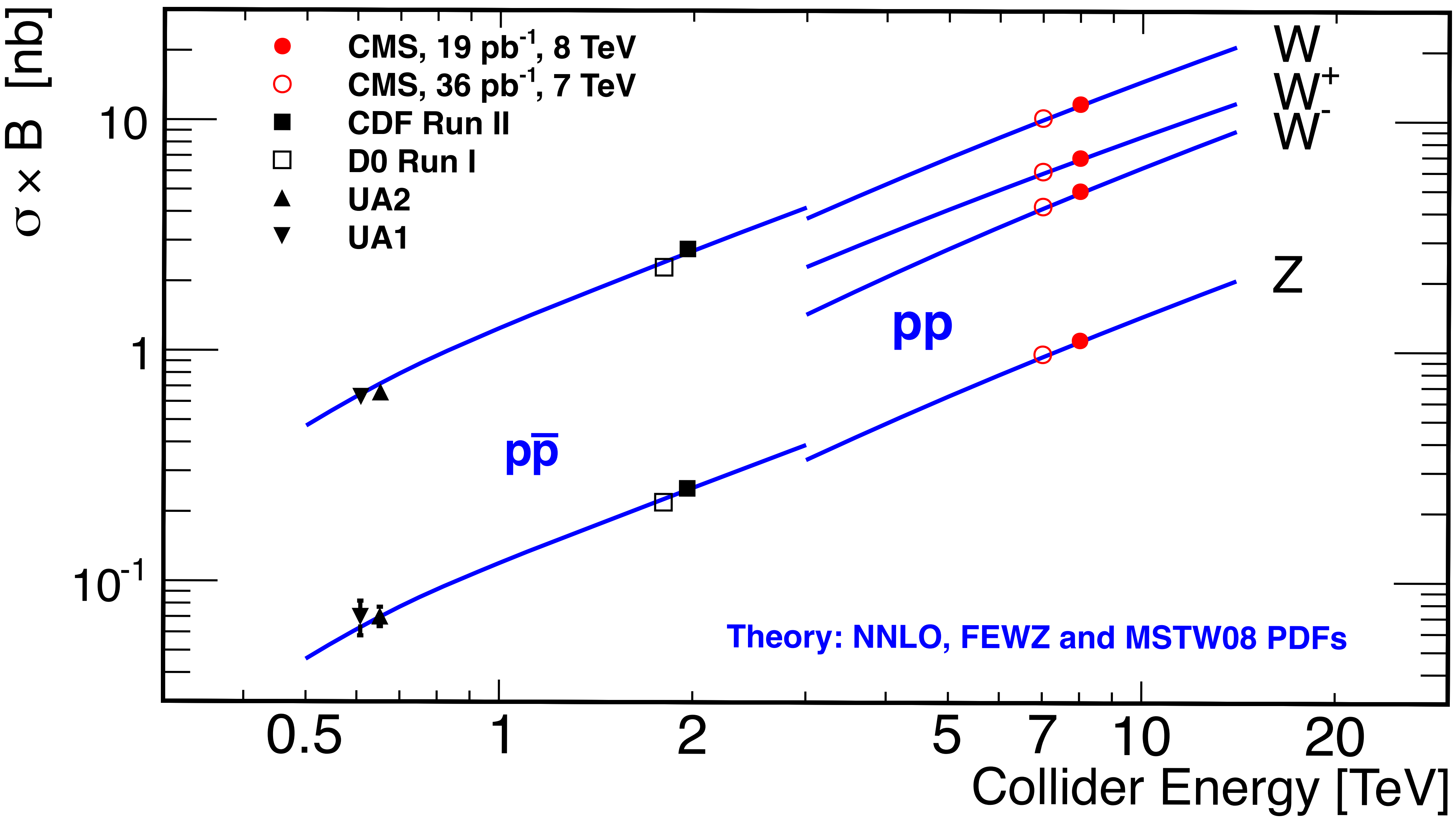
Cross-sections ratio



more u-dbar than d-ubar in pp collisions, therefore charge asymmetry is expected

Exp. and theory uncertainties cancel in the ratios
Generally good agreement

W and Z x-sec vs √s



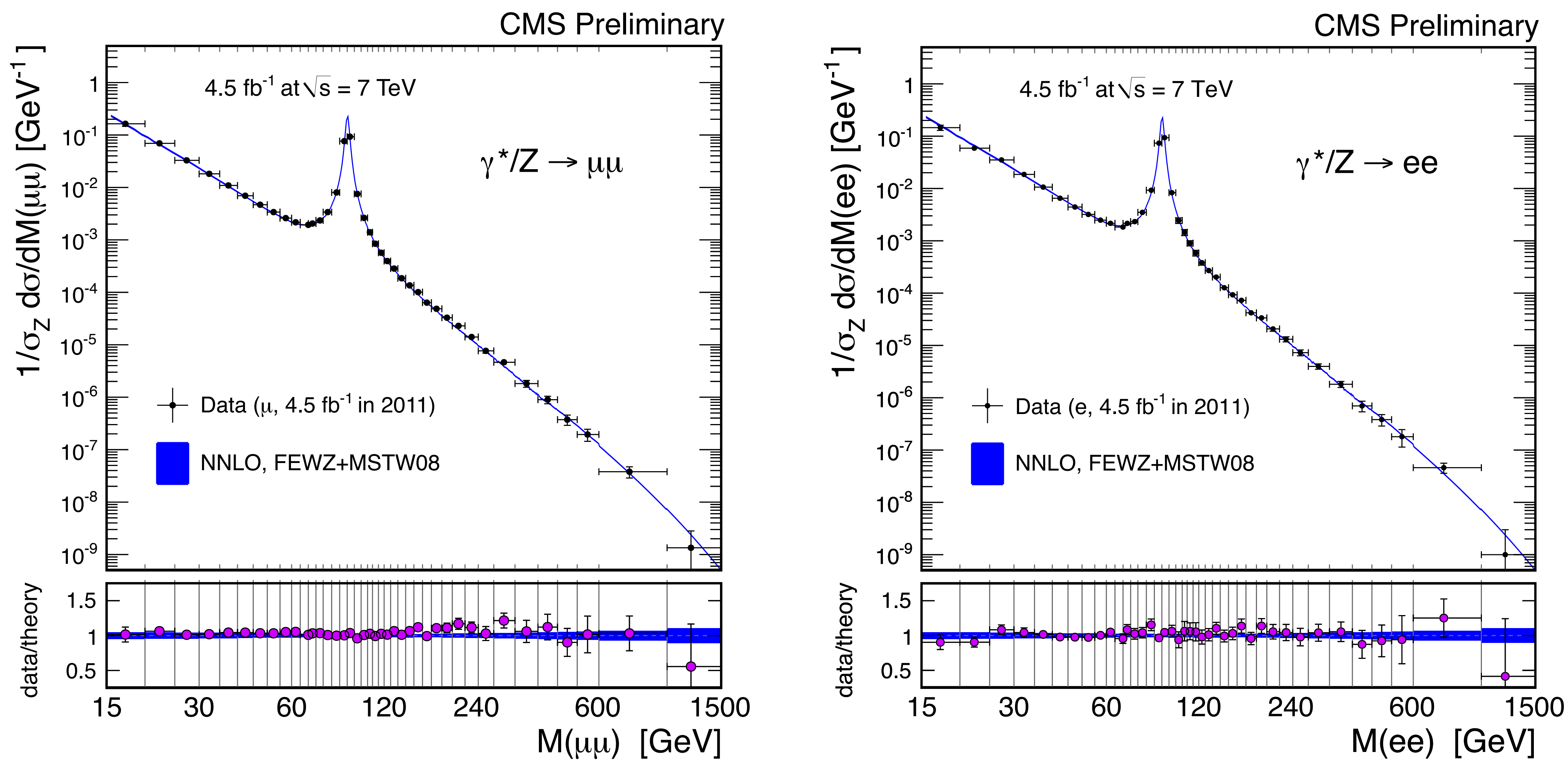
Excellent agreement with NNLO predictions

Drell-Yan $d\sigma/dM_{ll}$ @ 7 TeV

Source of large background for searches with isolated dileptons

Distribution is unfolded for resolution and corrected for acceptance and QED final-state radiation

Predictions are normalized to Z peak cross section (60 < Mll < 120 GeV)



Excellent agreement with FEWZ+MSTW2008

CMS-PAS-EWK-11-007

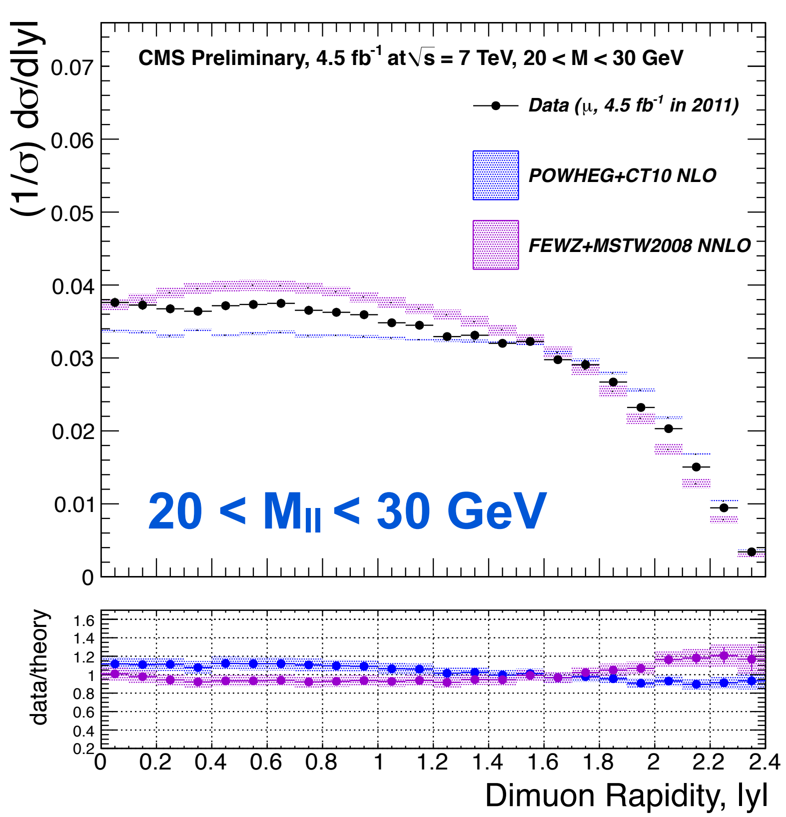
Drell-Yan $d^2\sigma/dydM_{ll}$ @ 7 TeV

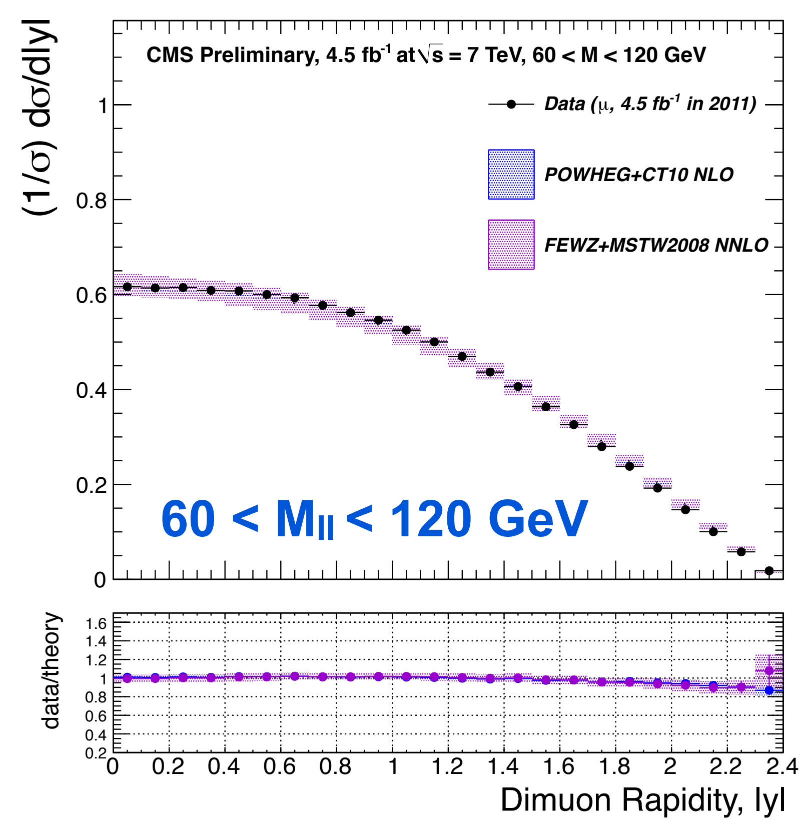
A measurement in bins of M_{ll} provide even better constraints on PDFs

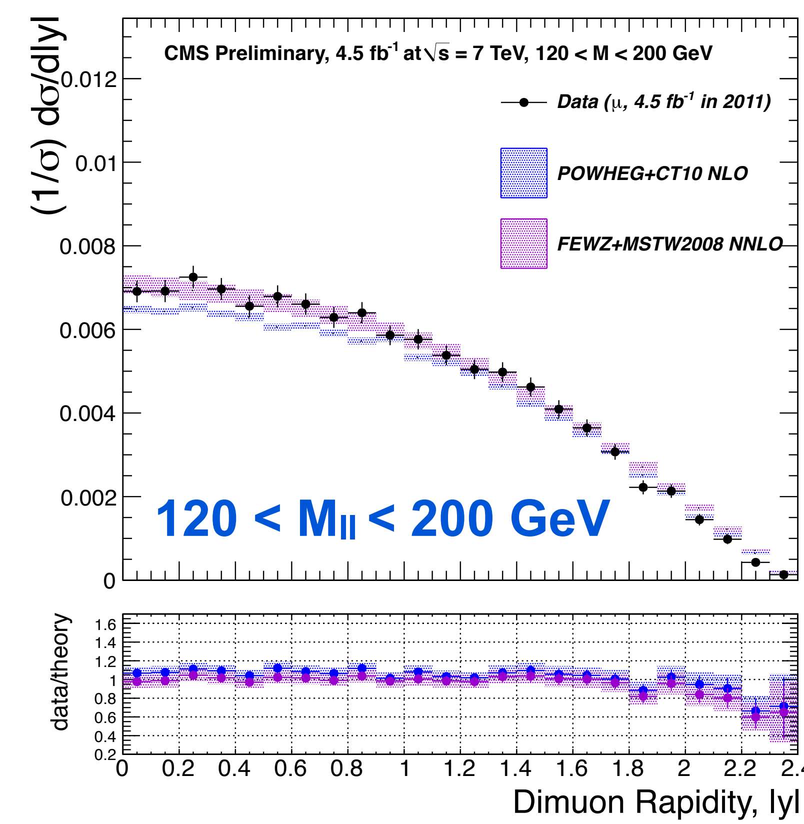
Dimuon in a restricted acceptance: $M_{\mu\mu} > 20$ GeV and $|y| < 2.4$

Yields normalized to the Z peak region

Distribution corrected for final state QED radiation

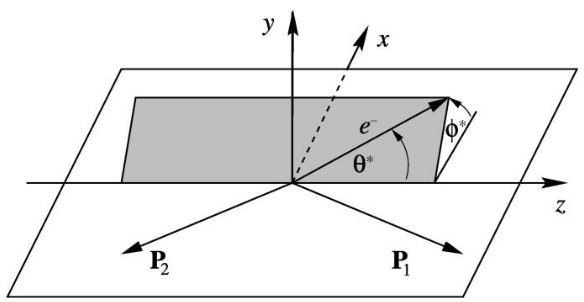


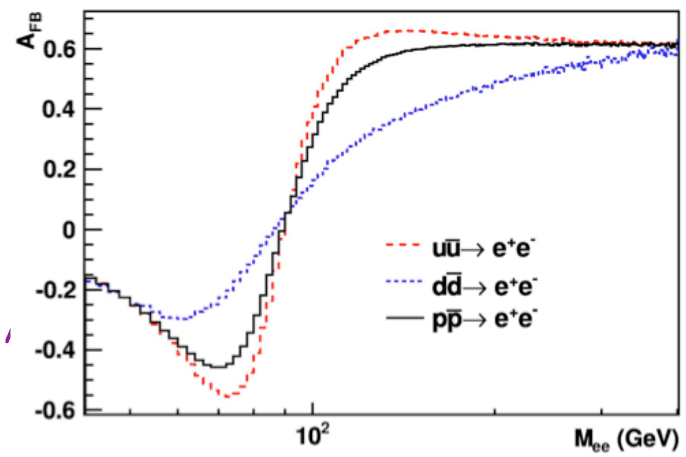


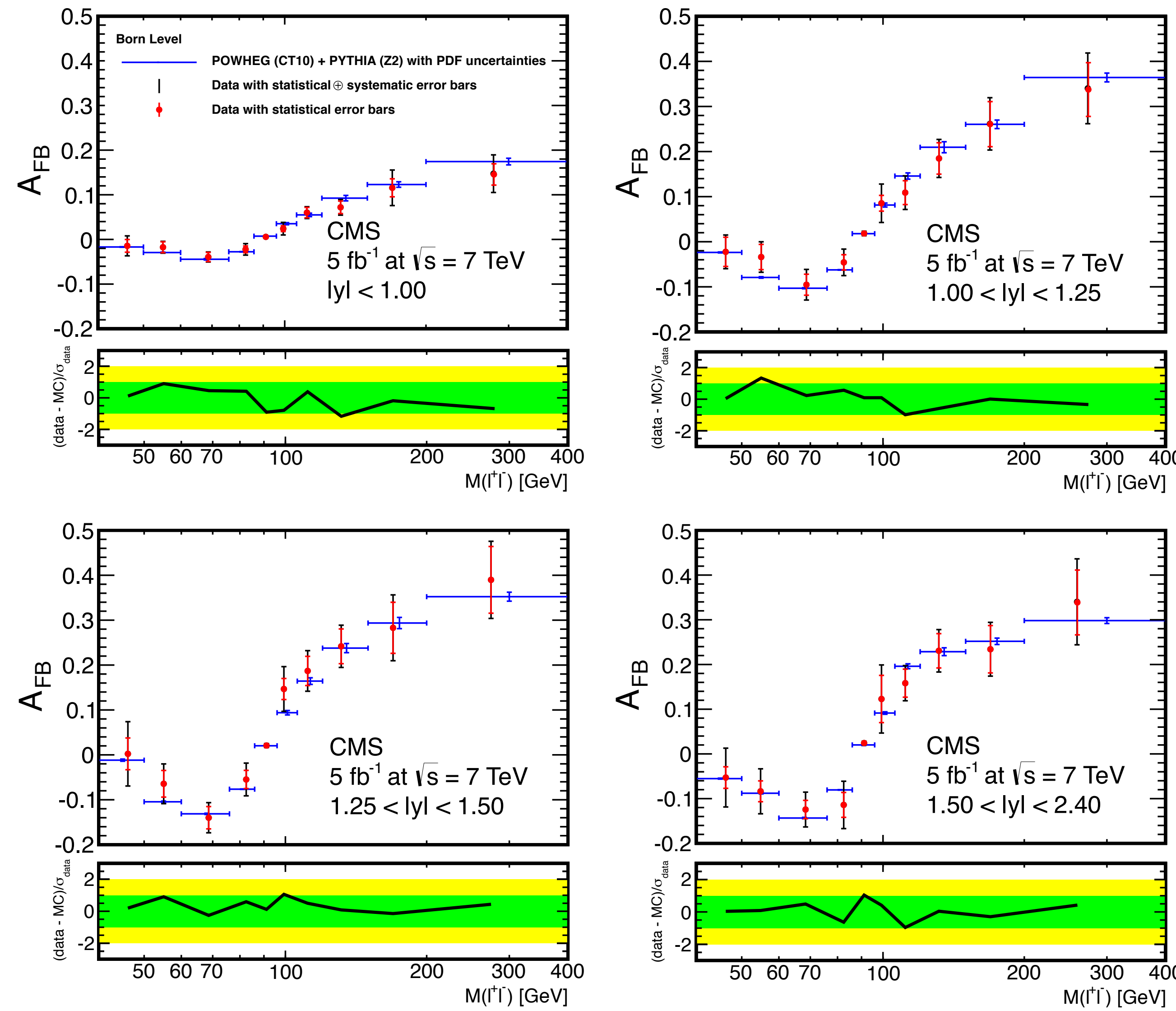


Significant differences between data, POWHEG NLO and FEWZ NNLO calculations at low masses are observed

Forward-Backward Asymmetry (7 TeV)







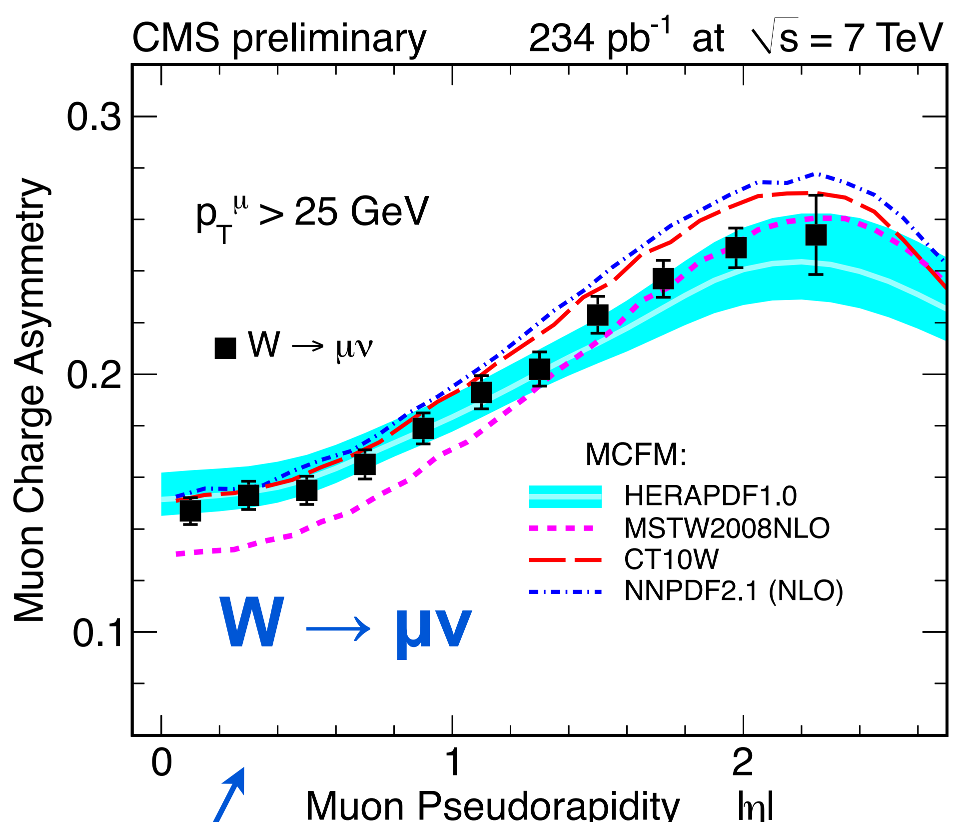
- Asymmetries at the Z pole sensitive to $sin^2\theta^l_{eff}$
- cos θ^* approximated by Collins-Soper angle wrt to beam direction closer to dilepton direction
- Results are unfolded, corrected for QED FSR, combined between e and μ channels in the acceptance, $p_T(\mu) > 20$ GeV, $|\eta| < 2.4$ and $M_{ll} > 40$ GeV

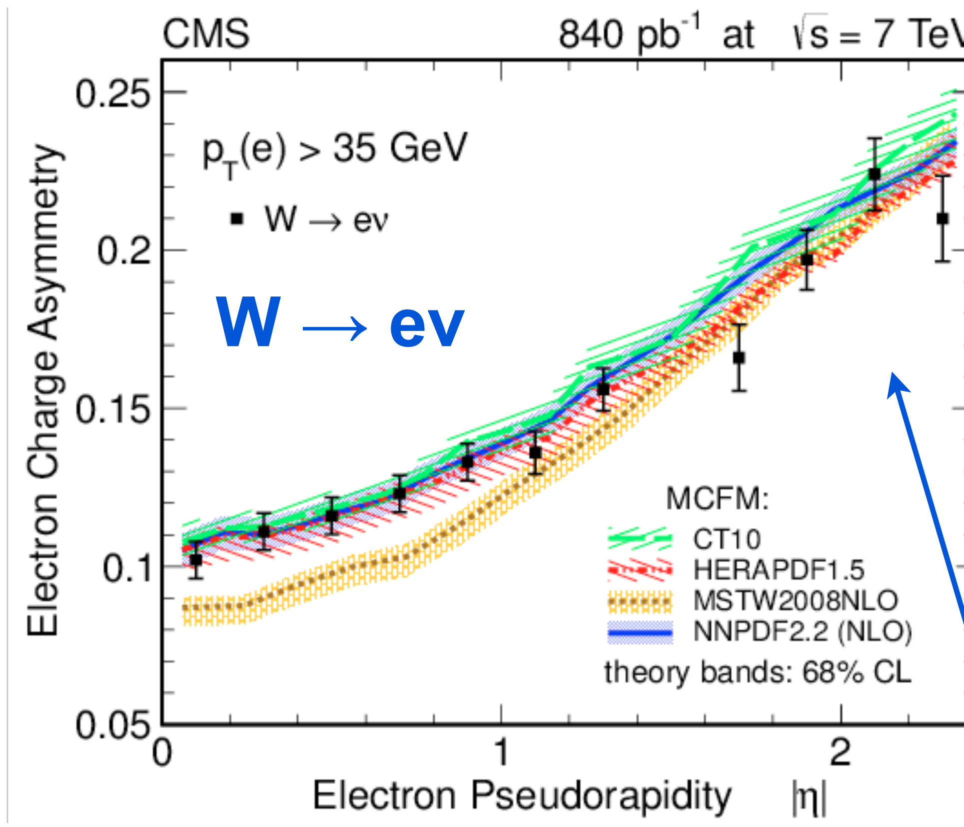
arXiv:1207.3973

Good agreement with SM predictions

W charge asymmetry @ 7 TeV

$$A(\eta) = \frac{d\sigma/d\eta(W^+\to l^+\nu) - d\sigma/d\eta(W^-\to l^-\nu)}{d\sigma/d\eta(W^+\to l^+\nu) + d\sigma/d\eta(W^-\to l^-\nu)}$$





Flatter in data than expected

CMS-PAS-EWK-11-005

PRL 109 (2012) 111806

Larger background for high η

Provides significant constraints on PDF fits

Results agrees with NLO, except for MSTW2008

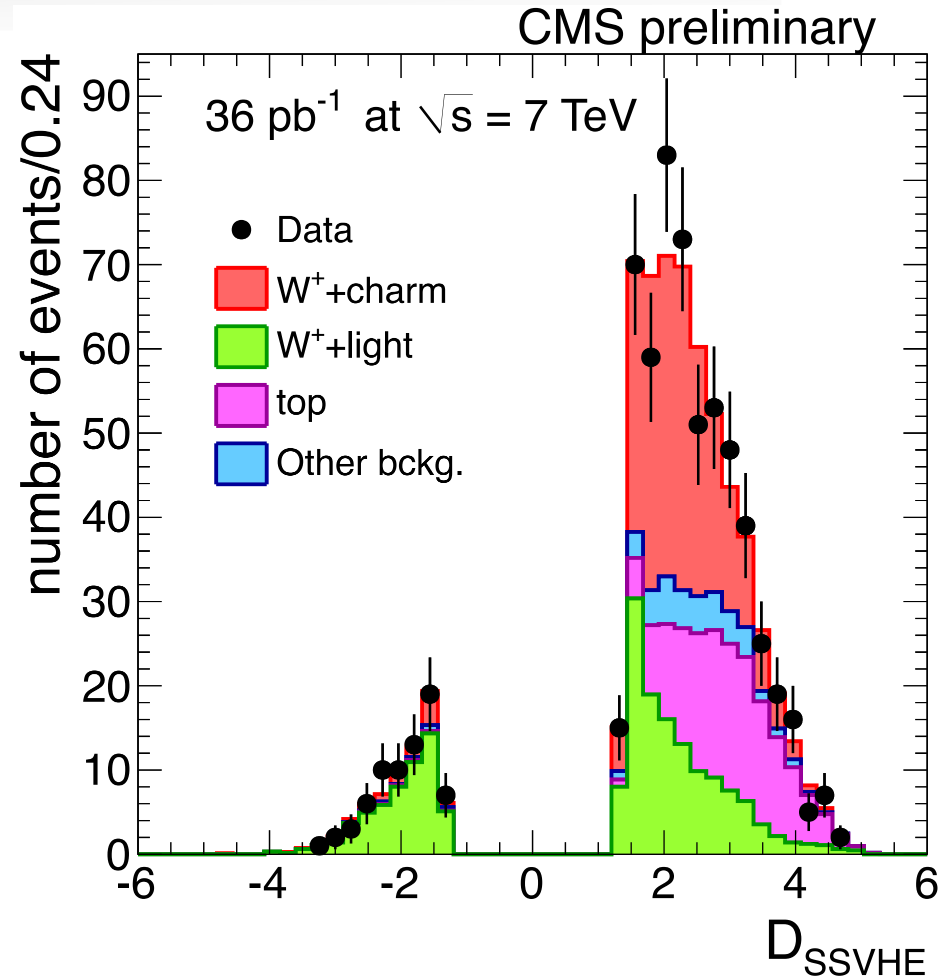
W+c

Provides information on **strange quark** pdf's

Select W(→ $\mu\nu$) + ≥ 1 jet, search for a secondary vertex and fit lifetime discriminant using template functions

Results in the acceptance

- $p_T^{\mu} > 25$ GeV/c, $\eta^{\mu} < 2.1$
- $p_T^{jet} > 20$ GeV/c, $\eta^{jet} < 2.1$



CMS-PAS-EWK-11-013

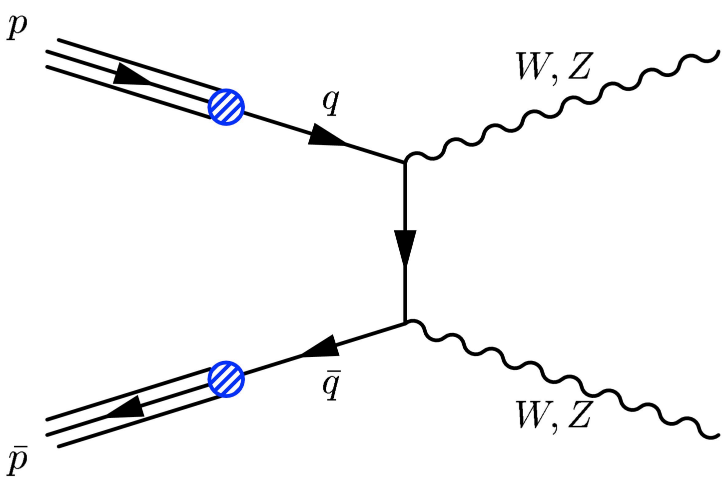
$$R_c^{\pm} = \frac{\sigma(W^+ + \bar{c} + X)}{\sigma(W^- + c + X)} = 0.92 \pm 0.19\,(stat.) \pm 0.04\,(syst.)$$

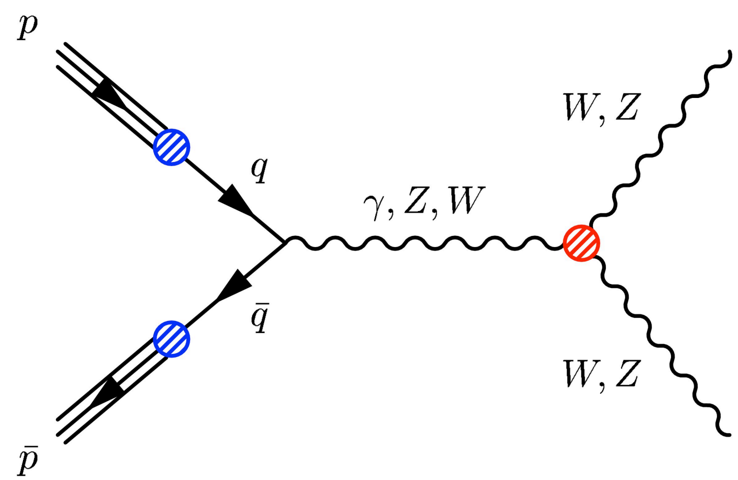
$$R_c = \frac{\sigma(W + c + X)}{\sigma(W + jet + c)} = 0.143 \pm 0.015\,(stat.) \pm 0.024\,(syst.)$$

Ratio	MCFM (CT10)	MCFM (MSTW08)	MCFM (NNPDF21)
$R_c^{\pm}$	$0.915^{+0.006}_{-0.006}$	$0.881^{+0.022}_{-0.032}$	0.902 ± 0.008
R_c	$0.125^{+0.013}_{-0.007}$	$0.118^{+0.002}_{-0.002}$	0.103 ± 0.005

Good agreement but large dependence of MCFM predictions on R_c from pdf

Diboson production at LHC





Coupling	Parameters	Channel
WWγ	λ_γ, $\Delta\kappa_\gamma$	WW,Wγ
WWZ	λ_Z, $\Delta\kappa_Z$, Δg_1^Z	WW,WZ
ZZγ	h_3^Z, h_4^Z	Zγ
Zγγ	h_3^γ, h_4^γ	Zγ
ZZZ	f_4^Z, f_5^Z	ZZ
ZγZ	f_4^γ, f_5^γ	ZZ

Triple gauge couplings:

- Charged triple gauge couplings (WWZ, WWγ) allowed
- Neutral triple gauge couplings (ZZZ, ZZγ) forbidden in Standard Model

Anomalous couplings lead to enhanced cross section, larger boson pT

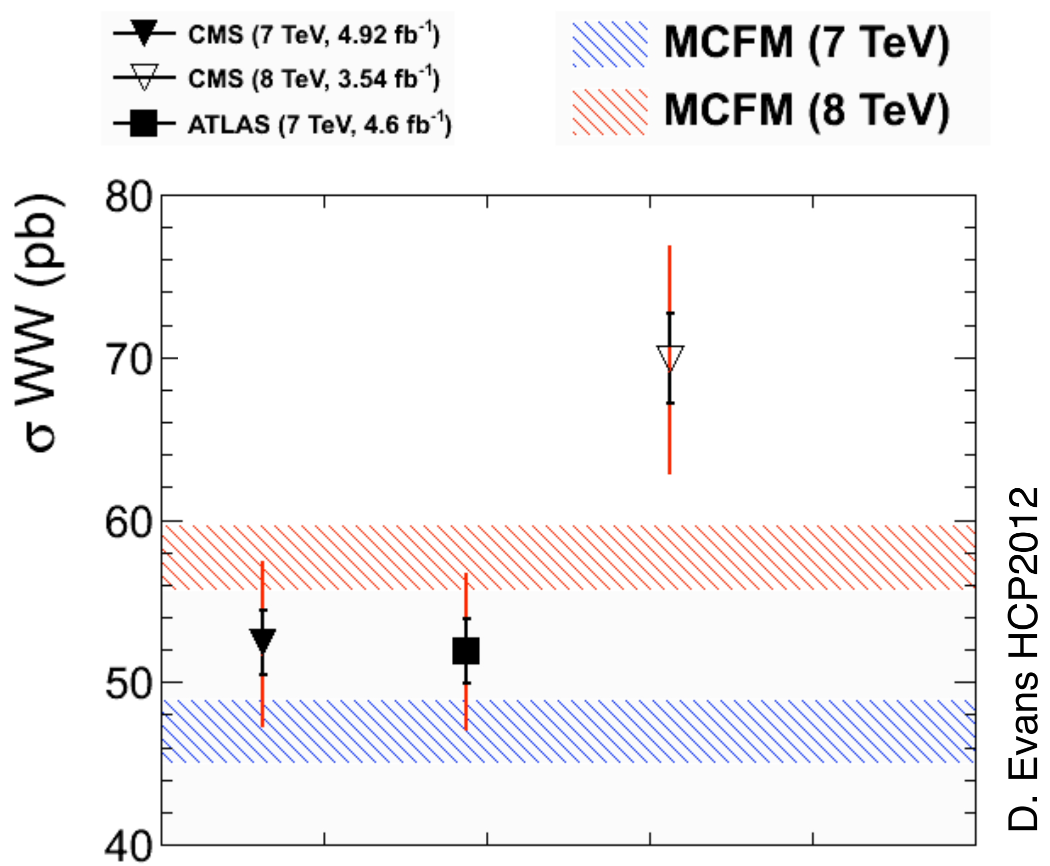
Diboson production:

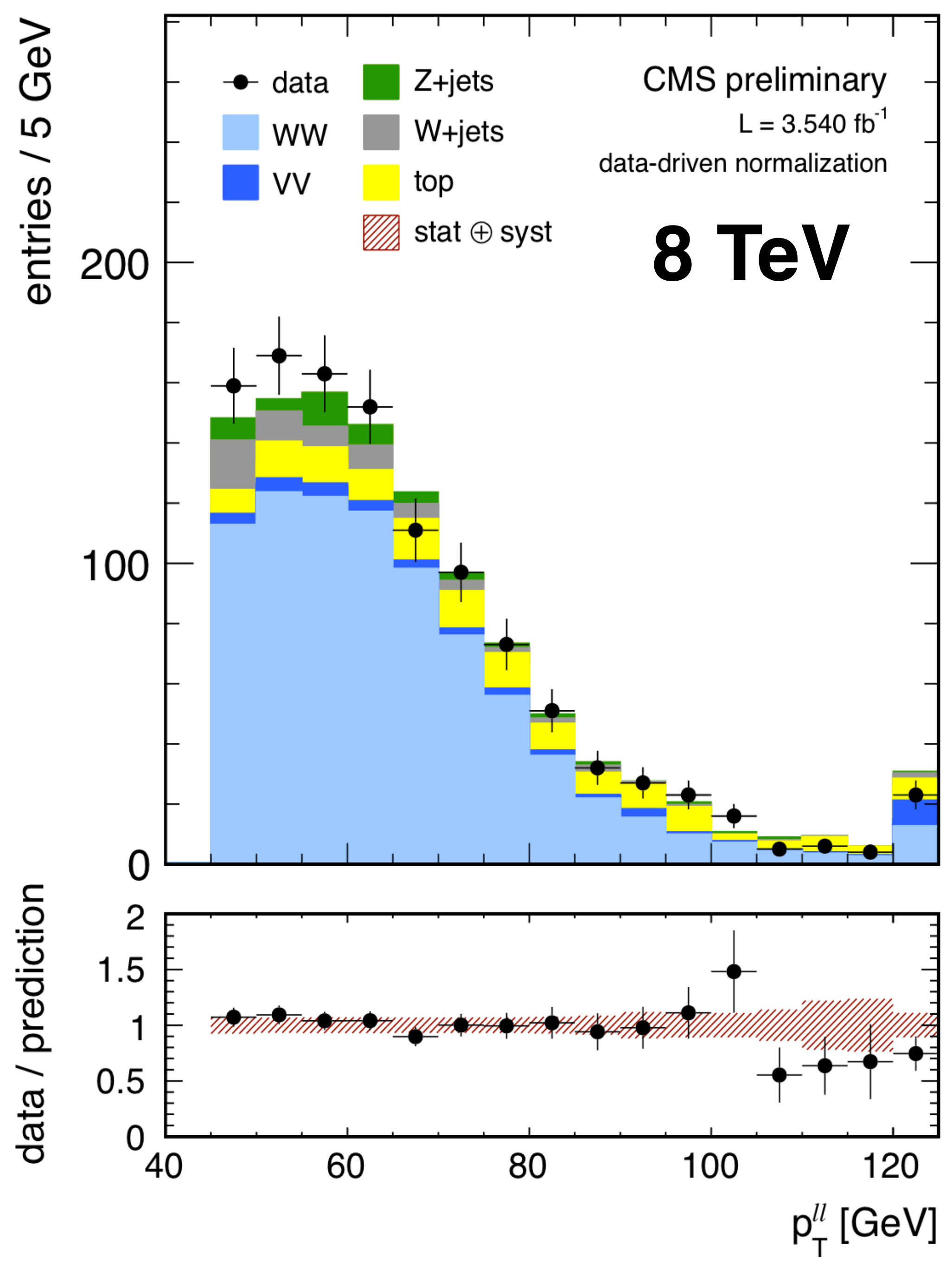
- provides a direct measurement of (anomalous) triple gauge couplings
- is an important background to Higgs and BSM searches

WW→lνlν (8 TeV)

- Signal selection: dileptons + MET
- Backgrounds
  - Z→ll: Z veto + high MET
  - W+jets: tight lepton id
  - tW and ttbar: jet veto

CMS-PAS-SMP-12-013



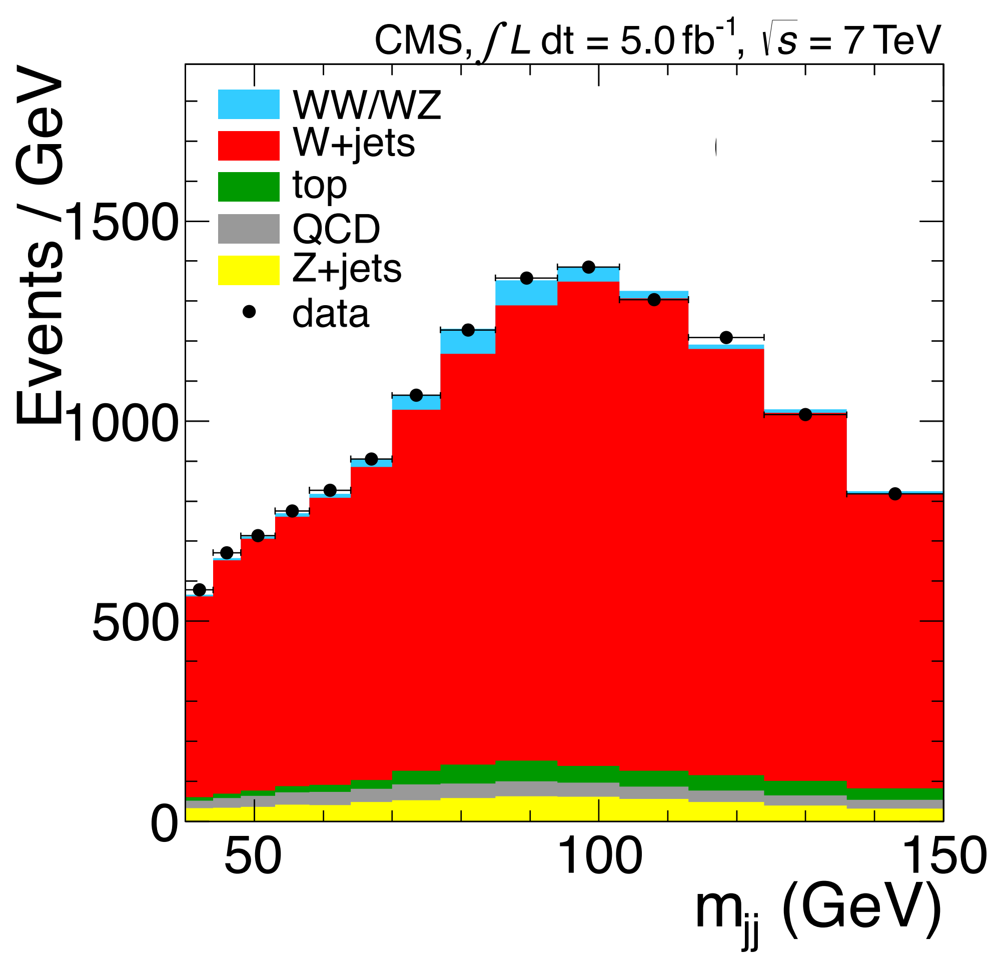


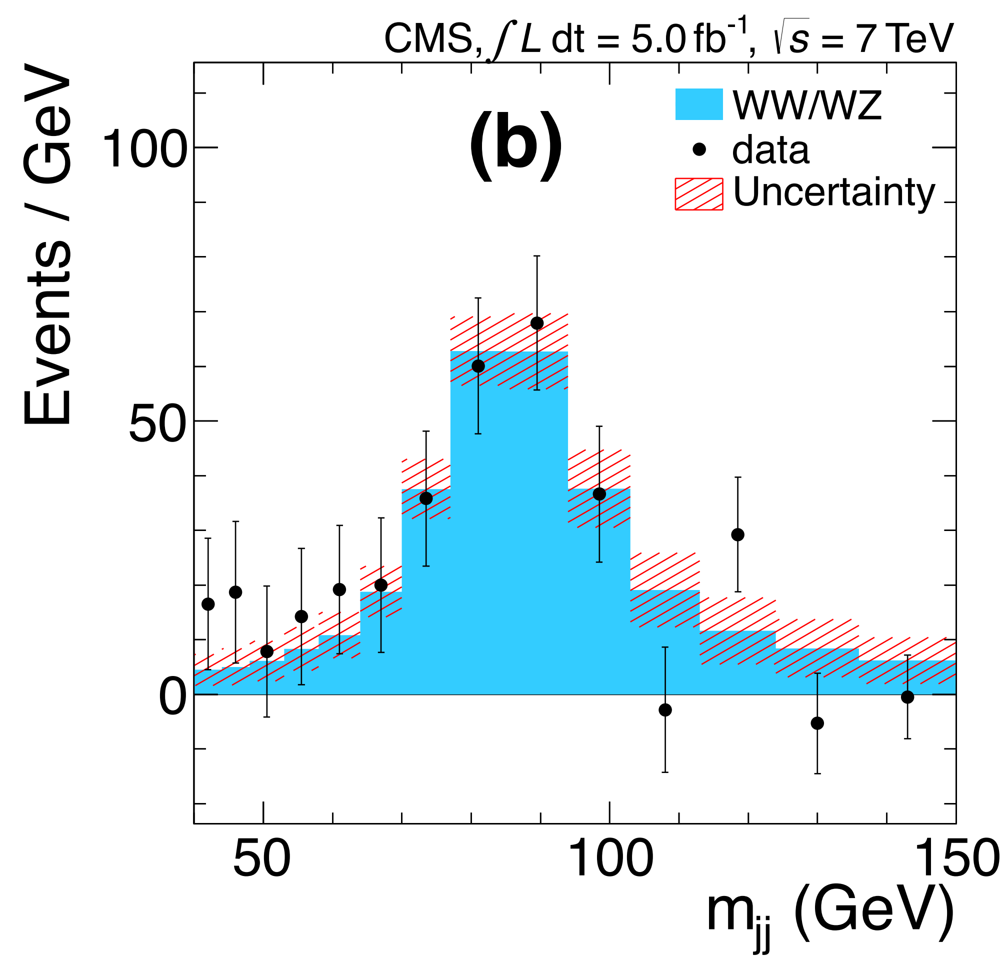
Results slightly above theoretical prediction

Difference between 8 TeV result and theory value is (22 ± 13)% of theory value

WW/WZ→lνjj (7 TeV)

- Larger branching ratio, but larger background
- Cross-section extracted from a unbinned maximum-likelihood fit to m_{jj}
- W+jets background is fitted using a combination of simulated samples with different renormalization/factorization and matching scales



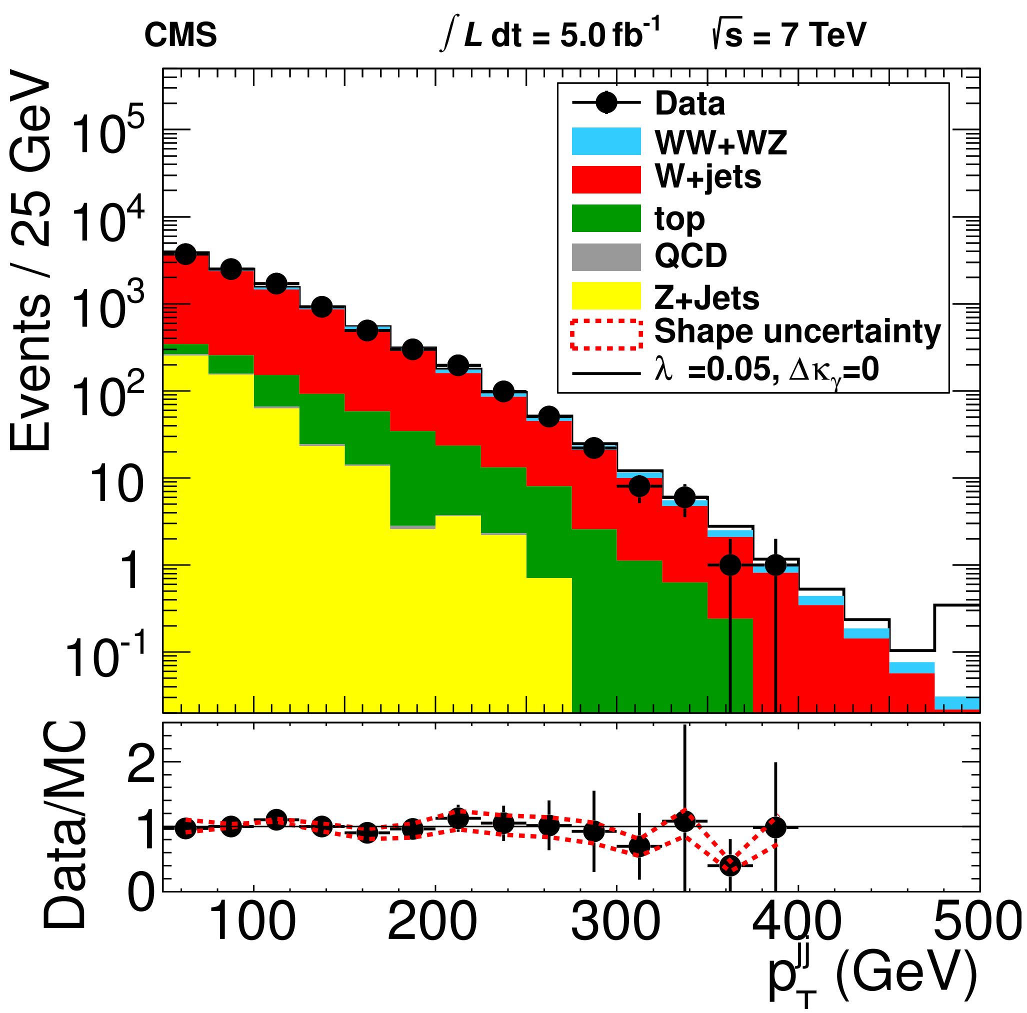


σ(WW+WZ) = 68.89 ± 8.71 (stat) ± 9.70 (syst) ± 1.52 (lumi) pb

compatible with NLO predictions: 65.6 ± 2.2 pb

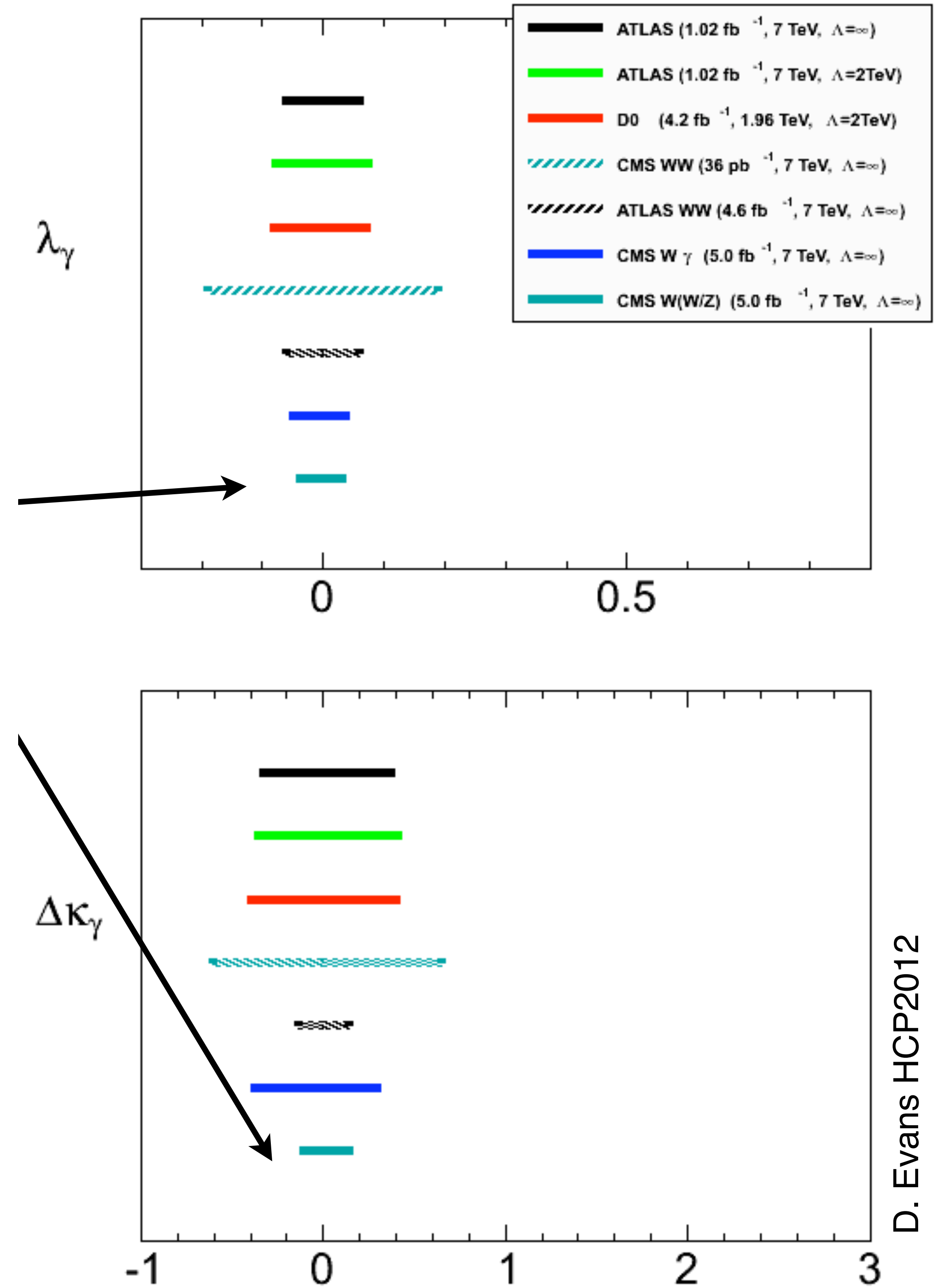
aTGC limit with WW→lνjj

- Extracted from WW p_T



$$-0.038 < \lambda_Z < 0.030$$

$$-0.111 < \Delta\kappa_\gamma < 0.142$$



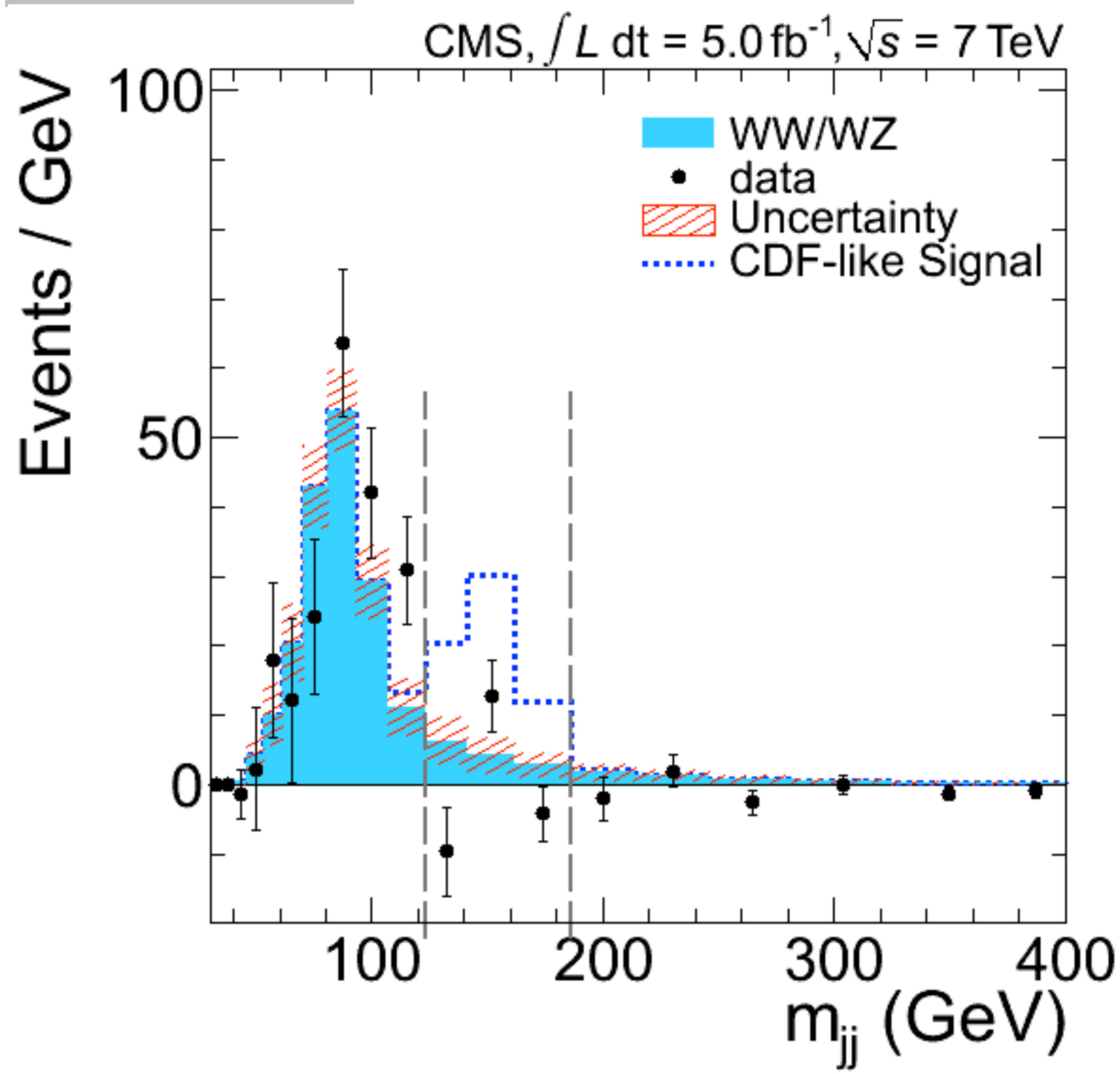
Best limit from LHC using full 2011 data

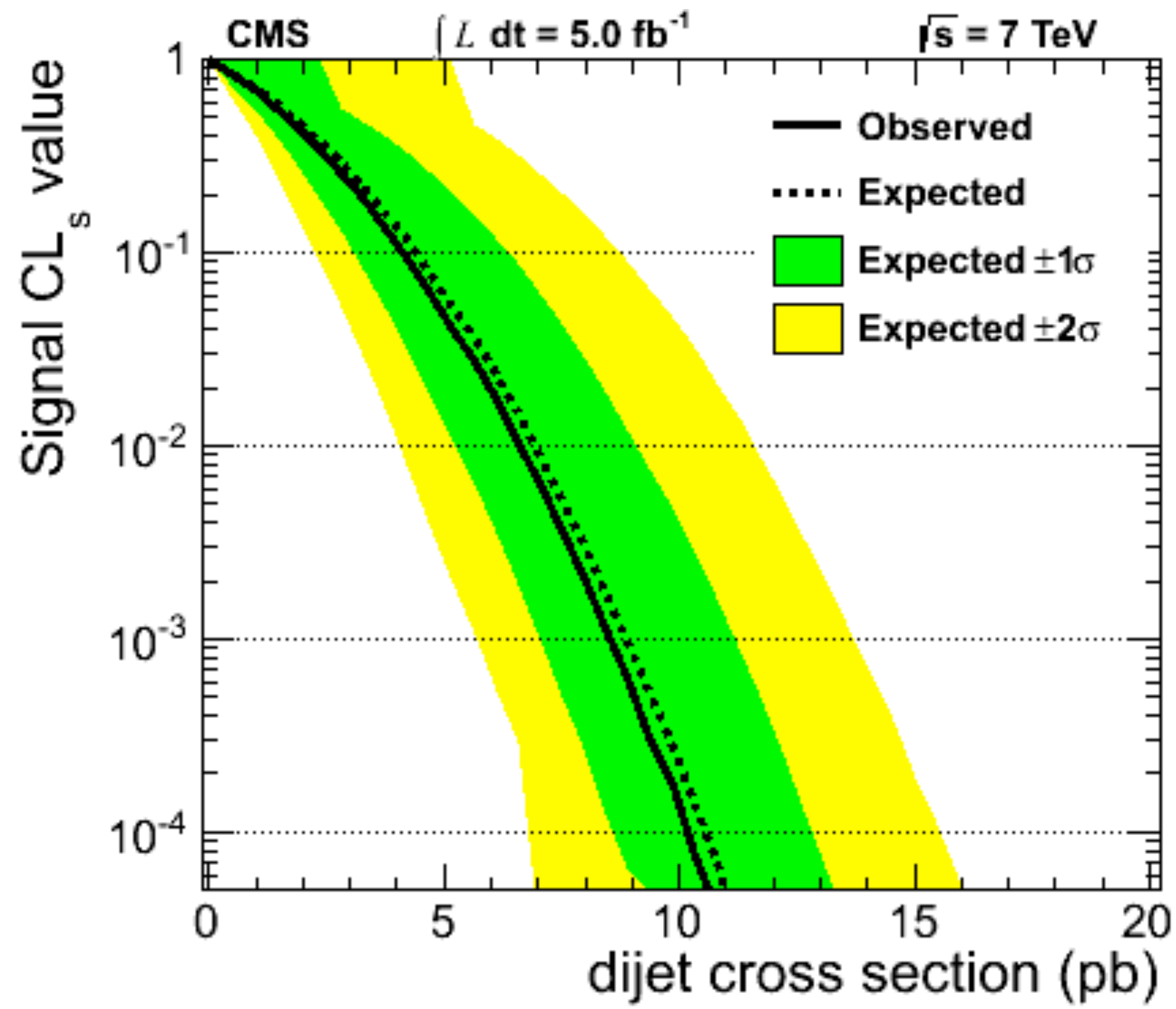
Dijet mass resonances in W+2 jets

The dijet mass in WW/WZ →lνjj has been searched for new resonances

Assuming H-like efficiency, as in WH searches, limit has been set for a generic Gaussian signal hypothesis with M_{jj}=150 GeV and width=15 GeV

arXiv:1208.3477





ZZ→2l2l’ (8 TeV)

ZZ→2l2l’ (e or μ) is almost background free

ZZ→2l2τ increase signal acceptance by 10% but higher background

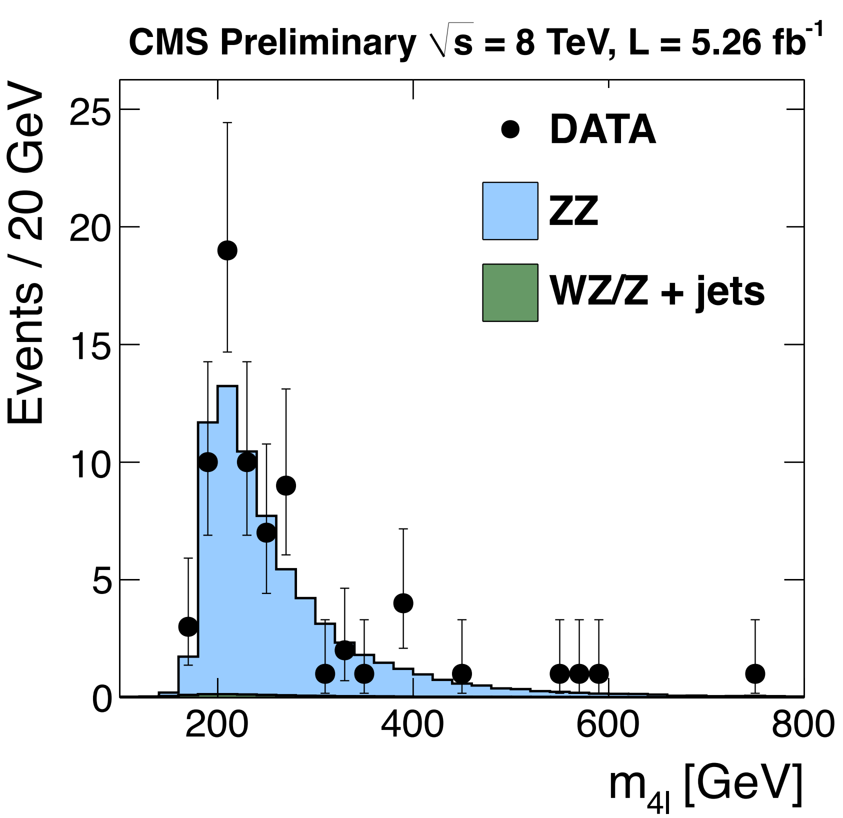
- $20 < M_{vis} < 90$ GeV for $\tau_e\tau_\mu$
- $30 < M_{vis} < 90$ GeV otherwise

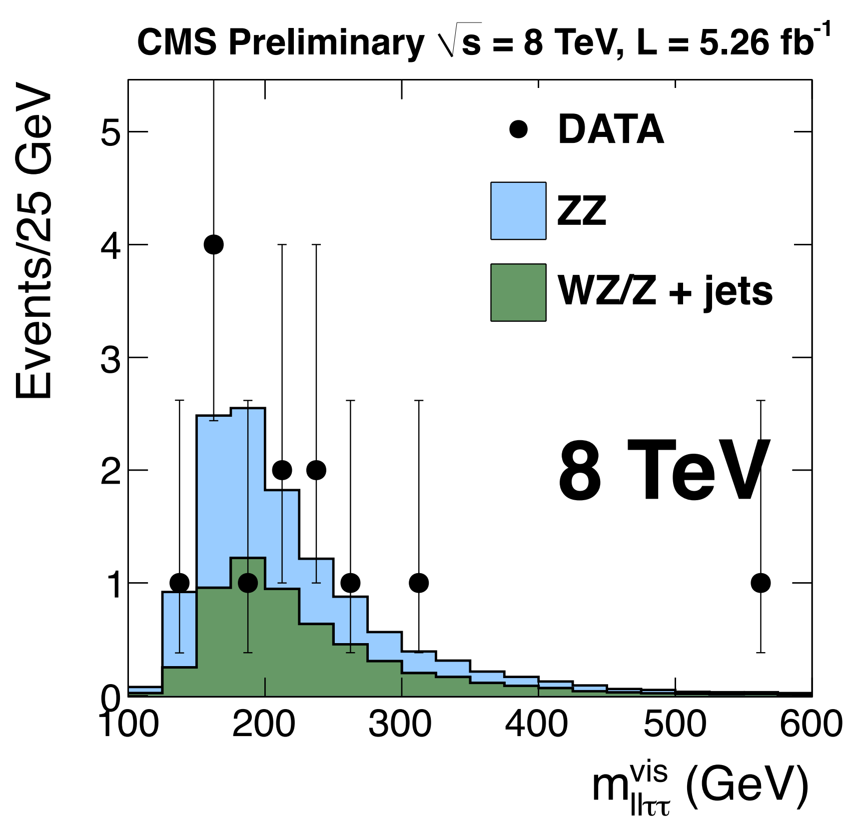
Background from control samples (same sign dileptons or inverted cuts)

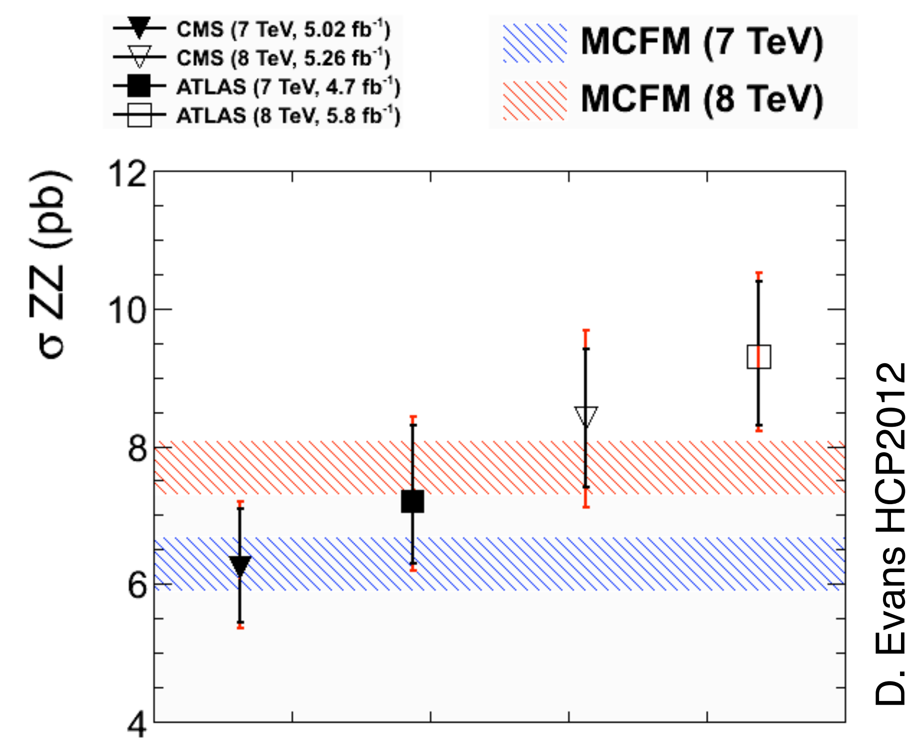
Results from a simultaneous likelihood fit the yields in all channels

Good agreement with SM both at 7 TeV and 8 TeV

CMS-PAS-SMP-12-014

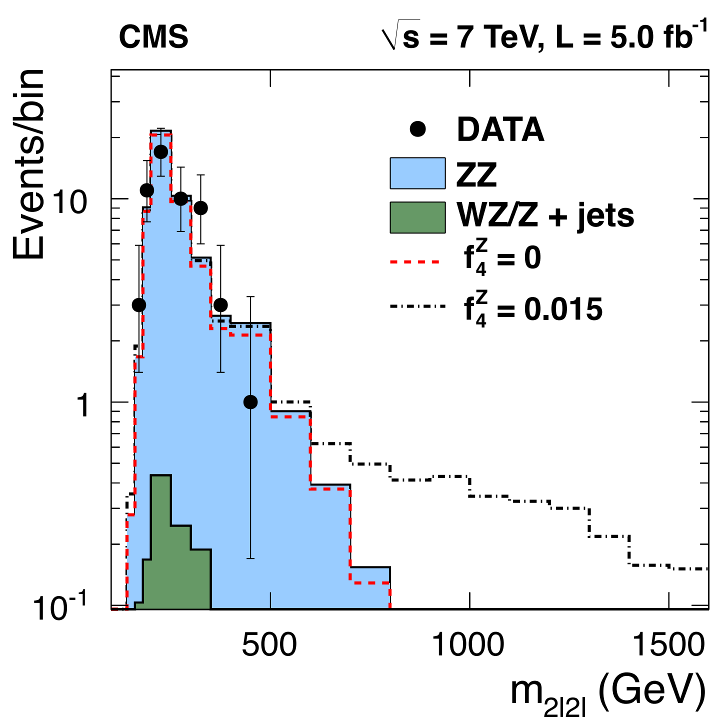


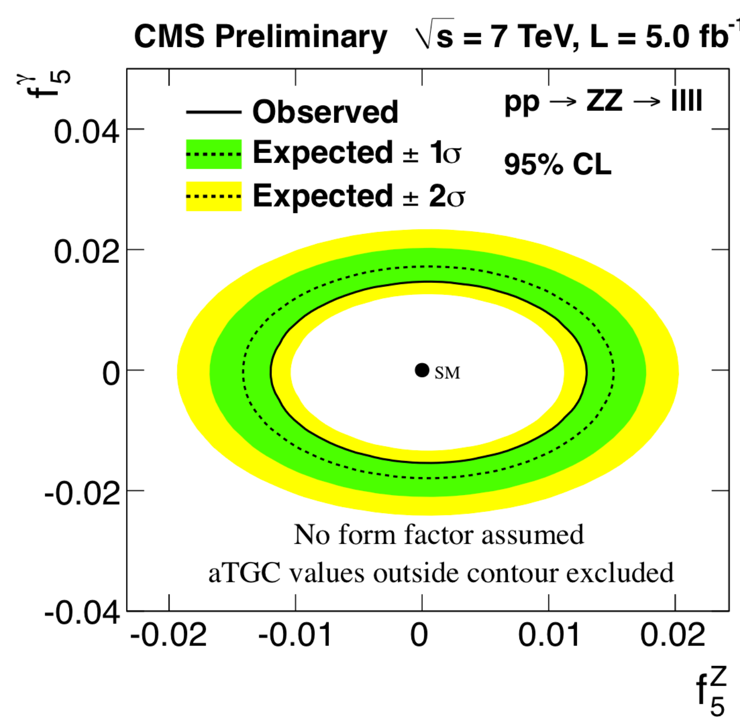


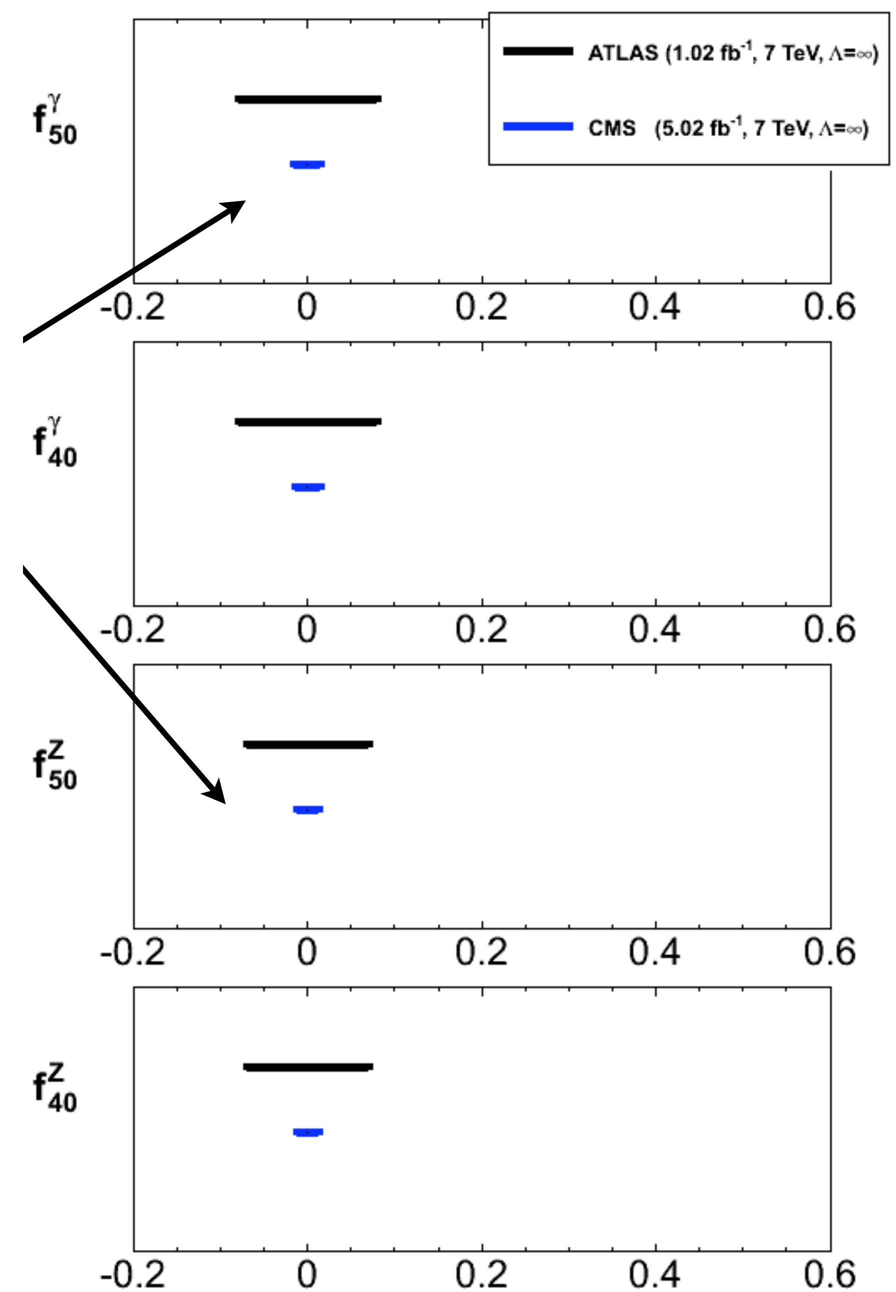


aTGC limits with ZZ→2l2l’

Limits sets on ZZZ and ZγZ couplings using 4l invariant mass







$$-0.012 < f_4^Z < 0.013$$
$$-0.012 < f_5^Z < 0.013$$

arXiv:1211.4890

$$-0.014 < f_4^\gamma < 0.014$$
$$-0.015 < f_5^\gamma < 0.015$$

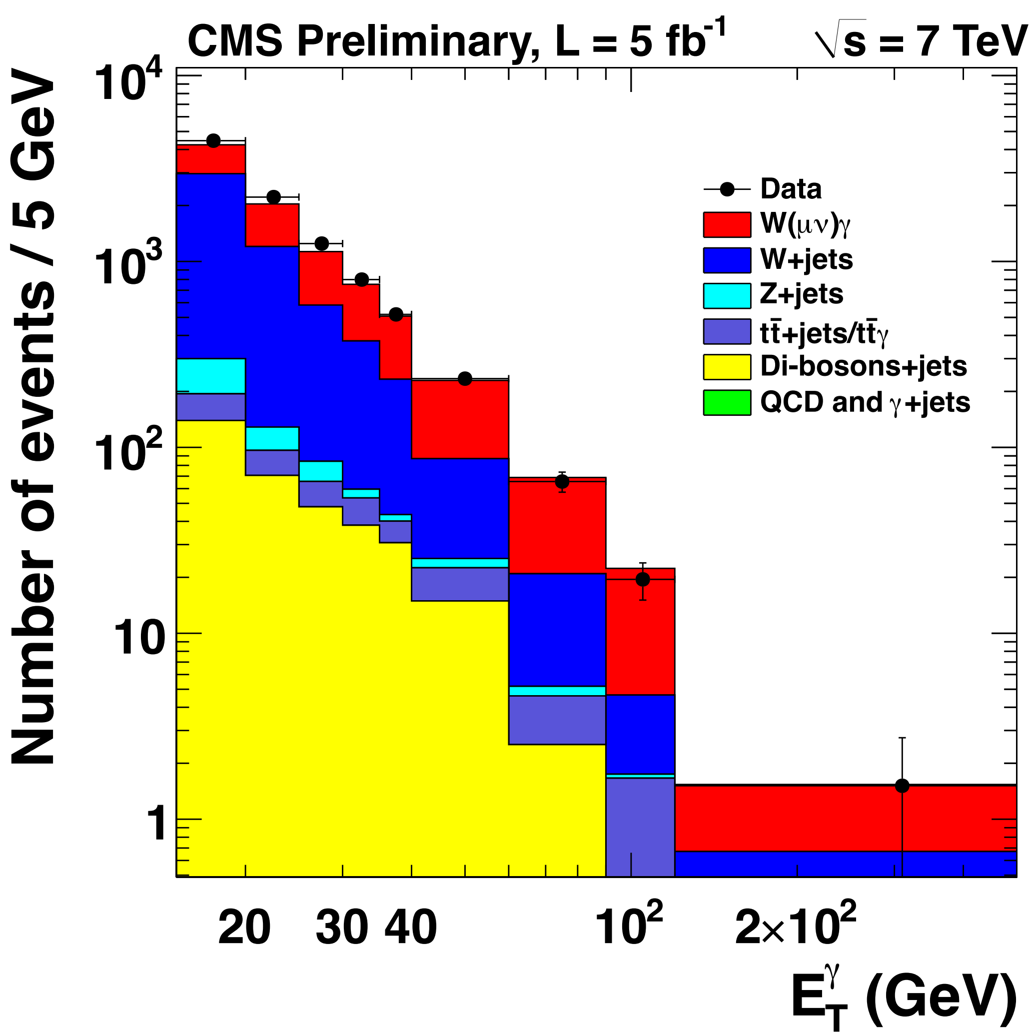
D. Evans HCP2012

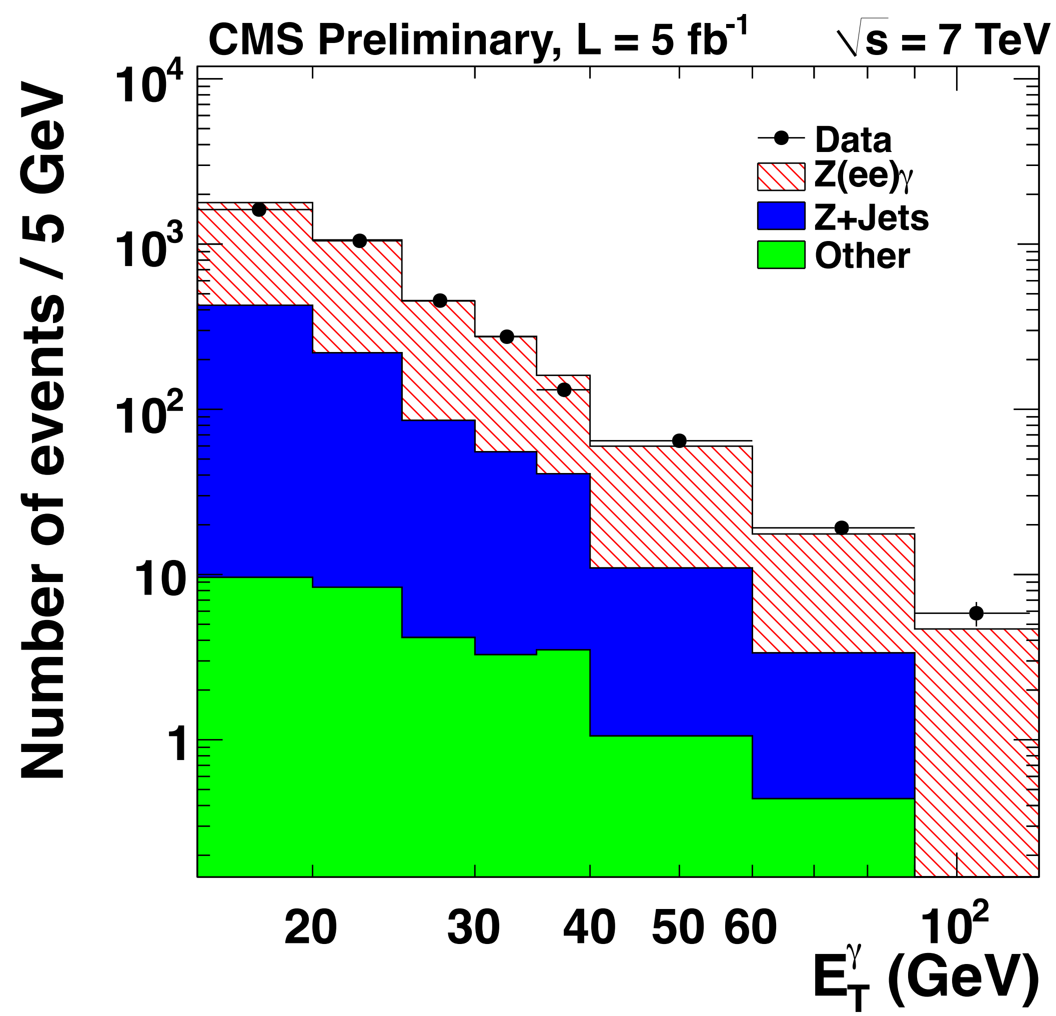
W(lν)γ/Z(ll)γ (7 TeV)

Main selection cuts:

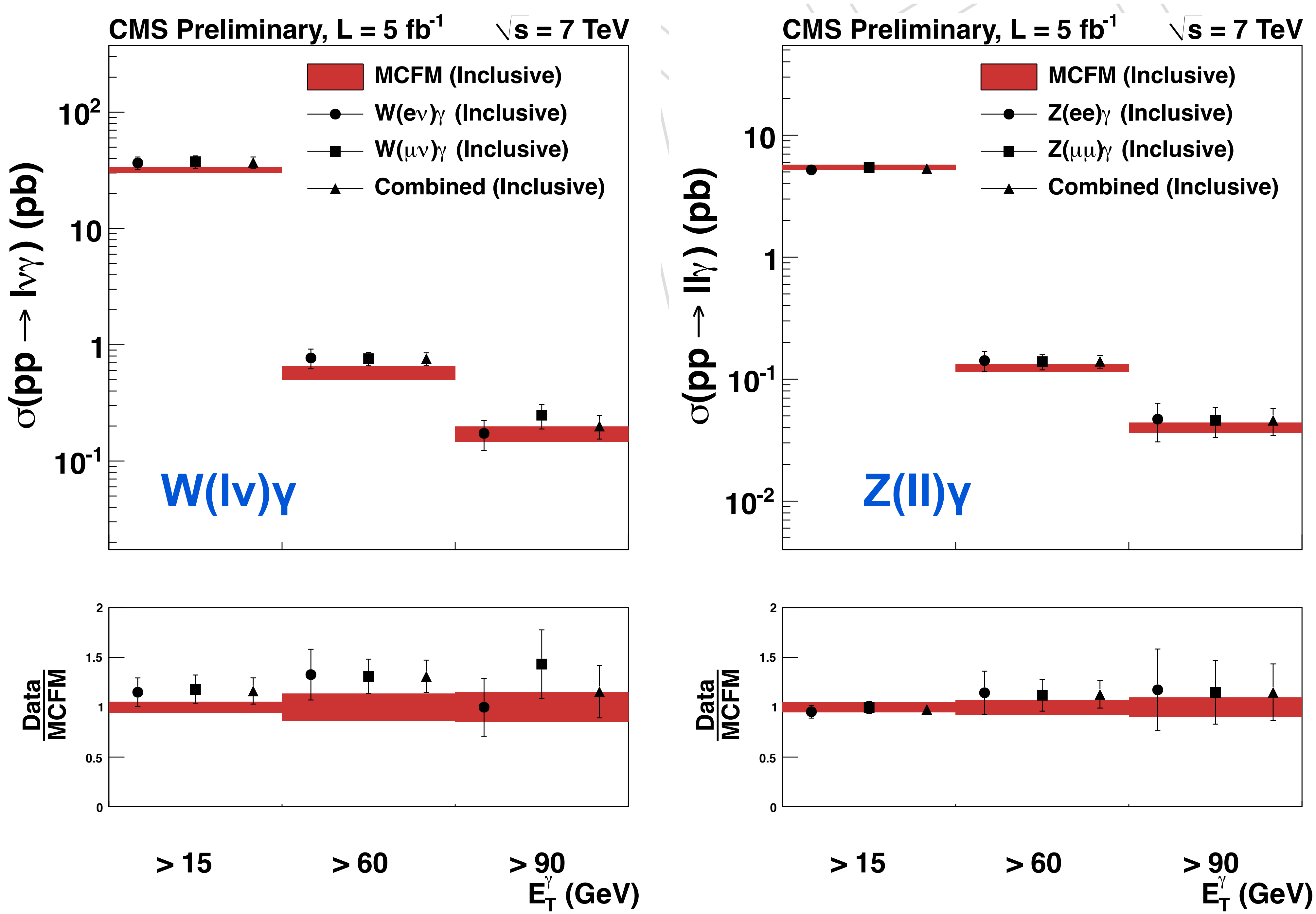
- lepton pT > 20 GeV, 35 GeV for W→eν
- m_T^W > 70 GeV to remove QCD bkg and surpass electron trigger turn-on

Background due to mis-id photon from a template fit to a shower shape variable





W(lν)γ/Z(ll)γ: comparison to MCFM



Comparison to MCFM shows no significative deviation from SM

Limits on aTGCs have been also set

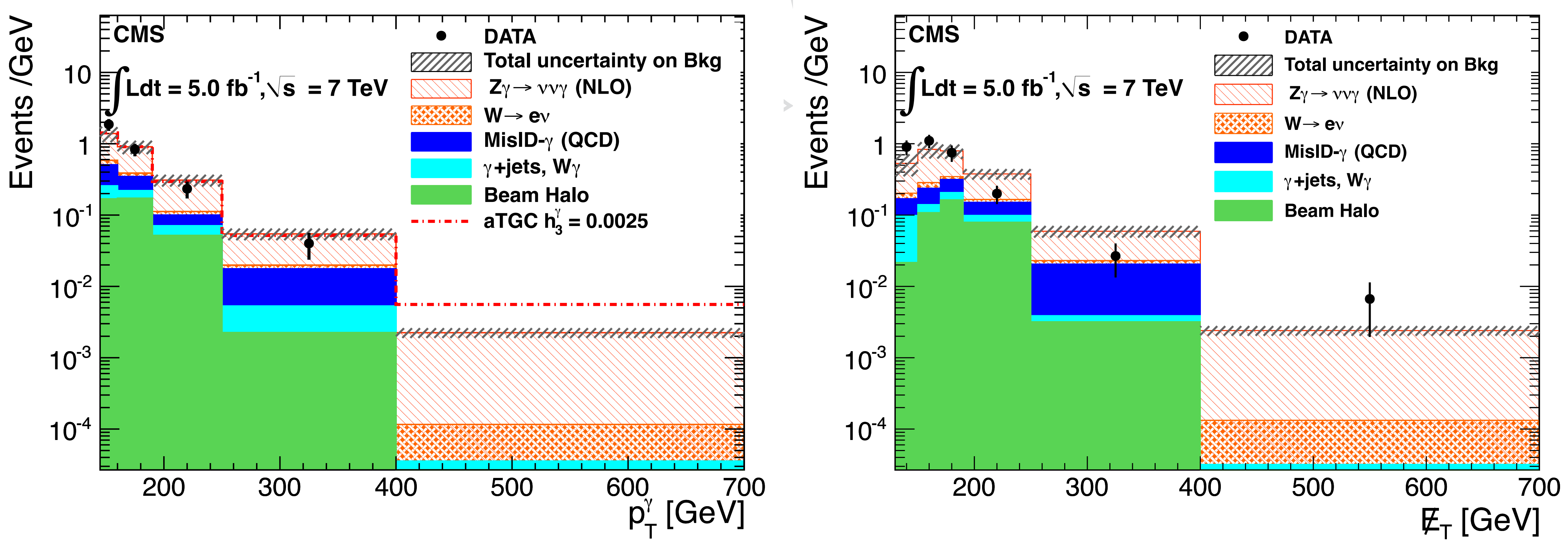
Zγ→ννγ

First measurement of Zγ→ννγ at √s = 7 TeV

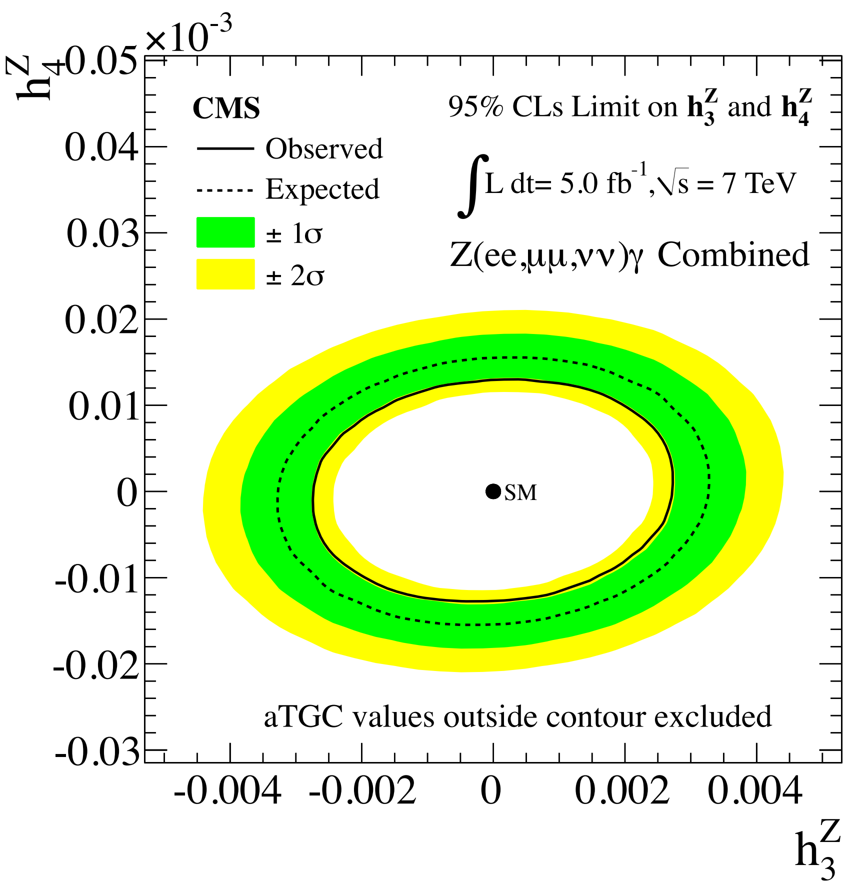
- Difficult because of large instrumental and non-collision backgrounds
- Photon |η| < 1.4, ET > 145 GeV, MET > 130 GeV and no other significant activity
- Most backgrounds and efficiencies are estimated with data-driven methods

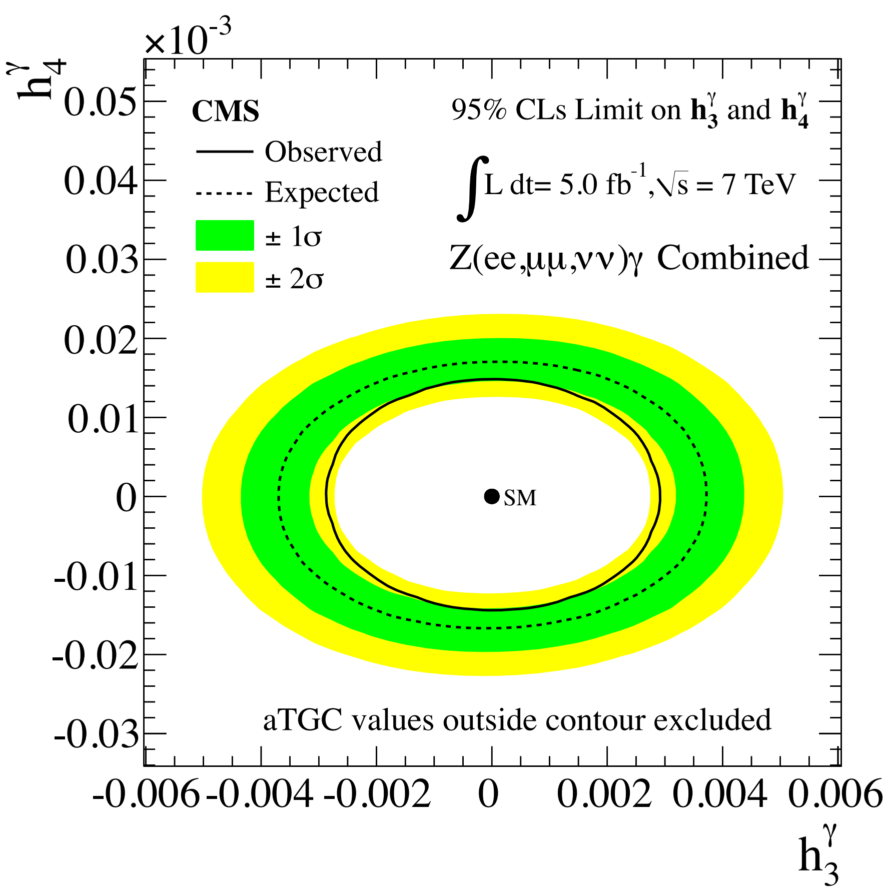
Result: σ = 21.3 ± 4.2 (stat.) ± 4.3 (syst.) ± 0.5 (lumi.) fb

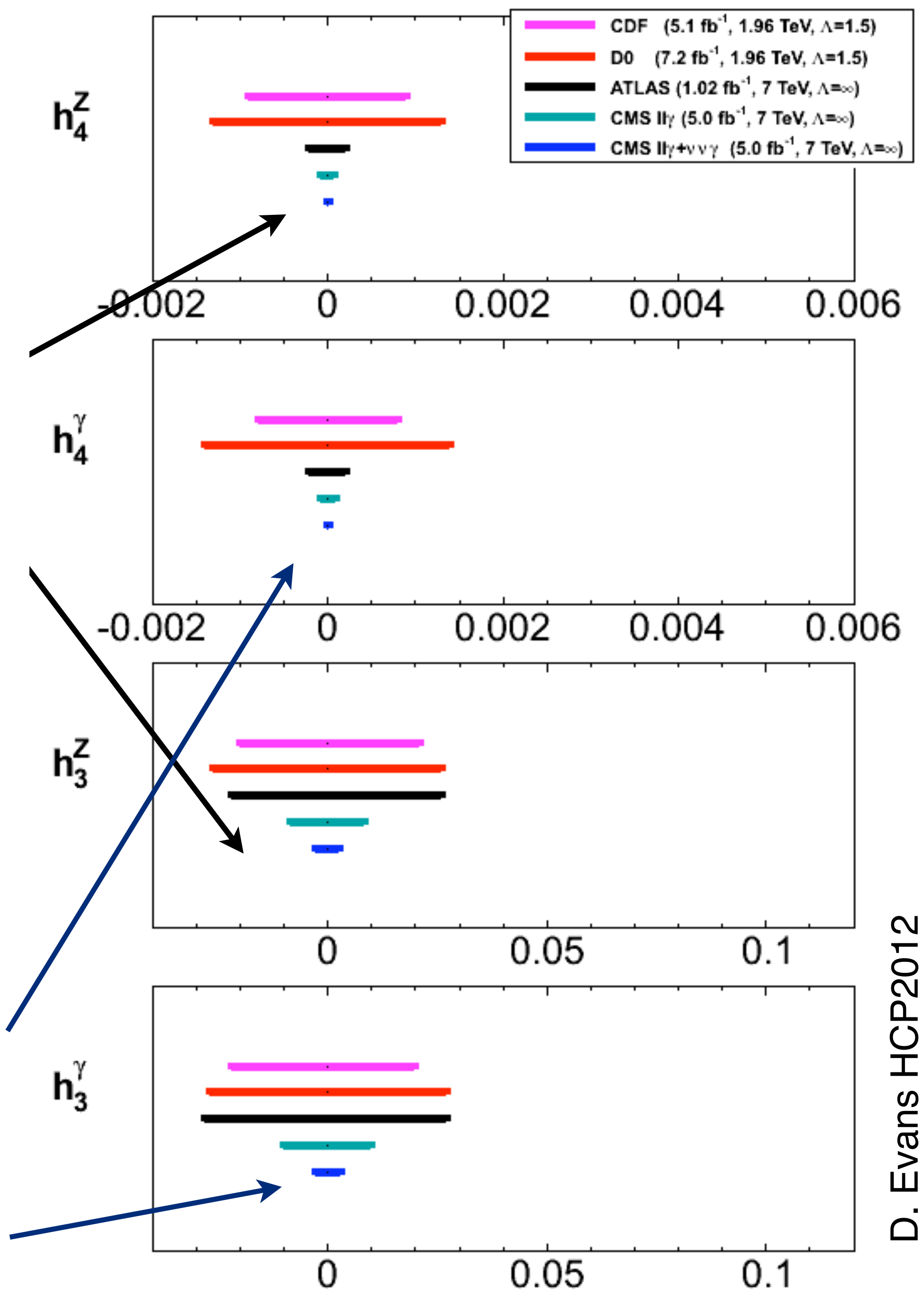
BAUR prediction (NLO+NLL): σ = 21.9 ± 1.1 fb



aTGC combined limit







Combining Zγ→llγ and Zγ→ννγ significantly increases sensitivity to neutral aTGC

Z→4l (7 TeV)

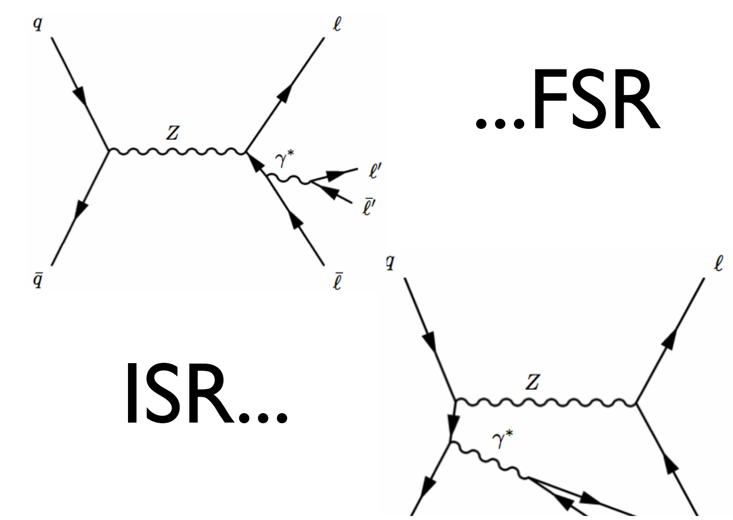
Four leptons in a phase space similar to Higgs search

Can be used for direct calibration of Higgs mass and resolution

Signal definition:

- $80 < m_{4l} < 100$ GeV
- mll > 4 GeV for all possible pairs

Background from Zγ*→4l and Z+X



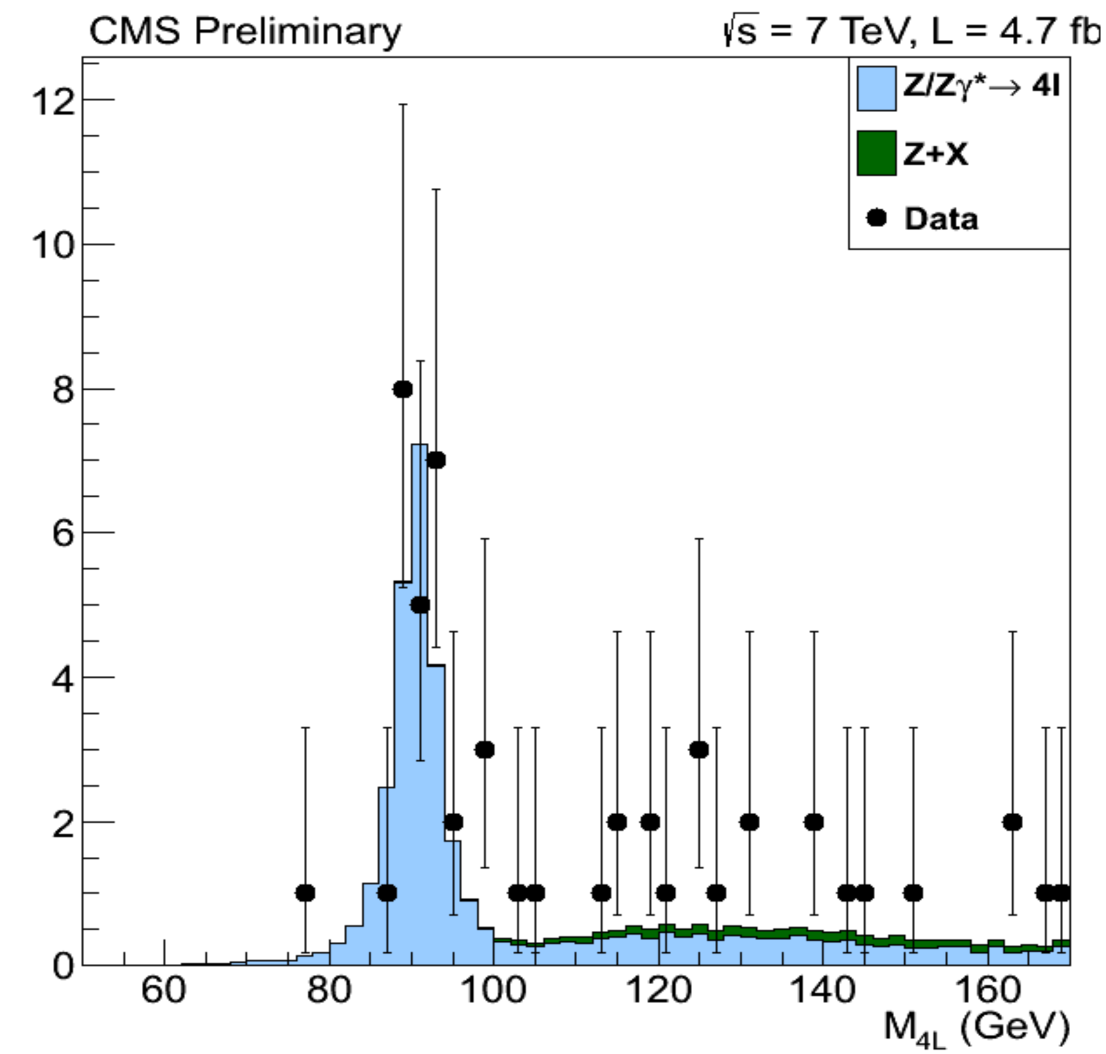
Theory (CalcHEP)

BR: 4.45×10^{-06}

Cross Section: 120 ± 4.92 fb

$$\sigma \times BR(Z \to 4\ell) = 125^{+26}_{-23}(\text{stat})^{+9}_{-6}(\text{syst})^{+7}_{-5}(\text{lumi})\ \text{fb},$$

$$BR(Z \to 4\ell) = 4.4^{+1.0}_{-0.8}(\text{stat}) \pm 0.2(\text{syst}) \times 10^{-6}.$$



Conclusions

CMS has provided many electroweak measurements that test the SM @ 7TeV & 8TeV

- Typical precision comparable to or better than size of NLO corrections
- Most results limited by systematics

So far, electroweak measurements are in agreement with SM predictions over several order of magnitude in production cross-sections

Significant constraints set on pdf and new physics

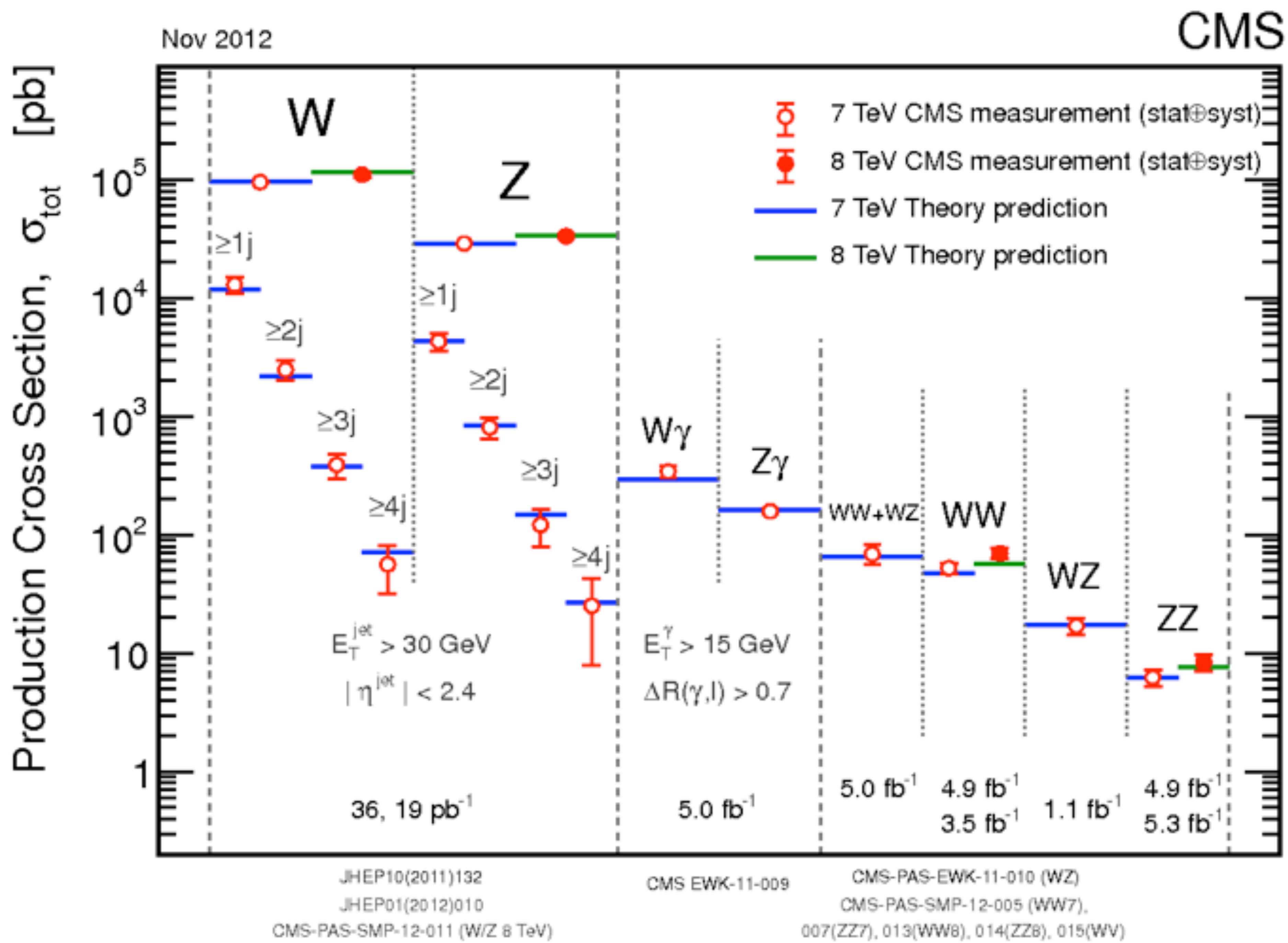
- using differential distribution increase sensitivity
- limits on aTGC most sensitive in most channels

More results on 8 TeV to come...

Stay tuned!

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

CMS EWK results outlook

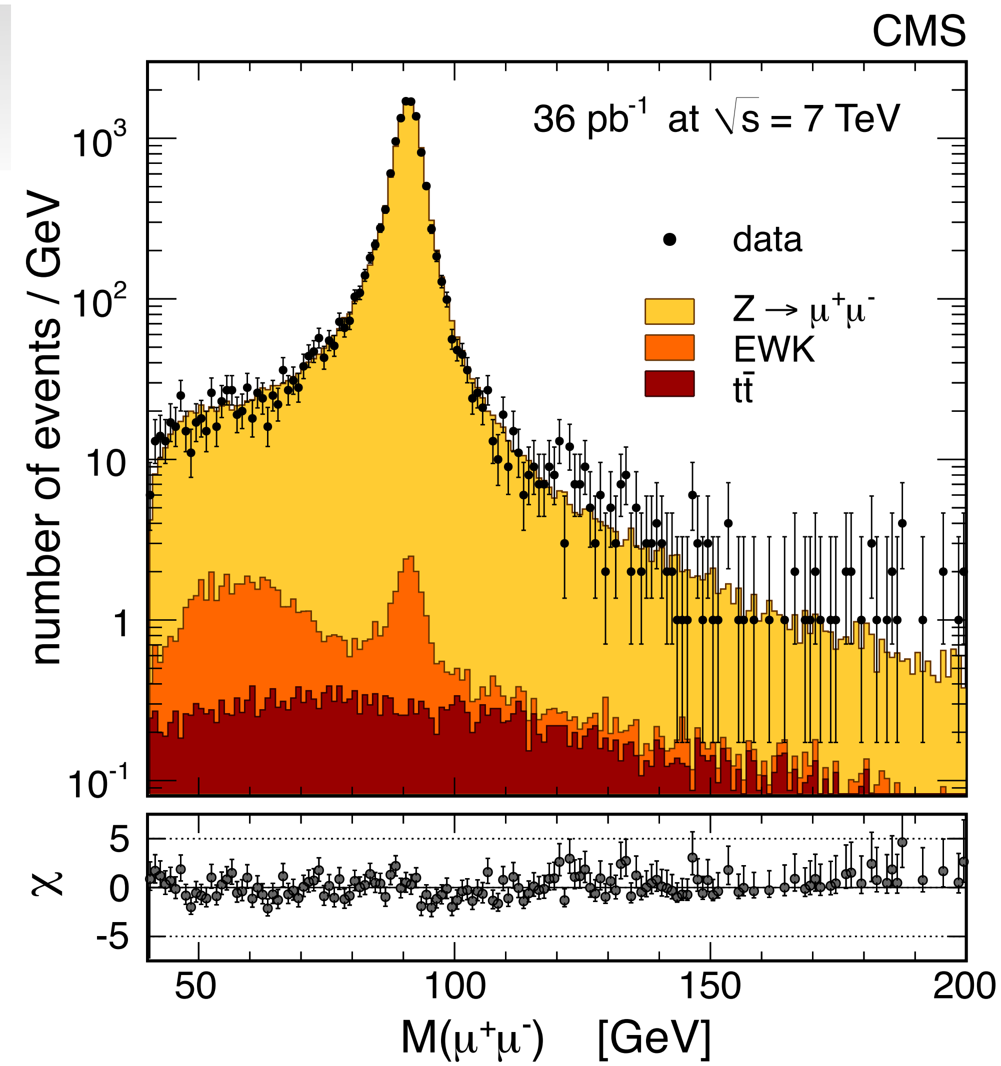


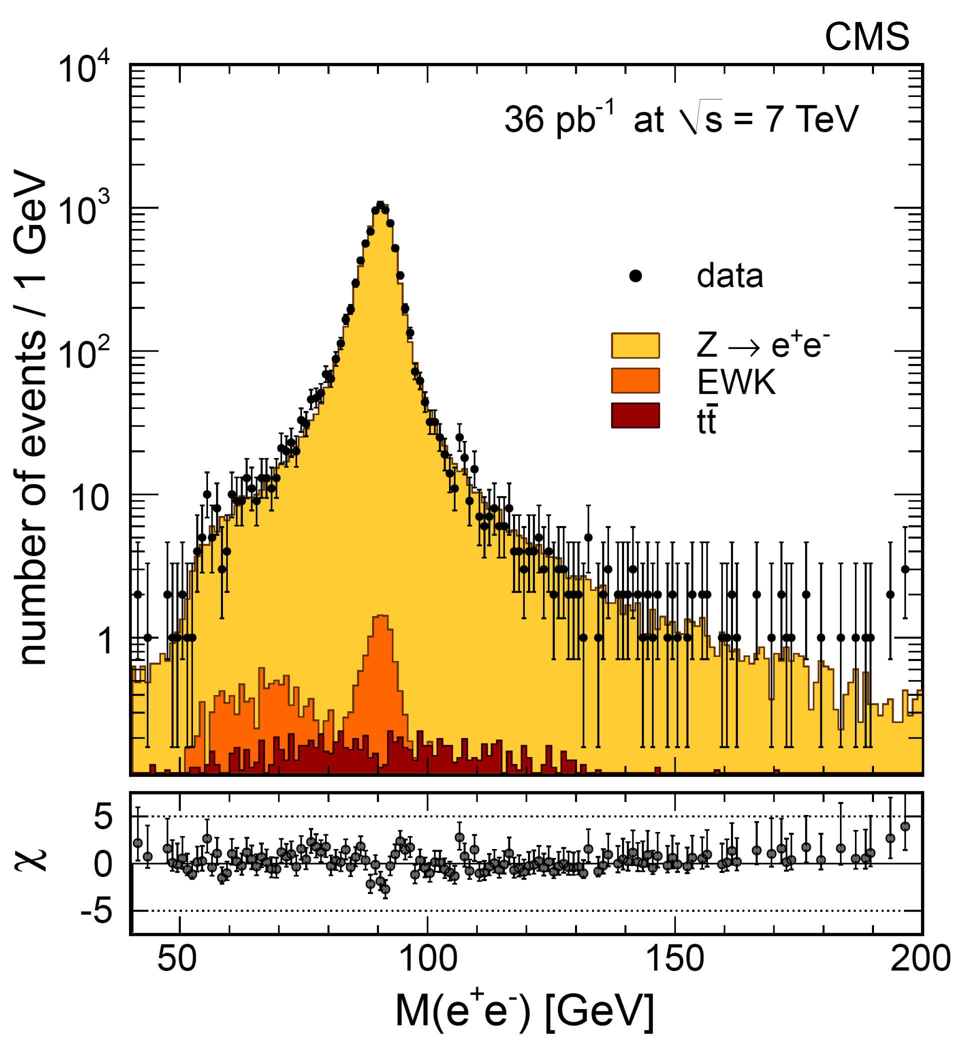
Many thanks to the conference organizers for the nice place and warm atmosfere!

Backup slides

Muons and electrons

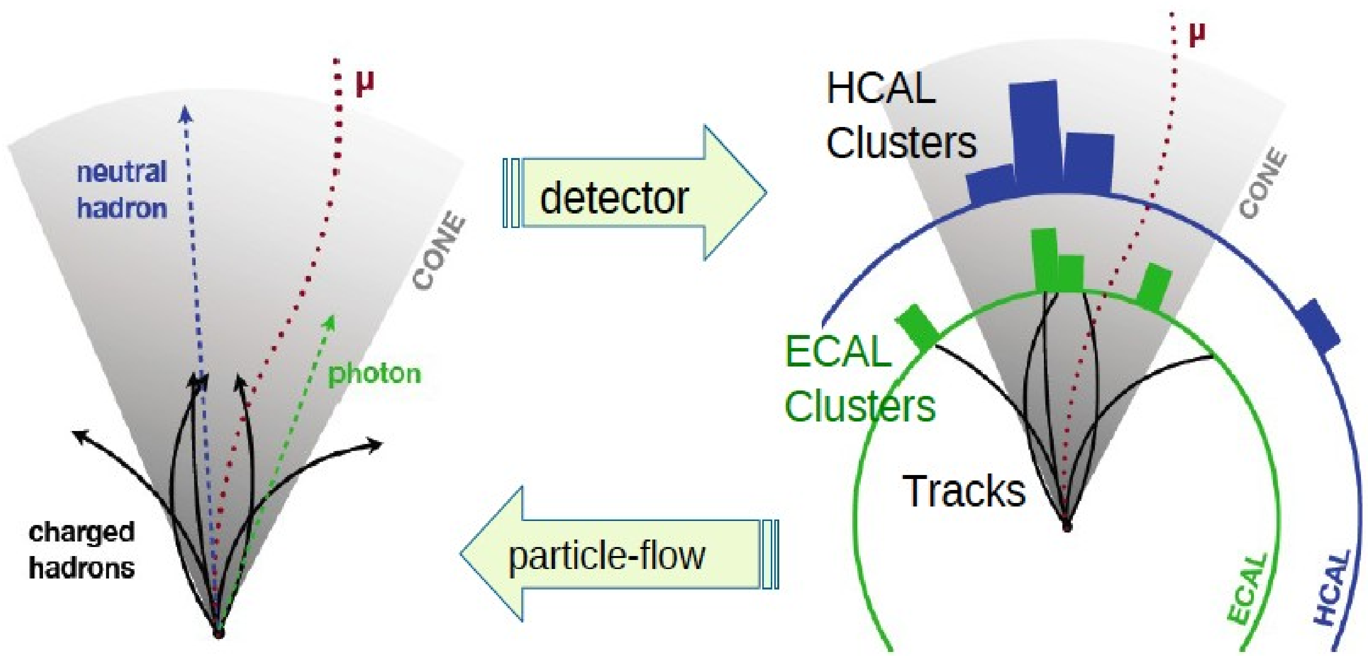
- Muon resolution dominated by inner tracking for p_T<200 GeV. Typical p_T resolution for EWK studies: 1-2%
- Muon chambers: redundant trigger and coverage, muon identification
- Good identification capabilities: muons can be reconstructed both in inner tracker and muon spectrometer

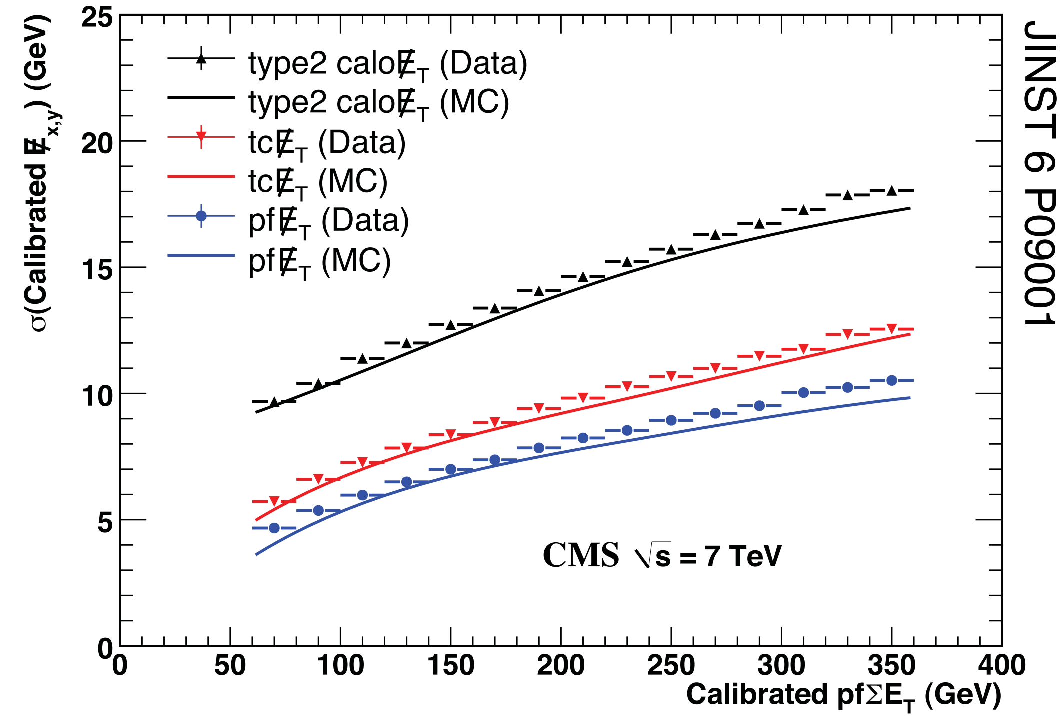




- Excellent energy resolution thanks to the precise $PbWO_4$ crystal calorimeter. Typical E_T resolution for EWK studies: 1%
- Good charge assignment and track matching thanks to fitting techniques that take into account bremsstrahlung emission
- Identification based on shower shape variables, tracking matching and Had./El. ratio (good agreement with the simulations)

MET w/ Particle-flow



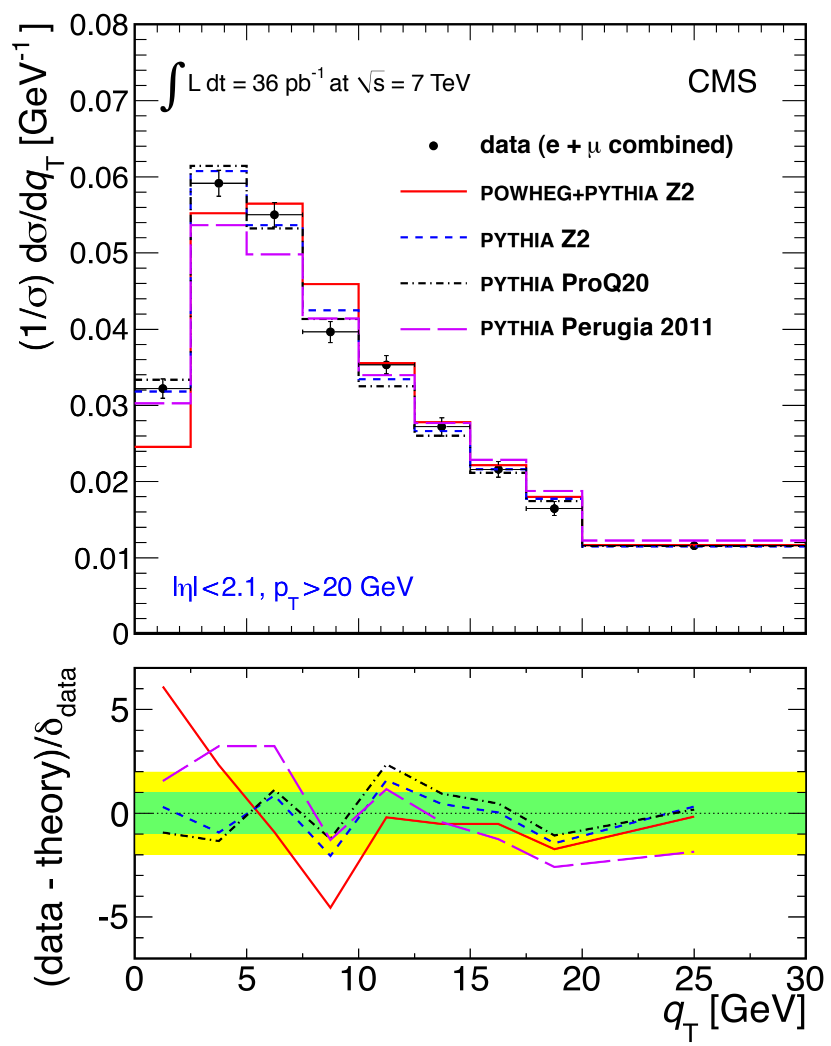


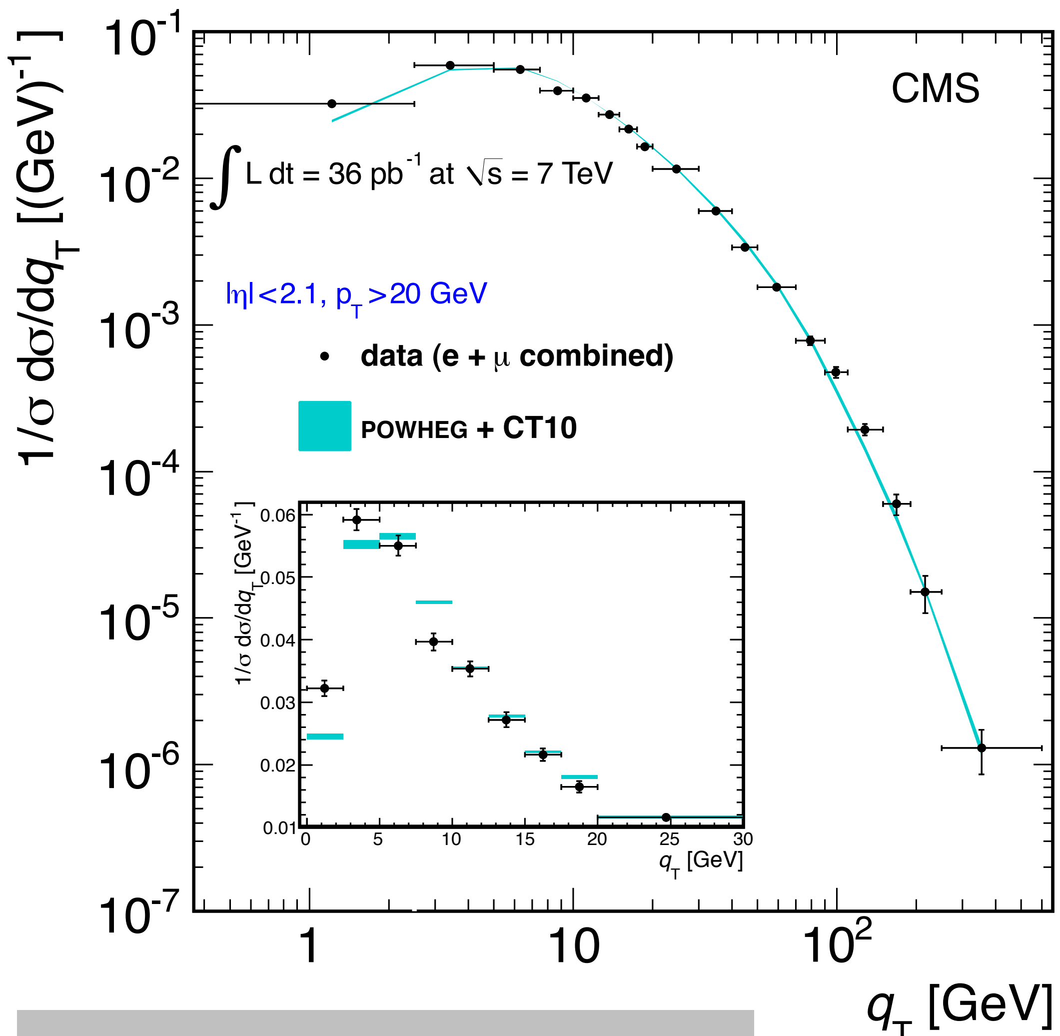
- In CMS, charged particles get well separated due to the huge tracker volume and the high magnetic field (3.8 T)
- CMS has an excellent tracking resolution, able to go to down to very low momenta (~few hundred MeVs)
- CMS has also an excellent electromagnetic calorimeter with good granularity
- In multijet events, only 10% of the energy corresponds to neutral (stable) hadrons

Big improvement in resolution on jet energy and missing transverse energy using Particle-flow

Z p_T and differential x-sec

Probes hard gluon pdf at high p_T while it is dominated by UE tunes at low p_T





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POWHEG+PYTHIA6 shows some discrepancies in the lower region

Boosted-W polarization results

electrons muons

$P_T(W) > 50$ GeV

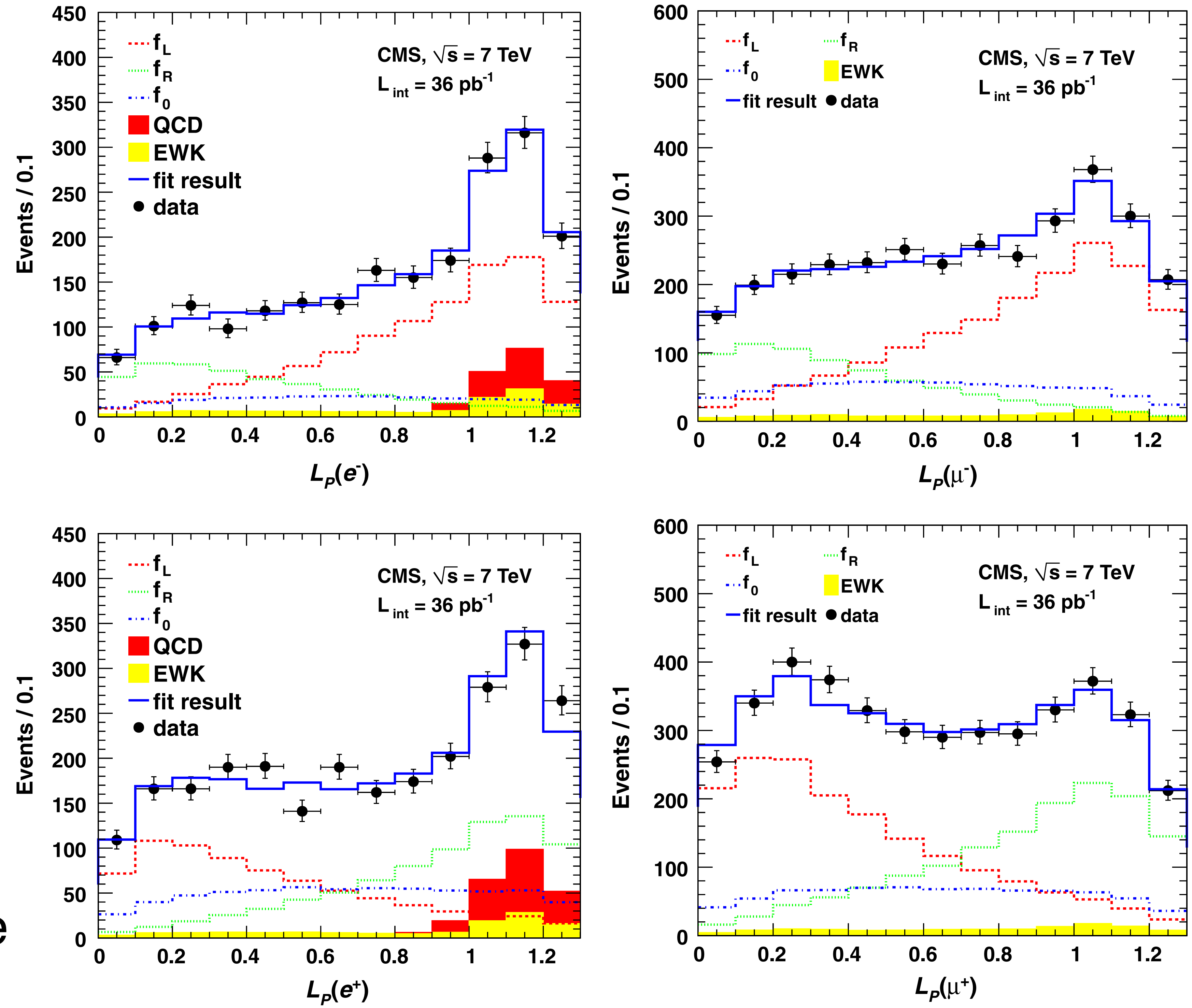
$P_Z(W)$ undetermined

=> can not measure polarization directly from lepton direction in W rest frame

Use instead Lepton Projection:

$$\mathrm{LP} = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$$

where only transverse variable are involved



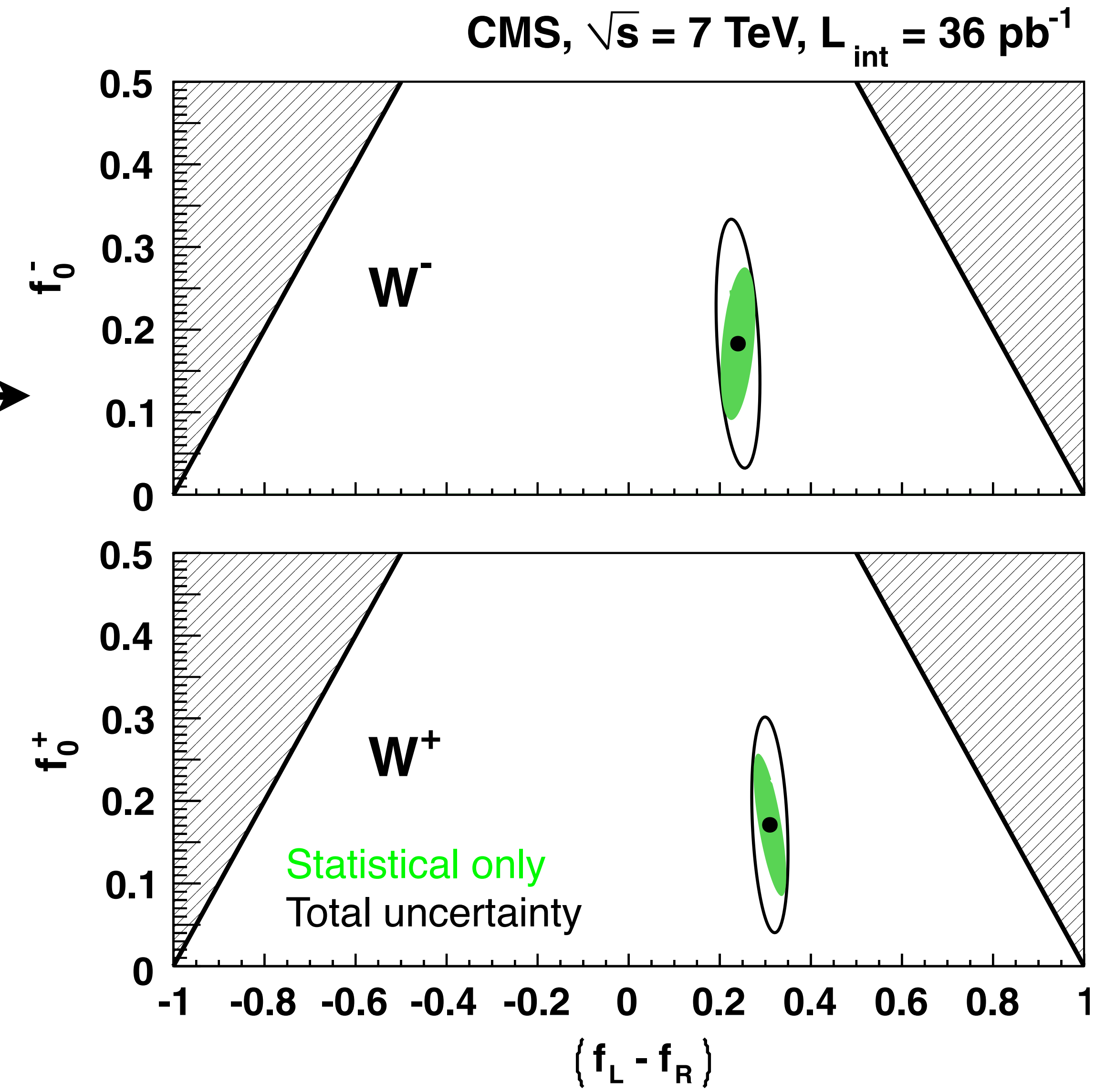
W-

W+

Boosted-W polarization results

Consistent results in muon and electron channels

Muon fit yields the most precise measurement →



Systematics dominated by MET uncertainty

f_L-f_R > 0 => predominant left-handed polarization for W^+ and W^- (respectively 7.8σ and 5.1σ from 0)

With current sensitivity W^+ and W^- polarization do not differ significantly

Results in agreement with *Bern Z. et al. Phys.Rev.D84:034008,2011* →

	CMS	NLO	ME+PS	LO
$W^+ (f_L - f_R)$	$0.300 \pm 0.031 \pm 0.034$	0.308	0.283	0.309
$W^- (f_L - f_R)$	$0.226 \pm 0.031 \pm 0.050$	0.248	0.222	0.235
$W^+ f_0$	$0.192 \pm 0.075 \pm 0.089$	0.200	0.187	0.198
$W^- f_0$	$0.162 \pm 0.078 \pm 0.136$	0.193	0.179	0.190

aTGC

- LEP parameterization (Δ is defined as a difference from the SM prediction)
  - light Higgs boson scenario

$$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \cdot tan^2\theta_w \;\; \text{and} \;\; \lambda_Z = \lambda_\gamma = \lambda$$

  - Effectively reduces number of unknown variables to three
    - For Wγ this reduces the number of free parameters to two

- Hagiwara-Ishihara-Szalapski-Zeppenfeld (HISZ)
  - Assumes the coupling between SU(2) × U(1) fields and Higgs double are the same

$$\Delta\kappa_Z = \frac{1}{2}\Delta\kappa_\gamma(1 - tan^2\theta_w), \Delta g_1^Z = \frac{\Delta\kappa_\gamma}{2cos^2\theta_w} \;\; \text{and} \;\; \lambda_Z = \lambda_\gamma = \lambda$$

  - Reduces number of free parameters to two

- Equal coupling relation
  - Two free parameters

$$\Delta g_1^Z = \Delta g_1^\gamma = 0$$

$$\Delta\kappa_Z = \Delta\kappa_\gamma \;\; \text{and} \;\; \lambda_Z = \lambda_\gamma = \lambda$$

Summary slide by Y. Maravin

Zγ→ννγ bkg and efficiency estimates

- Backgrounds

Source	Number of selected events
Misidentified jets	11.2 ± 2.8
Beam-gas processes	11.1 ± 5.6
Misidentified electrons	3.5 ± 1.5
$W\gamma$	3.3 ± 1.0
$\gamma\gamma$	0.6 ± 0.3
γ+jet	0.5 ± 0.2
Total	30.2 ± 6.5
$Z\gamma \to \nu\nu\gamma$ (NLO)	45.3 ± 6.9
data	73

Misidentified jets → using EM-enriched multi-jets events

Beam-gas processes → from a fit to seed timing distribution

Misidentified electrons → inverting pixel hits requirements

$W\gamma$, $\gamma\gamma$, γ+jet → from MC

- Efficiency
  - Trigger turn-on from prescaled triggers
  - Photon-id from T&P using Z → ee
  - Veto efficiency from W→eν and Z → ee