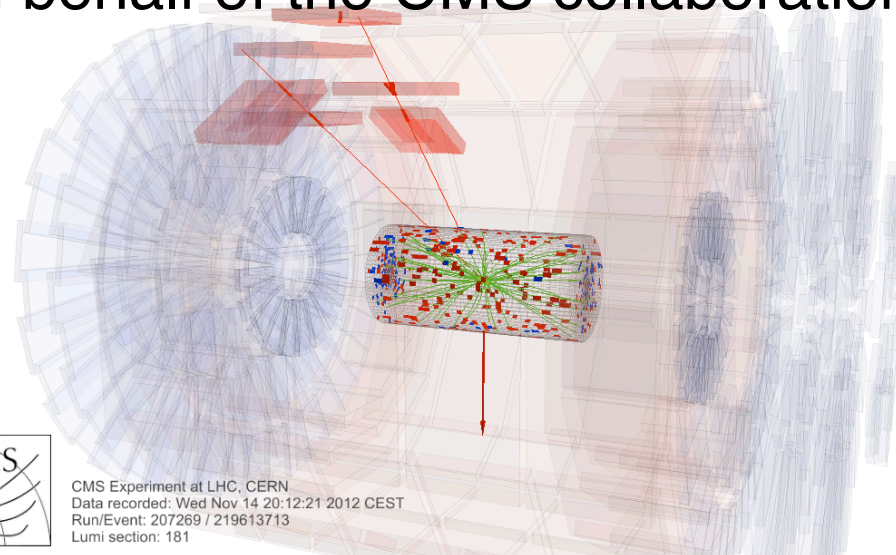


New diboson results at CMS

**28/10/2014 - MBI 2014 conference,
Brookhaven National Laboratory**

Nicolas Chanon - ETH Zürich
on behalf of the CMS collaboration



CMS Experiment at LHC, CERN
Data recorded: Wed Nov 14 20:12:21 2012 CEST
Run/Event: 207269 / 219613713
Lumi section: 181



Outline

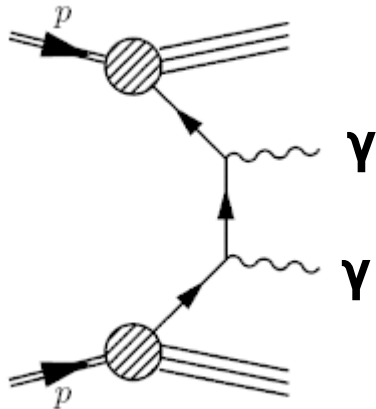
New diboson results from CMS:

- PAPER** - $VZ \rightarrow 2l2b$ at 8 TeV - SMP-13-011
- PAPER** - $ZZ \rightarrow 4l$ at 8 TeV - SMP-13-005
- PAS** - $ZZ \rightarrow 2l2\nu$ at 7 and 8 TeV - SMP-12-016
- PAPER** - $\gamma\gamma$ production at 7 TeV - SMP-13-001
- NEW !** - $Z\gamma$ production at 8 TeV - SMP-13-014

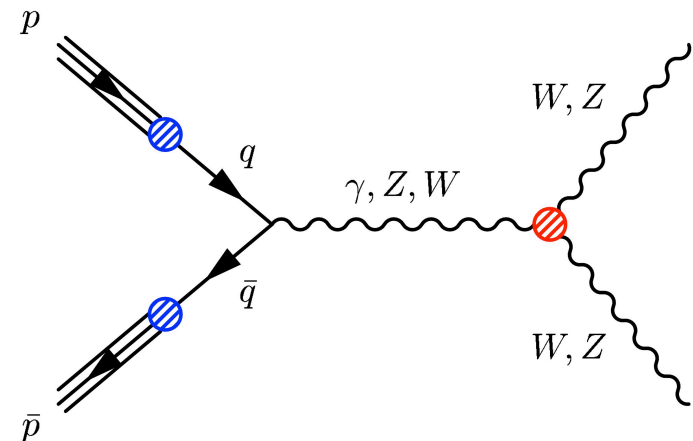
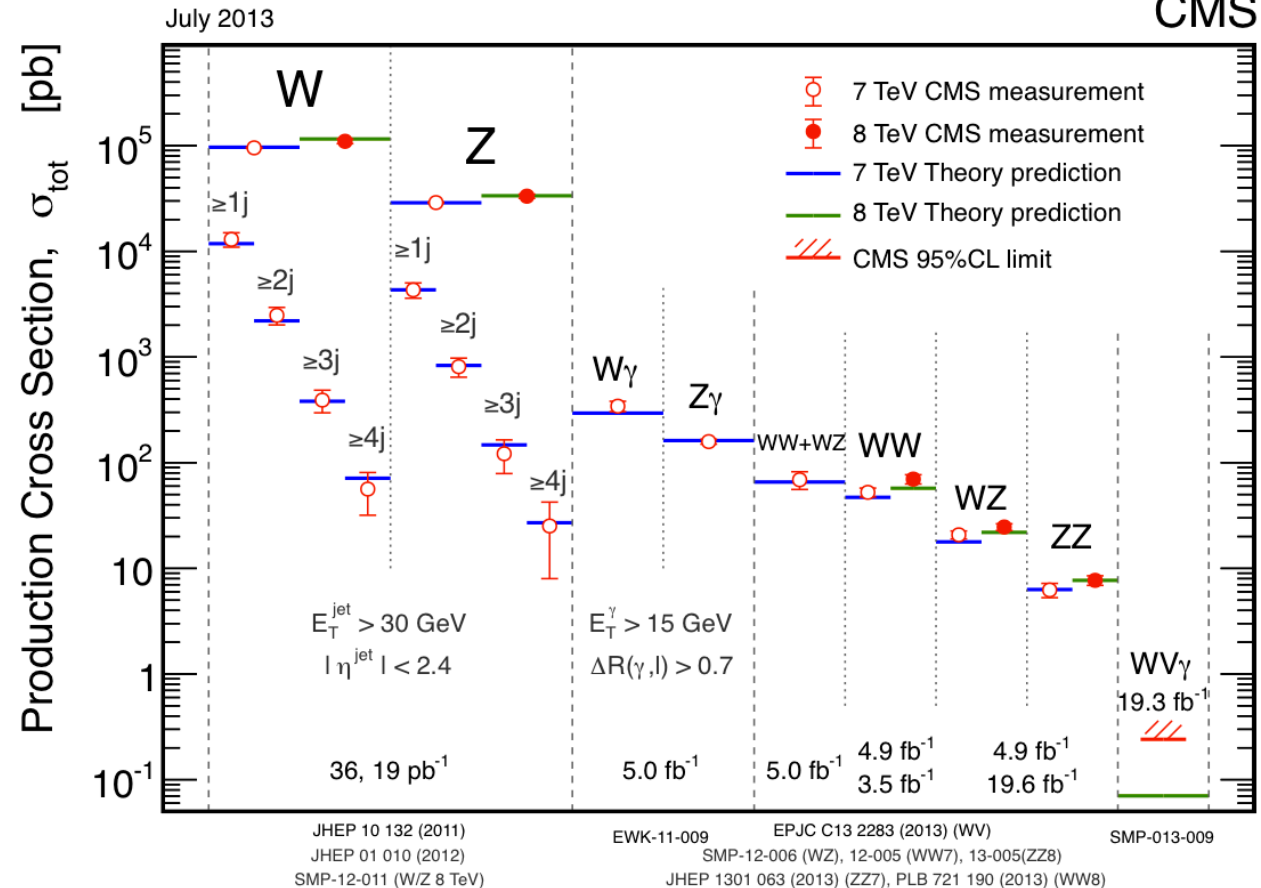


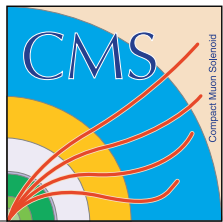
Diboson physics

- **Cross-section measurement:** important test of perturbative QCD
- VV processes are background to Higgs and new physics searches



- **Anomalous triple gauge boson couplings** searches
- Probes Electroweak sector and search deviation from standard model
- Neutral TGC not allowed in the SM



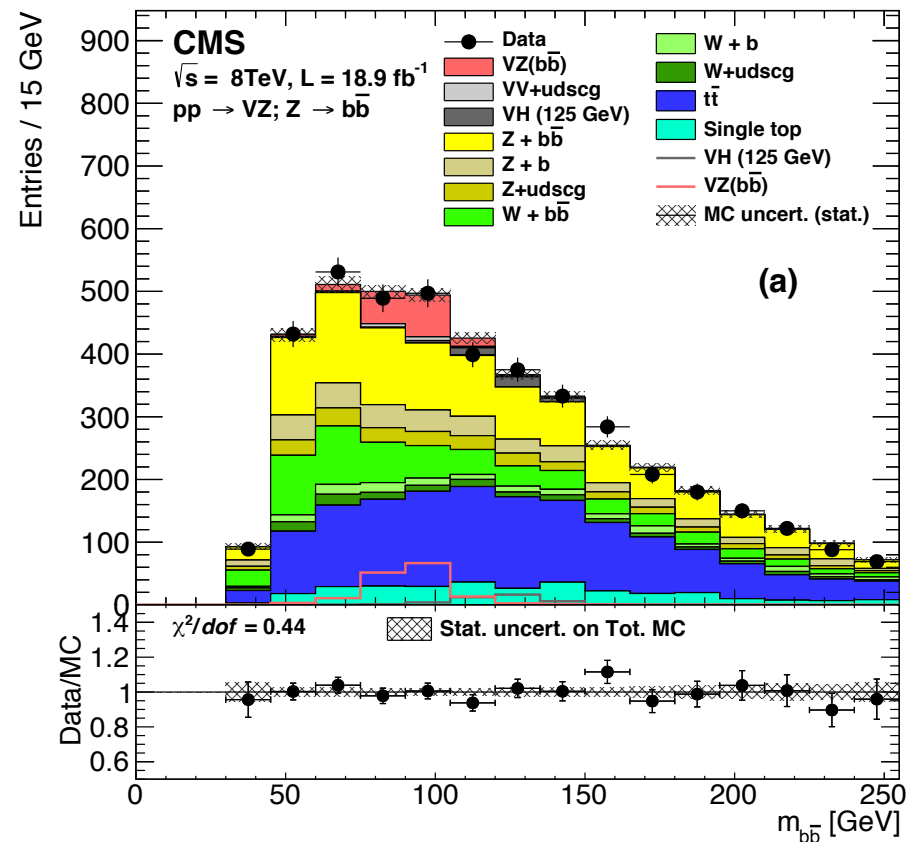
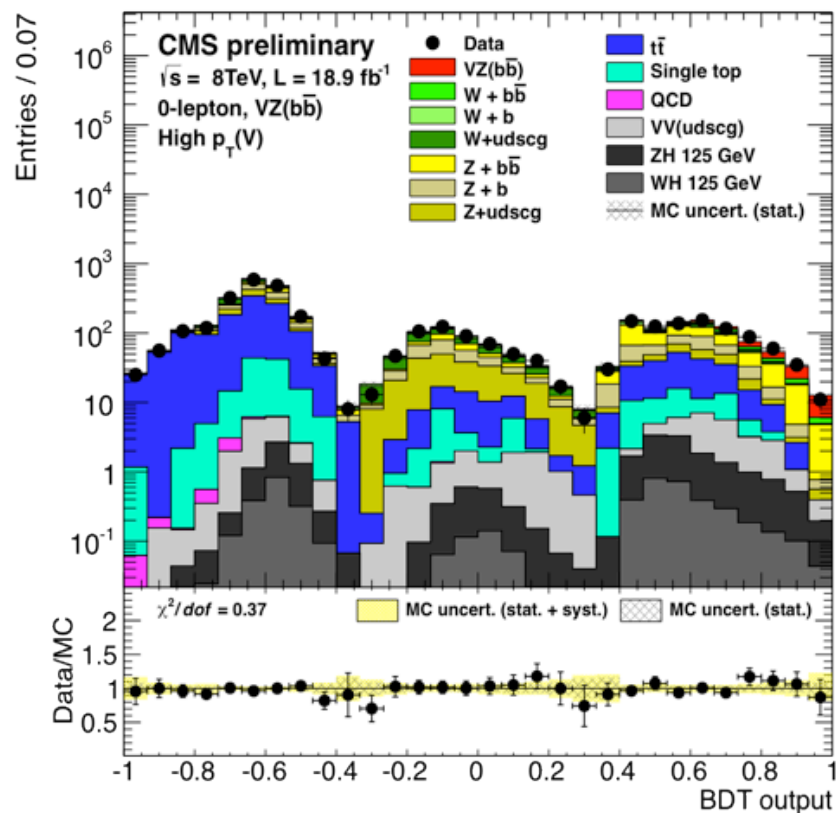


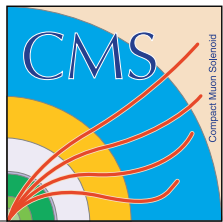
VZ(2b) cross-section

Eur. Phys. J. C 74 (2014) 2973

PAPER

- VZ(bb) (V=W,Z) Final state: 2l2b, lvbb, vvbb (l=e,μ)
- Main backgrounds: Zbb, Wbb, ttbar,
- Multivariate analysis:
 - Use lepton and jet kinematics, b-tagging and mET information
 - Use 3 “staggered” BDT, trained against ttbar, W/Z+jets, and all background
- Signal clearly visible with Mbb distribution



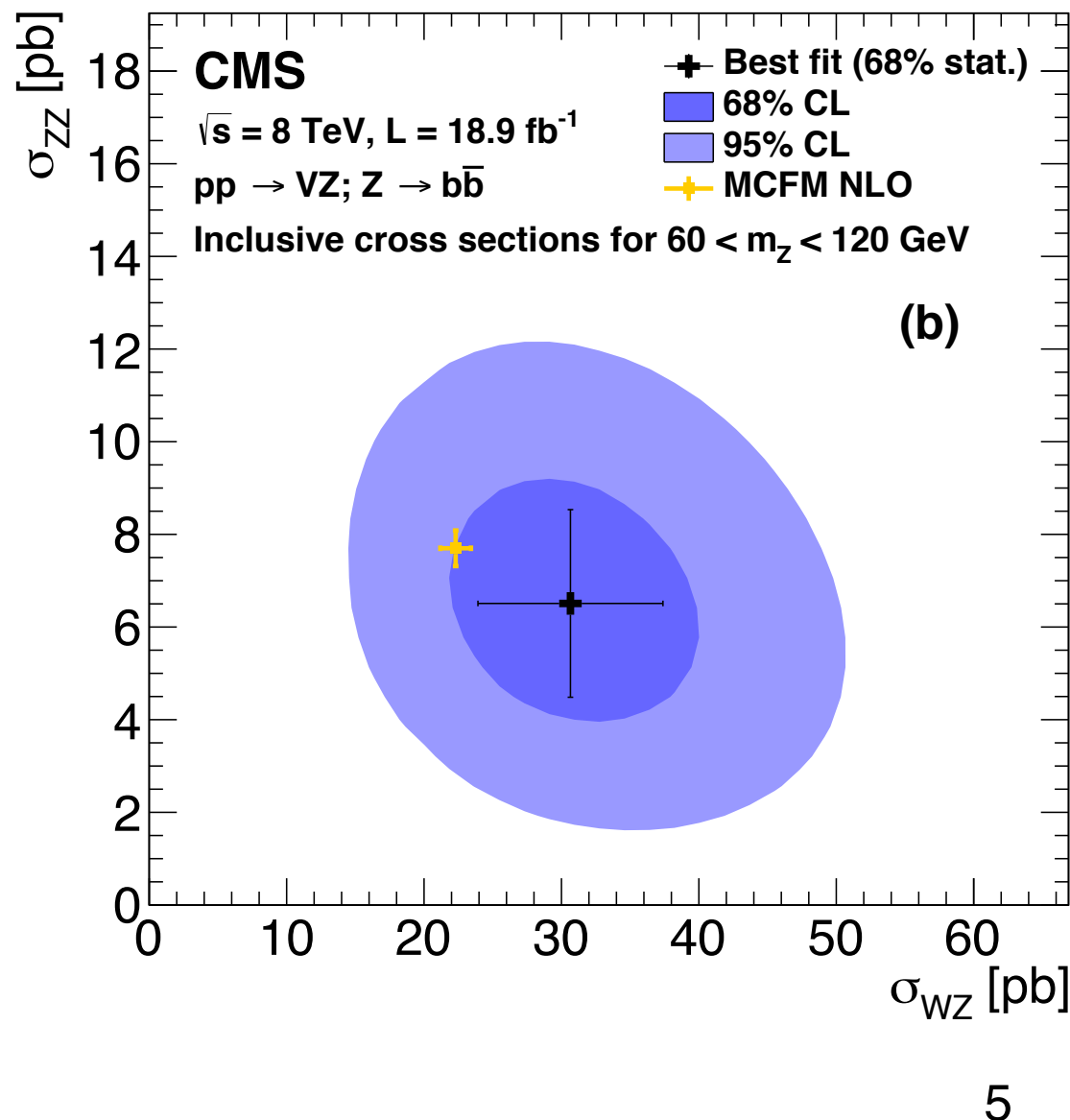
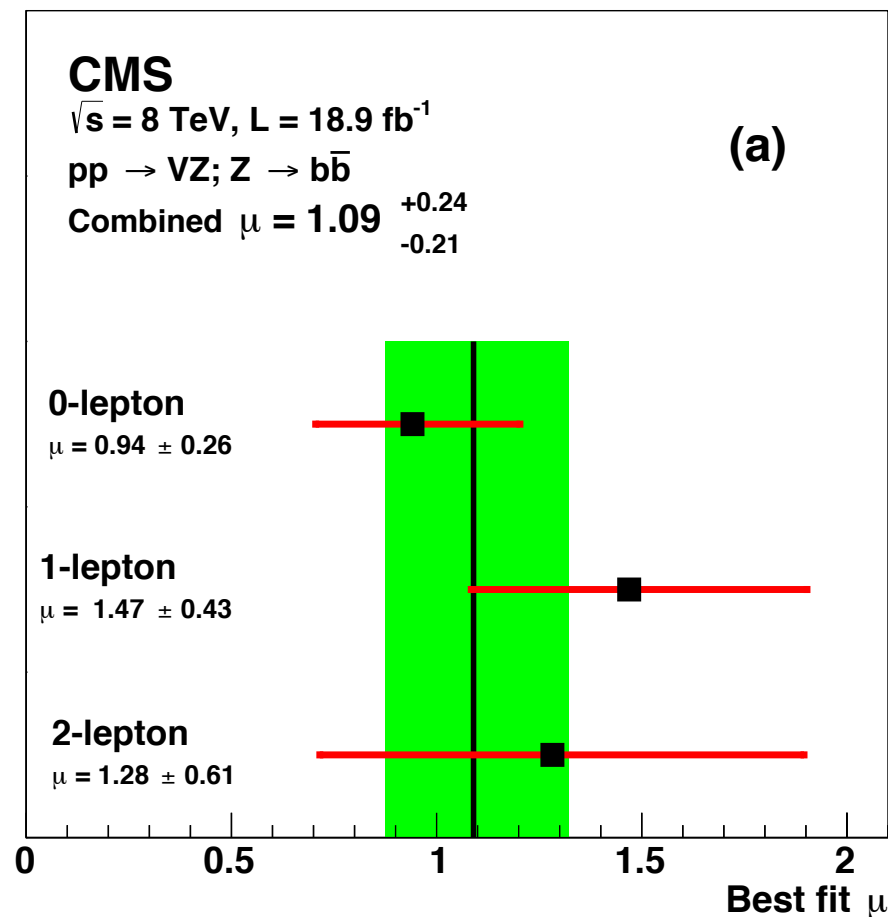


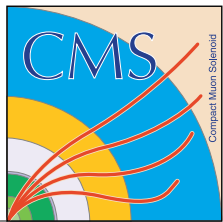
VZ(2b) cross-section

Eur. Phys. J. C 74 (2014) 2973

PAPER

- Significance: **>6 σ with BDT** (4 σ with Mjj)
- Best sensitivity from Z(vv) then W(lv)
- Cross-section compatible with SM NLO predictions



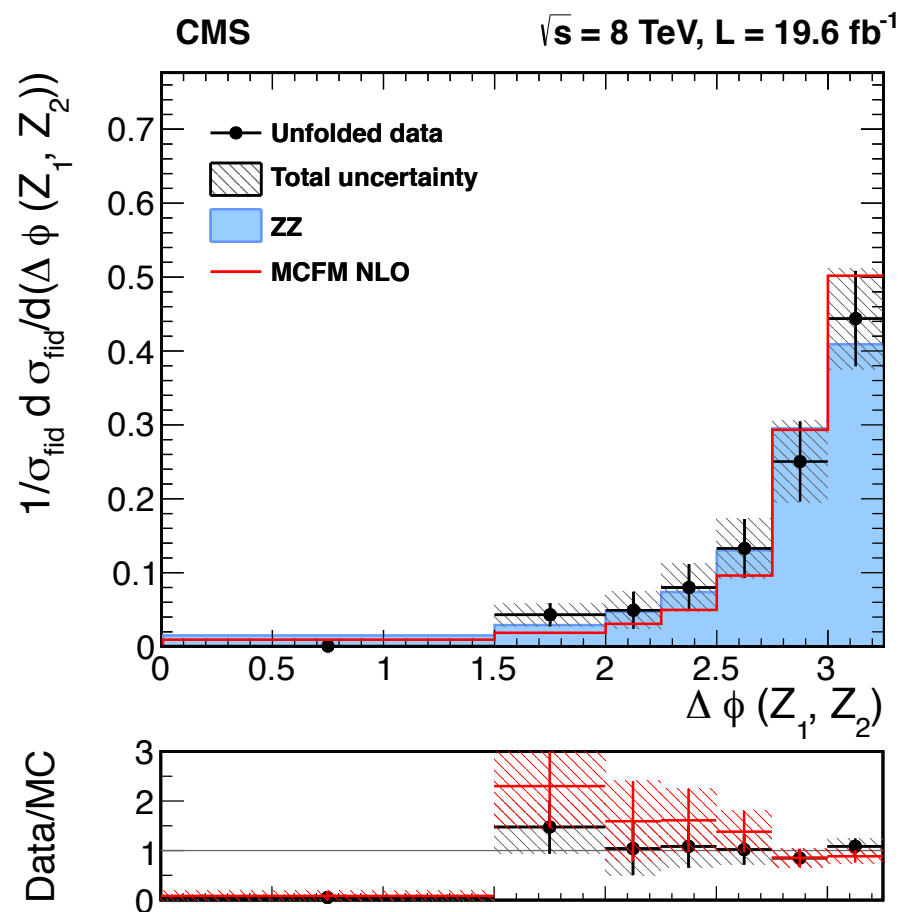
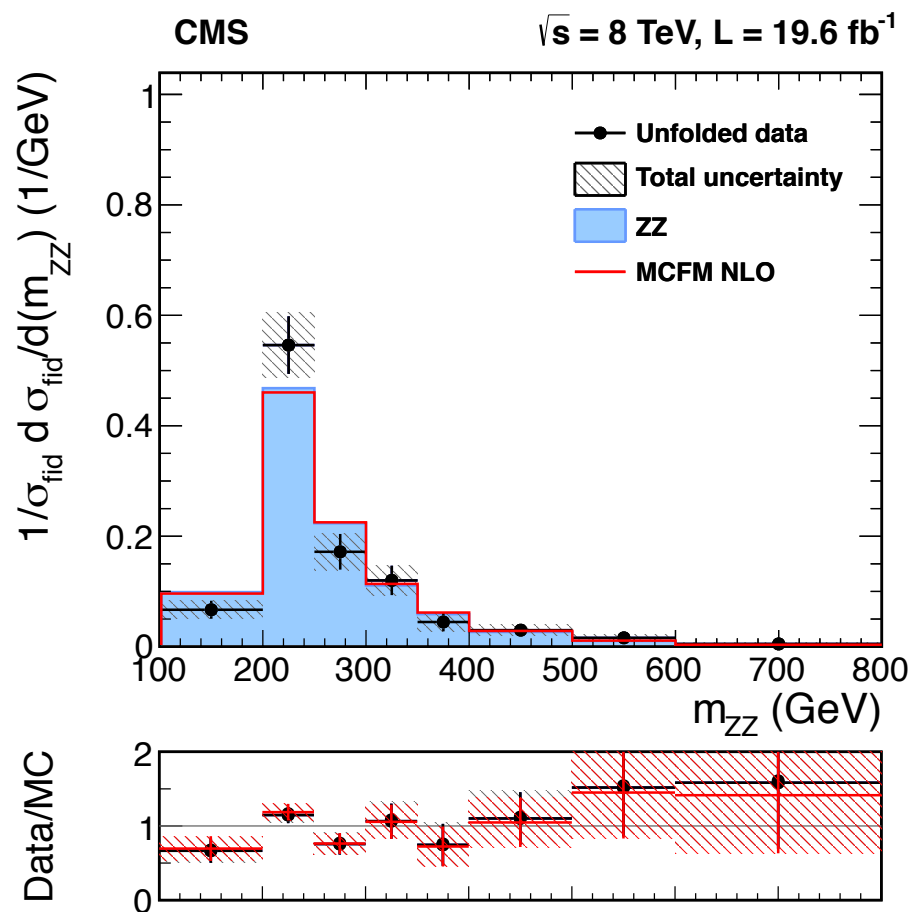


$ZZ \rightarrow 4l$ cross-section

arxiv:1406.0113 (submitted to PLB)

PAPER

- Final states: $4e$, $2e2\mu$, 4μ , $2l2\tau$
- 2 pair of opposite sign isolated leptons at the vertex consistent with onshell Z's.
- Main background: Z +jets (estimated with inverted isolation), $t\bar{t}$, WZ
- Differential cross-sections measured for 8 observables





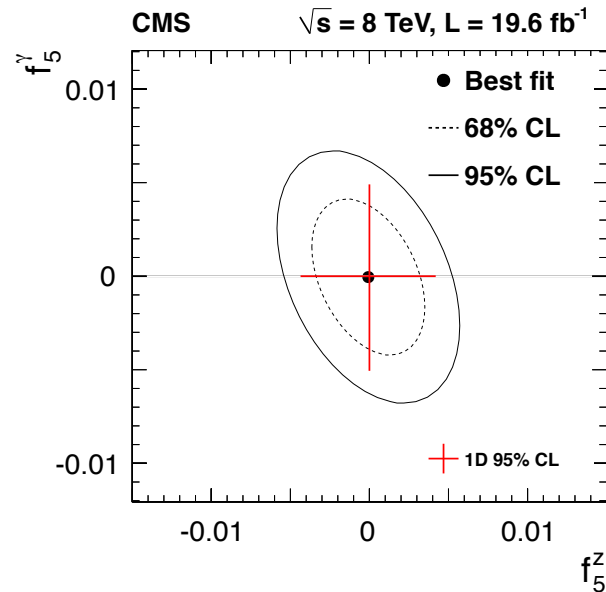
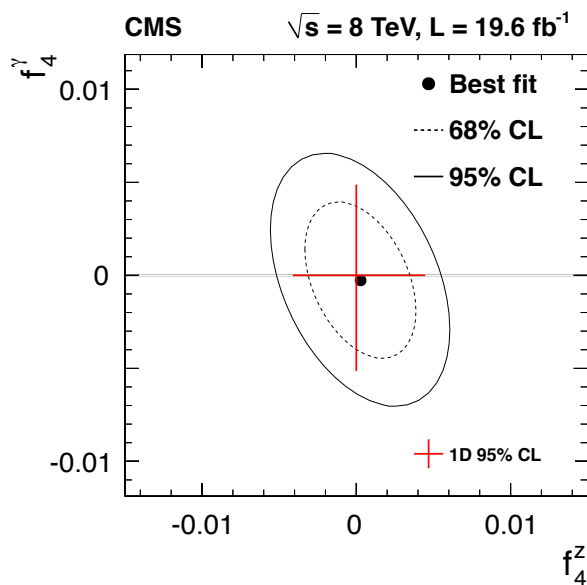
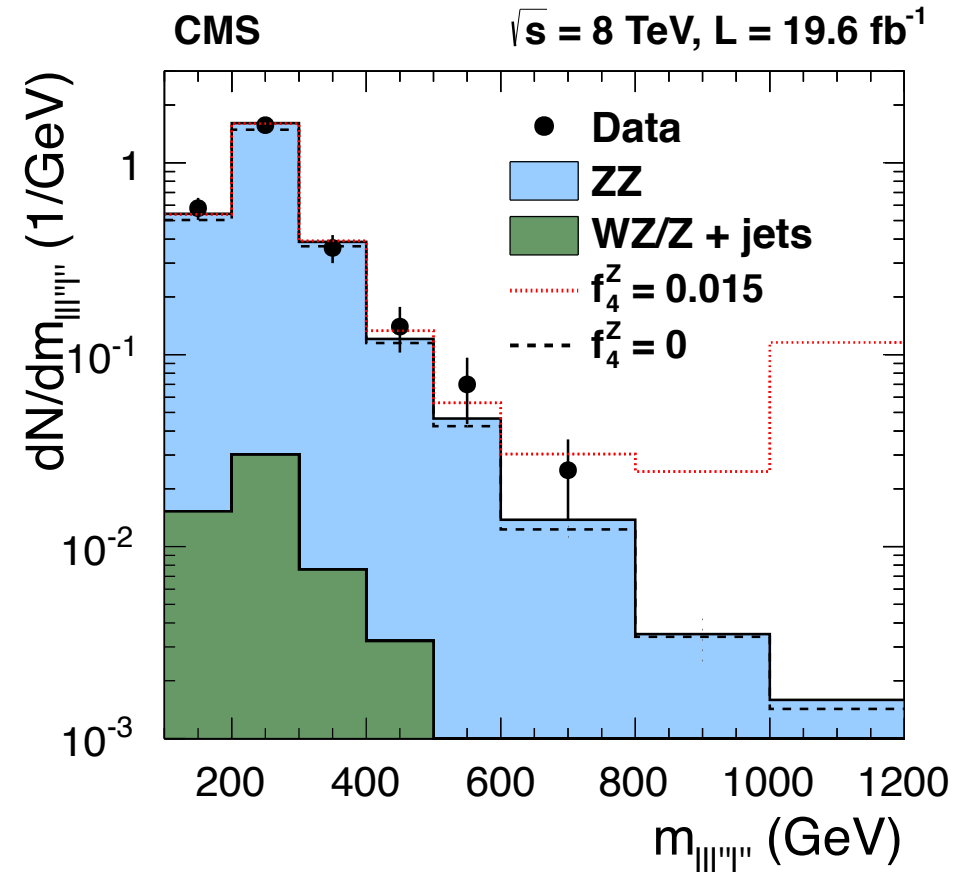
ZZ→4l aTGC searches

arxiv:1406.0113 (submitted to PLB)

PAPER

aTGC searches

- Search for anomalous vertices $ZZ\gamma$ and ZZZ
- Anomalous couplings enhance boson pT
- Search performed for looking excess in data at high ZZ invariant mass
- Results improves over 7 TeV results by a factor ~ 2.5

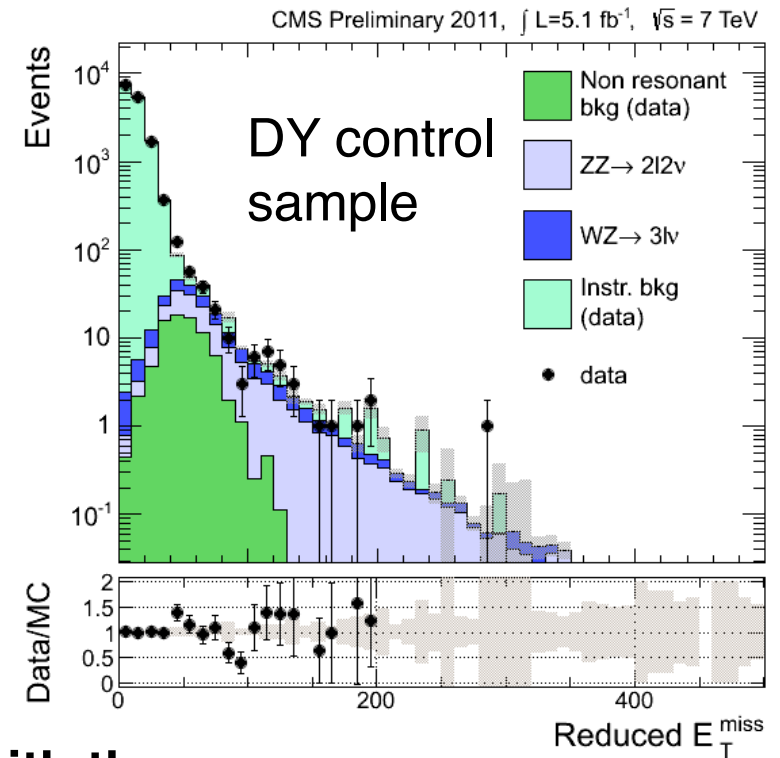
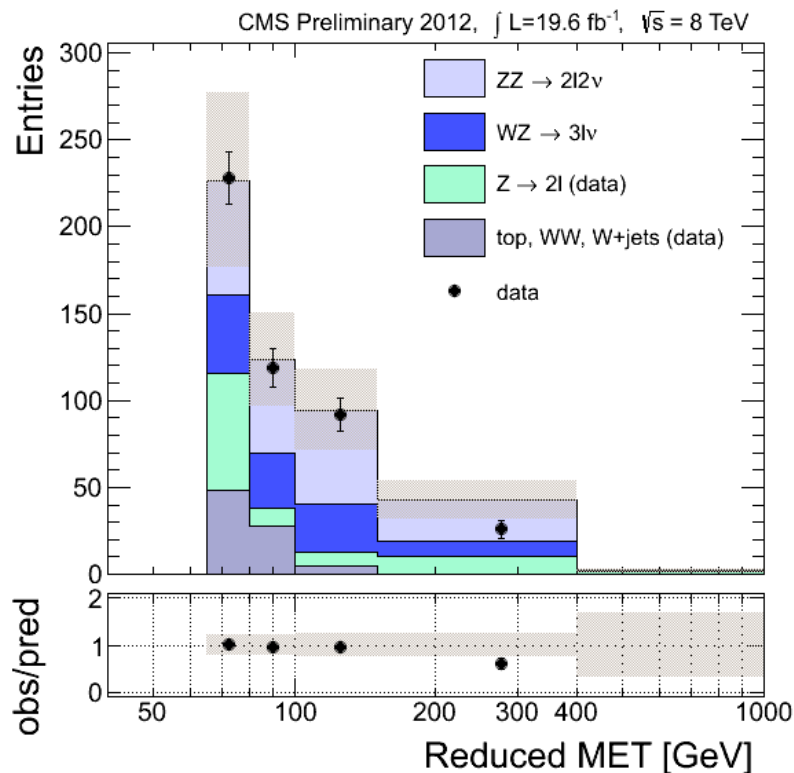




$ZZ \rightarrow 2l2\nu$

SMP-12-016, 4.9fb^{-1} at 7 TeV and 19.6fb^{-1} at 8 TeV

- Final state: $2e+m\text{ET}$, $2\mu+m\text{ET}$
- DY estimated from photon control sample in data
- Top, WW, estimated $e\mu$ sample and Z mass sideband in data
- Cross-section measured using a reduced mET variable



Good agreement with theory:

- 7 TeV

Data $\sigma = 5.0_{-1.4}^{+1.5}$ (stat) $_{-1.0}^{+1.3}$ (syst) ± 0.2 (lumi) pb

NLO $\sigma = 6.83_{-0.10}^{+0.13}$ pb

- 8 TeV

Data $\sigma = 6.8_{-0.8}^{+0.8}$ (stat) $_{-1.4}^{+1.8}$ (syst) ± 0.3 (lumi) pb

NLO $\sigma = 8.38_{-0.12}^{+0.15}$ pb

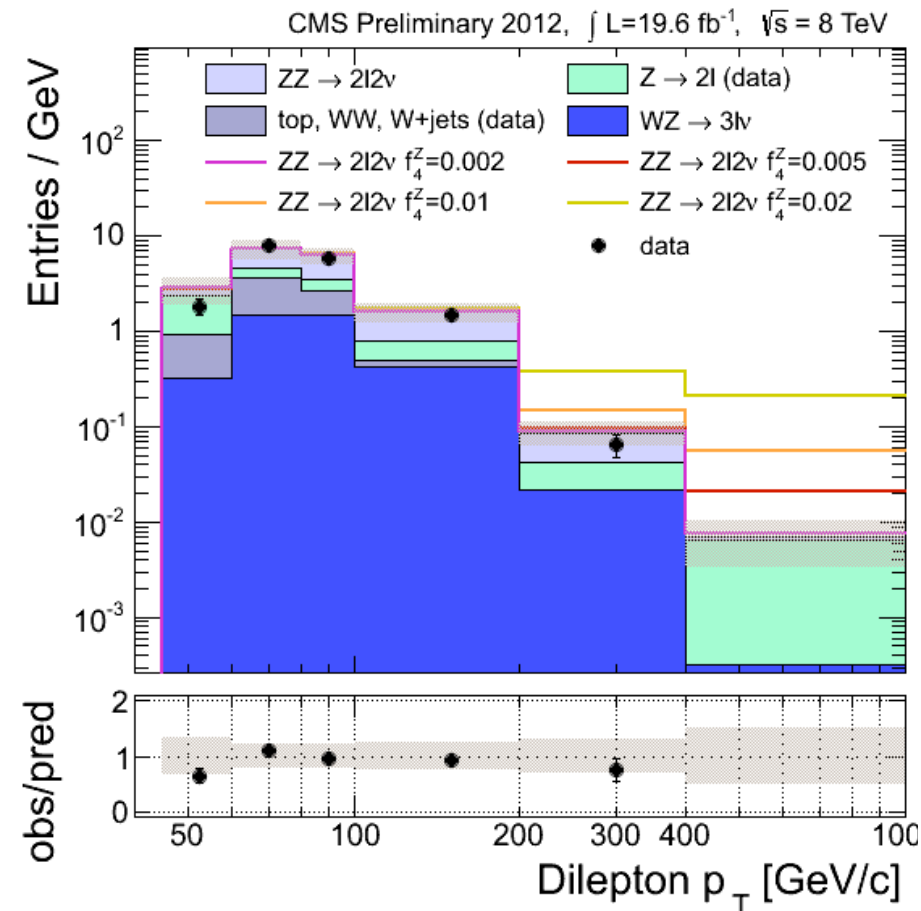


$ZZ \rightarrow 2l2\nu$

SMP-12-016, 4.9fb^{-1} at 7 TeV and 19.6fb^{-1} at 8 TeV

aTGC searches:

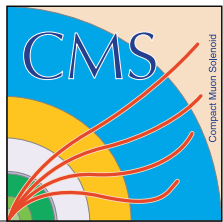
- Search for anomalous vertices $ZZ\gamma$ and ZZZ
- Anomalous couplings enhance boson p_T : search performed using Z p_T
- Results with $ZZ(2l2\nu)$ are $\sim 25\%$ better than $ZZ(4l)$ results



Nov 2013

$ZZ\gamma, ZZZ$ vertices				ATLAS Limits	CMS Prel. Limits
f_4^γ		ZZ	-0.015 - 0.015	4.6 fb^{-1}	
		ZZ	-0.004 - 0.004	19.6 fb^{-1}	
		ZZ (2l2v)	-0.004 - 0.003	$5.1, 19.6 \text{ fb}^{-1}$	
f_4^Z		ZZ	-0.013 - 0.013	4.6 fb^{-1}	
		ZZ	-0.004 - 0.004	19.6 fb^{-1}	
		ZZ (2l2v)	-0.003 - 0.003	$5.1, 19.6 \text{ fb}^{-1}$	
f_5^γ		ZZ	-0.016 - 0.015	4.6 fb^{-1}	
		ZZ	-0.005 - 0.005	19.6 fb^{-1}	
		ZZ(2l2v)	-0.004 - 0.004	$5.1, 19.6 \text{ fb}^{-1}$	
f_5^Z		ZZ	-0.013 - 0.013	4.6 fb^{-1}	
		ZZ	-0.005 - 0.005	19.6 fb^{-1}	
		ZZ (2l2v)	-0.004 - 0.003	$5.1, 19.6 \text{ fb}^{-1}$	

aTGC Limits @95% C.L.

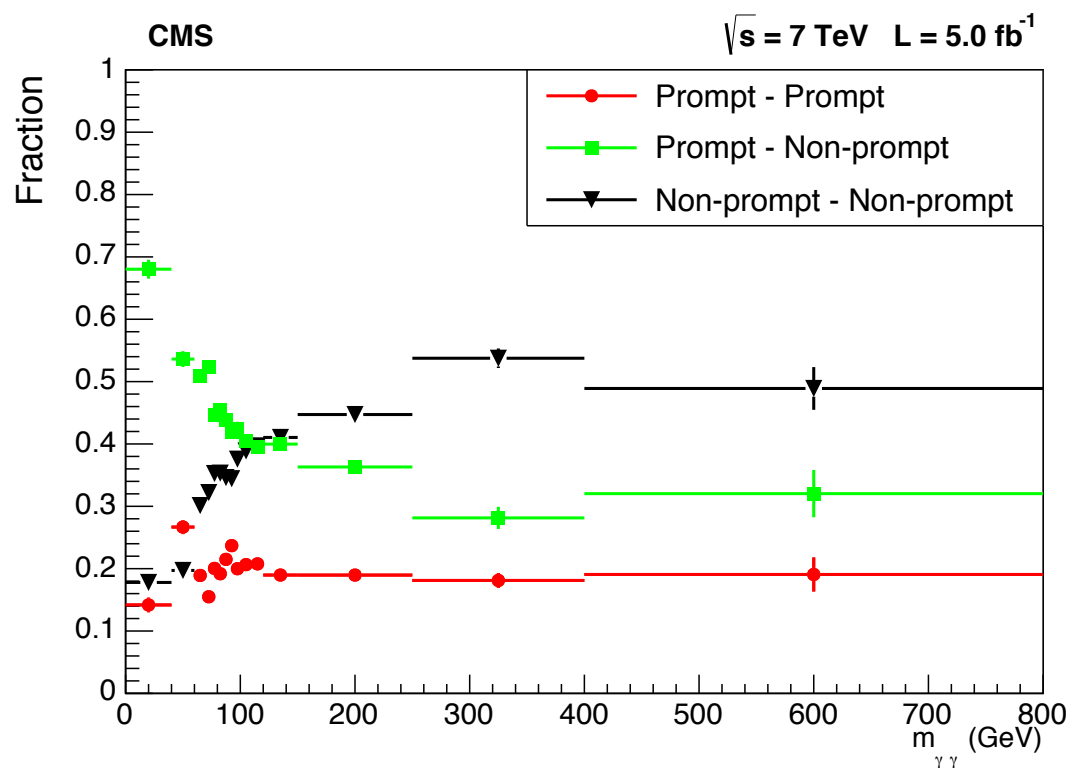
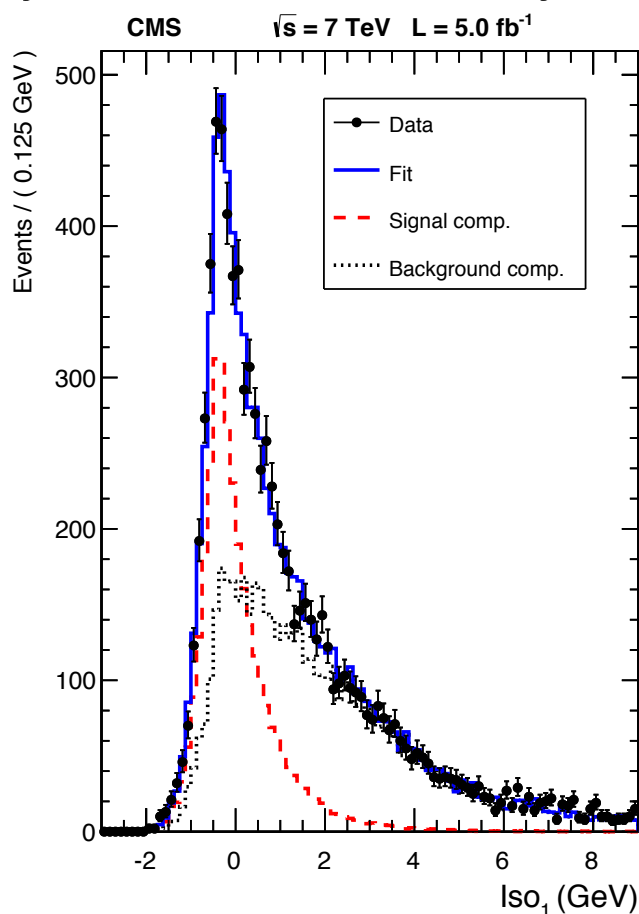


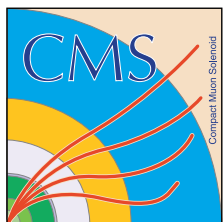
Diphoton cross-section

arxiv:1405.7225 (accepted by EPJC)

PAPER

- **Kinematical range:** $|\eta_{\gamma}| < 2.5$, $E_{T,\gamma 1} > 40$, $E_{T,\gamma 2} > 25$ GeV, $\Delta R(\gamma_1, \gamma_2) > 0.45$
- **Differential cross-section** measured as a function of $M_{\gamma\gamma}$, $P_{T,\gamma\gamma}$, $\Delta\Phi(\gamma_1, \gamma_2)$, $\cos(\theta^*)$
- **Background:** boosted neutral mesons ($\pi^0 \rightarrow \gamma\gamma$) reconstructed as a single γ (fake)
- **Method:** particle-flow photon isolation template to subtract statistically the background
- Purely data-driven: $\sim 10\%$ systematic uncertainties

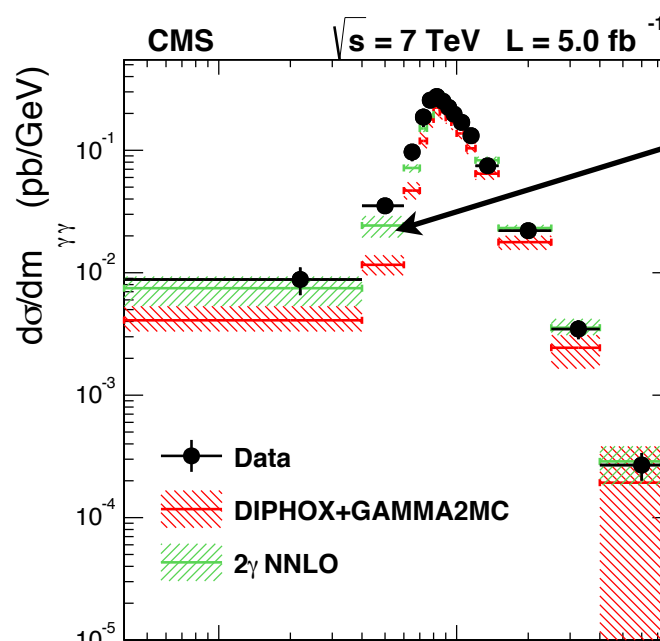
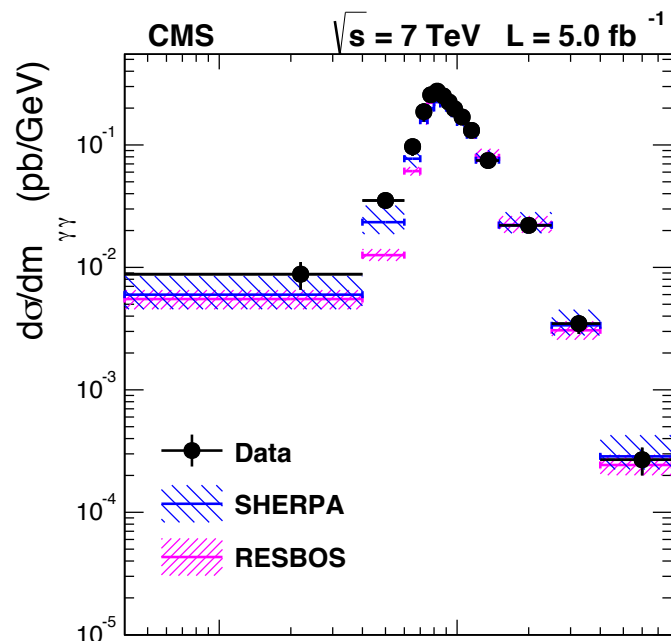




Diphoton cross-section

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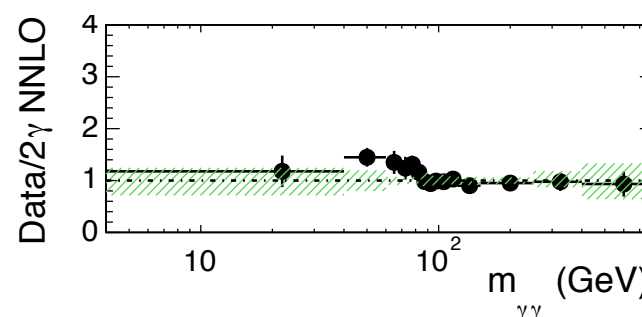
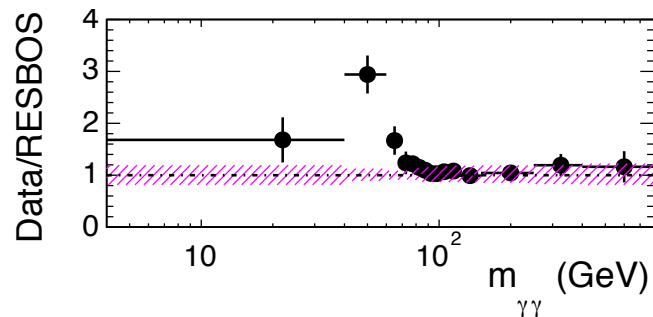
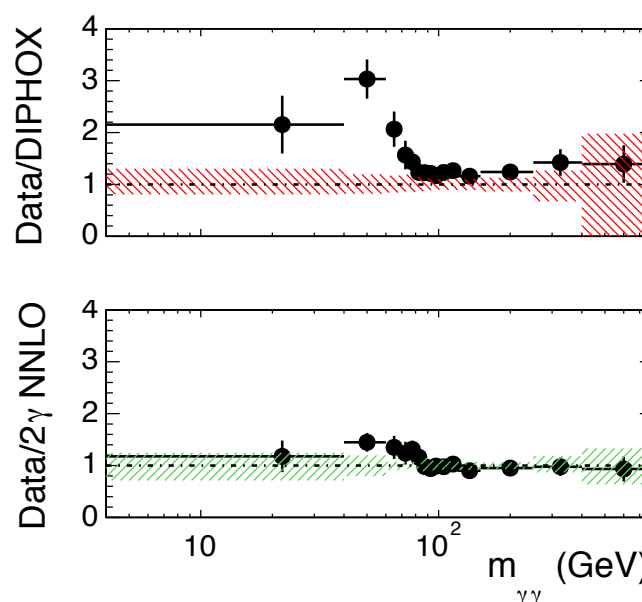
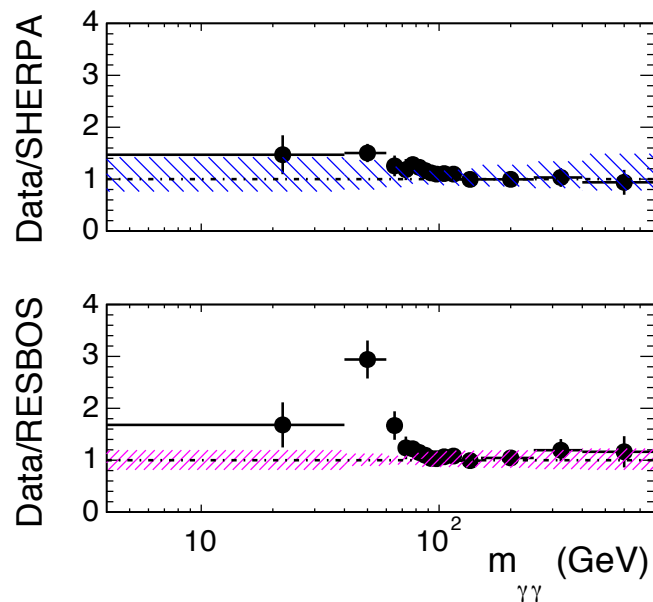
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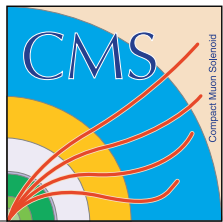


NNLO enhanced region

- **NNLO** predictions improve a lot the data/MC agreement

- **Sherpa** (with up to 3 matrix-element extra-jets) shows also a good agreement

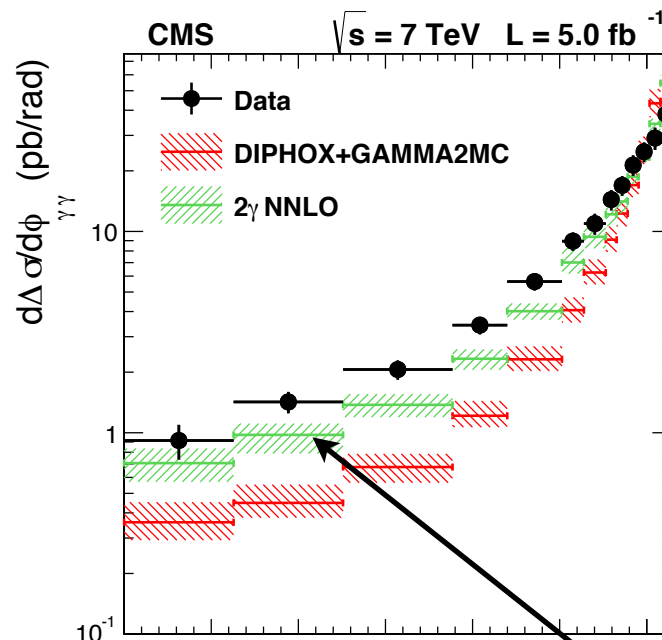
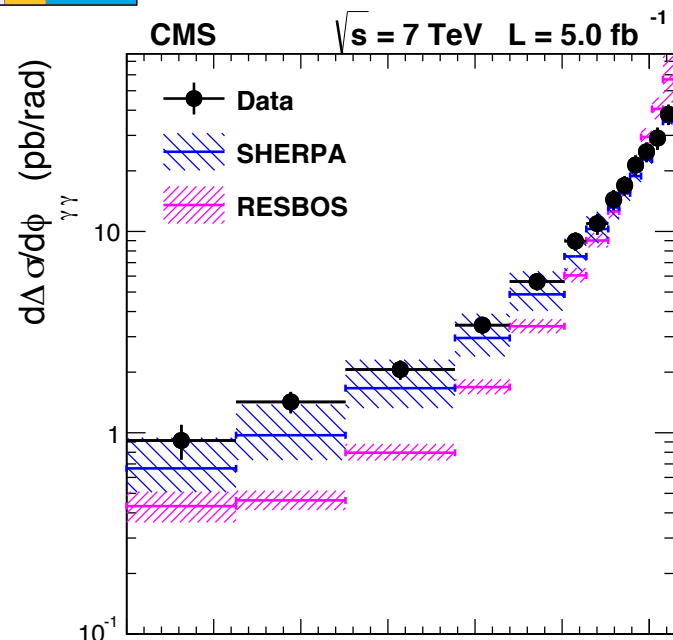




Diphoton cross-section

arxiv:1405.7225 (accepted by EPJC)

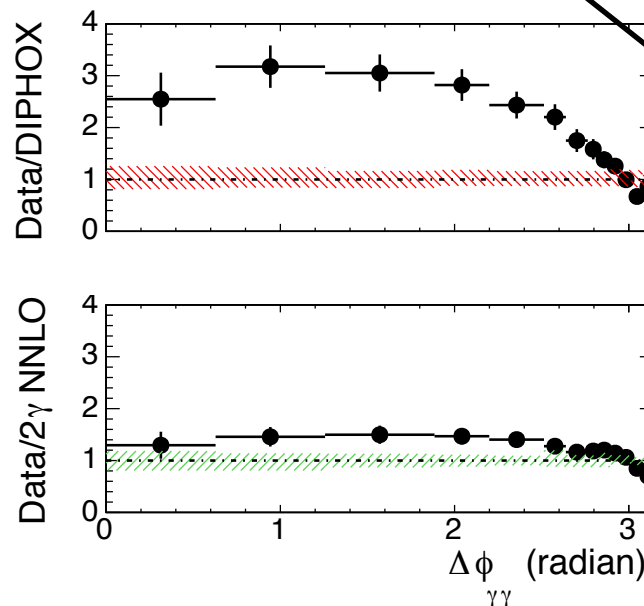
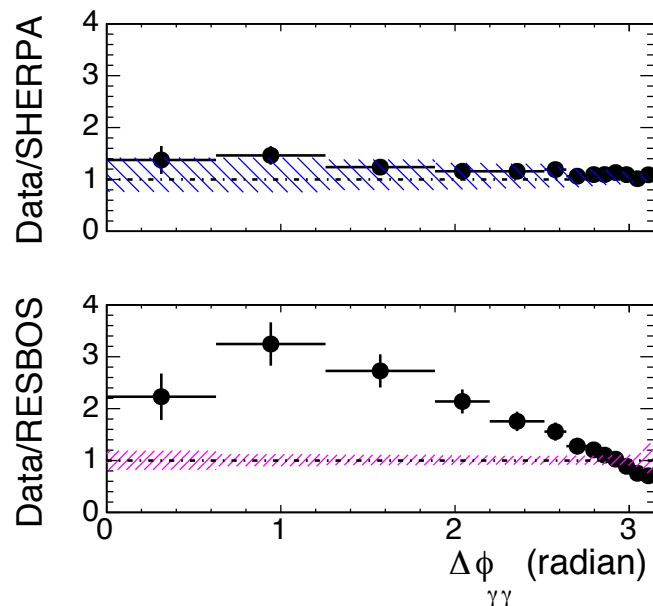
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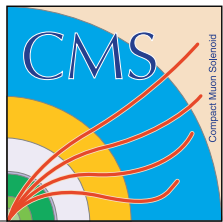


- **NNLO** predictions improve a lot the data/MC agreement

- **Sherpa** (up to 3 ME extra-jets) shows also a good agreement

- Still an **excess in data at low $\Delta\Phi$** (sensitive to missing higher order QCD effects)





$Z\gamma \rightarrow l\bar{l}\gamma$ cross-section

NEW

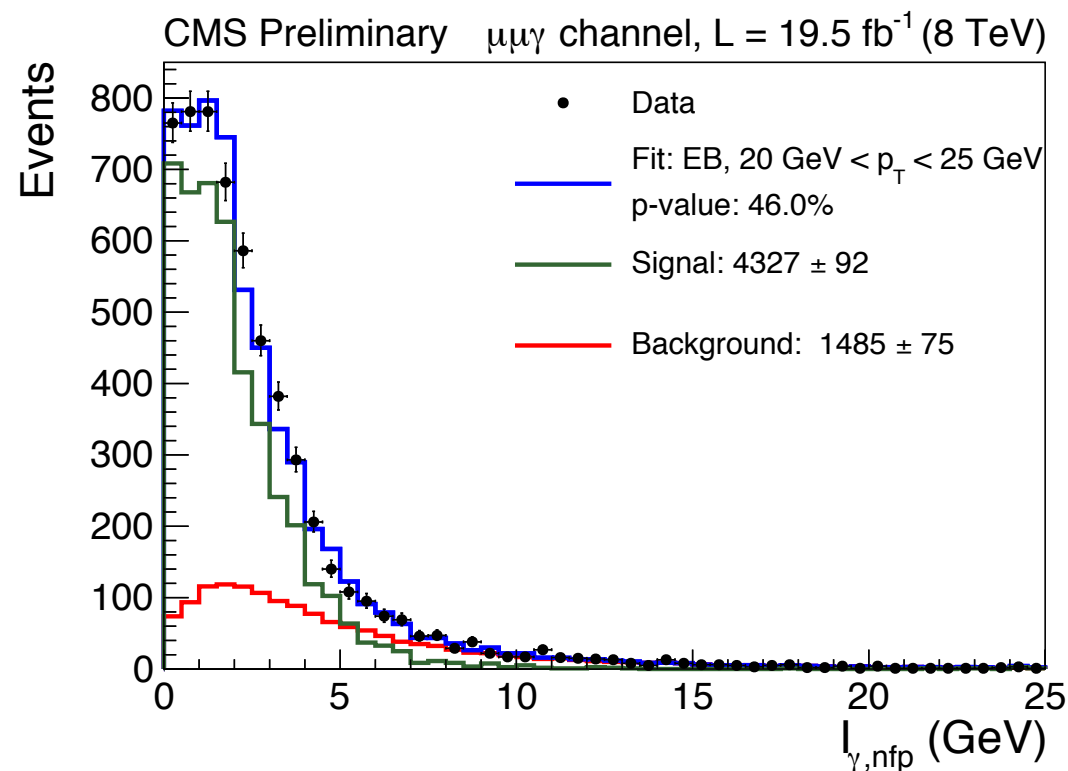
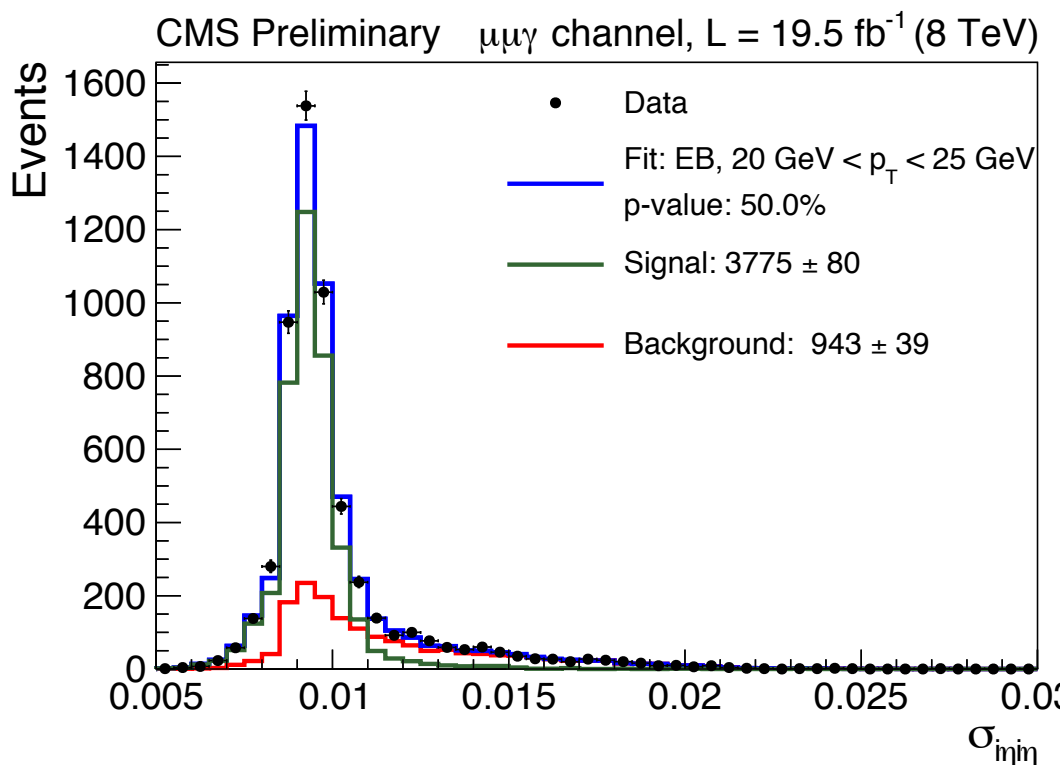
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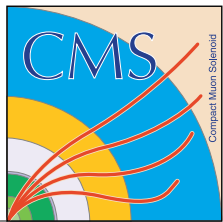
Kinematical range:

- Leptons $M_{ll} > 50$ GeV, $p_{T,l} > 20$ GeV, photons $|\eta_\gamma| < 2.5$, $E_{T,\gamma} > 15$ GeV, $\Delta R(\gamma, l) > 0.7$ (selects ISR)

Two methods are combined to estimate jets faking photons background:

- Particle-flow photon isolation template
- η width of the energy deposit (" $\sigma_{\eta\eta}$ ")
- Sideband regions tuned to minimize bias in MC





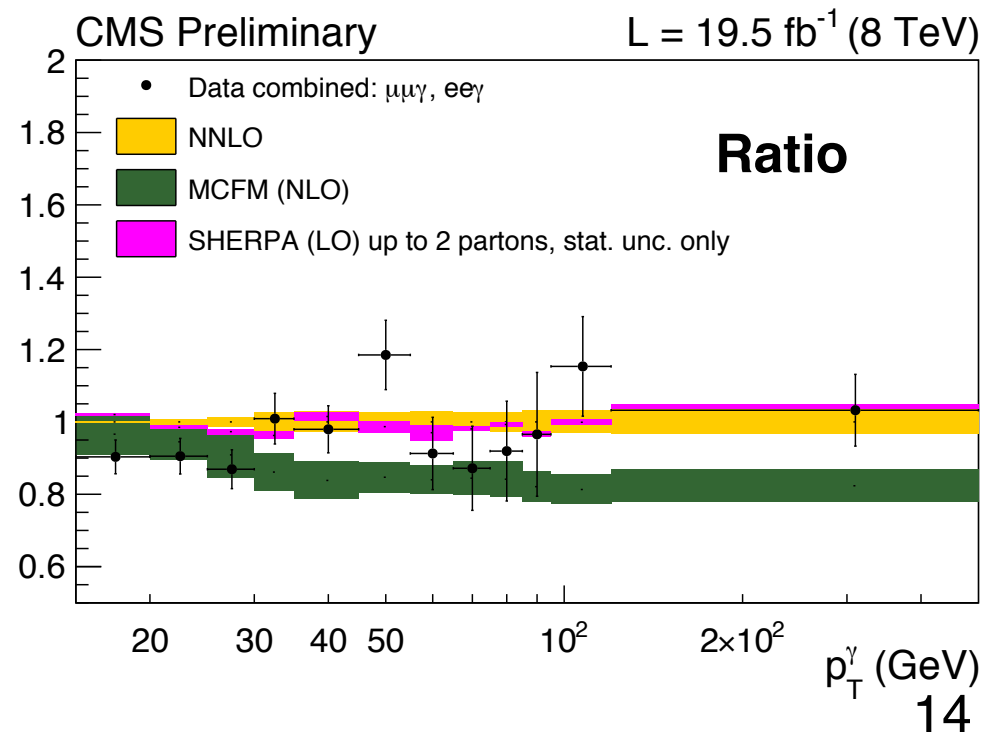
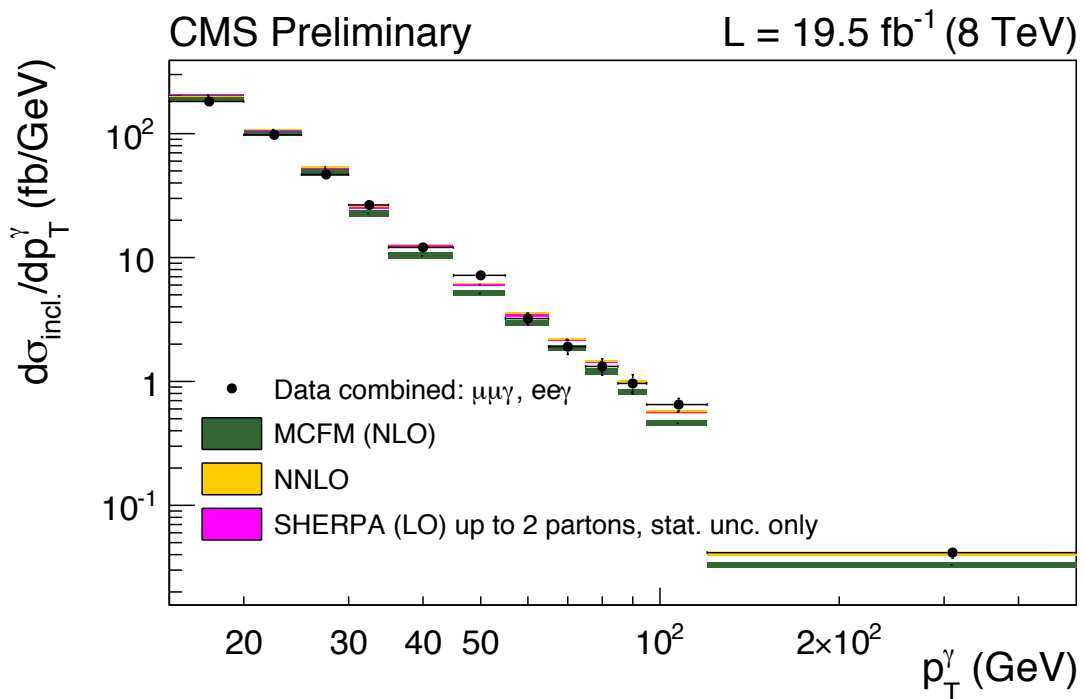
$Z\gamma \rightarrow l\bar{l}\gamma$ cross-section

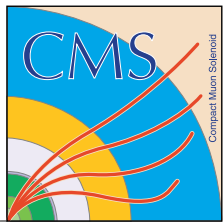
NEW

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP13014>

Inclusive cross section measured vs photon p_T

- For the first time **comparison with NNLO** [Grazzini, Kallweit, Rathlev, Torre, hep-ph:1309.7000]: good agreement
- **Kinematical range:** Leptons $M_{ll} > 50$ GeV, $p_{T,l} > 20$ GeV, $|\eta_l| < 2.5$, photons $|\eta_\gamma| < 2.5$, $E_{T,\gamma} > 15$ GeV, $\Delta R(\gamma, l) > 0.7$





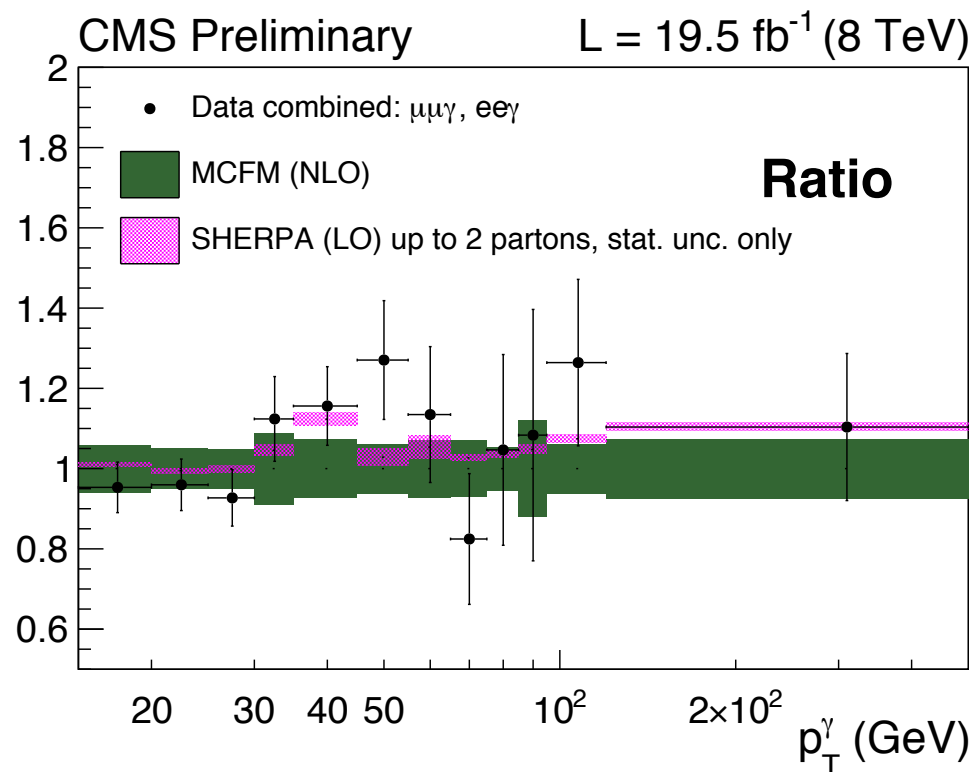
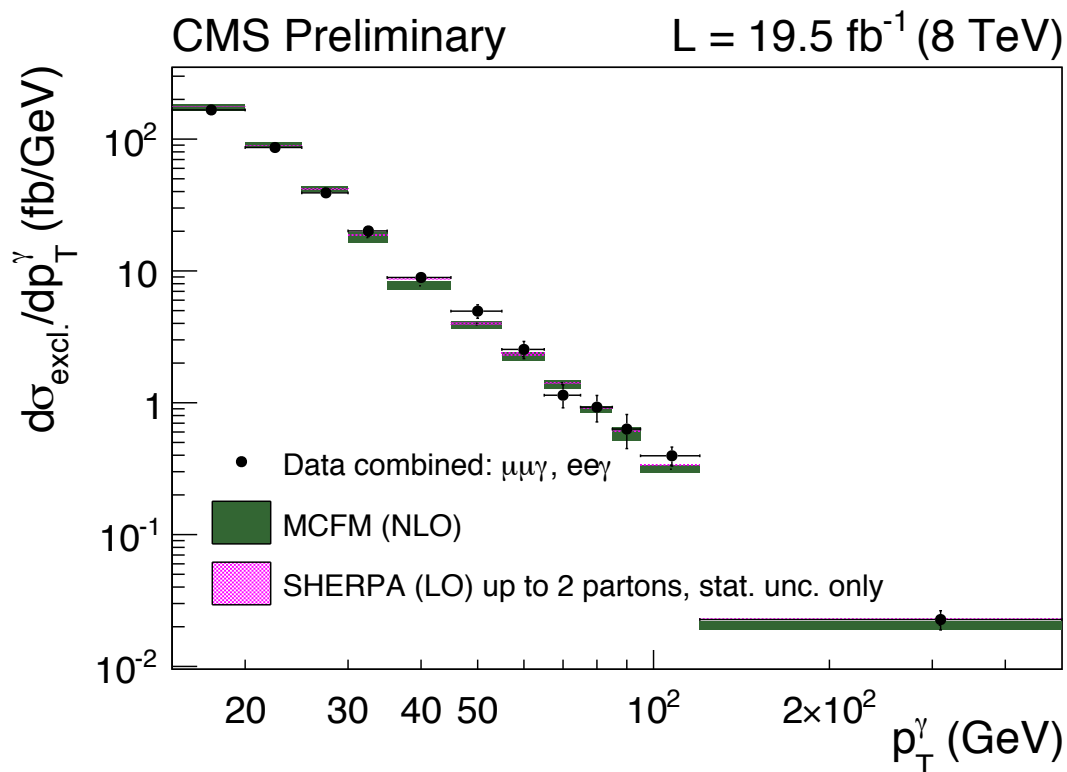
$Z\gamma \rightarrow l\bar{l}\gamma$ cross-section

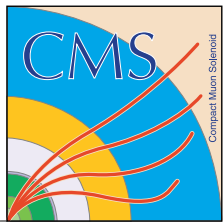
NEW

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP13014>

Exclusive cross-section with jet veto:

- Comparison with MCFM (NLO) and Sherpa with jet-veto: good agreement also with NLO because of softer phase-space
- **No jet with $p_T > 30$ GeV in $|\eta_l| < 2.4$**





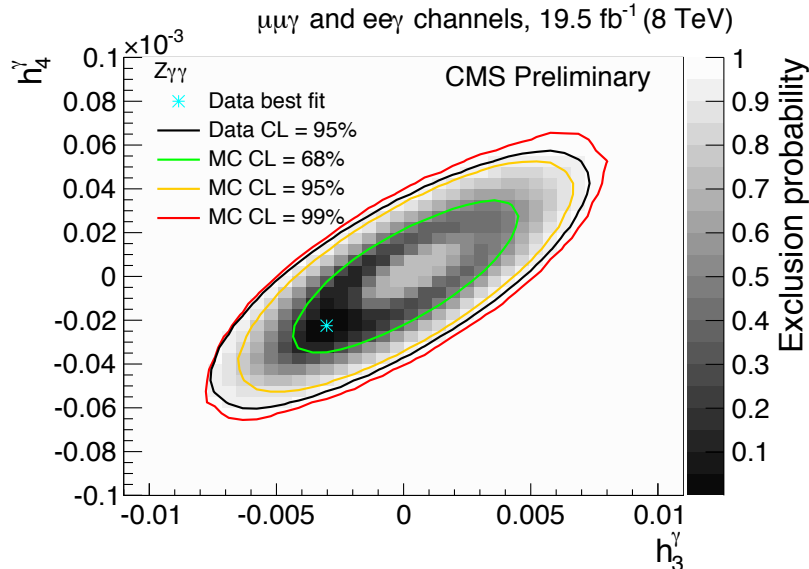
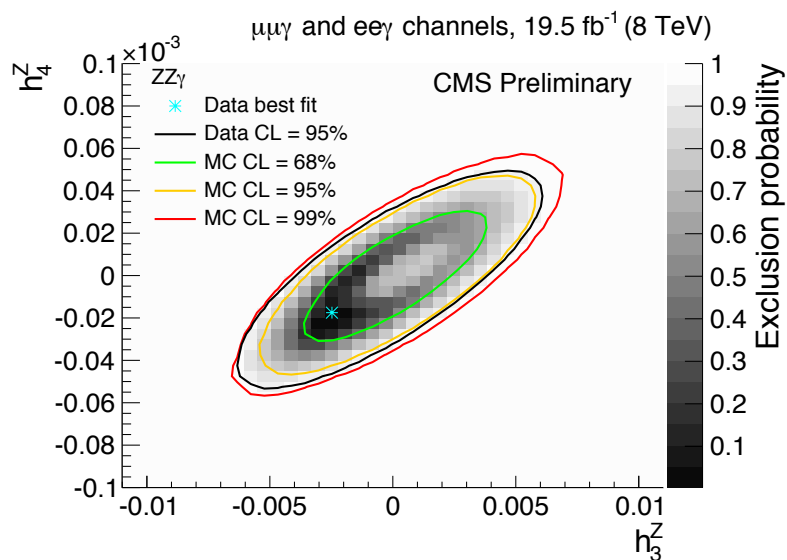
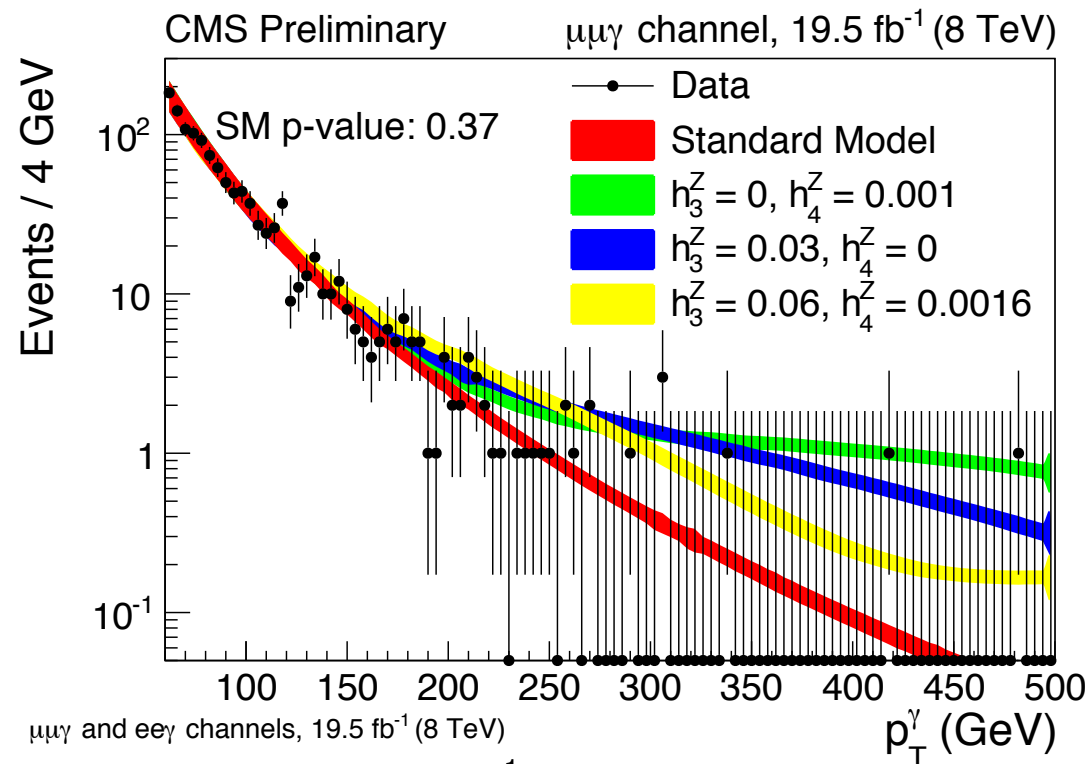
$Z\gamma \rightarrow l\bar{l}\gamma$ cross-section

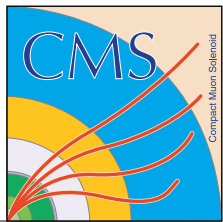
NEW

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP13014>

aTGC measurement:

- Limits set using **photon p_T**
- Limits on **$ZZ\gamma$, $Z\gamma\gamma$** vertices
- Improvement by a factor 2.5-3 over the previous 7 TeV measurement





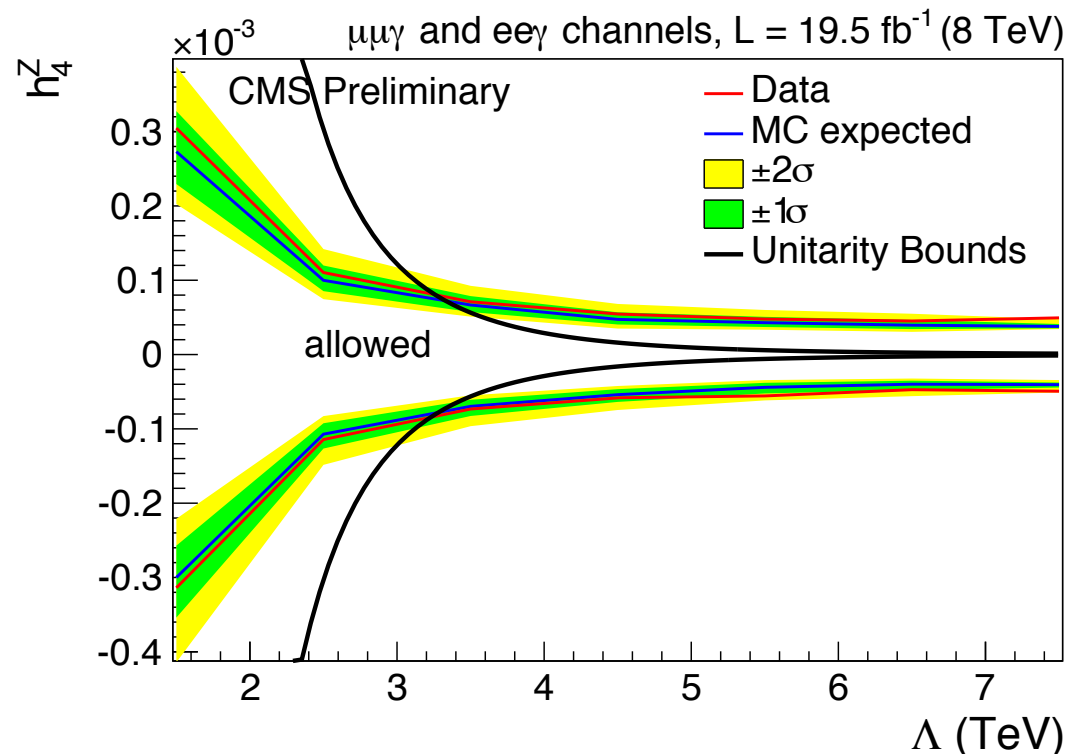
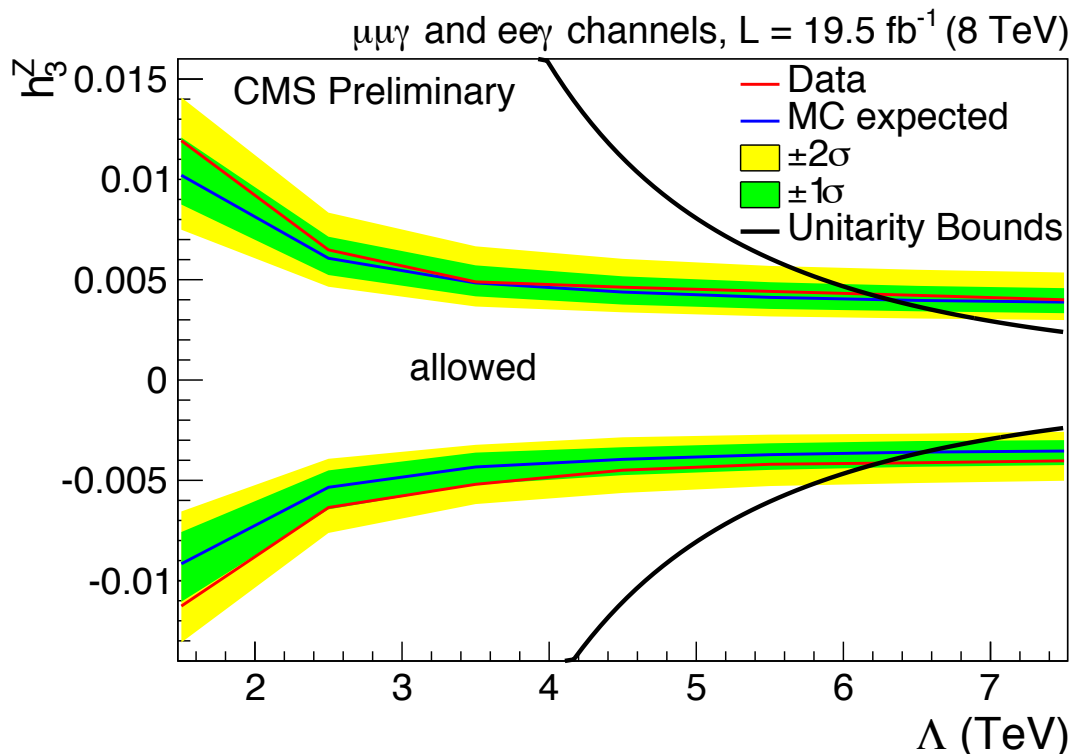
$Z\gamma \rightarrow l\bar{l}\gamma$ cross-section

NEW

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP13014>

Behavior using a form factor and unitarity bounds

- The non-unitarized limit can be recovered with a infinity form factor
- Unitarity bound (computed with VBFNLO website) crossed for a form factor of around 6 TeV (h3Z) or 3.5 TeV (h4Z)
- Below, the measurement probes aTGC in the unitarity region





Conclusions

Diboson measurements and aTGC

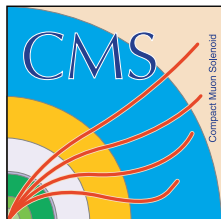
- Measurements on Diphotons, $VZ(bb)$ at 8 TeV, $ZZ(4l)$ at 8 TeV and $ZZ(2l2\nu)$ at 7 and 8 TeV were presented

New result on $Z(l\bar{l})\gamma$:

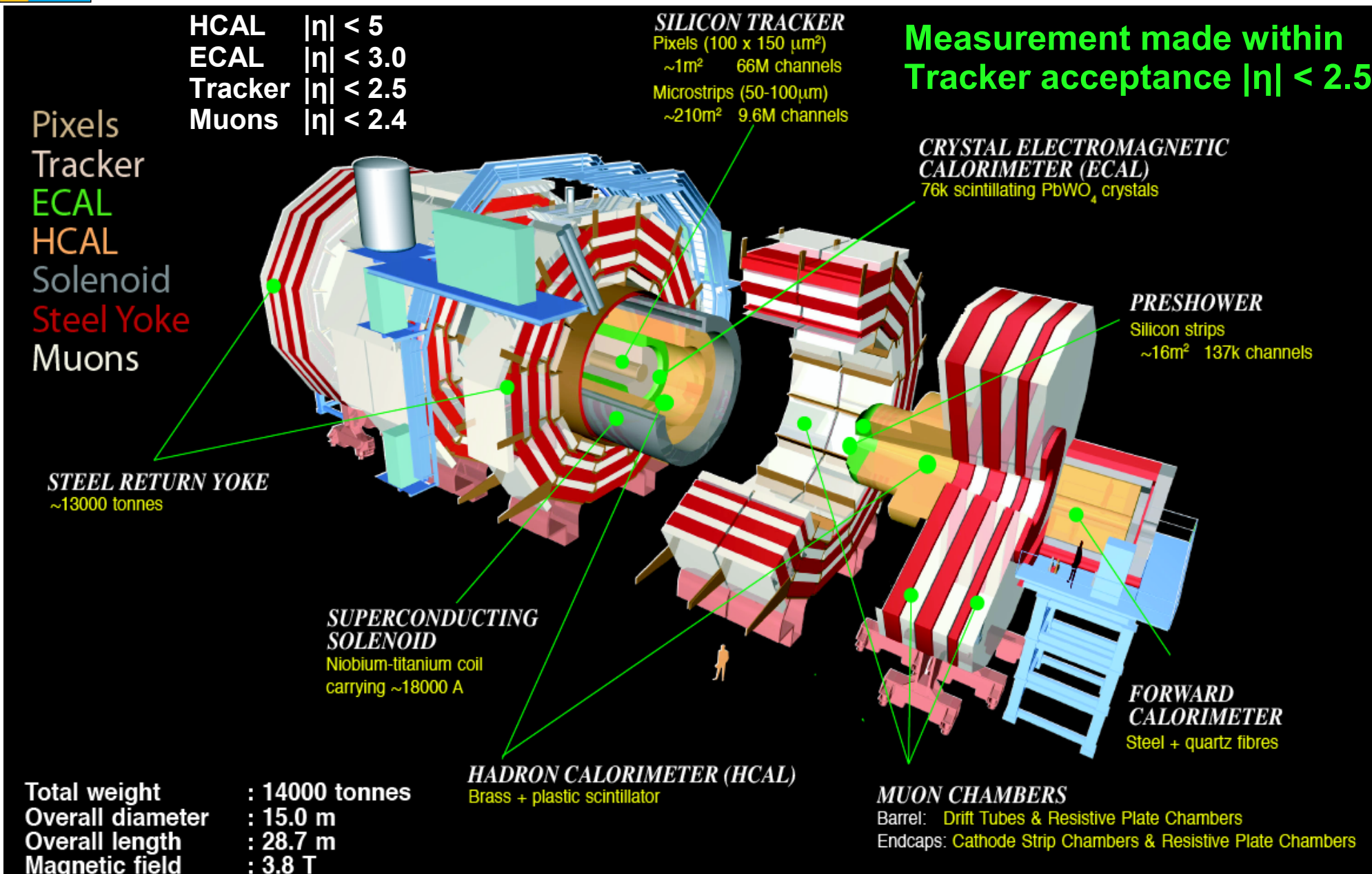
- Agreement with NNLO predictions
- Improvement of aTGC limits by a factor ~ 3 over the previous 7 TeV measurement
- Probing aTGC in the unitarity regime for a large range of form factors

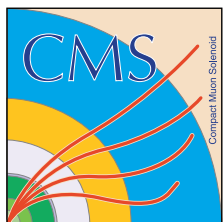
Thank you!

BACK-UP SLIDES



CMS detector





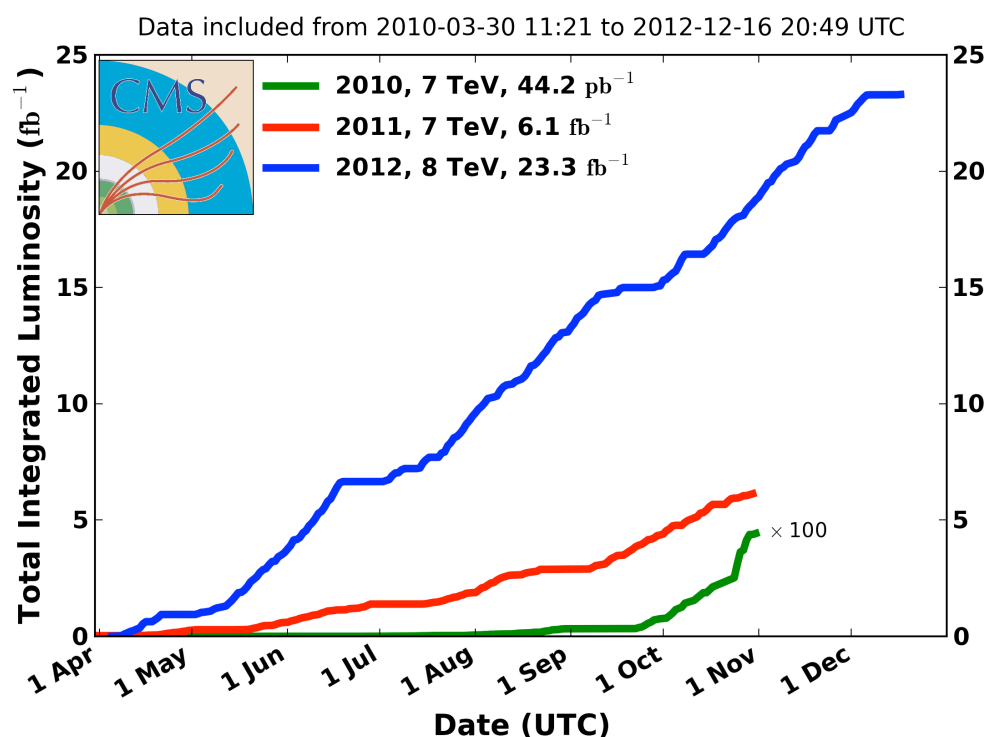
Luminosity conditions

Analyses presented in this talk are using:

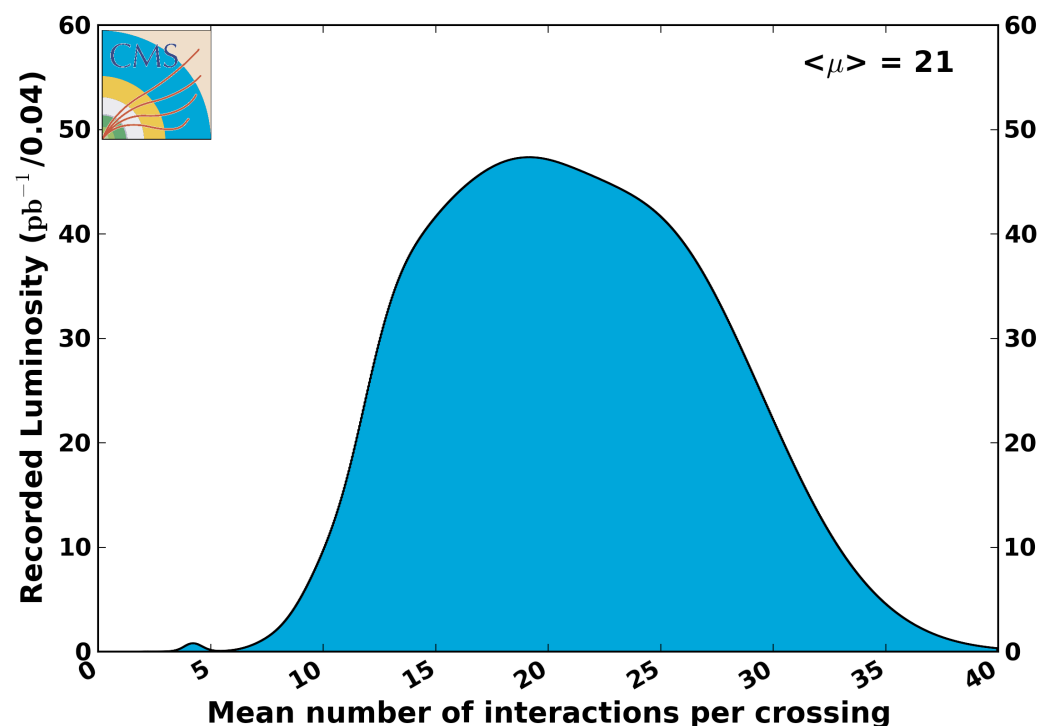
- 5.1 fb⁻¹ of 7 TeV data in 2011
- Up to 20 fb⁻¹ of 8 TeV data in 2012

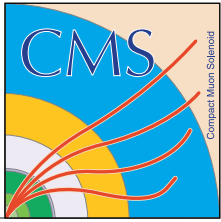
Pileup mean interaction ~21 in 2012 (~10 in 2011)

CMS Integrated Luminosity, pp



CMS Average Pileup, pp, 2012, $\sqrt{s} = 8$ TeV





CMS electromagnetic calorimeter(ECAL)

The **ECAL** is made of scintillating crystals of PbWO₄ :

- **Barrel** : 36 “supermodules” with 1700 crystals each (coverage $|\eta| < 1.48$)
- **Endcaps** : 268 “supercrystals” with 25 crystals each (coverage $1.48 < |\eta| < 3.0$)

Furthermore, a **preshower** made of silicon strip sensors is located in front of the endcaps ($1.65 < |\eta| < 2.6$)

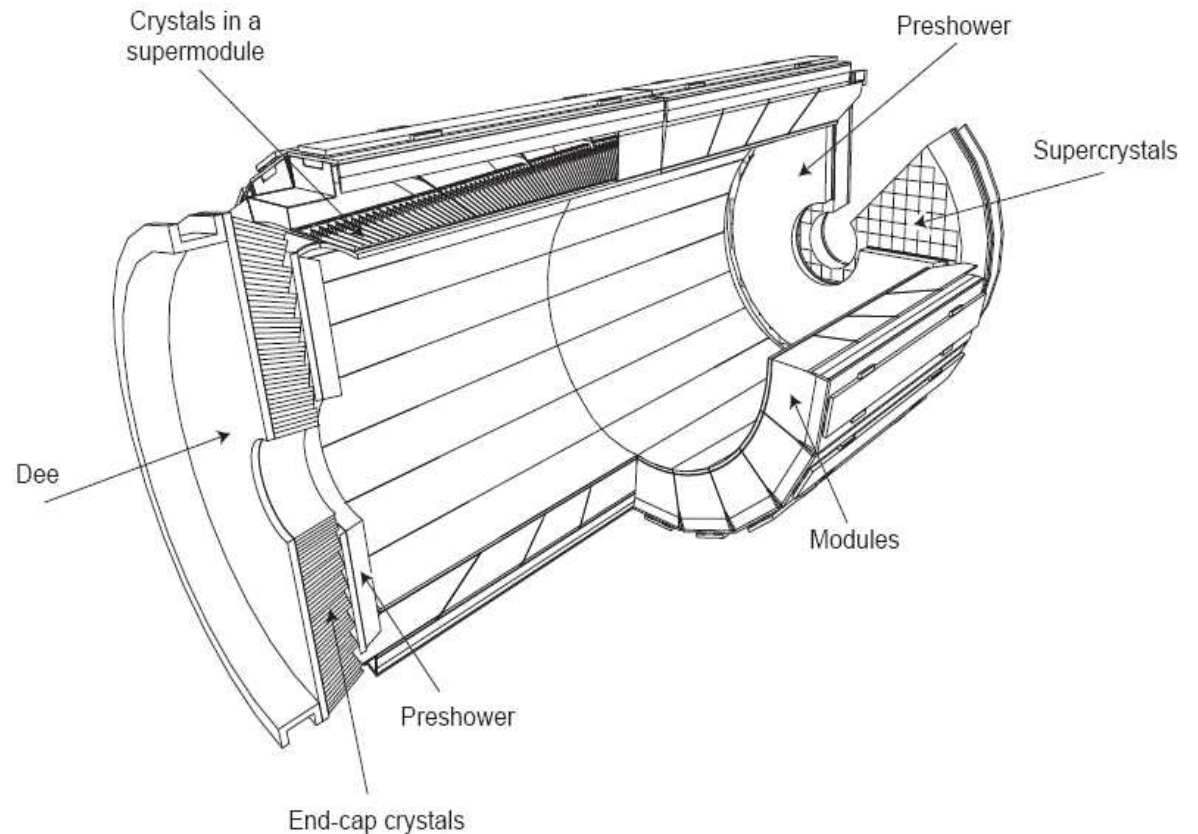
Energy resolution (measured in electron test beam) :

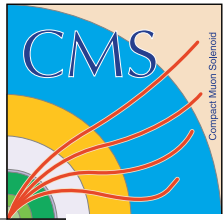
$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E(\text{GeV})}} \oplus \frac{b}{E(\text{GeV})} \oplus c$$

$a = 2.8\%$ stochastic term

$b = 12\%$ noise term

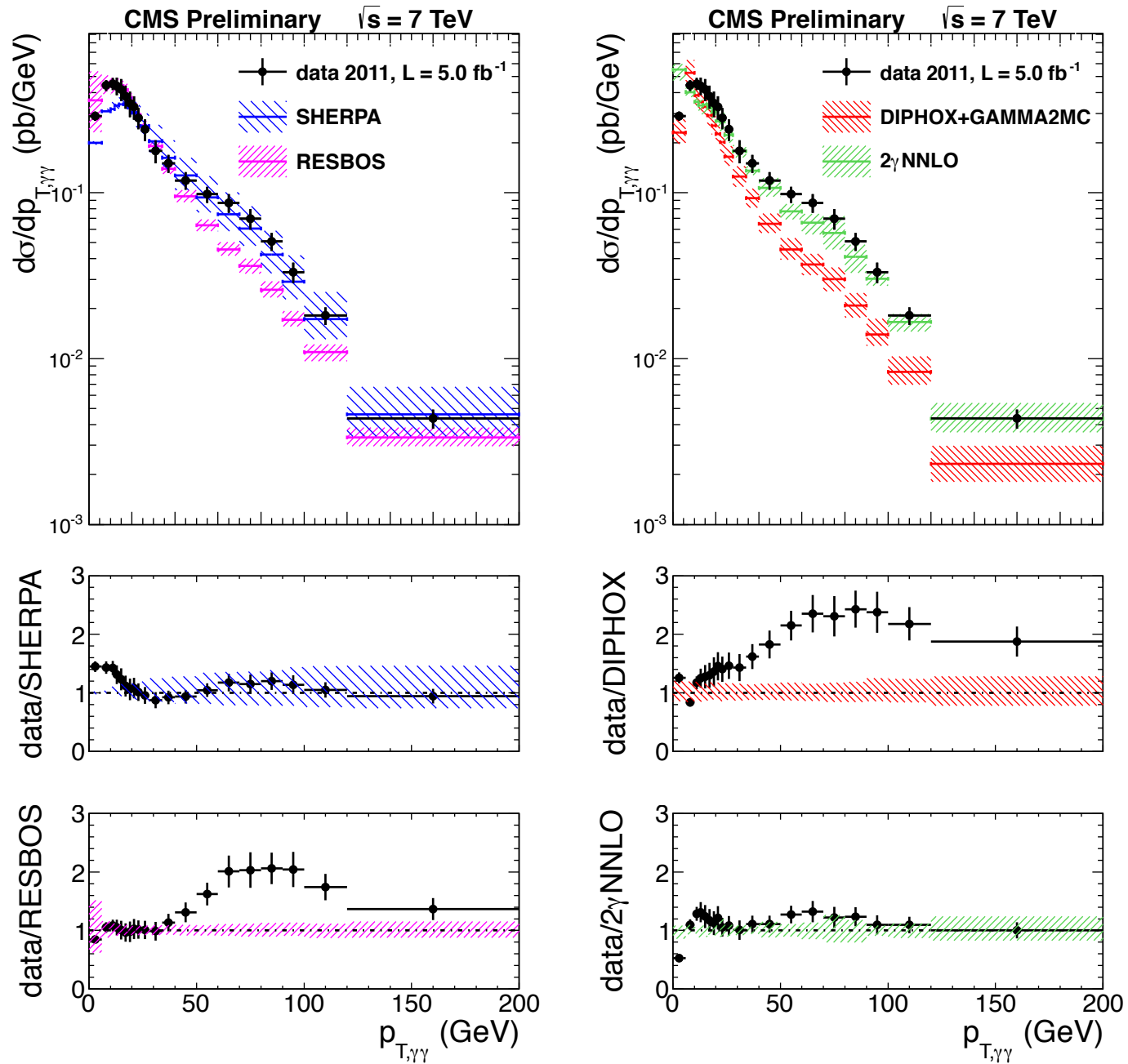
$c = 0.3\%$ constant term





Diphoton cross-section

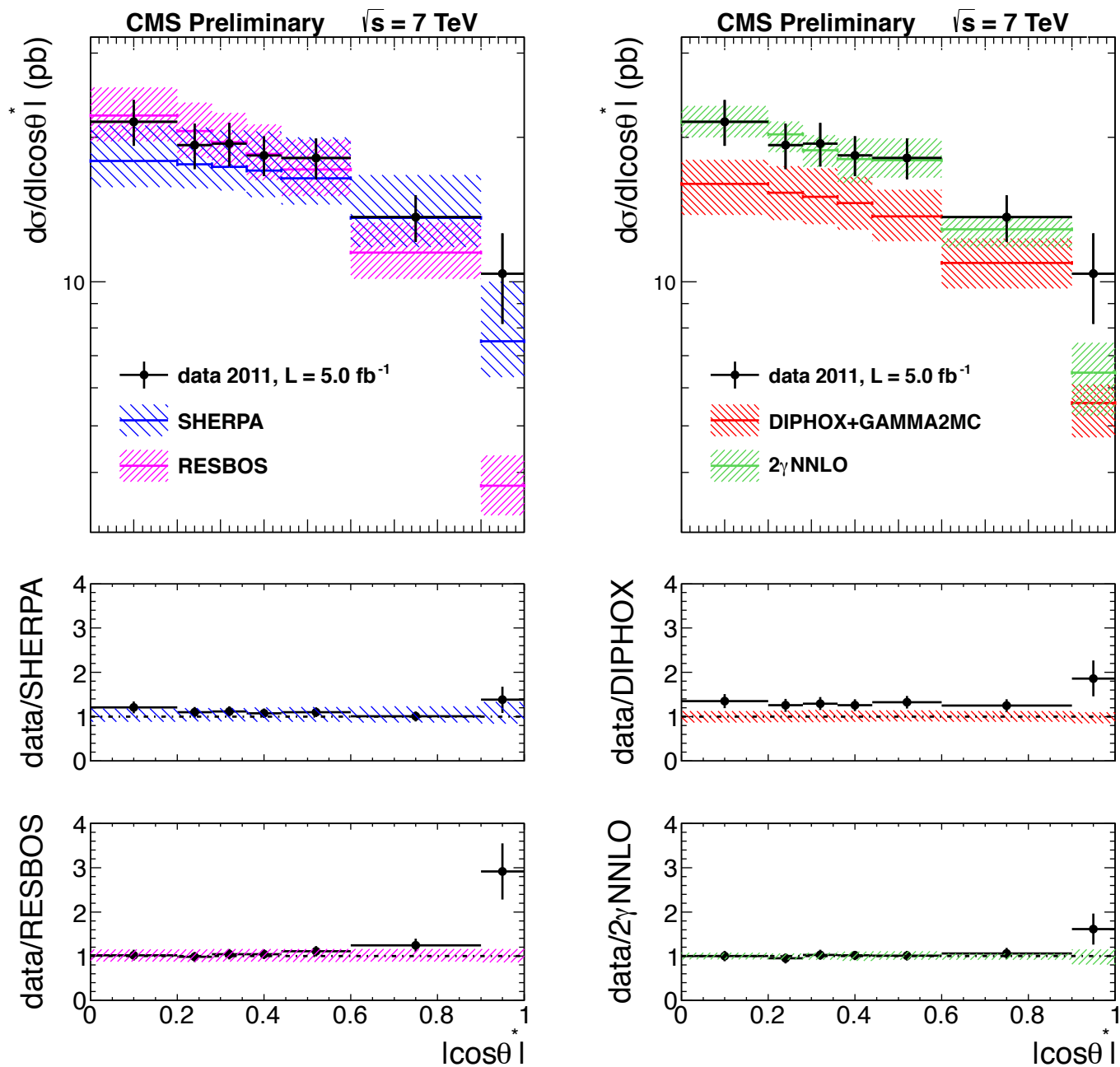
SMP-13-001, 4.7fb^{-1} at 7 TeV





Diphoton cross-section at 7 TeV

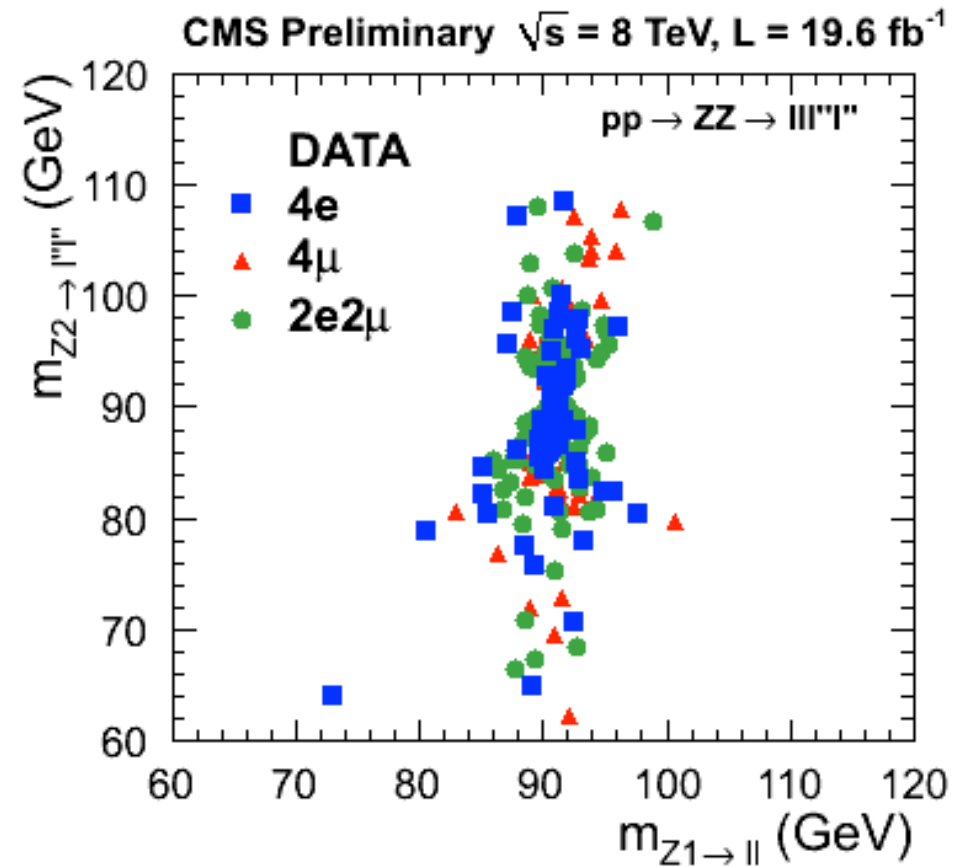
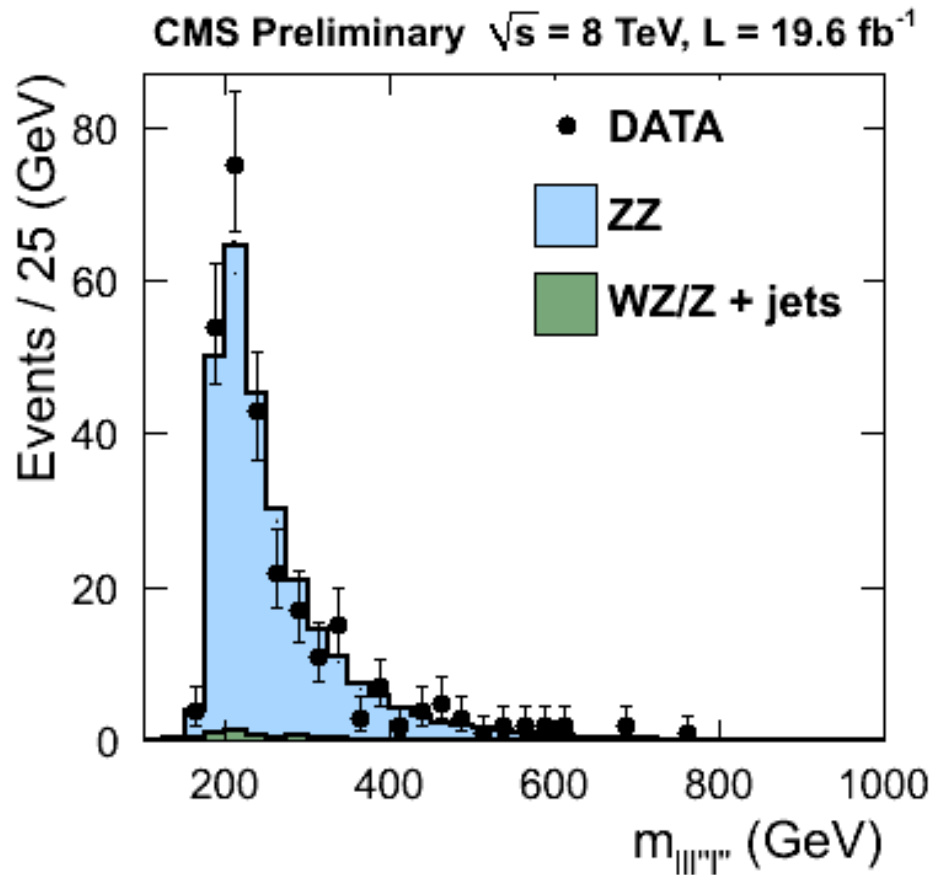
SMP-13-001, 4.7fb⁻¹ at 7 TeV





$ZZ \rightarrow 4l$ at 8 TeV

SMP-13-005, 19.6fb^{-1} at 8 TeV





$ZZ \rightarrow 2l2\nu$

SMP-12-016, 4.9fb^{-1} at 7 TeV and 19.6fb^{-1} at 8 TeV

- clustered recoil ($\vec{R}_{clust}$), vectorial sum of the particle-flow jets reconstructed in the event;
- unclustered recoil ($\vec{R}_{uncl}$), sum of all particle-flow candidates in the event, with the exception of the two leptons; it is constructed as the vectorial sum of the particle-flow E_T^{miss} and the dilepton p_T , with opposite sign.

On each axis (i = parallel/orthogonal to the dilepton), the reduced E_T^{miss} projection is defined as

$$\text{red-}E_T^{\text{miss}^i} = p_{T,\ell\ell}^i - \min(R_{clust}^i, R_{uncl}^i).$$