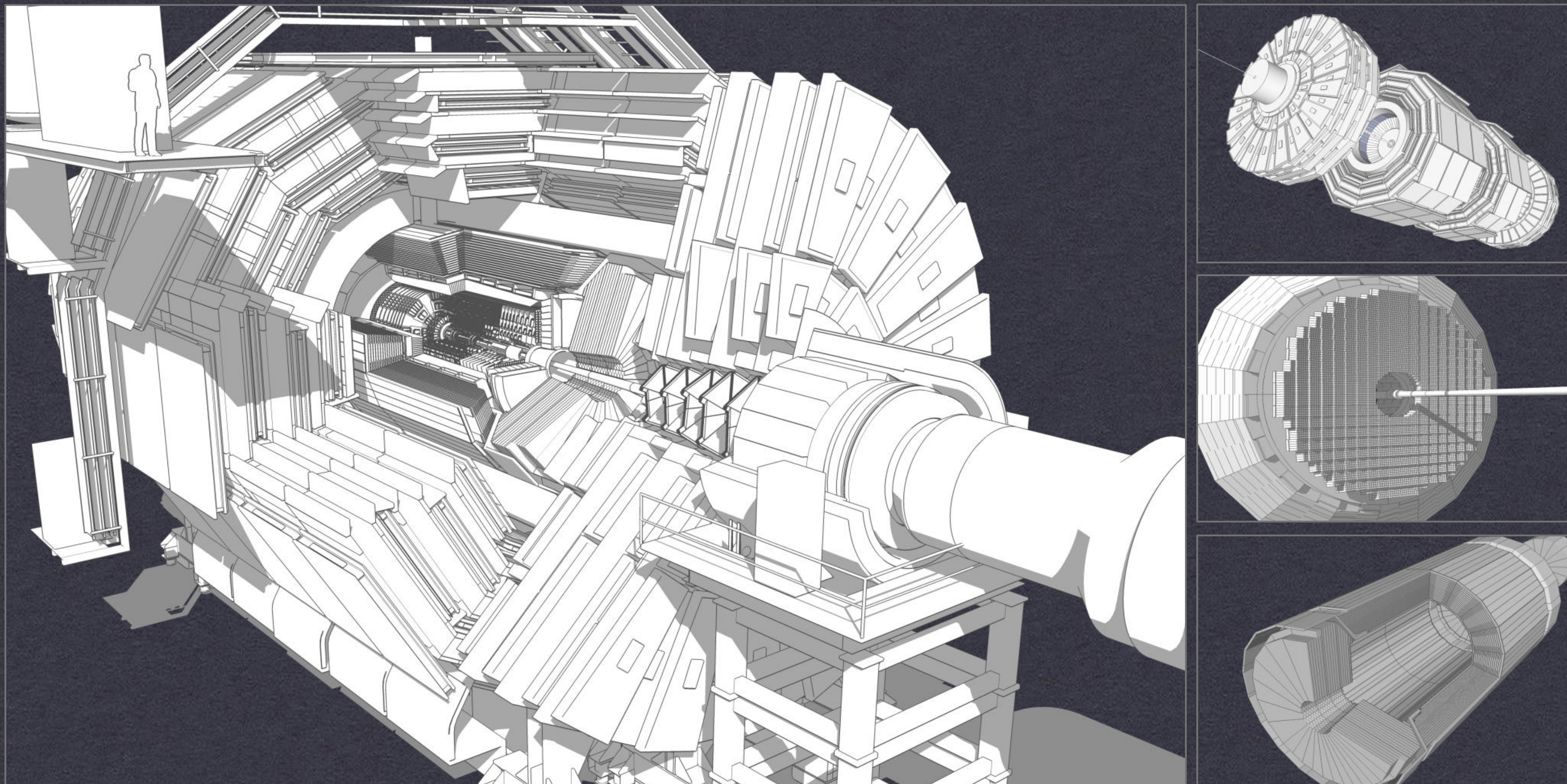


SM photon production measurements at CMS

on behalf of the CMS collaboration

Kadir Ocalan, Necmettin Erbakan University

“Ankara YEF Günleri 2015” Workshop, METU, Ankara

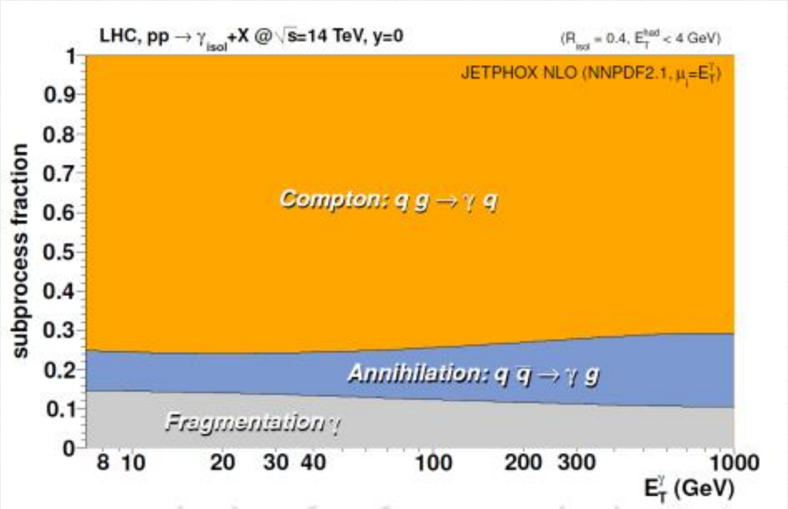
Outline

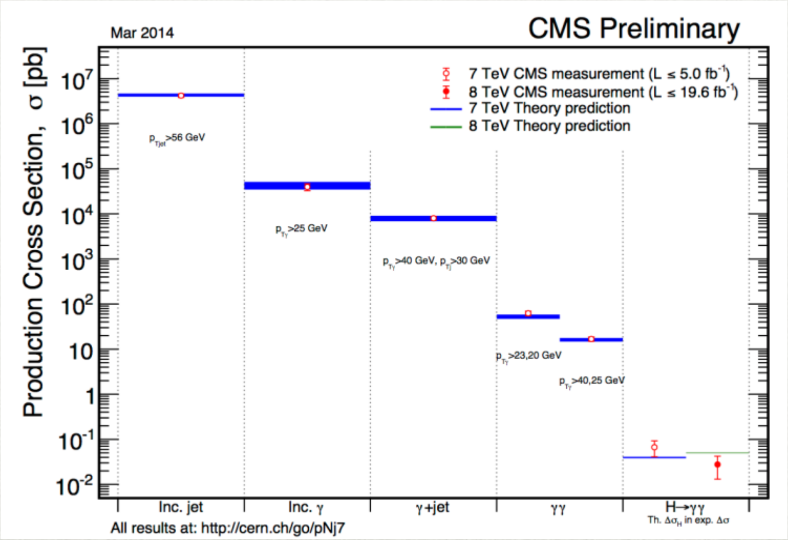
- Photon production
- Photon reconstruction
- Photon identification and isolation
- Isolated photon differential cross section (Phys. Rev. D 84, 052011)
- Photon + jets differential cross sections (JHEP 06 (2014) 009)
- Z/photon + 1 jet rapidity distributions (Phys. Rev. D 88, 112009)
- Diphoton differential cross sections (Eur. Phys. J. C 74 (2014) 3129)
- Z + jets / photon + jets cross section ratios (CMS-PAS-SMP-14-005)
- Conclusion
- Back-up slides

- In this talk, CMS SMP QCD photon public results are reviewed:
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP#Photon_jets
- EWK photon results will not be covered here:
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP#gamma_V

Photon production

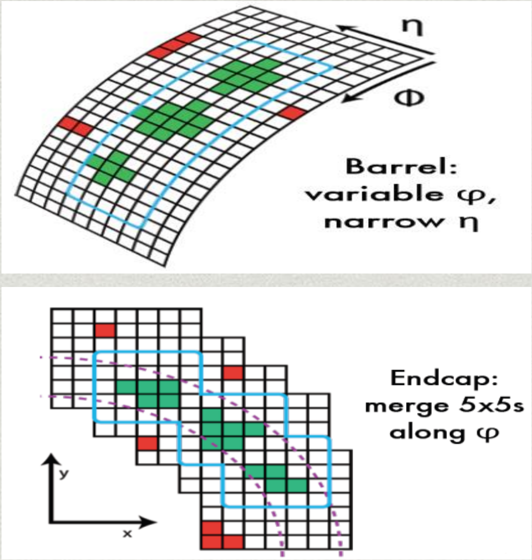
- Production mechanisms
  - Direct photons
    - quark-gluon compton-like scattering
    - quark-anti-quark annihilation
  - Fragmentation photons
- Physics Motivations
  - testing pQCD to high precision
  - constraining parton distribution functions (PDFs)
  - modeling backgrounds for BSM and Higgs
  - valuable for jet energy calibration and missing energy modeling
  - reference for similar measurements in heavy ion collisions

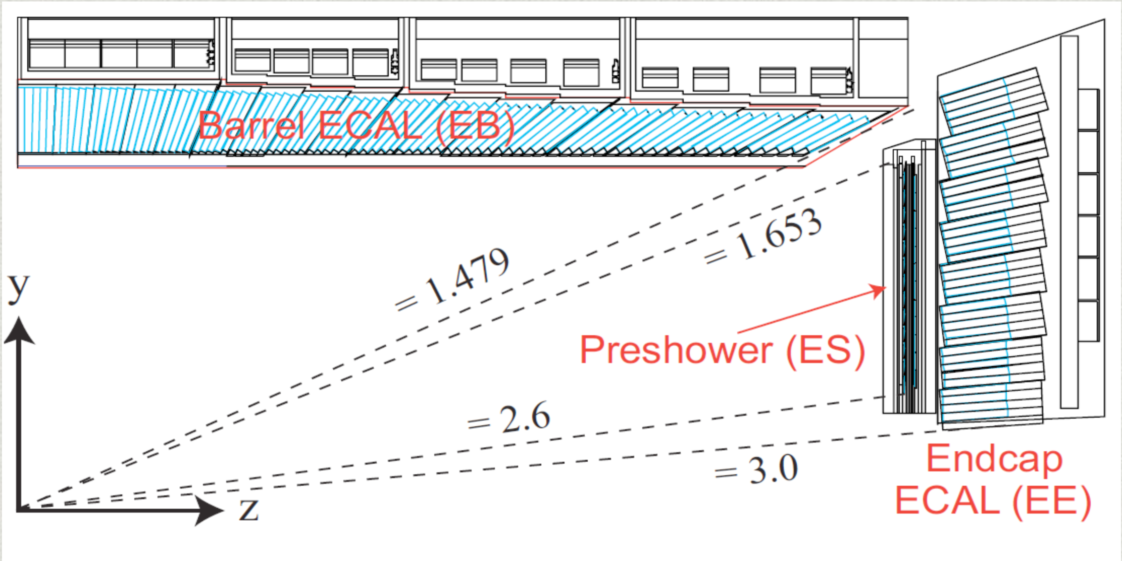




Photon reconstruction

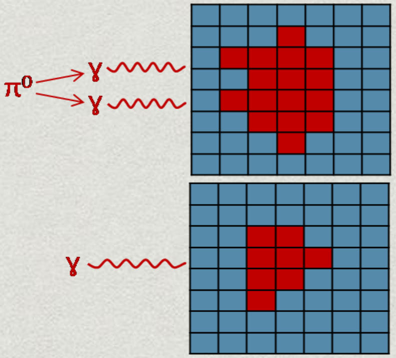
- Reconstructed from the energy deposits in the ECAL by grouping crystals into 'superclusters':
  - In the ECAL barrel region (|η| < 1.479), 35 crystals wide in φ and 5 crystals in η
  - In the ECAL endcap region (1.479 < |η| < 3.0), arrays of 5x5 crystals in x-y plane
    - Preshower energy is included
- Hybrid (in EB) and Multi5x5 (in EE) superclustering algorithms are used
- Energy is corrected for better resolution (the material losses in front of the tracker)



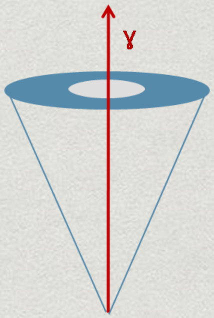


Photon identification / isolation

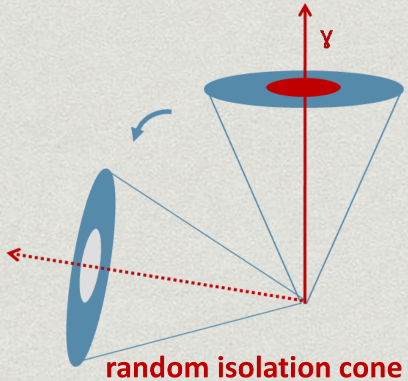
- Two main methods to discriminate a signal photon from a background one:
  - the shape of the shower measured in the ECAL crystals ($\sigma_{\eta\eta}$)
  - the isolation energy in a cone around photon direction (Iso)
- Calorimetric or PF-particle flow isolation sums and shower shape variable are accompanied by other selections (like H/E, $R_9=E_{3X3}/E_{RAW}$, …)
- For very loosely isolated photons, template fitting techniques are used for the extraction of signal (prompt) photons
- Caution: Above identification requirements are valid for data and LO MC generators, for NLO tools Iso < 5 GeV for ΔR=0.4 cone is used



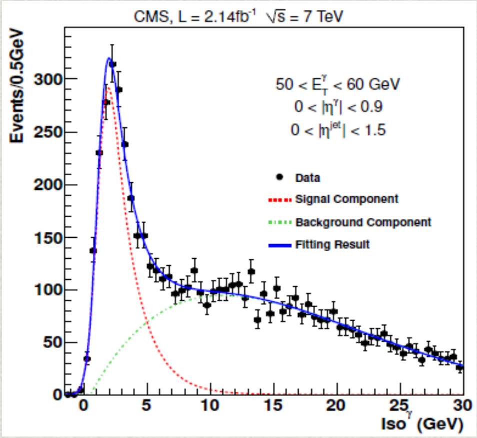
shower shape



isolation cone



random isolation cone



template fitting example on Iso

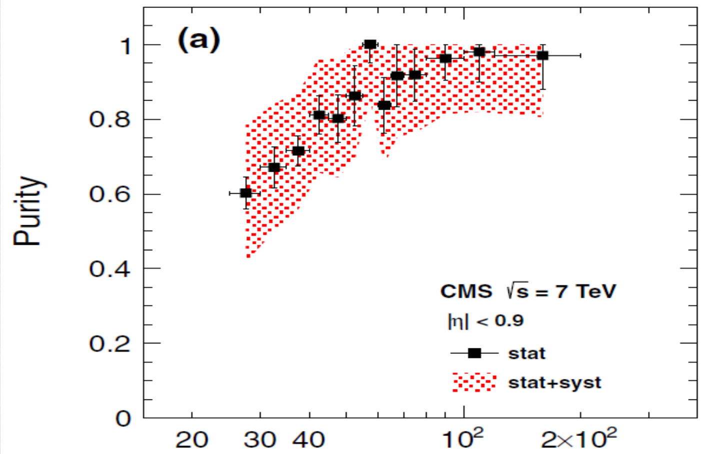
Isolated photon cross section

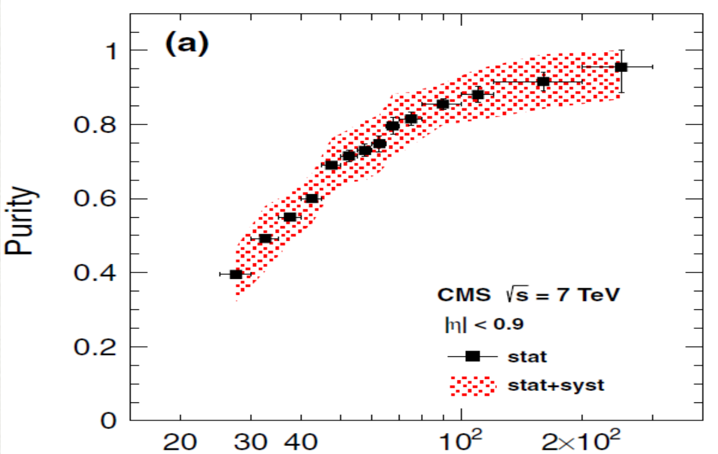
- Single photon differential cross section
  - using 36 /pb data at 7 TeV
  - pT: 25 – 400 GeV
  - |η| < 2.5

$$\frac{d^2\sigma}{dE_T d\eta} = \frac{N^\gamma \cdot U}{L \cdot \varepsilon \cdot \Delta E_T \cdot \Delta\eta}$$

- Signal photon extraction by two methods
  - Conversion : E_T^{ECAL}/p_T^{TRK} ratio
  - Isolation: Iso = $Iso_{TRK} + Iso_{ECAL} + Iso_{HCAL}$

Cut	Signal region	Sideband region
	Photon conversion method	
H/E	<0.05	<0.05
Iso_{TRK} (GeV)	$<(2.0 + 0.001E_T)$	$(2.0 + 0.001E_T) - (5.0 + 0.001E_T)$
Iso_{ECAL} (GeV)	$<(4.2 + 0.003E_T)$	$<(4.2 + 0.003E_T)$
Iso_{HCAL} (GeV)	$<(2.2 + 0.001E_T)$	$<(2.2 + 0.001E_T)$
barrel: $\sigma_{\eta\eta}$	<0.010	0.010–0.015
endcap: $\sigma_{\eta\eta}$	<0.030	0.030–0.045
	Isolation method	
H/E	<0.05	<0.05
barrel: $\sigma_{\eta\eta}$	<0.010	0.0110–0.0115
endcap: $\sigma_{\eta\eta}$	<0.028	>0.038

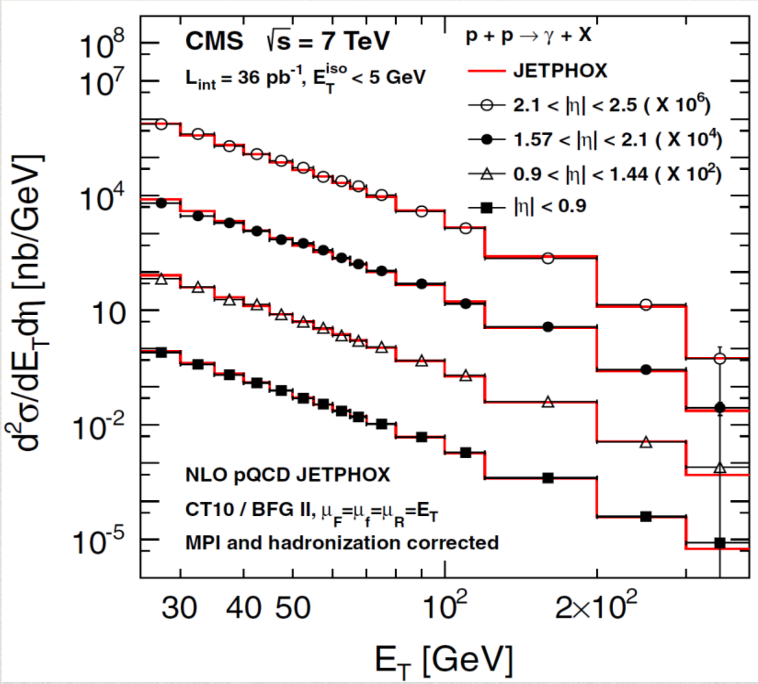


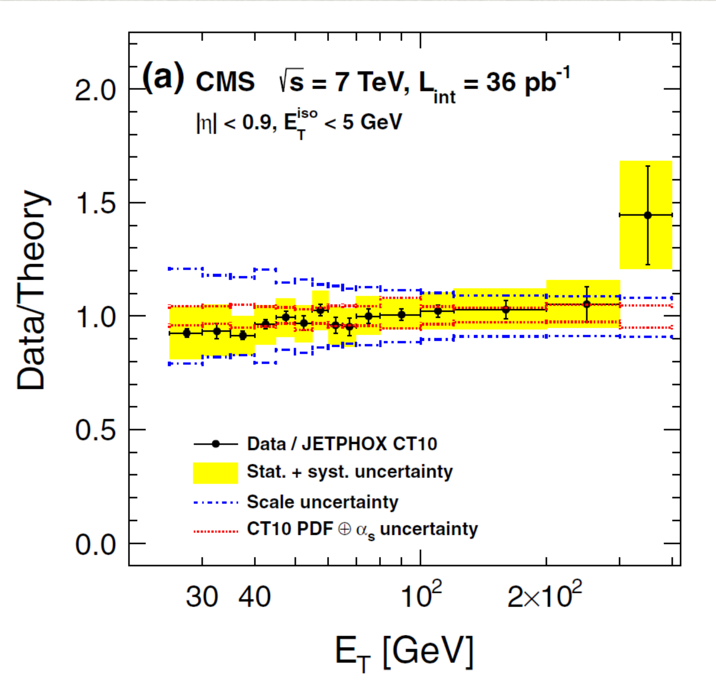


Measured photon purities from conversion (top) and isolation (bottom) methods

Isolated photon cross section

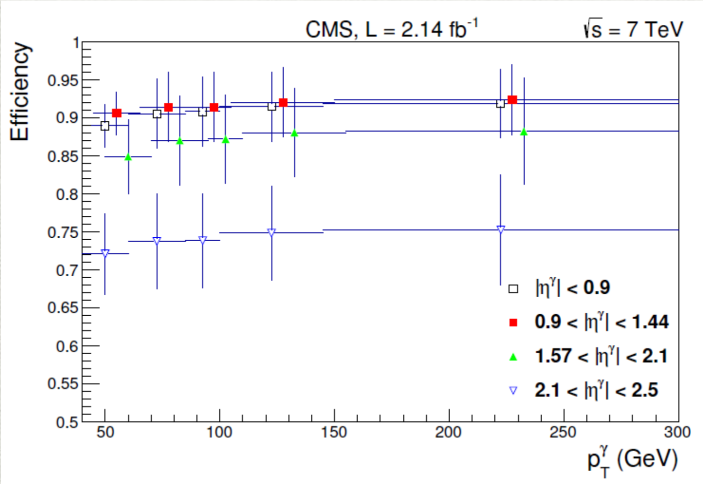
- Data corrected for efficiency and unfolding factors
- Theory predictions by JETPHOX NLO with CT10 PDFs
- Good agreement between data and predictions
- Overestimation of data at low ET, but within uncertainties



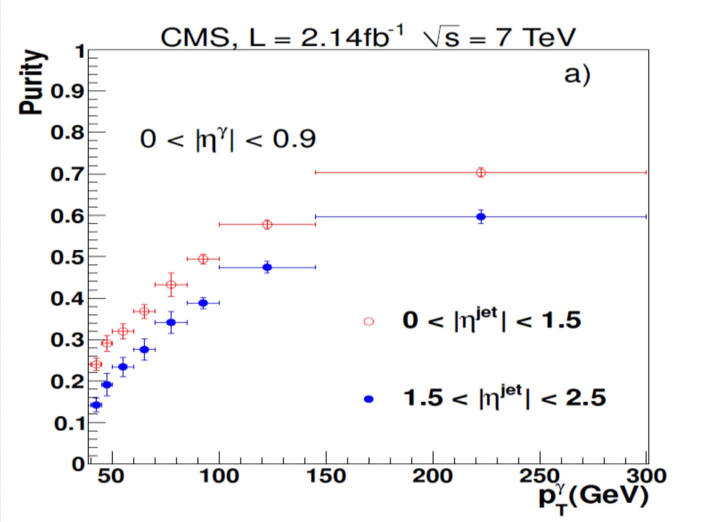


Photon + jets cross sections

- Triple differential cross section in 8 different photon - jet η configurations
- Photon+jet production is directly sensitive to gloun PDF in proton ([Nucl. Phys. B 860 (2012) 311–338]())



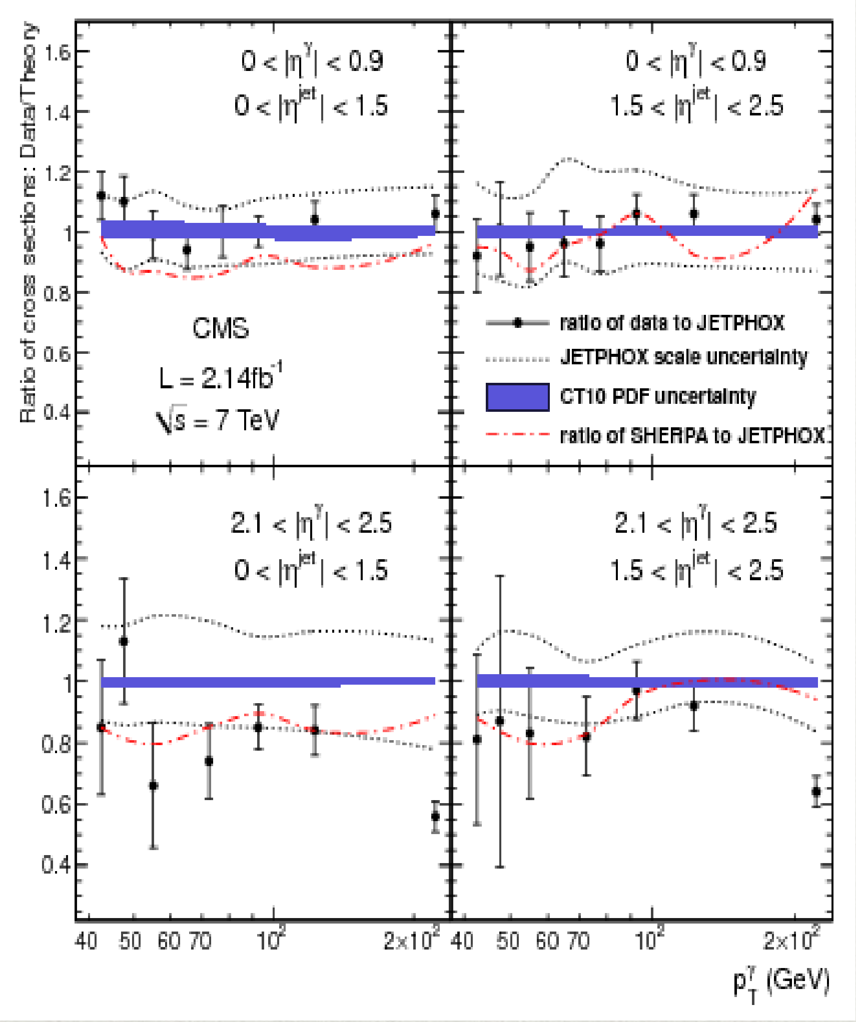
- Examined kinematic region:
  - 40 < photon pT < 300 GeV
  - one or more jet with pT > 30 GeV
  - both objects with |η| < 2.5



- Data unfolded to correct for detector effects after efficiency corrections and background subtraction:
  - ~70-90% total photon selection efficiency
  - ~20-70% purity for loosely isolated photon

Photon + jets cross sections

- Theory predictions:
  - JETPHOX NLO (CT10 PDF)
  - SHERPA LO (CTEQ6M PDF)
- Agreement with data over most of the kinematic regions
- Theories reproduce ratios fairly well
- Exception for cases of photons measured in $2.1<|\eta(\gamma)|<2.5$ for central and forward jets
- SHERPA tends to be lower than JETPHOX



Z/photon + 1 jet rapidity distributions

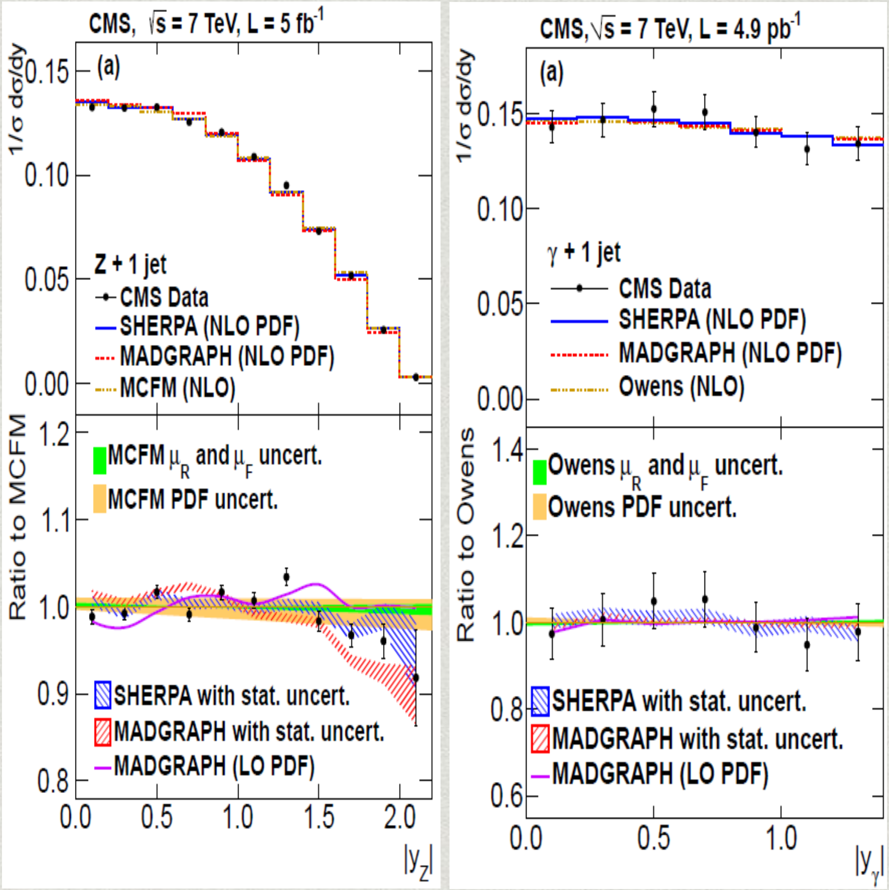
- Measured rapidity distributions of Z/ɣ and exactly 1 jet

$$\text{Rapidity: } y = \frac{1}{2}\ln\left[\frac{(E + p_z)}{(E - p_z)}\right]$$

- Z / ɣ + 1 jet selection:
  - leptons with pT>20 GeV and |η| < 2.1
  - dilepton mass 76 < mll < 106 GeV
  - photon pT > 40 GeV and|η| < 1.44
  - one jet with pT > 30 GeV and |η| < 2.4

- Choices for theoretical tools:
  - SHERPA+APACIC++(PS)+PYTHIA(hadronization) with NLO CTEQ6.6M PDF
  - MADGRAPH+PYTHIA(PS+hadronization) with LO and NLO CTEQ6 PDF

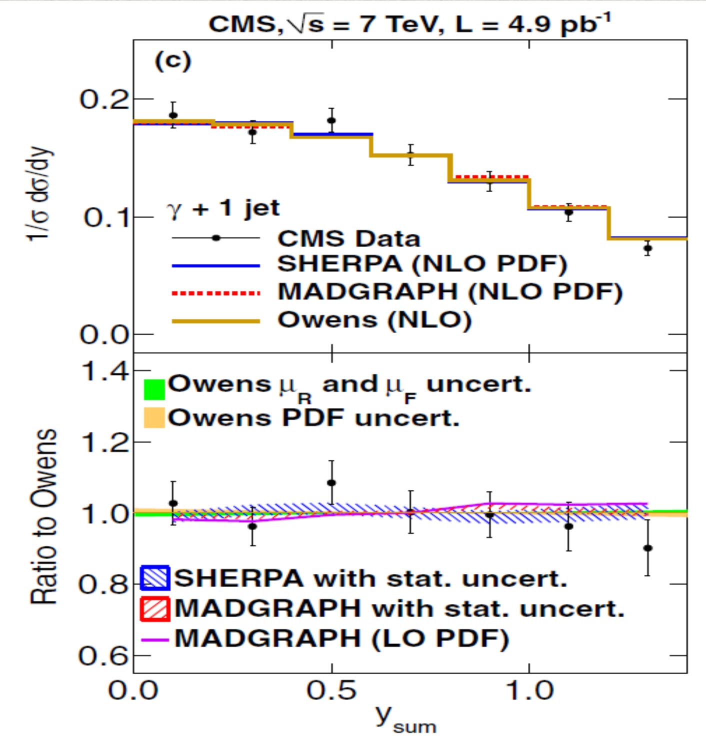
- Owens (MCFM) for ɣ+jet (Z+jet) NLO calculation

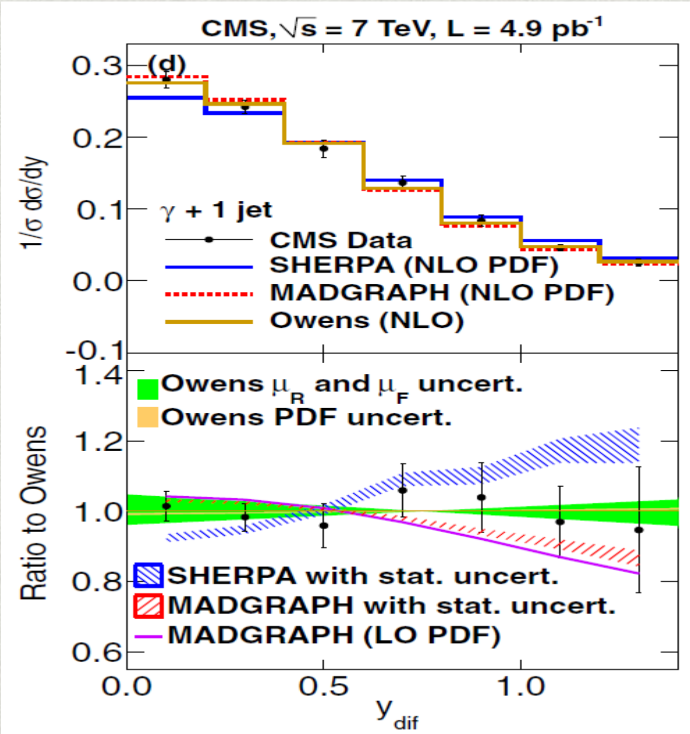


- $y_{z(ɣ)}$ and y_{jet} agree with NLO predictions, SHERPA, and MADGRAPH
- Insufficient statistical precision for ɣ part (effective L_{int} = 4.9 pb^{-1})

Z/photon + 1 jet rapidity distributions

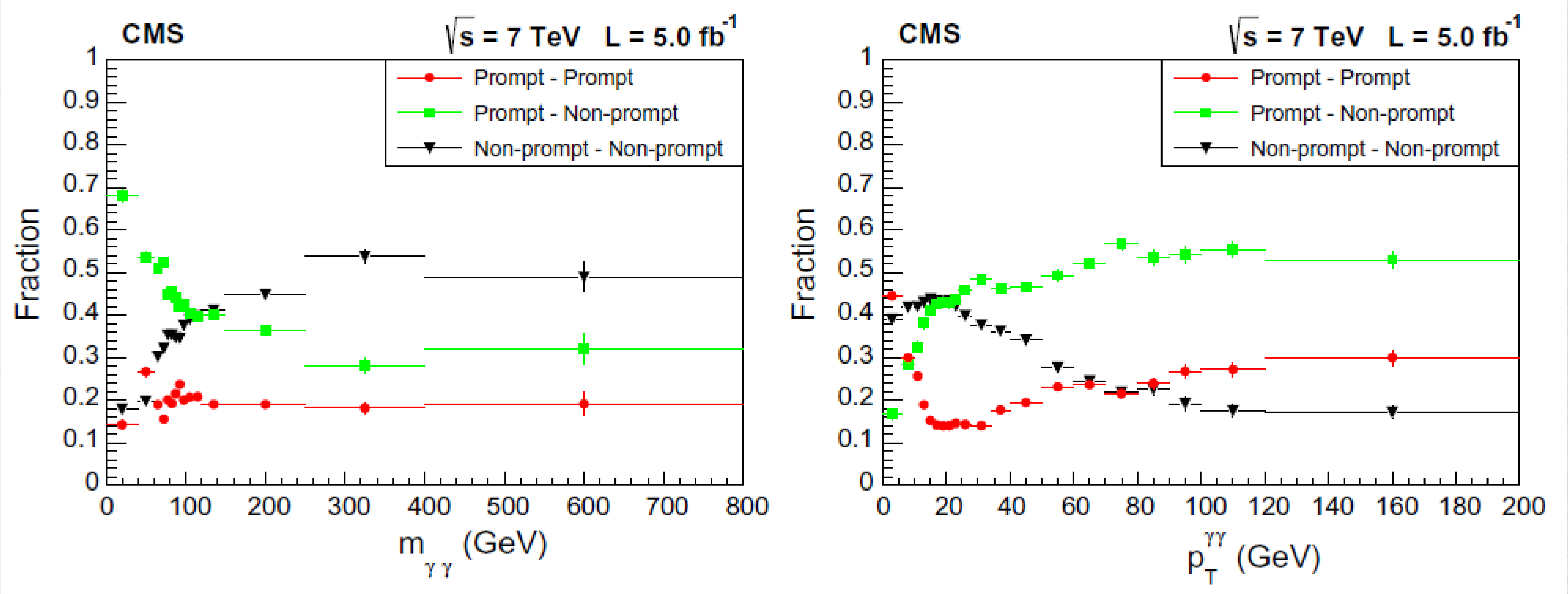
- Construct y_{sum} and y_{dif} from y_V (V=Z or γ) and y_{jet}: $y_{sum} = \frac{|y_{Z/\gamma} + y_{jet}|}{2}$ $y_{dif} = \frac{|y_{Z/\gamma} - y_{jet}|}{2}$
- Comparison of γ + 1 jet data with tools:
  - for y_{sum}: consistent data description by all predictions
  - for y_{dif}: best described by Owens NLO better than 10%, SHERPA and MADGRAPH exhibit discrepancies at forward values





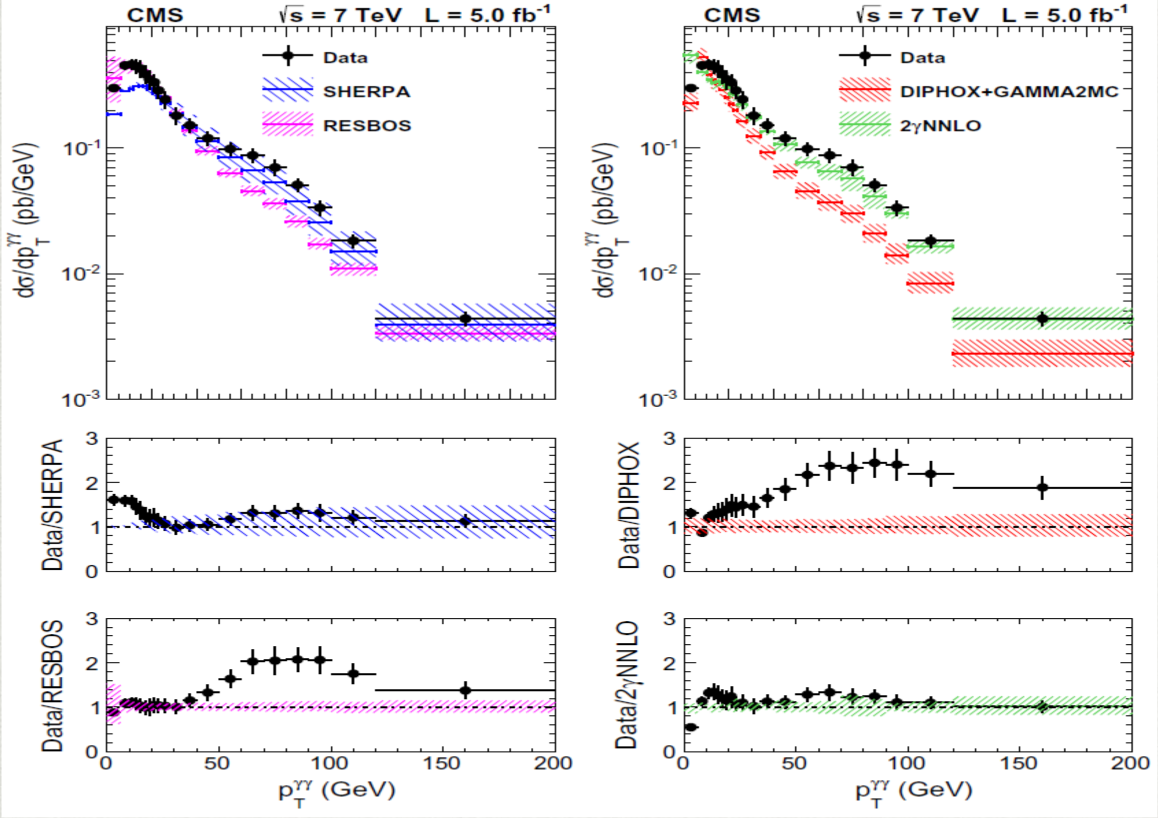
Diphoton differential cross sections

- Measurement of photon pairs with 5 /fb at 7 TeV data
  - as functions of $m_{\gamma\gamma}$, $pT_{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$, and $\cos\theta^*(\gamma\gamma)$
- Spectrum available for $pT_{\gamma1(2)}$>40(25) GeV, $|\eta|<2.5$, $\Delta R>0.45$
- Constituting major background for Higgs (JHEP 1306 (2013) 081)
- Random Cone isolation ($\Delta R<0.4$) in azimuthal separation



Diphoton differential cross sections

- Measured data are compared to varieties of generators
- Best description of data by Sherpa and 2ɣNNLO
- Measured total xsec: $\sigma = 17.2 \pm 0.2(\text{stat.}) \pm 1.9(\text{syst.}) \pm 0.4(\text{lum.})$ pb

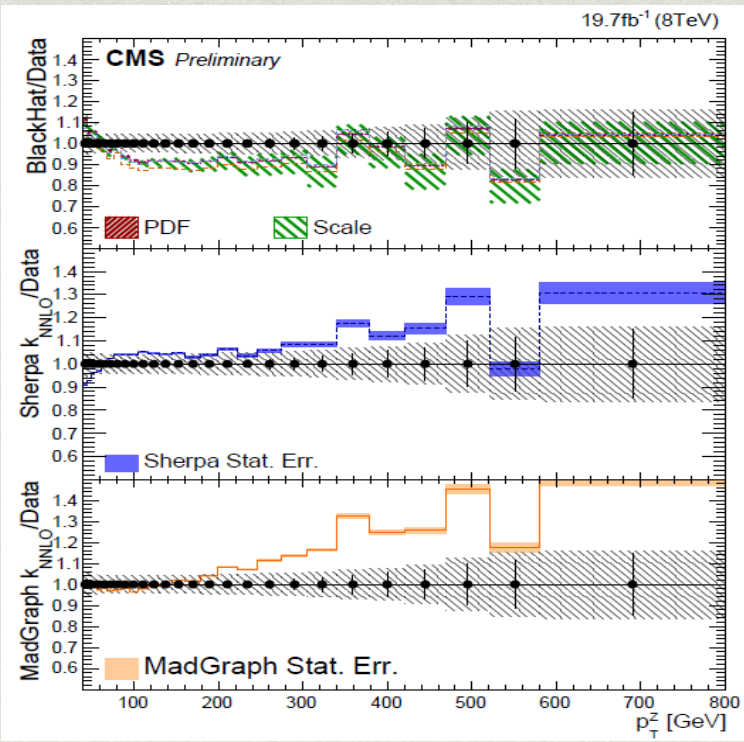


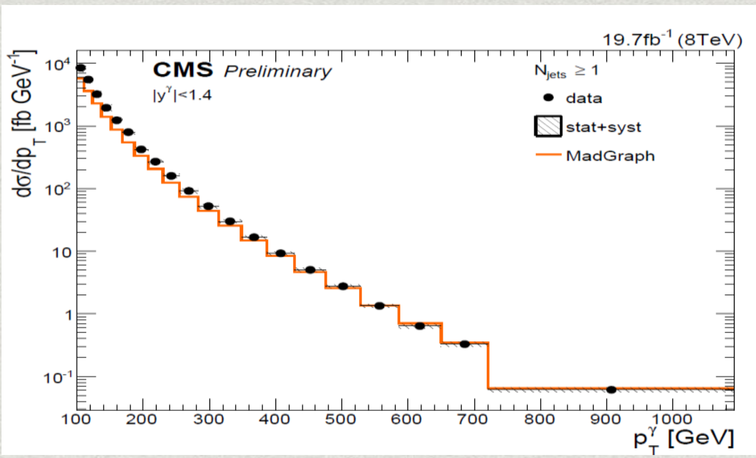
More differential distributions in Backups

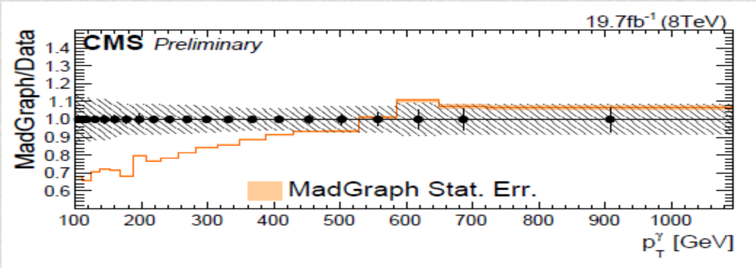
Theoretical settings:
- LO: Sherpa with CT10 PDF
- NLO: Diphox+Gamma2MC, Resbos with CT10 PDF
- NNLO: 2ɣNNLO with MSTW2008 PDF
- all use $m_{\gamma\gamma}$ as μ_F and μ_R

Z + jets / photon + jets cross section ratios

- Cross section and ratios with 19.7 /fb data at 8 TeV
- Modeling missing energy (Z->νν) by ɣ + jets
- Measured purity ranges between 70-90 % with RC isolation approach
- MadGraph (CTEQ6L1 PDF) and Sherpa (CT10 PDF) with NNLO corrections
- BlackHat NLO with MSTW2008 PDF for theory comparison



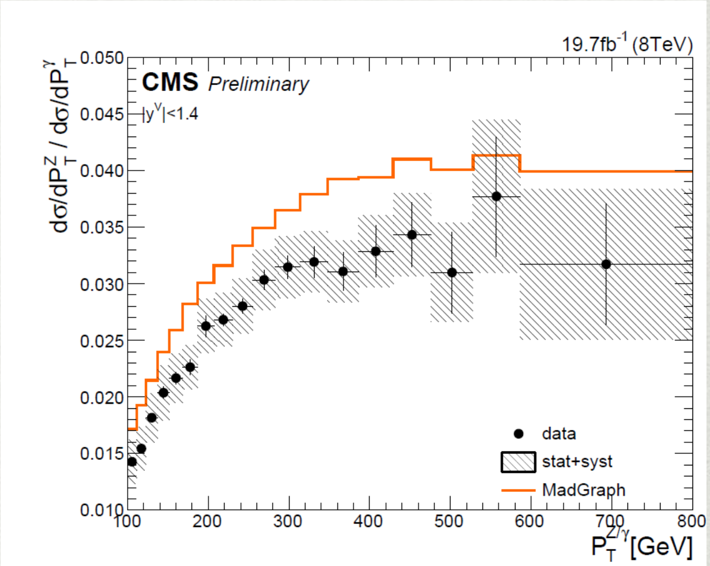




Z + jets / photon + jets cross section ratios

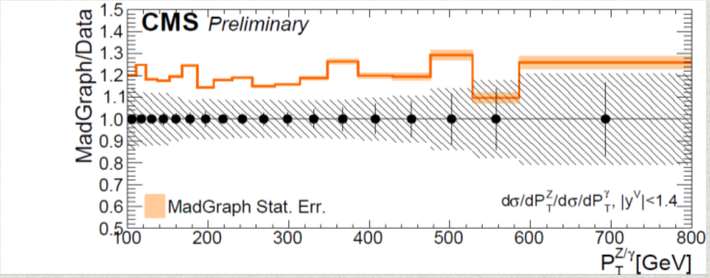
- Measured ratios of cross sections for the phase space:
  - Z/photon pT > 100 GeV, $|y_V| < 1.4$
  - Njets ≥ 1, 2, 3 and HT > 300 GeV for Njets ≥ 1
- Some systematics cancel, improved precision

$$Ratio = \frac{\sigma_{Z\to ll}(p_T^Z > 314GeV)}{\sigma_\gamma(p_T^\gamma > 314GeV)} = 0.0322 \pm 0.0008(stat) \pm 0.0020(syst)$$



Turn-on around pT ≈ 300-350 GeV

$$Ratio_{total} = 0.957 \pm 0.066$$



MadGraph+Pythia6 overestimates data

More ratios in back-ups.

Conclusion

- CMS has explored photon productions in most relevant areas with 7 TeV data
- Data comparisons with LO and NLO predictions are presented on photon differential cross sections
- Theoretical predictions overall agree with data (Sherpa, JETPHOX, and 2γNNLO perform well) but show some discrepancies
- CMS SM physics program will continue to provide an excellent benchmark to tune the predictions with the ongoing photon analyses of the 8 TeV dataset (Run 1) and the planned photon analyses of 13 TeV dataset for the next LHC run (Run 2)

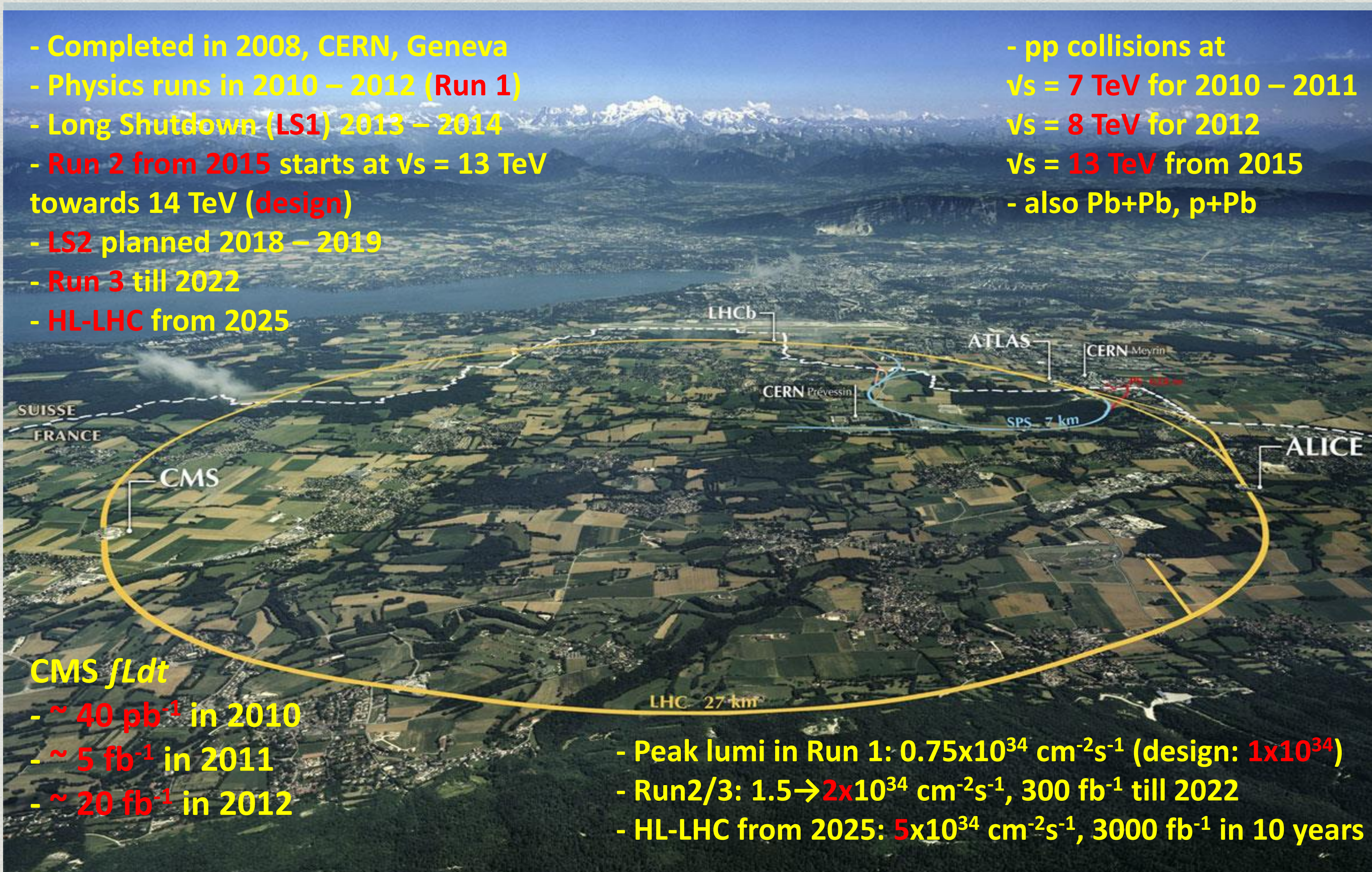
“Thank you for your attention”

“Back-up slides”

LHC operations

- Completed in 2008, CERN, Geneva
- Physics runs in 2010 – 2012 (Run 1)
- Long Shutdown (LS1) 2013 – 2014
- Run 2 from 2015 starts at √s = 13 TeV towards 14 TeV (design)
- LS2 planned 2018 – 2019
- Run 3 till 2022
- HL-LHC from 2025

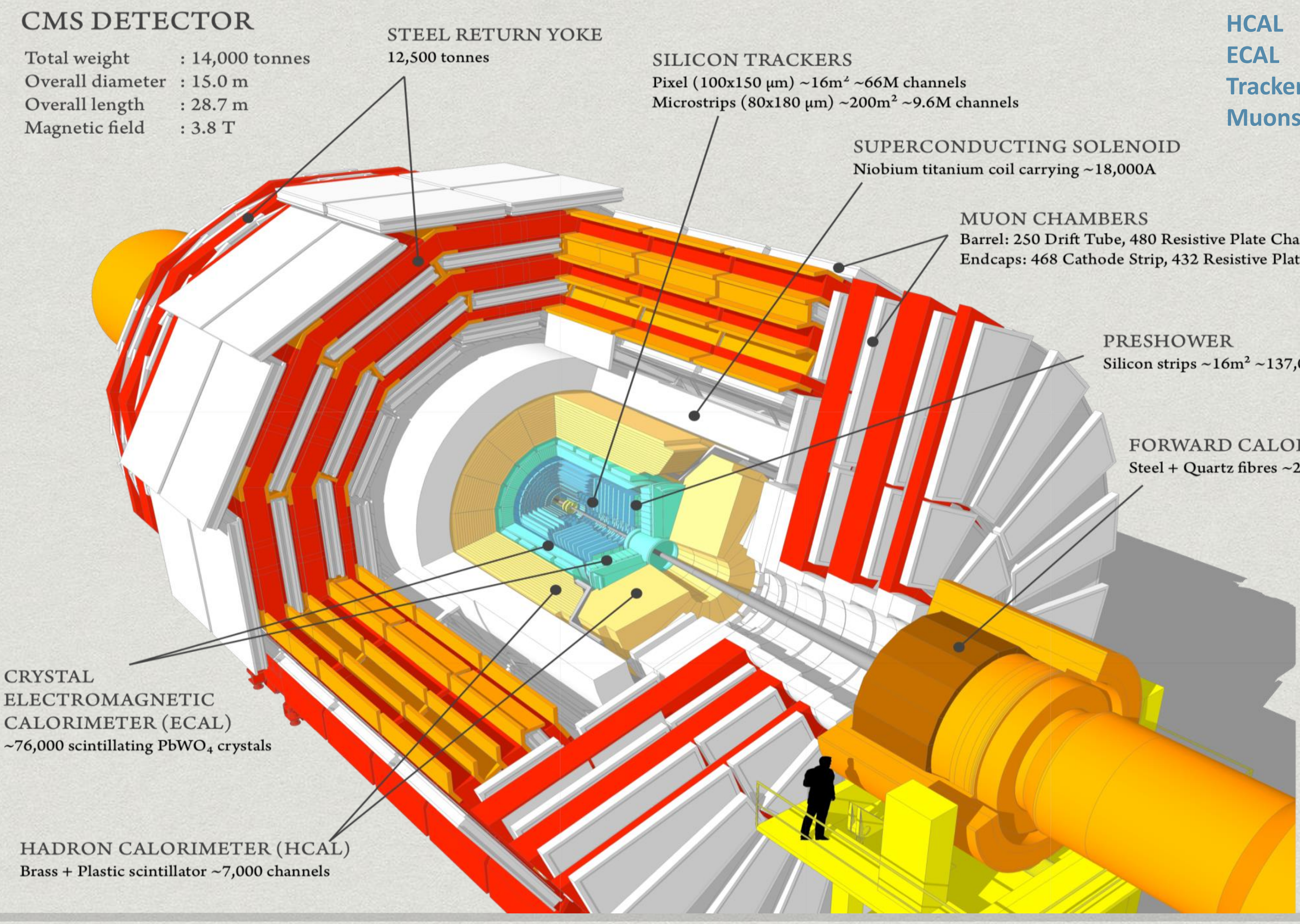
- pp collisions at
  √s = 7 TeV for 2010 – 2011
  √s = 8 TeV for 2012
  √s = 13 TeV from 2015
- also Pb+Pb, p+Pb



CMS $\int L dt$
- ~ 40 pb^{-1} in 2010
- ~ 5 fb^{-1} in 2011
- ~ 20 fb^{-1} in 2012

- Peak lumi in Run 1: 0.75×10^{34} $cm^{-2}s^{-1}$ (design: 1×10^{34})
- Run2/3: 1.5→2×10^{34} $cm^{-2}s^{-1}$, 300 fb^{-1} till 2022
- HL-LHC from 2025: 5×10^{34} $cm^{-2}s^{-1}$, 3000 fb^{-1} in 10 years

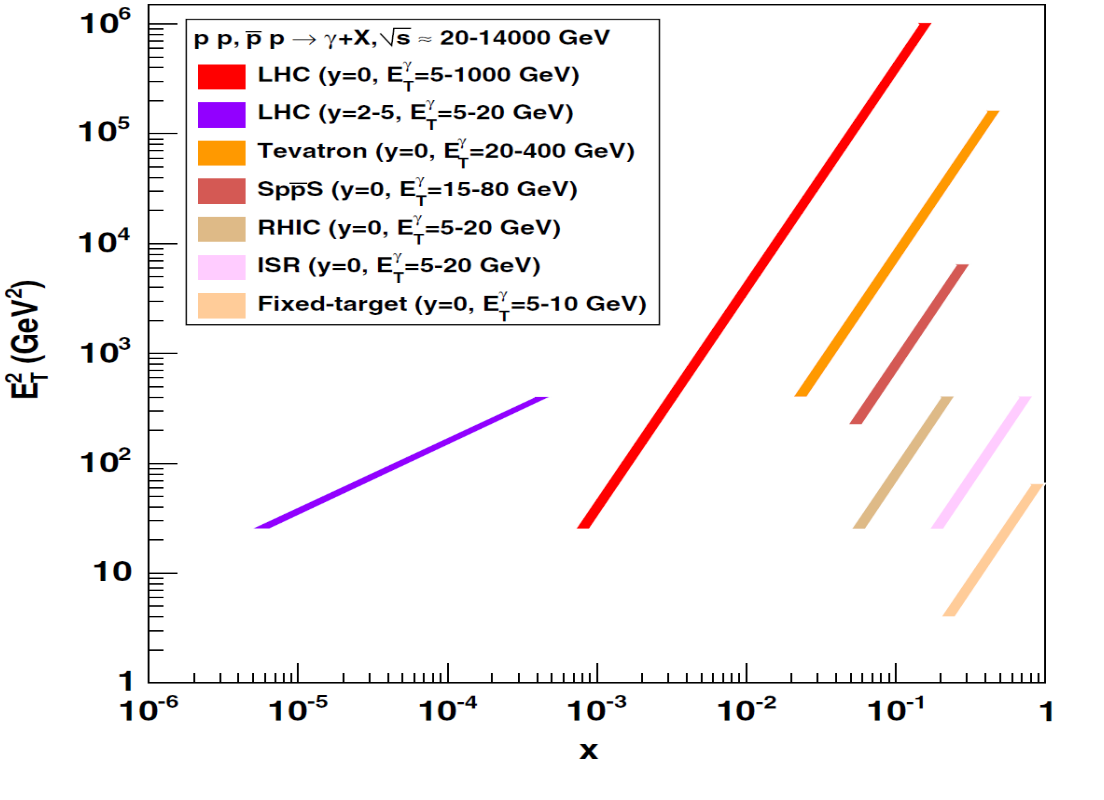
CMS detector



HCAL $|\eta| < 5$
ECAL $|\eta| < 3.0$
Tracker $|\eta| < 2.5$
Muons $|\eta| < 2.4$

Photon Physics @ LHC

- Kinematical region probed by existing prompt photon measurements at fixed-target (Fermilab) and collider (ISR, RHIC, SppS, Tevatron) energies, and expected range probed at the LHC at central (y=0) and forward (y=2–5) rapidities.
- More than 30 years of experimental data varying from 20 GeV to 14 TeV energies

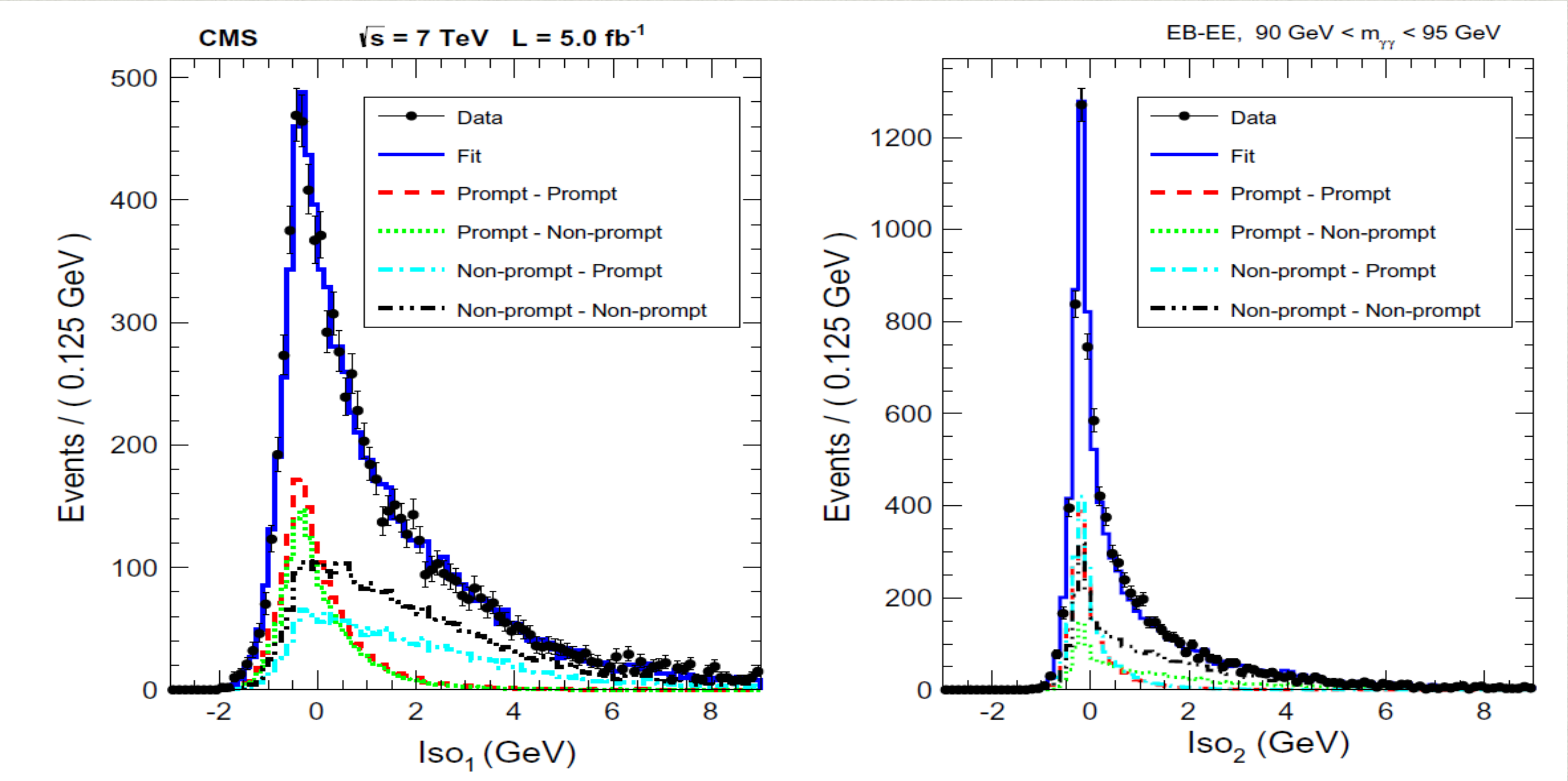


- **CMS central rapidity coverage: ~0.007 < x < 0.114**
- **Extends to a much lower x region for forward rapidity**

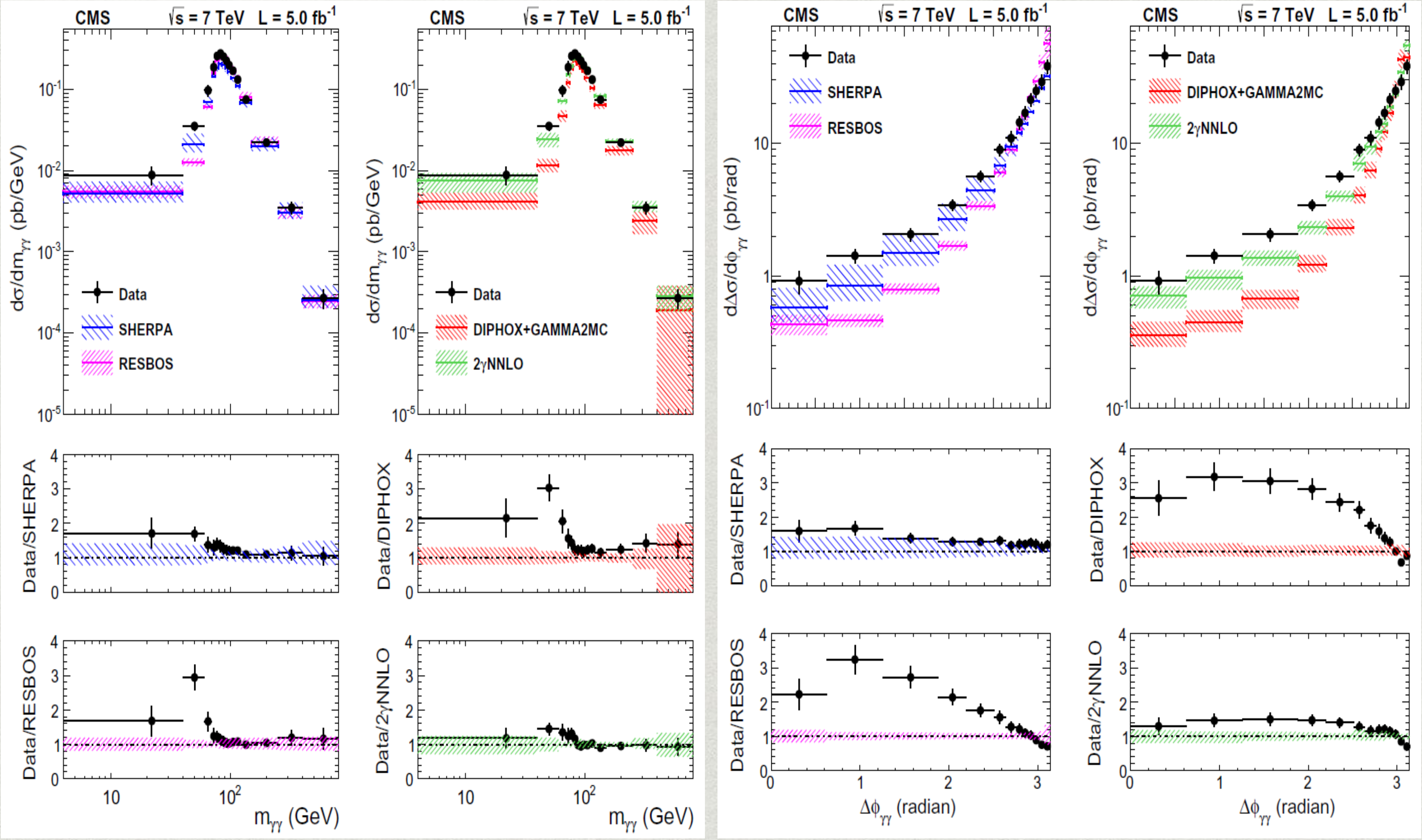
$$x = x_T \times e^{-y} = 2p_T \times e^{-y} / \sqrt{s}$$

- **LHC probes a couple of orders of magnitude lower parton momentum fraction x compared to previous measurements** (R. Ichou and D. d'Enterria, Phys. Rev. D 82, 014015 (2010))

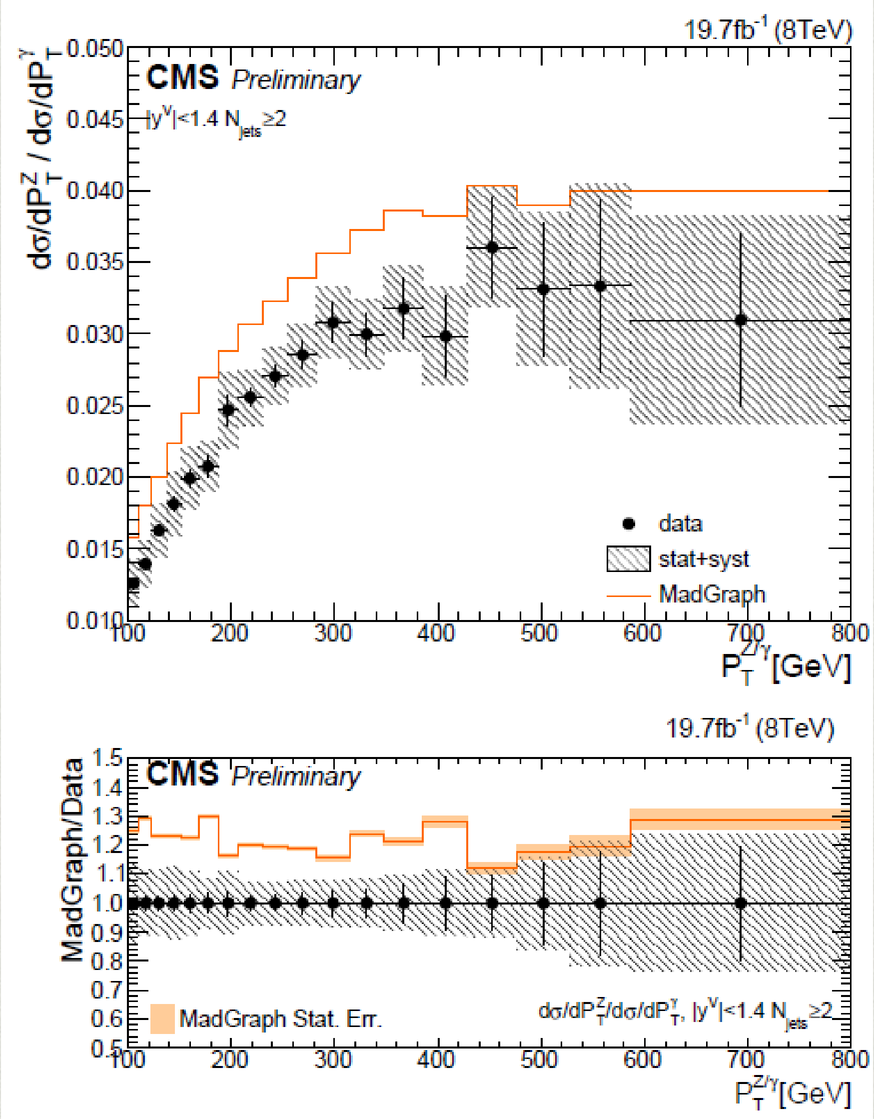
Diphoton template fitting



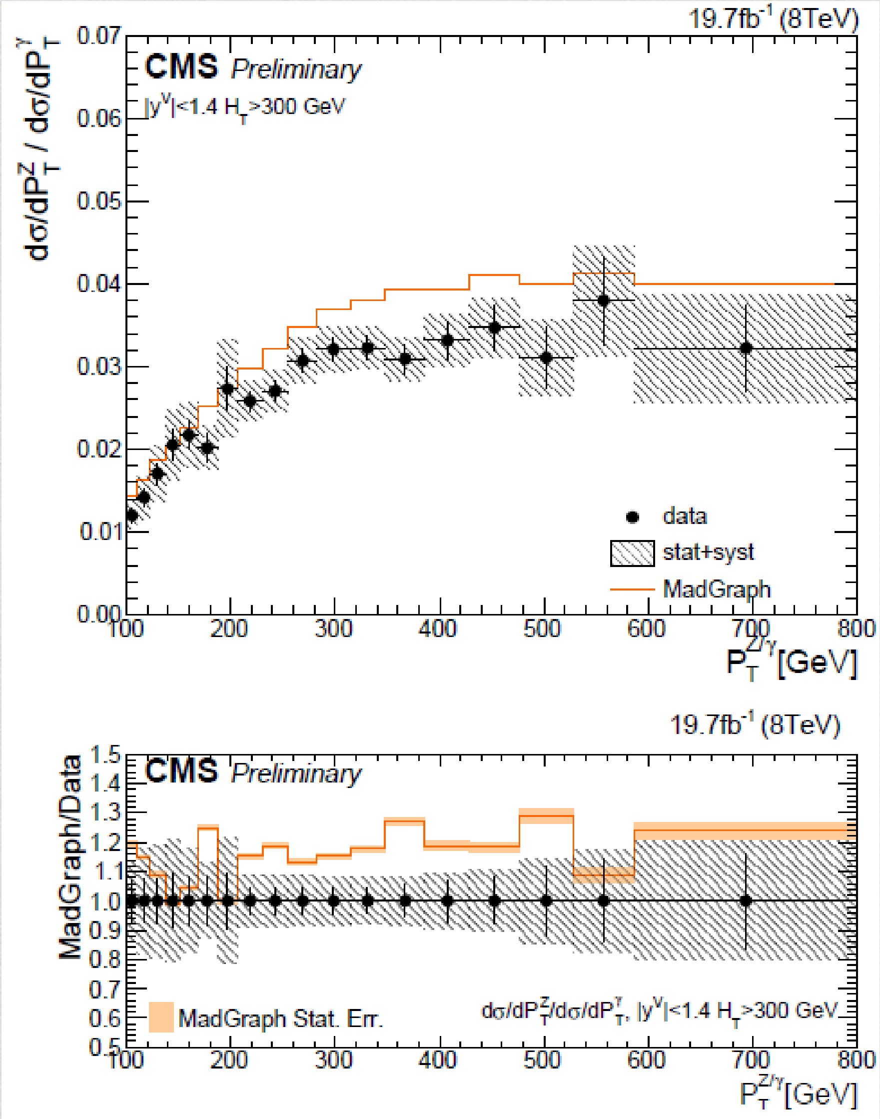
Diphoton differential distributions



Z/γ ratios



19.7fb-1 (8TeV)
CMS Preliminary
|yV|<1.4 Njets≥2
dσ/dPTZ / dσ/dPTγ
data
stat+syst
MadGraph
PTZ/γ[GeV]
MadGraph/Data
MadGraph Stat. Err.
dσ/dPTZ/dσ/dPTγ, |yV|<1.4 Njets≥2



19.7fb-1 (8TeV)
CMS Preliminary
|yV|<1.4 HT>300 GeV
dσ/dPTZ / dσ/dPTγ
data
stat+syst
MadGraph
PTZ/γ[GeV]
MadGraph/Data
MadGraph Stat. Err.
dσ/dPTZ/dσ/dPTγ, |yV|<1.4 HT>300 GeV