Inclusive Photon Spectra at $\sqrt{s} = 7$ TeV

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For

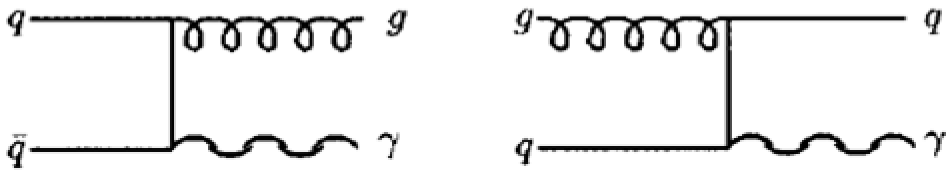
CMS collaboration

Contents

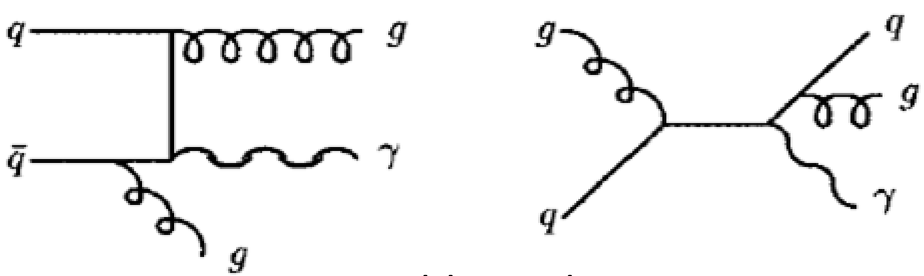
- Introduction to single photon measurements
  - Definition of isolated photons
- History of single photon measurements
- ECAL @ CMS
- Details of the analysis
- Isolated photon measurement at CMS for 7 TeV pp collisions
  - Comparison with theory

Prompt Photons

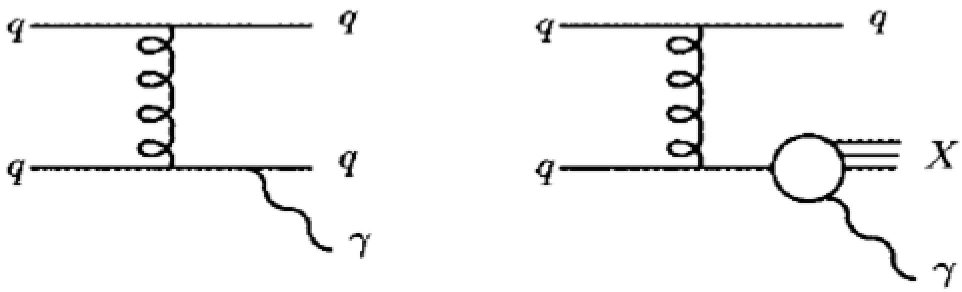
Direct Photons



NLO Photons



Bremsstrahlung Photons



- Prompt photon production is an experimental probe of the hard scattering dynamics
  - Study perturbative QCD
  - Jet energy scale calibration
  - Background to H->γγ and BSM searches
- More than 30 years of experimental data available with center-of-mass energy of collisions ranging from ~20 GeV to 1.96 TeV
  - Today we will be presenting the results from CMS at 7 TeV
- Two main leading order contributions
  - Compton scattering
  - Annihilation of quarks

Background for measuring prompt photons comes from the neutral meson decays

Definition of Isolated Photons

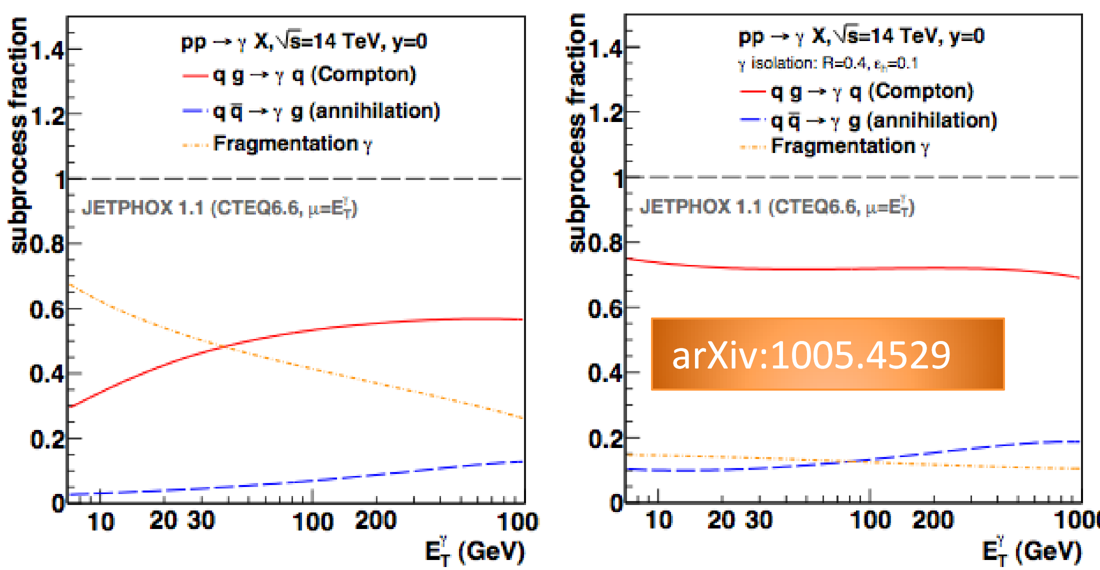
- Measuring prompt photons experimentally
  - An isolation criterion around the photon candidates is applied to suppress the background from pi0's etc.
  - Requiring isolation also effects the fragmentation contribution

Definition of Isolated photons : Similar both theoretically and experimentally

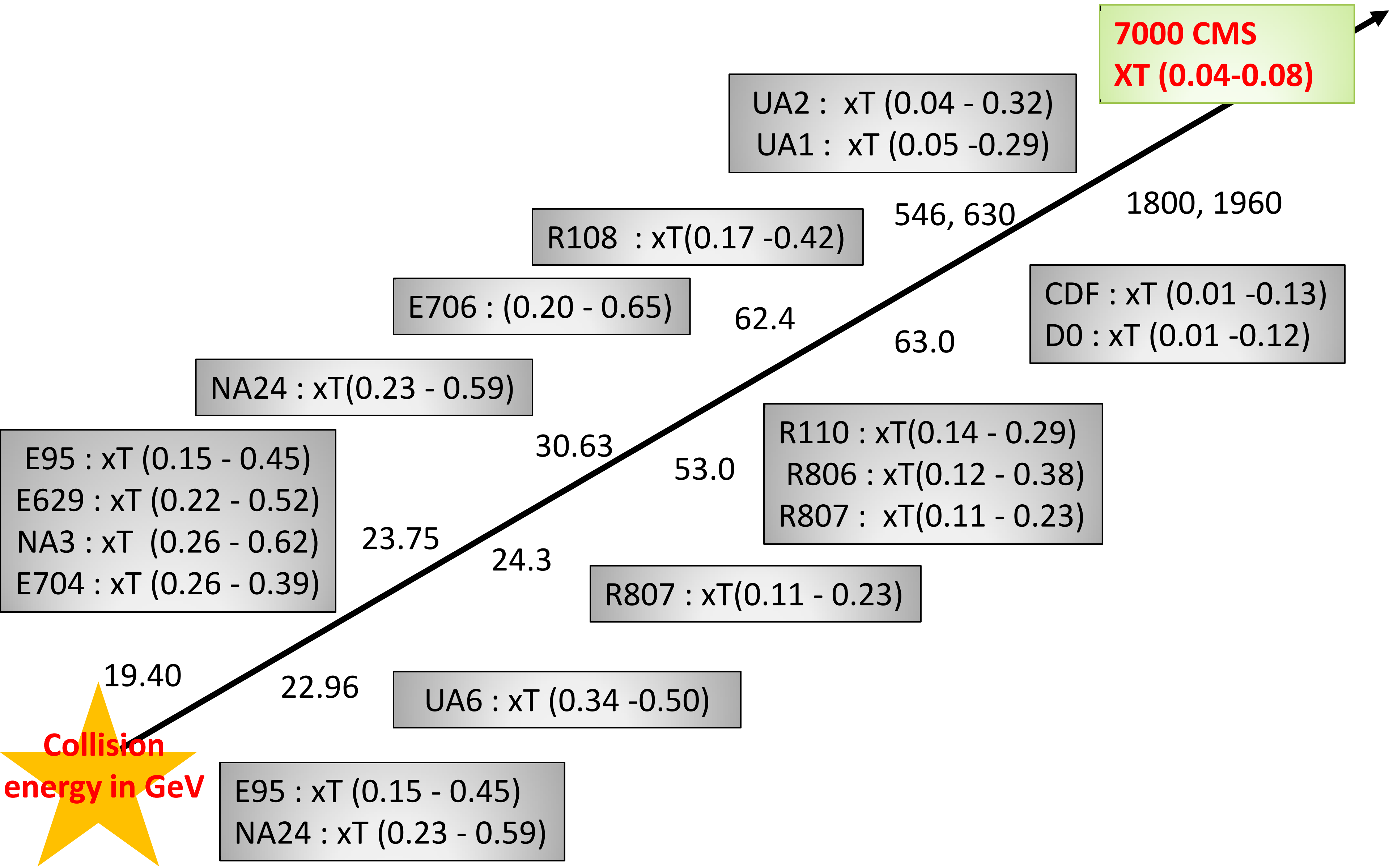
$$\sqrt{(\Delta \varphi)^2 + (\Delta \eta)^2} \leq R$$

$$E_{had}(R) \leq E_{uppercut}$$

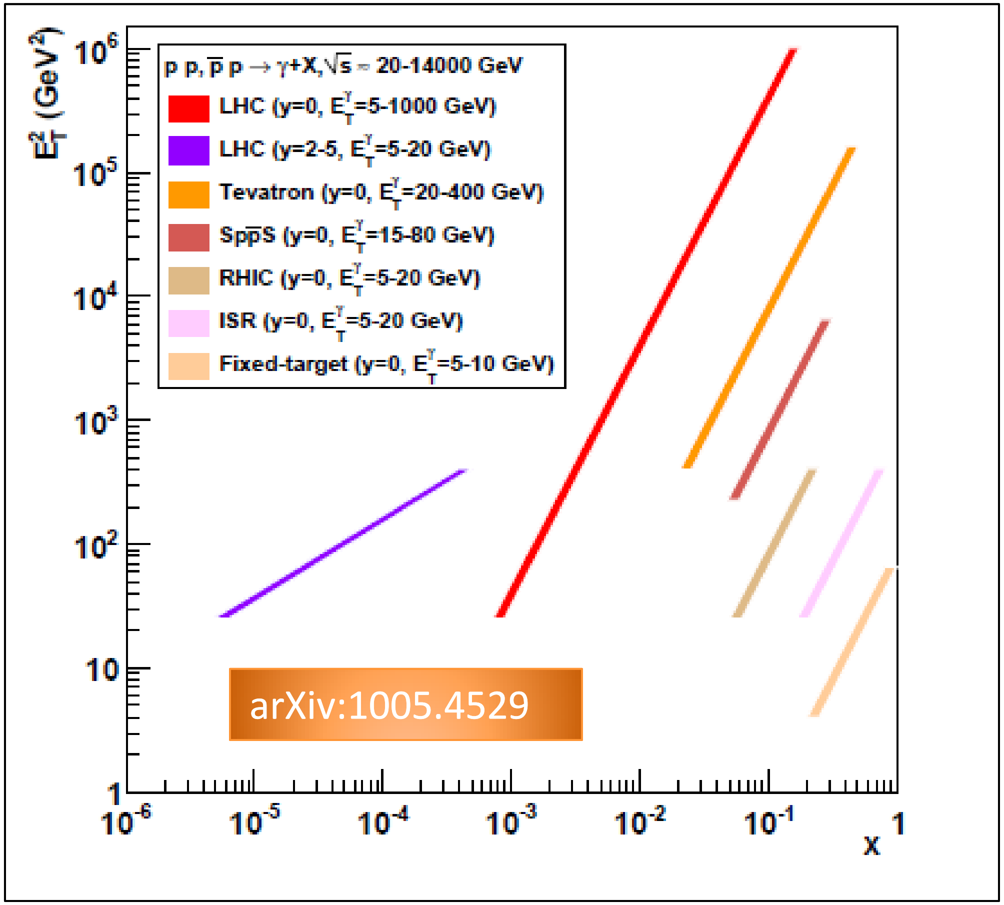
- Theoretical Calculation
  - both the direct and the fragmentation pieces is accounted for
  - Beyond LO, the distinction between the direct and fragmentation becomes dependent on the renormalization and fragmentation scheme



History of Isolated Photon Measurement

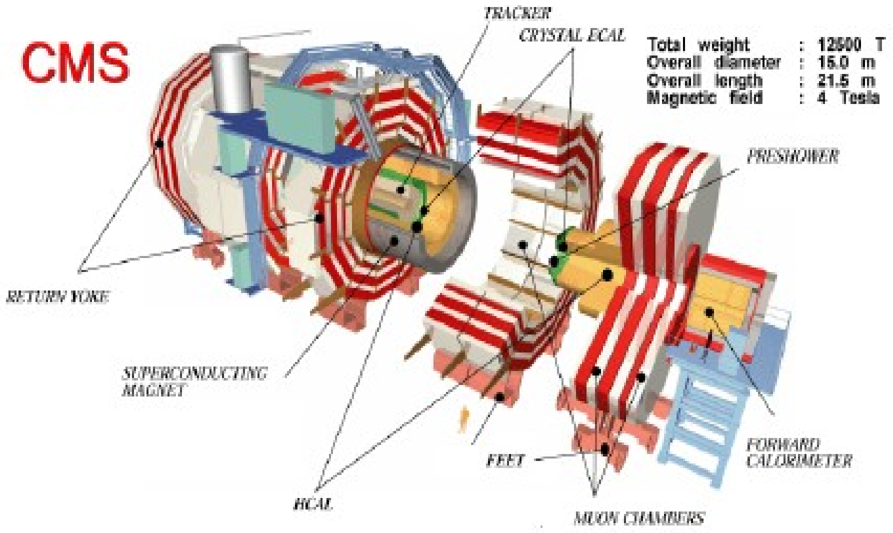


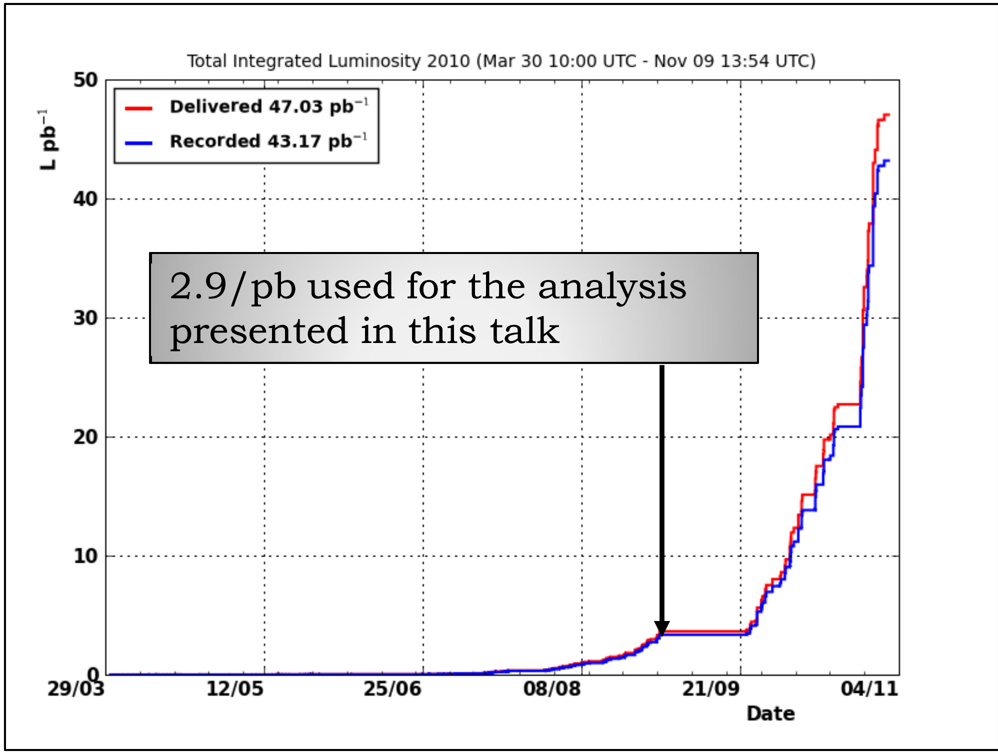
Photons @ LHC



- X reach of the photons at LHC is a couple of orders of magnitude lower than the previous experiments
- Dominance of the Compton scattering cross-section gives possibility of clean probe to constrain gluon pdf's

CMS Detector

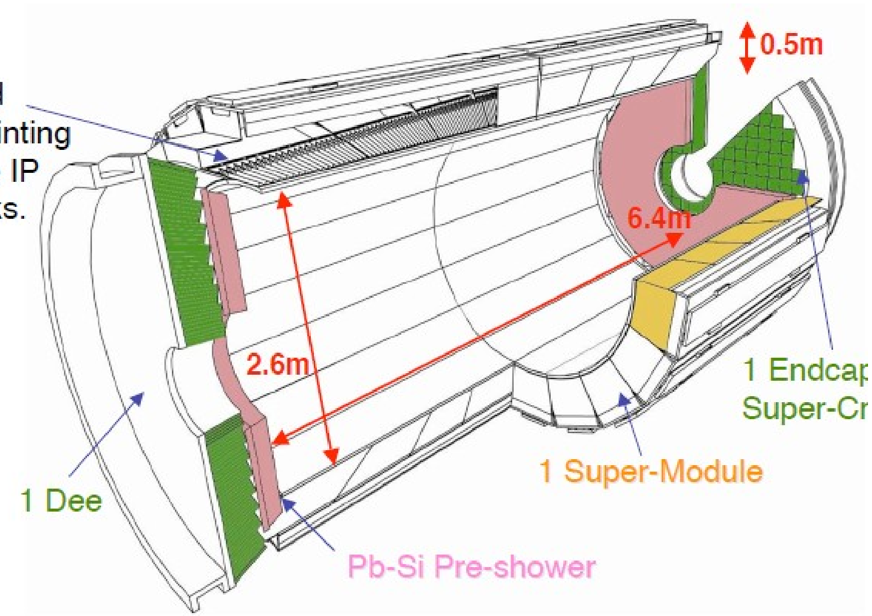


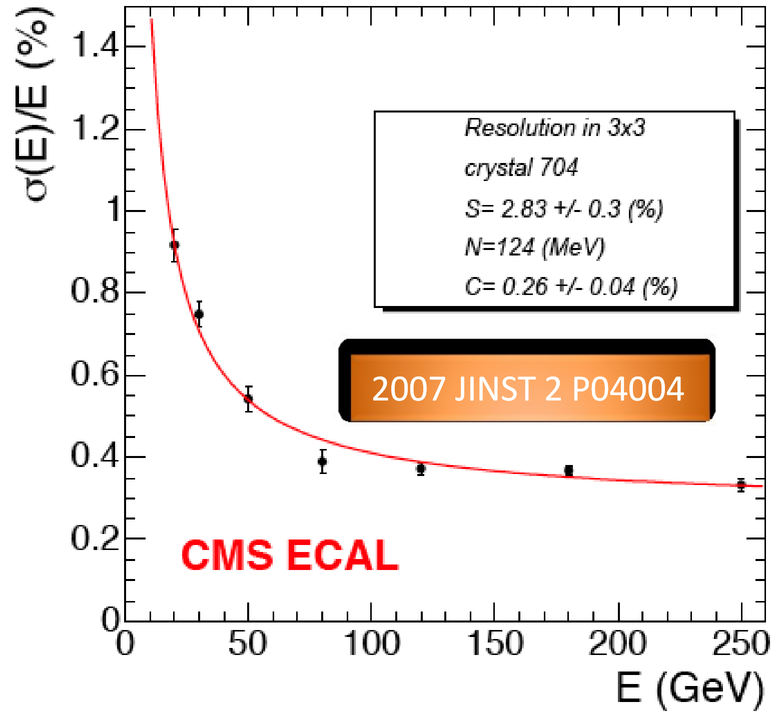


- CMS is a general purpose detector
- Approximate scale of the project: 66M pixel channels, 10M silicon channels, 75k crystals, 150k silicon preshower channels, 15k HCAL channels, 250 DT chambers (170k wires), 470 CSC chambers (200k wires), 900 RPC chambers, 50 kHz DAQ system (10k CPU cores), GRID computing (50k cores)
- Two level trigger system

Electromagnetic Calorimeter

Crystals are projective and positioned pointing slightly off the IP to avoid cracks.





Barrel (EB):

- 61200 crystals total
- 36 Supermodules (SM), each 1.7k crystals

Endcap (EE):

- 14648 crystals total
- 4 Dees, each 3662 crystals
- Crystals combined into SuperCrystals of 5x5 crystals

Isolated Photon Measurement @ CMS

$$\frac{d^2\sigma_{\gamma,isolated}}{dE_T^\gamma d\eta^\gamma} = \frac{1}{\Delta E_T^\gamma \Delta\eta^\gamma} \frac{N_{Yeild}^\gamma(\Delta E_T^\gamma, \Delta\eta^\gamma)}{L \cdot U \cdot \varepsilon}$$

E_T^γ – Transverse energy of the photon

η^γ – Pseudorapidity of the photons

$N_{Yield}^\gamma(\Delta E_T^\gamma, \Delta\eta^\gamma)$ – signal yield of photons passing the isolation condition

ε – Signal efficiency

U – Correction of reconstruction effect

L - Luminosity

Barrel only photons
-1.45< η <1.45

E_T bins
21-23
23-26
26-30
30-35
35-40
40-45
45-50
50-60
60-85
85-120
120-300

Data and Event Selection

- Data presented in this talk is collected during the 2010 7TeV pp running
  - 2.9/pb of integrated luminosity
- Monte-Carlo
  - PYTHIA
  - Full detector simulation using GEANT
  - Gamma + Jet and Dijet events
- Event selection
  - $|z|<18$ cm
  - n.d.o.f.>4, require at least 4 tracks
  - Scraping filter, remove beam scraping events
- Photon selection
  - Isolation variable (defined in the next slide)
    - Iso_{TRK} <2.0GeV
    - Iso_{ECAL} <4.2GeV
    - Iso_{HCAL} <2.2GeV
    - H/E < 0.05
  - Pixel seed veto , veto events with pixel seeds compatible with electron tracks

Photon Isolation Variables

Isolation variable

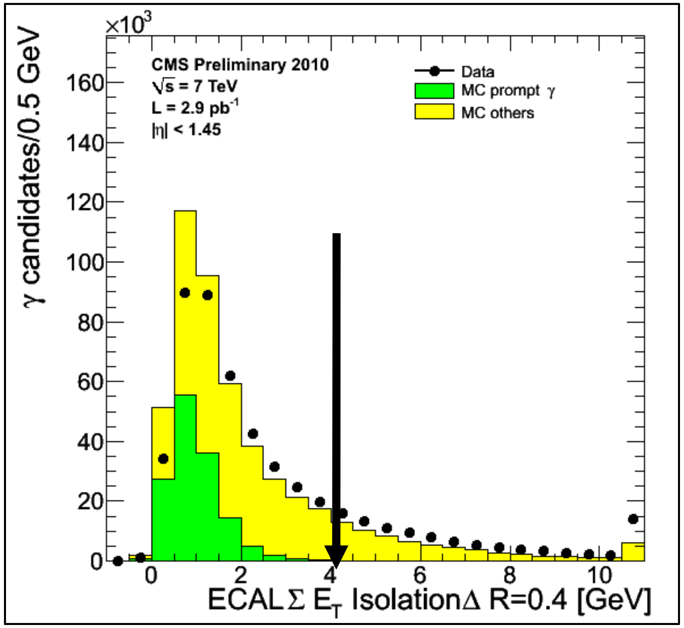
$Iso_{TRK} = \Sigma_{R<0.4}$ track p_T

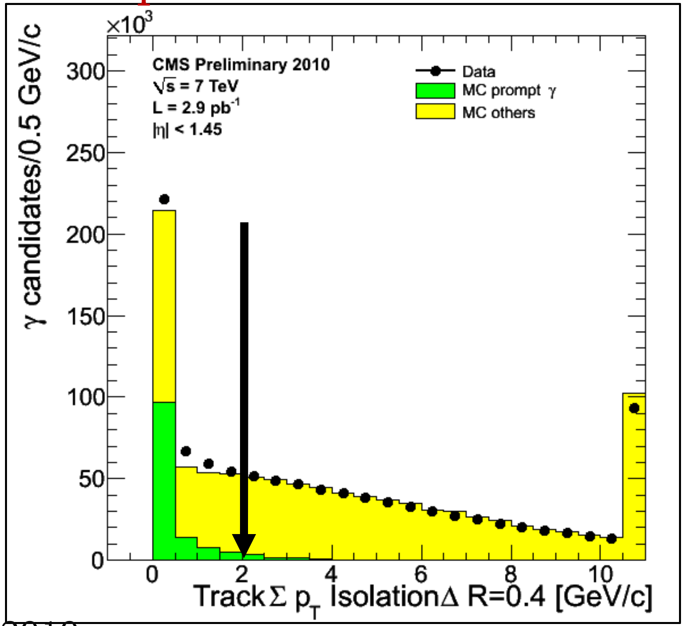
$Iso_{ECAL} = \Sigma_{R<0.4}\, E_{T\ ECAL}$

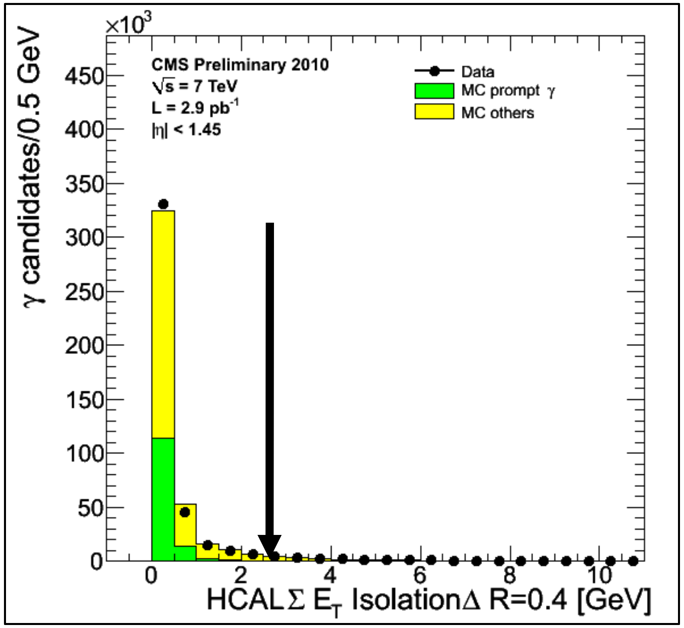
$Iso_{HCAL} = \Sigma_{R<0.4}\, E_{T\ HCAL}$

$H/E = \Sigma_{R<0.15}\, E_{HCAL}/E_{ECAL}$

- Defined as a hollow cone removing a central eta strip
  - Suited for use of electrons as control sample

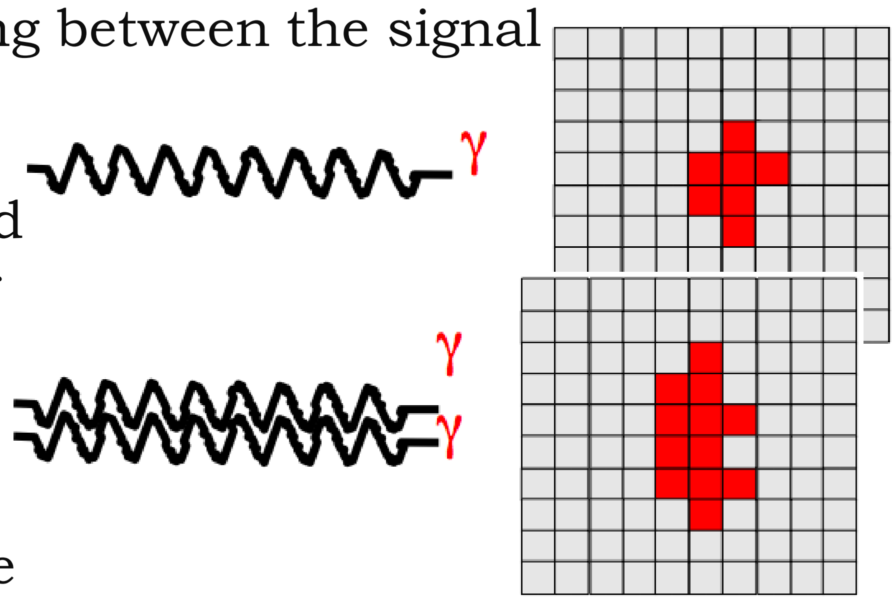






Photon Signal Yield Extraction Technique

- Using the difference in the showering between the signal and background events.

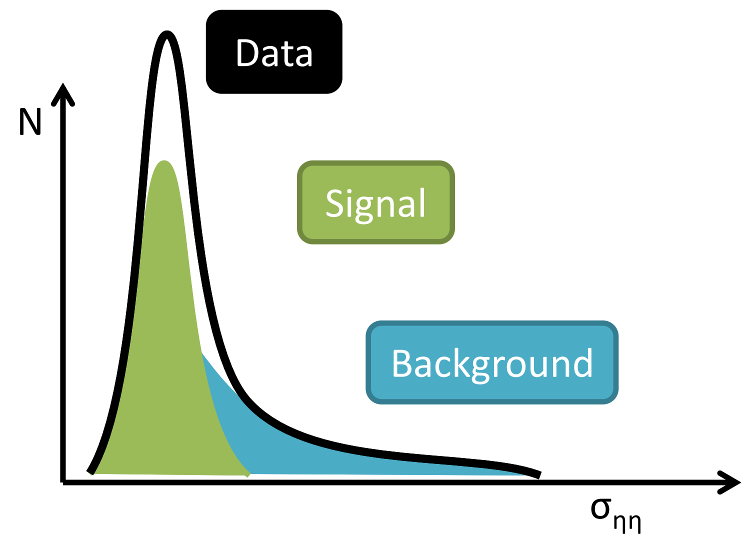


- Data shower shape template is fitted with signal and background shower shape using the extended log maximum likelihood optimization.
- Signal template is obtained from the Monte-Carlo and the background template is obtained from the data.

Shower shape definition

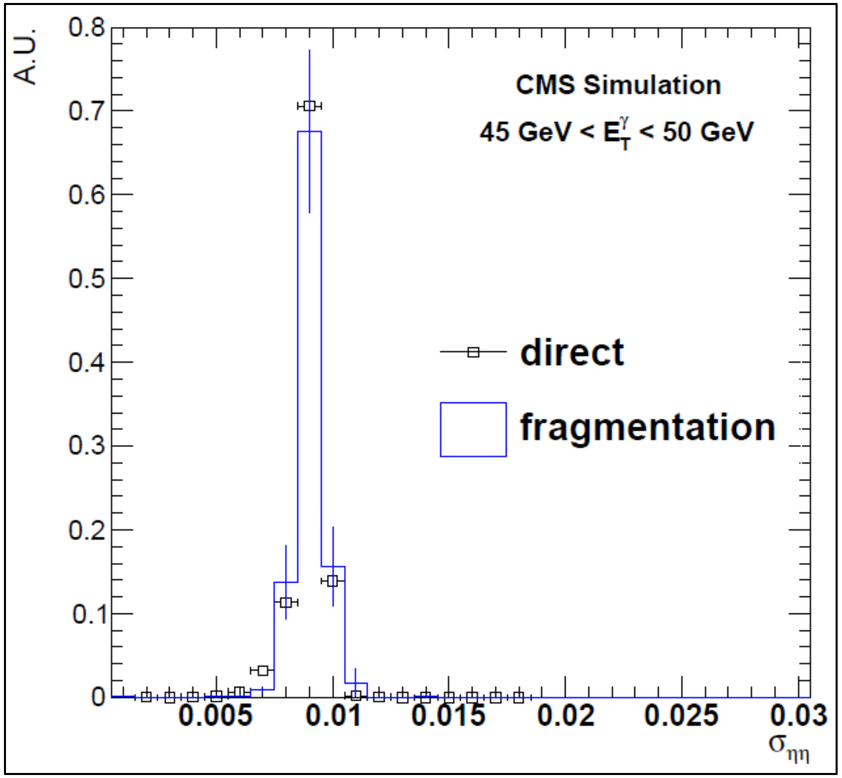
$$\sigma_{i\eta i\eta}^{2} = \frac{\sum (\eta_i - \bar{\eta})^2 w_i}{\overline{w_i}}, \quad \bar{\eta} = \frac{\sum \eta_i w_i}{\sum w_i}$$

$$w_i = \max(0, 4.7 + \log(E_i / E_{5X5}))$$



Signal Shape Template

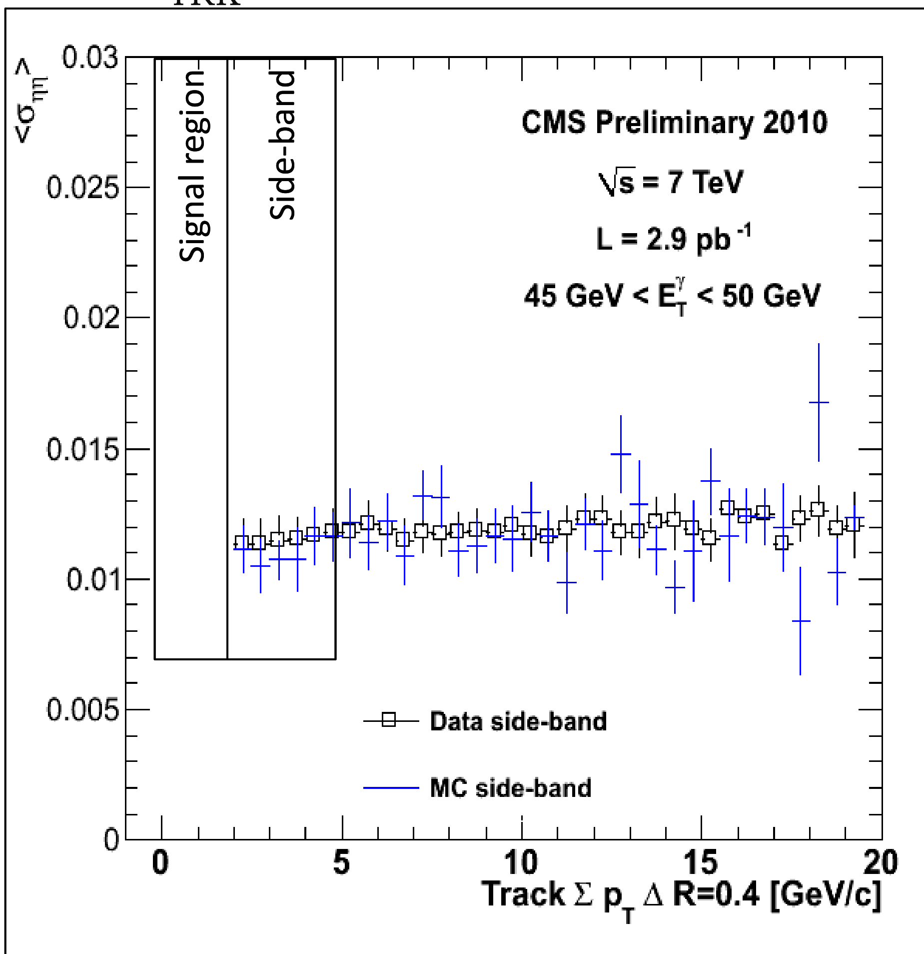
- Signal shape is extracted from the PYTHIA Monte-Carlo
  - Generator level isolation requirements are used
  - Both direct photon (Gamma + Jet) and fragmentation photon samples that pass the generator level isolation cuts are used
- The shape of the template changes as a function of the transverse momentum of the photon

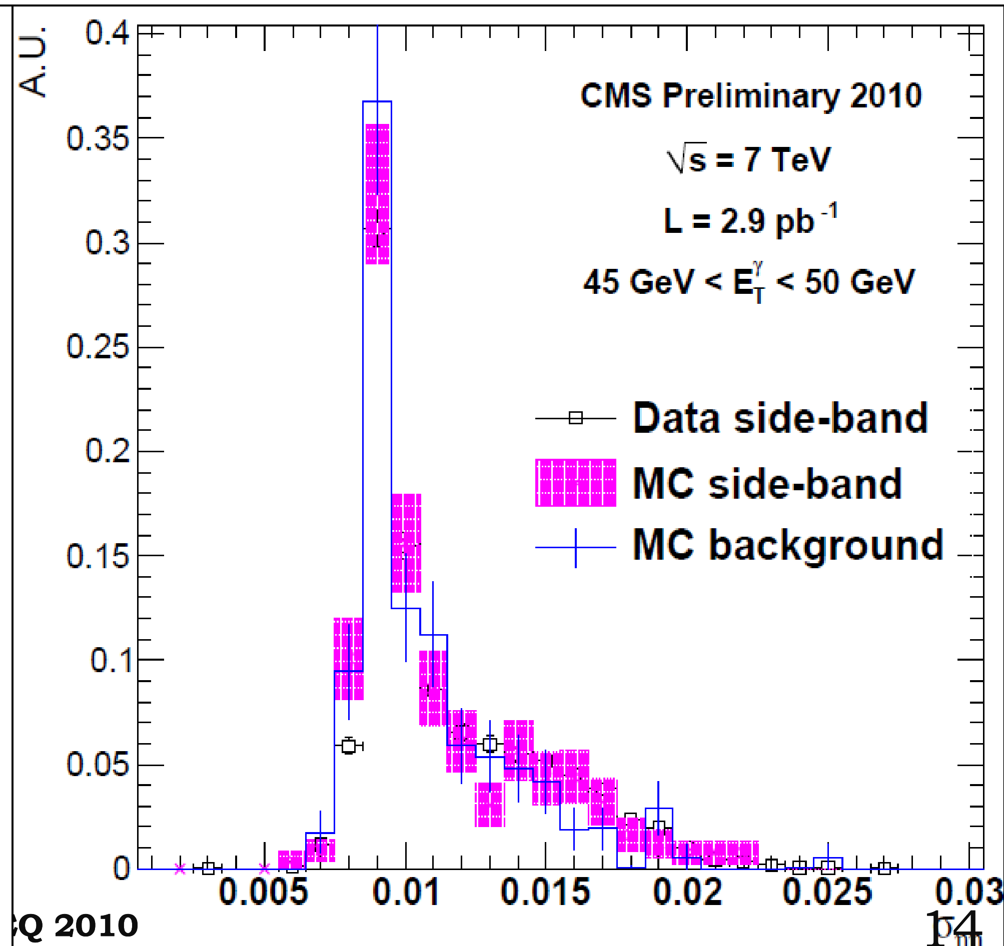


- Correction is applied to signal template to account discrepancy between the data and MC
  - Electrons from the Z's are used as a control sample to obtain the corrections to signal shape template
  - The value of correction $+(8\pm3)\times10^{-5}$

Background Shape Template

- For background, use $\sigma_{i\eta i\eta}$ distribution from events in track isolation side-band:
  - $2 < Iso_{TRK} < 5$ GeV
- Upper limit reduces bias from positive correlation between $\sigma_{i\eta i\eta}$ and Iso_{TRK}

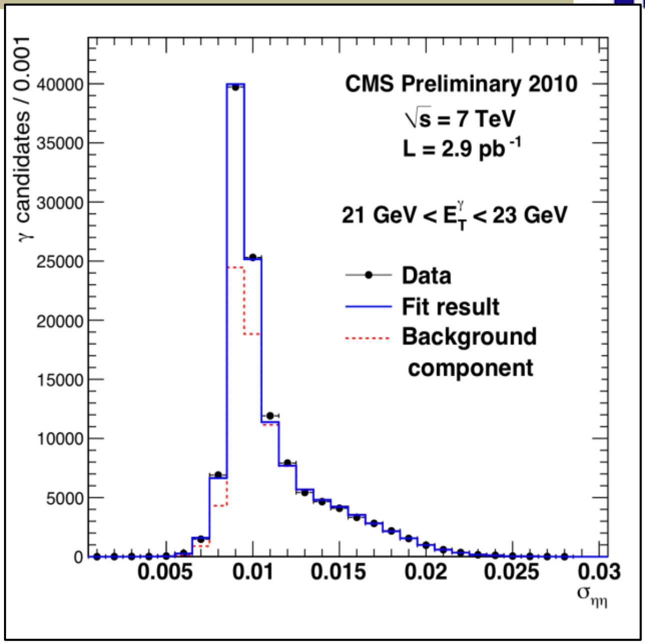


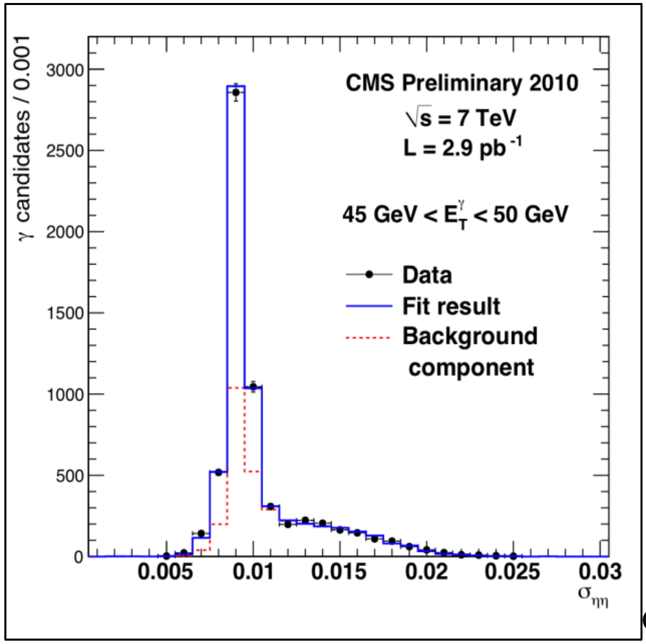


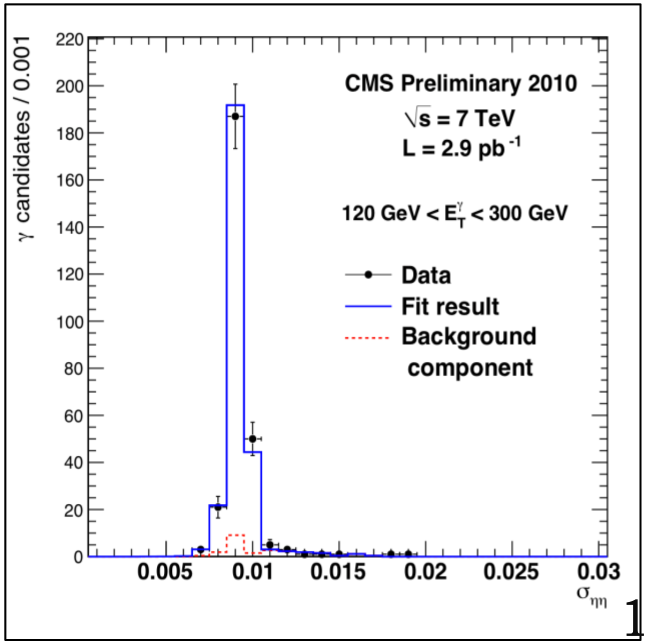
Signal Yield Extraction

- Two component fit to the data to extract signal yield is presented
- Fit performed independently for different pT bins

$$\mathcal{L} = -\ln L = -(N_{\mathcal{S}} + N_{\mathcal{B}}) + \sum_{i=1}^{n} N_i \ln(N_{\mathcal{S}}\mathcal{S}_i + N_{\mathcal{B}}\mathcal{B}_i)$$

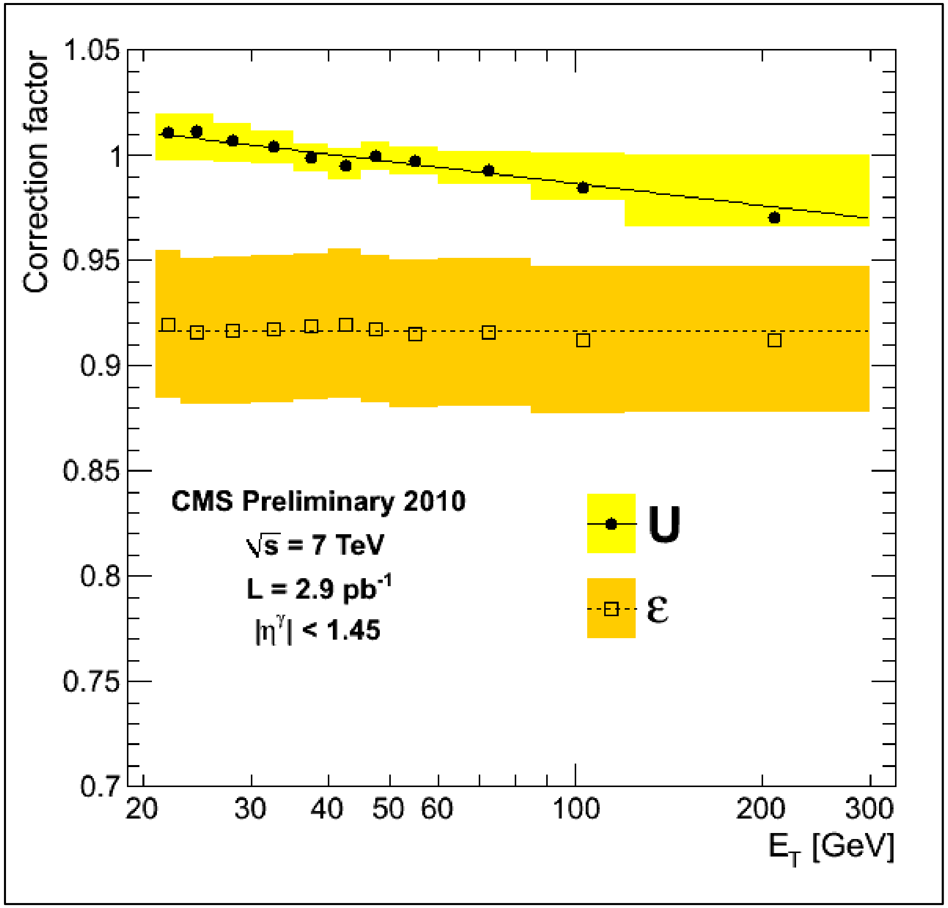






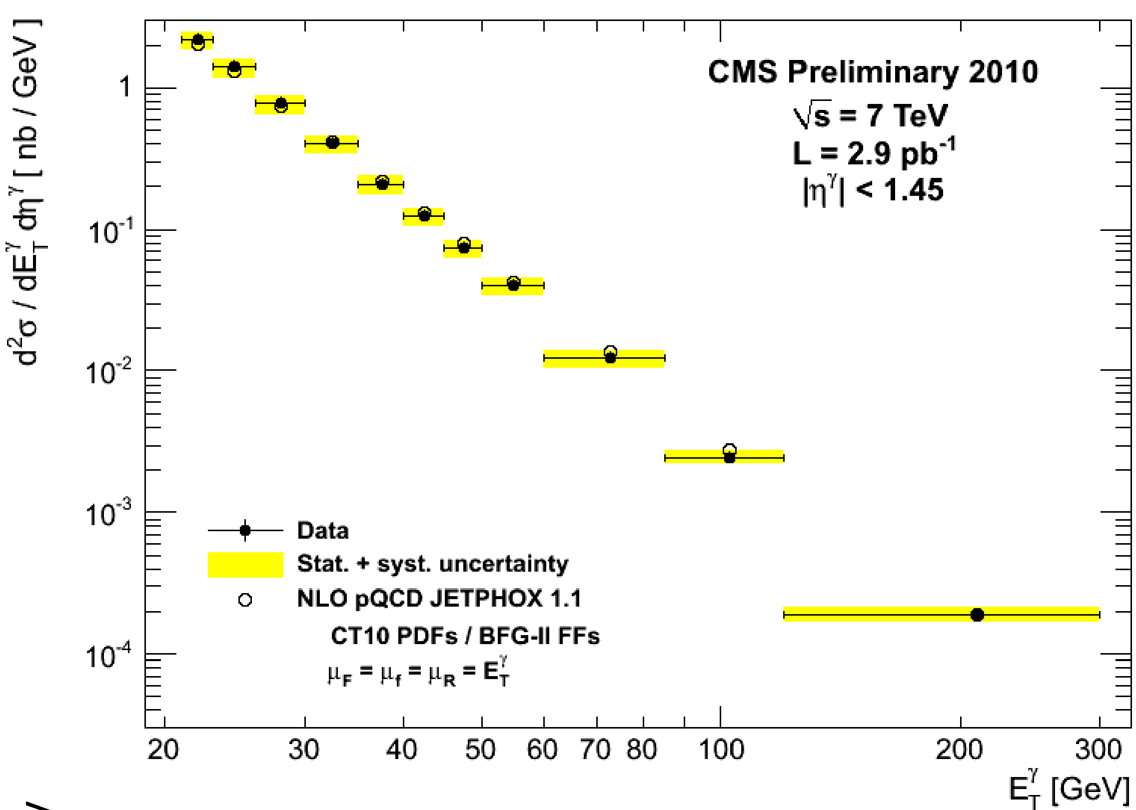
Efficiency Correction to Signal

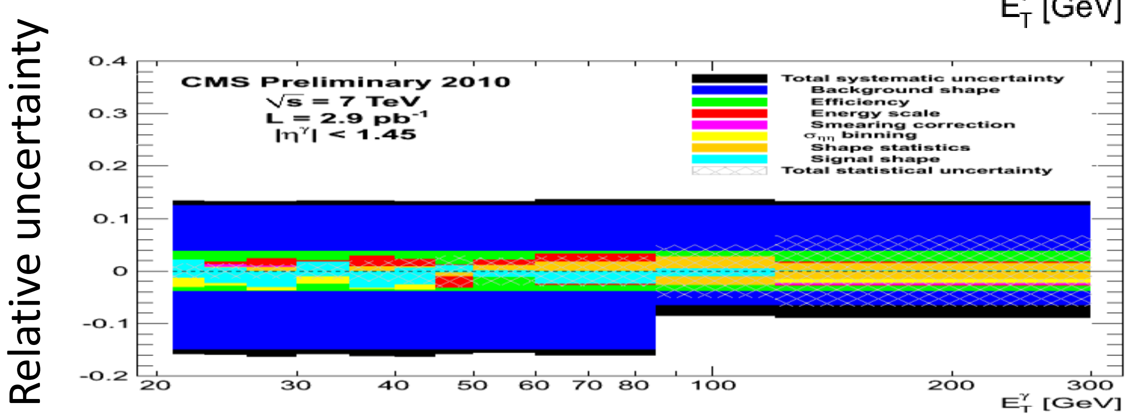
- All efficiencies determined w.r.t. "isolated" definition
- $\varepsilon = \varepsilon_{Trigger} \times \varepsilon_{RECO} \times \varepsilon_{Photon\ ID} = 91.6\%$
  - $\varepsilon_{Trigger}$=100%, the efficiency of the L1 and HLT selection
  - ε_{RECO}=98.9%, the absolute reconstruction efficiency in MC
  - $\varepsilon_{photonID}$ the efficiency of the isolation requirements, 92.7% in photon MC.



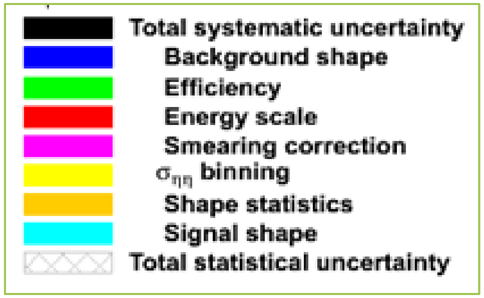
- Correction due to reconstruction effects~ 3% obtained using the MC

Isolated Photon Spectrum @ CMS



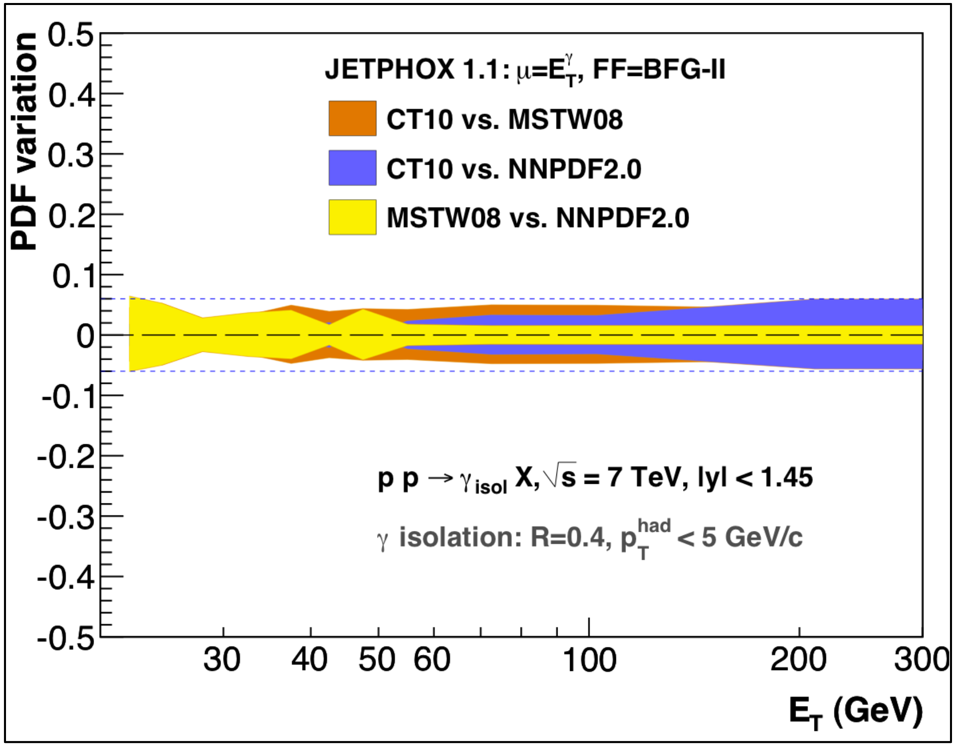


- Good agreement with the NLO predictions from JETPHOX is observed
- Total systematic uncertainty is varies between 8.9% to 16.3% depending on the transverse momentum bin.
  - Dominant systematic uncertainty comes from background shape



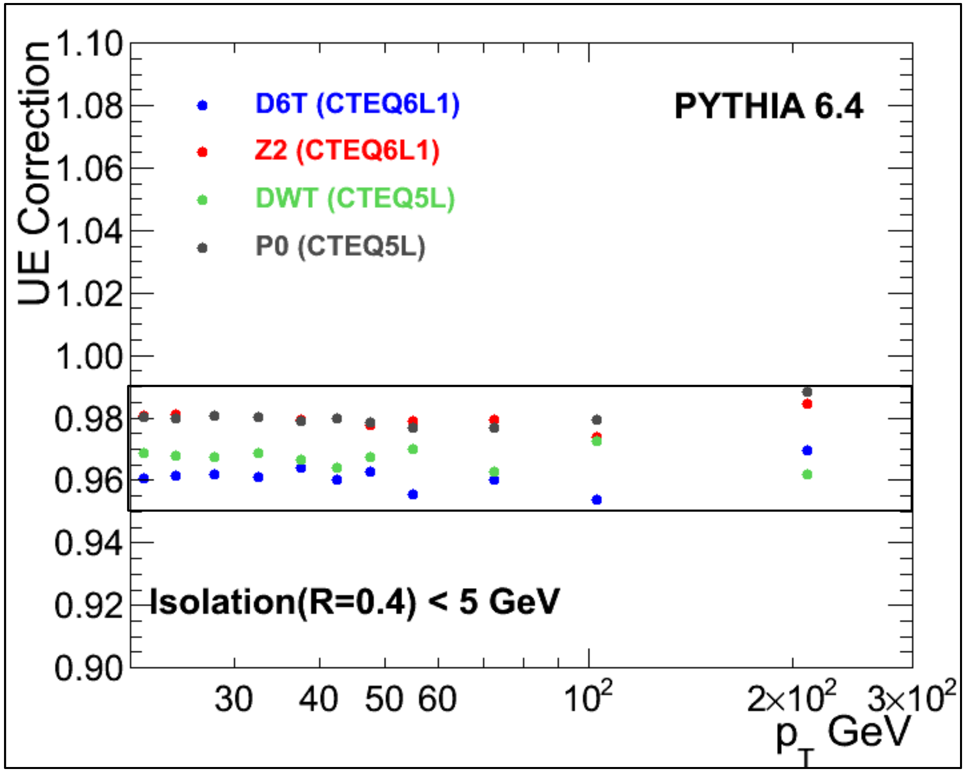
JetPHOX prediction

- NLO pQCD
  - JETPHOX 1.1, CT10 PDFs, BFG II FFs
  - Renormalisation, fragmentation, and factorization scales set to E_T
  - Require "isolated" definition: ΣE_T<5 GeV within R<0.4
- Scale uncertainty
  - 6 to 11% with ET, change all scales to ET/2 and 2ET
- PDF uncertainty
  - 6% over full ET range
  - Envelope of CT10, MSTW08 and NNPDF2.0 (PDF4LHC recommendation)
- CTEQ6M instead of CT10: 3%
- BFG I instead of BFG II: <1%



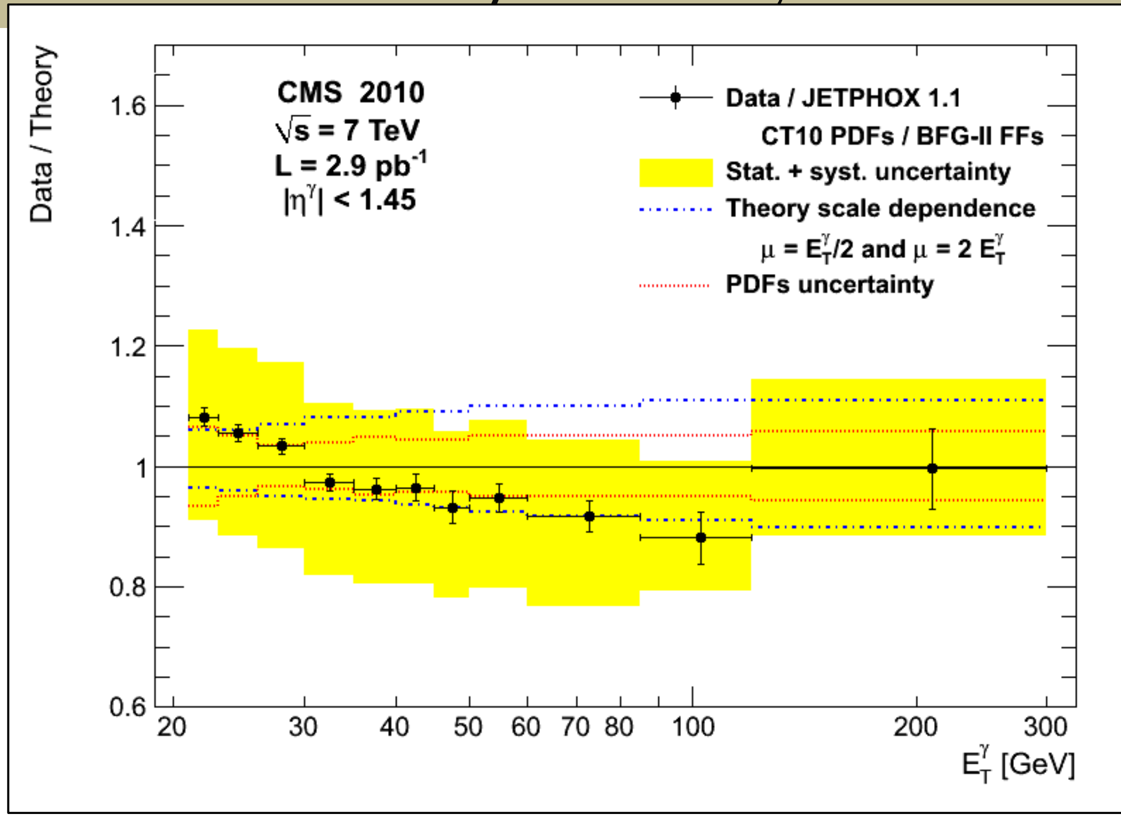
Non-perturbative corrections to the NLO prediction

- Non-perturbative effects increase energy in isolation cone
- Correction is obtained by comparing the efficiency of isolation cut of 5GeV in a cone of radius 0.4with and without:
  - Multi-parton interactions
  - Hadronization
- Final correction is the mean of the four different tunes considered
  - D6T
  - Z2
  - DWT
  - P0
- ~3% overall correction applied to the NLO calculation



Data/Theory

At √s = 7TeV CMS probes a low x value of ~0.001 (With |η|<1.45)

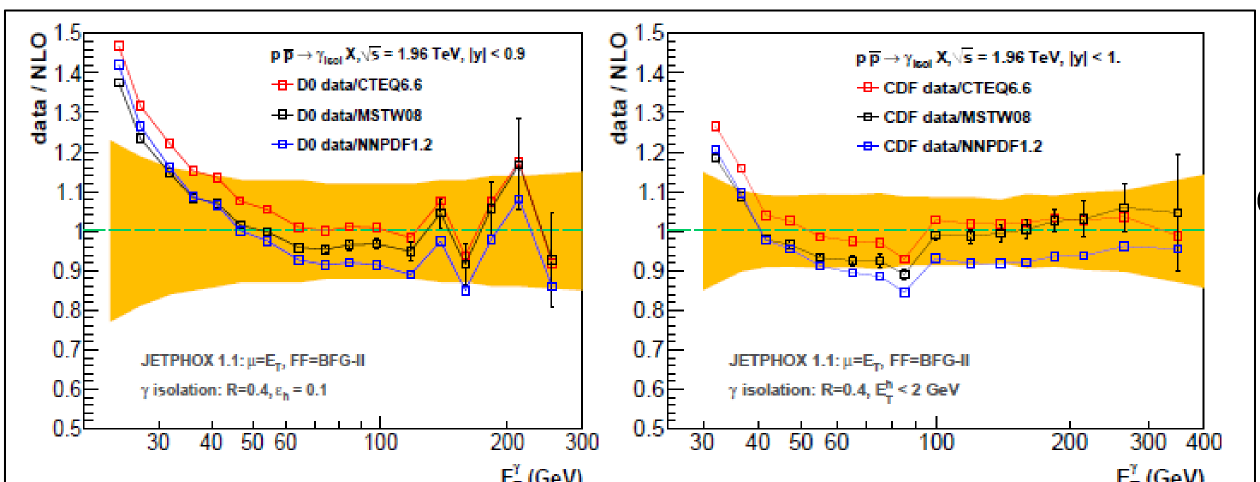


The NLO calculation agrees better with the data at low transverse momentum compared to precious experiments

arXiv:1005.4529

D0
0.01 < xT < 0.12

Phys. Lett. B 639 (2006) 151



CDF
0.01 < xT < 0.13

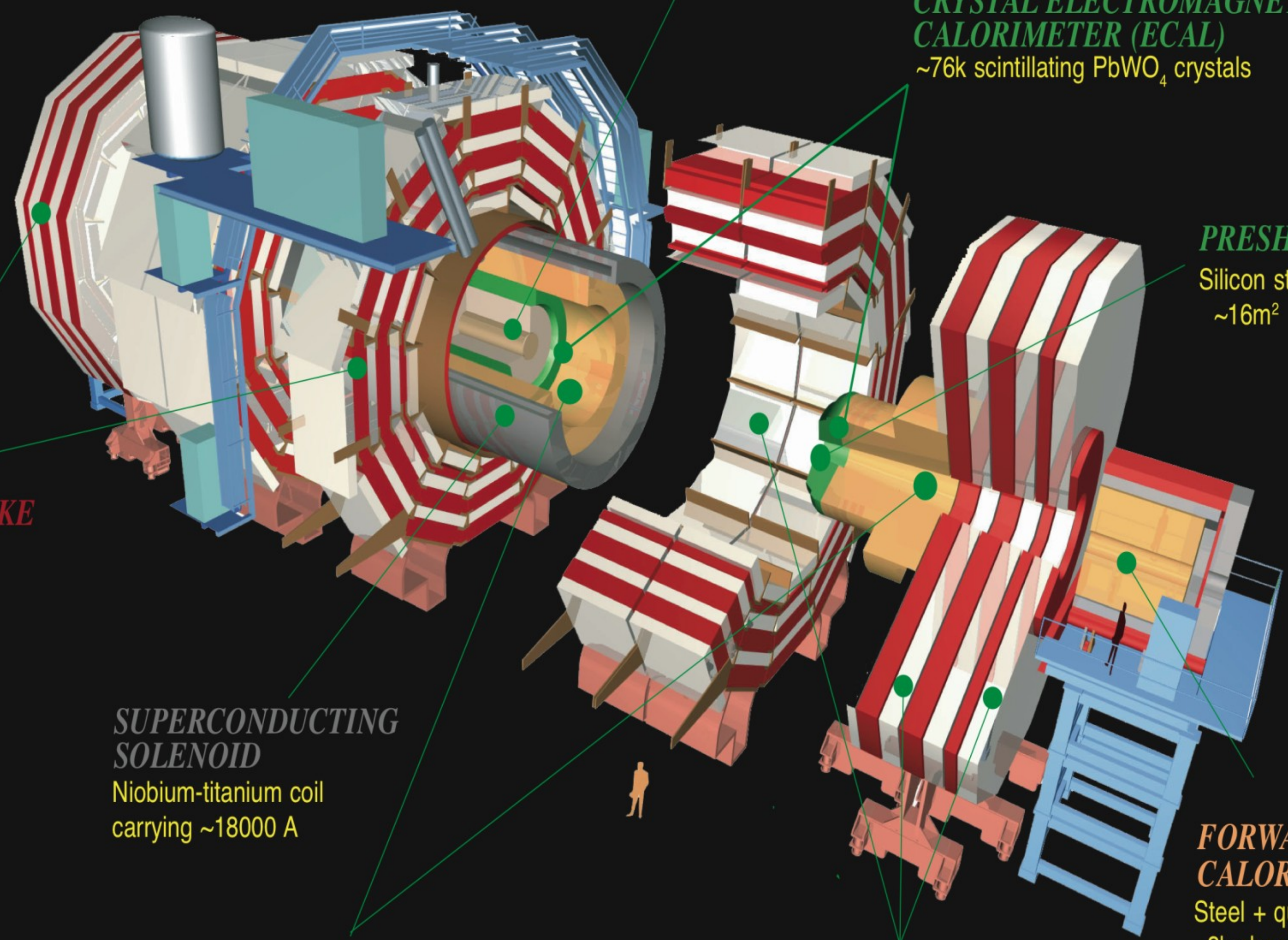
Phys. Rev. D 80 (2009) 111106

Conclusion

- In this talk, we present the first inclusive isolated photon cross-section measurement at 7TeV using the CMS detector
  - This measurement mainly takes advantage of the excellent ECAL resolution
  - This result explores lower x value compared to previous measurement
- We also present the comparison with NLO calculation obtained using the JETPHOX program
  - A good agreement between data and theory is observed
- Stay tuned for more results from CMS
  - Differential gamma + jet cross-section…..

Additional Slides

CMS Detector



Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

History of isolated photon measurement

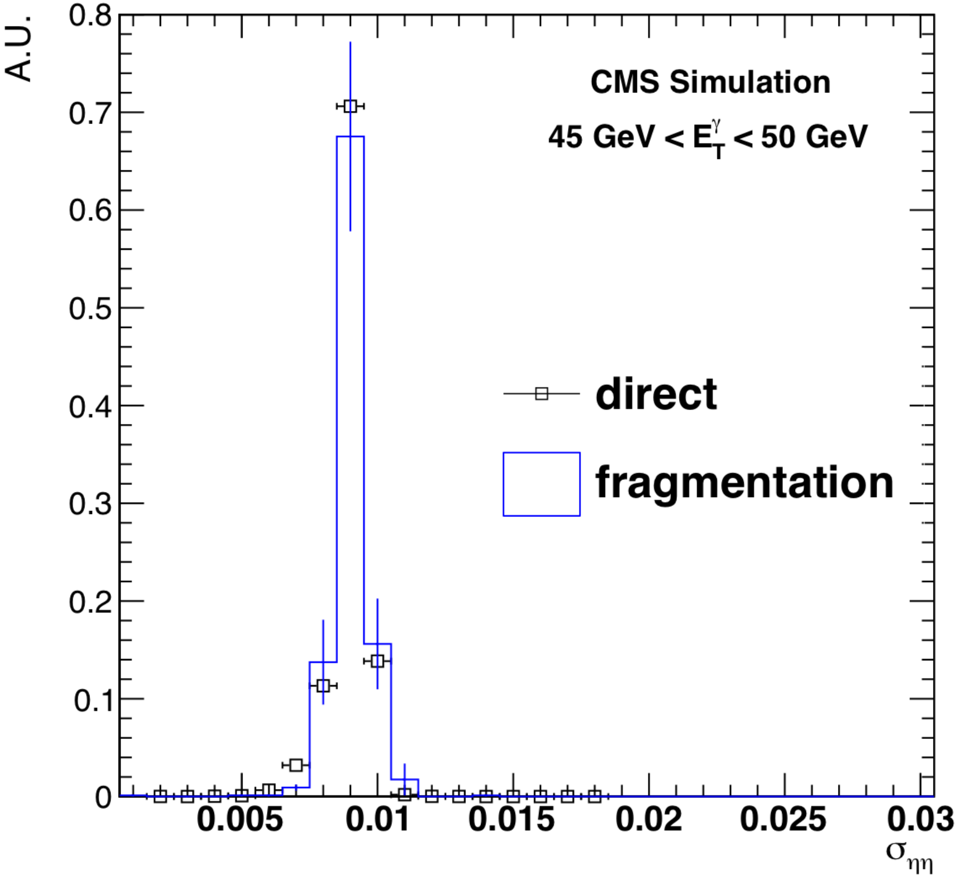
Collaboration	GeV	Beam	Target	x_T range	y, eta, xF
E95	19.40, 23.75	p	Be	0.15 < xT < 0.45	−0.7 < y < 0.7
E629	19.40	p, pi+	C	0.22 < xT < 0.52	−0.75 < y < 0.2
NA3	19.40	p, pi+-	C	0.26 < xT < 0.62	−0.4 < y < 1.2
E704	19.40	p	p	0.26 < xT < 0.39	−0.15 < xF < 0.15
NA24	23.75	p, pi+-	p	0.23 < xT < 0.59	−0.65 < y < 0.52
WA70	22.96	p, pi+-	p	0.35 < xT < 0.61	−0.35 < xF < 0.55
UA6	24.3	P,pbar	p	0.34 < xT < 0.50	−0.2 < y < 1.0
E706	30.63	p,pi-	Be	0.20 < xT < 0.65	−0.7 < y < 0.7
R108	62.4	p	p	0.17 < xT < 0.42	−0.45 < y < 0.45
R110	63.0	p	p	0.14 < xT < 0.29	−0.8 < y < 0.8
R806	63.0	p	p	0.12 < xT < 0.38	−0.2 < y < 0.2
R807	53.0	P,pbar	p	0.11 < xT < 0.23	−0.4 < y < 0.4
R807	63.0	P	p	0.15 < xT < 0.33	−0.7 < y < 0.7
UA2	630	pbar	p	0.04 < xT < 0.32	−0.76 < η < 0.76, 1.0 < |η|< 1.8
UA1	546, 630	pbar	p	0.05 < xT < 0.29	−0.8 < η < 0.8,0.8 < |η|< 1.4, 1.6 < |η|< 3.0
E741(CDF)	1800	pbar	p	0.01 < xT < 0.13	−0.9 < |η| < 0.9
E740(D0)	1800	pbar	p	0.01 < xT < 0.12	−0.9 < η < 0.9, 1.6 < |η| < 2.5
CDF (Run II)	1960	pbar	p	0.01 < xT < 0.13	−1.0 < η < 1.0
D0 (Run II)	1960	pbar	p	0.01 < xT < 0.12	−0.9 < η < 0.9

1997 J. Phys. G: Nucl. Part. Phys. 23 A1

Direct and Fragmentation Photons

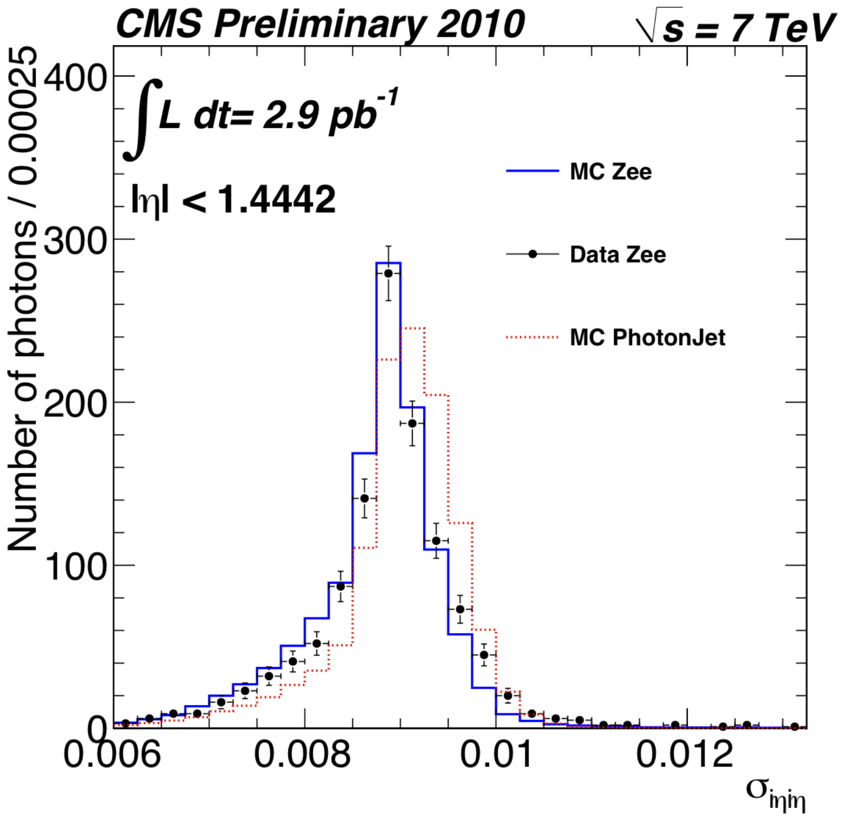
Signal shape taken from **direct photons** in Photon-Jet MC.

Fragmentation photons in di-jet MC have identical shapes.



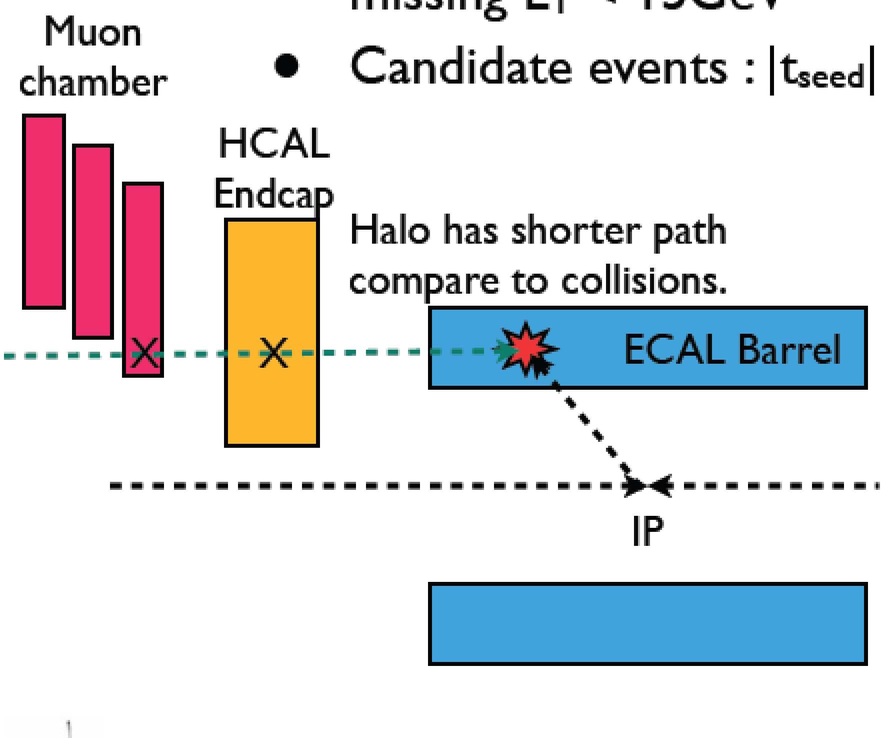
Correction to the Signal Shape Template

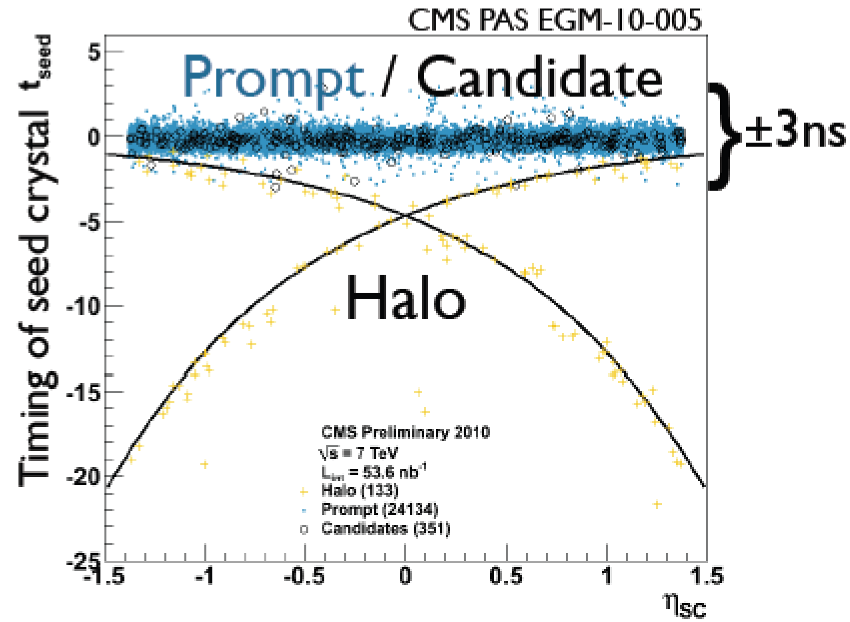
- Electrons from the Z's are used as a control sample to obtain the corrections to signal shape template
- Photon and Z electron $\sigma_{i\eta i\eta}$ distributions are similar in MC.
- Measured $<\sigma_{i\eta i\eta}>$ difference between Zee data and Zee MC:
  - $(8\pm3)\times10^{-5}$
  - $(0.9\pm0.3)\%$ of $<\sigma_{i\eta i\eta}^{\gamma\ MC}>$
- Correct photon values by $+(8\pm3)\times10^{-5}$



Beam Halo

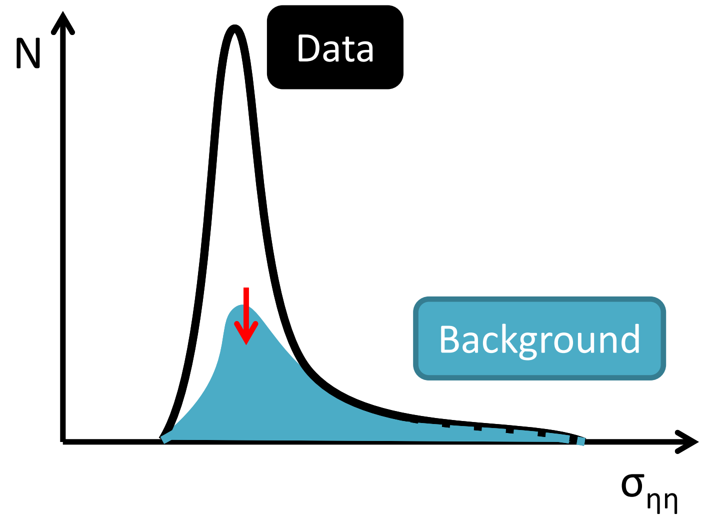
- Halo contribution is estimated from data by
  - Halo events : tagged by muon chamber
  - Prompt events : seed crystal timing $|t_{seed}| < 3$ns with missing $E_T < 15$GeV
  - Candidate events : $|t_{seed}| < 3$ns with missing $E_T > 25$GeV

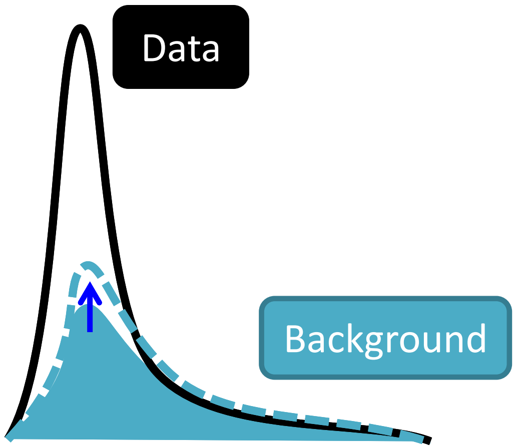




Background systematics

- Two concurrent effects:
  - **Side-band has more Iso$_{TRK}$ activity** than that of background in the signal region
    - Emphasizes tail, depresses peak
    - Makes signal seem larger
      - Negative error bar
  - **Presence of signal** in the non-isolated side-band
    - Emphasizes peak
    - Makes signal seem smaller
      - Positive error bar





Background shape systematics: procedure to estimate effect

- Toy MC: repeat fits using same signal shape and changing background
- For **side-band activity**
  - **Sample** from **Jet MC truth**.
  - **Fit** with **Jet MC side-band**.
- For **presence of signal**
  - **Sample** from **Jet MC side-band**.
  - **Fit** with **realistic side-band** (PhotonJet + Jet).