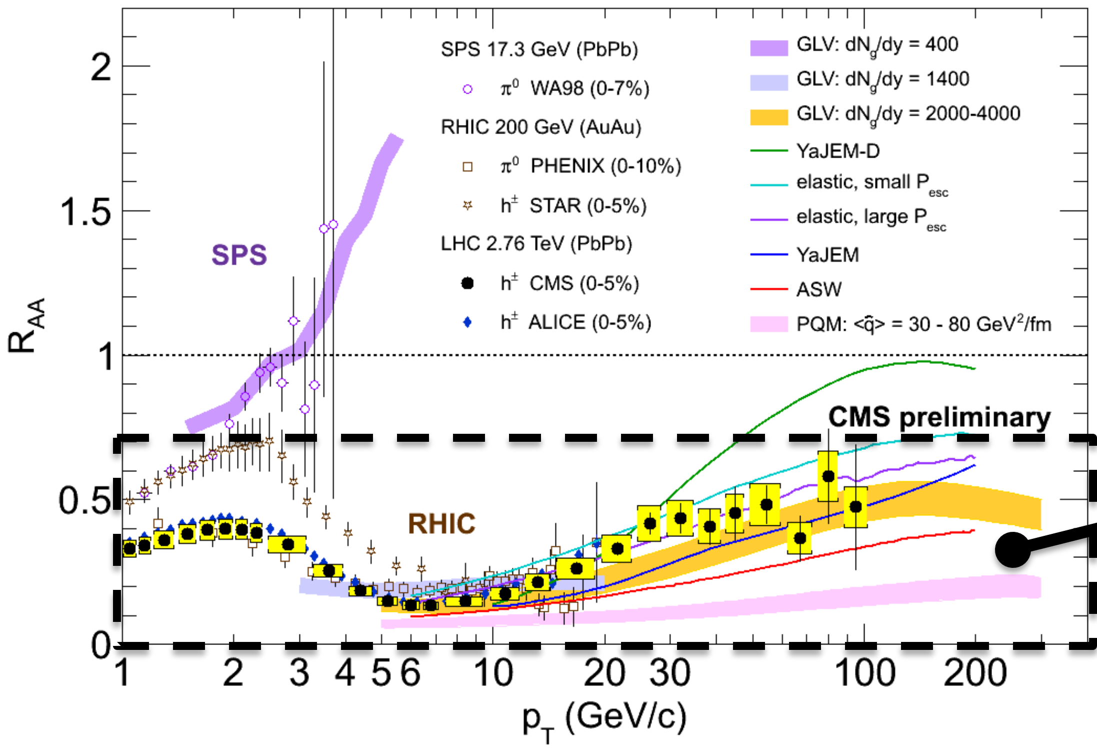
Measurement of isolated photons in PbPb collisions at $\sqrt{s}$ = 2.76TeV with CMS detector

Massachusetts Institute of Technology

Yongsun Kim

for the CMS Collaboration

Motivation – R_{AA}



R_{AA}

Ratio of PbPb spectrum to pp spectrum normalized by number of binary collisions $\langle N_{coll} \rangle$

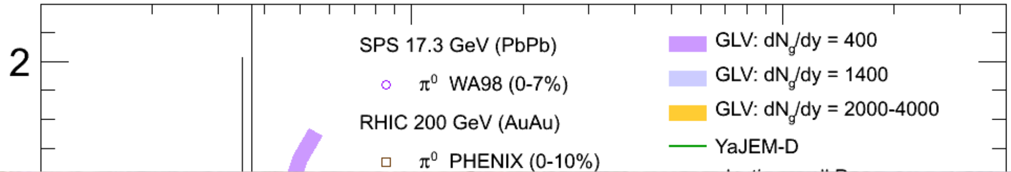
Charged particle $R_{AA} < 1$

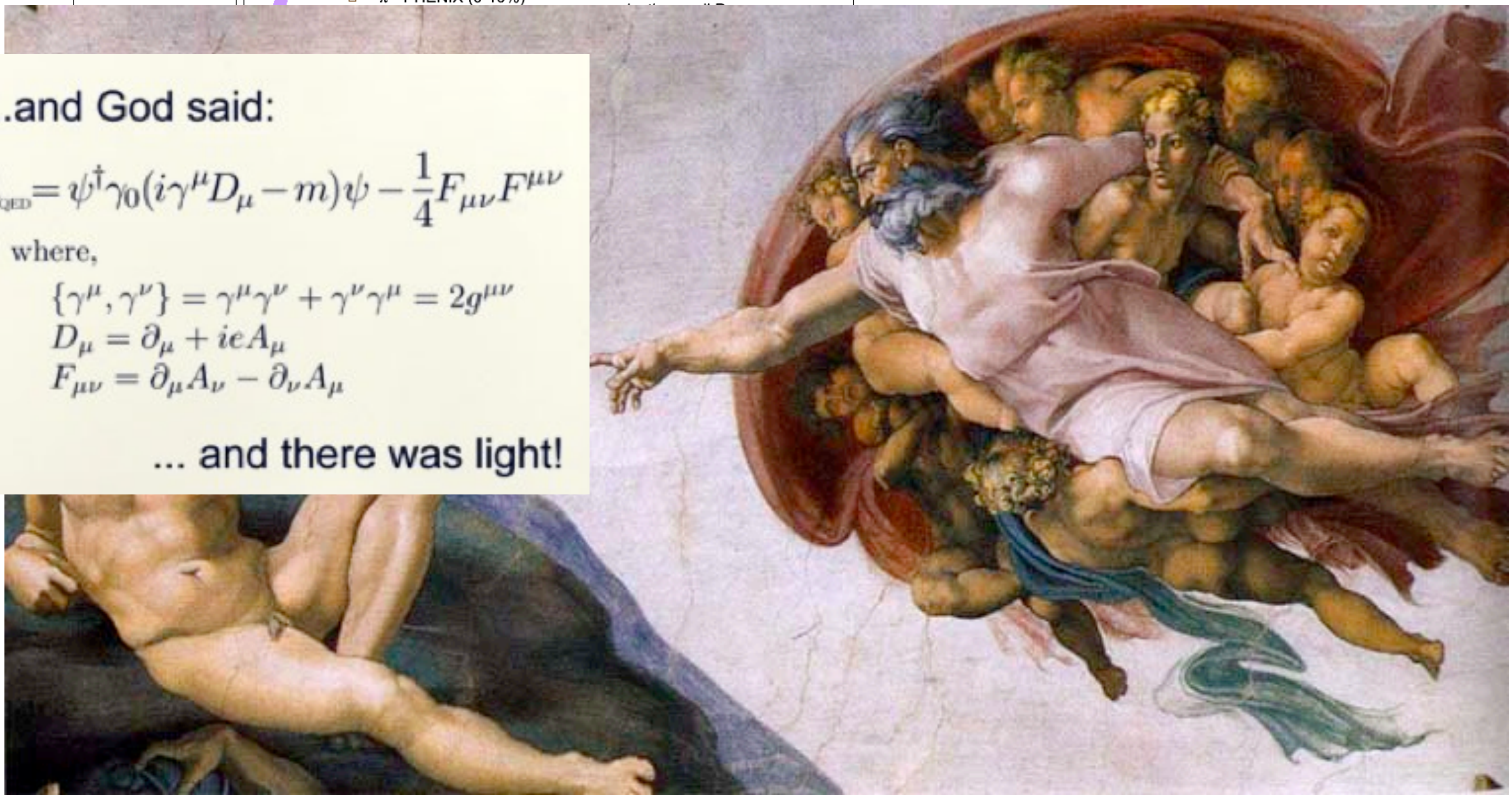
Indirect evidence of jet quenching.

Andre Yoon (Thursday)

Yen-Jie Lee (Plenary)

Motivation – Genesis





...and God said:

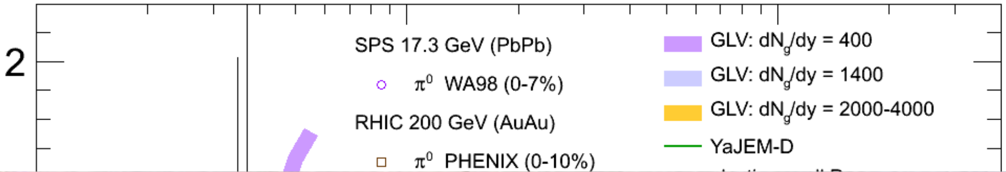
$$\mathcal{L}_{QED} = \psi^\dagger \gamma_0 (i\gamma^\mu D_\mu - m)\psi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

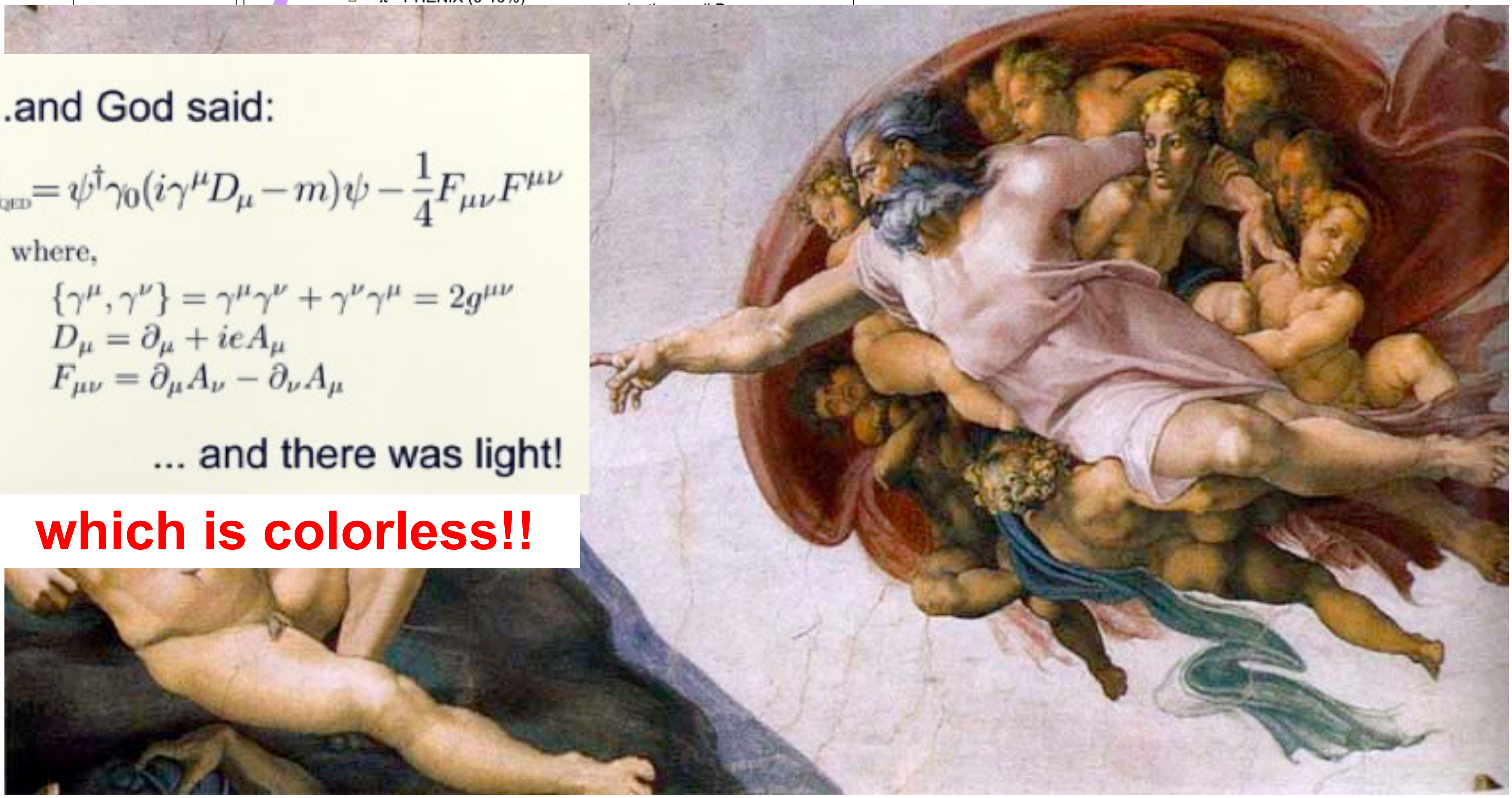
where,

$$\{\gamma^\mu, \gamma^\nu\} = \gamma^\mu \gamma^\nu + \gamma^\nu \gamma^\mu = 2g^{\mu\nu}$$
$$D_\mu = \partial_\mu + ieA_\mu$$
$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

... and there was light!

Motivation – Genesis





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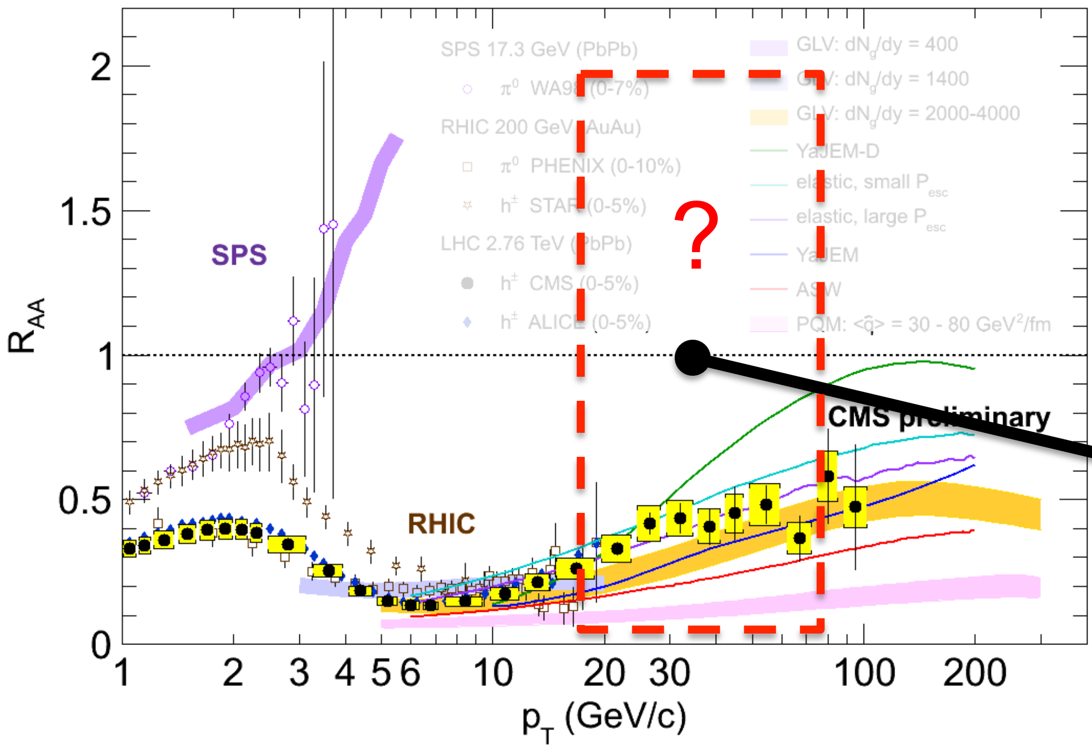
... and there was light!

which is colorless!!

Motivation



R_{AA}

Ratio of PbPb spectrum to pp spectrum normalized by number of binary collisions $<N_{coll}>$

Photon measured 20 – 80 GeV

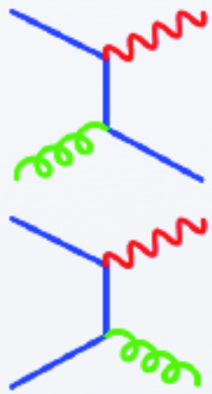
- Photon is not quenched in medium, therefore its R_{AA} can be used to check the **initial state of PbPb collision**
- First adaptation of pp photon identification methods to heavy ion experiment.

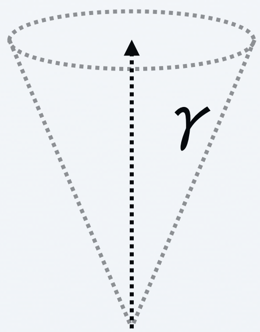
Why **isolated** photons?

Leading order

Compton

Annihilation





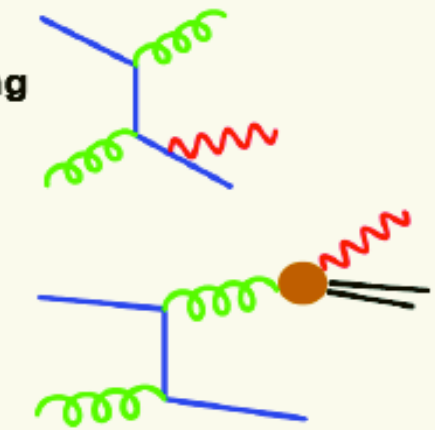
Isolated

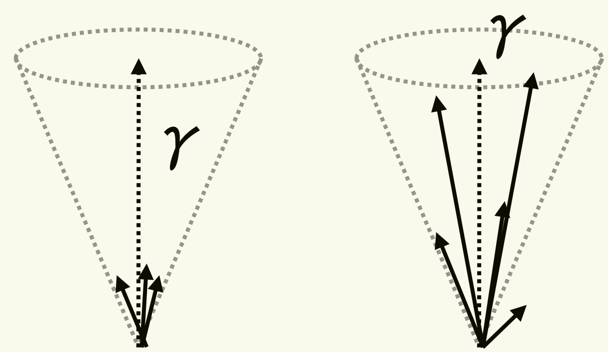
Ideally want to measure LO

Higher orders

Bremsstrahlung

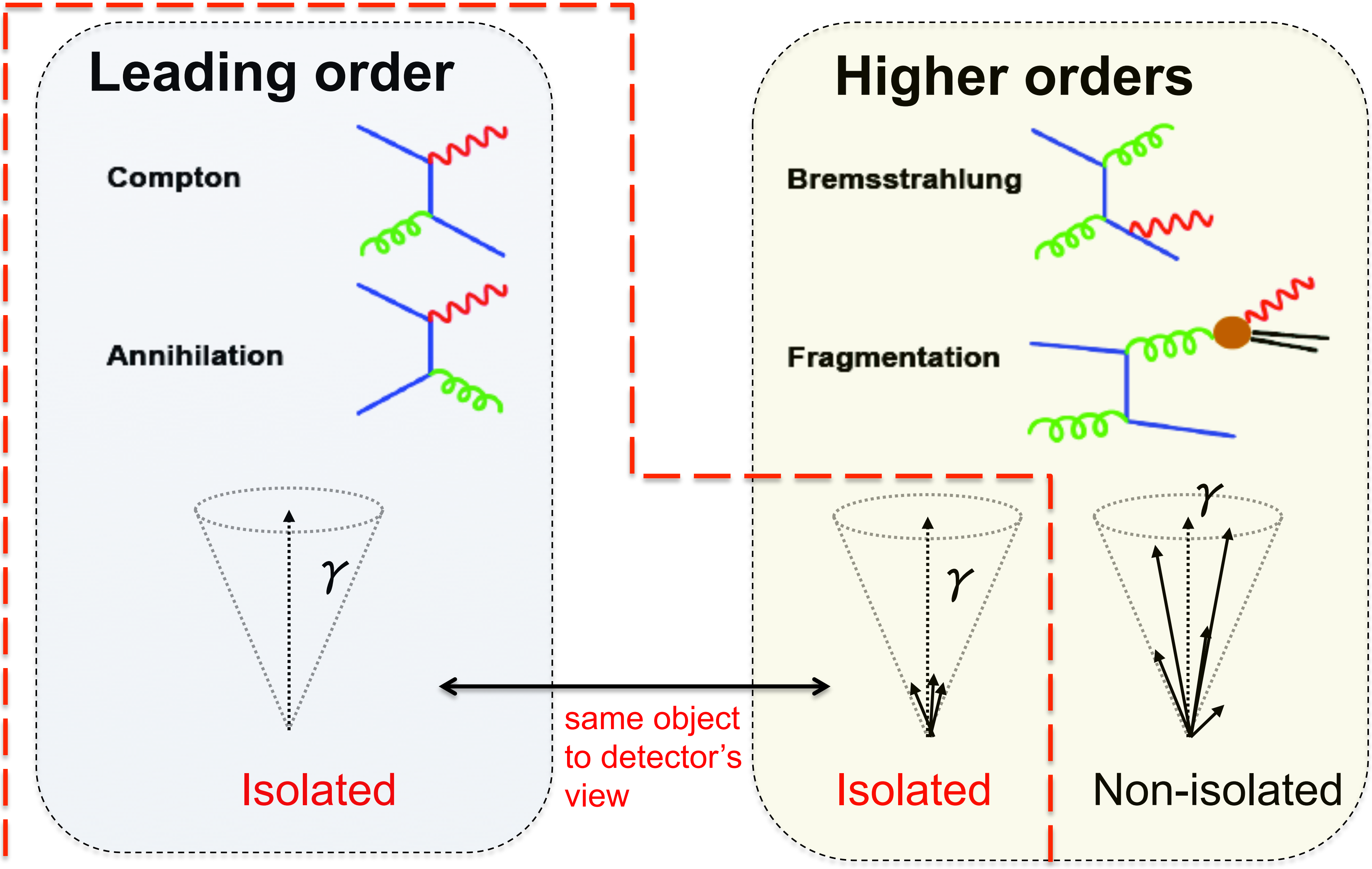
Fragmentation





Isolated Non-isolated

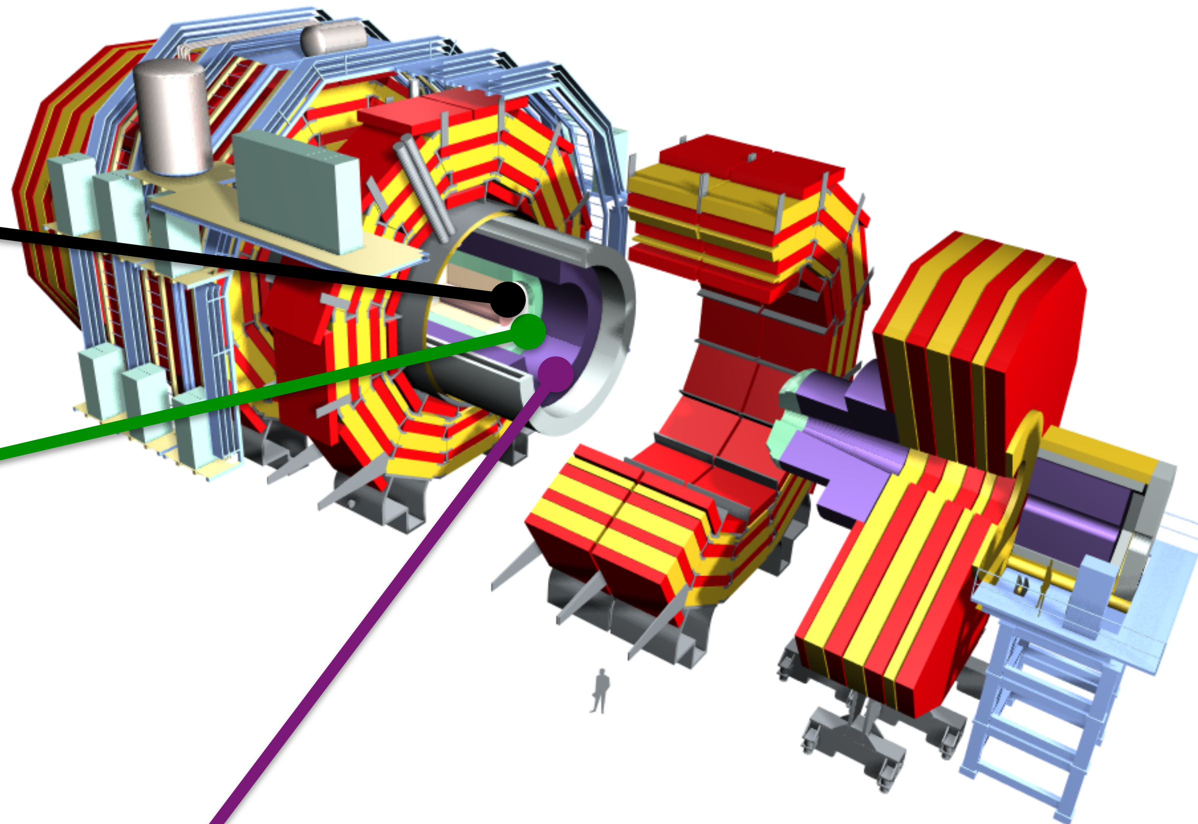
Why **isolated** photons?



Experimentally possible borderline = Isolation

Reasonable cut for theoretical calculation as well.

CMS is excellent for photon hunting



Si tracker

vertex determination

reject electron

Ecal ($PbWO_4$)

$|\eta| < 3$ with 75848 crystals

$\Delta\eta \times \Delta\Phi = 0.017 \times 0.017$

Transverse shower shape

Intrinsic energy resolution (~1%)

2π radians covered

Hcal for Isolation criteria.

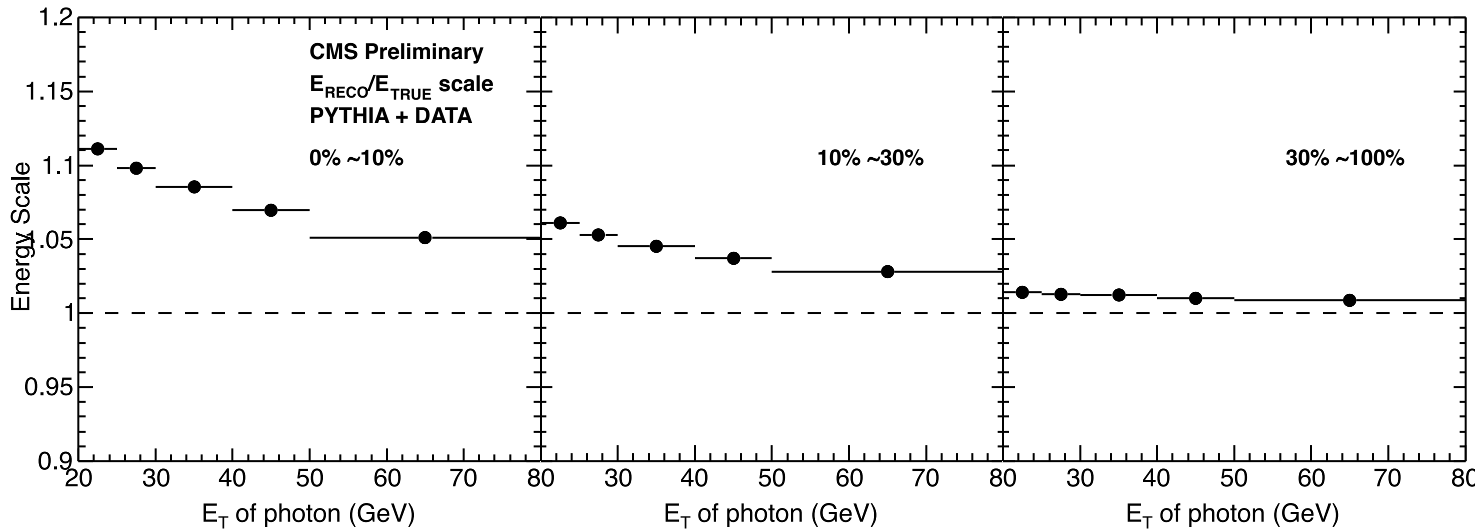
Photon energy scale & fluctuation

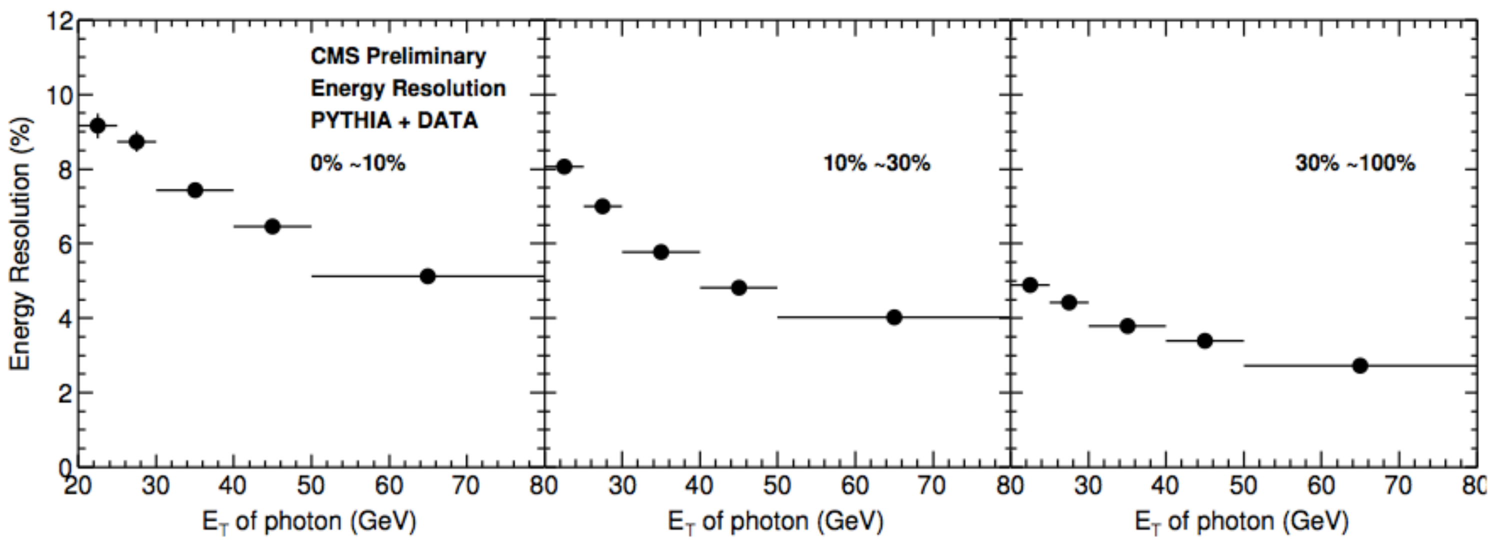
Background particle fluctuation is 8 – 10% for < 40GeV in central events

Above 40GeV, photon reconstruction performance is similar to pp

Energy scale factor used for offline correction

Energy resolution factor used to de-convolute final spectra





Data trigger

- From PbPb Collision of

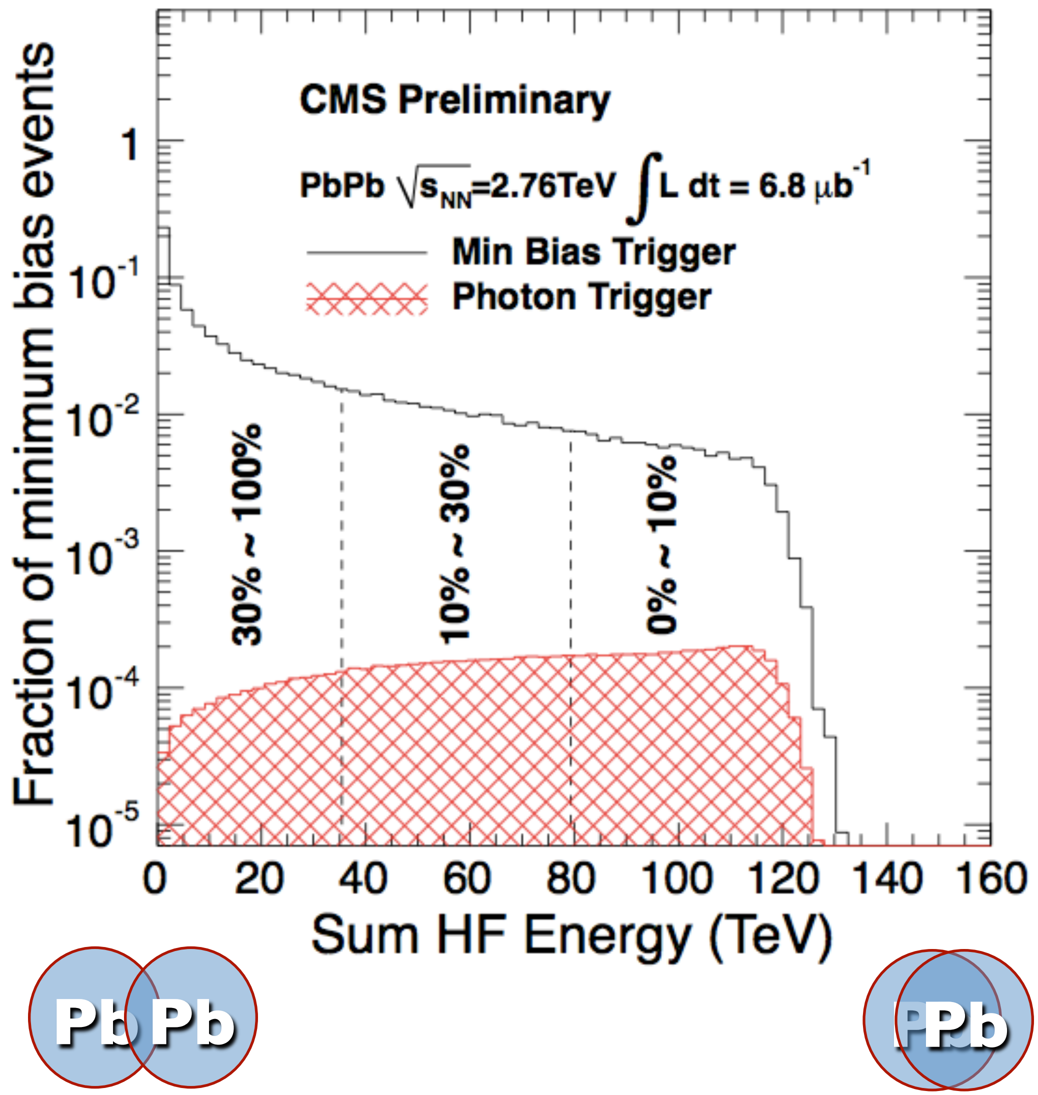
  $\sqrt{s_{NN}}$ = 2.76 TeV

  $\int Ldt$ = 6.8 μb^{-1}

- Photons are measured
  - |η| < 1.44
  - **E_T of 20 – 80 GeV** (5 bins)
  - 3 centrality bins

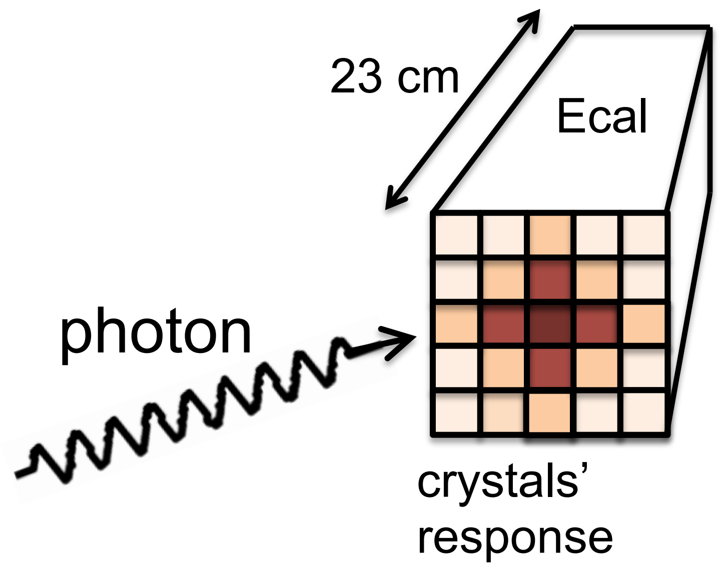
    0 – 10%, 10 – 30%, 30 – 100 %
  - 6000 signals counted

    (before efficiency correction)



Photon reconstruction

- Photon is reconstructed in Ecal using **Island clustering algorithm**
  - Ref. (CERN-LHCC-2006-001)
- Main background is neutral mesons
  - π^0 and η decaying into two photons
  - In high E_T, decayed photons are almost collinear, and make single cluster
- Background rejection strategies are described in following slides

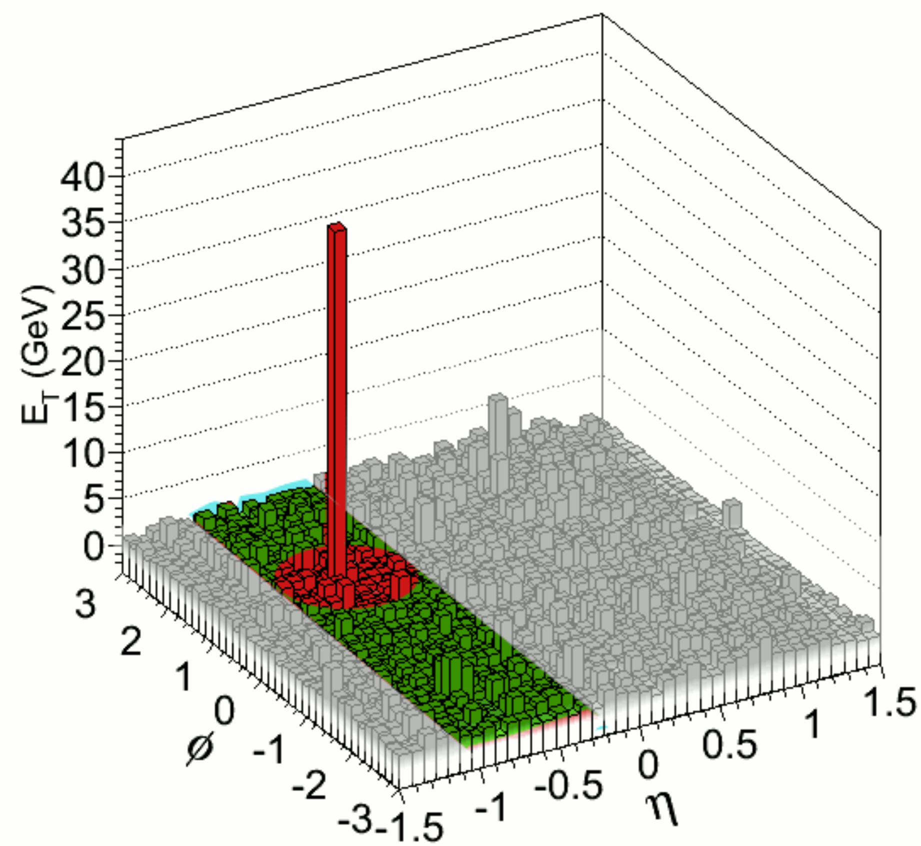


Crystal size : 2.2 cm x 2.2 cm

94% of energy in 3x3 crystals

Isolation criteria

- π^0 and η are produced from jet fragmentation
- **Isolation cut** rejects such jets
  - $E_{Hcal}/E_{Ecal} < 0.2$
  - ΣE_T of particles in cone around candidates measured $\Sigma E_T < 5$GeV



ΣE_T of Ecal + Hcal

Cone ΔR = 0.4

Isolation criteria

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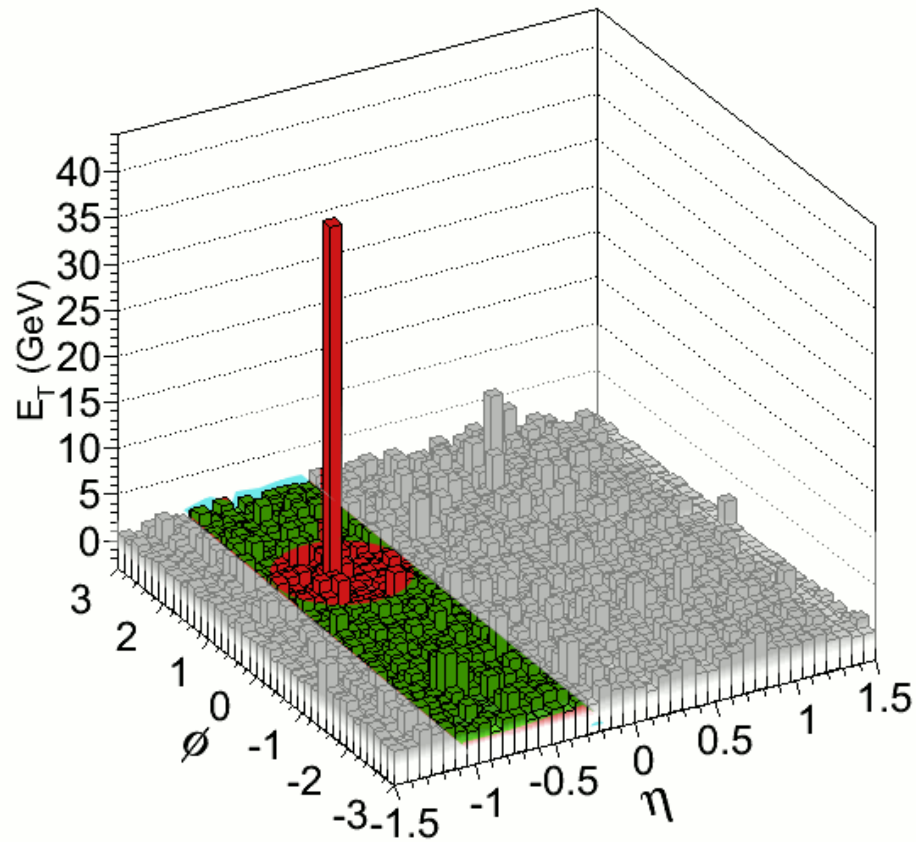
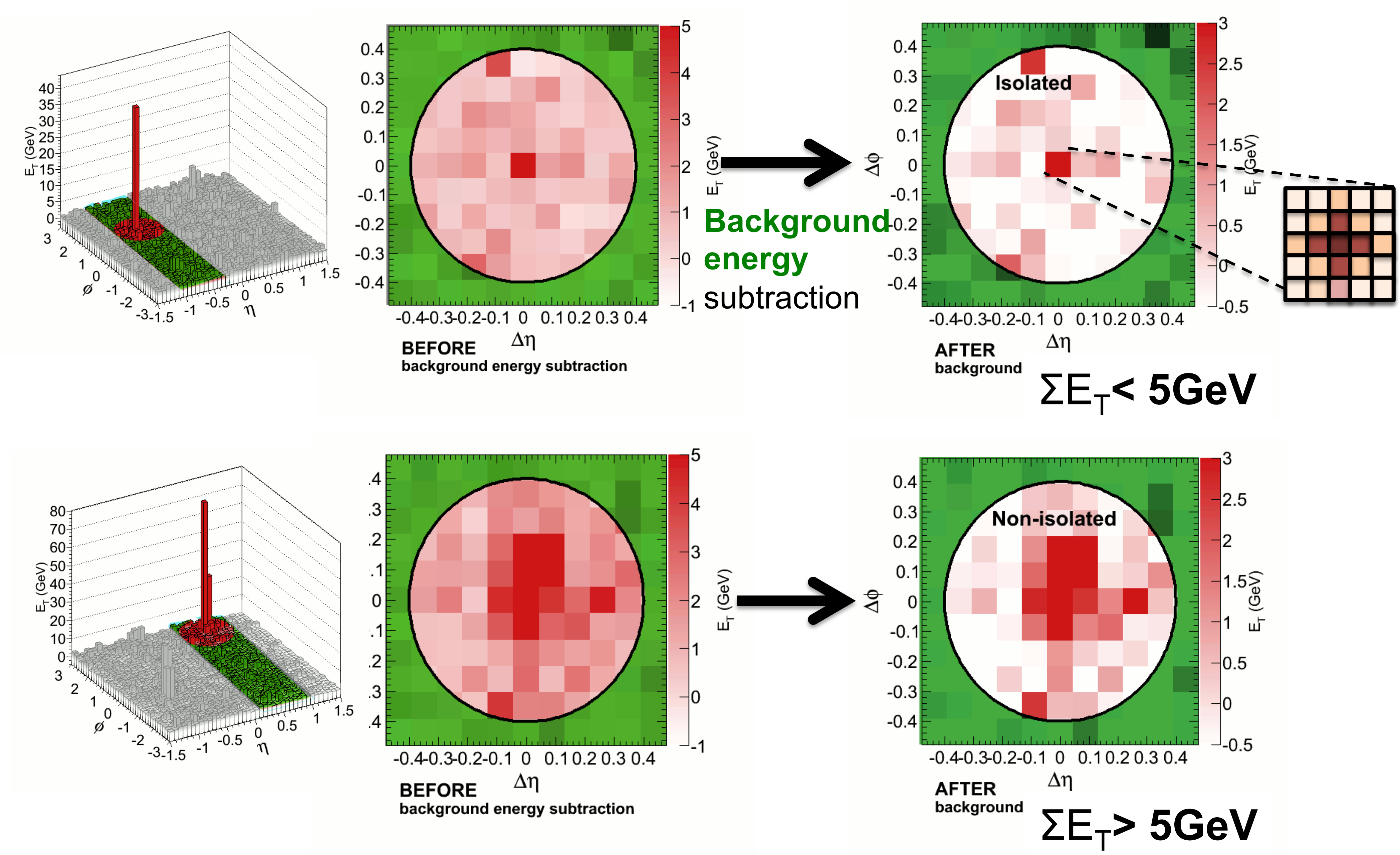
  - $E_{Hcal}/E_{Ecal} < 0.2$
  - ΣE_T of particles in cone around candidates measured $\Sigma E_T < 5$GeV
- Count out **background**
  - **Energy in the cone** is on top of **Uncorrelated Background energy**
  - Heavy ion background energy subtraction event-by event



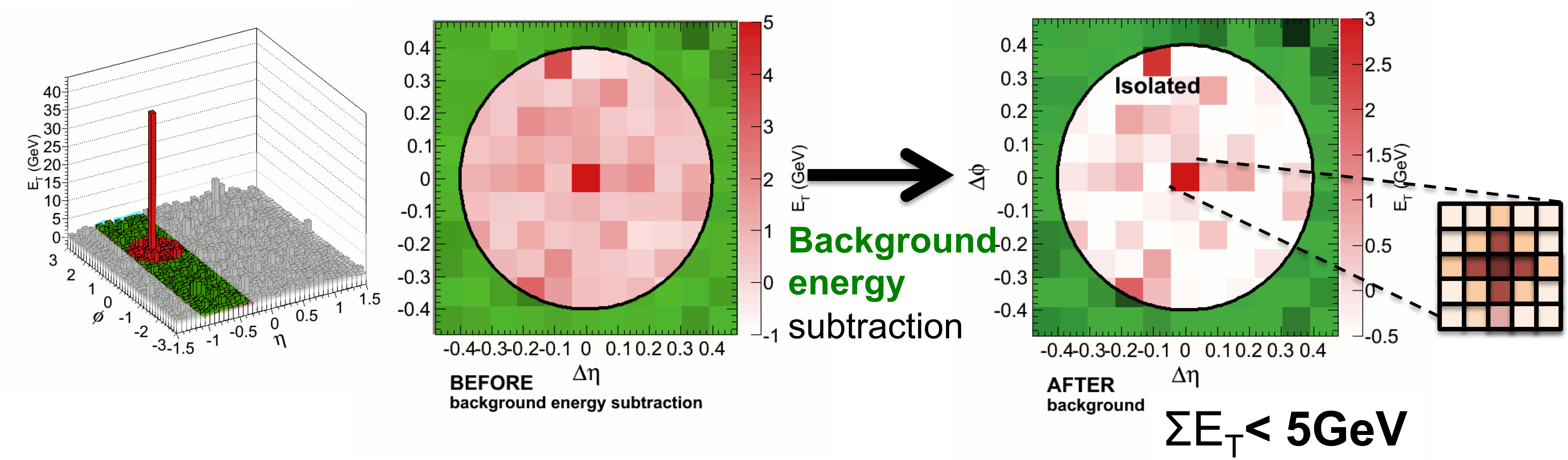
ΣE_T of Ecal + Hcal

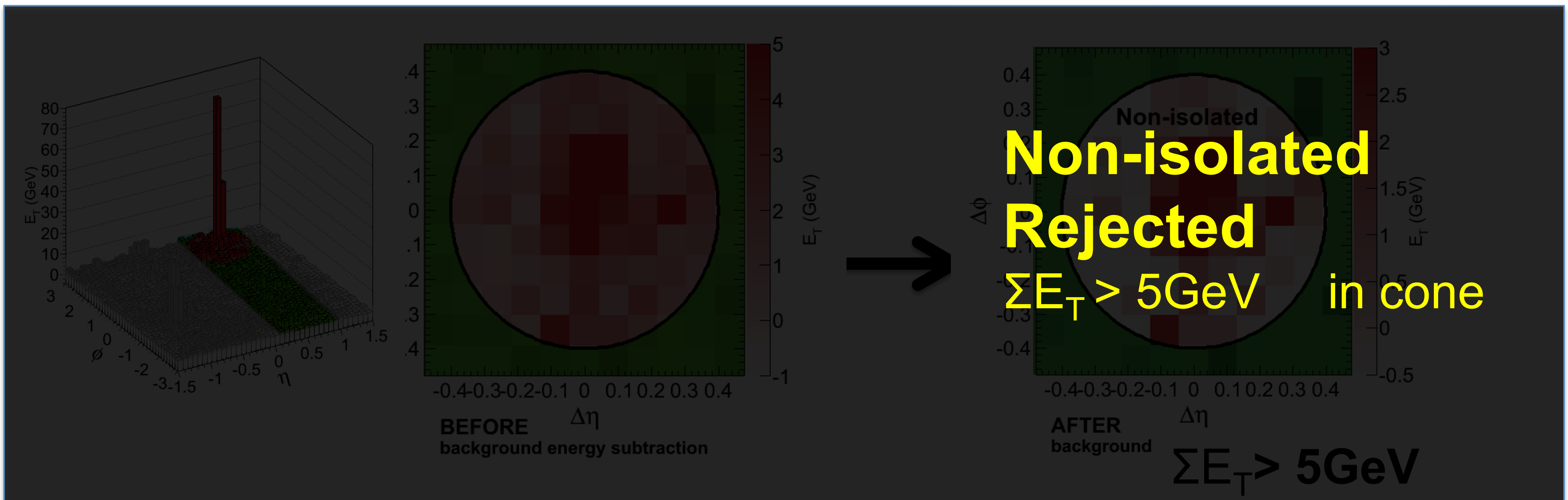
Cone ΔR = 0.4

Isolation criteria - example



Isolation criteria - example





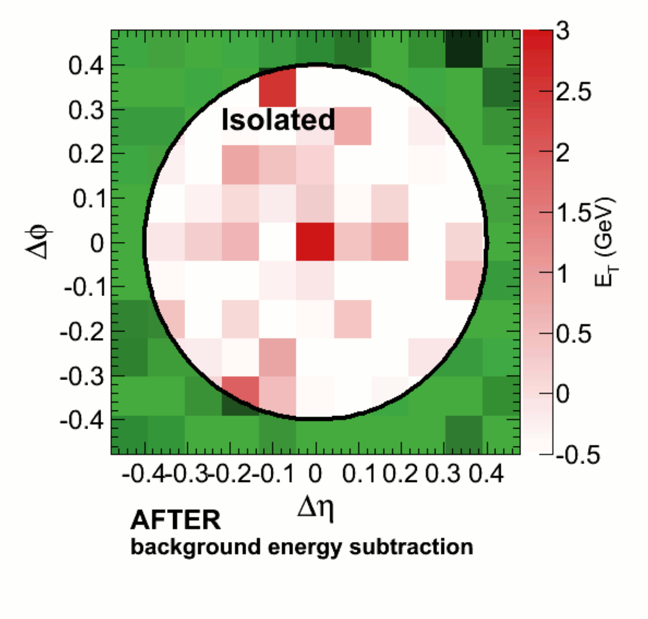
Non-isolated

Rejected

$\Sigma E_T > 5\text{GeV}$ in cone

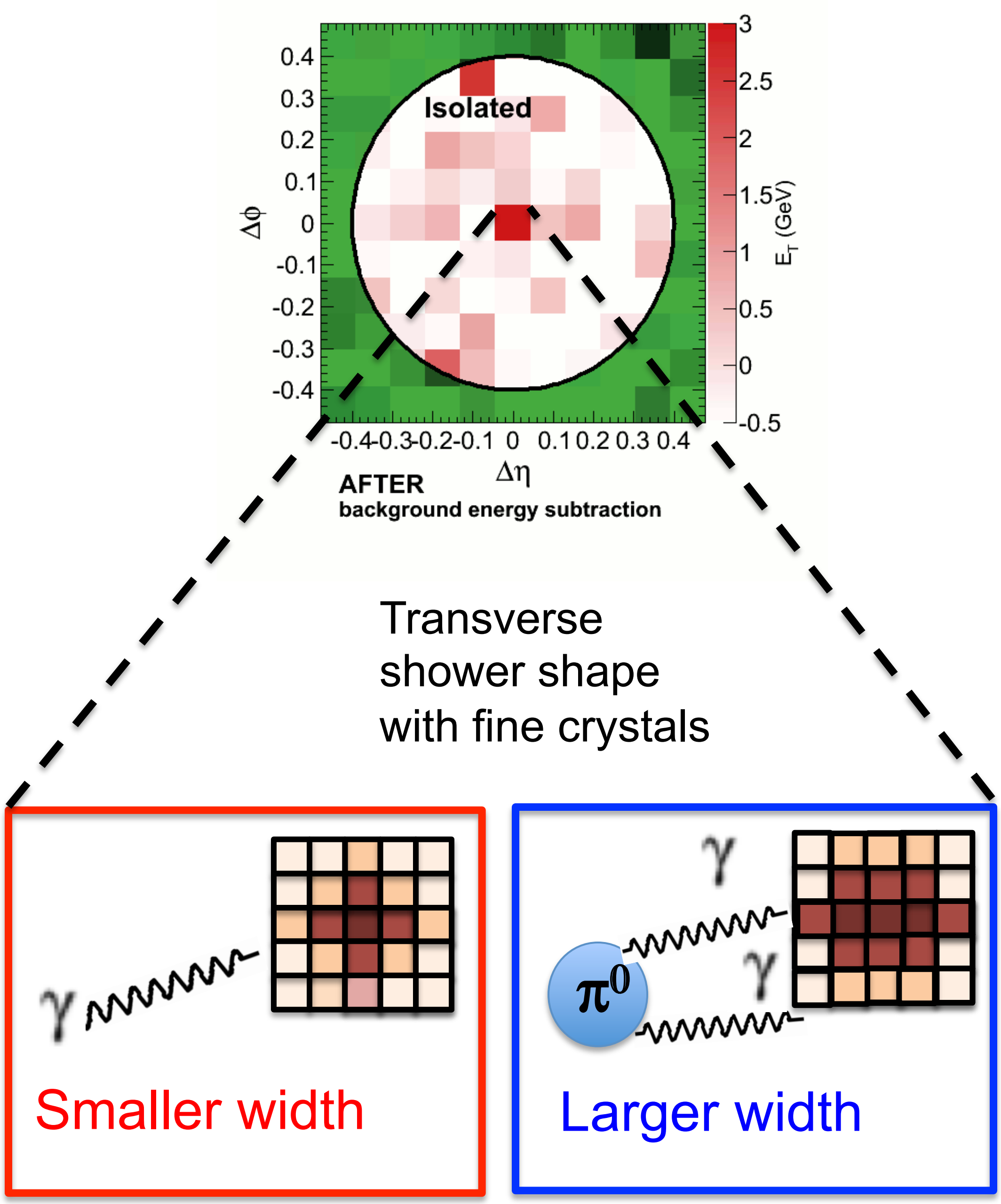
Signal extraction

- Even after isolation cut, some π^0 and η still remain
  - Fragmented from jets with high-z, becoming **Isolated π^0 and η**
- Impossible to reject event-by-event



Signal extraction

- Even after isolation cut, some π^0 and η still remain
  - Fragmented from jets with high-z, becoming **Isolated π^0 and η**
- Impossible to reject event-by-event ➔ statistical approach
- Use Ecal's **fine segmentation**
  - Δη x ΔΦ = 0.017 x 0.017



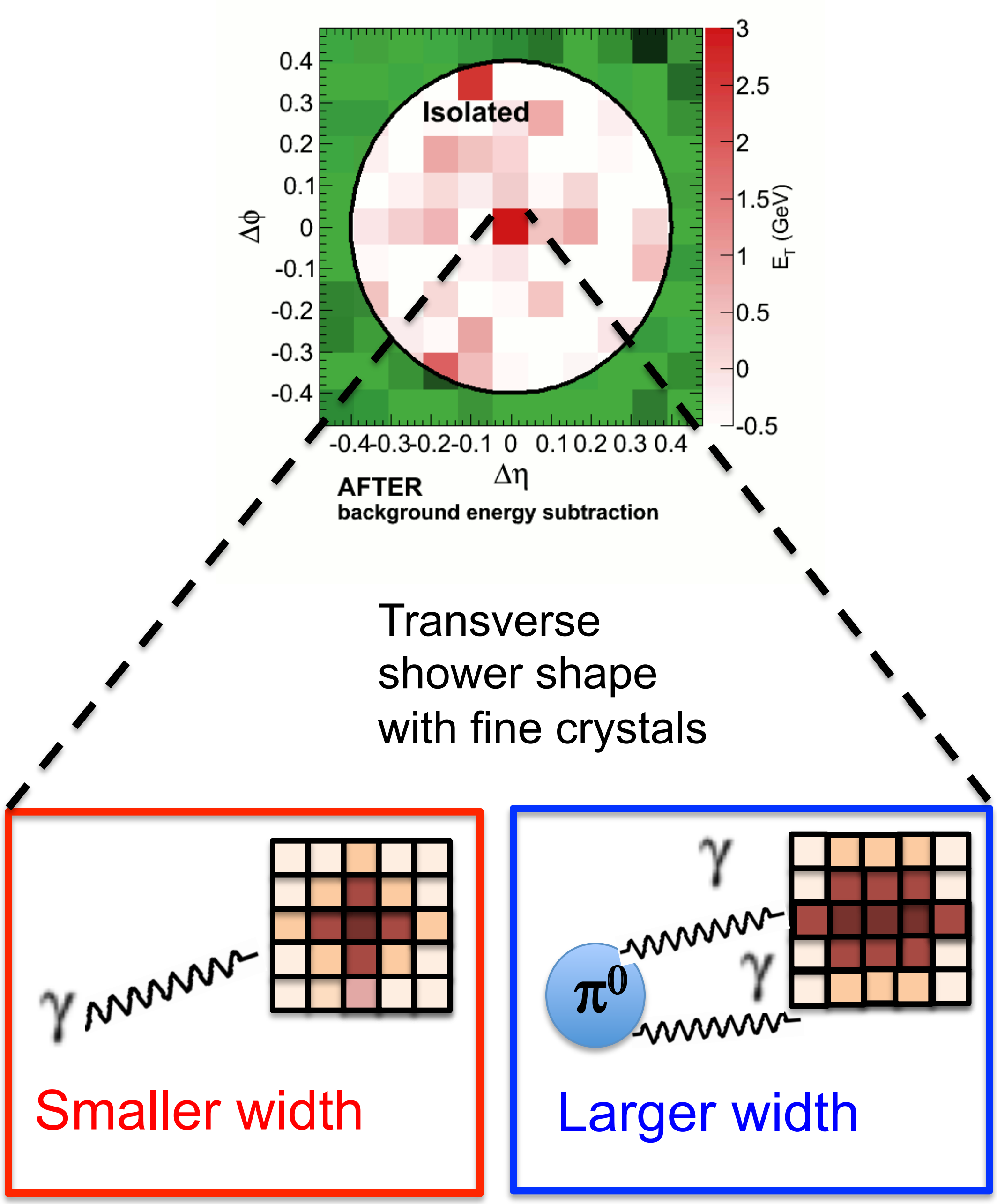
Signal extraction

- Quantify transverse shower shape on Ecal crystals

$$\sigma^2_{i\eta i\eta} = \frac{\sum_i^{5\times5} w_i(\eta_i - \bar{\eta}_{5\times5})^2}{\sum_i^{5\times5} w_i}$$

,where $w_i = \max(0, 4.7 + \ln(E_i/E))$

- Wider shape ➔ larger value



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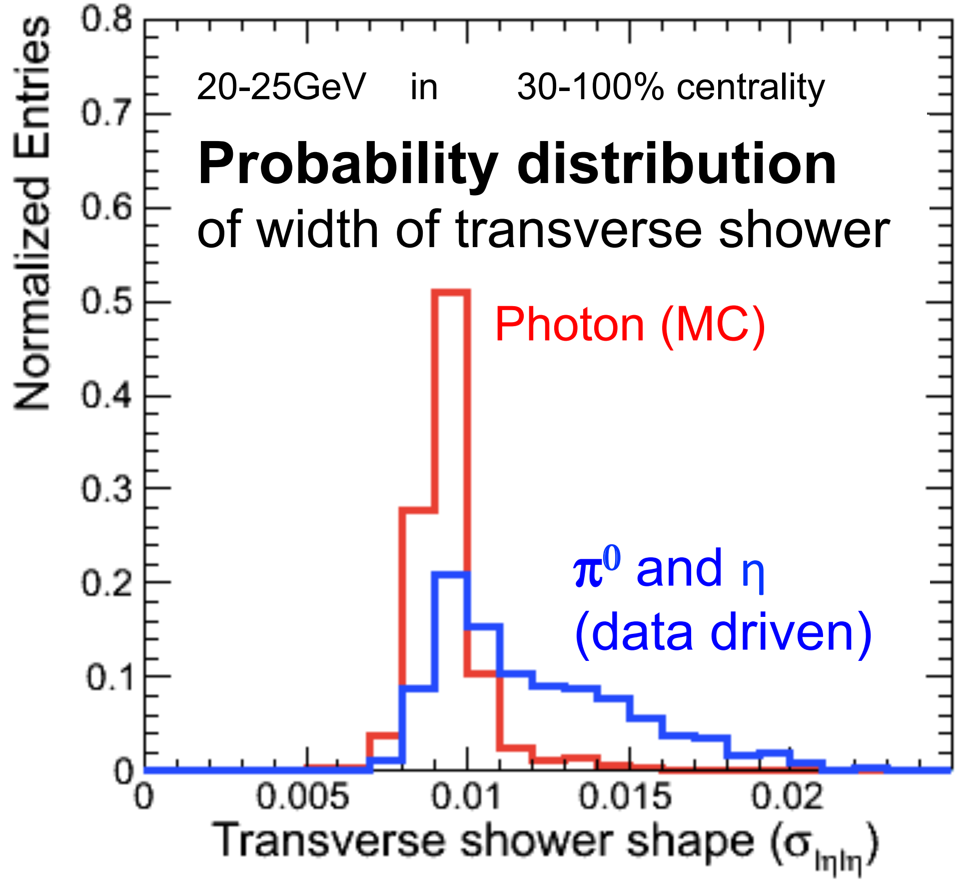
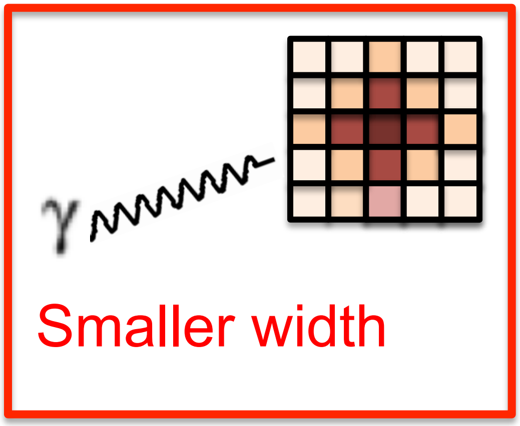
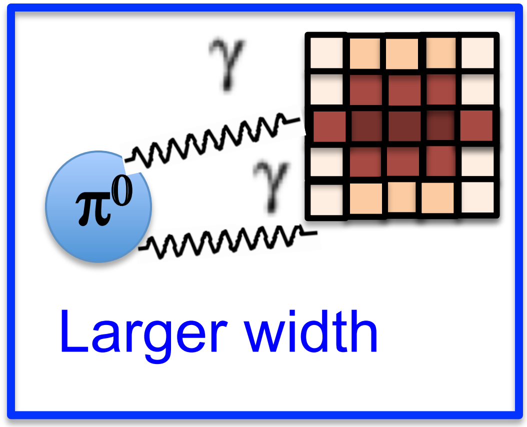
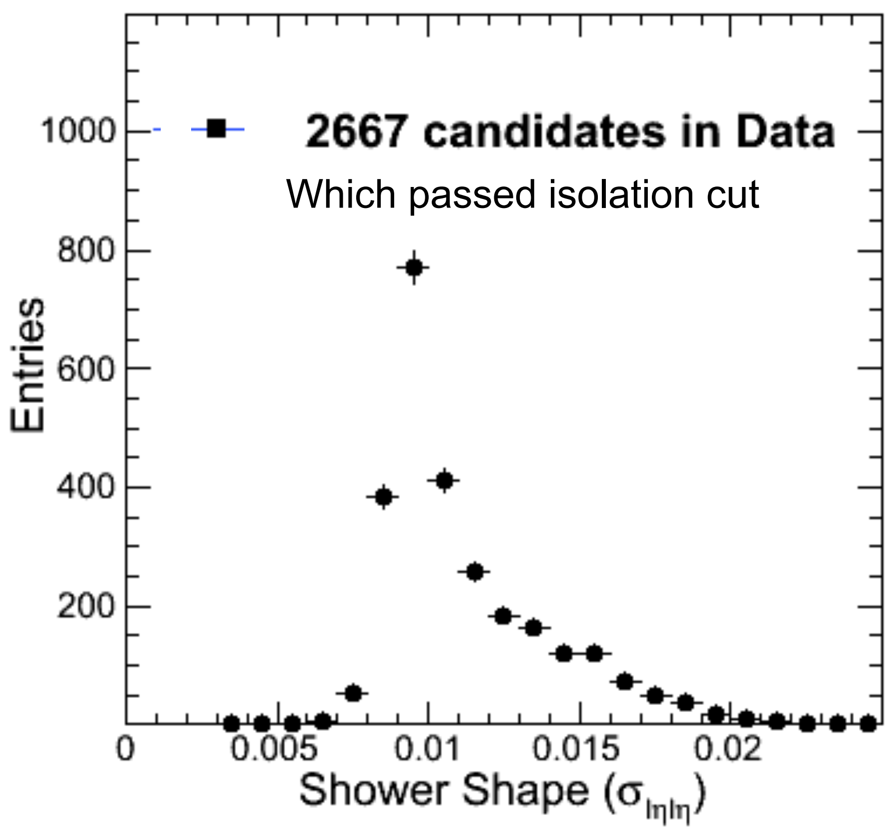
- Wider shape ➔ larger value
- Probability distribution function of this value is called **Template**

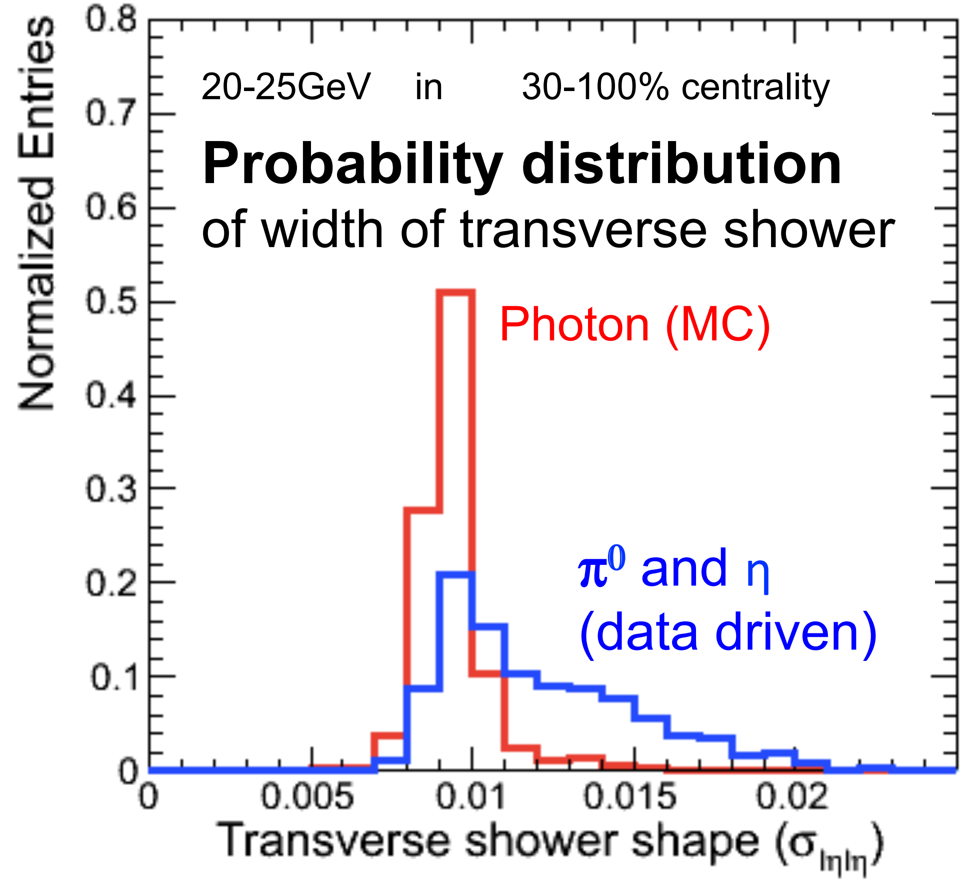






Signal extraction

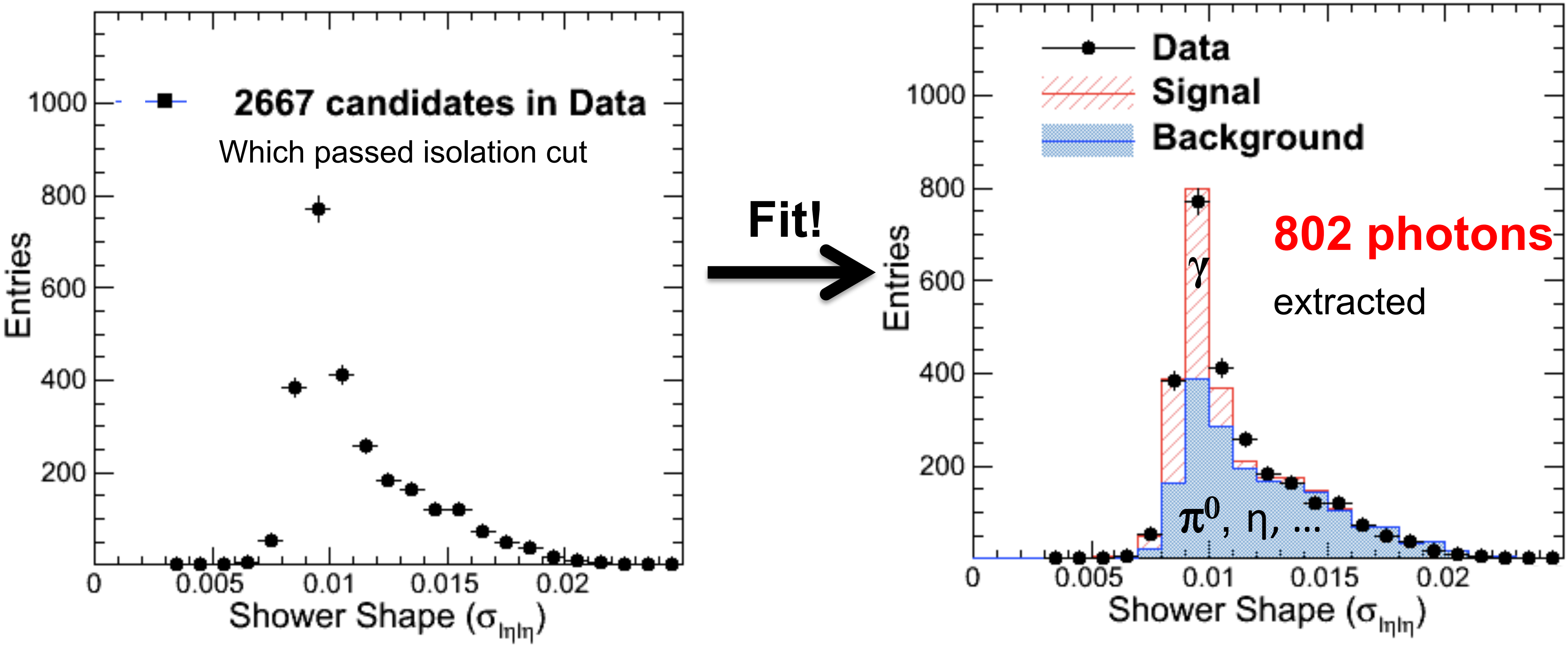




Data = Superposition of photon + background templates

Q : How many **photons** inside?

Signal extraction

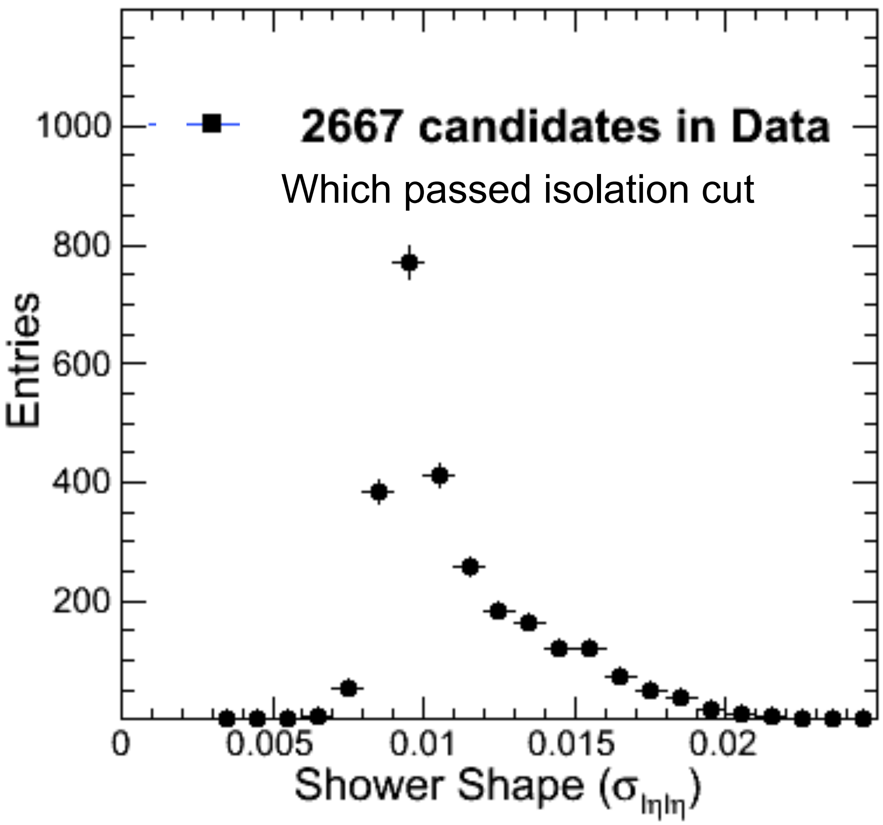


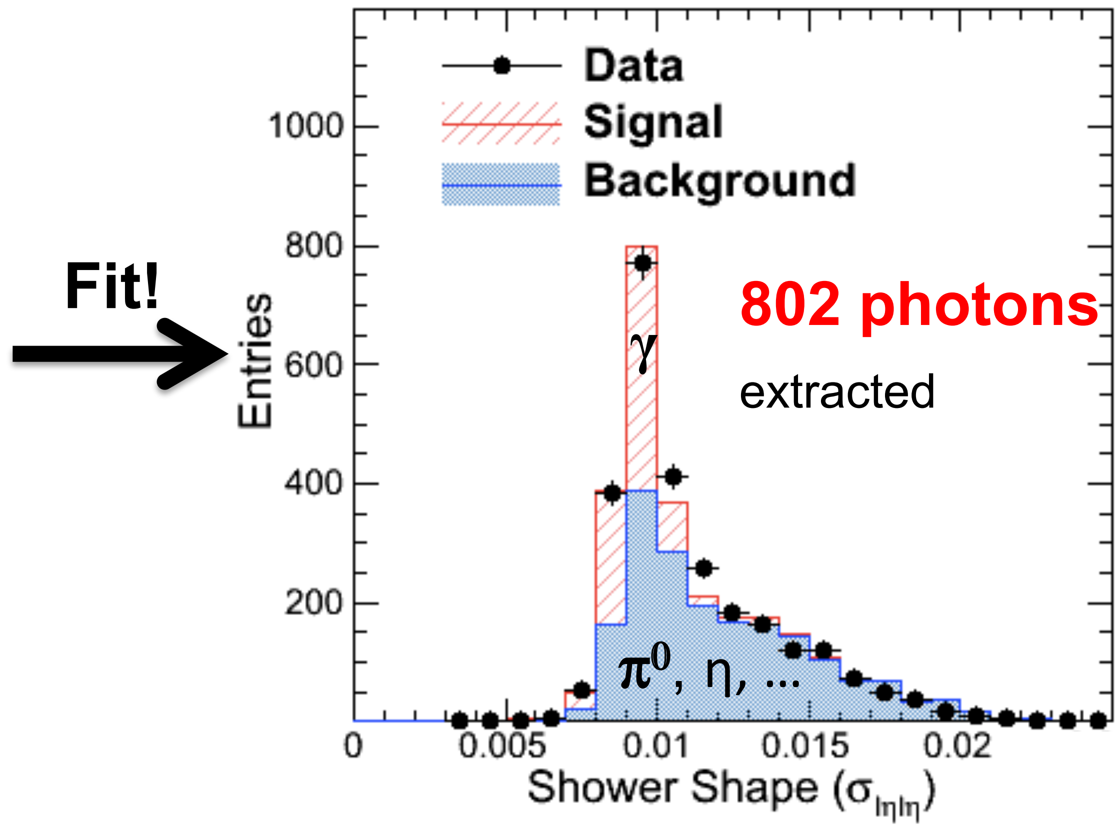
Data = Superposition of photon + background templates

Q : How many **photons** inside?

A : 802

Signal extraction

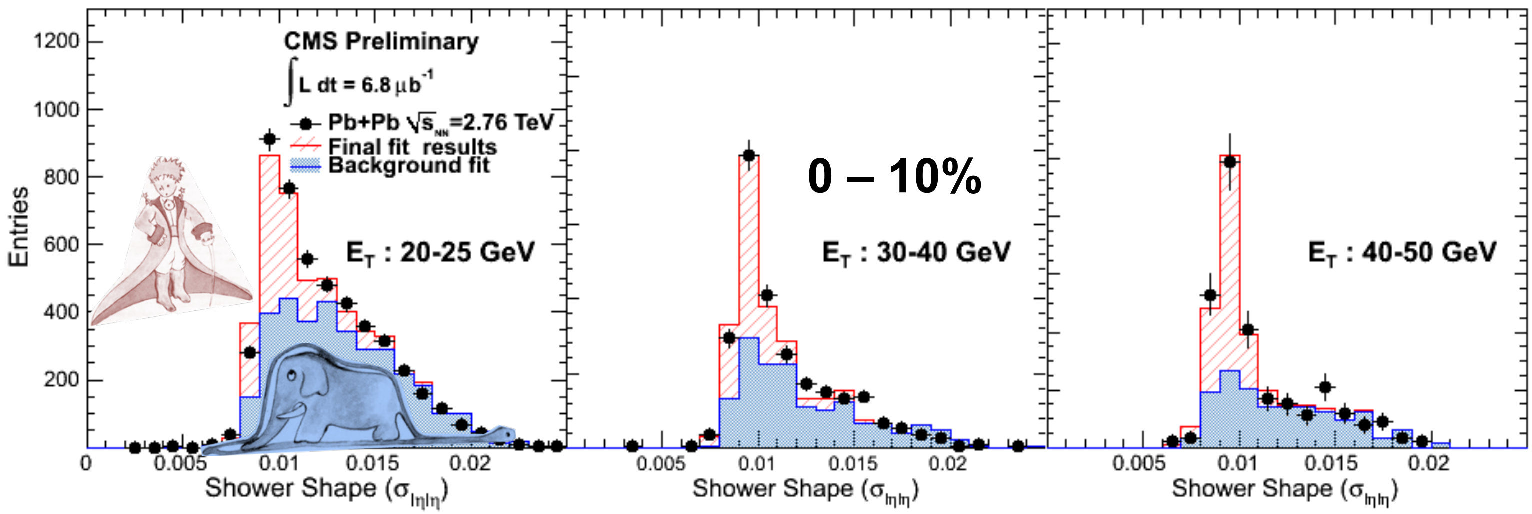




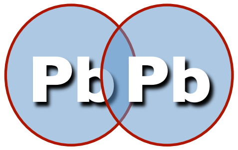
- By the way, where did we get shower shapes of pure photon and pure π^0/η?
  - **Photon template** obtained from MC
  - **Background template** obtained from non-isolated π^0 and η in jet
    - Data driven method

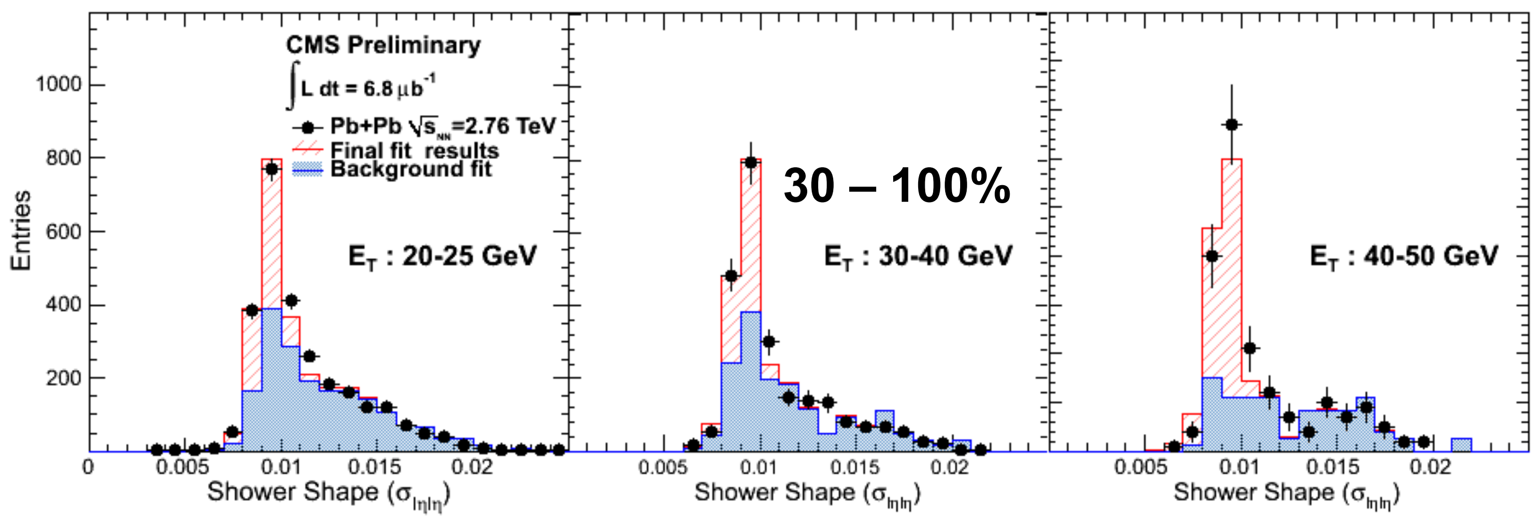
More examples

Central events
0 – 10%



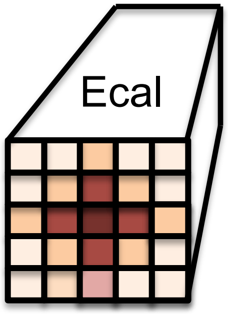
Perepheral events
30 – 100%





Quick review of analysis

- Photon reconstructed in Ecal
  - ➔ Photon : π^0 = 1 : O(100)



Quick review of analysis

- Photon reconstructed in Ecal
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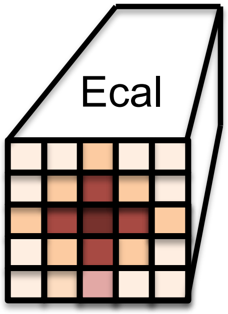
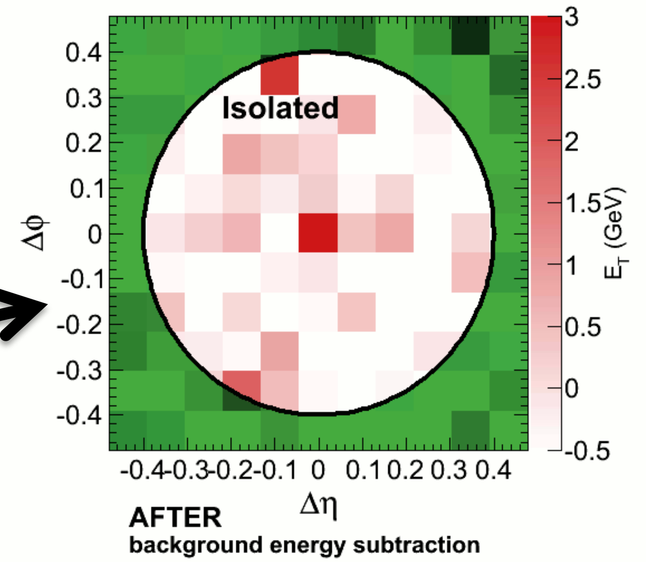
- Isolation cut using E_T in isolation cone
  - ➔ Photon : π^0 = 1 : O(1)





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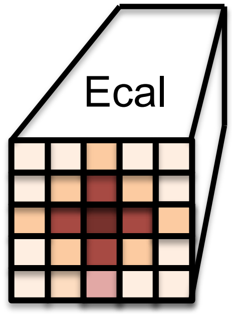

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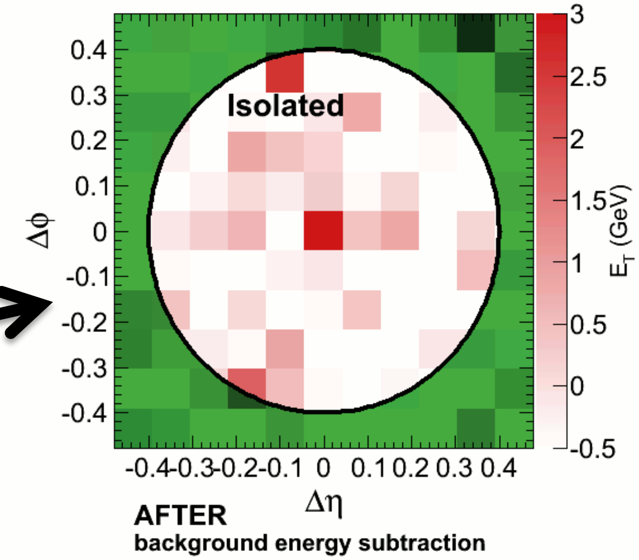
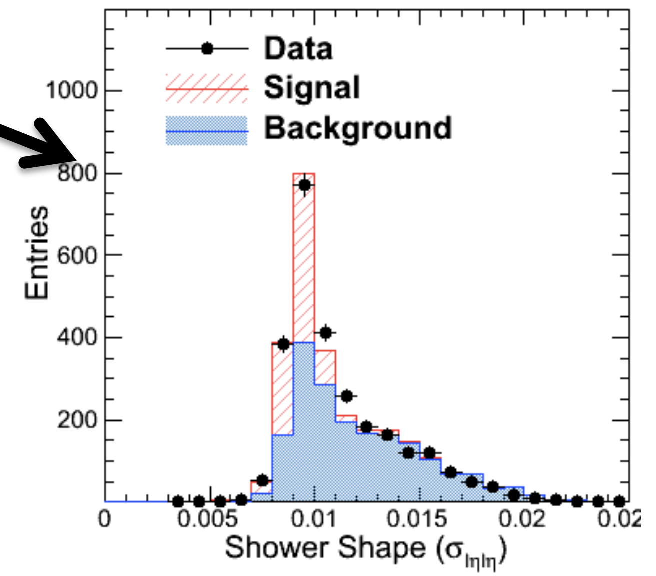


- Count photons using template methods



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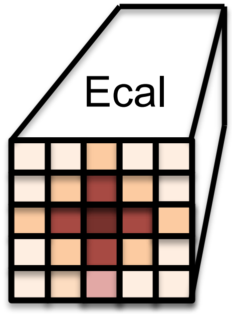

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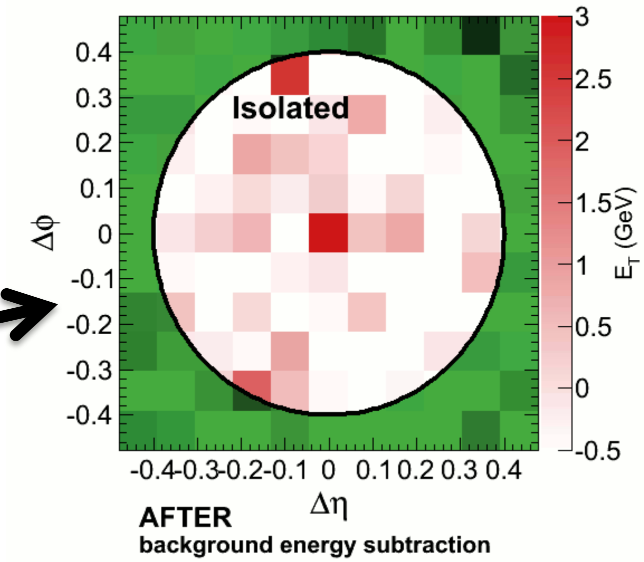

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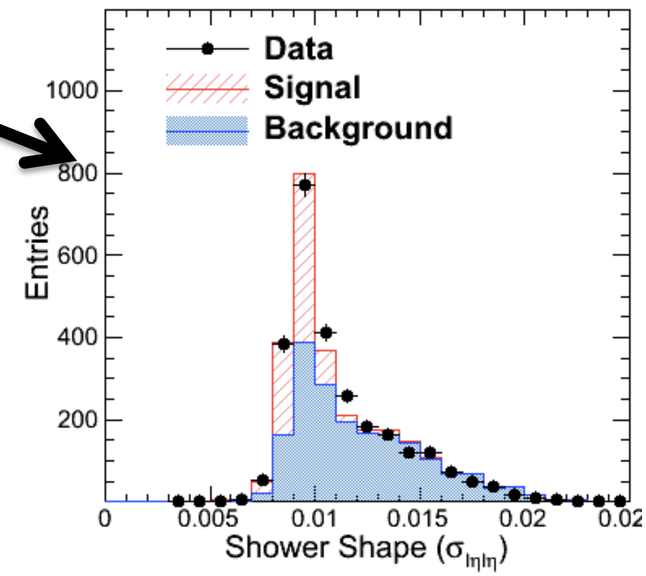
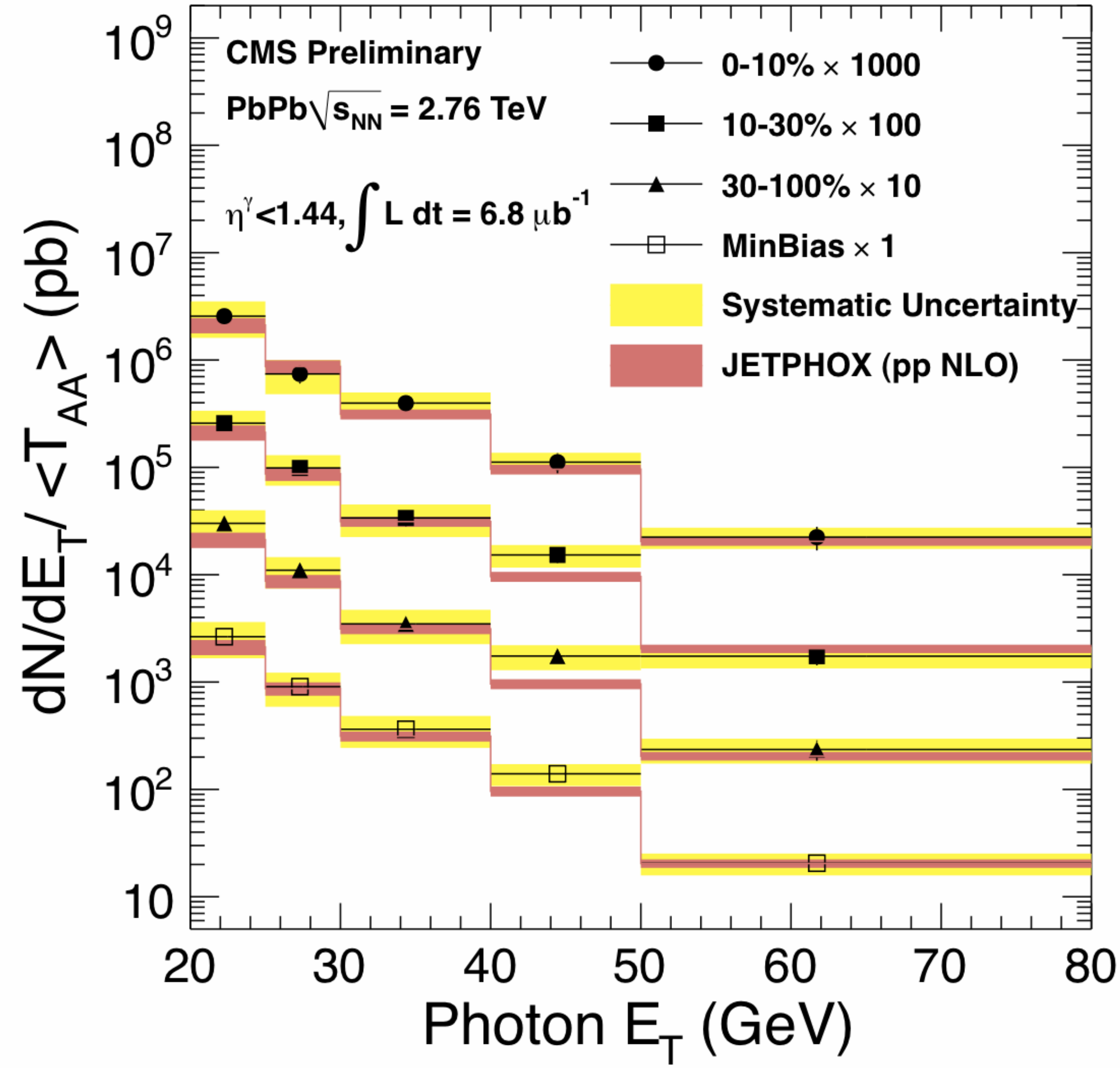


- Correction factors applied
  - Isolation efficiency : 70 – 90%
  - Acceptance : ~95%

- Now, PbPb **photon spectra** on next slide

Isolated photon spectrum

- dN/dE_T is scaled by T_{AA}
  - T_{AA} : tickness factor, the cross-section of N-N inside PbPb collision
- Systematic uncertainty is 21 – 37%
- Compared to pp reference

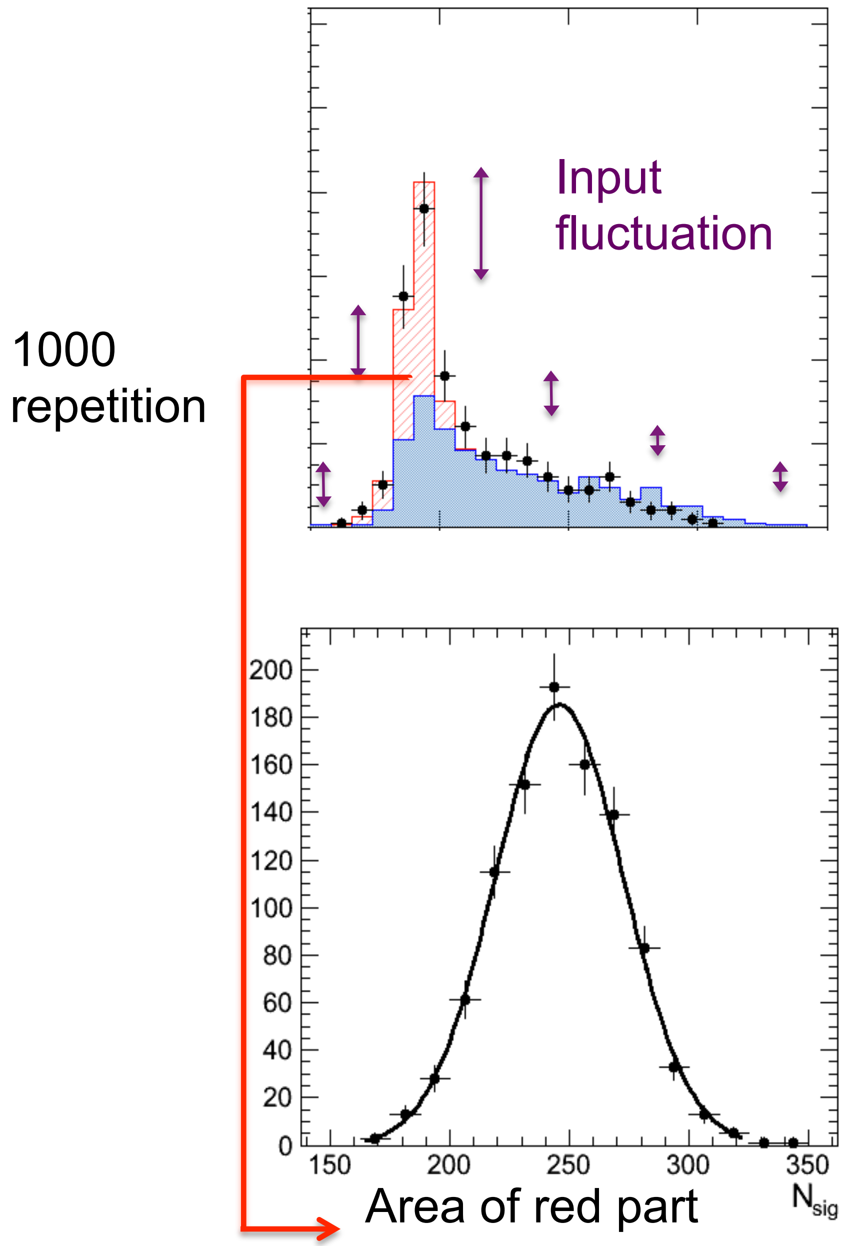


Statistical uncertainty

- Toy MC study

- Artificially fluctuate the templates and data points according to Gaussian distribution

- After several times of re-fitting, check how the number of extracted signals (red area) are varied



Systematic uncertainty

- Shower shape of photon signal obtained from MC
  - Slightly different shower shapes of MC and data
  - Compared electrons from Z->ee events in MC vs data
  - 2 – 5% uncertainty propagates
- Shower shape of background from non-isolated probes in jets
  - Collinear particles around π^0 and η may contaminate shower shape
  - MC study to check how much the results affected
  - 12 – 30% uncertainty
- **Overall systematic uncertainty 21 – 37%**
  - Including efficiency correction(5 – 9 %), energy resolution (10%), electron subtraction (4 – 8%), energy fluctuation on cluster (2 – 4%), etc

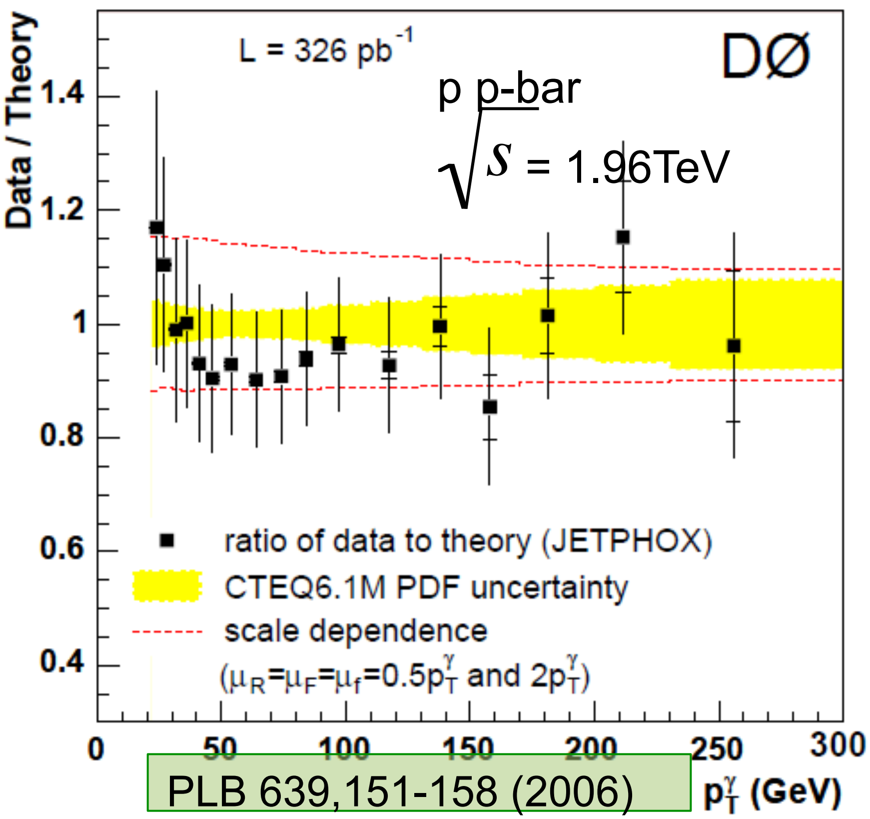
pp reference

- Need **pp spectrum at 2.76TeV** as the denominator for R_{AA}

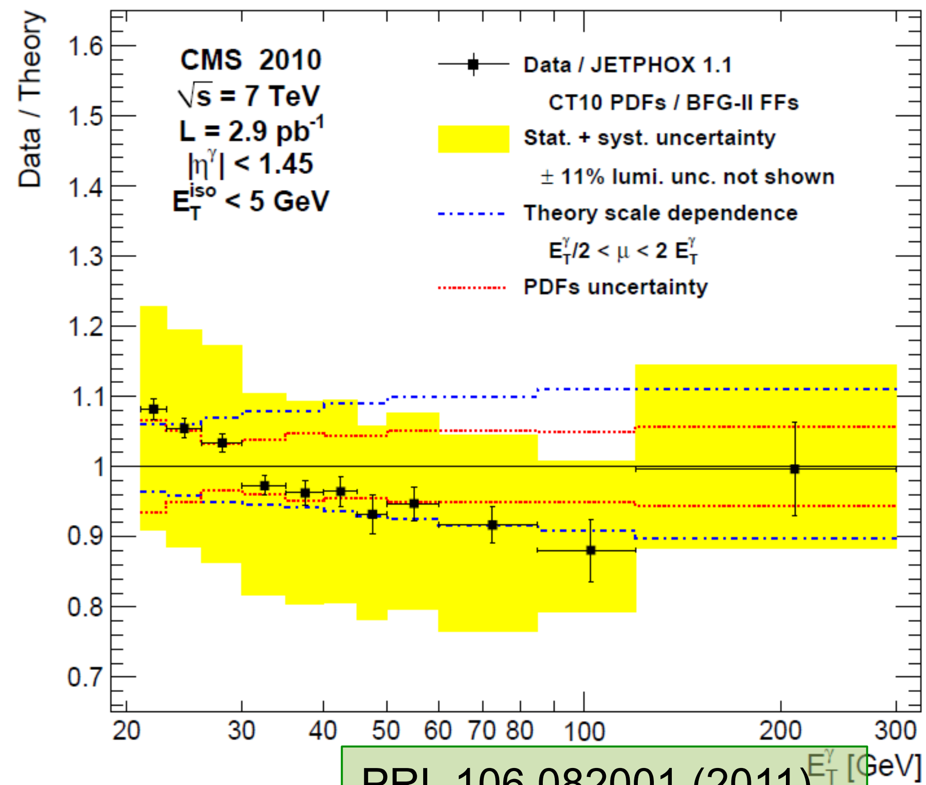
- We have taken pp data from LHC, but not finished analysis.

pp reference from NLO calculation

- **JETPHOX** [JHEP 05 (2002) 028] NLO calculator
- CT10 PDFs and BFG-II fragmentation function
- Reasonable description of p+p(bar) at 7(1.96) TeV

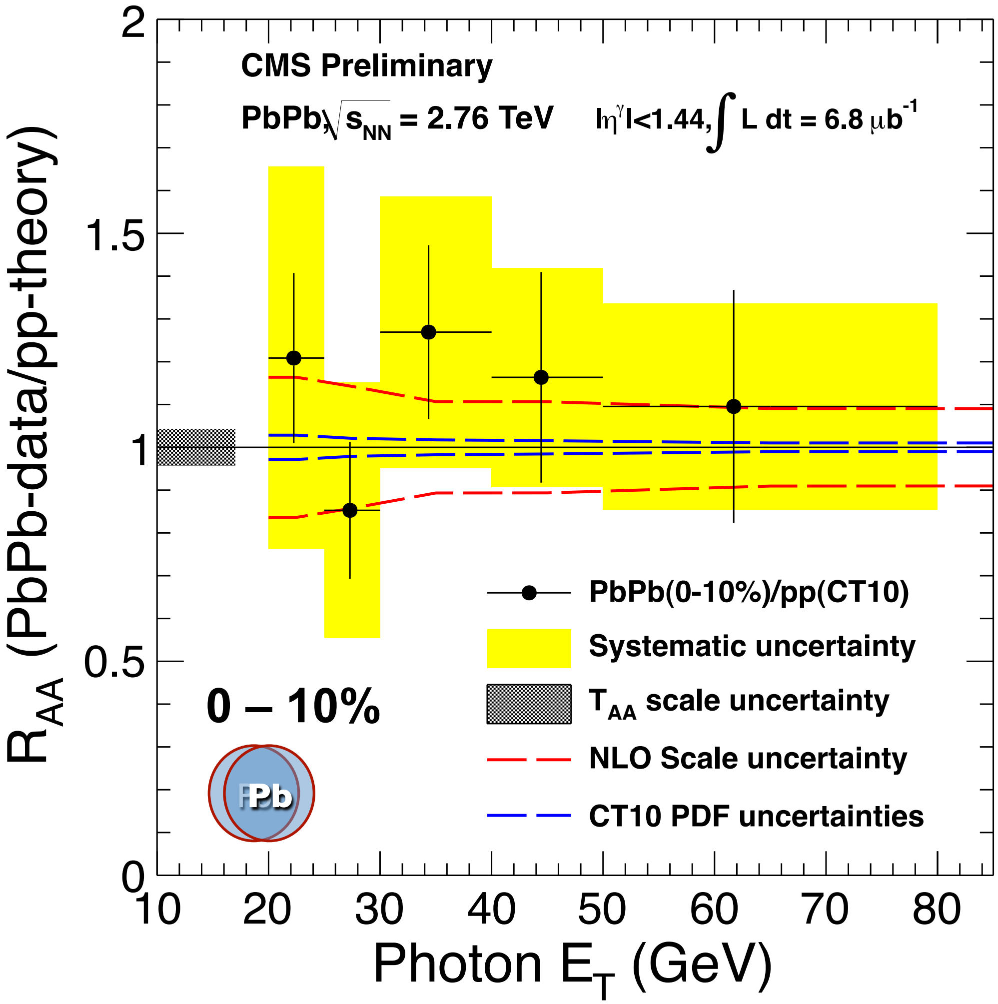


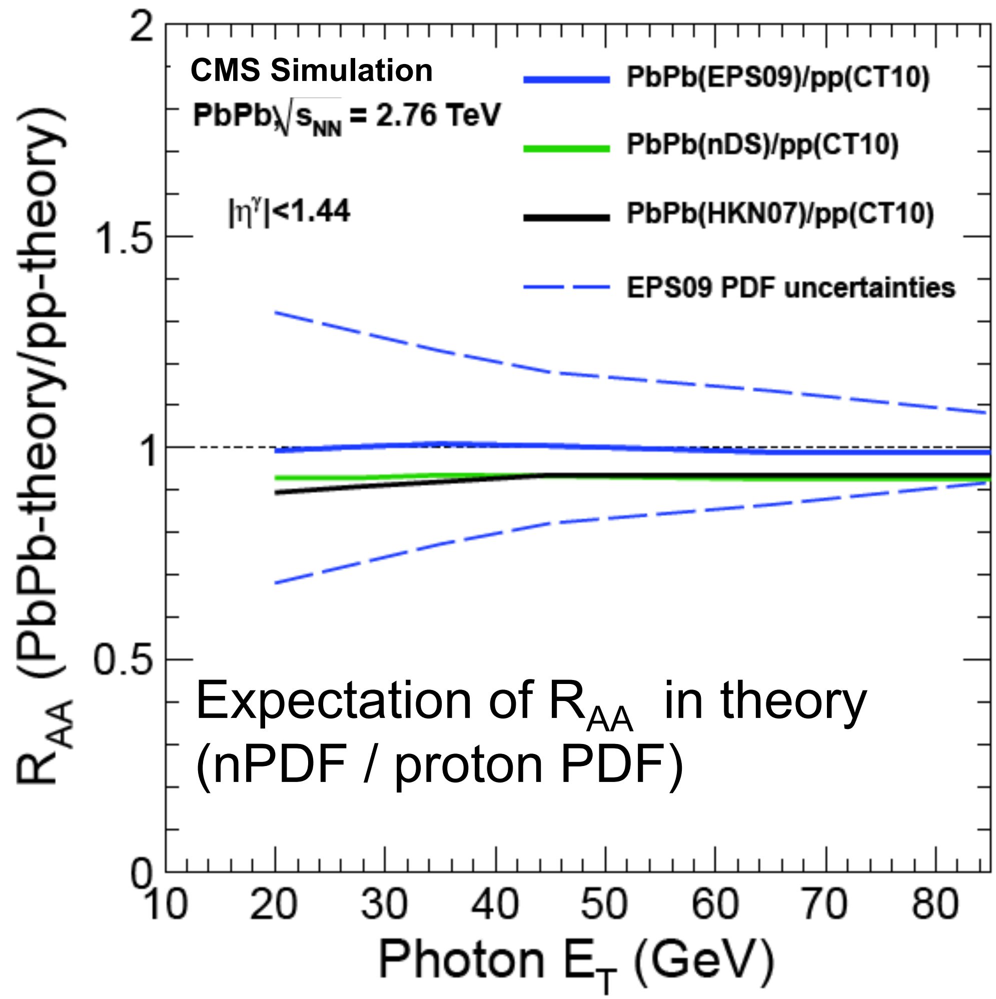
PLB 639,151-158 (2006)



PRL 106,082001 (2011)

R_{AA} in the most central events





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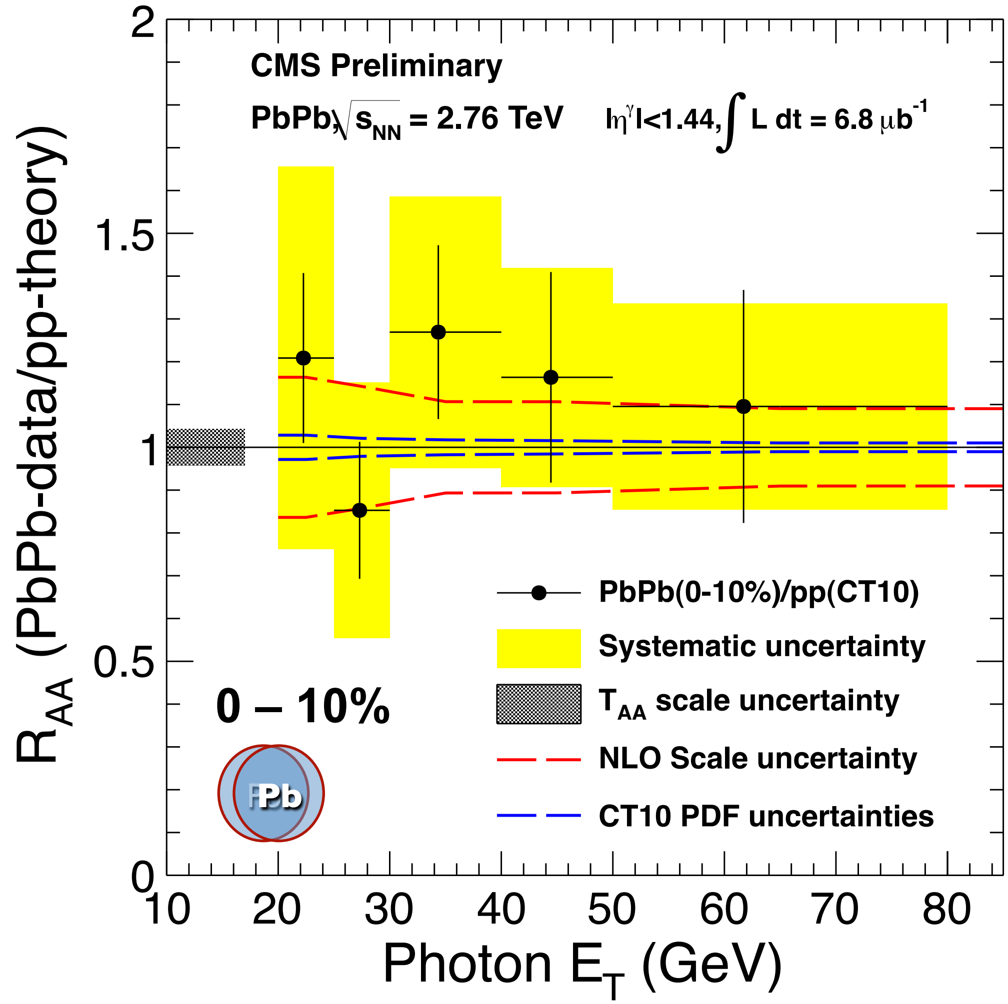
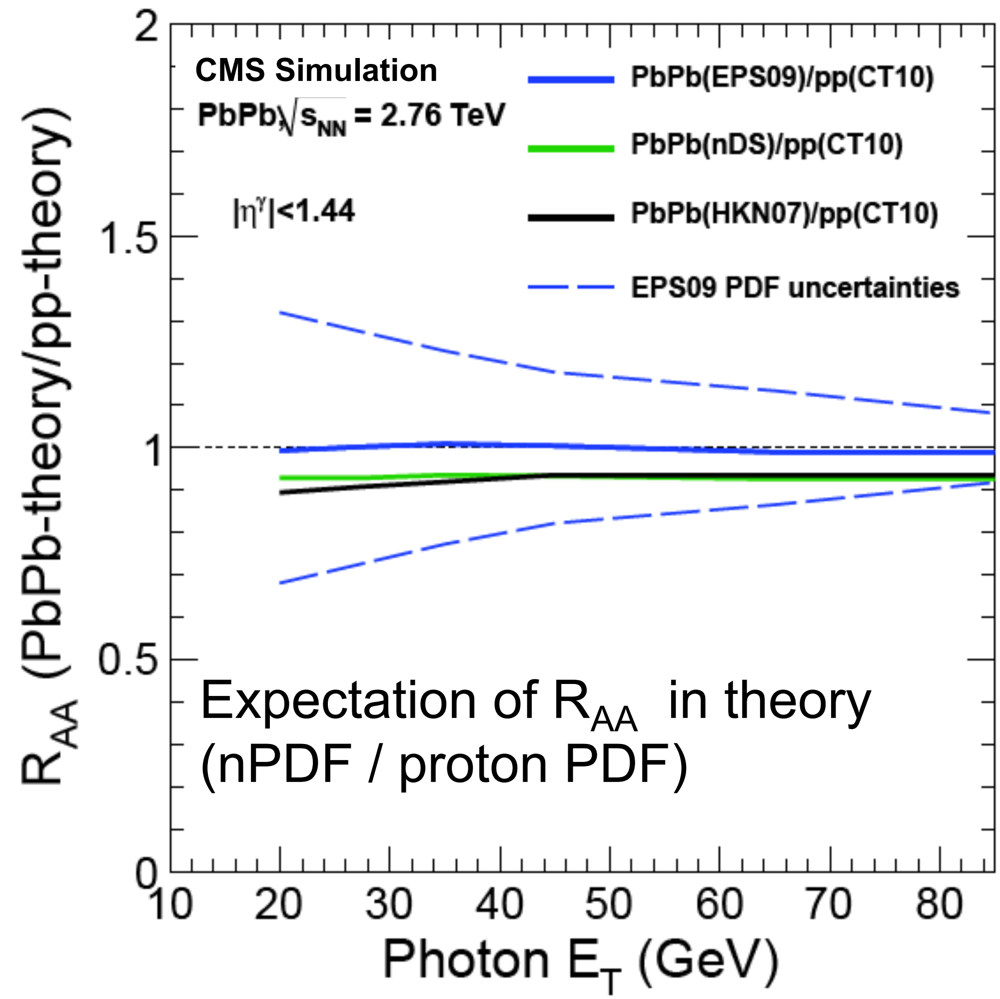
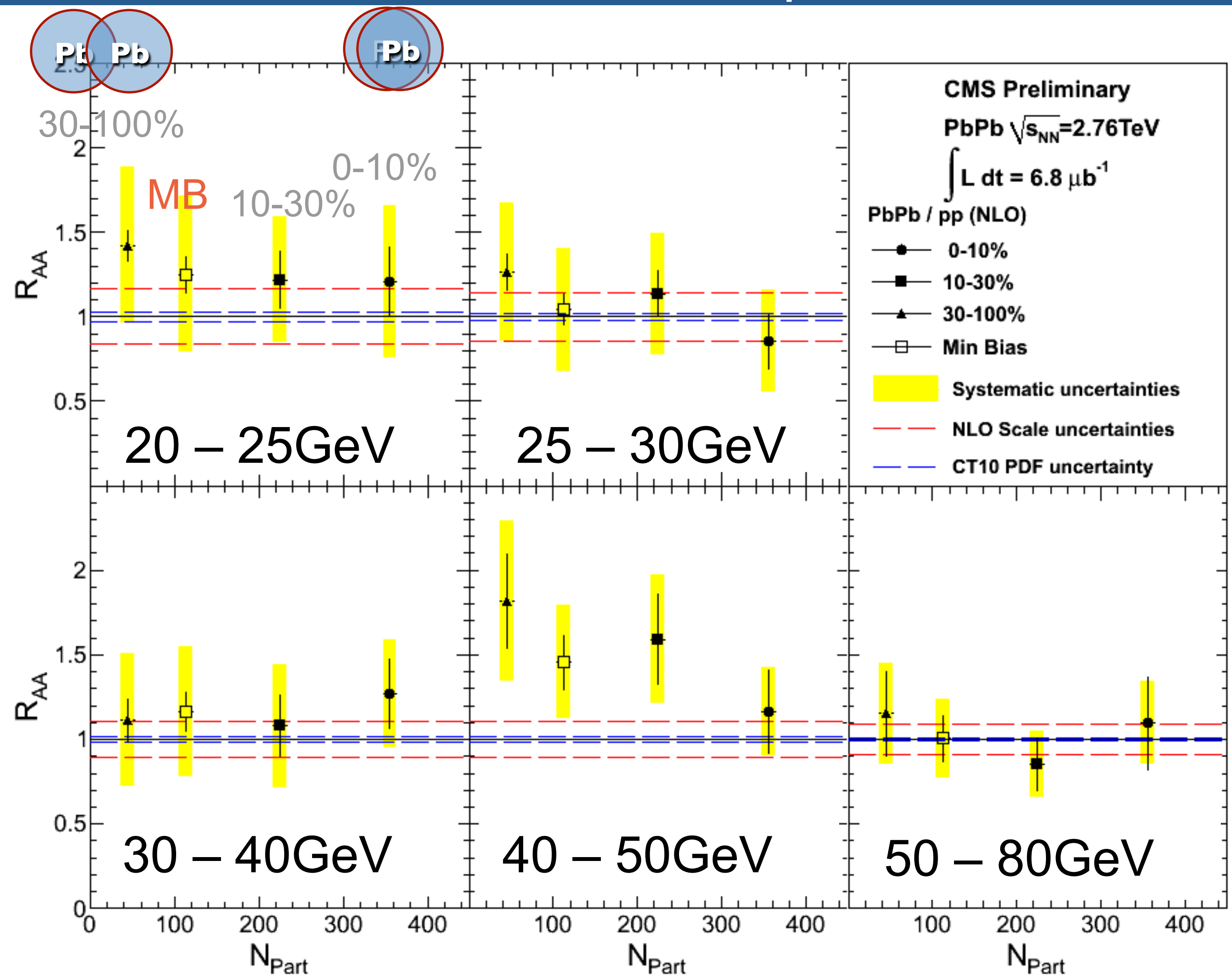




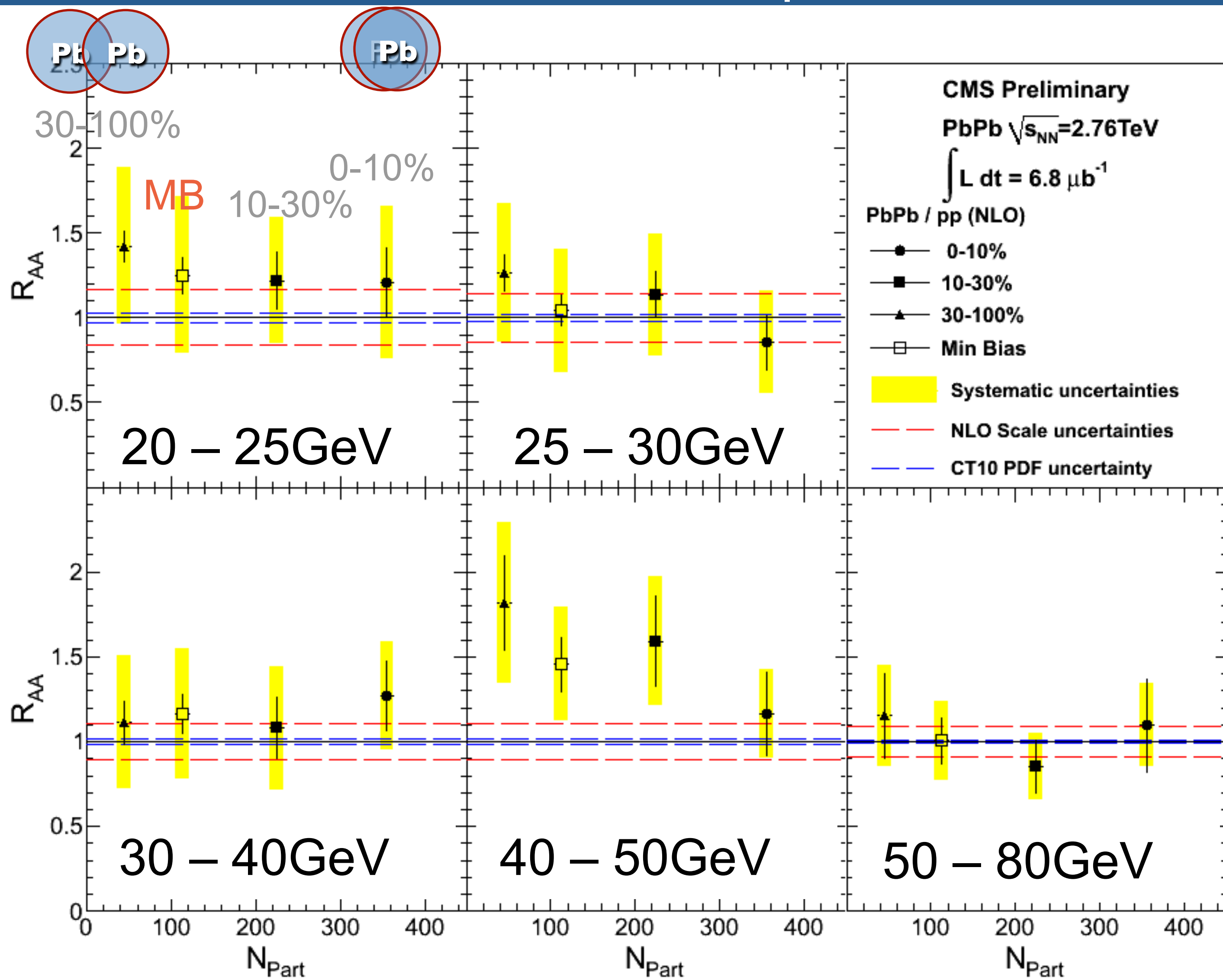
Message 1

R_{AA} vs. E_T is flat

R_{AA} vs N_{part}


Pb Pb
Pb
30-100%
MB
10-30%
0-10%
CMS Preliminary
PbPb $\sqrt{s_{NN}}$=2.76TeV
$\int$L dt = 6.8 μb^{-1}
PbPb / pp (NLO)
0-10%
10-30%
30-100%
Min Bias
Systematic uncertainties
NLO Scale uncertainties
CT10 PDF uncertainty
20 – 25GeV
25 – 30GeV
30 – 40GeV
40 – 50GeV
50 – 80GeV
R_{AA}
N_{Part}

R_{AA} vs N_{part}



Message 2

No dependence of R_{AA} on N_{part}

Room for improvement

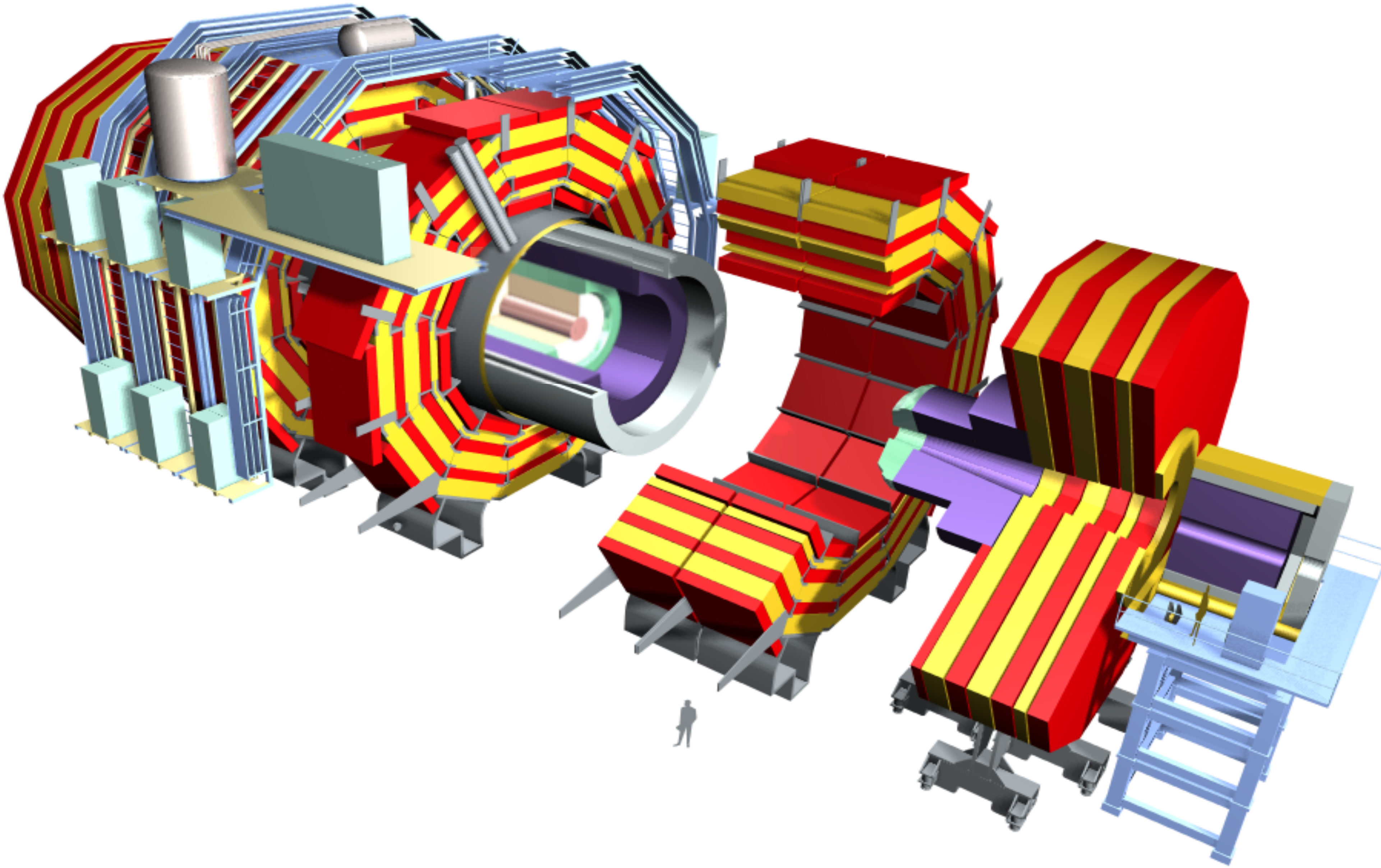
- More studies ongoing to reduce the statistical uncertainty
  - Current uncertainty assigned conservatively
- Better control of background shower shape
  - Parametrization of template would reduce huge uncertainty, expecially in high p_T, where data-driven backgrounds are non-isolated π^0 are not enough
- **pp data** is being analyzed
  - Expected uncertainty of 10%(stat), 10 – 15%(sys)

Conclusion

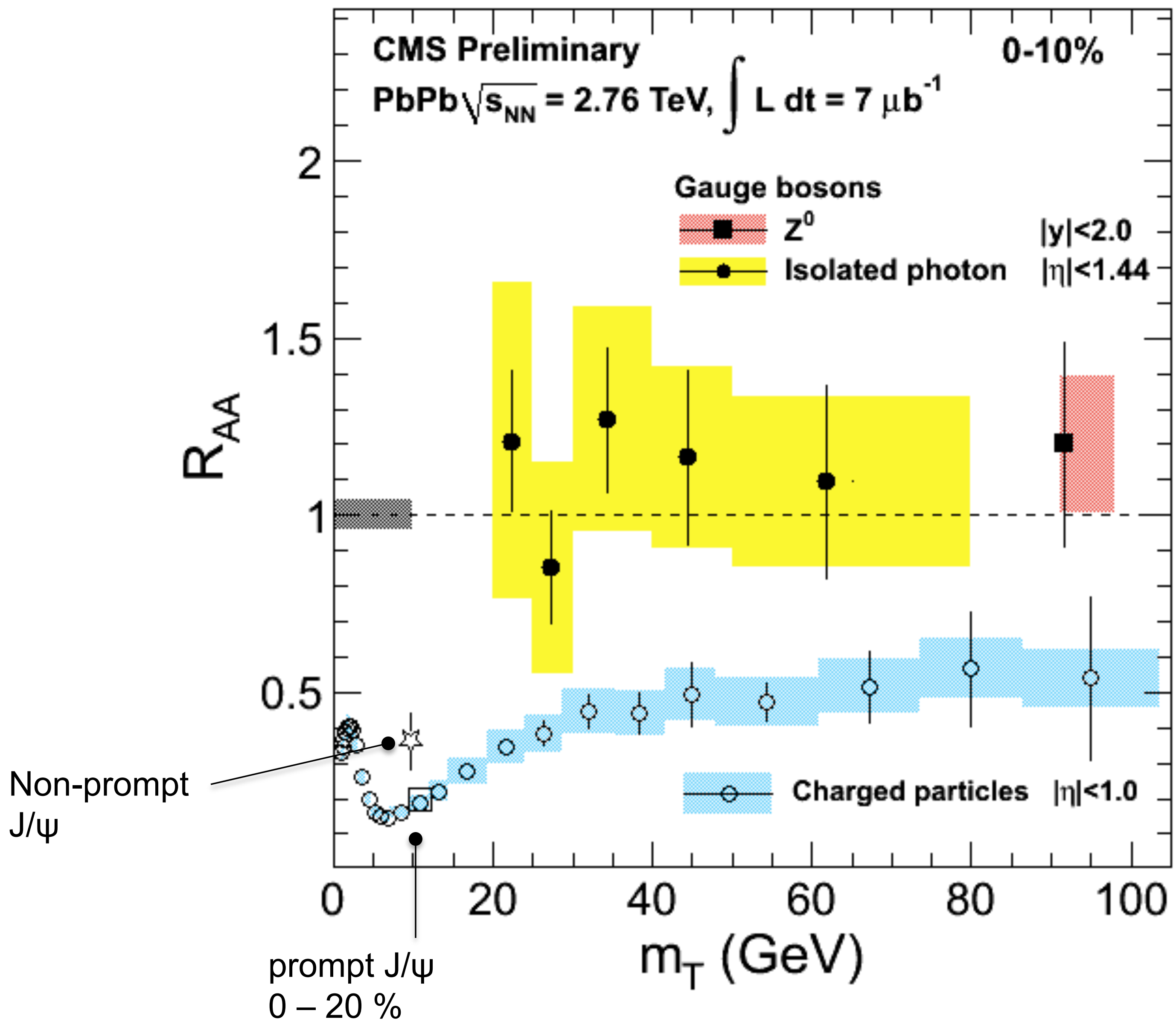
- **First ever measurement** of isolated photon spectra in heavy ion collision experiment

- **No evidence of modification in the initial state** of hard scattering production in heavy ion collision
  - i.e. production of isolated photon is same as in pp multiplied by the number of binary collisions
- Establishes the basis for the future researches which use photons as unmodified hard probes
  - Inclusive photon spectrum (iso vs non-iso photon)
  - Gamma-jet correlation (modification energy, shape, fragmentation of jet after photon tagging)

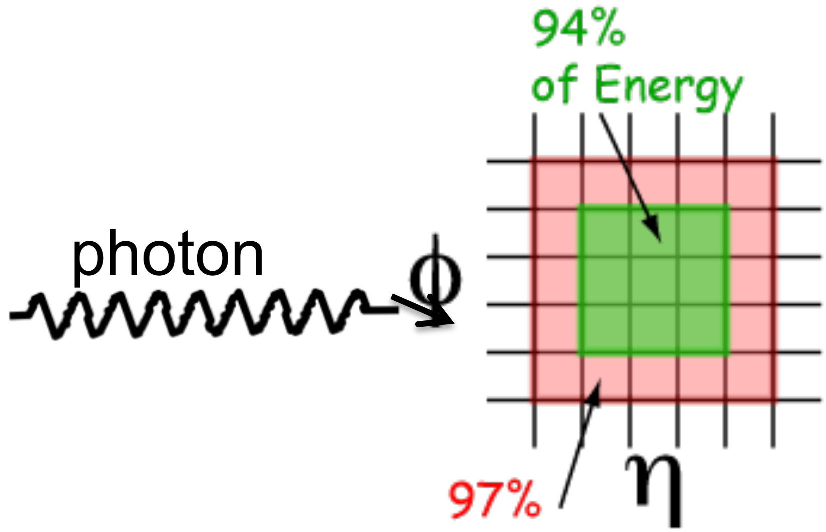
BACKUP

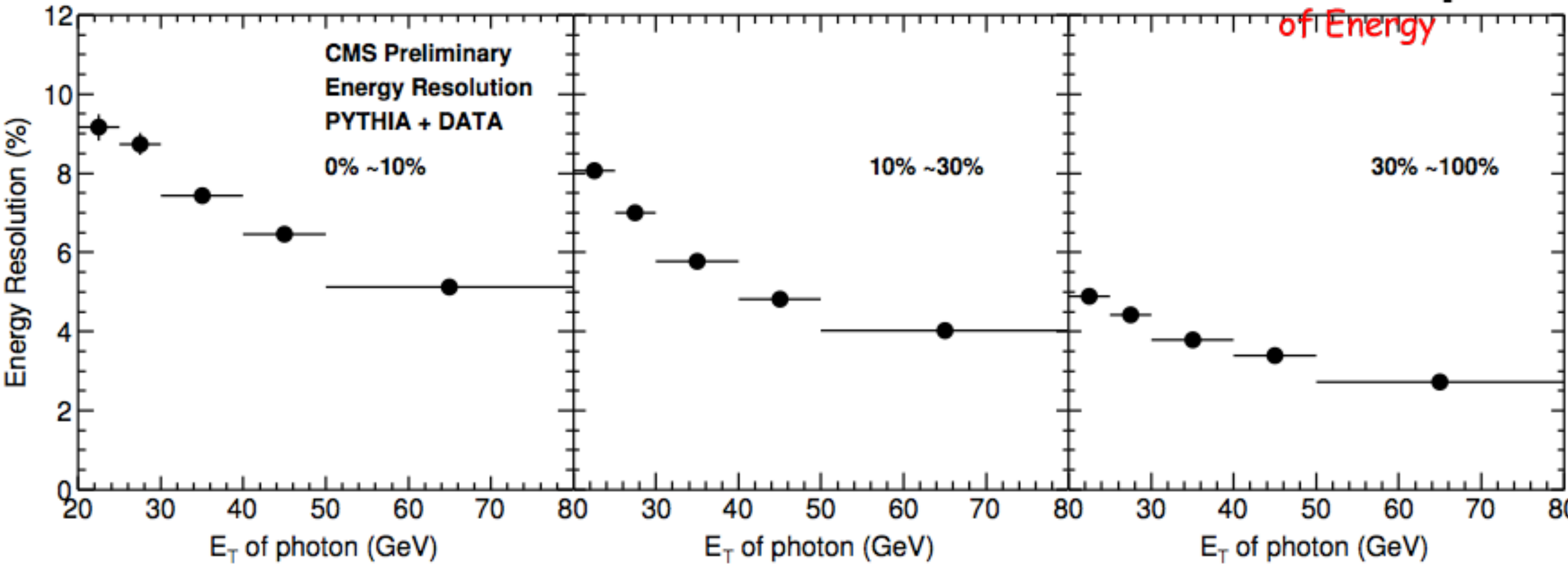


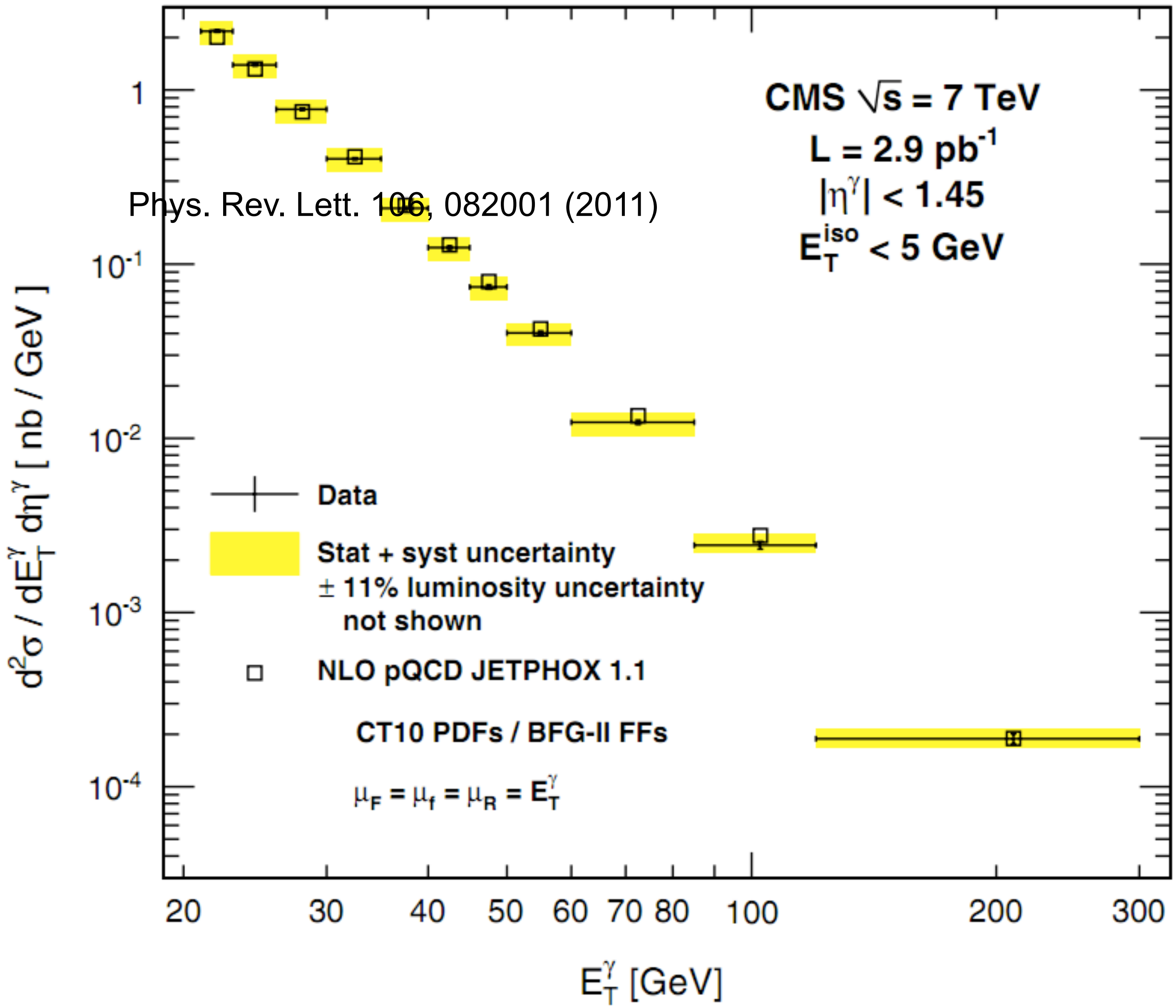
CMS R_{AA}


CMS Preliminary
0-10%
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV, $\int L\,dt = 7\ \mu b^{-1}$
Gauge bosons
Z^0 |y|<2.0
Isolated photon |η|<1.44
Charged particles |η|<1.0
R_{AA}
m_T (GeV)
0
20
40
60
80
100
0.5
1
1.5
2
Non-prompt J/ψ
prompt J/ψ 0 – 20 %

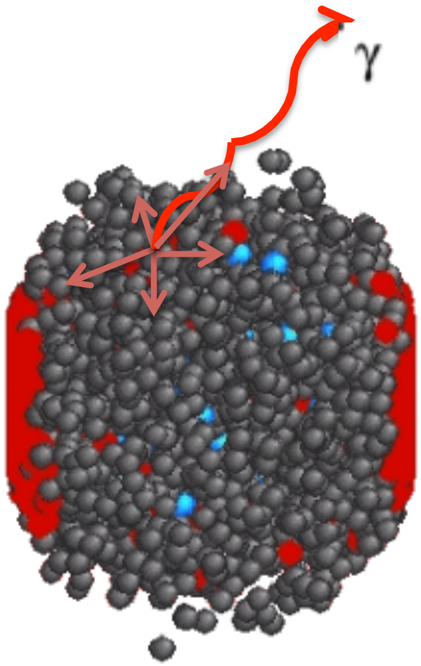
Photon reconstruction





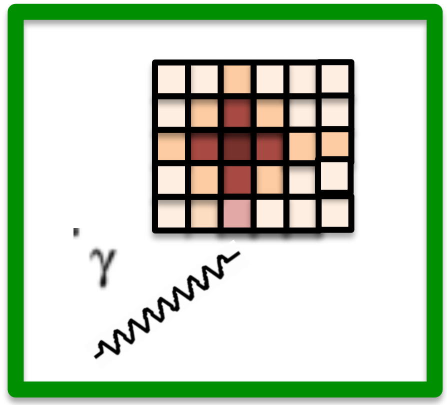


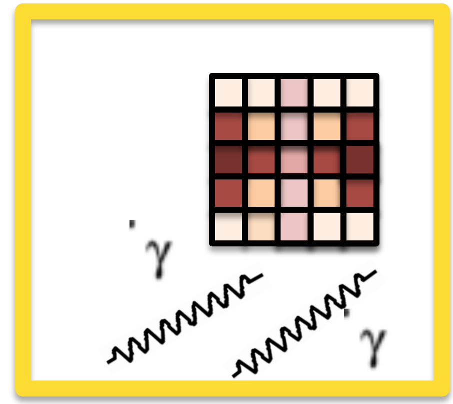
CMS √s = 7 TeV
L = 2.9 pb-1
|ηγ| < 1.45
E_T^iso < 5 GeV
Phys. Rev. Lett. 106, 082001 (2011)
Data
Stat + syst uncertainty
± 11% luminosity uncertainty
not shown
NLO pQCD JETPHOX 1.1
CT10 PDFs / BFG-II FFs
μF = μf = μR = E_T^γ
d2σ / dE_T^γ dηγ [nb / GeV]
E_T^γ [GeV]


γ

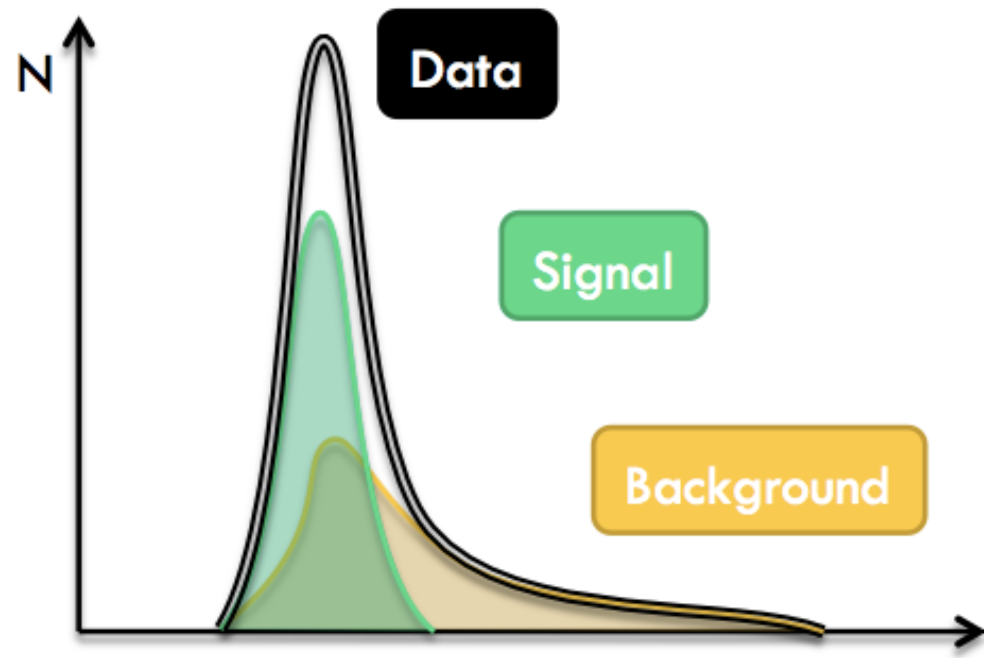
Signal extraction

- Yet, after isolation cut, there are pi0s and eta which are fragmented in Jet with high-z.





- We used statistical approach by quantifying the shower shape on EM calorimeter thanks to fine segments.



$$\sigma_{\eta\eta}^2 = \sum_{i=1}^{25} w_i(\eta_i - \bar{\eta})^2 / \sum_{i=1}^{25} w_i,$$

$$w_i = \max(0, 4.7 + \ln(E_i/E))$$

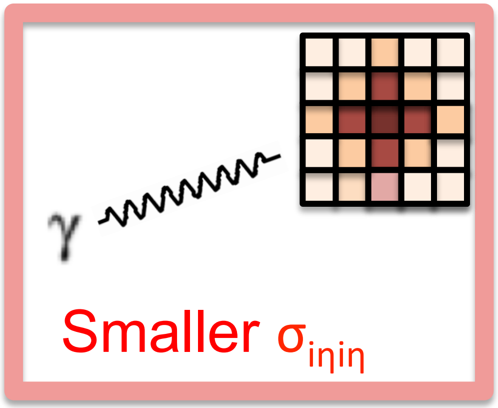
Signal extraction

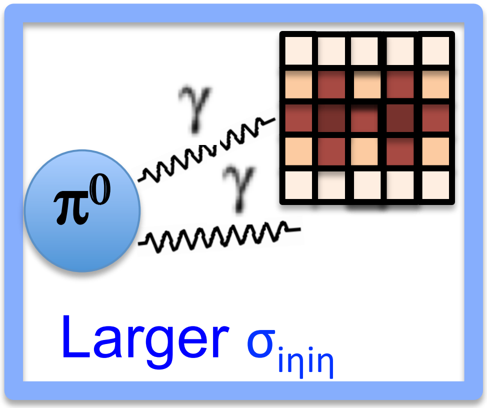
- Even after isolation cut, isolated π^0 and η remained. (fragmented in jets with high-z)
- Statistical approach to separate photons from them, by quantifying shower shape on Ecal crystals.

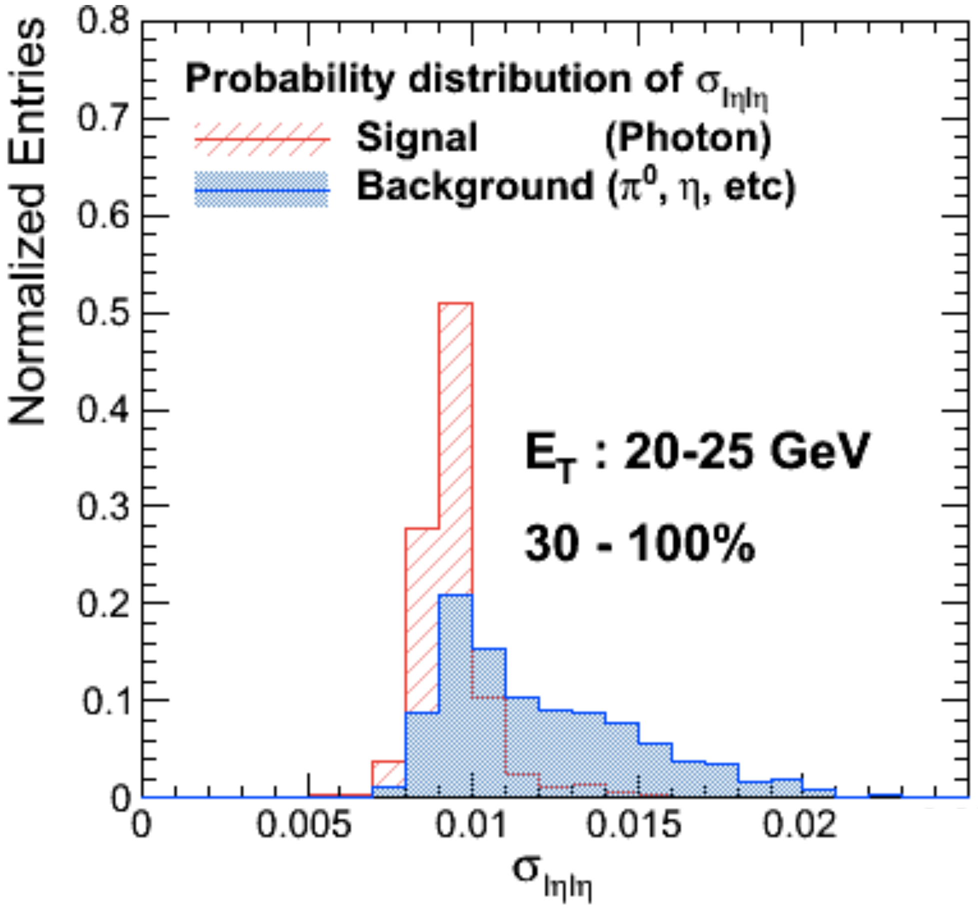
$$\sigma_{\eta\eta}^2 = \sum_{i=1}^{25} w_i(\eta_i - \bar{\eta})^2 / \sum_{i=1}^{25} w_i,$$

$$w_i = \max(0, 4.7 + \ln(E_i/E))$$

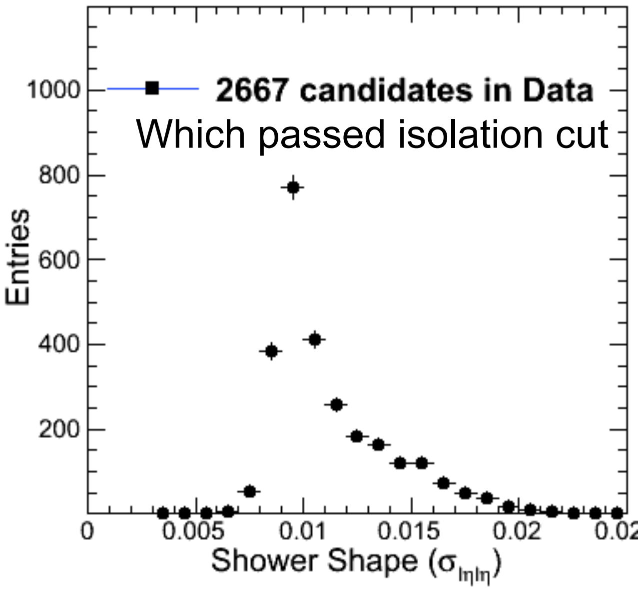
- Probability distribution function of this value is called **Template.**

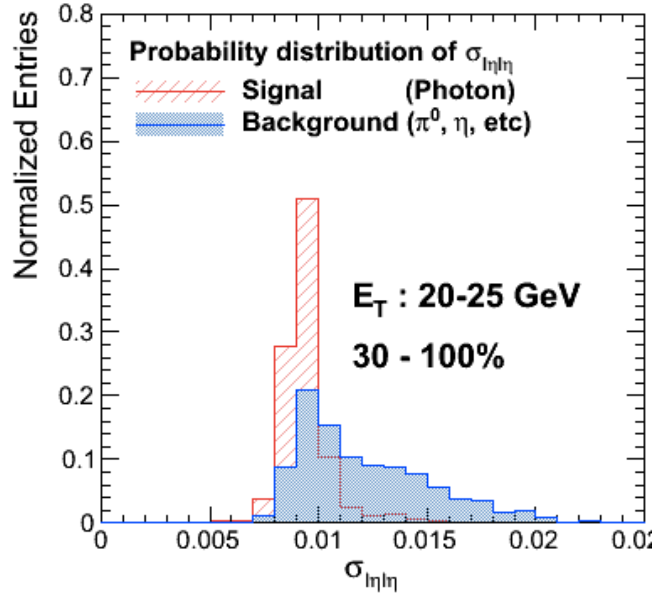


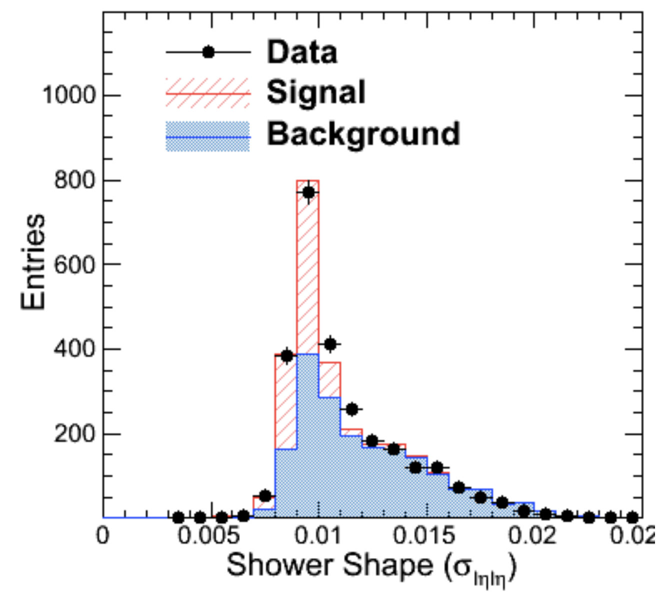




Signal extraction







How many are signals out of 2667 candidates? → Fit with signal and background templates → 802 are isolated photons

- **Signal template**
- Data-driven **Background template** from non-isolated π^0 and η in data.