Nuclear modification factors from the CMS experiment

Yen-Jie Lee

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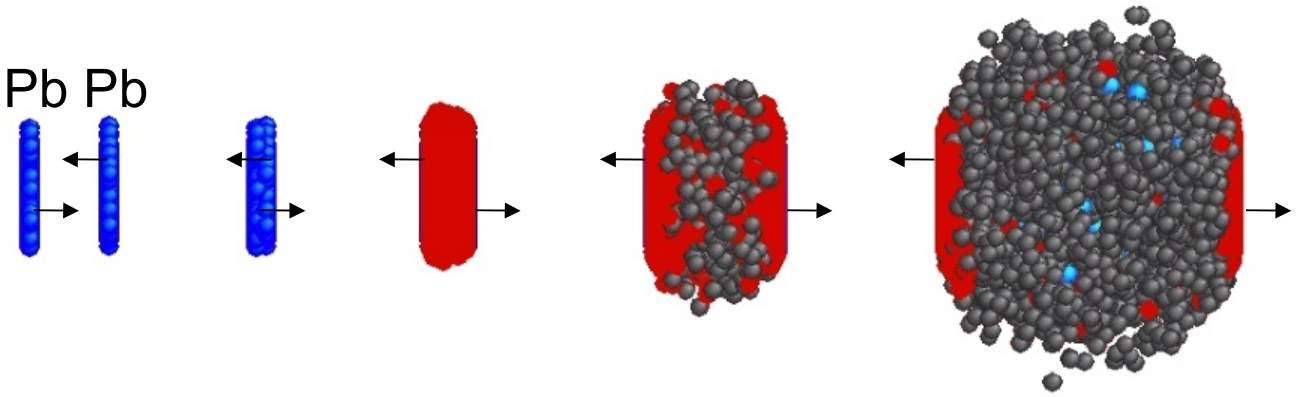
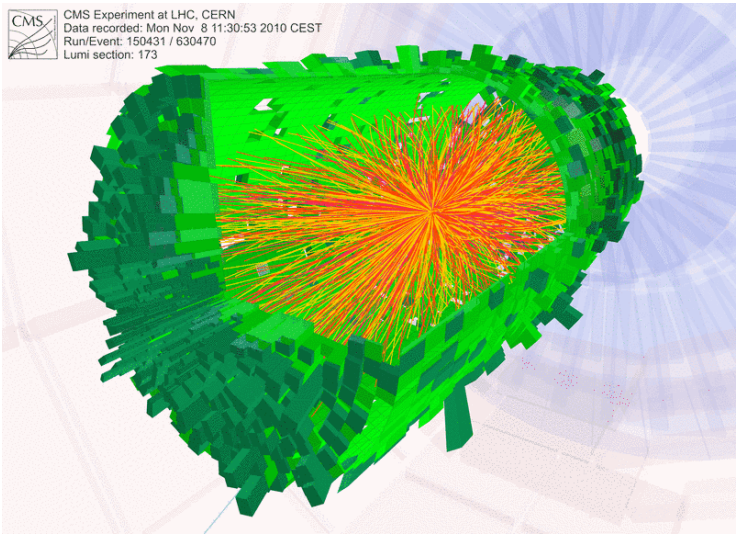
for the CMS Collaboration

CMS studies of the nuclear modification factors





- PbPb data sample used in this talk:
  PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, $\int Ldt \sim 7\ \mu b^{-1}$

- Study of the colorless probes

- Study of the jet quenching and medium modification by looking at the magnitude of the charged particle suppression
  Complementary to direct jet reconstruction

- Results are compared with parton energy loss models

Nuclear modification factor

$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta} \sim \frac{\text{“QCD Medium”}}{\text{“QCD Vacuum”}}$$

- $R_{AA} > 1$ (enhancement)
- $R_{AA} = 1$ (no medium effect)
- $R_{AA} < 1$ (suppression)

PbPb measurements

Z boson

Isolated photon

Charged particle

pp reference spectrum

NLO calculation from POWHEG
JHEP 07(2008)06

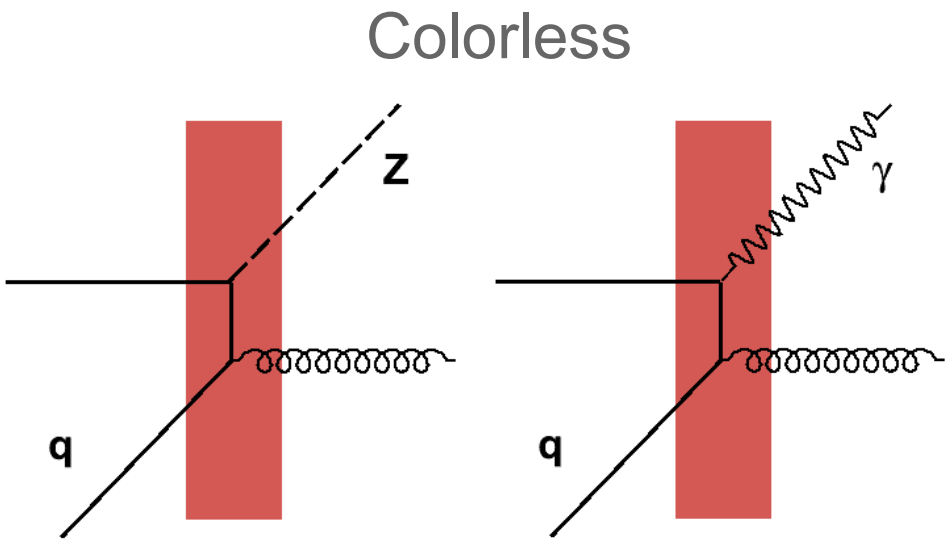
NLO calculation of isolated photon from JETPHOX
JHEP 0205 (2002) 028

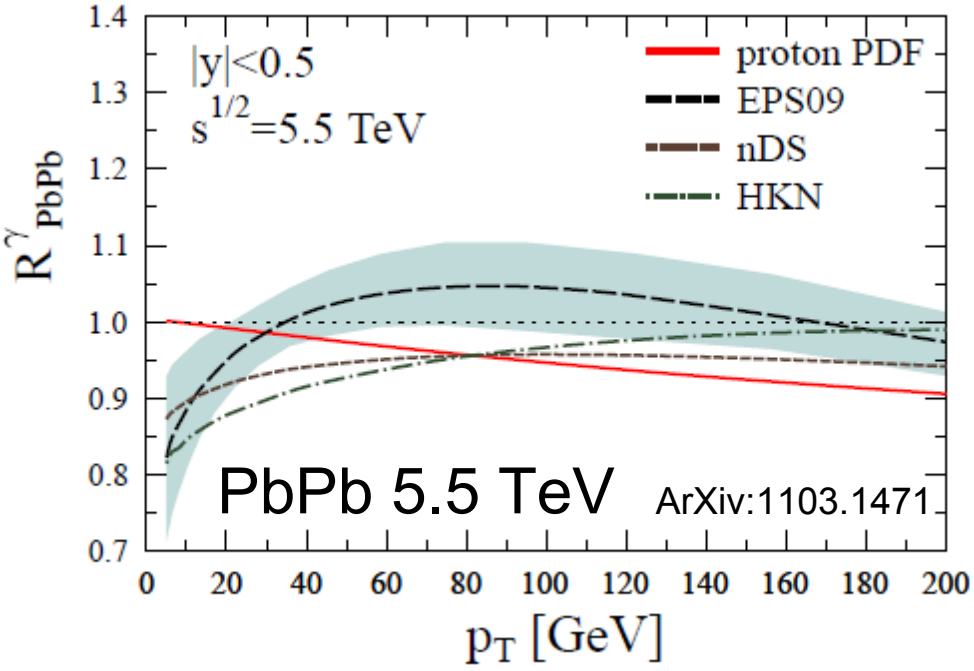
Interpolation from CMS pp measurements at 0.9, 2.36 and 7 TeV.
Arxiv: 1104.3547 submitted to JHEP

$$T_{AA} = \frac{\langle N_{coll} \rangle}{\sigma_{pp}^{inel}}$$

"NN equivalent integrated luminosity per AA collision"

CMS studies of the colorless probes

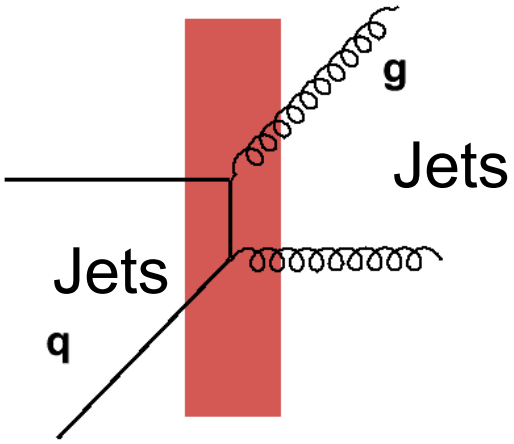


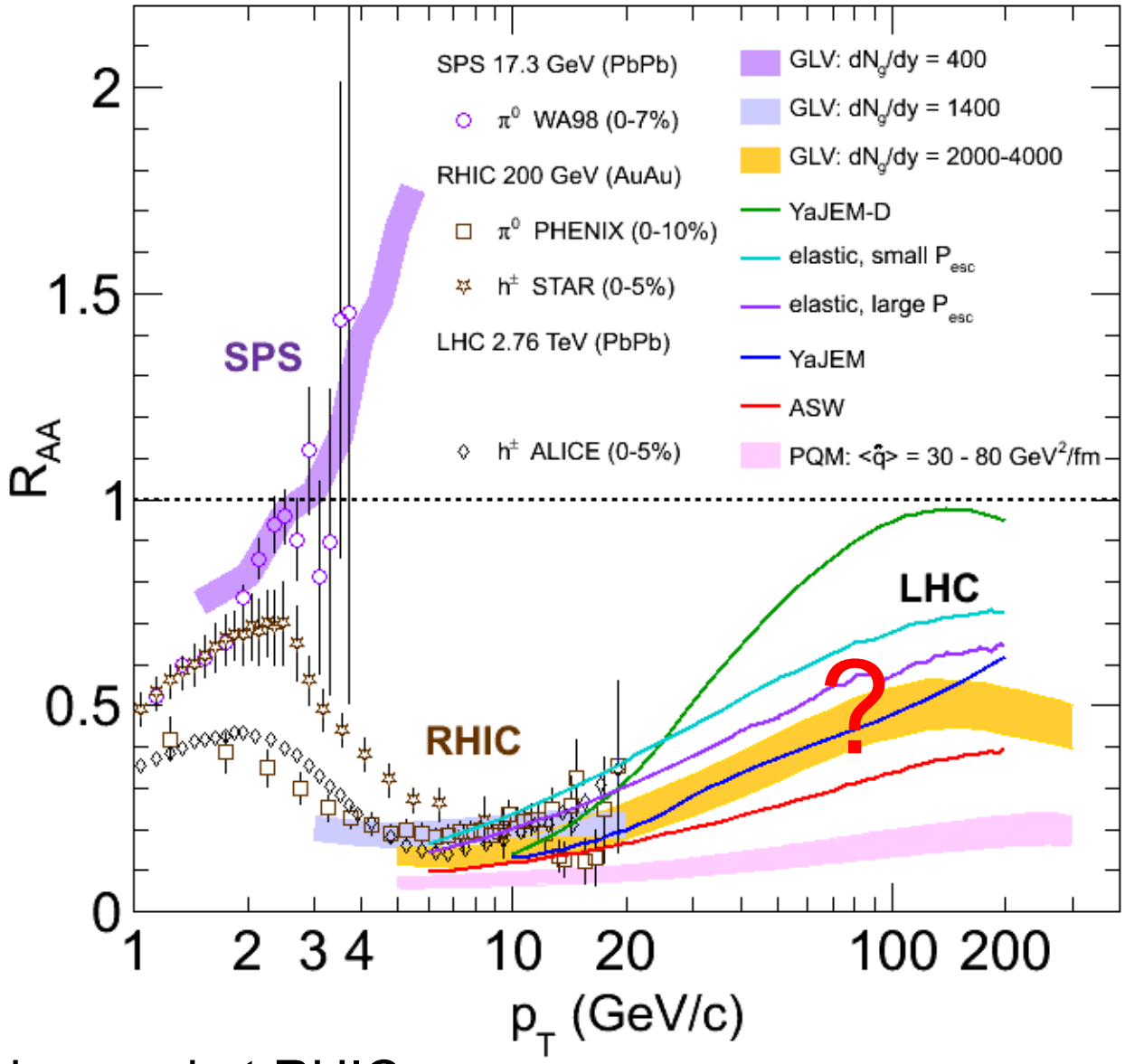


- Z bosons:
  - First measurement of the Z boson production in PbPb
- Photons:
  - Measurement of isolated photons to reject decay photons
  - Probe the nuclear parton distribution function
  - Future analysis: shadowing effect at low p_T and isospin effects at high p_T
- Used to check the initial state and # of binary collisions

CMS studies of the charged particles

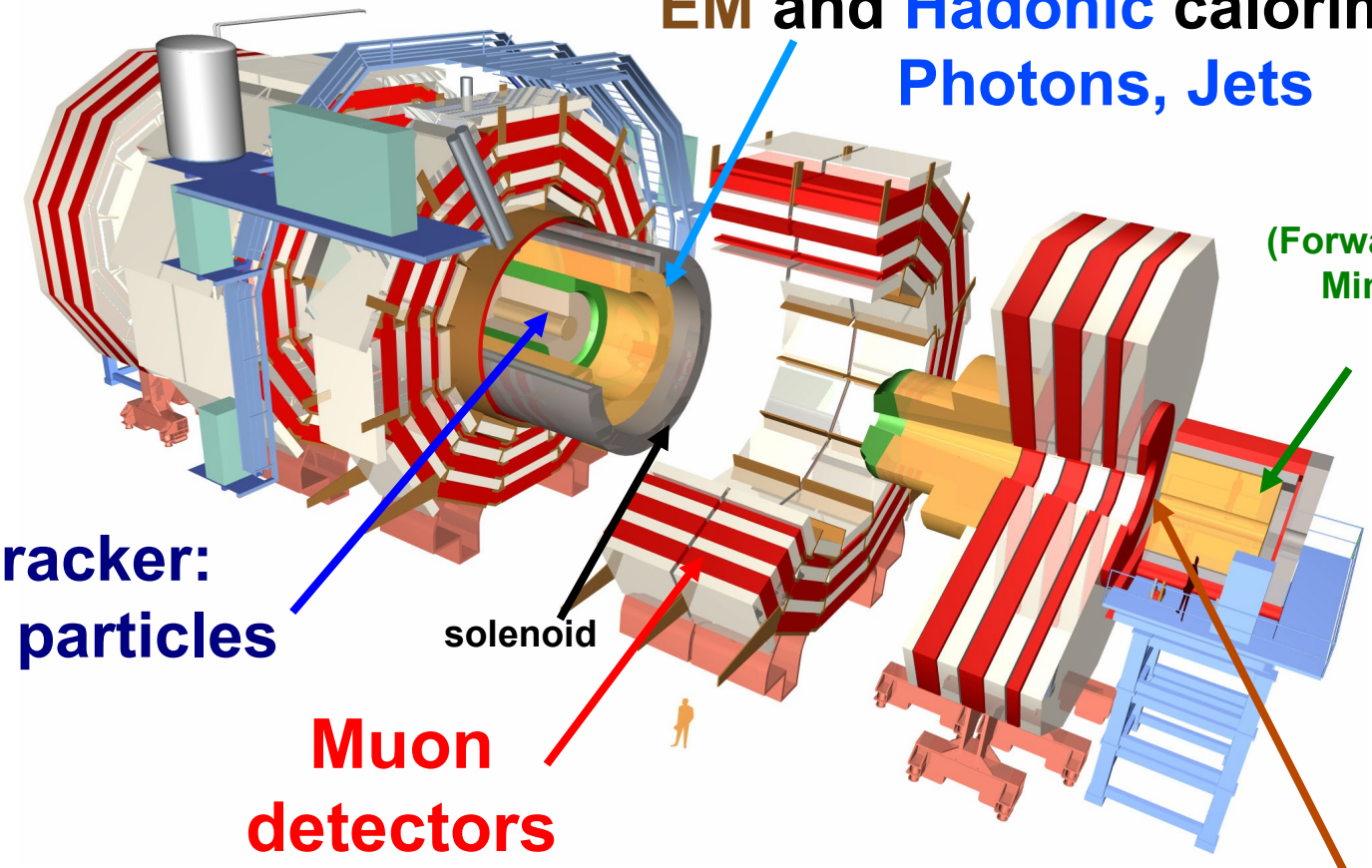
Color charged

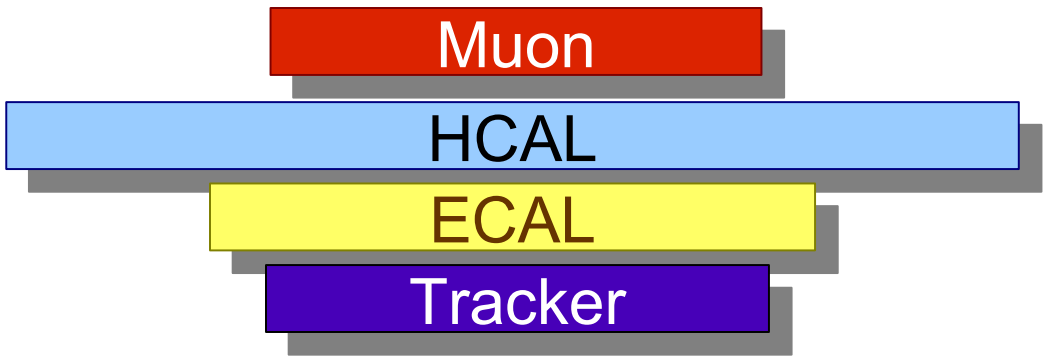




- Charged particles:
  - Large suppression observed at RHIC
  - Study of the final state and medium modification

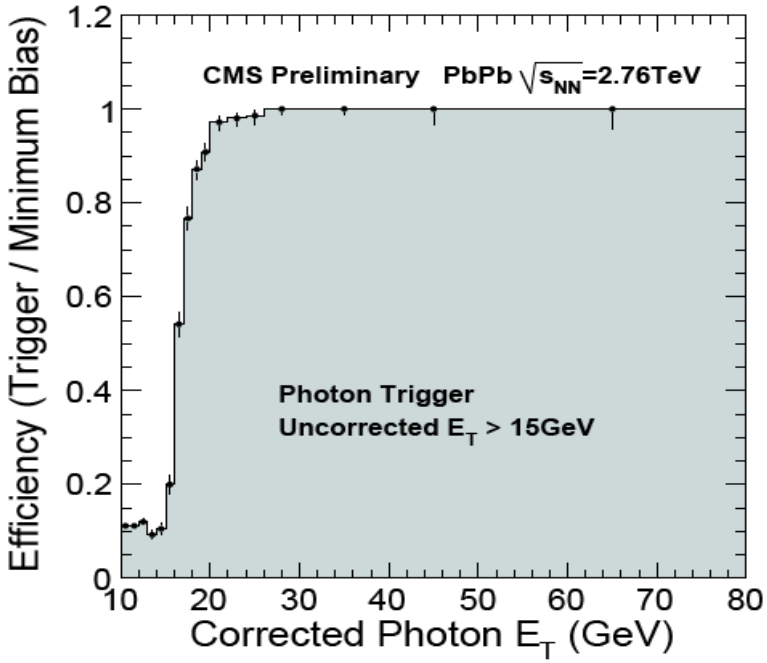
CMS detector

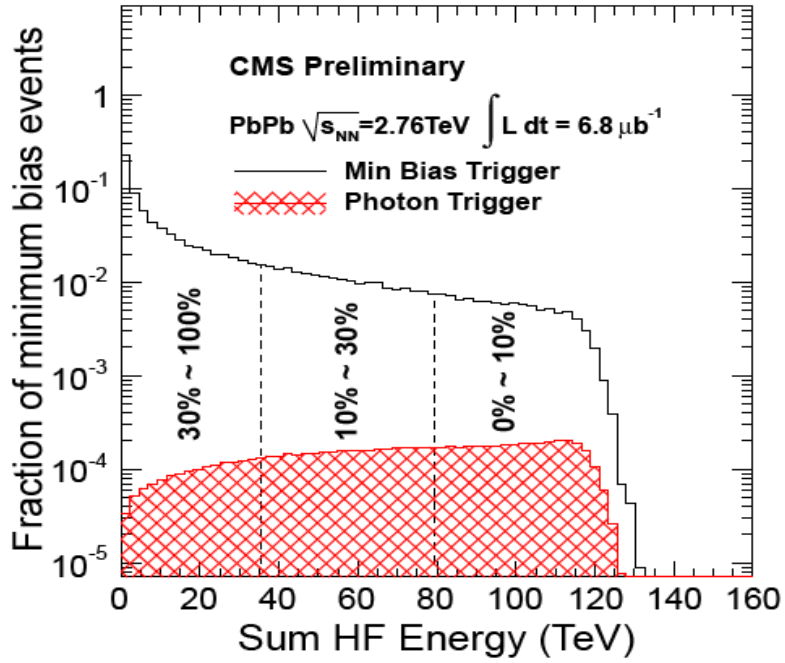




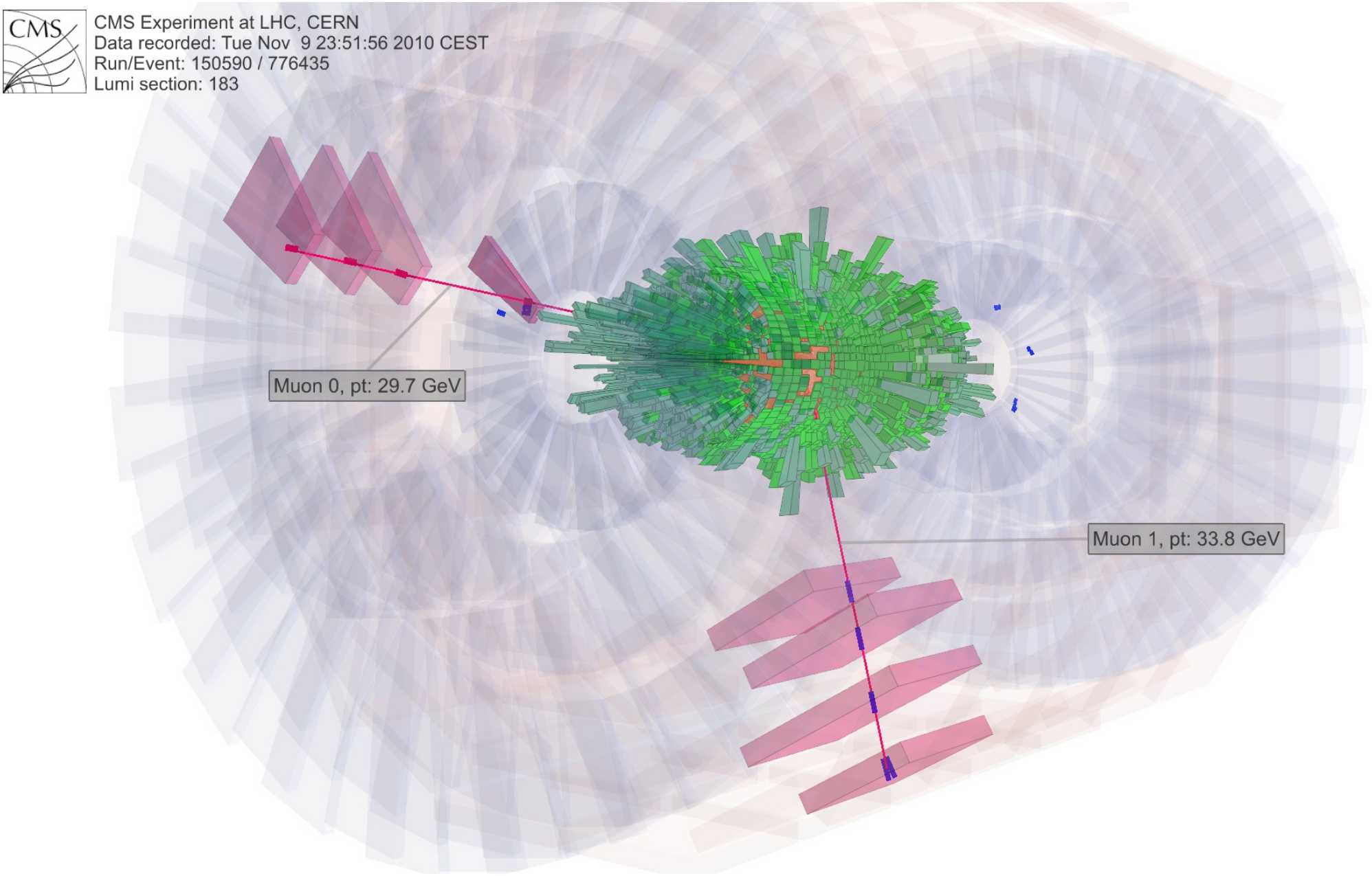
Trigger and event selection

- MinBias Trigger:
  - Coincidence of BSC or Forward calorimeter signal
  - Trigger efficiency: 97% ± 3%
- Di-Muon Trigger:
  - Two reconstructed tracks in the muon detector with p_T > 3 GeV/c
- Photon Trigger:
  - Uncorrected photon E_T> 15 GeV
- Jet Trigger: [gives high p_T reach]
  - Uncorrected jet E_T> 35, 50 GeV
- Centrality determination:
  - Forward calorimeter (HF) energy





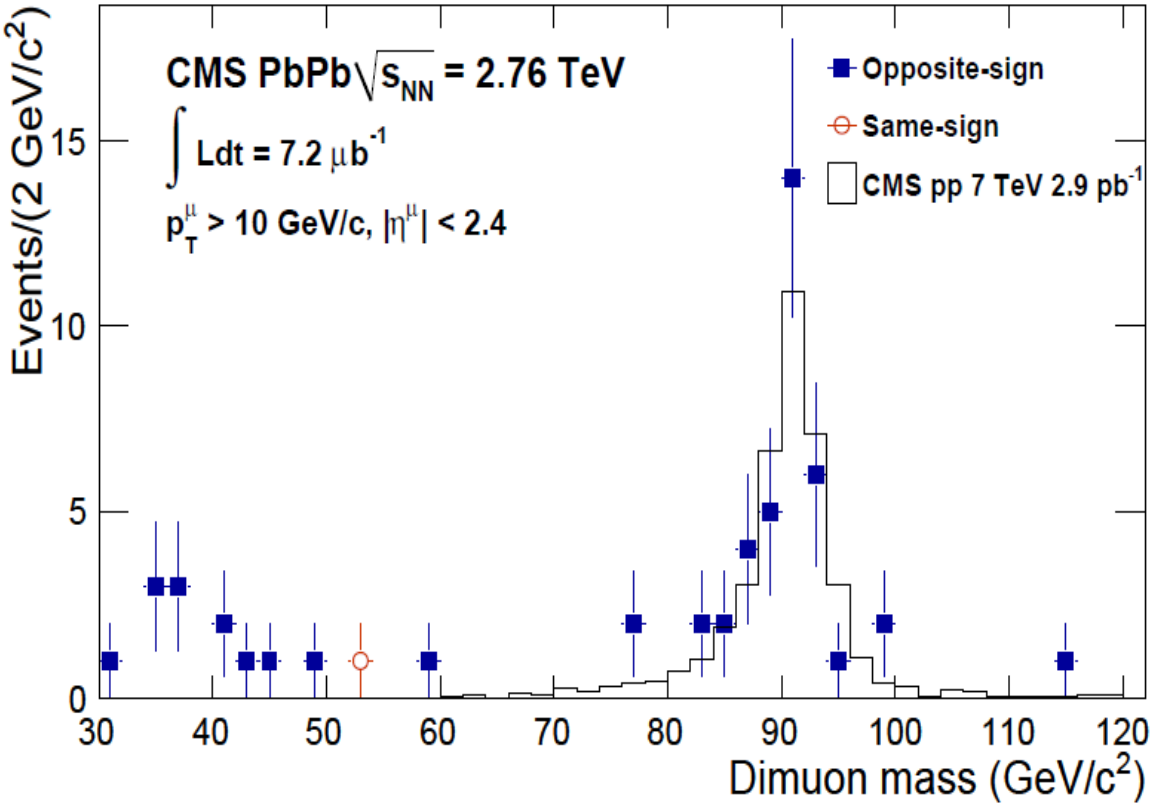
Our first $Z \rightarrow \mu^+\mu^-$ candidate in PbPb

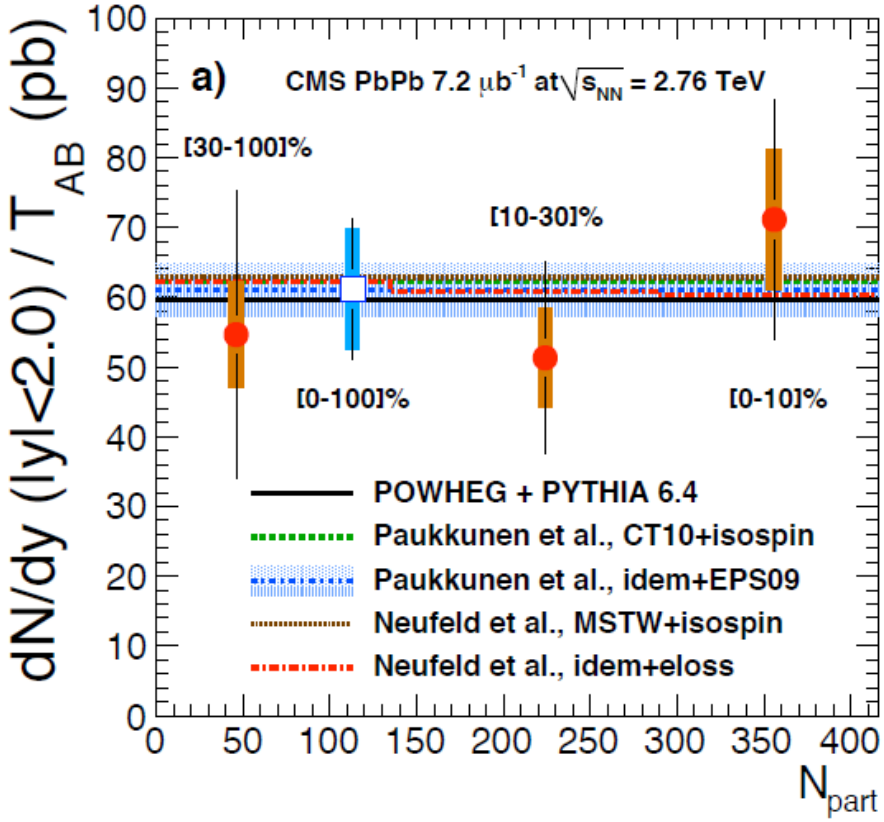


Study of Z→ $\mu^+\mu^-$ in PbPb collisions

ArXiv:1102.5435 accepted by PRL

See Jorge Robles's talk on Thu 3pm

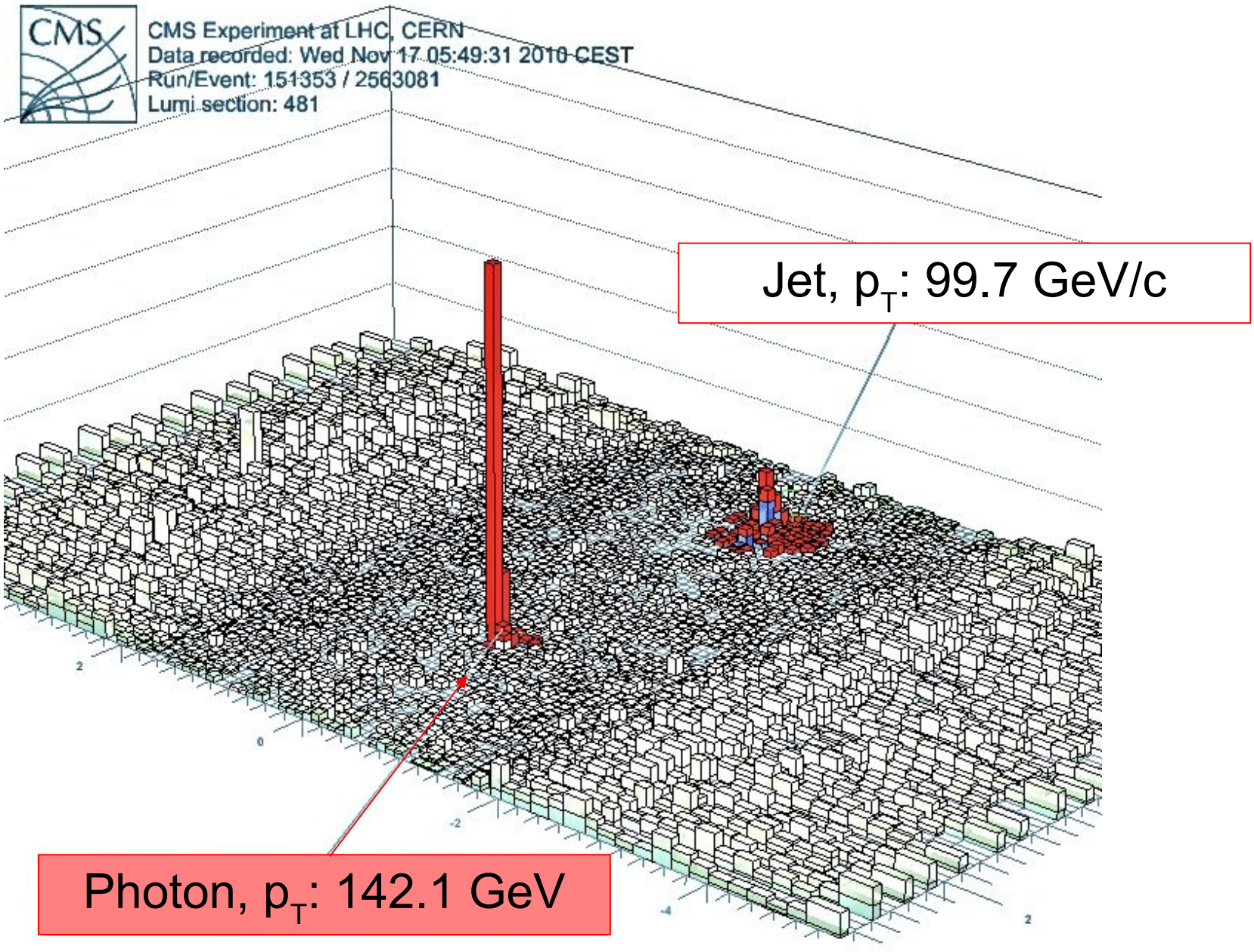




- Clean Z signals from opposite-sign di-muon
- T_{AA} normalized yield is consistent with POWHEG (NLO)
- No modification is found with respect to the pp reference

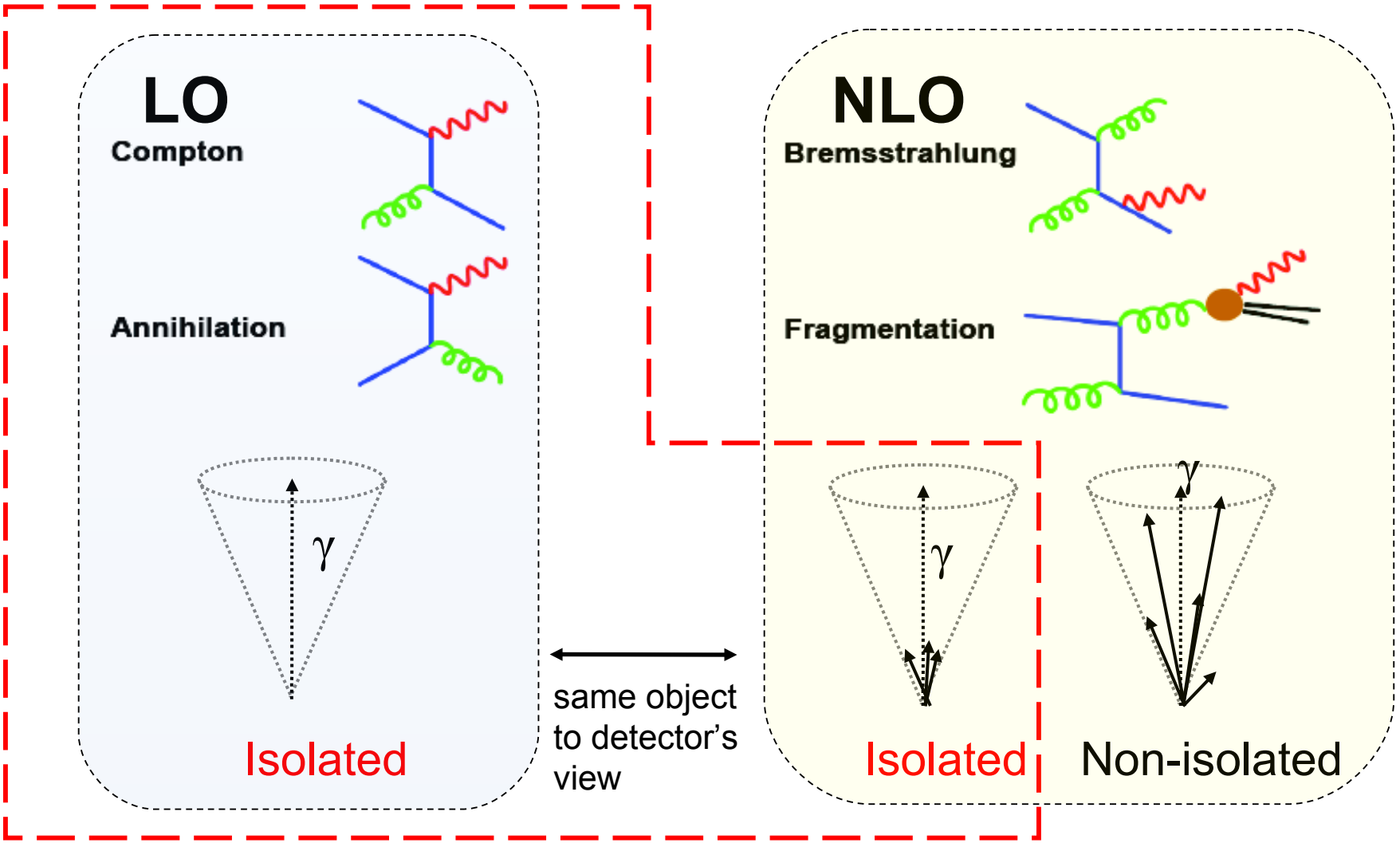
$$T_{AA} = \frac{\langle N_{coll} \rangle}{\sigma_{pp}^{inel}}$$

Isolated photons in PbPb collisions



Isolated high p_T photons

- Ideal: Direct photon from hard scattering
- Real world: Background from the decay and fragmentation photons.
- Solution: Measurement of the isolated photons



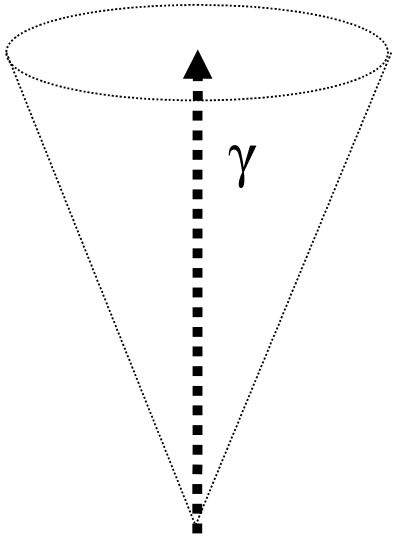
Photon isolation in PbPb

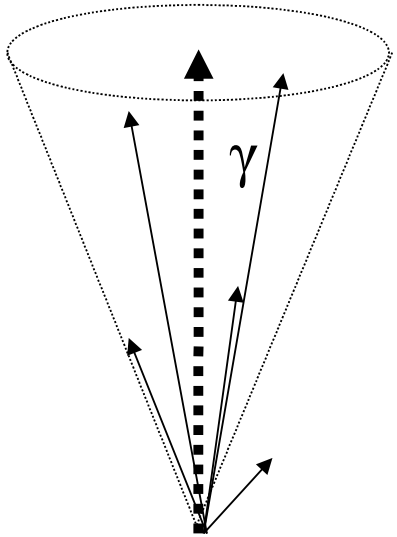
Generator level

$\Delta R<0.4$, $\Sigma E_T^{\text{IsoCone}} < 5$ GeV

with only particles from the same hard scattering

Particles from the same hard scattering



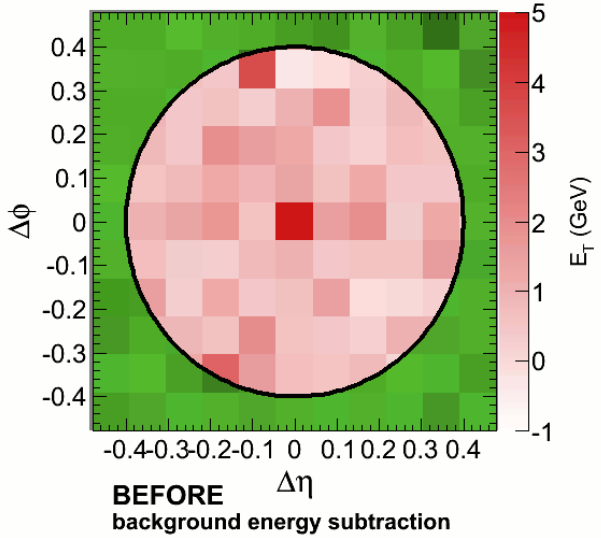


CMS Experiment

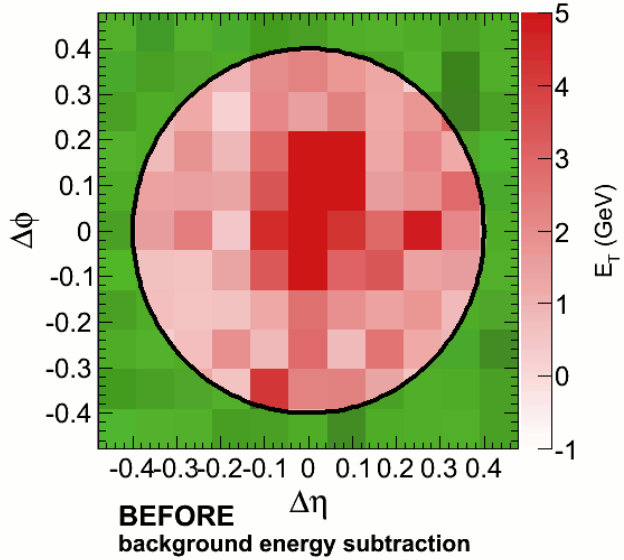
Sum E_T (p_T) from Calorimeter and tracker

Contribution from underlying event

Isolated photon

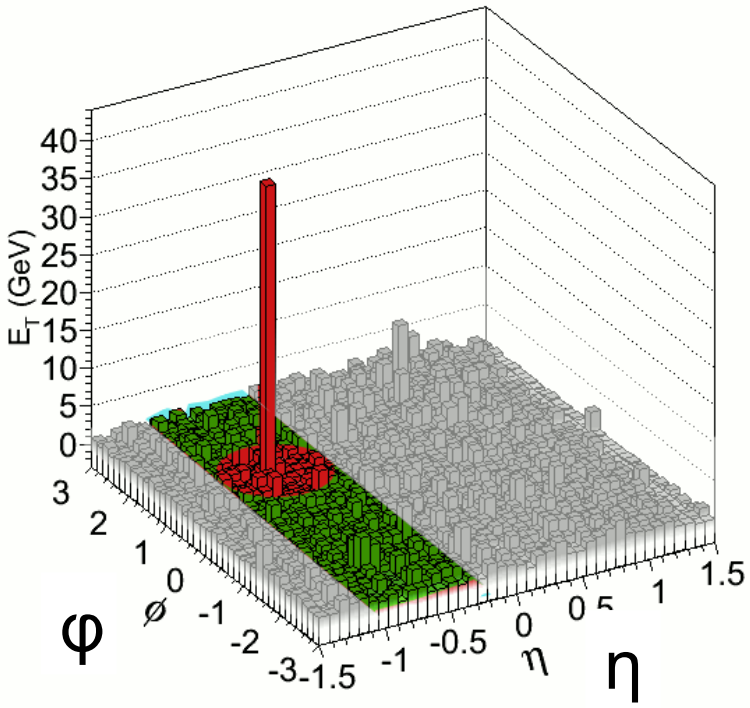


Photon candidate from jet

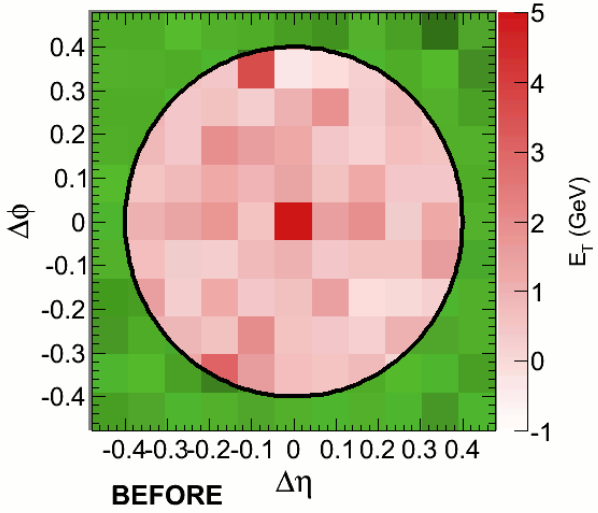


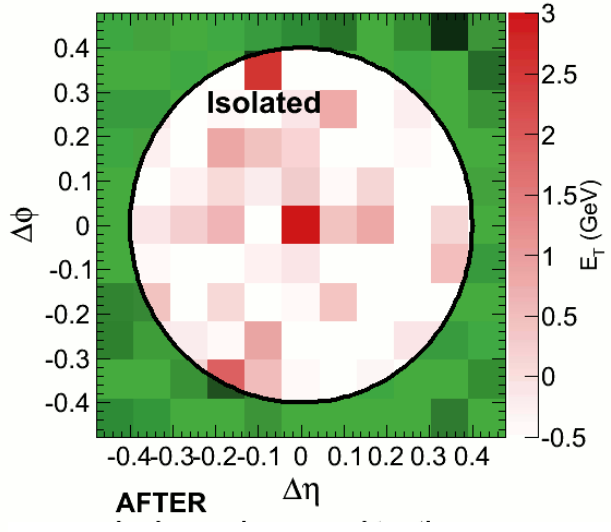
Background subtraction

- Background subtracted isolation by using the mean E_T per unit area in the η strip and remove the underlying event contribution inside the isolation cone

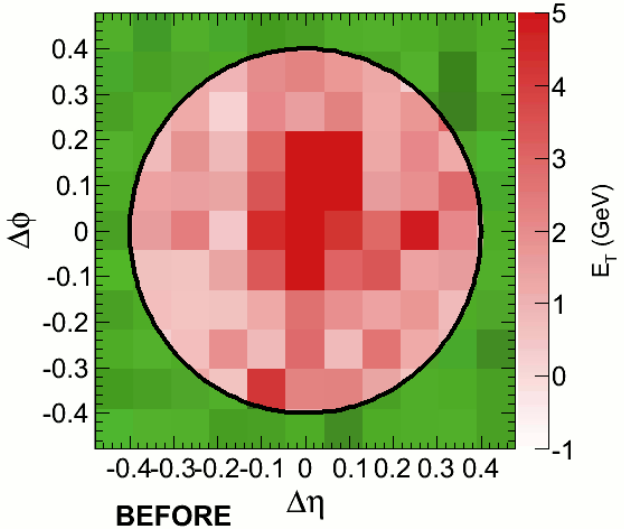


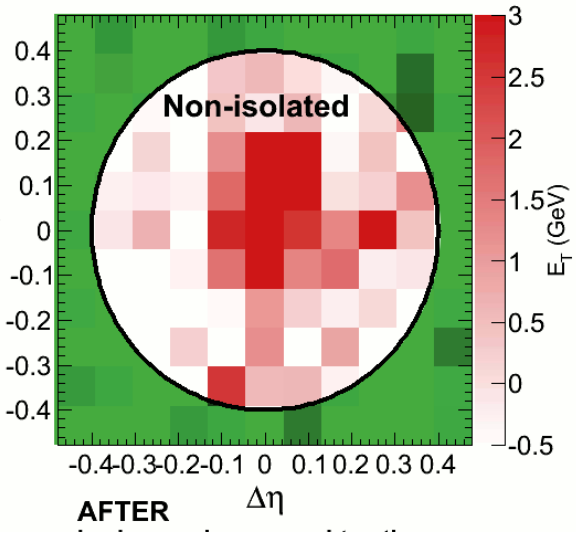
Isolated photon





Photon candidate from jet





See Yongsun Kim's talk on Fri 5pm

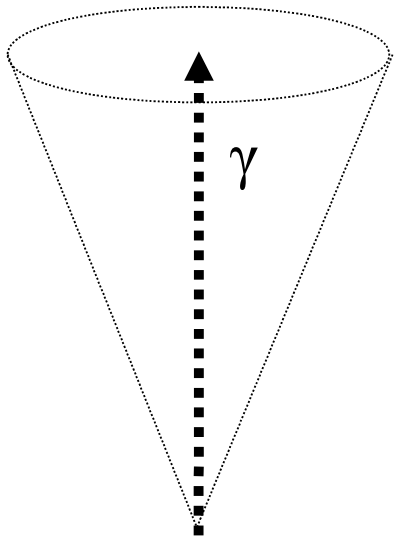
Background subtracted isolation in PbPb

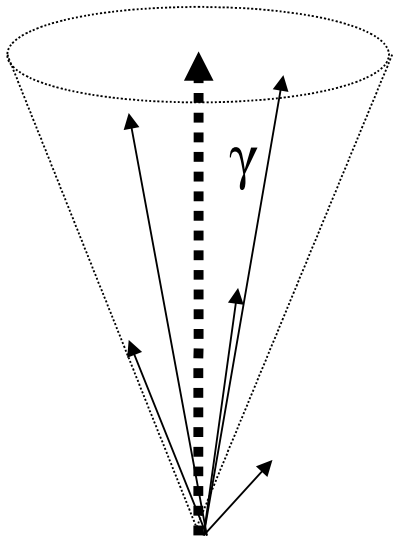
Generator level

$\Delta R<0.4$, $\Sigma E_T^{IsoCone} < 5$ GeV

with only particles from the same hard scattering

Particles from the same hard scattering

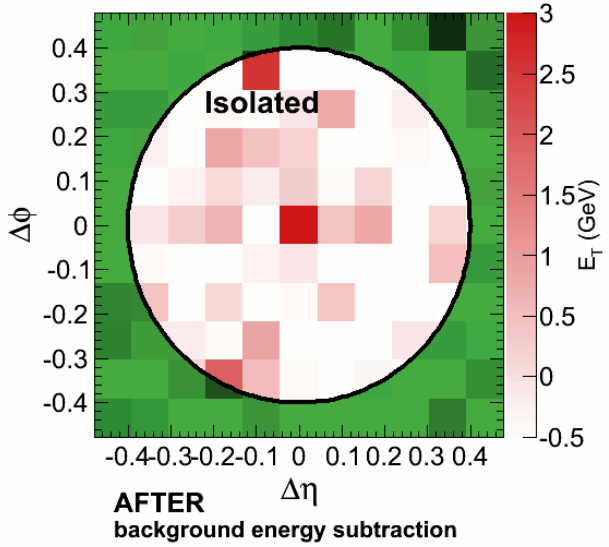




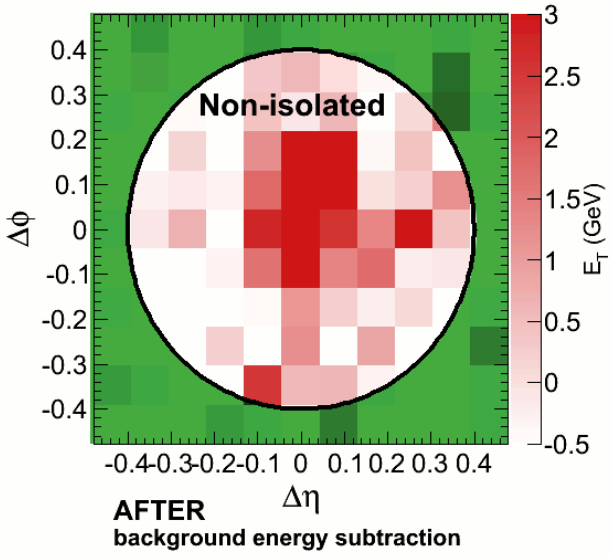
CMS Experiment

Sum E_T (p_T) from Calorimeter and tracker < 5 GeV with background subtracted

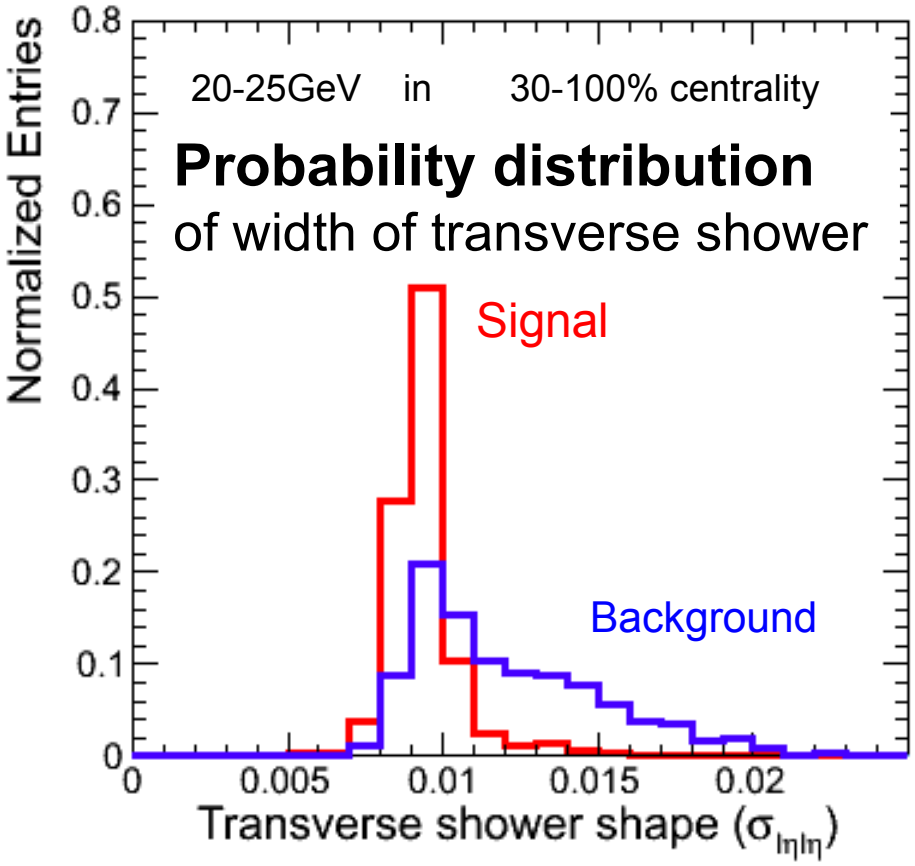
Isolated photon



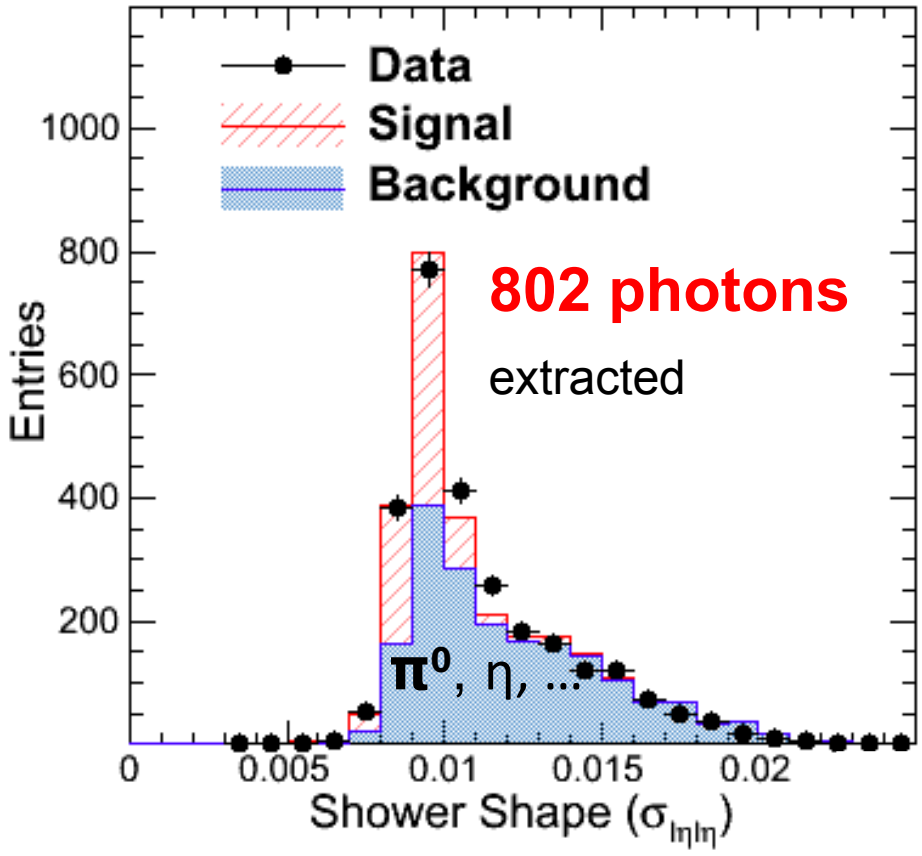
Photon candidate from jet



Photon signal extraction



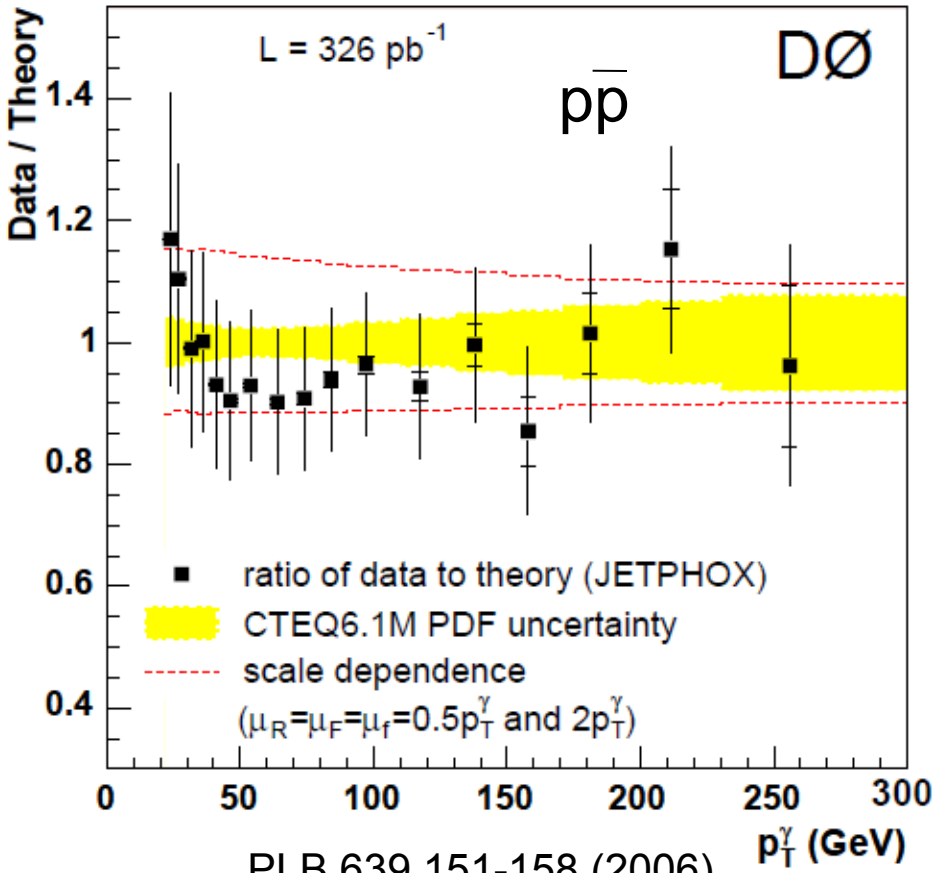
Fit



- A technique used in CMS pp analysis
- Signal template: obtained from PYTHIA+MinBias data
- Background template: obtained from non-isolated π^0, η in jet, obtained using a data driven method

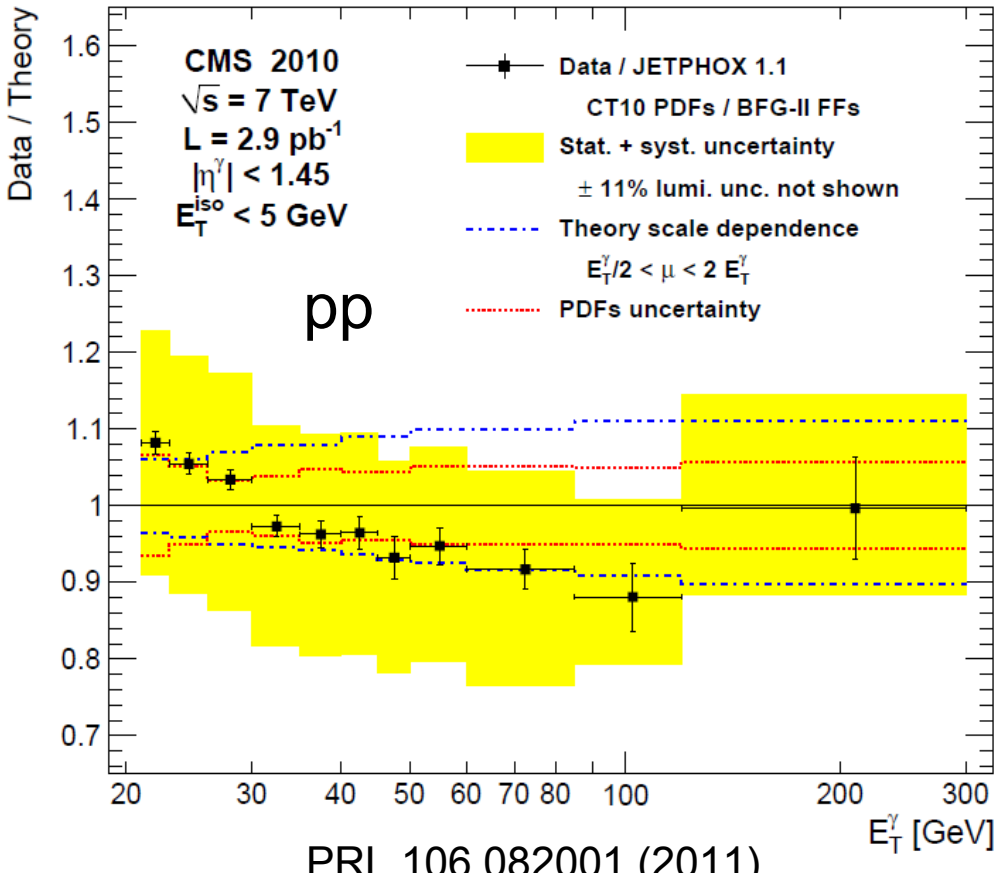
Photon pp reference spectrum

$p\bar{p}$ at $\sqrt{s}$ = 1.96 TeV



PLB 639,151-158 (2006)

pp at $\sqrt{s}$ = 7 TeV

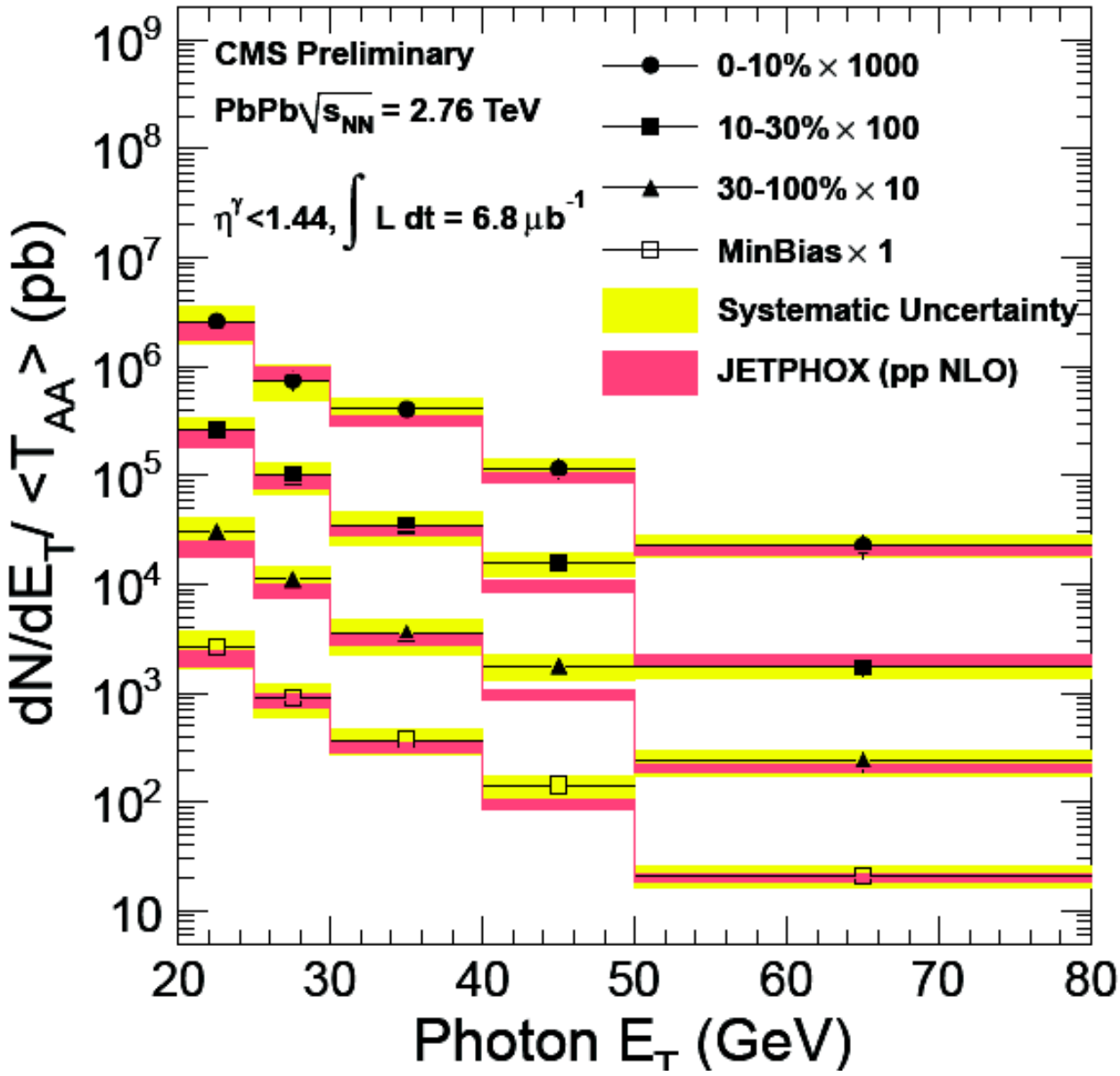


PRL 106,082001 (2011)

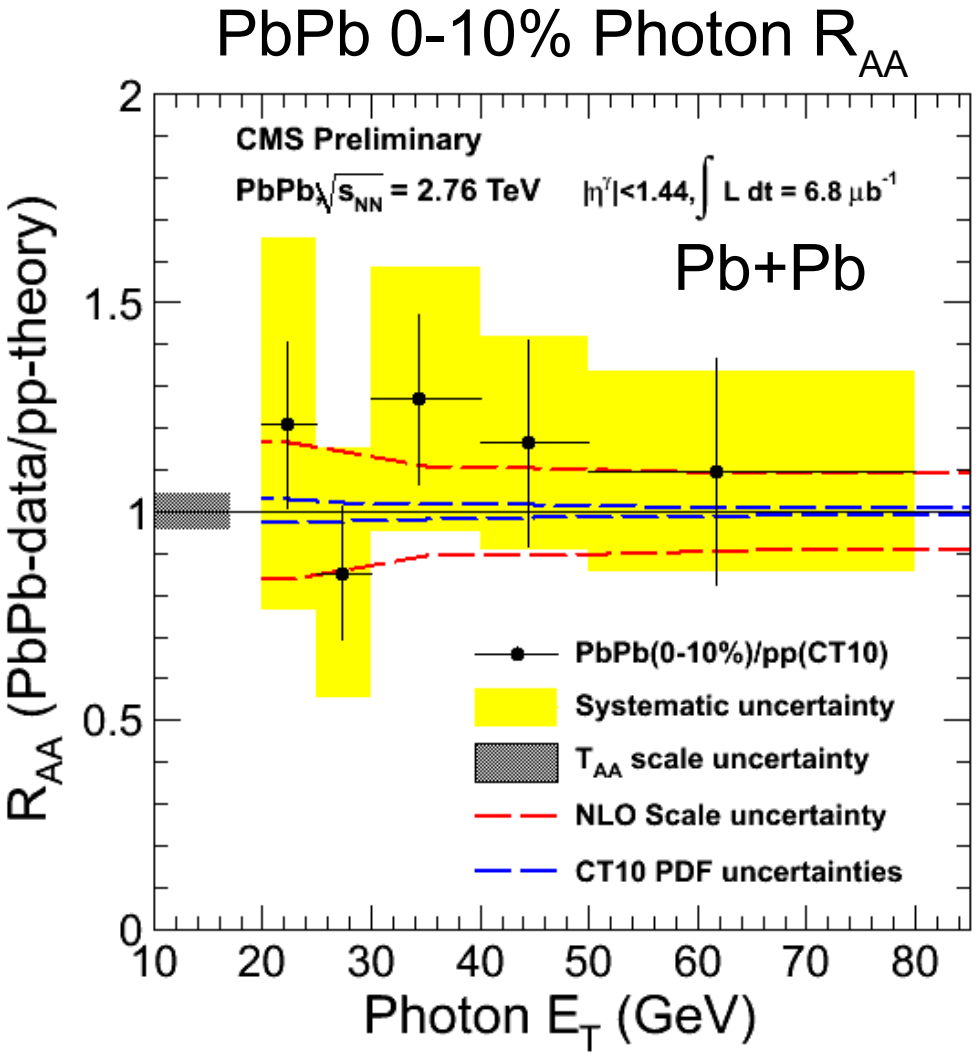
- JETPHOX calculation agrees with data within 20%
- Photon pp reference:
  - NLO calculation from JETPHOX with CT10 PDFs / BFG-II FFs
  - Photon isolation requirement: E_T<5 GeV in a cone of ΔR<0.4

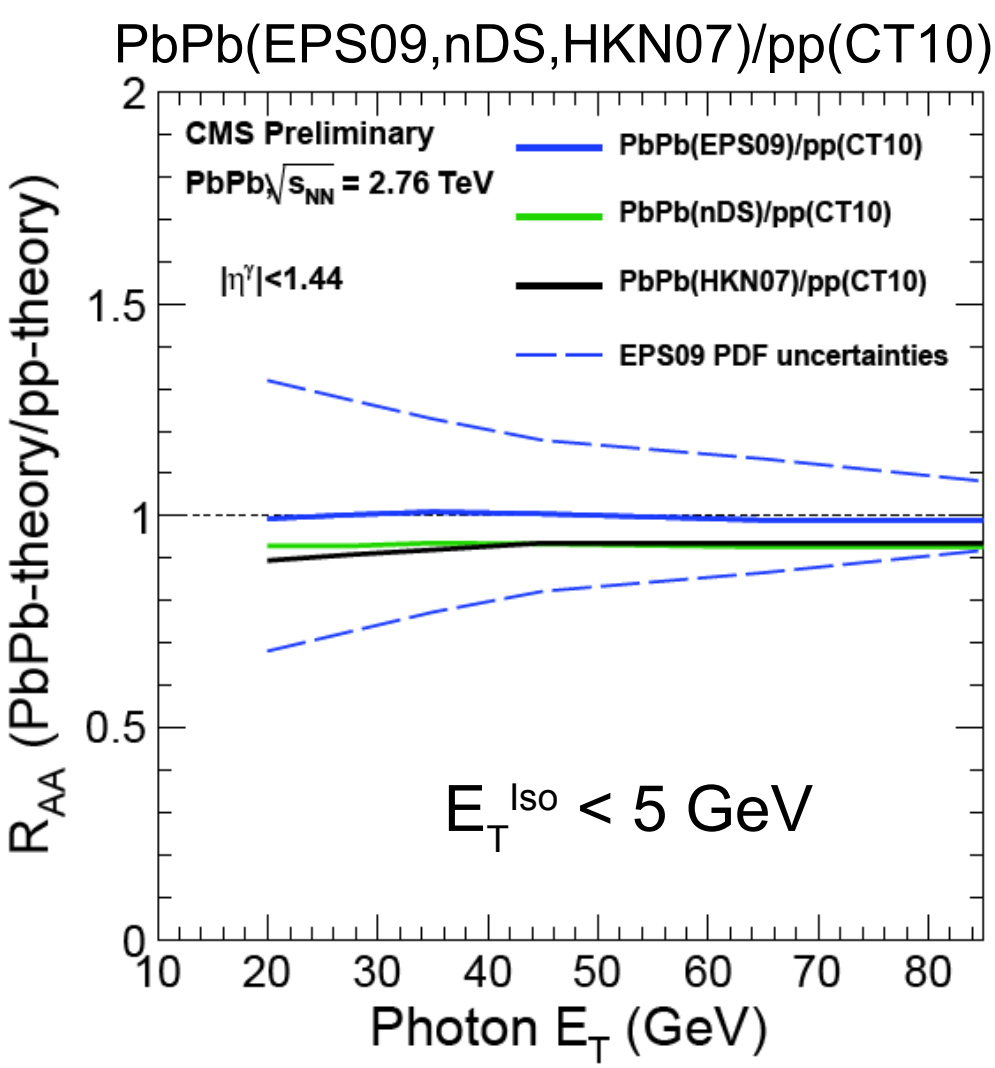
Photon E_T spectra in PbPb collision

- The reconstructed photon spectra in each centrality bin is scaled by T_{AA}
- Results are consistent JETPHOX calculation



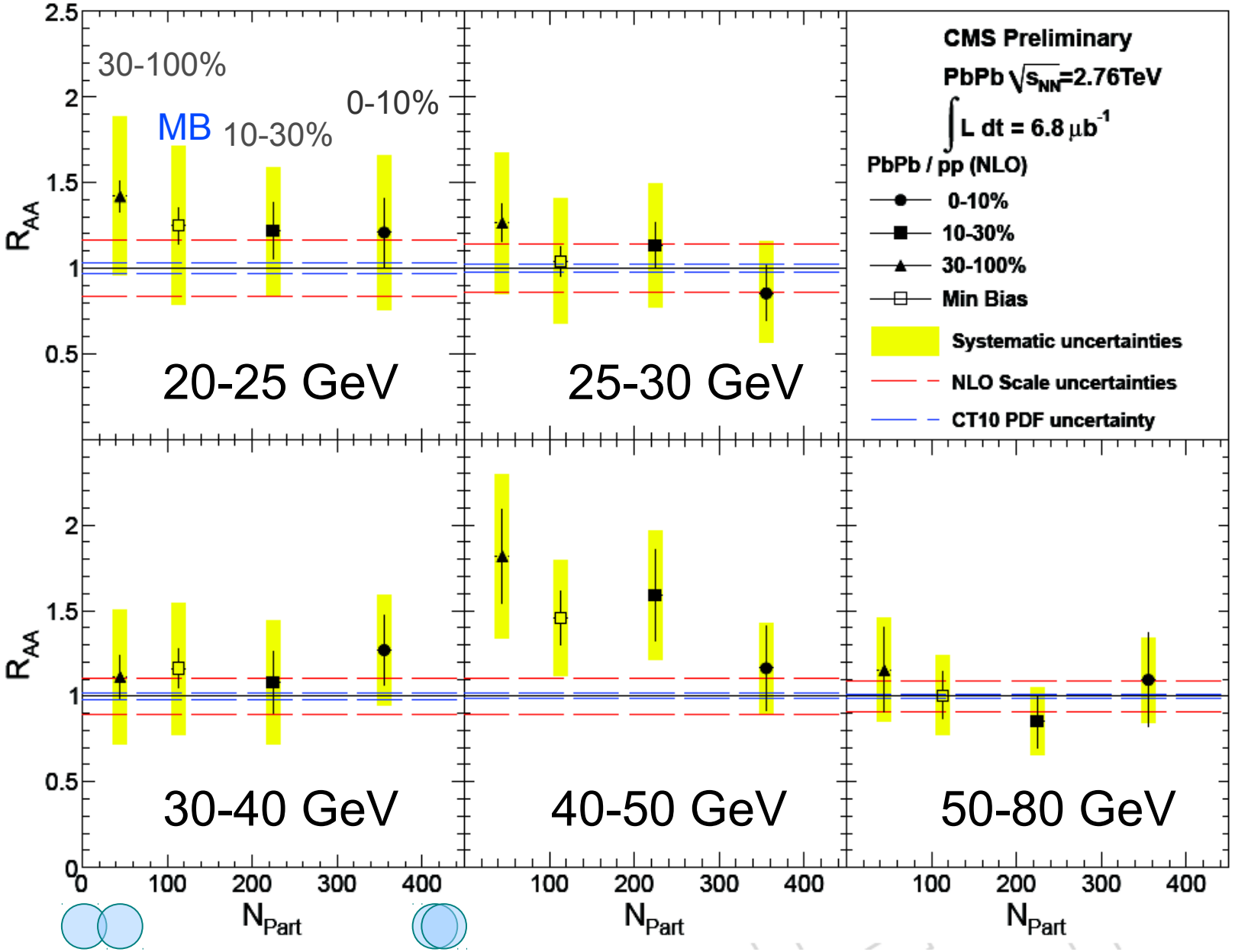
Isolated photon R_{AA} in 0-10% PbPb collisions





- CMS measured the isolated photon R_{AA} for the first time
- The photon R_{AA} at 0-10% is consistent with unity

Isolated photon R_{AA} vs N_{Part}



No centrality dependence

Summary of colorless probes

- No modification of the initial state. The hard scattering processes scale with the number of binary collisions from the Glauber model

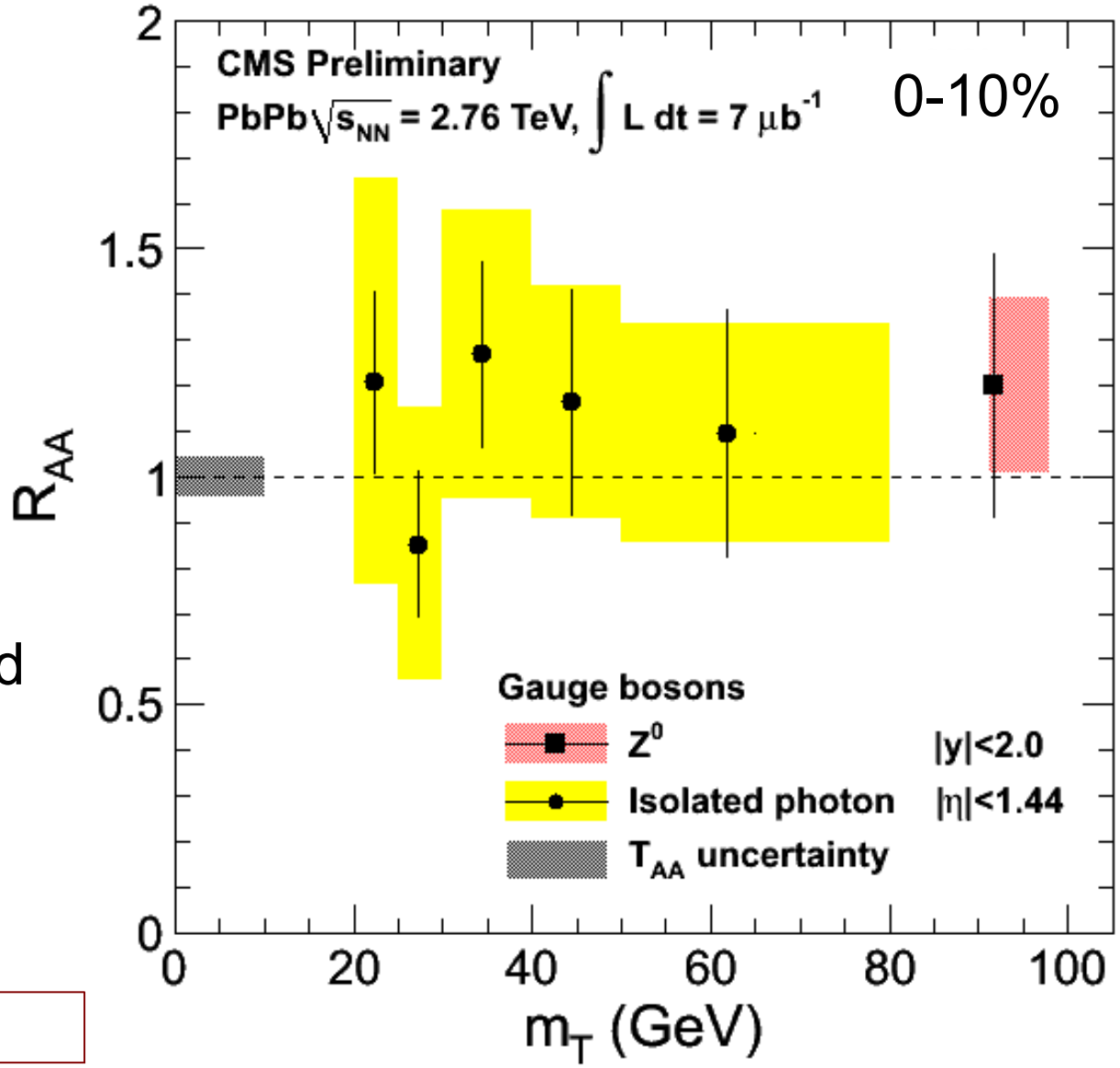
- Baseline for the study of charged particle production

- High statistics run in 2011 will shrink both statistical and systematic uncertainties

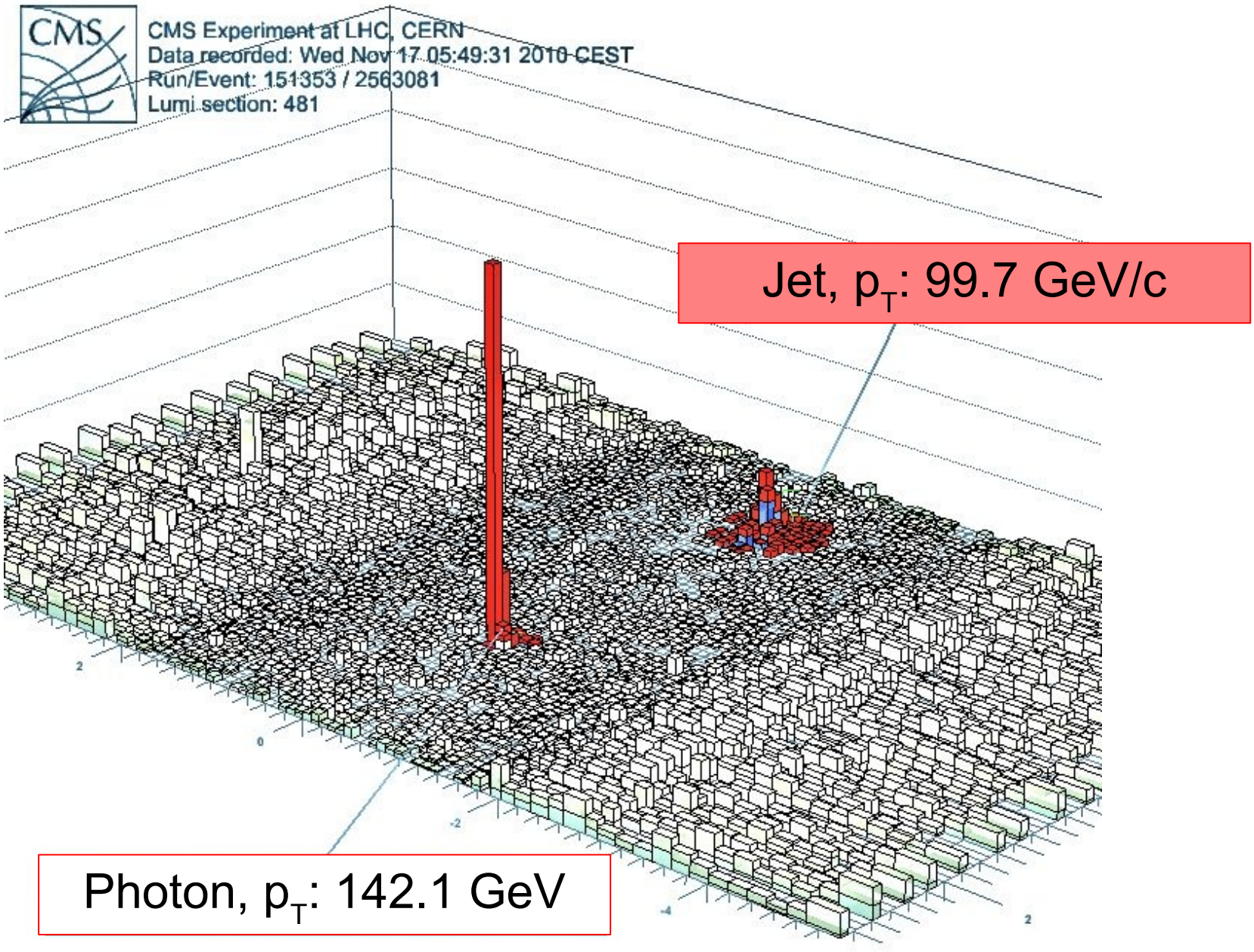
Analysis of $Z \rightarrow e^+e^-$ and $W \rightarrow \mu\nu$ are on-going

See Lamia Benhabib's poster

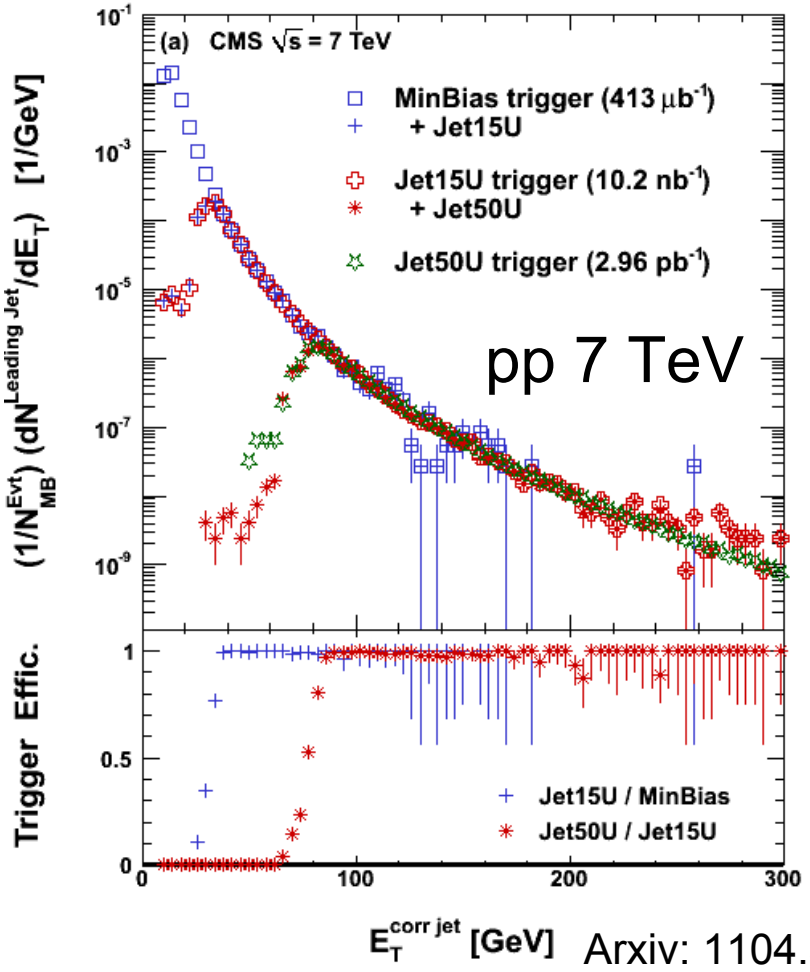
PbPb 0-10% Central

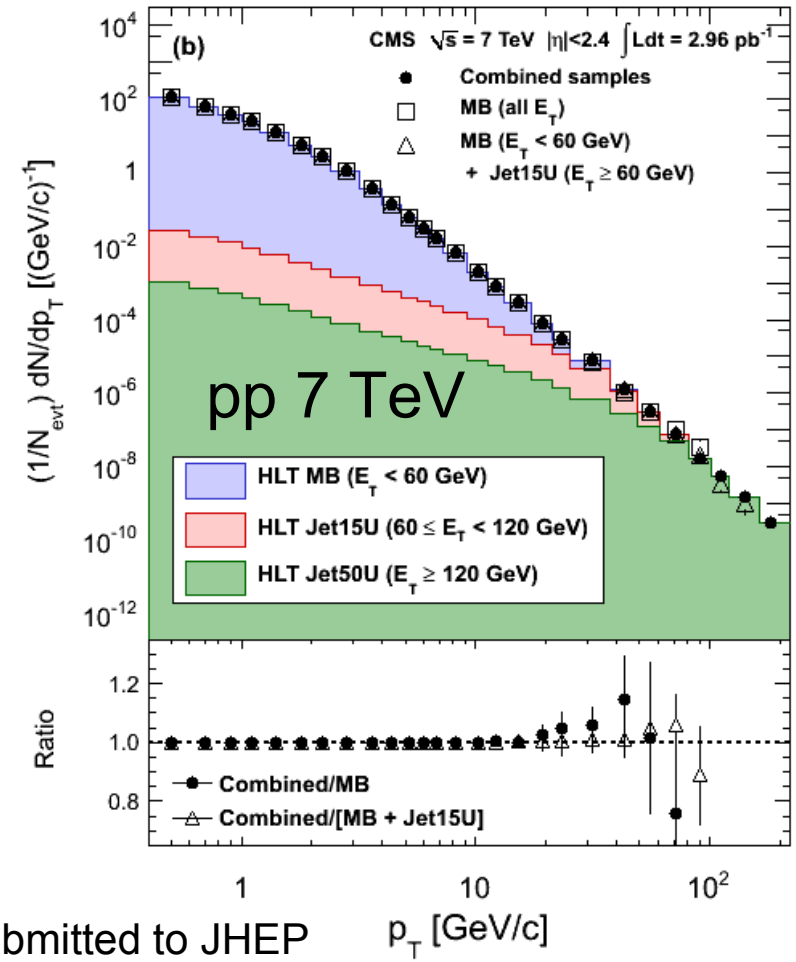


γ-jet event in PbPb collisions



Charged particles spectra in pp collisions





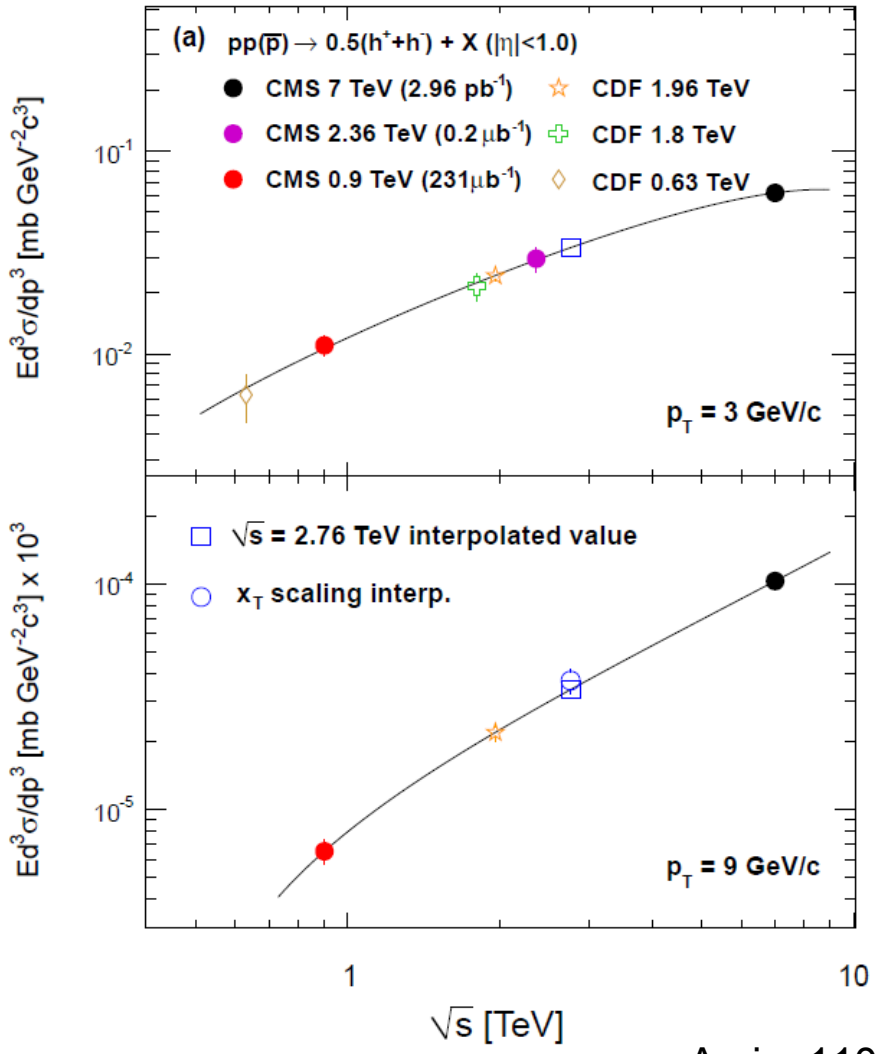
Arxiv: 1104.3547 submitted to JHEP

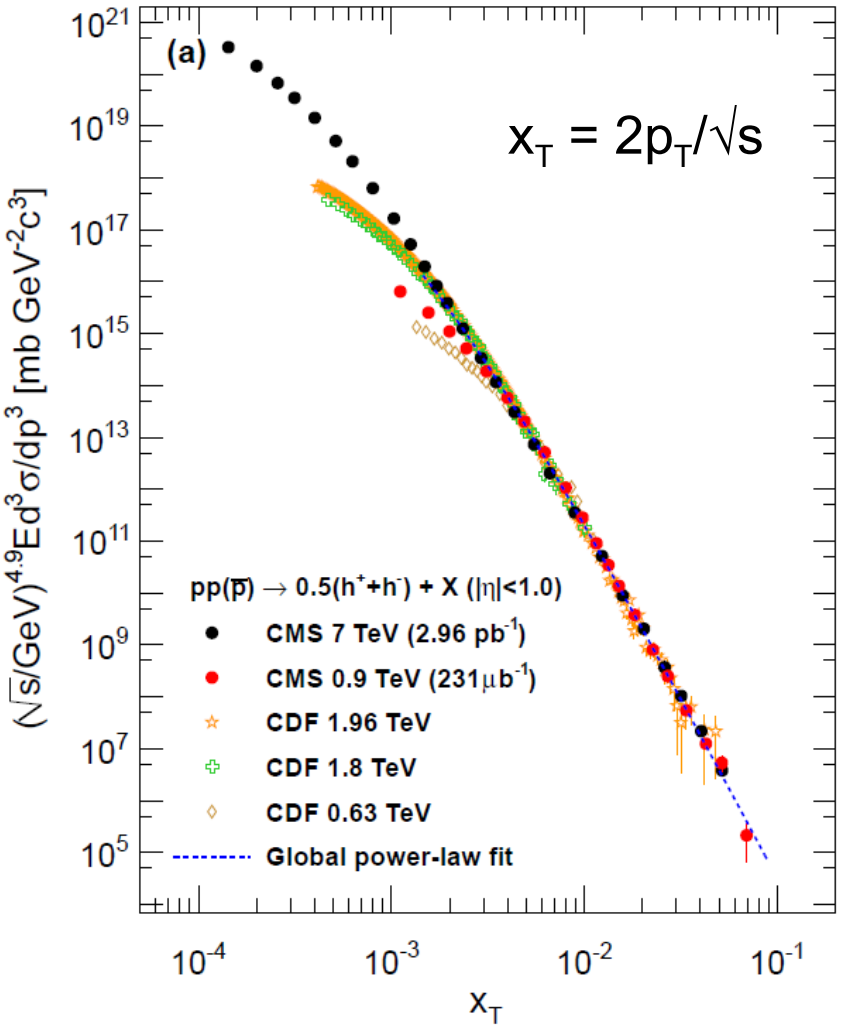
- Measurements in pp collisions at $\sqrt{s}$ = 0.9, 7 TeV with jet trigger
- 4 times higher p_T reach than any other experiments
- Calorimeter triggering:
  Lower the fake rate of the high p_T tracks

Charged particle pp reference

For p_T<10 GeV/c: Bin-by-bin interpolation from experimental data

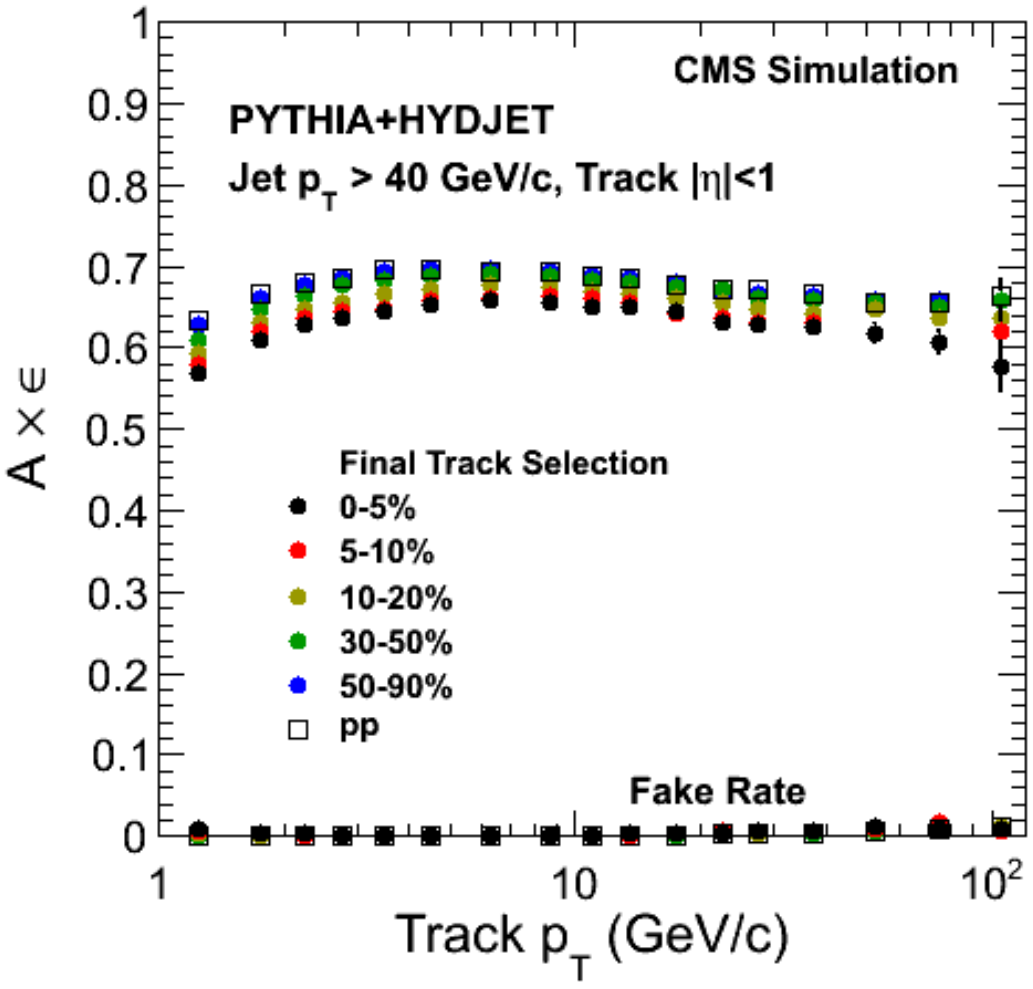
For p_T>10 GeV/c: (NLO-based) x_T-scaling of existing data





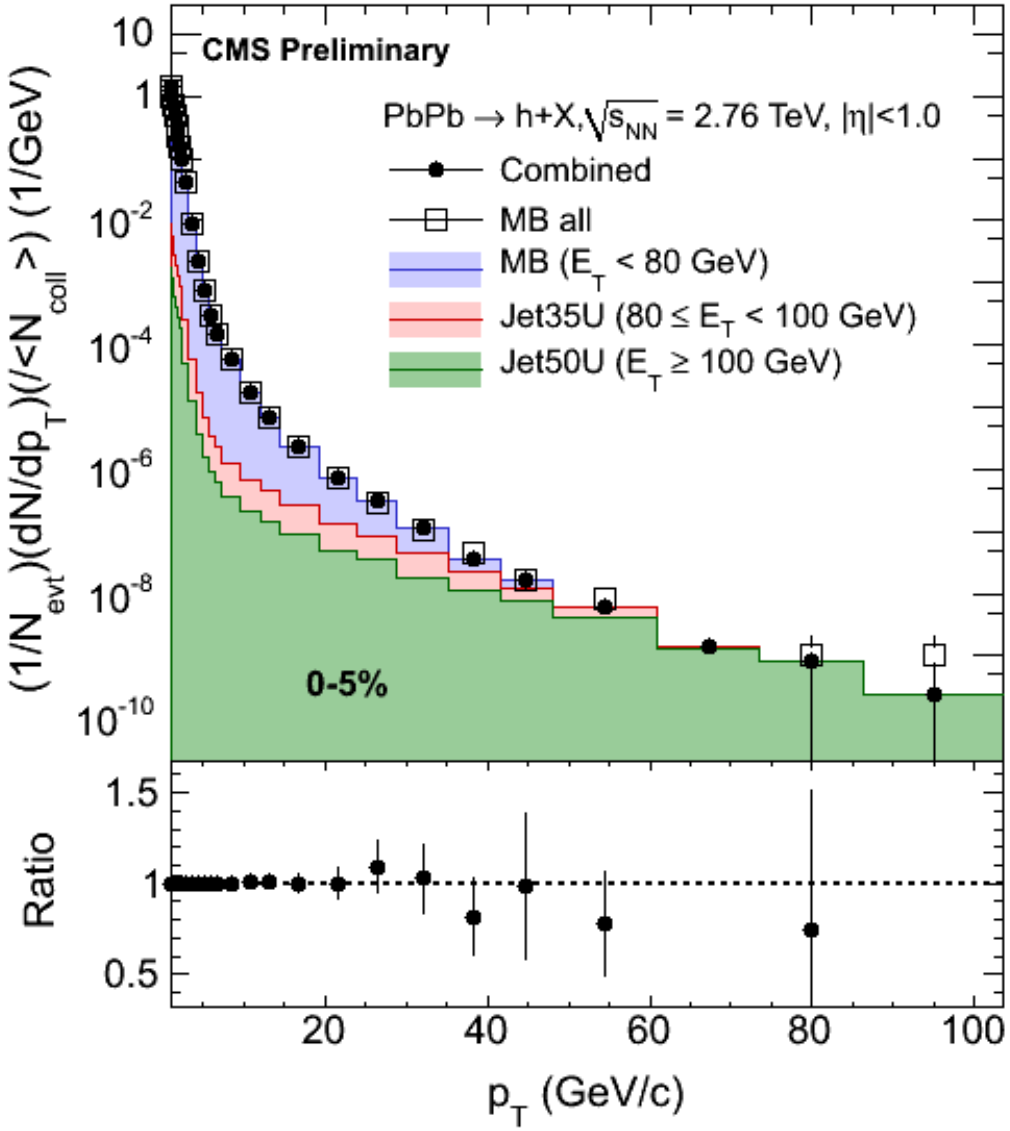
Arxiv: 1104.3547 submitted to JHEP

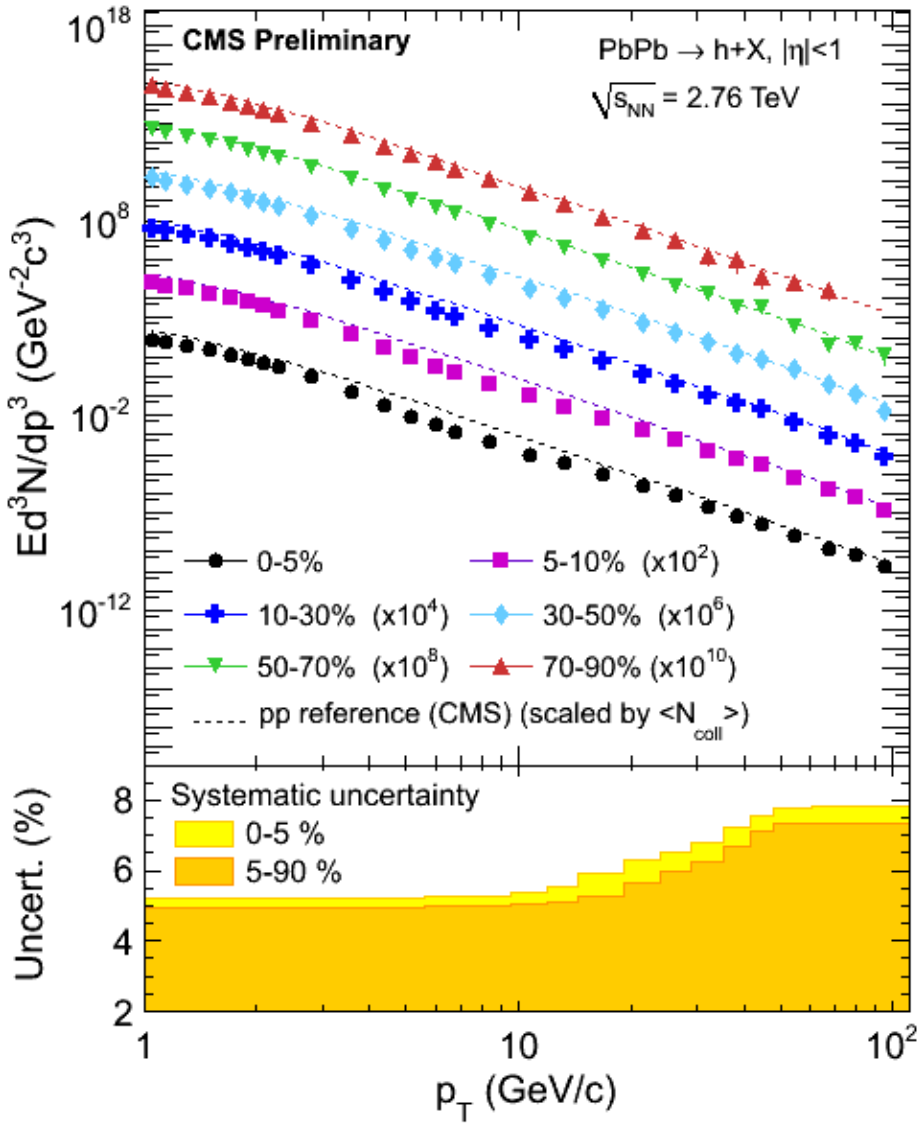
Tracking Performance in CMS



- Efficiency ~65% and Fake < 3% up to 100 GeV/c
- Momentum resolution is below 3% (correction < 3%) up to 100 GeV/c
- Fake rates cross-checked by calorimeter matching and sideband of the impact parameter distributions

Charged particle spectra in PbPb collisions

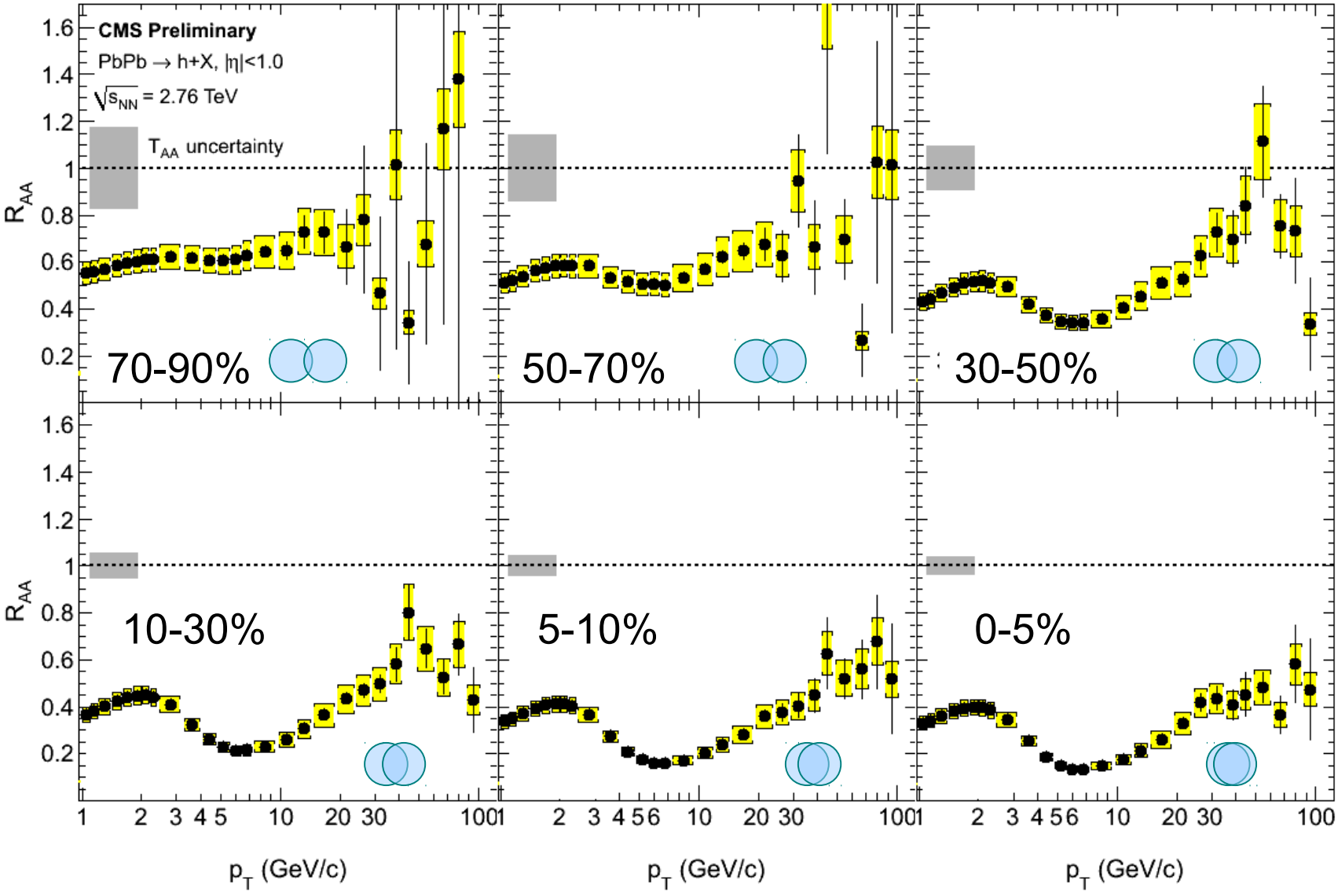




- Extended the p_T reach with jet triggers up to 100 GeV/c

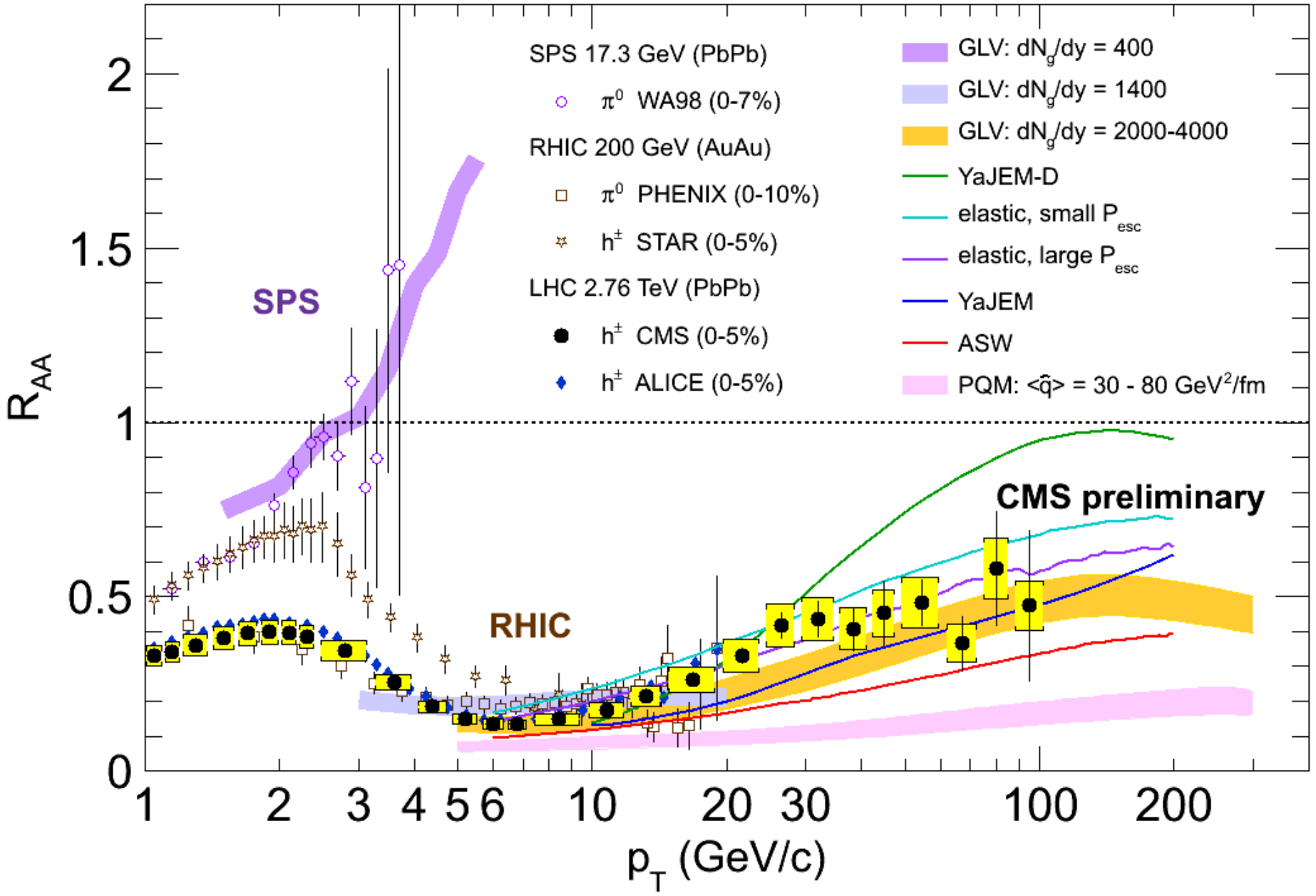
See Andre S. Yoon's talk on Thu 4pm

Charged particle R_{AA} in different centralities



- Dip structure developing as a function of centrality
- R_{AA} increases as a function of p_T in the p_T>10 GeV/c region

Charged particle R_{AA} compared to models



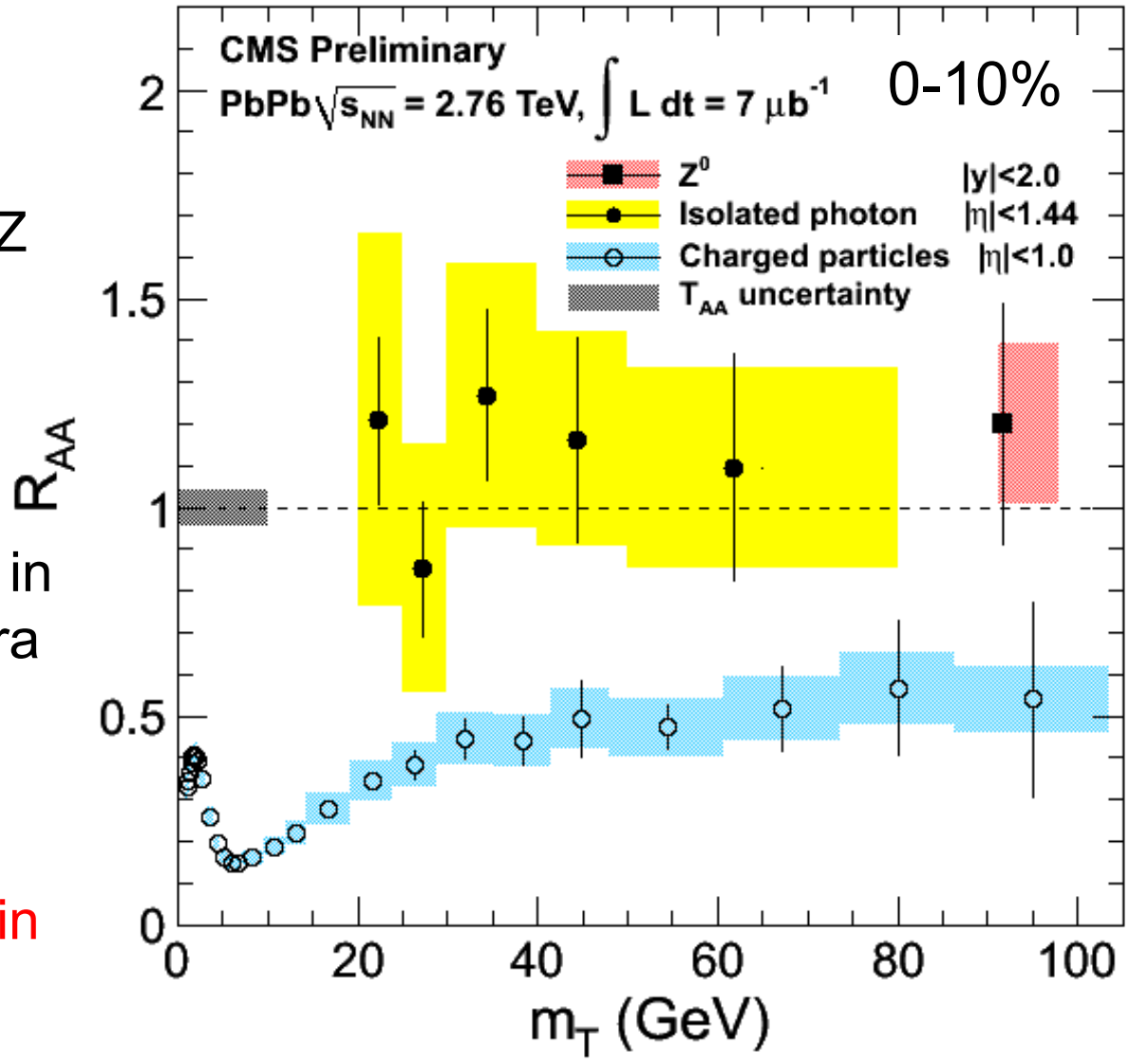
Strong constraint on the parton energy loss models

Summary

- CMS has measured the R_{AA} of isolated photons, Z and charged particles

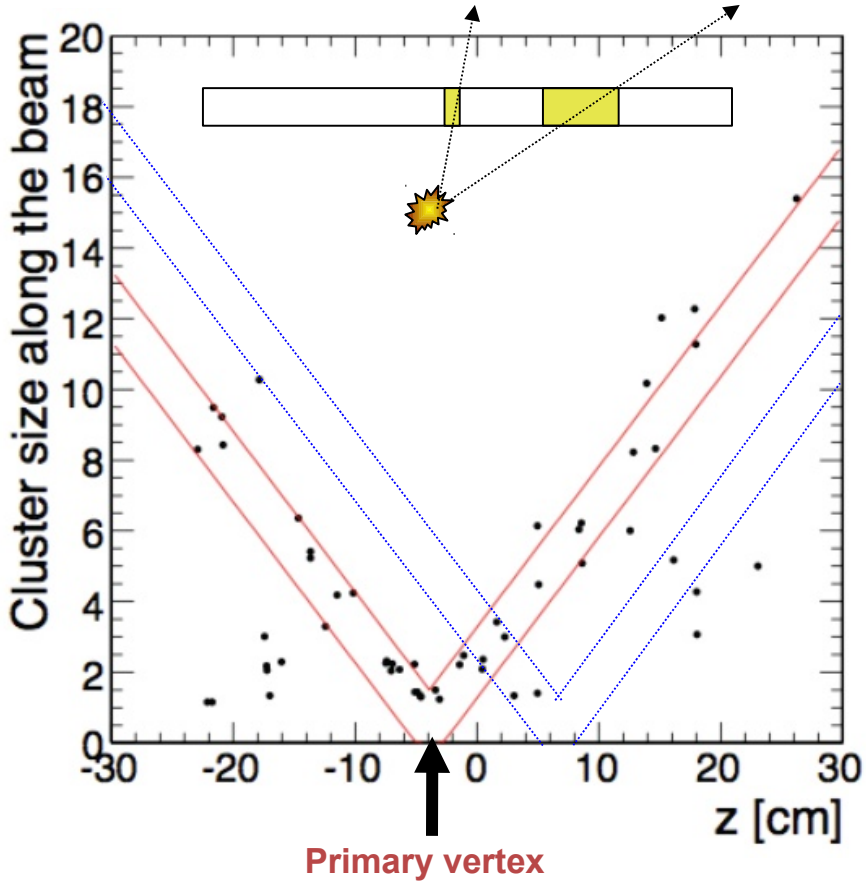
- No modification is observed in Z and photon production. Confirmation of the Glauber scaling for the pQCD probes

- Large suppression is observed in the PbPb charged particle spectra which is due to the final state medium modification. Extended the high p_T reach to 100 GeV/c. The R_{AA} rises to ~ 0.5 at high p_T in 0-10% central events. Strong constraints on the parton energy loss models

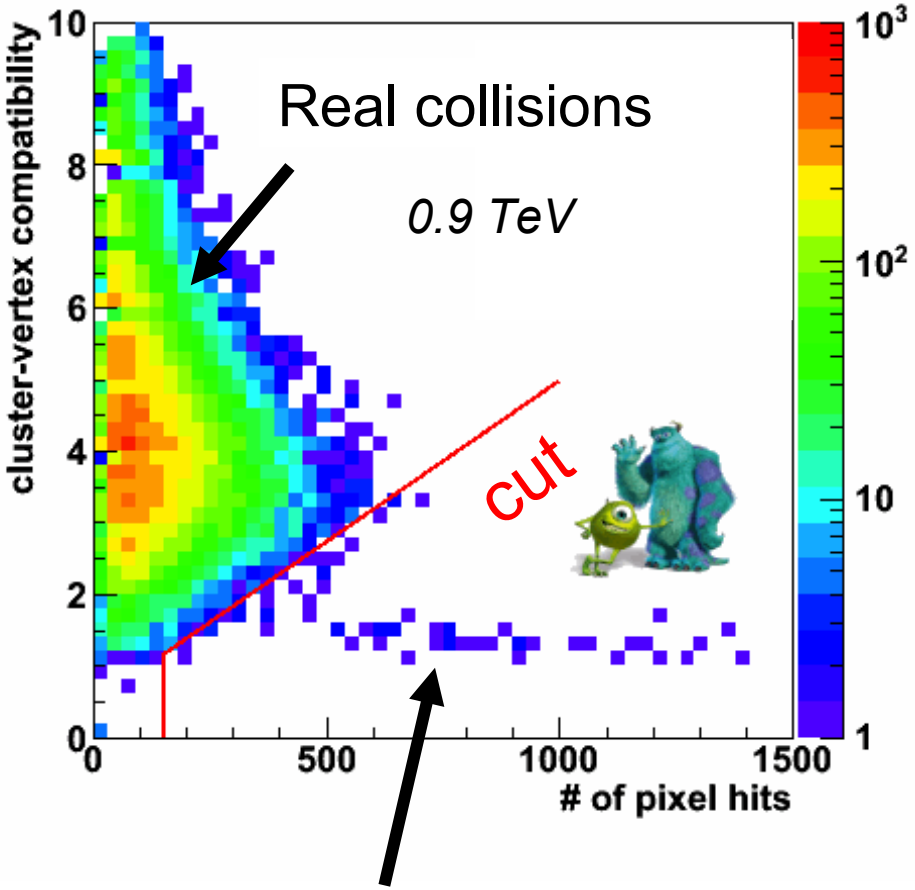


Backup slides

Beam scraping event rejection



Vertex-cluster compatibility:
Ratio of $N_{clusters}$ in the V shape and
$N_{clusters}$ in the V-shape offset by 10 cm

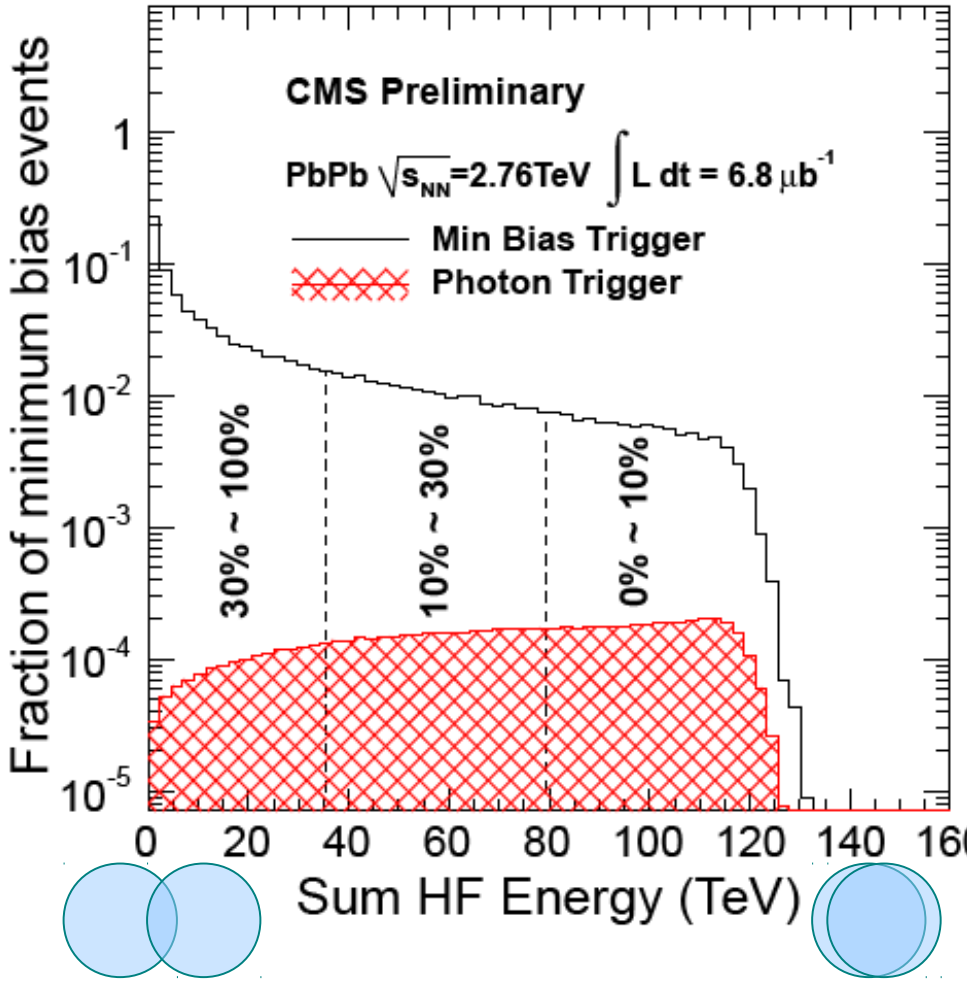


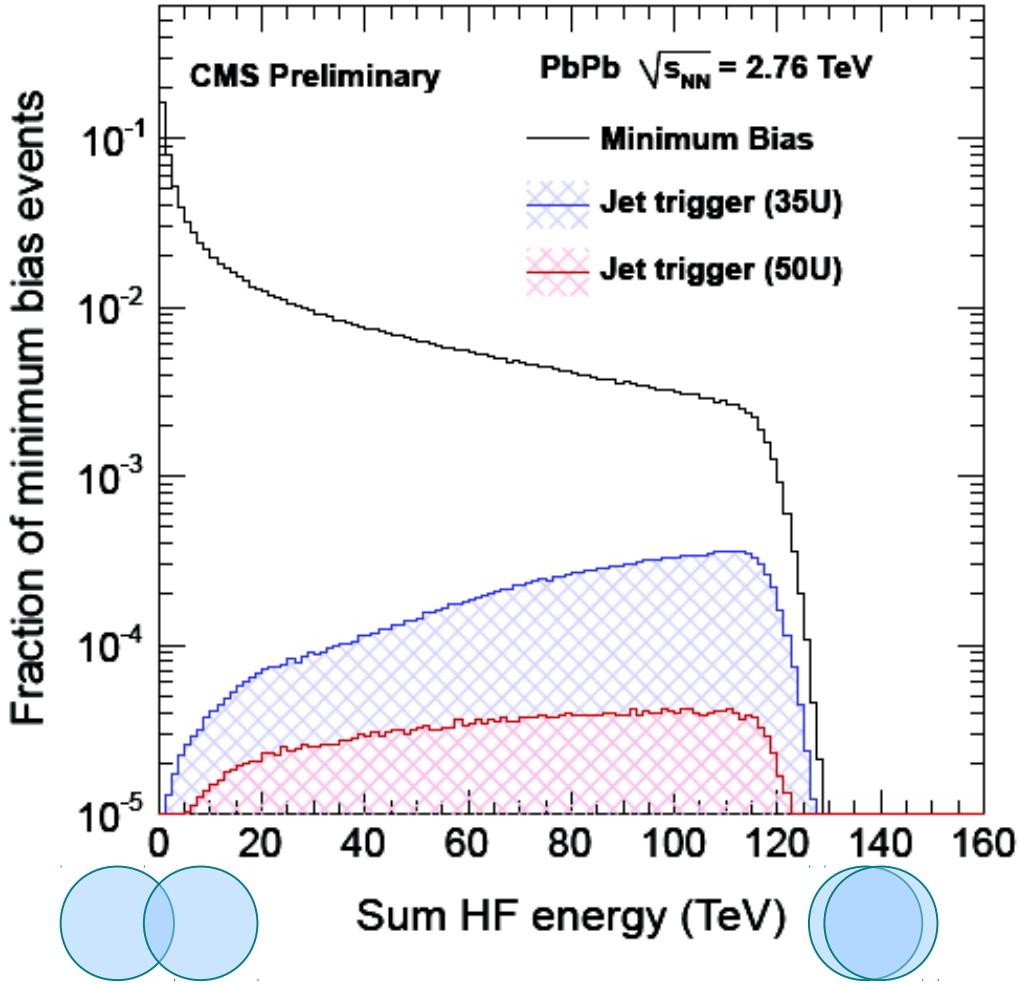
Beam-scraping events have a lot of pixel hits but ill-defined vertex

Remaining beam-gas fraction:
2×10^{-5} (neglected)

Centrality Determination

- Forward calorimeter (HF) is used for centrality determination.
- The distribution of the total energy in HF is used to divide the sample into centrality bins.

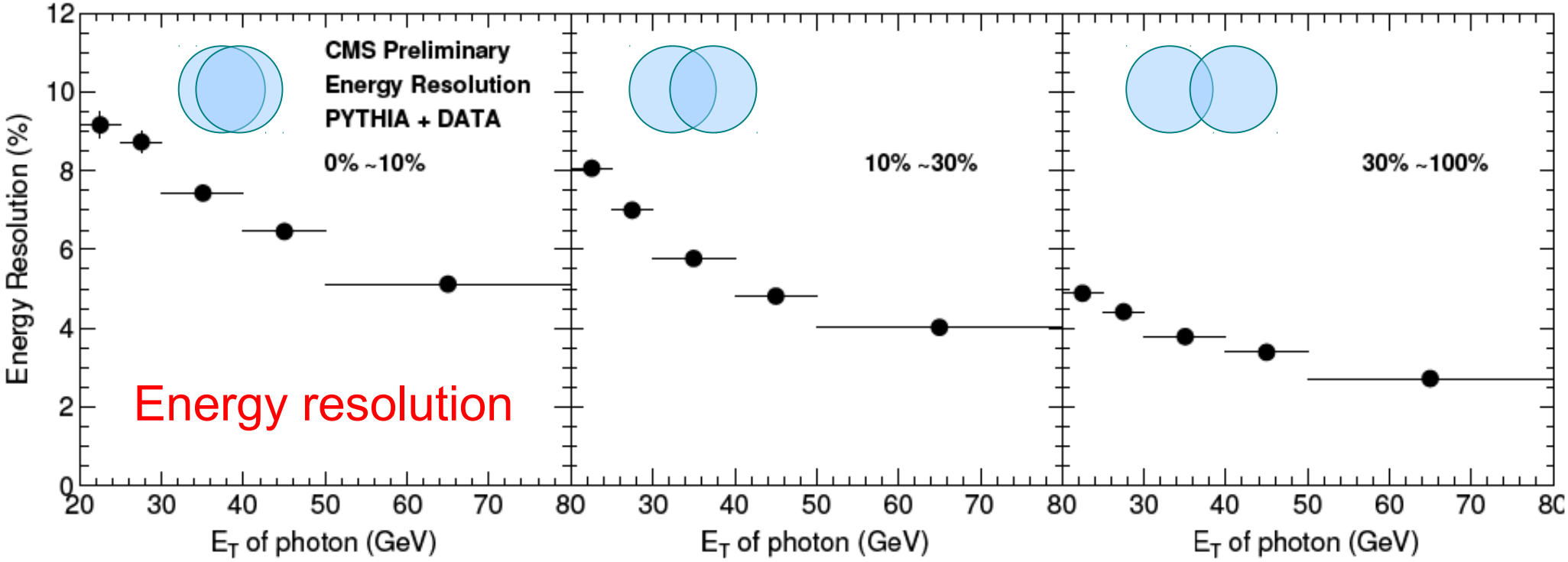




Photon

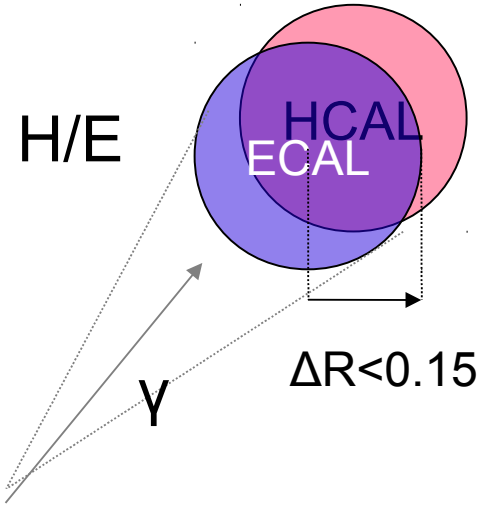
- Reconstructed from CMS ECAL Barrel ($|\eta|<1.44$) and $E_T > 20$ GeV
- Additional photon energy correction is applied to remove the underlying Pb+Pb event contribution. (1 – 11%). Corrected statistically by PYTHIA + MB.

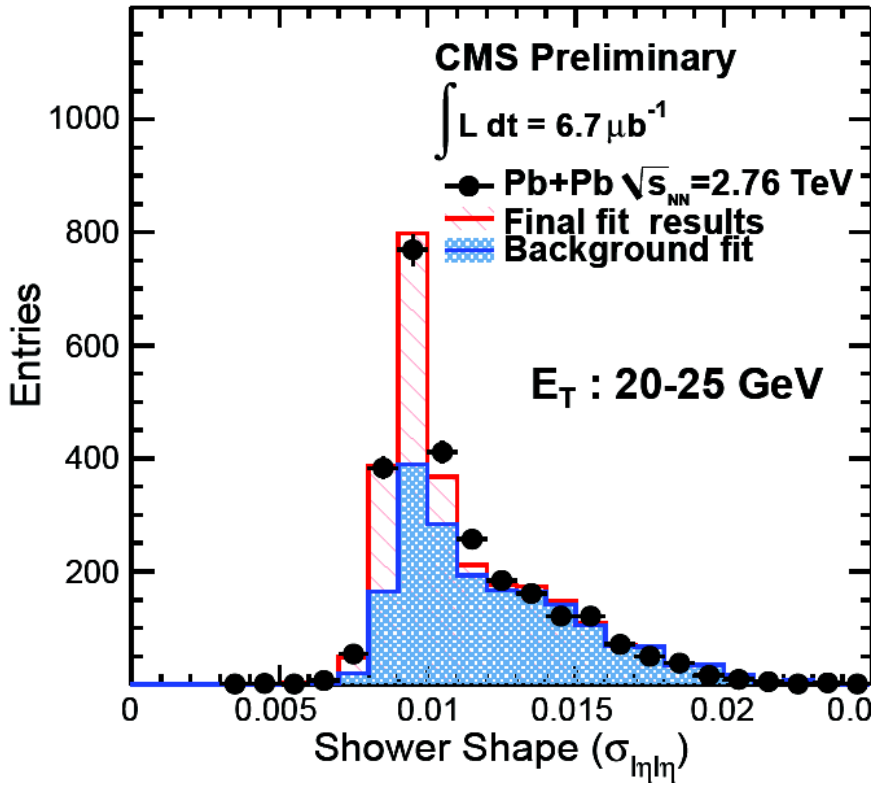
- Photon energy resolution is 2 – 10% as a function of event centrality and photon pT (20 – 80 GeV).



Photon ID and isolation

- Photon ID:
  - Hadronic / EM energy < 20%
- SumIso: (Iso_{ECAL} + Iso_{HCAL} + Iso_{Track})
  - Background subtracted.
  - Photon candidate E_T subtracted in ECAL.
  - Cone size: $\Delta R < 0.4$
  - SumIso < 5 GeV
- Signal Extraction:
  Transverse shower shape $\sigma_{i\eta i\eta}$
  - Shower width in the η direction
  - Data driven background shape.
  - Separate isolated photons from the isolated π^0, η





See Yongsun Kim's talk on 5/27 5pm

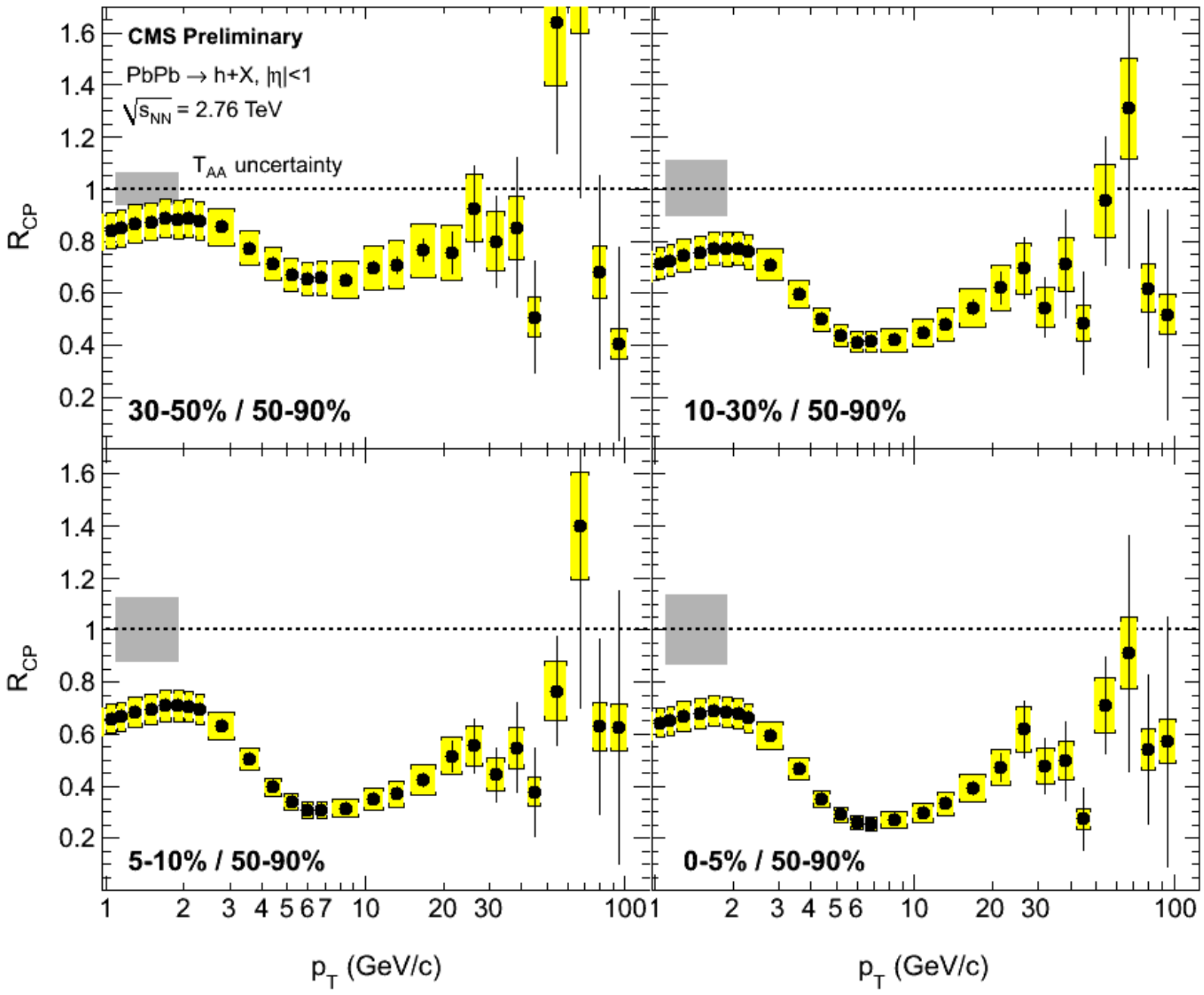
Charged particle systematic uncertainties

Source	Uncertainty [%]
Reconstruction efficiency	3.0–4.5
Non-primary and fake tracks	2.5–4.0
Momentum resolution and binning	3.0
Normalization of jet-triggered spectra	0.0–4.0
Total for PbPb spectra	4.9–7.8

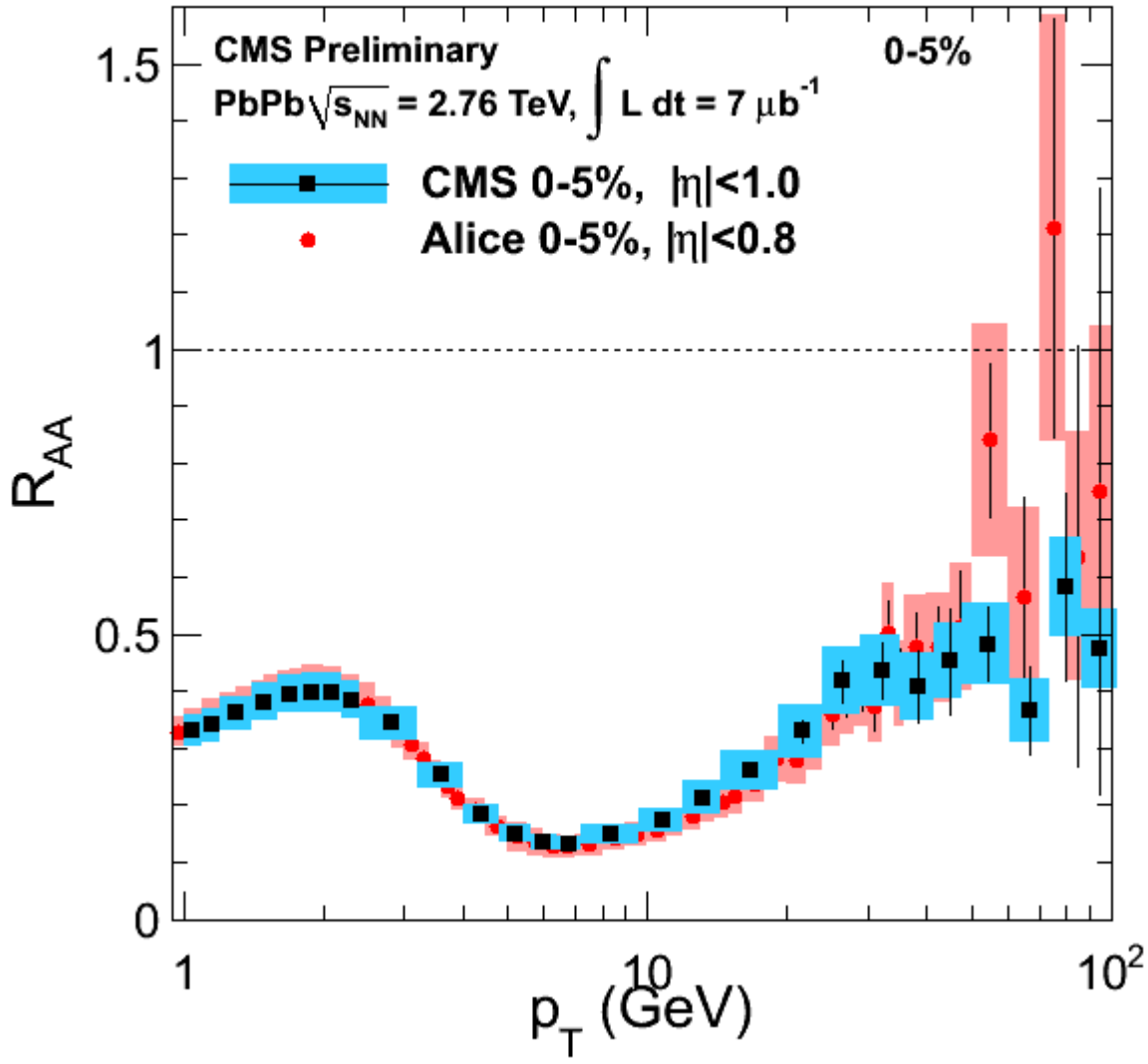
Source	Uncertainty [%]
Total for PbPb spectra	4.9–7.8
T_{AA} determination	4.1–18
Interpolated pp reference spectrum	6.8–13
Total for R_{AA}	9.3–24

$R_{CP}(p_T)$ for Different Centralities

$$R_{CP} = \frac{d^2N_{AA} / dp_T d\eta / N_{coll}(\text{central})}{d^2N_{AA} / dp_T d\eta / N_{coll}(\text{peripheral})}$$



Comparison between CMS and ALICE R_{AA}



Comparison between CMS and WHDG