Direct photon/W/Z overview at RHIC and LHC

Yen-Jie Lee (CERN)

Electroweak probes

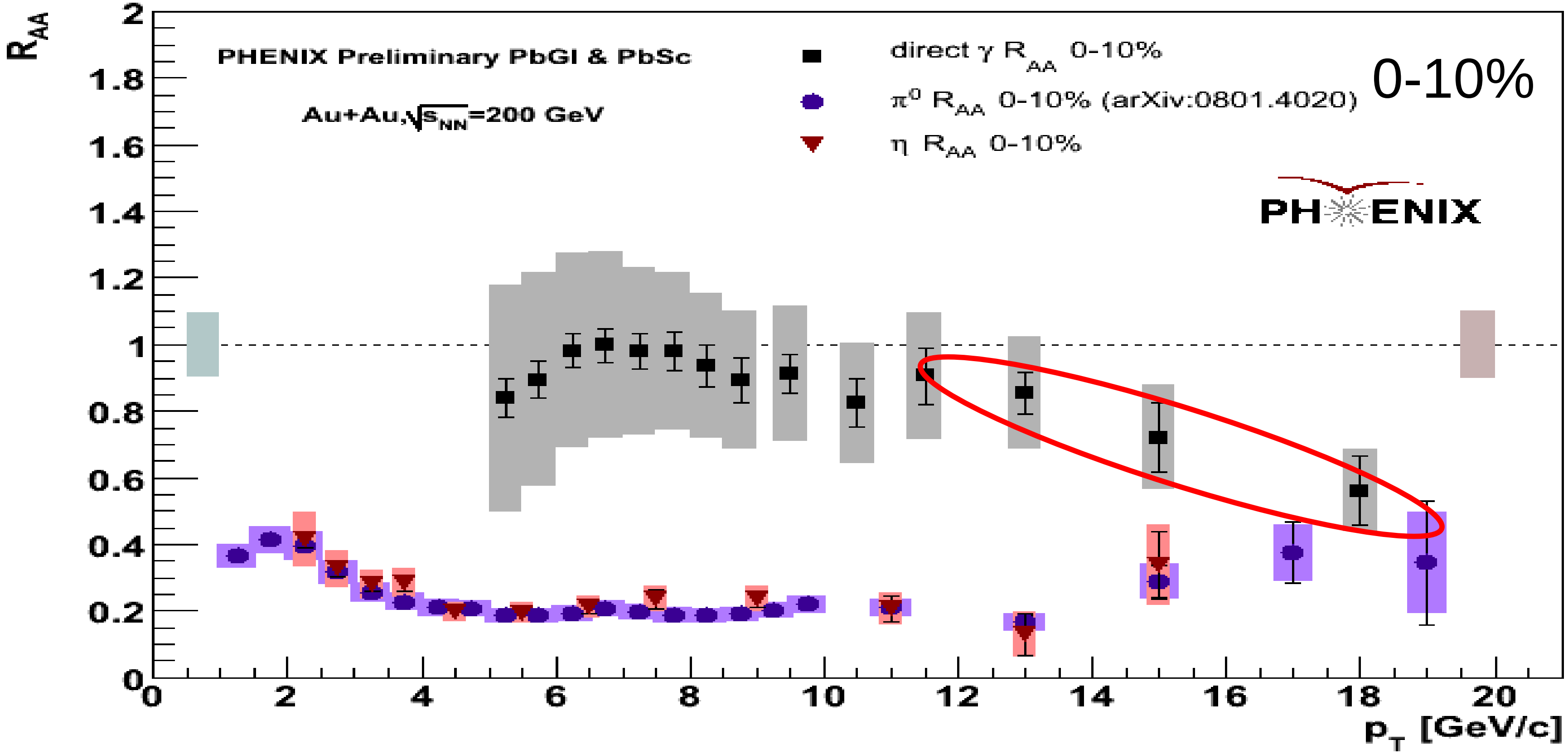
- The questions we want to answer with electroweak probes:
  - Thermalized system in AA collisions?
    - Low p_T thermal photons, compare pp and AA
  - Validity of N_{coll} scaling of hard process and nPDF?
    - Check the validity of N_{coll} calculation (ex. from Glauber Model)
    - Constraint the nPDF:
      - "Trivial modification": isospin effect
      - Modifications: shadowing effect, etc.
  - Reference for the jet quenching studies?
    - High p_T photon R_{AA}
    - Impact of the isolation requirement

Electroweak probes in RHIC and LHC

- RHIC data:
  - Direct photons from PHENIX
- LHC data:
  - Direct photons from ALICE at low p_T
  - Isolated photons at high p_T
  - Z boson production
  - W boson production

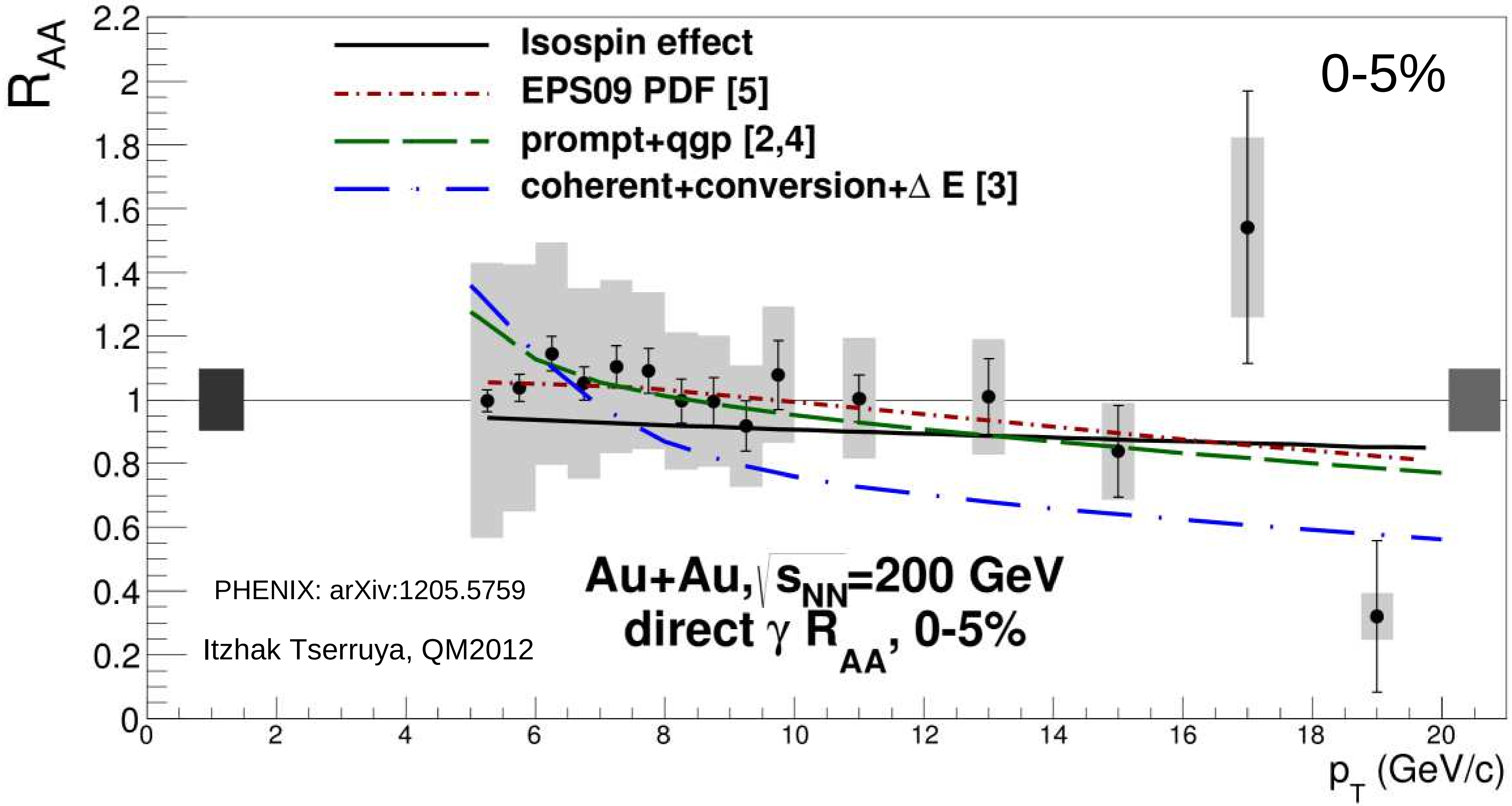
Direct photons at RHIC

- PHENIX preliminary result of direct photons R_{AA} at high p_T



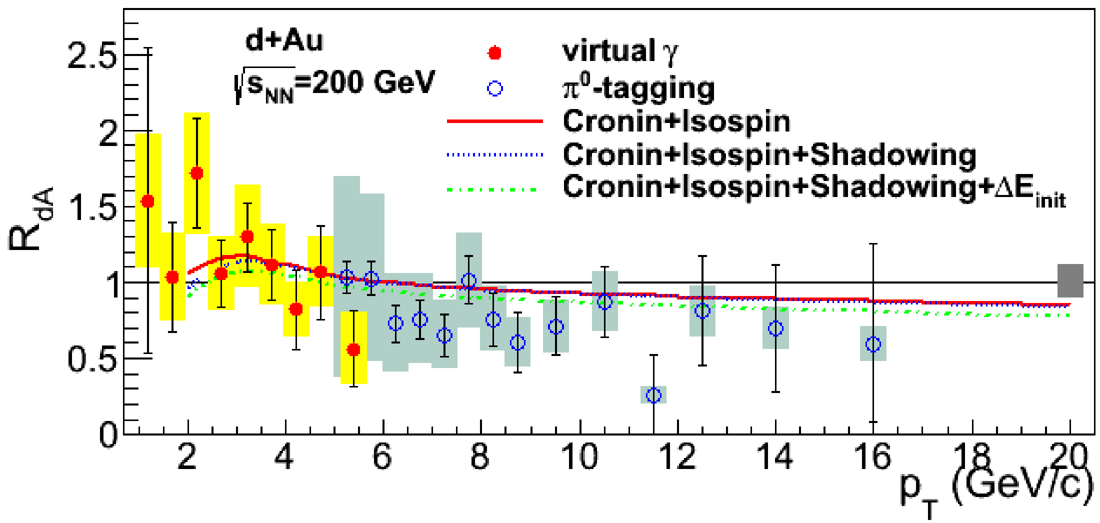
Direct photons at RHIC

- PHENIX final result of direct photons R_{AA} at high p_T



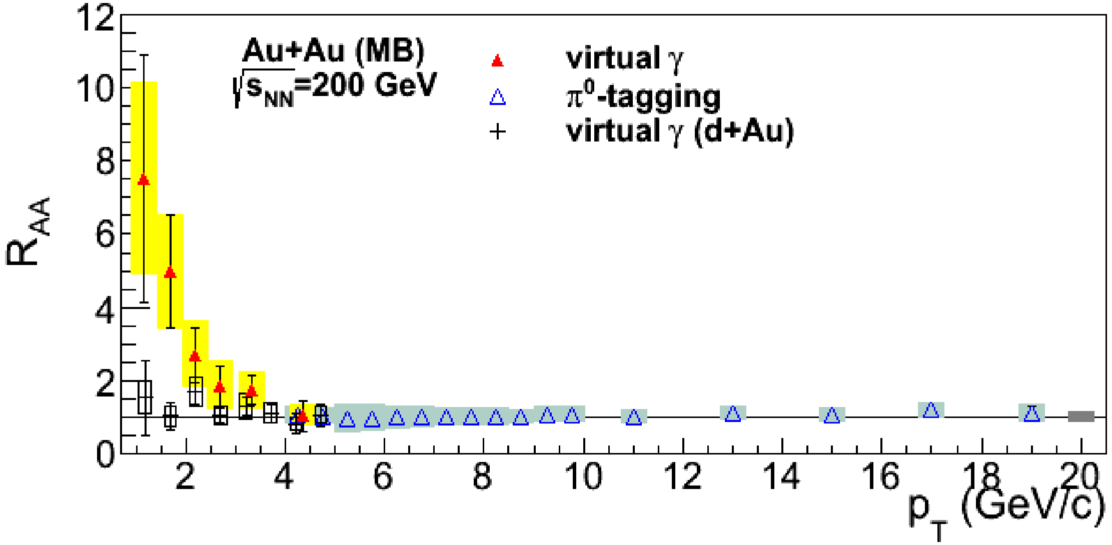
- Consistent with calculation with nPDF
- Isospin effect is seen at high p_T

Direct photons in dAu and AuAu



arXiv:1208.1234

R_{dA} is consistent with unity

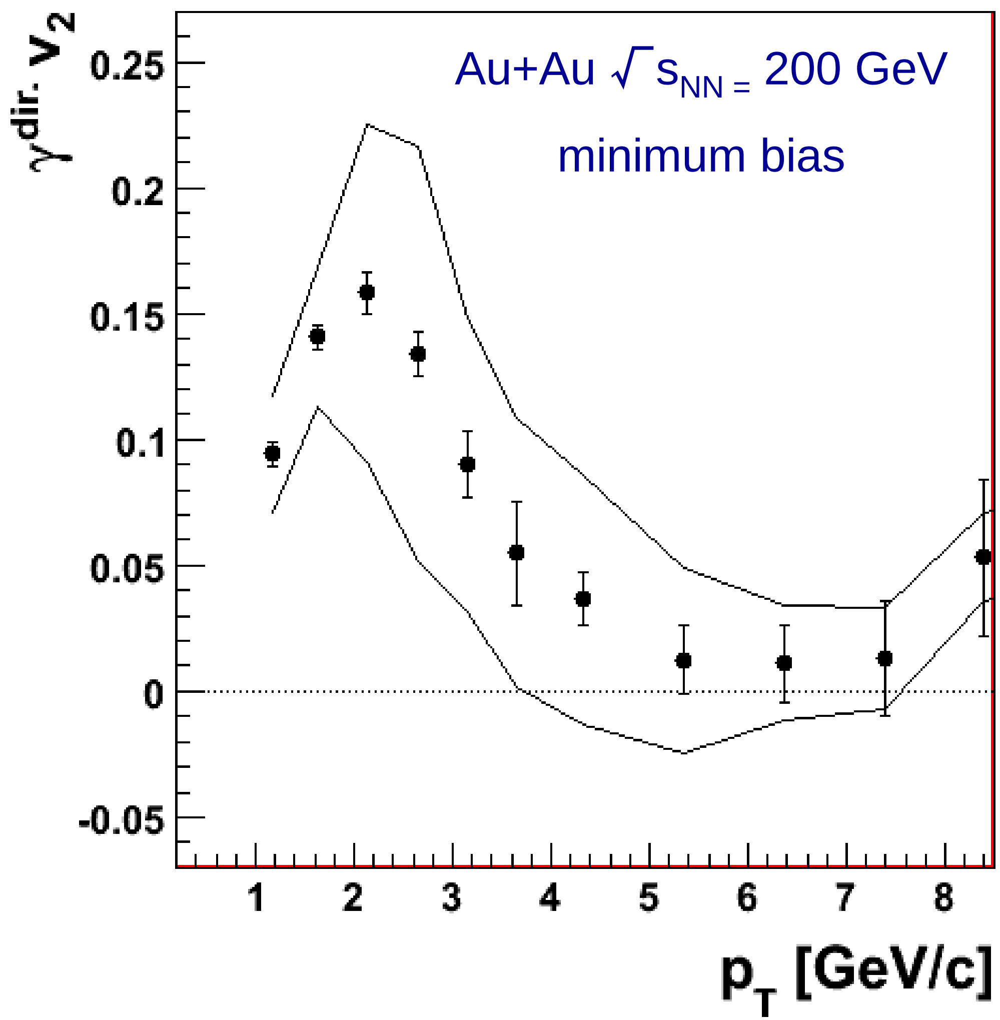


Large excess of γ observed in Au+Au is not due to initial state effects

Itzhak Tserruya, QM2012

Direct photons v_2 in AuAu collision

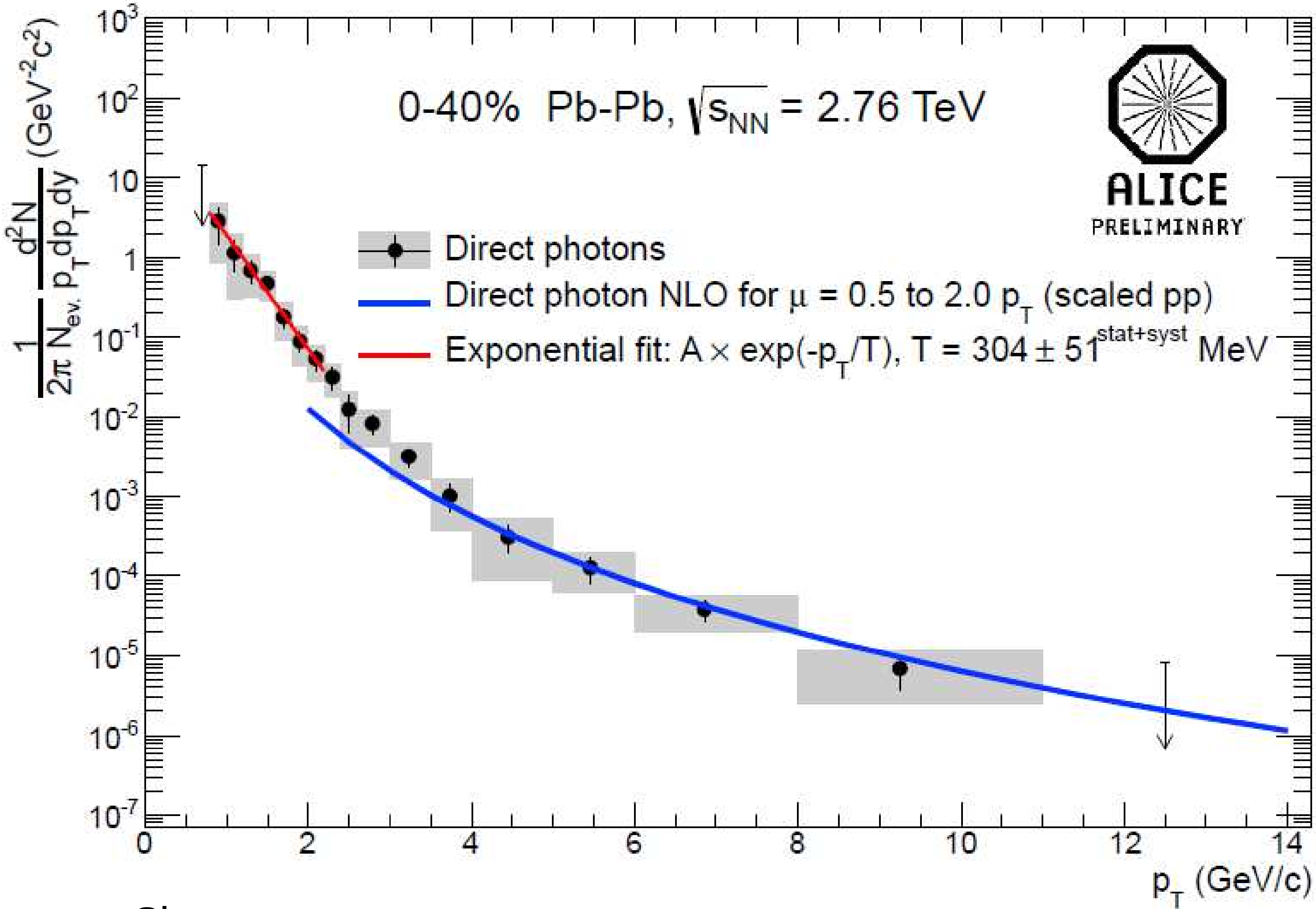
arXiv:1105.4126



- Large v_2 at p_T < 4 GeV/c where thermal photons dominate
- v_2 consistent with 0 at high p_T where prompt photons dominінate

Large v_2 implies late emission whereas thermal radiation implies early emission

Direct photons at LHC



Slope:

PHENIX measurement: T_{RHIC} = 221 ± 19 (stat) ± 19 (syst) MeV

ALICE measurement: T_{LHC} = 304 ± 51 (stat+syst) MeV

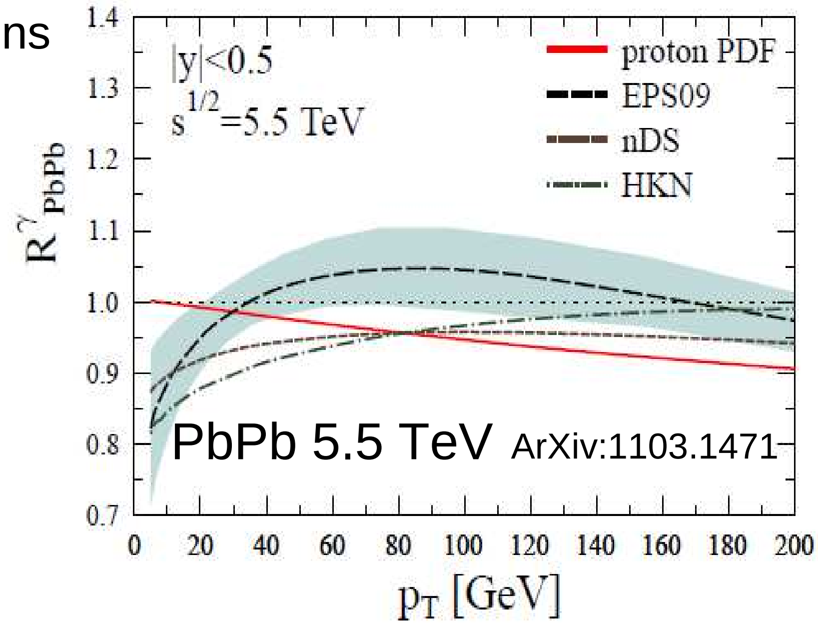
Summary of direct photon measurements

- PHENIX updated the photon R_{AA} with pp reference, consistent with nPDF prediction
- No significant exceeds at low p_T in dAu collisions
- ALICE result: hint of hotter QGP in LHC
- Puzzling results from low p_T direct photon v_2

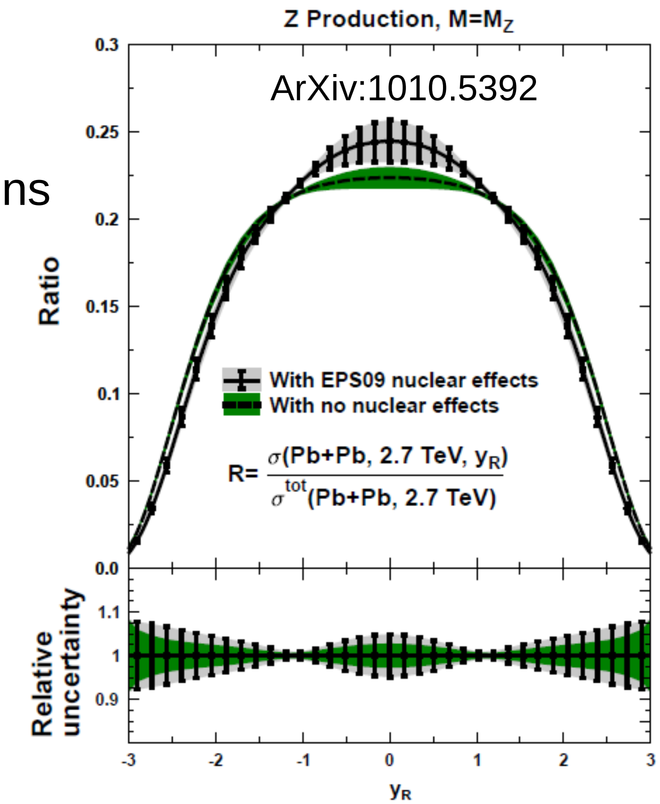
Constrain the nPDF

- Good theoretical control on high p_T photons, Z and W bosons
- Need multiple channels and p_T dependent studies to distinguish if the problem is from N_{coll} scaling or nPDF
  - W boson: isospin effect in muon charge asymmetry
  - Expected modification of high p_T photon and Z production at the LHC energy due to nPDF: 0-20% level

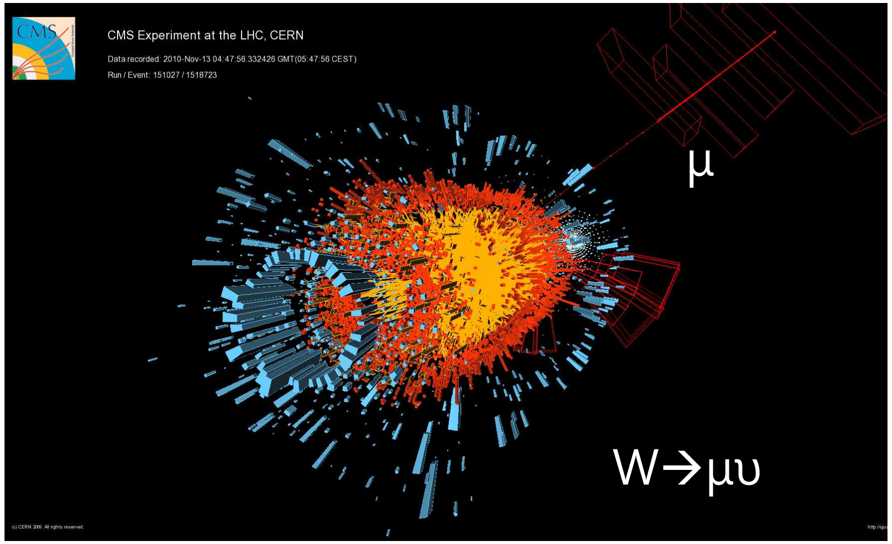
Photons



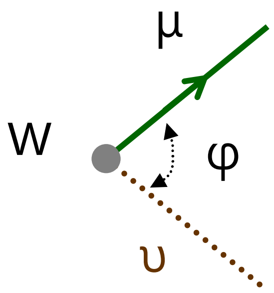
Z bosons



W boson

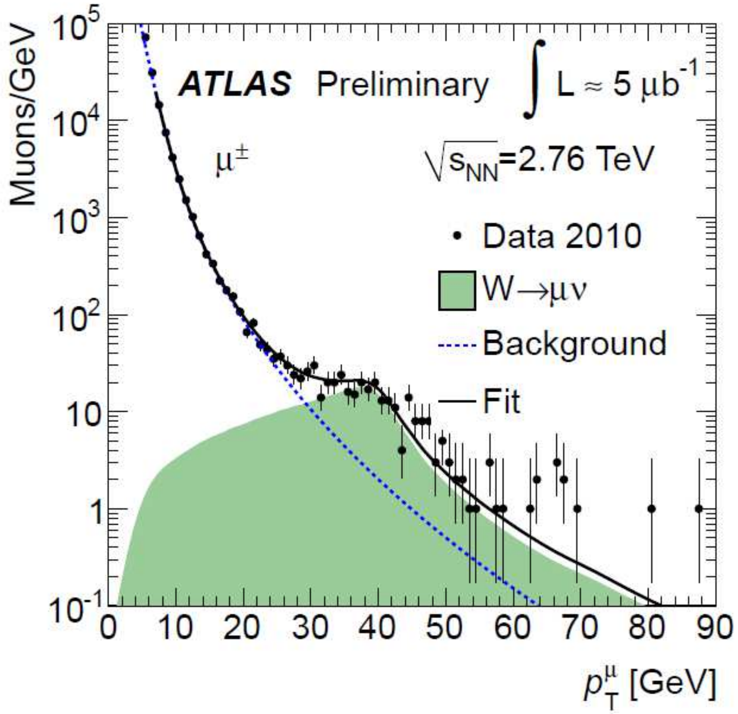


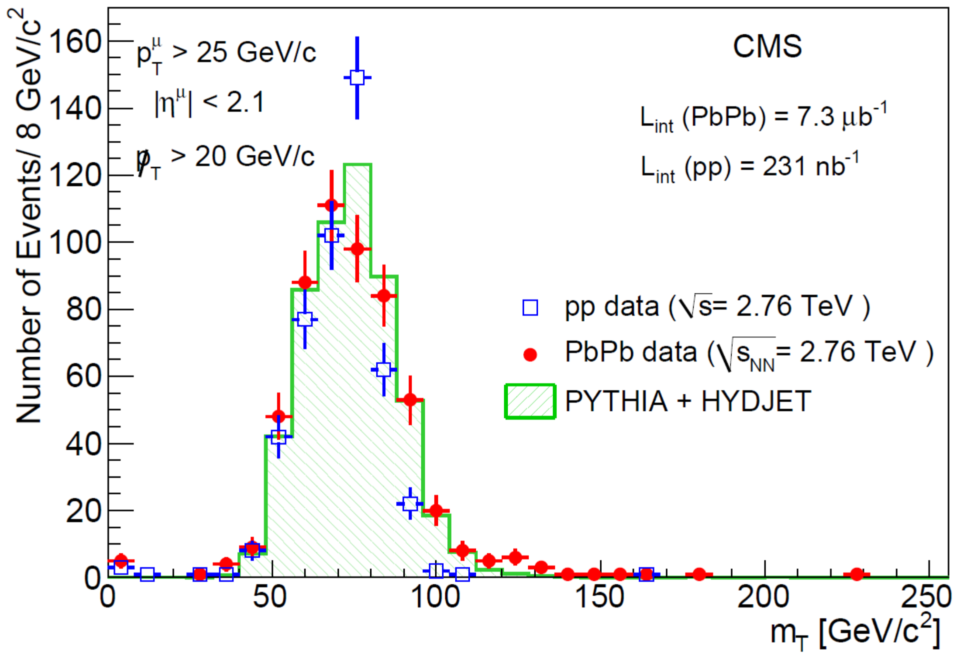
W→μυ   Single high p_T μ + Missing p_T



$\not{p}_T = -\sum \vec{p}_T$ of all charged tracks with p_T > 3 GeV/c

Transverse mass $m_T = \sqrt{2 p_T^{\mu} \not{p}_T (1 - \cos\phi)}$





W boson R_{AA}

CMS $R_{AA}(W) = 1.04 \pm 0.07 \pm 0.12$

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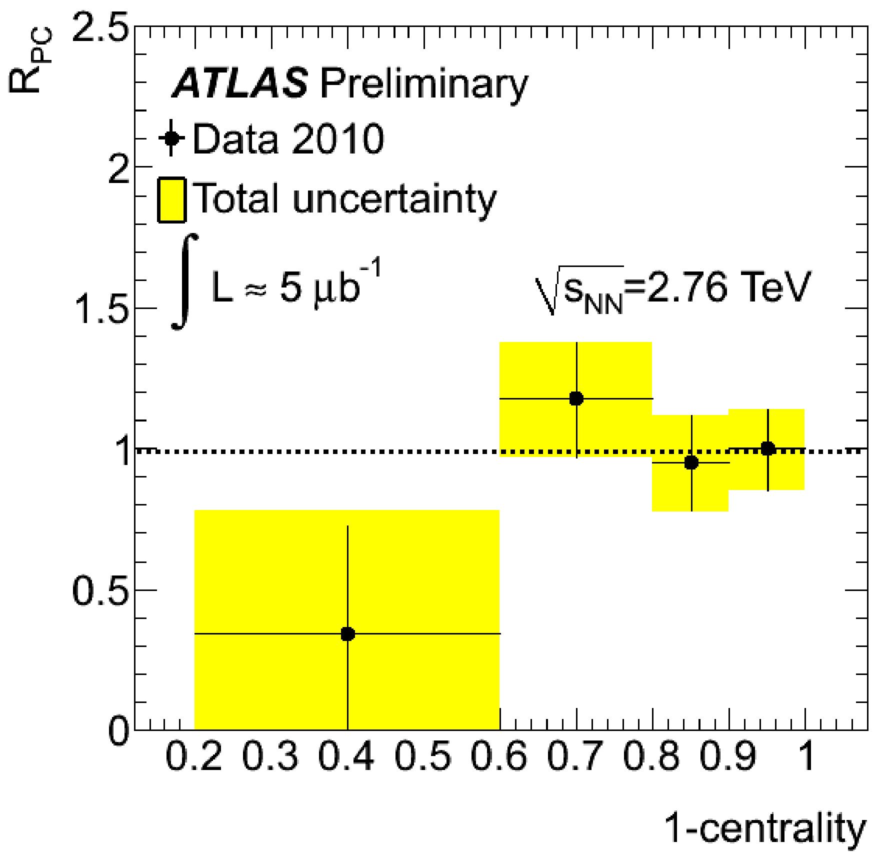

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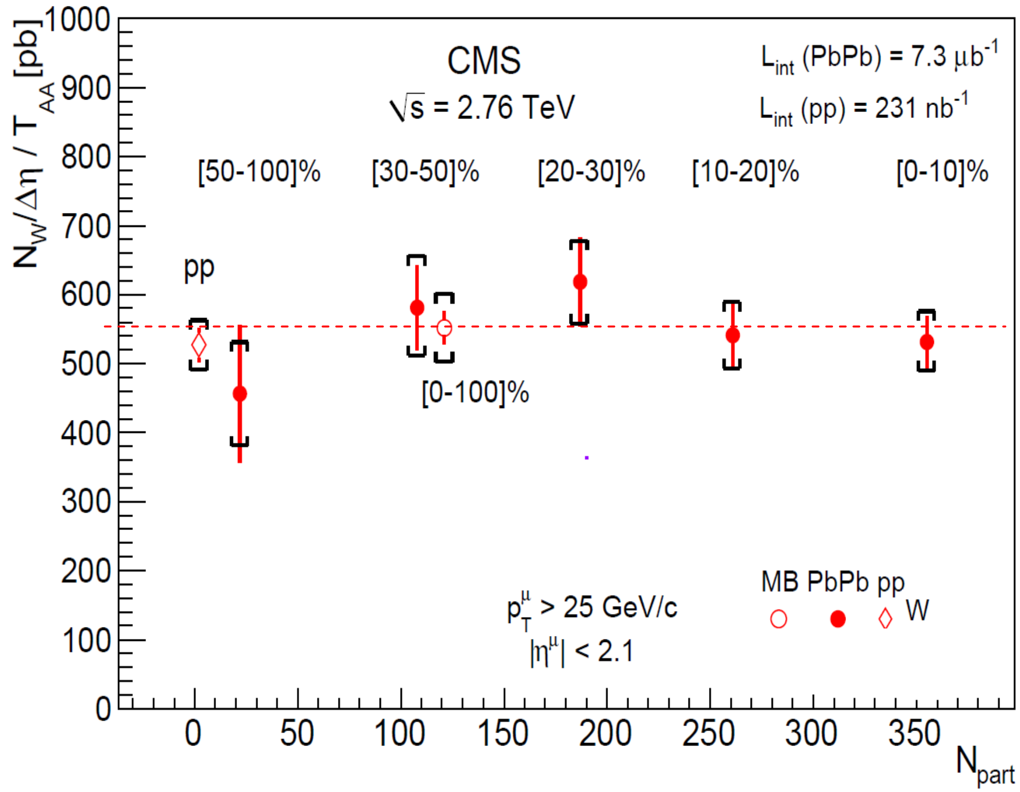


- Normalized yield does not vary as a function of centrality

Centrality independence

$dN_{AA} / T_{AA} = d\sigma_{pp} \times R_{AA}$

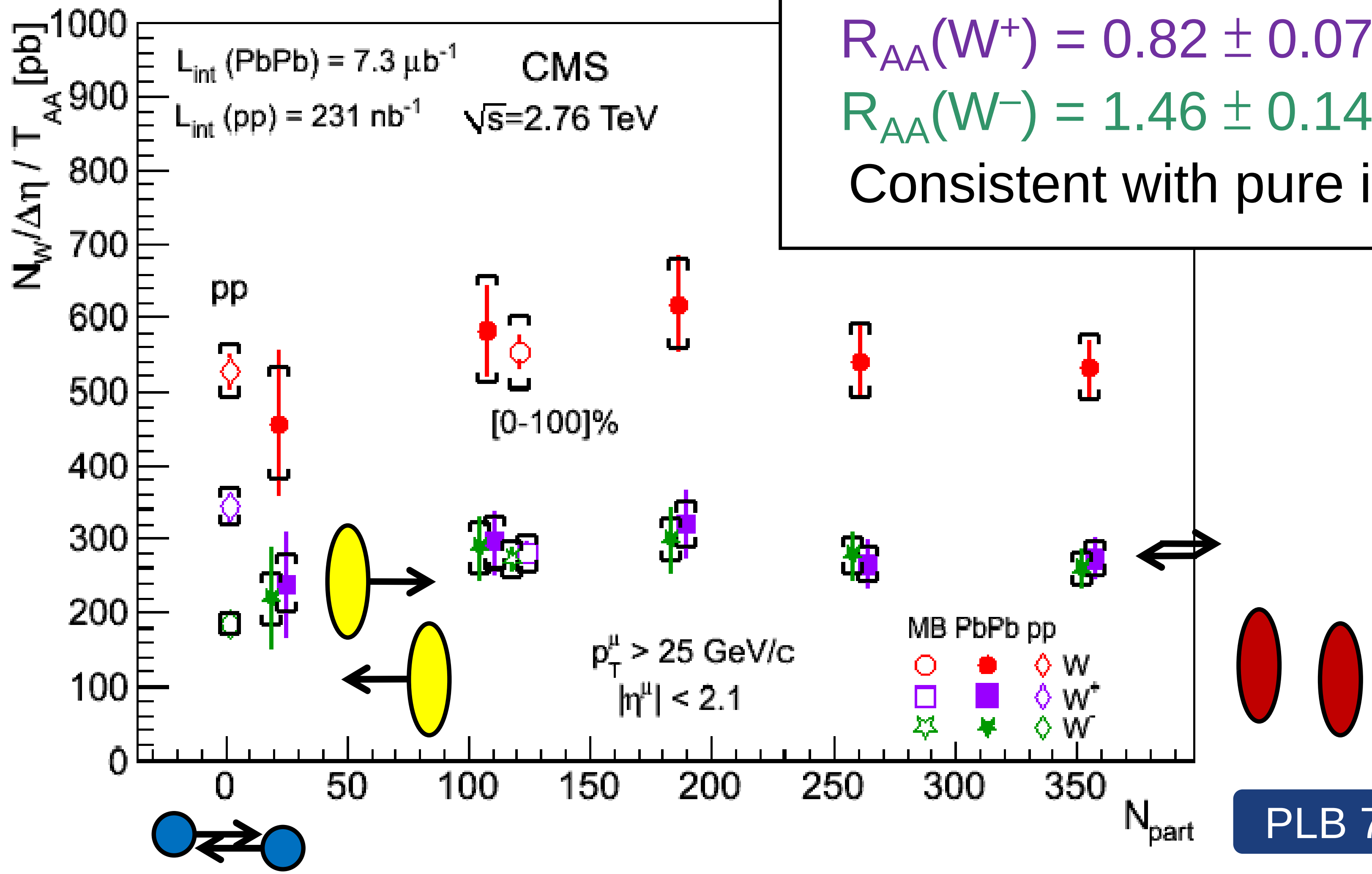
2010 PbPb ≈ pp data

$R_{AA}(W) = 1.04 \pm 0.07 \pm 0.12$

$R_{AA}(W^+) = 0.82 \pm 0.07 \pm 0.09$

$R_{AA}(W^-) = 1.46 \pm 0.14 \pm 0.16$

Consistent with pure isospin



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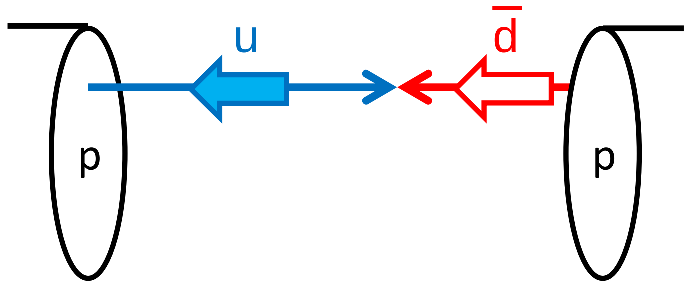
W boson production

$$@\,\mathrm{LO}: u\bar{d} \rightarrow W^{+} \;\&\; \bar{u}d \rightarrow W^{-}$$

→ Less W^+ and more W^- in PbPb than in pp (*isospin* effect)

- Cancels for $W^+ + W^-$



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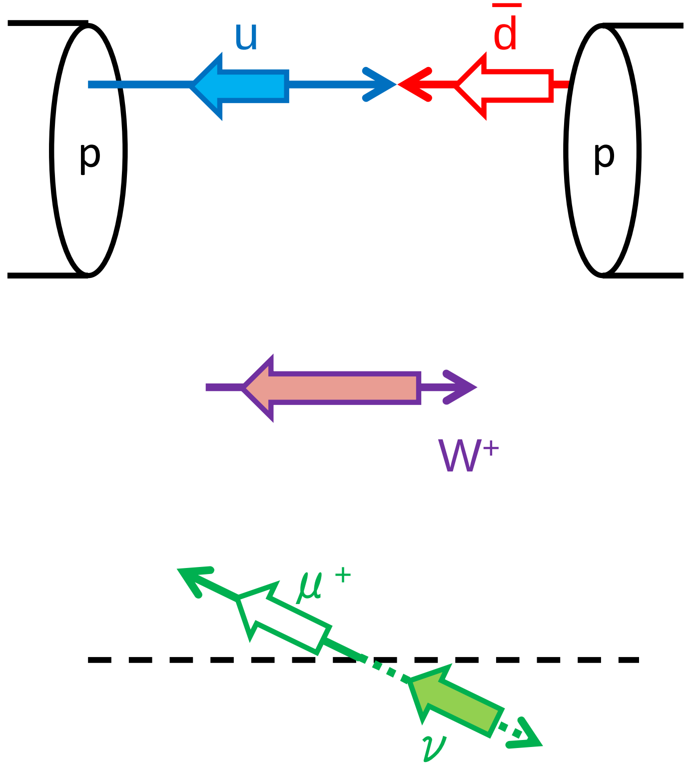


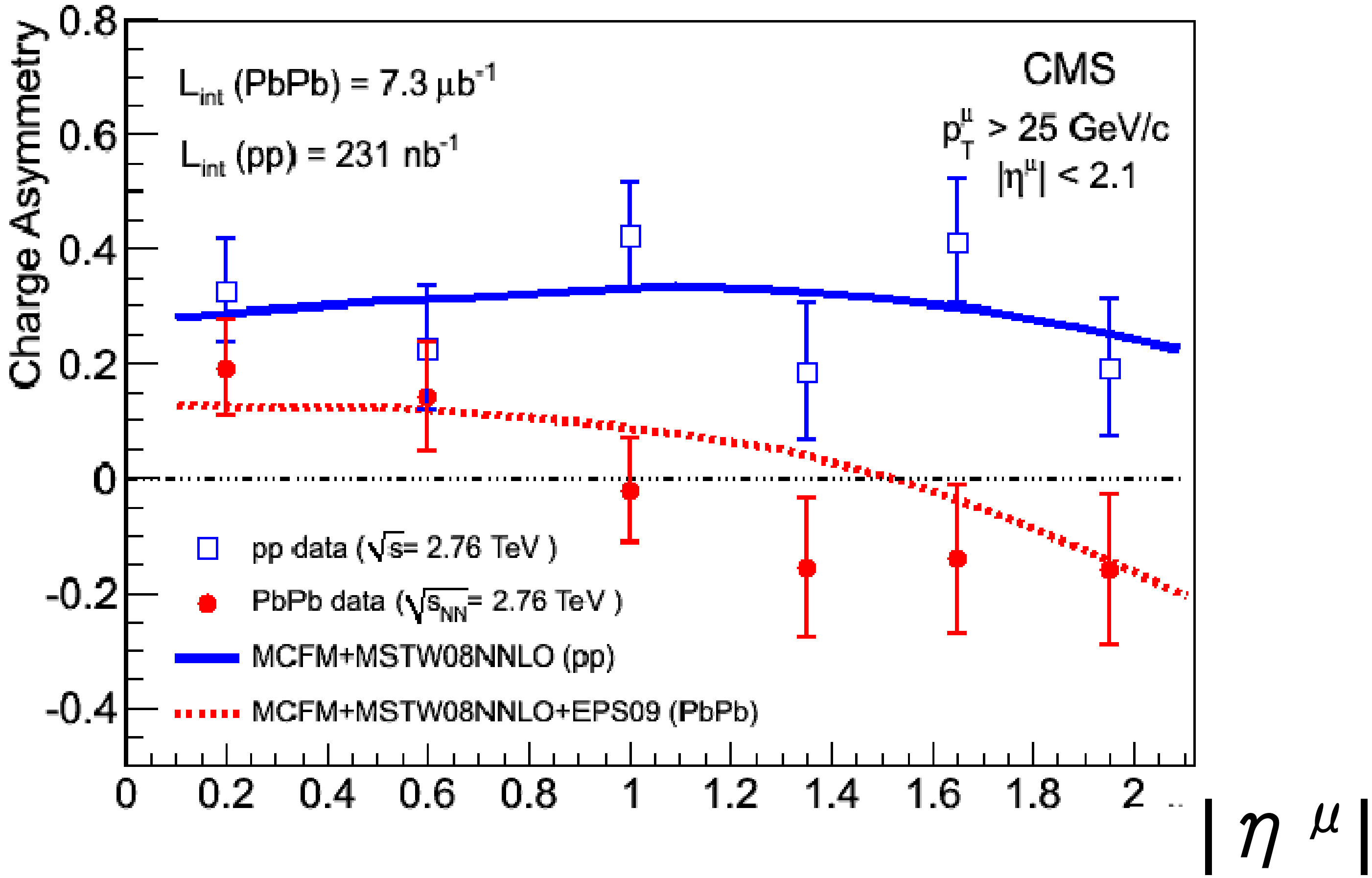
- W boosted towards the valence quark (higher rapidity)
- Spin conservation → μ^{+} (μ^{-}) boosted back to (away from) midrapidity

→Different muon rapidity distributions (not heavy-ion specific) between W^{+} and W^{-}

Muon charge asymmetry

Less up quarks make less W^+ in PbPb than in pp

$$\frac{N^+ - N^-}{N^+ + N^-}$$



Isospin effect bringing down asymmetry by 0.2 to 0.4

(EPS09 modifications are 0.03 at most)

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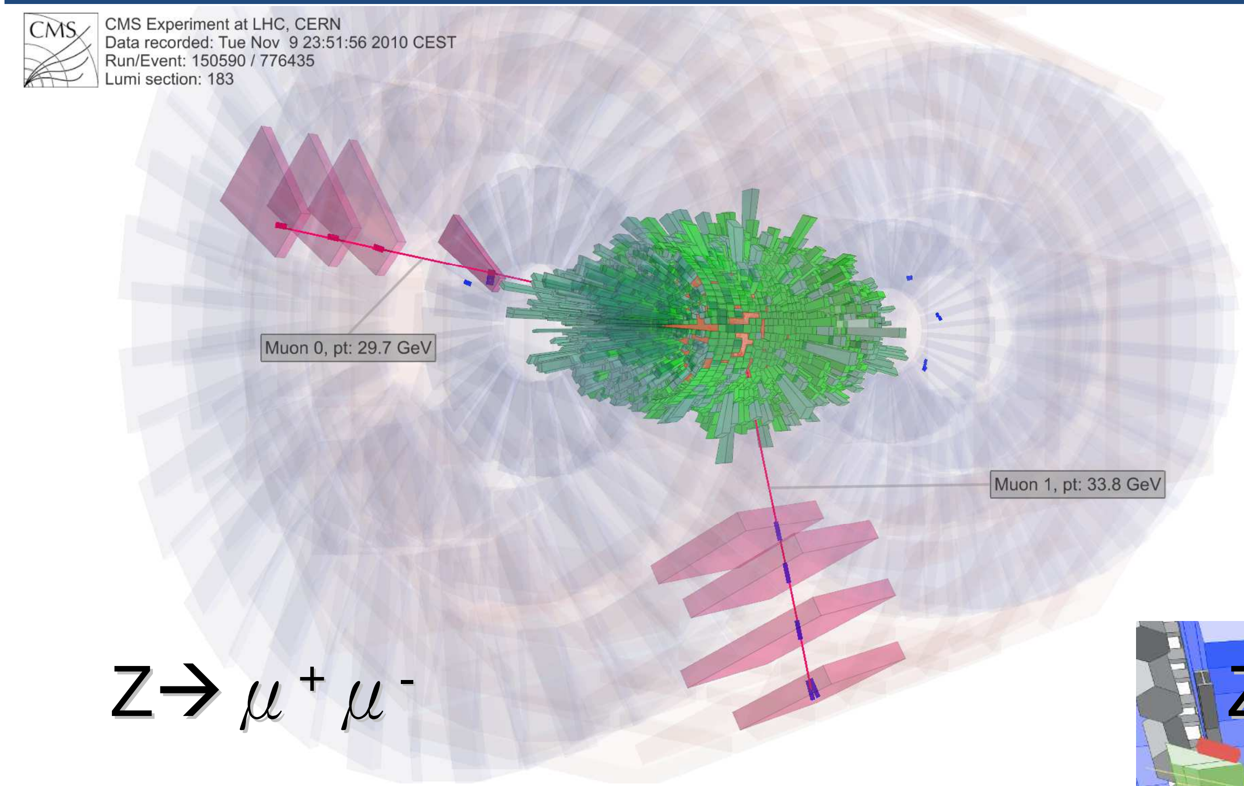
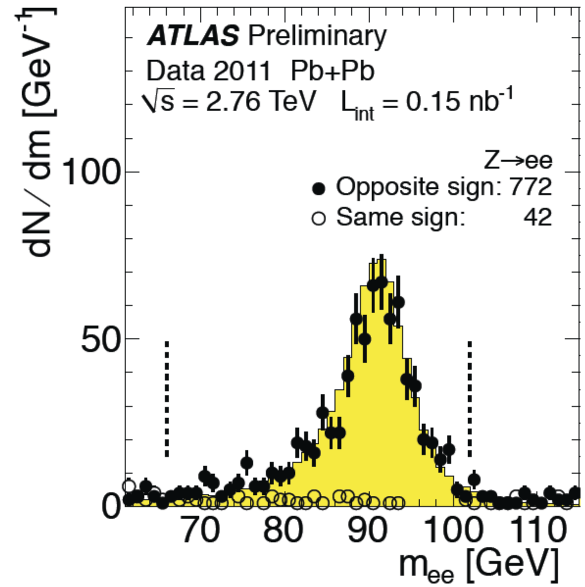
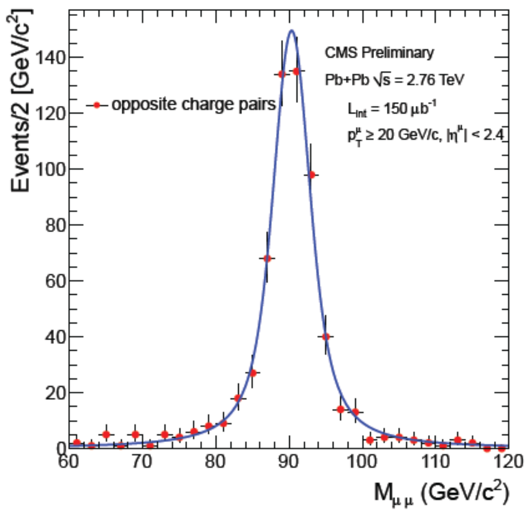
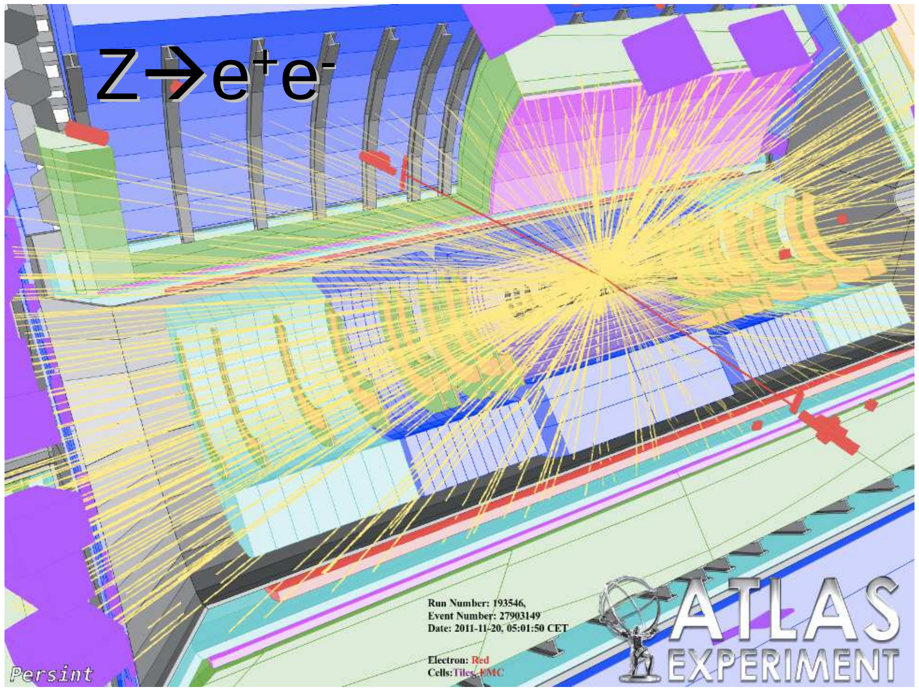
Z boson production in PbPb collisions



$Z \rightarrow \mu^+ \mu^-$

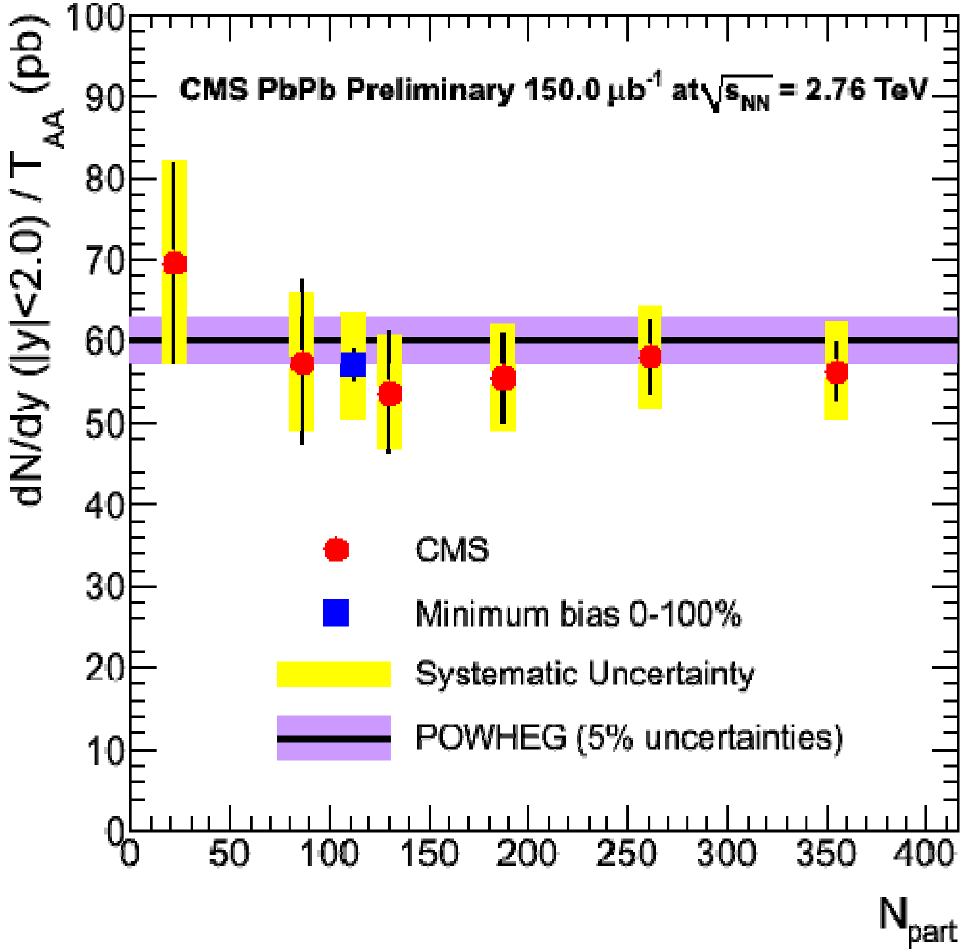






Z boson production in PbPb collisions

CMS-PAS-HIN-12-008



$R_{AA} = 0.95 \pm 0.03 \pm 0.13$

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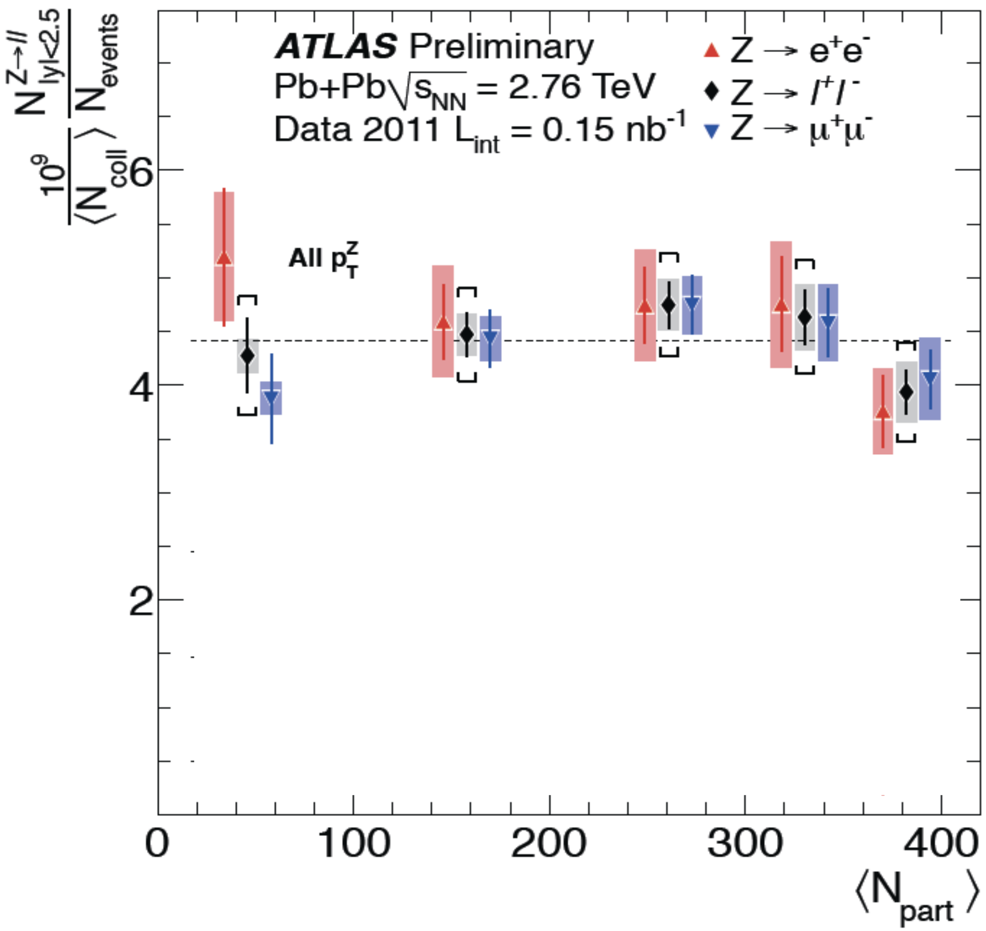
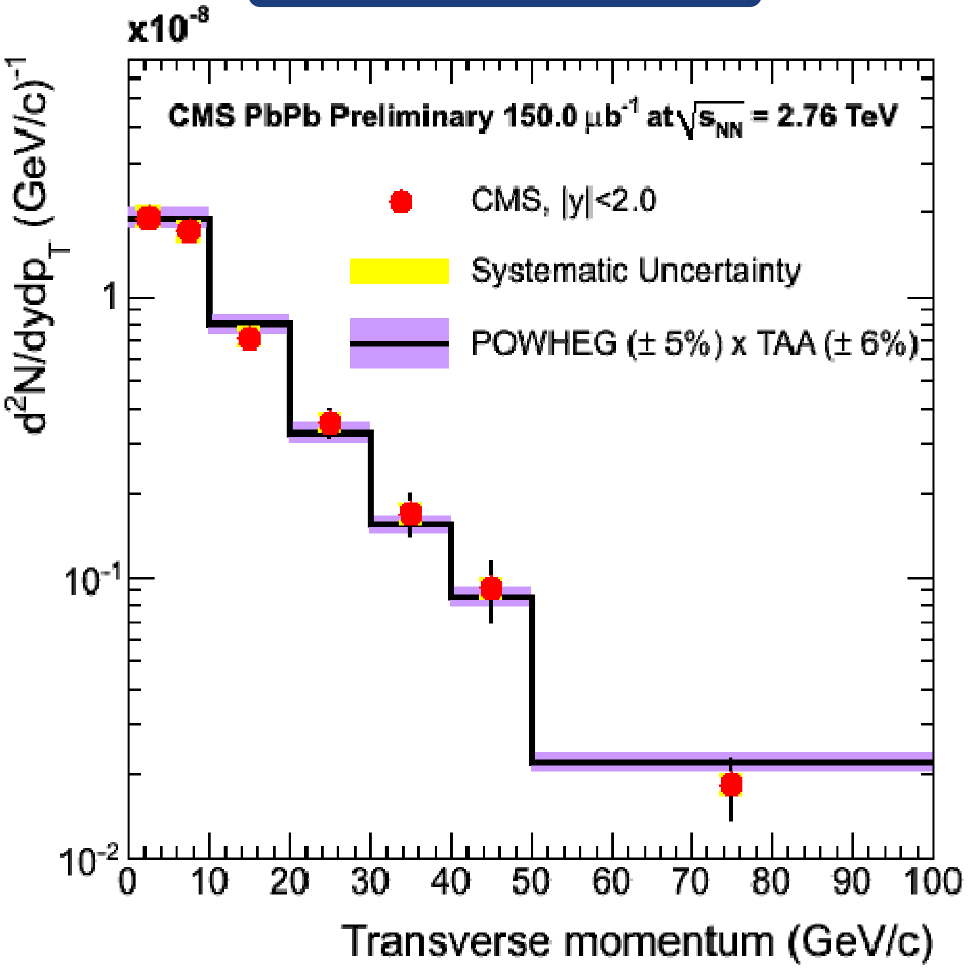


- Normalized yield does not vary as a function of centrality

Z boson production in PbPb collisions

CMS-PAS-HIN-12-008



- Z p_T distribution is consistent with POWHEG prediction

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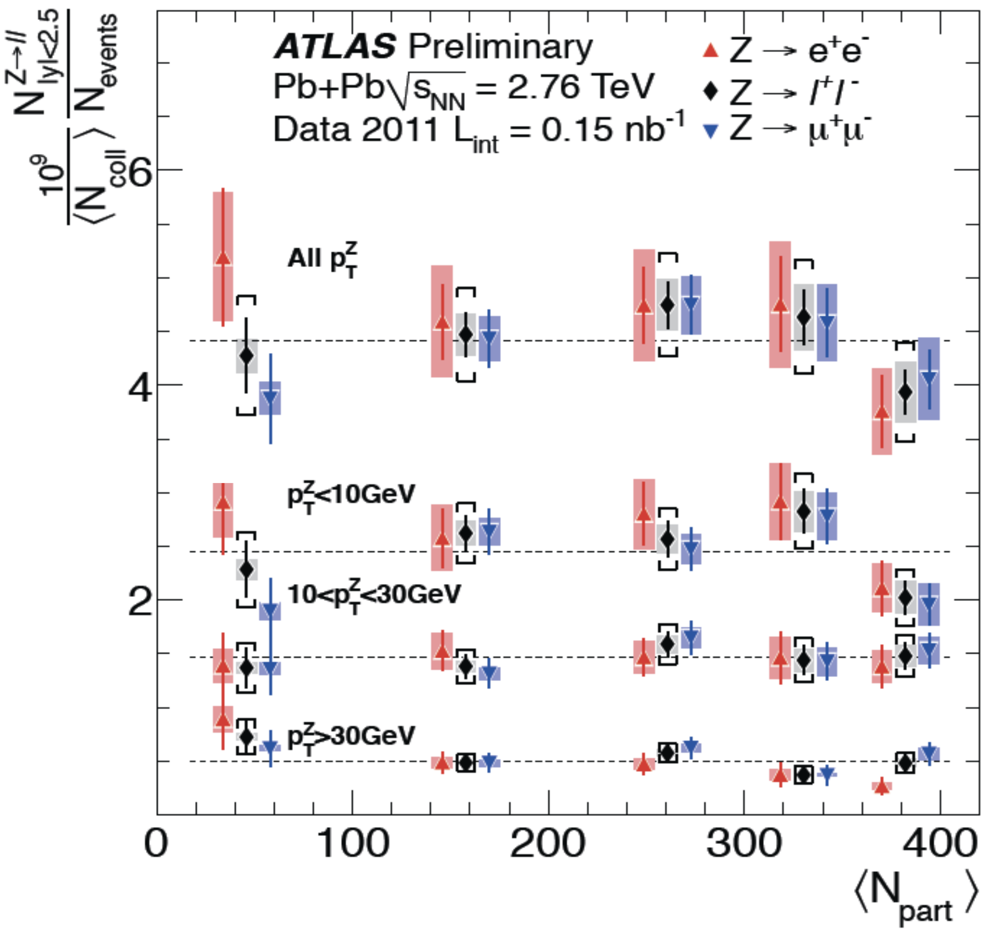
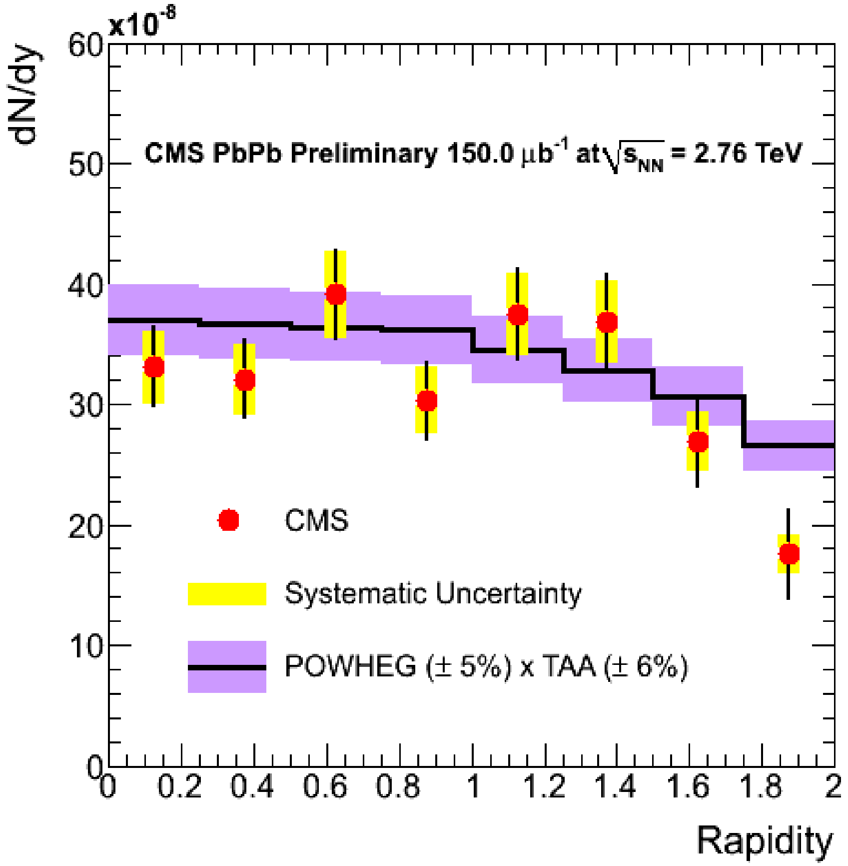


- Normalized yield is not varying as a function of centrality for all Z p_T ranges

Dependence on y and p_T

CMS-PAS-HIN-12-008



Reference: POWHEG

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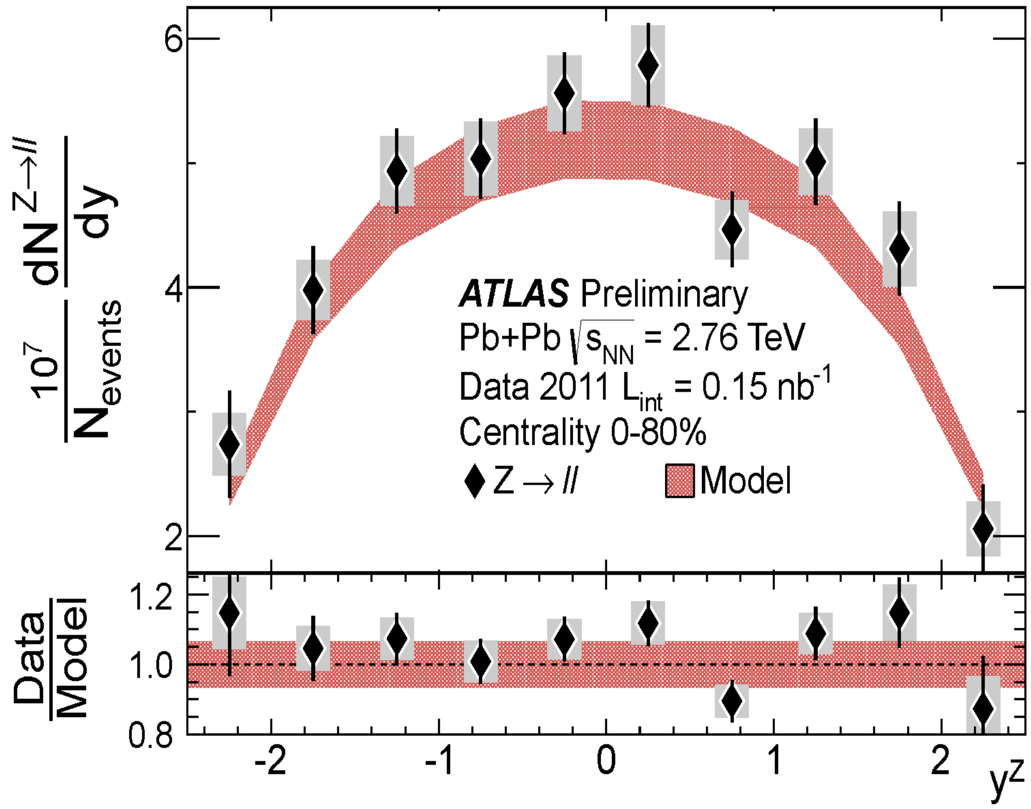
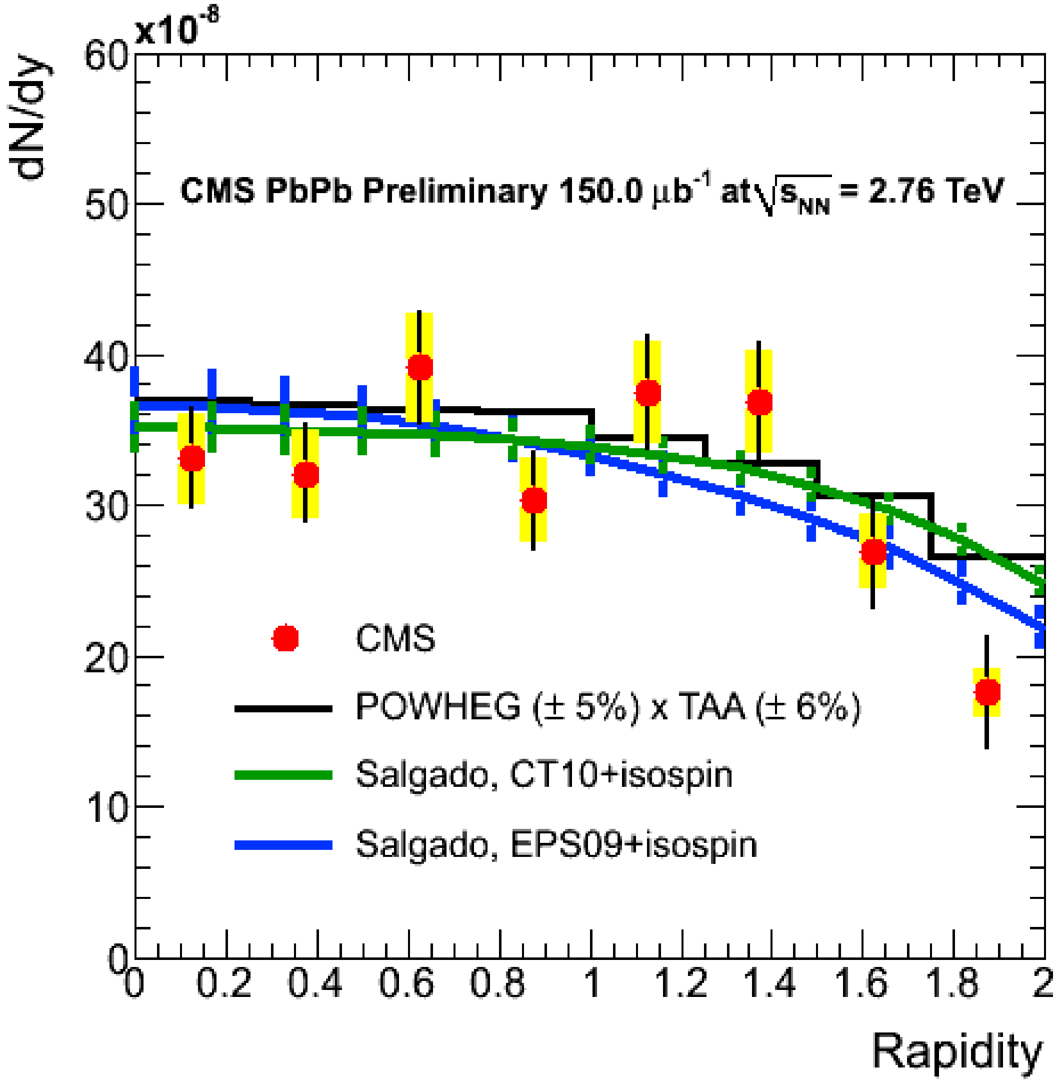


Reference: "Pythia NNLO"

- No strong deviation from absolutely-normalised reference from both experiment

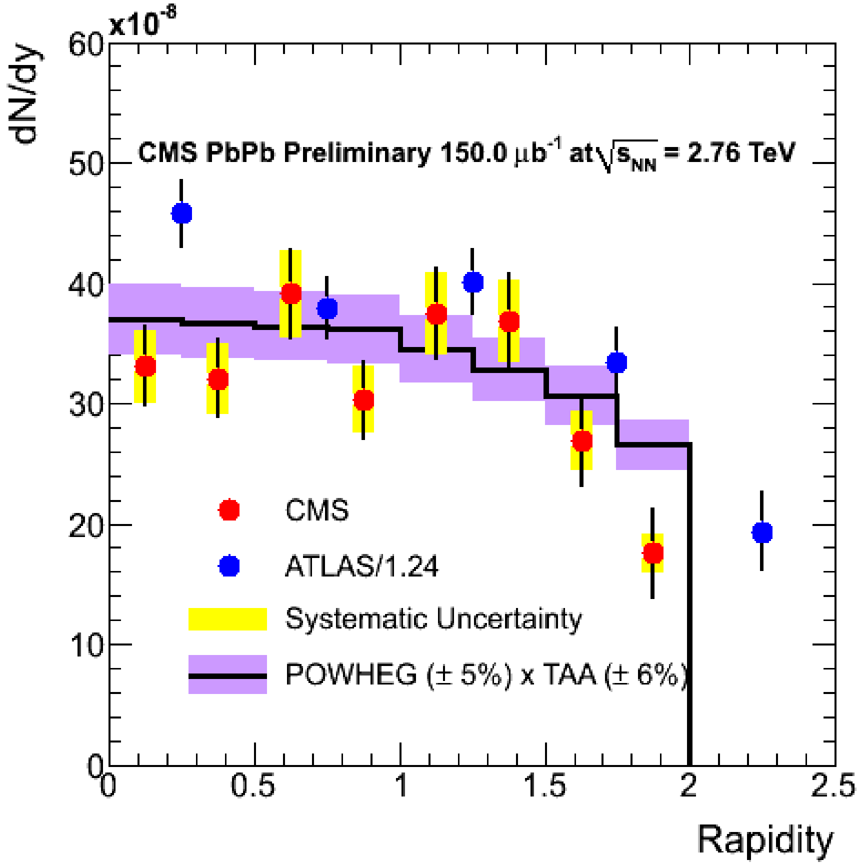
Shadowing effects on Z production



- No strong deviation from the EPS09+isospin reference

ATLAS vs CMS corrected yields

- ATLAS: 1223 Z→ $\mu\ \mu$
- CMS: 616 Z→ $\mu\ \mu$
- Comparison between CMS and ATLAS
  - positive-negative rapidity averaged ATLAS result
  - Systematics not displayed (comparable to statistics)
- 80-100% centrality rescaled to 0-100%
  - N_{coll}(0-80%) / N_{coll} (0-100%) = 452 / 363 = 1.24
- Significant tension, especially at small rapidity



CMS-PAS-HIN-12-008
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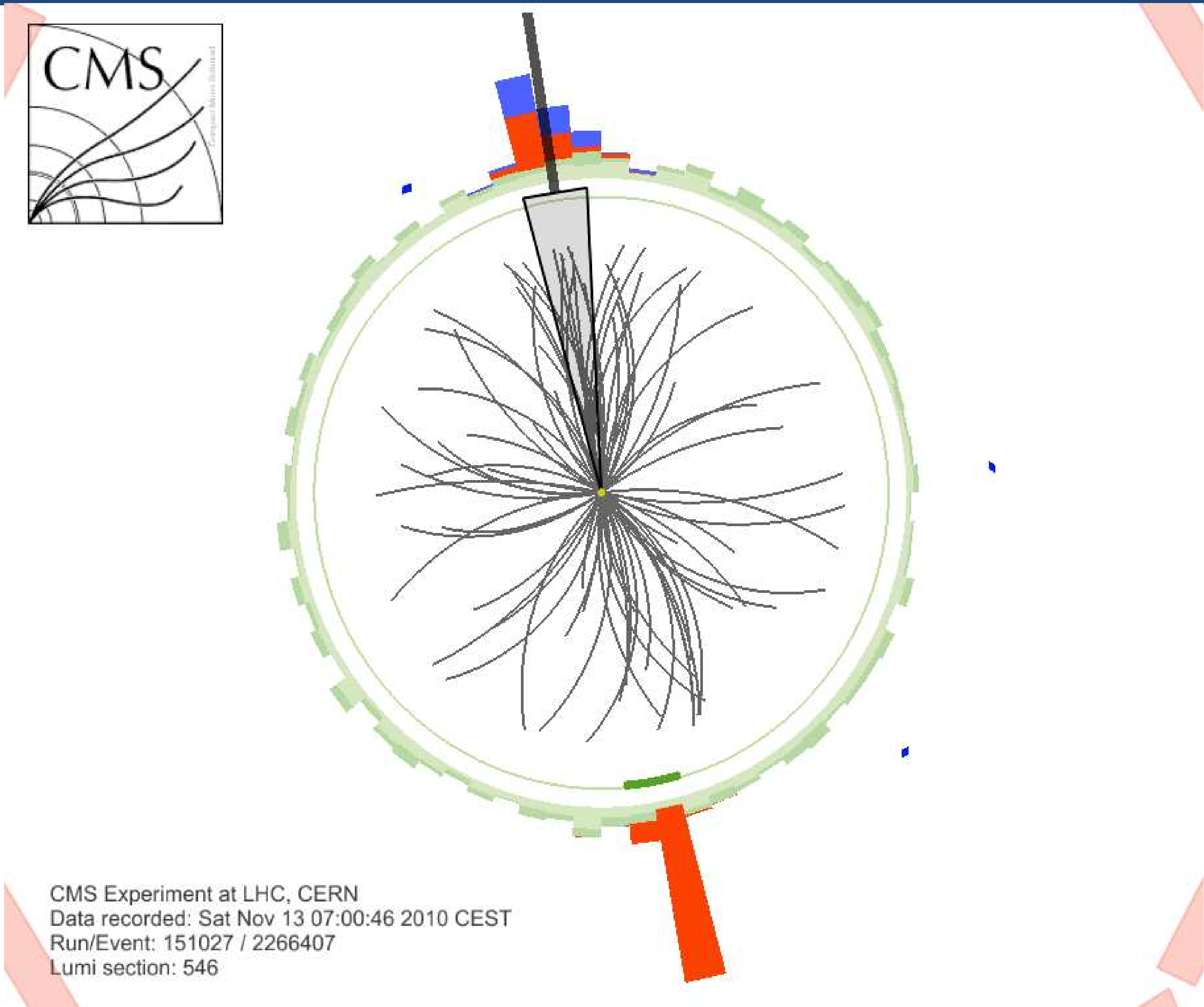
Summary from W and Z bosons

- W boson muon charge asymmetry:
  - Sensitive to isospin effect
  - Consistent with MCFM expectation

- Z boson:
  - Very clean signal from di-electron and di-muon channels
  - Significant tension between CMS and ATLAS, especially in mid-rapditiy
  - R_{AA} ~ 1 from both experiment, but use different theoretical references (POWHEG vs. “PYTHIA NNLO”)

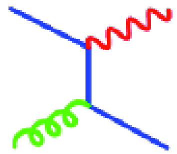
Isolated photons at LHC



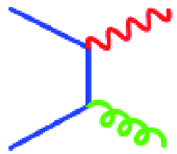
Photons

LO

Compton

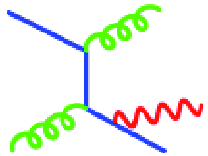


Annihilation

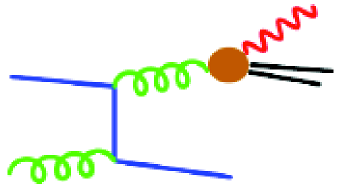


NLO

Bremsstrahlung



Fragmentation



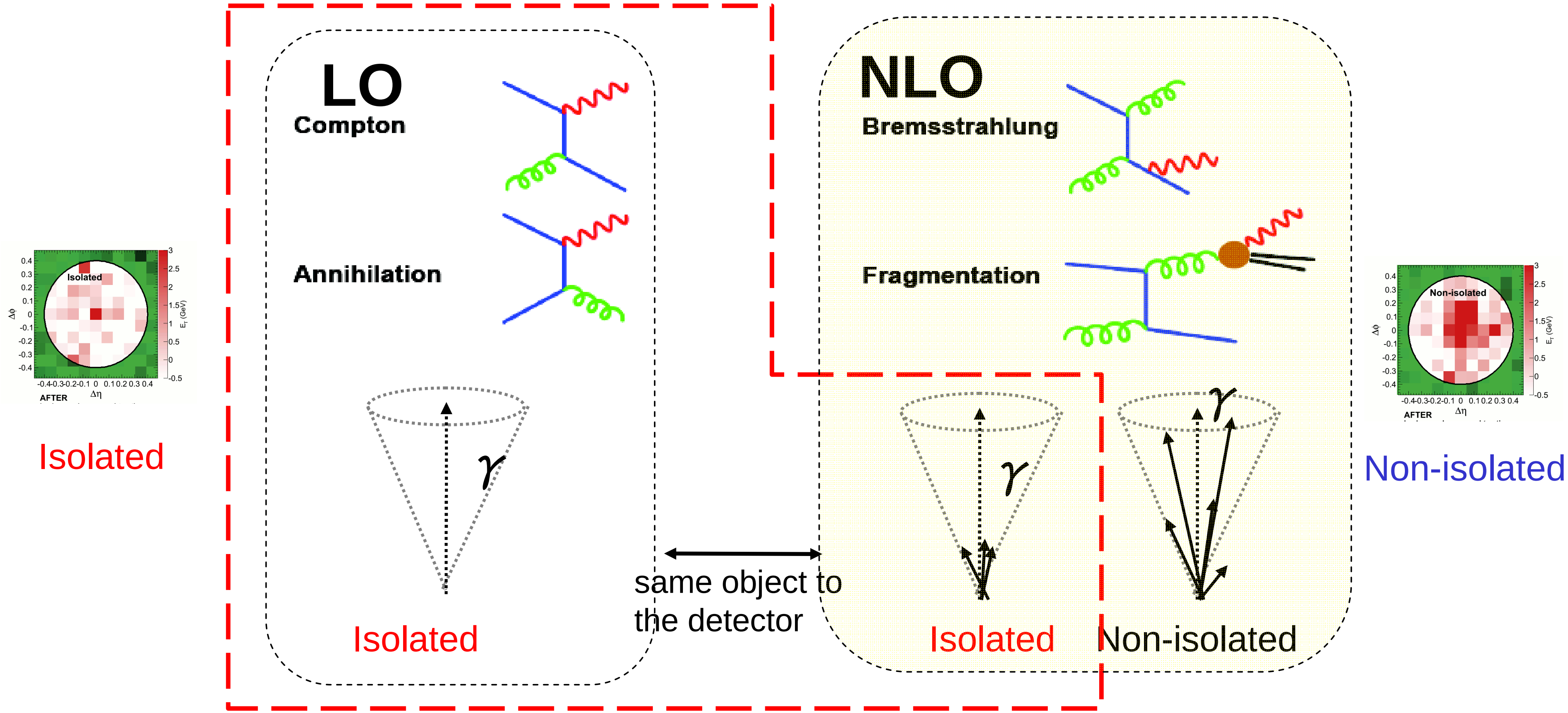
- Ideally: LO photons from hard scattering

- Real world:
  huge background from decay and fragmentation photons

- Need a consistent definition between measurements and theoretical calculations

Isolated high p_T photons

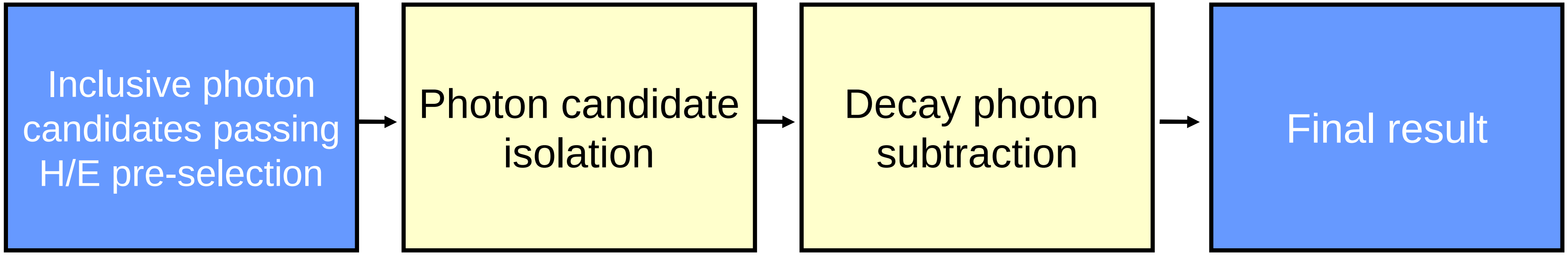
- Solution: measurement of the isolated photons
- Decay photons from hadrons in jets such as π^0, $\eta \rightarrow \gamma\gamma$ are largely suppressed
- UE subtracted isolation variables are developed



Isolated photon measurements

	CMS	ATLAS
Pseudorapidity	$\|\eta\|<1.44$	$\|\eta\|<1.3$
Transverse Energy	>20 GeV	>45 GeV
Isolation requirement	$E_T<5$ GeV in $\Delta R<0.4$	$E_T<6$ GeV in $\Delta R<0.3$

Analysis procedure

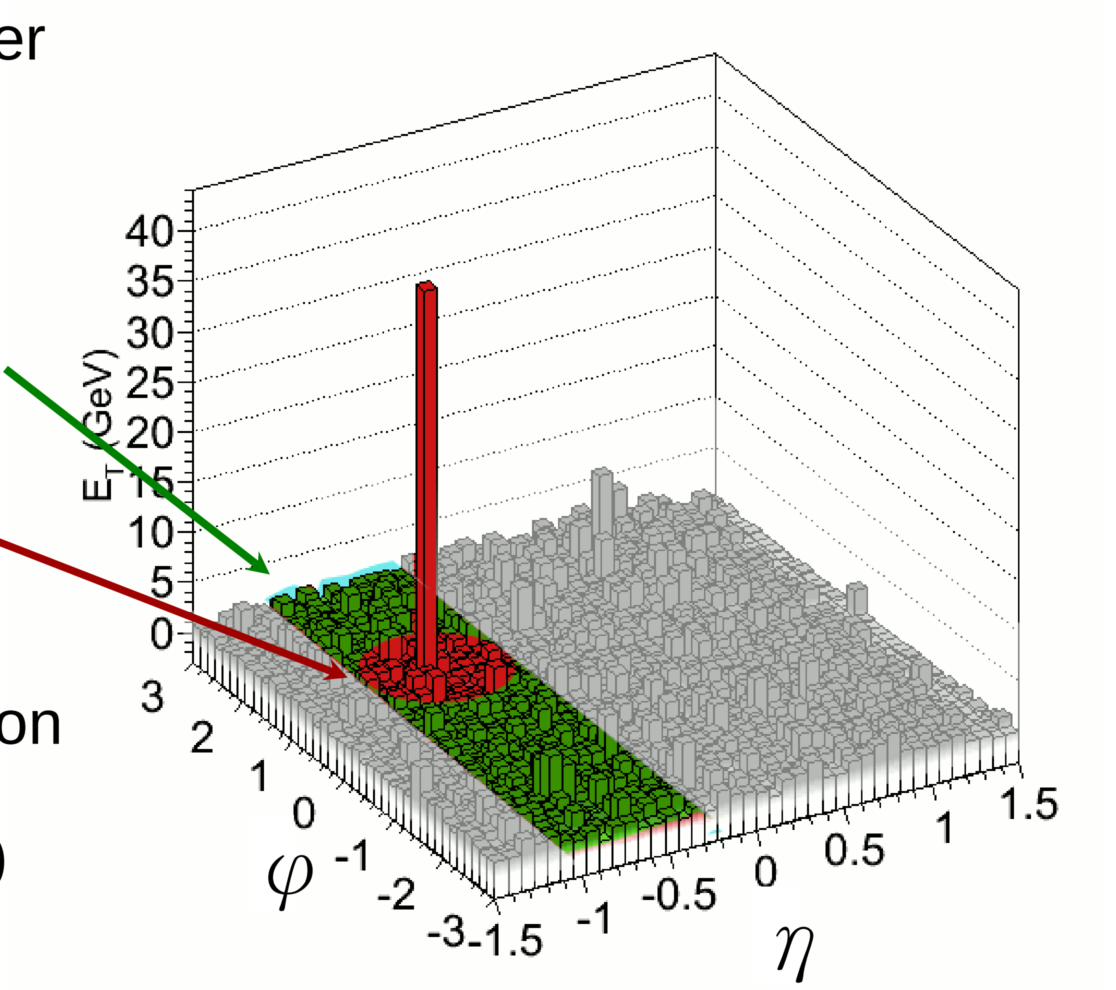


Background subtraction in PbPb

In PbPb collisions, almost ***no*** photons are isolated due to other particles from the underlying event

CMS: Use the mean E_T per unit area in an η strip to subtract background inside the isolation cone $\Delta R<0.4$

ATLAS: using the same subtraction method as jet reconstruction (Ψ_2 and v_2 measured by FCAL)



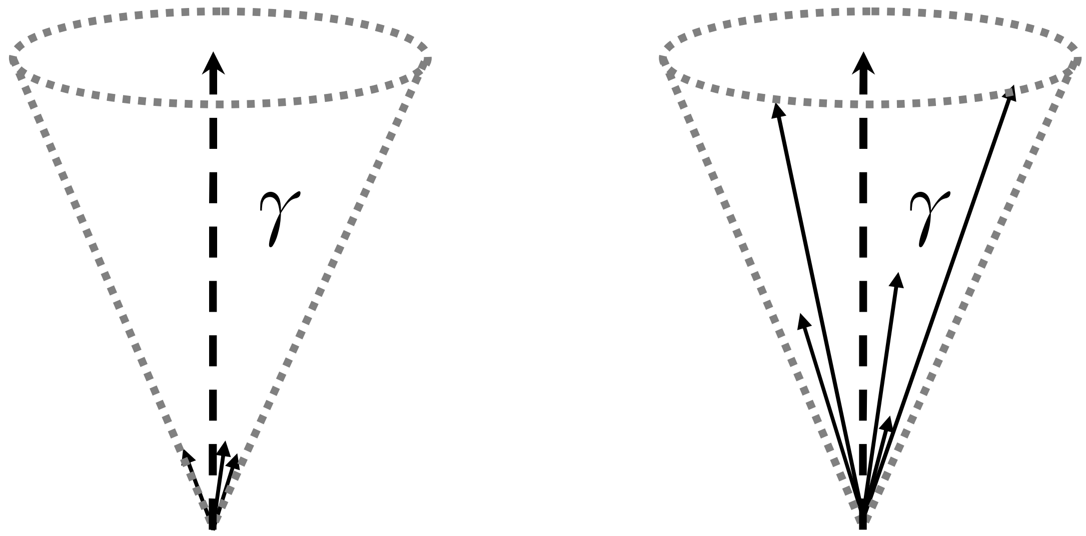
$$E_{Tj}^{\text{sub}} = E_{Tj} - A_j\,\rho_i(\eta_j)\left(1 + 2v_{2i}\cos\left[2\left(\phi_j - \Psi_2\right)\right]\right)$$

Photon isolation criteria in CMS

Generator level: $\Delta R<0.4$

$\Sigma E_T^{IsoCone} < 5$ GeV

with only particles from the same hard scattering

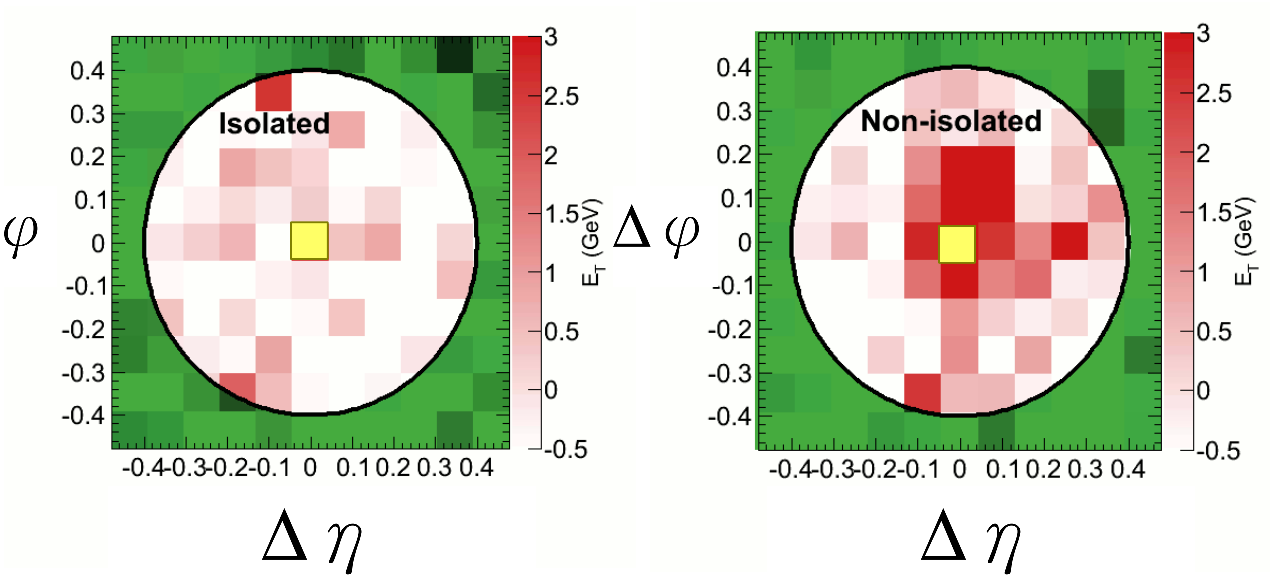


Isolated photon   Non-isolated photon

CMS data: $\Delta R<0.4$

$\Sigma E_T^{IsoCone} < 5$ GeV

using the calorimeter and tracker minus background



Photon isolation criteria in ATLAS

- ATLAS photon isolation:
  - $E_T(R_{iso}=0.3)$ – transverse energy in a cone of R_{iso} around the photon axis
    - UE energy fluctuations and di-jet background
    - Width of $E_T(R_{iso}=0.3)$ in 0-10% photon+jet events is 6 GeV
  - Isolation requirement: $E_T(R_{iso}=0.3) < 6$ GeV

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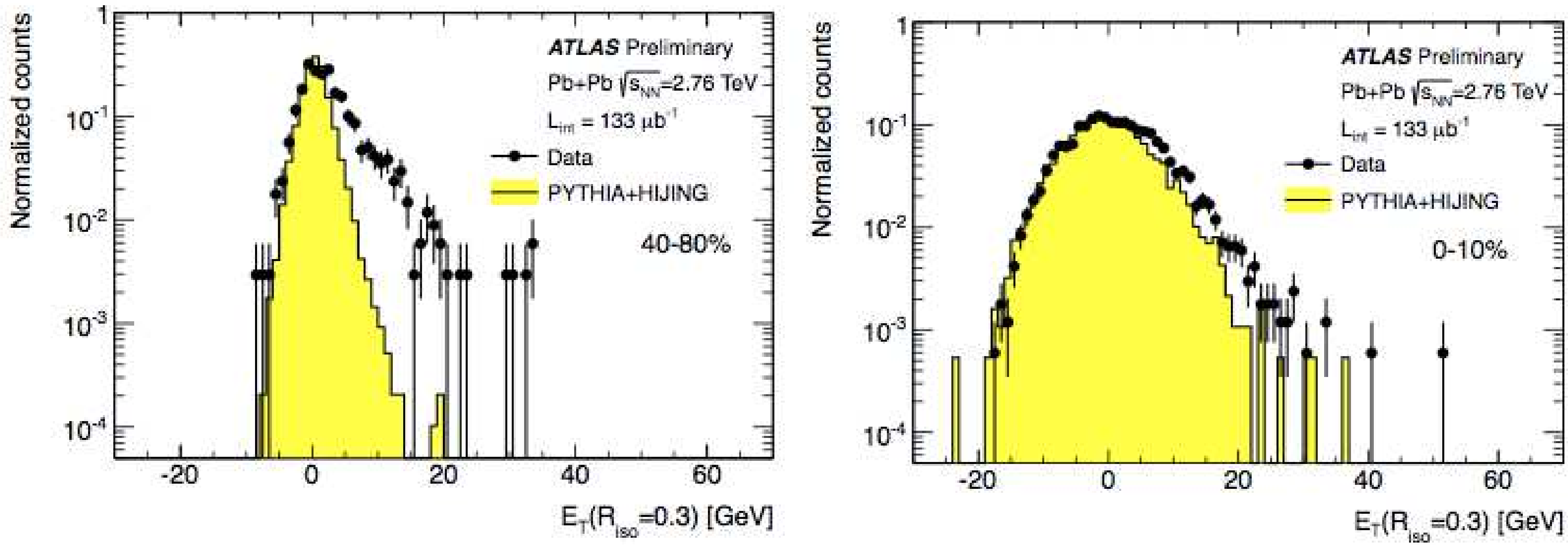
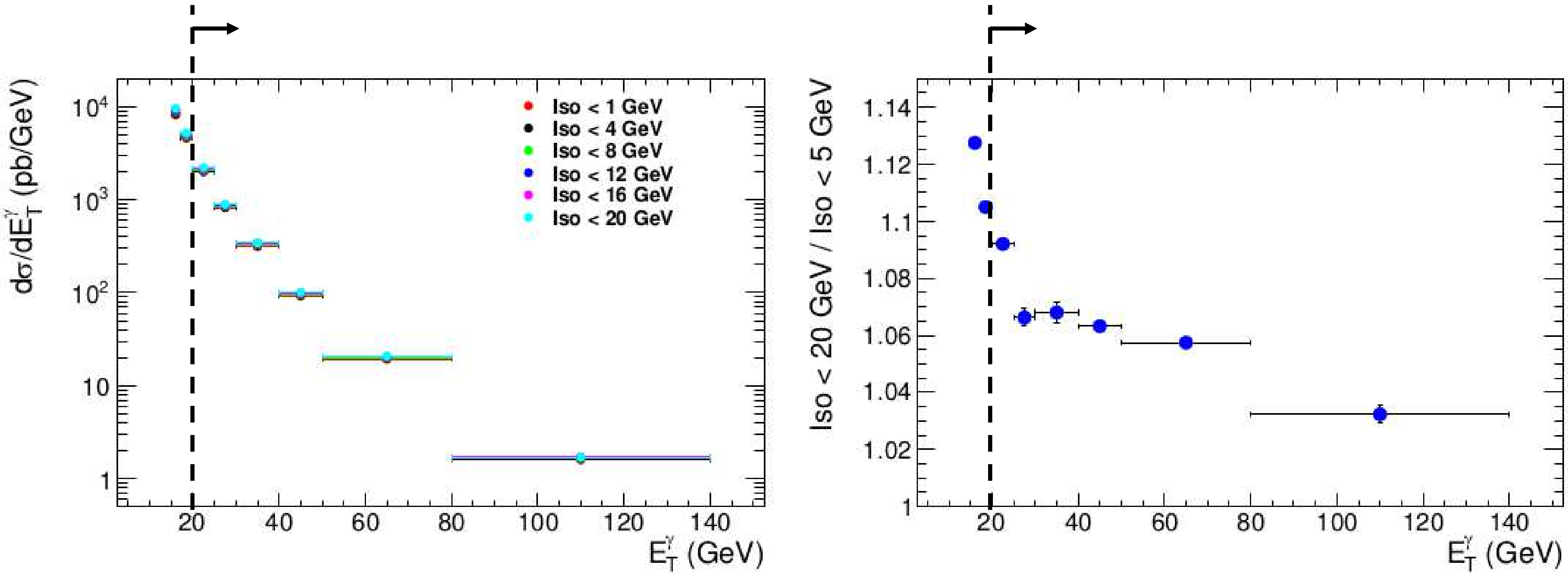


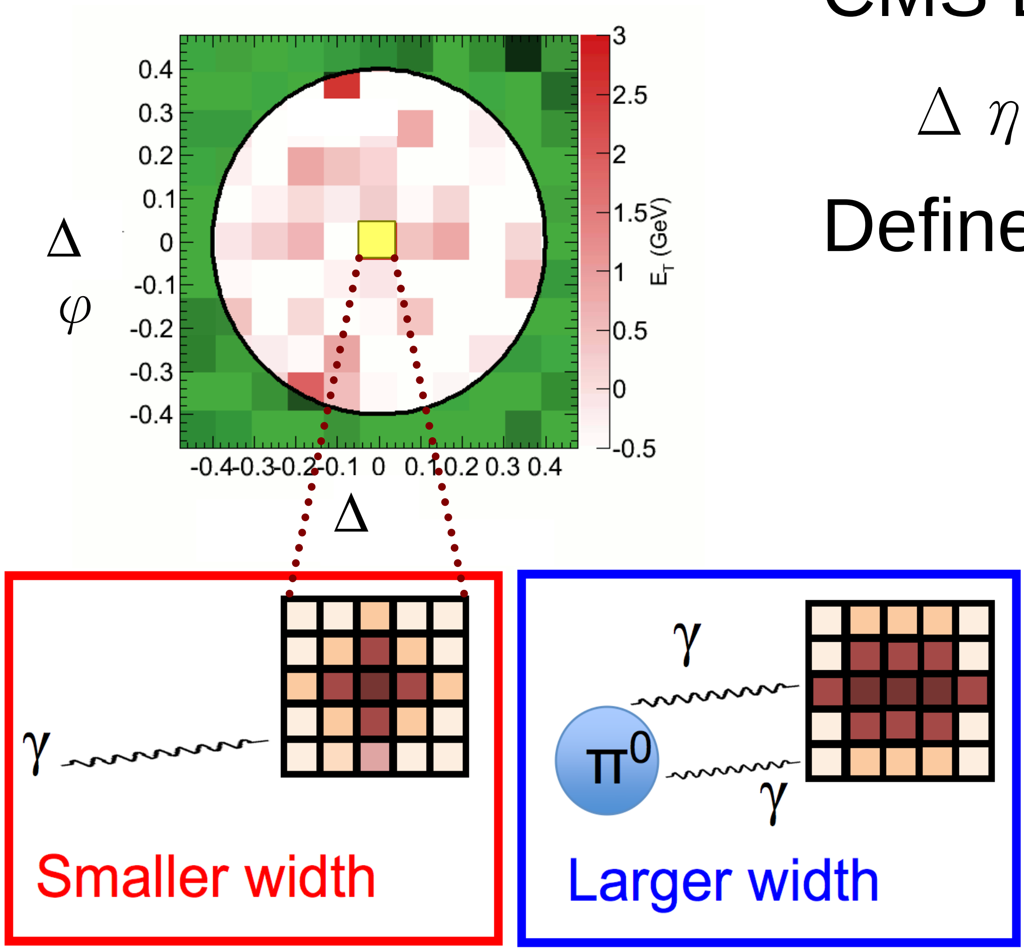
Effect of photon isolation from JETPHOX



JETPHOX calculation with different isolation requirement within a cone of R=0.4 and photon $|\eta|<1.44$

Variation from Iso<5 to Iso<20 cause ~3-9% change in the cross-section calculation

Removing decay photons



CMS ECAL's fine segmentation

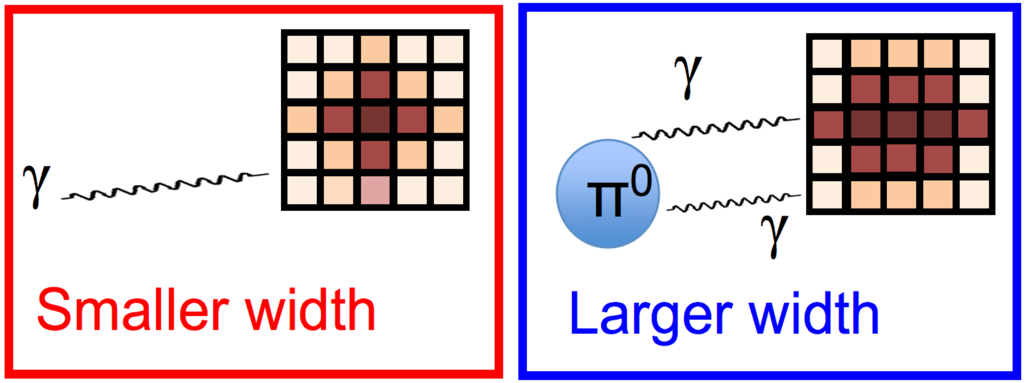
$\Delta\,\eta$ x $\Delta\,\Phi$ = 0.0174 x 0.0174

Define a "width" parameter:

$$\sigma_{\eta\eta}^2 = \frac{\sum w_i \left(\eta_i - \langle\eta\rangle\right)^2}{\sum w_i}$$

$$w_i = \max\left(0,\ \ 4.7 + \ln\left(\frac{E_i}{E_{Total}}\right)\right)$$

Removing decay photons



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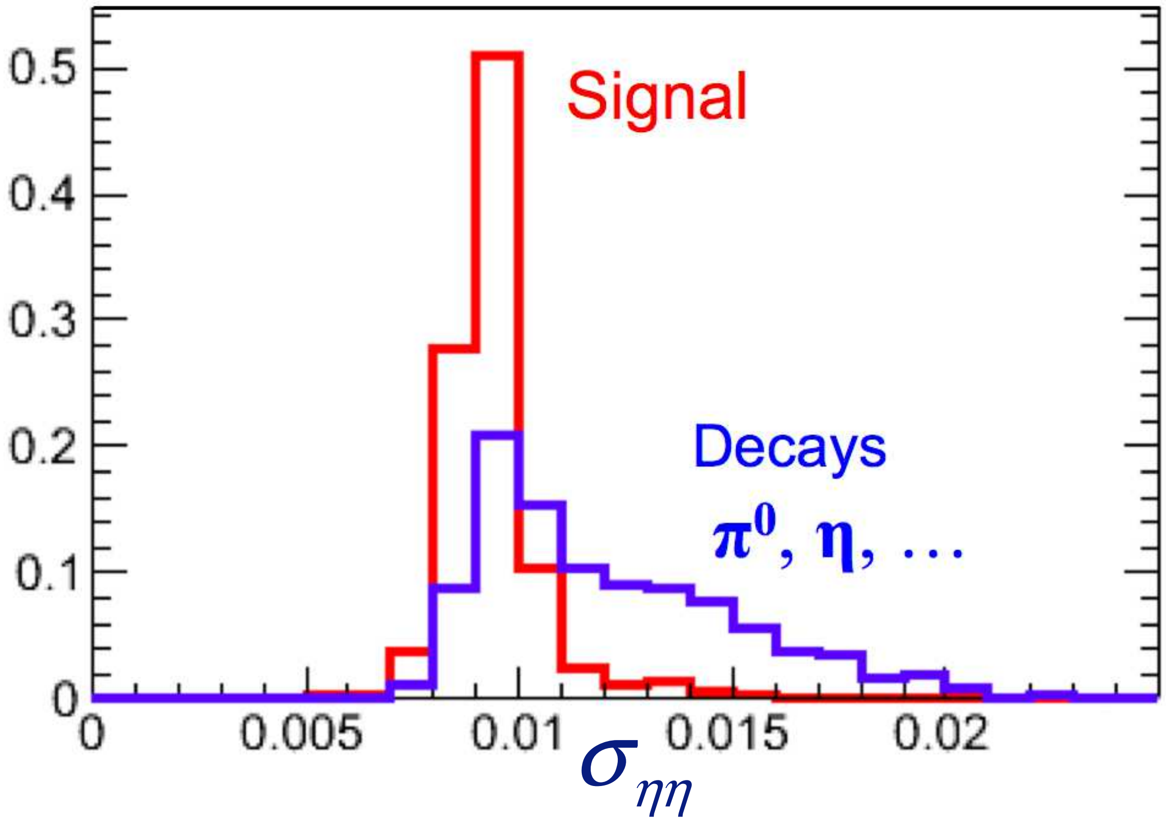
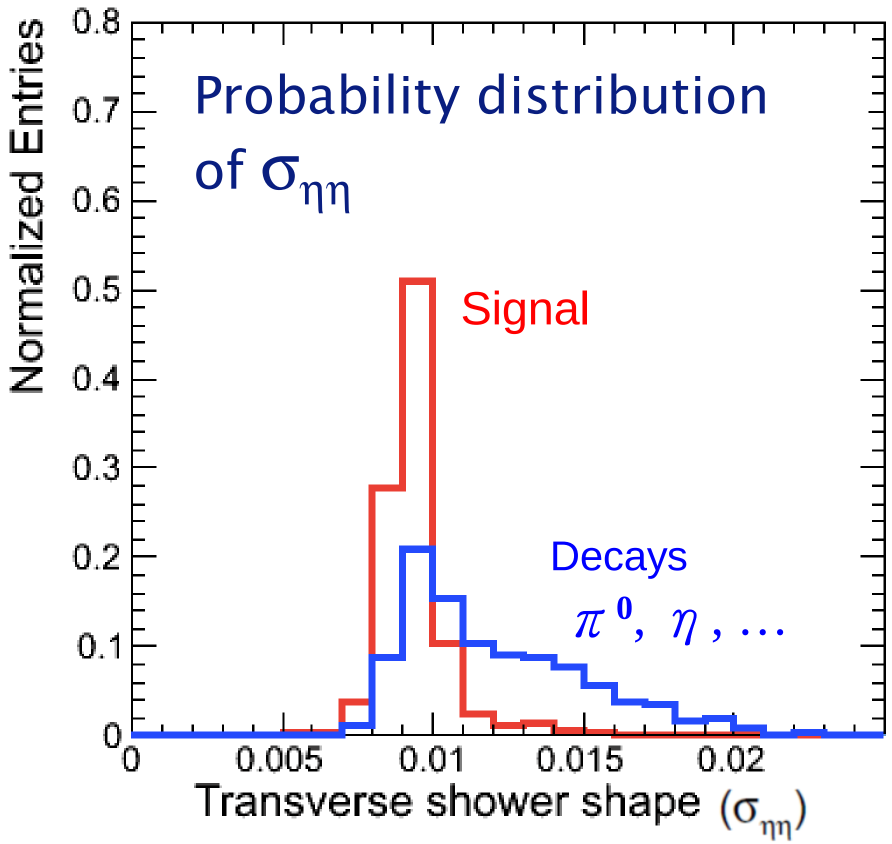


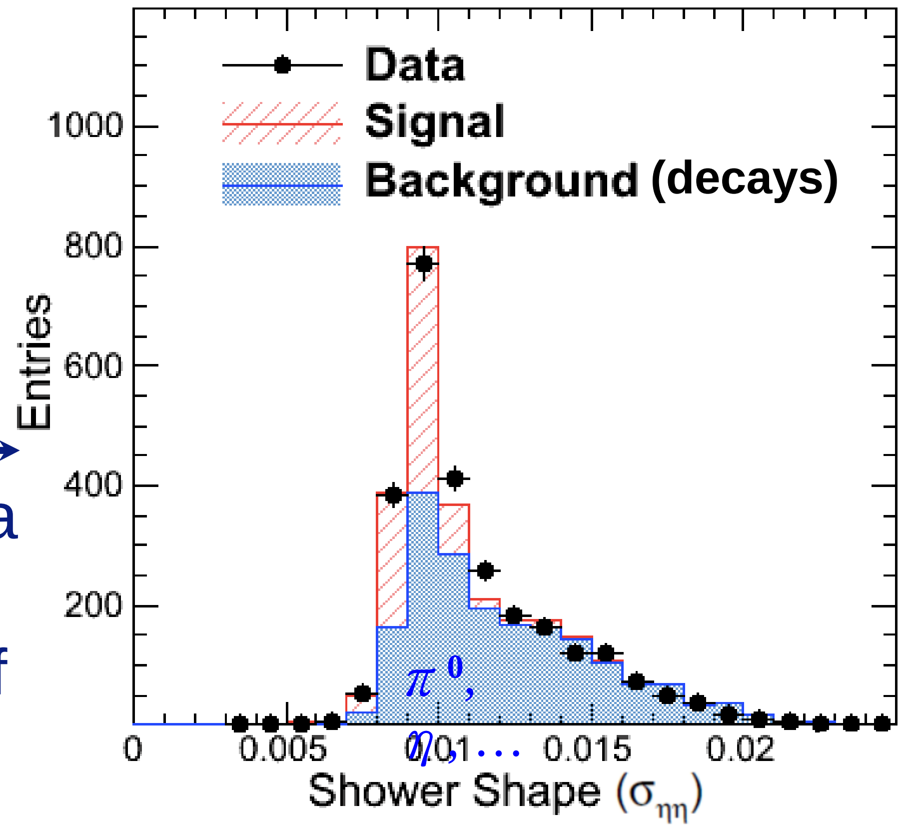
After isolation & shower shape cut:

Purity ~ 50-70%

Details of removing decay photons



Fit data with a sum of the 2

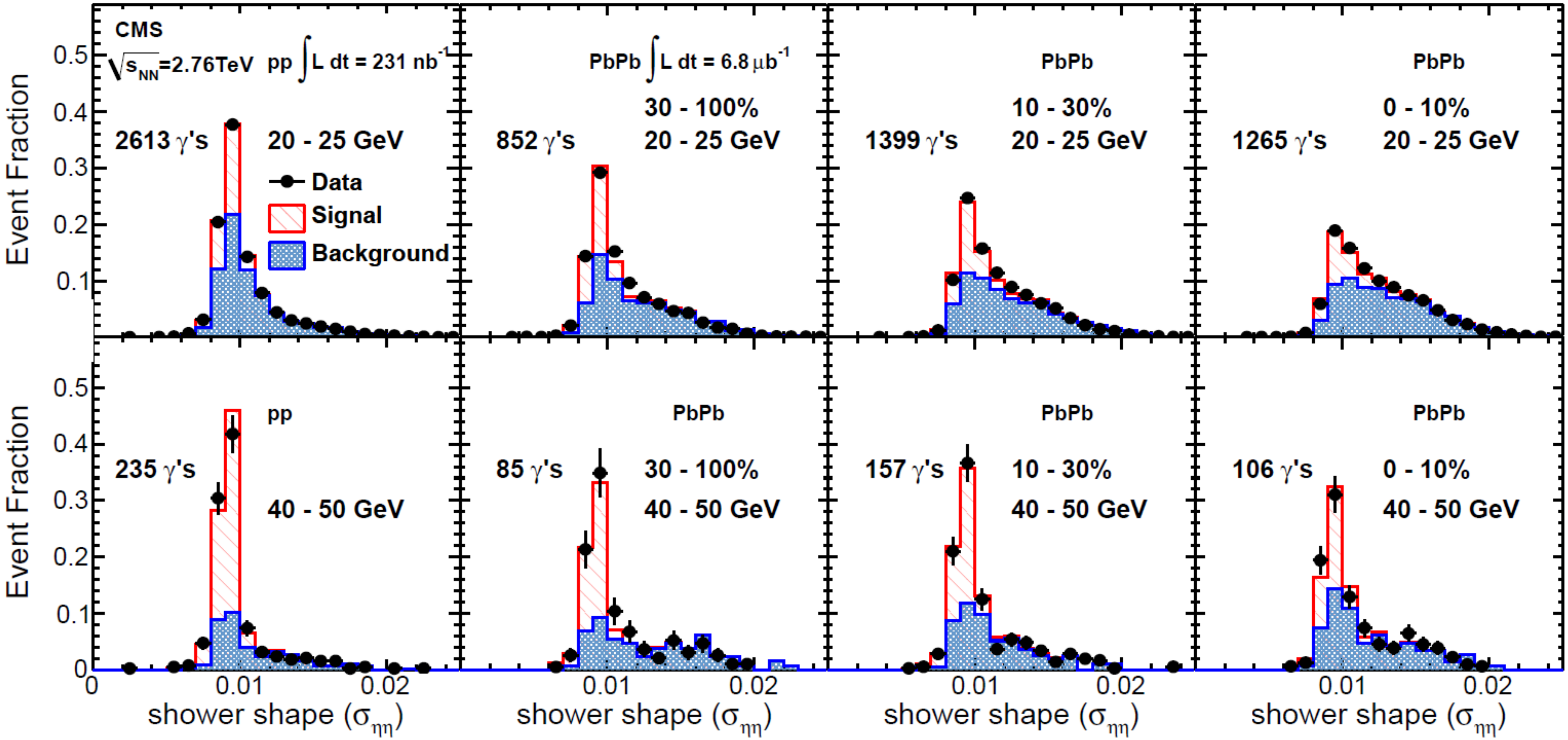


A technique also used in CMS pp analysis:

Signal template: obtained from PYTHIA+MinBias data

Decay template: Using a data-driven method with non-isolated photons: $\Delta R<0.4$, 6 GeV < $\sum E_T^{IsoCone}$ < 11 GeV

Fitting signal+decay photons



Signal template and background (decay) template extracted in separate bins of photon E_T and collision centrality

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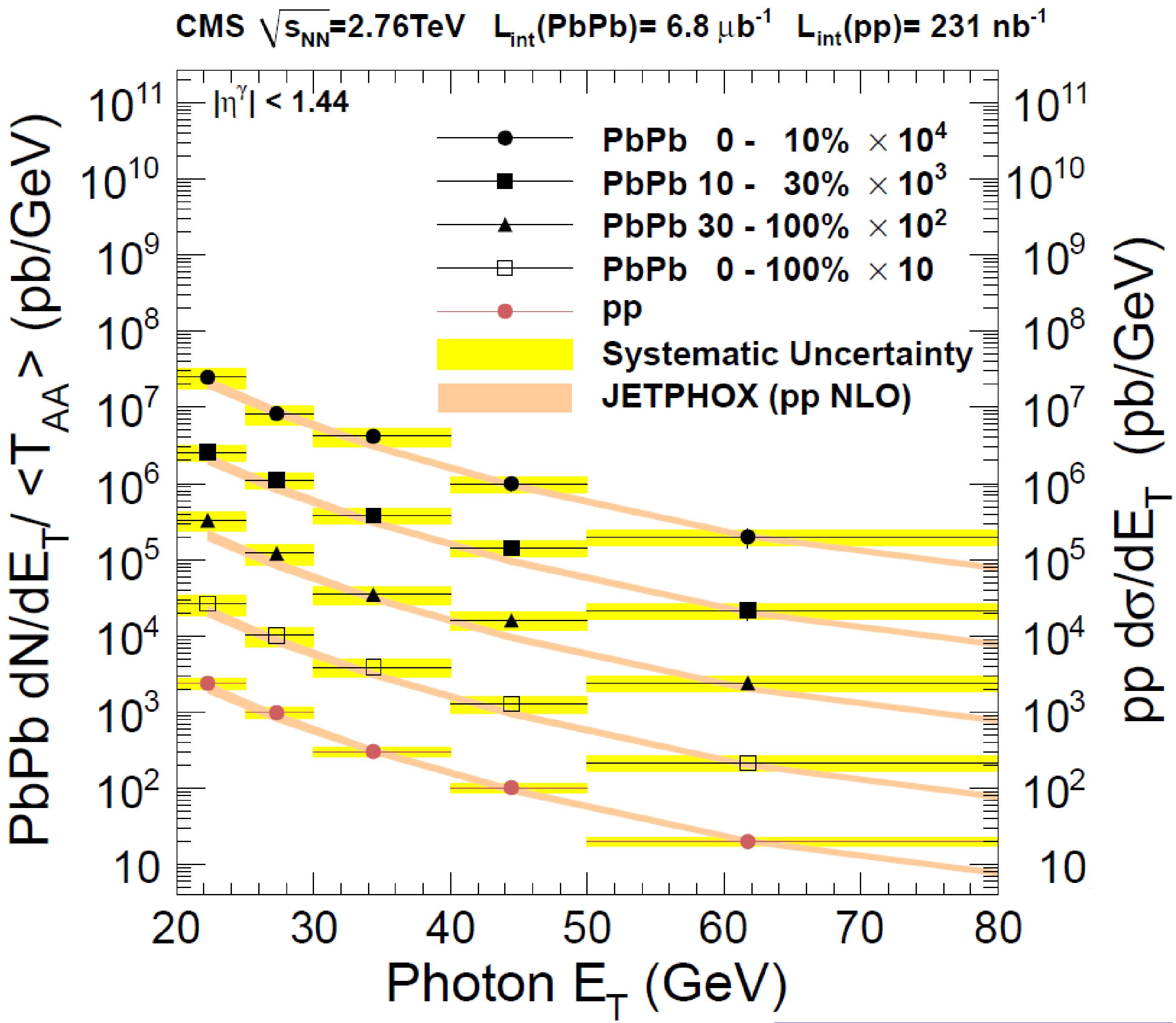
Photon E_T spectra in pp and PbPb

Reconstructed photon spectra scaled by T_{AA}

Consistent with JETPHOX using pp PDF (CT10).



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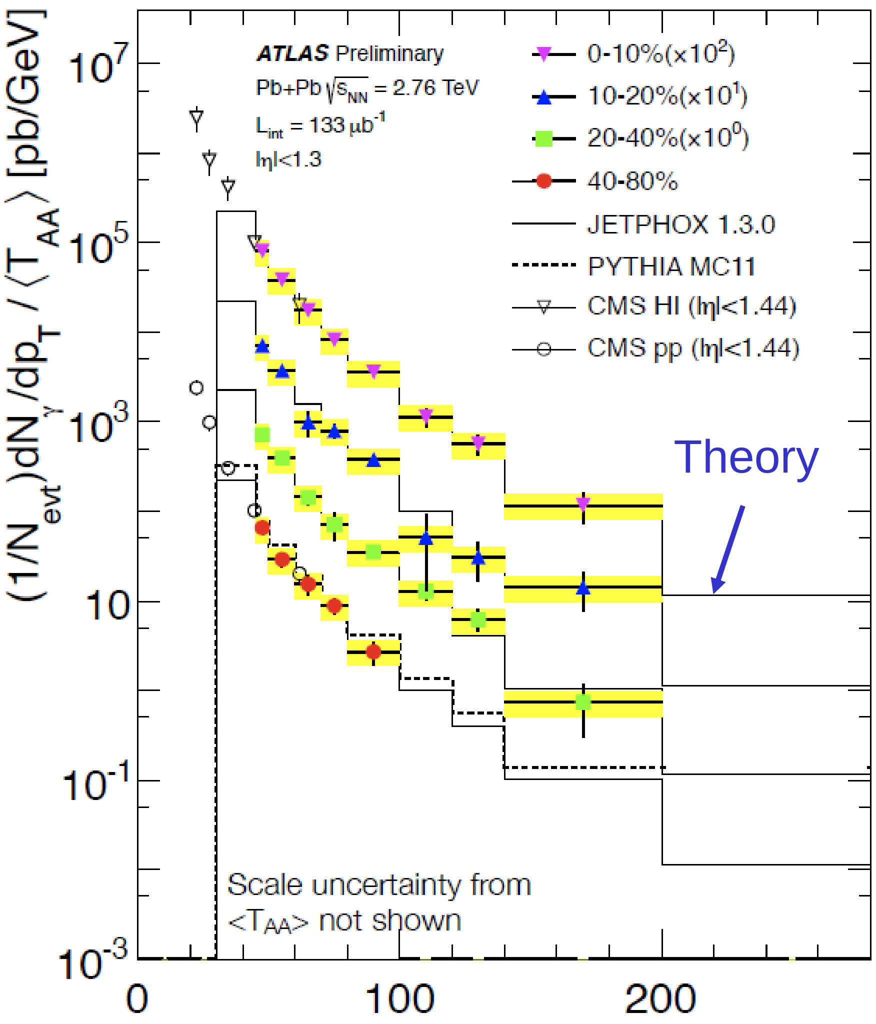
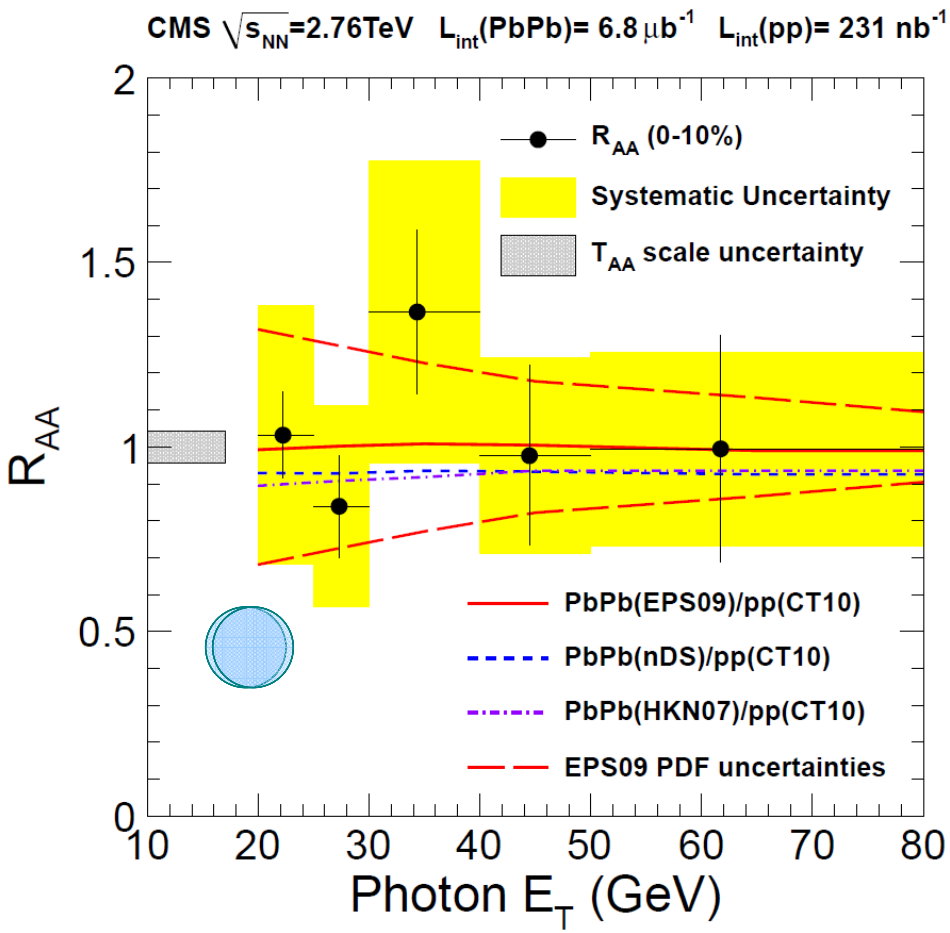
Isolated photon R_{AA}



ATLAS-CONF-2012-052

0-10% PbPb compared to pp



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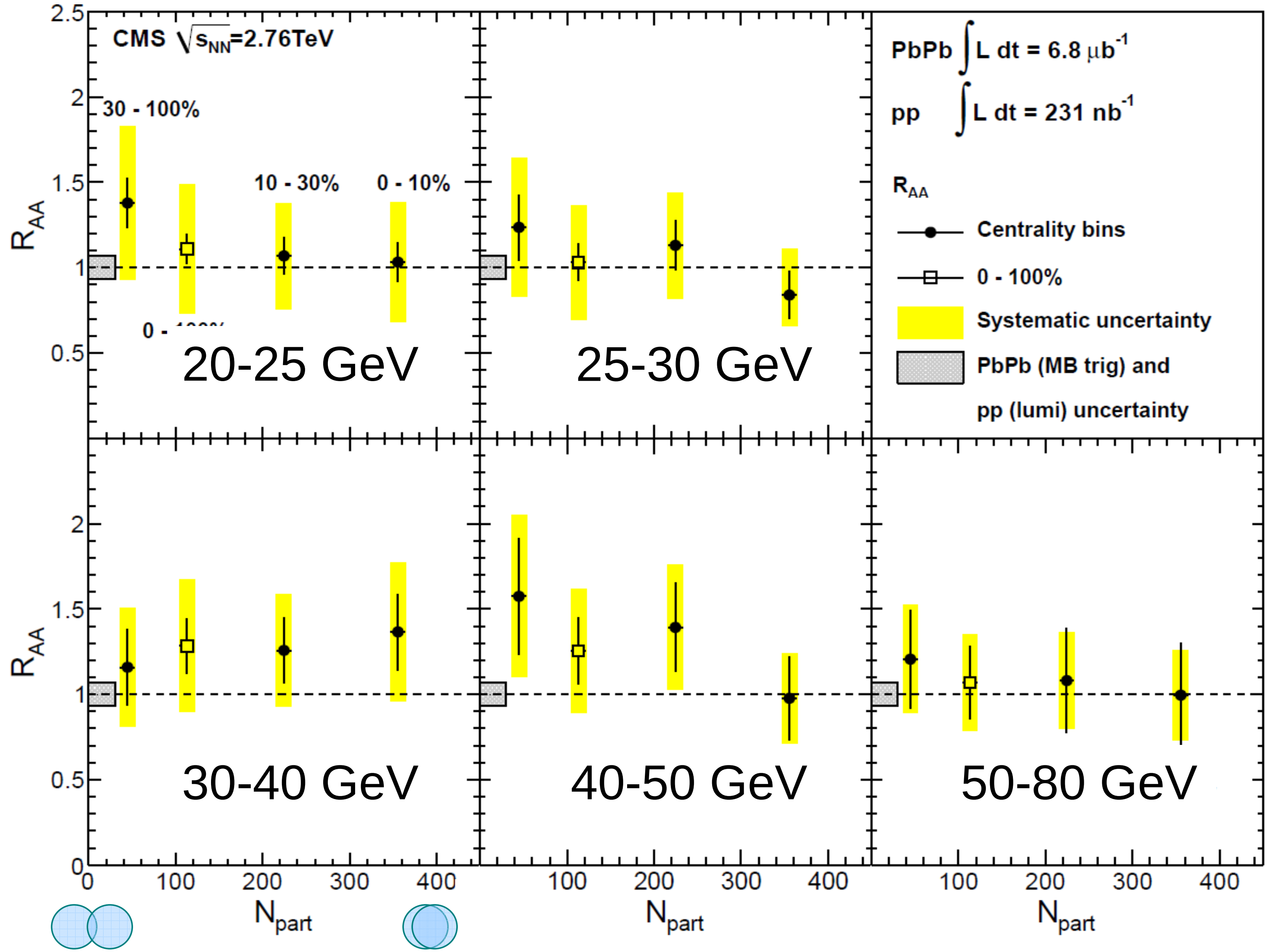
- Results are consistent between ATLAS and CMS
- No modification of the photons (within 20-40%)

Isolated photon R_{AA} vs E_T & Centrality



No dependence on centrality or E_T

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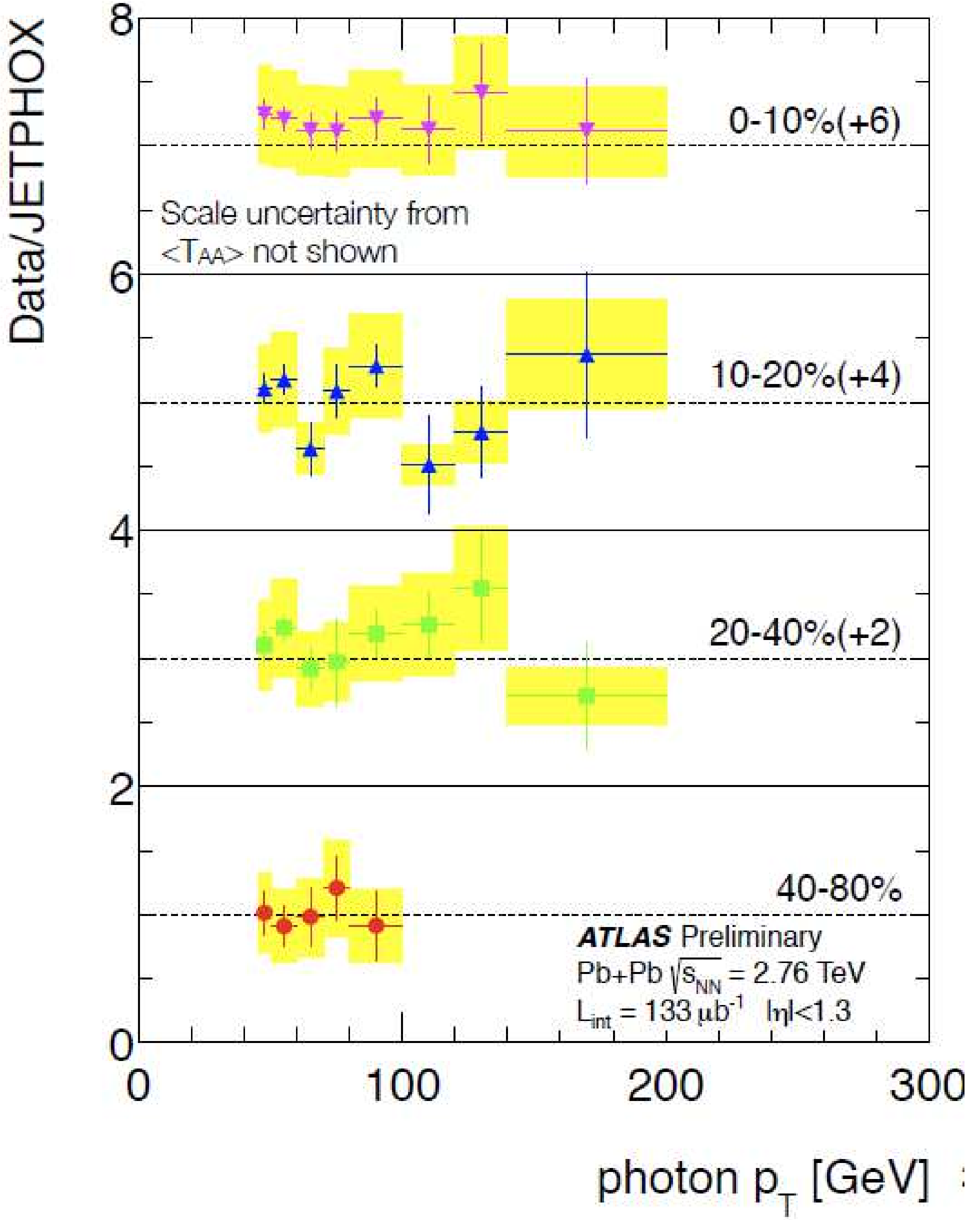
Isolated photon R_{AA} vs E_T & Centrality

ATLAS-CONF-2012-119



Systematic uncertainties (CMS)

Source	pp	PbPb centrality 0–10%	PbPb centrality 10–30%	PbPb centrality 30–100%
Efficiency	1–5%	5–9%	5–7%	5–6%
Signal modeling	3–5%	1–5%	3–5%	1–4%
Background modeling	9–13%	15–23%	14–16%	12–21%
Electron veto	1%	3–6%	3–5%	3–5%
Photon isolation definition	2%	7%	5%	2%
Energy scale	3–6%	9%	9%	9%
Energy smearing	1%	4%	4%	4%
Shower-shape fit	3%	5%	5%	5%
Anomalous signal cleaning	1%	1%	1%	1%
N_{MB}	–	3%	3%	3%
Luminosity	6%	–	–	–
Total without T_{AA}	14–16%	23–30%	22–25%	23–28%
T_{AA}	–	4%	6%	12%
Total	14–16%	23–30%	23–26%	26–31%

Main sources of systematic uncertainties:

Background modeling and photon energy scale

Systematic uncertainties (CMS)

Source	pp	PbPb centrality 0–10%	PbPb centrality 10–30%	PbPb centrality 30–100%
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Background modeling → data driven, can be reduced by adding more statistics

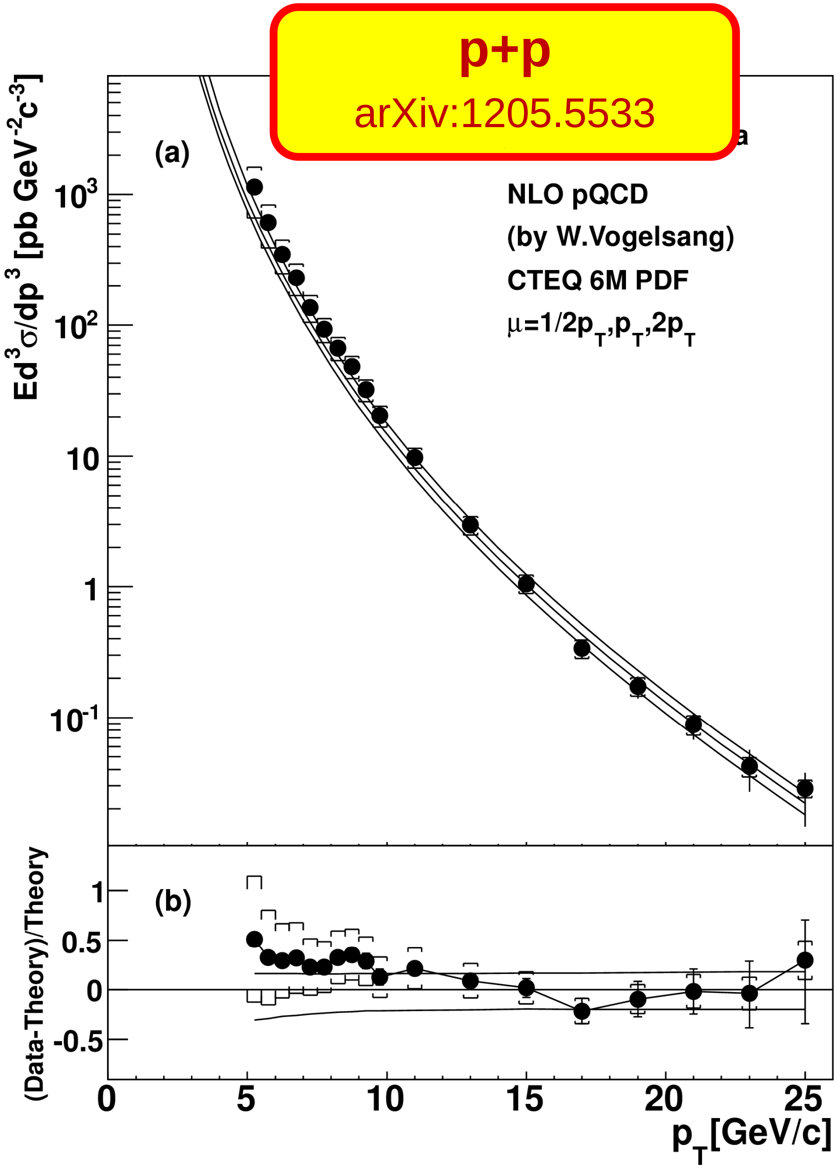
Photon energy scale → control sample from Z→ee and event mixing

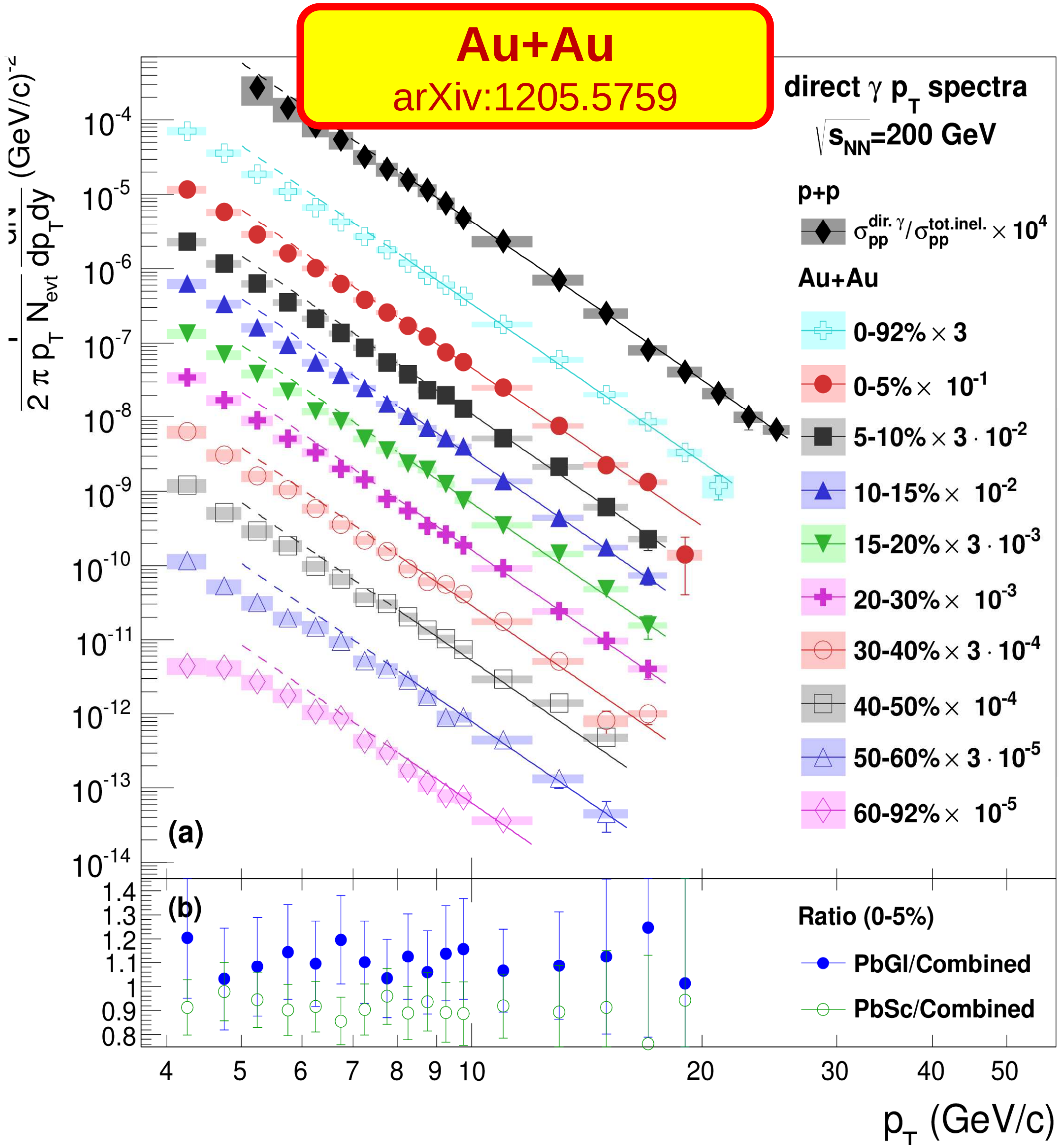
Summary of isolated photons

- Input to nPDF:
  - Isolated photons are not modified (within 20-40% systematical uncertainty)
  - Systematic uncertainty is ~ nPDF uncertainty
  - Possible future improvements on the systematics on the background modeling and photon energy scale
- Good agreement between ATLAS and CMS results
- Input to jet quenching studies:
  - Pro: higher statistics, Con: large background
  - Need to take care of the possible bias due to the isolation requirement in jet quenching studies (ex: photon-hadron correlation, medium response)

Backup slides

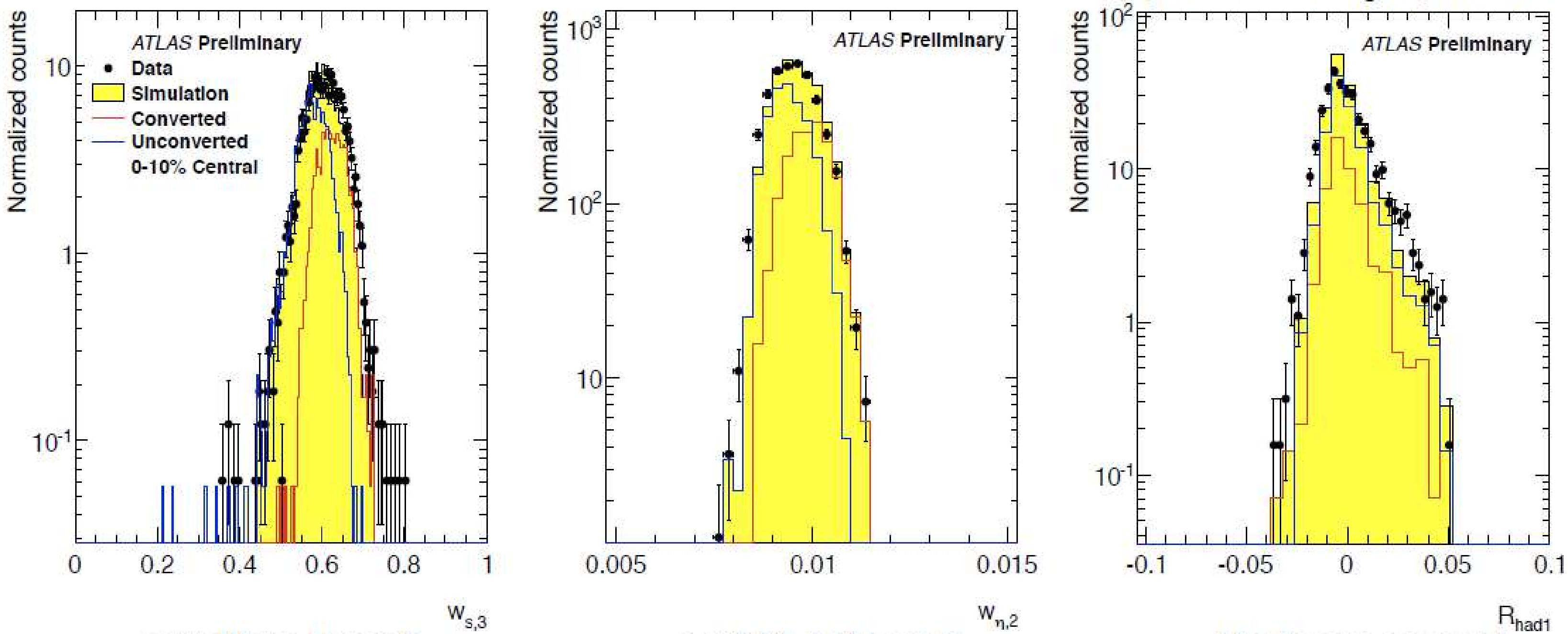
Direct photons at RHIC





Photon performance: shower shapes

40 < p_T < 70 GeV tight photons



η width in layer 1 (strip units)

η width in layer 2 (η units)

Hadronic energy/ cluster energy

Comparison of tight photons with fully simulated photon+jet events, **total MC (yellow)**, **unconverted (blue)**, and **converted (red)** photons.
Small p_T and η dependent shifts (from pp) applied to MC.

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