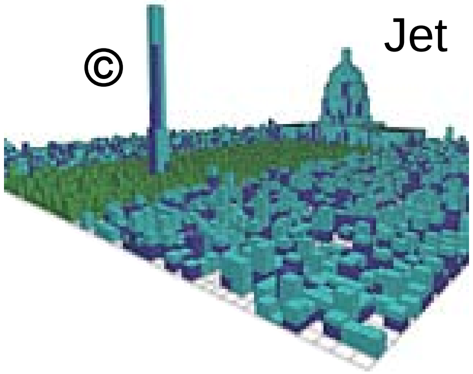
Review of photon physics results at Quark Matter 2012



Gustavo Conesa Balbastre

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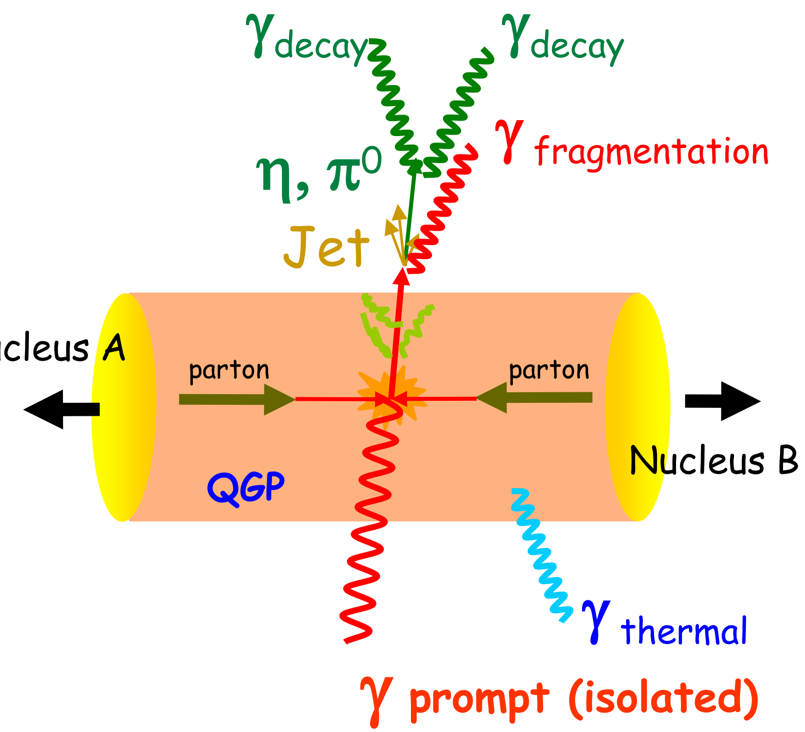
Why photons?

- Direct **thermal**: Produced by the QGP
  - ➔ Measure medium temperature
  - ➔ $R_{AA} > 1$, $v_2 > 0$
- Direct **prompt**: QCD LO/NLO processes, not modified by QGP, correlated with QCD jet
  - ➔ Validate pQCD predictions
  - ➔ Isolated γ : $R_{AA} = 1$, $v_2 = 0$
  - ➔ jet : $R_{AA} < 1$, $v_2 > 0$, D(z) modified, jet quenching
- **Decay** (π^0, η,□): belong to a QCD jet
  - ➔ Validate pQCD predictions
  - ➔ $R_{AA} < 1$, $v_2 > 0$, jet quenching

... and to find the Higgs ...



What have we learned?

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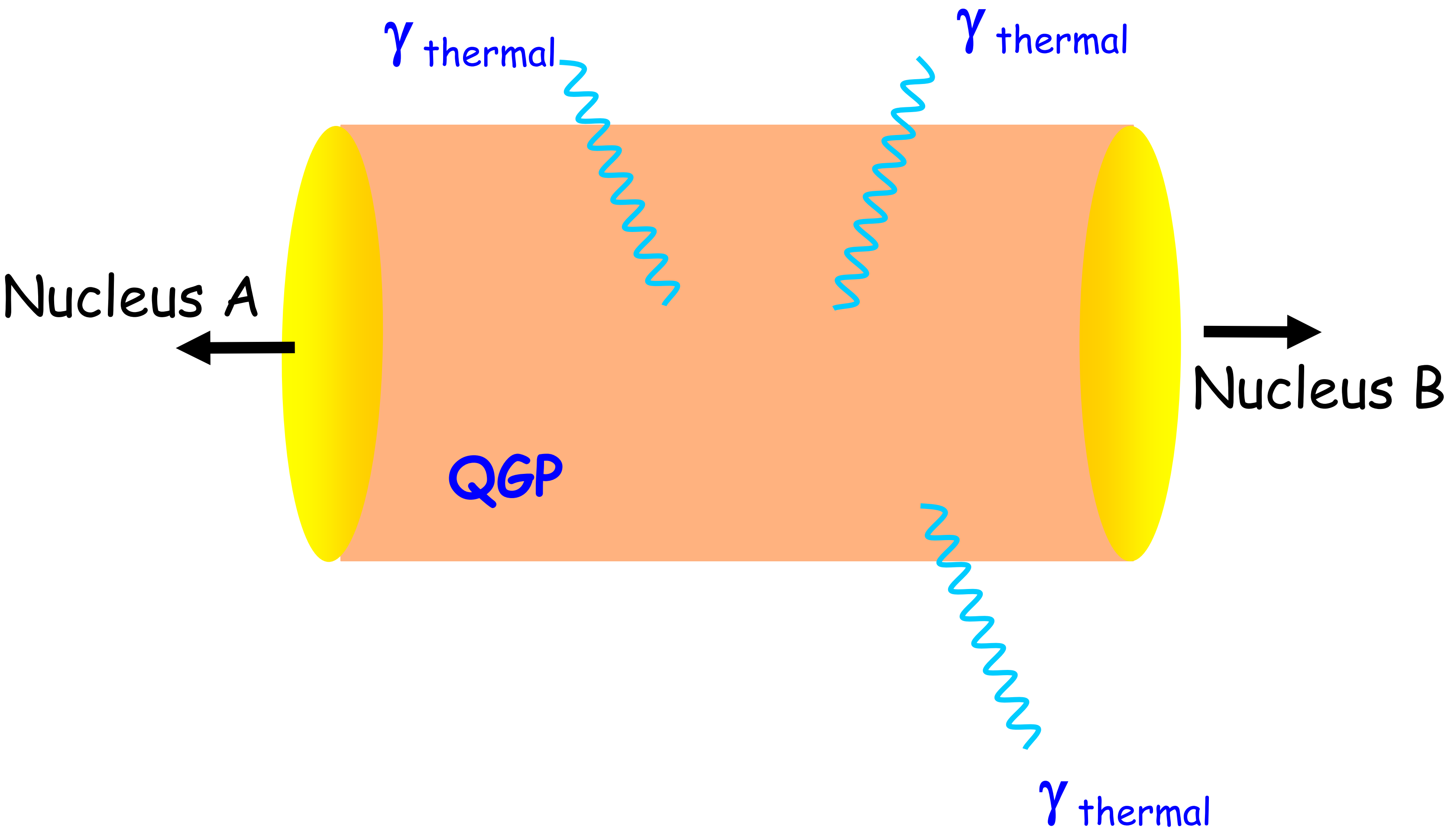
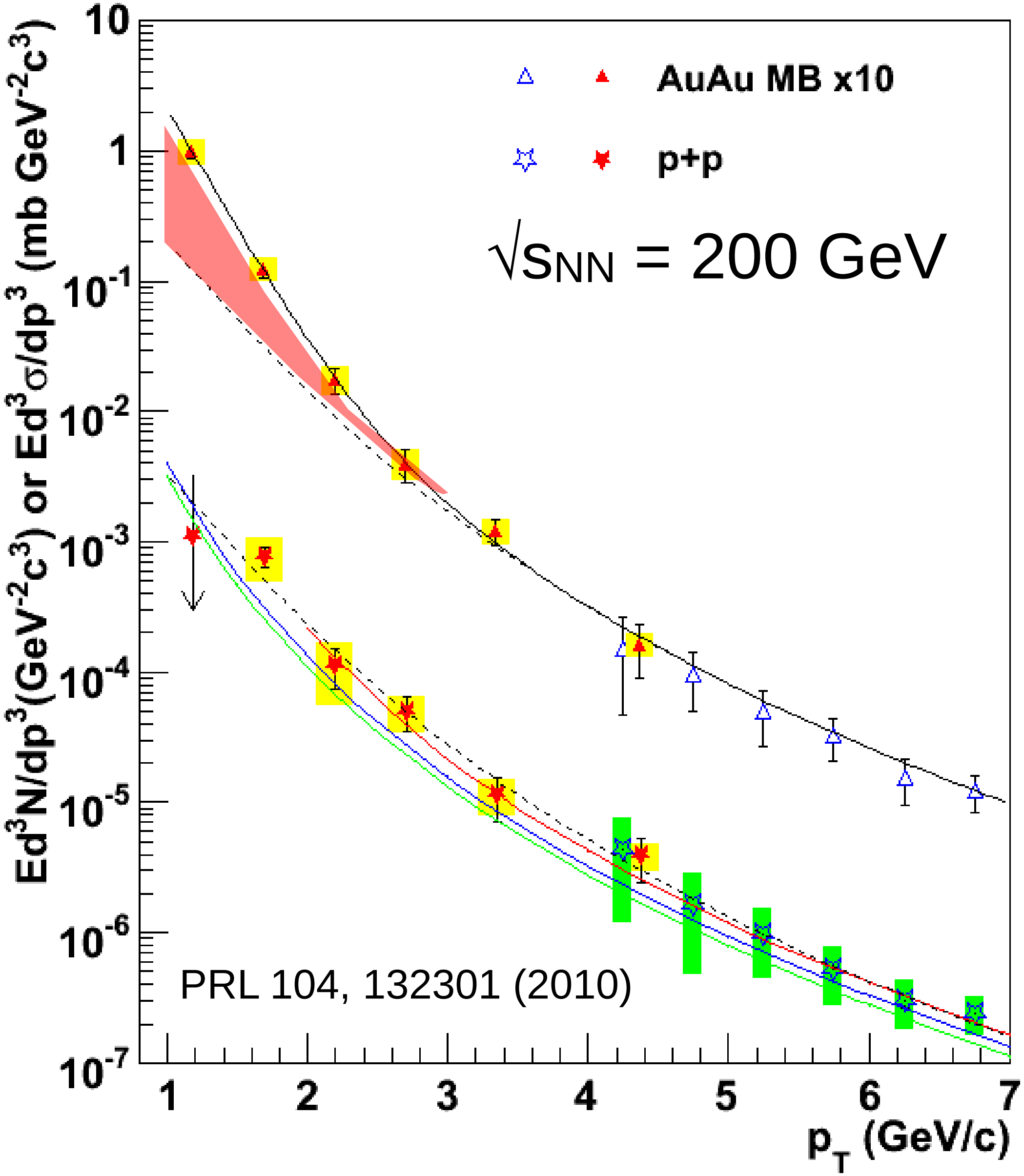
Thermal photons



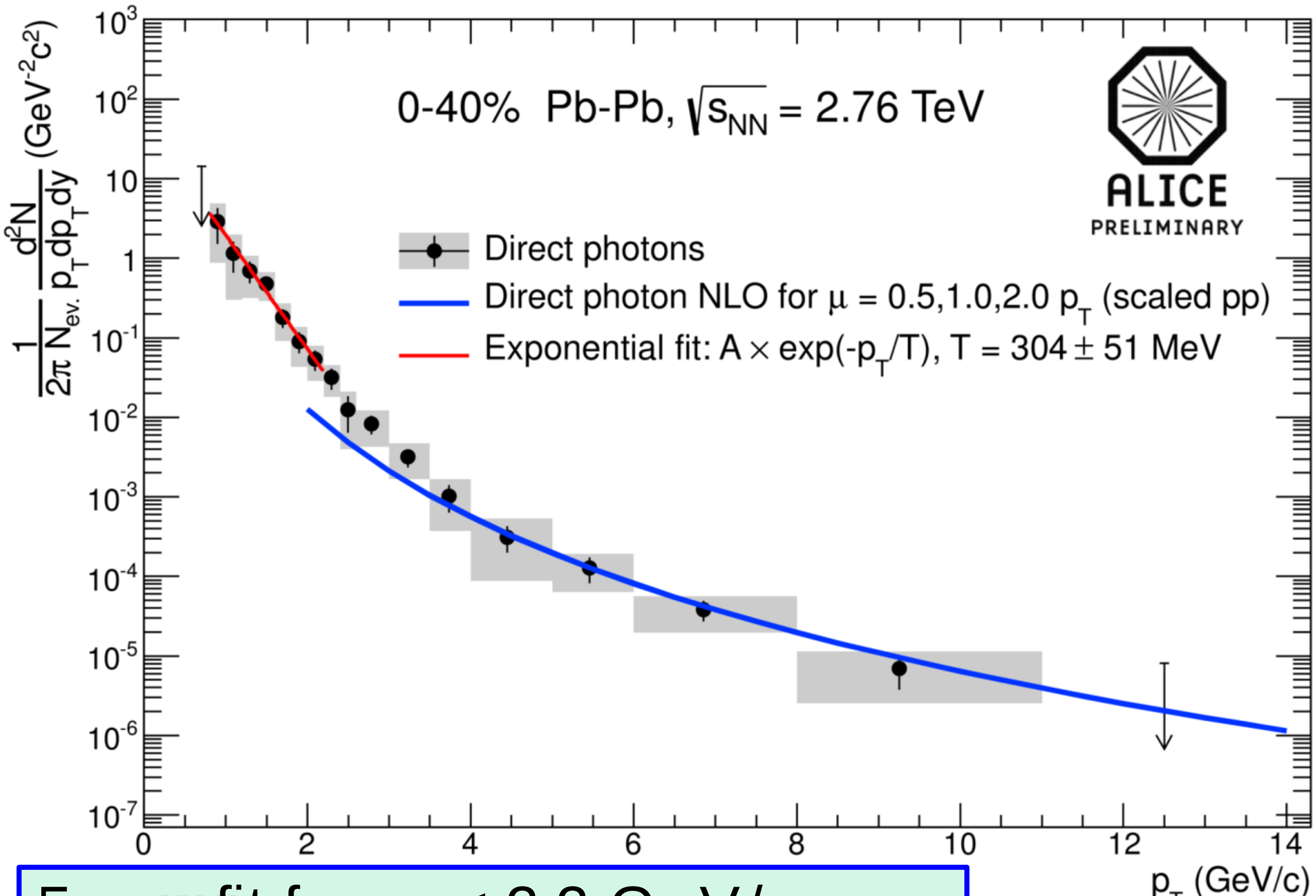
Direct photon production : PHENIX



- Direct photon excess above *p+p* spectrum
- Exponential (consistent with thermal)
- T= 221±19^{stat}±19^{sys} MeV
- No excess in d-Au collisions (QM2011)

What about LHC?

Direct photon production: ALICE



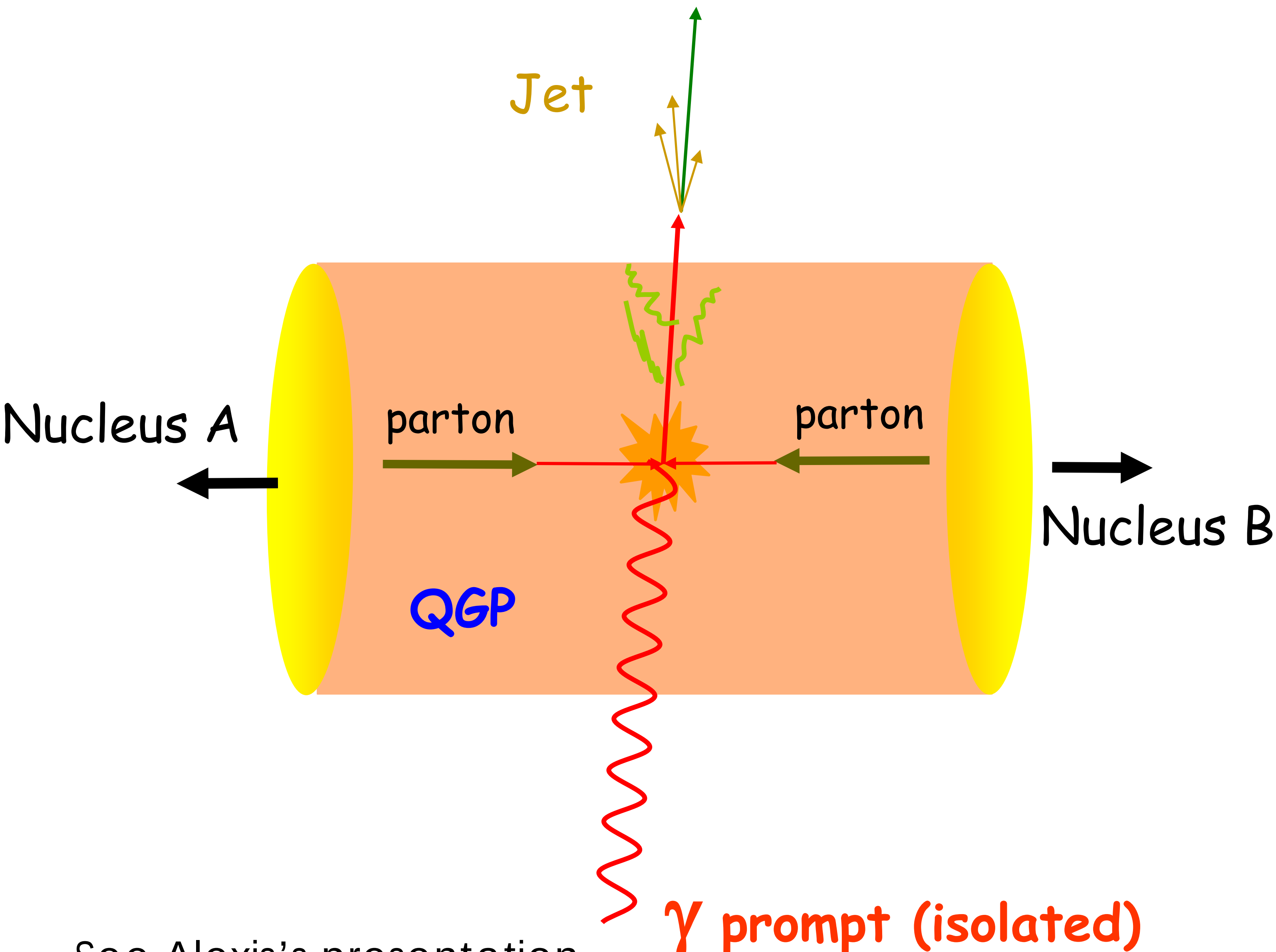
p_T < 2 GeV/c :
~20% excess of direct photons
p_T > 4 GeV/c :
agreement with N_{coll}-scaled NLO

Expo. fit for p_T < 2.2 GeV/c
inv. slope T= 304±51$^{stat+sys}$ MeV
for 0–40% Pb–Pb at √s 2.76 TeV
PHENIX: T= 221±19^{stat}±19^{sys} MeV
for 0–20% Au–Au at √s 200 GeV

... new guinness record! ...

Let's go to higher γ energy ...

Prompt photons



See Alexis's presentation
for analysis of isolated photons in ALICE

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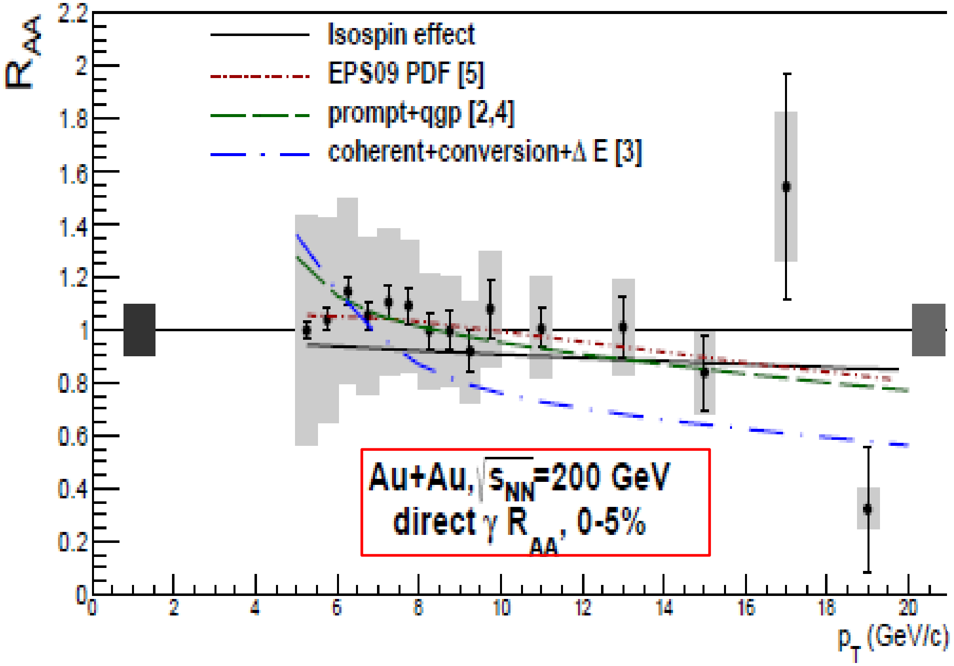
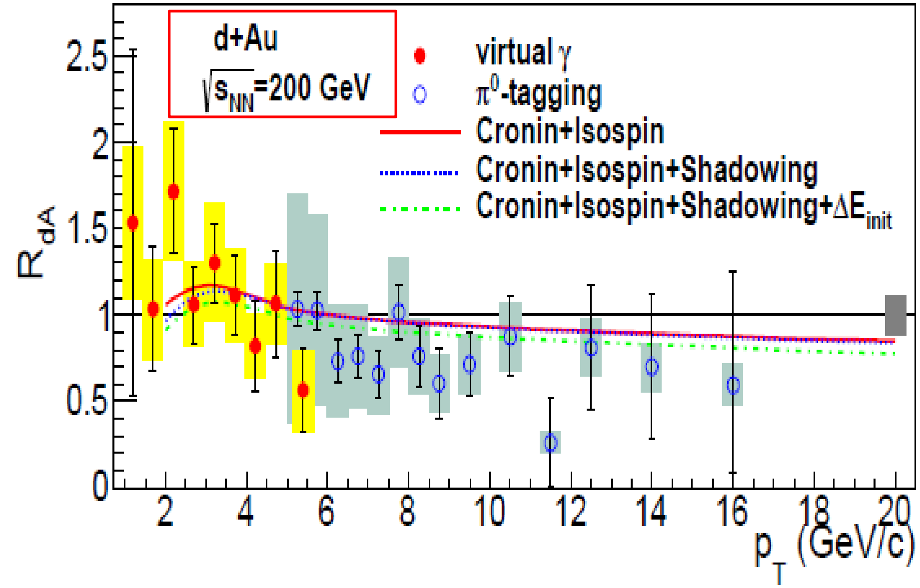
Direct photon production : PHENIX

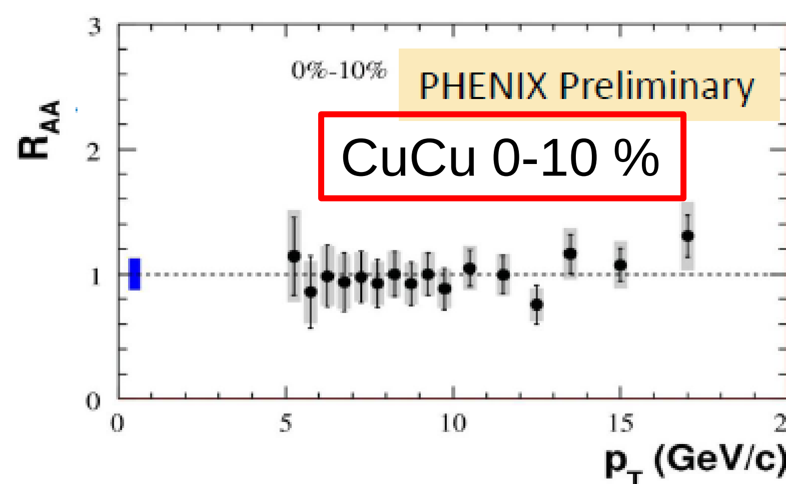
Submitted PRL arXiv:1205.5759



arXiv:1208.1234



- No direct photon suppression in AuAu, CuCu and dAu at √s=200 GeV



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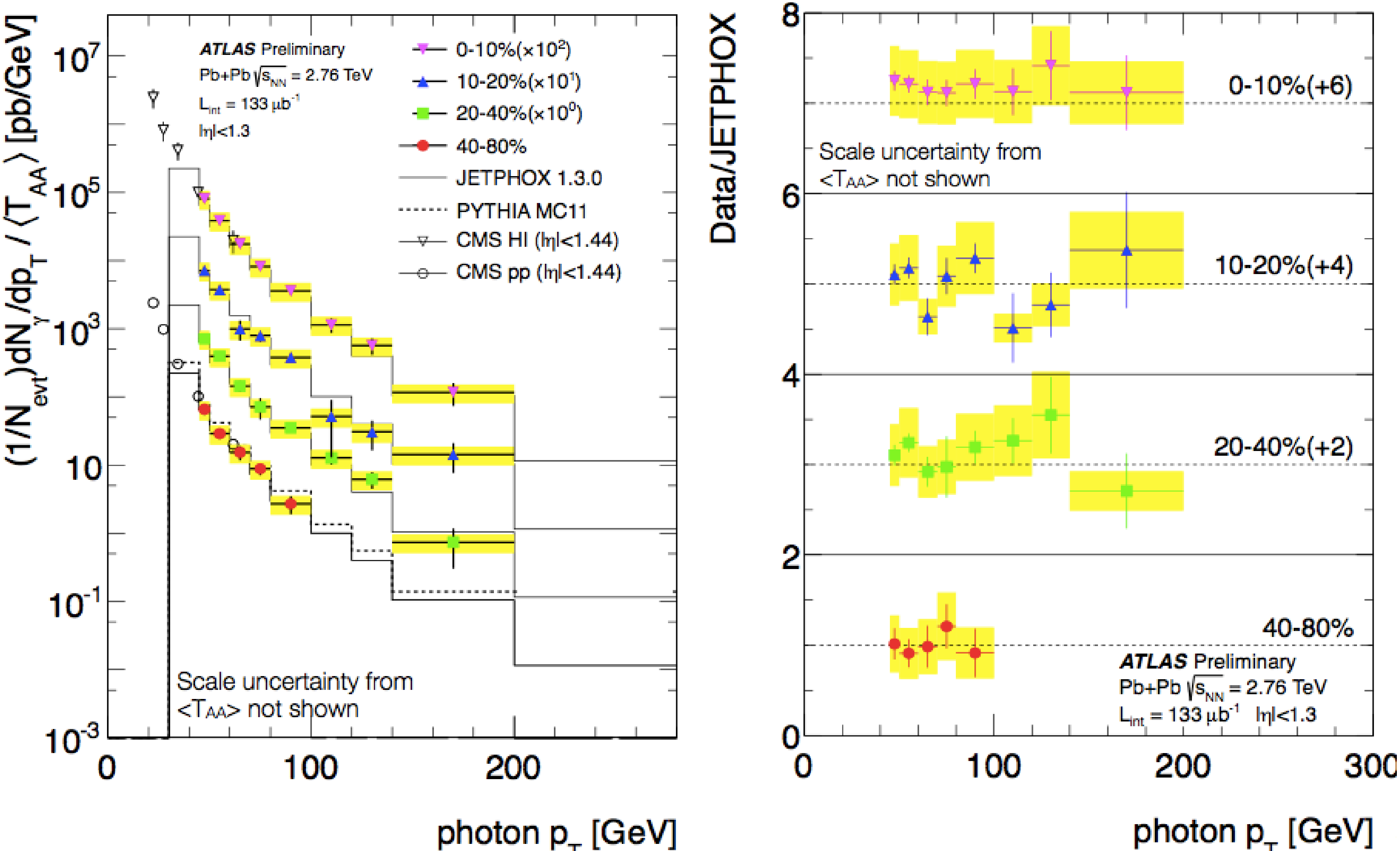
Let's go to even higher γ energy at LHC …

Isolated photon production: ATLAS



- Good agreement with NLO predictions
- No suppression
- Similar for Z

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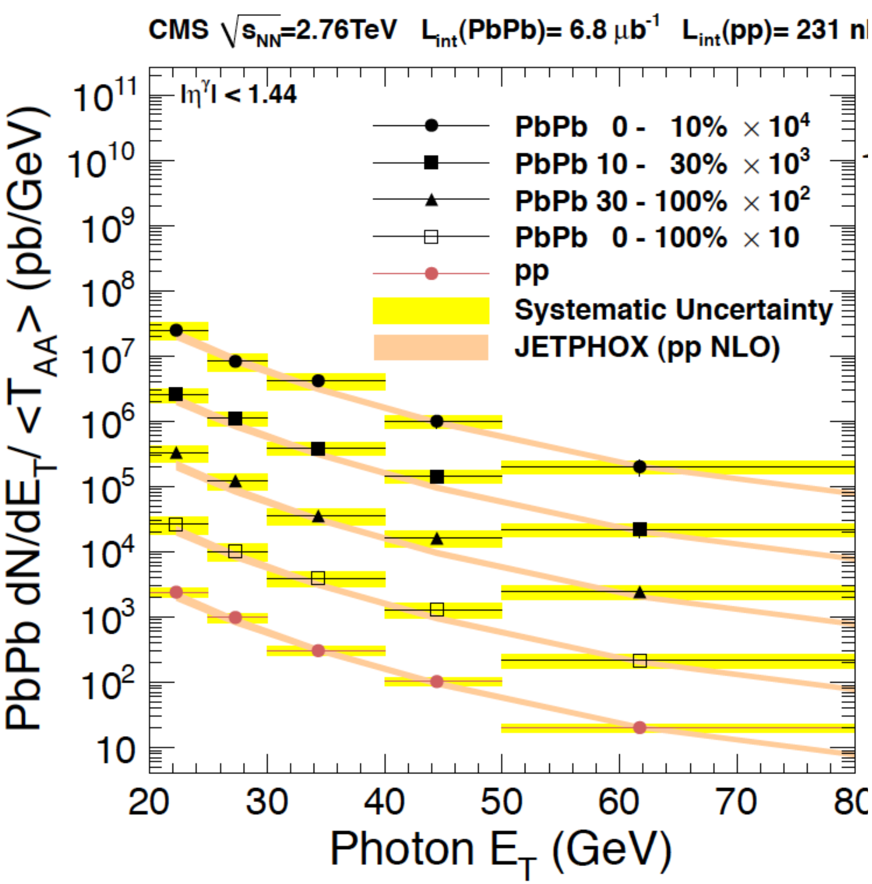
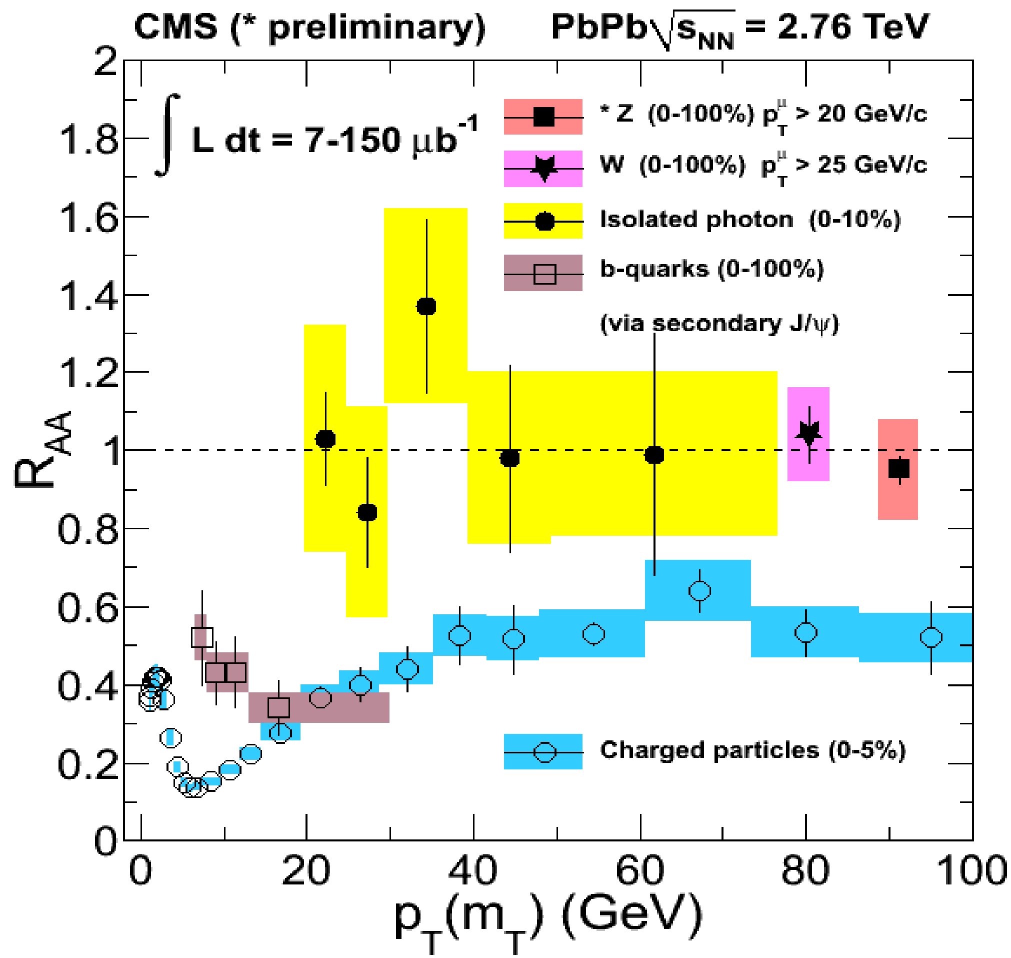
Isolated photon production: CMS





- Bosons: isolated γ, W and Z, are not suppressed unlike other particle species and jets

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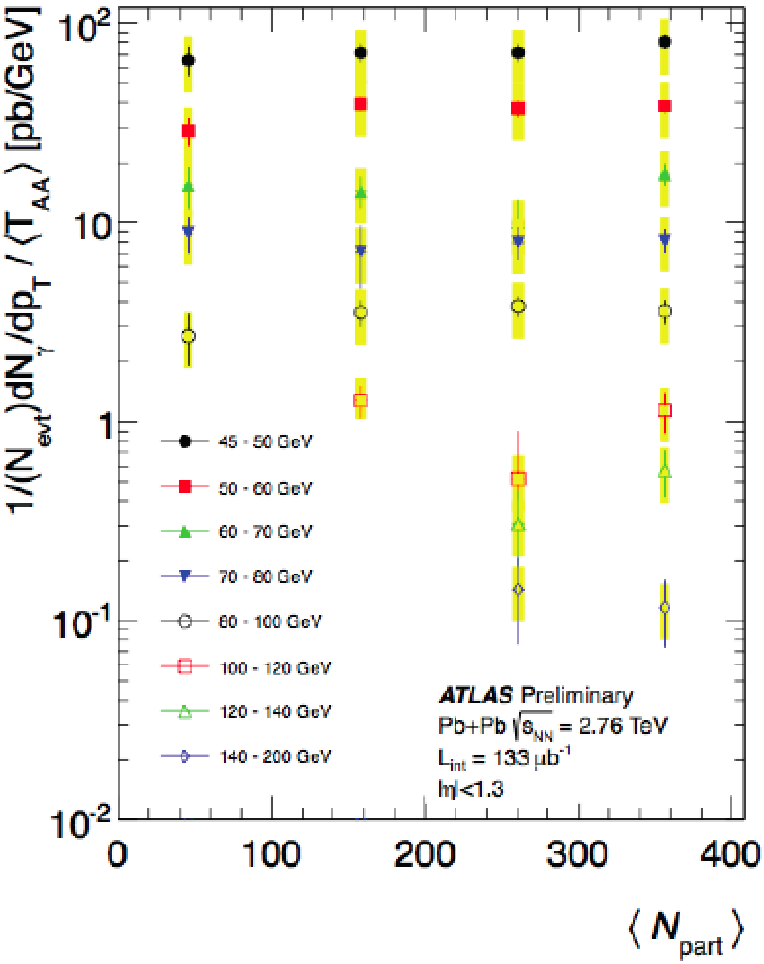
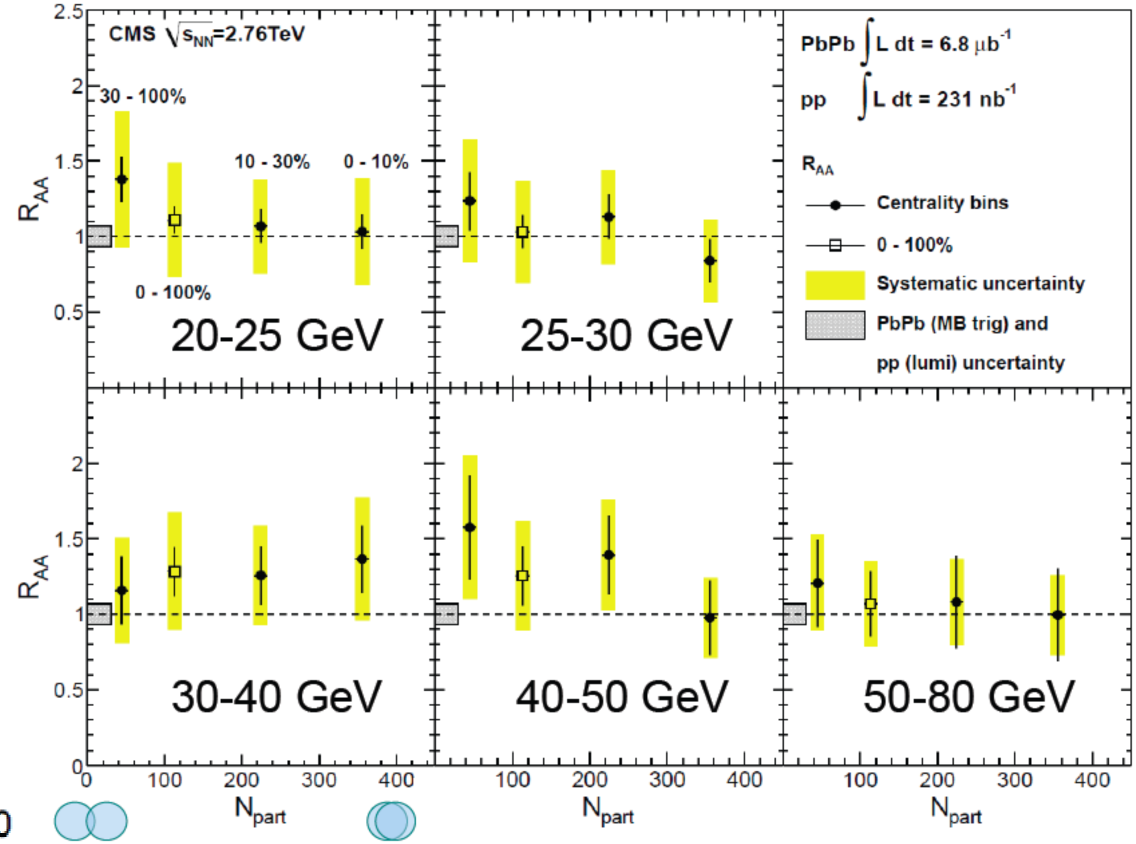
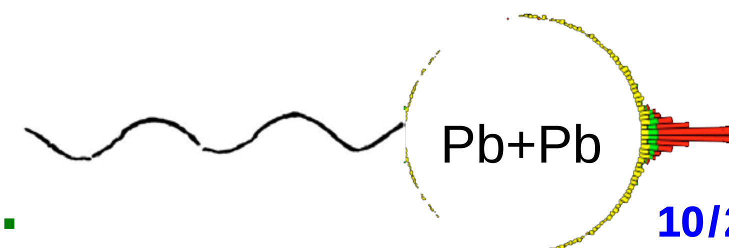
Isolated photon production:
ATLAS - CMS





- No dependence on centrality

Let's see what happens to the jet in the opposite side ...



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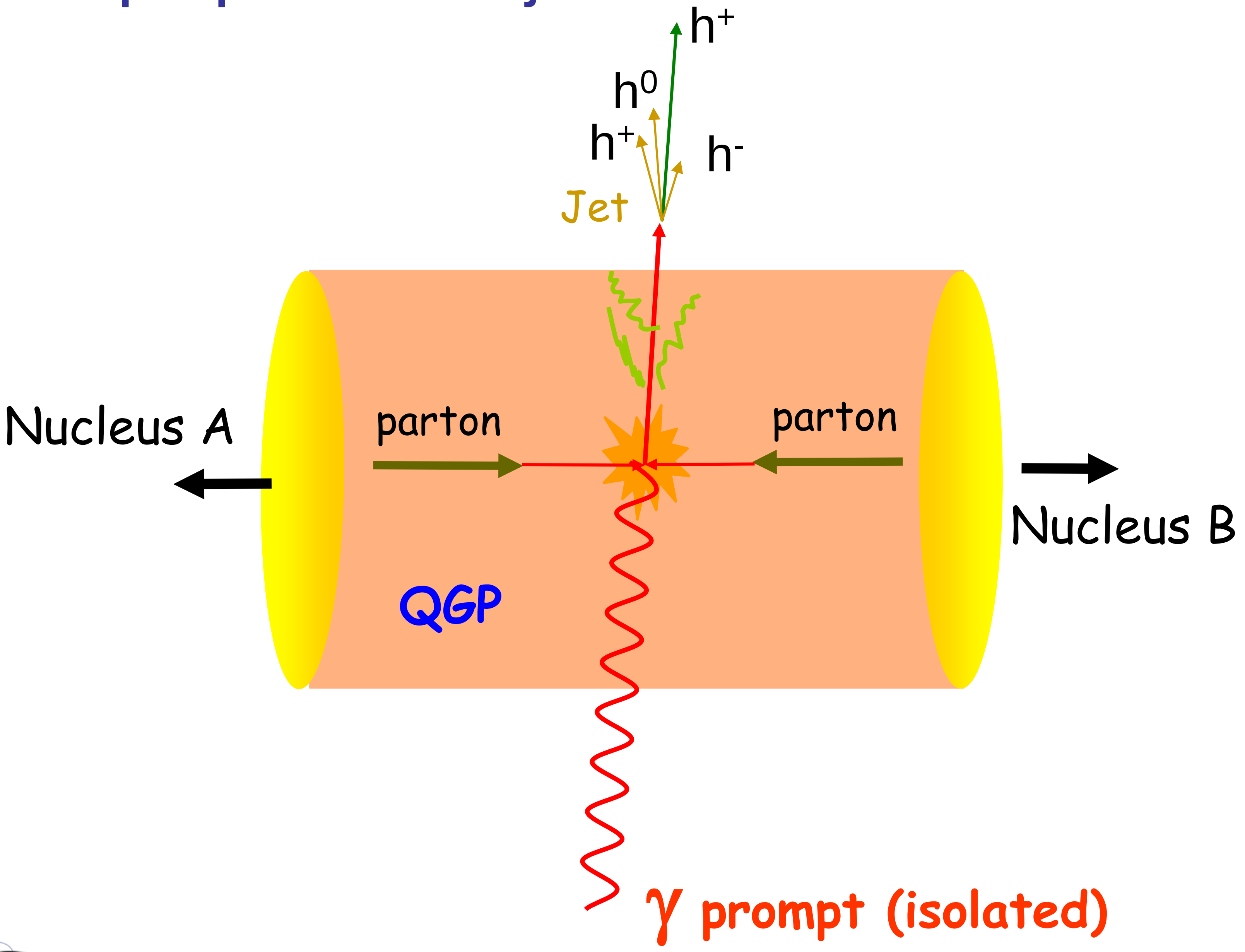
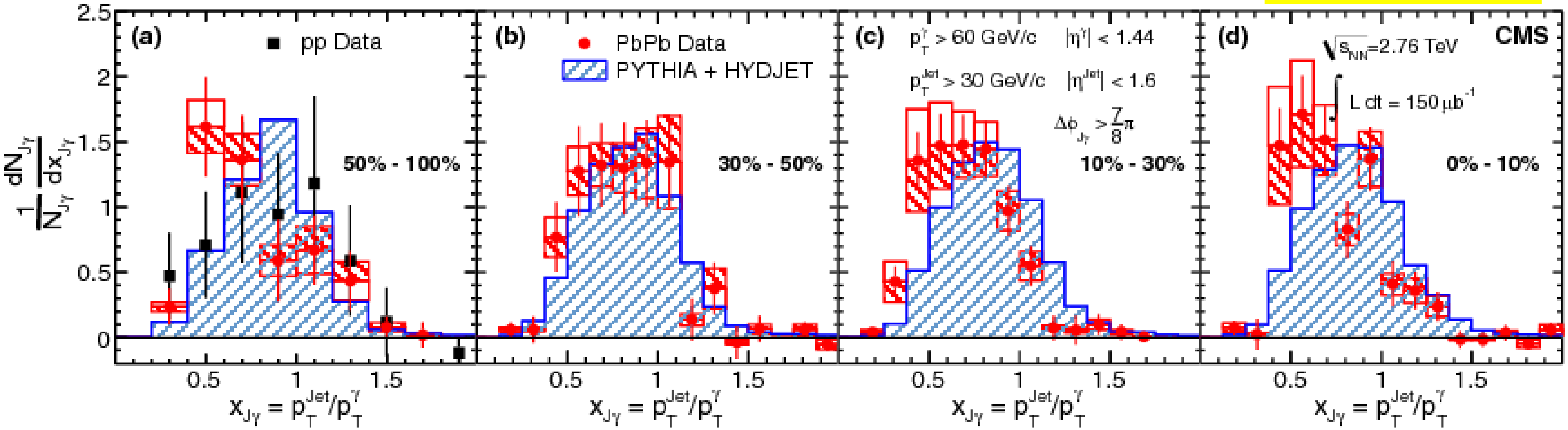
Prompt photons-jet/hadron correlations



CMS

arXiv:1206.0206



- Photons serve as an unmodified energy tag for the jet partner
- Ratio of the p_T of jets to photons : $\mathbf{x_{J\gamma}=p_T^{jet}/p_T^\gamma}$ is a direct measure of the jet energy
- Gradual centrality-dependence of the $x_{J\gamma}$ distribution

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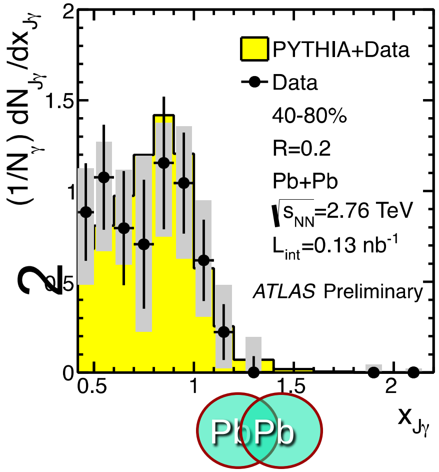
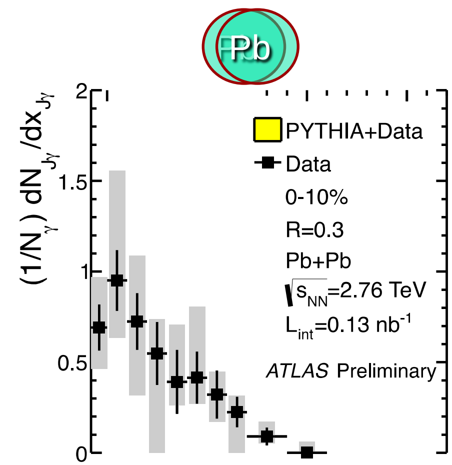
ATLAS

40-80% | 20-40% | 10-20% | 0-10%

R=0.2



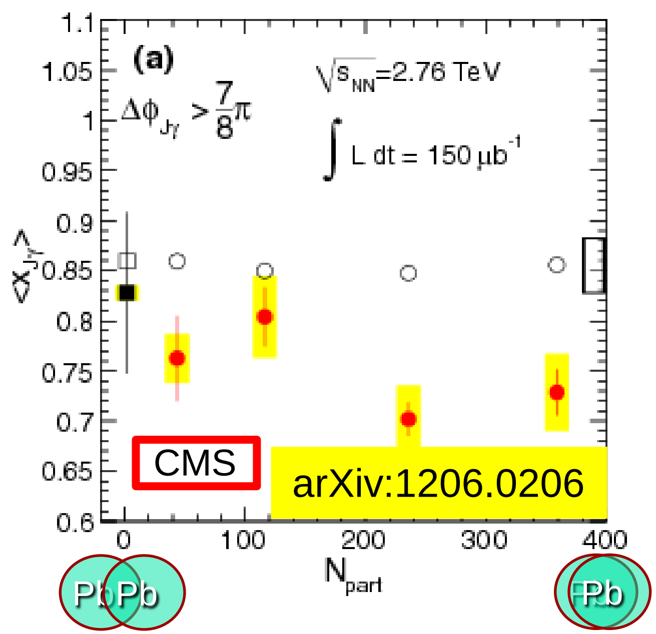
R=0.3

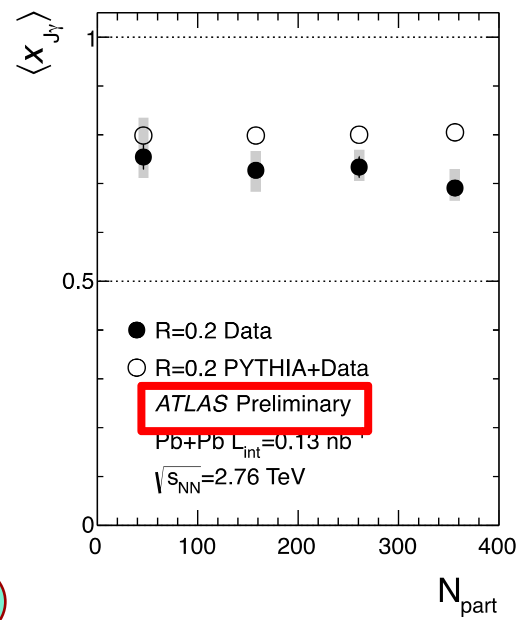


- Distributions: $\mathbf{x_{J\gamma} = p_T\,(jet)\ /\ p_T\,(\gamma)}$ normalized to N γ (black points) compared to Pythia (yellow area)
- Clear shift in data distribution in central events compared to Pythia **Where is the missing energy?**

Direct photon – jet correlation : ATLAS-CMS

$x_{J\gamma} = p_T^{jet}/p_T^{\gamma}$





- Different experimental cuts! (jet pT, cone size)
- Centrality dependent downward shift of $\langle x_{j\gamma} \rangle$ (jets more quenched)
- Jets lose ~14% of their initial energy in central collisions

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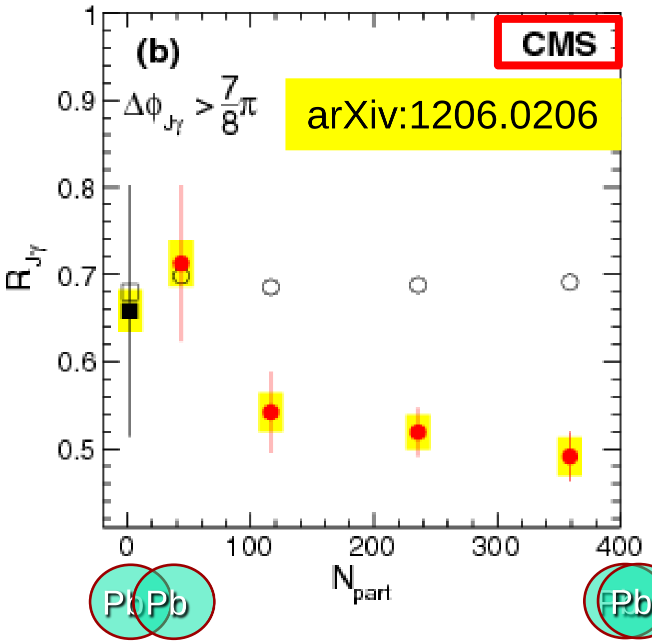
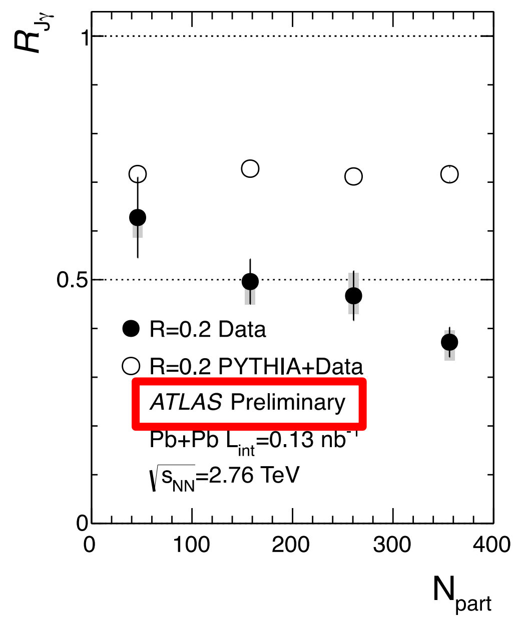
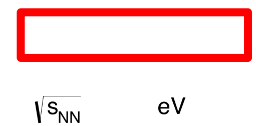
Direct photon – jet correlation : ATLAS-CMS



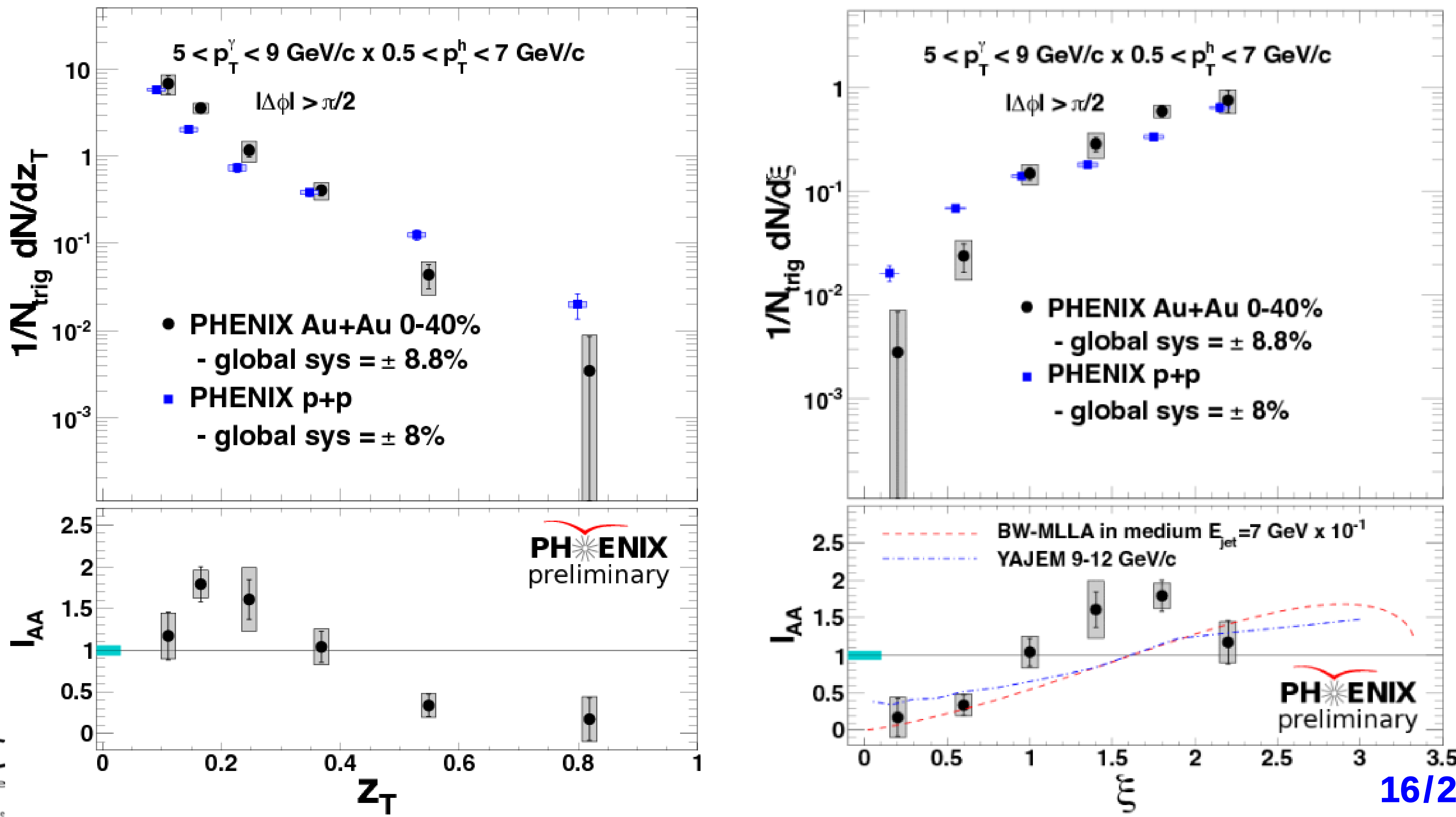




- $R_{J\gamma}$ = fraction of photons with jet partner,
  - CMS p_T jet >30 GeV/c, p_T photon 60 GeV/c
- Centrality dependent downward shift of $R_{j\gamma}$ (lower jet yield)
- ~20%-30% of photons lose their jet partner

Direct photon – h correlation : PHENIX

- Another approach correlate the photon with the hadrons in the opposite side measuring $z_T = p_T\,(\text{hadron}) / p_T\,(\gamma)$
- Advantage : Loose or no restriction on the hadrons



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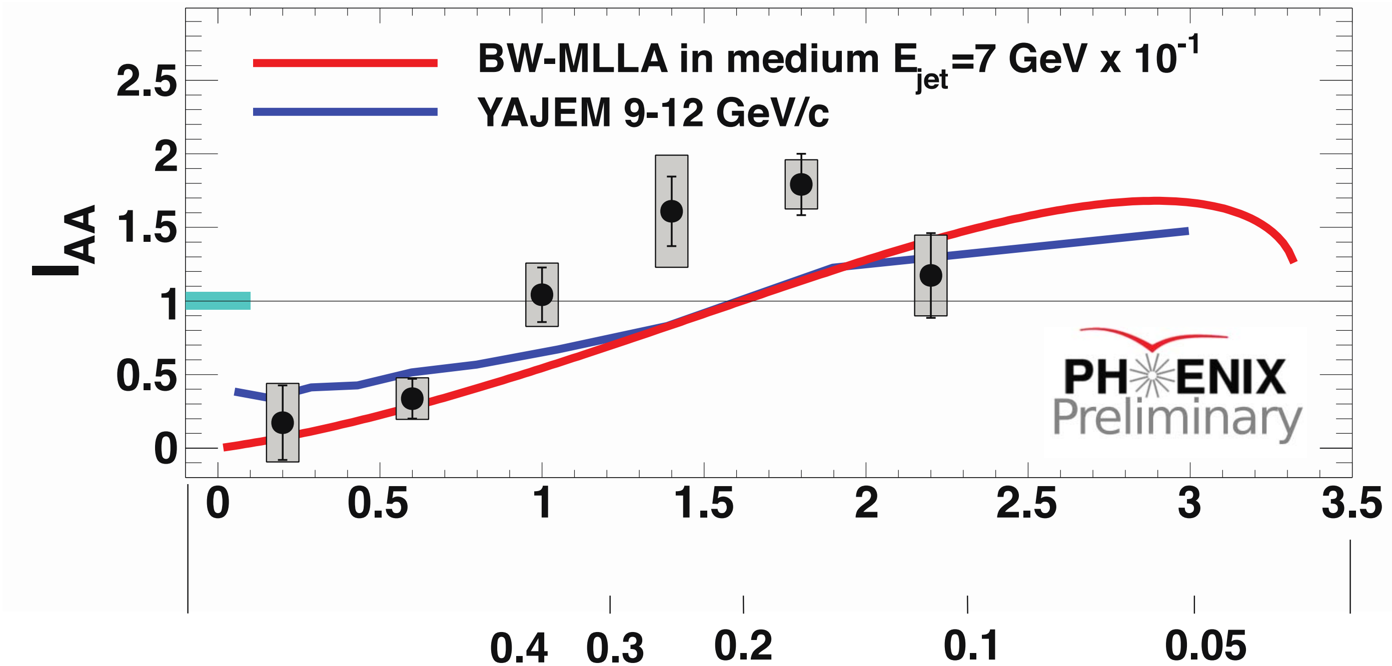
Direct photon – h correlation : PHENIX



- Significant large suppression at small ξ
- Sizable enhancement at large ξ
- Energy loss depletion + wide angle recovery
- These features present in theory calculations : Loose or no restriction on the hadrons location (no jet cone)

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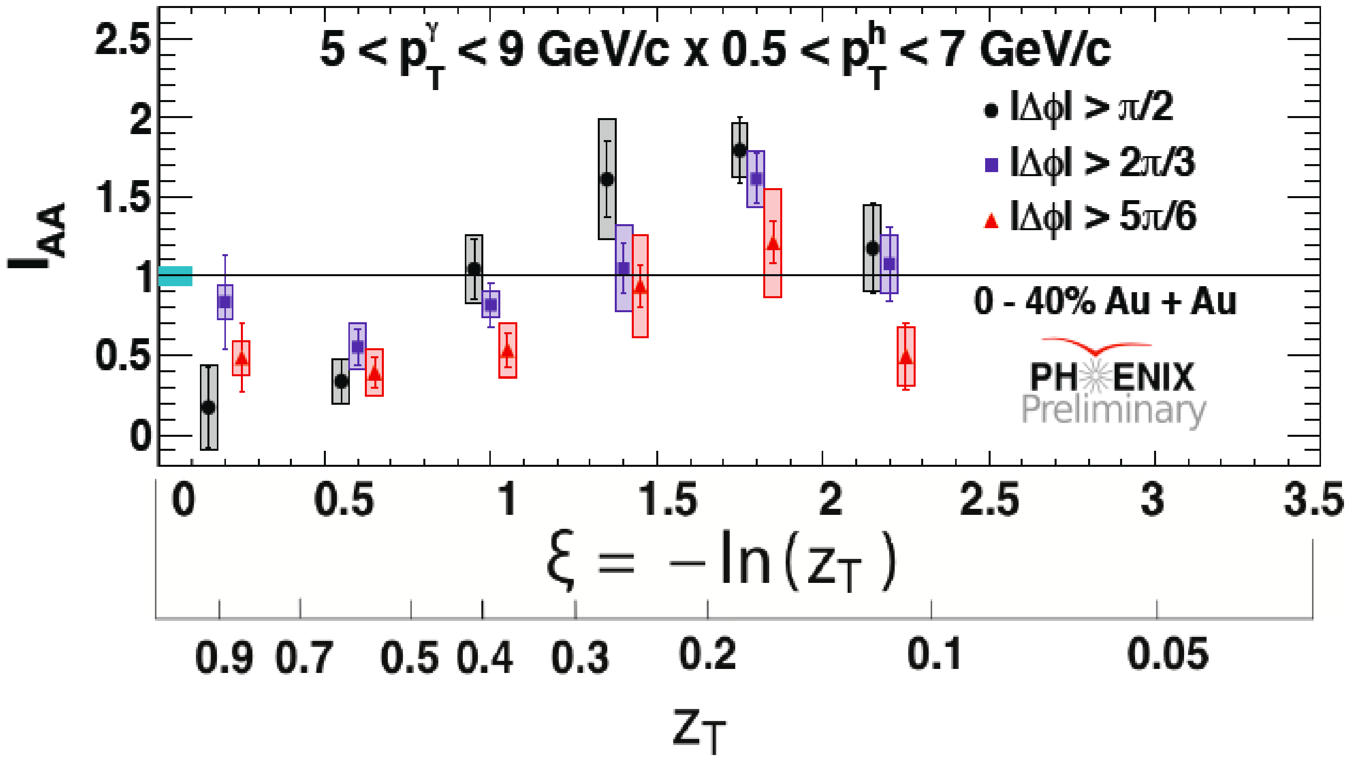
Direct photon – h correlation : PHENIX



- Integrating in φ ranges we see an evolution with the angle
- Qualitatively consistent: Rise from low xi to high xi present in all integration ranges
- Less in the “head” region!
- Broadening of the away side fragmentation

And at LHC?

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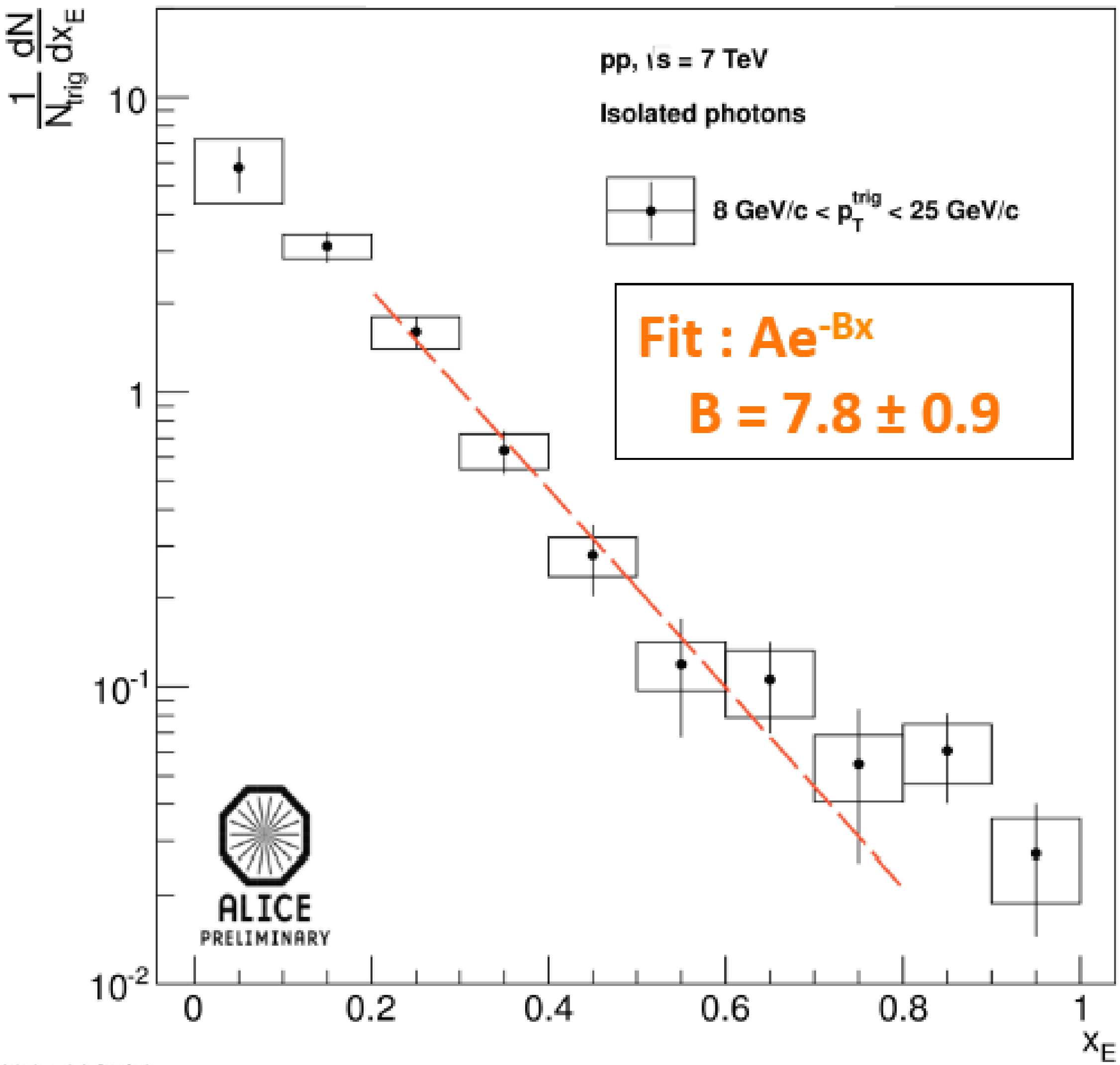
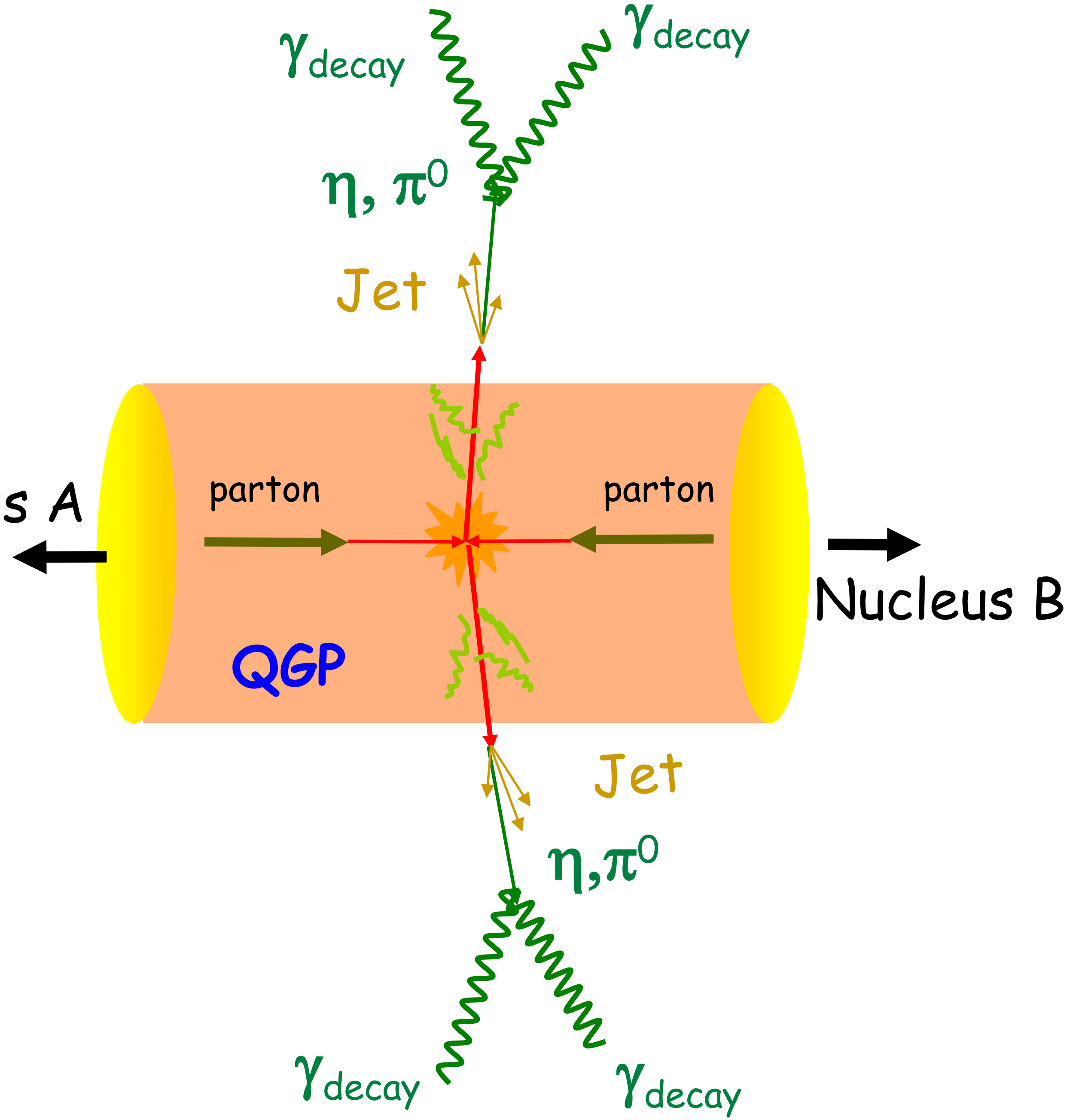
Direct photon – h correlation : ALICE

$$x_E = -\frac{p_T^h}{p_T^\gamma}\cos\Delta\Phi$$



- First step of the analysis : measuring the pp reference
- Slope in agreement with predictions
  - We expect a change in the slope and trend in PbPb!
- See Nicolas presentation for details

Neutral mesons



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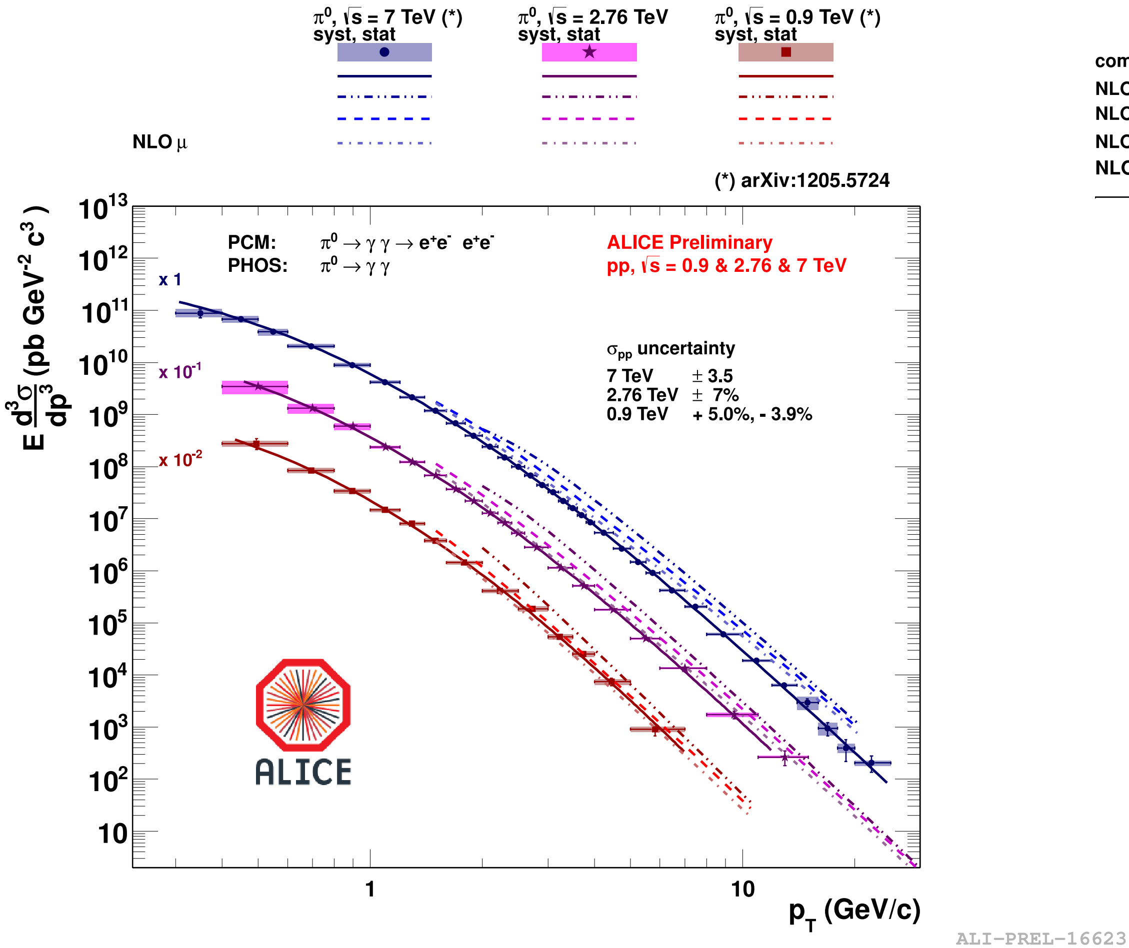
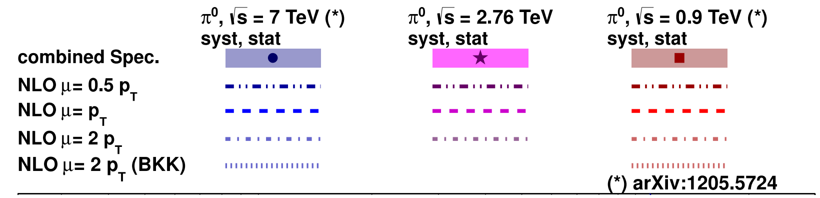
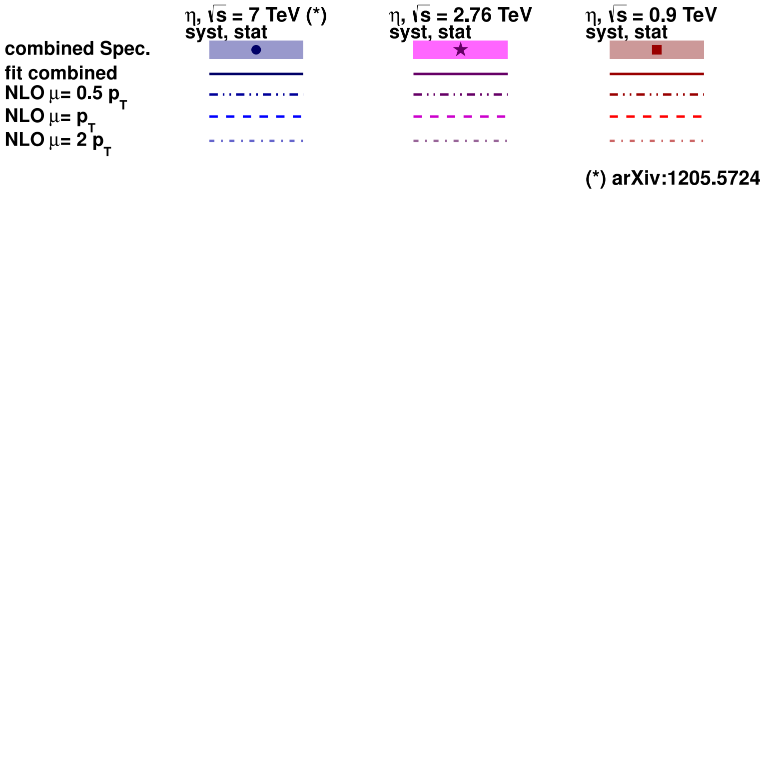
π^0 in p p : ALICE



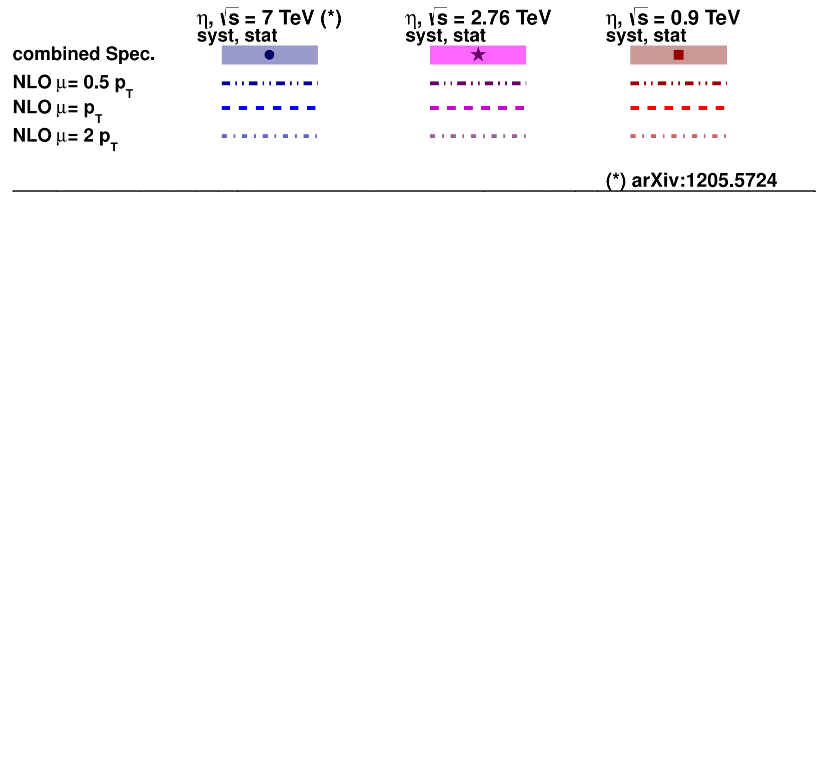


- pQCD NLO calculations reproduce data at $\sqrt{s}$=0.9 TeV, but overestimate π^0 spectrum at $\sqrt{s}$=2.76 and 7 TeV.
- 7 and 0.9 TeV data published online last week in PRL B http://dx.doi.org/10.1016/j.physletb.2012.09.015

η in p p : ALICE



ALI-PREL-16602



ALI-PREL-16609

- pQCD NLO calculations overestimate η spectrum at √s=2.76 and 7 TeV.
- 7 and 0.9 TeV data published online last week in PRL B http://dx.doi.org/10.1016/j.physletb.2012.09.015

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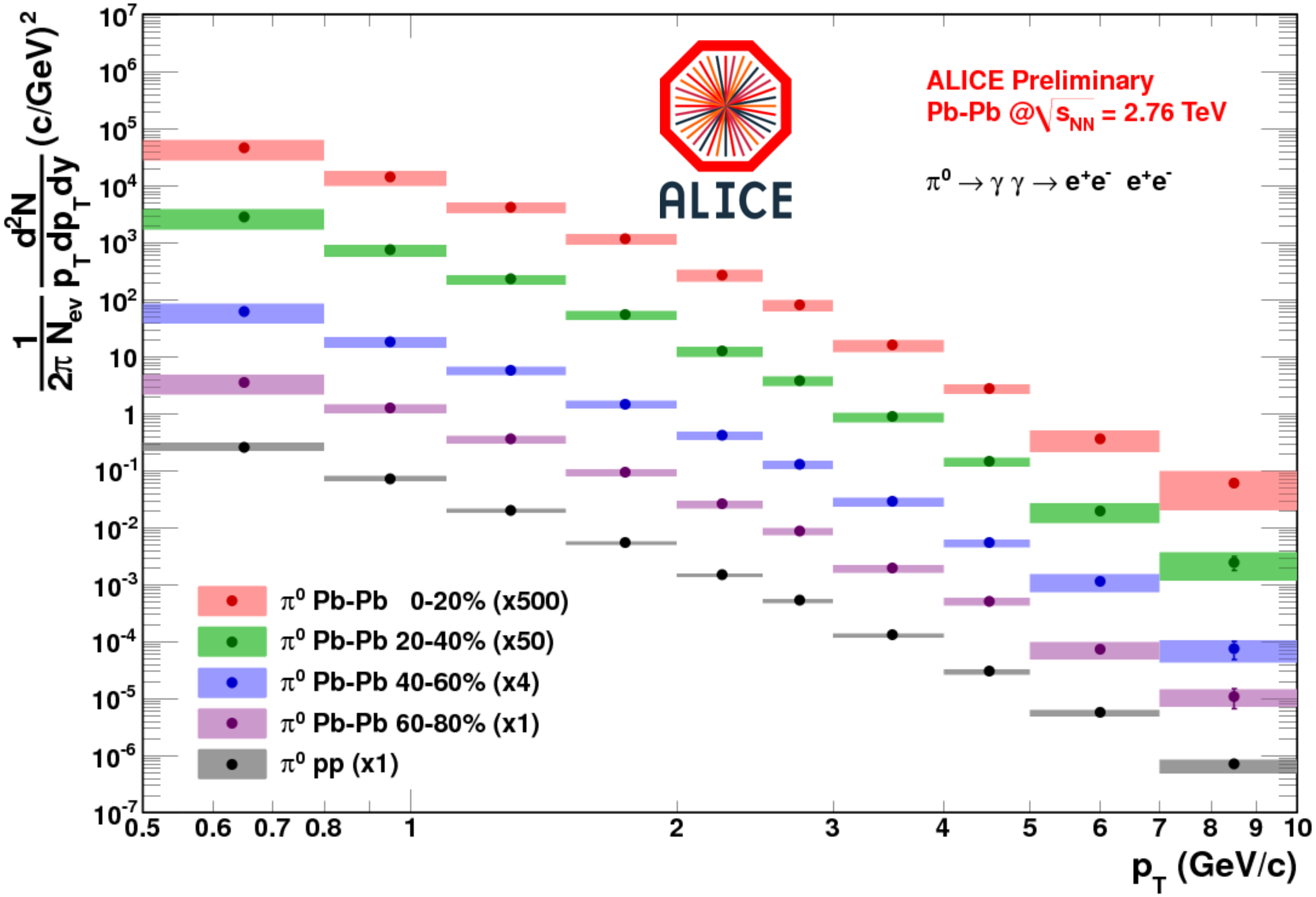
π^0 in PbPb : ALICE



Measurement up to 10 GeV/c, to be extended

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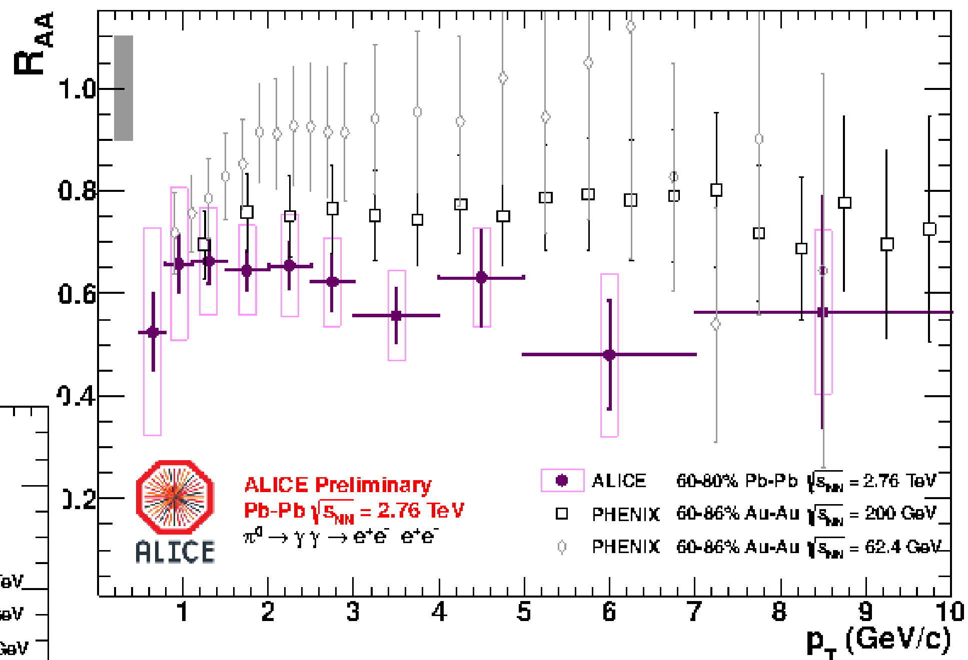
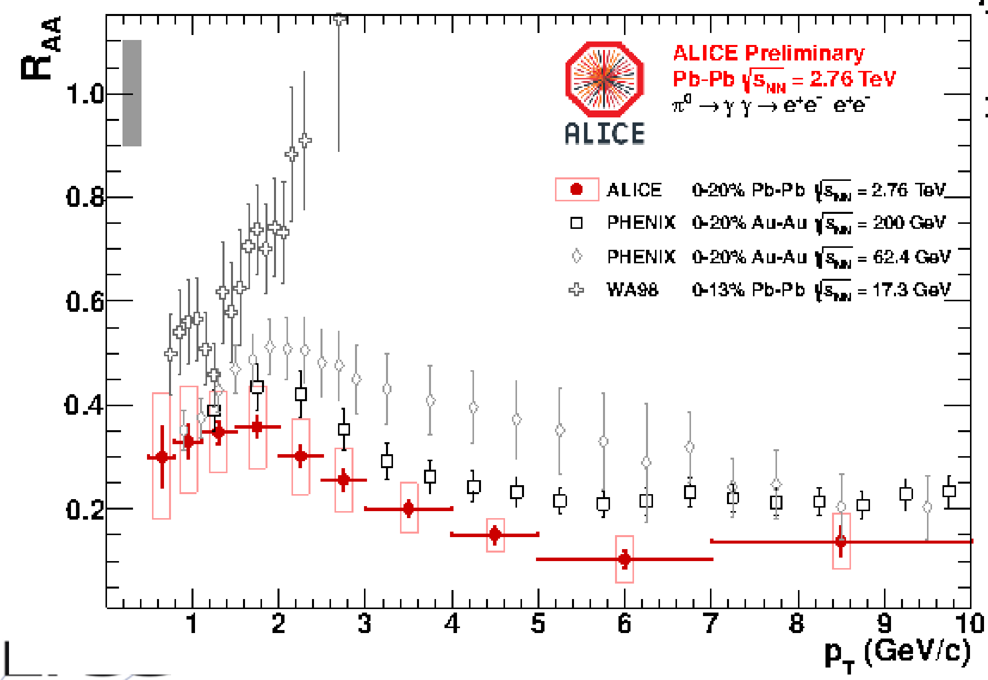
π^0 in PbPb : ALICE

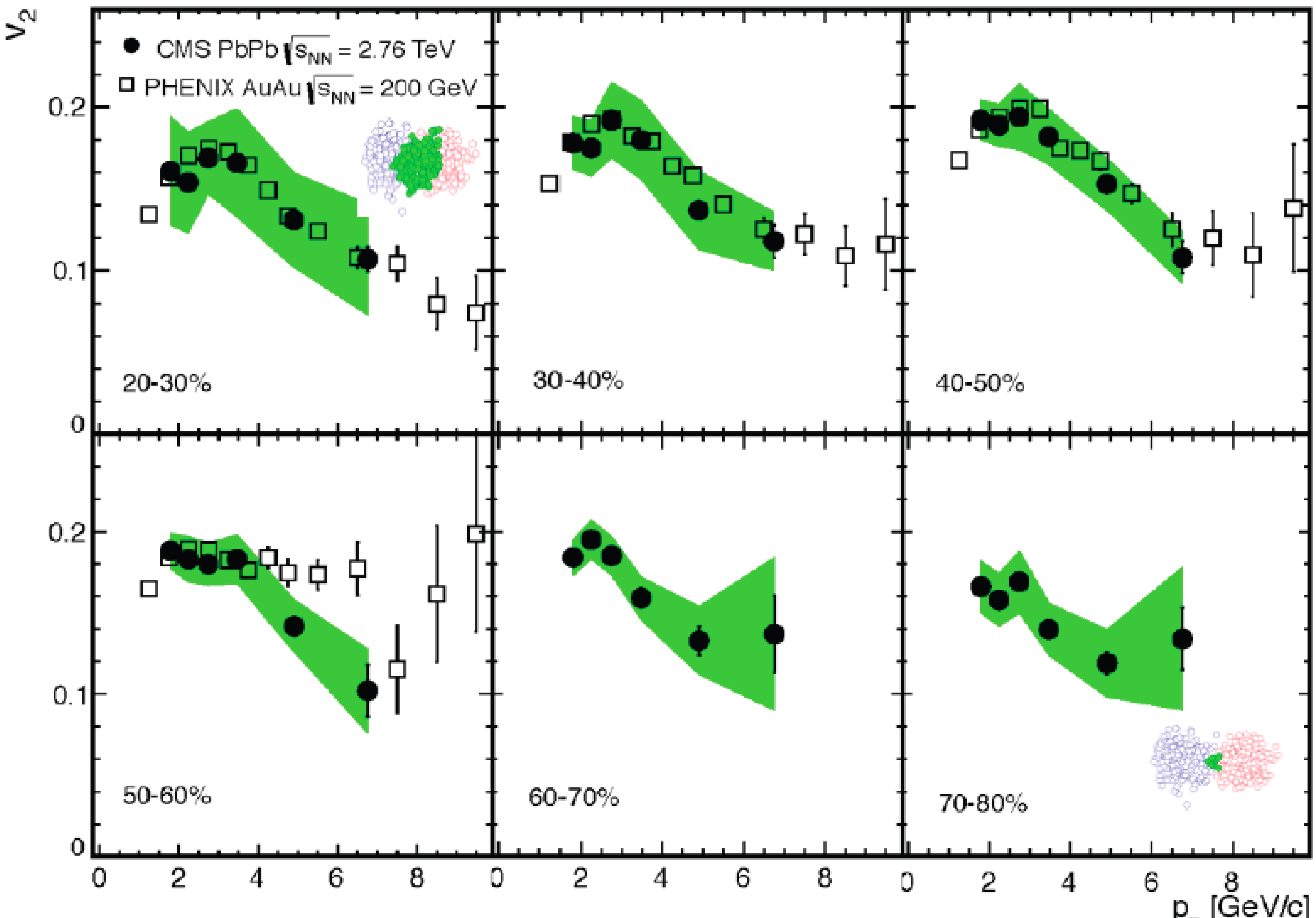
- Suppression follows the energy dependence seen at RHIC energies
- Suppression agrees with charged pion R_{AA} within errors





[S.Bathe et al., PHENIX collaboration.
J. Phys. G: Nucl. Part. Phys. 38 (2011) 124001]

π^0 v_2 in PbPb : CMS



- With x14 increase in energy, no significant change from RHIC
- A bit lower than charged particles v_2 (back-up)
- Similar results in ALICE - QM2011

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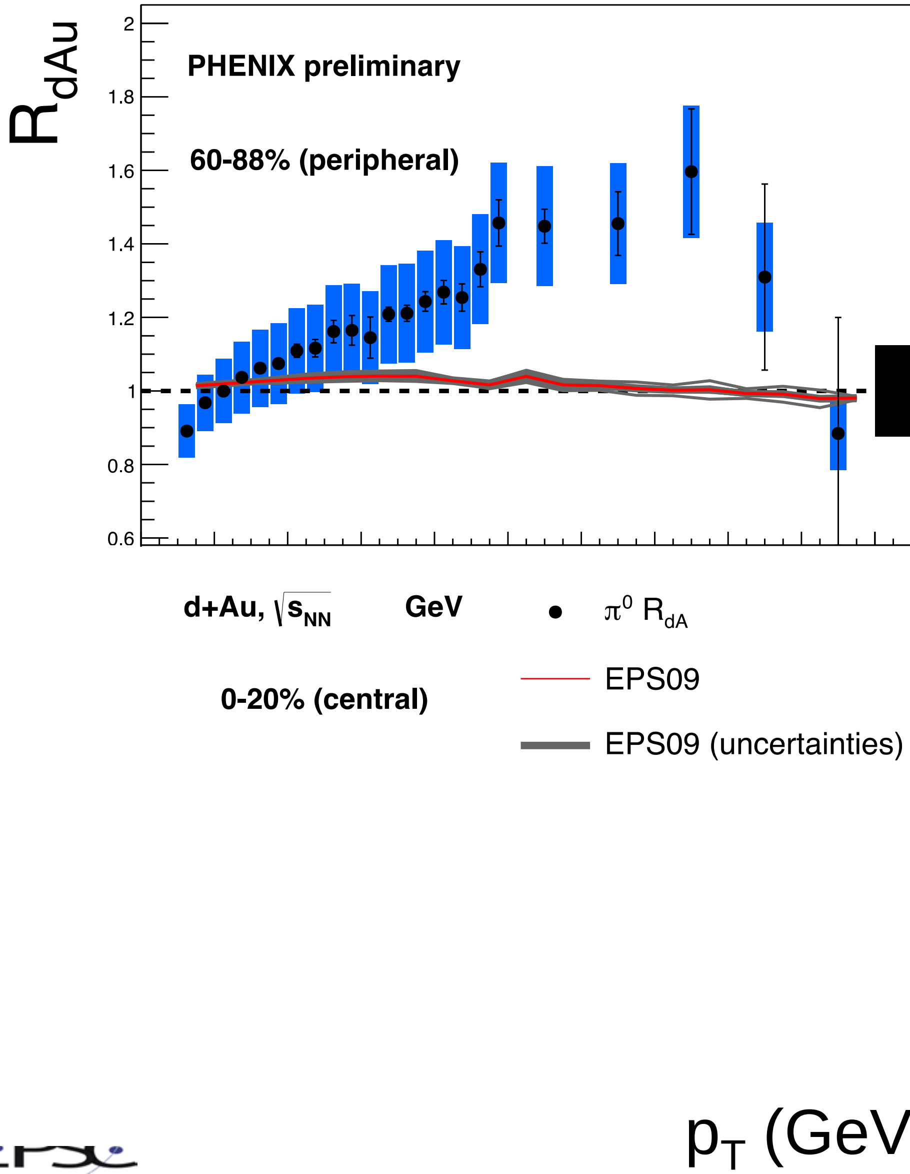
π^0 in d-Au : PHENIX



Shadowing calculation uses EPS09 PDF modification* + Glauber MC + PYTHIA (x,Q^2) sampling for π^0.

Shadowing effects match in central, but not in peripheral

*nPDF modification assumed to scale linearly with longitudinal nuclear thickness.

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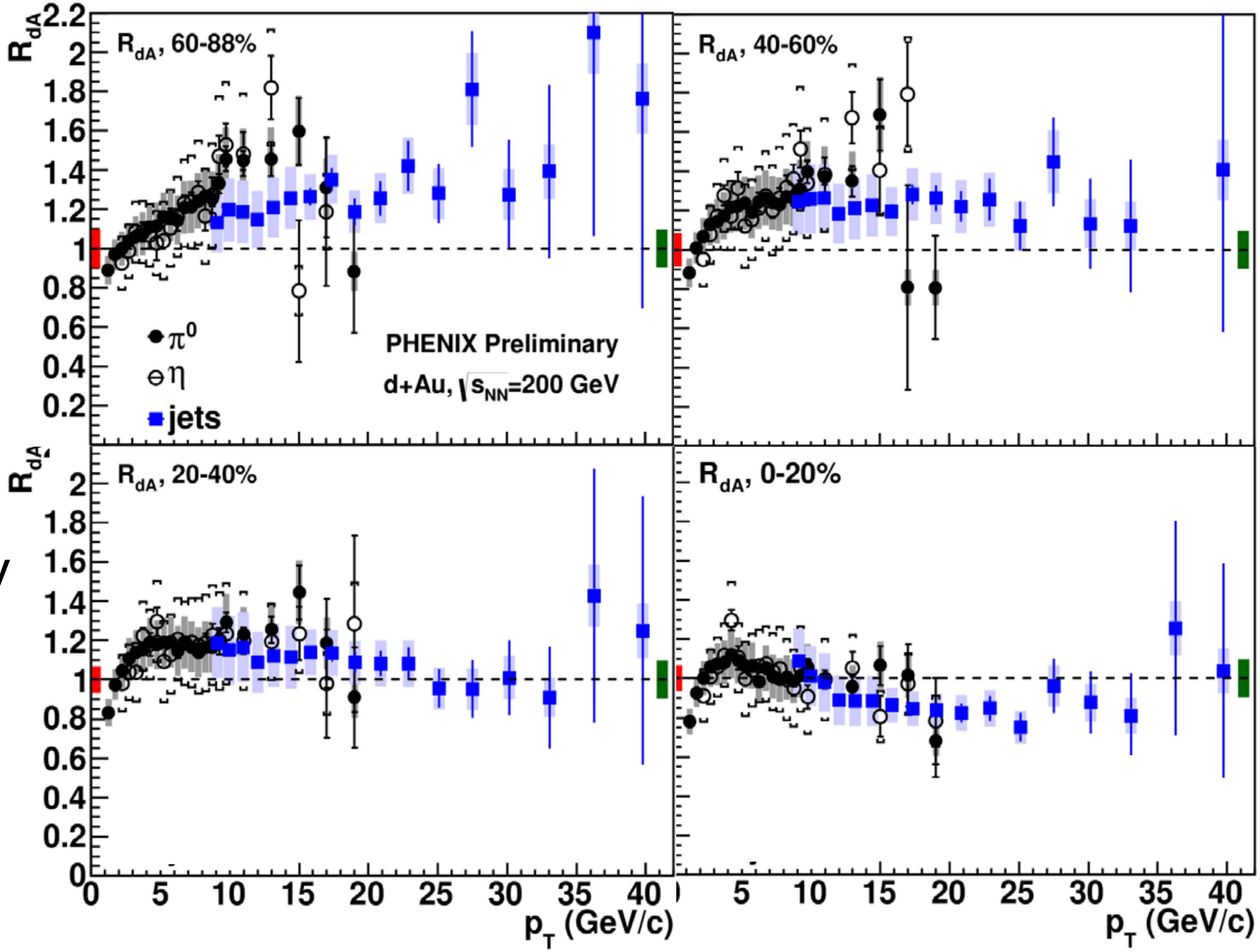
π^0 in d-Au : PHENIX

π^0 and jets of same p_T sample slightly different parton scales, but let's overlay them anyways…



Good agreement within uncertainties, and given the difference in observables.

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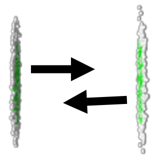
What do we know so far ...

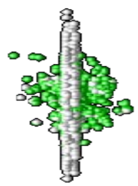
- The matter at LHC attains a Temperature of the order of 300 MeV and 220 MeV at RHIC
  - What is the v_2? CNM at LHC?
- Direct prompt photons (and bosons) production is not affected by the QGP nor CNM (at RHIC)
  - What is the v_2? CNM at LHC?
- The jets correlated with direct photons
  - are modified and suppressed in the nuclear hot medium
  - The hard core remains, soft particles emitted at large angles
- Neutral mesons (π^0, η)
  - Not fully reproducible by pQCD in pp collisions at 2.76 and 7 TeV
  - Are suppressed in PbPb-AuAu collisions, not in dAu central, enhancement in peripheral
    - Interesting to see in coming pPb

Back-up

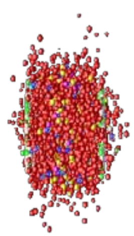
Photon sources



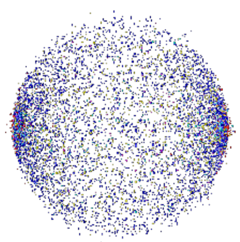
Pre-equilibrium:
Prompt photons



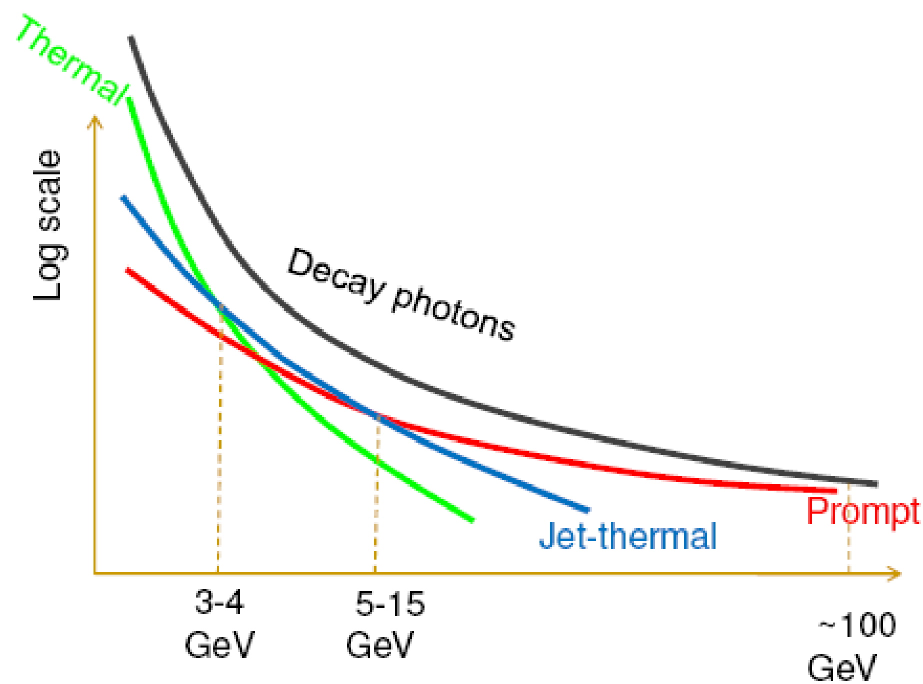
Equilibrium:
Thermal-Bremsstrahlung-
jet conversion photons

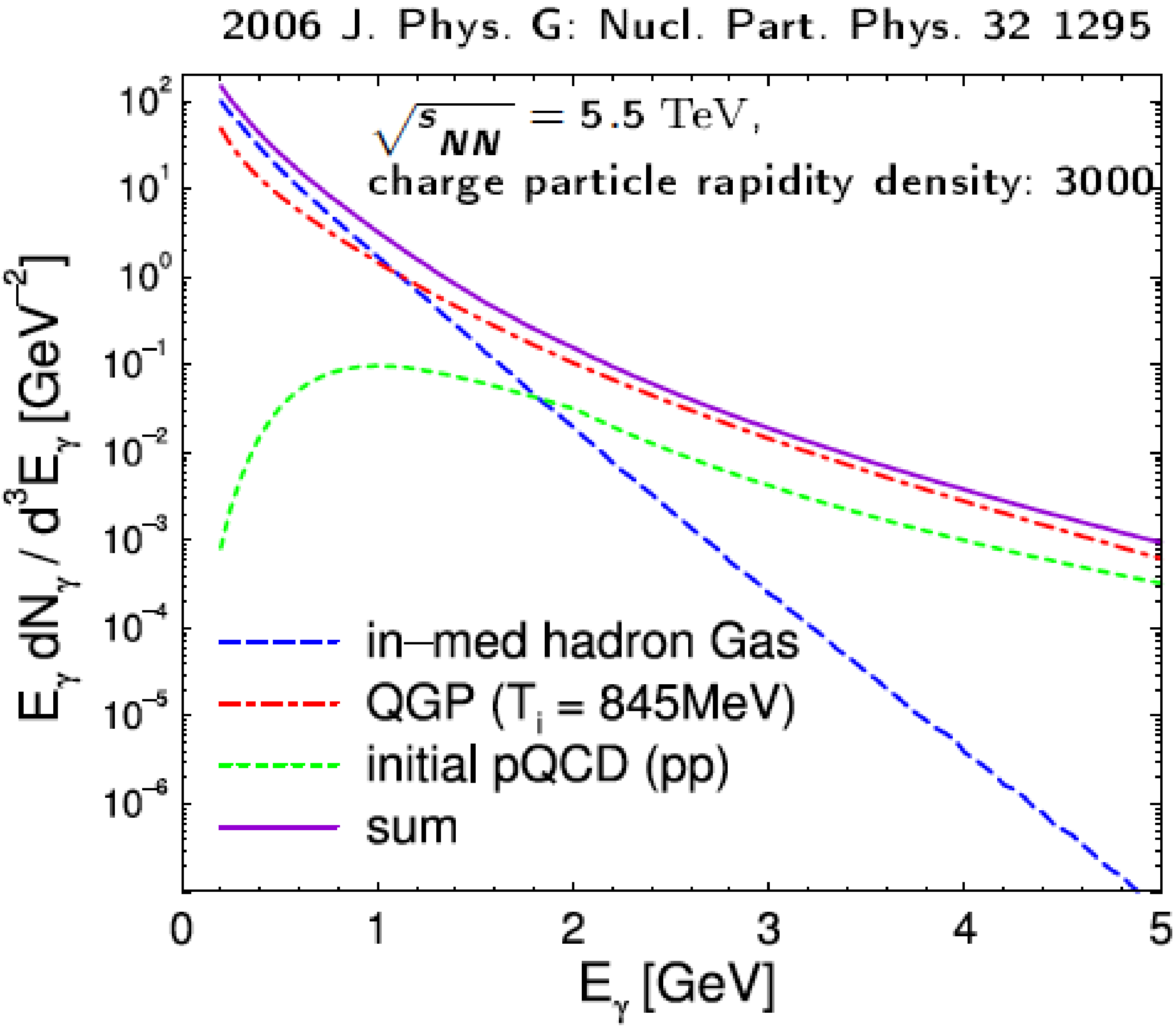


Freeze-out
Decay photons



- Photons are produced during all stages of the collision.
- Challenge:
  - Disentangle the different sources.
  - Neutral mesons decay.
    - But decay photons provide a first choice probe of medium effects
  - Identify real photons (EM calorimetry, trigger) and e+e- from virtual and converted photons (tracking and PID, trigger)





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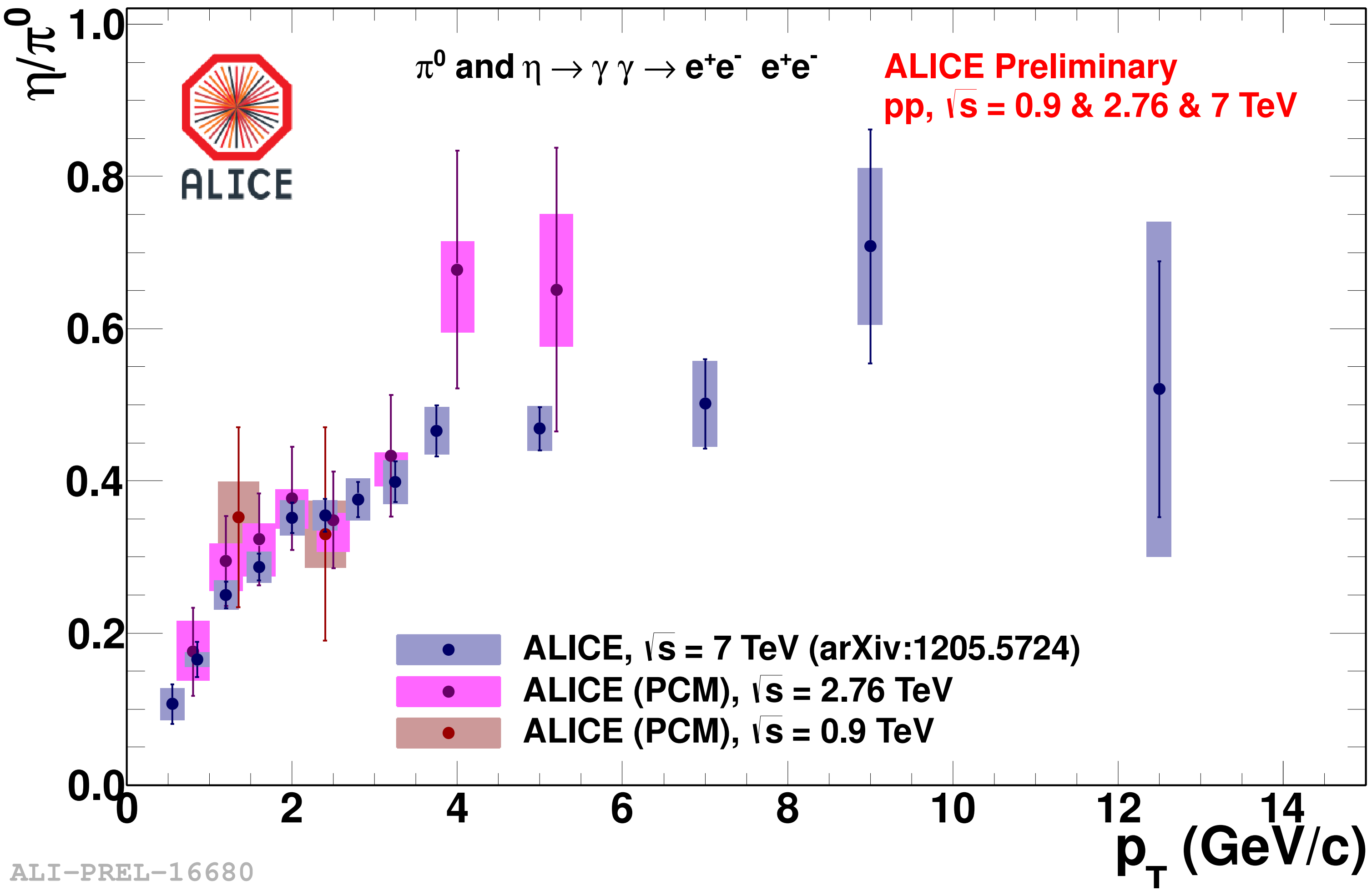
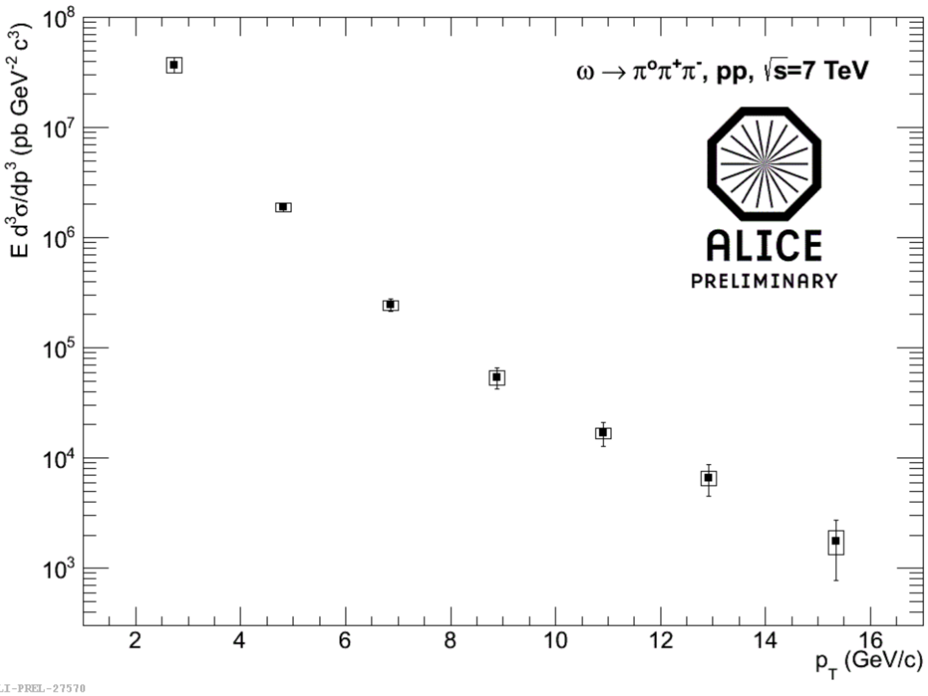
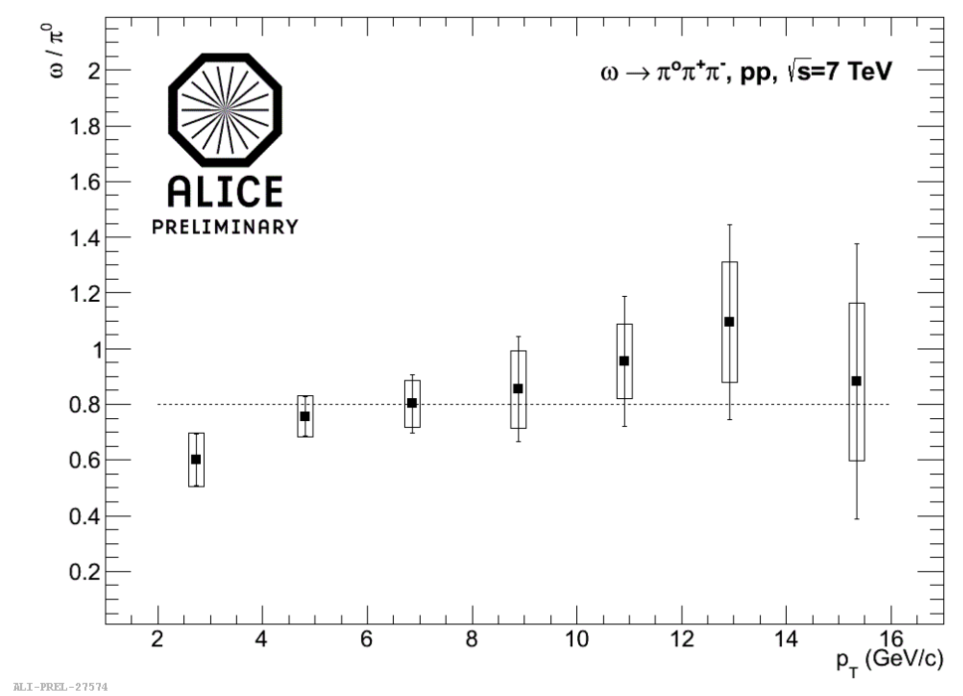
Neutral mesons in ALICE : η/π^0 in pp



In agreement with ratio at smaller energies

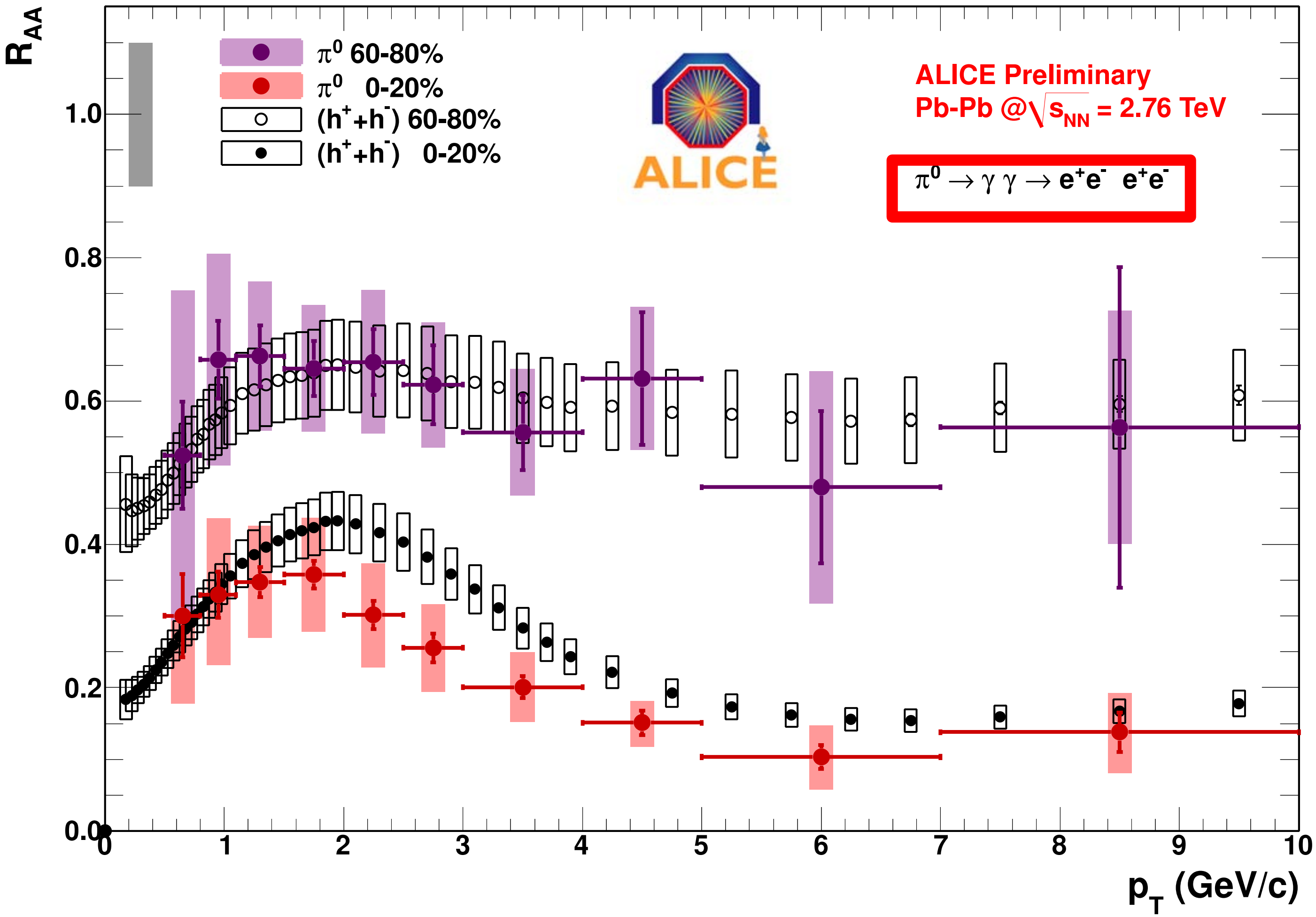
ω in p p : ALICE





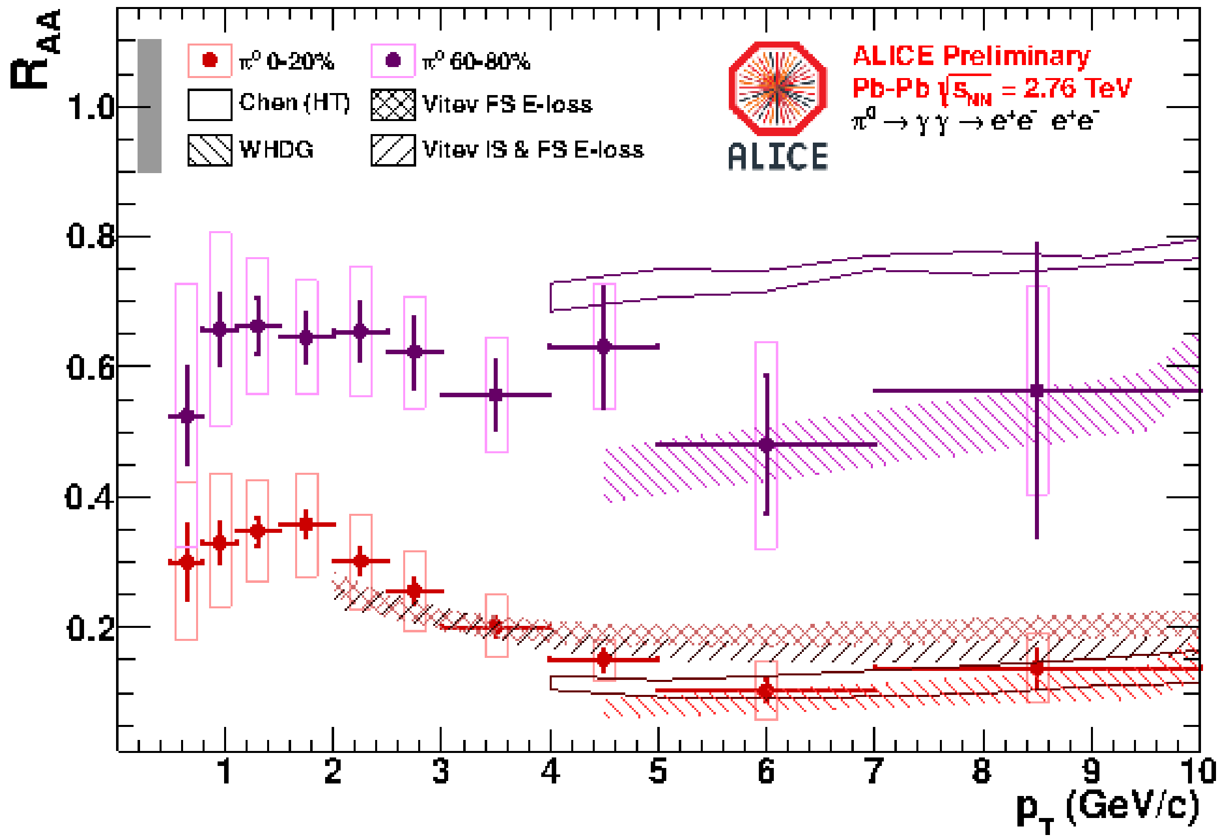
Ratio at smaller energies in agreement

π^0 and $h^\pm$ R_{AA}



Different shape in 0-20% compared to $h^\pm$, due to baryon/meson difference

Neutral mesons in ALICE : π^0 in PbPb



- WHDG model reproduces both strength and centrality dependence
- Chen (HT) fails to reproduce centrality dependence
- Vitev's model agrees with data in central collisions.

- W. A. Horowitz. Int.J.Mod.Phys**.** **E16** (2007) 2193–2199, arXiv:nucl-th/0702084 [NUCL-TH].
- X.-F. Chen, T. Hirano, E. Wang, X.-N. Wang, and H. Zhang. Phys.Rev. **C84** (2011) 034902, ArXiv:1102.5614 [nucl-th].
- R. Sharma, I. Vitev, and B.-W. Zhang. Phys.Rev. **C80** (2009) 054902, arXiv:0904.0032[hep-ph].

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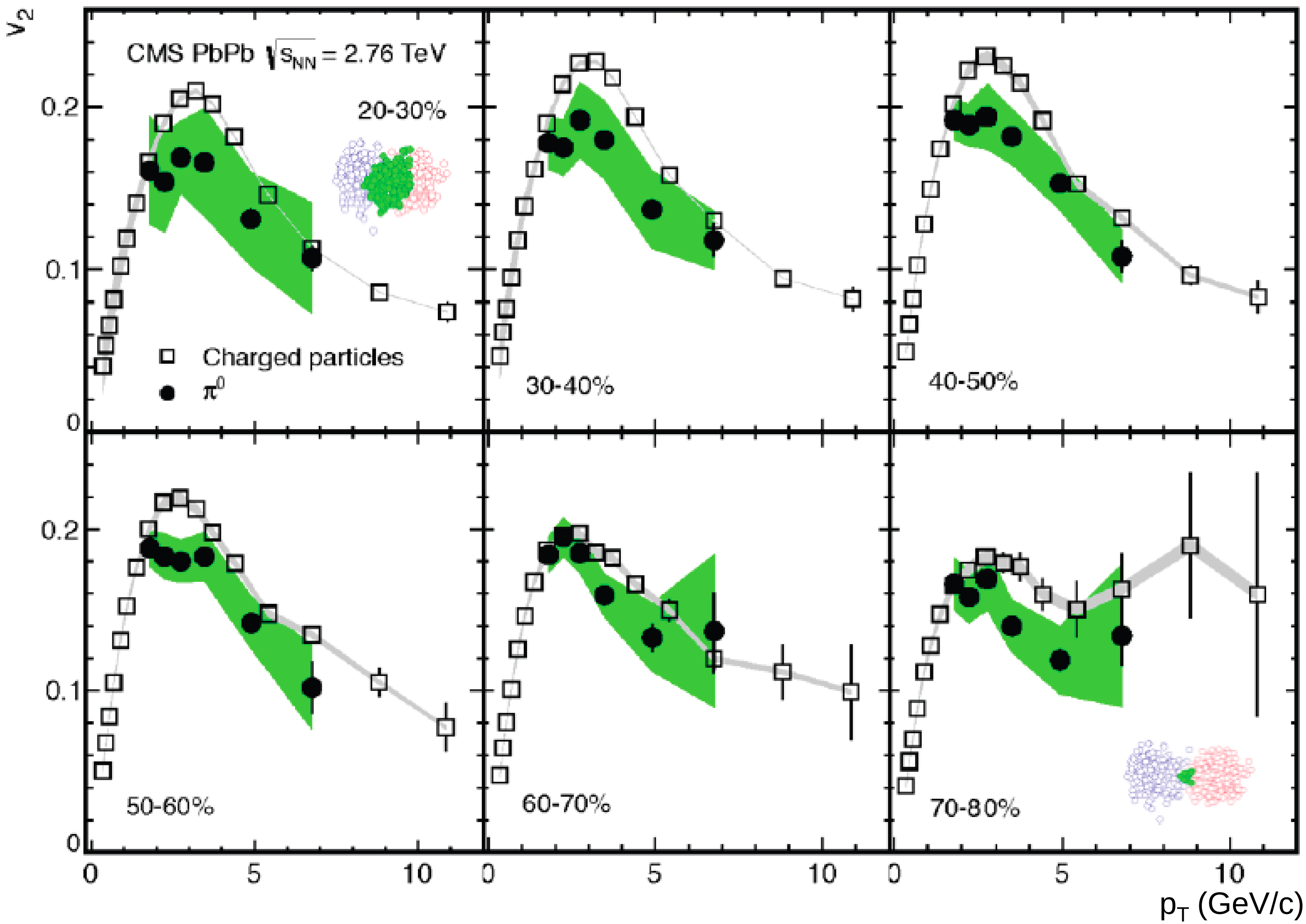
π^0 V2 at CMS



- Charged hadrons v2 higher than pi0 v2
- Consistent with higher v2 for baryons

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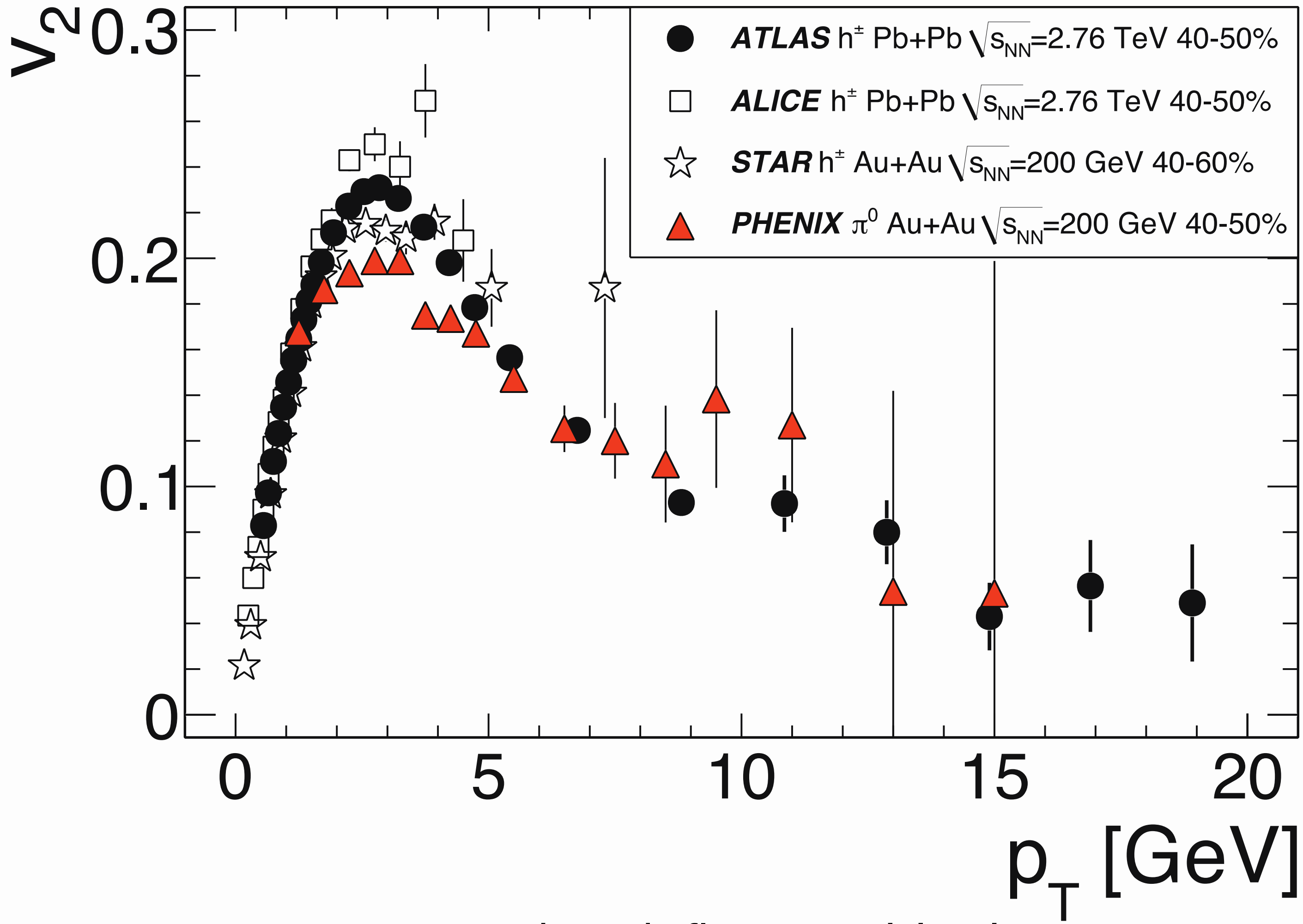
π^0 v_2 at PHENIX



ATLAS, PLB 707 (2012) 303

ALICE, PRL 105 (2010) 252302

STAR, PRC 72 (2005) 014904

PHENIX, PRL 105 (2010) 142301

- Low p_T comparison influenced by baryon-meson admixture
- v_2 at large momentum is also very similar despite the change in beam energy

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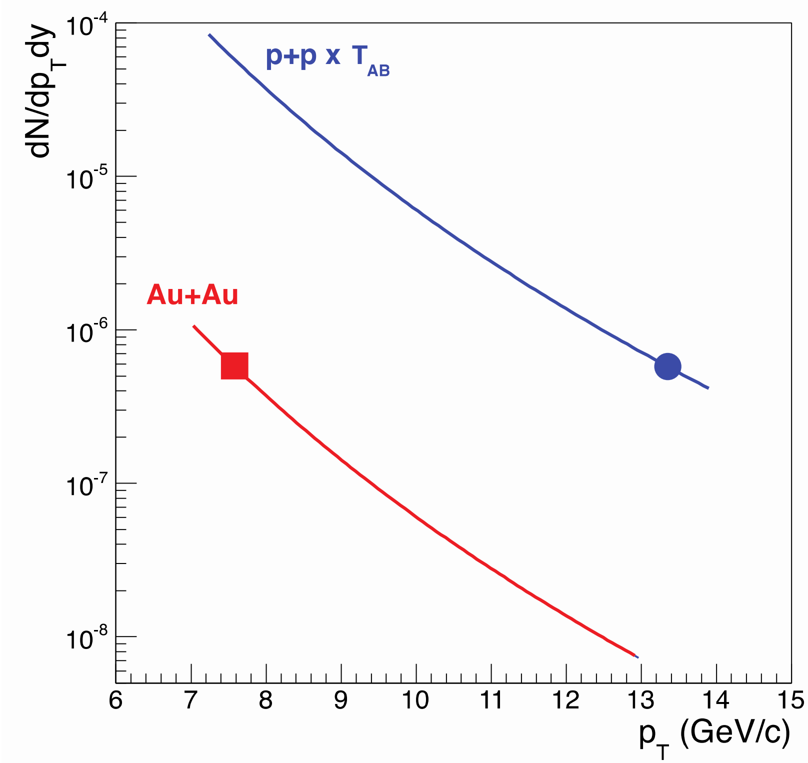
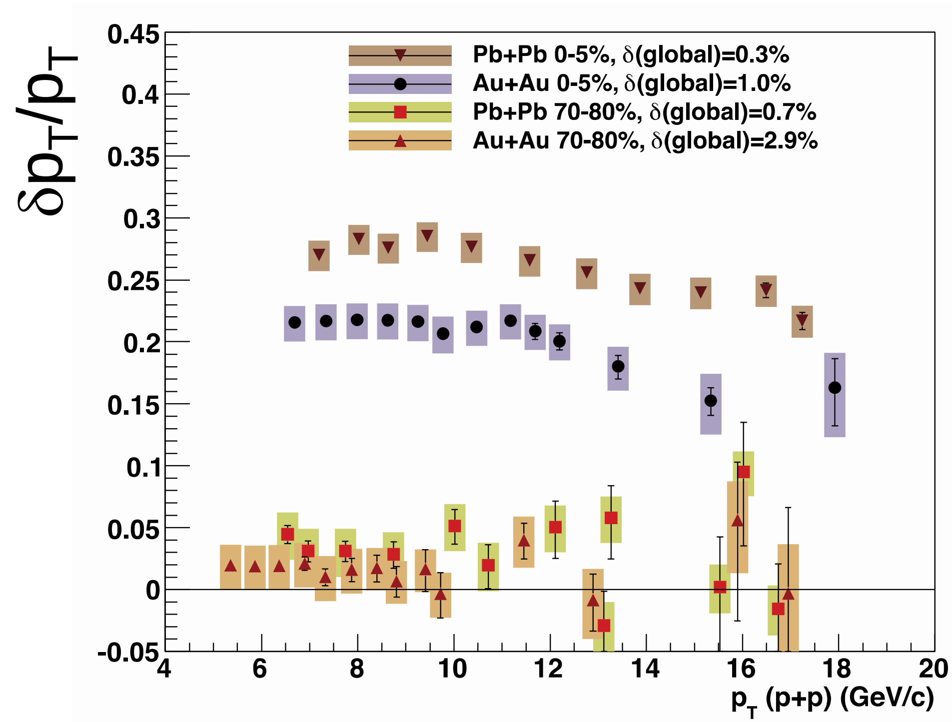
Fractional energy loss

arXiv:1208.2254





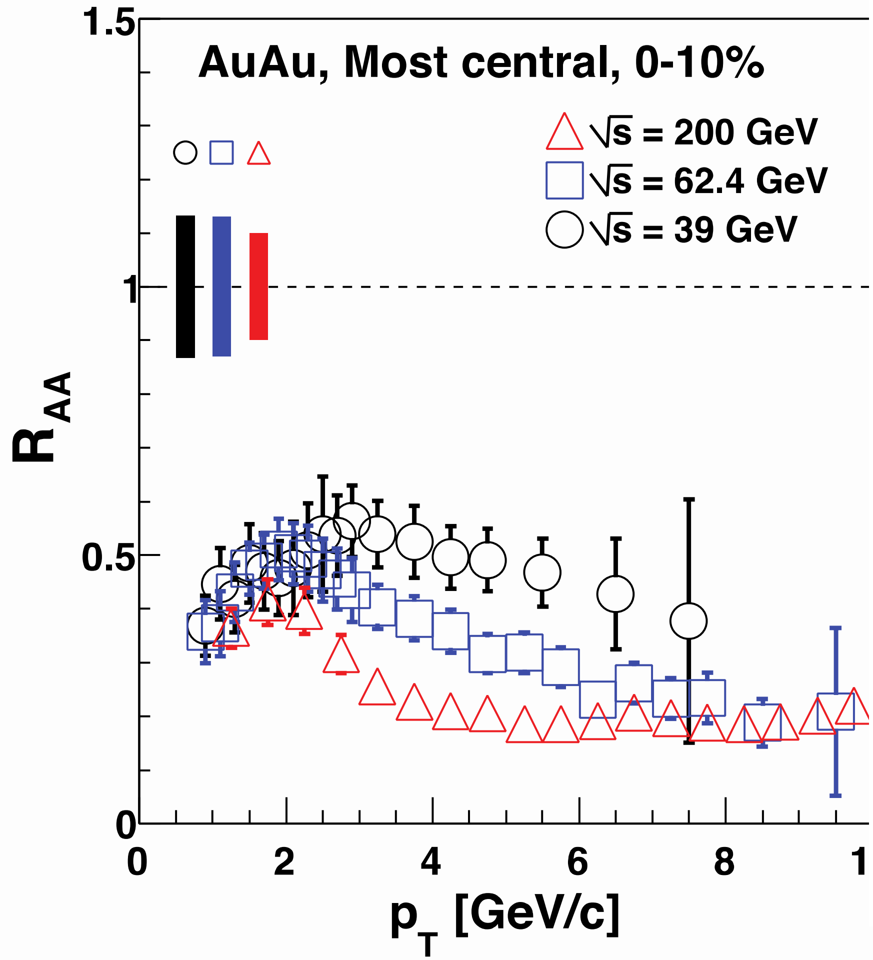
Spectral Shift Model

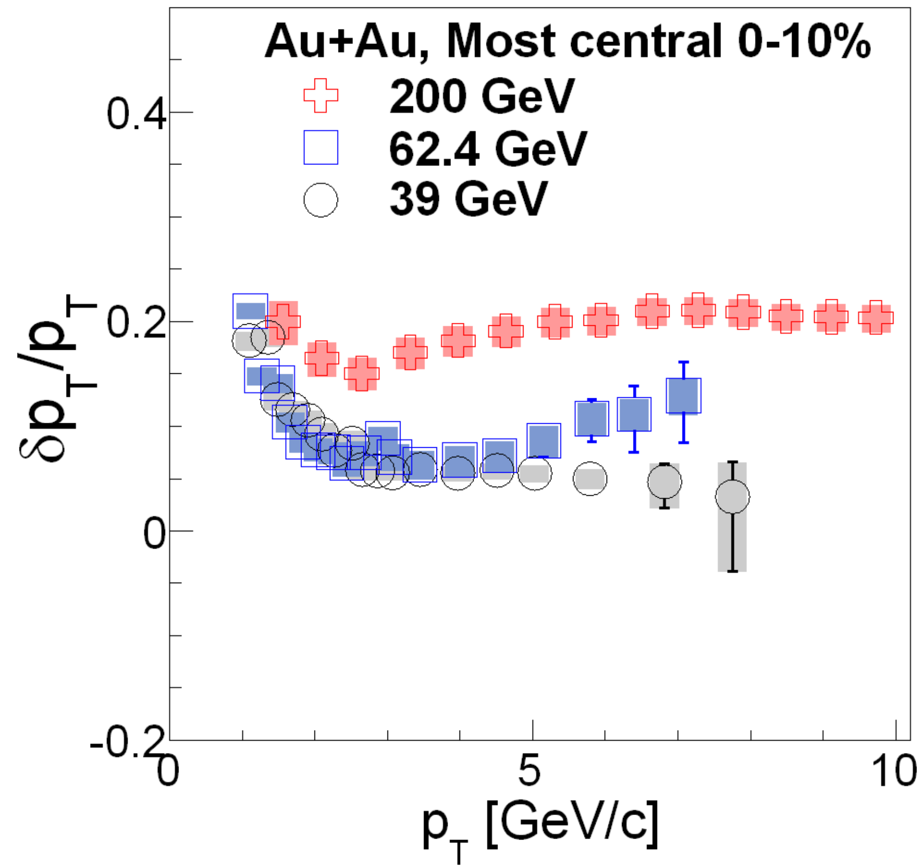
...a simple phenomenological model accounting for the spectral shape

Energy loss parameter increases at the LHC even when R_{AA} is nearly equivalent between the two

$\delta p_T / p_T$ vs energy

RHIC has run at multiple lower beam energies, and a similar examination gives...





- The earlier part of the trend, the energy loss parameter rises from lower RHIC beam energies to higher

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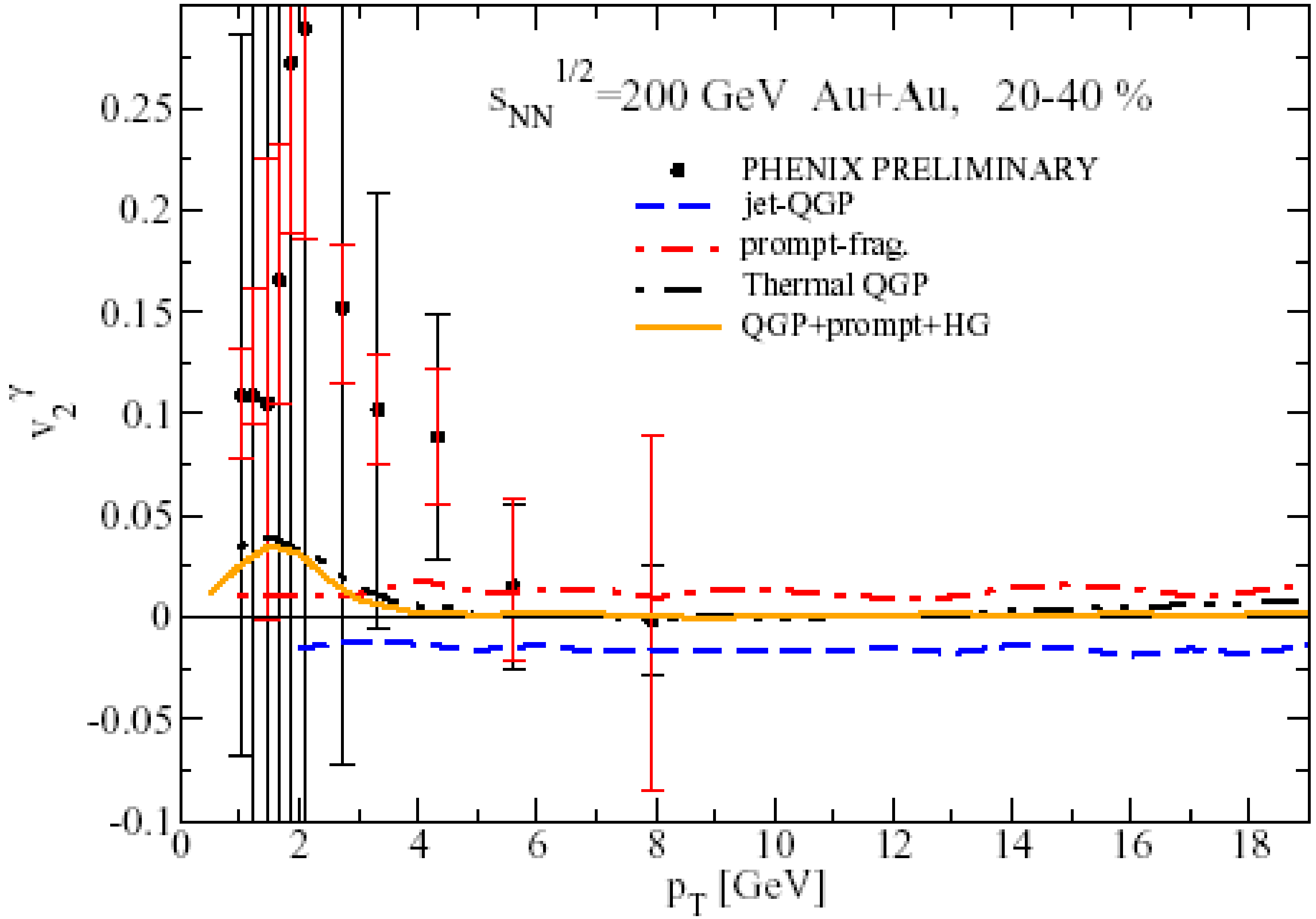
RHIC : PHENIX v_2



v2: small!
Consistent with zero
(within errors)