Neutral meson and direct photon analysis with ALICE

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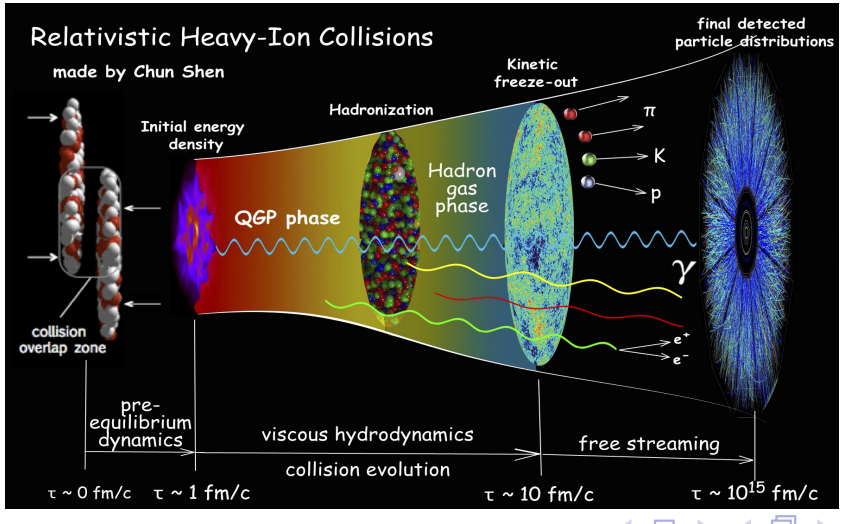
Introduction

Primary objective of ALICE is to study heavy collisions at the LHC.

- Colliding nuclei create deconfined state of quarks and gluons
  → QGP expands and cools
  → hadron gas forms at chemical freeze-out
  → hadrons free stream to detector at kinetic freeze-out.
- Photons are emitted at all stages of evolution of medium
- Created photons only interact electromagnetically with strongly coupled medium ⇒ information pertaining to medium at time of creation remains relatively undistorted
- Neutral meson measurement crucial for inferring photons directly emitted from medium



Introduction

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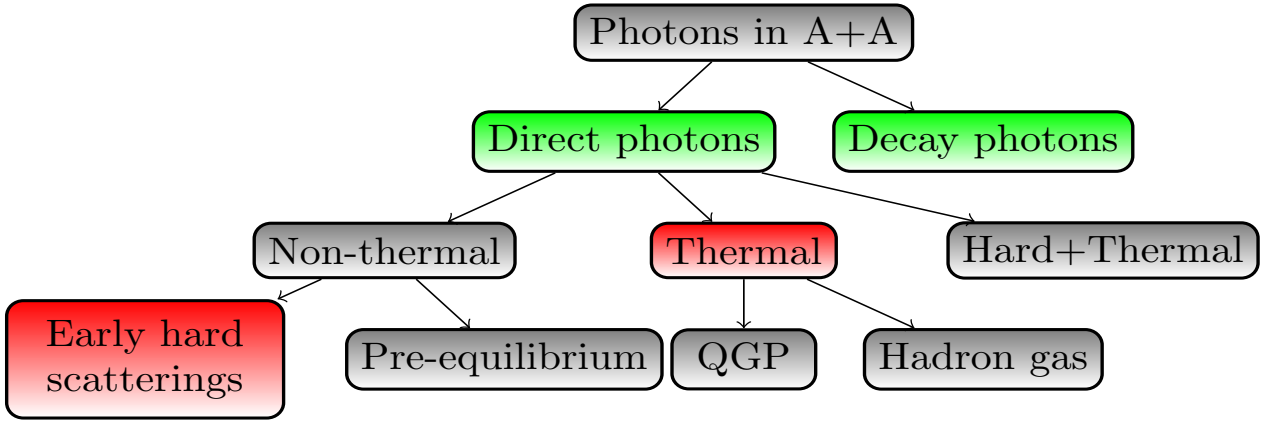
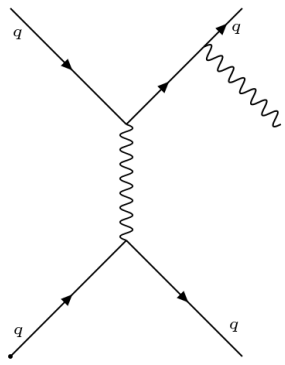
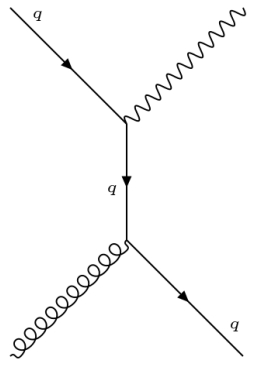




Thermal photon

Direct photons = photons that do not emanate from particle decays

- Thermal photons: Arising from thermal scattering in QGP and hadron gas, dominate at low p_T
- Photons from early hard scattering: Include prompt photons, dominate at high p_T
- Direct photon measurement at low p_T correlated to average medium temperature in AA collisions



Prompt photon

Neutral Mesons Motivation

- Meson and direct photon production in pp collisions provides test for perturbative QCD (pQCD)
- Meson measurements in pp and p-Pb act as a reference to measurements in AA collisions
- π^0 nuclear modification factor, R_{AA}, allows for testing of parton energy loss in QGP
- Neutral meson production (π^0, η) spectrum is necessary for direct photon search $\Rightarrow$ π^0 and η mesons account for 80% and 18% respectively of decay photon spectrum

ALICE detector

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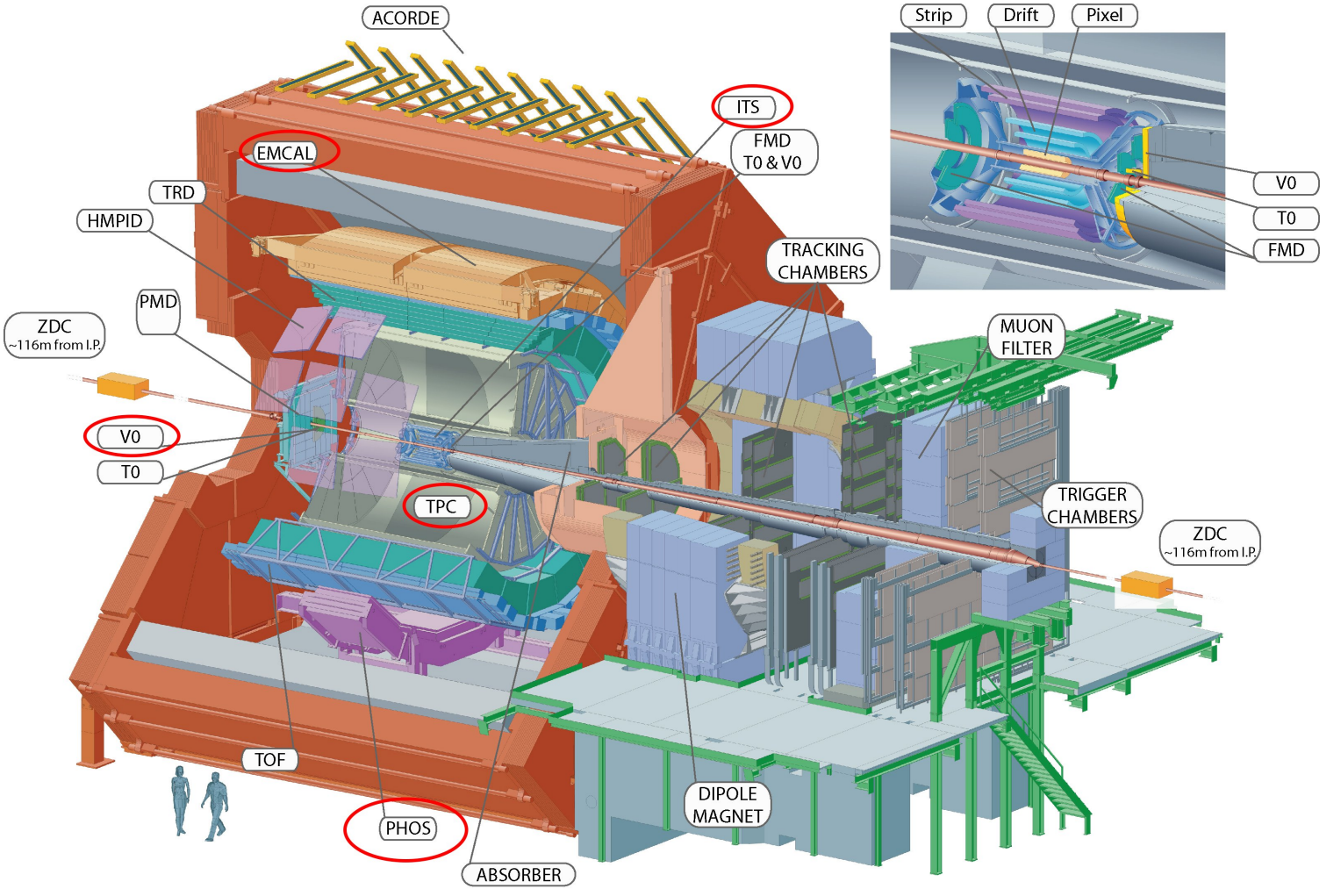


Neutral meson reconstruction

Neutral mesons are measured either by the PHOS and EMCal calorimeters or the Photon Conversion Method (PCM).

PHOS/EMCal:

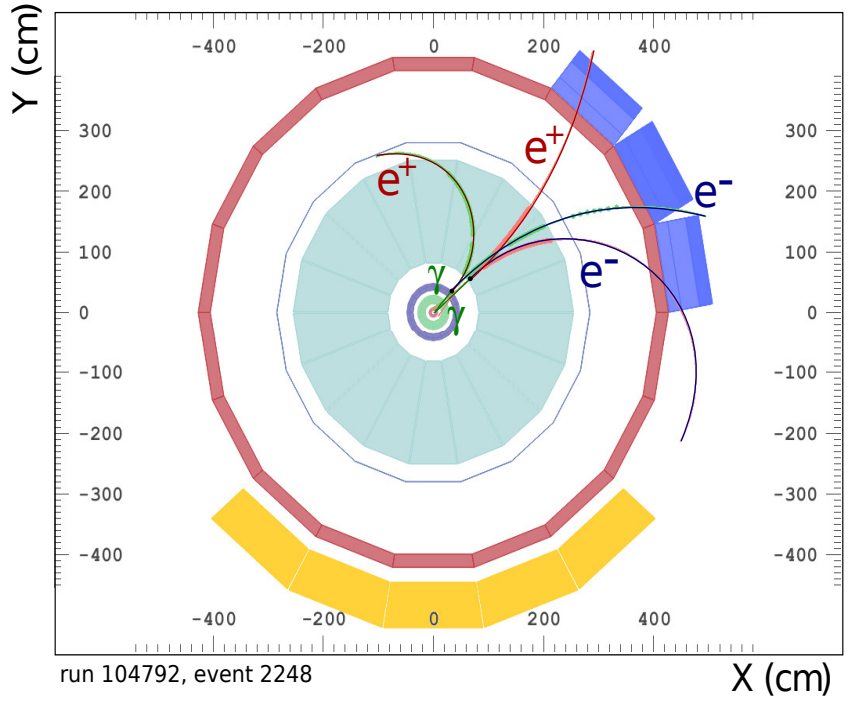
- Direct measurement of photon pairs: $\pi^0 \rightarrow \gamma + \gamma$
- Intermediate to high p_T range

PCM:

- Measurement of converted electron positron pairs with PCM:

$$\pi^0 \rightarrow \gamma(\rightarrow e^- e^+) + \gamma(\rightarrow e^- e^+)$$

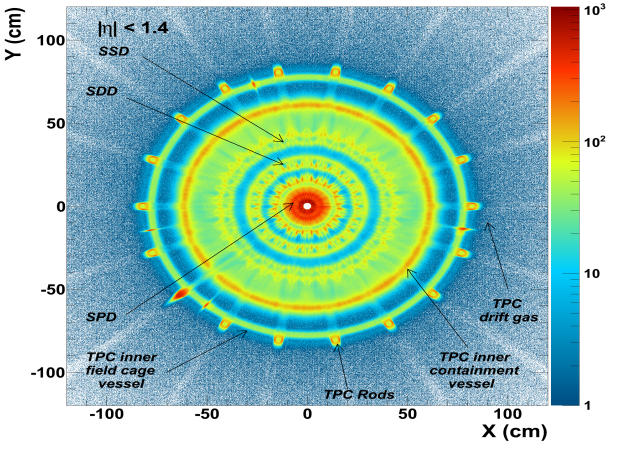
- Low (as low as 0.3 GeV/c) to intermediate p_T range
- Low conversion probability ~8% but large acceptance



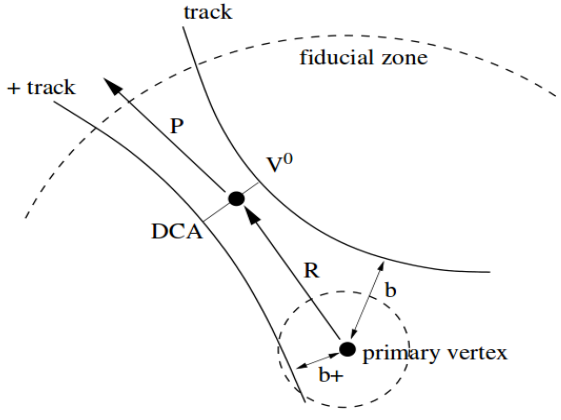
Reconstruction of π^0 candidate from e^+e^- pairs using PCM

PCM reconstruction

- V^0 reconstruction, combine two oppositely charged secondary tracks
- Impact parameter size less than given value $\Rightarrow$ track rejected
- DCA above 1 cm $\Rightarrow$ track pair rejected
- V^0's outside of fiducial zone rejected
- Momentum of track pair extrapolated to DCA $\Rightarrow$ V^0 momentum calculated
- Check if V^0 points to primary vertex



Distribution of conversion points in the azimuthal plane



Invariant Mass

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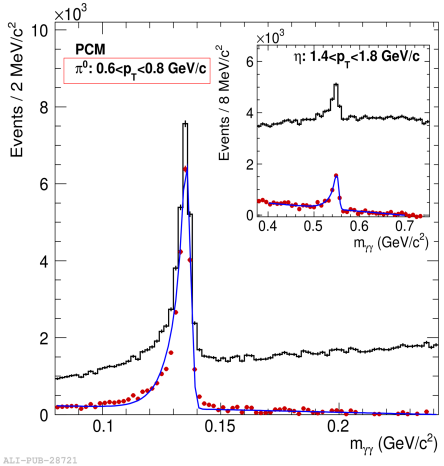
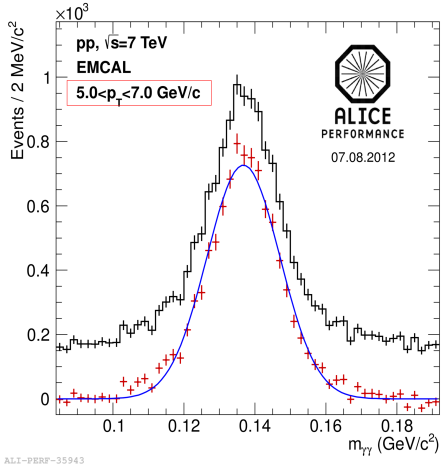
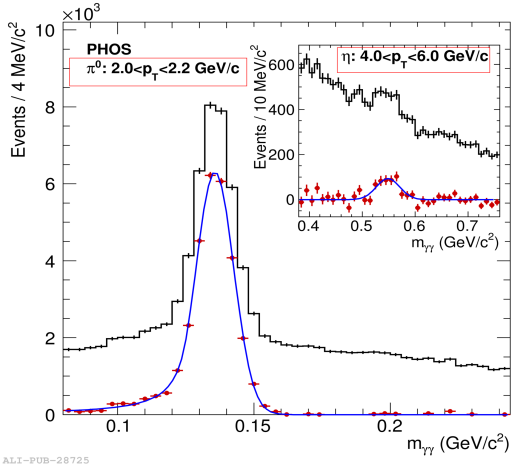
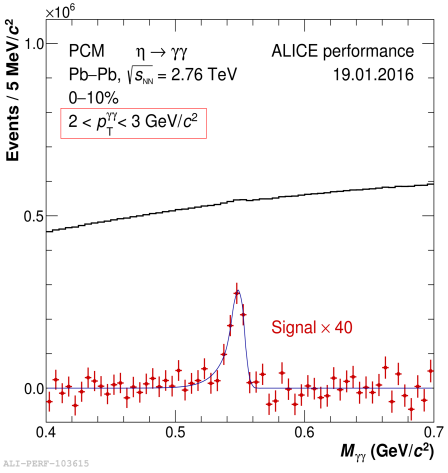
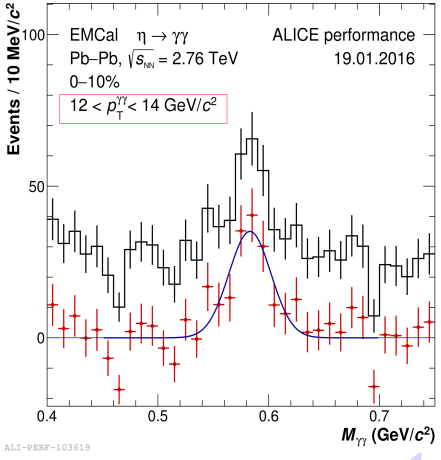
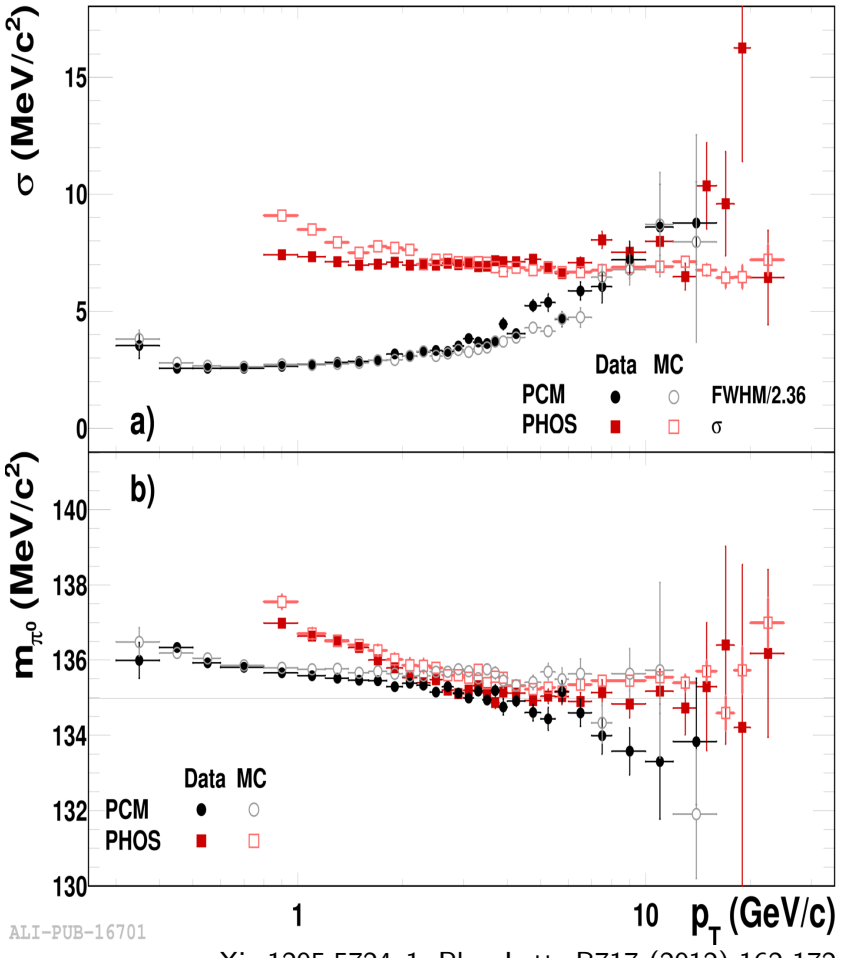
$$M_{\gamma\gamma} = \sqrt{2E_{\gamma 1}E_{\gamma 2}\left(1 - \cos\theta_{1,2}\right)}$$

	PCM	EMCal	PHOS
pp			
Pb-Pb			

+ : signal including background

+ : signal with background removed

− : fit to signal with background removed



arXiv:1205.5724v1, Phys.Lett. B717 (2012) 162-172

- Reconstructed π^0 peak width (a) and position (b) versus p_T in pp collisions at $\sqrt{s} = 7$ TeV in PHOS and PCM compared to Monte Carlo simulations
- Horizontal line in (b) represents nominal π^0 mass
- Both measurements particularly good at intermediate p_T
- Extremely large coverage when methods are combined

π^0 spectra in pp

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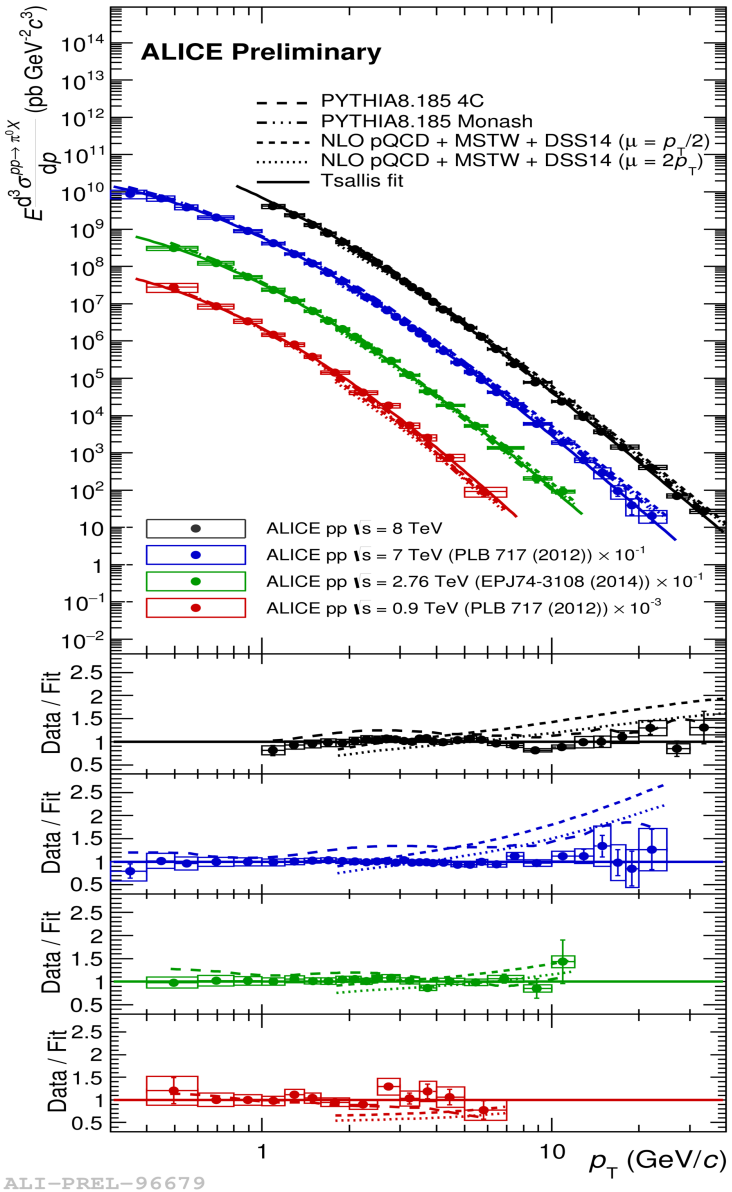

- Differential invariant cross-section of π^0 production in pp collisions at $\sqrt{s}$ =0.9 TeV, 2.76 TeV and $\sqrt{s} = 7$ TeV.
- Tsallis fit over full p_T range. Power law dependence at high p_T
- Horizontal line through unity indicates fit
- With increasing $\sqrt{s}$, NLO pQCD increasingly overpredicts measurements at high p_T

π^0 spectra in Pb-Pb

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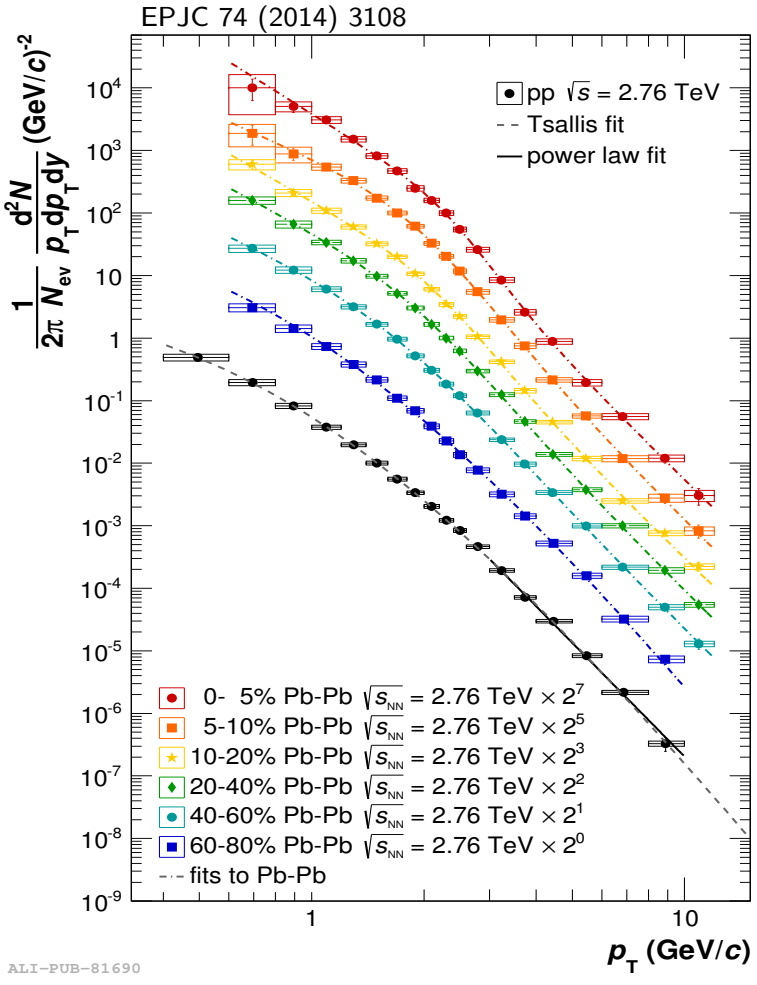
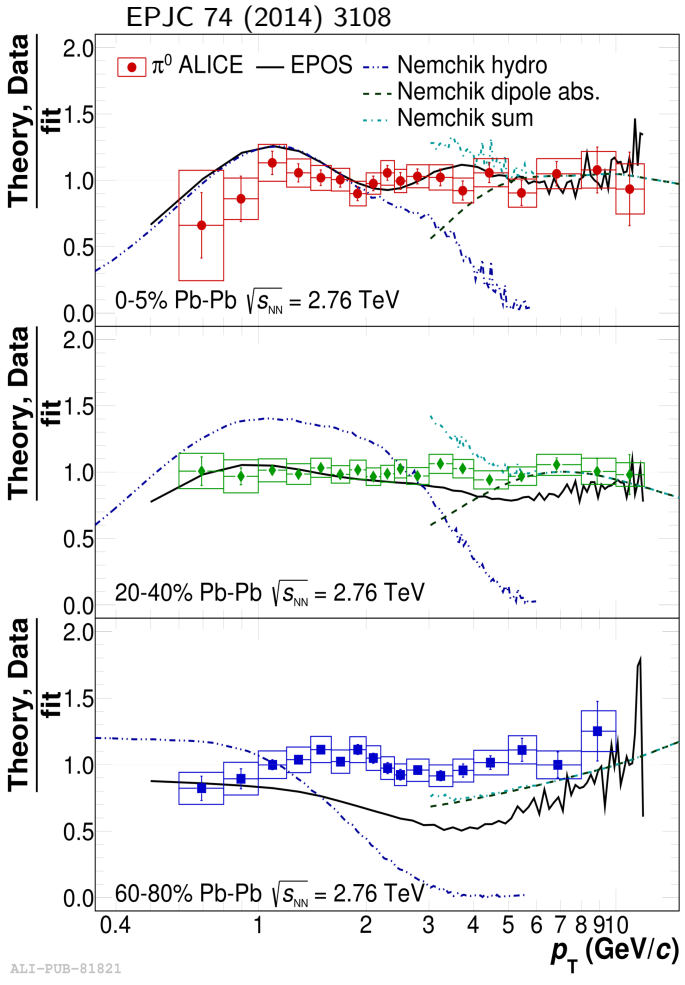
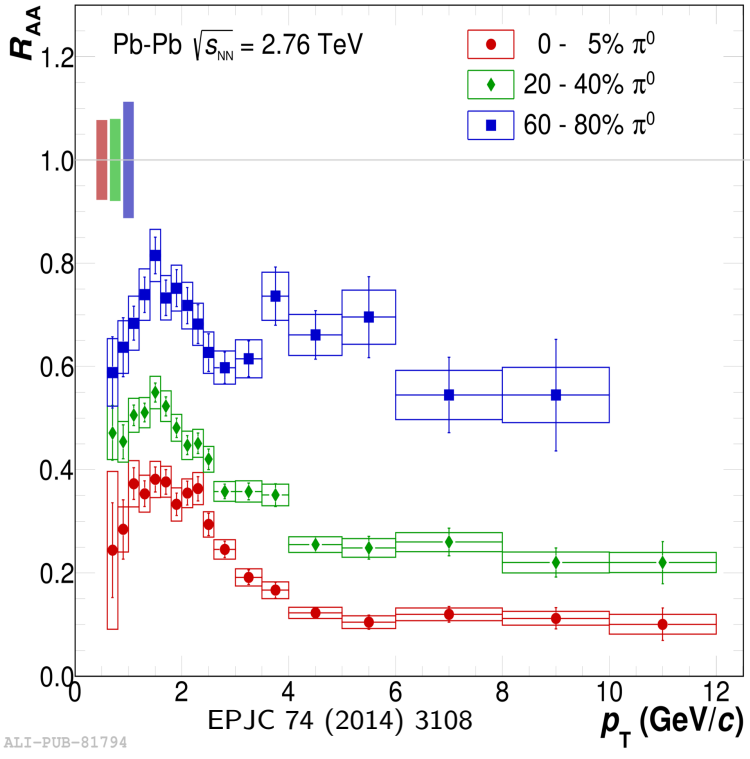




Nuclear modification factor

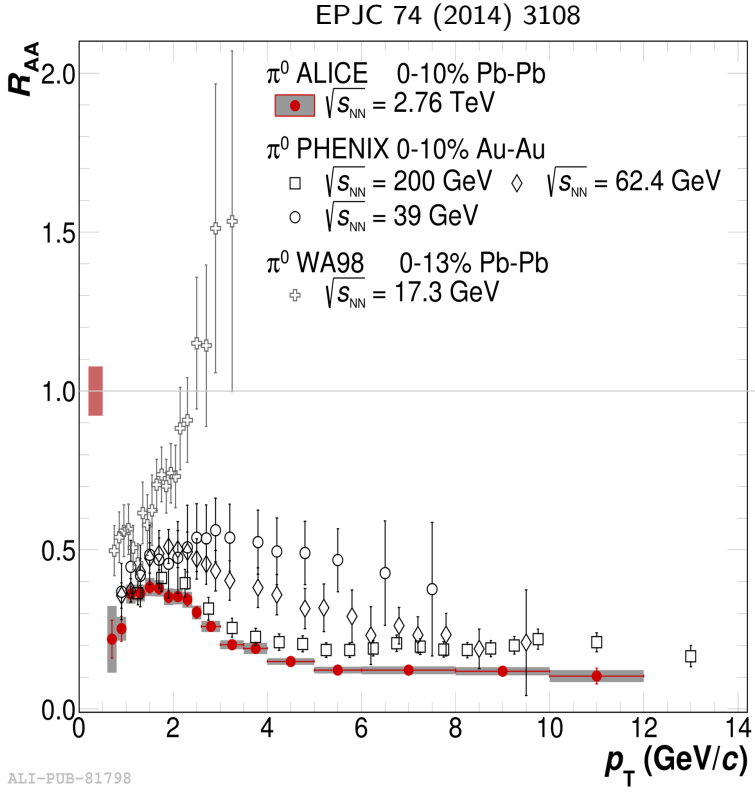
- π^0 R_{AA} for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for three centrality classes ranging from most central to peripheral.



- $R_{\mathrm{AA}} = \dfrac{\left(1/N_{\mathrm{AA}}^{evt}\right) \mathrm{d}^2 N_{\mathrm{AA}}^{\pi^0}/\mathrm{d}p_T\mathrm{d}y}{\langle T_{\mathrm{AB}} \rangle \times \mathrm{d}^2\sigma^{\pi^0_{pp}}/\mathrm{d}p_T\mathrm{d}y}$
- Boxes around unity represent uncertainty in average nuclear overlap function $\langle T_{\mathrm{AB}} \rangle = \sigma_{pp}^{\mathrm{inel}}/N_{\mathrm{coll}}$
- More central collisions exhibit greater suppression $\rightarrow$ larger medium created in more central collisions
- Strongest suppression at $p_T \gtrsim 3$ GeV/c

Nuclear modification factor

- ALICE π^0 R_{AA} measurements in most central collisions compared to those from PHENIX and SPS results
- R_{AA} decreases with increase in $\sqrt{s_{NN}}$
- Higher energy densities created in collisions with larger $\sqrt{s_{NN}}$ $\Rightarrow$ larger medium created
- R_{AA} maximum shifts towards lower p_T with increasing $\sqrt{s_{NN}}$



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Extraction of direct spectrum involves removal of large decay background

- π^0 & η input for simulation of full decay photon spectrum
- $\gamma_{\text{direct}} = \gamma_{\text{inc}} - \gamma_{\text{decay}}$

$$= \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{\text{inc}},$$

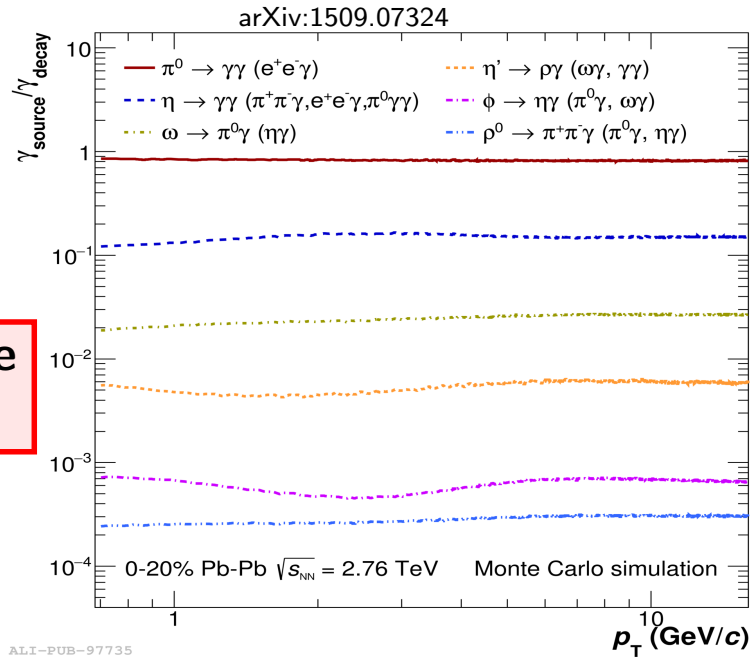
where $R_\gamma = \dfrac{\gamma_{\text{inc}}}{\pi^0} \Big/ \dfrac{\gamma_{\text{decay}}}{\pi^0_{\text{param}}}$ ← **Double Ratio**

- $\gamma_{\text{inc}}/\pi^0 =$ measured,

$\gamma_{\text{decay}}/\pi^0_{\text{param}} =$ parameterization

$\Rightarrow$ systematic uncertainty reduced

- $R_\gamma > 1 \Rightarrow$ presence of direct photons



Distributions of fraction of specific meson decay spectrum over total decay spectrum for several mesons

Double Ratio

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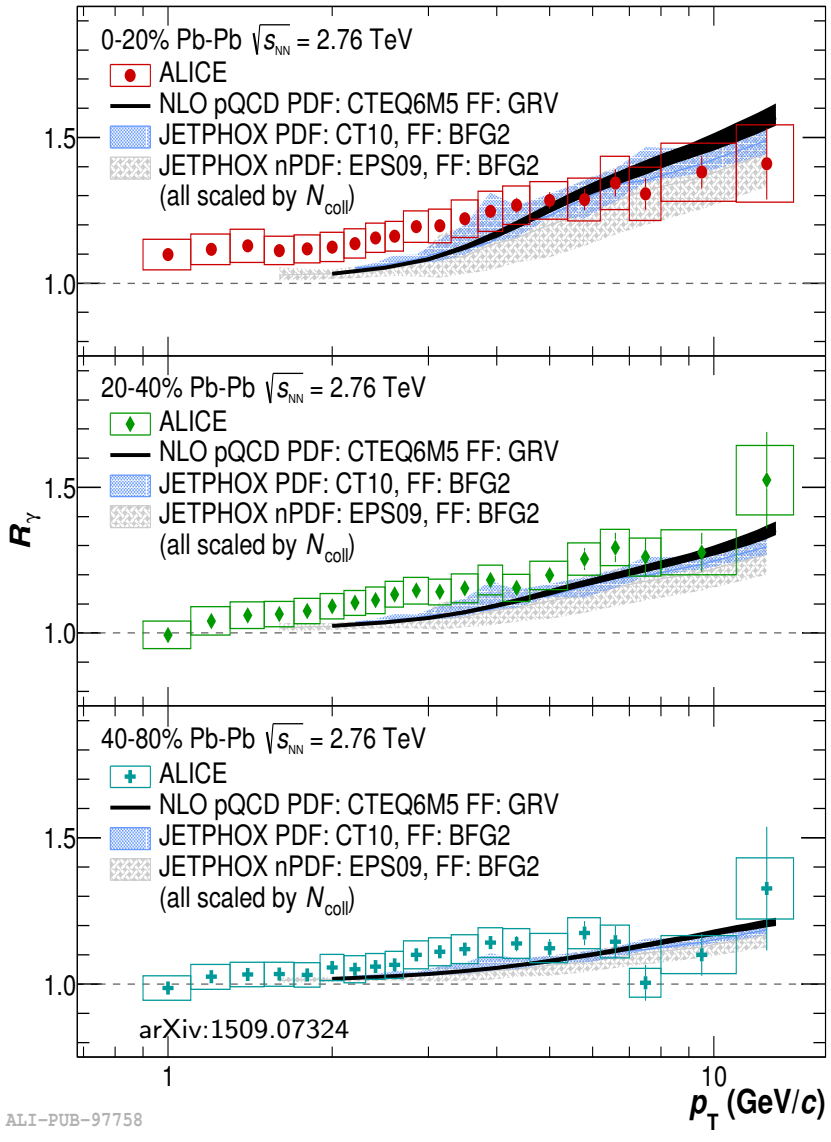
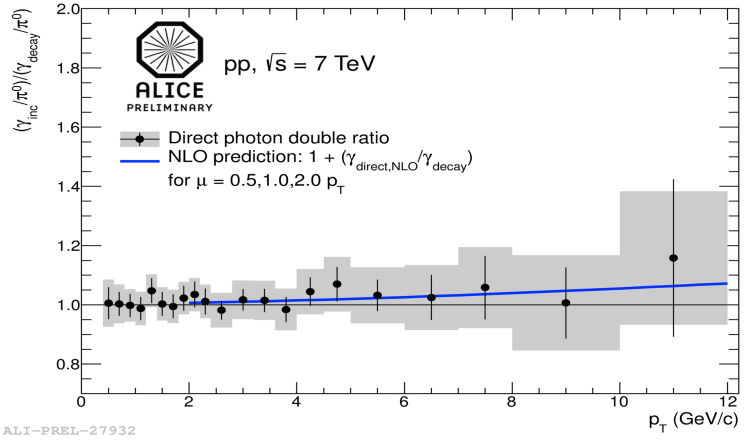


ALI-PUB-97758

- $\sim$ 30% excess in R_γ at large p_T for all centrality classes
- pQCD predictions underpredict R_γ at low p_T ($\lesssim$ 4 GeV/c) in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV
- Measurements at $\sqrt{s} = 7$ TeV in agreement with NLO pQCD



ALI-PREL-27932

Direct Photon Spectrum

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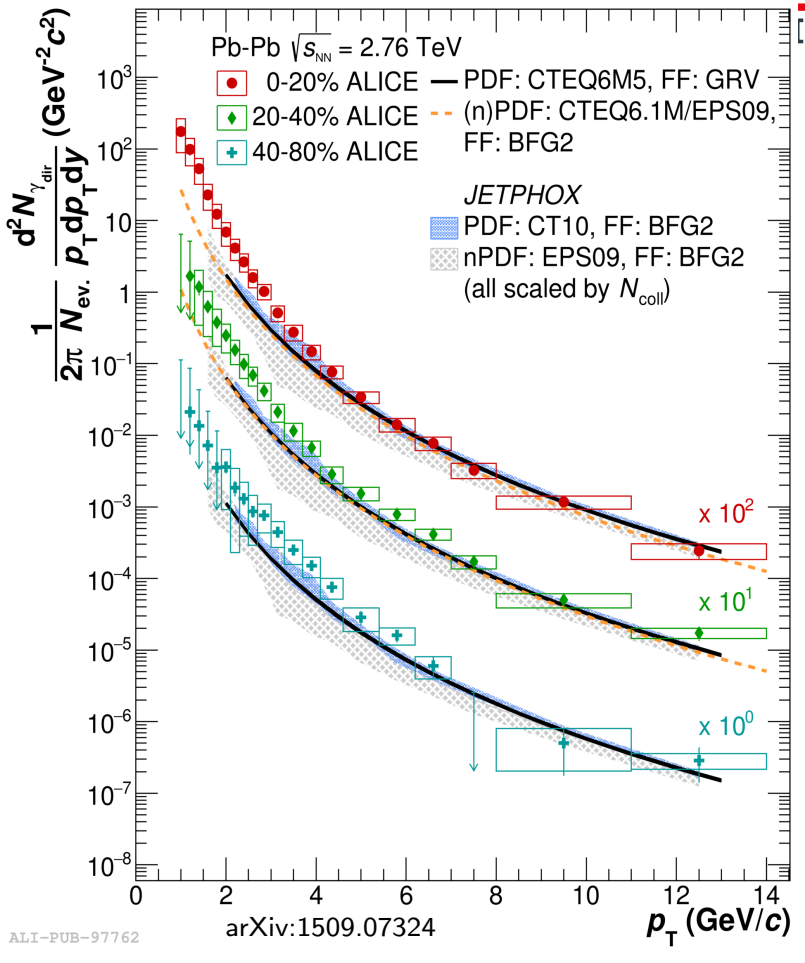
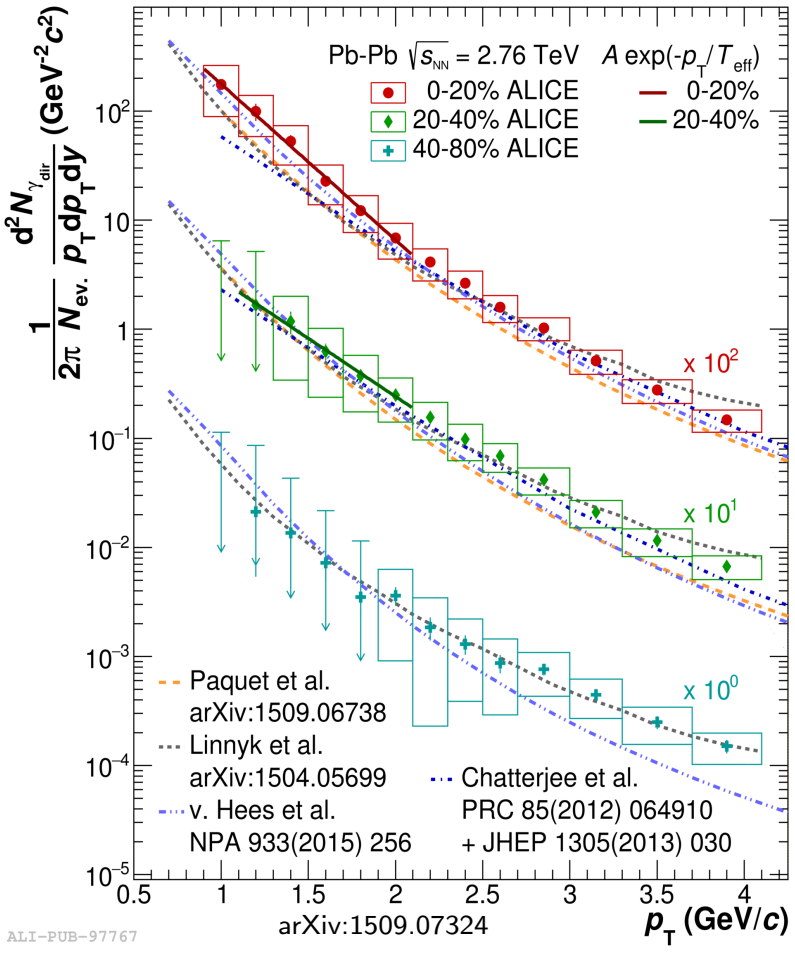
- Direct photon spectrum for Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV for three centrality classes
- Measurements performed over p_T range $0.9 < p_T < 14$ GeV/c
- NLO pQCD and JETPHOX predicitions are in good agreement with data for $p_T > 5$ GeV/c
- Once again, excess at low p_T above pQCD predictions is observed
- Excess in centrality class 0-20% at low p_T of ~10-15% with 2σ significance



Direct Photon Spectrum

Several models used in spectral fit, with all assuming formation of QGP and pQCD photons at high p_T but differing treatment of space-time evolution:

- Paquet et al.: 2+1 viscous hydro with IP-GLASMA initial conditions
- Linnyk et al.: off-shell transport, microscopic description of evolution
- v. Hees et al.: ideal hydro
- Chatterjee et al.: 2+1 hydro
- Exponential $A\exp\left(-p_T/T_{\mathrm{eff}}\right)$, fitted to low p_T range of spectrum.
- Inverse slope parameter $T_{eff} = 297 \pm 12^{stat} \pm 41^{syst}$ MeV

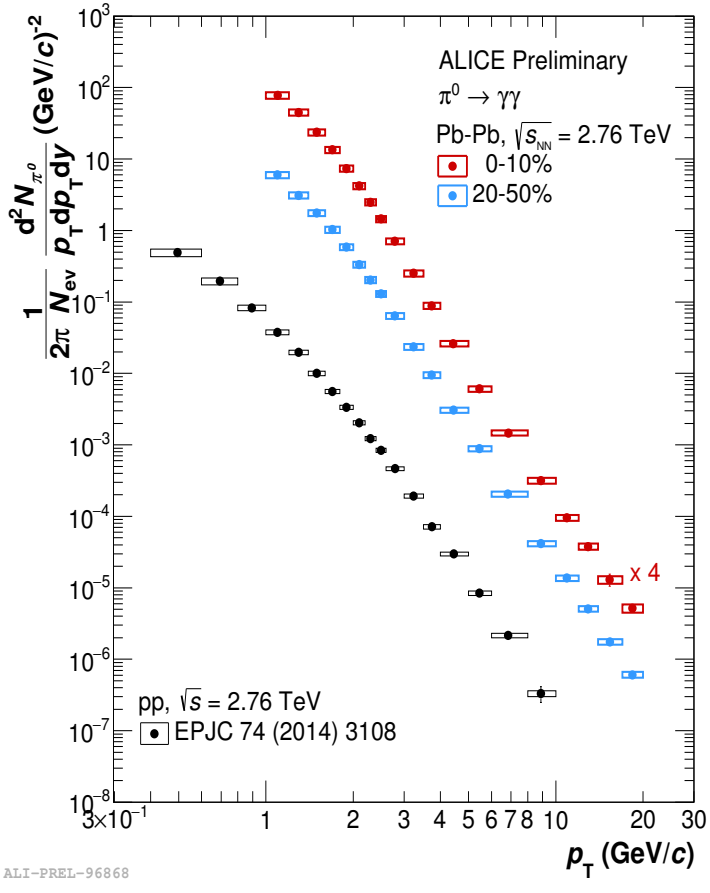


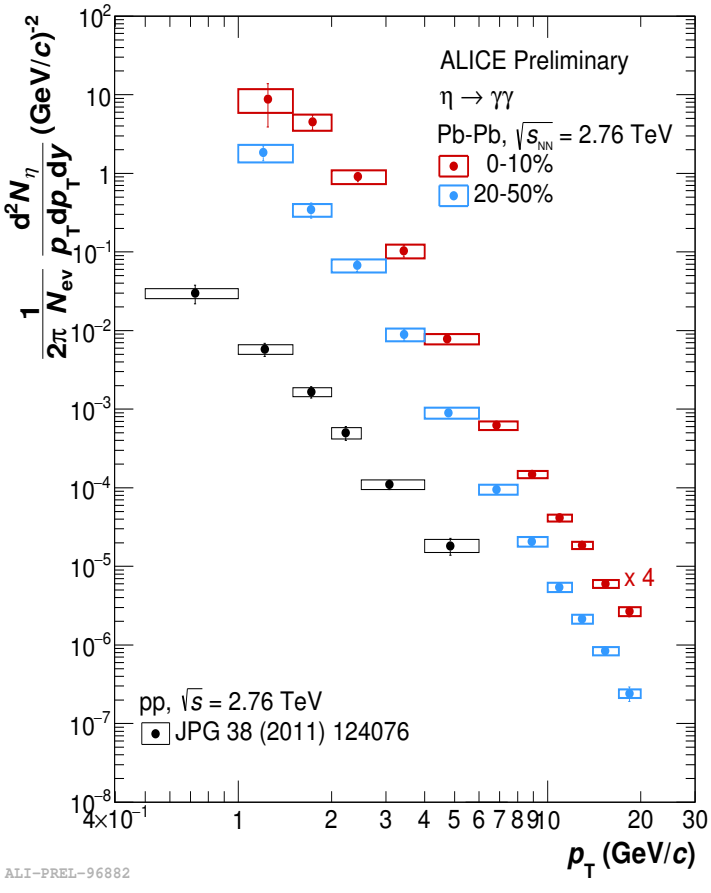
Summary

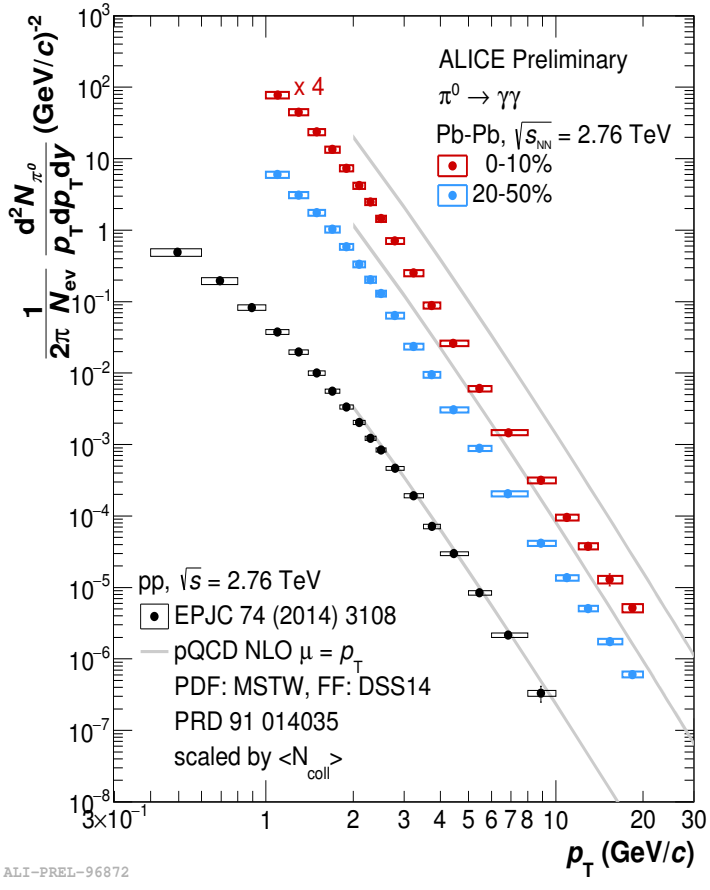
- In ALICE, PHOS, EMCal and PCM are used to measure neutral mesons and photons
- Combined methods cover a large p_T range
- In pp collisions, cross-sections measured at several $\sqrt{s}$, allow for the testing of pQCD
- Large suppression of π^0's in Pb-Pb at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV in most central collisions is observed
- Direct photon spectrum in both pp and Pb-Pb measured:
  - pp, R_γ shows good agreement with pQCD predictions
  - Excess in R_γ above pQCD predictions at low p_T in Pb-Pb is observed
- Inverse slope parameter, T_{eff}, extracted from low p_T region of direct photon spectrum.
- Outlook: Perform analysis of Pb-Pb data at $\sqrt{s_{NN}} = 5.02$ TeV

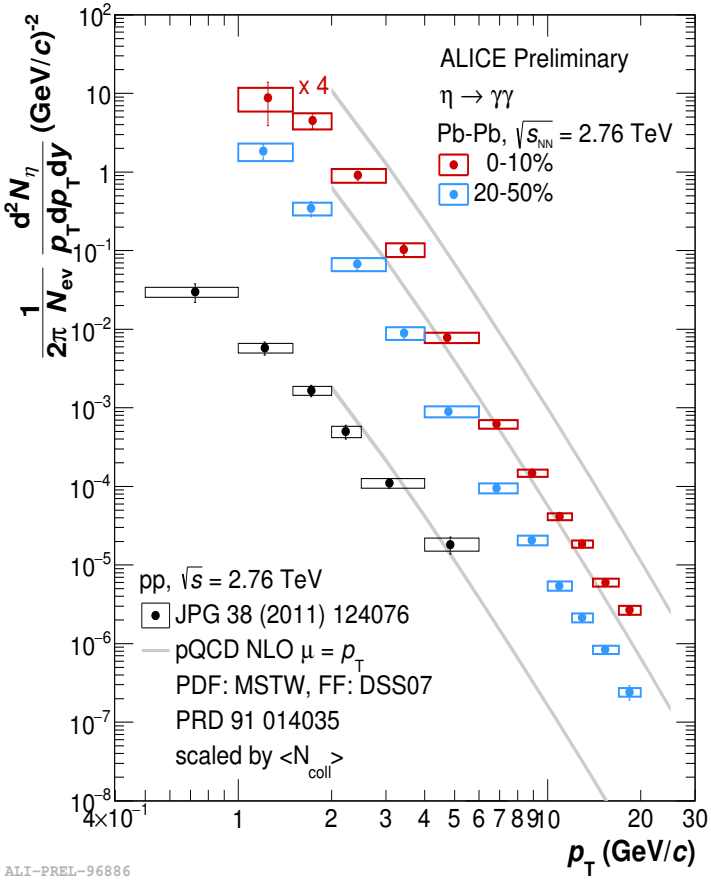
Additional Slides

π^0 and η spectra over extended p_T






ALICE Preliminary
$\pi^0 \rightarrow \gamma\gamma$
Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
0-10%
20-50%
x 4
pp, $\sqrt{s}$ = 2.76 TeV
EPJC 74 (2014) 3108
pQCD NLO $\mu = p_T$
PDF: MSTW, FF: DSS14
PRD 91 014035
scaled by <N_{coll}>
$\frac{1}{2\pi}\frac{1}{N_{ev}}\frac{d^2N_{\pi^0}}{p_T dp_T dy}$ (GeV/c)$^{-2}$
p_T (GeV/c)
ALI-PREL-96872


ALICE Preliminary
$\eta \rightarrow \gamma\gamma$
Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
0-10%
20-50%
x 4
pp, $\sqrt{s}$ = 2.76 TeV
JPG 38 (2011) 124076
pQCD NLO $\mu = p_T$
PDF: MSTW, FF: DSS07
PRD 91 014035
scaled by <N_{coll}>
$\frac{1}{2\pi}\frac{1}{N_{ev}}\frac{d^2N_{\eta}}{p_T dp_T dy}$ (GeV/c)$^{-2}$
p_T (GeV/c)
ALI-PREL-96886