

Hard Probes 2016
September 23-27, 2016
Wuhan, China

Neutral meson production in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC



ALICE

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25 Sep. 2016

Physics Motivation

In pp collisions

New: π^0 in pp at $\sqrt{s} = 8$ TeV

- Understanding particle production

In Pb-Pb collisions

New: η in Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV

- Study for parton energy loss

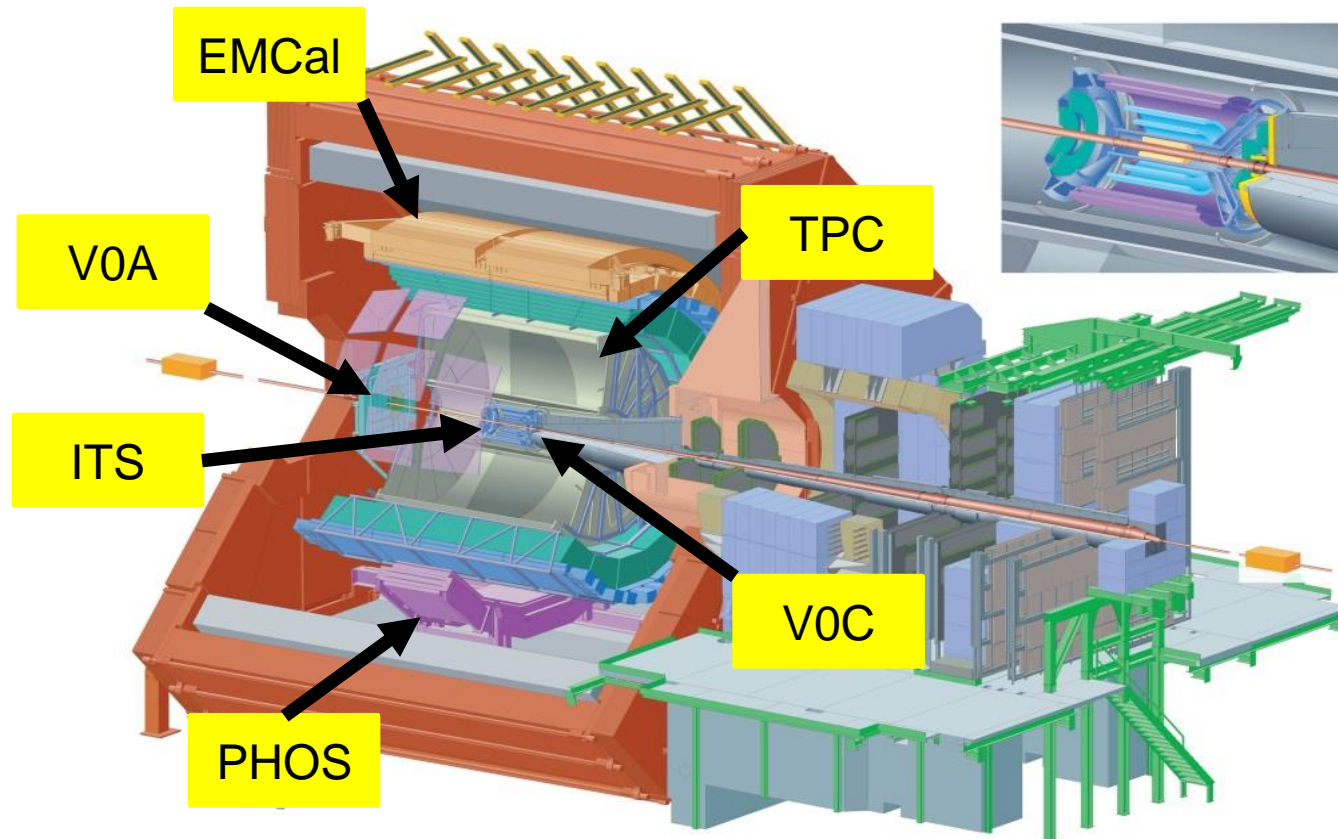
In p-Pb collisions

New: π^0 & η in p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV

- Disentangling the suppression coming from initial condition of colliding nuclei or final state effects in Pb-Pb collisions

- Comparison to model predictions
- π^0 and η are main sources of backgrounds in the direct photon measurement

ALICE Experiment in Run1 (2011-2013)



- Electromagnetic calorimeters: **PHOS** and **EMCal**
- Tracking and particle identification: **ITS** and **TPC**
- Centrality determination via multiplicity: **V0A** ($2.8 < \eta < 5.1$) and **V0C** ($-3.7 < \eta < -1.7$)

Photon Detection in ALICE (Run1)

• PHOS

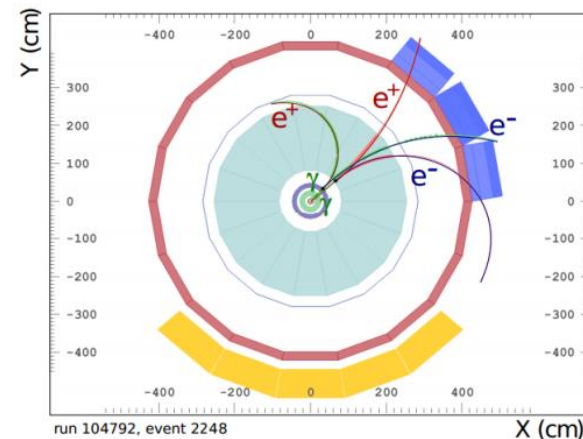
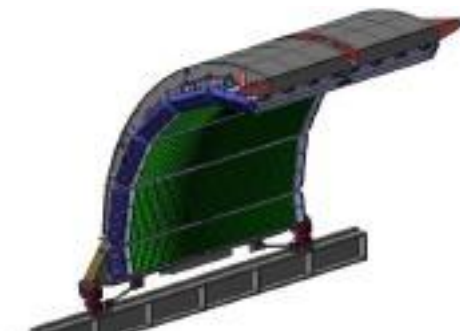
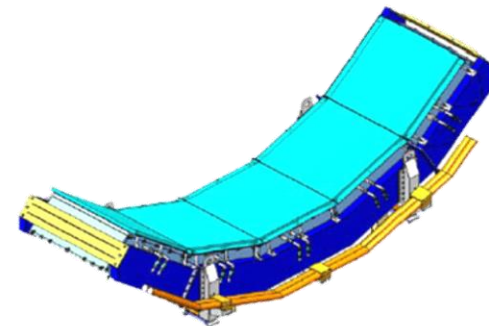
- Located at 4.6 m from the ALICE IP
- PbWO_4 crystal and APD readout
- $|\eta| < 0.13$, $260^\circ < \varphi < 320^\circ$
- Cover the intermediate to high- p_T (1-40 GeV/c)

• EMCal

- Located at 4.4 m from the IP
- PbSc sandwich calorimeter
- $|\eta| < 0.7$, $80^\circ < \varphi < 180^\circ$
- Cover the intermediate to high- p_T (1-20 GeV/c)

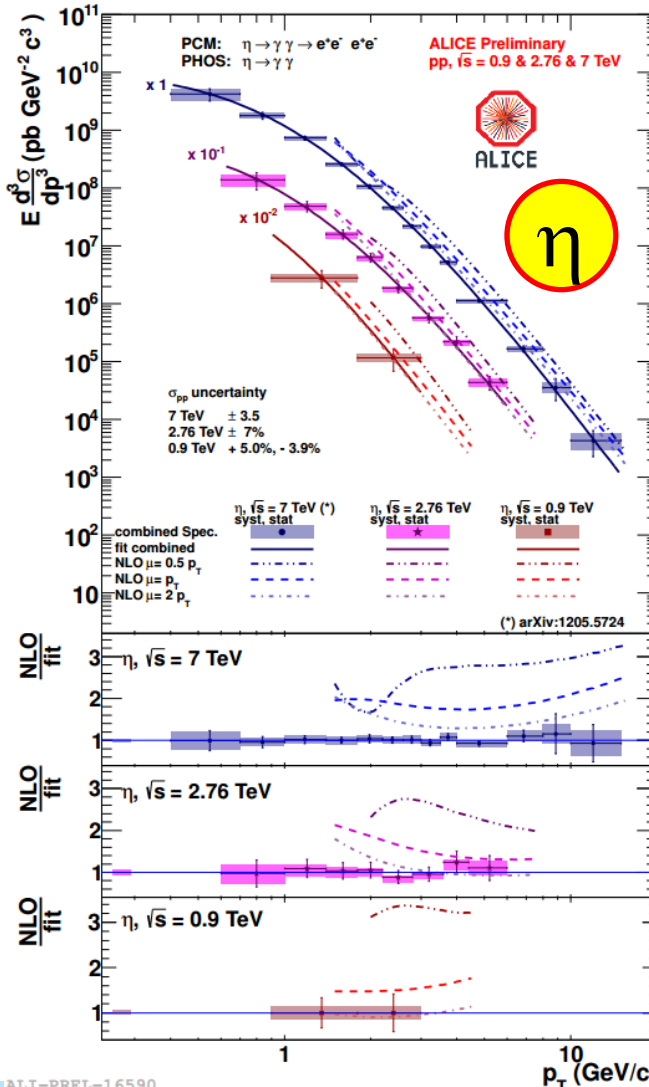
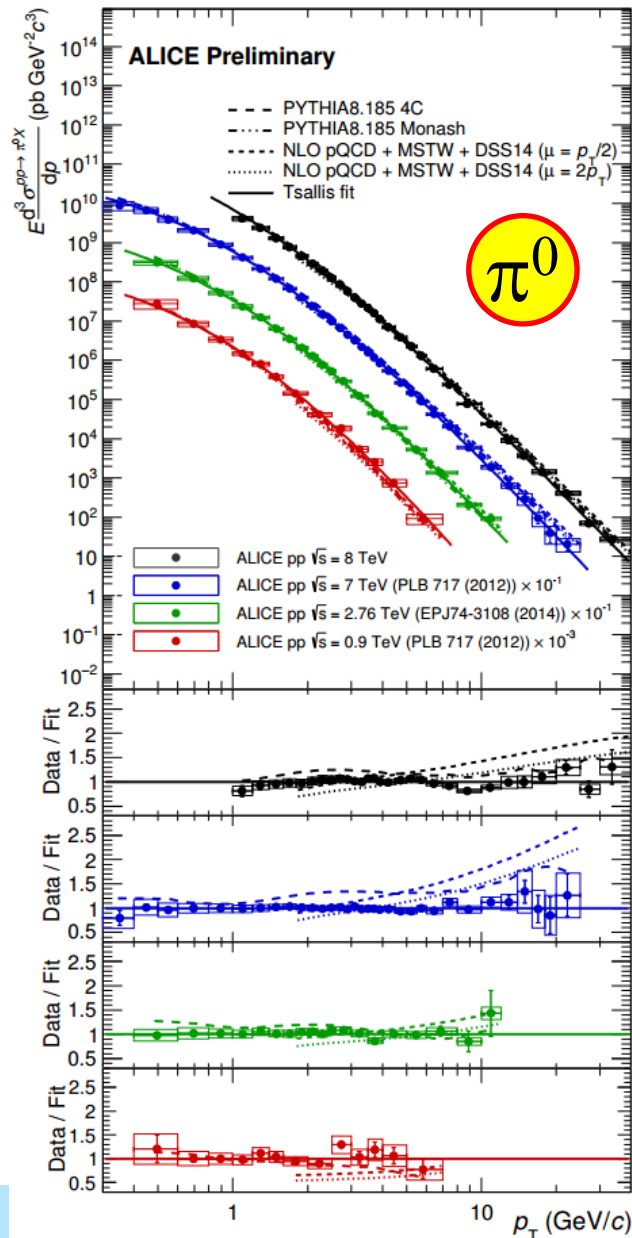
• Photon Conversion Method (PCM)

- Photon conversion in TPC and ITS
- $|\eta| < 0.9$, $0^\circ < \varphi < 360^\circ$
- PCM conversion probability $\sim 8.5\%$
- Cover the low to intermediate p_T (0.3-14 GeV/c)



π^0 and η Yields in pp with PHOS+PCM

- First π^0 measurement in pp at $\sqrt{s} = 8$ TeV
- π^0 yields are measured in pp collisions at $\sqrt{s} = 0.9, 2.76, 7$ and 8 TeV

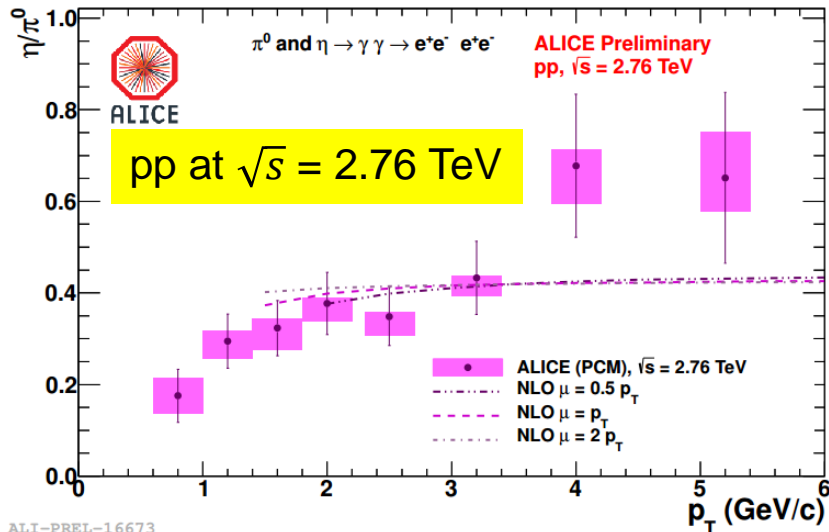


- η yields are measured in pp collisions at $\sqrt{s} = 0.9, 2.76$ and 7 TeV
- Reasonable agreement between data and NLO pQCD for $\sqrt{s} = 0.9$ and 2.76 TeV

π^0 : PDF:MSTW, FF: DSS14
 η : PDF:Cteq6M5, FF: AES

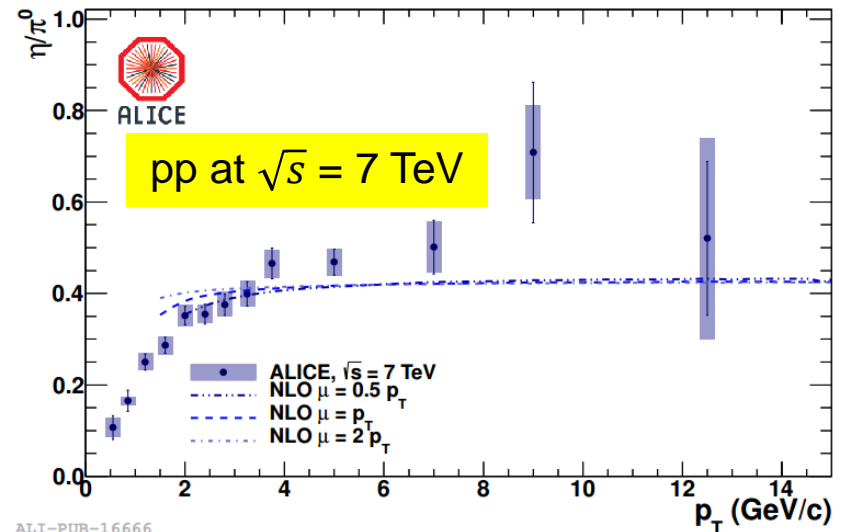
PLB717 (2012) 162-172
 Eur. Phys. J. C (2014) 74-3108
 arXiv: 1512.05250
 (QM2015 proceedings)

η/π^0 Ratio in pp



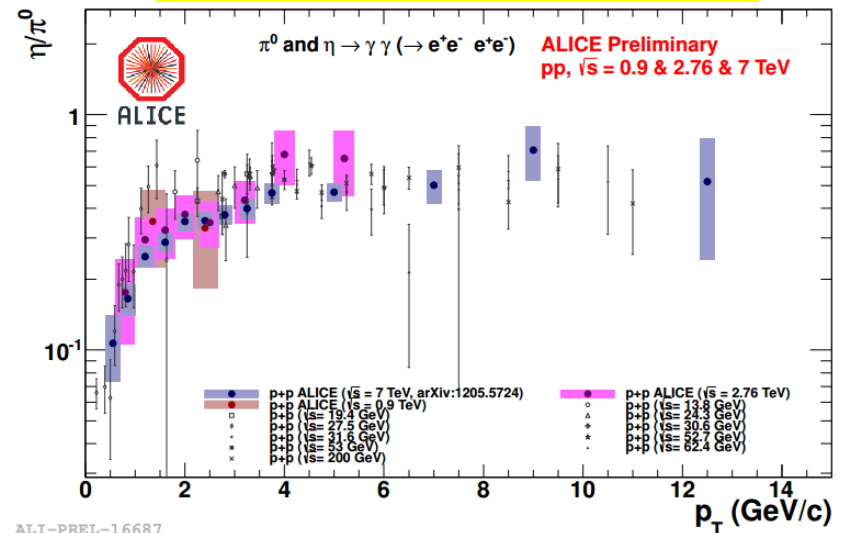
ALI-PREL-16673

η : PDF:CTEQ6M5, FF: AES
 π^0 : PDF:CTEQ6M5, FF: DSS



ALI-PUB-16666

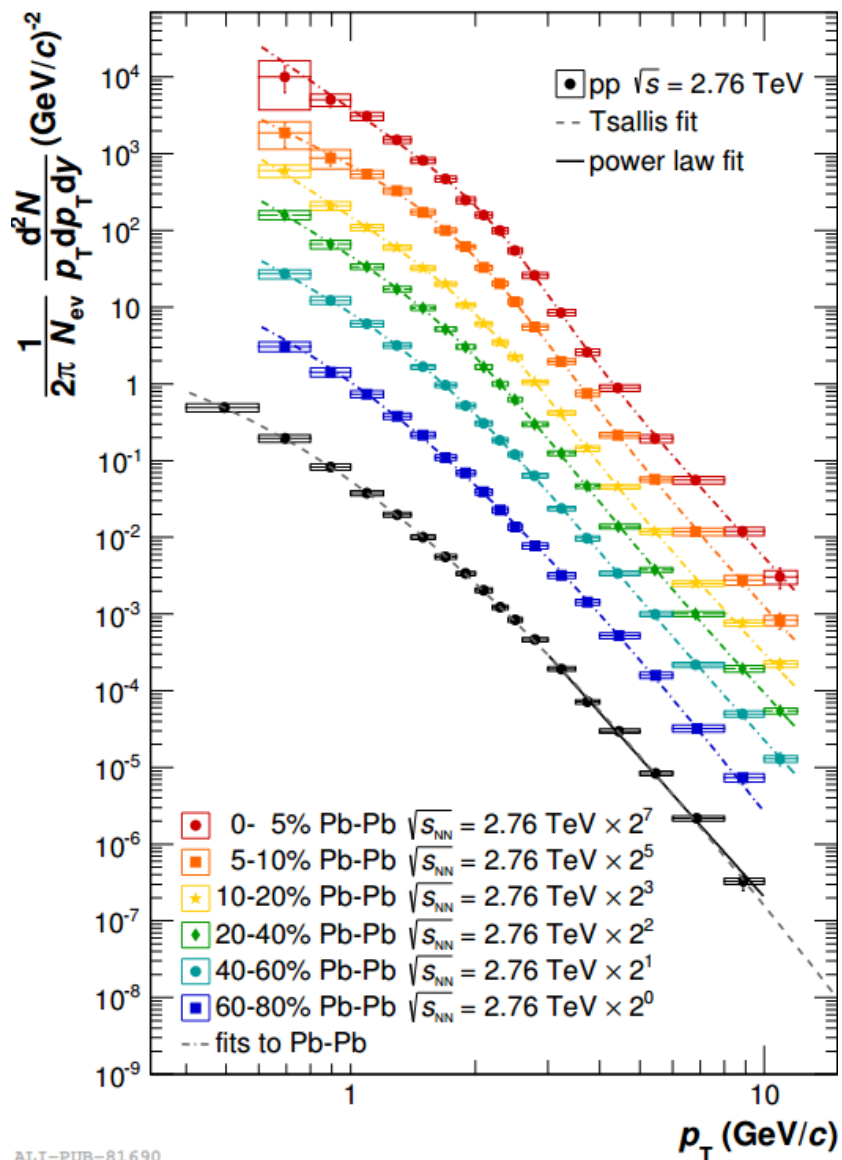
Comparison to world results



ALI-PREL-16687

- pQCD calculation reproduces well data
- η/π^0 ratio at ALICE is consistent with world results in pp collisions at all energies

π^0 Yields in Pb-Pb 2010 data with PHOS+PCM

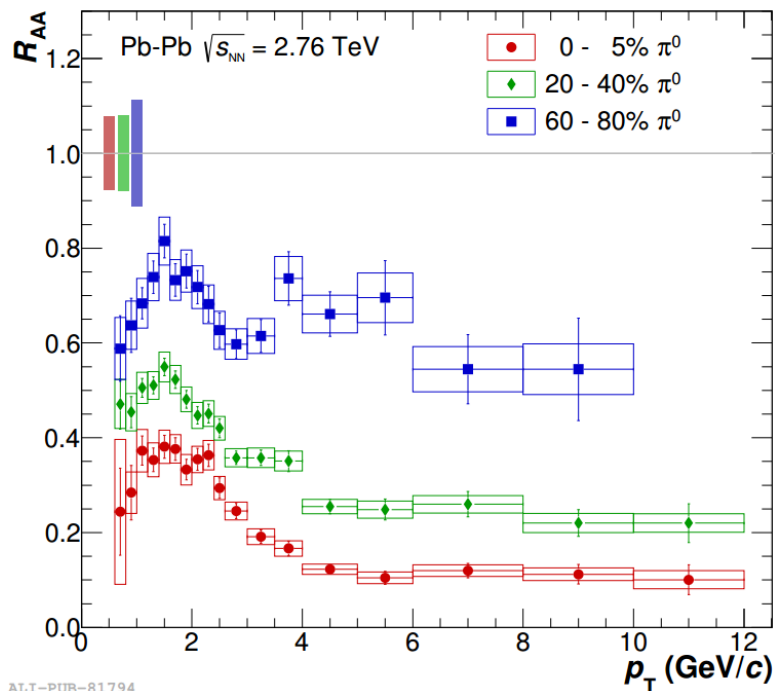


ALI-PUB-81690

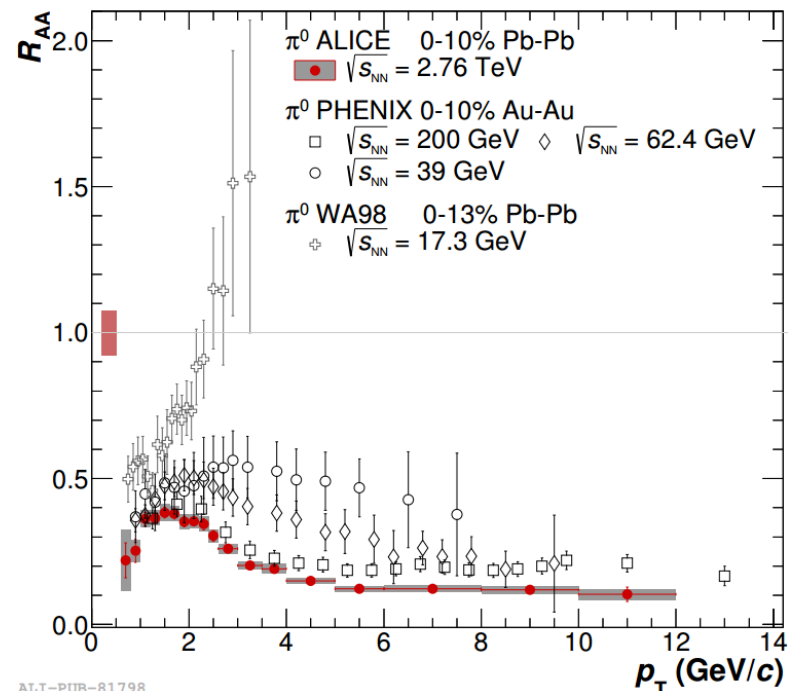
Eur. Phys. J. C (2014) 74-3108

- π^0 yields measured in six centrality classes
- Clear modification of the spectrum in central collisions
- Not enough statistics for η in 2010 data

Nuclear Modification Factor $R_{\text{Pb-Pb}}^{\pi^0}$



Eur. Phys. J. C (2014) 74-3108

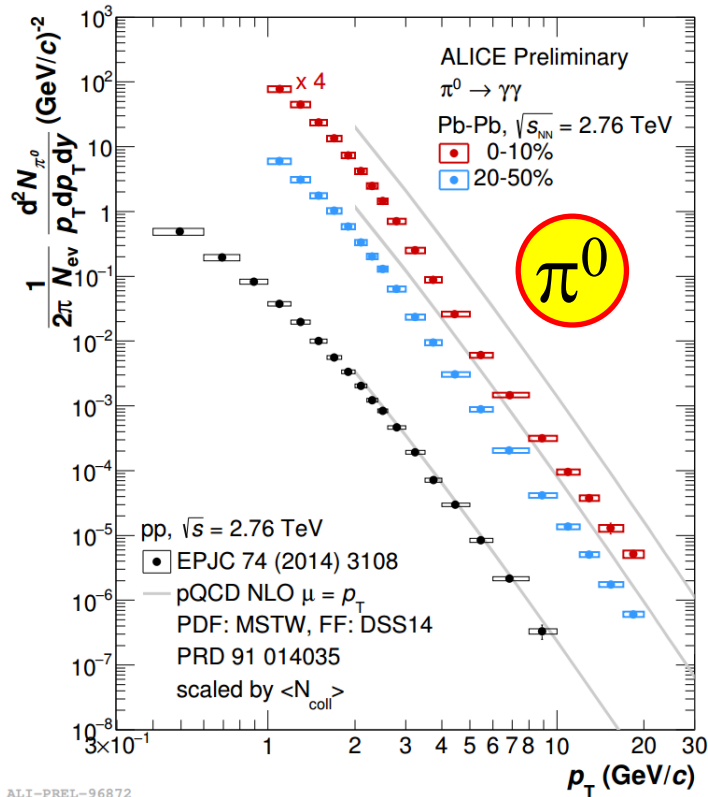


PHENIX: PRL 109 (2012) 152301
 PHENIX: PRL 101 (2008) 232301
 WA98: PRL 100 (2008) 242301

$$R_{\text{AA}}(p_{\text{T}}) = \frac{d^2N/dp_{\text{T}}dy|_{\text{AA}}}{\langle T_{\text{AA}} \rangle \times d^2\sigma/dp_{\text{T}}dy|_{\text{pp}}}$$

- Strong π^0 suppression at high p_{T} in central Pb-Pb collisions
 → Stronger suppression for more central collisions
- $R_{\text{AA}}^{\pi^0}$ at LHC is lower than at RHIC and at SPS

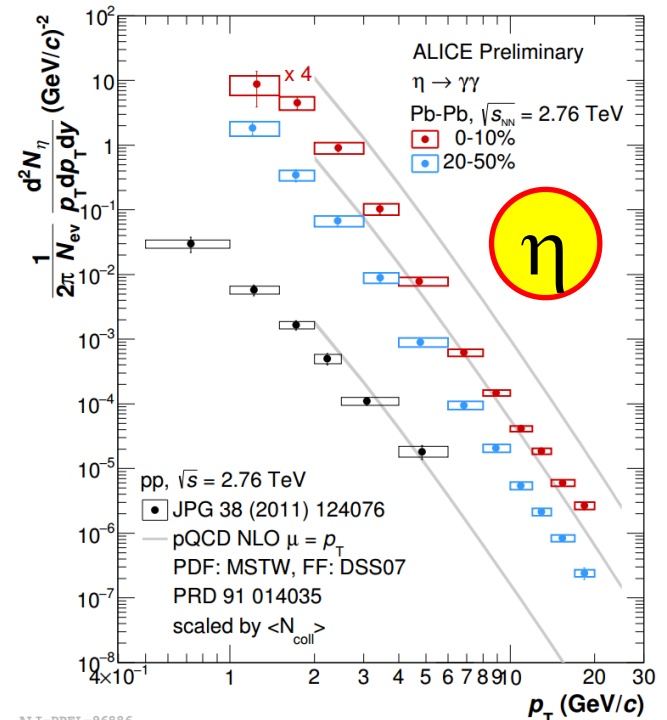
π^0 and η Yields in 2011 data with EMCAL+PCM



ALI-PREL-96872

[arXiv: 1512.05250](https://arxiv.org/abs/1512.05250)

- 2011 data has more statistic than 2010 data (~10 times)
- π^0 reaches higher p_T (20 GeV/c)



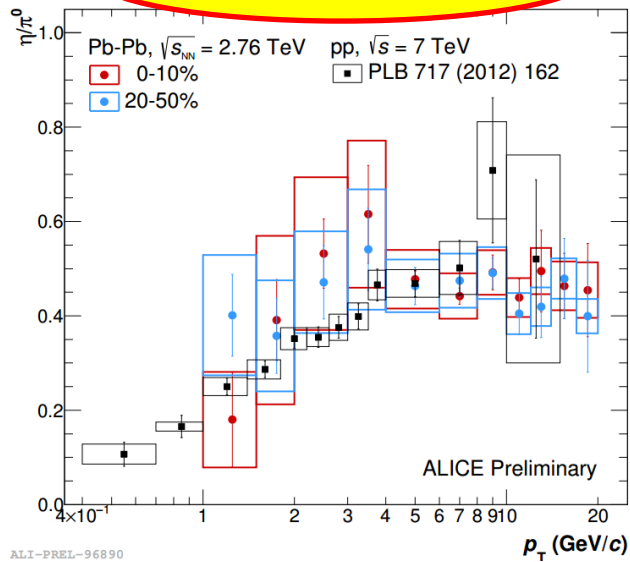
ALI-PREL-96886

[arXiv: 1512.05250](https://arxiv.org/abs/1512.05250)

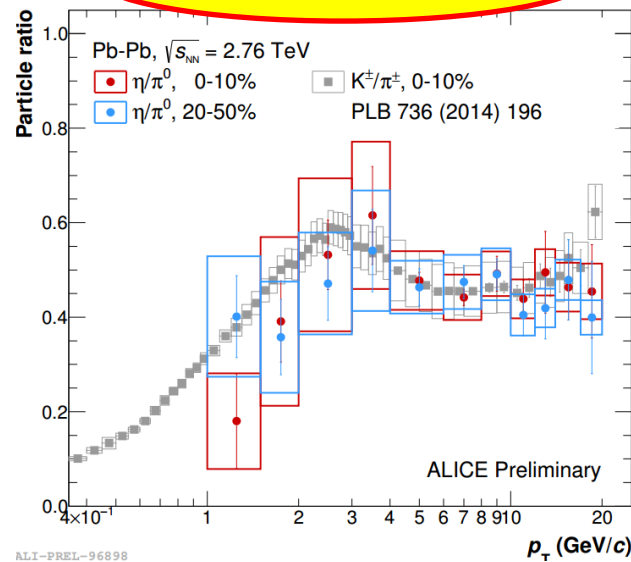
- First η measurement in Pb-Pb at the LHC
- Comparison with NLO pQCD calculation (PRD 91 (2015) 014035) shows suppression both for π^0 and η .

η/π^0 Ratio in Pb-Pb

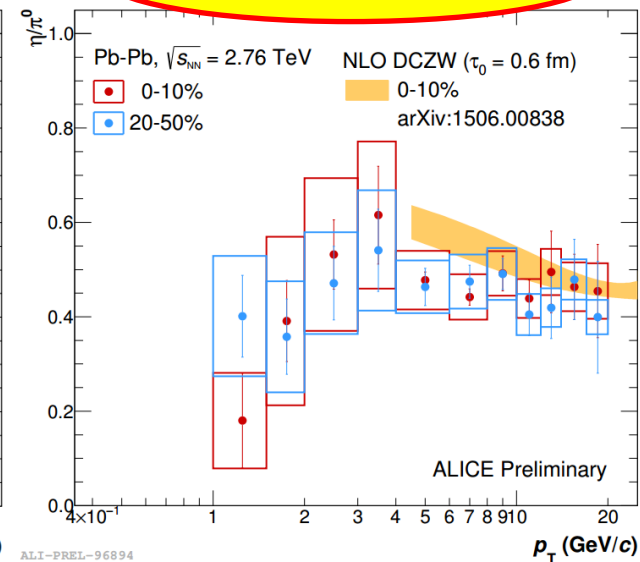
Comparison with pp



Comparison with K/π



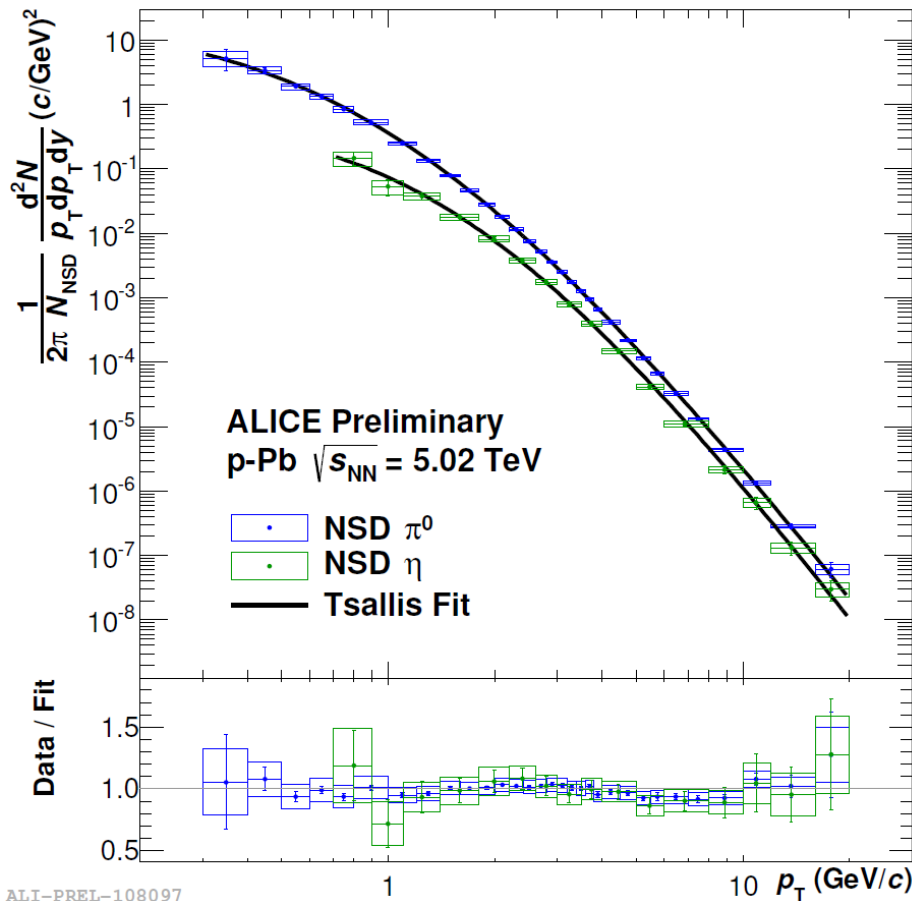
Comparison with model



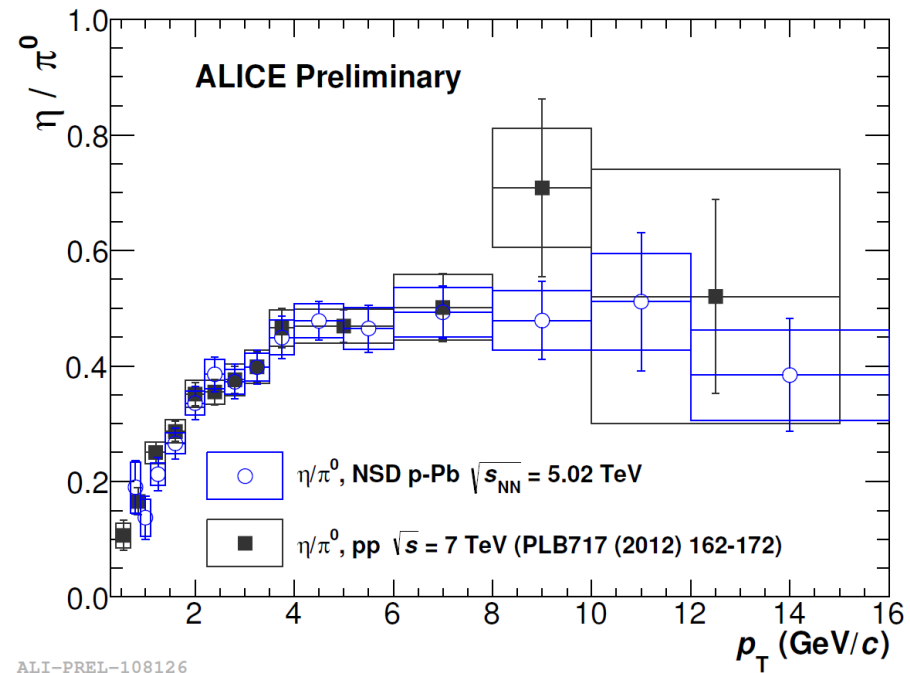
arXiv: 1512.05250

- η/π^0 ratio is measured in Pb-Pb collisions in two centrality classes
- Comparison to η/π^0 ratio in pp shows comparable values
- Comparison to K^\pm/π^\pm ratio shows similar behavior
- pQCD NLO calculation at high p_T with energy loss reproduce the data
 → p_T region 4-6 GeV/c sensitive to initial transport coefficient

Invariant Yields and η/π^0 Ratio in p-Pb

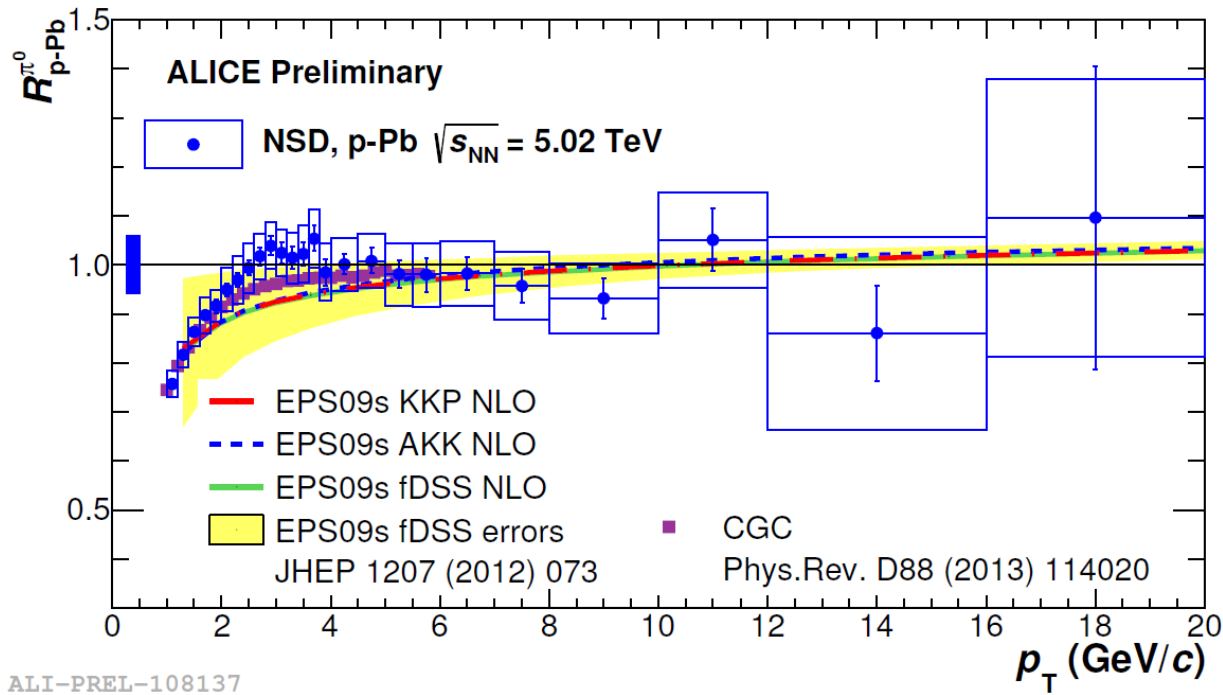


- First π^0 and η measurements in p-Pb



- η/π^0 ratio consistent with PCM result in pp collisions at $\sqrt{s} = 7$ TeV
→ Ratio does not depend on the collision system

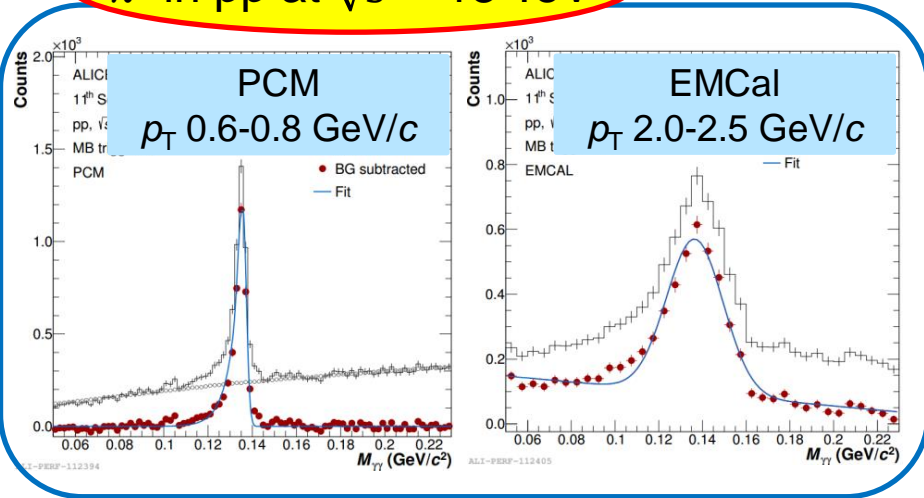
Nuclear Modification Factor $R_{p-Pb}^{\pi^0}$



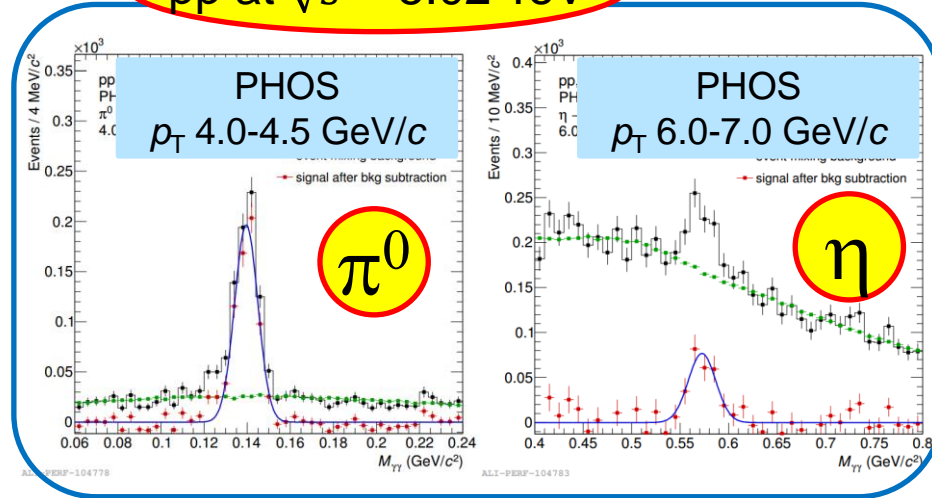
- No reconstructed pp reference available for $\sqrt{s} = 5.02$ TeV
 → Using published π^0 spectra in pp collisions at $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 7$ TeV for interpolation with power law
- $R_{p-Pb}^{\pi^0}$ is consistent with unity above 2 GeV/c and agrees with model predictions.

Neutral Meson Performance in Run2

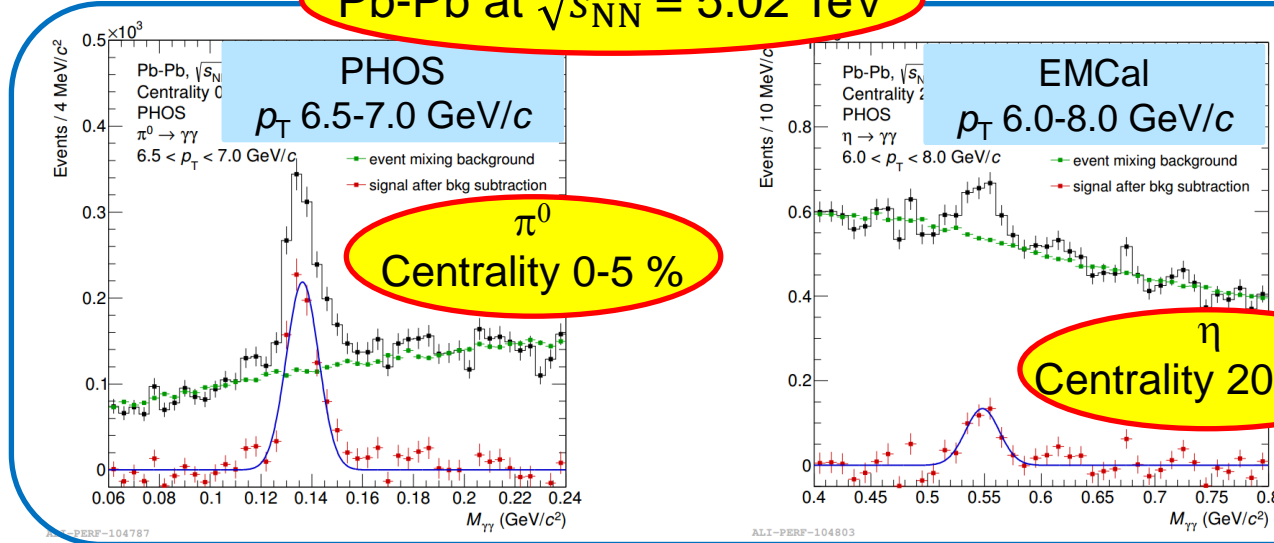
π^0 in pp at $\sqrt{s} = 13$ TeV



pp at $\sqrt{s} = 5.02$ TeV



Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV



PHOS performance is shown in Daiki's poster

Summary

ALICE experiment measures neutral meson (π^0 and η) yields with different methods (PHOS, EMCal and PCM) in different collision system (pp, Pb-Pb and p-Pb)

In pp collisions

- Reasonable agreement with NLO pQCD for $\sqrt{s} = 0.9$ and 2.76 TeV
- Good agreement of η/π^0 ratio with pQCD calculations

In Pb-Pb collisions

- Invariant π^0 yields are measured by PHOS+PCM (2010 data) and EMCal+PCM (2011 data)
- π^0 suppression becomes stronger with more central collisions

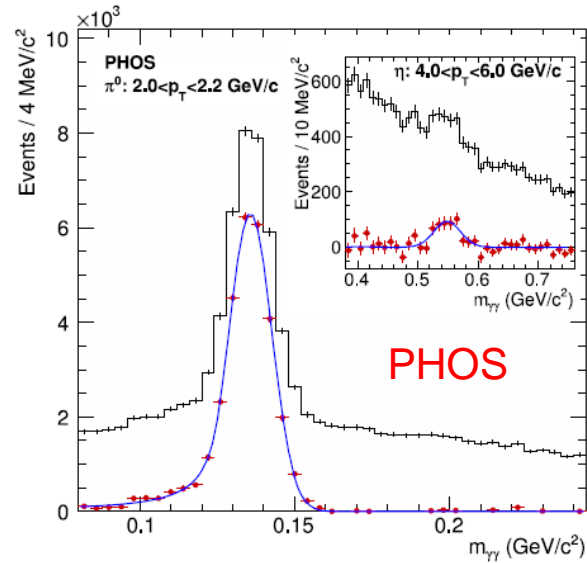
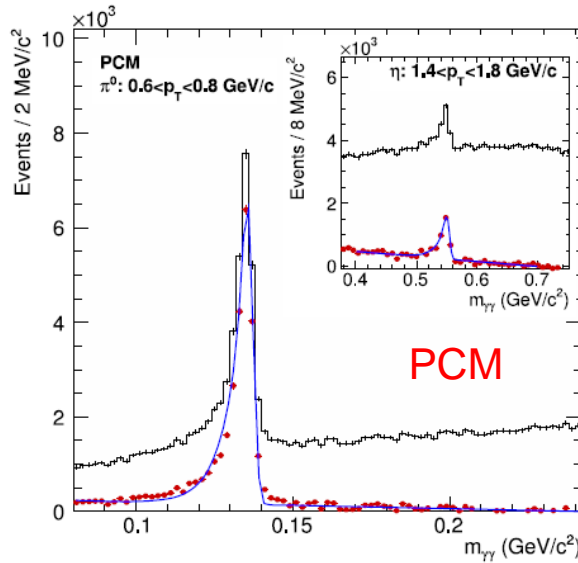
In p-Pb collisions

- η/π^0 ratio does not depend on collision system
- $R_{p-Pb}^{\pi^0}$ is consistent with unity above $p_T > 2$ GeV/c

- Publications for pp at $\sqrt{s} = 8$ TeV, pp and Pb-Pb at $\sqrt{s} = 2.76$ TeV and p-Pb to appear soon
- LHC Run2 analysis is ongoing

Backup

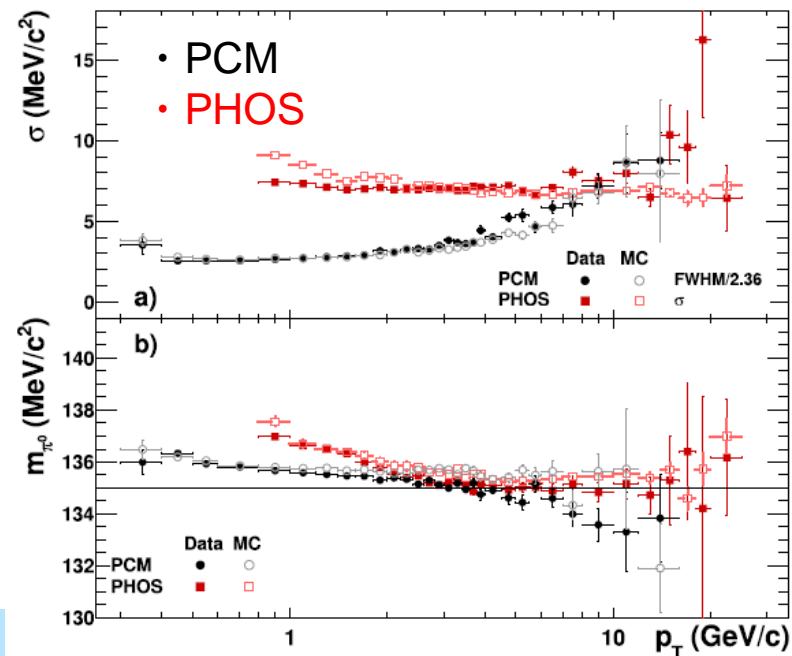
Peak Position and Width in pp 7 TeV



$$m_{\gamma\gamma} = \sqrt{2E_1 \times E_2 \times (1 - \cos \theta)}$$

E_1, E_2 : photon energy

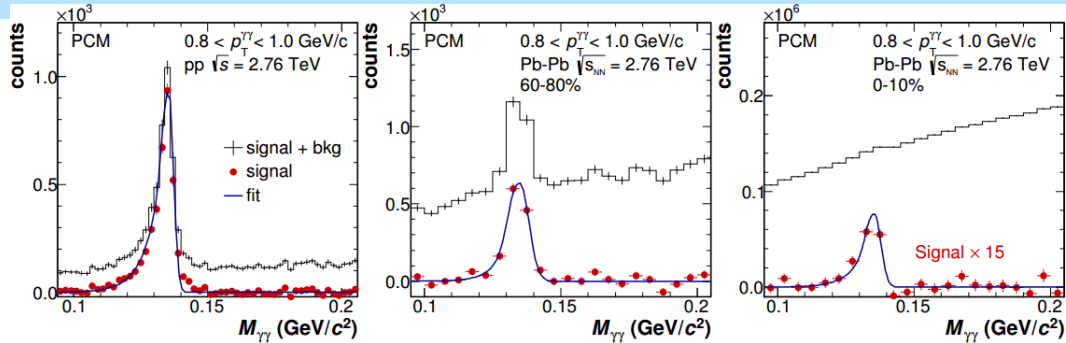
θ : opening angle



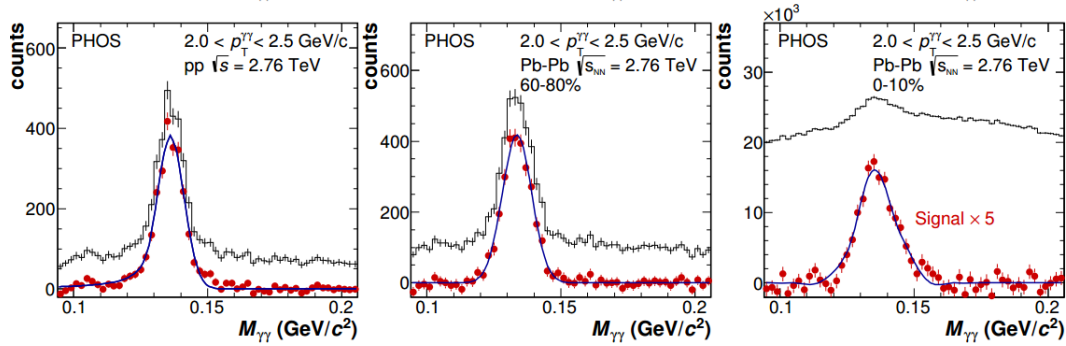
Phys. Lett. B 717 (2012) 162-172

Peak Position and Width in Pb-Pb 2.76 TeV

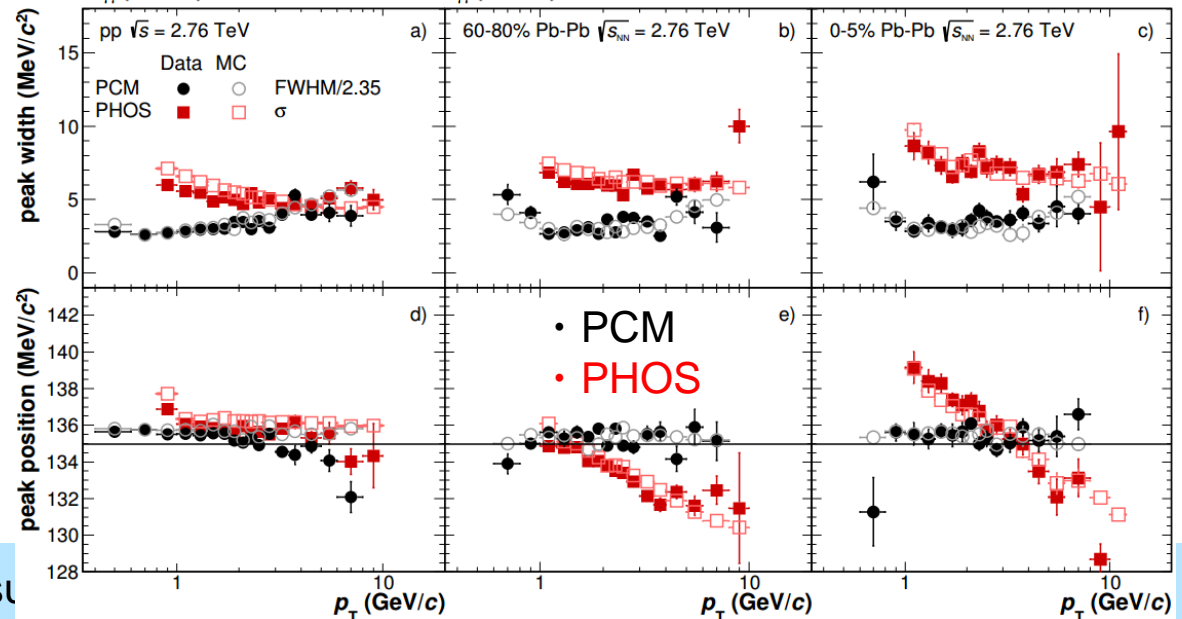
PCM



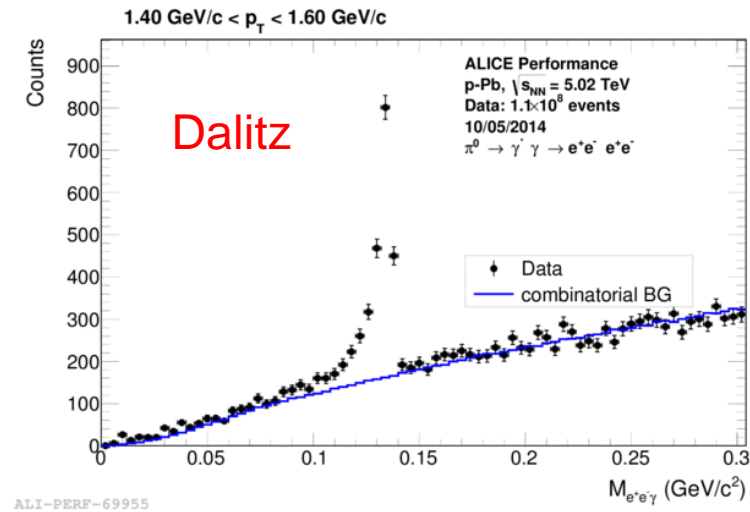
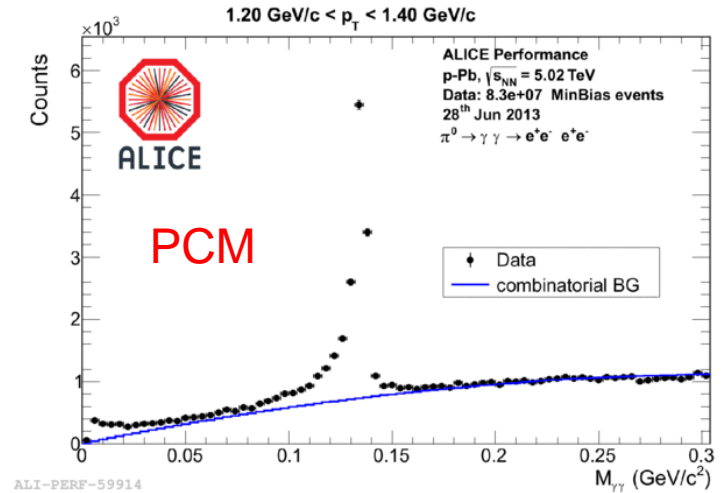
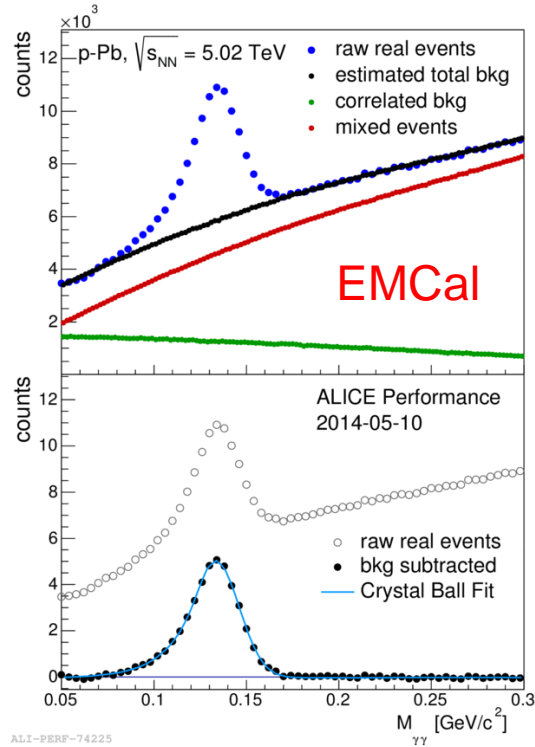
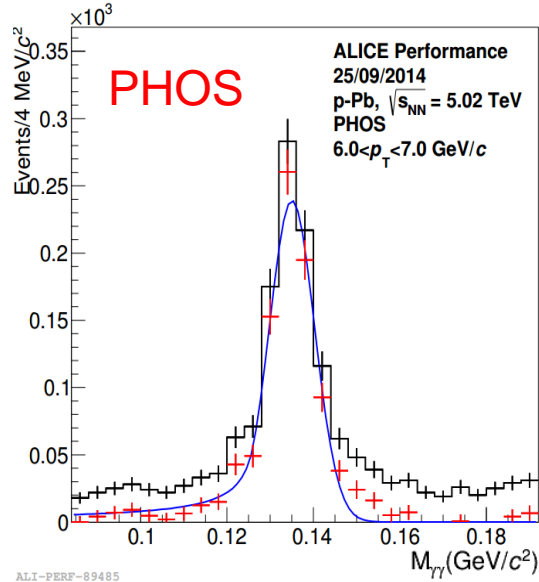
PHOS



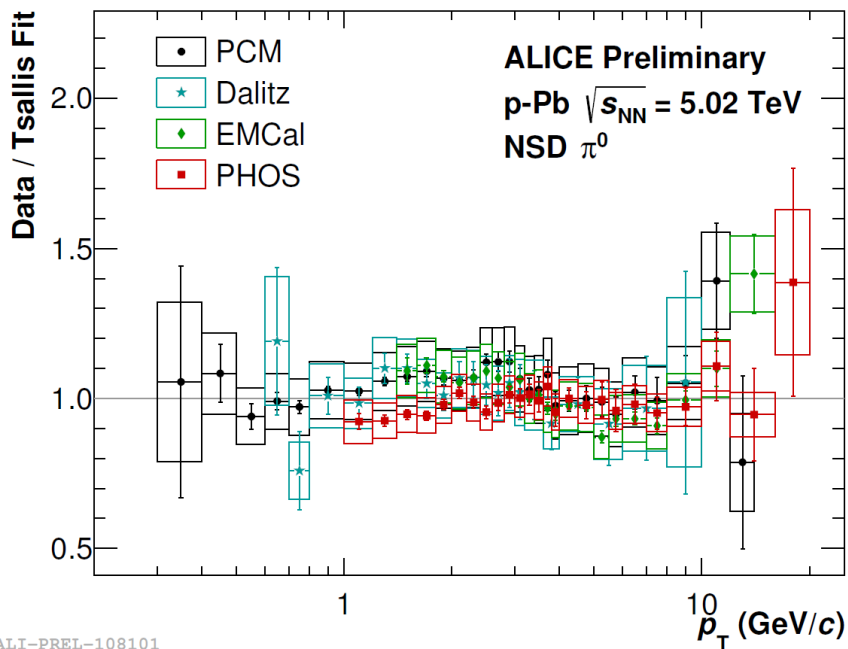
Eur. Phys. J. C (2014) 74-3108



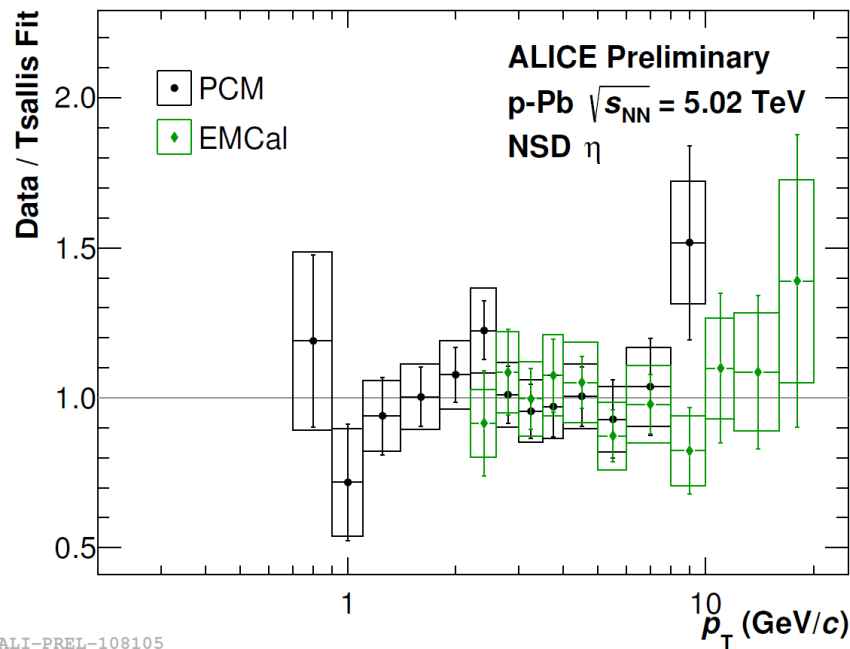
Mass Reconstruction in p-Pb



Comparison of π^0 and η Yields in p-Pb



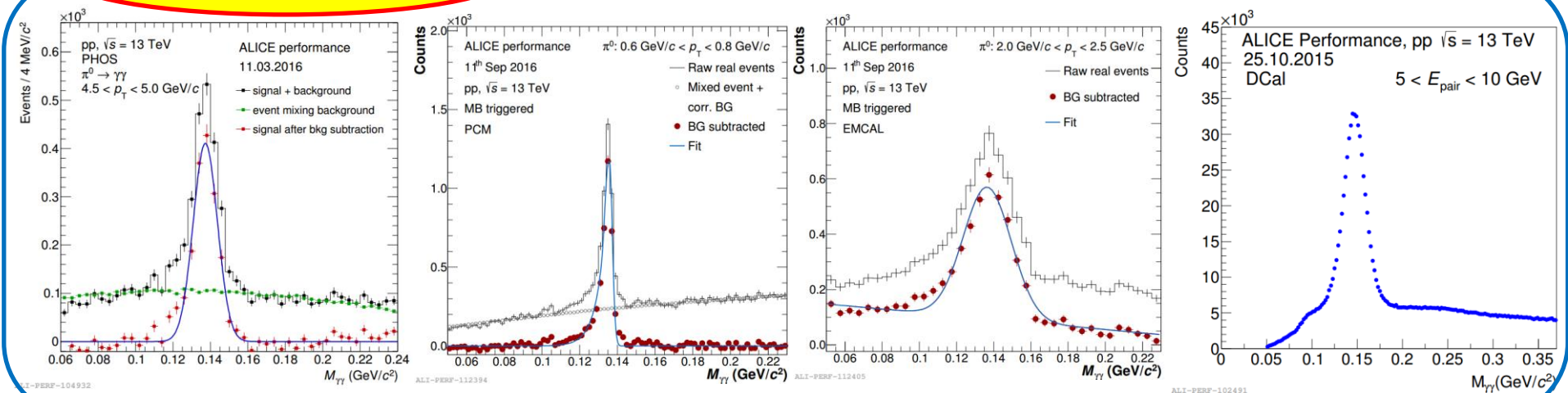
ALI-PREL-108101



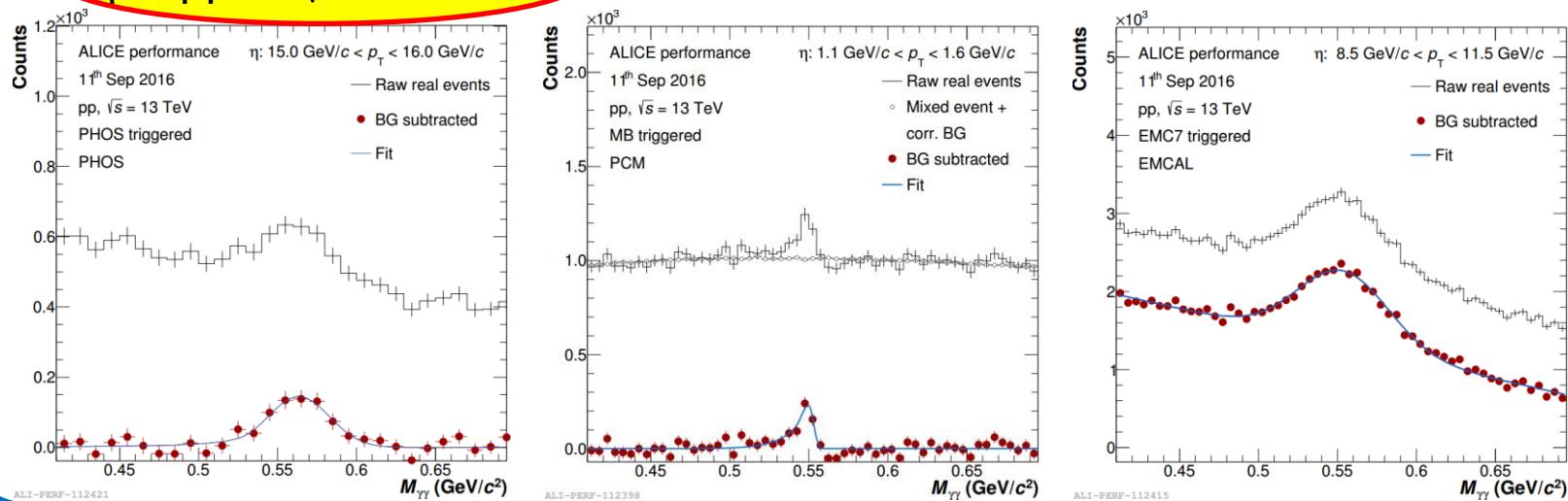
ALI-PREL-108105

Neutral Meson Performance in pp at 13 TeV

π^0 in pp at $\sqrt{s} = 13$ TeV



η in pp at $\sqrt{s} = 13$ TeV



Published Papers & Analysis in Progress

- **pp collisions at $\sqrt{s} = 0.9, 2.76$ and 7 TeV (PHOS+PCM)**
 - Phys. Lett. B 717 (2012) 162-172, CERN-PH-EP-2012-001, arXiv: 1205.5724
 - Eur. Phys. J. C (2014) 74-3108, CERN-PH-EP-2014-091, arXiv: 1405.3794
 - Nucl. Phys. A 931 (2014) 438-443
- **Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV (PHOS+PCM, 2010 data)**
 - Eur. Phys. J. C (2014) 74-3108, CERN-PH-EP-2014-091, arXiv: 1405.3794
 - Nucl. Phys. A 931 (2014) 438-443
- **Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV (EMCal+PCM, 2011 data)**
 - Nucl. Phys. A 931 (2014) 438-443
 - To be published (arXiv: 1512.05250)
- **pp at $\sqrt{s} = 8$ TeV (PHOS, EMCal and PCM)**
 - Nucl. Phys. A 931 (2014) 438-443
 - To be published (arXiv: 1512.05250)
- **p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV (PHOS, EMCal and PCM)**
 - To be published
- **pp at $\sqrt{s} = 5.02$ TeV and 13 TeV, Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV**
 - Analyses in progress