Light meson nuclear modification factor in p-Pb collisions over an unprecedented p_T range with ALICE

Joshua König, Goethe-Universität Frankfurt
for the ALICE collaboration

XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects
Virtual Event, April 12-16, 2021

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

BMBF Forschungsschwerpunkt ALICE Experiment 202 ALICE

ALICE

Introduction

Nuclear modification factor of light neutral-meson spectra up to high transverse momentum in p–Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV

p_T spectra measured up to 200 GeV/c (π^0) and 50 GeV/c (η)
Extension of π^0 spectrum in pp $\sqrt{s} = 8$ TeV
η/π^0 ratio
Nuclear modification factor R_{pA}

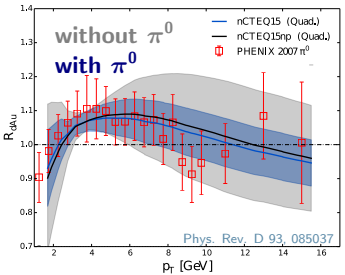
Paper on arXiv since April 7, 2021
arXiv:2104.03116

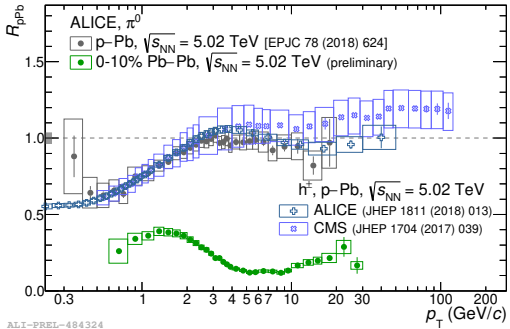
Inclusive π^0 and η production in p-Pb $\sqrt{s_{NN}} = 5.02$ TeV
Nuclear modification factor R_{pA} (Eur. Phys. J. C (2018) 78: 624)
Multiplicity dependent Q_{pA} (preliminary 2018)

Motivation

Nuclear modification factor in p-Pb

- Probing theories on initial and final state effects:
  - → Gluon saturation (CGC)
  - → p_T broadening (Cronin effect)
  - → Energy loss
- Constrains on nuclear PDFs
- Baseline measurement for Pb-Pb





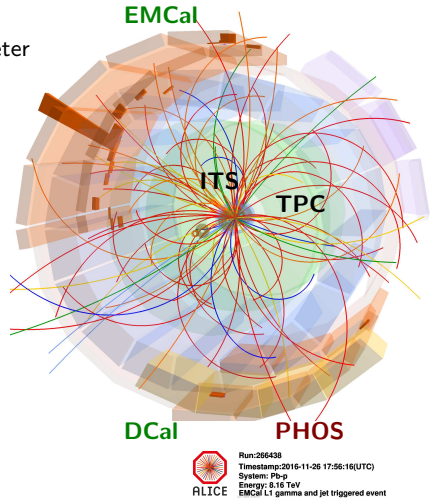
p-Pb at $\sqrt{s_{NN}} = 8.16$ TeV

- Direct comparison to p-Pb $\sqrt{s_{NN}} = 5.02$ TeV
  - → Energy dependence
- Lower and higher x reach than in $\sqrt{s_{NN}} = 5.02$ TeV

Photon measurement with ALICE in LHC Run 2

Electromagnetic calorimeter (EMCal + DCal)

- Lead-scintillator calorimeter
- EMCal acceptance:
  $|\eta| < 0.7$
  $\Delta\varphi = 107^\circ$
  Run 1: $\Delta\varphi = 100^\circ$
- DCal acceptance:
  $0.22 < |\eta| < 0.7$
  $\Delta\varphi = 60^\circ$
  and
  $|\eta| < 0.7$
  $\Delta\varphi = 7^\circ$



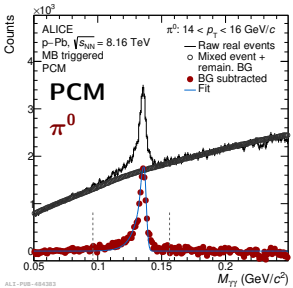
Photon Conversion Method (PCM)

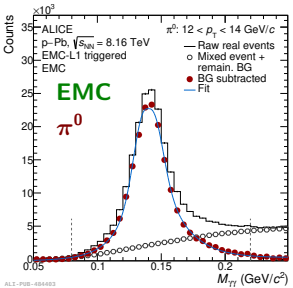
- Utilizing γ conversion probability of $\approx 8\%$
- Using $e^{\pm}$ V0-tracks from ITS + TPC
- Electron PID via $\mathrm{d}E/\mathrm{d}x$ from TPC
- Acceptance: $|\eta| < 0.9$

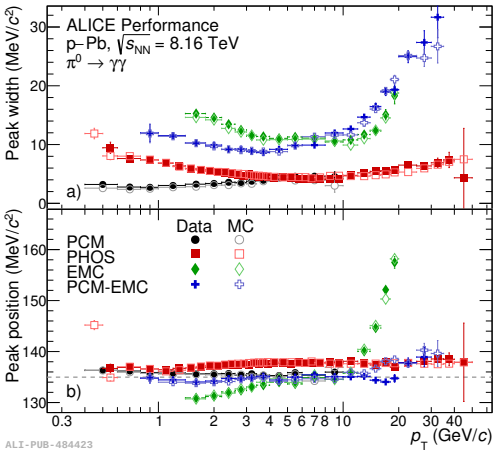
Photon Spectrometer (PHOS)

- Lead-tungsten crystals
- Acceptance:
  $|\eta| < 0.12$
  $\Delta\varphi = 70^\circ$
  Run 1: $\Delta\varphi = 60^\circ$

Neutral meson measurement with ALICE







Invariant mass based reconstruction techniques

- Background described by mixed event technique + residual linear background
- Signal parameterized with Gaussian + exponential tail
- Integration around estimated mass position

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

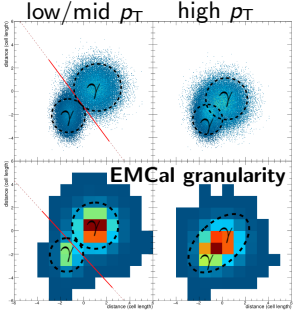
Neutral meson measurement with ALICE

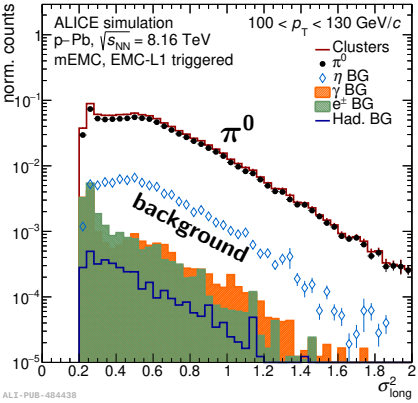
Purity based reconstruction technique

- Opening angle of π^0 decay γ's decreasing with rising p_T
- **Using merged EMCal clusters at high p_T**

→ Differentiate merged π^0 from single γ clusters via long axis of shower ellipse (σ^2_{long})

→ **High π^0 purity ($> 80\%$)**



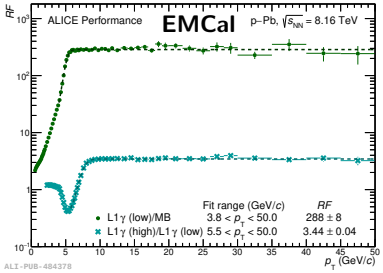


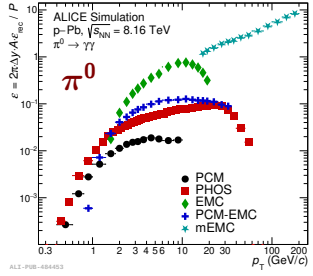
- Correct abundance in MC simulation for:
  η-mesons, $e^{\pm}$ from weak decays and prompt photons
- Extensive studies of EMCal:
  Energy response at very high energies and shower shape description

Corrections

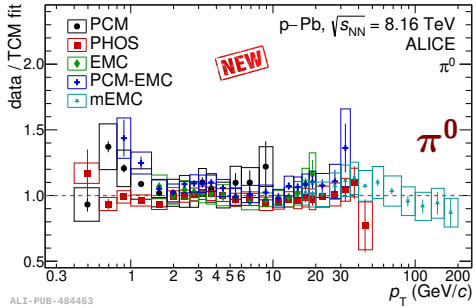
$$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = \frac{1}{2\pi p_{\mathrm{T}}}\frac{1}{\mathcal{L}_{\mathrm{int}}}\frac{P}{A\varepsilon_{\mathrm{rec.}}}\frac{F_{\text{pile-up}}N^{\pi^0(\eta)} - N^{\pi^0}_{\mathrm{sec.}}}{\Delta y \Delta p_{\mathrm{T}}}$$

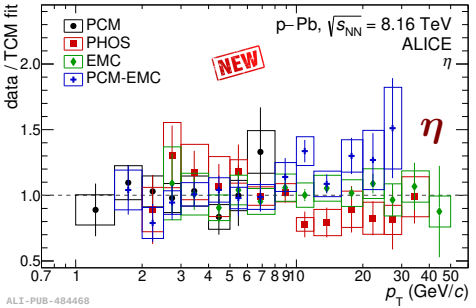
- $\mathcal{L}_{\mathrm{int}}$: $\frac{N_{\mathrm{evt.}}}{\sigma_{\mathrm{INT7}}}(\cdot RF)$
  - → Calo triggers: **Trigger rejection factor (*RF*)** via ratio of cluster spectra
- P: π^0 purity (mEMC only) ($> 80\%$)
- $A\varepsilon_{\mathrm{rec.}}$: Acceptance and reconstruction efficiency
  - → Efficiency includes energy resolution correction
  - → PCM efficiency includes conversion probability ($\approx 8\%$)
- $F_{\text{pile-up}}$: Out of bunch pile up correction for PCM
- $N^{\pi^0}_{\mathrm{sec.}}$: Secondary π^0 from K^0_s, K^0_L and Λ from **data-driven cocktail simulation**





Combination of different methods

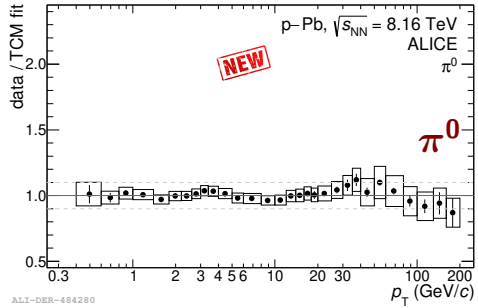


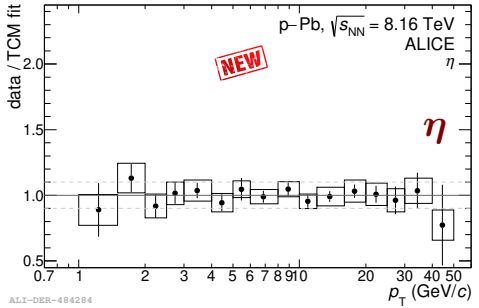


- **Good agreement between all 5(4) methods**
- Dominating systematic uncertainty:
  - → Material unc.: 9% for PCM and 4.2% for EMC
  - → Shower overlap and π^0 energy resolution: 7-10% for mEMC
  - → Signal extraction

new paper: arXiv:2104.03116

Combination of different methods





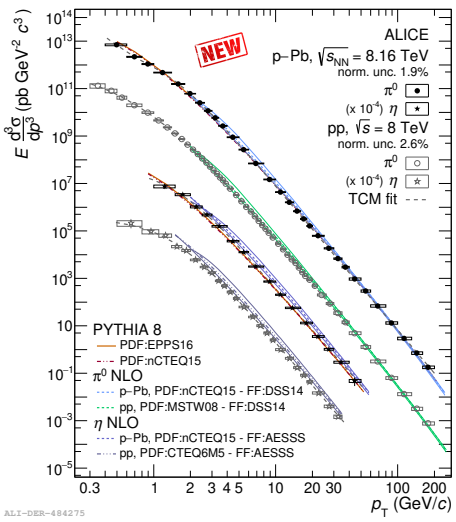
- **Good agreement between all 5(4) methods**
- Dominating systematic uncertainty:
  - → Material unc.: 9% for PCM and 4.2% for EMC
  - → Shower overlap and π^0 energy resolution: 7-10% for mEMC
  - → Signal extraction

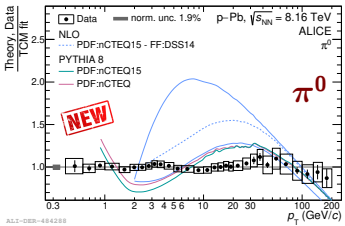
- **Combination of spectra** with BLUE method
  - → Based on statistical and systematical uncertainties
  - → Taking correlations between methods into account

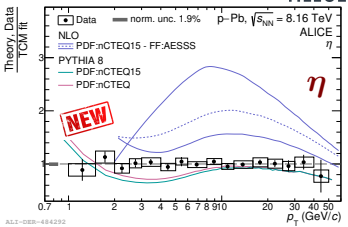
new paper: arXiv:2104.03116

BLUE: Nucl. Instrum. Meth. A 270 (1988) 110.

Invariant cross section





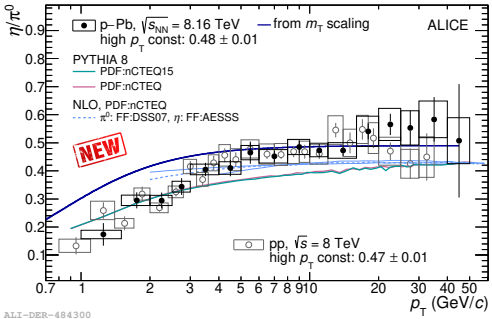


- Inv. cross section in p-Pb $\sqrt{s_{NN}} = 8.16$ TeV
  - π^0: $0.4 \leq p_T < 200$ GeV/c
  - η: $1.0 \leq p_T < 50$ GeV/c
- **Extended pp reference** at $\sqrt{s} = 8$ TeV up to $p_T = 200$ GeV/c compared to previous publication
- NLO overshoots data
- PYTHIA 8 does not describe shape of spectra

new paper: arXiv:2104.03116

NLO calculations from W. Vogelsang

η/π^0 ratio

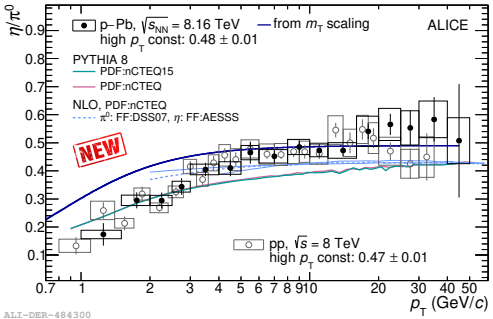


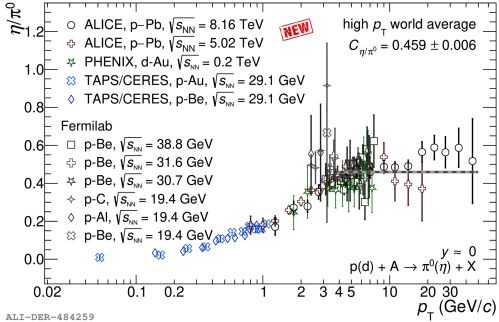
- **Good agreement** between pp $\sqrt{s} = 8$ TeV and p-Pb $\sqrt{s_{NN}} = 8.16$ TeV
- High p_T const:
  p-Pb: 0.48 ± 0.01
  pp: 0.47 ± 0.01

→ **No system dependence observed**

new paper: arXiv:2104.03116

η/π^0 ratio





- **Good agreement** between pp $\sqrt{s} = 8$ TeV and p-Pb $\sqrt{s_{NN}} = 8.16$ TeV
- High p_T const:
  p-Pb: 0.48 ± 0.01
  pp: 0.47 ± 0.01

→ **No system dependence observed**

η/π^0 in p-A collisions

- **Universal behavior for all collision energies**
- High p_T world average slightly below value for p-Pb $\sqrt{s_{NN}} = 8.16$ TeV

→ Most measurements not fully in saturation range

new paper: arXiv:2104.03116

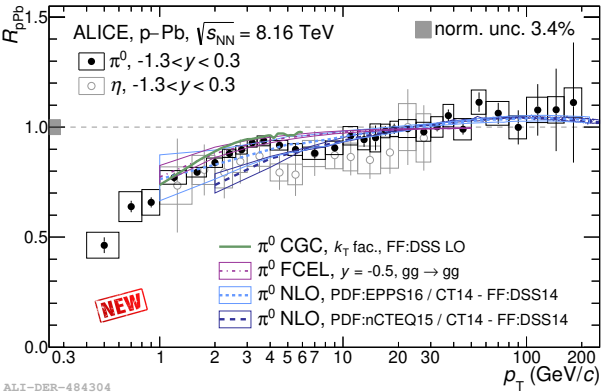
Nuclear modification factor

- **R_{pA} for π^0 and η in agreement**
- **Significant suppression at low p_T**
- **No suppression for $p_T > 10$ GeV/c**
- Systematic uncertainties for π^0 below 5% for most of p_T range
- pp reference scaled from $\sqrt{s} = 8$ TeV to match center of mass energy and rapidity window

$$R_{pA} = \frac{1}{A_{Pb}} \frac{d^2\sigma_{pPb}}{dp_T dy} \Big/ \frac{d^2\sigma_{pp}}{dp_T dy}$$

Comparison to theory

- **Low p_T suppression in agreement** with CGC and FCEL (energy loss) models and NLO calculations



new paper: arXiv:2104.03116

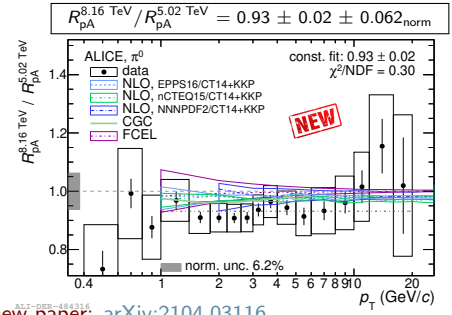
Theory calculations from: T. Lappi and H. Mäntysaari (CGC) - arxiv:1309.6963, F. Arleo et. al. (FCEL) arxiv:2003.06337

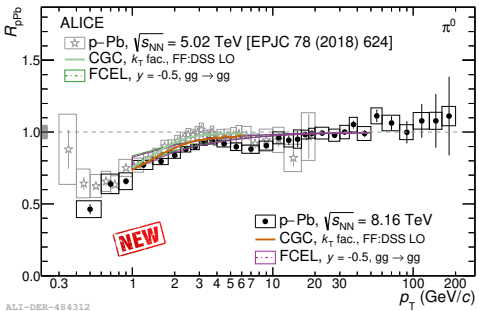
Nuclear modification factor - comparison

Comparison to p-Pb $\sqrt{s_{NN}} = 5.02$ TeV

- **Factor 10 higher p_T reach** in p-Pb $\sqrt{s_{NN}} = 8.16$ TeV
  - → Probing larger Q^2 at high p_T and lower x at low p_T
- Low p_T suppression compatible within uncertainties

→ Data **hints at larger suppression in $\sqrt{s_{NN}} = 8.16$ TeV**
(Large norm. unc. from interpolated pp $\sqrt{s} = 5$ TeV ref.)





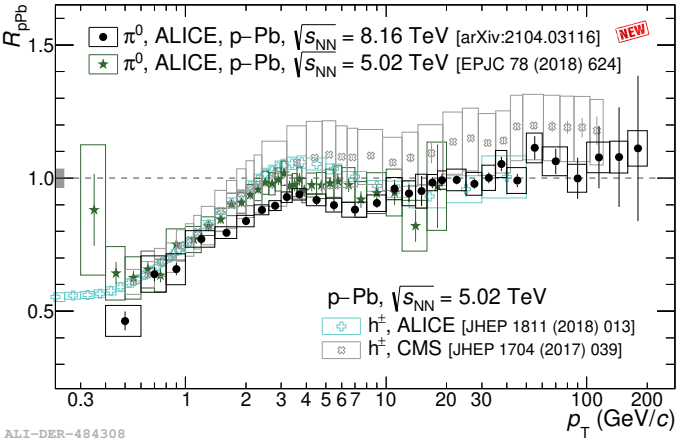
Comparison to theory

- Energy loss model predicts only very small energy dependence
- CGC model predicts stronger energy dependence
  - → Gluon saturation effects or stronger shadowing

new paper: arXiv:2104.03116

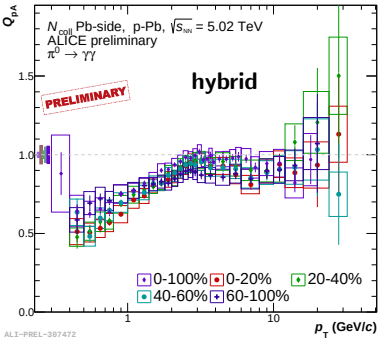
Nuclear modification factor - comparison

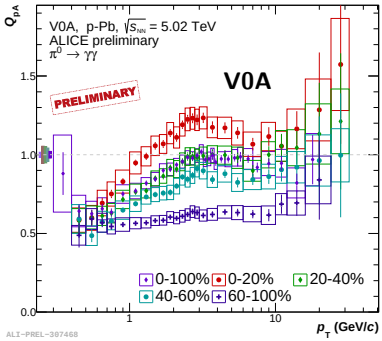
- **No enhancement above unity observed** unlike charged hadrons from CMS
- No strong suppression at mid/high p_T observed
  - $\rightarrow$ Negligible final state effects in p-Pb



new paper: arXiv:2104.03116

Results from p-Pb $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV





Results

- **Published paper** with LHC-Run 1 data
- Preliminary results for **multiplicity dependent** analysis with different estimators

$$Q_{\mathrm{pA}}^{\mathrm{mult}} = \frac{1}{\langle N_{\mathrm{coll}}^{\mathrm{mult}} \rangle} \frac{\mathrm{d}^2\sigma_{\mathrm{pPb}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} \Big/ \frac{\mathrm{d}^2\sigma_{\mathrm{pp}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}$$

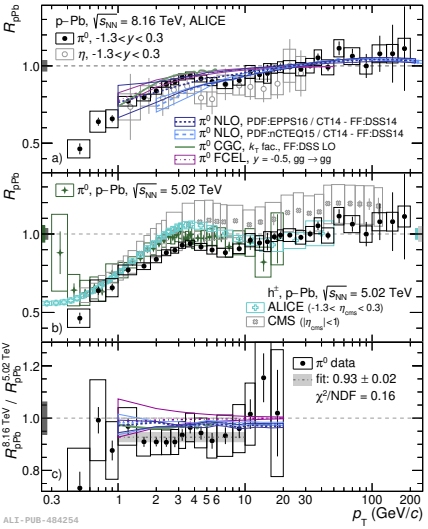
Ongoing analyzes

- LHC-Run 2 p-Pb dataset: **6x more stat.**
- **pp data at same center of mass energy** currently beingy analyzed

→ **Reducing norm. uncertainty**

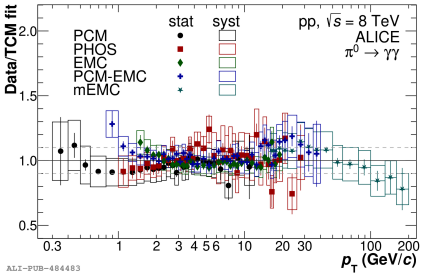
Summary

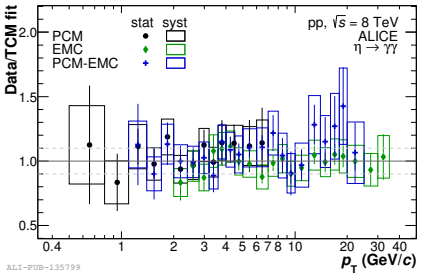
- **π^0 and η meson differential invariant cross section in p-Pb $\sqrt{s_{NN}} = 8.16$ TeV and pp $\sqrt{s} = 8$ TeV**
  - → Highest identified particle p_T spectra
- η/π^0 ratio for pp $\sqrt{s} = 8$ TeV , p-Pb $\sqrt{s_{NN}} = 8.16$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV in agreement
- **R_{pA} in p-Pb $\sqrt{s_{NN}} = 8.16$ TeV :**
  - → **No suppression/enhancement for $p_T > 10$ GeV/c**
  - → Hint at larger suppression at low p_T than in p-Pb $\sqrt{s_{NN}} = 5.02$ TeV
- Outlook: **Large dataset in p-Pb $\sqrt{s_{NN}} = 5.02$ TeV** and **pp ref. at same center of mass energy** currently analyzed

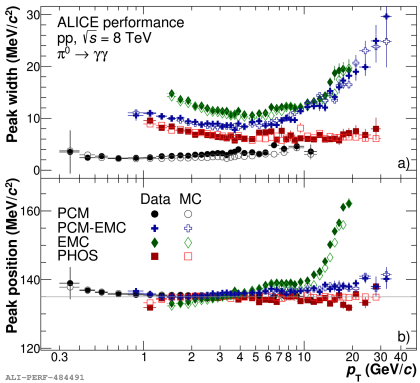


Backup

Additional plots for pp $\sqrt{s} = 8$ TeV

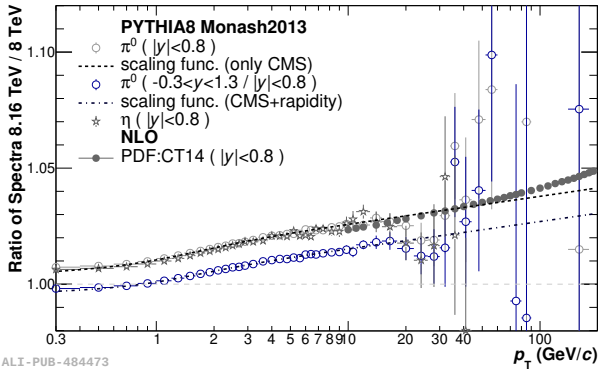






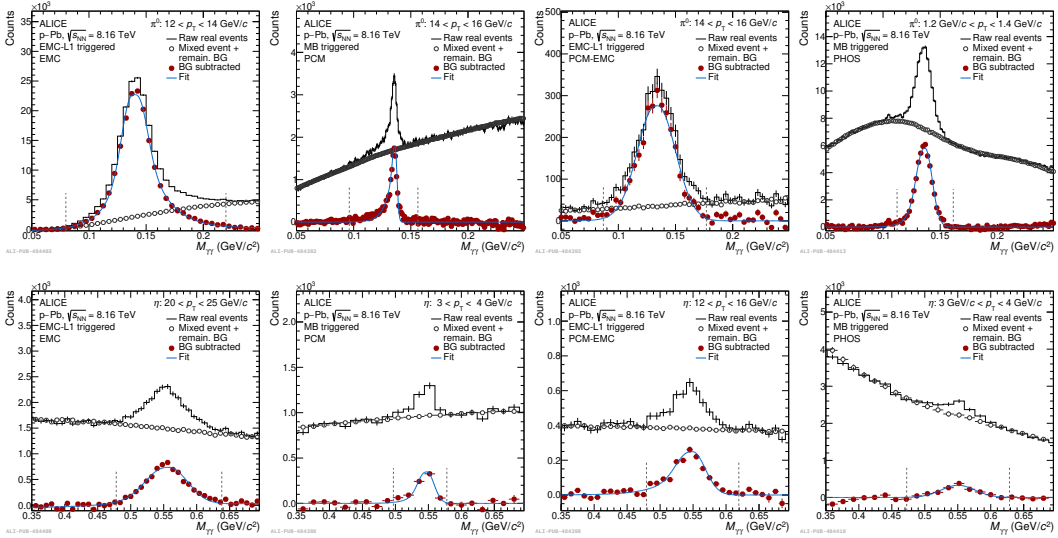
- Good agreement between all methods for π^0 and η
- MC describes peak properties observed in data

Scaling factor for pp $\sqrt{s} = 8$ TeV R_{pA} calculation



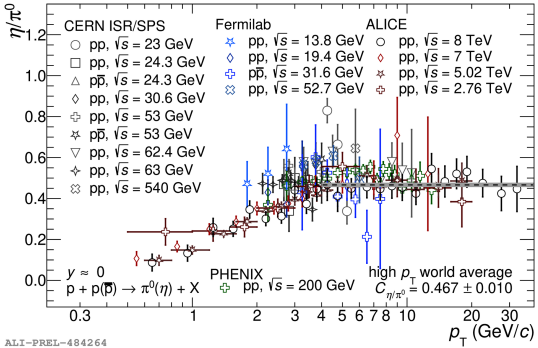
- Scaling factor applied to pp $\sqrt{s} = 8$ TeV for shifting the spectrum to $\sqrt{s}$= 8.16 TeV and to correct rapidity range

Example invariant mass distributions



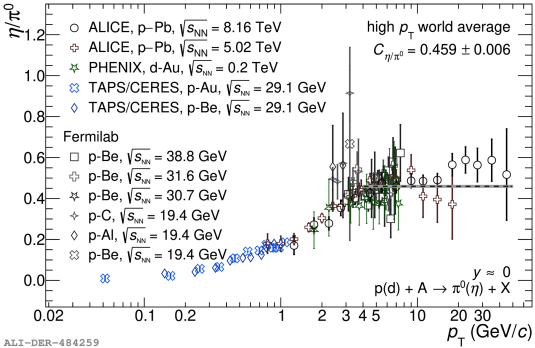
η/π^0 world average

pp collisions



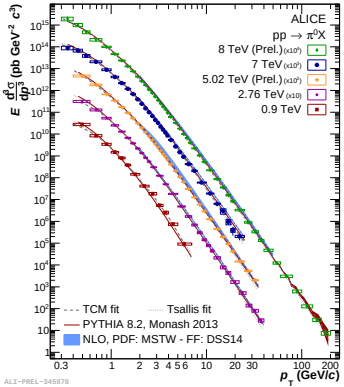
ALI-PREL-484264

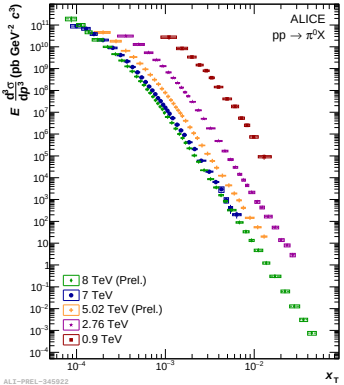
p-A collisions

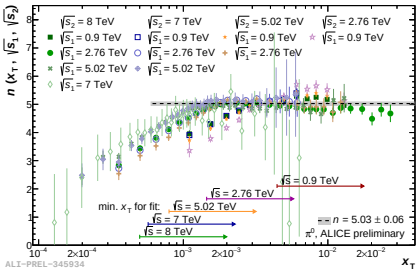


ALI-DER-484259

x_T-scaling







$$x_T = \frac{2p_T}{\sqrt{s}}$$