ALICE

HARD PROBES 2020

International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

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

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π^0 and η meson production with ALICE

New results in this talk

Inclusive π^0 and η meson p_T spectra in pp, $\sqrt{s} = 8$ TeV and p-Pb, $\sqrt{s_{NN}} = 8.16$ TeV

measured up to $p_T = 200$ GeV/c for π^0 and 50 GeV/c for η
at mid-rapidity: $|y_{lab}| < 0.8$, $\Delta y_{cms} = -0.465$

Minimum bias and EMCal-L1 triggered data
2012 pp, $\sqrt{s} = 8$ TeV: $\mathscr{L}_{int} \sim 615$ nb^{-1}
2016 p-Pb $\sqrt{s_{NN}} = 8.16$ TeV: $\mathscr{L}_{int} \sim 160$ nb^{-1} **NEW!**

η/π^0 ratio in p-Pb, $\sqrt{s_{NN}} = 8.16$ TeV up to 50 GeV/c

comparison to NLO and Pythia 8

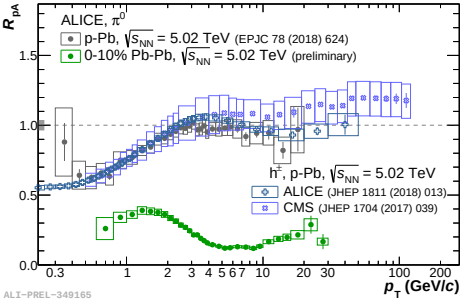
π^0 and η nuclear modification factor R_{pPb} at $\sqrt{s_{NN}} = 8.16$ TeV up to very high p_T

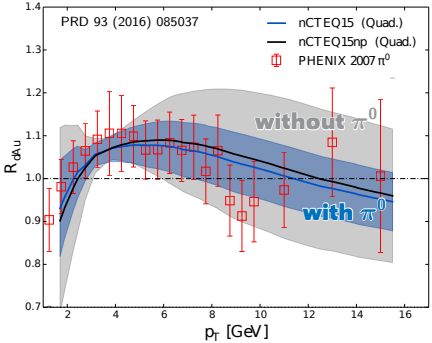
comparison to theory and measurements in p-Pb, $\sqrt{s_{NN}} = 5.02$ TeV

Nuclear modification factor

- Both spectra at same energy and kinematic region
- **Probes initial and final state effects**
  - → (anti-)shadowing
  - → gluon saturation (CGC)
  - → p_T-broadening (Cronin)
  - → energy loss (cold matter)

$$R_{\mathrm{pPb}} = \frac{\mathrm{d}^2\sigma_{\mathrm{pPb}}/\mathrm{d}p_T\mathrm{d}y}{A_{\mathrm{Pb}} \times \mathrm{d}^2\sigma_{\mathrm{pp}}/\mathrm{d}p_T\mathrm{d}y}$$





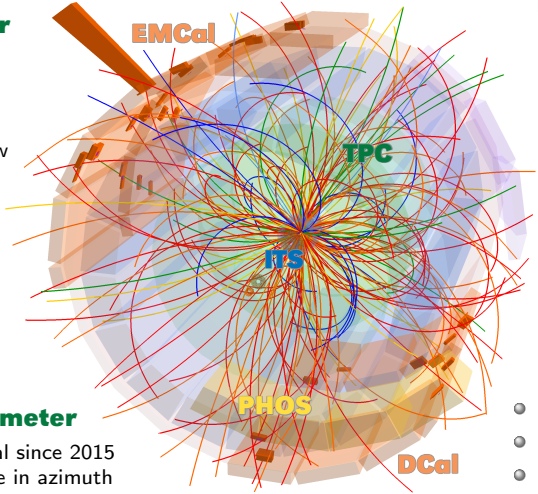
Motivation for our measurement

- Baseline for more differential measurements
- Probe **lower** x **and larger** Q^2 **than previous measurements** at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
  → new **constraints on nuclear PDFs** at low and high x

Measuring photons, π^0 and η mesons with ALICE

EMCal calorimeter (EMC)

- Pb/scintillator sampling calorimeter
- Large acceptance but low resolution
- Granularity 0.014×0.014 mrad^2



DCal calorimeter

- Extension of EMCal since 2015 $\rightarrow$ located opposite in azimuth

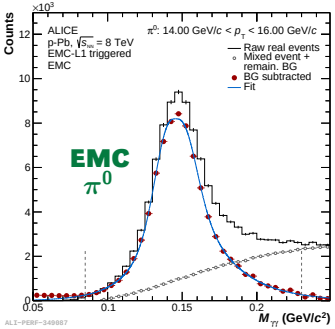
Photon Conversion Method (PCM)

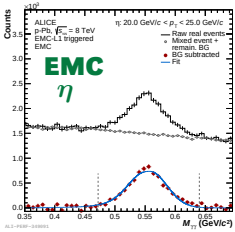
- Central barrel based tracks
- ITS: silicon detectors around IP
- TPC: large time projection chamber $\rightarrow$ provides $e^{\pm}$ PID via dE/dx
- $|\eta| < 0.9$ and full azimuth
- conversion in detector material $\rightarrow$ conv. probability $\sim 8\%$

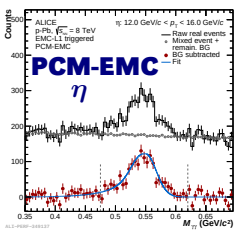
Photon Spectrometer (PHOS)

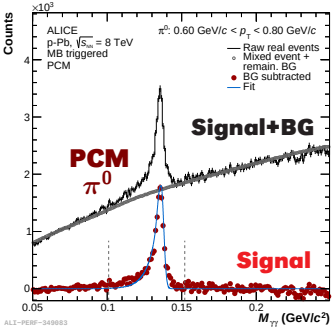
- Lead tungstate crystals
- High resolution but small acceptance
- Granularity: $\Delta\eta \times \Delta\varphi = 0.004 \times 0.004$ mrad^2

Measuring photons, π^0 and η mesons with ALICE



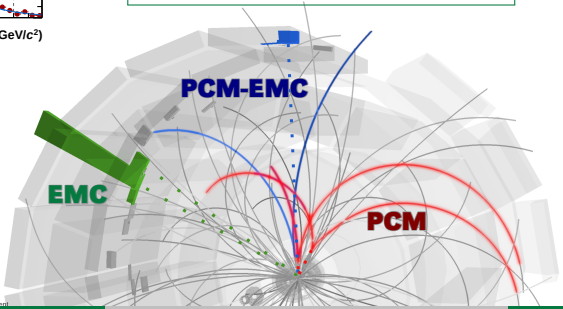






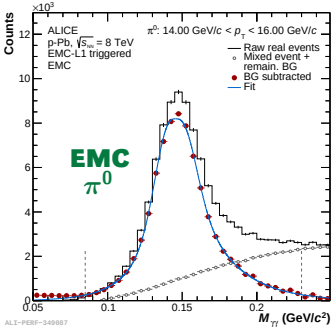
$$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{12})}$$

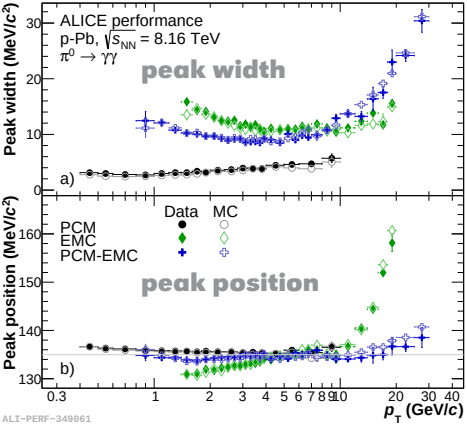
- **Excess in invariant mass** around π^0 and η mass
- Signal extraction in narrow p_T bins

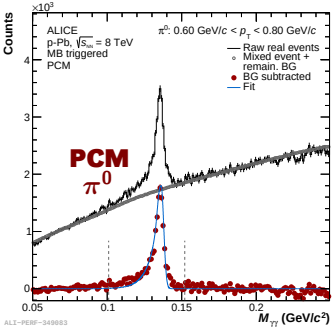


- **Event mixing** for combinatorial background
- Signal fitted with: Gaussian+exponential+linear
- Integration in wide range for raw yields

Measuring photons, π^0 and η mesons with ALICE



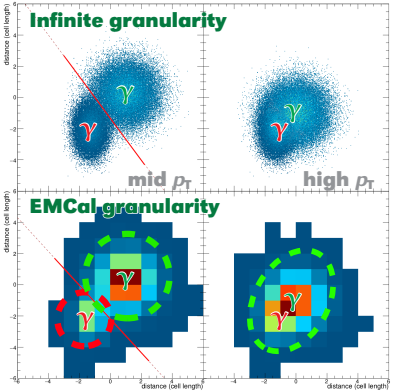




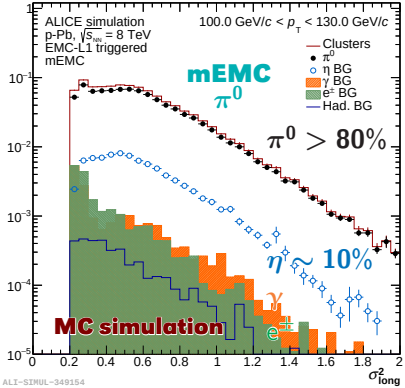
- High resolution with PCM
- **Very good agreement between data and MC**
- π^0 extraction with EMC limited to $p_T < 20$ GeV/c due to EMCal resolution

Measuring π^0 mesons via merged EMCal clusters

- **π^0 opening angles for $p_T > 20$ GeV/c smaller than EMCal resolution**
- **Long axis of cluster (σ^2_{long}) used as discriminator**
  $\rightarrow$ rejection of clusters with $\sigma^2_{\text{long}} < 0.2$



- **Nonlinearity of EMCal energy response important at high energies**
  $\rightarrow$ first single particle analysis at $E_{\text{cluster}} > 50$ GeV/c
  $\rightarrow$ extensive studies on testbeam data and laboratory setup

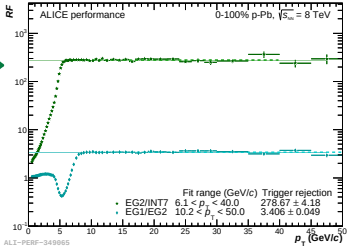


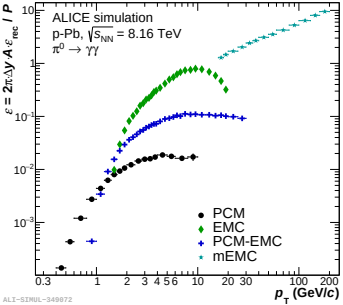
- Shower shape well described in MC with additional detector effect emulations (cross talk)

Correction factors

$$E\frac{d^3\sigma^{pp\to\pi^0(\eta)+X}}{dp^3} = \frac{1}{2\pi p_T}\frac{1}{\mathscr{L}_{\rm int}}\frac{\epsilon_{\rm pur}}{A\cdot\epsilon_{\rm rec}}\frac{F_{\text{pile-up}}\cdot N^{\pi^0(\eta)} - N^{\pi^0}_{\rm sec}}{\Delta y\Delta p_T}$$

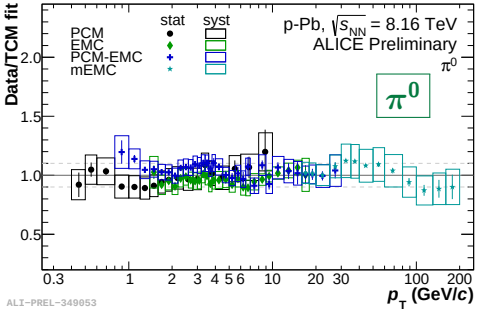
- $\mathscr{L}_{\rm int}$: Integrated luminosity with **trigger rejection factor** RF
  $\rightarrow$ EMCal gamma triggers: EG2 ($RF \sim 278$) and EG1 ($RF \sim 950$)
- $\epsilon_{\rm pur}$: Purity (only mEMC) of $\sim 80\%$ dominated by η mesons
- $A \cdot \epsilon_{\rm rec}$: Acceptance and reco. efficiency
  $\rightarrow$ contains **conversion probability and resolution**
- $F_{\text{pile-up}}$: Out-of-bunch pileup correction (PCM)
- $N^{\pi^0}_{\rm sec}$: Secondary π^0 from K^0_S, K^0_L and Λ from **data driven cocktail simulations** ($\sim 3-10\%$ depending on p_T)

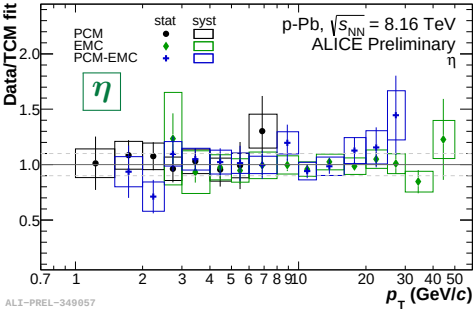




Neutral meson spectra in p-Pb

Comparison of individual measurements





- Comparison of different methods via ratio to fit of combined spectrum
  → **agreement within uncertainties of all methods**
- Dominating **systematic uncertainties**:

→ Yield extraction and material unc. of 9% for PCM and 4.2% EMC

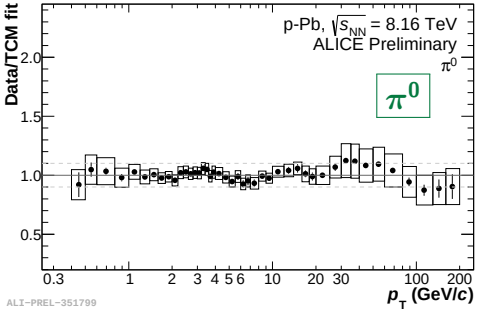
→ Shower overlap and π^0 energy resolution of 7-10% for mEMC

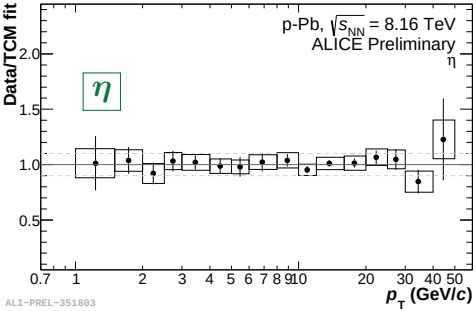
- **Combination of 4(3) reconstruction techniques via BLUE method** for $\pi^0(\eta)$
  → accounted for correlation of uncertainties
- Total uncertainty of final spectra:
  → $\sim$ 7% for π^0 and $\sim$ 10% for η
- p_T reach: $\pi^0 : 0.4 < p_T < 200$ GeV/c, $\eta : 1.0 < p_T < 50$ GeV/c

TCM: two component model fit - EPJC 75 (2015) 166

Neutral meson spectra in p-Pb

Combination of measurements





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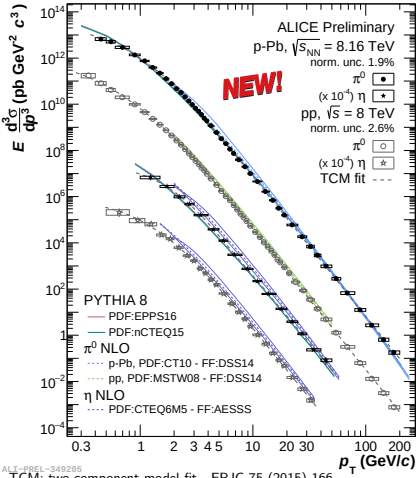
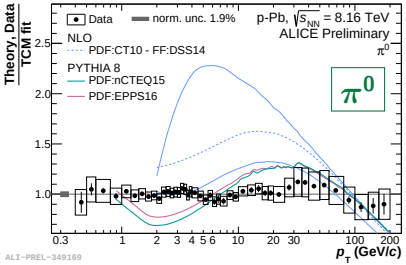
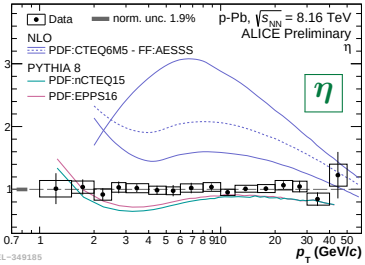
Neutral meson spectra and η/π^0 ratio

Comparison to theory

- **π^0 and η inv. cross-sections in p-Pb, $\sqrt{s_{NN}} = 8.16$ TeV**
- **Extended π^0 reference measurement up to 200 GeV/c** (was 35 GeV/c [EPJC 78 (2018) 263]) in pp, $\sqrt{s} = 8$ TeV with mEMC
- **NLO overestimates spectra while Pythia underpredicts at low p_T**
  → updated η FF needed
- **η/π^0 ratio measured up to 50 GeV/c**
  → high p_T value: 0.50 ± 0.02
  → consistent with ratio from pp







NLO calculations from W. Vogelsang

TCM: two component model fit - EPJC 75 (2015) 166

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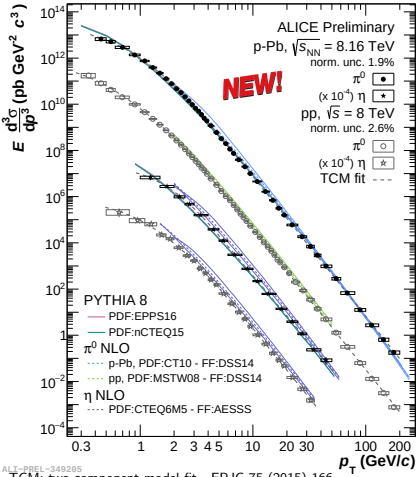

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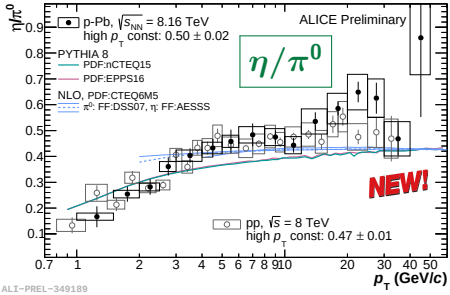

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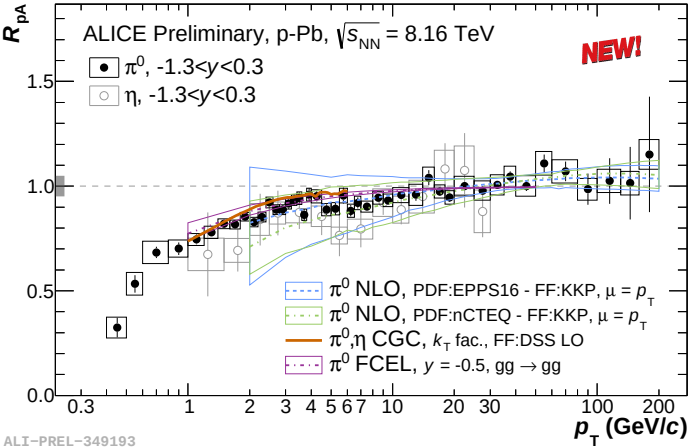
Nuclear Modification Factor

Comparison to theory

- R_{pPb} calculated with pp, $\sqrt{s} = 8$ TeV reference **scaled for center of mass energy and rapidity shift** obtained from Pythia 8
- Systematic uncertainties $< 5\%$ for most of p_T range
- η **meson** R_{pPb} **compatible with** π^0 R_{pPb}
- **Low p_T suppression consistent with CGC and energy loss (FCEL) calculations**
- **No modification for $p_T > 10$ GeV/c observed within uncertainties**
  $\rightarrow$ negligible final state effects
- Provides new constrains for nPDF uncertainty at low ($x < 10^{-2}$) and high x

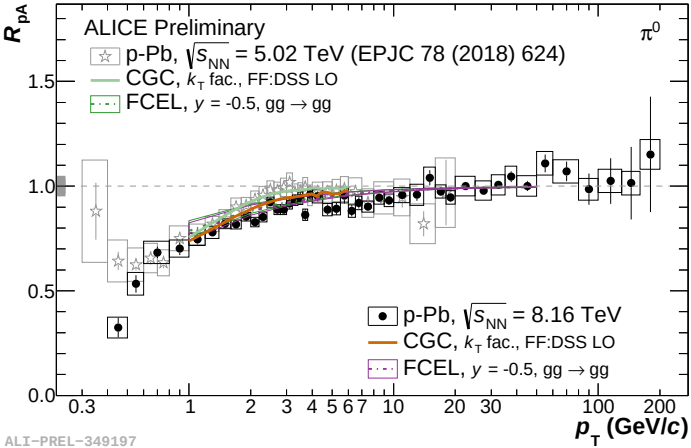


Theory calculations from: T. Lappi and H. Mäntysaari (CGC) - arxiv:1309.6963, F. Arleo et. al. (FCEL) - arxiv:2003.06337

Nuclear Modification Factor

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

- Order of magnitude higher p_T reach of new measurement
  → **probing larger Q^2 at high p_T and lower x at low p_T**
- **Stronger low p_T suppression** consistent with CGC and FCEL calculations
  → possible stronger shadowing or gluon saturation effects in the higher center of mass system
  → only minimally larger energy loss in cold nuclear matter predicted



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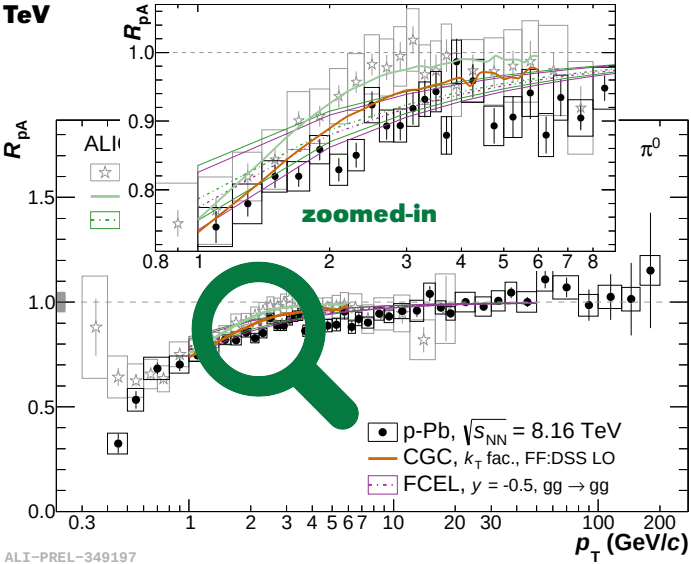

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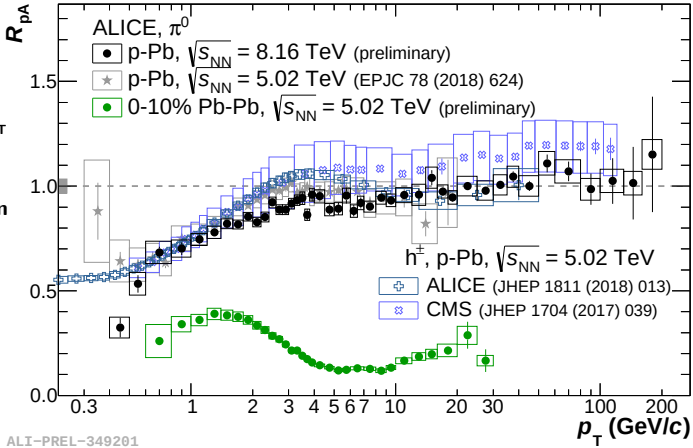
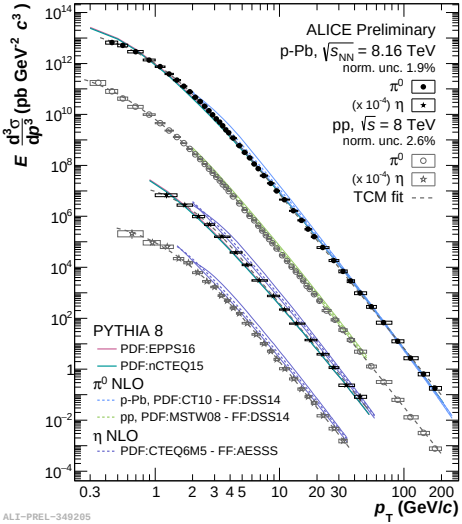
Nuclear Modification Factor

Comparison to charged hadrons and Pb-Pb

- Compared to CMS charged hadrons **no high p_T enhancement** for π^0 and η observed within uncertainties
- **Strong suppression from Pb-Pb not present in p-Pb**
  $\rightarrow$ negligible final state effects in the small collision system

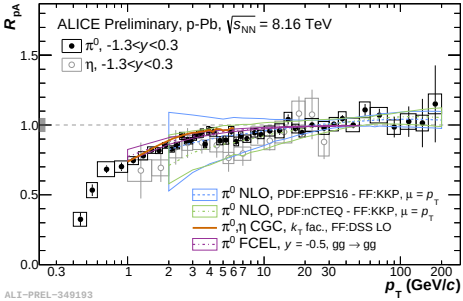


Summary



π^0 and η meson differential invariant cross sections presented for unprecedented p_T ranges in p-Pb, $\sqrt{s_{NN}} = 8.16$ TeV and pp, $\sqrt{s} = 8$ TeV

- η/π^0 ratio reported with high p_T ratio of 0.50 ± 0.02
- **R_{pPb} consistent with unity for $p_T > 10$ GeV/c**
  $\rightarrow$ low p_T suppression stronger compared to $\sqrt{s_{NN}} = 5.02$ TeV consistent with energy loss and CGC calculations
- Provides new input to constrain nuclear PDF's at low and high x



Backup

References

- **NLO calculations**
  → Werner Vogelsang
  (CT10/DSS14,MSTW08/DSS14,CTEQ6M5/AESSS)
- **Energy loss calculations (FCEL)**
  → F. Arleo et. al. - arxiv:2003.06337
- **Color glass condensate calculations (CGC)**
  → T. Lappi and H. Mäntysaari - arxiv:1309.6963

Thank you for all theory inputs!

Extended reference measurement

- Extension of published pp, $\sqrt{s} = 8$ TeV measurement using the mEMC analysis
  $\rightarrow$ p_T reach increased from 35 GeV/c to 200 GeV/c