



# Particle Production at Large Transverse Momentum with ALICE

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for the ALICE Collaboration



# Introduction

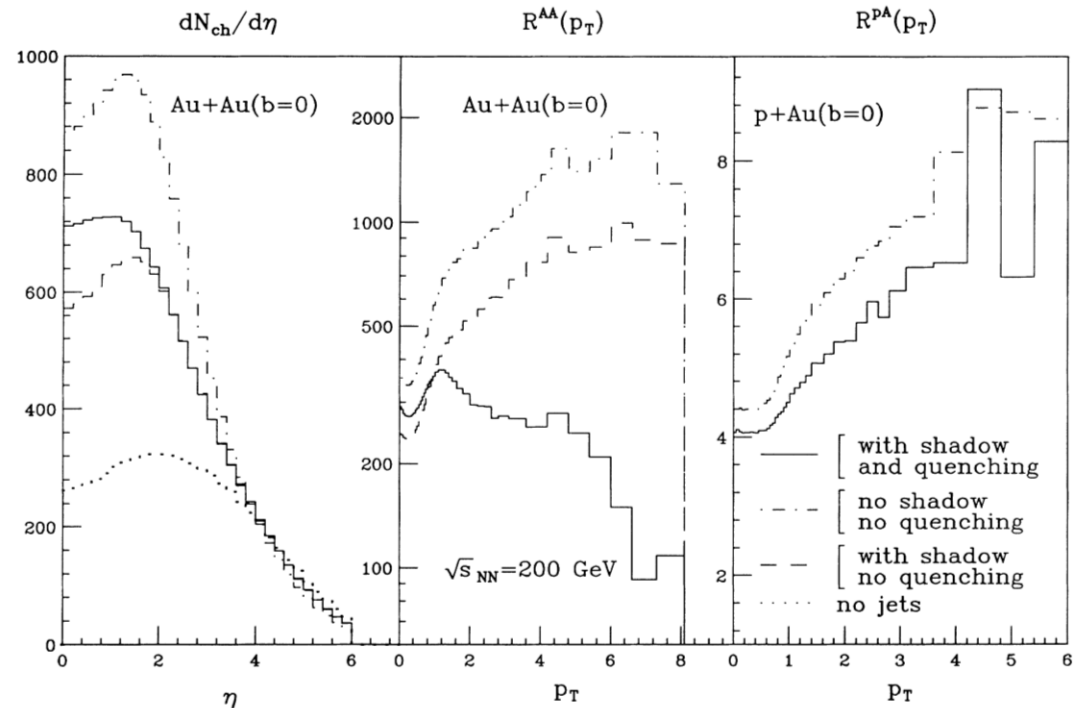
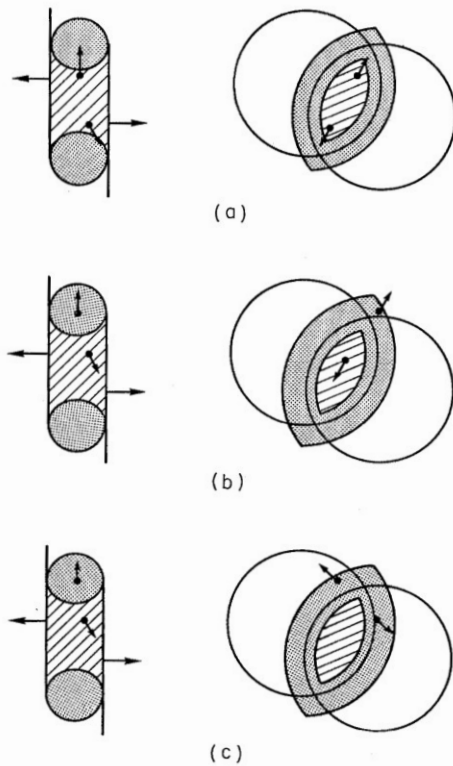


J. D. Bjorken,  
FERMILAB-PUB-82-059-THY (1982)

VOLUME 68, NUMBER 10

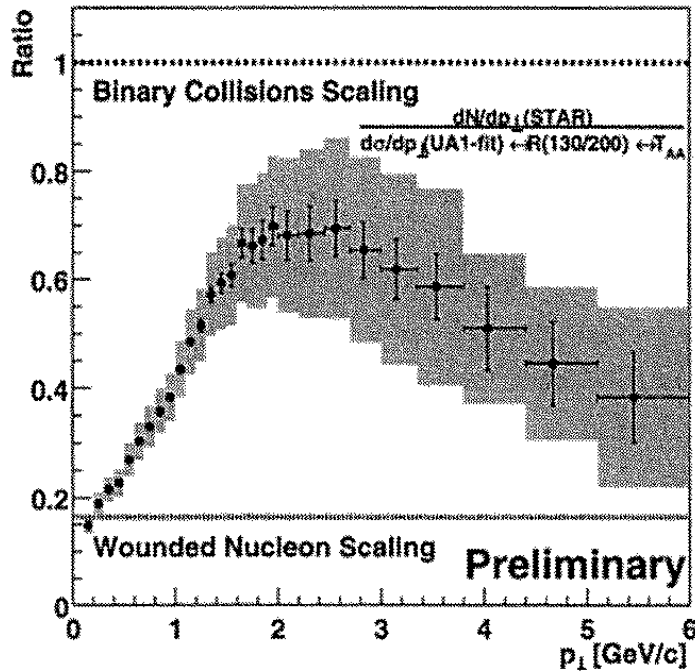
PHYSICAL REVIEW LETTERS

9 MARCH 1992

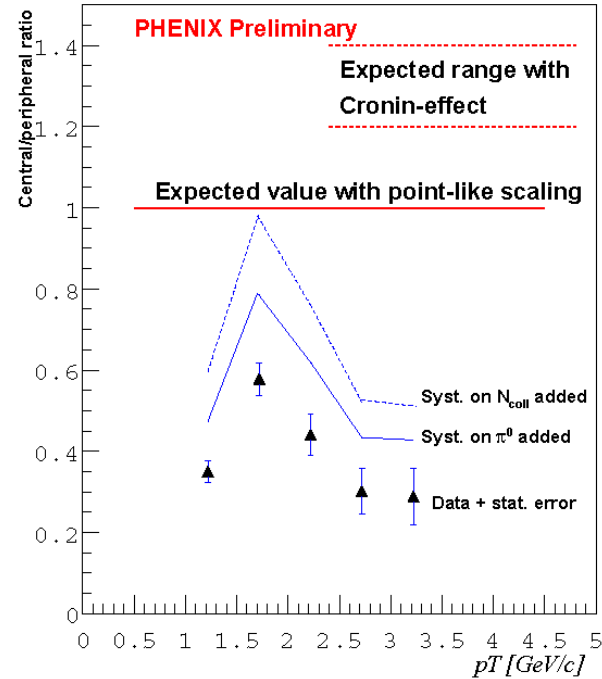


X.N. Wang and M. Gyulassy,  
PRL 68 (1992).

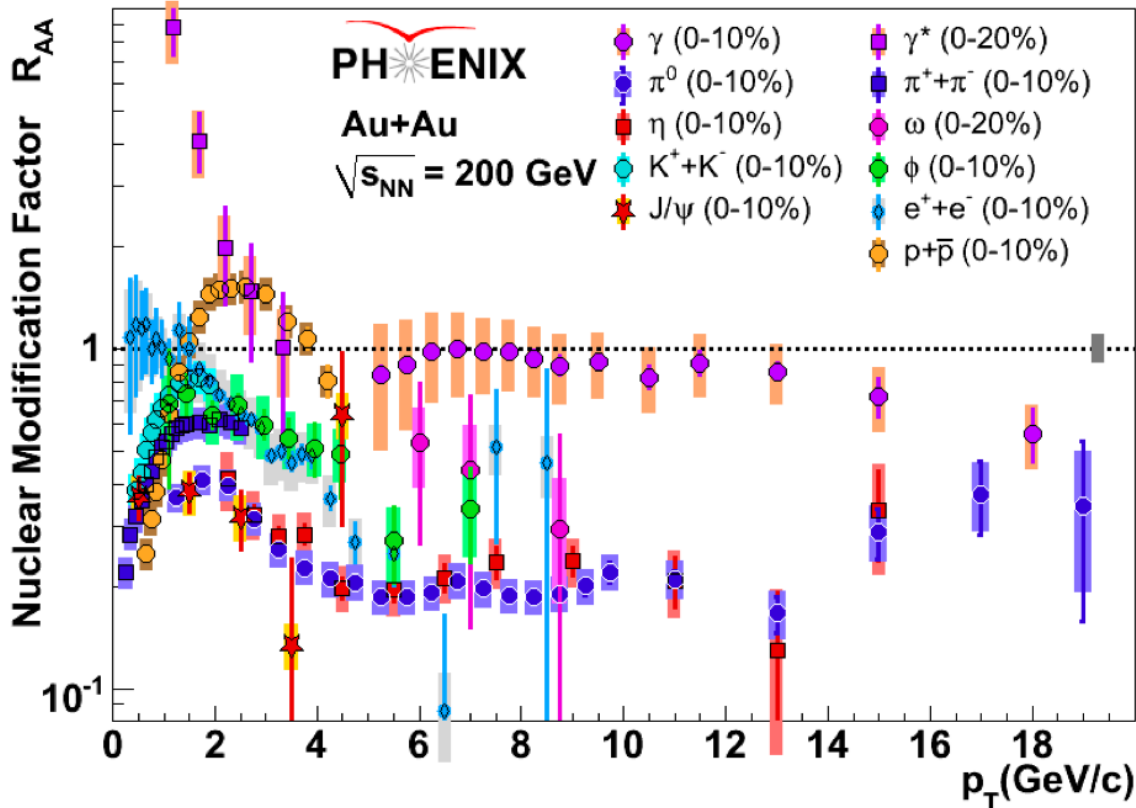
STAR, Quark Matter 2001



PHENIX, Quark Matter 2001



# $R_{AA}$ at RHIC - data



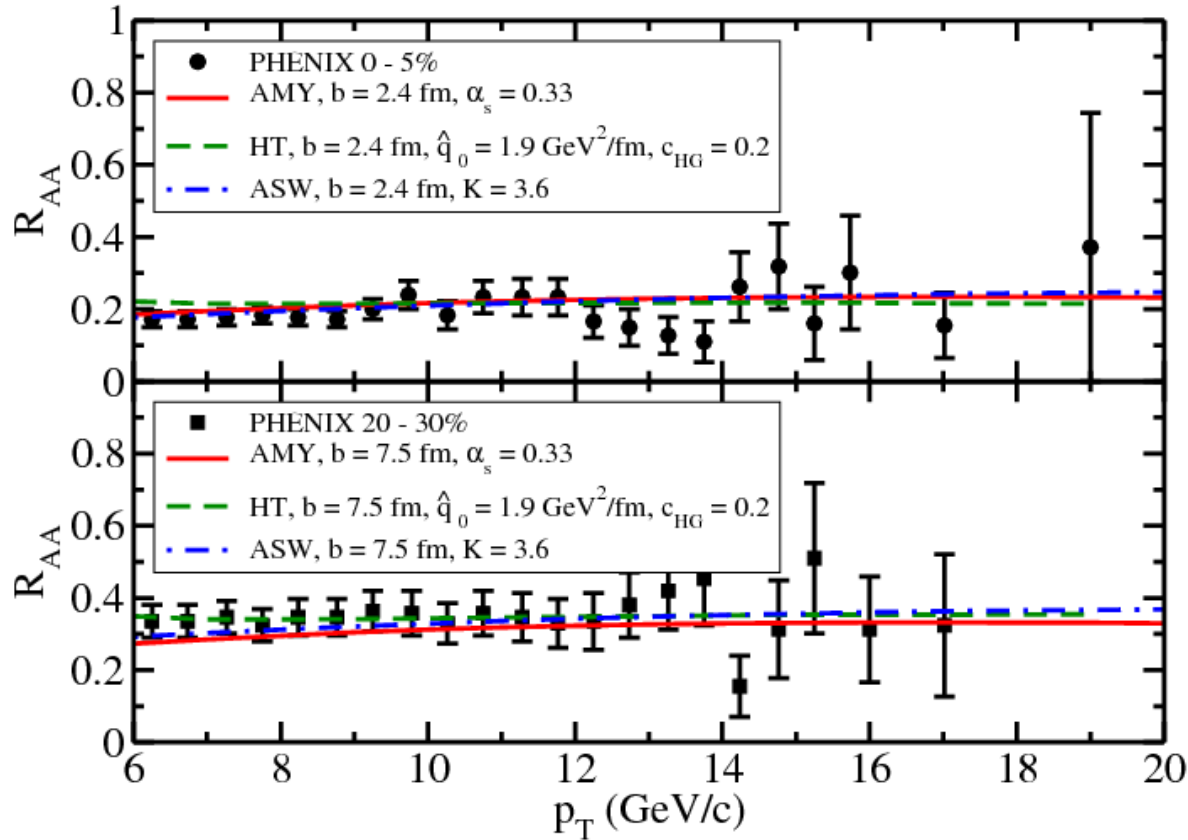
very detailed experimental information available by now:

- $p_T$  reach 20 GeV/c
- identified hadrons, leptons, photons
- reaction plane dependence
- pp and d-Au reference data

# $R_{AA}$ at RHIC - models



Bass et al, PRC79, 024901



- good description by theory
- but extraction of medium parameters still ambiguous

# The Large Hadron Collider



- pp up to  $\sqrt{s}=14$  TeV
  - Pb-Pb up to  $\sqrt{s_{NN}}=5.5$  TeV
- abundant production of hard probes

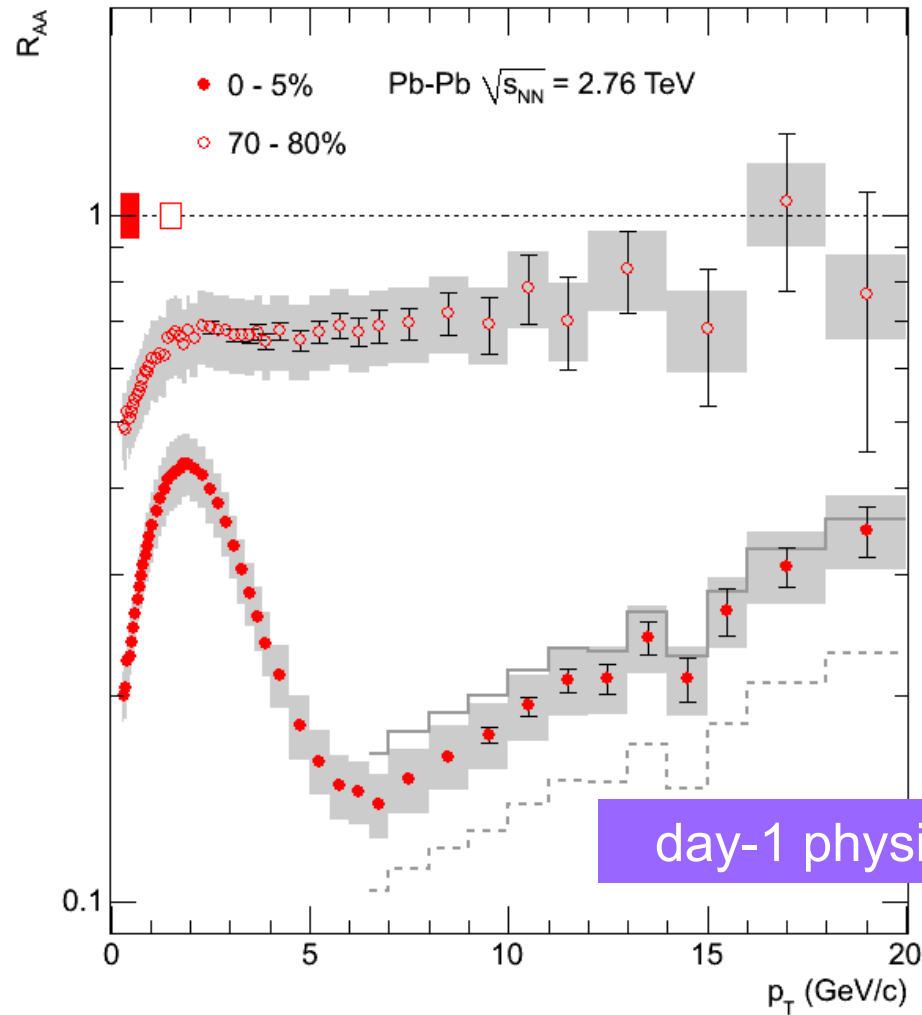
8,6 km

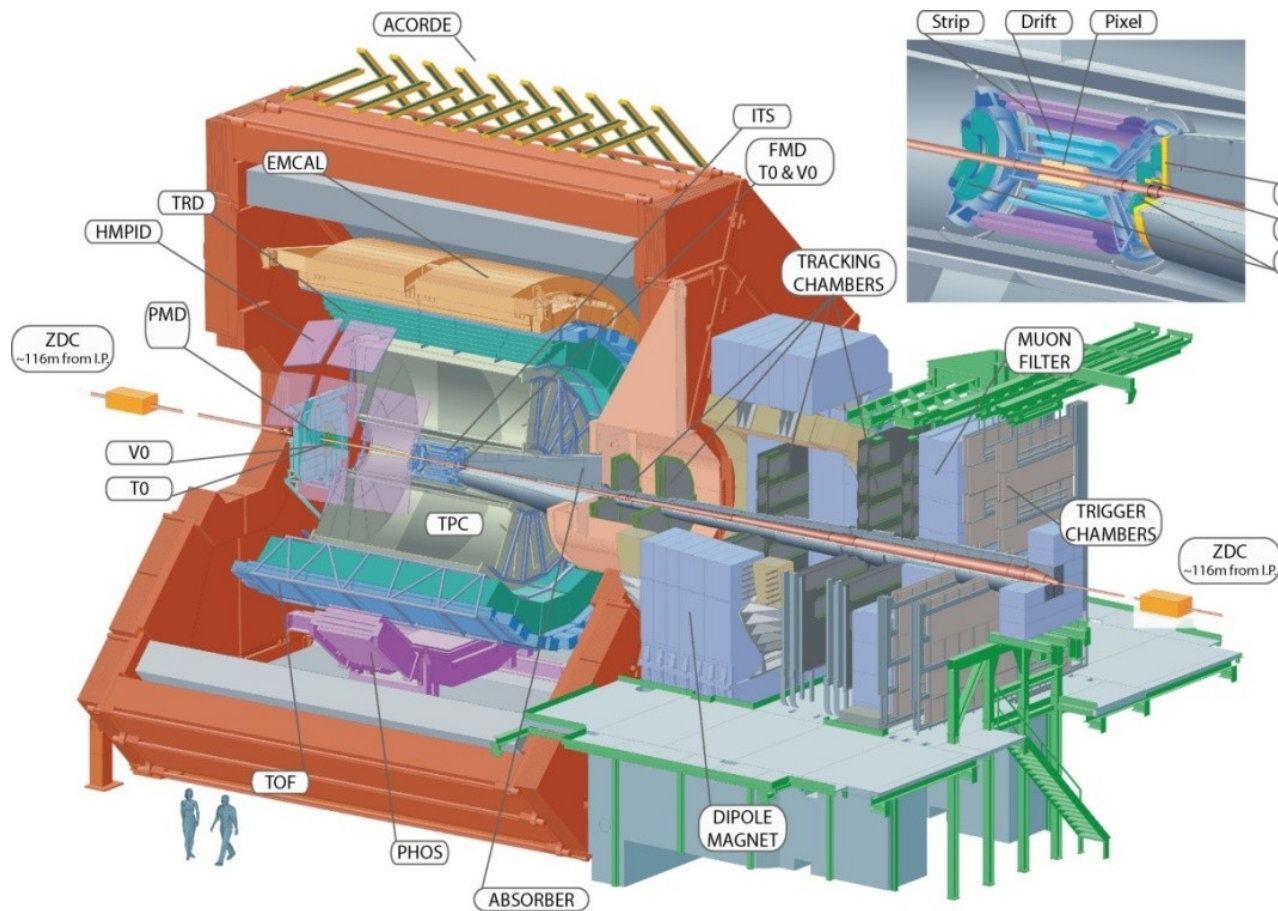


# The Large Hadron Collider



ALICE Collaboration, Phys. Lett. B696 (2011)





**Central Detectors:**  
Inner Tracking System  
Time Projection Chamber  
Time-of-Flight  
Transition Radiation Detector

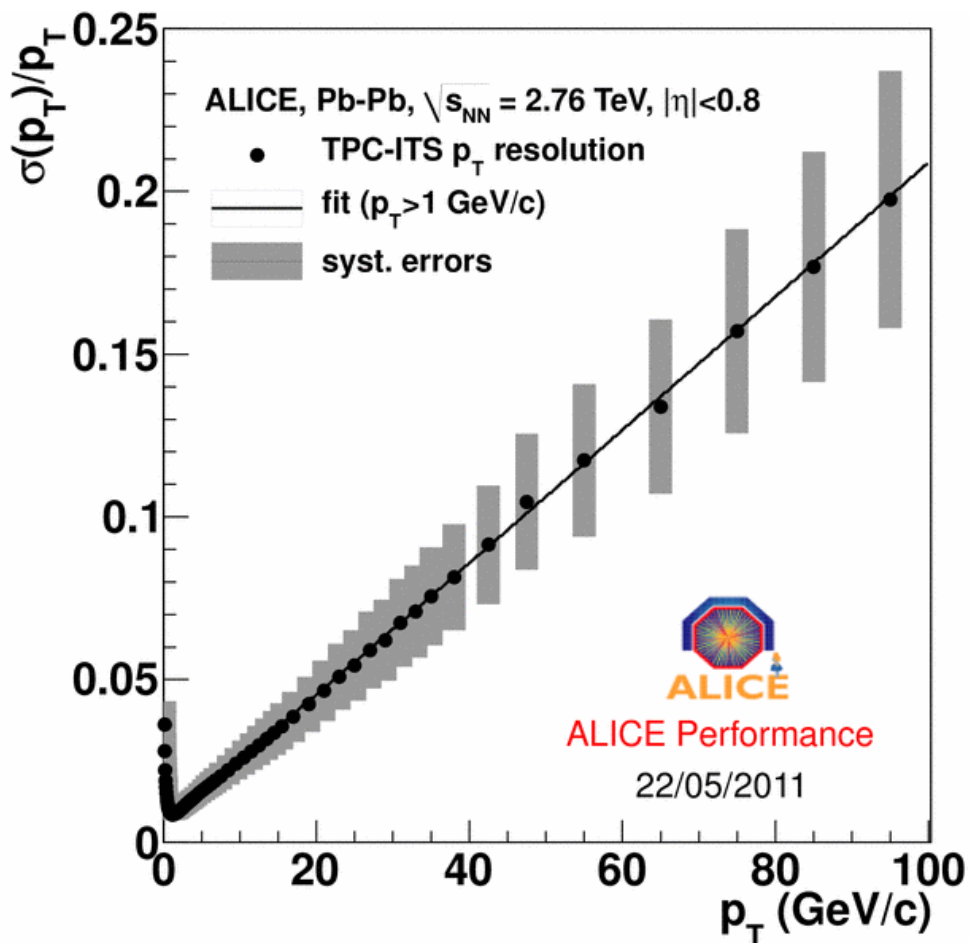
**Spectrometers:**  
High Momentum PID (RICH)  
Photon Multiplicity  
Forward Multiplicity  
Muon Spectrometer

**Calorimeters:**  
EM Calorimeter  
Photon Spectrometer (PHOS)  
Zero Degree Calorimeter

**Trigger:**  
Trigger Detectors  
pp High-Level-Trigger



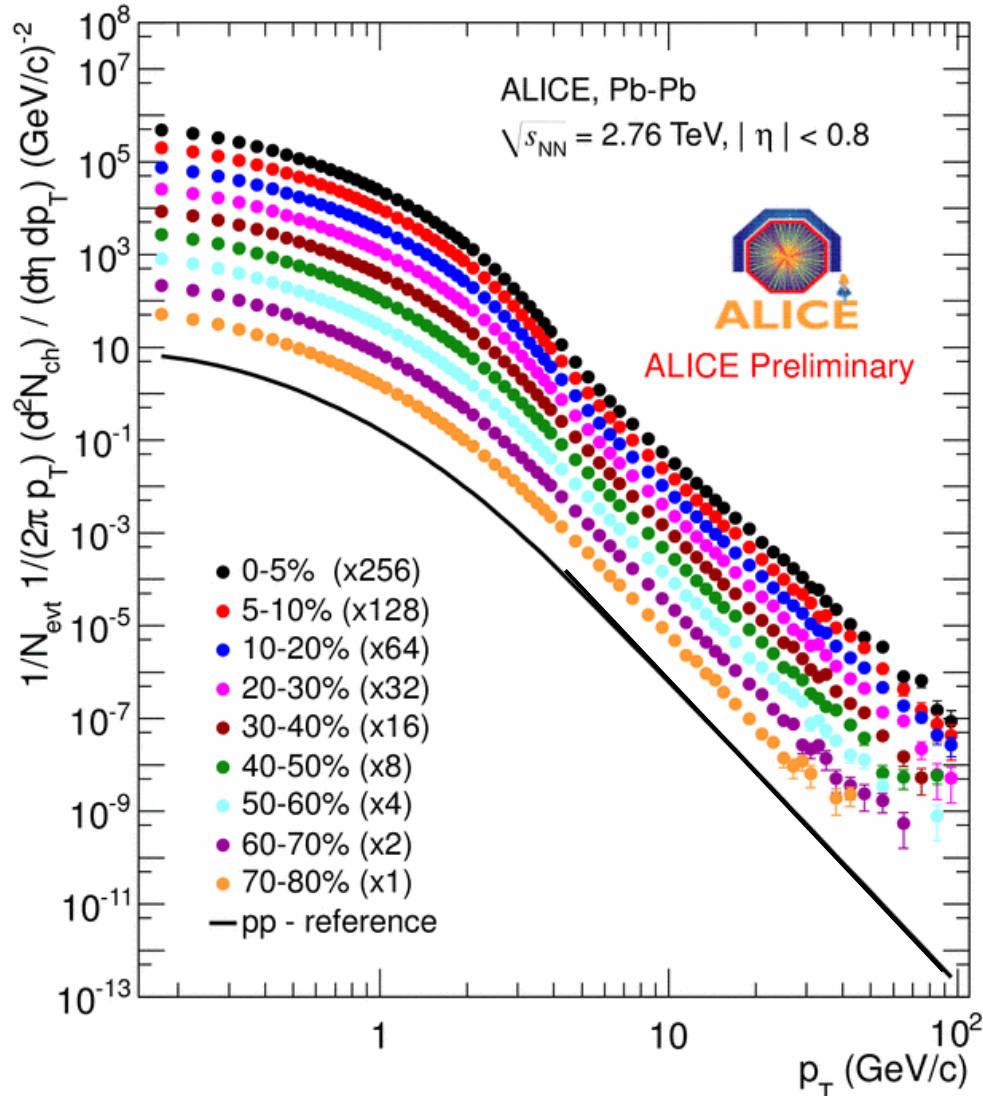
# momentum resolution



- combined TPC-ITS momentum resolution:

$$\sigma(p_T)/p_T = 20\% \text{ at } p_T = 100 \text{ GeV/c}$$

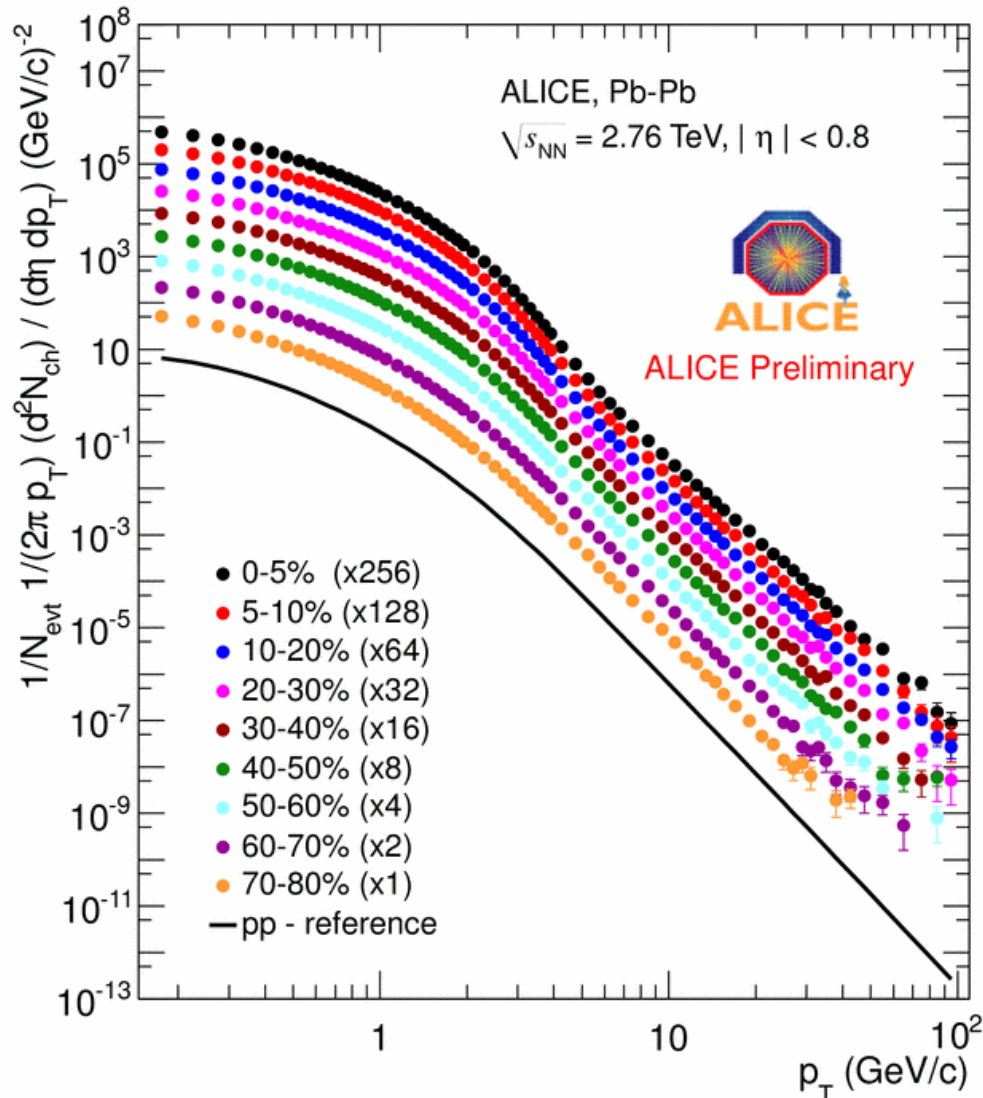
# Pb-Pb: charged particle spectra



Talk: J. Otwinowski

- charged particle spectra in Pb-Pb at  $\sqrt{s_{NN}} = 2.76 \text{ TeV}$  out to  $p_T = 100 \text{ GeV}/c$
- strong modification of the spectral shape in central collisions

# Pb-Pb: charged particle spectra



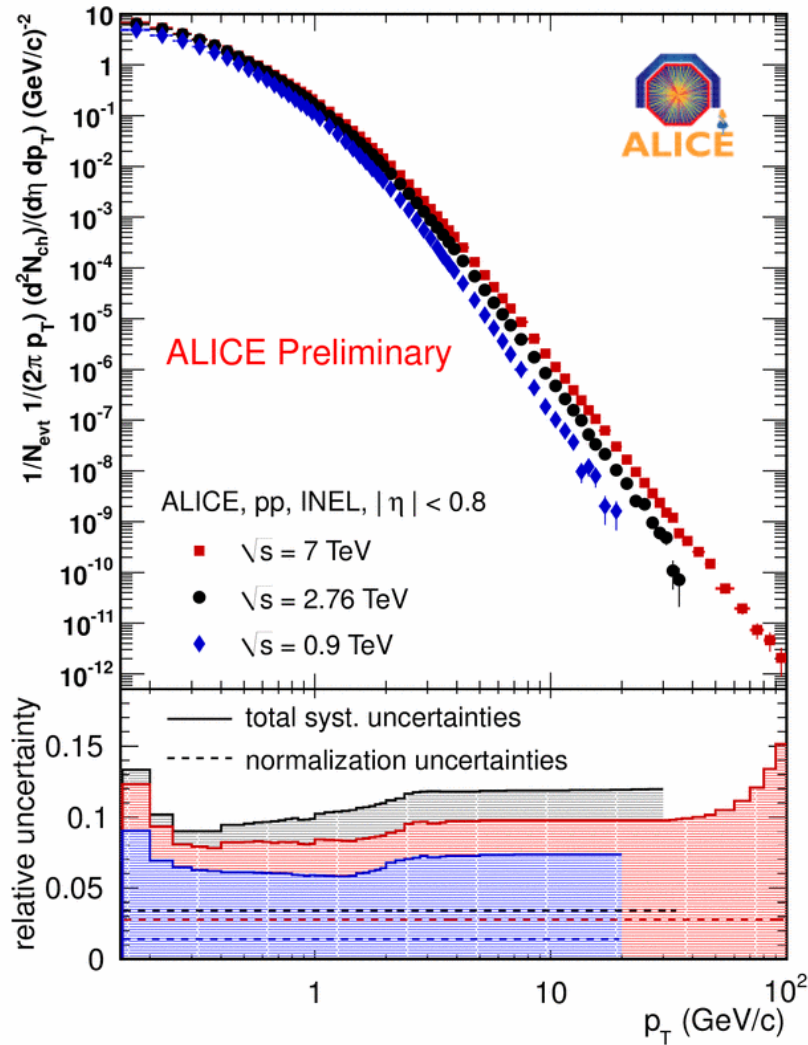
Talk: J. Otwinowski

- charged particle spectra in Pb-Pb at  $\sqrt{s_{NN}} = 2.76 \text{ TeV}$  out to  $p_T = 100 \text{ GeV/c}$
- strong modification of the spectral shape in central collisions

$$R_{AA} = \frac{d^2 N^{AA} / dp_T d\eta}{\langle N_{coll} \rangle d^2 N^{pp} / dp_T d\eta}$$

$$\langle N_{coll} \rangle = \langle T_{AA} \rangle \cdot \sigma_{pp}^{INEL}$$

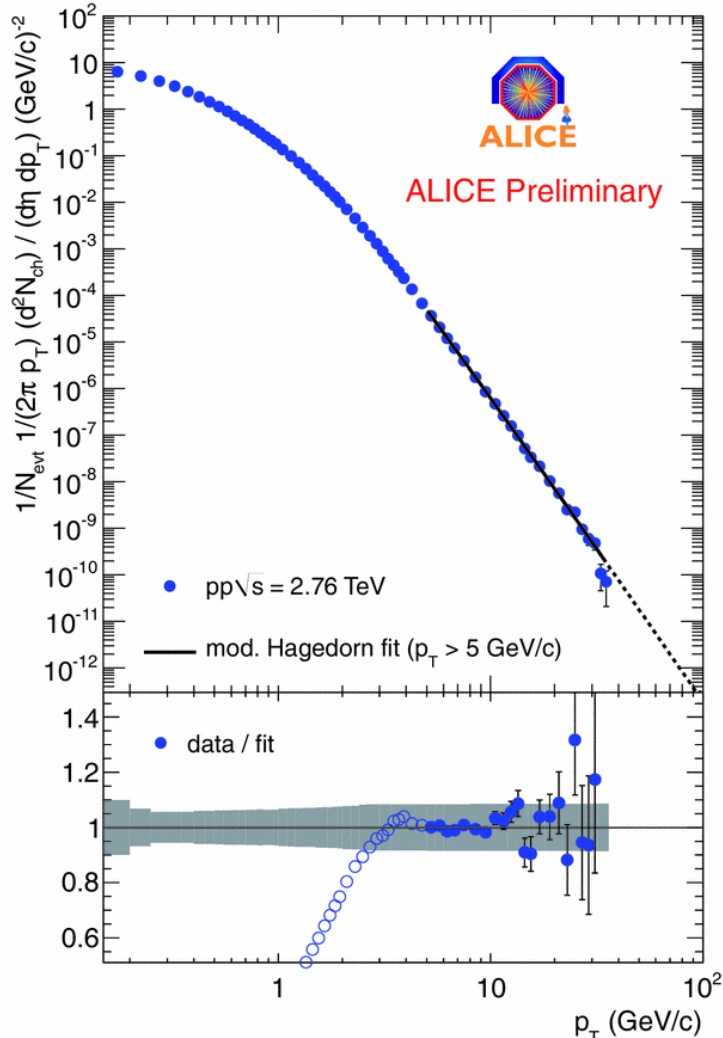
# pp: charged particle spectra



Poster: M. Knichel

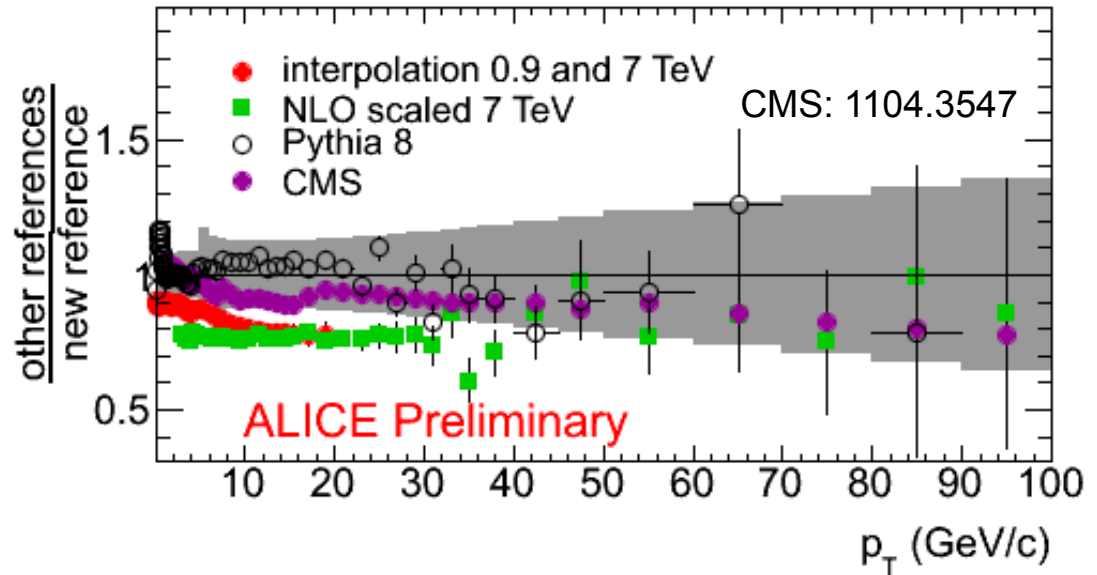
- charged particle spectra in pp at  $\sqrt{s} = 0.9, 2.76, 7$  TeV
- 2.76 TeV: reference measurement for pp baseline

# pp reference

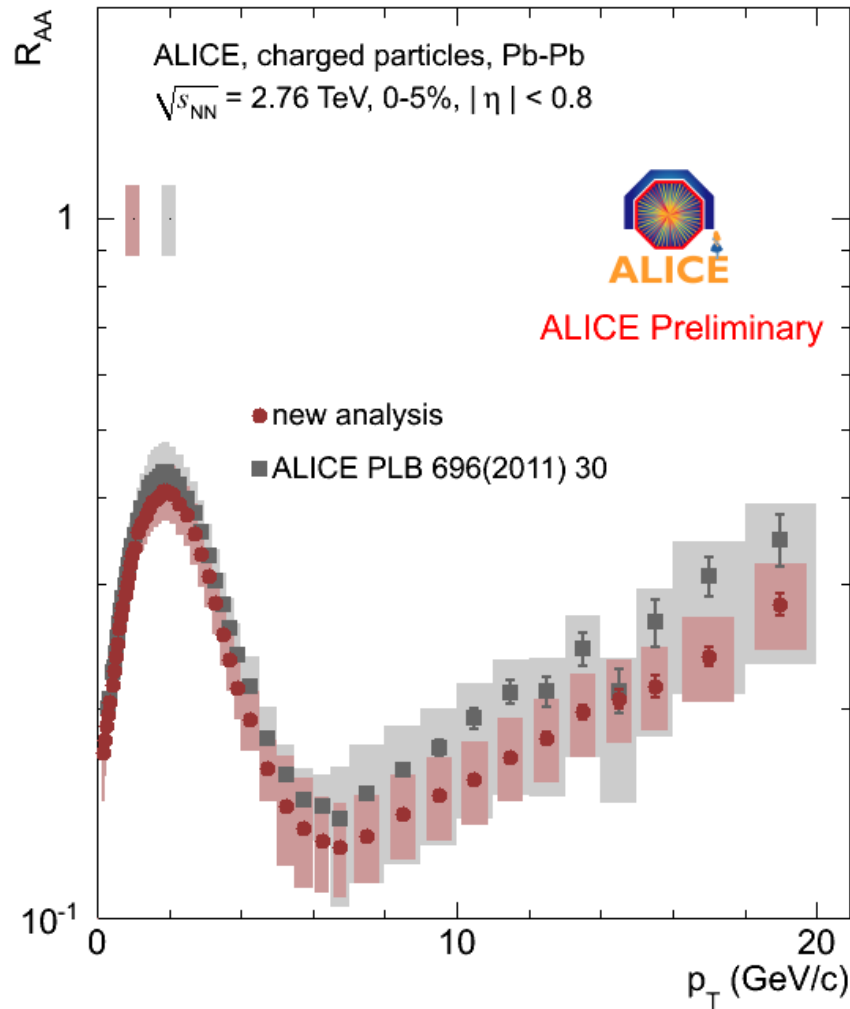


pp reference spectrum derived from:

- measured data points for  $p_T \leq 5$  GeV/c
- extrapolation of Hagedorn fit for  $p_T > 5$  GeV/c

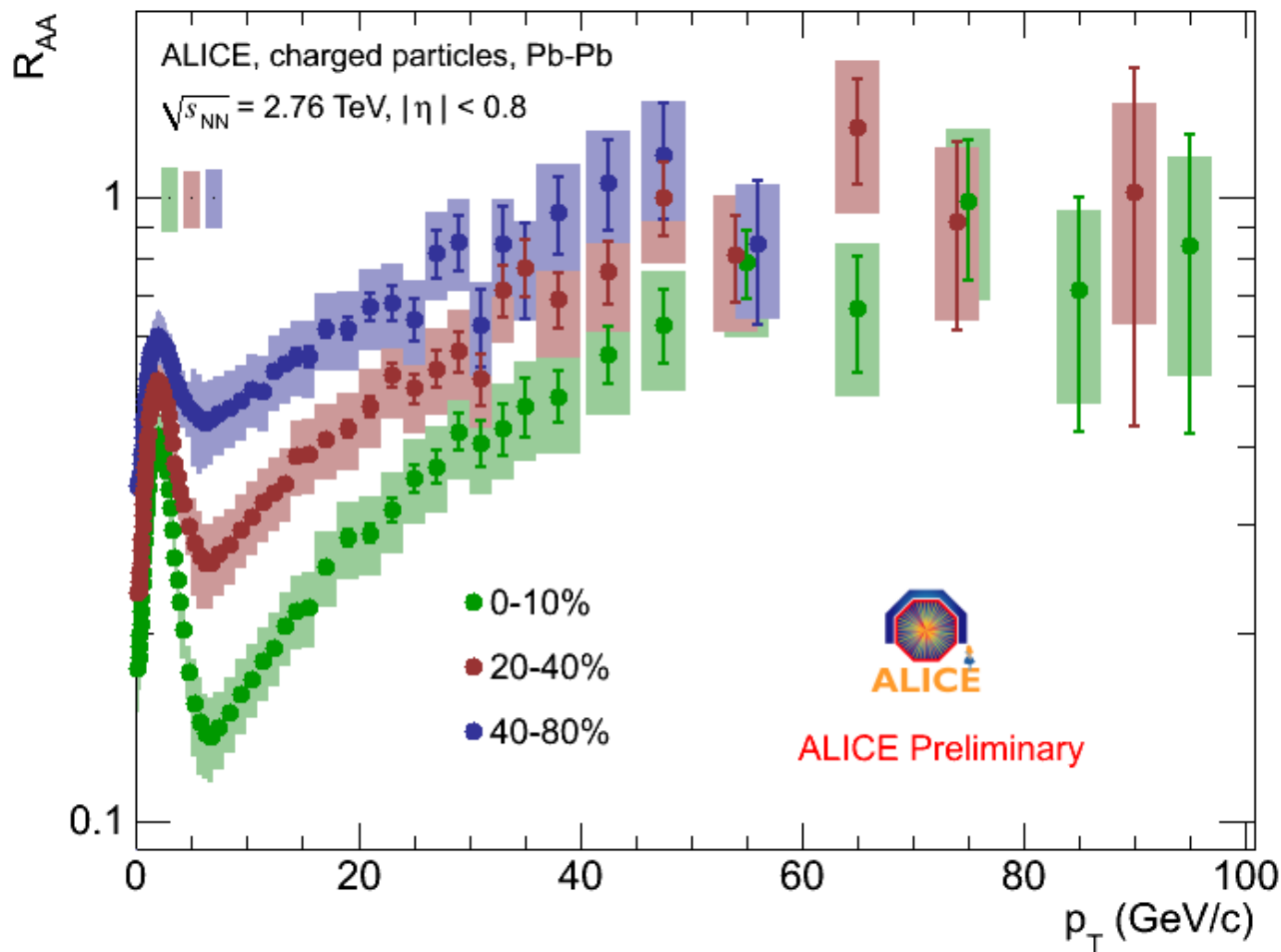


# $R_{AA}$ with new pp reference



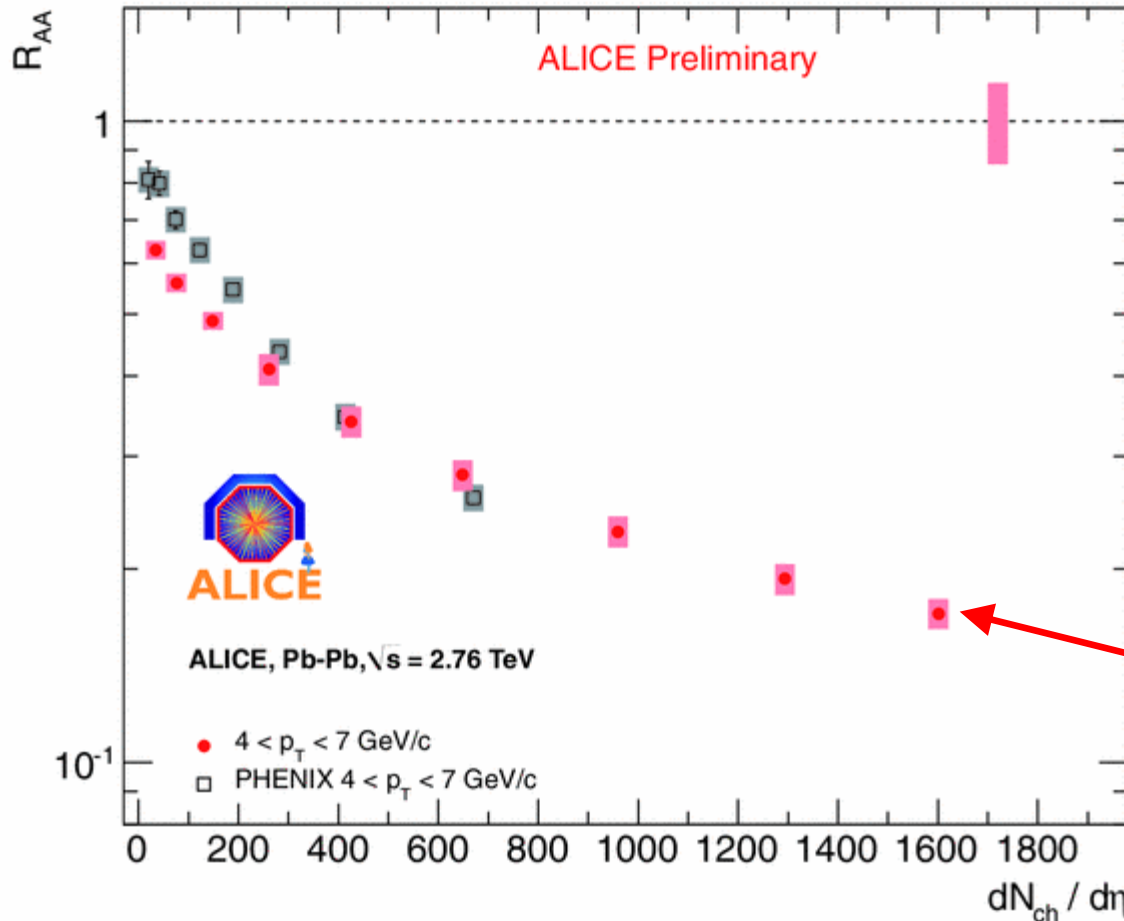
- **good agreement** with published results
- **significant improvement** of systematic uncertainties

# charged particle $R_{AA}$



- pronounced centrality dependence below  $p_T = 50 \text{ GeV}/c$
- minimum at  $p_T \approx 6-7 \text{ GeV}/c$
- strong rise in  $6 < p_T < 50 \text{ GeV}/c$
- no significant centrality and  $p_T$  dependence at  $p_T > 50 \text{ GeV}/c$

# charged particle $R_{AA}$ – centrality dependence

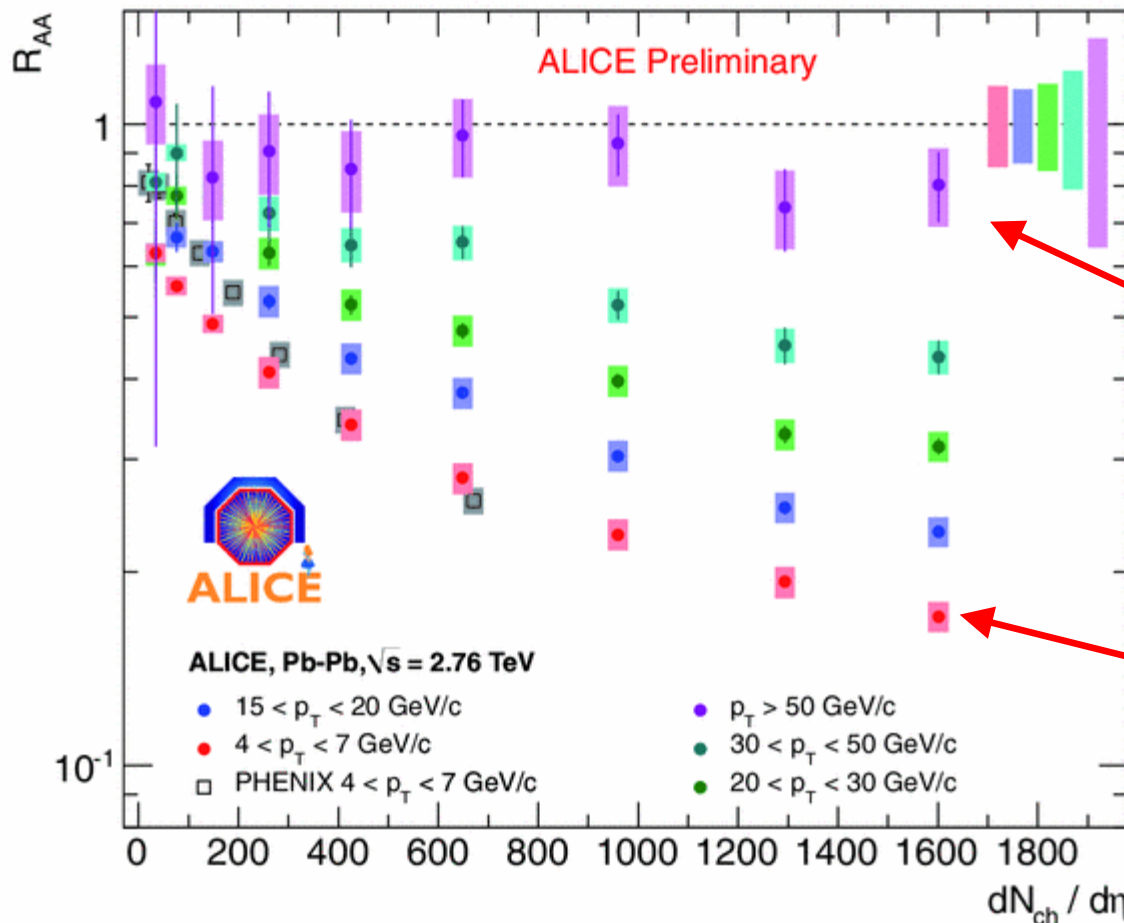


**low  $p_T$ :**

- approximate scaling with multiplicity density,
- matching also RHIC results



# charged particle $R_{AA}$ – centrality dependence



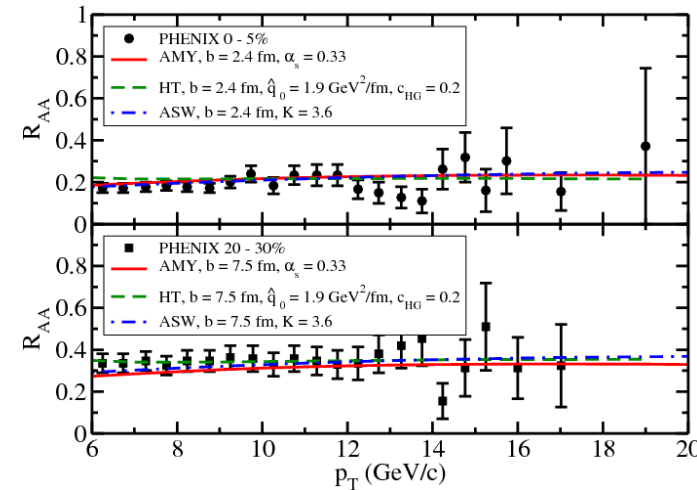
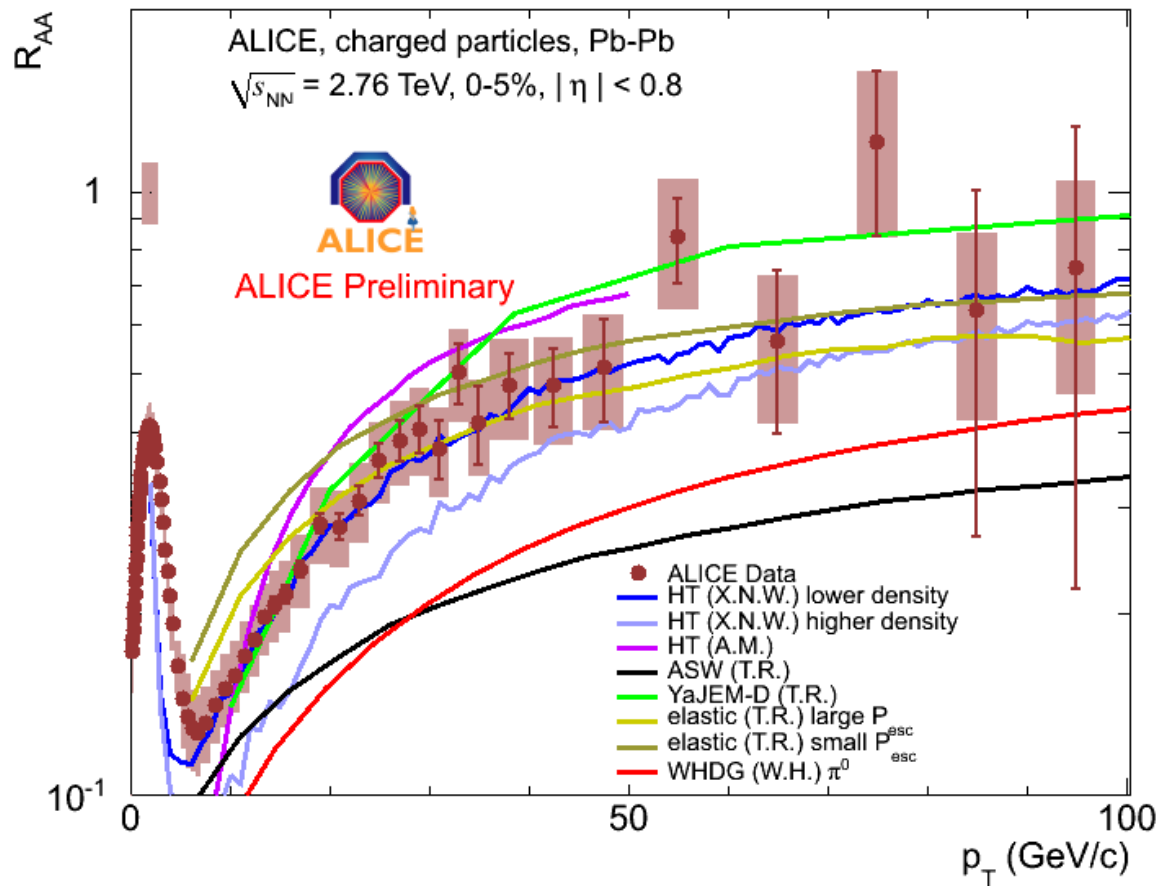
**high  $p_T$ :**

- weak suppression, no significant centrality dependence

**low  $p_T$ :**

- approximate scaling with multiplicity density,
- matching also RHIC results

# charged particle $R_{AA}$ - models



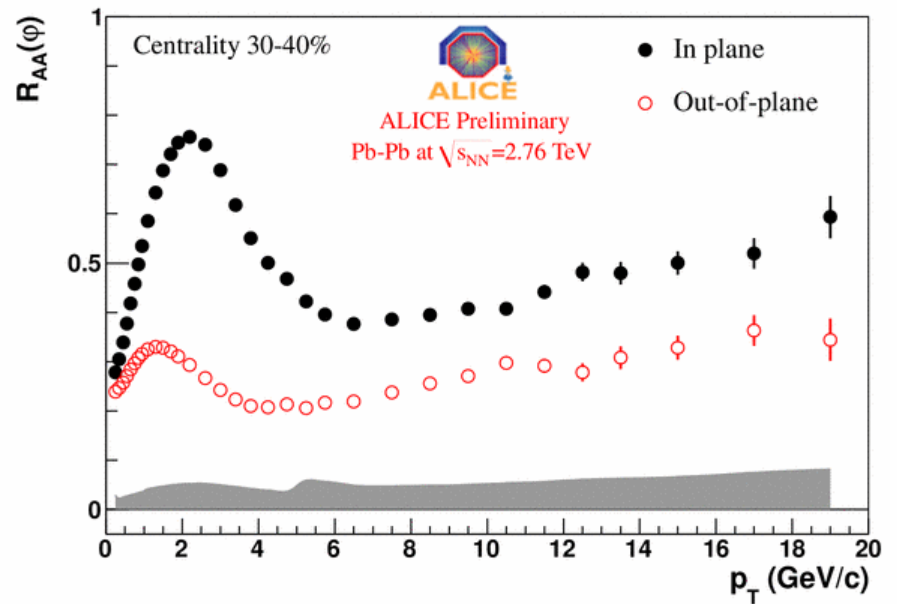
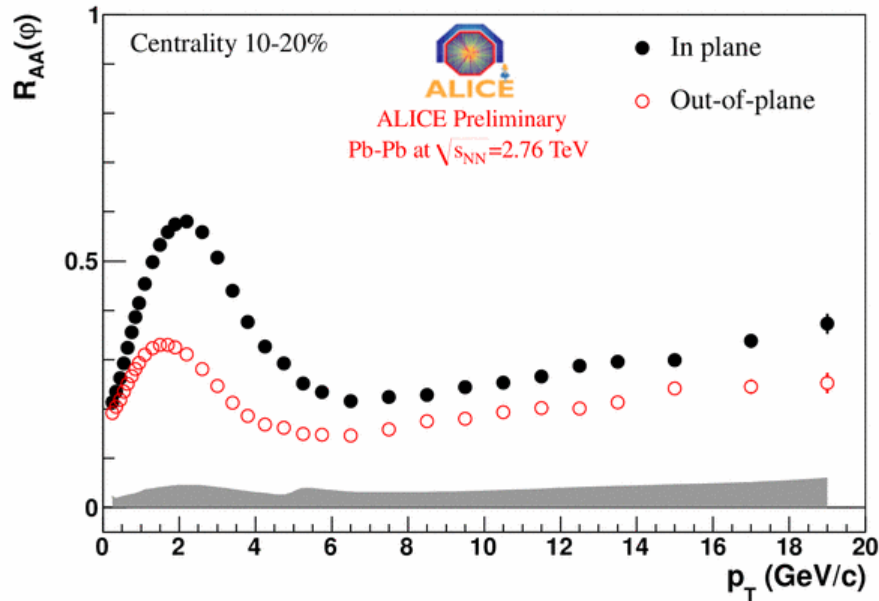
- pronounced  $p_T$  dependence of  $R_{AA}$  at LHC

→ sensitivity to details of the energy loss distribution

# reaction plane dependent $R_{AA}$



Talk: A Dobrin

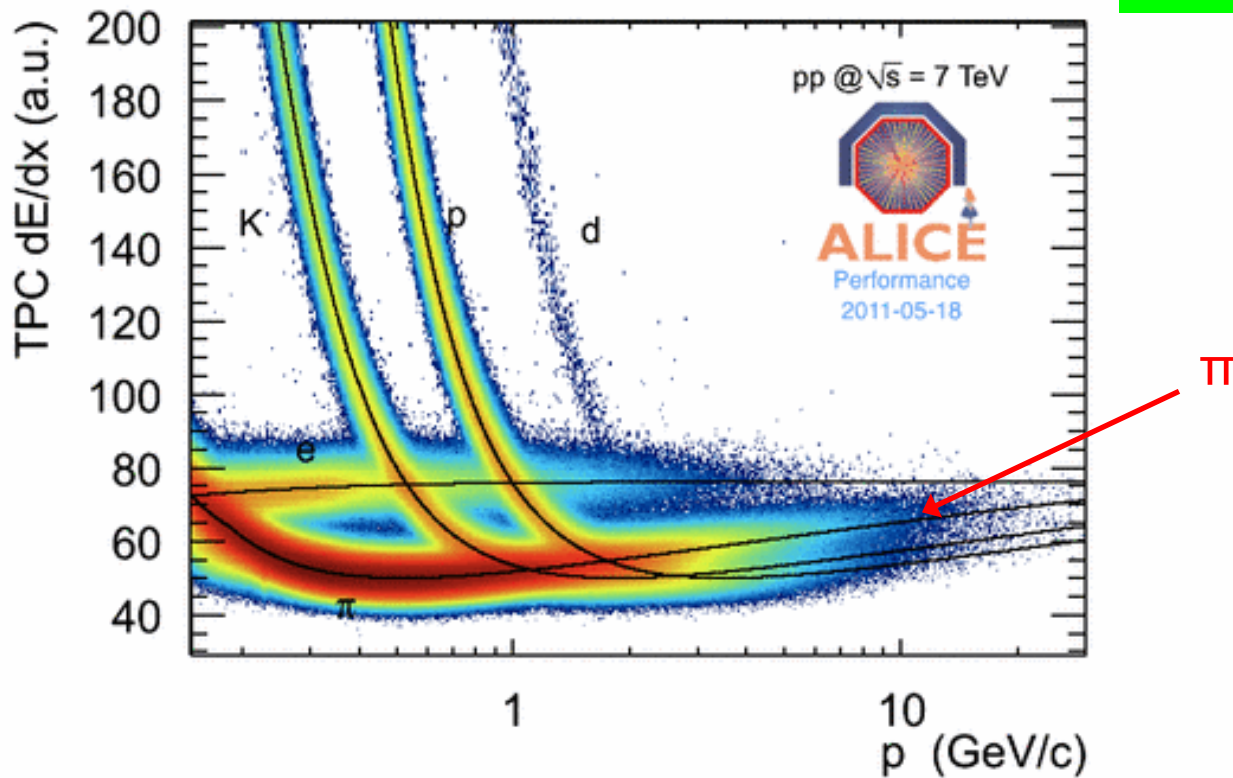


$$R_{AA}(\varphi) = R_{AA}(1 + 2v_2 \cos(2\varphi))$$

# particle identification: $dE/dx$



Talk: A Kalweit



- almost constant separation of pions to K, p above  $p = 3$  GeV/c

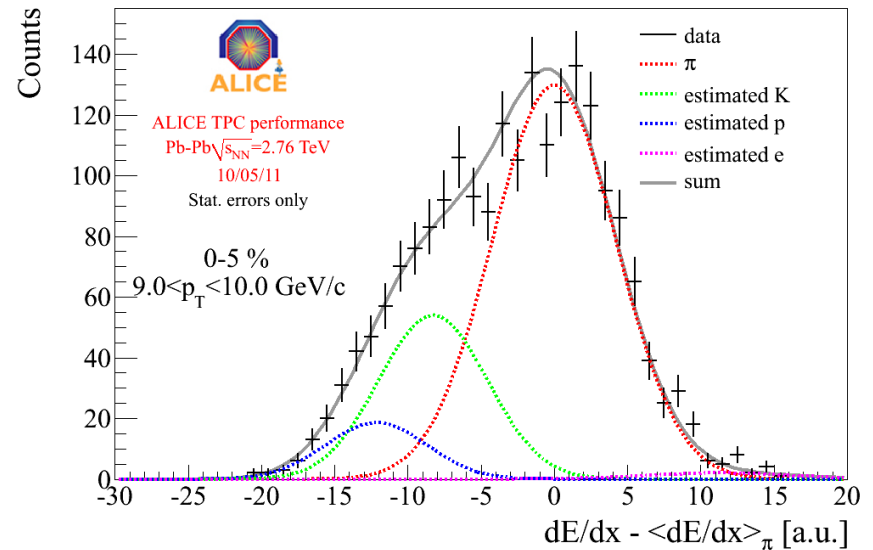
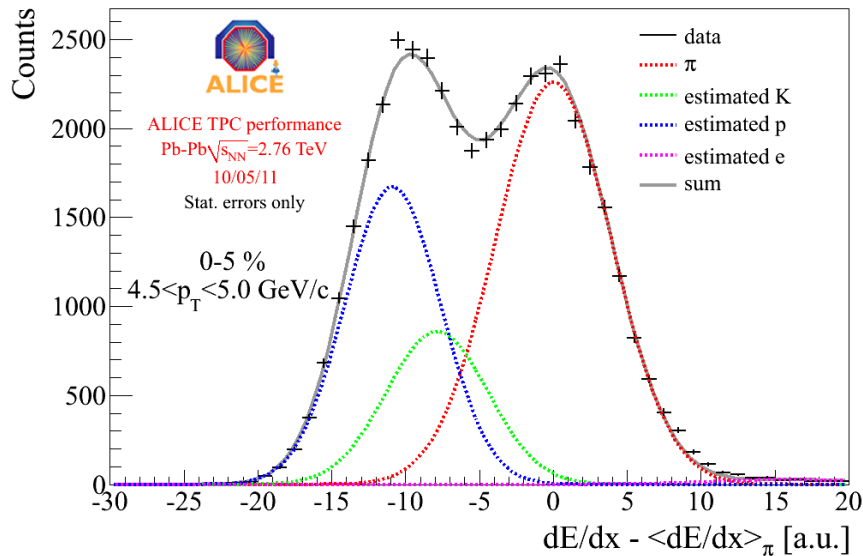
# pion identification at high $p_T$



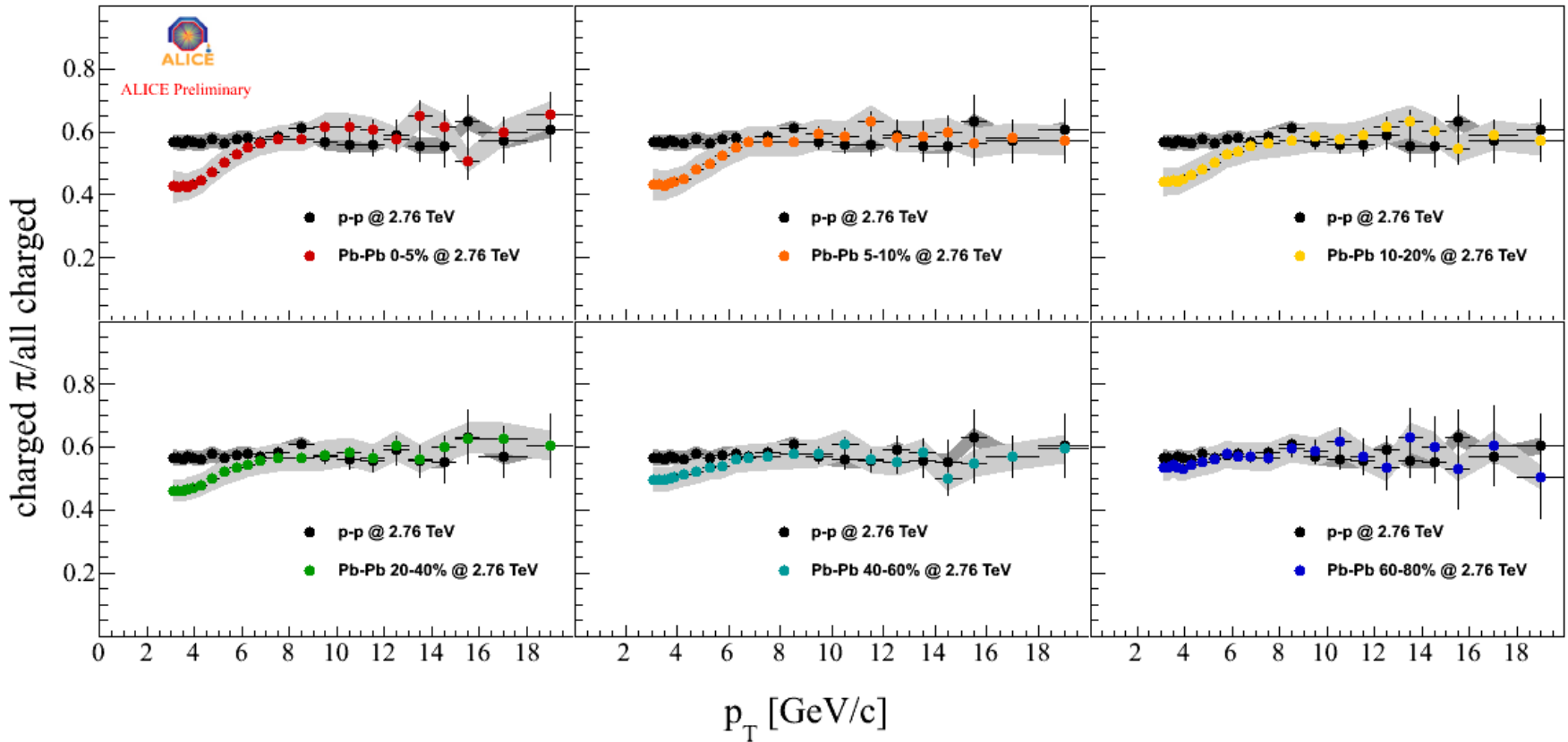
Poster: P. Christiansen

$$\frac{d^2 N_\pi}{dy dp_T} = \frac{E}{p} \frac{d^2 N_{ch}}{d\eta dp_T} \times \frac{\epsilon_\pi}{\epsilon_{ch}} \times \frac{N_\pi}{N_{ch}}$$

← from TPC dE/dx

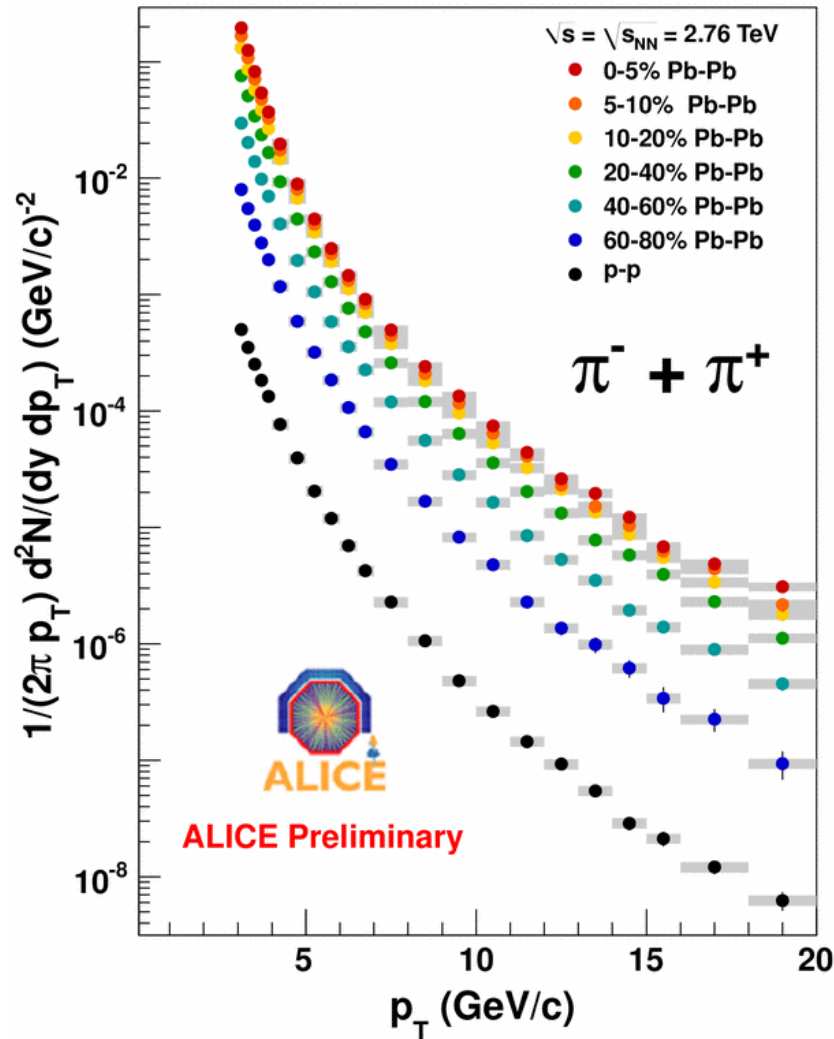


# charged pion fraction



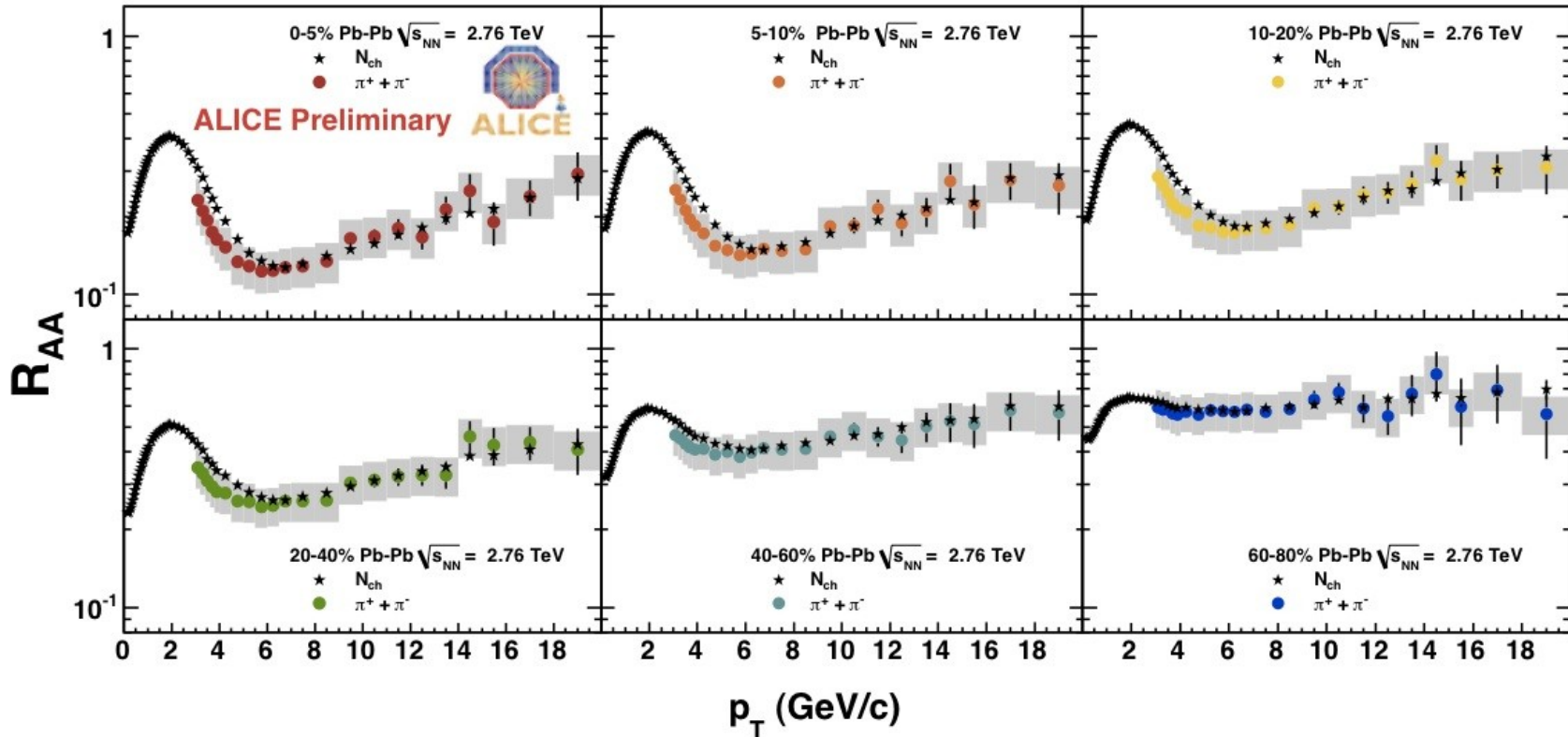
- no centrality dependence of pion-to-charged ratio for  $p_T > 6$  GeV/c

# charged pion spectra



- charged pion spectra out to  $p_T = 20 \text{ GeV}/c$

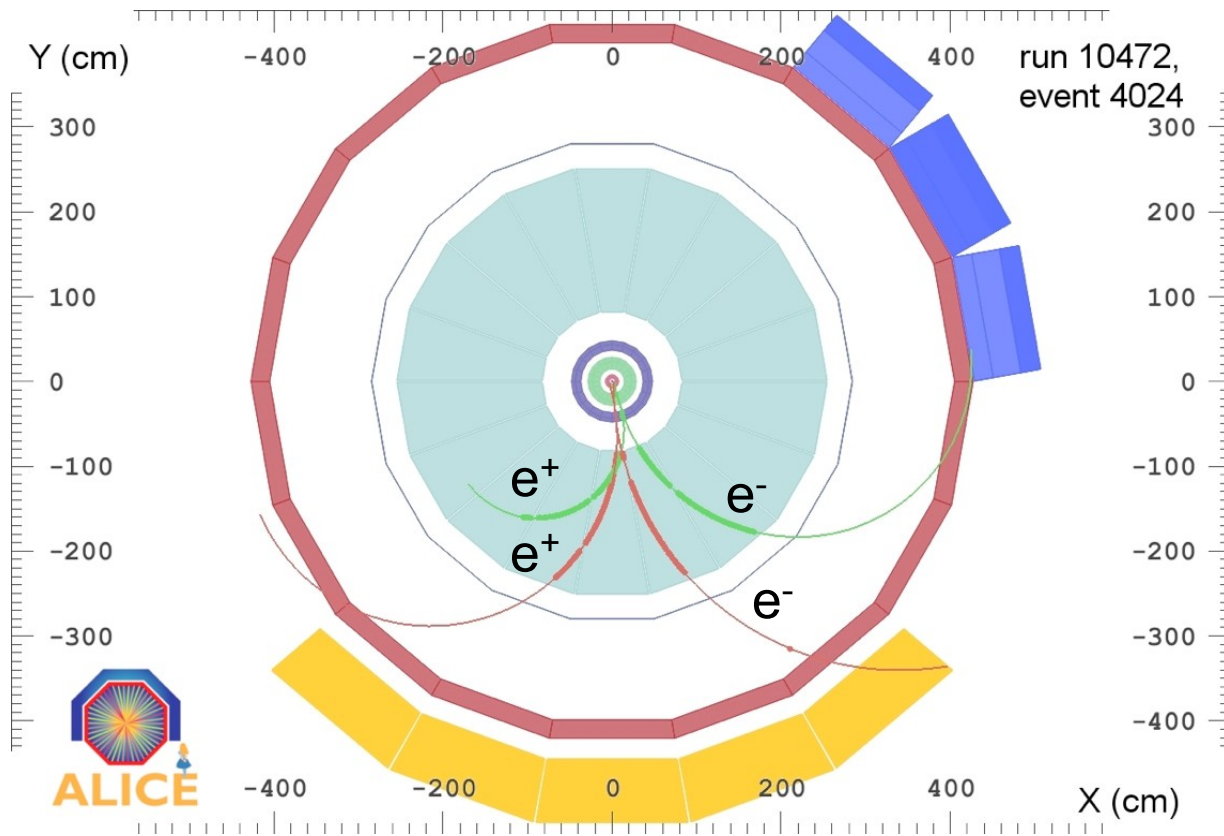
# charged pion $R_{AA}$



- agrees with charged particle  $R_{AA}$ 
  - in peripheral events
  - for  $p_T > 6$  GeV/c
- is smaller than charged particle  $R_{AA}$  for  $p_T < 6$  GeV/c



# secondary vertex reconstruction



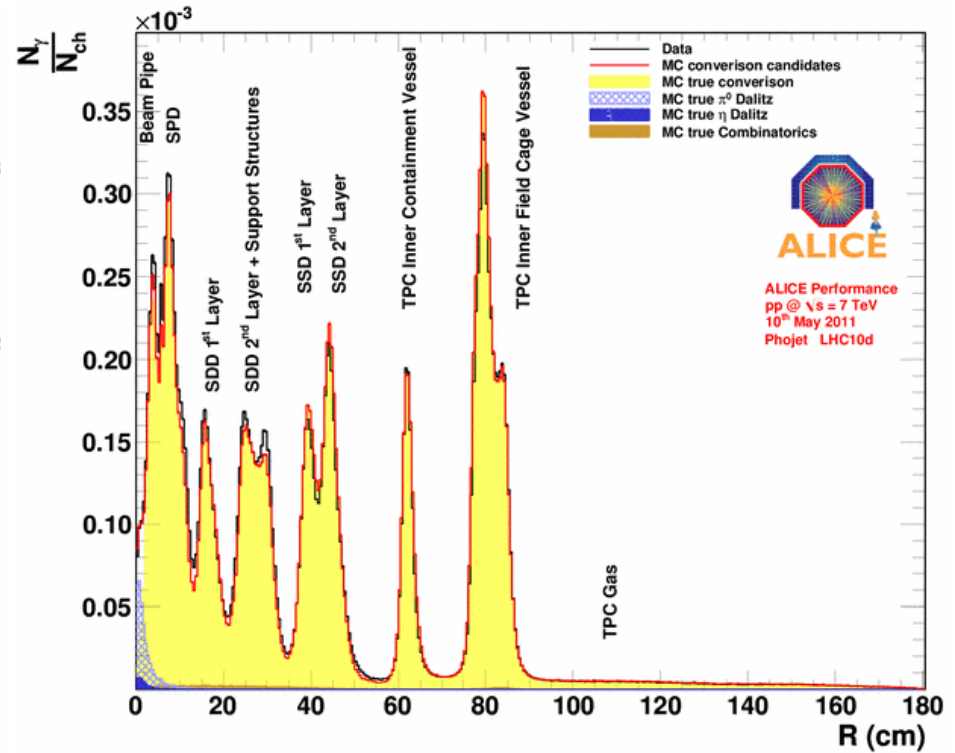
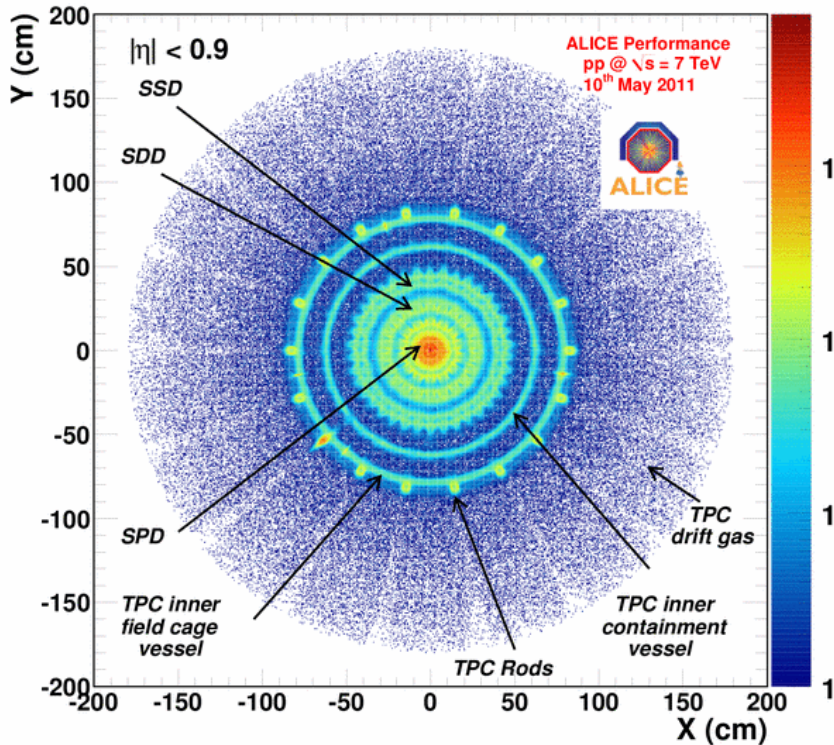
$$\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^-e^+e^-$$

$$\Lambda \rightarrow \pi^- p$$

$$K_s^0 \rightarrow \pi^+ \pi^-$$

# photon conversions

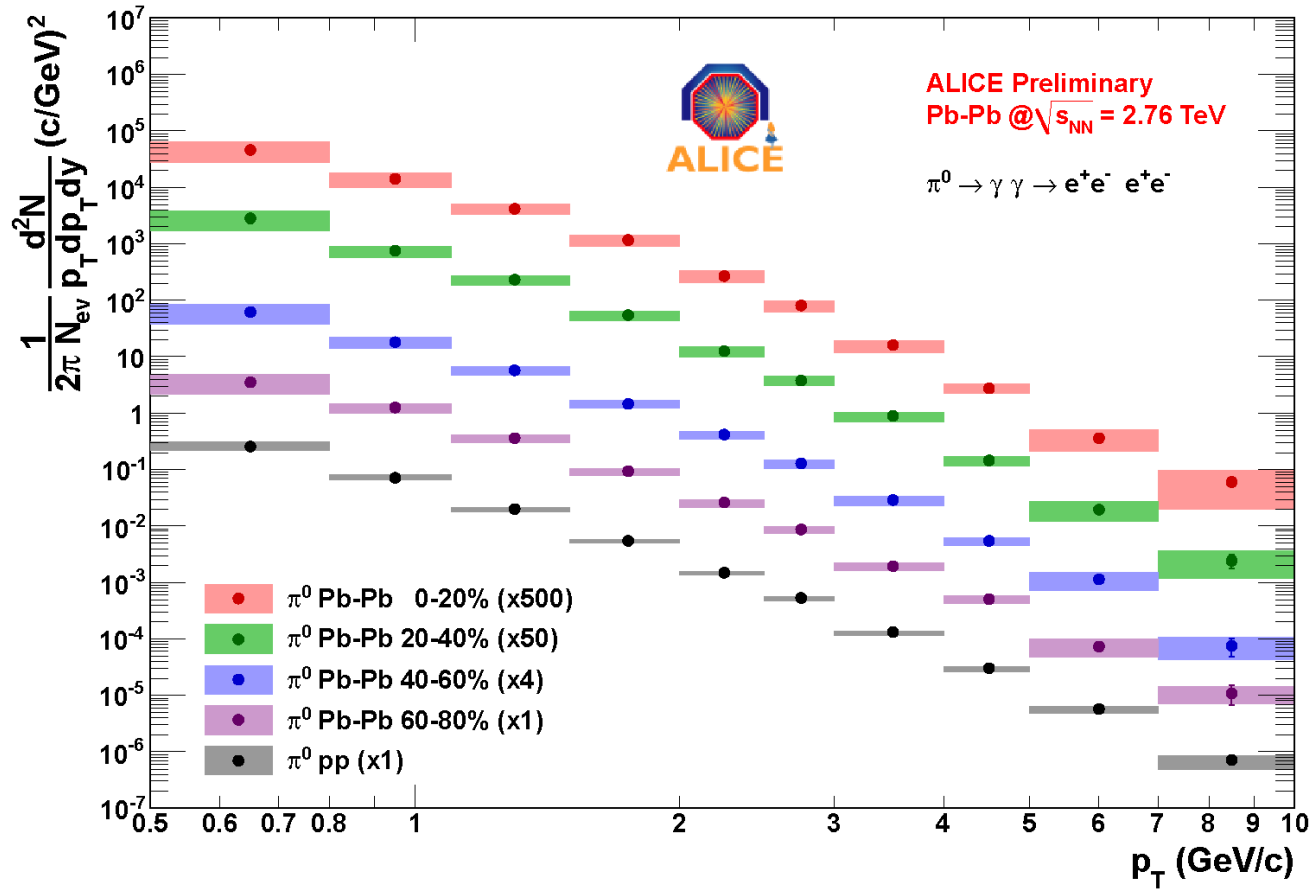
Talk: K. Reygers



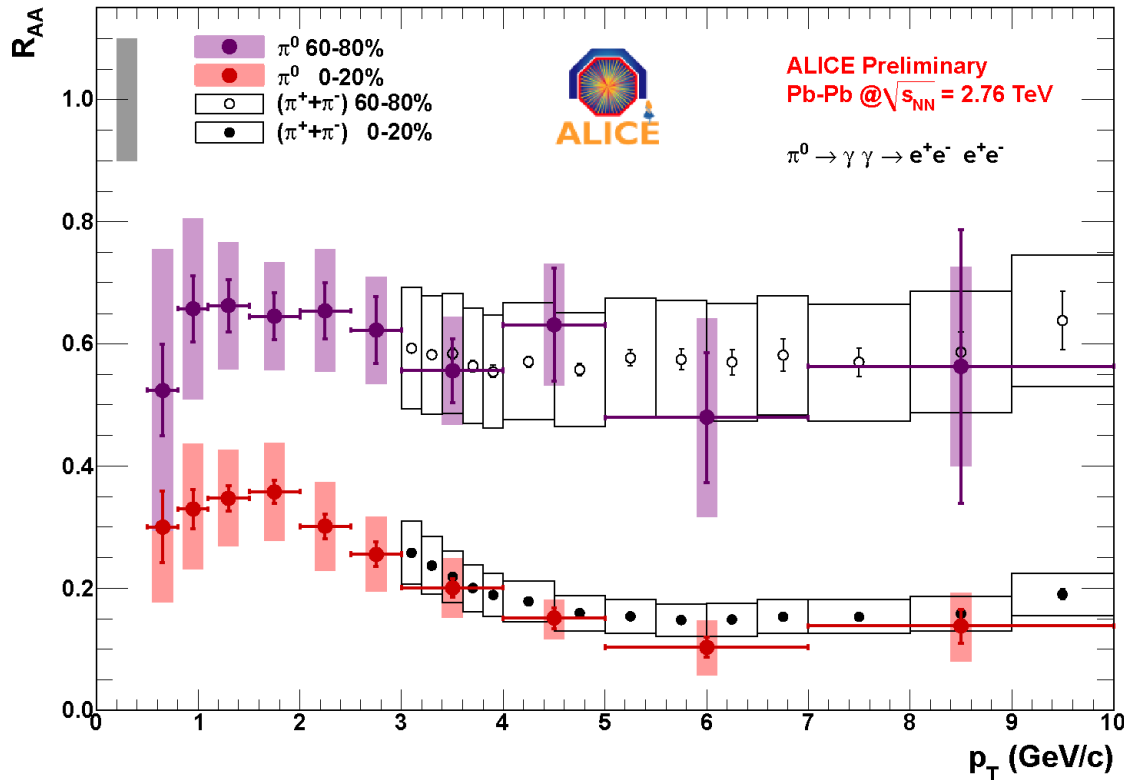
- ALICE material budget (11.4%  $X_0$  up to middle of TPC) agrees within +3.4%/-6% with its implementation in GEANT

# $\pi^0$ spectra in pp and Pb-Pb

Talk: G. Balbastre

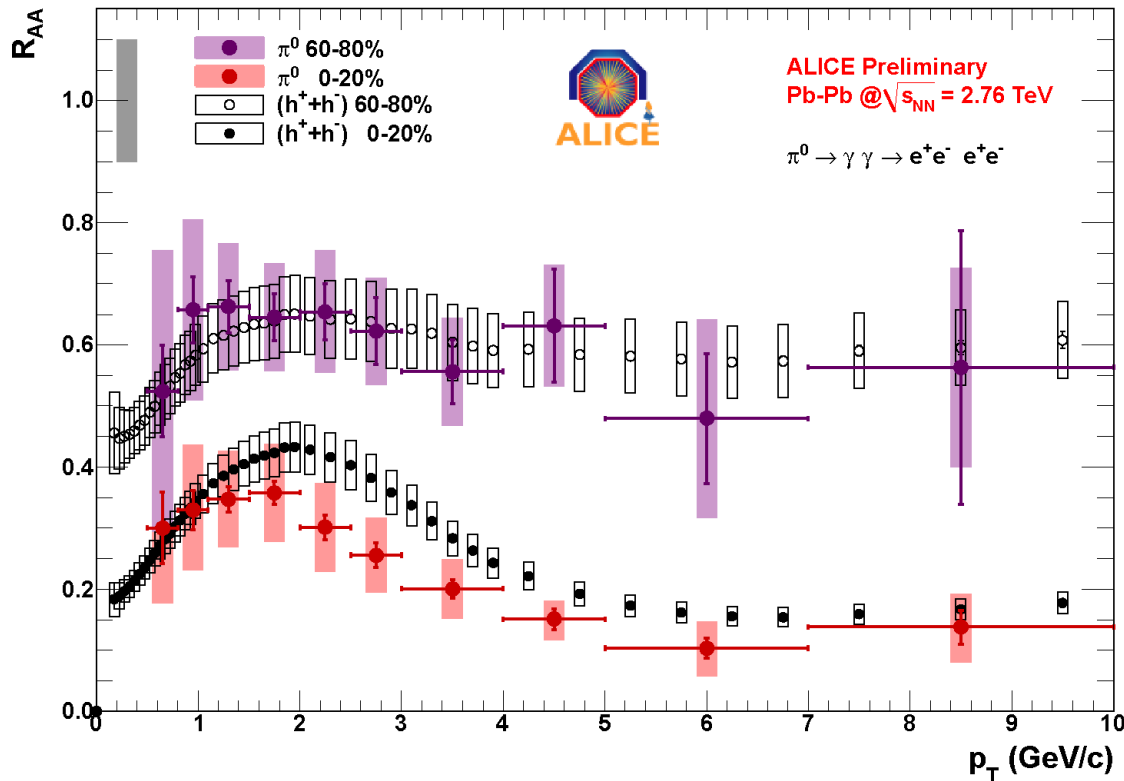


# $\pi^0 - R_{AA}$ : comparison to $\pi^+ + \pi^- - R_{AA}$



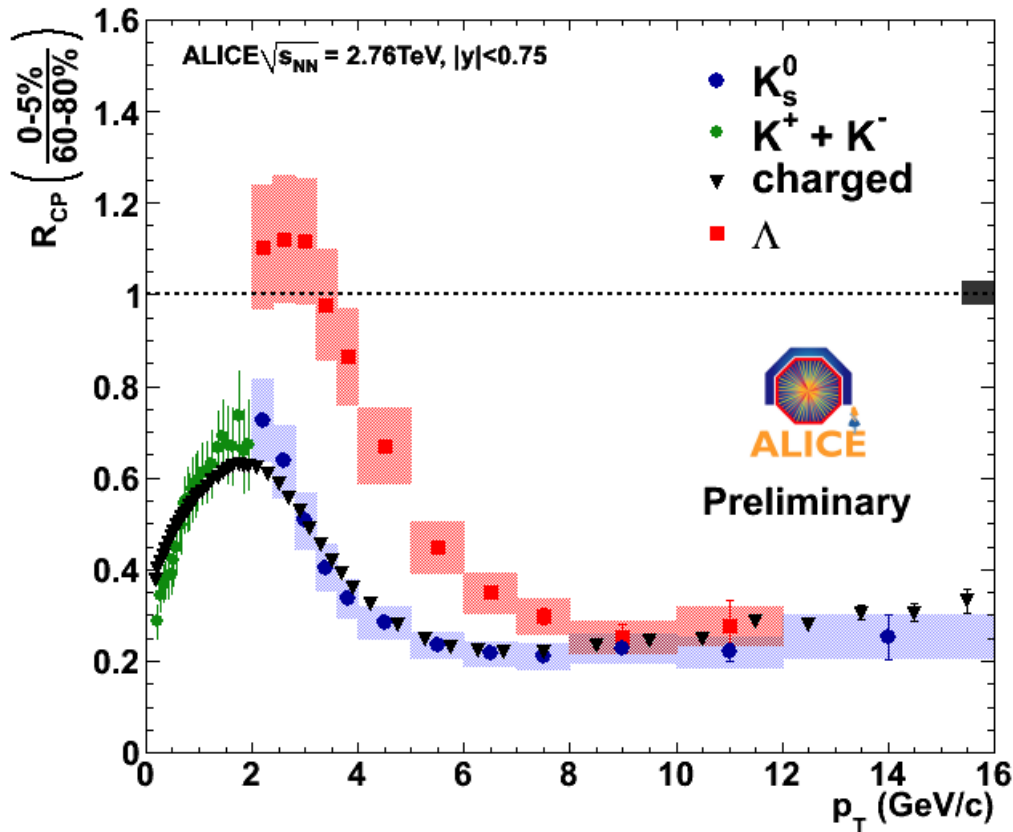
- good agreement between charged pion and  $\pi^0 - R_{AA}$

# $\pi^0 - R_{AA}$ : comparison to charged particle $R_{AA}$



- good agreement between charged pion and  $\pi^0 - R_{AA}$
- compatible with charged particle  $R_{AA}$  in peripheral events
- is lower in central events at  $2 < p_T < 5$  GeV/c

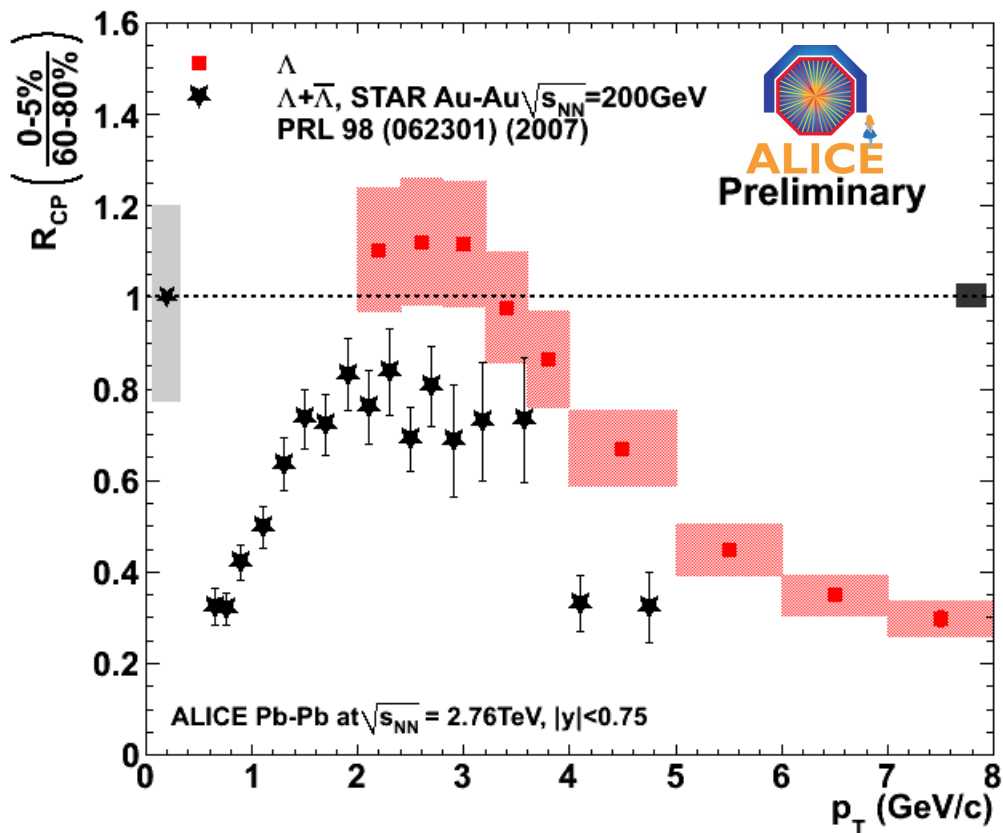
# $\Lambda$ and $K_s^0 - R_{CP}$



Talk: S. Schuchmann

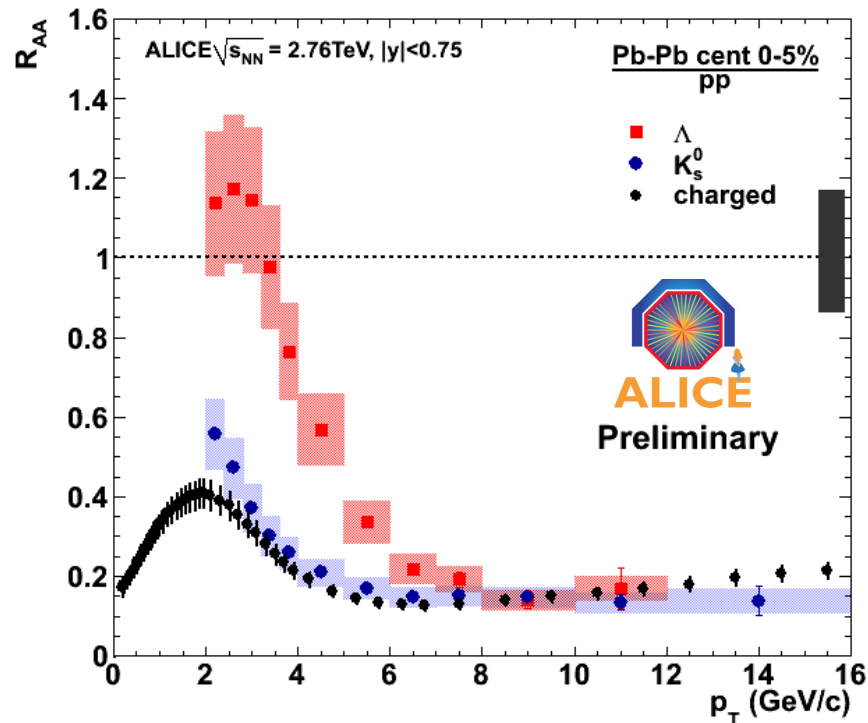
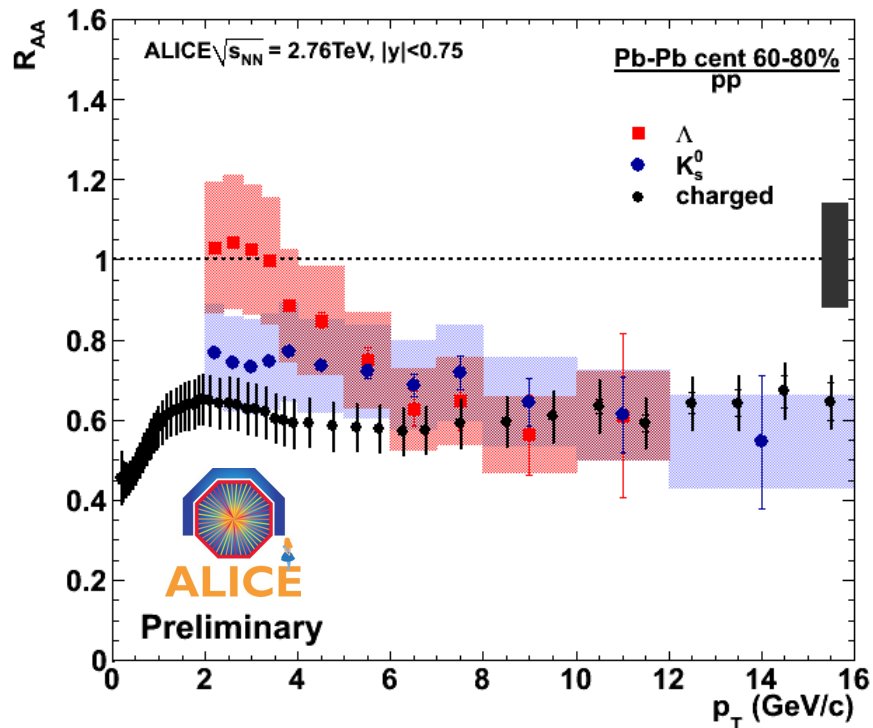
- $K_s^0 - R_{AA}$  very similar to that of charged particles:  
strong suppression of  $K_s^0$  at high  $p_T$
- $\Lambda - R_{AA}$  significantly larger than charged at intermediate  $p_T$ :  
enhanced hyperon production counteracting suppression
- for  $p_T > 8$  GeV/c,  $\Lambda$  and  $K_s^0 - R_{AA}$  similar to charged particle  $R_{AA}$ :  
strong high- $p_T$  suppression also of  $\Lambda$

# $\Lambda - R_{CP}$ : comparison to RHIC



- $K^0_s - R_{AA}$  very similar to that of charged particles:  
**strong suppression of  $K^0_s$  at high  $p_T$**
- $\Lambda - R_{AA}$  significantly larger than charged at intermediate  $p_T$ :  
**enhanced hyperon production counteracting suppression**
- above 8 GeV/c,  $\Lambda$  and  $K^0_s - R_{AA}$  are similar to charged:  
**strong high- $p_T$  suppression also of  $\Lambda$**
- $\Lambda$  enhancement reaches out to higher  $p_T$  than at RHIC
- magnitude of  $R_{CP}$  compatible

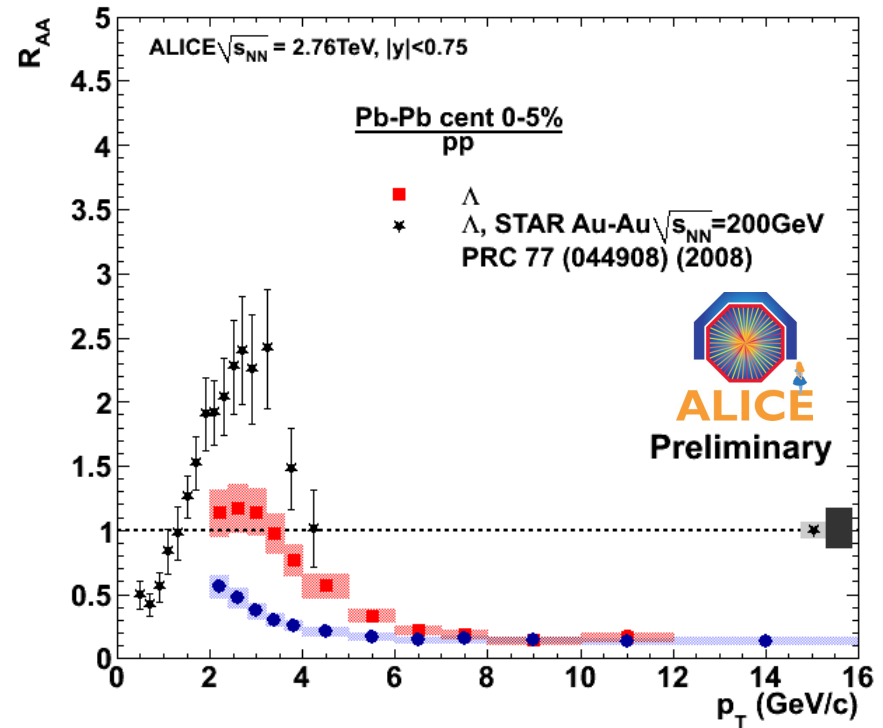
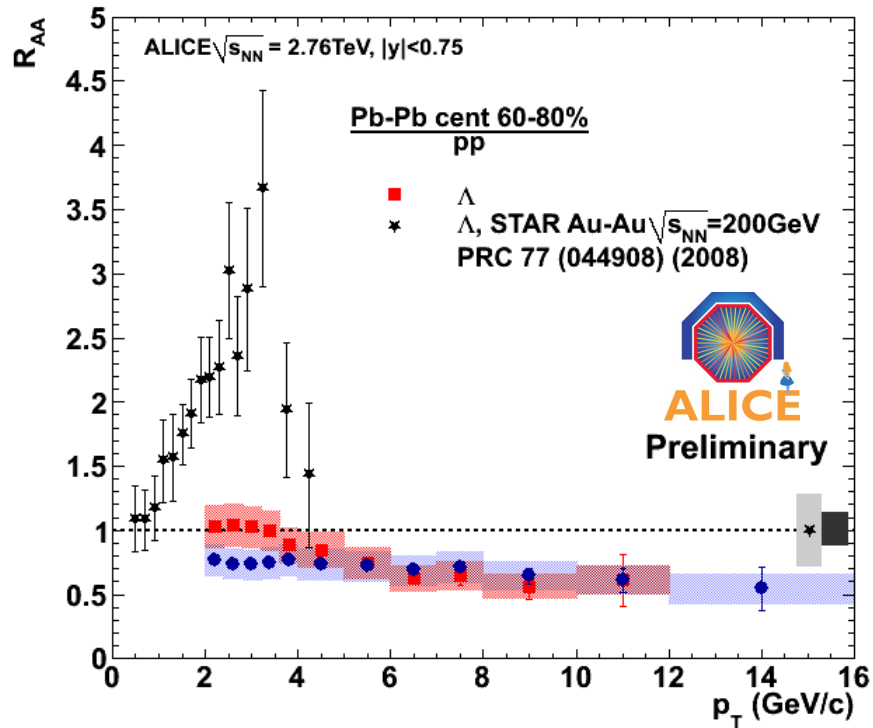
# $\Lambda$ and $K_s^0 - R_{AA}$



- high- $p_T$ : suppression of  $\Lambda$  and  $K_s^0$  similar to charged particles
  - intermediate  $p_T$ : moderate enhancement in peripheral collisions
- central  $R_{AA}$  similar to  $R_{CP}$



# $\Lambda$ and $K^0_S - R_{AA}$ : comparison to RHIC



- strong nuclear enhancement of  $\Lambda$  observed at RHIC not seen at the LHC

- charged particle  $p_T$  spectra in Pb-Pb at  $\sqrt{s_{NN}} = 2.76$  TeV measured with ALICE at the LHC
- new reference  $p_T$  spectrum derived from pp collisions at  $\sqrt{s} = 2.76$  TeV
- strong suppression charged particle production observed at  $p_T < 50$  GeV/c
- comparison to RHIC data suggests that suppression scales with the charged particle density
- at  $p_T > 50$  GeV/c, no strong centrality dependence of charged particle production is observed
- results on identified particles will allow to disentangle the interplay between quark and gluon energy loss, and recombination mechanisms at intermediate  $p_T$



# comparison ALICE-CMS

