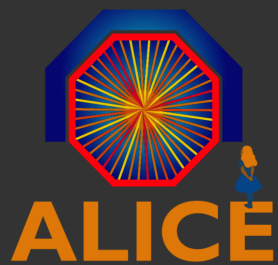


# *Charged Particle Production at Large Transverse Momentum in Pb-Pb Collisions at $\sqrt{s}=2.76$ TeV Measured with ALICE at the LHC*

Jacek Otwinowski  
(for the ALICE Collaboration)

QM 2011



Pb+Pb @  $\sqrt{s} = 2.76$  ATeV

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# Motivation

- Heavy Ion Physics  $\leftrightarrow$  Study of nuclear matter at extreme conditions
- RHIC : “The production of charged hadrons at high  $p_T$  is suppressed in central Au-Au collision compared to the superposition of nucleon-nucleon collisions”
- Dominant production mechanism for high  $p_T$  charged hadrons
  - Fragmentation of high  $p_T$  partons from hard scatterings at an early stage of nuclear collisions
- Suppression is considered to be an energy loss of partons, traversing a hot, dense QCD medium  $\rightarrow$  the Quark-Gluon-Plasma (QGP)
- Understanding the suppression goes towards understanding the medium properties of the QGP

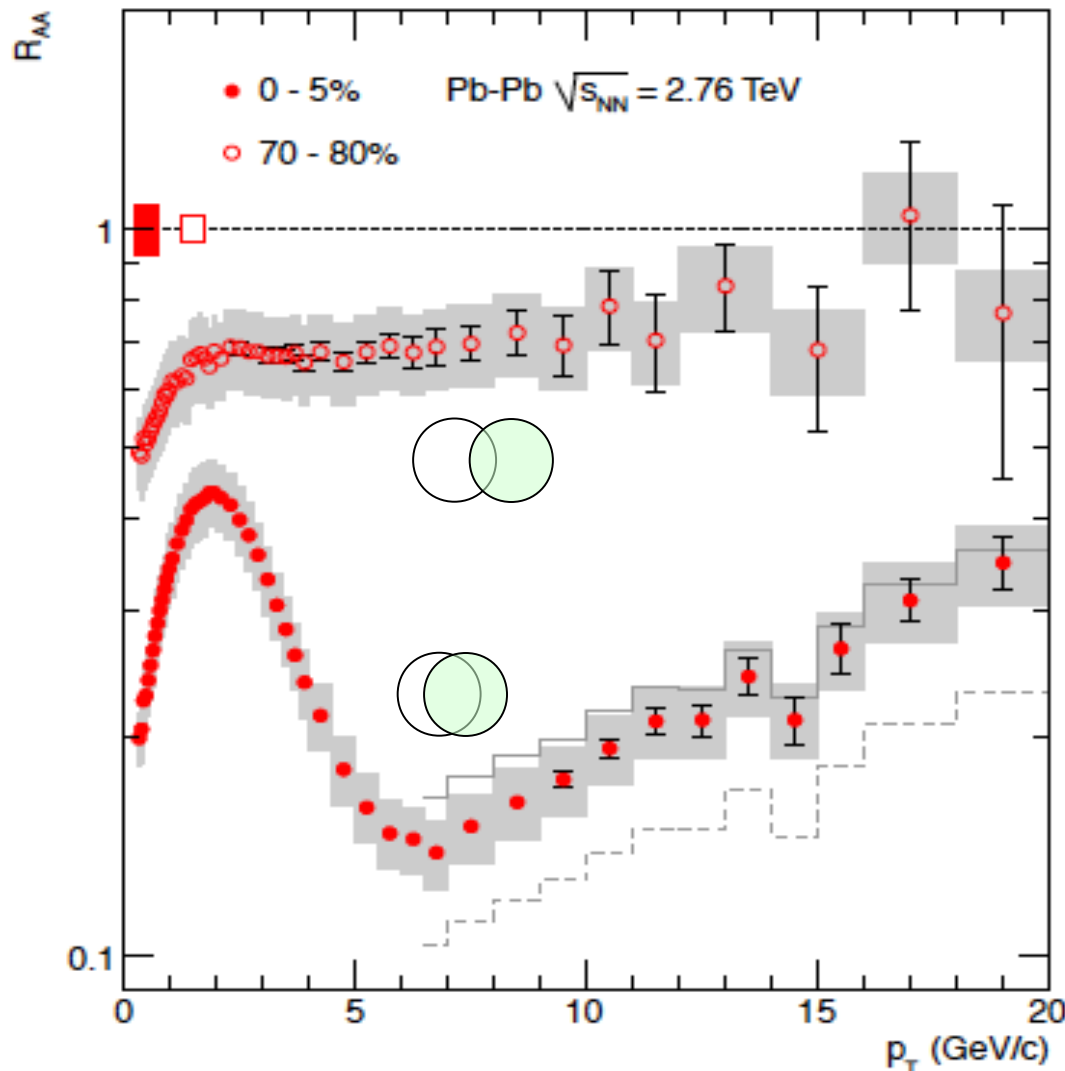
$\rightarrow$  *What happens at LHC energies ?*

# Nuclear Modification Factor - $R_{AA}$

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At LHC first published by ALICE  
Phys. Lett. B696 (2011) 30-39

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA}) d^2 N_{ch}^{AA} / d\eta dp_T}{\langle N_{coll} \rangle (1/N_{evt}^{pp}) d^2 N_{ch}^{pp} / d\eta dp_T}$$



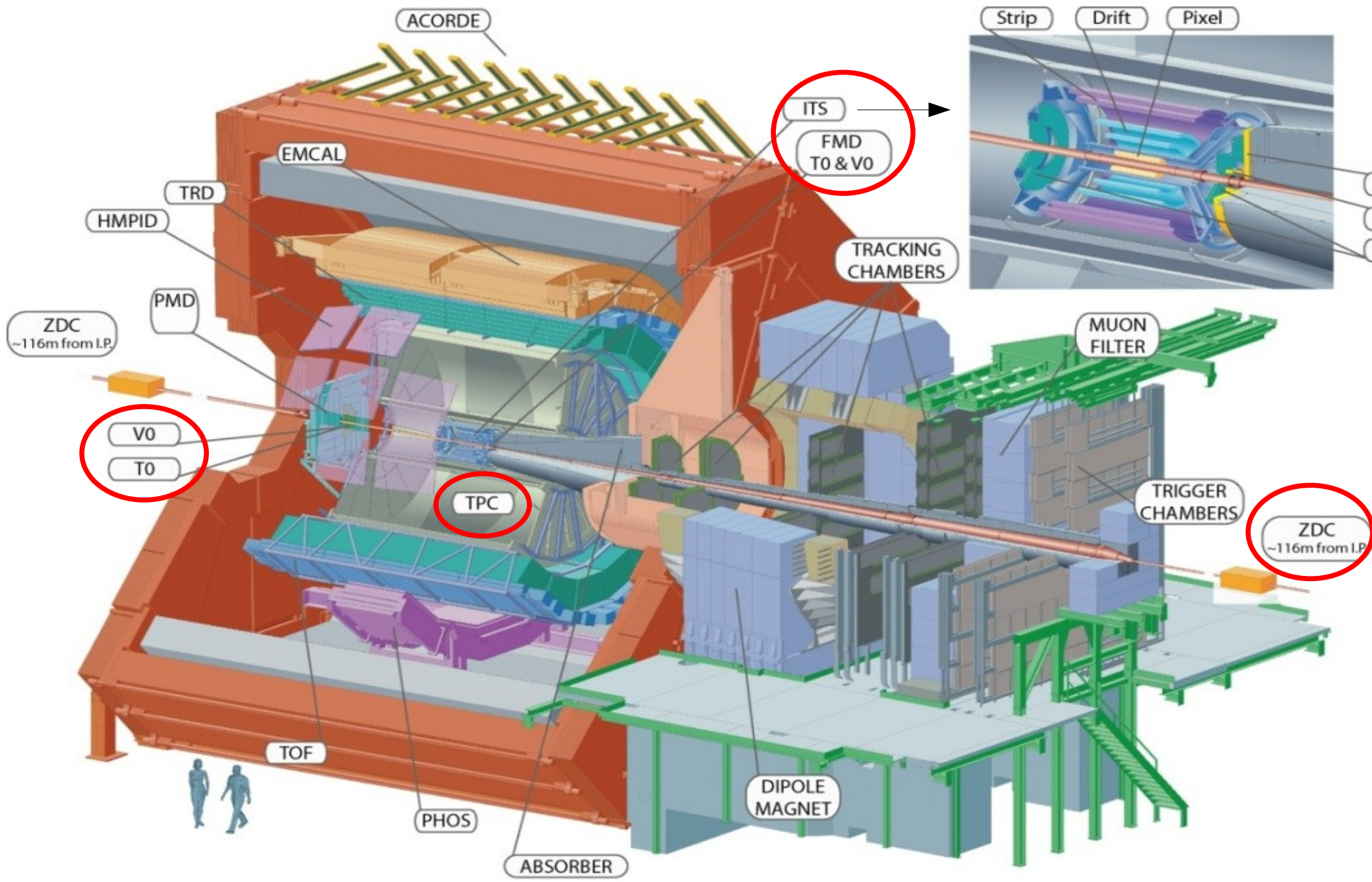
- $R_{AA}$  - ratio of charged particle yield in A-A collisions to the yield in pp collisions scaled by the number of binary collisions ( $N_{coll}$ )
  - $N_{coll}$  from Glauber MC
- Quantifies nuclear medium effects
- Does the a A-A collision behave like  $N_{coll}$  pp collisions?

**In this talk:**

**$R_{AA}$  evolution vs centrality and  $p_T$  in extended  $p_T$  range and using new pp reference will be presented.**



# ALICE - A Large Ion Collider Experiment



# Pb-Pb measurements in 2010

## Min. Bias Trigger (98% efficiency)

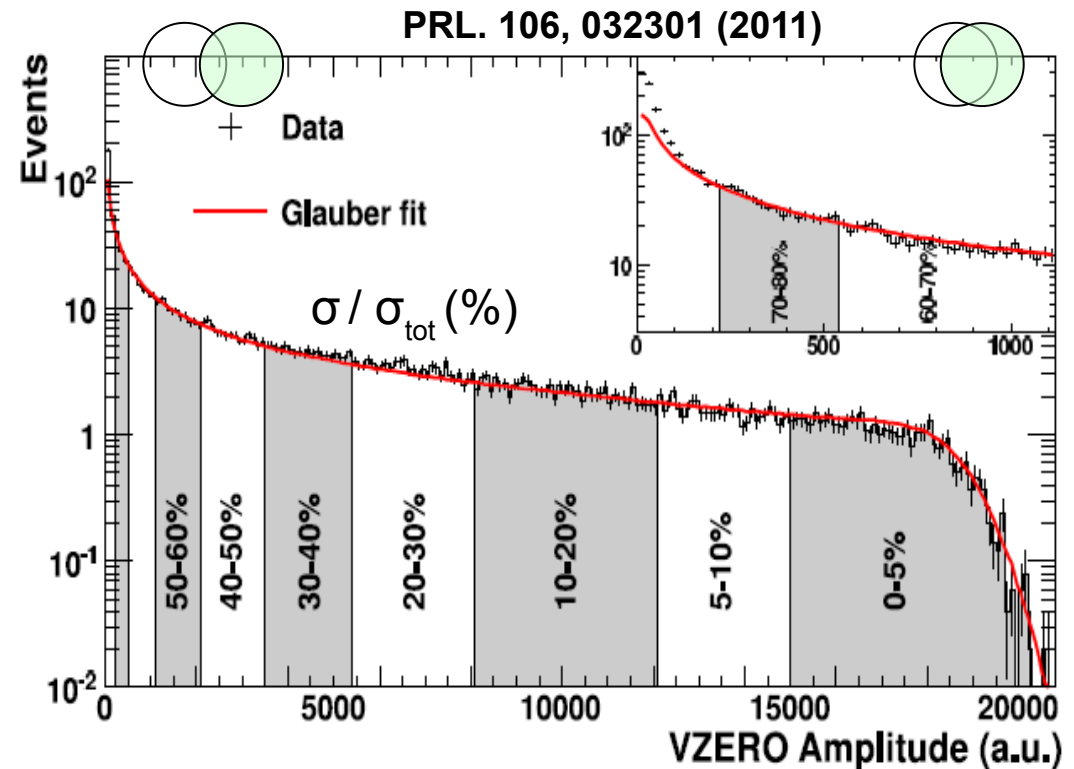
- V0 forward hodoscopes:  $2.8 < |\eta| < 5.1$  and  $-3.7 < |\eta| < -1.7$
- Silicon Pixel Detector (SPD):  $|\eta| < 2.0$
- Zero Degree Calorimeter (ZDC):  $\pm 116$  m from interaction point
- 20M Pb-Pb events selected for  $R_{AA}$

## Tracking detectors $|\eta| < 0.8$ :

- Inner Tracking System (ITS):  
(6 silicon layers,  $\sigma_x \sim 100 \mu\text{m}$ )
- Time Projection Chamber (TPC):  
( $R = 2.5$  m x  $Z = 5$  m barrel,  
transverse momentum ( $p_T$ ) and  $dE/dx$   
measurements)

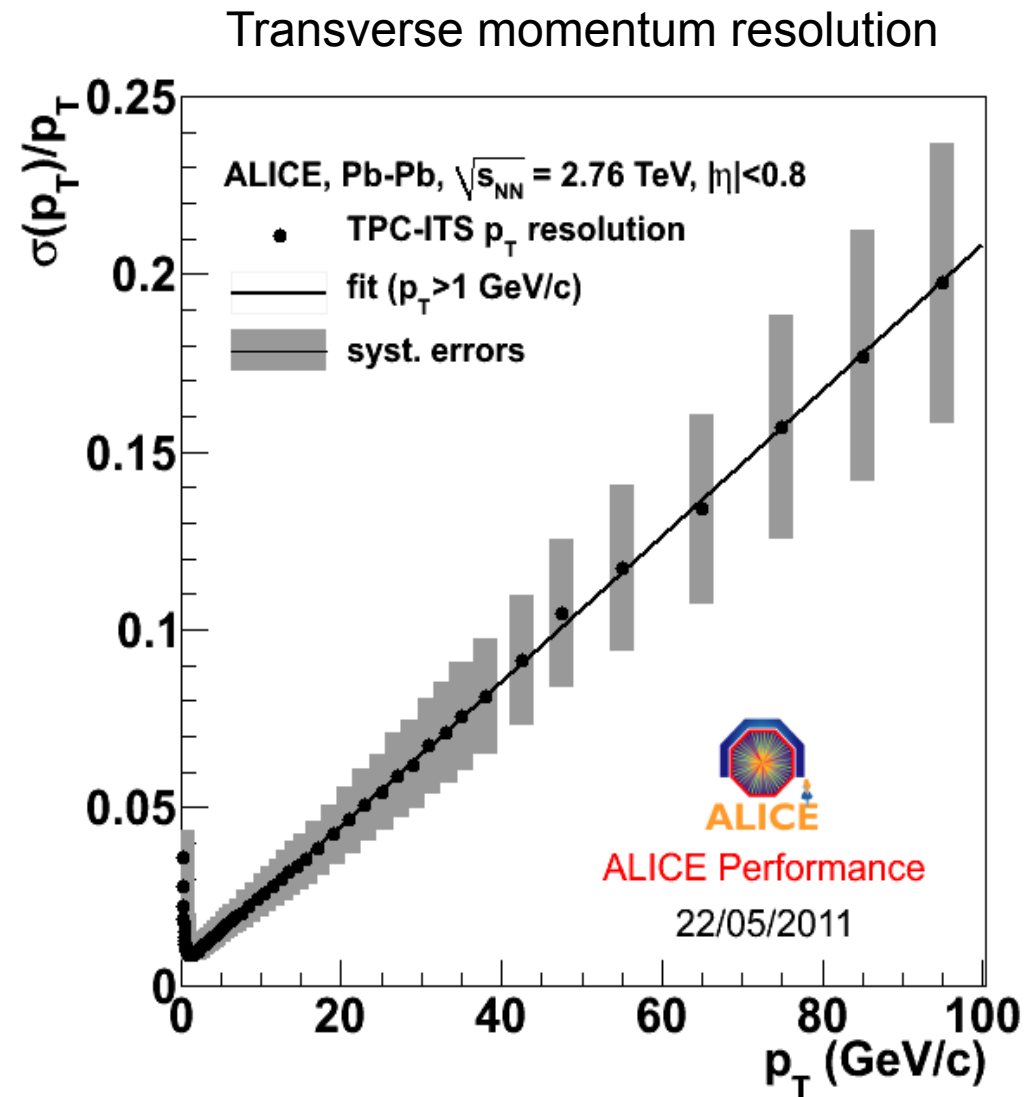
## Centrality Determination:

- Centrality measures (V0 ampl., tracks, hits, ZDC vs V0, V0 vs tracks)
- Relation between collision centrality and ( $\langle N_{part} \rangle$ ,  $\langle N_{coll} \rangle$ ...) from Glauber model



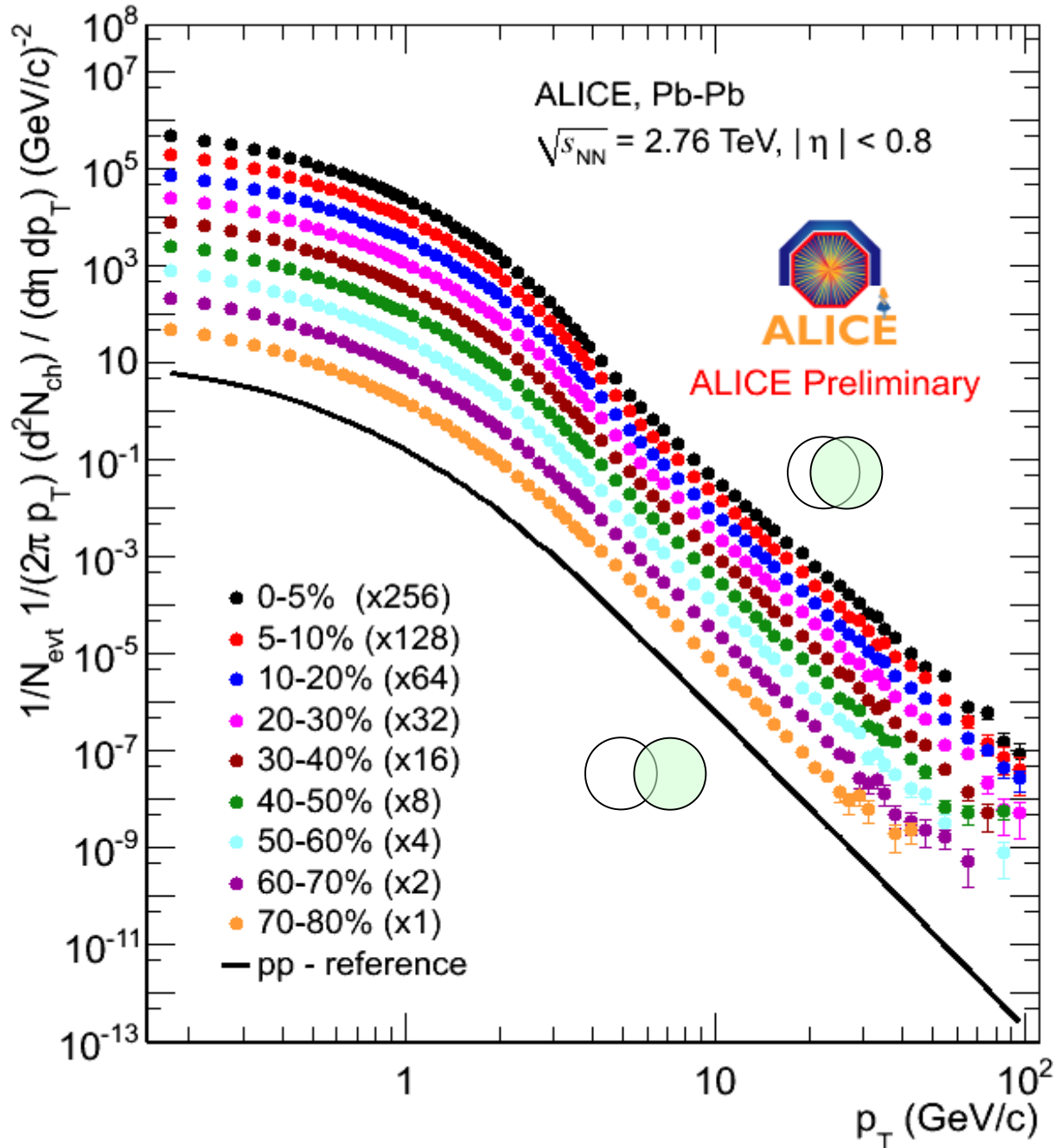
# $p_T$ reconstruction in Pb-Pb

- $p_T$  analysis for Pb-Pb uses ITS+TPC selected tracks:
  - Small contamination of secondary particles :  $< 2\%$  at  $p_T > 1$  GeV/c (estimated using data driven DCA studies)
  - Good transverse momentum resolution determined from track residuals (verified with  $K_s^0$  and cosmic ray measurements)
    - Better  $p_T$  resolution expected soon (factor 2 compared to current setup)
- Track acceptance  $|\eta| < 0.8$



# $p_T$ spectra in Pb-Pb collisions

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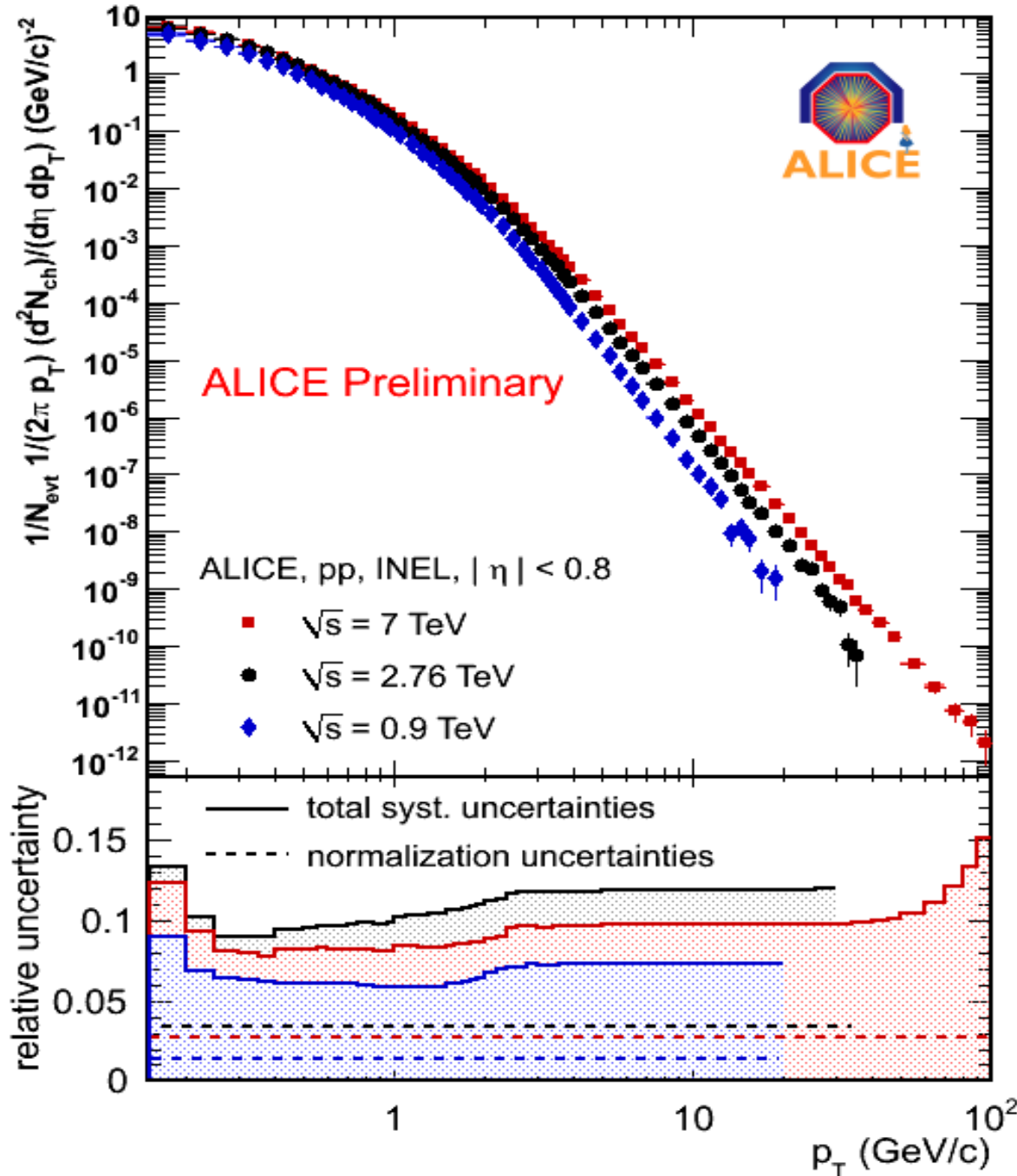


- Fully corrected  $p_T$  spectra
- $p_T$  reach 100 GeV/c
- Shape of  $p_T$  distribution changes with collision centrality
- Systematic errors evaluated in  $p_T$  bins for each centrality class
- pp reference shown as solid line



# $p_T$ spectra in pp collisions

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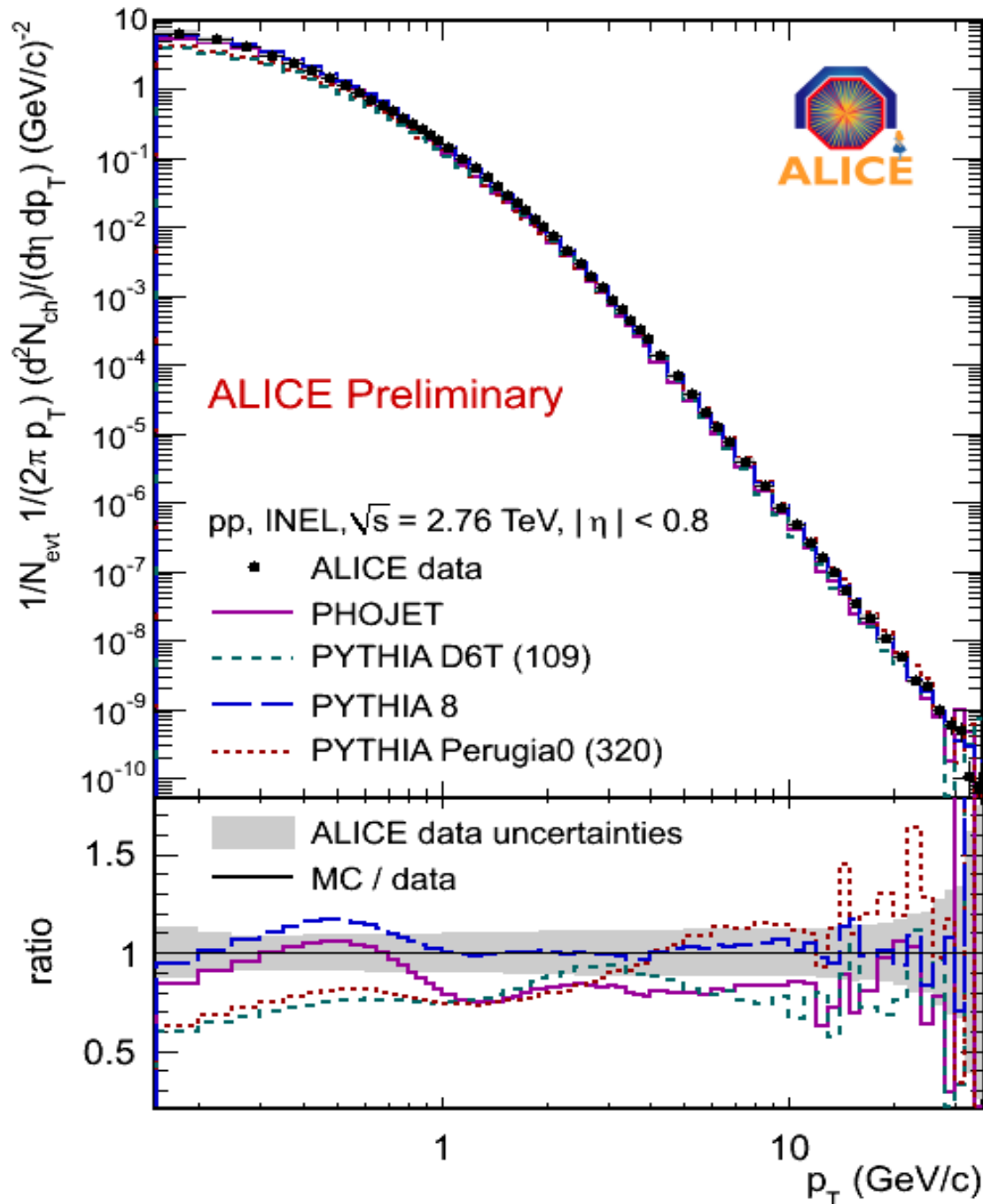


- Fully corrected  $p_T$  spectra measured in pp collisions at 0.9 / 2.76 / 7 TeV
- $p_T$  reach 100 GeV/c in pp 7 TeV data
- pp reference for  $R_{AA}$  constructed using pp 2.76 TeV data
- 0.9 and 7 TeV data used to cross check pp reference (alternative references)

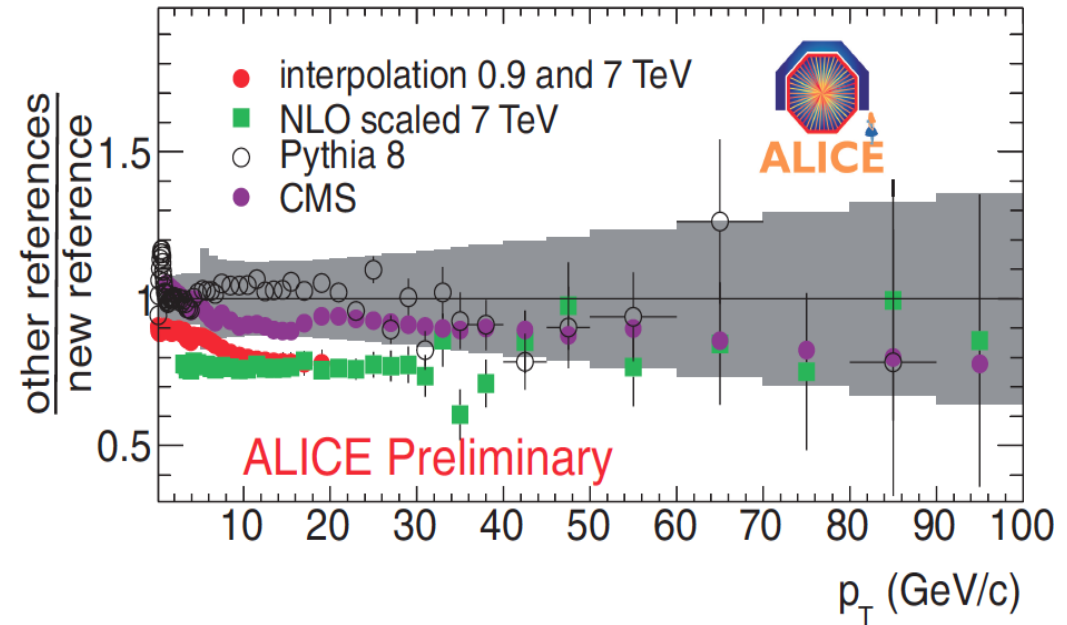
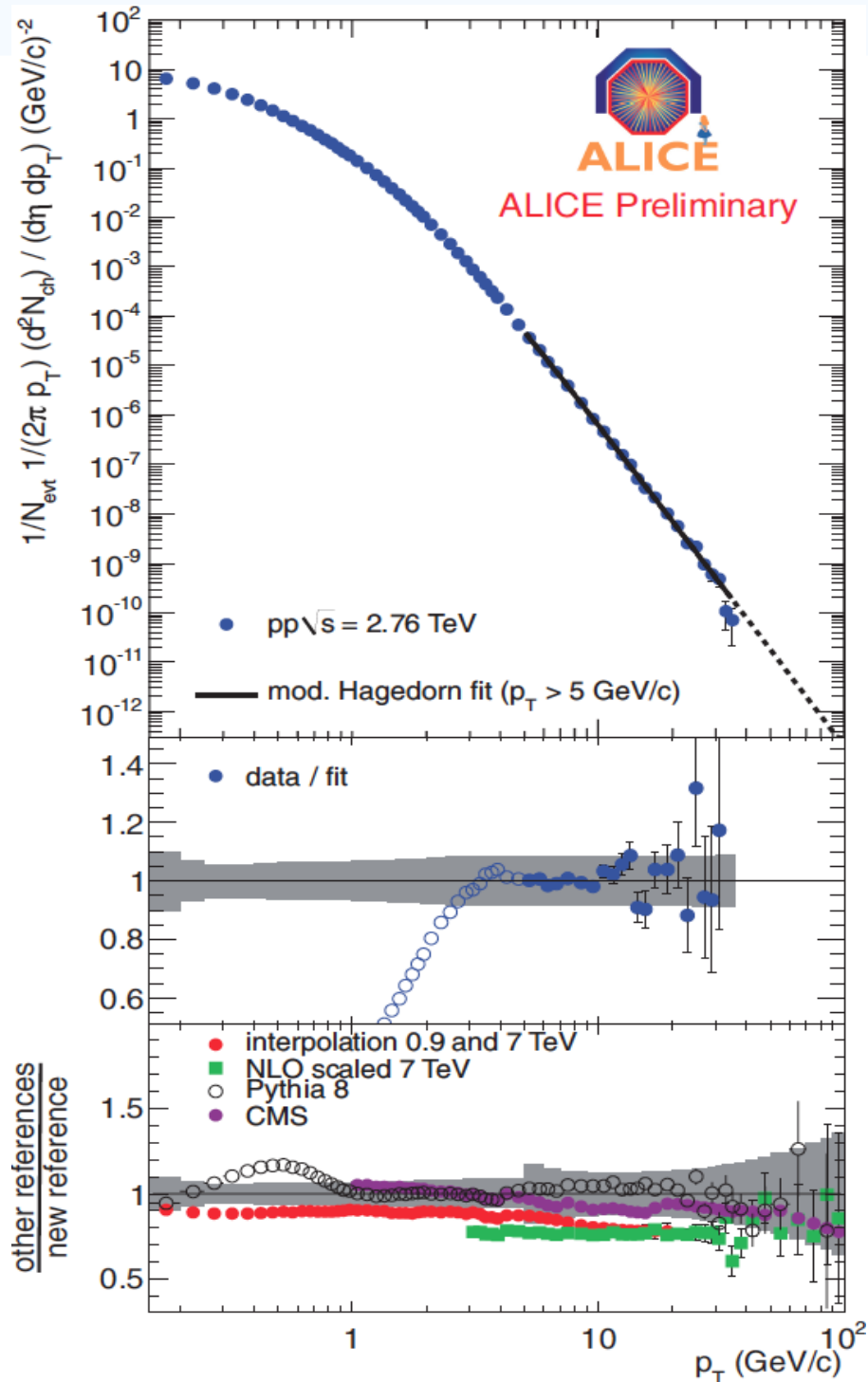


# $p_T$ spectrum in pp at 2.76 TeV

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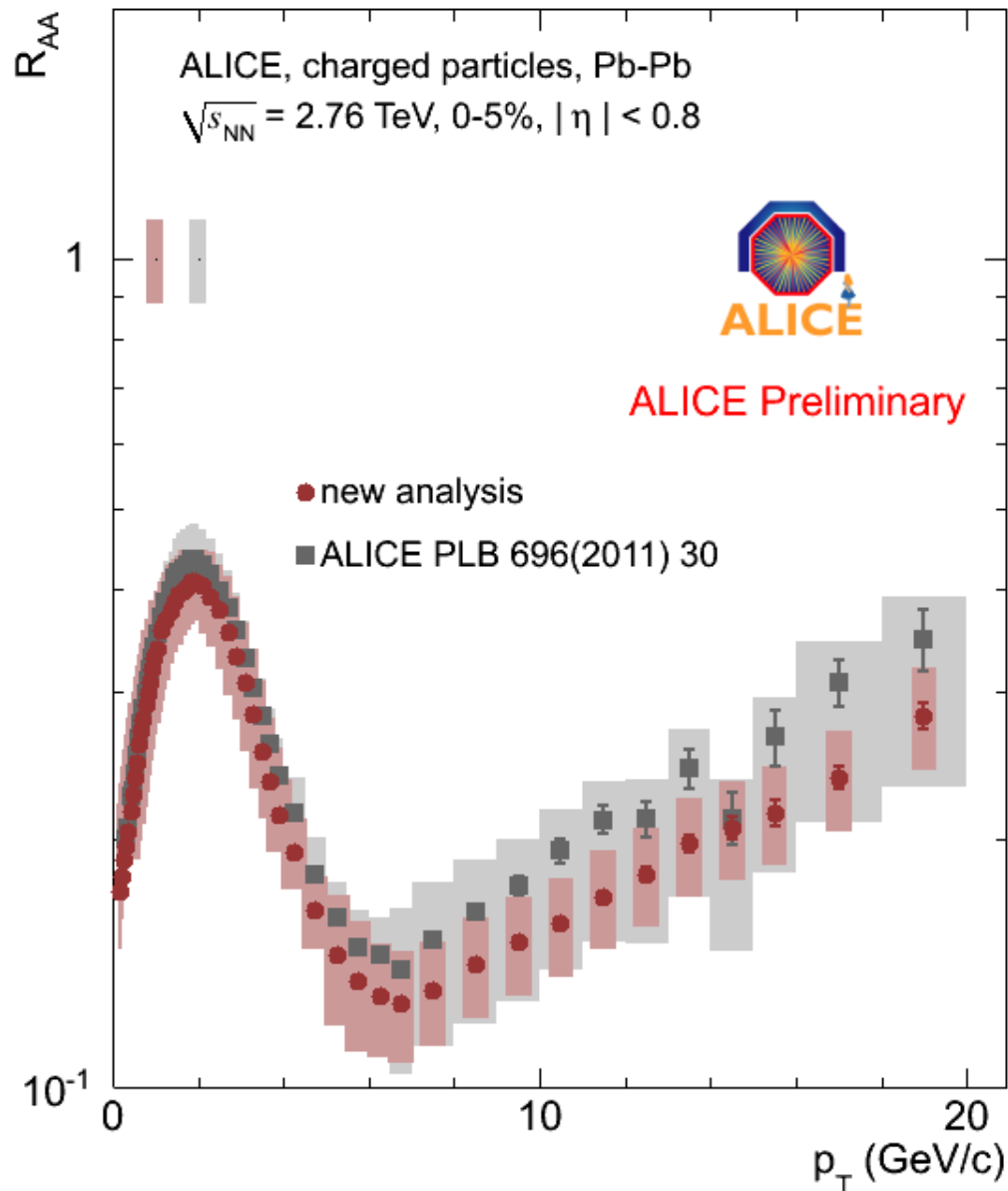


- Fully corrected  $p_T$  spectra measured in pp collisions at 2.76 TeV
  - $p_T$  shape above 1 GeV/c properly described by MC
  - $p_T$  reach 35 GeV/c
- Extrapolation required to build pp reference up to  $p_T = 100$  GeV/c

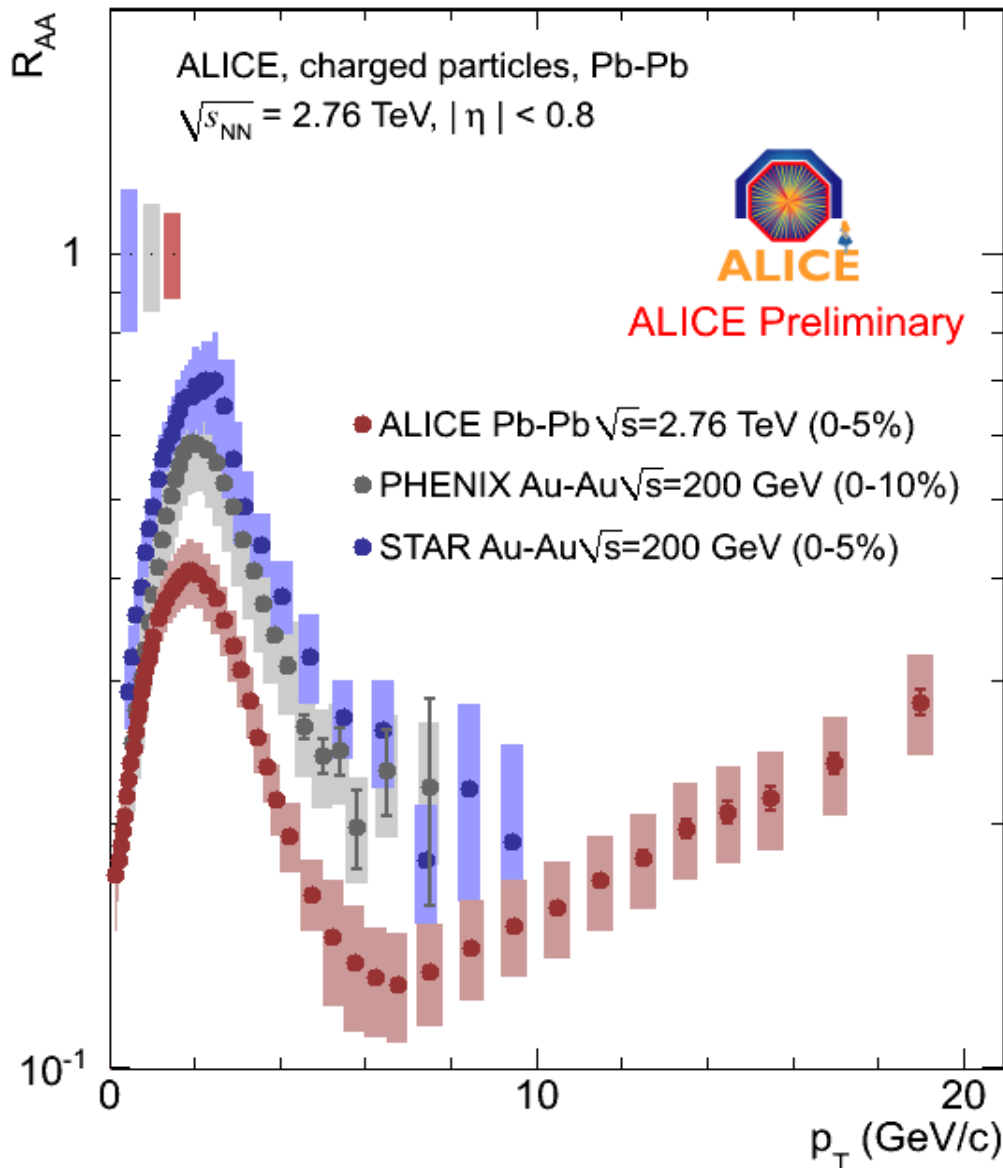


- pp reference
  - 0.15 - 5 GeV/c - measured  $p_T$  spectrum
  - 5 - 30 GeV/c – parametrization using “modified Hagedorn” fit
  - $p_T > 30 \text{ GeV}/c$  – extrapolation using fit function
- Good agreement in comparison to other references and Pythia 8

# New ALICE measurement for $R_{AA}$



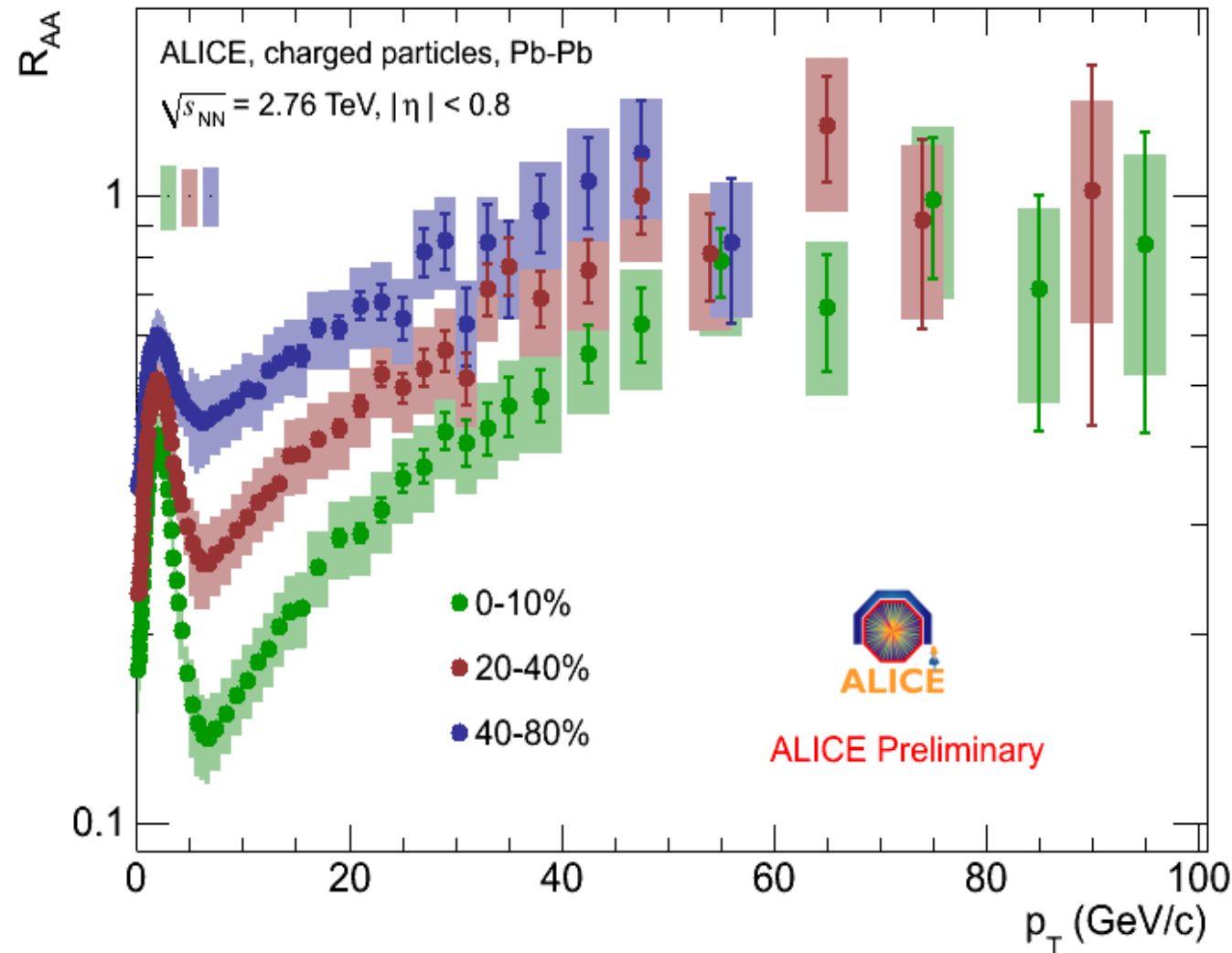
- New  $R_{AA}$  analysis using new pp reference is in agreement with published results
  - Smaller systematic errors
- Smaller increase of  $R_{AA}$  with  $p_T$  visible due to harder pp reference  $p_T$  spectrum



## Charged particles ALICE vs RHIC:

- Stronger suppression observed as compared to RHIC
- Different centrality classes shown for RHIC

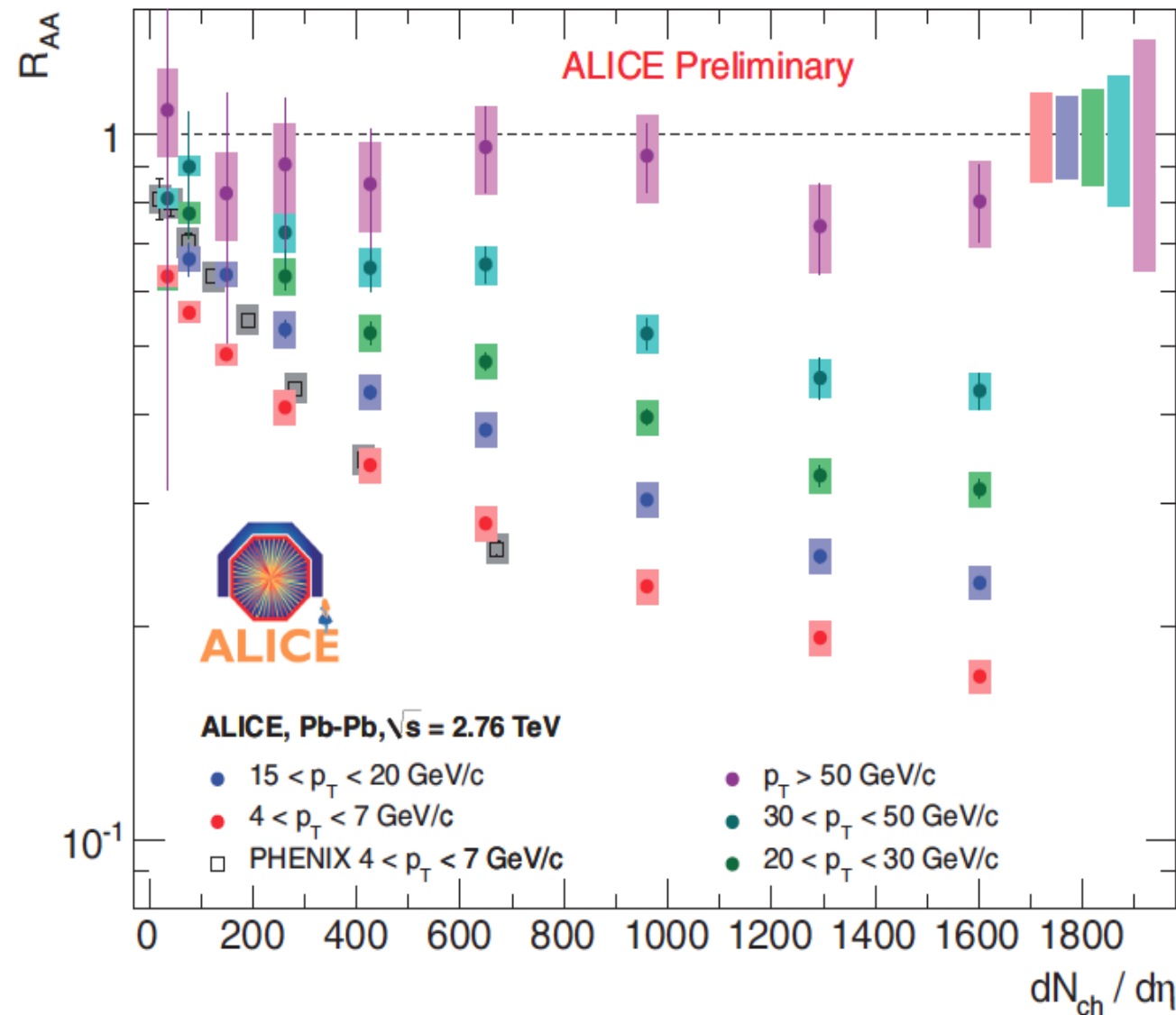




## Charged particles:

- $R_{AA}$  shown in  $p_T$  range (0.15 – 100 GeV/c)
- Different suppression pattern depending on collision centrality
- $R_{AA}$  has minimum at  $p_T = 6-7$  GeV/c in all centralities
- Hint of leveling off above 50 GeV/c

# $R_{AA}$ vs particle multiplicity in $p_T$ bins

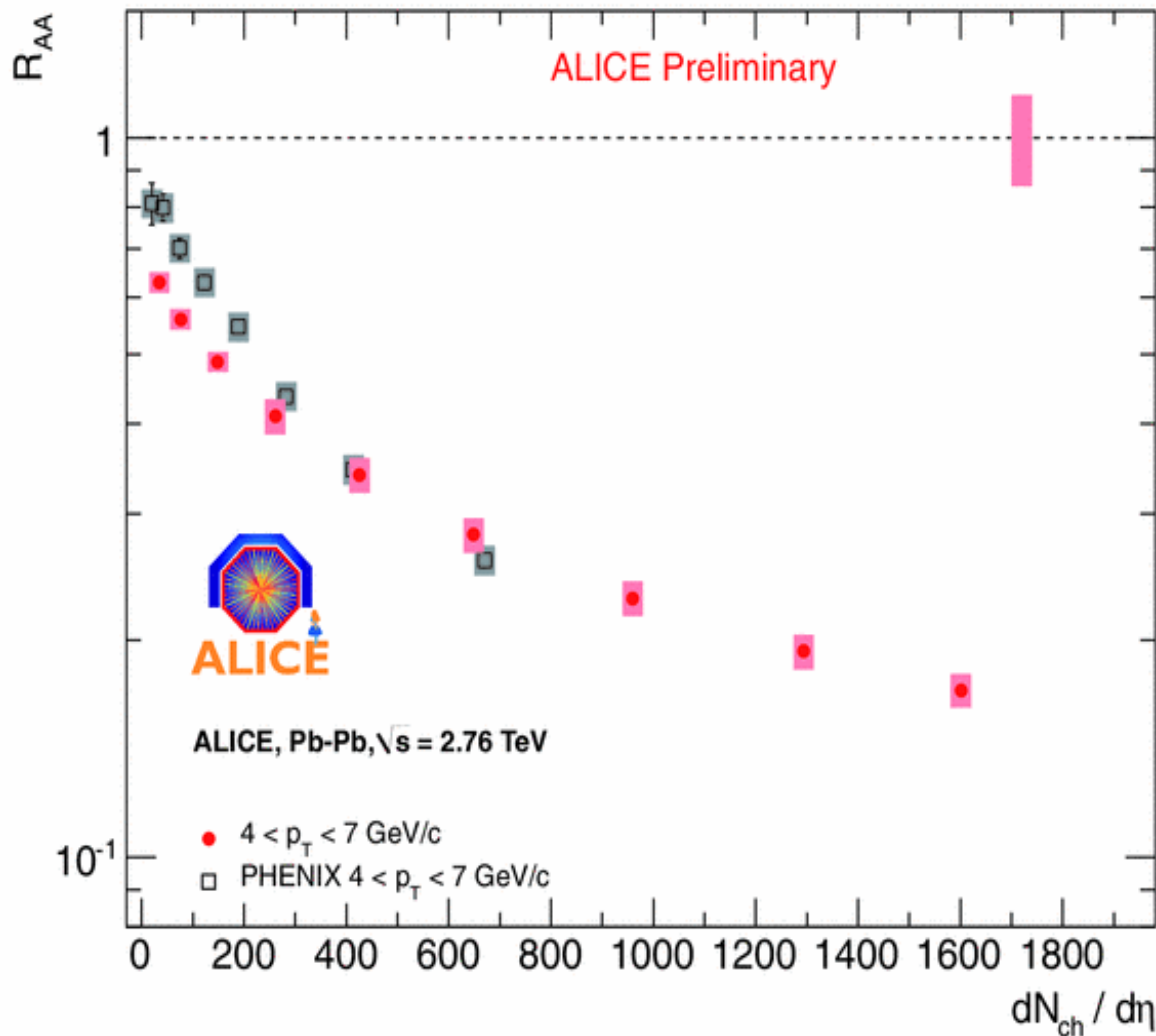


Evolution of  $R_{AA}$  with particle multiplicity ( $dN_{ch}/d\eta$ ) shows different suppression pattern depending on  $p_T$

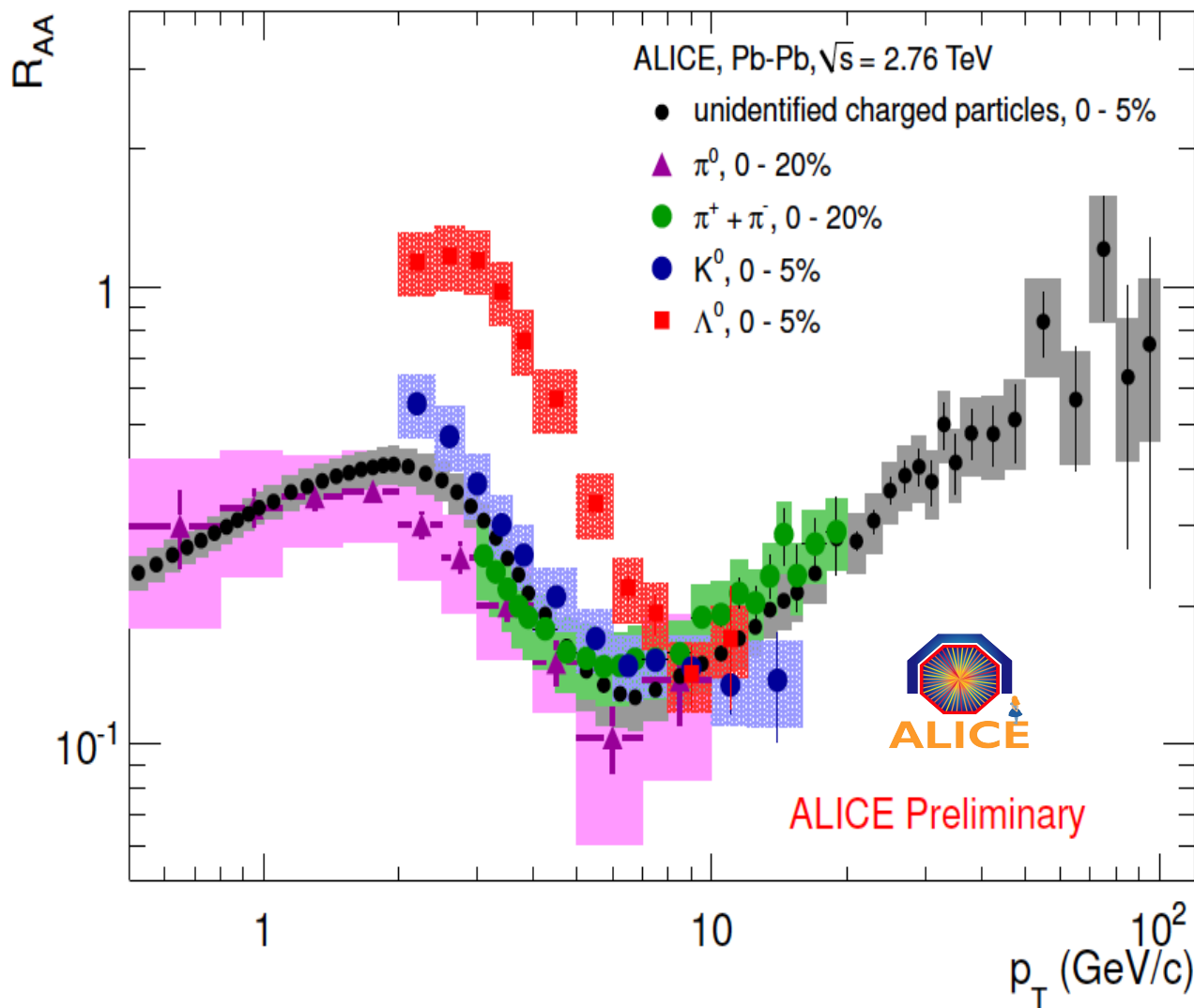
- High- $p_T$  particle suppression independent of  $dN_{ch}/d\eta$
- Small- $p_T$  particle suppression strongly depends on  $dN_{ch}/d\eta$

# $R_{AA}$ vs particle multiplicity – ALICE vs PHENIX

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- Agreement with PHENIX measurements for  $dN/d\eta > 200$  ( $p_T = 4-7$  GeV/c)



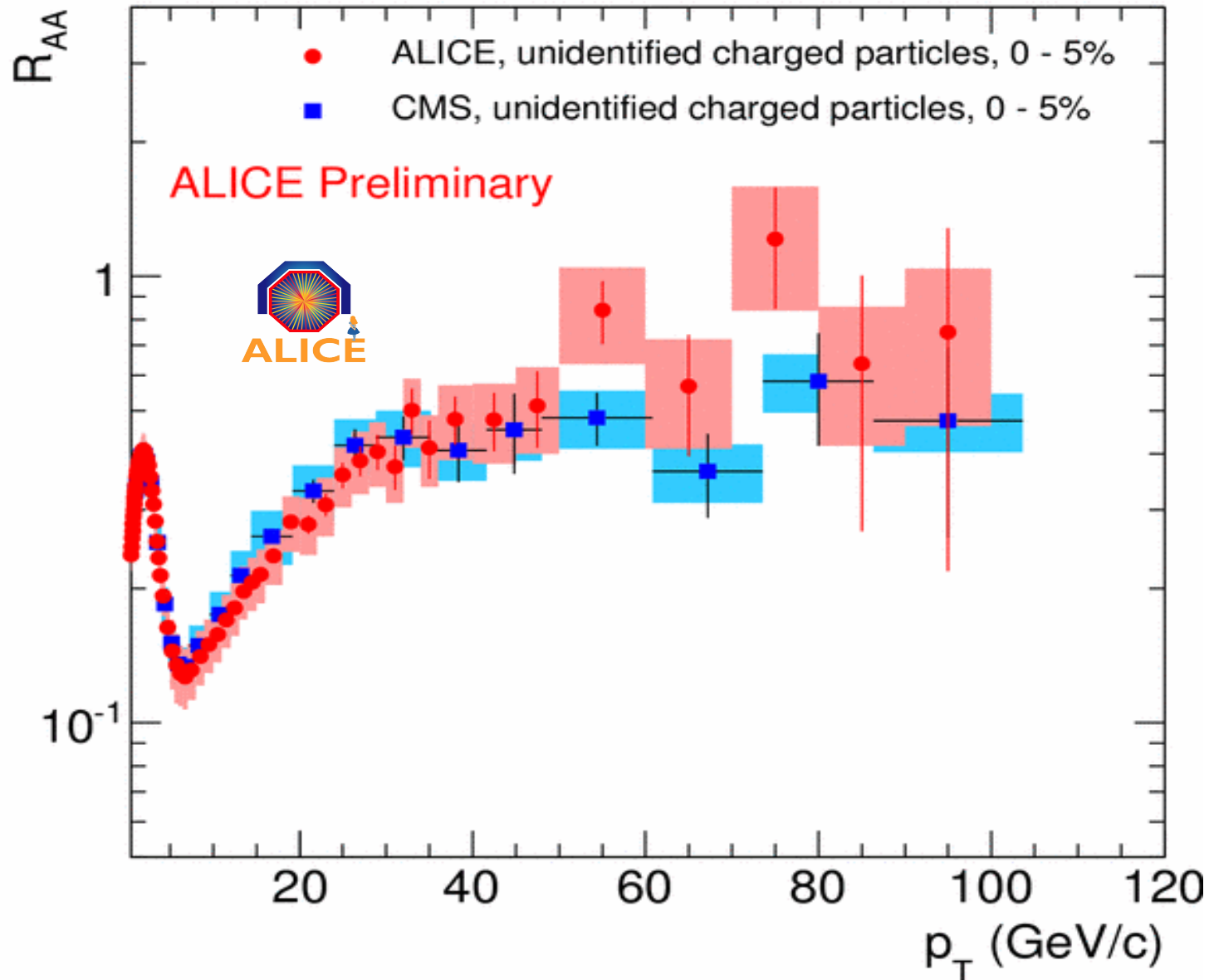
## All charged vs identified particles

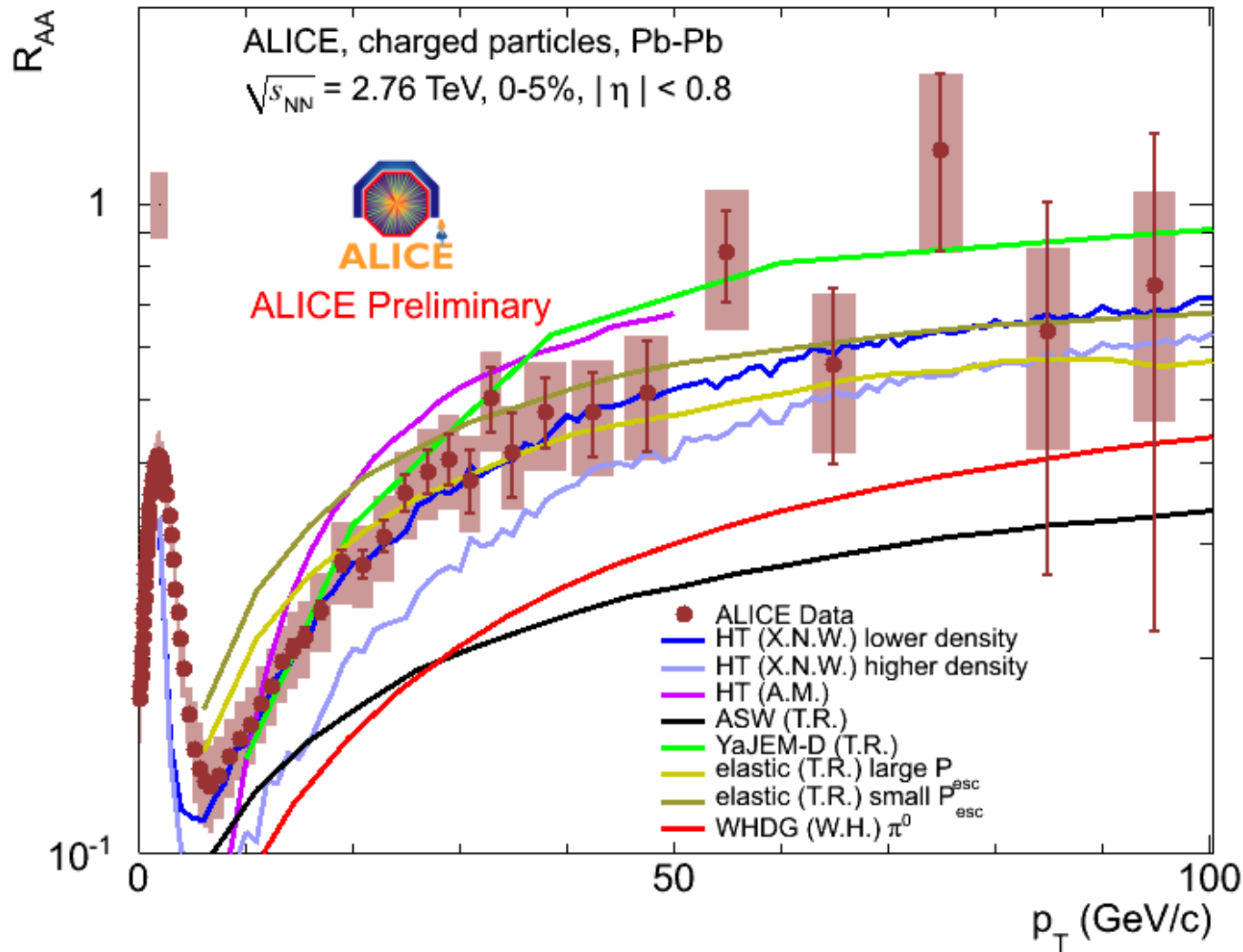
- Similar suppression pattern as compared to  $\pi$
- $K^0_s$  and  $\Lambda^0$  show different suppression pattern
- $\pi$ ,  $K^0_s$  and  $\Lambda^0$  approach the same  $R_{AA}$  value at 7-8 GeV/c



# $R_{AA}$ comparison – ALICE vs CMS

Good agreement with CMS





- Reasonable good agreement of parton energy loss models with ALICE data
- Models tuned on RHIC data
  - more comparison is coming

- ALICE measured  $R_{AA}$  in very large  $p_T$  range (0.15-100 GeV/c)
- Strong suppression at high- $p_T$  in central collisions
- Hint of leveling off at very large transverse momentum in most central collisions
- High- $p_T$  particle suppression independent of  $dN_{ch}/d\eta$
- Small- $p_T$  particle suppression depends strongly on  $dN_{ch}/d\eta$
- All particle species approach the same  $R_{AA}$  value at 7-8 GeV/c
- Comparison to parton energy loss models started