ALICE summary of Light Flavor results at intermediate and high p_T

WWND, January 2015

Tuva Richert, Lund University,
on behalf of the ALICE collaboration

Outline

- The ALICE detector
- Charged particles without identification
- Identified light flavor particles at high p_T
- The intermediate p_T puzzle

...discussed in terms of

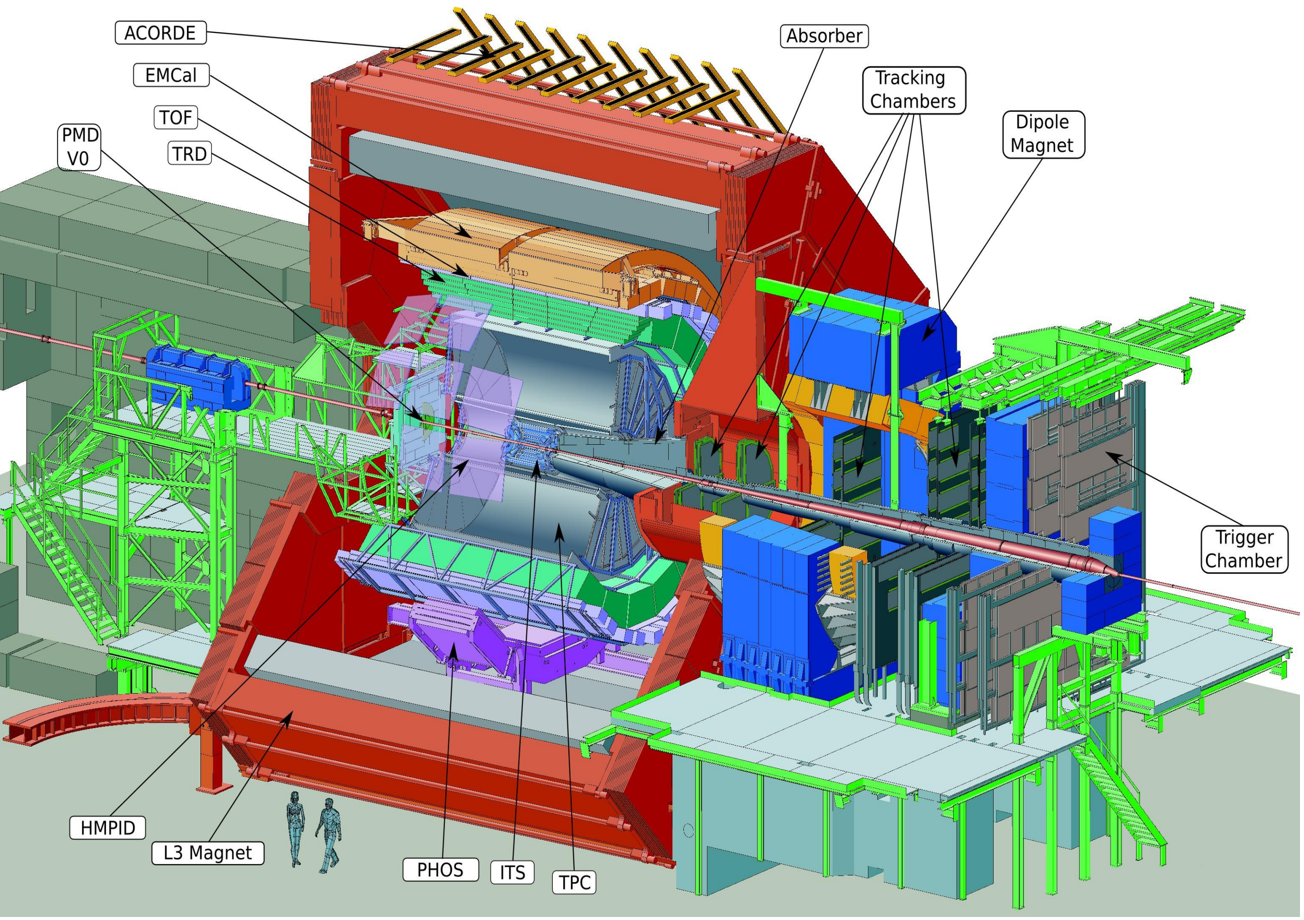
particle ratios

and

nuclear modification factors

The ALICE detector

Data taking during Run-1
pp at √s=0.9, 2.76, 7, and 8 TeV
p-Pb at √s=5.02 TeV
Pb-Pb at √s= 2.76 TeV



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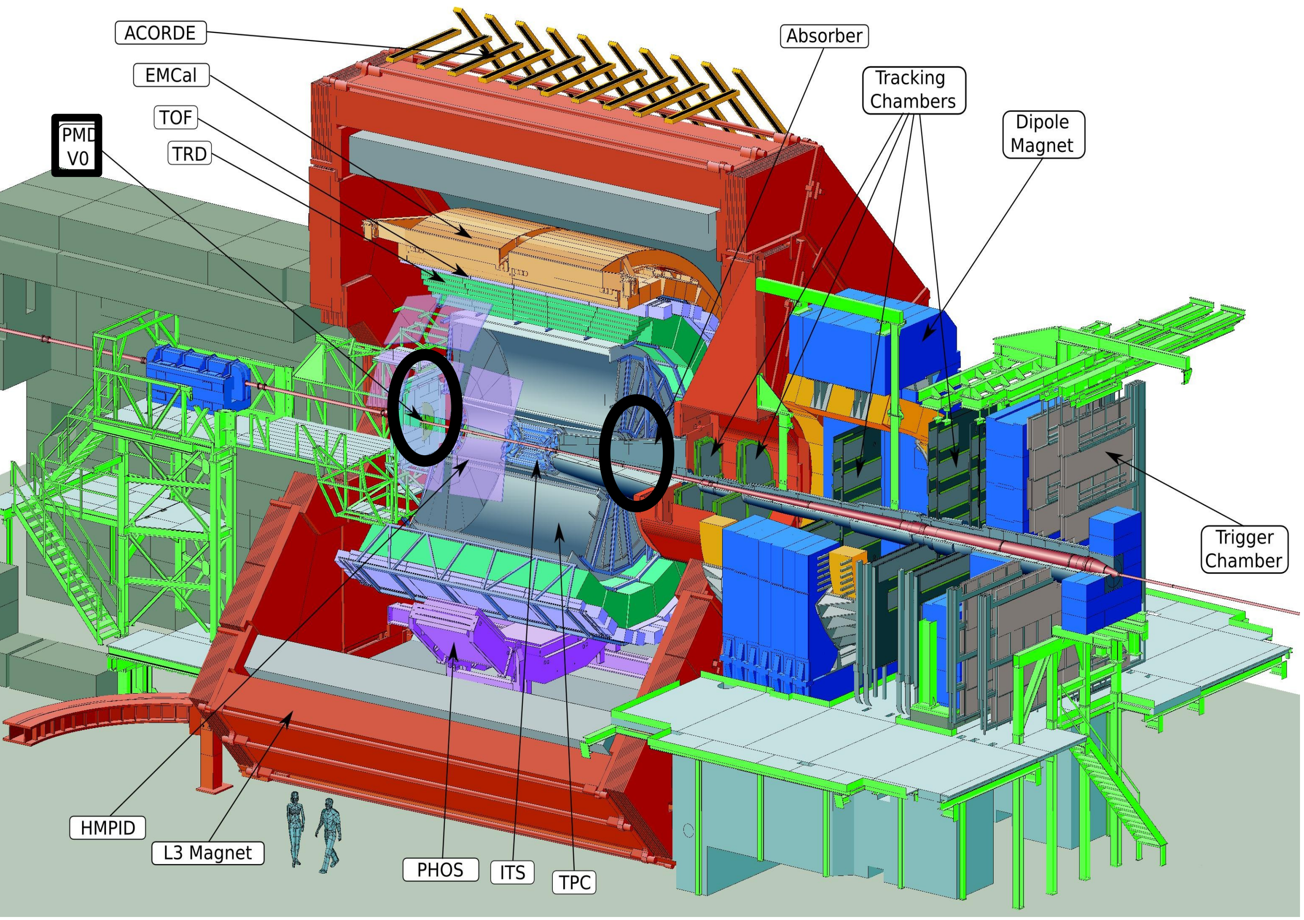
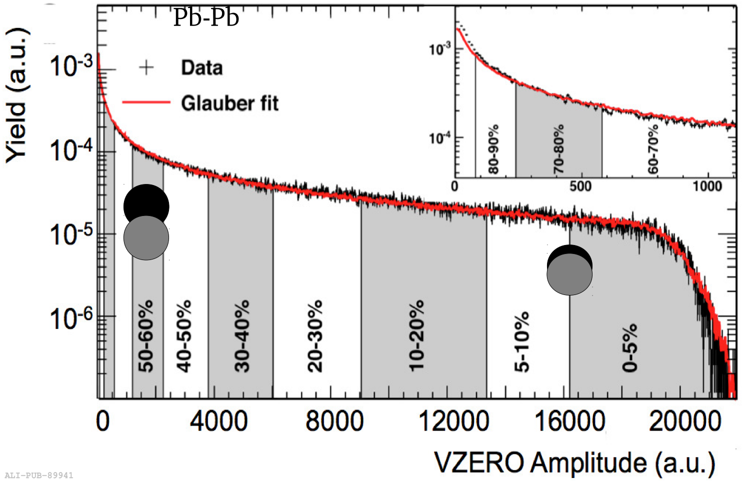


- **VZERO** for trigger and event-class determination



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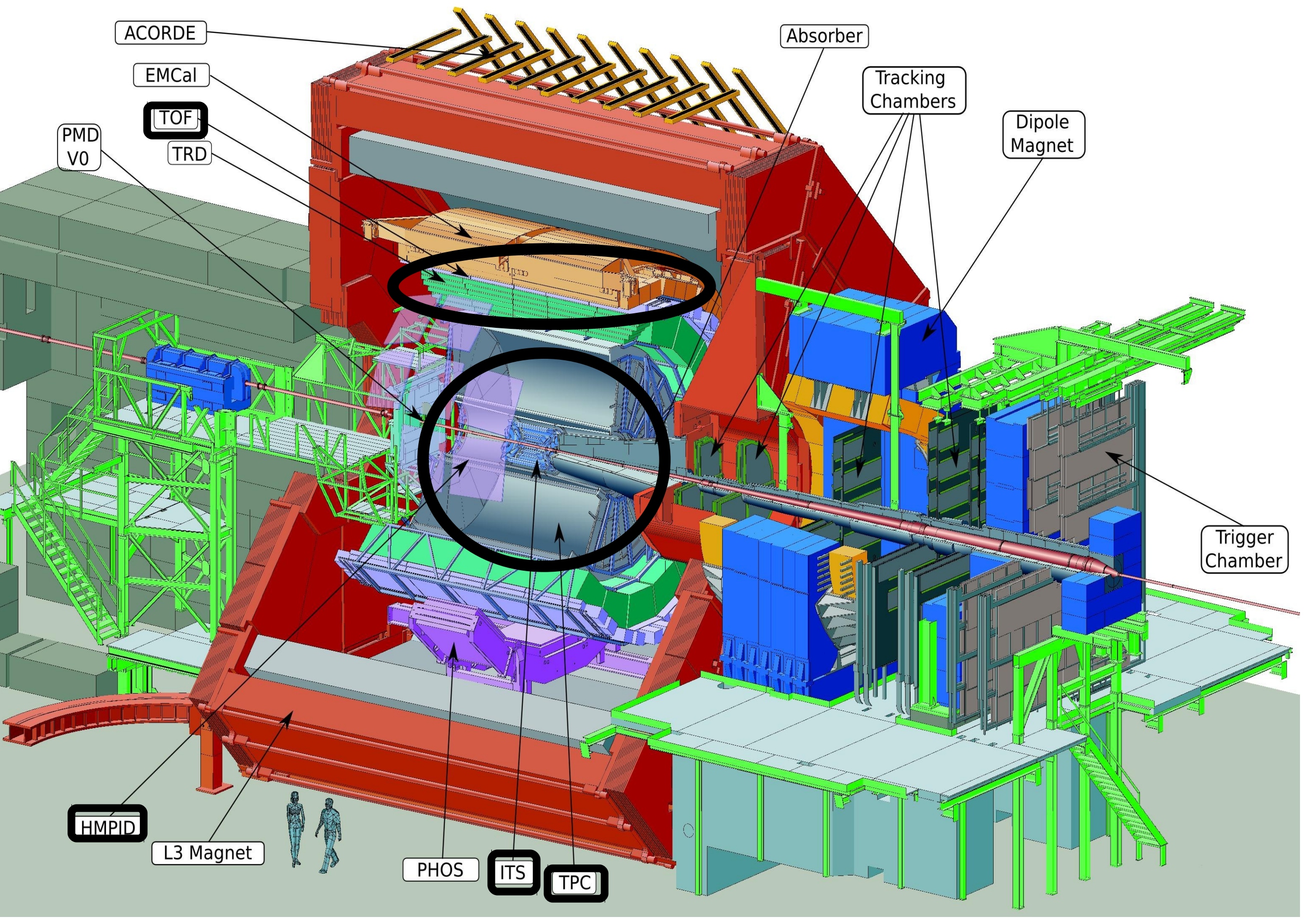

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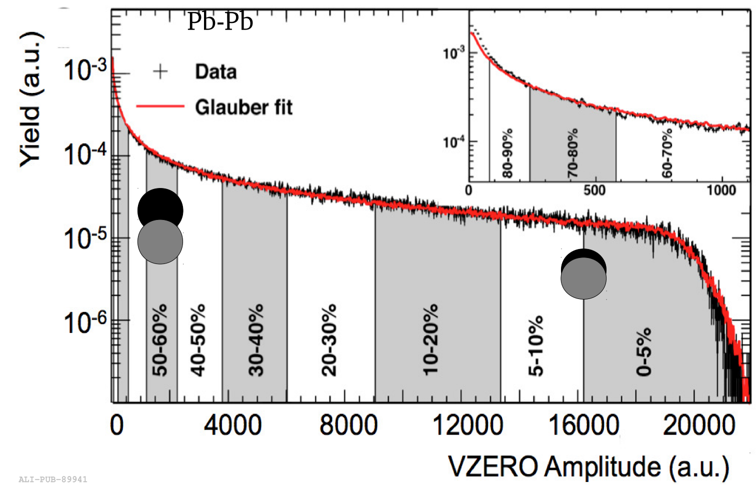
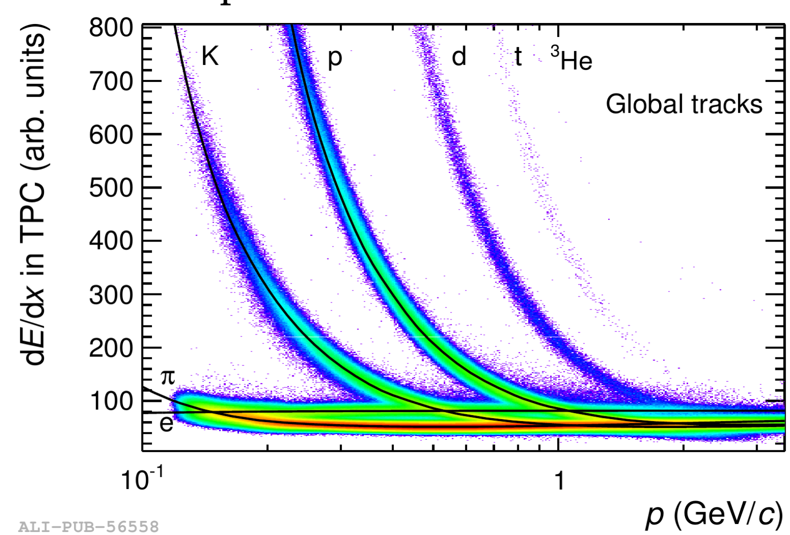
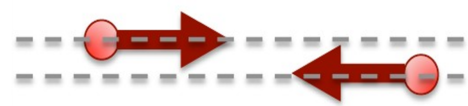


- **ITS+TPC+TOF+HMPID** for particle identification

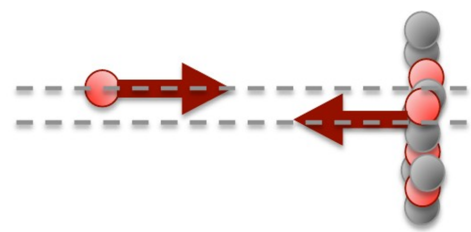


Particle production at intermediate and high p_T – what can ALICE do?

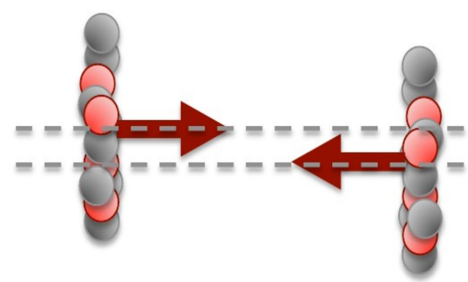
- **pp**
  - Test pQCD
  - Fragmentation functions
  - Tune MC generators
  - Reference for p-Pb and Pb-Pb

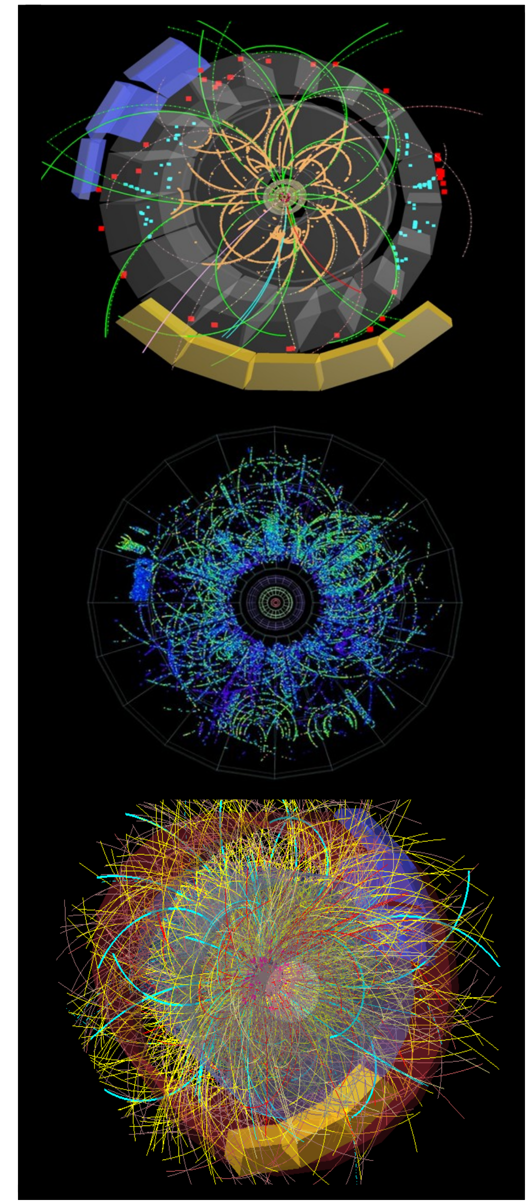


- **p-Pb**
  - Initial state nuclear matter effects
  - Reference for Pb-Pb
  - Collectivity effects?



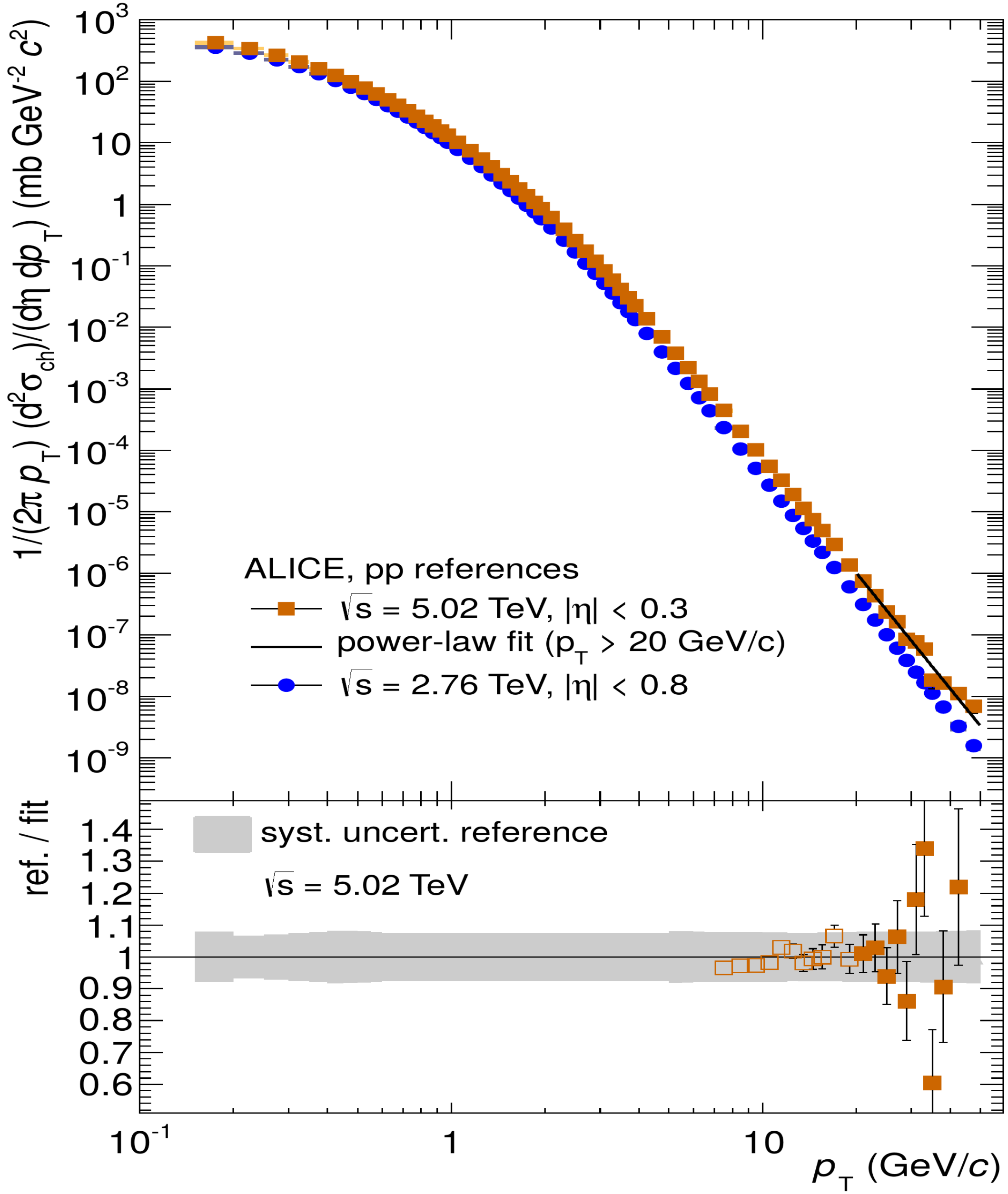
- **Pb-Pb**
  - Thermal particle production
  - Collective expansion
  - Parton energy loss
  - Modified fragmentation





pp reference – charged particles

- Measured reference at **$\sqrt{s}$ = 2.76 TeV**
- p_T>32 GeV/c: parametrization



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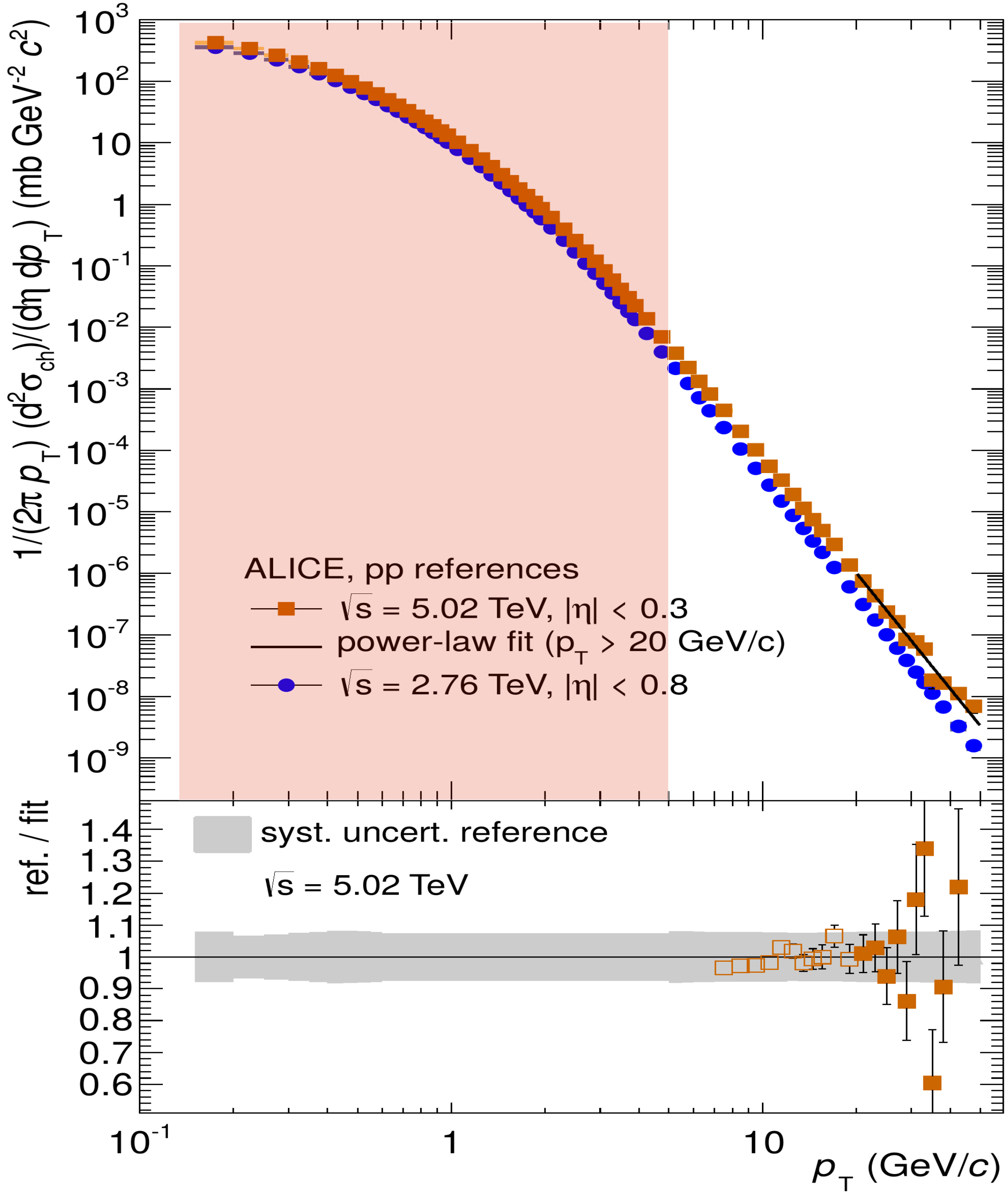
  a) low p_T: interpolation between 2.76 and 7 TeV, assuming power-law



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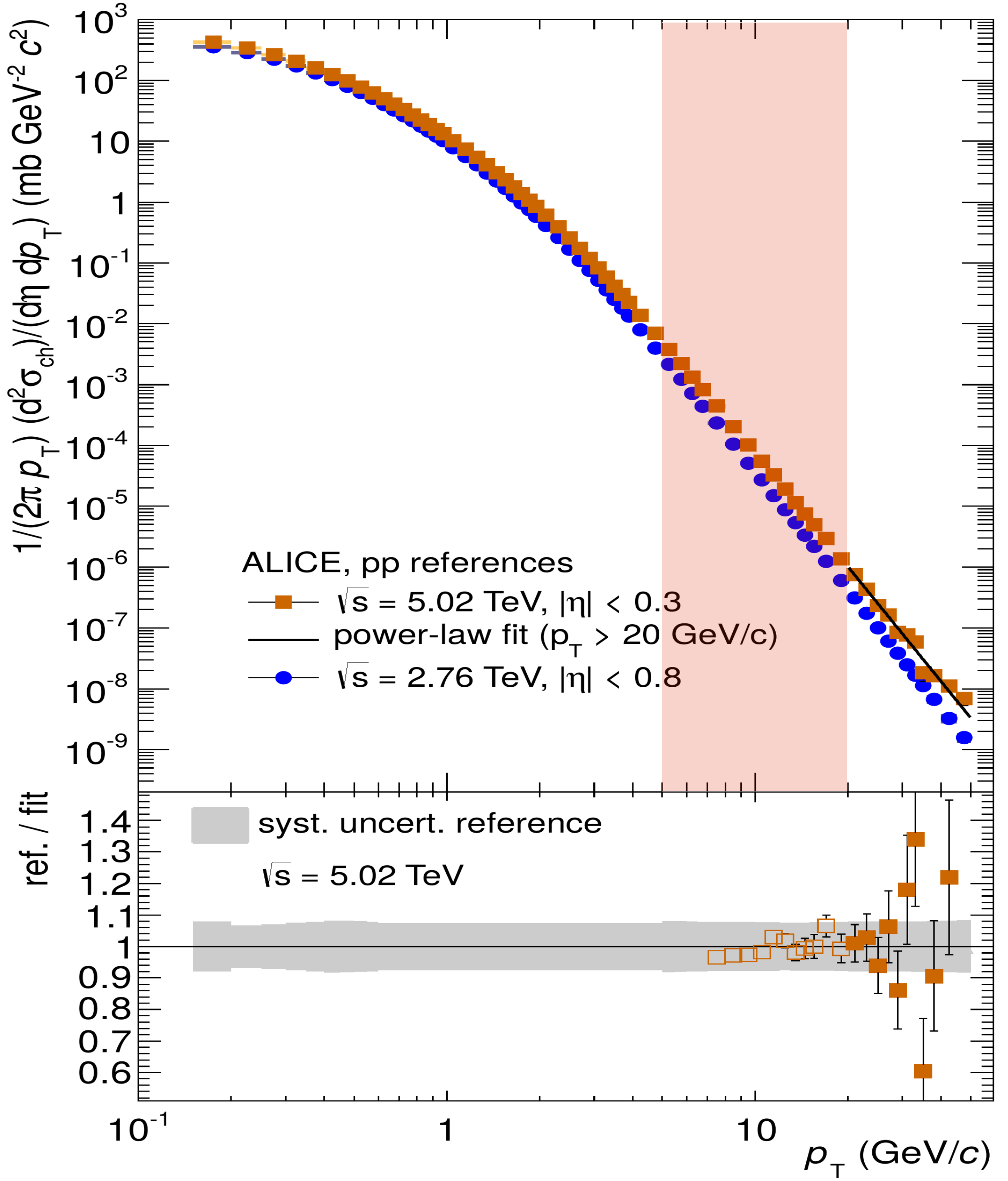
  b) mid-high p_T: 7 TeV scaled with ratio from NLO-pQCD



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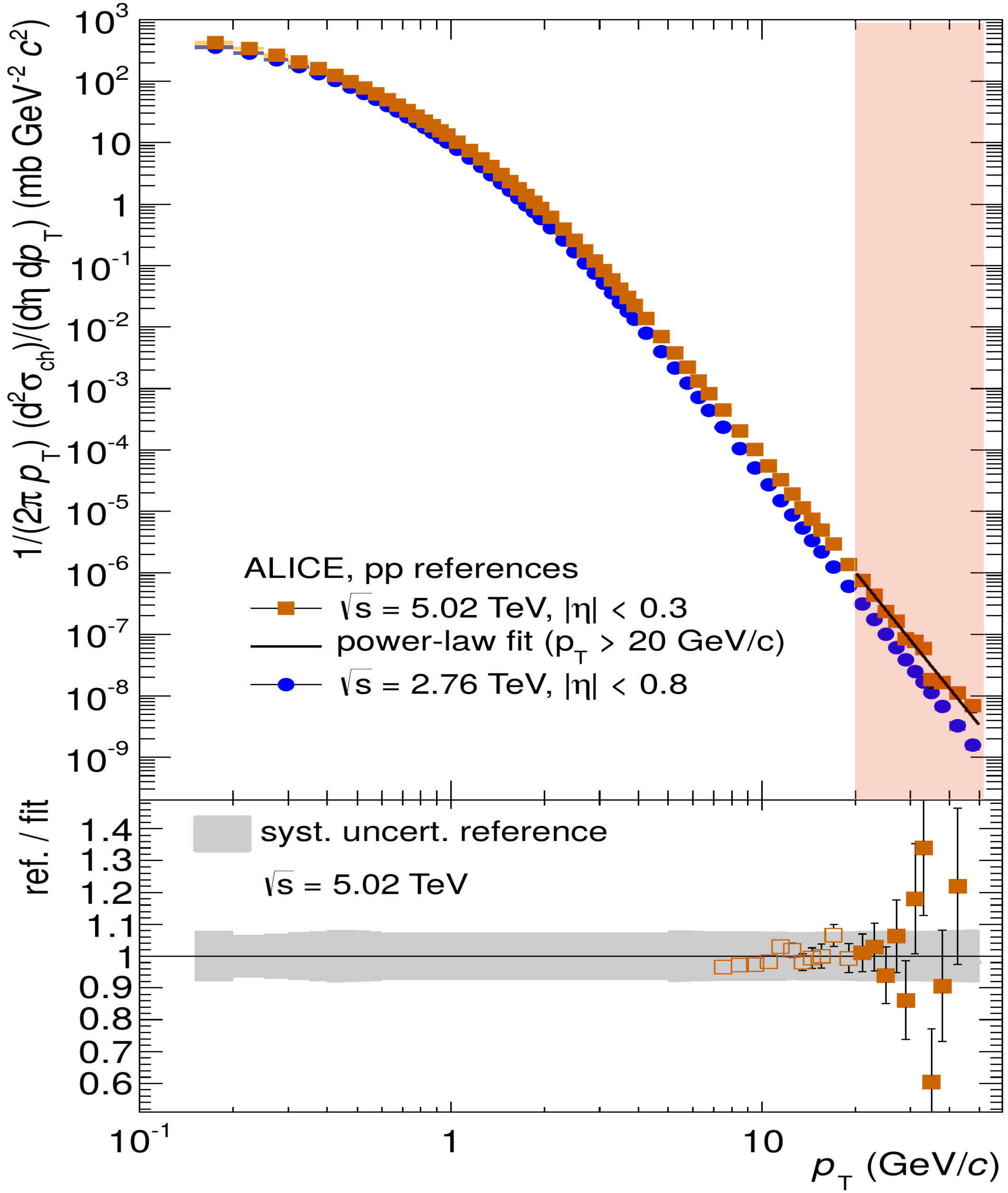
  b) mid-high p_T: 7 TeV scaled with ratio from NLO-pQCD

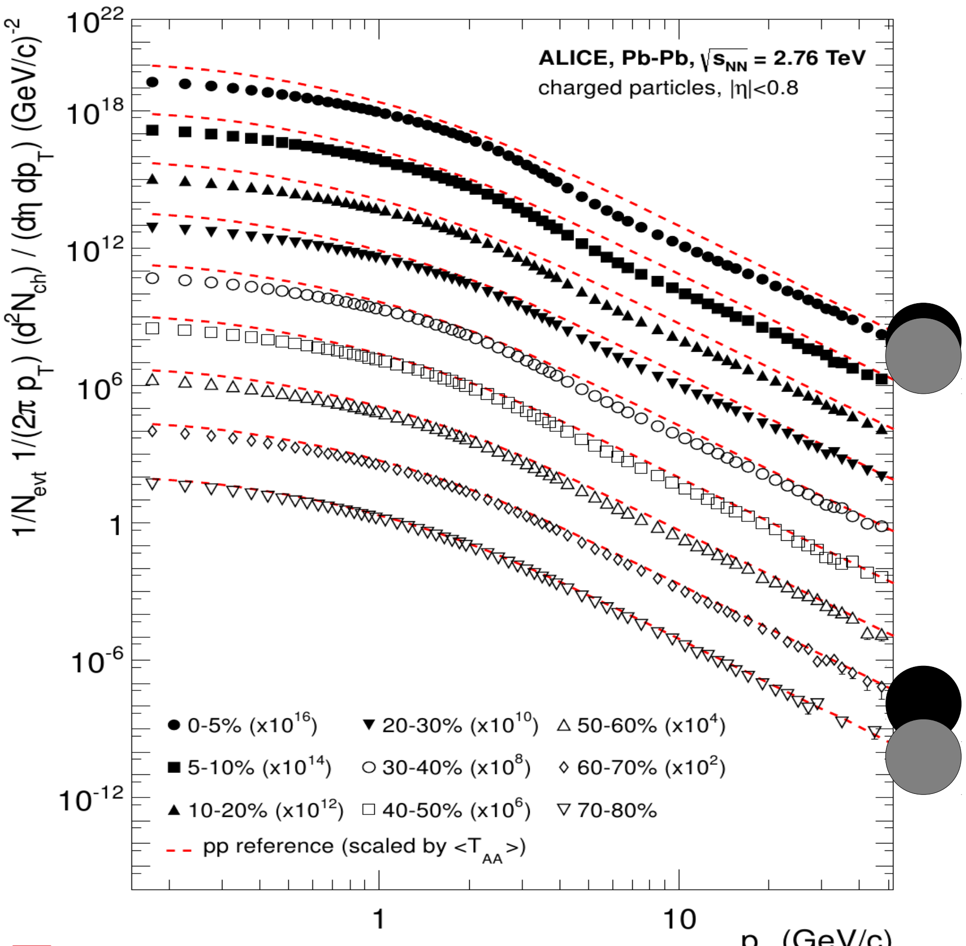
  c) very high p_T: NLO-scaled reference is parametrized (power-law function)



Pb-Pb – charged particles

Spectra

- Peripheral: similar to pp
  → pQCD and vacuum fragmentation
- Central: depletion
  → suppression at high p_T



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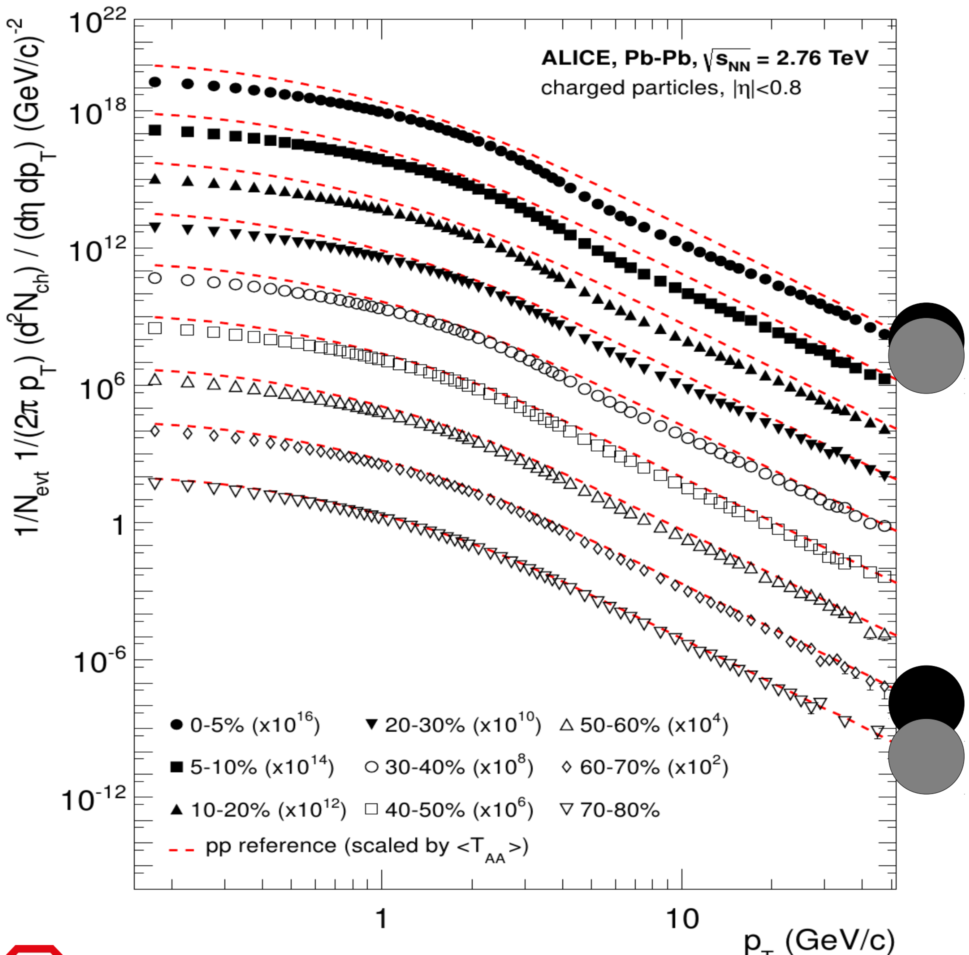
Nuclear modification factor

- Understand medium-induced mechanisms
- Describes relative energy loss
- Disentangle suppression effects

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



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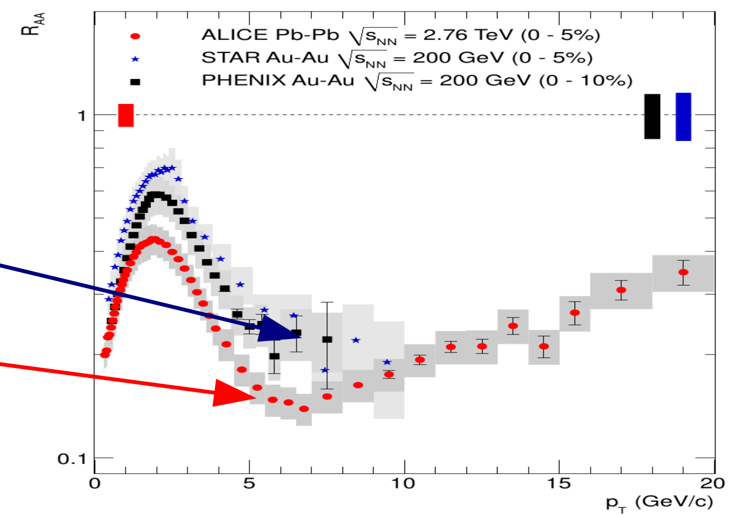
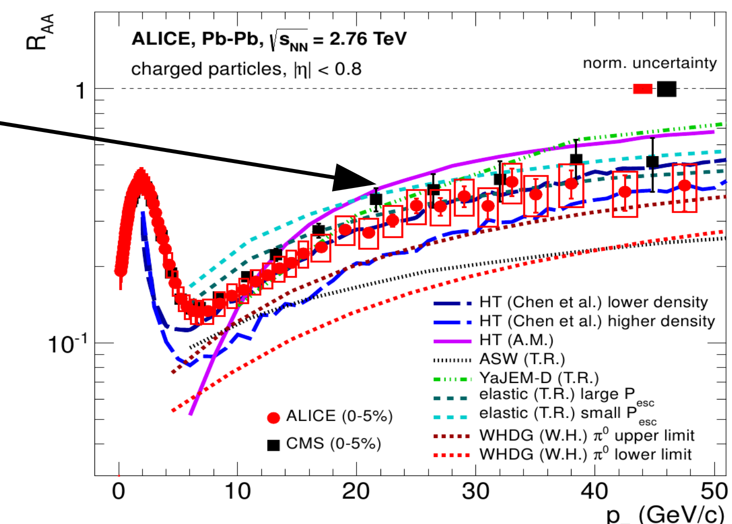
R_{AA} at RHIC Au–Au $\sqrt{s_{NN}}$ = 200 GeV

- Suppressed by factor 5

R_{AA} at LHC Pb–Pb $\sqrt{s_{NN}}$ = 2.76 TeV:

- Stronger suppression
  → denser medium ($dN_{ch}/d\eta$) at LHC
  → larger energy loss
  (but also q/g ratio and steepness of spectra)
- Suppression decreases at larger p_T
- Many models describe this decrease





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Pb-Pb and p-Pb – charged particles

Spectra

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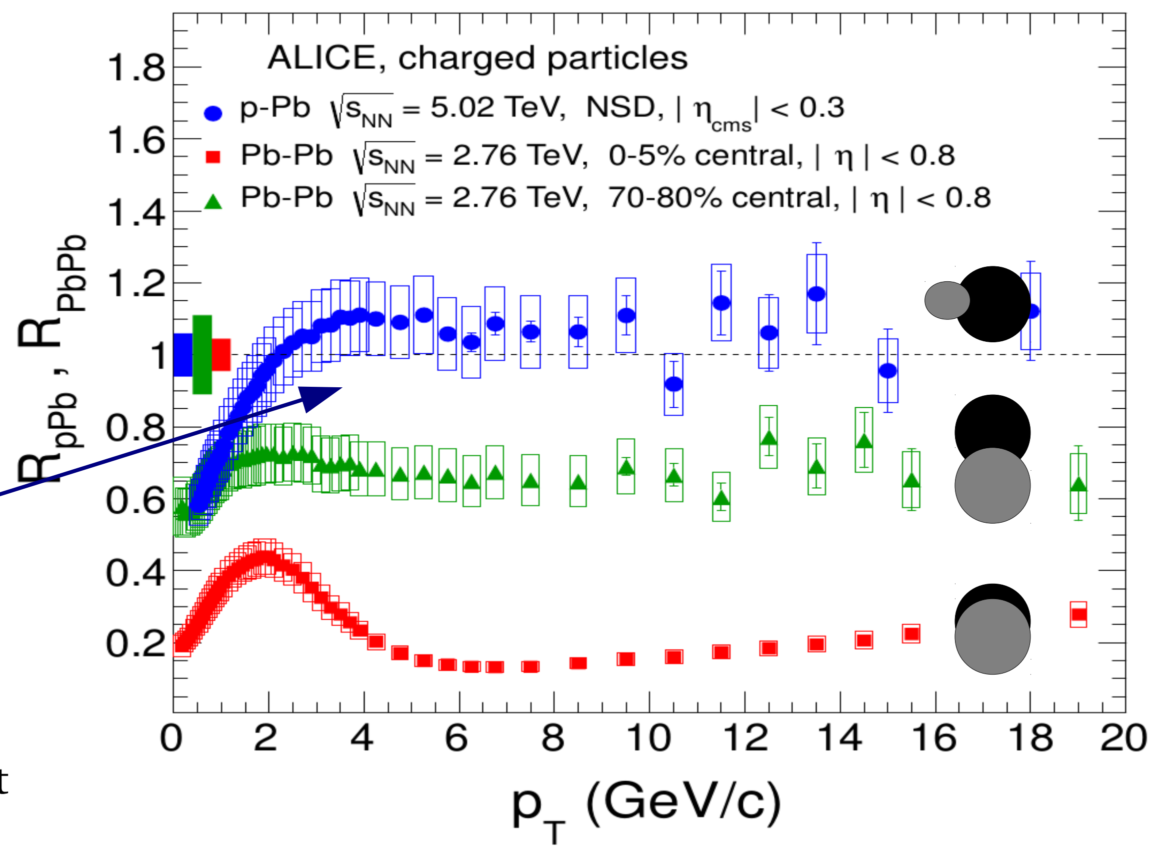
R_{pA} = 1 at mid-high p_T

- Small Cronin effect
- Higher p_T: similar to pp (N_{coll} scaling)
  → Absence of nuclear effects
  → Pb-Pb suppression not an initial-state effect
  → Jet quenching in medium created in Pb-Pb collisions



Pb-Pb and p-Pb – charged particles

Spectra

- Peripheral: similar to pp
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- Central: depletion
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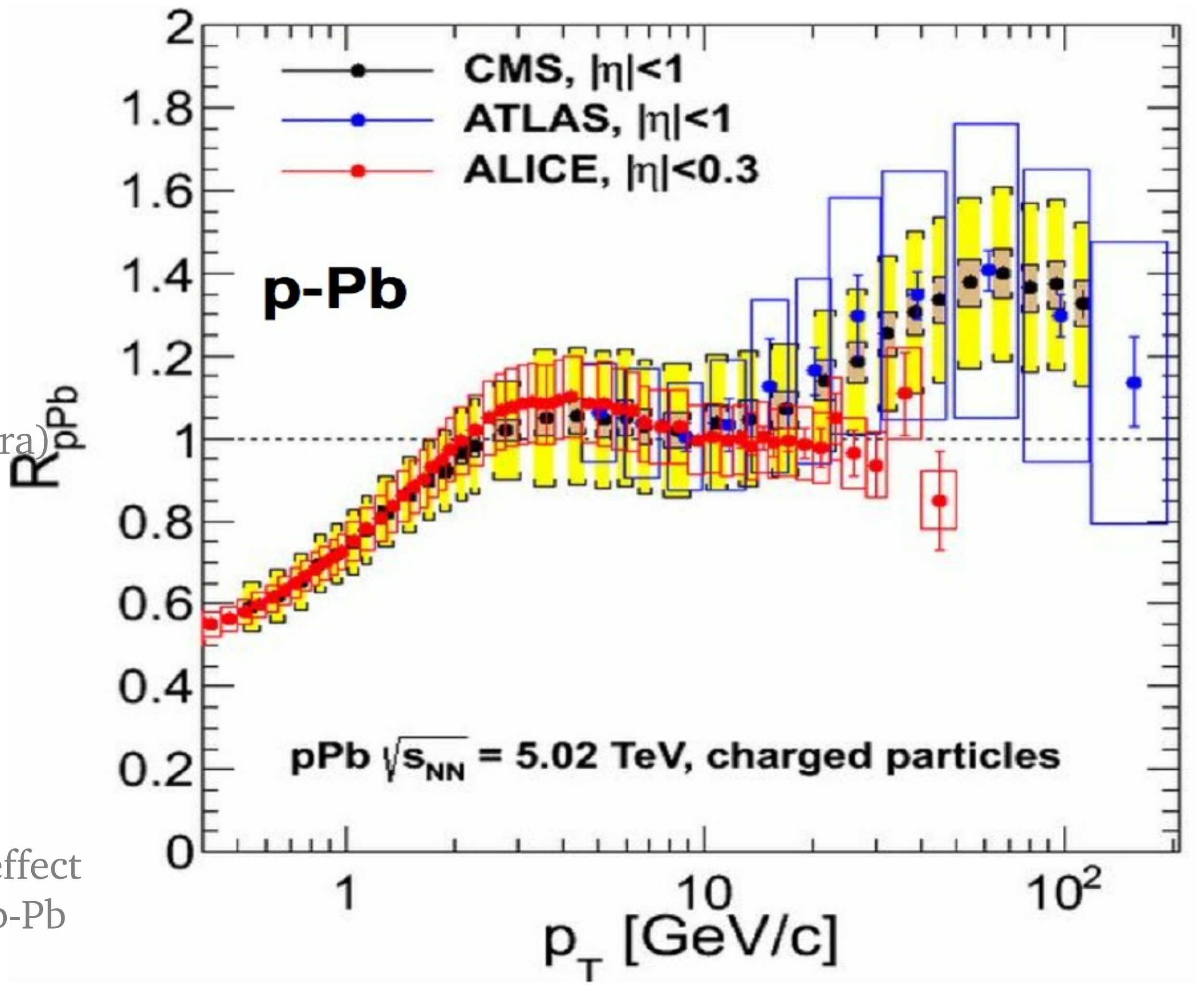
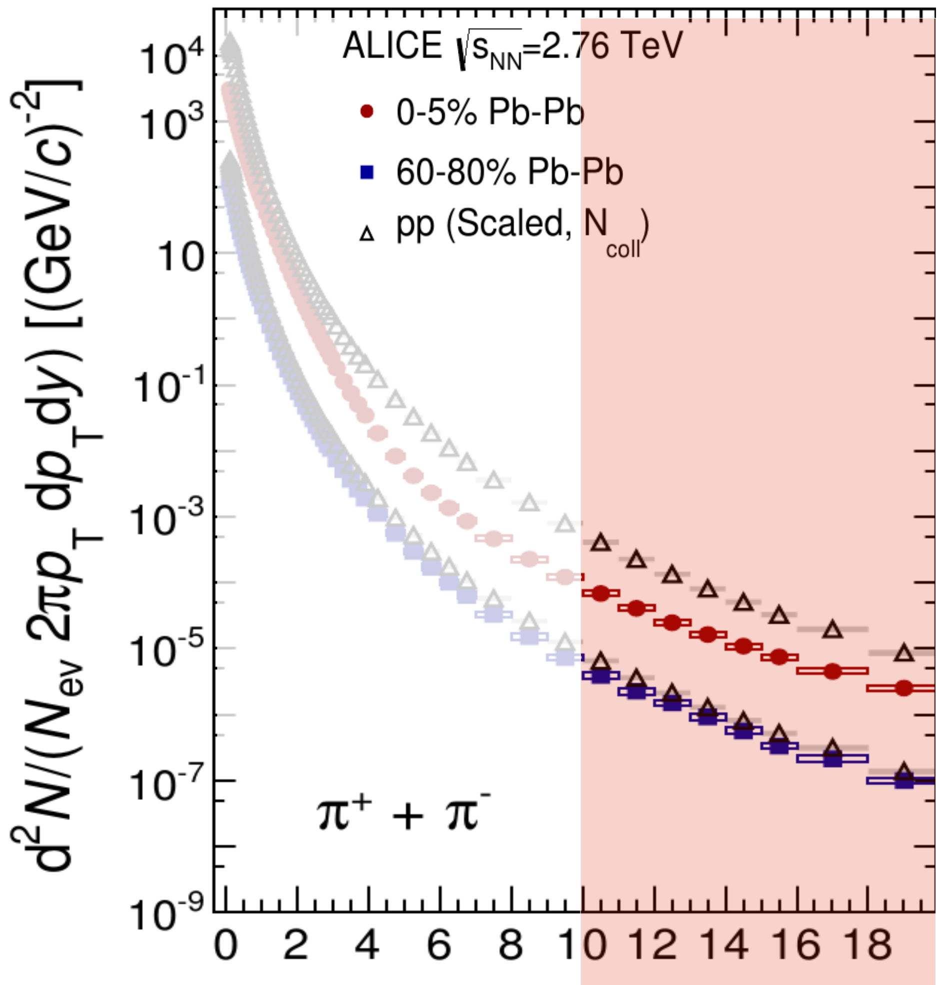
Comparison to ATLAS and CMS

- Extended p_T to 50 GeV/c (ALICE)
- ATLAS and CMS see a rise at very high p_T
  → not seen in ALICE
- The difference is larger in the reference spectra



HIGH p_T



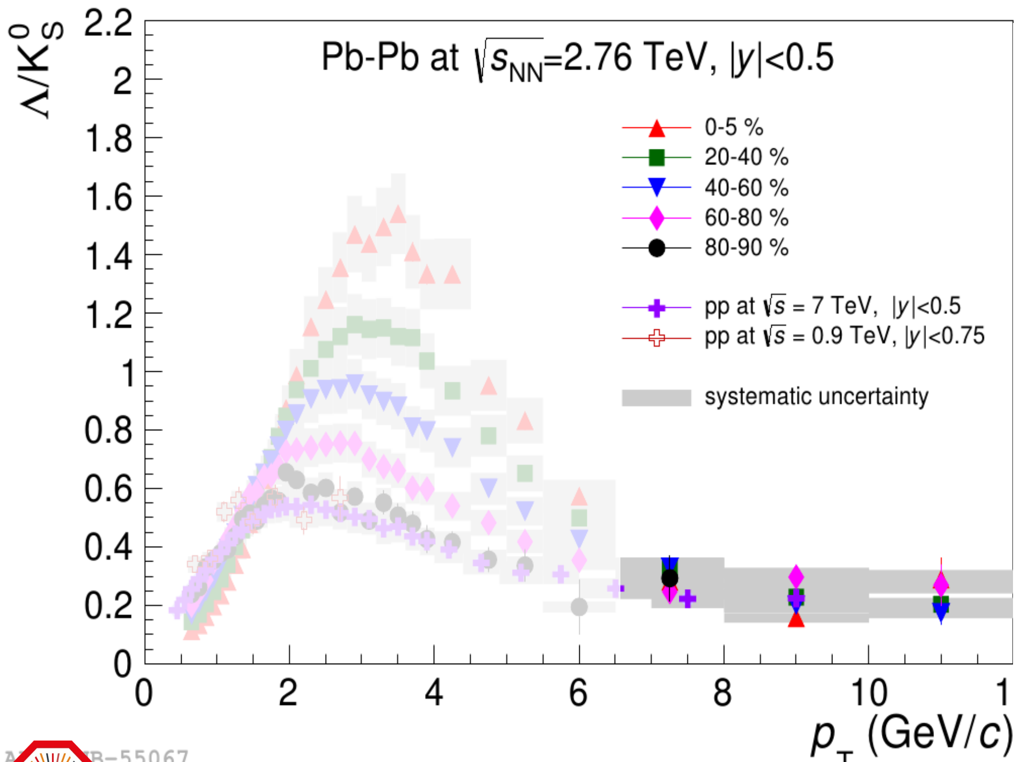
ALICE √sNN=2.76 TeV
0-5% Pb-Pb
60-80% Pb-Pb
pp (Scaled, Ncoll)
π+ + π-
d2N/(Nev 2πpT dpT dy) [(GeV/c)-2]
10^4
10^3
10
10^-1
10^-3
10^-5
10^-7
10^-9
0
2
4
6
8
10
12
14
16
18

Pb-Pb – identified – high p_T ratios

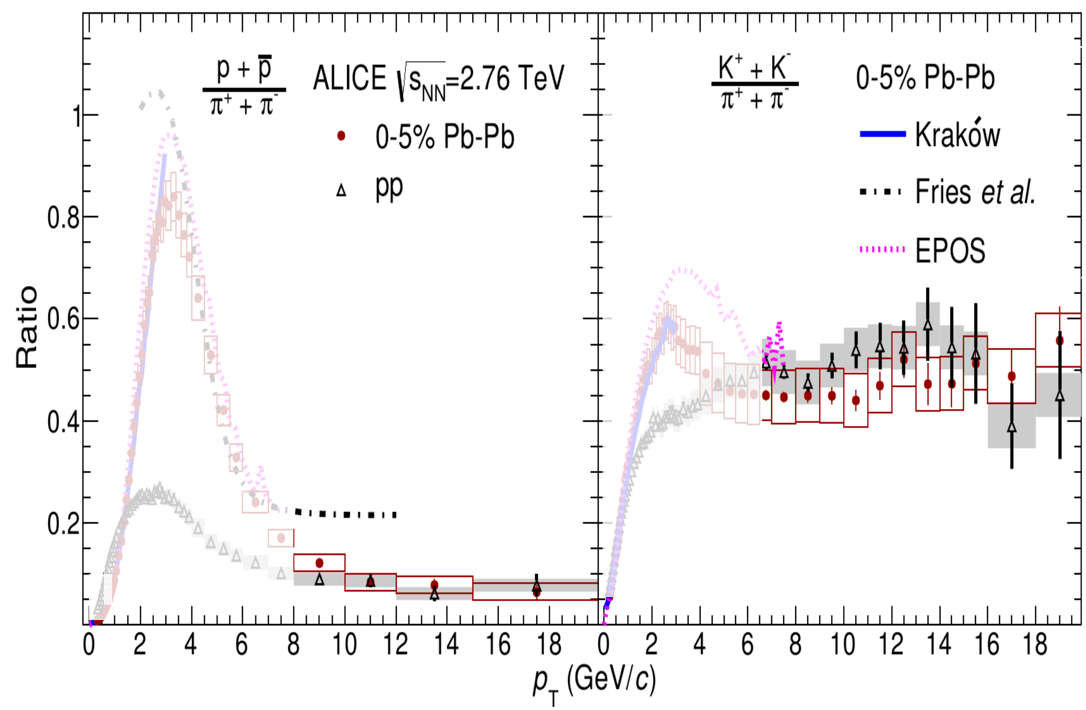
All ratios consistent with pp for $p_T > 8$ GeV/c

→ hard processes dominated by fragmentation
→ fragmentation is vacuum-like
→ not modified by medium

Λ/K^0_s

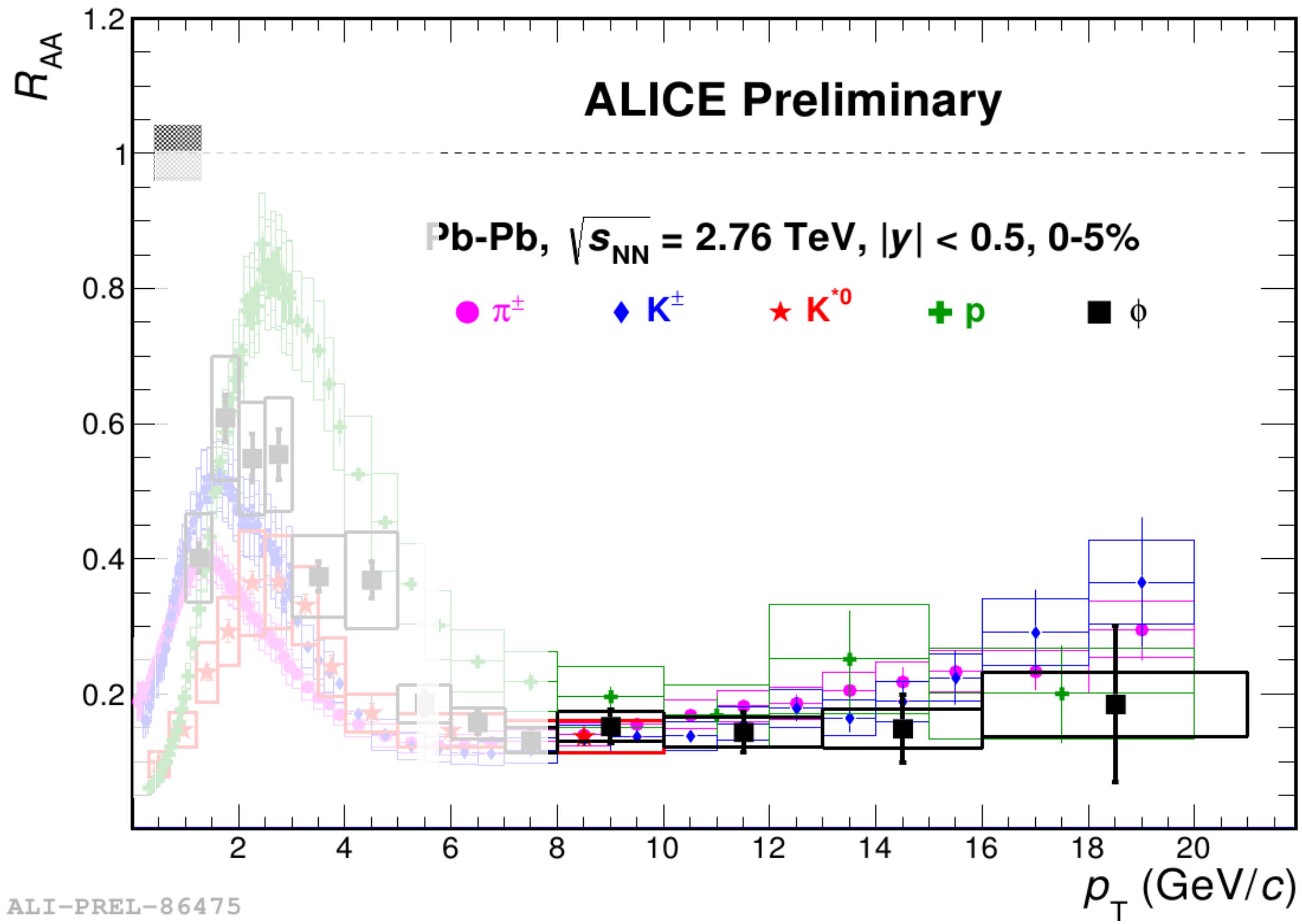


p/π K/π



Pb-Pb – identified – high p_T R_{AA}

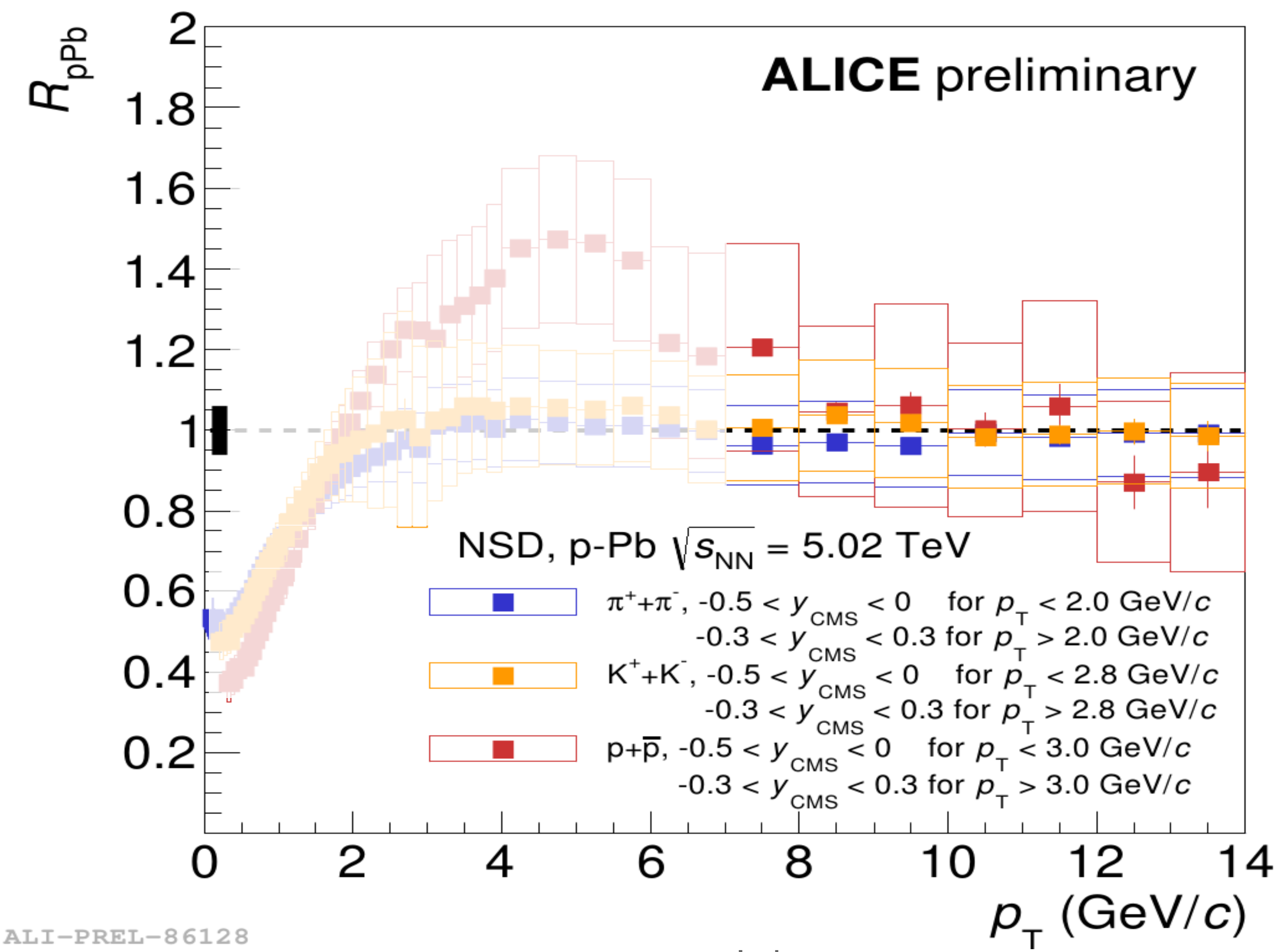
All hadrons equally suppressed
→ no mass ordering (at high p_T)
→ large energy loss due to medium



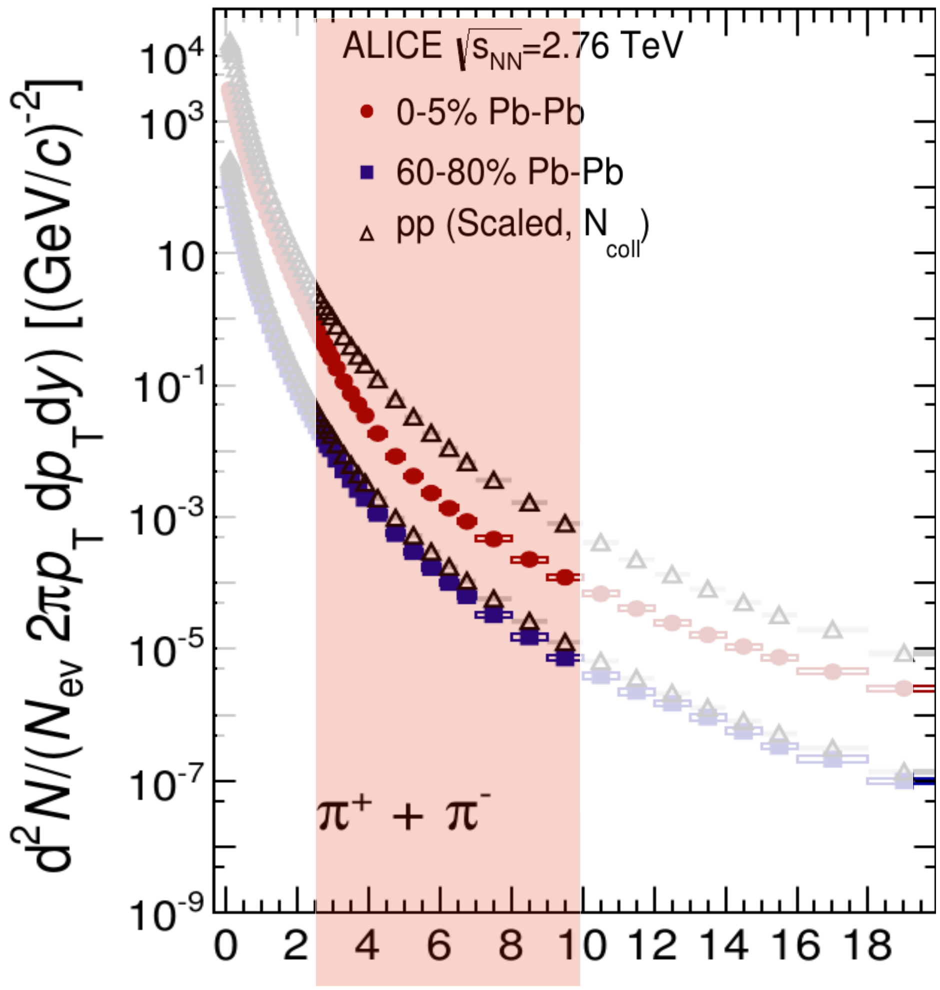
p-Pb – identified – high p_T R_{pA}

No suppression in p-Pb high p_T

→ no initial state effects in Pb-Pb suppression

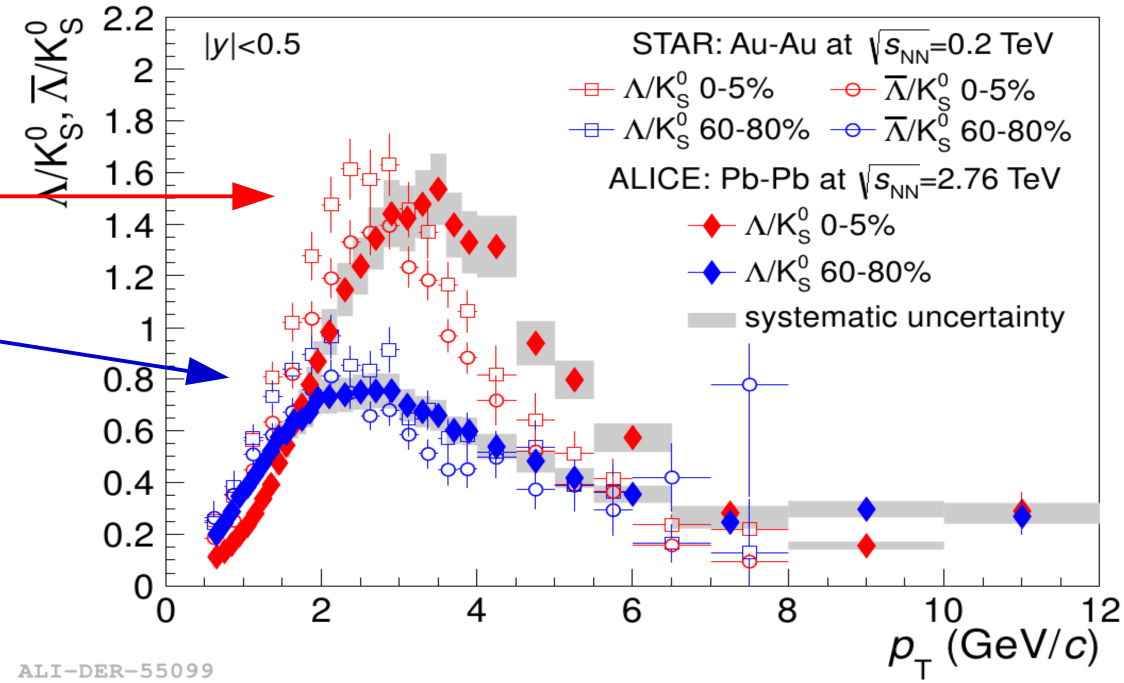


INTERMEDIATE p_T

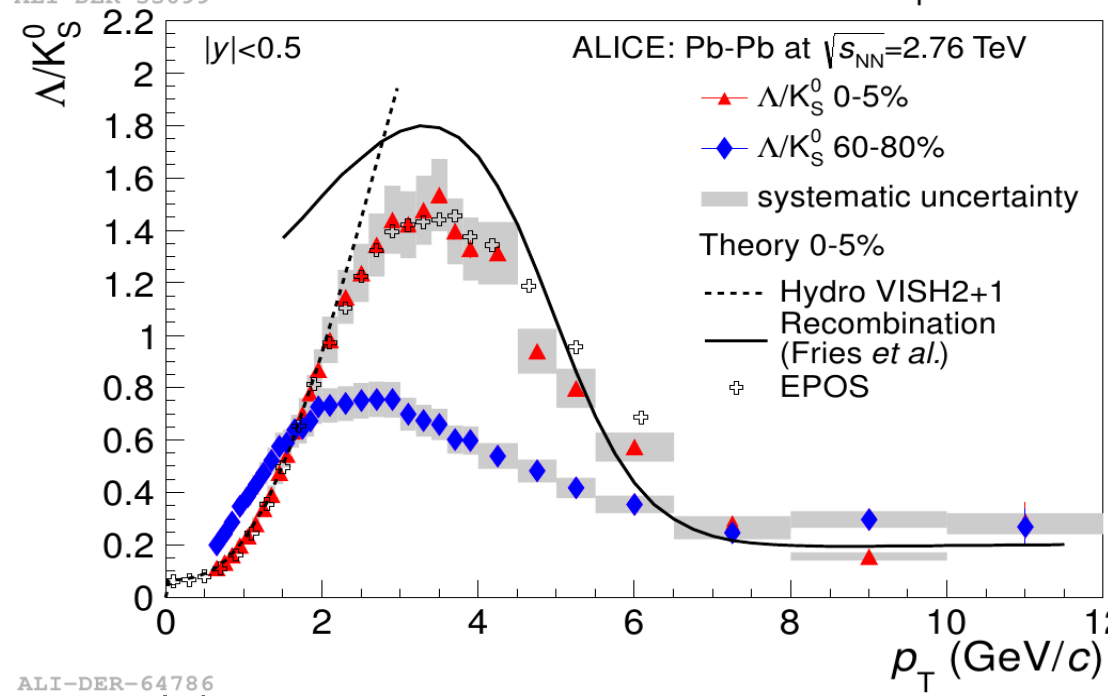


Pb-Pb – identified: Λ and K^0_s – ratios

- Intermediate p_T: enhancement of Λ to K^0_s → baryon/meson enhancement
- Decreases with decreasing centrality
- Shift of maximum position to lower p_T

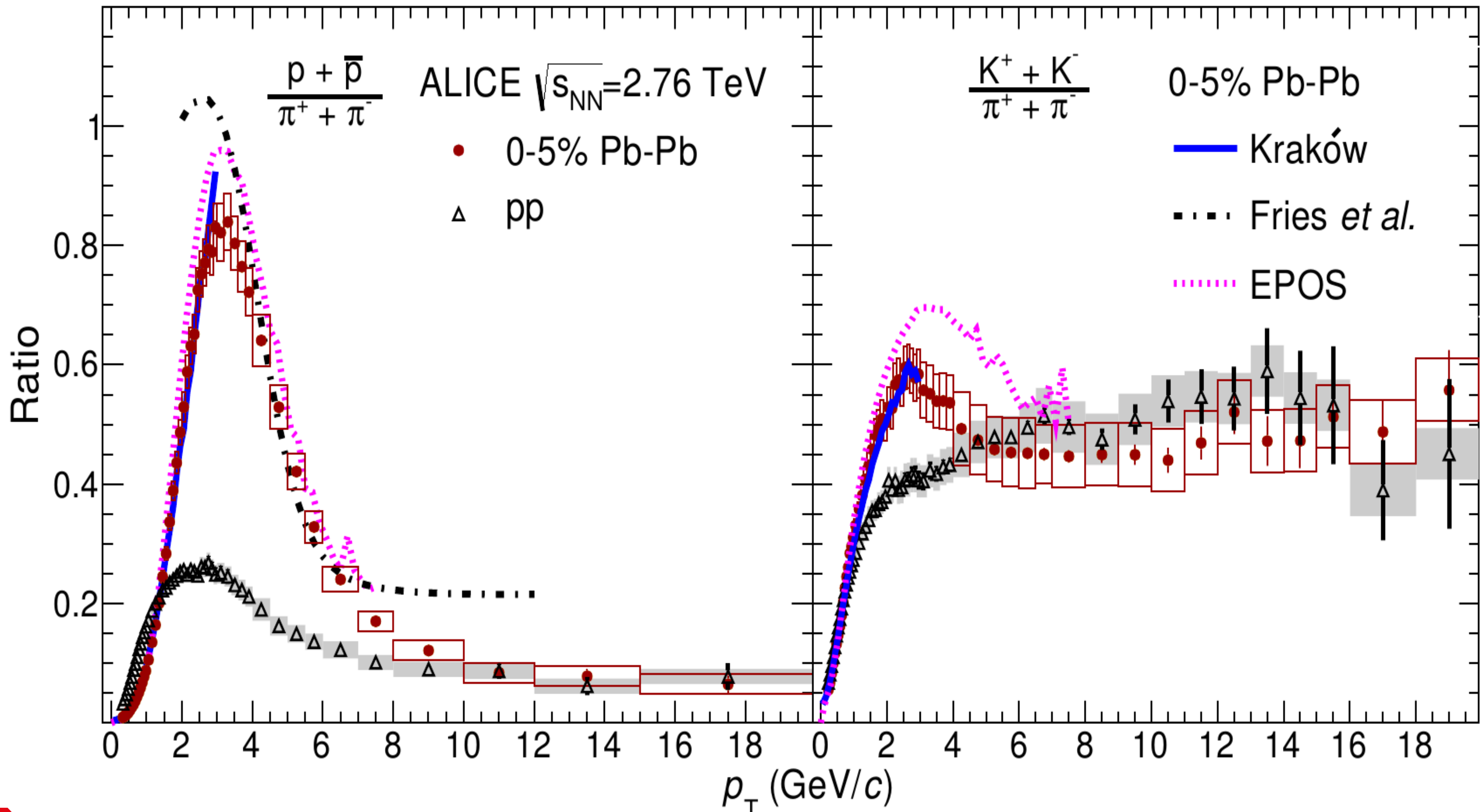


- Models with modified fragmentation and hadronization due to medium describe data quantitatively well
- EPOS: takes into account interaction between jets and the hydrodynamically expanding medium
- Fries et al.: recombination model – reproduces shape, but overestimates enhancement



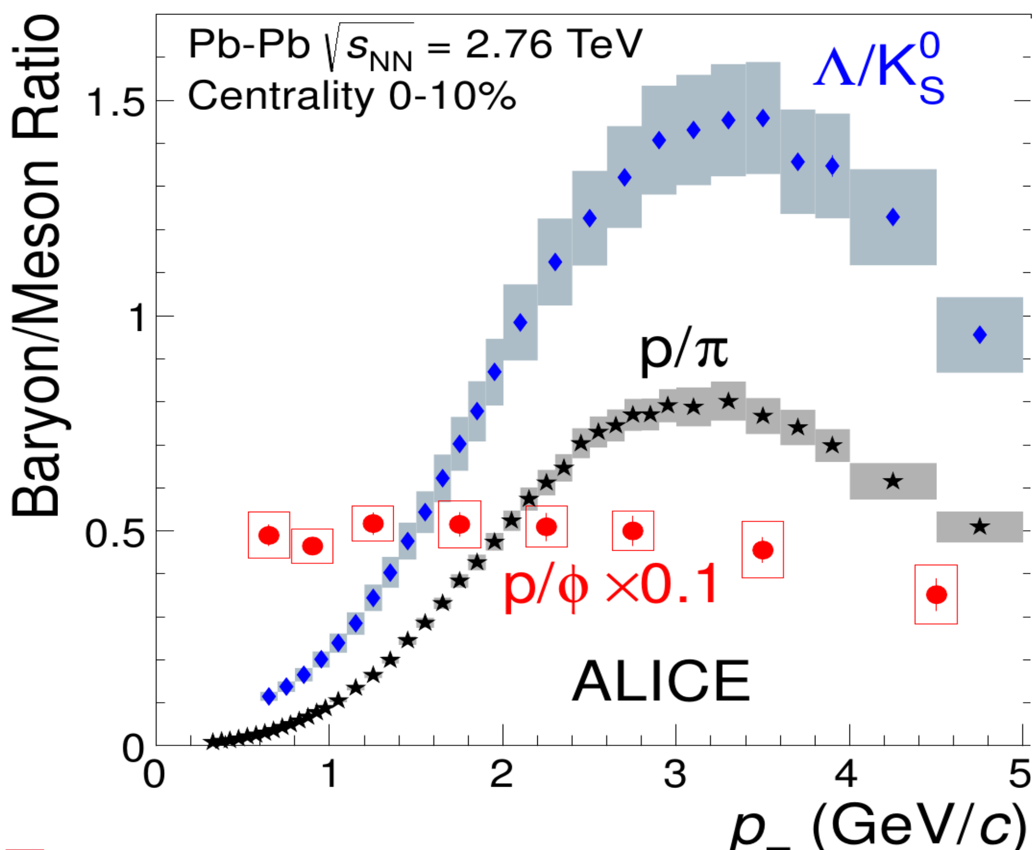
Pb-Pb – identified: π, K, p – ratios

- p/π (baryon/meson) and K/π (meson/meson!) ratios: peak at $p_T \approx 3$ GeV/c in central Pb–Pb
  → number of constituent quarks does not determine the spectral shape?
- EPOS: recombination only occurs for soft thermal radially flowing partons (soft coalescence)
  → more consistent with data, but overestimates the peaks

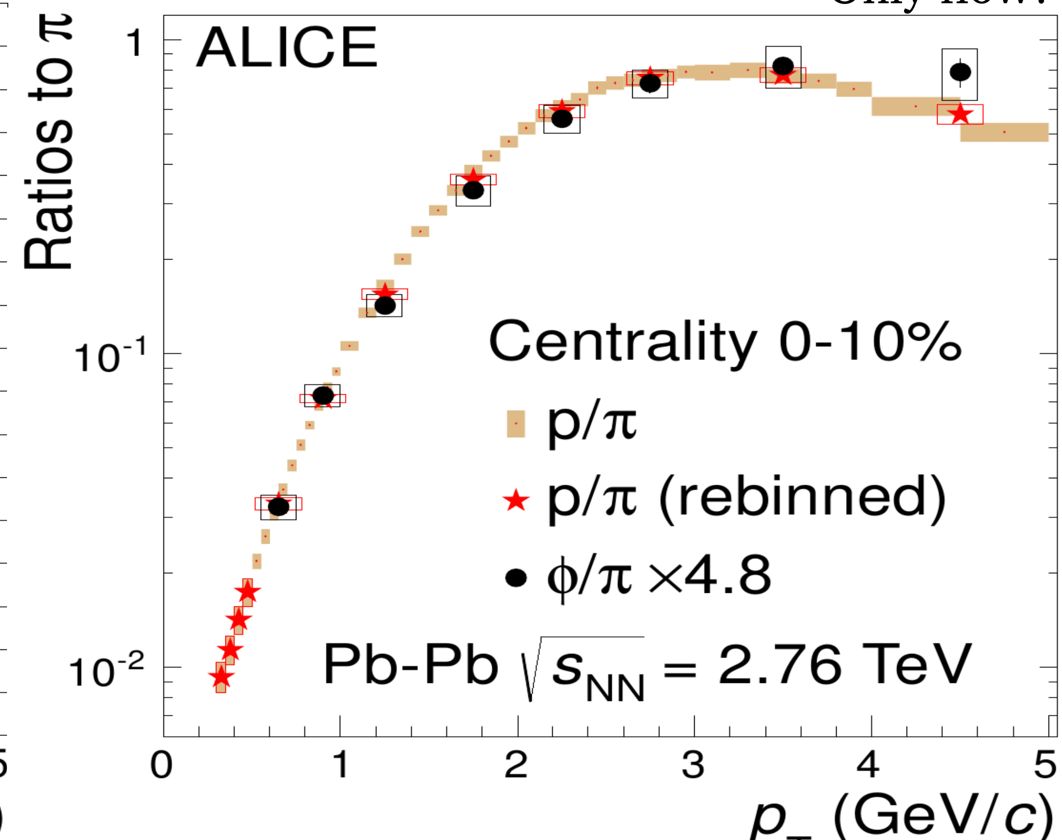


Pb-Pb – identified: ϕ – ratios

- So far: baryon/meson enhancement in **p/π** and **Λ/K^0_s** in central Pb–Pb, intermediate p_T
  → coalescence of quarks?
- Baryon/meson of similar mass: **p/ϕ**
  → no difference in p_T distribution → no enhancement!
  → ϕ spectrum similar to proton spectrum
  → hadron mass seems to be the driving parameter (hydro flow)

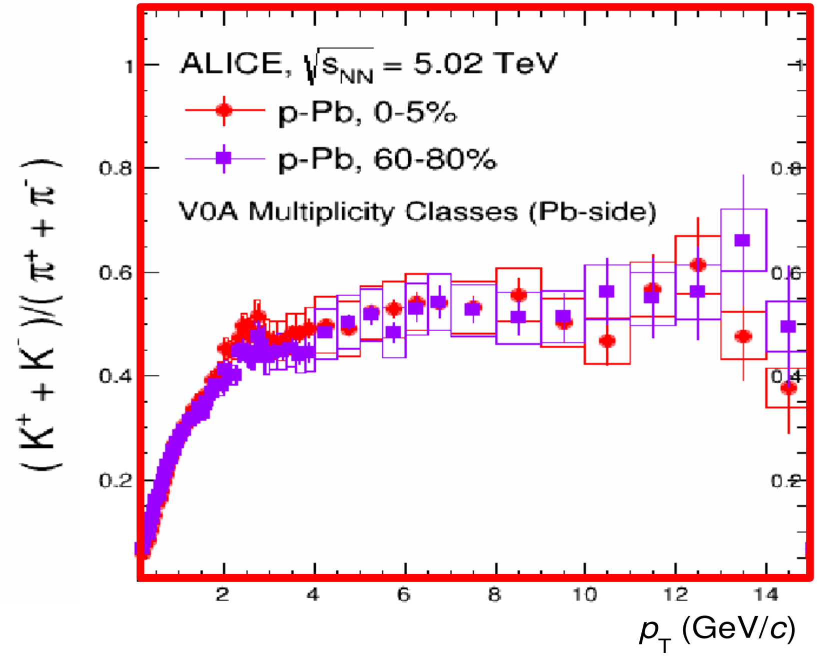


Only flow?



p-Pb and Pb-Pb – identified – ratios

- No significant multiplicity dependence in p-Pb K/π at mid- to high-p_T



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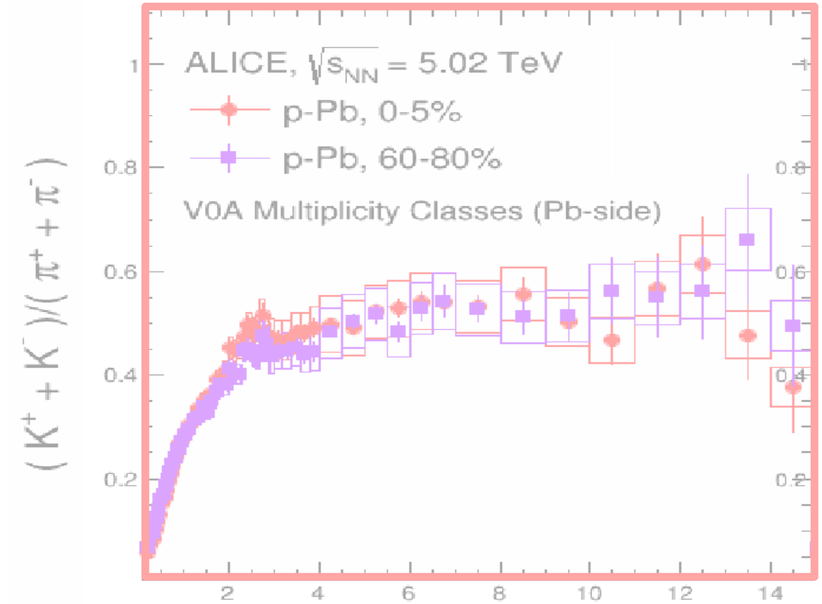
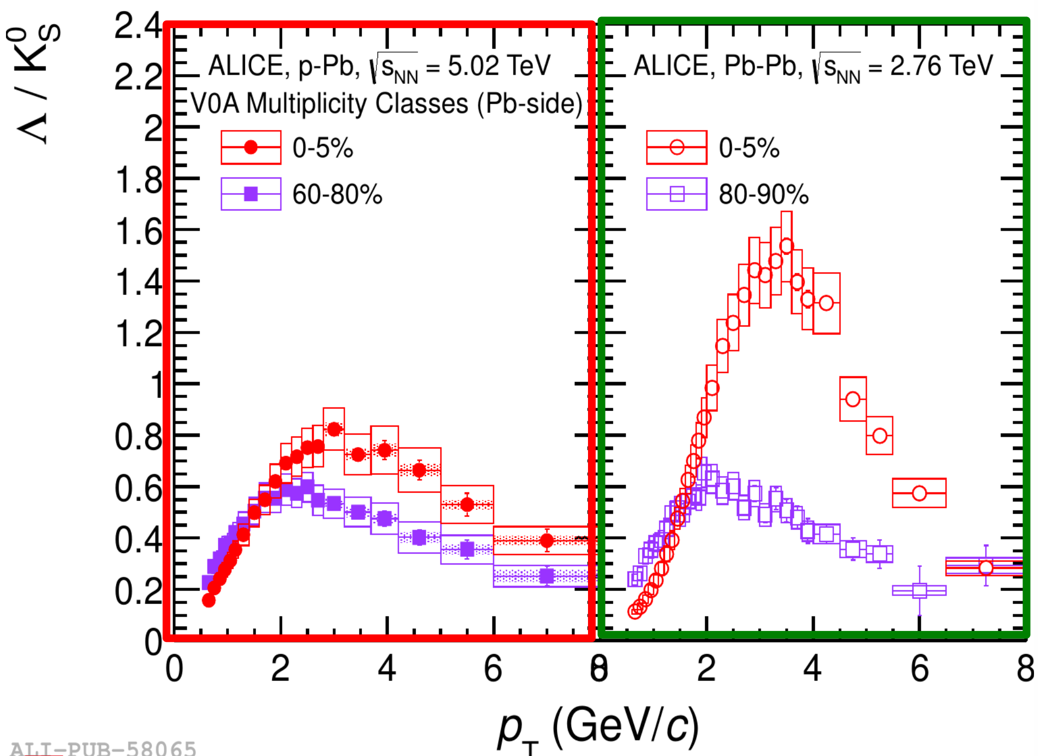
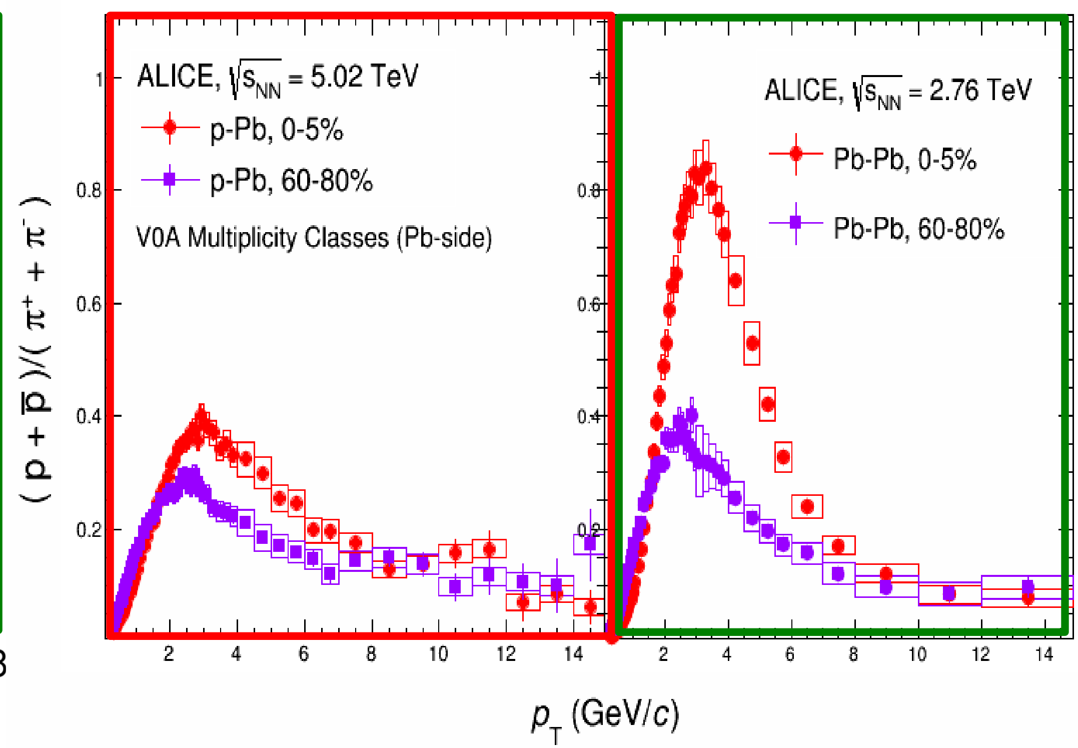


- Λ/K^0_s and p/π enhancement at intermediate p_T
- Baryon to meson ratio increases with multiplicity
- Qualitatively similar (magnitude differs) to Pb-Pb (explained by flow-like effects)



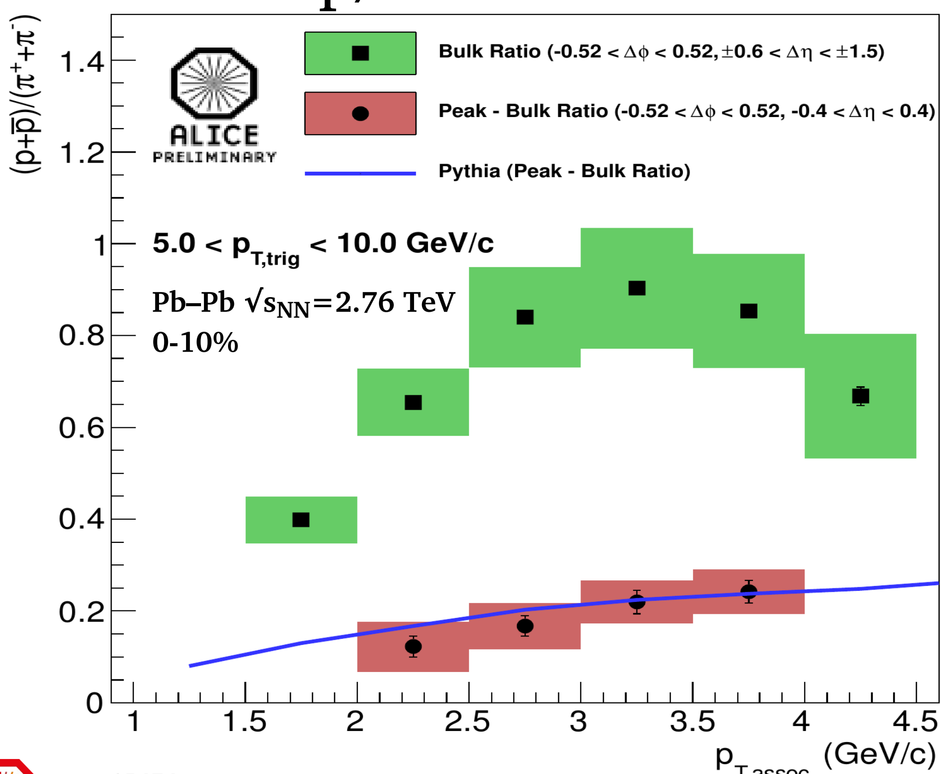


Interplay between soft and hard physics

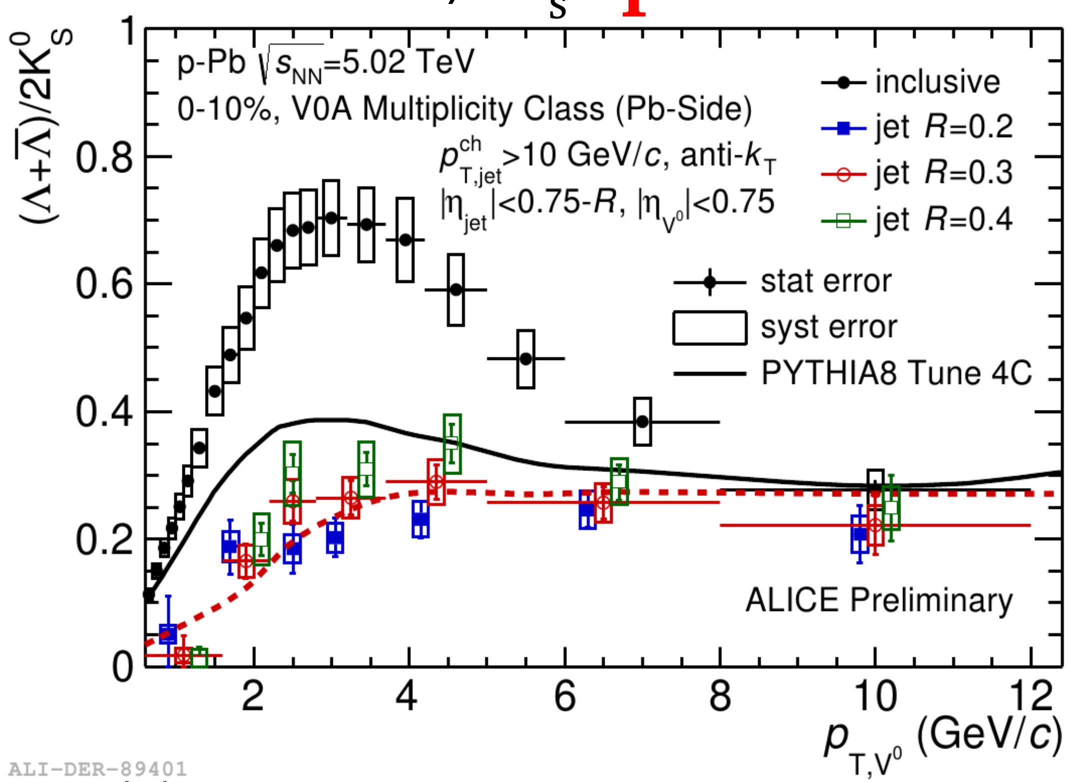
- Origin of enhancement?
- Different hadronization mechanisms:
  a) parton fragmentation (jet – hard)
  b) collective effects (bulk – soft)
- Separating hadrons produced in bulk (underlying events) from those associated with a high-p_T particle (jet)

- **Pb-Pb**: p/π in bulk and jet by correlation method
  → baryon-meson enhancement is a bulk effect
- **p-Pb**: Λ/K^0_s (jet reconstruction method) same conclusion

p/π **Pb-Pb**



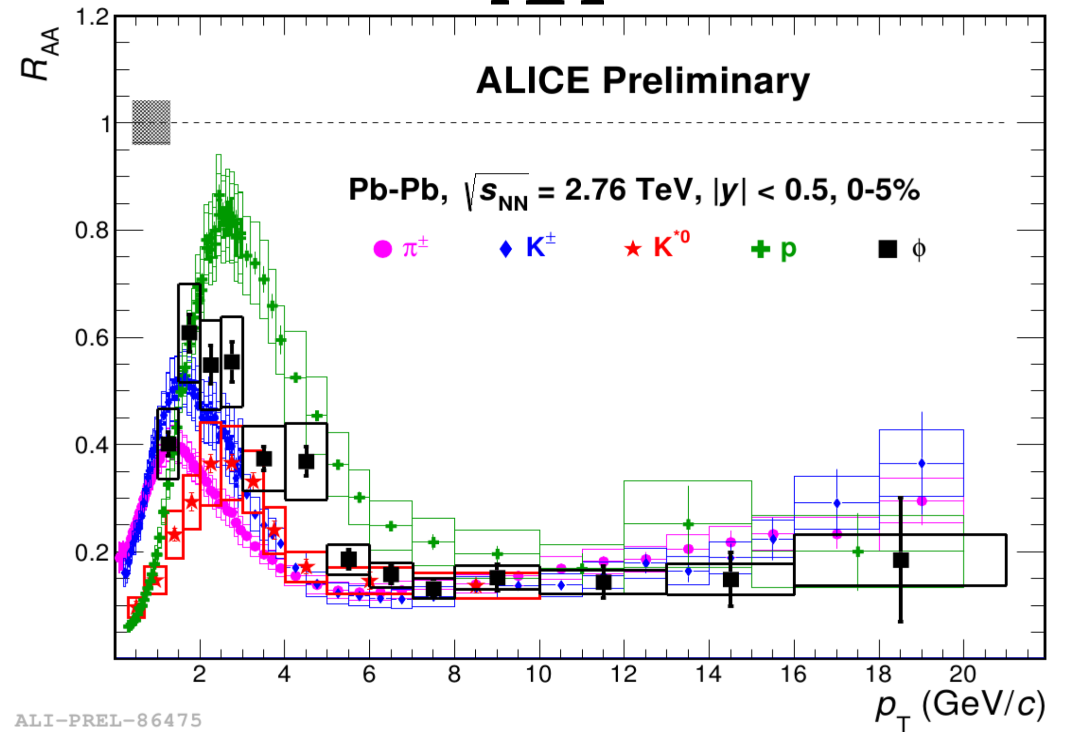
Λ/K^0_s **p-Pb**



Pb-Pb – identified – R_{AA}

π, K, p

- p less suppressed than K and π
  → consistent with particle ratios
- Mass ordering at intermediate p_T



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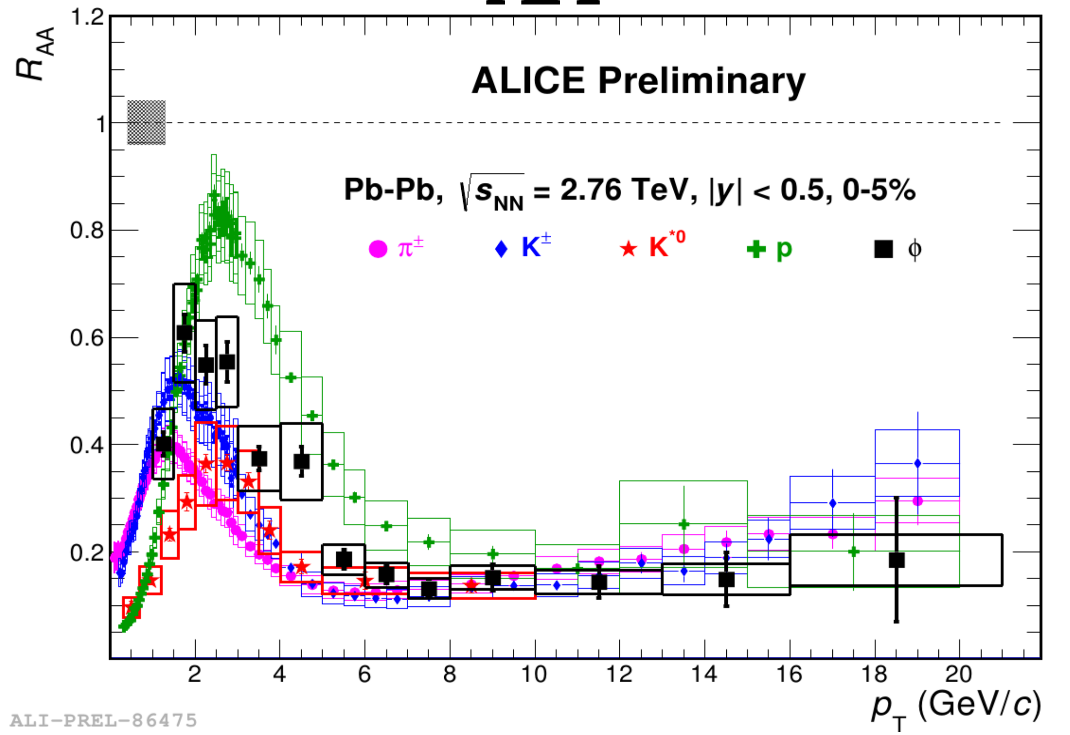
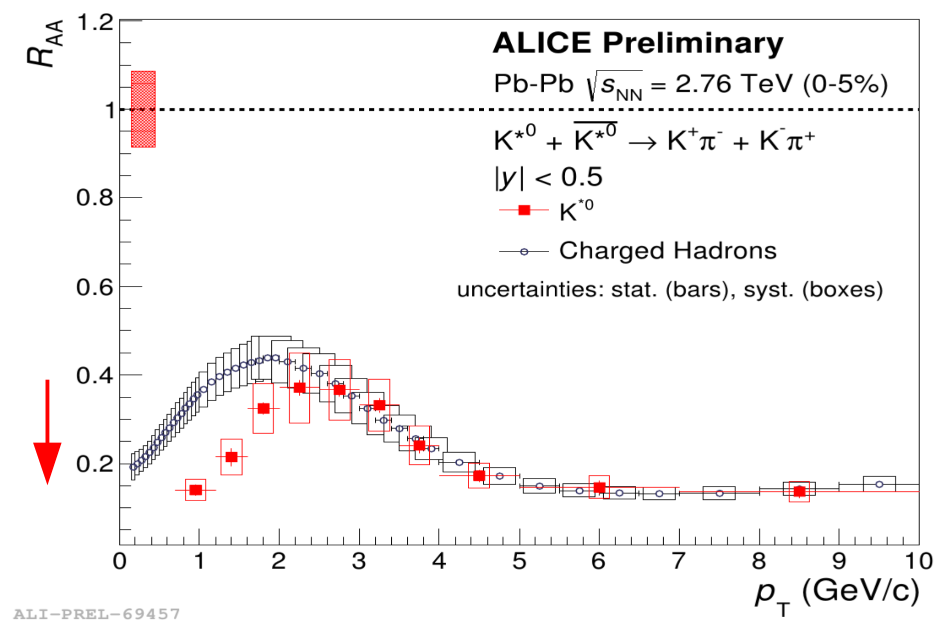
K*

- More supression of K* than of charged hadrons for low p_T (consistent with re-scattering)





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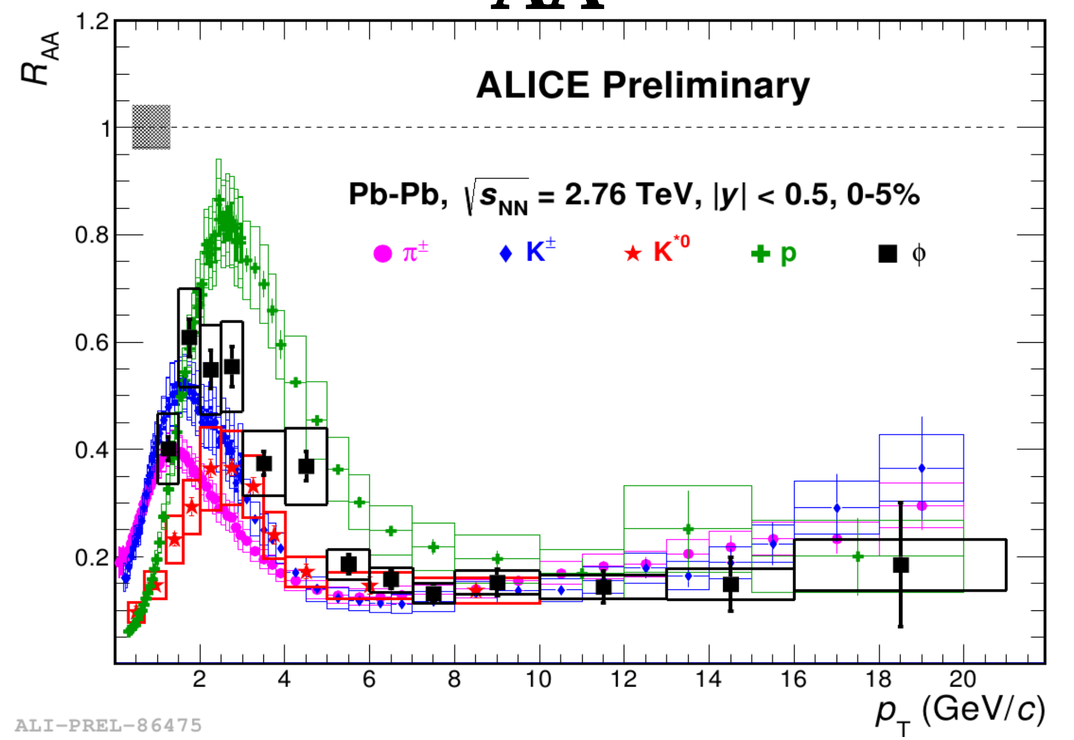
ϕ: a meson with the mass of a proton

- RHIC: differences between the p and ϕ
  → favor of recombination
- LHC: differences between p and ϕ



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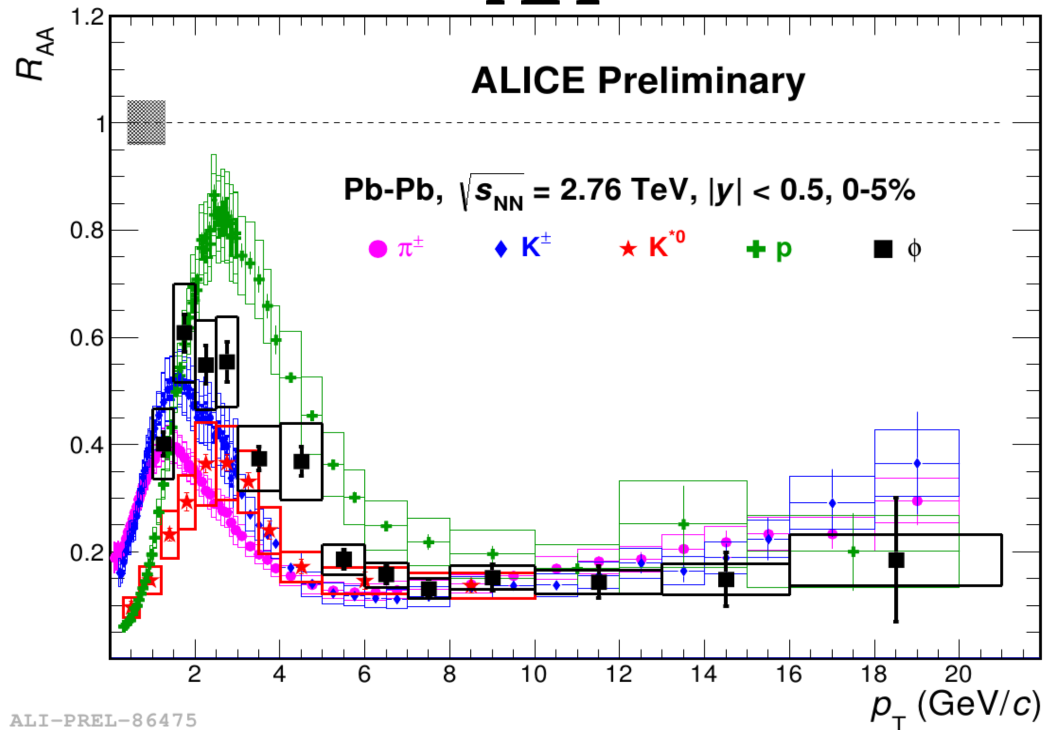
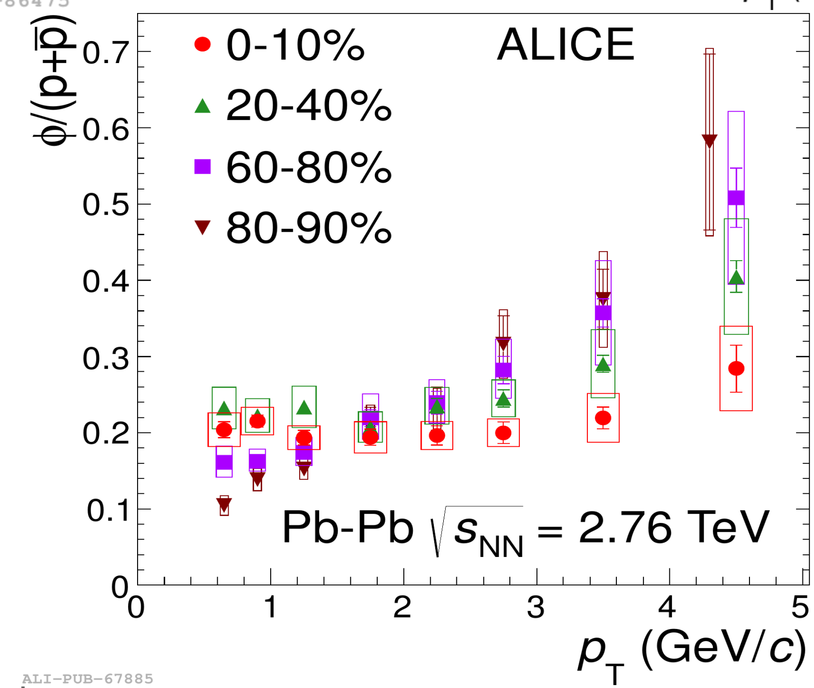
  → differences in pp reference spectra





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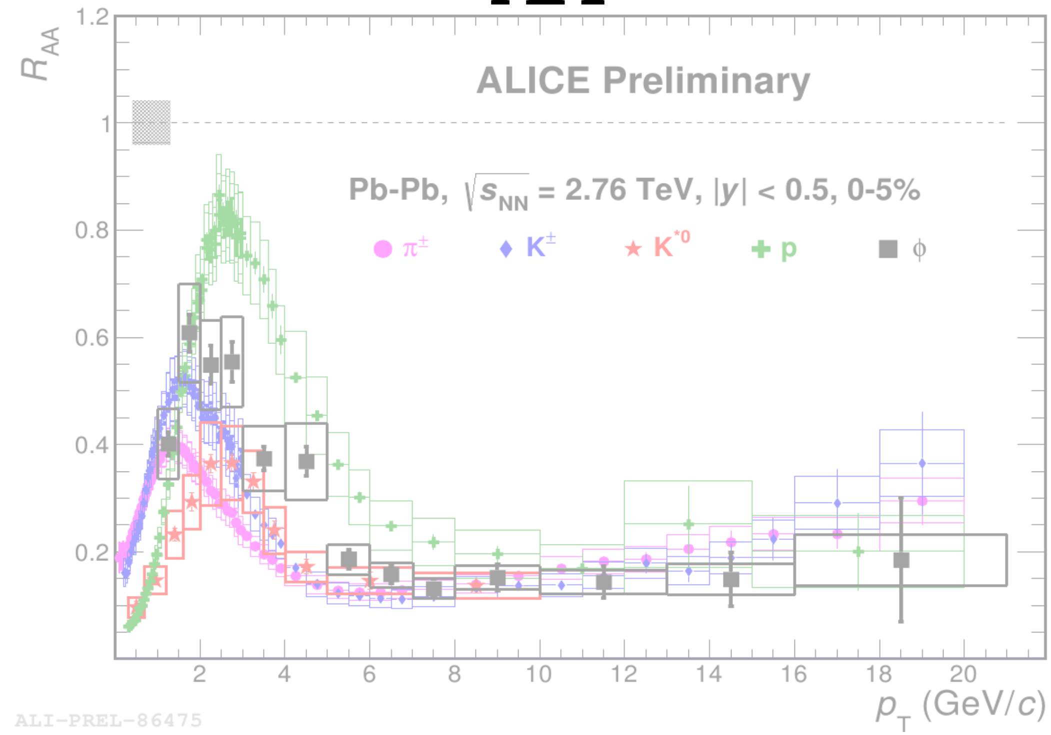
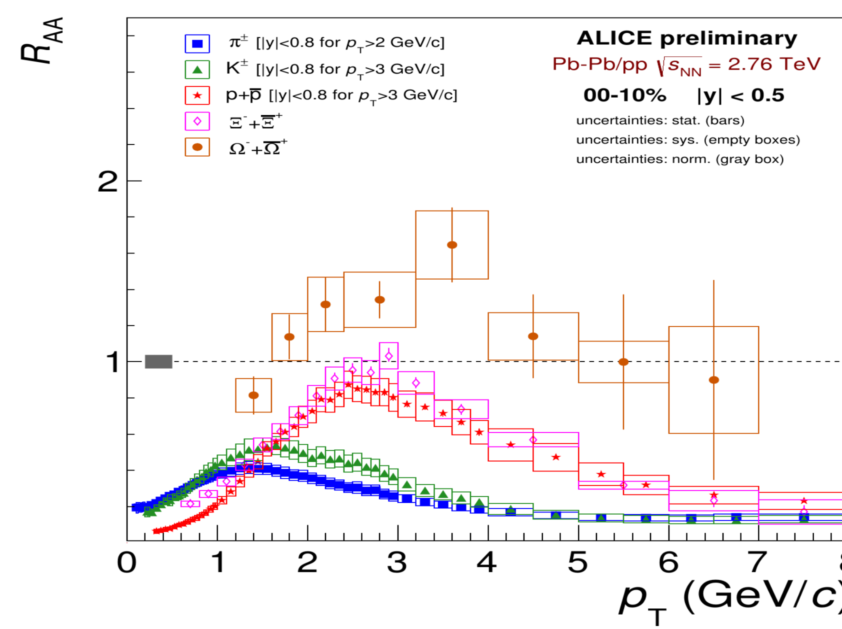
Ξ and Ω

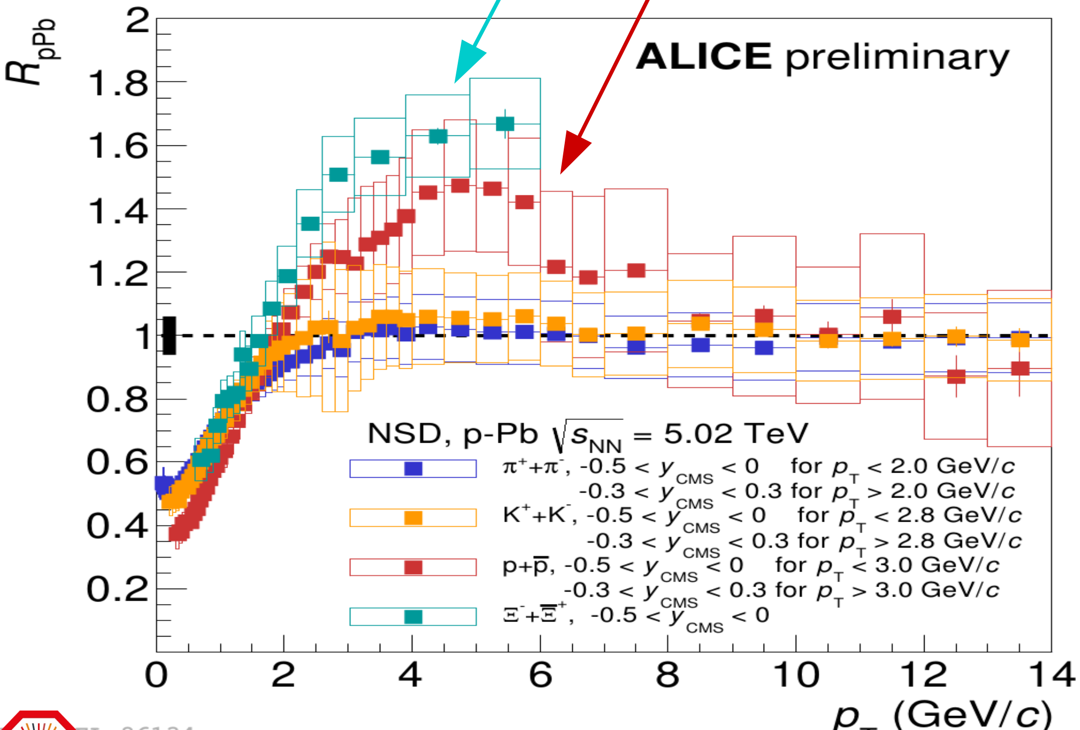
- **Ω** = very heavy baryon, enhanced over **Ξ**
  → mass effect (flow push)?
  → strangeness enhancement/canonical suppression





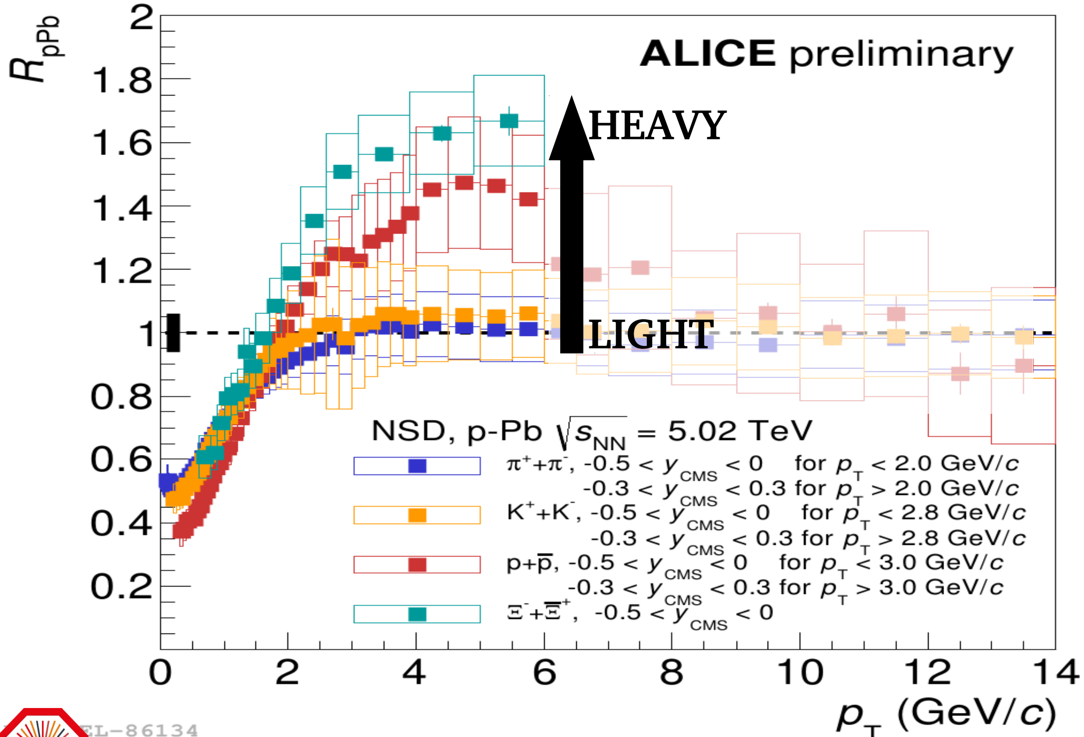
p-Pb – identified – R_{pA}

- Enhancement for Ξ and p



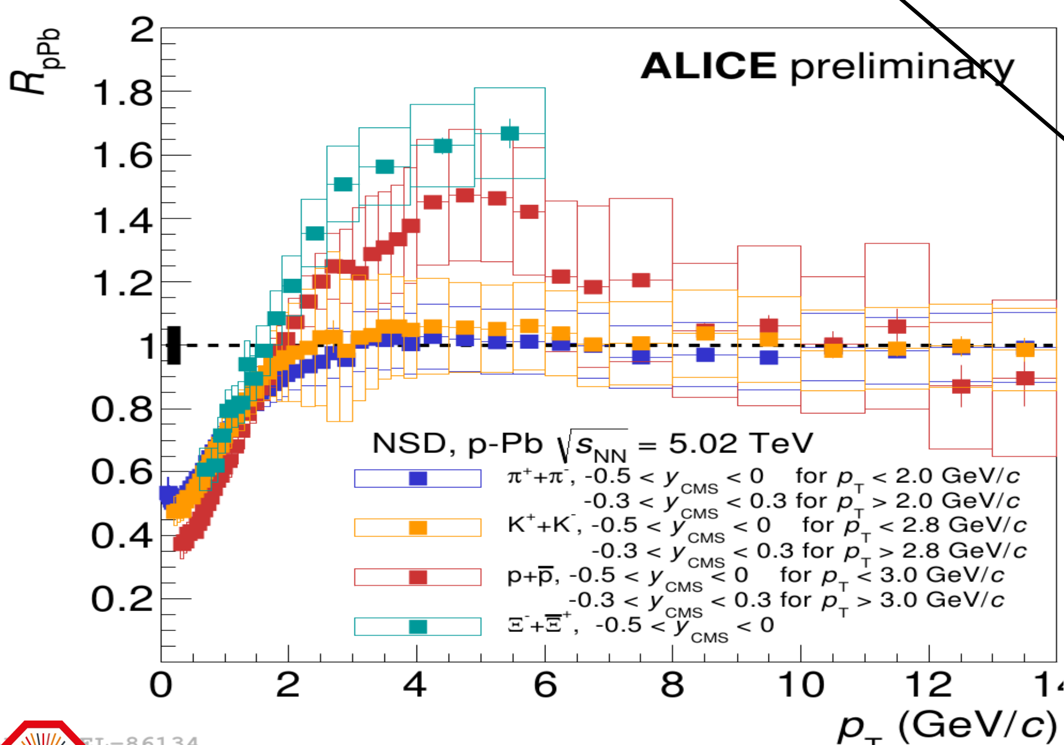
p-Pb – identified – R_{pA}

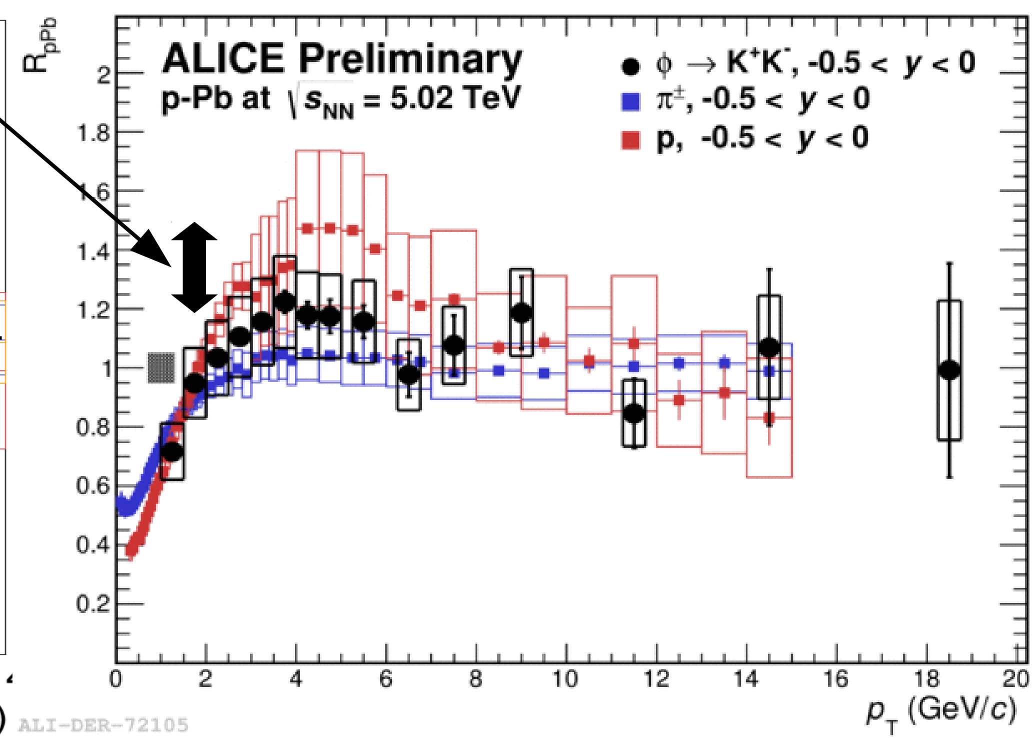
- Enhancement for Ξ and p
- Increase of peak with multiplicity faster for heavier than lighter
  → mass ordering π → K → p → Ξ
- Mass ordering similar in Pb-Pb and p-Pb
  → flow in p-Pb?



p-Pb – identified – R_{pA}

- Enhancement for Ξ and **p**
- Increase of peak with multiplicity faster for heavier than lighter
  → mass ordering **π** → **K** → **p** → Ξ
- Mass ordering similar in Pb-Pb and p-Pb
  → flow in p-Pb?
- **ϕ** breaks the mass ordering ($m_p \approx m_\phi$)





Summary

High p_T

- Same suppression is seen for all light quark systems created in Pb-Pb
  → the chemical composition of leading particles from jets in the medium is similar to that of vacuum jets
- No suppression in p-Pb seen
  → Pb-Pb suppression is a final-state hot-matter effect

Intermediate p_T: particle ratios

- Pb-Pb: K/π (mass dependent) enhancement
- Pb-Pb: ϕ has same spectra shape as p
  → supports hydrodynamic picture in central Pb-Pb collisions
- p-Pb: similar features as in Pb-Pb
  → collectivity in p-Pb?

Intermediate p_T: nuclear modification

- Pb-Pb: π, K, p mass ordering
- Pb-Pb: Ω enhanced compared to Ξ
  → Mass effect? Strangeness enhancement?
- p-Pb: mass ordering as in Pb-Pb
  But ϕ breaks mass ordering picture

Interplay between soft and hard physics

- New methods developed for this purpose, e.g. jet=peak-bulk
- Baryon/meson enhancement seems to be a bulk effect in both Pb-Pb and p-Pb, and unmodified in jet-like structures

Conclusions

- Many unresolved pieces in the puzzle; for Run-2 we need new concrete theoretical ideas or to ask the question in a new way that allows us to look for much smaller effects than we expected before Run-1

THANK YOU!

for you attention

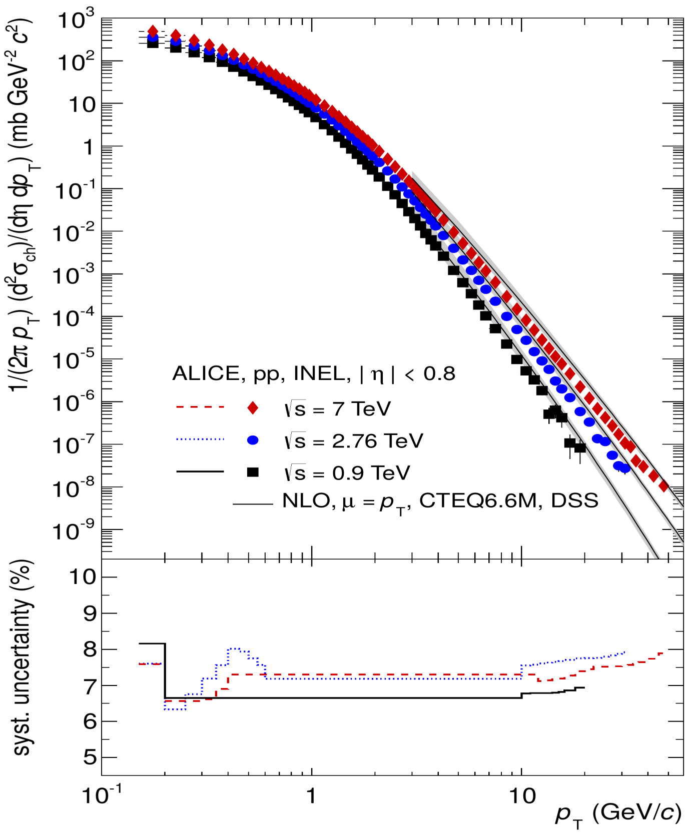
Old Swedish skiing movie that everyone should see to not feel bad in the piste tomorrow...

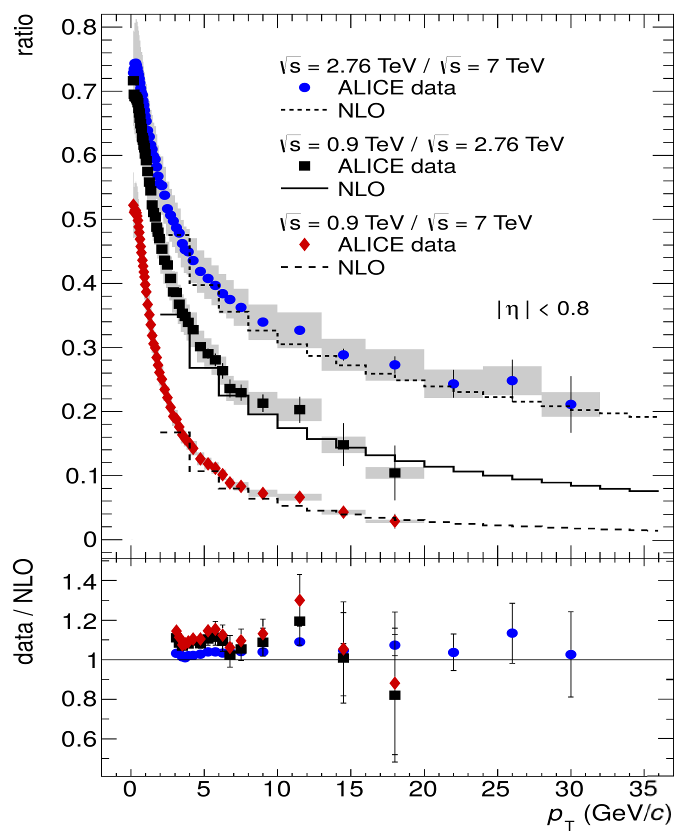
BACK UP

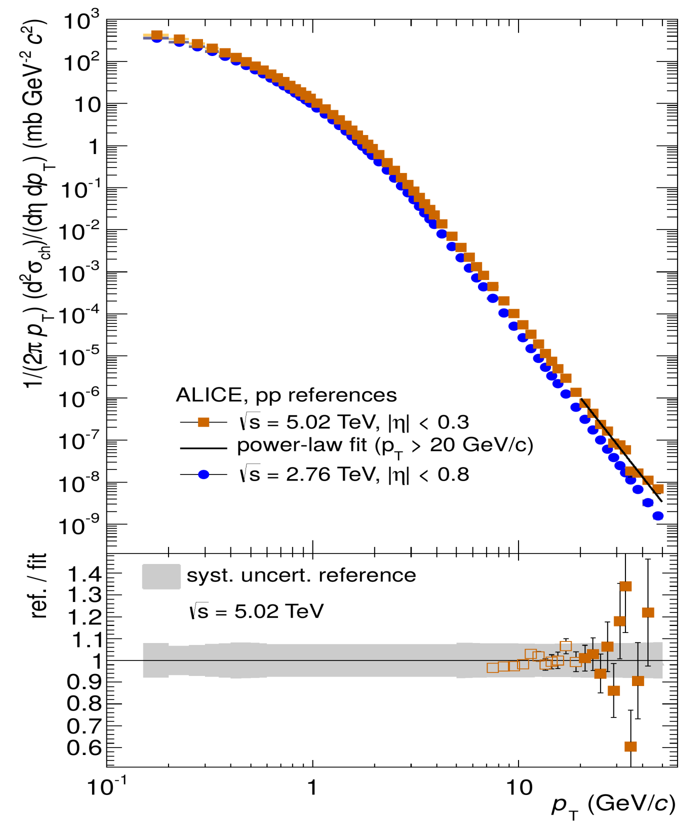
pp – all charged particles

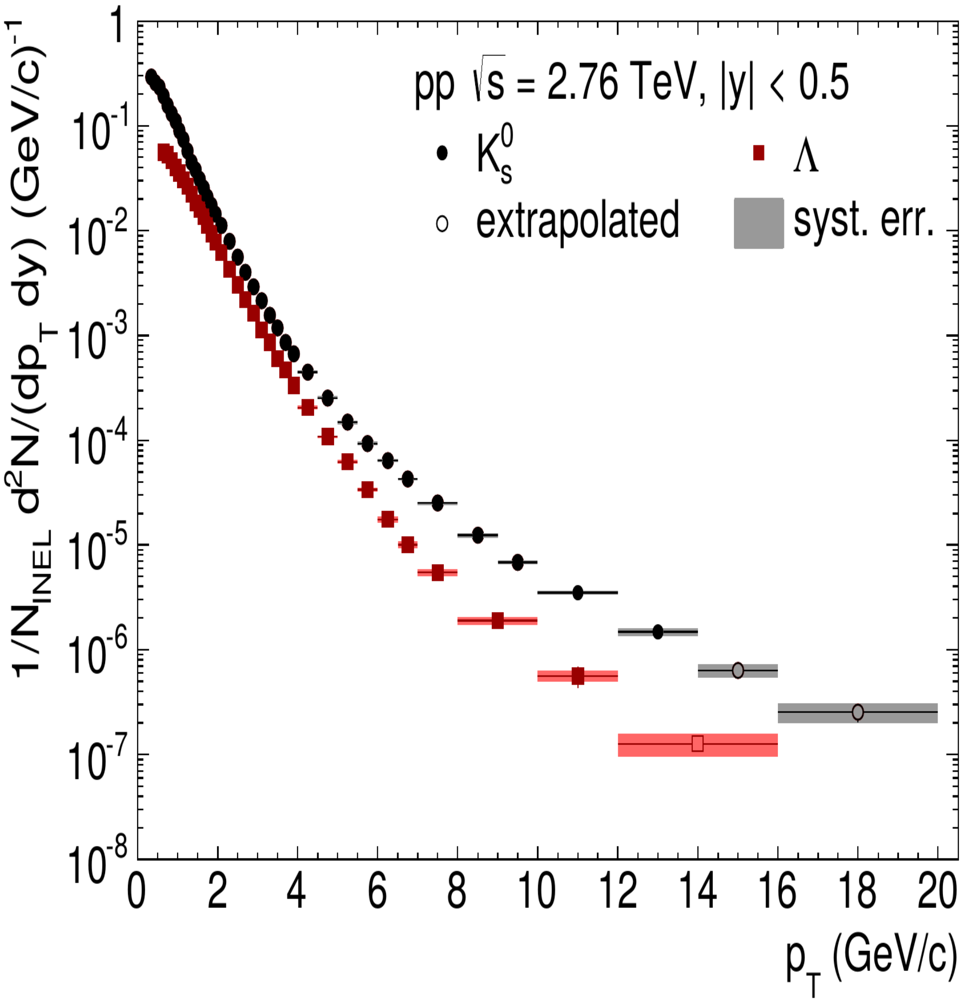
- Relative increase of cross section with √s agrees with NLO-pQCD
- Hard parton-parton scattering qualitatively described by NLO-pQCD → constraining parton distribution and fragmentation functions

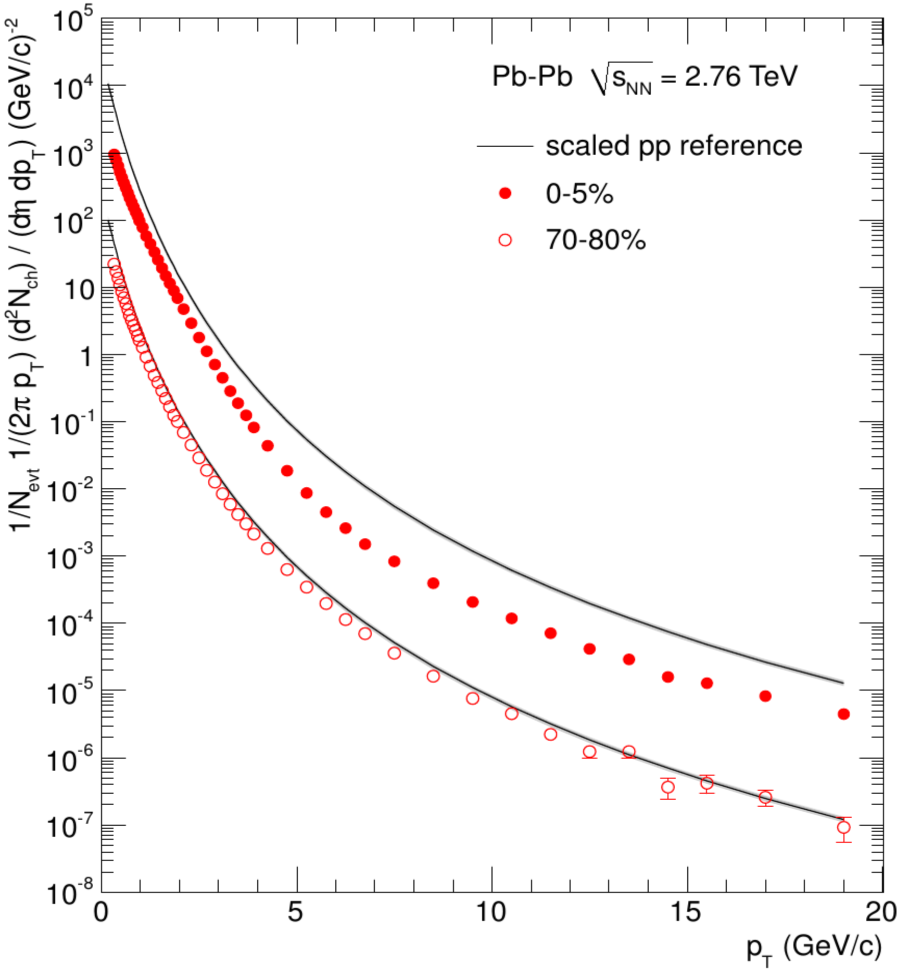
- Reference at √s = 2.76 TeV: pT>32 GeV/c: parametrization
- Reference at √s = 5.02 TeV:
  a) low pt: interpolation assuming power-law
  b) mid-high pt: scaled with ratio from NLO-pQCD
  c) very high pt: NLO-scaled reference is parametrized (power-law function)







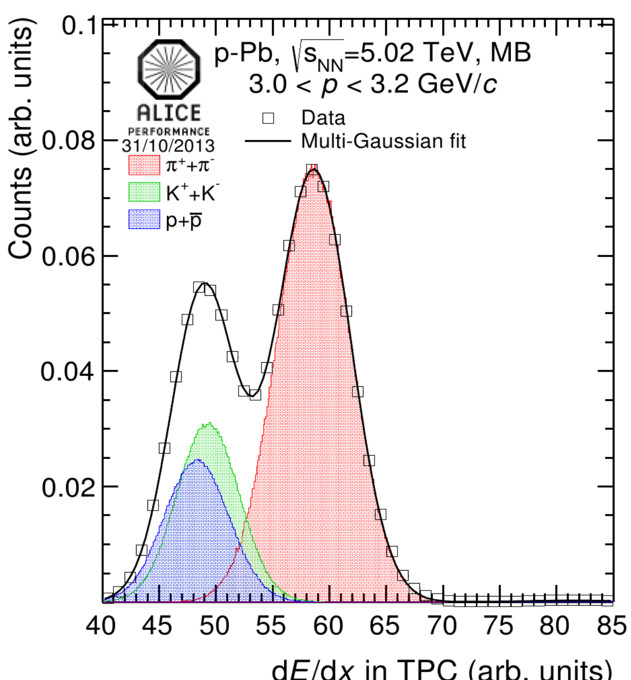

pp $\sqrt{s}$ = 2.76 TeV, |y| < 0.5
K^0_s
Λ
extrapolated
syst. err.
$1/N_{INEL}\ d^2N/(dp_T\ dy)\ (GeV/c)^{-1}$
p_T (GeV/c)

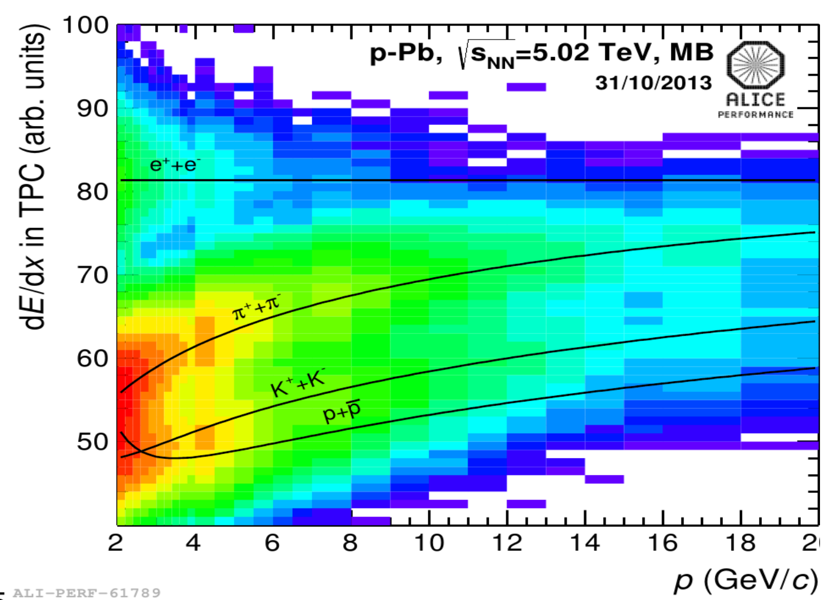

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
scaled pp reference
0-5%
70-80%
$1/N_{evt}\ 1/(2\pi\ p_T)\ (d^2N_{ch})\ /\ (d\eta\ dp_T)\ (GeV/c)^{-2}$
p_T (GeV/c)

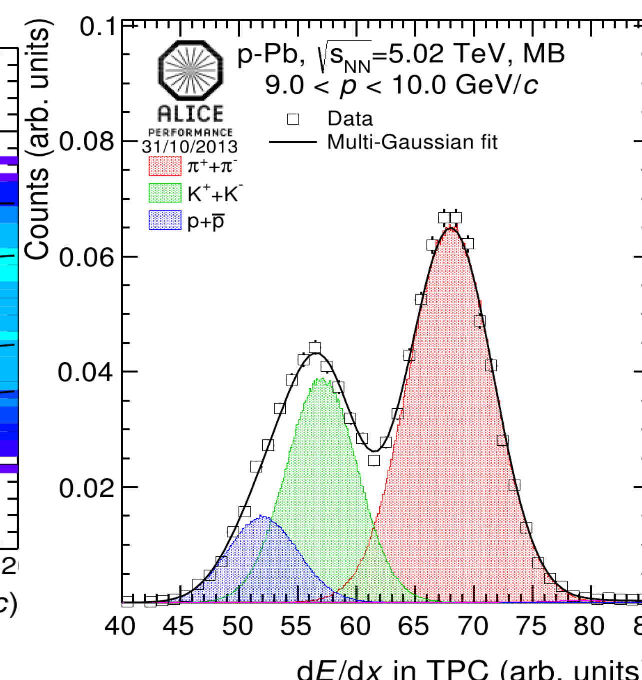
Pb-Pb – identified

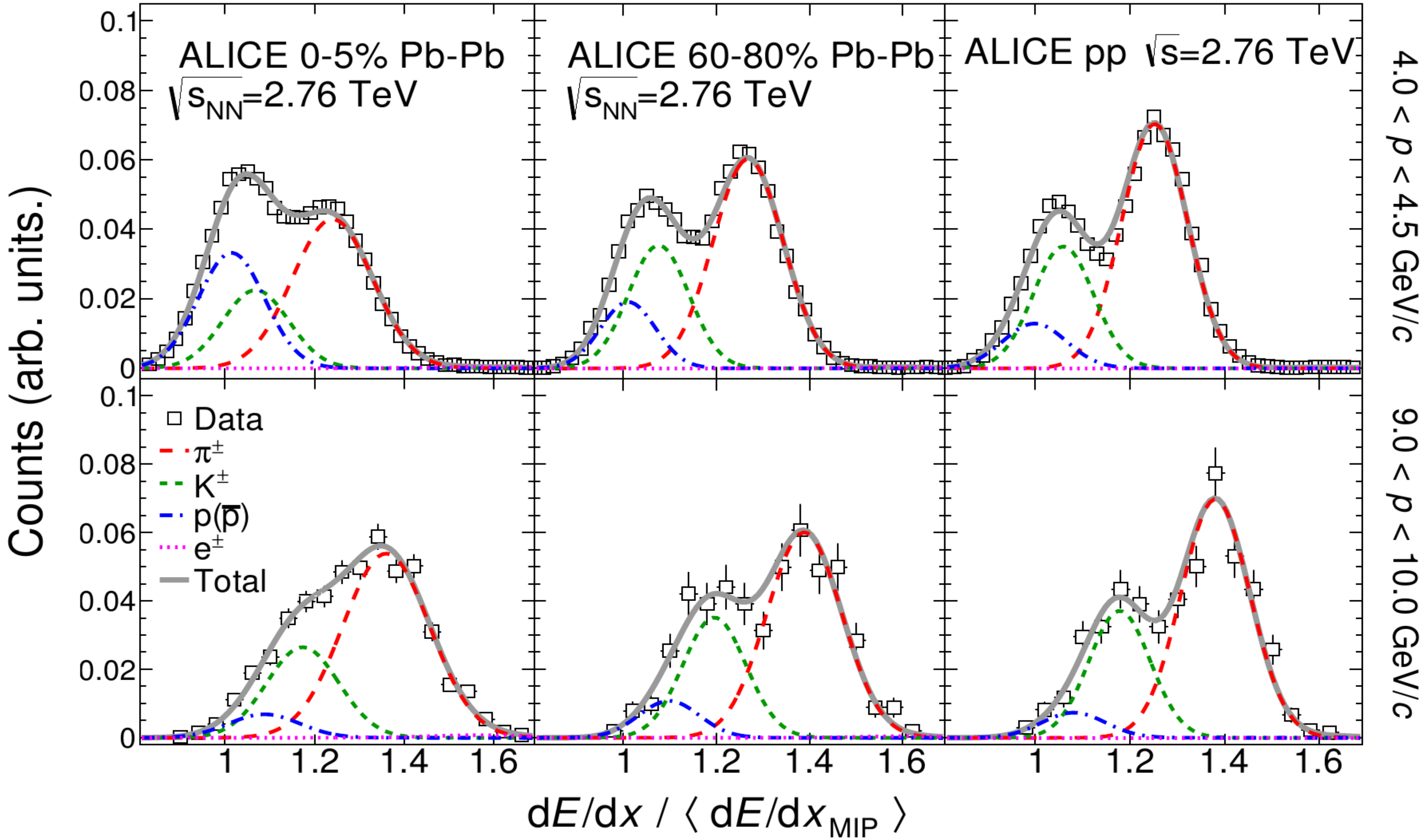
- Additional info by PID
  a) Differences of fragmentation and energy loss between quarks and gluons to baryons and mesons
  b) Differences in their interaction with the medium

- Relativistic rise: particle species not well separated
  → statistical PID needed
- dE/dx obtained as truncated mean of the 0-60% lowest charge samples associated with the track in the TPC
- Pion, kaon, and proton yields extracted by fitting a sum of four Gaussian
- Secondary pions and protons obtained from K^0_s and Λ decays
  → fix peak positions and widths
  → 12 → 4 degrees of freedom

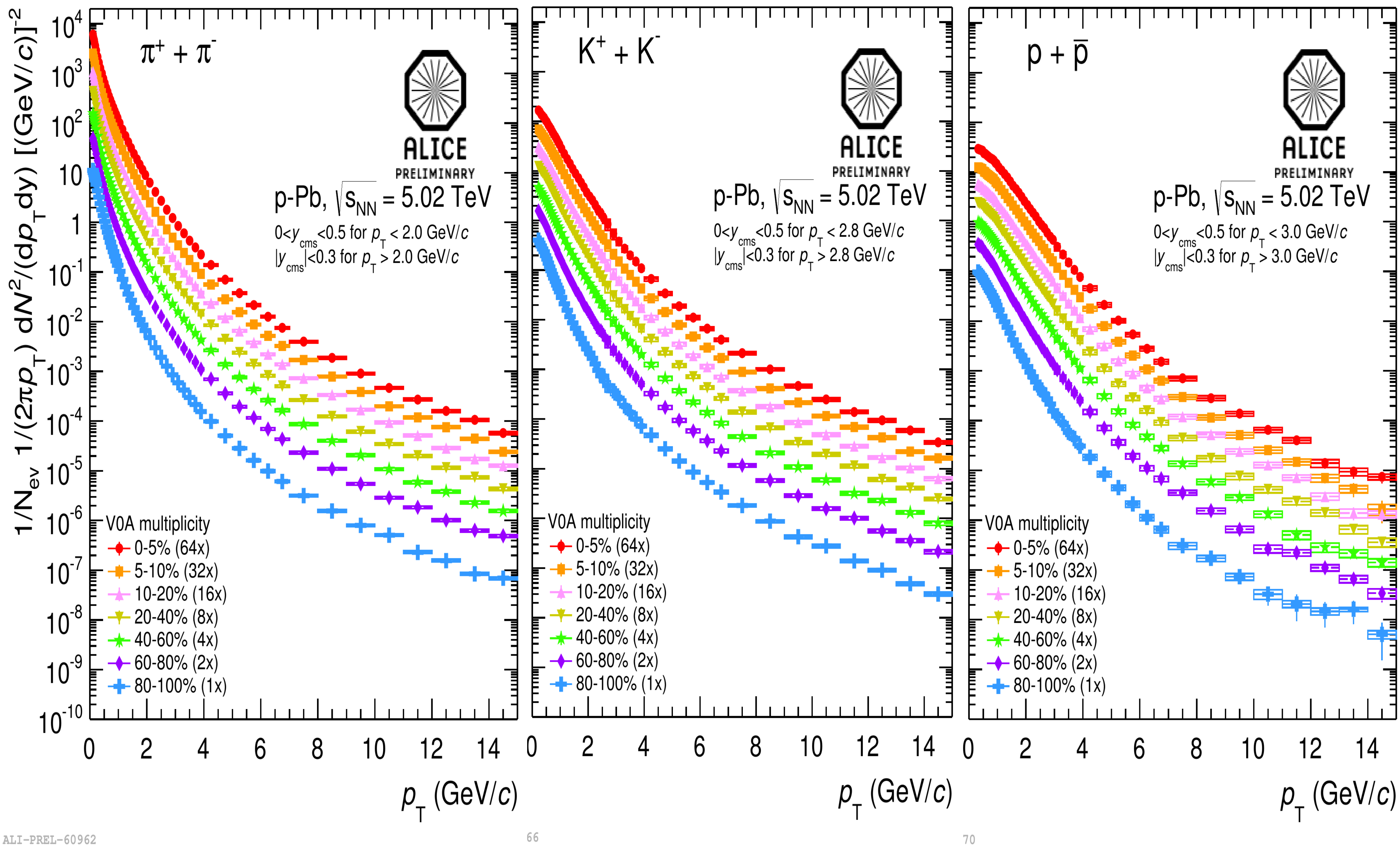




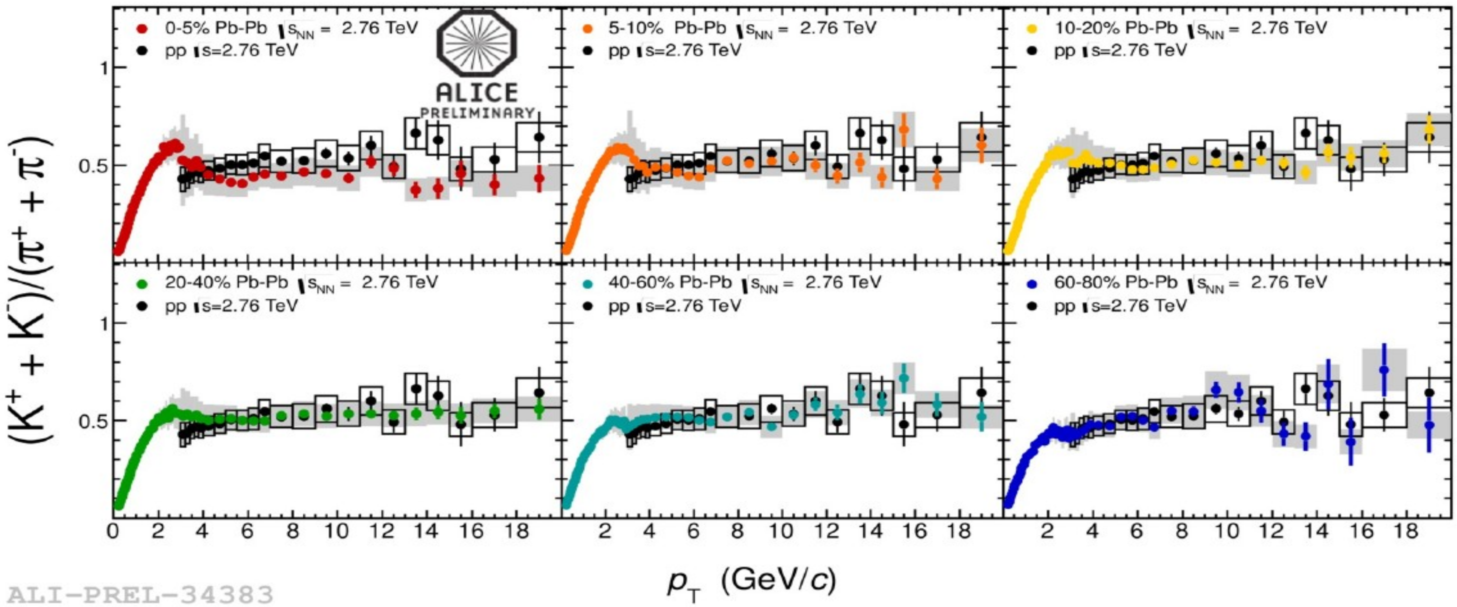




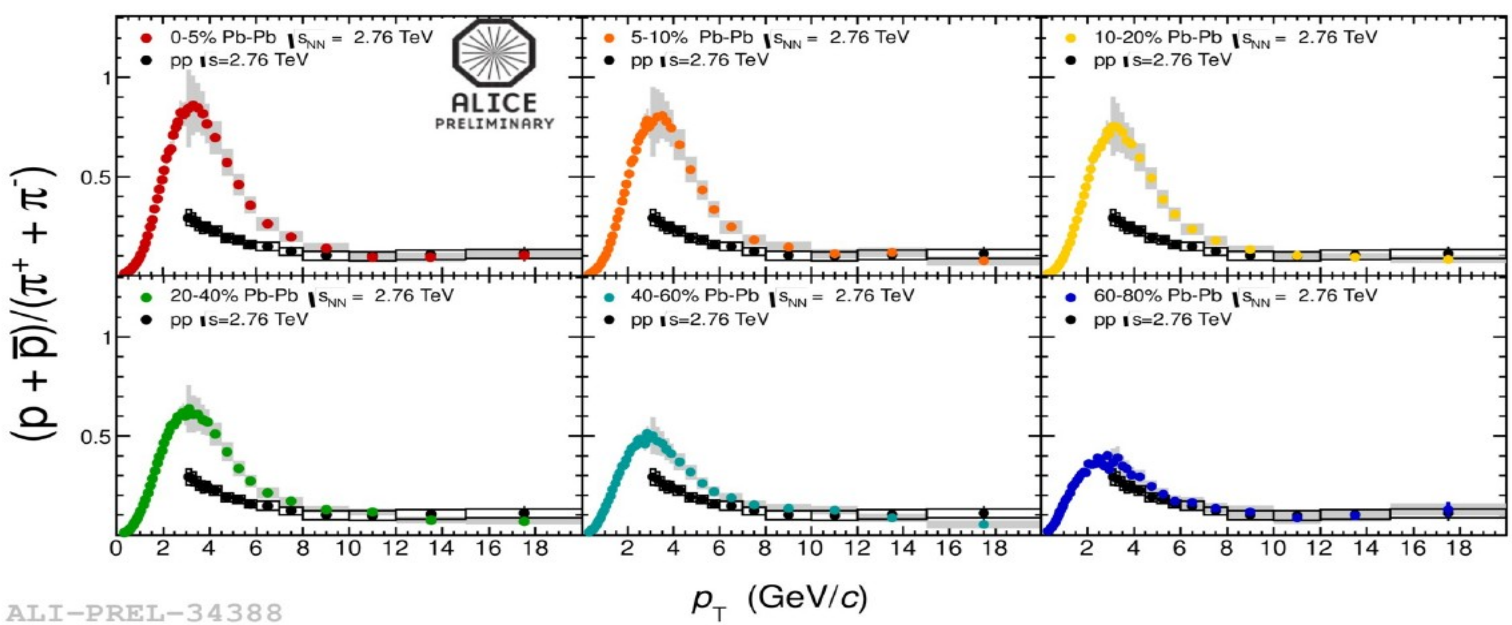
- dE/dx distributions measured for $|\eta| < 0.2$ and normalized to the integrated yields
- Signals fitted to a sum of four Gaussian functions (solid line)
- Two p intervals are shown for central (left) and peripheral (center) Pb–Pb; and pp (right) collisions
- Individual yields are shown as dashed curves



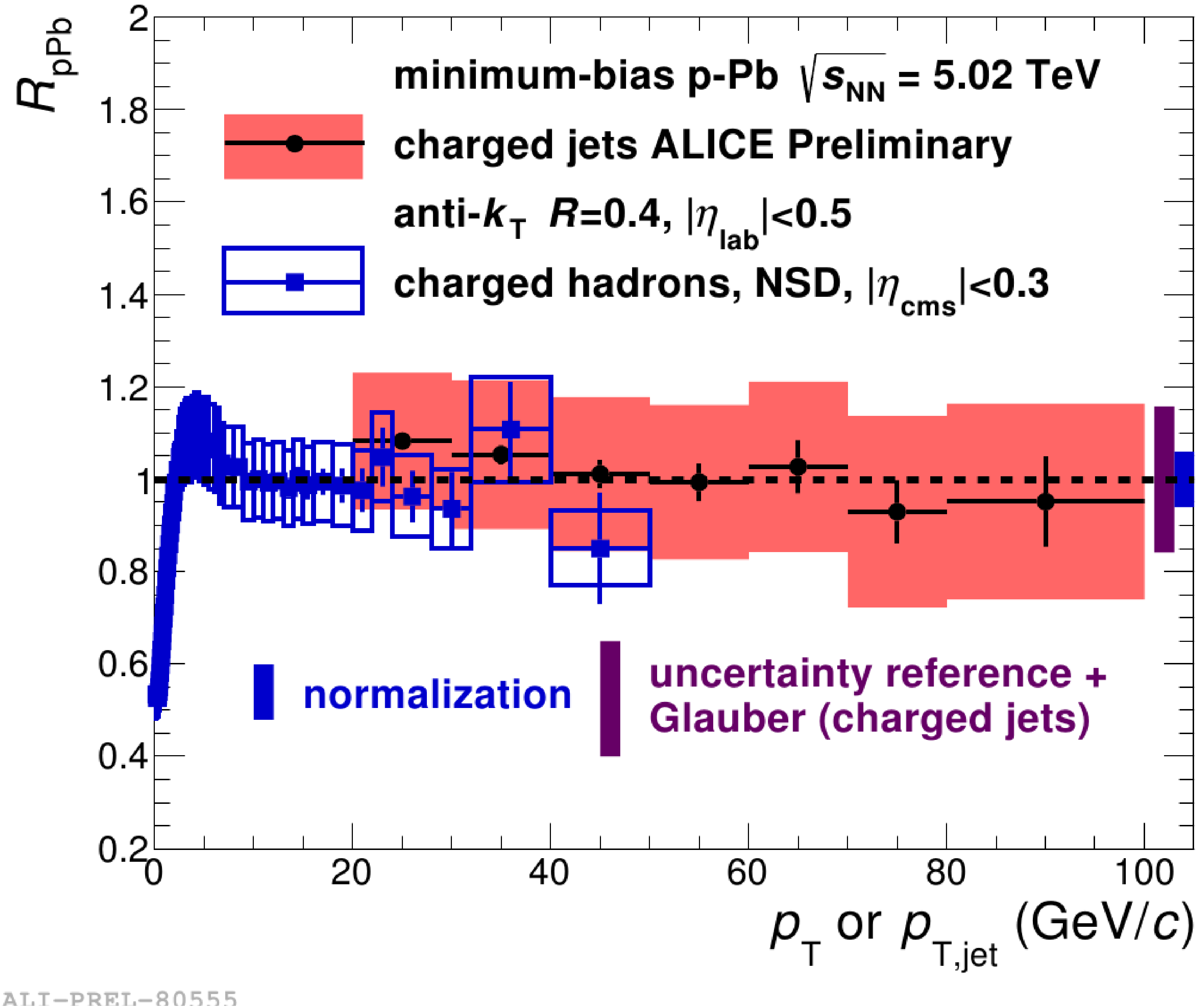
π+ + π-
K+ + K-
p + p̄
ALICE PRELIMINARY
p-Pb, √sNN = 5.02 TeV
0<ycms<0.5 for pT < 2.0 GeV/c
|ycms|<0.3 for pT > 2.0 GeV/c
0<ycms<0.5 for pT < 2.8 GeV/c
|ycms|<0.3 for pT > 2.8 GeV/c
0<ycms<0.5 for pT < 3.0 GeV/c
|ycms|<0.3 for pT > 3.0 GeV/c
V0A multiplicity
0-5% (64x)
5-10% (32x)
10-20% (16x)
20-40% (8x)
40-60% (4x)
60-80% (2x)
80-100% (1x)
1/Nev 1/(2πpT) dN2/(dpTdy) [(GeV/c)]-2
pT (GeV/c)
ALI-PREL-60962



In the intermediate p_T region: 2-7 GeV/c, the ratio exhibits an evolution from the most central to the most peripheral Pb-Pb collisions.



Intermediate p_T: 2-7 GeV/c, enhancement of the baryon to meson ratio.



R_{pPb}
minimum-bias p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
charged jets ALICE Preliminary
anti-k_T R=0.4, $|\eta_{lab}|$<0.5
charged hadrons, NSD, $|\eta_{cms}|$<0.3
normalization
uncertainty reference +
Glauber (charged jets)
p_T or $p_{T,jet}$ (GeV/c)
ALI−PREL−80555