Resonances – hadronic interactions – system size dependence

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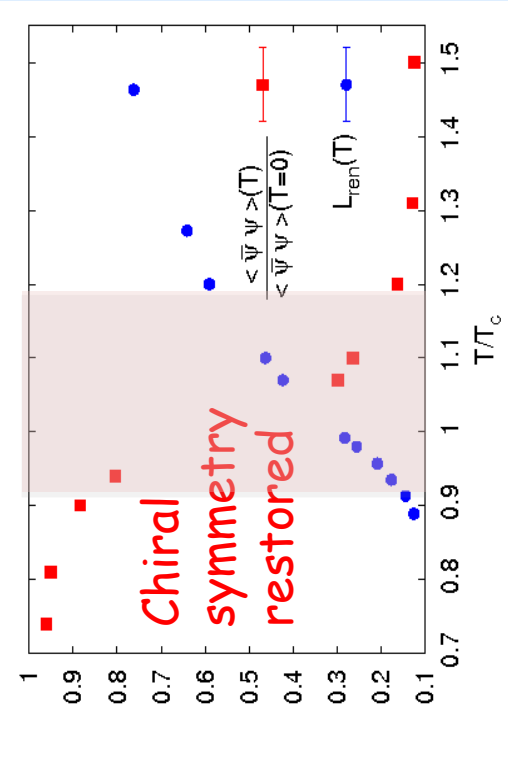
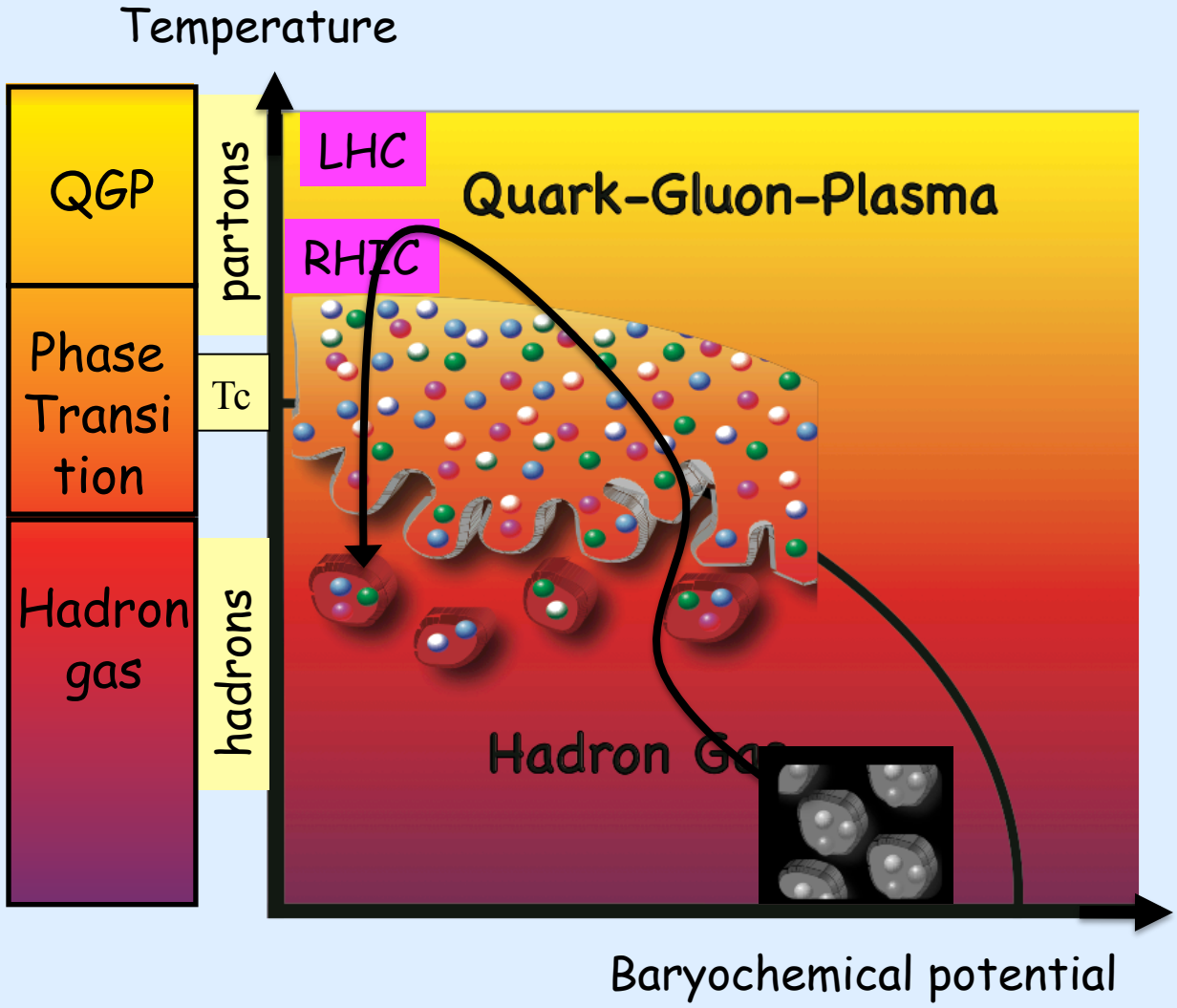
- Hadronic Phase
- ALICE K(892) + Φ(1020)
  - EPOS + UrQMD
- p-Pb data (medium ?)

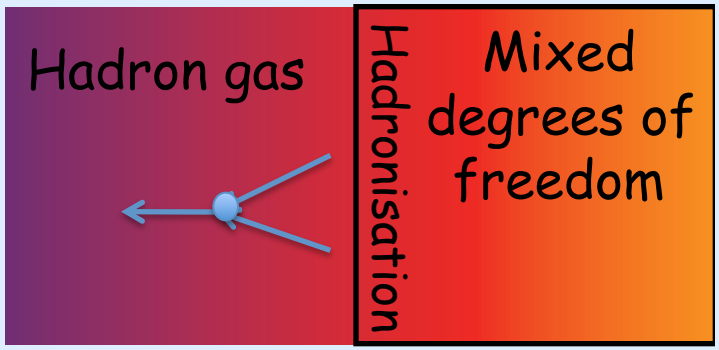
Phase diagram of nuclear matter (QCD)





2T(time and temperature) of hadronic medium

central A+A collision

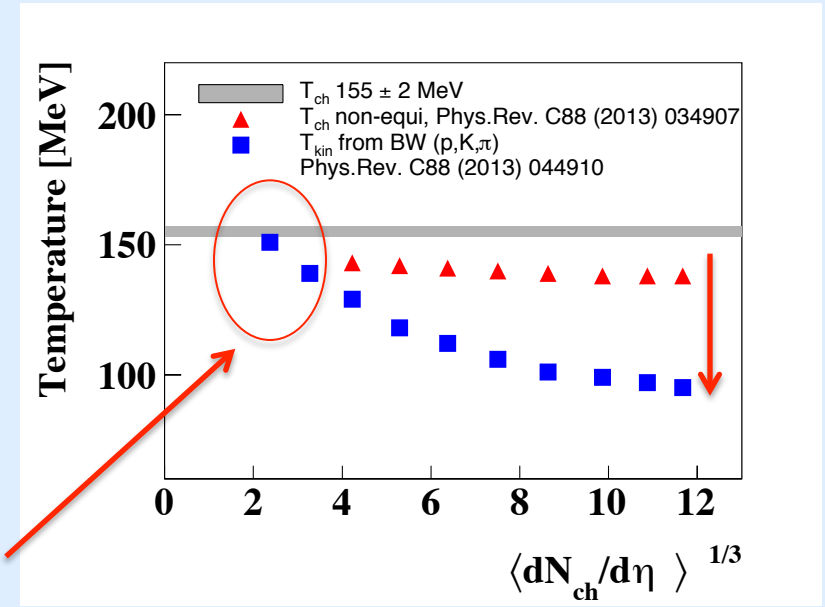


Kinetic freeze-out

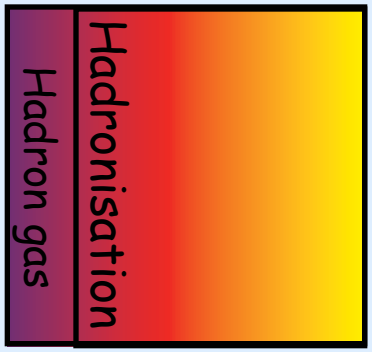
Chemical freeze-out

Centrality dependence

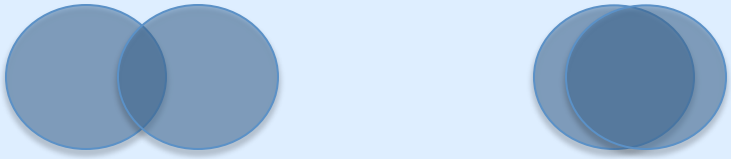
centrality dependence of temperature



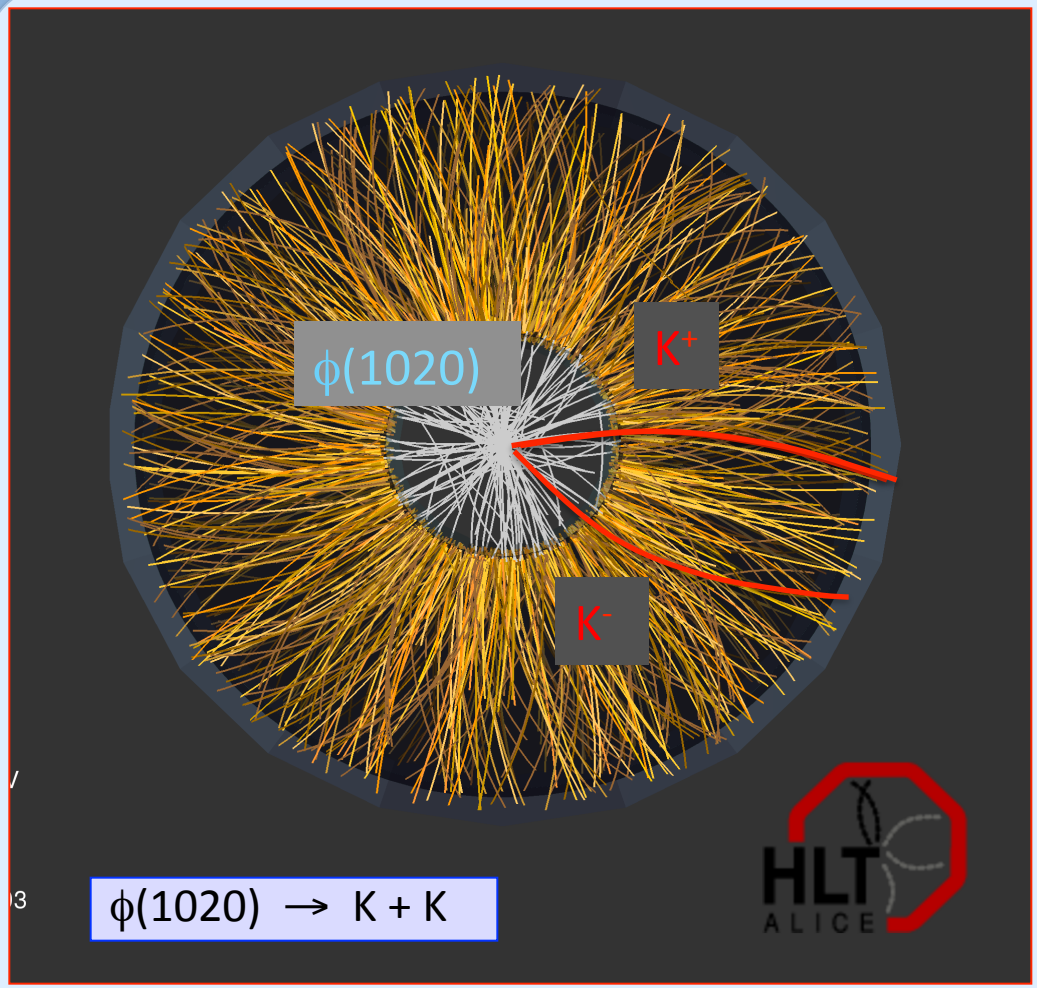
peripheral A+A collision



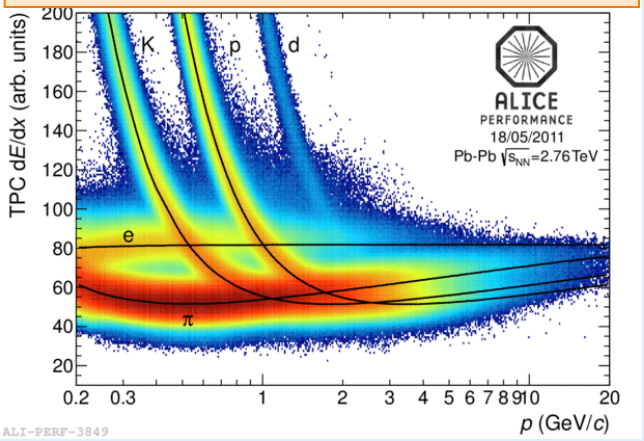
close to chemical freeze-out



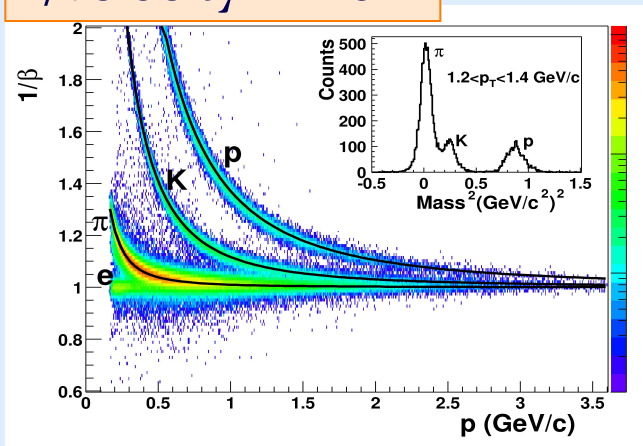
Resonance reconstruction



Energy loss in TPC dE/dx



1/velocity in ToF



K*(892) and ϕ(1020) production in Pb-Pb collisions at sqrt(sNN) = 2.76 TeV

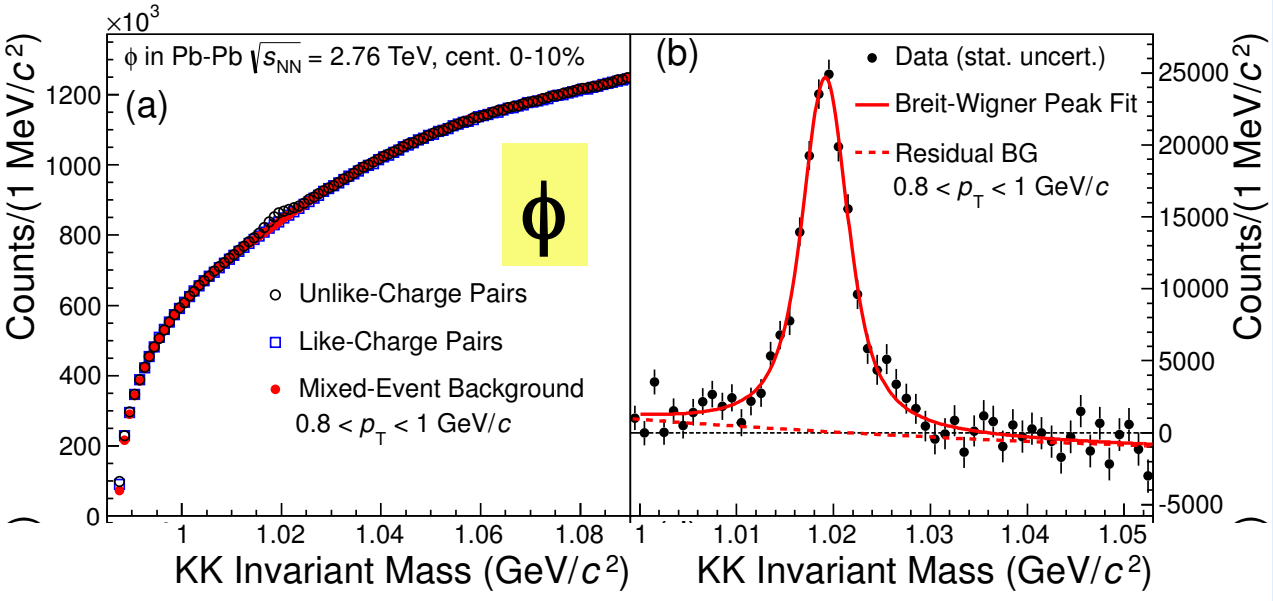
PRC91 (2015) 024609

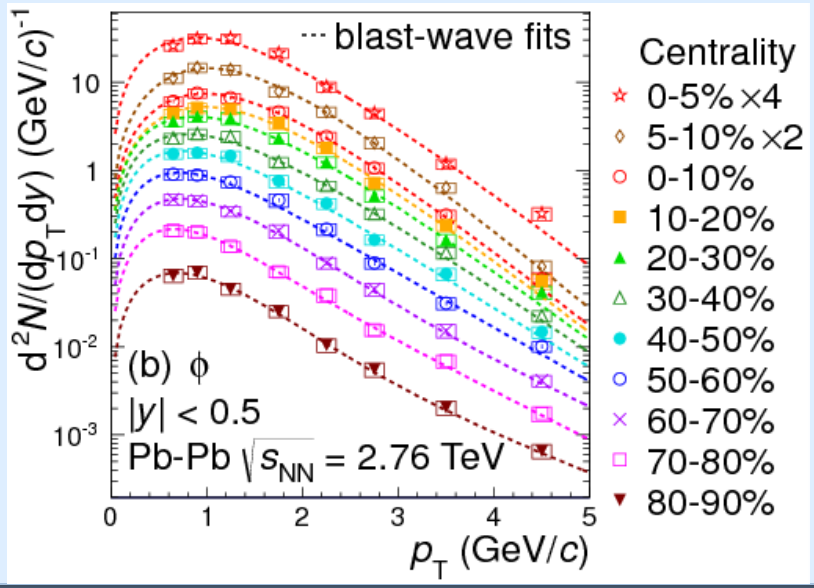
$$m_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

$\phi(1020) \rightarrow K^+ + K^-$

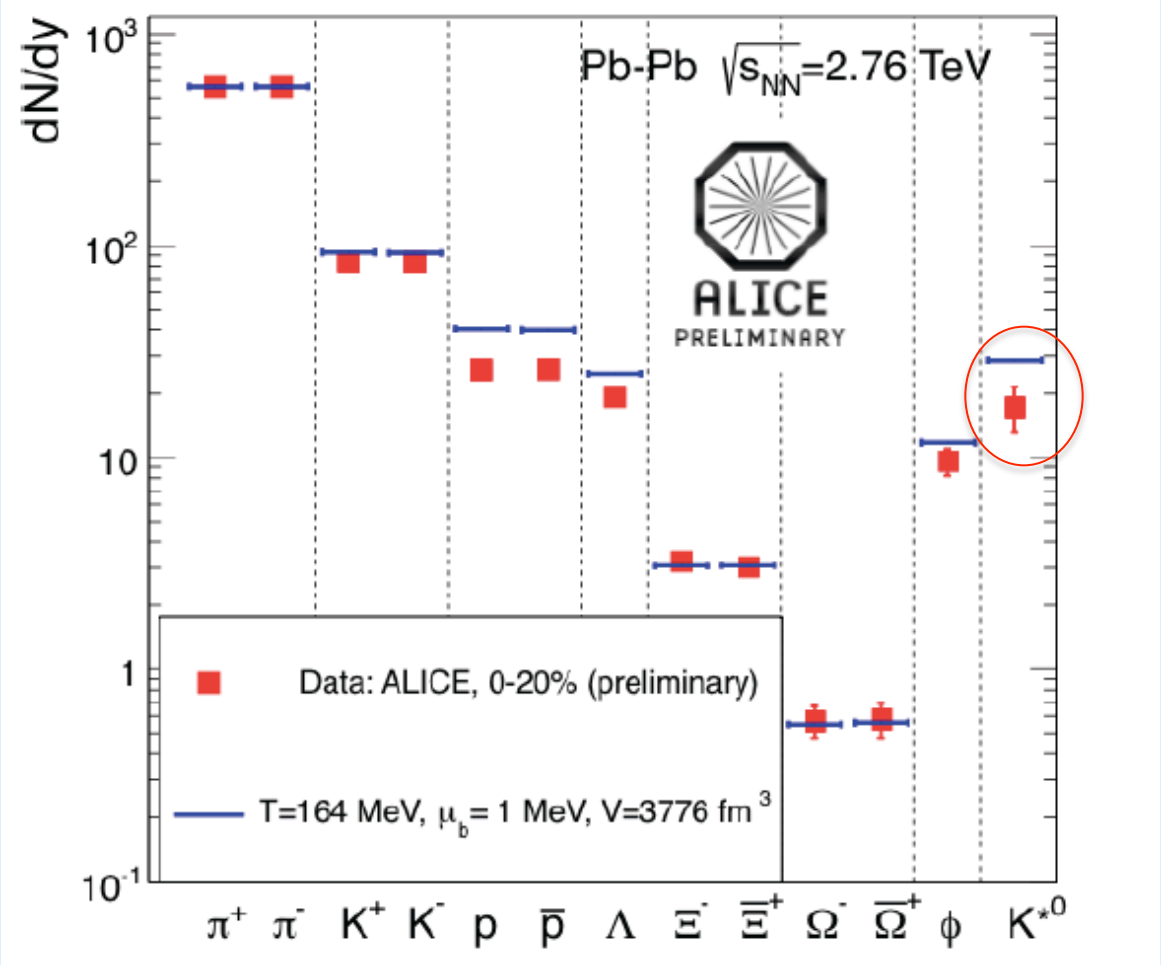
$K^*(892)^0 \rightarrow \pi^\pm + K^\pm$

Resonance signals and background





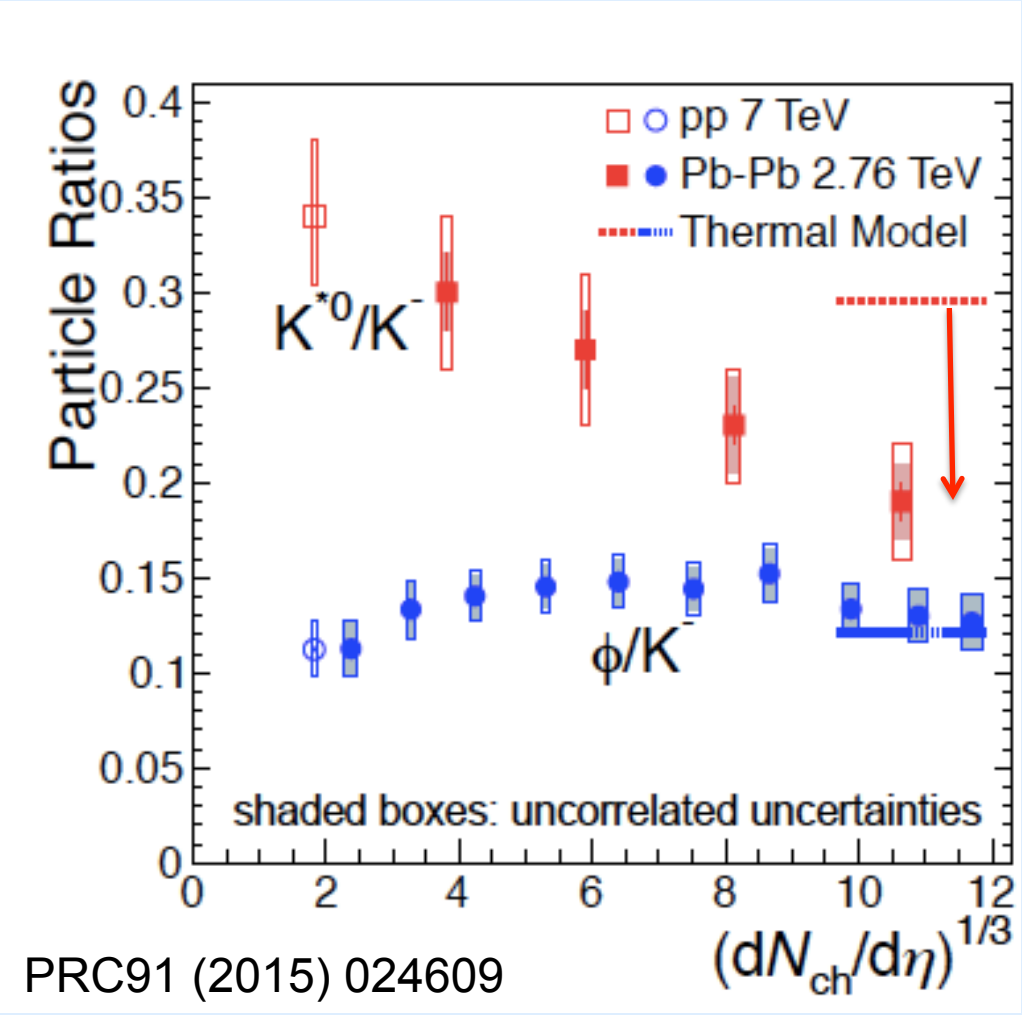
Resonances at chemical freeze-out (Pb-Pb)



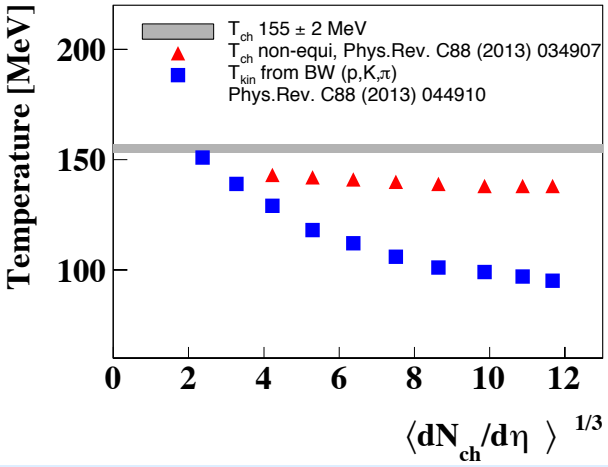
Chemical freeze-out:
T = 164 MeV

ϕ(1020) close to chemical freeze-out model (T= 164 MeV)
K* yield lower than predicted by chemical freeze-out model

Resonance ratio in Pb-Pb collisions (ALICE)



PRC91 (2015) 024609



RHIC: Hadronic lifetime > 4-5 fm/c (in central collisions)
Fireball lifetime ~ 10 fm/c
→**partonic lifetime ~ 5 fm/c**
CM, G. Torrieri and J. Rafelski, hep-ph/0206260

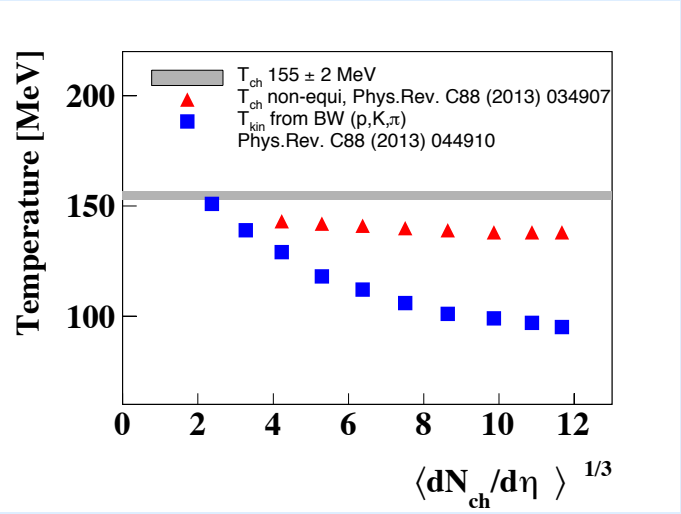
K*/K suppression vs centrality (volume)
ϕ/K does not show any suppression with respect to pp

Resonances in EPOS (+UrQMD)

AG Knospe, CM, K Werner, J Steinheimer, M Bleicher

Count resonances:

1.) EPOS + UrQMD OFF (~ 168 MeV)
from core + corona contribution
core ~ thermal distribution



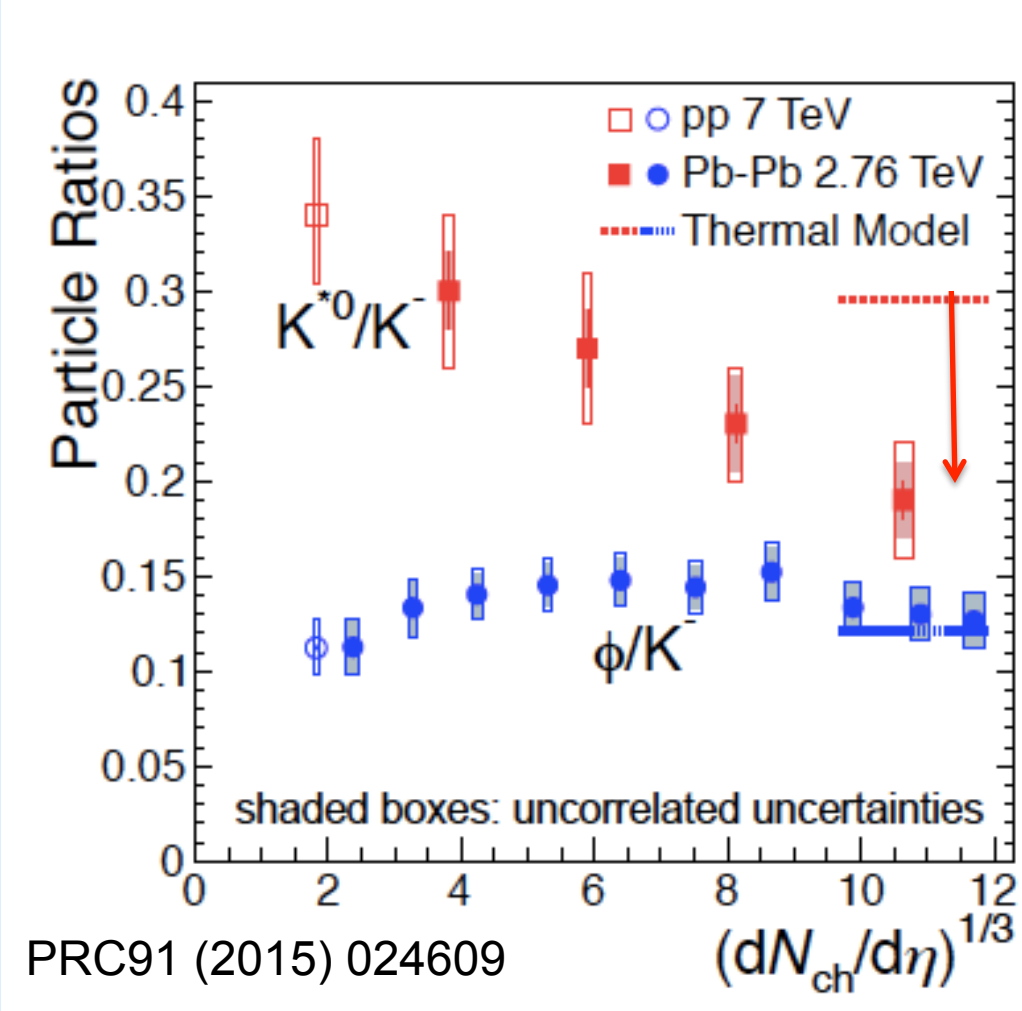
2.) EPOS + UrQMD ON

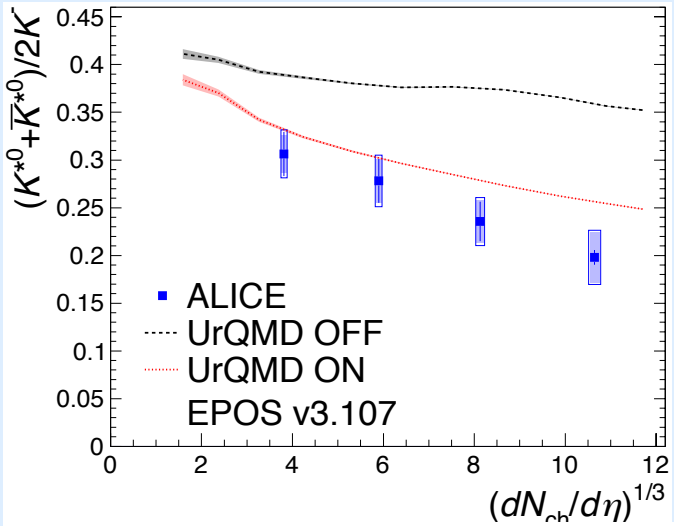
- follow decay particles in hadronic medium
- count resonance when all decay particles do not interact (elastic or pseudo-elastic)

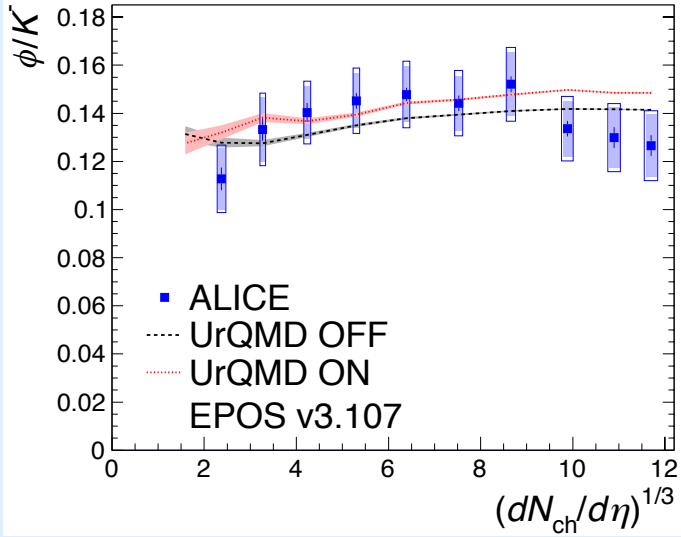
Resonance	decay channel	branching ratio	lifetime (fm/c)
$\rho(770)^0$	$\pi^+ + \pi^-$	1	1.335
$K^*(892)^0$	$\pi^- + K^+$	0.67	4.16
$\phi(1020)$	$K^+ + K^-$	0.489	46.26
$\Delta(1232)^{++}$	$\pi^+ + p$	1	1.69
$\Sigma(1385)^+$	$\pi^+ + \Lambda$	0.870	5.48
$\Sigma(1385)^-$	$\pi^- + \Lambda$	0.870	5.01
$\Lambda(1520)$	$K^- + p$	0.225	12.54
$\Xi(1530)^0$	$\pi^+ + \Xi^-$	0.67	22

Resonance ratios (EPOS+UrQMD)

AG Knospe, CM, K Werner, J Steinheimer, M Bleicher

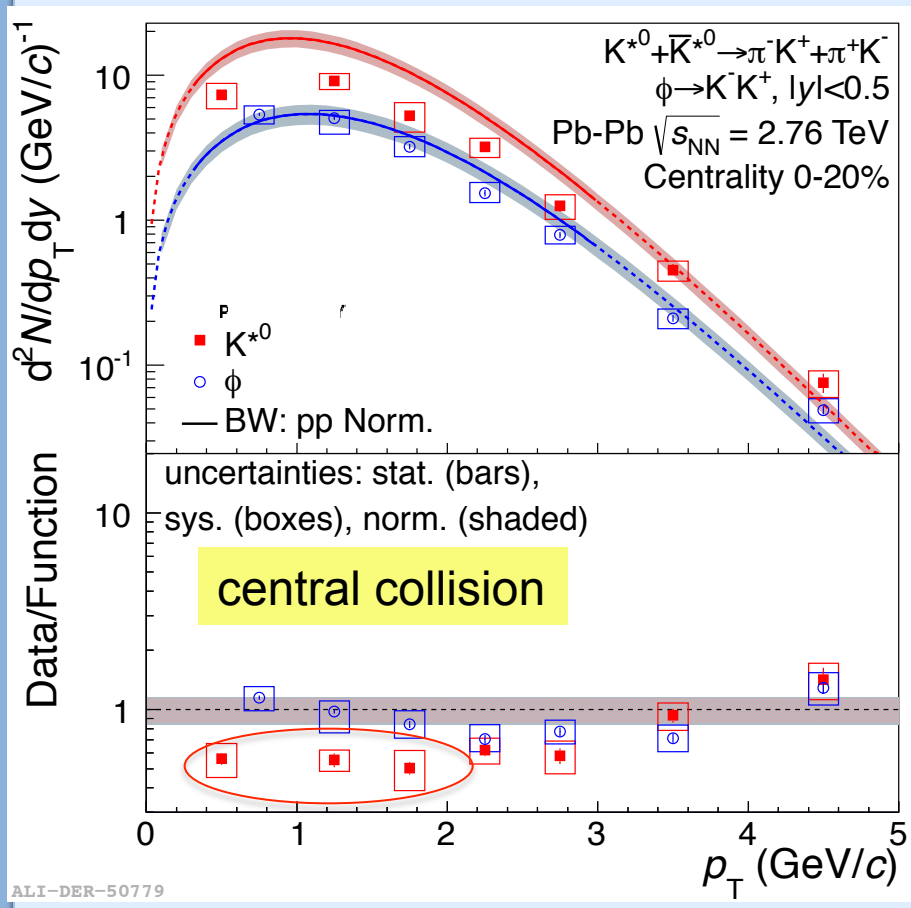


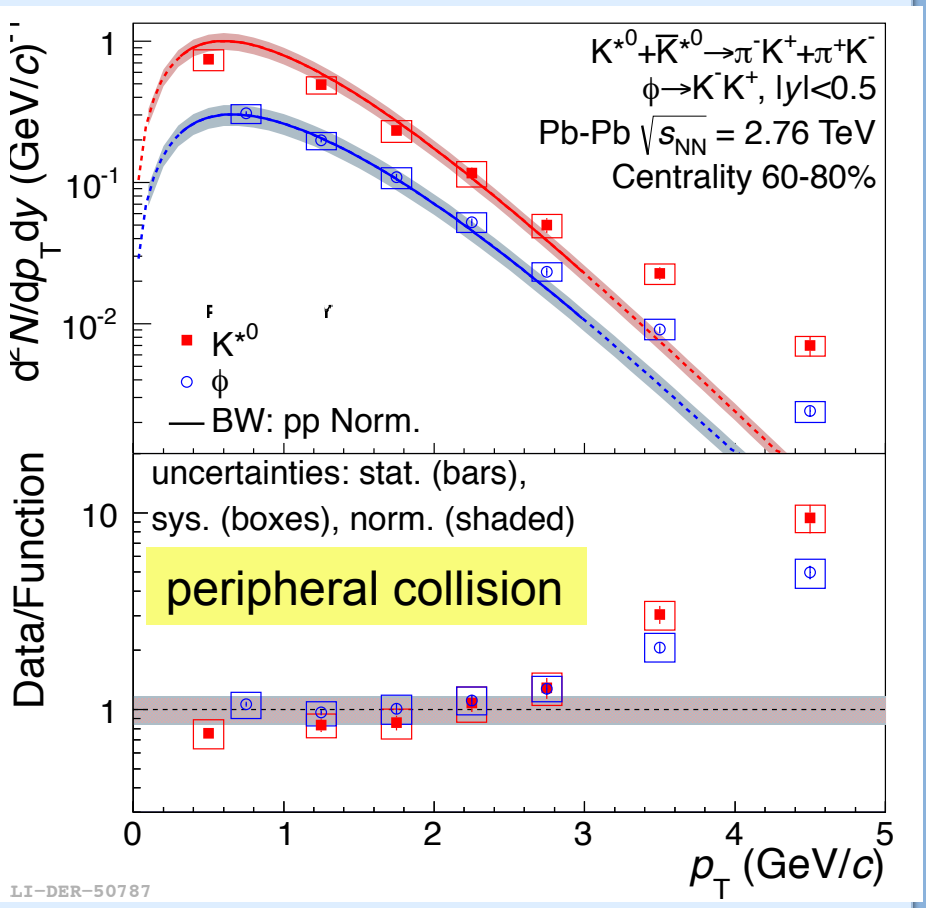




Comparison to Blast-Wave

BW from p,K and π , yield K*(PbPb) = K(PbPb) x K*(pp)/K(pp) (ϕ)

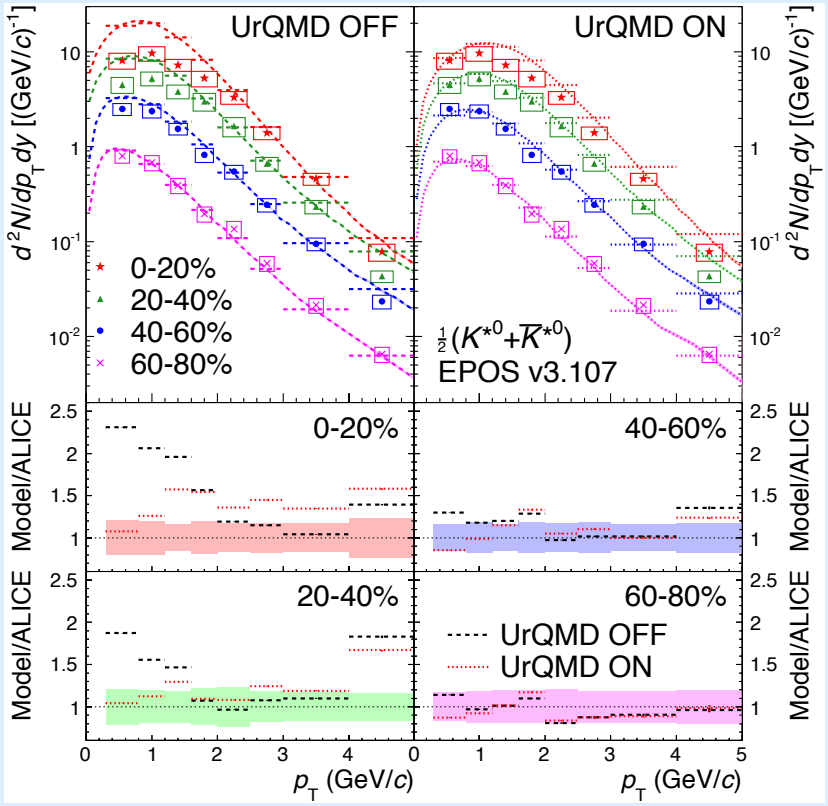


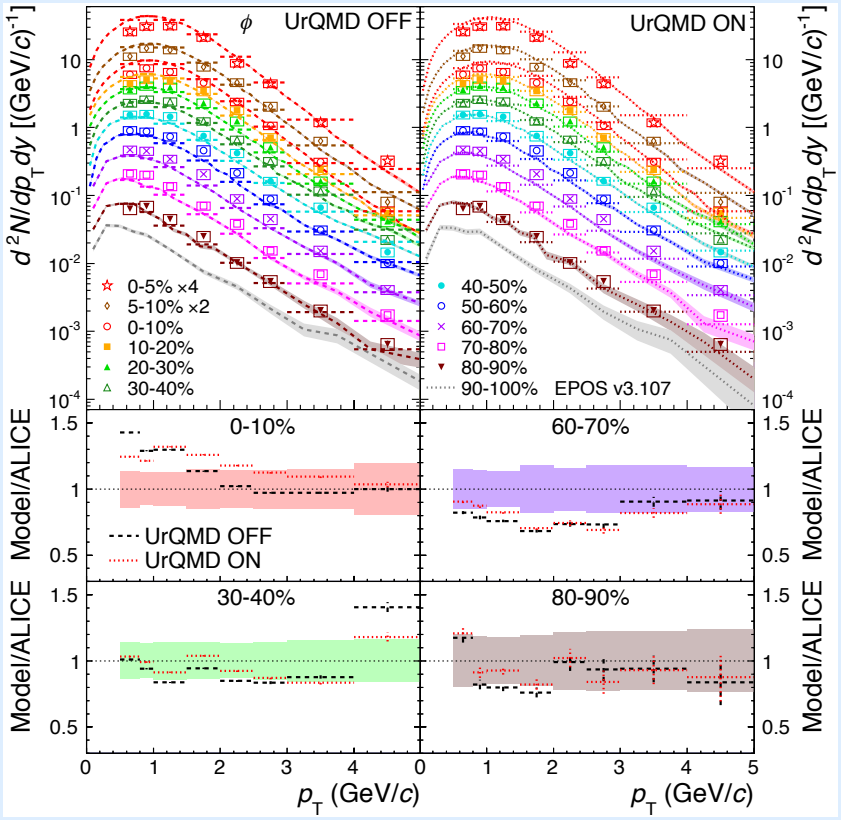


Re-scattering → K* signal loss in low p_T region in central collision

EPOS + UrQMD (OFF and ON)

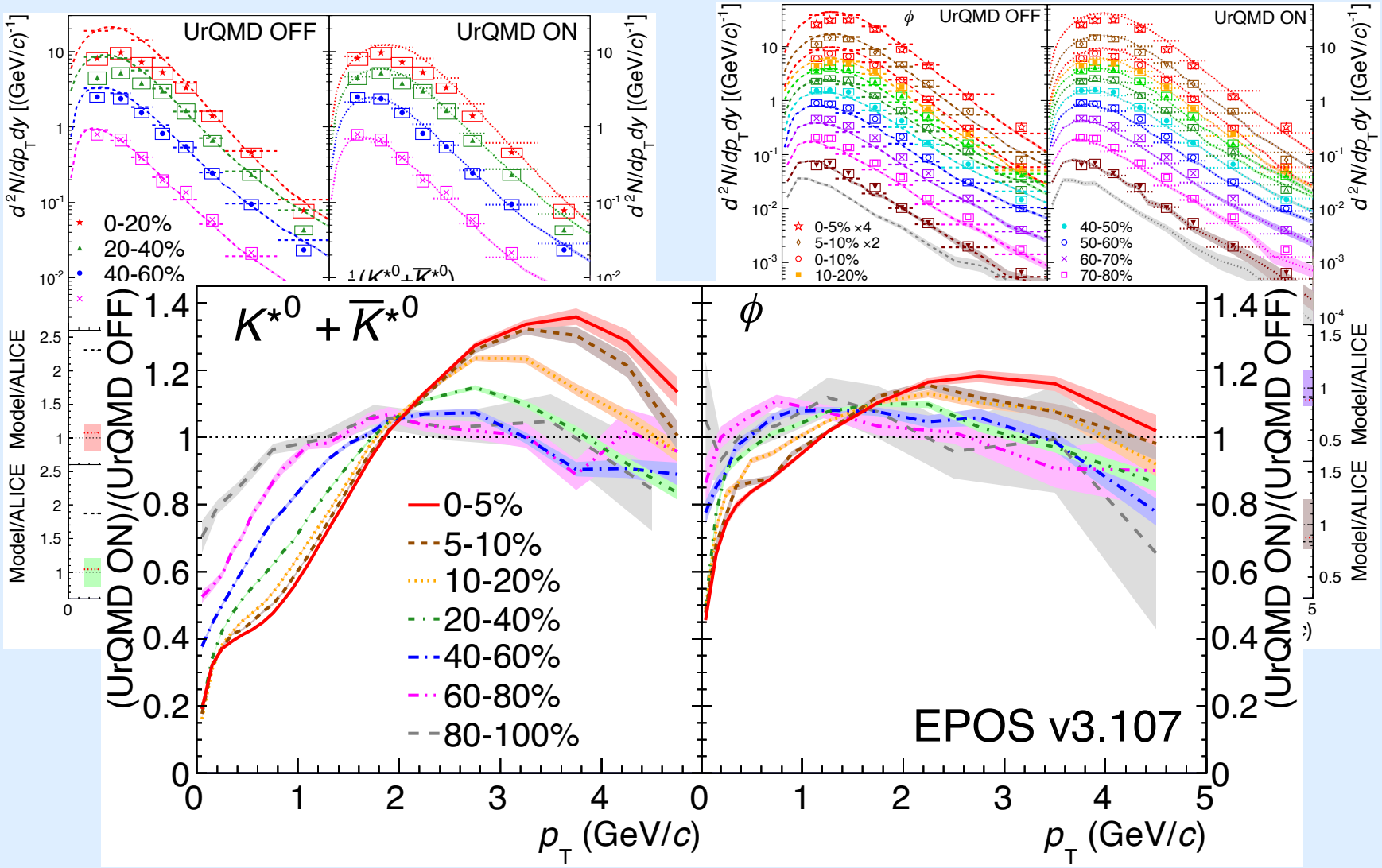
- hadronic phase



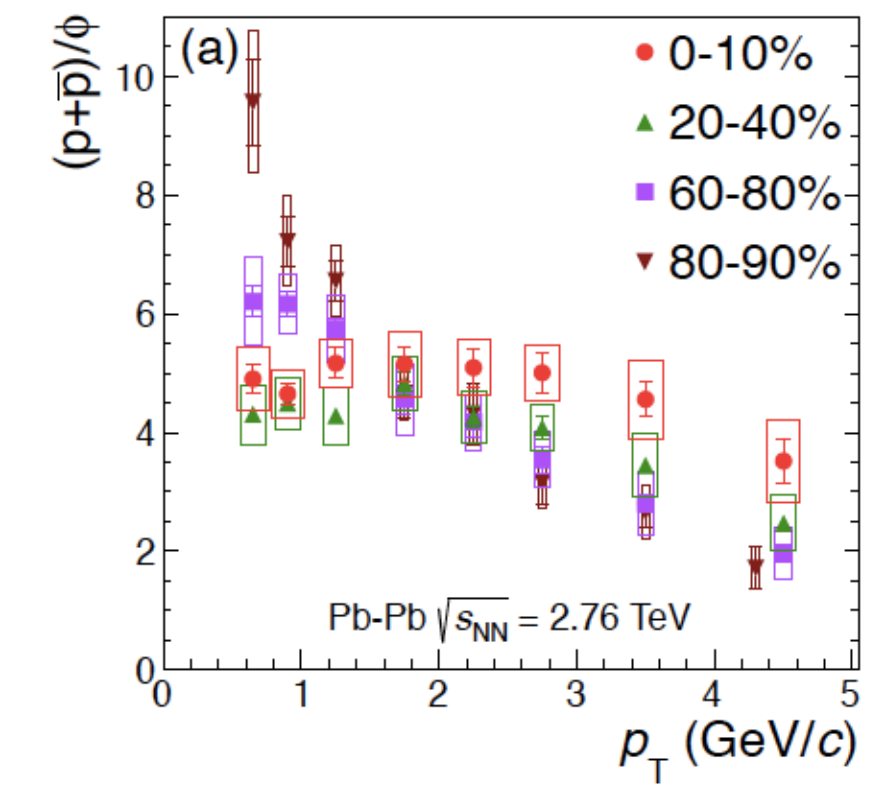


EPOS + UrQMD ON describes K* suppression in low p_T region

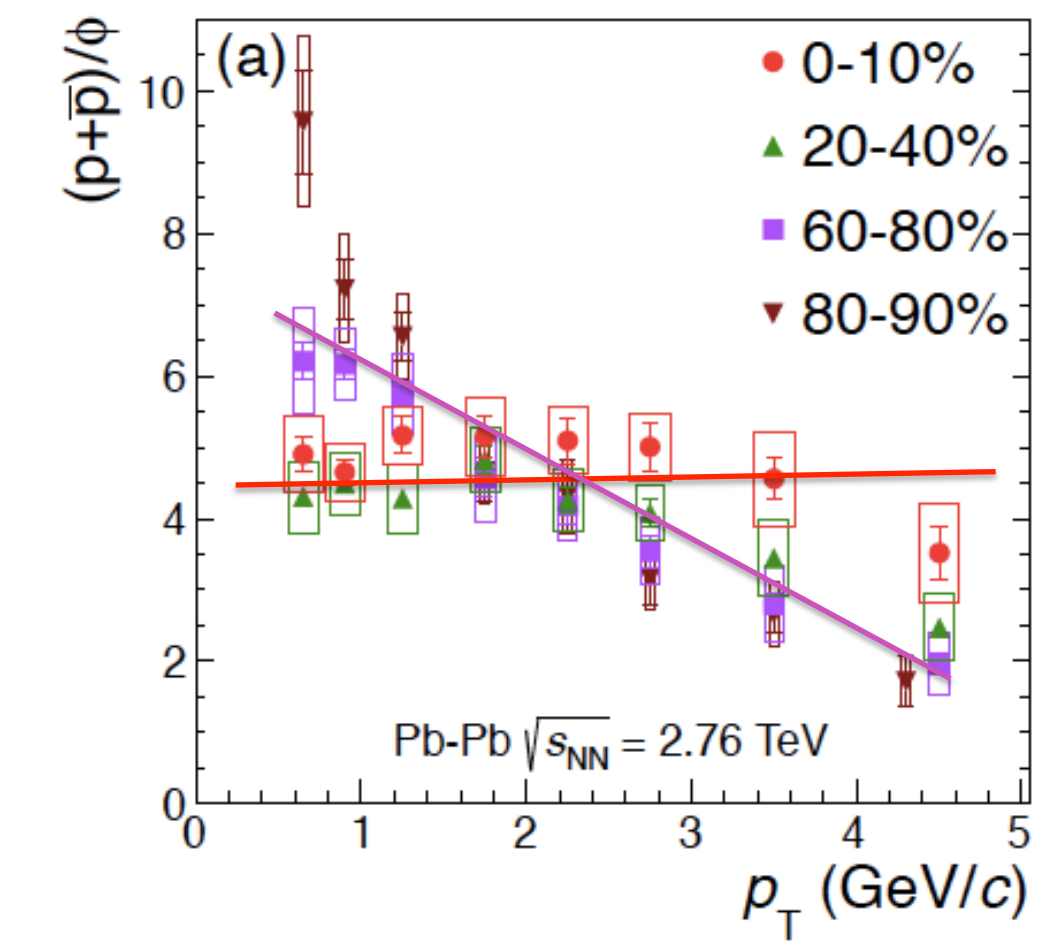
Momentum spectra – Data – EPOS+UrQMD



p/ϕ(1020 ratio (same mass)

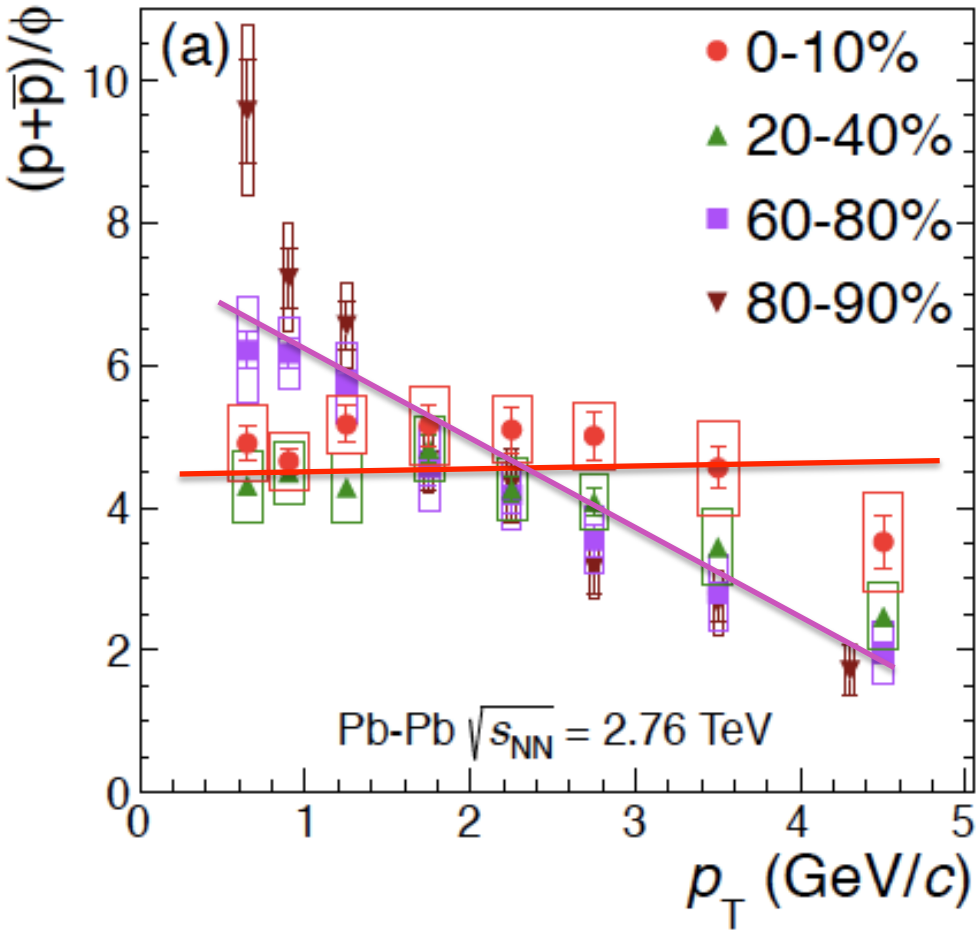


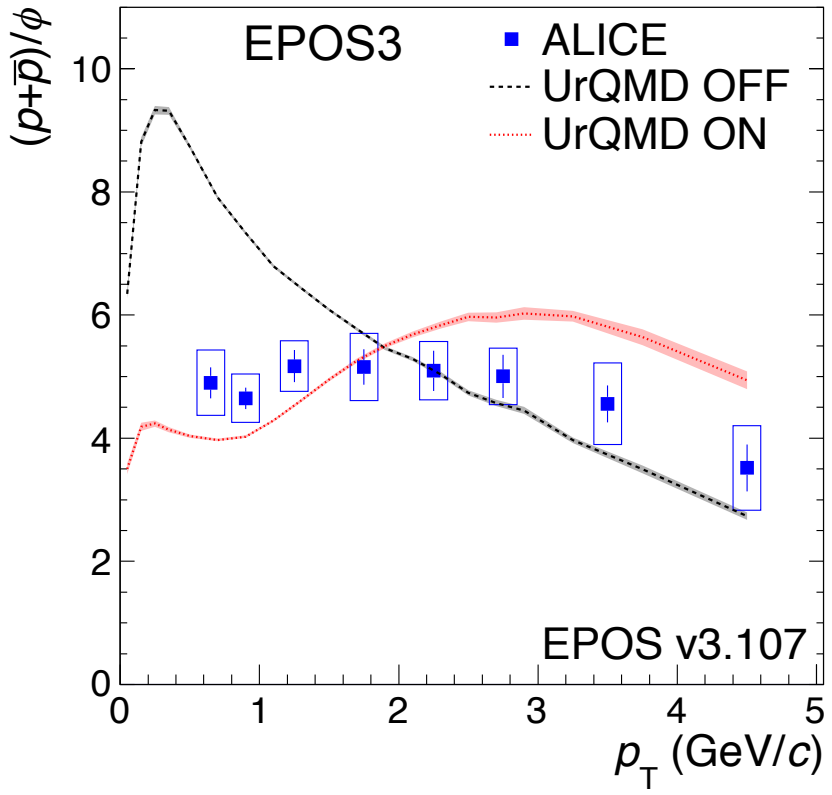
$\phi(1020)/p$ ratio (same mass)



Same mass: Looks like same radial flow effect in central Pb-Pb collisions, but not in peripheral collisions
→ different production mechanism in peripheral collisions ?

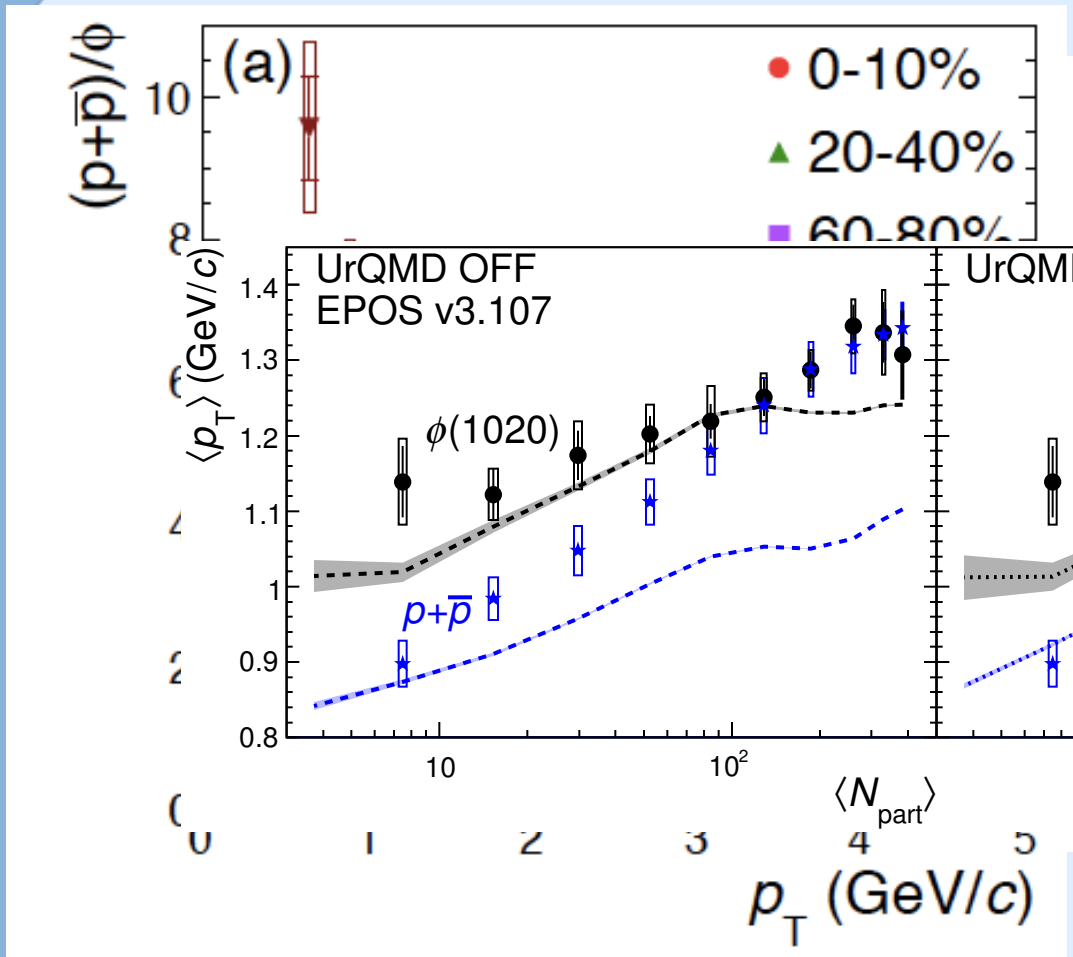
ϕ(1020)/p ratio (same mass)

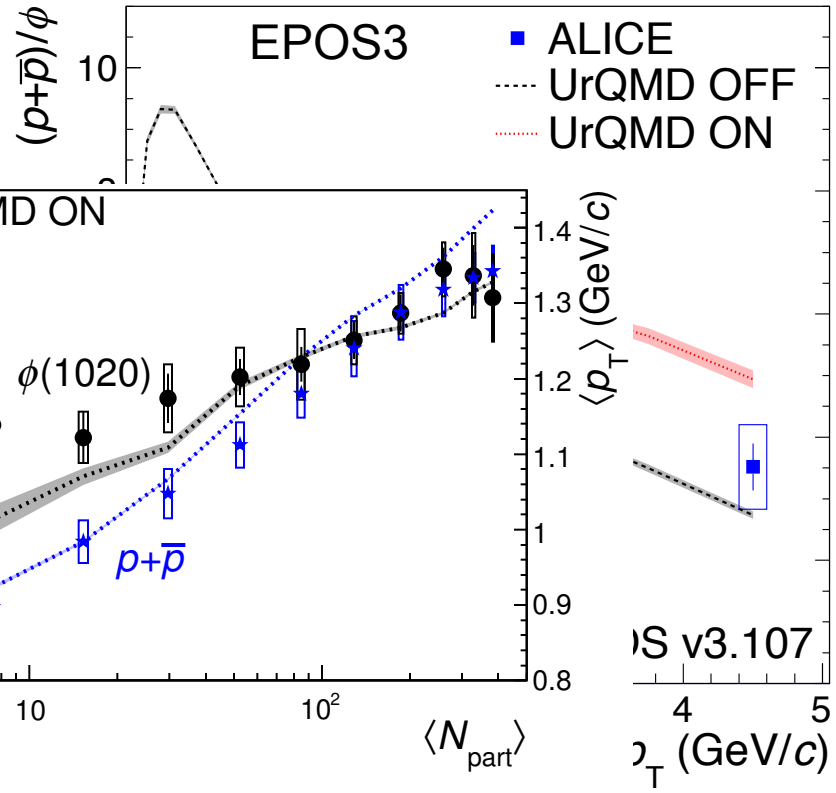




Same mass, same radial flow effect in central Pb-Pb collisions, but not in peripheral collisions
→ different production mechanism in peripheral collisions ?

$\phi(1020)/p$ ratio (same mass)



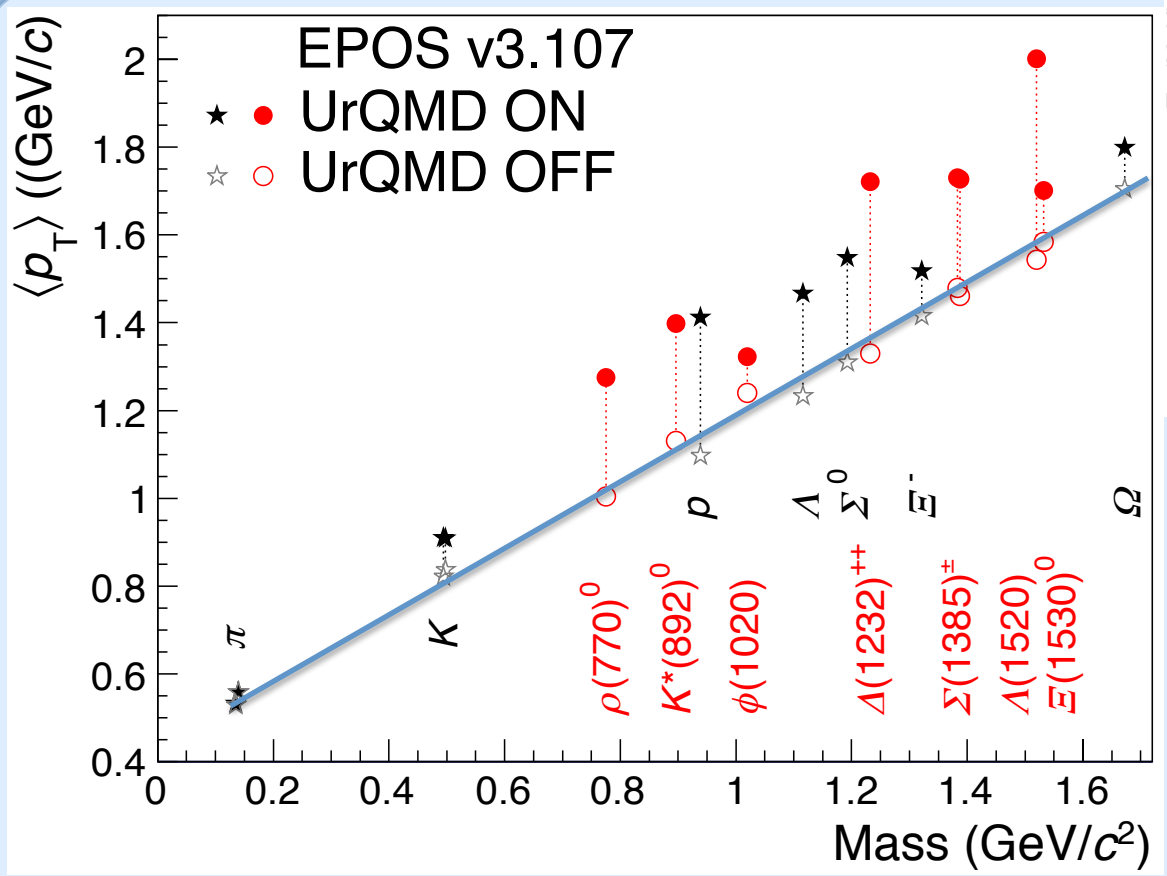


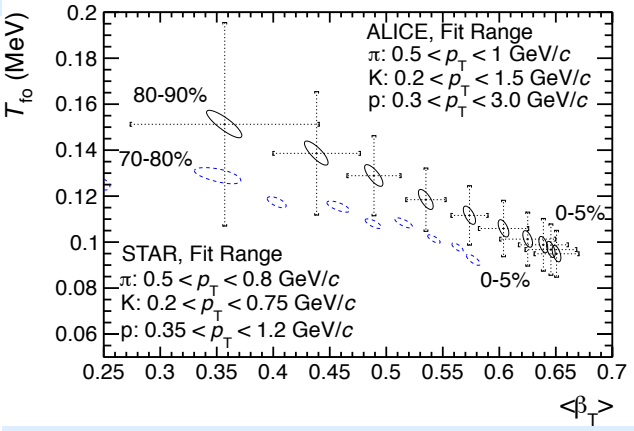
→ Hadronic phase has different contributions to momentum spectrum

Change of mean transverse momentum

- Scattering of decay daughters (resonances) (decrease low p_T)
- Directed flow (increase high p_T)
- Feed down from resonances and weak decays (increase high p_T)
- Annihilation (decrease low p_T)

Mean transverse momentum in Pb-Pb (0-5%)

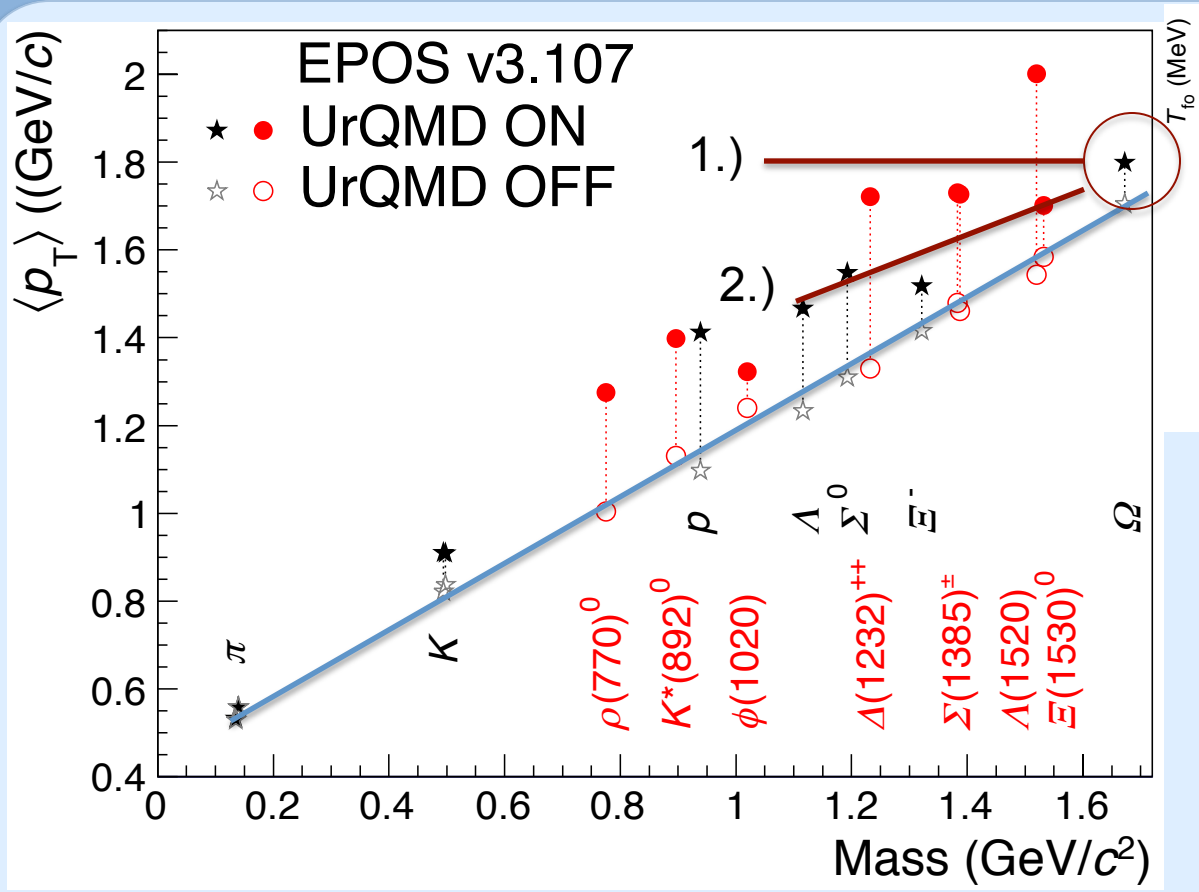


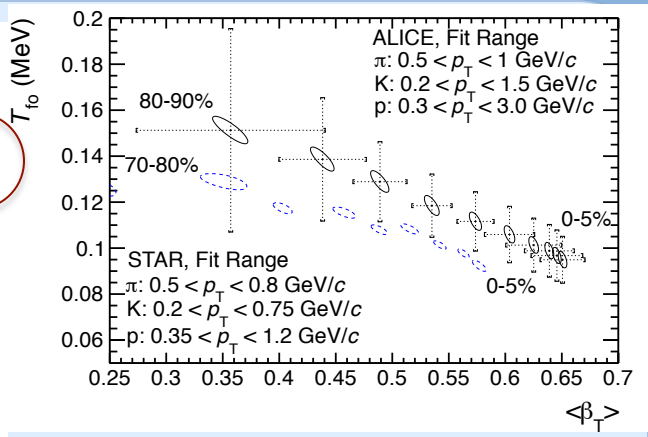


Radial flow β and Kinetic freeze-out T_kin

$\langle p_T \rangle \sim T_{eff} = T_{kin} + \frac{1}{2} m \langle \beta \rangle^2$

Mean transverse momentum Pb-Pb (0-5%)



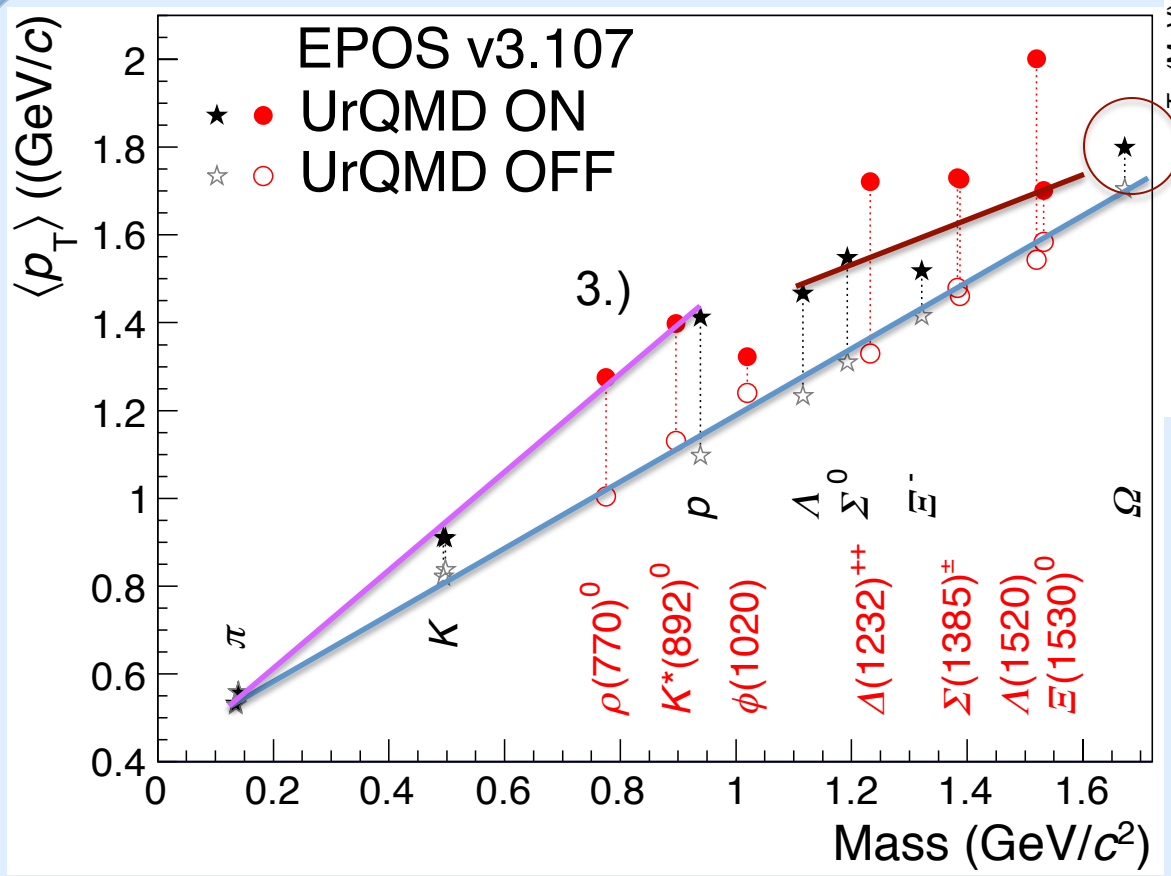


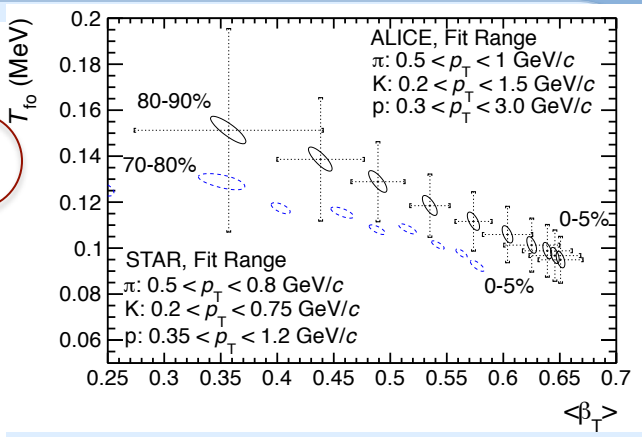
Omega:
1.) T = large T_kin, small β
2.) T = low T_kin, large β
One particle
→ not conclusive

Radial flow β and kinetic freeze-out T_kin

$T_{eff} = T_{kin} + \frac{1}{2} m \langle \beta \rangle^2$

Mean transverse momentum Pb-Pb (0-5%)





Omega:
T = large T_kin, small β
T = low T_kin, large β
One particle
→ not conclusive

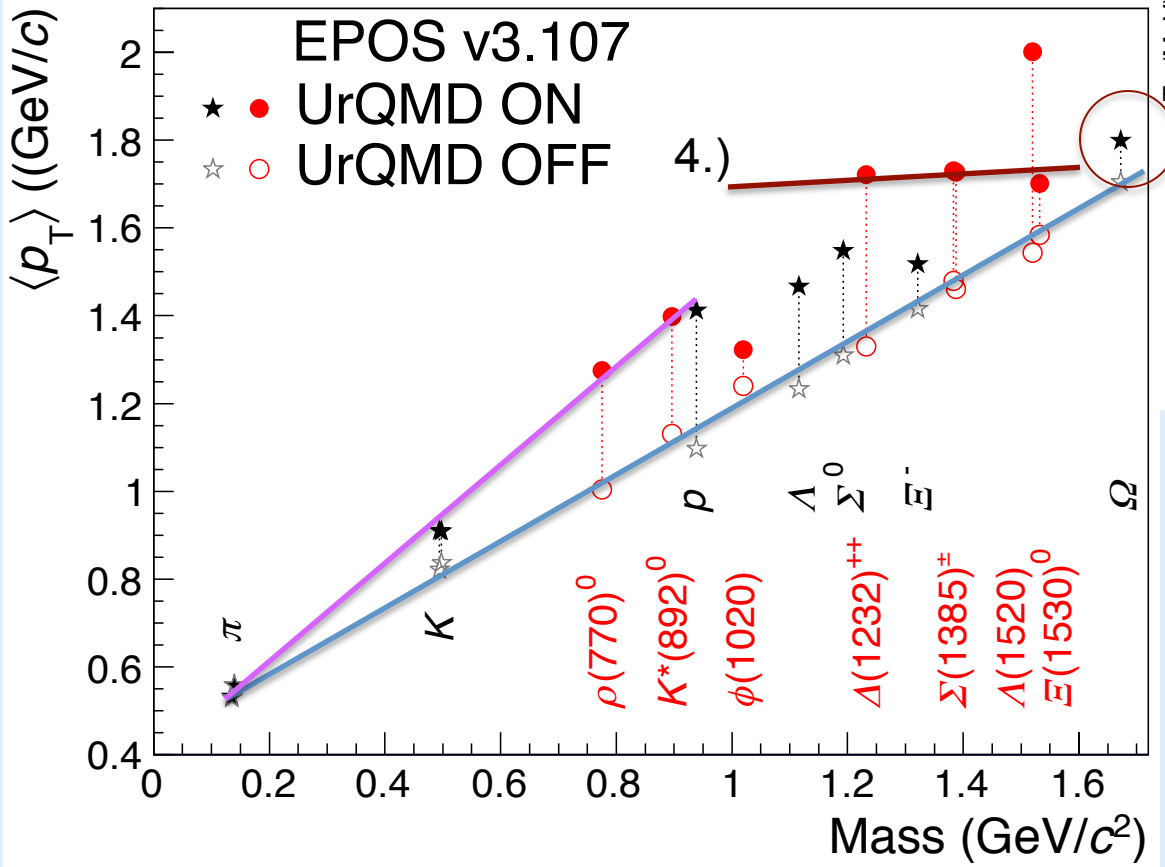
Ω,Ξ,Λ = large T_kin
3.) p,K π = low T_kin

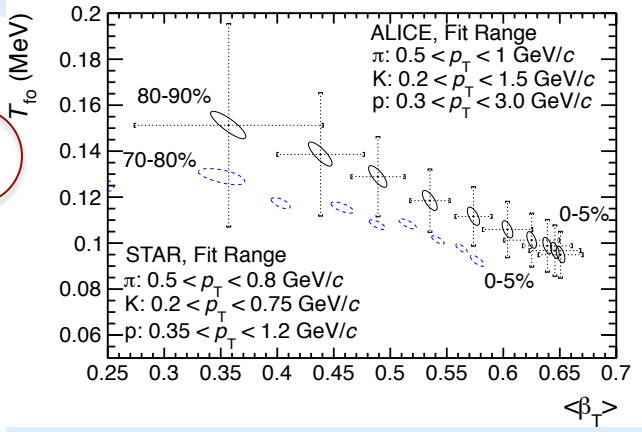
Radial flow β and kinetic freeze-out T_kin

$T_{eff} = T_{kin} + \frac{1}{2} m \langle\beta\rangle^2$

Hadronic phase changes $\langle p_T \rangle$ differently (feed-down, radial flow)
→ Need to understand contribution from hadronic phase

Mean transverse momentum Pb-Pb (0-5%)





Resonances + Ω:
4.) very large T_kin, small β
Resonances decouple late
→ in contradiction to interpretation of large T_kin

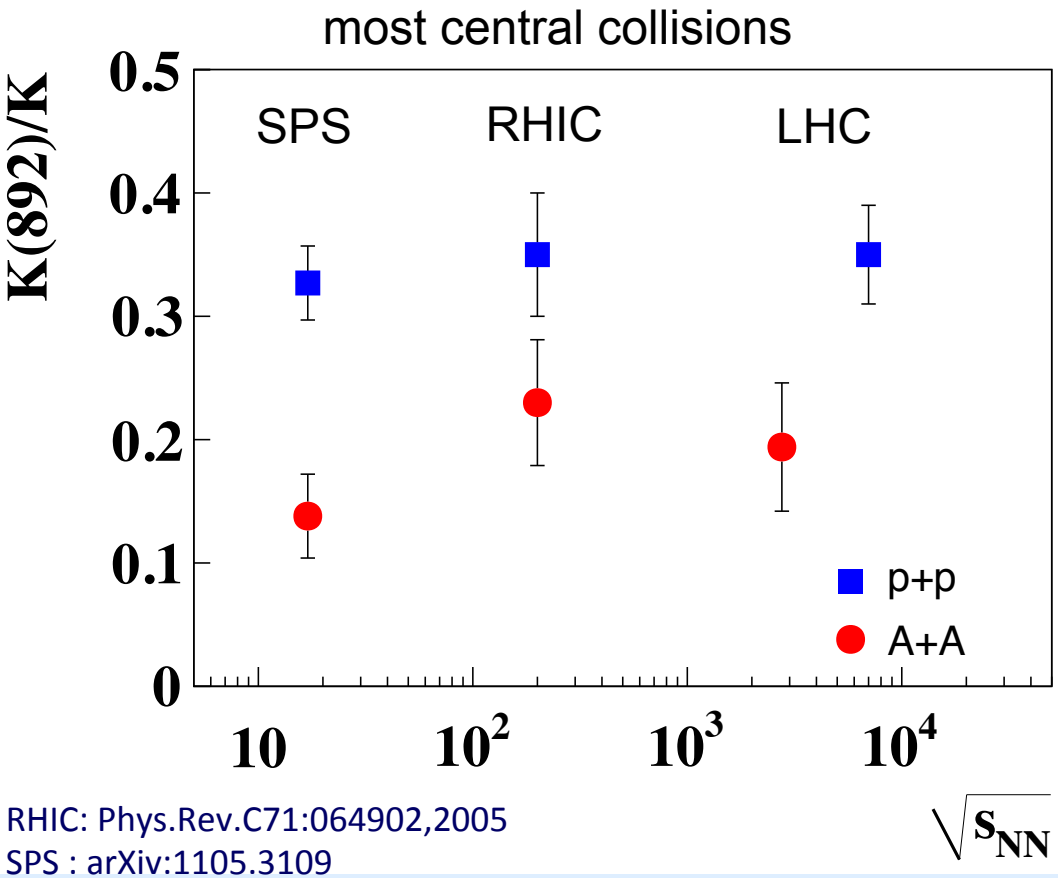
Radial flow β and kinetic freeze-out T_kin

$T_{eff} = T_{kin} + \frac{1}{2} m \langle \beta \rangle^2$

Hadronic phase changes $\langle p_T \rangle$ differently (feed-down, radial flow,…)
→ Need to understand contribution from hadronic phase

Lower energies

Resonance ratios (K*/K) vs energy

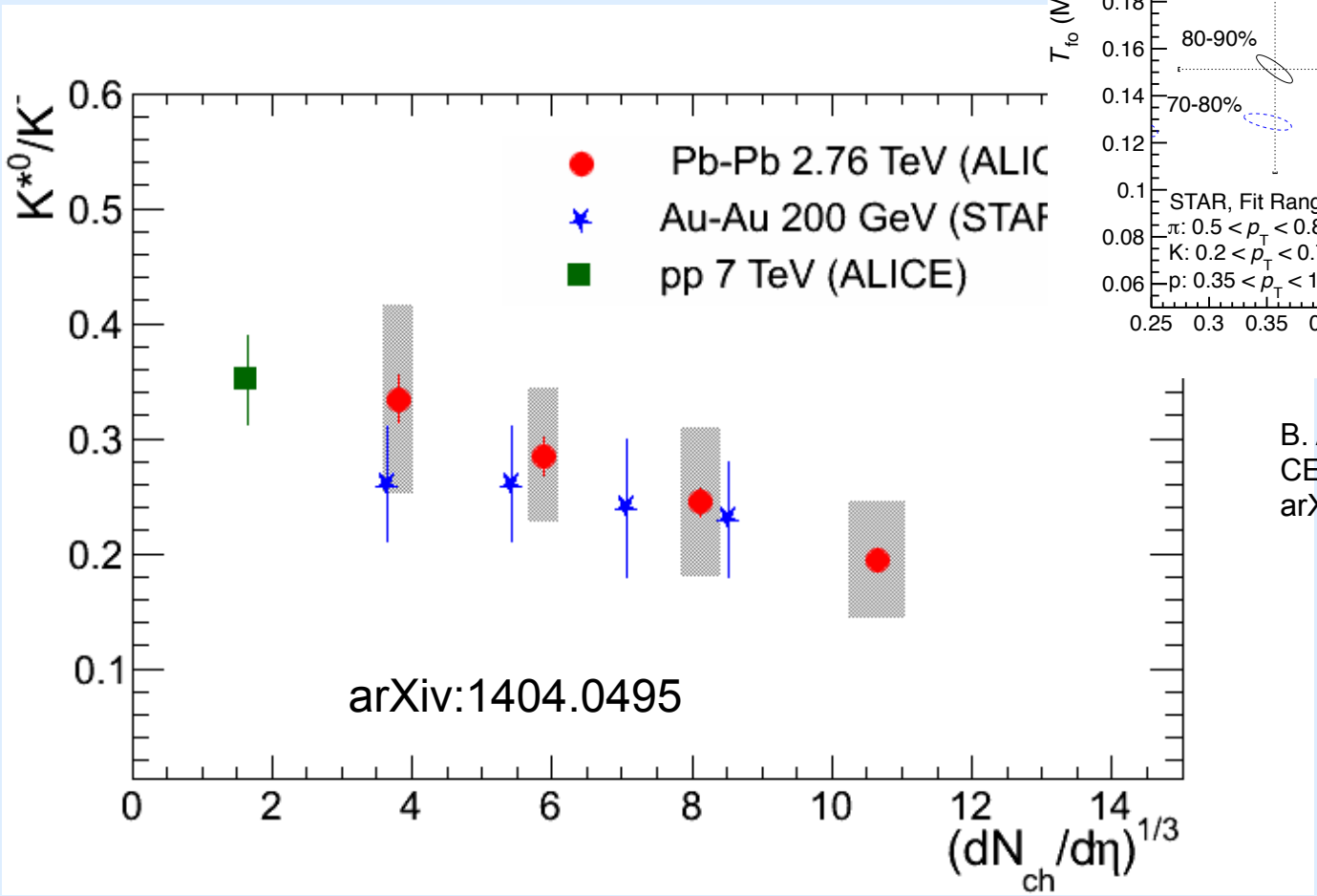


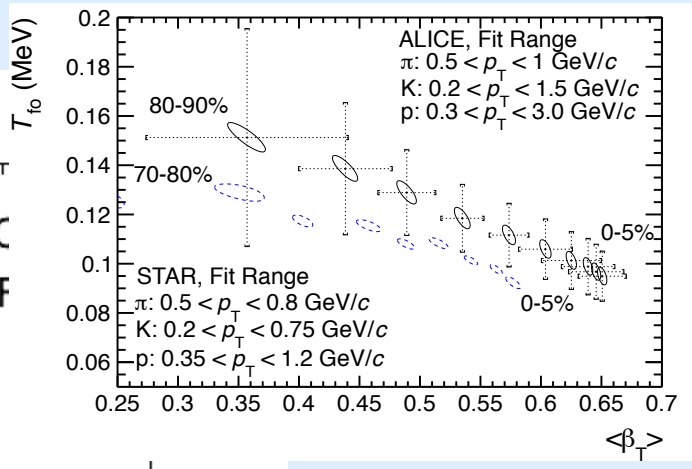
RHIC: Phys.Rev.C71:064902,2005
SPS : arXiv:1105.3109

RHIC: Hadronic lifetime > 4-5 fm/c (in central collisions)
Fireball lifetime ~ 10 fm/c
→**partonic lifetime ~ 5 fm/c**
CM, G. Torrieri and J. Rafelski, hep-ph/0206260

Larger resonance suppression at SPS and LHC (More re-scattering)

Resonance ratios vs centrality



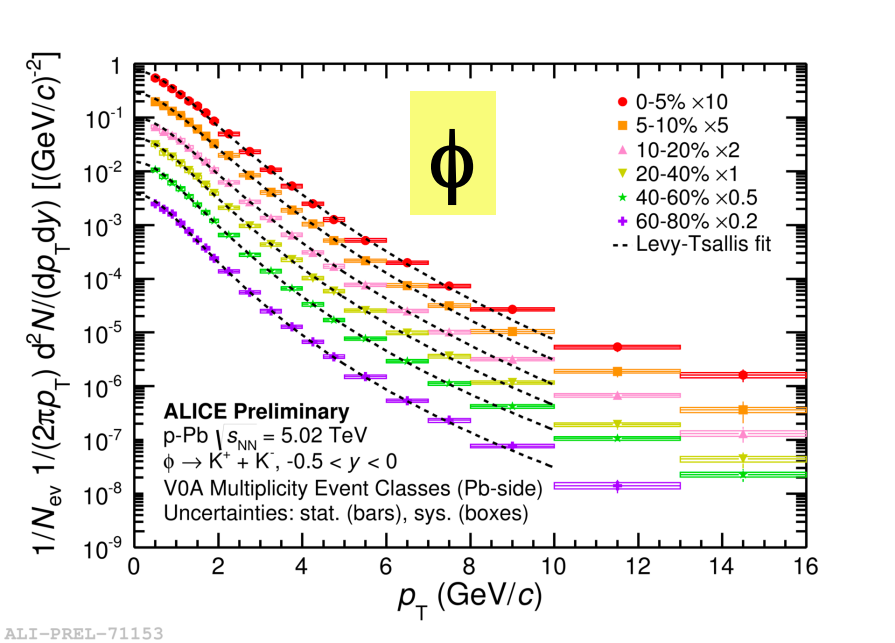


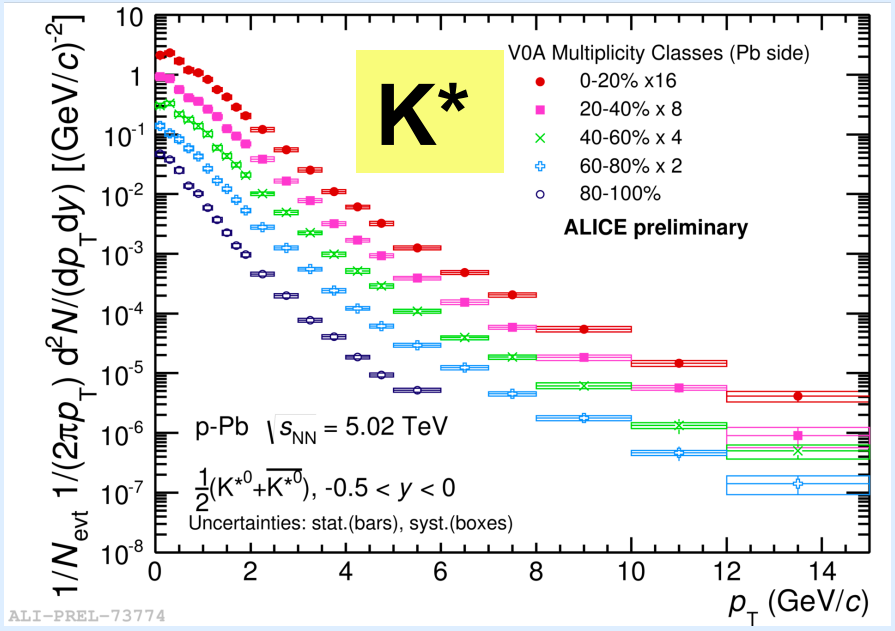
B. Abelev *et al*, CERN-PH-EP-2013-019, arXiv:13030737v1 (2013)

More particles produced at LHC energies than at RHIC energies
→ larger volume, lower kinetic freeze-out temperature

p-Pb collisions

p-Pb collisions at 5.02 TeV (ALICE)





Levy-Tsallis:

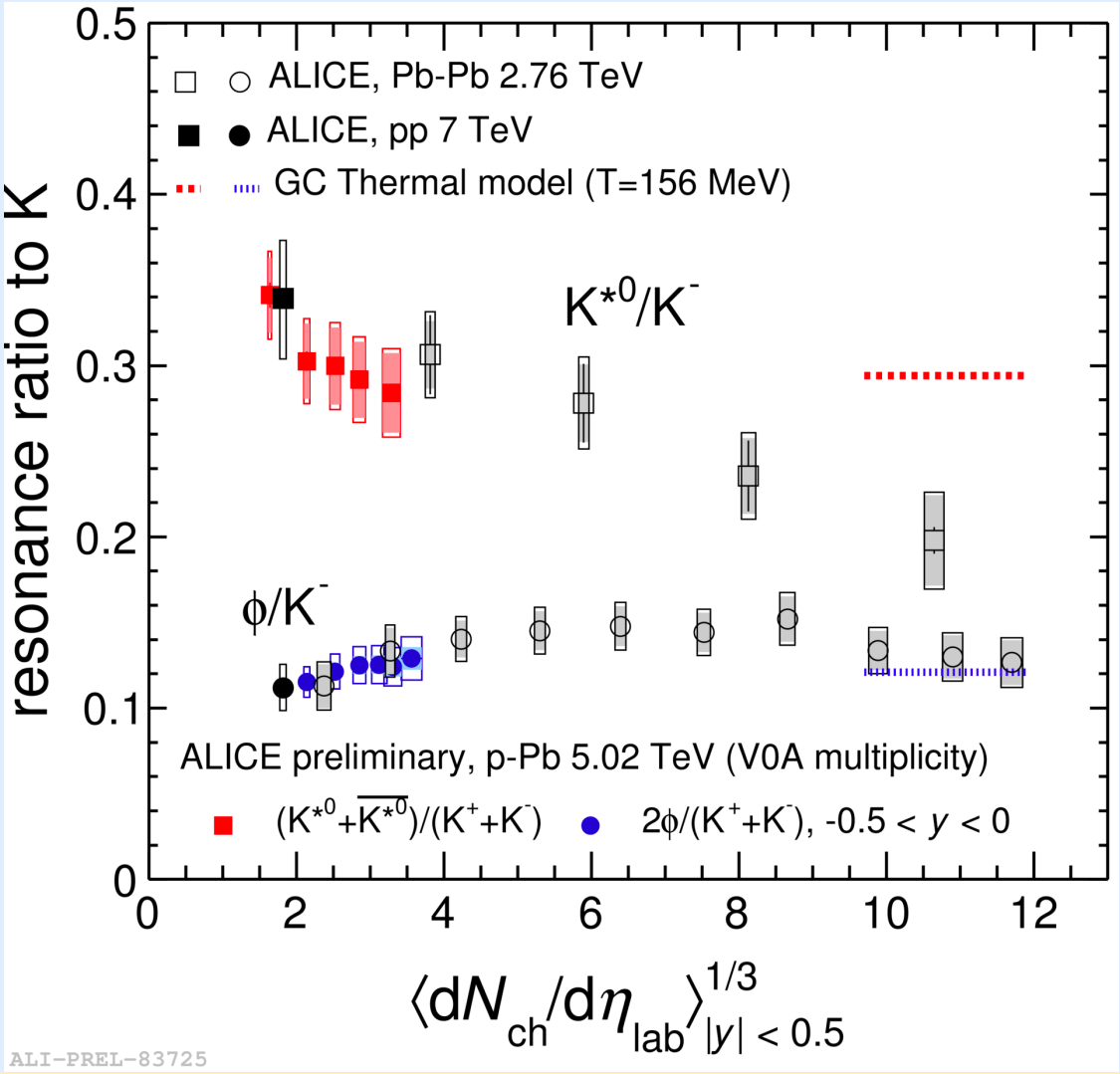
$$\frac{1}{N_{evt}}\frac{d^2N}{dydp_T} = p_T\frac{dN}{dy}\frac{(n-1)(n-2)}{nT[nT+m(n-2)]}\left[1+\frac{\sqrt{p_T^2+m^2}-m}{nT}\right]^{-n}$$

2013 data set for p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

K^{*0} spectra measured in $0<p_T<15$ GeV/c

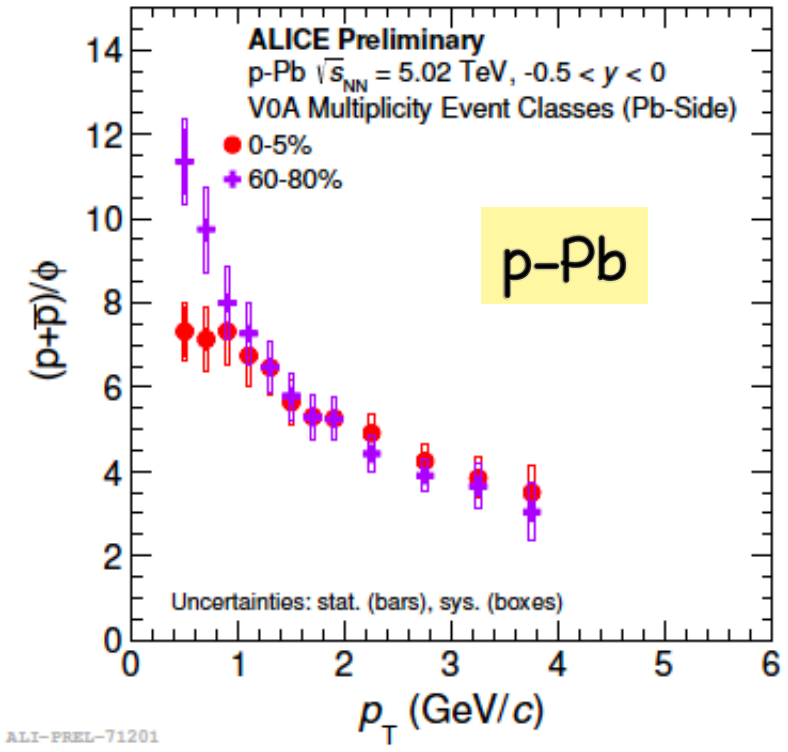
ϕ measured in $0.3<p_T<16$ GeV/c

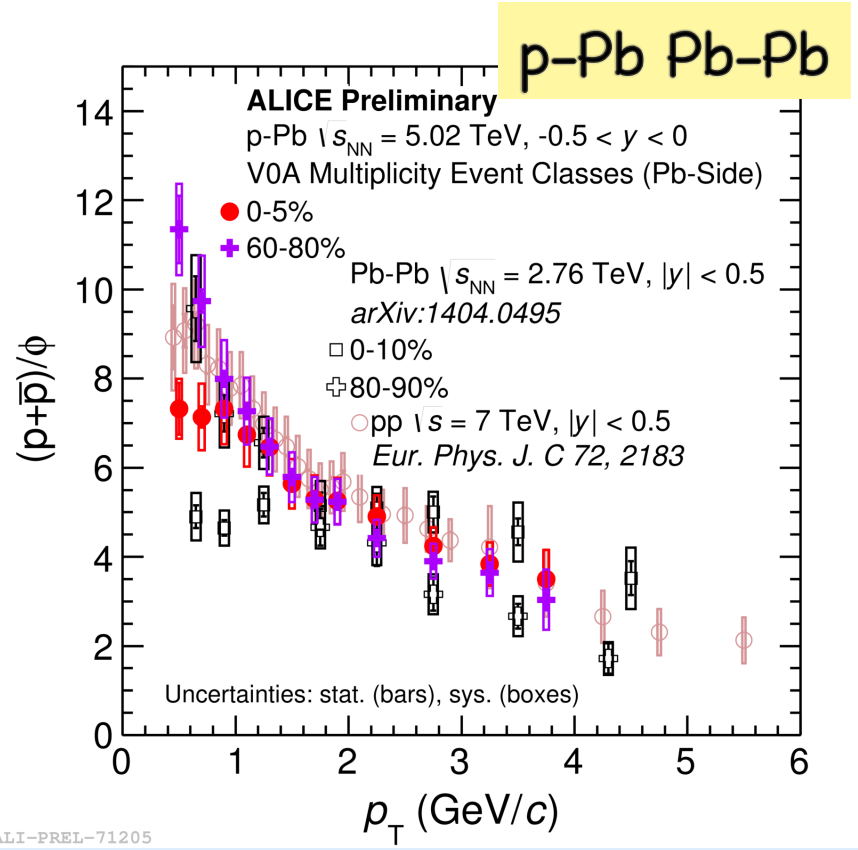
p-Pb collisions at 5.02 TeV (ALICE)



Slight decrease of K*/K ratio vs multiplicity → small hadronic medium ?

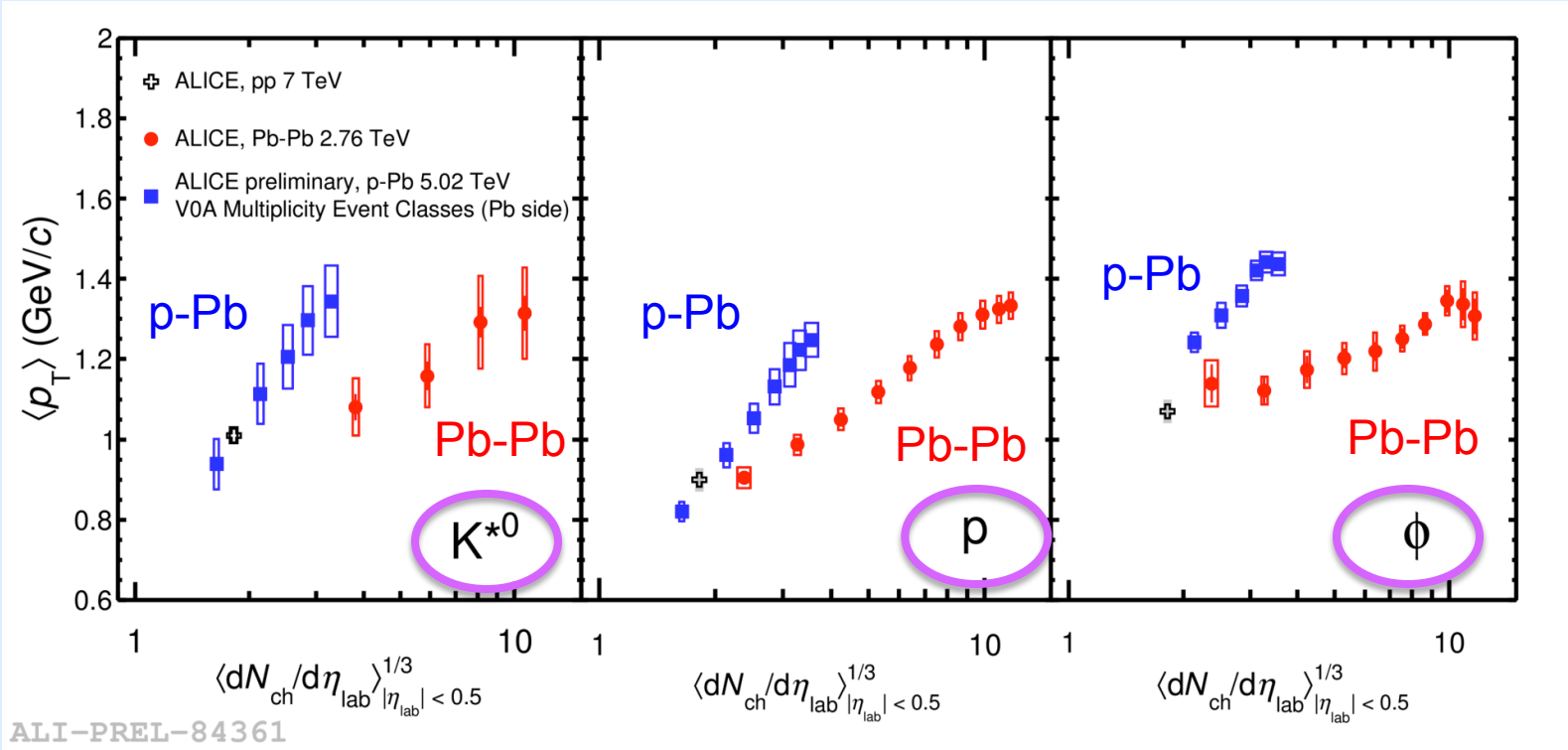
p/ϕ ratio (p-Pb compared to Pb-Pb collision)





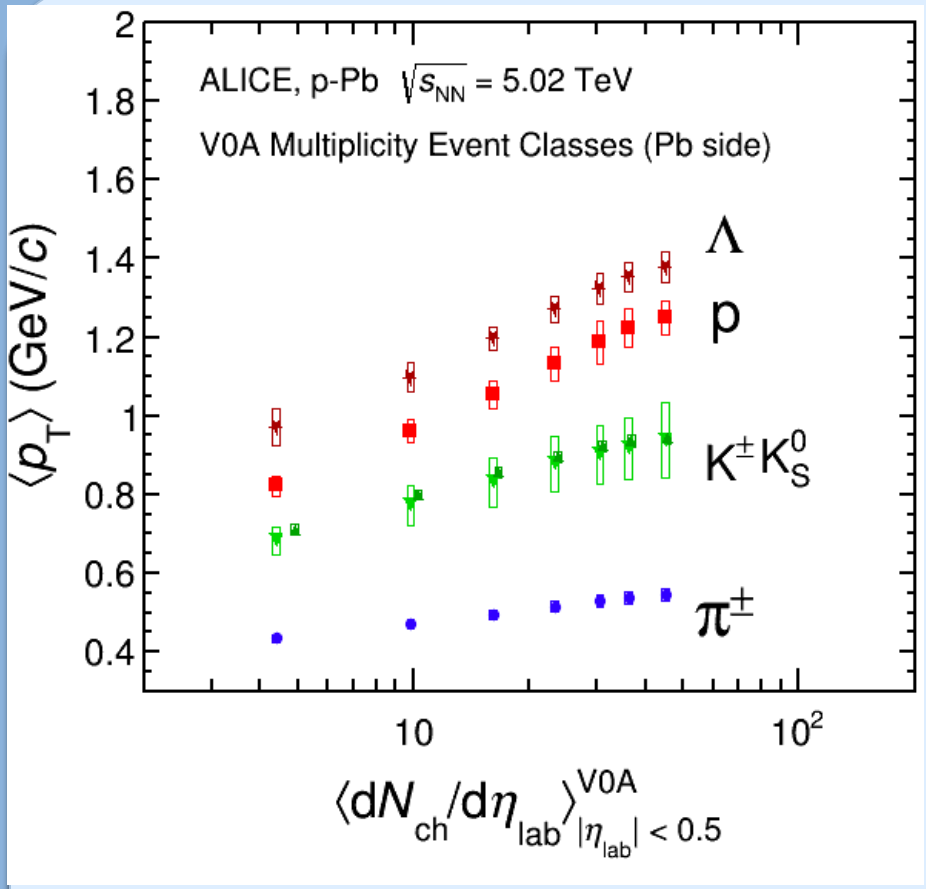
p/ϕ ration in p-Pb 0-5% is similar to 60-80% Pb-Pb
Do we have a medium in p-Pb collisions ?

p-Pb (mean transverse momentum vs centrality)

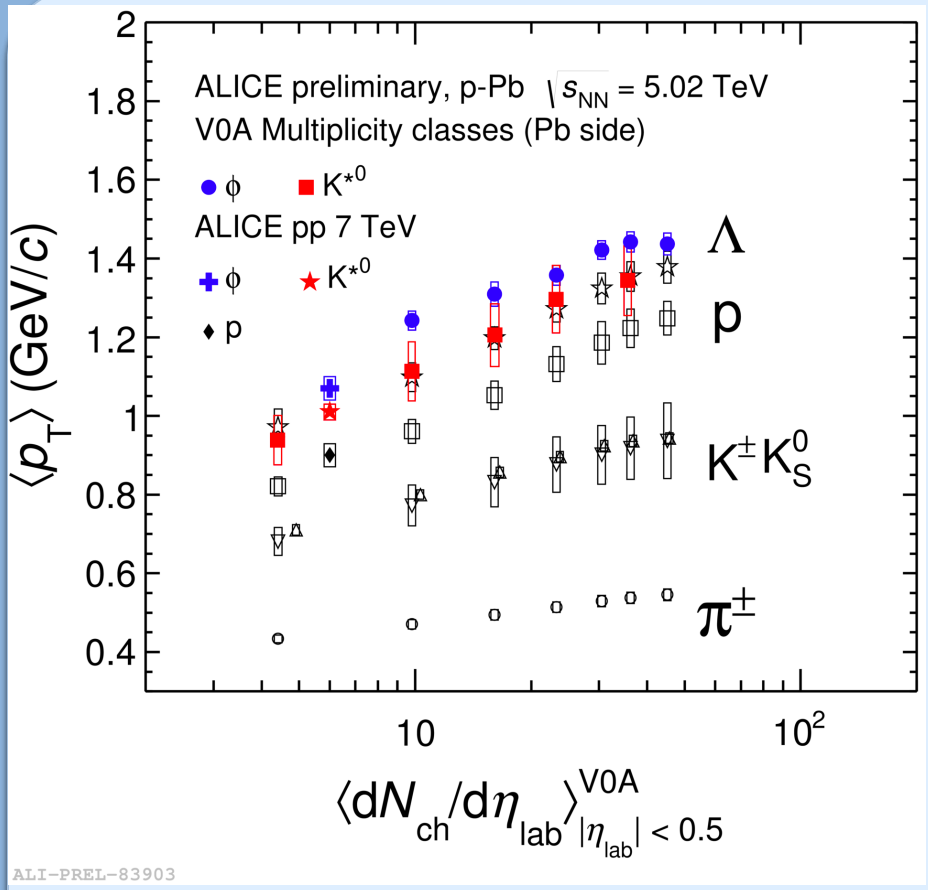


Steeper increase of <pT> for smaller systems is observed for stable particles as well (PLB 727 (2013) 371–380)
→ Same trend, but maximum is different

p-Pb mean transverse momentum

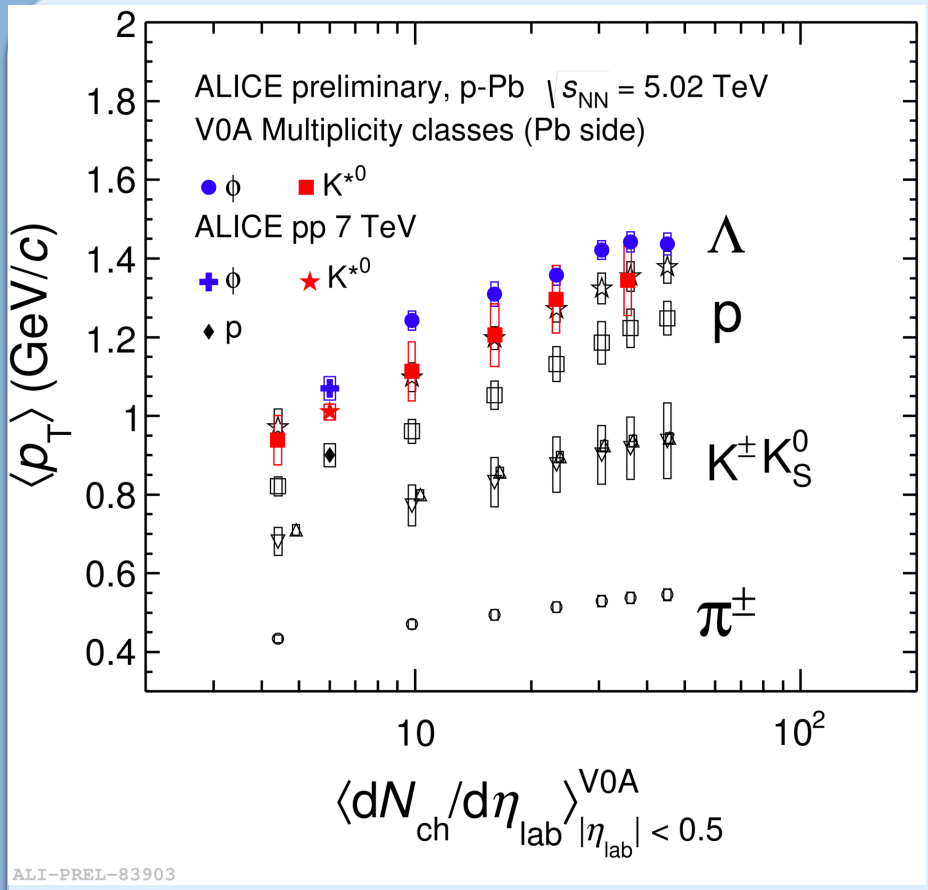


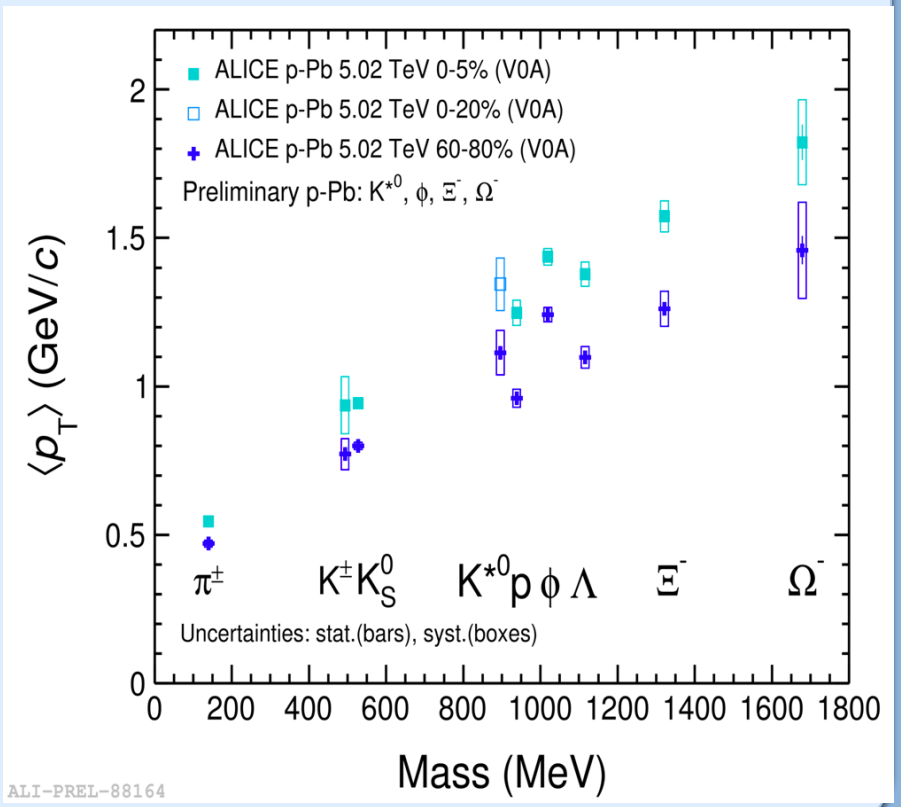
p-Pb mean transverse momentum



Is there a baryon/meson difference, or do resonances not follow mass ordering?

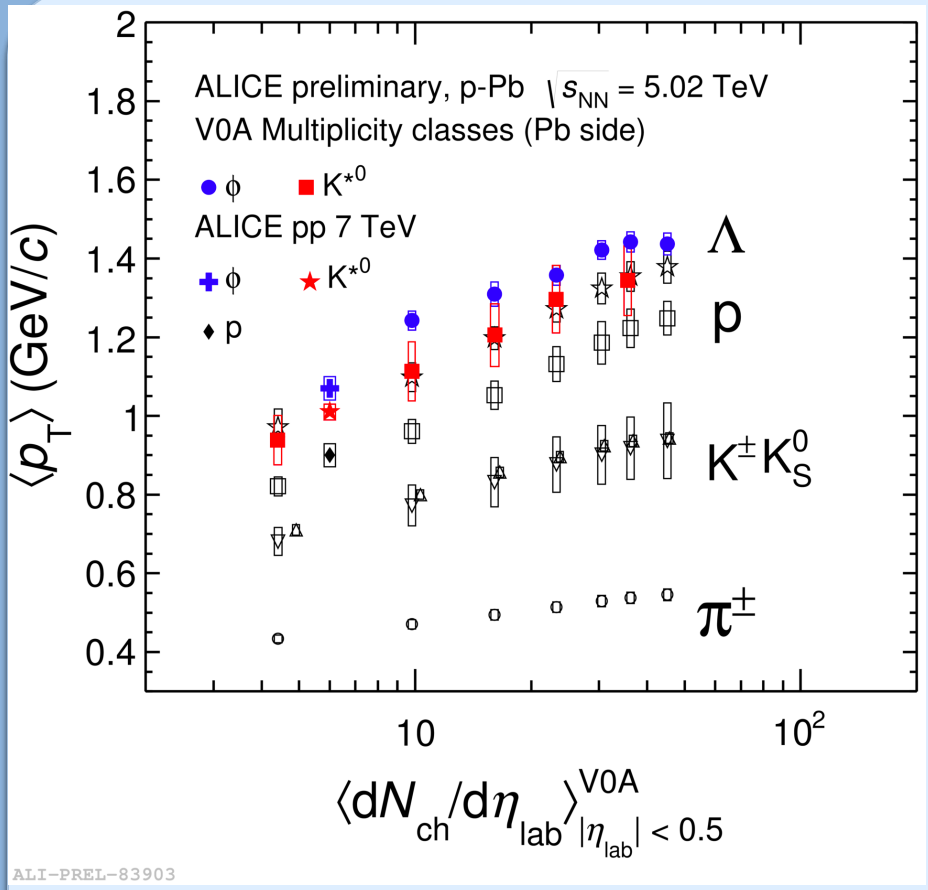
p-Pb mean transverse momentum

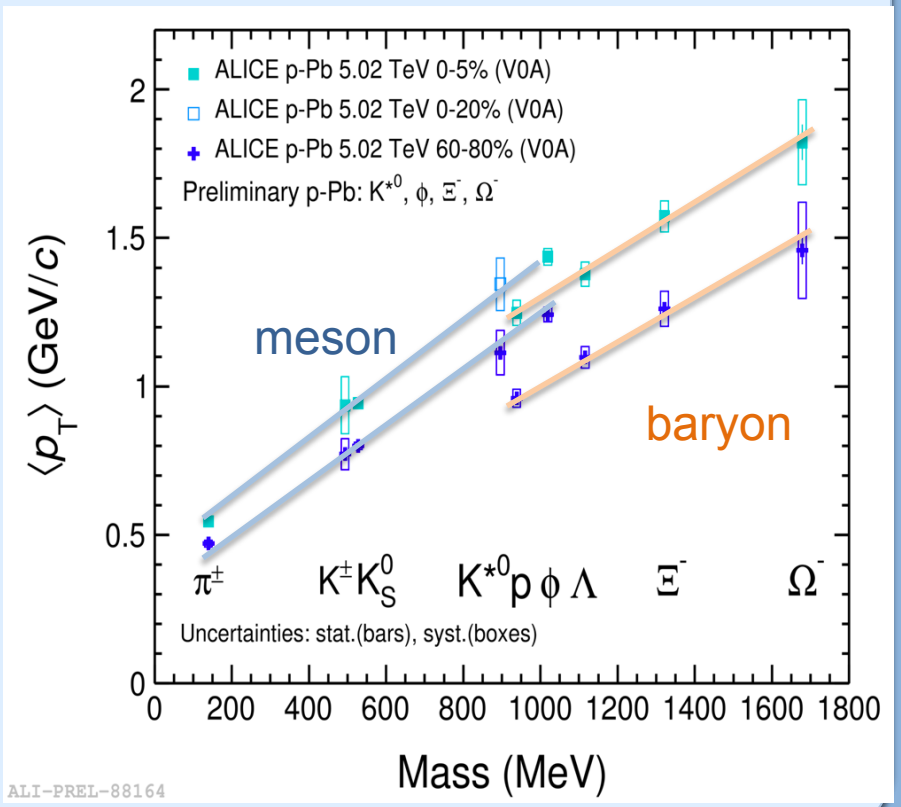




Is there a baryon/meson difference, or do resonances not follow mass ordering?

p-Pb mean transverse momentum





Is there a baryon/meson difference, or do resonances not follow mass ordering ?
Hadronic phase contribution ? → EPOS ?

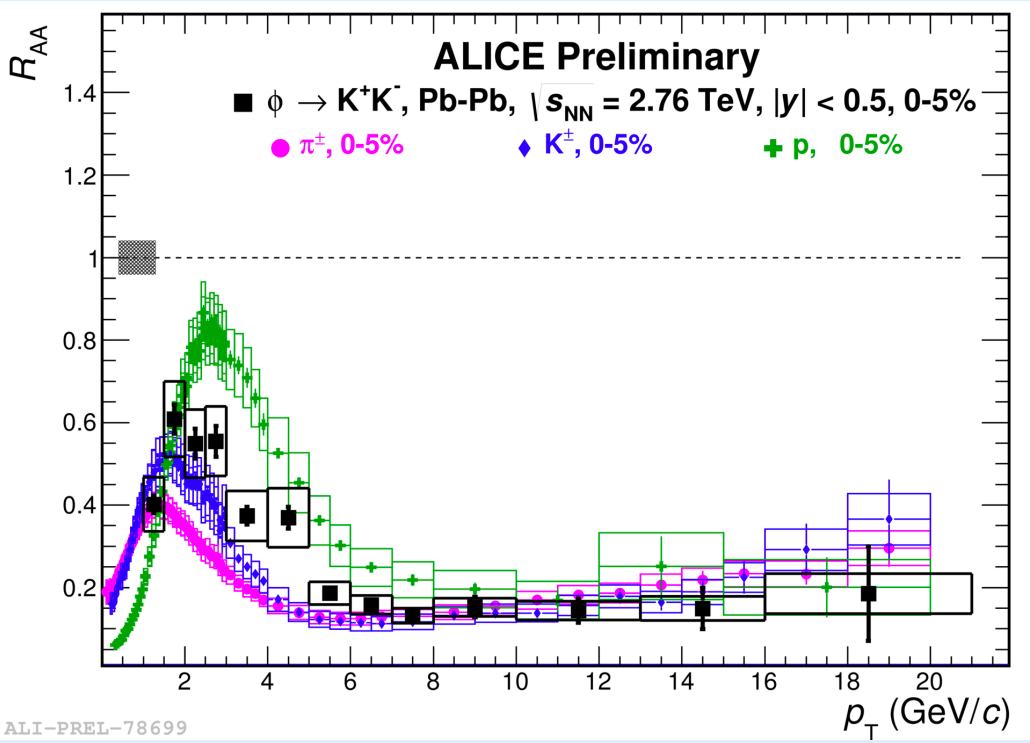
Conclusion

- Extended hadronic medium in A+A collisions
- Changes resonance yield and spectra.
- Changes spectra of ground state particles

→ need to understand contribution from hadronic phase

- High multiplicity p-Pb collisions show onset of extended hadronic medium

RAA (nuclear modification factor)



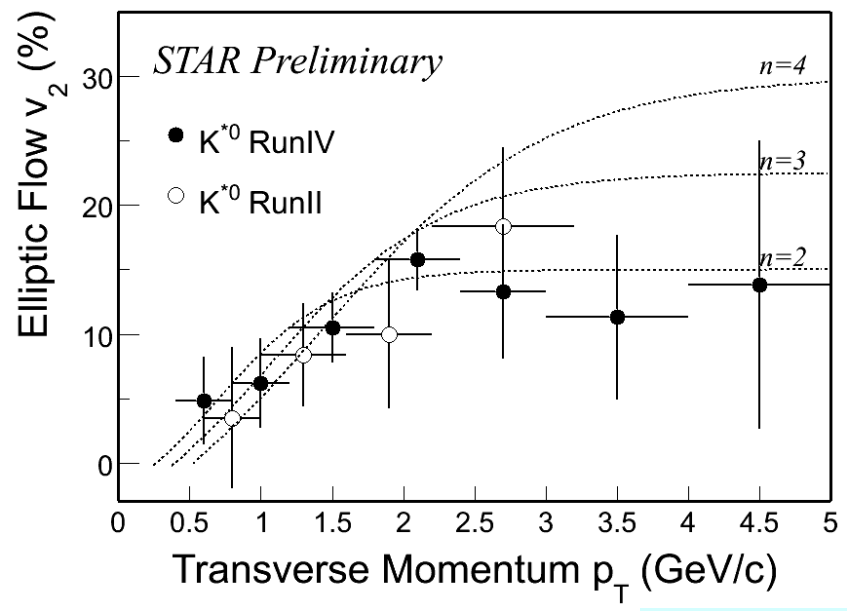
$$R_{AA} = \frac{d^2N/dp_T d\eta \ \ (Pb+Pb)}{T_{AA}\ d^2\sigma/dp_T d\eta \ \ (p+p)}$$

High-p_T (>8GeV/c):
no flavor dependence of light hadrons suppression

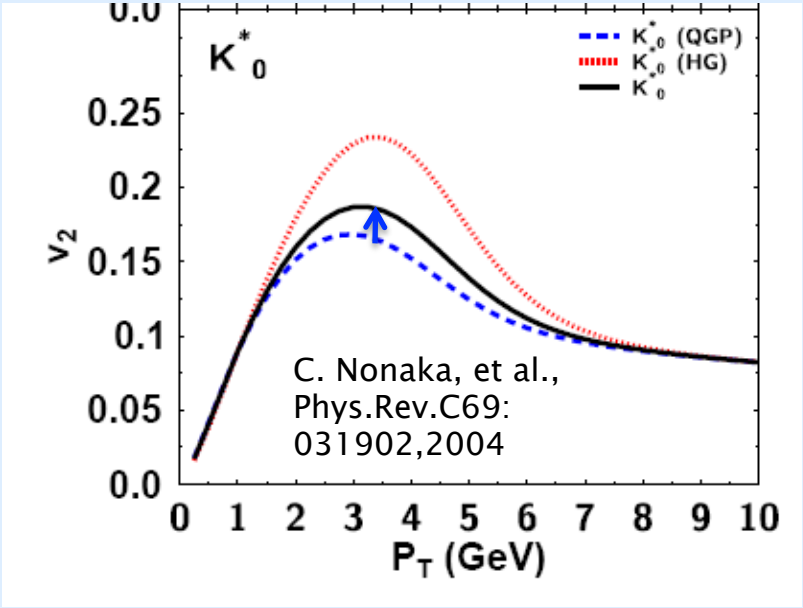
Intermediate-p_T (2-8 GeV/c):
- Larger suppression for $\phi(1020)$ than for proton
- Mass scaling → formation time dependence of energy loss
- Do we have meson baryon scaling ?

Regeneration might increase elliptic flow

minbias 200 GeV Au+Au



Recombination model



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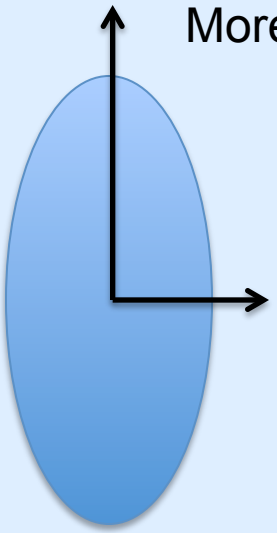
Partonic resonance generation:
Number of Constituent Quark (NCQ) scaling
at intermediate p_T (meson NCQ = 2)
Hadronic resonance (re)generation:
Regenerated resonances–final state interactions
NCQ = 4 ($K^* = K + \pi = 2+2$)

Error are too large to determine regeneration of K*

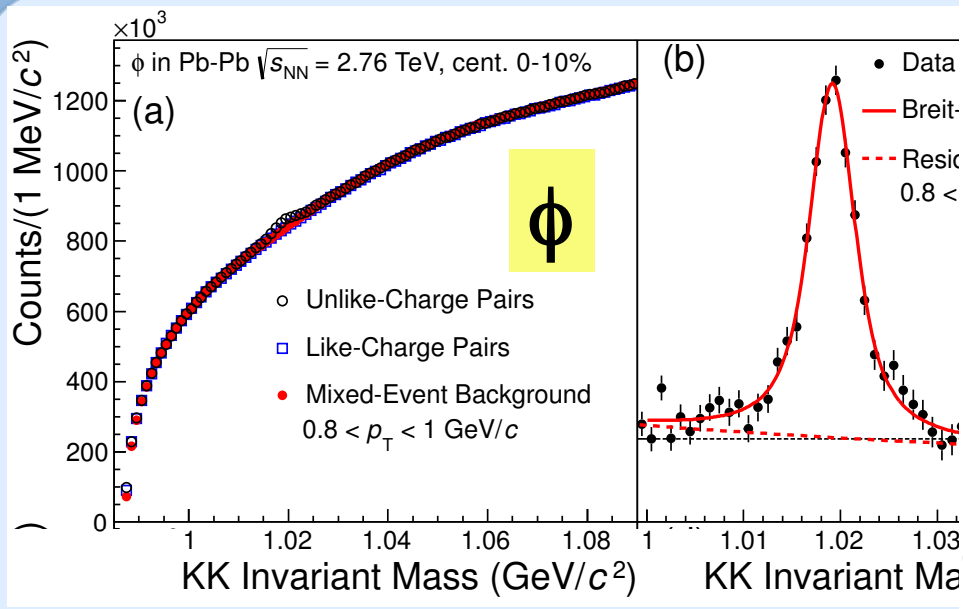
Influence of resonances

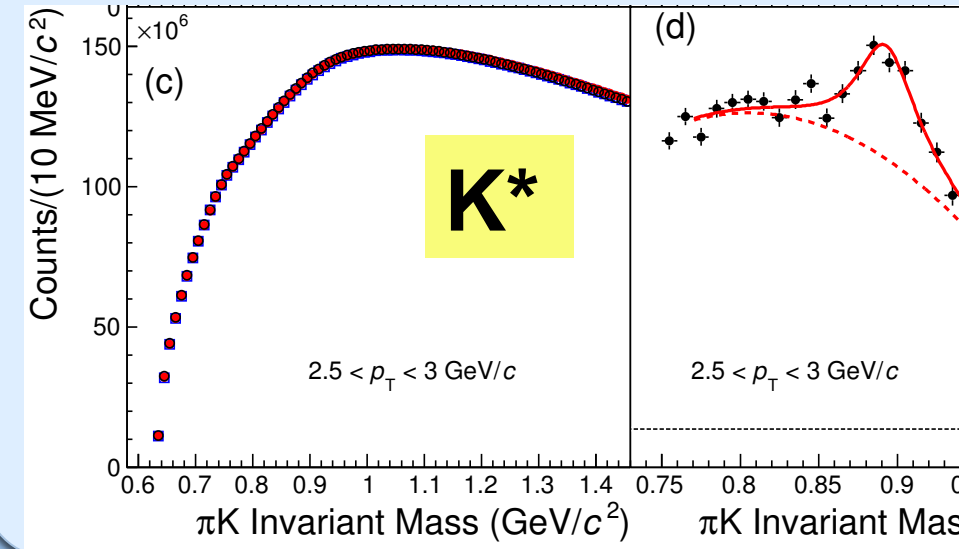


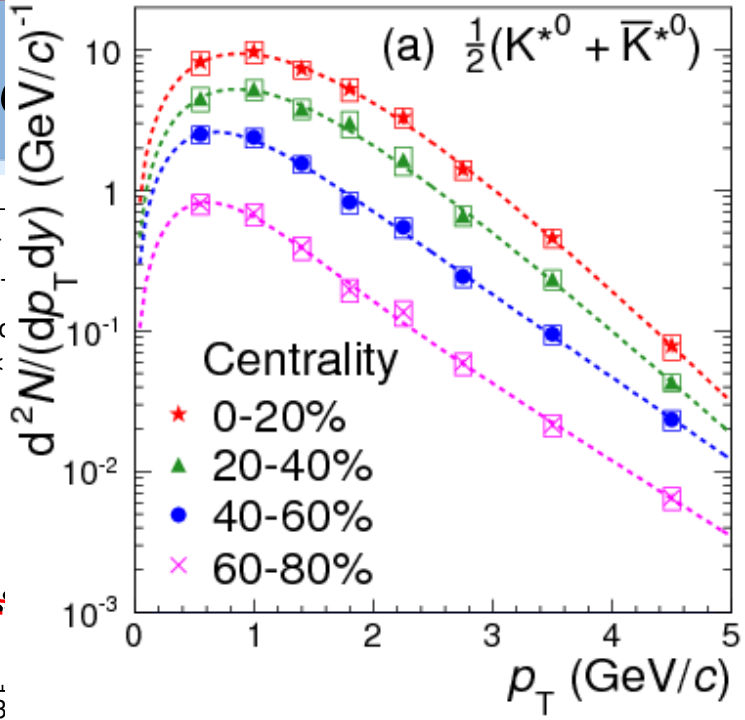
What happened to corrections/fluctuations after Inelastic scattering into another resonance ?

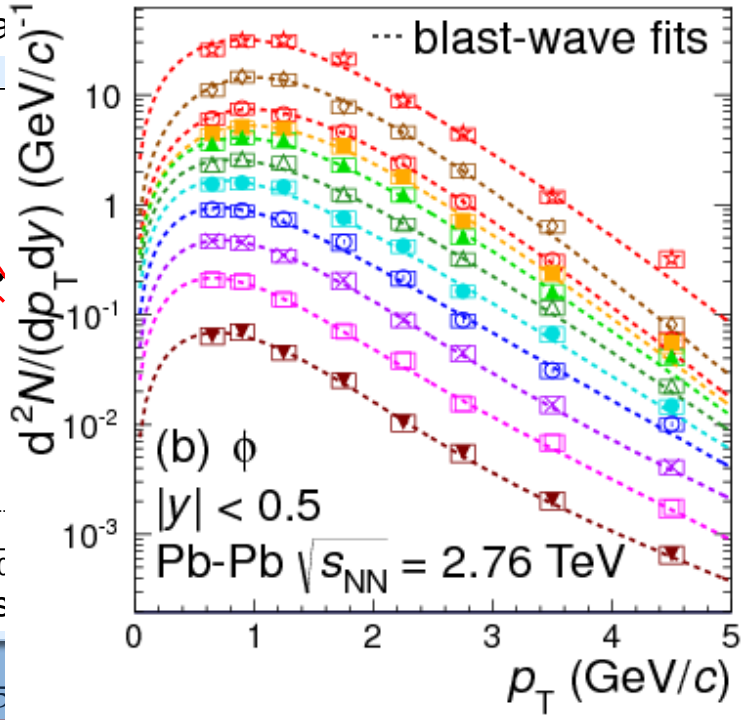
Important to measure resonances
and use microscopic models (hadronic phase)
→ influence of resonances on other signatures

Resonance signals

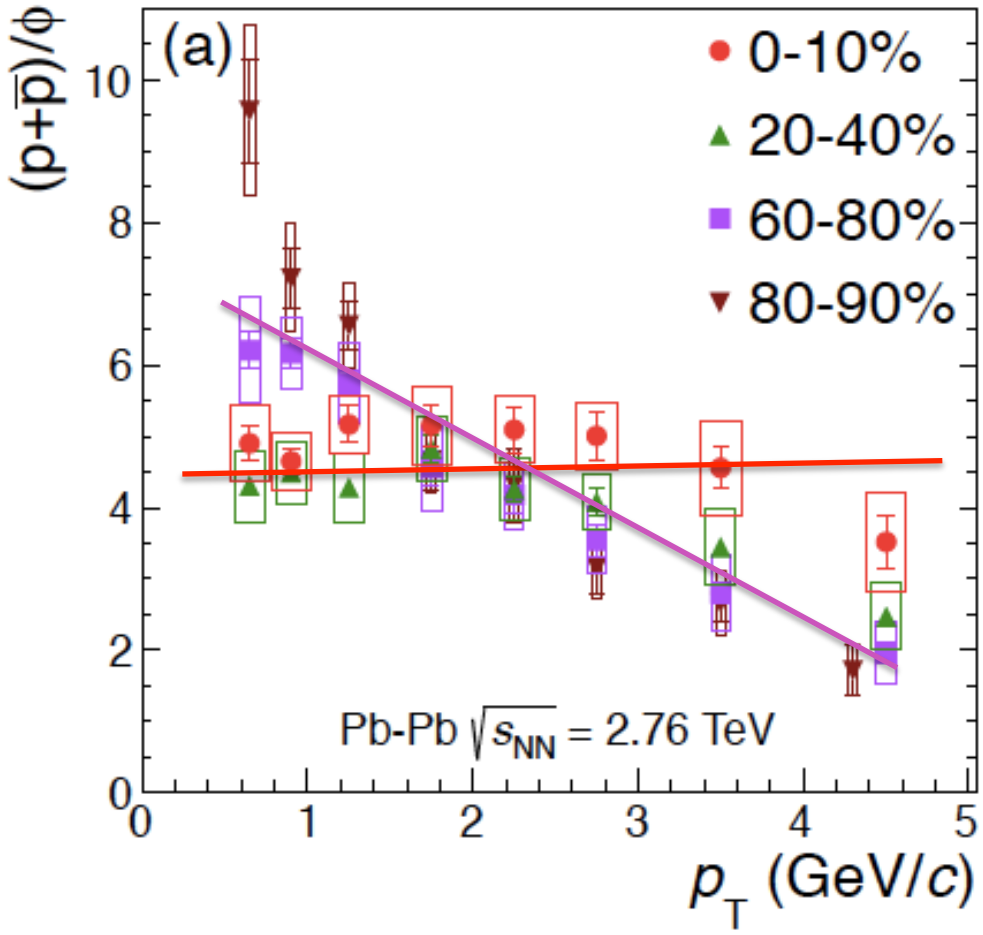


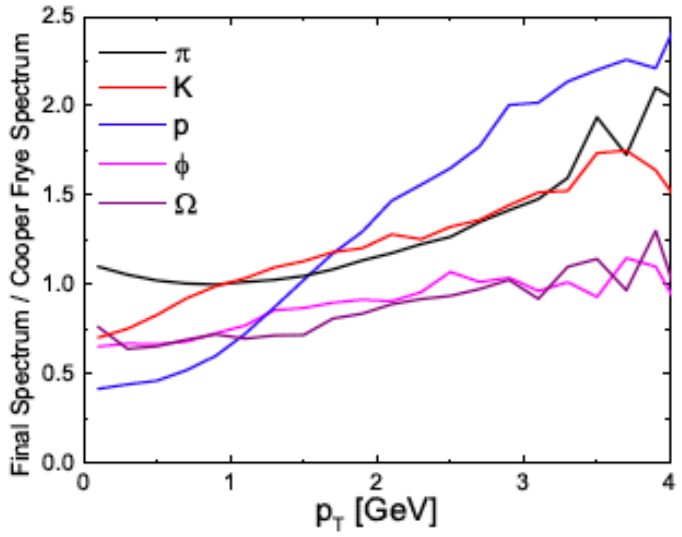






$\phi(1020)/p$ ratio (same mass)





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Same mass, same radial flow effect in central Pb-Pb collisions, but not in peripheral collisions
→ different production mechanism in peripheral collisions ?