Resonances in Heavy Ion collisions

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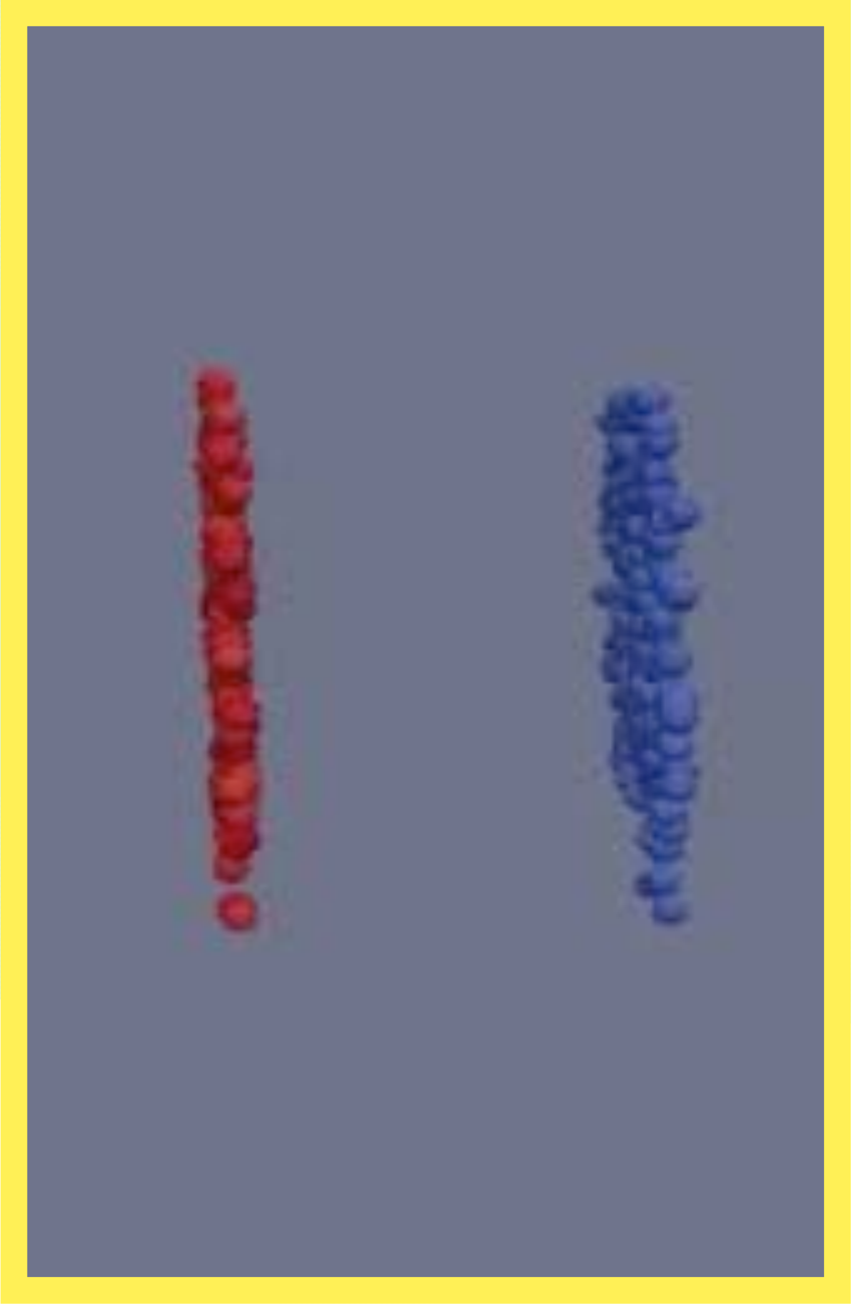
IIT BOMBAY

10th Asian Triangle Heavy-ion conference- ATHIC 2025 13/01/2025 - 16/01/2025

Heavy Ion collisions



Before collision

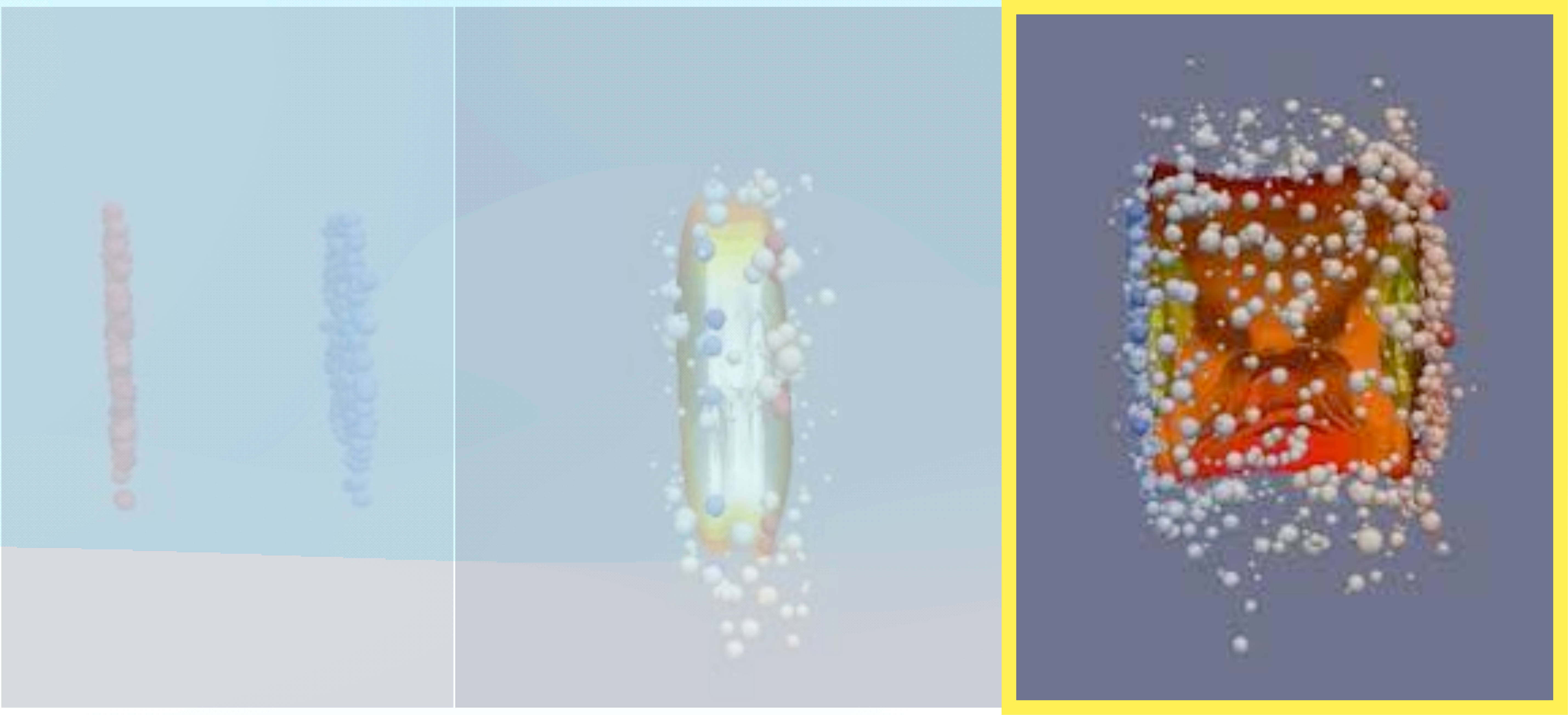
Ref: MADAI collaboration, Hannah Petersen and Jonah Bernhard

Heavy Ion collisions

Deconfined soup

Ref: MADAI collaboration, Hannah Petersen and Jonah Bernhard

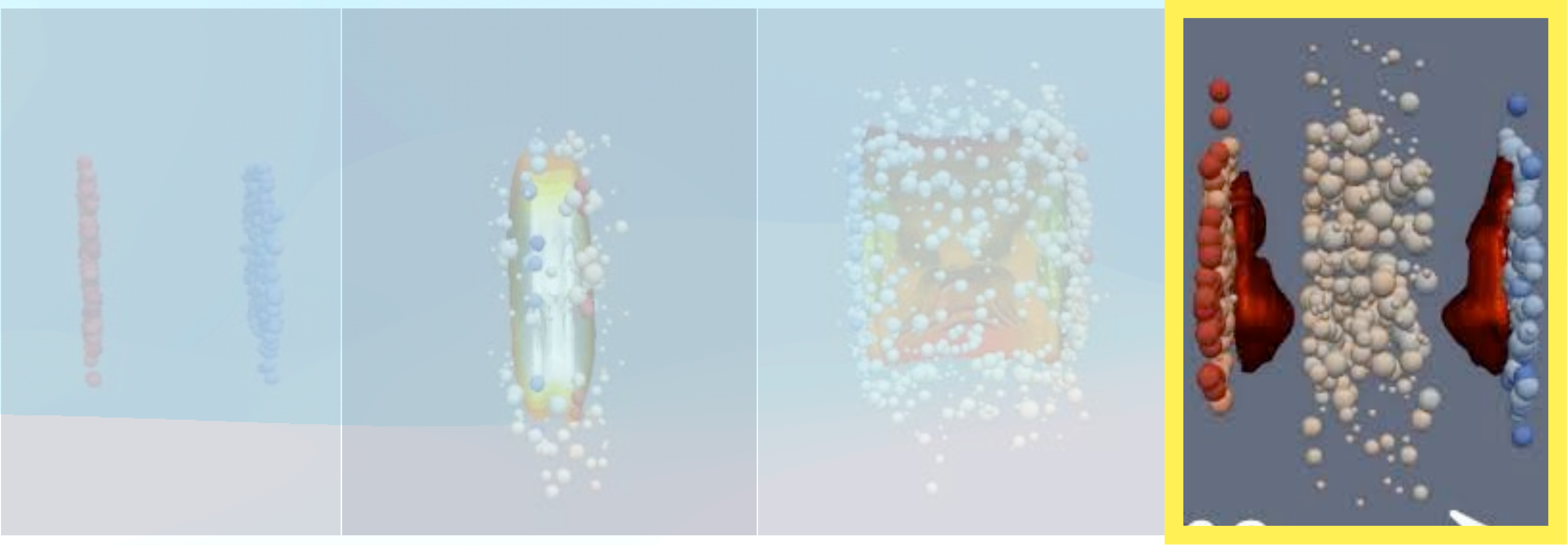
Heavy Ion collisions



Quark Gluon Plasma

Ref: MADAI collaboration, Hannah Petersen and Jonah Bernhard

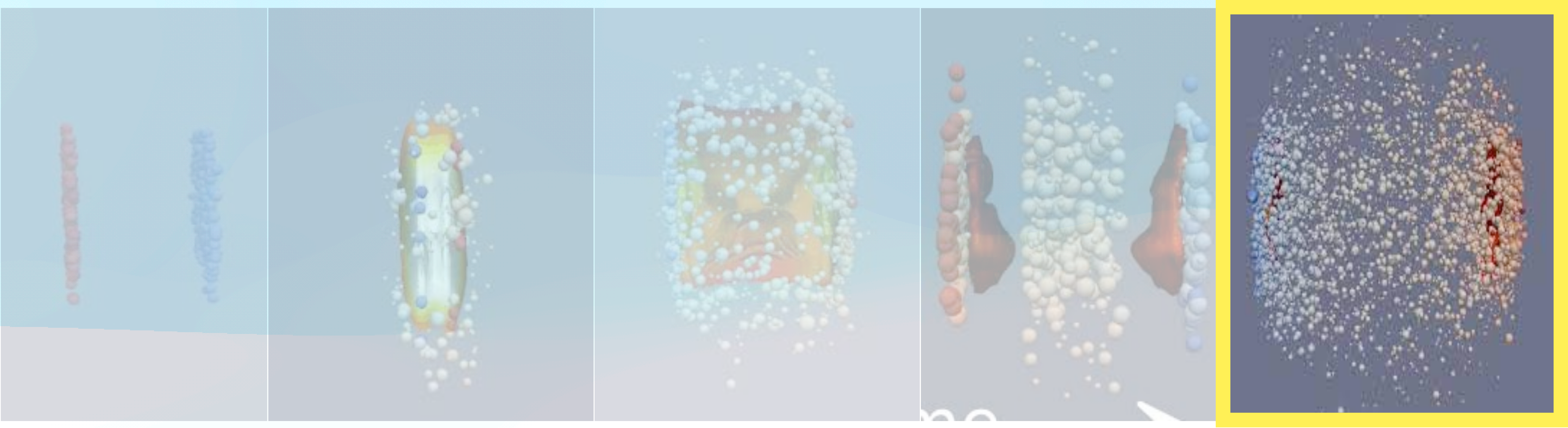
Heavy Ion collisions



Hadronization

Ref: MADAI collaboration, Hannah Petersen and Jonah Bernhard

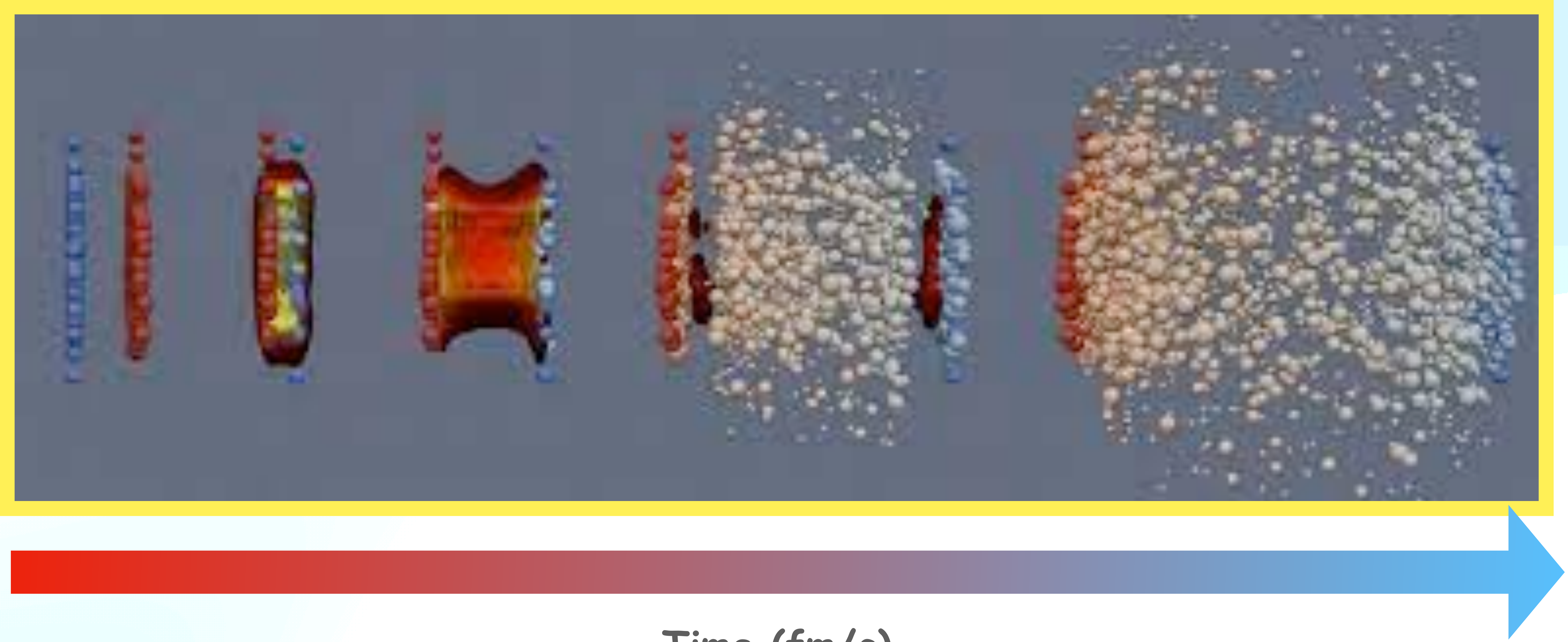
Heavy Ion collisions



Ref: MADAI collaboration, Hannah Petersen and Jonah Bernhard

Freeze-Out

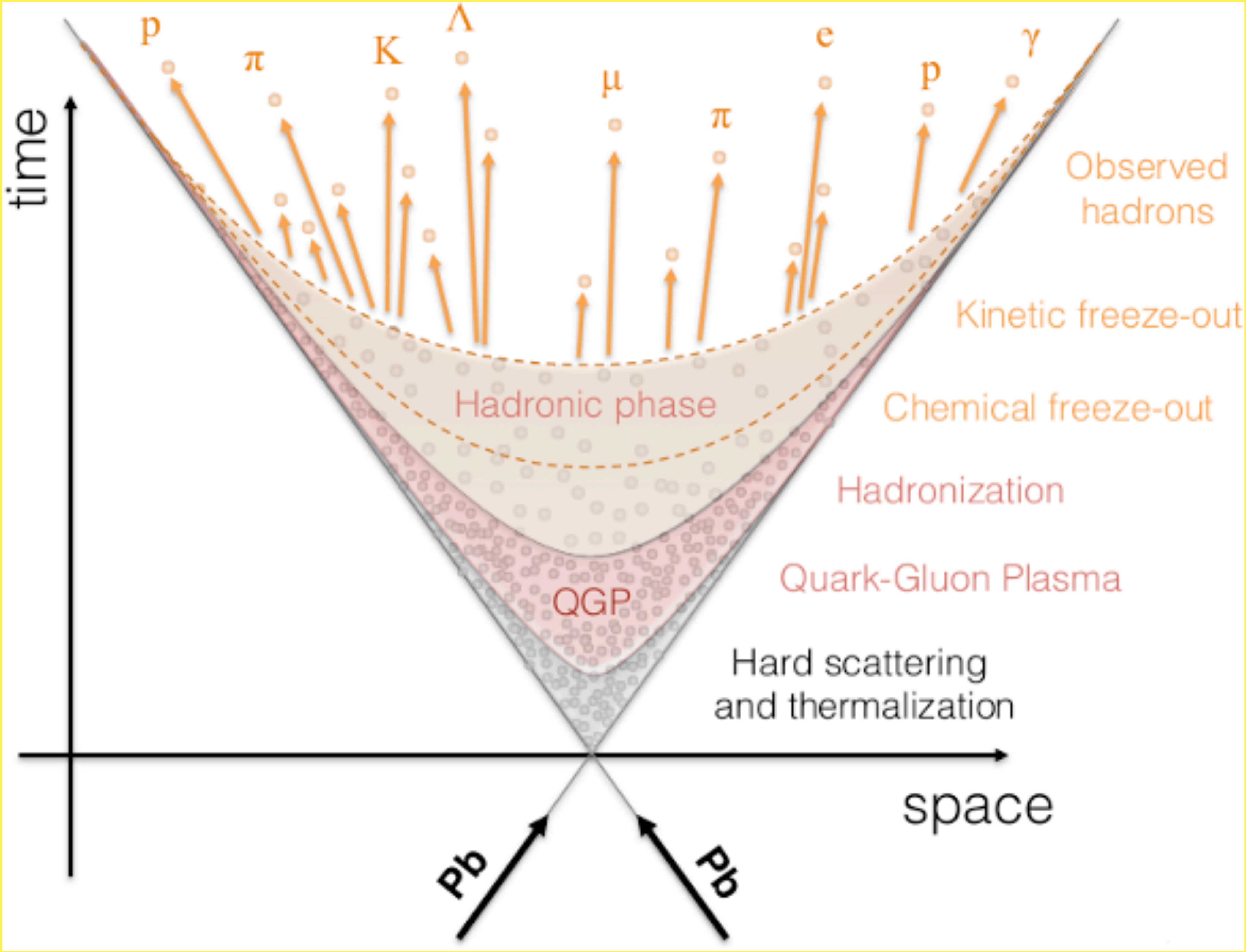
Heavy Ion collisions



Time (fm/c)

Ref: MADAI collaboration, Hannah Petersen and Jonah Bernhard

What are Resonances and why study them ?

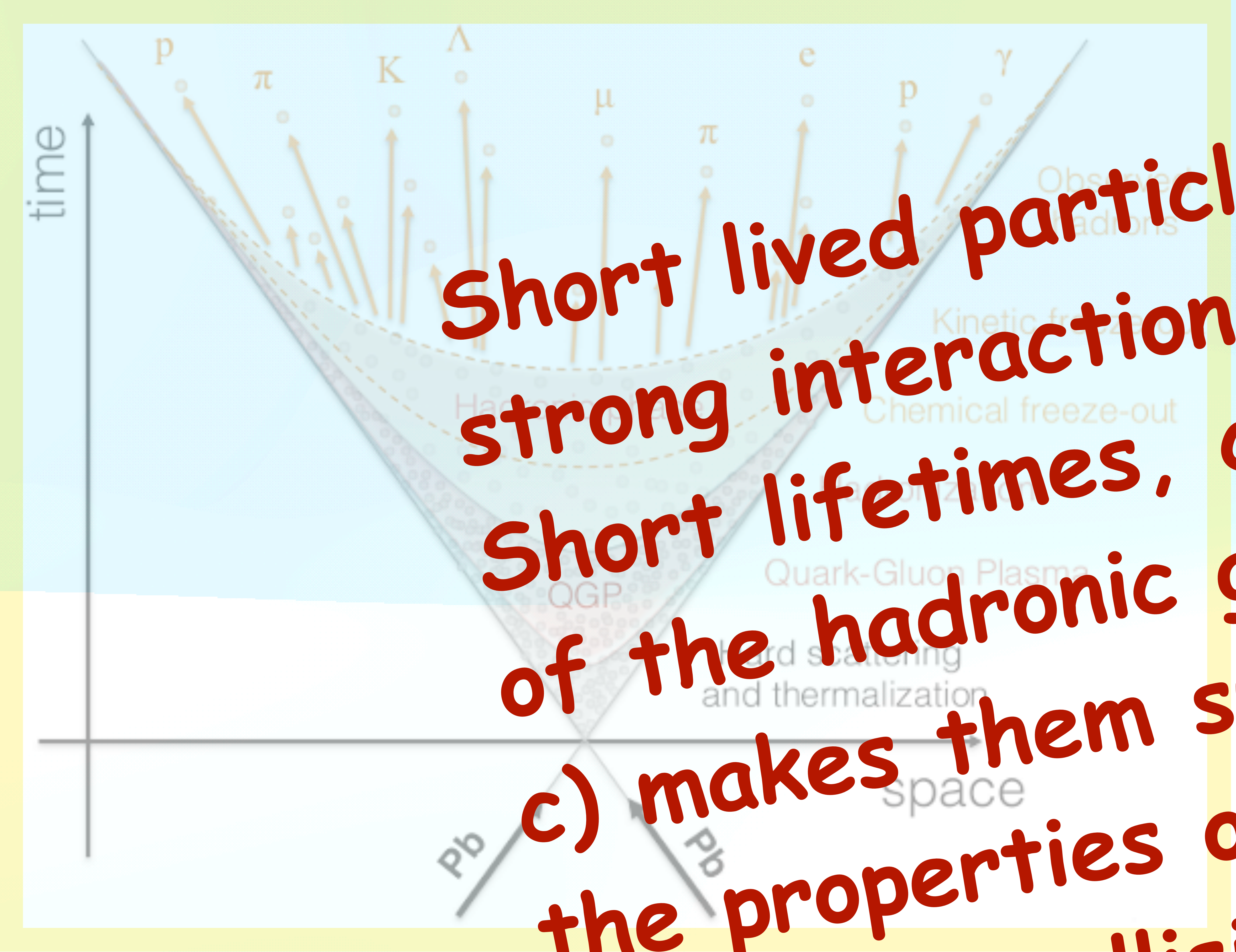


Experimental physicists observed pronounced peaks in the detection rate as they varied the collision energy.

Many of the bumps were very broad, suggesting the existence of particles that existed for barely more than a trillionth of a trillionth of a second.

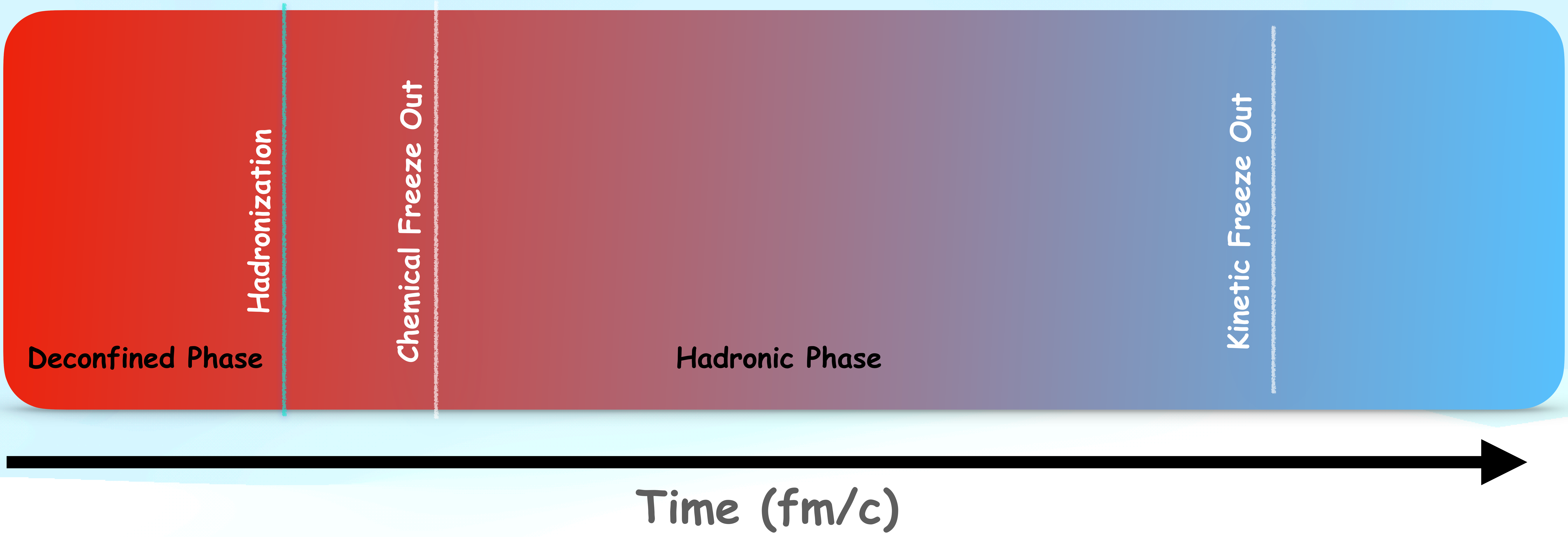
These new ephemeral particles were fundamentally no different from protons and neutrons except for their short lifetimes. These short-lived particles are often simply referred to as "resonances".

What are Resonances and why study them ?



Short lived particles that decay via strong interaction.

Short lifetimes, comparable to the one of the hadronic gas phase ($\tau \sim$ few fm/c) makes them suitable probes to study the properties of the hadronic phase in heavy-ion collisions.


Hadronization
Chemical Freeze Out
Kinetic Freeze Out
Deconfined Phase
Hadronic Phase
Time (fm/c)

Deconfined Phase
Hadronization
Chemical Freeze Out
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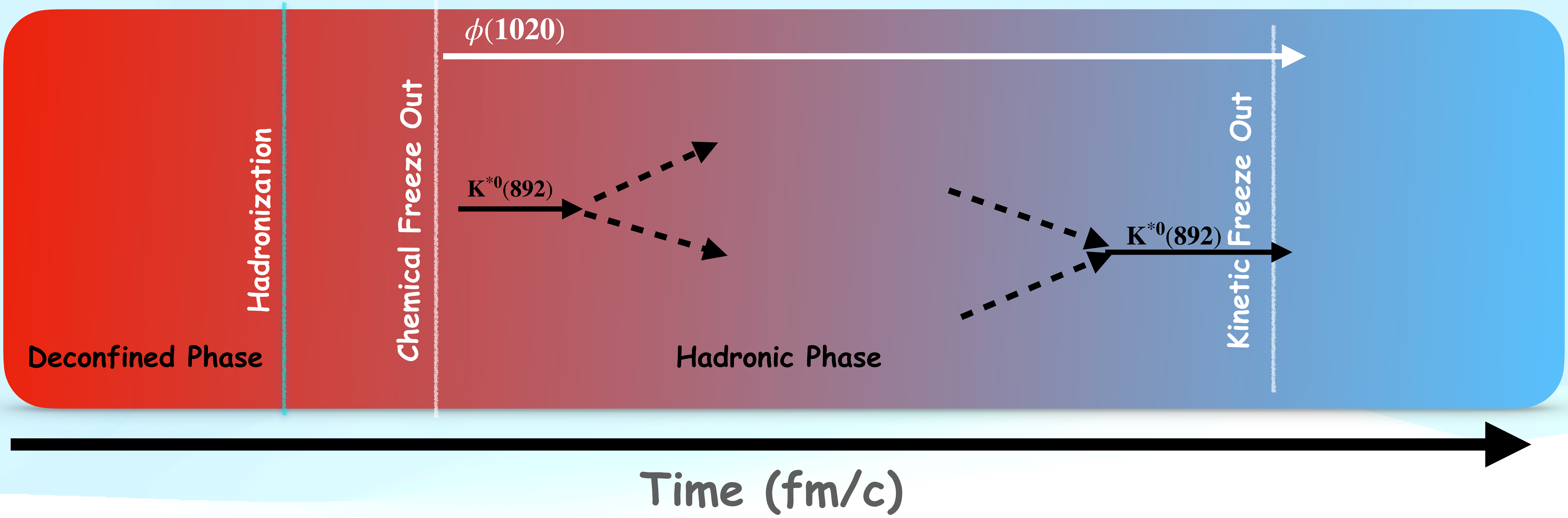
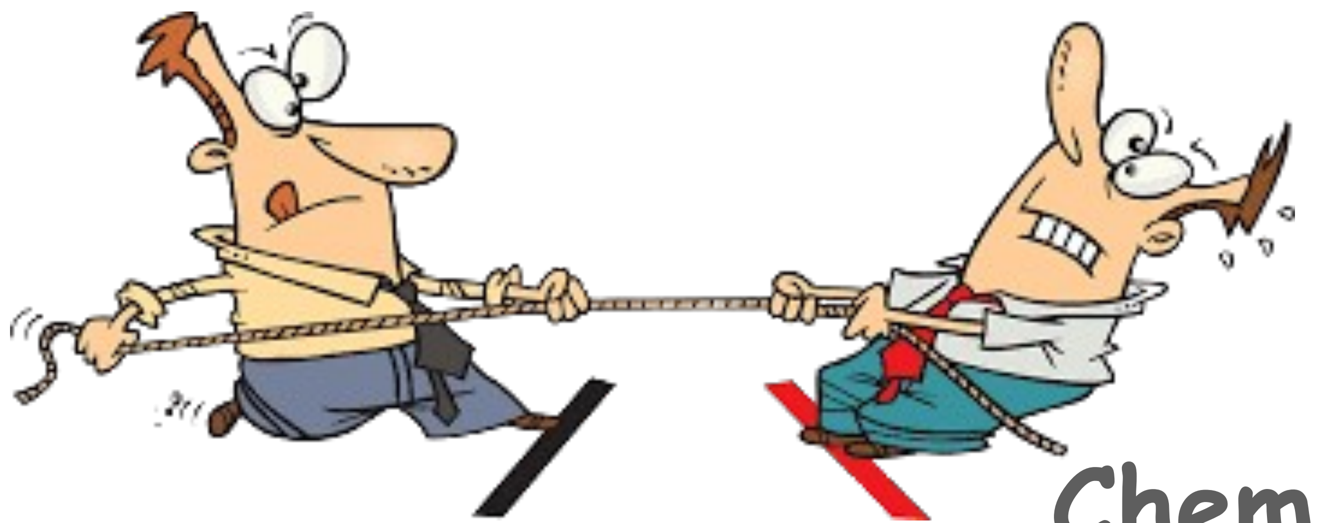
Deconfined Phase
Hadronization
Chemical Freeze Out
$\phi(1020)$
Hadronic Phase
Kinetic Freeze Out



Rescattering



Regeneration

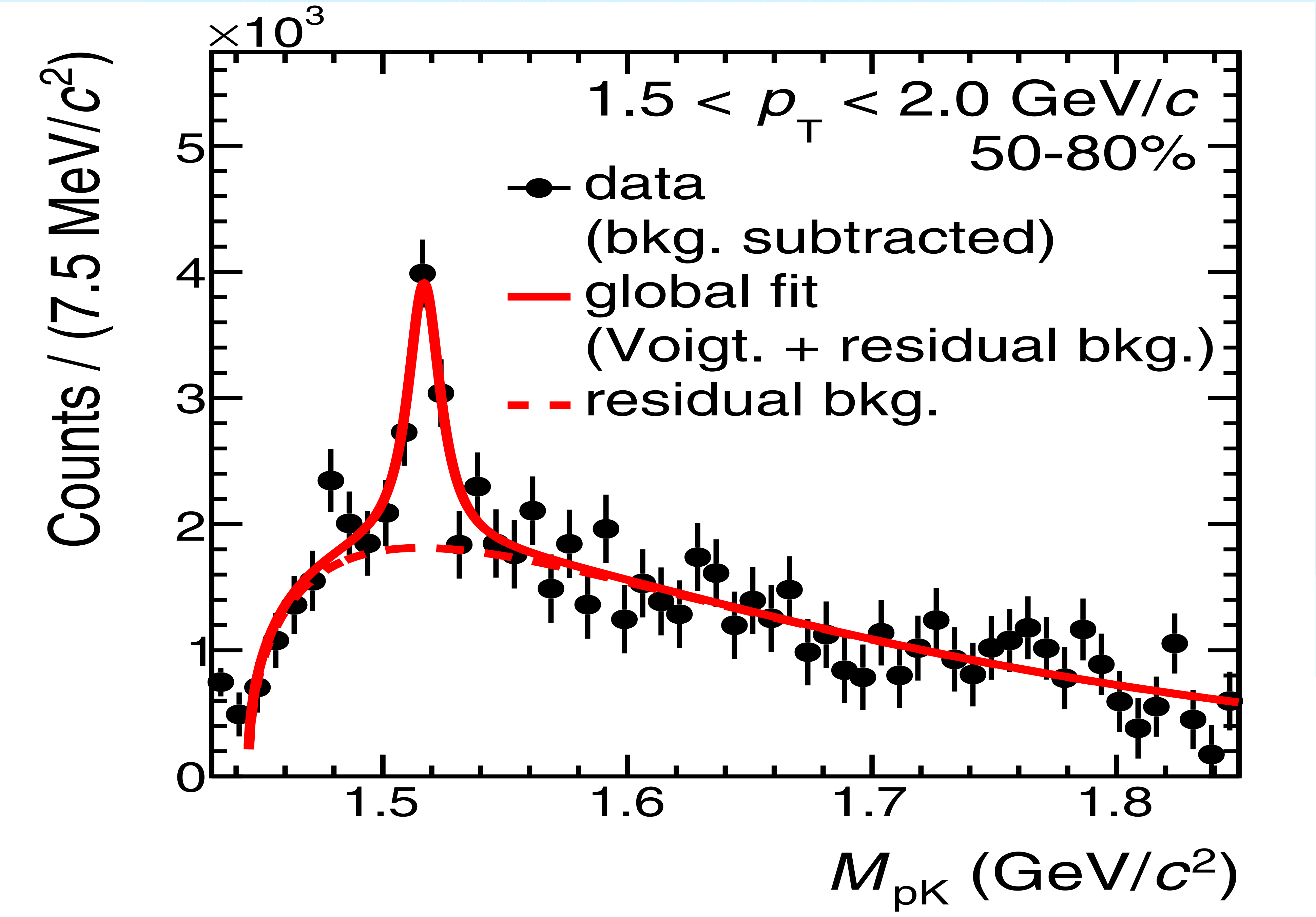
Final reconstructible resonance yield

Chemical Freeze out temperature
Duration of hadronic phase
Lifetime of resonance particle
Scattering cross-section of decay daughters

How do we detect resonances ?

- Reconstruction via invariant mass technique
- Background subtraction
- Fitting the signal with appropriate functions to extract yields

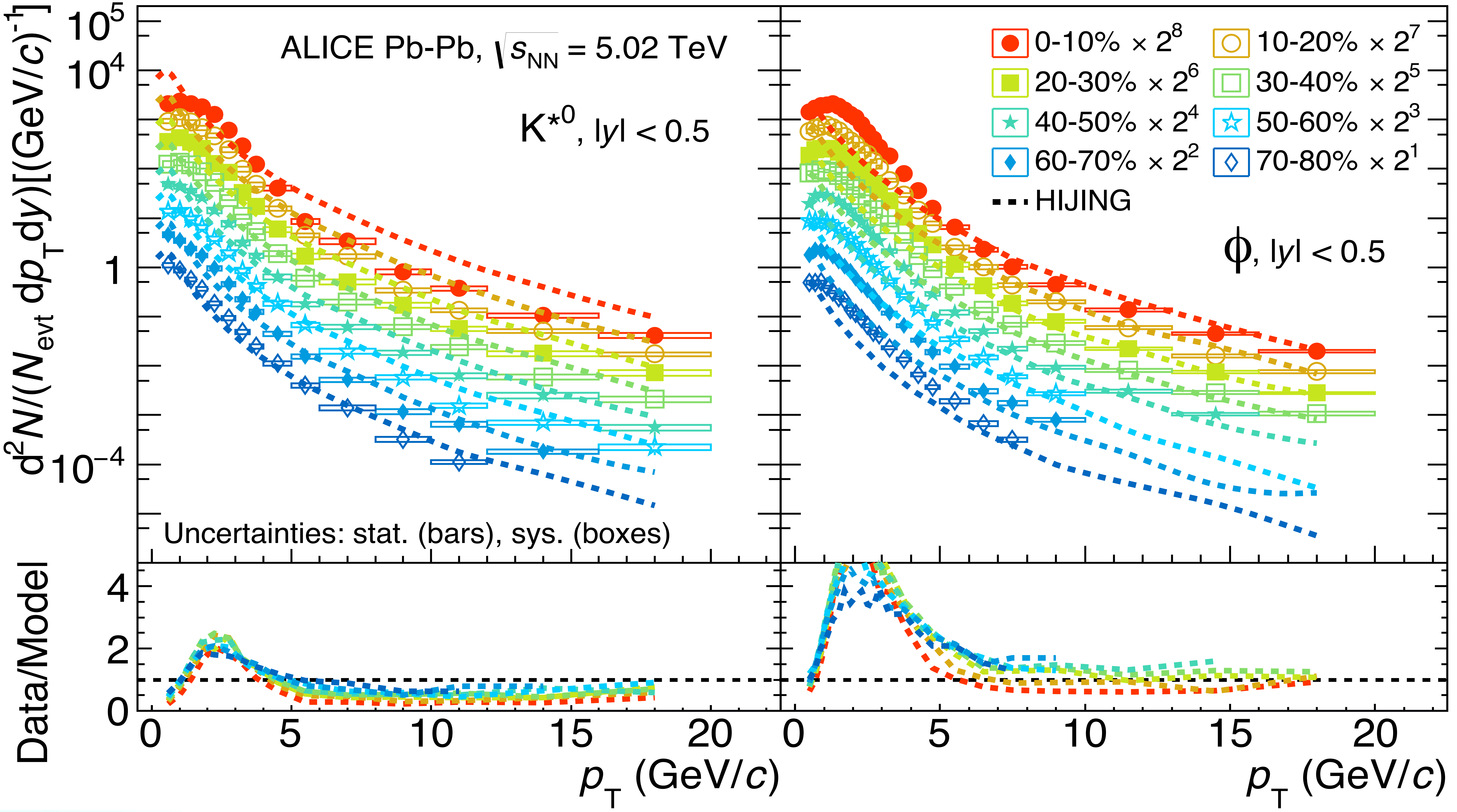
Phys. Rev. C 99, 024905 (2019)



Resonance	$\rho^0(770)$	K*(892)	$f^0(980)$	$\phi(1020)$	$f_1(1285)$	$\Sigma^{\pm}(1385)$	$\Lambda^0(1520)$	$\Xi^0(1530)$
τ(fm/c)	1.3	4.2	5 (with large uncertainties)	46	22.7	5.2	12.6	21.7
Quark content	$\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$d\bar{s}$		$s\bar{s}$		uus, dds	uds	uss

Mesonic Resonance : p_T spectra

Phys.Rev.C 106 (2022) 034907



Mesonic Resonance : p_T spectra

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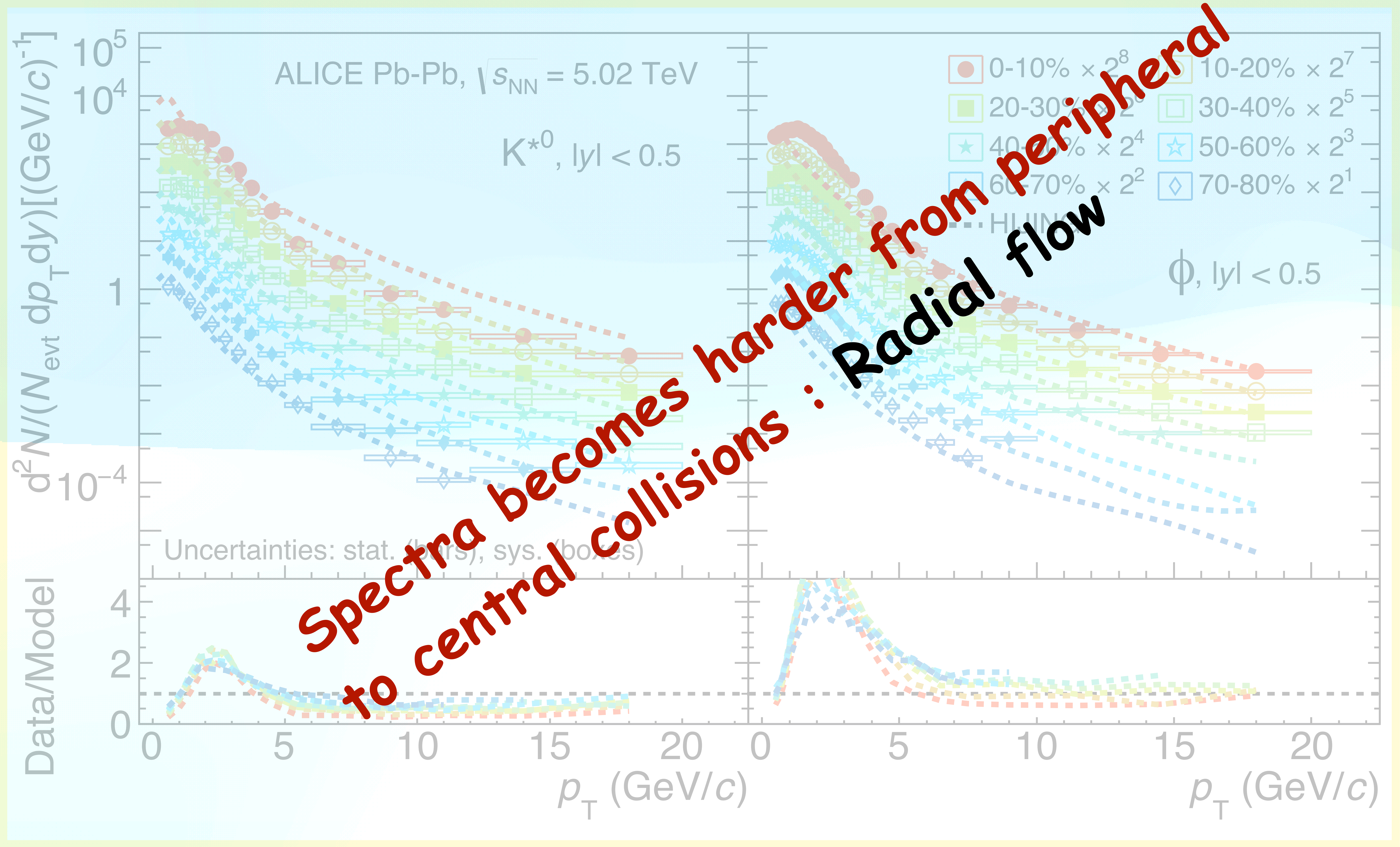
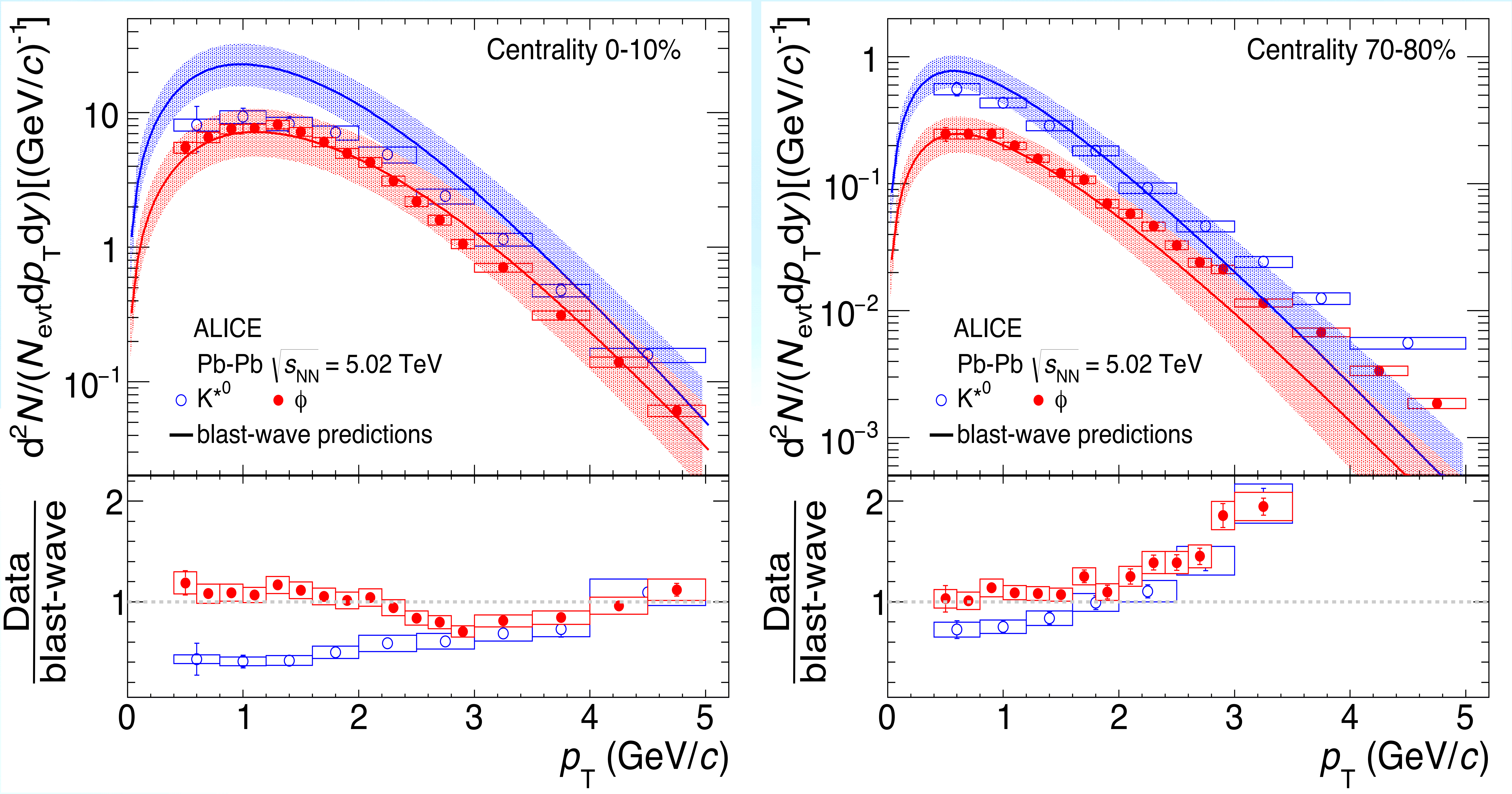


Spectra becomes harder from peripheral to central collisions : Radial flow

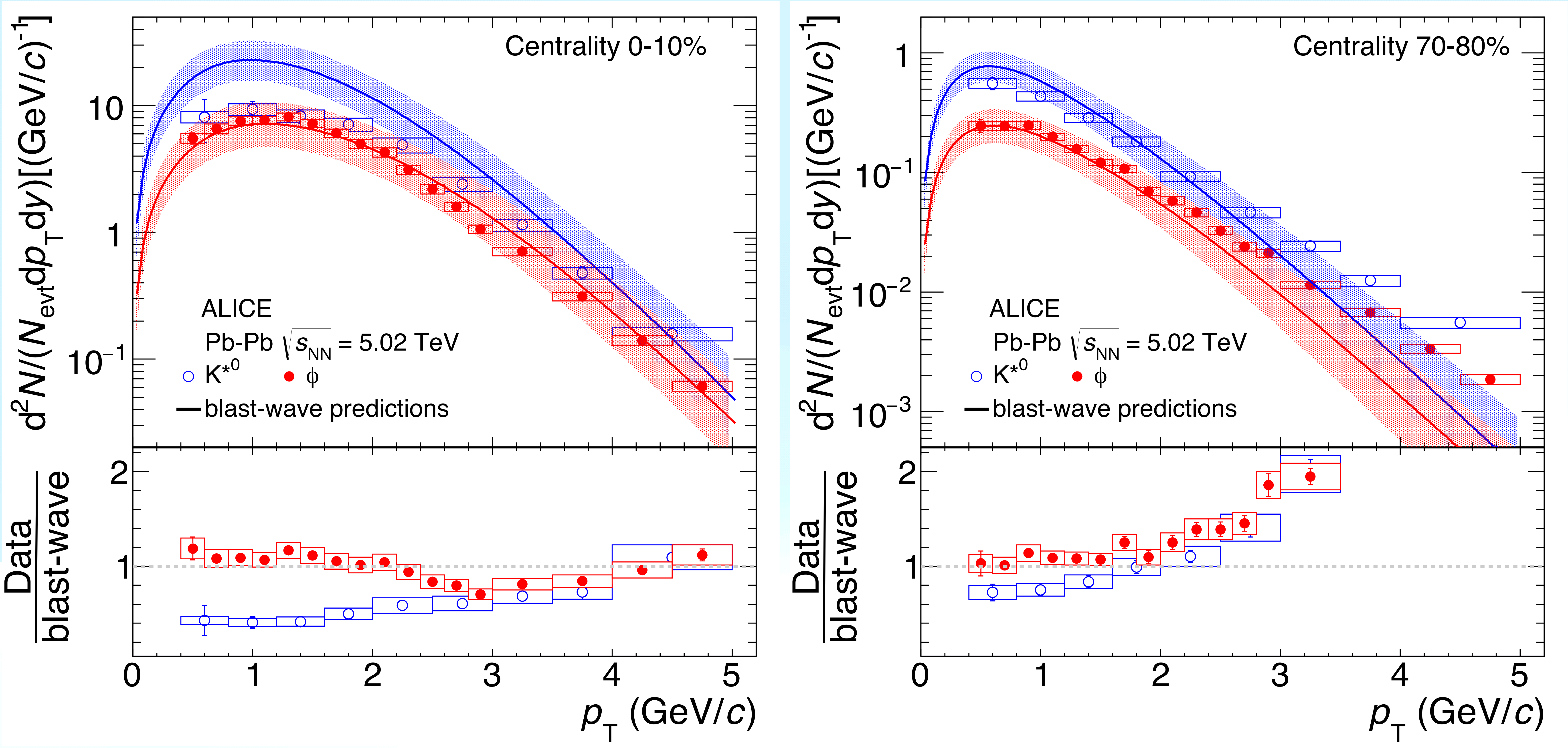
Mesonic Resonance : p_T spectra

Phys.Rev.C 106 (2022) 034907



Mesonic Resonance : p_T spectra

Phys.Rev.C 106 (2022) 034907

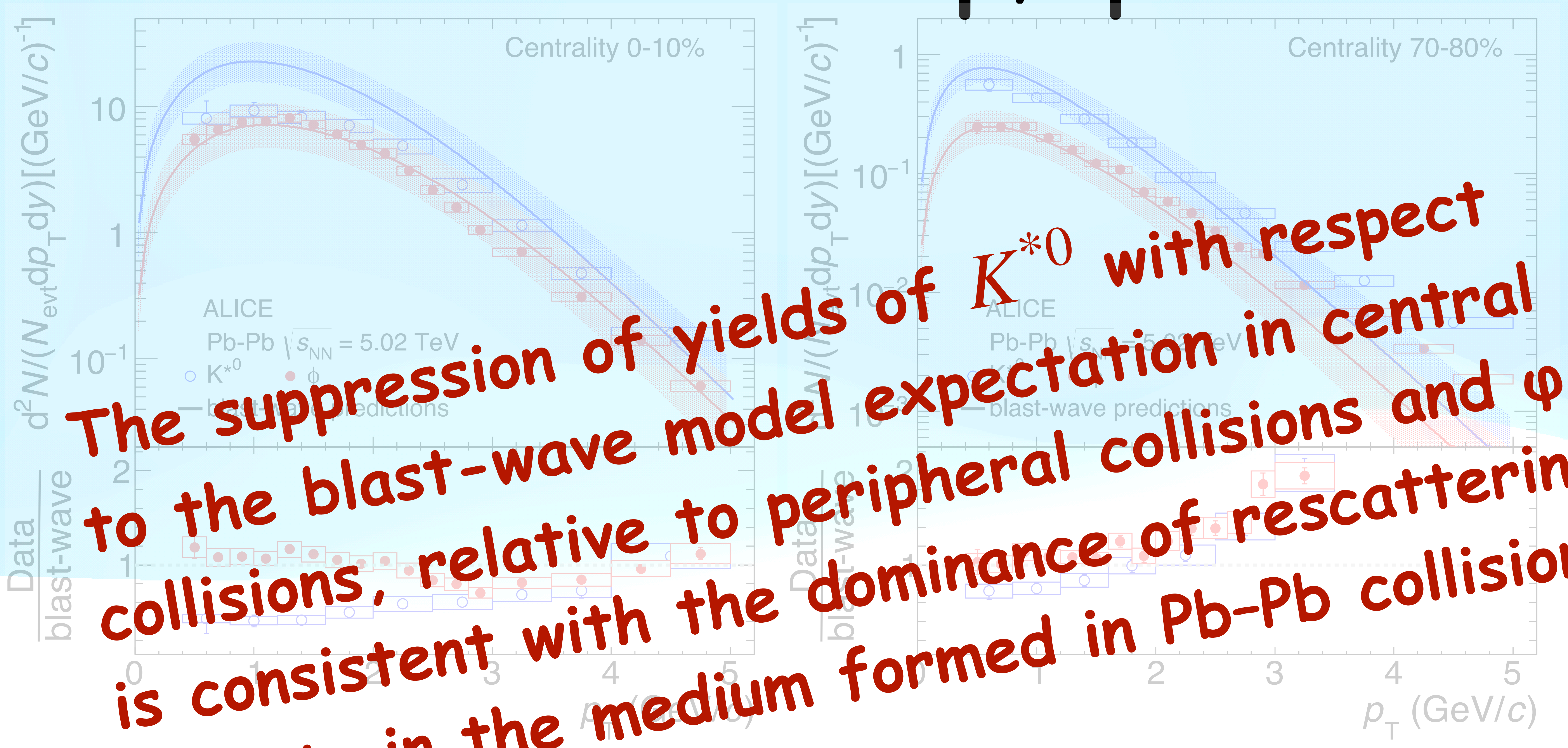


For low p_T (< 2 GeV/c), the data/blast wave for phi meson is close to unity and no significant difference between central and peripheral collisions.

For low p_T (< 3 GeV/c), the data/blast wave for K* meson is lower than unity with a deviation of ~(40 -60) % in central collisions.

Mesonic Resonance : p_T spectra

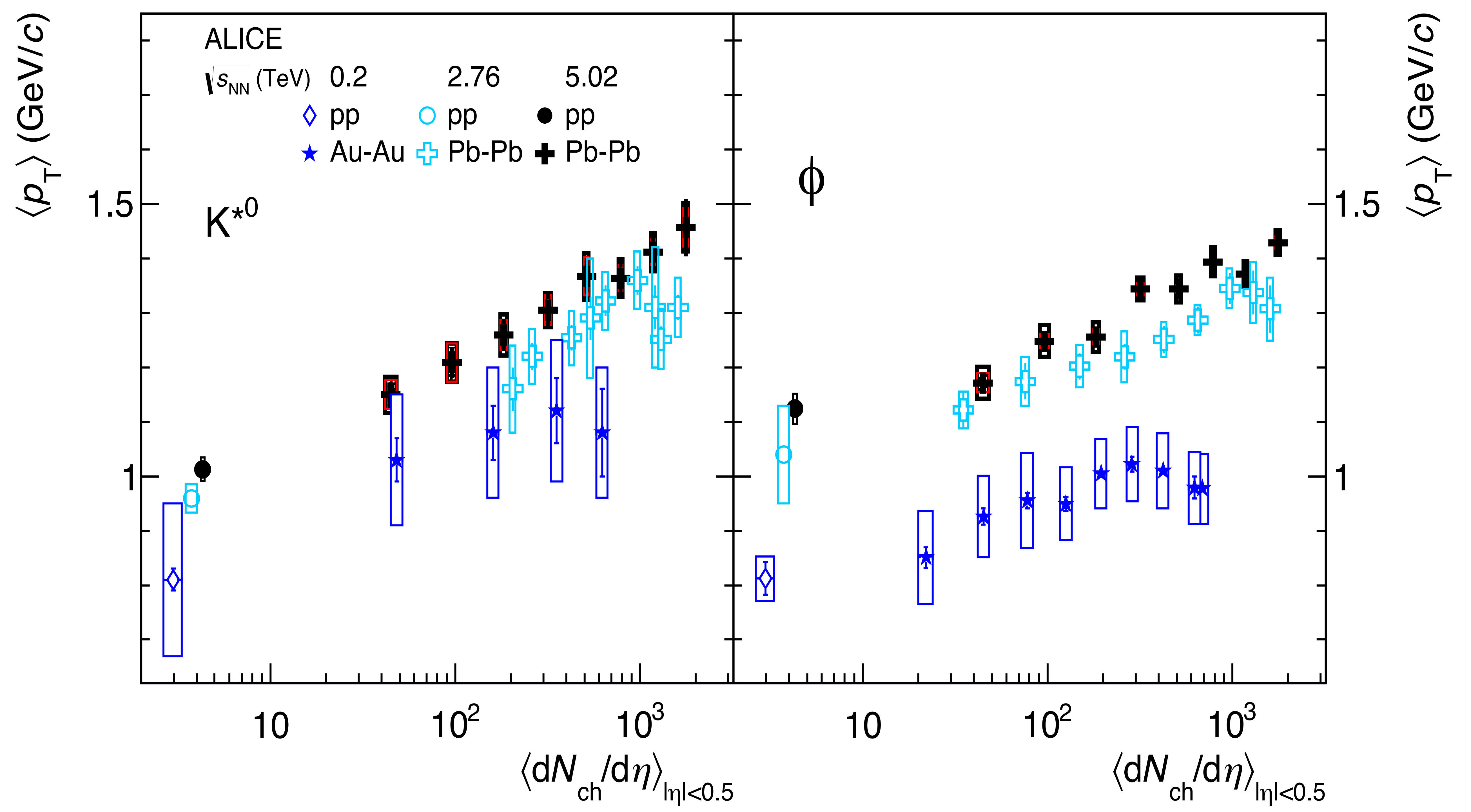
Phys.Rev.C 106 (2022) 034907



The suppression of yields of K^{*0} with respect to the blast-wave model expectation in central collisions, relative to peripheral collisions and φ mesons is consistent with the dominance of rescattering effects in the medium formed in Pb-Pb collisions.

Mean transverse momentum, $\langle p_T \rangle$

Phys.Rev.C 106 (2022) 034907



Mean transverse momentum, < p_T >

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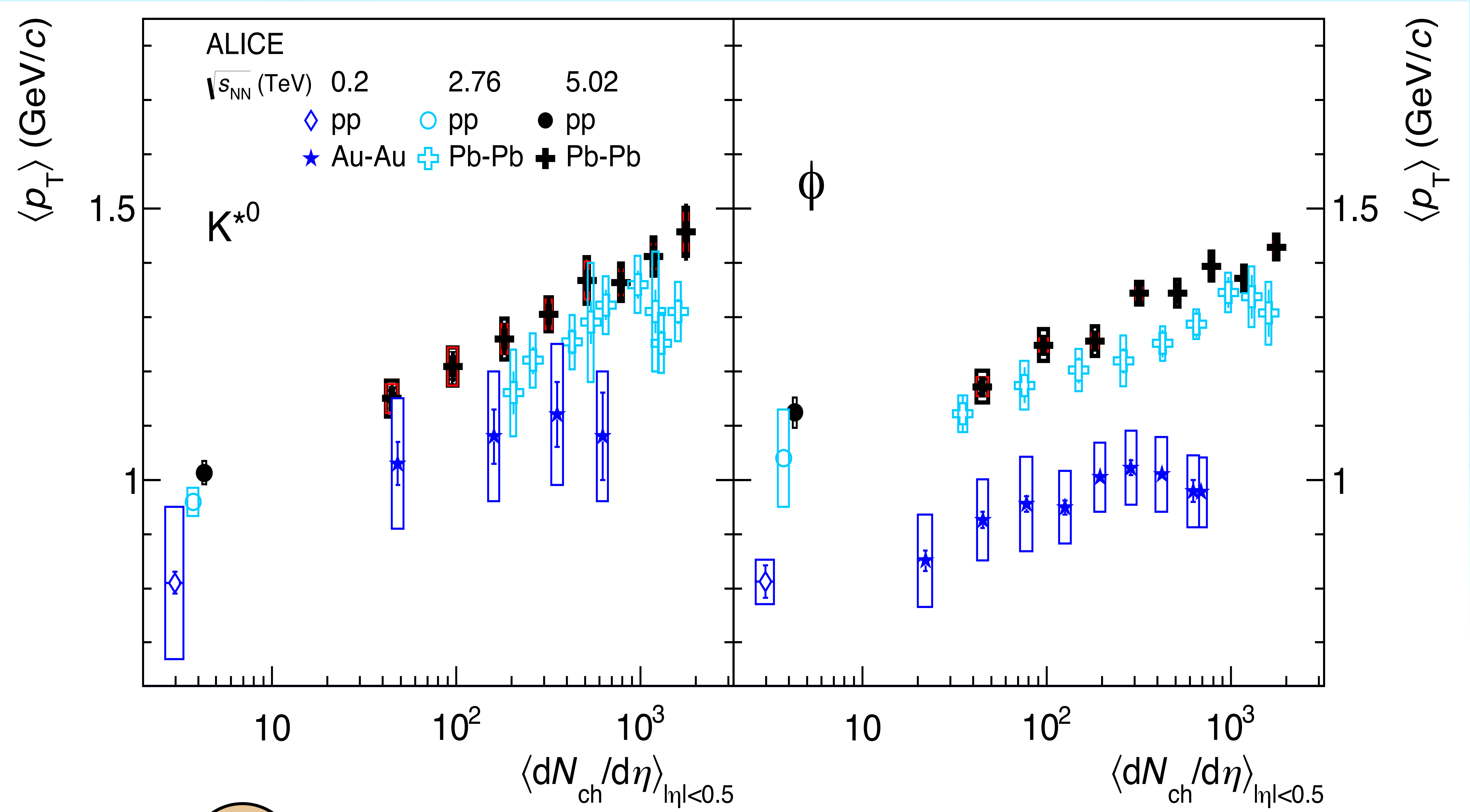

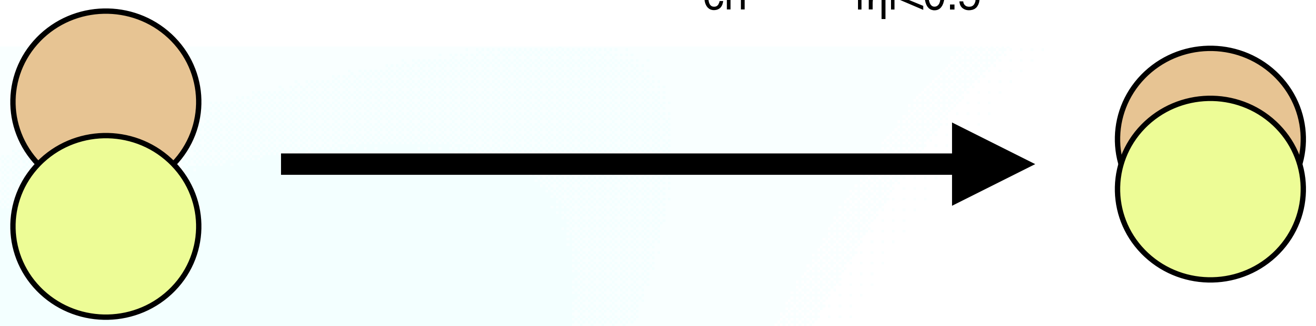

<p_T> values increase with charged particle multiplicity

Mean transverse momentum, < p_T >

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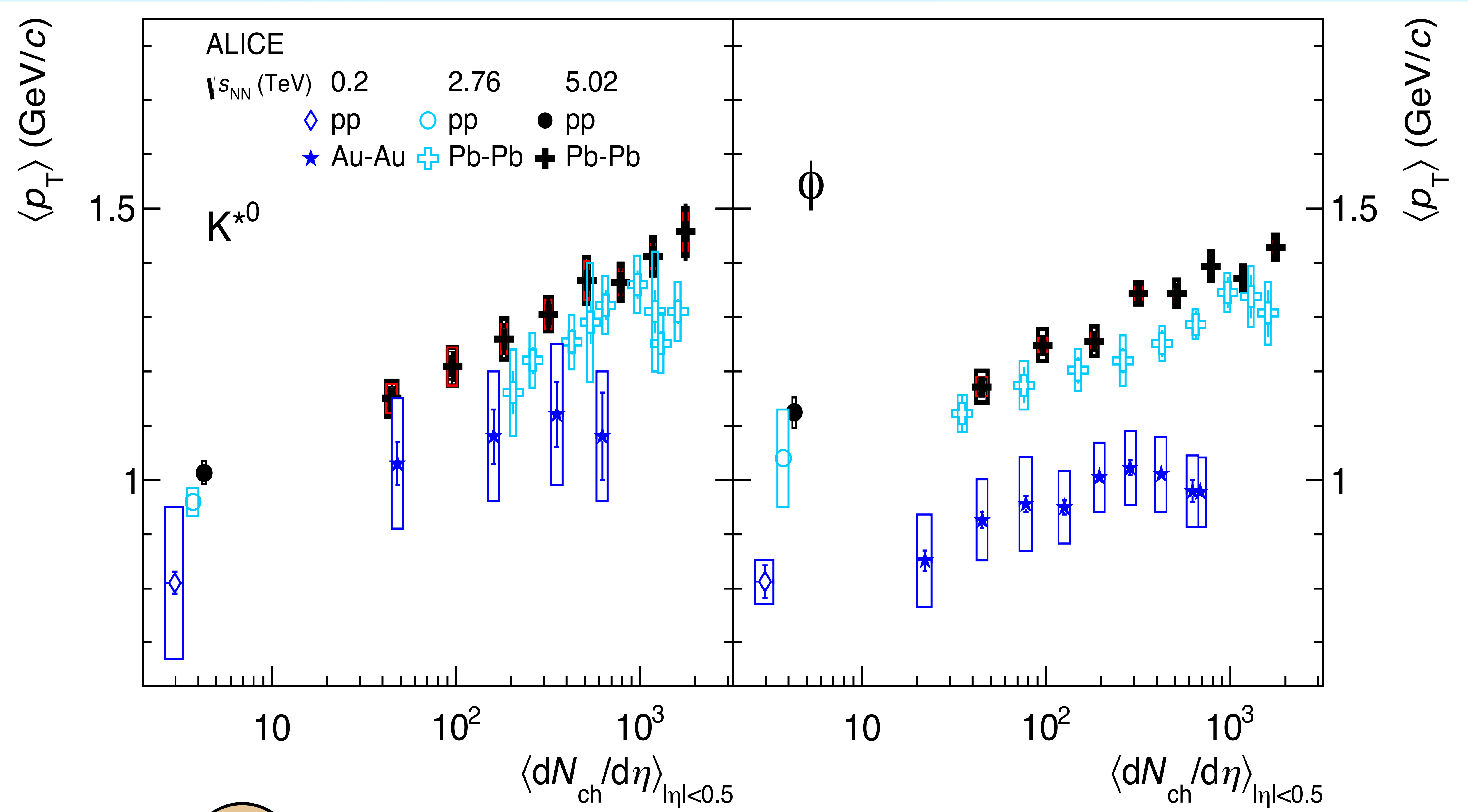

<p_T> values increase with charged particle multiplicity

Larger for higher energies at similar values of <$dN_{ch}/d\eta$>

Mean transverse momentum, < p_T >

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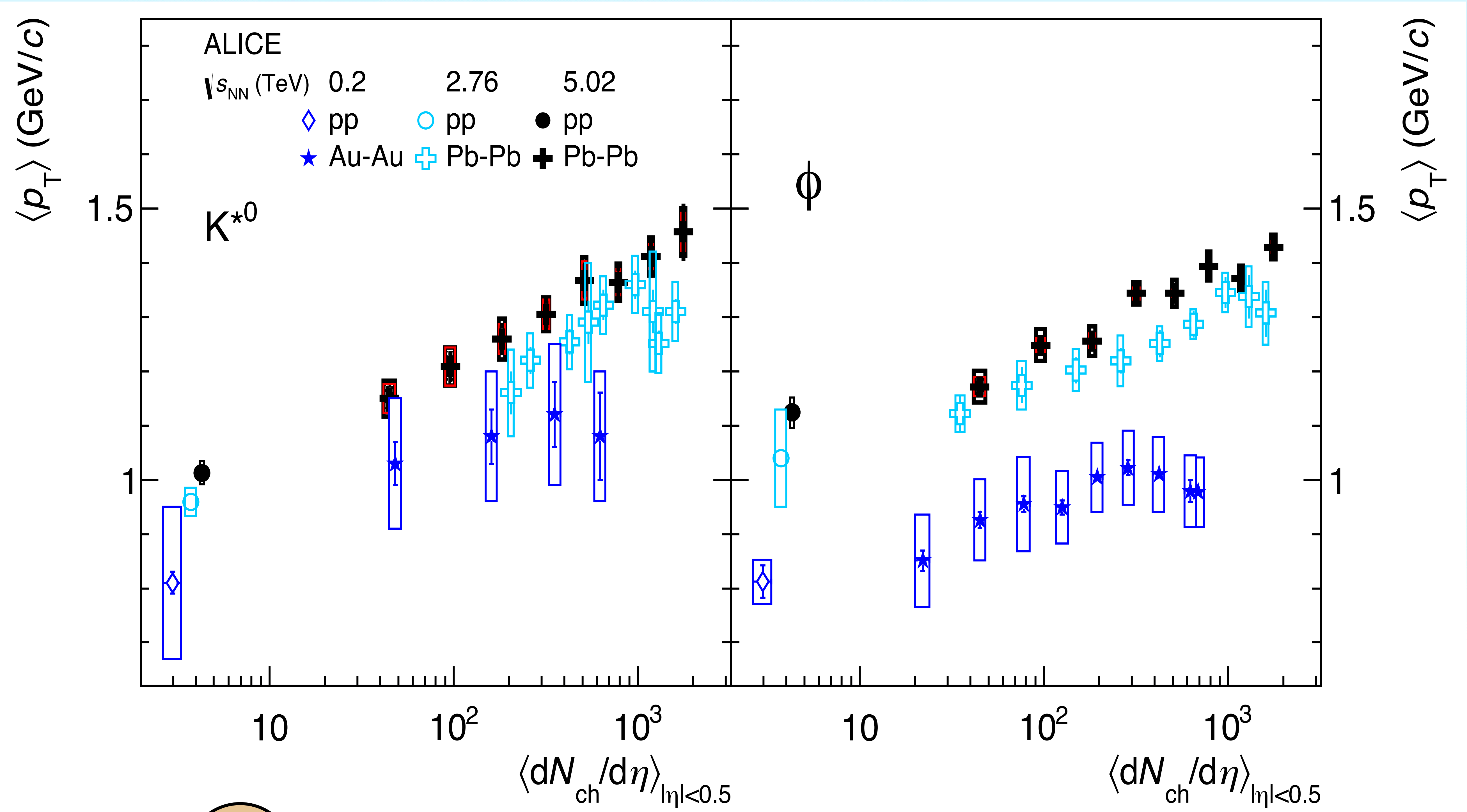

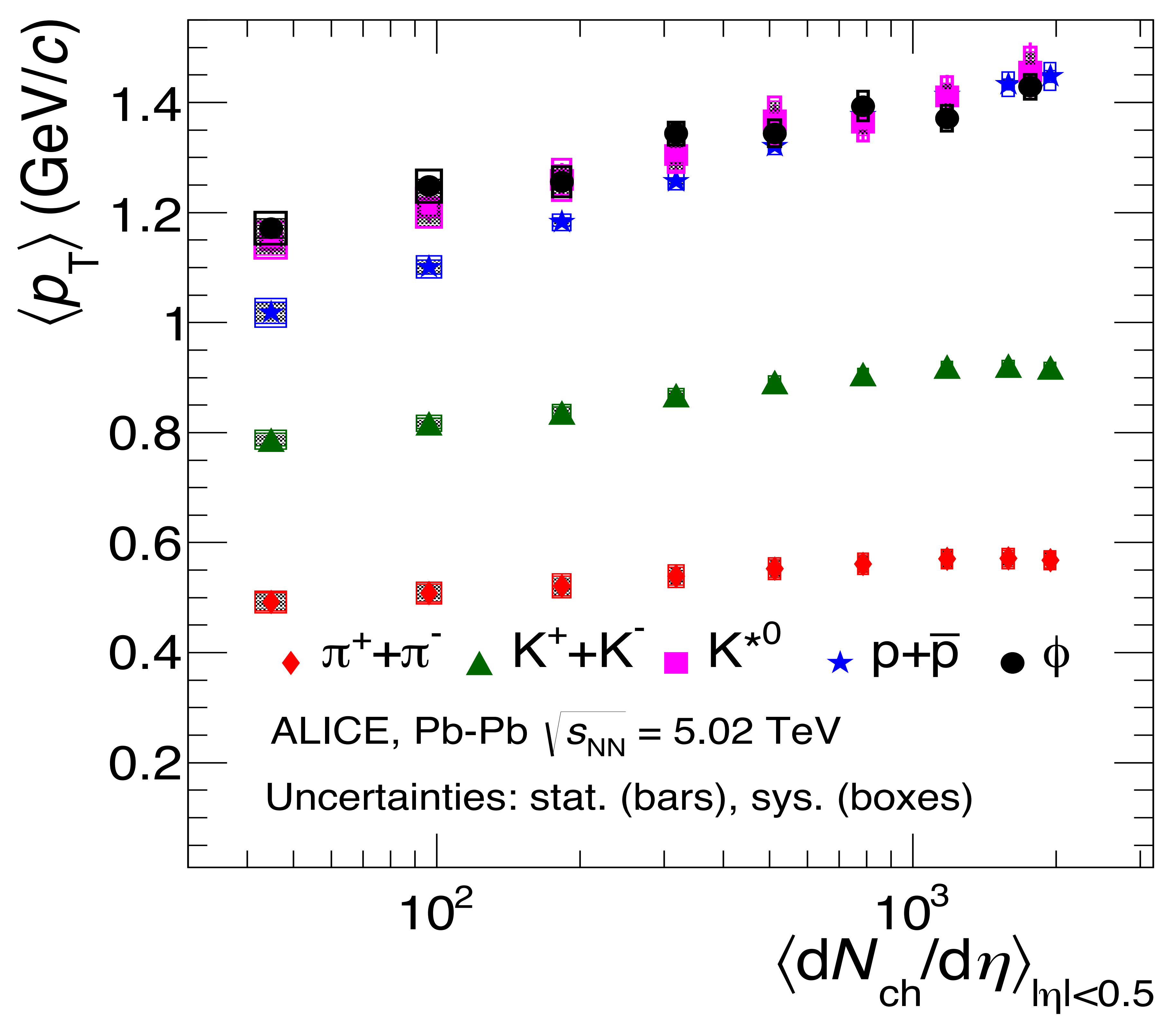

<p_T> values increase with charged particle multiplicity

Larger for higher energies at similar values of <$dN_{ch}/d\eta$>

Rise in <p_T> is steeper for hadrons with higher mass : Radial flow effect

Mean transverse momentum, $\langle p_T \rangle$

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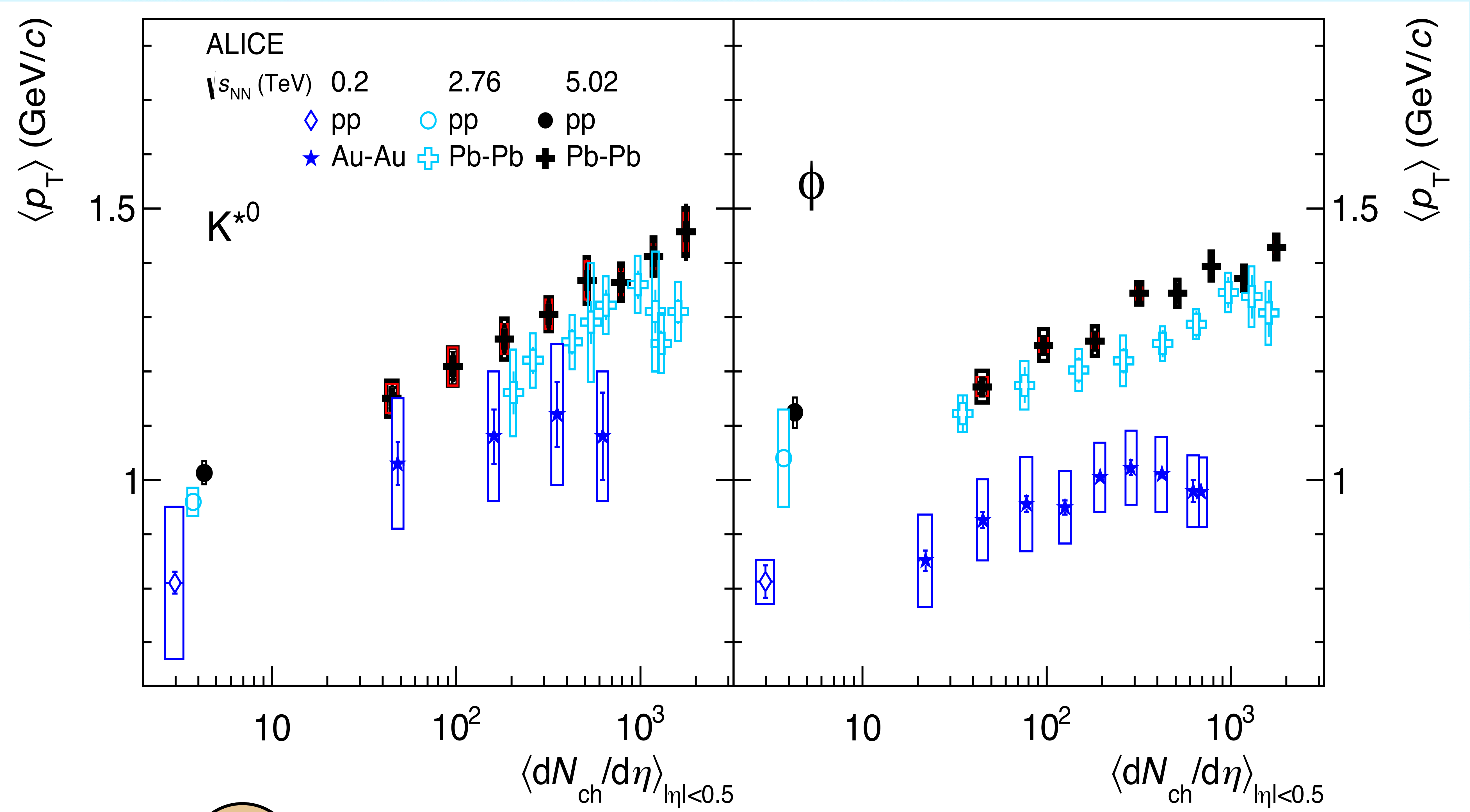
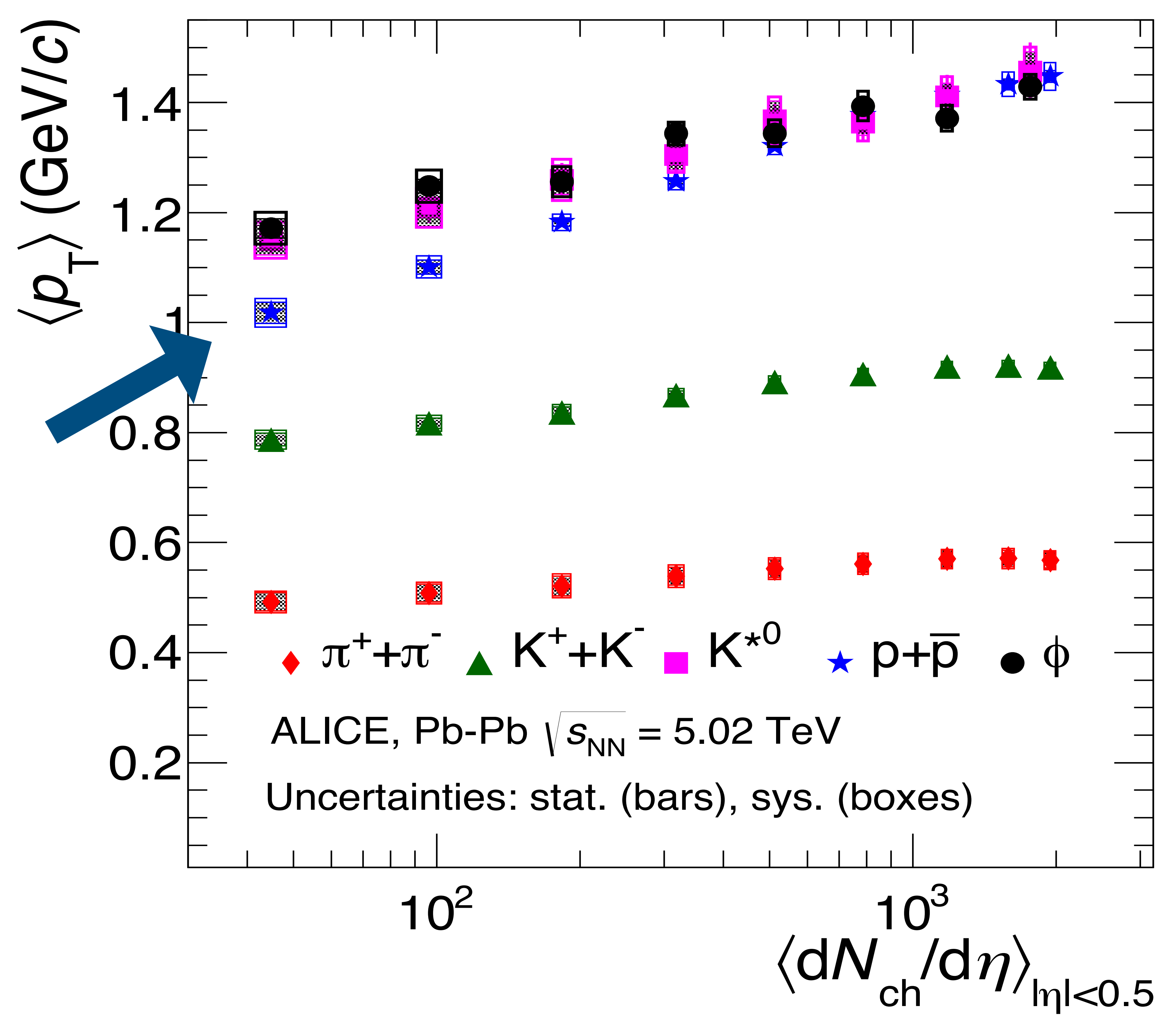
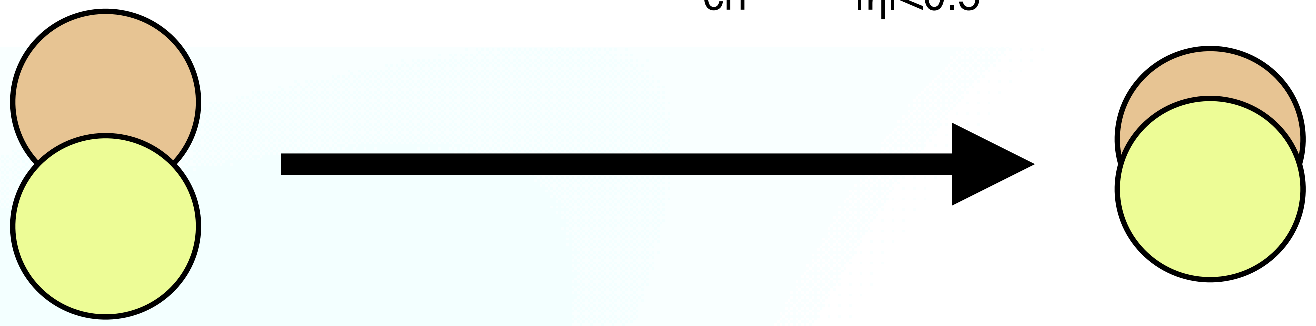






$\langle p_T \rangle$ values increase with charged particle multiplicity

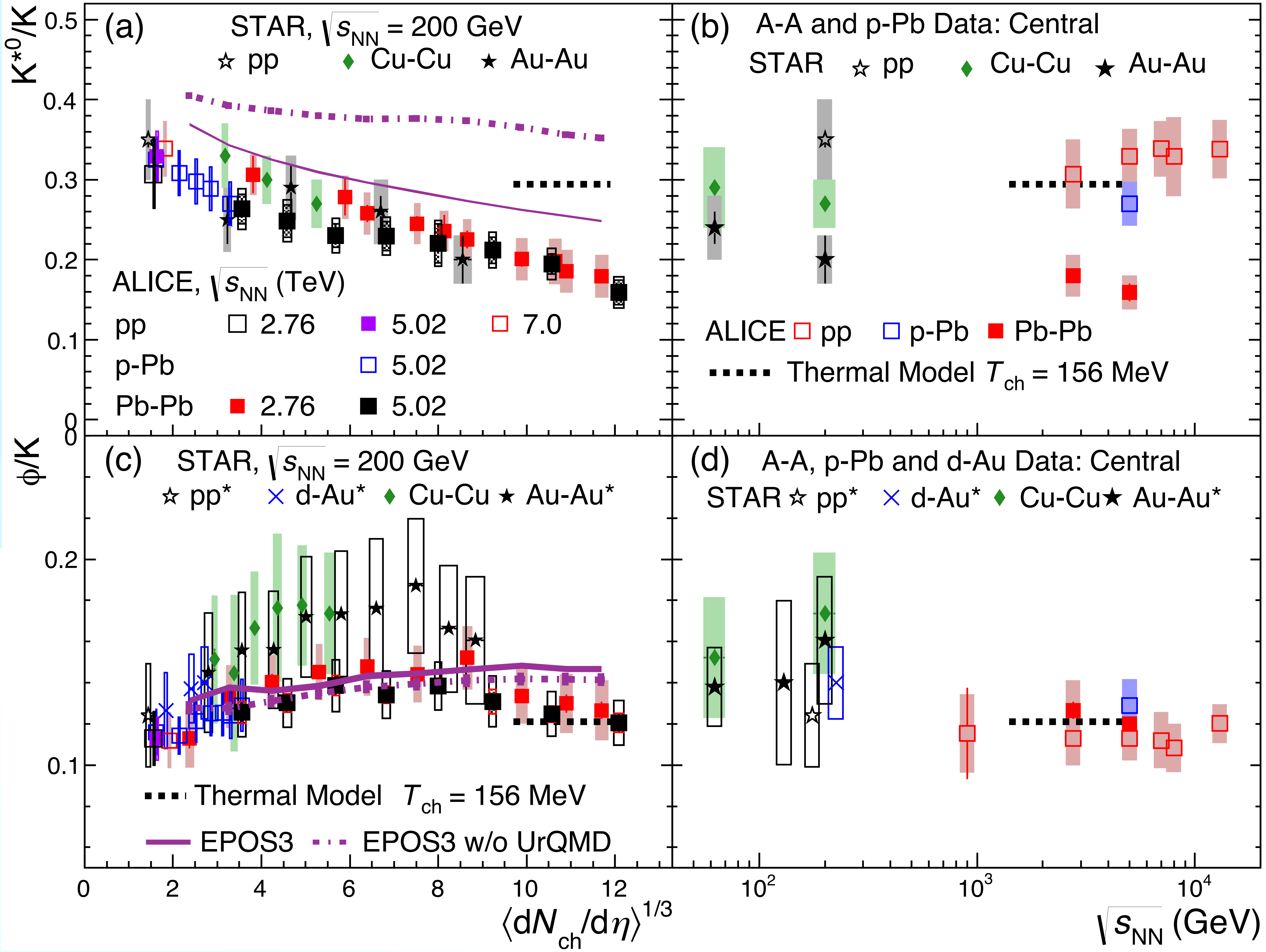
Larger for higher energies at similar values of $\langle dN_{ch}/d\eta \rangle$

Rise in $\langle p_T \rangle$ is steeper for hadrons with higher mass : Radial flow effect

Breaking of mass ordering in peripheral collisions.

Particle Ratios (K*0/K & ϕ/K)

Phys.Rev.C 106 (2022) 034907



K*/K :

Suppression of K*/K ratio from peripheral to central collisions.

Clear system and size dependence observed.

EPOS3 overestimates the data while predicts the trend.

Particle Ratios (K*/K & ϕ/K)

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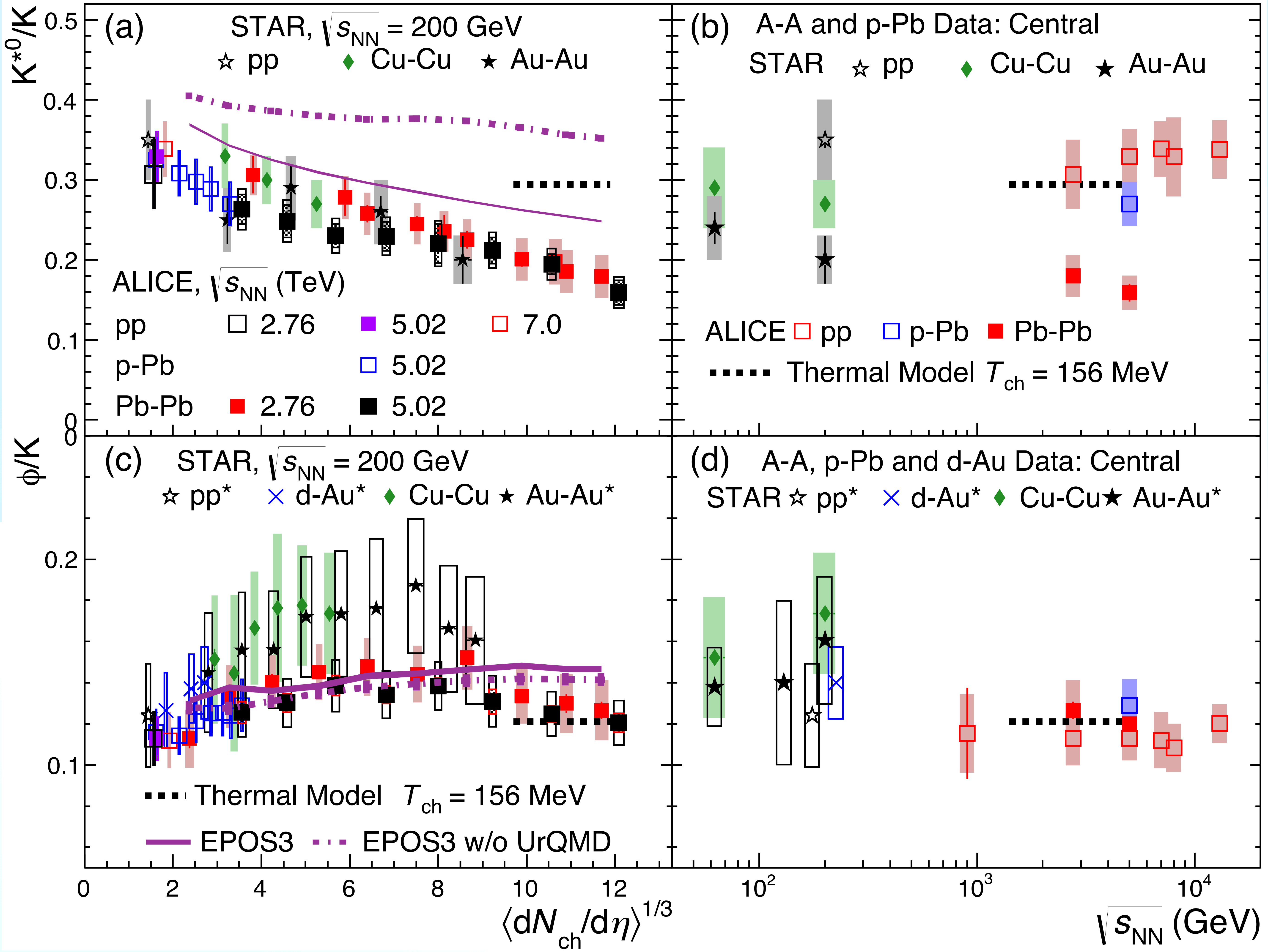

Dominance of re-scattering effect

Particle Ratios (K*/K & ϕ/K)

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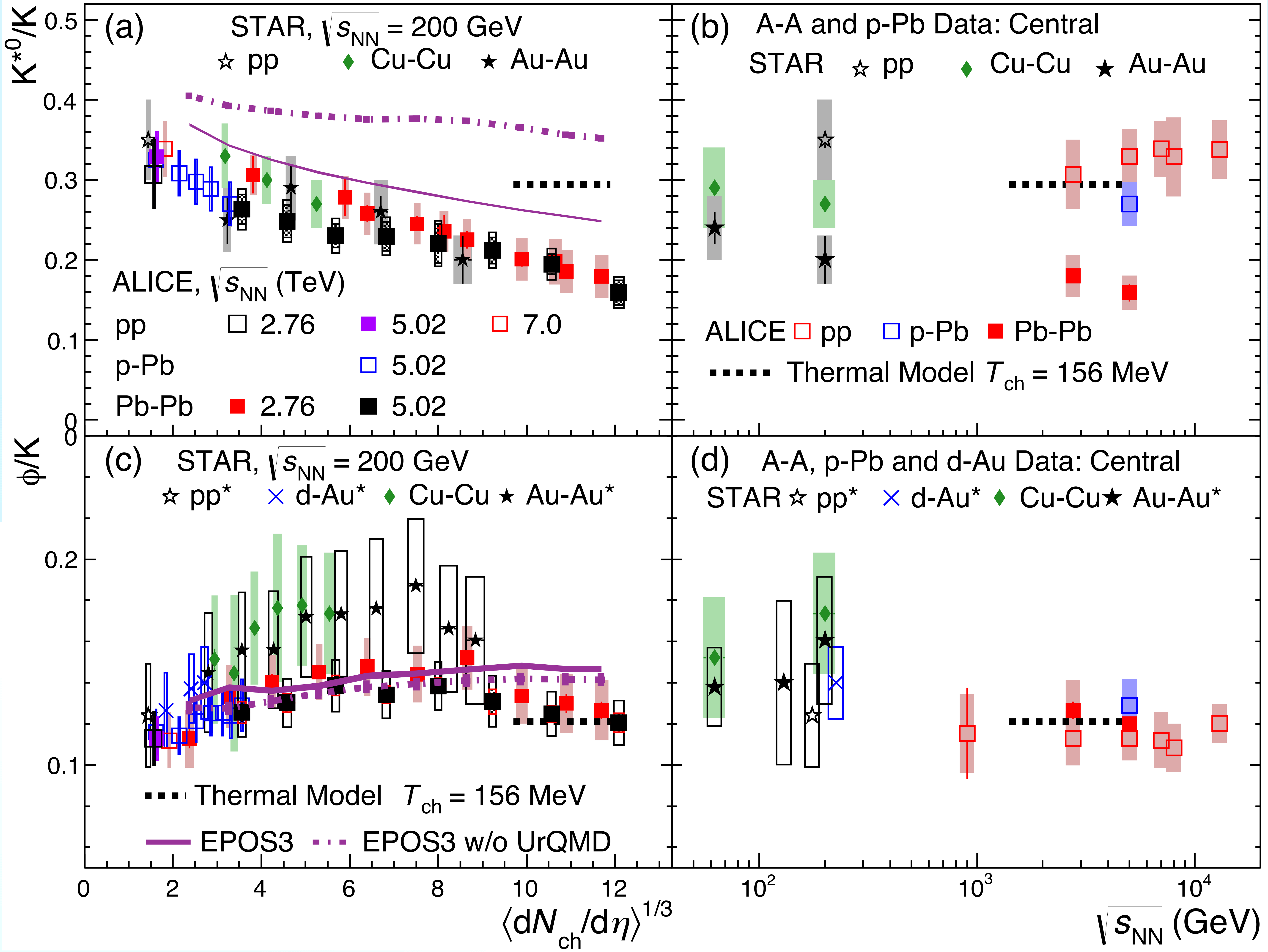
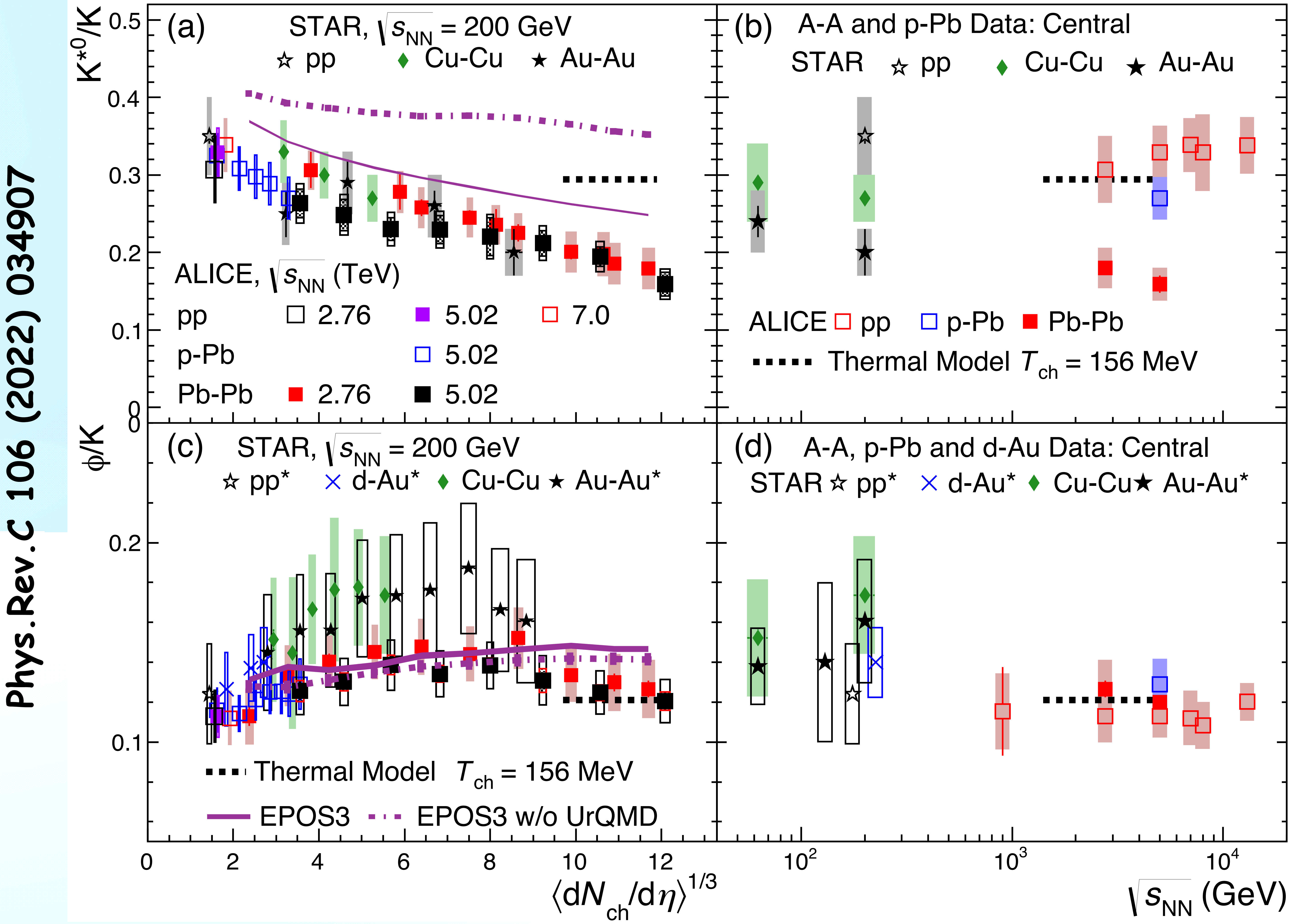


Dominance of re-scattering effect

ϕ/K :

No suppression of ϕ/K ratio from peripheral to central collisions. EPOS3 predicts the data well.

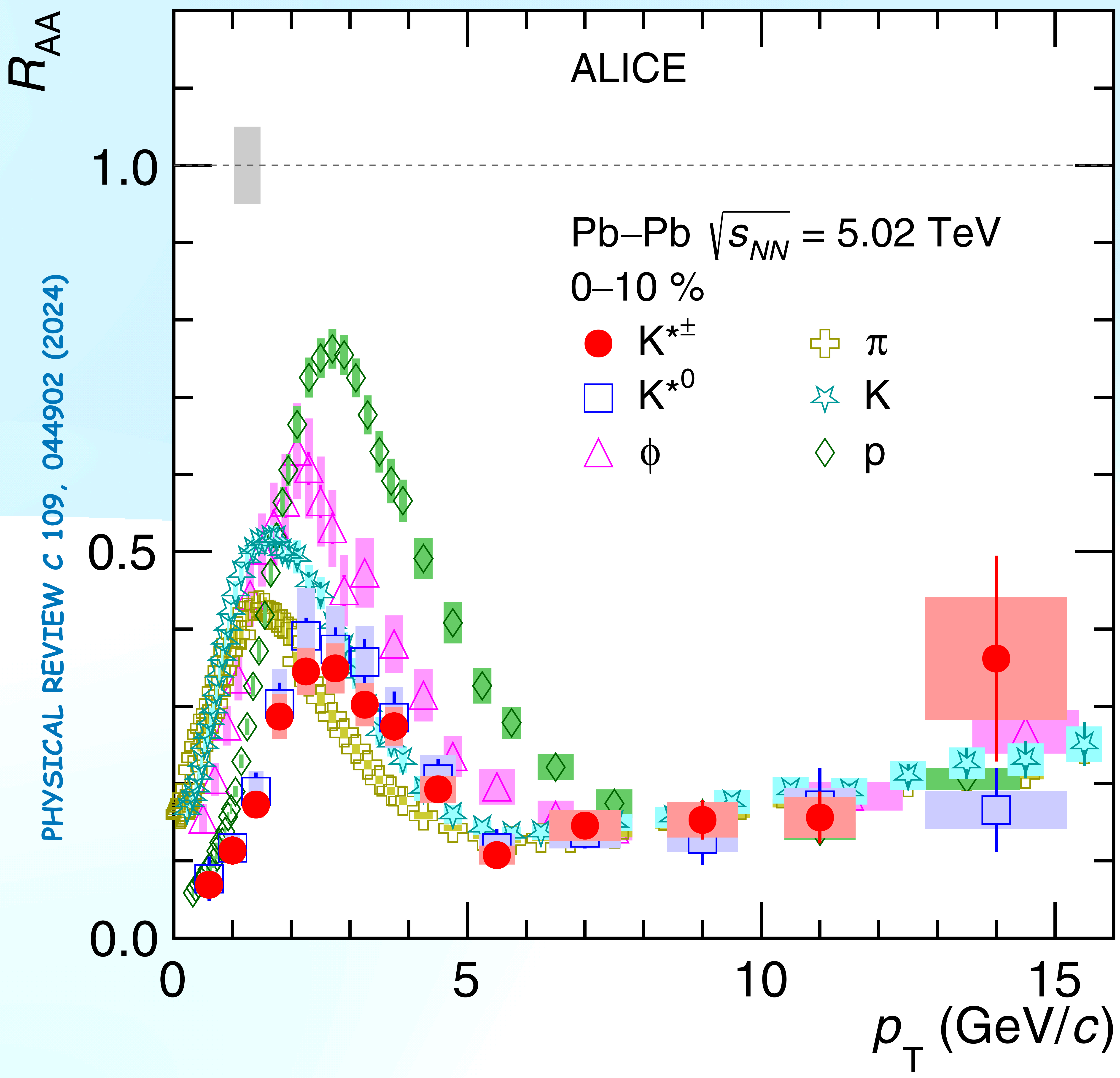
Particle Ratios (K*/K & ϕ/K)



Dominance of re-scattering effect

re-scattering effect not significant for ϕ

In-medium loss (I)



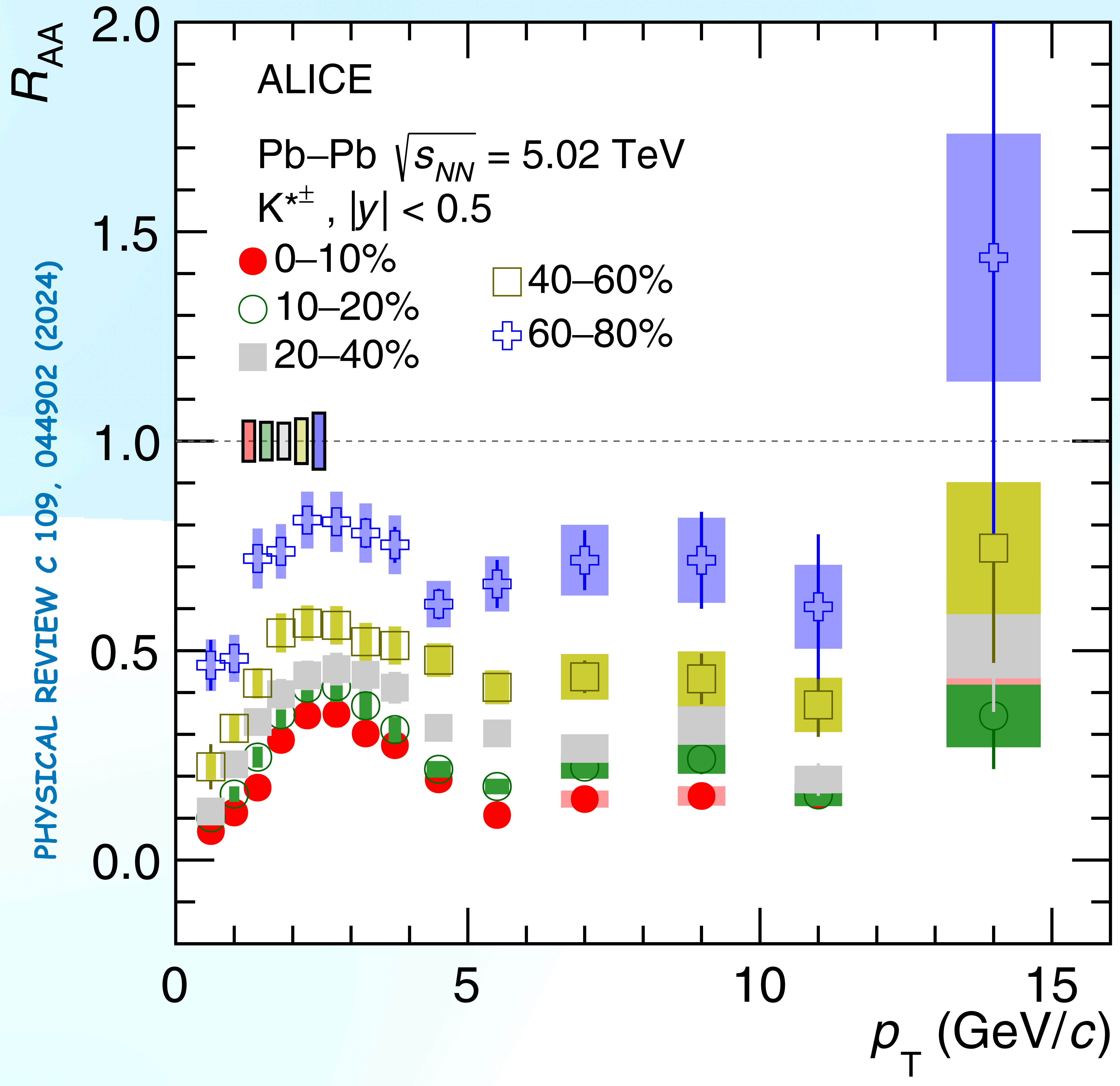
At low p_T (< 2 GeV/c), K* values are the smallest : consistent with the picture of the rescattering effect.

R_{AA} values in the intermediate-p_T range show species dependence with evidence of baryon-meson splitting.

For p_T > 8 GeV/c, all the particle species show similar R_{AA} within the uncertainties.

This observation suggests that suppression of various light flavored hadrons is independent of their quark content and mass for p_T > 8 GeV/c.

In-medium loss (II)

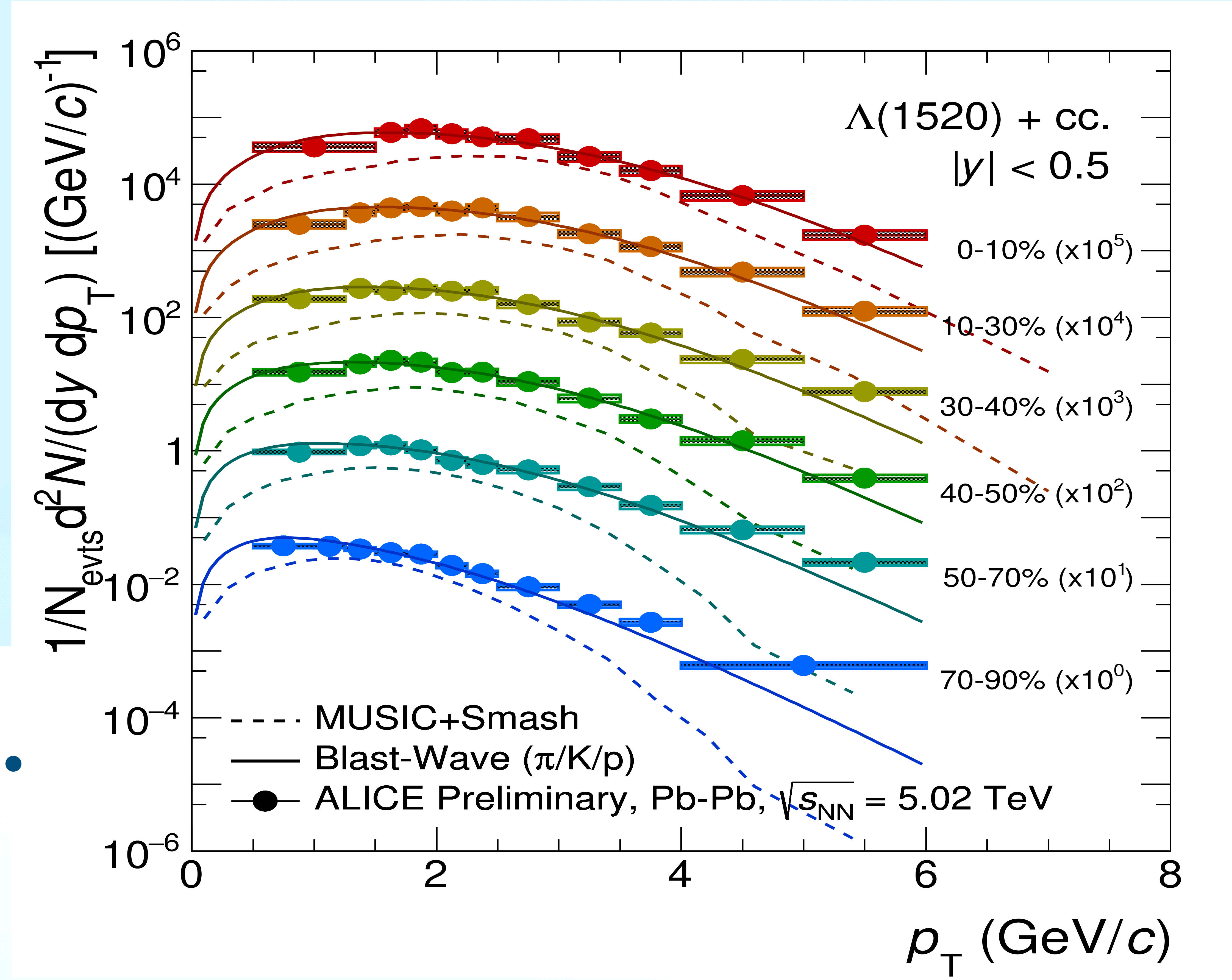


The R_{AA} of K* is found to be the smallest in most central collisions.

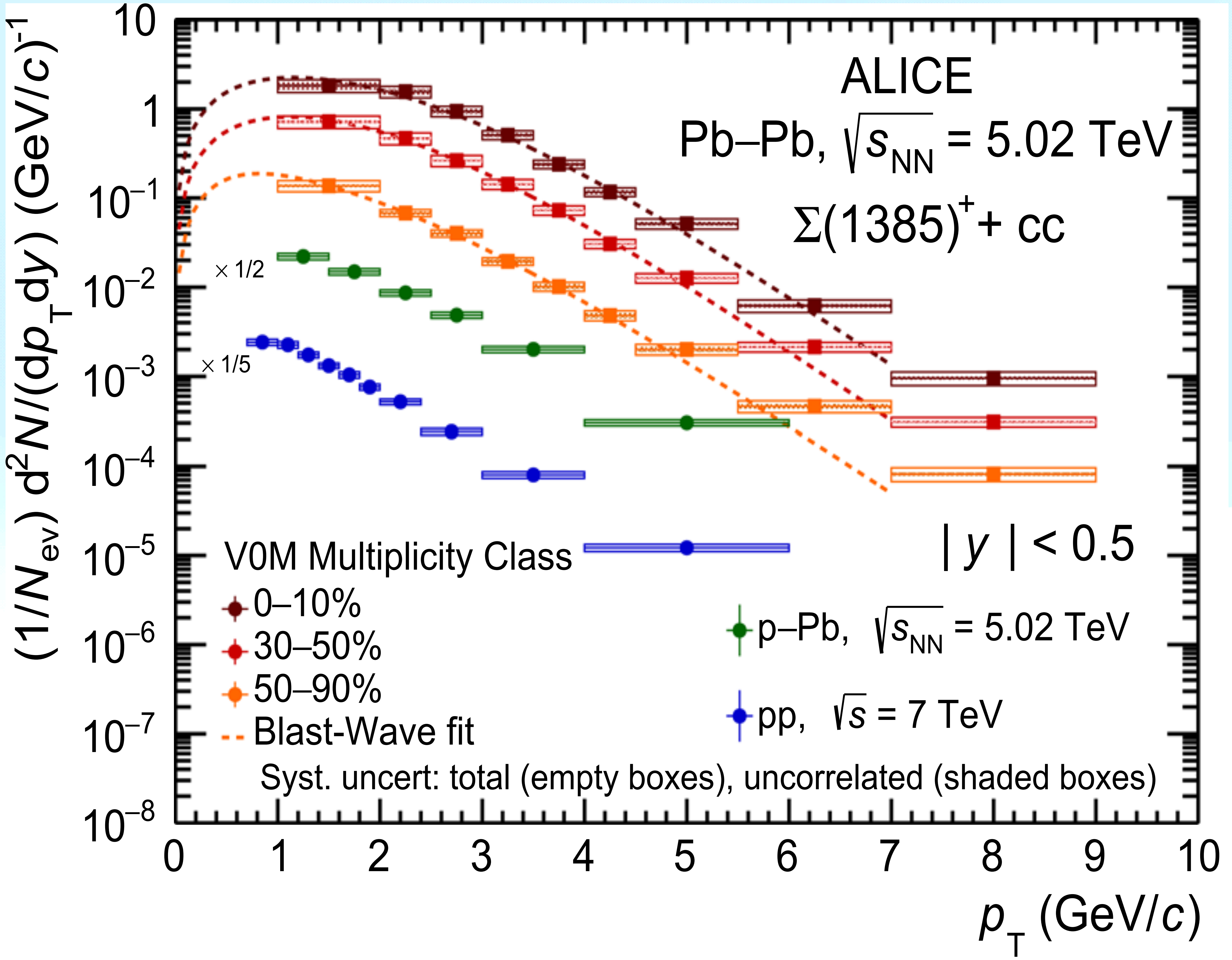
Gradually increases towards more peripheral collisions.

The results are consistent with centrality-dependent energy loss of partons.

Baryonic Resonance : p_T spectra



PoS LHCP2023 (2024) 269



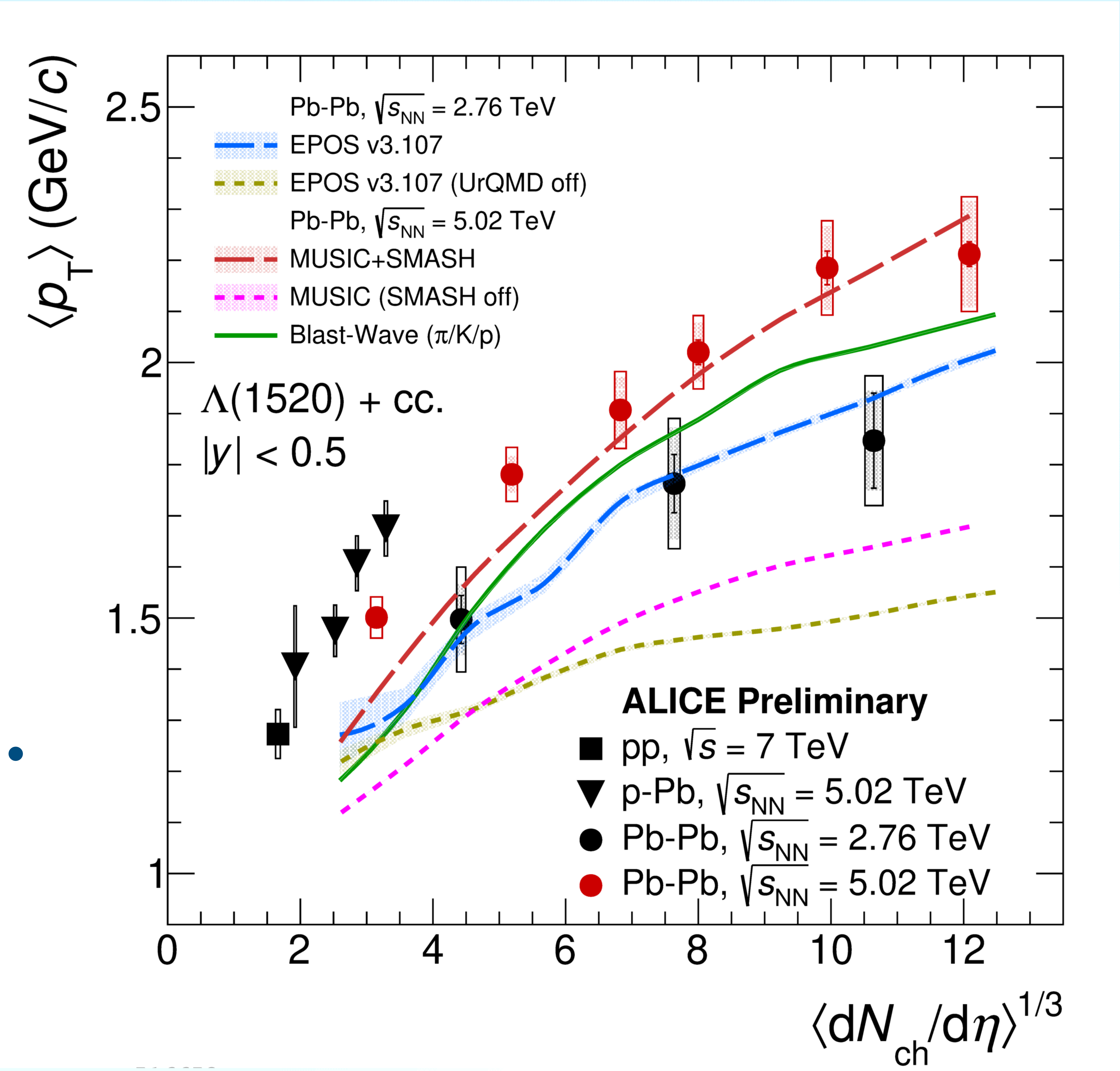
Eur. Phys. J. C (2023) 83:351

Good agreement with Blast-Wave (π/K/p fits).

Quite close to MUSIC hydrodynamic models with SMASH afterburner at low p_T

MUSIC slightly underestimates the data

Baryonic Resonance : <p$_T$>



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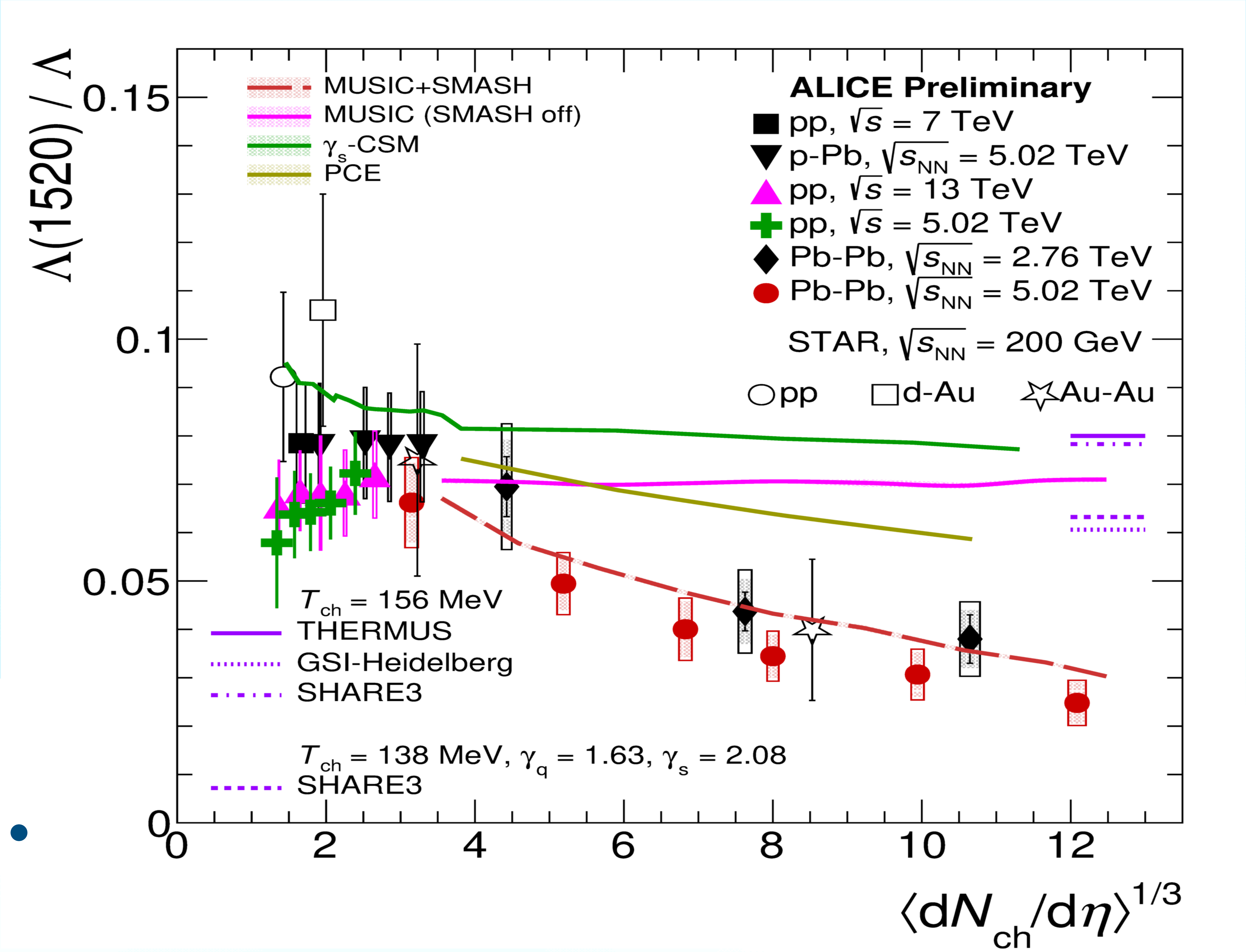
The <p$_T$> values increase from peripheral to central collisions (~47% higher)

Higher than Pb-Pb @ 2.76 TeV values and Blast-wave model predictions (π/K/p)

MUSIC and EPOS3 models give better predictions with hadronic phase modelling (SMASH and UrQMD).

Baryonic Resonance : Λ(1520)/Λ



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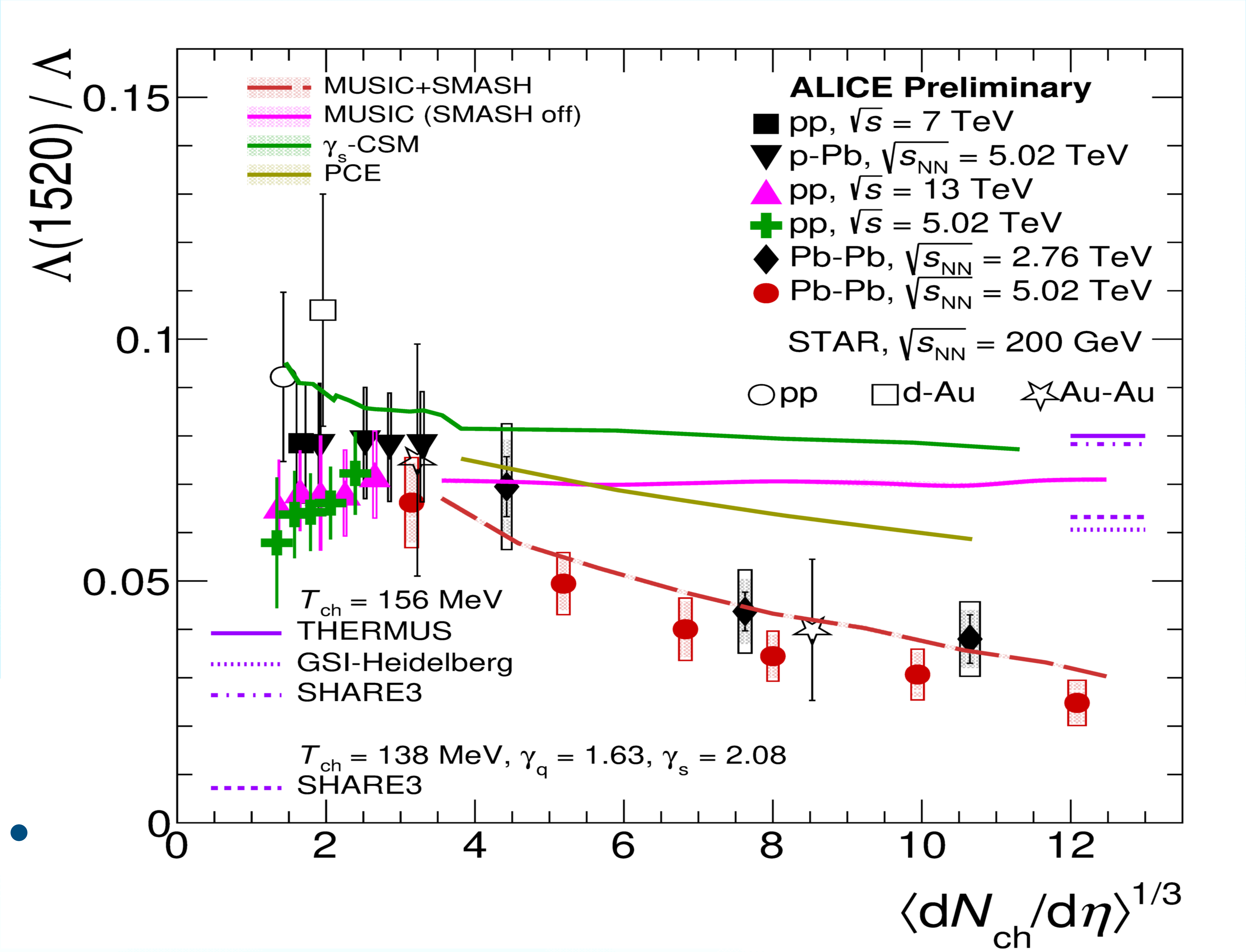
Baryonic Resonance : Λ(1520)/Λ



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The Λ(1520)/Λ yield ratio is suppressed in central collisions

MUSIC with SMASH afterburner reproduces the multiplicity suppression trend,

Thermal models do not reproduce the suppression trend.

$\Lambda(1520)/\Lambda$ and $\Sigma^{*\pm}/\pi^{\pm}$

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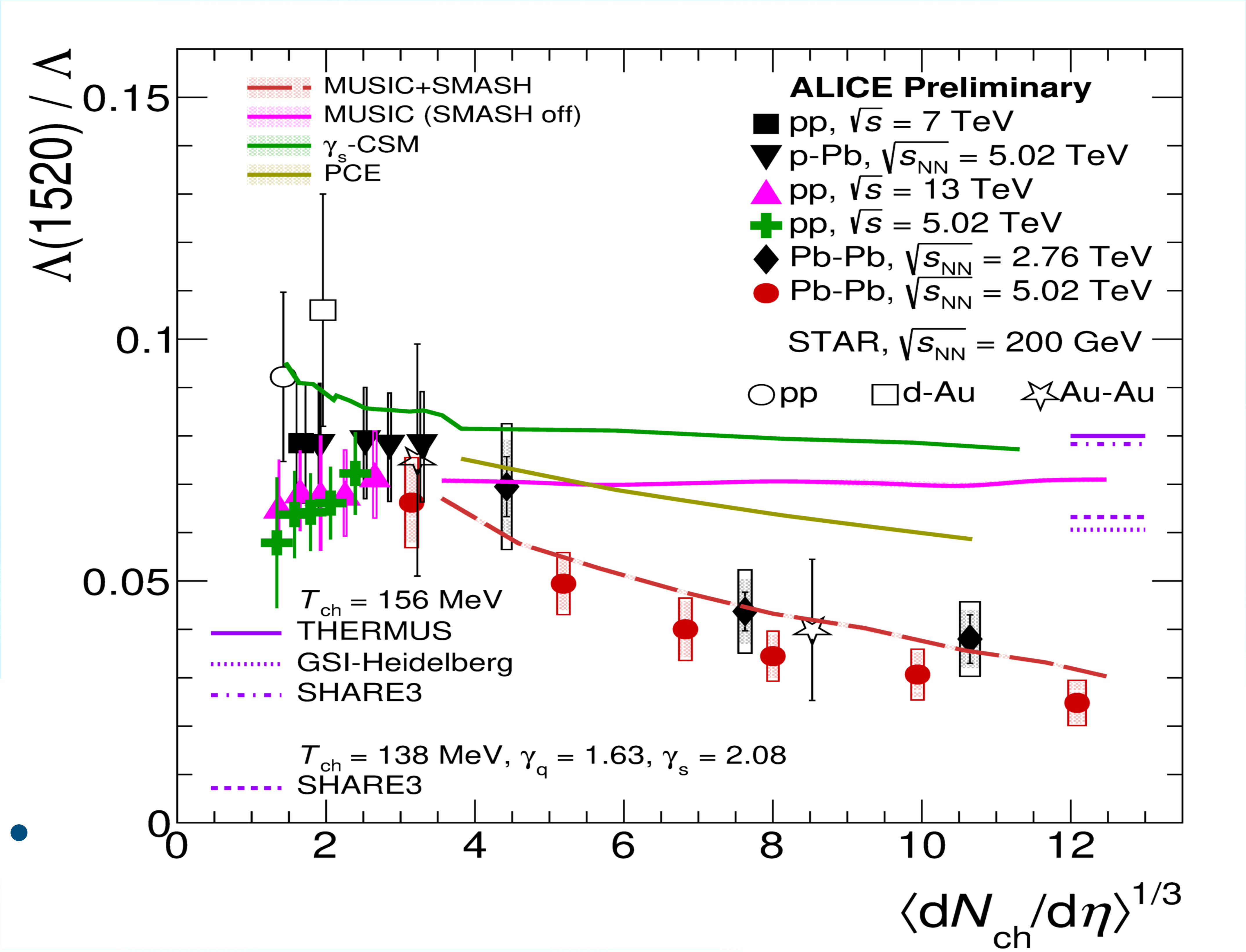

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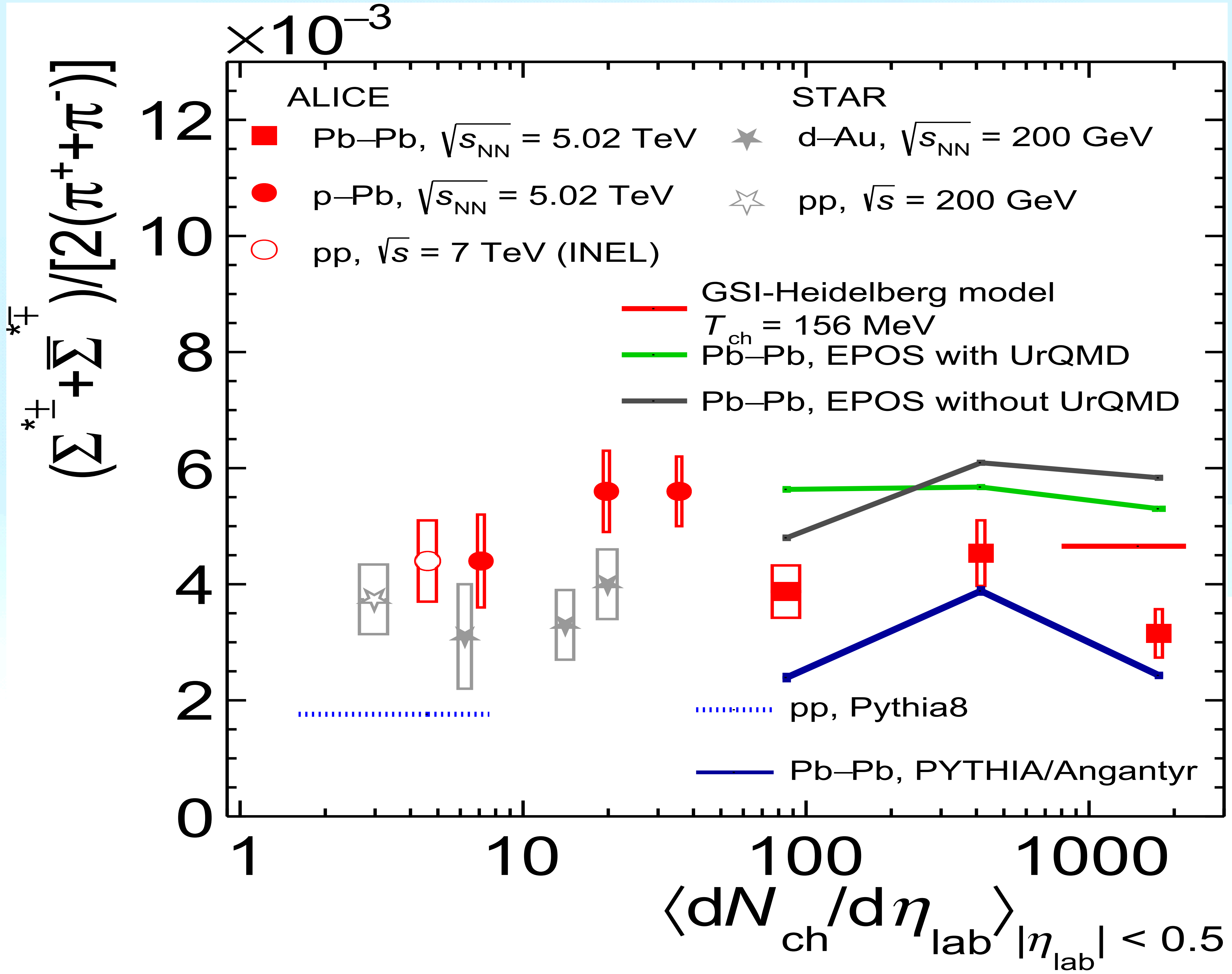

The $\Lambda(1520)/\Lambda$ yield ratio is suppressed in central collisions

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$\Lambda(1520)/\Lambda$ and $\Sigma^{*\pm}/\pi^{\pm}$

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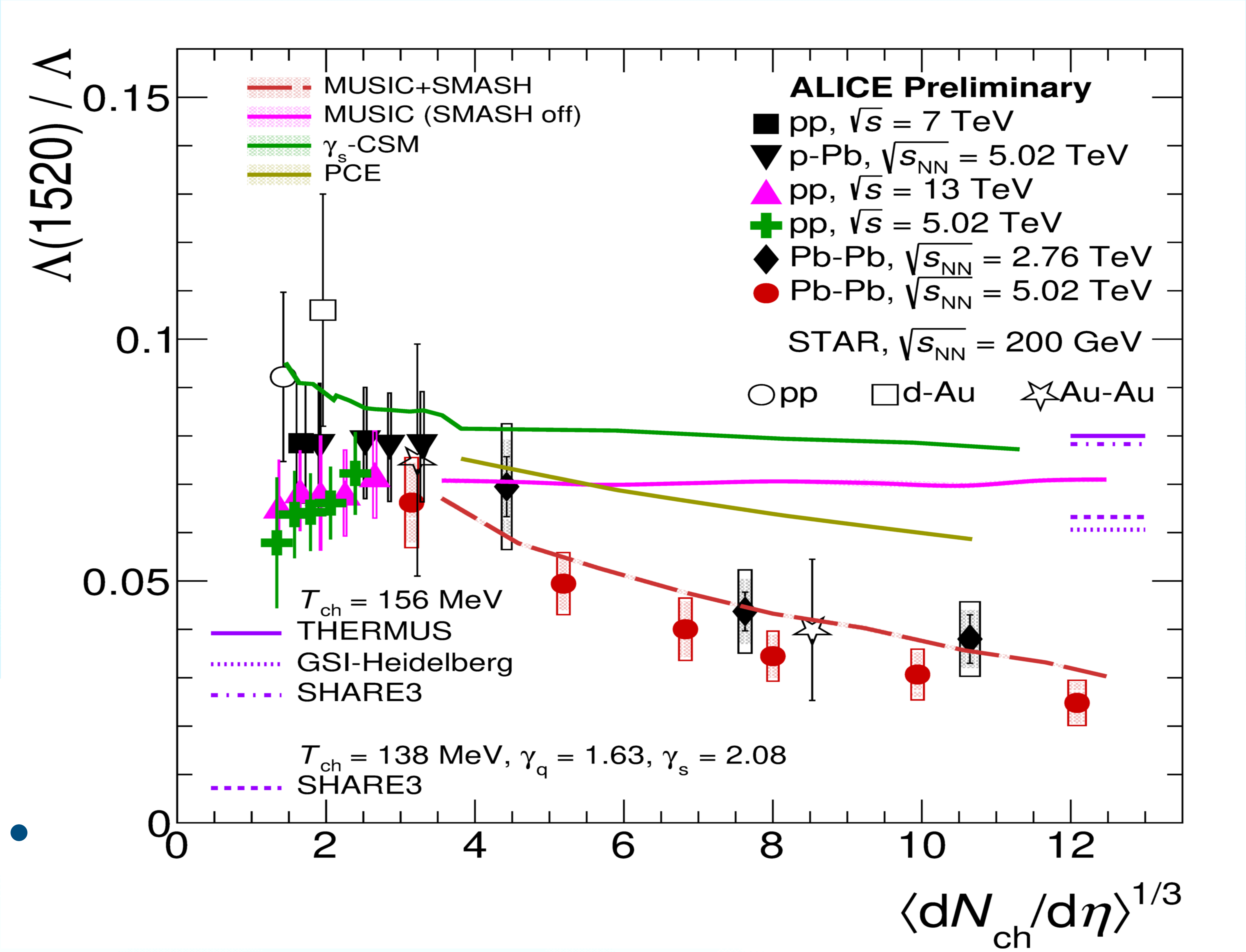

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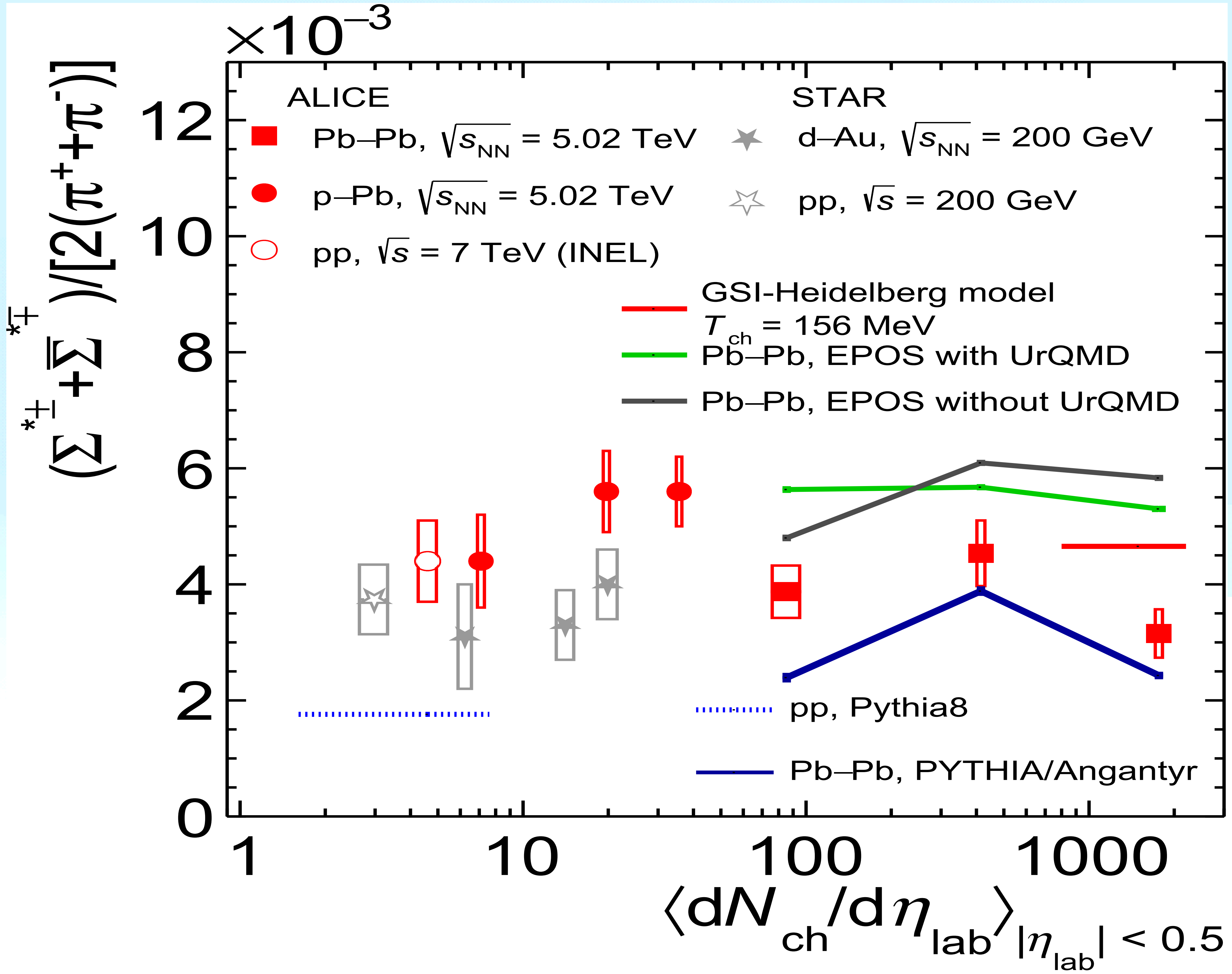


The $\Lambda(1520)/\Lambda$ yield ratio is suppressed in central collisions

MUSIC with SMASH afterburner reproduces the multiplicity suppression trend,

Thermal models do not reproduce the suppression trend.

The $\Sigma^{*\pm}/\pi^{\pm}$ ratio is slightly suppressed in central collisions (0-10%) wrt peripheral, p-Pb, pp collisions and predictions from statistical hadronisation models.

EPOS3 with UrQMD afterburner overestimates the data.

Summary

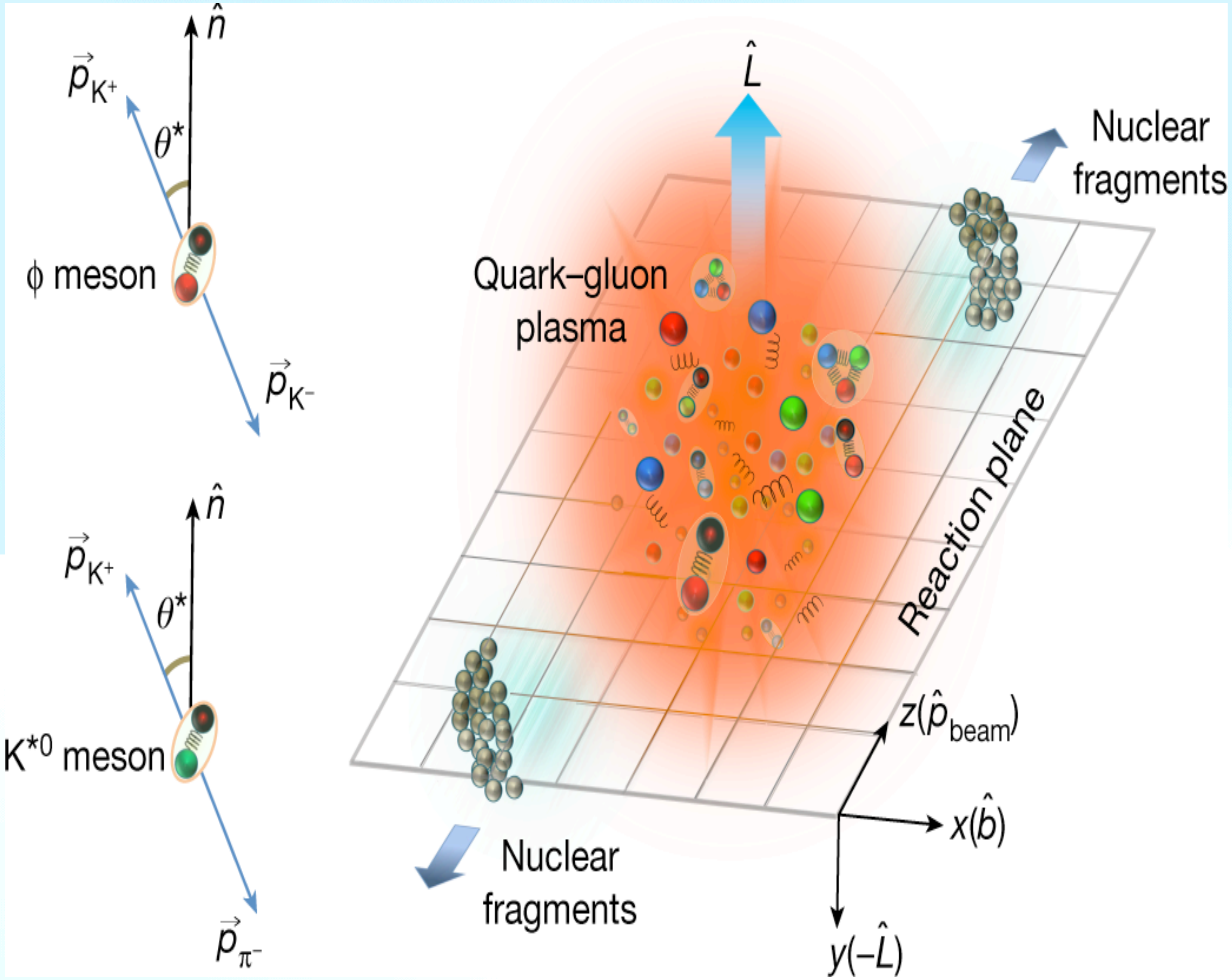
Hadronic resonances are valuable probes to study the properties of hadronic phase in heavy ion experiments

Suppression of short-lived resonances in large collision systems
- dominance of re-scattering over regeneration
- no suppression observed for the longer-lived resonances

There is lot of excitement for resonance studies in small systems and exotic sector.

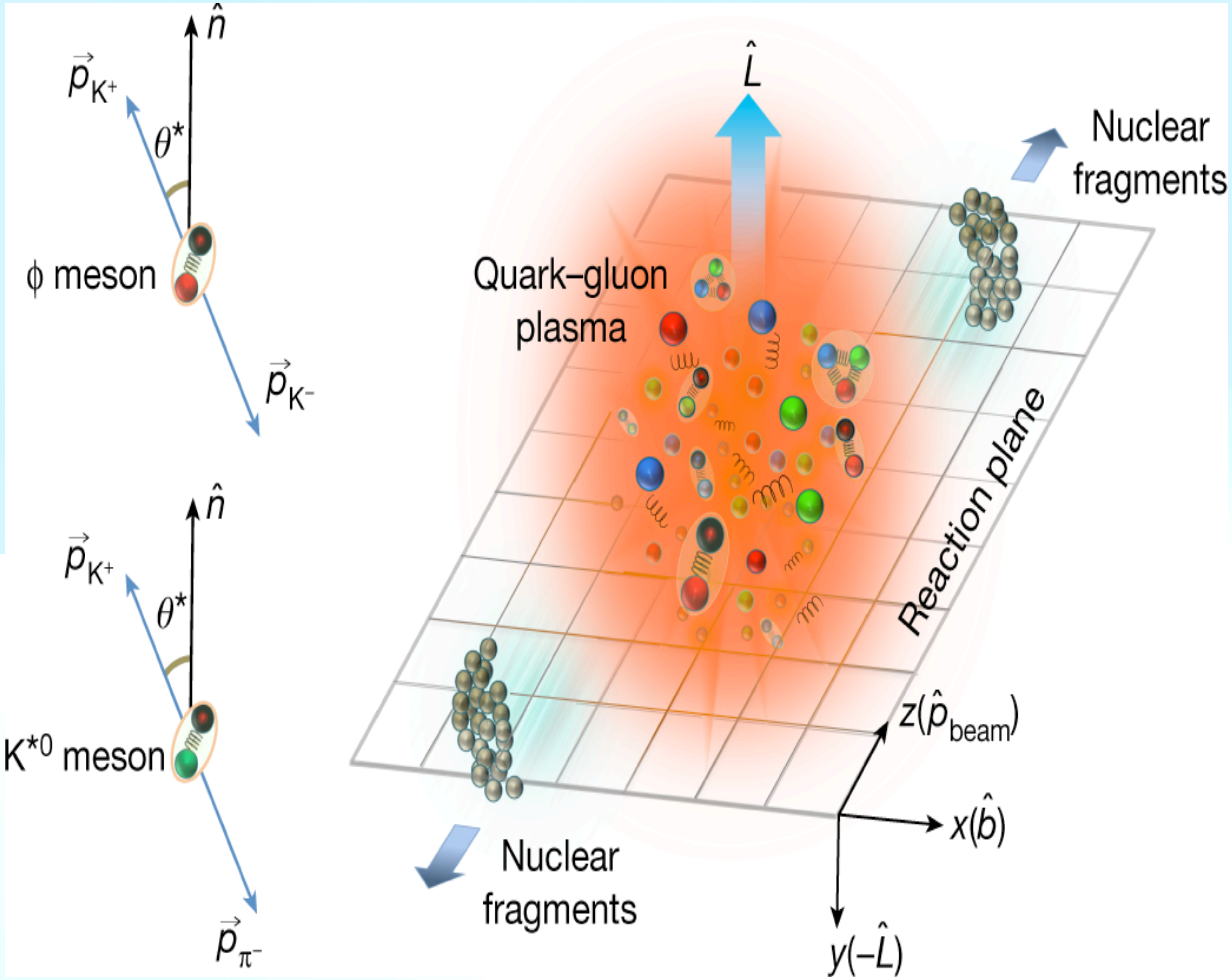
Global Spin Alignment

Nature 614, 244-248, (2023)



Global Spin Alignment

Nature 614, 244-248, (2023)



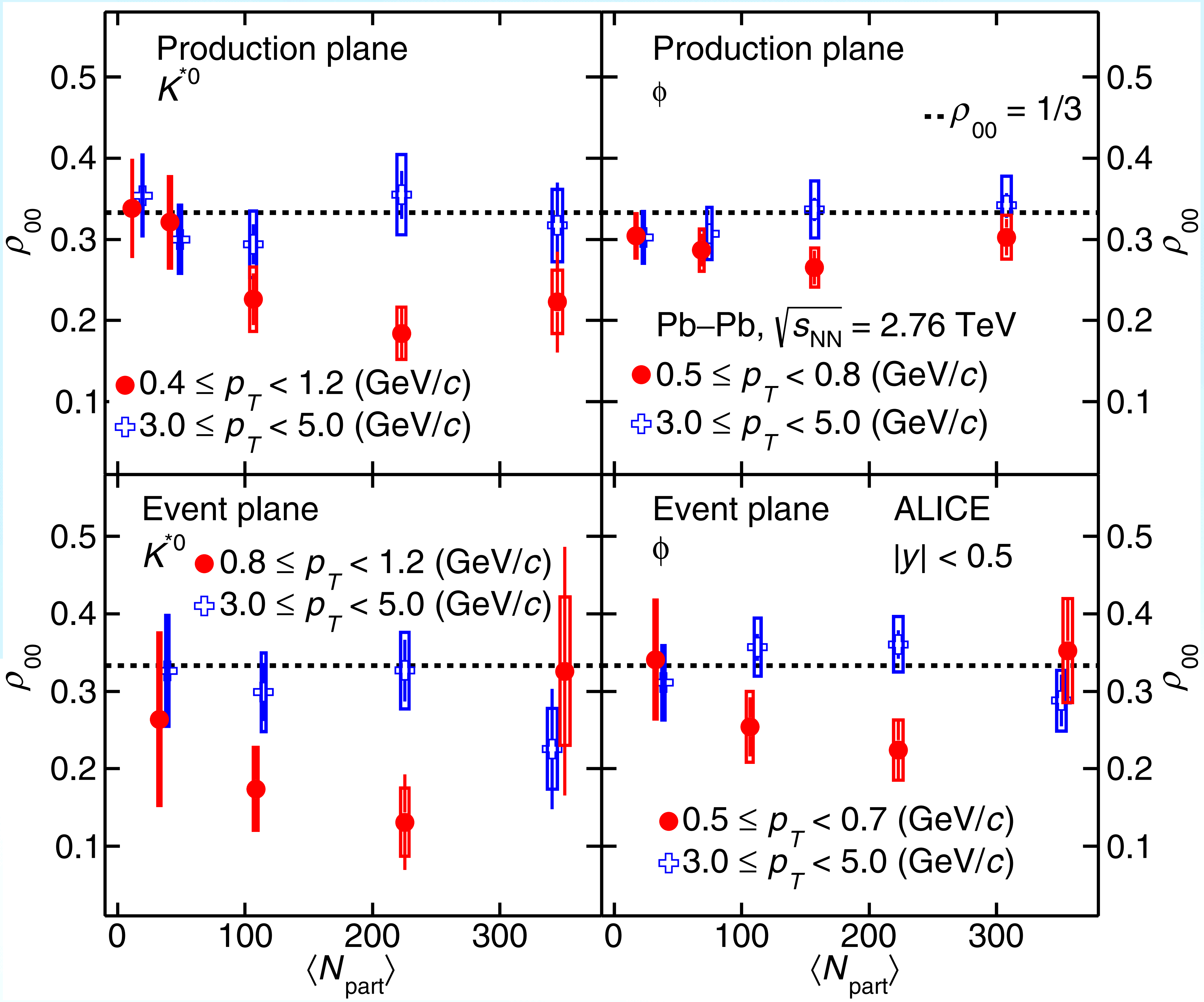
$$\frac{dN}{d(\cos\theta^*)} \propto (1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*$$

$\rho_{00} = 1/3$: no spin alignment

$\rho_{00} \neq 1/3$: possible signature of spin alignment

Global Spin Alignment

Phys. Rev. Lett. 125, 012301 (2020)



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