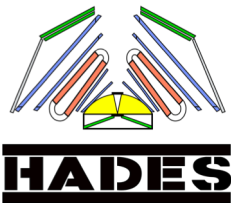


The 18th International Conference on Strangeness in Quark Matter

10-15 June 2019, Bari (Italy)



Experimental Summary

SQM2019



Strangeness in Quark Matter 2019

57 parallel talks
27 plenary talks



Disclaimer: these are only some results. I cannot do justice to all ongoing work!
(or, in other words, I apologize for not being complete!)

Elia, [Monday 9:00](#)



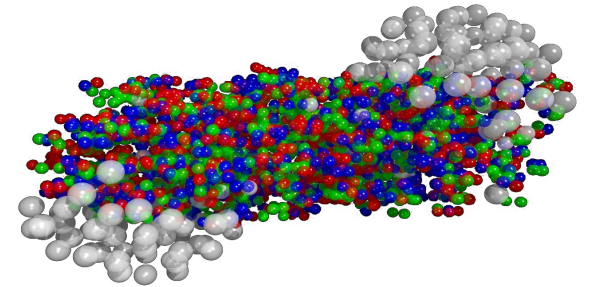
clickable

The outlook

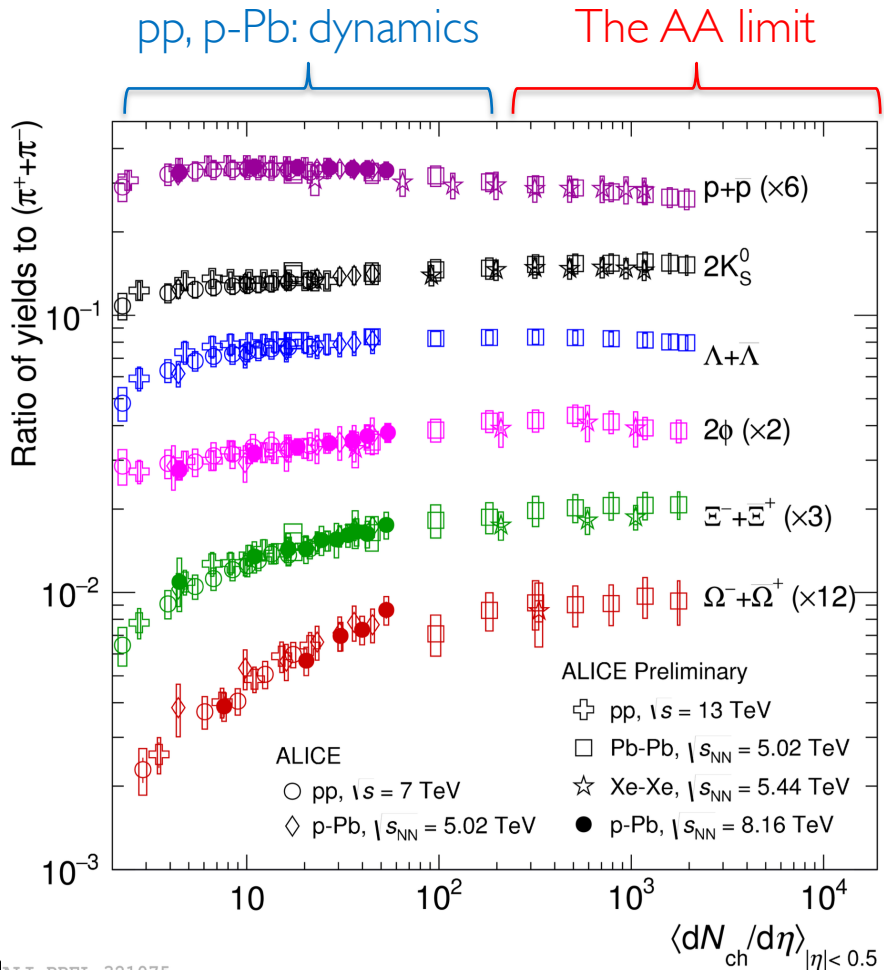
- Precision studies of LF and strangeness production mechanisms
- Bulk matter / soft physics and collectivity
- How are nuclei produced?
- Heavy flavor production and its relation to bulk
- Hadronic interactions, astrophysics and more
- The future

The outlook

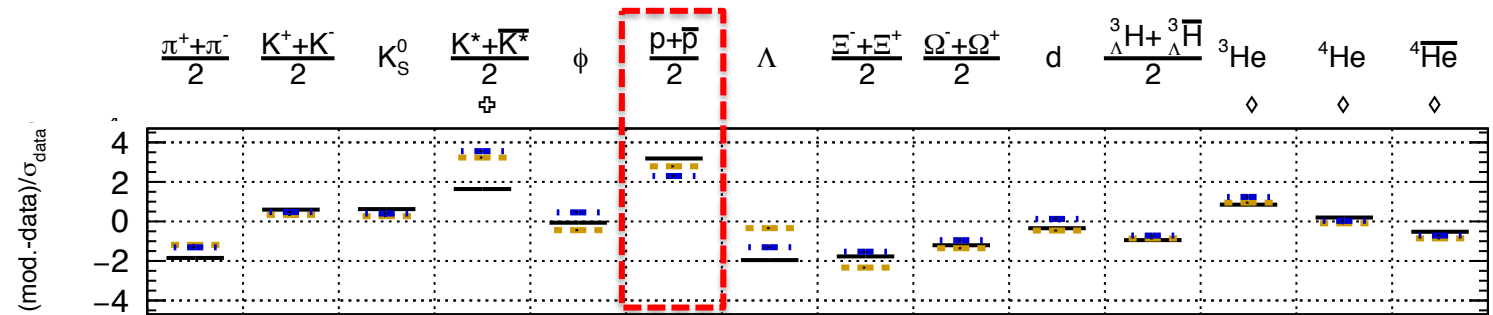
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LF and strangeness at the LHC: where we are



- **The AA limit:** thermally equilibrated particle production expected
 - Not perfect in first application of stat. hadr. models (SHMs):
 - Proton yield significantly lower than prediction?

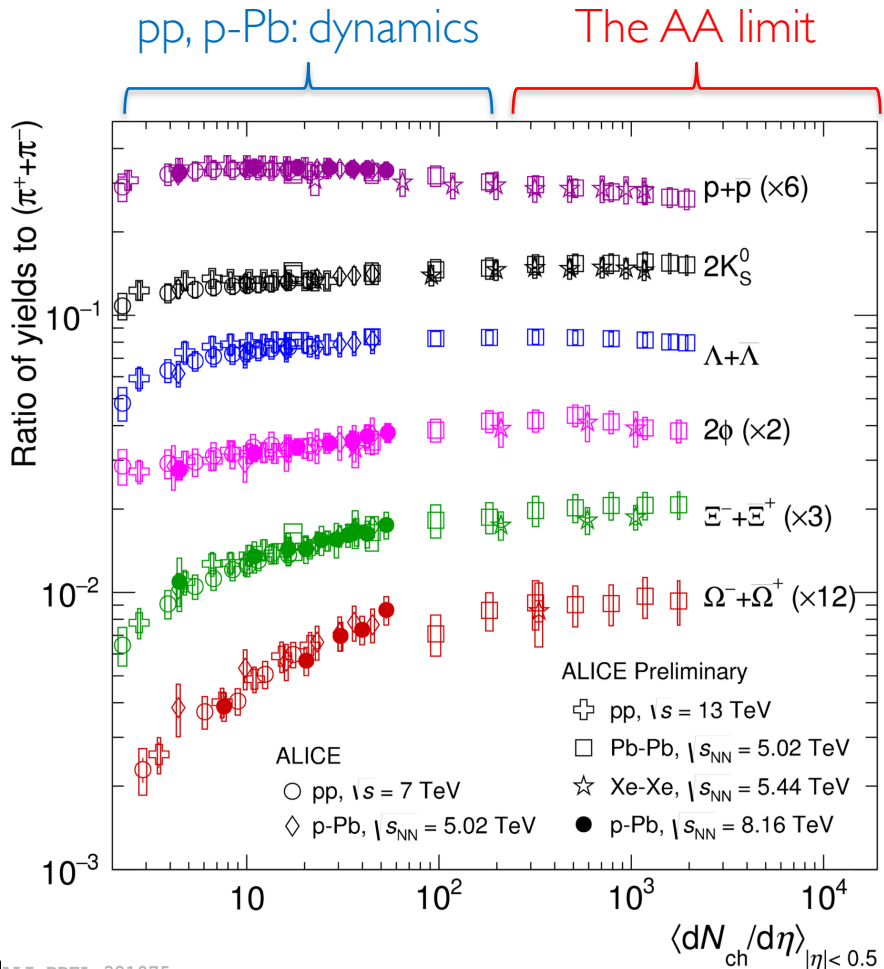


Model	T (MeV)	V (fm ³)	χ^2 /NDF
— THERMUS 2.3	155 ± 2	5924 ± 543	24.8/11
- - - GSI-Heidelberg	156 ± 2	5330 ± 505	19.6/11
- · - · SHARE 3	156 ± 3	4476 ± 696	15.1/11

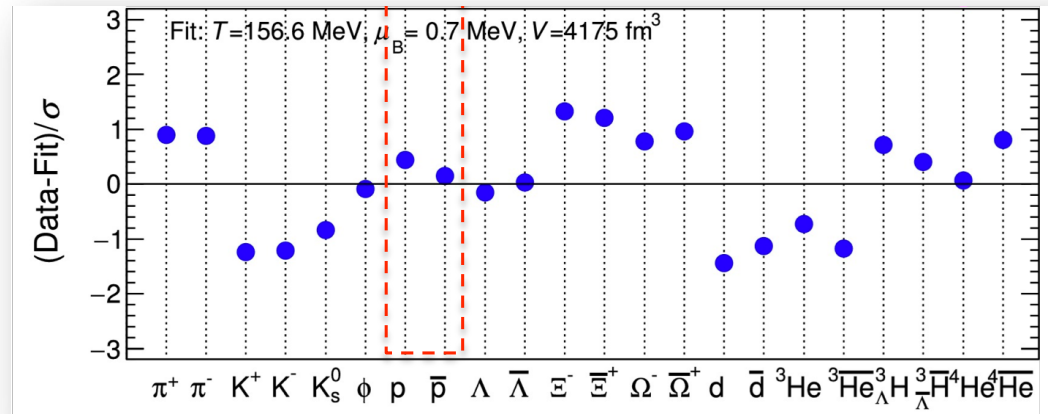
⊕ Not in fit
◇ Extrapolated

ALICE Collaboration, Nucl. Phys. A 971 (2018) 1-20

LF and strangeness at the LHC: where we are

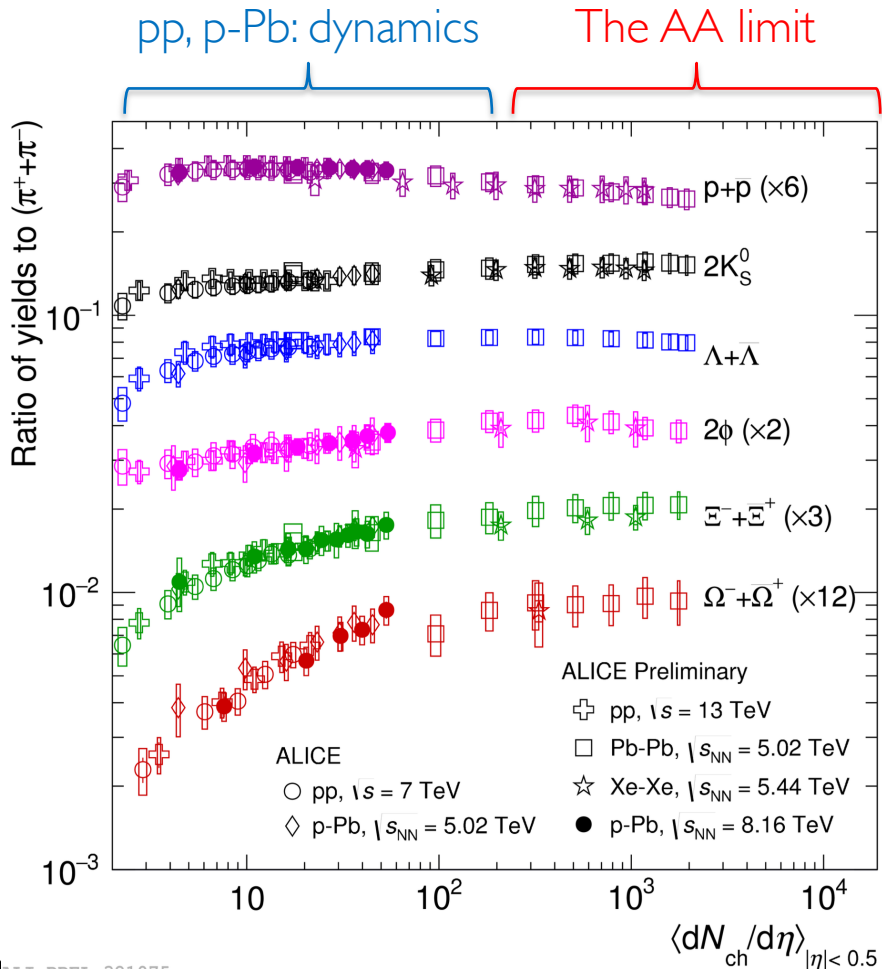


- **The AA limit:** thermally equilibrated particle production expected
 - Not perfect in first application of stat. hadr. models (SHMs)
- Potential explanations relying on hadronic interactions:
 - Proton-anti-proton annihilation
 - New: resonant and non-resonant πN and $\pi\pi N$ interactions
 - Correction implemented $\rightarrow \chi^2 = 16.9/19$



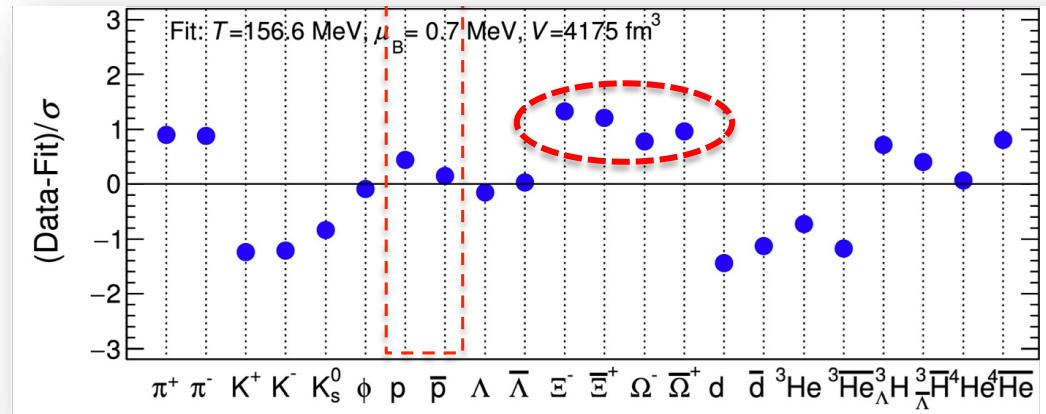
A. Andronic et al., PLB 792 (2019) 304-309

LF and strangeness at the LHC: where we are



- **The AA limit:** thermally equilibrated particle production expected
 - Not perfect in first application of stat. hadr. models (SHMs)
- Potential explanations relying on hadronic interactions:
 - Proton-anti-proton annihilation
 - New: resonant and non-resonant πN and $\pi\pi N$ interactions
 - Correction implemented $\rightarrow \chi^2 = 16.9/19$
- Other approaches: sequential freezeout

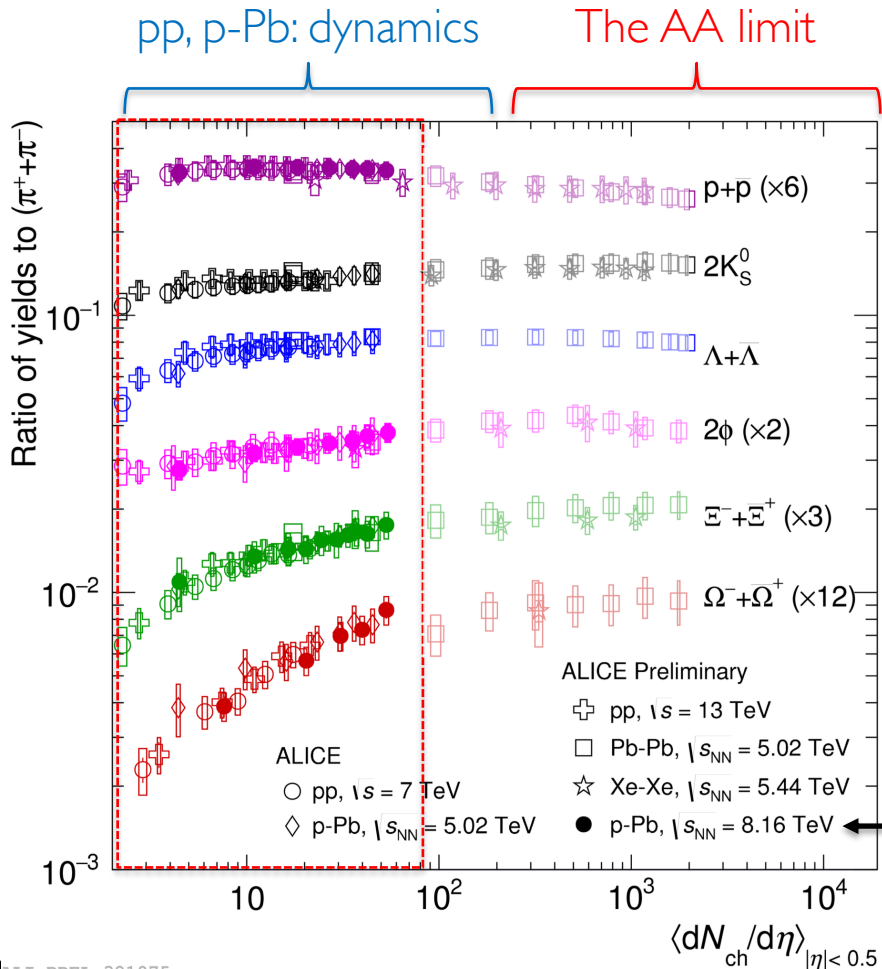
Bellwied, [Thursday 15:20](#)



A. Andronic et al., PLB 792 (2019) 304-309

Bellini, [Wednesday 9:00](#)

The role of small systems



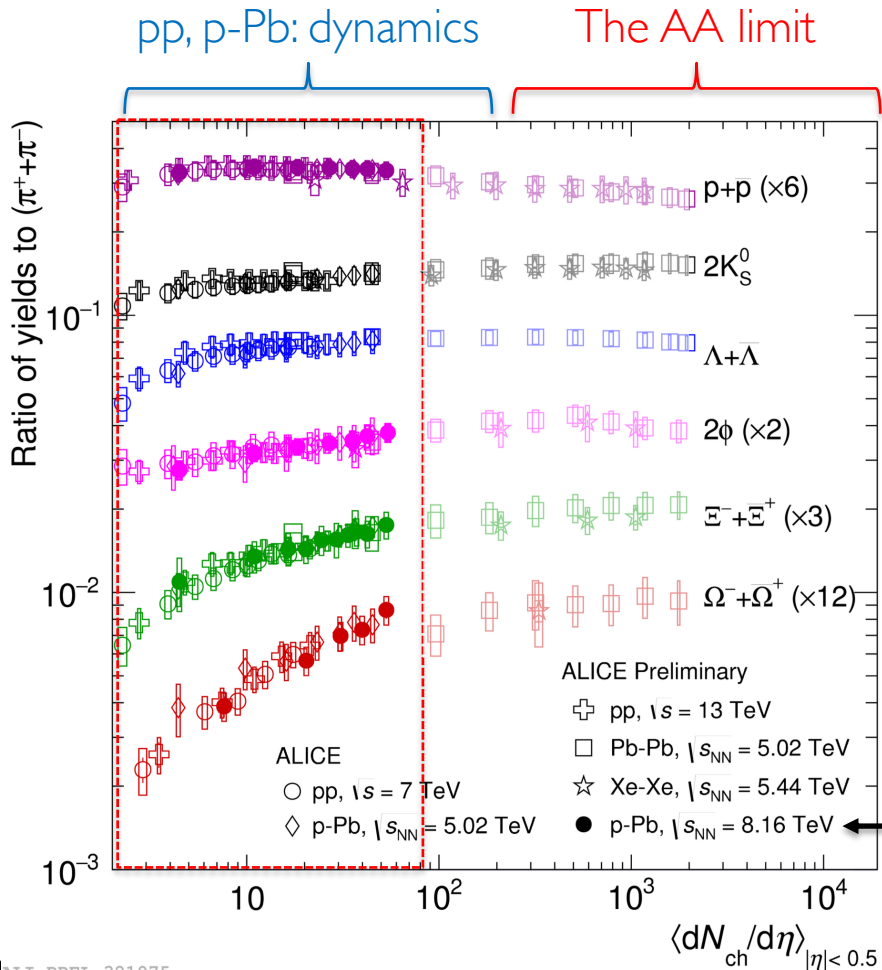
- pp and p-Pb: smooth, N_{ch} -dependent dynamics of particle ratios
- Plenty of dynamics present!
 - Where do we go from here (experimentally)?

Willsher,
Tuesday 16:10

Bellini, Wednesday 9:00

The role of small systems

- pp and p-Pb: smooth, N_{ch} -dependent dynamics of particle ratios
- Plenty of dynamics present!

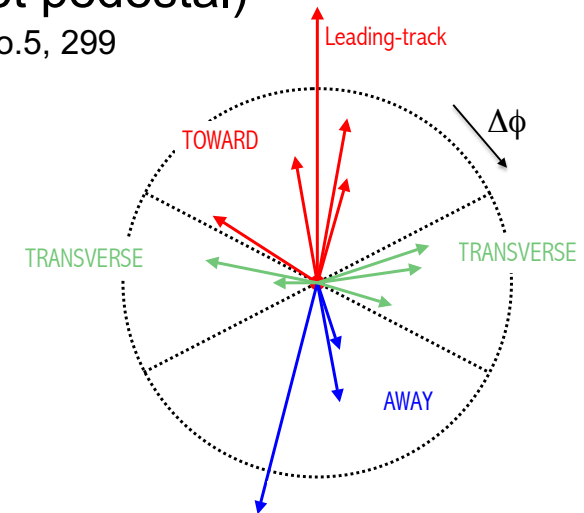


Willsher,
Tuesday 16:10

➤ define the relative
transverse activity classifier R_T in the
plateau region (jet pedestal)

Eur.Phys.J. C76 (2016) no.5, 299

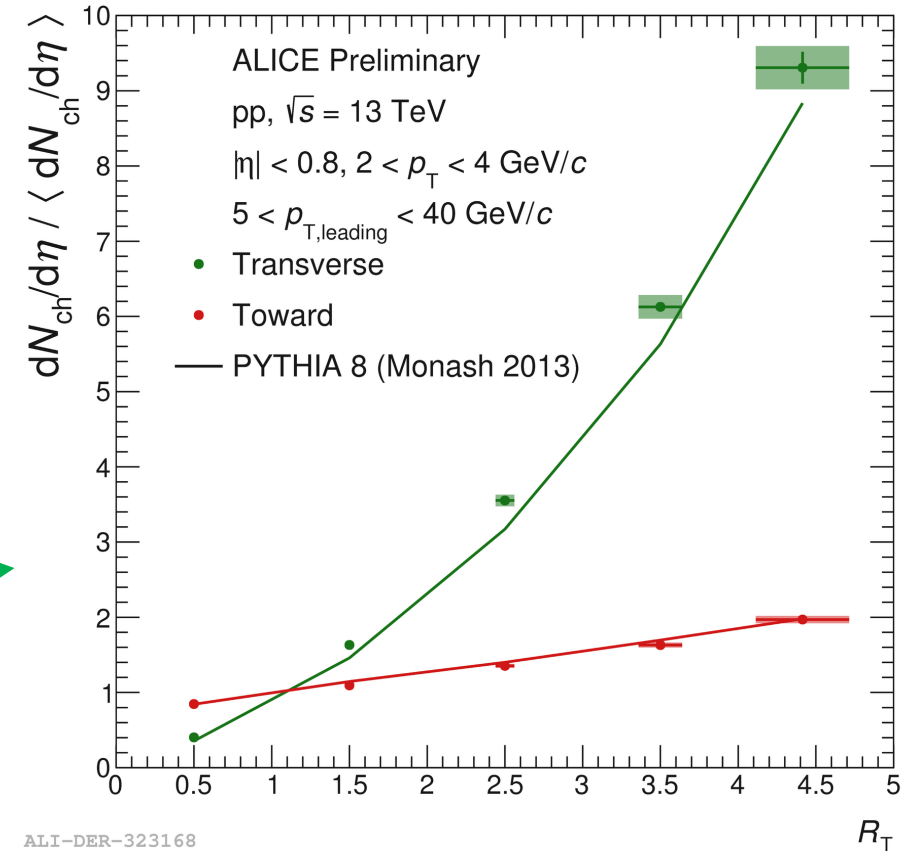
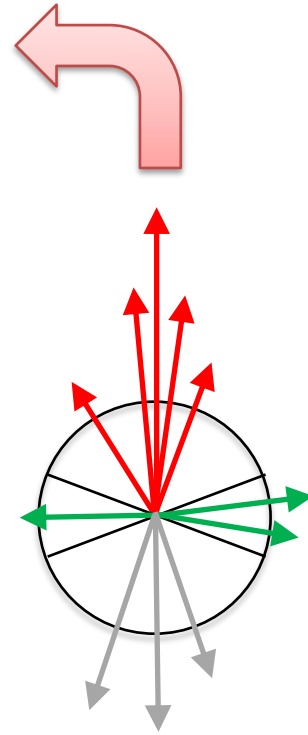
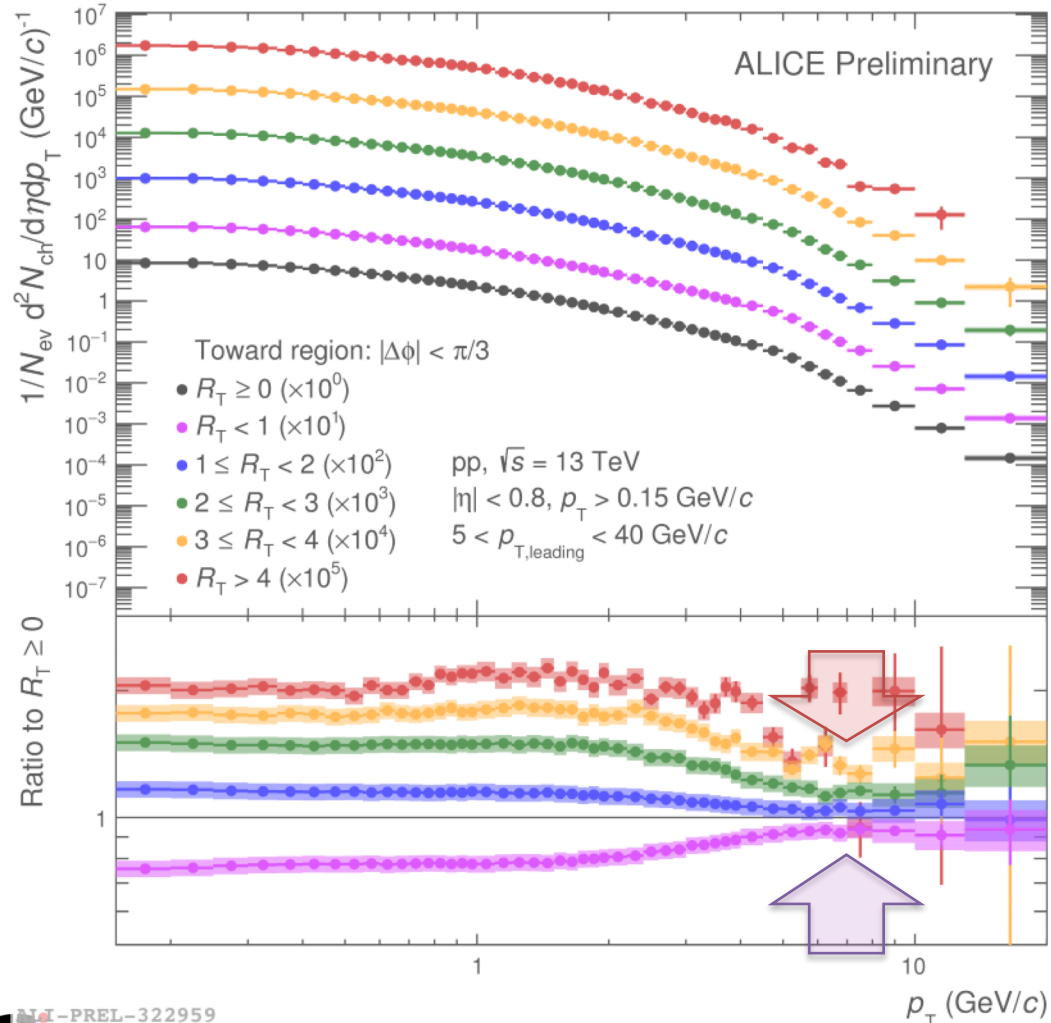
$$R_T = \frac{N_{inclusive}}{\langle N_{inclusive} \rangle}$$



Zaccolo, Tuesday 16:50

Bellini, Wednesday 9:00

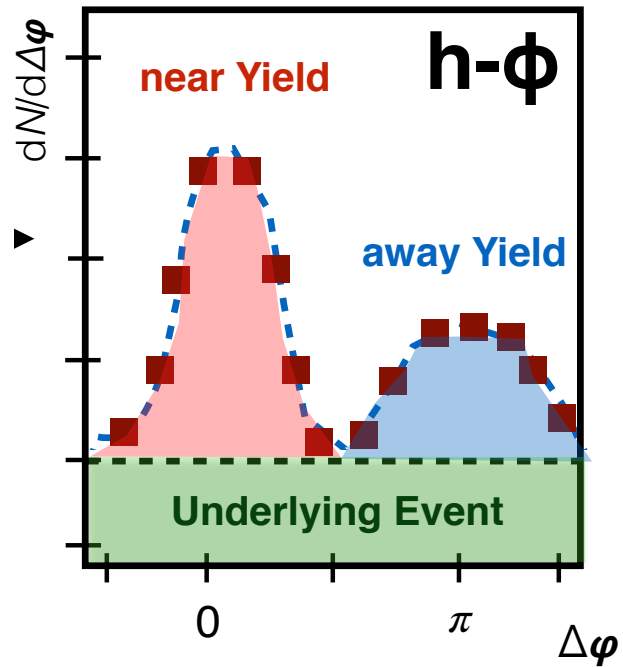
Transverse activity-differential study of pp collisions



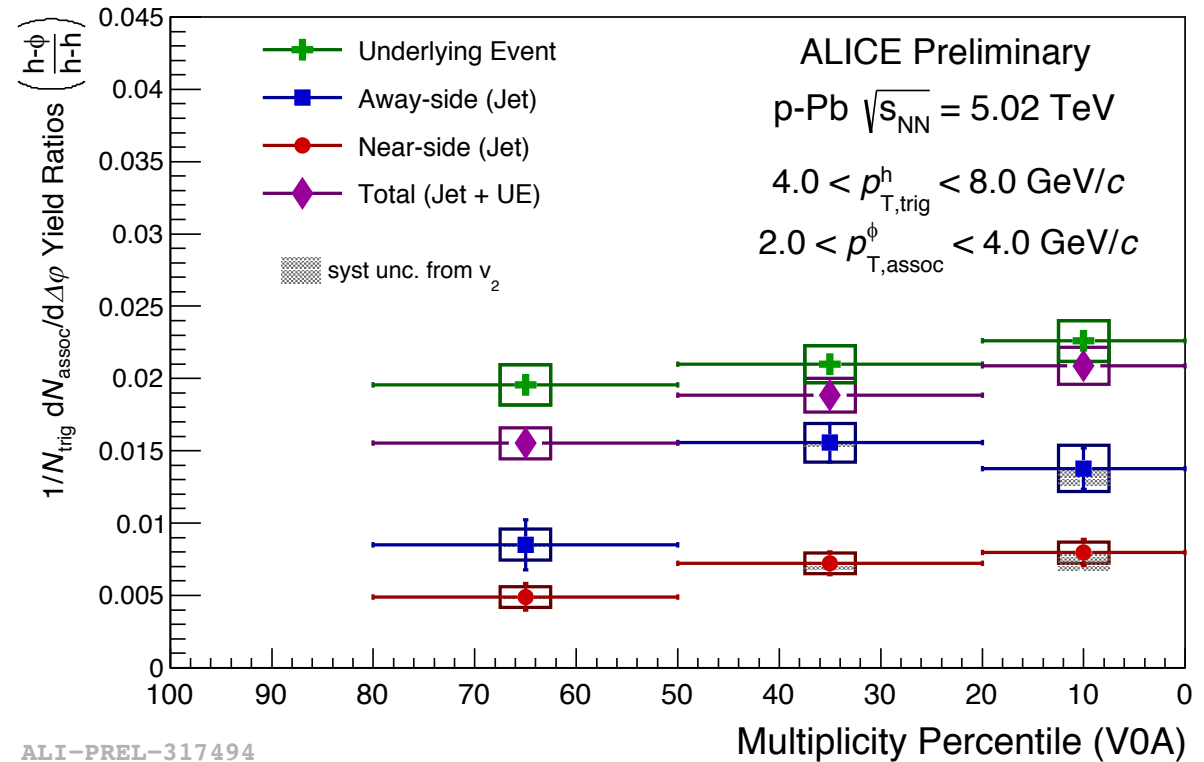
- Good separation of UE and jet-like component for h^\pm
- Very promising for other cases: J/ψ , etc!

Zaccolo, [Tuesday 16:50](#)

Jet-associated ϕ meson production



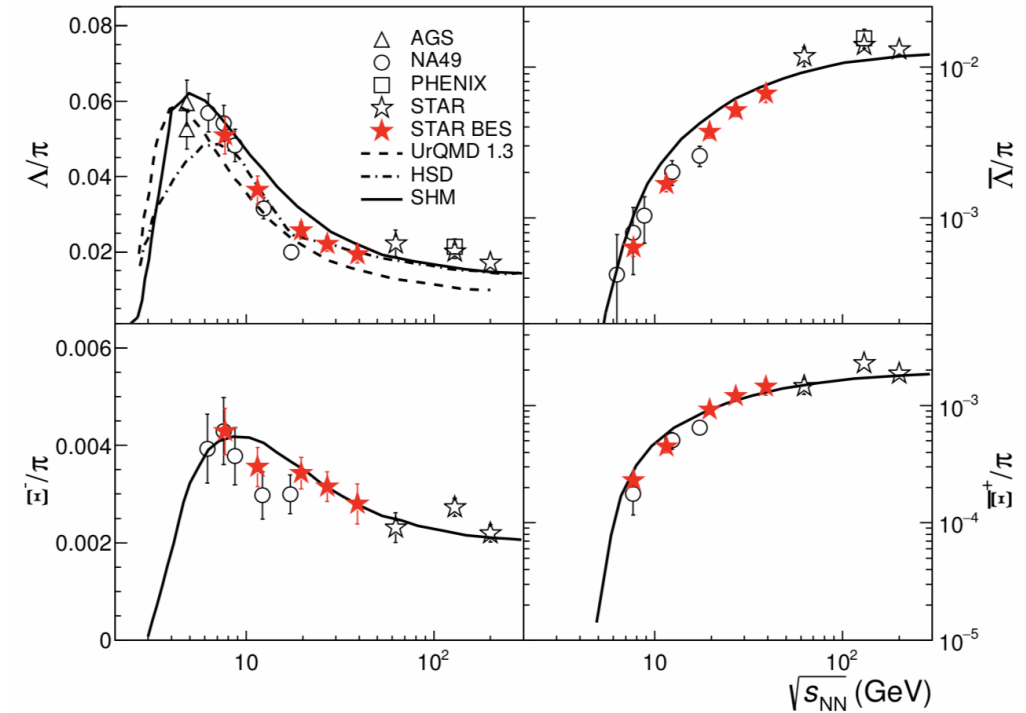
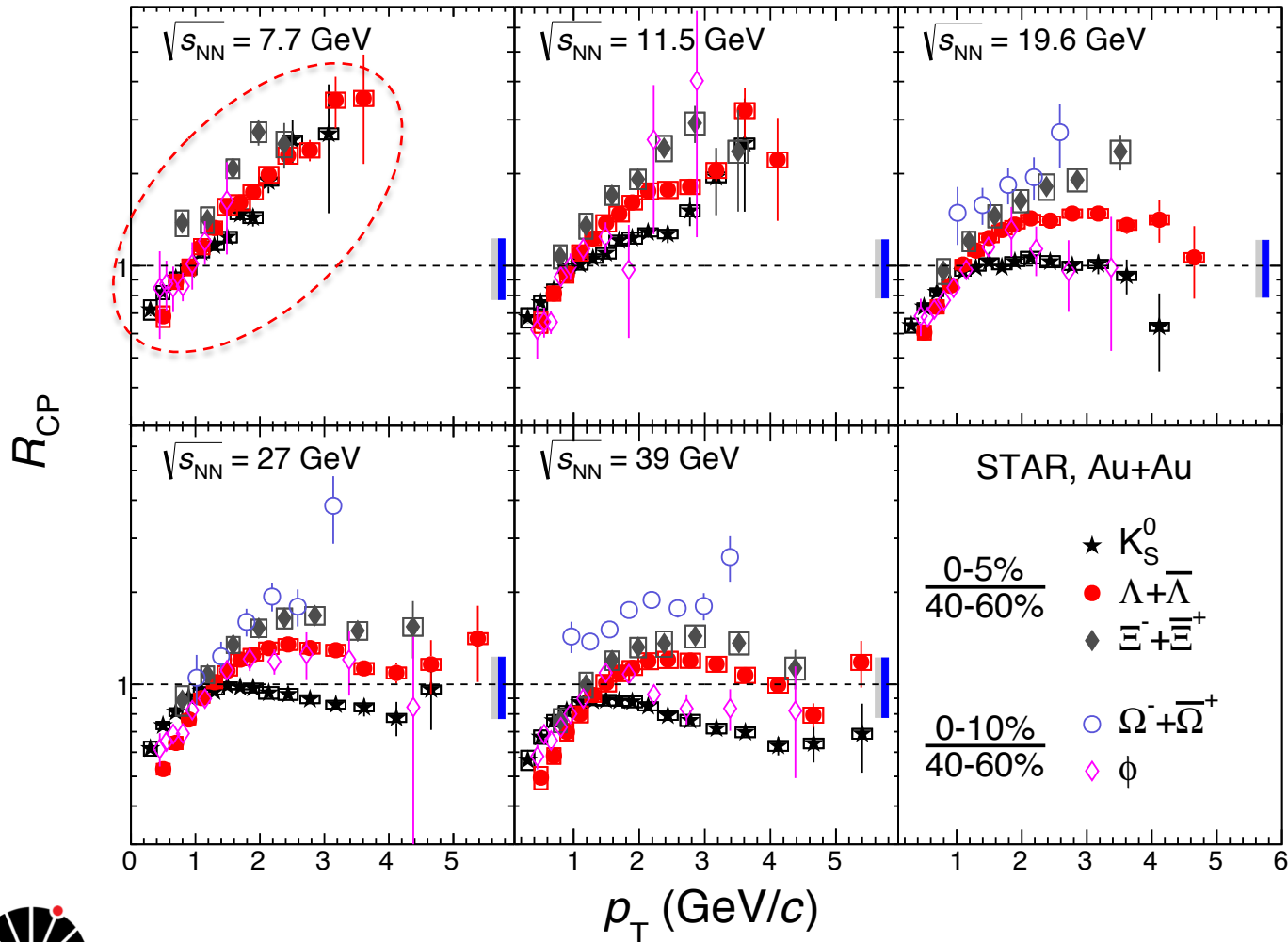
Blair, [Thursday 17:10](#)



ALI-PREL-317494

- Strangeness enhancement from where? Jets or soft component?
 - $(h-\phi)/(h-h)$ total pair ratios show an increase as a function of multiplicity
 - Production tends to be dominated by UE

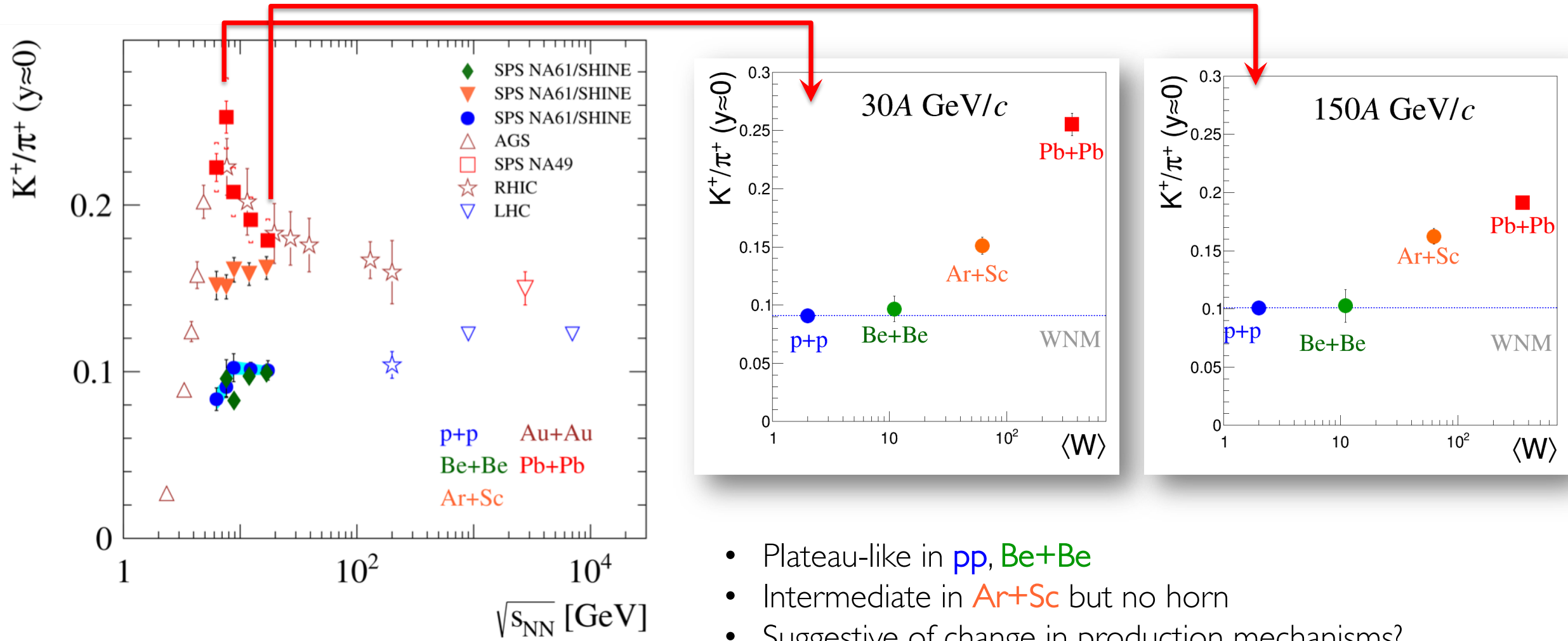
Strangeness at the BES



- Strangeness R_{CP} in Au+Au: species-independent below 11.5 GeV
- ~8 GeV: maximum net-baryon density

Zhao, [Tuesday 9:00](#)

NA61/SHINE: The K/π ratio



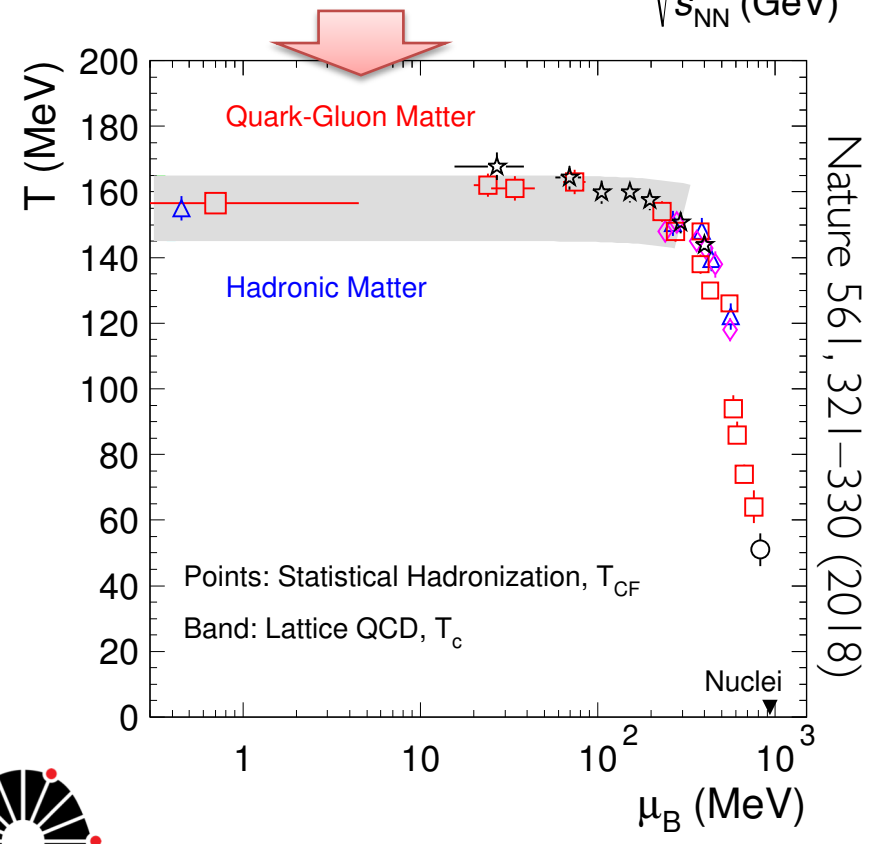
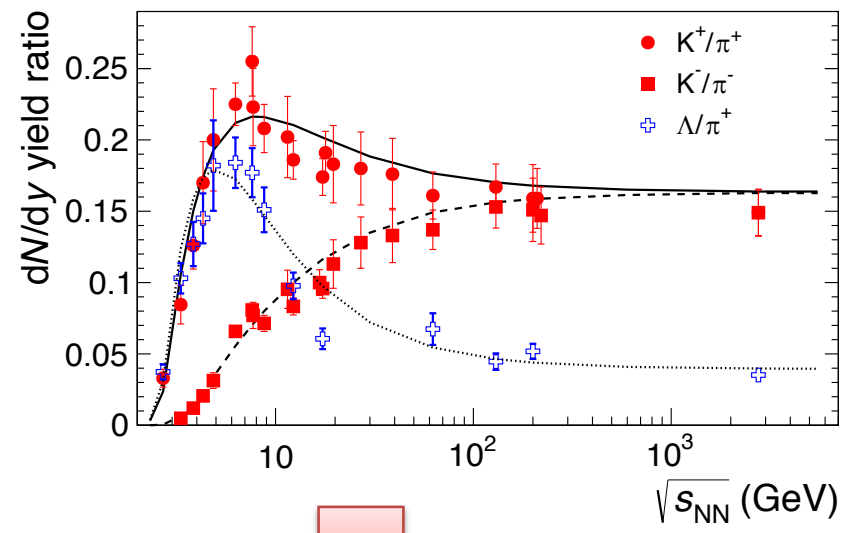
Podlaski, Tuesday 14:00

- Plateau-like in p+p, Be+Be
- Intermediate in Ar+Sc but no horn
- Suggestive of change in production mechanisms?
 - Is there a phase transition involved?

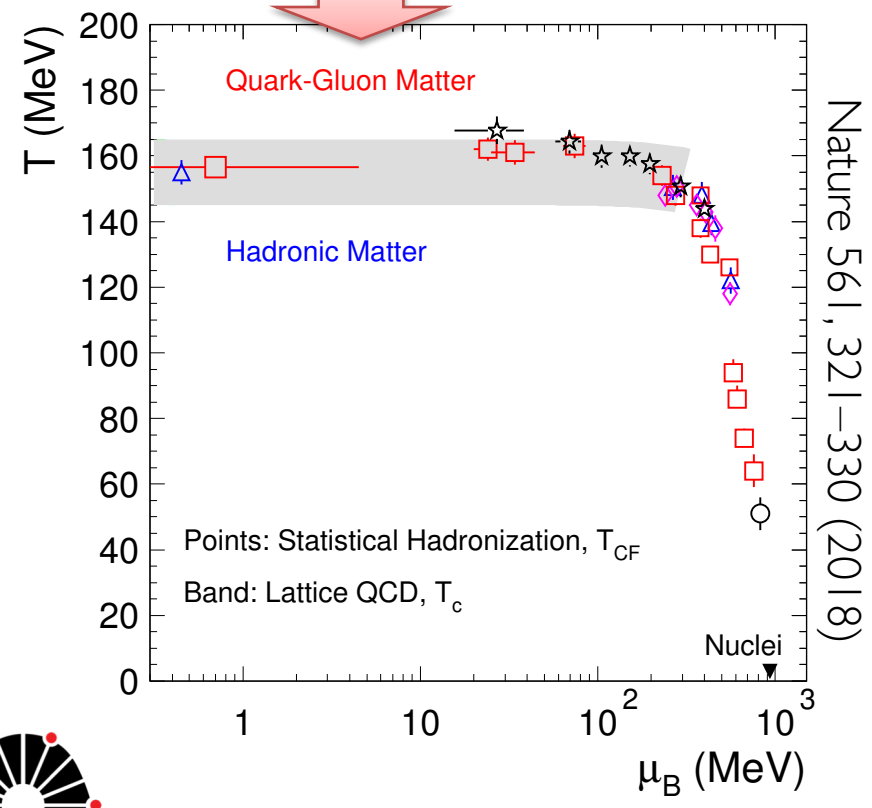
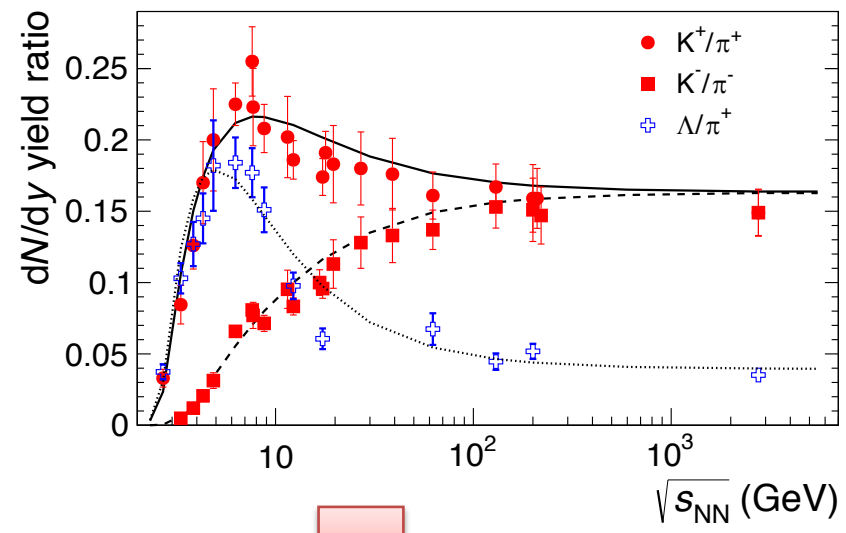


Studying the QCD phase diagram

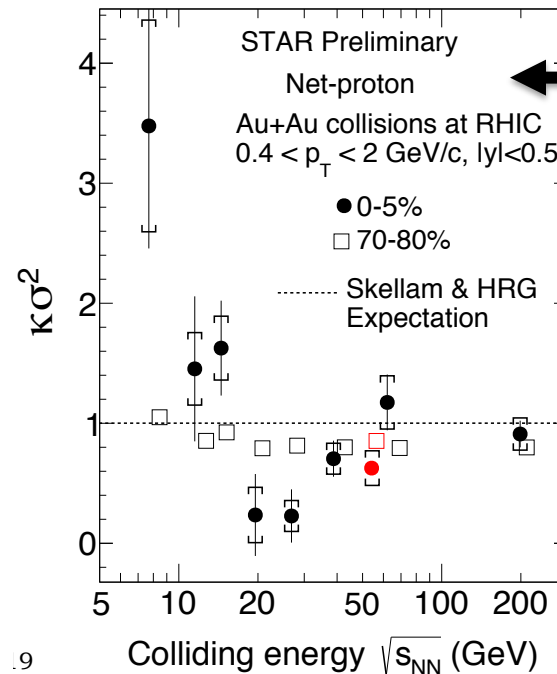
- What can we learn (experimentally) about the phase structure at the lower energies on top of that?



Studying the QCD phase diagram



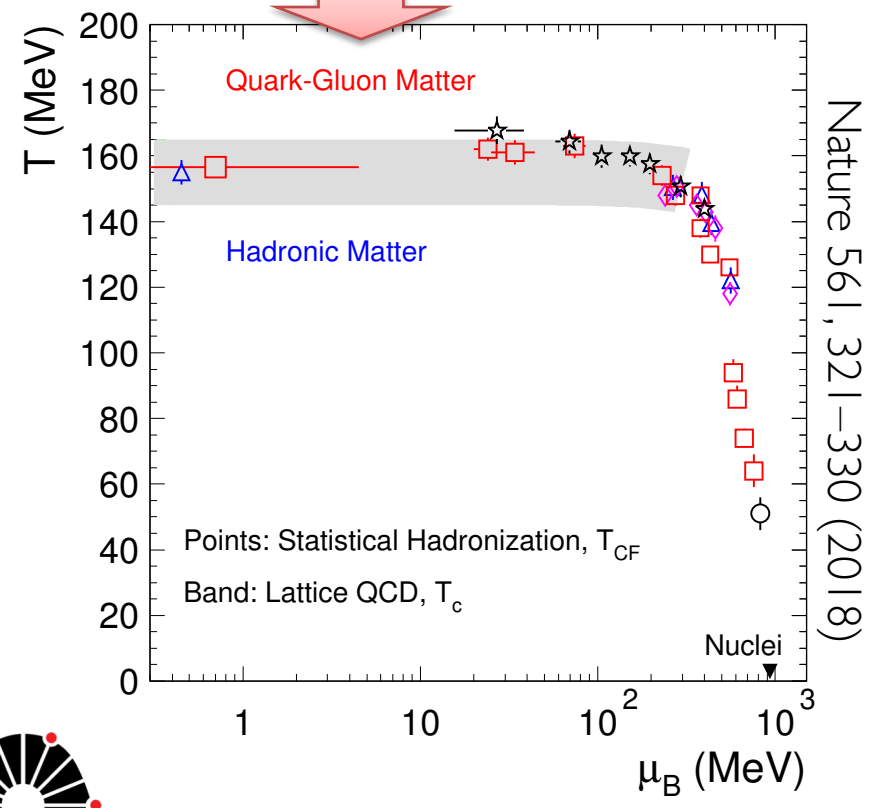
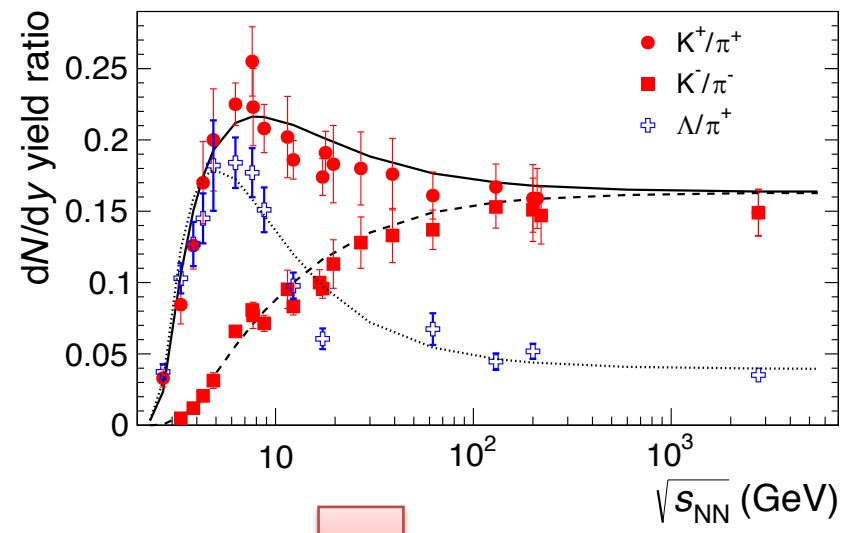
- What can we learn (experimentally) about the phase structure at the lower energies on top of that?
- Phase structure at the boundary
 - Study of fluctuations: higher moments of conserved charges
 - Phase transition and potential signature of critical point?



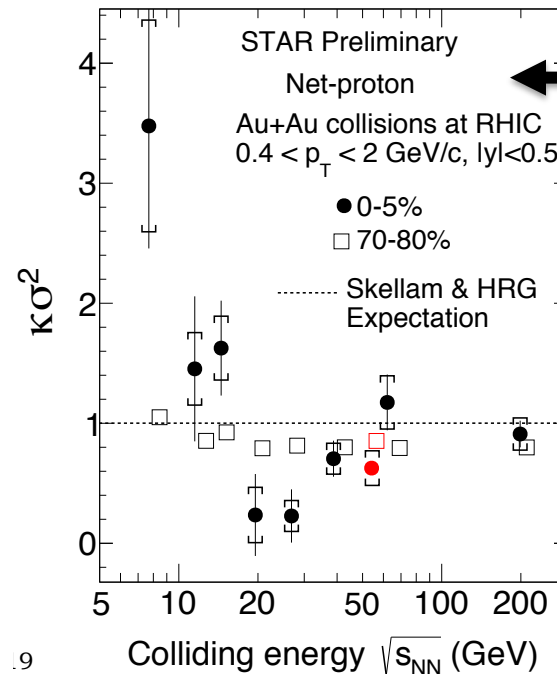
- Net-protons in the STAR BES:
 - Non-monotonic behavior below 39 GeV

Pandav, [Thursday 14:20](#)

Studying the QCD phase diagram



- What can we learn (experimentally) about the phase structure at the lower energies on top of that?
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- Net-protons in the STAR BES:
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Pandav, [Thursday 14:20](#)

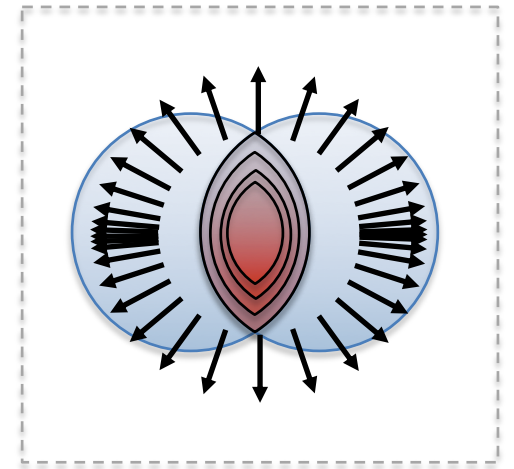
- And more: net kaons, lambdas
 - Extraction of (μ_B, T) using isentropic trajectories from IQCD and susceptibilities from cumulants

Stafford, [Thursday 15:00](#)
Bellwied, [Thursday 15:20](#)

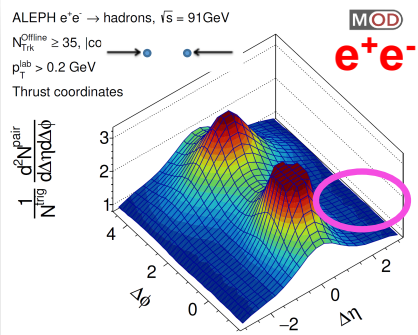


The outlook

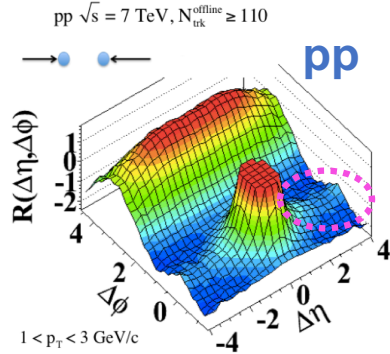
- Precision studies of LF and strangeness production mechanisms
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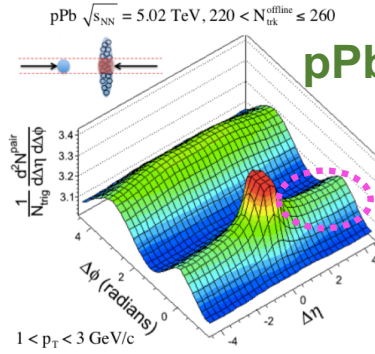
Flow from small to large: the challenge



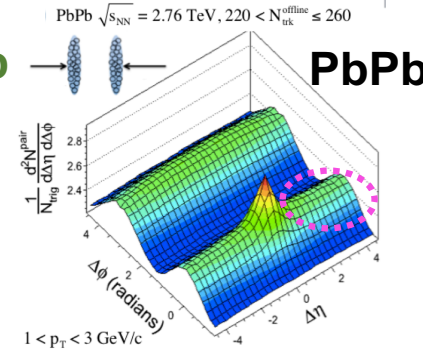
Badea et al., arXiv:1906.00489



CMS, JHEP09 (2010) 091



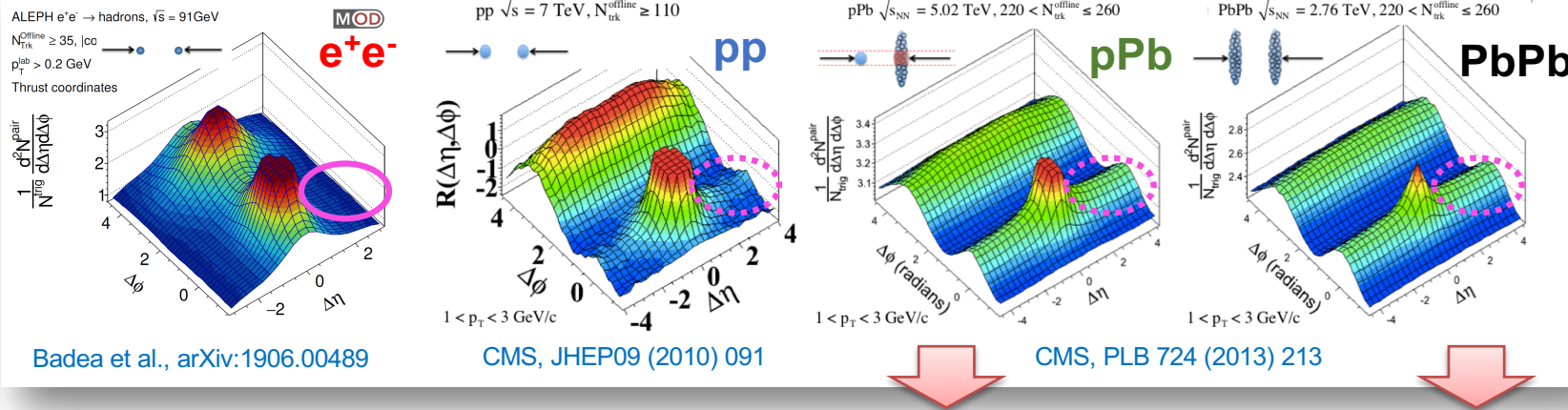
CMS, PLB 724 (2013) 213



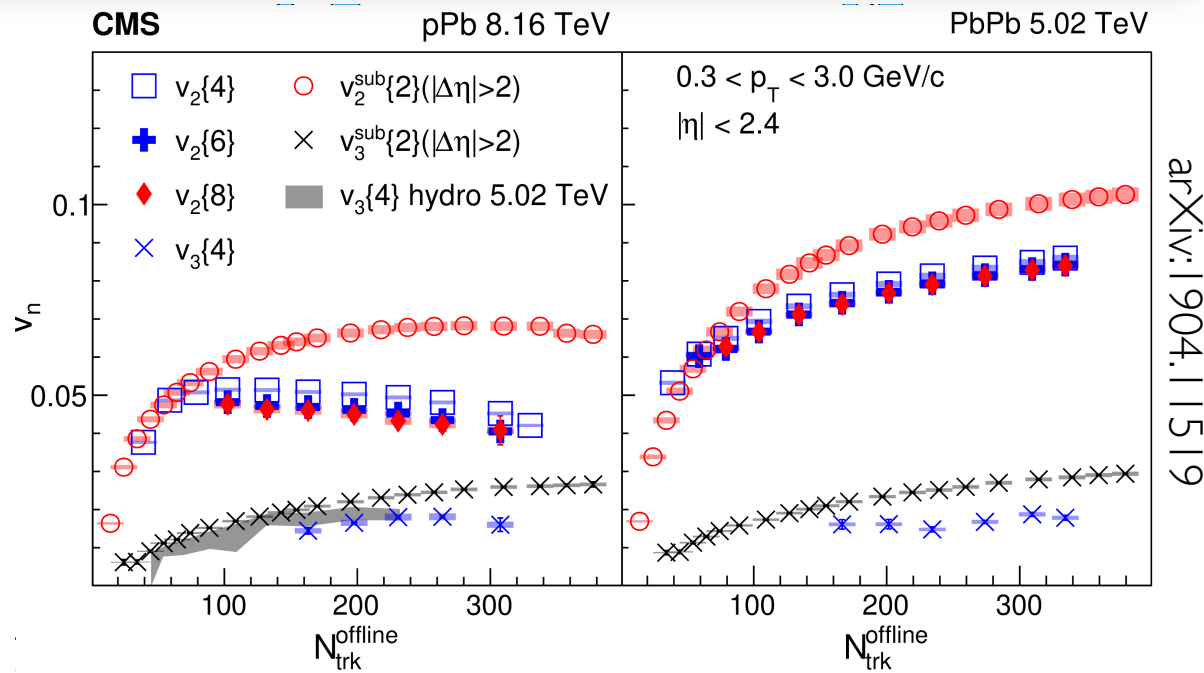
- The double ridge:
 - There in pp, p-Pb, Pb-Pb
 - Precision studies needed

Flow from small to large: the challenge

Heinz, Thursday 14:00



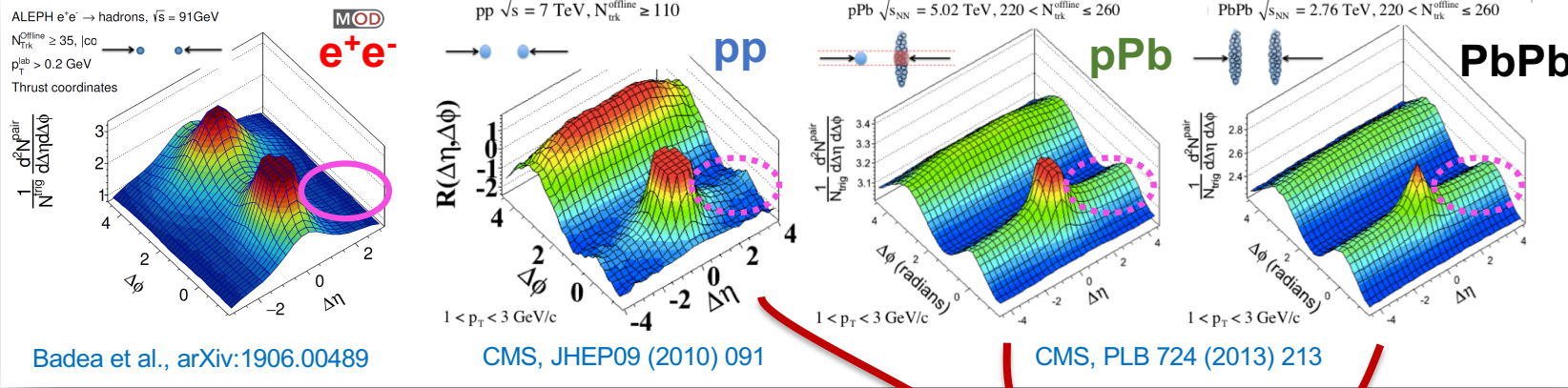
- The double ridge:
 - There in pp, p-Pb, Pb-Pb
 - Precision studies needed
- v_2, v_3 in p-Pb studied by CMS
- p-Pb: $v_2\{4\}/v_2\{2\} \cong v_3\{4\}/v_3\{2\}$
 - Anisotropy driven by fluctuations
 - not the case in Pb-Pb



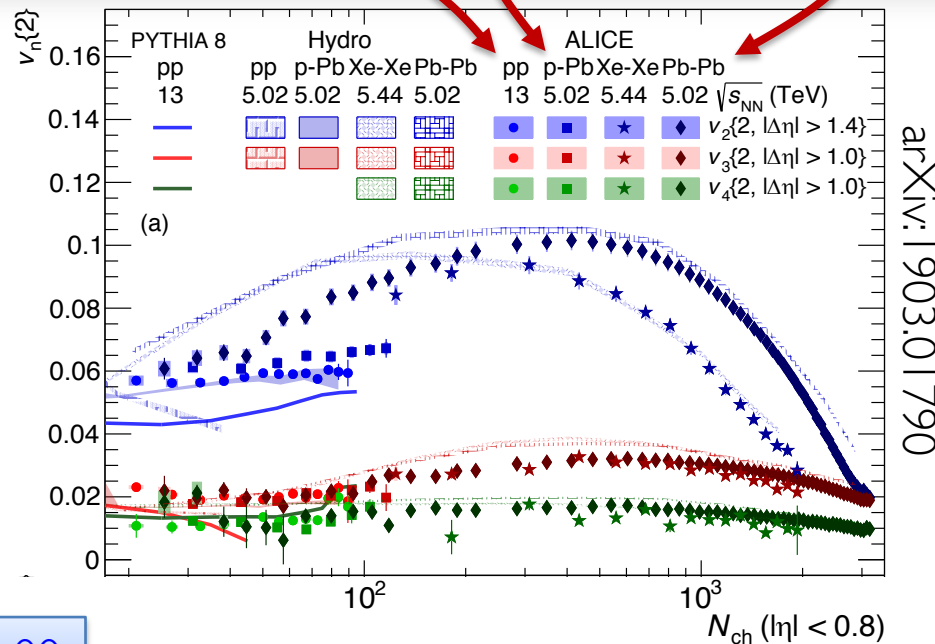
Pujahari, Tuesday 11:30



Flow from small to large: the challenge

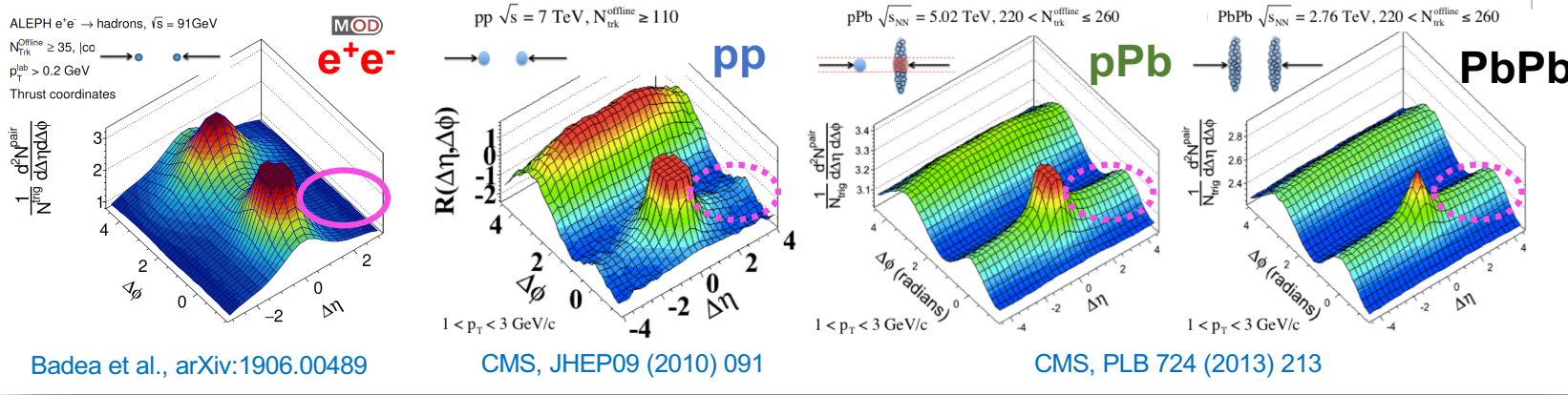


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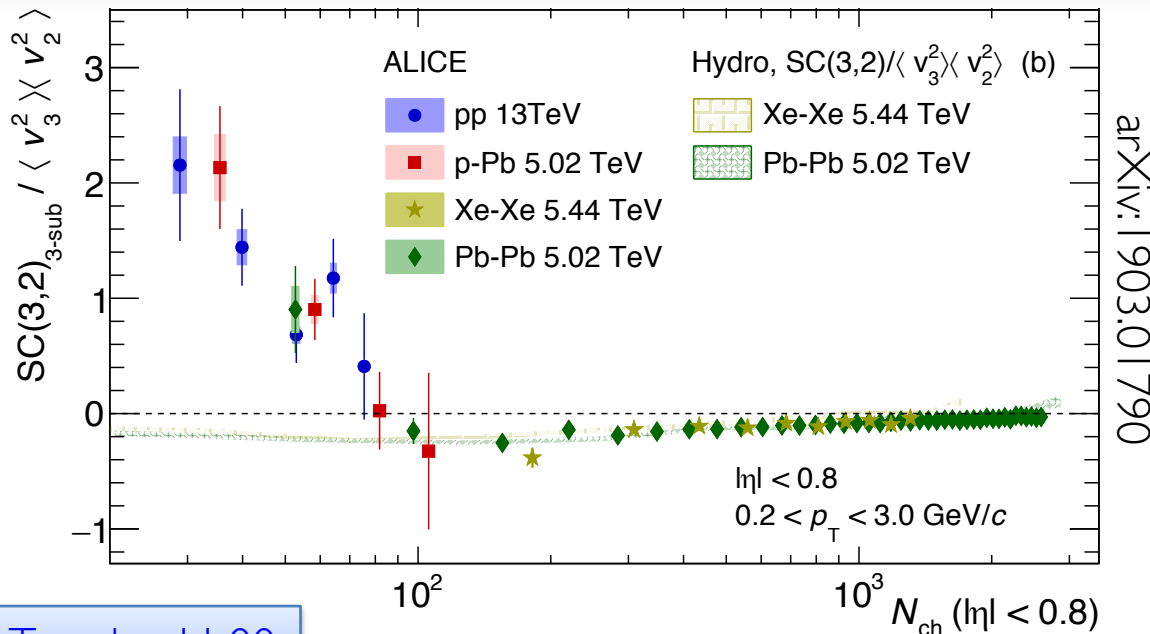


- ALICE: pp, p-Pb, Xe-Xe, Pb-Pb

Flow from small to large: the challenge

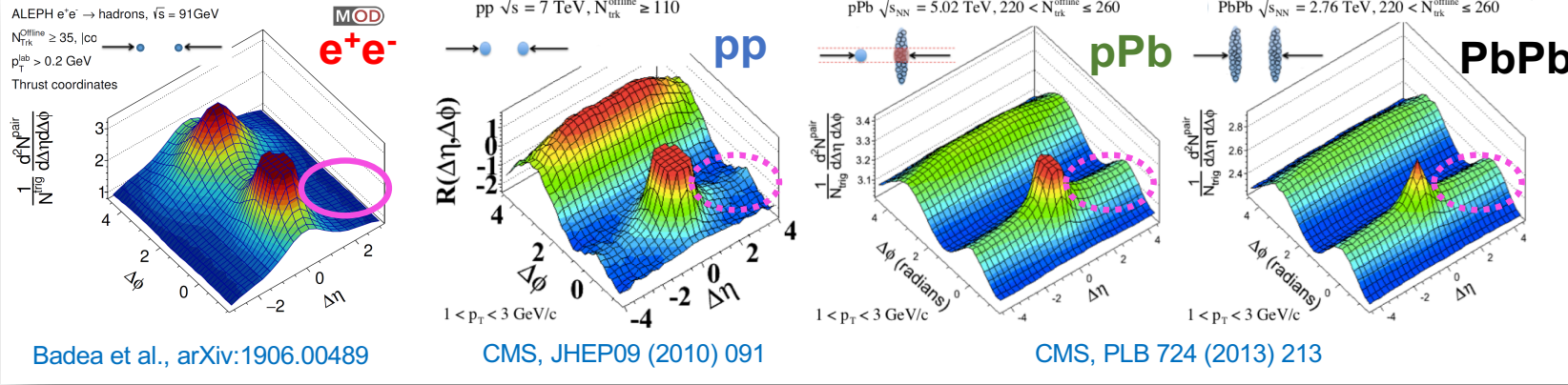


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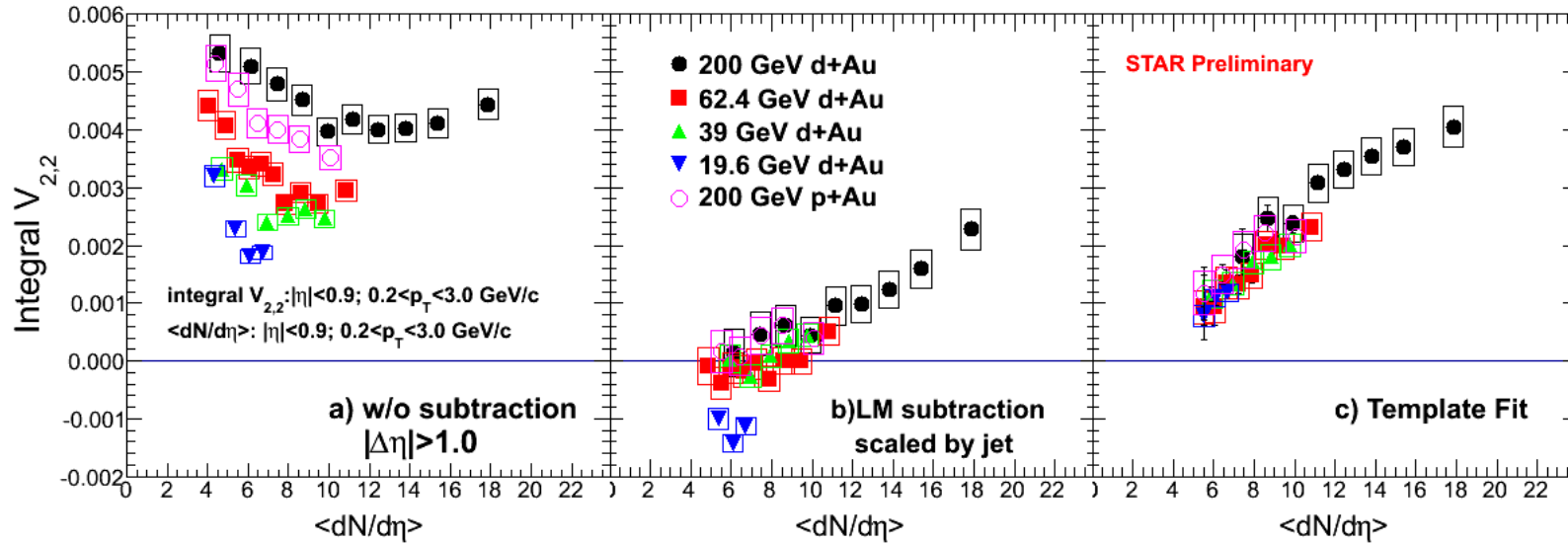


- ALICE: pp, p-Pb, Xe-Xe, Pb-Pb
- Sym. Cum. reveal a different fluctuation pattern for $N_{\text{ch}} < 100$

Flow from small to large: the challenge



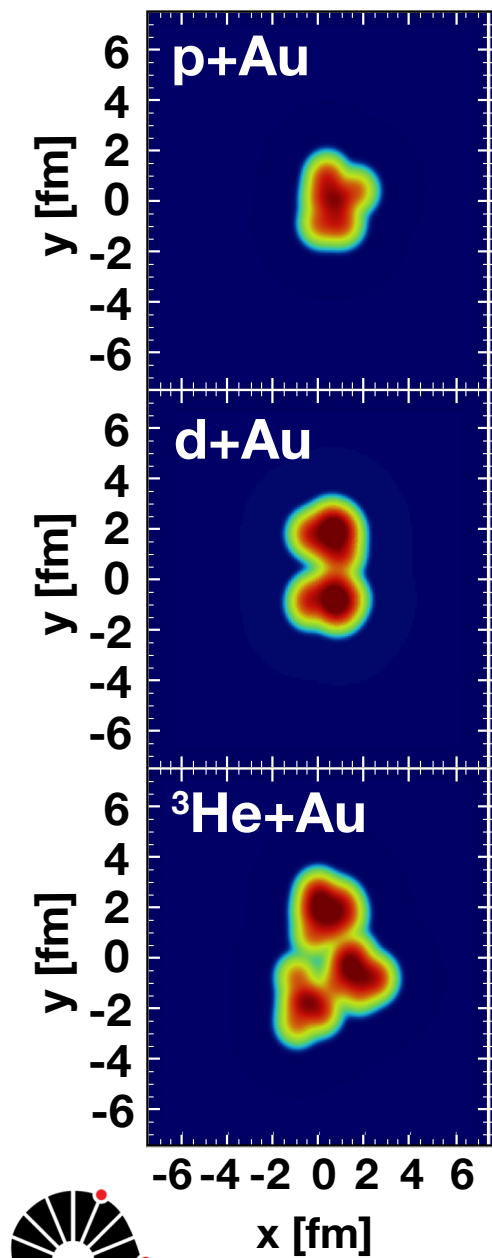
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- ALICE: pp, p-Pb, Xe-Xe, Pb-Pb
- Sym. Cum. reveal a different fluctuation pattern for $N_{\text{ch}} < 100$
- STAR measurements support nonzero flow in p+Au, d+Au

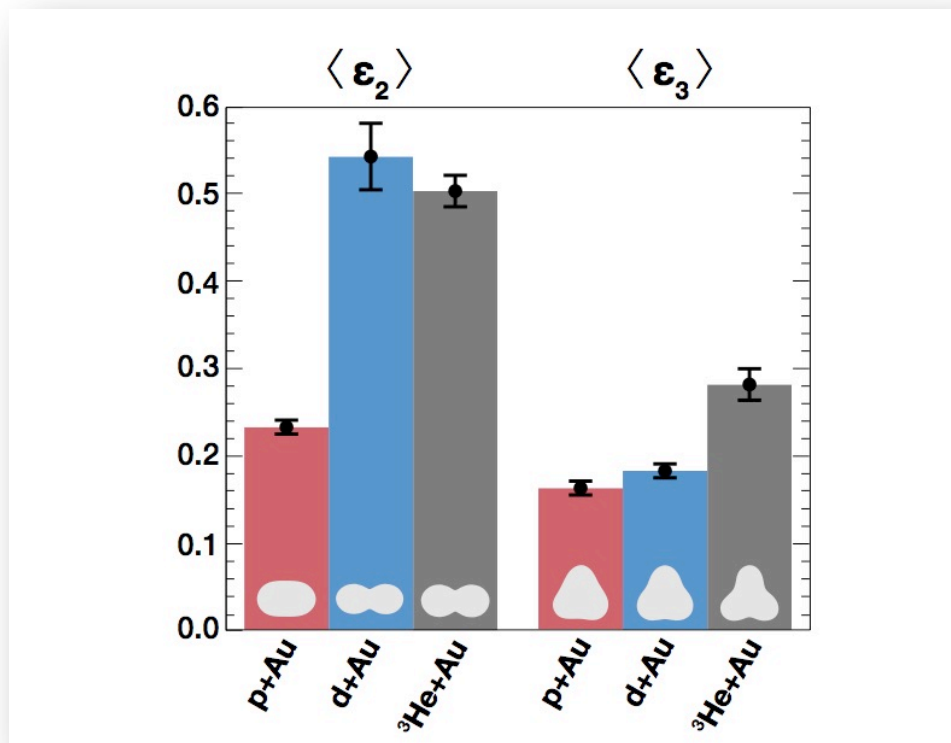
Pujahari, Tuesday 10:30

$t = 1.0 \text{ fm}/c$



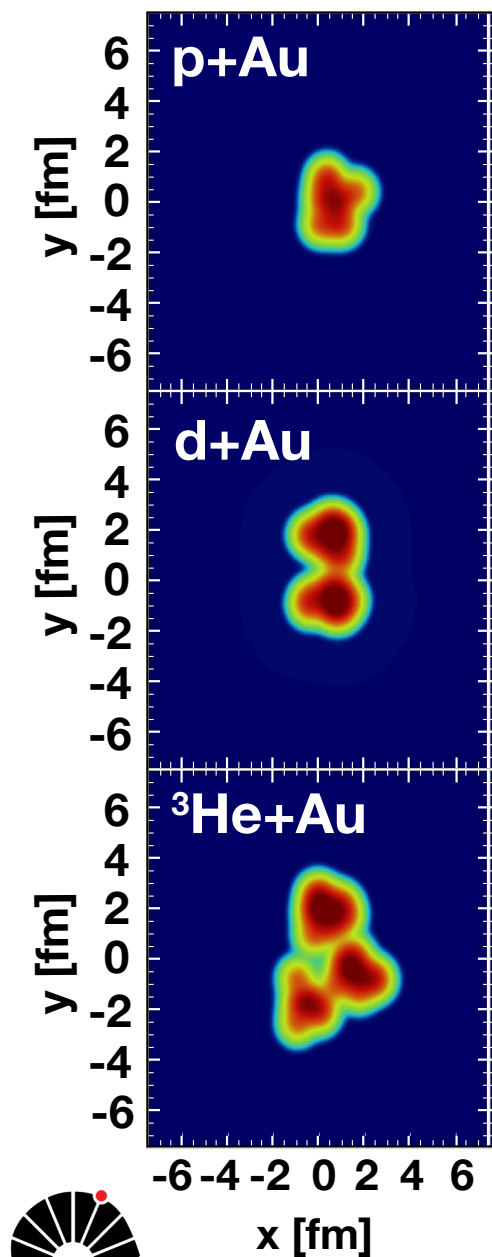
PHENIX: controlling geometry

Nature Physics **15**, 214–220 (2019)



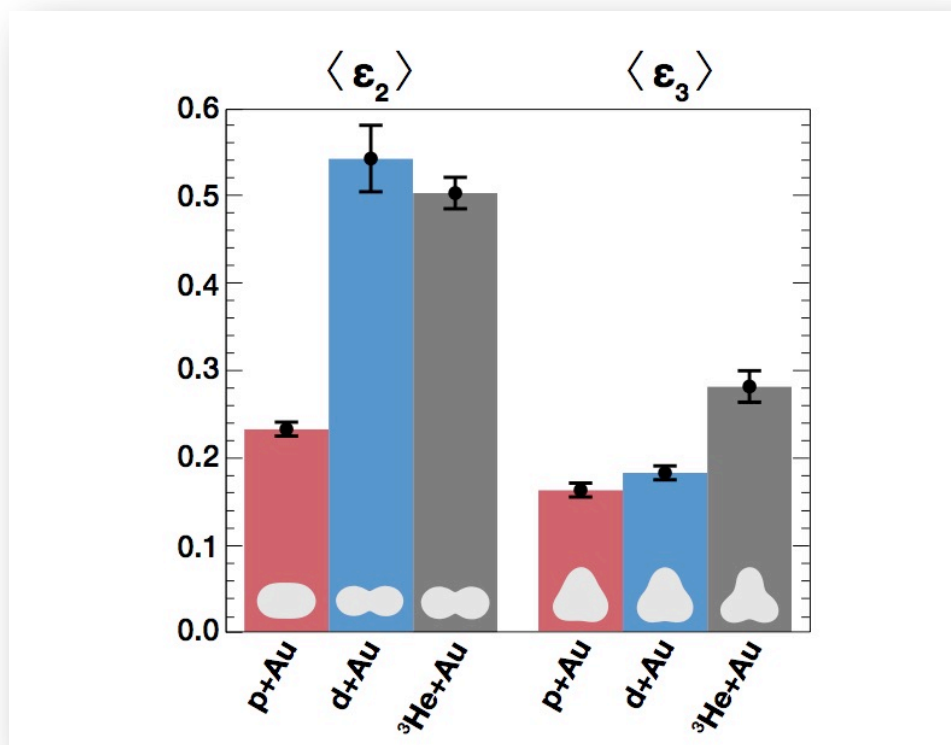
- Changing projectile: change in expected hydro response

$t = 1.0 \text{ fm}/c$

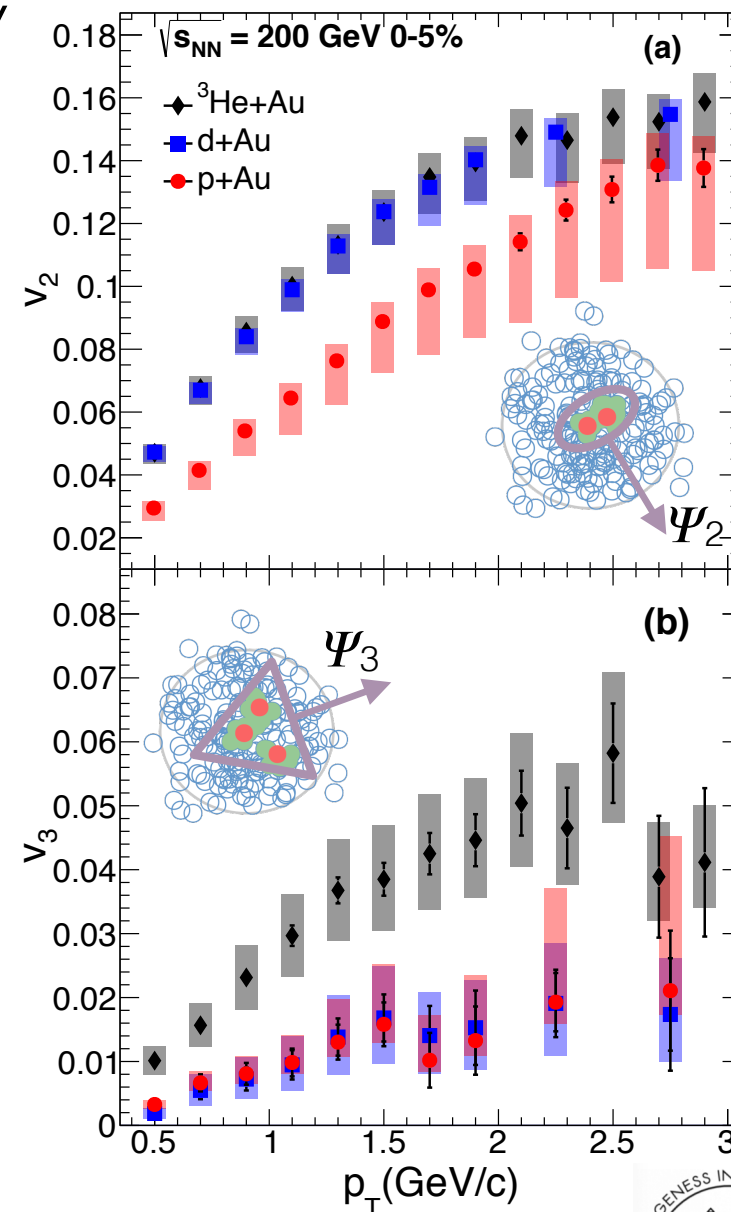


PHENIX: controlling geometry

Nature Physics **15**, 214–220 (2019)

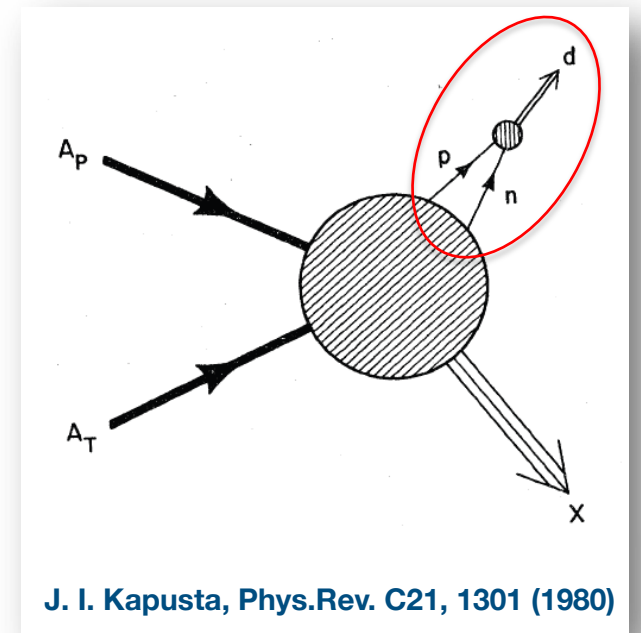


- Changing projectile: change in expected hydro response \rightarrow observed experimentally!
- Hydro simulations reproduce data
- “Creation of quark–gluon plasma droplets with three distinct geometries”



The outlook

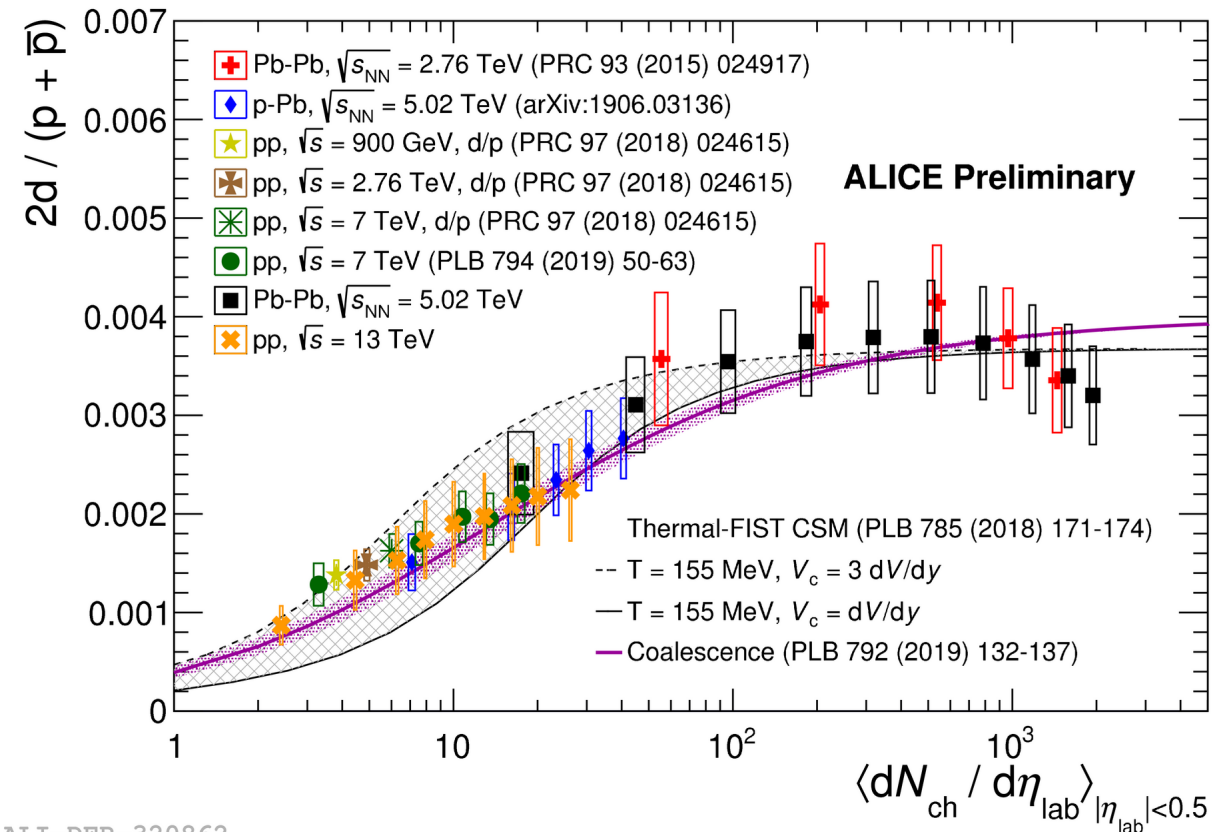
- Precision studies of LF and strangeness production mechanisms
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Deuteron production across systems from ALICE

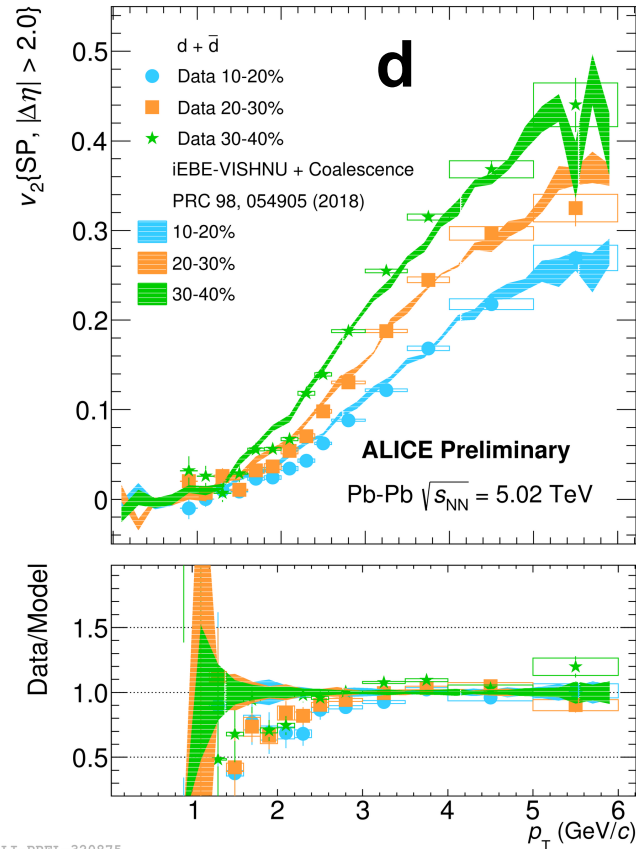
Barioglio, [Tuesday 16:30](#)

- Production models:
 - **Coalescence:** Nucleons that are close in the phase space form a nucleus via coalescence
 - **Statistical hadronization:** hadrons are emitted from the interaction region in statistical equilibrium at the chemical freeze-out
- New data from ALICE across systems →
 - Both models compatible

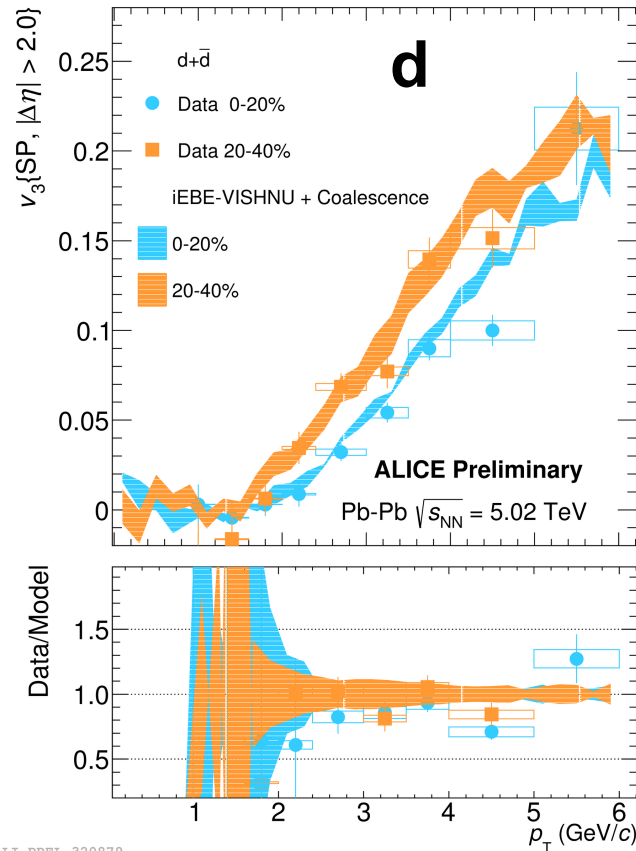


ALI-DER-320862

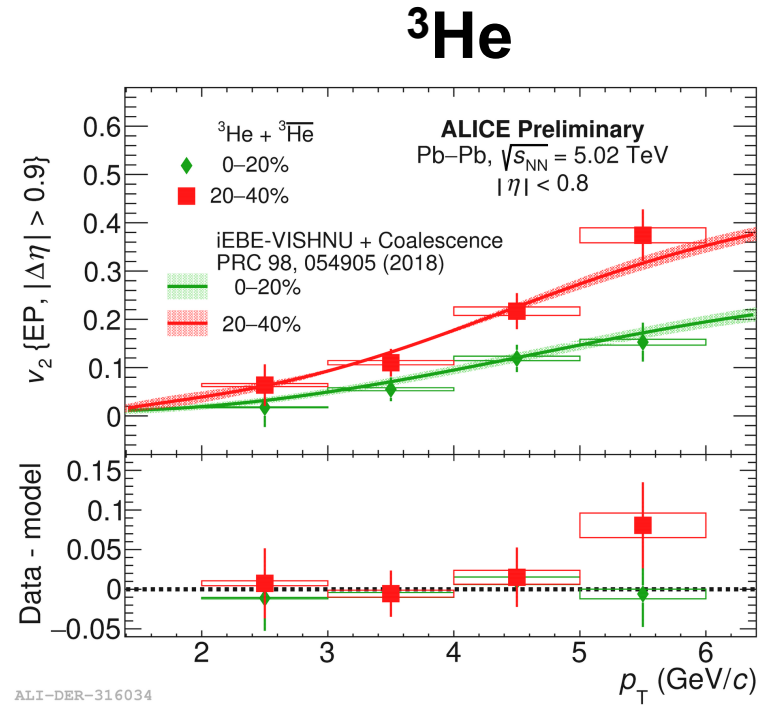
Elliptic and triangular flow of nuclei



ALI-PREL-320875



ALI-PREL-320879

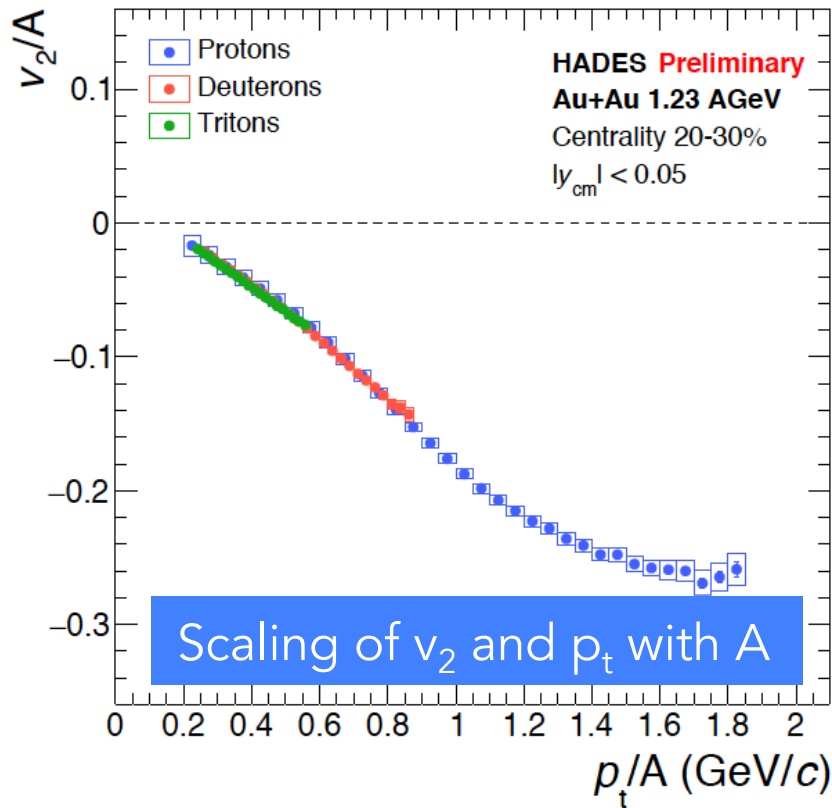


ALI-DER-316034

Caliva, Thursday 16:30

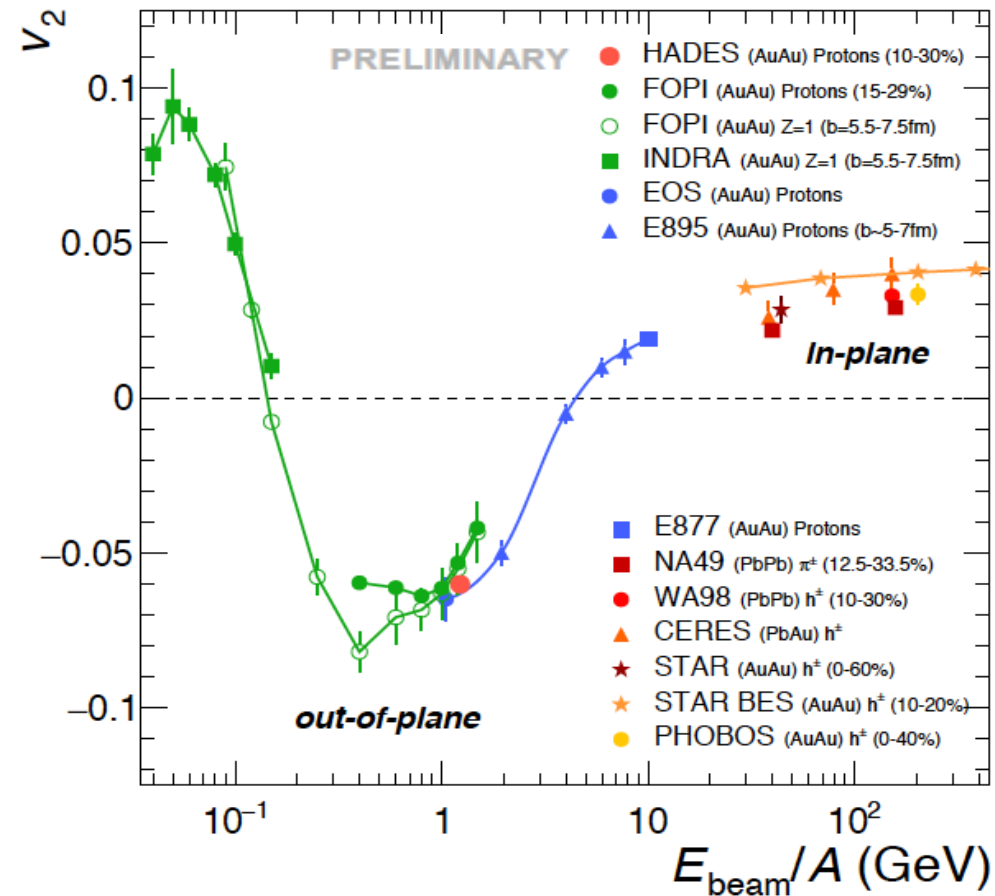
- Nuclei flow: further constraint on production mechanisms
- Consistent with coalescence with phase space distributions of nucleons generated by iEBE-VISHNU

Nuclei elliptic flow measured by HADES



- HADES studied p, d, t v_2 systematically
 - scales with A : coalescence?
 - ...and it's also negative

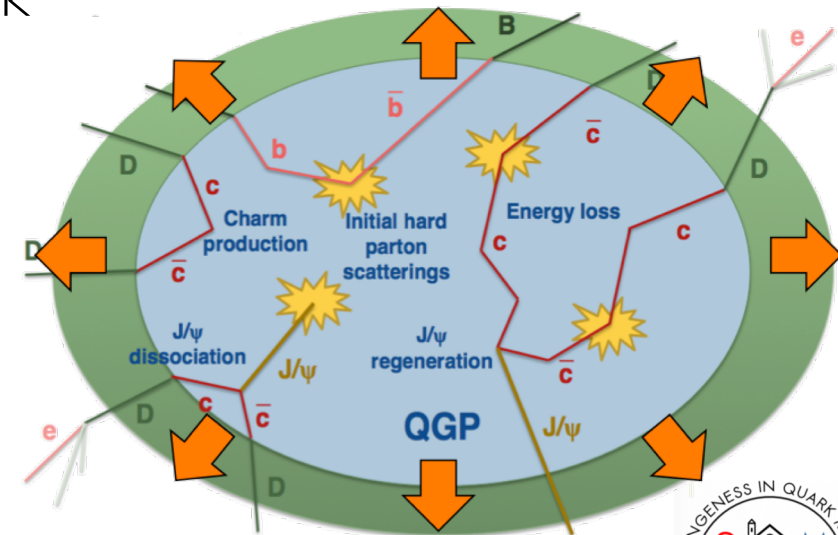
Chlad, Thursday, 16:30



- Sign inversion of v_2 : will have to be described by any potential universal model
- Further work needed on both exp and theory

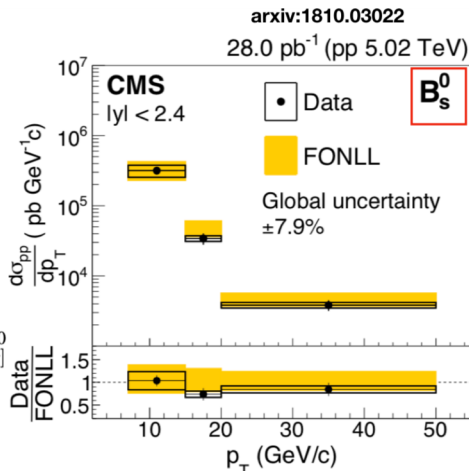
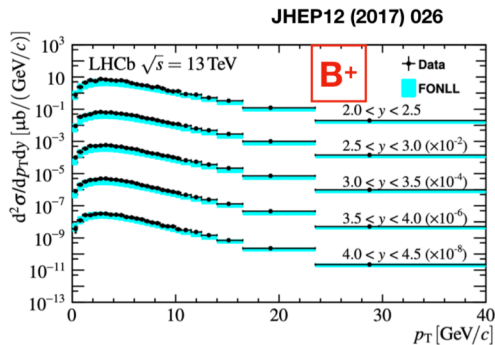
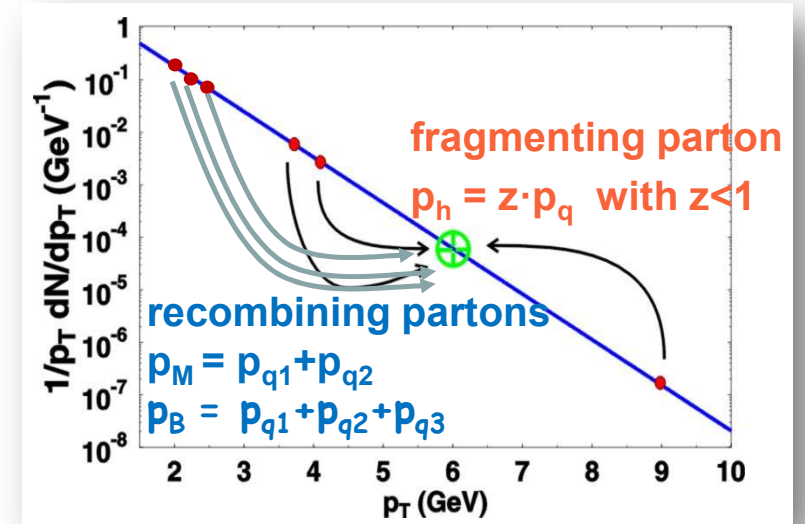
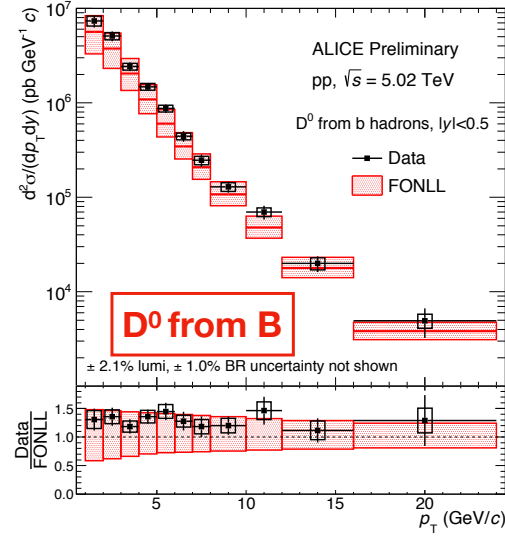
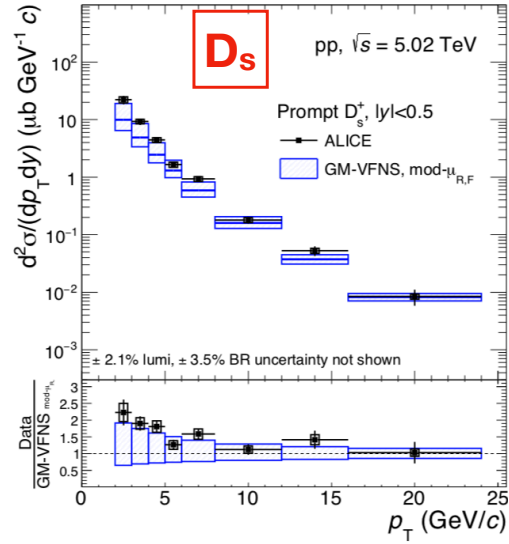
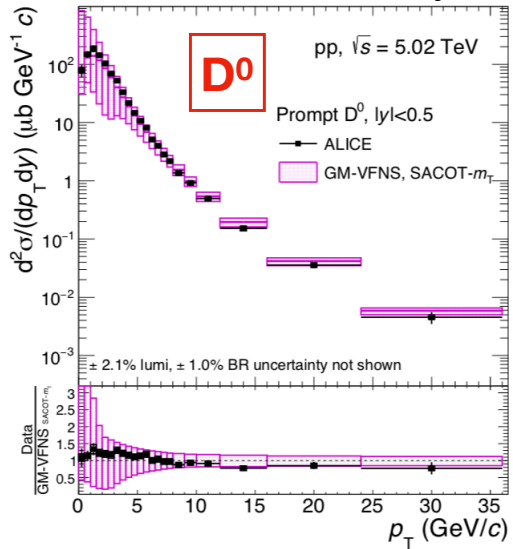
The outlook

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Open charm: D, B meson measurements in pp

Eur.Phys.J. C79 (2019) no.5, 388



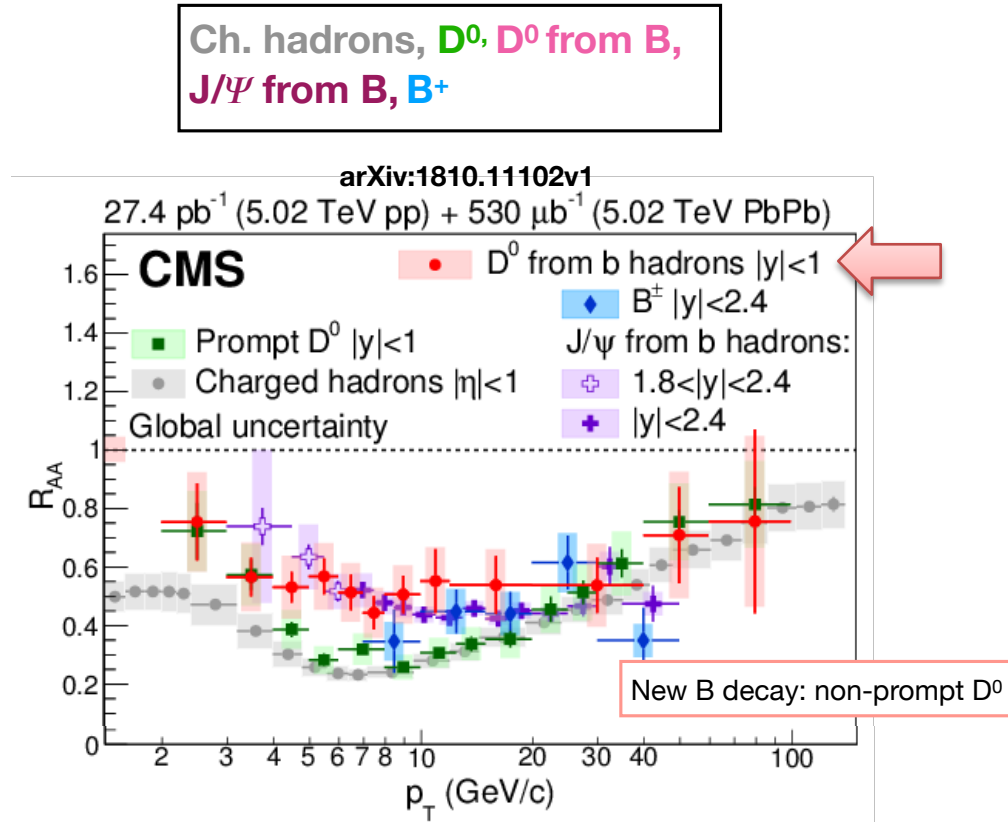
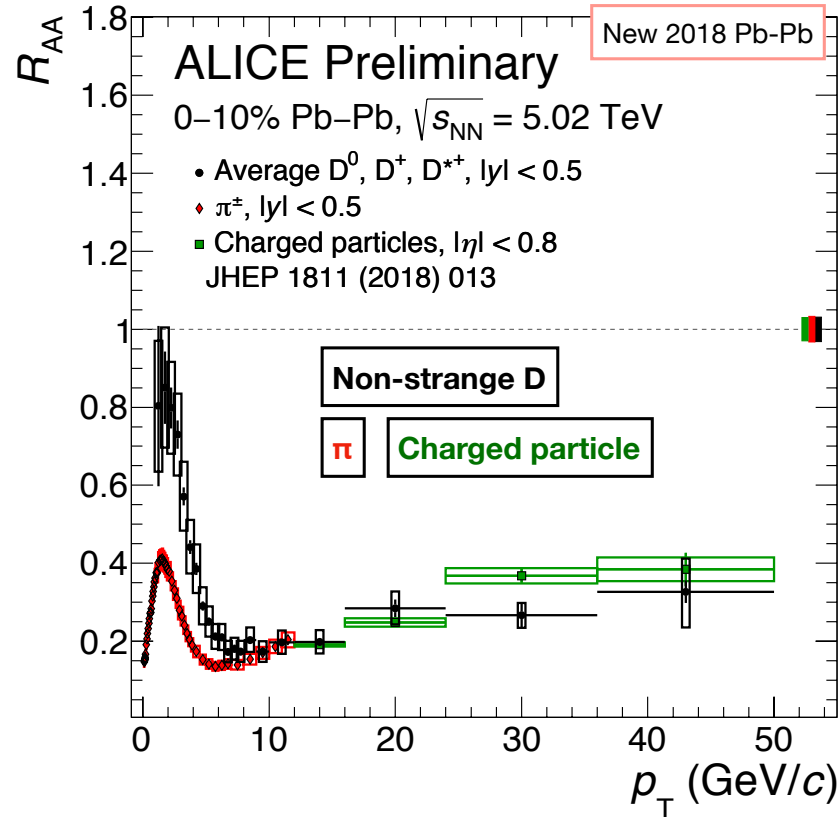
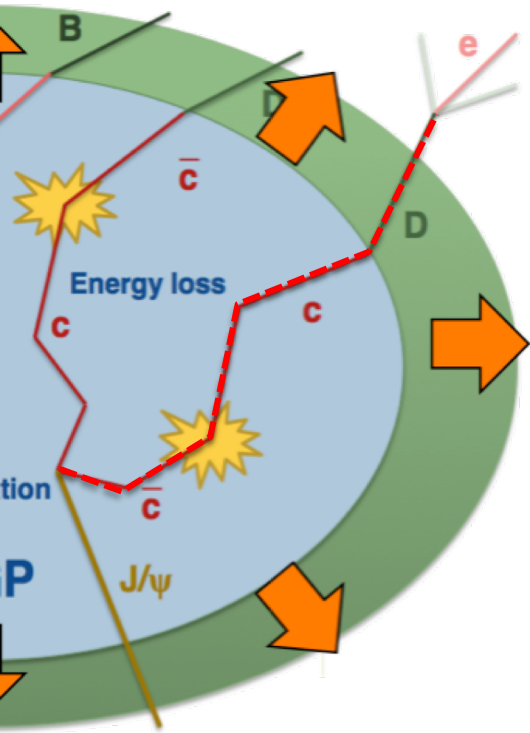
- pp: fragmentation reference
- Plethora of open charm measurements
- NLO description reasonable within uncertainties
- Fundamental reference for QGP studies

Rossi, [Monday 16:30](#)

Dhanker, [Tuesday 17:30](#)

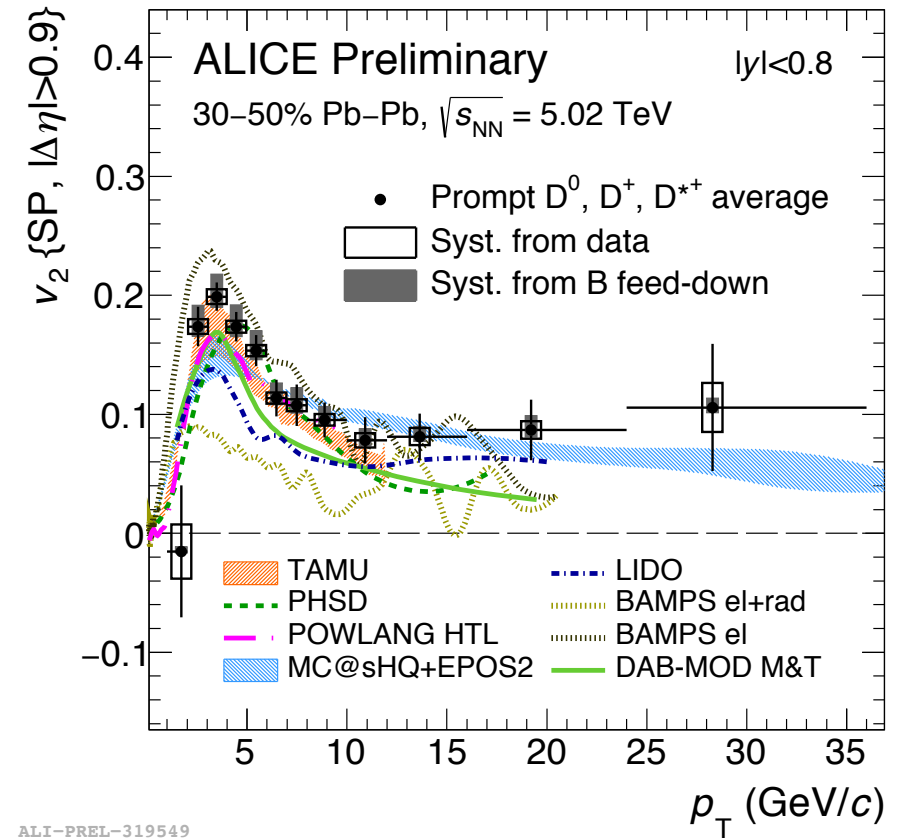
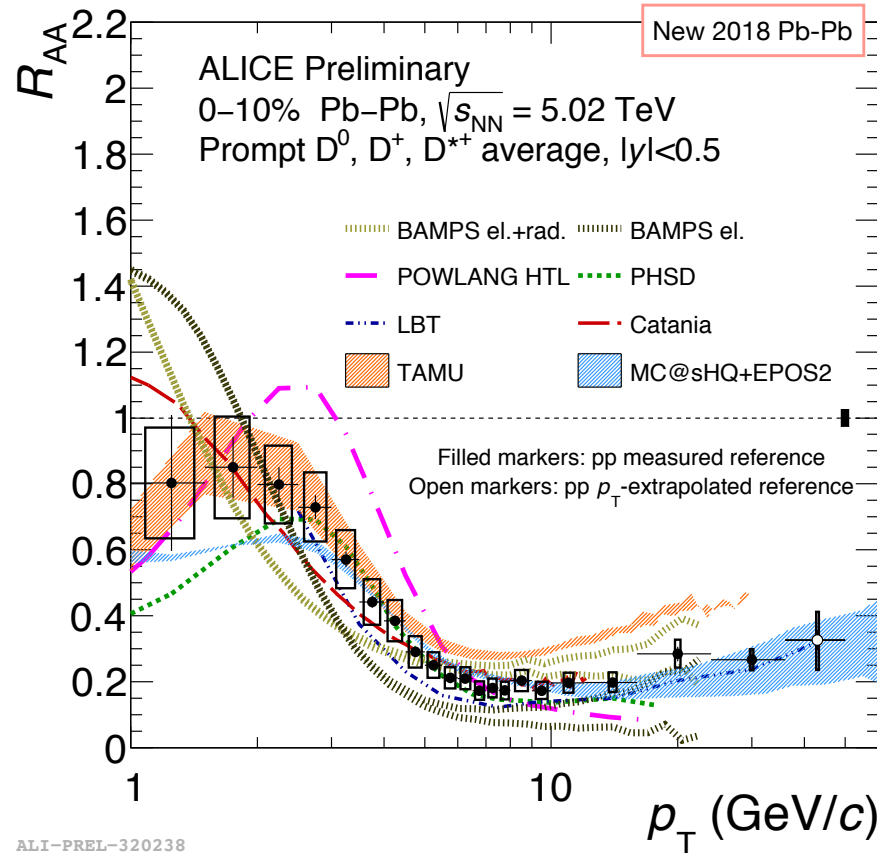
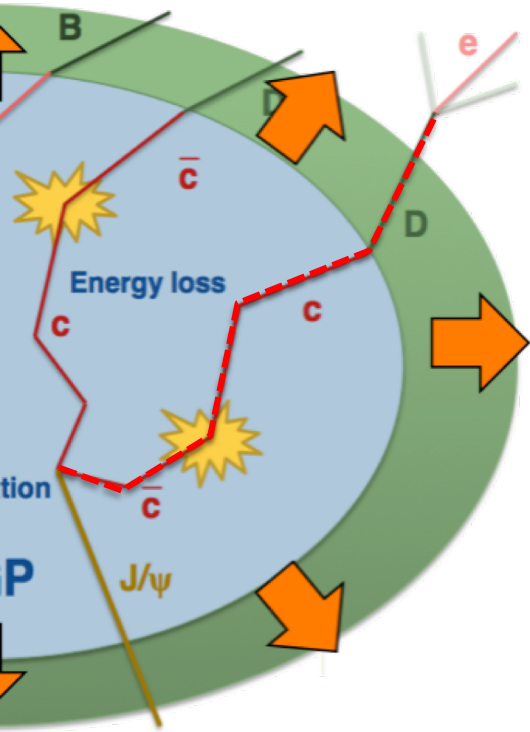
Jaelani, [Tuesday 16:10](#)

Open charm R_{AA}



- New results from ALICE and CMS quantify suppression: $D^0, D^0 \leftarrow b$
- Suppression similar at high p_T , different at low p_T :
 - $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$

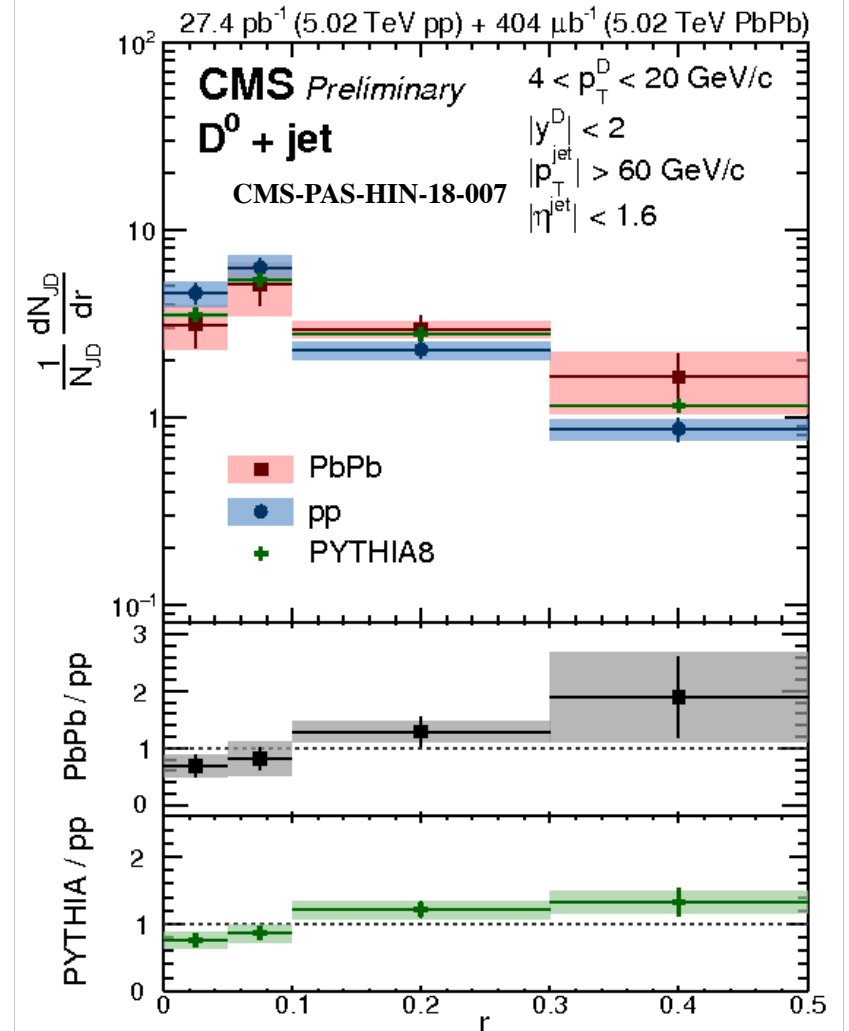
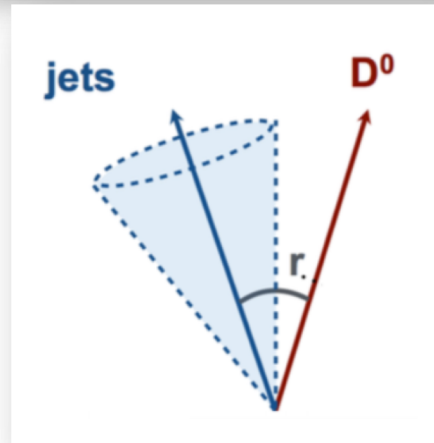
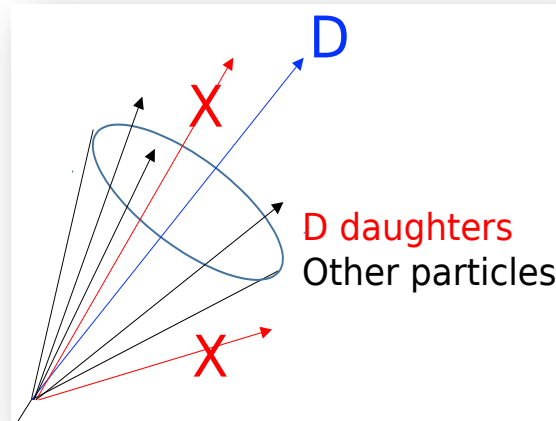
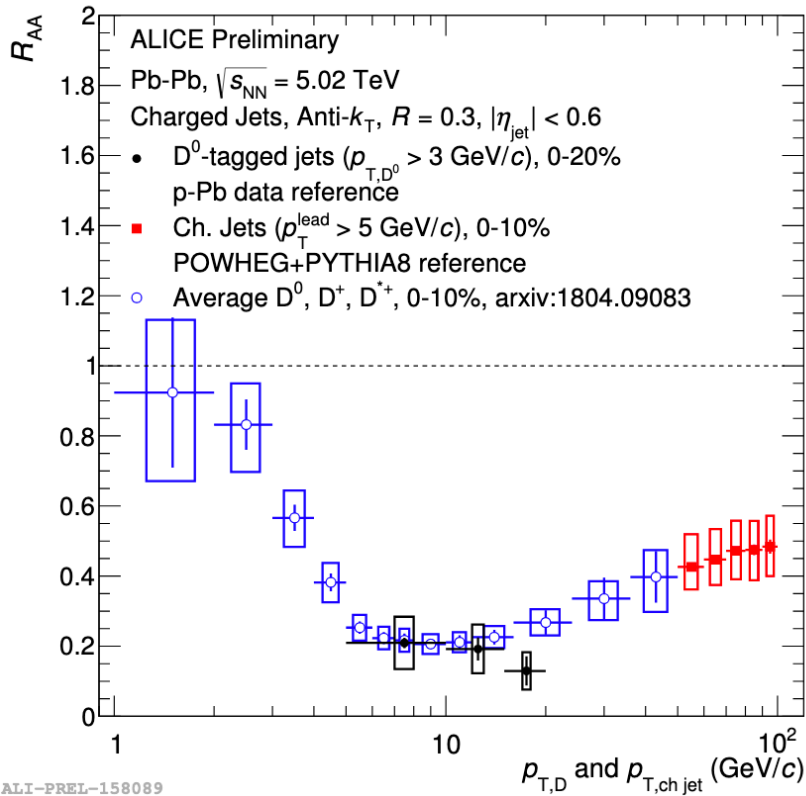
Charm $R_{AA} + v_2$: towards transport coefficients



- $R_{AA} + v_2$: constrains models for the characterization of the charm (and beauty!) interaction with the medium: transport

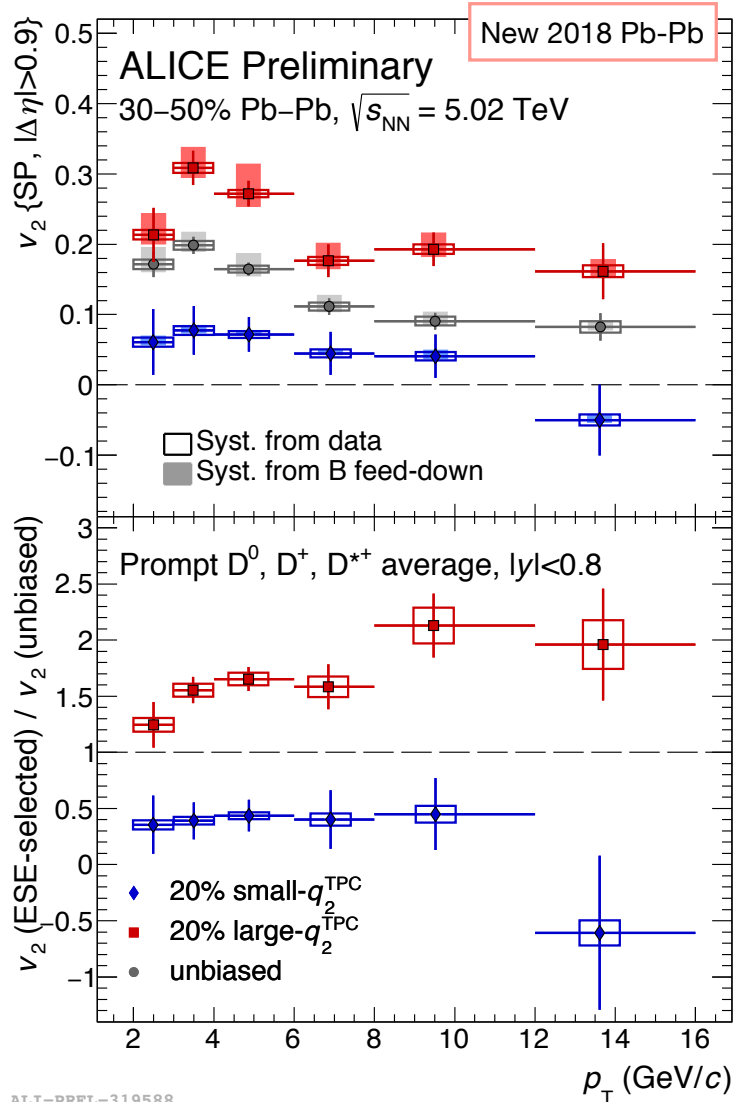
Jaelani, Tuesday 16:10

D-tagged jets in ALICE and CMS



- Radial distribution of the D0 mesons different in Pb-Pb if compared to p_T:
- pp more collimated?

D⁰ meson elliptic flow using event shape engineering



v_2 in classes of events selected in 30-50% with different initial geometrical shape eccentricity

‘reduced flow vector’ q_2 to quantify the **eccentricity** of the event

20% largest q_2 :
 v_2 increased

20% smallest q_2 :
 v_2 reduced

2018 data improve measurement reported in JHEP1902 (2019) 150

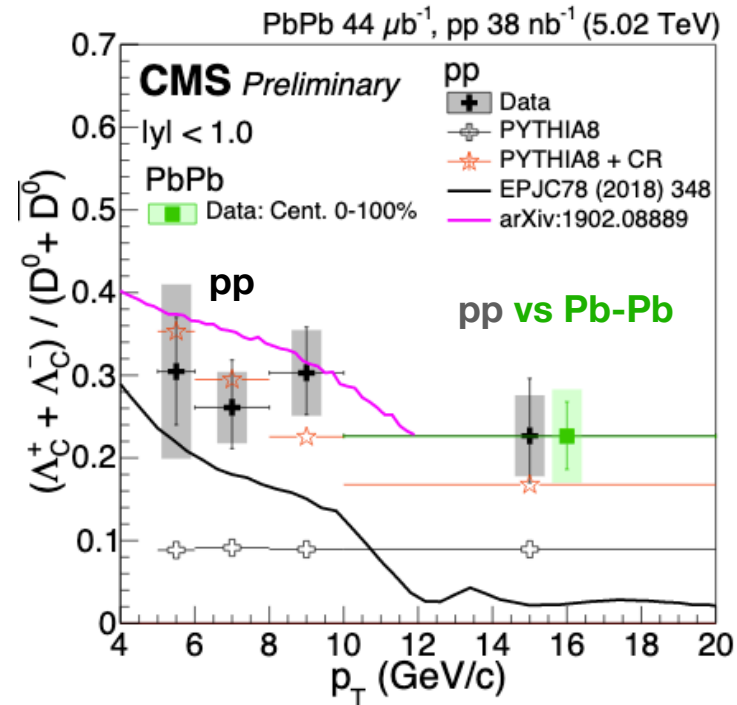
- A selection on the the elliptic flow of charged hadrons leads to a bias in the D⁰ meson elliptic flow:
→ Common mechanism
- Quantitative comparison to models provide further constraints!

Terrevoli, [Thursday 10:00](#)

Baryon/meson in the charm sector: Λ_c/D^0

arXiv:1906.03322

New



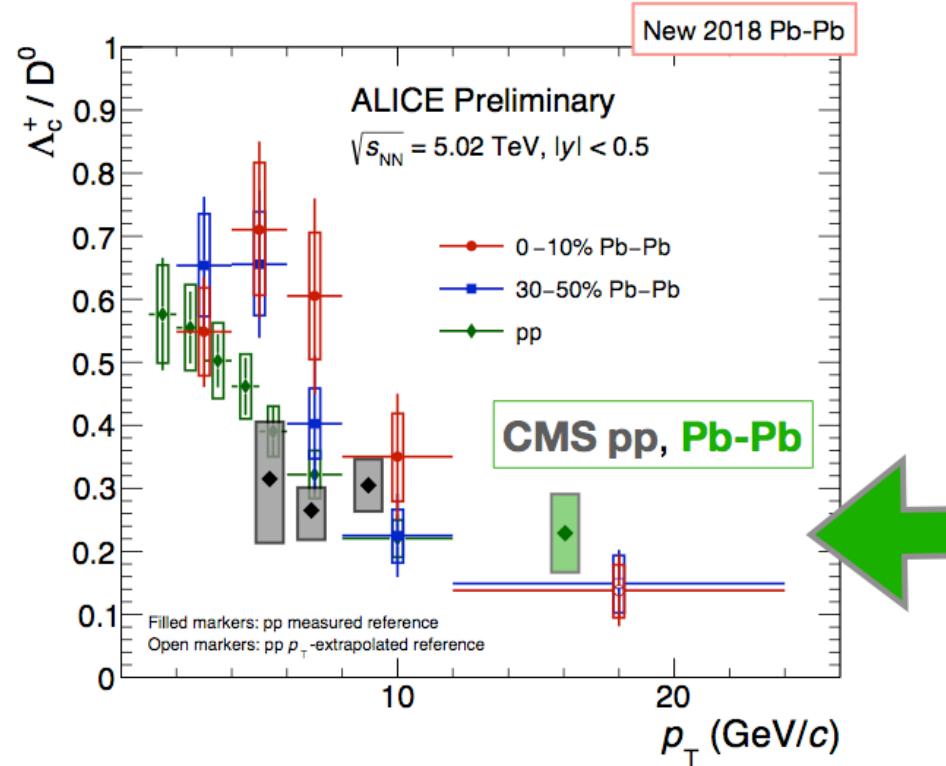
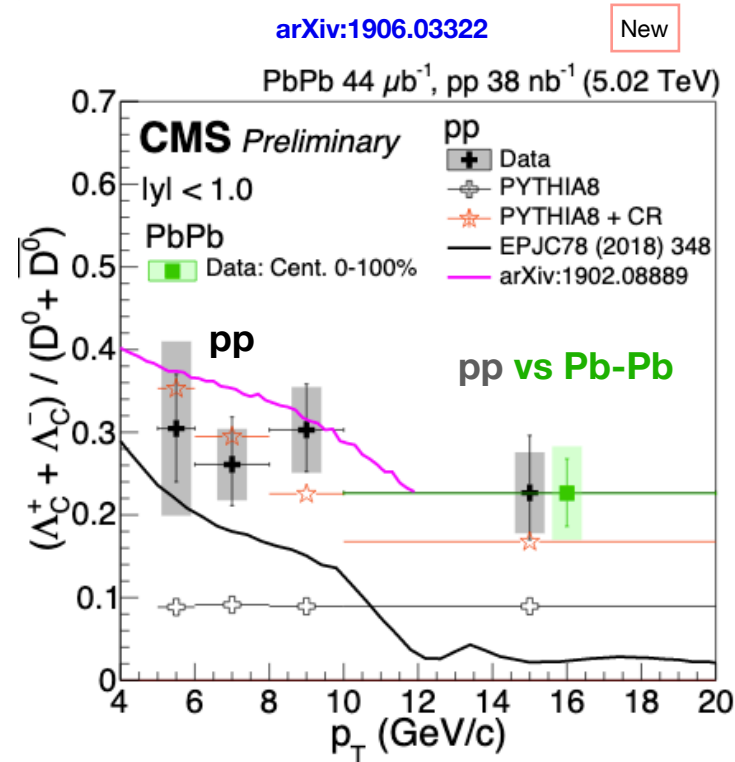
- Λ_c/D^0 in pp: matched by **improved CR** in PYTHIA (but beware caveats)

Prino, [Wednesday 12:00](#)

Xiao, [Tuesday 14:20](#)

Zampolli, [Tuesday 15:20](#)

Baryon/meson in the charm sector: Λ_c/D^0



ALI-PREL-321702

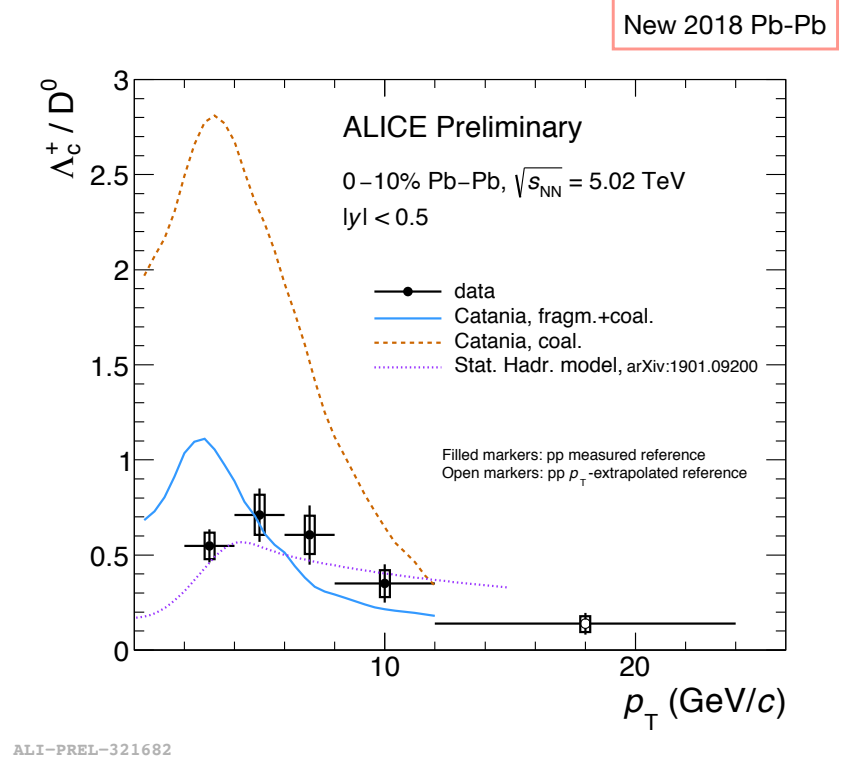
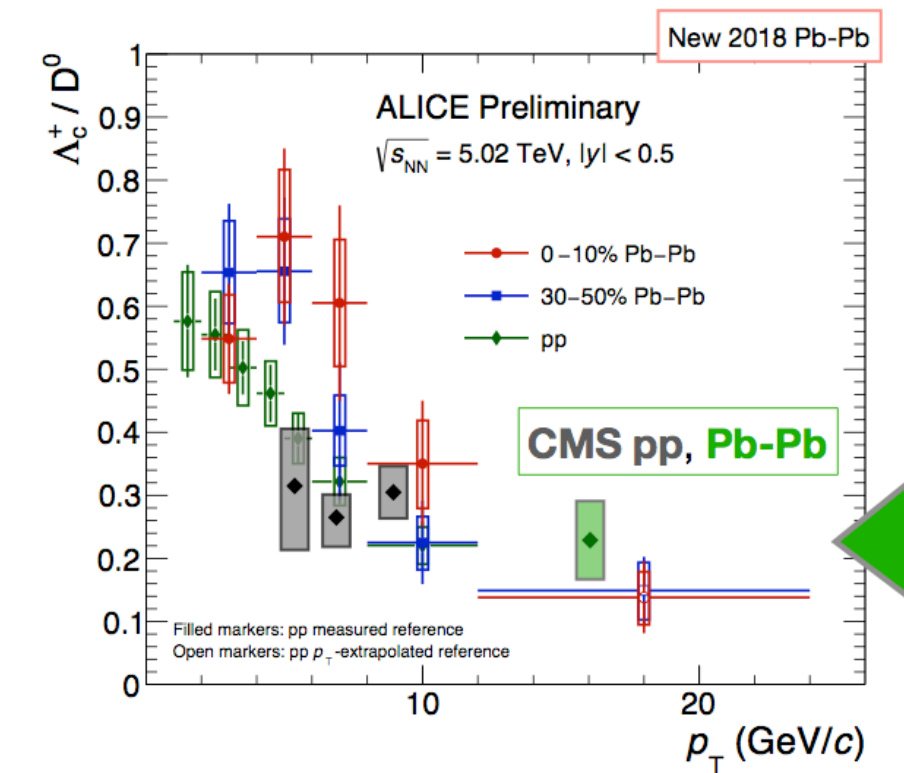
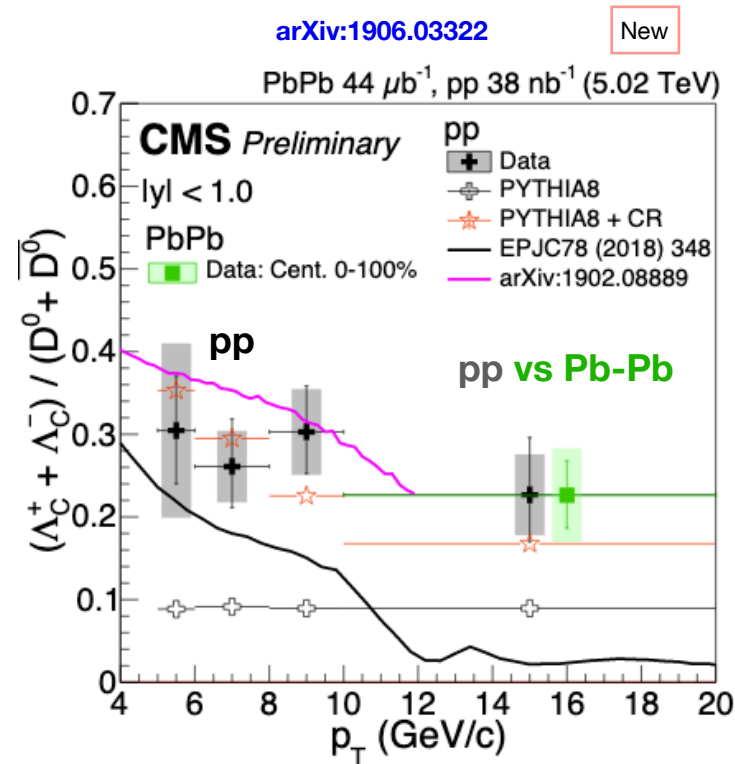
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- Λ_c/D^0 in Pb-Pb: hint of increase at mid- p_T ? Reminiscent of Λ/K_S^0 ?

Prino, [Wednesday 12:00](#)

Xiao, [Tuesday 14:20](#)

Zampolli, [Tuesday 15:20](#)

Baryon/meson in the charm sector: Λ_c/D^0



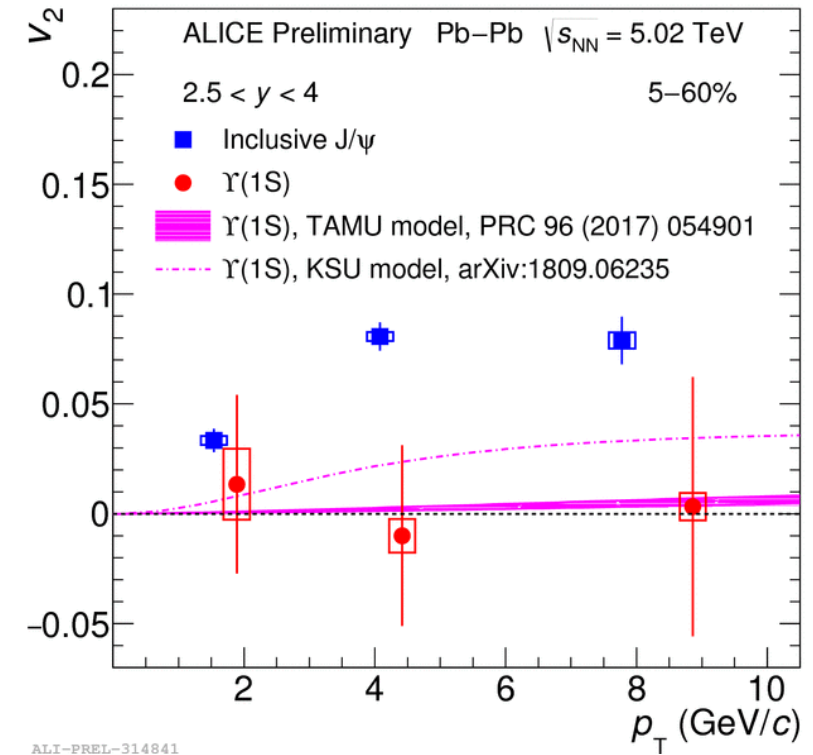
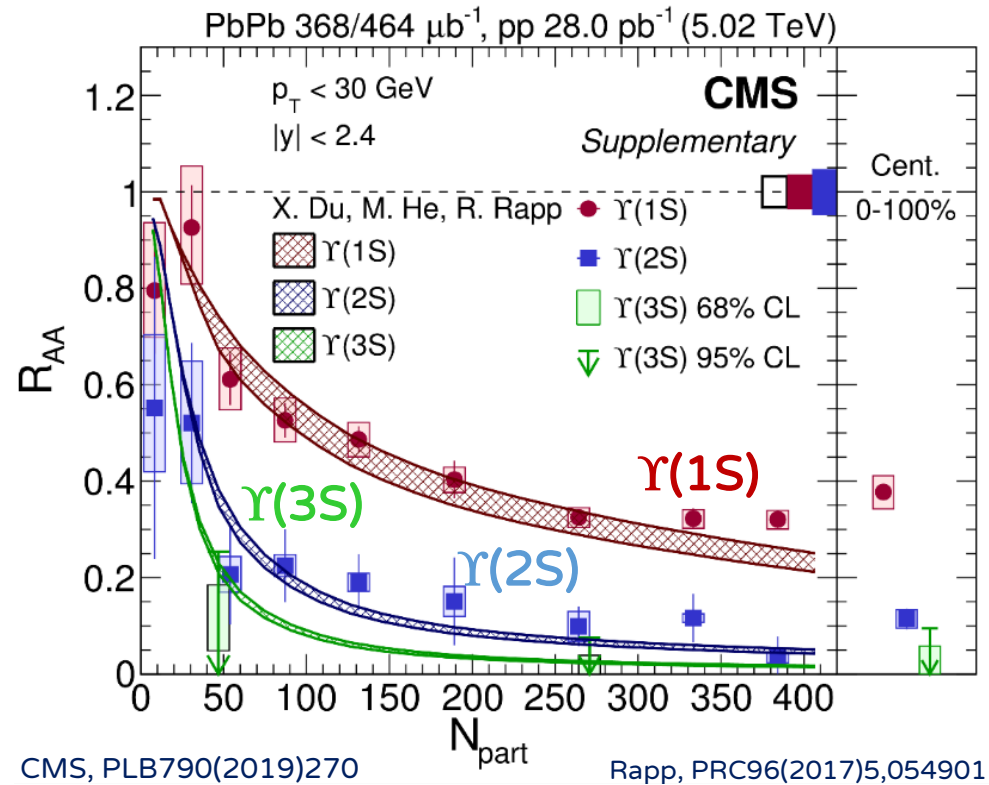
- Λ_c/D^0 in pp: matched by **improved CR** in PYTHIA (but beware caveats)
- Λ_c/D^0 in Pb-Pb: hint of increase at mid- p_T ? Reminiscent of Λ/K_S^0 ?
- Pb-Pb: **coalescence+fragmentation** or **stat. hadr. Model**
 - Improved measurements needed to constrain models

Prino, [Wednesday 12:00](#)

Xiao, [Tuesday 14:20](#)

Zampolli, [Tuesday 15:20](#)

Bottomonium: the Υ family



- R_{AA} of $\Upsilon(1S) > \Upsilon(2S) \Upsilon(3S)$: described by models with suppression and regeneration

- But: flow compatible with zero?
- Future measurements will add precision!

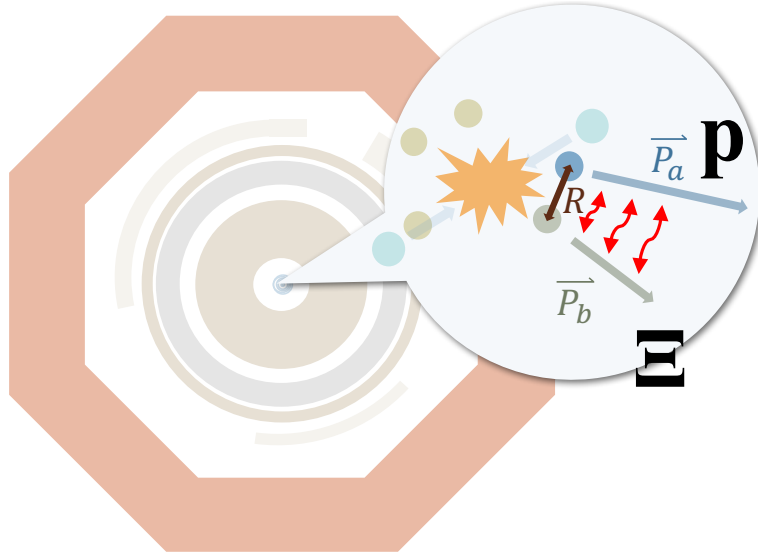
Fasanella, [Tuesday 17:30](#)

The outlook

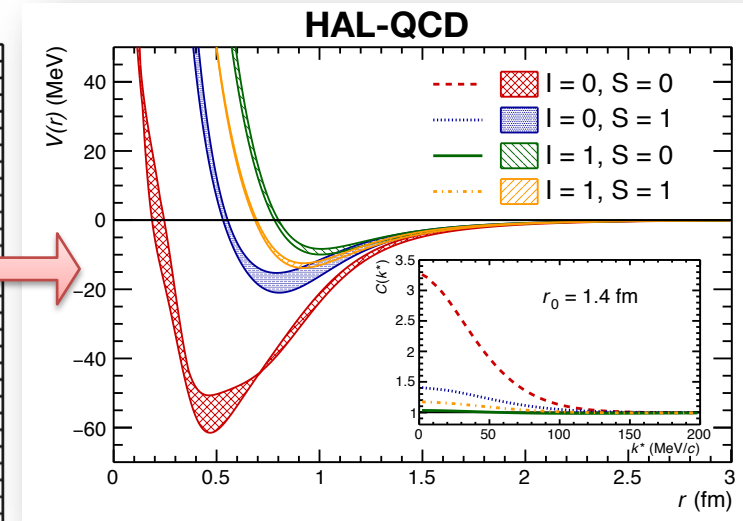
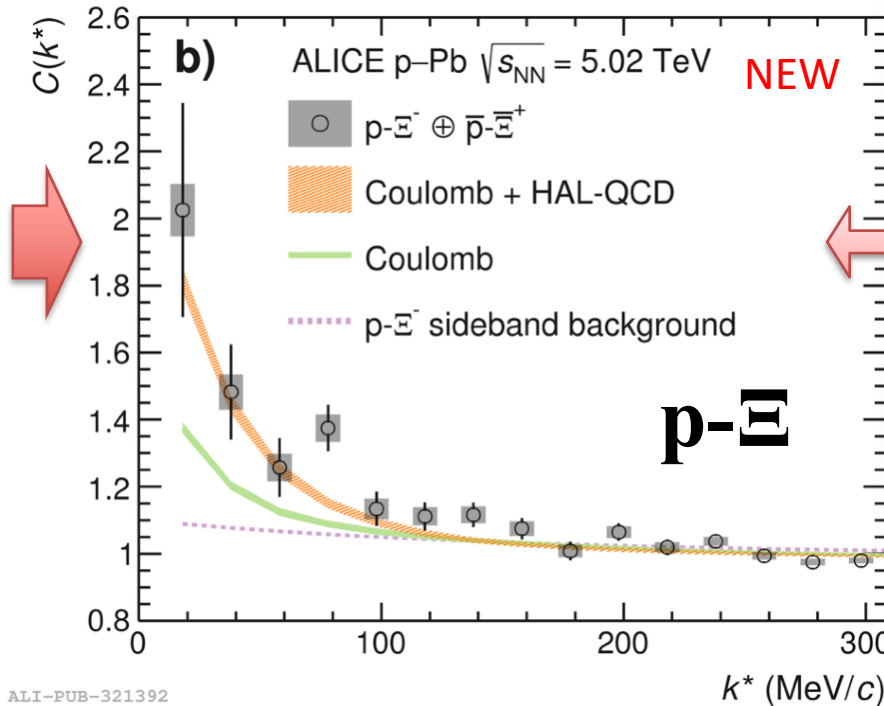
- Precision studies of LF and strangeness production mechanisms
- Bulk matter / soft physics and collectivity
- How are nuclei produced?
- Heavy flavor production and its relation to bulk
- Hadronic interactions, astrophysics and more
- The future



Probing hadronic interactions via femtoscopy



ALICE Collaboration, arXiv:1904.12198 [nucl-ex]



Experimental definition

Theoretical definition

$$C(k^*) = \mathcal{N} \frac{N_{\text{Same}}(k^*)}{N_{\text{Mixed}}(k^*)} = \int S(\vec{r}) |\Psi(\vec{k}^*, \vec{r})|^2 d^3\vec{r}$$

Theory, Hatsuda: [Tuesday 9:30](#)

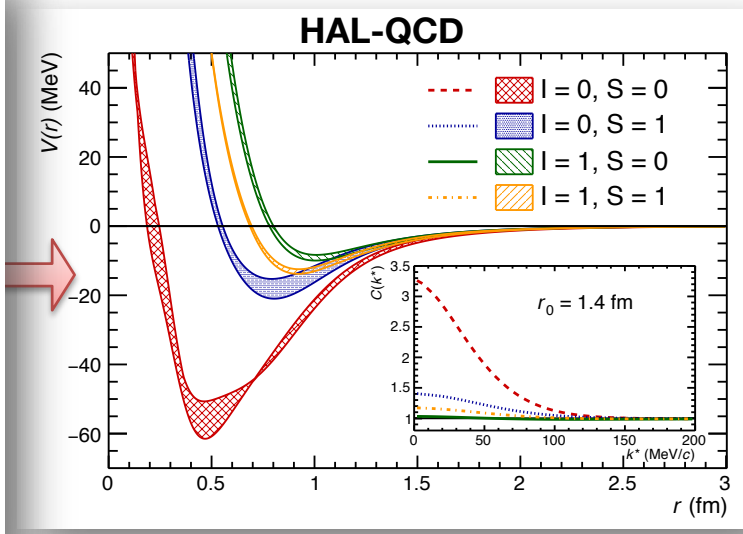
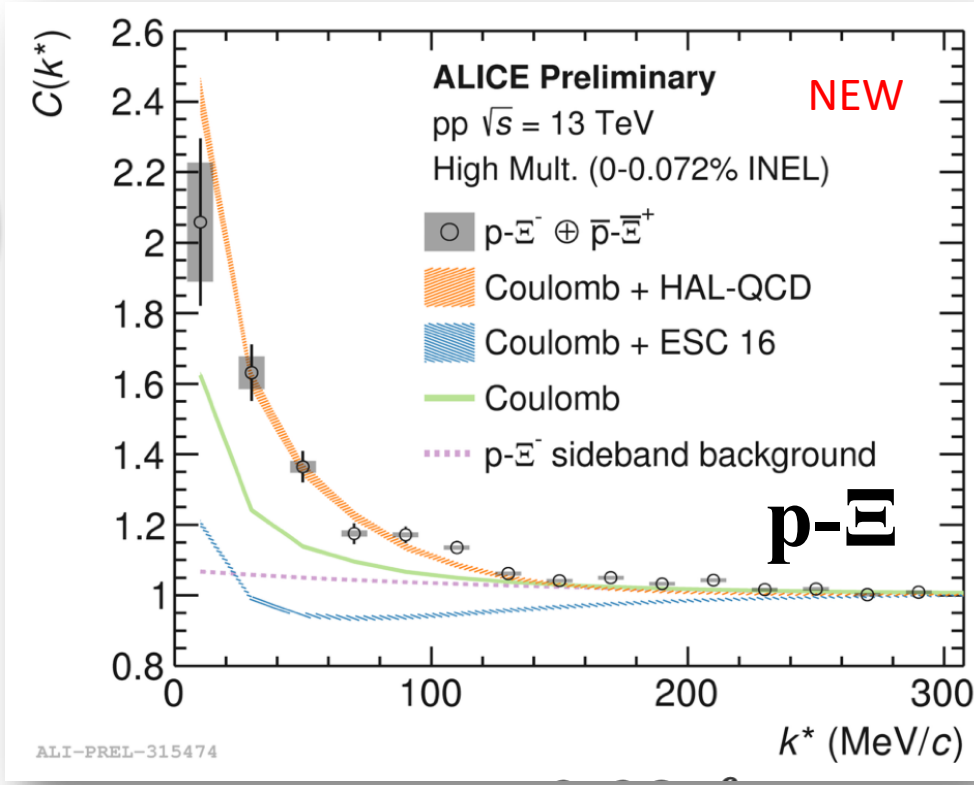
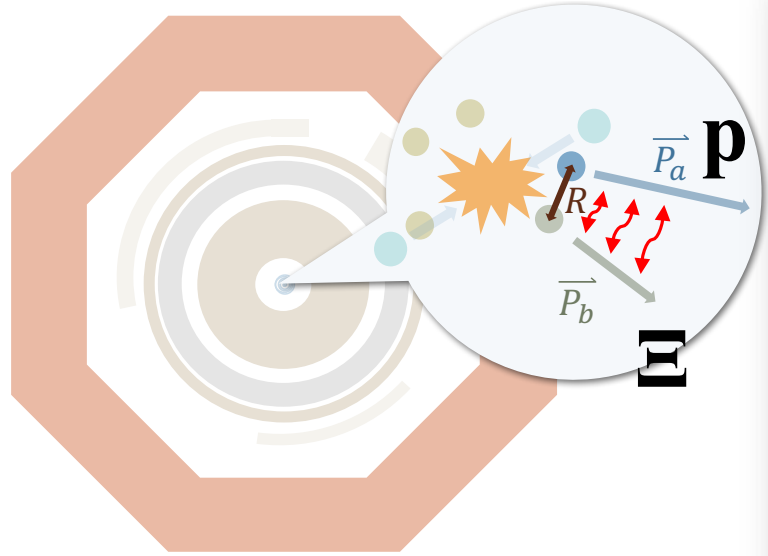
Theory, Talos: [Thursday 12:00](#)

Experimental, Fabbietti: [Tuesday 10:00](#)

Vazquez Doce, [poster](#)

- Measurement of $C(k^*)$ correlation functions provides direct information about the interaction potential
- Used for many particle species! Here: $p-\Xi$
 - Attractive interaction

Probing hadronic interactions via femtoscopy



Experimental definition

Theoretical definition

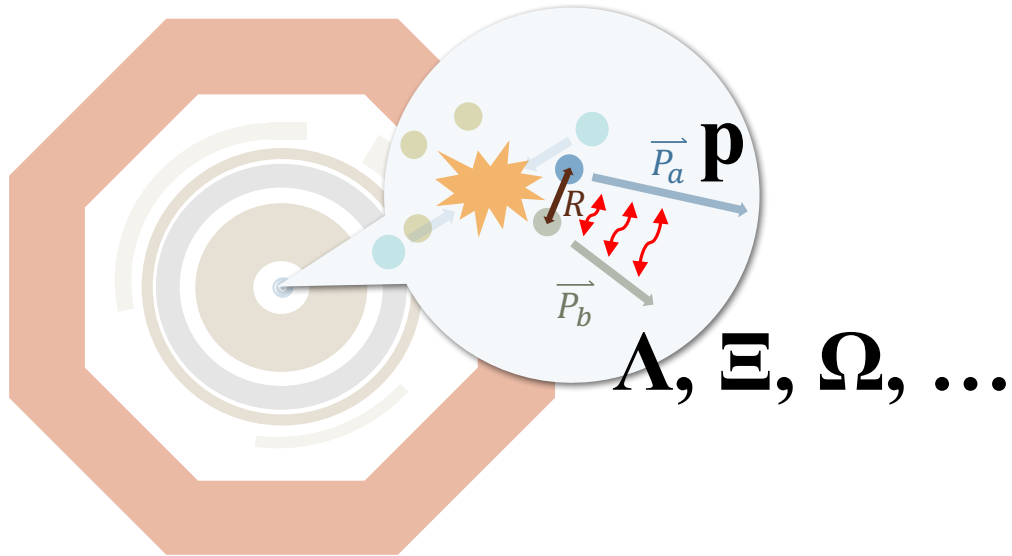
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Theory, Hatsuda: [Tuesday 9:30](#)
 Theory, Talos: [Thursday 12:00](#)
 Experimental, Fabbietti: [Tuesday 10:00](#)
 Vazquez Doce, [poster](#)

- More precise result just came out using high-multiplicity pp collisions
- Result important for neutron star EoS:
 - Favors hyperon presence → softens EoS



Probing hadronic interactions via femtoscopy



Experimental definition

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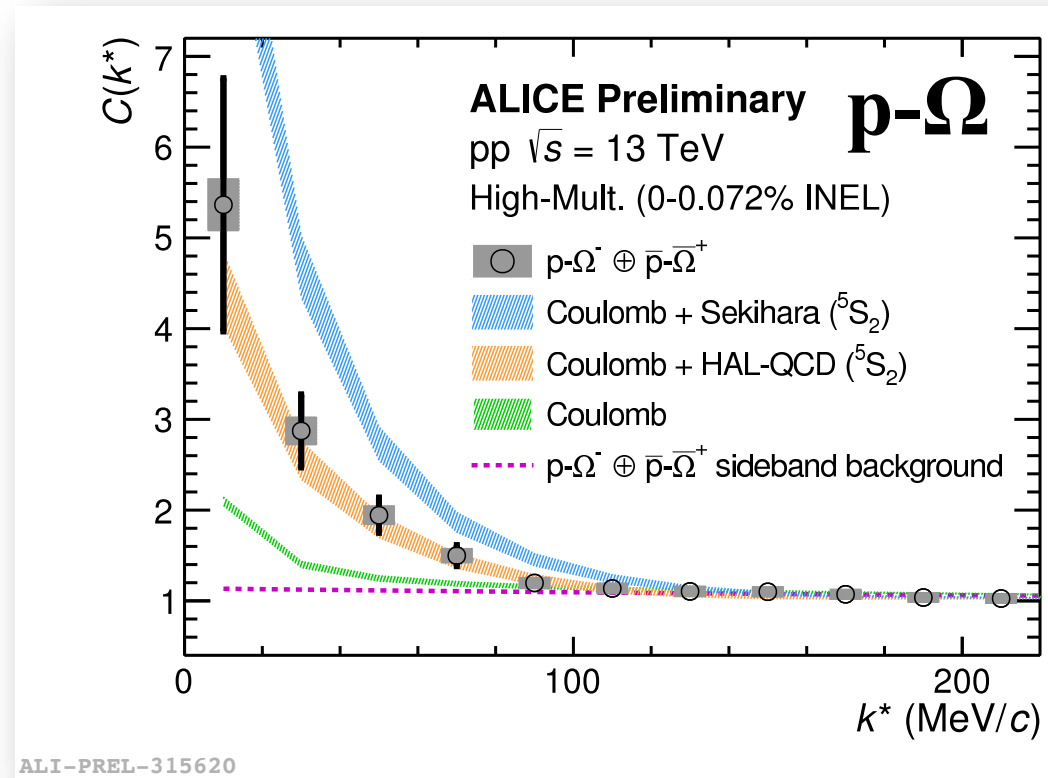
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Theory, Hatsuda: [Tuesday 9:30](#)

Theory, Talos: [Thursday 12:00](#)

Experimental, Fabbietti: [Tuesday 10:00](#)

Vazquez Doce, [poster](#)



- Many other interactions can be probed: attractive potential for p- Ω
- And more: p-Pb centrality selection provides a handle on source size

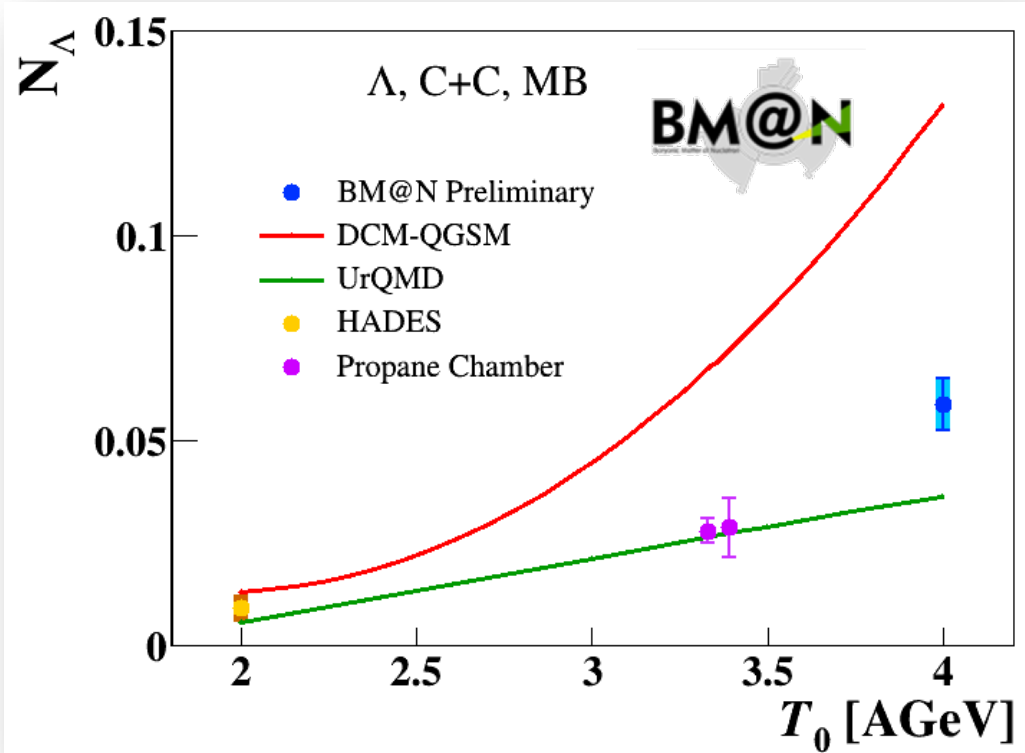
The outlook

- Precision studies of LF and strangeness production mechanisms
- Bulk matter / soft physics and collectivity
- How are nuclei produced?
- Heavy flavor production and its relation to bulk
- Hadronic interactions, astrophysics and more
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Coming up:

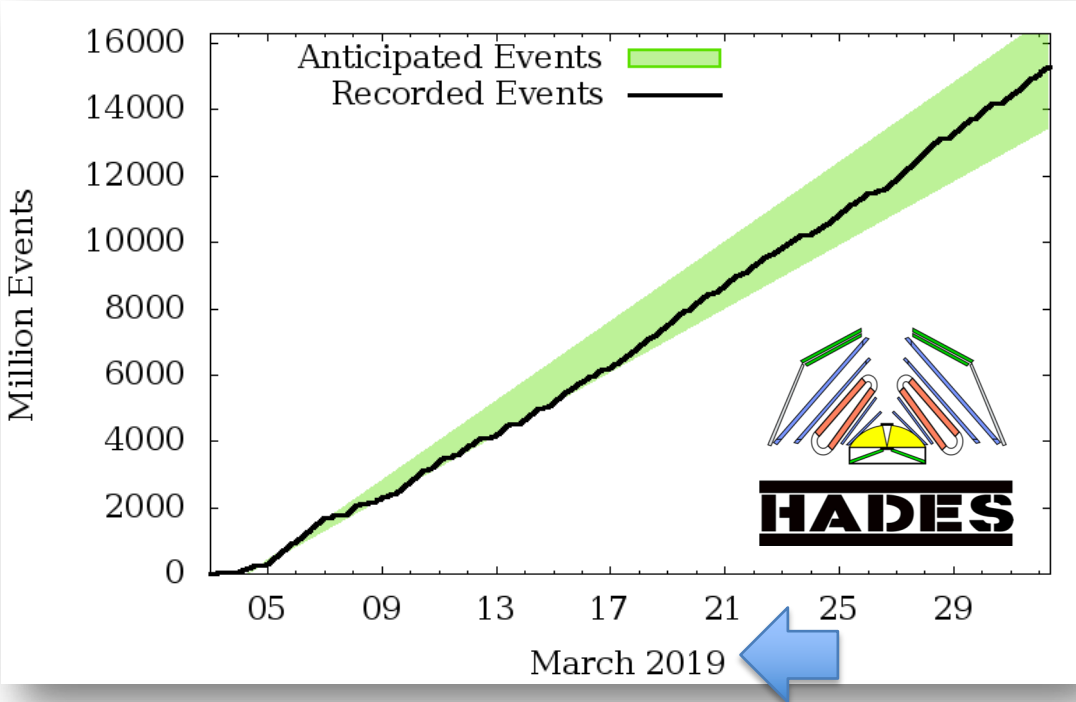
BM@N results: first results on strangeness out, more to come!

HADES: FAIR-phase 0



First results from BM@N on Λ :

Kapishin, [Monday 11:30](#)



Fair Phase 0

Lorenz, [Monday 11:00](#)

Common themes and questions to answer...

a.k.a. a tentative SQM2021+ wishlist

- **Homing in on hadronization and production mechanisms**
 - **Light flavor:** soft vs hard
 - **Heavy flavor:** recombination vs fragmentation
 - **Nuclei:** thermal vs coalescence
- Clarification / ruling out needed!
- **Energy scan and the phase transition**
 - More to come: critical point, fluctuations, BES
- **System size scan: hydro-like behavior is established everywhere?**
 - What does that mean? What about “fluctuations”?
 - better understanding of similarities (and differences!)
- **Hadron interactions / femtoscopy**
 - More exciting opportunities using high energy collisions as factories

Common themes and questions to answer...

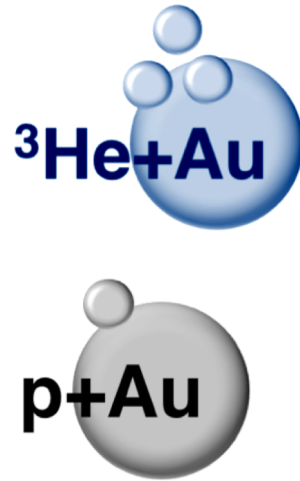
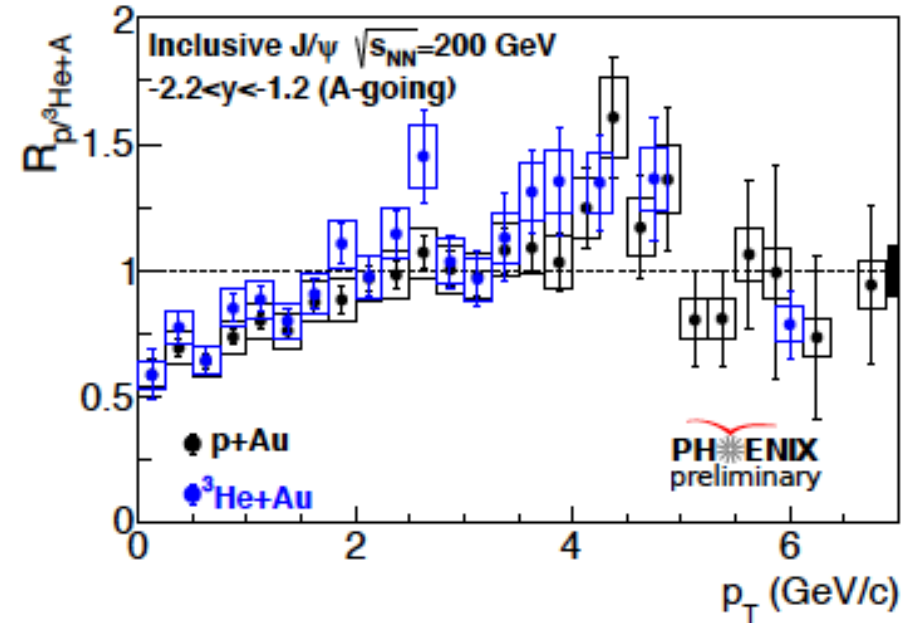
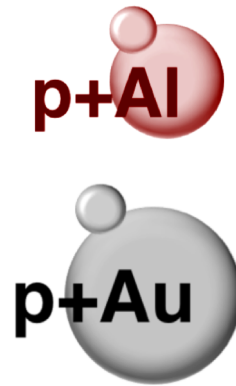
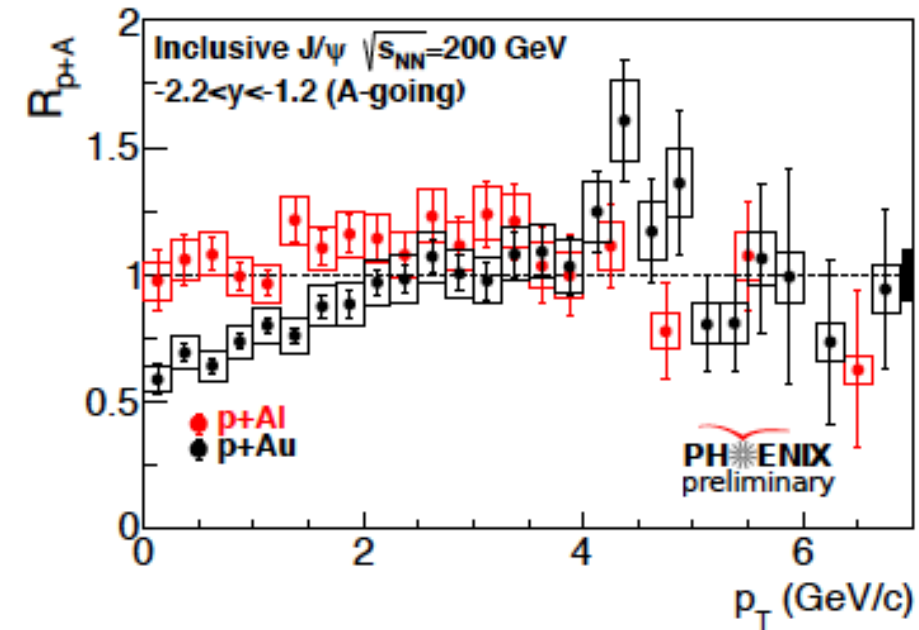
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Thank you!

Quarkonia in PHENIX

Nuclear modification in p+Al, p+Au, $^3\text{He}+\text{Au}$

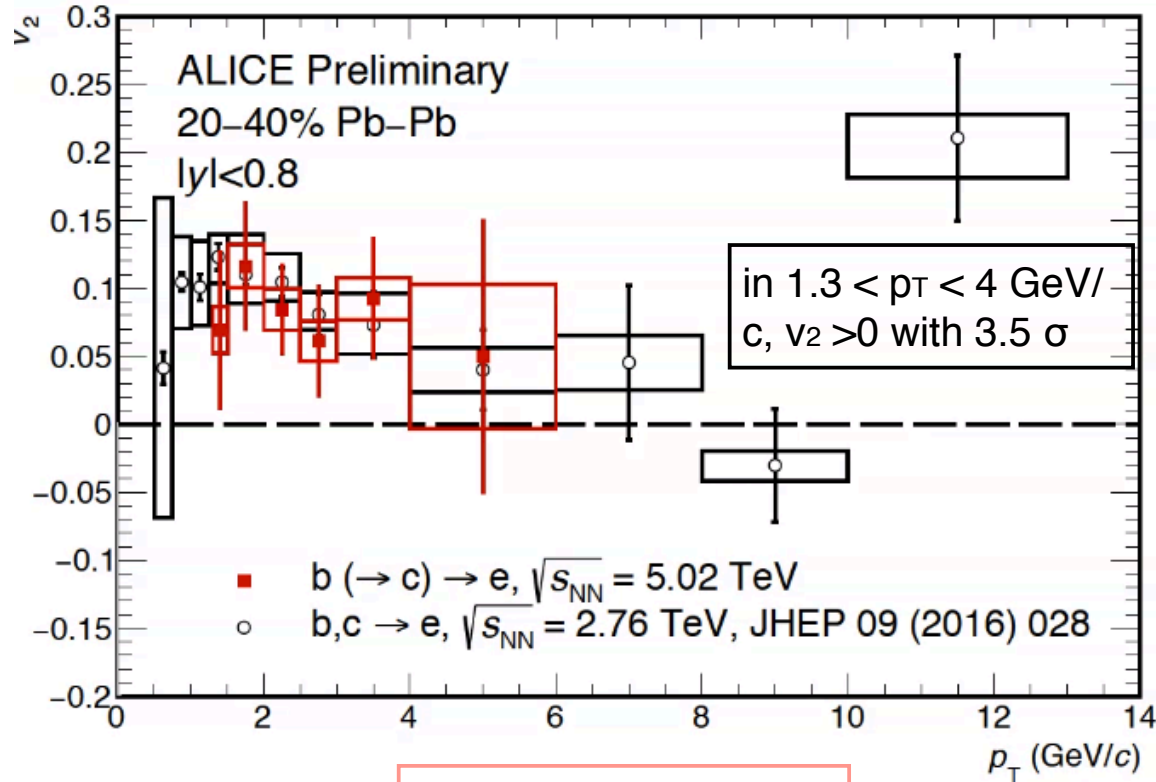


J/ψ modification factor also studied in geometry scan:

- Changing projectile influences the modification very little
- Changing target produces most of the change

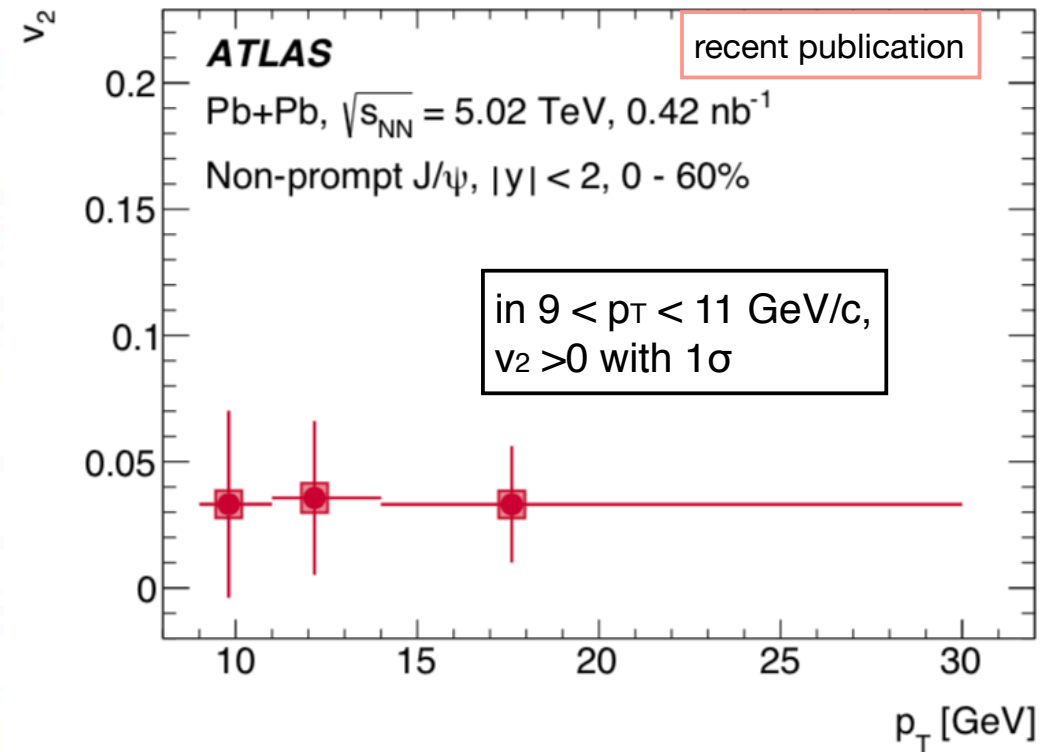
...and even beauty elliptic flow

v_2 of $b \rightarrow e$, v_2 of $b, c \rightarrow e$



First measurement at ALICE

Eur. Phys. J. C 78 (2018) 784



Beauty: also exhibits nonzero elliptic flow, though uncertainties are large at this point