Recent results on light flavors and correlations from ALICE

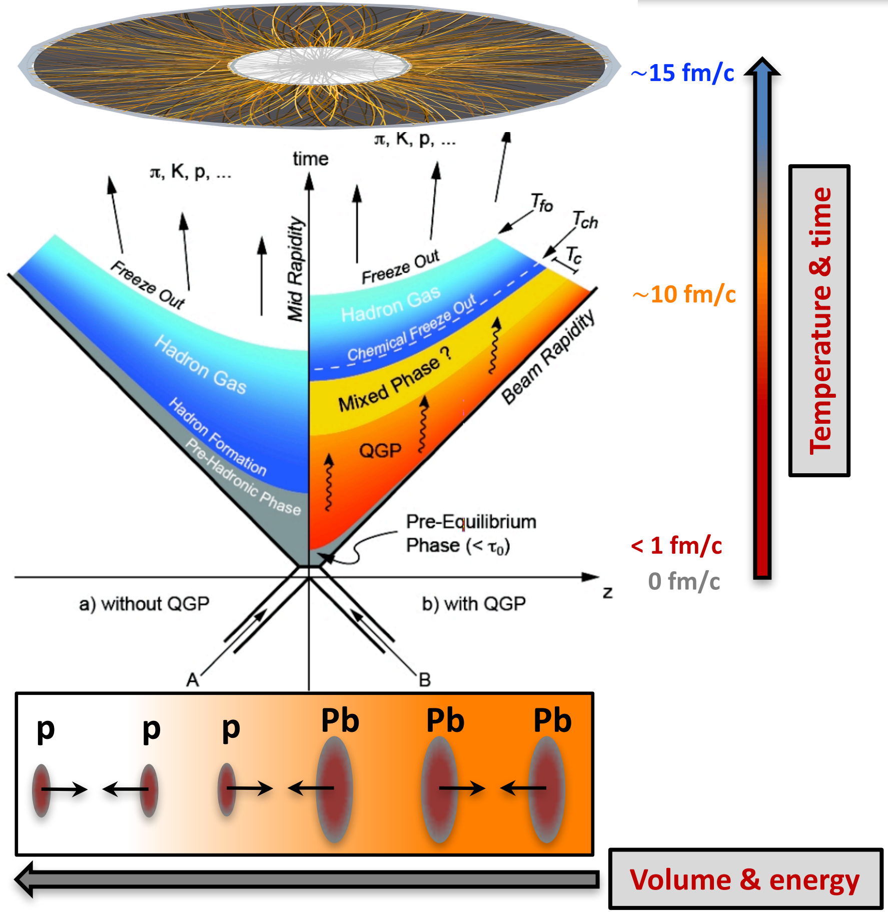
Mesut Arslandok
(Yale University)
on behalf of the ALICE Collaboration

Wright Laboratory

SQM 2024
The 21st International Conference on Strangeness in Quark Matter
3-7 June 2024, Strasbourg, France

Supported in part by:
U.S. DEPARTMENT OF ENERGY
Office of Science

QGP properties with strange and light quarks



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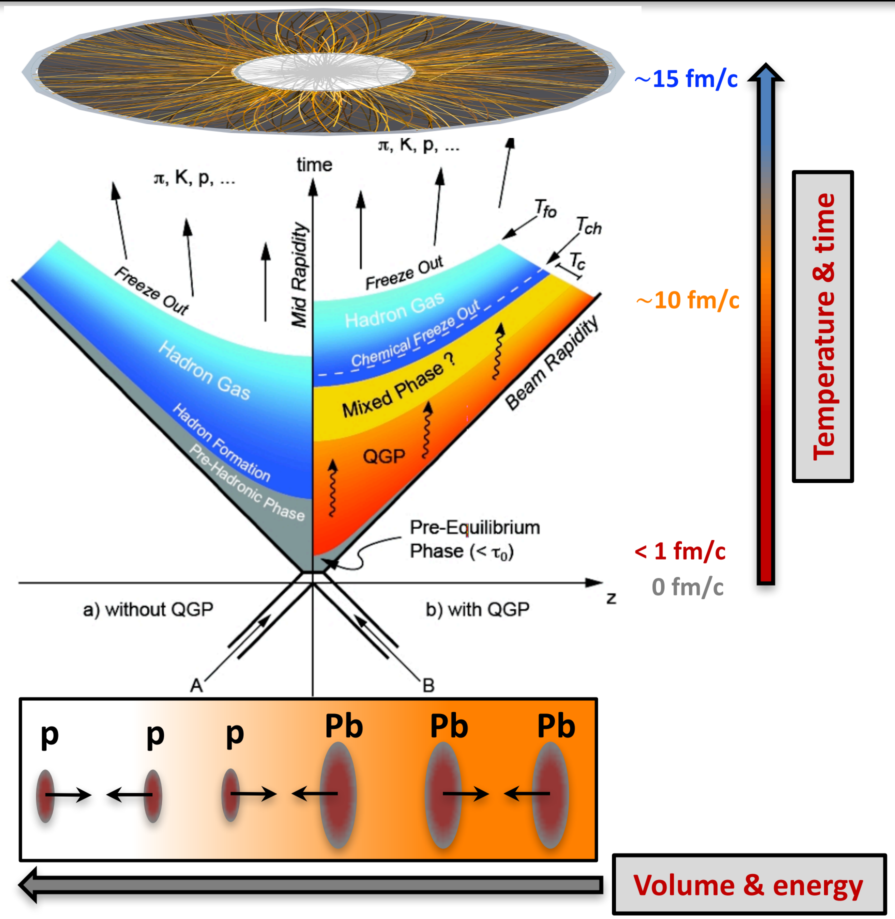

- **QGP as a thermodynamic system**
  - **Link to LQCD** via conserved-charge fluctuations
  - Do conserved charges feel the **early magnetic field**?
  - Can we extract the **speed of sound in the QGP**?
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  - String **fragmentation** and/or **statistical model** and/or **coalescence**?
  - Nature of **(hyper)nuclei** formation
  - Testing CPT symmetry via **multistrange particles**
  - **Exotic** resonances, tetraquarks etc.
- **Correlations**
  - Nature of correlations and their **origin in time**
  - **Size and shape of the system**
- **QGP/Collectivity in small systems?**

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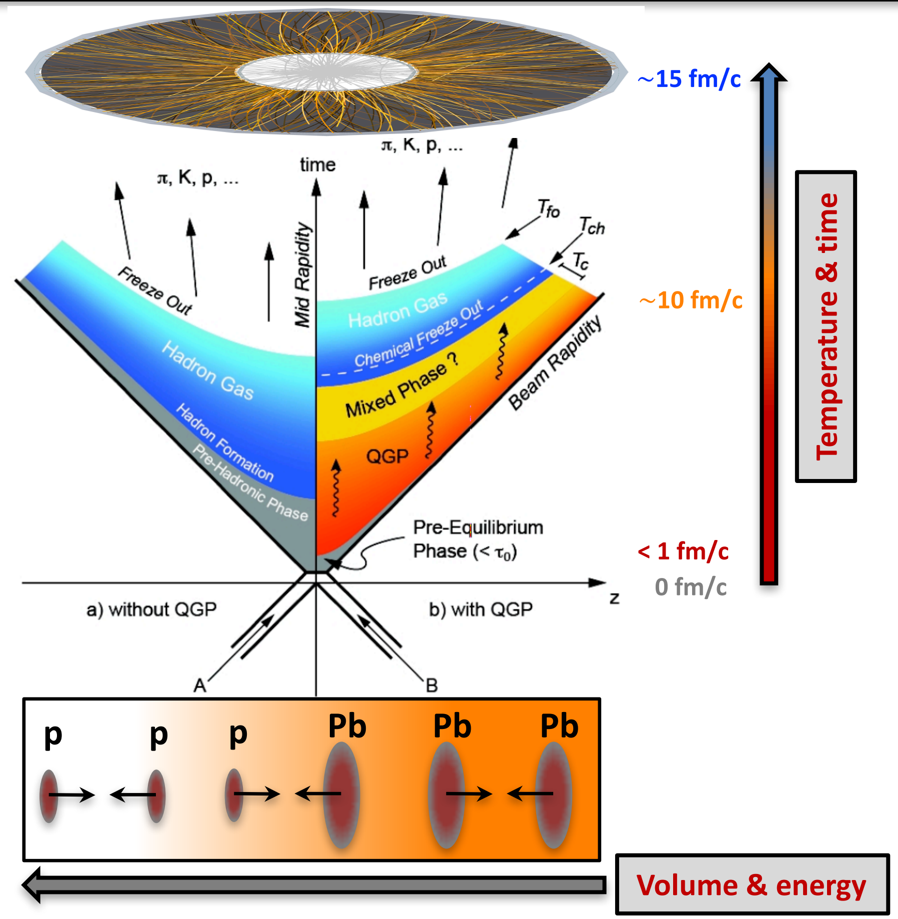

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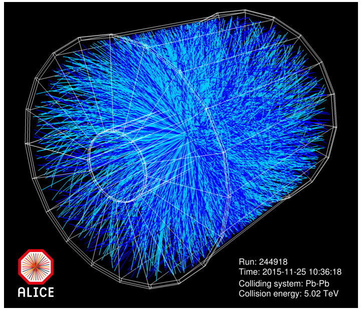
18 talks and 12 posters

A Large Ion Collider Experiment

Run 1 — 2



- **Time Projection Chamber (TPC)**
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- **V0**
  → Trigger and centrality determination
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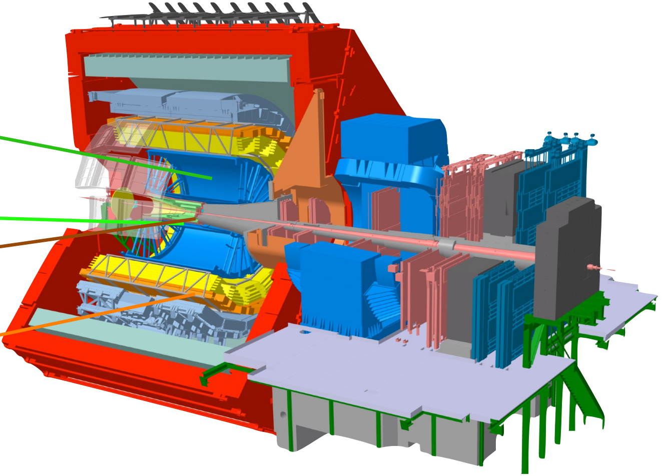

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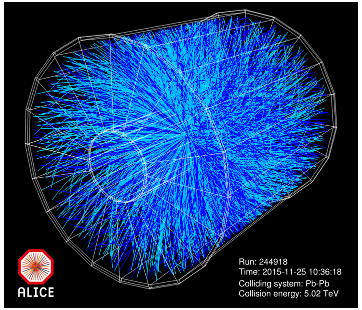
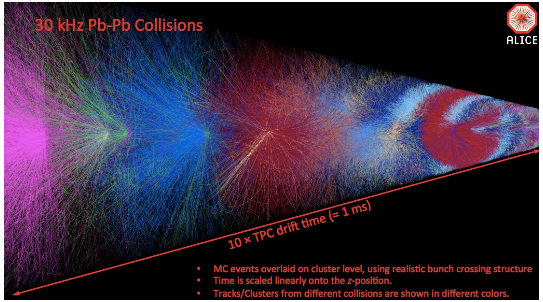


ALICE upgrade during long shutdown 2

- ✓ **Continuous readout → More statistics**
- ✓ Better **vertexing** and higher **efficiency** at low p_T
- ⟹ Online reconstruction and data compression

Run 3



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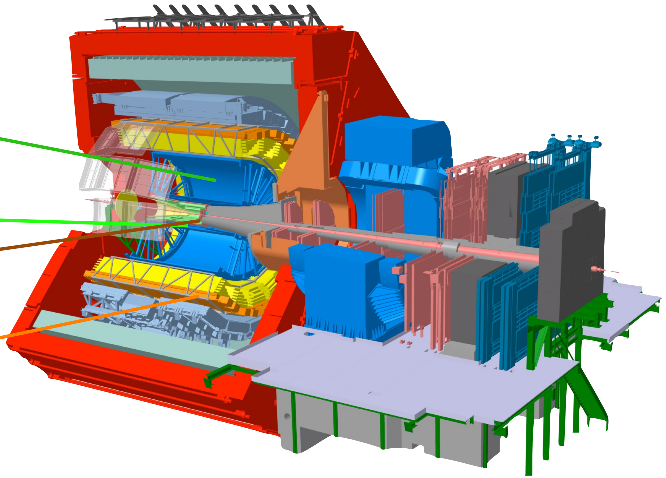

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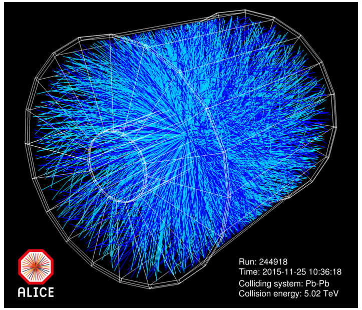

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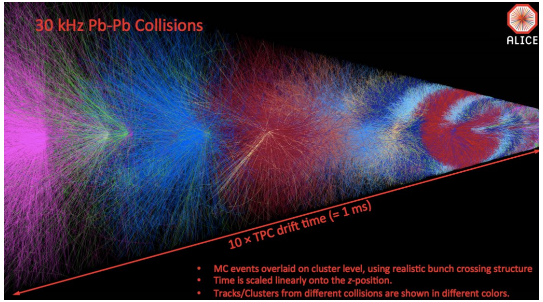

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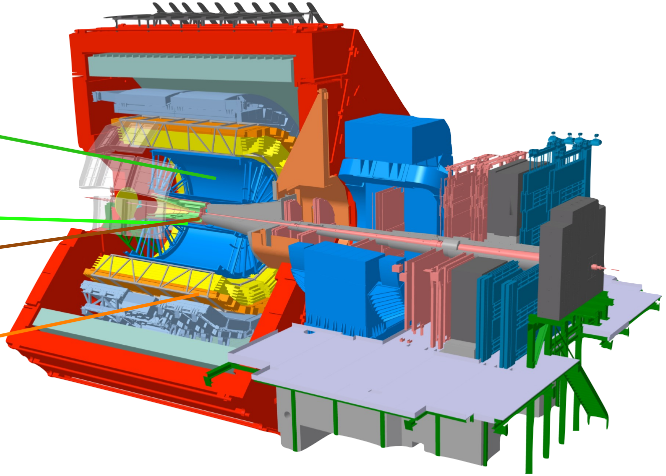

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  - → TOF, TRD, Muon Spectrometer, ZDC, Calorimeters

A Large Ion Collider Experiment

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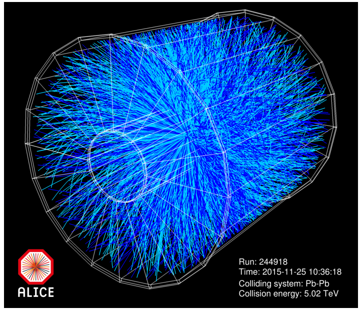

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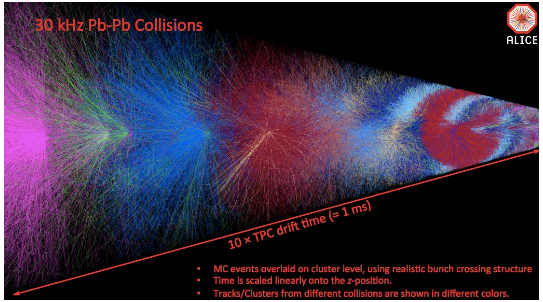

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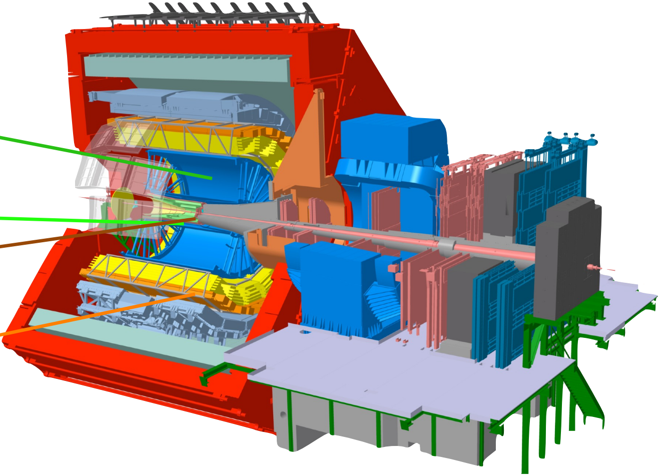

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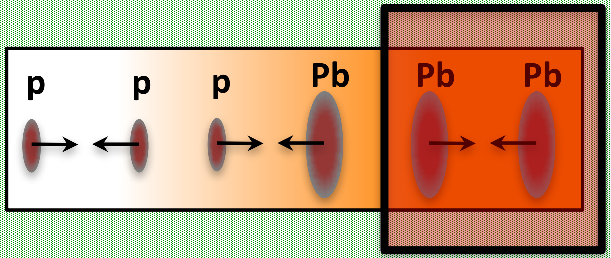
So far in Run 3: ~x800 more pp and **~x30 more Pb−Pb min. bias collisions**

4 June, Beomkyu Kim, Roman Nepeivoda
ALICE Coll., CERN-EP-2023-009

QGP as a thermodynamic system



Testing LQCD via event-by-event fluctuations

Baryon (B), strangeness (S) and charge (Q) conservation: How early does it happen?

Pb—Pb

LQCD ↔ **Experiment** ↔ **HRG**

$$\chi_2^B = \frac{\kappa_2(\Delta N_B)}{VT^3}$$

$$\rho(a,b) = \frac{\kappa_{11}(a,b)}{\sqrt{\kappa_2(a)\kappa_2(b)}}$$

κ_n → cumulants of $\Delta N_B = N_B - N_{\bar{B}}$

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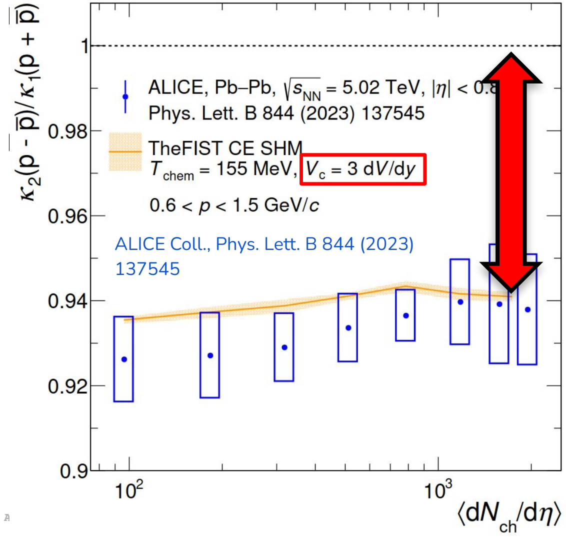

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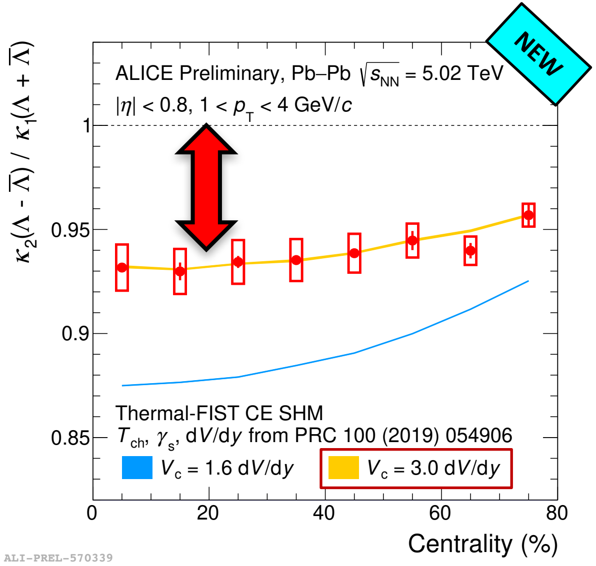

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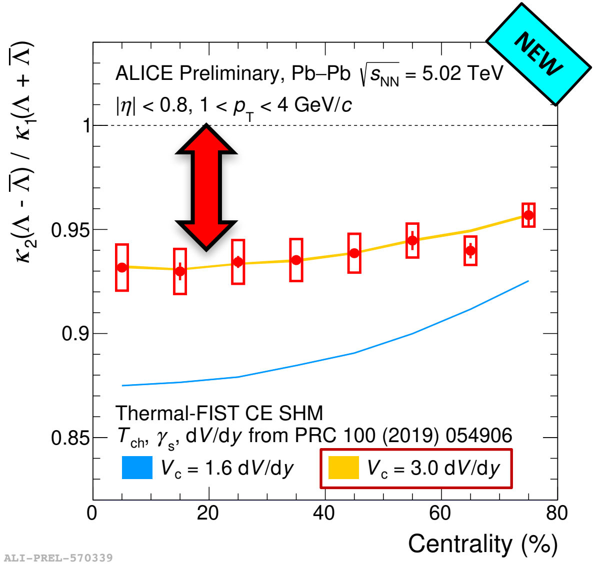
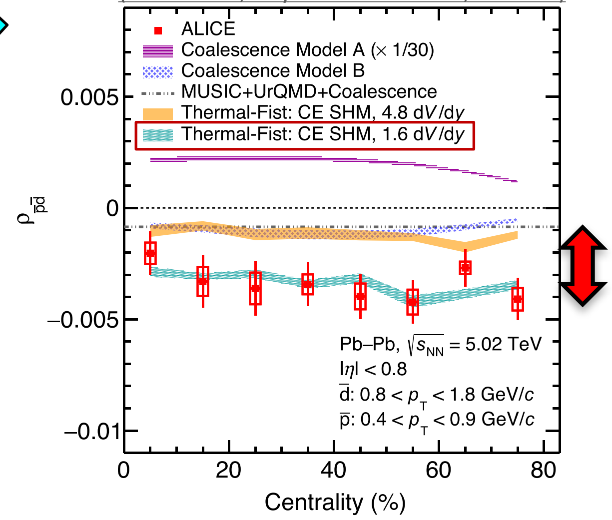


(ALICE Coll., Phys. Rev. Lett. 131, 041901)



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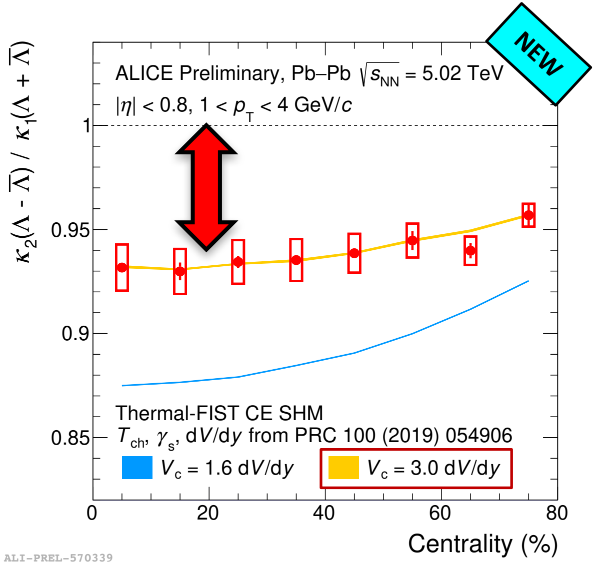

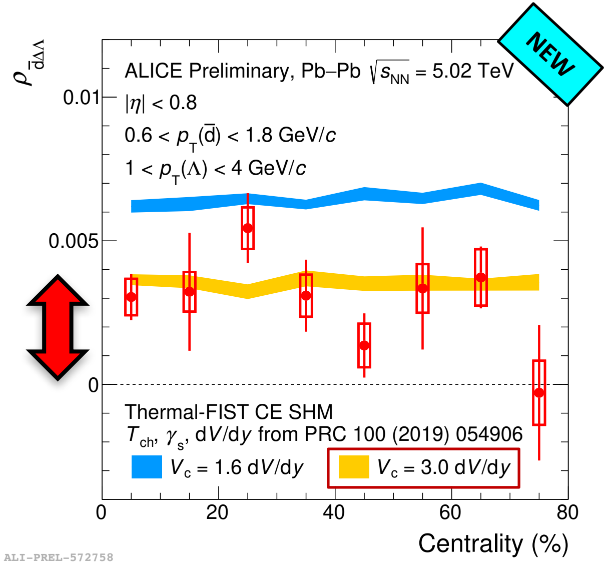

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4 June, Mario Ciacco

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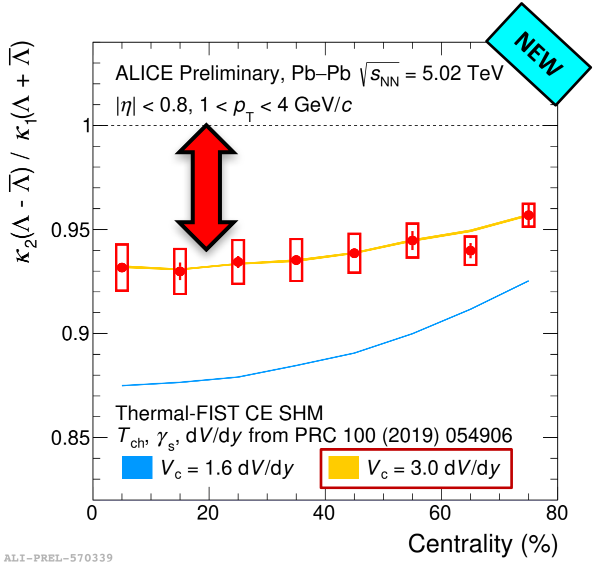

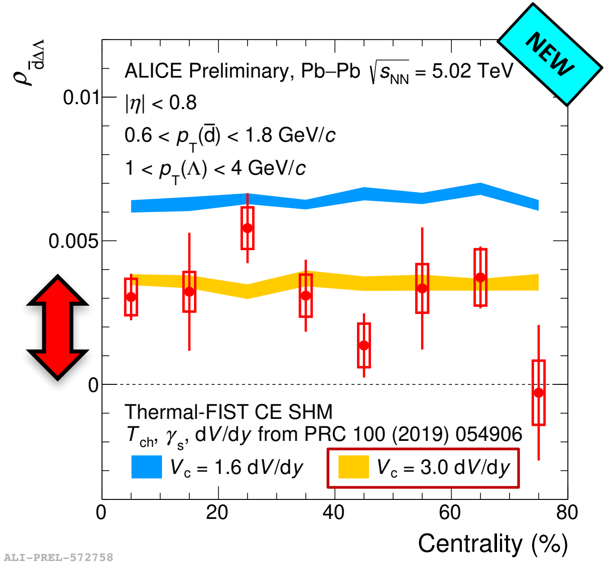

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*) Another approach for the V_c treatment is in progress (P. Braun-Munzinger, K. Redlich, A. Rustamov, J. Stachel, arXiv:2312.15534v1)

4 June, Mario Ciacco

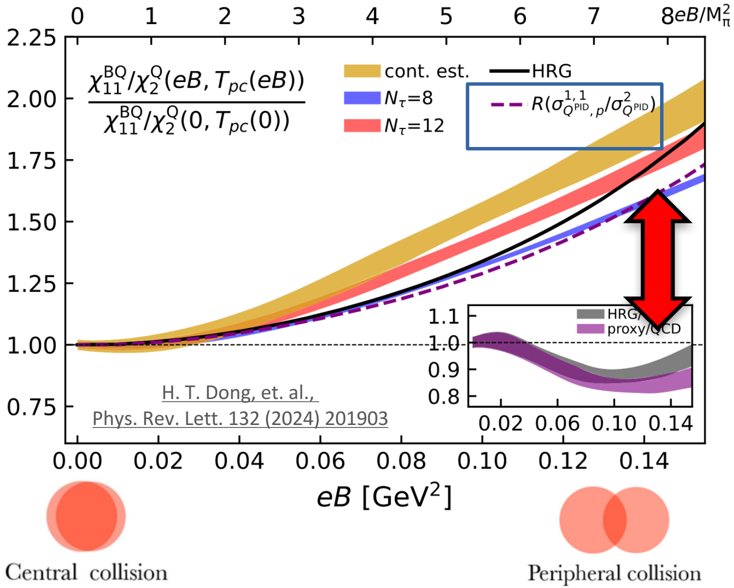
Conserved charge fluctuations to probe early magnetic field

Magnetic field + LQCD EOS → Any modification in chiral susceptibilities?

Pb—Pb

$$\chi^{lmn}_{\mathrm{B,S,Q}} = \frac{1}{VT^3}\sigma^{lmn}_{\mathrm{B,S,Q}}$$

Proxies:
Charge: K, π, p
Baryon: p
Strangeness: K



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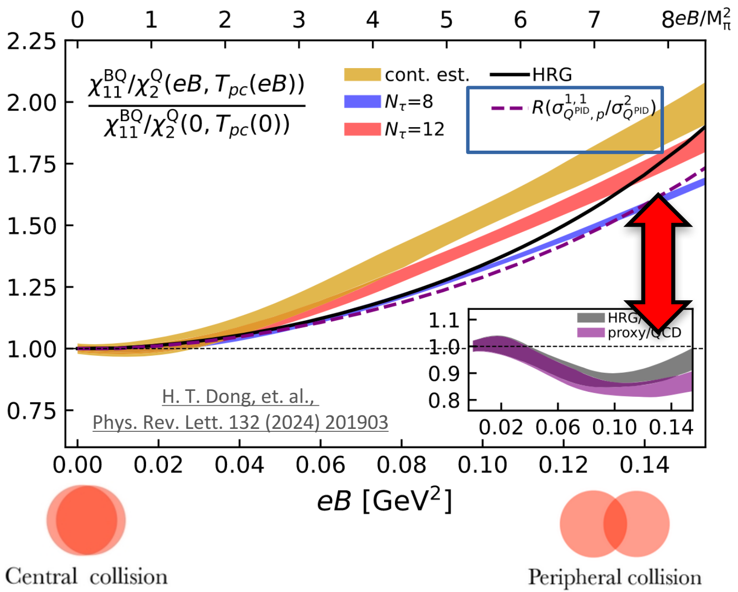

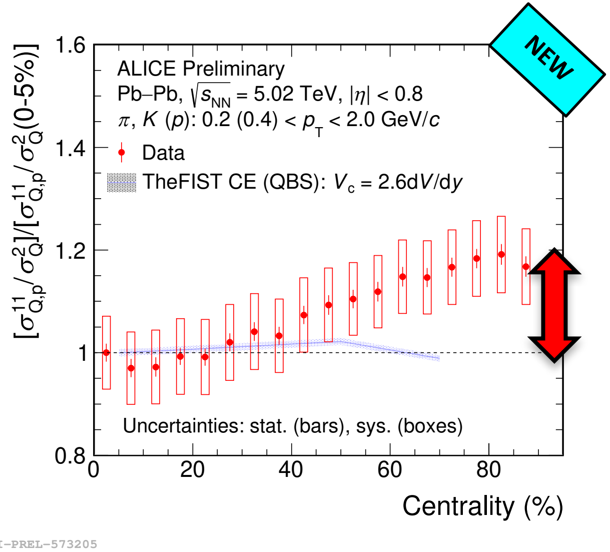

1) Increase towards peripheral collisions

4 June, Swati Saha

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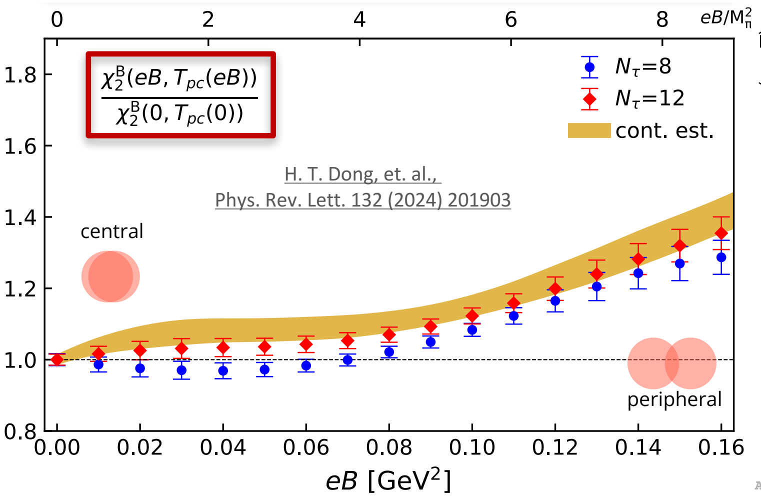
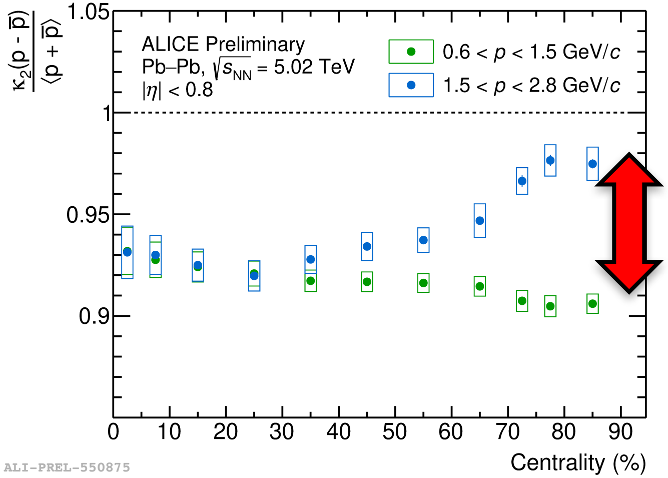




1) Increase towards peripheral collisions
2) **Similar behavior** is also observed in **net-p fluctuations** for the larger momentum range

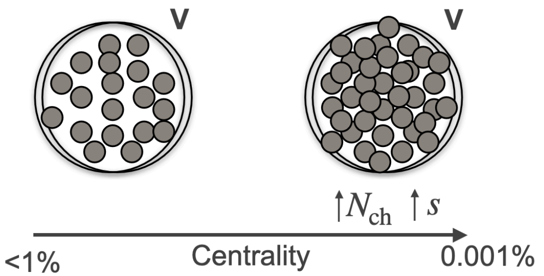
⟹ Magnetic field or ?

4 June, Swati Saha

Speed of sound in QGP

Can we extract the speed of sound in the QGP?

Pb—Pb



$$c_s^2 = \left.\frac{sdT}{Tds}\right|_{T_{\rm eff}} = \frac{d\ln\langle p_{\rm T}\rangle}{d\ln(N_{\rm ch}/d\eta)}$$

F. G. Gardim et. al, Nature Phys. 16 (2020) 6, 615-619

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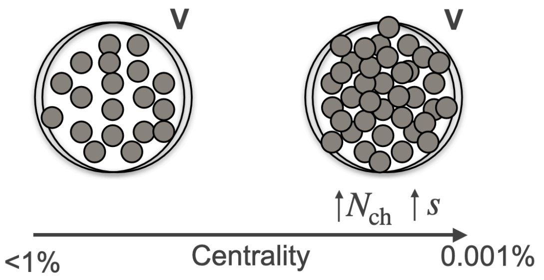

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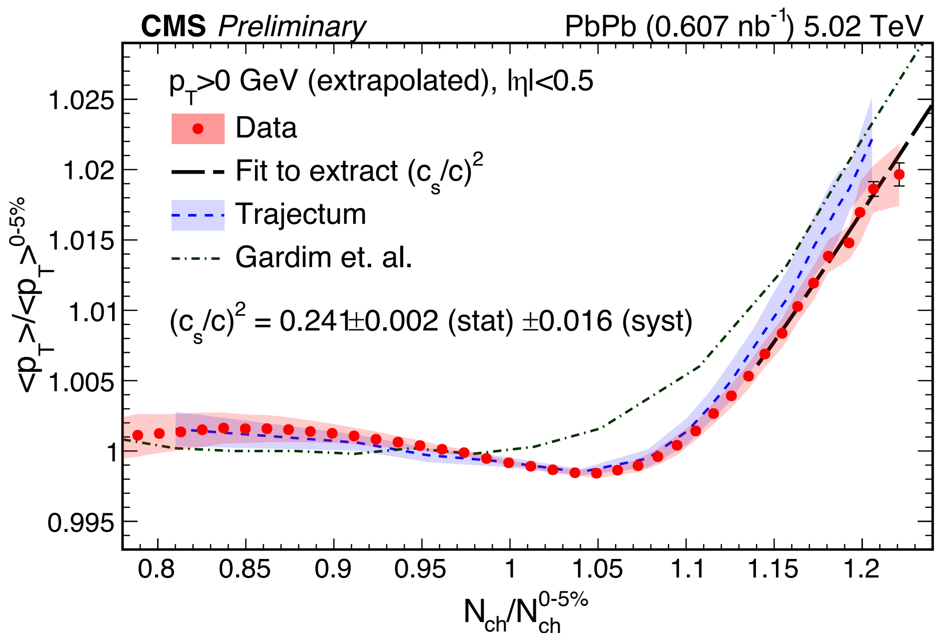

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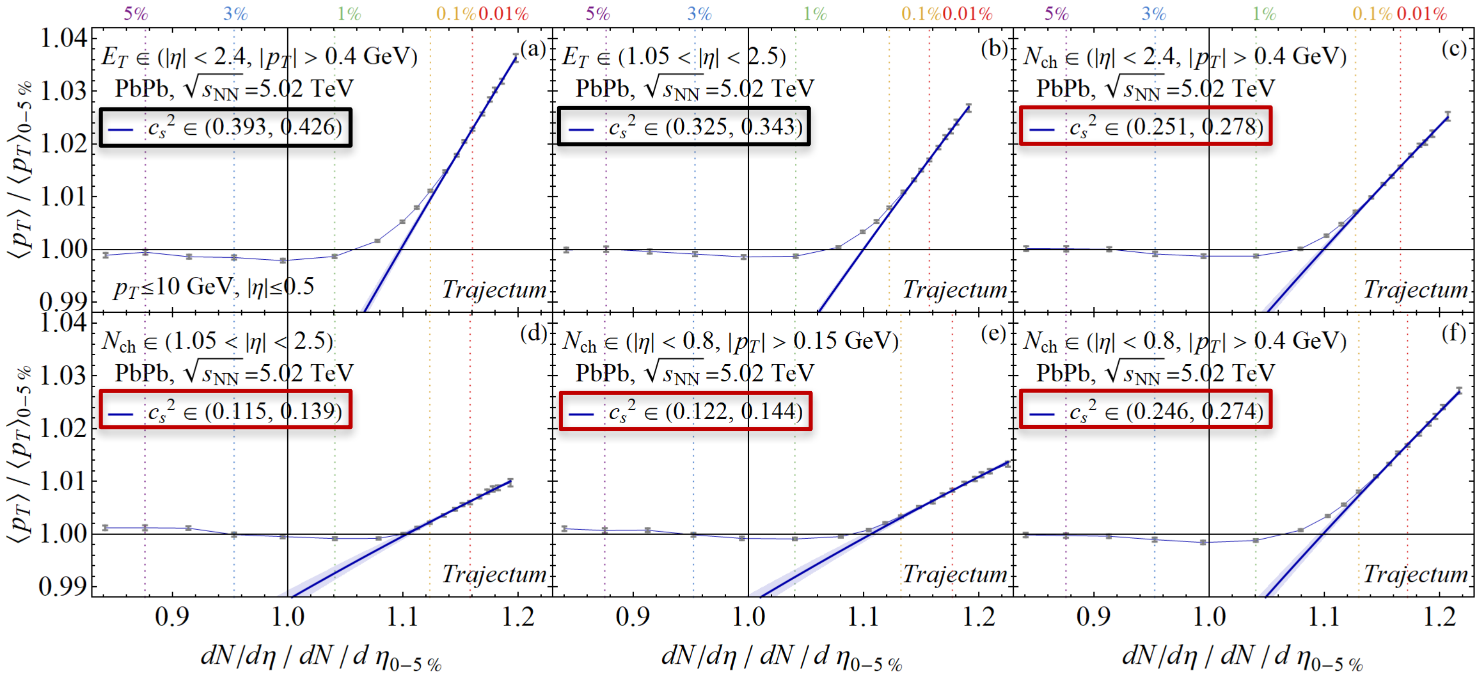

G. Nijs et. al., Phys. Lett. B 853 (2024) 138636

Impact of kinematic acceptance and centrality estimator?

Speed of sound in QGP

Pb—Pb

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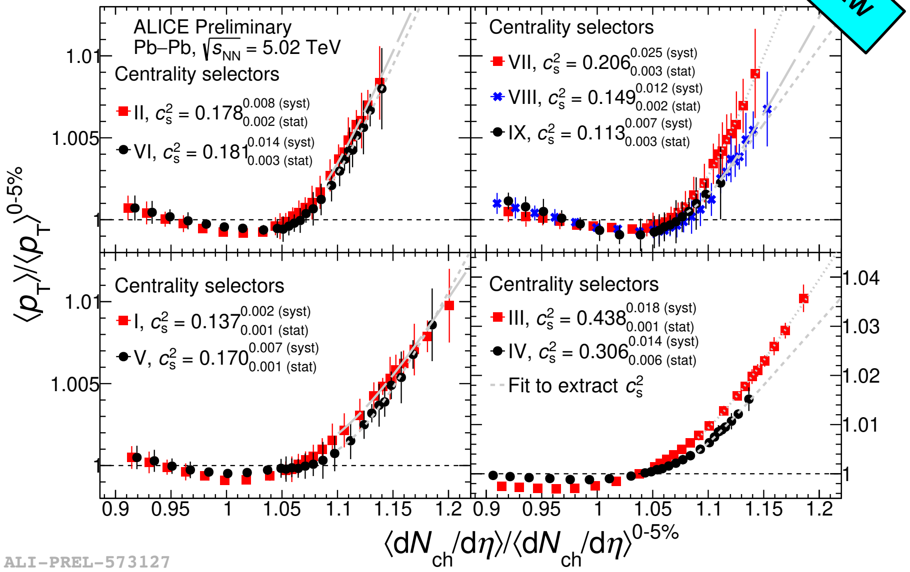
NEW



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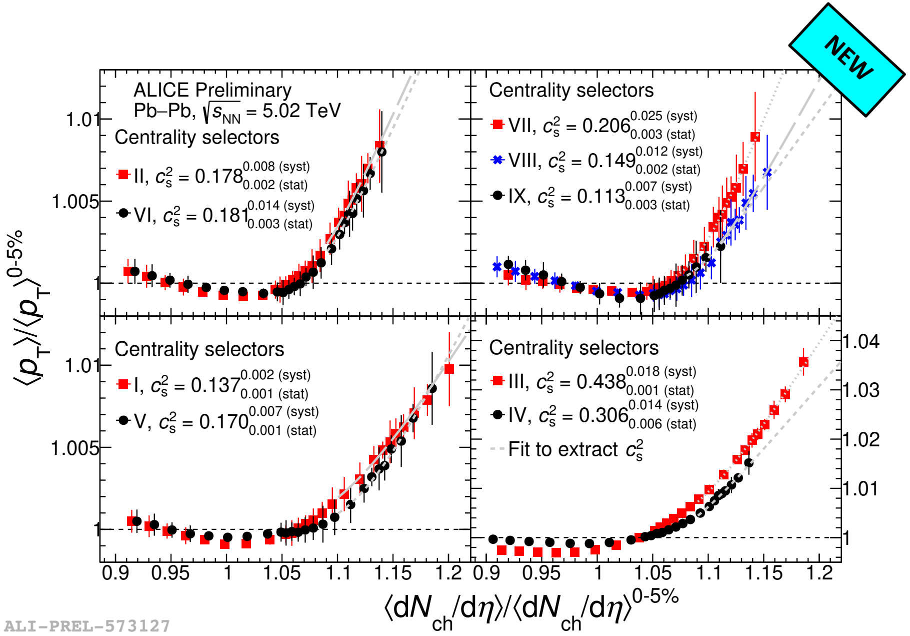
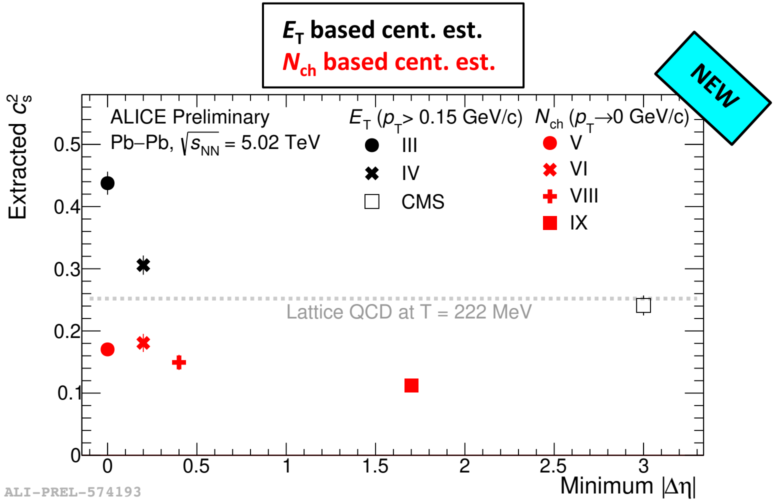


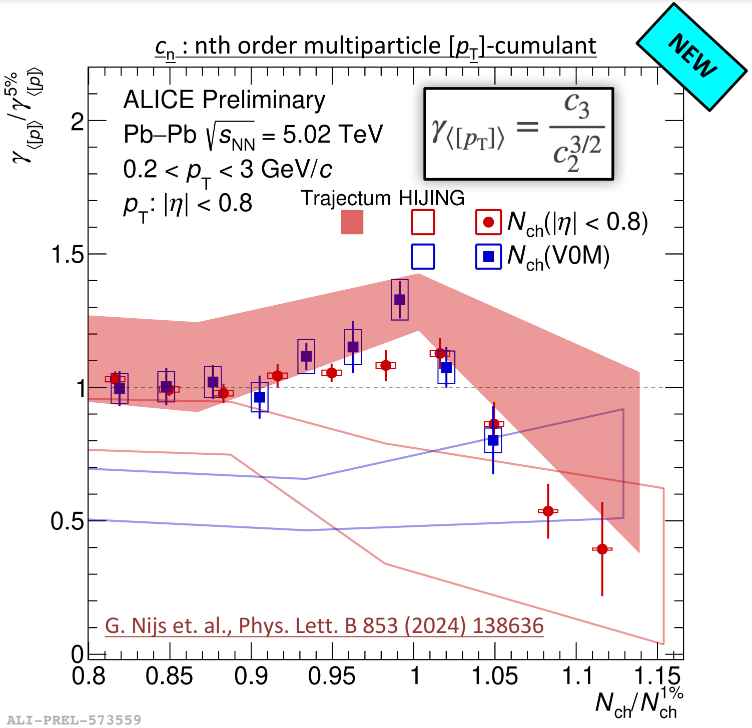


1) Our preliminary findings indicate a strong dependence on the kinematic acceptance and centrality estimator
2) How about higher order moments of $<p_T>$ distribution?

4 June, Emil Gorm Nielsen

Speed of sound in QGP

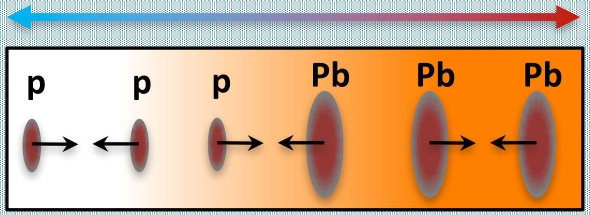
Pb–Pb



1) The data is described by the state-of-art hydrodynamic model up to 4th order ($c_s \in (0.122, 0.144)$ is obtained as in data using N_{ch} at midrapidity as centrality definition)

4 June, Emil Gorm Nielsen

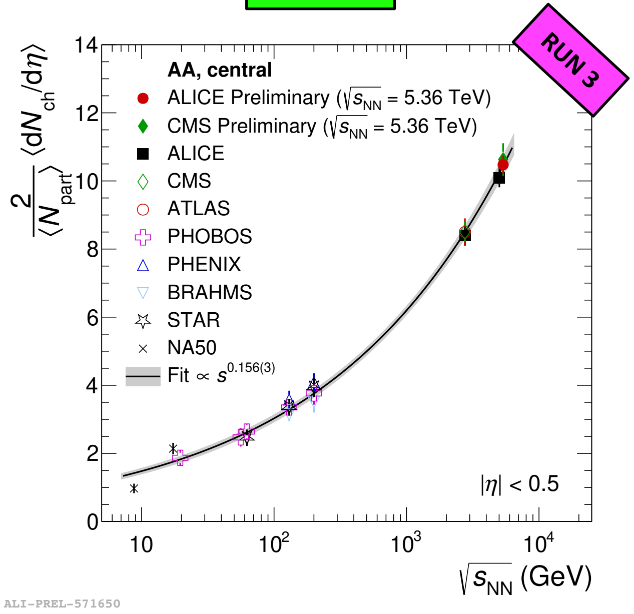
Particle production



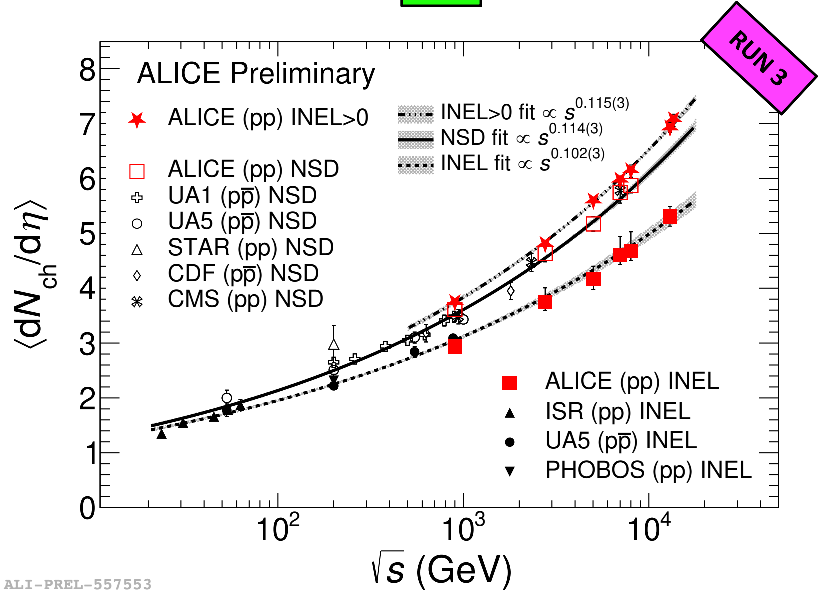
Particle production: Big picture

New Run 3 data fits with world trend

Pb—Pb



pp



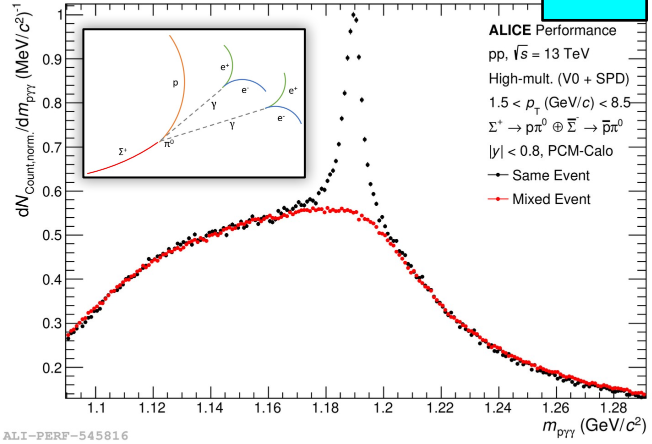
4 June, Beomkyu Kim,

(Multi)strange baryon production

pp

What can we learn from high precision (multi)strange baryon measurements?

NEW



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pp

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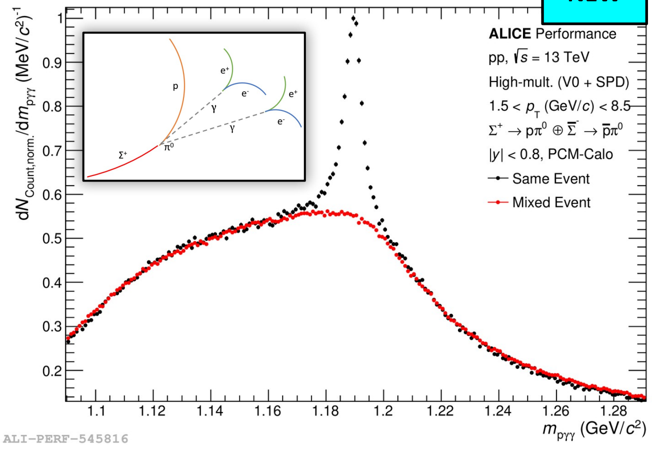

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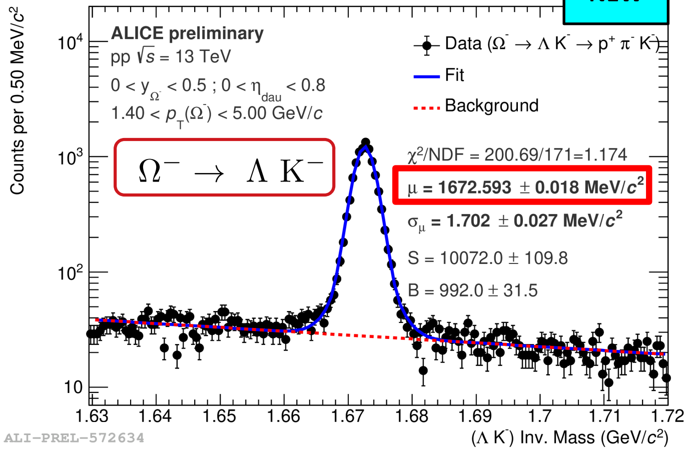

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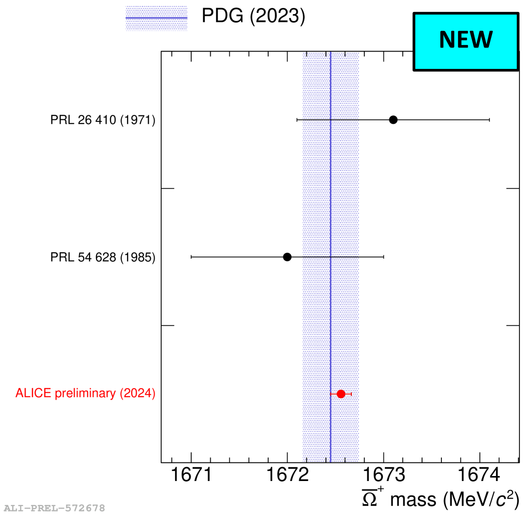


1) **Σ baryons:** New techniques will allow for Σ-hypernuclei search and hadron-Σ interaction measurements in Run 3
2) **Ξ and Ω:** World's most precise mass measurements
   - ✓ Present results still consistent with CPT symmetry

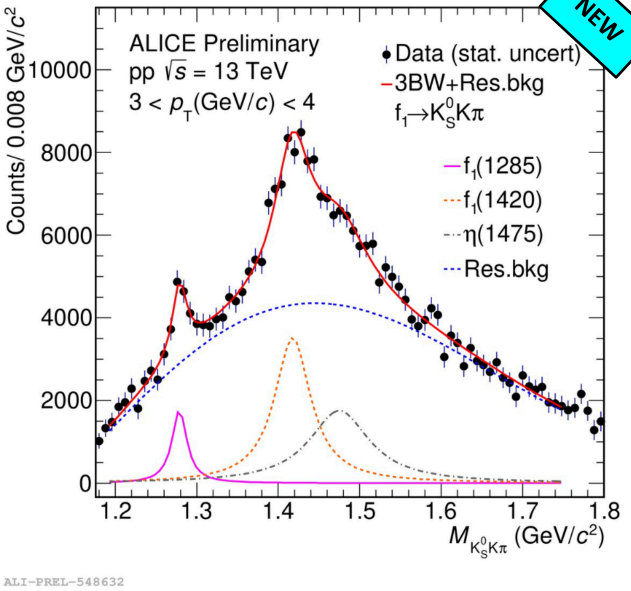
4 June, Pavel Gordeev, Romain Schotter

Nature of exotic resonances $f_0(980)$ and $f_1(1285)$?

What are their quark content?

pp

NEW



1) **First measurements** of inclusive $f_0(980)$ and $f_1(1285)$ resonances

Nature of exotic resonances $f_0(980)$ and $f_1(1285)$?

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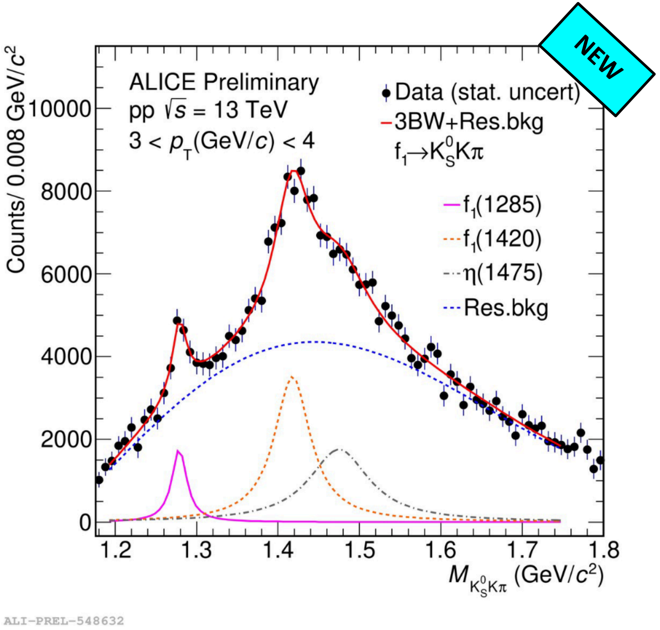
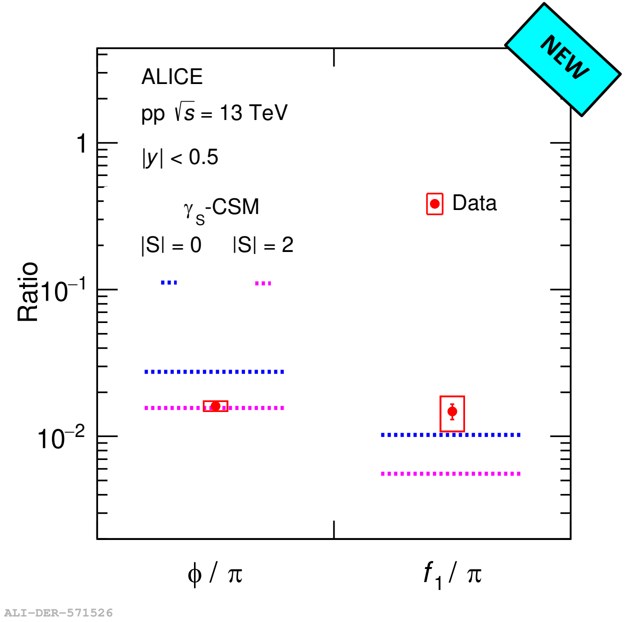




1) **First measurements** of inclusive $f_0(980)$ and $f_1(1285)$ resonances
2) $f_1(1285)$ data is consistent with **thermal model** calculations that **do not include strange quarks**

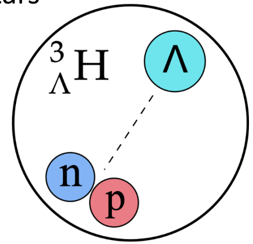
4 June, Prottay Das

Hypernuclei production

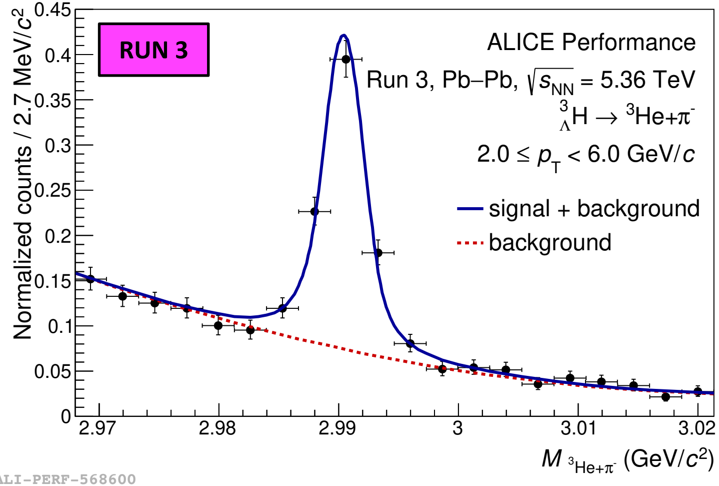
How does the nuclear production mechanism of hypernuclei works?

Pb—Pb

- ➢ hyperon-nucleon (Y-N) interaction → neutron stars



- ➢ Statistical hadronisation vs coalescence



ALI-PERF-568600

1) $^{3}_{\Lambda}\mathbf{H}$: High precision in Run 3 thanks to new ITS + TPC

Hypernuclei production

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pp & Pb–Pb

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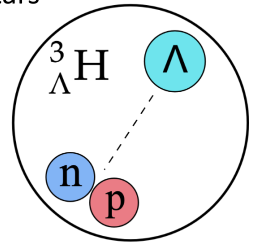

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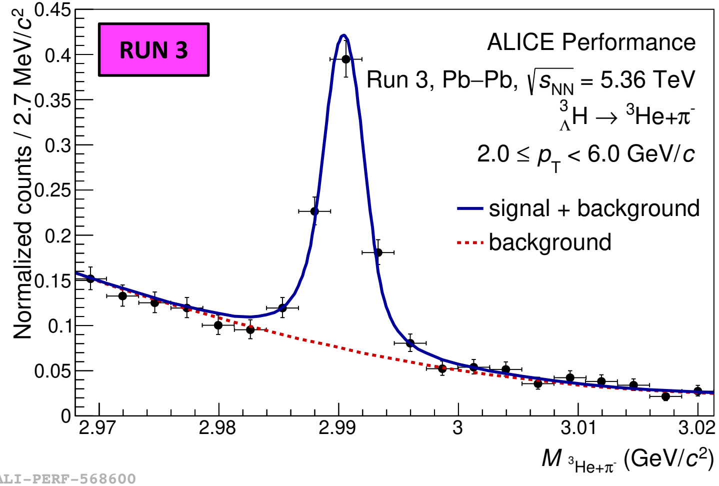
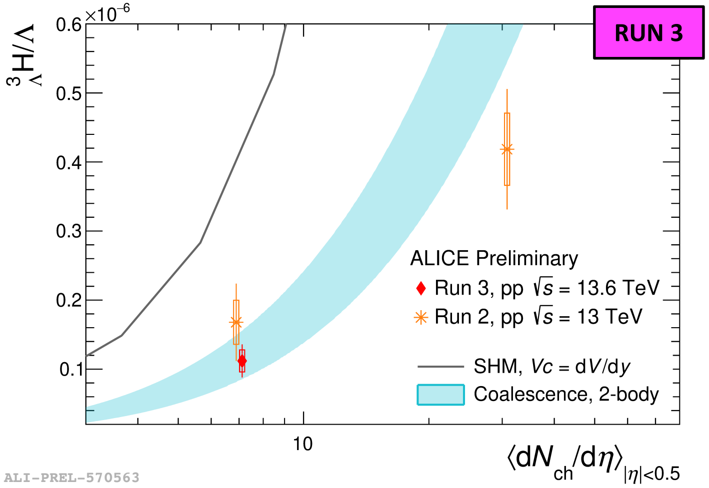




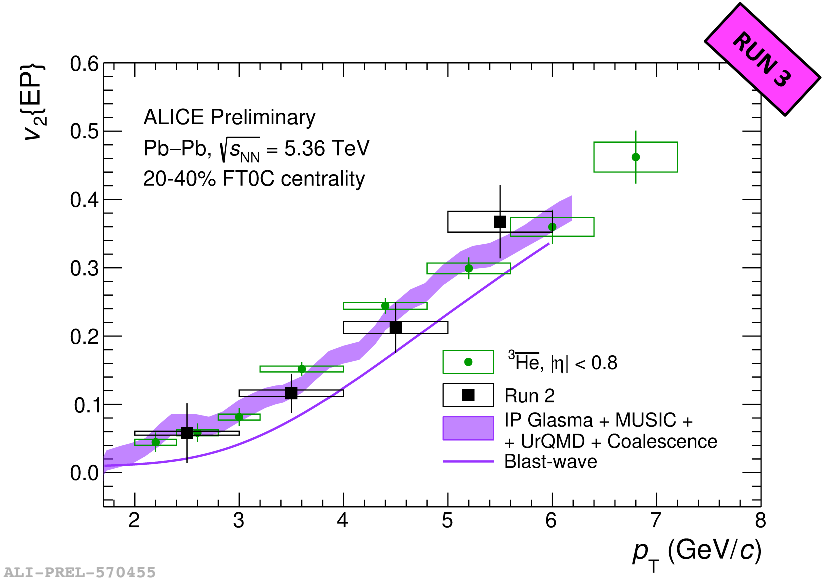
1) $^{3}_{\Lambda}\mathbf{H}$: High precision in Run 3 thanks to new ITS + TPC
2) pp results in Run 3 are compatible with Run 2 preliminary results and 2-body coalescence prediction

5 June, Yuanzhe Wang

Hypernuclei production

How does the nuclear production mechanism of hypernuclei works?

Pb–Pb



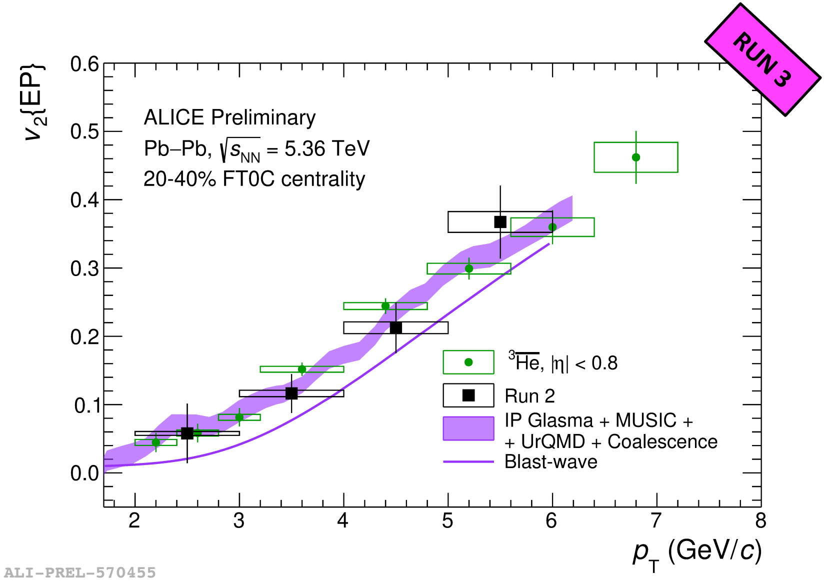
1) Significant improvement in $^{3}\overline{\mathrm{He}}$ flow measurements

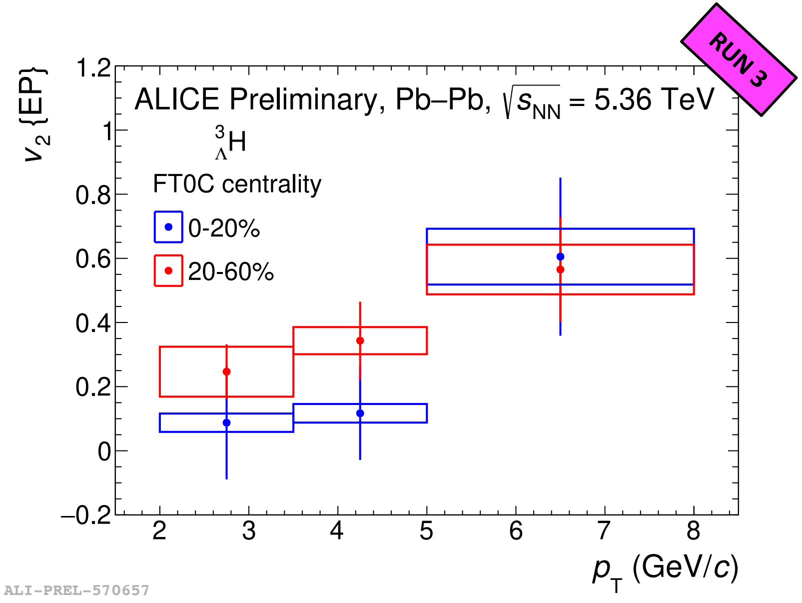
5 June, Yuanzhe Wang

Hypernuclei production

How does the nuclear production mechanism of hypernuclei works?

Pb—Pb

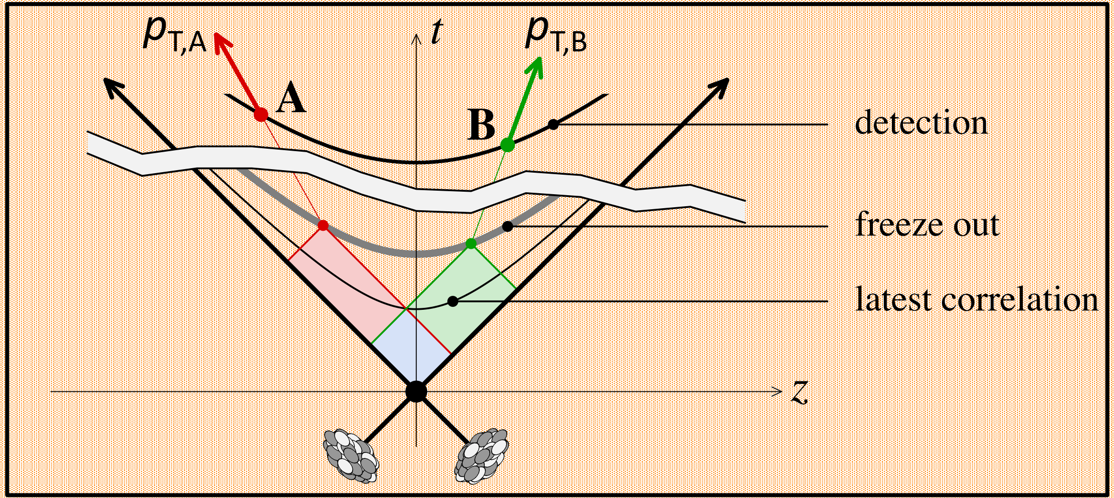




1) Significant improvement in $^{3}\overline{\mathrm{He}}$ flow measurements
2) First measurement of elliptic flow of $^{3}_{\Lambda}\mathbf{H}$

5 June, Yuanzhe Wang

Correlations

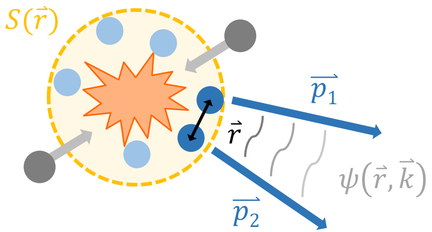


A. Dumitru, F. Gelis, L. McLerran, and R. Venugopalan, *Nucl. Phys. A* 810 (2008) 91

Two- and three-baryon systems

What can we learn from two-particle correlations in momentum space?

pp



$$k^* = |p_1^* - p_2^*|/2,\ \vec{r}^* = \vec{r}_1^* - \vec{r}_2^*$$

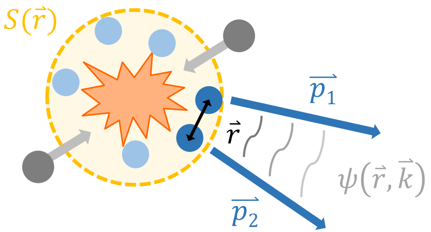
$$C(k^*) = \int S(\vec{r}^*)\left|\psi(\vec{k}^*,\vec{r}^*)\right|^2 d^3\vec{r}^* = \mathcal{N}\frac{\mathrm{N}_{same}(k^*)}{\mathrm{N}_{mixed}(k^*)}$$

$$\begin{cases} < 1, & \text{repulsion} \\ = 1, & k^* \to \infty \\ > 1, & \text{attraction} \end{cases}$$

Two- and three-baryon systems

pp

What can we learn from two-particle correlations in momentum space?



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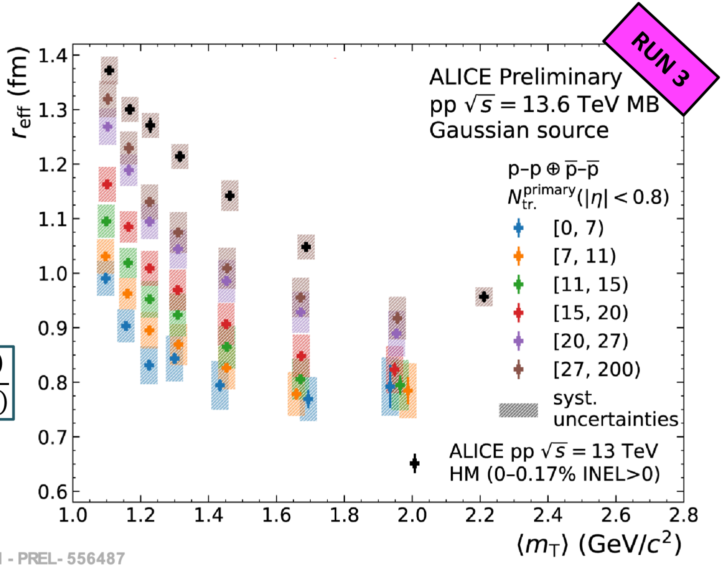
< 1, repulsion
$= 1$, $k^* \rightarrow \infty$
> 1, attraction

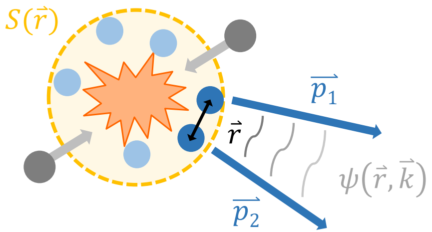


1) Shape and the size of the source

Two- and three-baryon systems

pp

What can we learn from two-particle correlations in momentum space?



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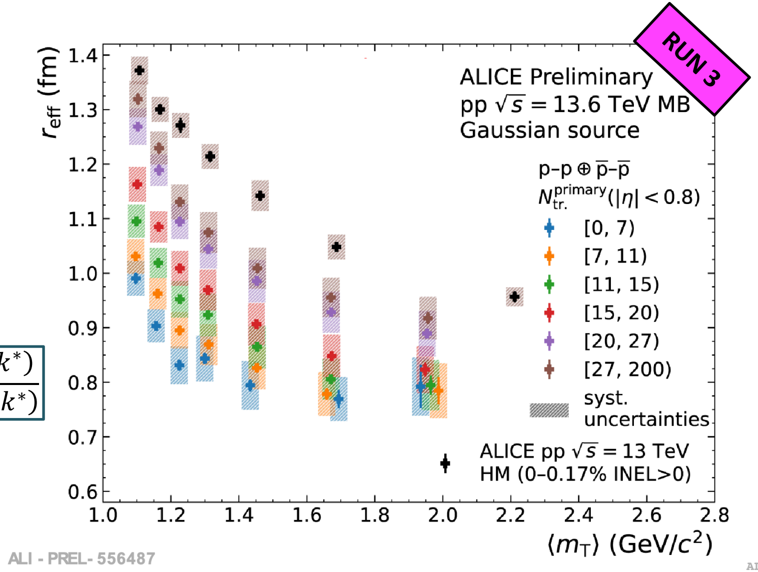
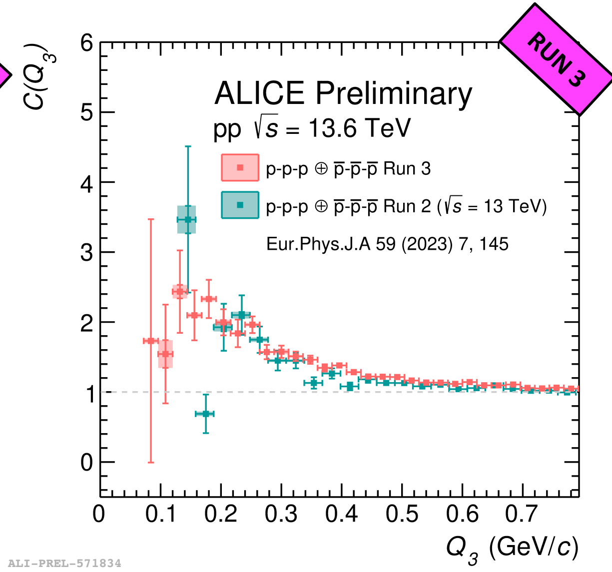




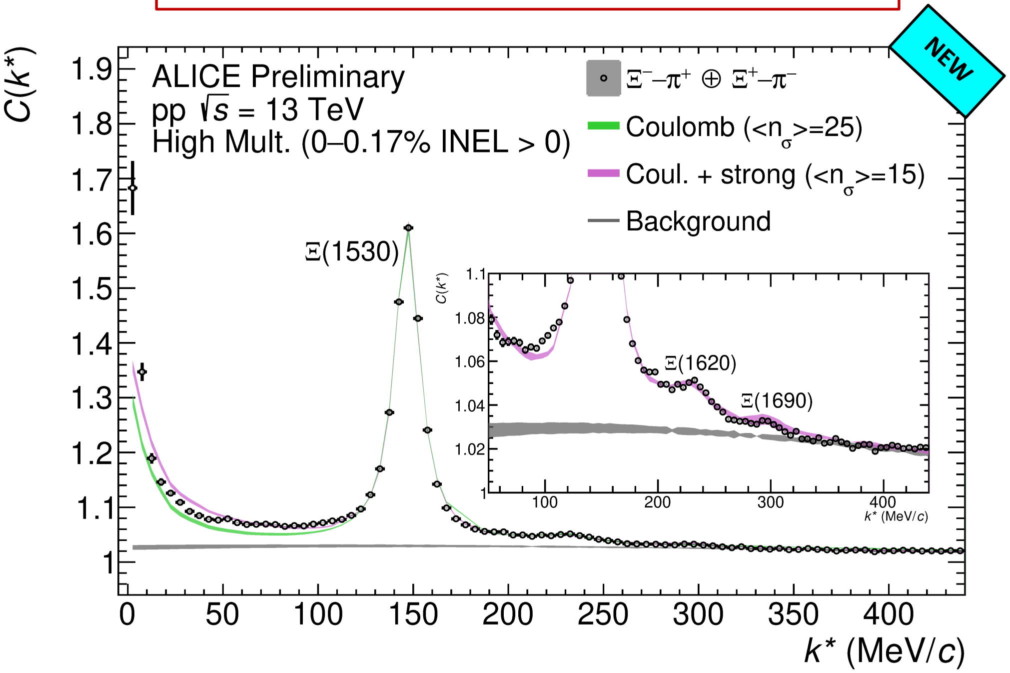
1) Shape and the size of the source
2) Nature of correlation: E.g. three-body forces significantly affect the **equation of state in neutron stars**
   ⟹ Only possible in Run 3 (by the end of Run 3, **150 times larger sample of triples expected** compared to Run 2 due to developed software triggers)

5 June, Anton Riedel & 4 June, Laura Serknyte

(Multi)strange meson-baryon interaction

pp

Search for exotic states via femtoscopy?



ALI-PREL-573869

Most precise data on ΞK and Ξπ at low momenta available → high sensitivity to coupled channels

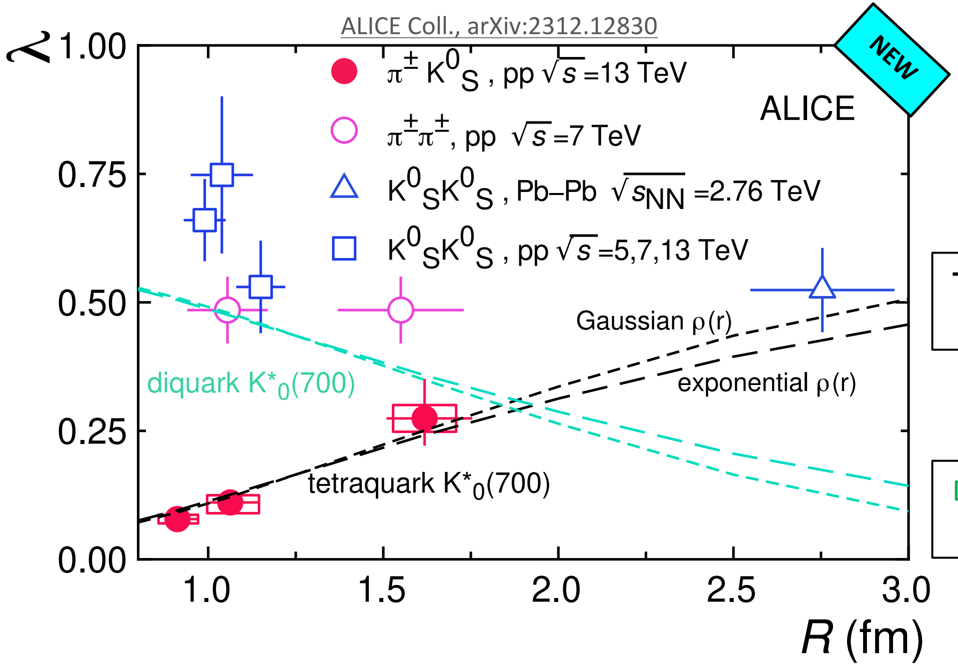
5 June, Valentina Mantovani Sarti

(Multi)strange meson-baryon interaction

pp

Search for exotic states via femtoscopy?

ALICE Coll., arXiv:2312.12830



Tetraquark model

Diquark model

The dependence of λ (correlation strength) on R (radius parameter of the boson source) is as expected by a geometric toy model assuming a tetraquark $\mathrm{K}_0^*(700)$

4 June, Thomas Humanic

QGP/Collectivity in small systems?

Collectivity in small systems

Is there collectivity in small systems? If so, is there an onset?

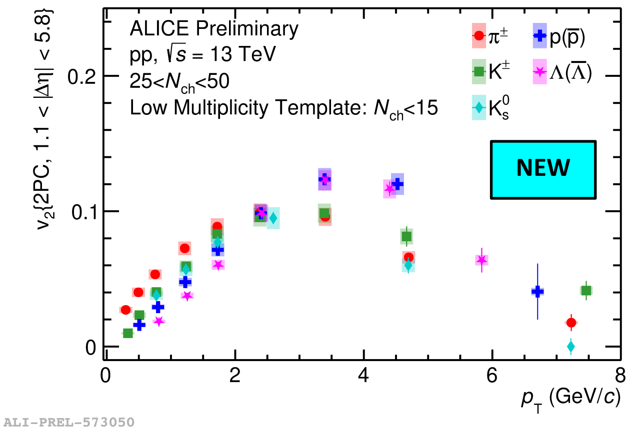
pp & p—Pb

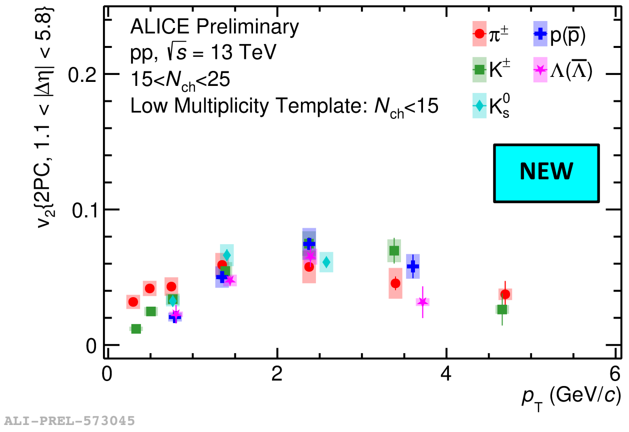
Collectivity in small systems

Is there collectivity in small systems? If so, is there an onset?

pp & p−Pb

Decreasing multiplicity





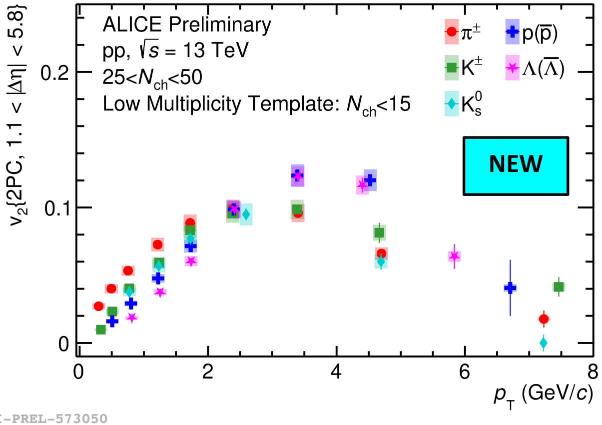
1) **15 < N_{ch} < 25 :** Baryon meson grouping and splitting (within 1σ confidence) disappears ⟹ hint of an onset!

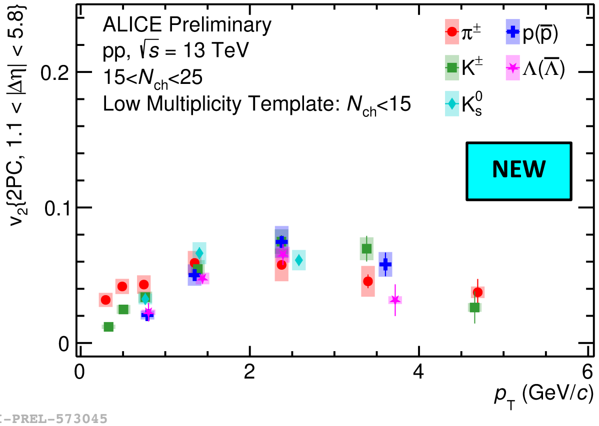
Collectivity in small systems

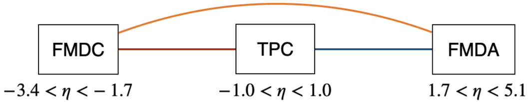
pp & p−Pb

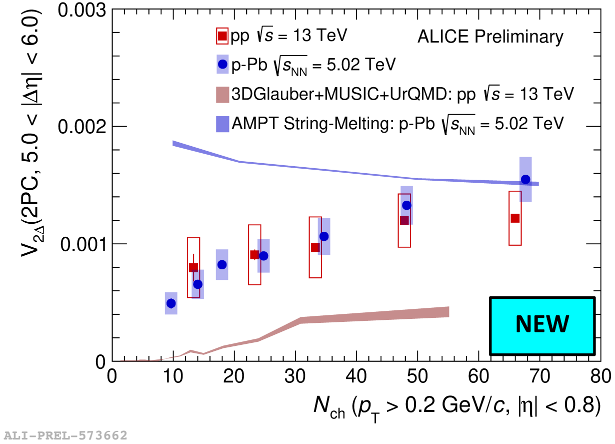
Is there collectivity in small systems? If so, is there an onset?

Decreasing multiplicity









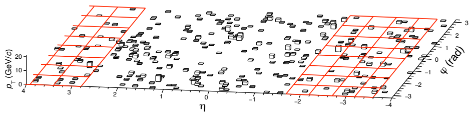
1) **15 < N_{ch} < 25 :** Baryon meson grouping and splitting (within 1σ confidence) disappears ⟹ hint of an onset!
2) **Longest-range correlation** studied down to lowest possible multiplicity ⟹ Proper understanding of the initial state is missing

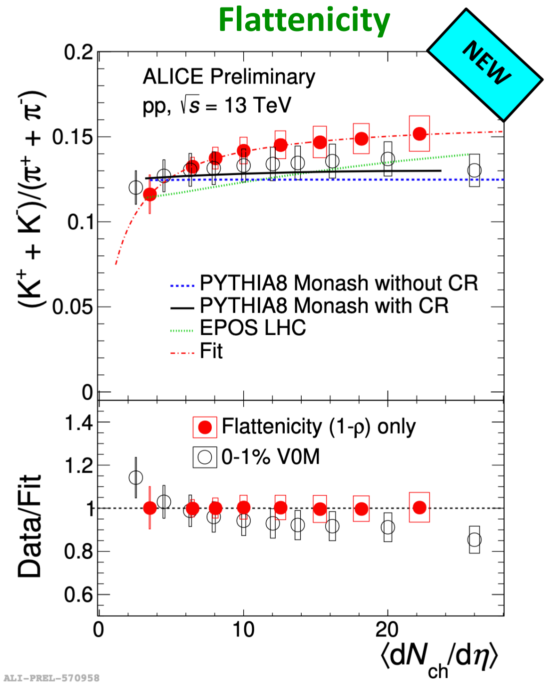
4 June, Debojit Sarkar

How important is the event topology in small systems?

pp

Small local Nch fluct.
→ small flattenicity values





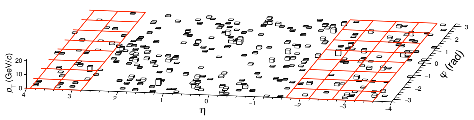
1) **Flattenicity** → Local multiplicity fluctuations: The particle ratios exhibit a steeper increase with multiplicity

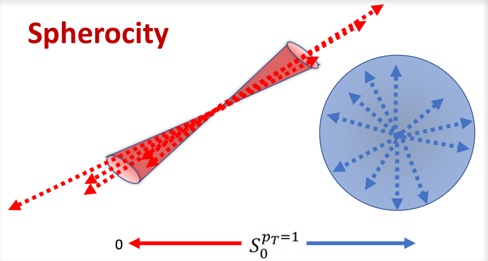
4 June, Adrian Nassipour, Antonio Ortiz

How important is the event topology in small systems?

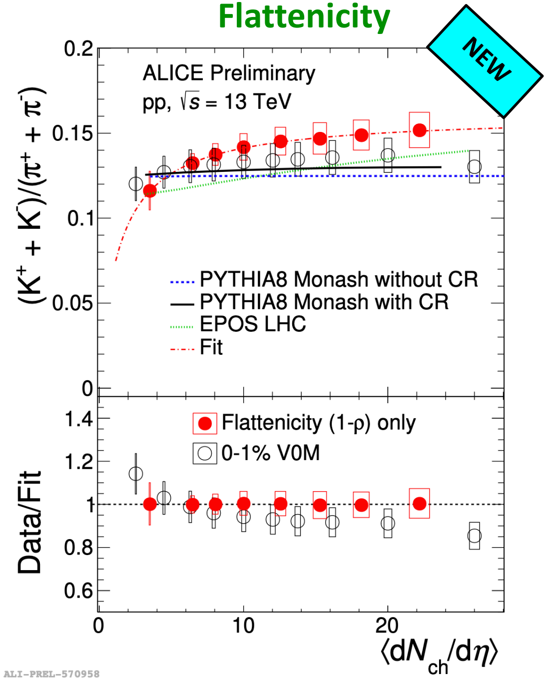
pp

Small local Nch fluct.
→ small **flattenicity** values

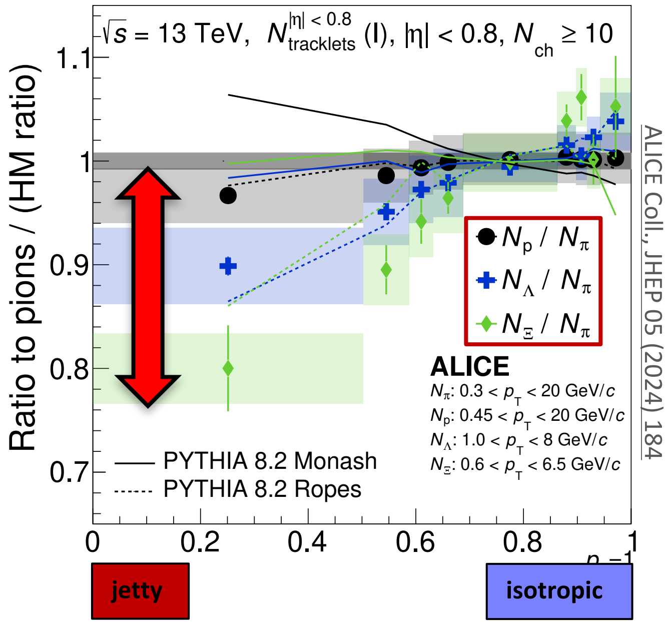




Flattenicity



Spherocity



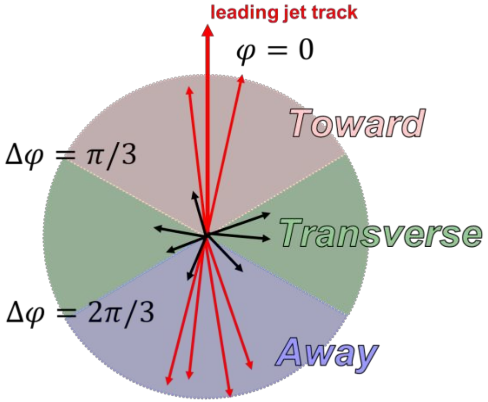
1) **Flattenicity** → Local multiplicity fluctuations: The particle ratios exhibit a steeper increase with multiplicity
2) **Spherocity** → Jet-like or isentropic: Significant suppression of yields in jetty events

4 June, Adrian Nassipour, Antonio Ortiz

(Multi-)strange hadron angular correlations

pp

Strangeness in/out of the jets?



(Multi-)strange hadron angular correlations

pp

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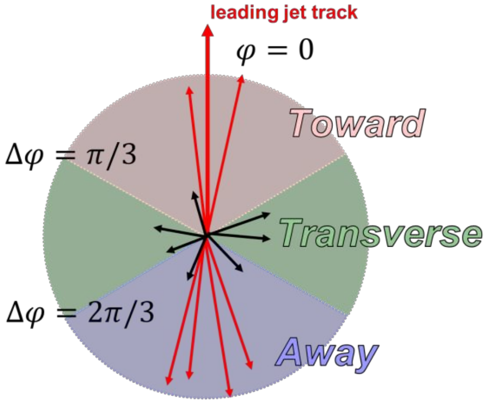
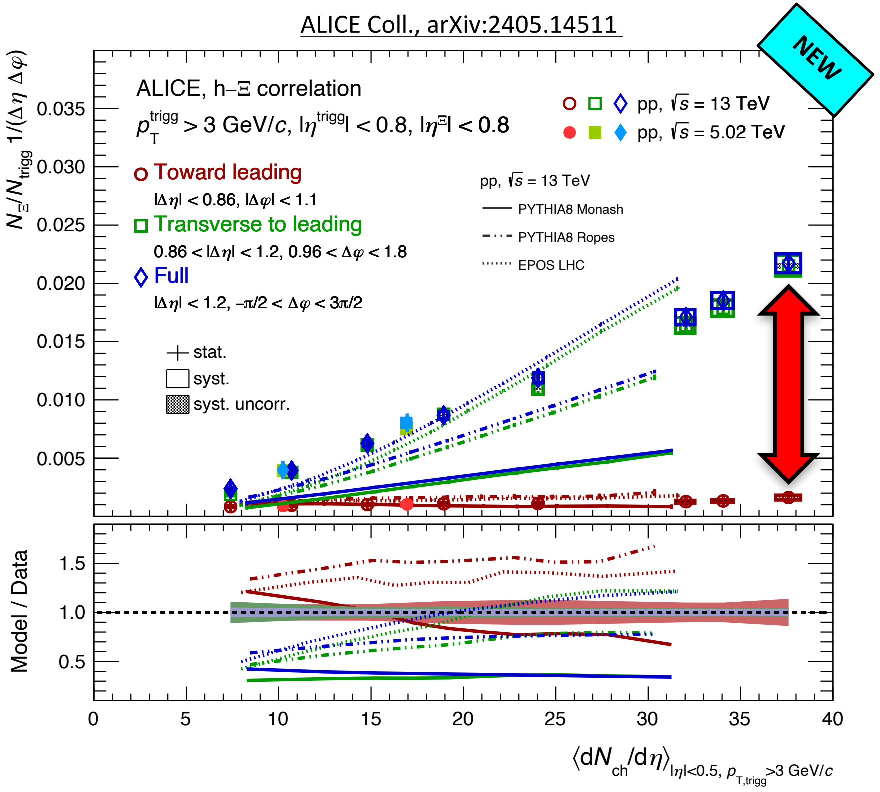


ALICE Coll., arXiv:2405.14511

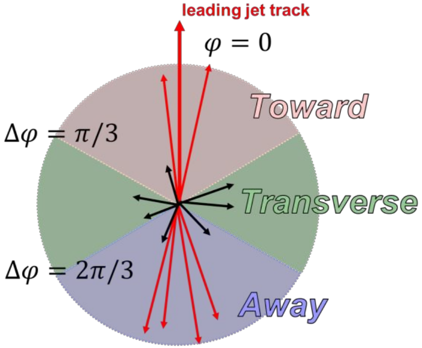


The contribution of **transverse-to-leading** wrt toward-leading production increases with multiplicity

4 June, Chiara de Martin

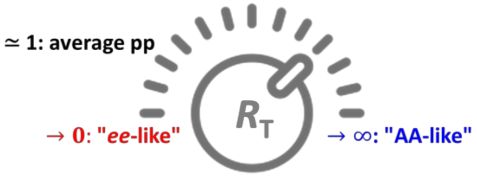
Deeper look at underlying event

pp



N_T : N_{ch} in transverse region

$$R_T = N_T \, / \, \langle N_T \rangle$$



Deeper look at underlying event

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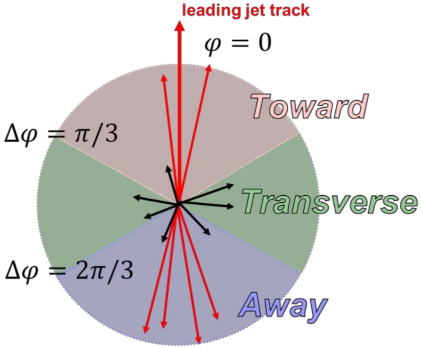

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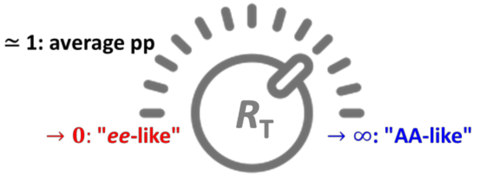
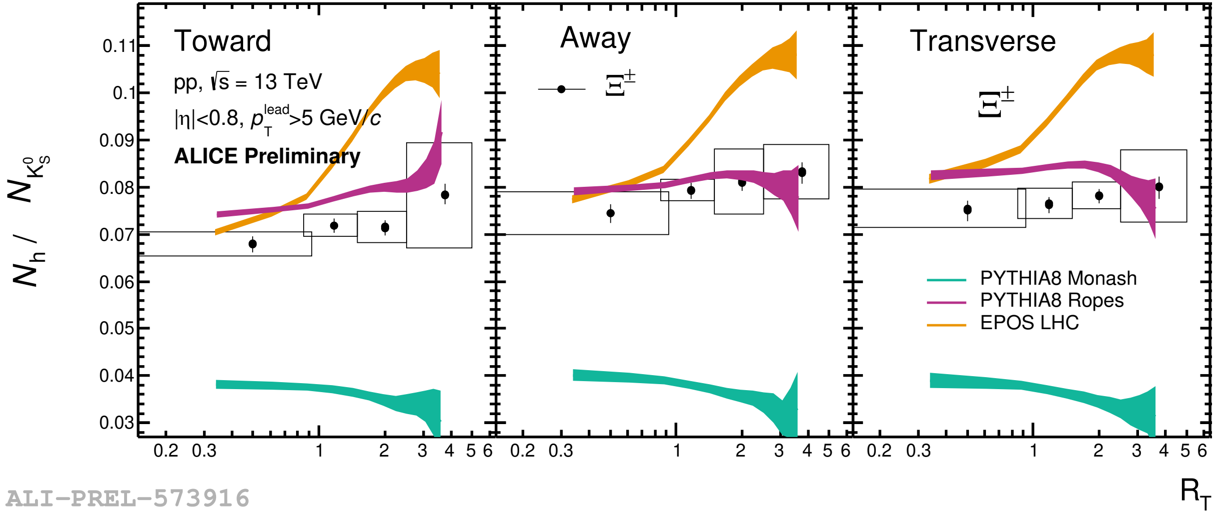




ALI−PREL−573916

1) Slight increase of strangeness production observed with increasing R_T
2) Evolution is weaker than the $\langle dN_{ch}/d\eta \rangle$ dependence, however more representative of the sheer increase in parton-parton activity

4 June, Oliver Matonoha

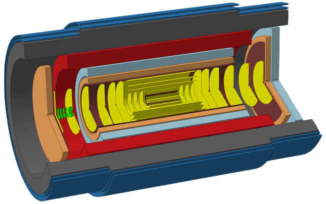
18 talks

Particle production	4 June, 16:50	Beomkyu Kim	**Charged-particle production** in pp collisions at 13.6 TeV and Pb-Pb collisions at 5.36 TeV with ALICE	Run 3
	4 June, 11:20	Antonio Ortiz	Particle production as a function of **charged-particle flattenicity** in small collision systems with ALICE	Run 2
	4 June, 17:50	Adrian Nassipour	**Light-flavour particle production** as a function of **transverse spherocity** with ALICE	Run 2
	4 June, 17:30	Oliver Matonoha	Production of **light and strange particles** as a function of the **underlying event activity** in small and large collision systems with ALICE	New Pub.
	4 June, 09:30	Pavel Gordeev	**Production of Σ baryons** as a function of multiplicity in pp collisions at the LHC with ALICE	Run 2
	4 June, 10:40	Romain Schotter	**Testing CPT symmetry with multistrange baryons** mass precision measurements with ALICE	Run 2
	4 June, 09:30	Prottay Das	Investigating the **hidden strangeness content of exotic resonance** with ALICE	Run 2
QGP EOS	4 June, 16:50	Mario Ciacco	Studying **(anti)nucleosynthesis** via event-by-event fluctuations at the LHC with ALICE	Run 2
	4 June, 17:10	Swati Saha	Study of **baryon-strangeness and charge-strangeness correlations** in Pb-Pb collisions at 5.02 TeV with ALICE	Run 2
	4 June, 11:40	Emil Gorm Nielsen	Probing the **speed of sound in QGP** with multi-particle $[p_T]$ cumulants in ALICE	Run 2
Correlations	5 June, 09:30	Anton Riedel	Differential measurement of the common particle emitting source using **p–p and p–Λ correlations** in pp collisions at 13.6 TeV with ALICE	Run 3
	4 June, 17:30	Laura Serknyte	Shedding light on strong interactions in **three-baryon systems** with ALICE Run 3 data	Run 3
	4 June, 09:10	Thomas Humanic	Investigating the nature of the **K*0(700) state with pi K0s correlations** with ALICE at the LHC	New Pub.
	5 June, 08:30	Valentina Mantovani Sarti	Novel constraints for the **multi-strange meson-baryon interaction** using correlation measurements with ALICE	Run 2
	4 June, 12:00	Chiara de Martin	Studying **(multi-)strange hadron angular correlation** with associated particles and their production with event topology using the ALICE detector	New Pub.
System size dependence	4 June, 08:30	Debojit Sarkar	Unraveling the **origin of collectivity in high and low multiplicity pp and p-Pb collisions** in ALICE at the LHC	Run 2
	4 June, 11:20	Roman Nepeivoda	Measuring the system size dependence of the **strangeness production** with ALICE	Run 3
	5 June, 08:50	Yuanzhe Wang	Investigating the **system size dependence of hypernuclei** production with A<5 using the ALICE detector	Run 3

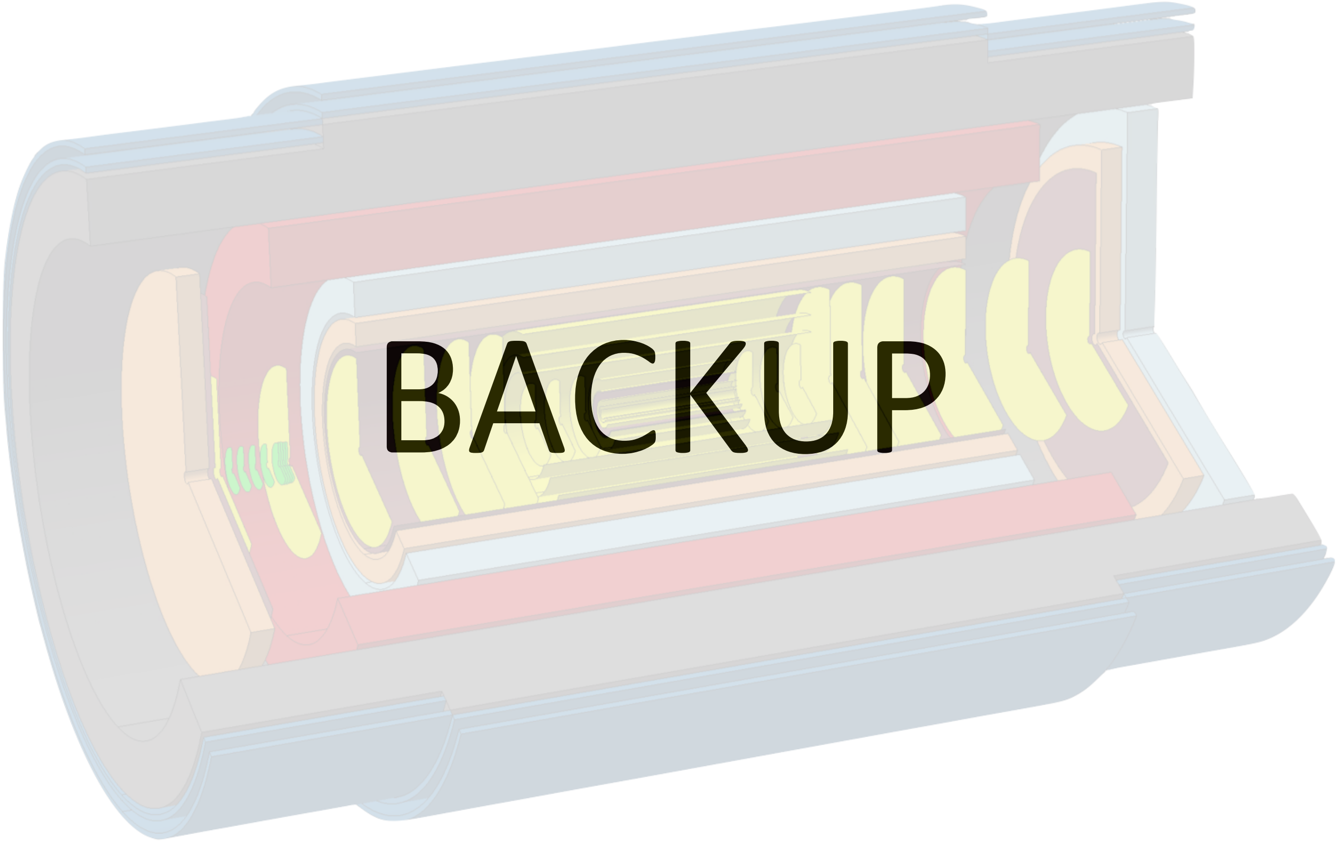
12 posters

Particle production	Upasana Sharma	**Multi-Strange hadron production** in Run 3 pp collisions with ALICE at LHC energies	Run 3
	Hyunji Lim	Study of **multiplicity-dependent ρ0(770) production** in pp collisions with ALICE	Run 2
	Navneet Kumar	**pi, K, and p production in high multiplicity pp collisions** at 13 TeV with ALICE	Run 2
	Su-Jeong-Li	Feasibility study for the **K1 measurement in pp collisions** with ALICE	Run 2
QGP EOS	Mario Ciacco	Chasing the **onset of QCD thermalisation** with ALICE	New Pub.
Correlations	Rik Spijkers	**Angular correlations between multi-strange hadrons** in pp collisions with ALICE	Run 3
	Anjaly Menon	**Anomalous kaon correlations** in Pb-Pb collisions at the LHC with ALICE	Run 2
	Chiara de Martin	Investigating strangeness production in pp collisions using **hadron-strangeness correlations** with ALICE at the LHC	Run 2
	Neelima Agrawal	**Proton source measurement** in pp collisions at 900 GeV with the femtoscopy technique	Run 3
	Victor Luis Gonzalez Sebastian	Clocking the particle production and tracking of **strangeness balance and radial flow effects** at top LHC energy with ALICE	Run 3
System size dependence	Sara Pucillo	New insights on strange quark hadronization measuring **(multi-)strange hadron production** in small collision systems with ALICE	Run 2
	Sonali Padhan	Exploring the **hadronic resonances in high-multiplicity pp collisions** at LHC energies with ALICE	Run 2

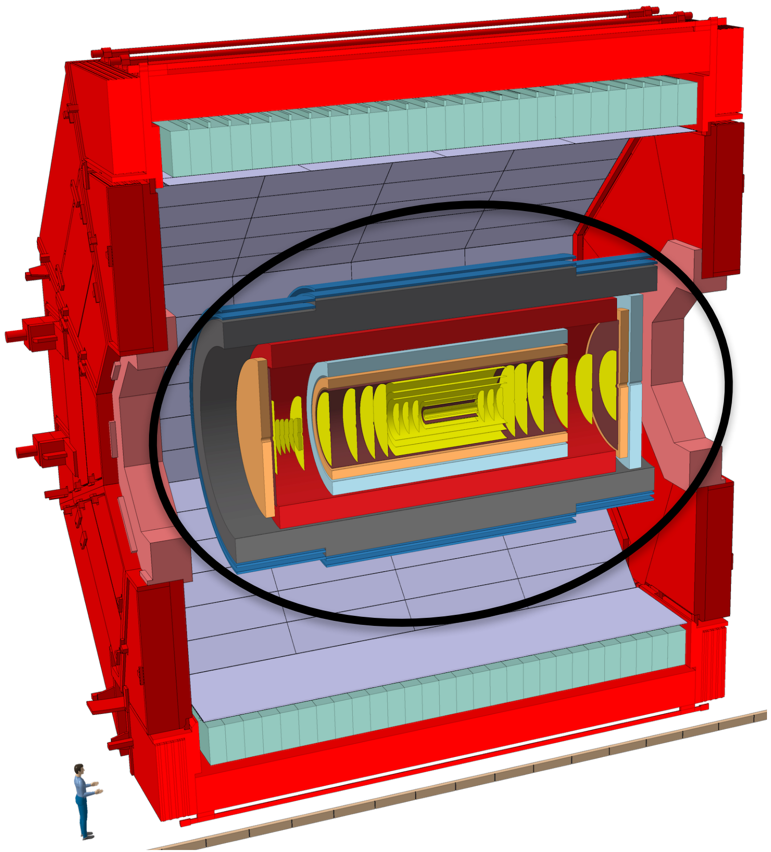
- Lots of exciting new data to be shown at this conference and Run 3 analyses are only just beginning
- **Future:**
  - **End of Run 4** → x100 minimum-bias statistics with respect to Run 1 and 2
  - **ALICE 3** → Large acceptance and PID coverage, high statistics, high efficiency, excellent vertexing …



4 June, Giacomo Volpe
ALICE Coll., CERN-LHCC-2022-009



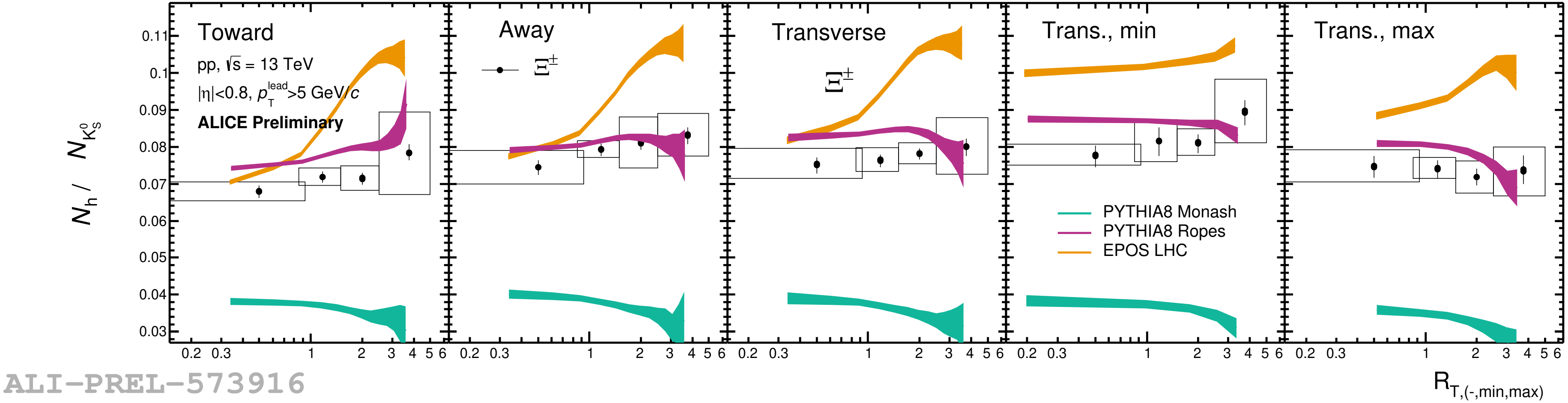
BACKUP



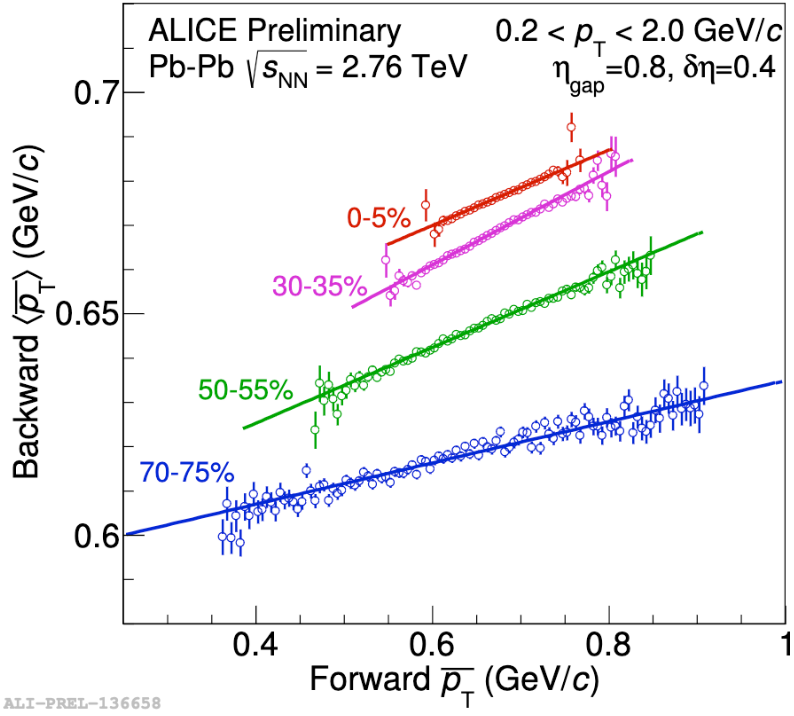
ALICE Coll., CERN-LHCC-2022-009

- ✓ **High statistics** → O (10^9) billion events
- ✓ **Large acceptance** → |η|< 4
- ✓ **High PID purity** → 0.3 < p < 10 GeV/c
- ✓ **High efficiency** → ~95%
- ✓ **Excellent vertexing** → O (3μm) resolution

Observable	Label	Centrality estimation	$\langle p_T \rangle$ and $\langle dN_{ch}/d\eta \rangle$	η gap
N_{ch} in TPC	I	$\lvert\eta\rvert \leq 0.8$	$\lvert\eta\rvert \leq 0.8$	0
	II	$0.5 \leq \lvert\eta\rvert \leq 0.8$	$\lvert\eta\rvert \leq 0.3$	0.3
E_T in TPC	III	$\lvert\eta\rvert \leq 0.8$	$\lvert\eta\rvert \leq 0.8$	0
	IV	$0.5 \leq \lvert\eta\rvert \leq 0.8$	$\lvert\eta\rvert \leq 0.3$	0.3
$N_{tracklets}$ in SPD	V	$\lvert\eta\rvert \leq 0.8$	$\lvert\eta\rvert \leq 0.8$	0
	VI	$0.5 \leq \lvert\eta\rvert \leq 0.8$	$\lvert\eta\rvert \leq 0.3$	0.3
	VII	$0.3 < \lvert\eta\rvert \leq 0.6$	$\lvert\eta\rvert \leq 0.3$	0
	VIII	$0.7 \leq \lvert\eta\rvert \leq 1$	$\lvert\eta\rvert \leq 0.3$	0.4
N_{ch} in V0	IX	$-3.7 < \eta < -1.7 + 2.8 < \eta < 5.1$	$\lvert\eta\rvert \leq 0.8$	1.7



Toward
pp, √s = 13 TeV
|η|<0.8, p_T^{lead}>5 GeV/c
ALICE Preliminary
Away
Ξ±
Transverse
Ξ±
Trans., min
Trans., max
PYTHIA8 Monash
PYTHIA8 Ropes
EPOS LHC
$N_h / N_{K^0_S}$
$R_{T,(-,min,max)}$
ALI−PREL−573916


ALICE Preliminary
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
0.2 < p_T < 2.0 GeV/c
η_{gap}=0.8, $\delta\eta$=0.4
0-5%
30-35%
50-55%
70-75%
Backward $\langle \overline{p_T} \rangle$ (GeV/c)
0.7
0.65
0.6
0.4
0.6
0.8
1
Forward $\overline{p_T}$ (GeV/c)
ALI-PREL-136658

(b)