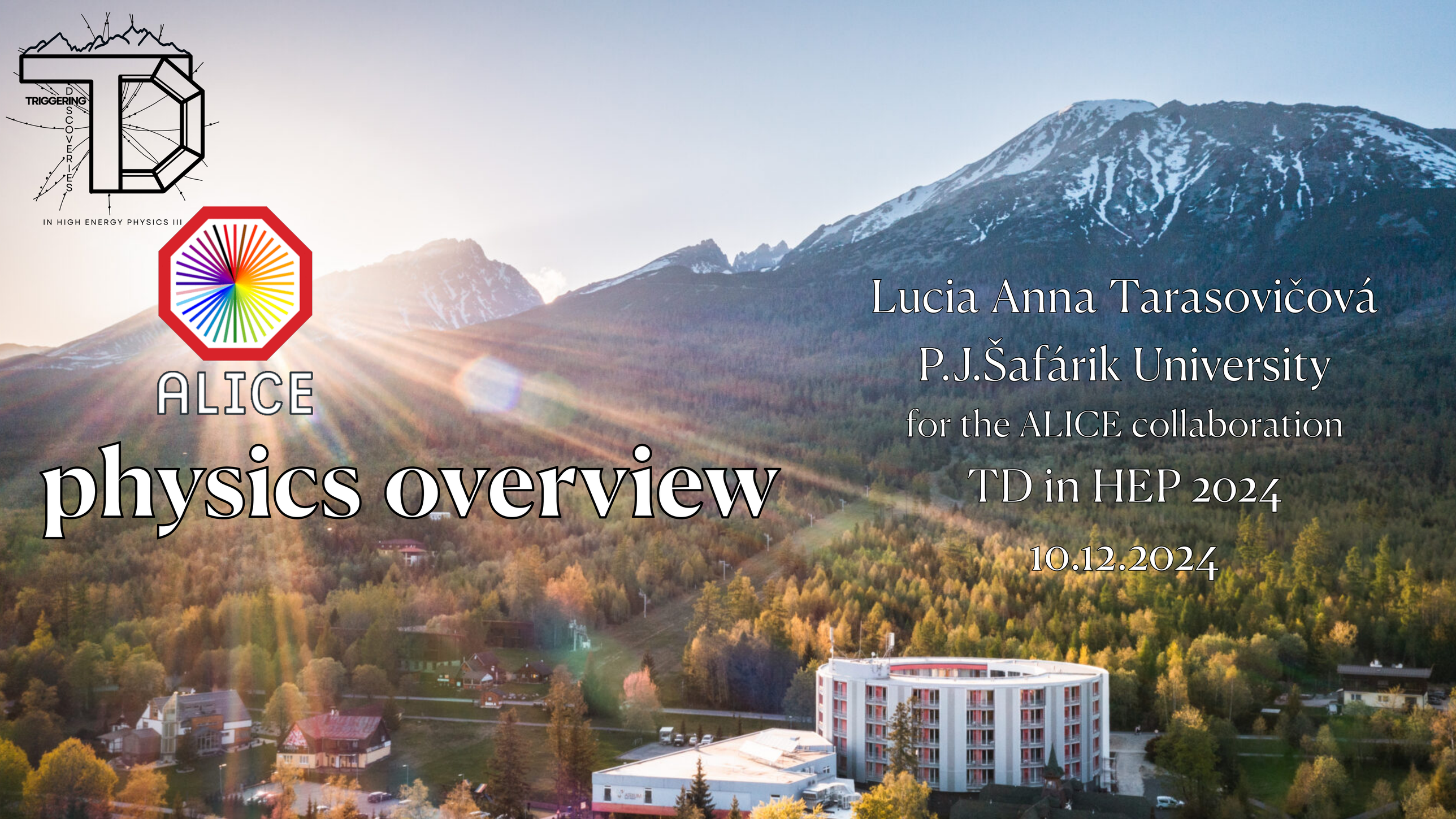


physics overview

Lucia Anna Tarasovičová
P.J.Šafárik University
for the ALICE collaboration

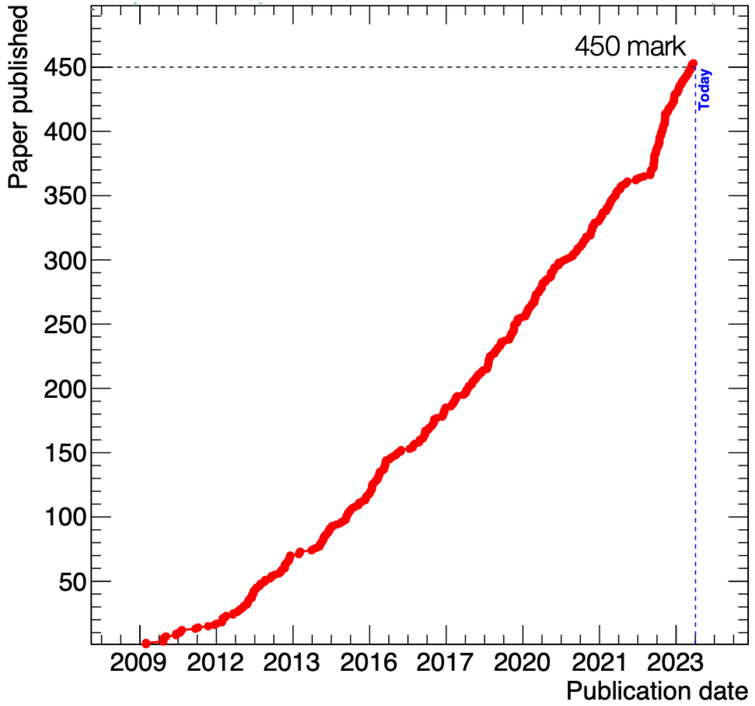
TD in HEP 2024

10.12.2024

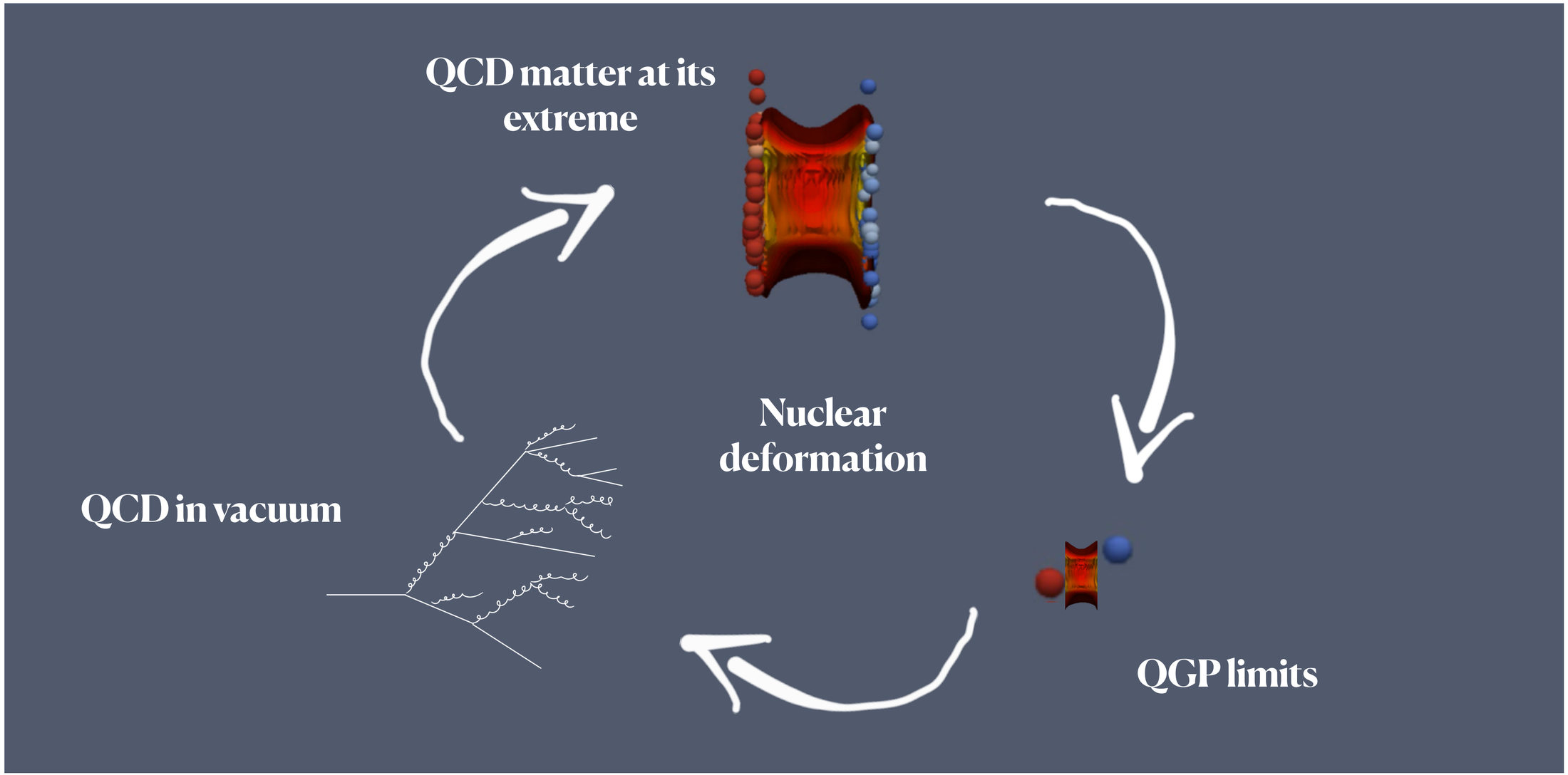
The ALICE Collaboration

- 40 countries
- 169 institutes
- 2004 members

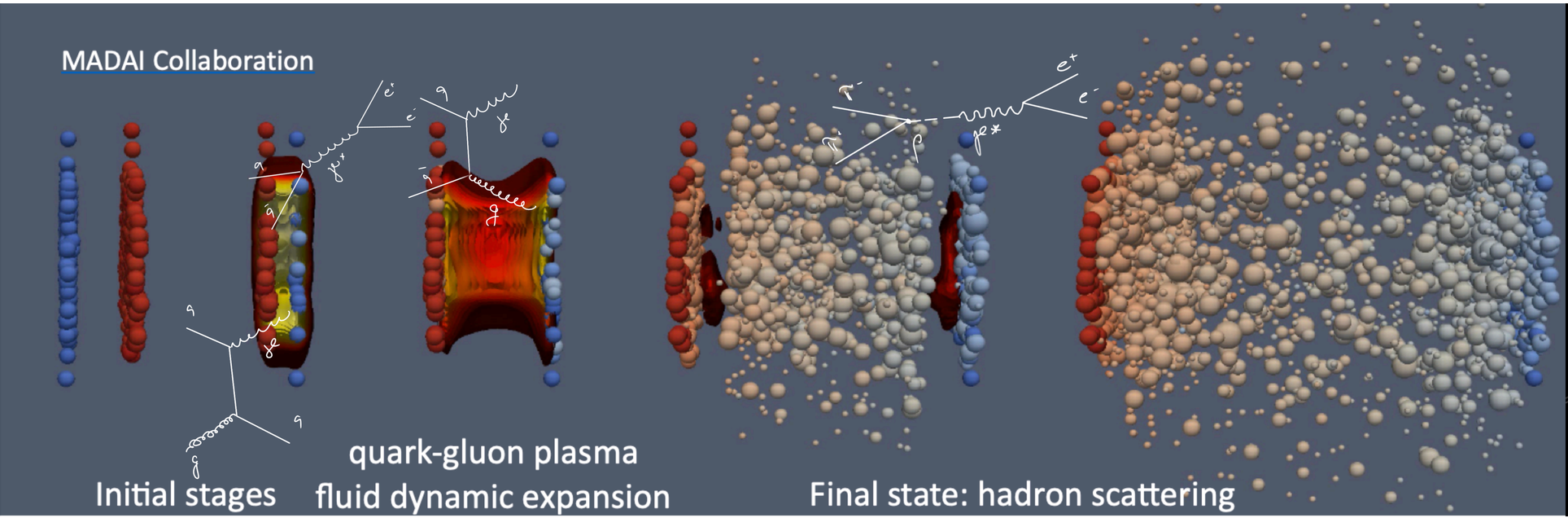
https://alice-publications.web.cern.ch/submitted

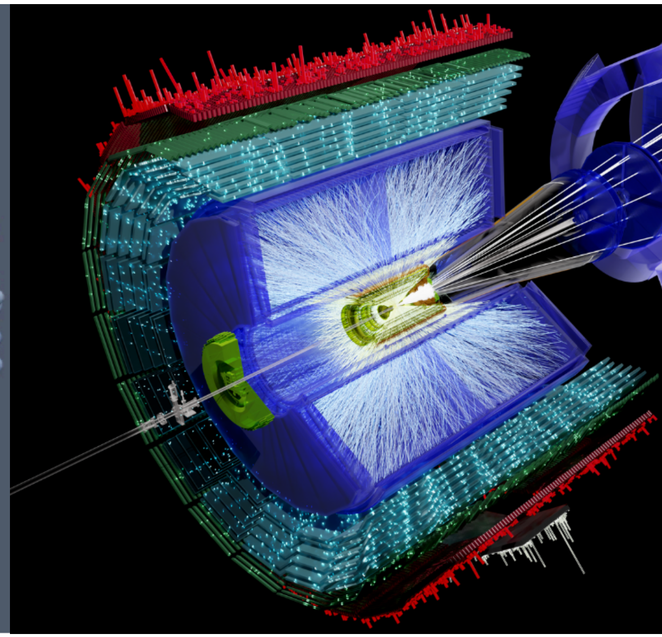


Physics at ALICE

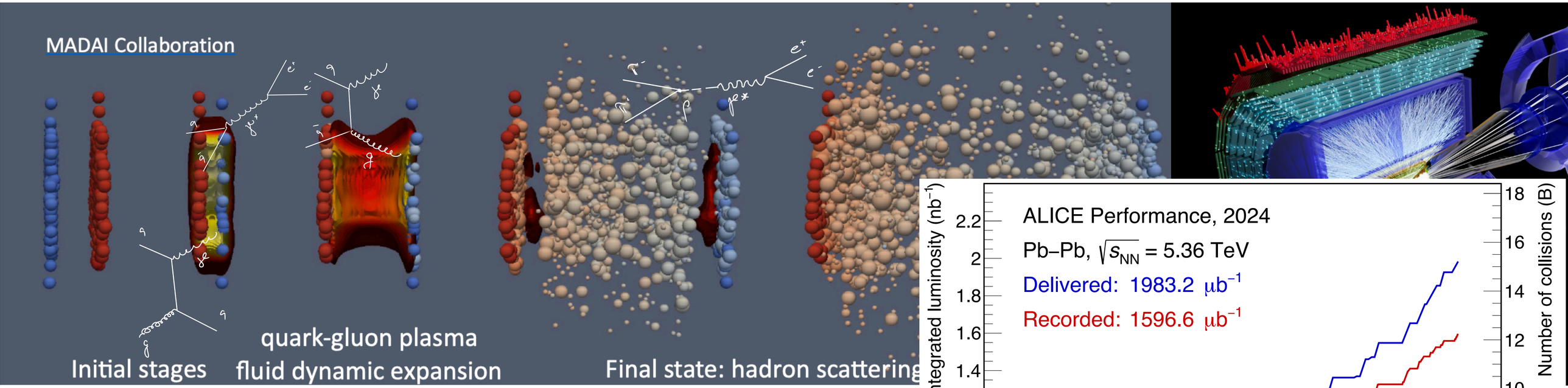


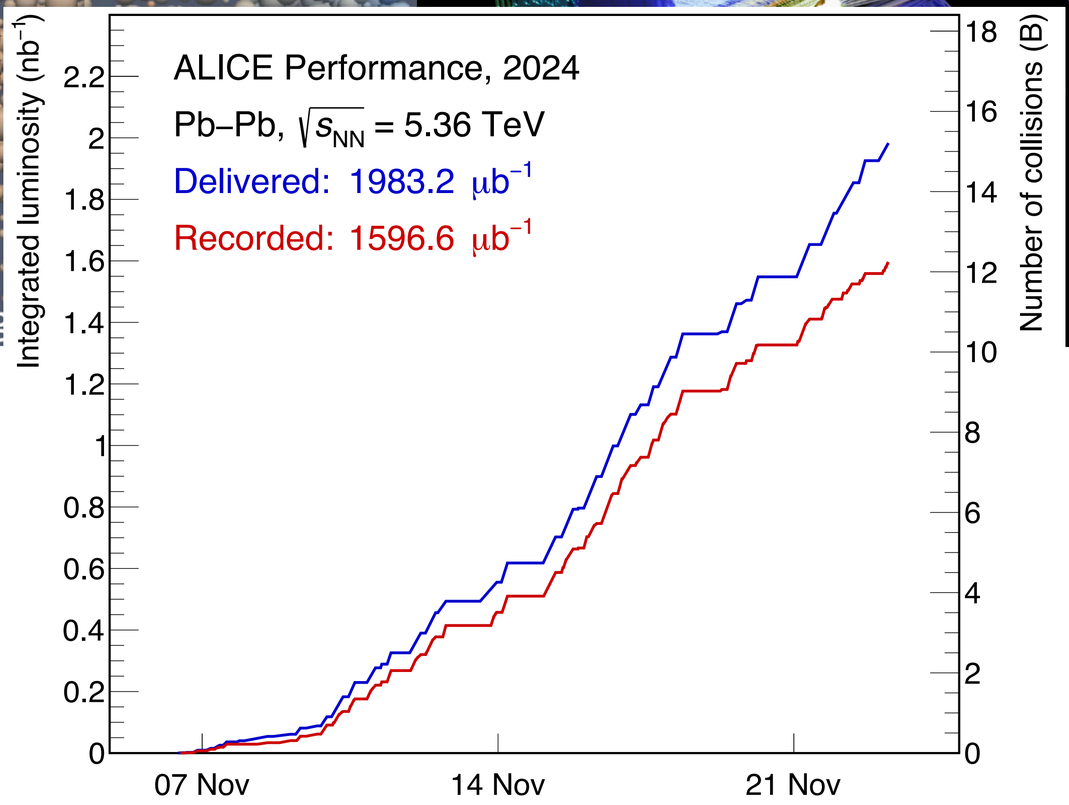
QCD matter at its extreme





QCD matter at its extreme

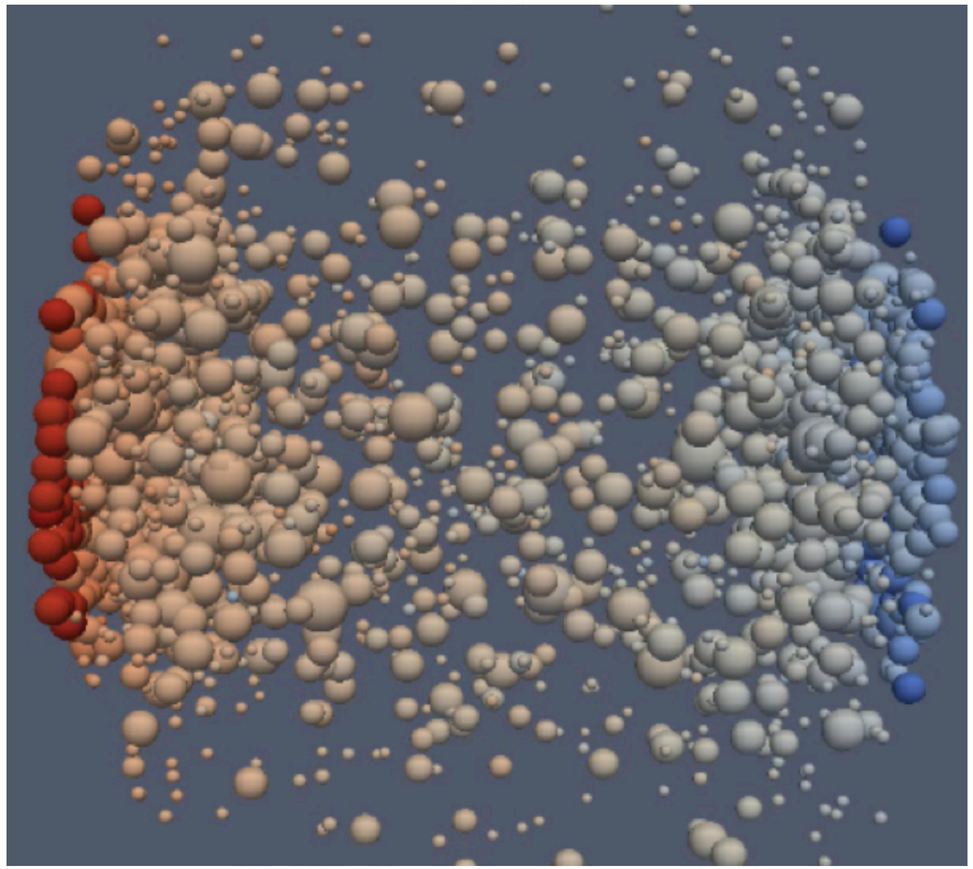


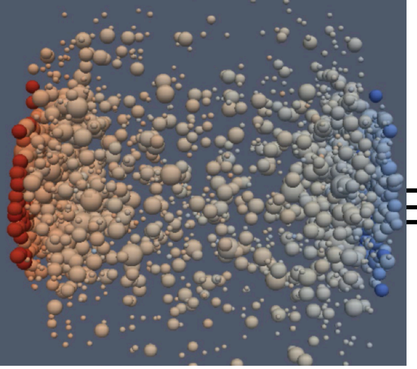


- Different systems:
  - Pb—Pb
  - Xe—Xe
  - O—O (planned for 2025)

More about O—O perspectives in talk by G.G. Barnafoldi
Tuesday 10.12., 17:05

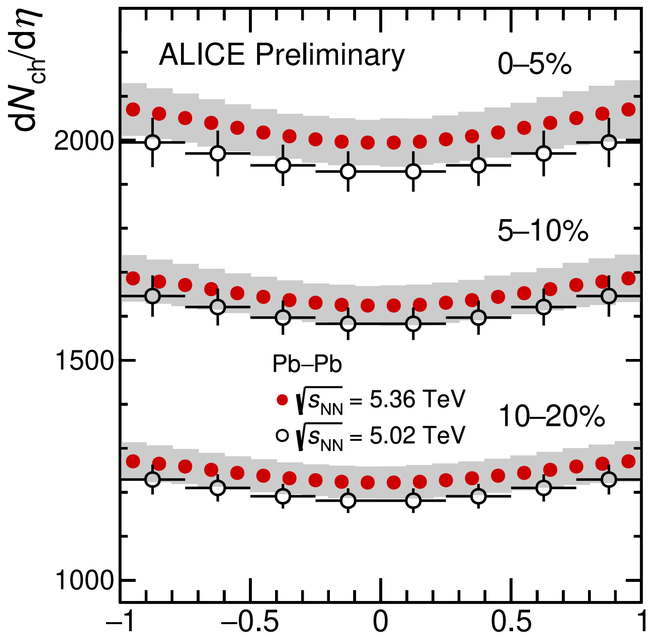
Final state



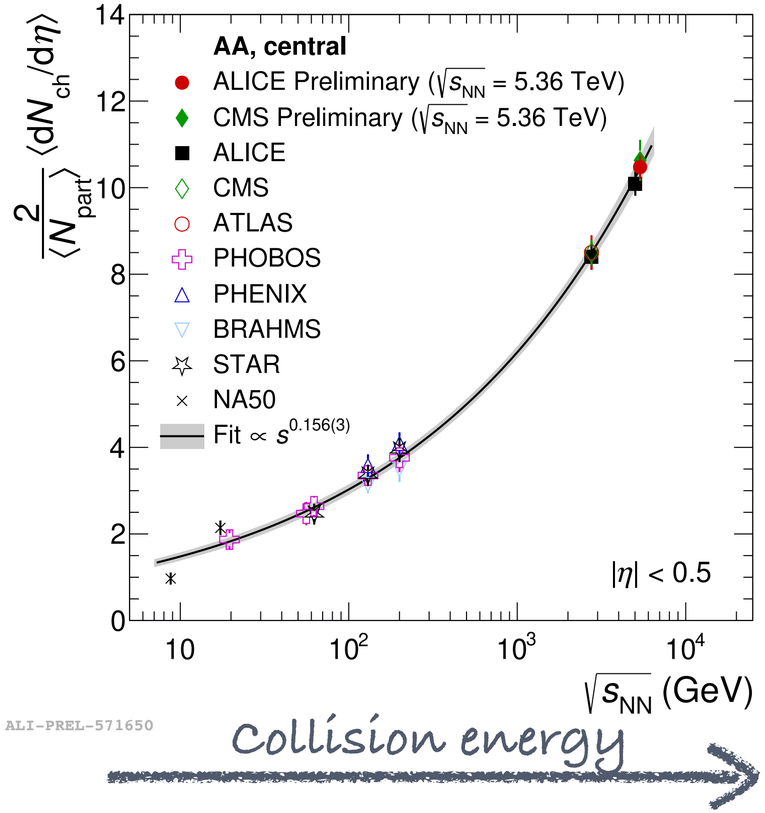


Charged-particle pseudorapidity density ($dN_{ch}/d\eta$)

RUN 3



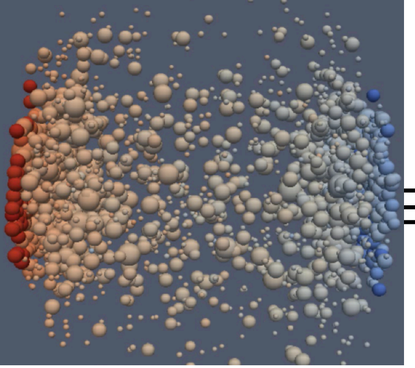
ALI-PREL-571331



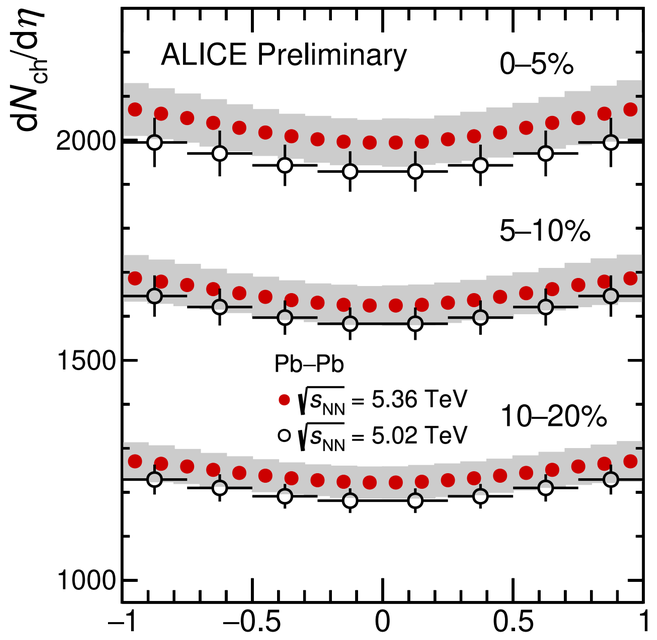
ALI-PREL-571650

Collision energy

- New results in line with other experiments and expectations



Charged-particle pseudorapidity density ($dN_{ch}/d\eta$)



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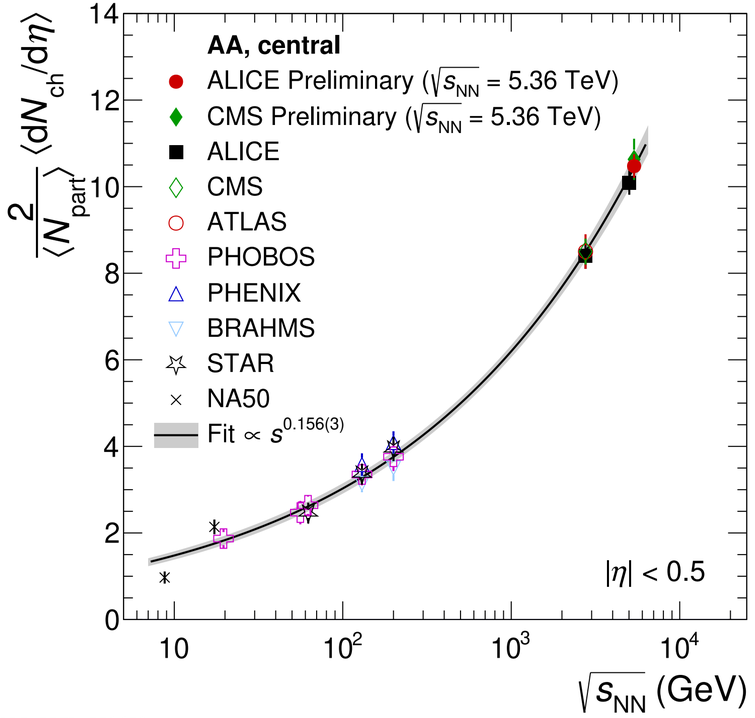
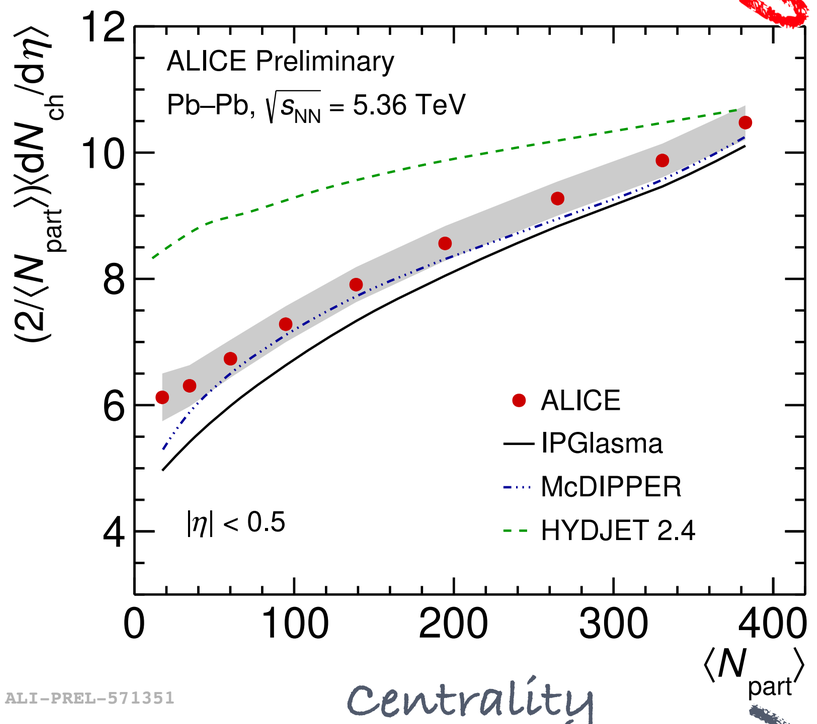


ALI-PREL-571650

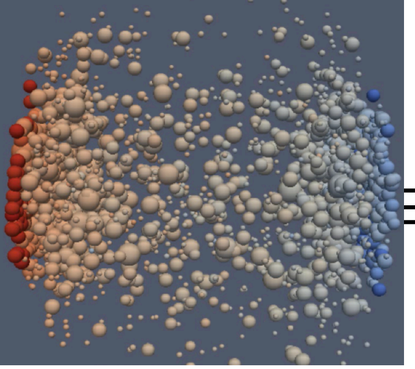


ALI-PREL-571351

RUN 3

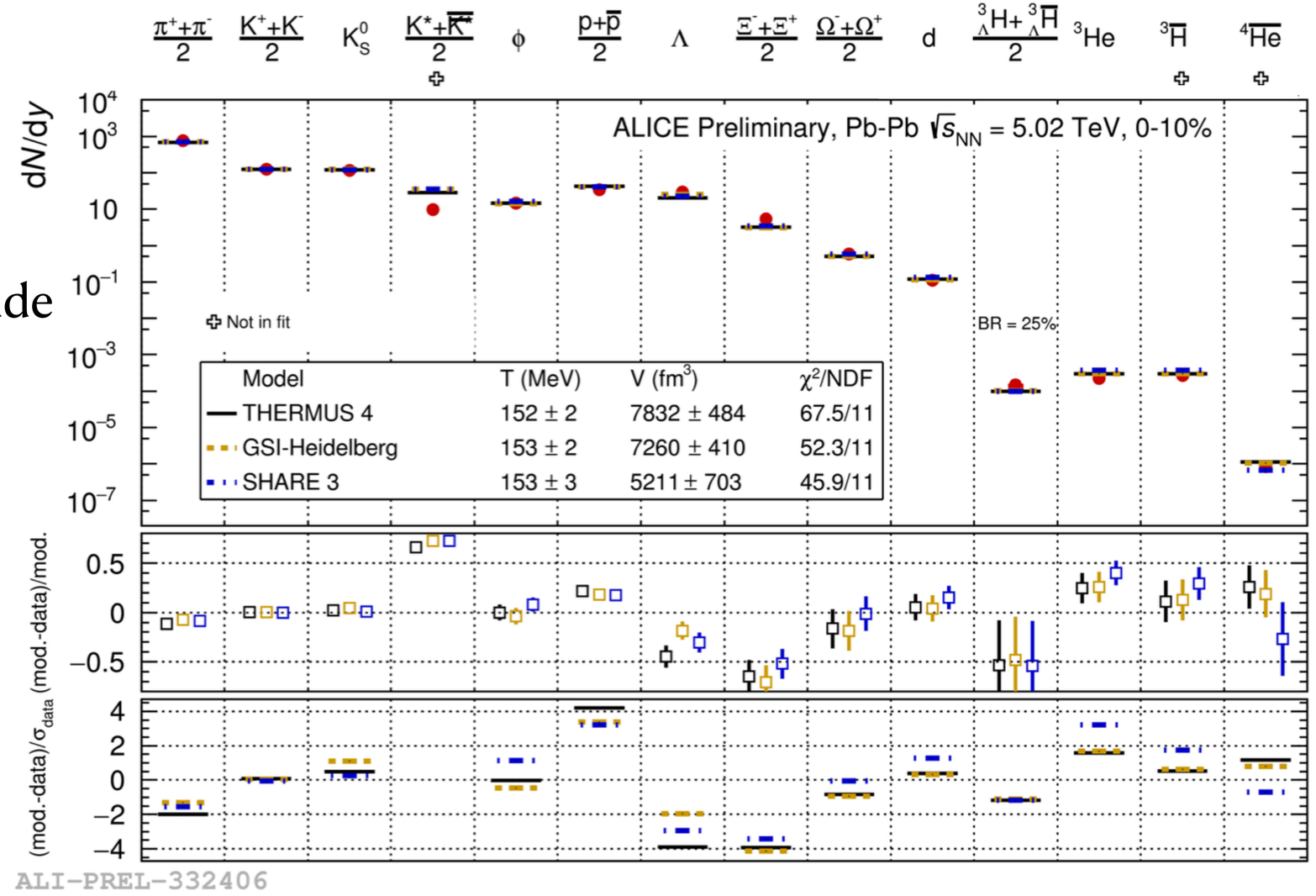
Centrality

- Initial state models with hydro evolution describe the data well

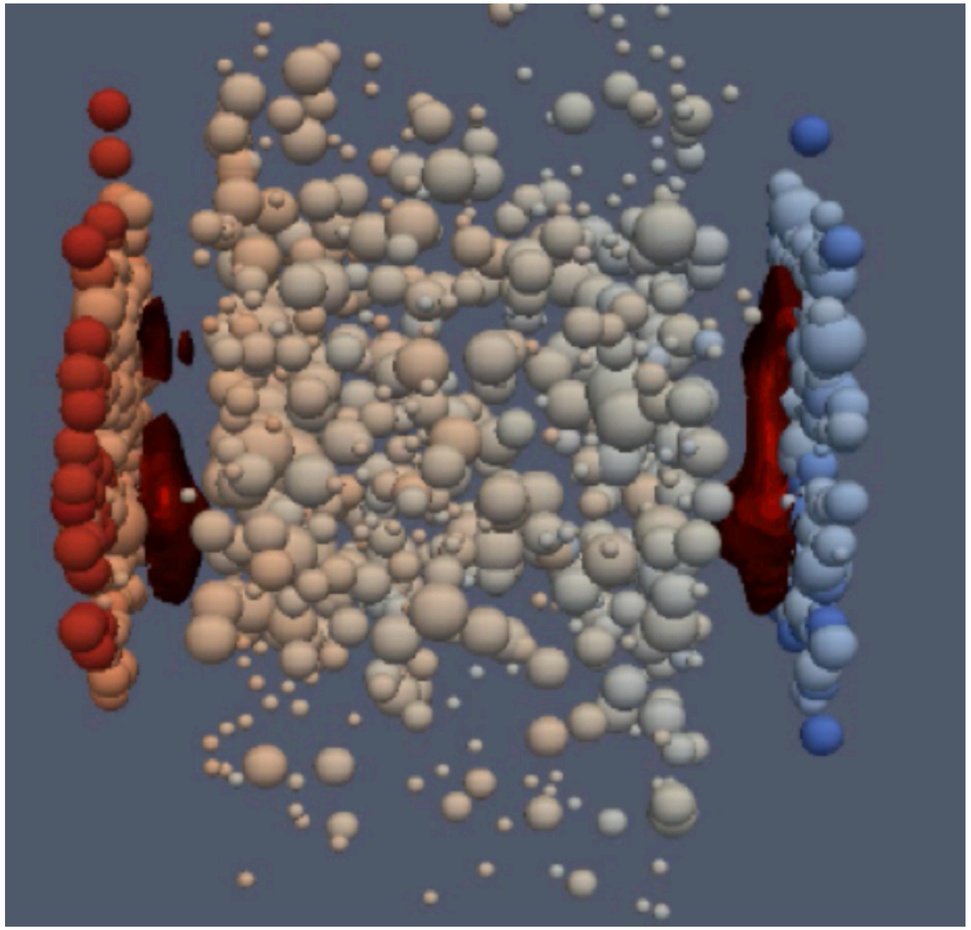


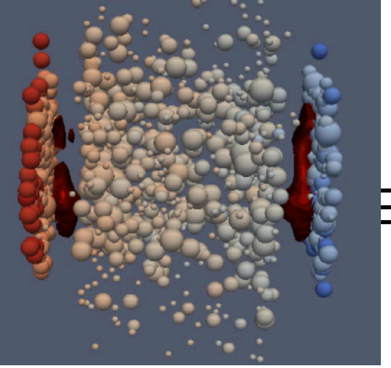
Identified hadron yields (d*N*/d*y*)

- Full set of identified integrated yields
  - Spanning 10 orders in magnitude
- Described by SHM
  - Macroscopic model
  - Parameters: (T, V, μ_B)



Hadronisation

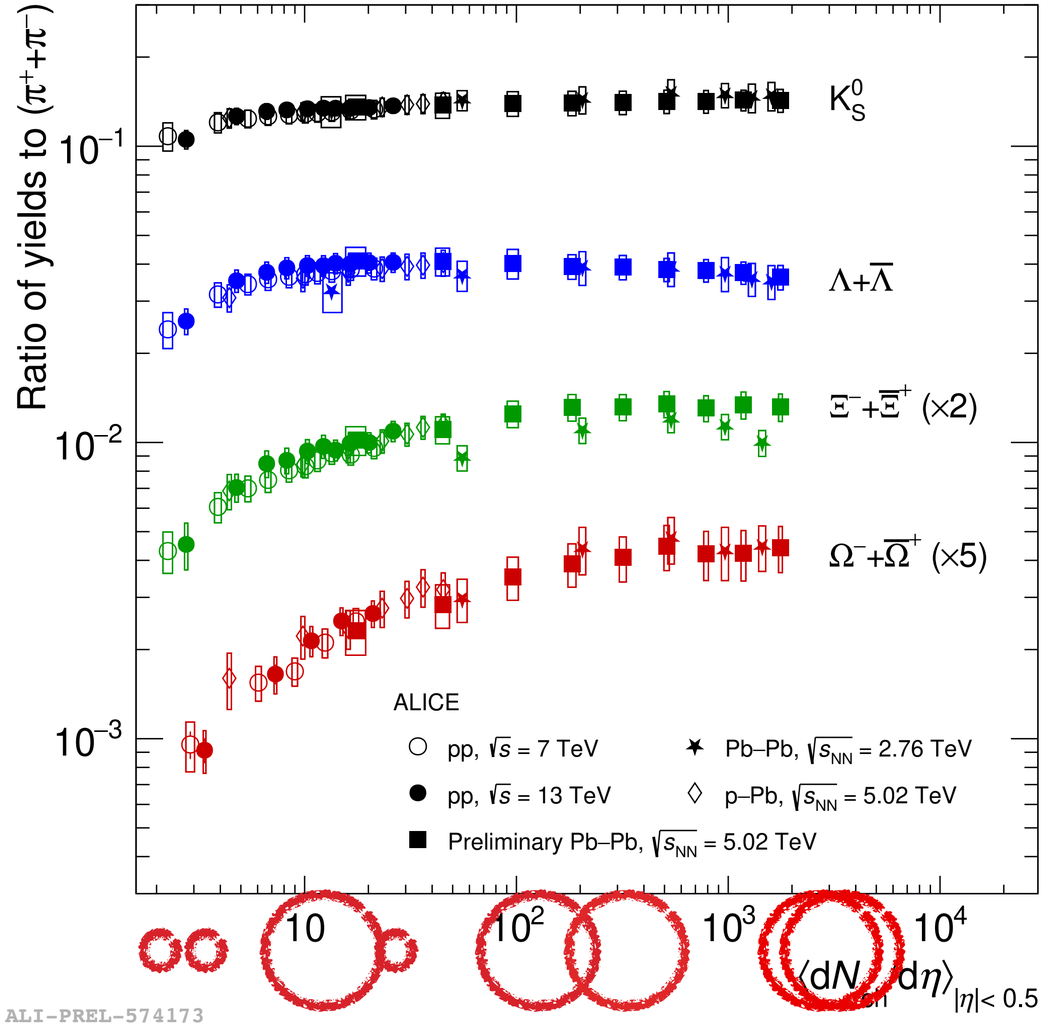




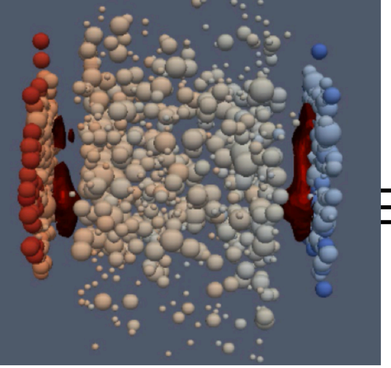
Strange hadron production

- Ratios of strange particles over pions
  - Continuous increase from small to large systems with multiplicity
  - Final yields depend only on the multiplicity

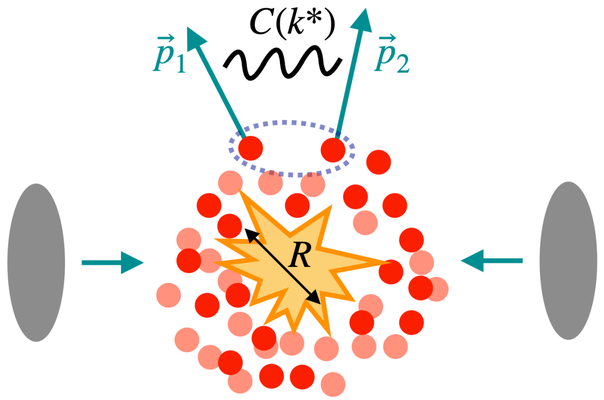
More in talk by P.Kalinak
Friday 13.12., 11:50



System size

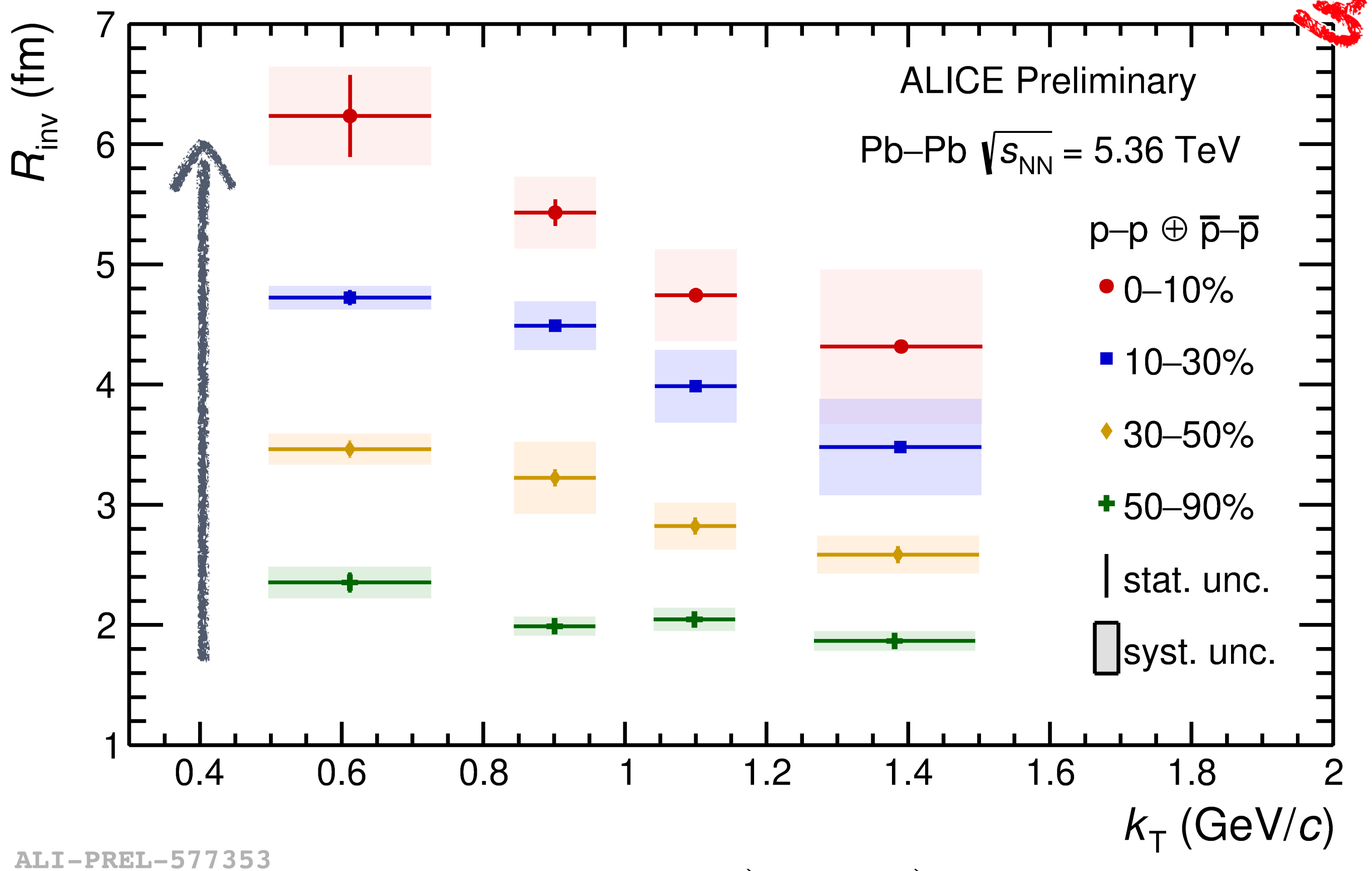


Emitting source size



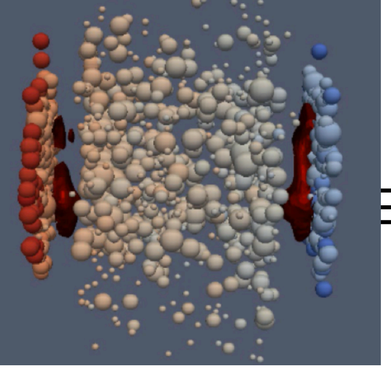
- Dynamics typical for Pb—Pb
  - **Increase** of the source size with centrality

RUN 3

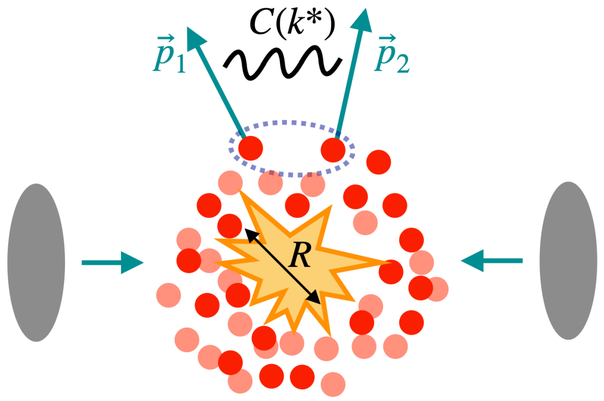


ALI-PREL-577353

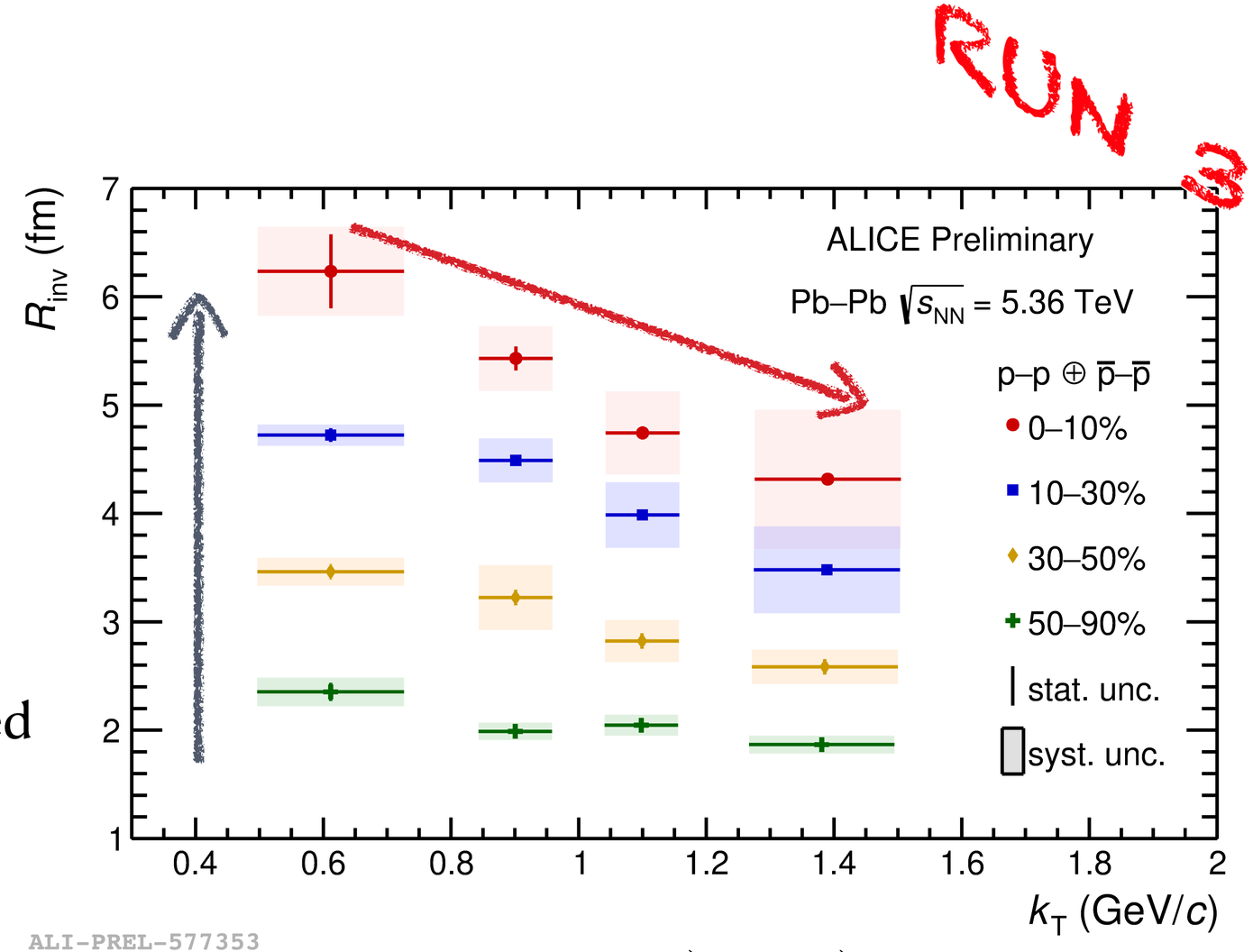
$$k_T = 0.5\,|\vec{p}_{T,1} + \vec{p}_{T,2}|$$



Emitting source size

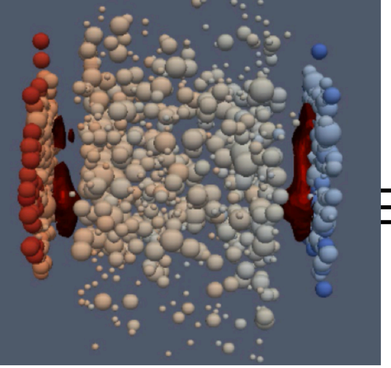


- Dynamics typical for Pb—Pb
  - **Increase** of the source size with centrality
  - **Decrease** of the R_{inv} with k_{T} - caused by radial flow
    - Stronger effect in more central collisions



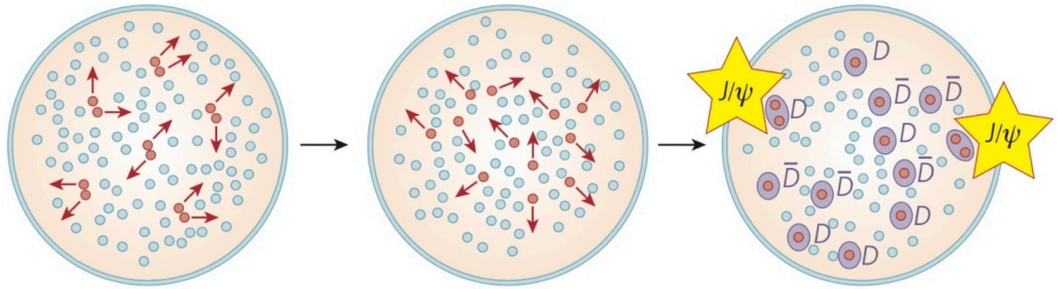
ALI-PREL-577353

$$k_{\mathrm{T}} = 0.5\,|\vec{p}_{\mathrm{T},1} + \vec{p}_{\mathrm{T},2}|$$



J/ψ recombination

$$R_{AA} = \frac{\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}{\langle T_{AA} \rangle \times \frac{\mathrm{d}\sigma_{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$



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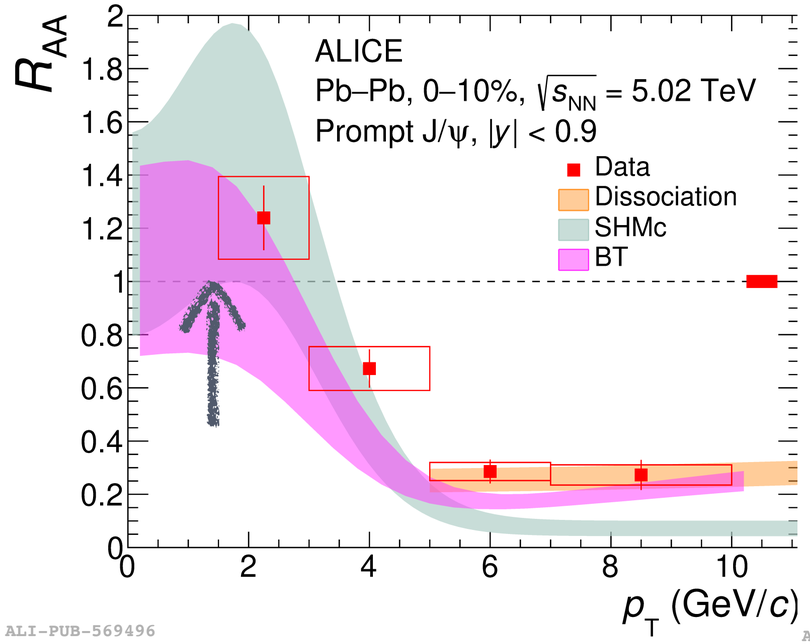
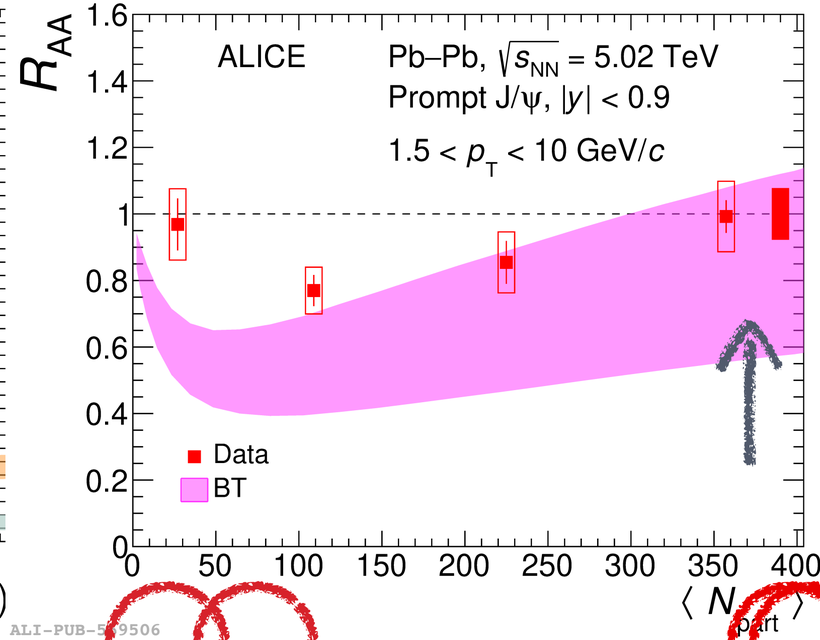
Nature 448 (2007) 302

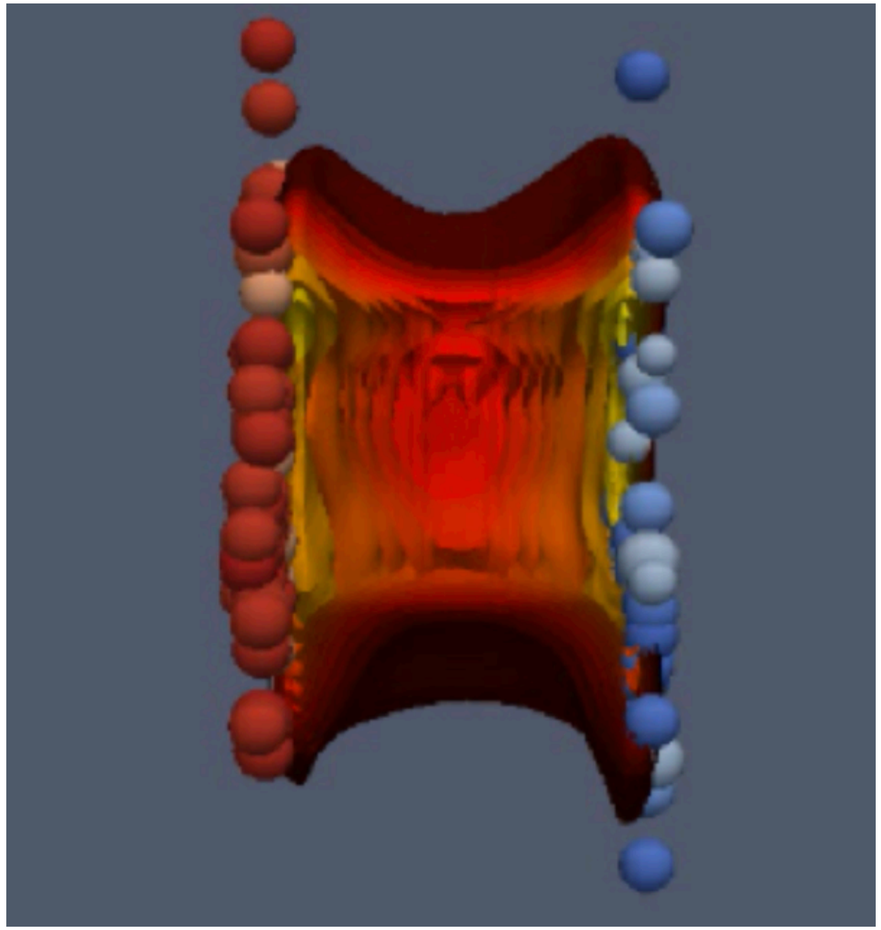
- **Increase** of the R_{AA} for decreasing p_{T} and increasing centrality
  - In line with recombination
  - Good agreement with the SHMc and BT models

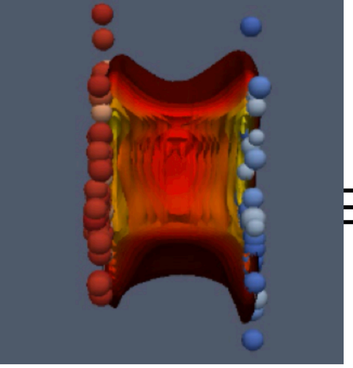




JHEP 02 (2024) 066

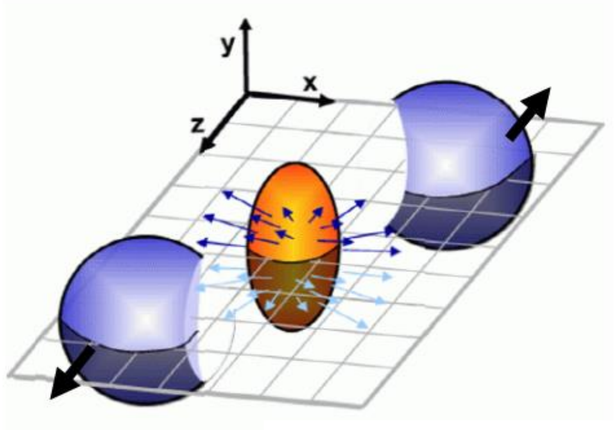
QGP (hydrodynamic) expansion

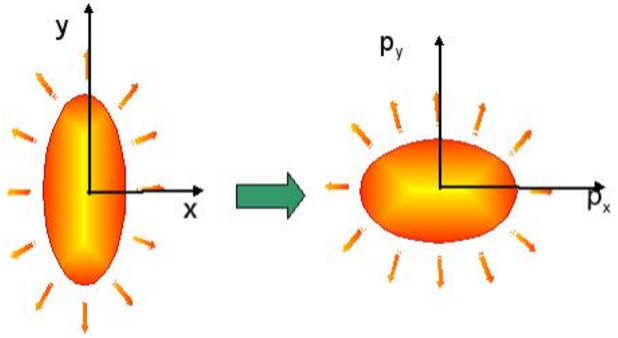




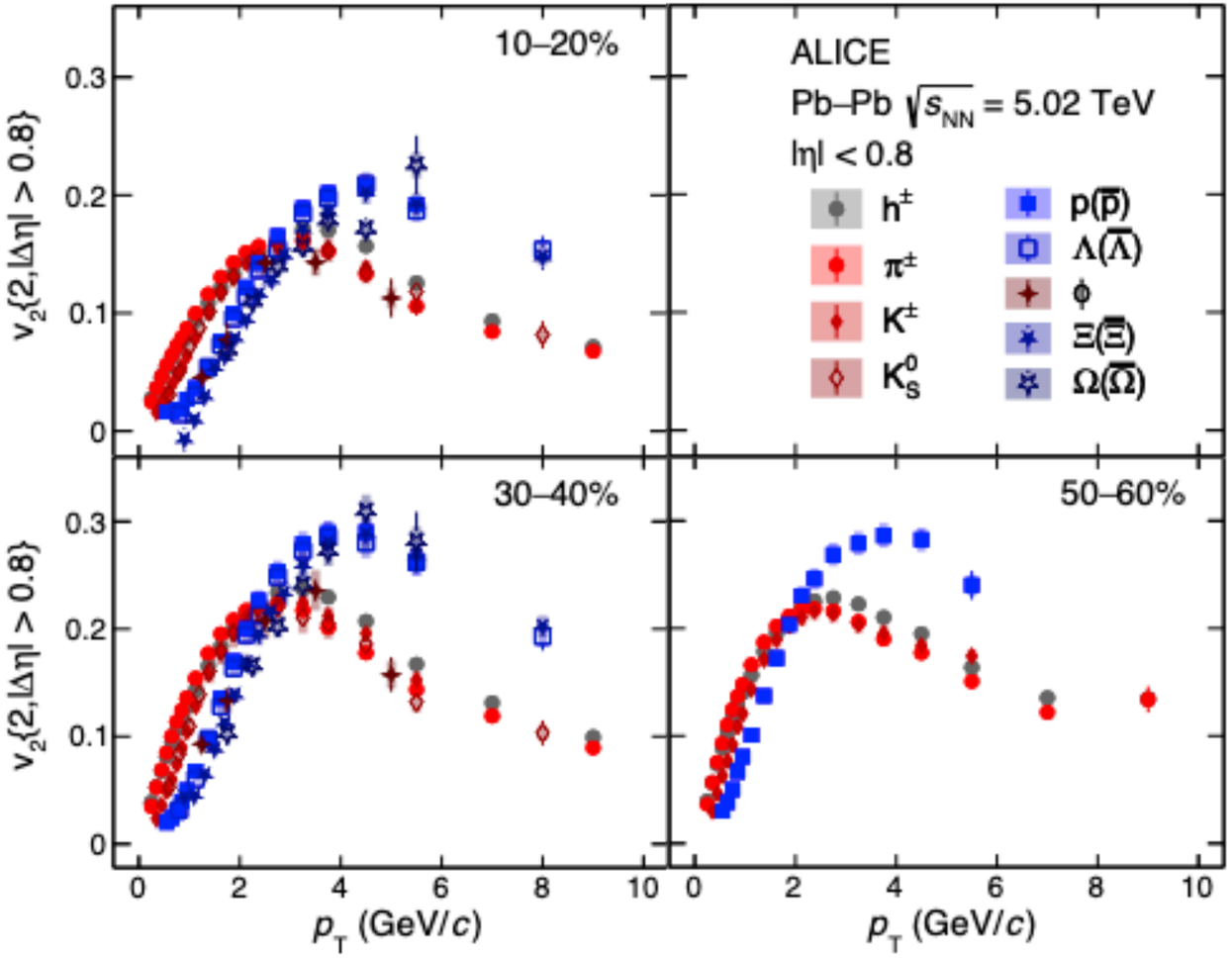
Elliptical flow of identified particles

- Spatial anisotropy → momentum anisotropy





$$v_2 = \langle \cos[2(\varphi - \psi)] \rangle$$



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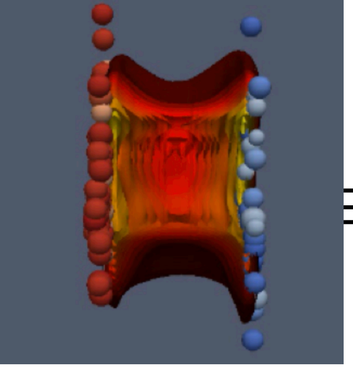
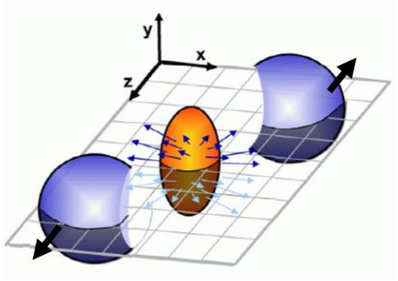
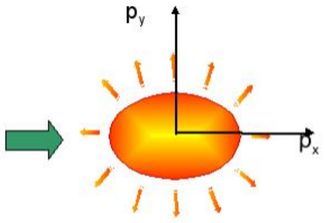


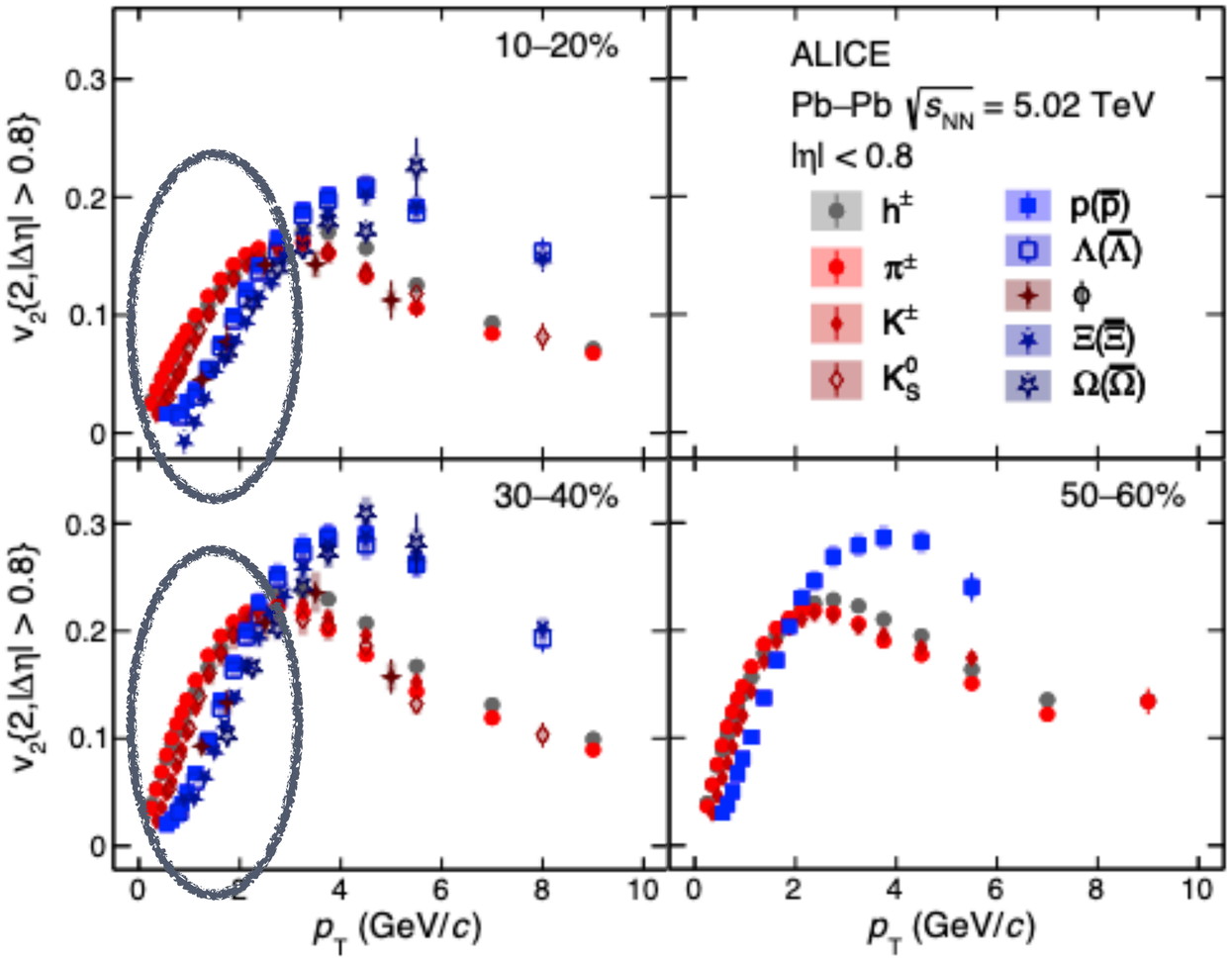
Elliptical flow of identified particles





$$v_2 = \langle \cos[2(\varphi - \psi)] \rangle$$

- Full set of identified particles
- **Mass ordering** at low p_T
  - Common velocity of all hadrons - radial flow



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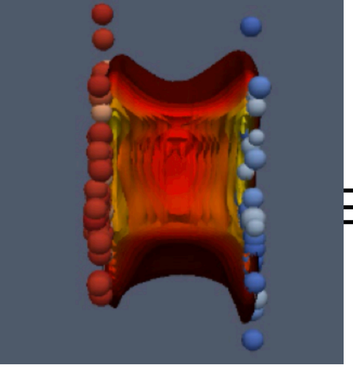
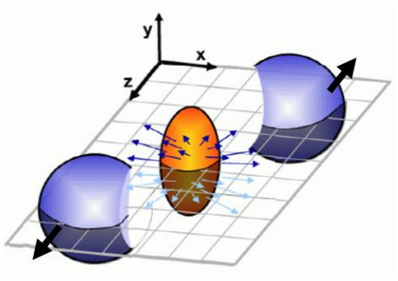
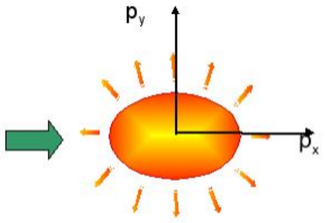
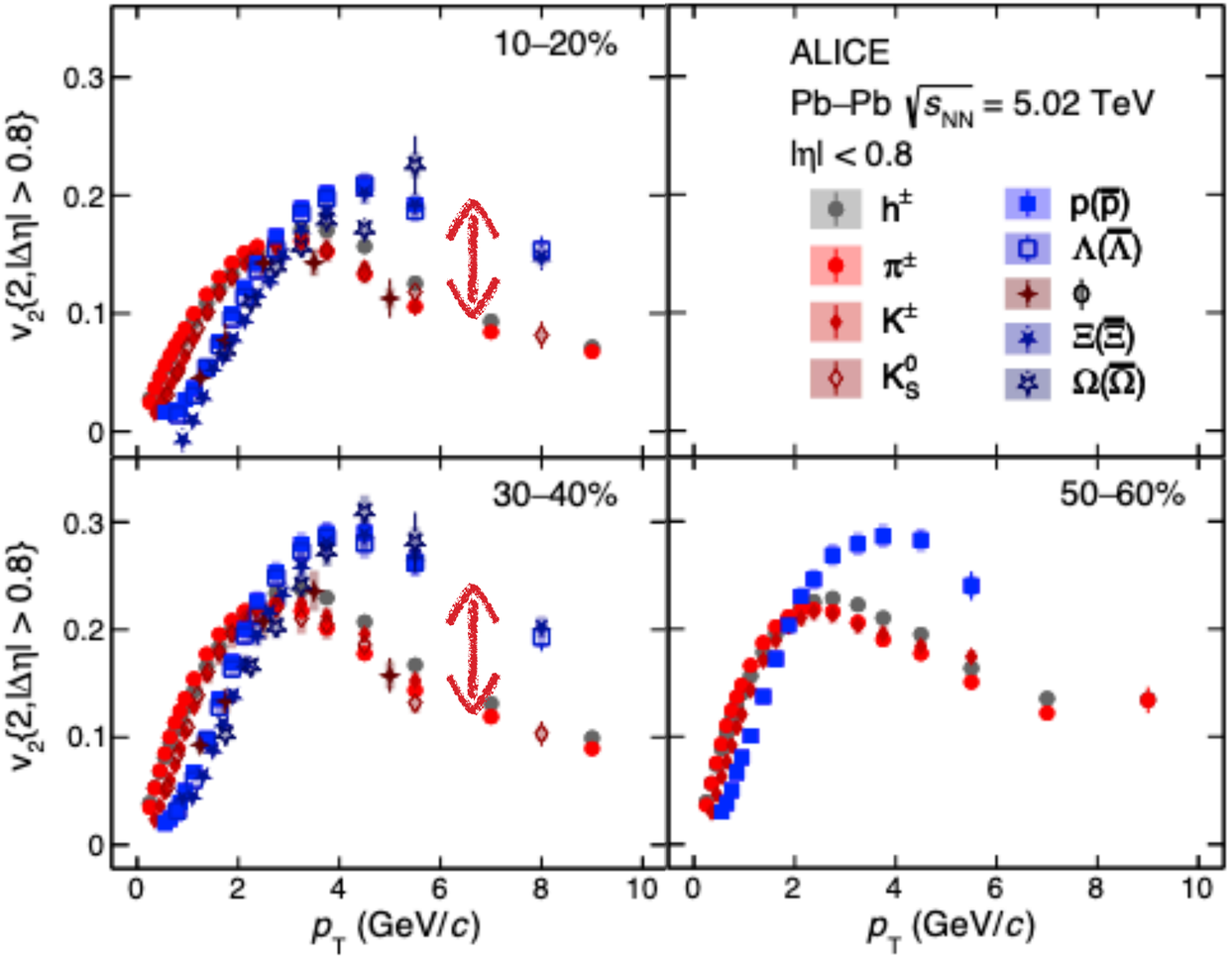


Elliptical flow of identified particles





$$v_2 = \langle \cos[2(\varphi - \psi)] \rangle$$



- Full set of identified particles
- **Mass ordering** at low p_T
  - Common velocity of all hadrons - radial flow
- Baryon/meson **grouping and splitting** at intermediate p_T
  - Hadrons created via coalescence
  - ϕ **meson** follows the meson line

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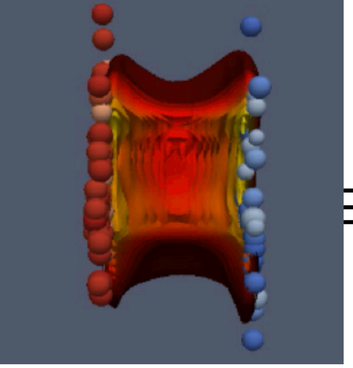
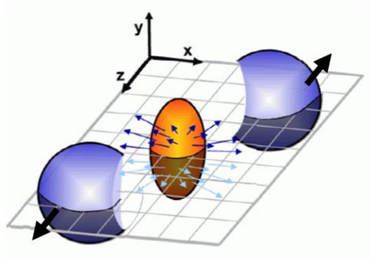
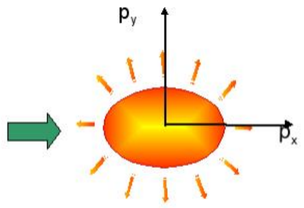
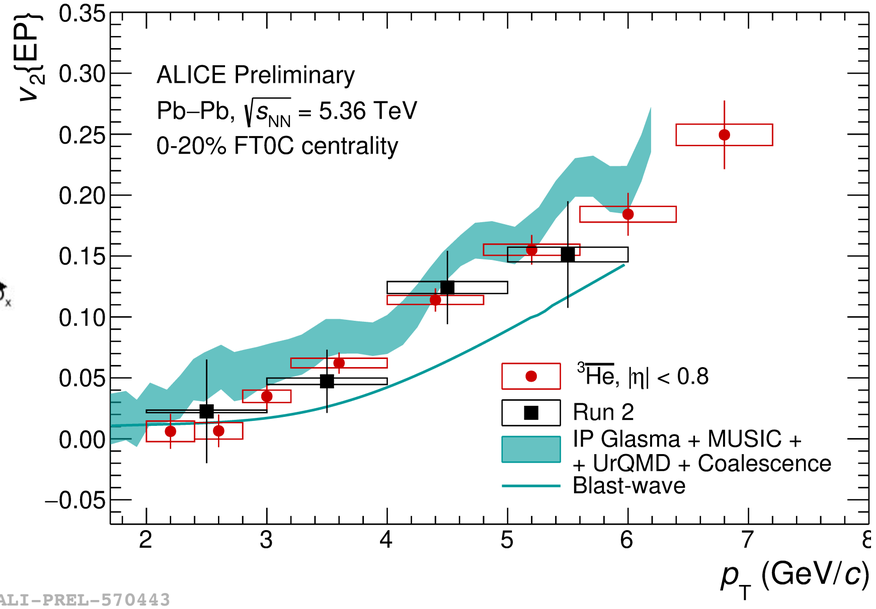
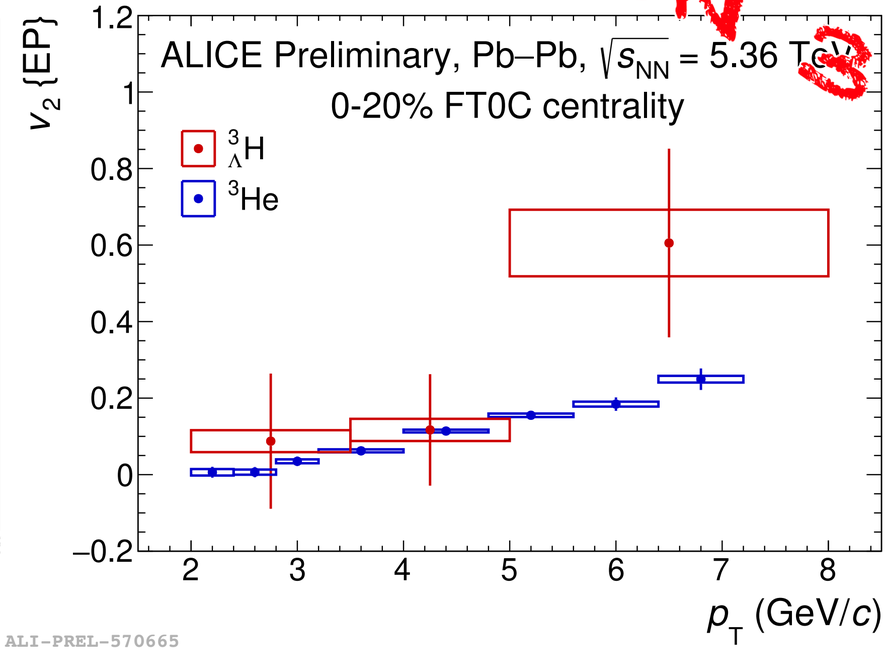
Elliptical flow of light nuclei







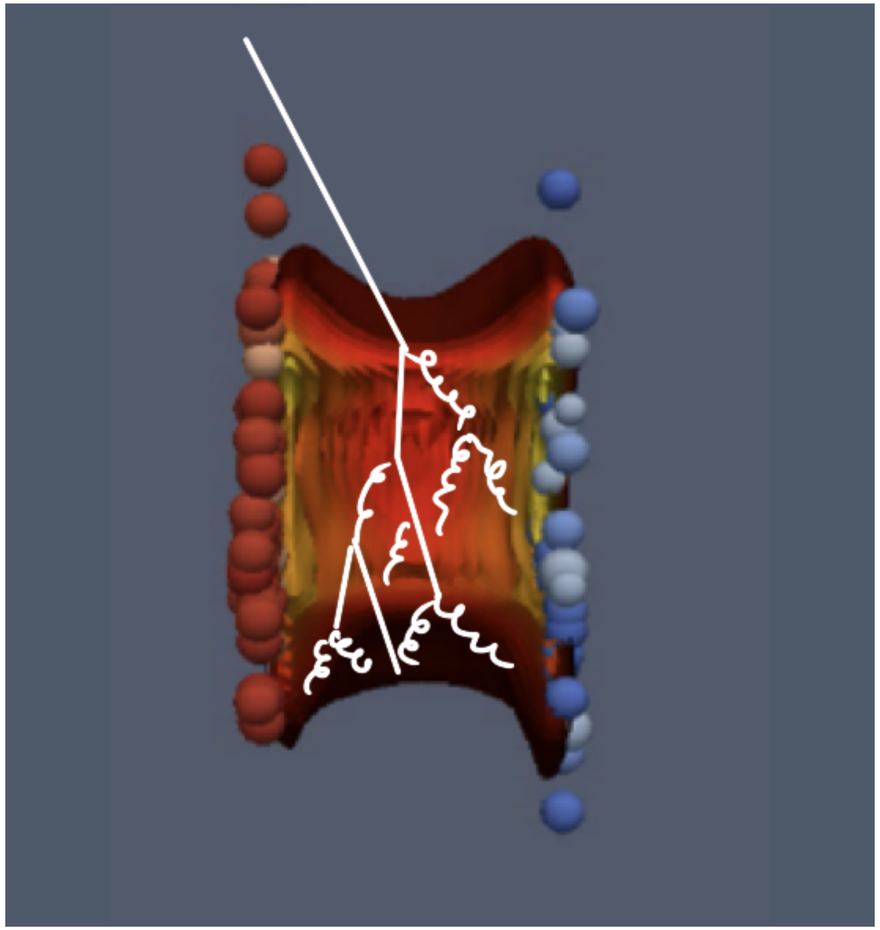


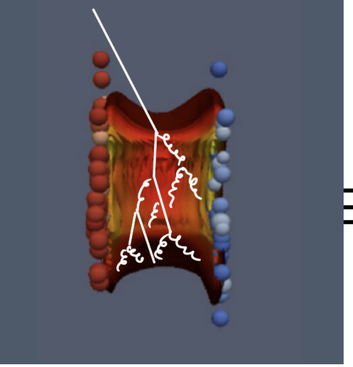


RUN 3

- v_2 of $^3\overline{\mathrm{He}}$ in Run3 - better precision
  - Discriminating power between coalescence and BlastWave (fit to π/K/p)
- First ever measurement of hypertriton flow
  - Compatible with $^3\overline{\mathrm{He}}$ v_2 within the uncertainties

Hard parton interactions with QGP





Semi-inclusive jet energy distribution

$$I_{AA} = \frac{\Delta_{\text{recoil}}(p_{\text{T}})_{\text{AA}}}{\Delta_{\text{recoil}}(p_{\text{T}})_{\text{pp}}}$$

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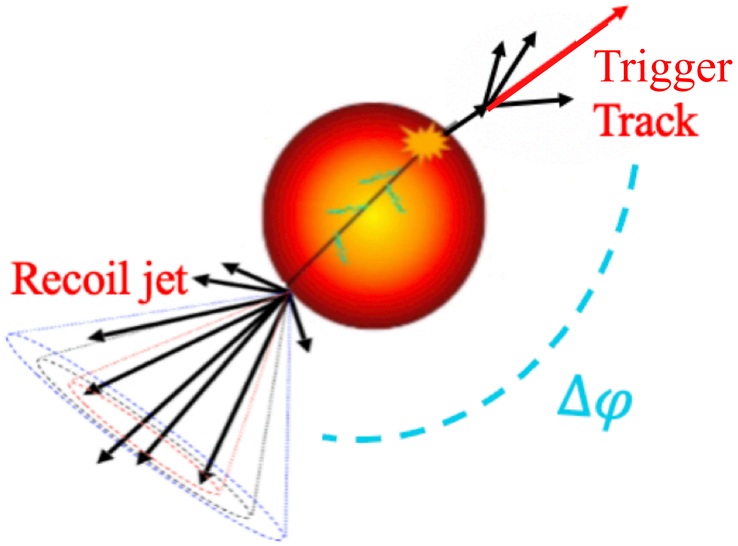
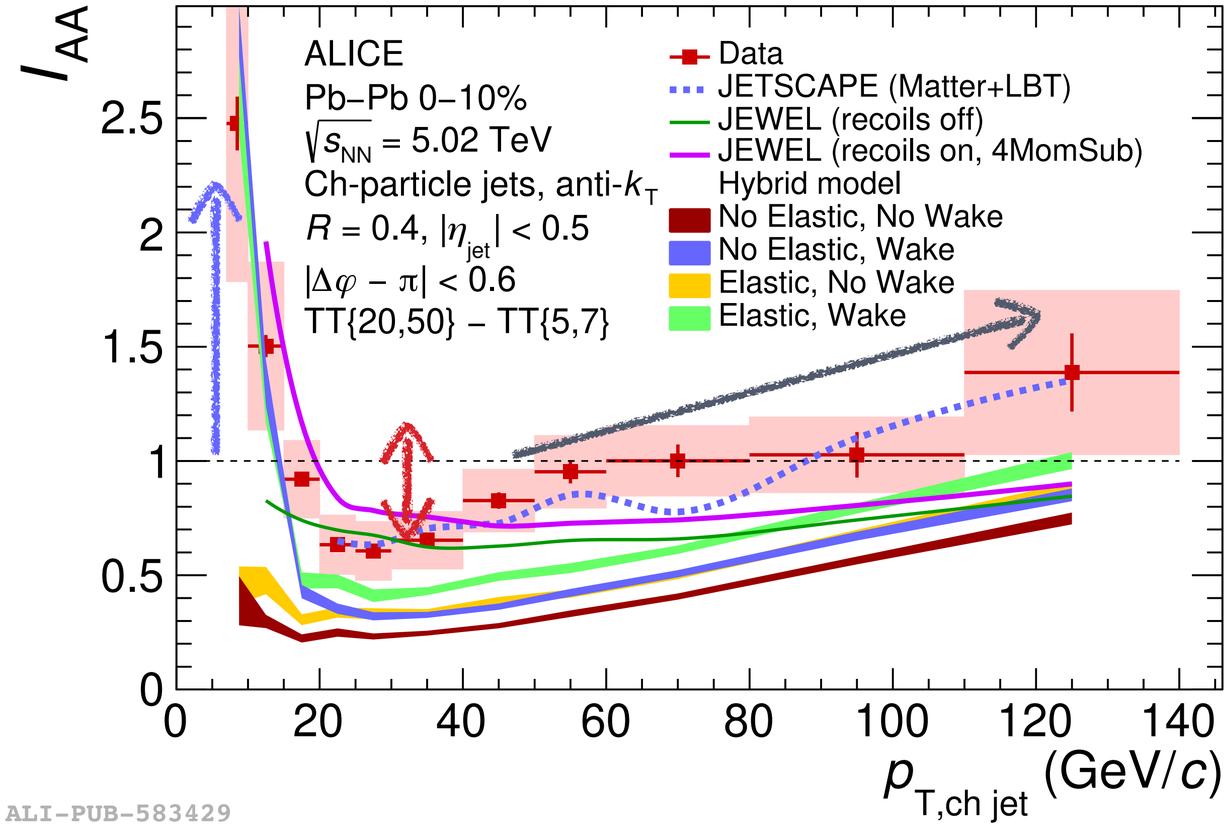
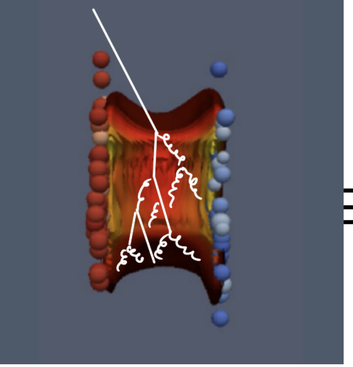
- First measurement of semi-inclusive jet yields down to low p_{T}



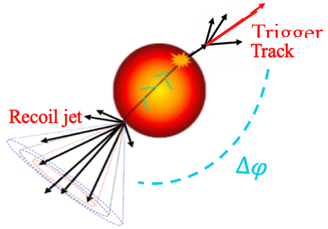


ALI-PUB-583429

PRC 110 (2024) 014906



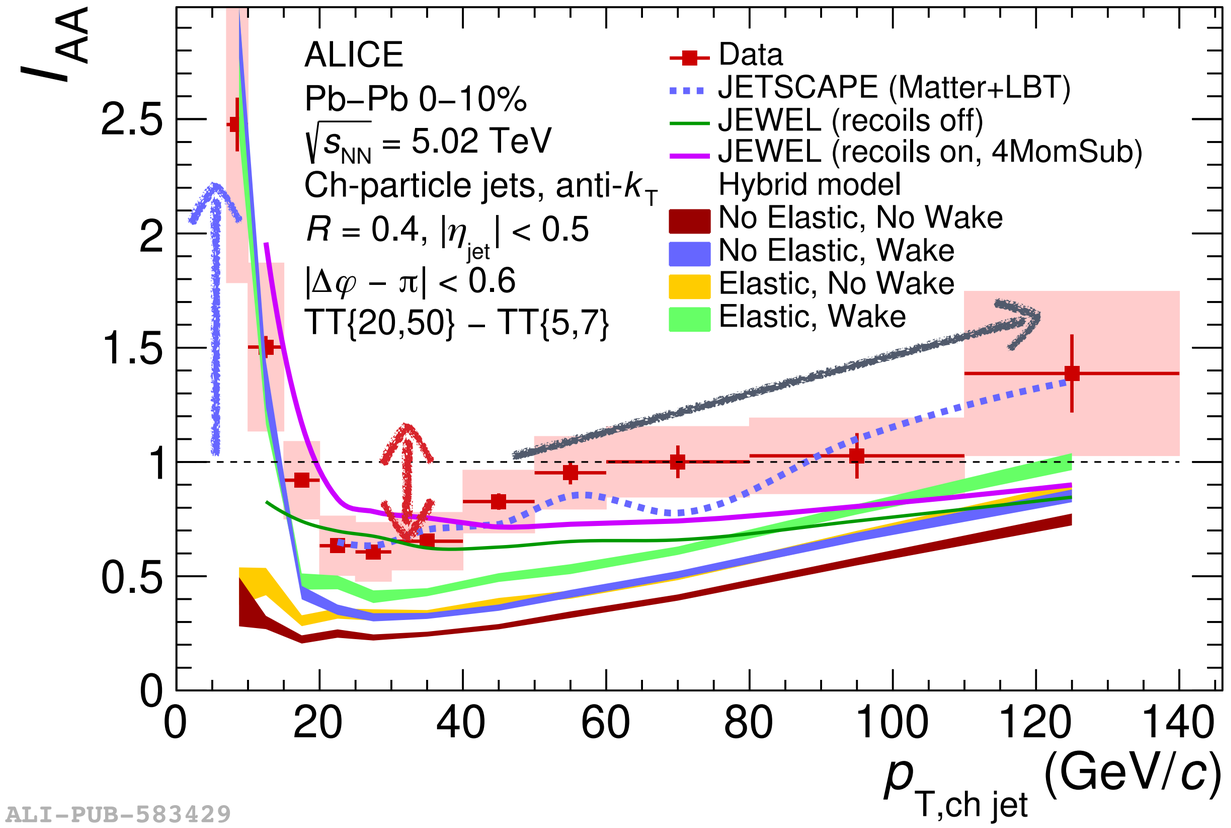
Semi-inclusive jet energy distribution



$$I_{AA} = \frac{\Delta_{\mathrm{recoil}}(p_{\mathrm{T}})_{\mathrm{AA}}}{\Delta_{\mathrm{recoil}}(p_{\mathrm{T}})_{\mathrm{pp}}}$$

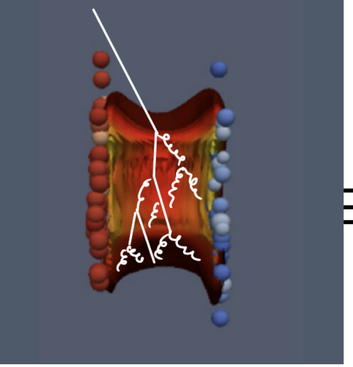
PUBLISHED

- First measurement of semi-inclusive jet yields down to low p_{T}
- **Jet yield enhancement** at low p_{T} - hint of energy recovery
- **Jet yield suppression** at intermediate p_{T} - jet energy loss
- **Rising trend** at high p_{T} - interplay of jet quenching and jet production



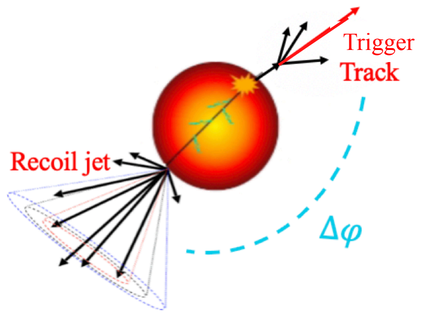
ALI-PUB-583429

PRC 110 (2024) 014906

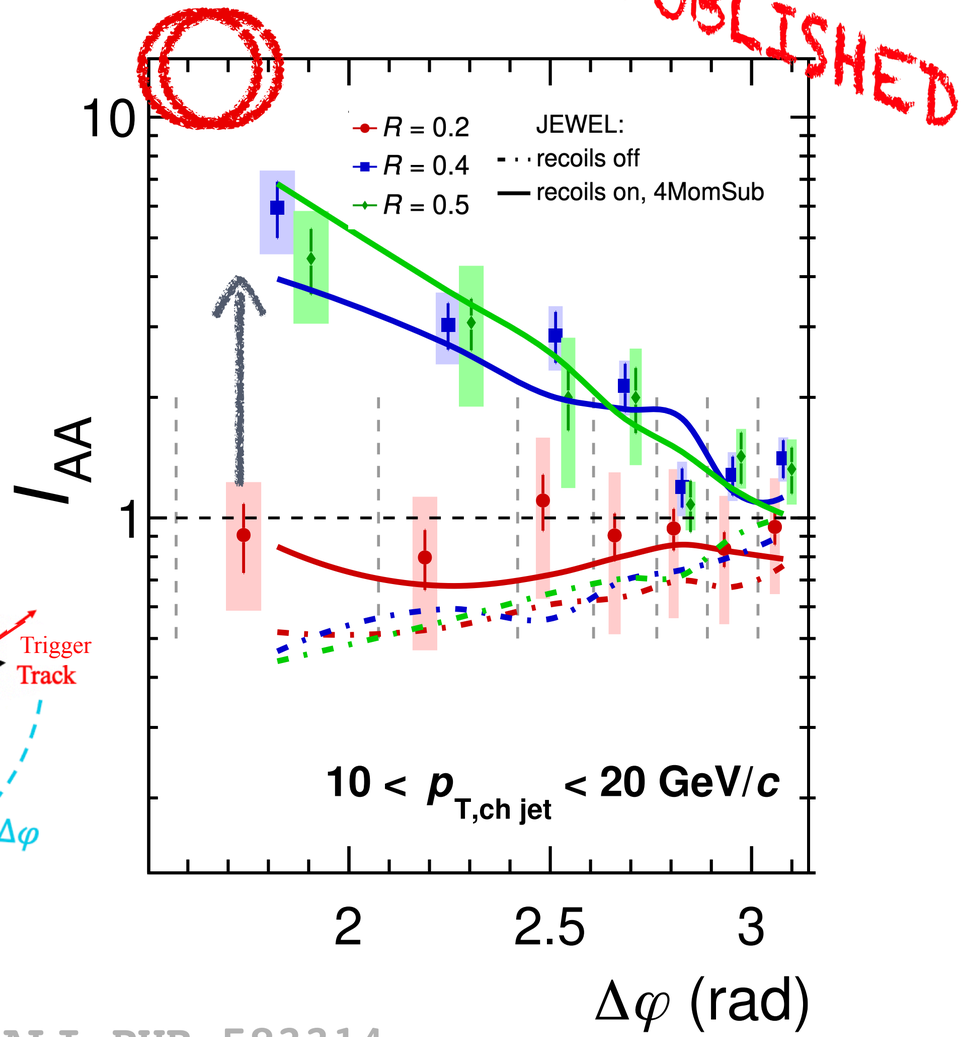


Recoil jet azimuthal modification

- **Broadening** of recoil jets from R=0.2 to R=0.4
  - Characteristic of medium response
  - Soft radiation is recovered with increasing radius
- All features reproduced by **JEWEL** with recoils on
  - The broadening is consistent with medium response

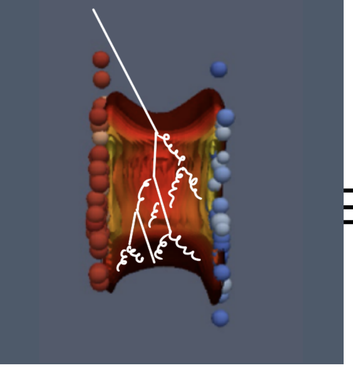


PUBLISHED



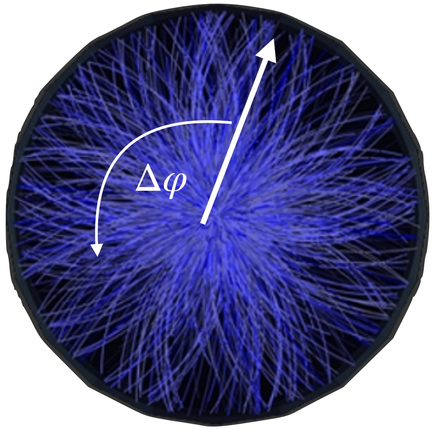
ALI-PUB-583314

PRL 133 (2024) 022301

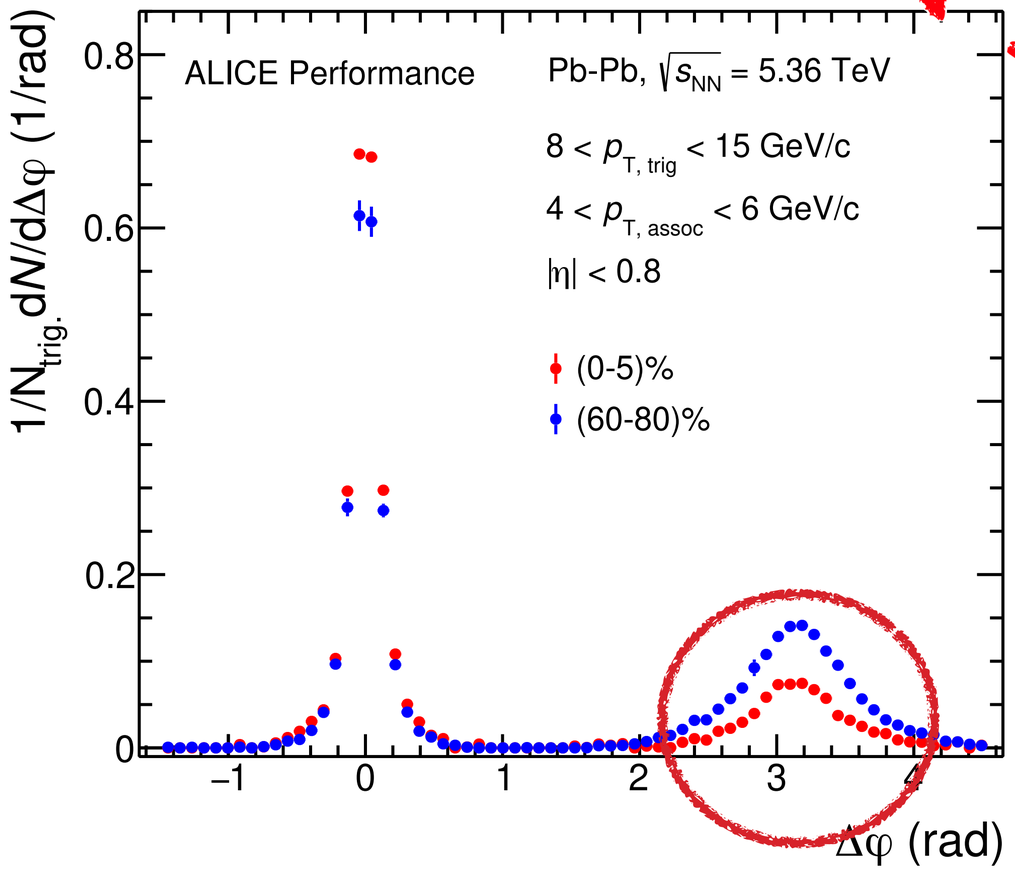


Jet quenching via dihadron correlations

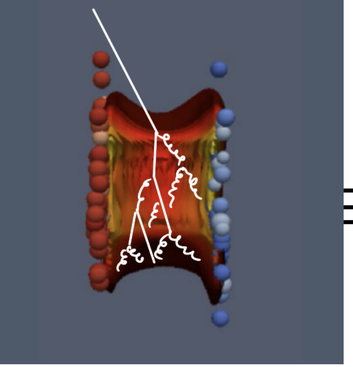
- High p_T track used as a jet proxy
- Comparison between central and peripheral collisions - medium modification:
  - **Suppression** of the away-side peak



RUN 3

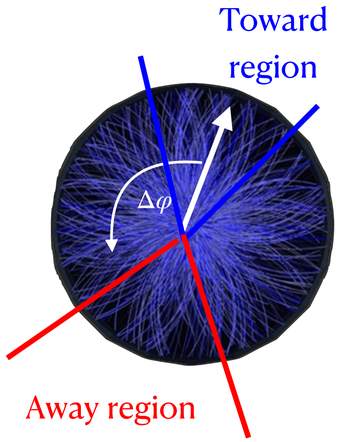


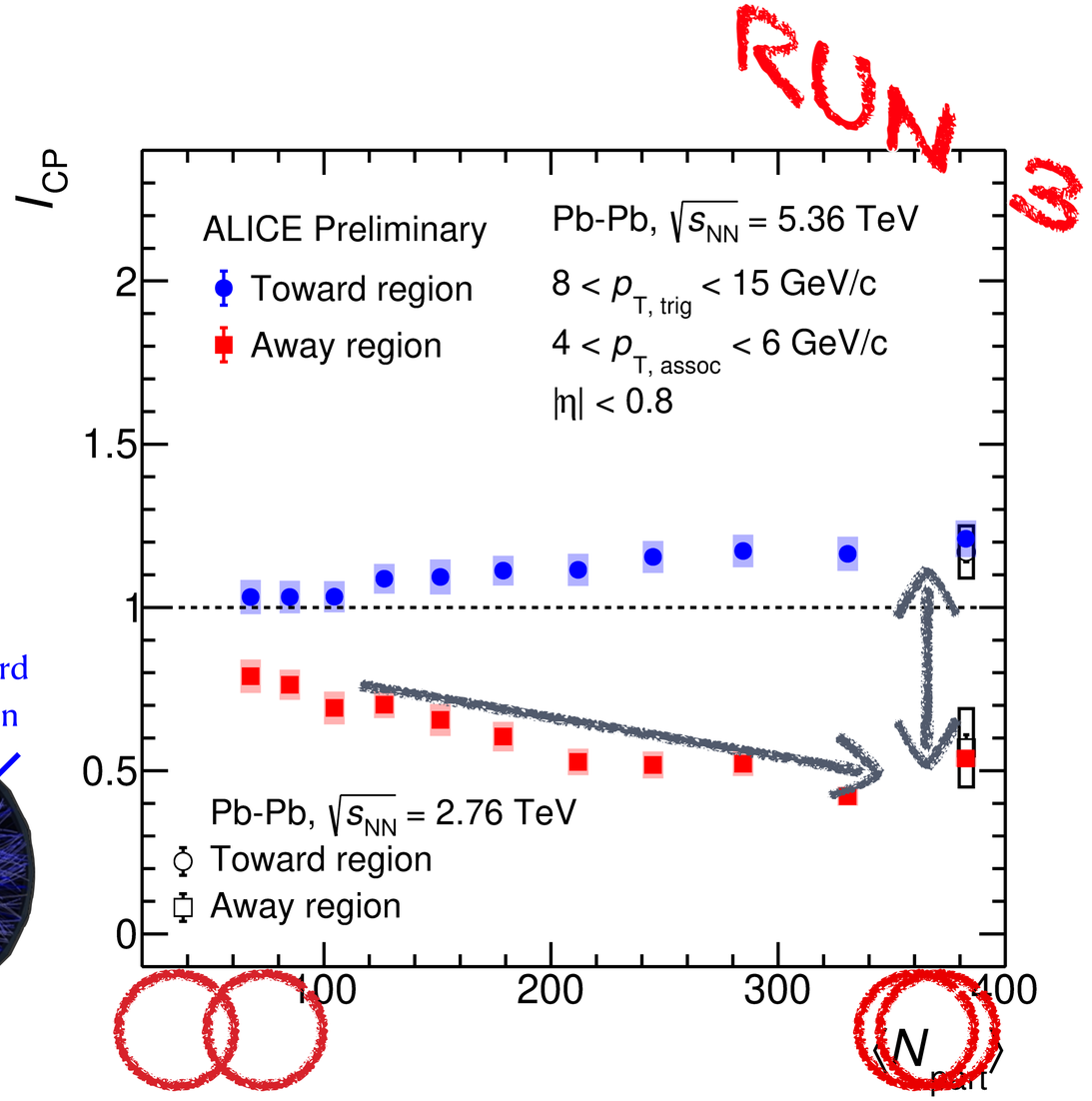
ALI-PERF-577184



Jet quenching via dihadron correlations

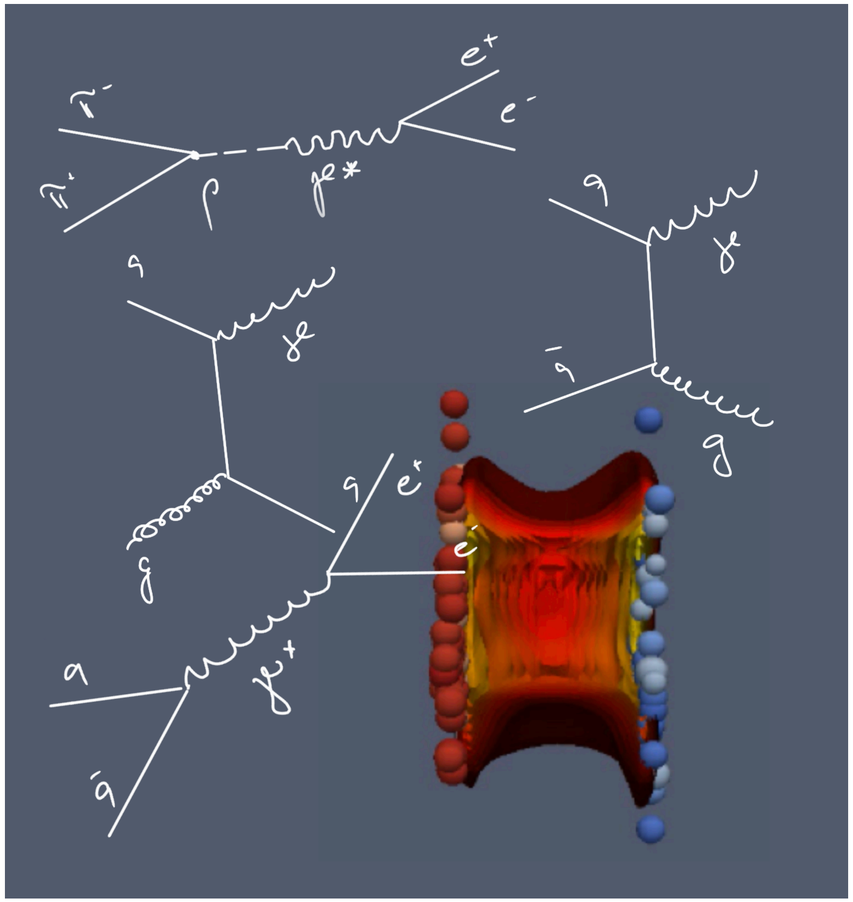
- Trigger particle used as a jet proxy
- Comparison between central and peripheral collisions - medium modification:
  - **Suppression** of the away-side peak
    - **Stronger** towards central collisions - more medium
  - **Enhancement** of the near-side peak

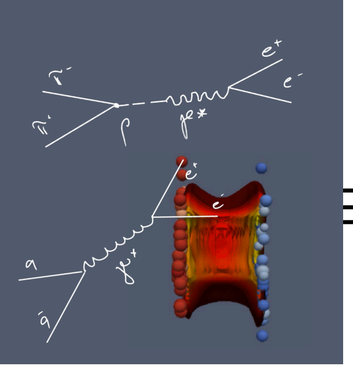




ALI-PREL-577179

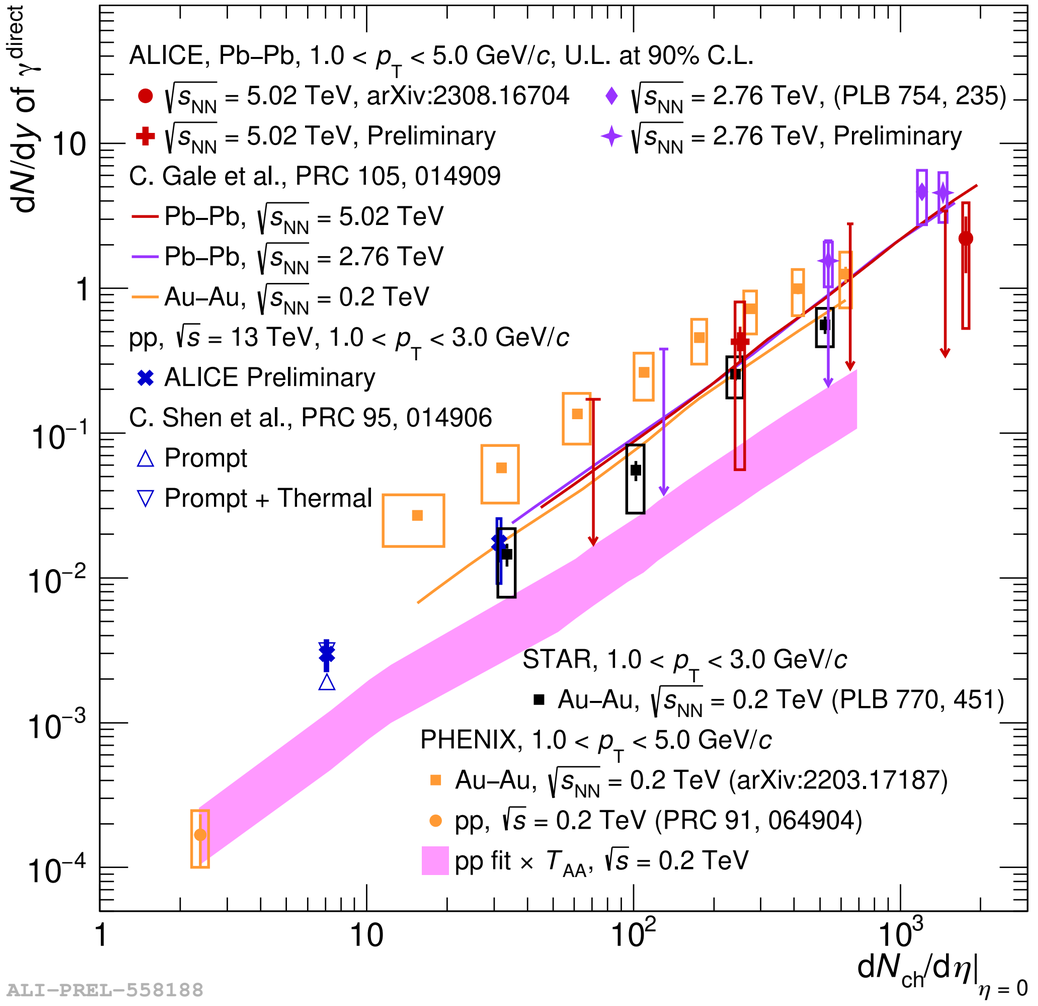
Thermal radiation

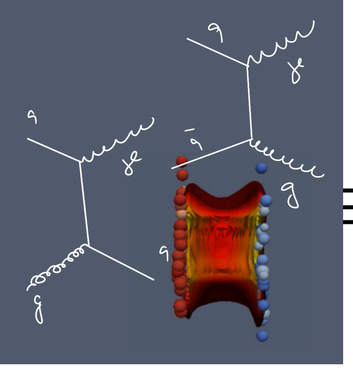




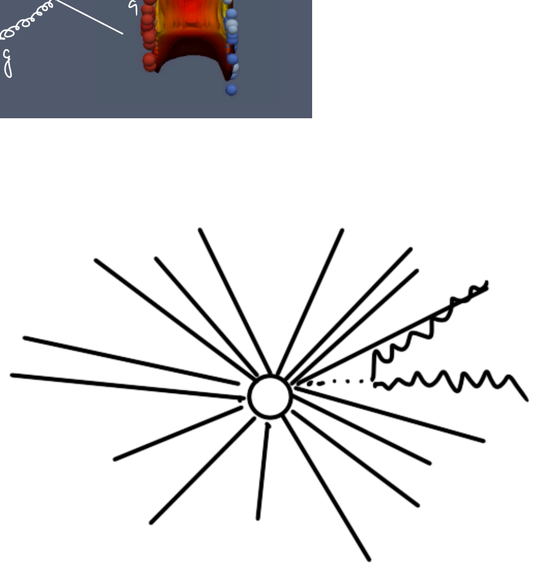
Search of the onset of thermal radiation

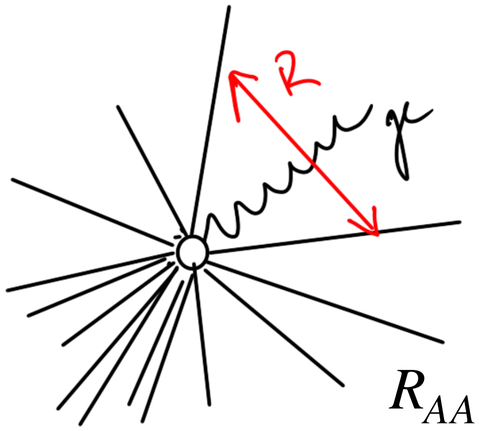
- Recent measurements in agreement with model predictions:
  - **Real photons** (PLB. 754 (2016) 235)
  - **Virtual photons** (arXiv:2308.16704)
- Small systems crucial for the theoretical model
  - **New data points** for MB and HM pp collisions
    - First measurement in small systems at low p_{T} at the LHC





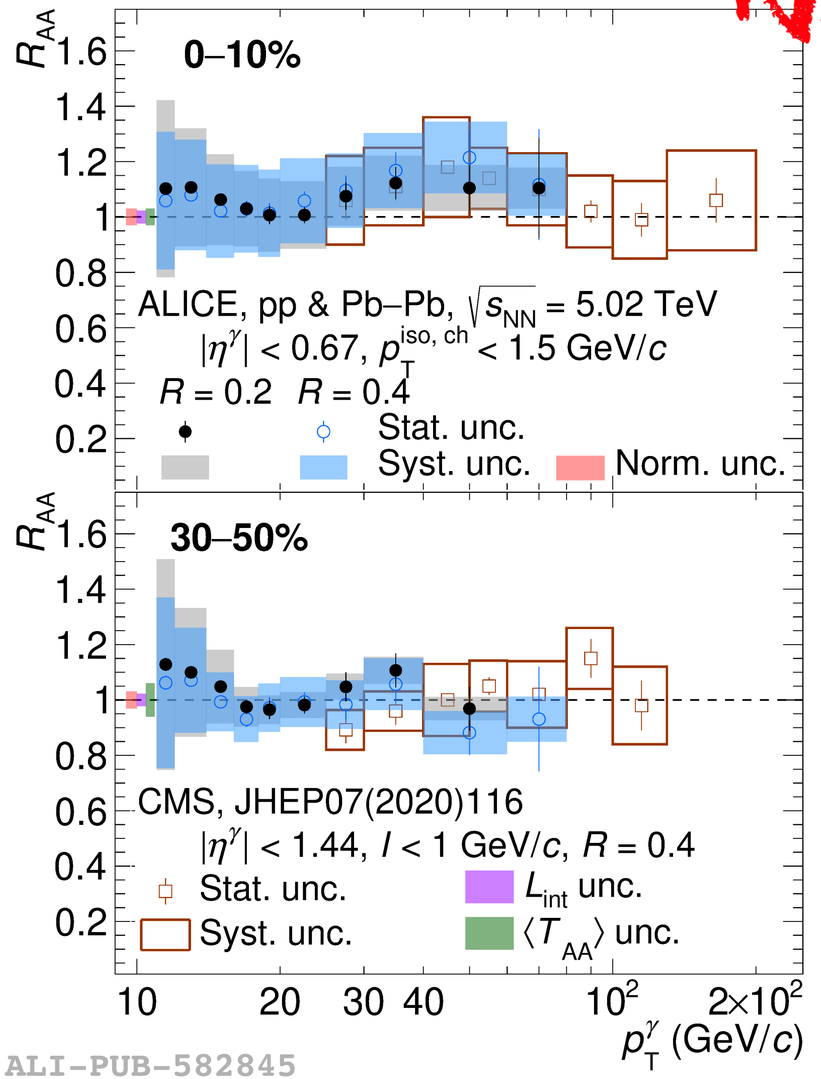
Isolated photon measurement





$$R_{AA} = \frac{\frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}{\langle T_{AA} \rangle \times \frac{\mathrm{d}\sigma_{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$

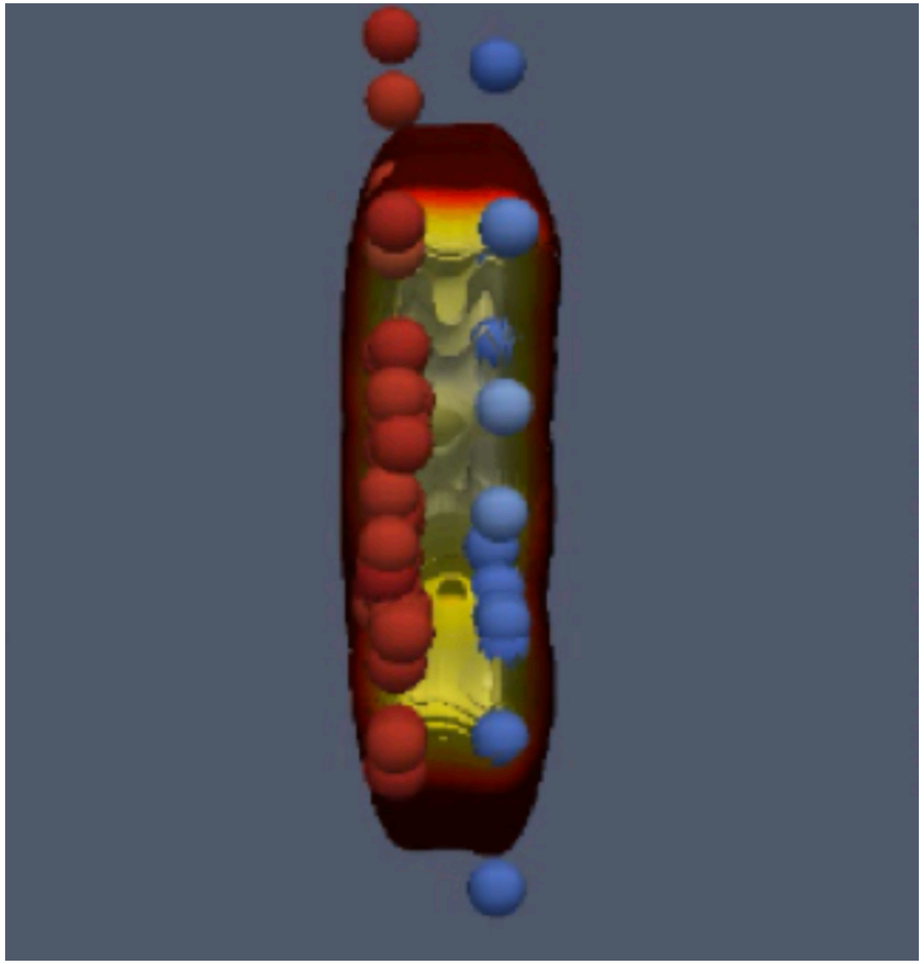
- Isolated within two radii
- R_{AA} consistent with unity
  - In contrast with hadrons - no interaction with QGP
  - Equivalent results for both radii

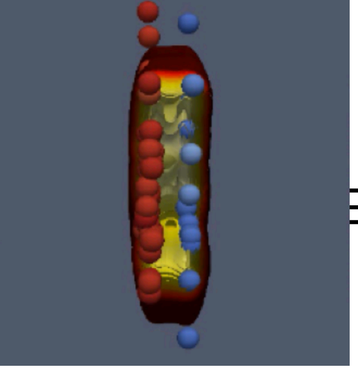


ALI-PUB-582845

arXiv:2409.12641

Initial Stages

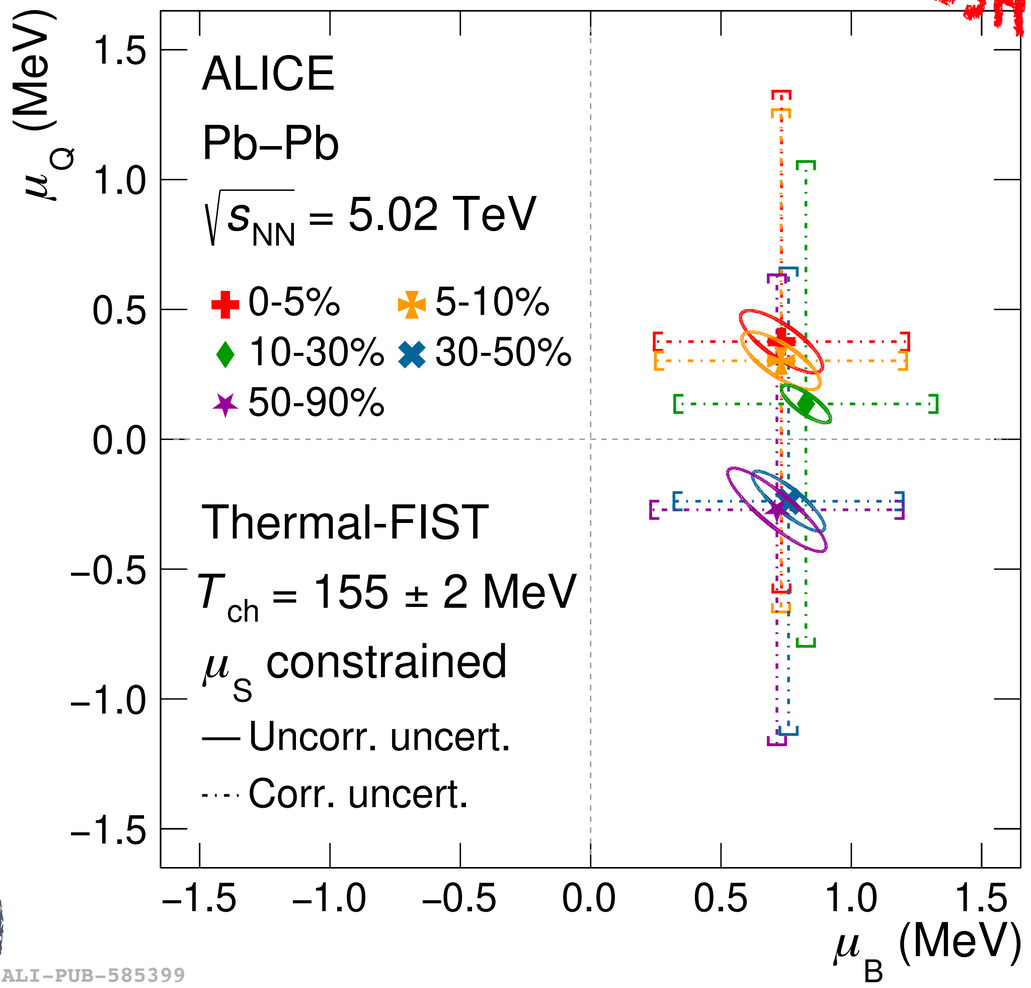




Precise measurement of the chemical potentials

PUBLISHED

- Chemical potentials extracted from the fits of antimatter/matter ratios
  - Previous uncertainty decreased by a factor of ≈ 8
- No centrality dependence and the value compatible with 0
  - Nuclear transparency regime reached even in the most central collisions

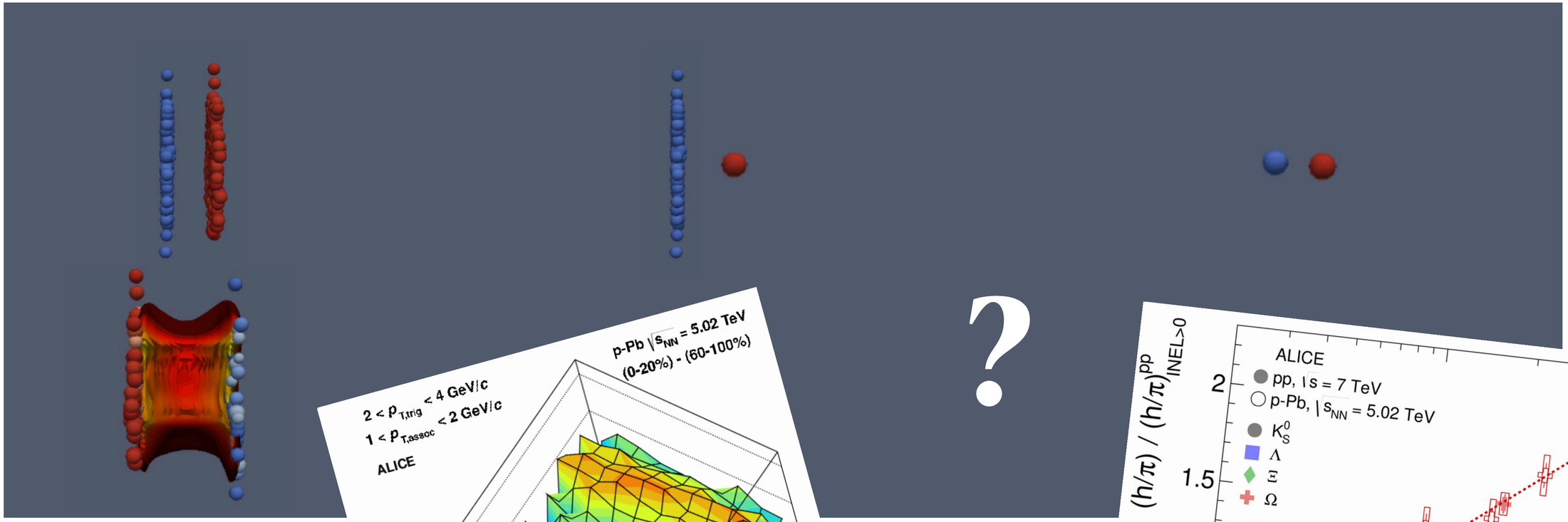


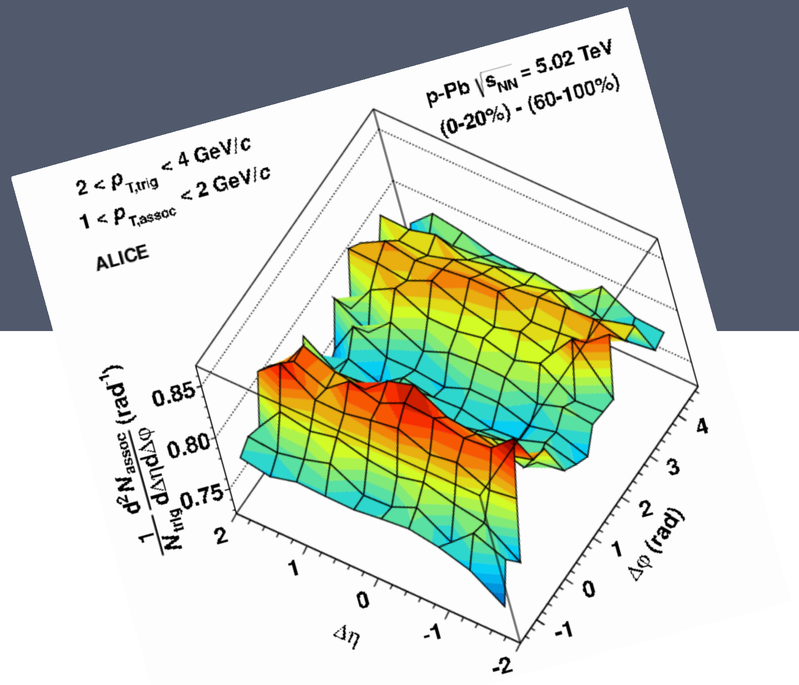
ALICE final

$$\mu_B = 0.71 \pm 0.45 \text{ MeV} \qquad \mu_Q = -0.18 \pm 0.90 \text{ MeV}$$

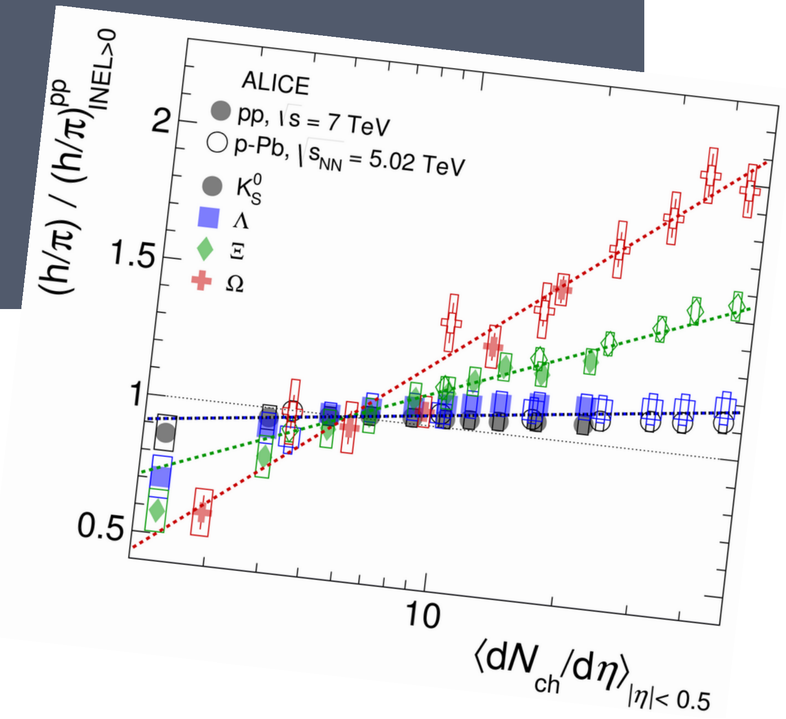
Phys. Rev. Lett. 133 (2024) 092301

Search for QGP limits



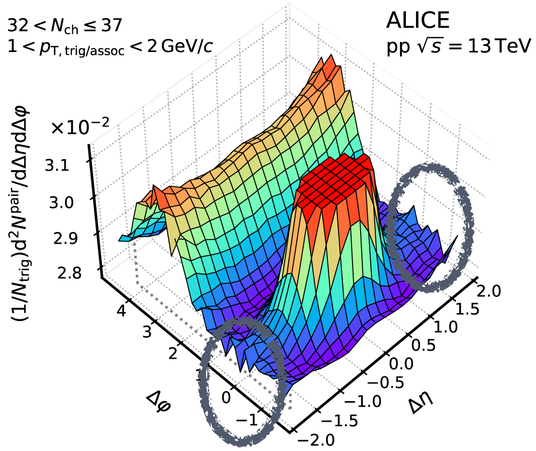


?

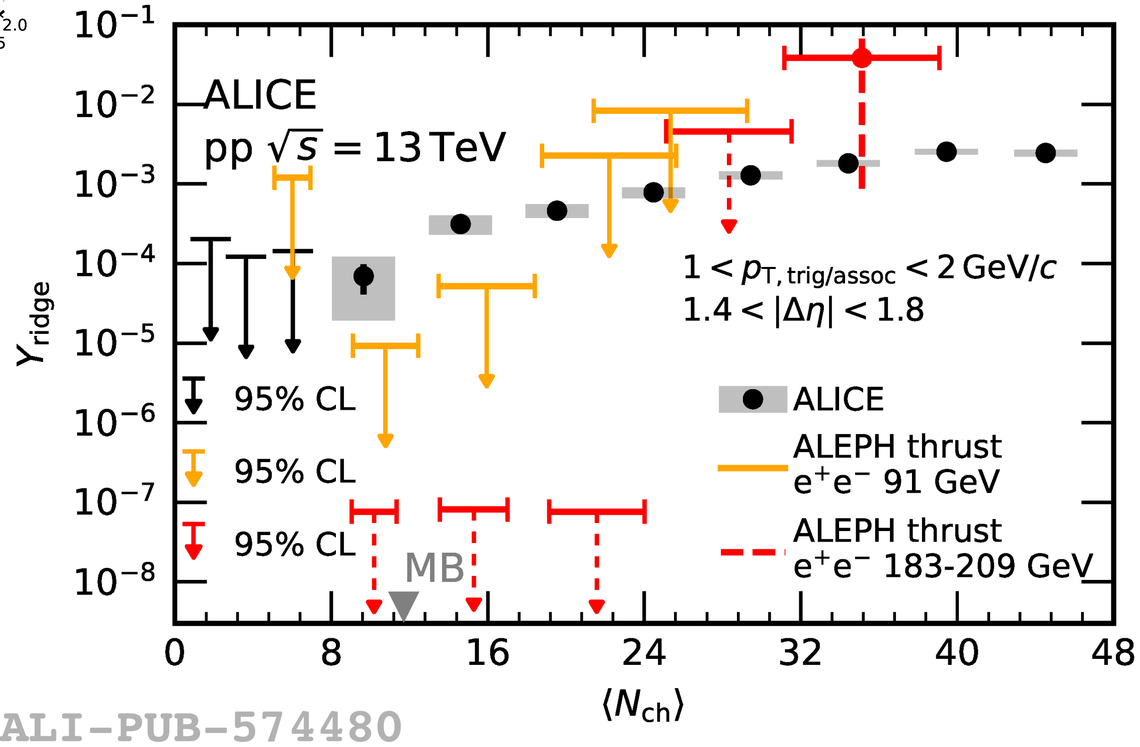


Long-range correlations at low multiplicities

PUBLISHED



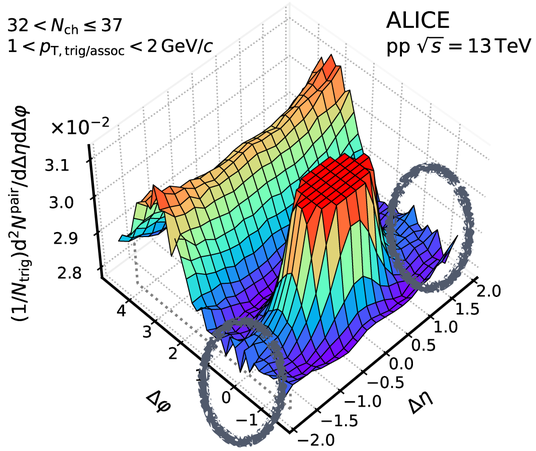
- Measurement of long-range correlations in η
- Extracted ridge yield compared with the from $e^+ + e^-$: $Y^{pp}_{ridge} > Y^{e^+e^-}_{ridge}$
  - 5σ (best) at **91 GeV**
  - 6.3σ (best) at **183-209 GeV**



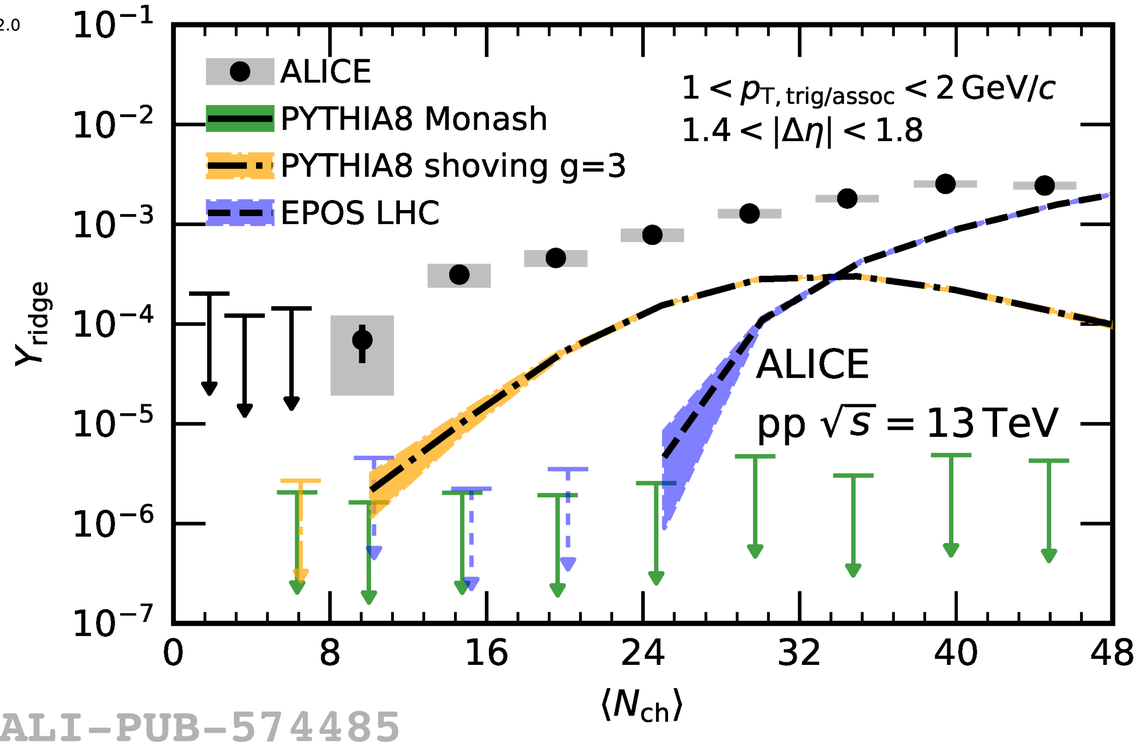
PRL 132 (2024) 172302

Long-range correlations at low multiplicities

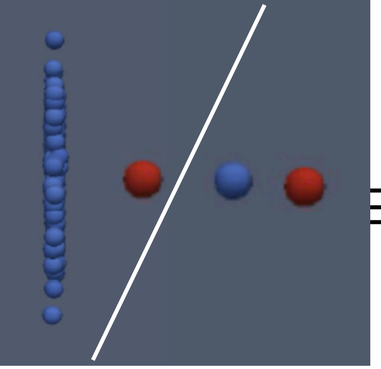
PUBLISHED



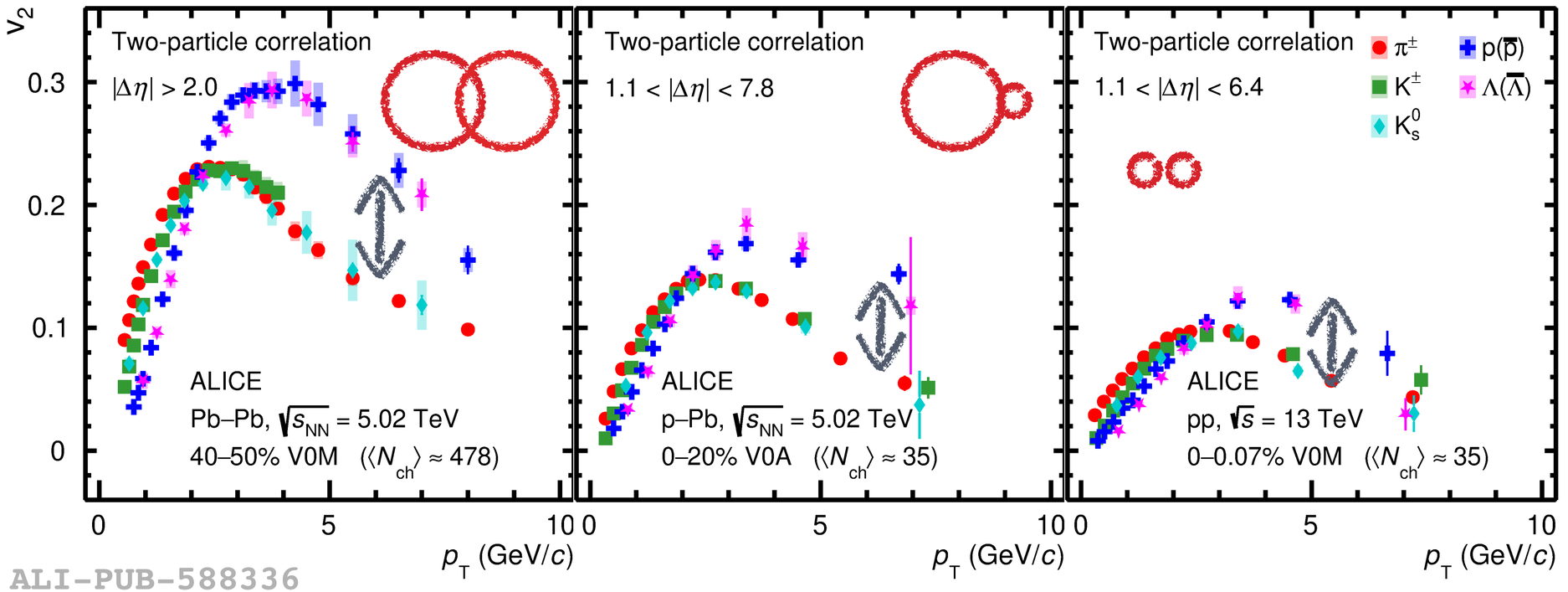
- Measurement of long-range correlations in η
- Extracted ridge yield compared with the from $e^+ + e^-$: $Y^{pp}_{ridge} > Y^{e^+e^-}_{ridge}$
  - 5σ (best) at **91 GeV**
  - 6.3σ (best) at **183-209 GeV**
- Not reproduced by the models



PRL 132 (2024) 172302



Elliptical flow of identified particles

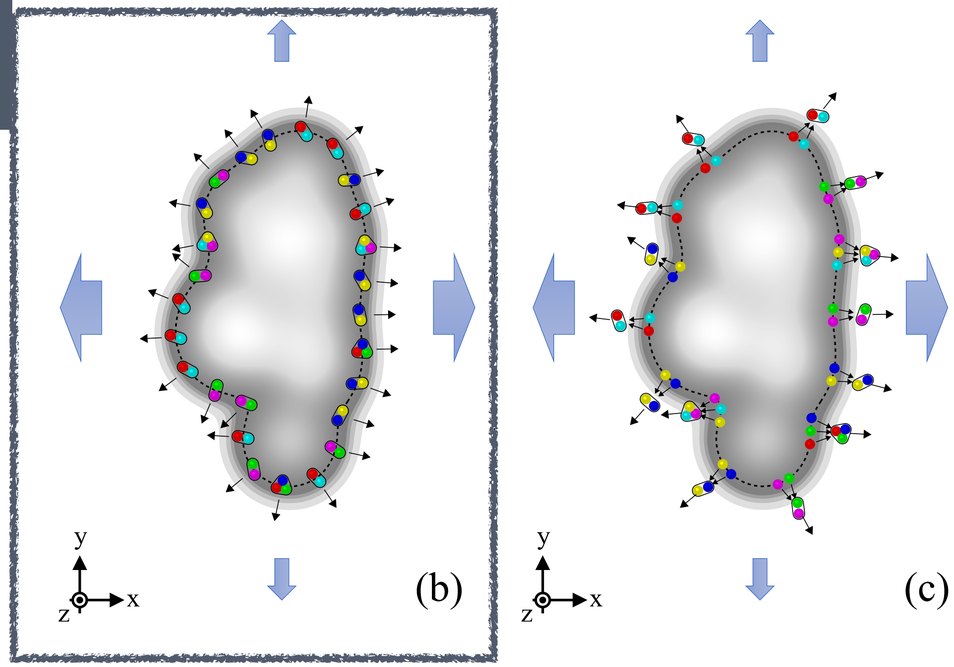


ALI-PUB-588336

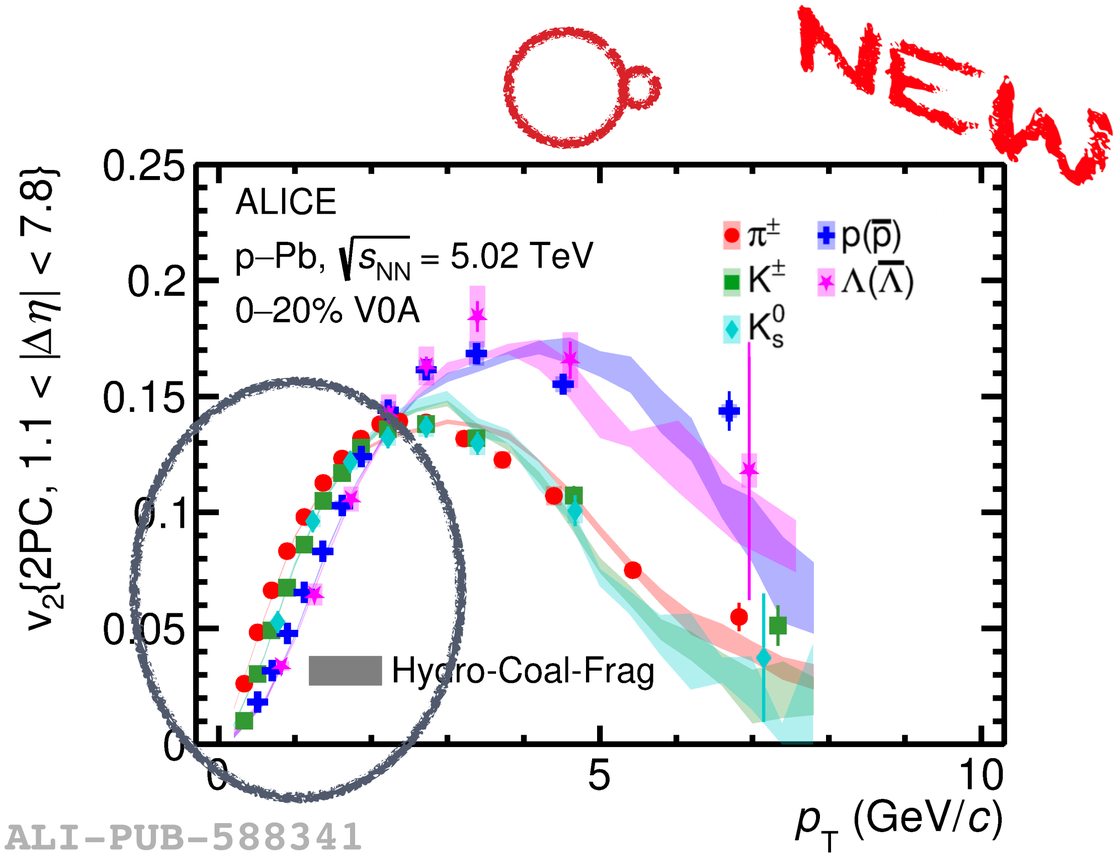
arXiv:2411.09323

- Similar shape in all 3 collision systems
- Significant **baryon/meson splitting and grouping** also in pp and p—Pb collisions

Elliptical flow of identified particles



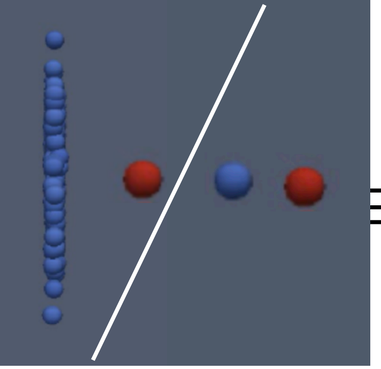
10.5281/zenodo.13819739

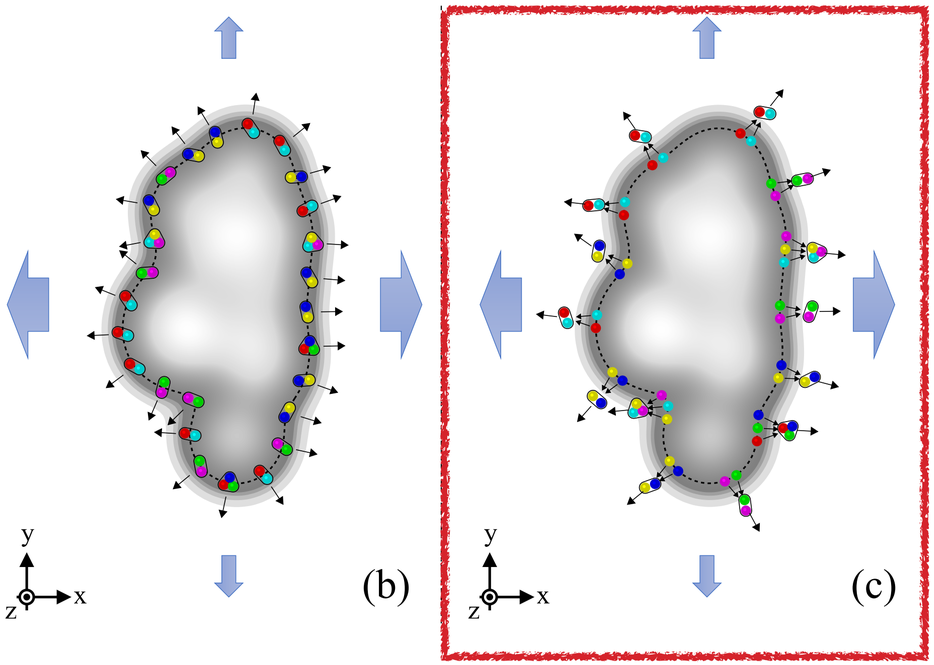


- **Mass ordering** at low p_T - hadrons emitted in a common velocity field

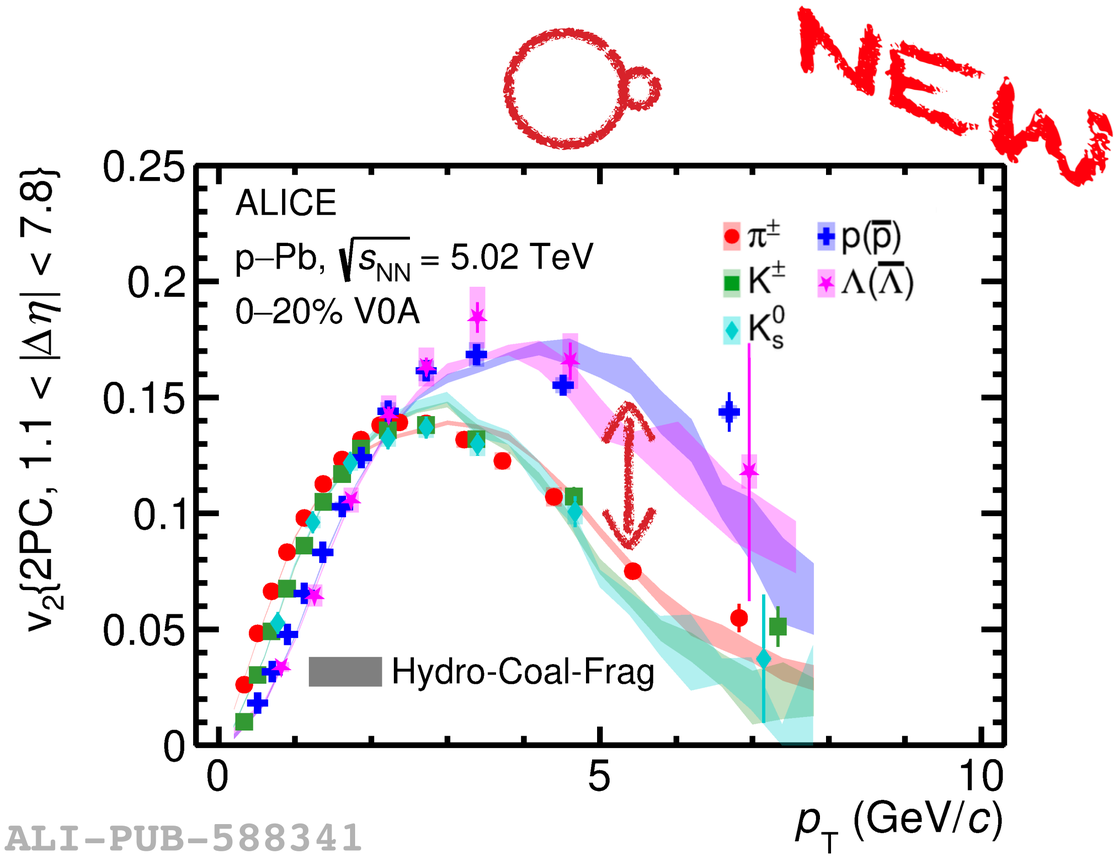
arXiv:2411.09323

Elliptical flow of identified particles





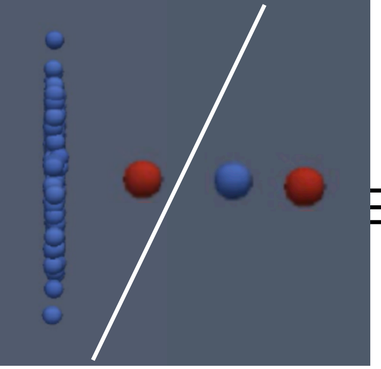
10.5281/zenodo.13819739

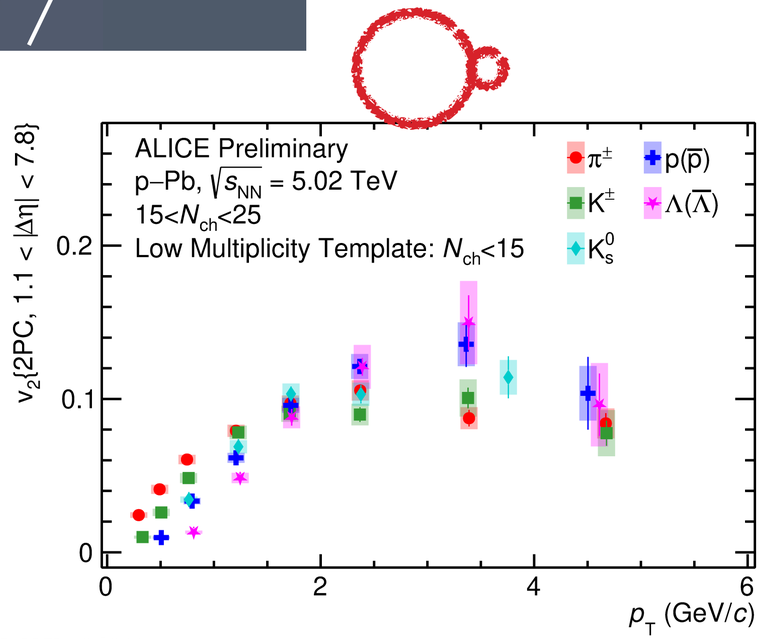


- **Mass ordering** at low p_T - hadrons emitted in a common velocity field
- **Baryon/meson splitting and grouping** described by model including coalescence

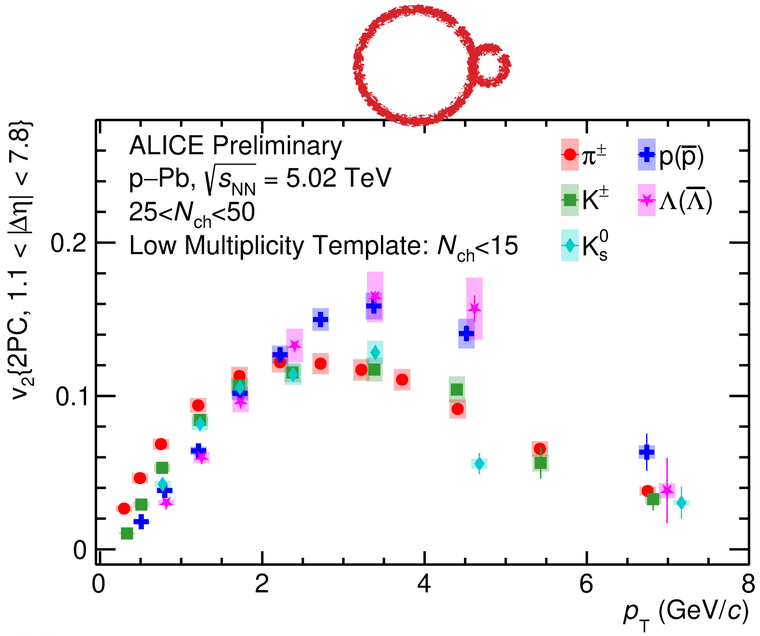
arXiv:2411.09323

Elliptical flow - multiplicity evolution

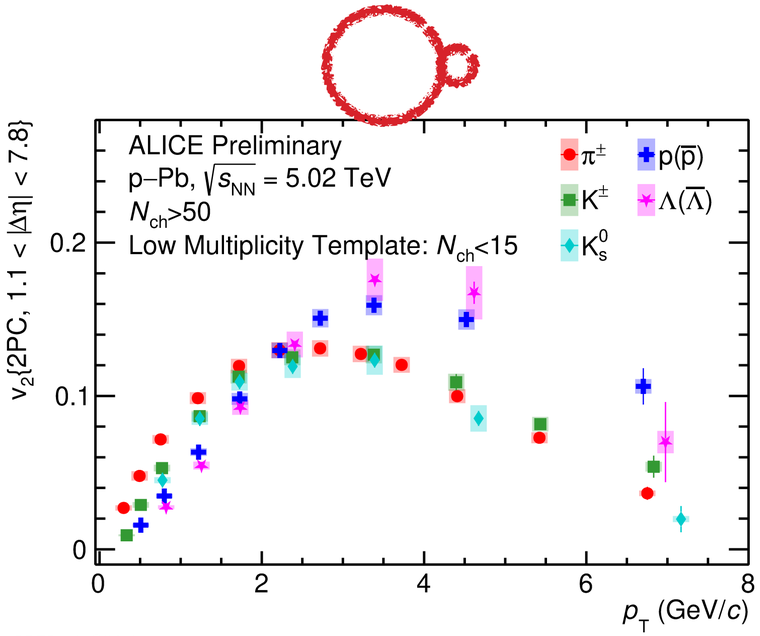




ALI-PREL-573055



ALI-PREL-573060



ALI-PREL-573065

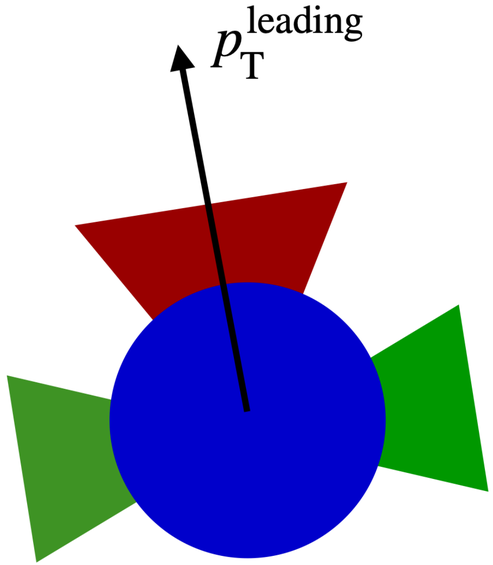
Multiplicity

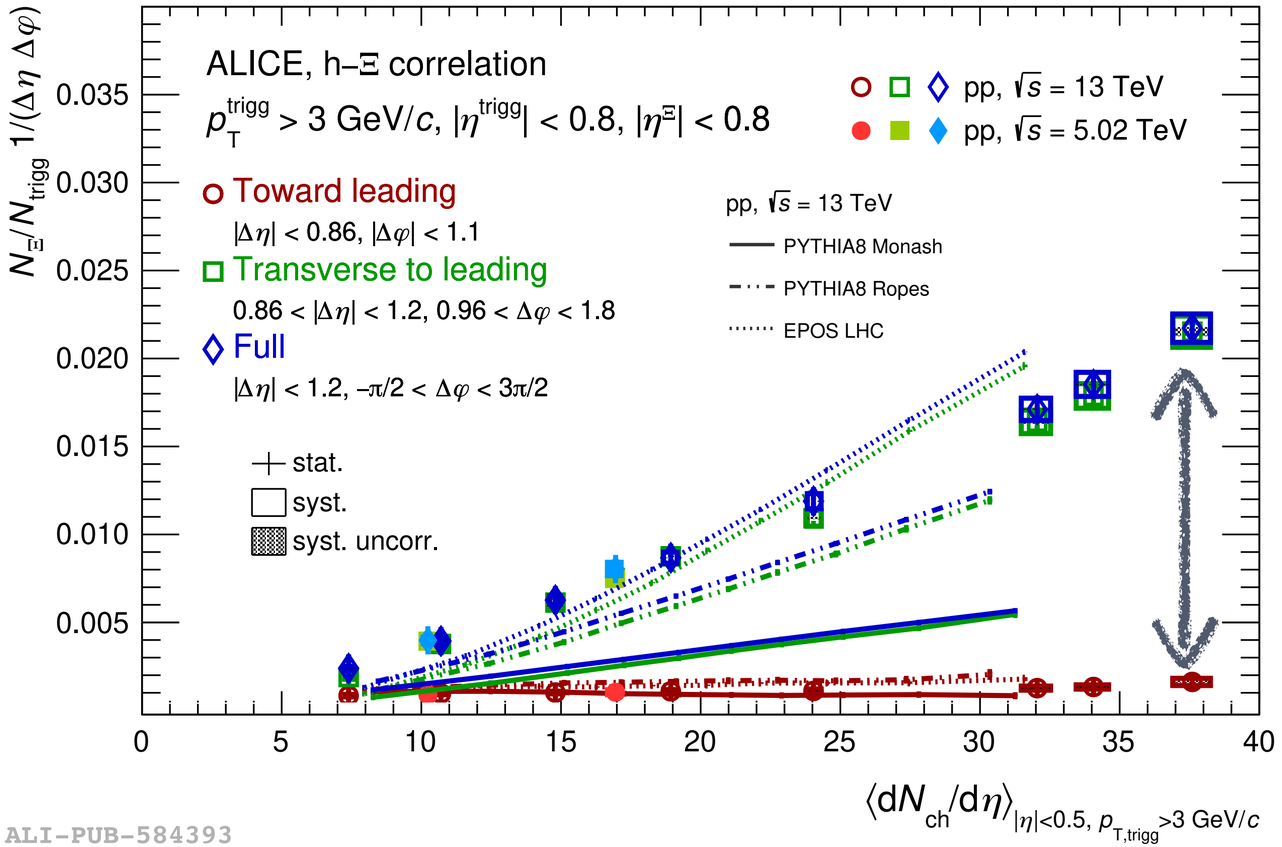
- The grouping and splitting disappears in collisions with low multiplicities
- Mass ordering remains, but up to lower p_T

Strangeness enhancement origin search

PUBLISHED

- Majority of the **total production** - in **UE**





ALI-PUB-584393

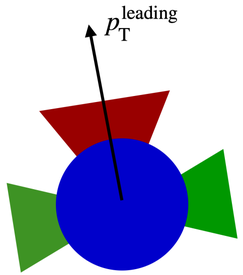
JHEP 09 (2024) 204

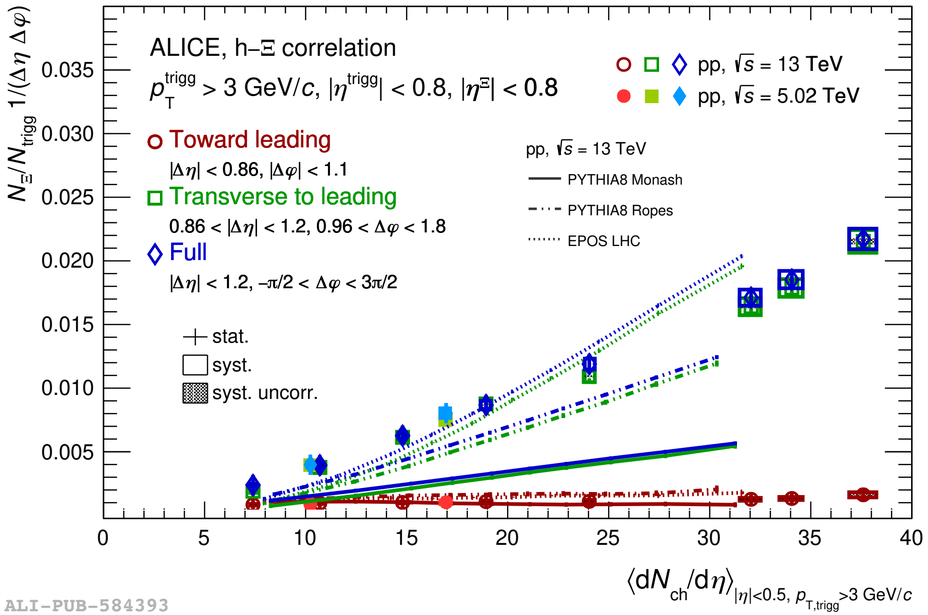
Strangeness enhancement origin search

$$\frac{S=2}{S=1}$$

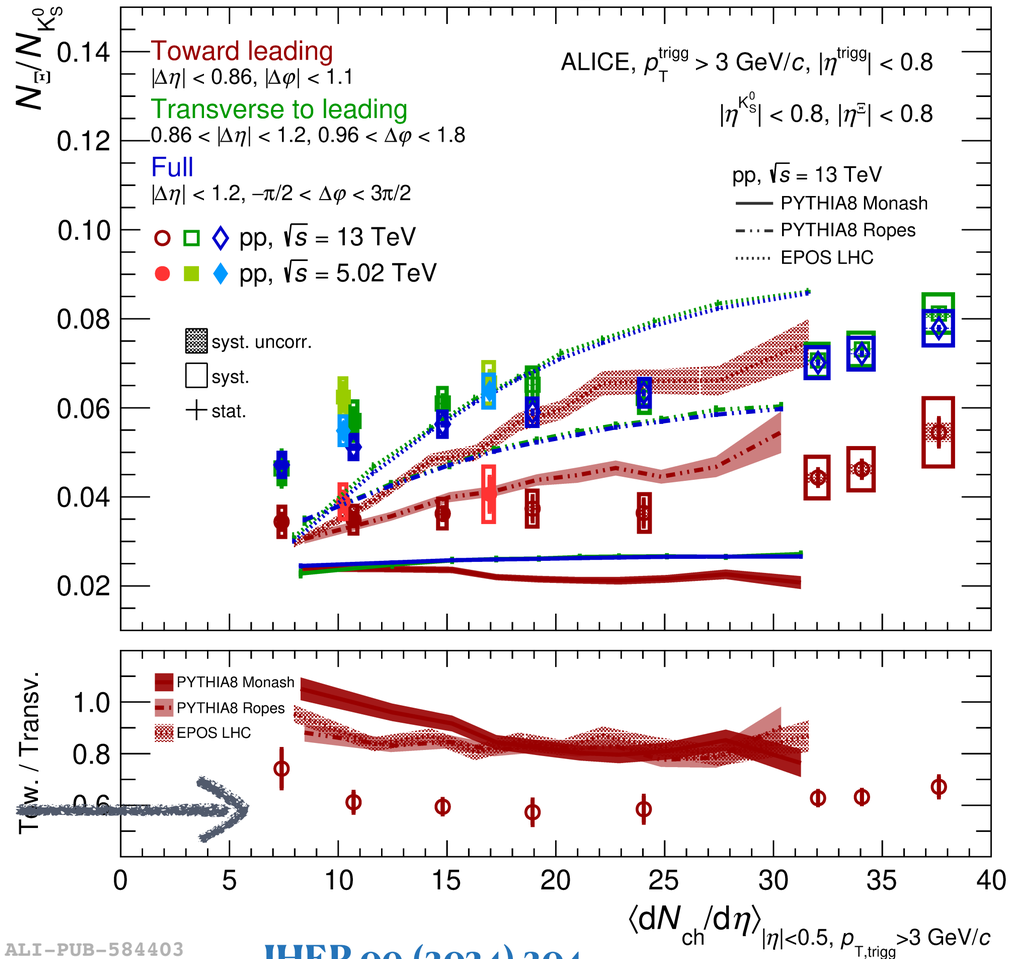
PUBLISHED

- Majority of the **total production** - in **UE**
- Steepness of the strangeness increase
  - Similar in **jets** and **UE**





ALI-PUB-584393

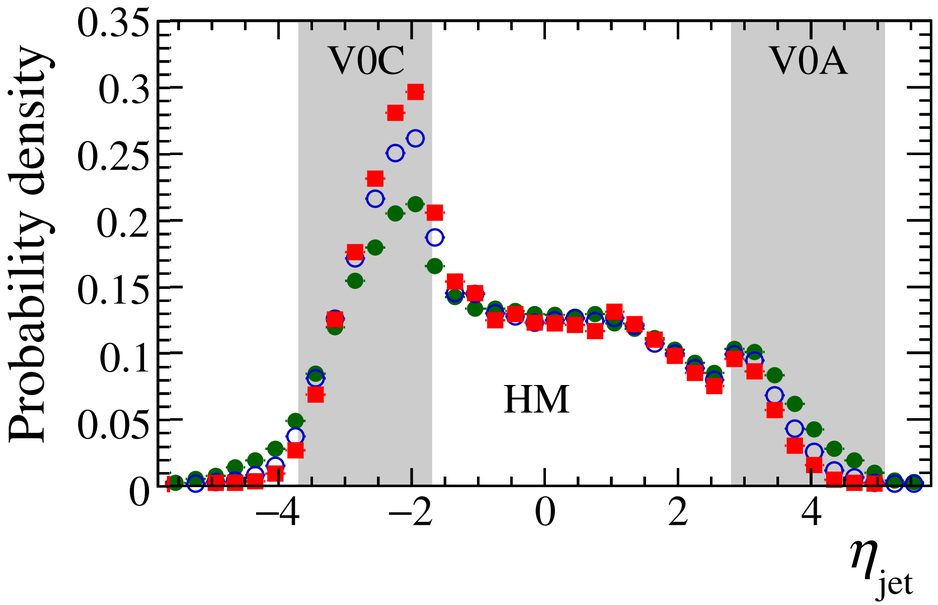


ALI-PUB-584403

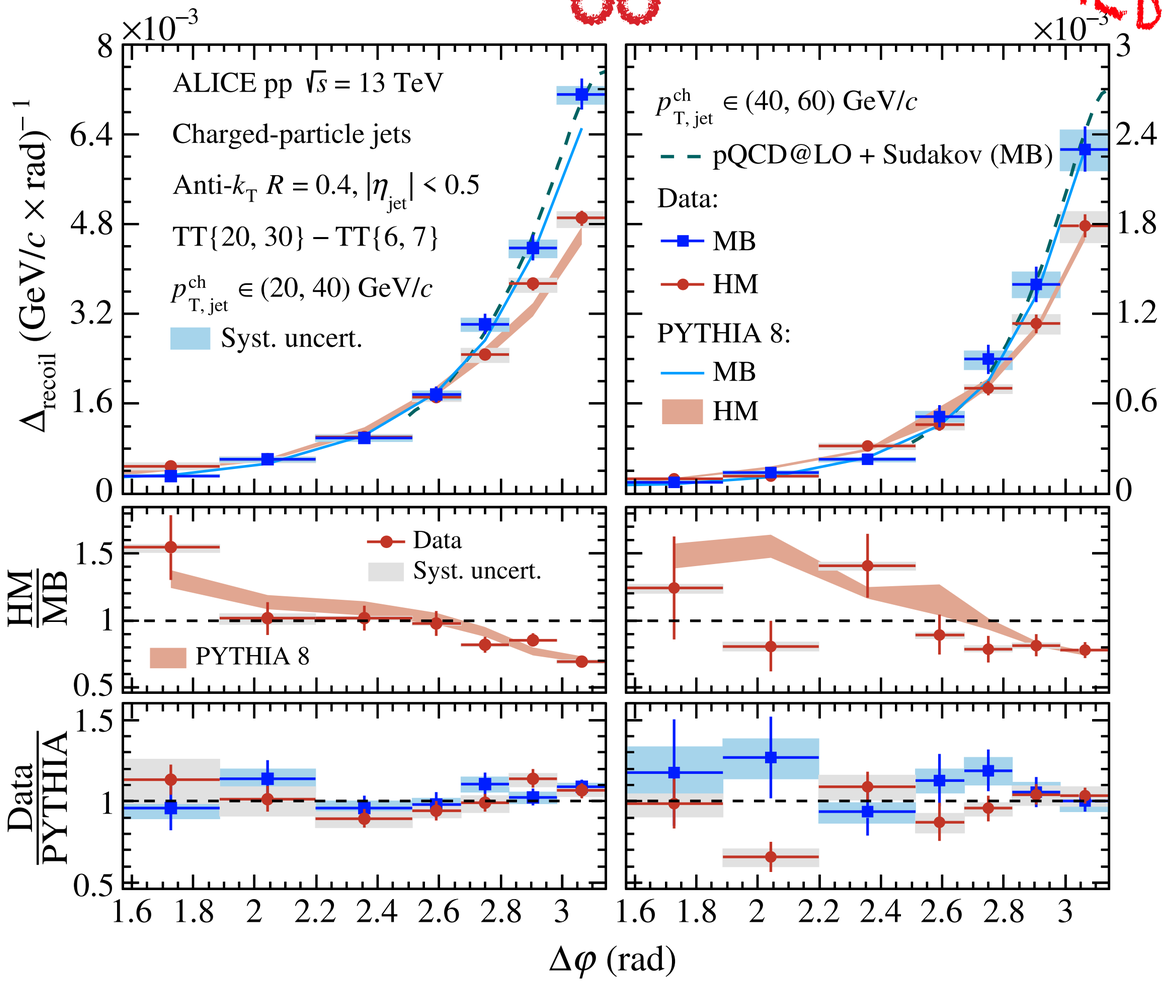
JHEP 09 (2024) 204

Search for jet quenching in small systems

- Recoil jets in **HM collisions**:
  - Broader and smaller yield
  - Signs of jet quenching in Pb—Pb
  - Explained by the **event selection biases**

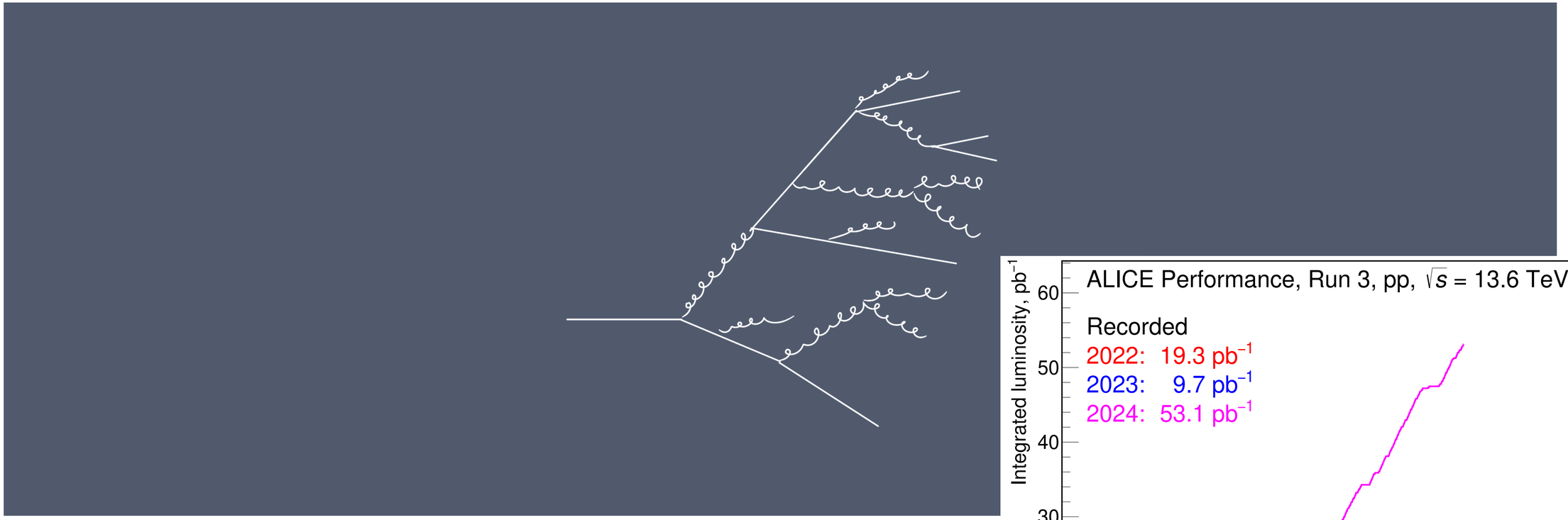


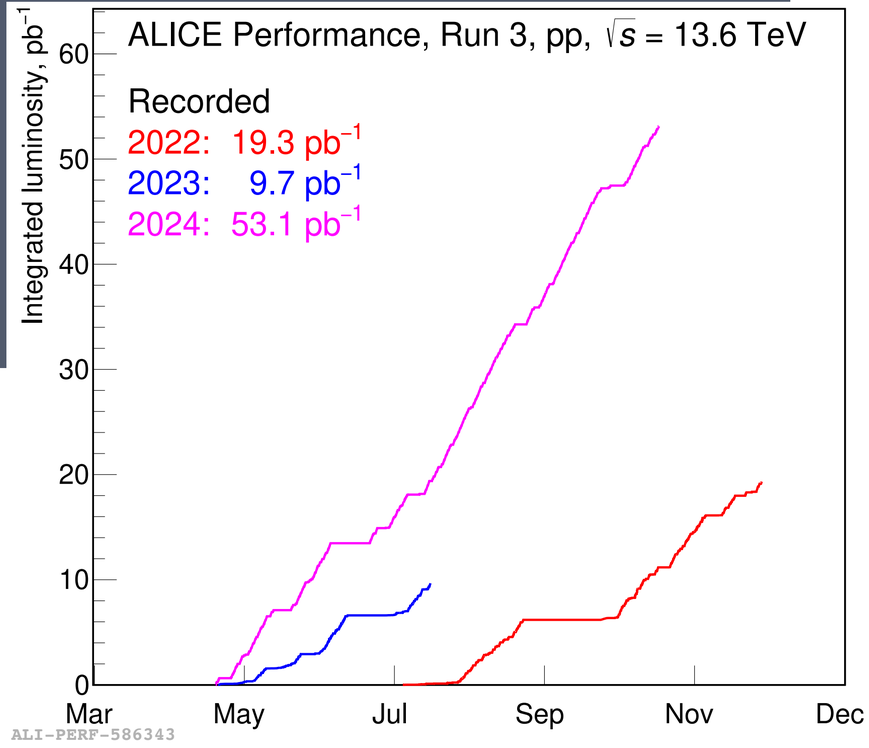
PUBLISHED



JHEP 05 (2024) 229

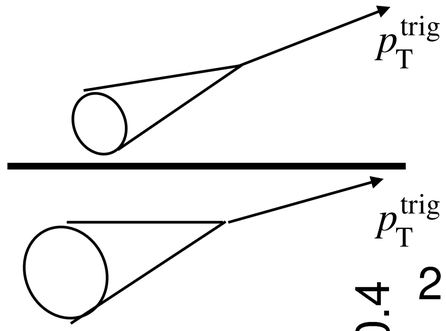
QCD in vacuum





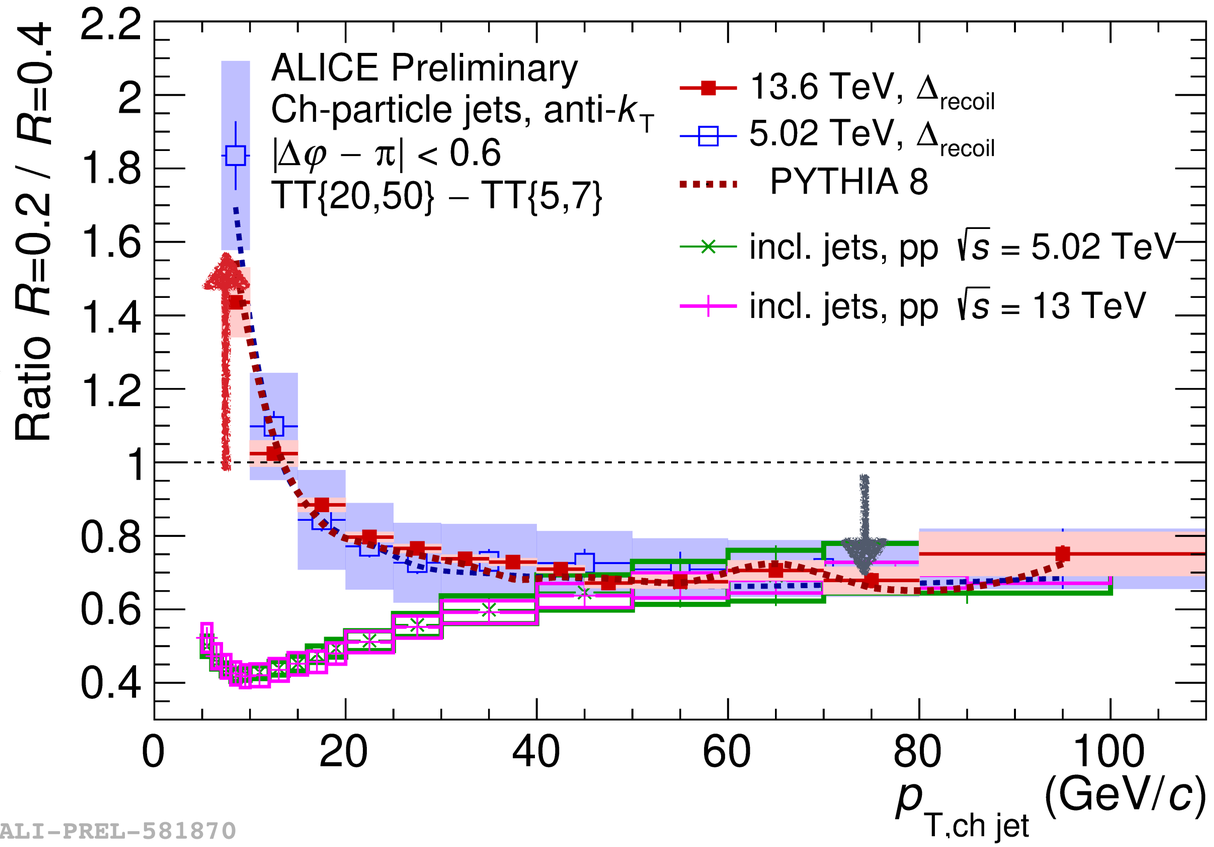
Offline trigger overview by A.A.Riedel on Thursday 12.12., 16:45

Jet shapes



RUN 3

- No visible energy dependence
- Agreement between inclusive and semi-inclusive measurement at high p_T
- **Suppression for high p_T** - due to the energy distribution in jet
- **Enhancement of small jets at low p_T**
  - NLO effects ?
  - Jet splitting ?



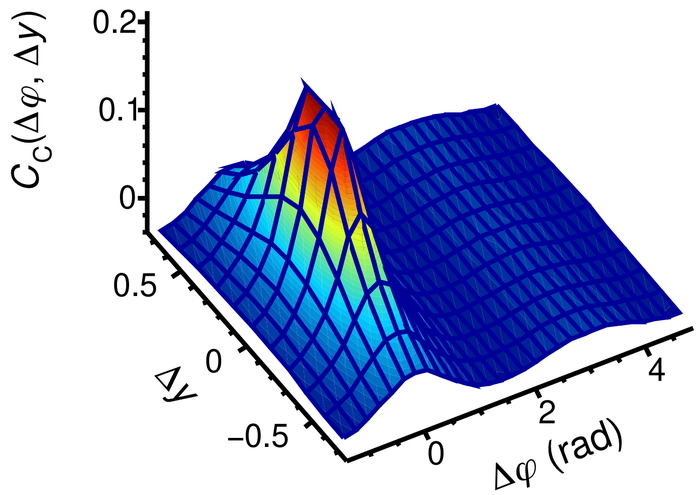
5.02 TeV: Phys.Rev.C 110 (2024) 1, 014906

Baryon correlation puzzle

- Like-sign proton correlation function looks **different** that for mesons

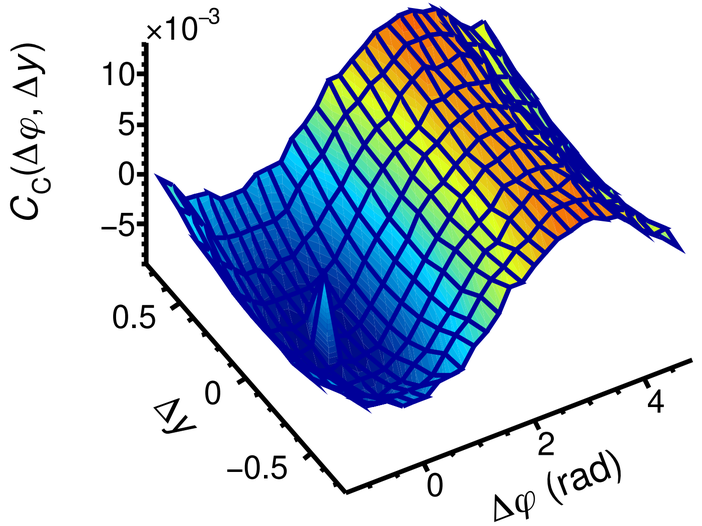
ALICE preliminary, pp $\sqrt{s}$ = 13 TeV

$\pi^-\pi^- + \pi^+\pi^+$, 0–20%



ALI-PREL-541689

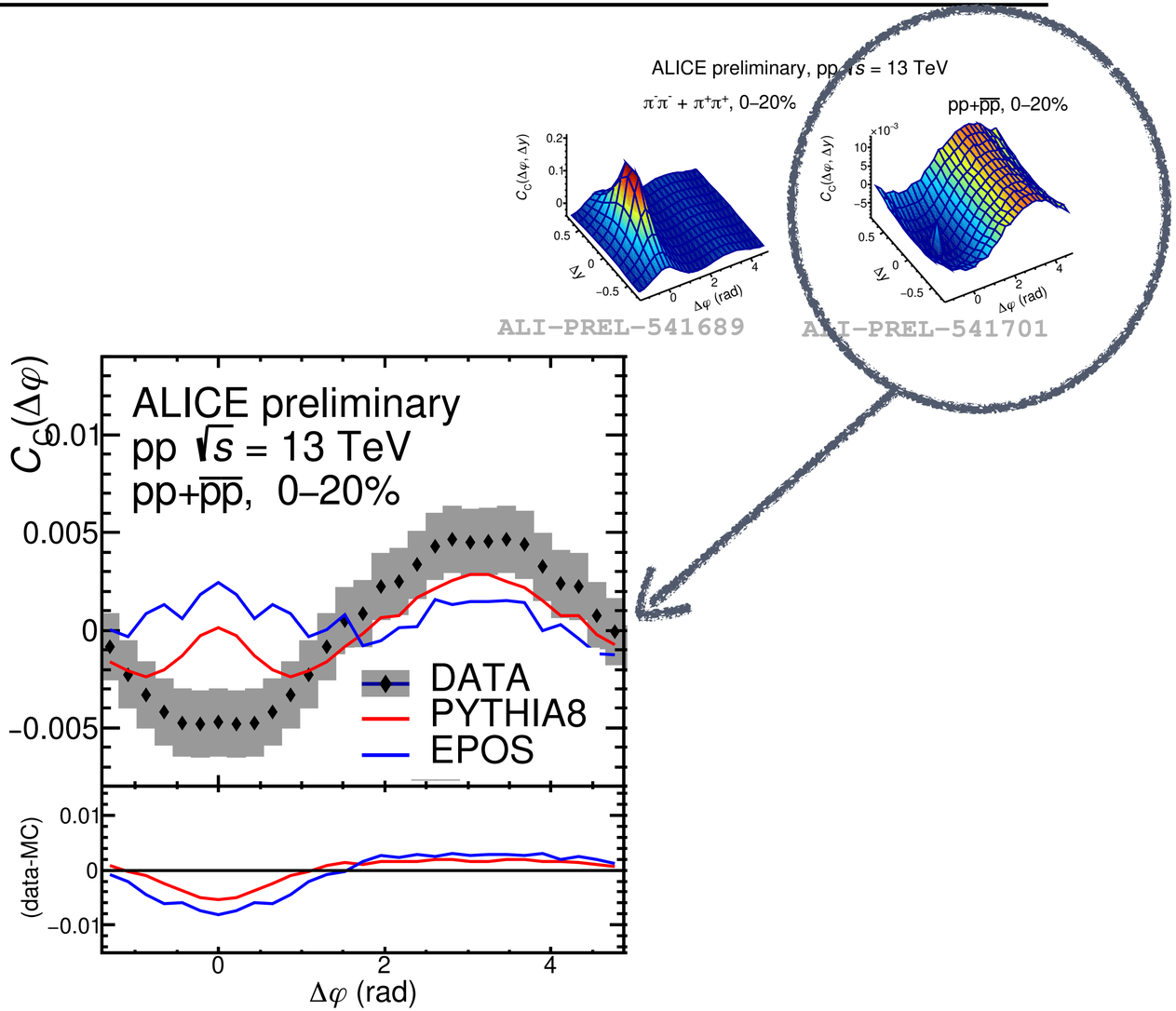
pp+$\overline{\text{pp}}$, 0–20%



ALI-PREL-541701

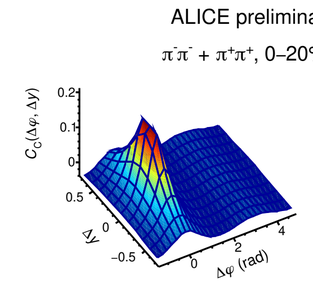
Baryon correlation puzzle

- Like-sign proton correlation function looks **different** that for mesons
- The anticorrelation not described by models
- A possible mass effect?



Baryon correlation puzzle

- Like-sign proton correlation function looks **different** that for mesons
- The anticorrelation not described by models
- A possible mass effect?:
  - Visible also for other baryons:
    - $p\Lambda + \bar{p}\bar{\Lambda}$
    - $\Lambda\Lambda + \bar{\Lambda}\bar{\Lambda}$
    - Ξp, $\Xi\Lambda$, $\Xi\Xi$ (JHEP 09 (2024) 102)



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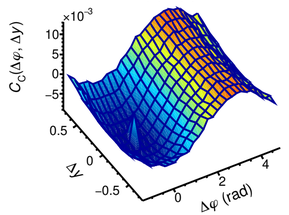

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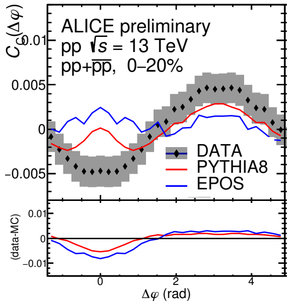
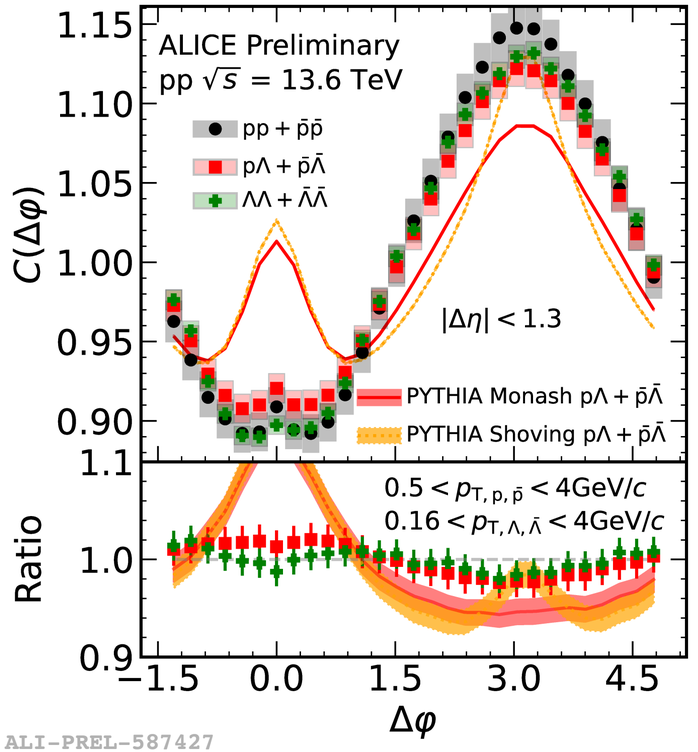


ALI-PREL-541773



ALI-PREL-587427

RUN 3

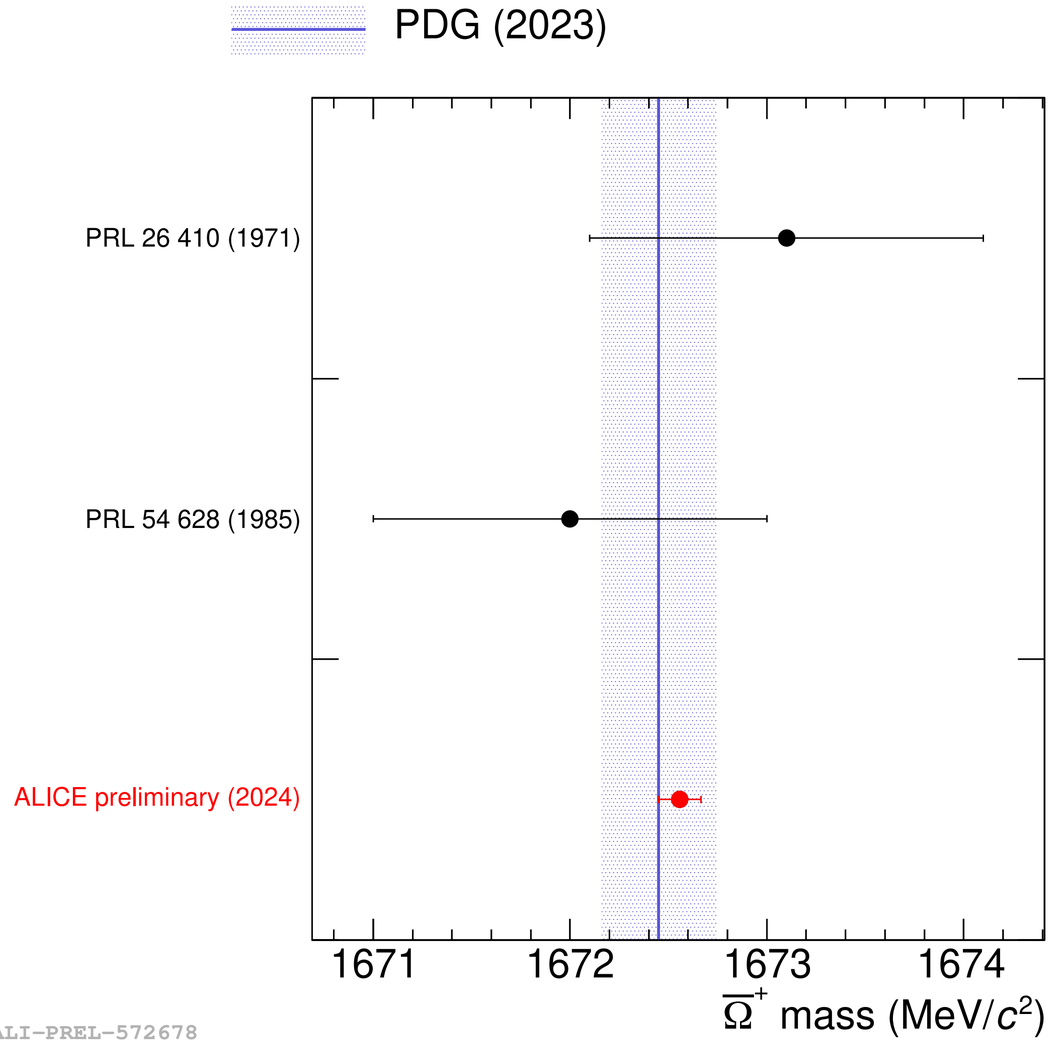
Baryon mass measurement

- From ~30.000 ($\Xi^- + \overline{\Xi}^+$) and ~20.000 ($\Omega^- + \overline{\Omega}^+$), with 96% and 90% purities respectively
- Precision dominated by the systematic uncertainties

ALICE Preliminary

$$M(\Xi^-) = 1321.975 \pm (\text{stat.})0.026 \pm (\text{syst.})0.078 \text{ MeV}/c^2$$
$$M(\overline{\Xi}^+) = 1321.964 \pm (\text{stat.})0.024 \pm (\text{syst.})0.083 \text{ MeV}/c^2$$

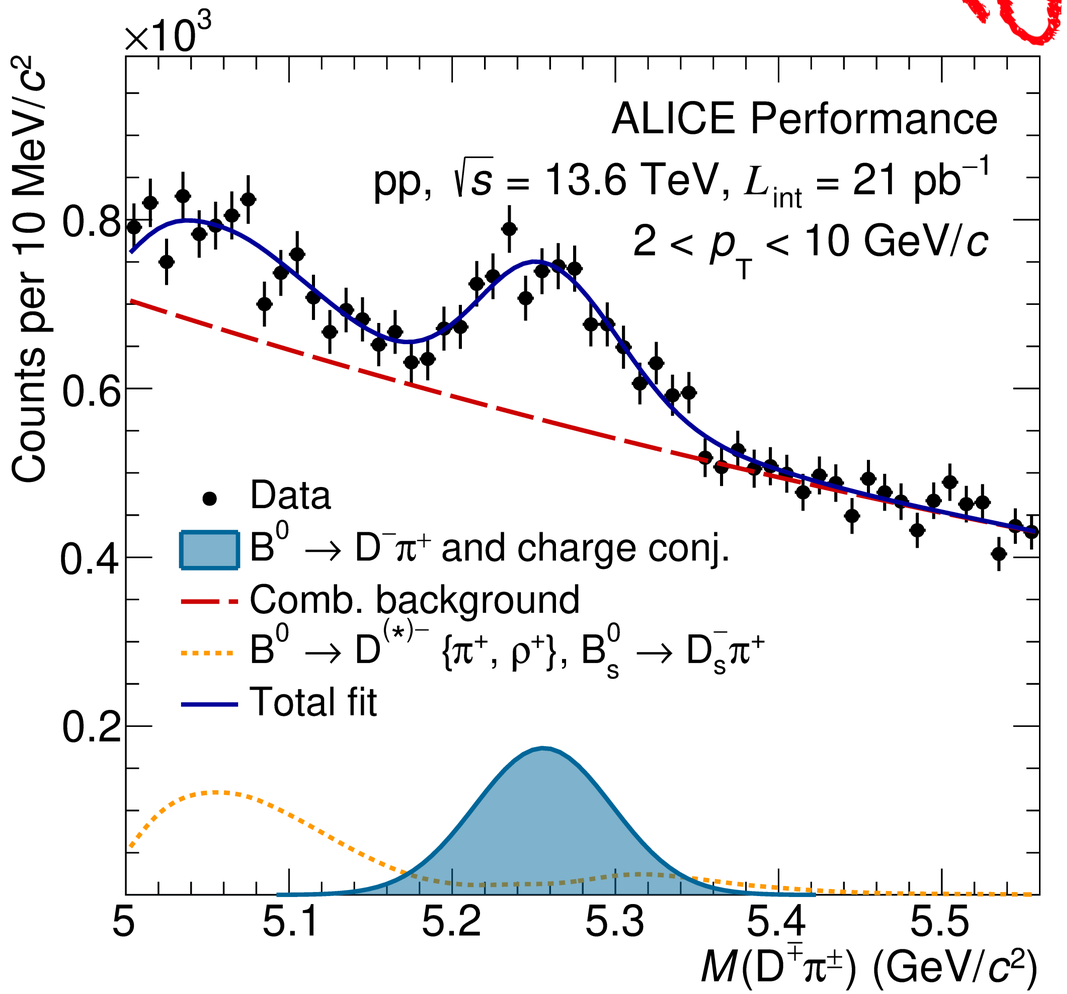
$$M(\Omega^-) = 1672.511 \pm (\text{stat.})0.033 \pm (\text{syst.})0.102 \text{ MeV}/c^2$$
$$M(\overline{\Omega}^+) = 1672.555 \pm (\text{stat.})0.034 \pm (\text{syst.})0.102 \text{ MeV}/c^2$$



ALI-PREL-572678

Direct observations of bottom hadrons

- First direkt measurement of bottom mesons with ALICE
- Thanks to high statistics and dedicated triggers in 2024
- More similar measurements to come
  - b-jets tagging
  - Multicharm measurements



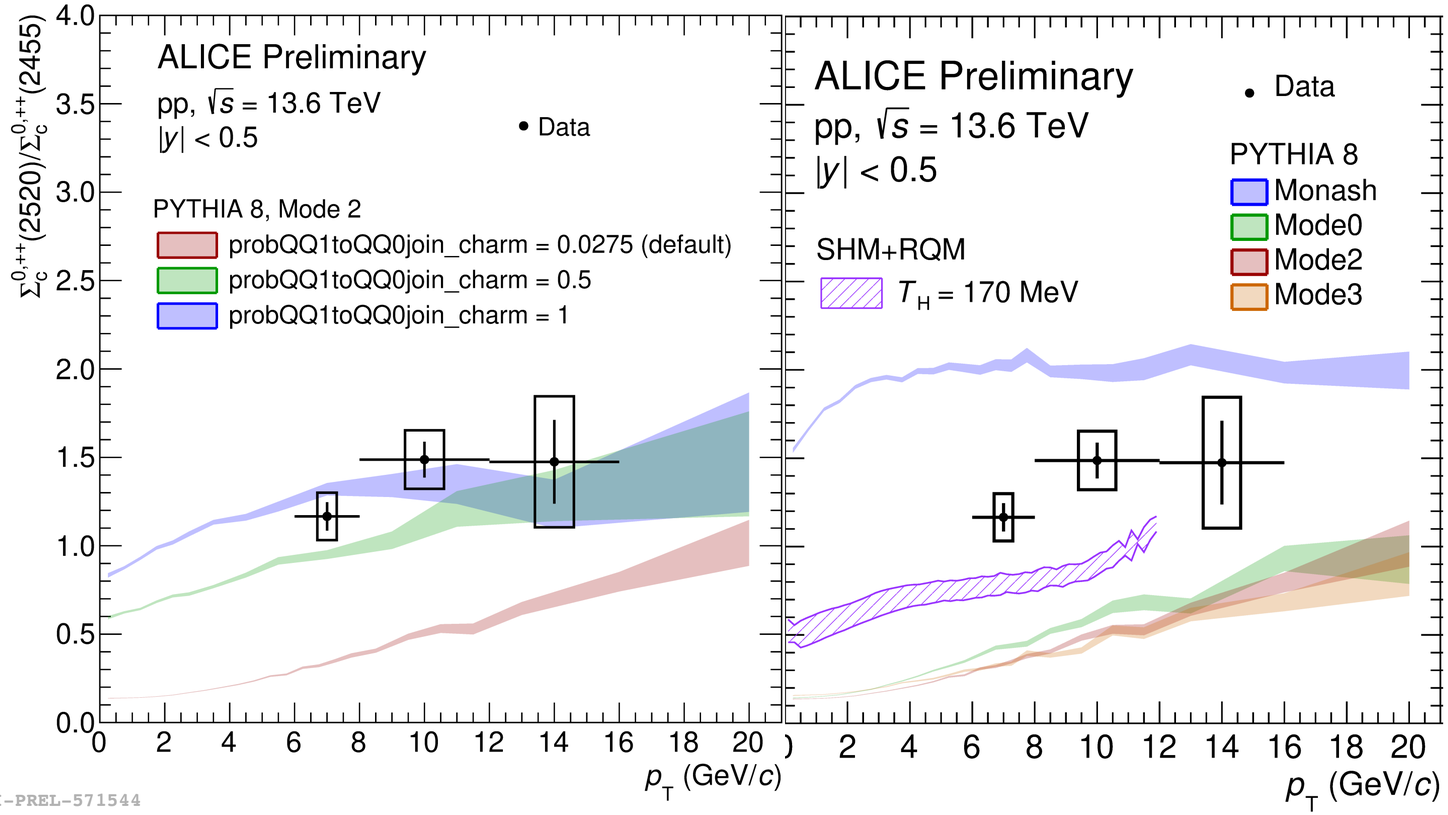
RUN 3

Measurement of new charm states

$$\frac{\Sigma_c^{0,++}(2520)}{\Sigma_c^{0,++}(2455)}$$

RUN 3

- First measurement of the $\Sigma_c^{0,++}$ (2520) together with $\Sigma_c^{0,++}$ (2455)
- Comparable yield for both resonances
- Not described by default PYTHIA
  - Tuning of parameters improve the description
  - Amount of suppression for heavy diquark spin 1 state w.r.t spin 0



ALI-PREL-571544

ALI-PREL-574270

Probing of the fragmentation functions

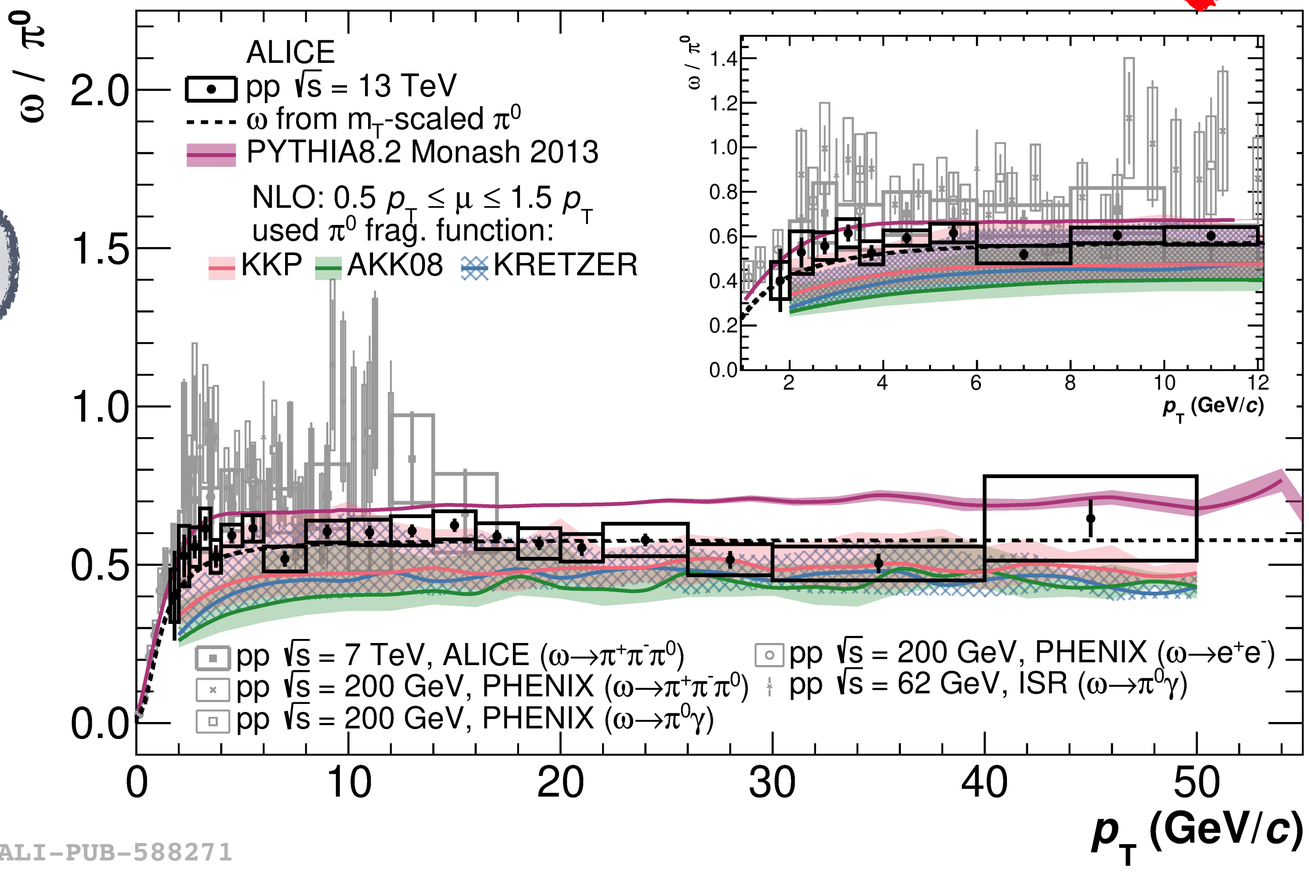
- Most precise determination of the ratio up to 50 GeV/c

ALICE final

$$C^{\omega/\pi^0} = 0.578 \pm (\text{stat.})0.006 \pm (\text{syst.})0.013$$

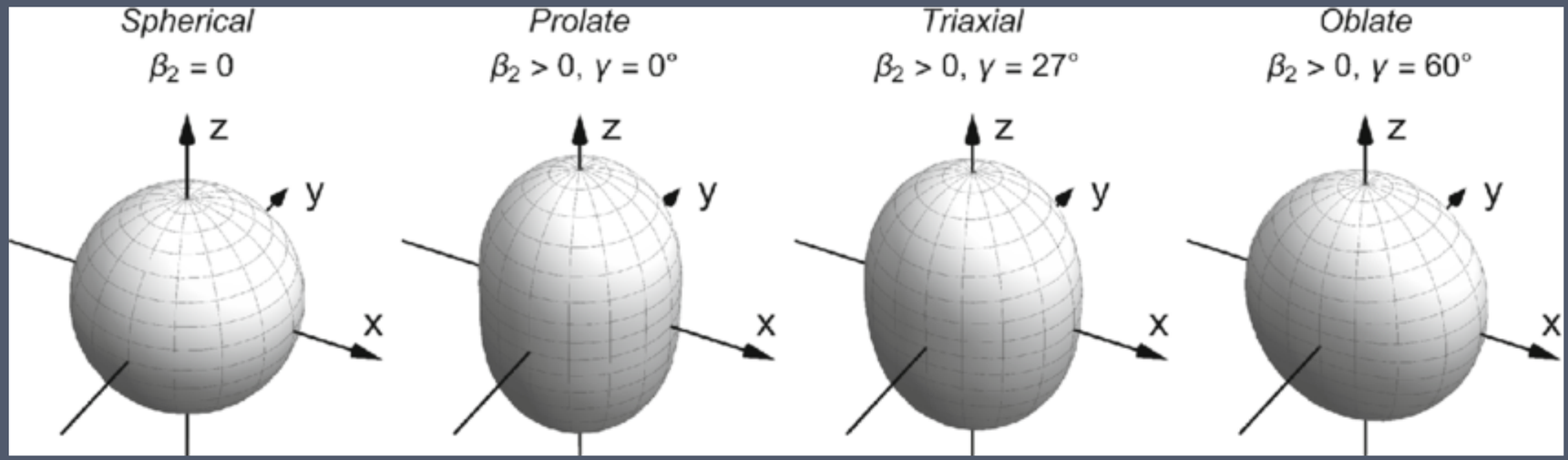
- PYTHIA overestimate the ratio
- Different fragmentation functions agree within uncertainty
- Empirical m_{T}-scaling works well in the full p_{T} range

NEW



arXiv:2411.09432

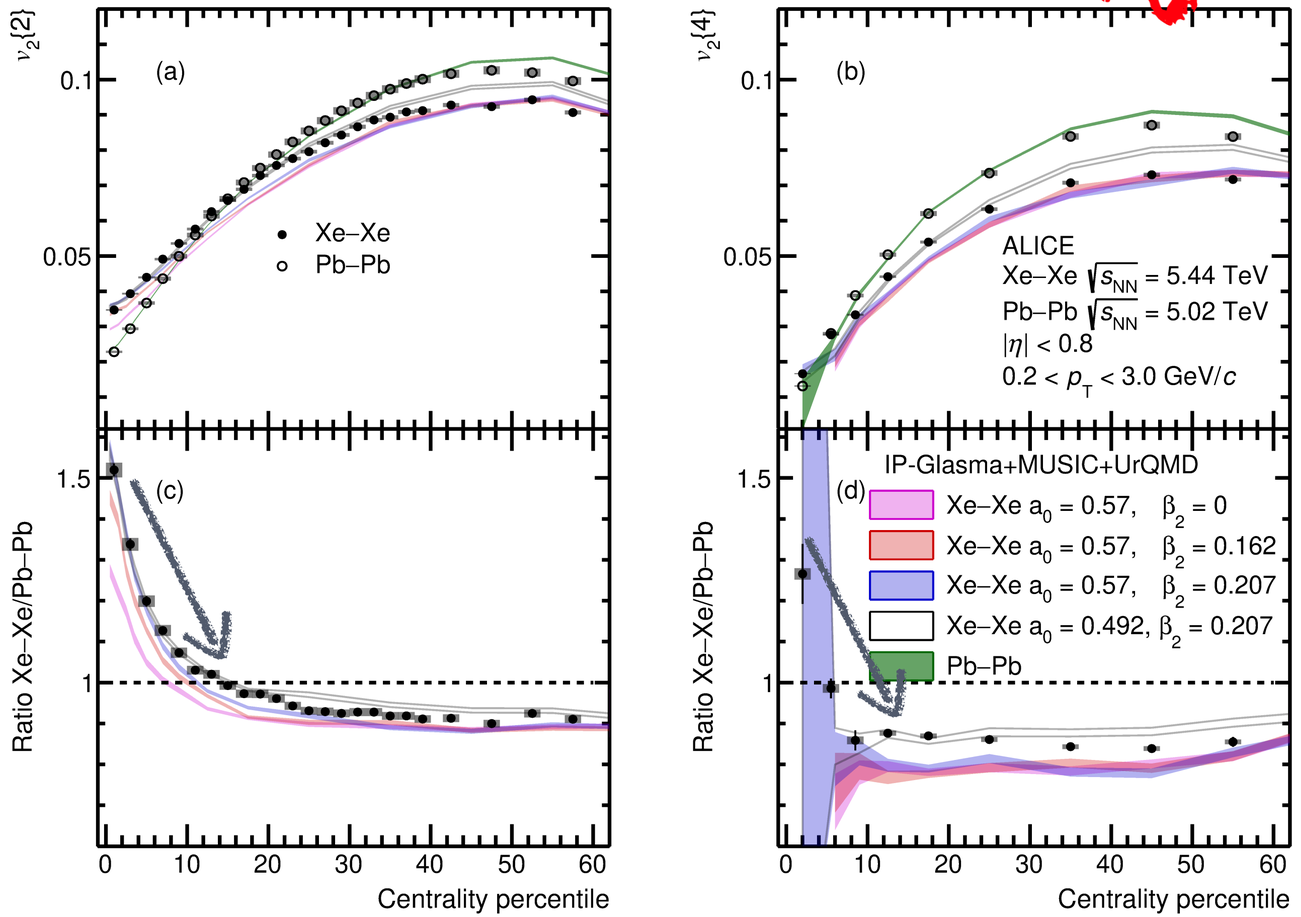
Nuclear structure



Xenon deformation

NEW

- Similar dynamic evolution - final state effects cancel out in the ratios
- **Steep decrease** of the ratio in the most central collisions
  - In Xe—Xe - fluctuations more pronounced
  - Model with quadruple deformation $\beta_2 = 0.207$ match the data



ALI-PUB-578007

arXiv:2409.04343

Conclusion and Outlook

- Many new measurements regarding QGP and its limits, QCD in vacuum and nuclear modification
- Run3 is ongoing - many new measurements to come
  - Factor 10 higher statistics in Pb—Pb
  - Offline triggers for pp collisions →rare processes
- Run4 in preparation
  - FoCal will allow for low-x measurements

FoCal overview talk by D. Tapia Takaki Tuesday 10.12., 13:50

Stay tuned!

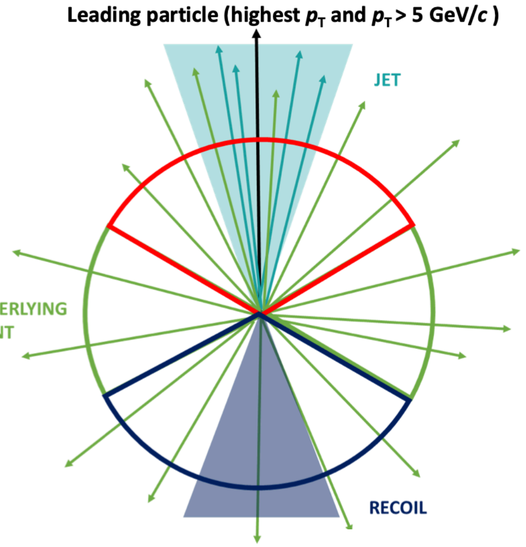
All ALICE talks

- ALICE FoCal project overview - D. Tapia Takaki - 10.12., 13:50
- Advancements in photonuclear J/ψ production in ultra-peripheral Pb–Pb collisions from Run 2 and early results from Run 3 in ALICE - D. Krupova - 10.12., 16:40
- ALICE trigger system Run1/Run2 - R. Lietava - 12.12., 9:45
- ALICE Central Trigger Processor in Run3 - I. Ahuja - 12.12., 10:10
- ALICE software trigger run3/run4 - A.A.Riedel - 12.12., 16:45
- ALICE3 - N. Jacazio -13.12., 9:00
- Production of strange and multi-strange particles with ALICE experiment at LHC - P. Kalinak - 13.12., 11:50

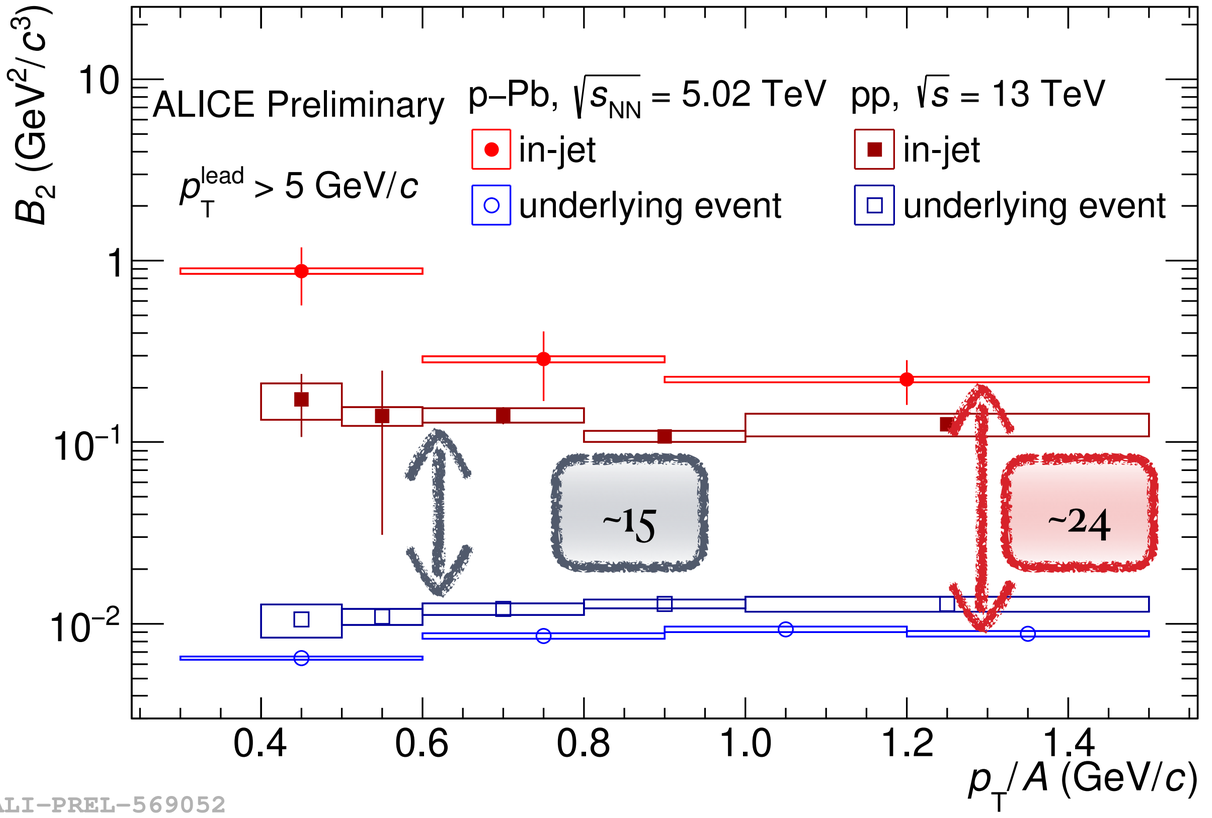
Back Up

Deuteron production

$$B_2 = \frac{\left(\frac{1}{(2\pi/3)p_{\mathrm{T}}^{\mathrm{d}}}\left(\frac{\mathrm{d}^2N}{\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{d}}\right)}{\left(\frac{1}{(2\pi/3)p_{\mathrm{T}}^{\mathrm{p}}}\left(\frac{\mathrm{d}^2N}{\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}\right)_{\mathrm{p}}\right)^2}$$



- Gap between jet and UE parameter - consistent with coalescence picture
- Larger gap for **p—Pb** collisions w.r.t. **pp**
  - Larger source size in p—Pb?
  - Stronger momentum correlations?



pp: PRL 131 (2023) 042301 [Erratum: PRL 132 (2024) 109901]