Production of light/strange particles vs. the underlying event activity in small/large systems with ALICE

Oliver Matonoha
on behalf of ALICE collaboration

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ALICE

LUND UNIVERSITY

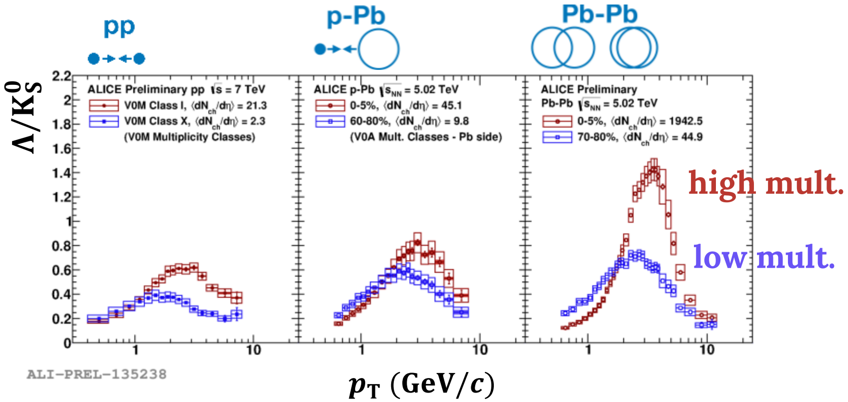
CTU
CZECH TECHNICAL UNIVERSITY IN PRAGUE

Quark-gluon plasma (QGP) and small systems

- Small systems (pp, pA) exhibit many „QGP-typical“ behaviours at LHC energies:
- *Anisotropic flow*

see D. Sarkar, Tue 8:30

- *Quarkonium dissociation*
- *Radial flow:*
  - Boost of heavier particles to higher p_T



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- *Radial flow:*
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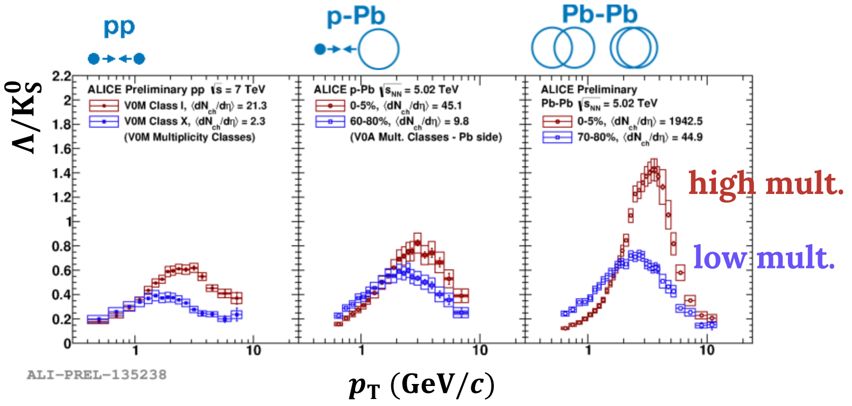
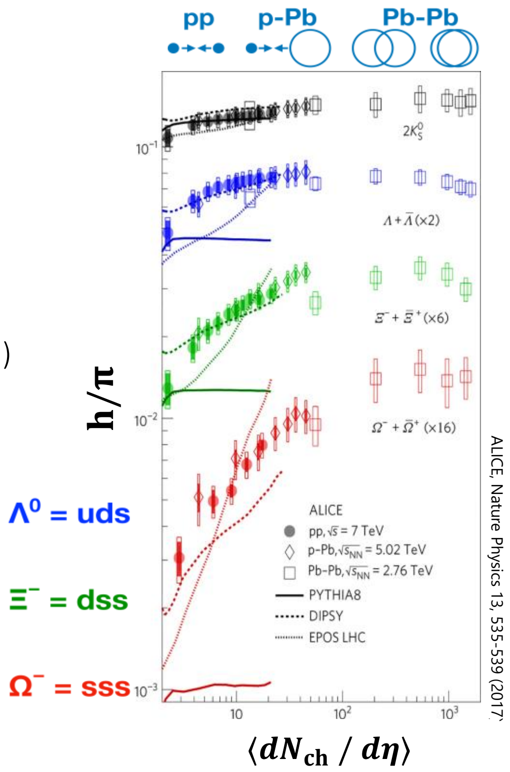
- *Strangeness enhancement:*
  - **s**-quark produced also thermally ($T \sim m_s$)
  - More strangeness content → bigger effect

  see Ch. Martin, Tue 12:00
  G. v.Weelden, Wed 9.50



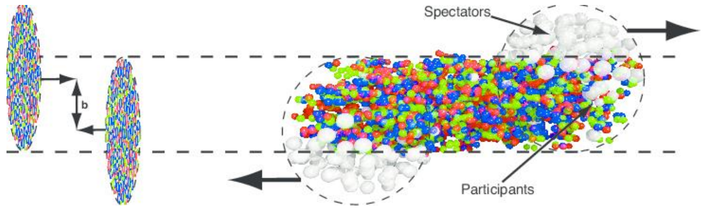


QGP and non-QGP mechanisms provide similarly valid explanations to data.

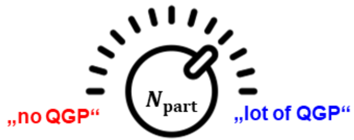
***Similar evolution w.r.t. to multiplicity** increase regardless of system size!*

QGP features in small systems – the role of multiplicity

- <u>AA collisions:</u>



- Higher N_{ch} arises from increase in the amount of colliding matter: N_{part}
- N_{part} and N_{ch} are directly related, can be determined from models



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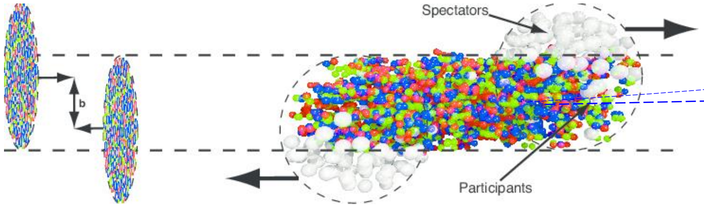

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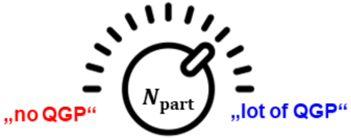
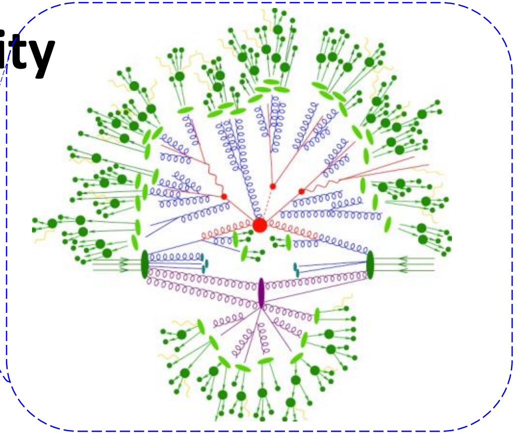
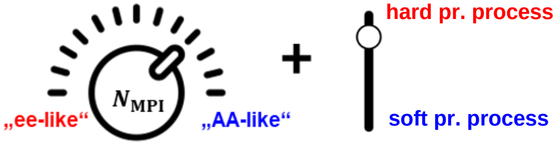


- pp collisions:



- $N_{\mathrm{part}} = 2$, $N_{\mathrm{coll}} = 1$, but multiplicity N_{ch} can vary a lot! Sometimes comparable with peripheral AA, where QGP is produced
- Complex picture: N_{ch} cannot be directly linked to the initial state and consists of
  - **„softer“ contribution:** from multiple semi-hard partonic interactions (MPI)
  - **„harder“ contribution:** from the primary process and wide-angle initial/final state radiation (ISR/FSR)



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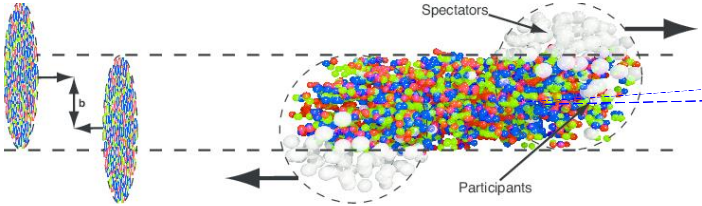

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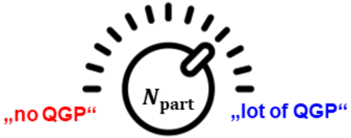

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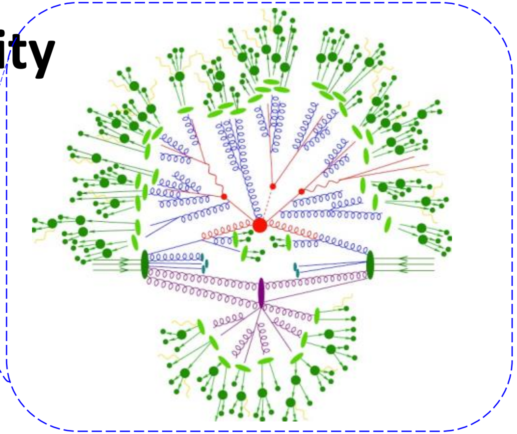

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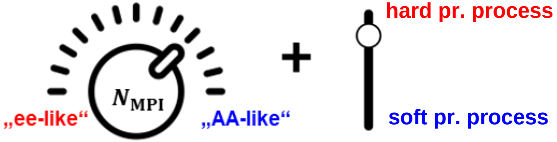

- *How to isolate the number of parton-parton interactions n_{MPI}?*

Accessing the n_{MPI}

- Relationship between N_{ch} and n_{MPI} is complex:
  - $N_{\mathrm{ch}} \propto n_{\mathrm{MPI}}$
  - $N_{\mathrm{ch}} \propto$ hardness of the prim. process
  - $N_{\mathrm{ch}} \rightarrow$ smaller impact parameter $\rightarrow$ harder events are more probable
- Non-trivial dependences in both directions
  $\rightarrow$ Accessing n_{MPI} from N_{ch} also biases dominant physics sub-processes of our events

see A. Ortiz, Tue 11:20

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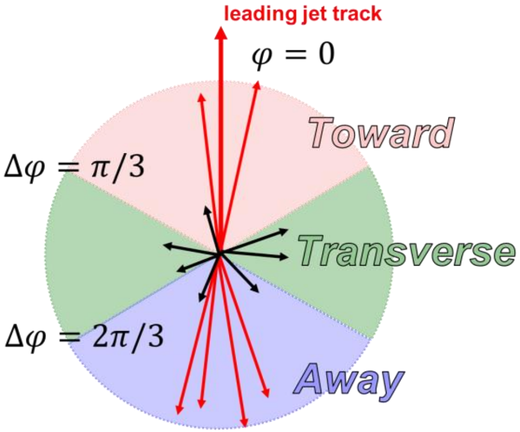
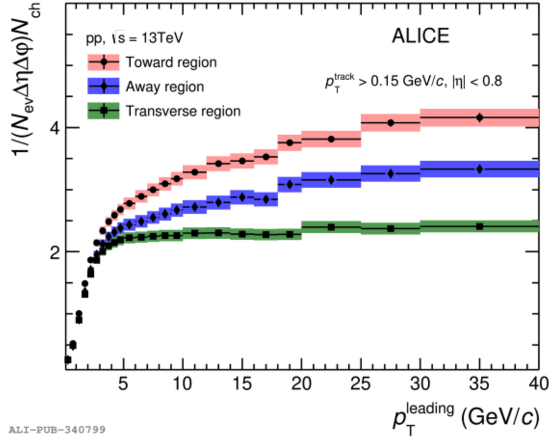
  - collection of all particles **NOT** originating from the primary process or related fragmentation



- Studied by measuring $\frac{1}{\Delta\eta\Delta\varphi}\frac{1}{N_{\mathrm{ev}}} N_{\mathrm{ch}}$ in Toward/Transverse/Away, w.r.t. to the highest-momentum track $p_{\mathrm{T}}^{\mathrm{lead}}$
- ***Naturally disentangles soft/and hard:***
- In Toward/Near, Away:
  - Jet fragmentation, scales with $p_{\mathrm{T}}^{\mathrm{lead}}$
- In Transverse region:
  - Only UE (MPI, ISR/FSR, beam remnants)
  - From $p_{\mathrm{T}}^{\mathrm{lead}} \gtrsim 5\ \mathrm{GeV}/c$, N_{ch} becomes independent of $p_{\mathrm{T}}^{\mathrm{lead}}$

JHEP04 (2020) 192



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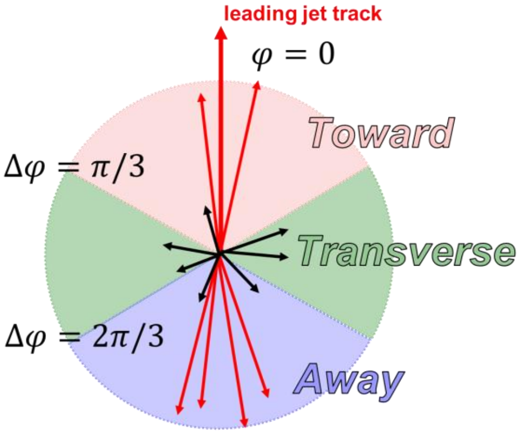

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N_{ch} in the Transverse region $\equiv N_{\mathrm{T}}$ (UE activity)

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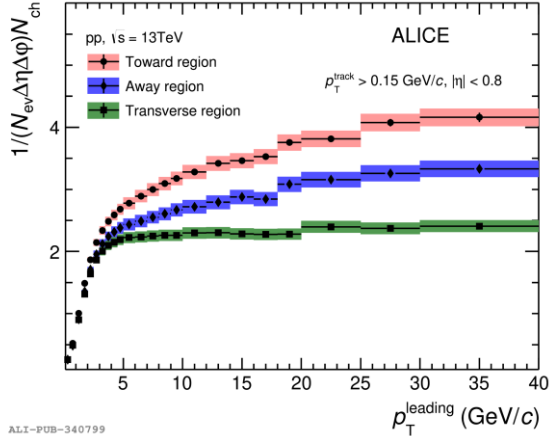
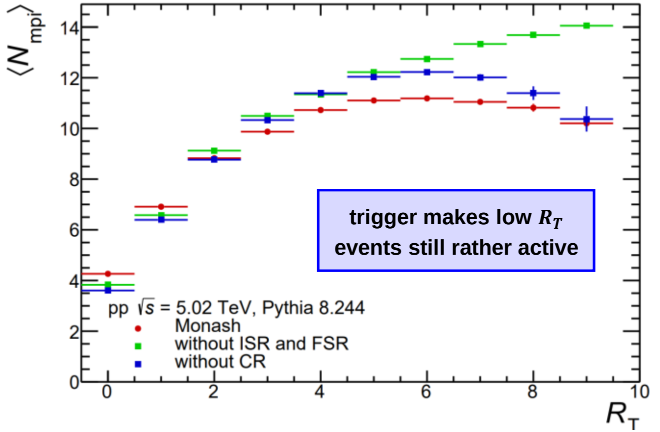
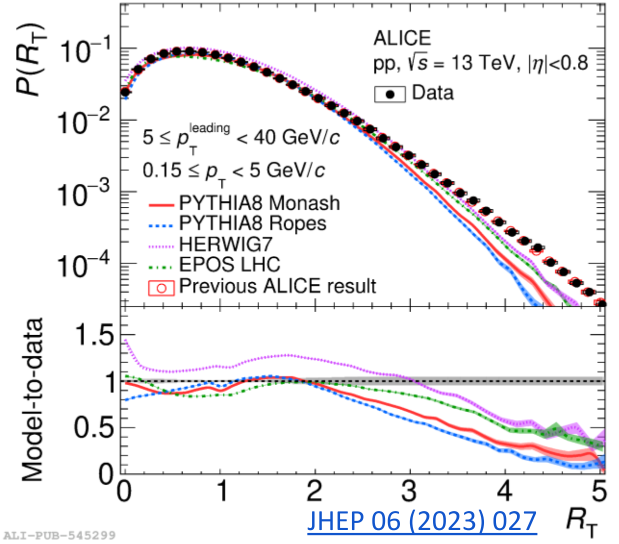


Relative underlying (transverse) activity R_{T}

- $R_{\mathrm{T}} = N_{\mathrm{T}} \,/\, \langle N_{\mathrm{T}} \rangle$
  - in events with a trigger $p_{\mathrm{T}}^{\mathrm{lead}} > 5$ GeV/c
  - proposed as a clean proxy of $\langle n_{\mathrm{MPI}} \rangle$ T. Martin, P. Skands, S. Farrington *EPJ C 76, 5 (2016)*

G. Bencédi, A. Ortiz, S. Tripathy: J. Phys. G: Nucl. Part. Phys. 48 (2021) 015007





[JHEP 06 (2023) 027]

Relative underlying (transverse) activity R_T

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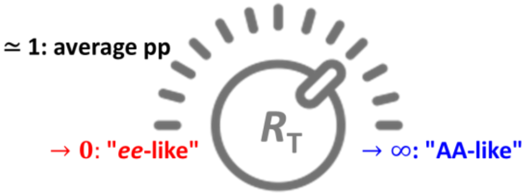

- R_T selects different event composition:
  - $R_T \to 0$: dominant jet, lower $\langle n_{\text{MPI}} \rangle$
  - $R_T \to \infty$: dominant UE, higher $\langle n_{\text{MPI}} \rangle$

- Measuring particle production in:
  - **Toward/Away** vs. R_T: tests the effect of mixing the jet- and UE-related production
  - **Transverse** vs. R_T: tests the soft production as a function of event $\langle n_{\text{MPI}} \rangle$

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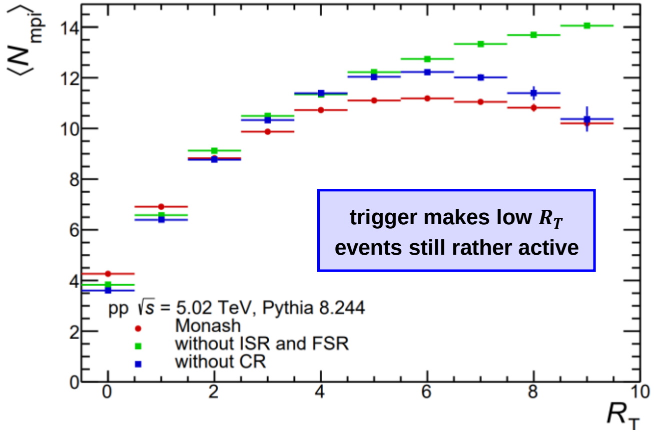
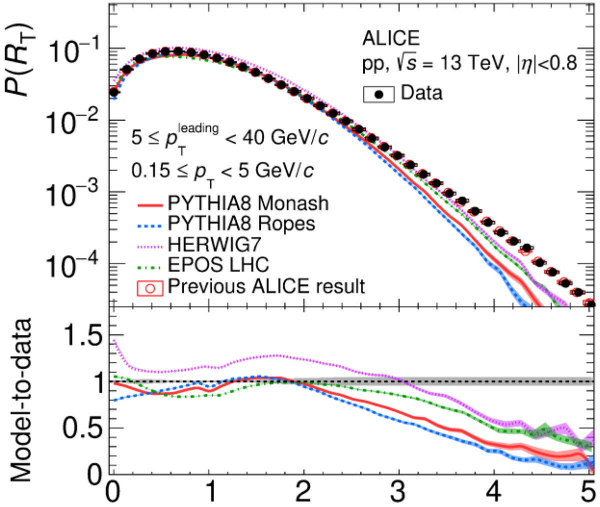
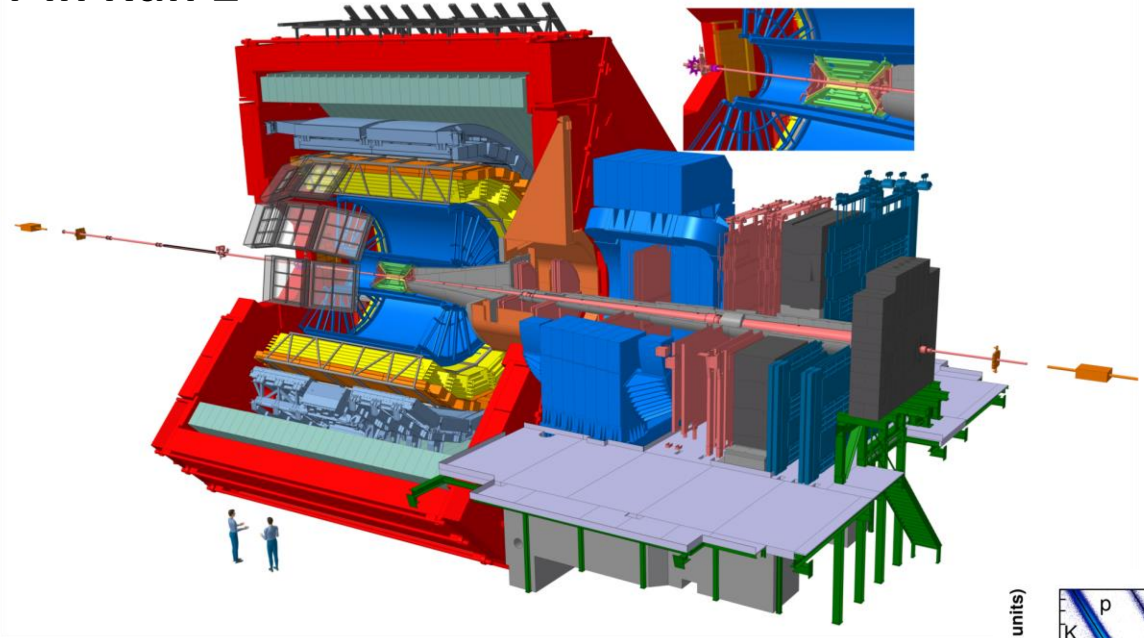
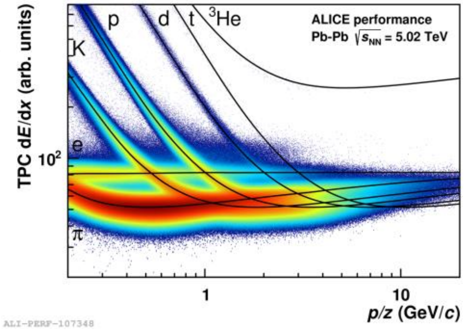




JHEP 06 (2023) 027

ALICE detector in Run 2



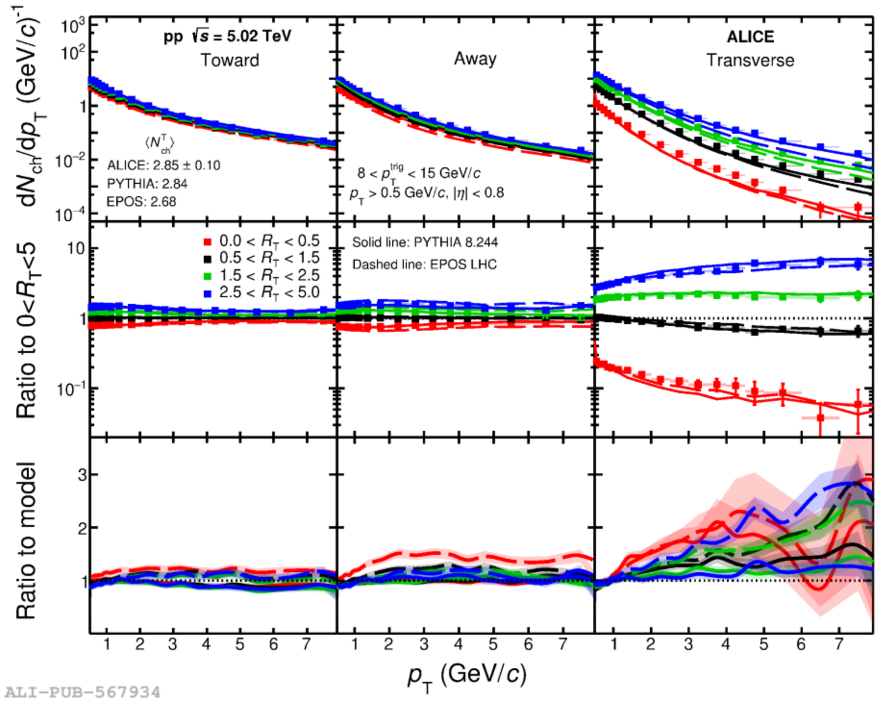


- Heavy-ion dedicated detector at the LHC, tracking and identifying particles from $p_{\mathrm{T}} > 0.15\ \mathrm{GeV}/c$
- Most important sub-detectors for particle identification and tracking are ***Time Projection Chamber (TPC)*** and Inner Tracking System (ITS)
- Full azimuthal coverage, $|\eta| < 0.9$

R_T distribution and $h^{\pm}$ spectra

NEW publication
JHEP 01 (2024) 056

- The R_T distibution measured and compared accros different $\sqrt{s}$ = 2.76 TeV, 5.02 TeV, 7 TeV, 13 TeV
- Charged hadron p_T spectra measured in **pp**, p-Pb, Pb-Pb collisions



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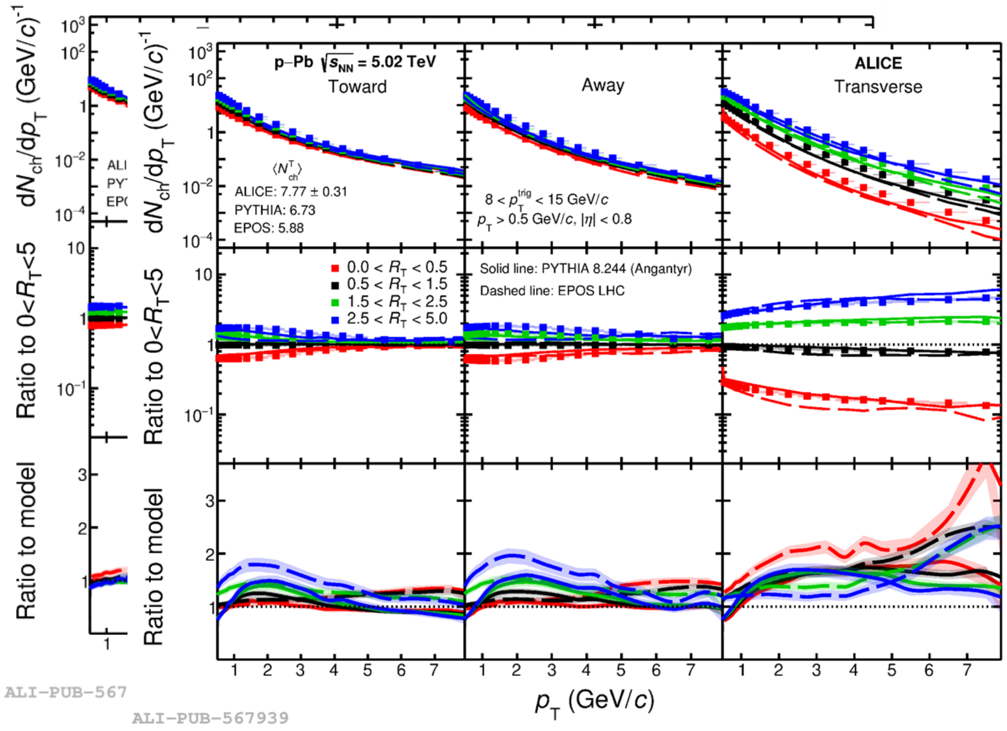

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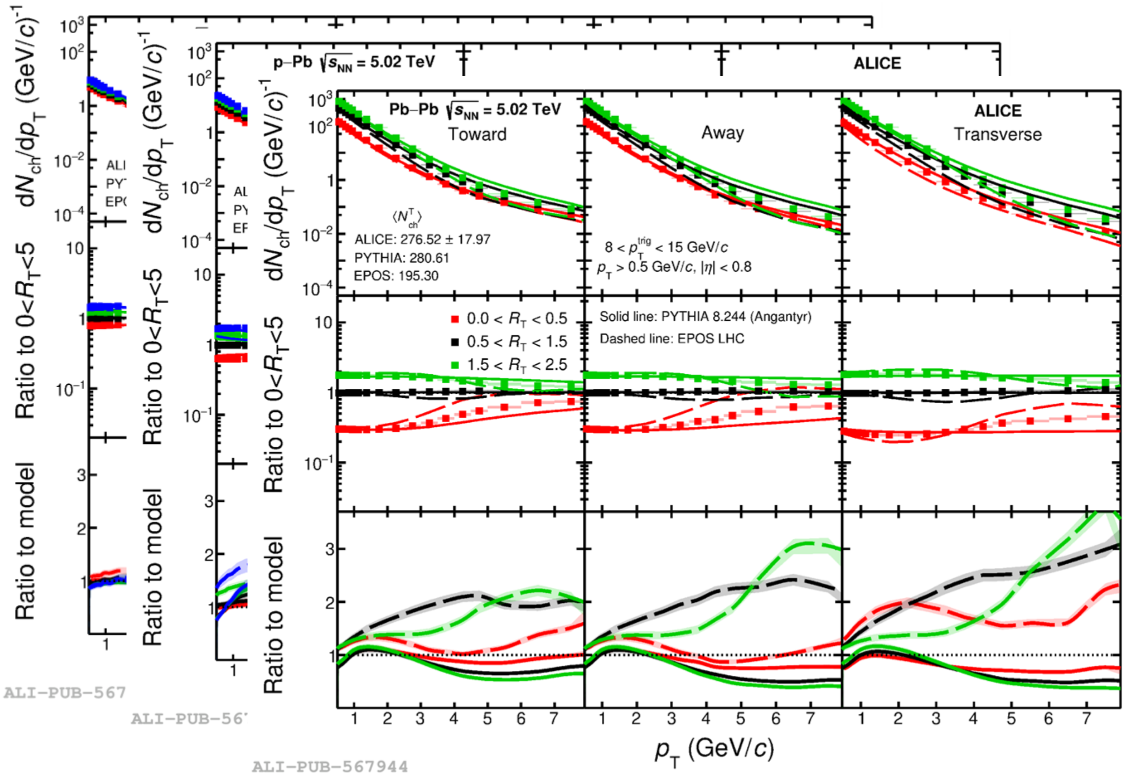

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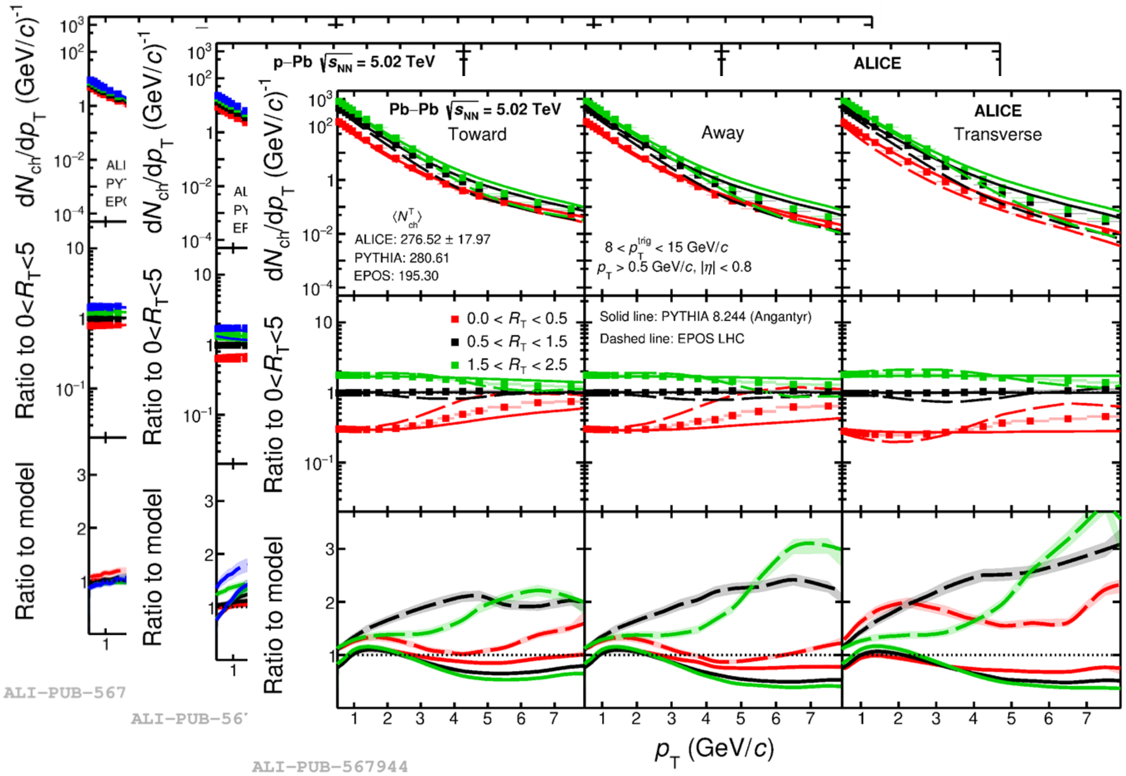
- Charged hadron p_T spectra measured in pp, p-Pb, Pb-Pb collisions
- Results indicate the presence of high-multiplicity jets in the Transverse regions



Even cleaner proxy of $\mathrm{n}_{\mathrm{MPI}}$?

- Contamination in transverse by another jet, e.g. from hard ISR/FSR
  → losing sensitivity to n_{MPI}
- How to disentangle the effects of ISR/FSR and high n_{MPI}?

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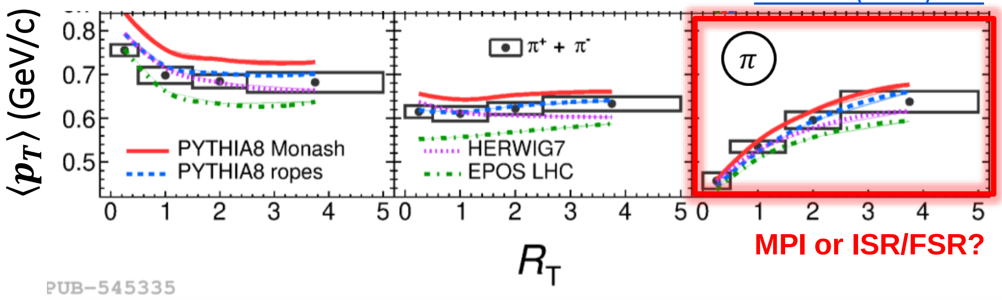

MPI or ISR/FSR?

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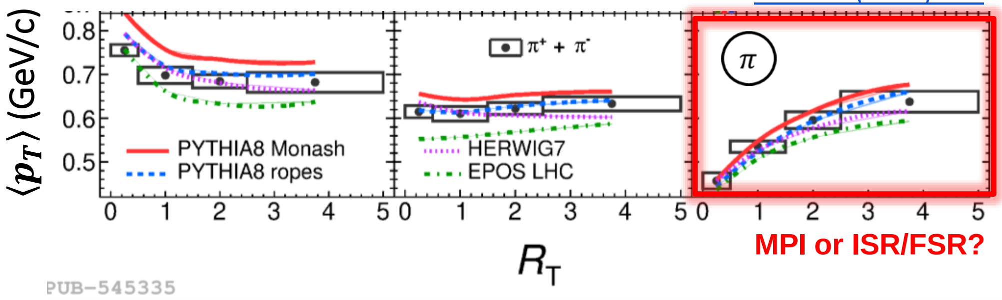

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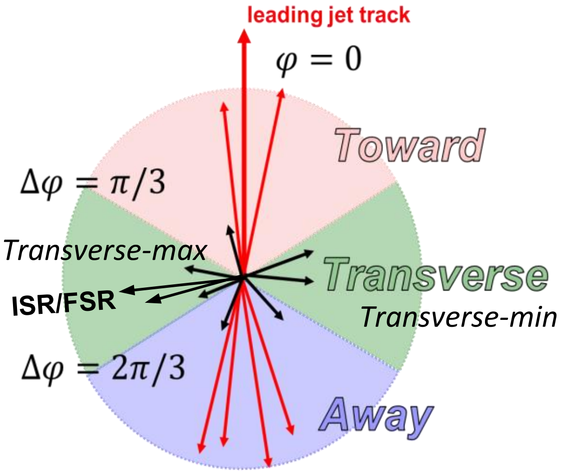

- The two sub-regions of *transverse* ($\frac{\pi}{3} < \Delta\varphi \leq \frac{2\pi}{3}$ and $\frac{-2\pi}{3} < \Delta\varphi \leq \frac{-\pi}{3}$) are classified as *transverse-min* and *transverse-max* based on the N_{T} in each (event-by-event)
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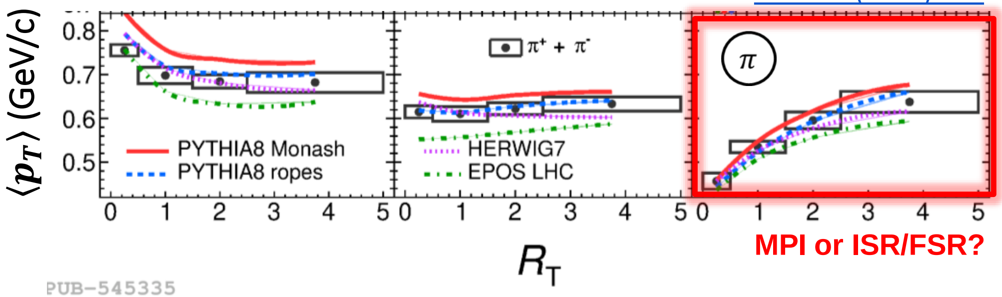

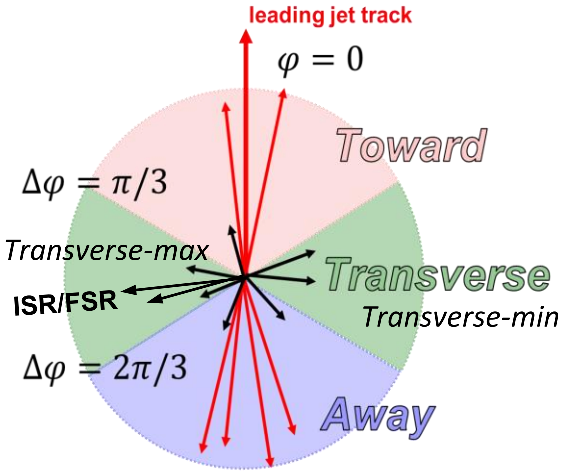

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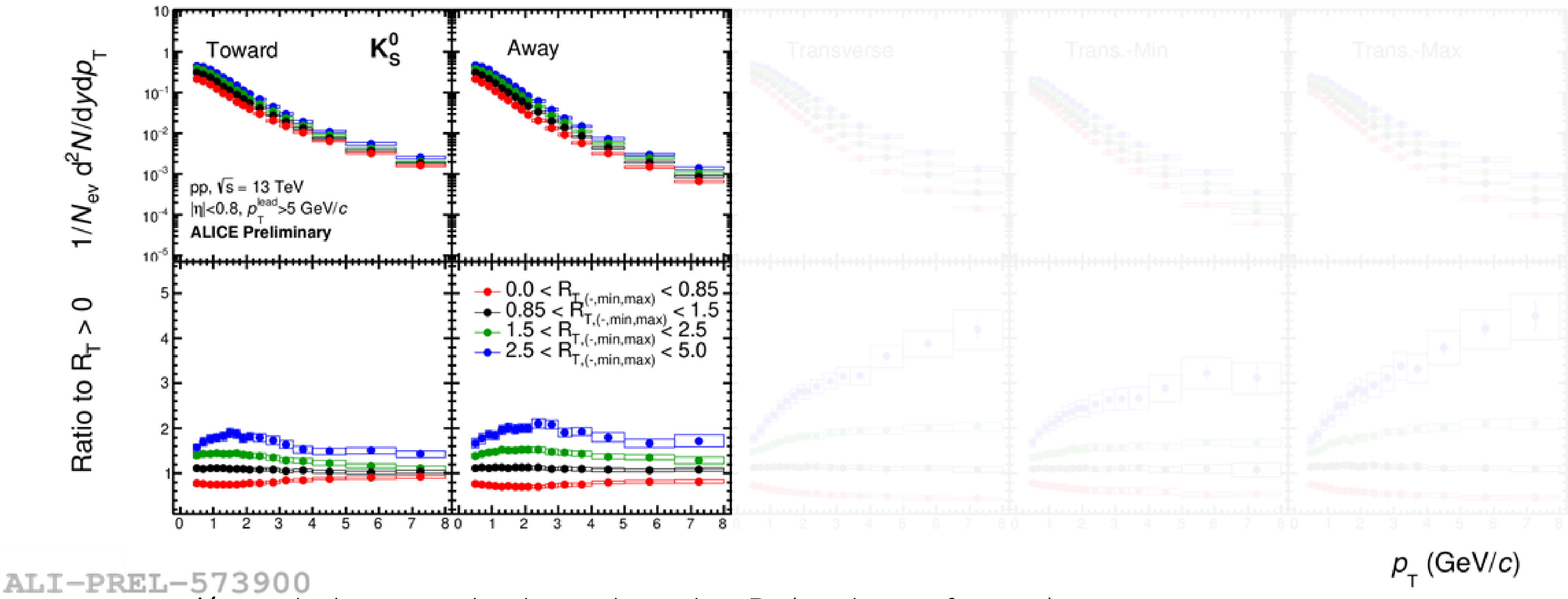
- The two components of N_{T} are labeled $N_{\mathrm{T,min}}$ and $N_{\mathrm{T,max}}$
- Trivially,
  - $N_{\mathrm{T}} = N_{\mathrm{T,min}} + N_{\mathrm{T,max}}$
  - *Transverse-max*: contains soft UE + ISR/FSR
  - *Transverse-min*: contains only soft UE
  - Analogously:

$$R_{\mathrm{T,min}} = N_{\mathrm{T,min}} / \langle N_{\mathrm{T,min}} \rangle \quad \propto n_{\mathrm{MPI}}$$
$$R_{\mathrm{T,max}} = N_{\mathrm{T,max}} / \langle N_{\mathrm{T,max}} \rangle \quad \propto \text{ISR/FSR}$$

$\mathrm{R_{T,min}}$ *suggested as one of the cleanest probes of* $\langle \mathrm{n_{MPI}} \rangle$!

p_{T} spectra: K_{S}^{0}

NEW!



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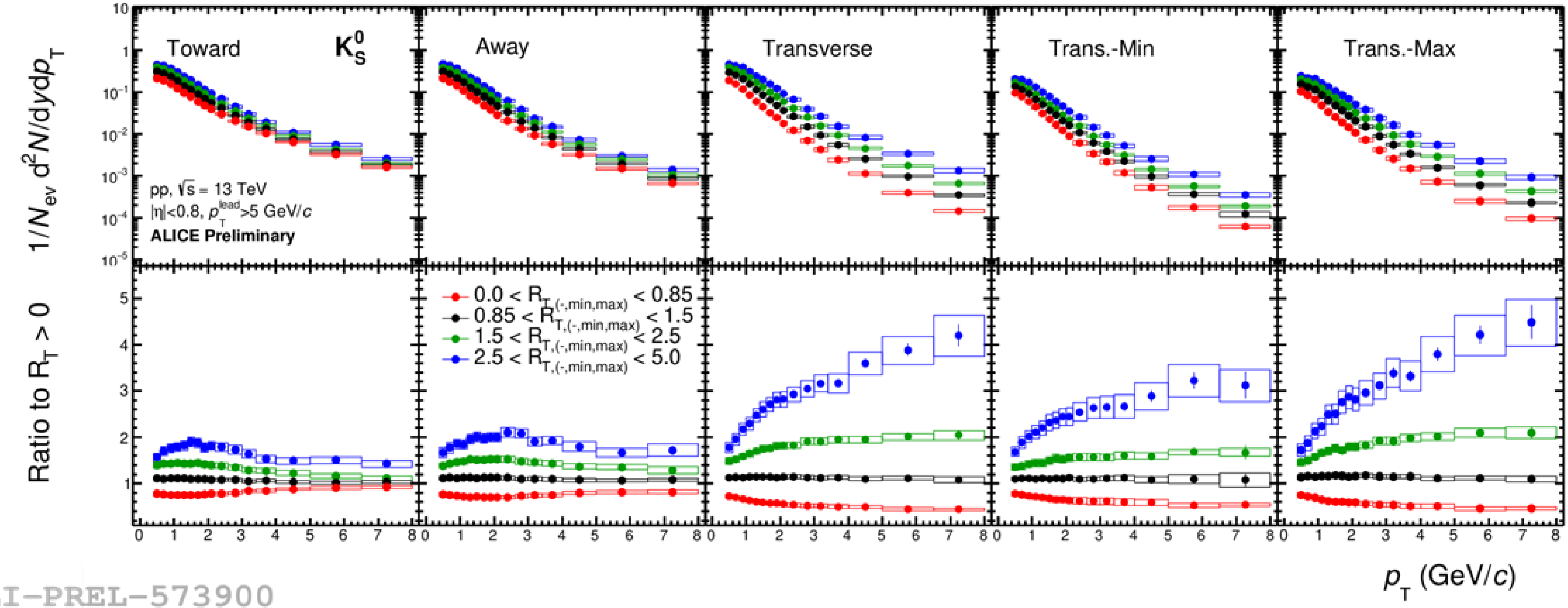


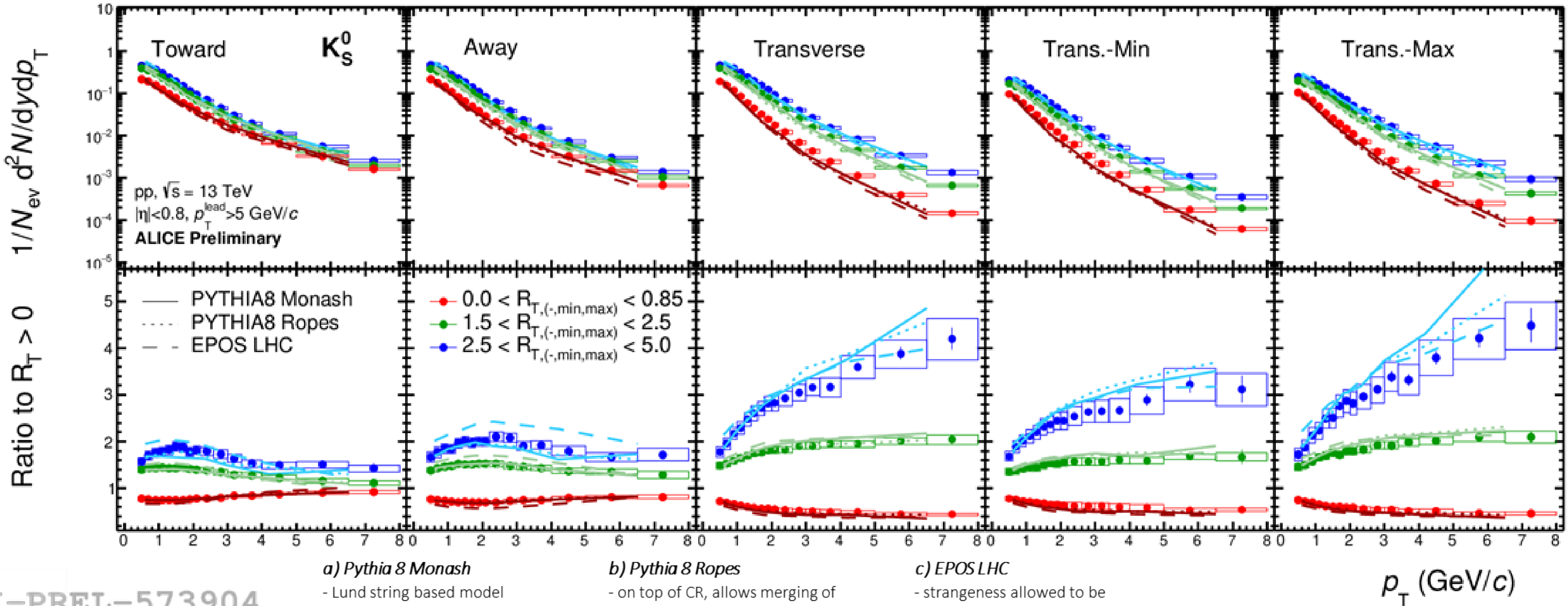
ALI-PREL-573900

- *Toward/Away*: high-p_{T} particles do not depend on R_{T} (production from jet)
- *Transverse(-max):* hardening with R_{T} → events with high R_{T} are more likely to contain high- p_{T} particles (ISR/FSR?)
- *Transverse-min:* similar, but seems to saturate for high $R_{\mathrm{T,min}}$

p_T spectra: K_S^0, comparison with models

Λ spectra in back-up

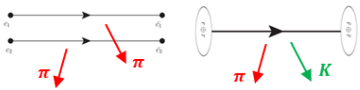
NEW!



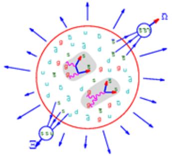
ALI-PREL-573904

a) Pythia 8 Monash
- Lund string based model
- implements Colour Reconnection (CR), which mimicks radial flow

b) Pythia 8 Ropes
- on top of CR, allows merging of overlapping strings into higher tension ropes -> enhances strangeness



c) EPOS LHC
- strangeness allowed to be produced thermally QGP droplets



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p_{T} spectra: Ξ (comparison with models)

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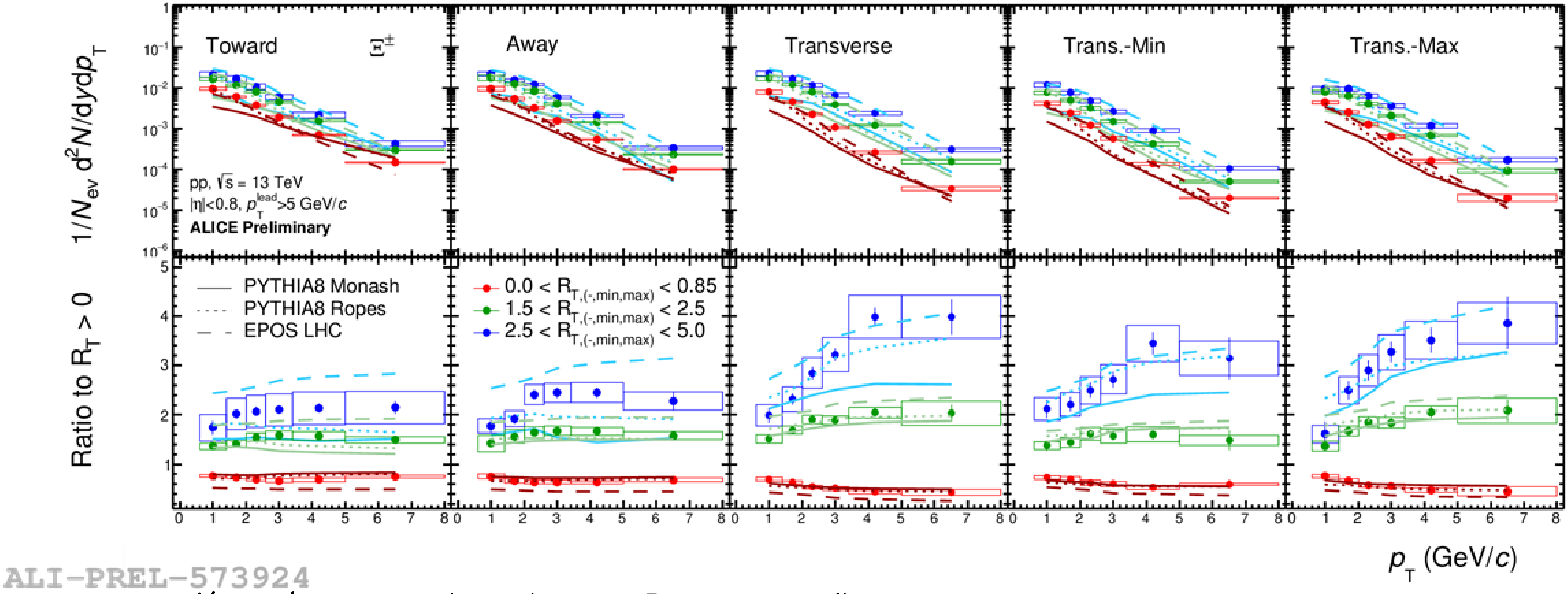
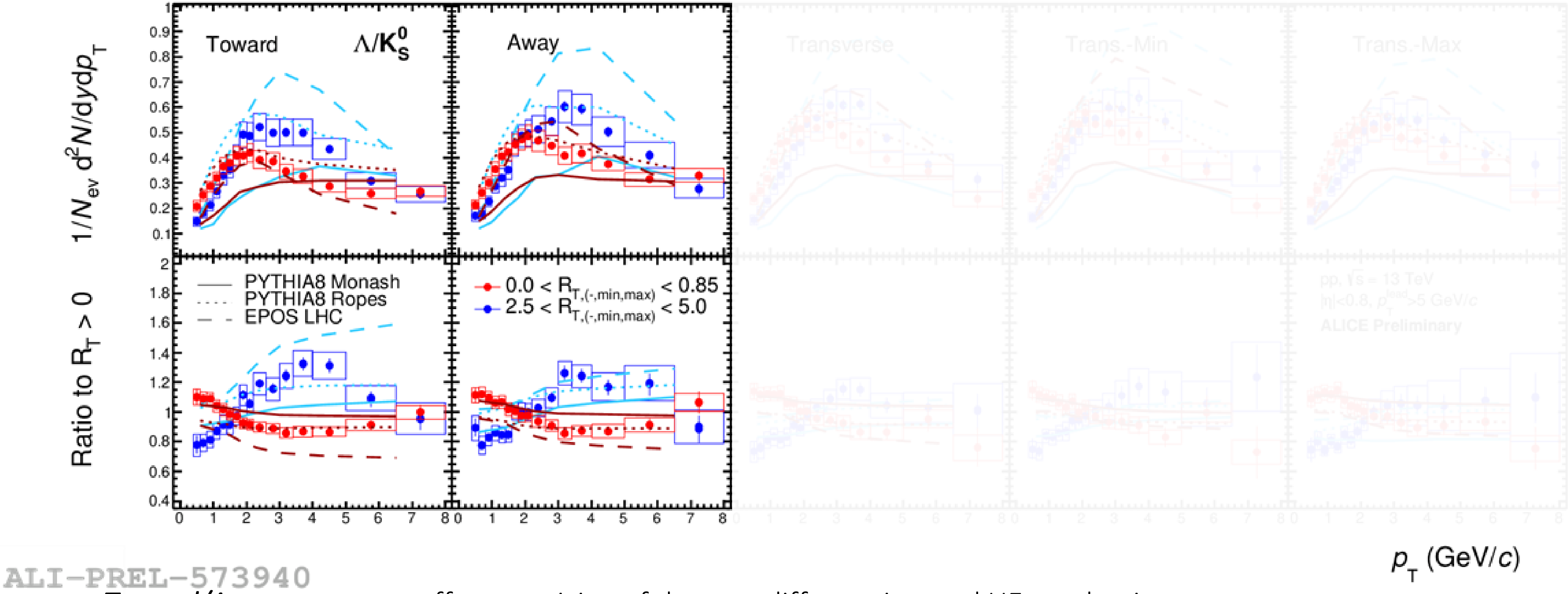


- *Toward/Away/Transverse*: dependence on R_{T} present in all regions
- *Transverse regions:* no sizable differences
- EPOS LHC strongly overpredicts the effect of R_{T} selection on Ξ in the regions with jet fragmentation

Studying „radial flow“-like behaviour with Λ/K^0_S

Ξ / K^0_S in back-up

NEW!



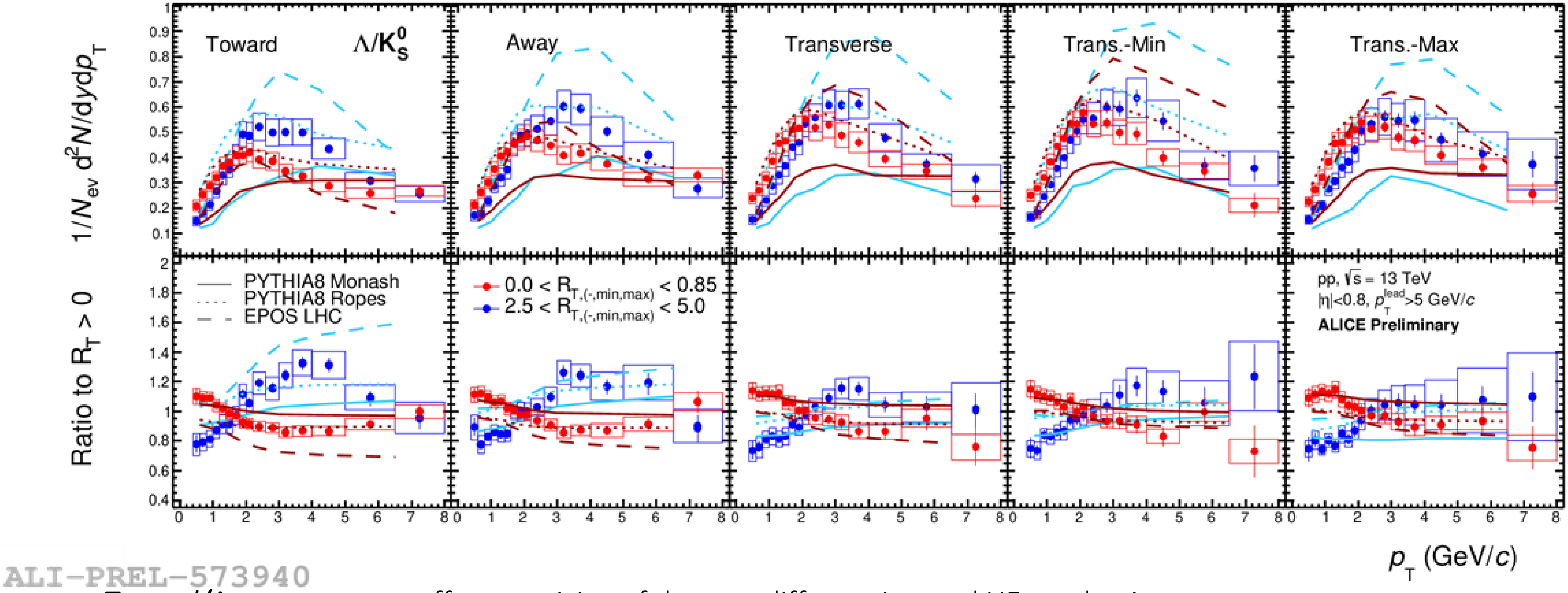
- *Toward/Away*: strongest effect → mixing of the very different jet- and UE-production

See also:
ALICE PLB 827 (2022) 136984

Studying „radial flow“-like behaviour with $\Lambda/\mathrm{K_S^0}$

Ξ / K_S^0 in back-up

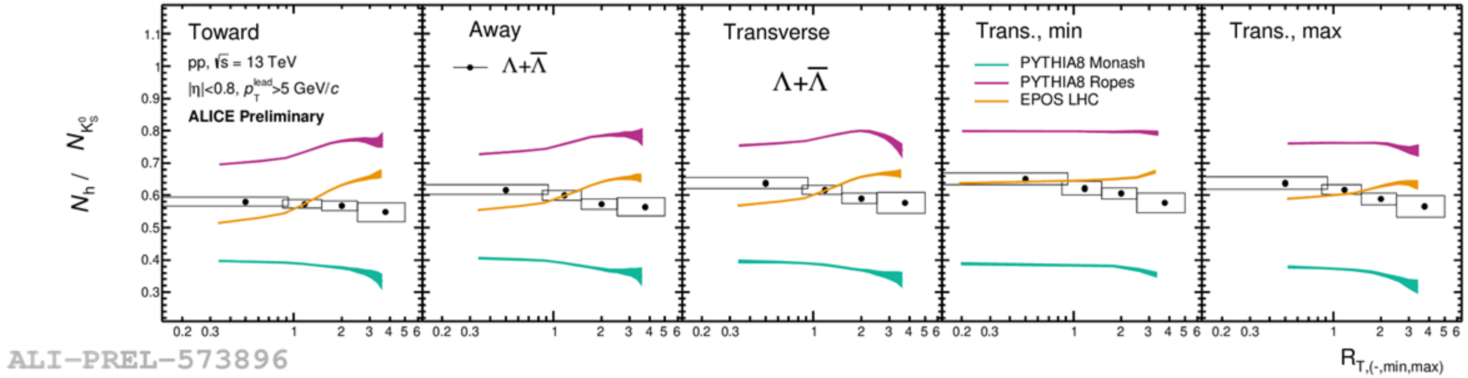
NEW!



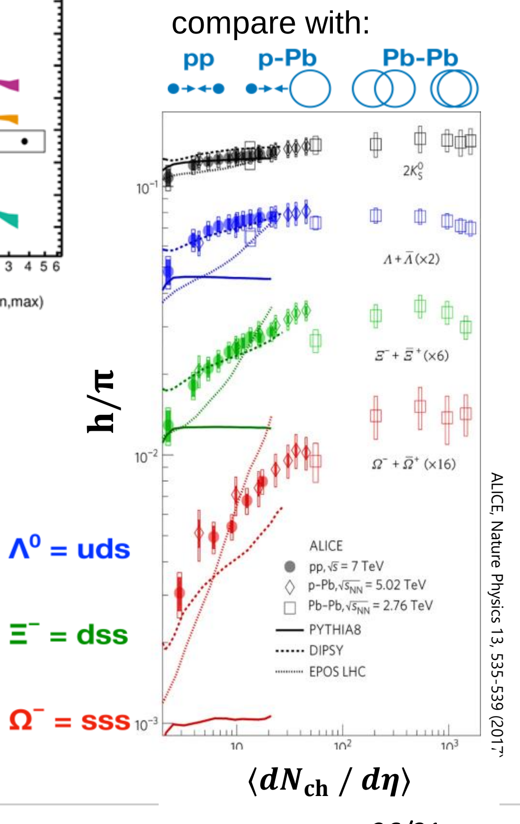
- *Toward/Away*: strongest effect → mixing of the very different jet- and UE-production
- *Transverse-min*: comparable to *Transverse* and *Transverse-max* → flow-like boost also solely from increase in n_{MPI}

Studying strangeness enhancement with $N_h/N_{K_S^0}$

NEW!



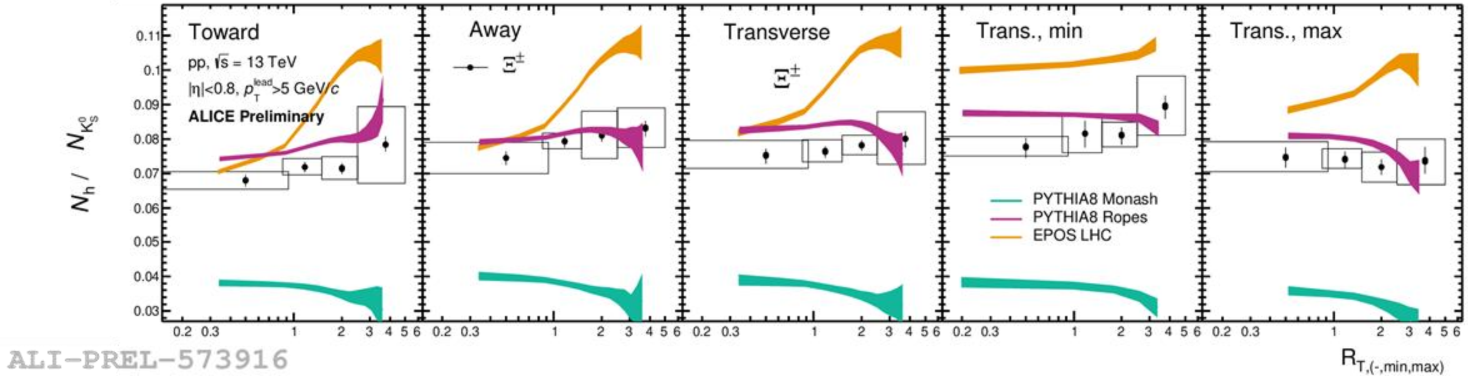
compare with:



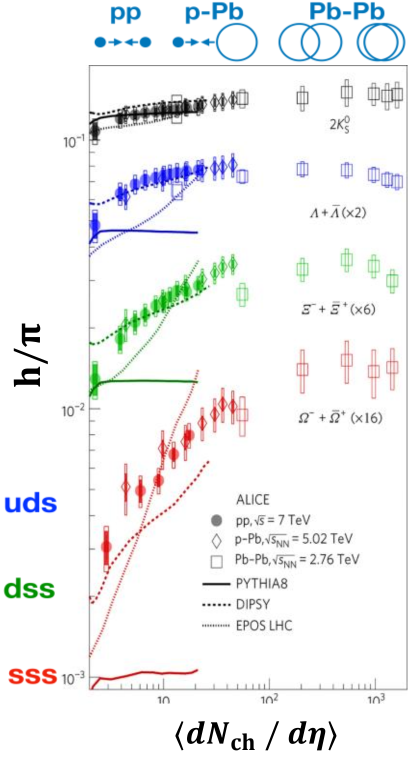
- **Λ:** displays no apparent sensitivity on the R_T and region

Studying strangeness enhancement with $N_h / N_{K^0_S}$

NEW!



compare with:



Λ^0 = uds

Ξ^- = dss

Ω^- = sss

ALICE, Nature Physics 13, 535-539 (2017)

- **Λ:** displays no apparent sensitivity on the R_T and region
- **Ξ:** strangeness enhancement observed with increase in R_T
  - the strongest effect is seen in the n_{MPI}-sensitive *transverse-min* whilst not evident in the ISR/FSR-sensitive *transverse-max*

None of the models can describe the observed enhancement

- Ξ has a weaker evolution than the $\langle dN_{ch} / d\eta \rangle$ study, however more representative of the sheer increase in parton-parton activity

Conclusions

- ***R_T, the magnitude of UE***: can classify low-n_{MPI} and high-n_{MPI} events
  - R_T is measured in ALICE in pp at $\sqrt{s}$ = 2.76 TeV, 5.02 TeV, 7 TeV, 13 TeV, and also in p-Pb and Pb-Pb

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- ***Strangeness*** is measured in pp at $\sqrt{s}$ = 13 TeV vs. R_{T}/ $R_{\mathrm{T,min}}$/ $R_{\mathrm{T,max}}$

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    - *(Toward)* **:** The largest effect seems to be mimicked by mixing the jet- and UE-related production
    - *(Transverse-min)* **:** The effect is also driven by n_{MPI} alone

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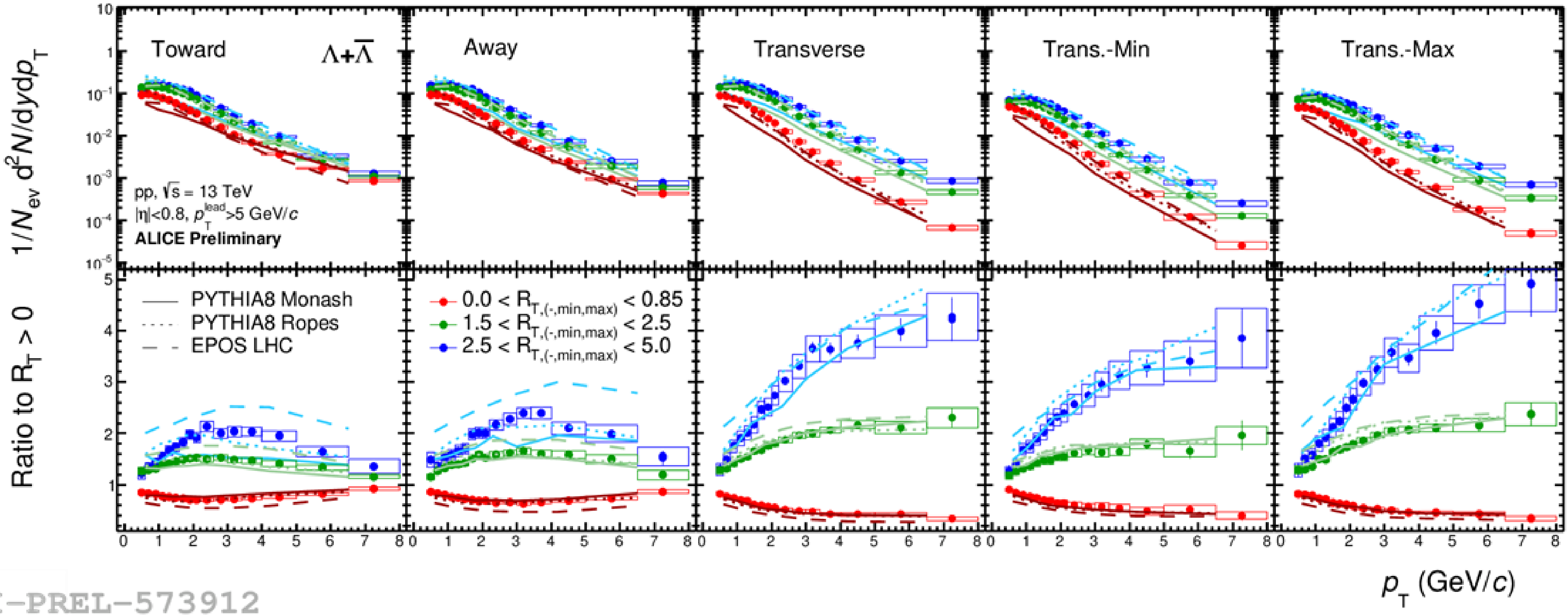
  - Λ/K^0_S shows typical radial flow features
    - *(Toward) :* The largest effect seems to be mimicked by mixing the jet- and UE-related production
    - *(Transverse-min) :* The effect is also driven by n_{MPI} alone
  - N_{Ξ} / $N_{\mathrm{K}^0_{\mathrm{S}}}$ shows clear enhancement
    - *(Transverse-min) :* enhancement seemingly most sensitive to n_{MPI}
    - *(Transverse-max) :* no enhancement in the ISR/FSR emphasised region
  - Despite the very controlled R_{T} approach, all models have limited success across the different observables

Thank you for your attention!

BACKUP

p_T spectra: Λ

NEW!



ALI−PREL−573912

Particle ratio Ξ/K^0_S

NEW!