Probing jet hadrochemistry with measurements of π, K, and p in jets and the underlying event in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE

Sierra Cantway for the ALICE collaboration

Yale University

Hot Jets: Advancing the Understanding of High Temperature QCD with Jets

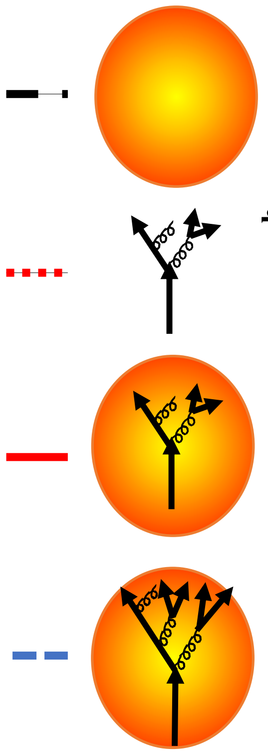
Loomis Lab (UIUC)

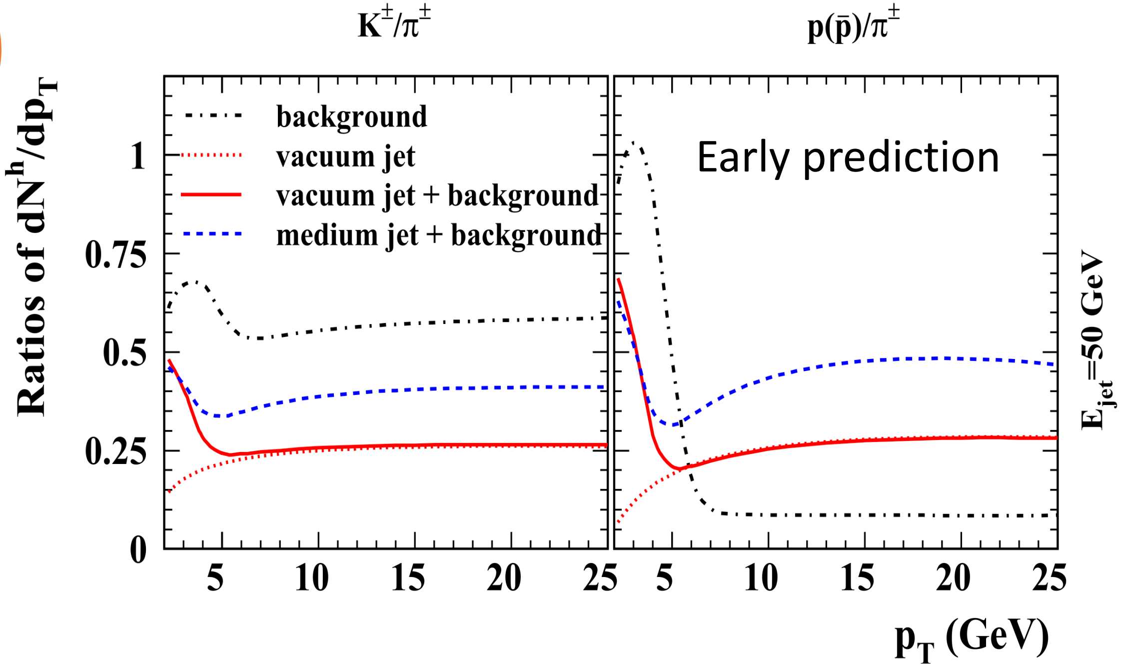
1/10/24

Supported in part by

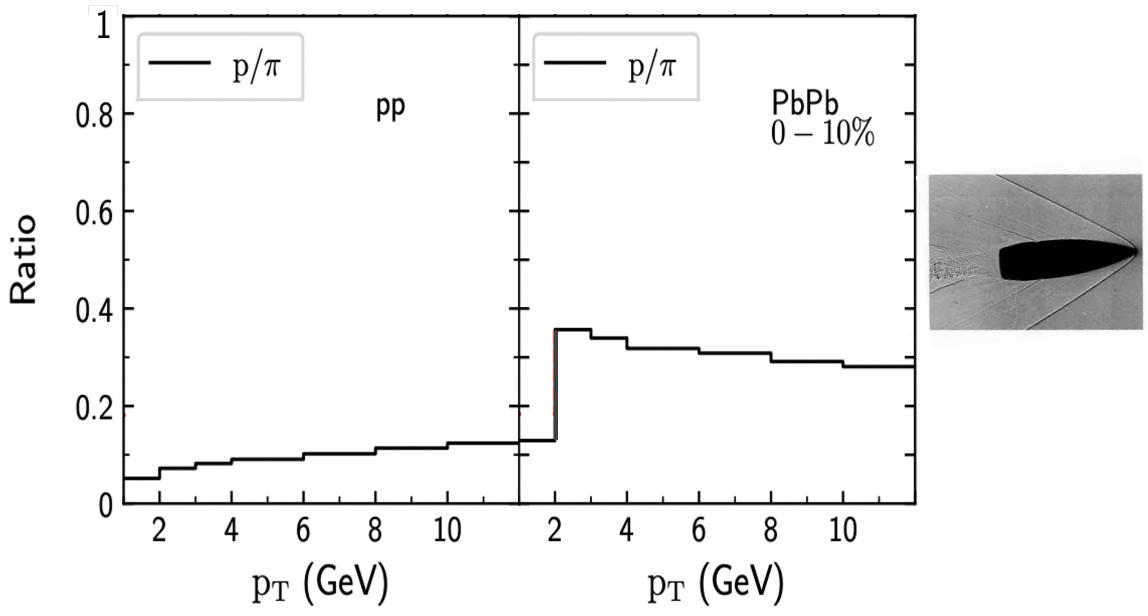
U.S. DEPARTMENT OF ENERGY

Different underlying physics mechanisms (e.g. **enhanced parton splitting** or **wake response**) → Different jet hadrochemistry modifications





S. Sapeta, U. A. Weidemann, EPJ C 55 (2008) 293-302



A. Luo et al., PLB 837 (2023), 137638

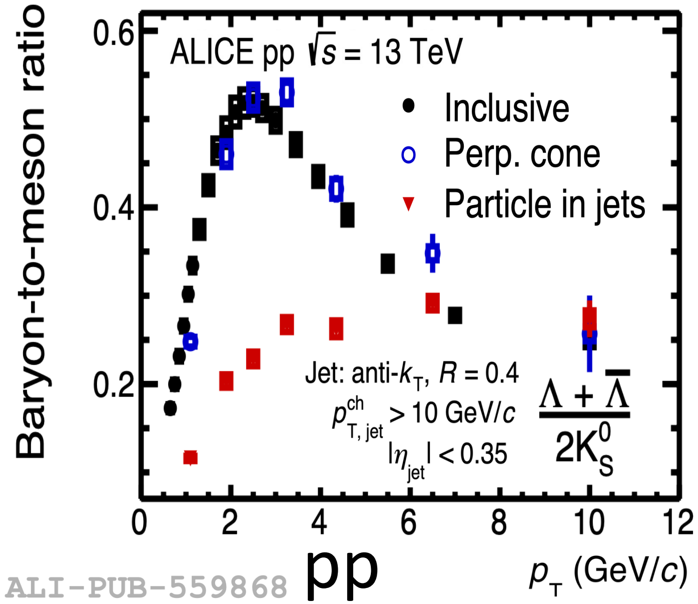
Enhanced parton splitting **Wake response**

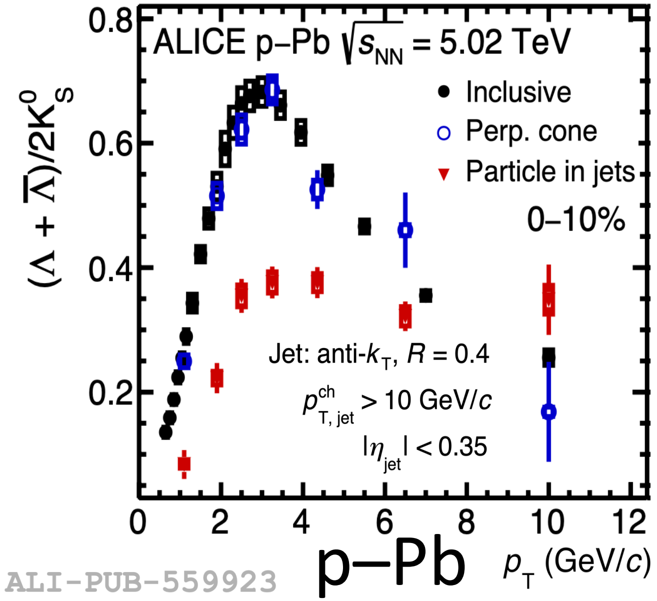
Measurements of **K/π and p/π ratios** in pp and Pb–Pb collisions within **jets and the underlying event (UE)**

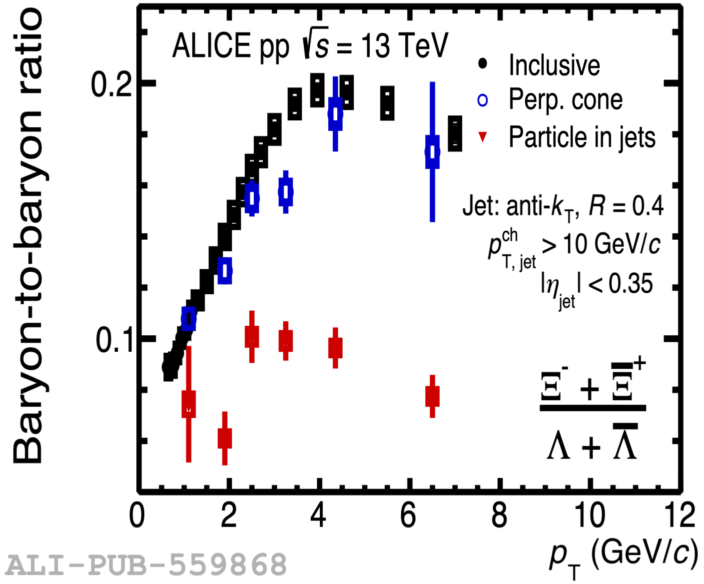
→ Sensitive to **jet-medium interactions**

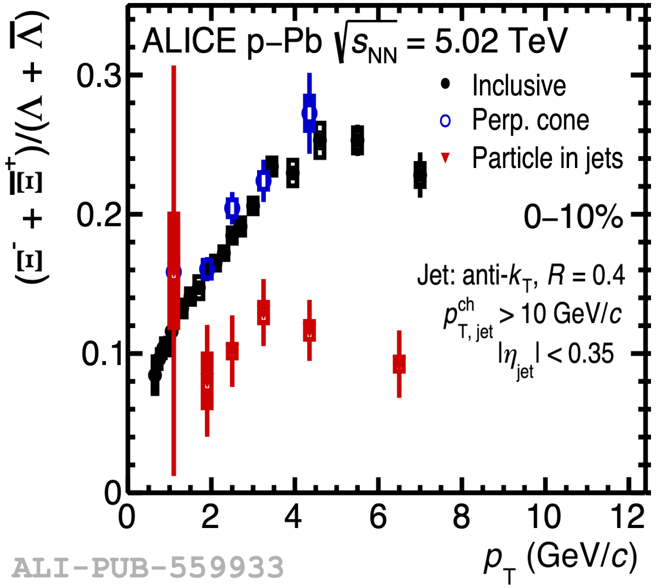
→ Investigate the relative contributions of **fragmentation and coalescence** in hadronization

ALICE Small System Measurements









Baryon

- ● Inclusive
- ○ Perp. cone ⟵ UE
- ▼ Particle in jets

Baryon and strangeness production of V^0s/cascades in jets is much lower than UE or inclusive in pp and p–Pb.

- Ω production is less clear

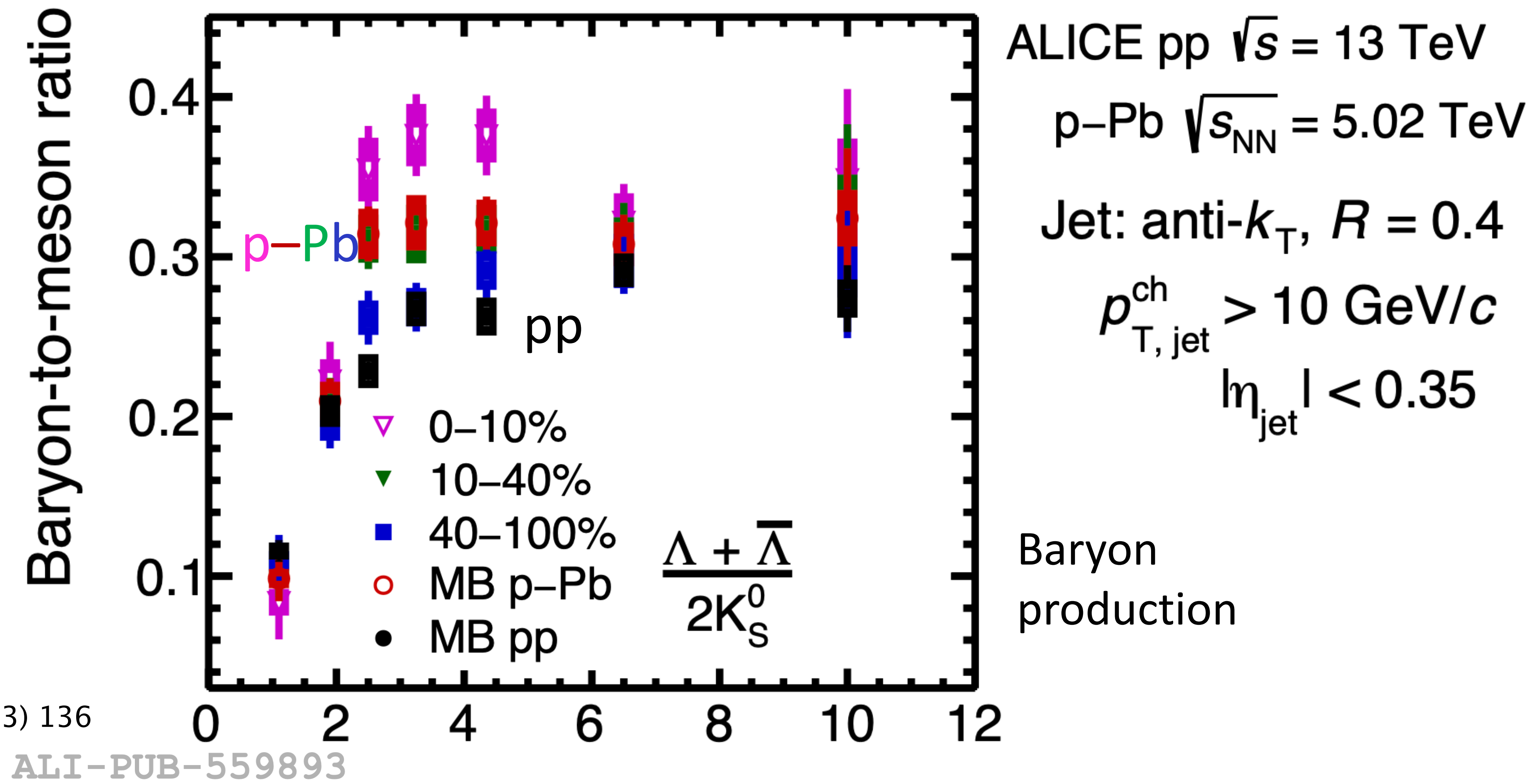
Strangeness

ALICE JHEP 07 (2023) 136

Other relevant measurements

ALICE Phys. Rev. C 101 (2020) 044907

ALICE Phys. Lett. B 827 (2022) 136984



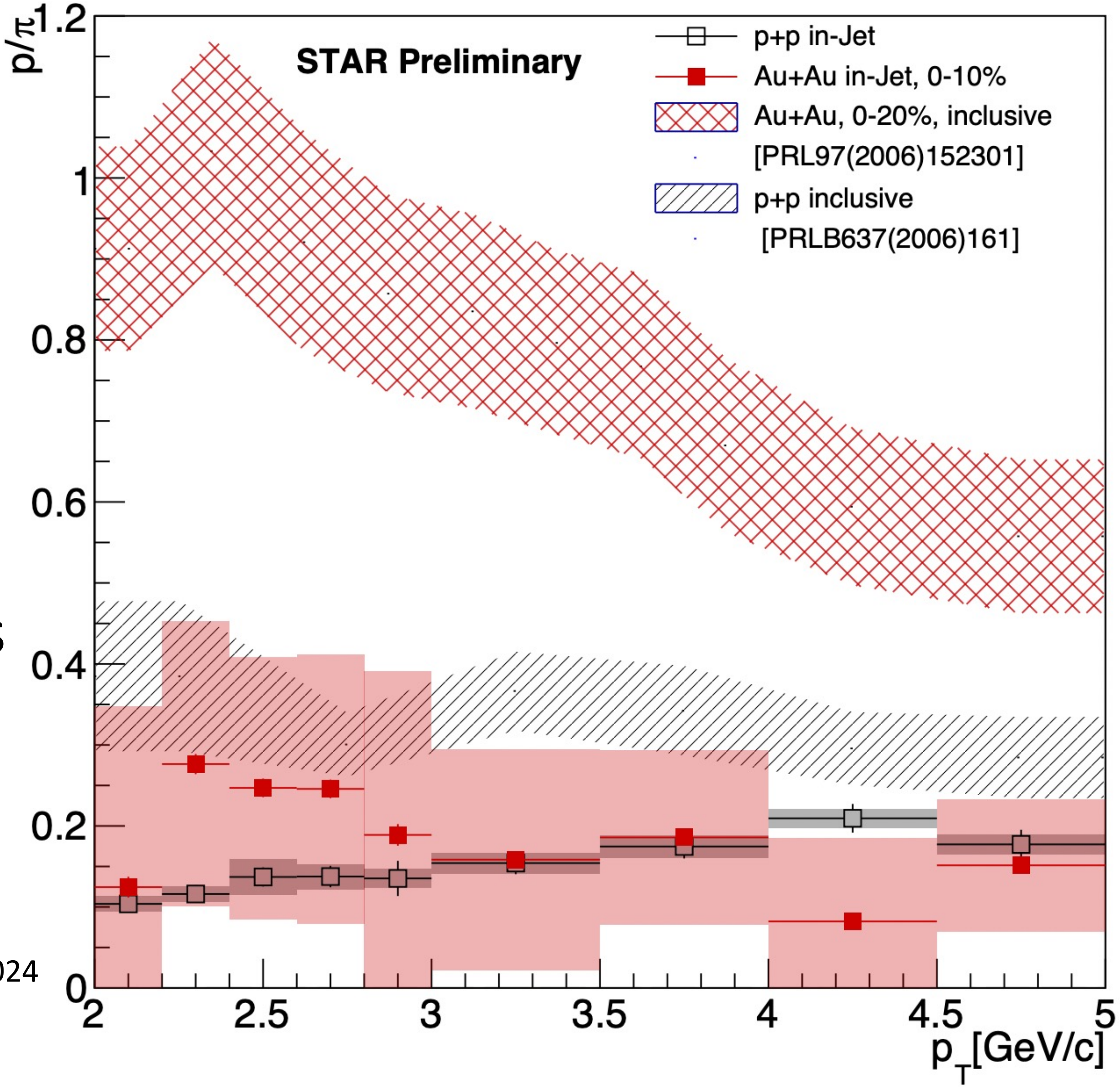
Baryon production

ALICE JHEP 07 (2023) 136

Λ/K^0_S ratio obtained in p–Pb collisions is systematically higher than that in pp collisions for $2 < p_T < 4$ GeV/c

STAR pp and Heavy-Ion Measurements

R = 0.4



Jet $p_T^{raw} > 9$ GeV/c

$p_T^{const} > 2$ GeV/c

RHIC jets with track bias do not exhibit p/π modification in heavy ion collisions within systematics

Large systematic from determination of **combinatorial jet contributions**

STAR Preliminary
G. Dale-Gau Hard Probes 2024

The ALICE Detector in Run 2

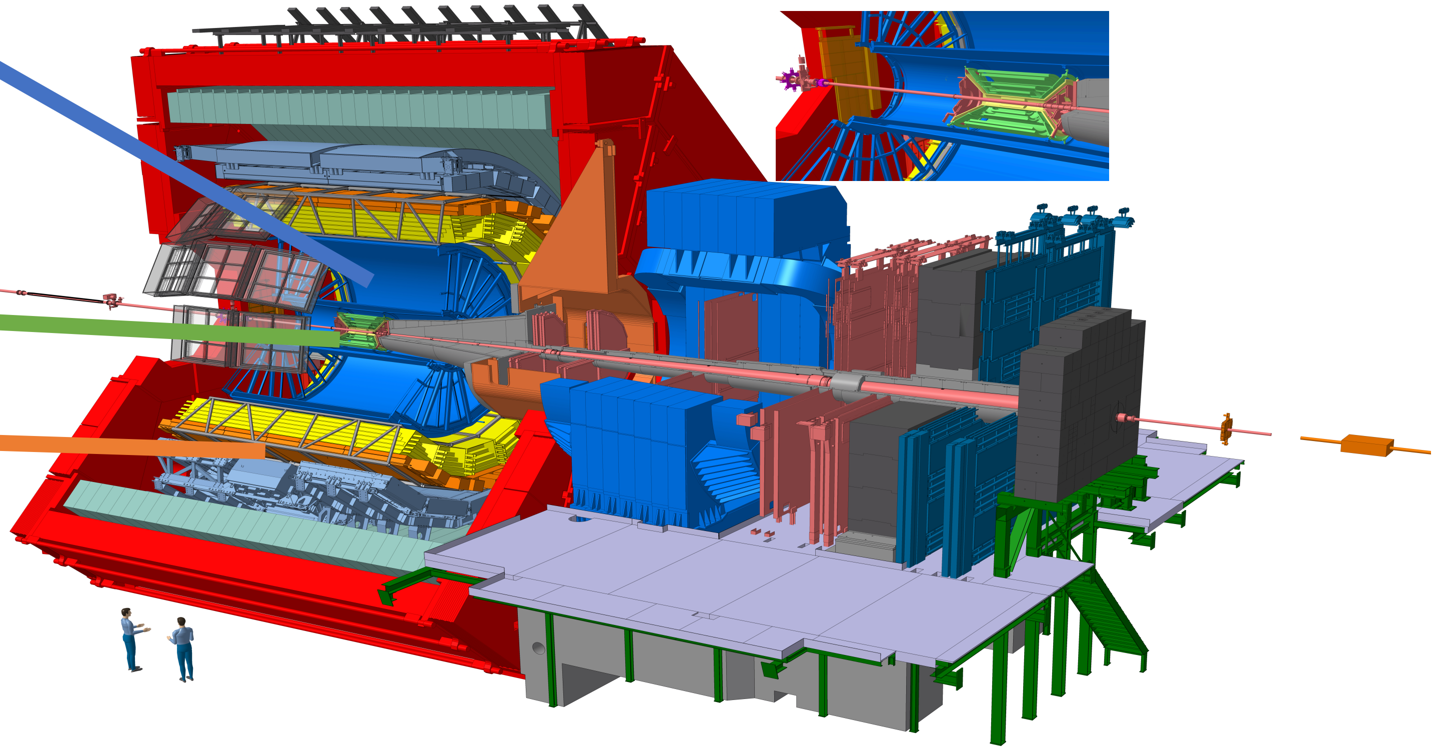
ALICE's excellent particle identification (PID) capabilities are ideal for this measurement!

Time Projection Chamber (TPC)

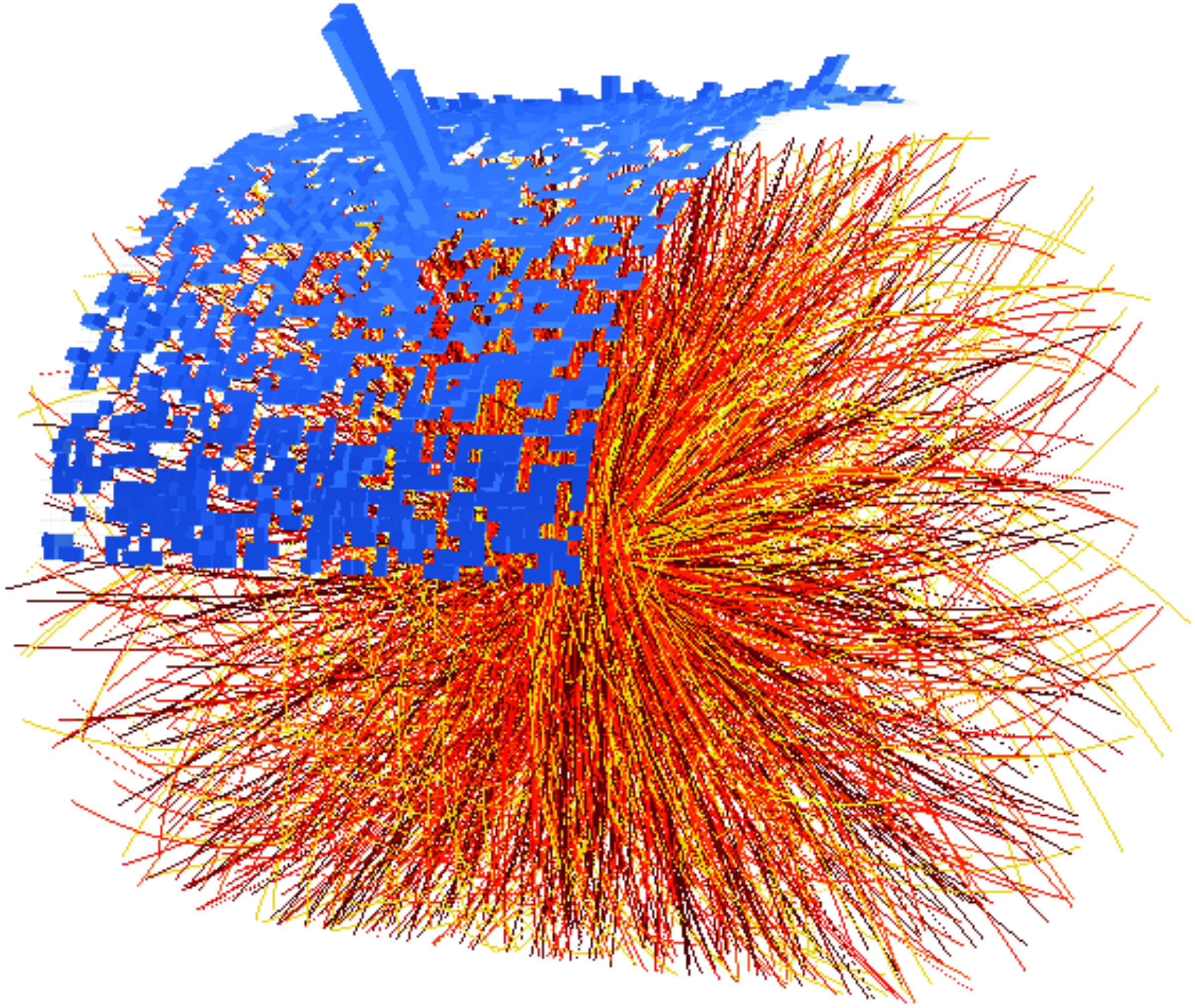
- Low p_{T} (0.25-0.8 GeV/c) and high p_{T} (3-20 GeV/c) PID via energy loss (dE/dx)
- Jet reconstruction via charged tracks (with ITS)

Time of Flight (TOF)

- Intermediate p_{T} (0.6-4.5 GeV/c) PID via particle velocity (β)



Jet Reconstruction



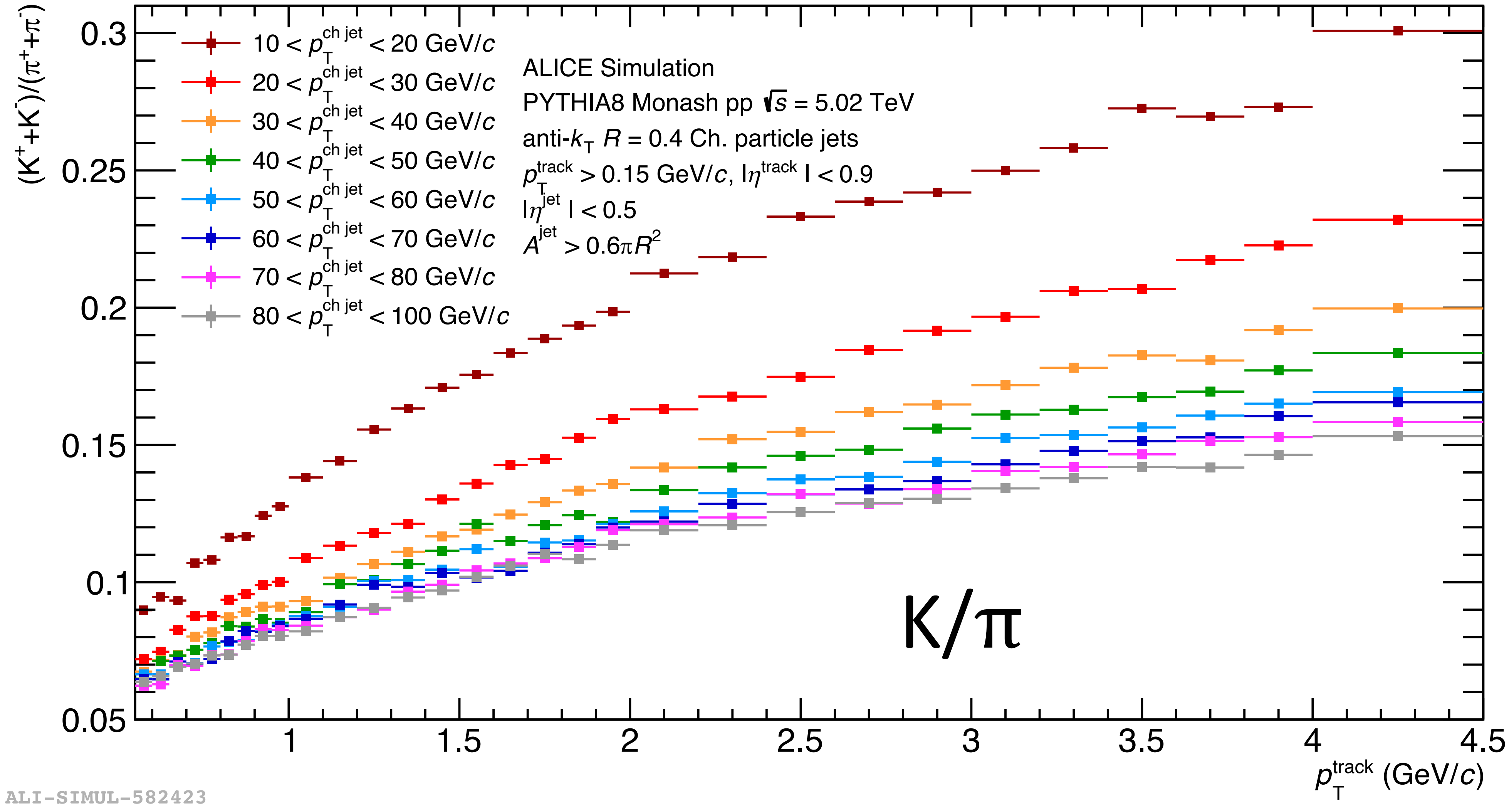
$p_{\mathrm{T\,ch\,jet}}^{\mathrm{raw\,sub}} = p_{\mathrm{T\,ch\,jet}}^{\mathrm{raw}} - A^{\mathrm{jet}}\,\rho$

anti-k_{T} R=0.4 charged-particle jets

$\boldsymbol{p_{\mathrm{T\,ch\,jet}}^{\mathrm{raw\,sub}} \neq p_{\mathrm{T}}^{\mathrm{ch\,jet}}}$

- $p_{\mathrm{T\,ch\,jet}}^{\mathrm{raw\,sub}}$: Raw jet p_{T} corrected with area-based pedestal subtraction
- $p_{\mathrm{T\,ch\,jet}}^{\mathrm{raw\,sub}} > 60$ GeV/c substantially reduces the effect of purely combinatorial jets

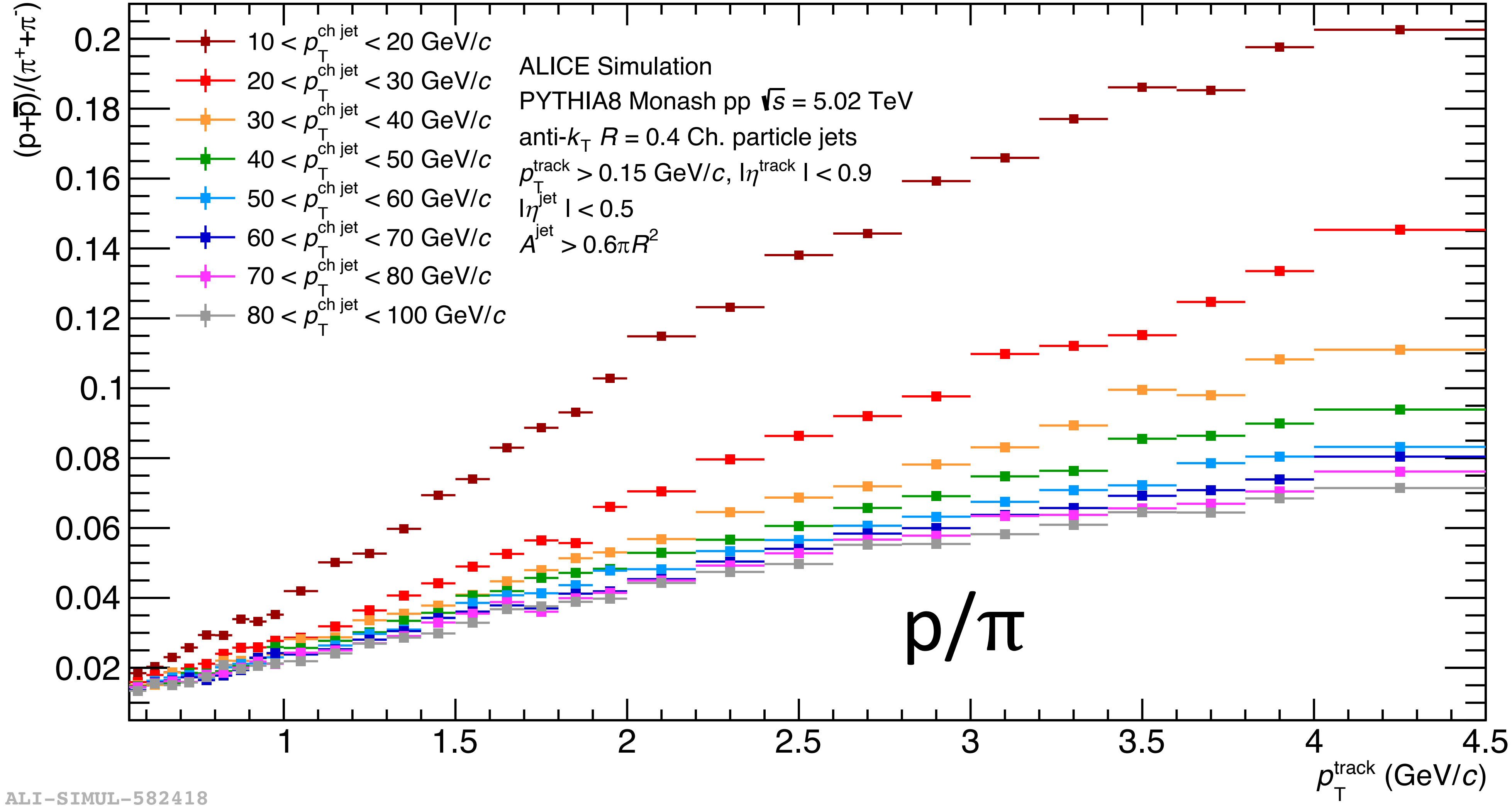
PYTHIA K/π dependence on $p_{T}^{\text{ch jet}}$



Expect **weak jet p_{T} dependence** in particle ratios

Currently accounted for in results' systematics by **varying minimum $p_{T\ \text{ch jet}}^{\text{raw sub}}$**

PYTHIA p/π dependence on $p_T^{\text{ch jet}}$



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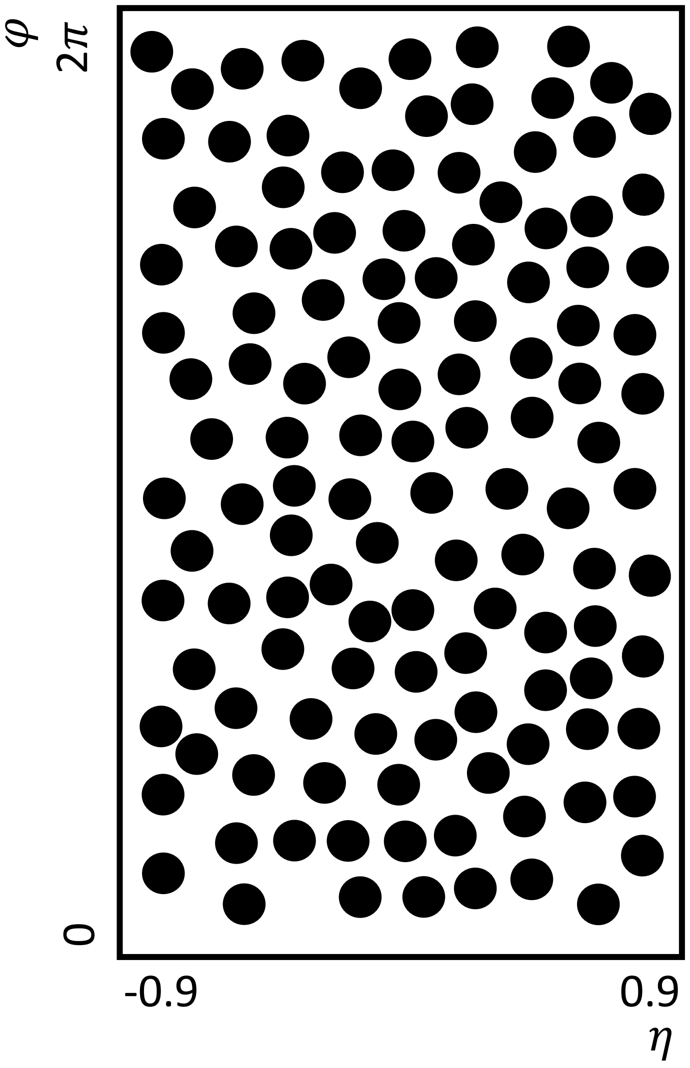
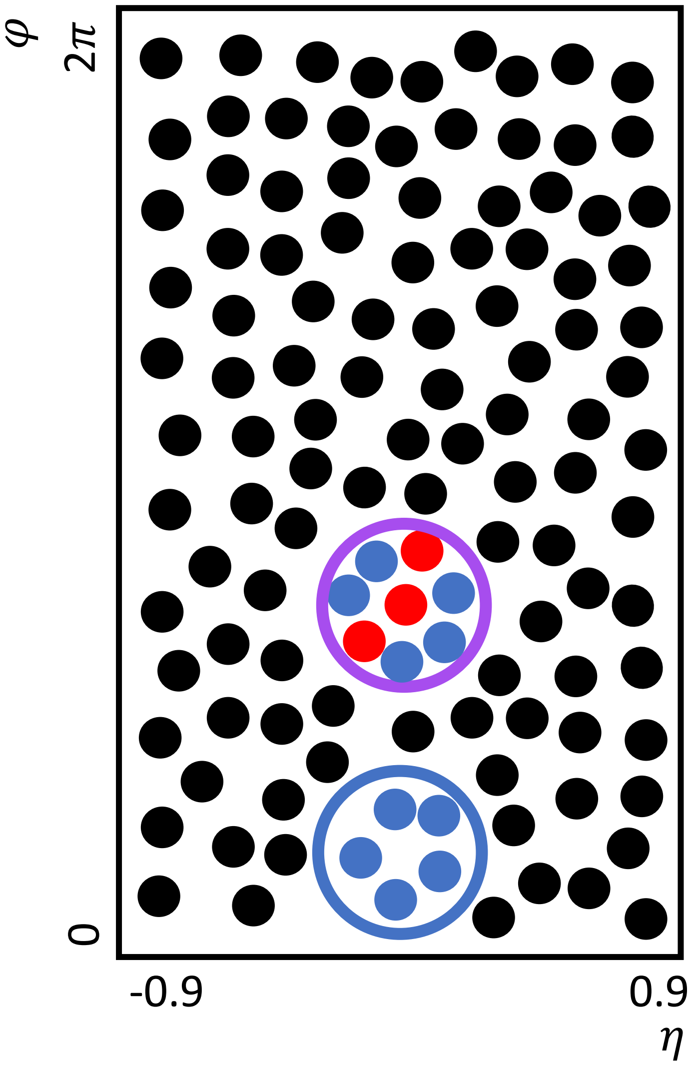
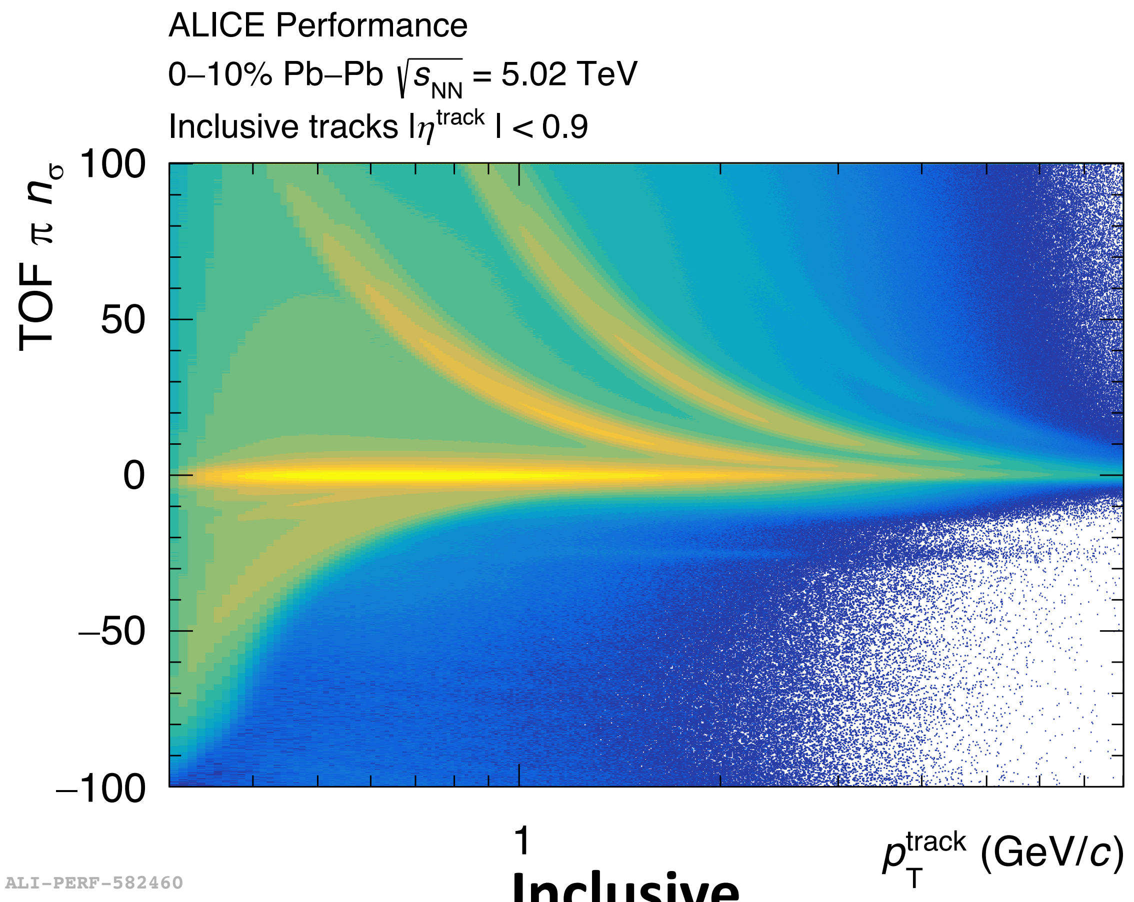
Particle Origins



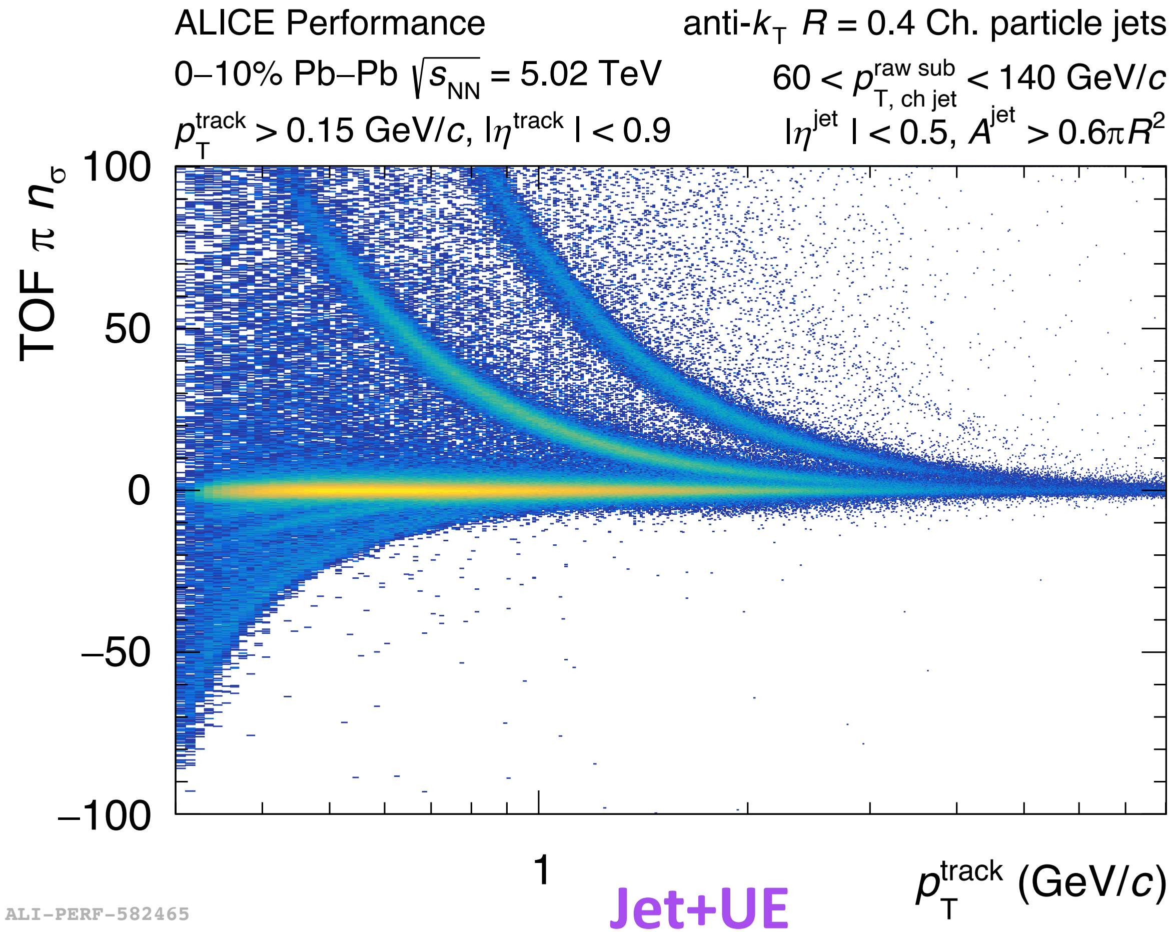


- PID is done on
  - **Inclusive particles** (regardless of jet presence)
  - All particles in anti-k_{T} **jet cone** (**jet**+**UE**)
  - Particles in **perpendicular cones** (**PC**)
    - R=0.4 cones at $\Delta\varphi$ = 90° and $\Delta\eta$ = 0 from selected jet cones
- **Still have UE particles inside the jet cones**
  - Particle-species-based UE subtraction is performed after PID with **PC**

These results: PID is performed via fits to TOF n_σ particle hypotheses



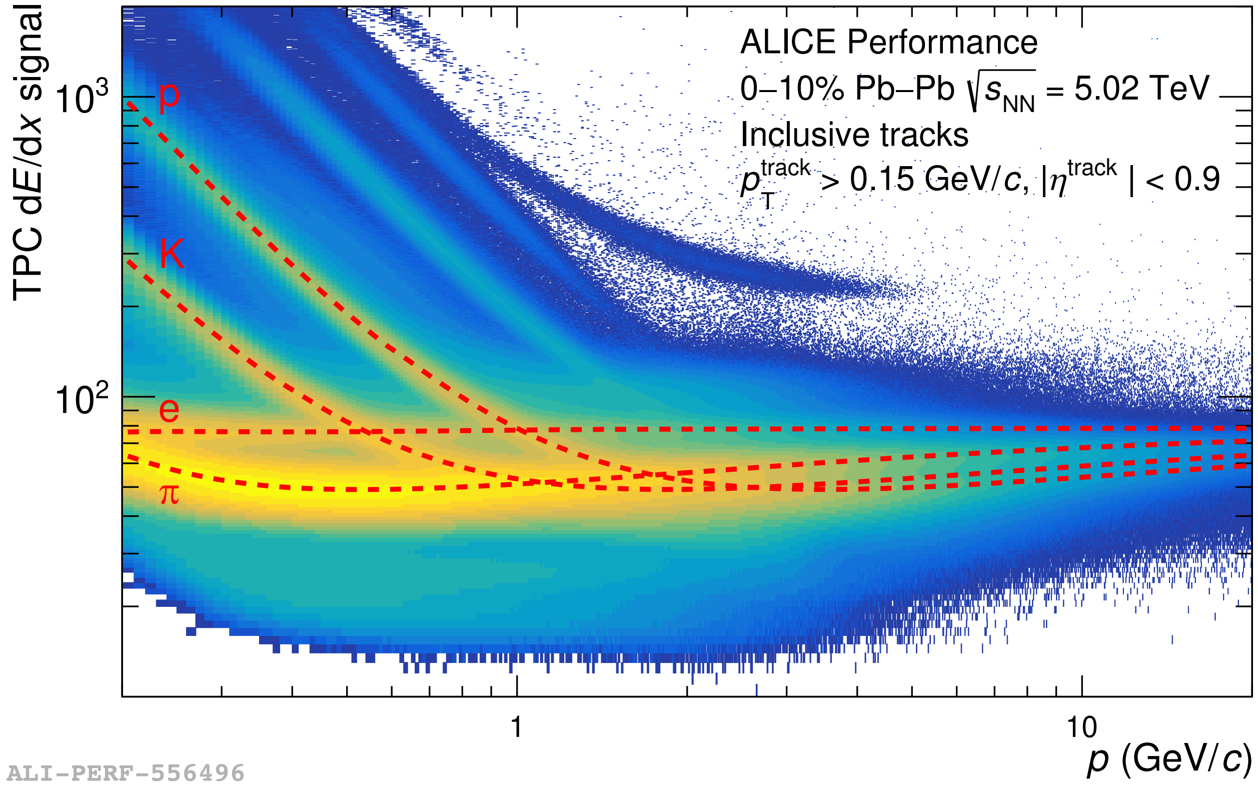
Inclusive



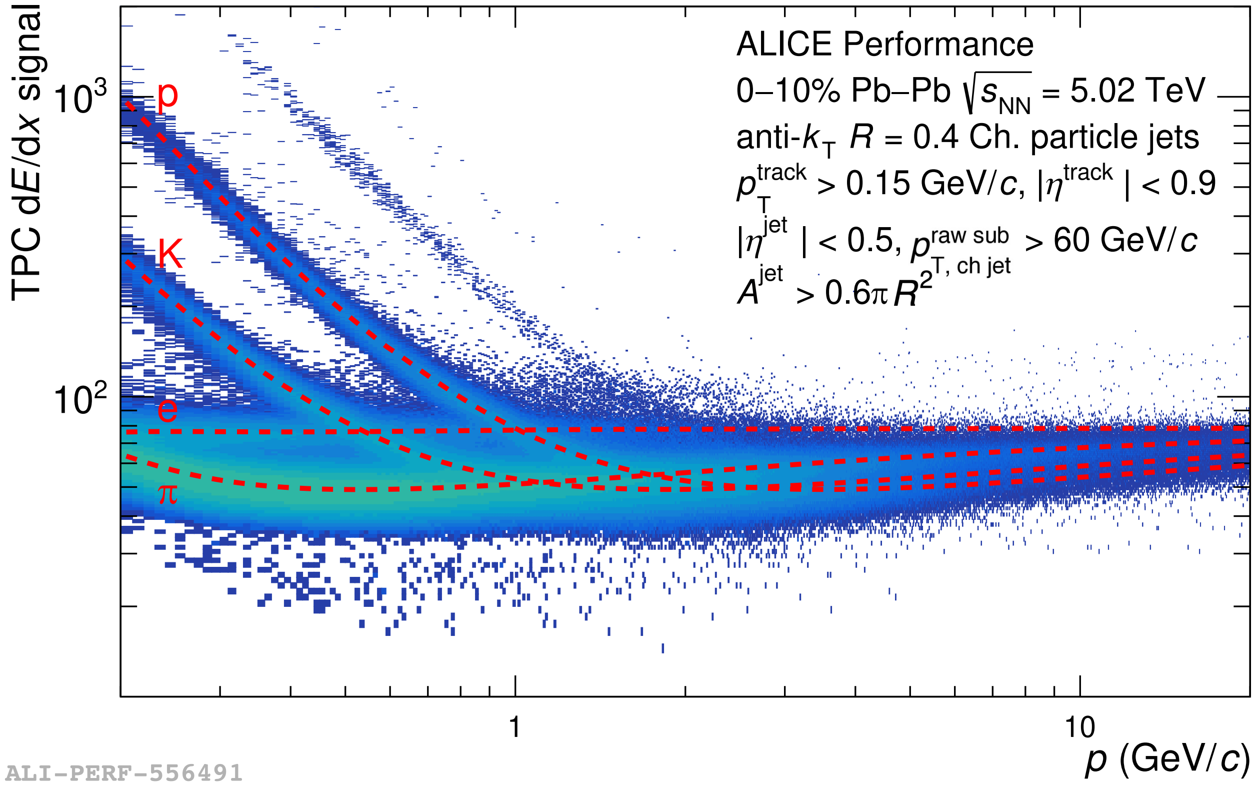
Jet+UE

Repeated for K, p particle hypotheses

TPC PID studies underway to extend p_T range



Inclusive

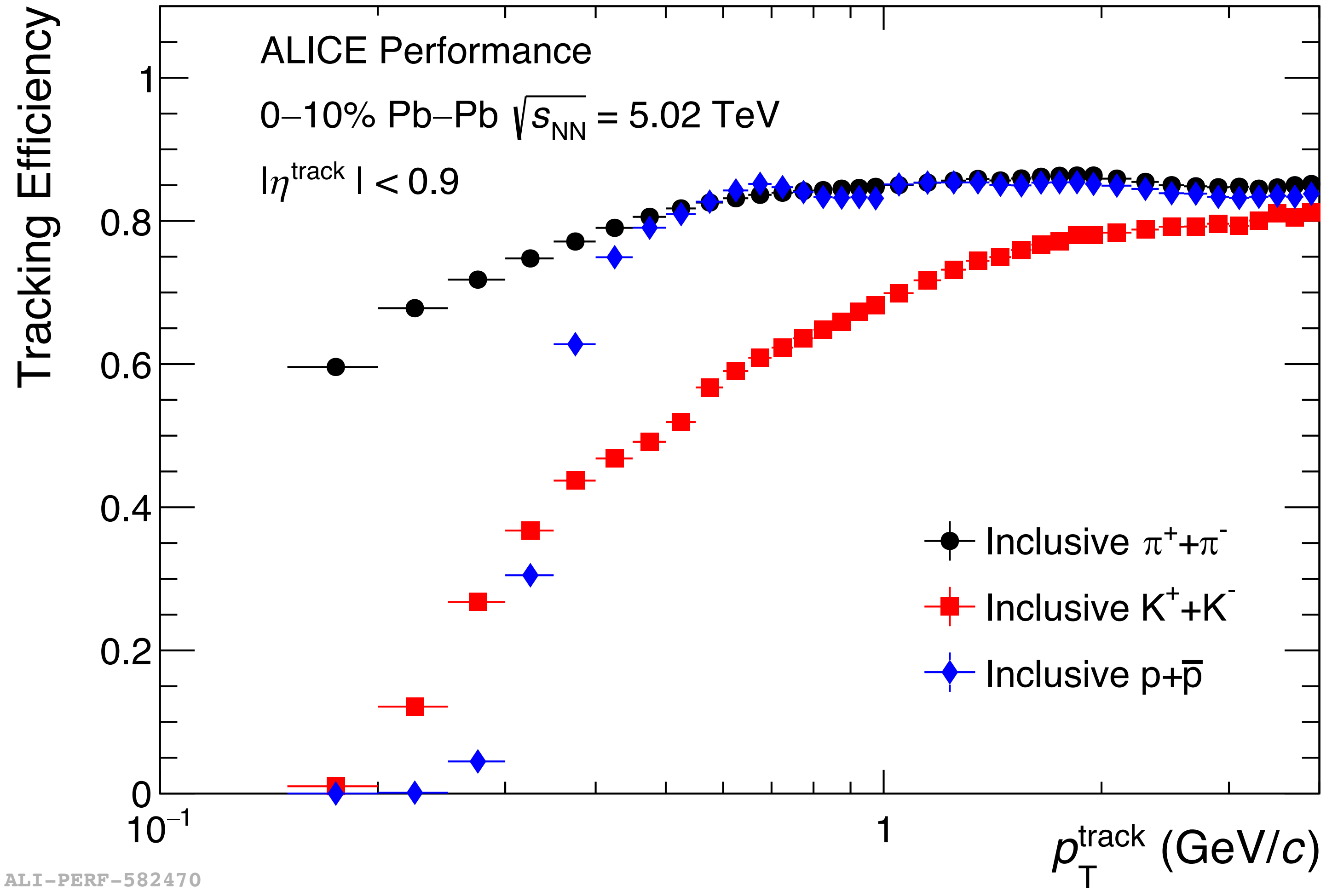


Jet+UE

PID Spectra Corrections

Standard PID spectra corrections were performed for inclusive, jet+UE, and PC particles

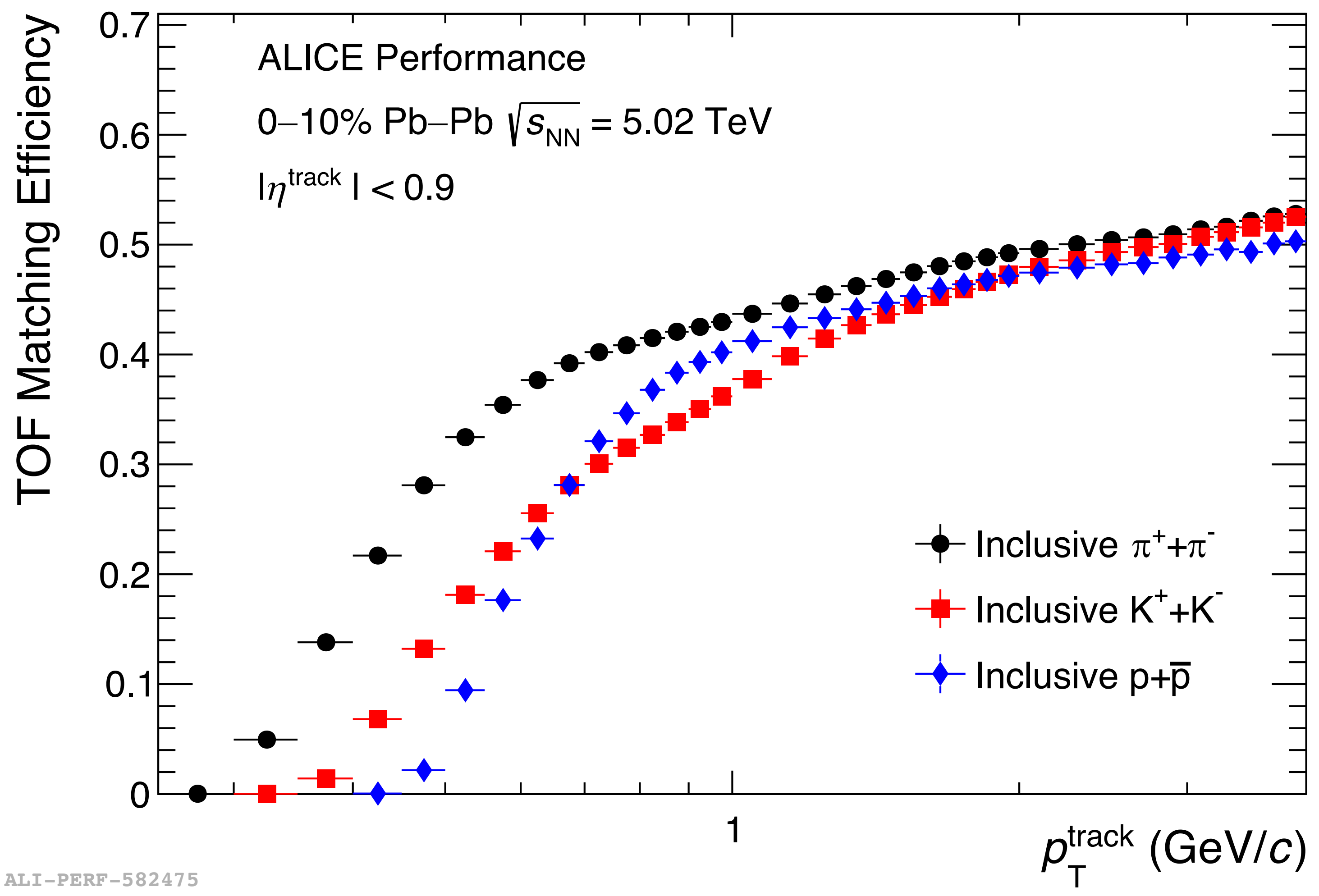
- **Tracking efficiency**
  - MC inclusive tracks measured / MC inclusive particles produced



PID Spectra Corrections

Standard PID spectra corrections were performed for inclusive, jet+UE, and PC particles

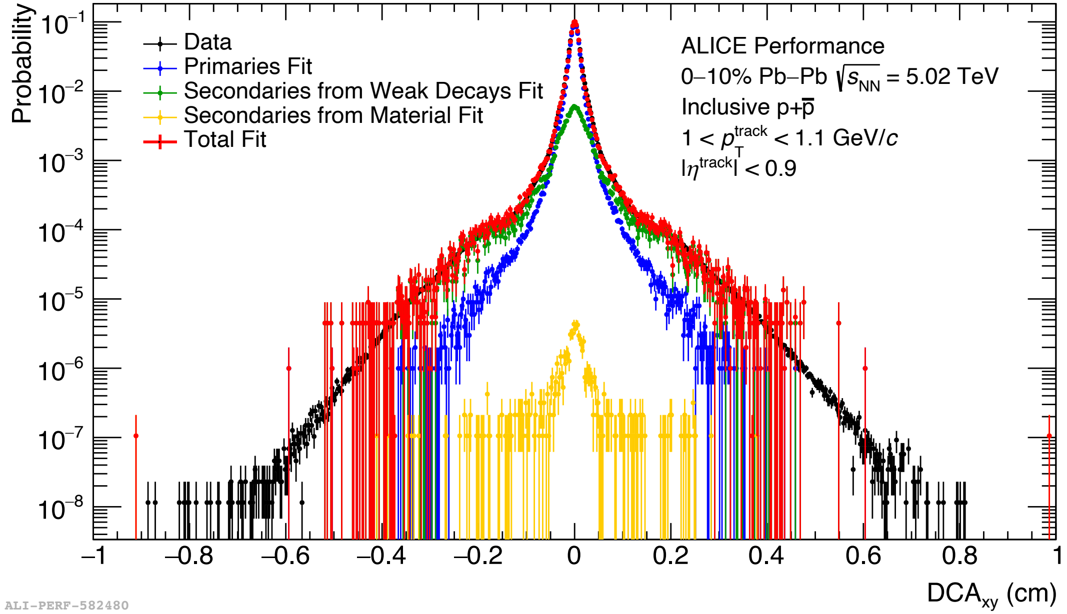
- Tracking efficiency
  - MC inclusive tracks measured / MC inclusive particles produced
- **TOF matching efficiency**
  - MC inclusive tracks measured and matched to a TOF signal / MC inclusive tracks measured

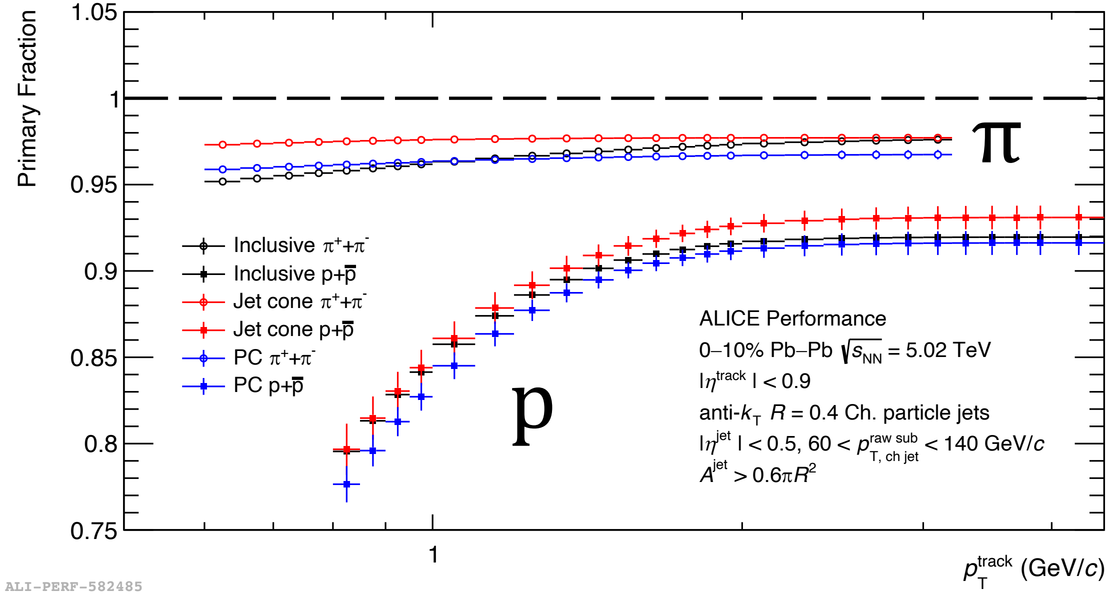


PID Spectra Corrections

Standard PID spectra corrections were performed for inclusive, jet+UE, and PC particles

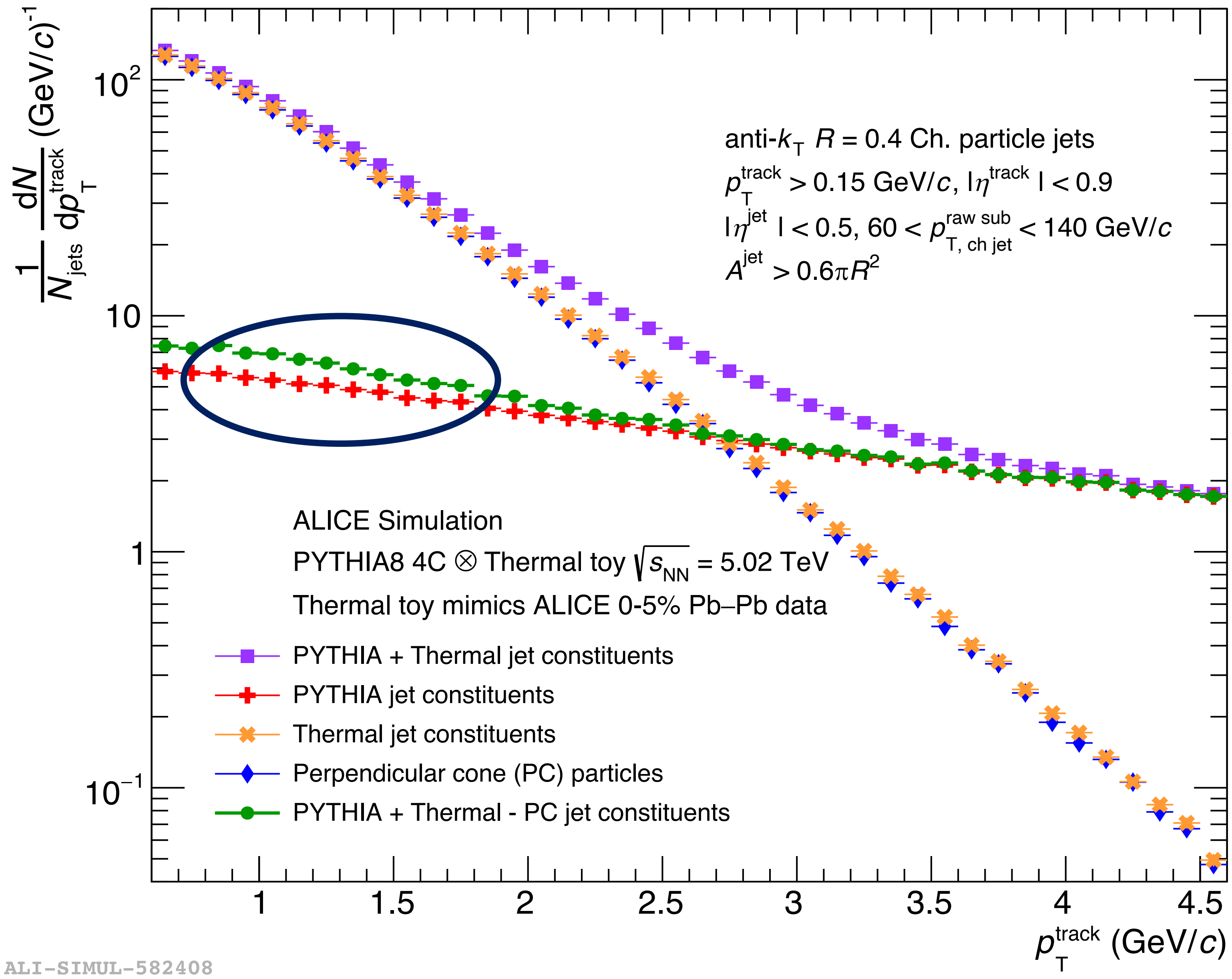
- Tracking efficiency
  - MC inclusive tracks measured / MC inclusive particles produced
- TOF matching efficiency
  - MC inclusive tracks measured and matched to a TOF signal / MC inclusive tracks measured
- **Primary fraction**
  - Data primary tracks / Data tracks measured





Toy Model Studies of Particle Species-Based UE Subtraction

- **Perpendicular cone (PC):** R=0.4 cones at $\Delta\varphi$ = 90° and $\Delta\eta$ = 0 from selected jet cones
- **PC** underestimates the **UE** particles in selected **PYTHIA+thermal** toy model jets



Particle Species-Based Underlying Event Subtraction

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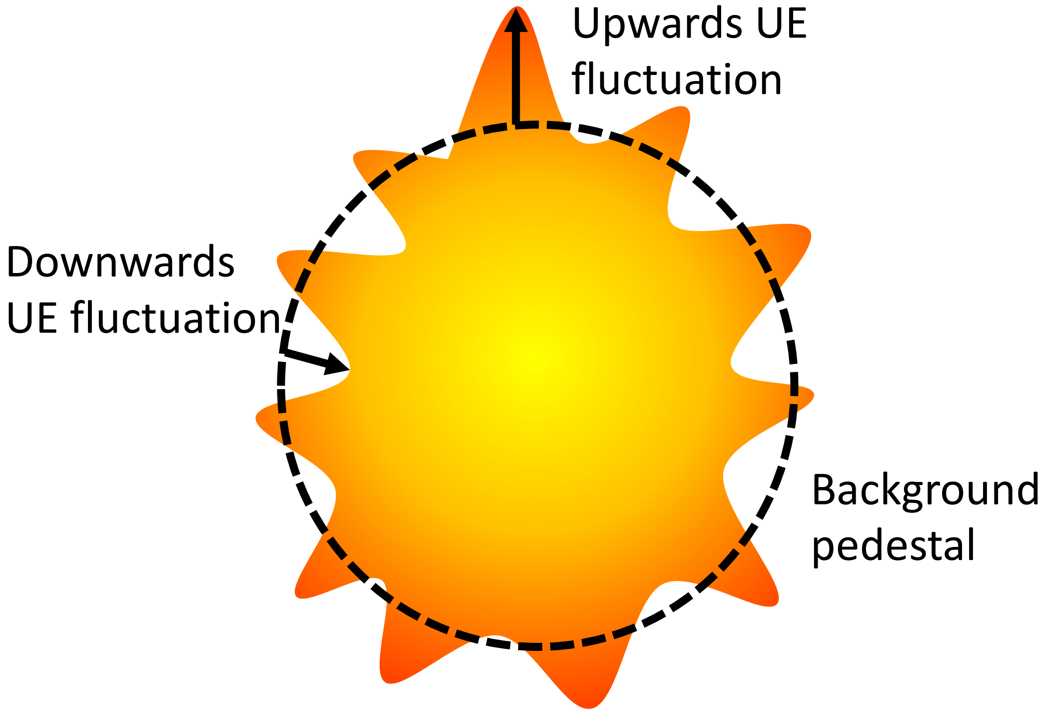

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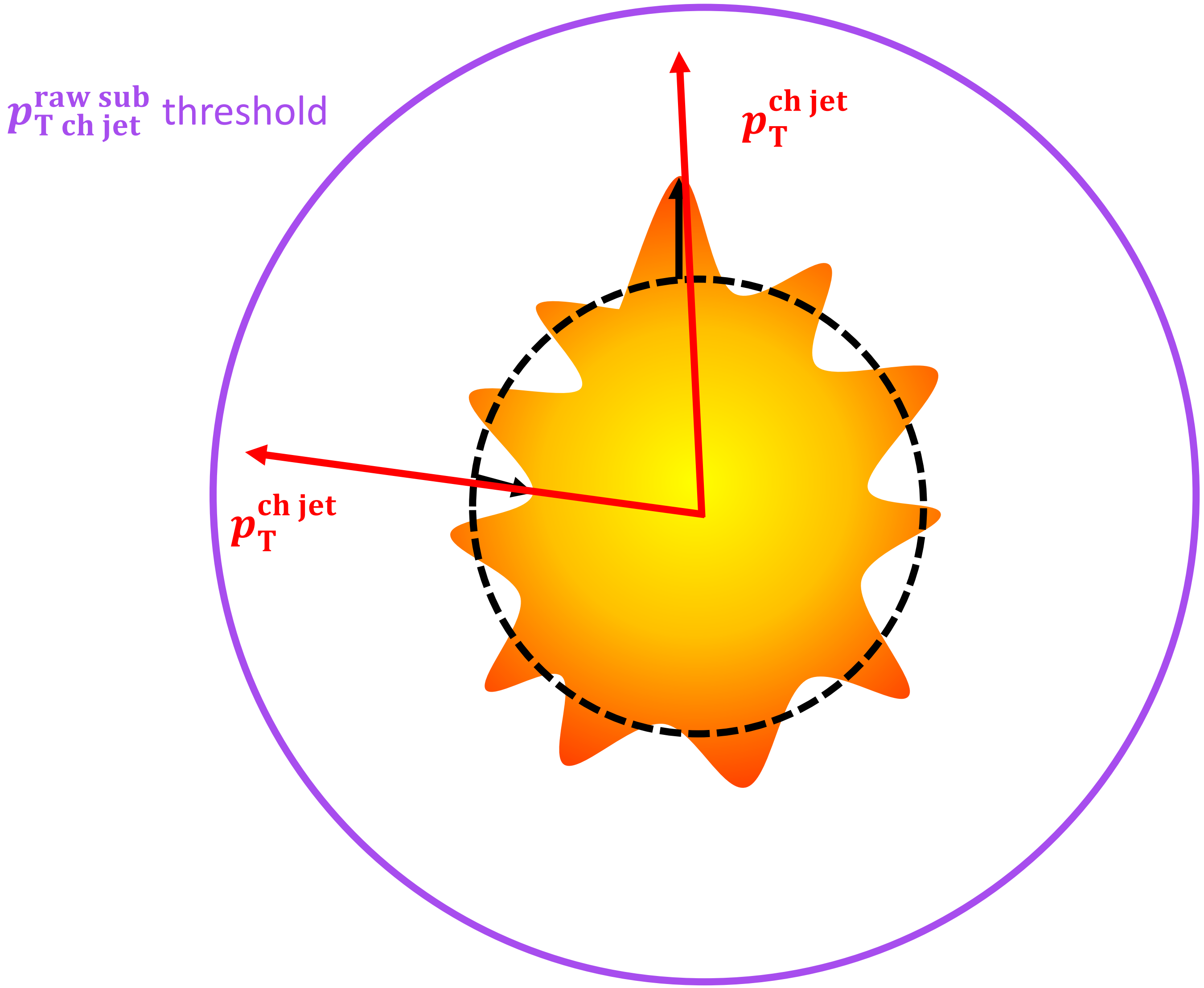

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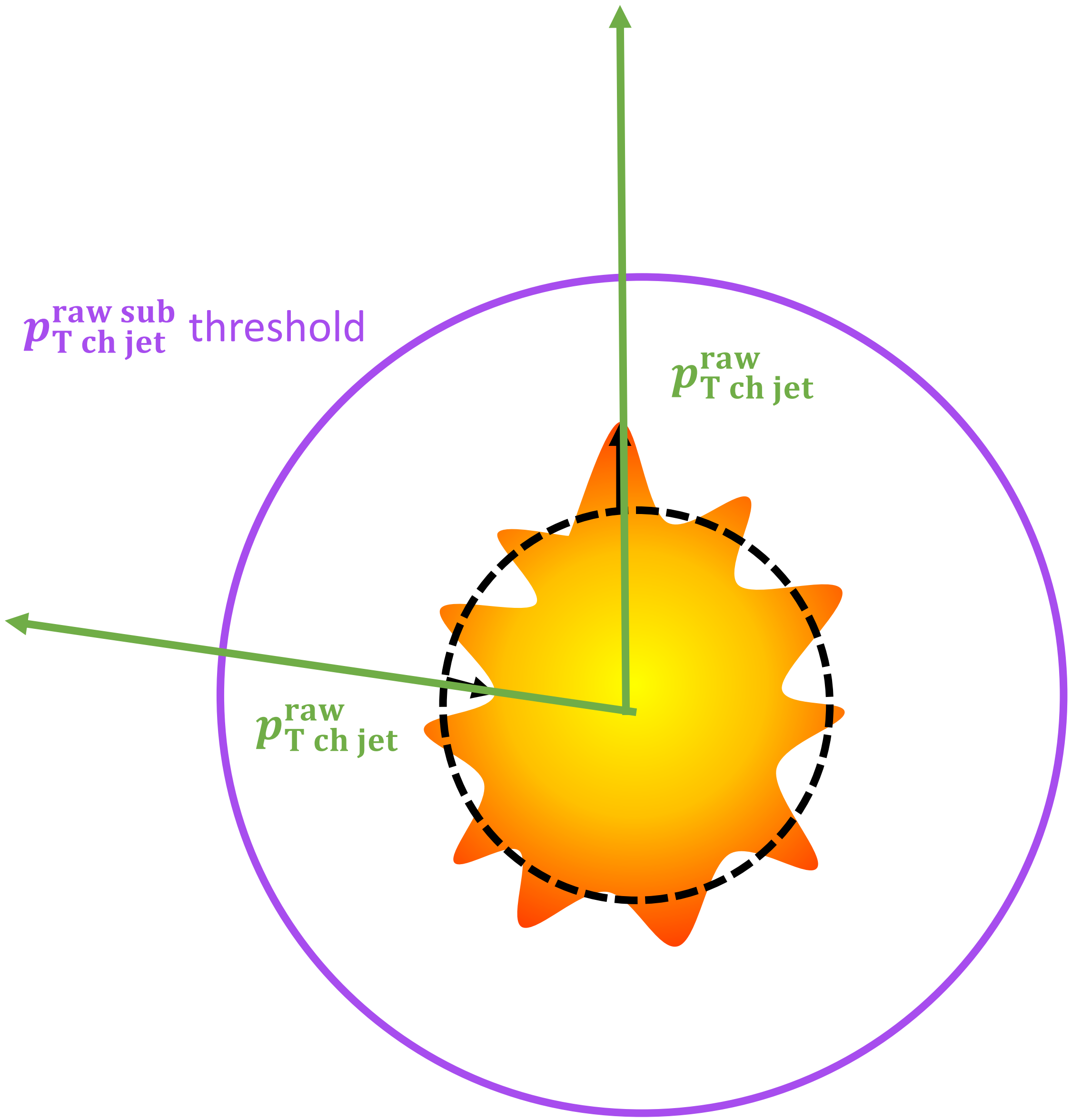
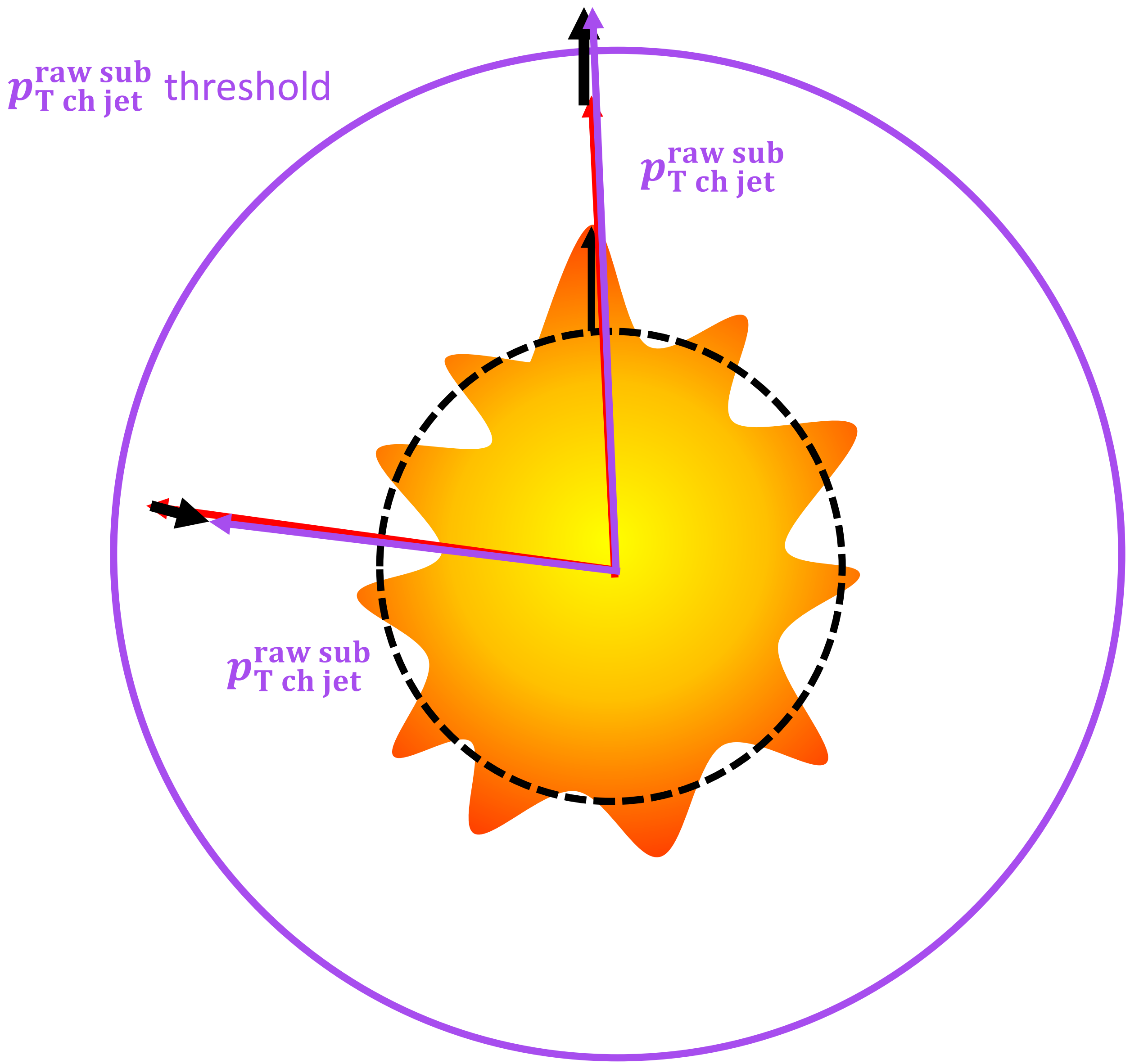


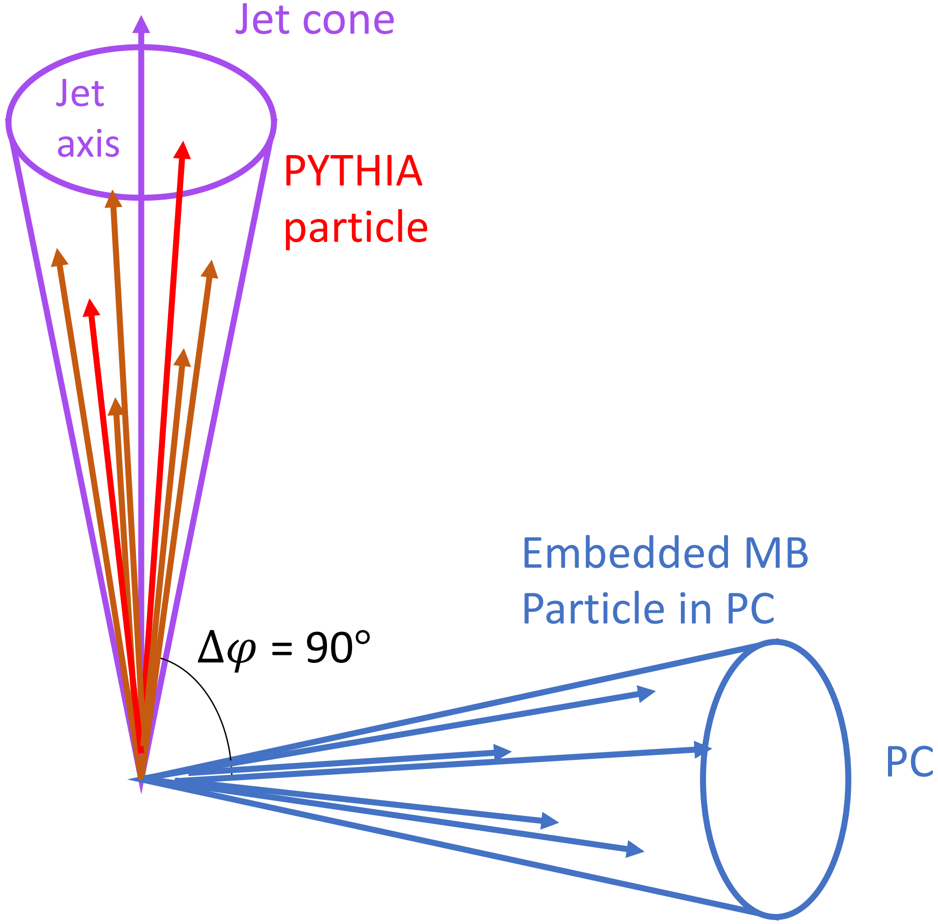
Particle Species-Based Underlying Event Subtraction

- **Perpendicular cone (PC):** R=0.4 cones at $\Delta\varphi$ = 90° and $\Delta\eta$ = 0 from selected jet cones
- **PC** underestimates the **UE** particles in selected **PYTHIA+thermal** toy model jets
- **Caused by an increased probability of selecting a jet on an upward fluctuation of the background from cutting on $p_{\mathrm{T\,ch\,jet}}^{\mathrm{raw\,sub}}$**



Scaling Factor

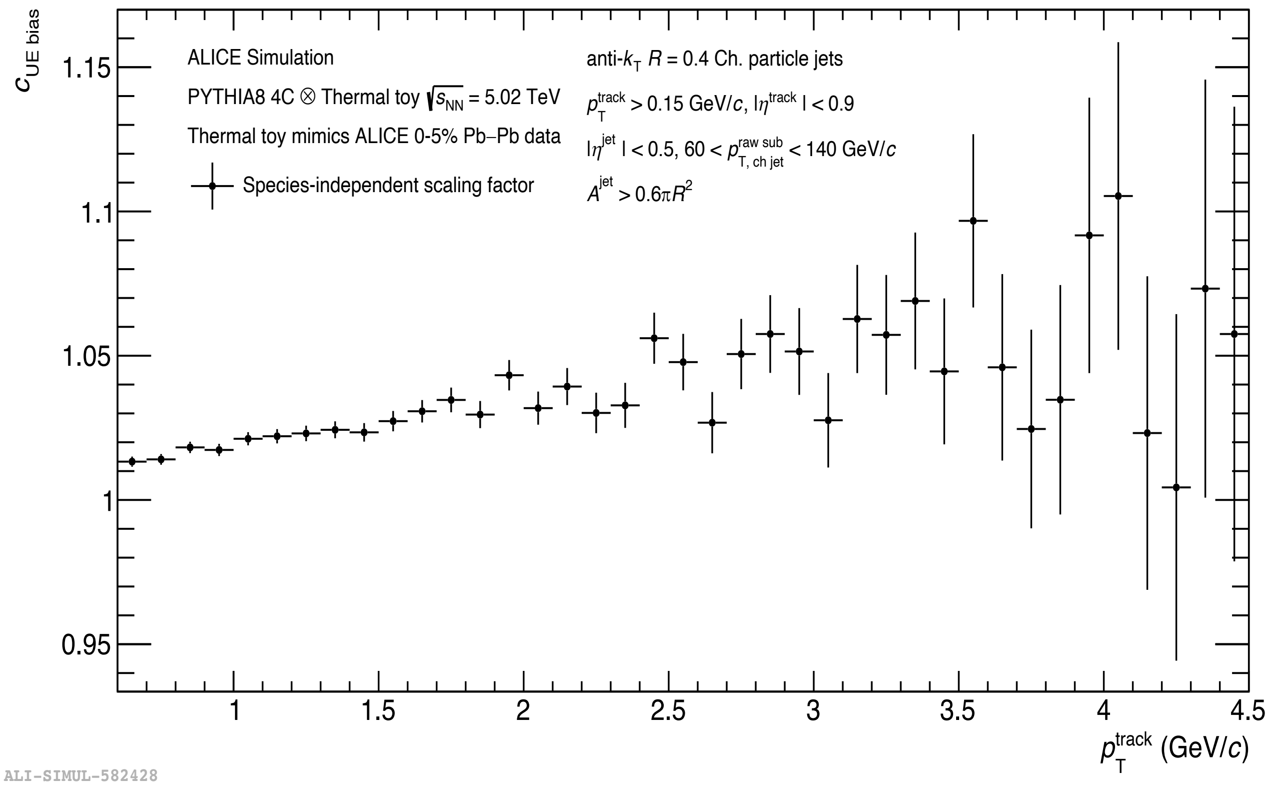
- **Scaling factor (UE in jets / UE in PC) obtained from PYTHIA embedded into ALICE MB data to account for this bias**
  - Separate scaling factor obtained for each particle species
  - Current systematic: Scaling vs no scaling to account for possible contamination from jets in the ALICE MB events used for embedding

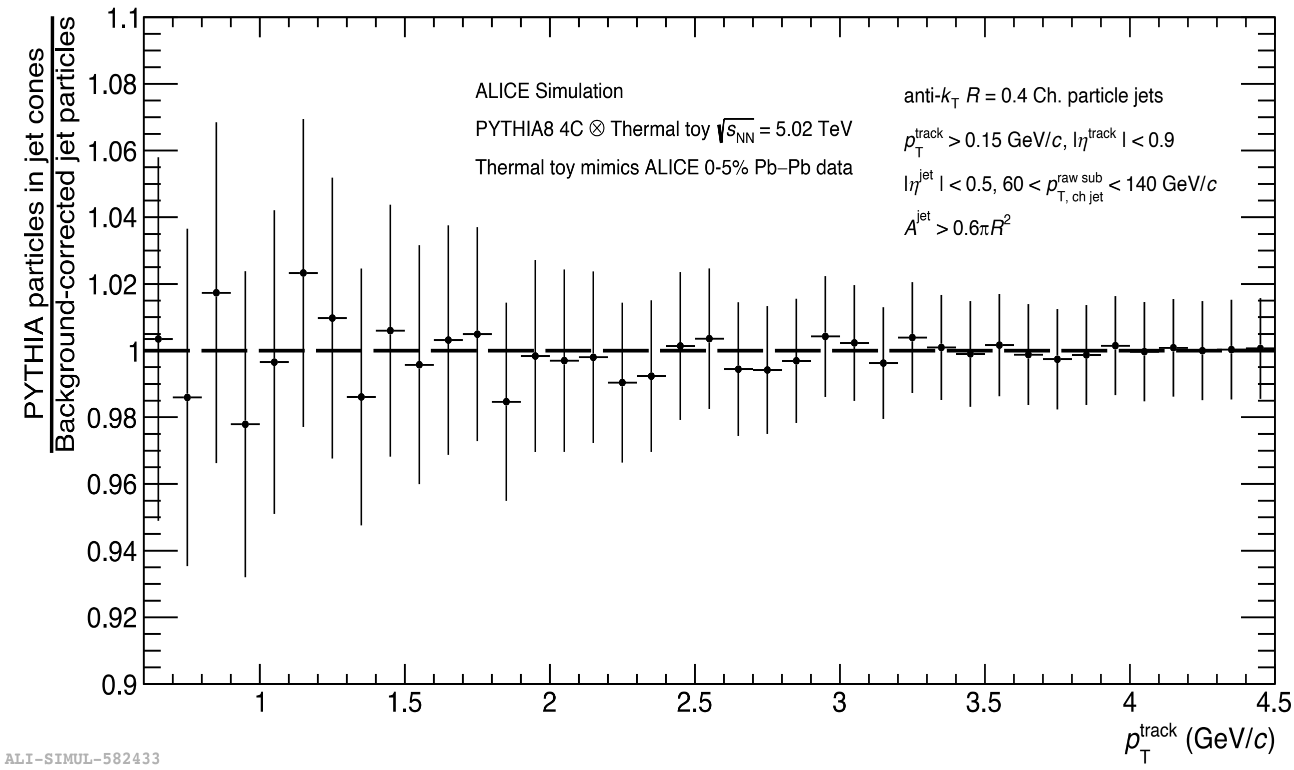


$$\rho = \frac{N_{\mathrm{tracks}}}{A_{\mathrm{acc}}}$$

$$\frac{\mathrm{d}\rho_{\mathrm{jet}}}{\mathrm{d}p_{\mathrm{T}}} = \frac{\mathrm{d}\rho_{\mathrm{jet+UE}}}{\mathrm{d}p_{\mathrm{T}}} - \frac{\mathrm{d}\rho_{\mathrm{PC}}}{\mathrm{d}p_{\mathrm{T}}} * \mathrm{c}_{\mathrm{UE\ Bias}} \quad \mathrm{c}_{\mathrm{UE\ Bias}}(p_{\mathrm{T}}) = \frac{\mathrm{d}\rho_{\mathrm{UE\ in\ selected\ jets}}}{\mathrm{d}p_{\mathrm{T}}} \Big/ \frac{\mathrm{d}\rho_{\mathrm{PC}}}{\mathrm{d}p_{\mathrm{T}}}$$

Toy Model Scaling Factor and Closure





$$c_{\text{UE Bias}}(p_T) = \frac{d\rho_{\text{UE in selected jets}}}{dp_T} \Big/ \frac{d\rho_{PC}}{dp_T}$$

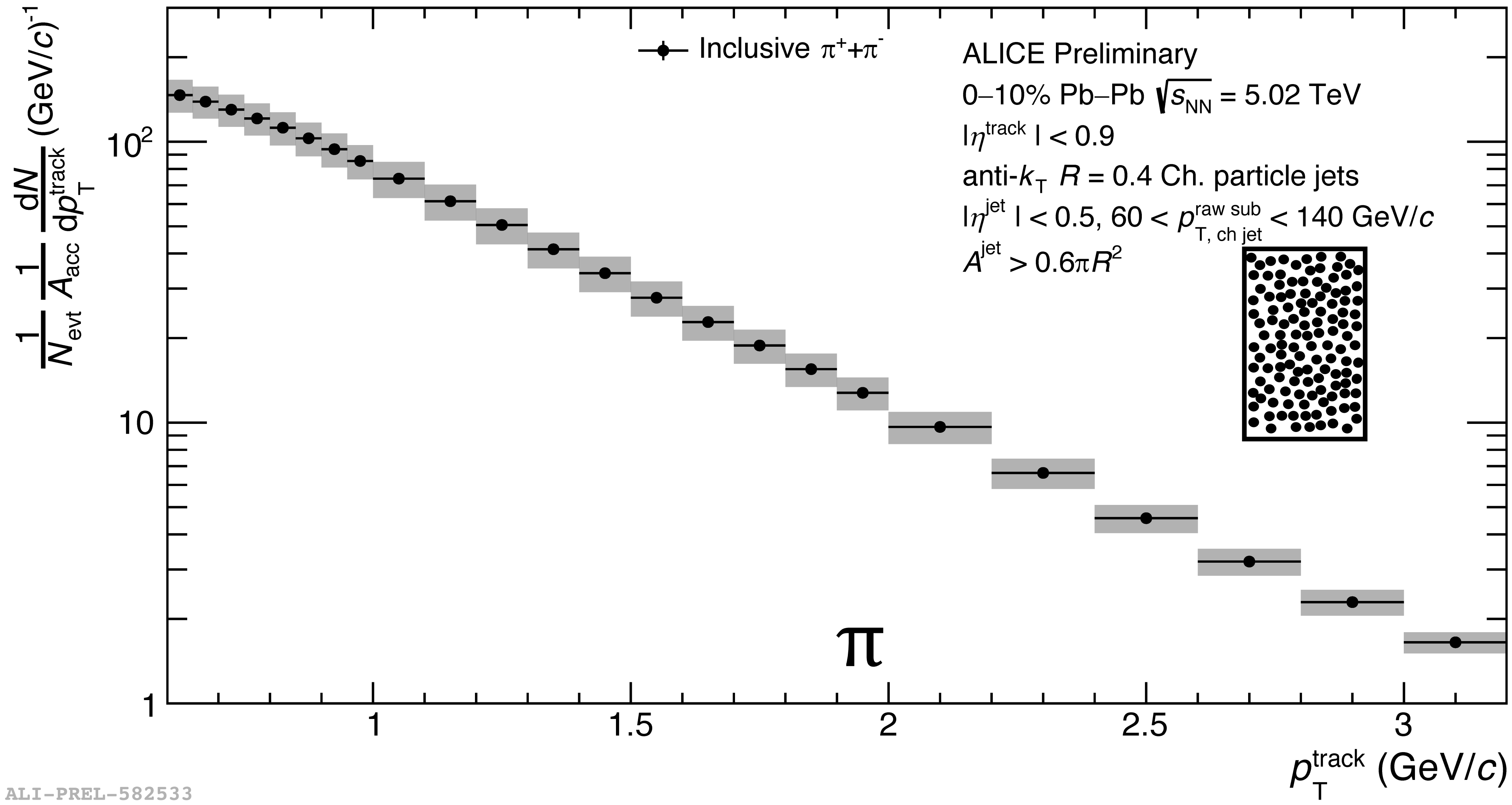
$$\frac{d\rho_{jet}}{dp_T} = \frac{d\rho_{jet+UE}}{dp_T} - \frac{d\rho_{PC}}{dp_T} * c_{\text{UE Bias}}$$

Closure achieved in toy thermal model

π Spectra

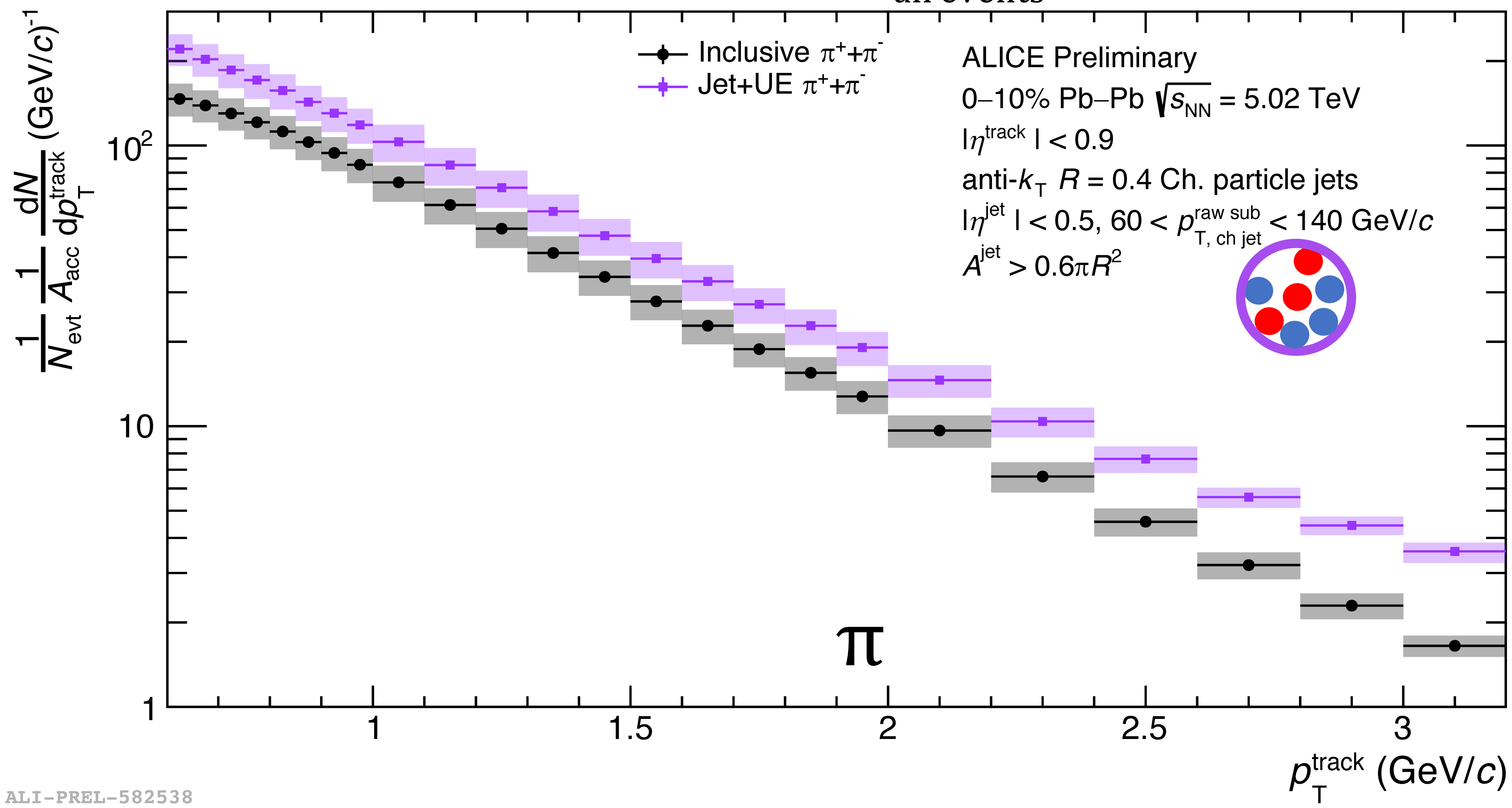
$$N_{\rm evt}^{\rm inc} A_{\rm acc}^{\rm inc} = N_{\rm evt}^{\rm inc} 1.8 * 2\pi$$

Normalizations are calculated differently for each particle origin



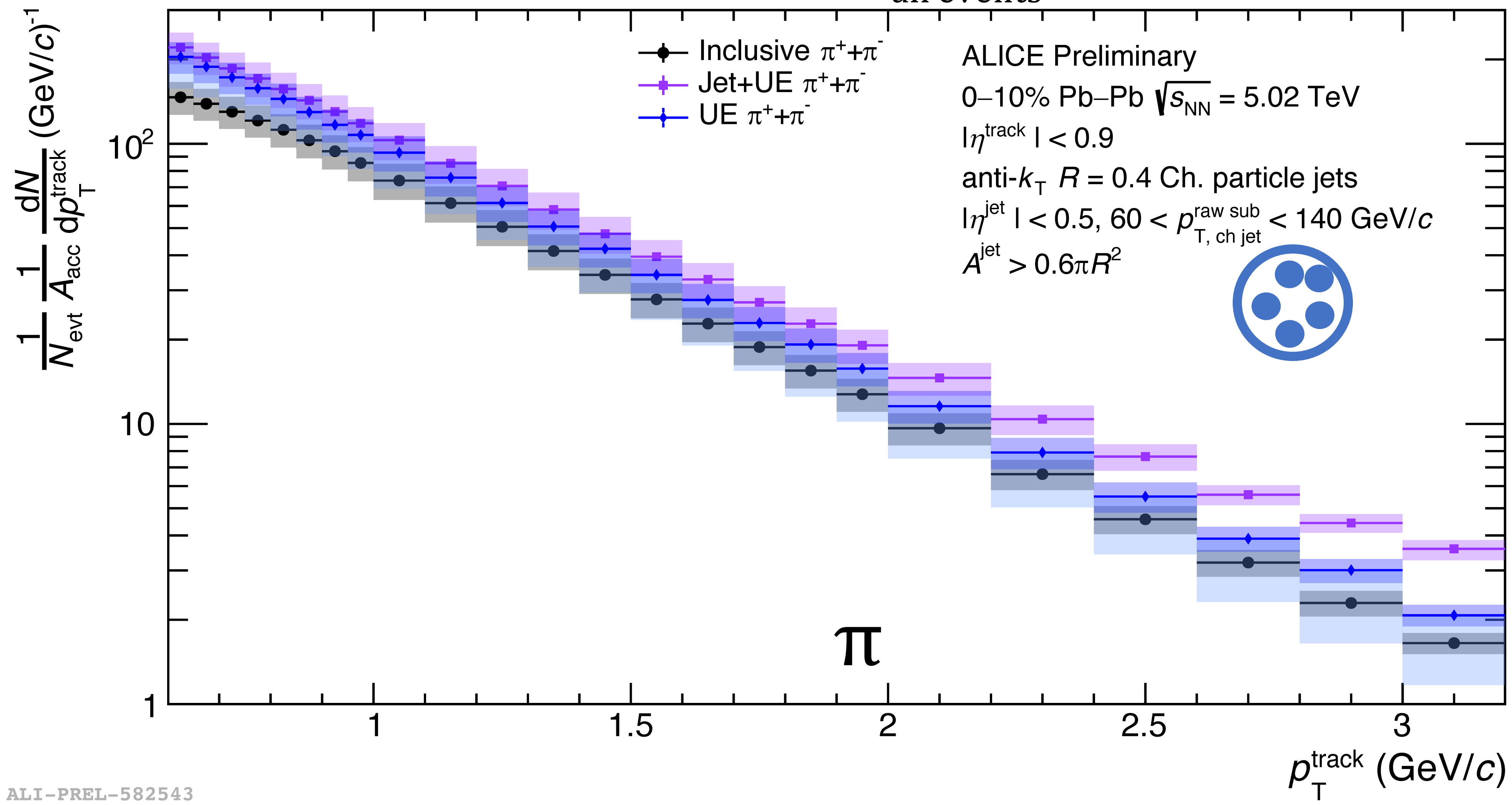
π Spectra

$$N_{\text{evt}}^{\text{inc}} A_{\text{acc}}^{\text{inc}} = N_{\text{evt}}^{\text{inc}} 1.8 * 2\pi \quad N_{\text{evt}}^{\text{jet+UE}} A_{\text{acc}}^{\text{jet+UE}} = \sum_{\text{all events}} A_{\text{jet cone}}$$



π Spectra

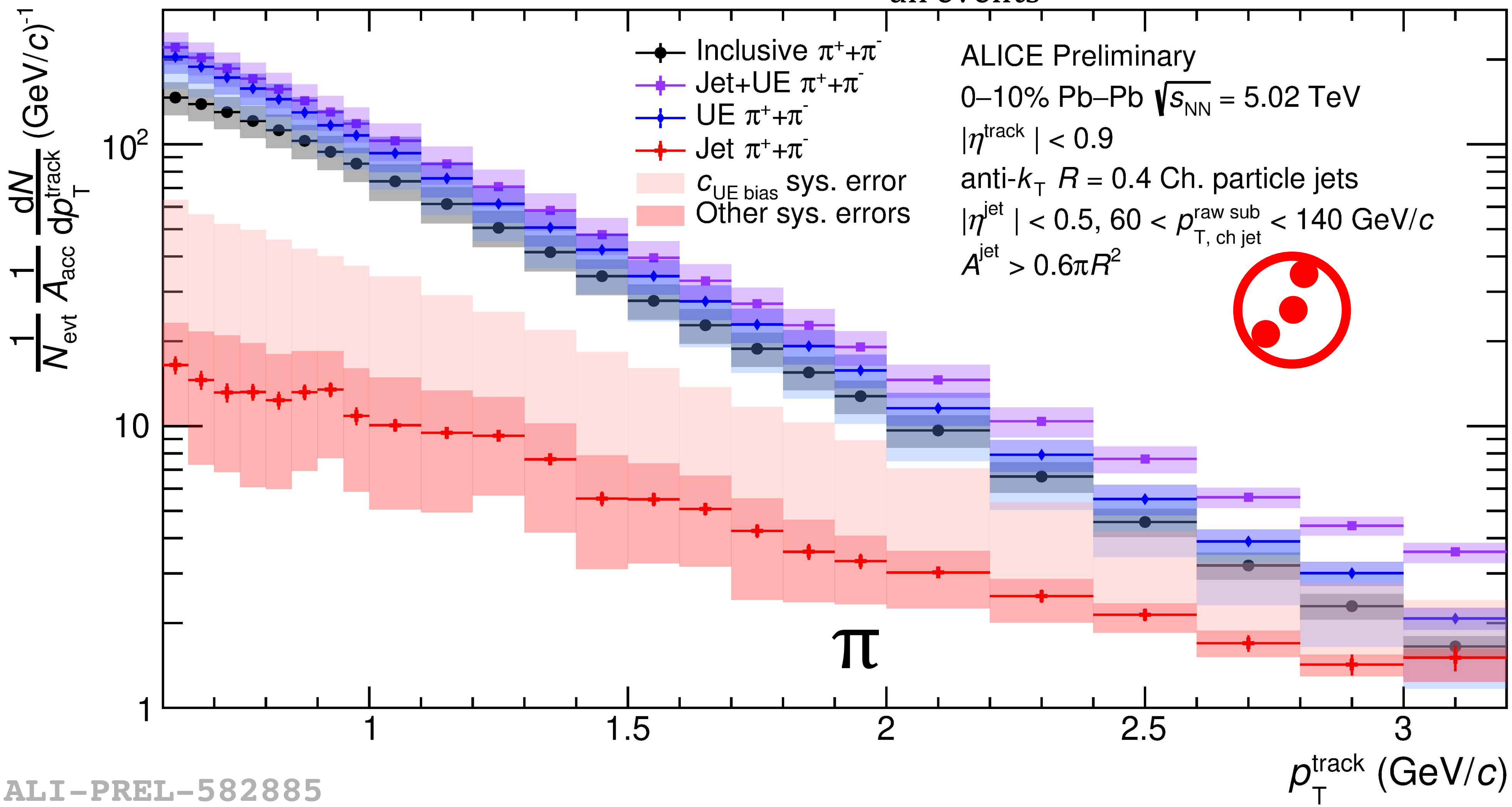
$N_{evt}^{inc} A_{acc}^{inc} = N_{evt}^{inc} 1.8 * 2\pi \quad N_{evt}^{jet+UE} A_{acc}^{jet+UE} = \sum_{\text{all events}} A_{\text{jet cone}} \quad N_{evt}^{UE} A_{acc}^{UE} = N_{\text{all events}}^{PC} \pi R^2$



- **UE** and **Inclusive** are **consistent**

π Spectra

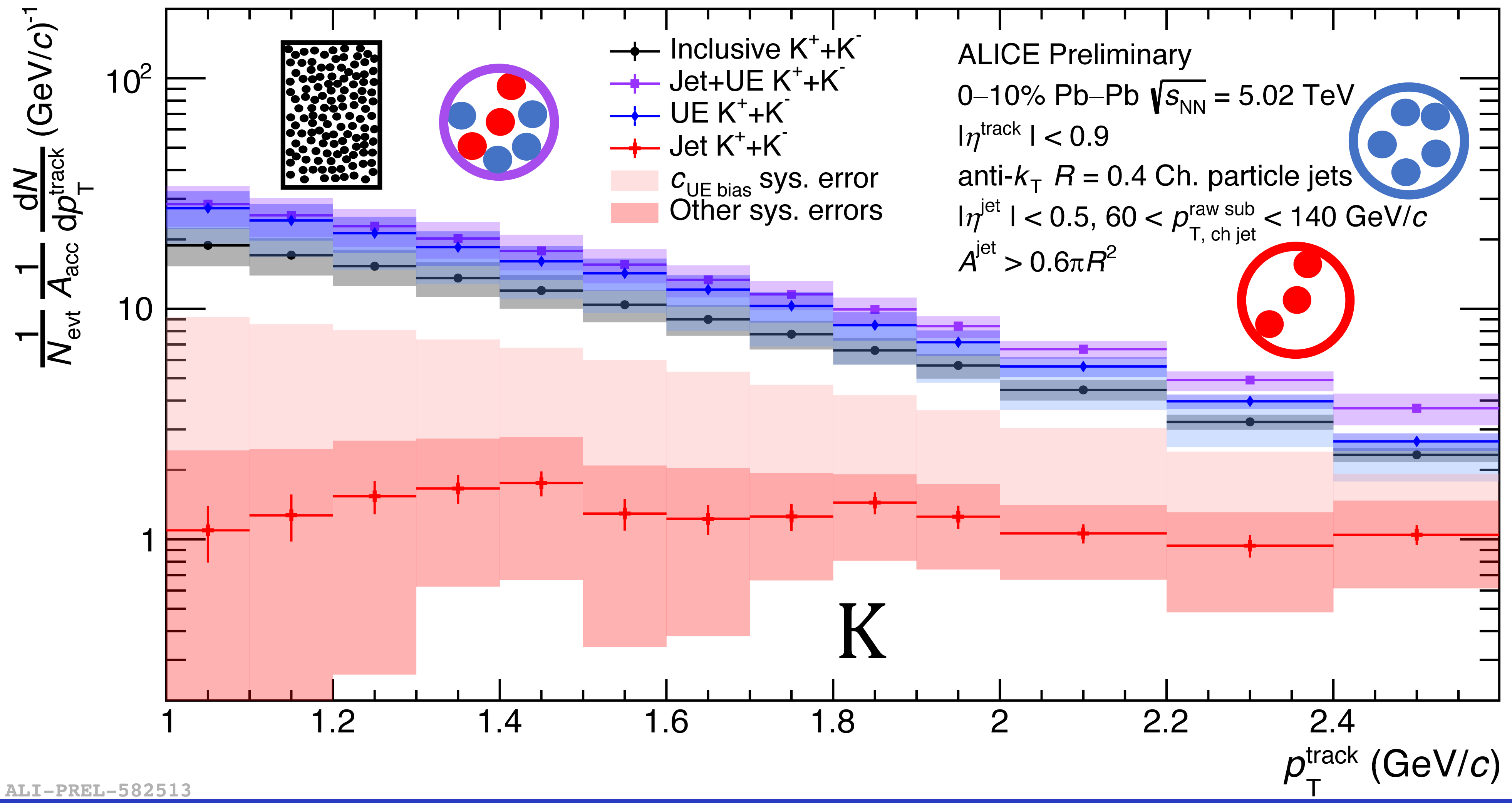
$$N_{evt}^{inc} A_{acc}^{inc} = N_{evt}^{inc} 1.8 * 2\pi \quad N_{evt}^{jet+UE} A_{acc}^{jet+UE} = \sum_{\text{all events}} A_{\text{jet cone}} \quad N_{evt}^{UE} A_{acc}^{UE} = N_{\text{all events}}^{PC} \pi R^2$$



- **UE** and **Inclusive** are **consistent**
- **Jet+UE is dominated by UE** particles in the p_T range considered
  - **Jet** portion gets **fractionally larger as p_T increases**

K Spectra

$$N_{evt}^{inc}A_{acc}^{inc} = N_{evt}^{inc}1.8 * 2\pi \quad N_{evt}^{jet+UE}A_{acc}^{jet+UE} = \sum_{\text{all events}} A_{\text{jet cone}} \quad N_{evt}^{UE}A_{acc}^{UE} = N_{\text{all events}}^{PC}\pi R^2$$



- **UE** and **Inclusive** are **consistent**
- **Jet+UE is dominated by UE** particles in the p_T range considered
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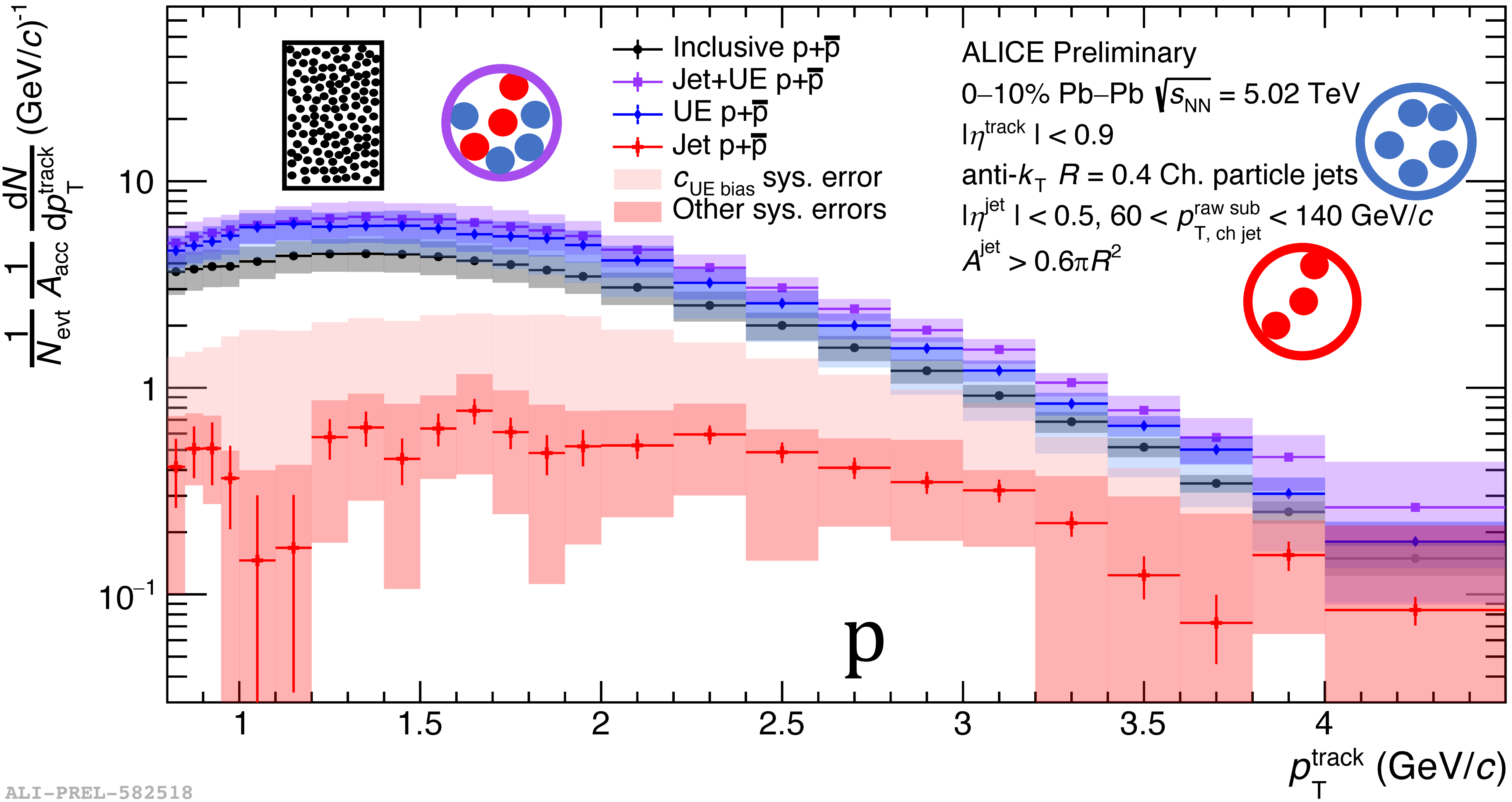
- **Fewer K than π for all cases**

p Spectra

$$N_{\mathrm{evt}}^{\mathrm{inc}} A_{\mathrm{acc}}^{\mathrm{inc}} = N_{\mathrm{evt}}^{\mathrm{inc}} 1.8 * 2\pi \quad N_{\mathrm{evt}}^{\mathrm{jet+UE}} A_{\mathrm{acc}}^{\mathrm{jet+UE}} = \sum_{\mathrm{all\ events}} A_{\mathrm{jet\ cone}} \quad N_{\mathrm{evt}}^{\mathrm{UE}} A_{\mathrm{acc}}^{\mathrm{UE}} = N_{\mathrm{all\ events}}^{\mathrm{PC}} \pi R^2$$



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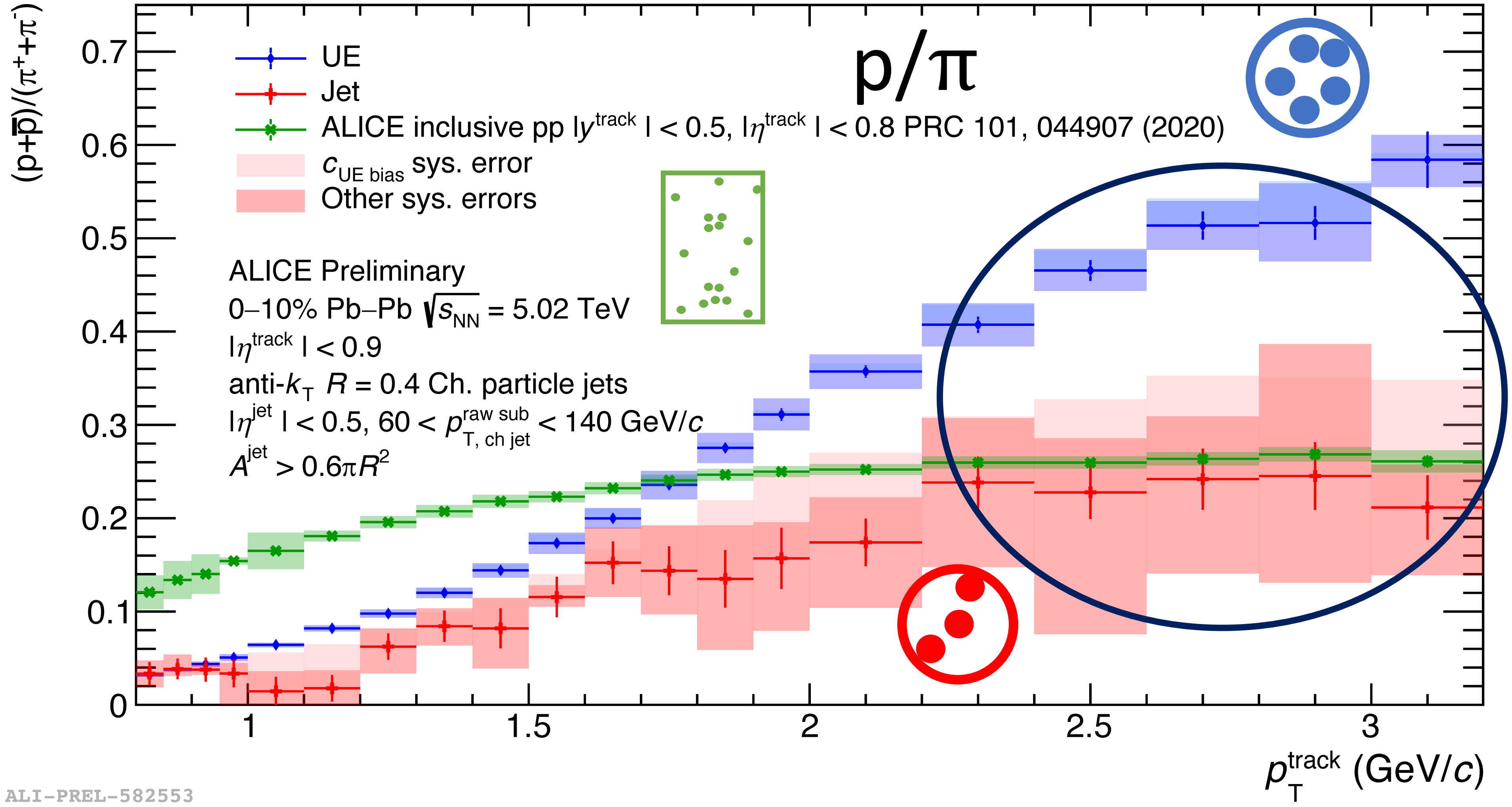
- **Fewer p than π for all cases**

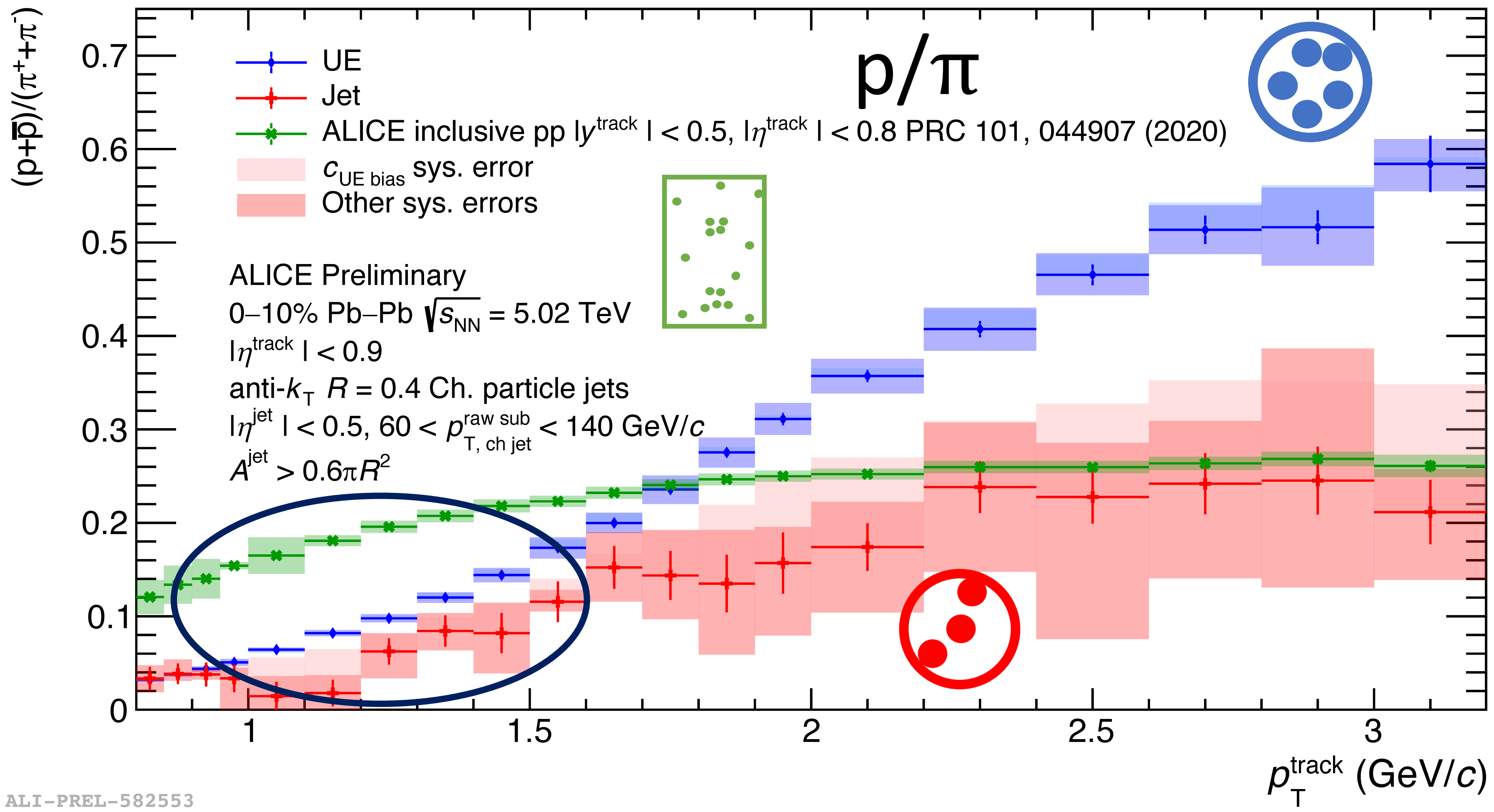
p/π Ratio



- Probing **baryon** production
- **Pb–Pb jet has lower p/π than Pb–Pb UE at intermediate p_T**

$c_{UE\ Bias}$ systematic uncertainty expected to be significantly reduced

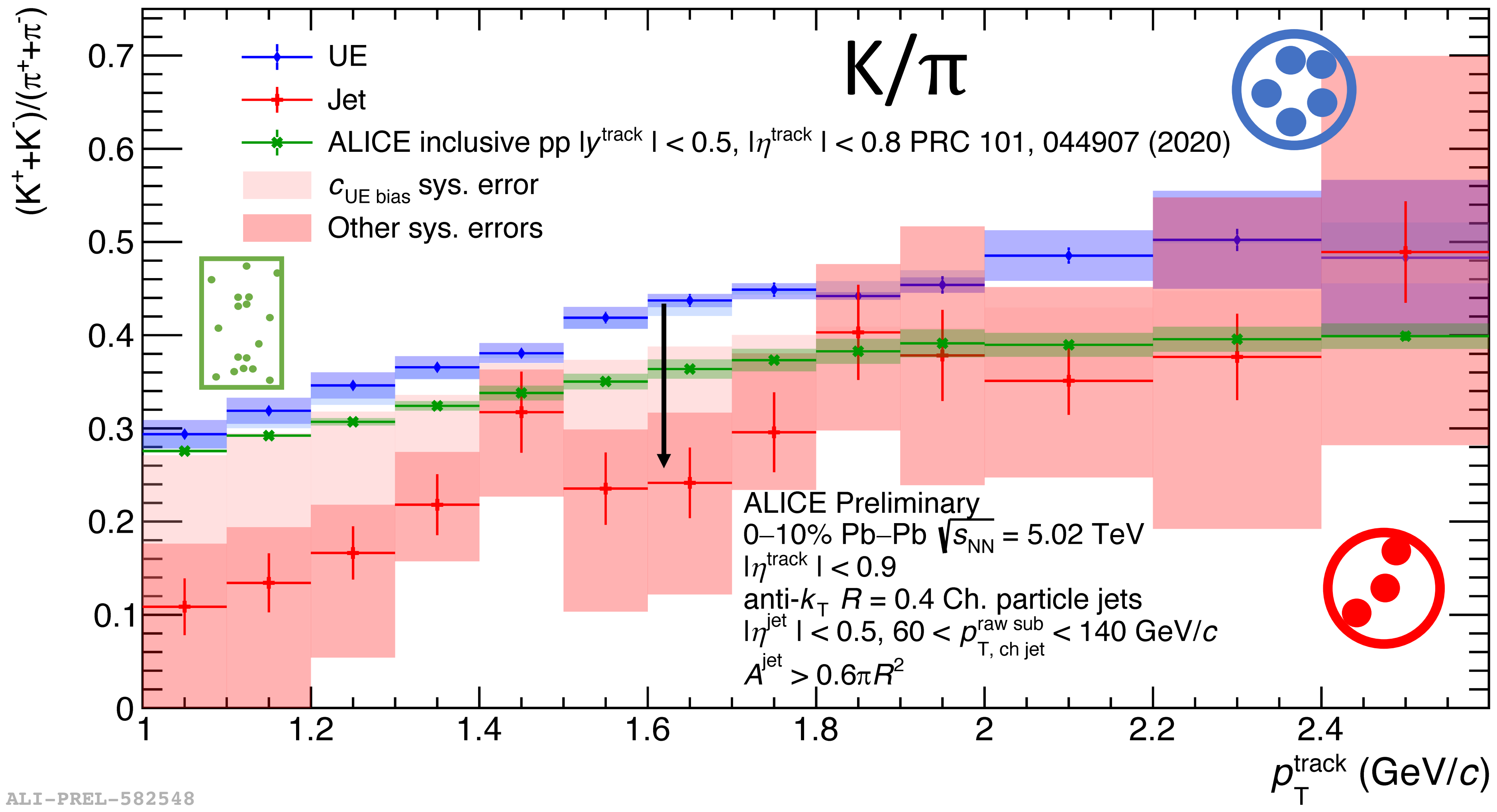
p/π Ratio



- Probing **baryon** production
- **Pb–Pb jet has lower p/π than pp inclusive at low p_T**
- But we need to compare to p/π in **pp jets** to probe jet modification → **pp jet** measurement in progress!

$c_{\text{UE Bias}}$ systematic uncertainty expected to be significantly reduced

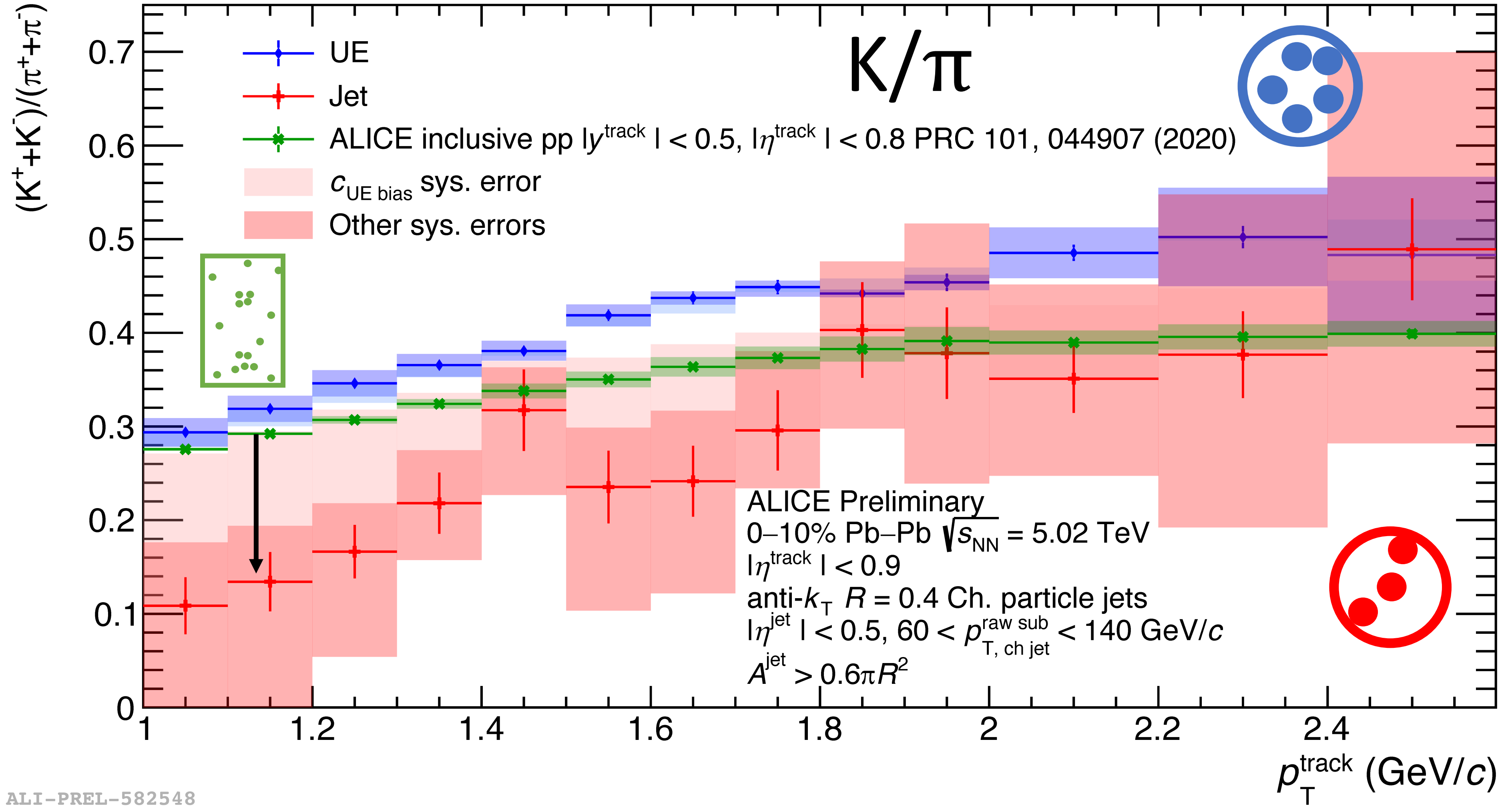
K/π Ratio



- Probing **strangeness** production
- **Pb–Pb jets hint at lower K/π than Pb–Pb UE**

$c_{UE\ Bias}$ systematic uncertainty expected to be significantly reduced

K/π Ratio



- Probing **strangeness** production
- **Pb–Pb jets hint at lower K/π than pp inclusive**
- But we need to compare to K/π in **pp jets** to probe jet modification → **pp jet** measurement in progress!

$c_{\mathrm{UE\ Bias}}$ systematic uncertainty expected to be significantly reduced

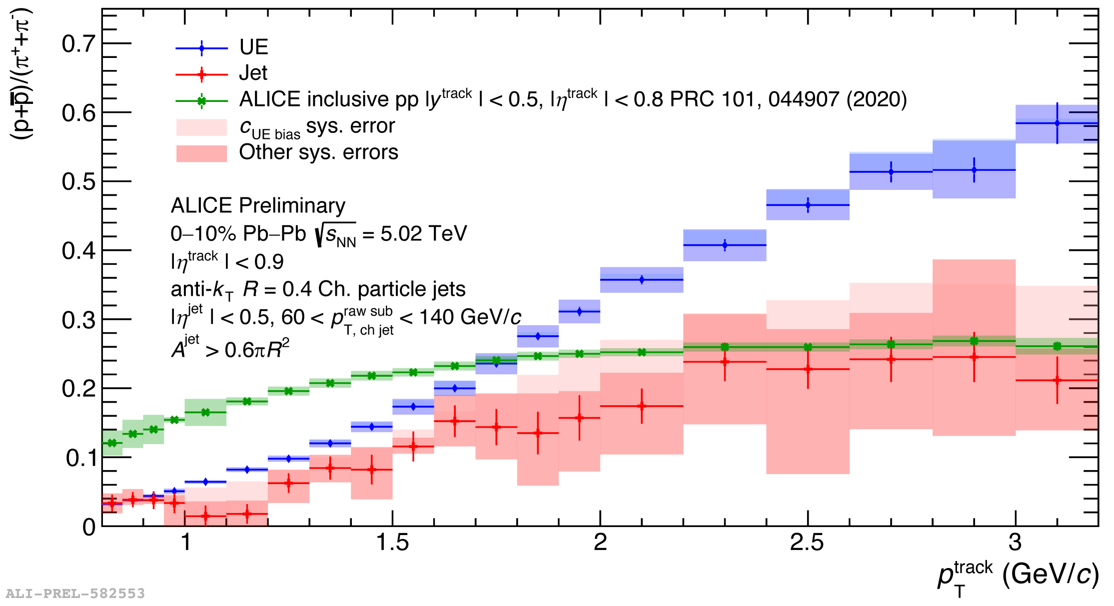
Summary & Outlook

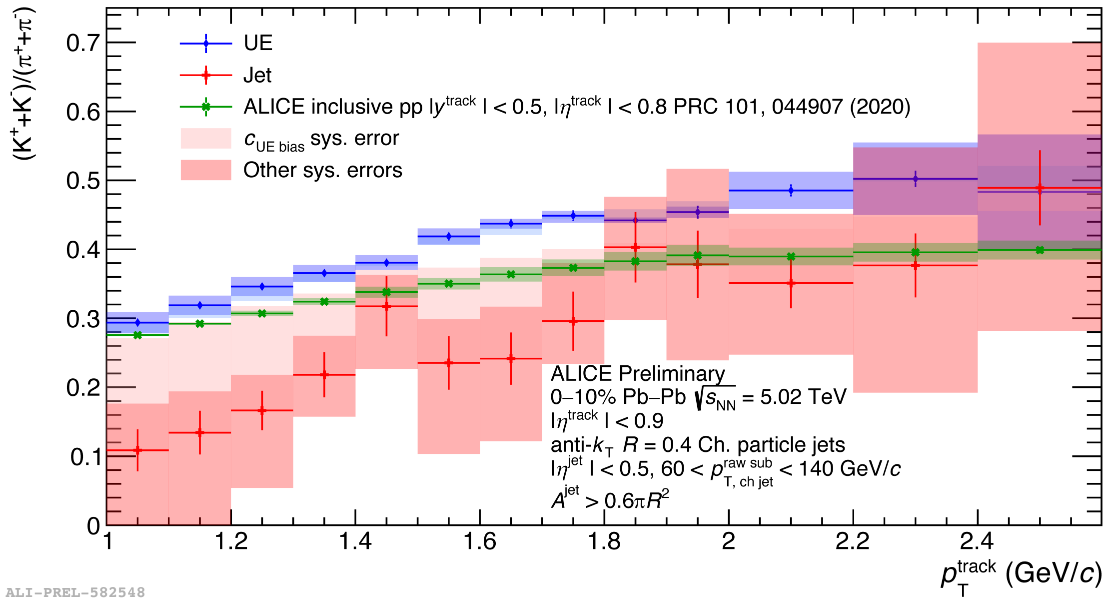
Summary

- **First measurement** of π, K, p in **jets** and **UE** in Pb–Pb collisions
- **Baryon** production in **Pb–Pb jets** less than **Pb–Pb UE**
  - Hint of less **strangeness** production in **Pb–Pb jets** than **Pb–Pb UE**
- **pp jet** K/π and p/π measurements needed
  - Probes possible jet hadrochemistry modification due to **modified fragmentation** or **medium response**

Outlook

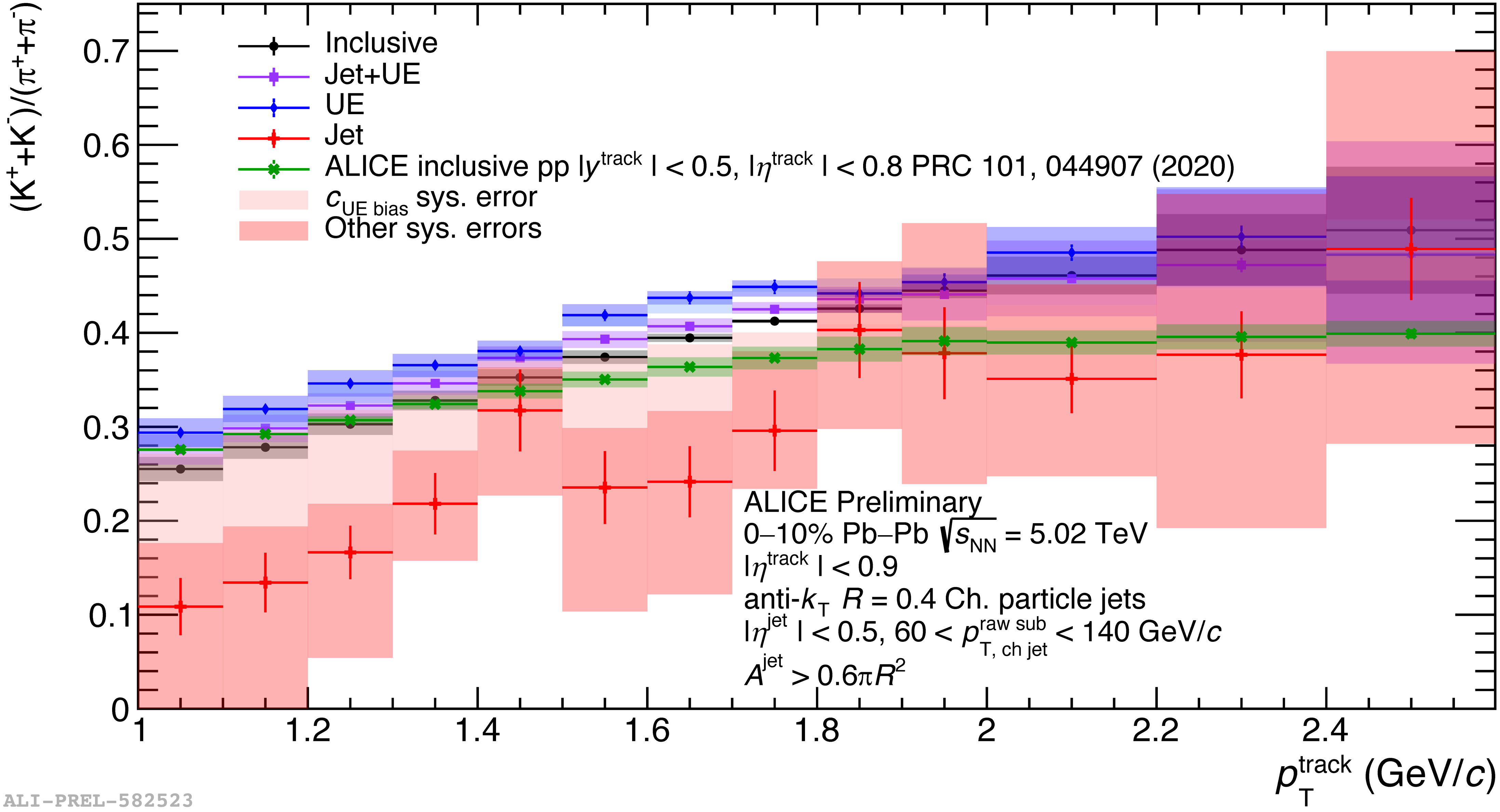
- Unfold to probe jet p_{T} dependence
- Extend PID p_{T} range with TPC
- Centrality dependence
- Radial distance from jet axis dependence
- Perform measurement in pp





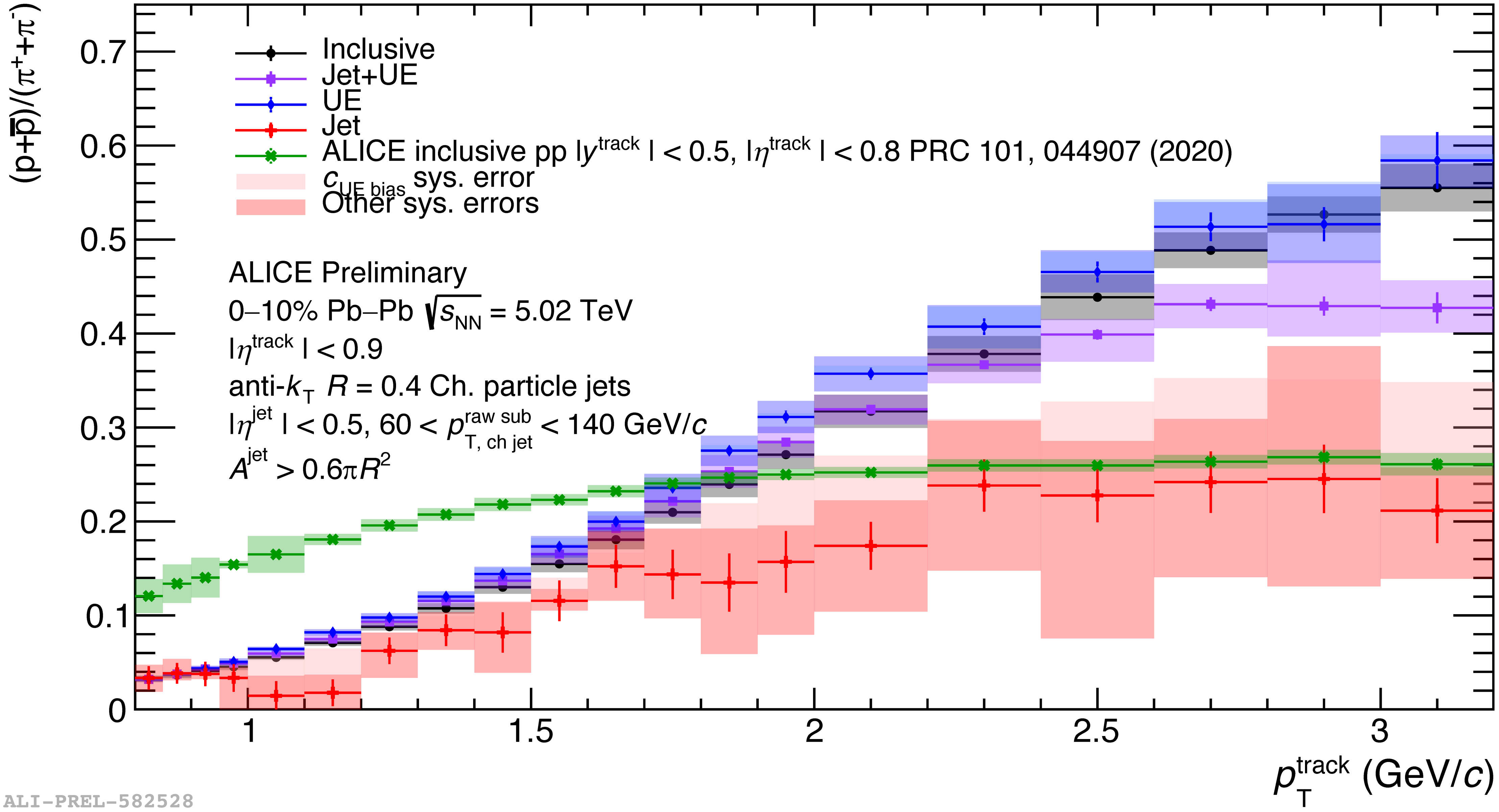
BACKUP

All Particle Origins K/π



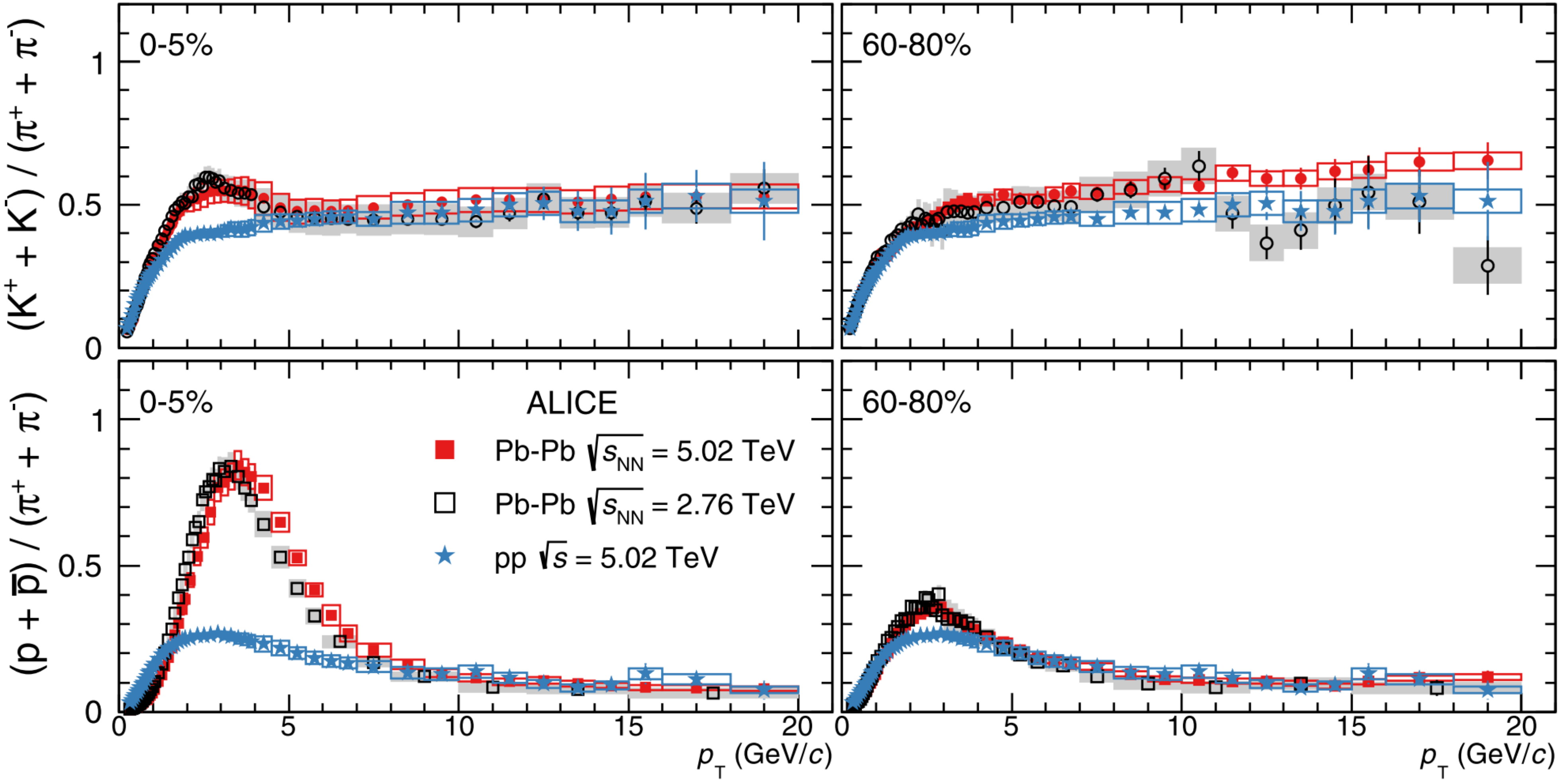
ALI-PREL-582523

All Particle Origins p/π



Previous Inclusive Measurements

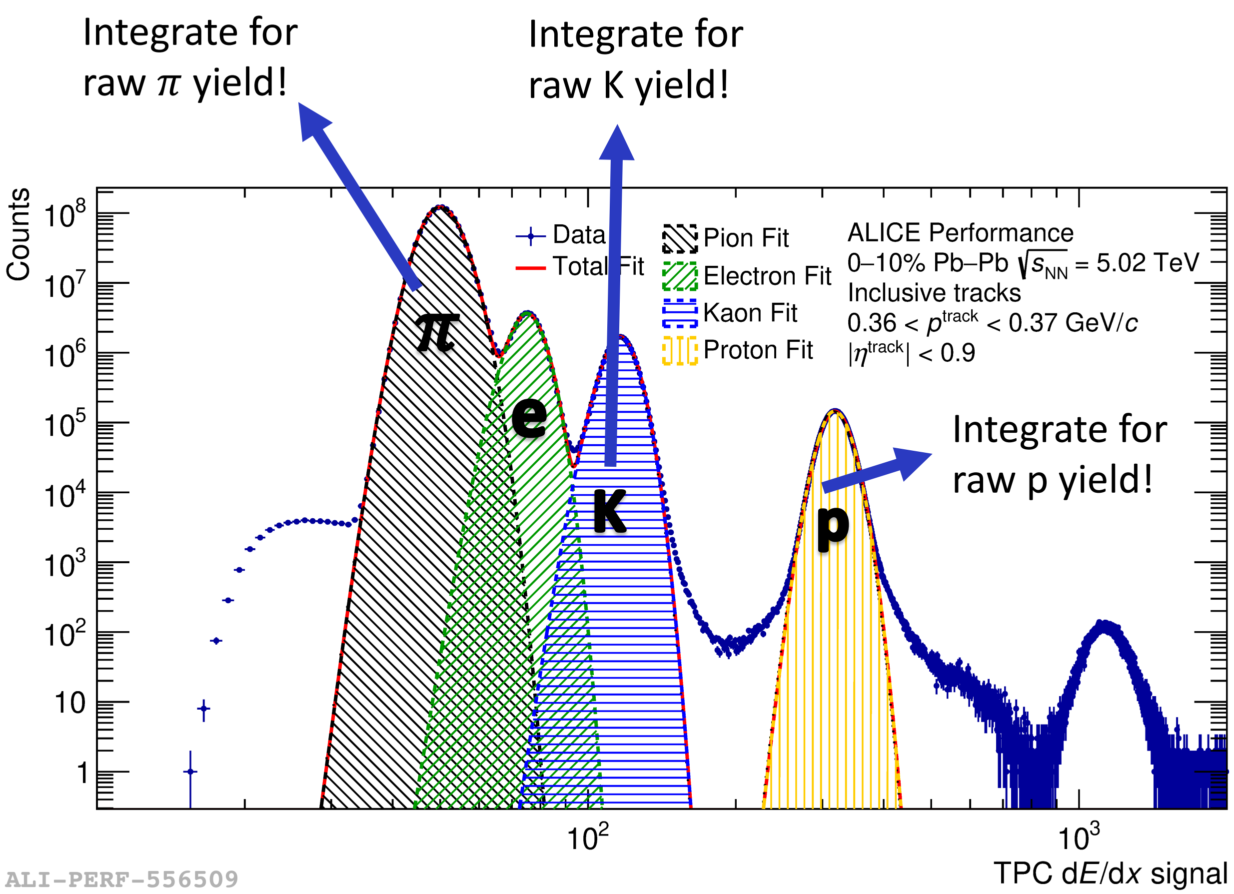
ALICE Collaboration, Phys. Rev. C 101, 044907 (2020)



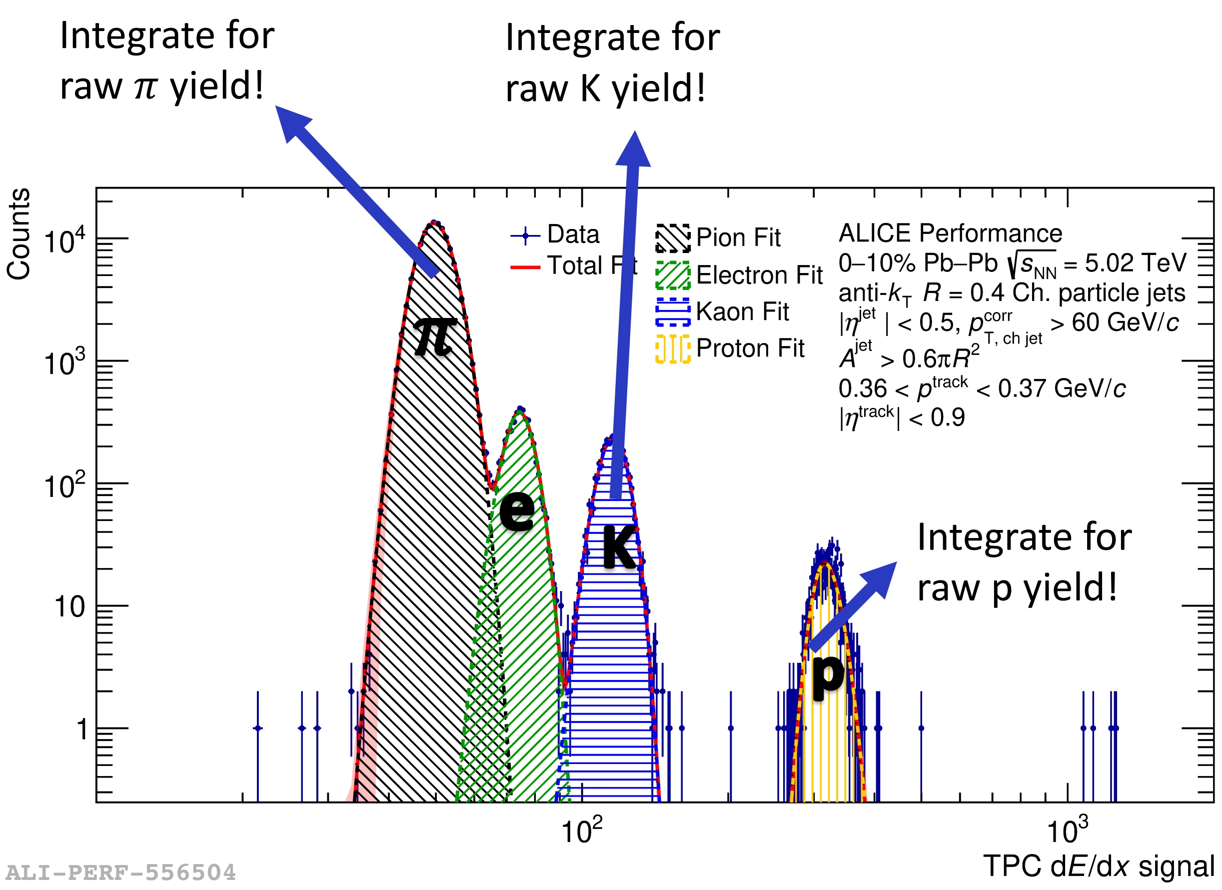
p/π and K/π enhanced in Pb-Pb inclusive particles at intermediate p_T compared to pp

TPC dE/dx PID Fits

$$f(x) = Ae^{-\left(\frac{|x-\mu|}{\sqrt{2}\sigma}\right)^{\beta}}\left(1+\mathrm{erf}\left(\alpha\frac{x-\mu}{\sigma\sqrt{2}}\right)\right)$$



Inclusive



Jets