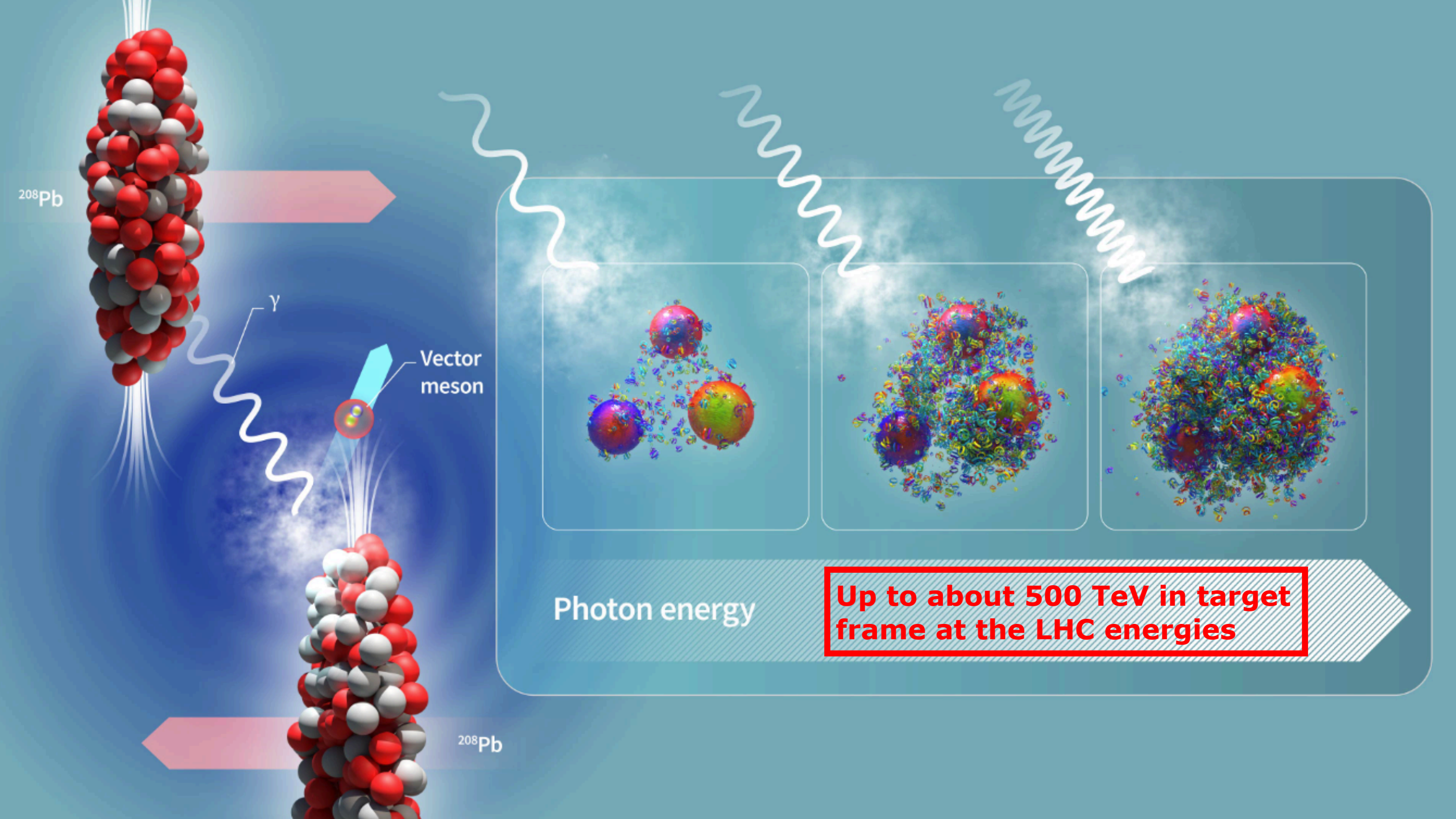
Overview of particle production in inelastic photonuclear interactions with ALICE

Simone Ragoni,

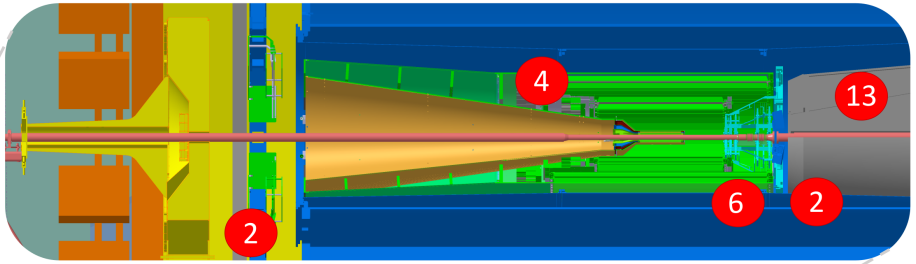
on behalf of the ALICE collaboration

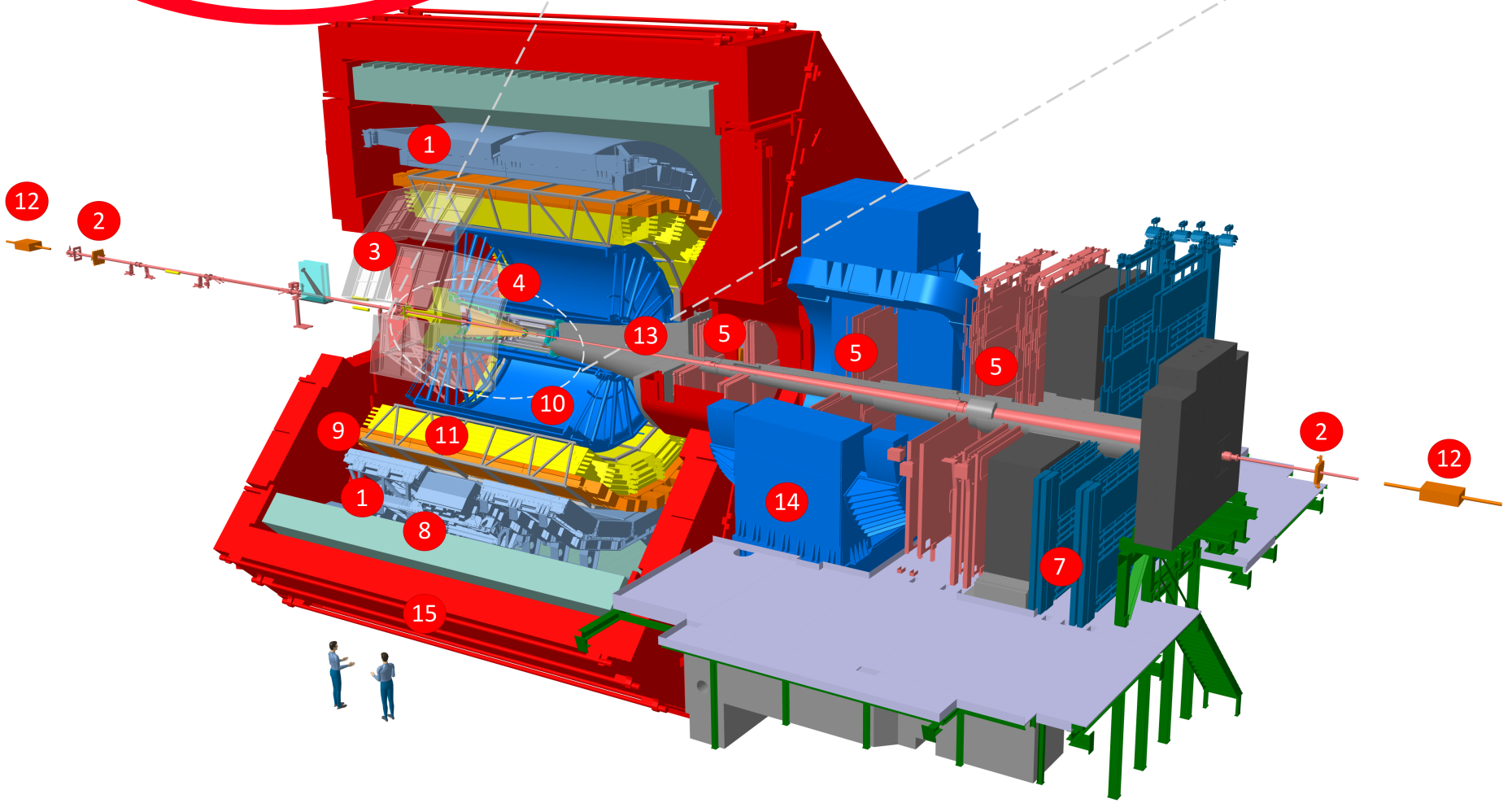
Creighton University, USA


^{208}Pb
γ
Vector meson
^{208}Pb
Photon energy
Up to about 500 TeV in target frame at the LHC energies

ALICE in Run 3

ITS 2: 7 layers of silicon pixel detectors with reduced material budget

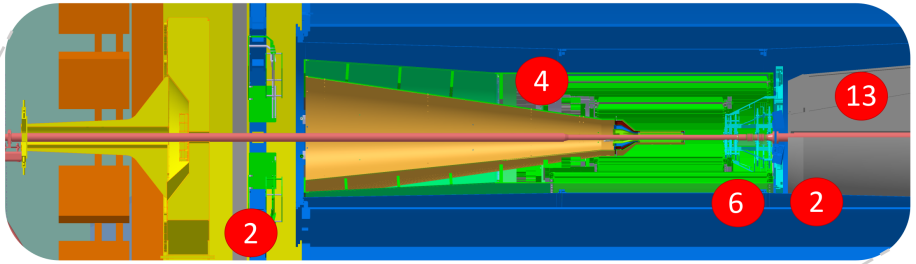




1. **EMCAL |** Electromagnetic Calorimeter
2. **FIT |** Fast Interaction Trigger
3. **HMPID|** High Momentum Particle Identification Detector
4. **ITS|** Inner Tracking System
5. **MCH|** Muon Tracking Chambers
6. **MFT|** Muon Forward Tracker
7. **MID|** Muon Identifier
8. **PHOS/CPV|** Photon Spectrometer
9. **TOF|** Time Of Flight
10. **TPC|** Time Projection Chamber
11. **TRD|** Transition Radiation Detector
12. **ZDC|** Zero Degree Calorimeter
13. **Absorber**
14. **Dipole Magnet**
15. **L3 Magnet**

ALICE in Run 3

ITS 2: 7 layers of silicon pixel detectors with reduced material budget

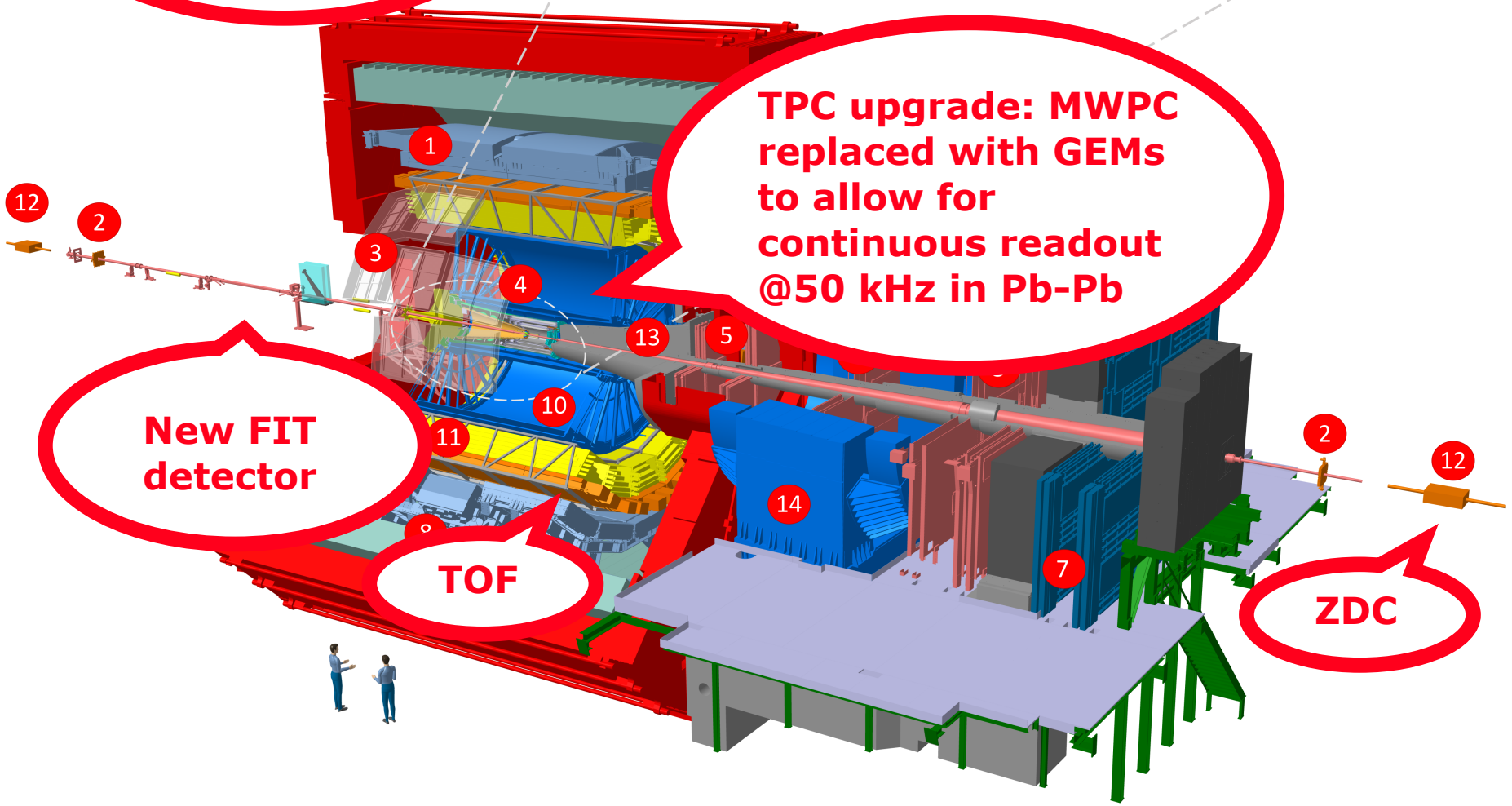


TPC upgrade: MWPC replaced with GEMs to allow for continuous readout @50 kHz in Pb-Pb

New FIT detector

TOF

ZDC



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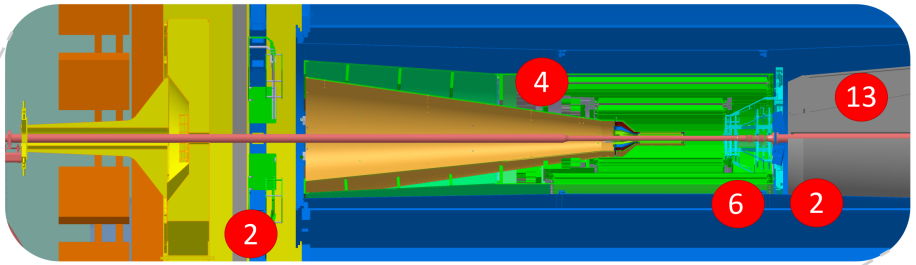
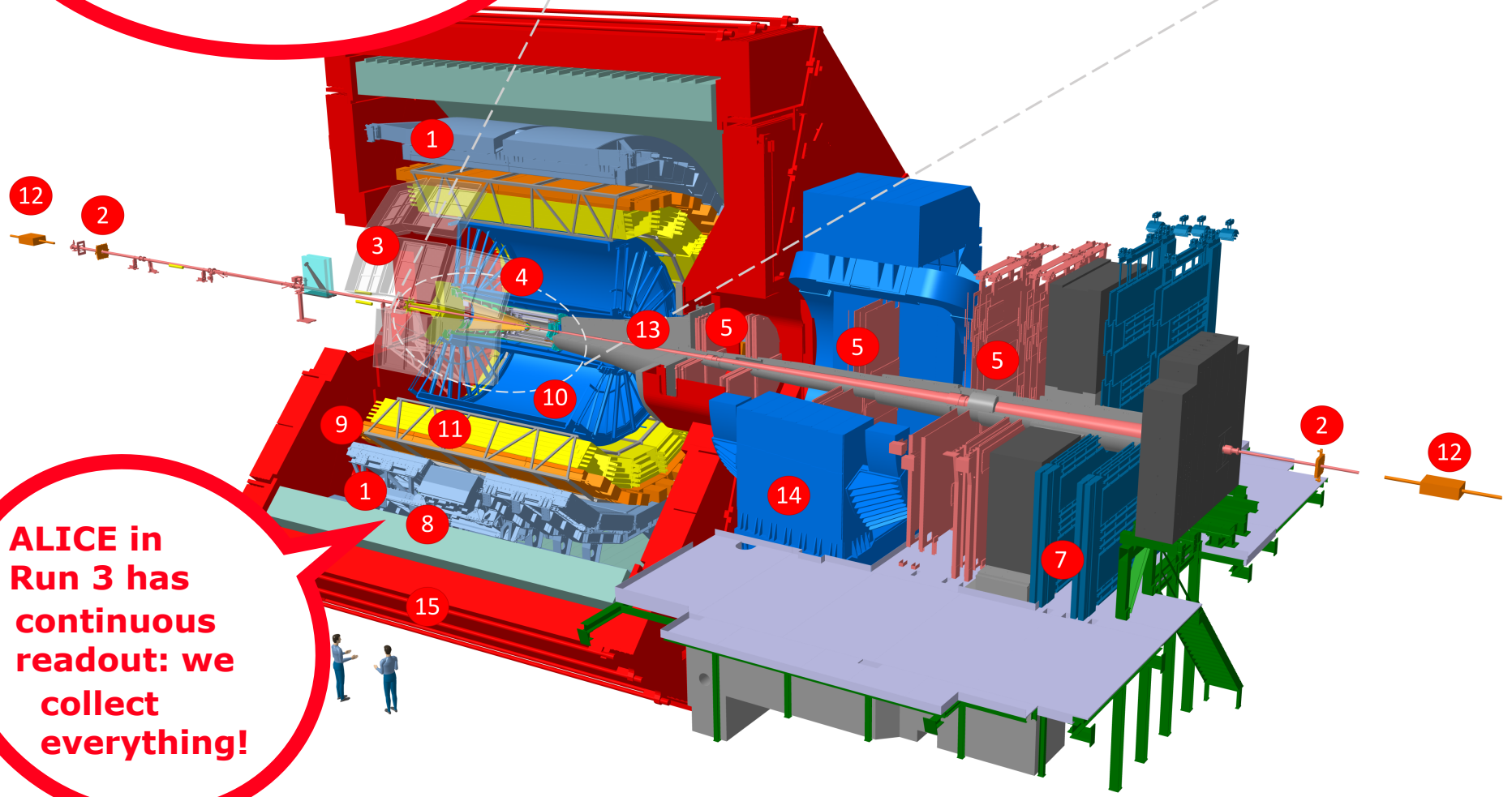
ALICE in Run 2 was triggered and our trigger was optimised for exclusive vector meson production





ALICE in Run 3 has continuous readout: we collect everything!

ALICE in Run 3

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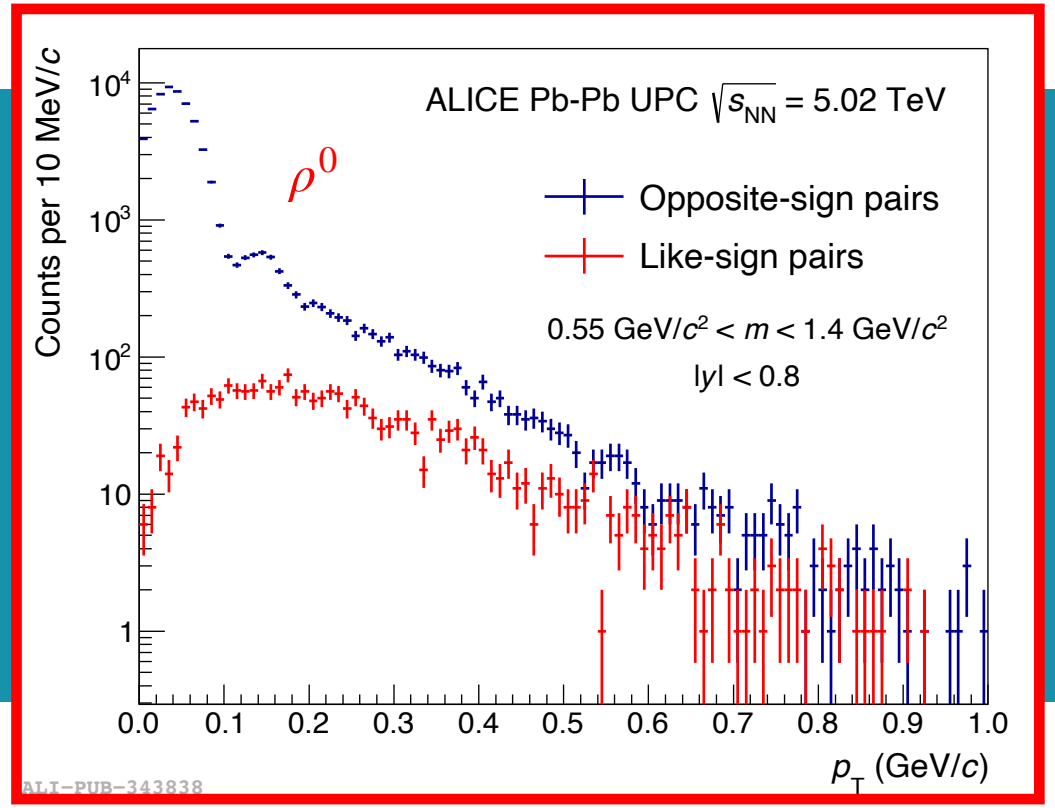
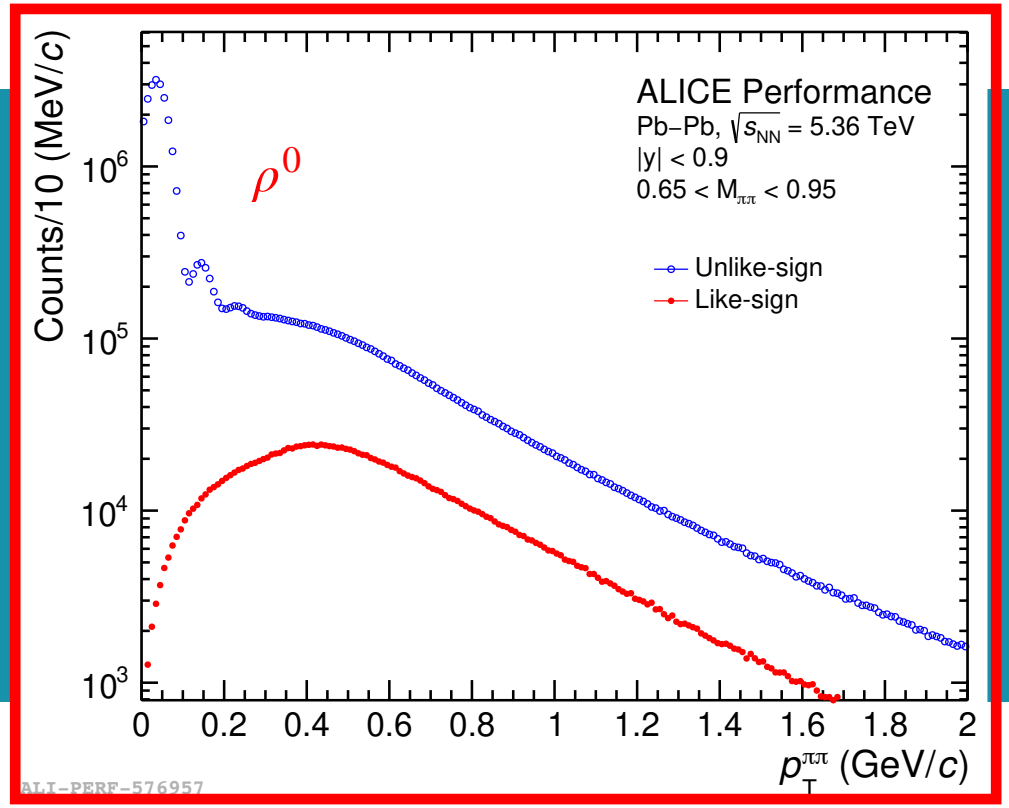
Data then… …and now

ALICE, JHEP 06 (2020) 035





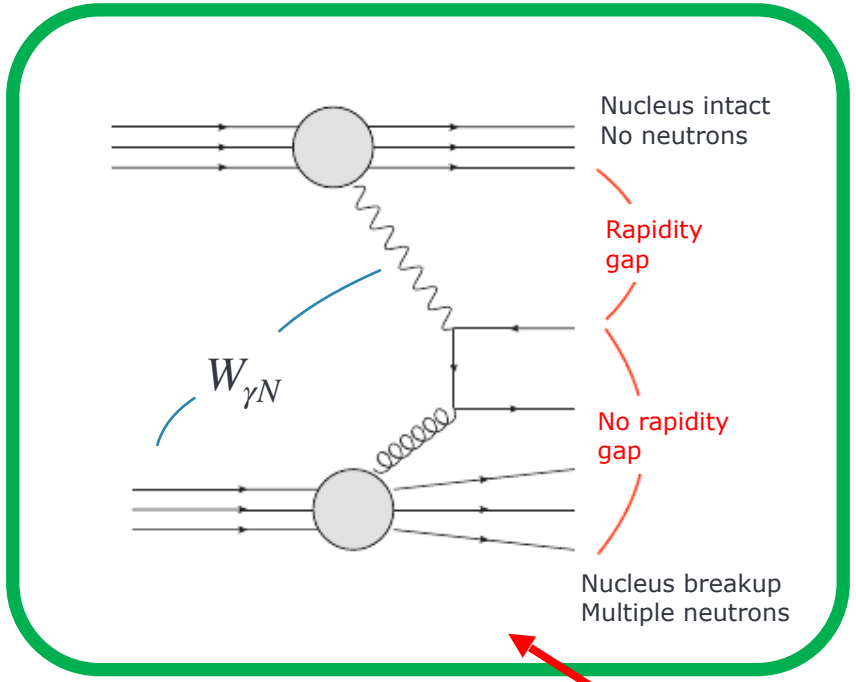
- About 50k raw ρ^0 in Run 2
- Angular measurements limited by statistics ALICE, *Phys.Lett.B* 858 (2024) 139017

- Millions of raw ρ^0 with only 2023 Pb-Pb data! More incoming

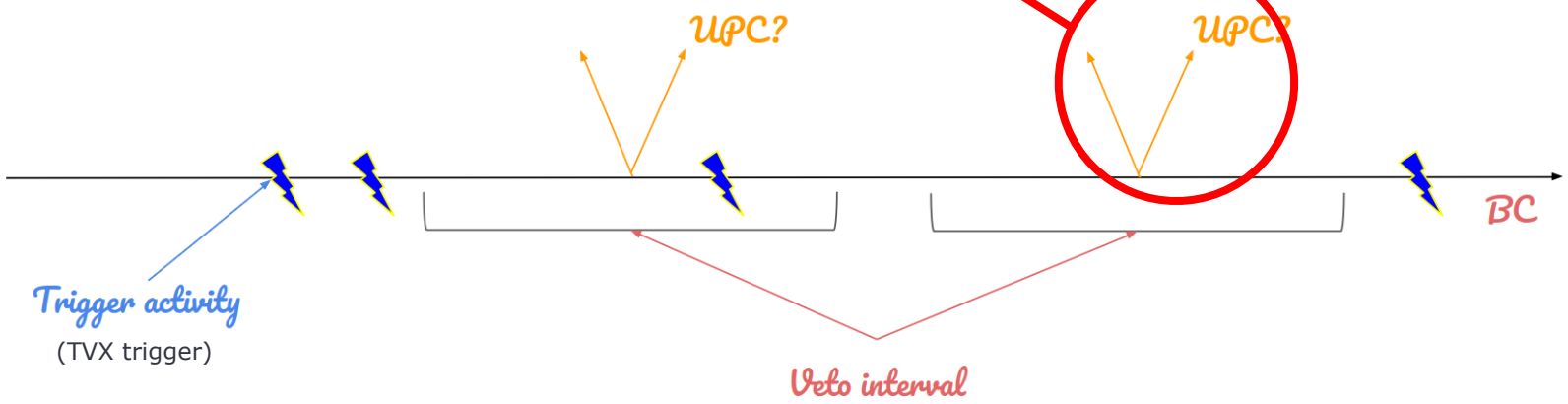

A NEW VENUE
INELASTIC UPC

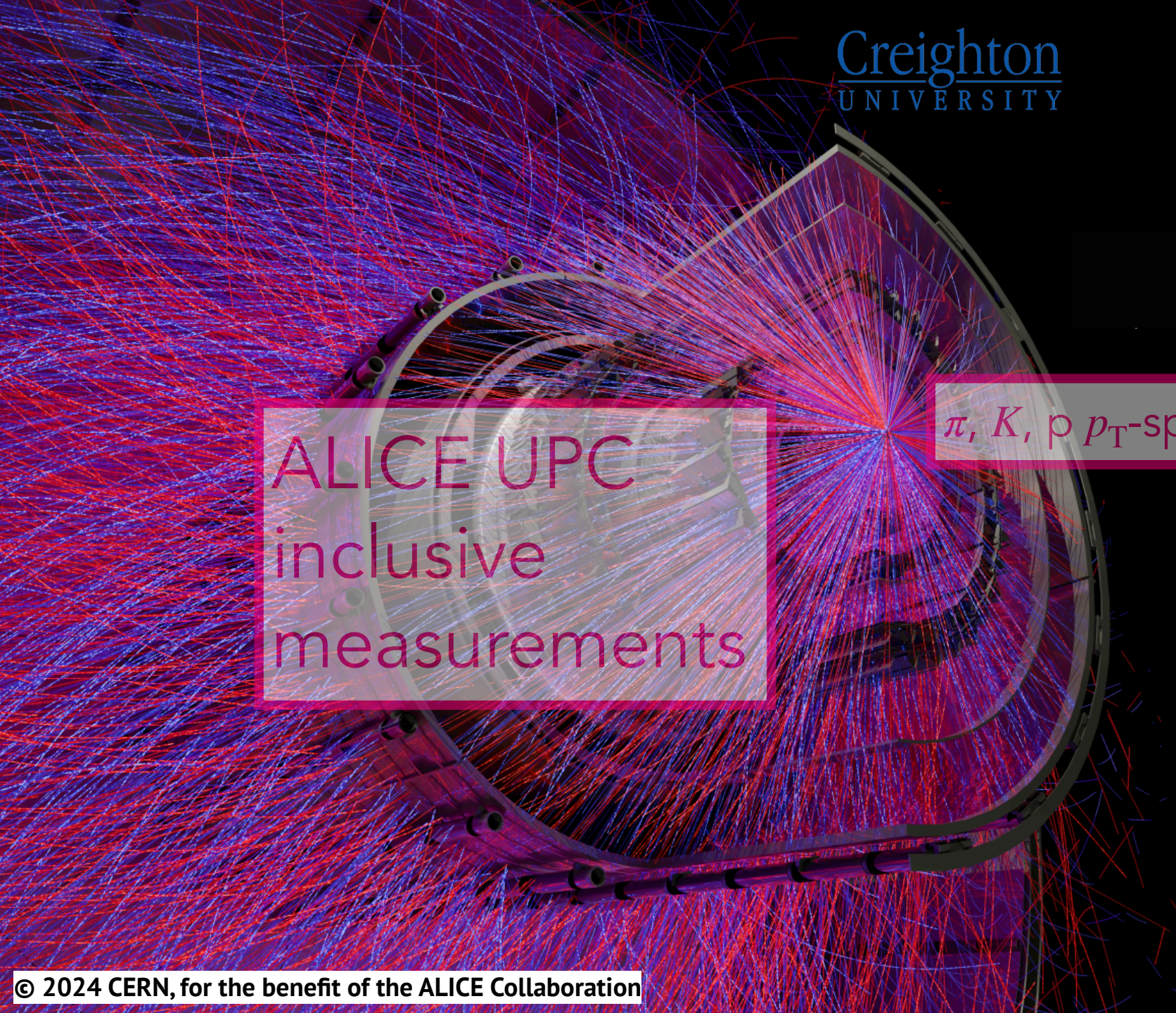
Inelastic UPCs

- Rapidity gap only on one side of the detector
- Multiplicity focused at forward rapidity



- $E_\gamma \sim 1 \rightarrow 100$ GeV
- $E_N = 2680$ GeV
- $40 \lesssim W_{\gamma N} \lesssim 900$ GeV





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ALICE UPC inclusive measurements

π, K, p p_{T}-spectra in UPCs

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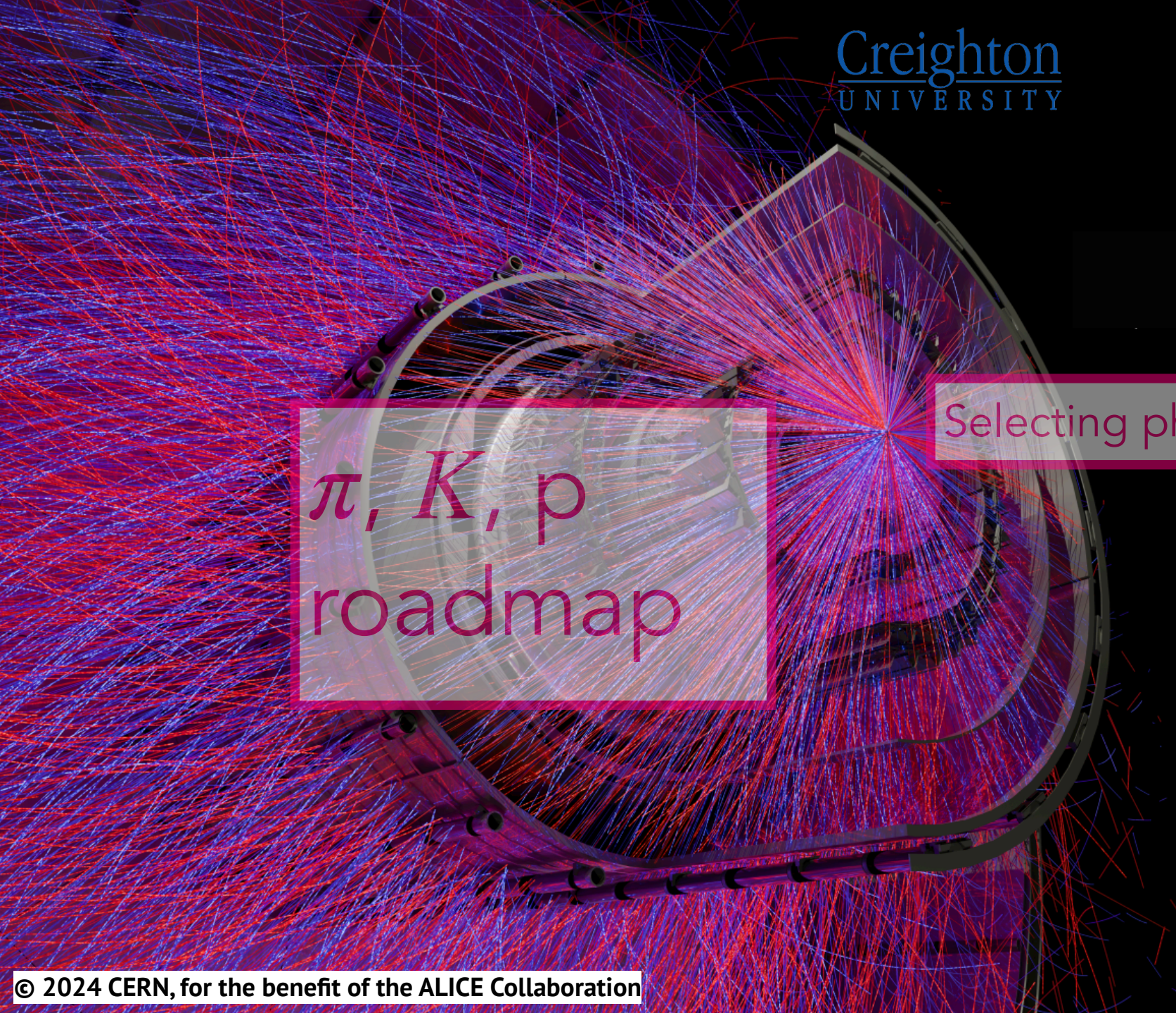

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π, K, p roadmap

Selecting photonuclear events in ALICE

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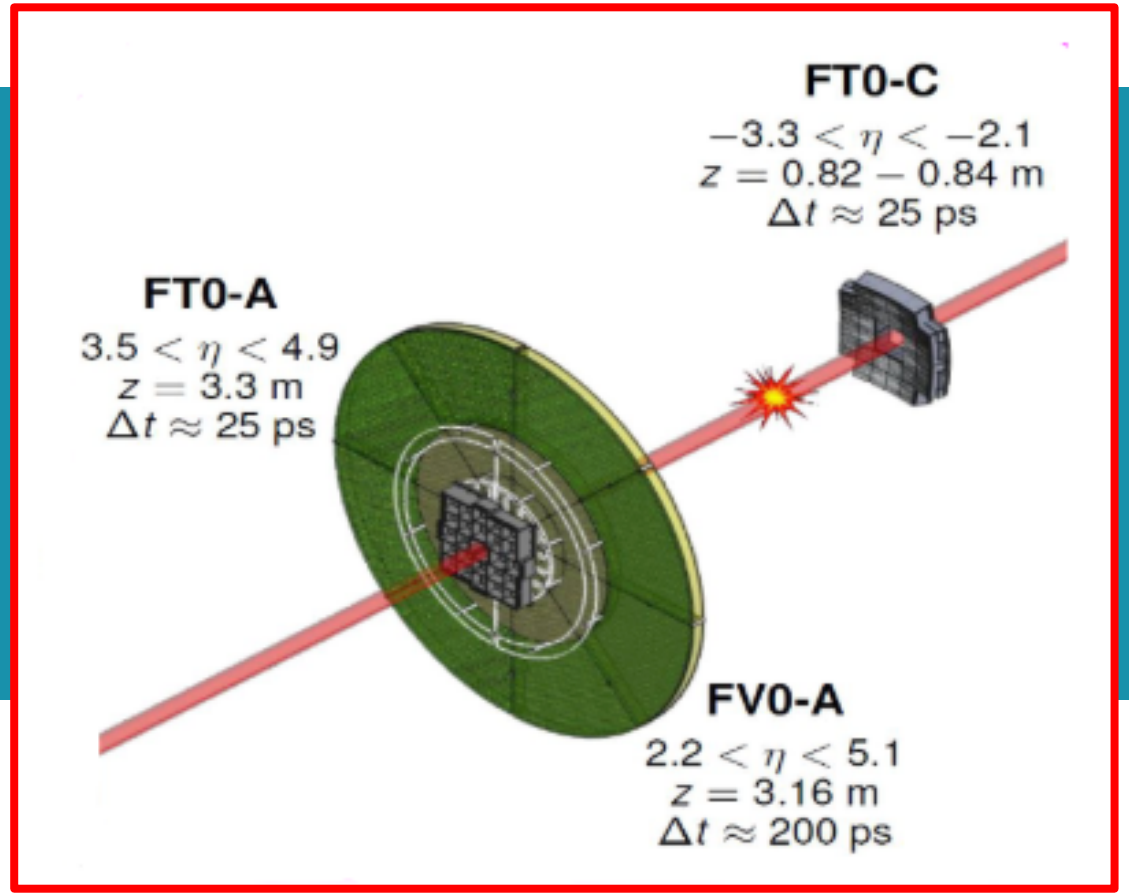
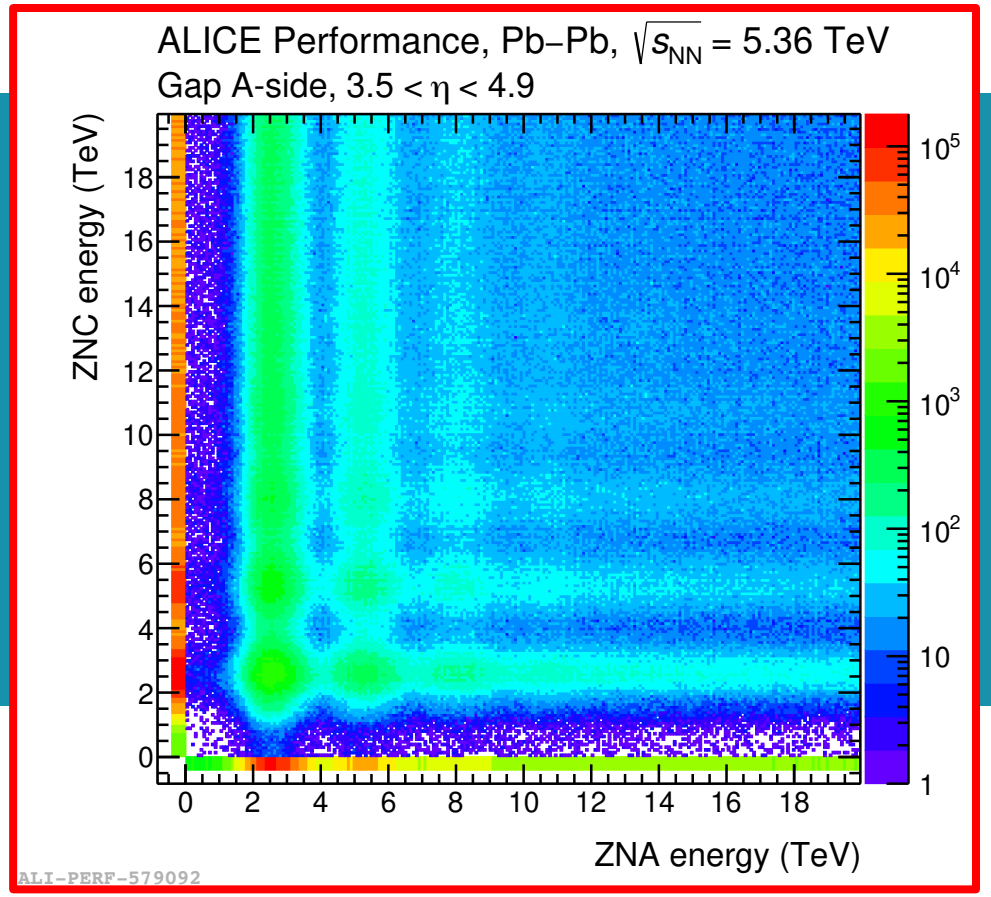
How to select a rapidity gap in ALICE

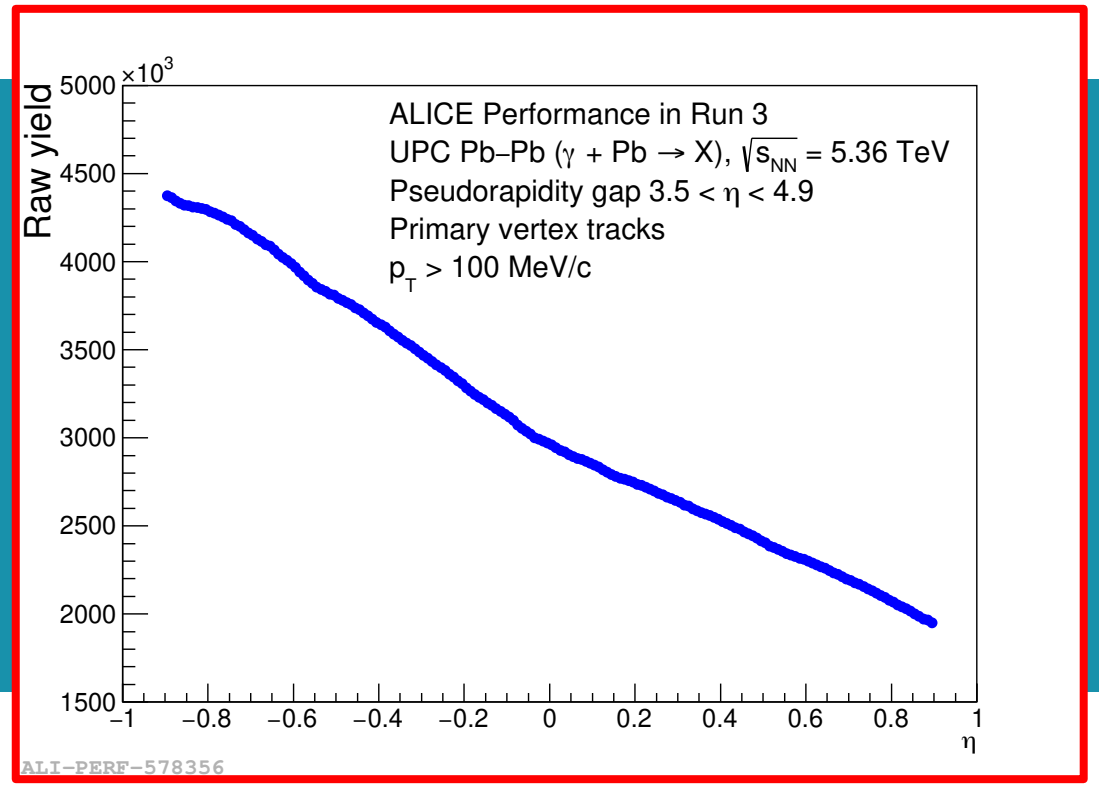


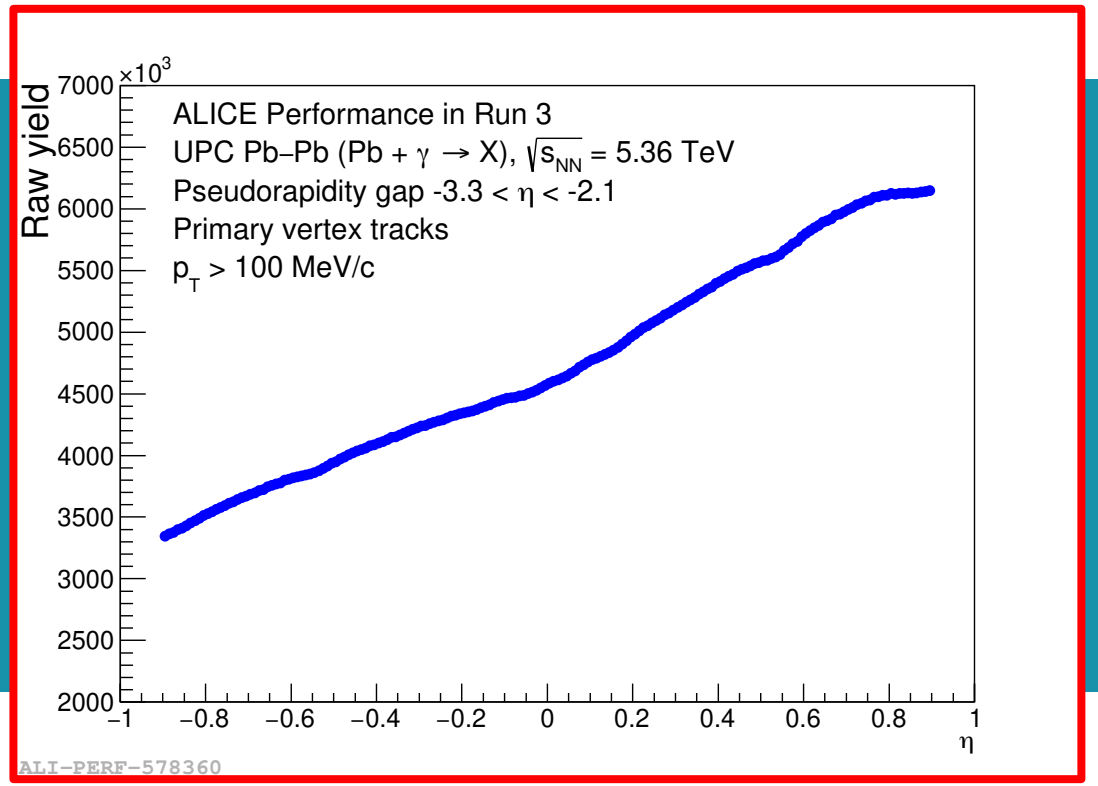


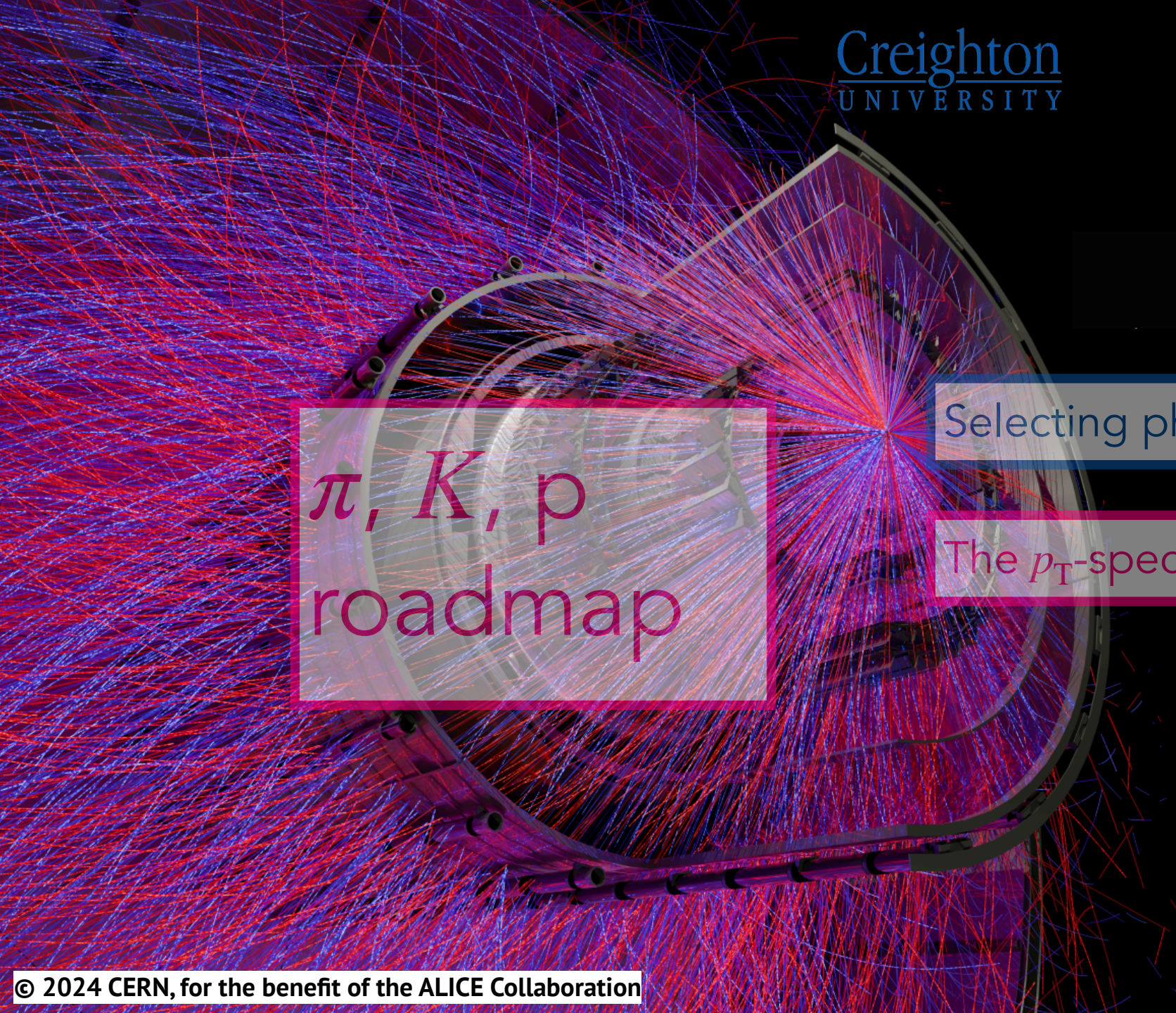
Inclusive photonuclear reactions selected using the new FIT (Fast Interaction Trigger) detector

And by checking the activity on our neutron ZDC (no activity on the side of the gap)

Asymmetric distributions







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$\pi, K,$ p roadmap

Selecting photonuclear events in ALICE

The p_{T}-spectra of π, K, p

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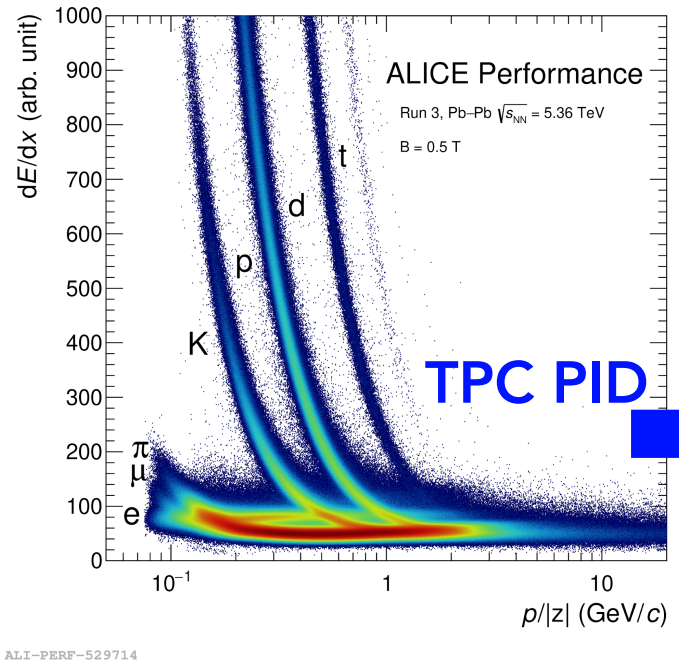
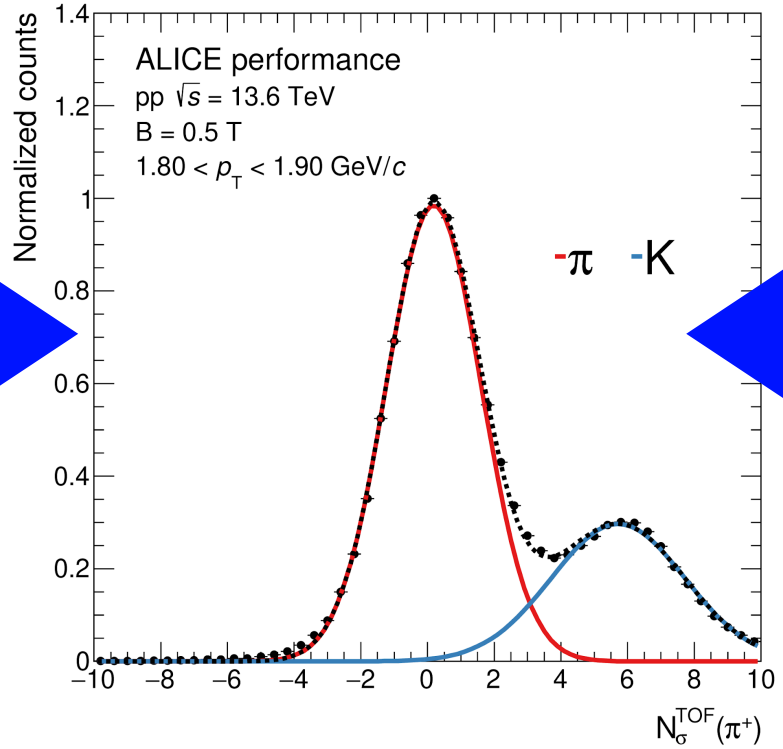
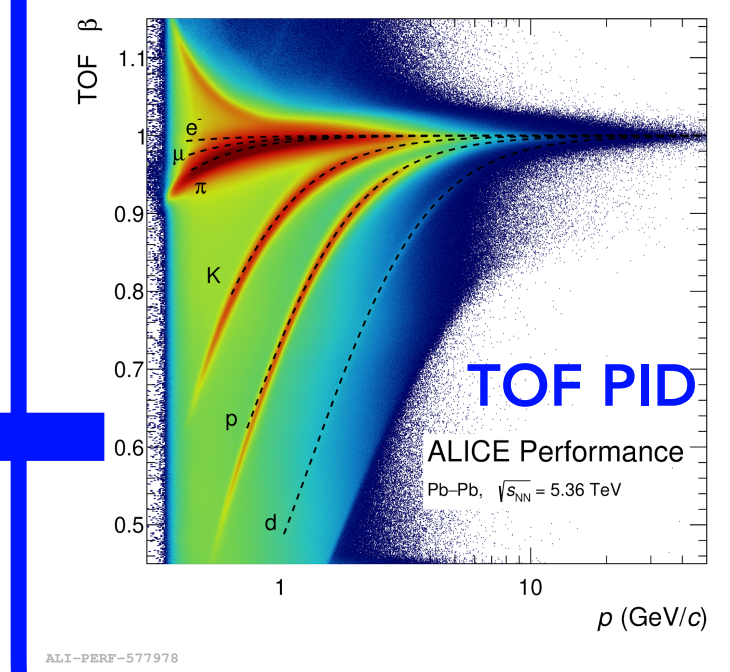
PID in ALICE

Signal extraction:

- Particle yields extracted using fits to the signal distributions in slices of p_{T}

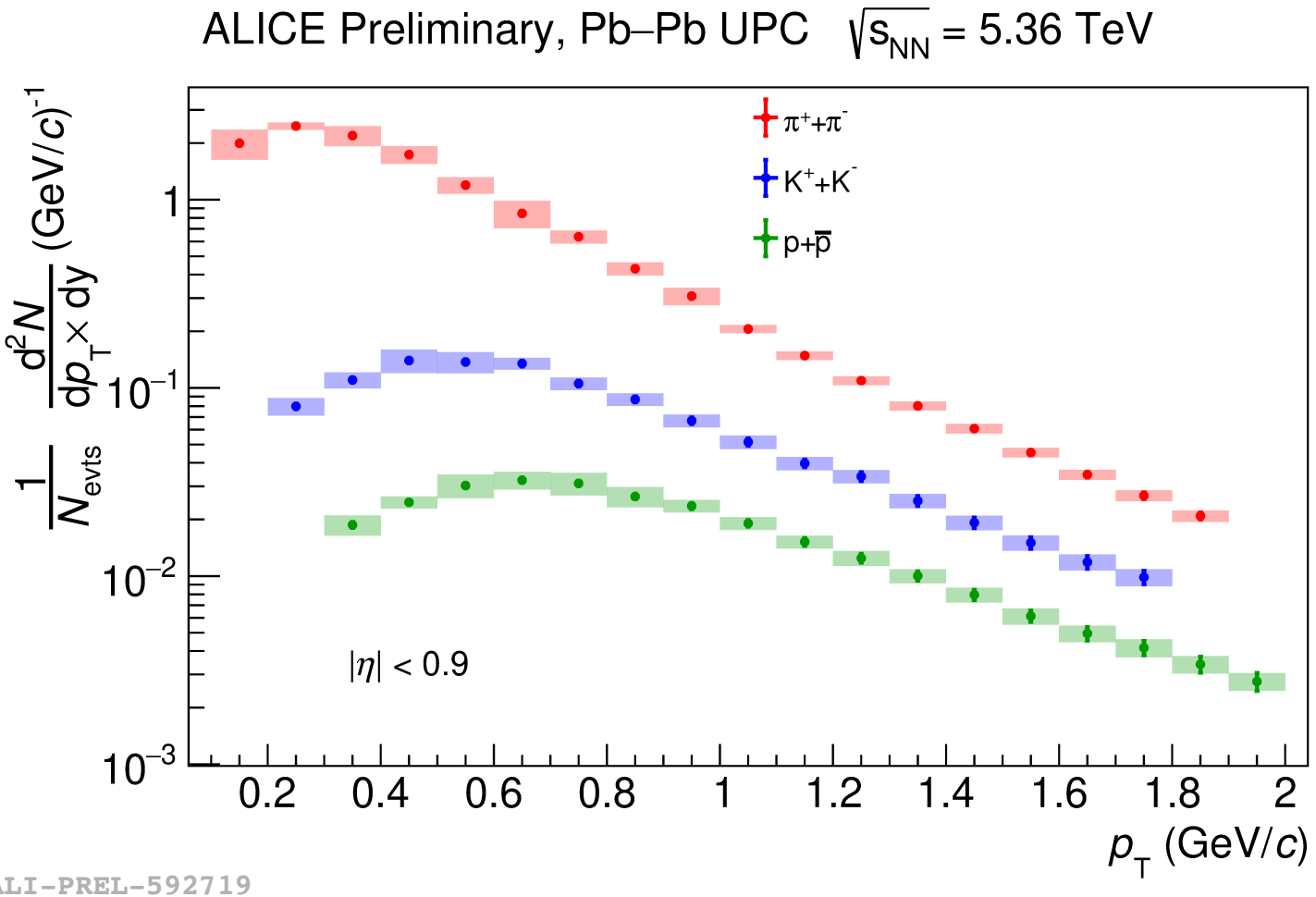






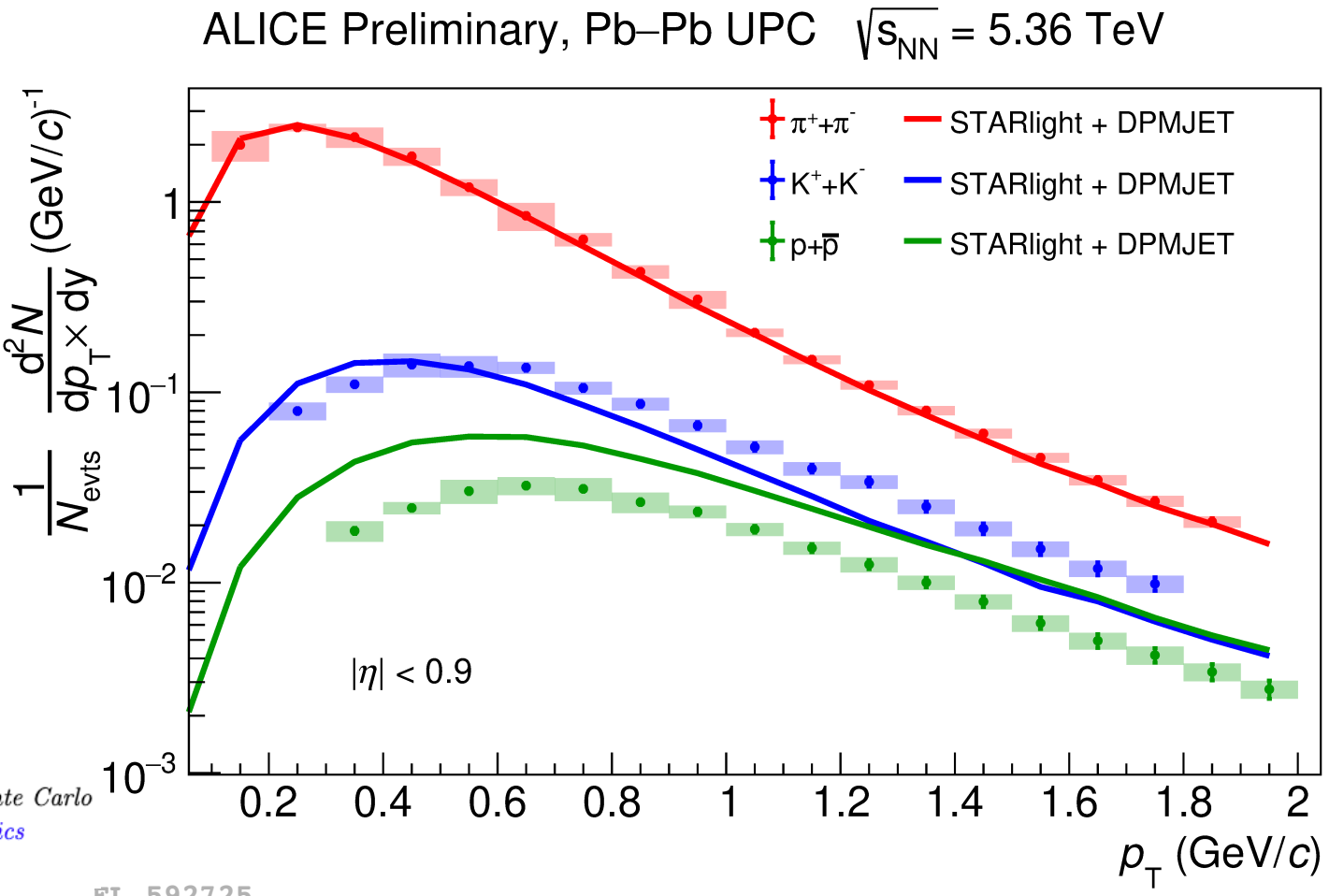
Fully corrected yields…

- Spectra measured up to $p_{\mathrm{T}} \sim 2$ GeV



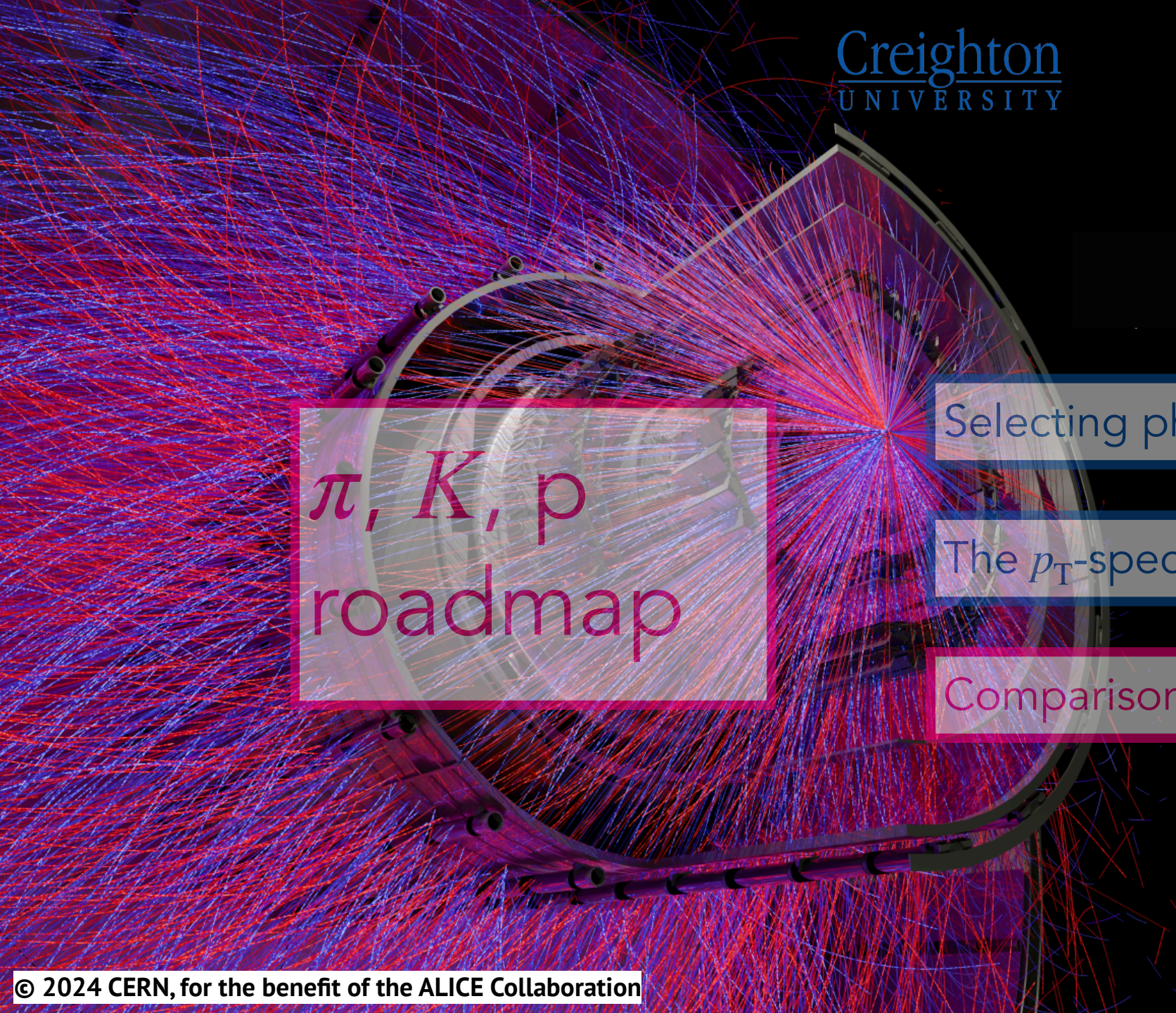
…with predictions too

- STARlight+DPMJET
  - [1] STARlight contributes with the photon flux
  - [2] DPMJET handles the nuclear break up
- Very good agreement in the pion sector
- Kaons and protons are a bit off in both normalisation and shape



[1] S. Klein, J. Nystrand, J. Seger, Y. Gorbunov and J. Butterworth, *STARlight: A Monte Carlo simulation program for ultra-peripheral collisions of relativistic ions*, Computer Physics Communications **212** (2017) 258.

[2] O. Djuvsland and J. Nystrand, *Single and Double Photonuclear Excitations in Pb+Pb Collisions at* $\sqrt{s_{NN}} = 2.76$ *TeV at the CERN Large Hadron Collider*, Phys. Rev. C **83** (2011) 041901 [1011.4908].



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$\pi, K,$ p roadmap

Selecting photonuclear events in ALICE

The p_{T}-spectra of π, K, p

Comparisons of $\langle p_{\mathrm{T}} \rangle$

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TCM

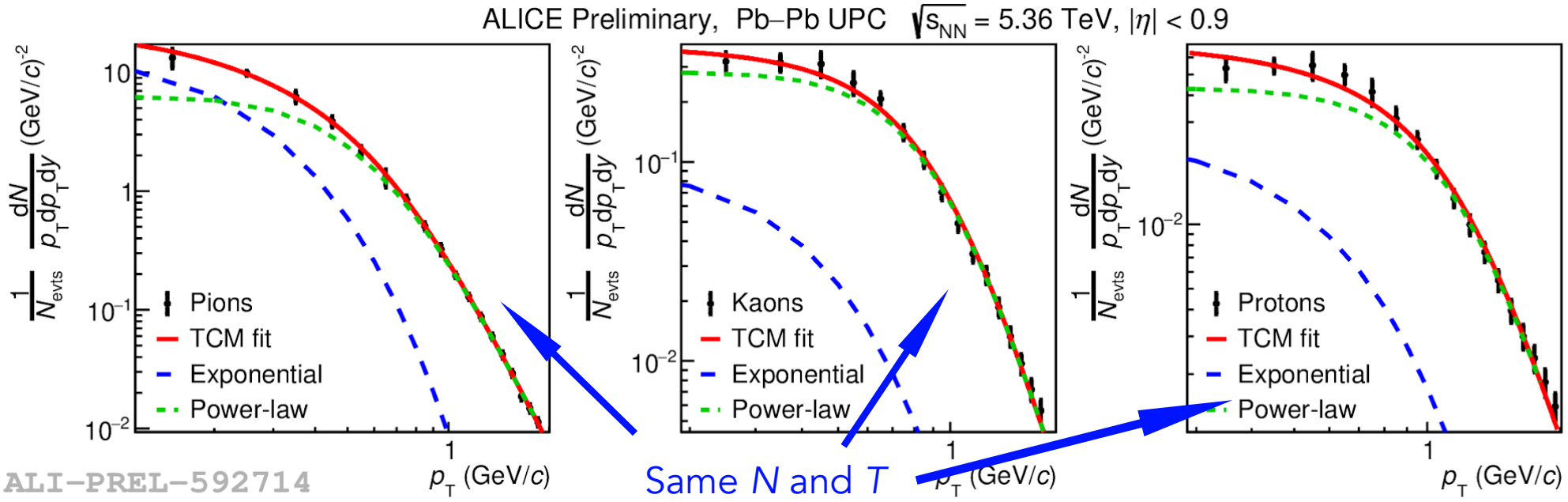
Significant expo contribution only in π

Also observed in pp and Pb-Pb

Description of the p_T-spectra:

- Integrated yields and $\langle p_T \rangle$ require a functional description for $p_T \to 0, +\inf$
- **Two-Component Model (TCM)** fits work quite well

$$\frac{1}{N_{ev}} \frac{d^2N}{p_T dp_T dy} = A_1 \cdot \exp(-E_{T_{kin}}/T_e) + \frac{A_2}{\left(1 + \frac{p_T^2}{T^2 N}\right)^N}$$

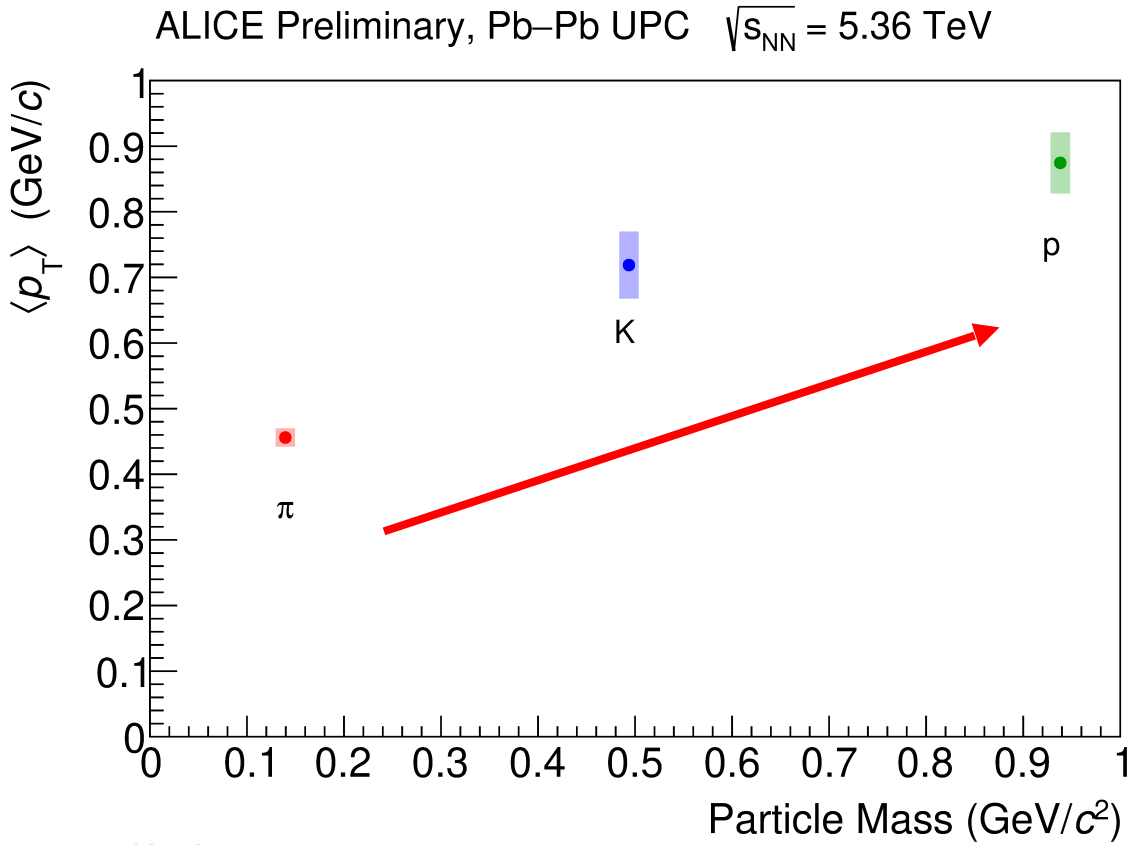


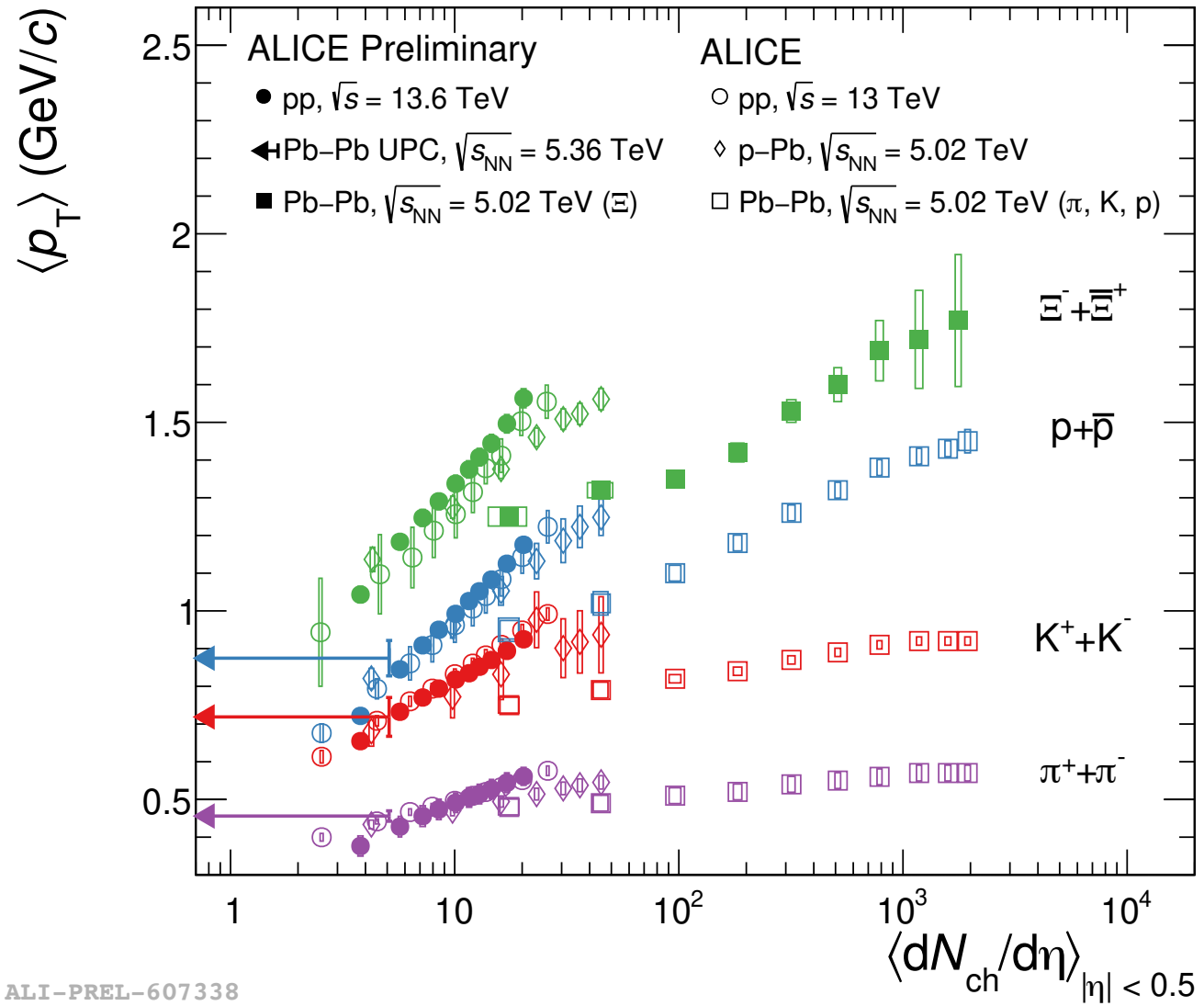
[1] A.Bylinkin and A. Rostovtsev, *Phys.Atom.Nucl.* 75 (2012) 999-1005, *Yad.Fiz.* 75 (2012) 1060-1066

[2] A.Bylinkin and A. Rostovtsev, Eur.Phys.J.C 74 (2014) 5, 2898

What about the $\langle p_{\mathrm{T}} \rangle$?

- Values agree well with pp and Pb-Pb data



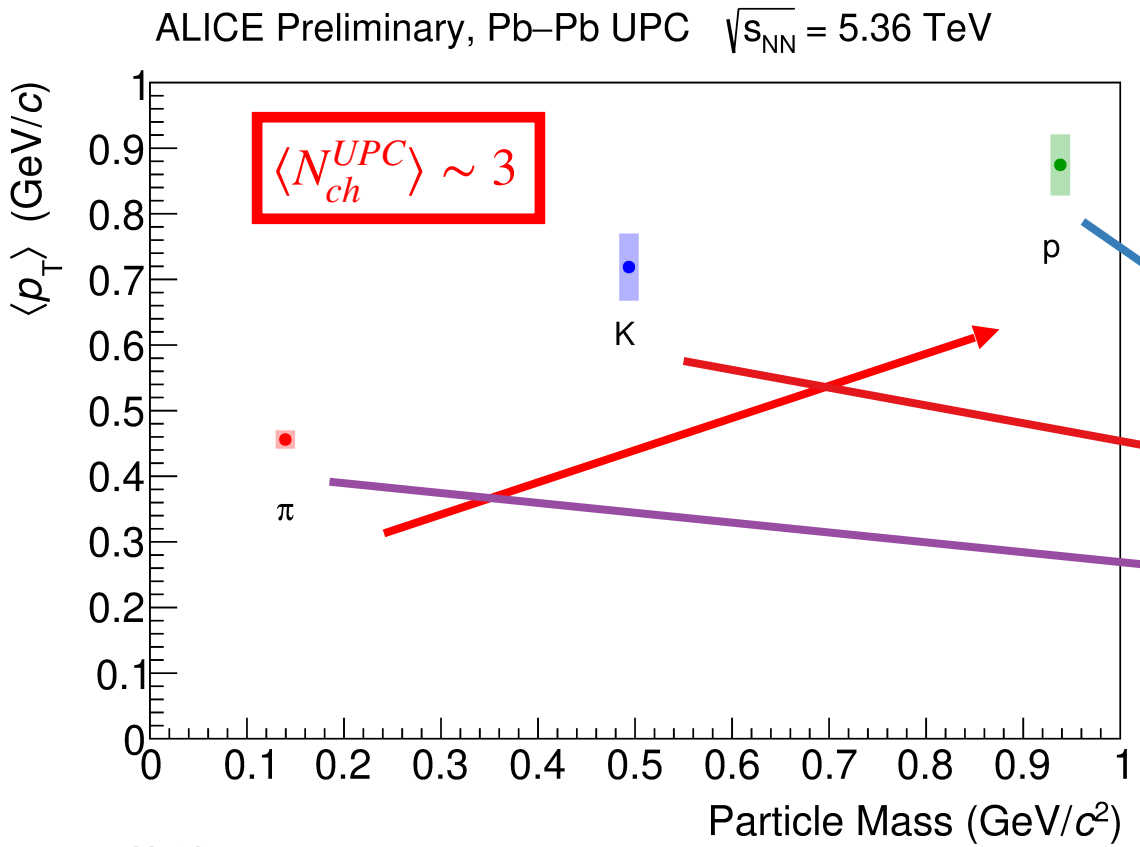


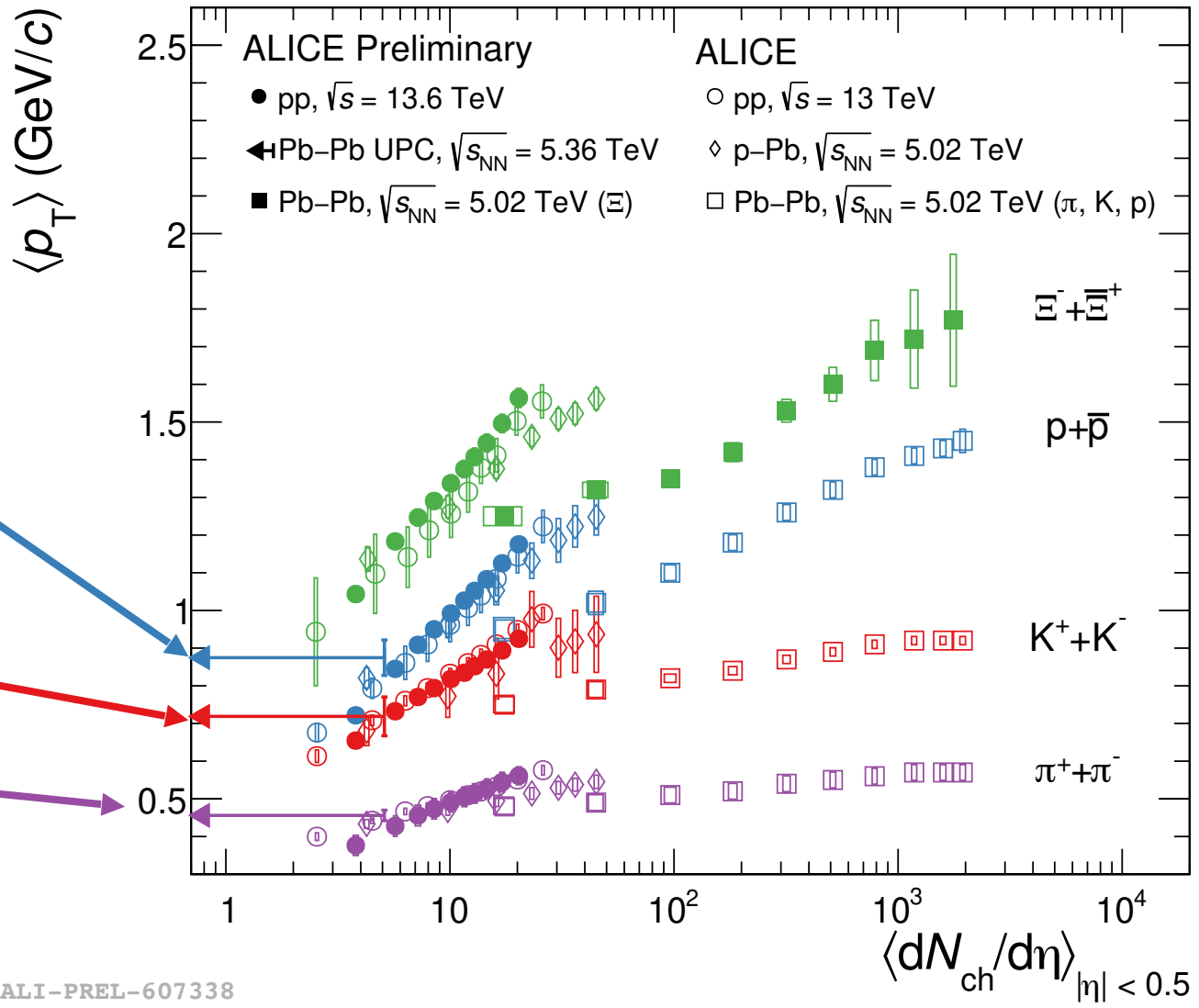
ALI-PREL-607338

ALI-PREL-592748

What about the $\langle p_T \rangle$?

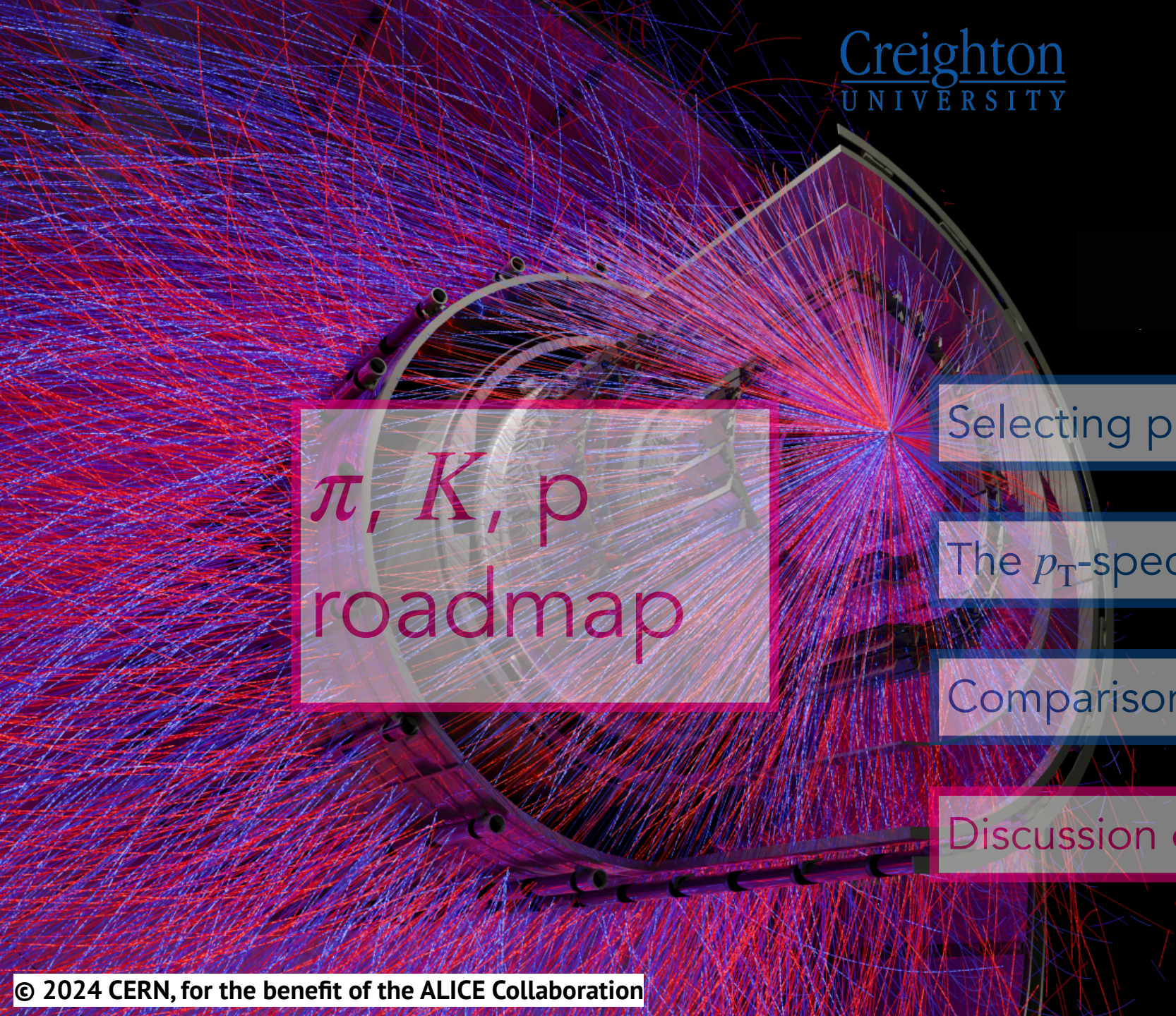
- Values agree well with pp and Pb-Pb data





ALI-PREL-607338

ALI-PREL-592748



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ALICE

$\pi, K,$ p roadmap

Selecting photonuclear events in ALICE

The p_{T}-spectra of π, K, p

Comparisons of $\langle p_{\mathrm{T}} \rangle$

Discussion on yield ratios

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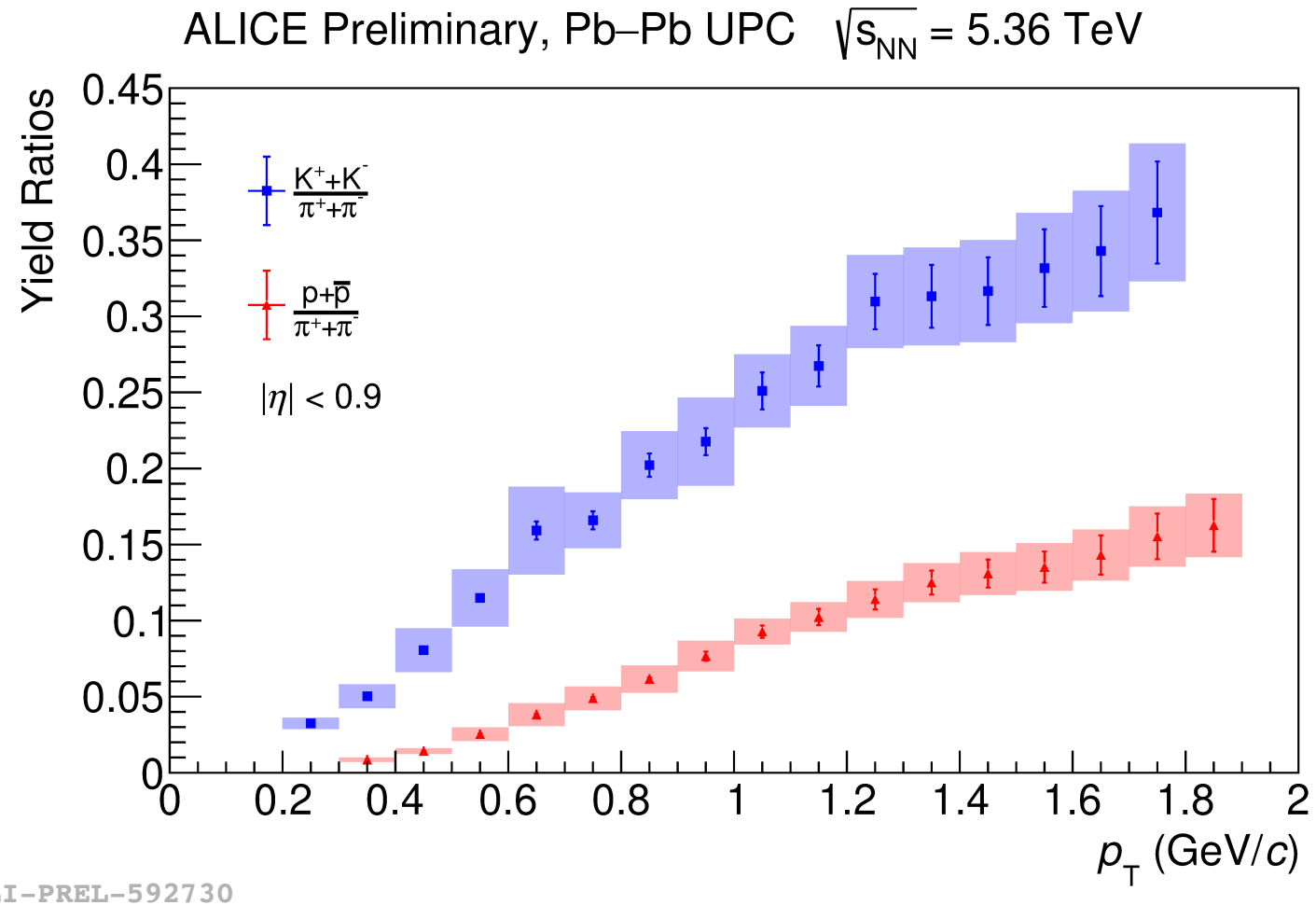
Yield ratios

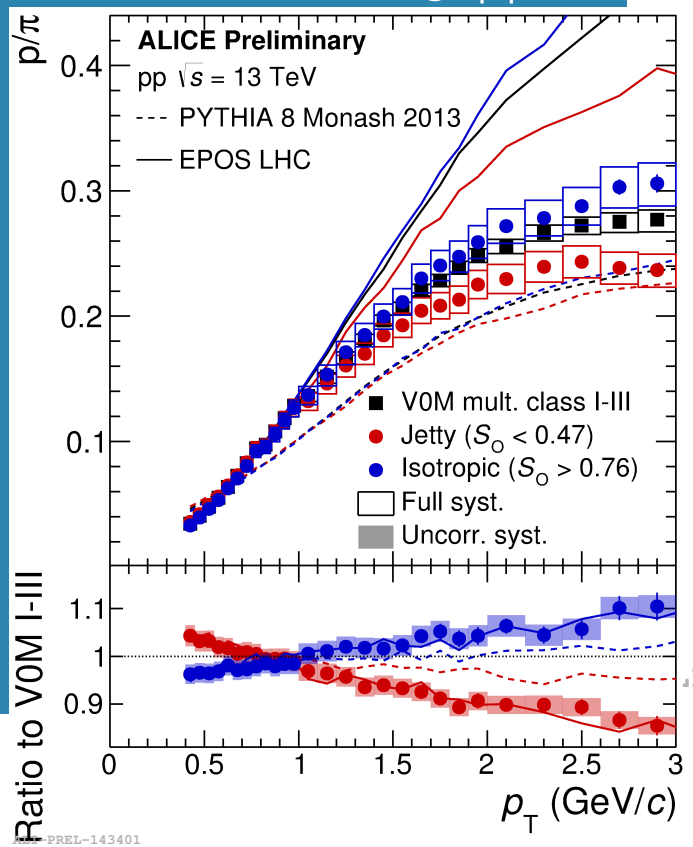
- Ratios of K/π and p/π up to $p_{\mathrm{T}} \sim 2$ GeV/c

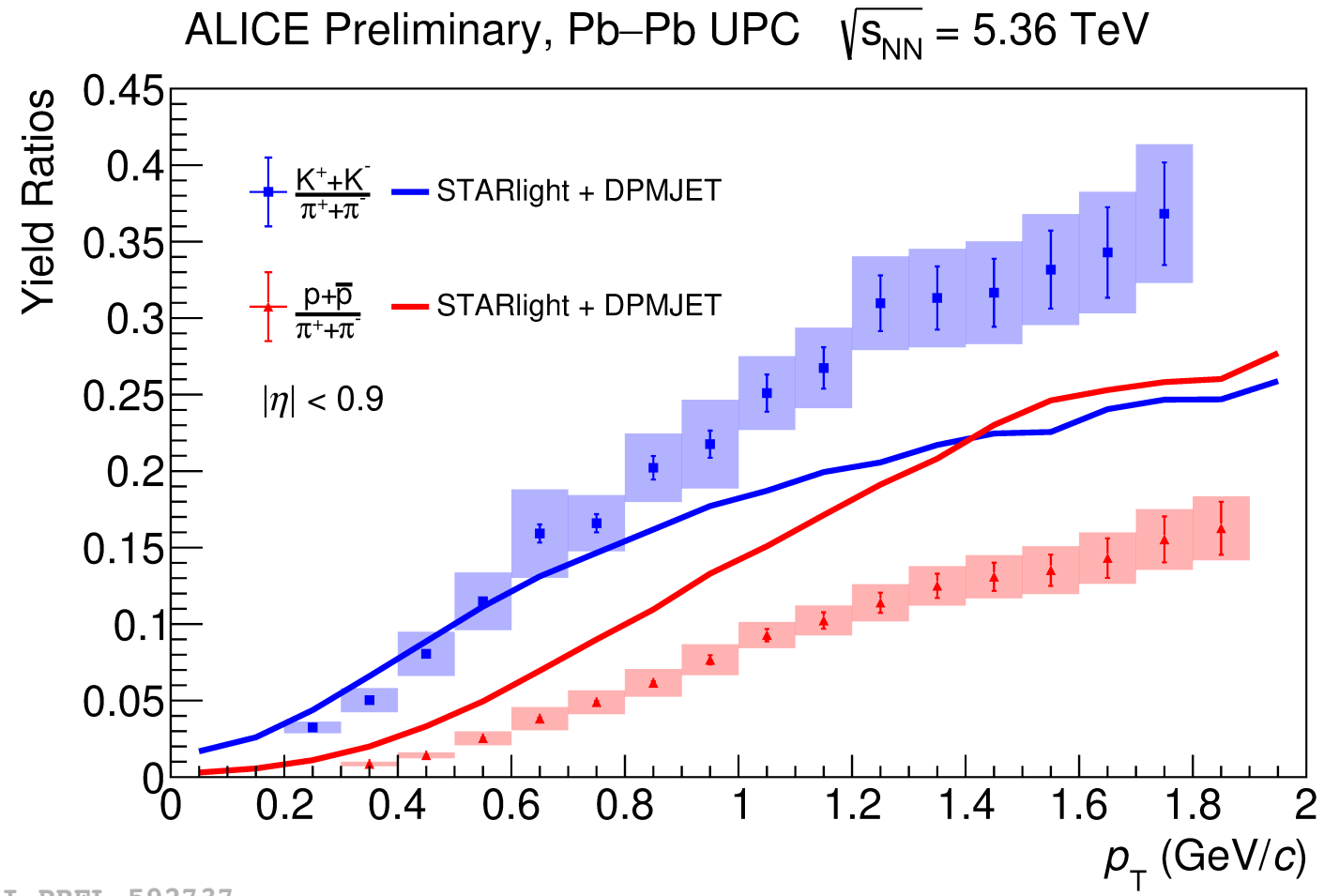


ALI-PREL-592730

Yield ratios

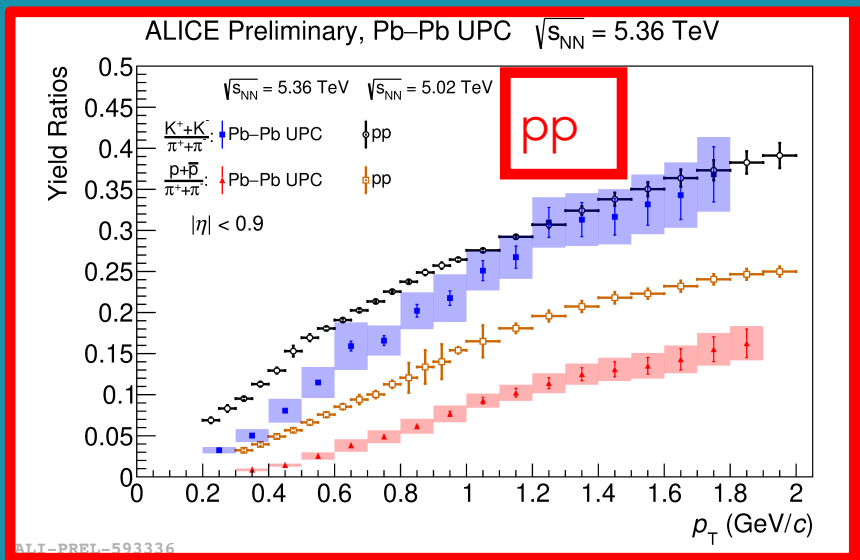
- Ratios of K/π and p/π up to $p_{\mathrm{T}} \sim 2$ GeV/c
- Monte Carlo models often fail to describe yield ratios also in e.g. pp collisions

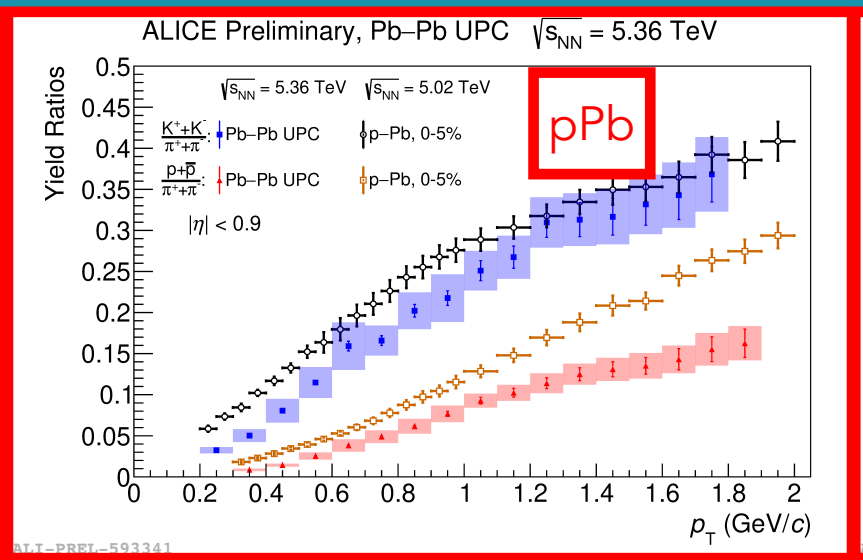


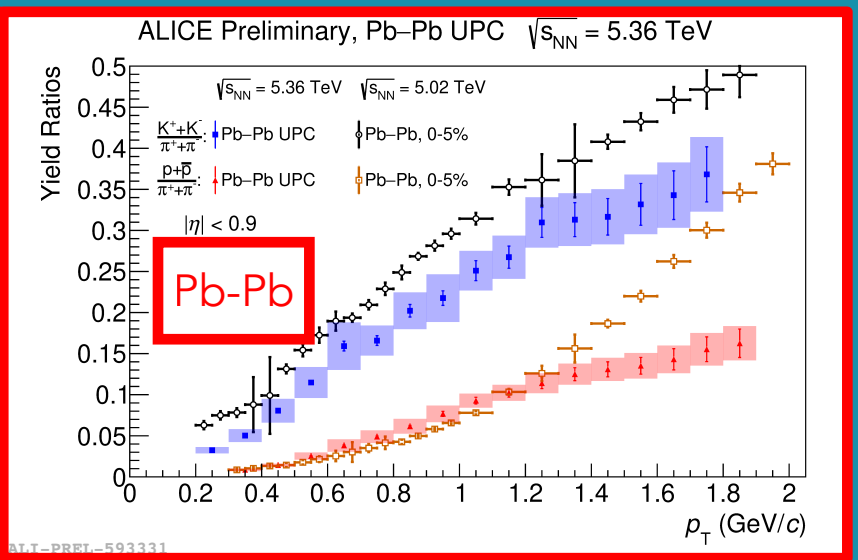


Yield ratios

Very boosted high-multiplicity event - asymmetric rapidity distributions from slide 13



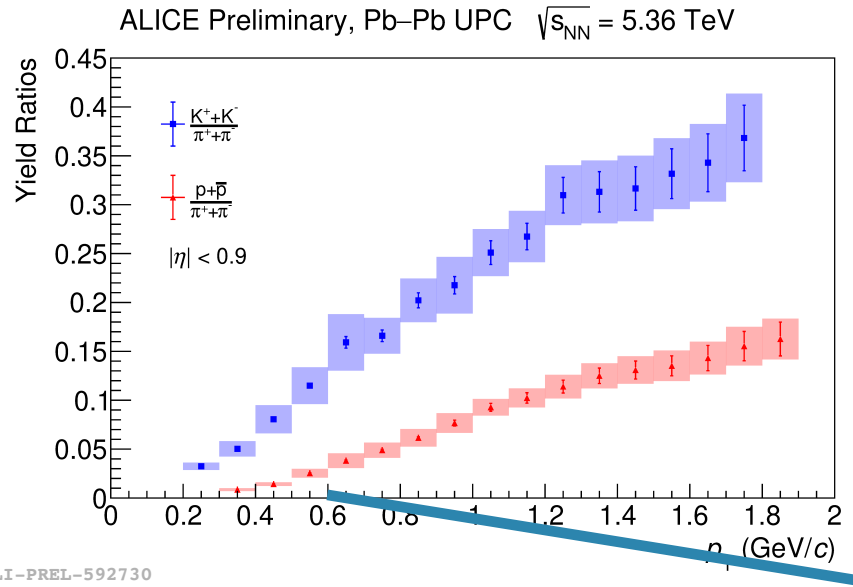


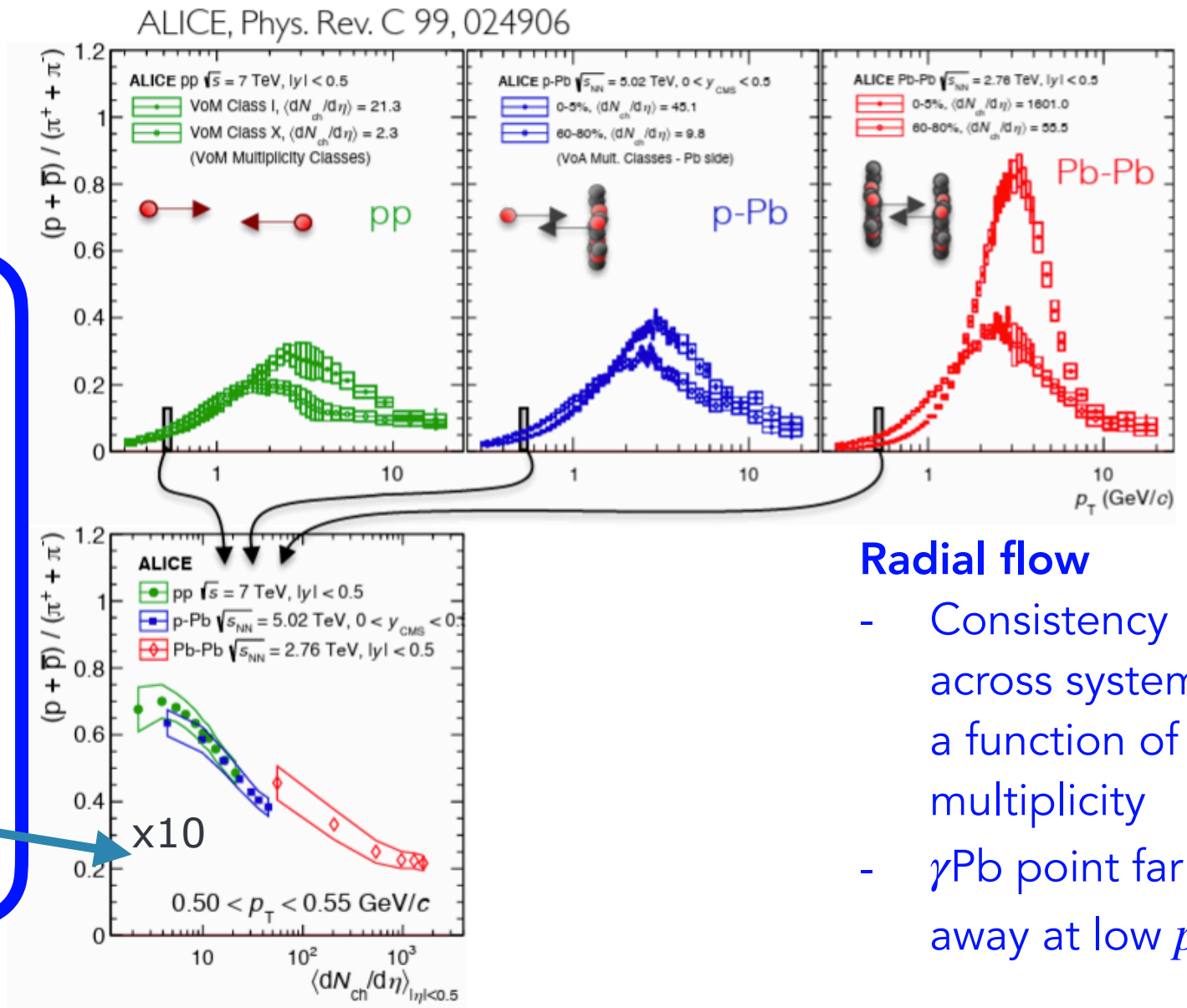


K/π: slightly lower value at low-p_T in γPb than in the other systems, i.e. pp, pPb, and Pb-Pb, shape agrees with pPb and Pb-Pb

p/π: baryon-to-meson suppression from small to larger systems, shape agrees better with pp and pPb

p/π ratios



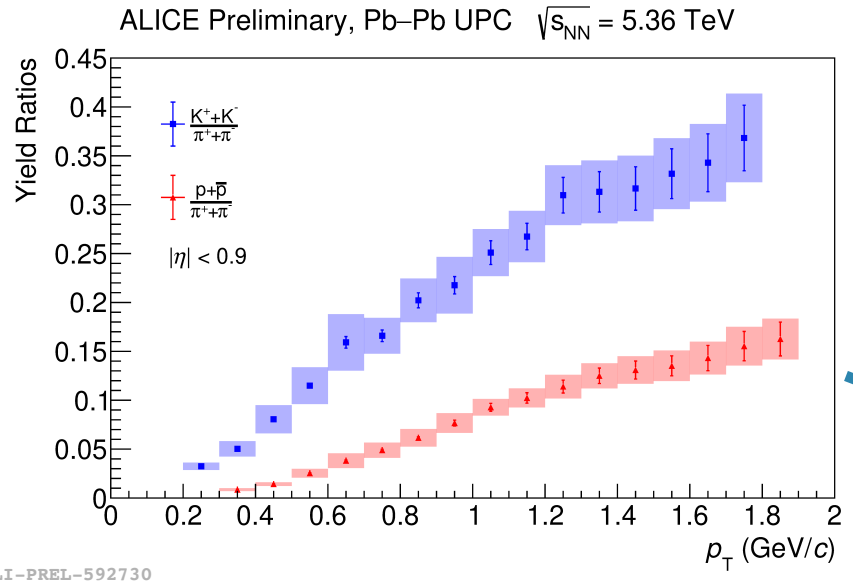


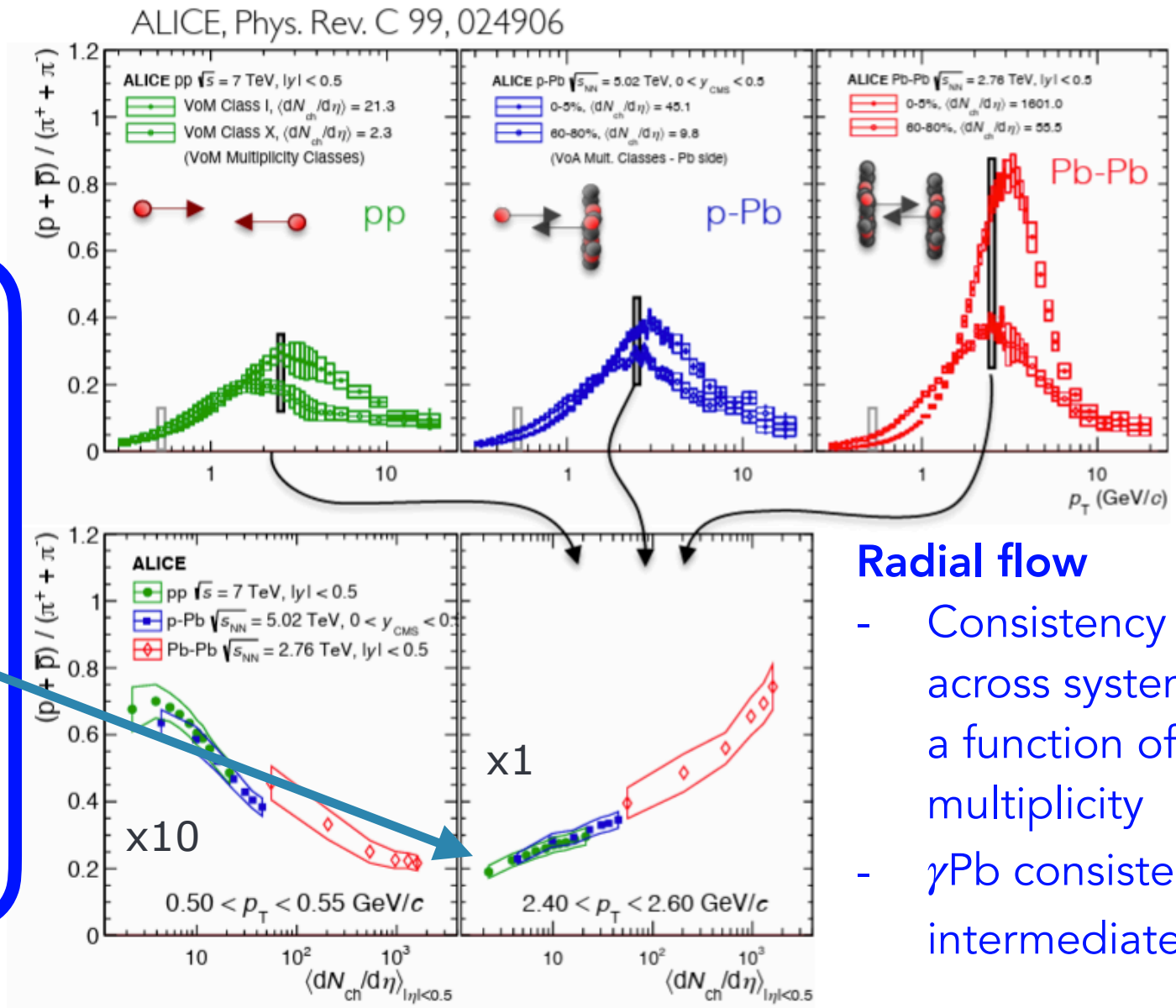
Radial flow

- Consistency across systems as a function of multiplicity
- γPb point far away at low p_T

Talk by R. Schotter 10/7: *System size dependence of light-flavor hadron production: from the smallest to the largest collision system at the LHC with ALICE*

p/π ratios

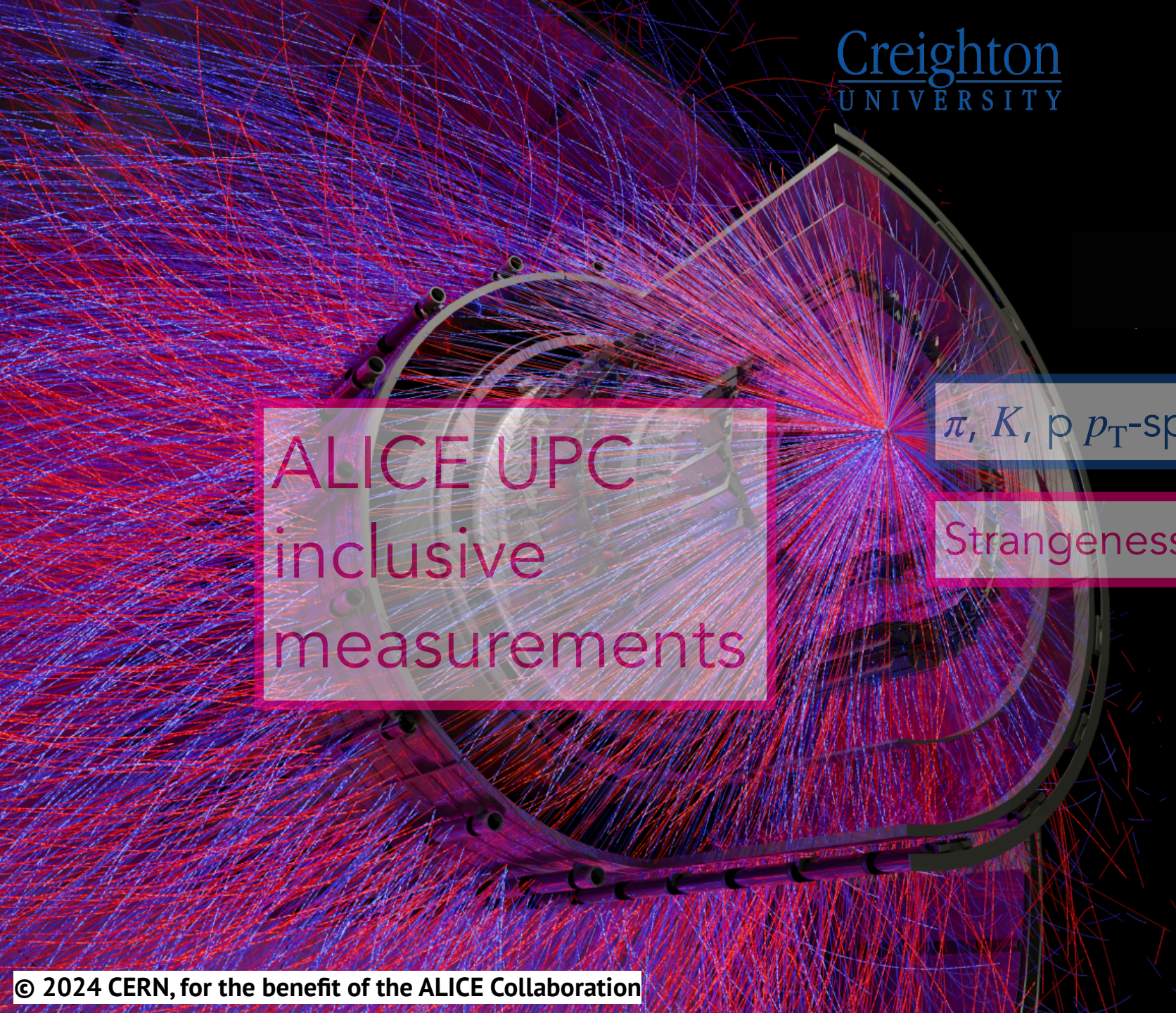




Radial flow

- Consistency across systems as a function of multiplicity
- γPb consistent at intermediate p_T

Talk by R. Schotter 10/7: *System size dependence of light-flavor hadron production: from the smallest to the largest collision system at the LHC with ALICE*



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ALICE

ALICE UPC inclusive measurements

- π, K, p p_{T}-spectra in UPCs
- Strangeness in UPCs

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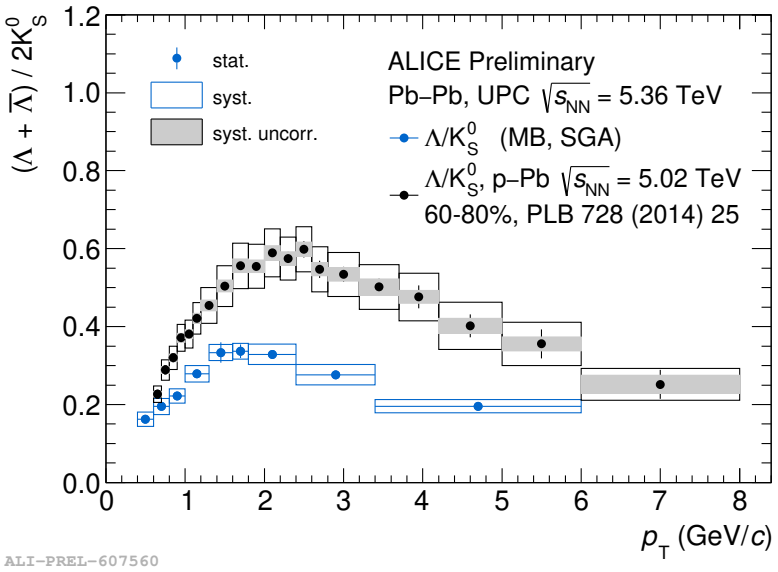
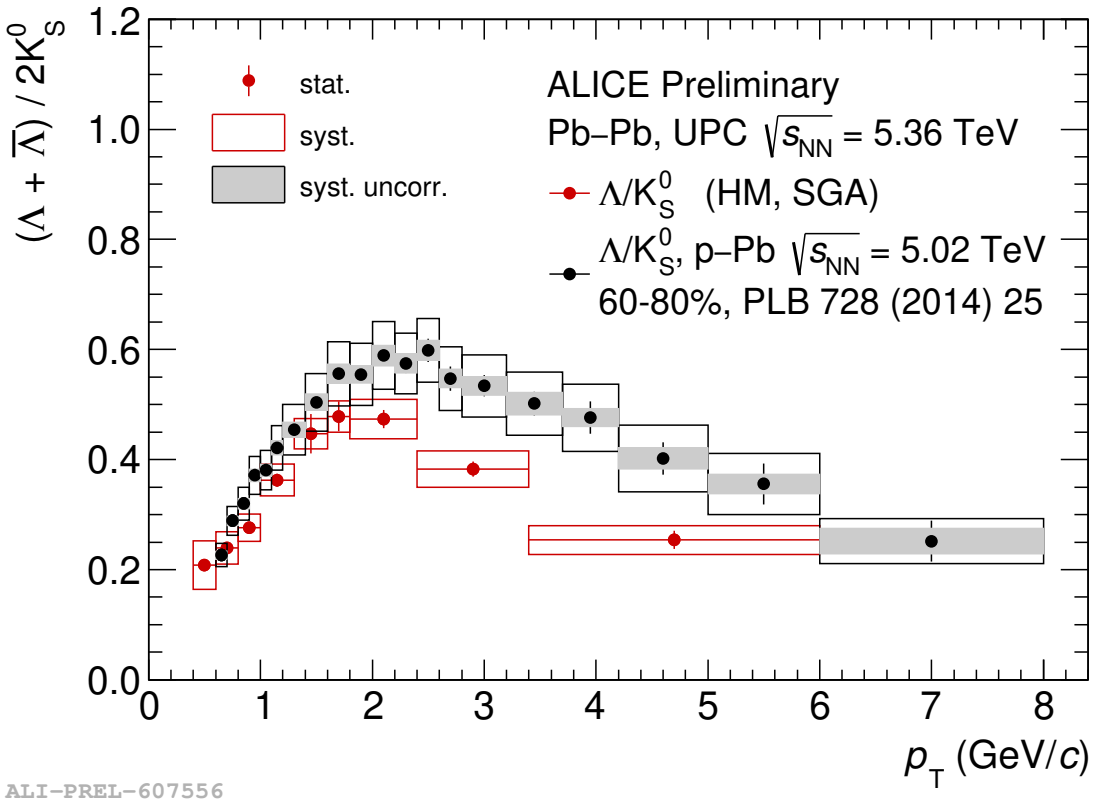
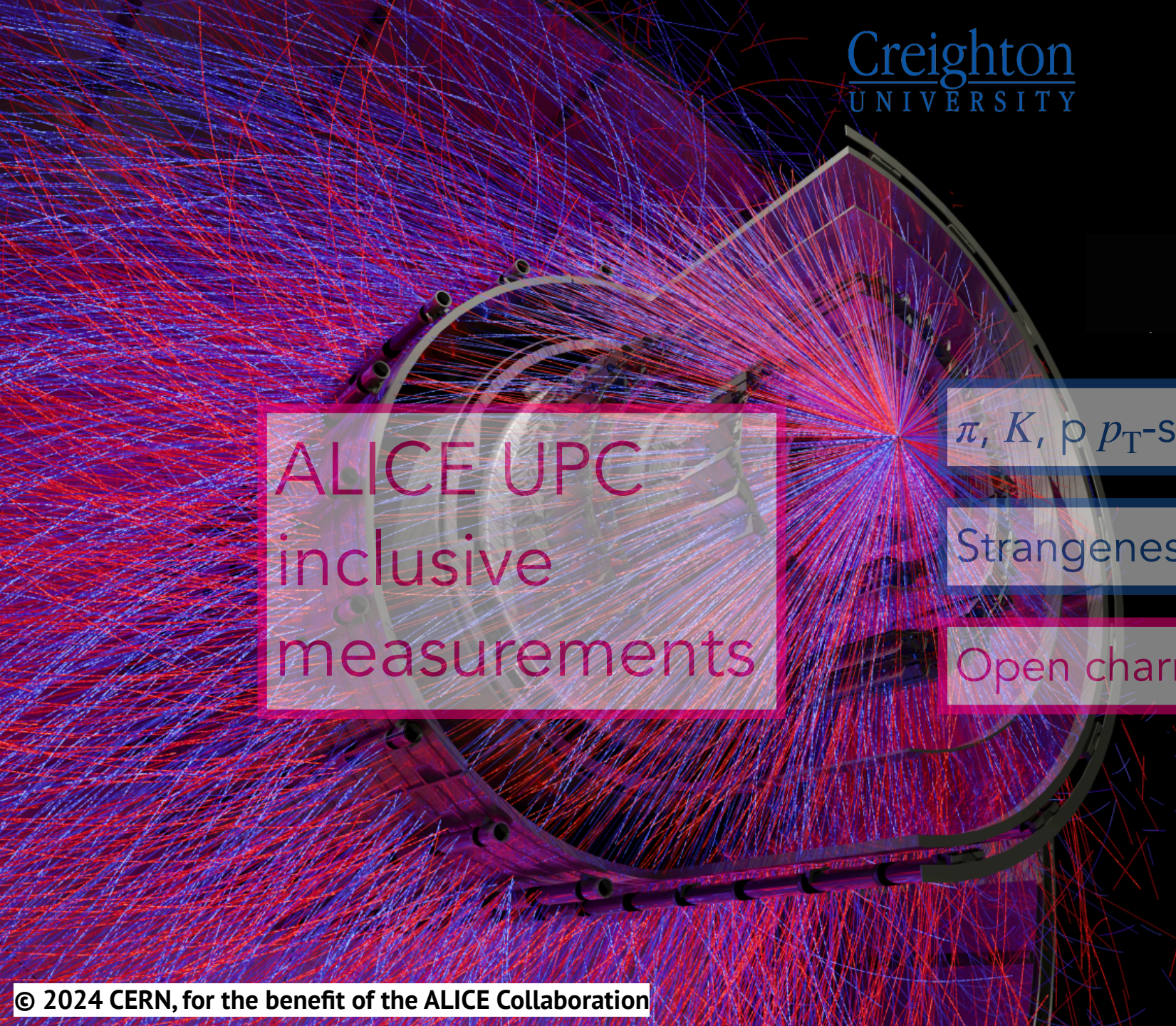
Baryon-to-meson



Radial flow

- Consistent with the ATLAS results *Phys.Rev.C* 111 (2025) 6, 064908
- γPb dominated by vector dominance model, similar to ρPb





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ALICE

ALICE UPC inclusive measurements

- π, K, p p_{T}-spectra in UPCs
- Strangeness in UPCs
- Open charm in UPCs

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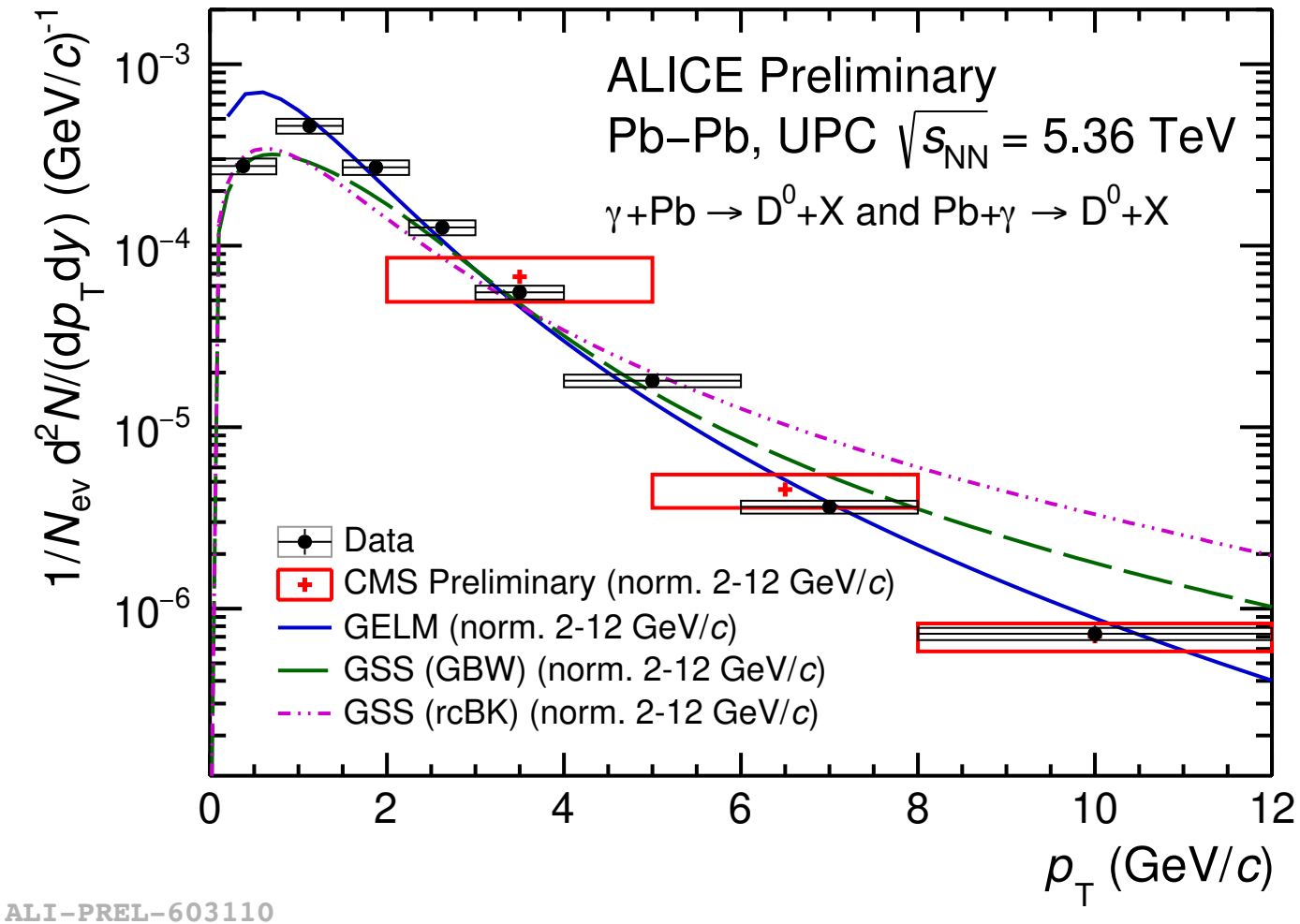
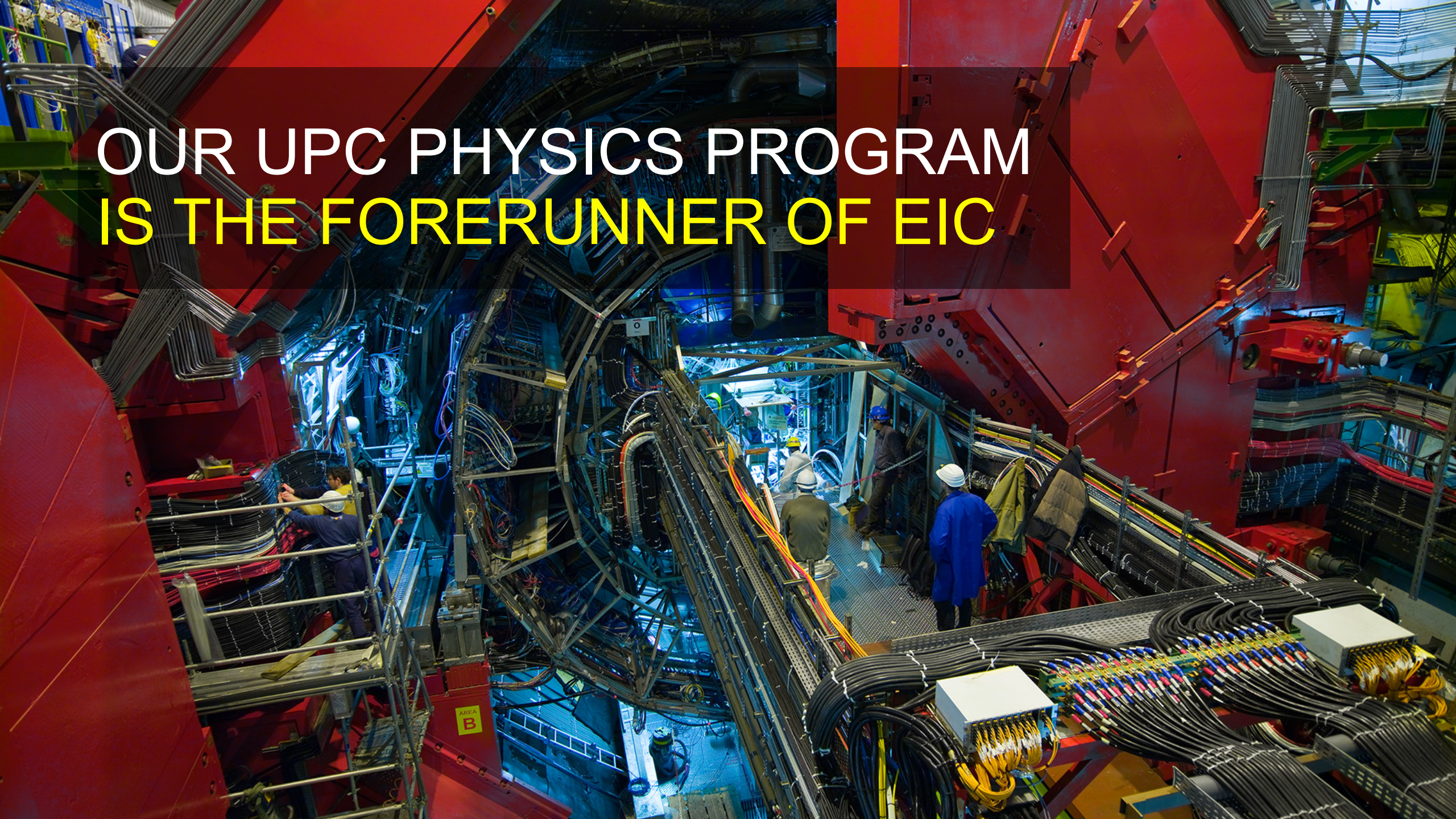
Open charm photoproduction

- $\langle p_{\mathrm{T}} \rangle$ not properly reproduced by models
- Only spectra from ALICE for now
- CMS cross sections are normalised in the 2-12 GeV/c region
- Only partial systematics from ALICE, so uncertainties between ALICE and CMS not directly compatible
- Measuring charm hadrons will give access to nPDFs at $x \sim 10^{-4}$
- p-Pb collisions expected for Run 4 will provide the reference for γp for nuclear effects





OUR UPC PHYSICS PROGRAM IS THE FORERUNNER OF EIC

Thank you!

- New wealth of data from continuous readout and Run 3!
- Exciting opportunities for inclusive UPCs!
- A new venue for the smallest of collision systems
  - Open charm for nPDFs
  - Exploring collectivity in small systems
  - Tuning models