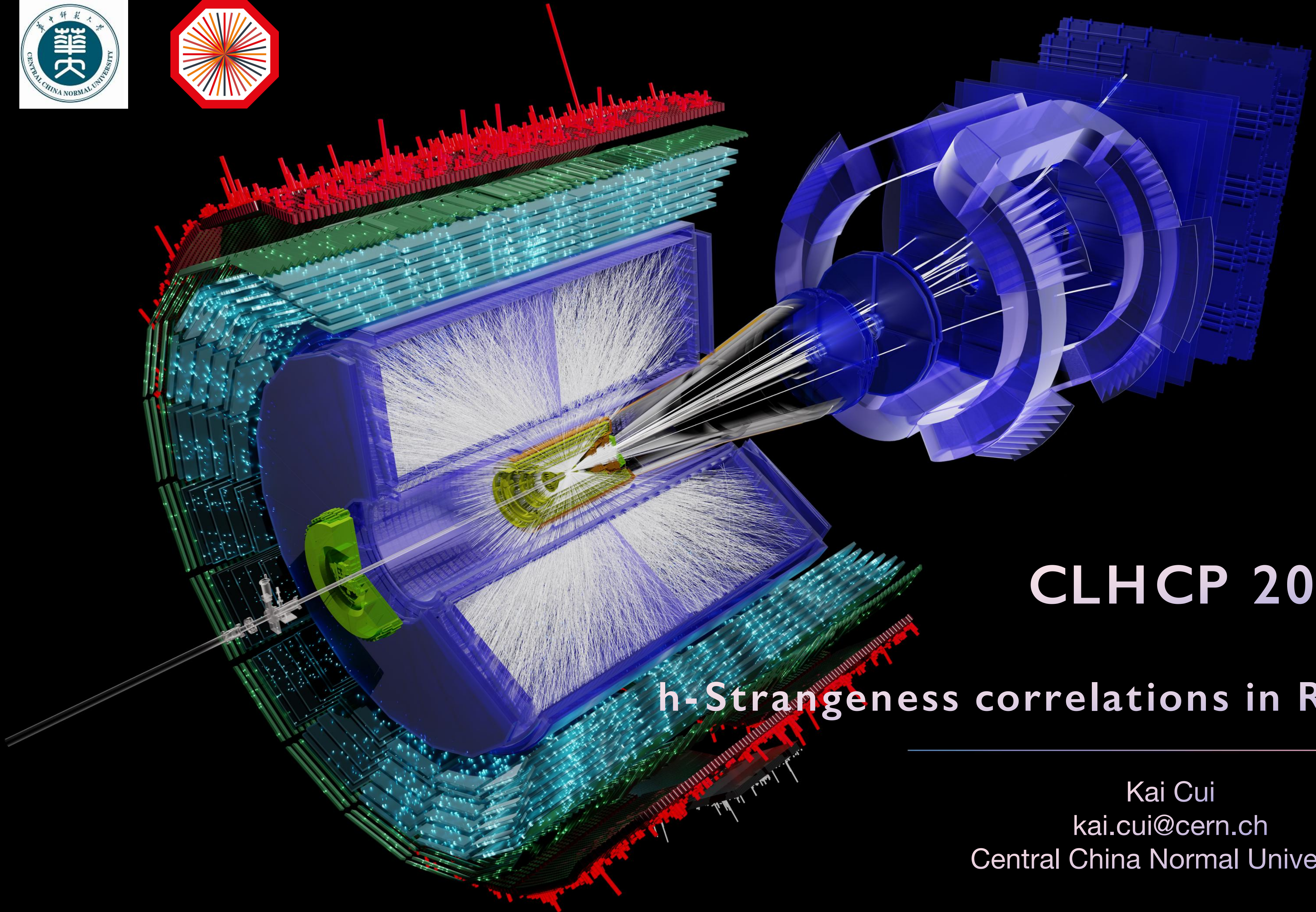

CLHCP 2024

h-Strangeness correlations in Run 3 with Alice

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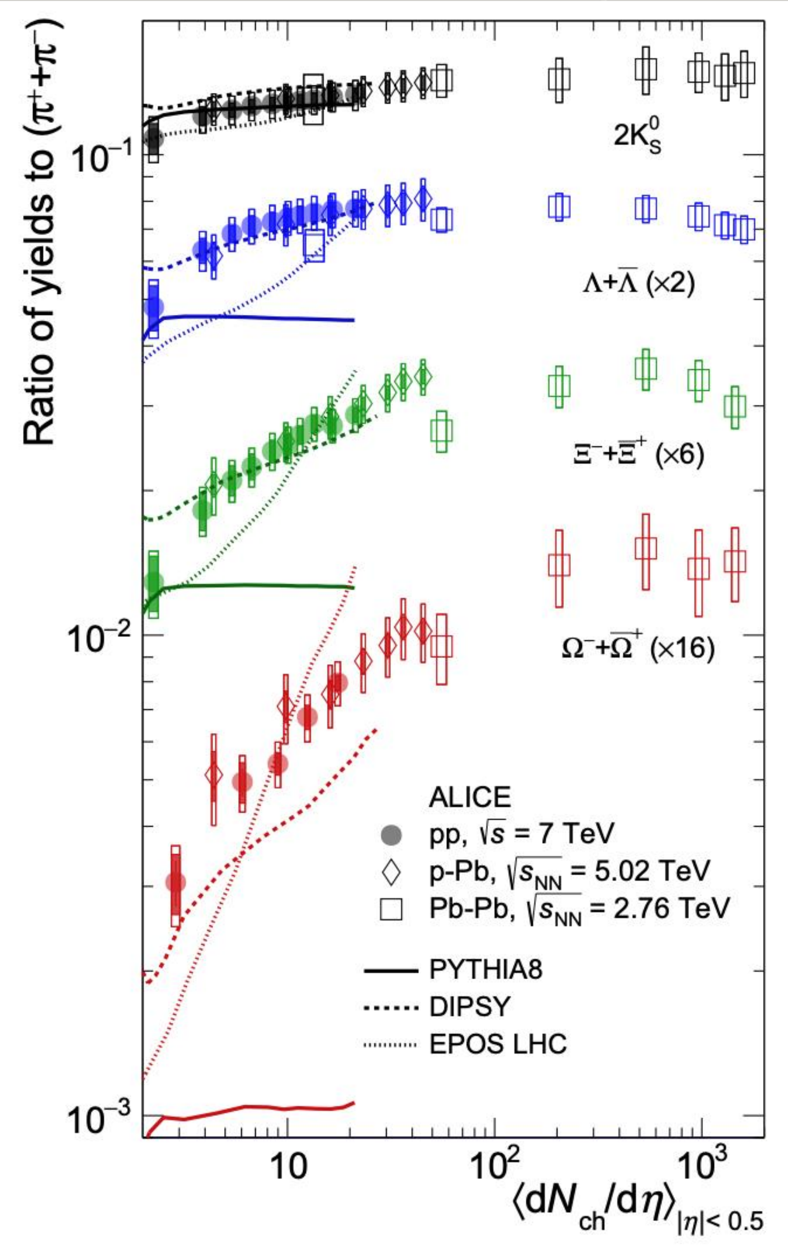
Outlines

- Introduction and motivation
- Data sample and event selection
- Analysis algorithm
- Preliminary results
- Summary



Introduction and motivation

- **Strangeness enhancement**: well-known in small systems by now
- Characterization: if the origin is common in all systems?

- Is strangeness enhancement correlated with high-momentum or low-momentum physics?

- The relationship between enhancement effect and strangeness

- Previous studies have done in Run 2 (Lund group)
- Now: take advantage of Run 3 data samples!
  - Enormous statistics may allow for very precise study

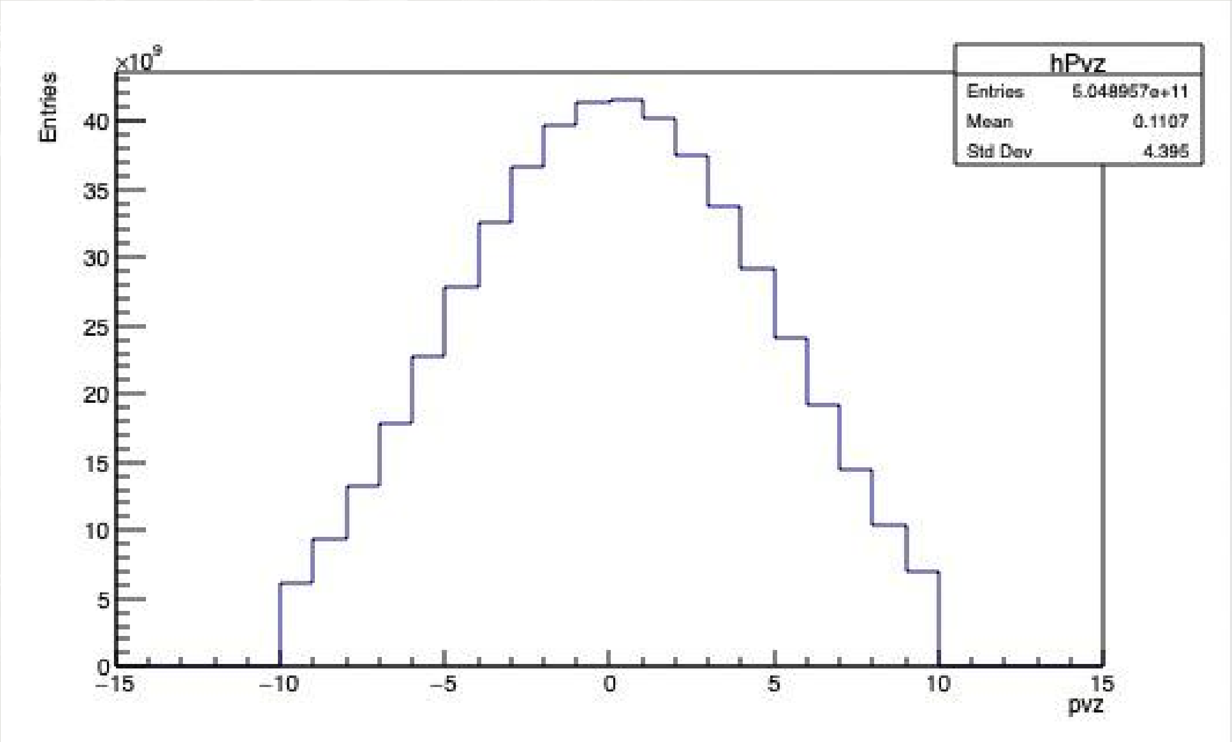
Data sample and event selection

- **Data:** pp collisions at 13.6 TeV collected in 2022
  500 x 10^9 events
- **Monte Carlo (MC):** LHC23k2d (anchored to the data)
  526 x 10^6 events

Event selection:

- sel8 (including selections on ITS ROF border and TimeFrame border)
- |z| < 10 cm
- INEL > 0 (at least one track with |eta| < 1 contributing to the PV)

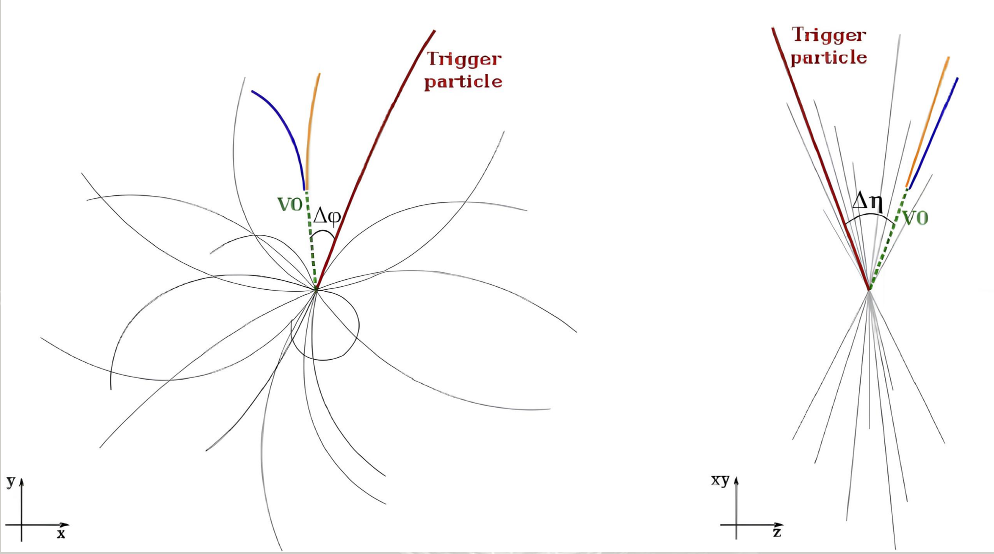
About 75% of the events pass these selections



Analysis algorithm: two-particle correlations

- Tool of choice: two-particle correlations
  - Trigger particle: high-momentum (settable) charged hadron
  - Associated particles: low-momentum (settable) strange particles such as K^0_S, Λ, Ξ^- to Ω^-

- Phase space selections:
  - trigger particles are from $2.0 < p_T < 50.0$ GeV/c
  - associated particles are from $0.0 < p_T < 15.0$ GeV/c



$$\Delta\varphi = \varphi_{asso} - \varphi_{trigg}$$

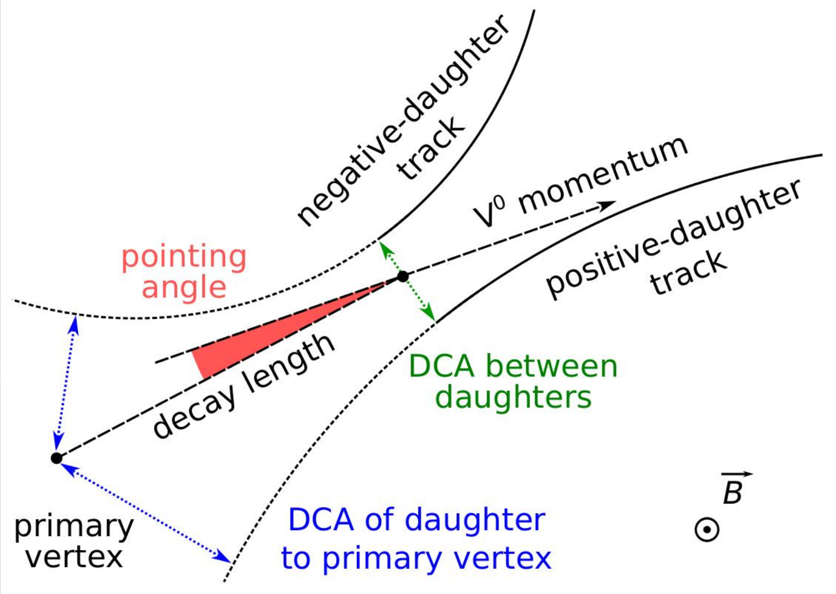
$$\Delta\eta = \eta_{asso} - \eta_{trigg}$$

Correlations done in vertex-Z ,p_T trigger and multiplicity bins for proper corrections
+ look at mult dependence

Trigger and V0 candidate selection

Trigger particle selections	
At least one hit in ITS	Yes
Number of TPC crossed pad rows	> 70
$\|\eta\|$	< 0.8
$\|DCA_{xy}\|$	$< (0.004 + 0.013/p_{\mathrm{T}}(\mathrm{GeV}/c))$ cm

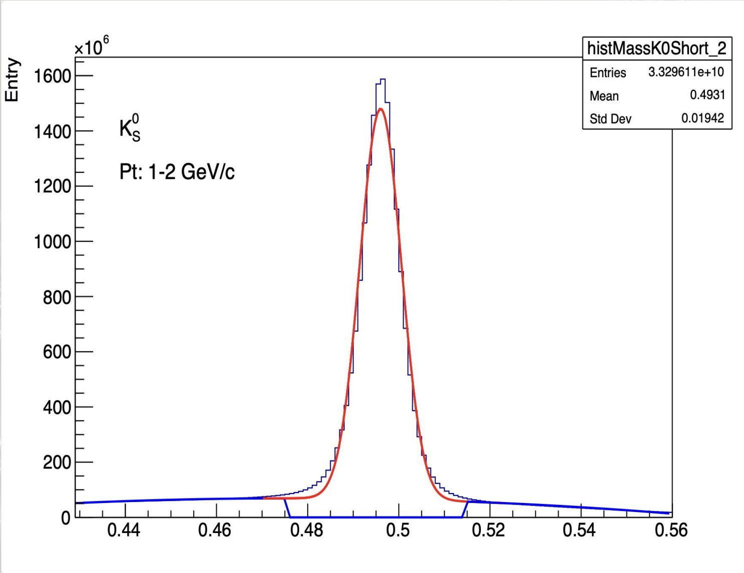
Table 1: Selections applied to identify trigger particles.

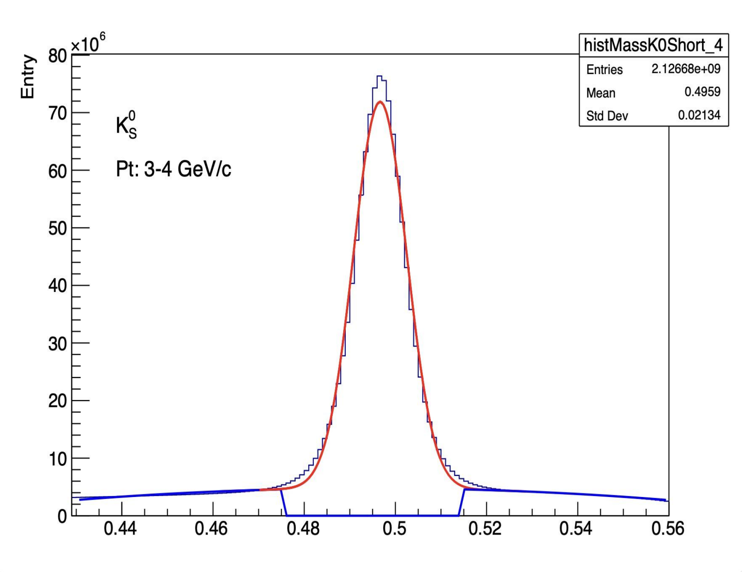


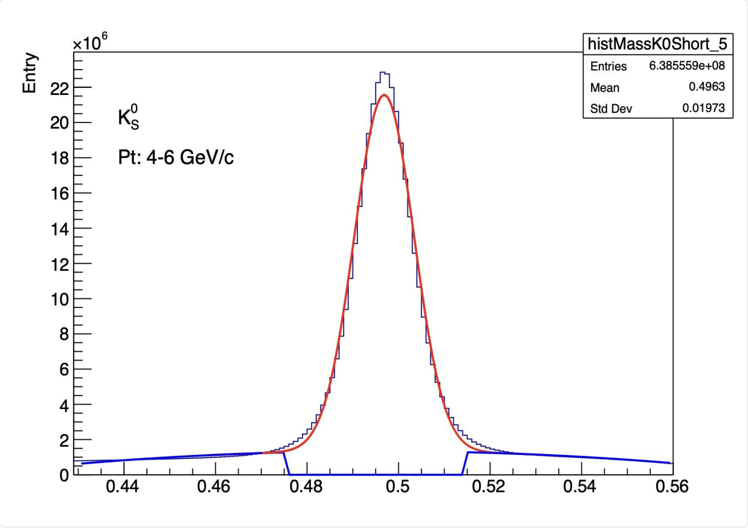
V^0 daughter tracks selections	
Number of TPC crossed pad rows	> 70
$\mathrm{d}E/\mathrm{d}x$ measured in the TPC	$< 4\sigma$ (< 20 in the MC)
Topological variables selections	
DCA daughters to primary vertex	> 0.1 cm
DCA between daughter tracks of the V^0	< 1 cm
$\cos(\theta_{\mathrm{P}})$	> 0.97(0.995)
V^0 decay radius r	$1.5 < r < 200$ cm
V^0 candidates selections	
$\|\eta_{V^0}\|$	< 0.8

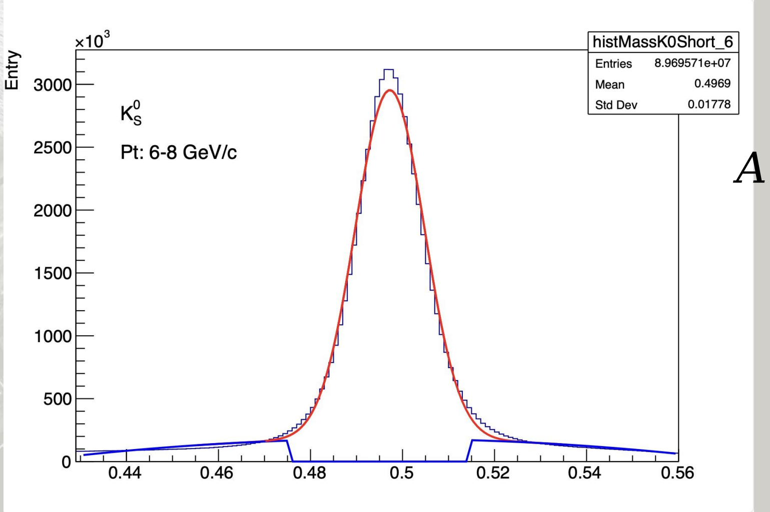
Table 2: Selections applied to identify $\mathrm{K}^0_{\mathrm{S}}$ (Λ) among the reconstructed V^0 candidates.

Invariant mass distributions of K_S^0









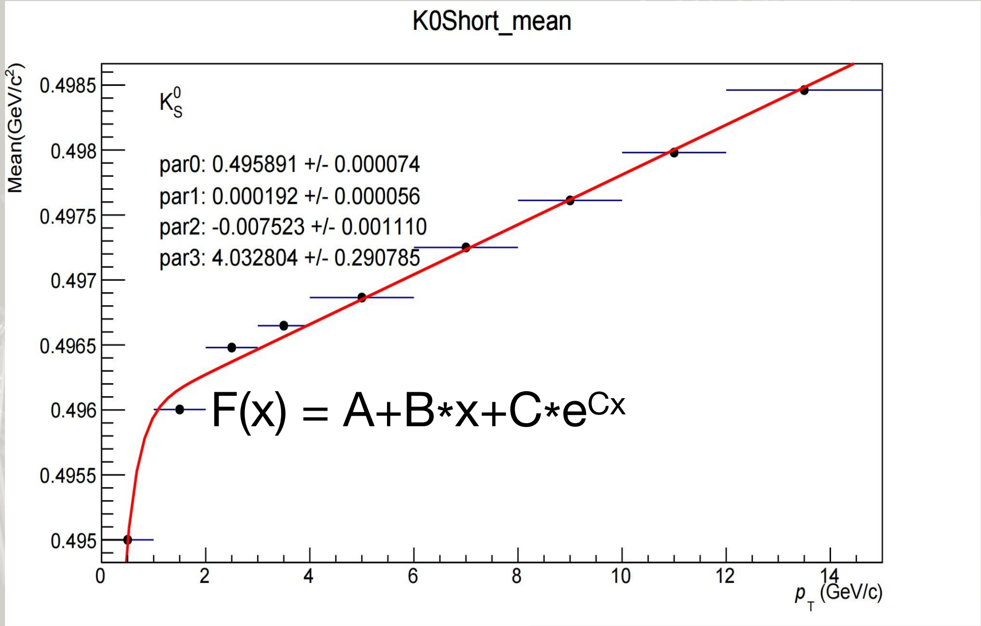
Background Fit:

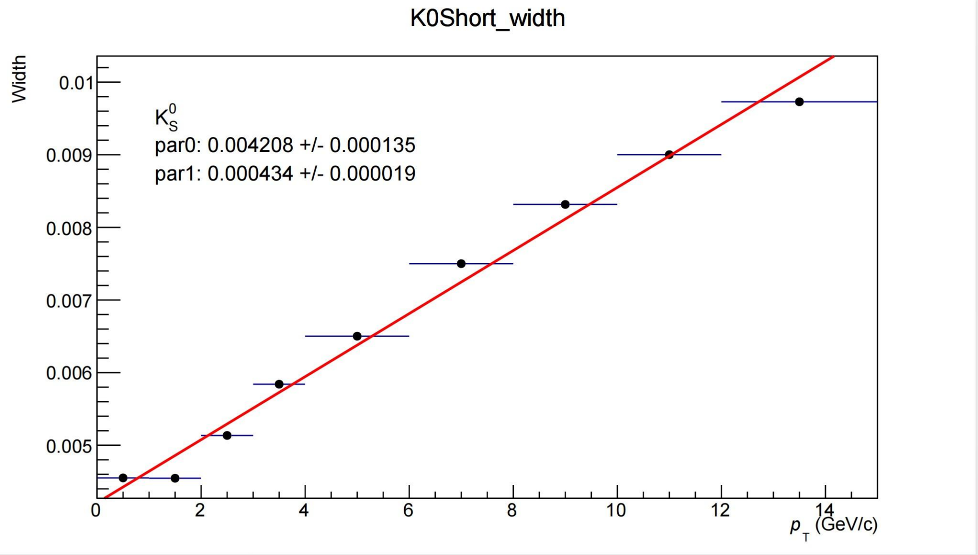
$A + B * x + C * x\text{^}2$

Signal Fit:

$A + B * x + C * x\text{^}2 \; + \; gaussian$

Parametrization for the mean and width of V0 mass distribution

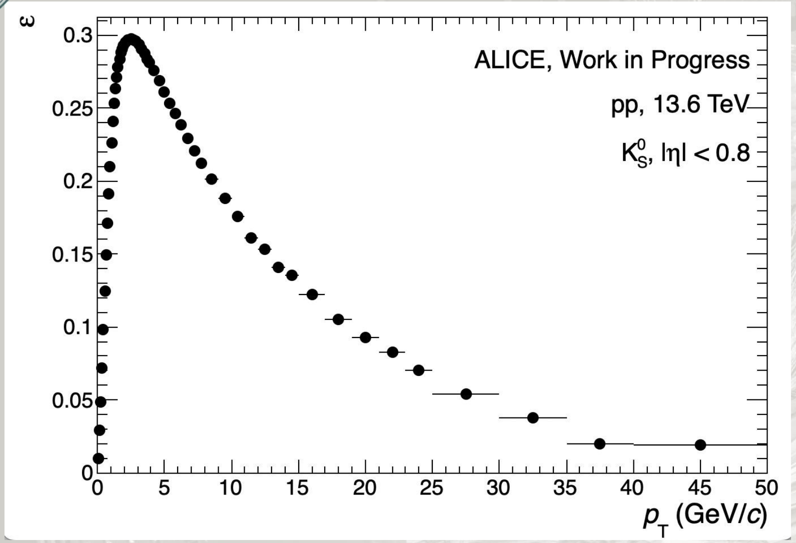


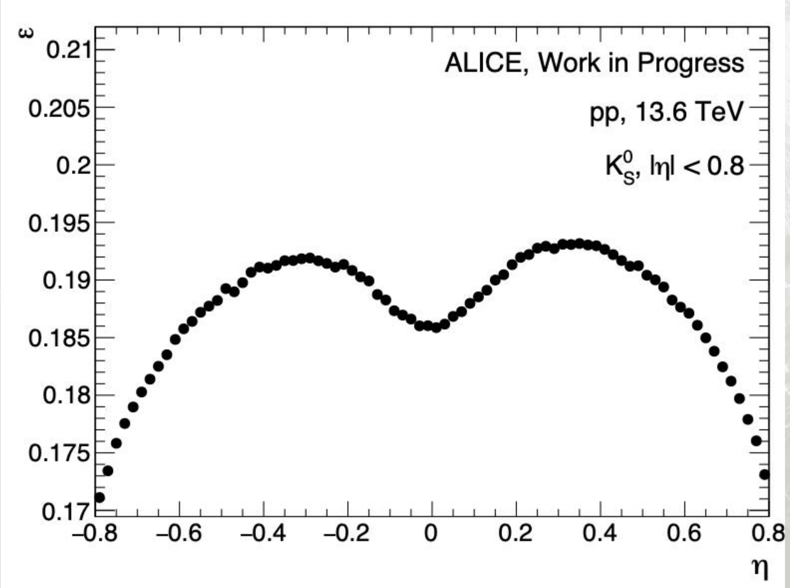


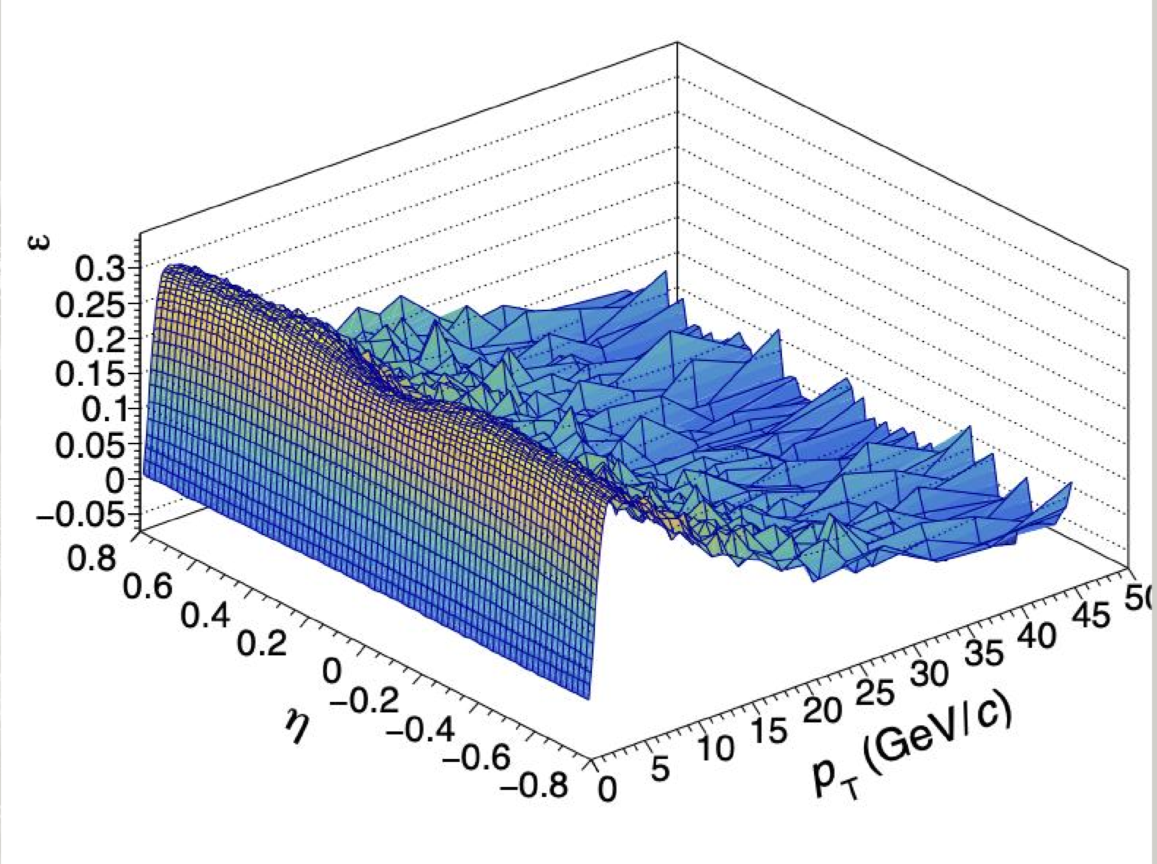
- Necessary as input to the correlation function studies

- Divide the invariant mass region into three parts:
  LeftBg region : [-10σ, -5σ]
  Signal region : [-5σ, 5σ]
  RightBg region : [5σ, 10σ]

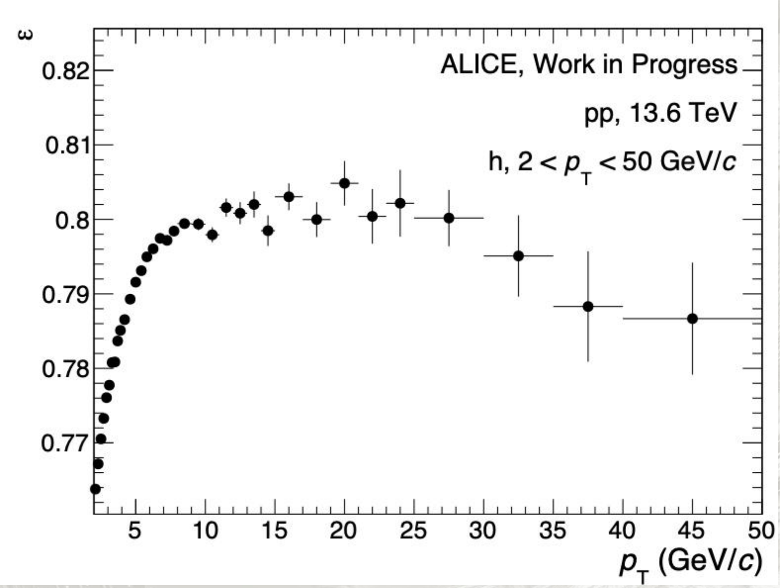
K_S^0 reconstruction efficiency

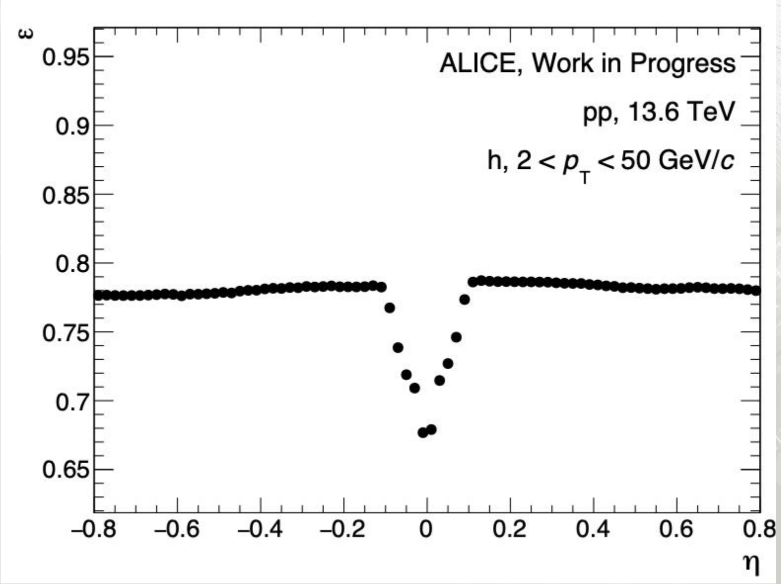


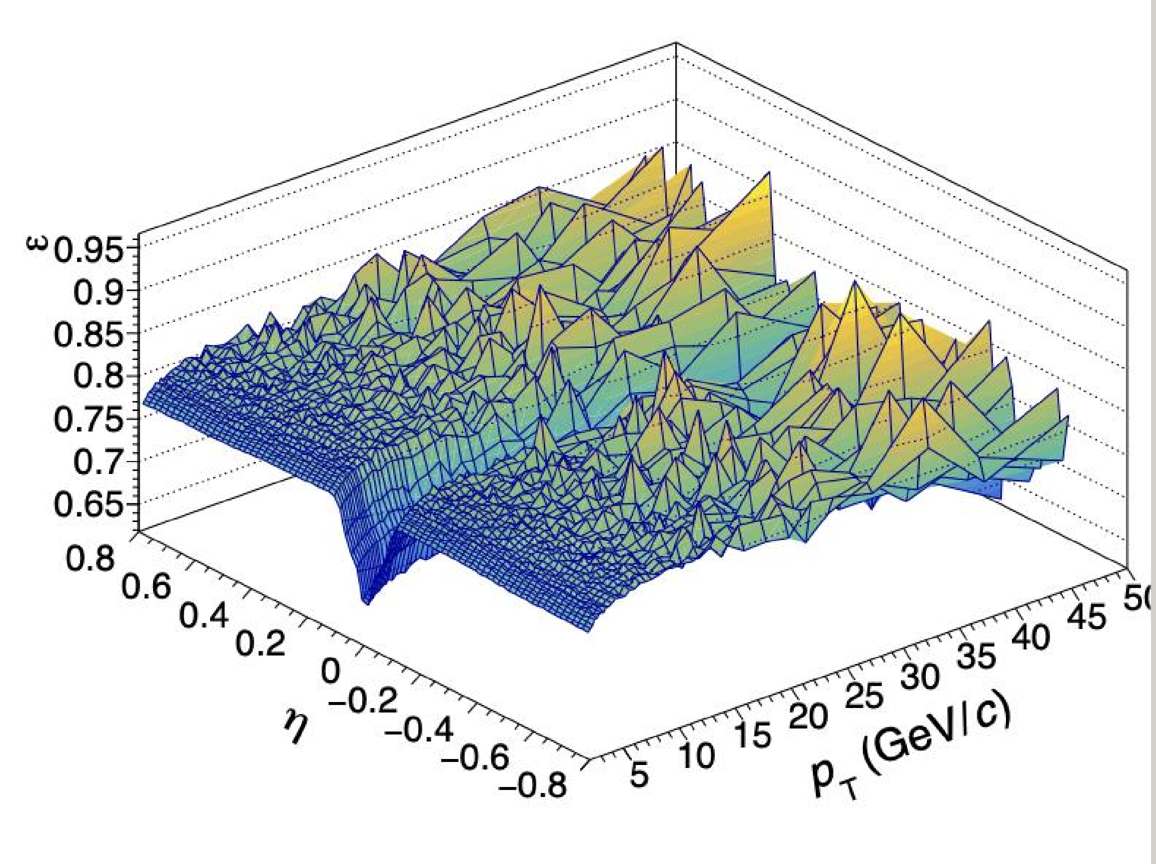




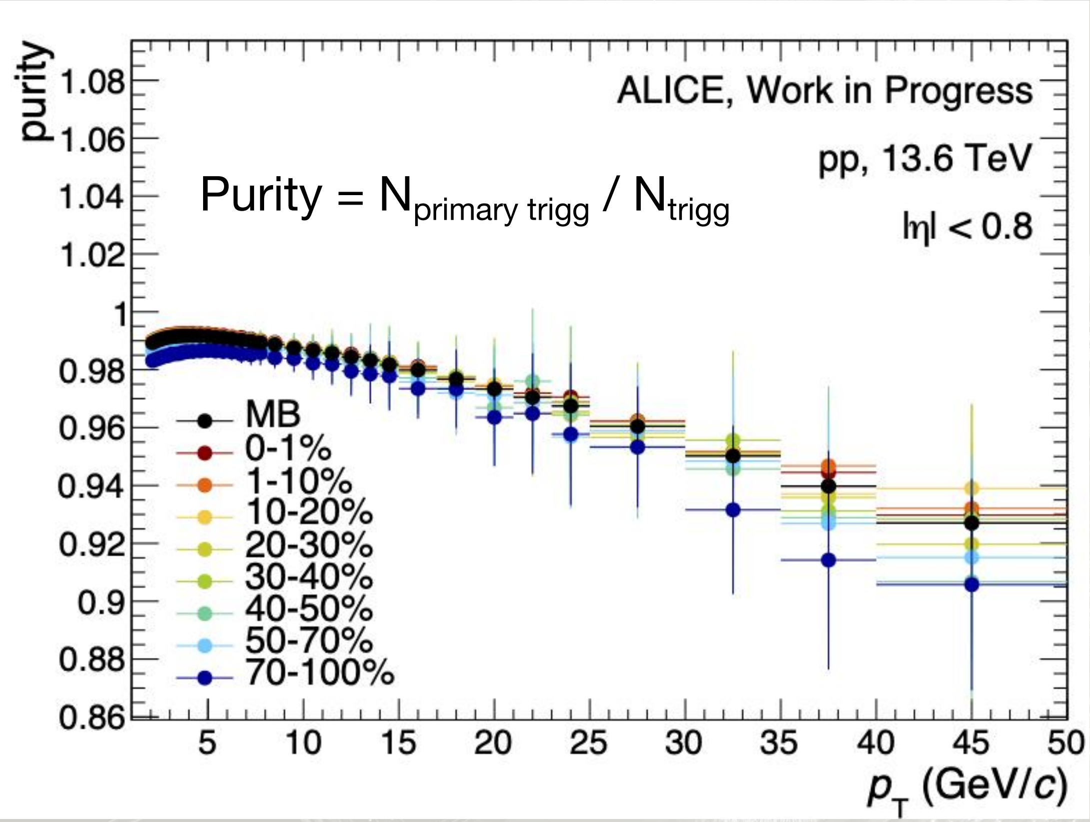
Trigger particle efficiency

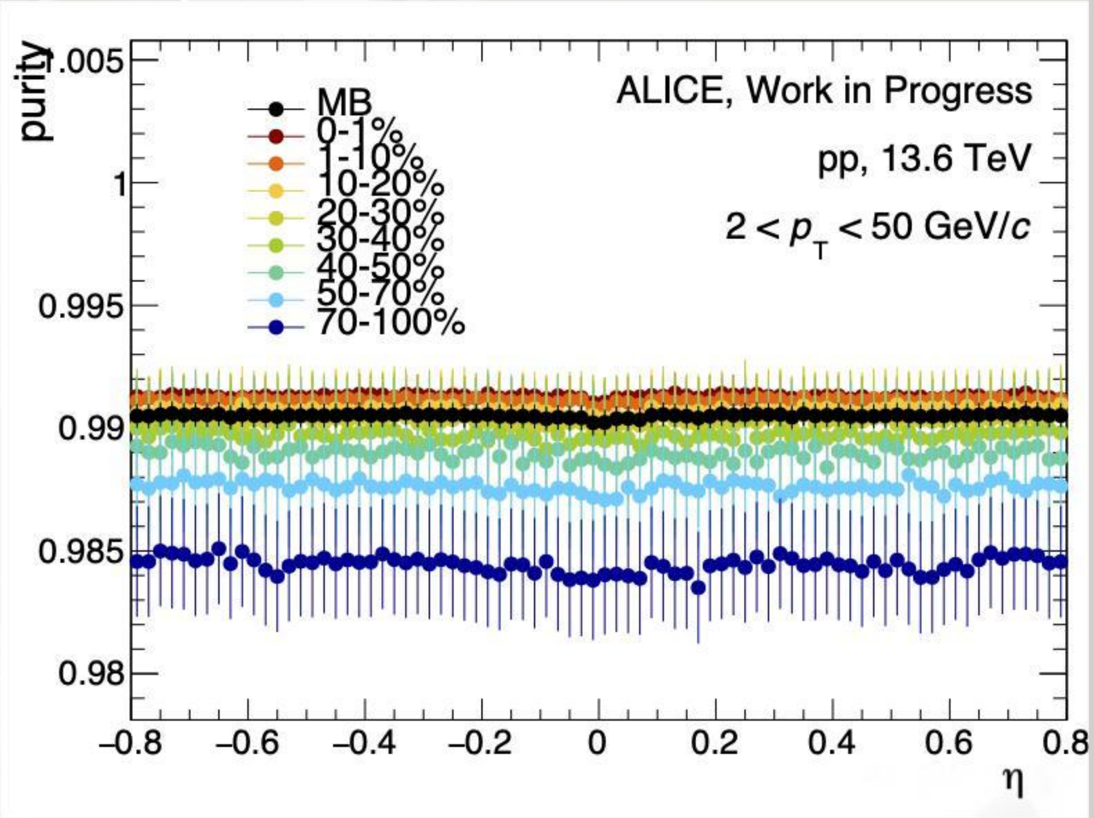






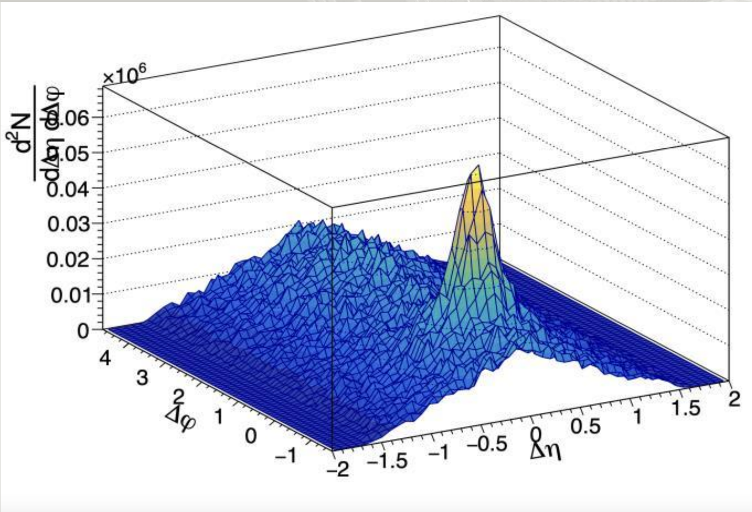
Trigger particle purity





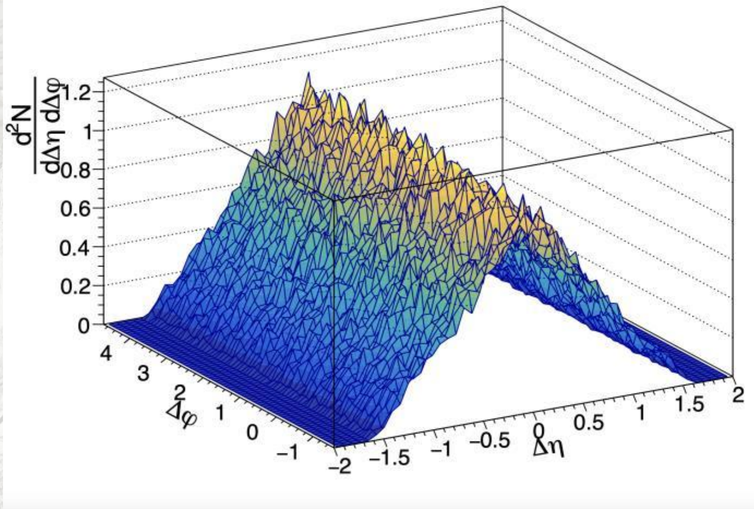
- Below 15 GeV/c purity higher than 98%
- Up to 50 GeV/c purity higher than 90%
- Small dependence on multiplicity – within 1%
- No dependence on eta

Mixed event correction



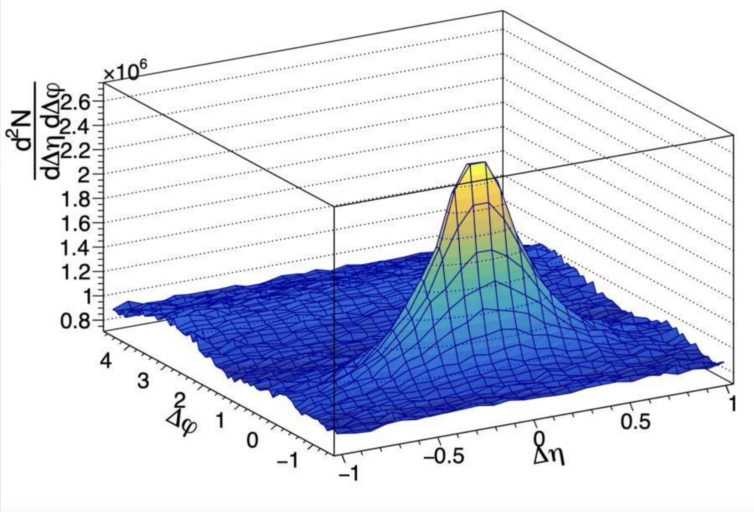
Same-event correlation

÷



Mixed-event correlation

=

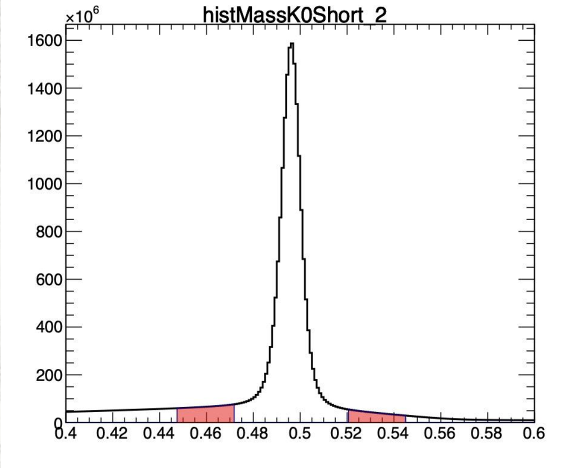


Acceptance-corrected function

$$C(\Delta\eta,\Delta\varphi) = \alpha\frac{C_{SE}(\Delta\eta,\Delta\varphi)}{C_{ME}(\Delta\eta,\Delta\varphi)}$$

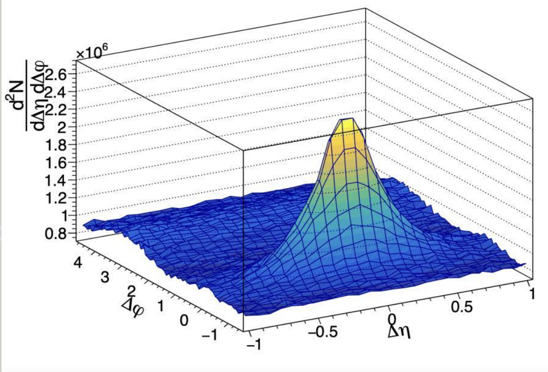
- C: corrected correlation function
- C_{SE}: same-event correlation function
- C_{ME}: mixed-event correlation function
- α: factor such that $C_{ME}(0,0) = 1$

Background subtraction



Current definition:

-10σ < left < -5σ < signal < +5σ < right < +10σ



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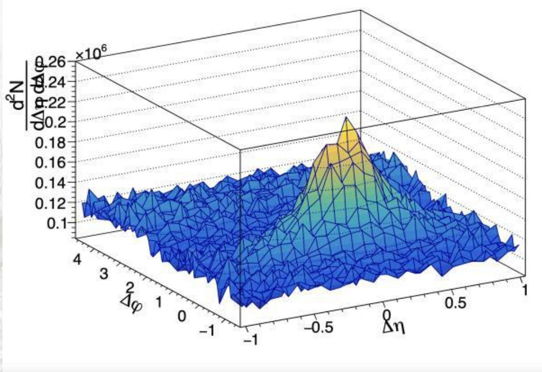

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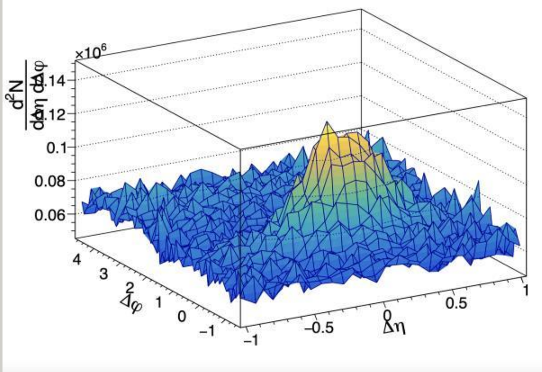
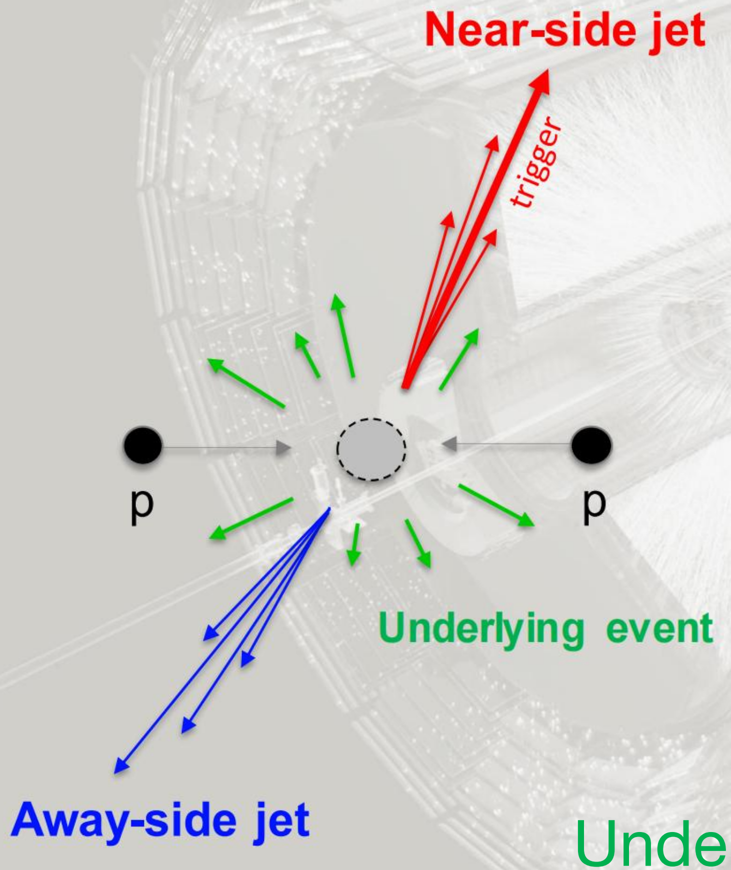
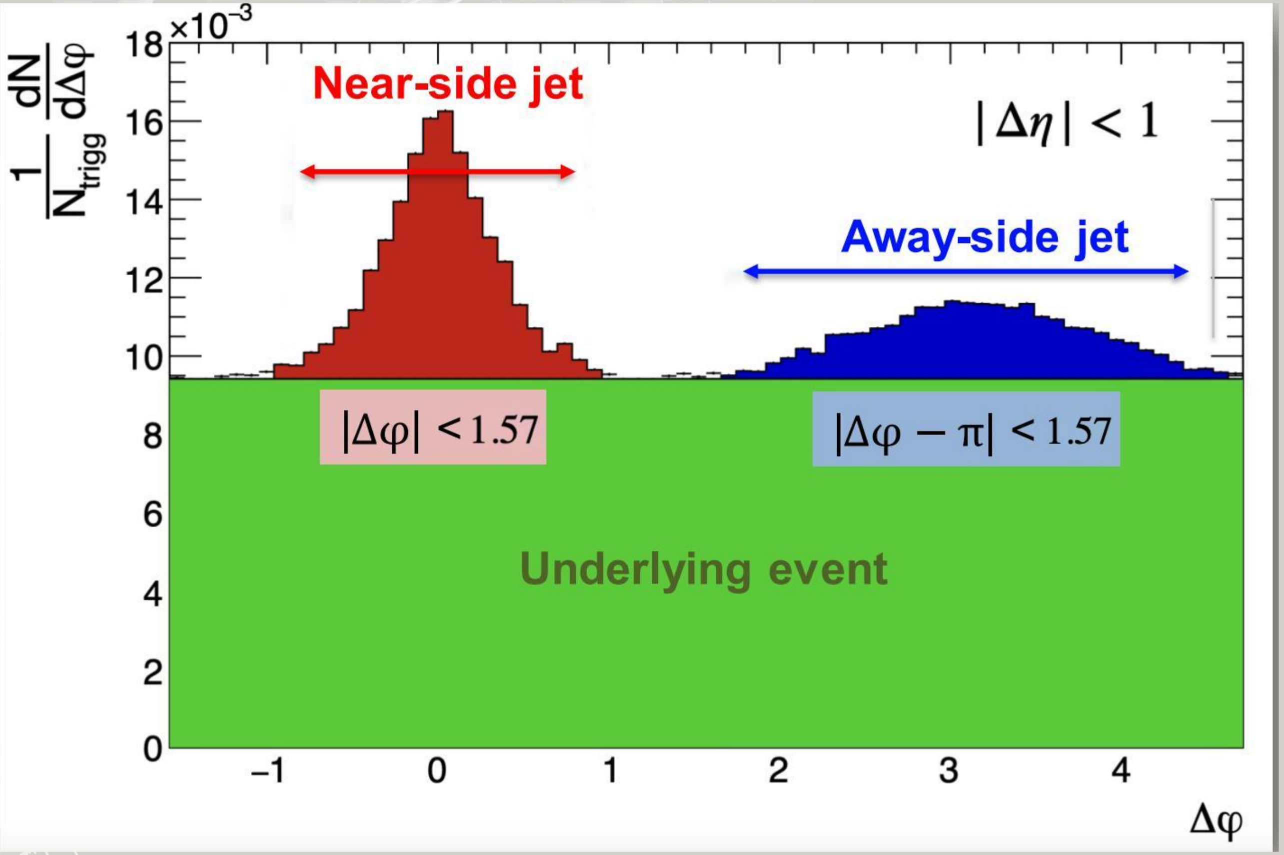


Signal region

Left and right background regions

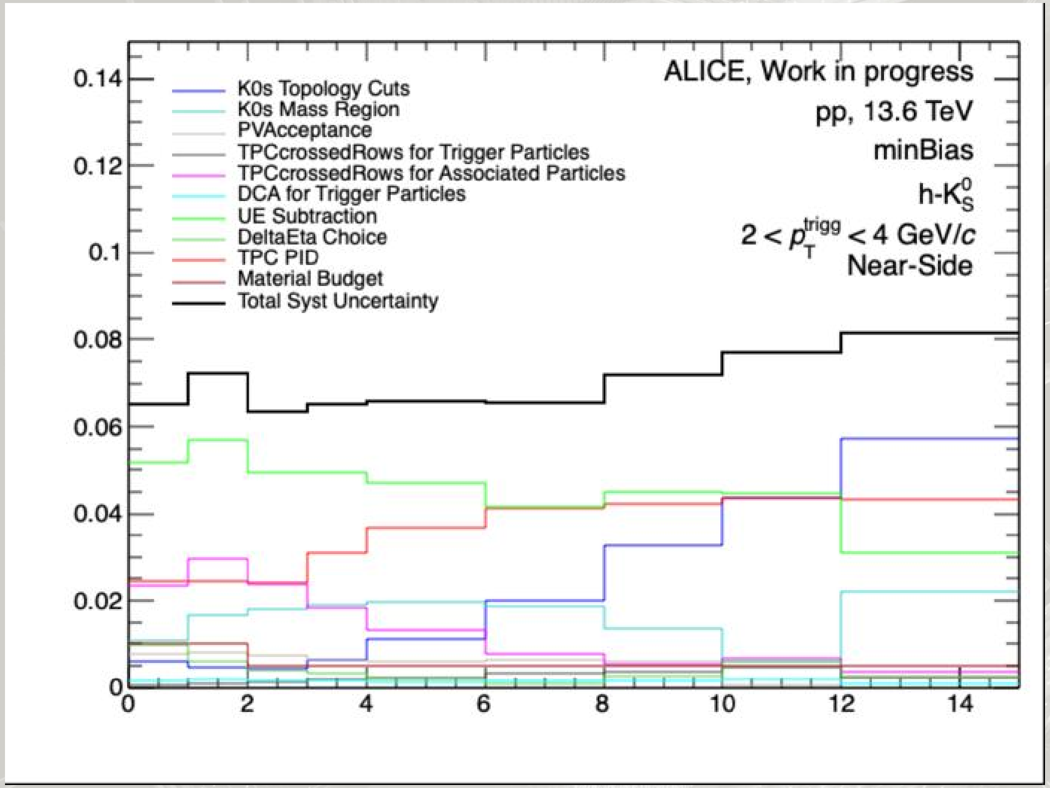
Near-side, away-side and underlying event yield extraction

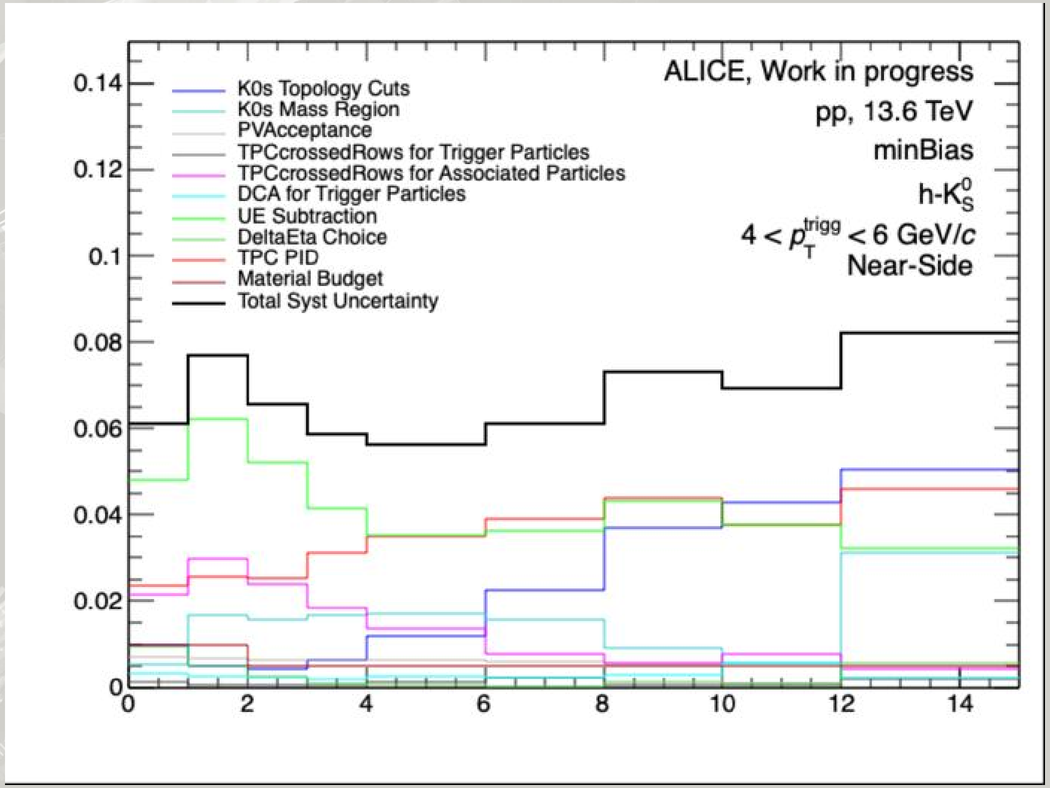




Underlying event *estimated by ZYAM* (zero yield at minimum)

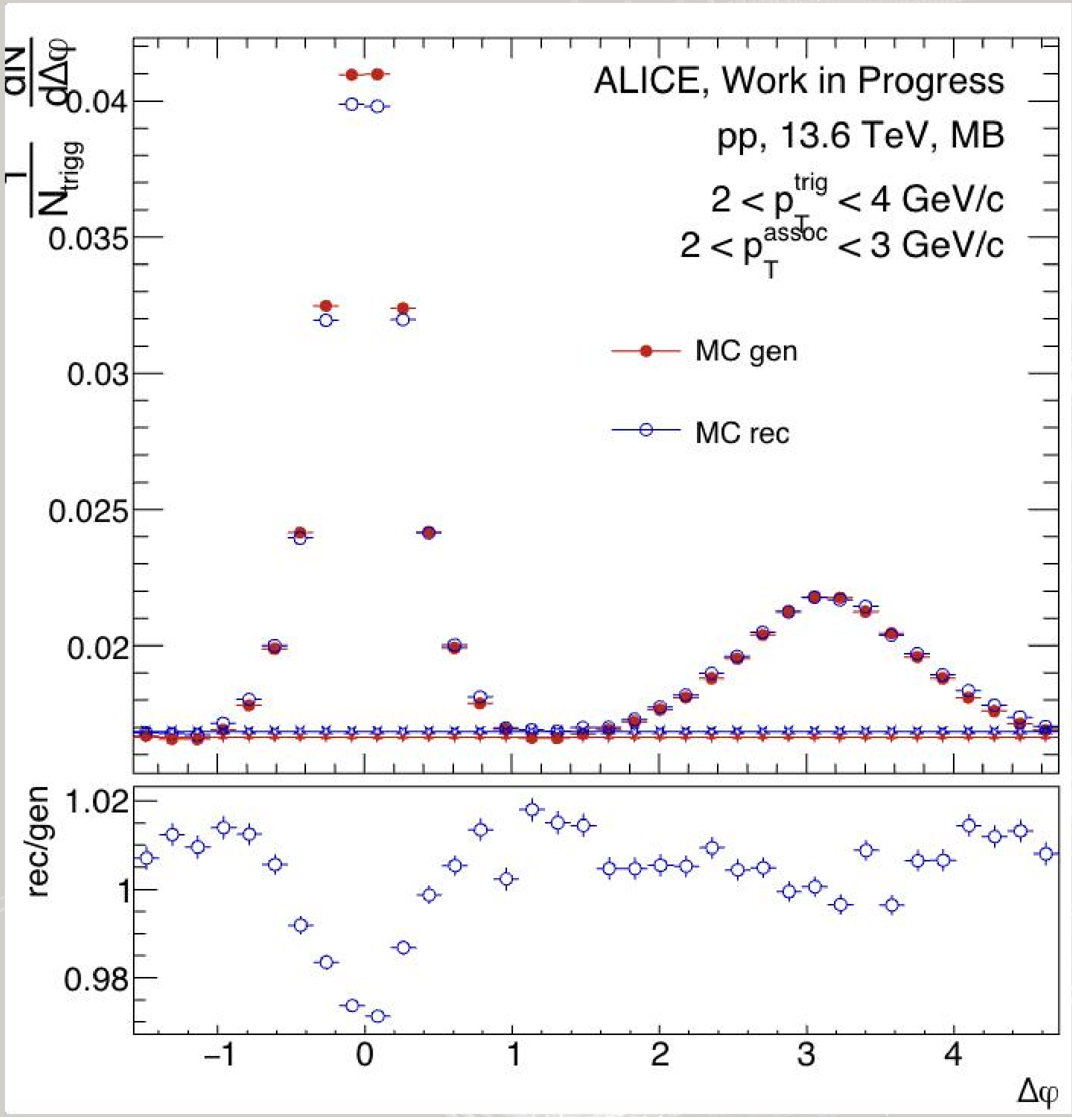
Systematic uncertainties (MB)

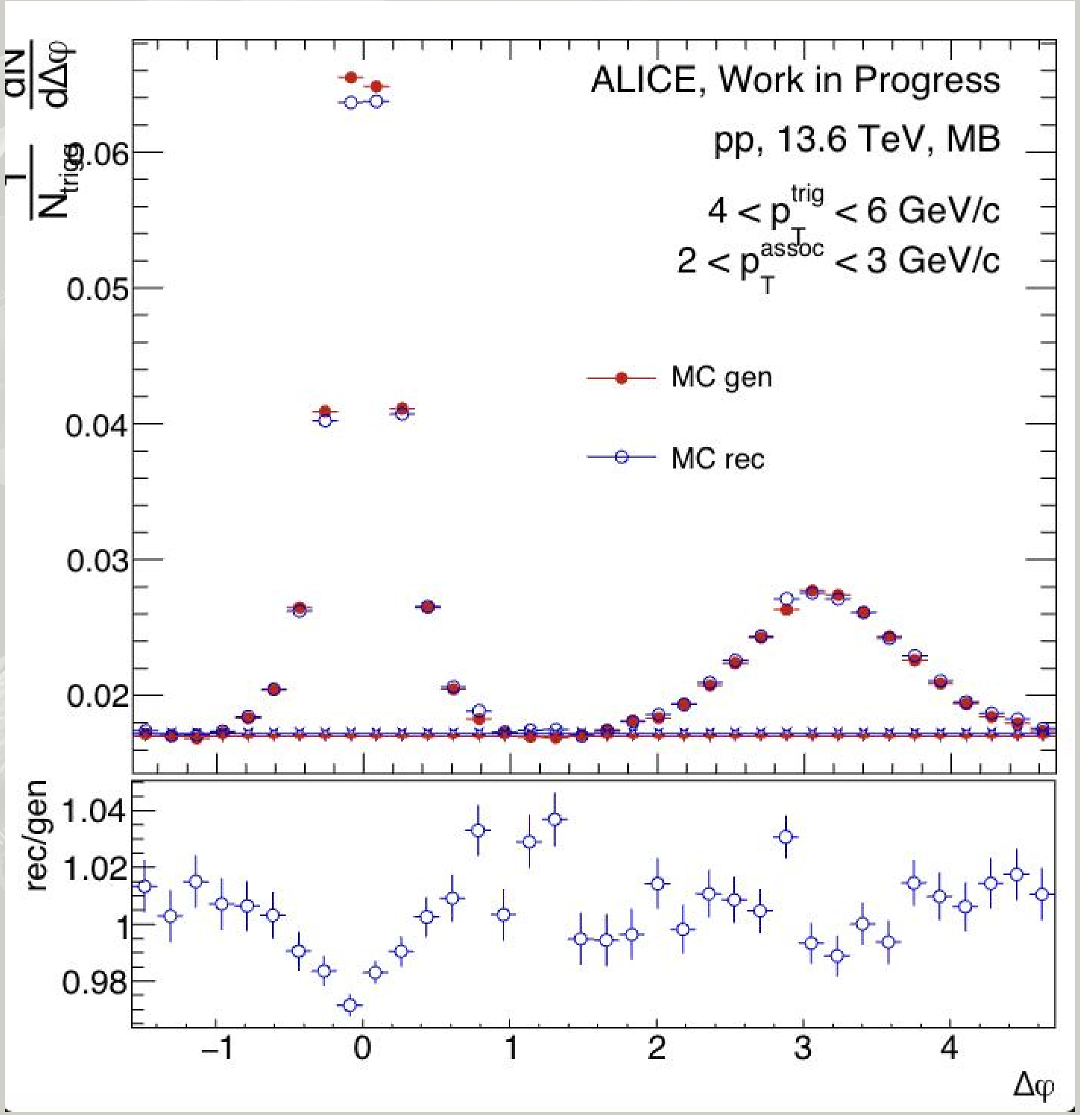




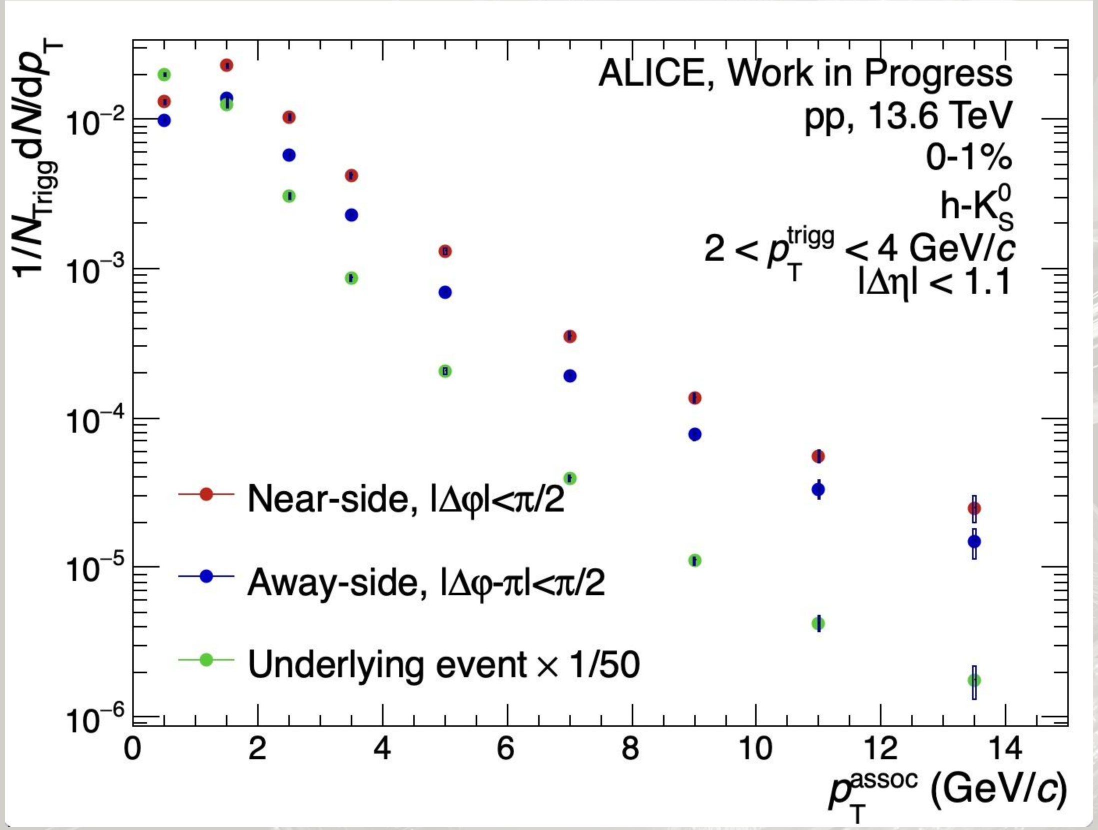
- Dominant sources : UE Subtraction & TPC PID & topological selections
- There is no significant dependence on pt,trigg and multiplicity

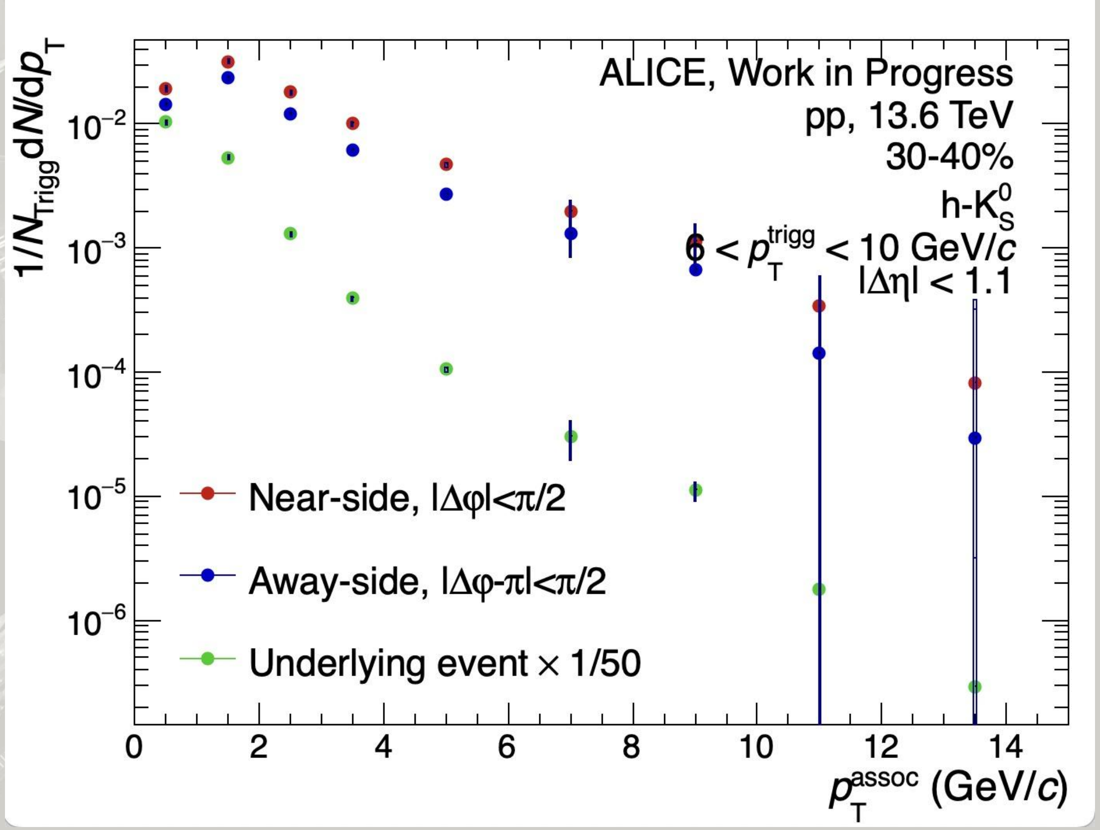
MC closure test





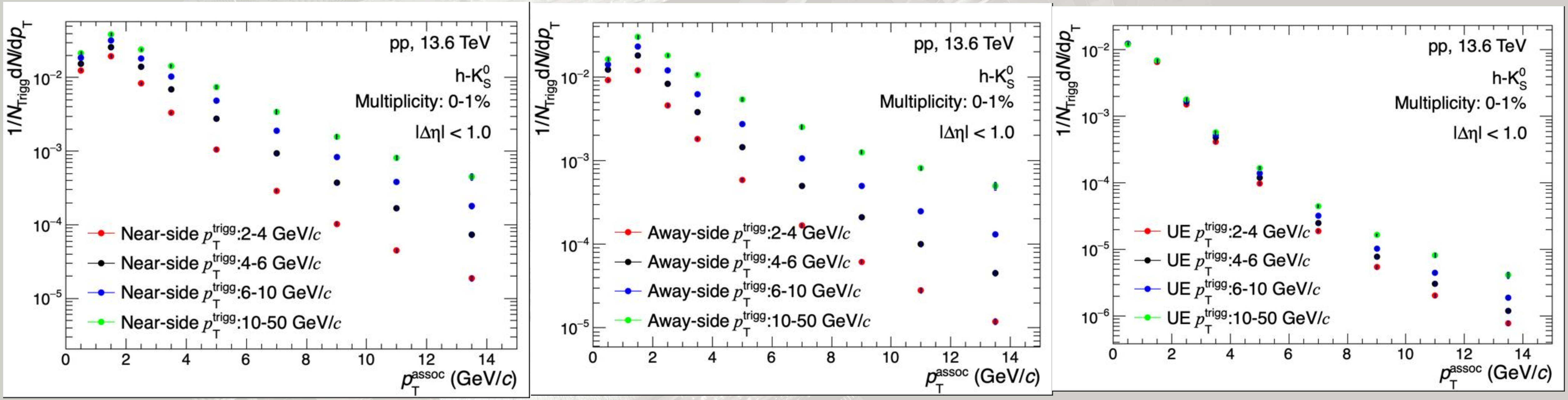
Corrected near-side, away-side and underlying event spectra





- The near-side and away-side spectra are **harder** than the underlying event ones, in all multiplicity classes and pt,trigg intervals

Corrected spectra as a function of the trigger particle momentum

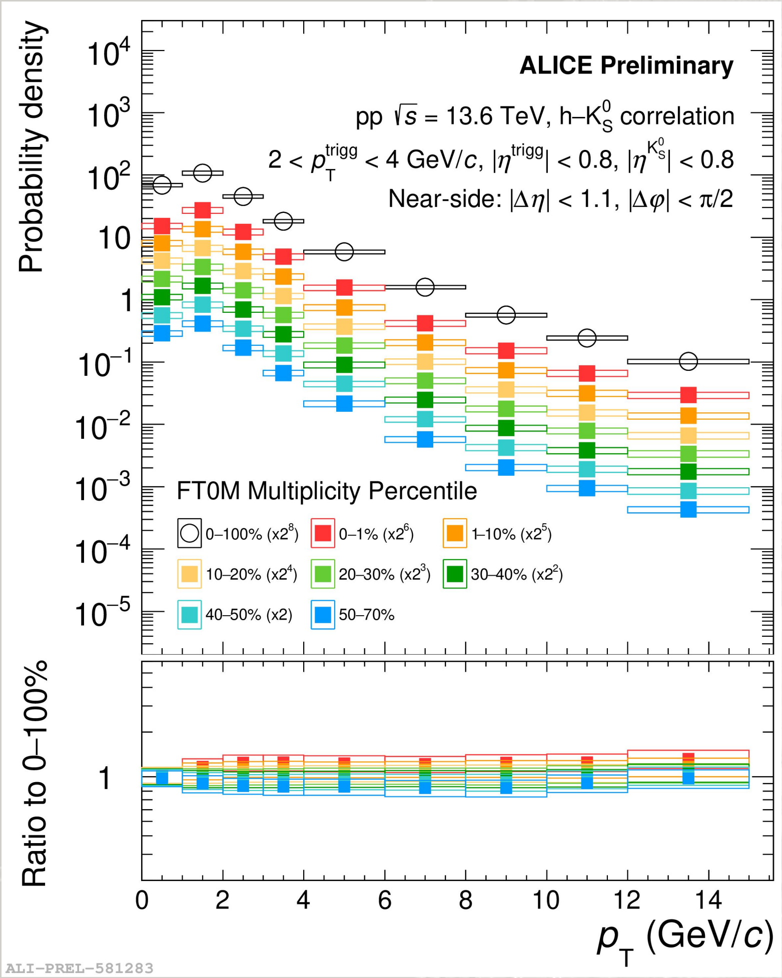


- For **NS and AS spectra**, the yields increase and the spectra become **harder with increasing pt,trigg**
- Little to no pt,trigg dependence for the **UE** spectra – as expected

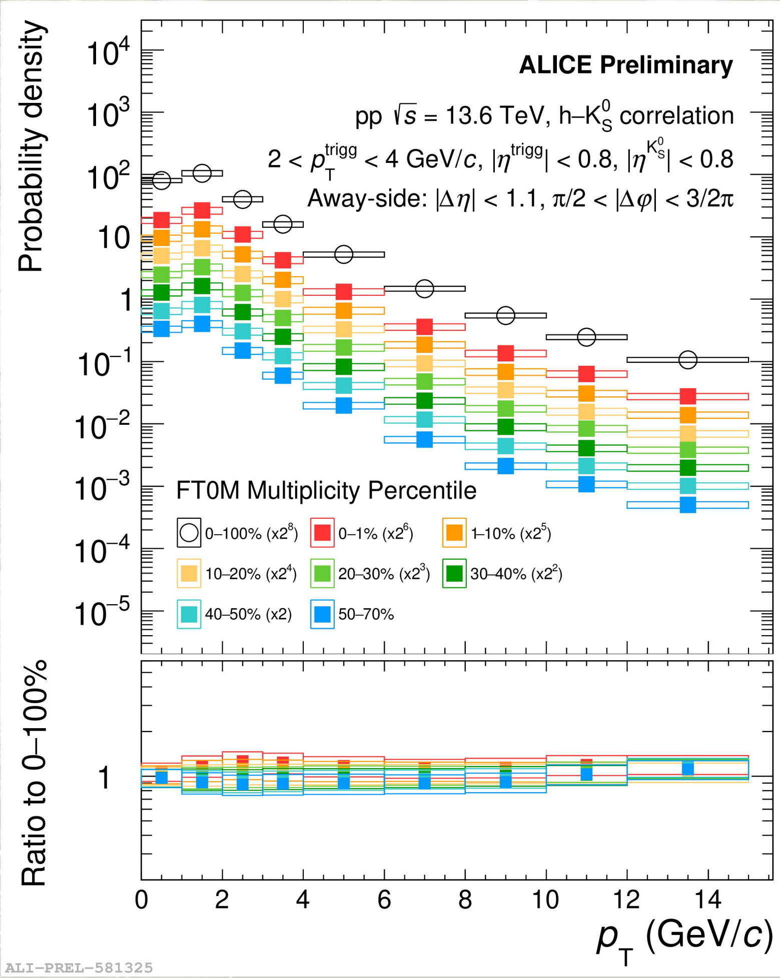
Corrected yields – Multiplicity dependence

$2 < p_{T,trigg} < 4$ GeV/c

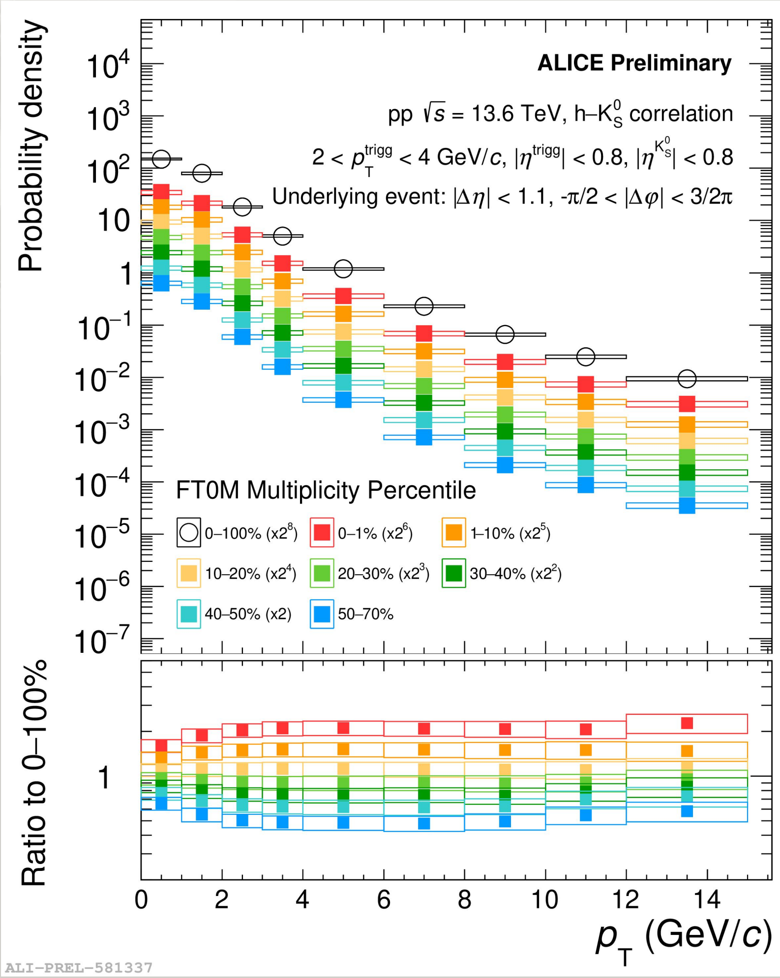
Near-side



Away-side



UE

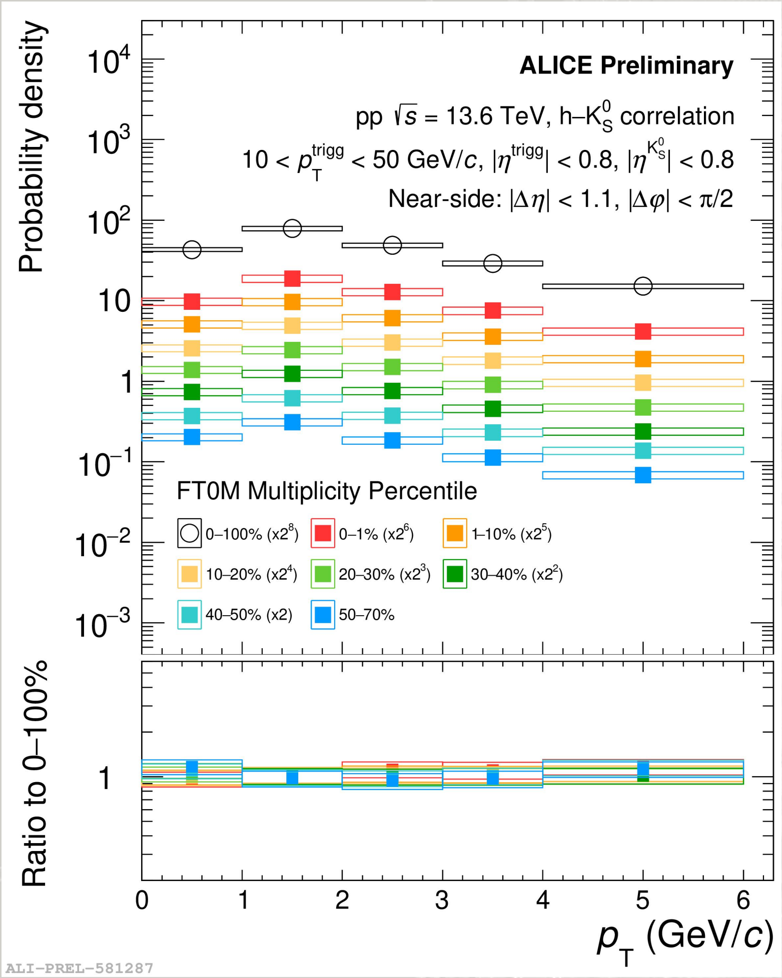


- The **UE spectra** show a **larger dependence on the multiplicity** than the NS and AS spectra

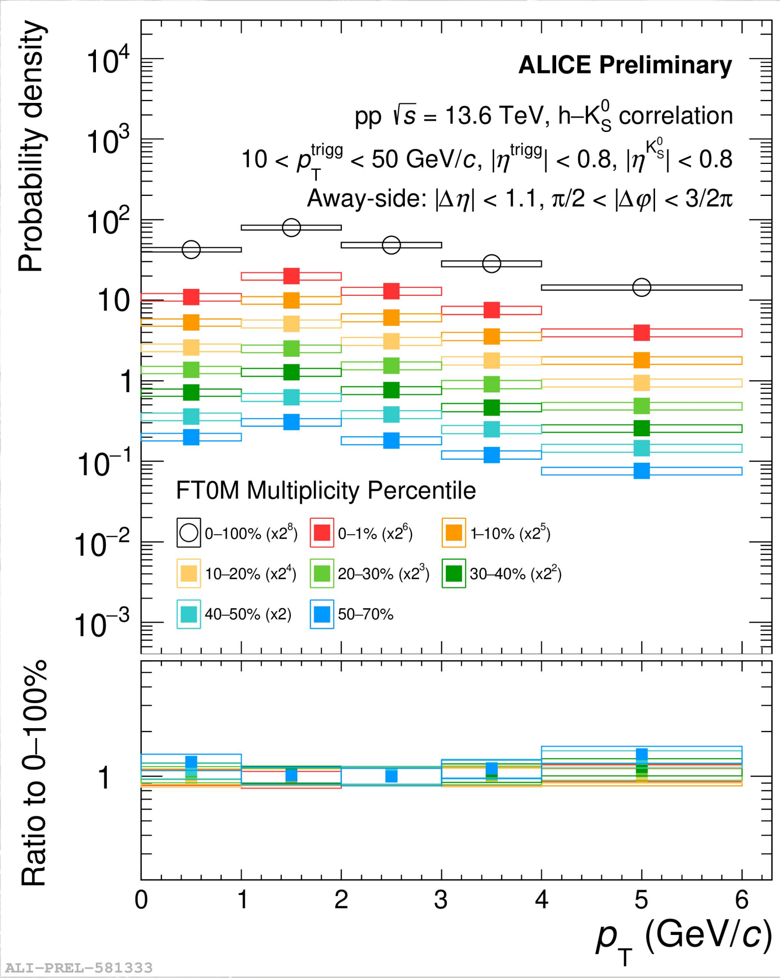
Corrected yields – Multiplicity dependence

$10 < p_{T,trigg} < 50$ GeV/c

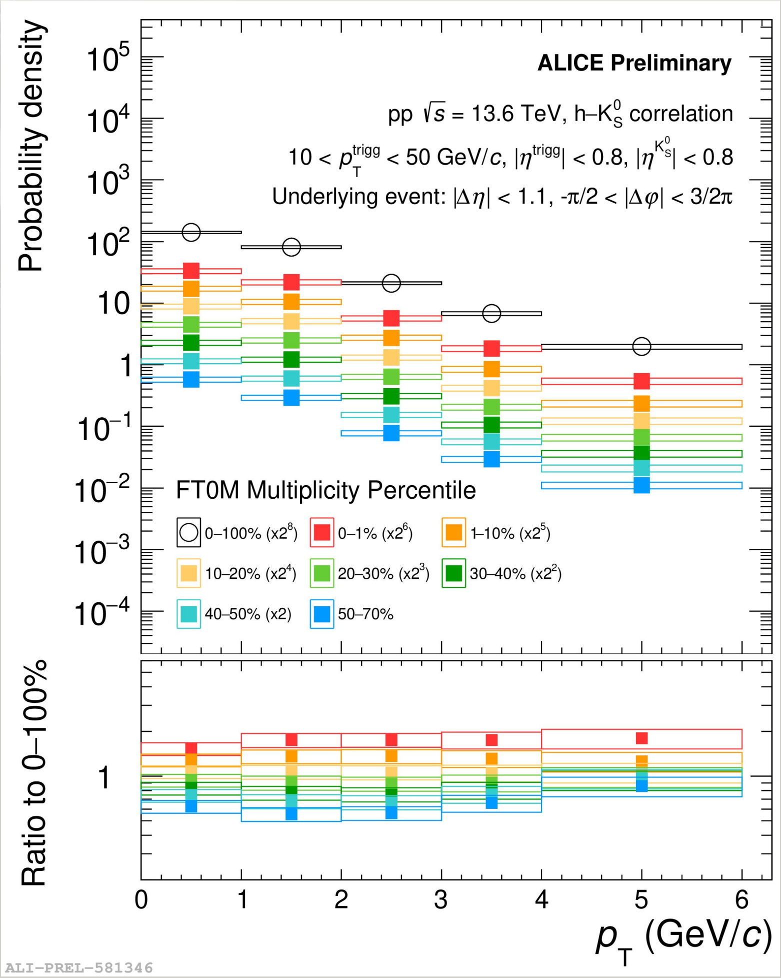
Near-side



Away-side

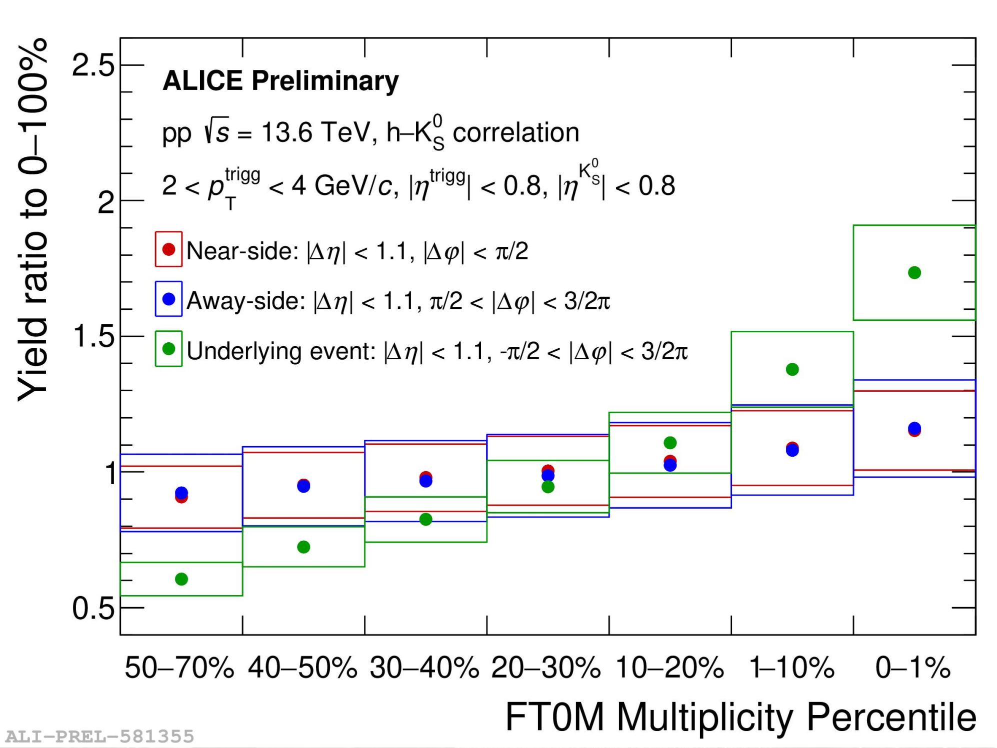


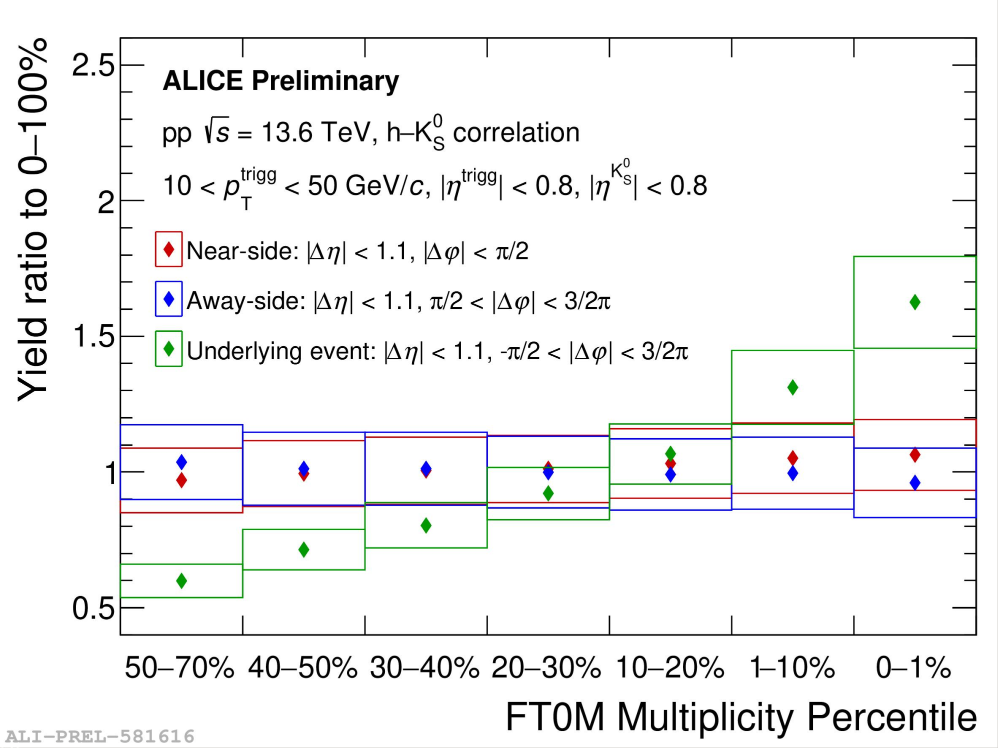
UE



- The multiplicity dependence of NS and AS spectra becomes smaller with increasing pt,trigg

Corrected yields vs multiplicity





- Underlying event yields increase with multiplicity
- Near-side and Away-side yields show slight dependence on multiplicity

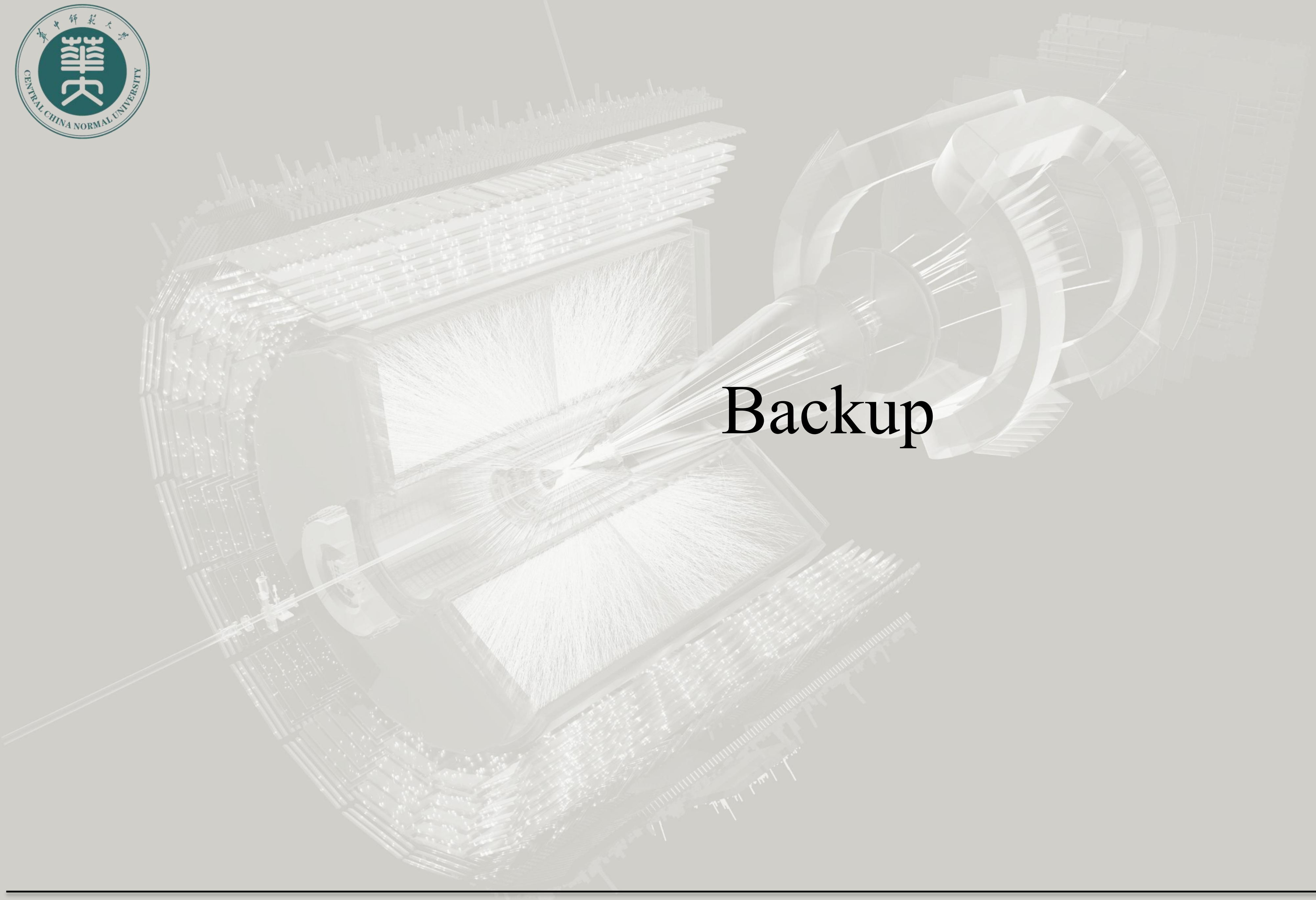
Summary

- Parameteraction for strangeness particles mass

- Corretions
  - Detector acceptance correction
  - Single particle efficiency
  - Background subtraction

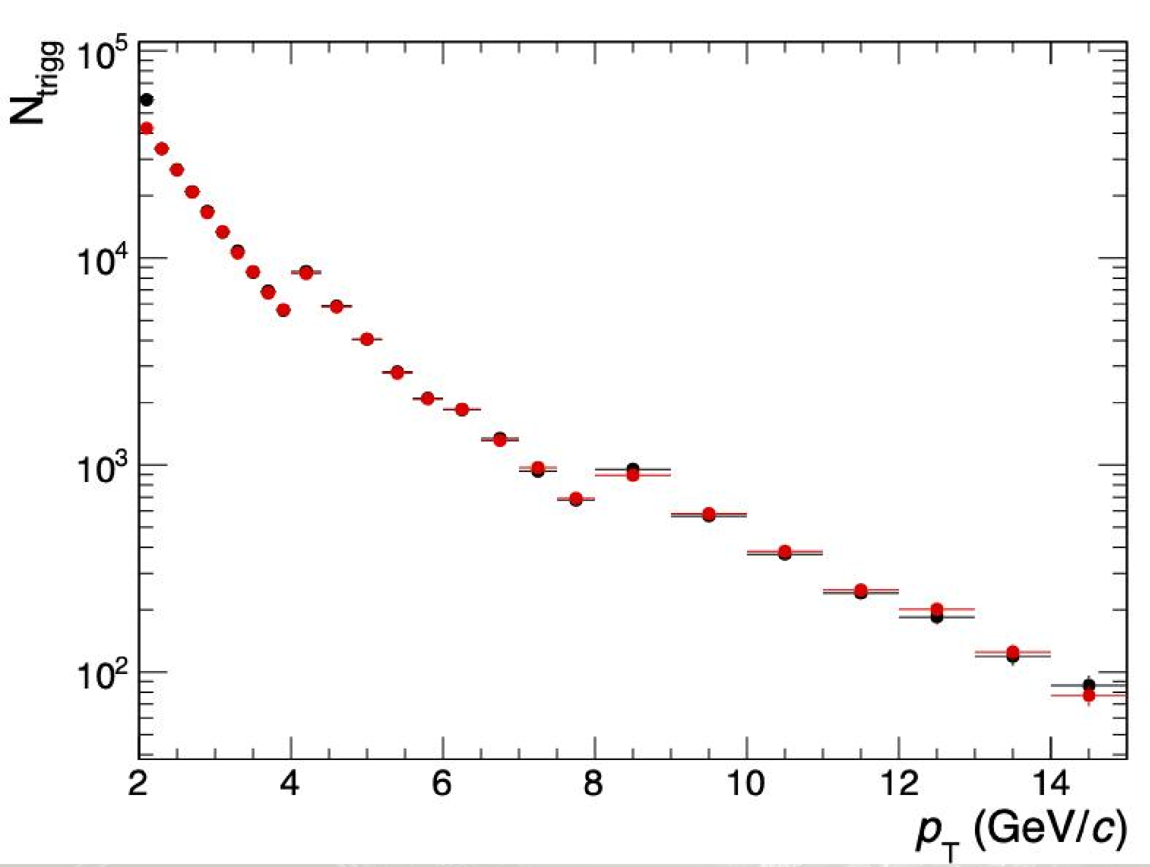
- Preliminary results
  - The Underlying event spectra show a larger dependence on the multiplicity than the Near-side and Away-side spectra
  - The multiplicity dependence of the Near-side and Away-side spectra becomes weaker with increasing $p_{\mathrm{T}}^{\mathrm{trigg}}$ while Underlying event spectra does not depend on $p_{\mathrm{T}}^{\mathrm{trigg}}$

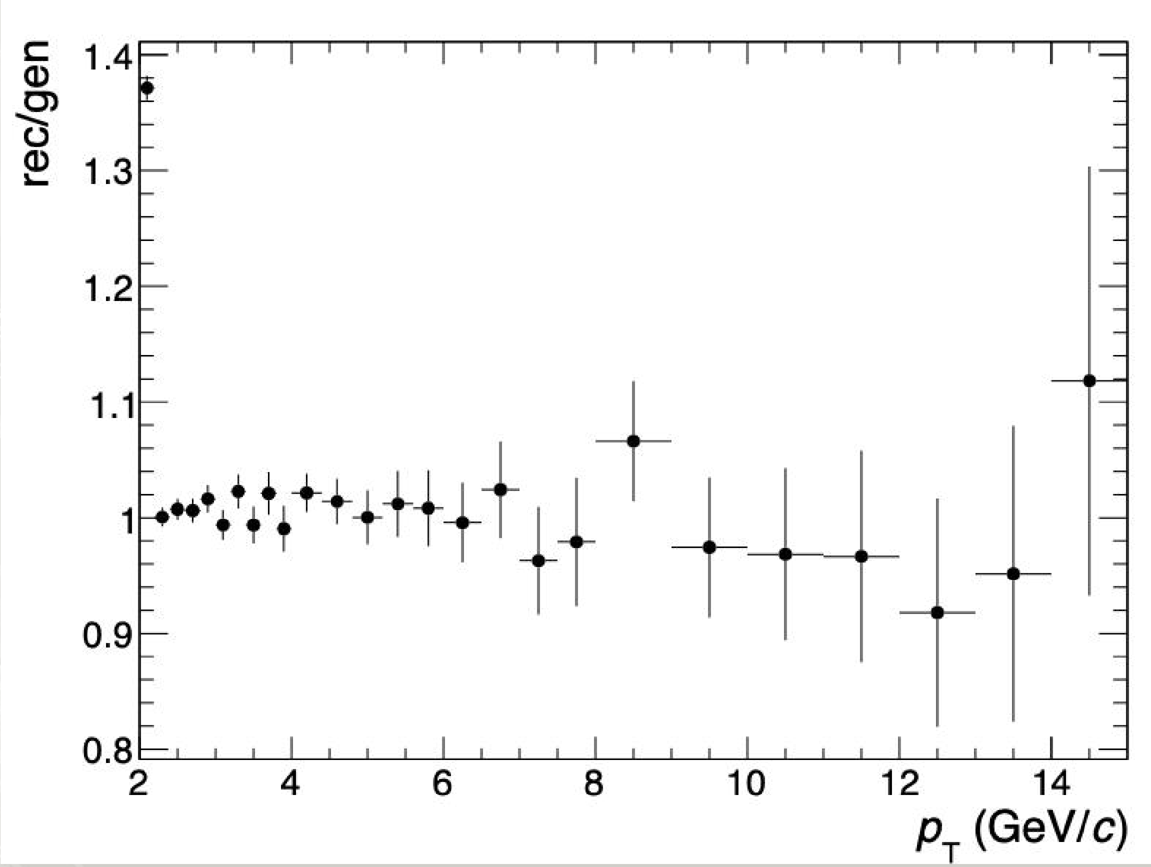
Thank You !



Backup

MC closure test: trigger particles versus momentum

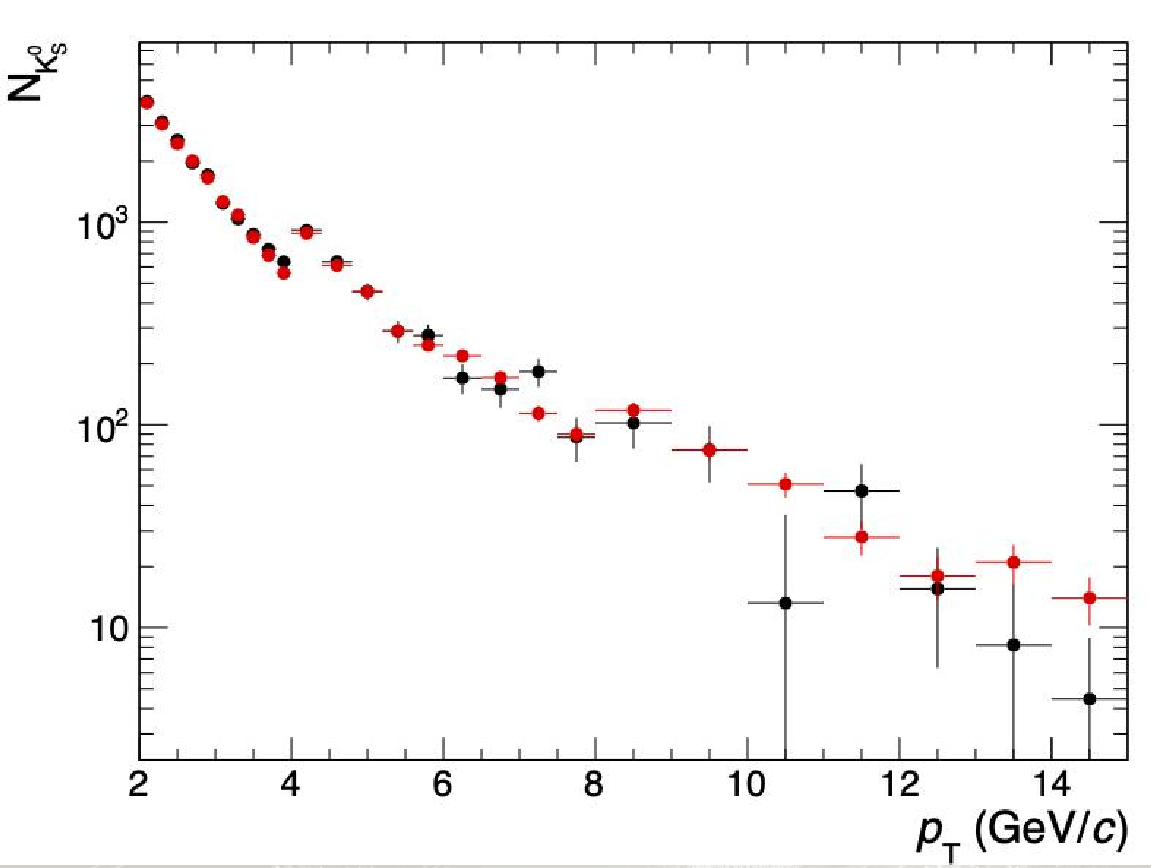


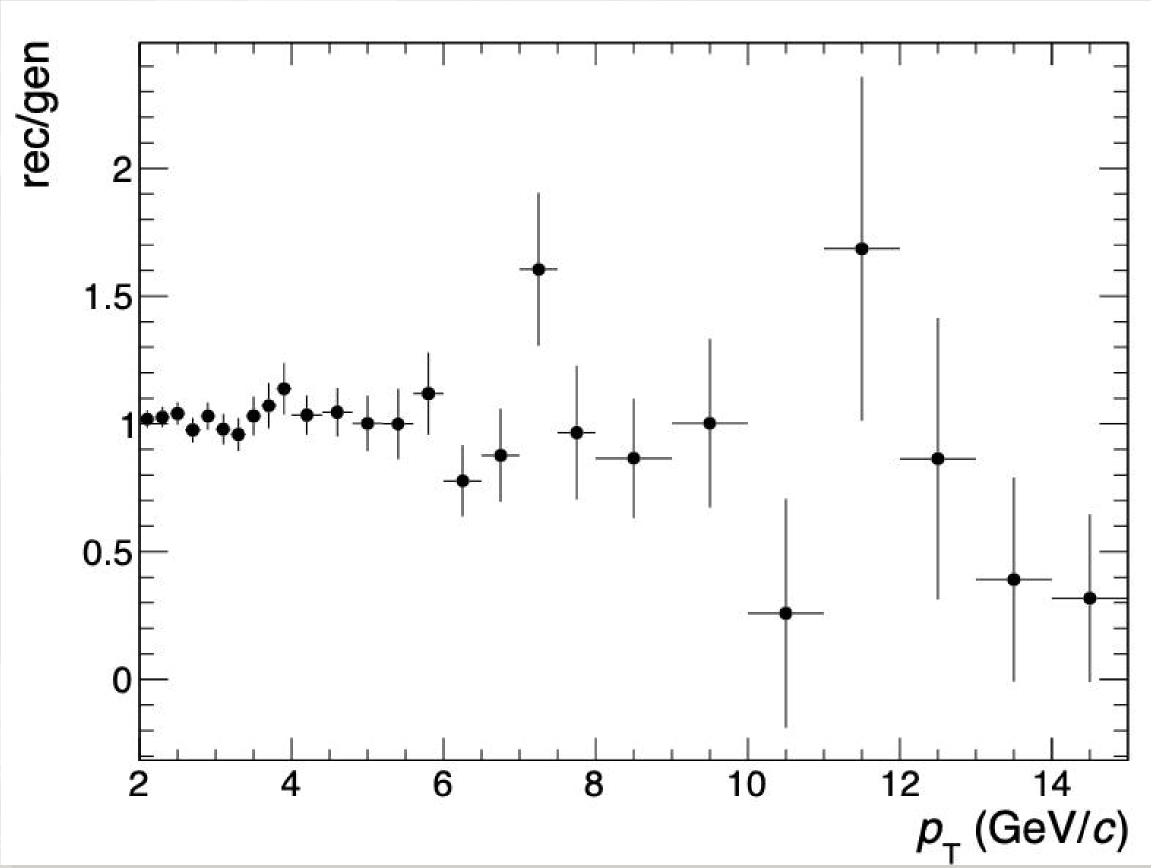


Data like scenario

Done locally on 5 files
Hyperloop tests onogoing

MC closure test: associated particles vs momentum

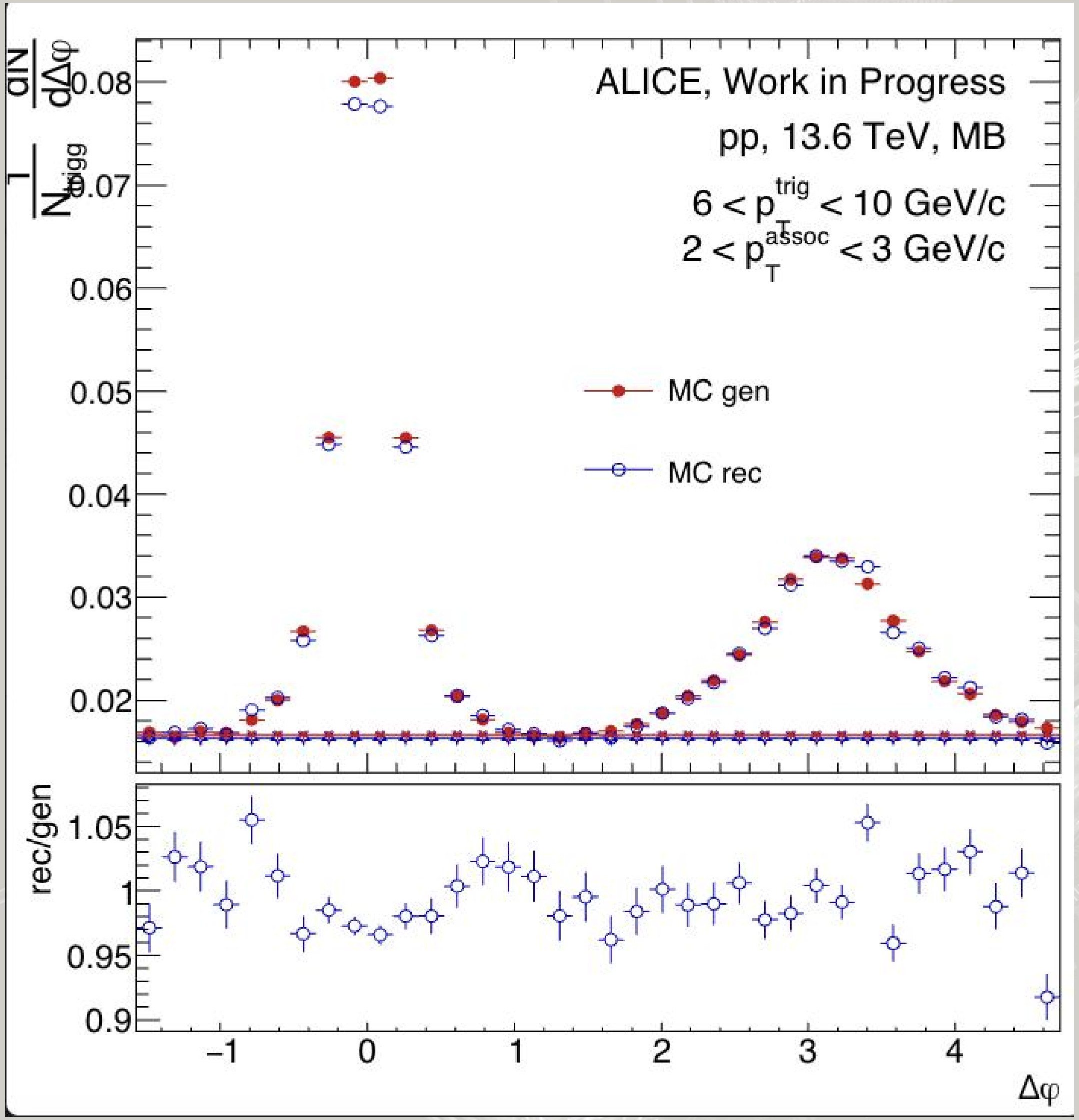


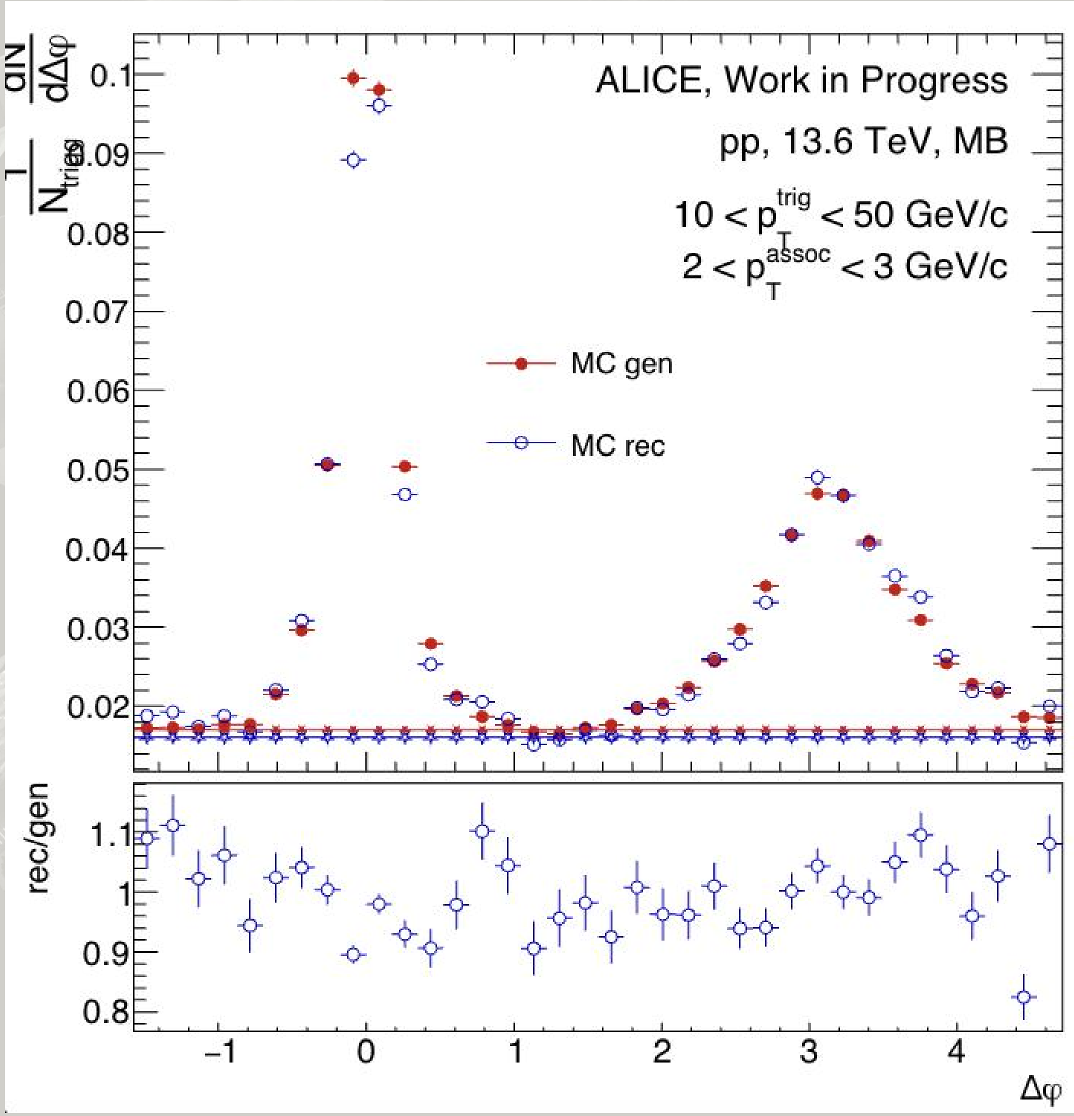


Data like scenario

Done locally on 5 files
Hyperloop tests onogoing

MC closure test

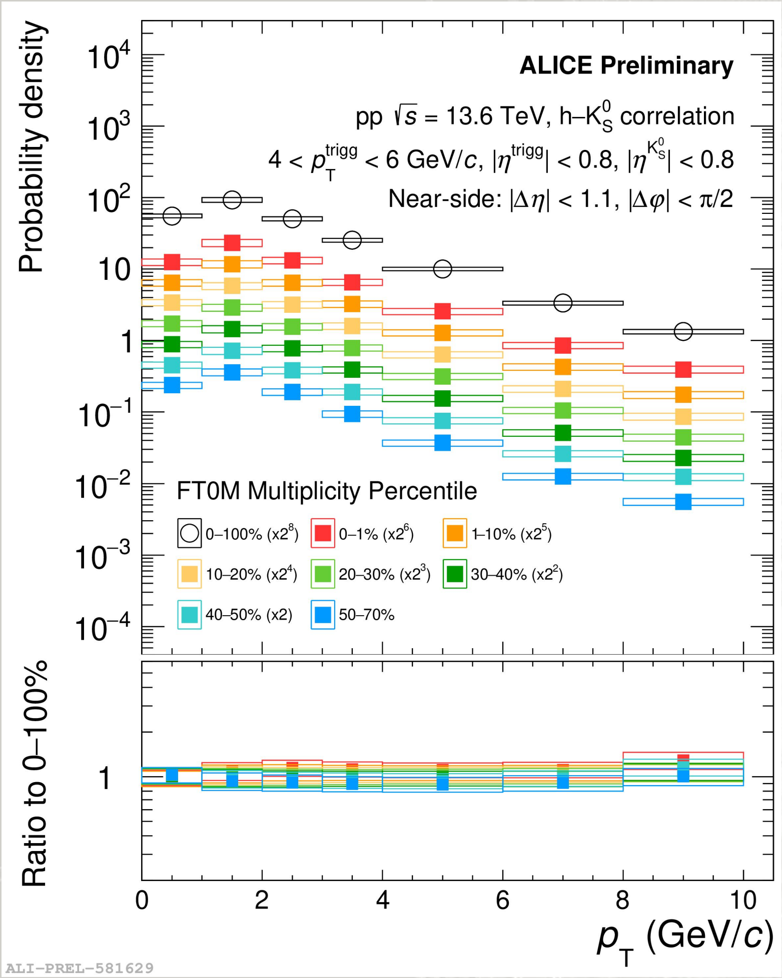




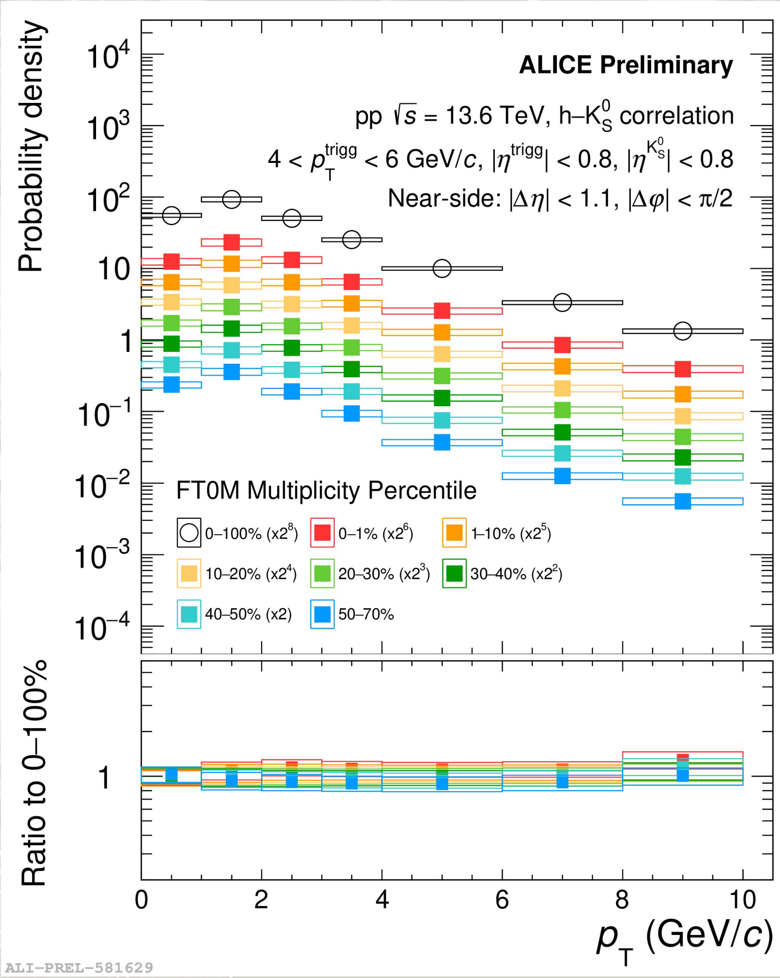
Corrected yields – Multiplicity dependence

$10 < p_{T,\mathrm{trigg}} < 50$ GeV/c

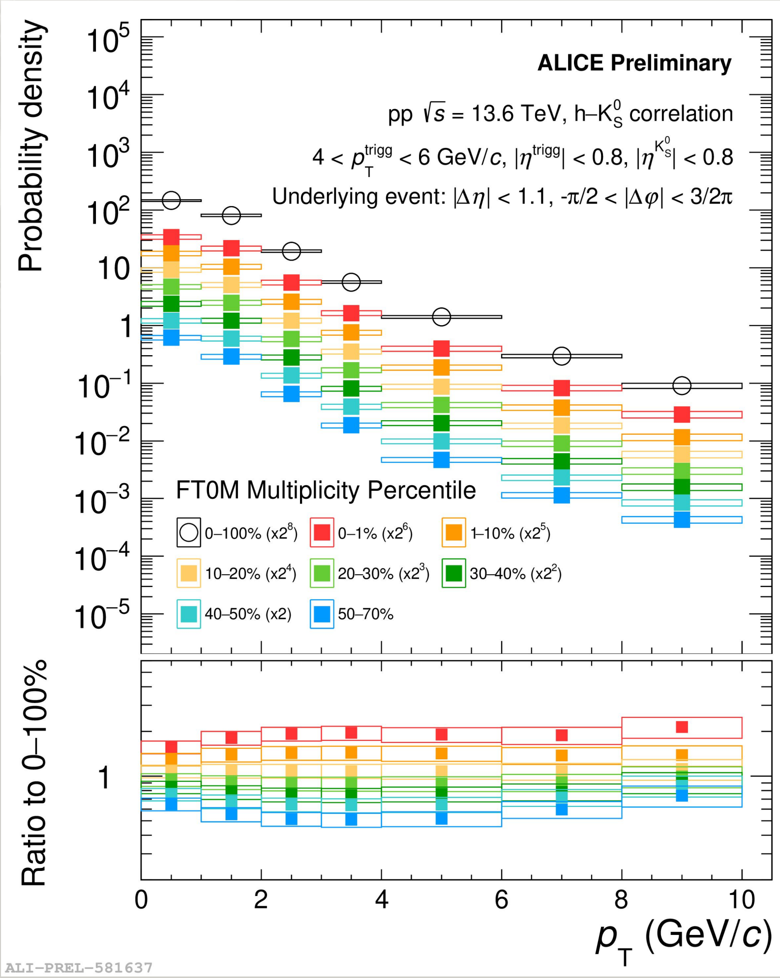
Near-side



Away-side



UE

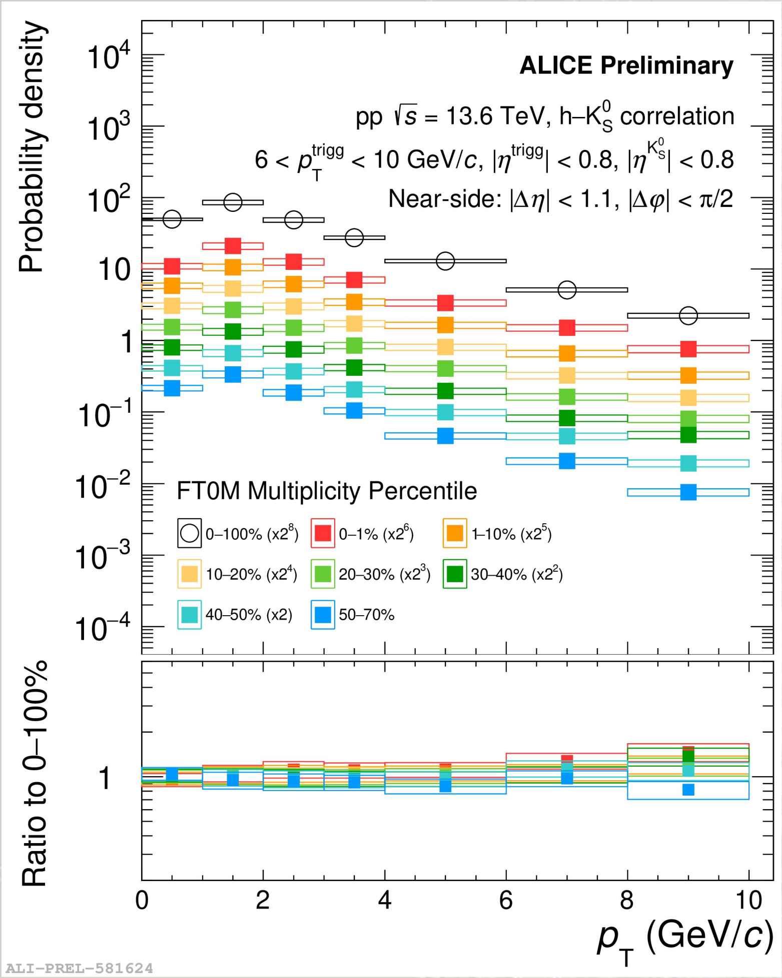


- The multiplicity dependence of NS and AS spectra becomes smaller with increasing pt,trigg

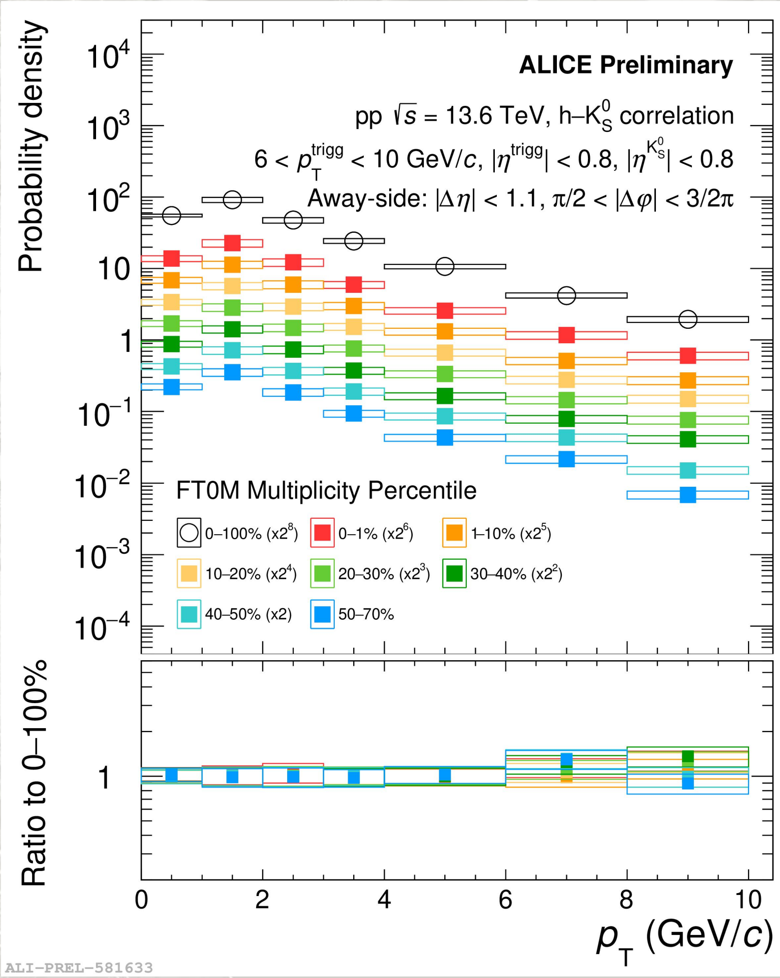
Corrected yields – Multiplicity dependence

$10 < p_{T,trigg} < 50$ GeV/c

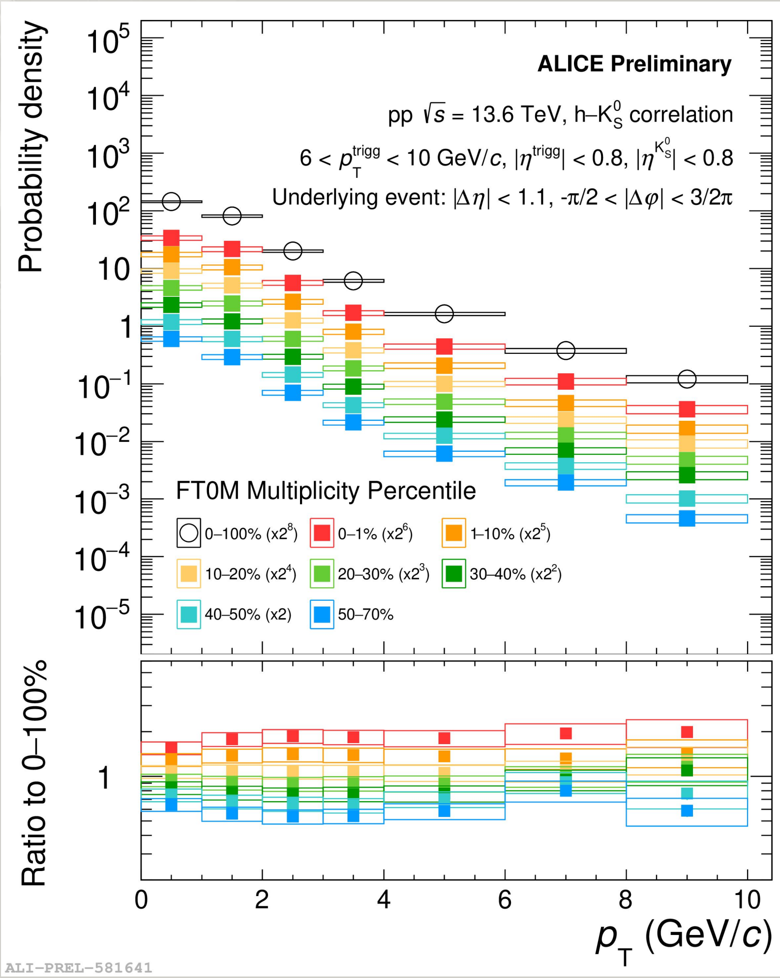
Near-side



Away-side

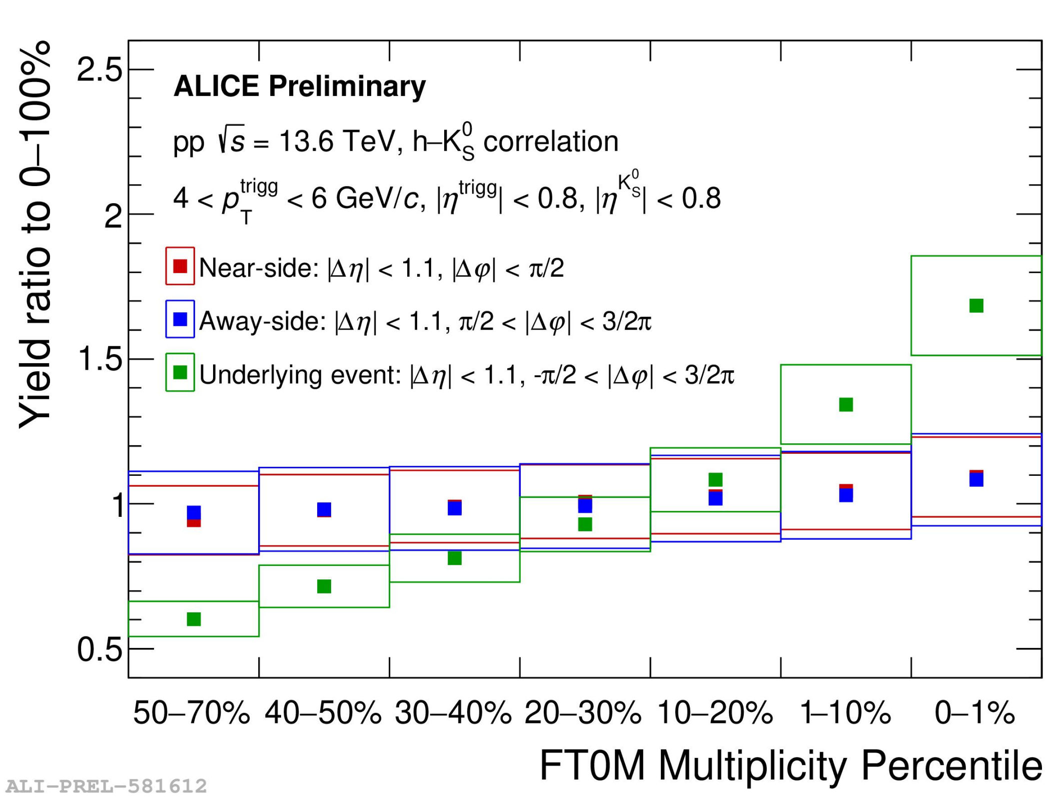


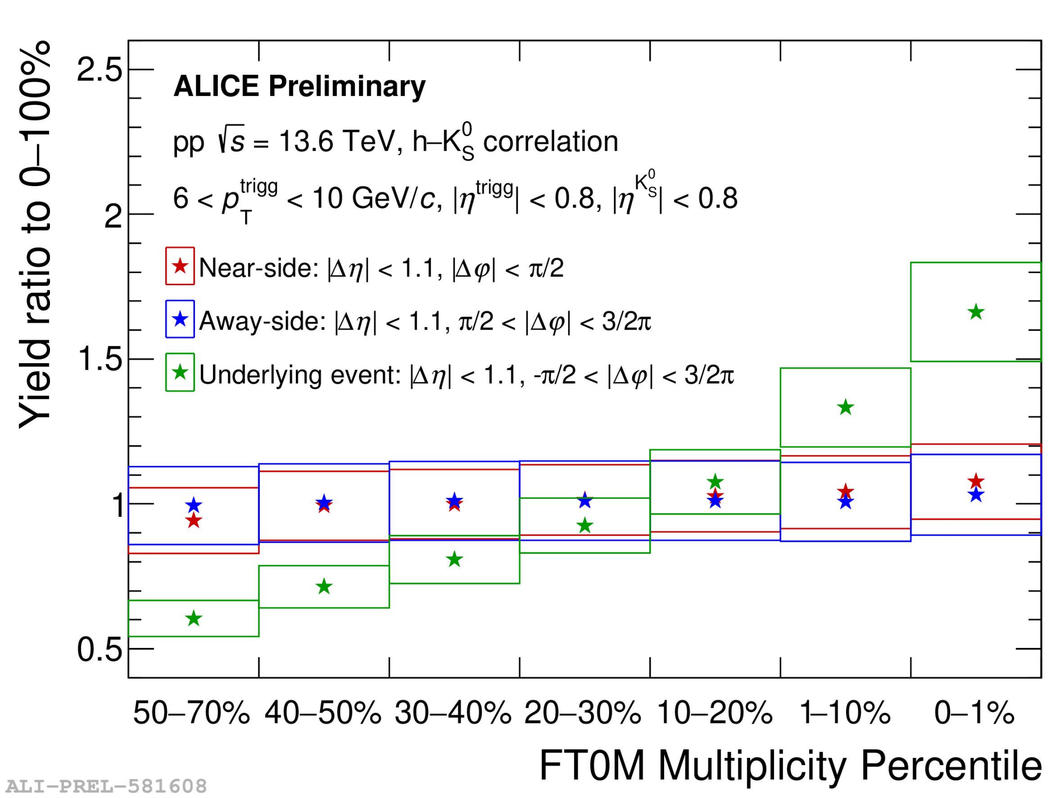
UE



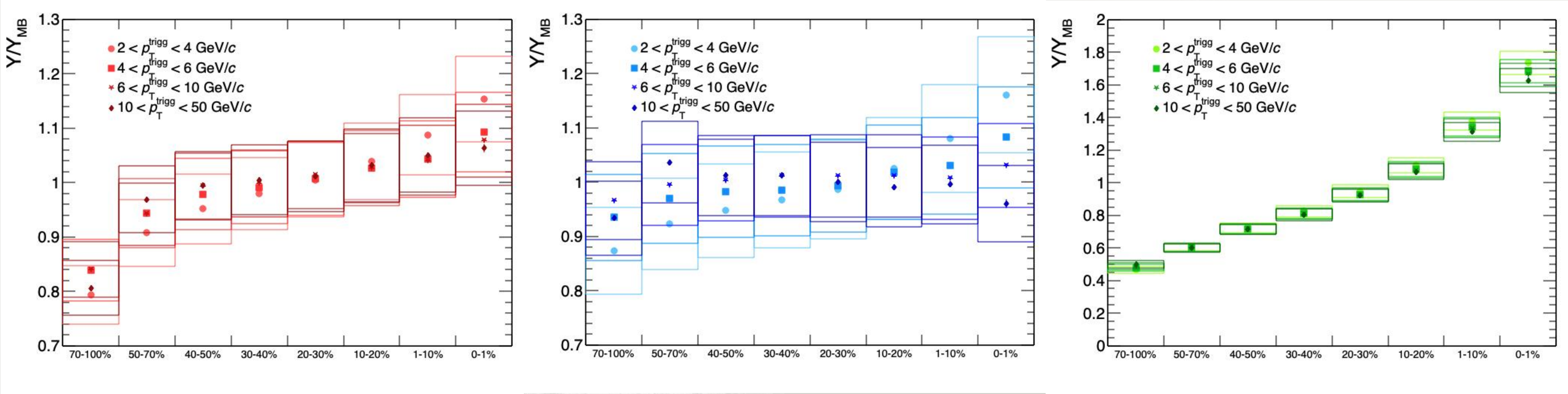
- The multiplicity dependence of NS and AS spectra becomes smaller with increasing pt,trigg

Corrected yields vs multiplicity



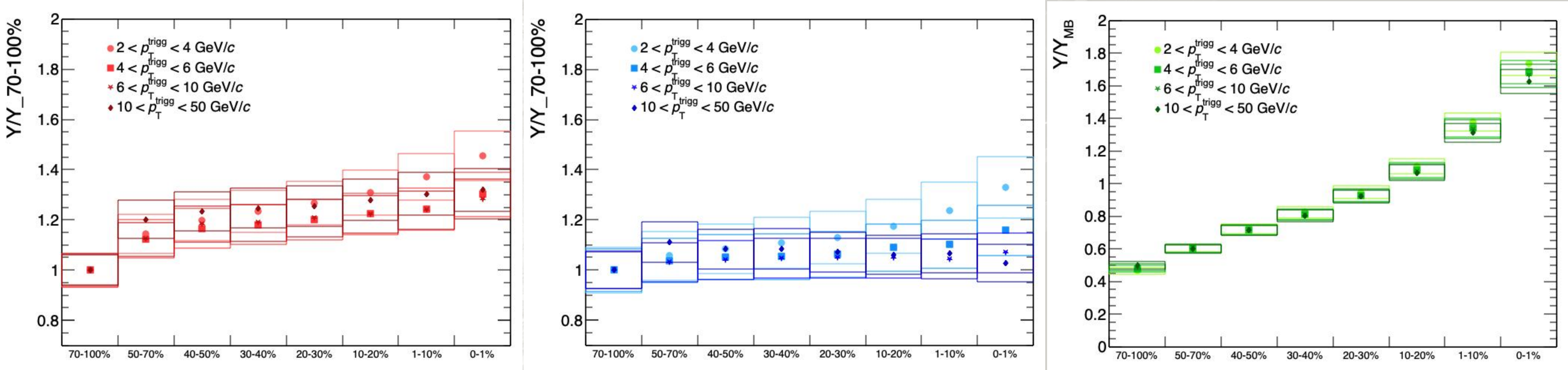


Corrected yields vs multiplicity



	Chi2/NDF Near-side	Chi2/NDF Near-side (no 70-100%)	Chi2/NDF Away-side
2 < pt,trigg < 4 GeV/c	21/7 (p = 0.004)	8.4/7 (p = 0.2)	6.6/7 < 1
4 < pt,trigg < 6 GeV/c	10/7 (p = 0.19)	3/7 < 1	1.8/7 < 1
6 < pt,trigg < 10 GeV/c	12/7 (p = 0.10)	2.8/7 < 1	0.45/7 < 1
10 < pt,trigg < 50 GeV/c	15/7 (p = 0.036)	1.5/6 < 1	1.4/7 < 1

Corrected yields vs multiplicity



	Chi2/NDF Near-side	Chi2/NDF Near-side (no 70-100%)	Chi2/NDF Away-side
2 < pt,trigg < 4 GeV/c	21/7 (p = 0.004)	8.4/7 (p = 0.2)	6.6/7 < 1
4 < pt,trigg < 6 GeV/c	10/7 (p = 0.19)	3/7 < 1	1.8/7 < 1
6 < pt,trigg < 10 GeV/c	12/7 (p = 0.10)	2.8/7 < 1	0.45/7 < 1
10 < pt,trigg < 50 GeV/c	15/7 (p = 0.036)	1.5/6 < 1	1.4/7 < 1

ALICE

Monte Carlo studies

- PYTHIA
  - –**First objective**: color ropes should reproduce the strangeness enhancement versus multiplicity
  - –**Second objective**: Color string shoving should cause a near-side, long-range ridge in 2pc studies

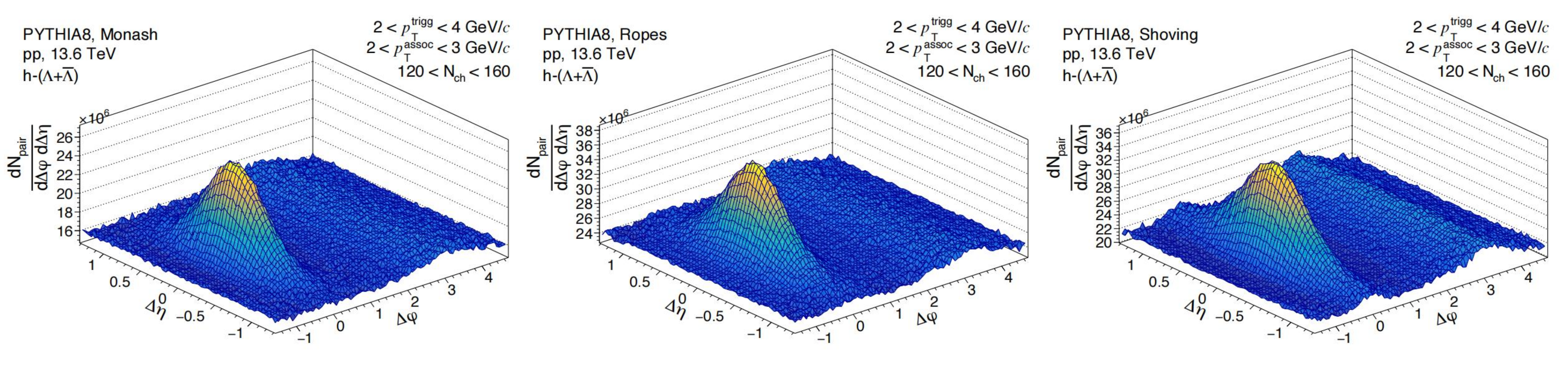
- Complementary effort in this analysis: quantify these effects in near-side, away-side and UE systematically so that this can then be readily compared to the final measurement

Monte Carlo studies: implementation details

- Different configurations tested, approximately 10^{10} events generated each:
  - –PYTHIA Monash 2013 standard setting
  - –PYTHIA with Color Ropes: prescription obtained from Christian Bierlich
  - –PYTHIA with String Shoving: prescription obtained from Christian Bierlich

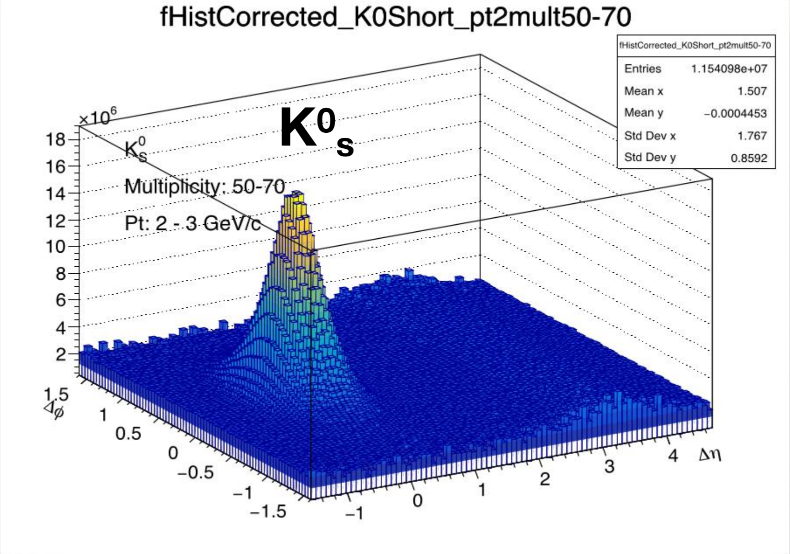
- Analysis done at pure MC level
  - –Same-event and mixed-event correlation functions done as in data
  - –Includes multiplicity-differential analysis all the way (also for event mixing), but vertex-Z differentiation unnecessary in MC
  - –Currently in development and being cross-checked: event mixing compared to $dN/d\eta$ distribution convolution for trigger and associated: eventually get rid of event mixing, less CPU

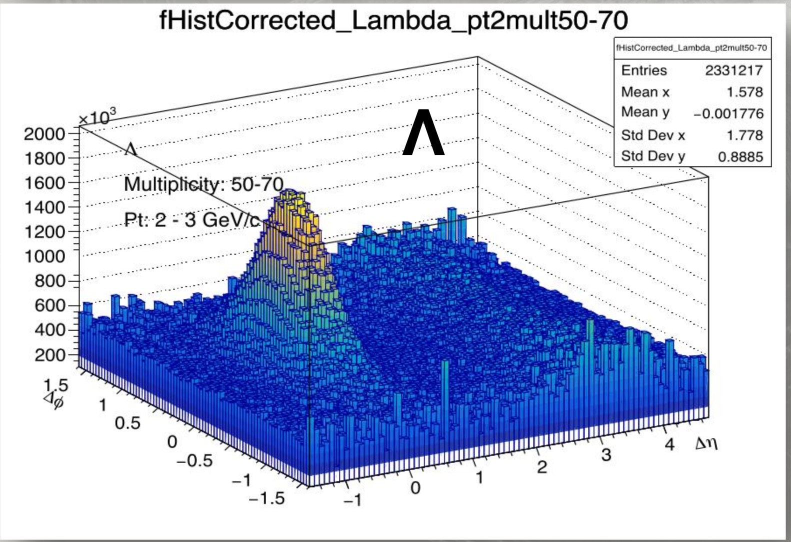
Example two-particle correlation plots: h- Λ



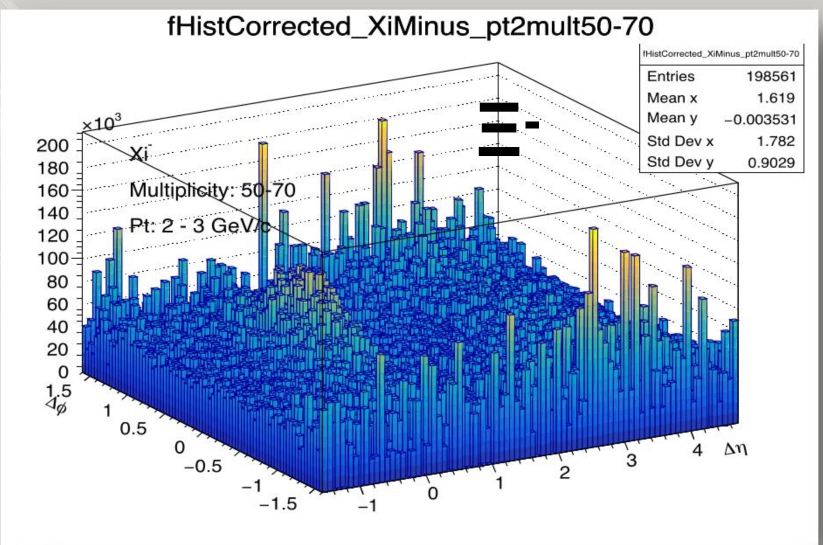
Near-side ridge visible in the shoving mode

Example two-particle correlation plots

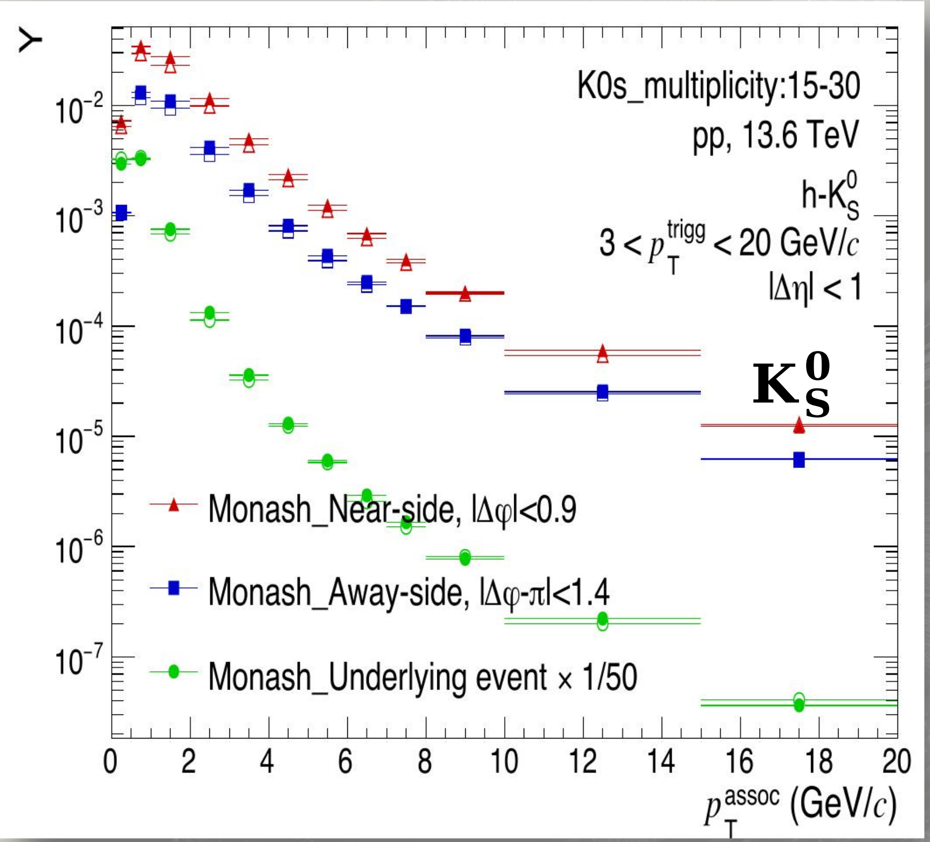


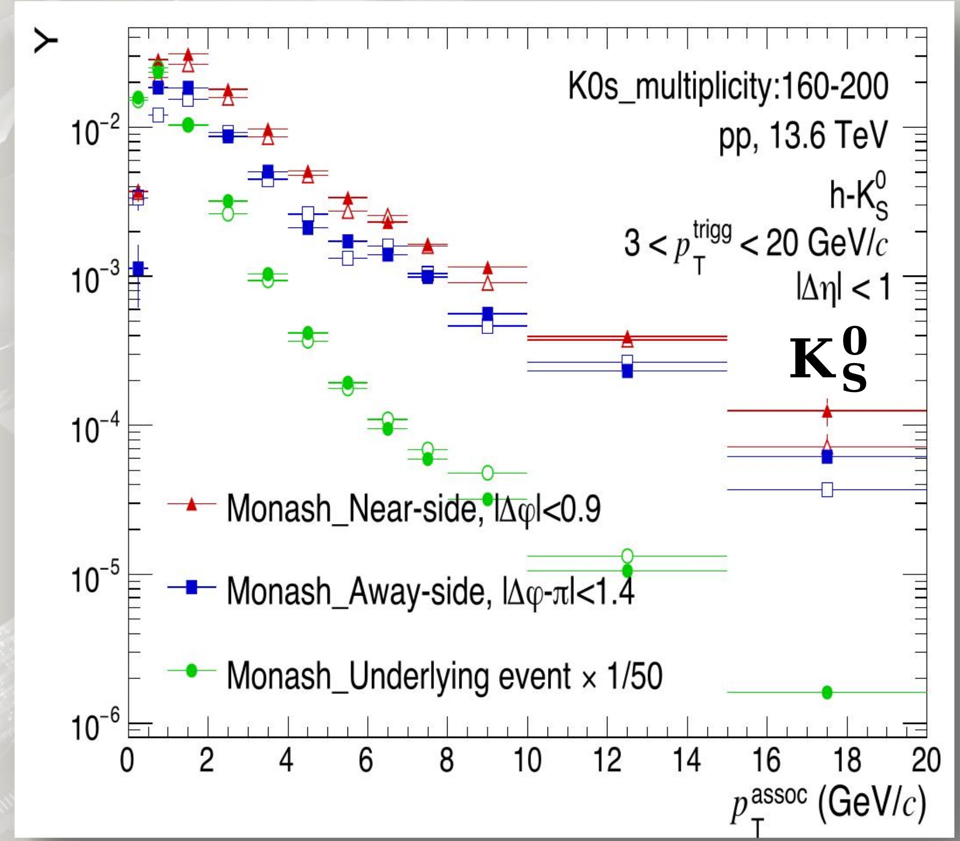


- Correlation functions very well populated for V0s
- Much more statistics-demanding for multi-strange baryons
- For comparing to Run 3 data analysis and to ensure MC modeling isn't a bottleneck, we may need more than 10^{10} events
  - MC LEGO trains restricted to 2×10^9 per train due to Int_t counting
  - Hyperloop on-the-fly MC probably a solution



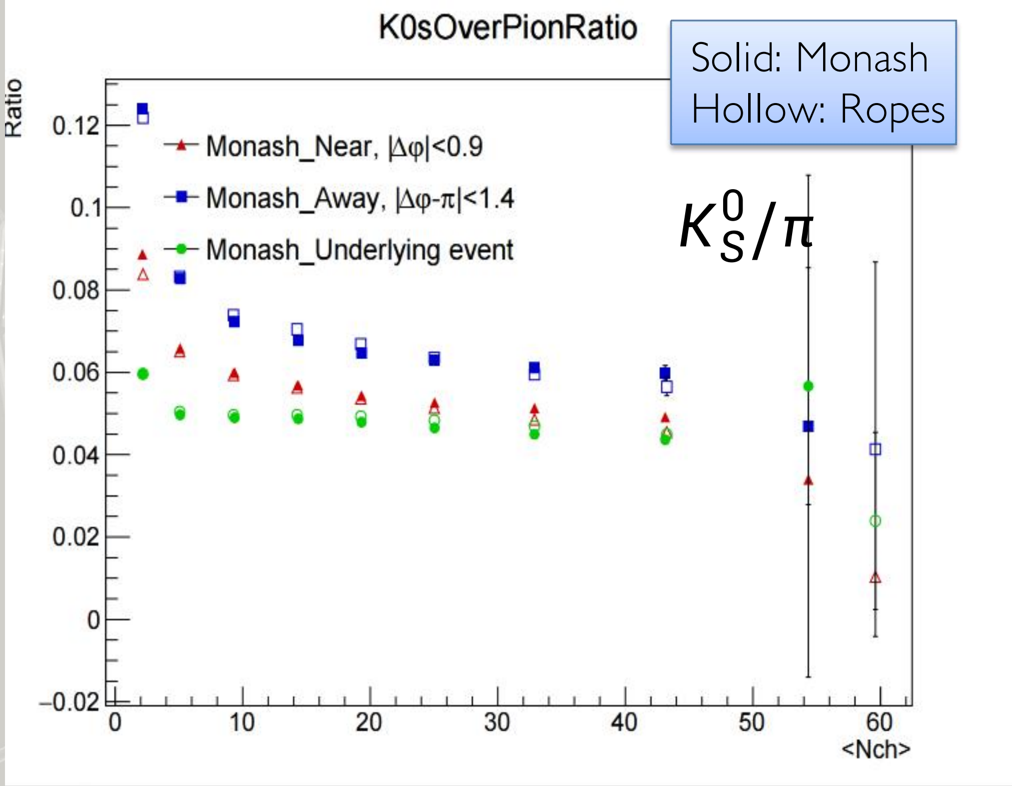
Example: yields as a function of associated p_T

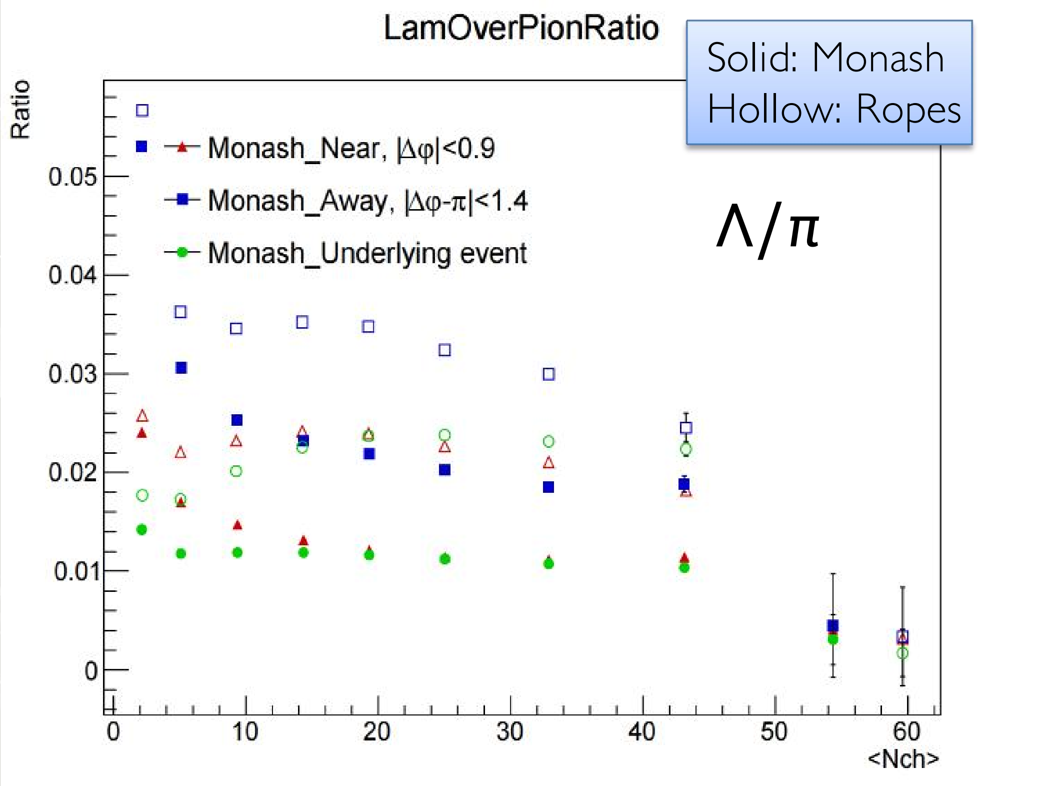




- Extraction in multiplicity bins corresponding to forward charged-particle counters
- Note: Use of multiplicities instead of percentiles: further plots will be done vs midrapidity $\langle dN_{ch}/d\eta \rangle$

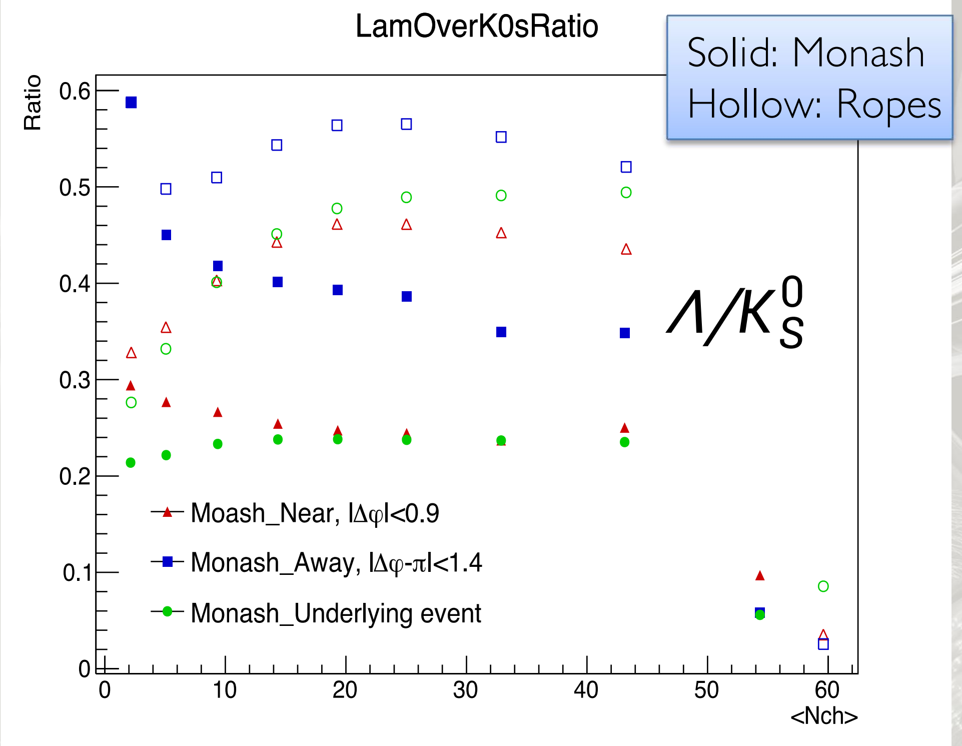
Particle ratios to π as a function of multiplicity: Monash versus Ropes

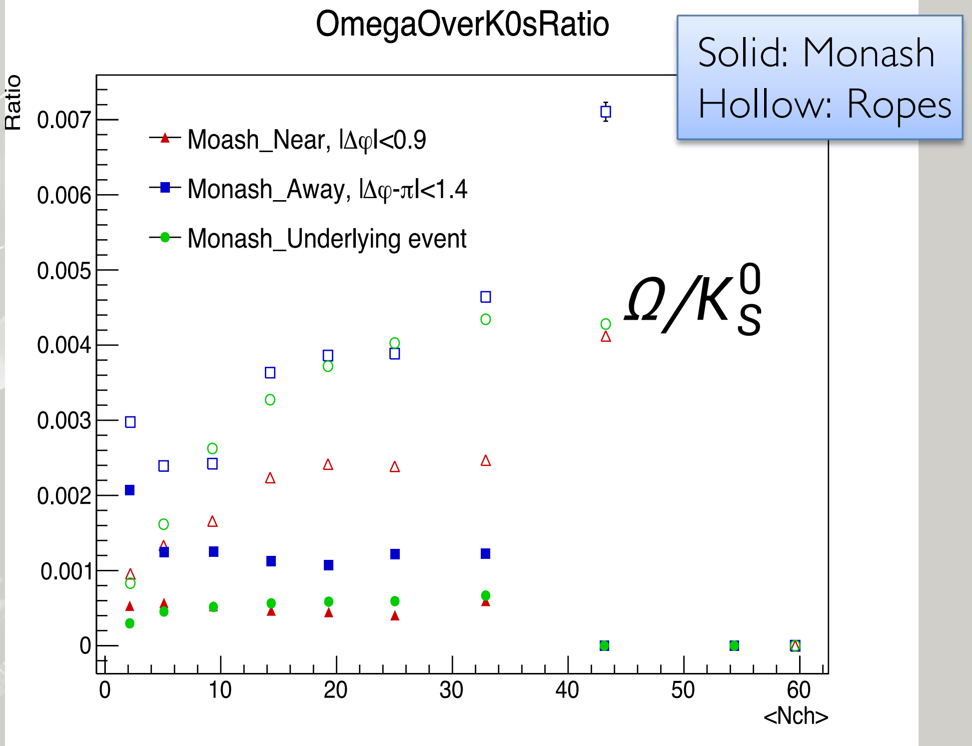




- Significant dynamical difference whenever color ropes are enabled
- Sizable impact not only in underlying event, but also in near and away sides

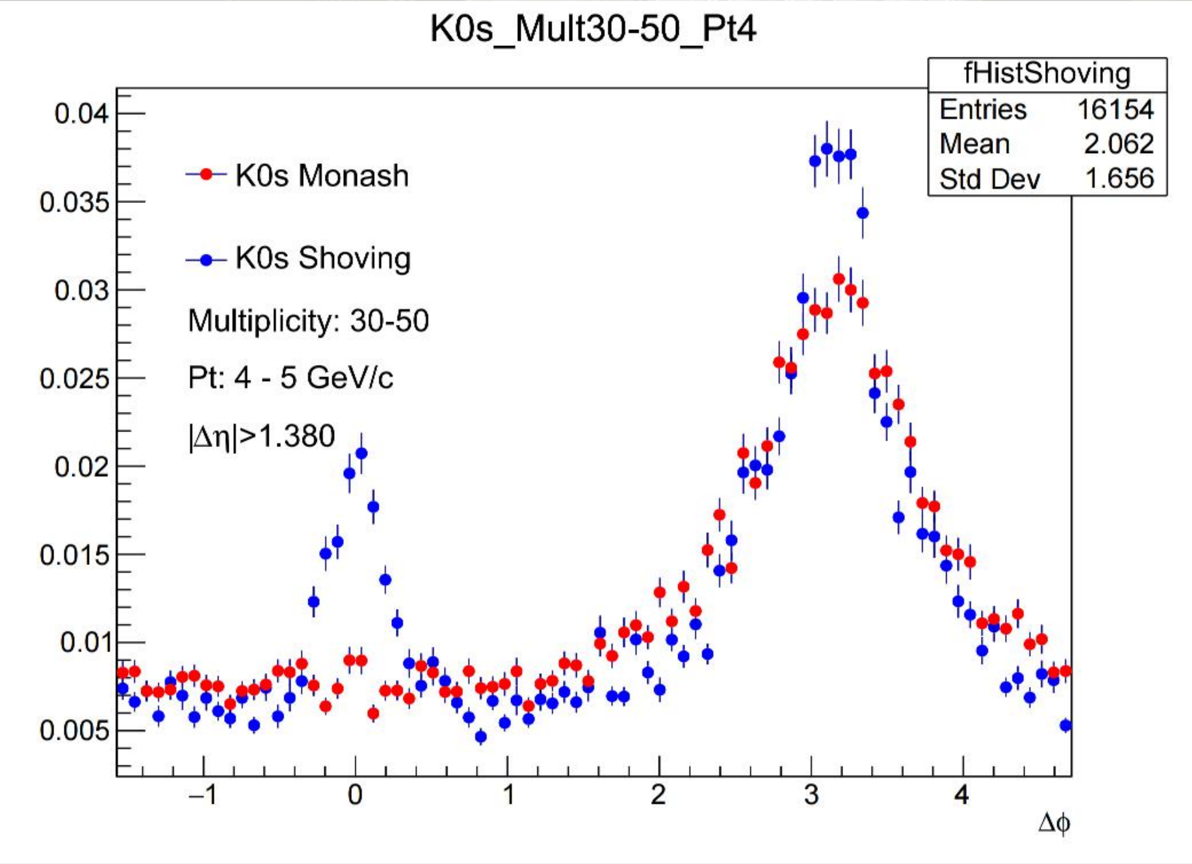
Particle ratios to K^0_S as a function of multiplicity: Monash versus Ropes





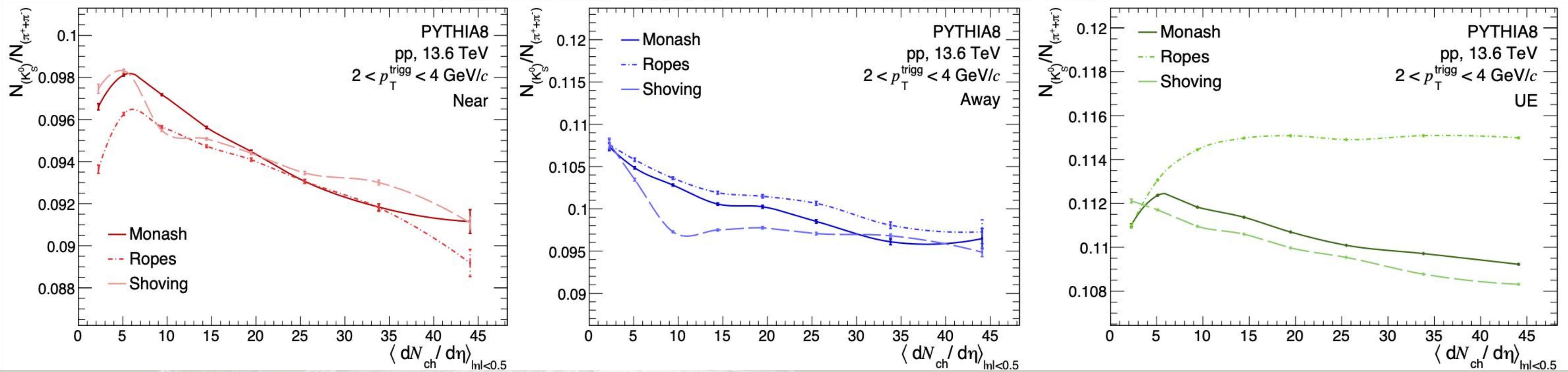
- Ratio to K^0_S calculated as a backup plan in case h-π analysis does not converge with bayesian PID, etc
- Physical conclusion is still rather similar: effect of ropes is very visible!
  - Note: first data point in ratio to pions dominates scale

Strangeness collectivity due to string shoving in PYTHIA



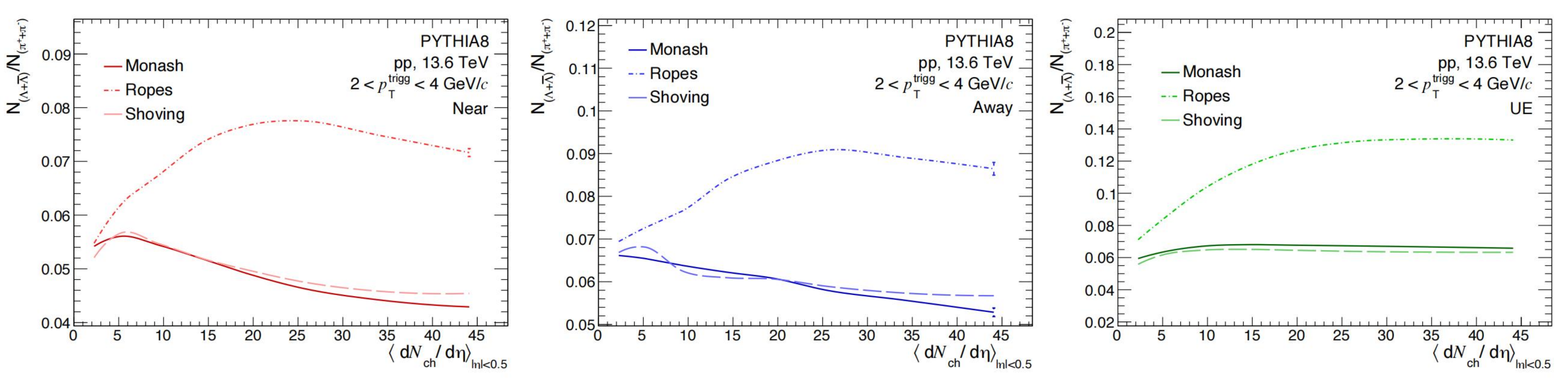
- Analysis method: project 2D correlation function using $|\Delta\phi| < \pi/2$ (select near-side+long-range)
- String shoving produces visible near-side long-range ridge, as expected
- Full characterization of momentum, multiplicity and species dependence ongoing
  - Might even require more than 1010 events for very rare particles such as Ω
  - Showcases also why this is a Run 3 analysis!

MC studies



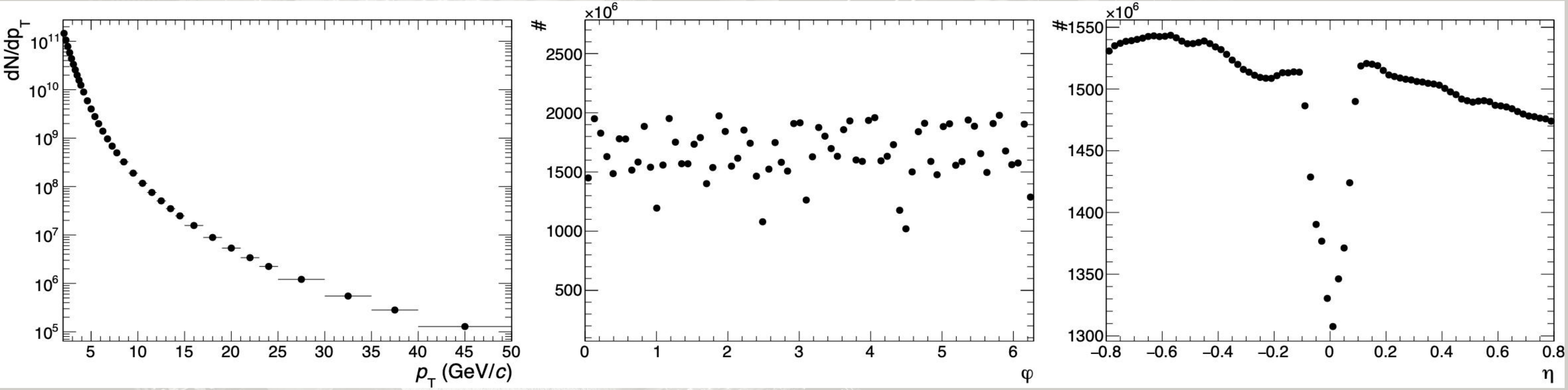
- **UE yields increase with multiplicity** and d**o not show any significant dependence on pttrigg**
- **NS and AS** yields per trigger particle **increase with pttrigg** (partially because low-pt trigg particle are not associated with jet production)
- **NS shows a hint of increase with multiplicity**, AS shows no dependence on multiplicity (to be quantified)

Particle ratios to π as a function of multiplicity: Λ



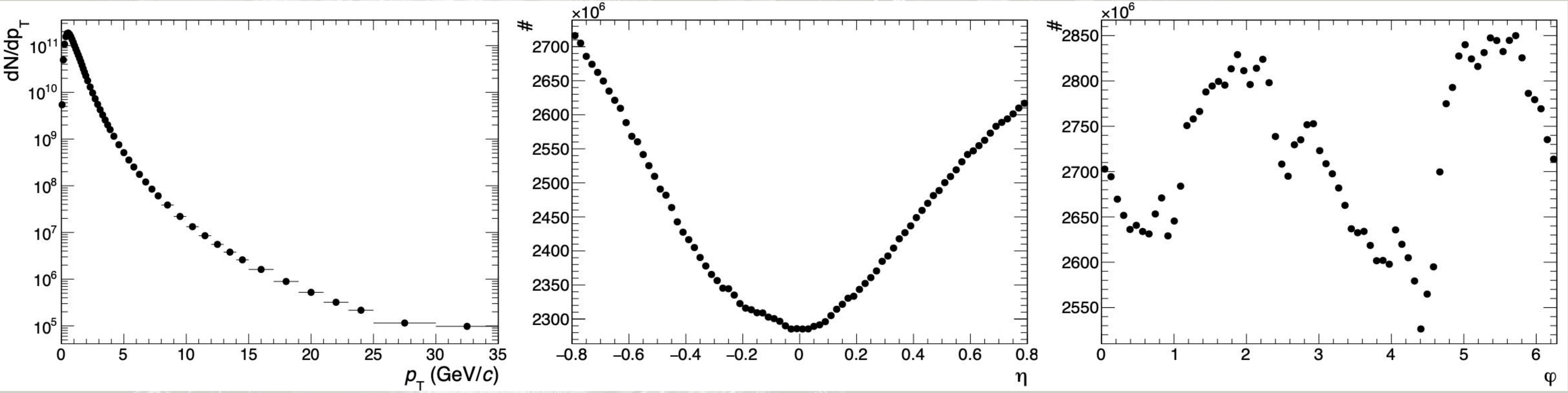
Strangeness enhancement present only in the ropes configuration in all regions

Trigger particle QA



ALICE

K0 QA

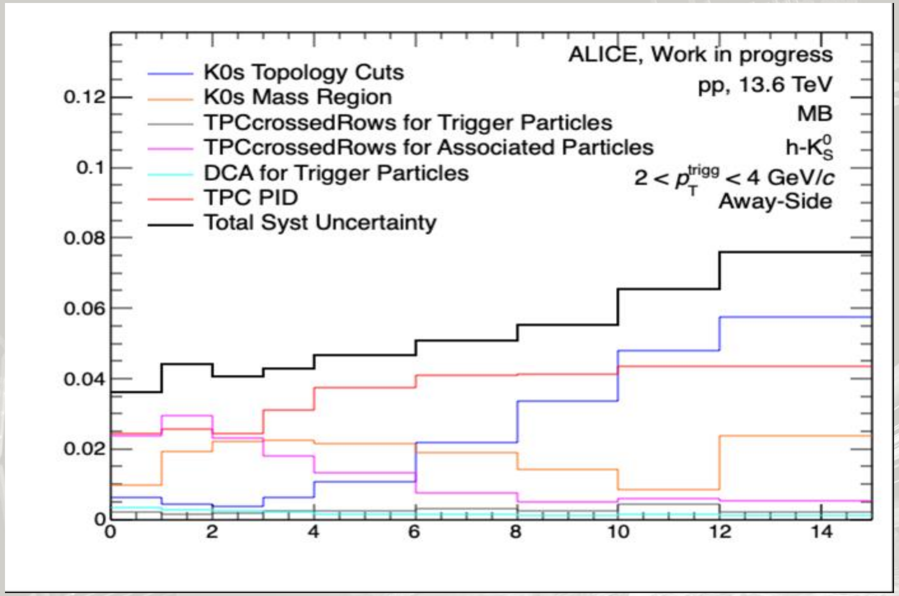


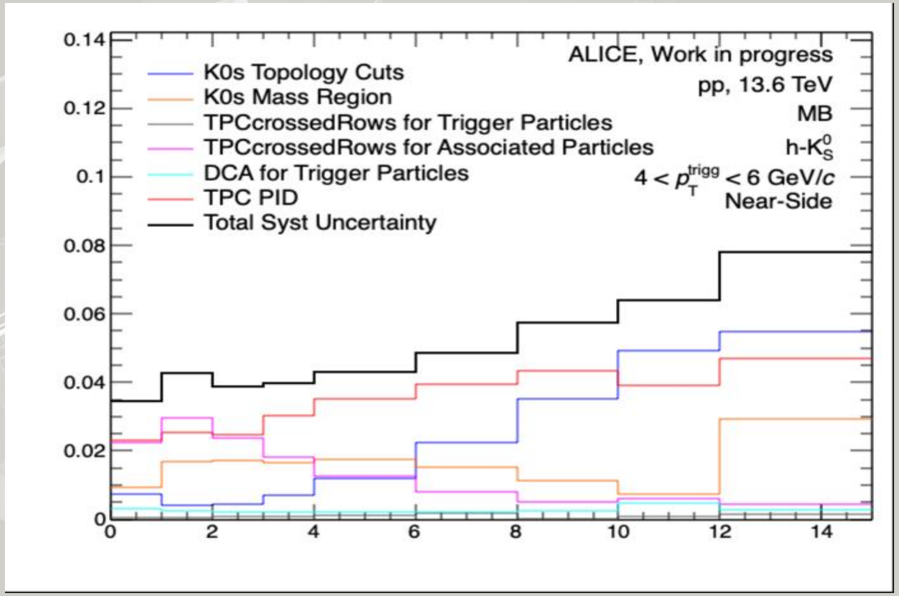
Systematic uncertainties

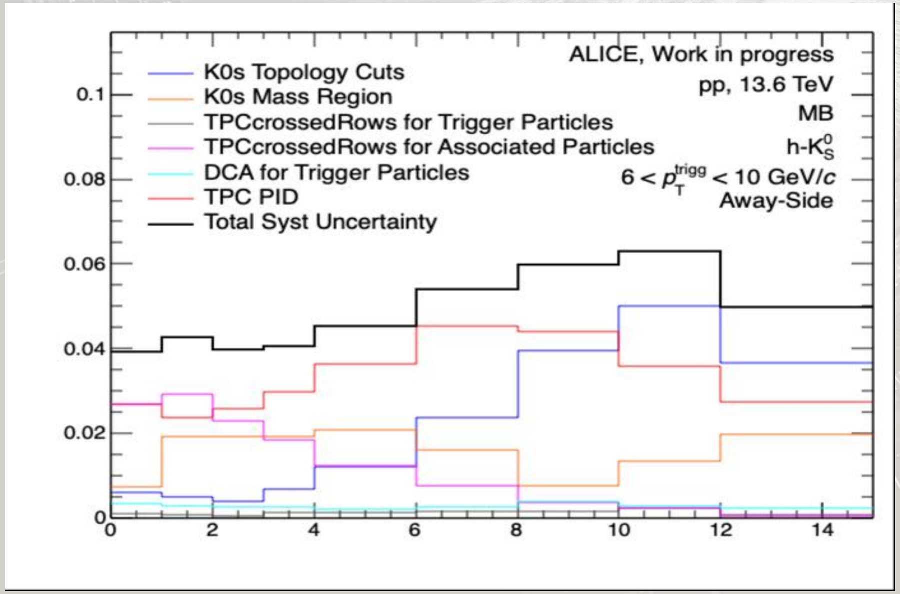
- PV position acceptance < 8 cm (varied from 10)
- Track quality of the trigger particle > 90 TPC crossed rows (varied from 70)
- Track quality of K0s daughter particles > 90 TPC crossed rows (varied from 70)
- DCA_xy of the trigger particle
- Topological variations of K0s (looser and tighter, varied all at once)
- Signal extraction window of the K0s candidates: 4σ and 6σ
- DeltaEta : 1.1−>1.05
- UE definition and subtraction
- Material budget uncertainty inherited from Run 2
- Barlow criterion not yet used
  - To be used in future studies to possibly reduce uncertainties
- MB uncertainty used for all multiplicity classes
  - Motivated by systematic evaluated in mult. bins:
  - Very similar at low p_T, only more erratic at high p_T (stat fluctuations)

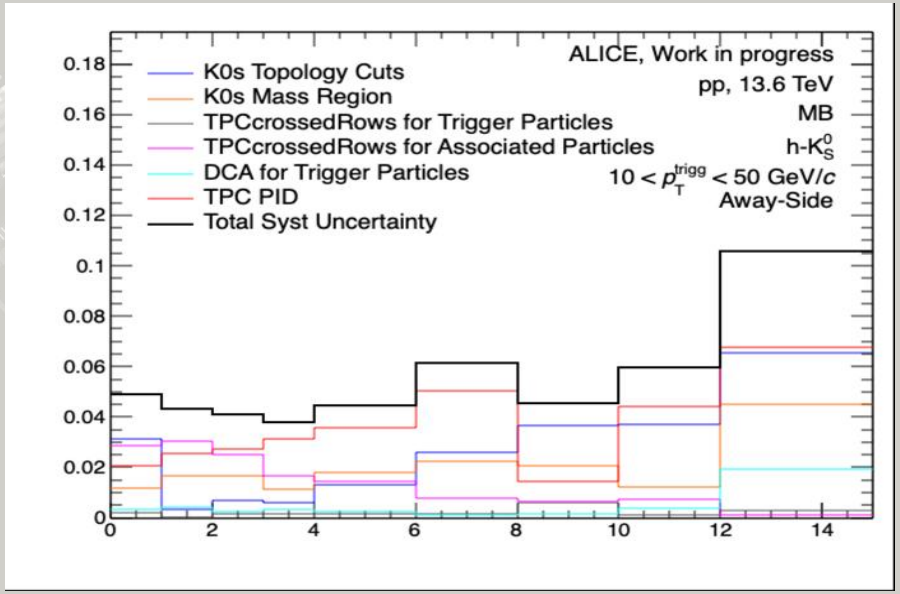
V^0 daughter tracks selections	
dE/dx measured in the TPC	$3\sigma - 5\sigma$
Topological variables selections	
DCA daughters to primary vertex	0.06 – 0.14 cm
DCA between daughter tracks of the V^0	0.8 – 1.2 cm
$\cos(\theta_P)$	0.965 – 0.98
Minimum V^0 decay radius r	0.5 – 0.9 cm

Systematic Uncertainty - MB

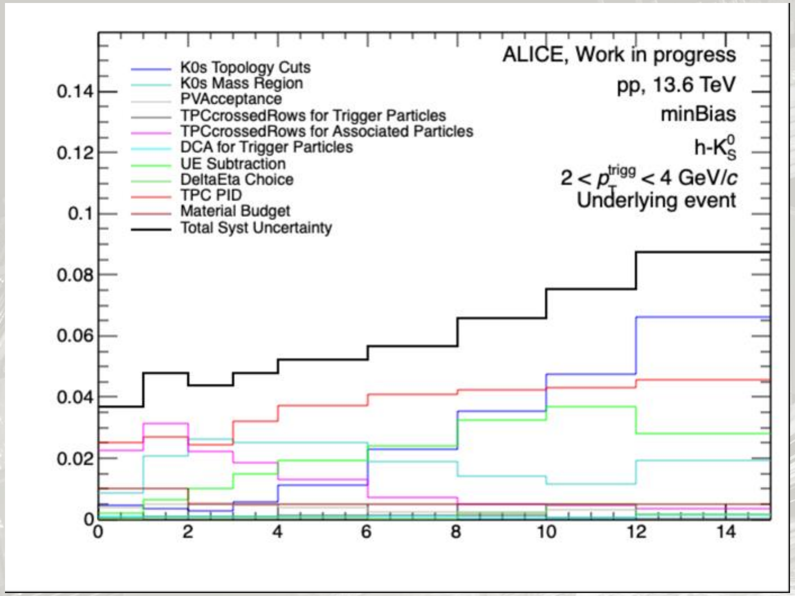


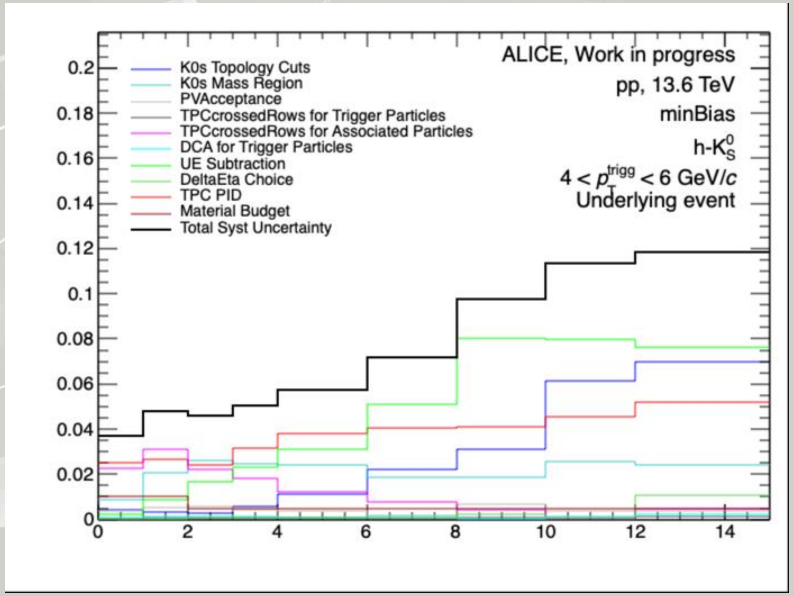


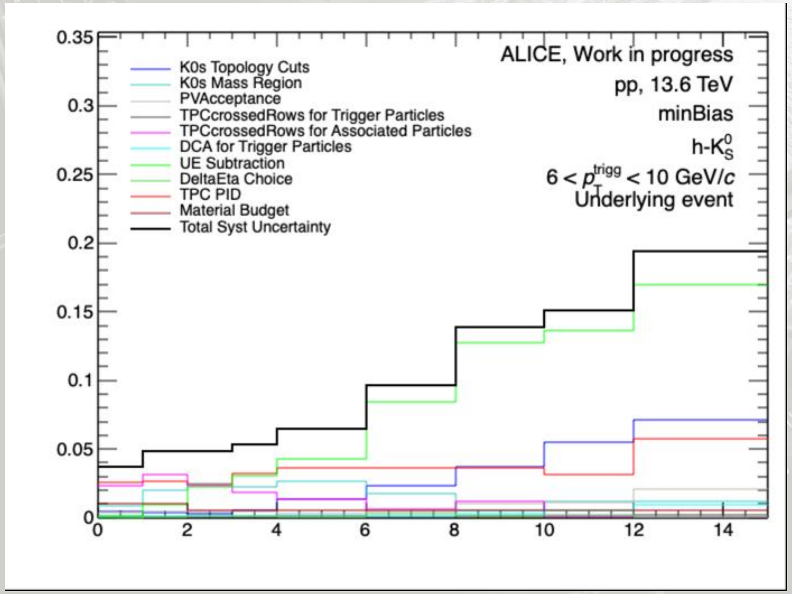


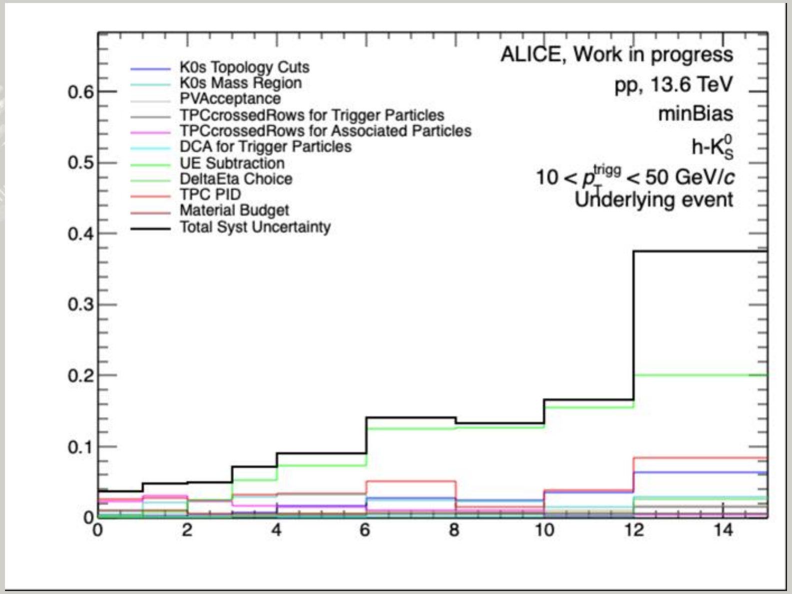


Systematic Uncertainty - MB

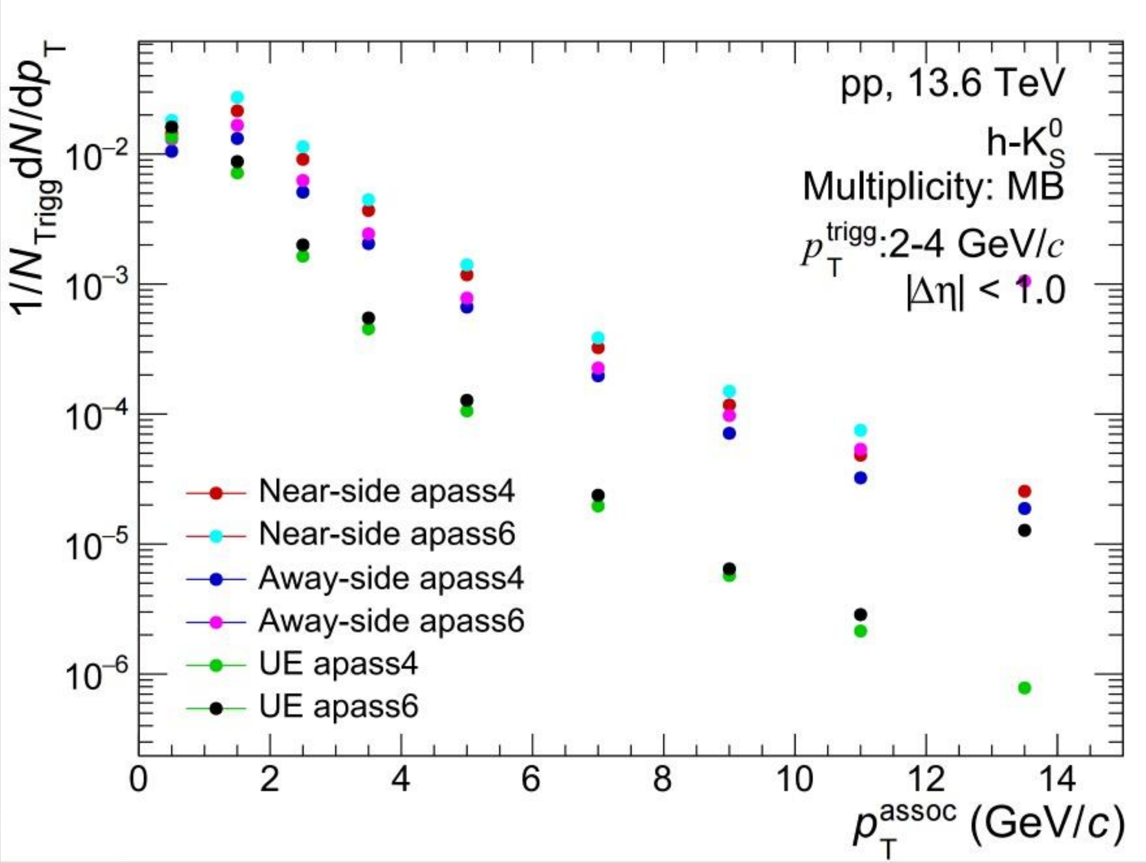


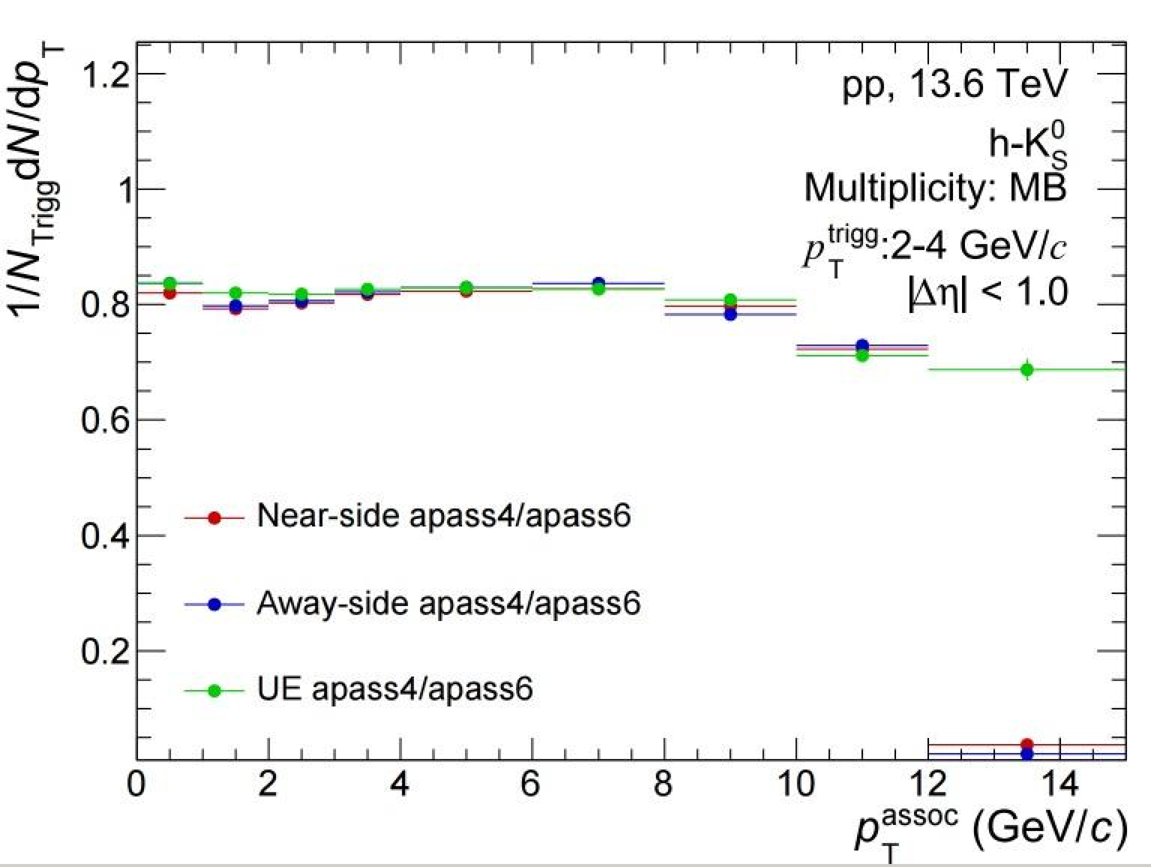






Apass6 Check





Apass6 Check----Corrected Spectrum