# Investigating strangeness enhancement via in-jet and medium production in p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with ALICE

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**on behalf of the ALICE Collaboration**

**XVI Workshop on Particle Correlations and Femtoscopy & IV Resonance Workshop**

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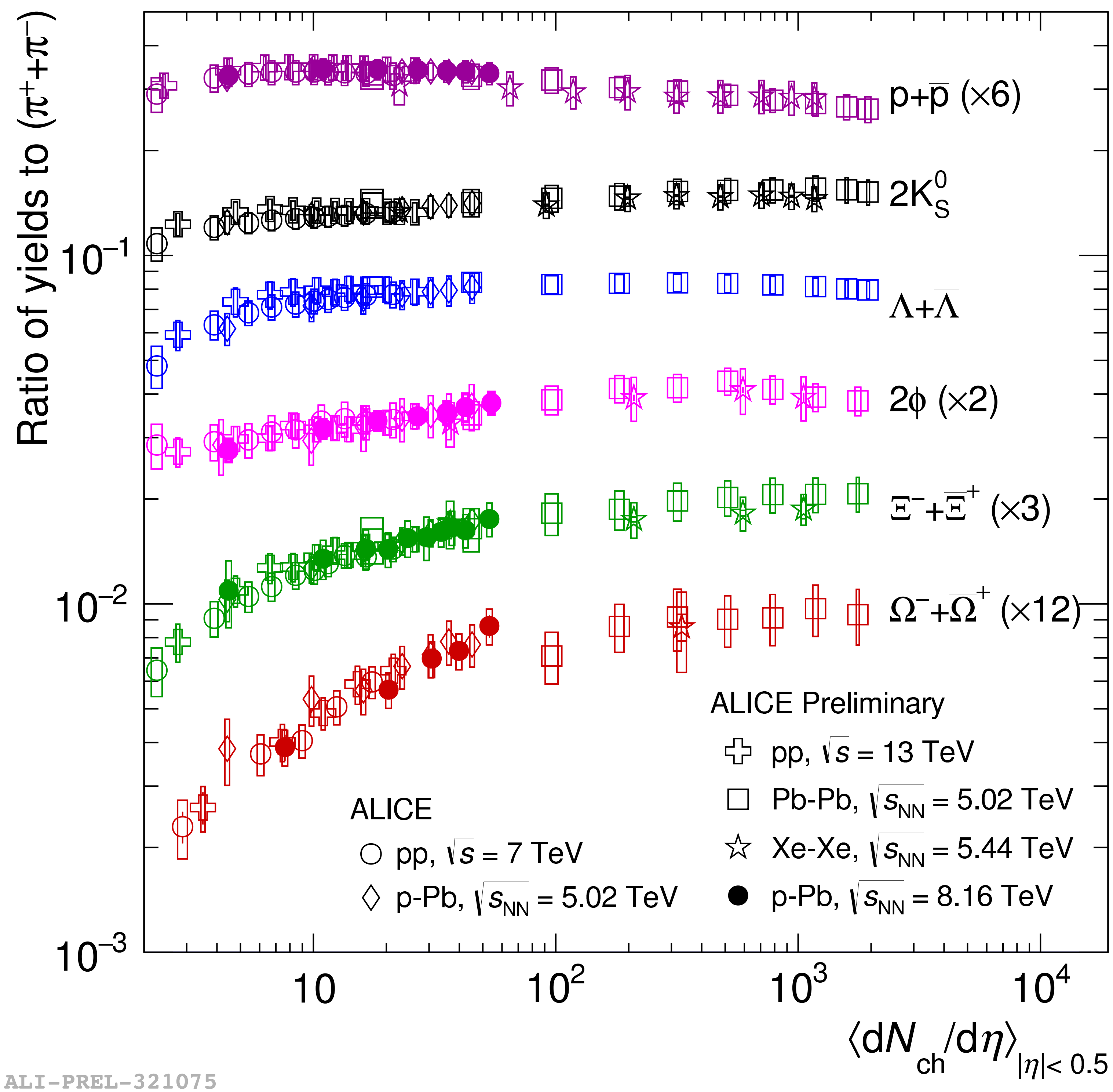
# Motivation: Strangeness Enhancement




- Increase in strange particle production as function of multiplicity across all collision systems
- Larger net strangeness -> Larger production increase (ϕ does not behave like s=0 particle!)

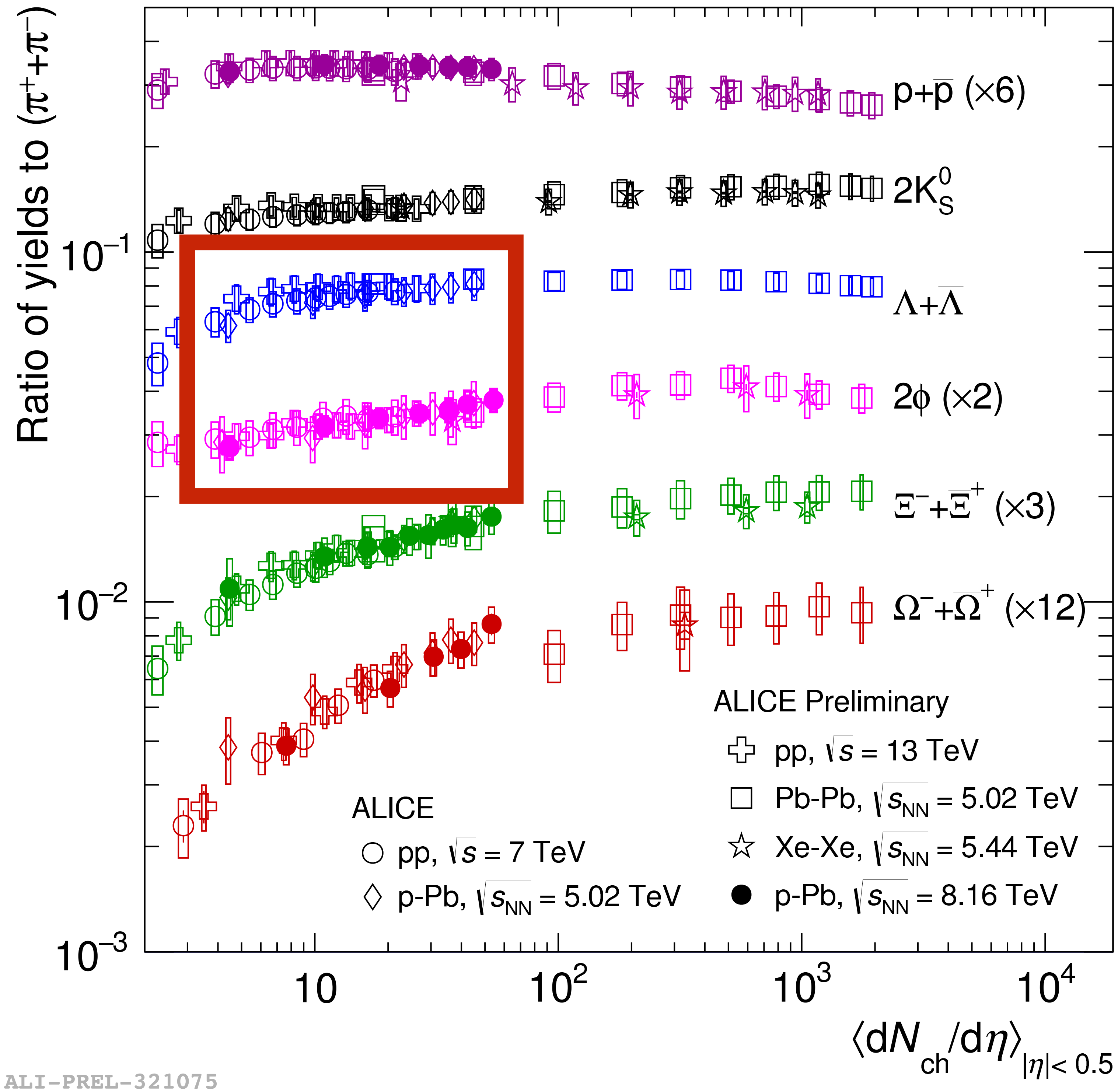
$\phi\ (s\bar{s}) \rightarrow |s|=0$

$\Lambda\ (uds) \rightarrow |s|=1$

$\Xi\ (uss) \rightarrow |s|=2$

$\Omega\ (sss) \rightarrow |s|=3$

# Motivation: Strangeness Enhancement




- Increase in strange particle production as function of multiplicity across all collision systems
- Larger net strangeness -> Larger production increase (ϕ does not behave like s=0 particle!)
- Intermediate sized collisions systems (p-Pb, high mult. pp) allow us to study the origin of this enhancement

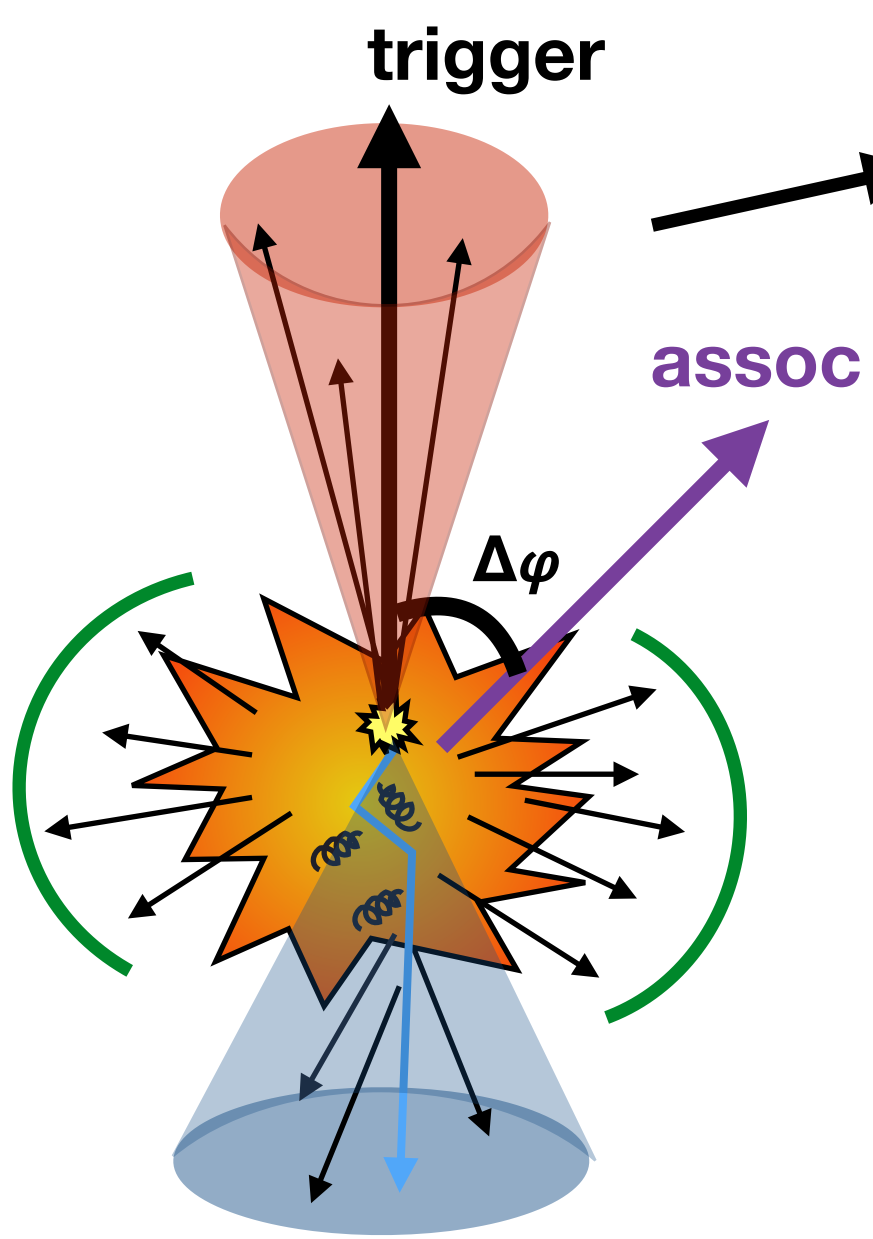
**What is the microscopic origin of this increase?**

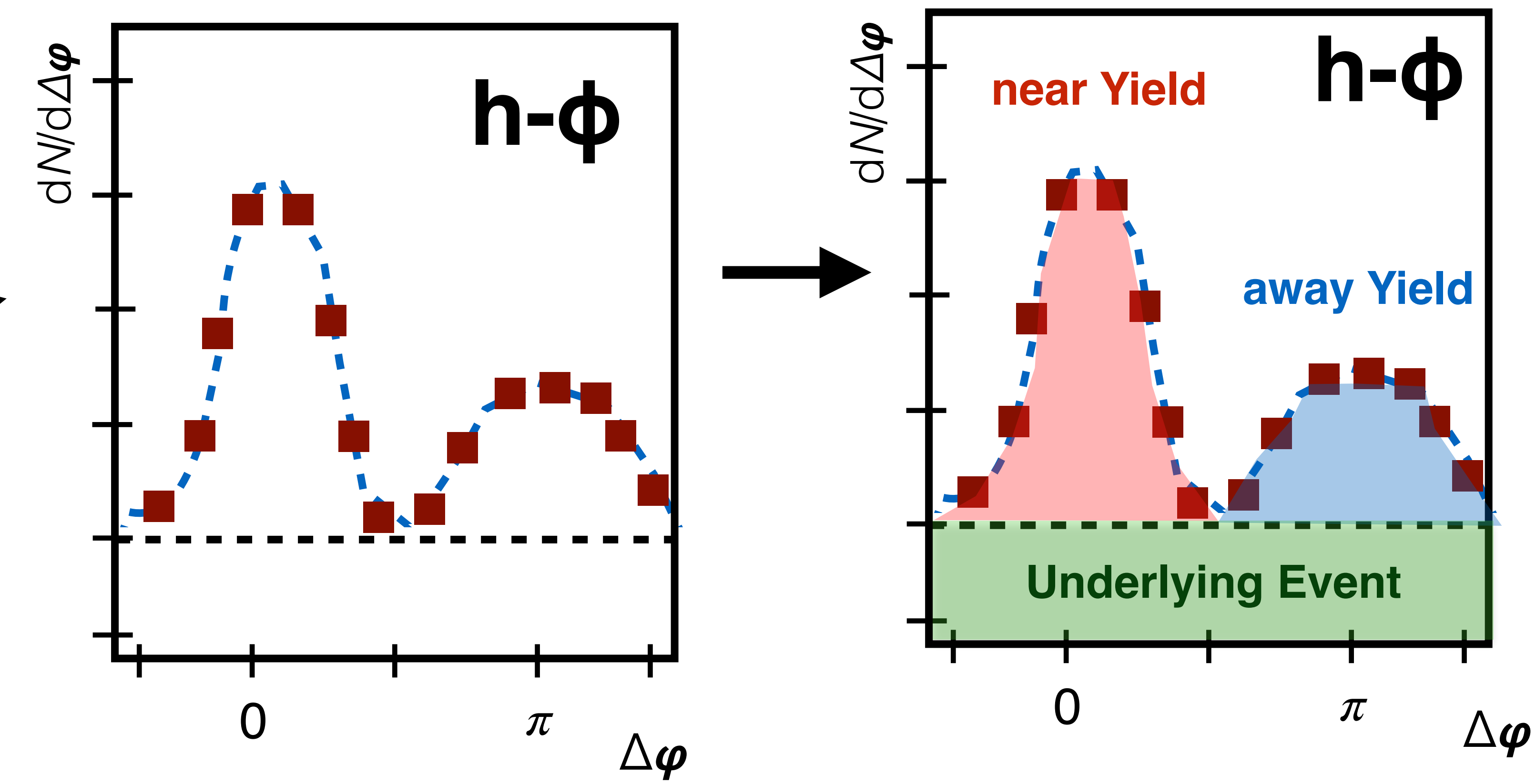
# Motivation: Using Correlations to Study Strangeness

## Identified Strange Associated Particles (φ, Λ)

**trigger: $4.0 < p_T^h < 8.0$ GeV/*c***

**assoc: $2.0 < p_T^\phi < 4.0$ GeV/*c***

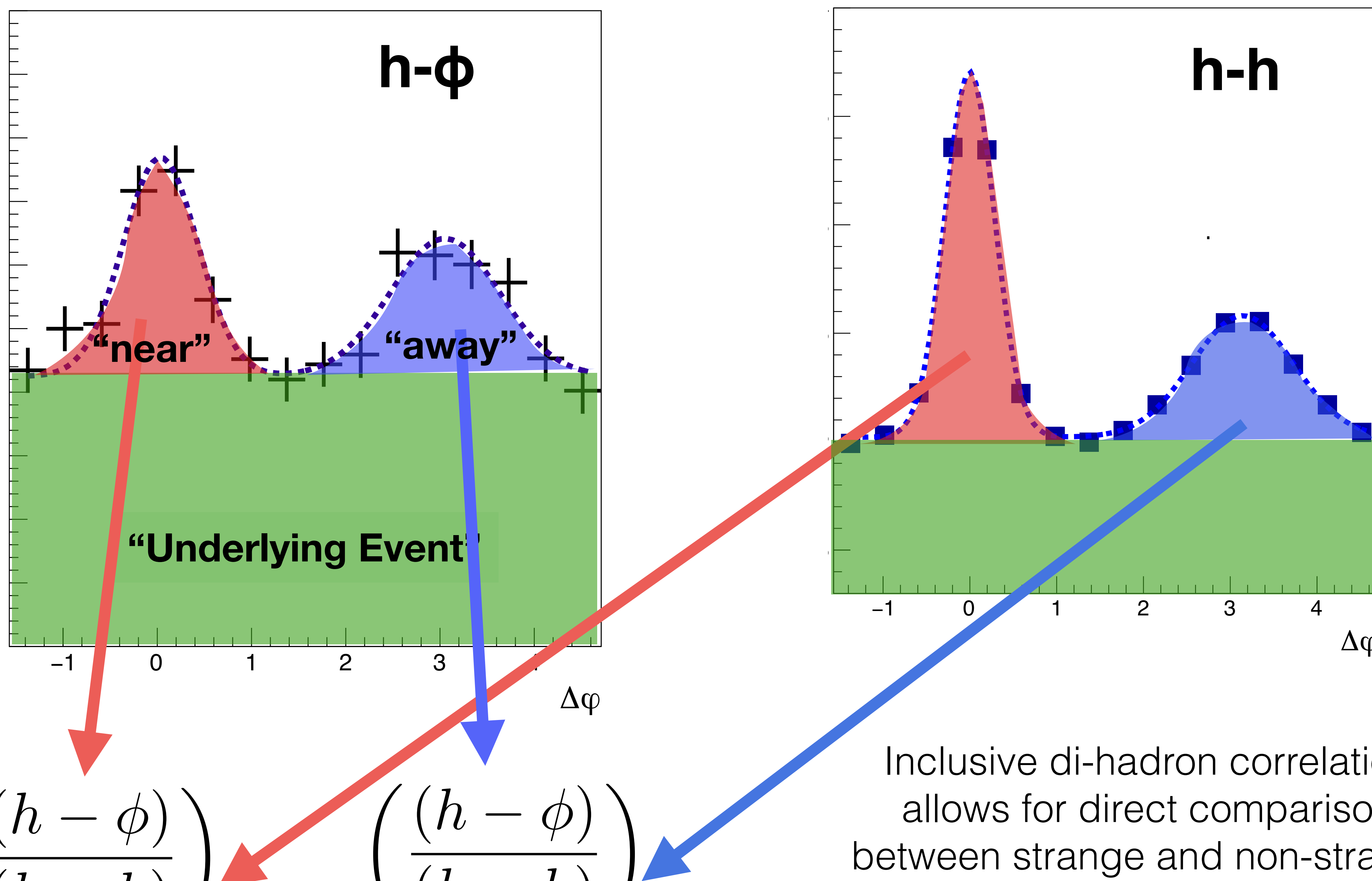



Measuring the angular correlation between a high $p_T$ hadron trigger (jet proxy) and a strange hadron gives us a way to separate out **strange quarks produced in jets** from **strange quarks produced in the underlying event**

**How does jet vs. non-jet production affect increase in strangeness?**

# Extracting Particle Yields from Angular Correlations




$$\left(\frac{(h-\phi)}{(h-h)}\right)_{\text{Near}} \qquad \left(\frac{(h-\phi)}{(h-h)}\right)_{\text{Away}}$$

Inclusive di-hadron correlation allows for direct comparison between strange and non-strange particle production/fragmentation

# ALICE Detector (Run 2)

Detectors of interest:

- Inner-Tracking System (ITS)
- Time Projection Chamber (TPC)
- Time of Flight (TOF)

**V0:** Multiplicity is measured in the forward rapidity region using small angle scintillating detectors

V0A: $2.8 < \eta < 5.1$
V0C: $-3.7 < \eta < -1.7$

**ITS:** tracking & vertex reconstruction

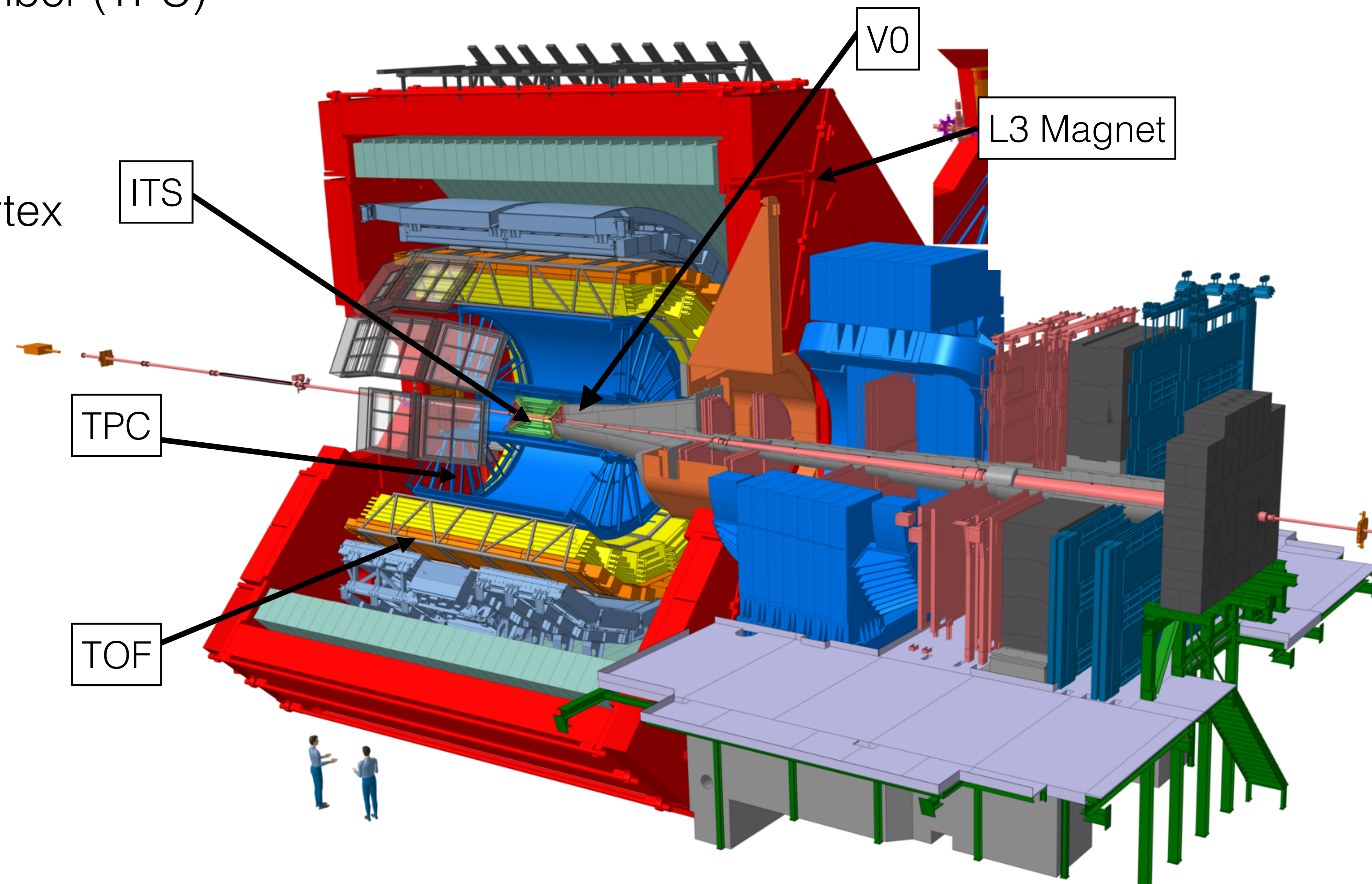
$|\eta| < 0.9$

**TPC**: tracking & PID

$|\eta| < 0.9$

**TOF**: PID information

$|\eta| < 0.9$

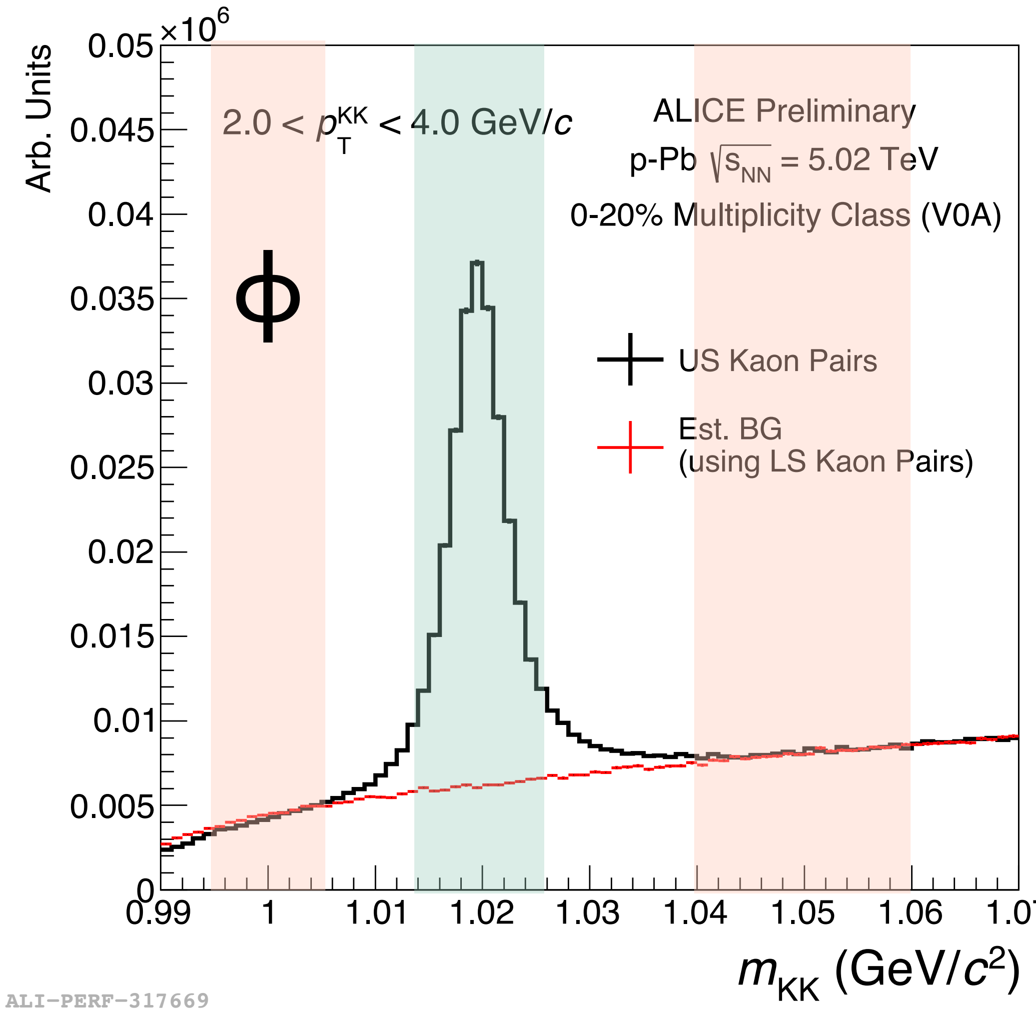


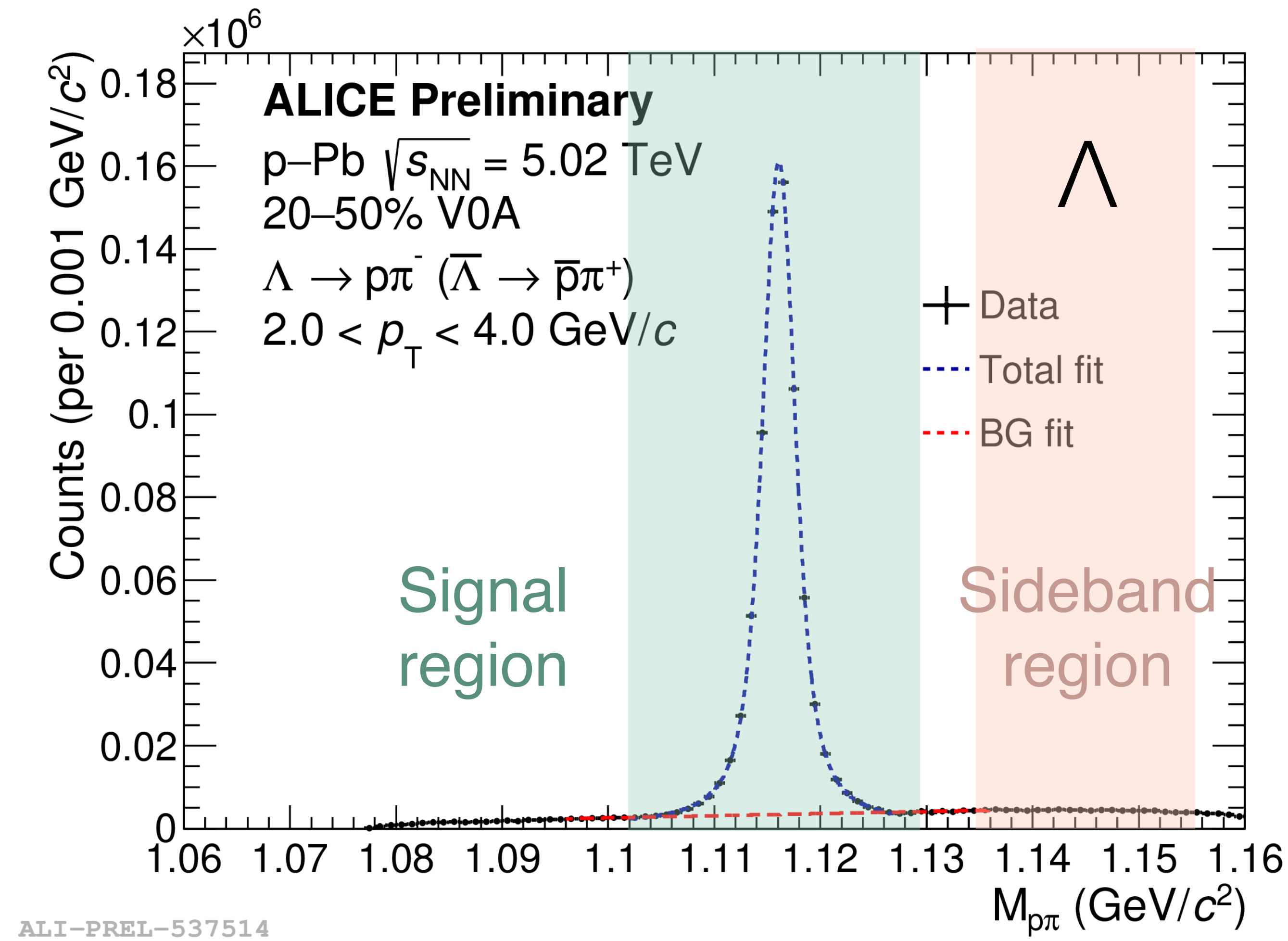

**ALICE Detector**

# $\phi$(1020) & $\Lambda$ Reconstruction

$\phi$(1020): **$s\bar{s}$** Main decay of interest: $\phi \rightarrow K^+ K^-$ (~49%)

$\Lambda$ : **uds** Main decay of interest: $\Lambda \rightarrow p+\pi$ (~64%)



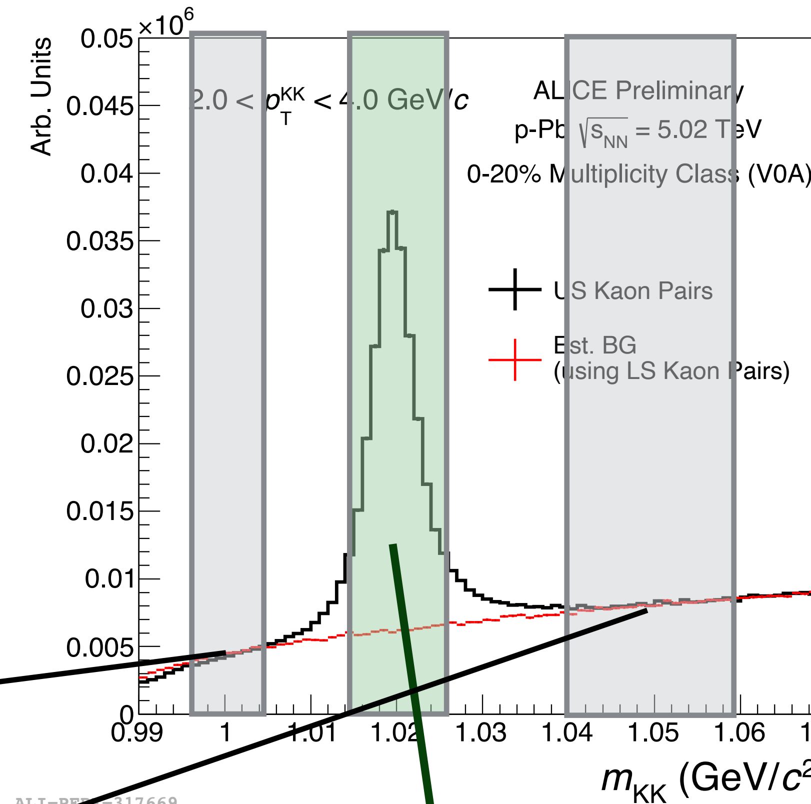




Scaled like sign distribution correctly estimates combinatorial BG under mass peak, gives scale factor for correlation corrections.

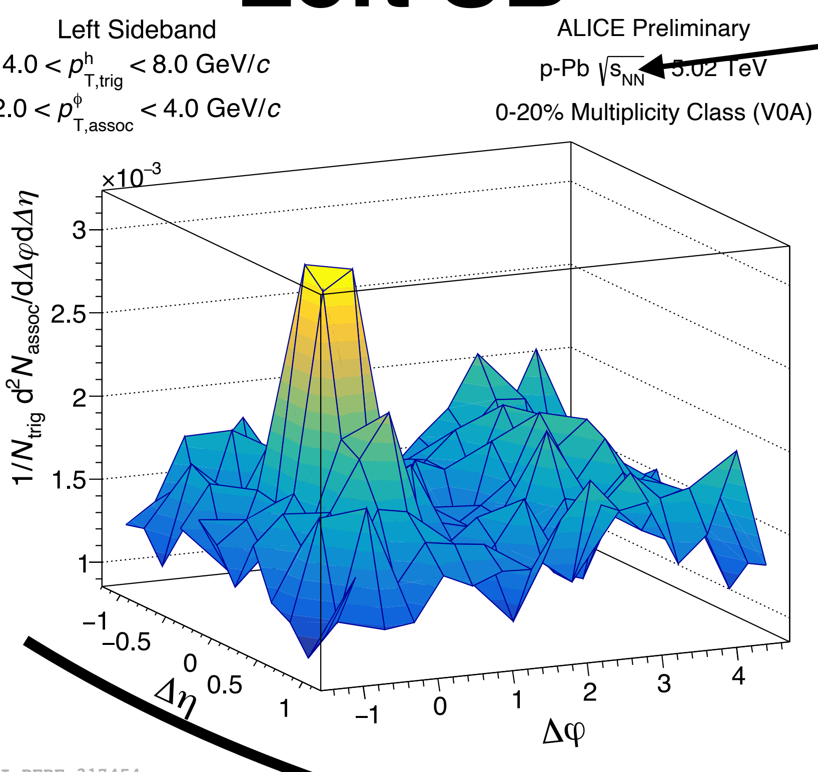
# Method: Correlation Background Estimation

Correlation contains Signal (h-ϕ) and Background (h-(KK)) components. **Signal/BG ≈ 2.5**

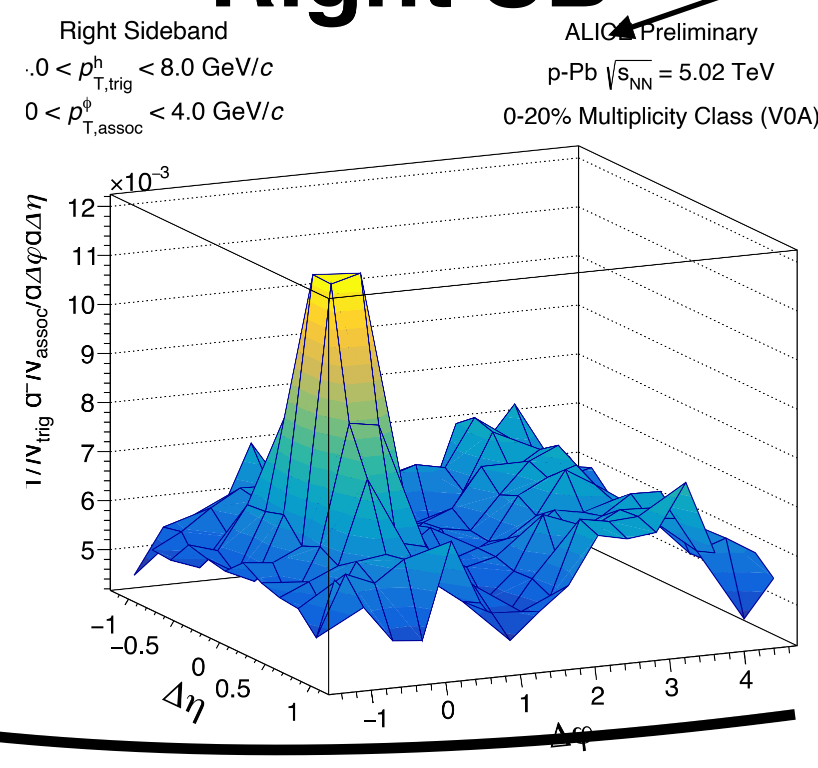
Averaging and scaling correlations in Sideband region (gray) gives estimate of BG in the peak region (green)

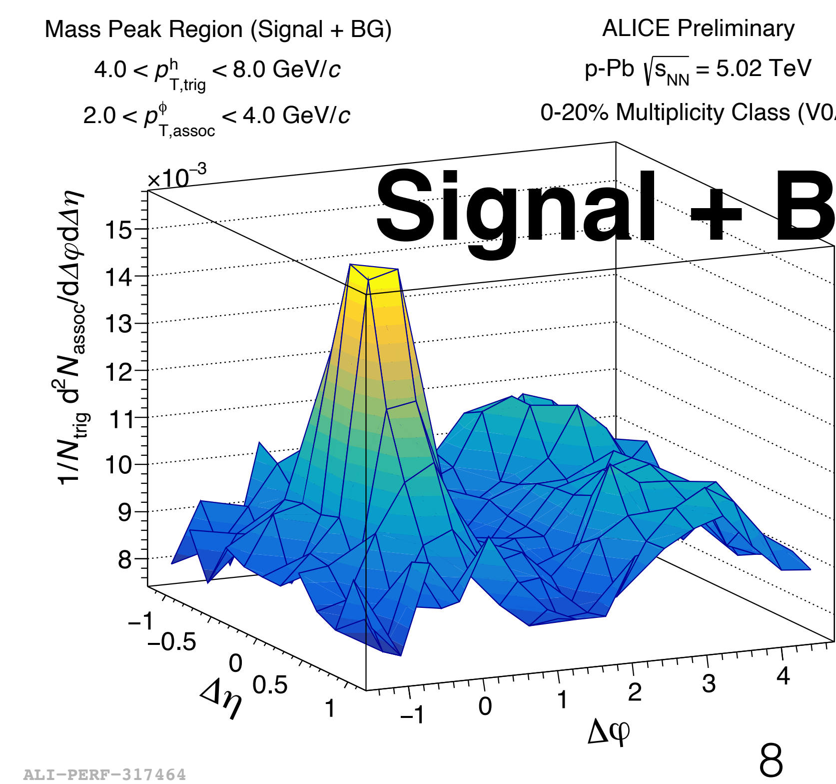



**Left SB**




**Right SB**




**Signal + BG**

**BG Estimation**

# Method: Correlation Background Estimation

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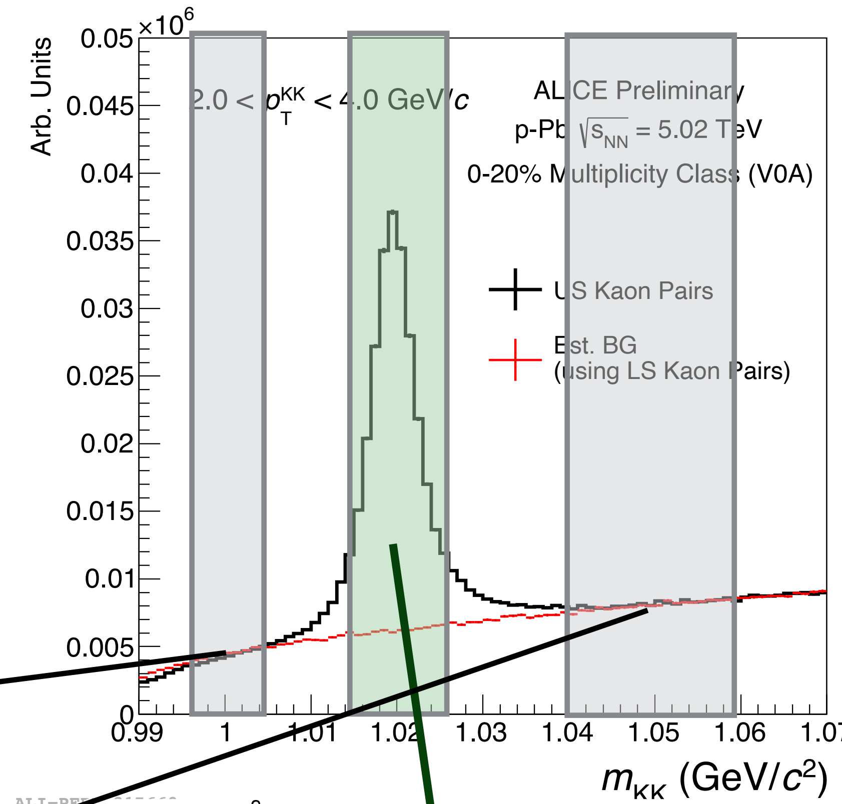
Averaging and scaling correlations in Sideband region (gray) gives estimate of BG in the peak region (green)

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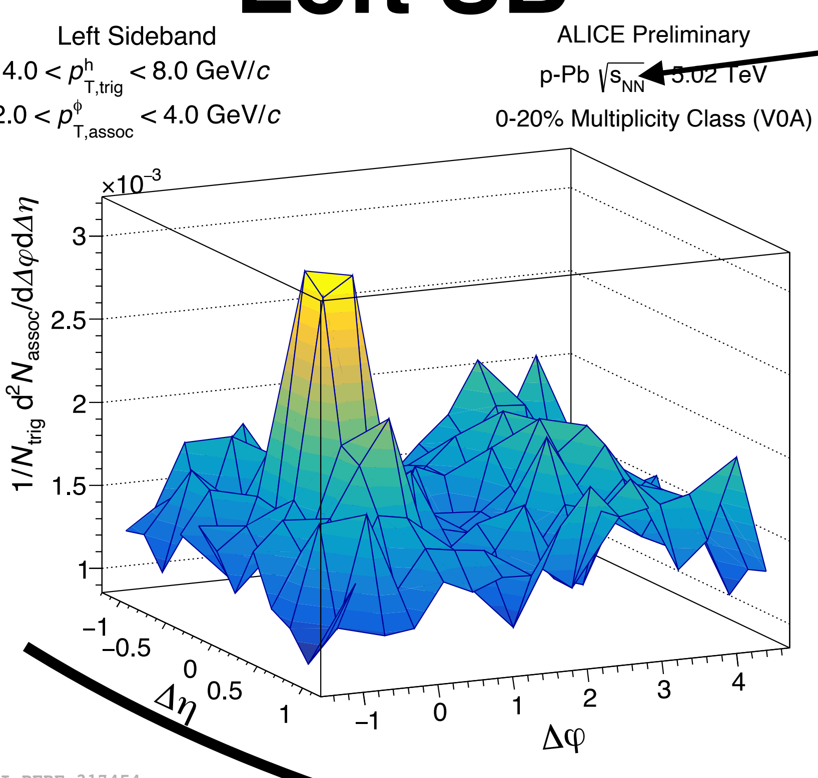
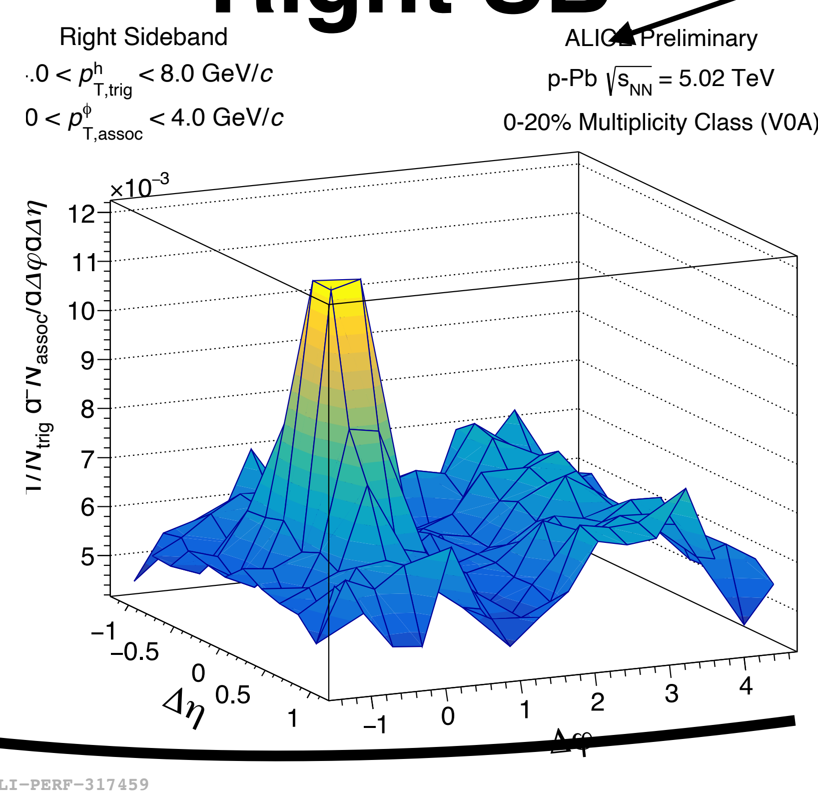
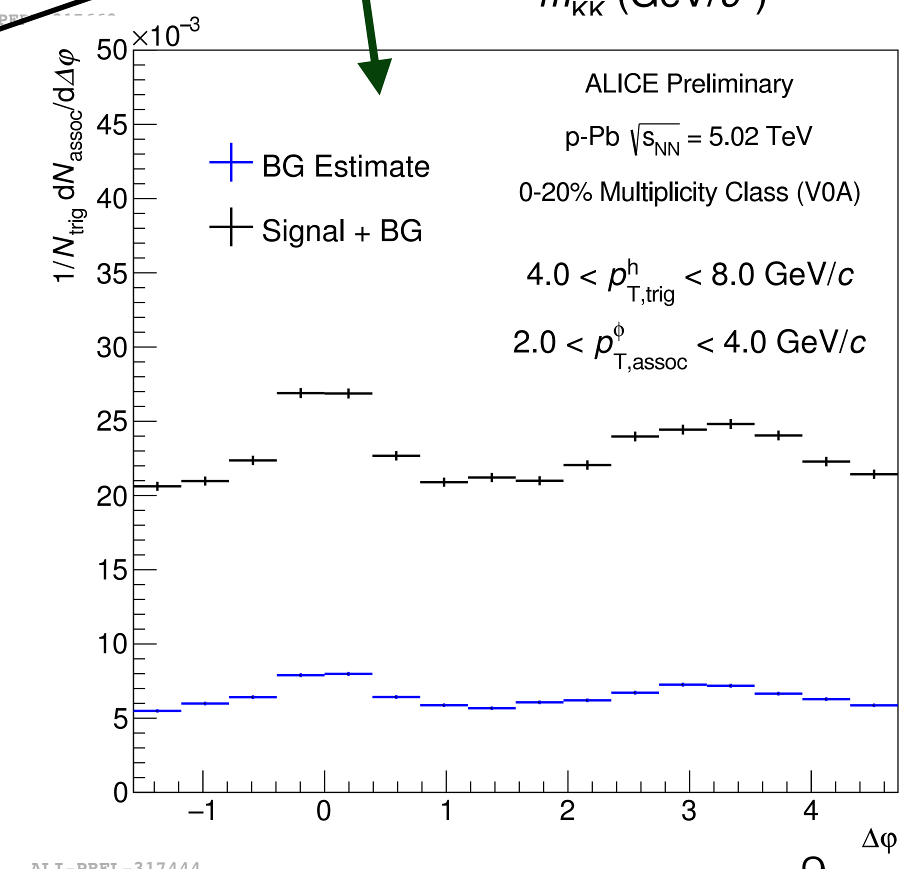



**Right SB**




**BG Estimation**

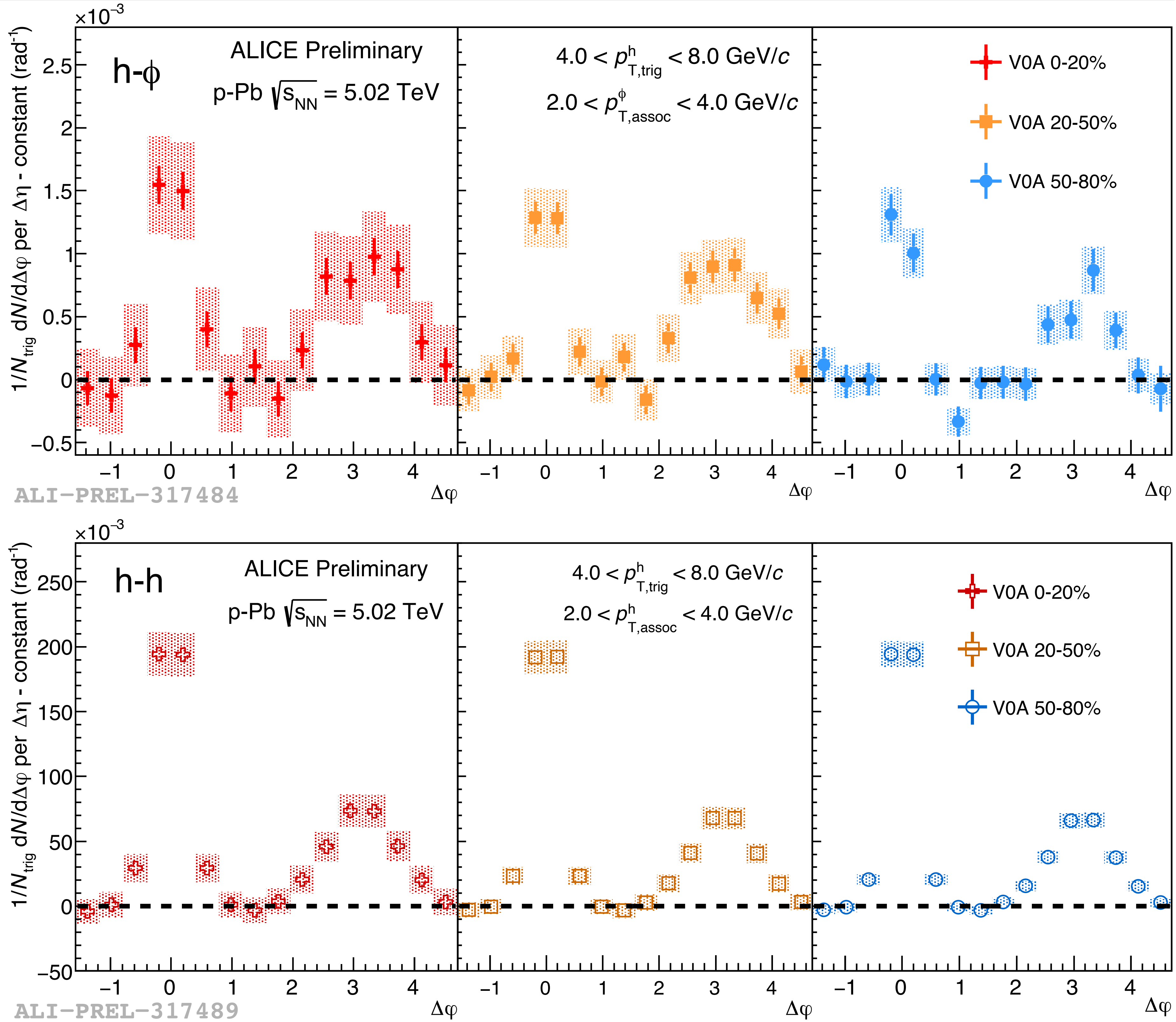


# h-ϕ and h-h Δ𝜑 Correlations

Jet yields extracted from projected 1D Δ𝜑 correlations

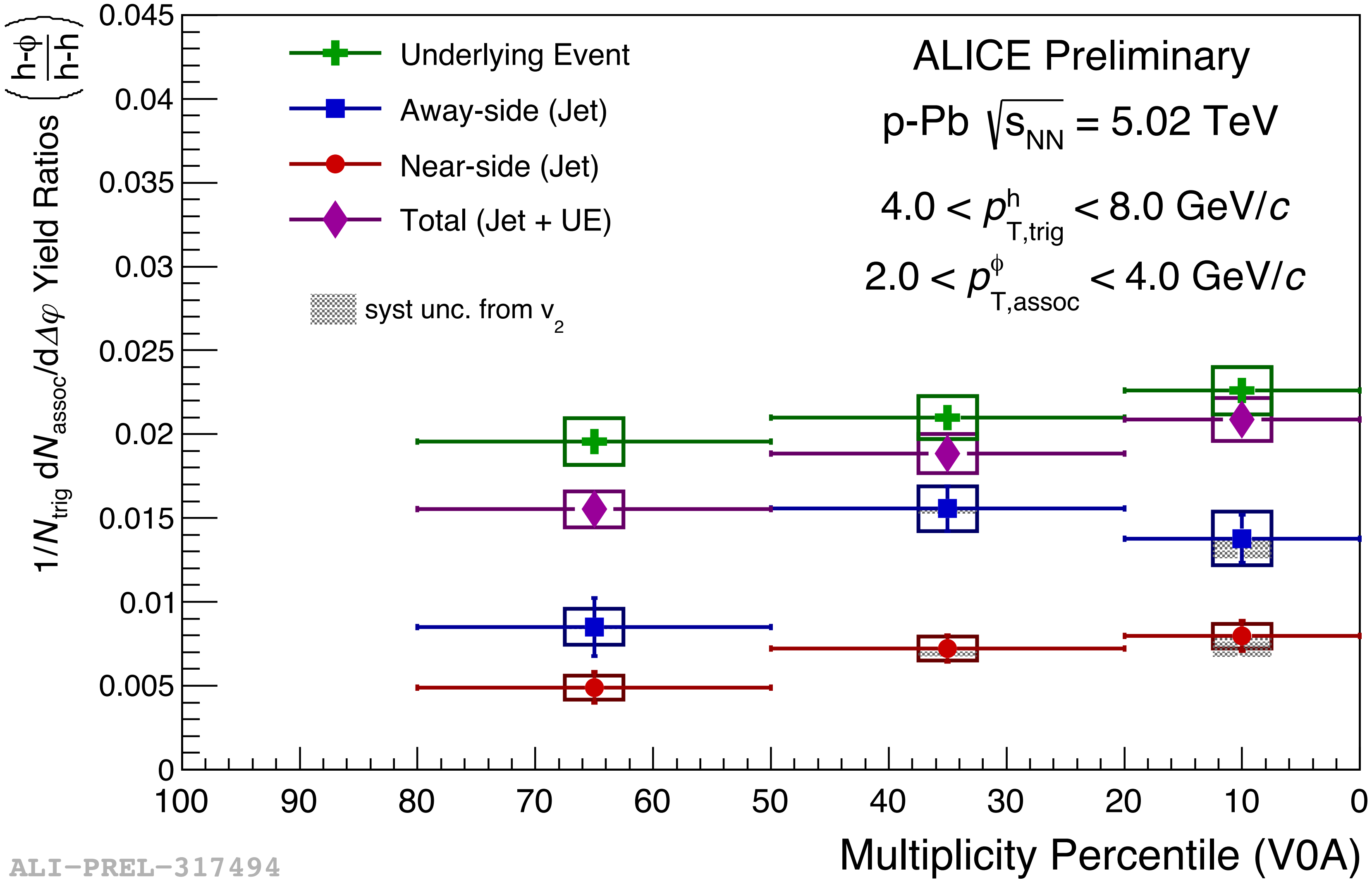
"Underlying event" pairs estimated with constant term under jet peaks

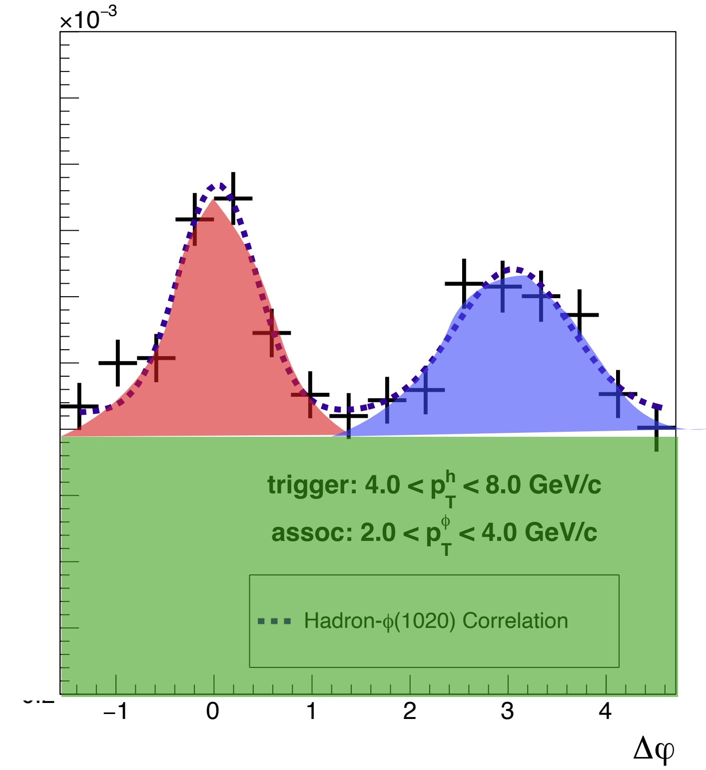
Di-hadron correlations give jet and "underlying event" yields for h-h pairs

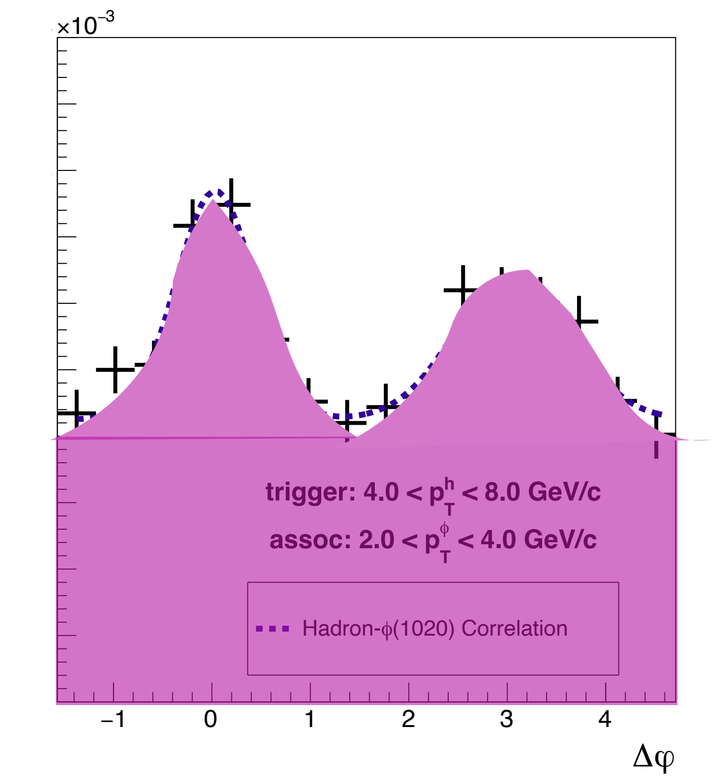


# (ϕ/h) ratio in Jet and Underlying Event

**(h-ϕ)/(h-h)**

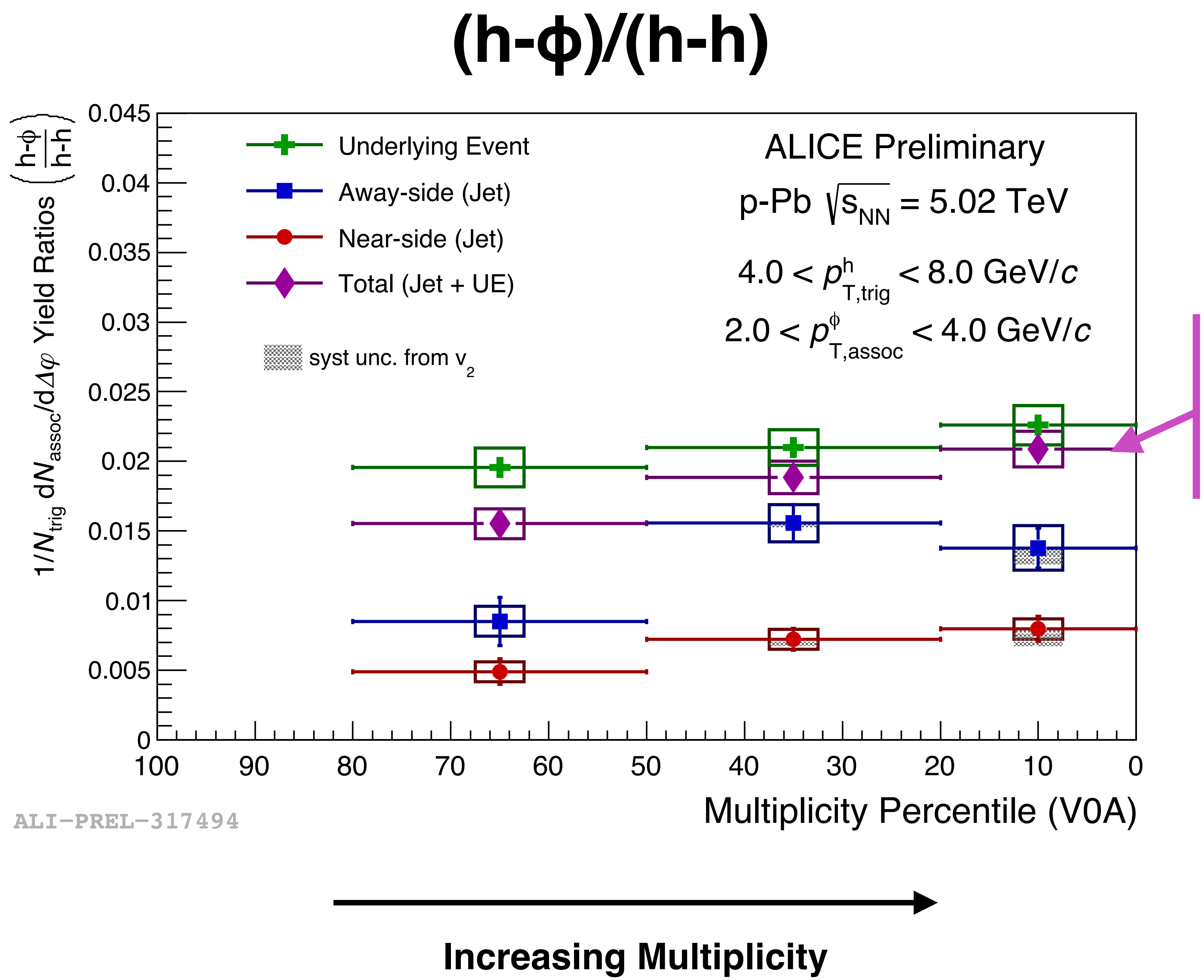



**Increasing Multiplicity**

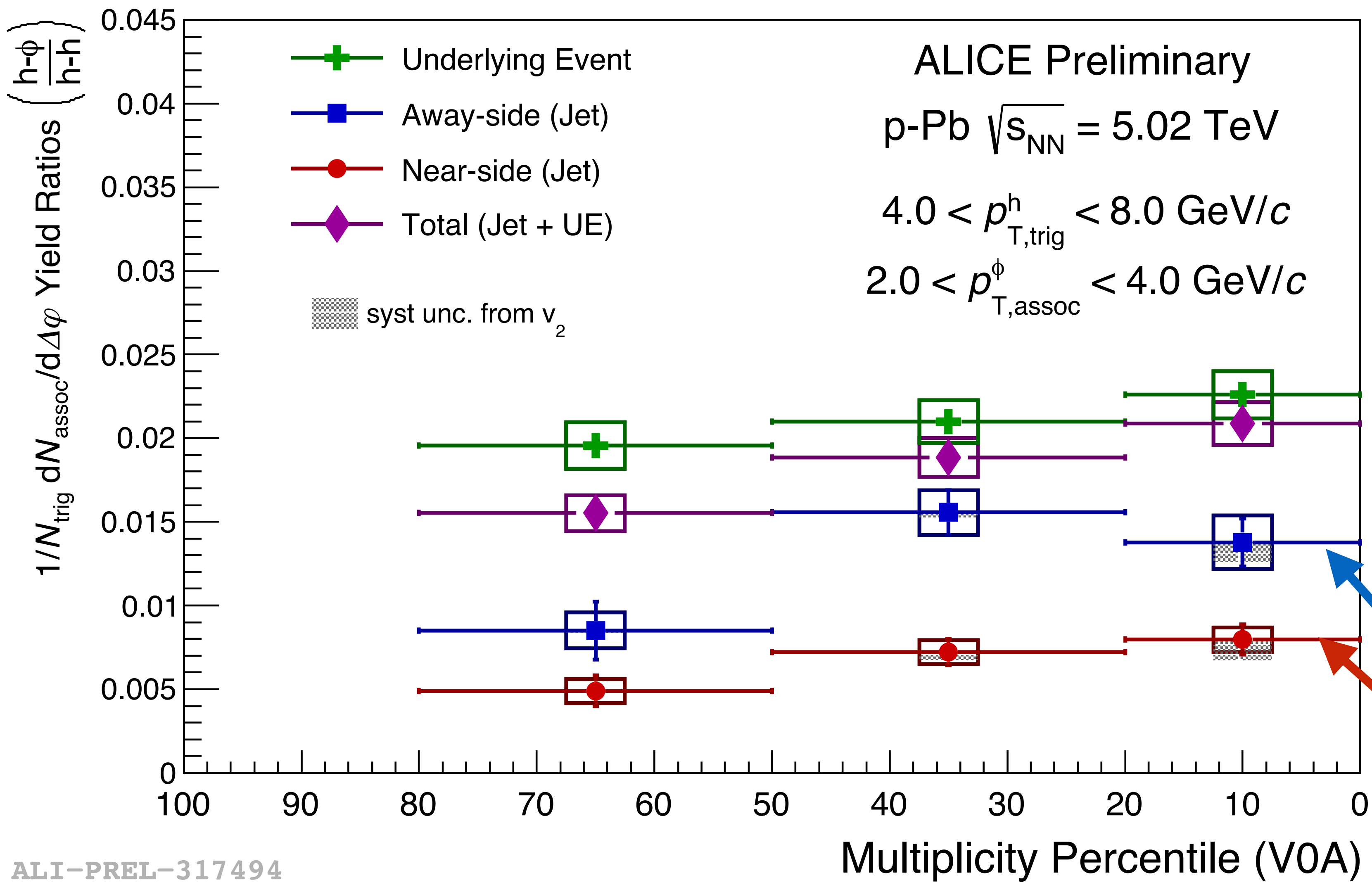
# (ϕ/h) ratio in Jet and Underlying Event




- Total h-ϕ/h-h pairs increases with multiplicity (as seen in inclusive $\phi/\pi$ measurement)

# (ϕ/h) ratio in Jet and Underlying Event

## (h-ϕ)/(h-h)



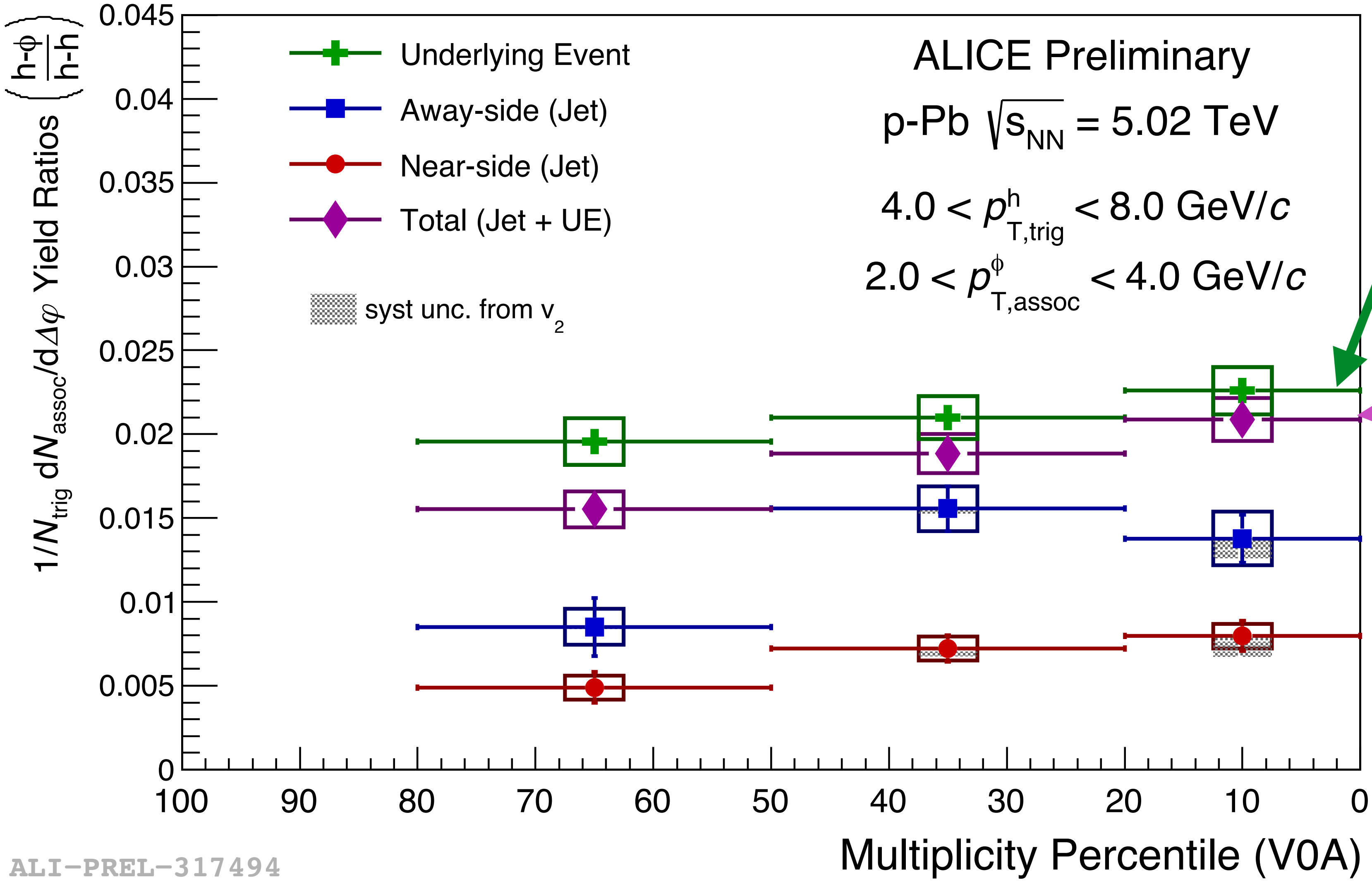

**Increasing Multiplicity**

### Jets (hard scattering)

- h-ϕ/h-h in **Jets** is lower than inclusive measurement
- Ratio in **Jets** slightly increases with multiplicity (changing jet production? jet-medium interaction?)
- Ratio in Away-side jet is higher than near-side, but increases with multiplicity at same rate

# (ϕ/h) ratio in Jet and Underlying Event

## (h-ϕ)/(h-h)




**Increasing Multiplicity**

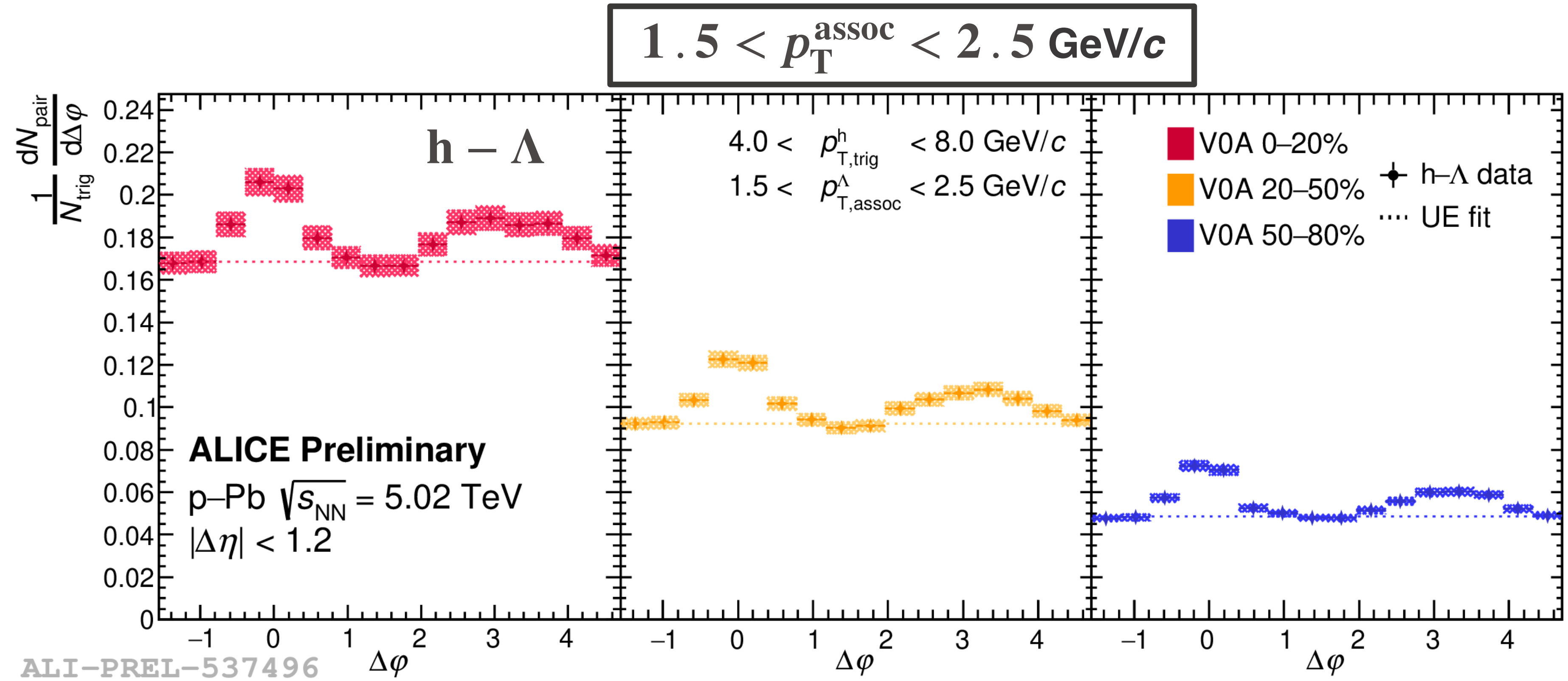
## UE (soft production)

- Ratio of h-ϕ/h-h in Underlying Event is systematically higher than Total pair ratio.
- Total pair ratio moves closer to Underlying Event ratio as multiplicity increases (the jet contribution to total pairs decreases vs multiplicity)

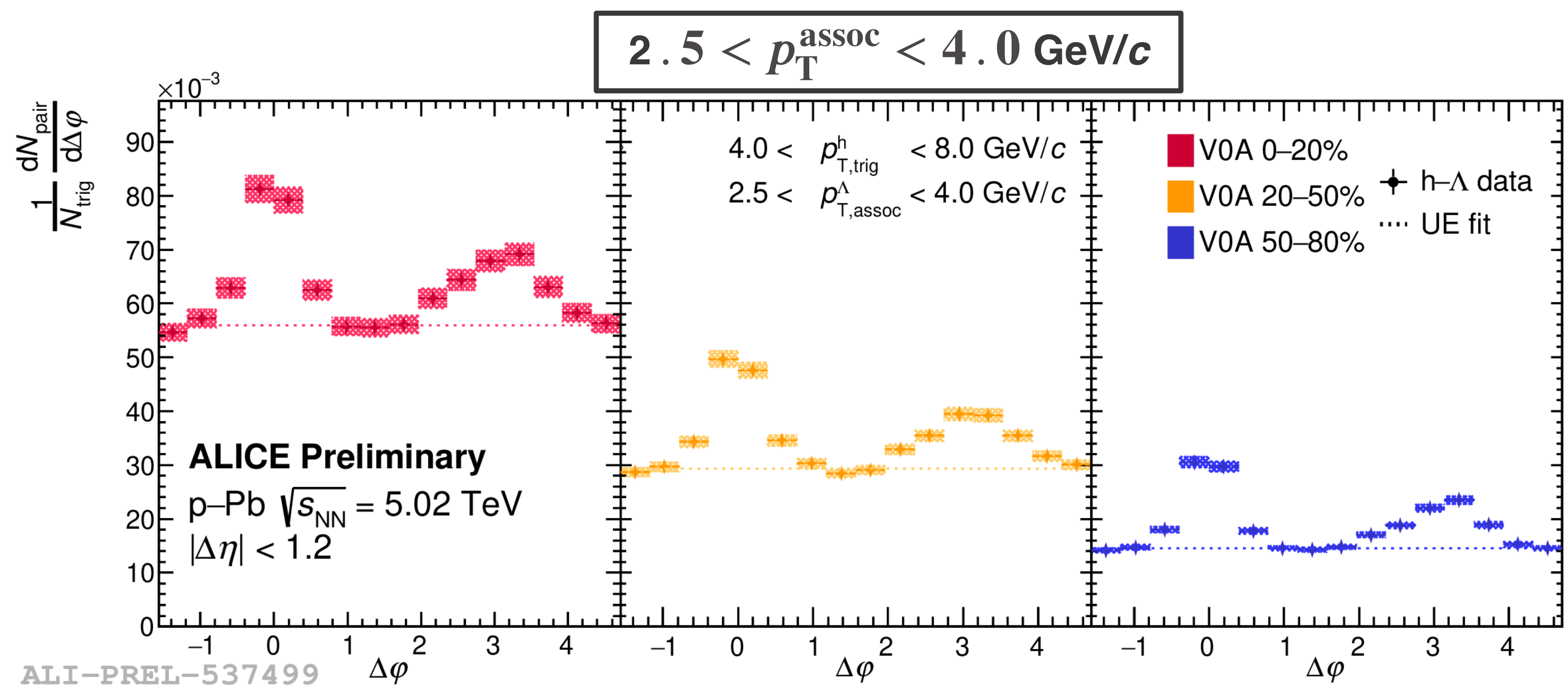
# h-Λ Δφ Correlations

$4 < p_{T}^{trigg} < 8$ GeV/$c$

Same technique of jet and underlying-event yield measurements as the ϕ



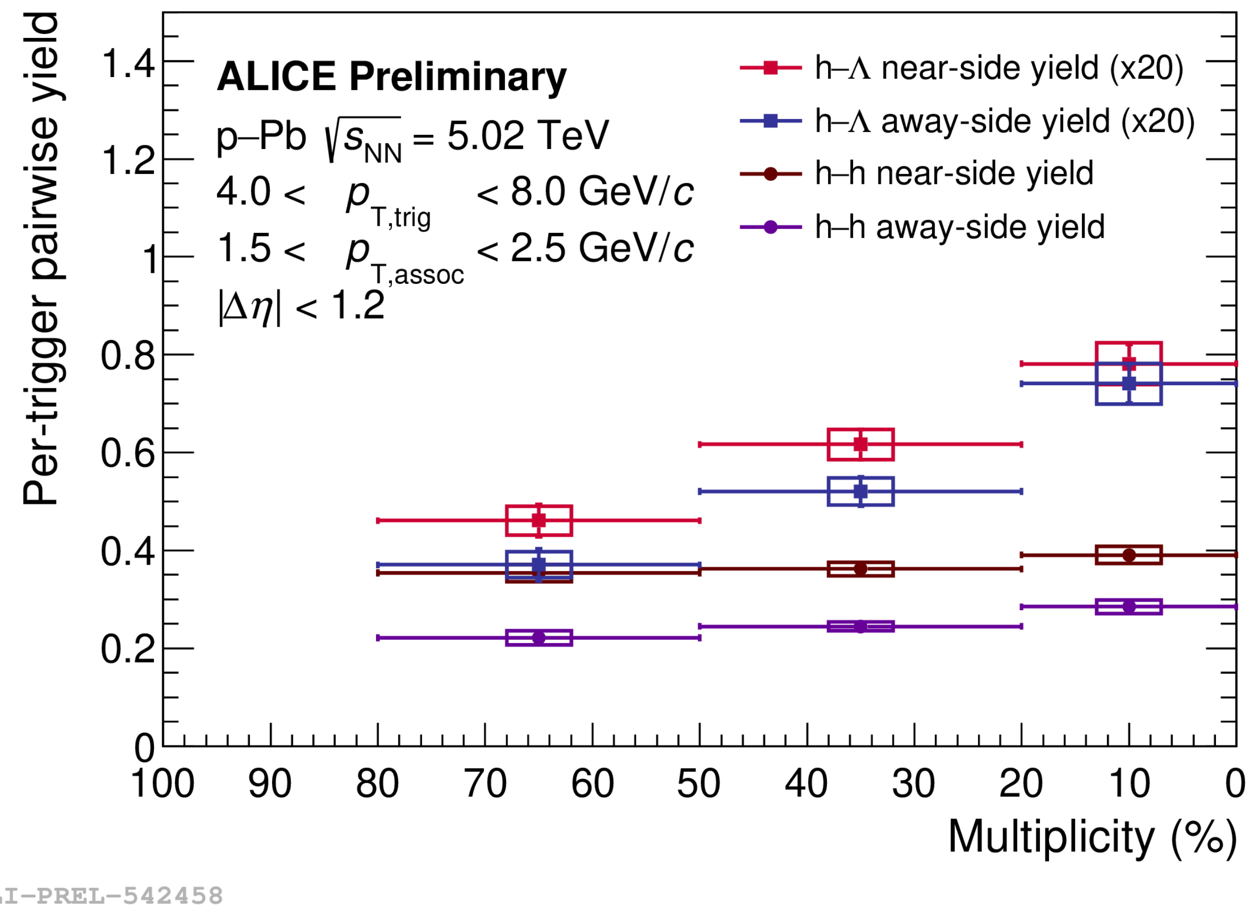

Split into a lower (top) and a higher (bottom) momentum range.



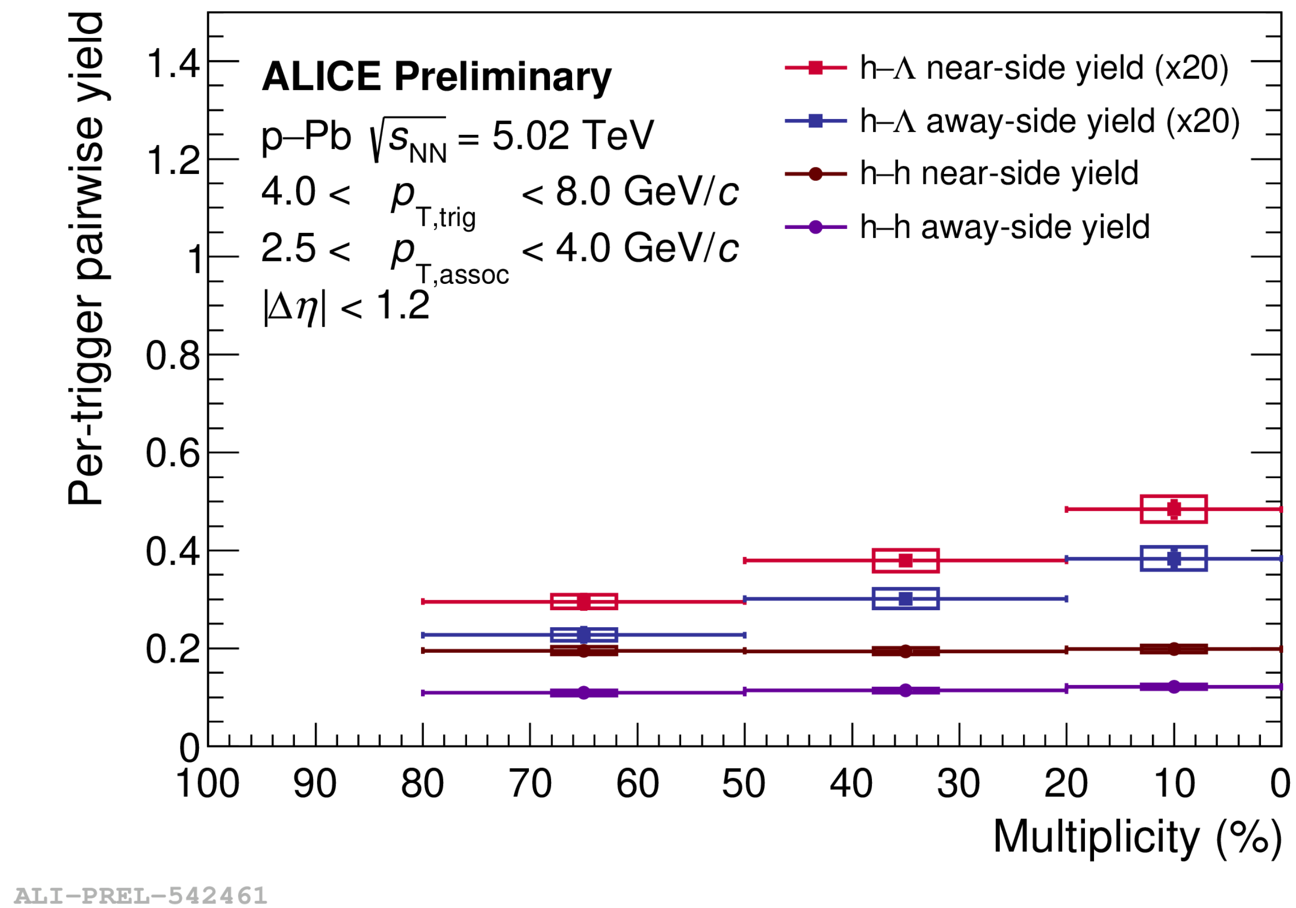
# h-Λ Jet yields

$4 < p_T^{trigg} < 8$ GeV/$c$

$1.5 < p_T^{assoc} < 2.5$ GeV/$c$



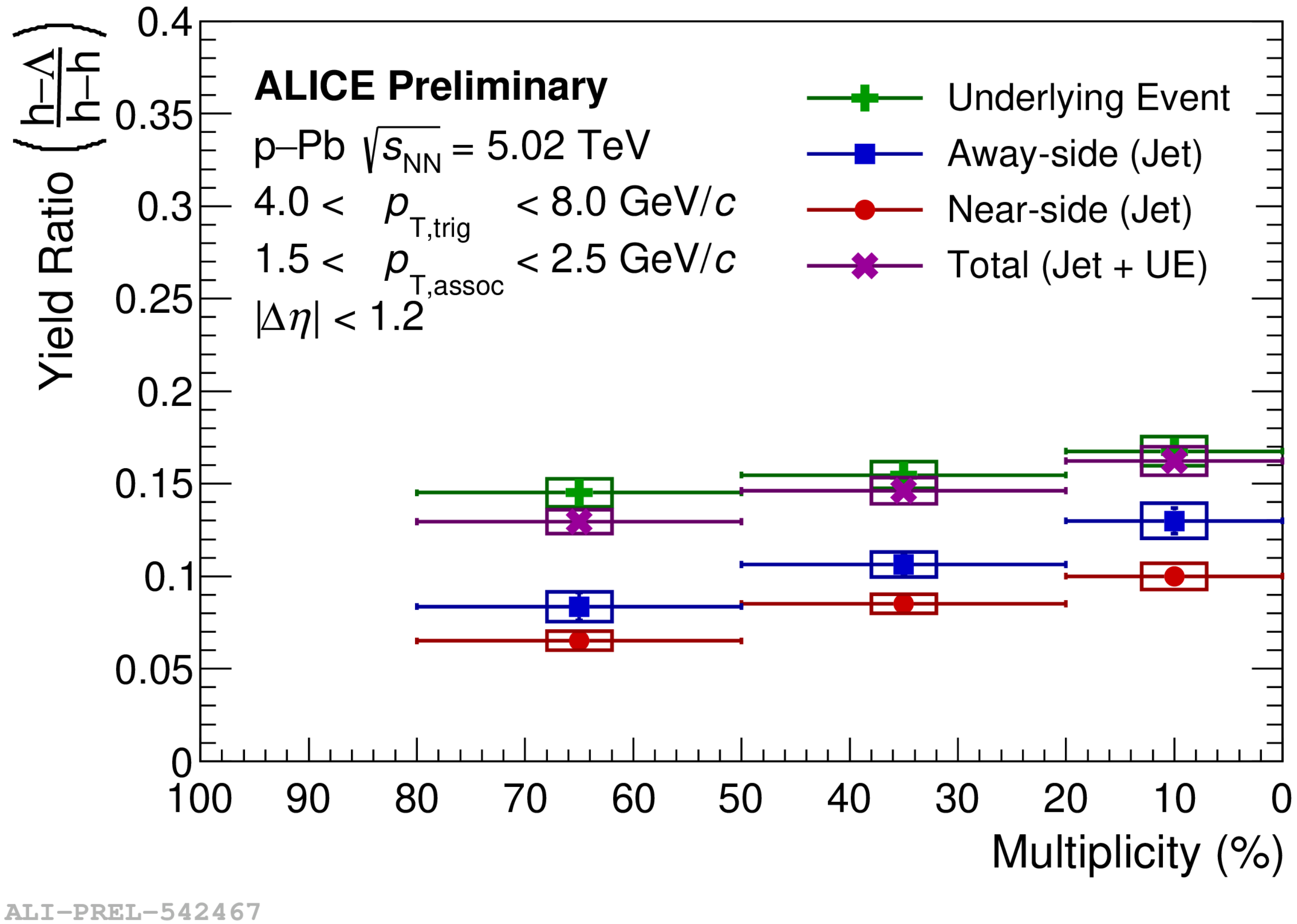

$2.5 < p_T^{assoc} < 4.0$ GeV/$c$



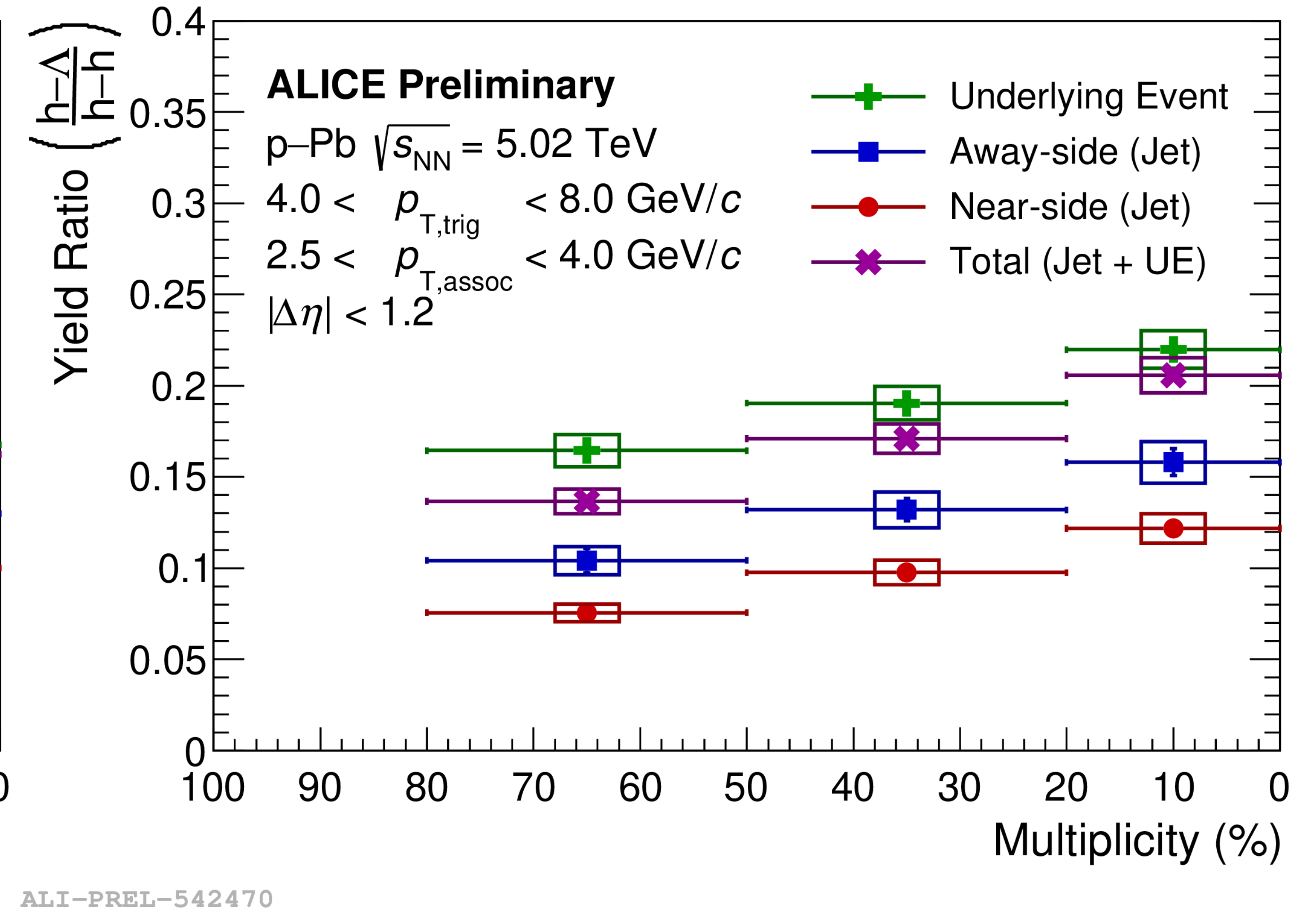

Per-trigger Λ yields in jets show significantly higher increase than inclusive hadrons as multiplicity increases (~70% increase vs ~10% increase). This is true for both Λ $p_T$ ranges

# (Λ/h) ratio in Jet and Underlying Event

$1.5 < p_T^{assoc} < 2.5$ GeV/$c$



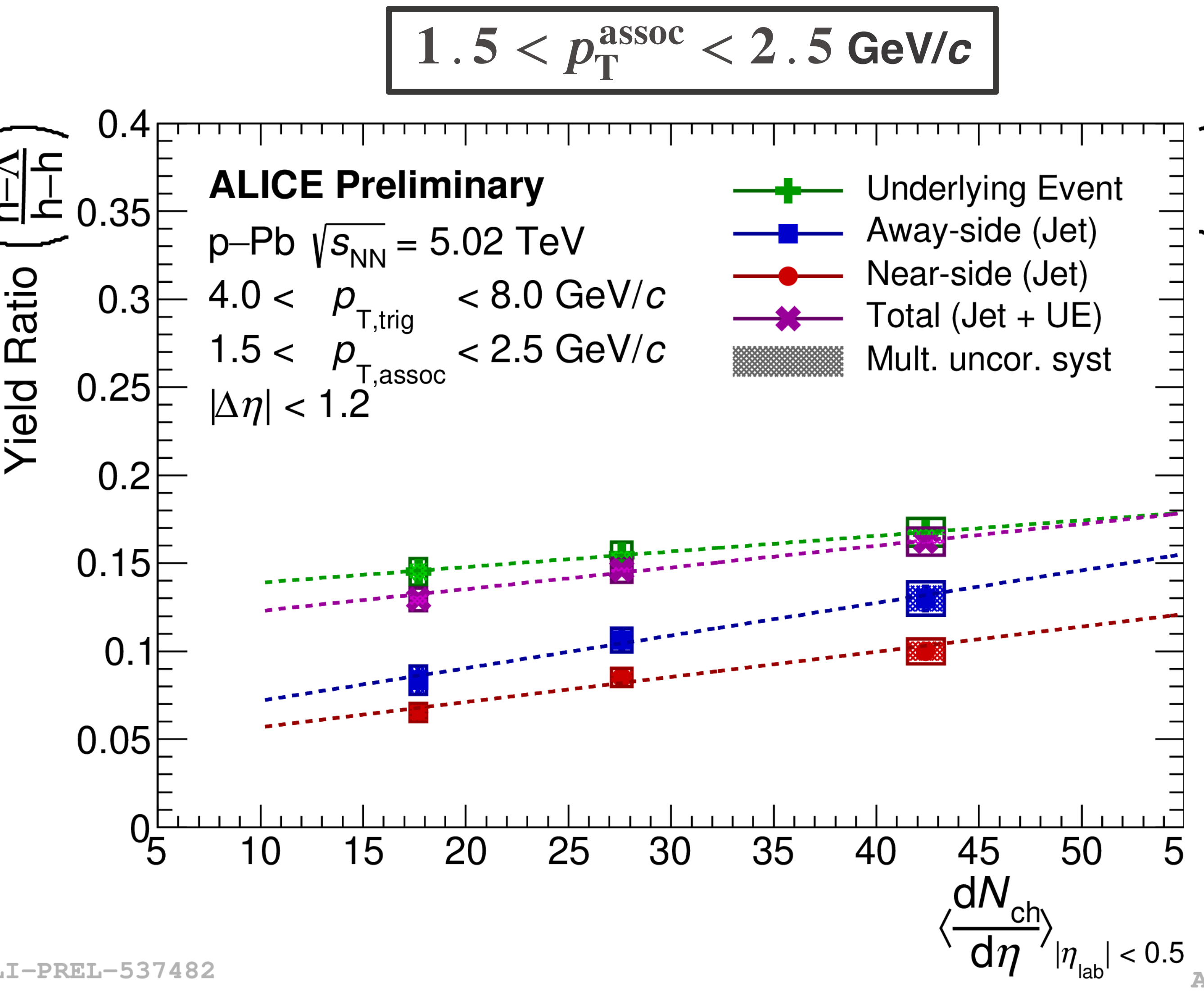

$2.5 < p_T^{assoc} < 4.0$ GeV/$c$

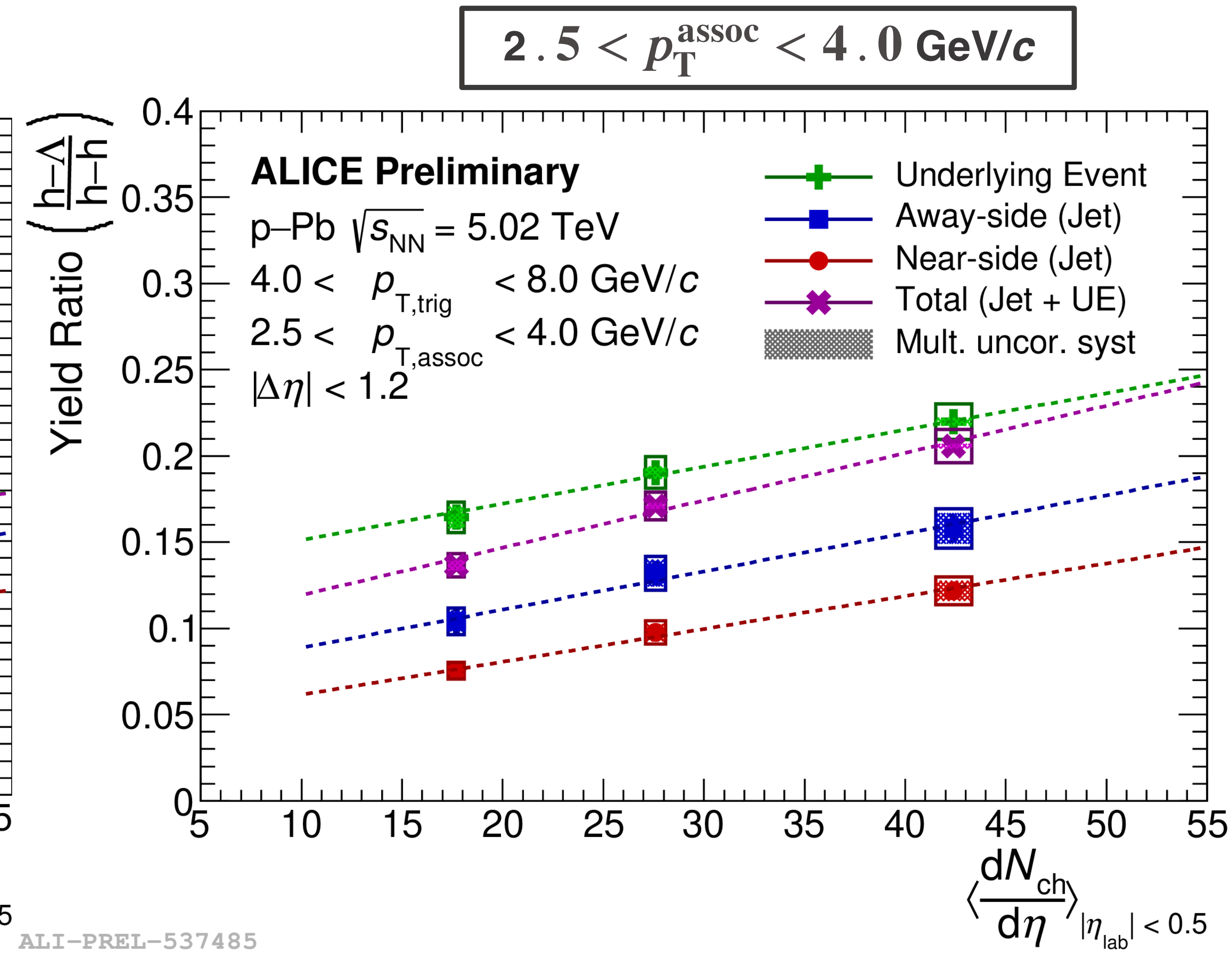



Λ/h ratios show same ordering as the ϕ/h ratios.

As seen in the jet yield measurement, in both momentum regions the ratio increases in the near and away-side jets

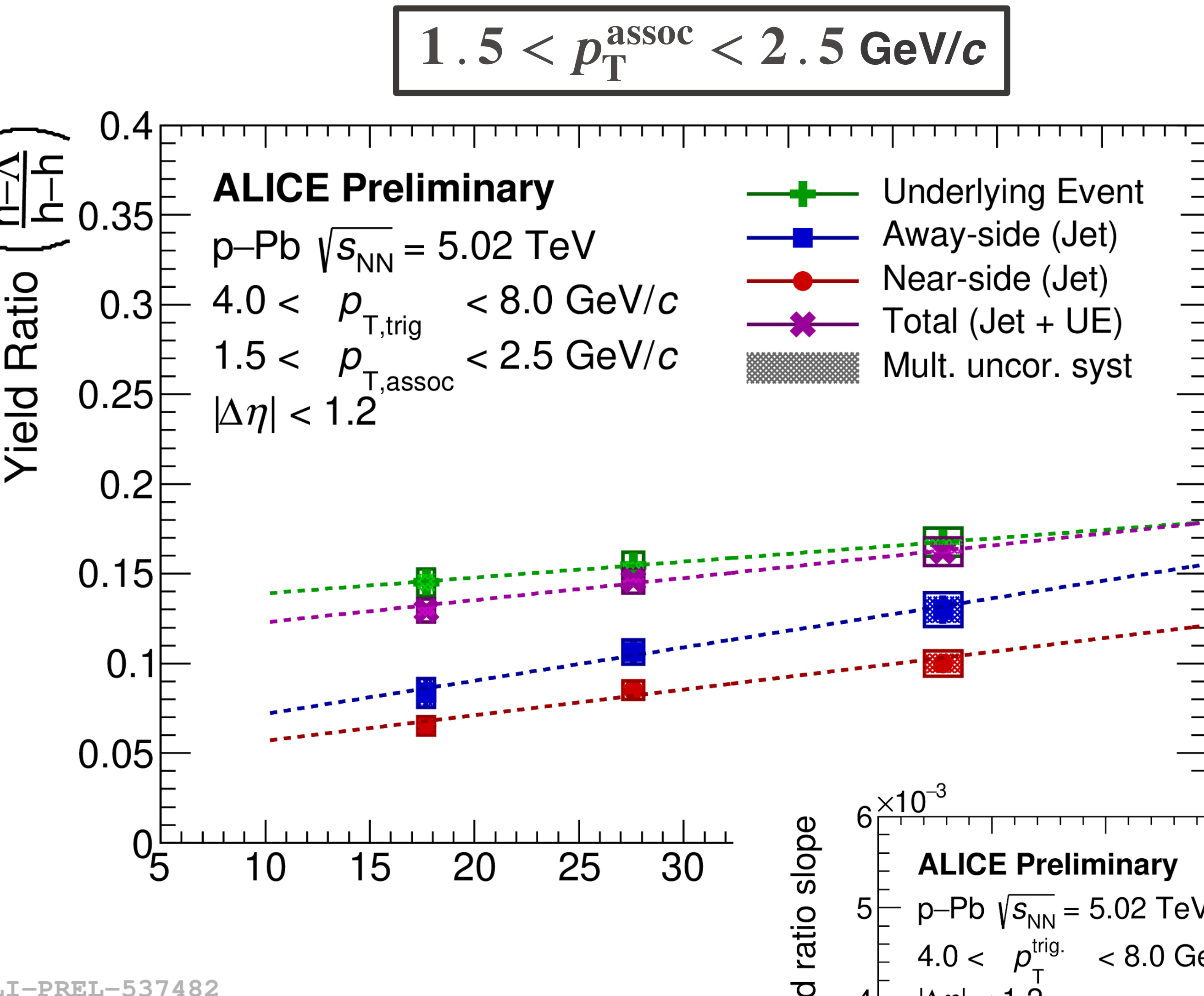
# (Λ/h) ratio in Jet and Underlying Event

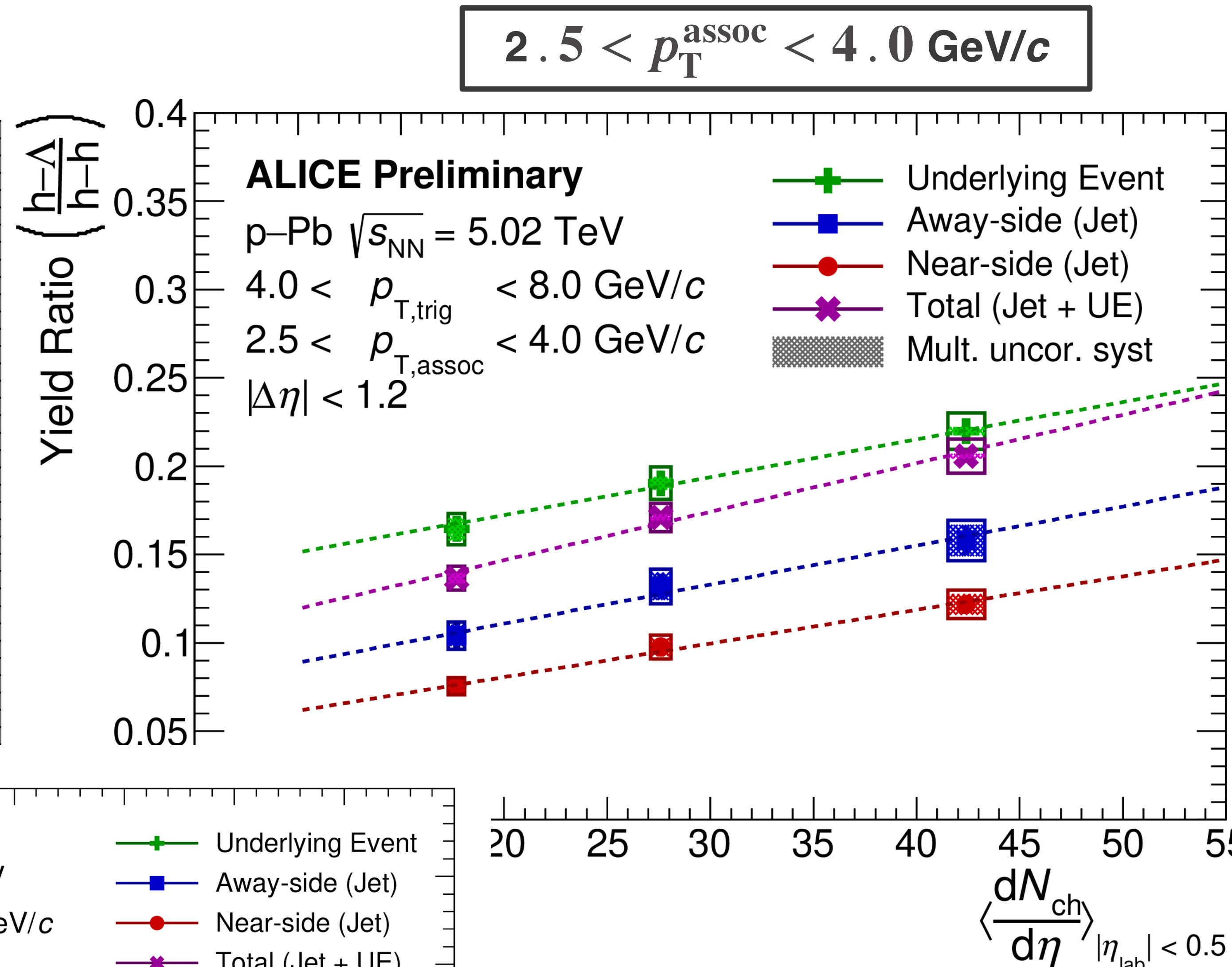


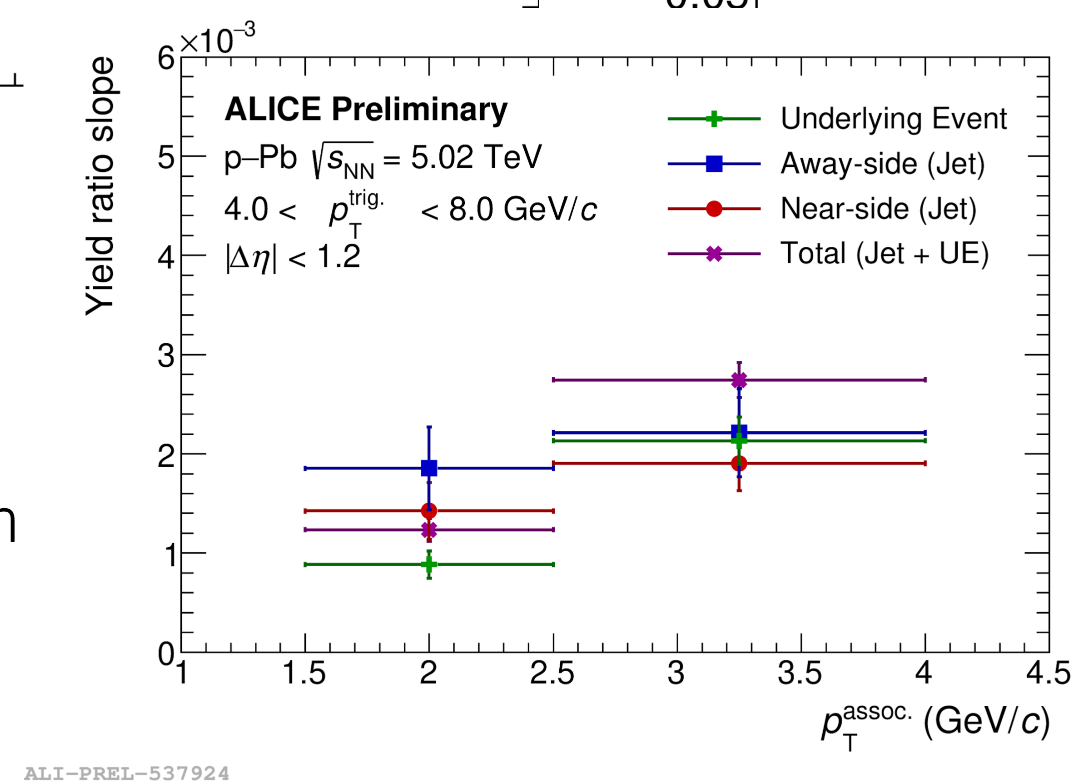




Plotting as a function of mean charged particle multiplicity allows for the slope of the ratio in each region to be compared with each other.

# (Λ/h) ratio in Jet and Underlying Event



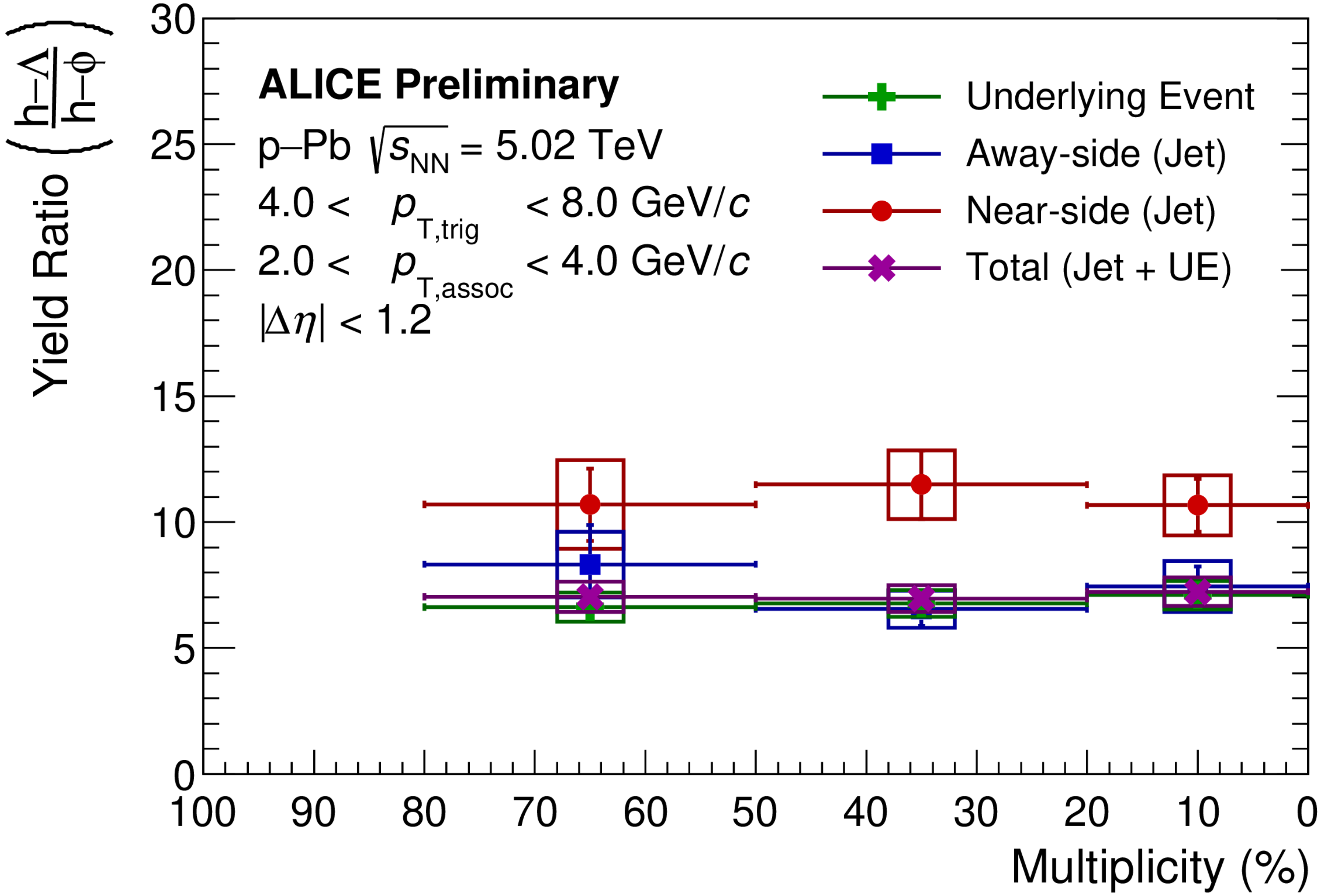




Larger increase is seen in all regions in the higher momentum measurement

Underlying event ratio in the lower momentum region shows smallest increase with multiplicity

# (Λ/ϕ) ratio in Jet and Underlying Event




ALI-PREL-542473

Comparing Λ/ϕ ratios in jet and underlying event shows no dependence on multiplicity, as expected from inclusive measurements (ϕ behaves as a s=~1-2 particle)

However, Λ/ϕ ratio is systematically higher in the nearside jet (difference in hidden vs open strangeness in jet fragmentation?)

# Conclusions

**h-ϕ & h-Λ correlations in p-Pb measured in ALICE**

- Underlying event (h-ϕ)/(h-h) and (h-Λ)/(h-h) ratios consistently higher than other production regions

→ **Strange particle production highest in the underlying event**

- As multiplicity increases, events shift towards higher fraction of production coming from the underlying event rather than jets

→ **Total ratio increase partly coming from different production methods between low and high multiplicity events**

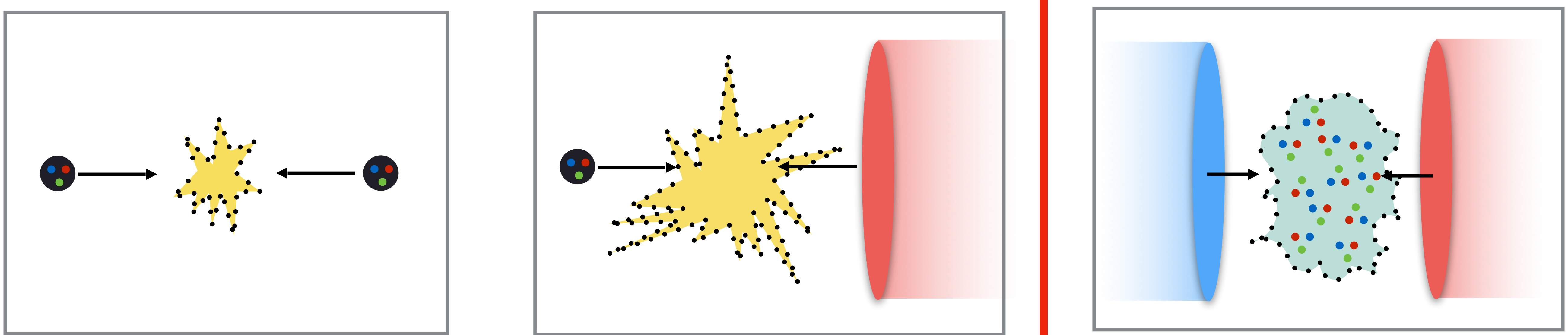
- (h-ϕ)/(h-h) and (h-Λ)/(h-h) ratios in the near and away-side jet increase with multiplicity

→ **Strange particle production is increasing in jets and underlying event!**

# Back-up

# Motivation: Small Systems

**pp** | **p-Pb** | **Pb-Pb**



used as reference for p-Pb and Pb-Pb collisions

allows for the probing of nuclear effects present in PbPb but with no(**?**) medium

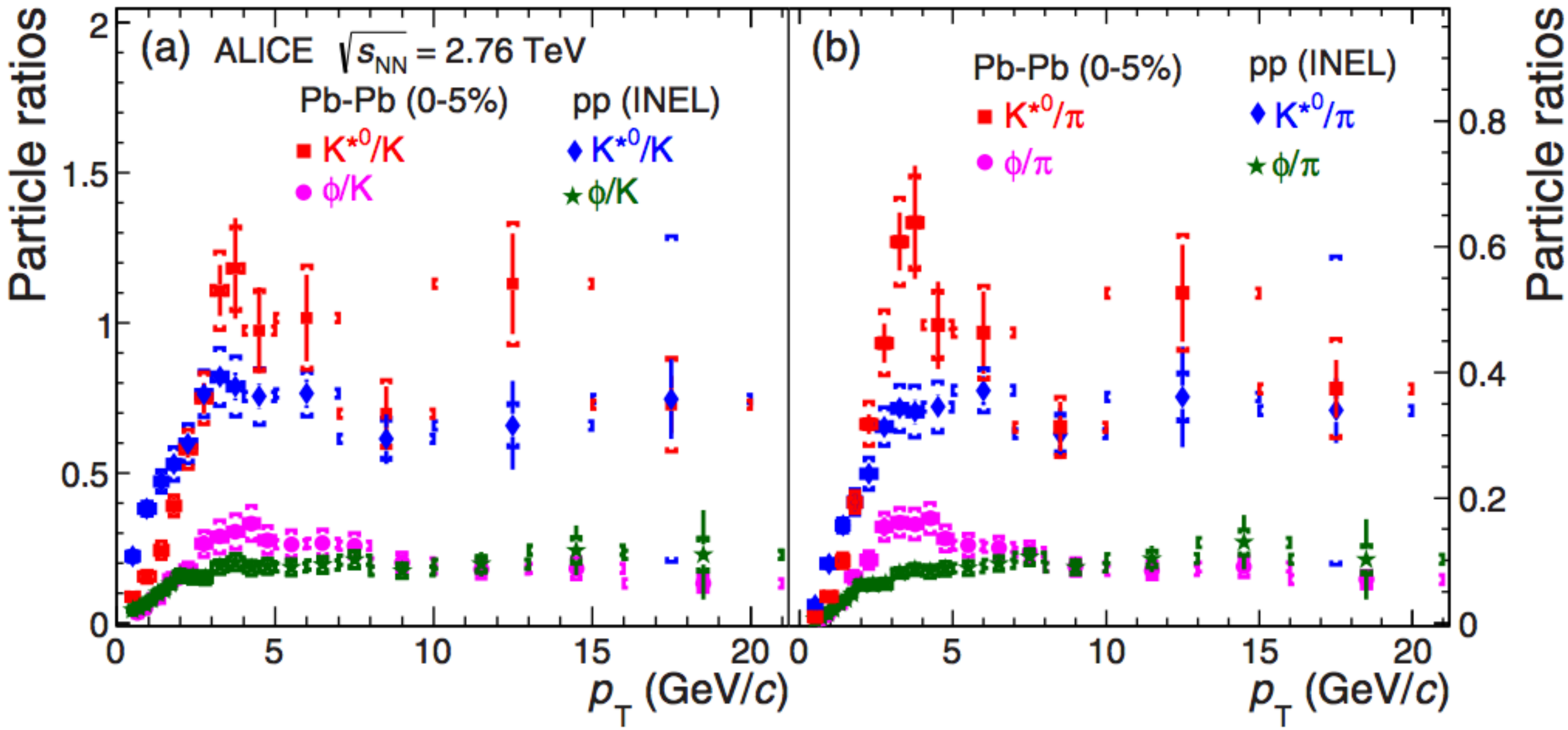
High energy heavy-ion collisions used to study QGP

**Increasing System Size** →

**<u>Open Question:</u>** Do the signatures of QGP “turn on” only for Pb-Pb? Or is there a smooth transition from pp to Pb-Pb collisions?

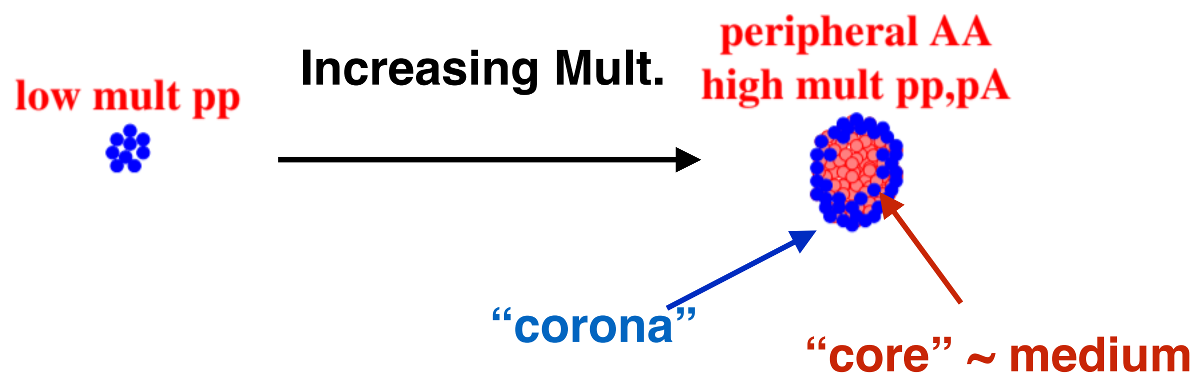
# Motivation: Particle Ratio in PbPb and pp

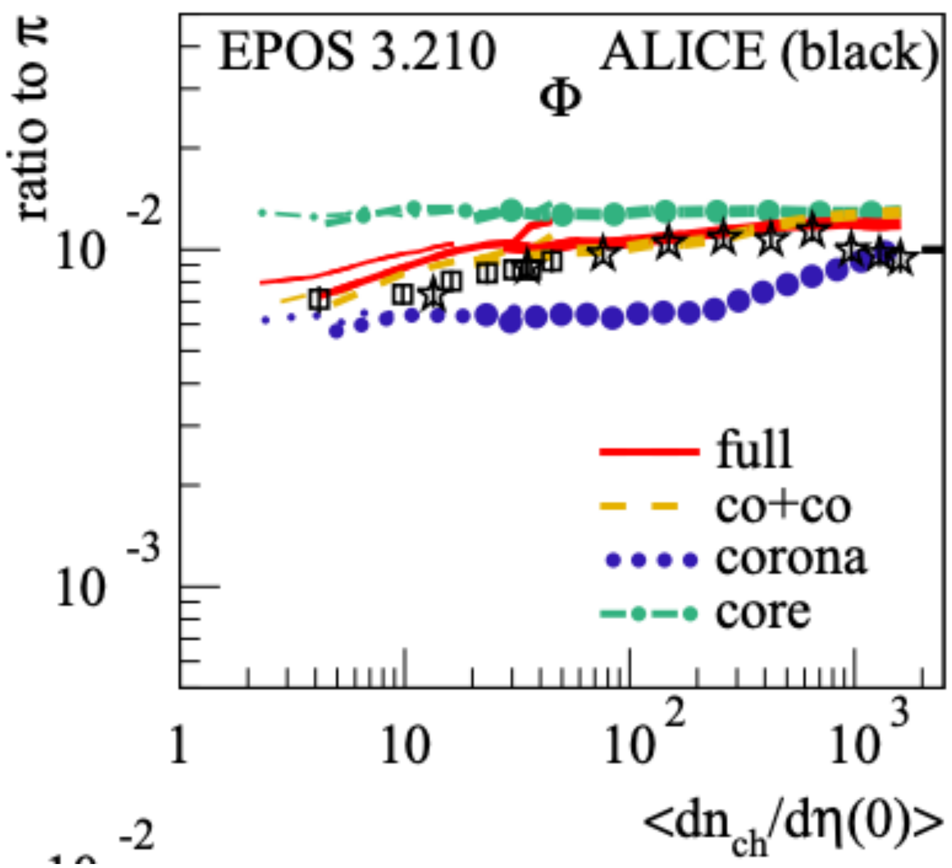
PRC 95 064606 (2017)




High Multiplicity PbPb collisions show the $\phi/\pi$ ratio (*right*) is enhanced compared to pp. The enhancement is most present in the ~1-5 GeV/c $p_T$ region, before converging at high $p_T$ for all collision systems/sizes.

# Motivation: ϕ/h ratios in p-Pb




**ϕ/π**

Can also be useful to see where this enhancement comes from in theory calculations.

Looking at EPOS, particle ratio in the “core” (hydro) and the “corona” (pp-like) stays mostly flat as a function of multiplicity.

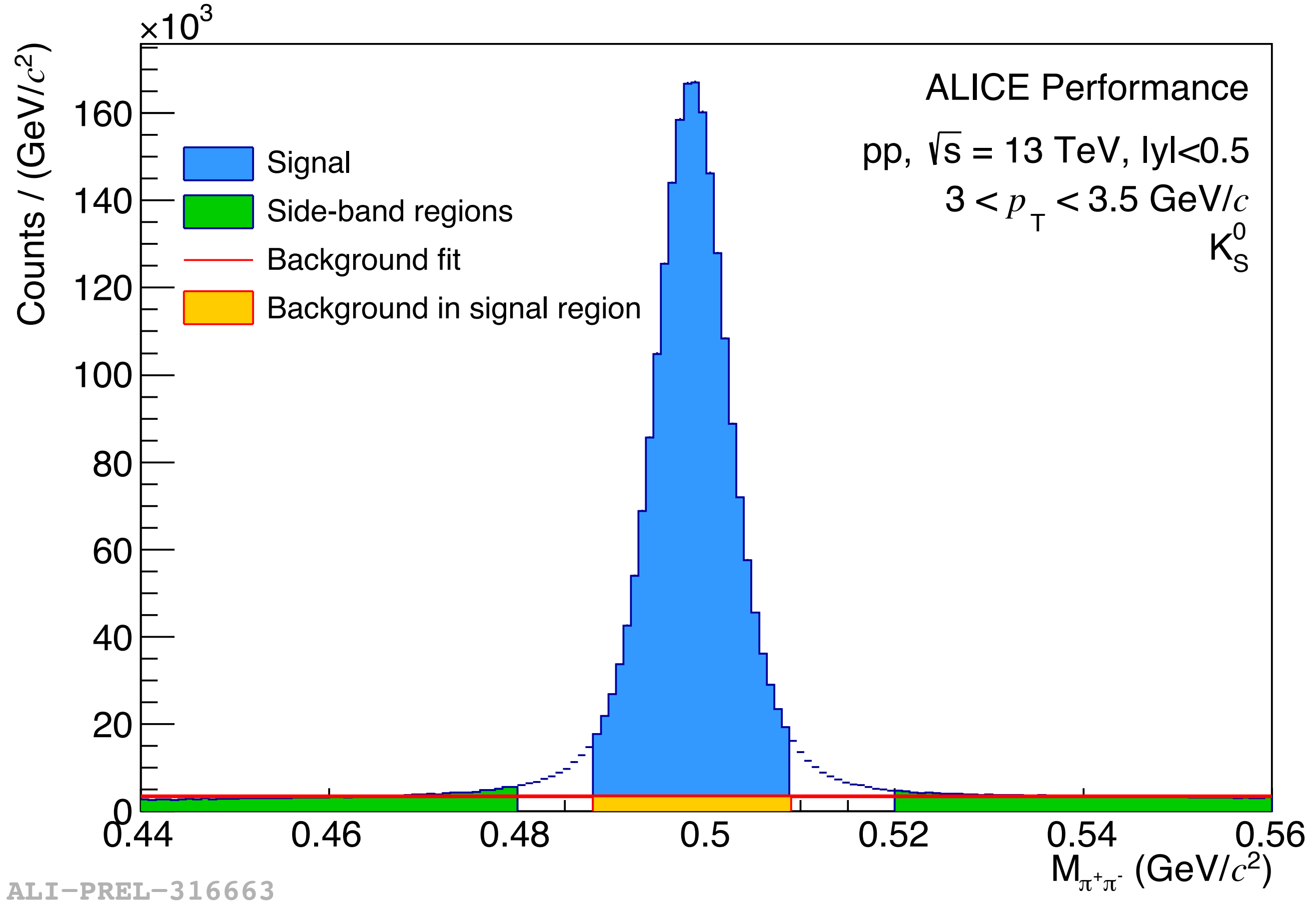
The total ratio still increases as a function of system size due to increased contribution of core

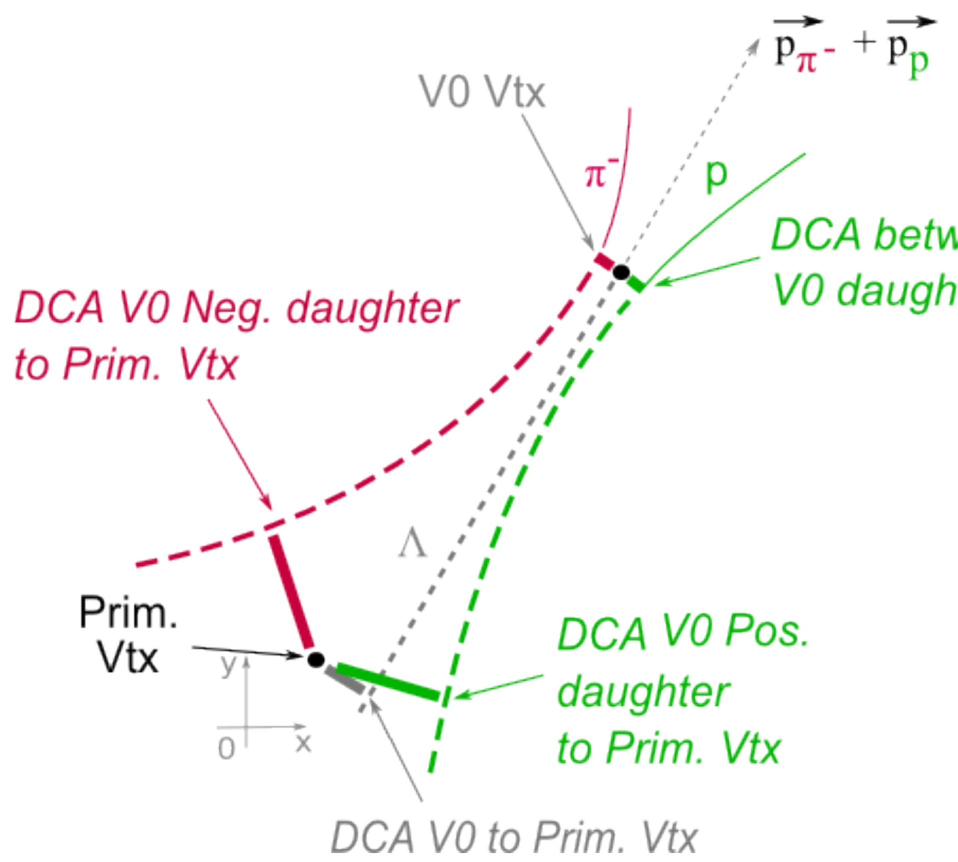
Resonance production in high energy collisions from small to big systems
arXiv:1812.06330v1

# Correlated background from fake $V^0$

$$\frac{dN^{full\ corrected}_{pair}}{d\Delta\varphi}(\Delta\varphi, p_T^{trigg}) = \frac{1}{N^{full\ corrected}_{trigg}}(p_T^{trigg})\left(\frac{dN^{corr}_{pair\ sig}}{d\Delta\varphi}(\Delta\varphi, p_T^{trigg}) - \frac{background}{signal + background}\frac{signal}{integral\ side}\frac{dN^{corr}_{pair\ side}}{d\Delta\varphi}(\Delta\varphi, p_T^{trigg})\right)$$

$$N^{full\ corrected}_{trigg}(p_T^{trigg}) = \frac{signal}{signal + backround}N^{\varepsilon\ corrected}_{trigg}(p_T^{trigg})$$



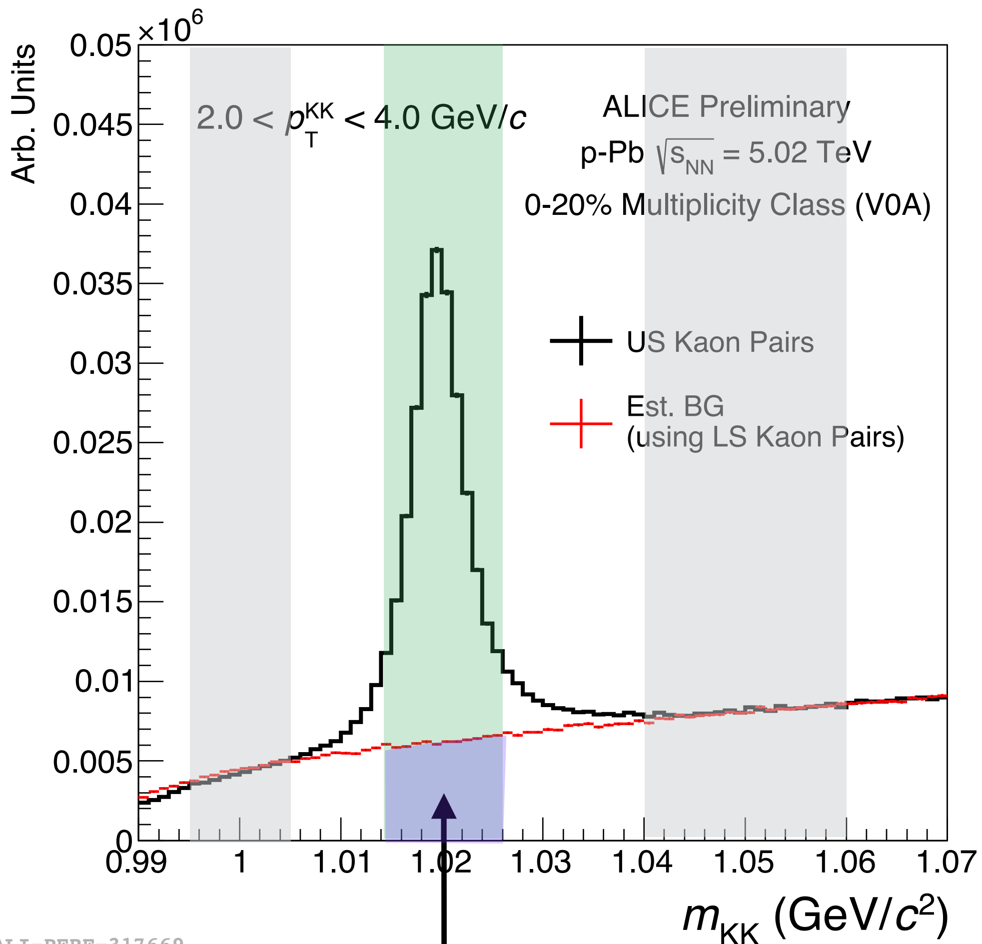

$K^0_S$ purity ~96% across entire trigger $p_T$ range

# Method: KK Background Estimation

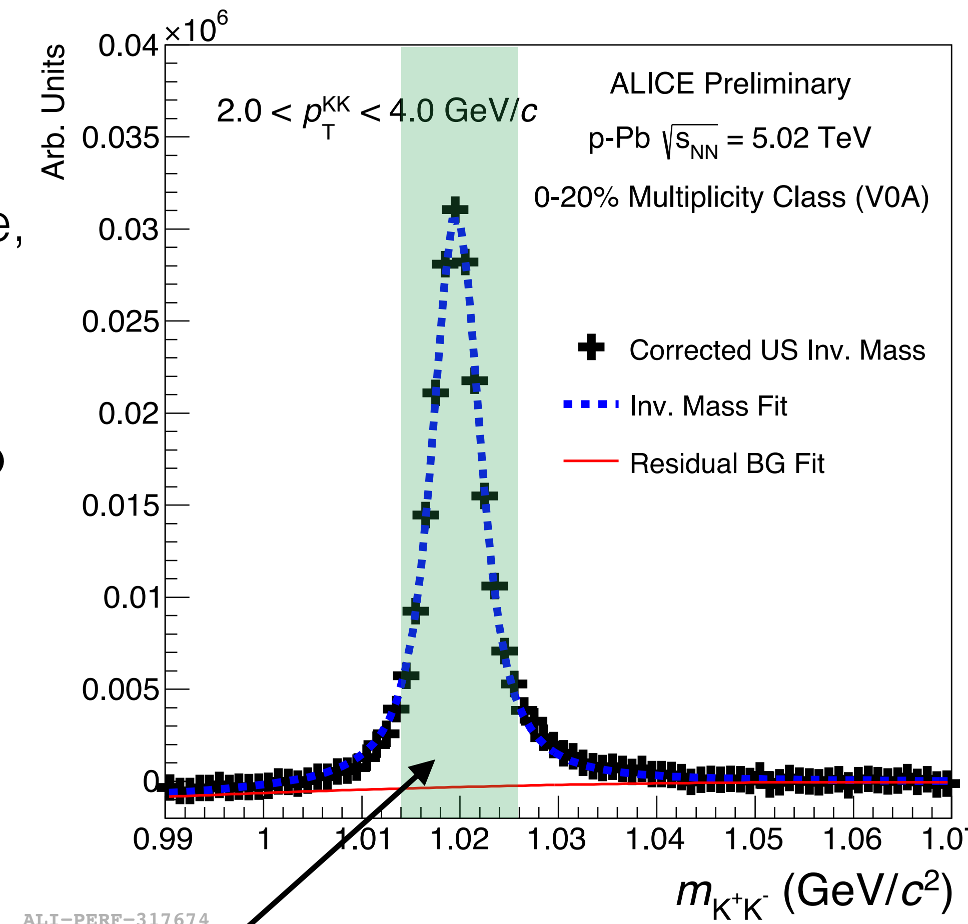
**RSB:** $0.995 < M_{KK} < 1.005$ GeV/$c^2$

**LSB:** $1.040 < M_{KK} < 1.060$ GeV/$c^2$

**Mass Peak:** $1.014 < M_{KK} < 1.026$ GeV/$c^2$




subtract off LS BG estimate, and fit with Voigt + pol2




Amount of BG underneath mass peak:

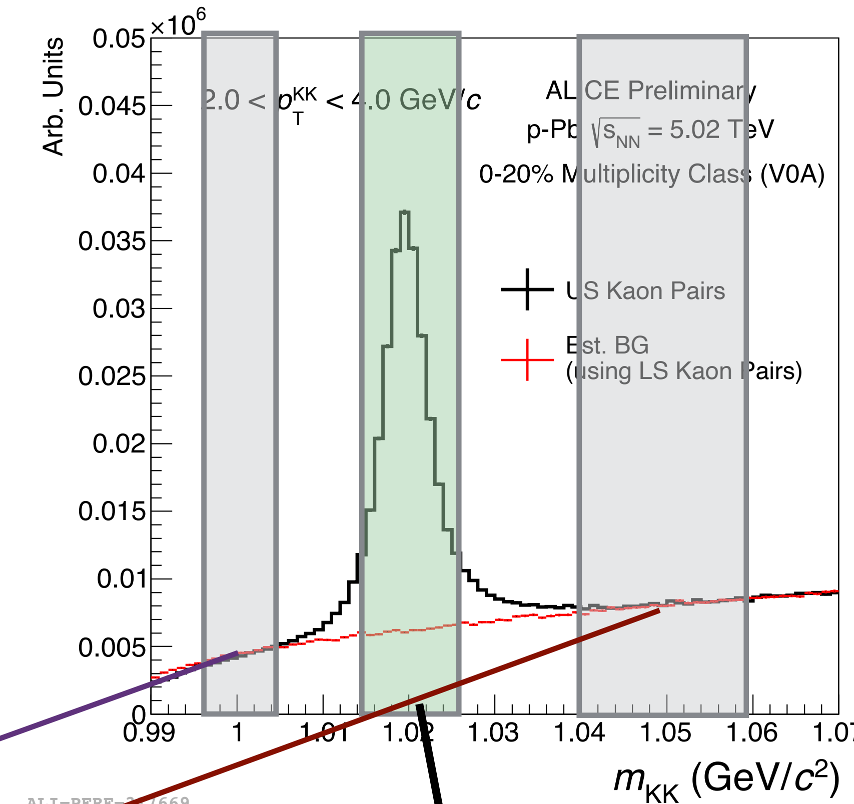
$$(\text{LS Peak Int.}) * \frac{\text{US SB Int.}}{\text{LS SB Int.}}$$

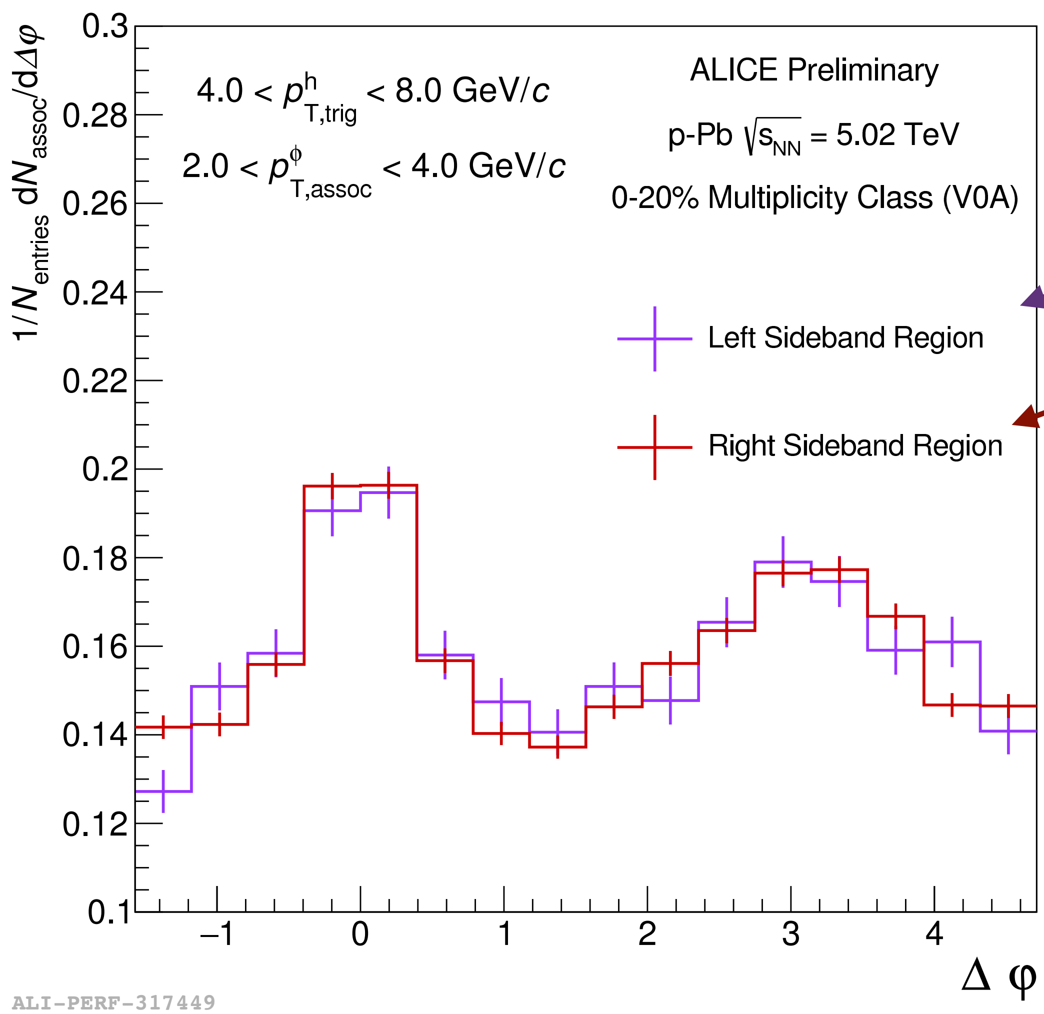
Use mass fit to calculate the percent of signal in the “mass peak” window used (~81%) = $(\text{Peak Range Correction})$

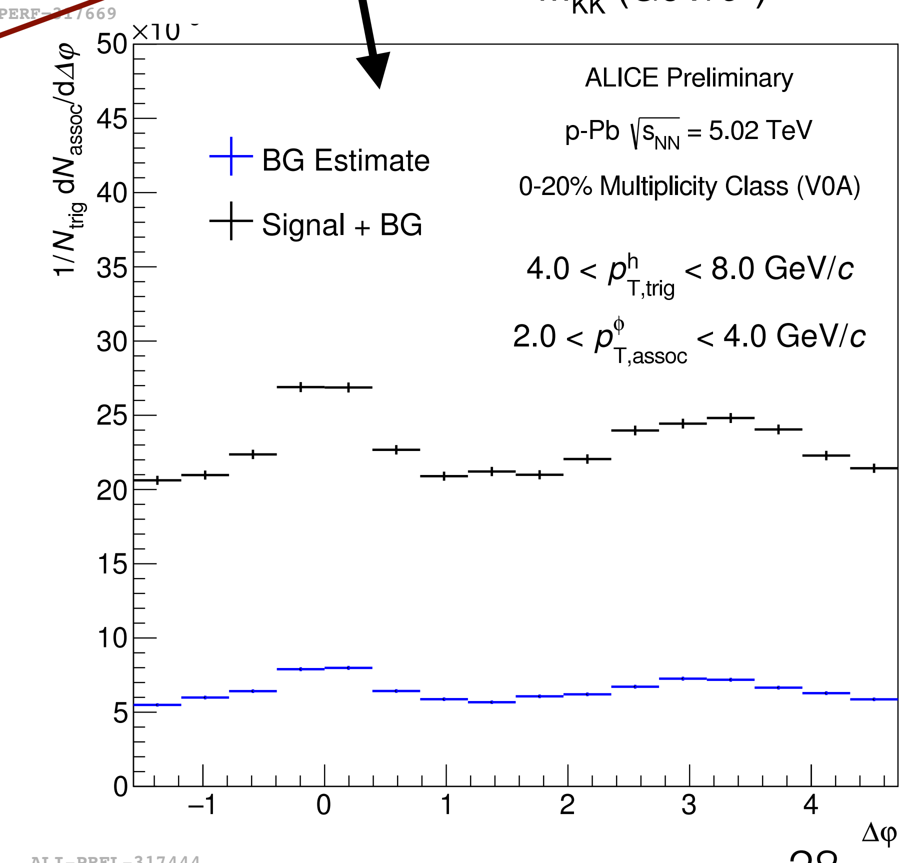
# Method: Correlation Background Estimation

Reconstructed ϕ from KK channel, so correlation has Signal (h-ϕ) and Background (h-(KK)) components (Signal/BG ~ 2.5)

Subtracting the scaled, averaged sideband correlations from the correlations in the peak region (green) removes this background.



# Per-trigger h-$\phi$(1020) 2D correlations

$$C_{trig}^{h-\phi}(\Delta\varphi,\Delta\eta) = (\text{Peak Range Correction}) * \Big( C_{trig}^{h-(USKK\ \text{Peak})}(\Delta\varphi,\Delta\eta) - (\text{LS Peak Int.}) * \frac{\text{US SB Int.}}{\text{LS SB Int.}} * \frac{1}{2} * (C_{trig}^{h-(USKK\ \text{LSB})}(\Delta\varphi,\Delta\eta) + C_{trig}^{h-(USKK\ \text{RSB})}(\Delta\varphi,\Delta\eta)) \Big)$$

with

$$C_{trig}(\Delta\varphi,\Delta\eta) = \frac{1}{N_{trig}^{corr}} \frac{1}{\varepsilon_{trig} * \varepsilon_{assoc}} \frac{B(0,0) * S(\Delta\varphi,\Delta\eta)}{B(\Delta\varphi,\Delta\eta)}$$

where

S($\Delta\boldsymbol{\varphi}$,$\Delta\eta$) = same event distribution,

B($\Delta\boldsymbol{\varphi}$,$\Delta\eta$) = mixed-event distribution

**$N_{trig}$** is the total number of trigger hadrons that fall in desired trigger $p_T$ range over all events, corrected for efficiency.