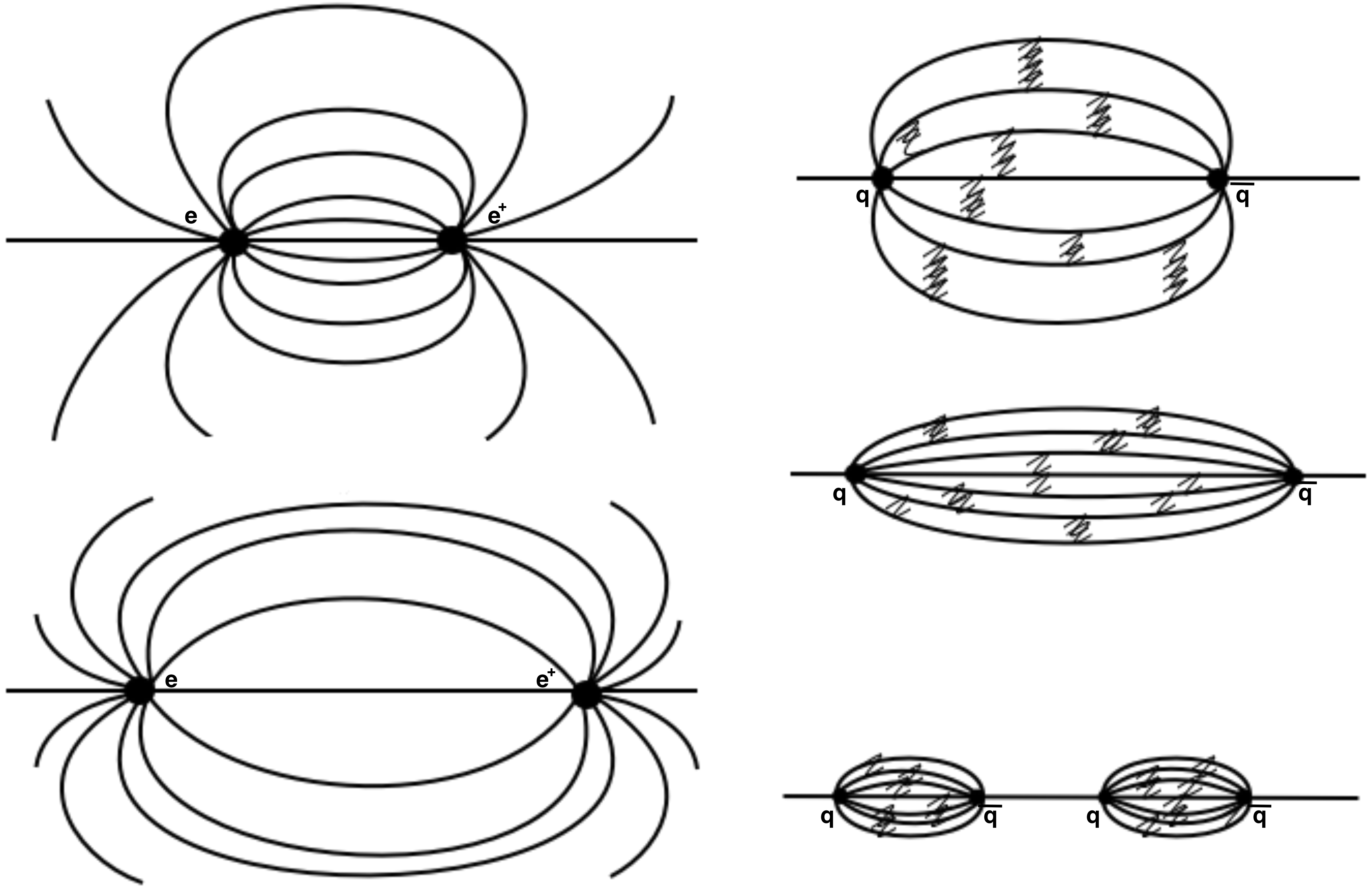
Di-hadron correlations of identified particles at high p_T in pp collisions at the LHC

Lucia Anna Tarasovičová
Westfälische Wilhelms-Universität Münster
NBI heavy-ion seminar
23.06.2022

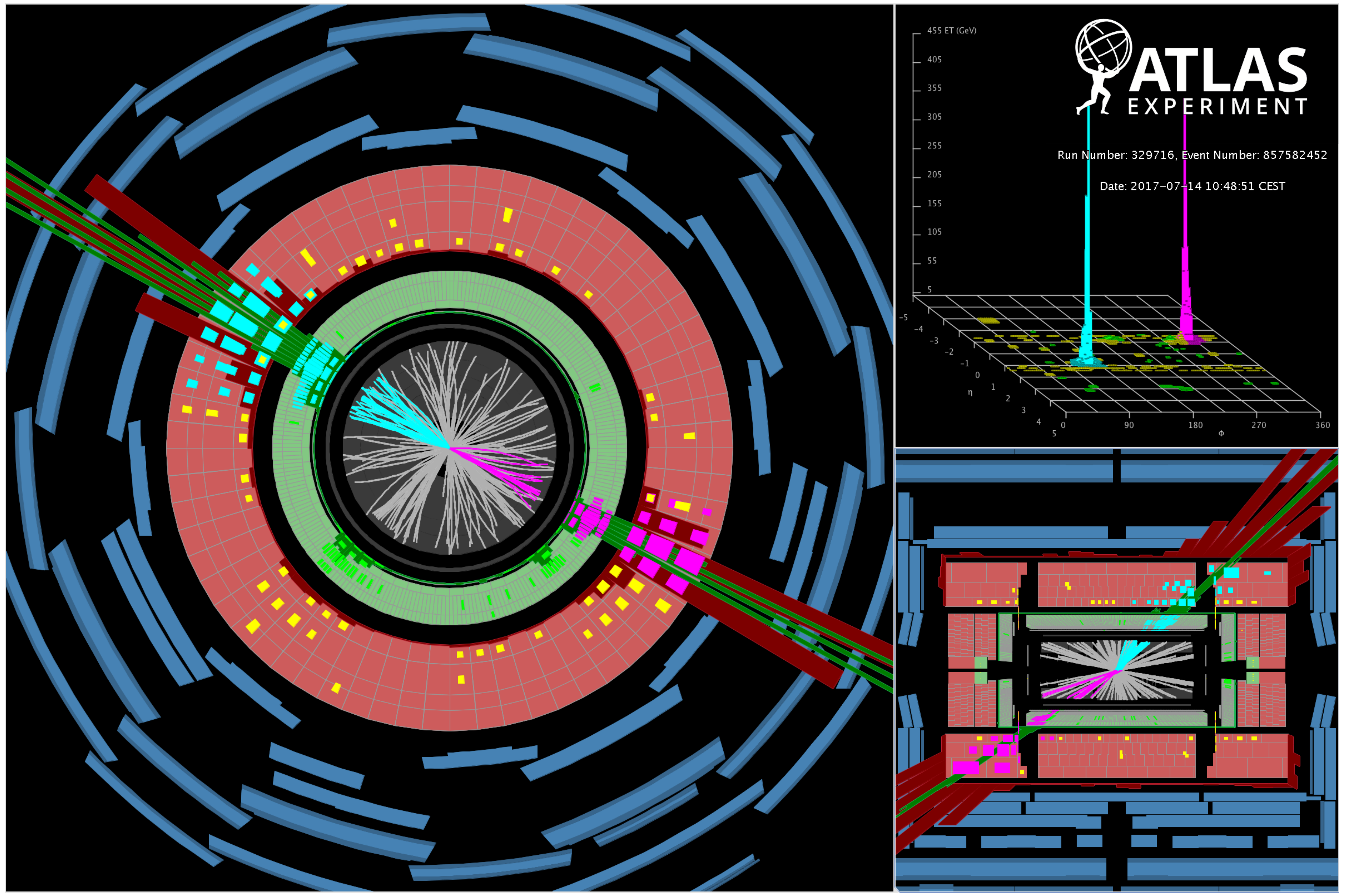
Jets



Differences between electrical and strong field

- Gluon self-interaction ⇒ tube-like field lines by increasing energy
- Creation of new $q\bar{q}$ pairs

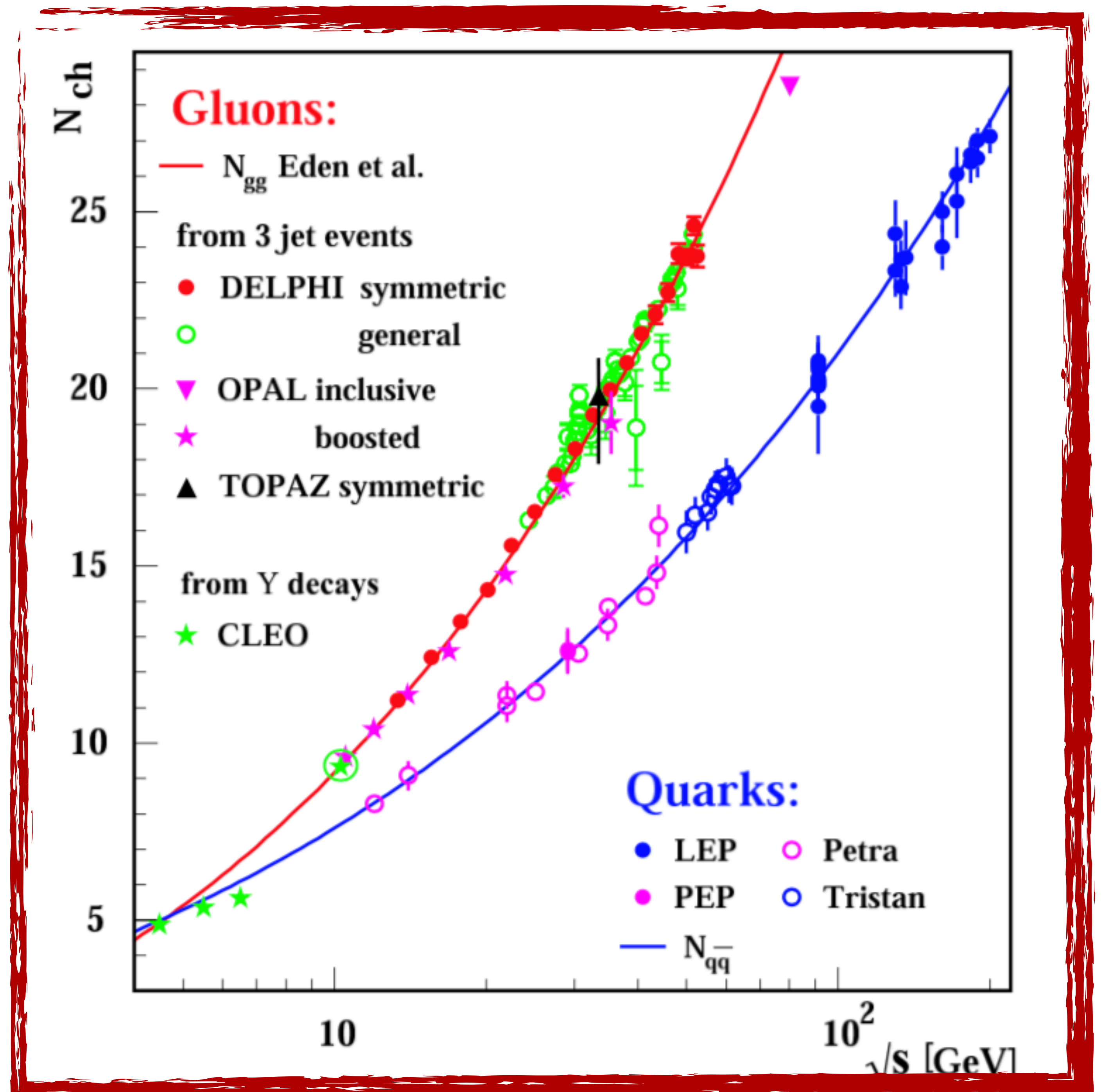
Jets



ATLAS event display with marked jets [1]

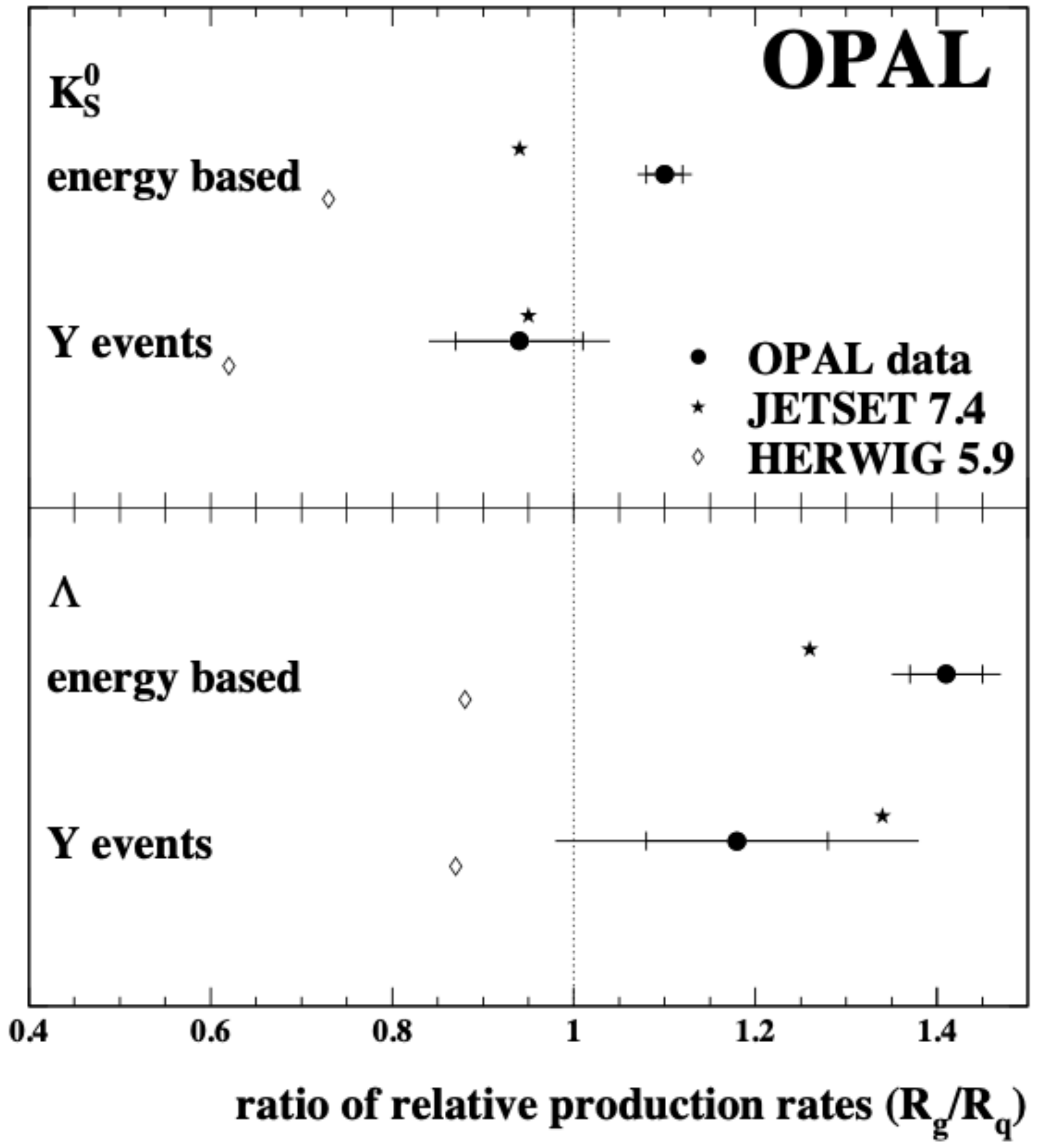
- Gluon self-interaction ⇒ tube-like field lines by increasing energy
- Creation of new $q\bar{q}$ pairs
- In detectors showers of hadrons in one direction
- Can be used to study the properties of the original parton

Quark / gluon jets



Jet multiplicity vs. collision energy [2]

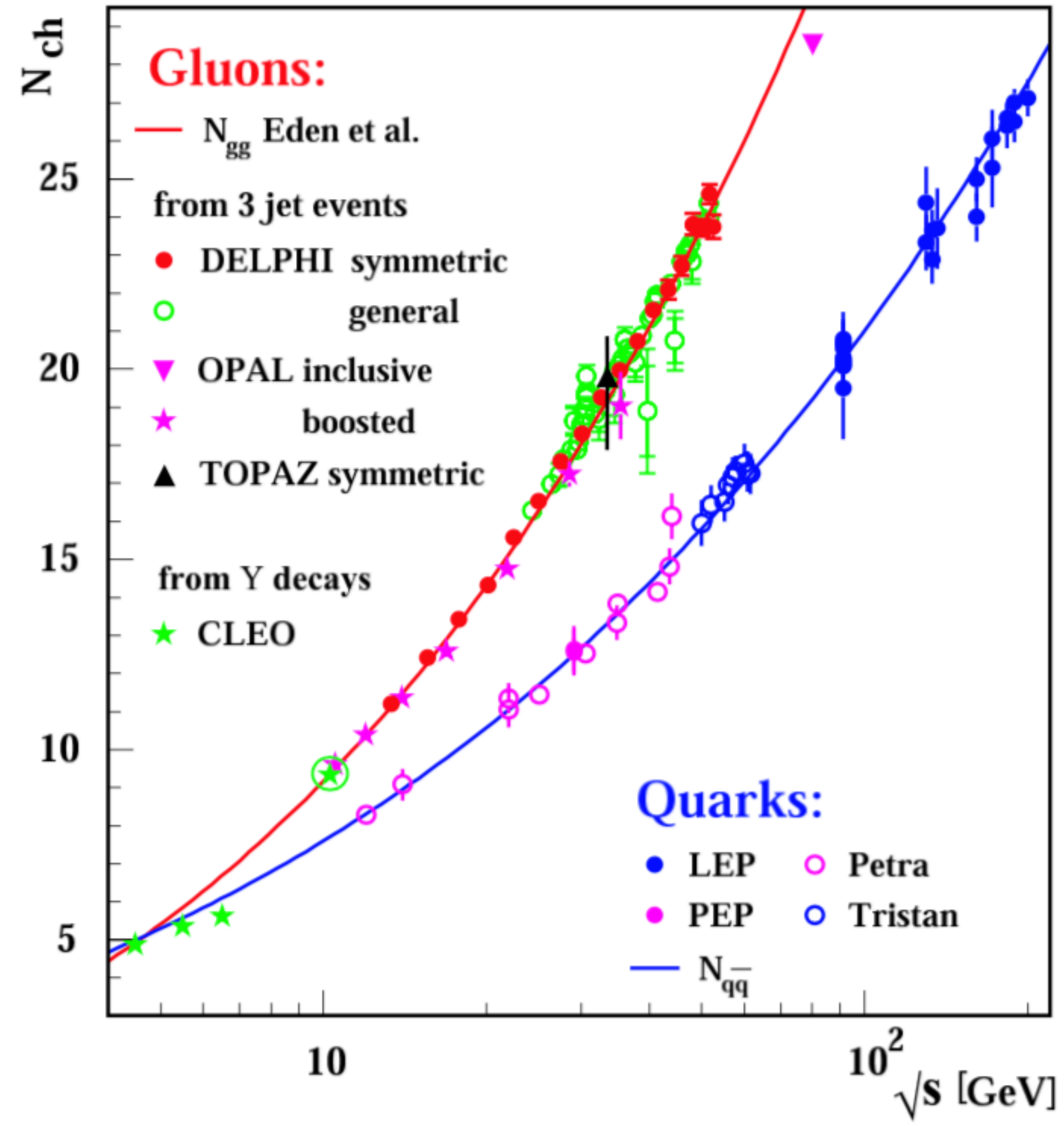
$e^+ + e^-$ collisions



Ratio of relative production of V⁰ in gluon to quark jets [3]

- Gluon jets in contrast to quark jets:
  - Higher multiplicity
  - Wider

Quark / gluon jets



Jet multiplicity vs. collision energy [2]

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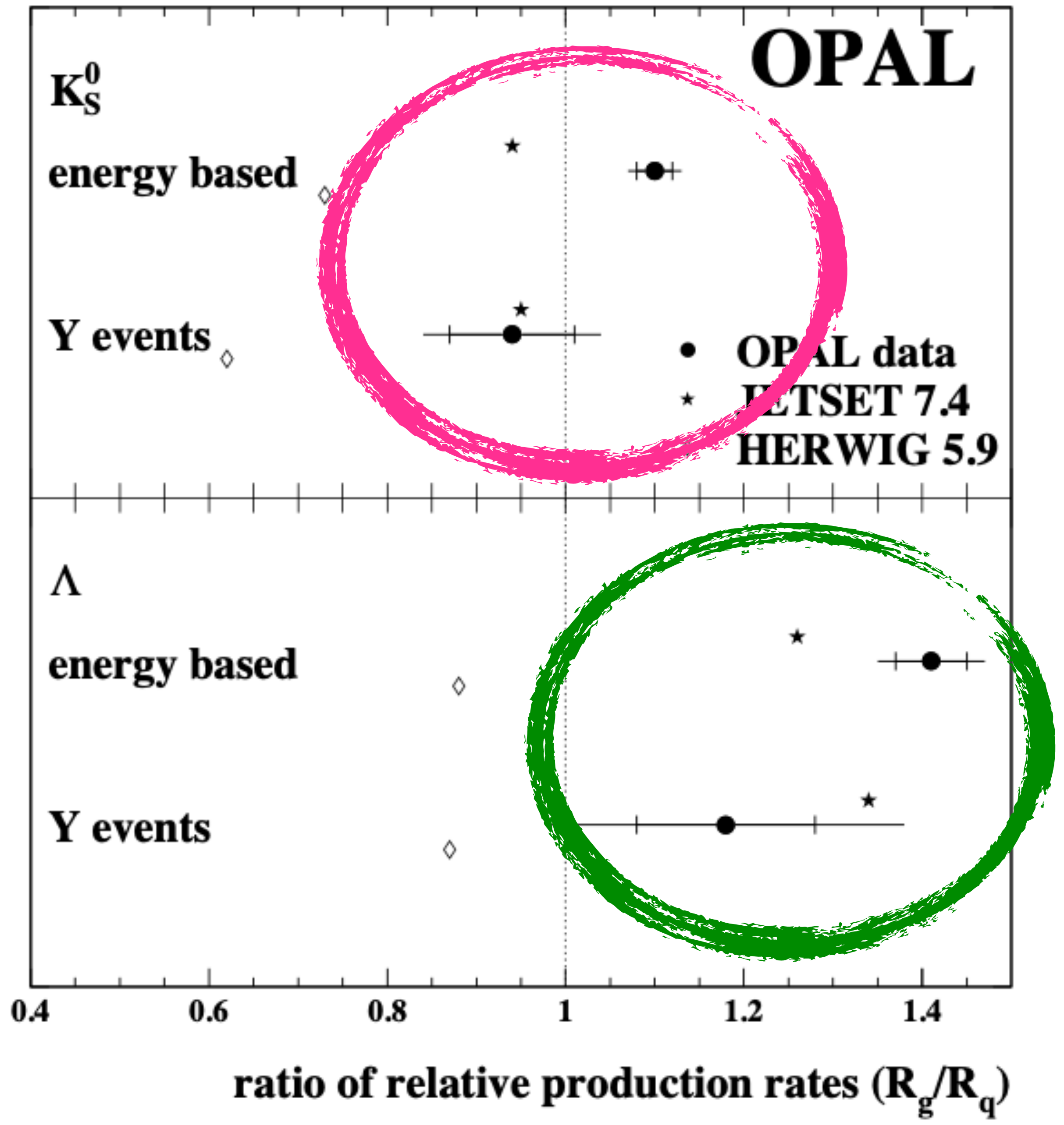
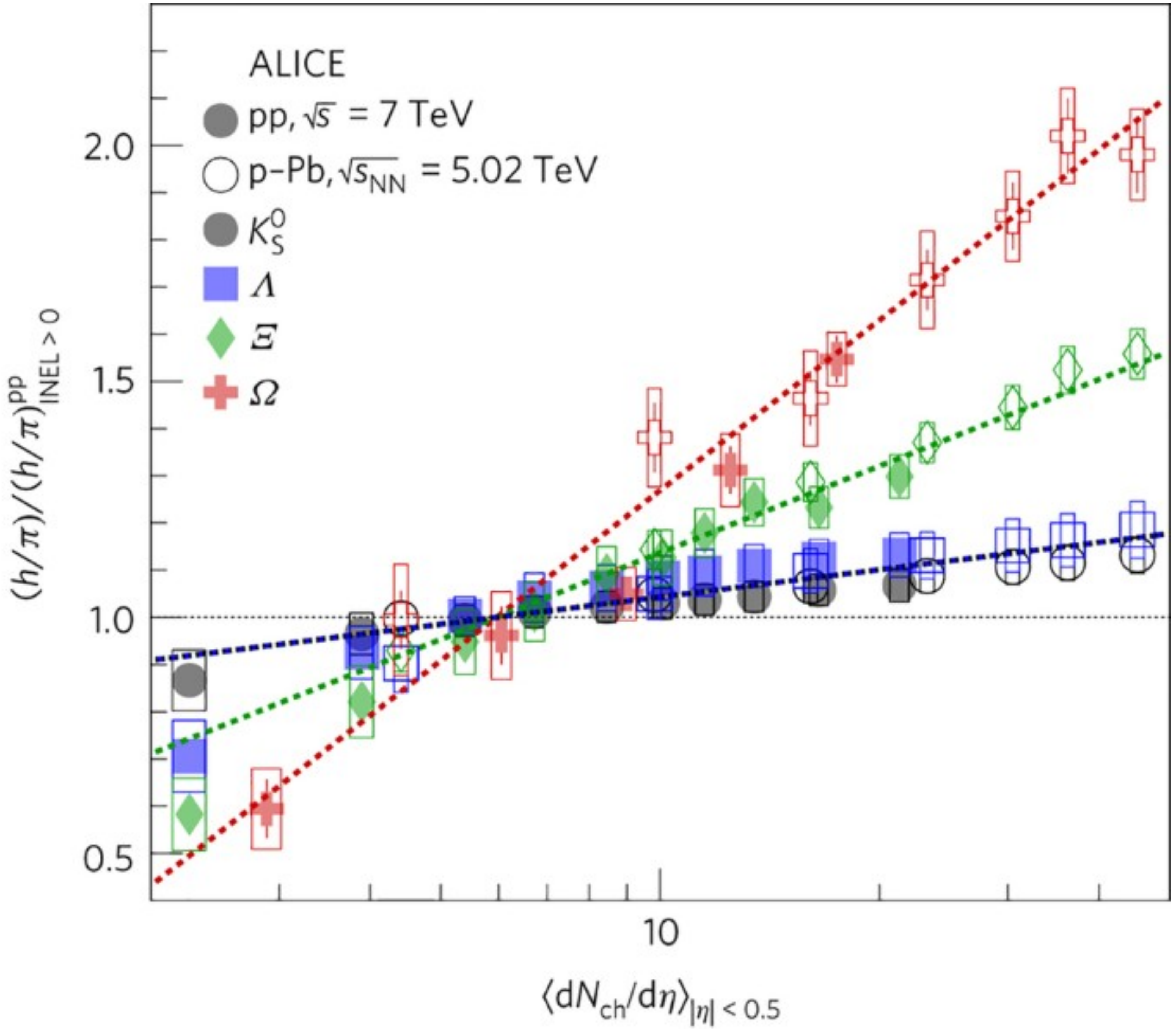


Ratio of relative production of V0 in gluon to quark jets [3]

- Gluon jets in contrast to quark jets:
  - Higher multiplicity
  - Wider
  - Higher production of Λ baryons, equal production of K^0_S mesons

How does the jet-peak yield depend on the trigger particle selection?

Strangeness enhancement



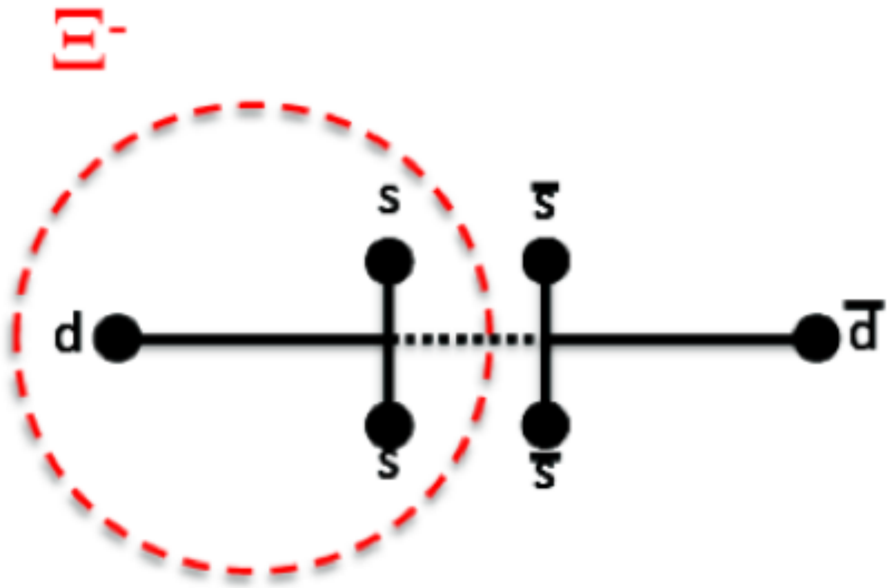
Particle yield ratios to pions normalised to the values measured in the inclusive pp sample[4]

- Enhanced relative strangeness production in high multiplicity small collision systems
- Steeper increase for more strange hadrons also in small collision systems

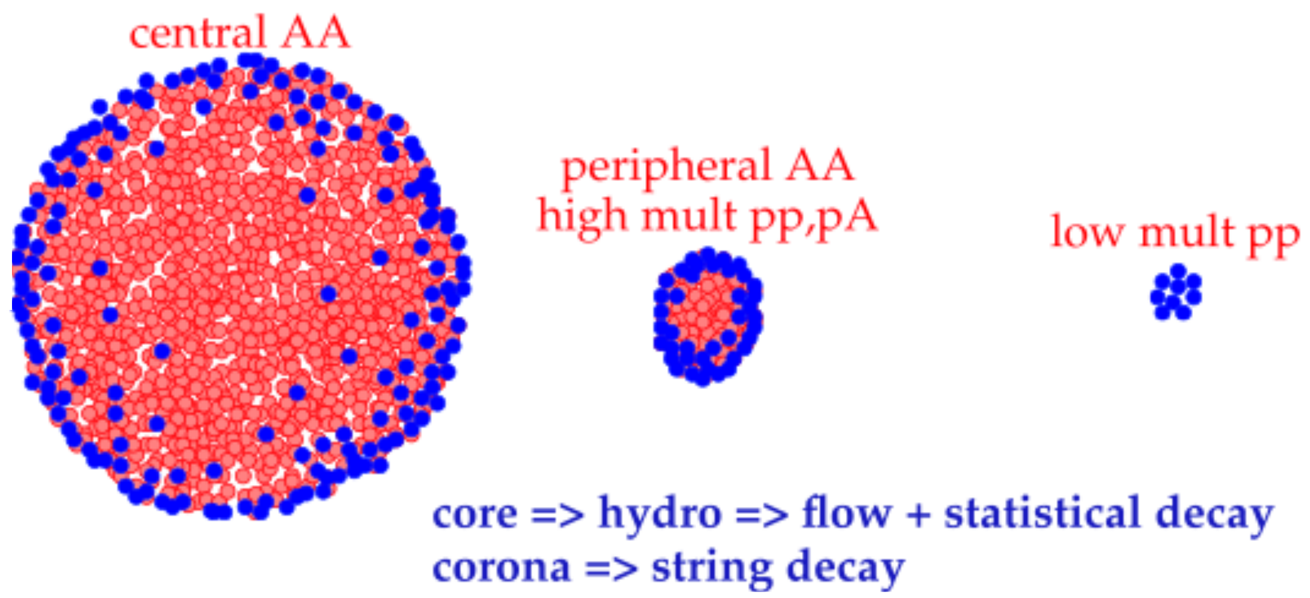
What is the contribution to the enhancement in small systems from hard and soft processes?

Different model descriptions

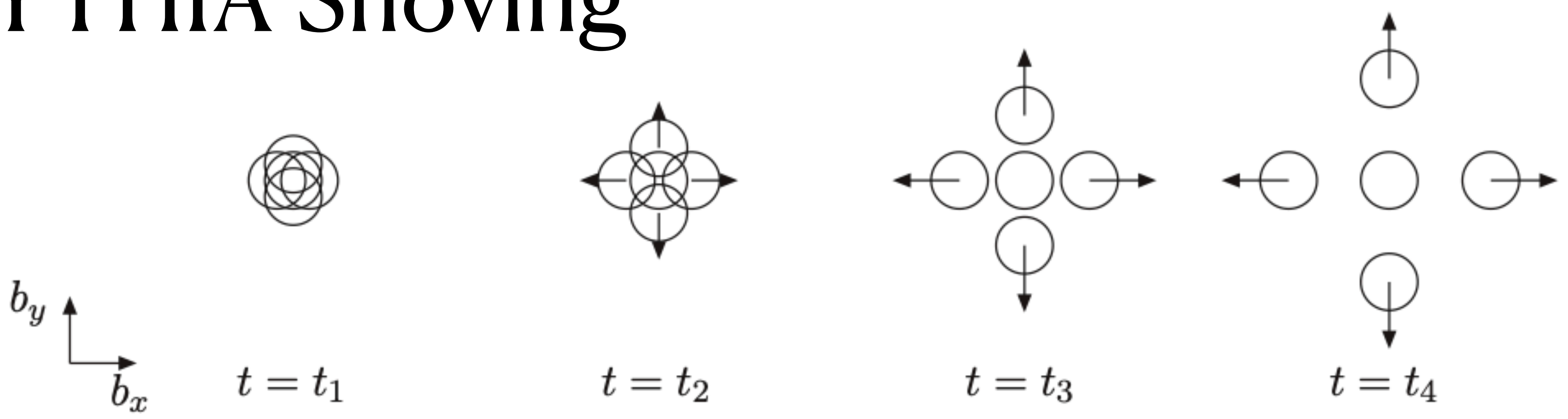
PYTHIA Monash



EPOS



PYTHIA Shoving

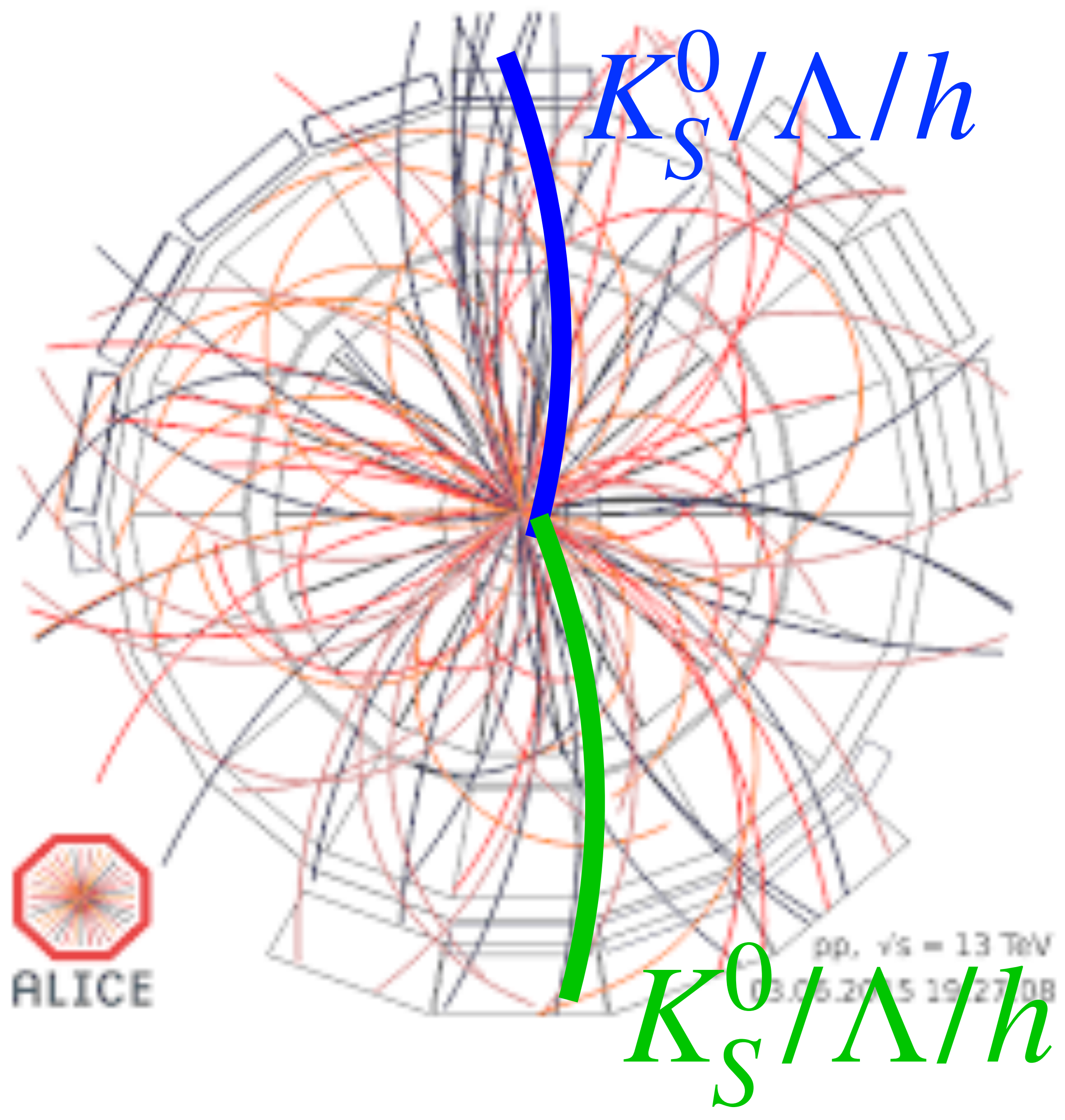


- Problems by modelling of strangeness in small systems
- Big differences between models in hadron production:
  - PYTHIA - mainly hadronisation
  - EPOS - core / corona
  - PYTHIA Shoving - strings become additional kicks in the overlap regions

Can comparison with different models bring more light to understanding of the strangeness production mechanism?

Di-hadron correlations

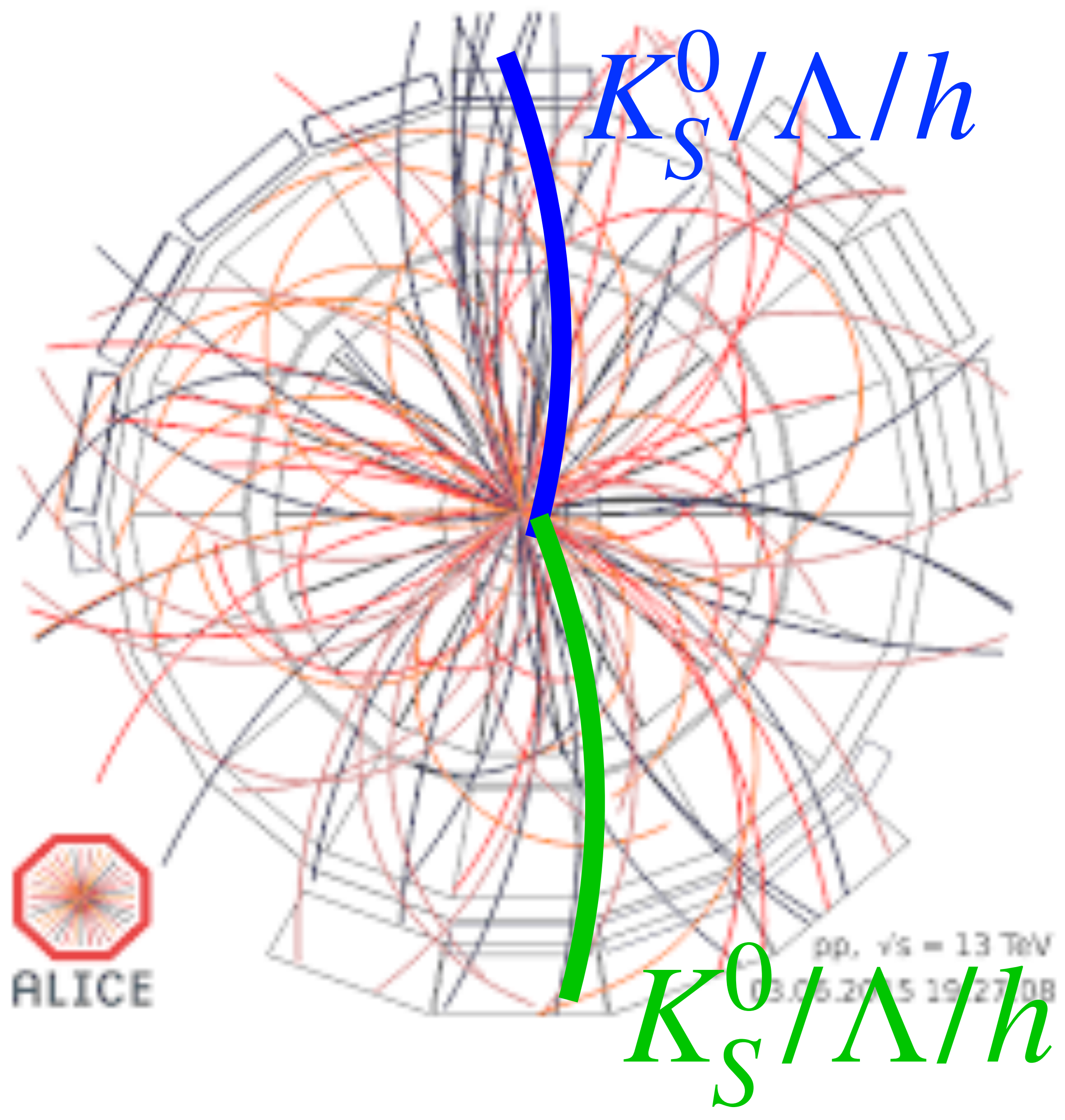
- Trigger particle - high p_T
  - The original jet parton included
- Associated particle - lower p_T

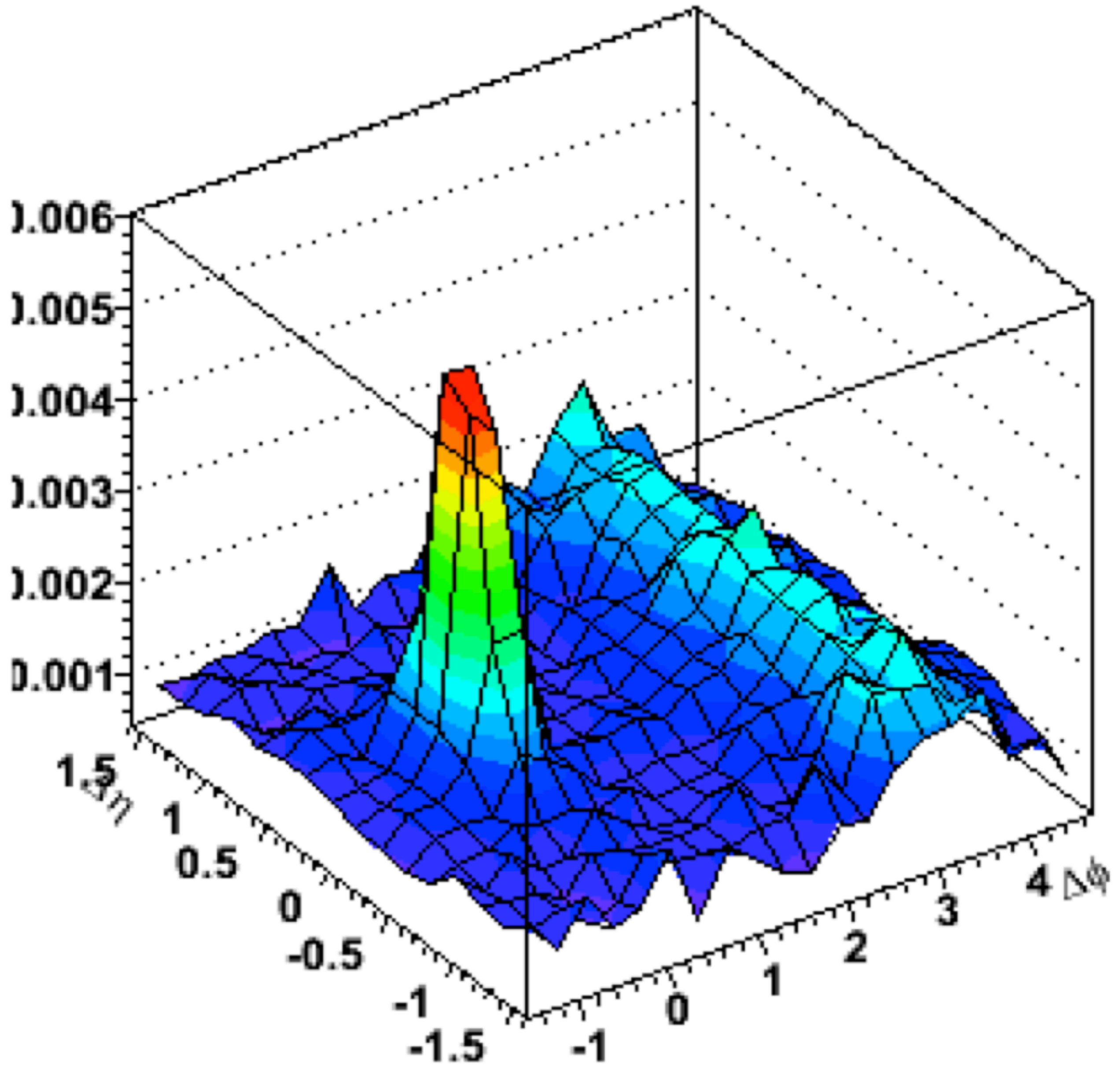


Di-hadron correlations

- Trigger particle - high p_T
  - The original jet parton included
- Associated particle - lower p_T
- Difference $\Delta\varphi = \varphi_{trigg} - \varphi_{assoc}$

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





- Correlation function:

$$\frac{d^2N_{pair}^{corr}}{d\Delta\varphi d\Delta\eta} = \frac{1}{N_{trigg}^{corr}} \frac{d^2N_{pair}^{raw}}{d\Delta\varphi d\Delta\eta} \frac{1}{\varepsilon_{trigg}} \frac{1-C}{\varepsilon_{assoc}} \frac{1}{\varepsilon_{pair}(\Delta\varphi\Delta\eta)}$$

Di-hadron correlations

- Trigger particle - high p_T
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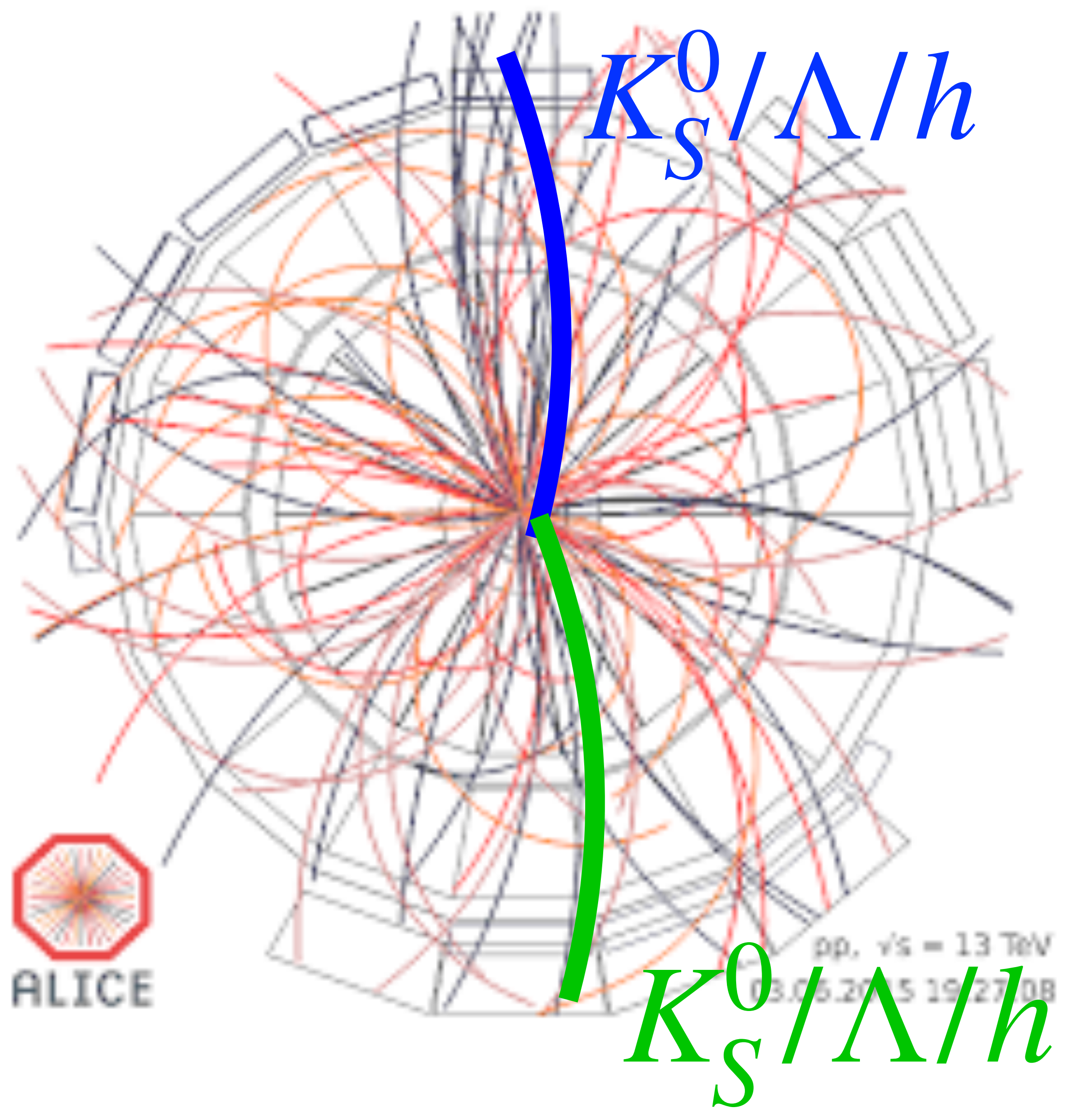

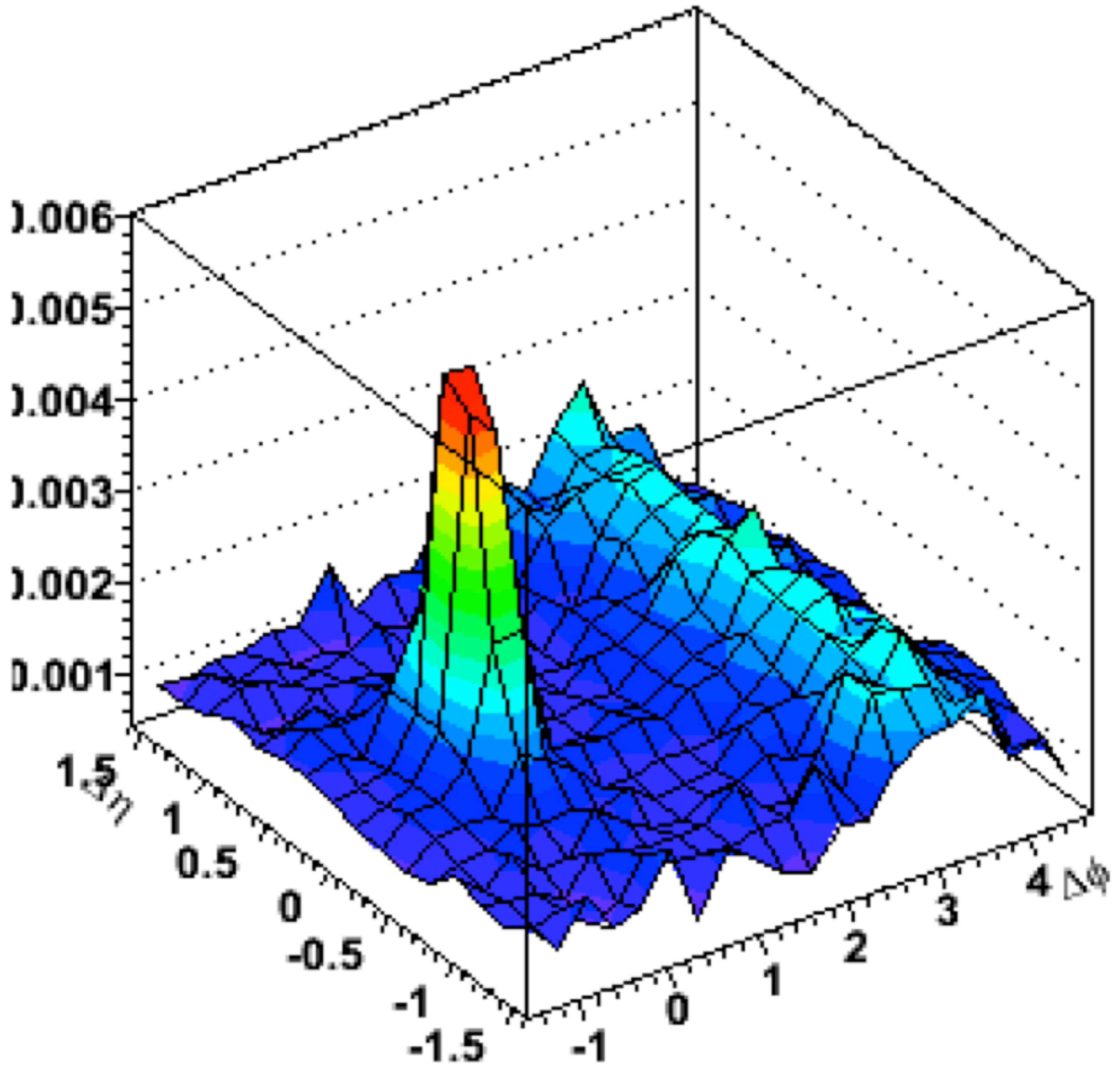

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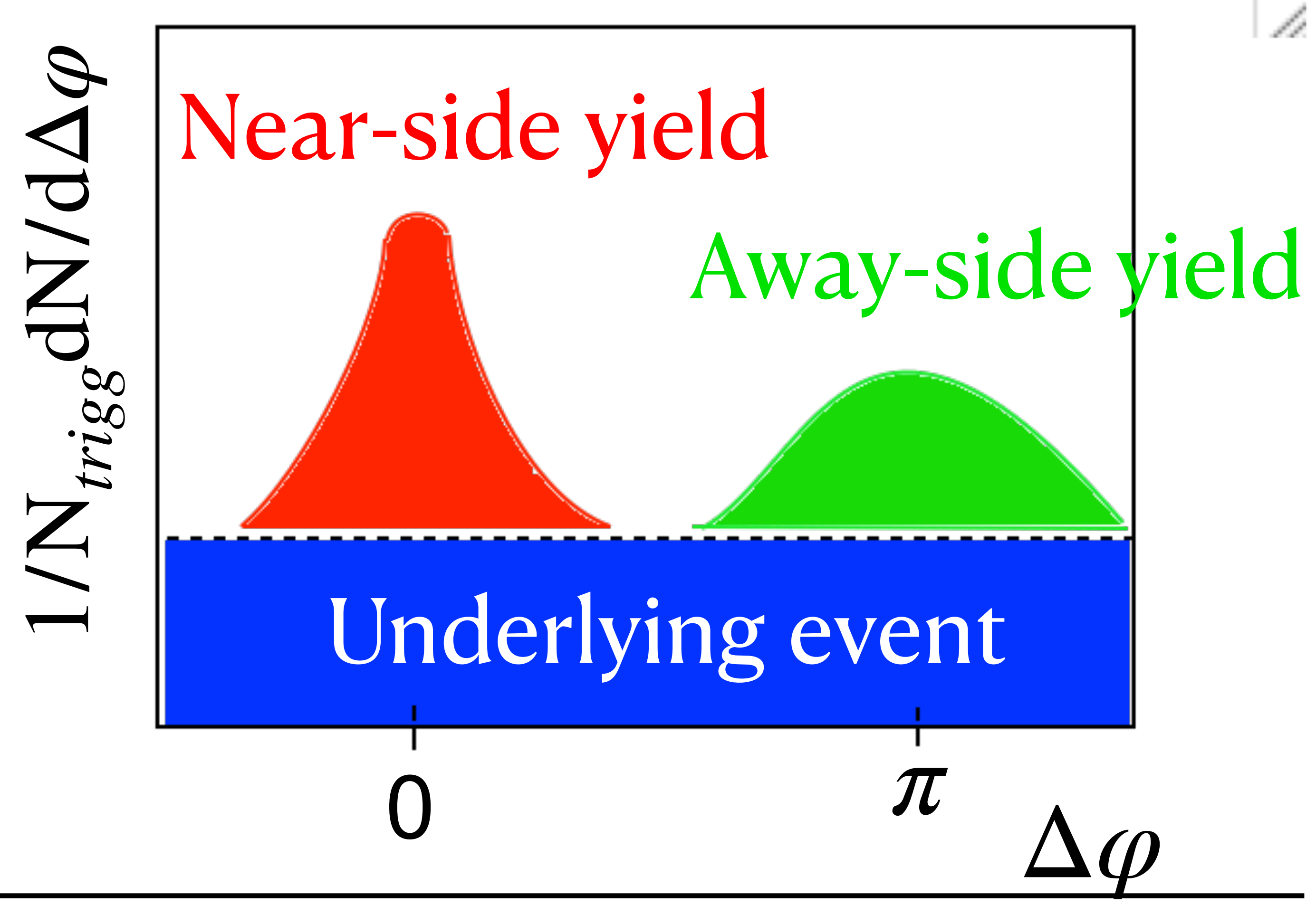
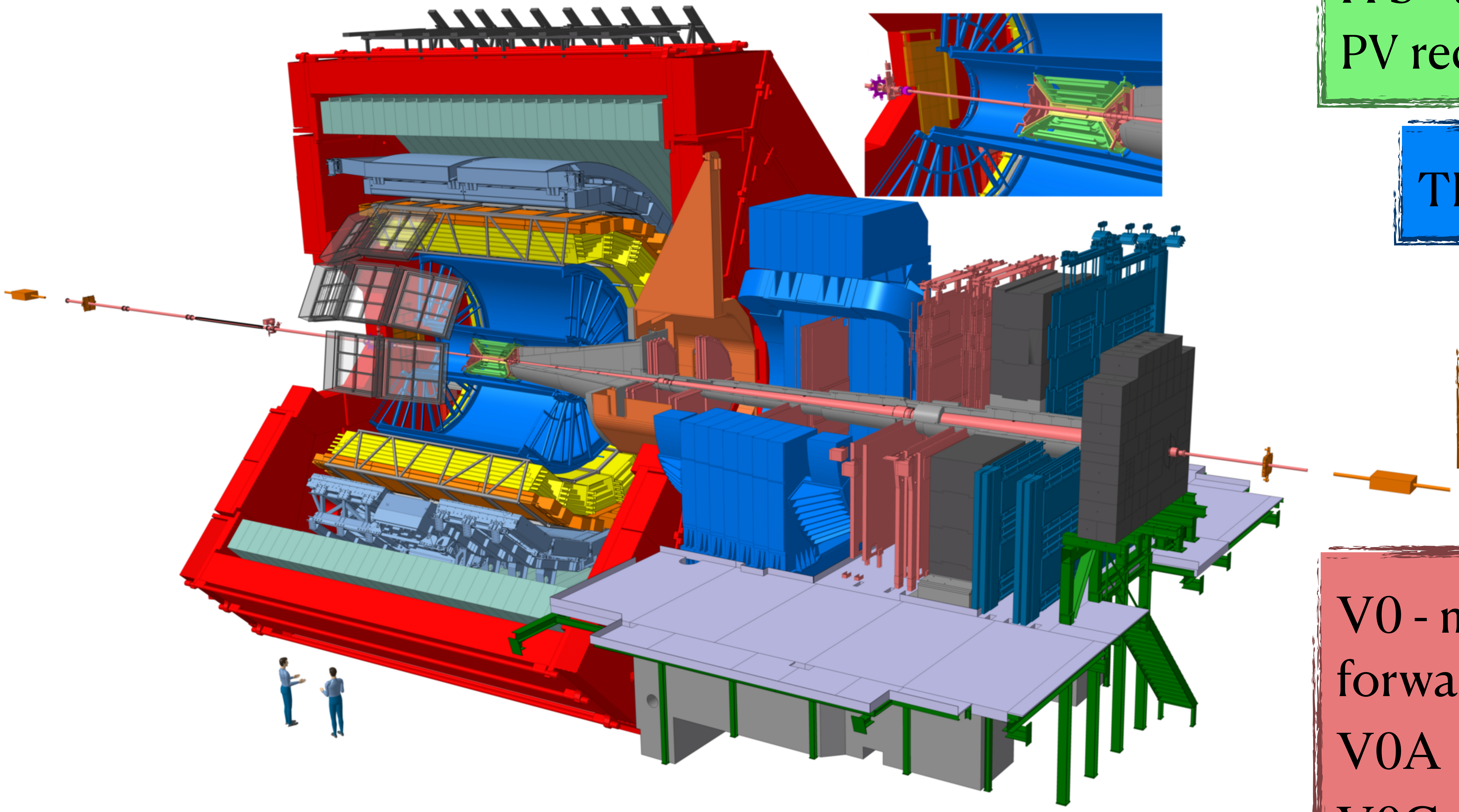
- $\Delta\varphi$ projection
- Yield calculation: $Y_J^{\Delta\varphi} = \int_{\Delta\varphi_1}^{\Delta\varphi_2} \frac{dN}{d\Delta\varphi} d\Delta\varphi$
- In this analysis: V^0-h ,hh and h-V^0 correlations



ALICE detector



ITS - tracking, pile-up rejection, PV reconstruction, $|\eta| < 0.9$

TPC - tracking, PID, $|\eta| < 0.9$

TOF - pile-up rejection, PID, $|\eta| < 0.9$

V0 - multiplicity estimation in forward and backward directions

V0A $2.8 < \eta < 5.1$

V0C $-3.7 < \eta < -1.7$

Event selection

- pp collisions at $\sqrt{s} = 13$ TeV
- Minimum bias trigger (kINT7)
- Primary vertex position within 10 cm from IP
- Pile-up rejection with help of PhysicsSelectionTask and

```
fAliEventCuts->SetupRun2pp();
fAliEventCuts->AcceptEvent(fEvent);
```

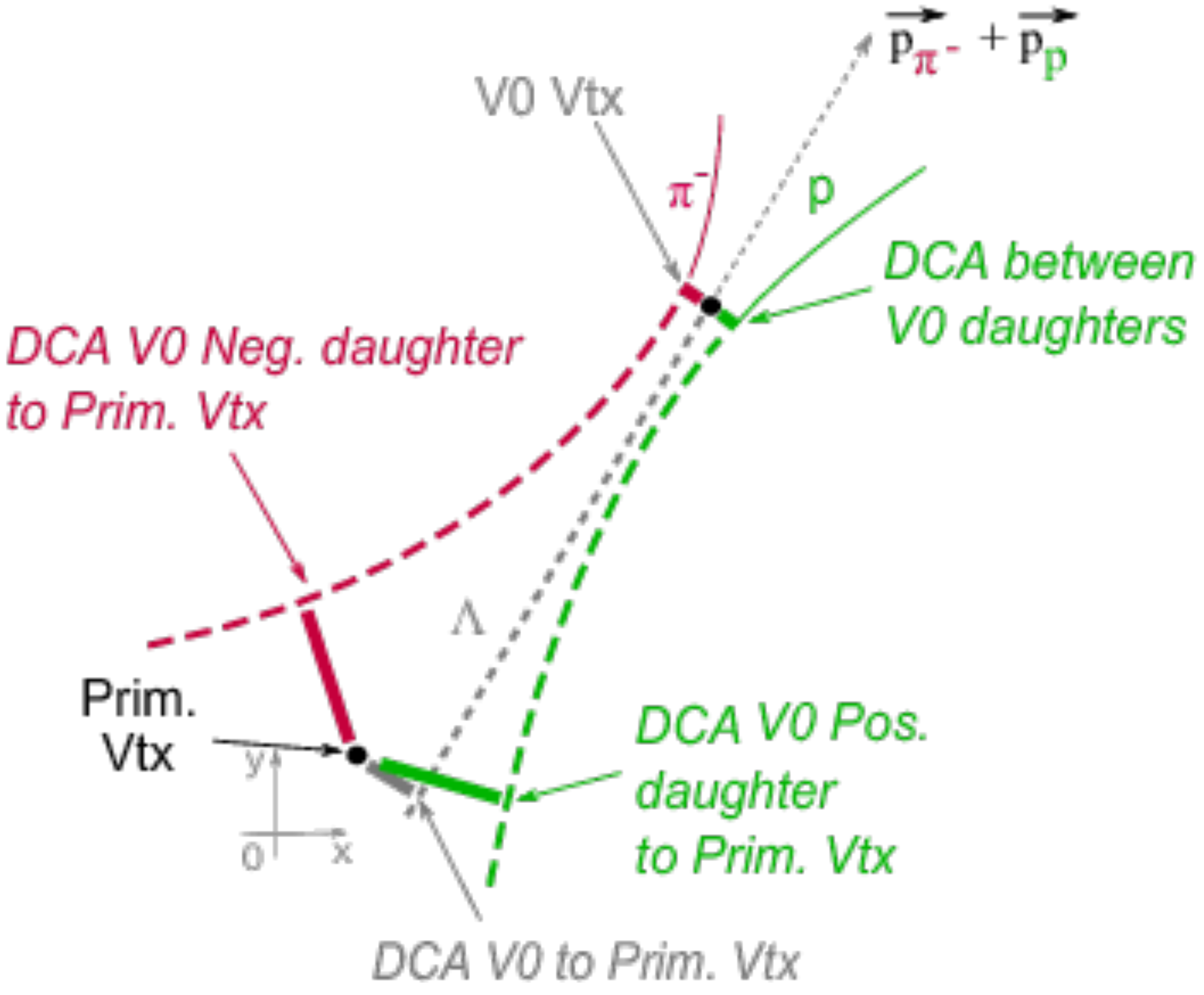
- Multiplicity estimation with

```
MultSelection->GetMultiplicityPercentile("V0M")
```

Track and V⁰ selection

$3 < p_{\mathrm{T}}^{\mathrm{trigg}} < 20\ \mathrm{GeV}/c \qquad 1\mathrm{GeV}/c < p_{\mathrm{T}}^{\mathrm{assoc}} < p_{\mathrm{T}}^{\mathrm{trigg}}$

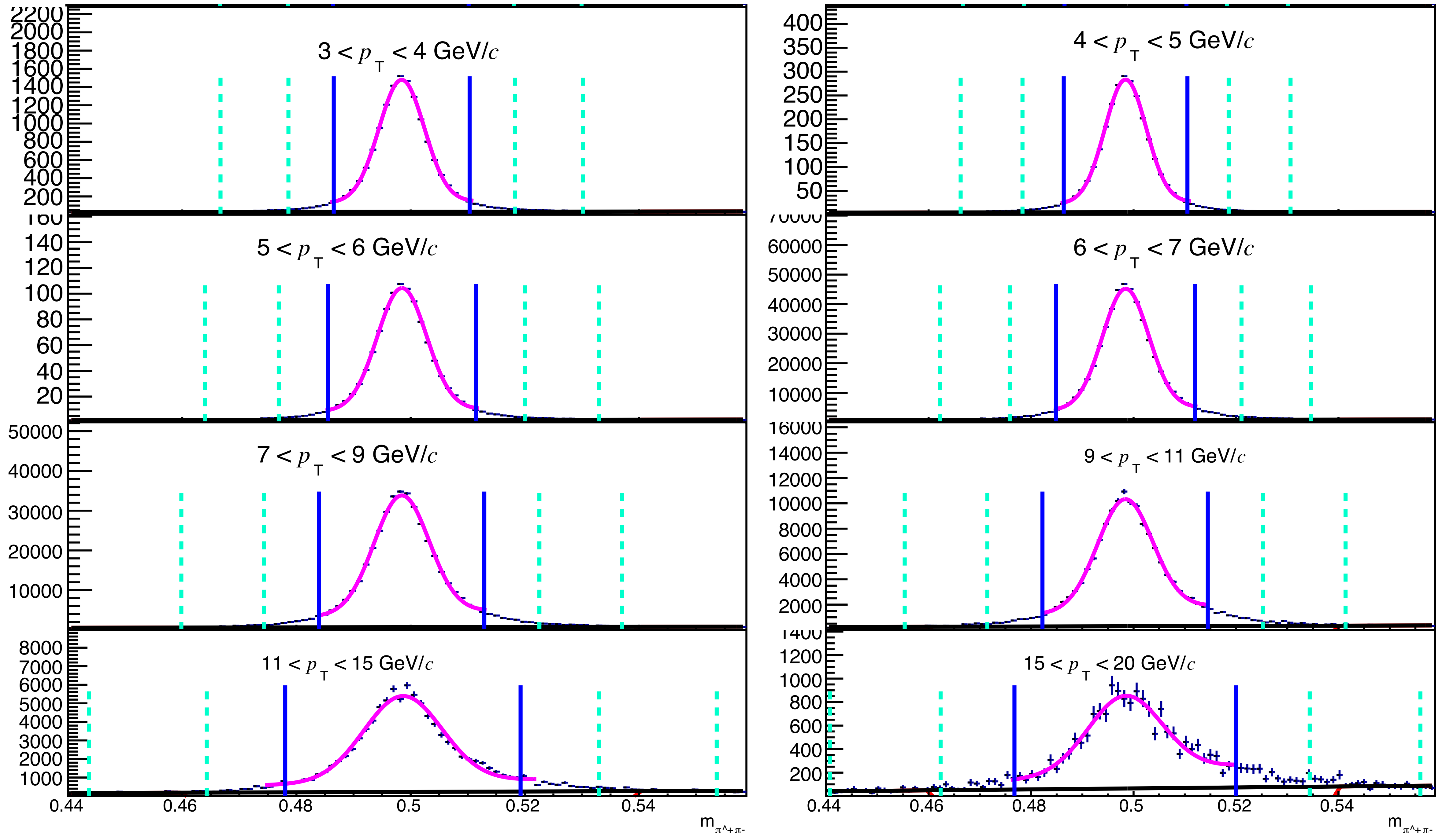
- $|\eta| < 0.8$
- FilterBit 256 and special tune
- Pairs with invariant mass of a hadron - rejected



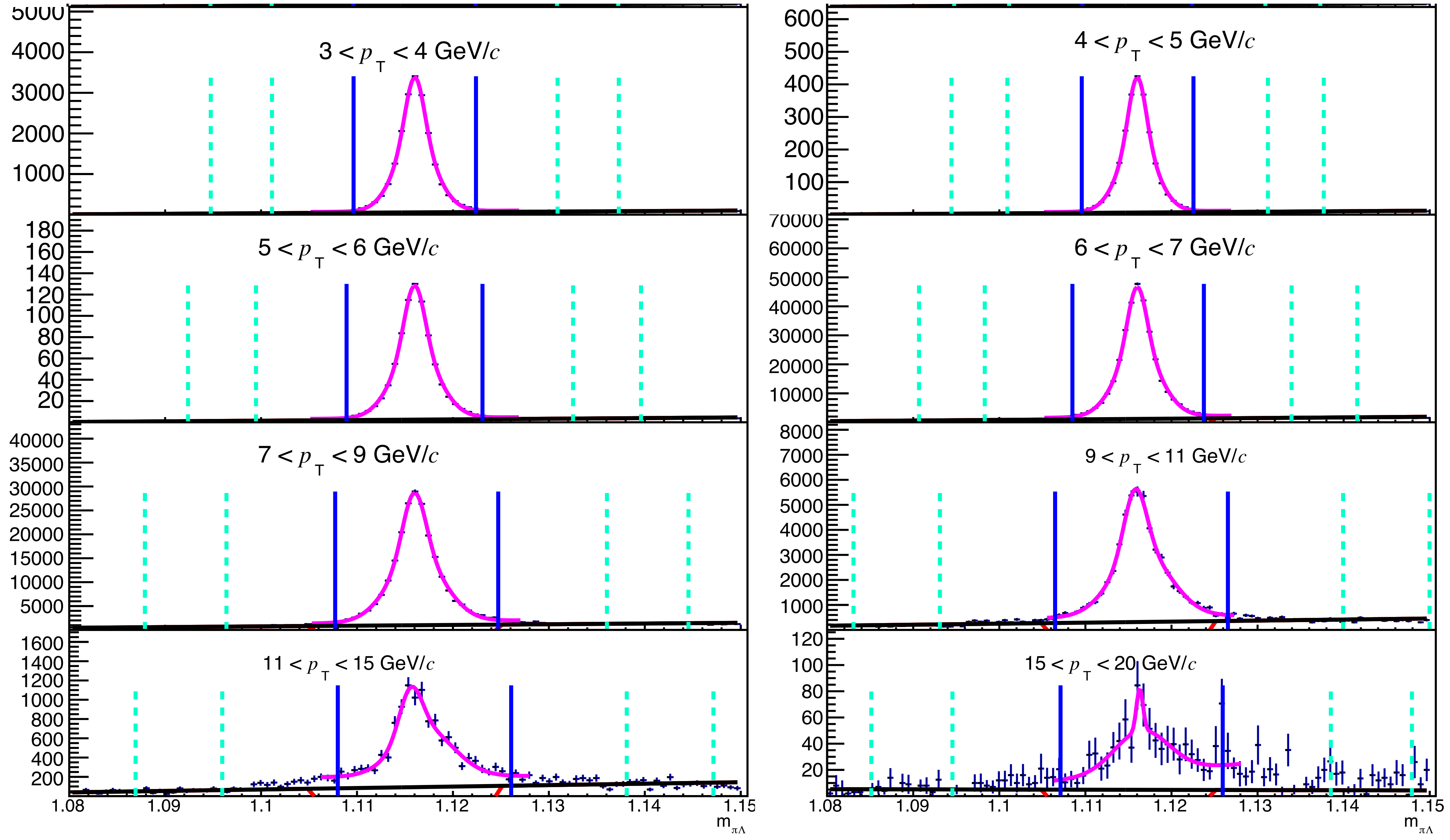
V^0 invariant mass

- Signal fit
- Background fit
- Signal region $\mu \pm 3\sigma$
- Side-bands region

K_S^0



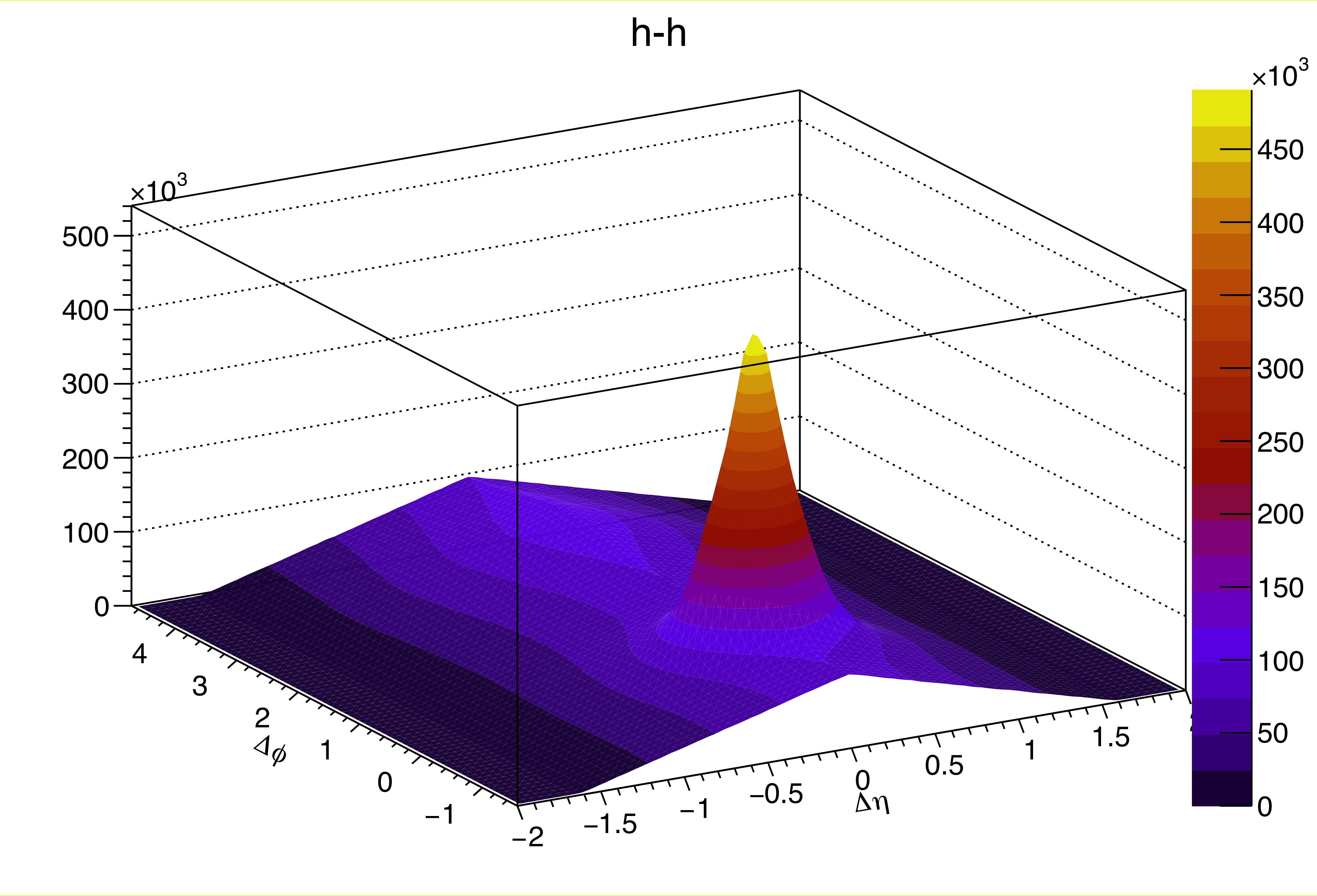
$\Lambda + \bar{\Lambda}$



Corrections

$$\frac{d^2N^{corr}_{pair}}{d\Delta\varphi d\Delta\eta} = \frac{1}{N^{corr}_{trigg}} \frac{d^2N^{raw}_{pair}}{d\Delta\varphi d\Delta\eta} \frac{1}{\varepsilon_{trigg}} \frac{1-C}{\varepsilon_{assoc}} \frac{1}{\varepsilon_{pair}(\Delta\varphi\Delta\eta)}$$

$$N^{corr}_{trigg} = \frac{1-C_{trigg}}{\varepsilon_{trigg}} N^{raw}_{trigg}$$



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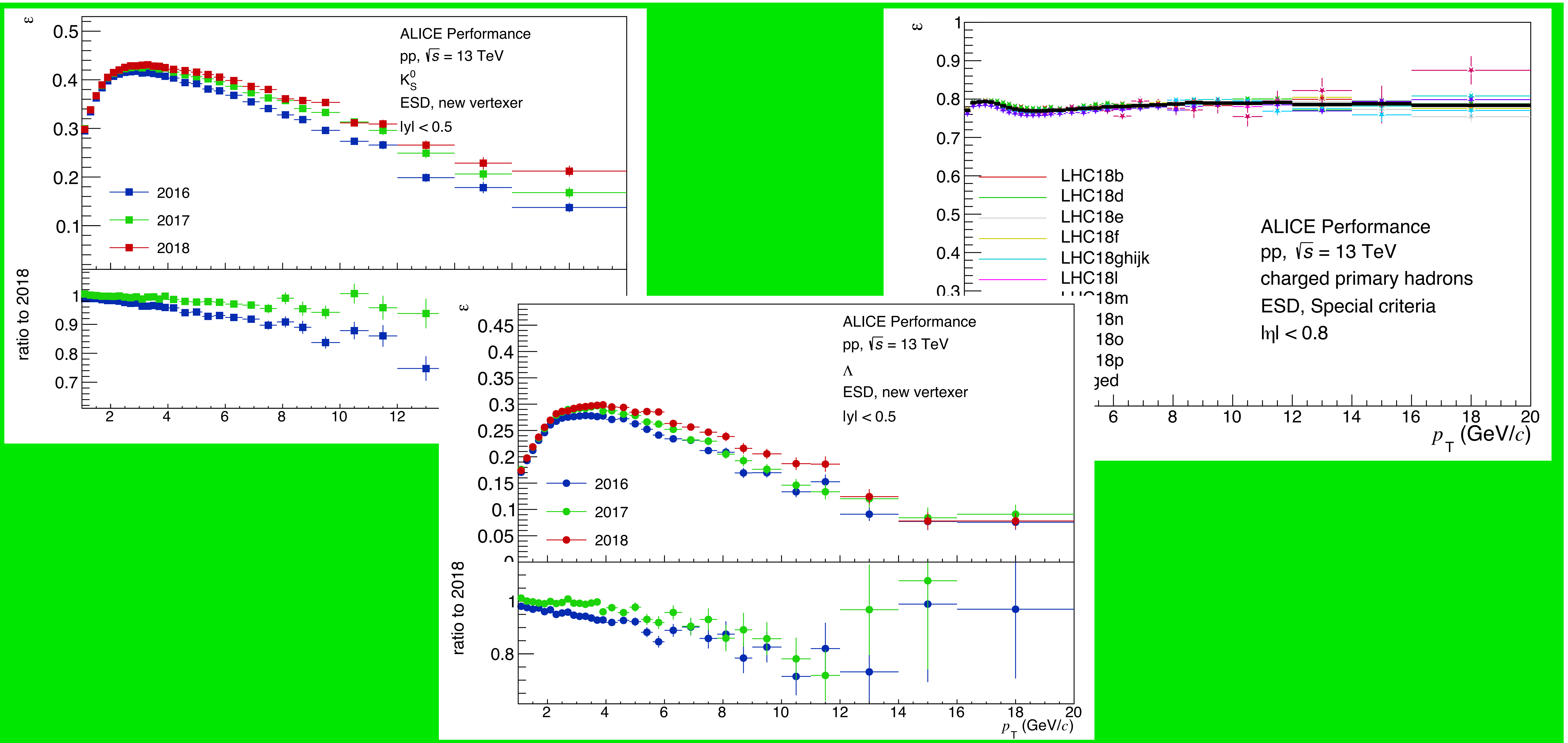
$$N^{corr}_{trigg} = \frac{1-C_{trigg}}{\varepsilon_{trigg}} N^{raw}_{trigg}$$

$$\varepsilon = \frac{N^{survived}_{primaries}}{N^{generated}_{primaries}}$$



Corrections

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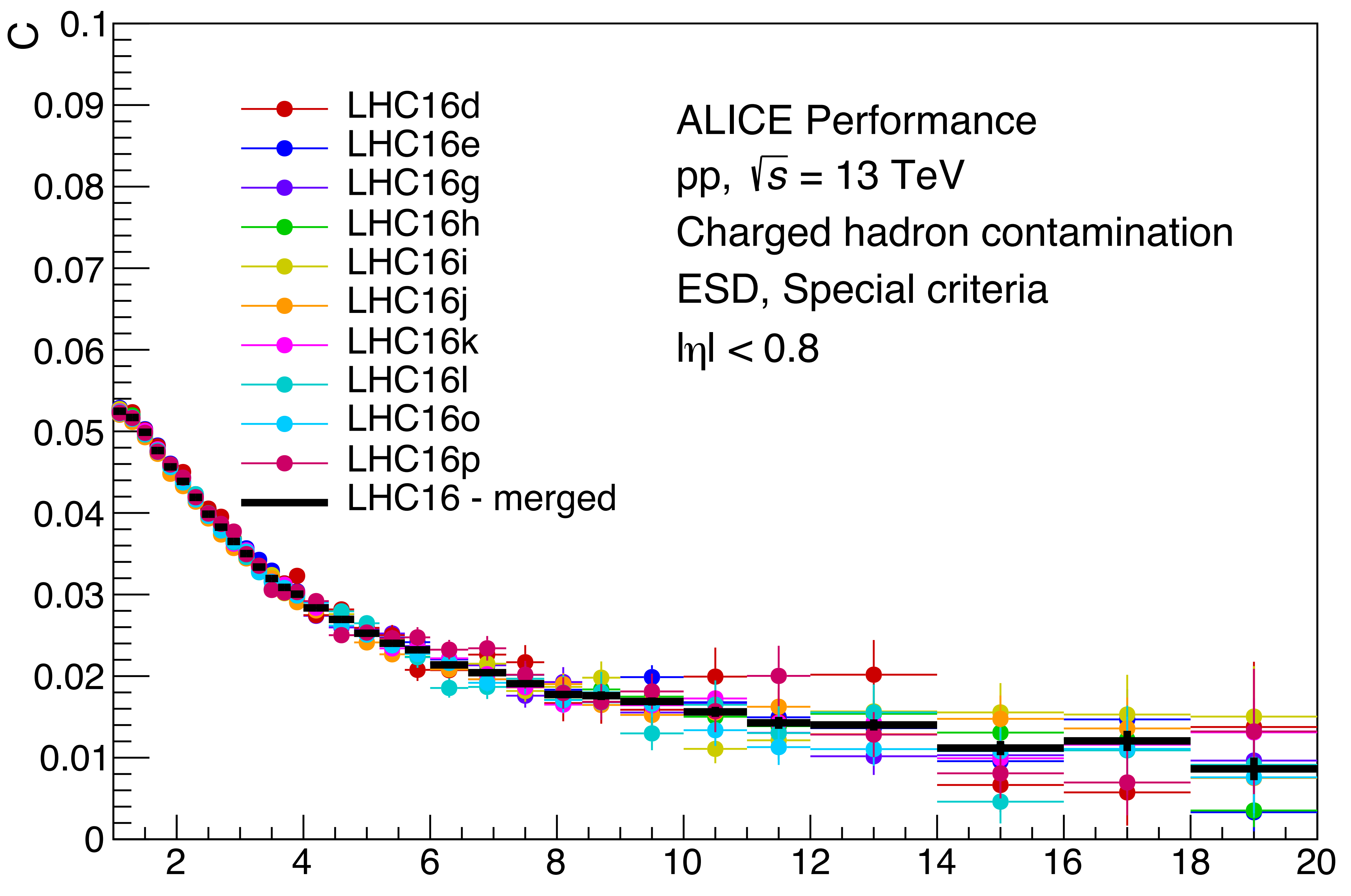
$$N^{corr}_{trigg} = \frac{1-C_{trigg}}{\varepsilon_{trigg}} N^{raw}_{trigg}$$

$$C = \frac{N^{survived}_{secondaries}}{N^{survived}_{particles}}$$



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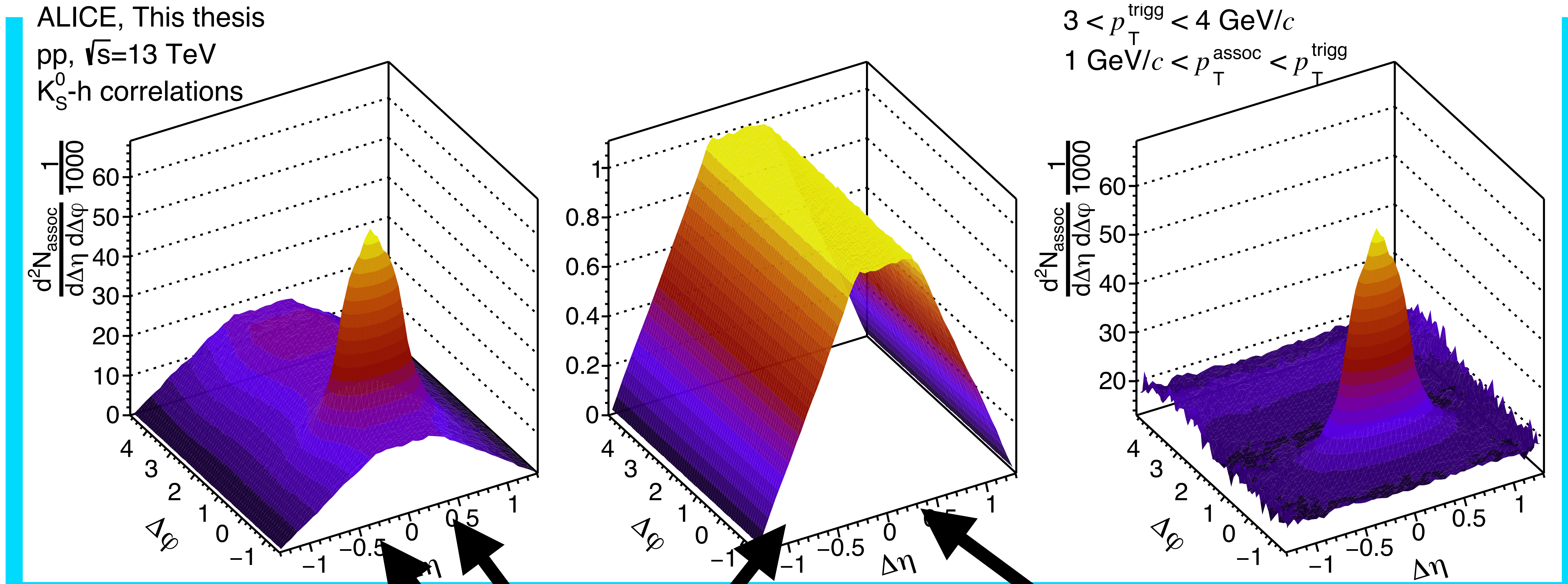
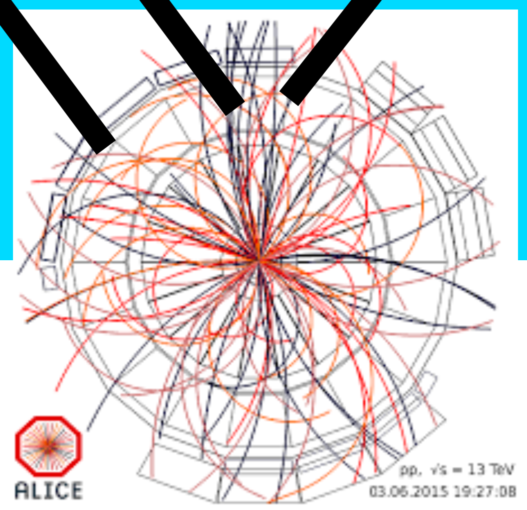
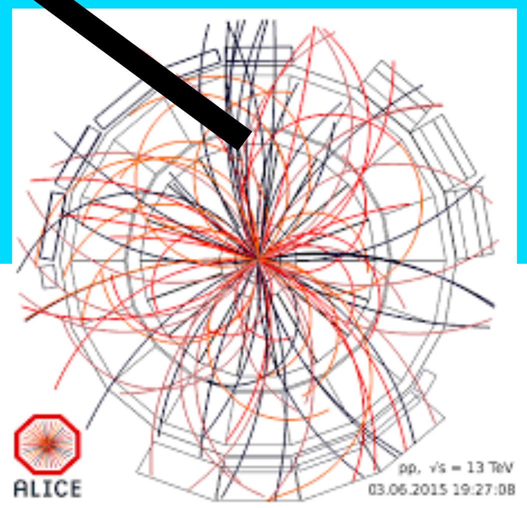
$$N^{corr}_{trigg} = \frac{1-C_{trigg}}{\varepsilon_{trigg}} N^{raw}_{trigg}$$

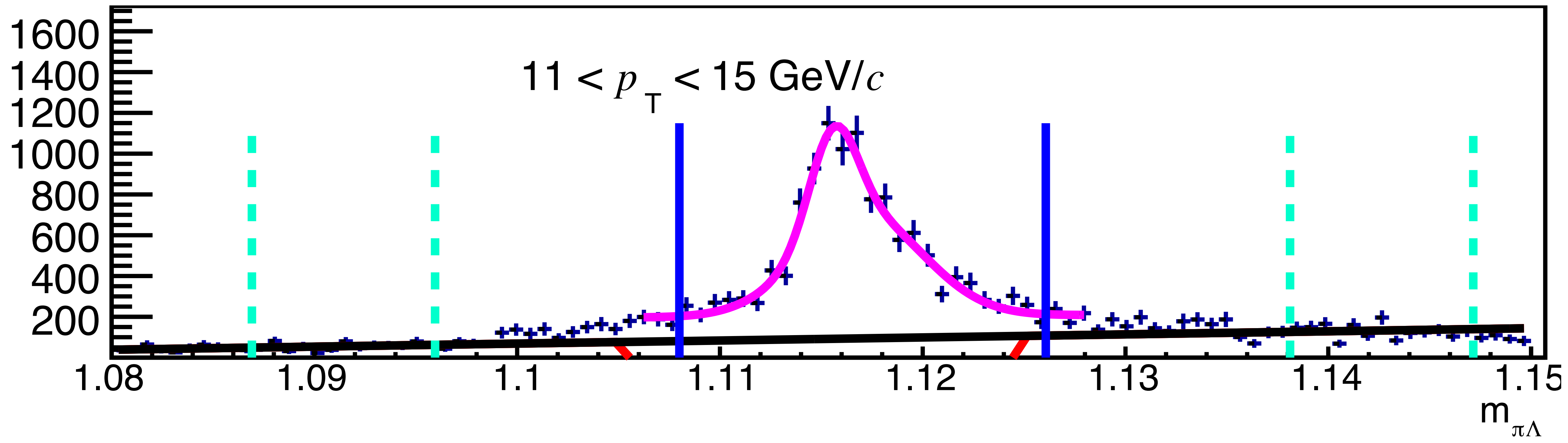
$$\varepsilon_{pair} = \frac{1}{\alpha} M(\Delta\eta\Delta\varphi)$$







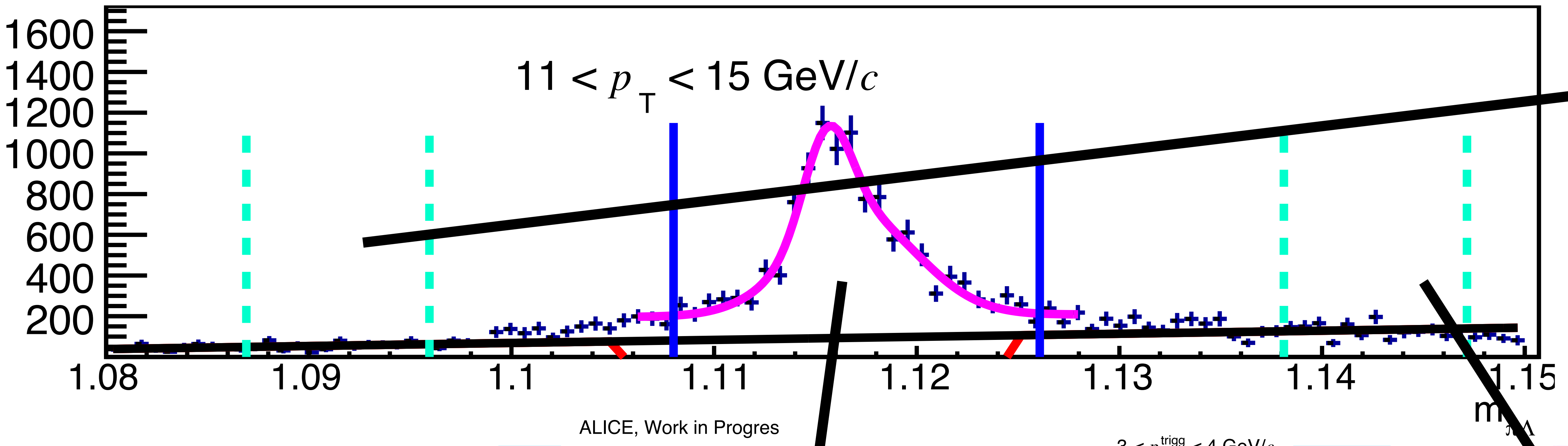
Correction for the contribution of misidentified V^0

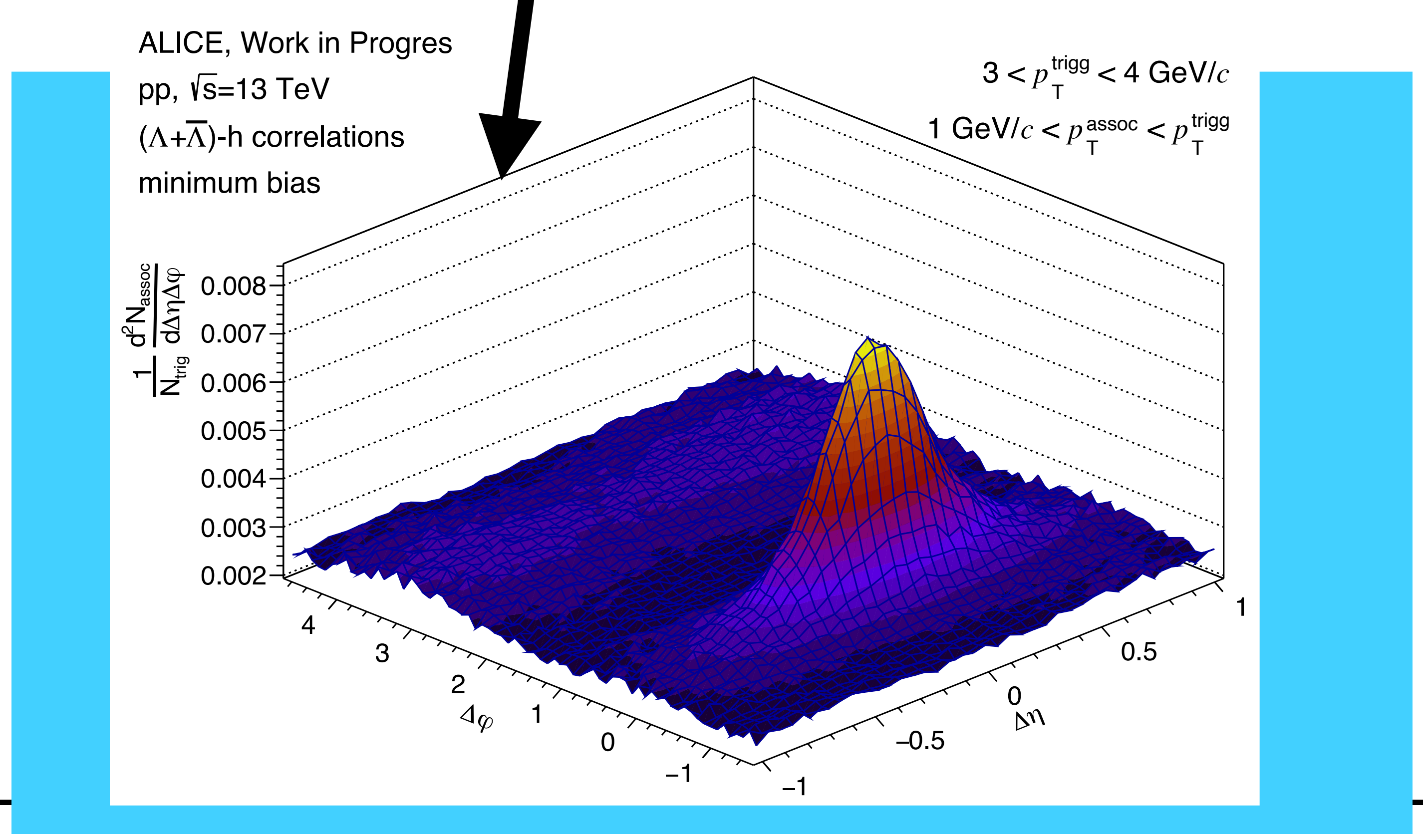


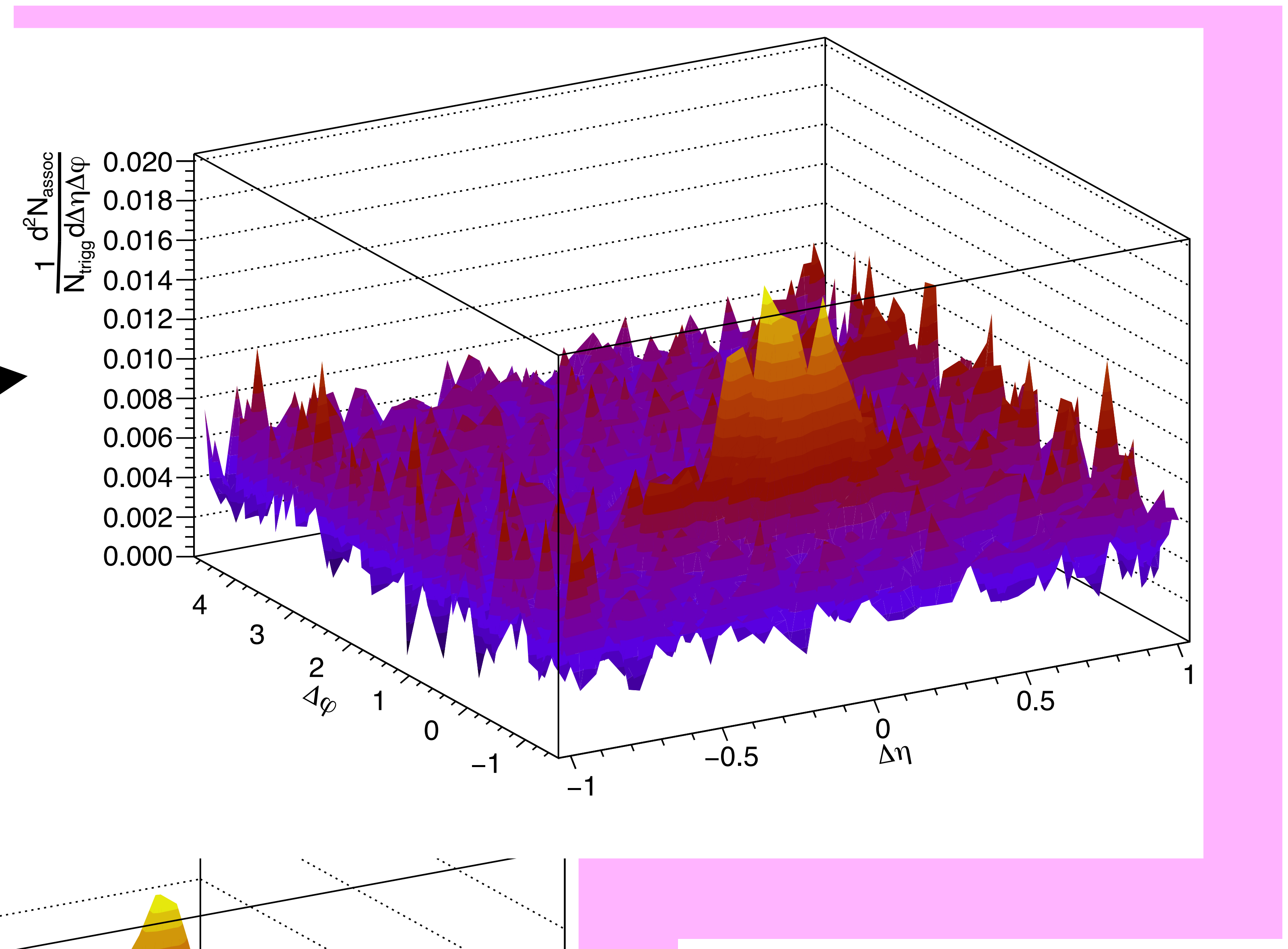
Correction for the contribution of misidentified V⁰

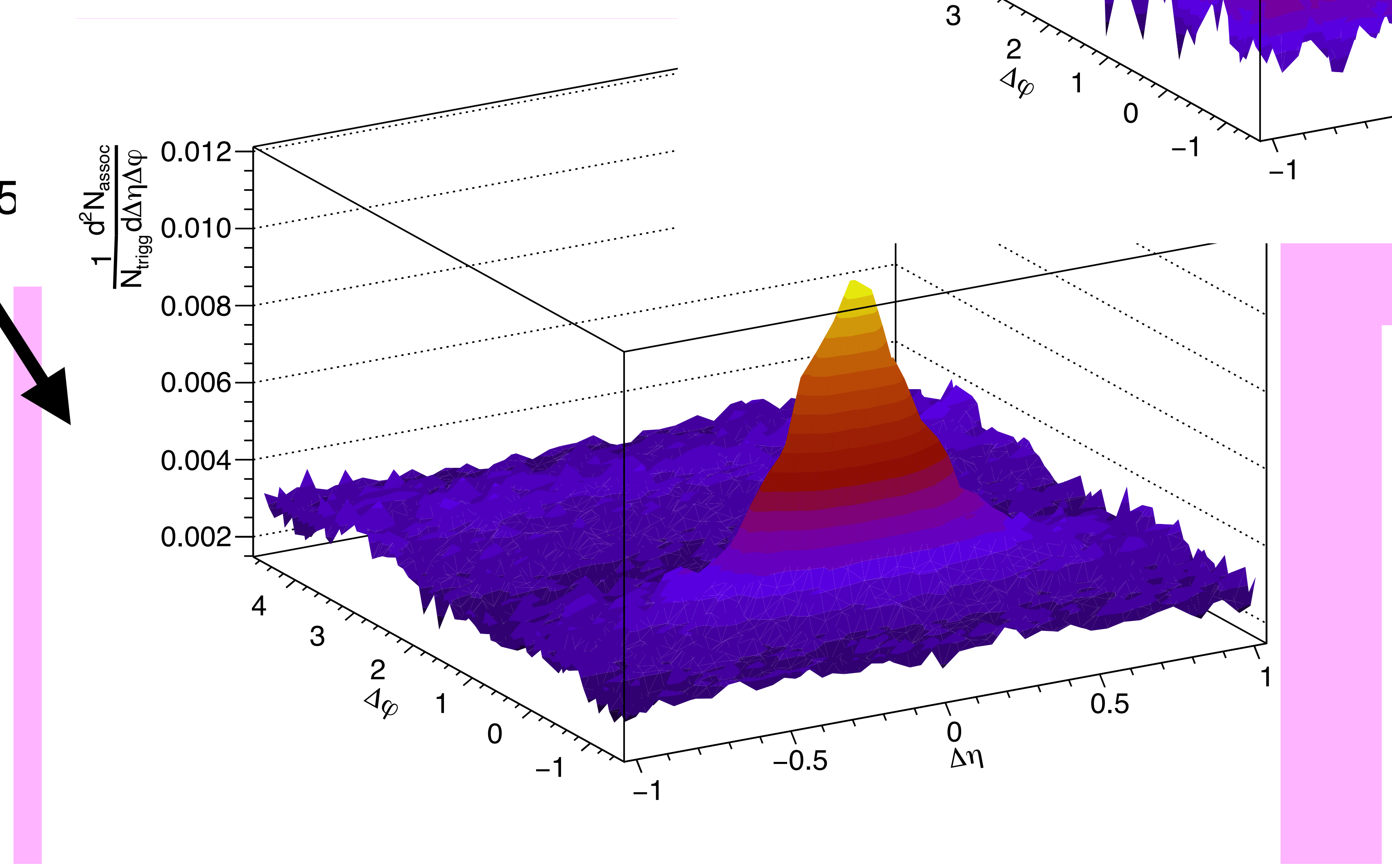
$$\frac{d^2N^{full\ corrected}_{pair}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta,p_T^{trigg}) = \frac{1}{N^{full\ corrected}_{trigg}}(p_T^{trigg})\left(\frac{d^2N^{corr}_{pair\ sig}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta,p_T^{trigg}) - \frac{d^2N^{corr}_{pair\ side}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta,p_T^{trigg})\right)$$

$$N^{full\ corrected}_{trigg} = \frac{signal}{signal + background}N^{corr}_{trigg}$$







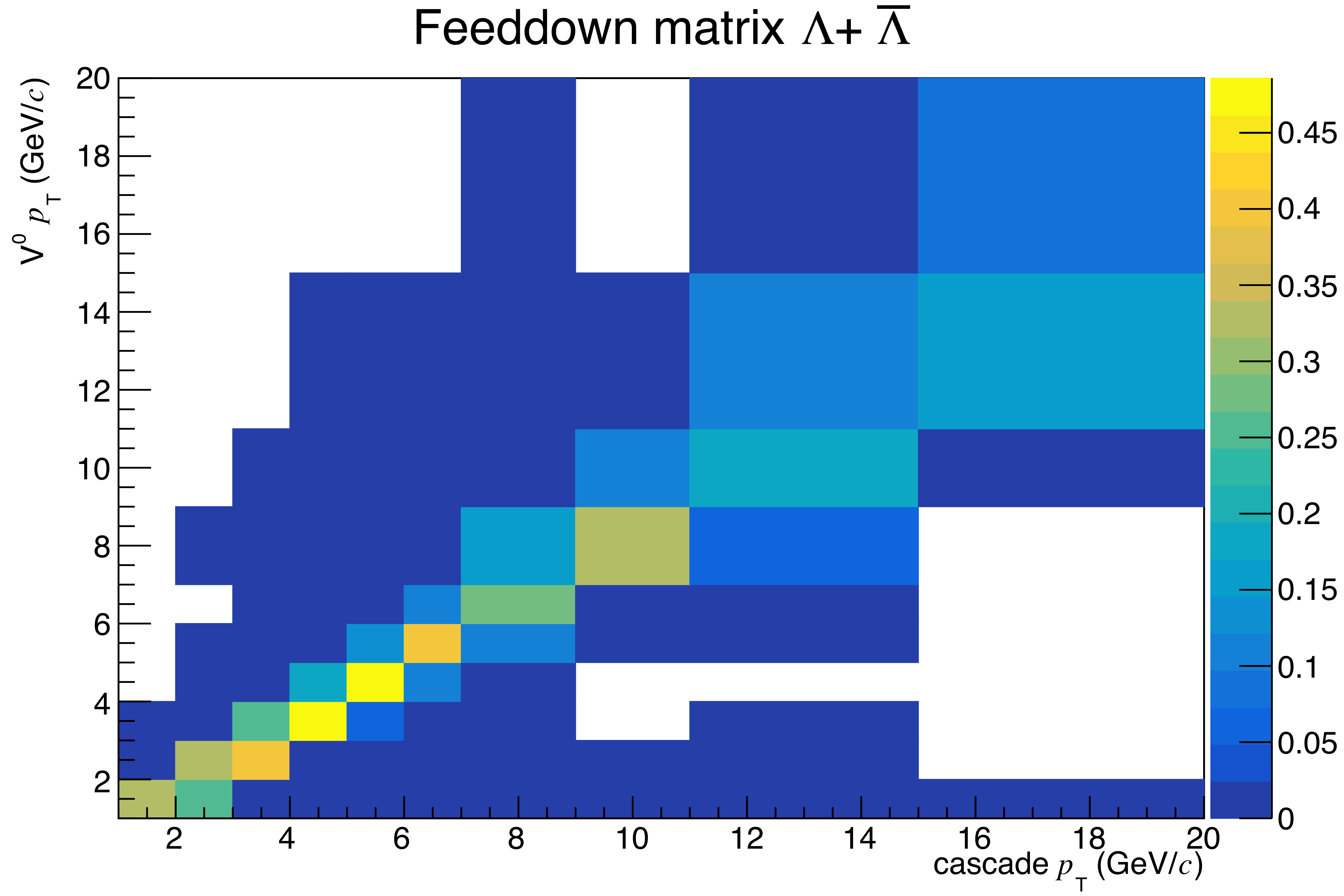


Feed-down correction

$\Lambda = \Lambda_{prim} + \Lambda_{sec}$ Corrected

$$\Lambda_{sec}(p_{\mathrm{T},i}) = F_{ij} \int_{p_{\mathrm{T},j}} \frac{\mathrm{d}N}{\mathrm{d}p_{\mathrm{T}}}(\Xi)\mathrm{d}p_{\mathrm{T}}$$

$$F_{ij} = \frac{N_{rec}(\Lambda)^{in\ bin\ i}_{from\ \Xi\ in\ bin\ j}}{N_{gen}(\Xi)^{in\ bin\ j}}$$



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$$\Lambda_{sec}(p_{T,i}) = F_{ij} \int_{p_{T,j}} \frac{dN}{dp_T}(\Xi) dp_T$$

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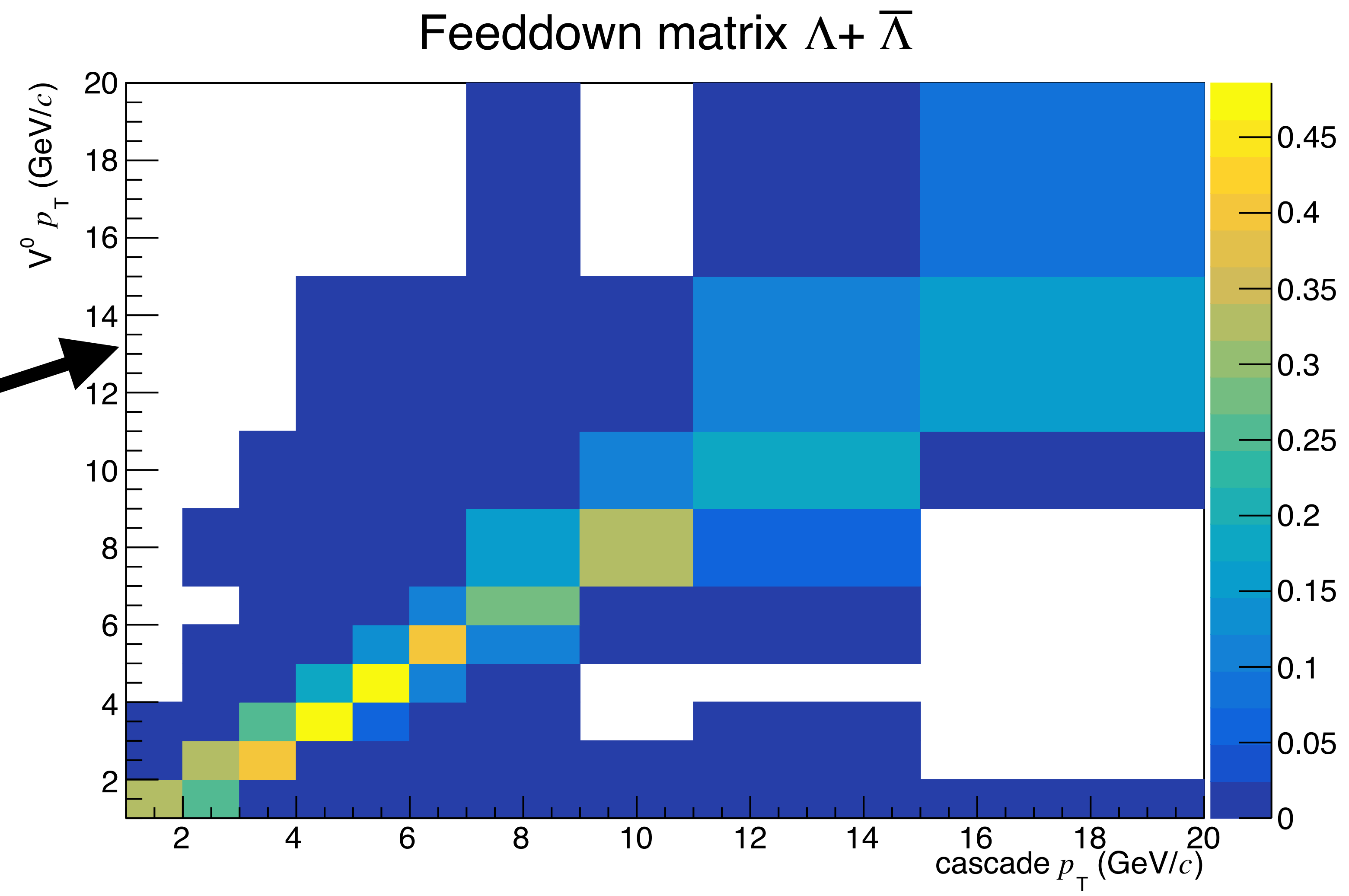
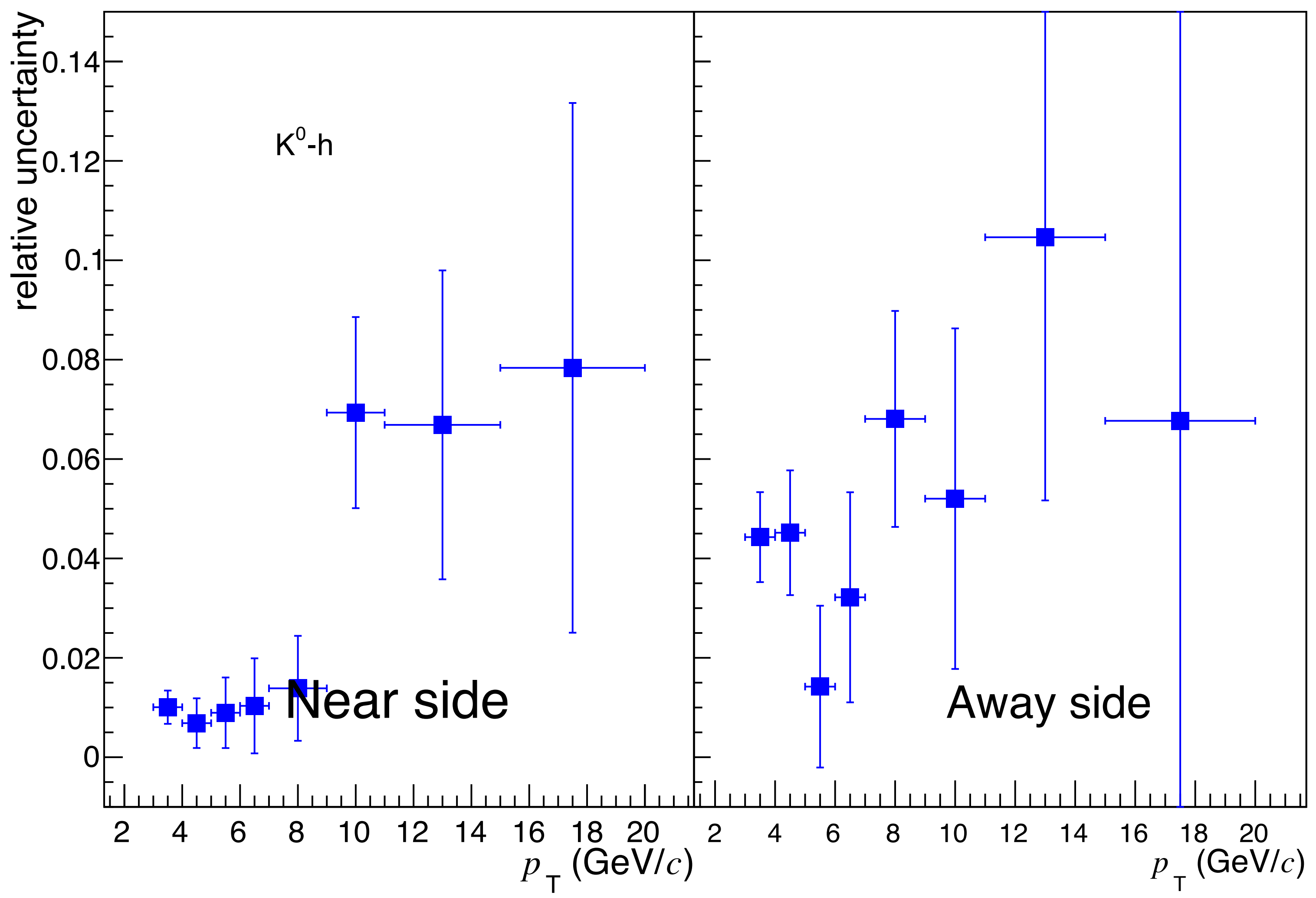


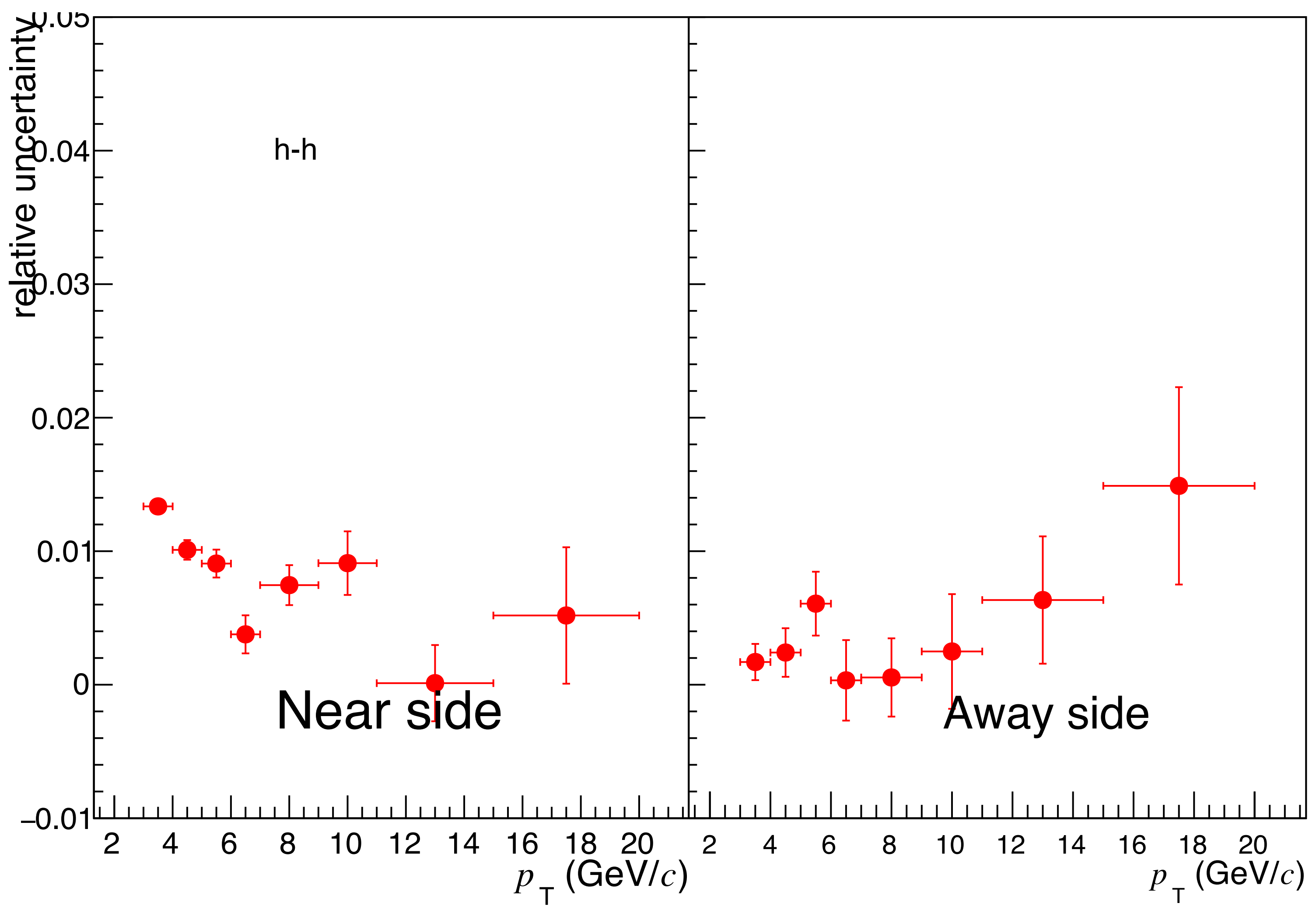
$$N^{final}_{trigg}(p_{T,i}) = C^{\Lambda}_{purity}(p_{T,i}) * (N^{measured}_{\Lambda}(p_{T,i}) - \frac{1}{\varepsilon_{\Lambda}}(p_{T,i}) * F_{ij} * C^{\Xi}_{purity}(p_{T,j}) * N^{measured}_{\Xi}(p_{T,j}))$$

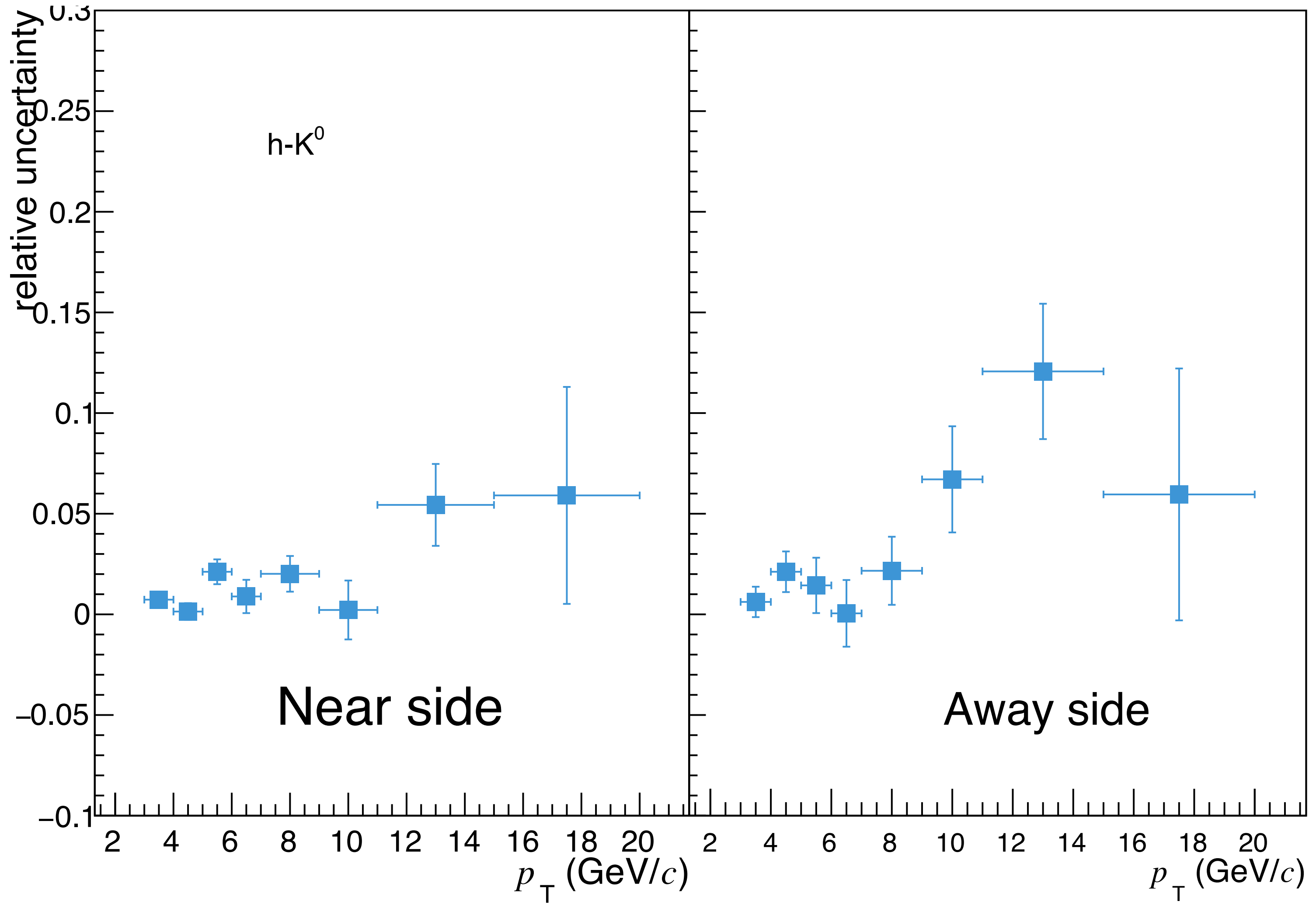
$$N^{final}_{\Lambda-h}(p_{T,i}) = N^{measured}_{\Lambda-h}(p_{T,i}) - \frac{1}{\varepsilon_{\Lambda}}(p_{T,i}) * F_{ij} * (N^{measured}_{\Xi-h}(p_{T,j}) - N^{side-band}_{\Xi-h}(p_{T,j})) - N^{side-band}_{\Lambda-h}(p_{T,i})$$

MC closure Test

- If all correction are done in a correct way:
$$\frac{Y_{MC}^{reconstructed}}{Y_{MC}^{generated}} = 1$$
- Relative uncertainty:
$$\frac{|Y_{gen} - Y_{rec}|}{Y_{gen}}$$







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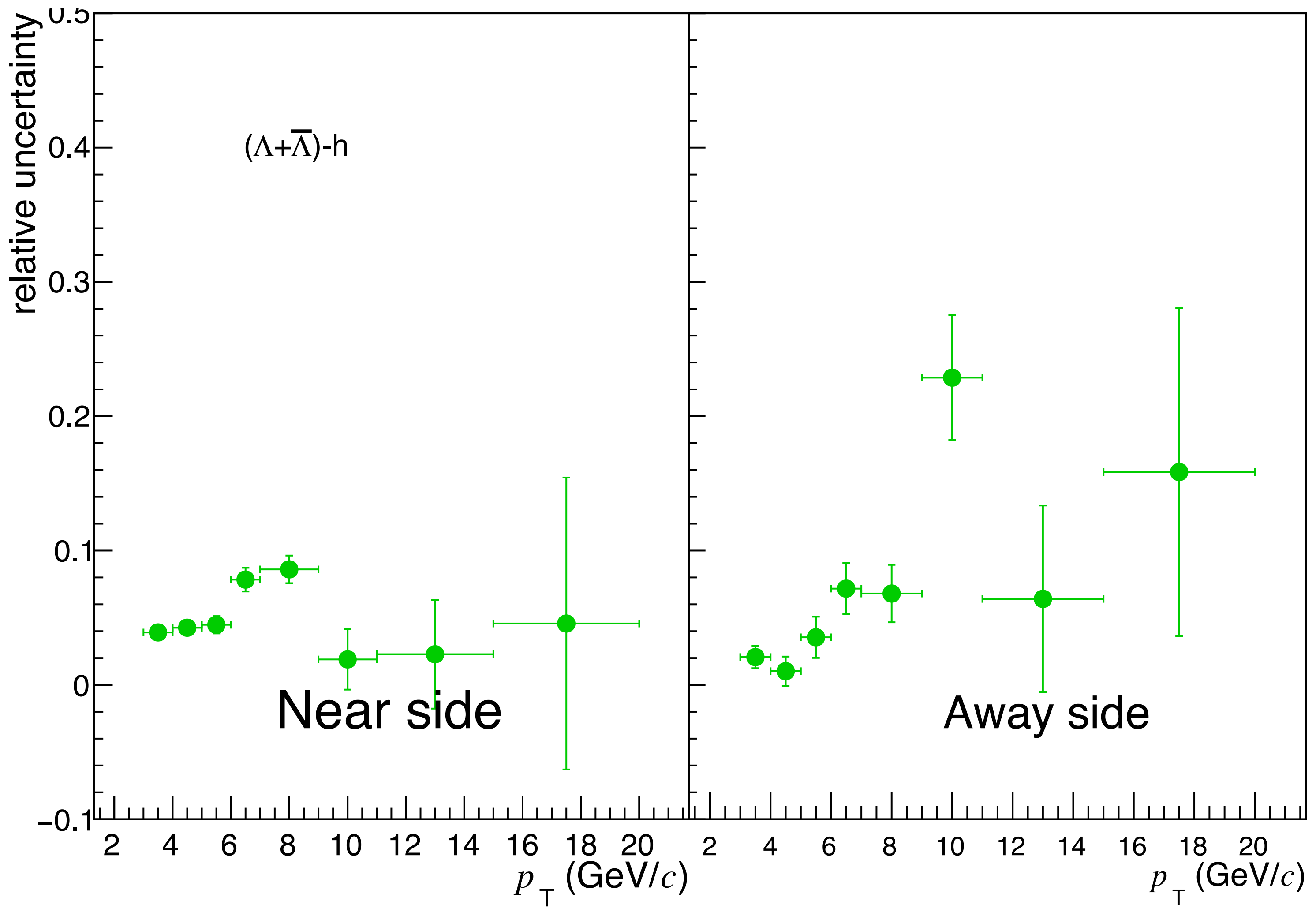
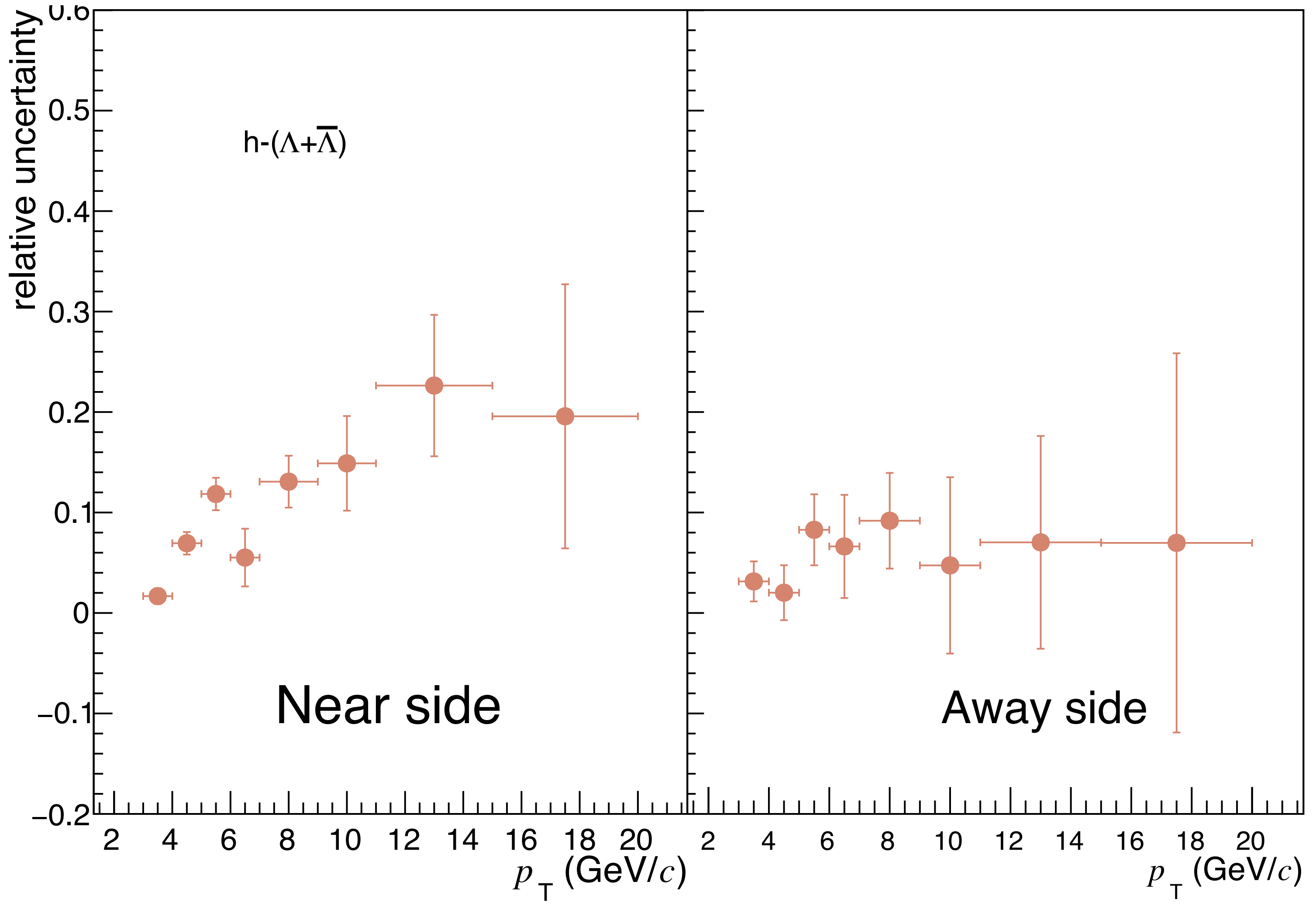




Residual non-closure yielding to additional systematical uncertainty:

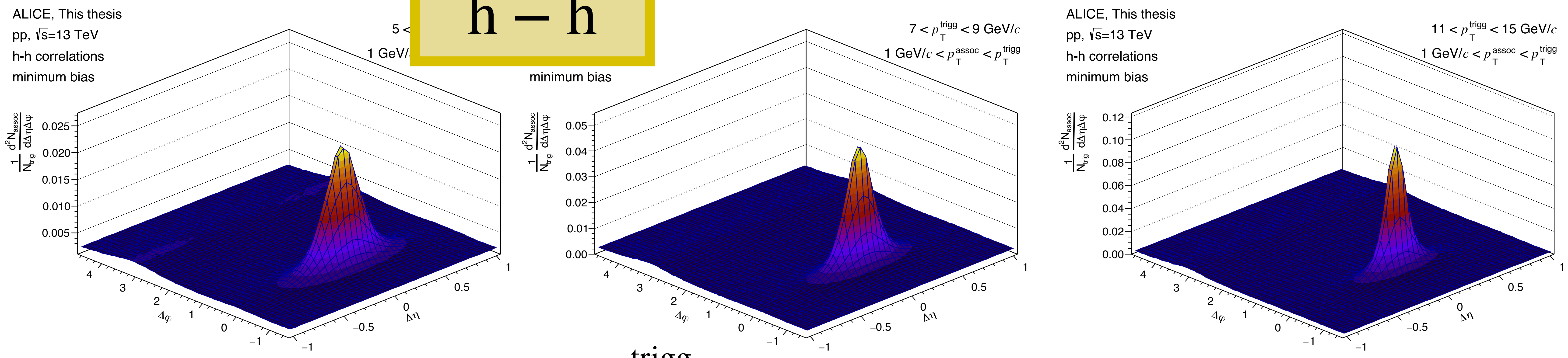
2.5%

4%

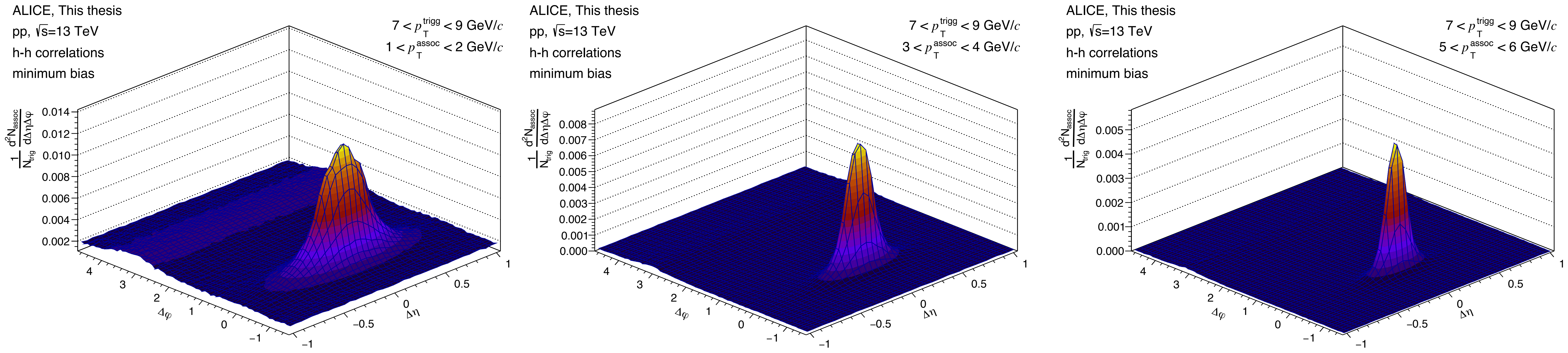
Results

2D correlation function

h – h



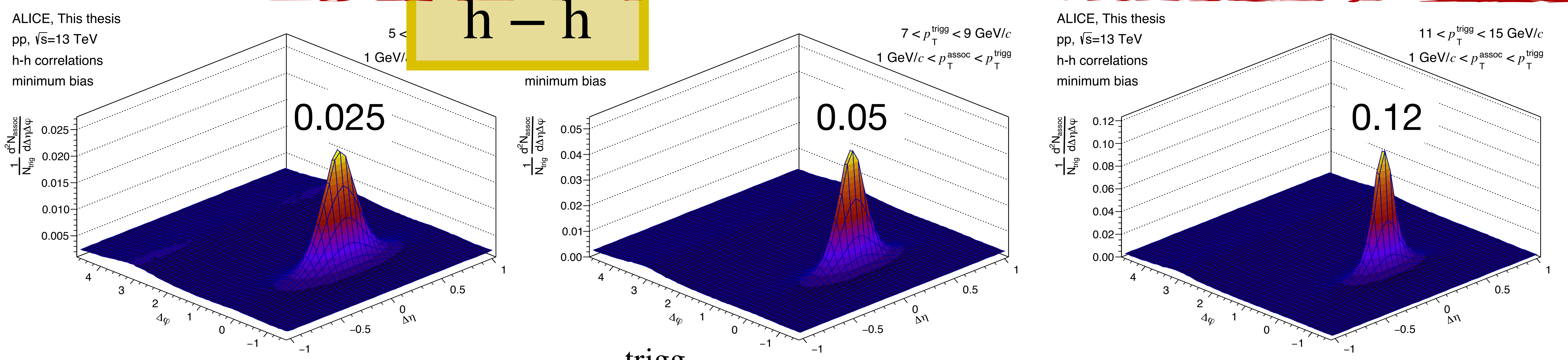
Increasing p_T^{trigg}



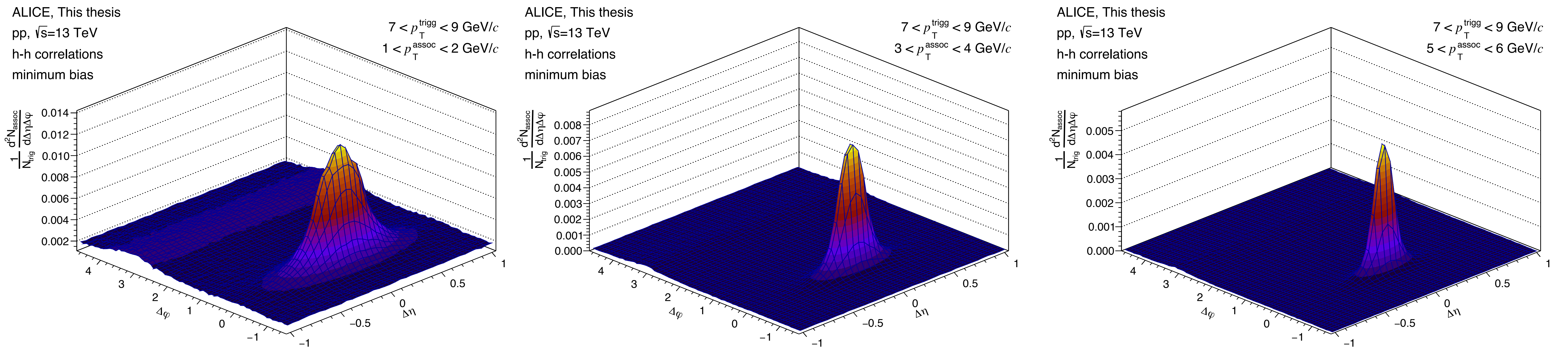
Increasing p_T^{assoc}

2D correlation function

h – h



Increasing p_T^{trigg}

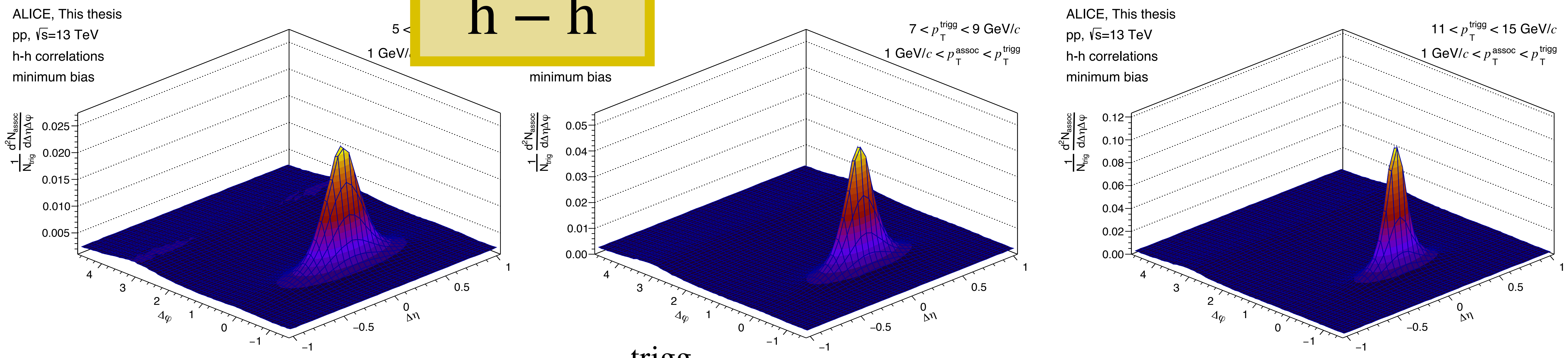


Increasing p_T^{assoc}

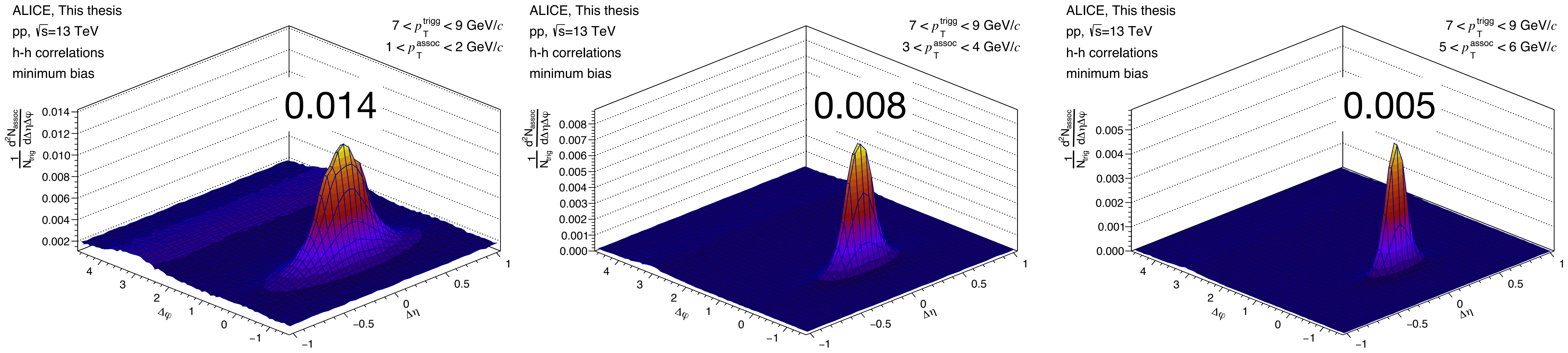
- Increase of the peak size with increasing p_T^{trigg} - more available energy

2D correlation function

h – h



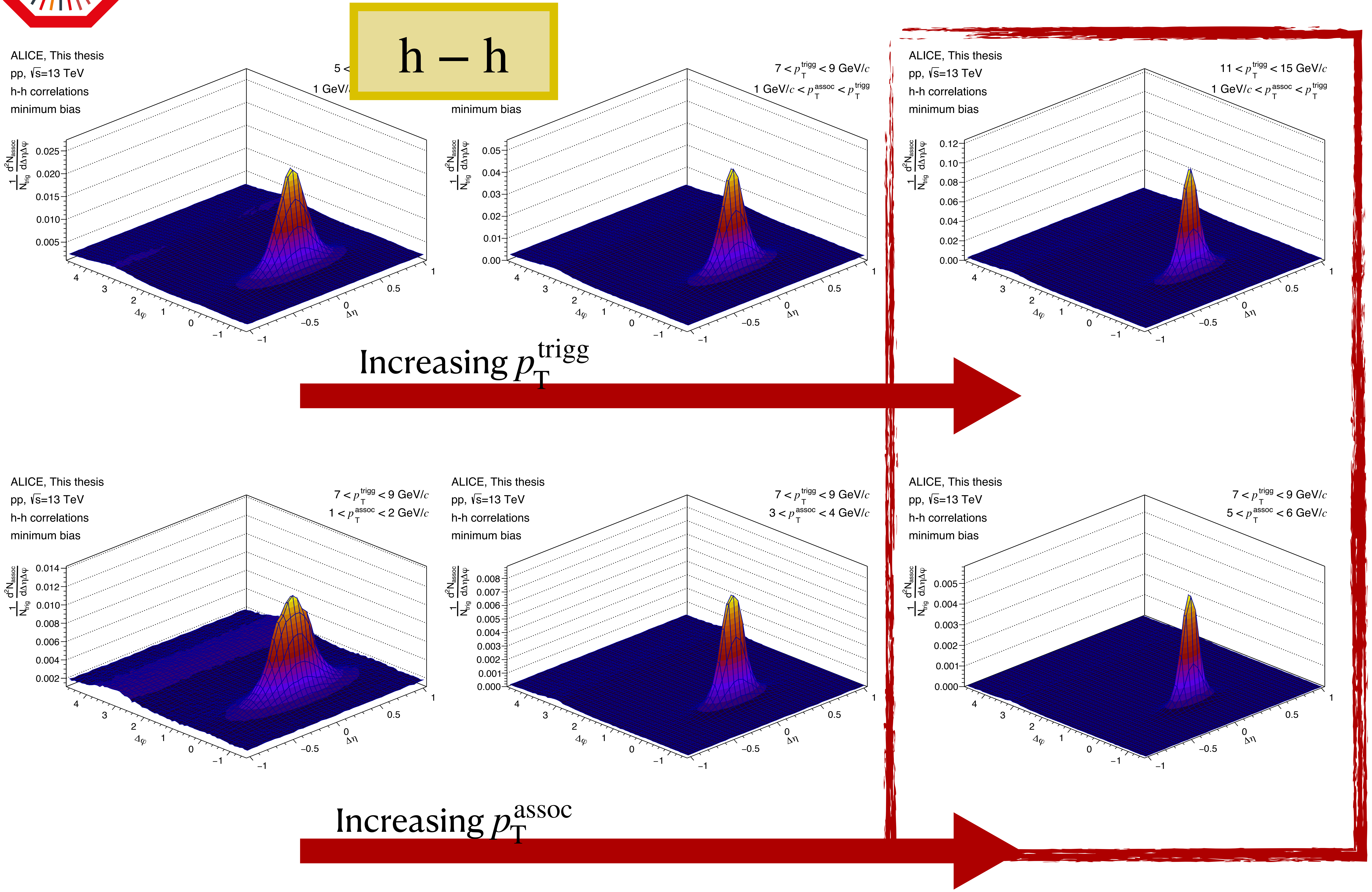
Increasing p_T^{trigg}



Increasing p_T^{assoc}

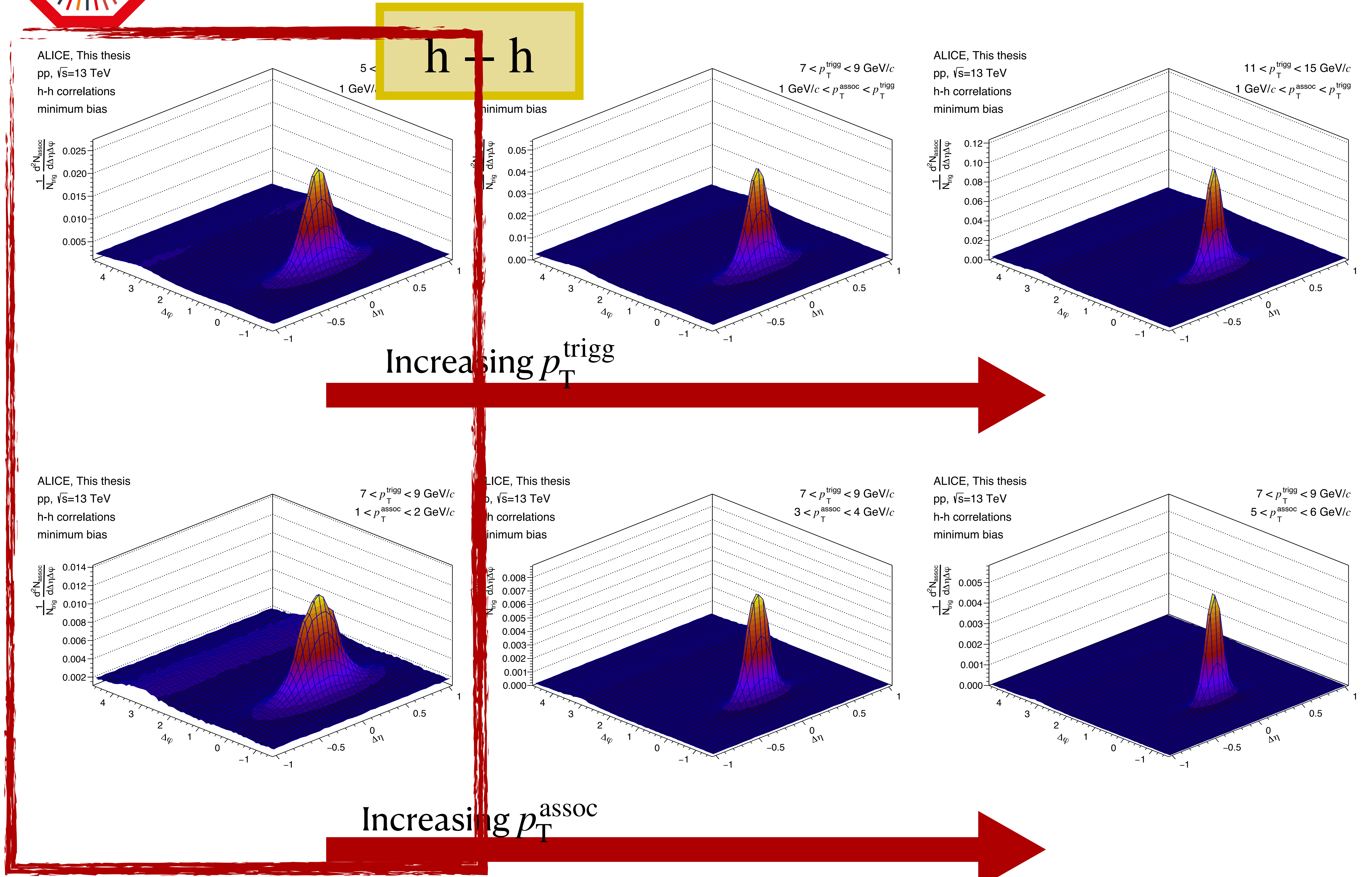
- Increase of the peak size with increasing p_T^{trigg} - more available energy
- Decrease of the peak size with increasing p_T^{assoc}

2D correlation function



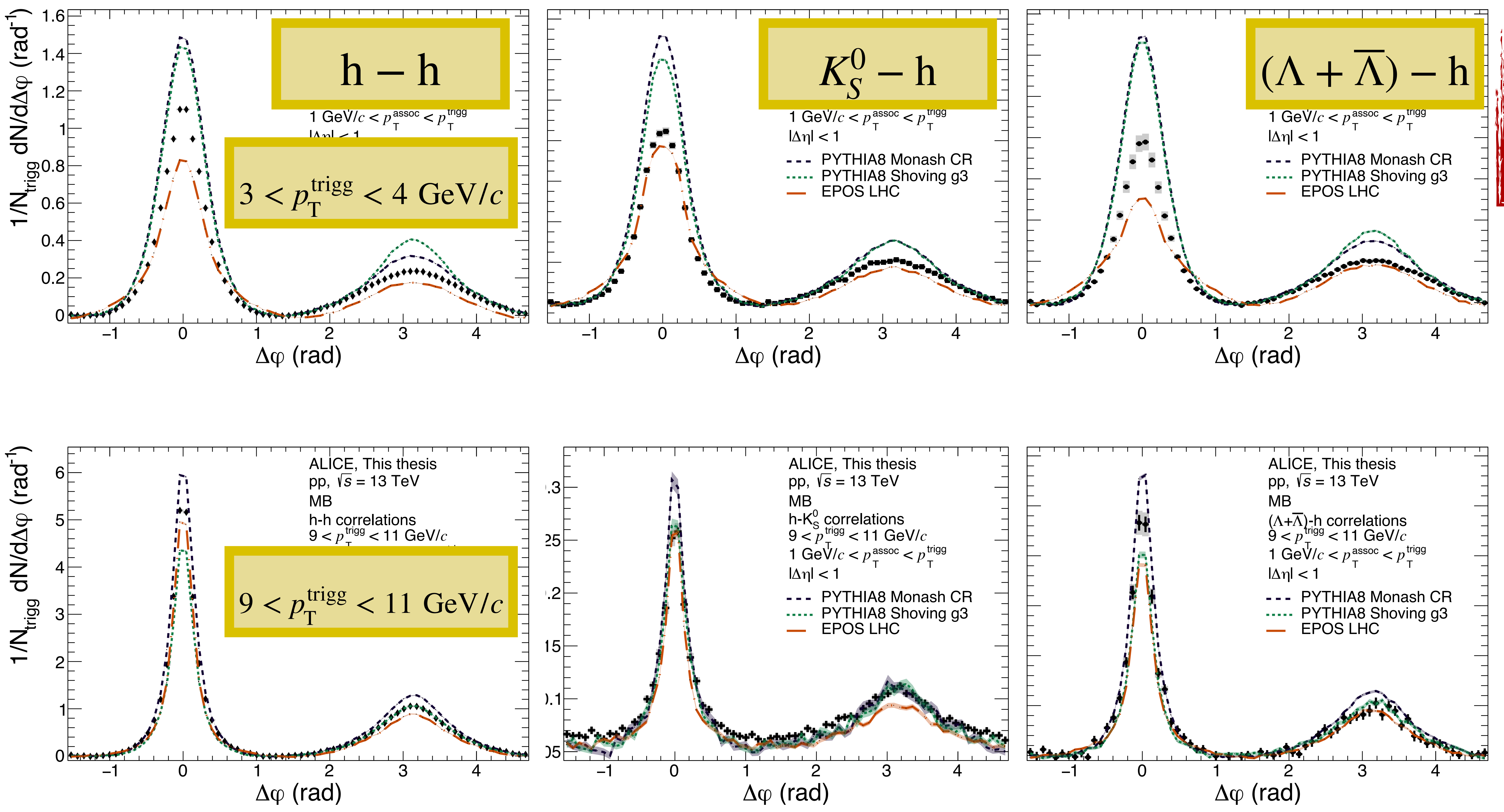
- Increase of the peak size with increasing p_T^{trigg} - more available energy
- Decrease of the peak size with increasing p_T^{assoc}
- Collimated peaks for high p_T - hard fragmentation

2D correlation function



- Increase of the peak size with increasing p_T^{trigg} - more available energy
- Decrease of the peak size with increasing p_T^{assoc}
- Collimated peaks for high p_T - hard fragmentation
- Broader peaks for low p_T^{assoc} or p_T^{trigg} - softer fragmentation

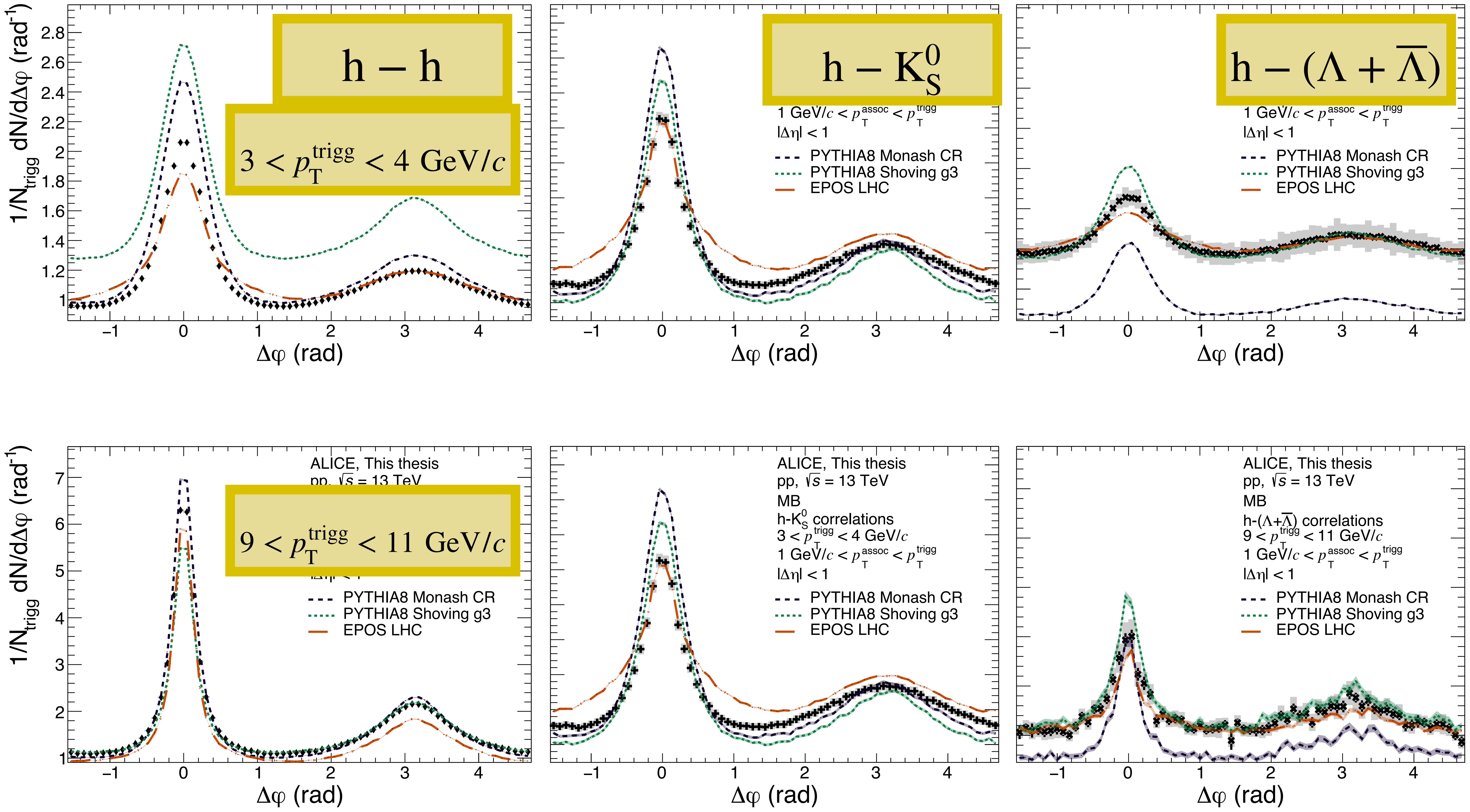
$\Delta\varphi$ projection with model comparison



- No model can give a proper description
- EPOS underestimates both peaks for all trigger particles except for K^0_S at higher p_T
- Bigger difference between PYTHIA8 models (Monash and Shoving) at higher p_T

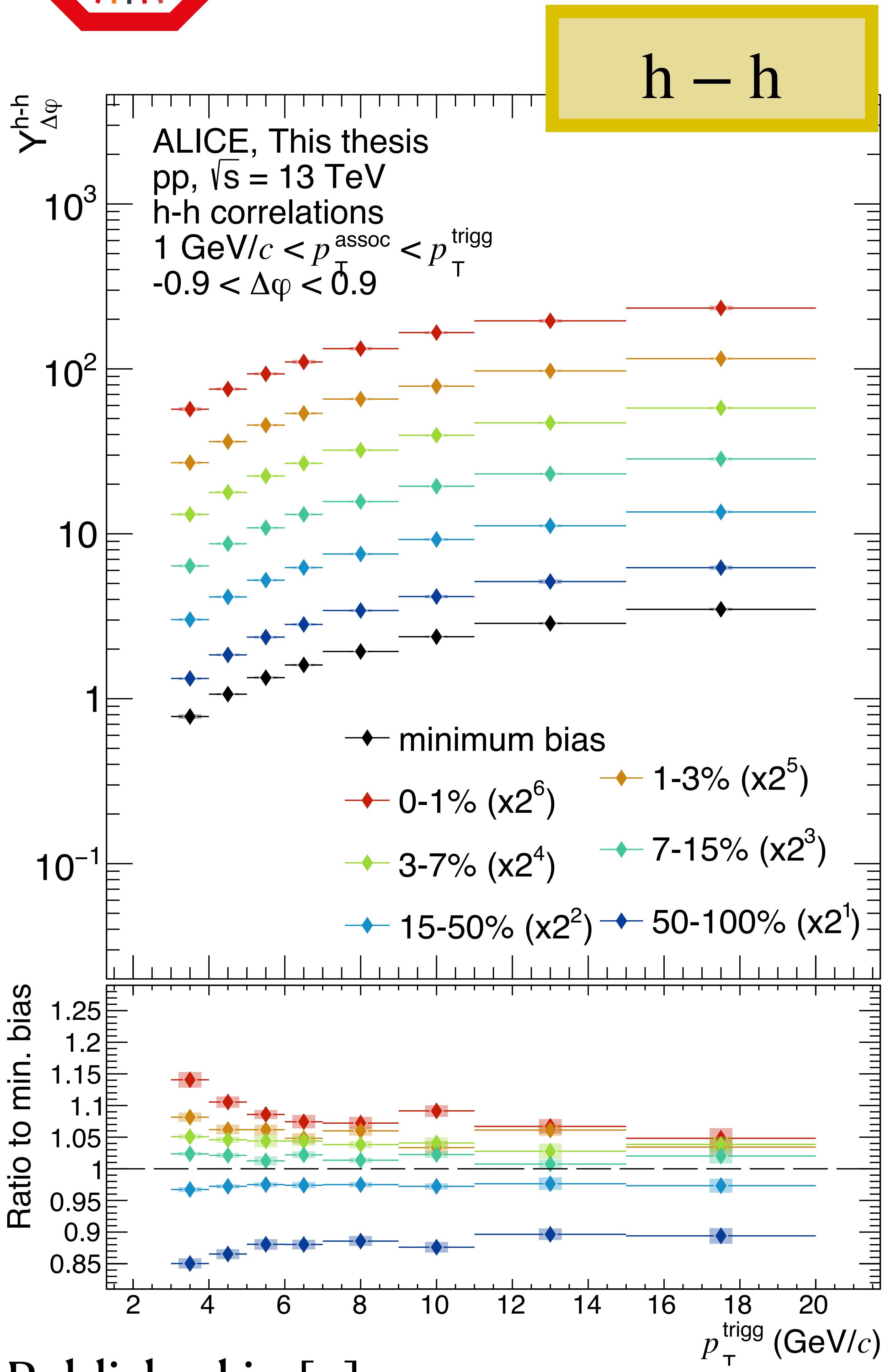
Published in [5]

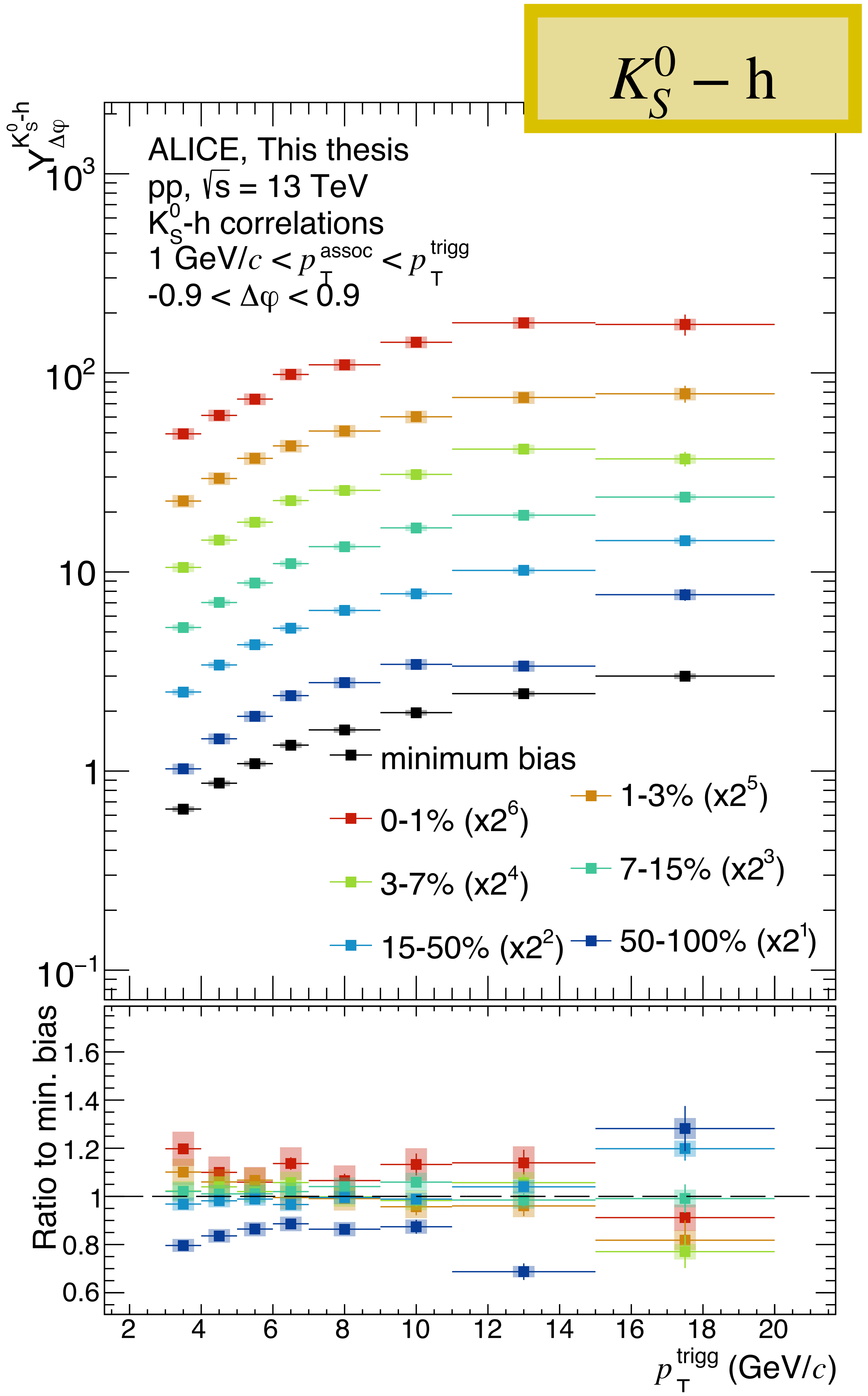
$\Delta\varphi$ projection with model comparison

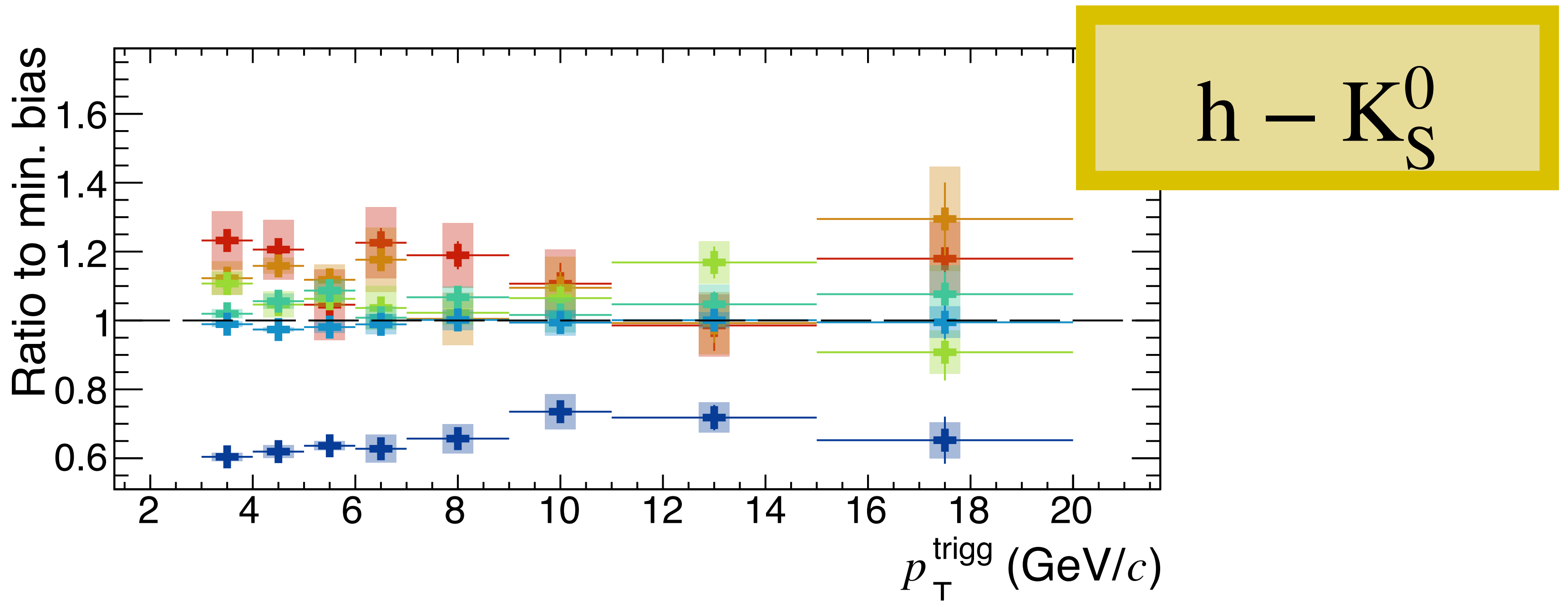


- No model can give a proper description
- Monash fits the underlying event for hh - good tuning on spectra, but underestimates $h - (\Lambda + \overline{\Lambda})$
- Shoving fits $h - (\Lambda + \overline{\Lambda})$ - improvement
- EPOS overestimates the peak widths

Integrated yields (p_T^{trigg} and multiplicity) - Near side

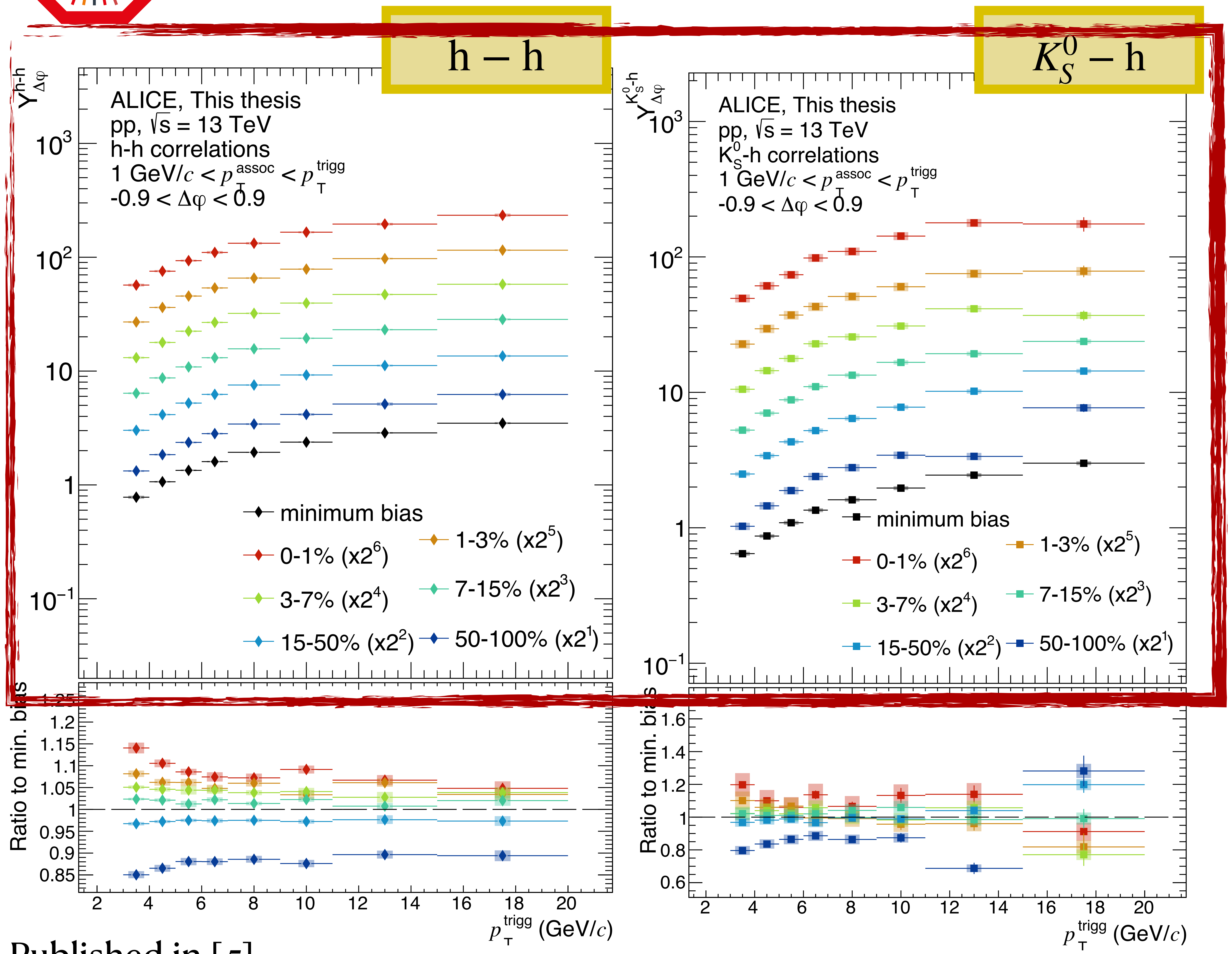




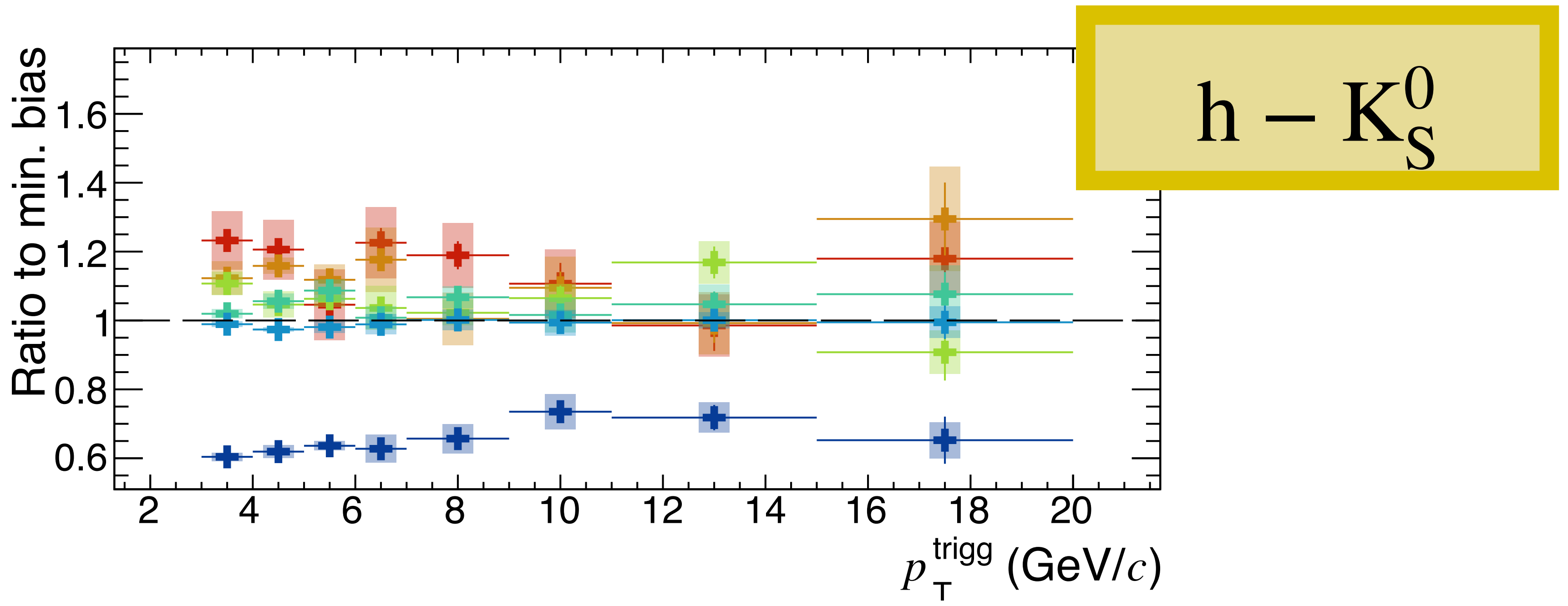


Published in [5]

Integrated yields (p_T^{trigg} and multiplicity) - Near side



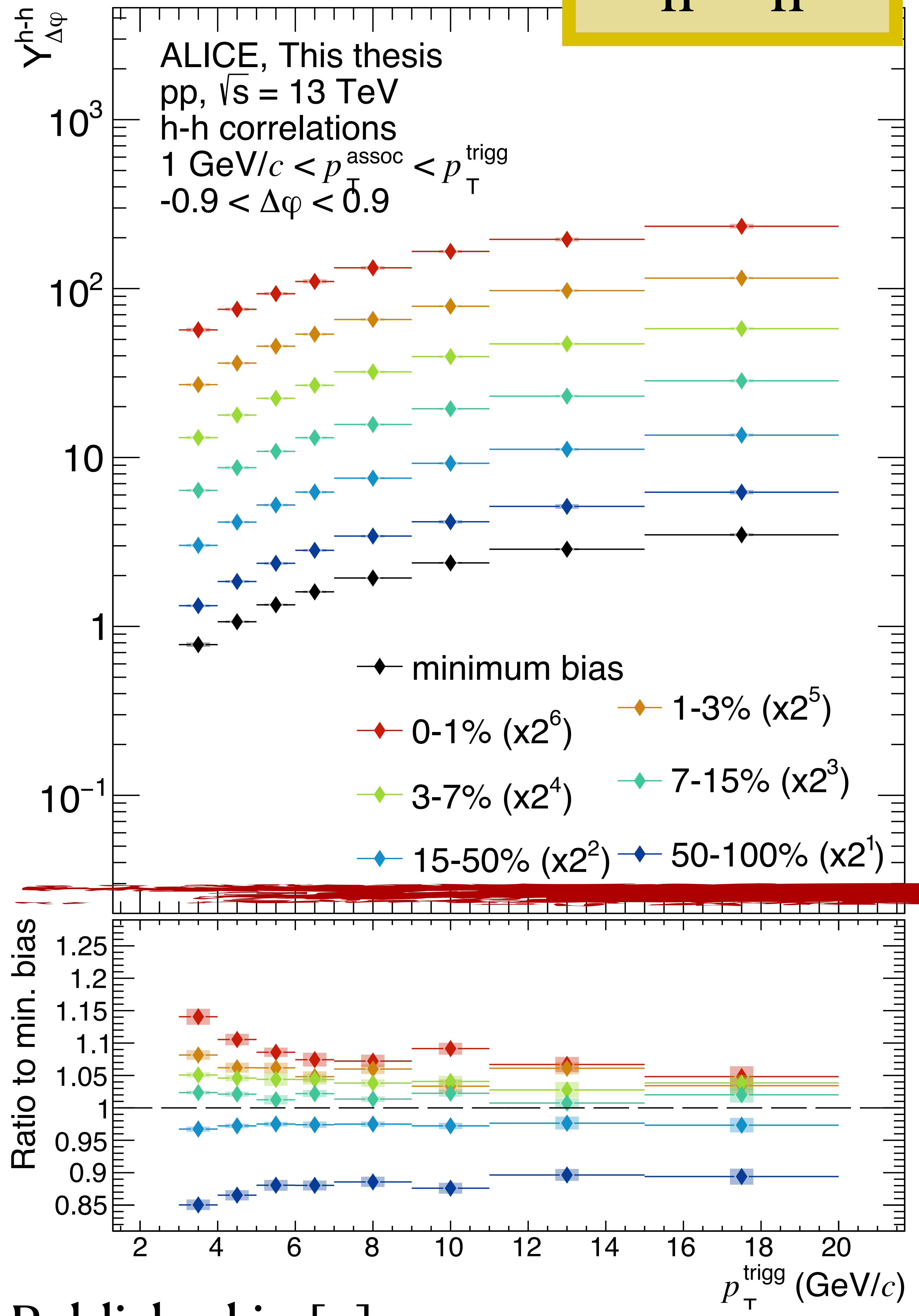
- An increasing trend with p_T^{trigg} caused by more available energy



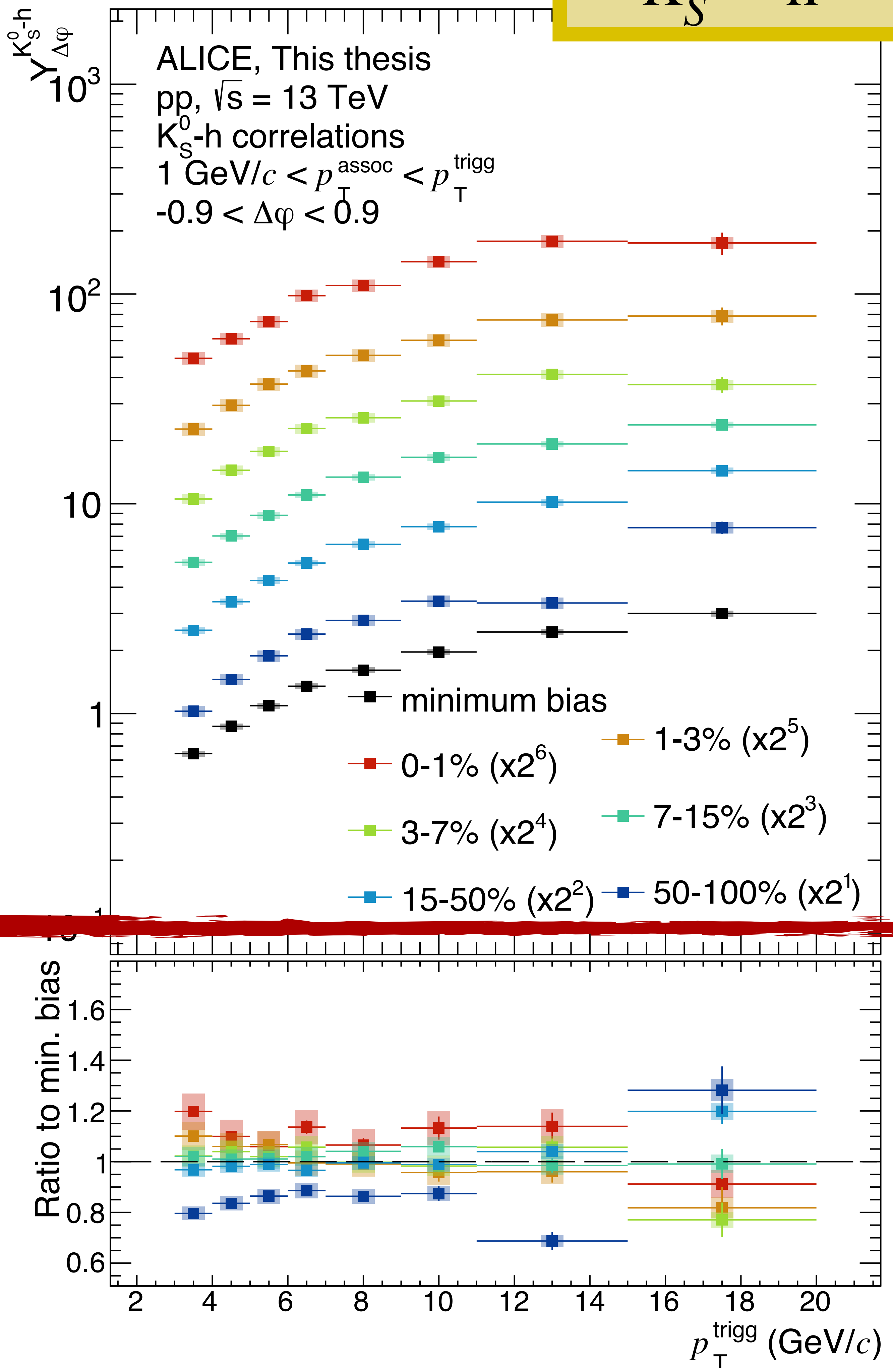
Published in [5]

Integrated yields (p_T^{trigg} and multiplicity) - Near side

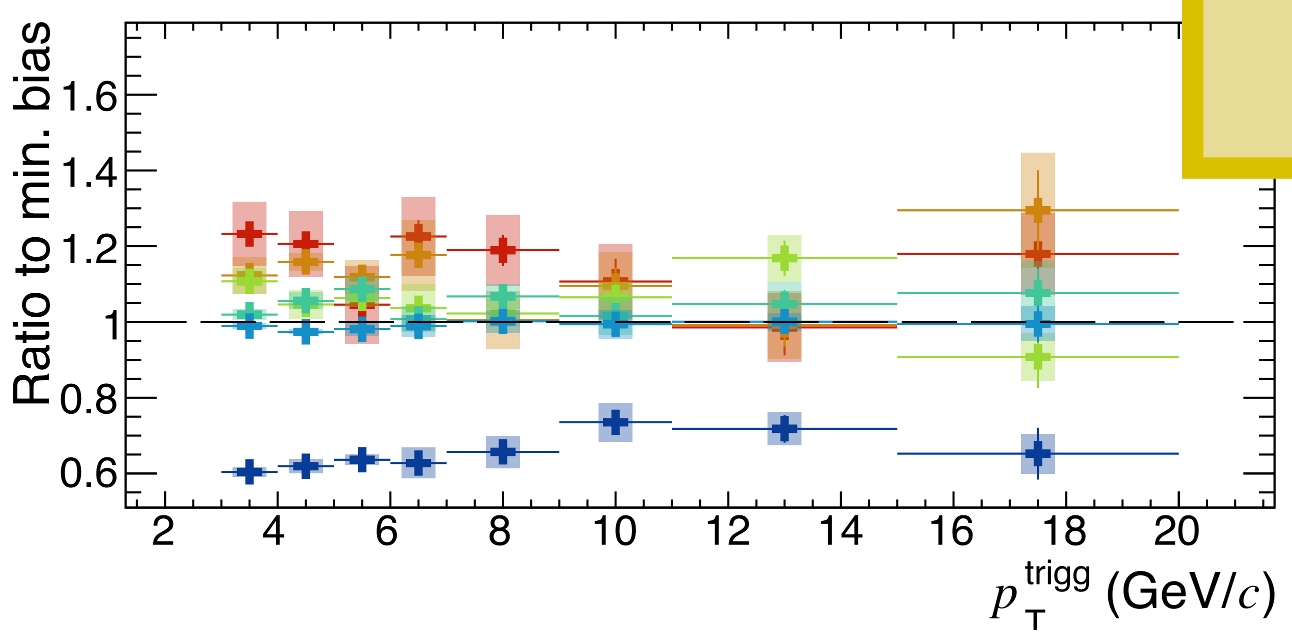
h – h



K_S^0 – h



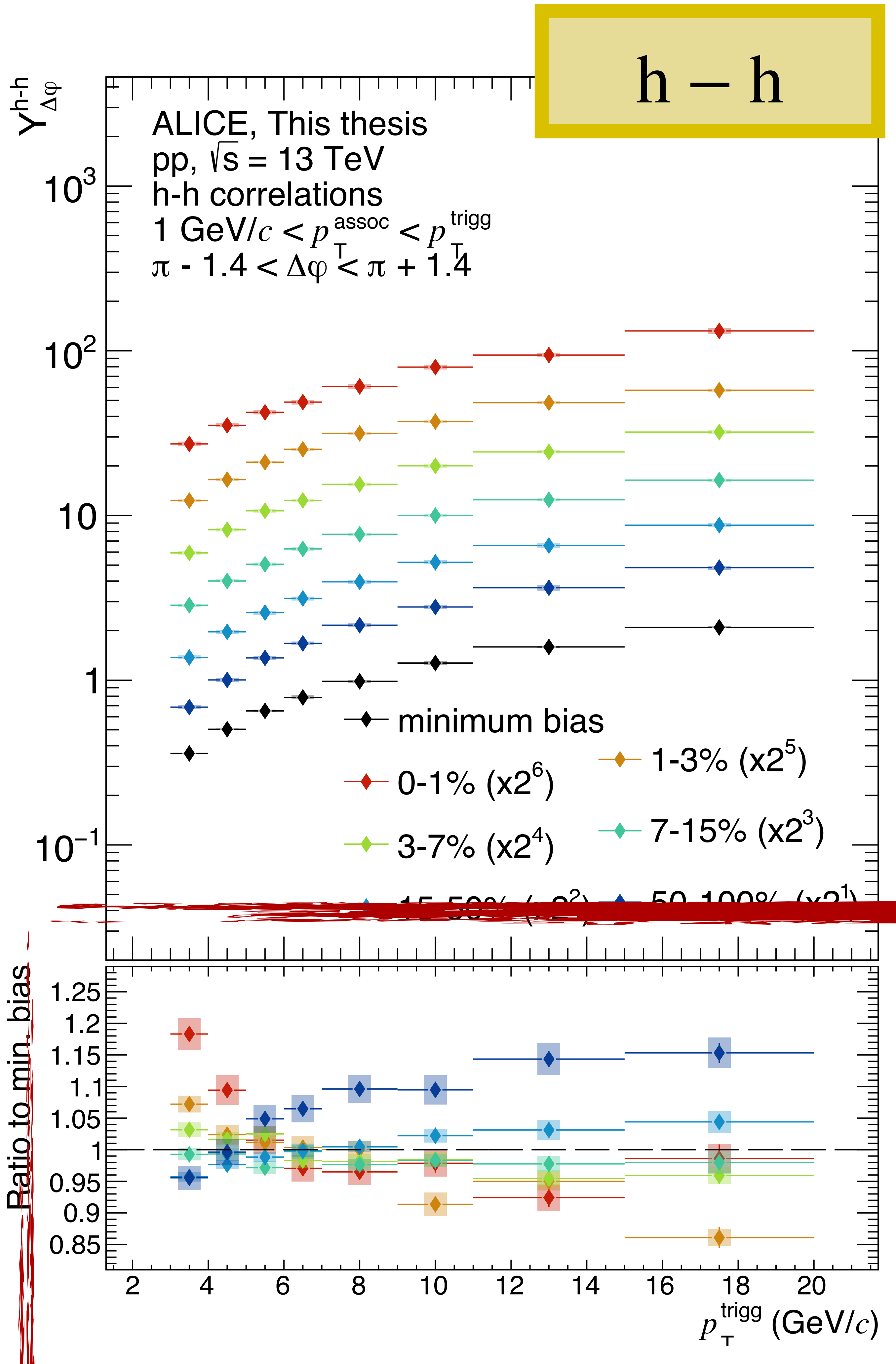
h – K_S^0

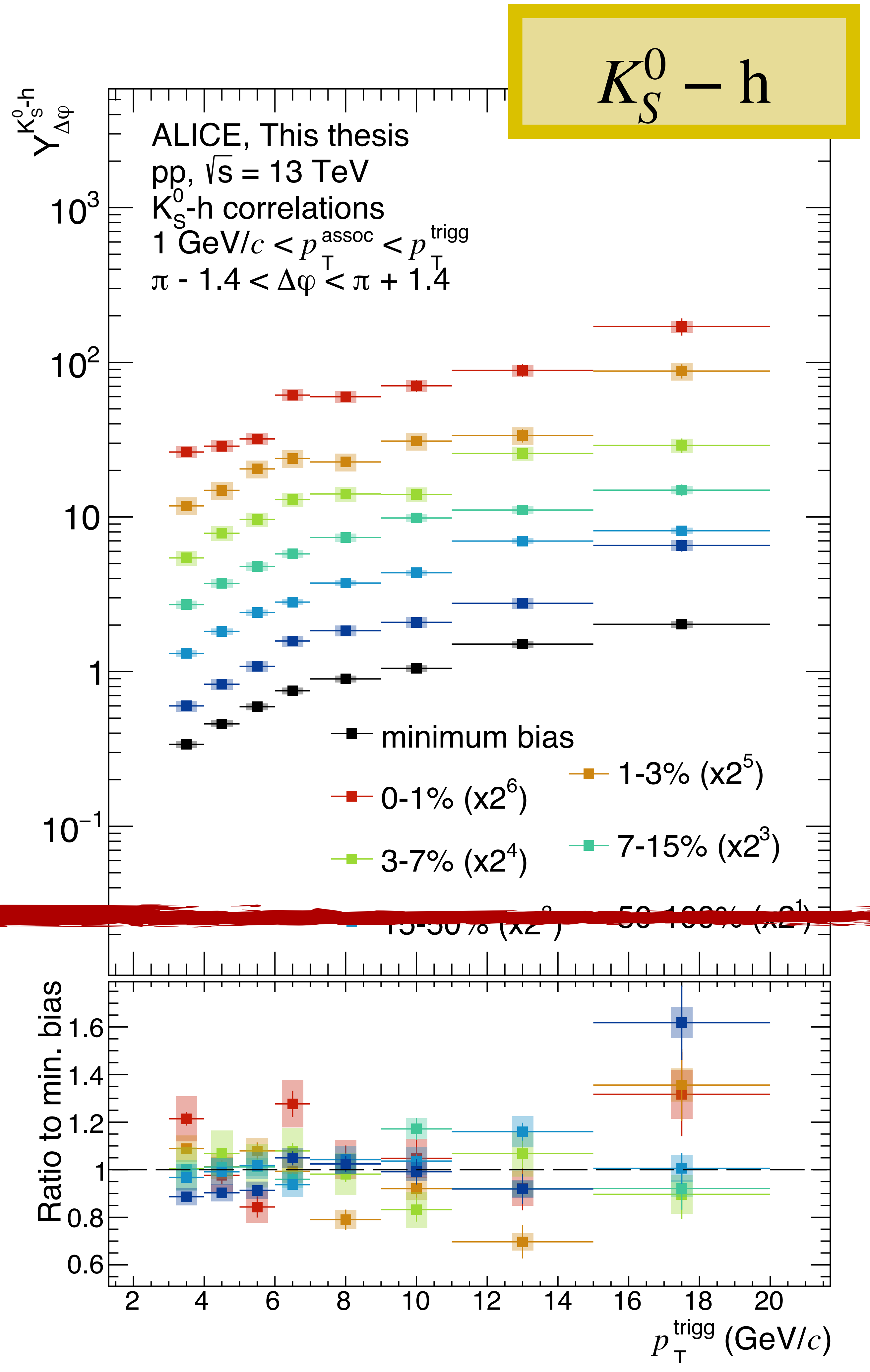


- An increasing trend with p_T^{trigg} caused by more available energy
- Clear multiplicity ordering in h-h, a hint of similar behaviour visible also in V^0-h and h-V^0 - collective ridge-like structure, other effects ?

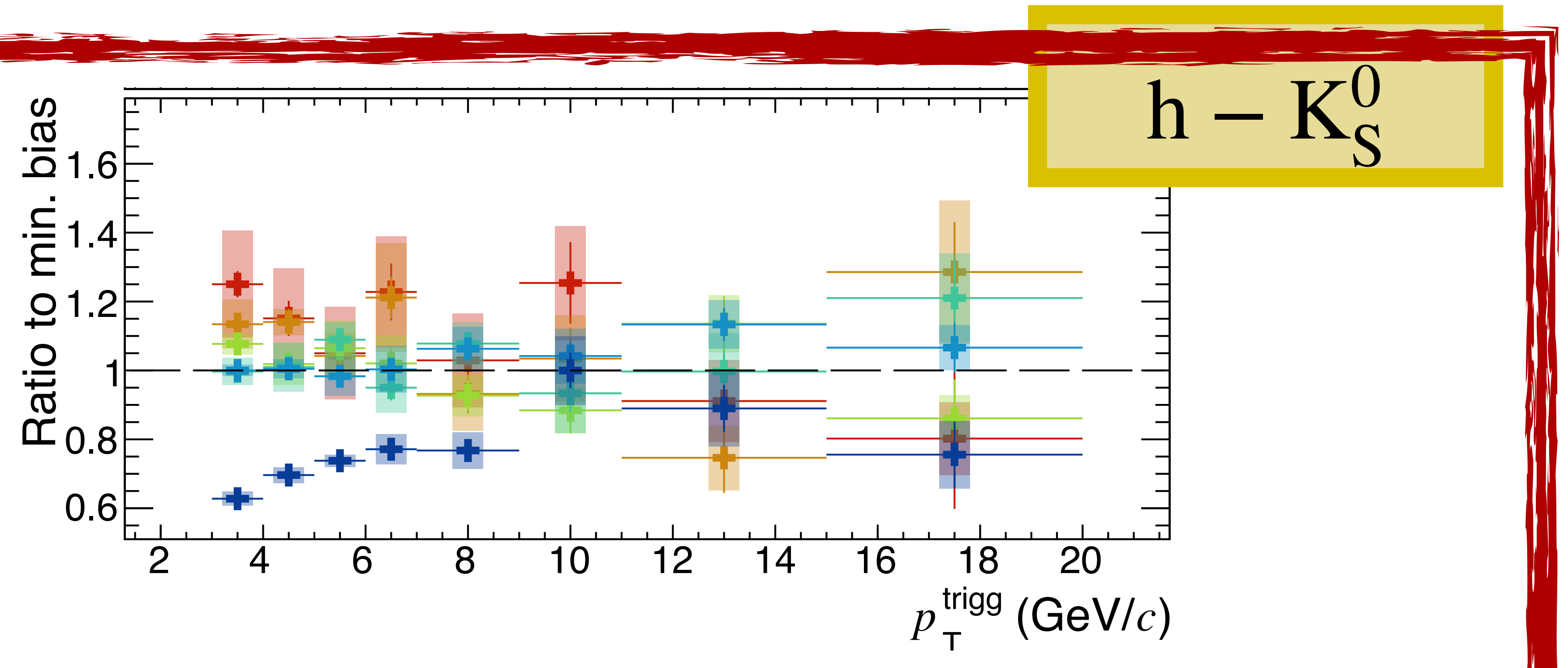
Published in [5]

Integrated yields (p_T^{trigg} and multiplicity) - Away side



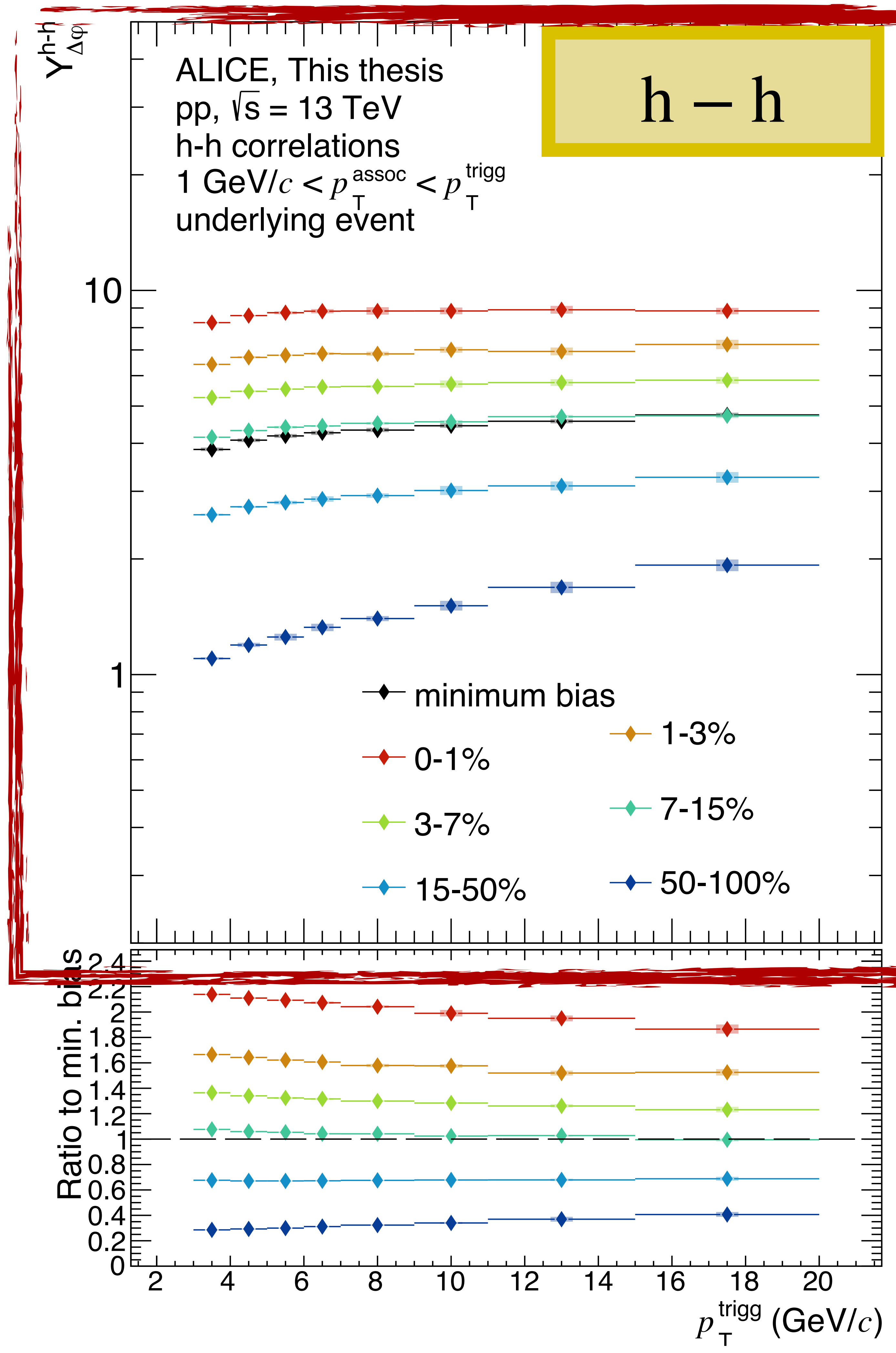


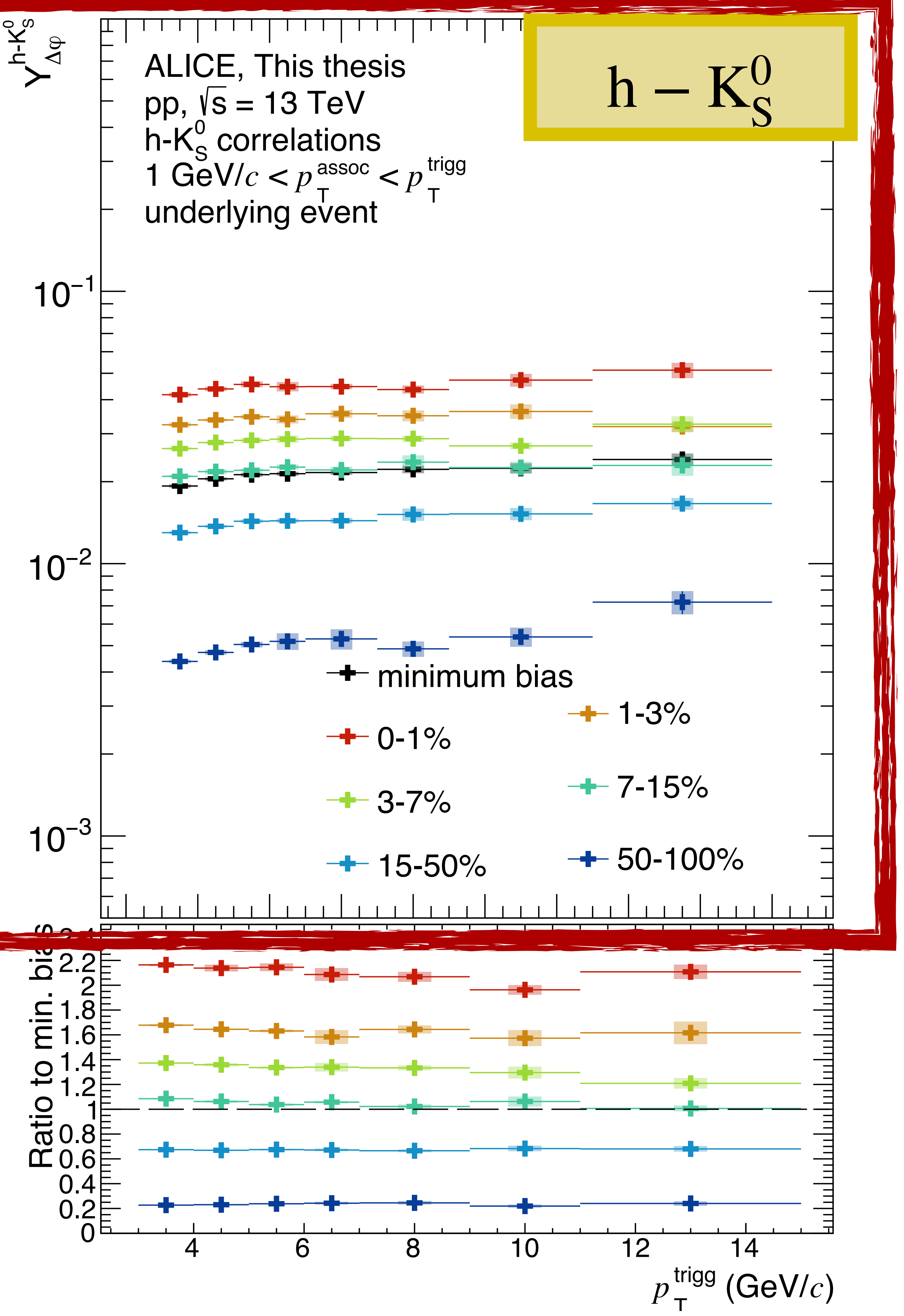
- Opposite multiplicity ordering at high p_T^{trigg} for hh and V^0-h
- caused by multiplicity selection bias
- h-V^0 rather unchanged - V^0 are not detected by the V0 detector



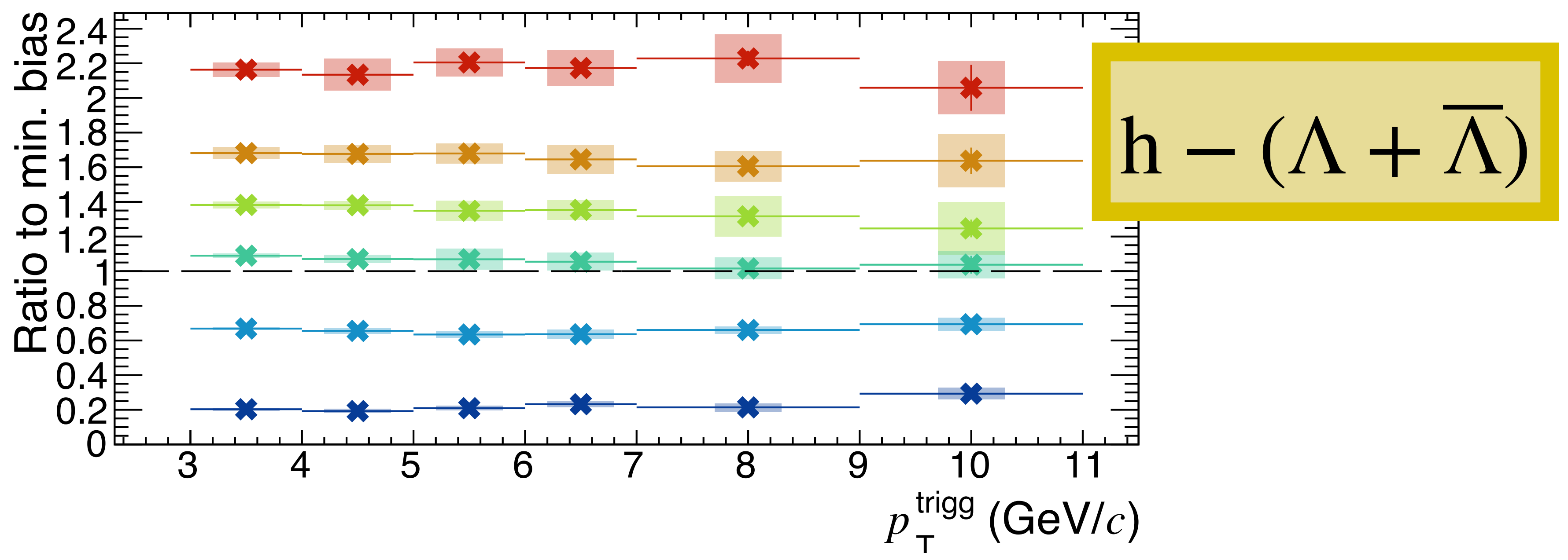
Published in [5]

Integrated yields (p_{T}^{trigg} and multiplicity) Underlying event

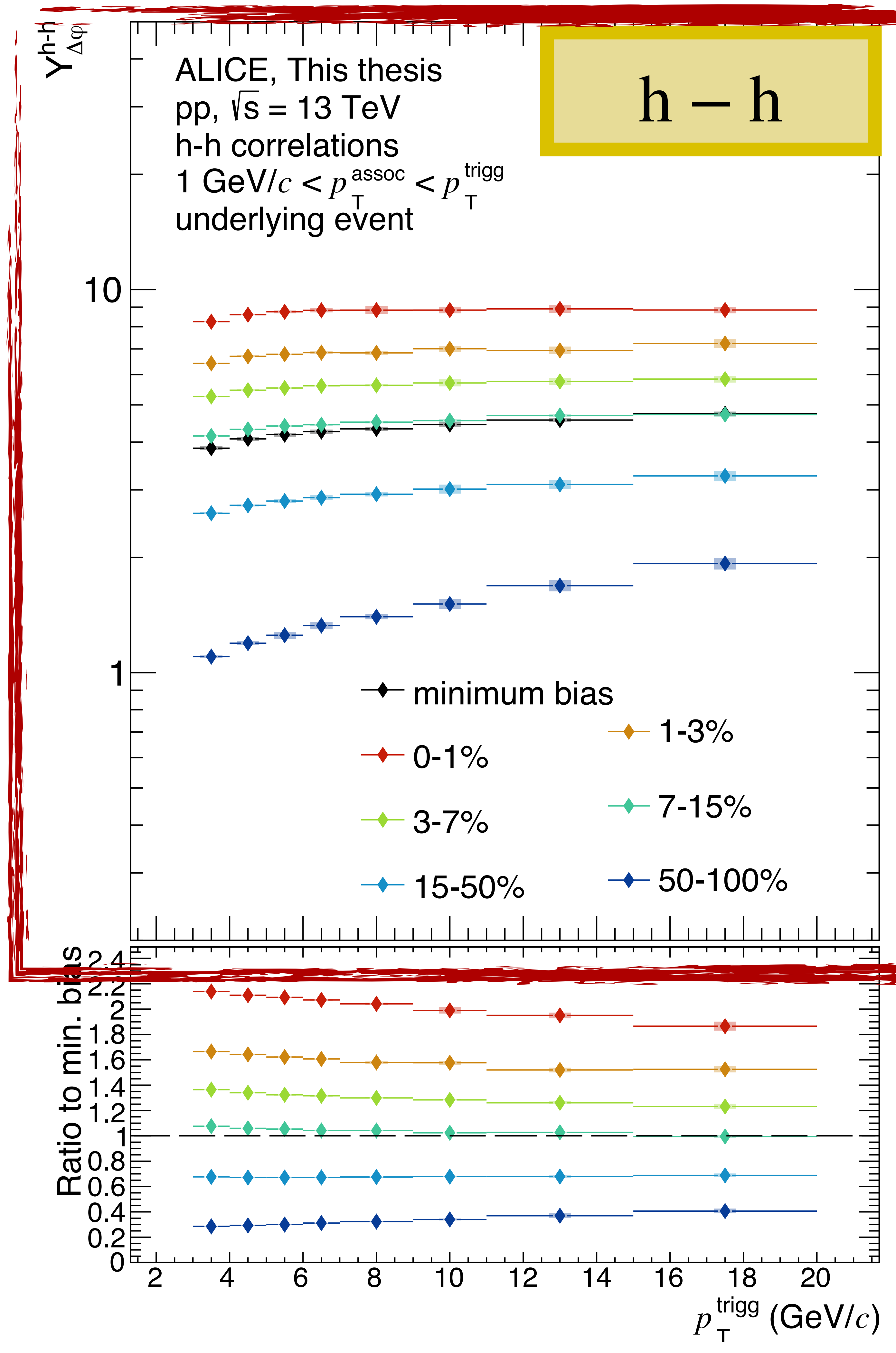


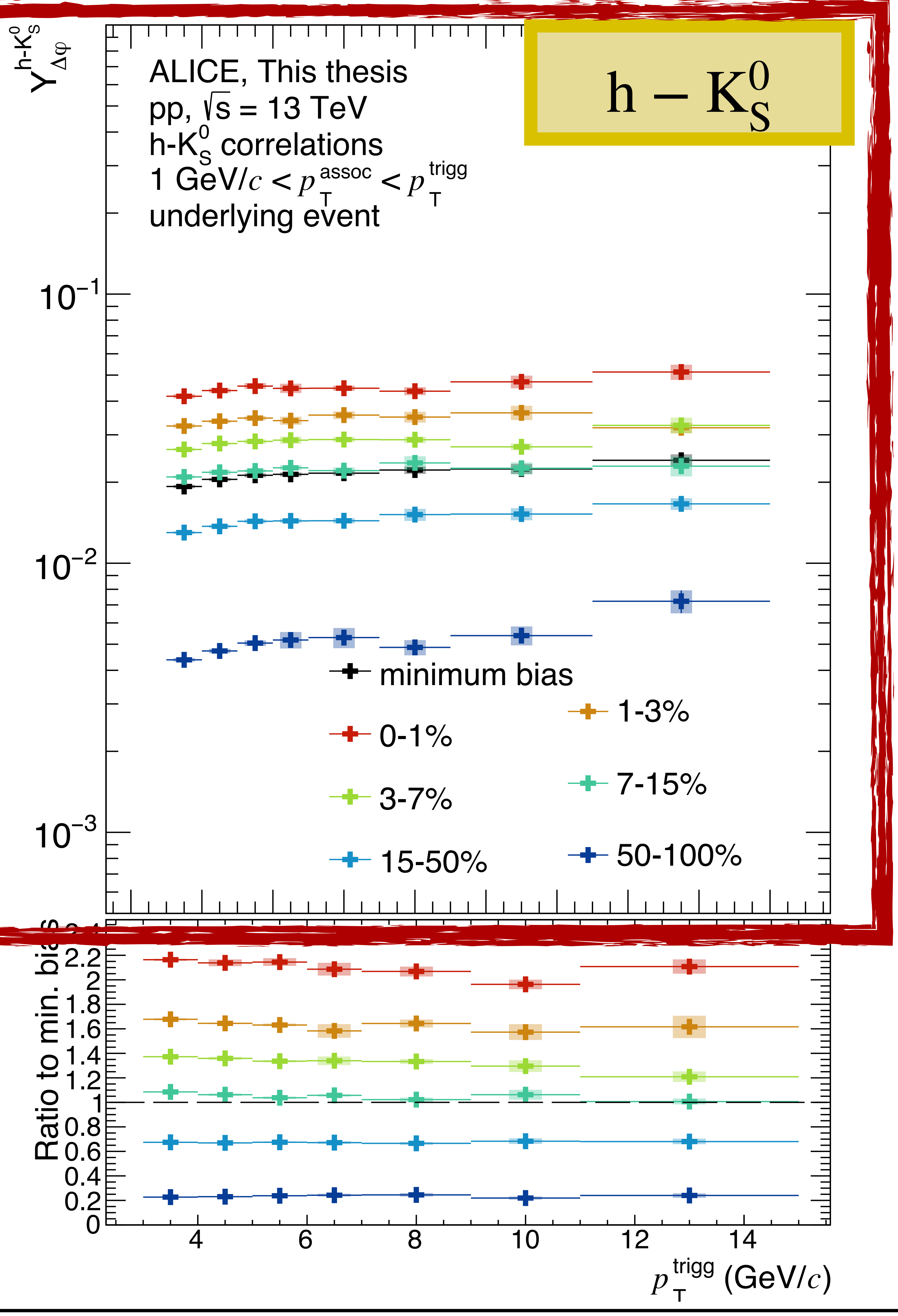


- Weak dependence on p_{T}^{trigg}

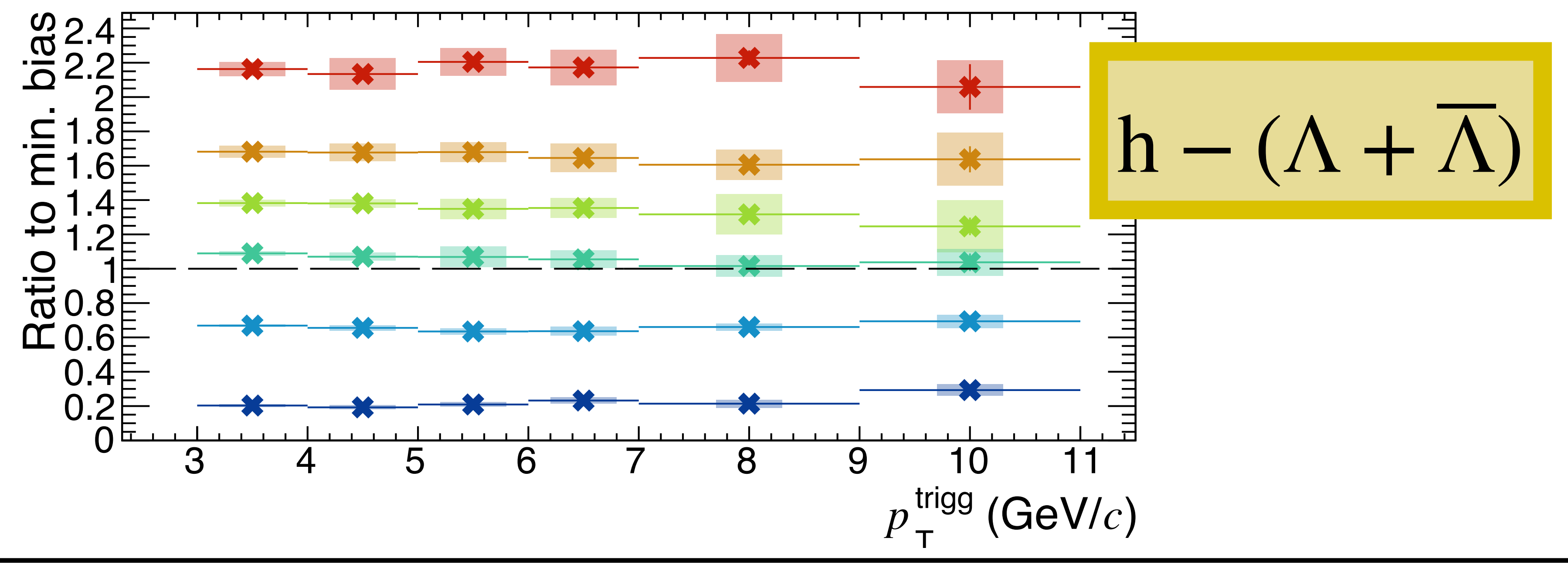


Integrated yields (p_T^{trigg} and multiplicity)
Underlying event

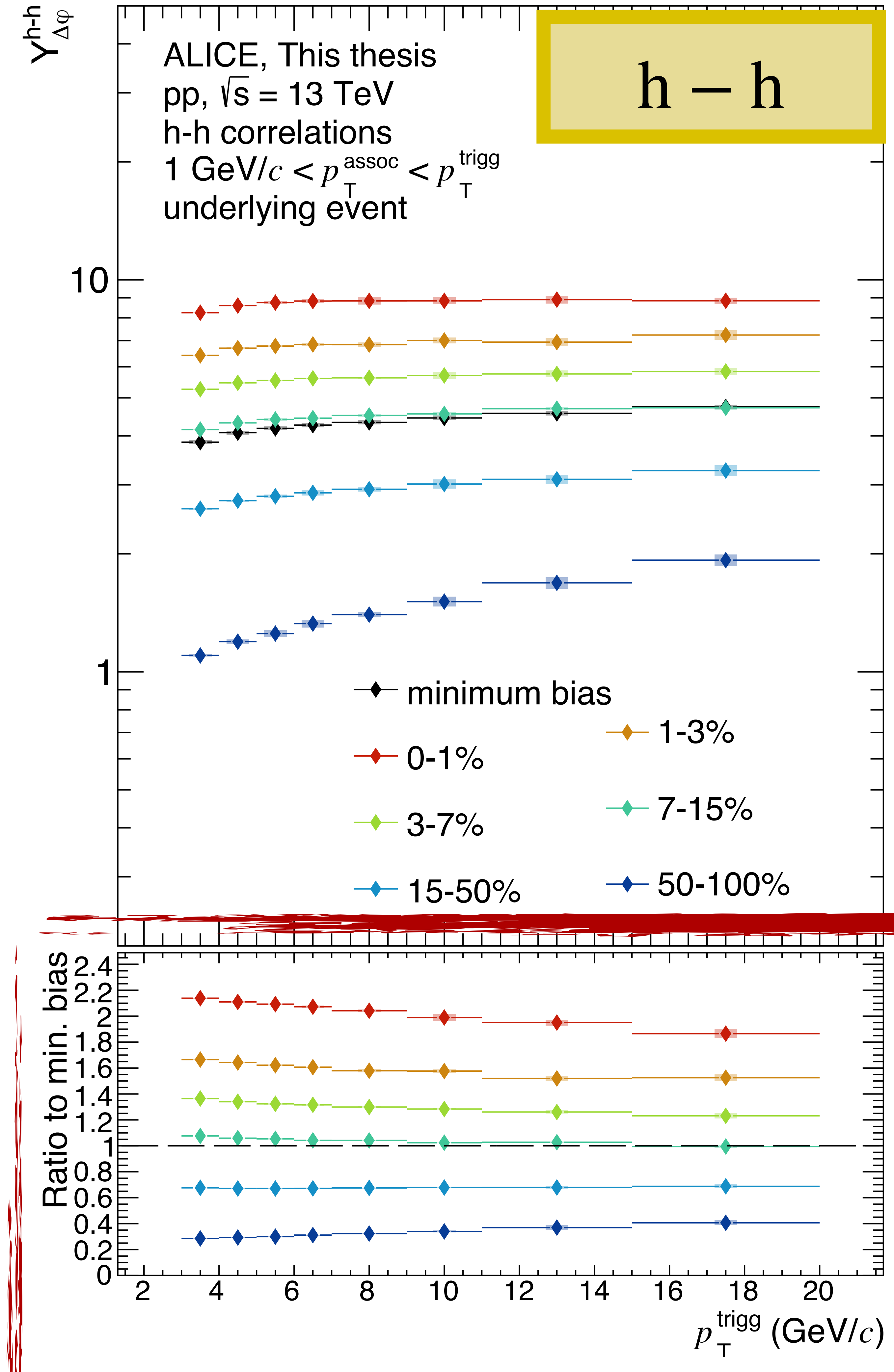


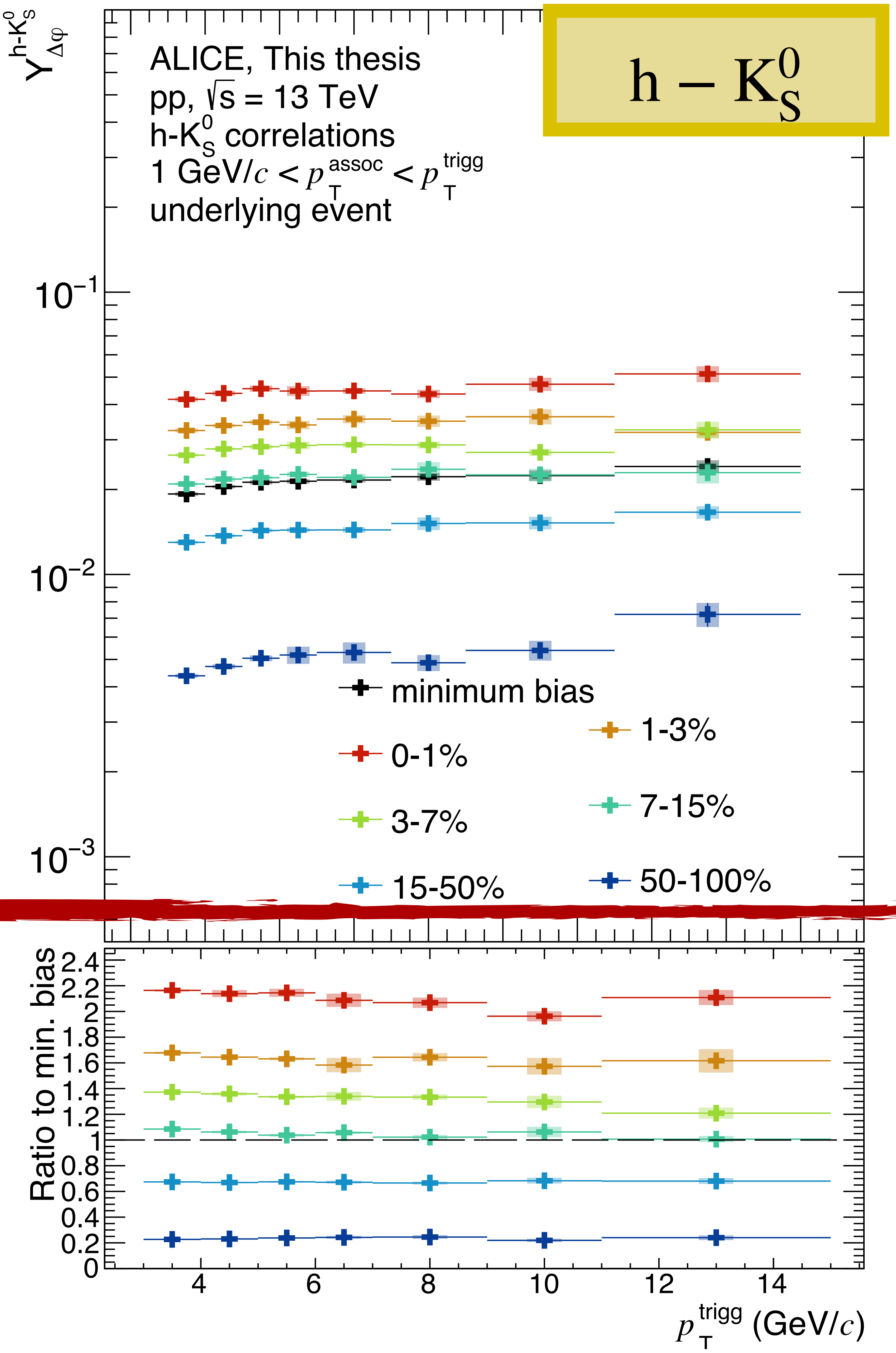


- Weak dependence on p_T^{trigg}
- Several magnitudes difference between yields of different associated particles

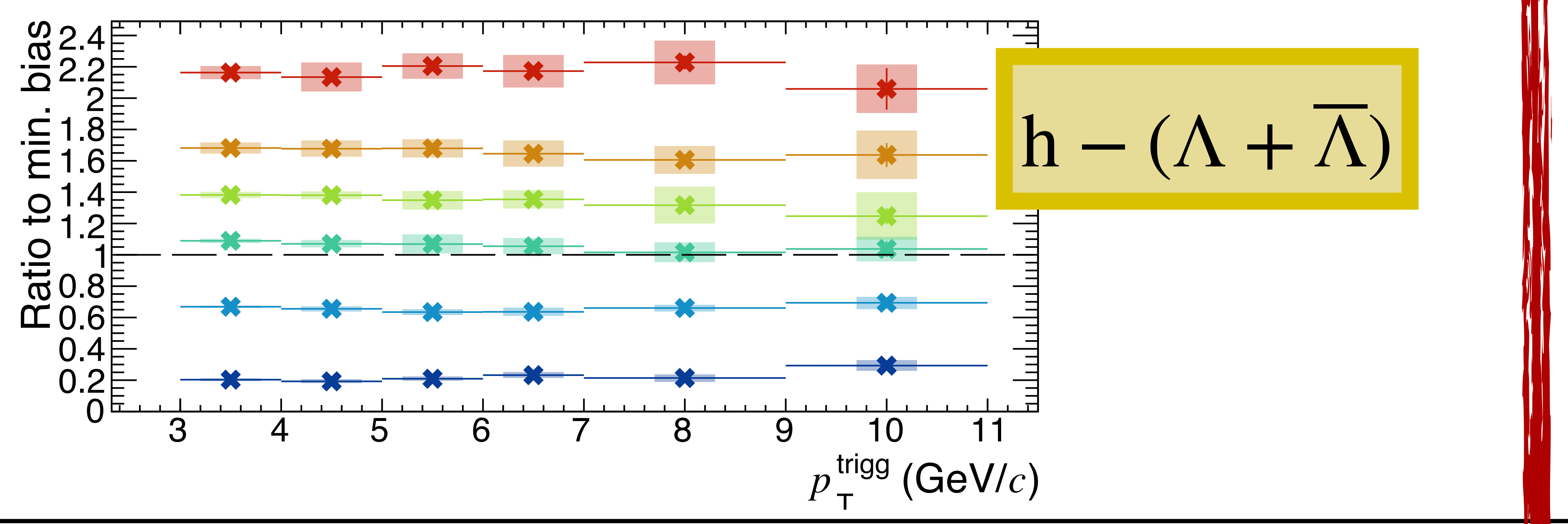


Integrated yields (p_T^{trigg} and multiplicity) Underlying event

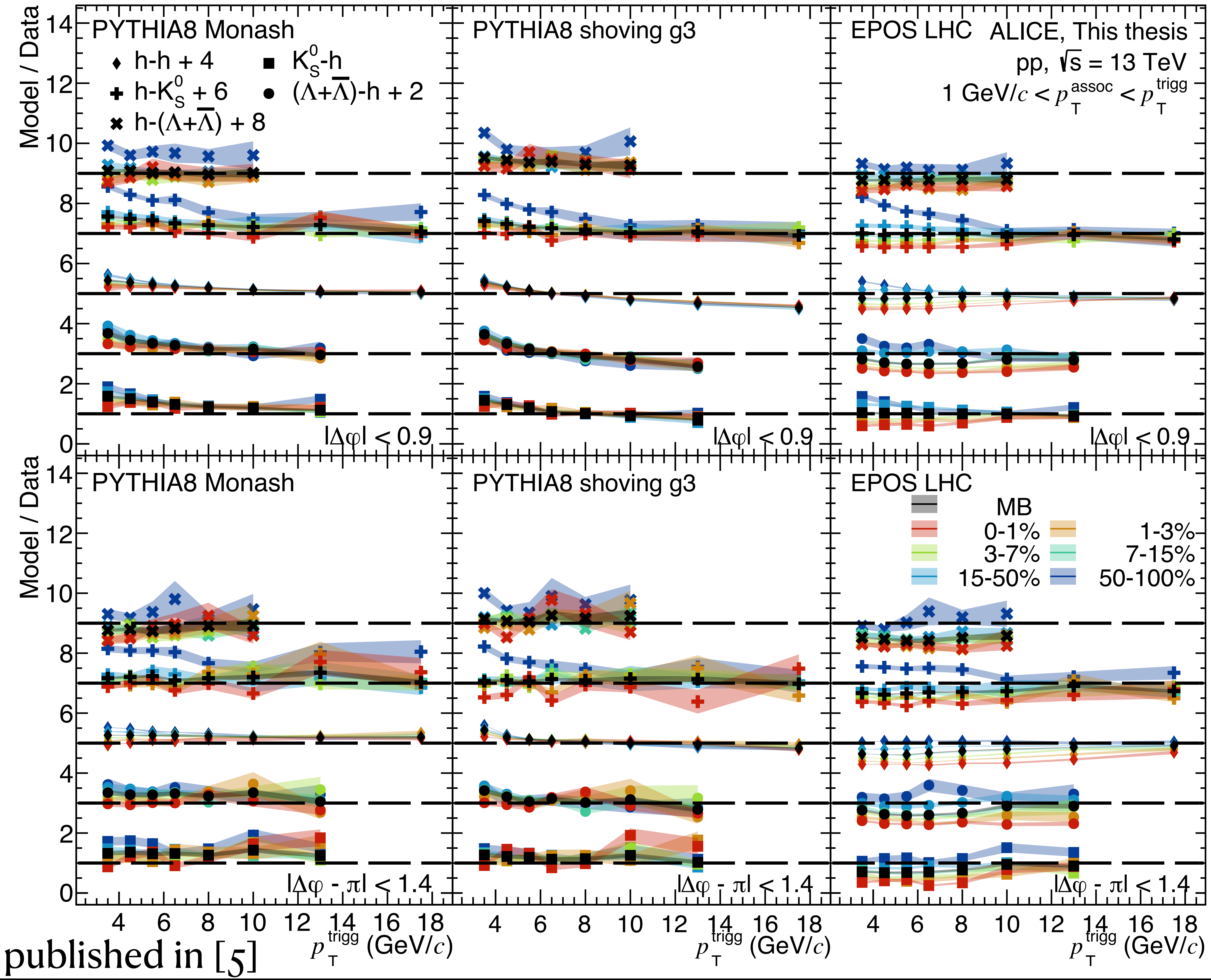




- Weak dependence on p_T^{trigg}
- Several magnitudes difference between yields of different associated particles
- Ratio to MB around the same for all associated particle species

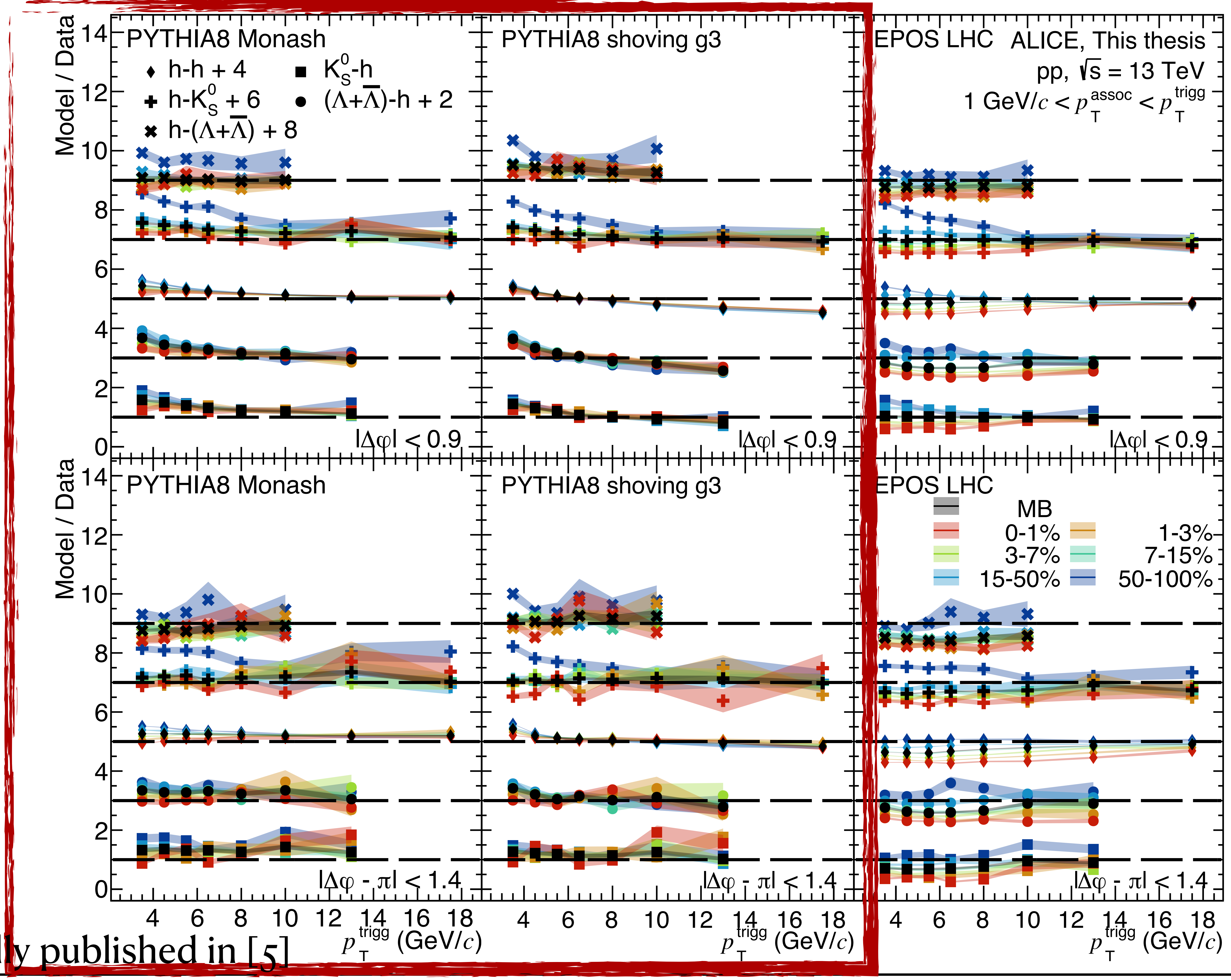


Yield (p_{T}^{trigg} and multiplicity)- model comparison



Partially published in [5]

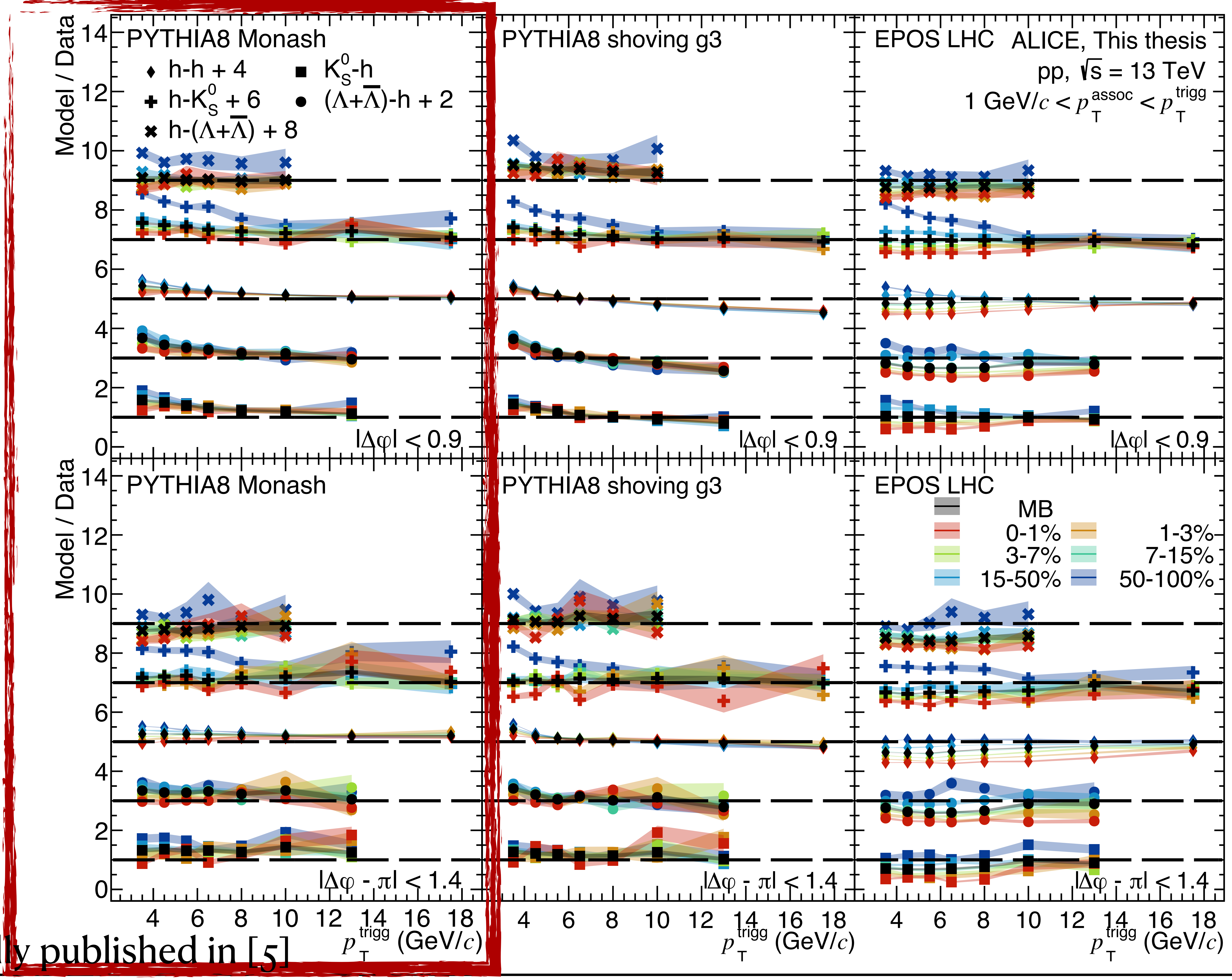
Yield (p_{T}^{trigg} and multiplicity)- model comparison



- PYTHIA8 - the deviation from data depends weakly on multiplicity

Partially published in [5]

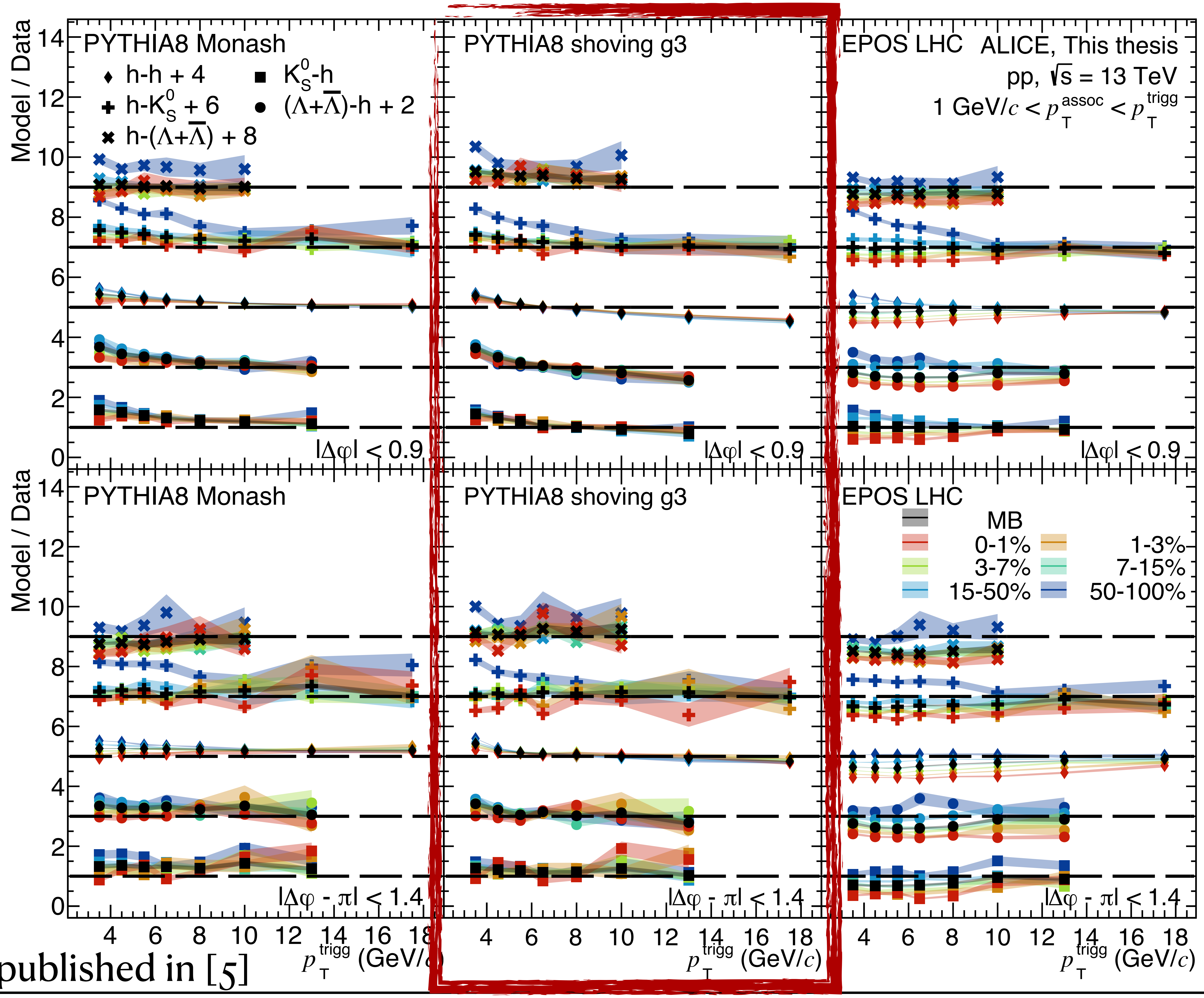
Yield (p_T^{trigg} and multiplicity)- model comparison



Partially published in [5]

- PYTHIA8 - the deviation from data depends weakly on multiplicity
- Monash tune better for hard processes

Yield (p_T^{trigg} and multiplicity)- model comparison



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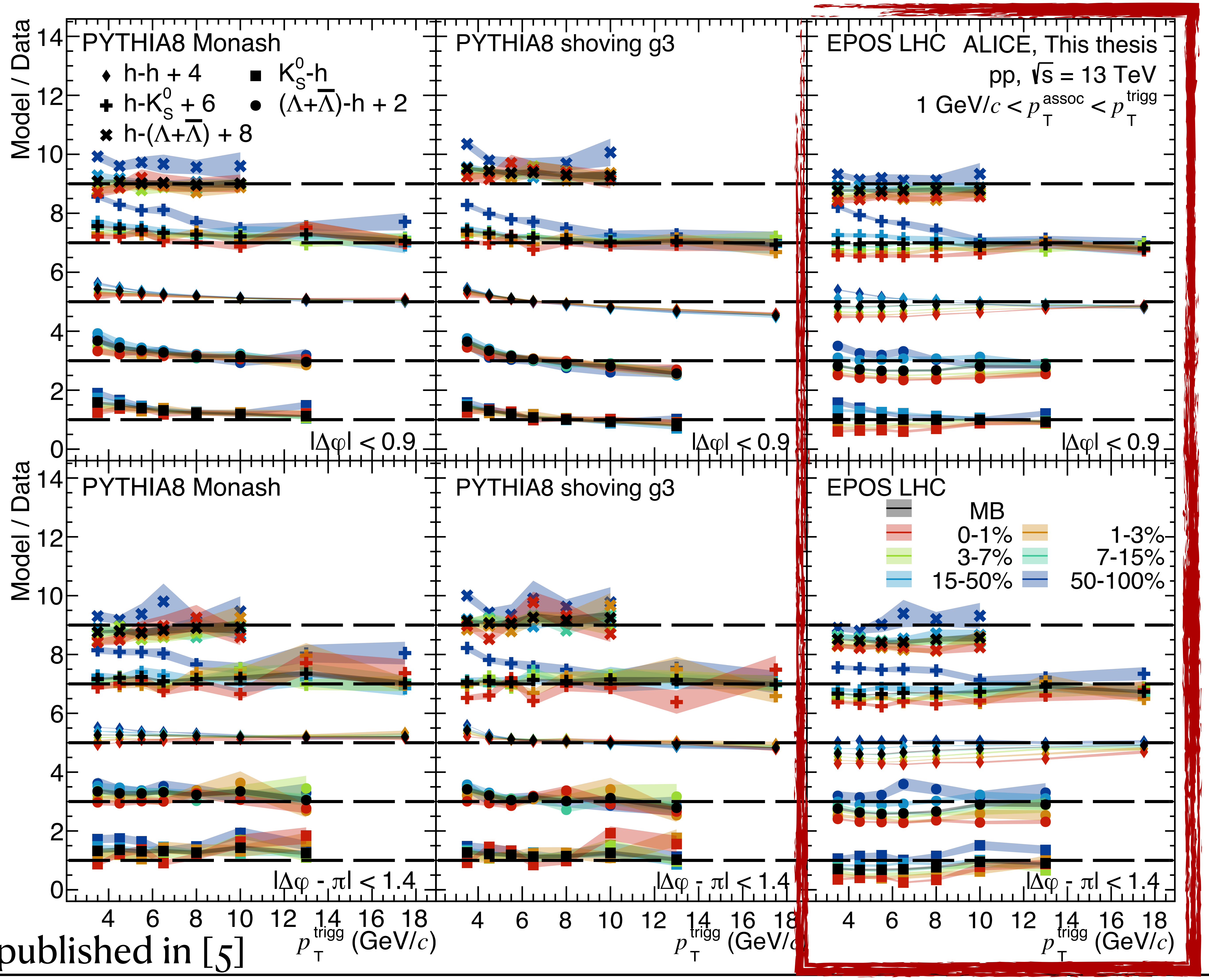
- PYTHIA8 - the deviation from data depends weakly on multiplicity
  - Monash tune better for hard processes
  - Shoving better for intermediate p_T

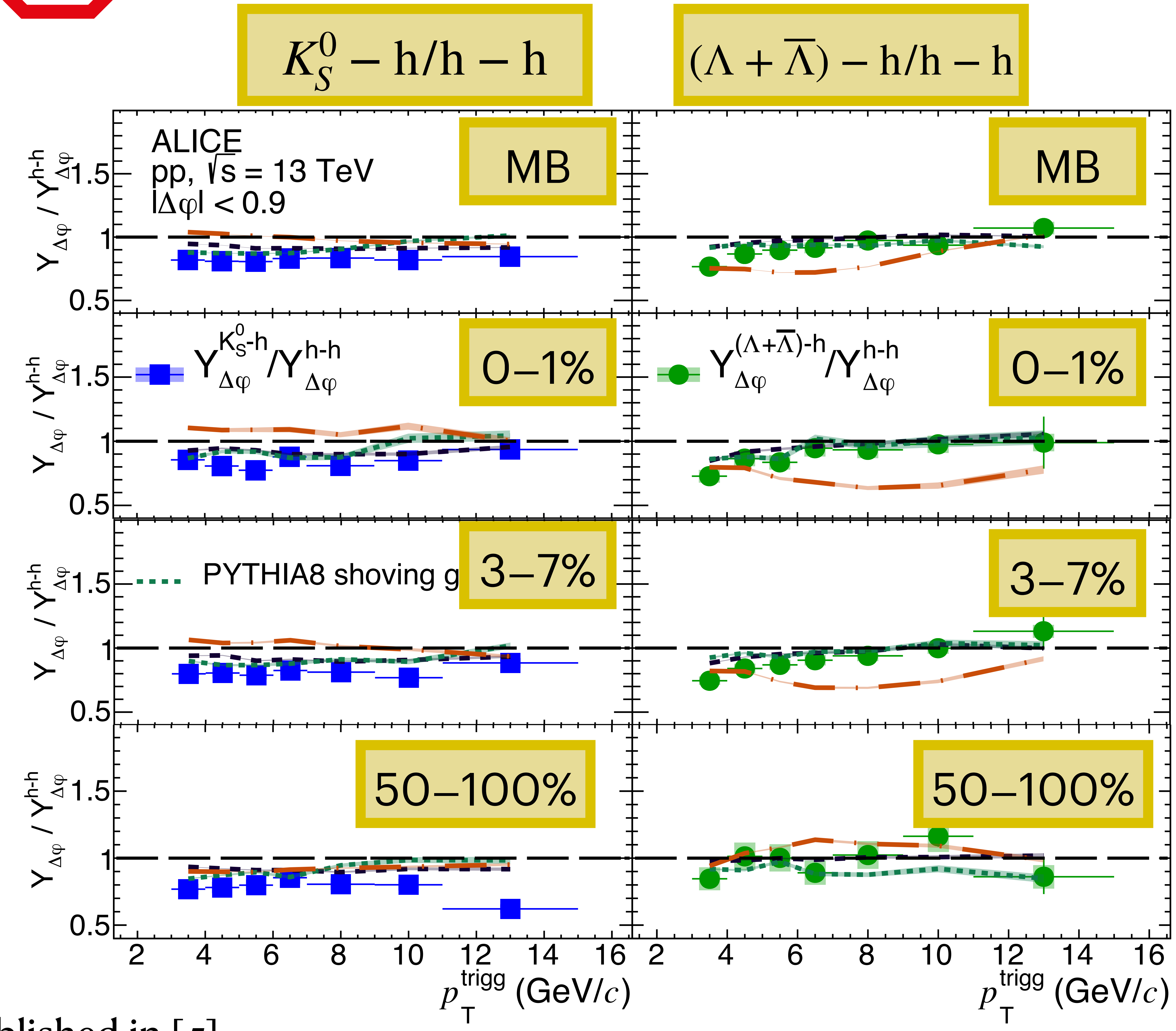
Yield (p_T^{trigg} and multiplicity)- model comparison



Partially published in [5]

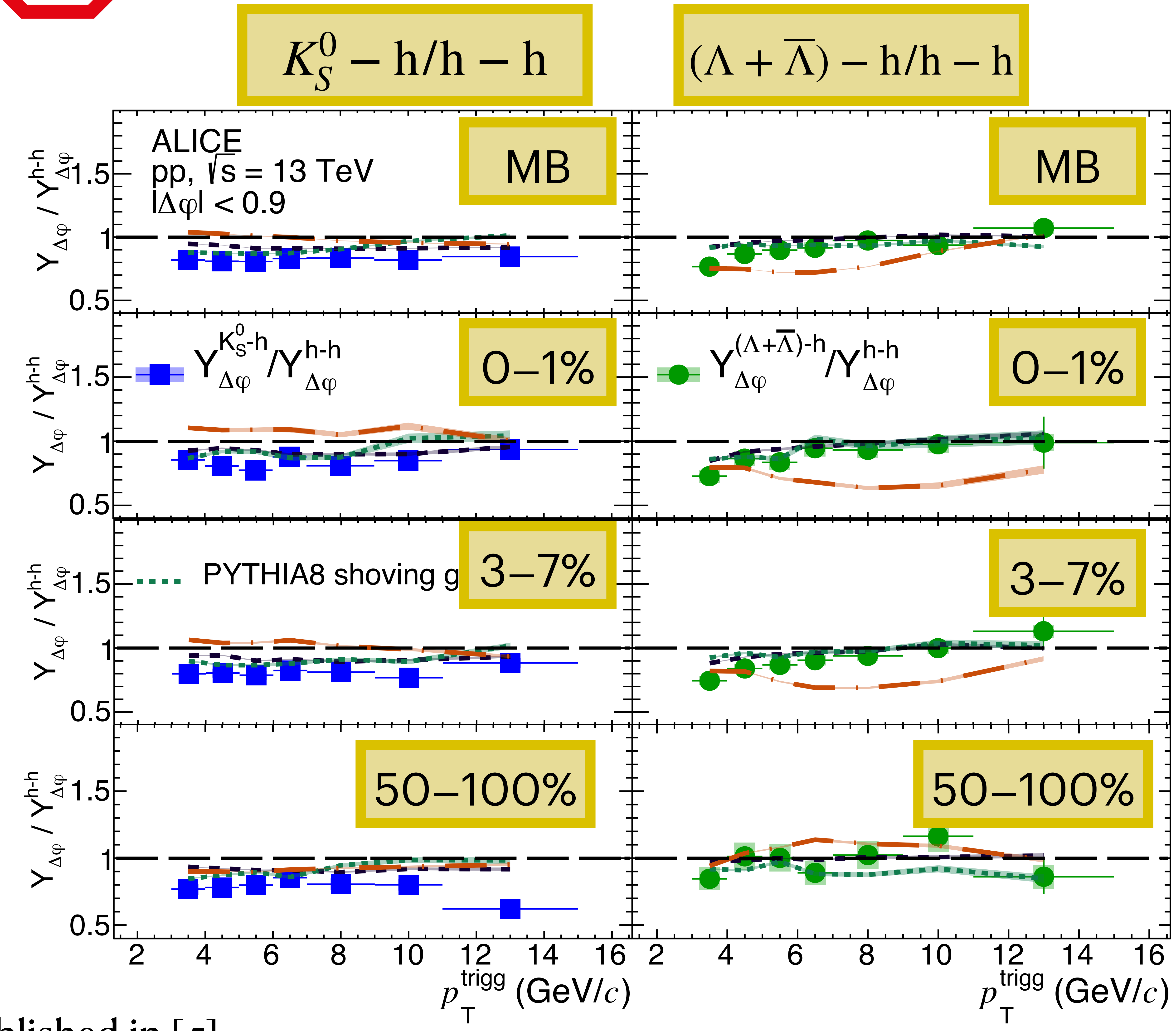
- PYTHIA8 - the deviation from data depends weakly on multiplicity
  - Monash tune better for hard processes
  - Shoving better for intermediate p_T
- EPOS LHC - strong dependence on multiplicity

Jet-like particle-yield ratios to h-h yields



Published in [5]

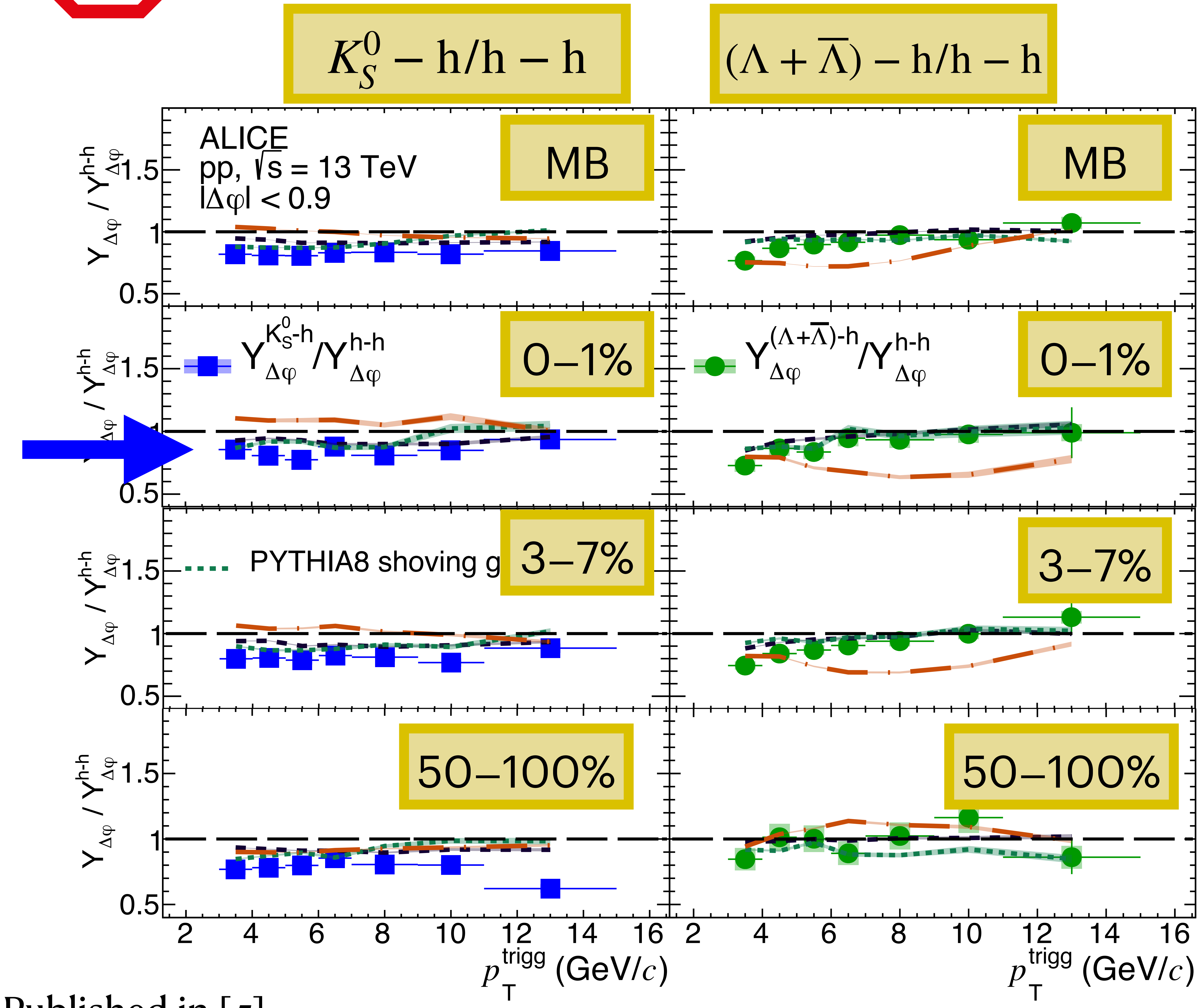
Jet-like particle-yield ratios to h-h yields



- No dependence on the event multiplicity
- Different trends of the ratio for different trigger particles:

Published in [5]

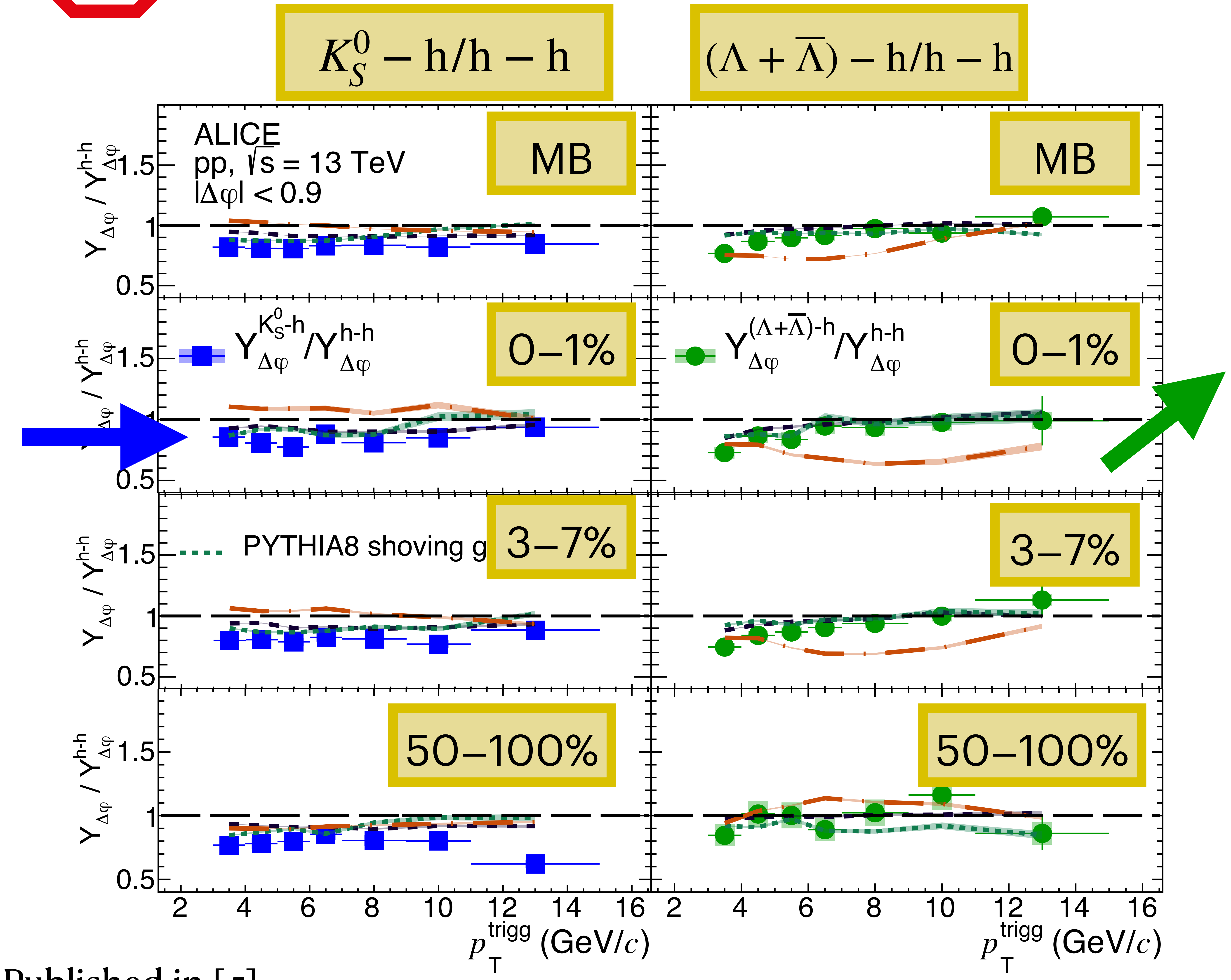
Jet-like particle-yield ratios to h-h yields



Published in [5]

- No dependence on the event multiplicity
- Different trends of the ratio for different trigger particles:
  - K^0_S - rather flat with p_T^{trigg} and below unity

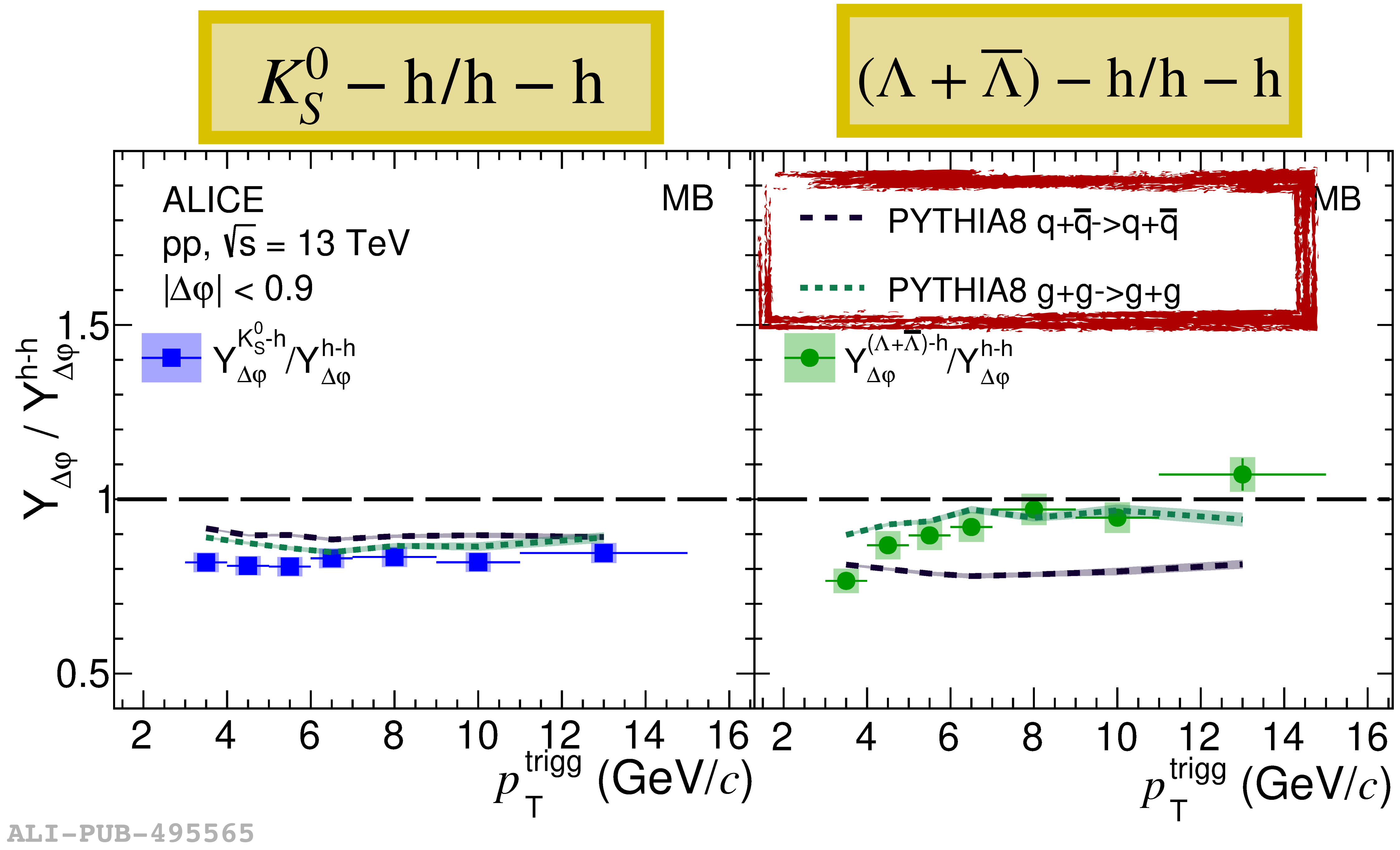
Jet-like particle-yield ratios to h-h yields



Published in [5]

- No dependence on the event multiplicity
- Different trends of the ratio for different trigger particles:
  - K_S^0 - rather flat with p_T^{trigg} and below unity
  - Λ increasing with p_T^{trigg}

Jet-like particle-yield ratios to h-h yields

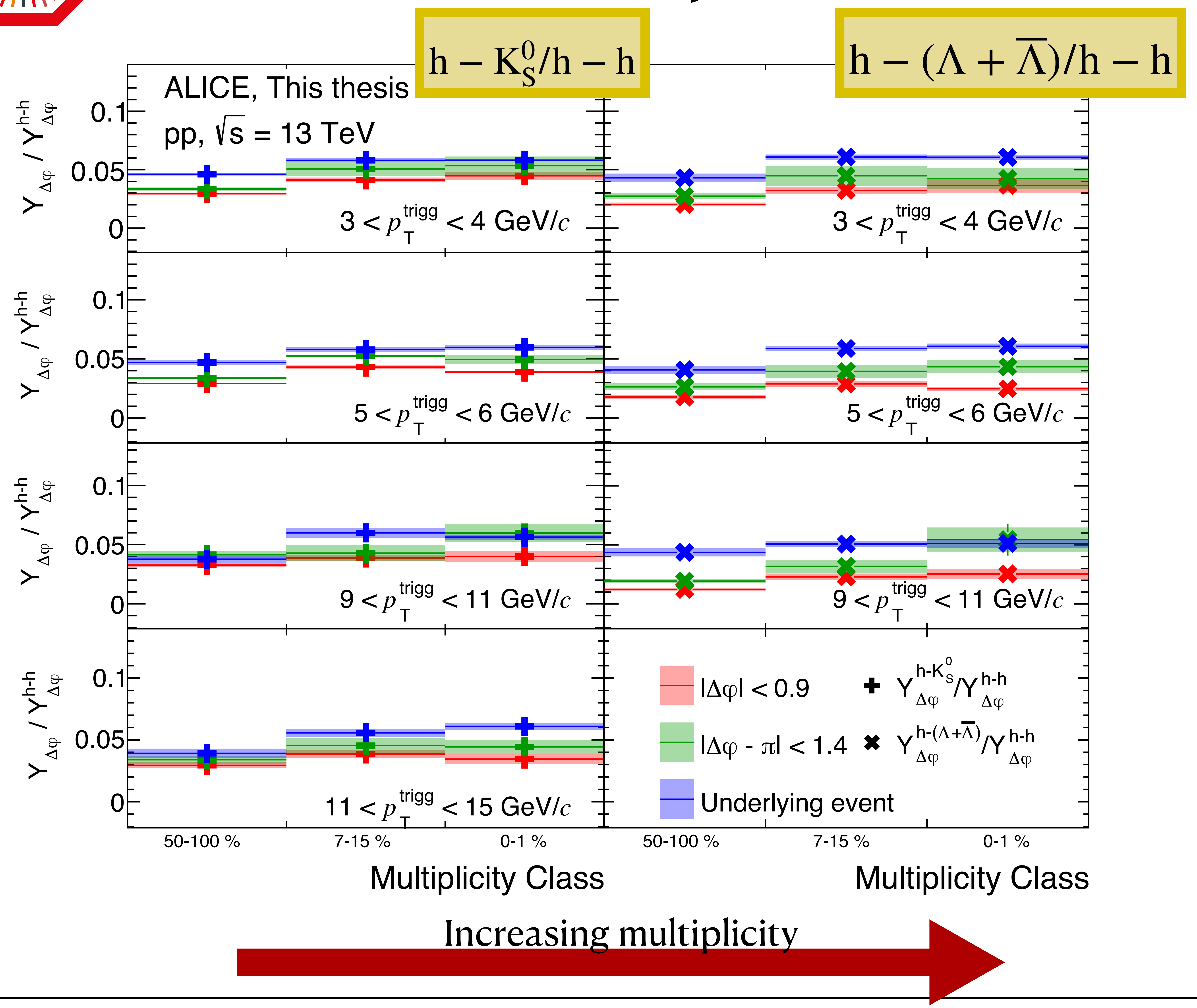


- Different trends of the ratio for different trigger particles:
  - K_S^0 - rather flat with p_T^{trigg} and below unity
  - Λ increasing with p_T^{trigg}
- No dependence on the event multiplicity

Triggering with high-p_T Λ causes a bias towards gluon jets

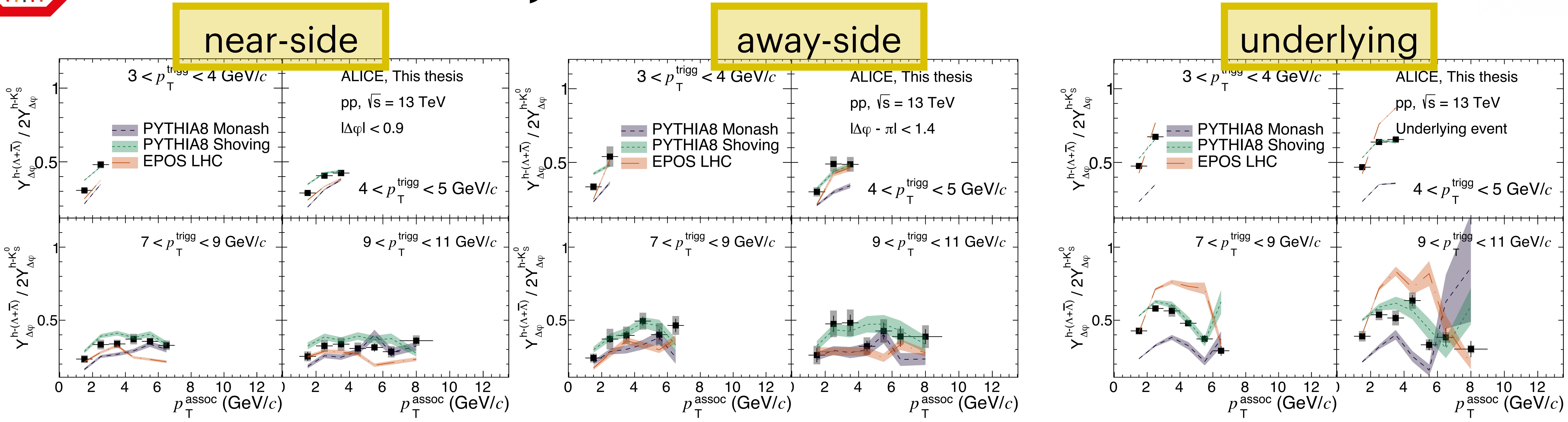
Published in [5]

Particle-yield ratios to h-h yields

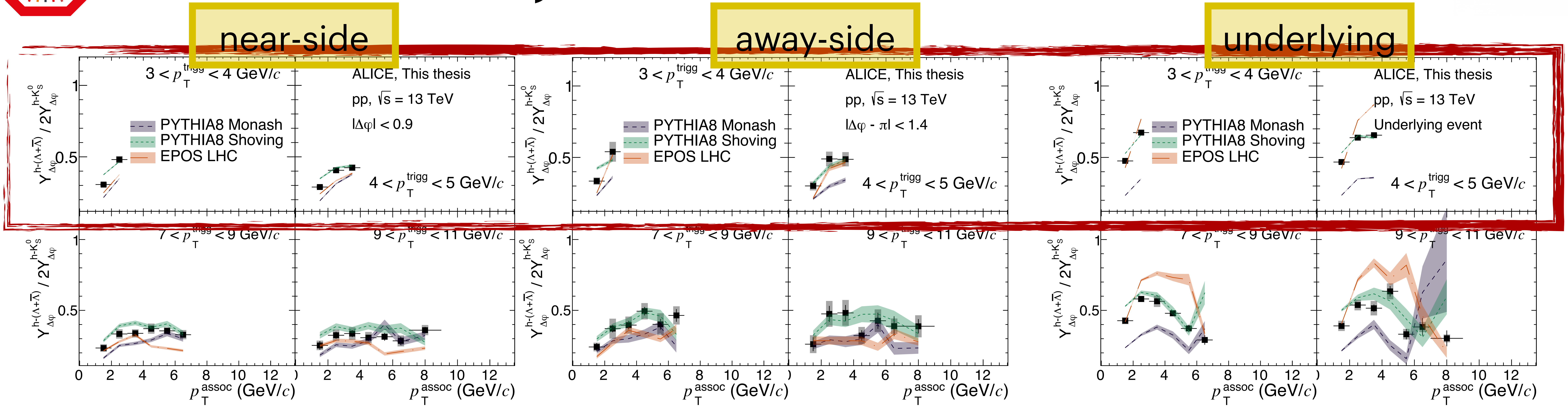


- No clear increase with multiplicity in each region
- Biggest difference in the first bin
- High multiplicity trigger - new point
- $h - \pi$ should be used as proper basis

Baryon To Meson Ratio

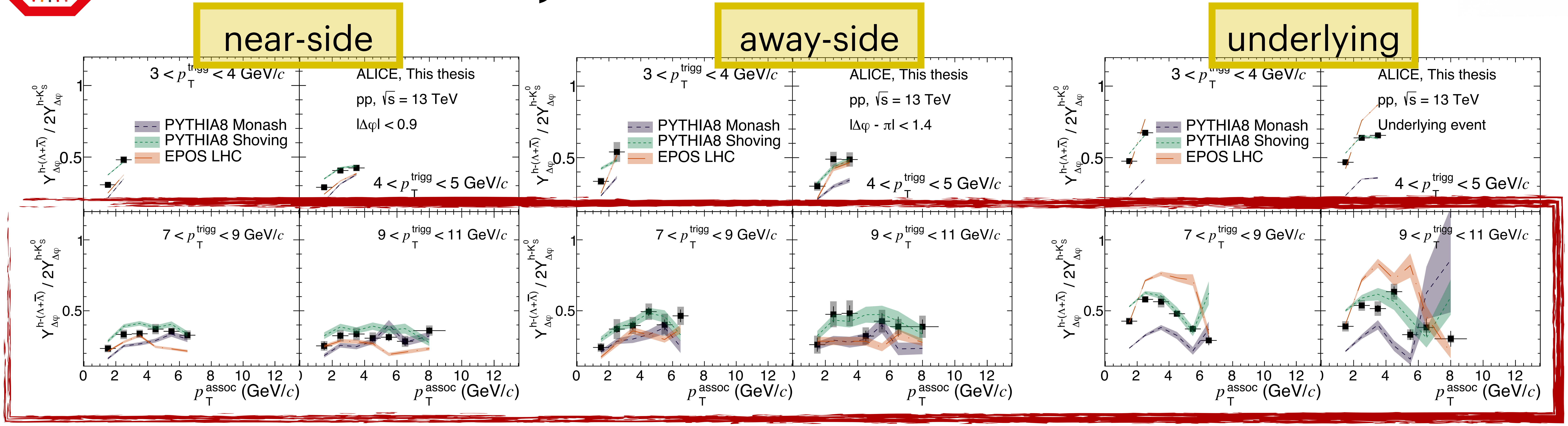


Baryon To Meson Ratio



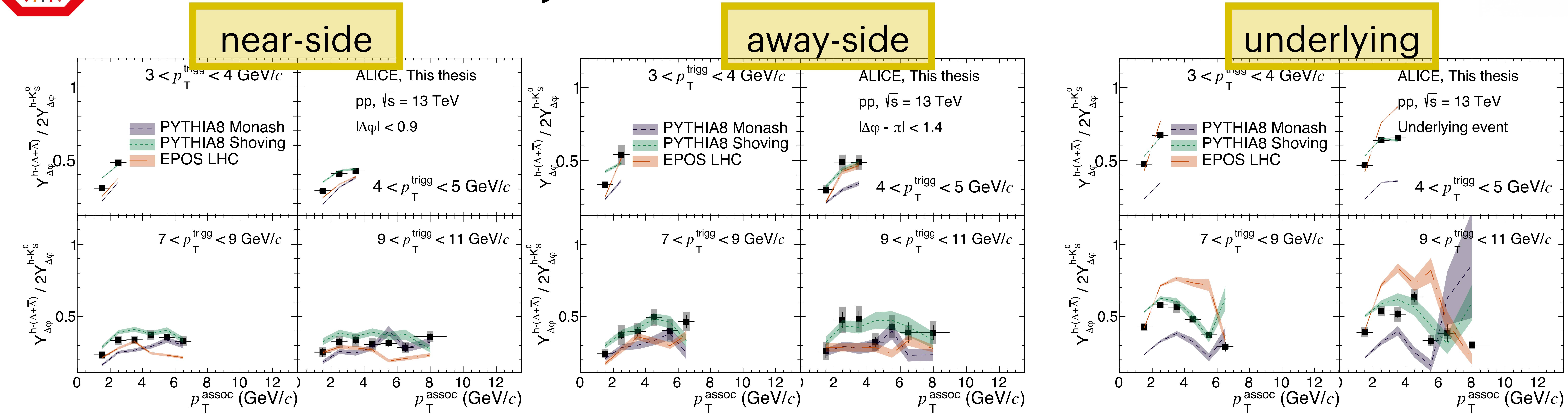
- Similar increasing trend in all three regions for low p_T^{trigg}

Baryon To Meson Ratio



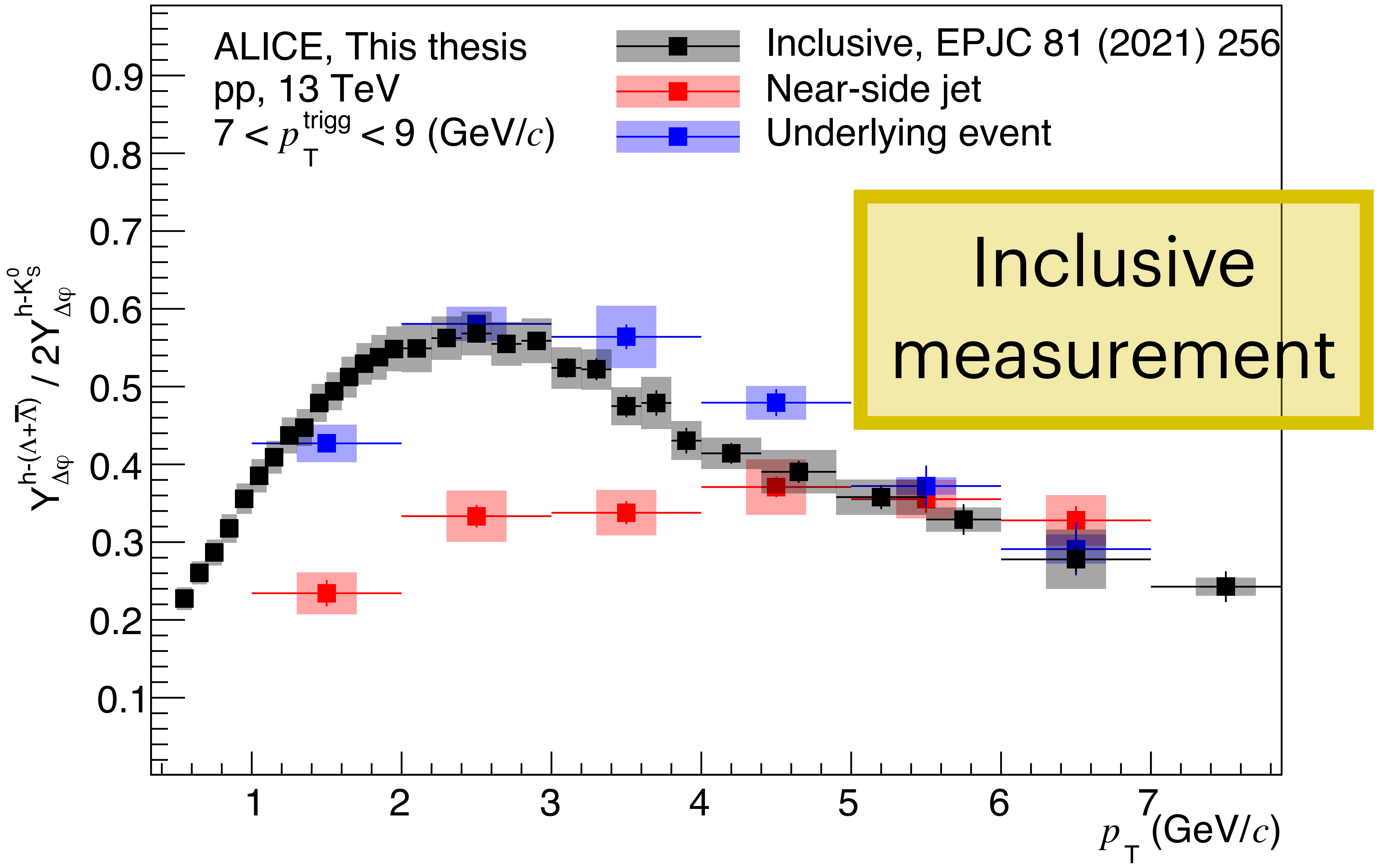
- Similar increasing trend in all three regions for low p_T^{trigg}
- The maximum visible only for underlying event for high p_T^{trigg} , near- and away-side rather flat

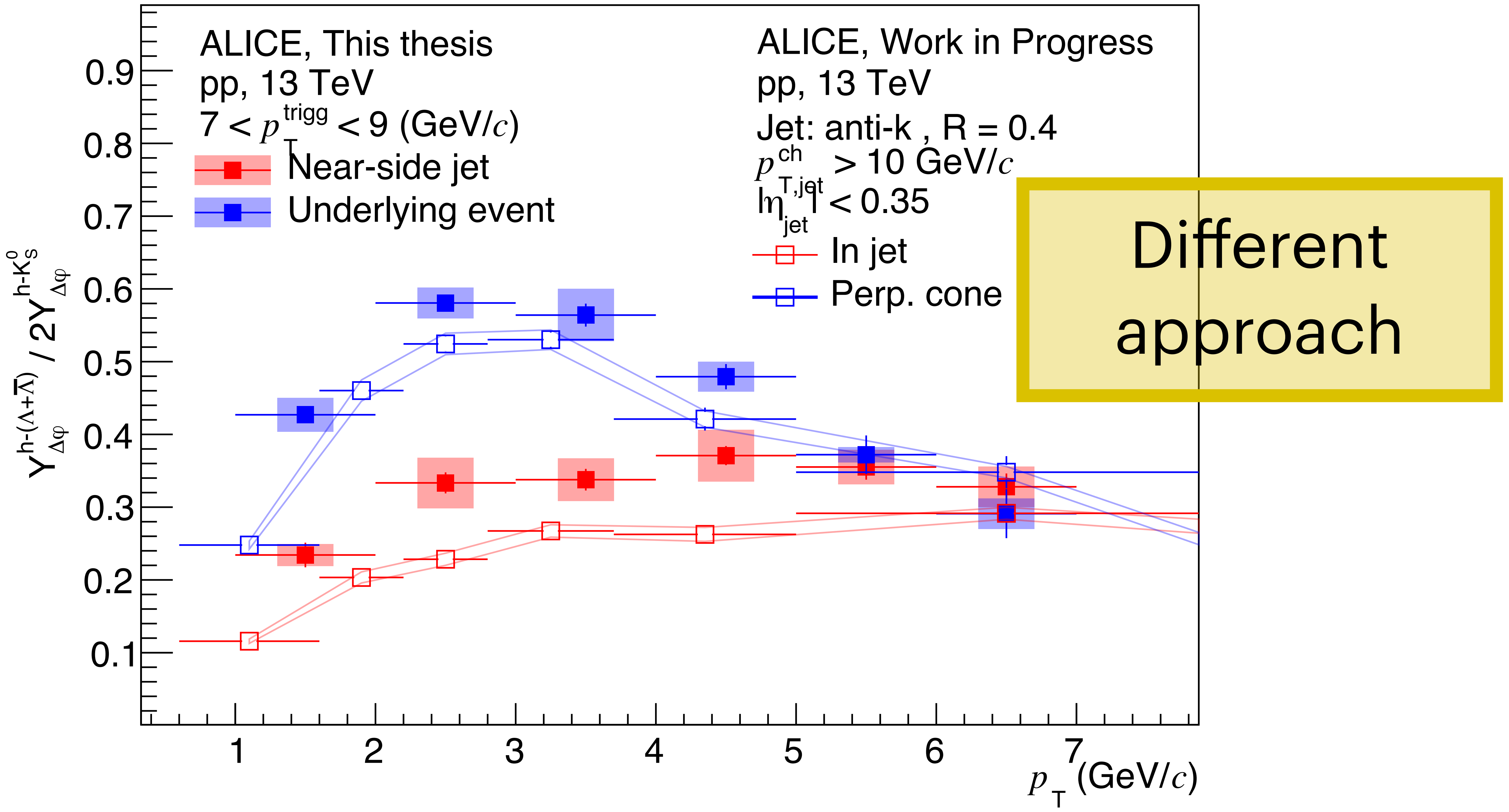
Baryon To Meson Ratio



- Similar increasing trend in all three regions for low $p_{\mathrm{T}}^{\mathrm{trigg}}$
- The maximum visible only for underlying event for high $p_{\mathrm{T}}^{\mathrm{trigg}}$, near- and away-side rather flat
- Best described by the PYTHIA8 Shoving model

Baryon To Meson Ratio





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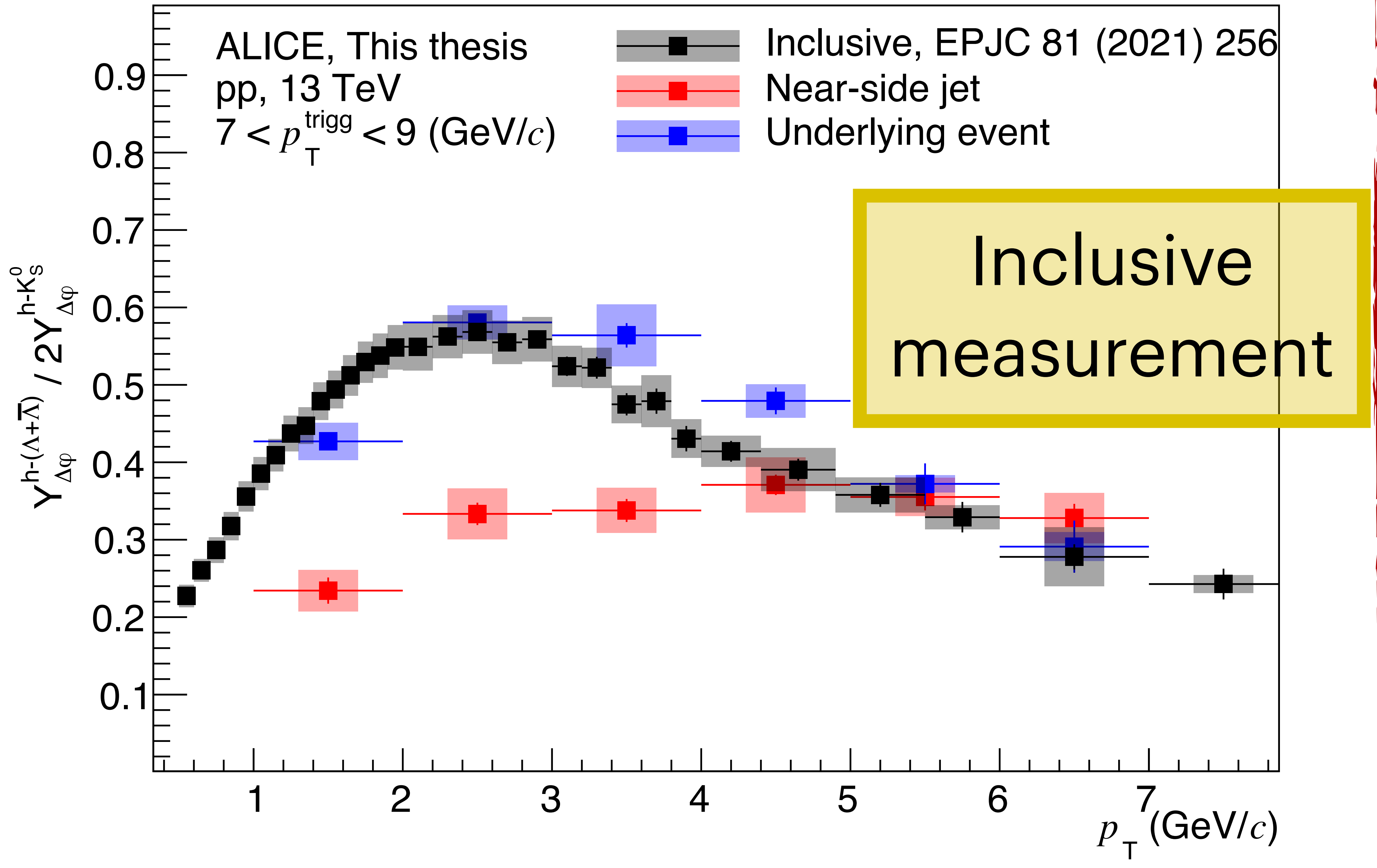
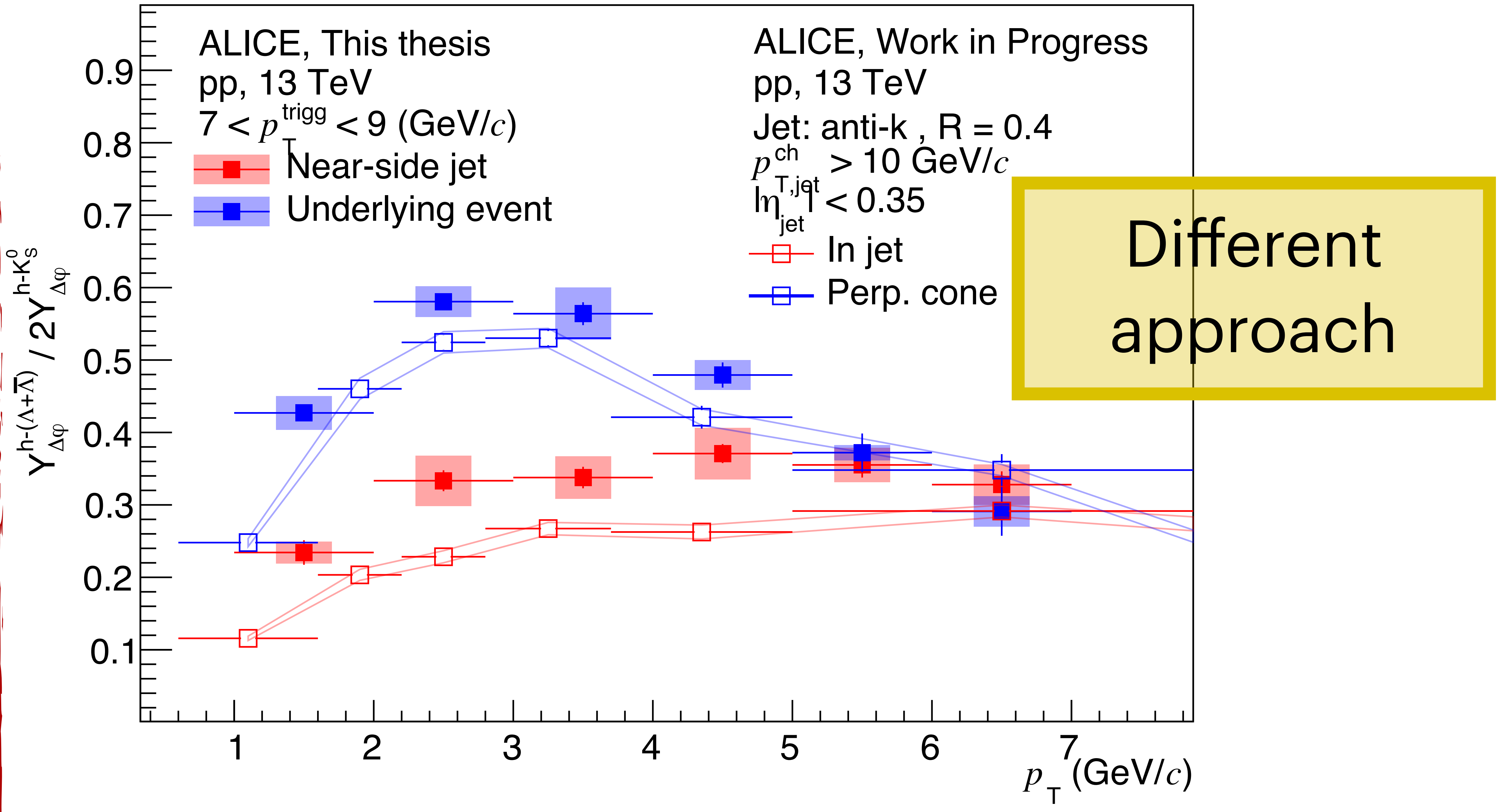
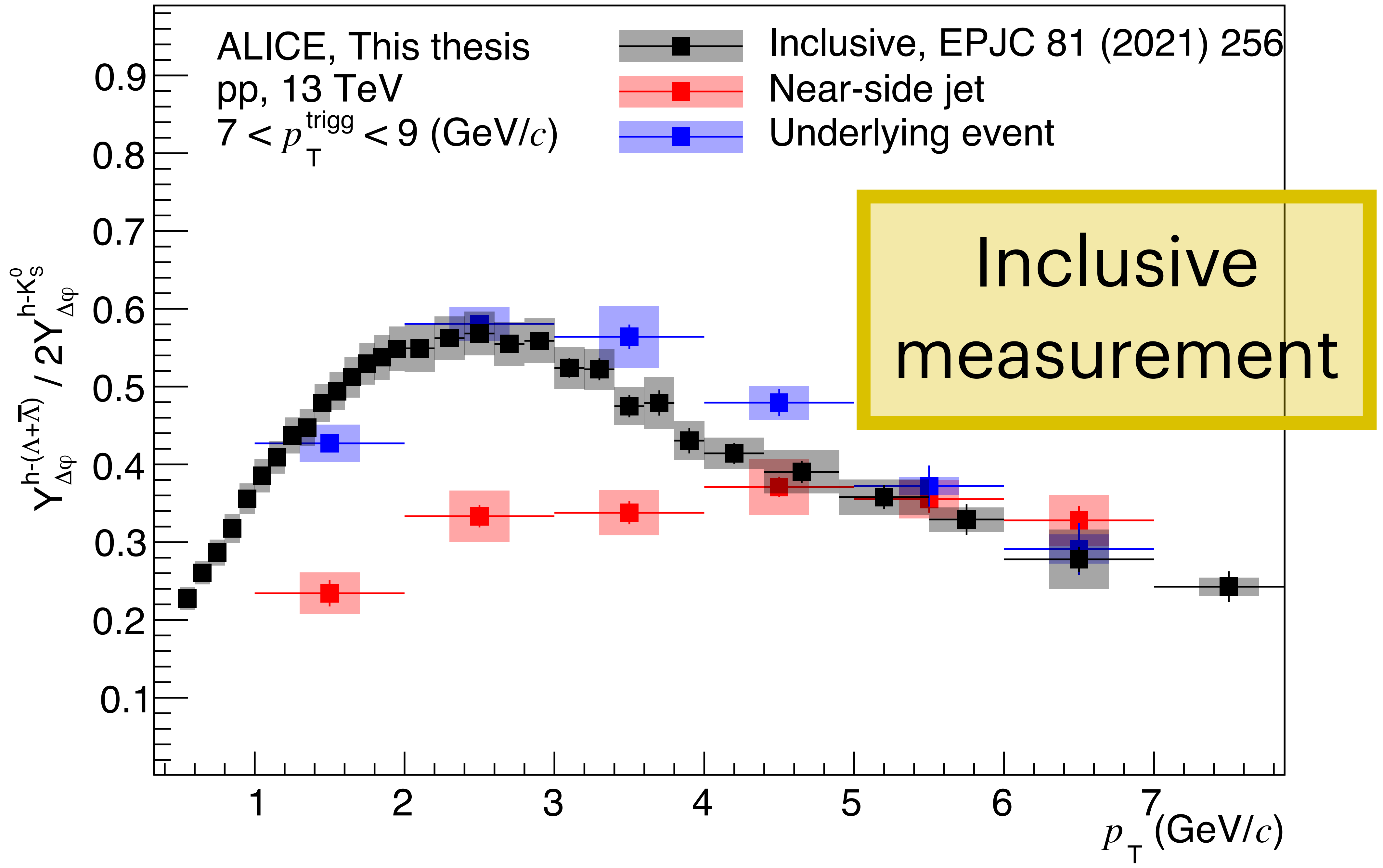
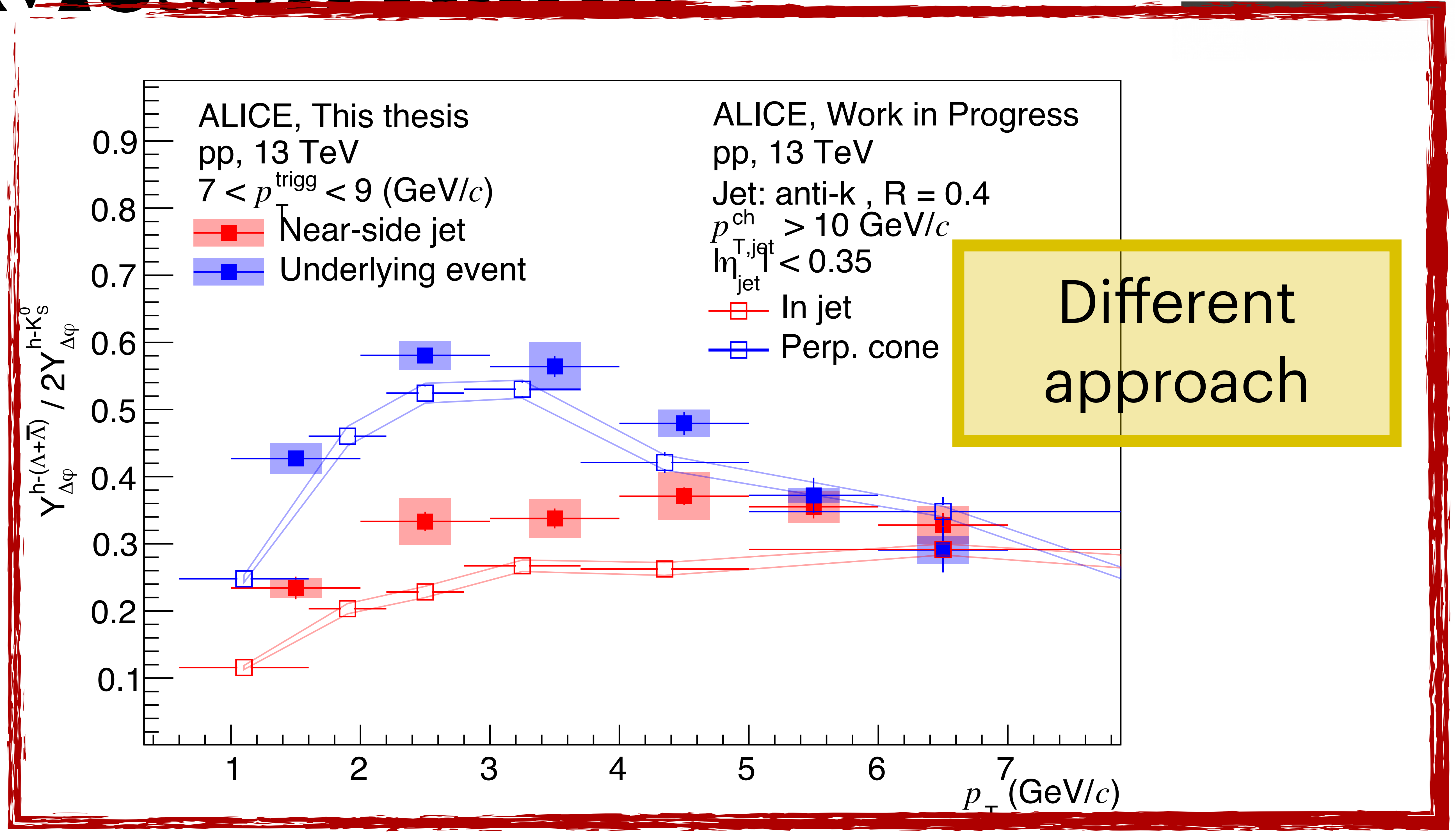




- The underlying event measurement - in agreement with inclusive measurement

Baryon To Meson Ratio





- The underlying event measurement - in agreement with inclusive measurement
- Consistency with jet-finder method (difference caused by kinematic selection)⇒ usable in Pb-Pb collisions

Summary

- V^0-h, h-h and h-V^0 correlations analysis performed within different pT and multiplicity intervals in pp collision at 13 TeV
- Per-trigger yield extracted and compared with MC models
- A difference between jet-like particle yields triggered with K^0_S and Λ with respect to charged hadron was observed in pp collisions at 13 TeV
  - Explanation (through PYTHIA8): triggering with Λ causes a bias towards gluon jets
- No clear multiplicity dependence of V^0 in or outside of jets
- The enhancement in $\Lambda + \overline{\Lambda}/2K^0_S$ ratio visible only for the outside of jet region

Thank you for your attention!

Questions

References

[1] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Physics
[2] ACTA PHYSICA POLONICA B, No 2, Vol. 36 (2005), page 433
[3] K. Ackerstaff et al. "Production of K_S^0 and Λ in quark and gluon jets from Z^0 decay". arXiv: hep-ex/9805025
[4] ALICE Collaboration "Enhanced production of multi-strange hadrons in high-multiplicity proton–proton collisions". arXiv: 1606.07424 [n ex].
[5] ALICE Collaboration "K_S^0- and (anti-)Λ-hadron correlations in pp collisions at $\sqrt{s}$ = 13 TeV". arXiv: 2107.11209 [nucl-ex].

Back-up

Track and V^0 selection

- $|\eta| < 0.8$
- FilterBit 256 and special tune
- Pairs with invariant mass of a hadron - rejected

Selection	Value
Online or On-The-fly	only offline
Rapidity |y|	<0.5
V^0 decay radius (cm)	>0.5
DCA Neg to PV (cm)	>0.06
DCA Pos to PV (cm)	>0.06
DCA V^0 daughters (σ)	<1
V^0 $\cos(\theta_{PA})(K_S^0)$	>0.97
V^0 $\cos(\theta_{PA})(\Lambda)$	>0.995
Proper lifetime K_S^0 (cm)	<20
Proper lifetime Λ (cm)	<30
Competing V^0 rejection K_S^0 (GeV/c^2)	<0.005
Competing V^0 rejection Λ (GeV/c^2)	<0.01
dE/dx (Nσ)	<3

Table 1: Selection criteria for V^0 candidates

Selection	Value
Pseudorapidity $\|\eta\|$	<0.8
Number of TPC Crossed Rows	>70
TPC Refit Flag	kTRUE
Number of Findable Clusters	>0
TPC Crossed Rows / Findable Ratio	>0.8

Table 2: Selection criteria for V^0 daughter tracks

$$3 < p_{\mathrm{T}}^{\mathrm{trigg}} < 20\ \mathrm{GeV}/c \qquad 1\mathrm{GeV}/c < p_{\mathrm{T}}^{\mathrm{assoc}} < p_{\mathrm{T}}^{\mathrm{trigg}}$$

Systematic Uncertainties Study

- Width of near- and away-side peaks ($-0.9 < \Delta\varphi < 0.9$; $\pi-1.4 < \Delta\varphi < \pi+1.4$)
  - $-0.8 < \Delta\varphi < 0.8; \pi - 1.34 < \Delta\varphi < \pi + 1.34$
  - $-1 < \Delta\varphi < 1; \pi - 1.5 < \Delta\varphi < \pi + 1.5$

- Primary vertex acceptance (10 cm)
  - 7 cm

- Binning in PVz for mixing (9 bins)
  - 7 bins

- Yield Calculation method (bin counting method)
  - Fit and integral

- Pedestal subtraction (average of 6 bins beside peaks)
  - Fit with constant function

- η range for the φ projection, near side ($|\Delta\eta| < 1$)
  - $|\Delta\eta| < 0.9$
  - $|\Delta\eta| < 1.1$

- Mixing scaling (Bin 0,π)
  - average of all bins with $\Delta\eta = 0$

- FiterBit (FB 256)
  - FB 32

- Wing Correction
  - Different range

- MC closure (2,5%)

- Cuts variation (Default)
  - Strict
  - Loose

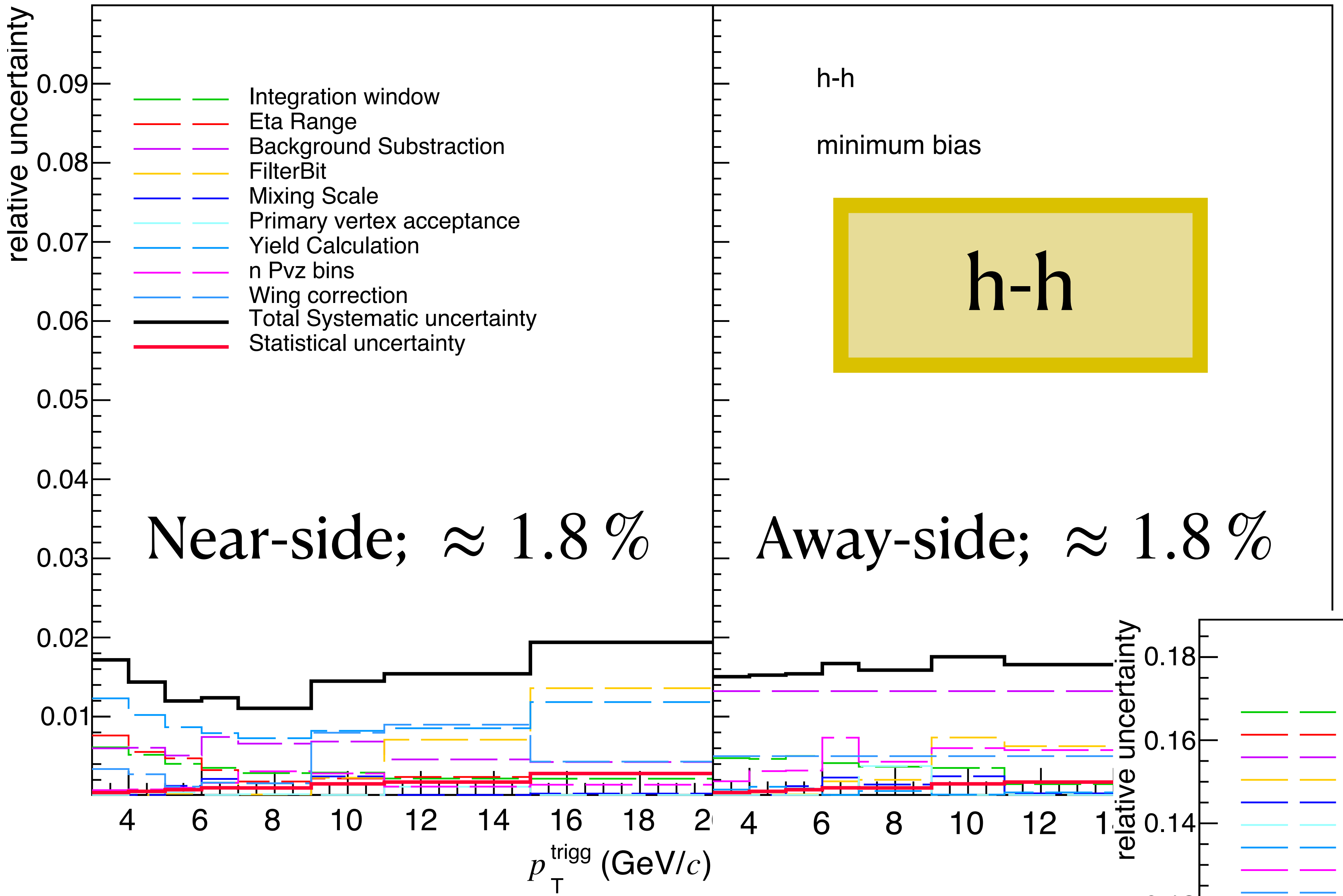
- Invariant mass acceptance (3 σ)
  - 2 σ
  - 4 σ

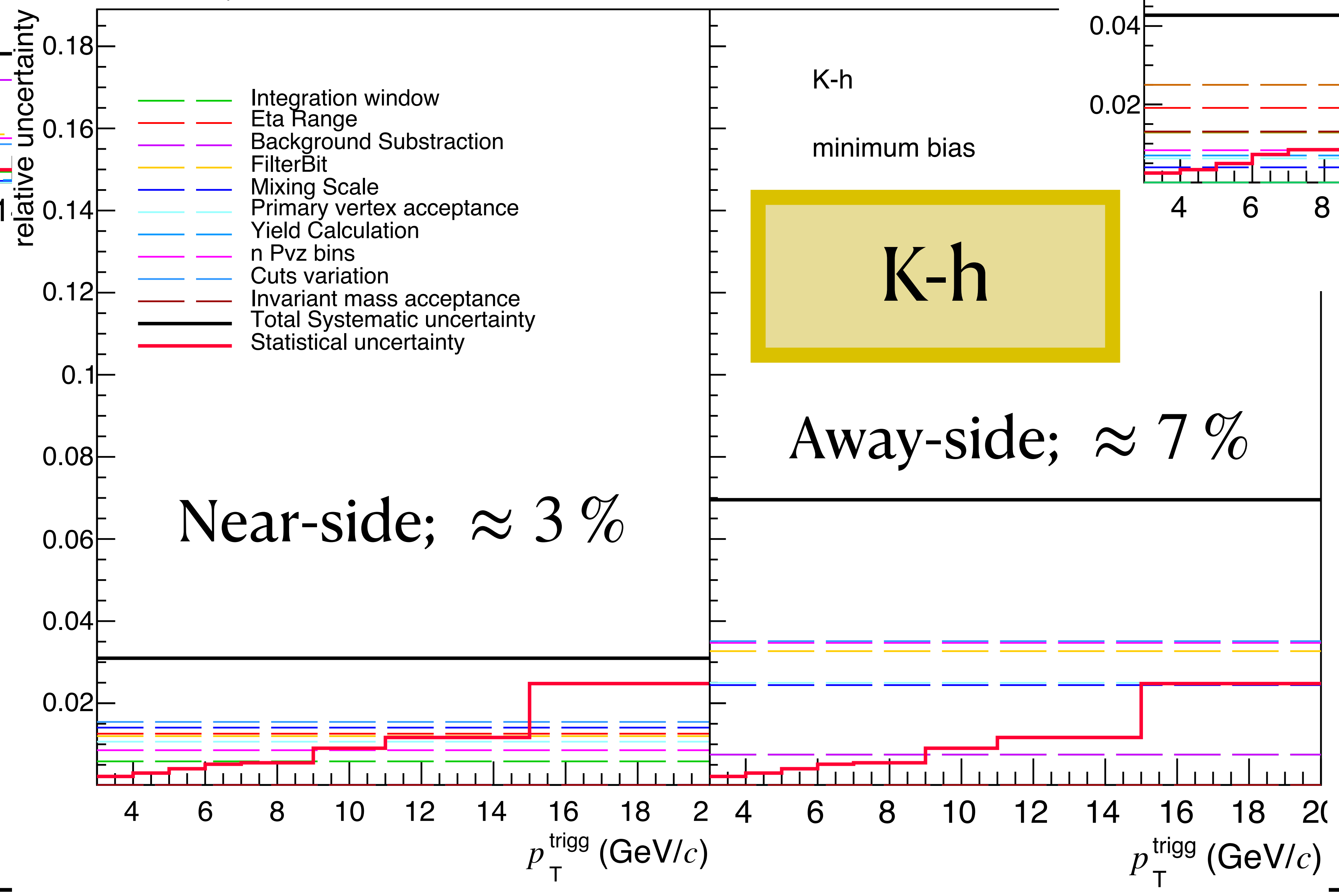
- Wing Correction (without)
  - With

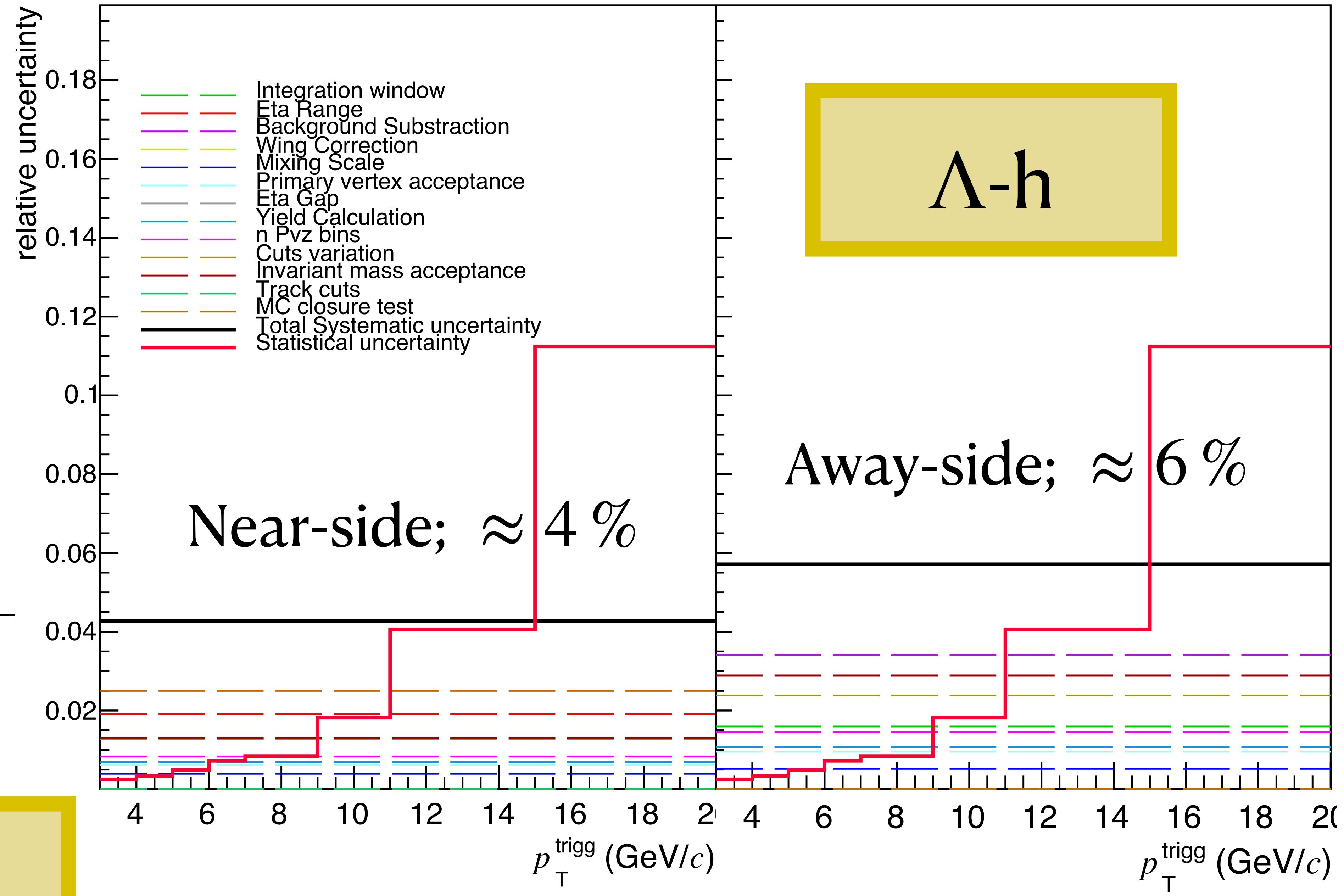
- Selection criteria for primary hadrons (DCA_XY 0.9, DCA_Z 2)
  - DCA_XY 0.6, DCA_Z 1.8
  - DCA_XY 1.3, DCA_Z 2.4

- Cascade cuts variation (Default)
  - Strict
  - Loose

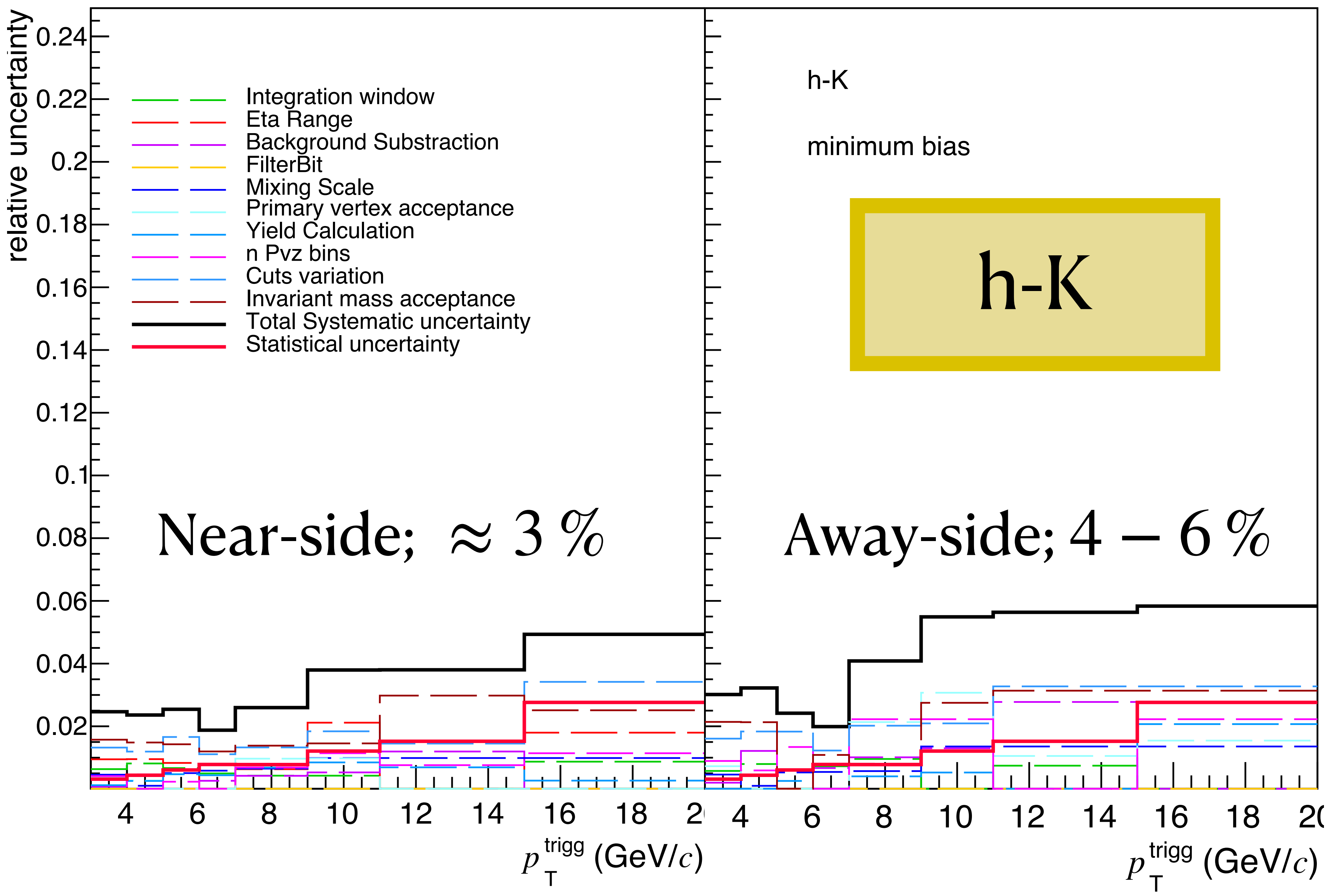
Systematic Uncertainties Study

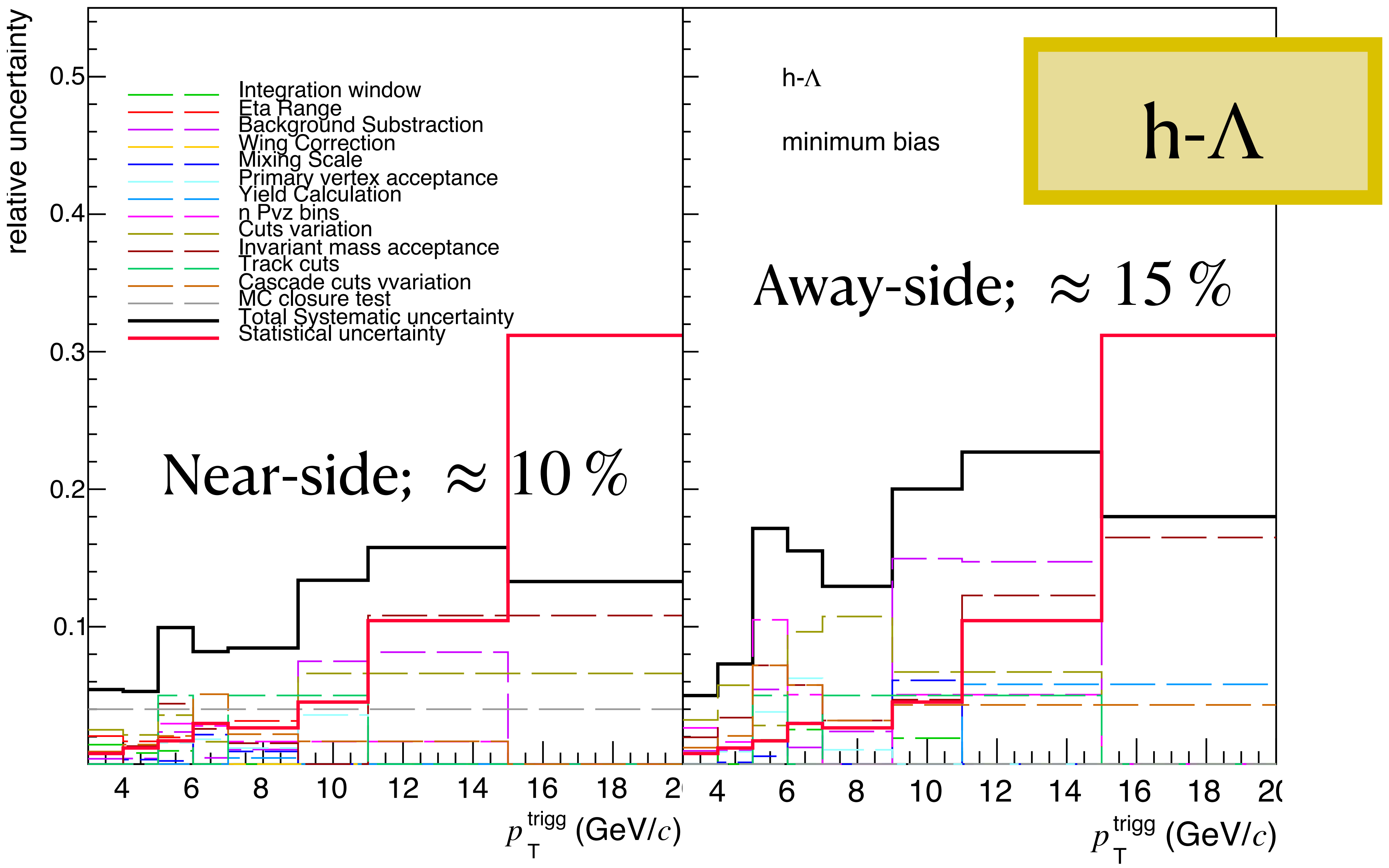


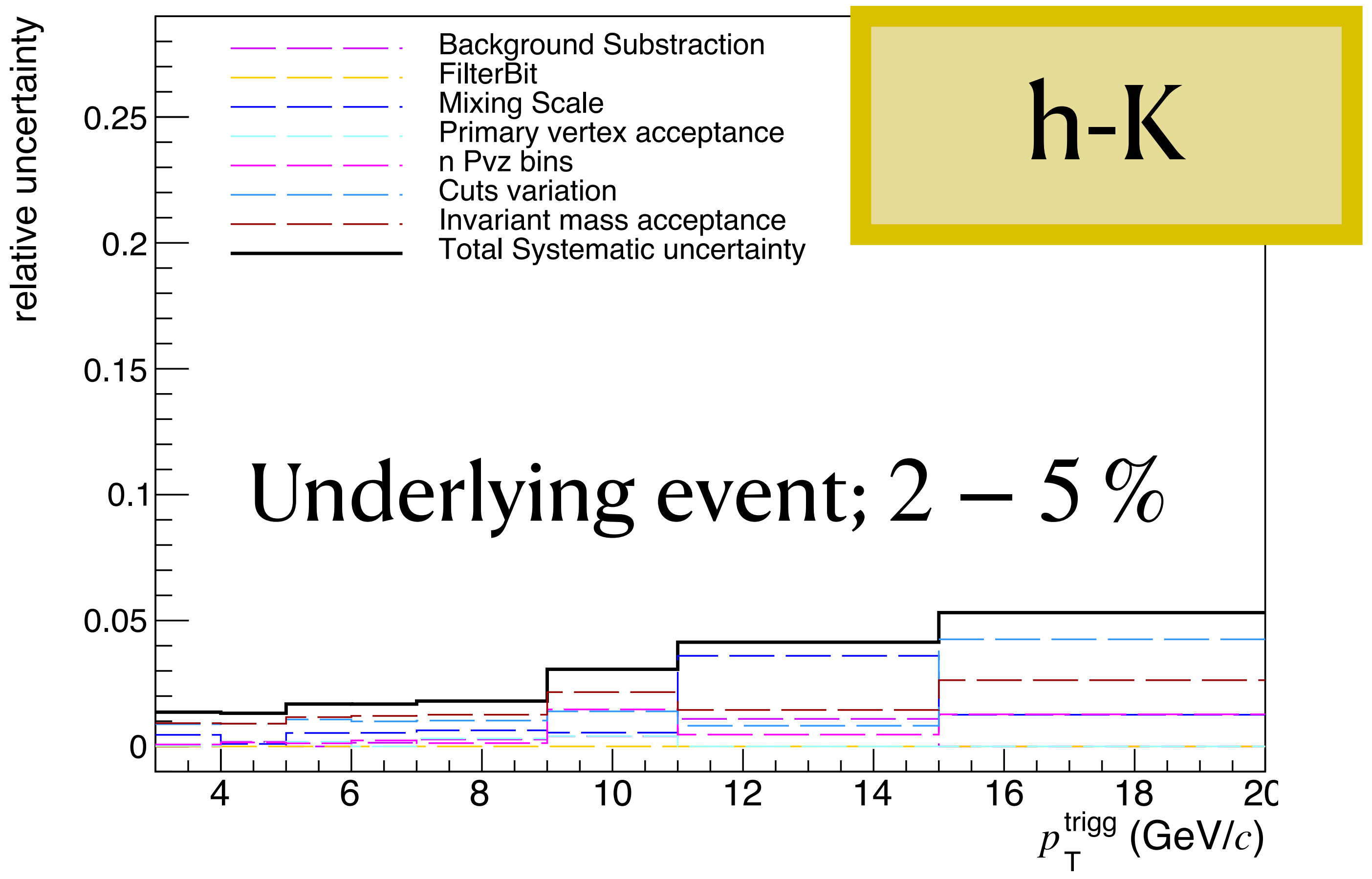


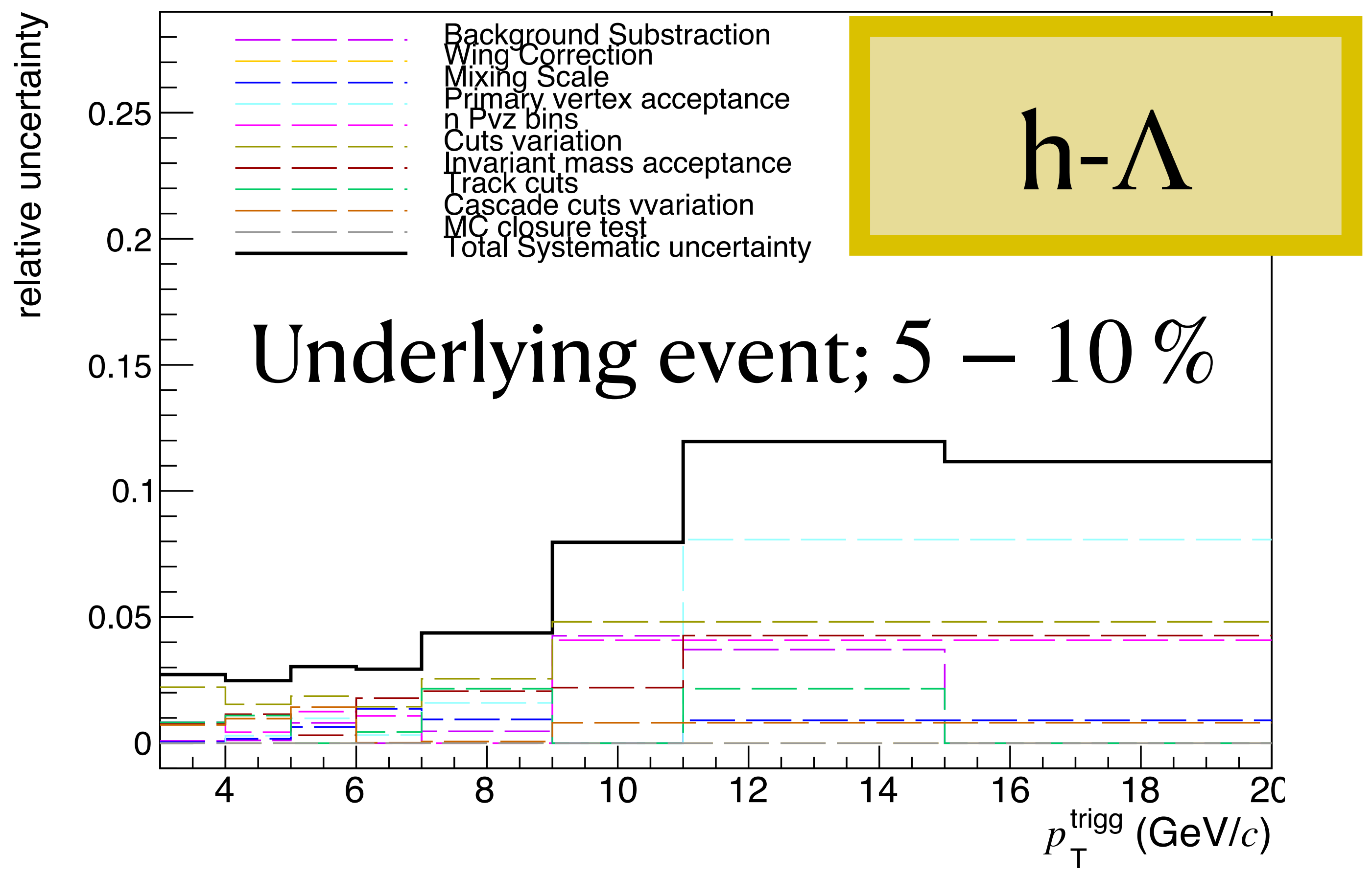


Systematic Uncertainties Study

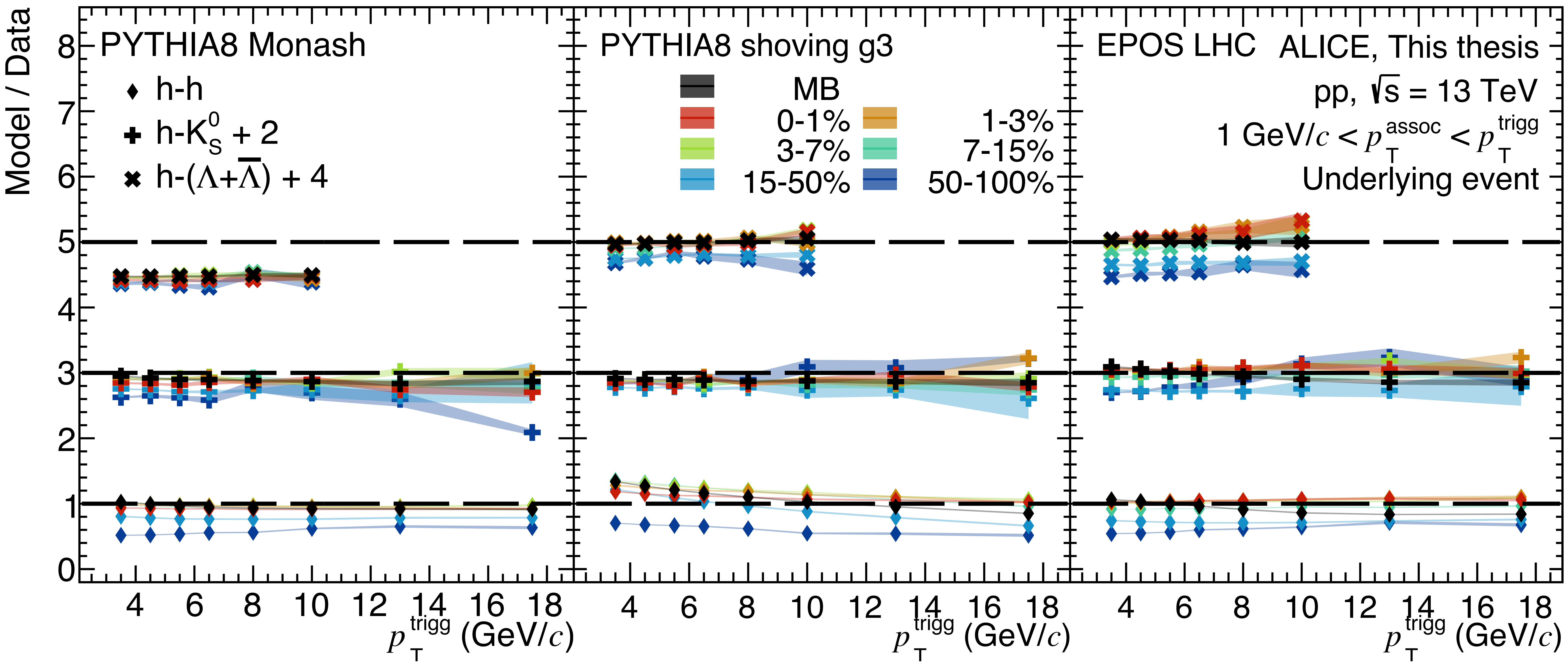




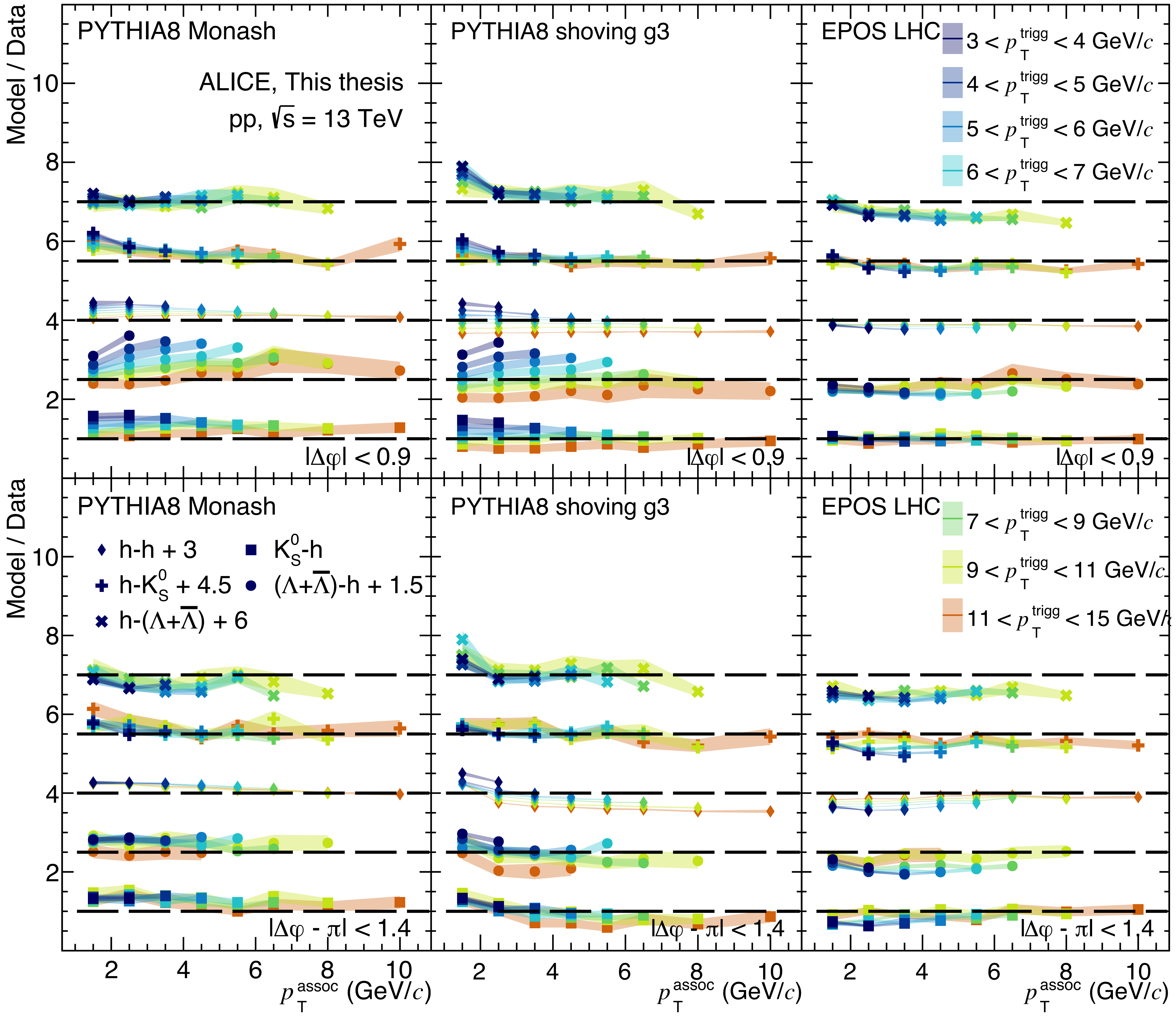




Yield (p_{T}^{trigg} and multiplicity)- model comparison



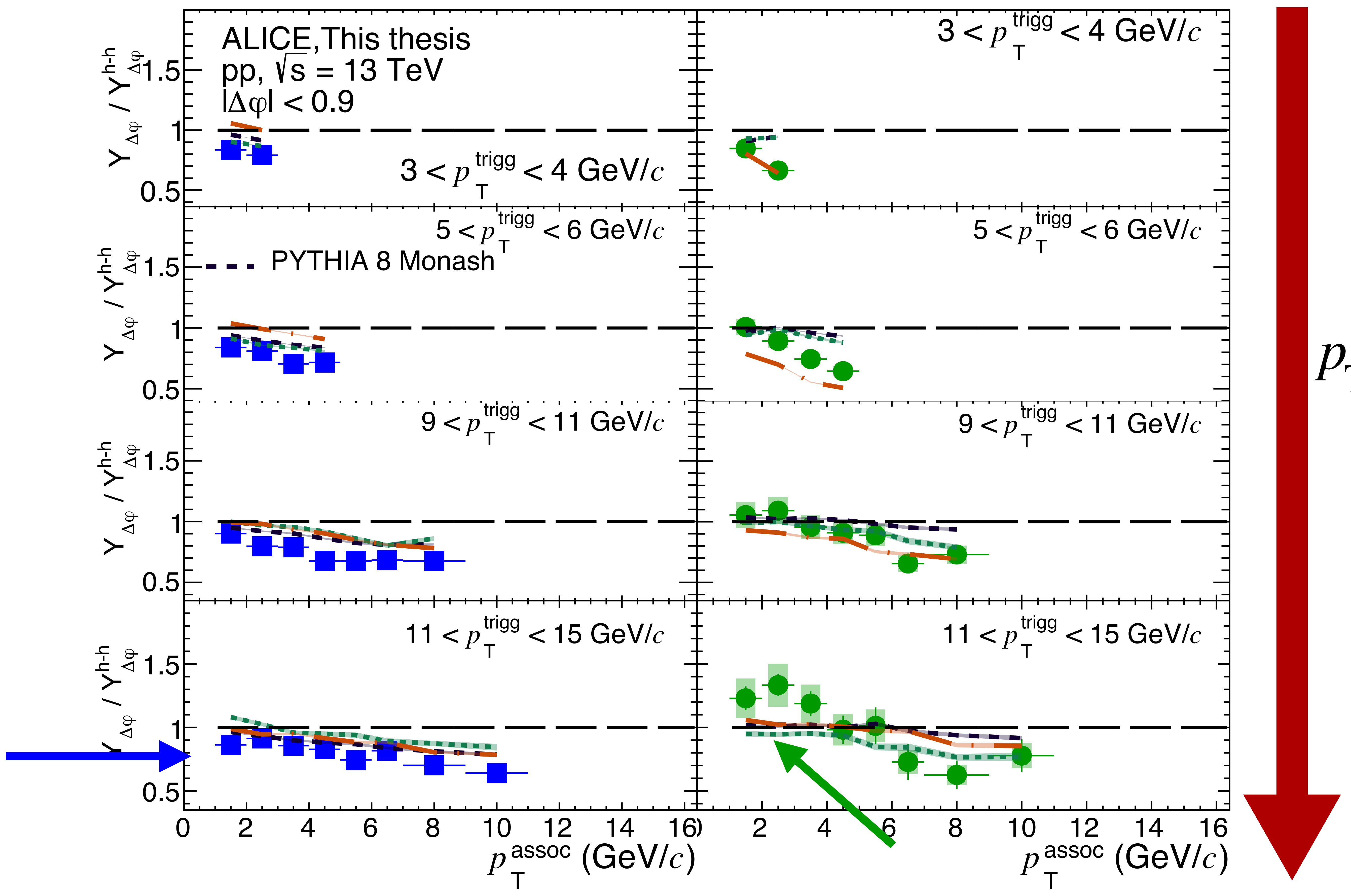
Yield (p_T^{assoc})- model comparison



Jet-like particle-yield ratios to h-h yields

$K_S^0 - \mathrm{h/h - h}$

$(\Lambda + \overline{\Lambda}) - \mathrm{h/h - h}$



- Different trends of the ratio for different trigger particles:
  - K_S^0 - below unity for all p_T^{trigg} intervals and p_T^{assoc} bins
  - Λ higher than K_S^0 and above unity for low p_T^{assoc} at high p_T^{trigg}

The bias towards gluon jets is more pronounced at the soft part of hard jets