# Study of leading transverse momentum fraction of $\Lambda(\overline{\Lambda})$ and $K^0_S$ in pp collisions at $\sqrt{s}$ = 13 TeV

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- Motivation
- Data sample and analysis strategies
- Systematic uncertainty
- Results

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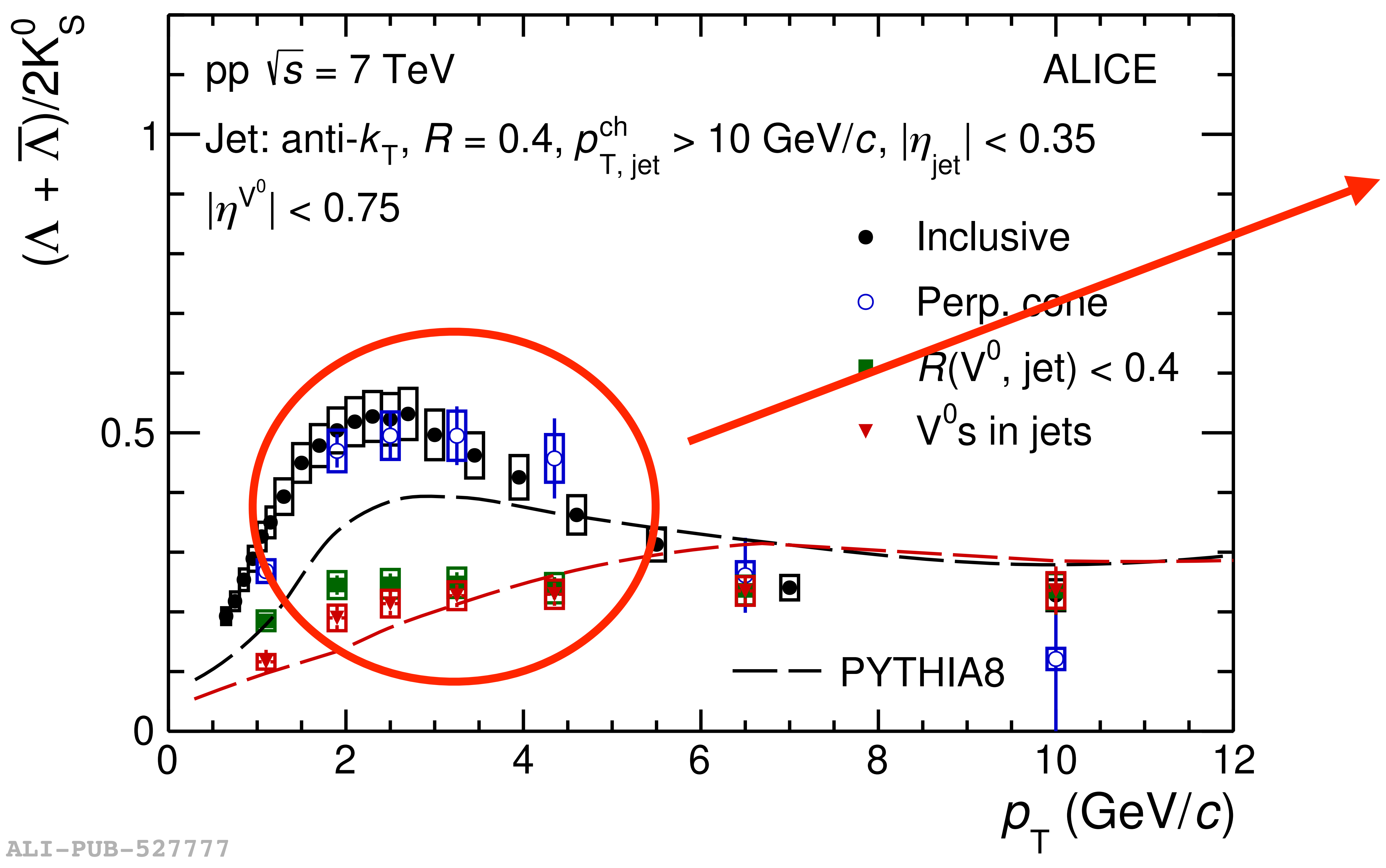
# Motivation

Phys. Lett. B 827 (2022) 136984




- Strange baryon-to-meson ratio enhancement in the underlying event (related to in jet production) observed in $p_T$ at 2–4 GeV/$c$ in pp (and p–Pb)
  - ➡ Suggests the enhancement is not attributed to the jet fragmentation
  - ➡ However, particles located in the ratio enhanced region are expected to be products of parton fragmentation and are likely the leading particles of low energy jets

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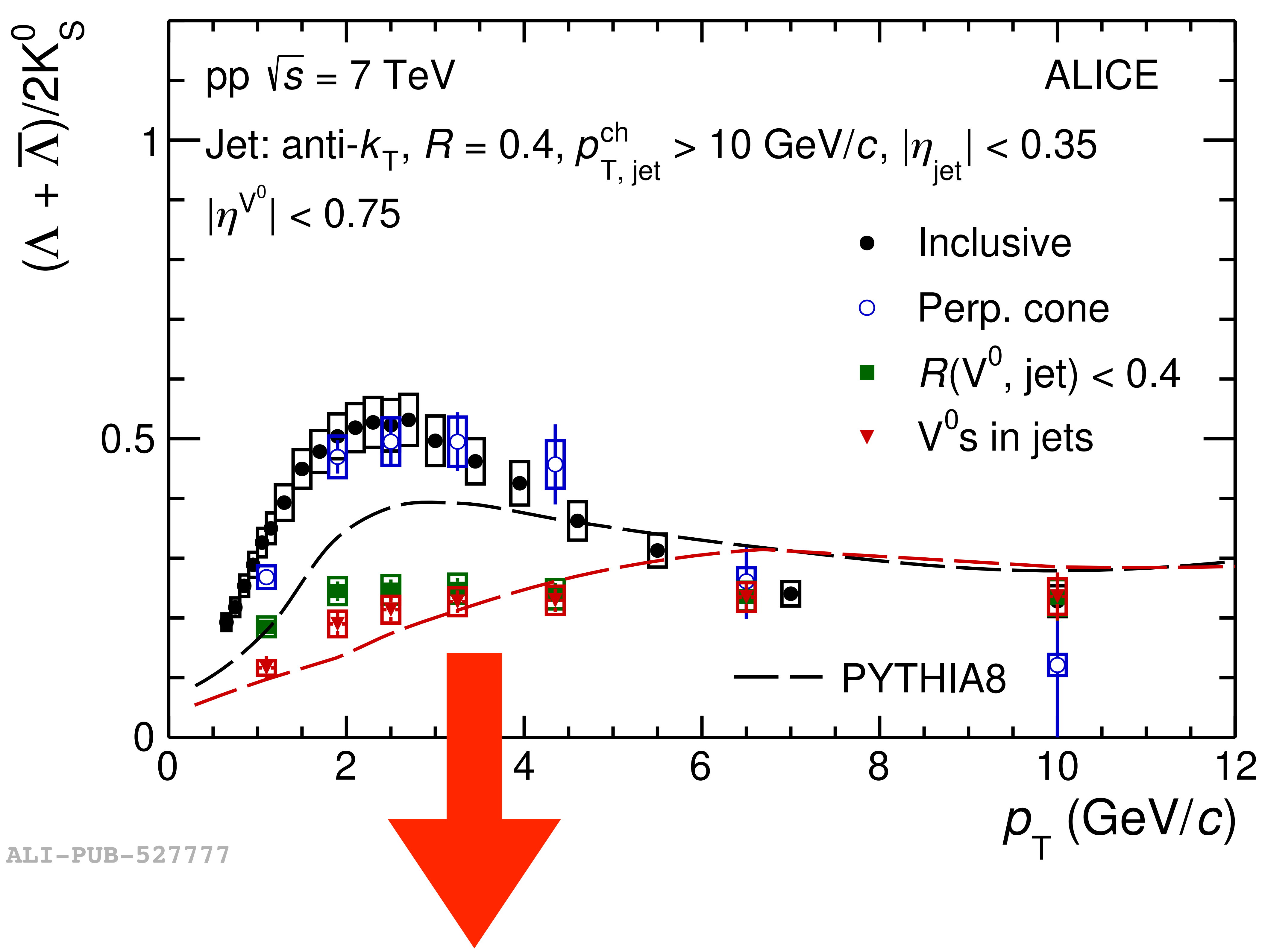


- Strange baryon-to-meson ratio enhancement in the underlying event (related to in jet production) observed in $p_T$ at 2–4 GeV/$c$ in pp (and p–Pb)
  - ➡ Suggests the enhancement is not attributed to the jet fragmentation
  - ➡ However, particles located in the ratio enhanced region are expected to be products of parton fragmentation and are likely the leading particles of low energy jets
- The in jet production is tagged by matching the jet cone
  - ➡ Λ-jet association depends also on momentum fraction
  - ➡ Recover the missing fragmentation pieces using two-particle correlations


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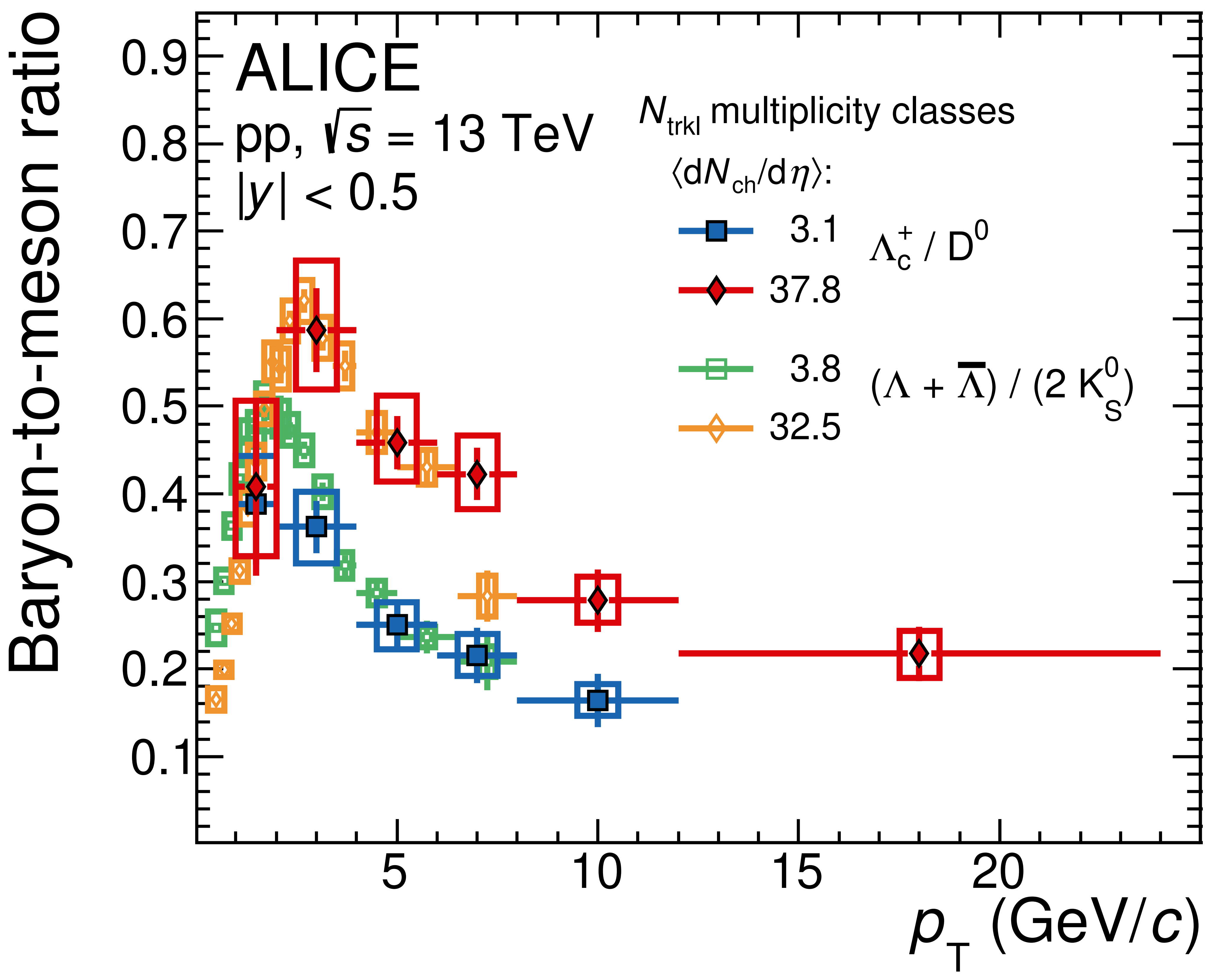
# Motivation



Phys.Lett.B 829 (2022) 137065




- Larger energy parton —> smaller $z$
- Smaller energy parton —> larger $z$

- Similar behavior observed in charm sector
  - ➡ Clearly from hard processes
- In this study
  - ➡ Measure $p_T$ fraction
  - ➡ Observable: $z = p_{T,trigger} / p_{T,jet}$
  - ➡ Choosing strange particle as trigger, charged primary particles as associated particles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# Event & Track selection



*a full sample list is in the backup*

**Data sample**

- ***Data:*** pp collisions $\sqrt{s} = 13$ TeV, 2016, 2017 and 2018 data, pass2, AOD ( AOD234 for LHC16k and LHC16l ), LHC17g and LHC18c are rejected according to QA
- ***Monte Carlo:*** general purpose MC, runs anchored data are selected

**Event and particle selections**

- ***Events:***
  AliVEvent::kINT7 (minimum bias), $|z_{vtx}| < 10$ cm, both IB and OOB PUs are rejected
- ***Trigger candidate selection*:**
  The hardest strange particle (candidate) in given event, $|\eta_{V0}| < 0.75$
- ***Associate particles*:**
  $p_T > 0.15$ GeV/$c$, $|\eta| < 0.8$, physical primary (FilterBit BIT8 tagged global hybrids with $|DCA_{xy}| < 2.4$ cm and $|DCA_z| < 3.2$ cm)
- ***MC particles*:**
  *Data selection* + IsPhysicalPrimary() + !IsFromSubsidiaryEvent()



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# Regular correlation analysis

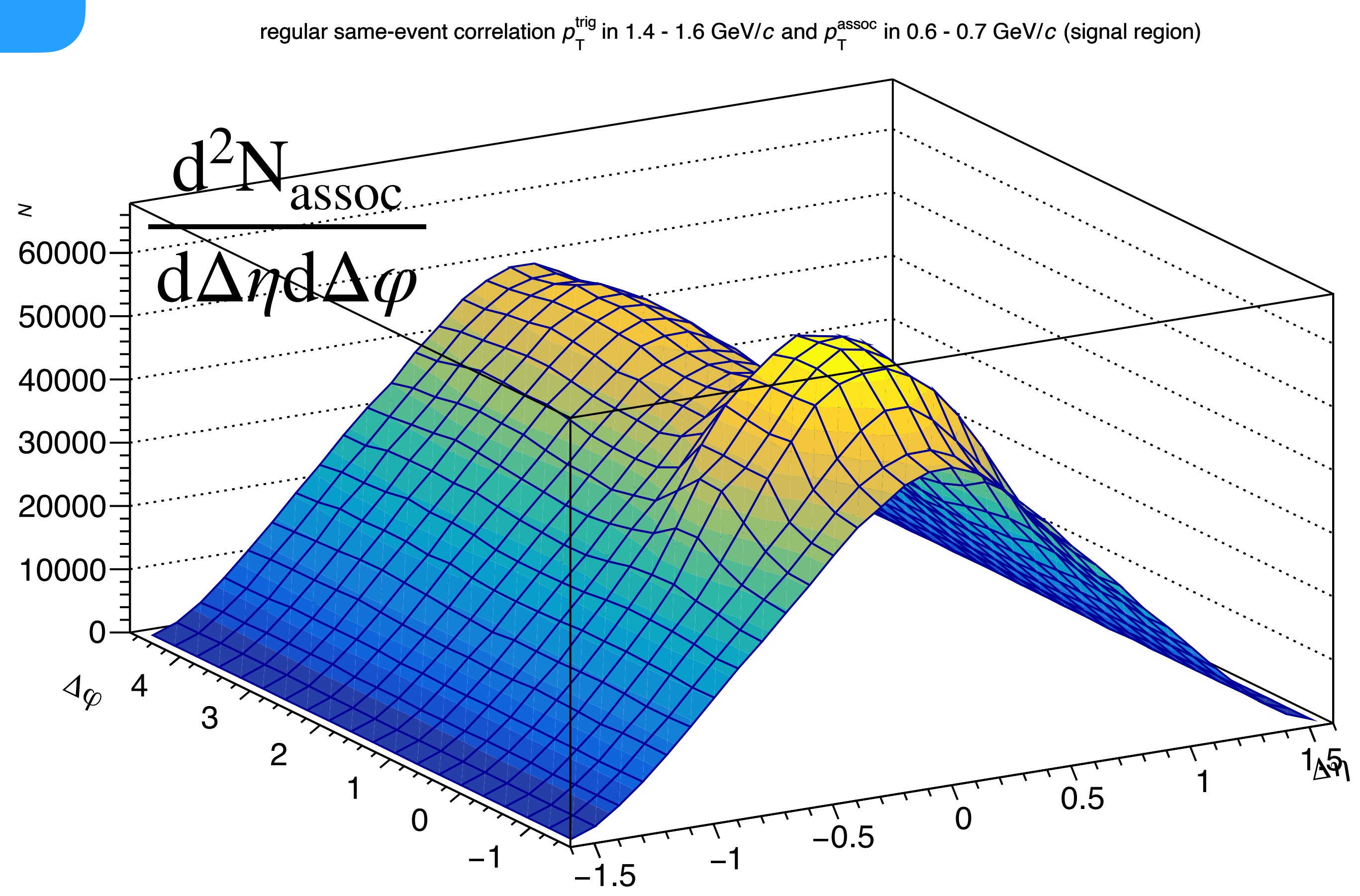
$K^0_S$

signal region

sideband region

sideband corrected

same event

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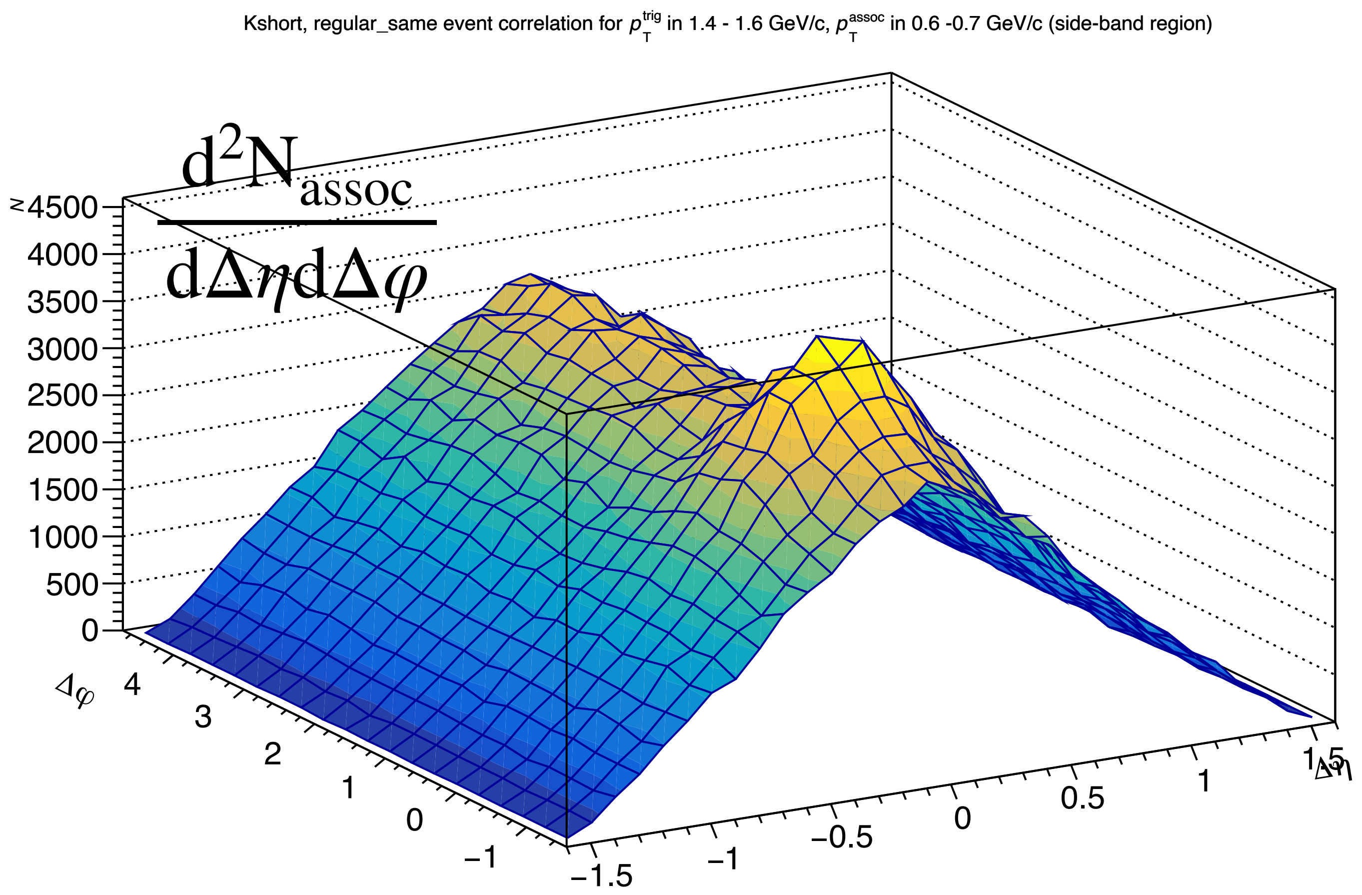


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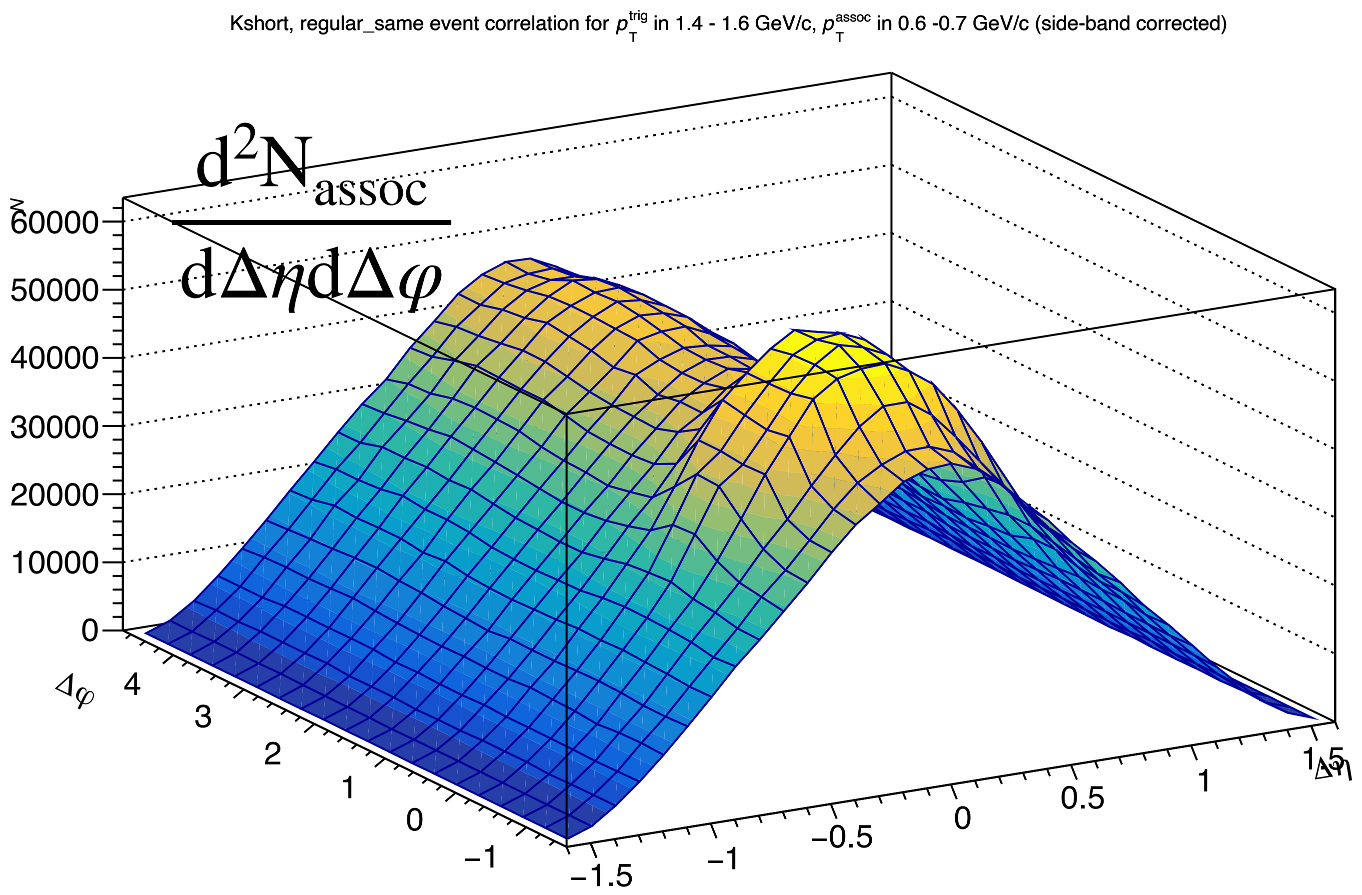
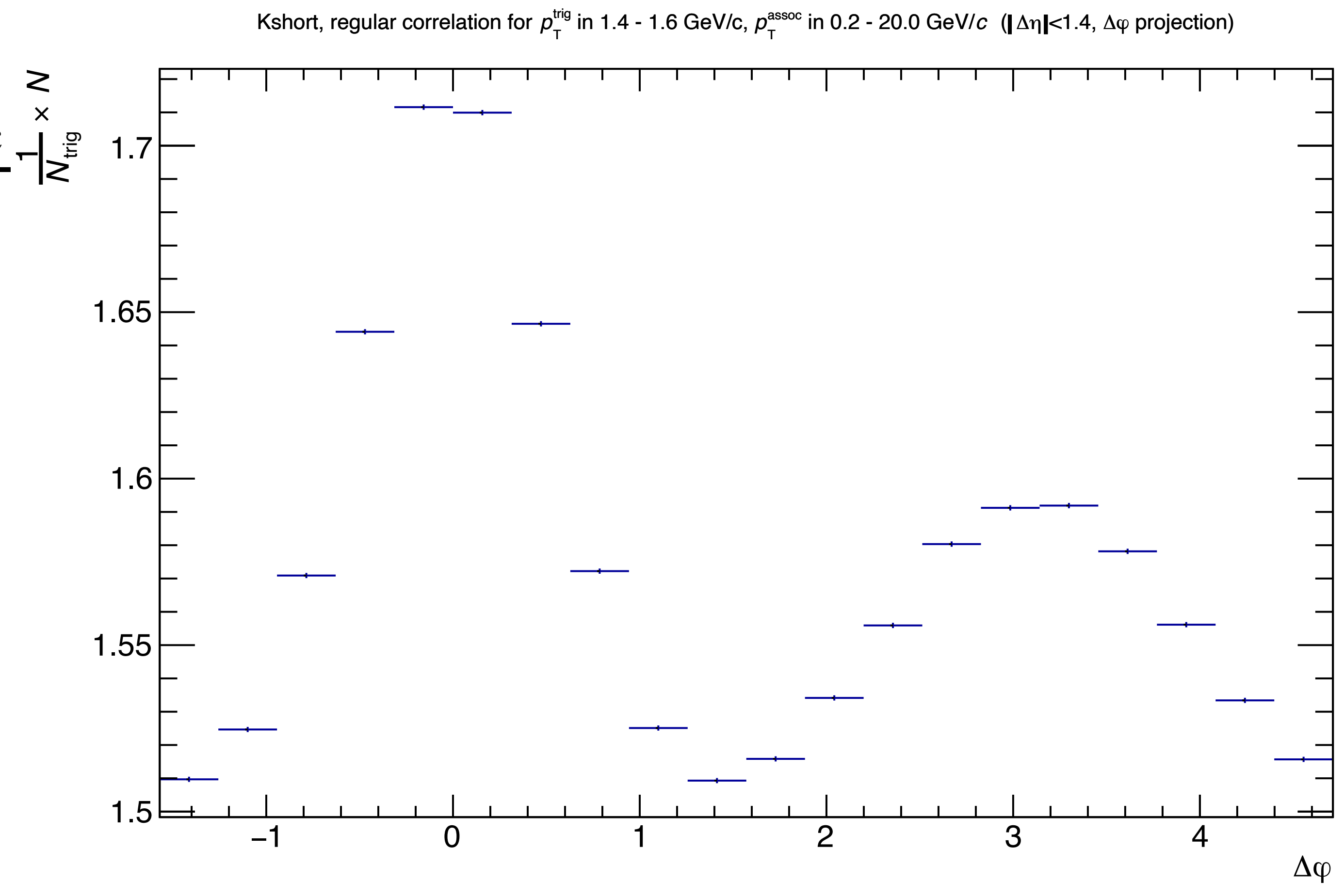



Example: a regular analysis results for $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ and $0.6\ \mathrm{GeV}/c < p_T^{assoc} < 0.7\ \mathrm{GeV}/c$ , tracking efficiency is considered

$\frac{1}{N_{trig}} \frac{dN_{assoc}}{d\Delta\varphi}$




example

- Raw correlation function
  - ➡ Jet yield can be obtained by applying acceptance and inefficiency corrections, and baseline subtraction

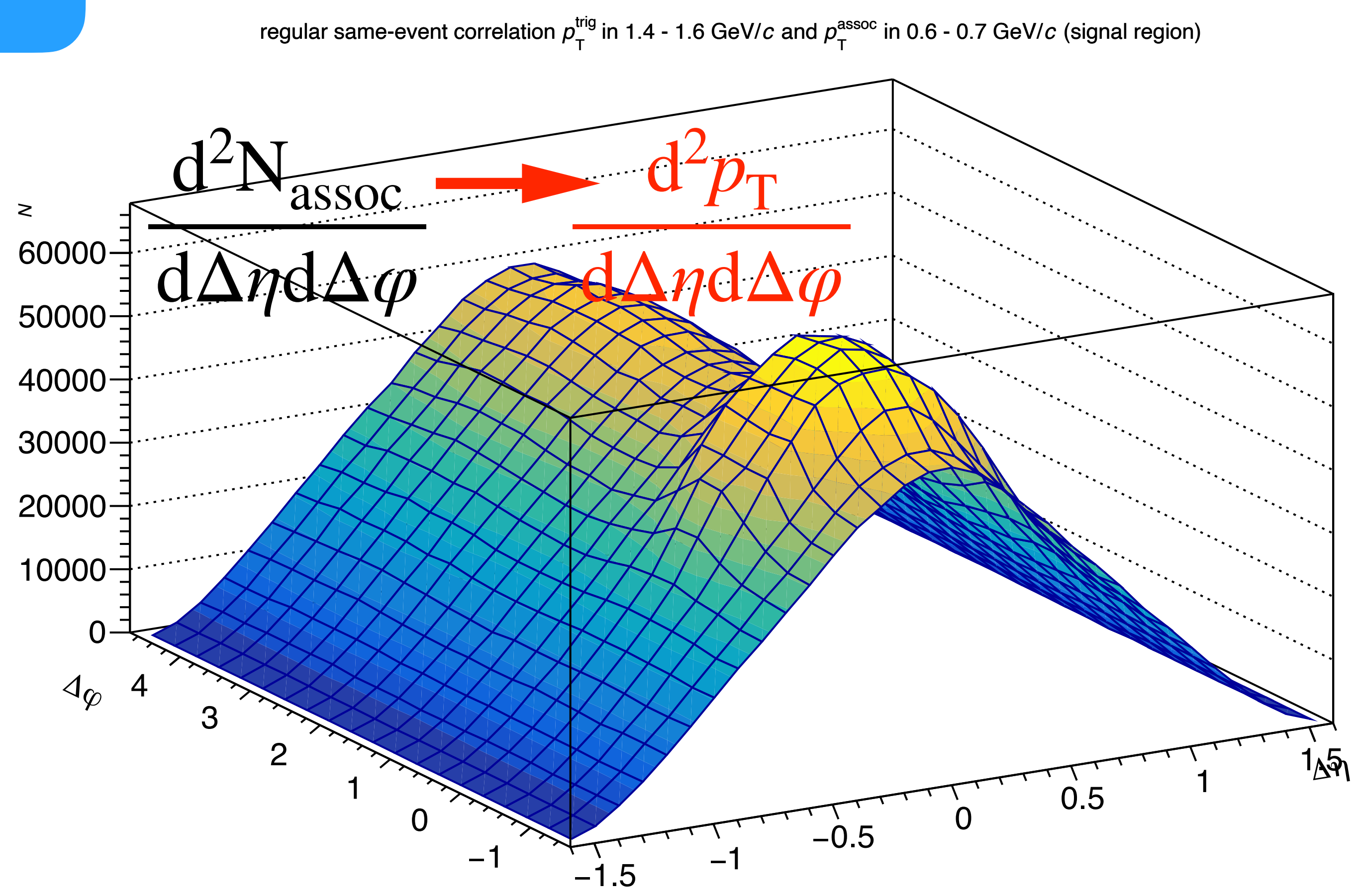
# $p_T$ weighted correlation analysis



$K^0_S$

same event

signal region

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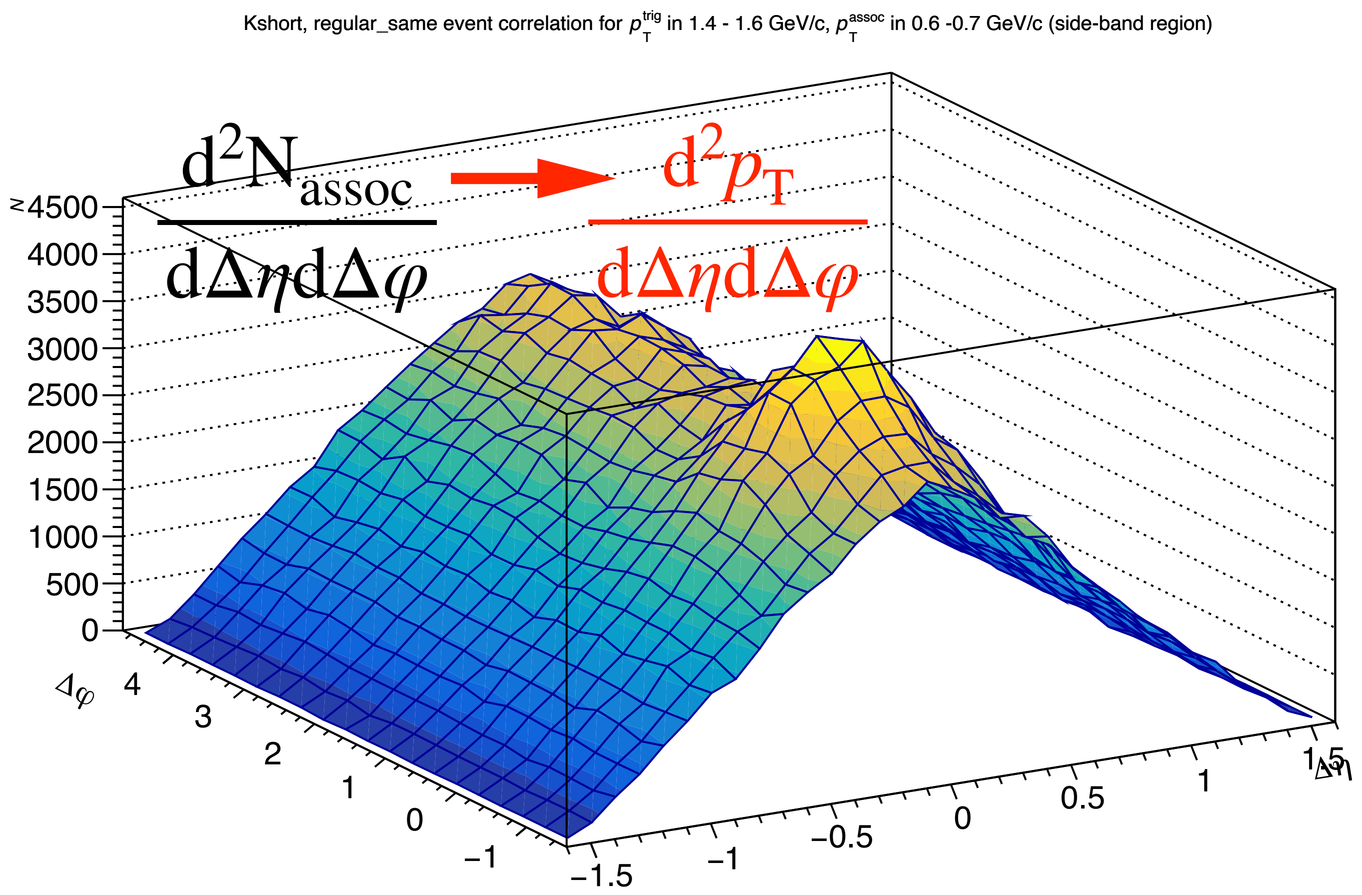
sideband region

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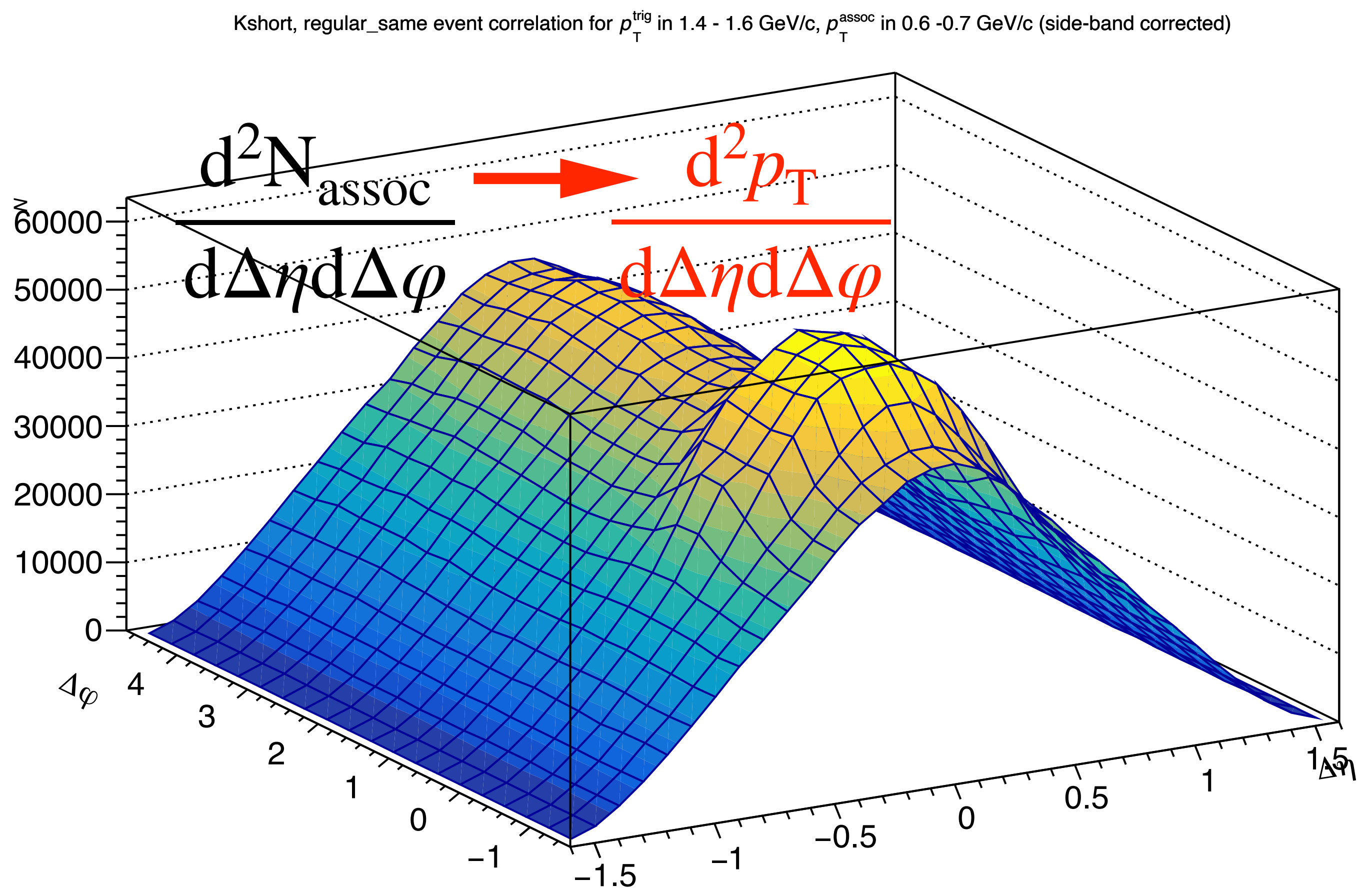
sideband corrected

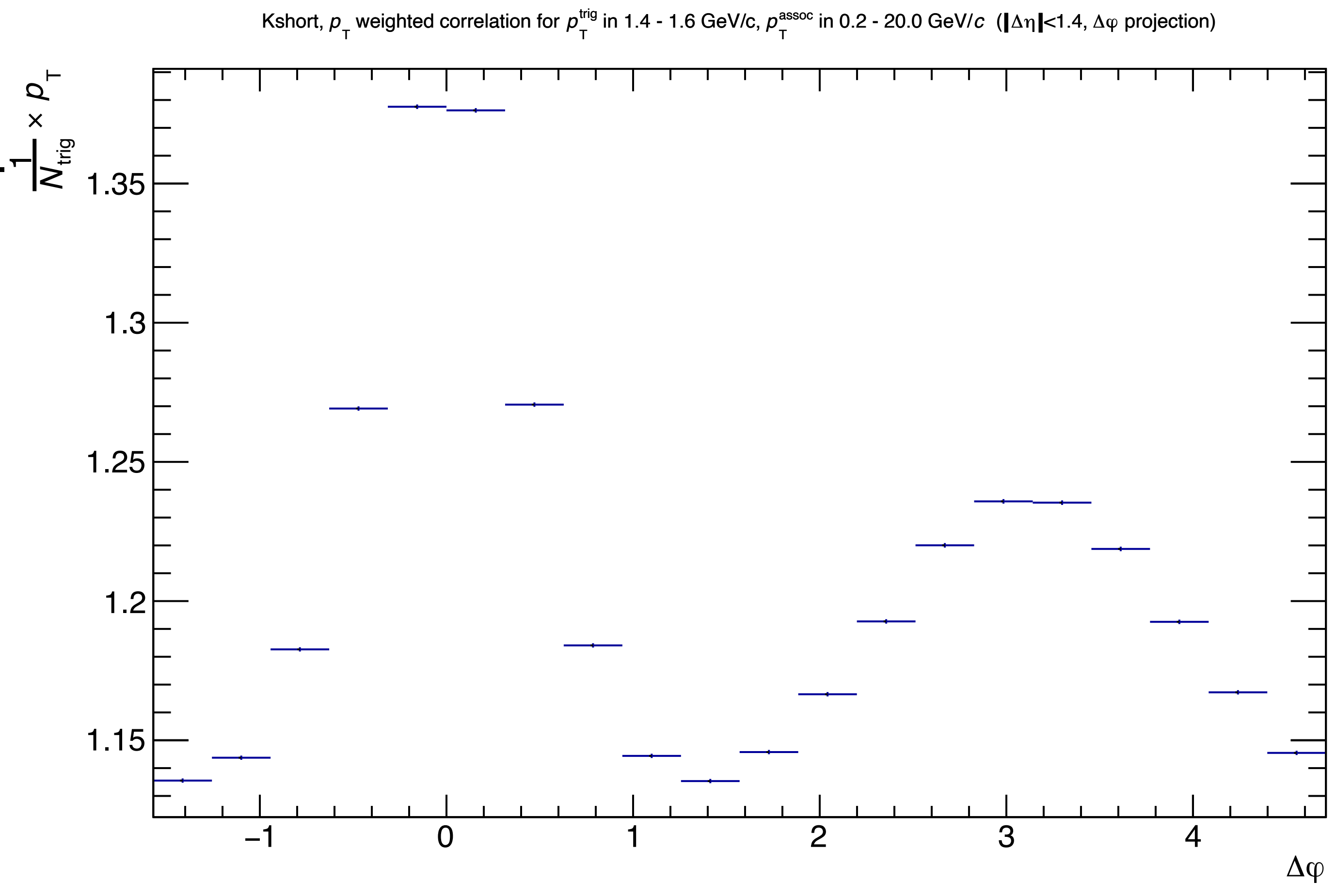



Example: a regular analysis results for $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ and $0.6\ \mathrm{GeV}/c < p_T^{assoc} < 0.7\ \mathrm{GeV}/c$, tracking efficiency is considered

$\frac{1}{N_{trig}}\frac{dN_{assoc}}{d\Delta\varphi}$

↓

$\frac{1}{N_{trig}}\frac{dp_T}{d\Delta\varphi}$




example

- Raw correlation function
  - ➡ Jet yield can be obtained by applying acceptance and inefficiency corrections, and baseline subtraction

Request in this analysis

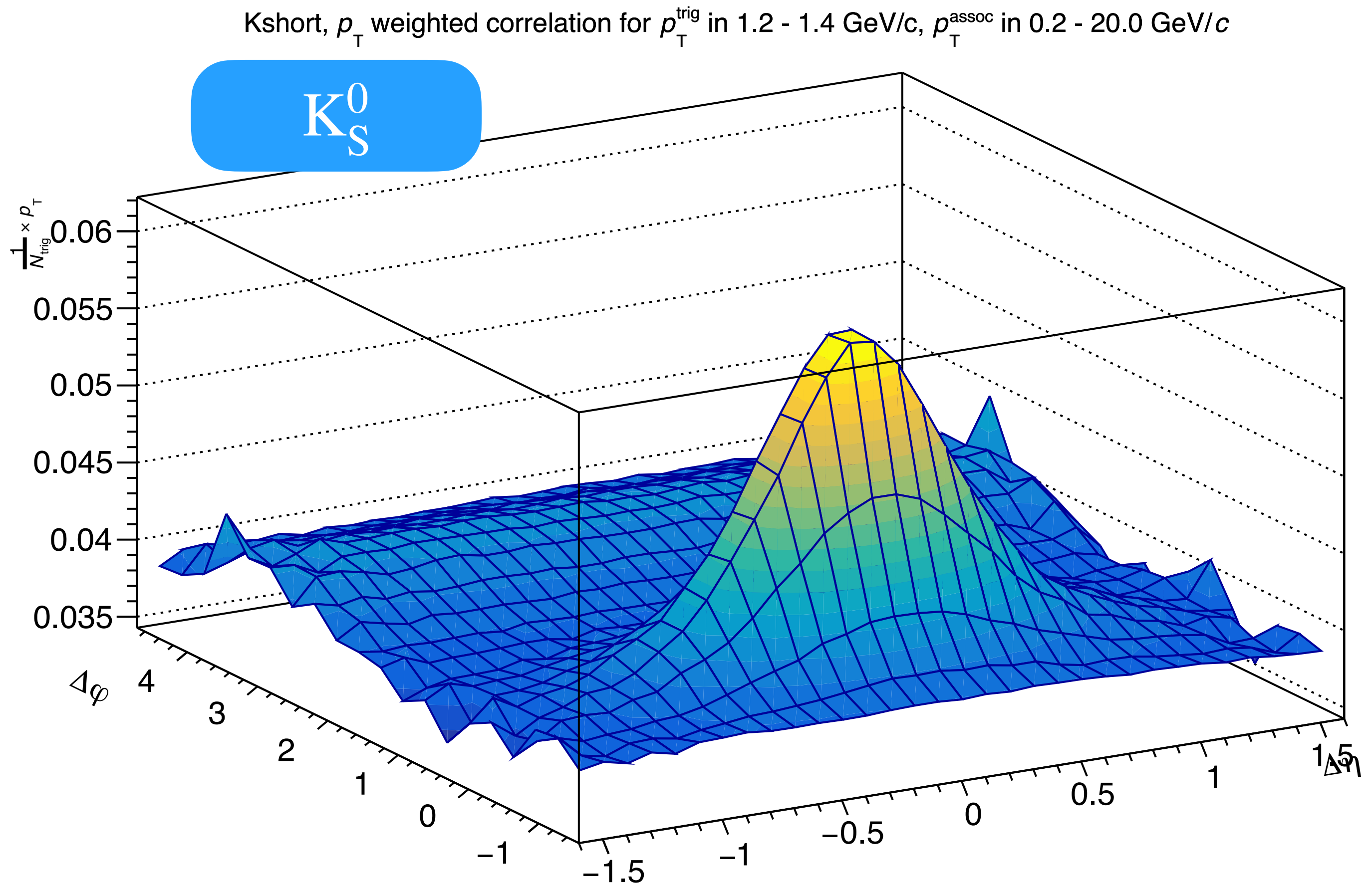
$$z = \frac{p_{T,trigger}}{p_{T,jet}}$$

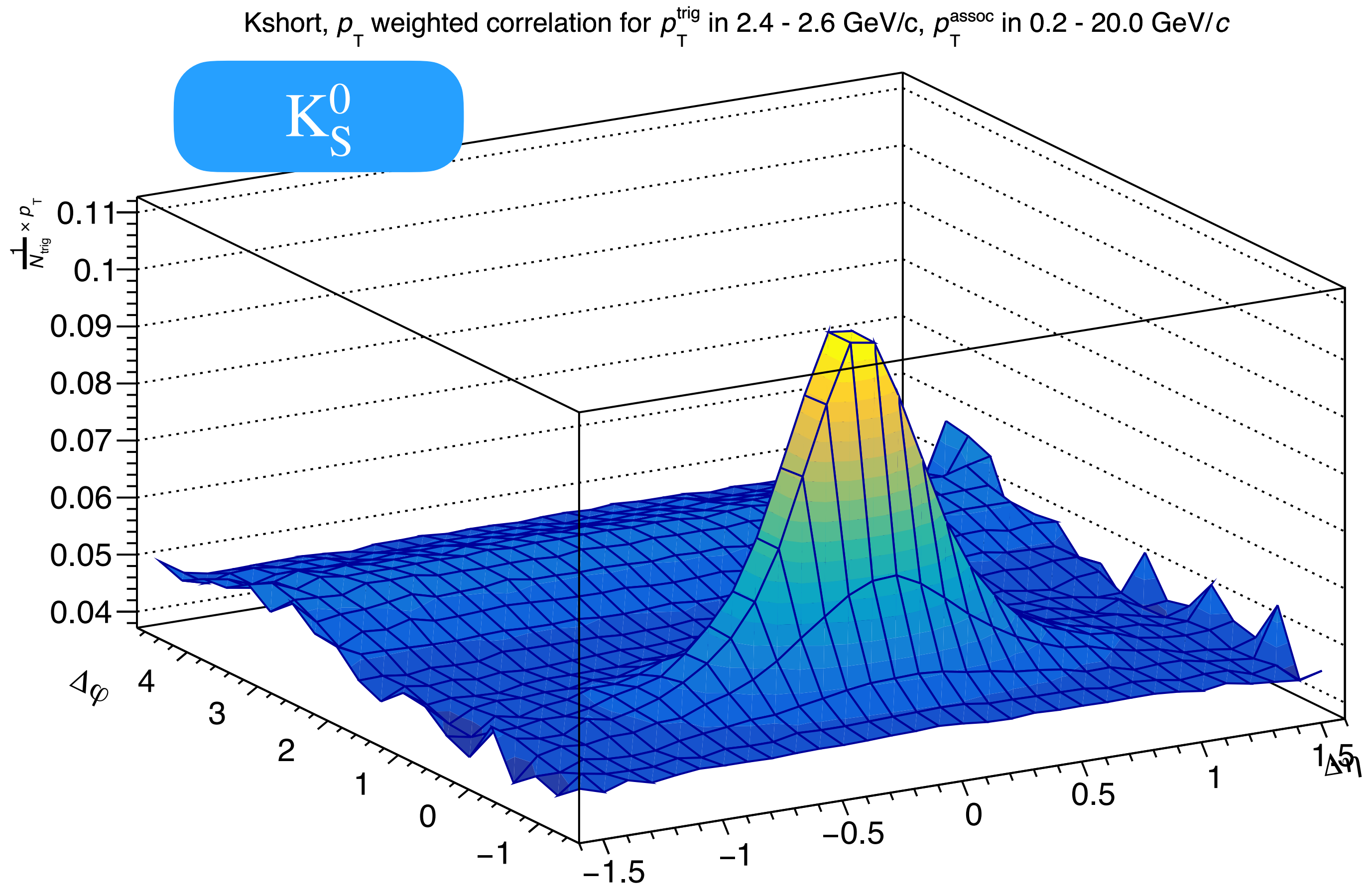
$p_{T,jet}$ represented by the sum $p_T$ of near side associated particles

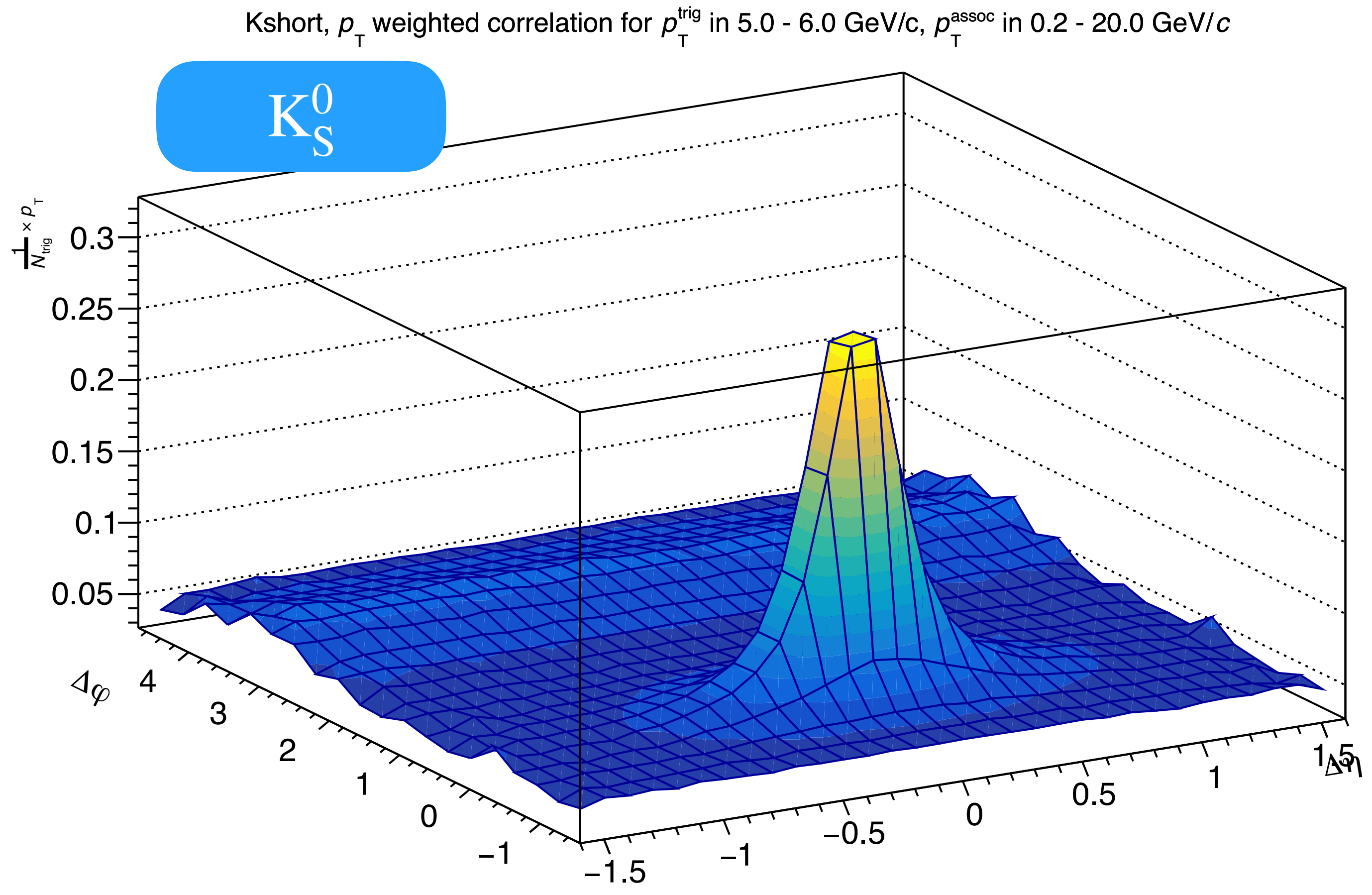
➡ Introduce a $p_T$ weight

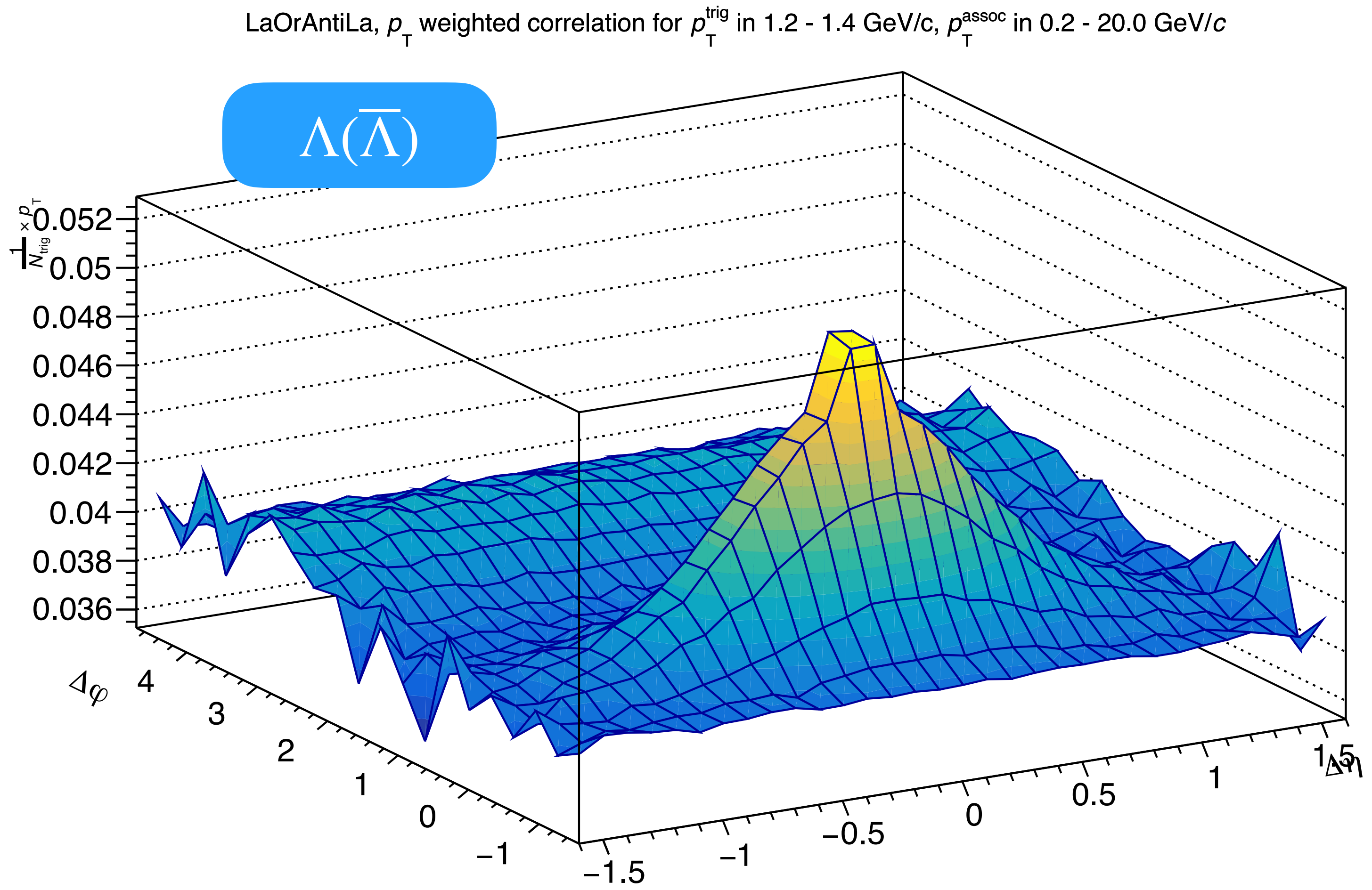
# Combined correlation function

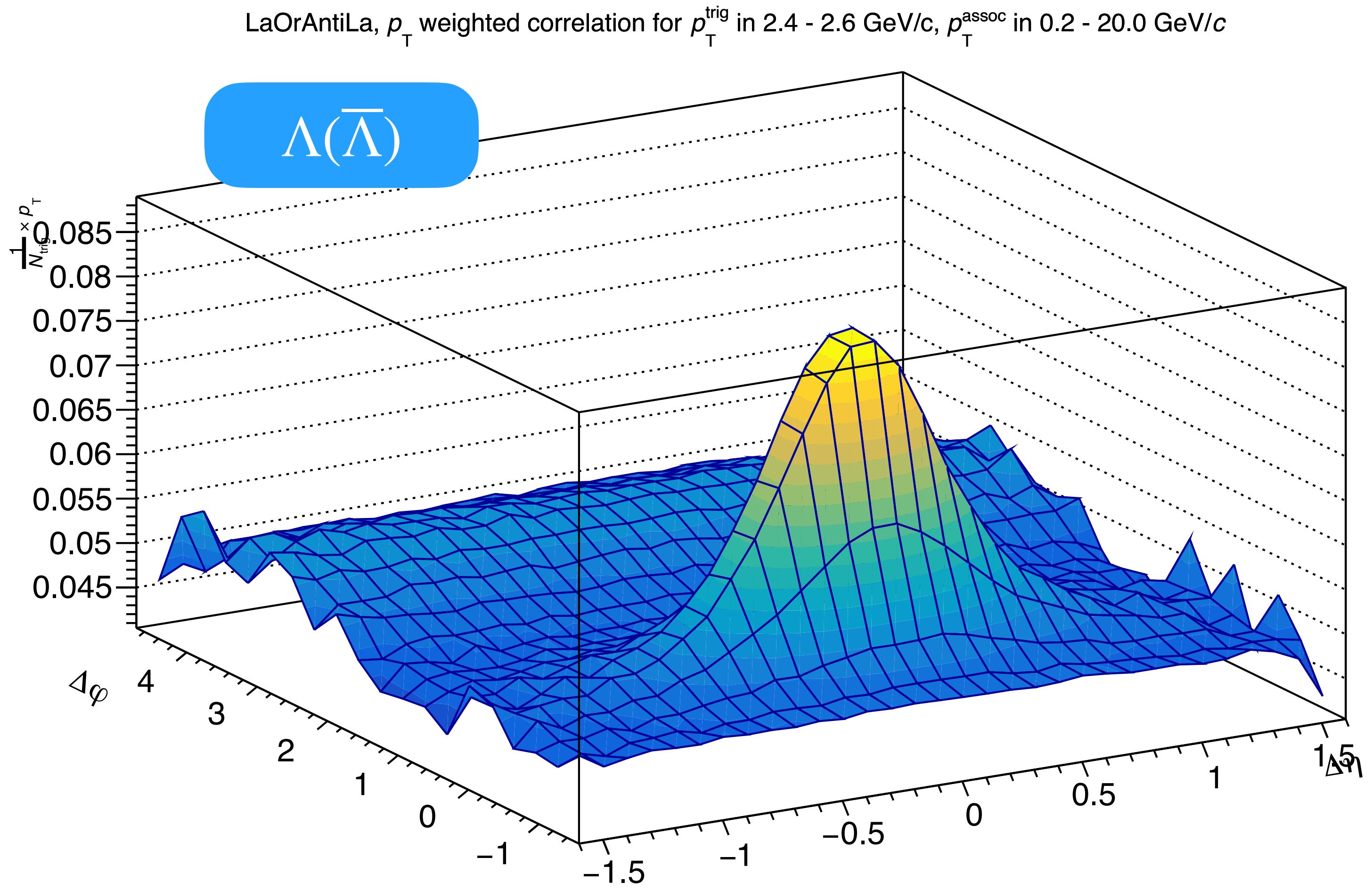
$1.2 < p_{\mathrm{T,\,trig}} < 1.4\ \mathrm{GeV}/c$ | $2.4 < p_{\mathrm{T,\,trig}} < 2.6\ \mathrm{GeV}/c$ | $5.0 < p_{\mathrm{T,\,trig}} < 6.0\ \mathrm{GeV}/c$

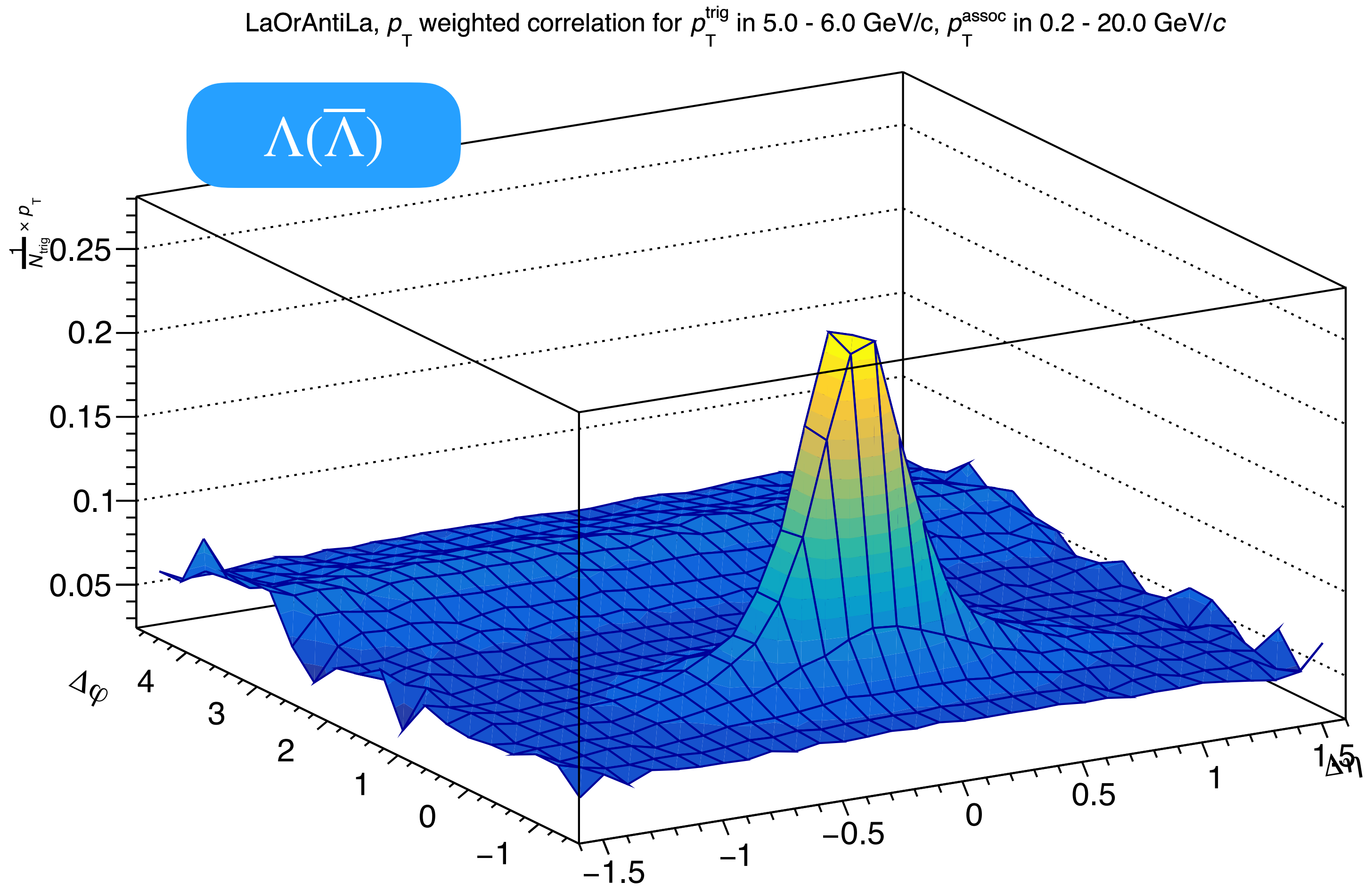



Analysis details are in backup slides

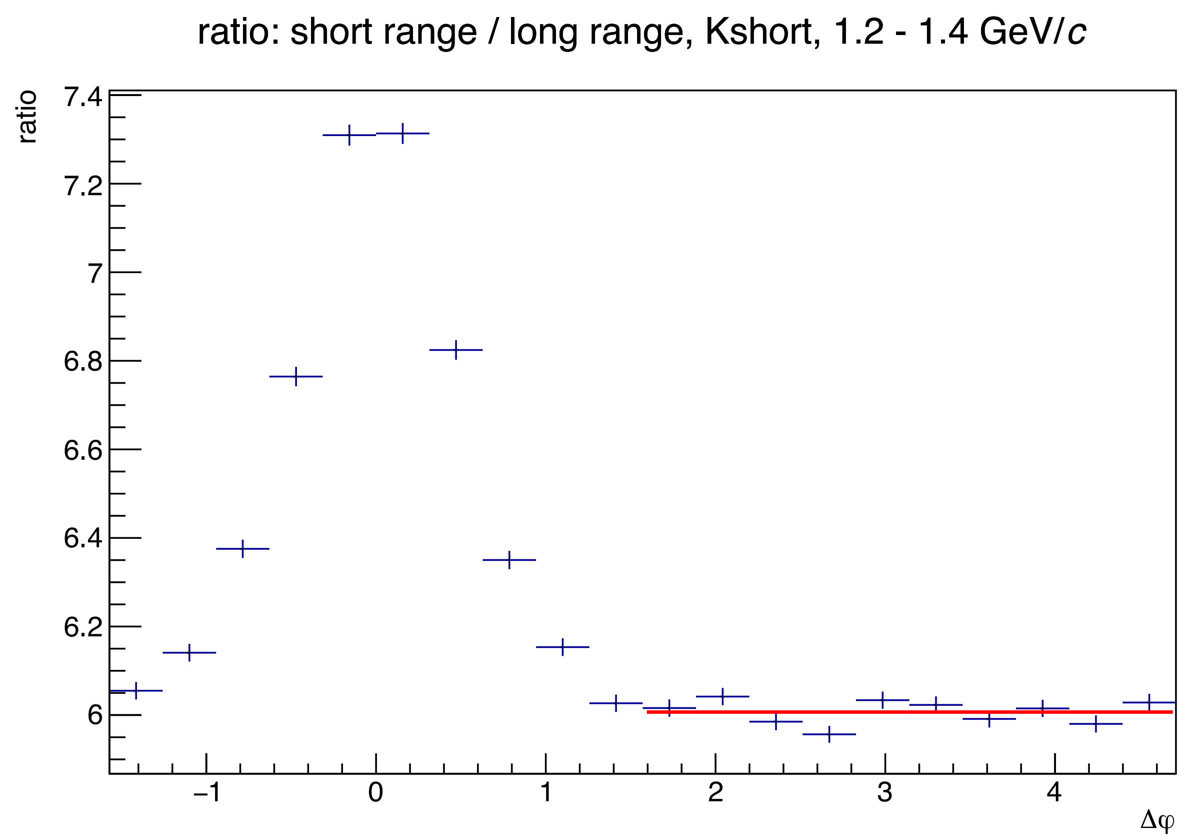
# Uncorrelated bkg subtraction

## $\eta$ gap method

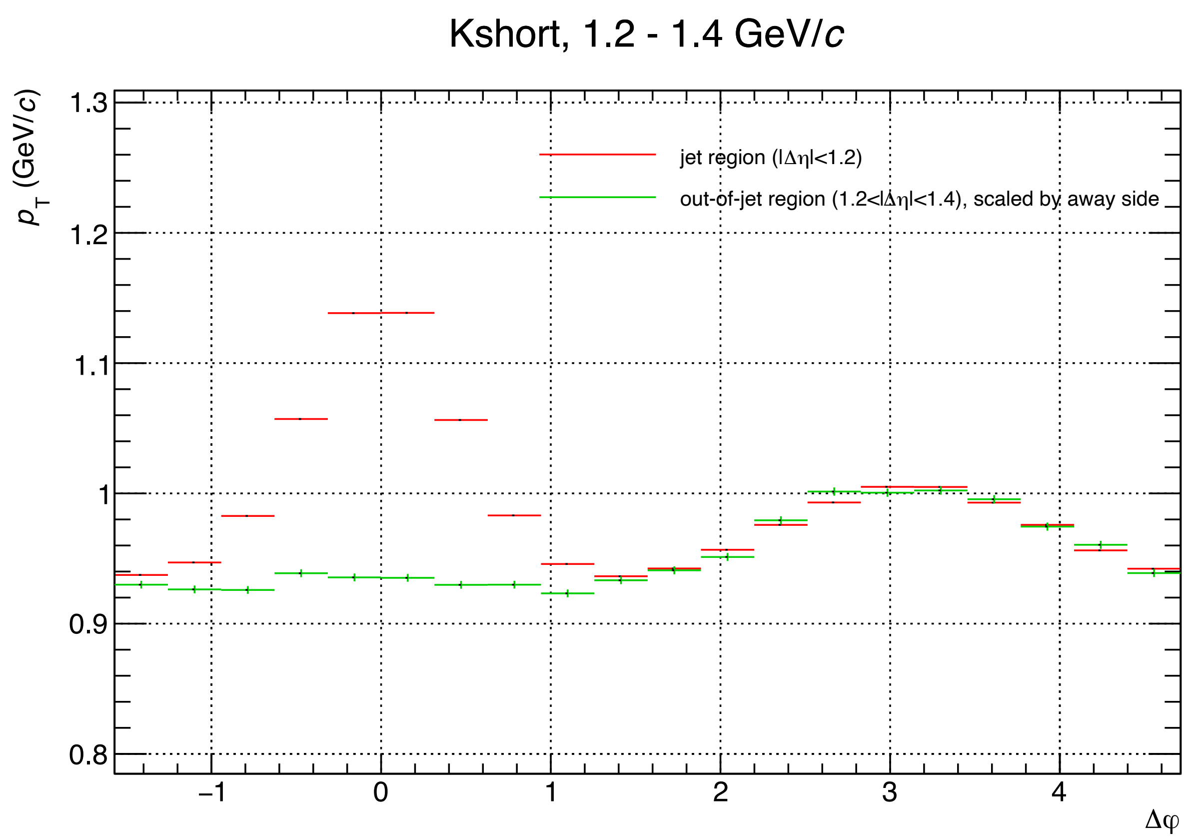
- Jet region: $|\Delta\eta| < 1.2$, out-of-jet (OOJ) region: $1.2 < |\Delta\eta| < 1.4$
- Make $\Delta\varphi$ projections within the jet and OOJ region, respectively
- Make ratio of the $\Delta\varphi$ projections and fit the away side with a constant, fitting range: $(1.58, 4.71)$
- Scale the $\Delta\varphi$ projections associated to the OOJ region by the fit results
- Subtract the scale plot from the $\Delta\varphi$ projections associated to the jet region

$$z = \frac{p_{\mathrm{T,trig}}}{p_{\mathrm{T,trig}} + \sum p_{\mathrm{T,assoc}}}$$

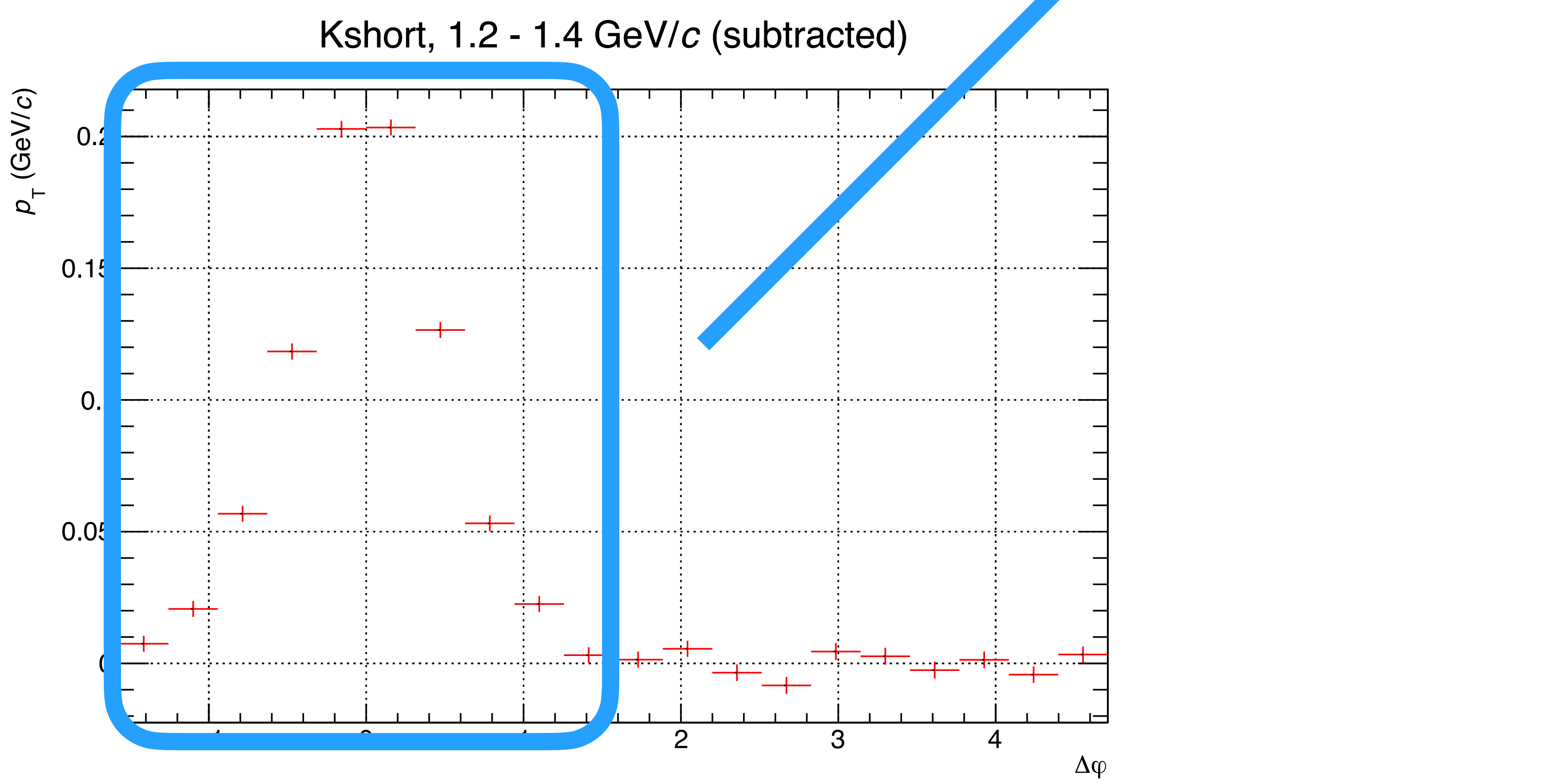
**Example: leading $K^0_S$ as trigger**, $1.2 < p_{\mathrm{T,\,trig}} < 1.4$ GeV/$c$




$\Delta\varphi$ projection ratio: jet region to OOJ region, and fit the AS




$\Delta\varphi$ projections: jet region and scaled OOJ region




Uncorrelated bkg subtracted

# Systematic uncertainty



**Systematic uncertainty sources in this analysis:**

① Event vertex acceptance region
② Choice of the signal extraction
③ Fitting function used to fit the background of the Inv.M distribution
④ Method to normalize the mix event correlation function
⑤ Selections on primary tracks
⑥ Choice of the jet region and out-of-jet region
⑦ OOB/IB PU
⑧ Material budget
⑨ Feed-down for leading $\Lambda(\overline{\Lambda})$
⑩ Auto-correlation effect
⑪ Secondary contamination effect

**All sources are examined by the Barlow check**

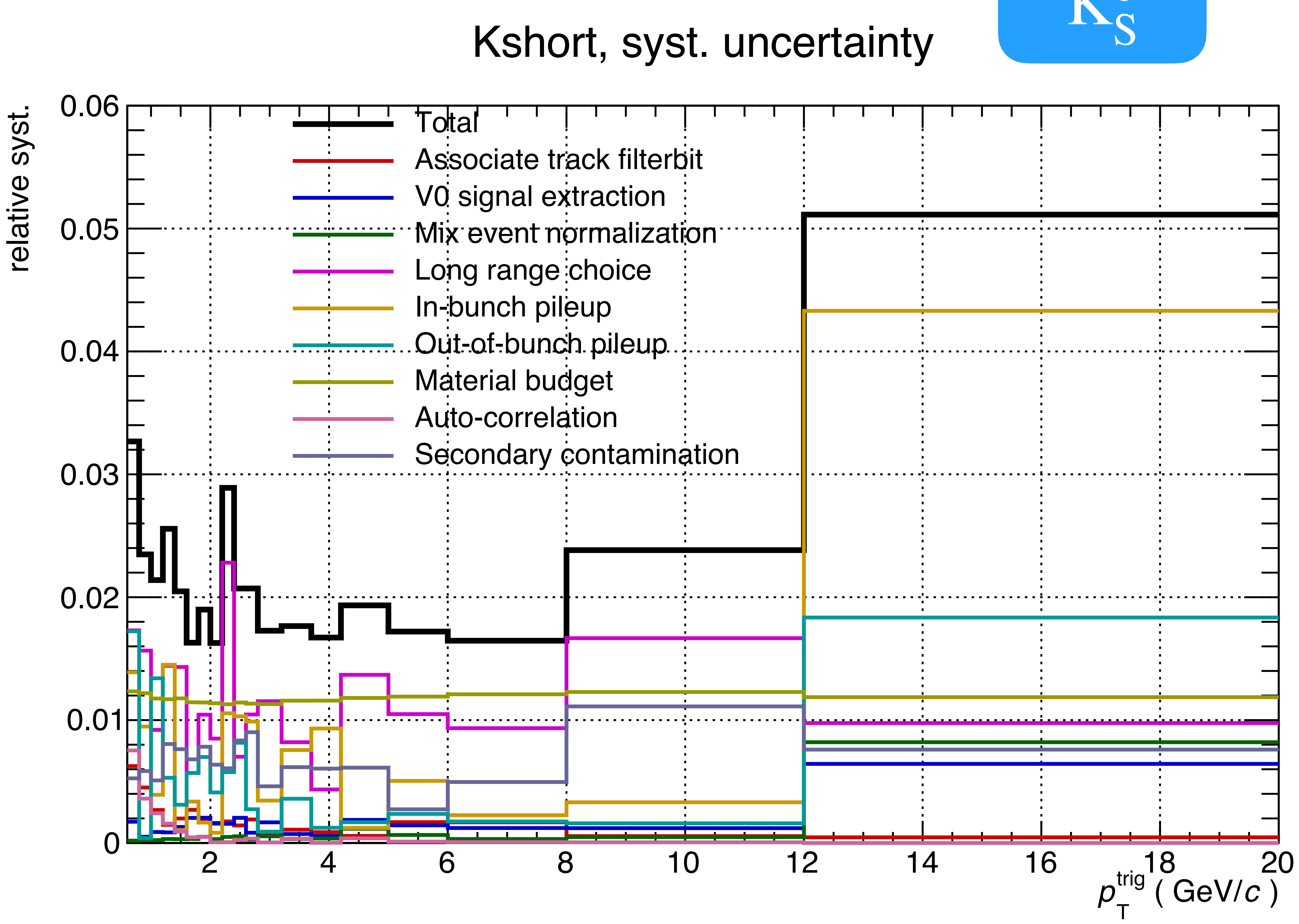
$$N = \frac{|z_{\text{variation}} - z_{\text{default}}|}{\sqrt{|\sigma^2_{\text{variation}} - \sigma^2_{\text{default}}|}}$$

Systematic uncertainty details are in backup slides

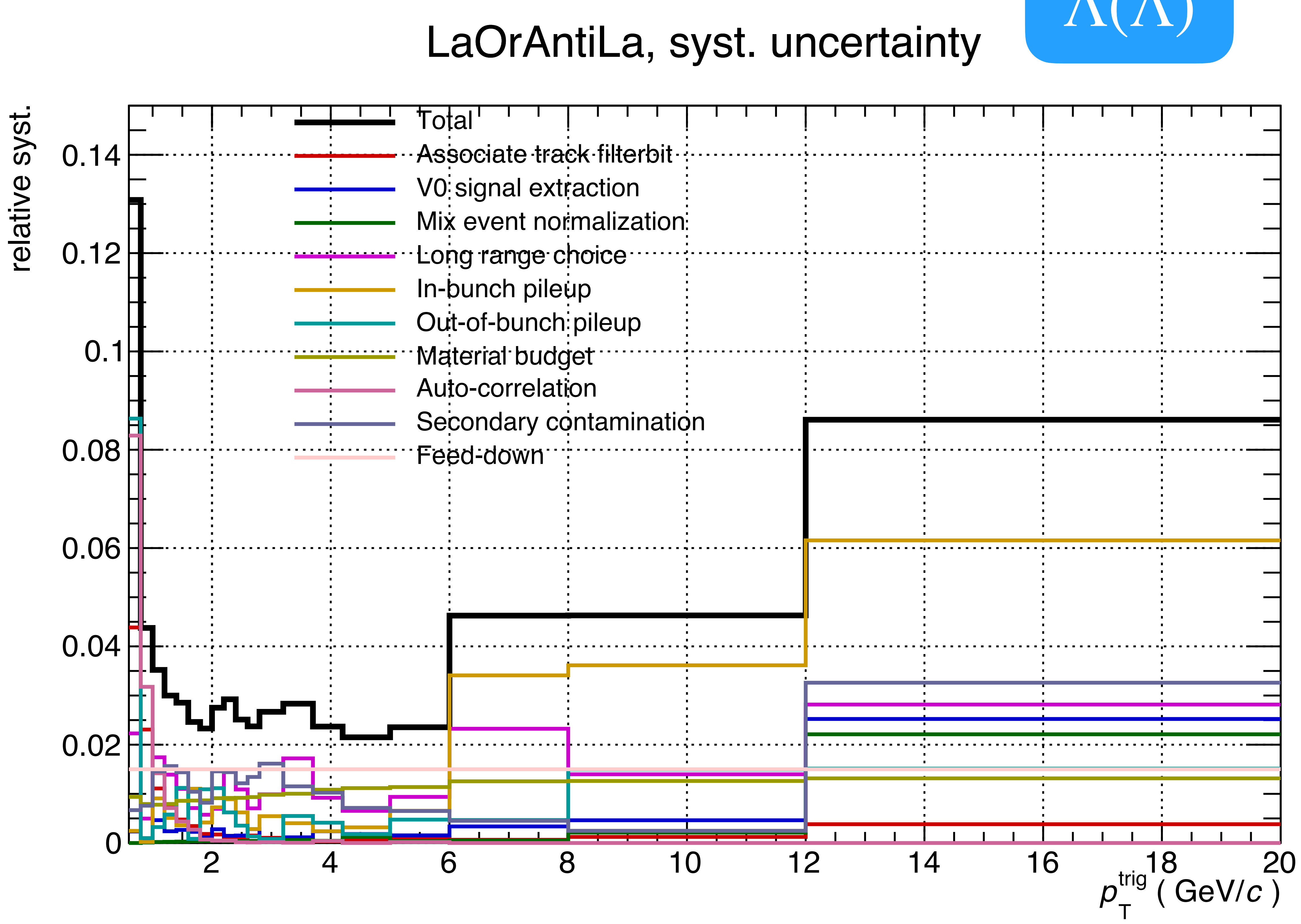
# Systematic uncertainty



$K^0_S$




$\Lambda(\overline{\Lambda})$

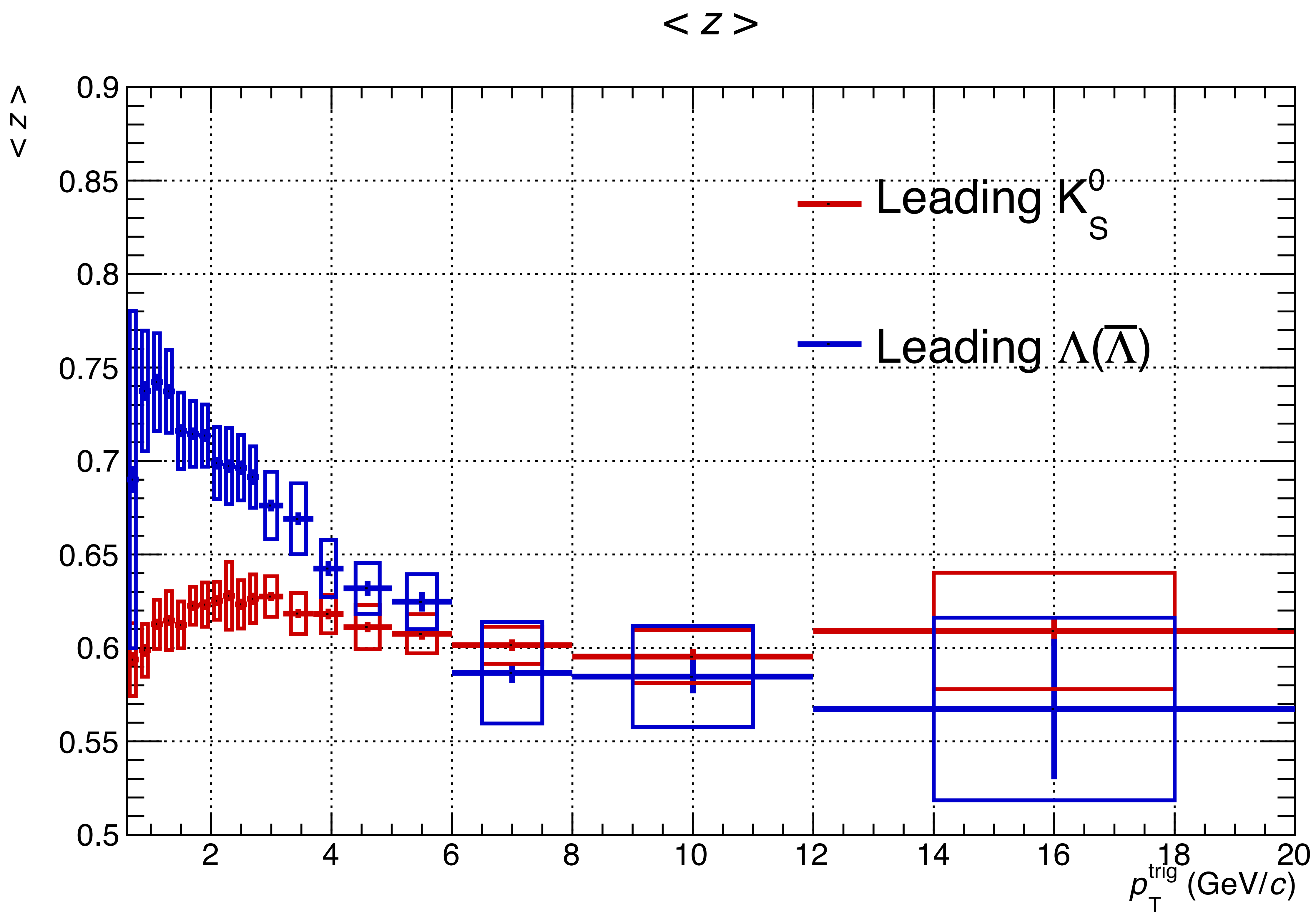


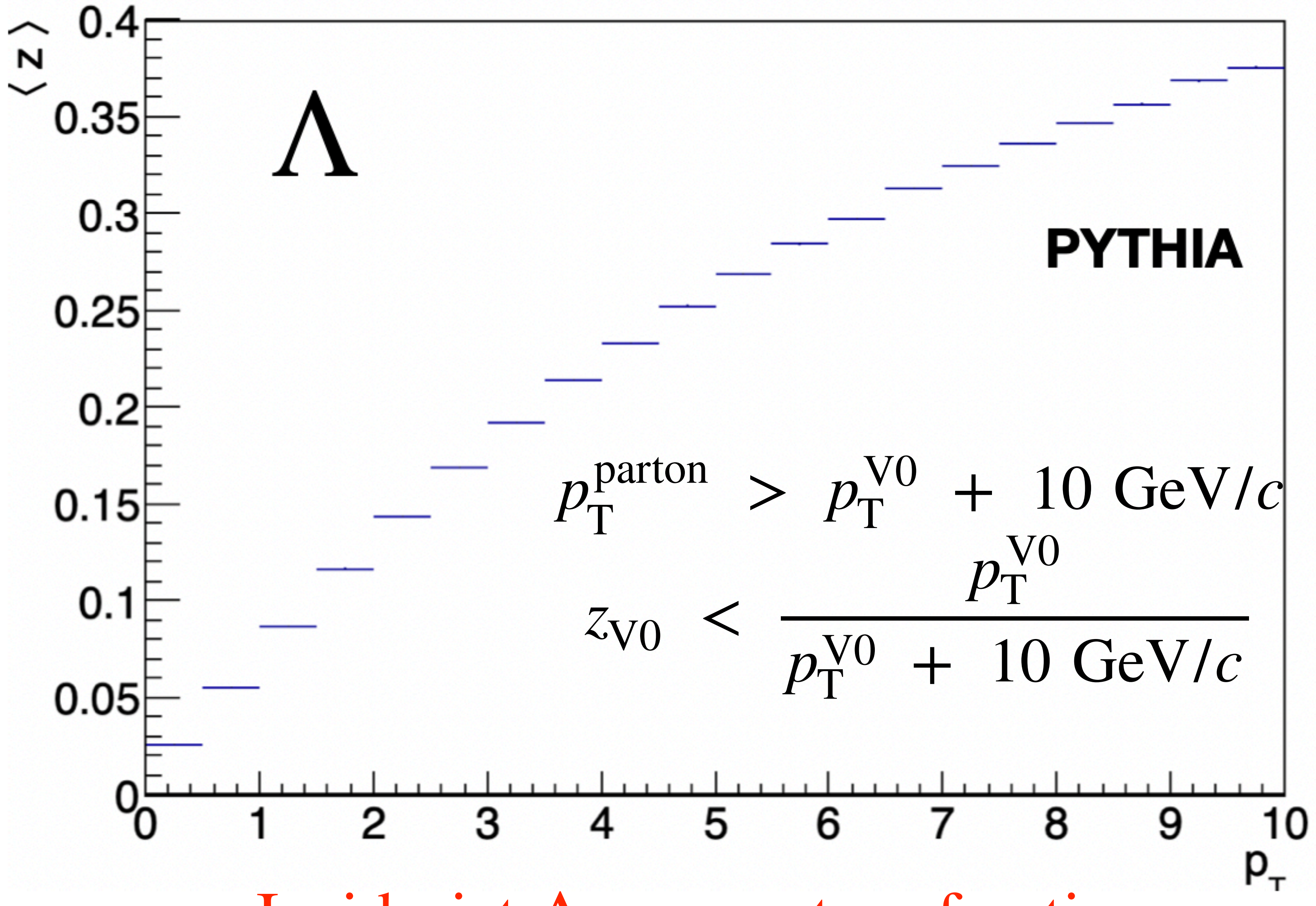

$$\sigma_{total} = \sqrt{\sum_i (\sigma_i^2)}$$

Systematic uncertainty details are in backup slides

# Results - <z>






Inside-jet Λ momentum fraction $z$
(Taken from A. Morsch' talk)

- When compare the in-jet and out-of-jet strange particles production, we are actually measuring particles with different <$z$>
- $\Lambda(\overline{\Lambda})$'s fragmentation is harder than $K^0_S$'s at low- and intermediate-$p_T$, the enhanced $\Lambda/K^0_S$ production ratio could be attributed to the difference of the fragmentation behaviors between two particle species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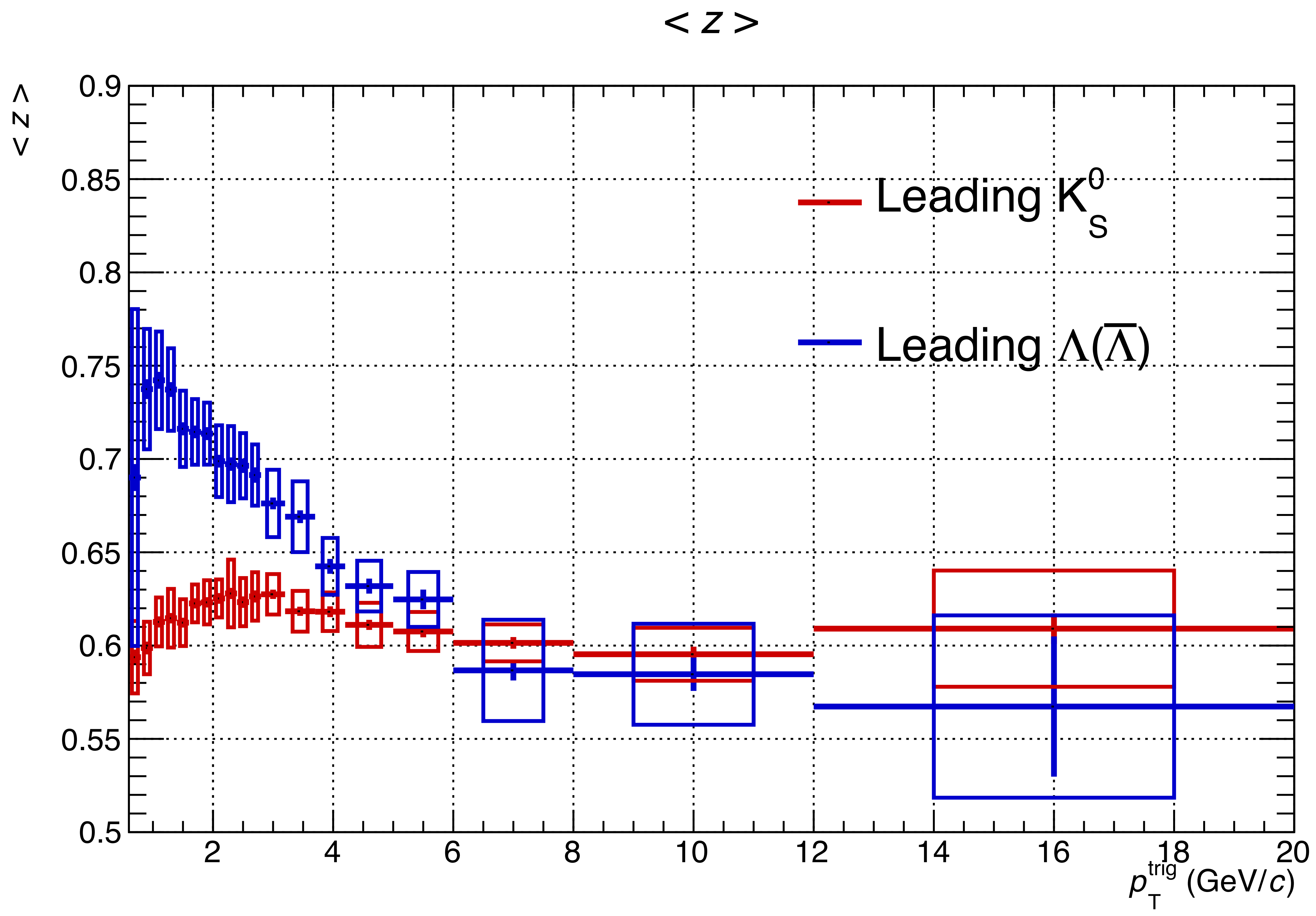
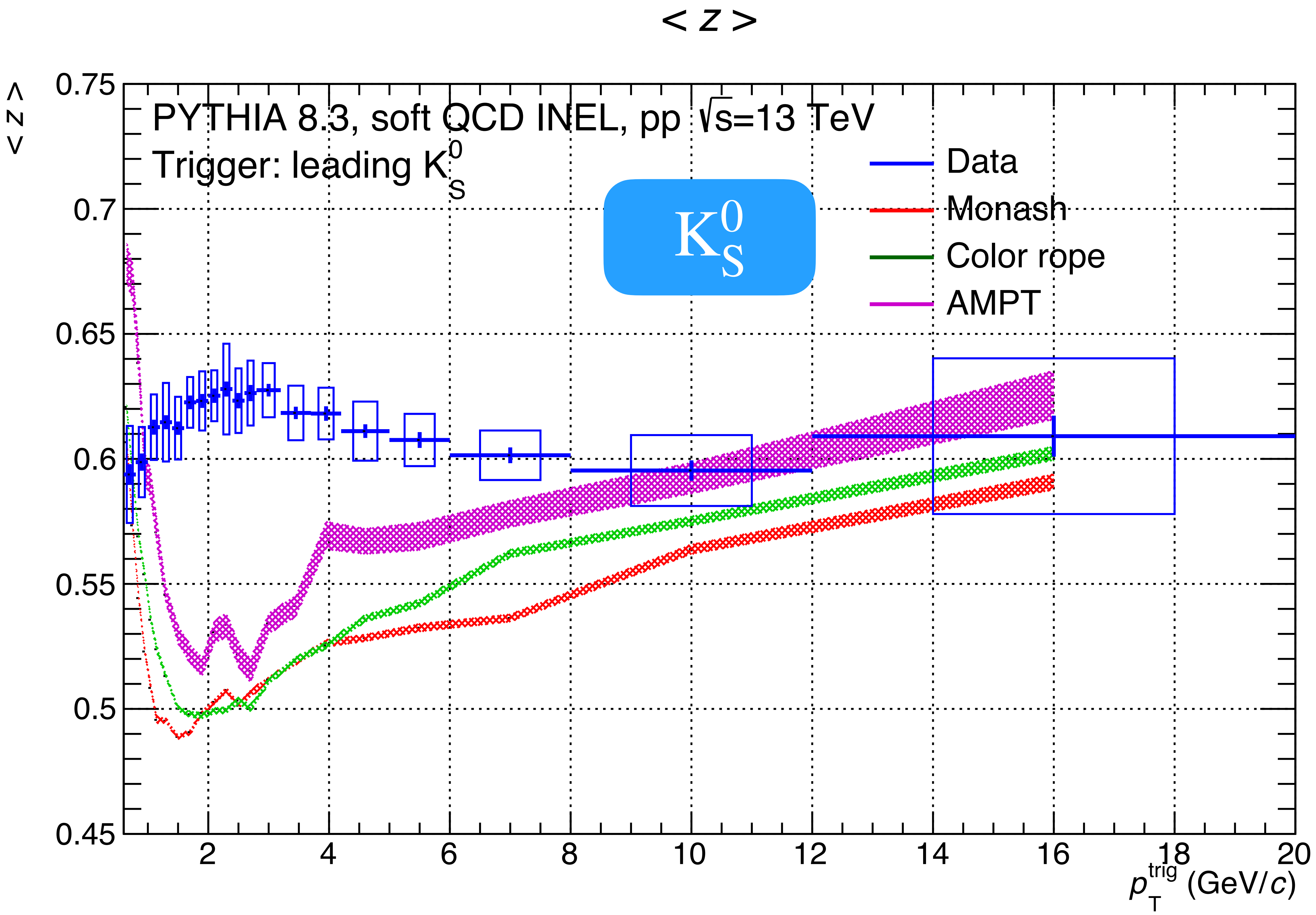
# Results - <z>

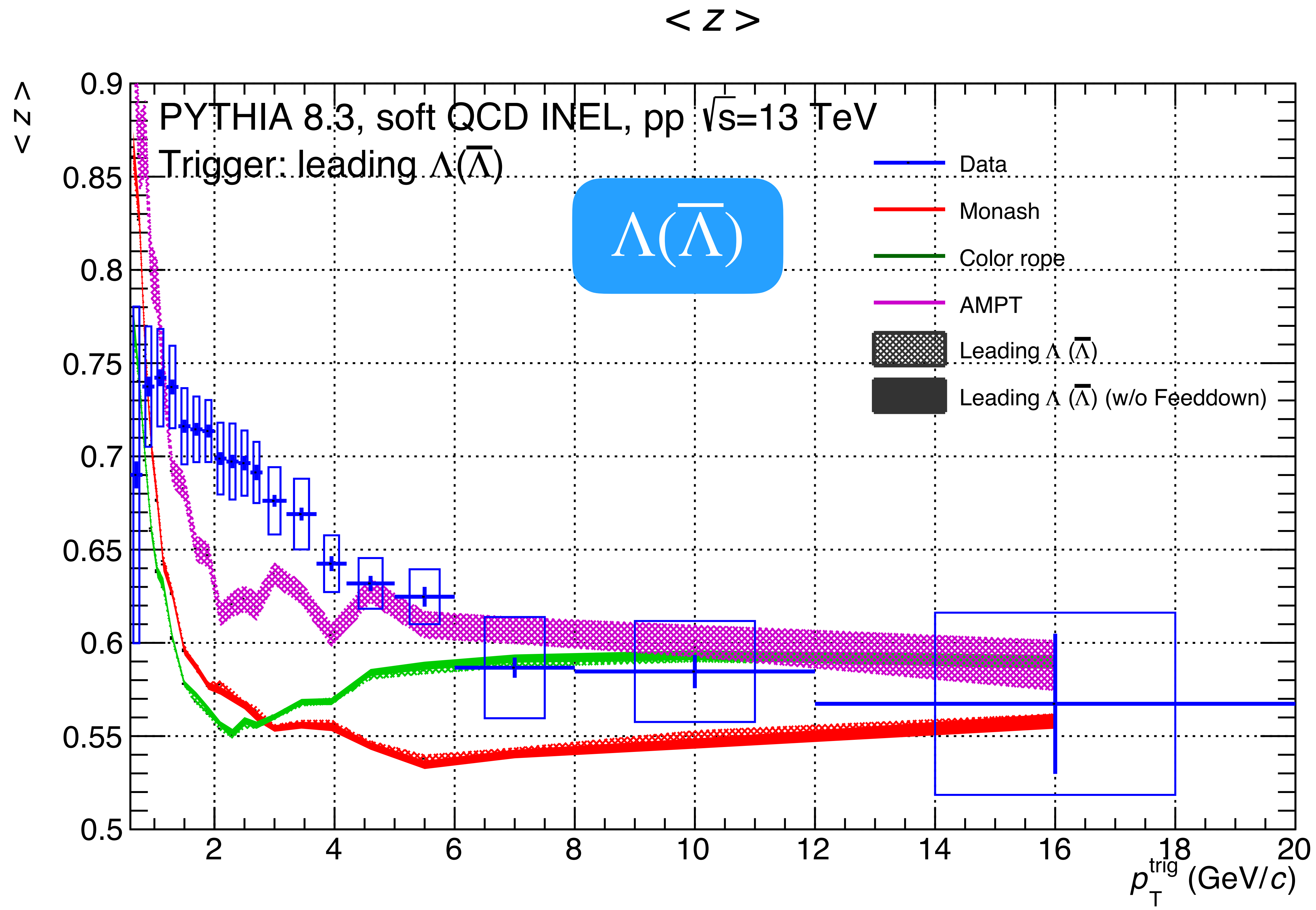



- Results suggests that the fragmentation of the strange particles is (relative) low energy partons with high <*z*> type
- <*z*> is nearly flat, indicating from low $p_T$ (the region usually assumed UE dominanted) to high $p_T$, the fragmentation properties do not change

# Results - <z> compared with predictions






- PYTHIA8 (fragmentation based hadronization) and AMPT (coalescence based hadronization) were studied
- Both PYTHIA8 (w/ and w/o color-reconnection implementations) and AMPT with string-melting implementation underestimate the data, especially at low- and intermediate-$p_T$
- This measurement provides novel constraints on the hadronization properties of strange hadrons as well as its Monte Carlo description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# Summary and paper proposal



**Summary:**

- First measurement of the leading strange particle's $p_{\mathrm{T}}$ fraction in mini-jets in pp collisions at $\sqrt{s}$ = 13 TeV using the novel correlation approach
- The fragmentation properties of strange baryon and strange meson are different, and the properties appear to be independent of hadron's $p_{\mathrm{T}}$
- Both PYTHIA8 (fragmentation) and AMPT (coalescence) with string-melting implementation underestimate the data, especially at low- and intermediate-$p_{\mathrm{T}}$, this measurement provides new constraints on the hadronization of strange particles and its Monte Carlo description

Thank you!

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# Backup



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# Systematic uncertainty details


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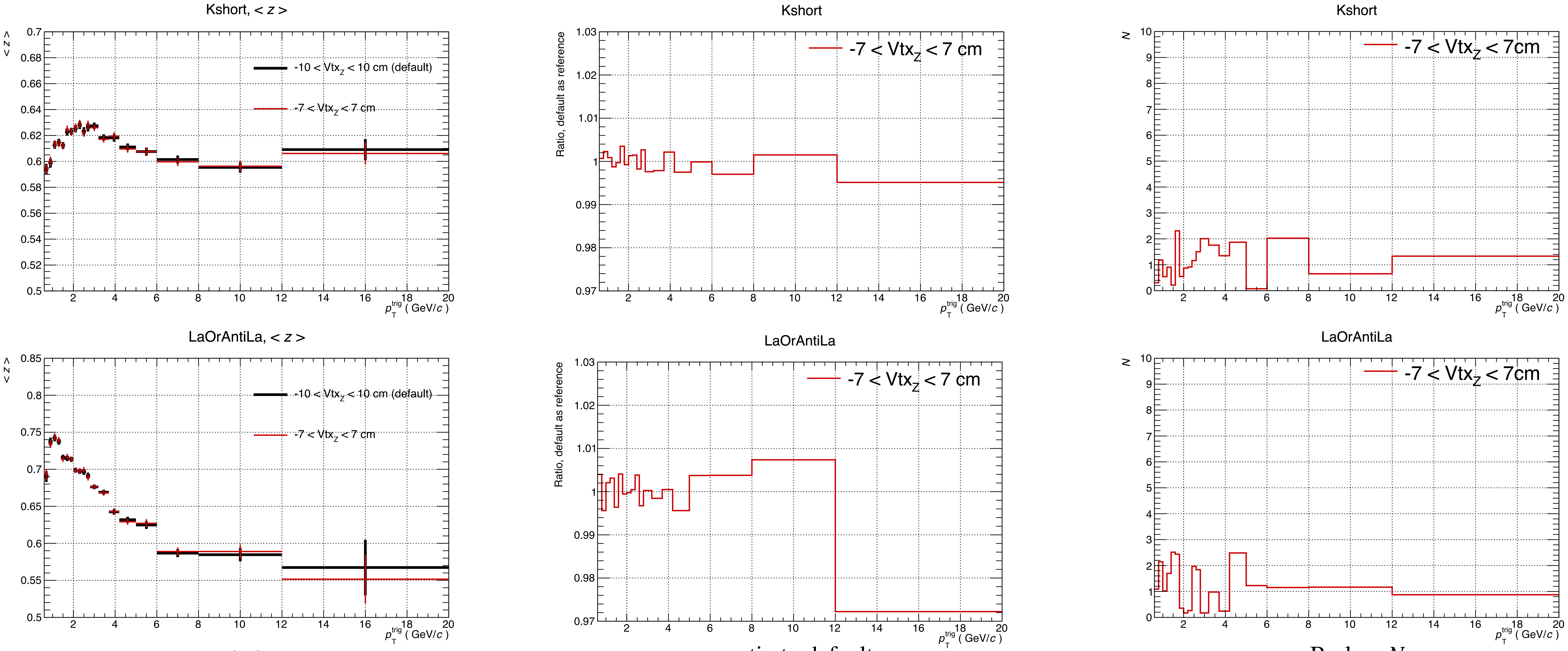
# Uncertainty - event vertex acceptance region

- Selections on vertex $z$ position:
  1. $-10 < Vtx_z < 10$ cm (**default**)
  2. $-7 < Vtx_z < 7$ cm

$K^0_S$

$\Lambda(\bar{\Lambda})$




$< z >$ ratio to default Barlow $N$

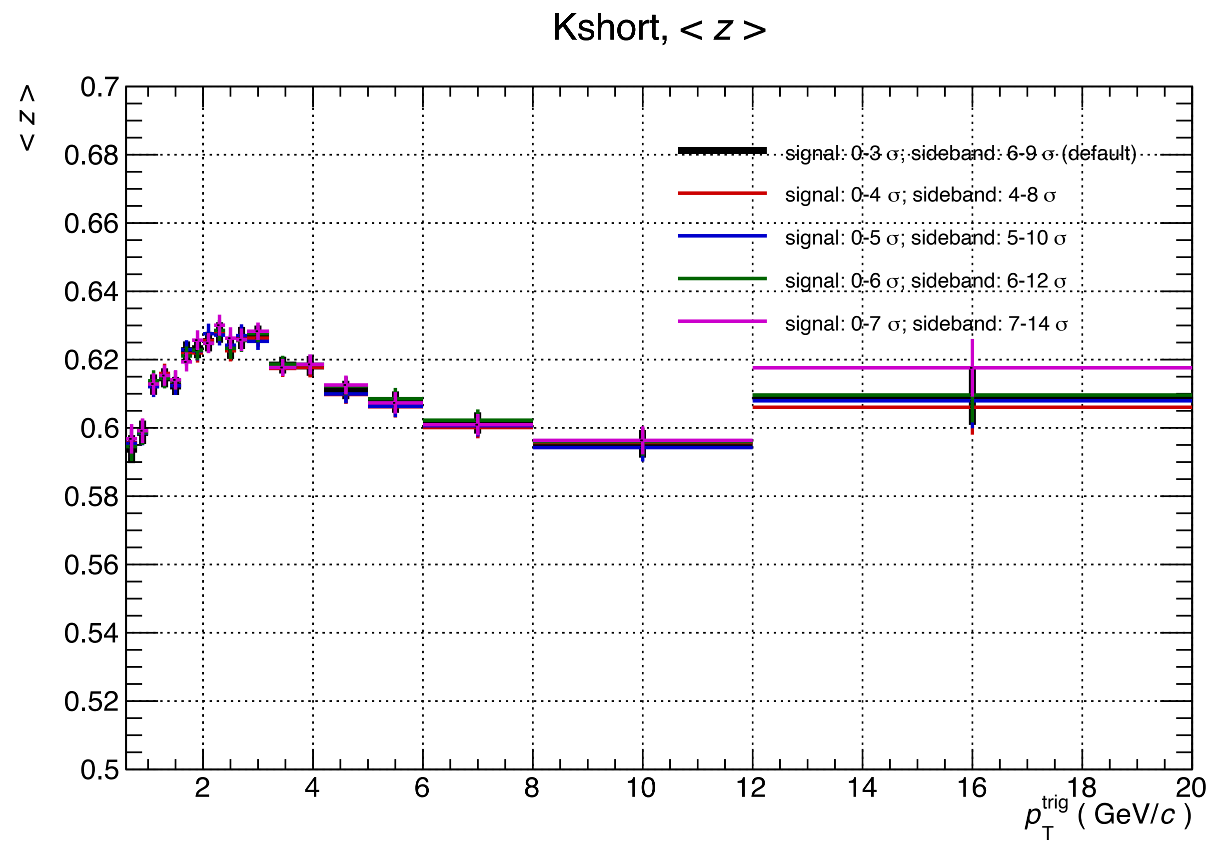
- For most $p_{\mathrm{T,\,trig}}$ intervals, Barlow $N < 2$, and $N < 2.5$ for all intervals
  ➡ Not take this source

# Uncertainty - signal extraction

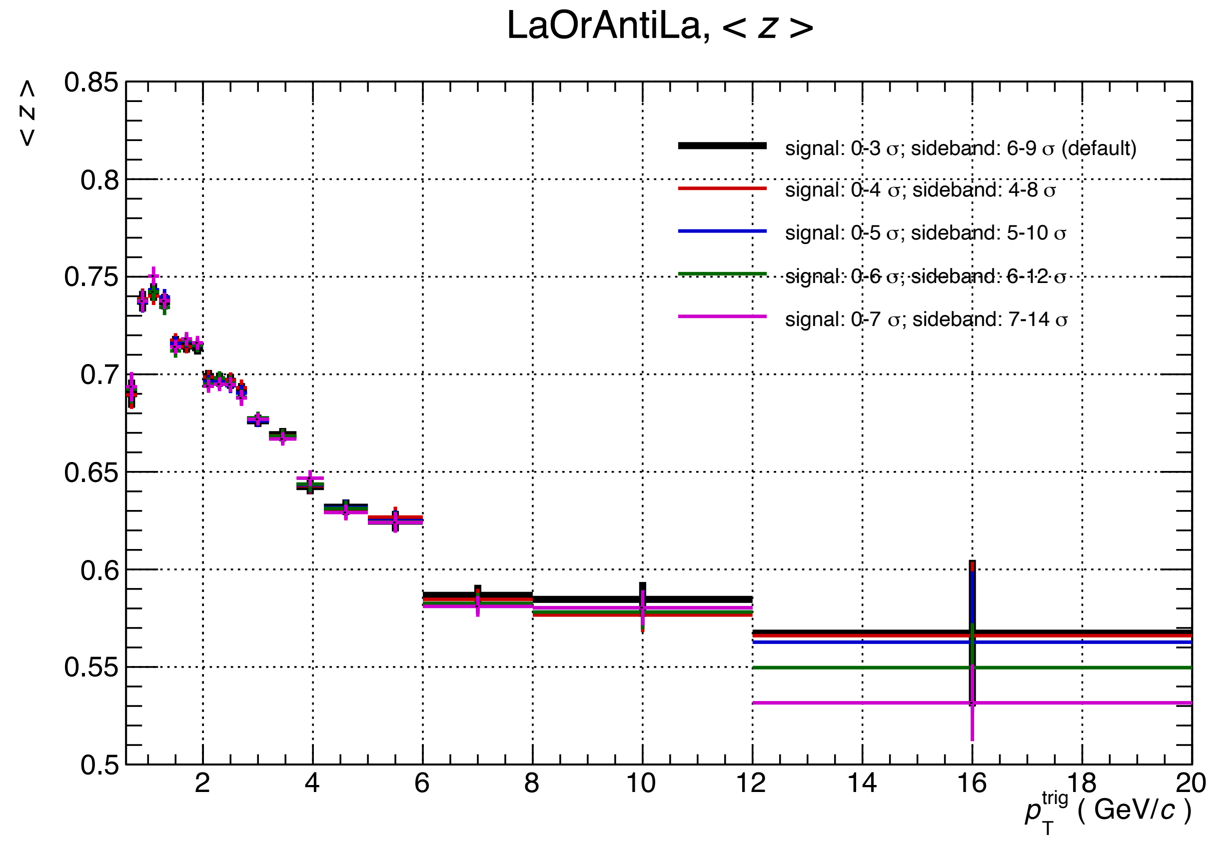
- Selection on signal and side band regions:

| # of sigma from mean value | | |
|---|---|---|
| | signal | side band |
| 1(**default**) | 0-3 | 6-9 |
| 2 | 0-4 | 4-8 |
| 3 | 0-5 | 5-10 |
| 4 | 0-6 | 6-12 |
| 5 | 0-7 | 7-14 |

$K^0_S$




$\Lambda(\overline{\Lambda})$




$< z >$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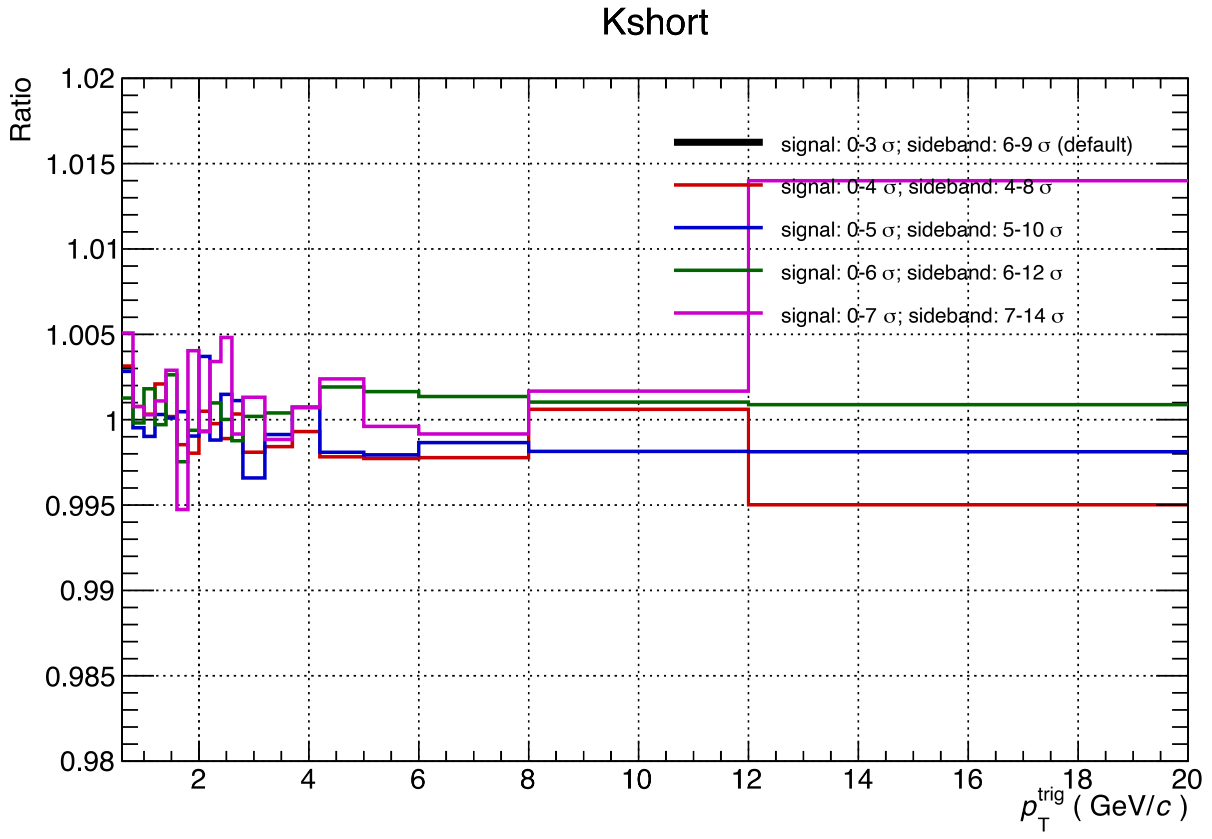
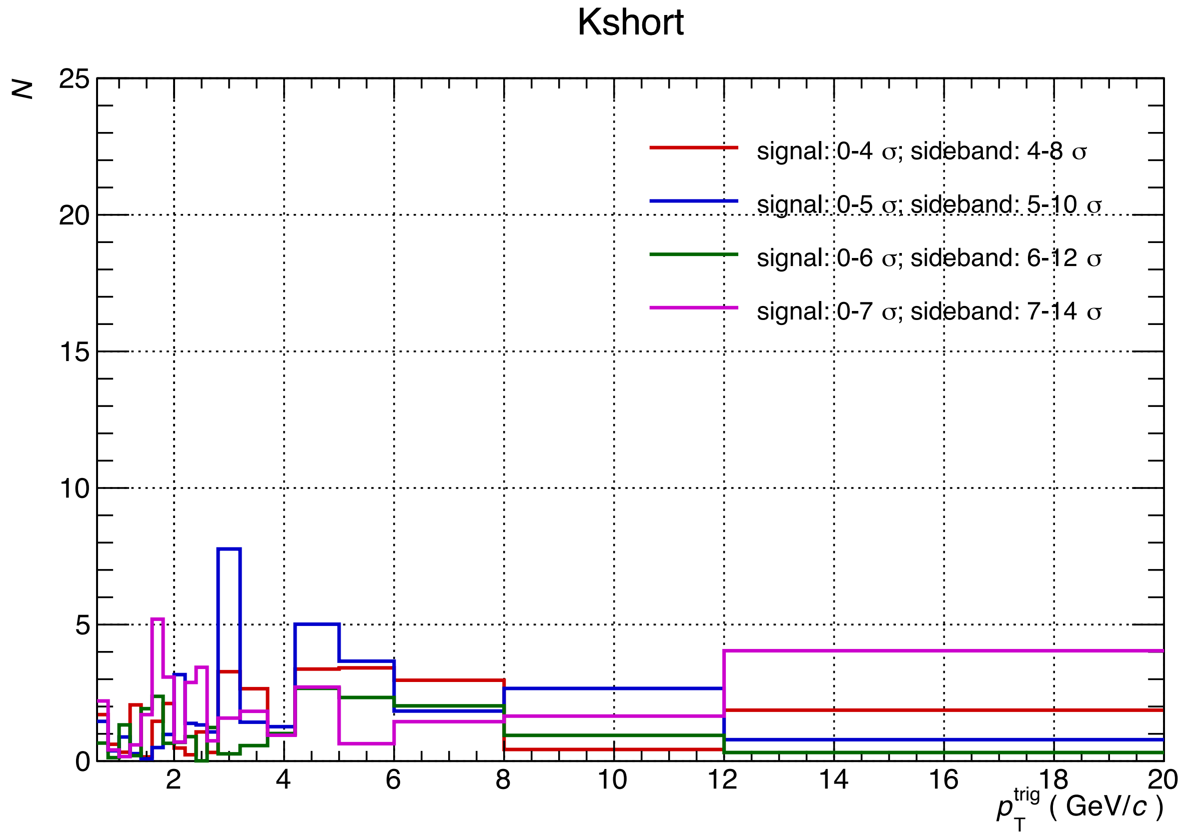
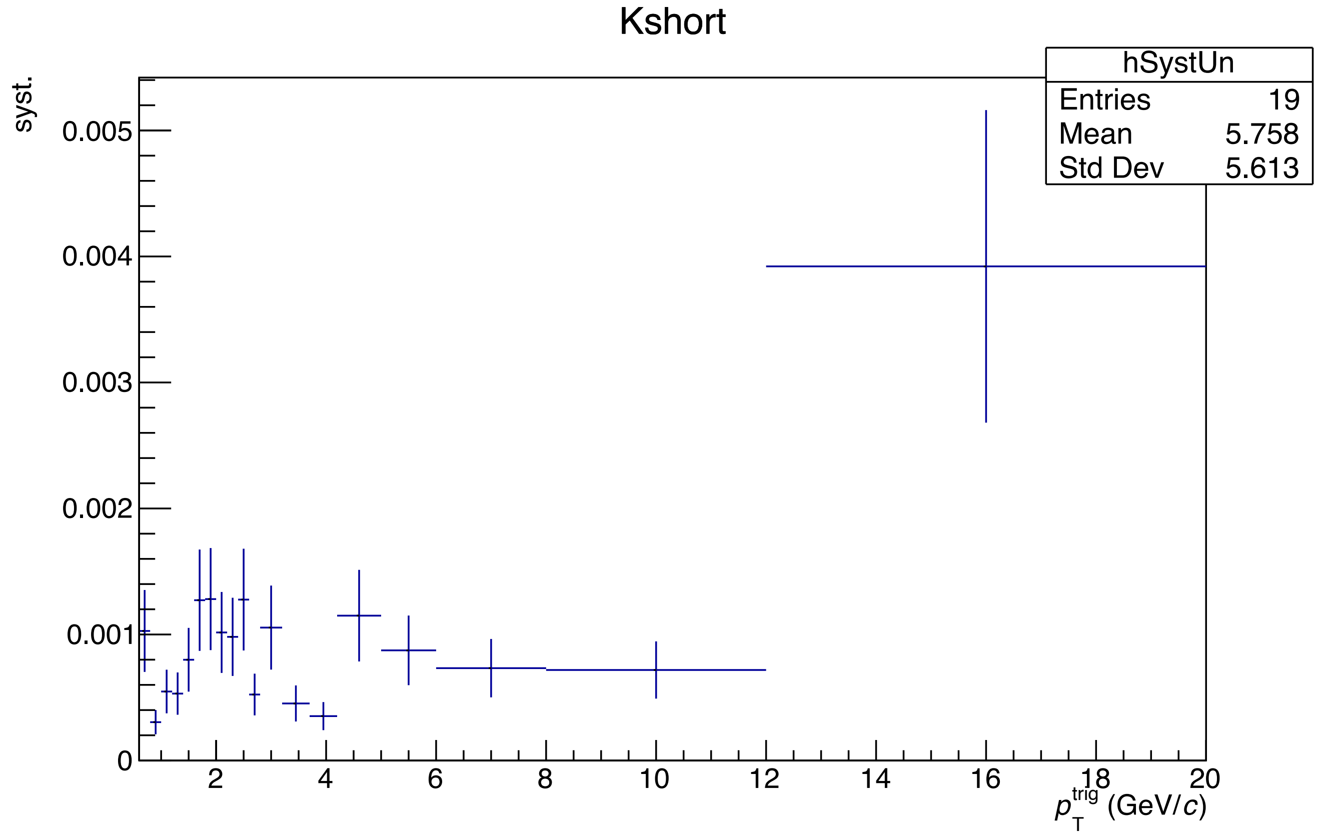
# Uncertainty - signal extraction

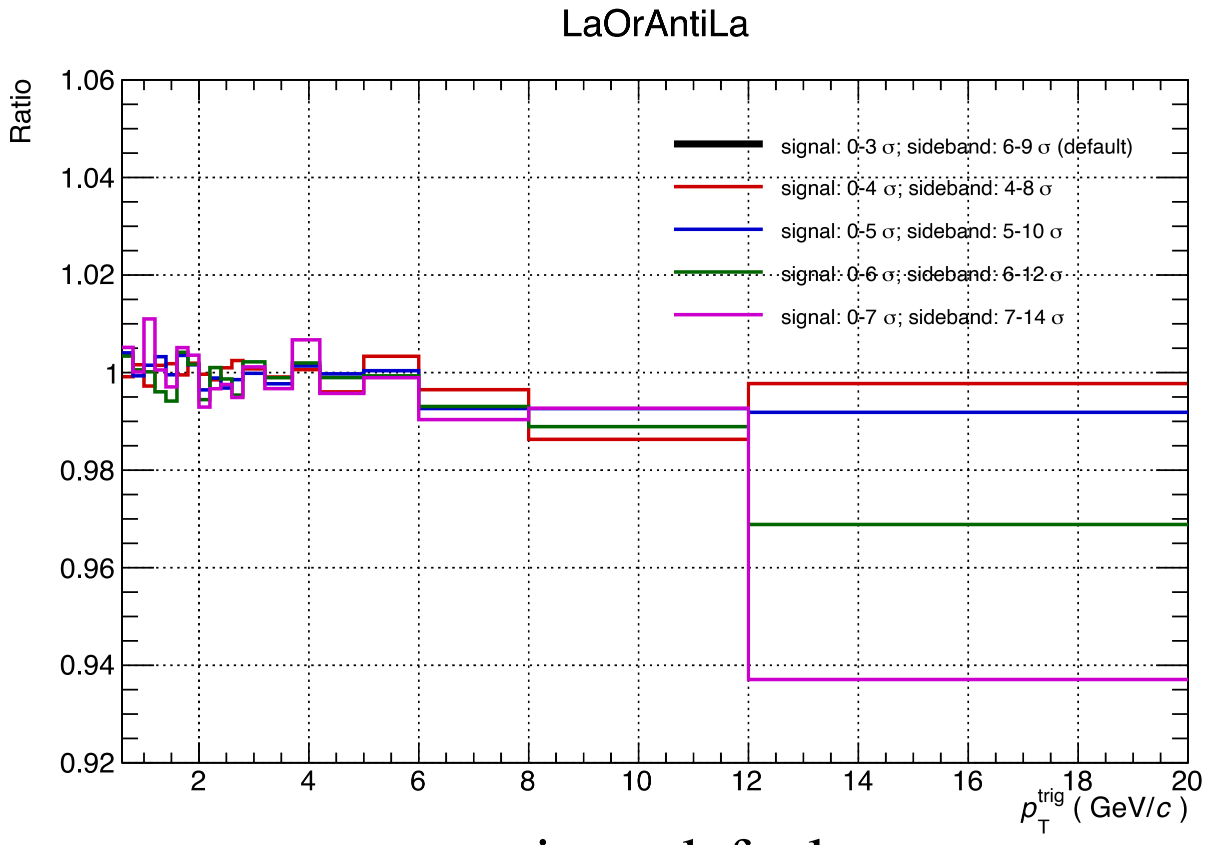
$K_S^0$

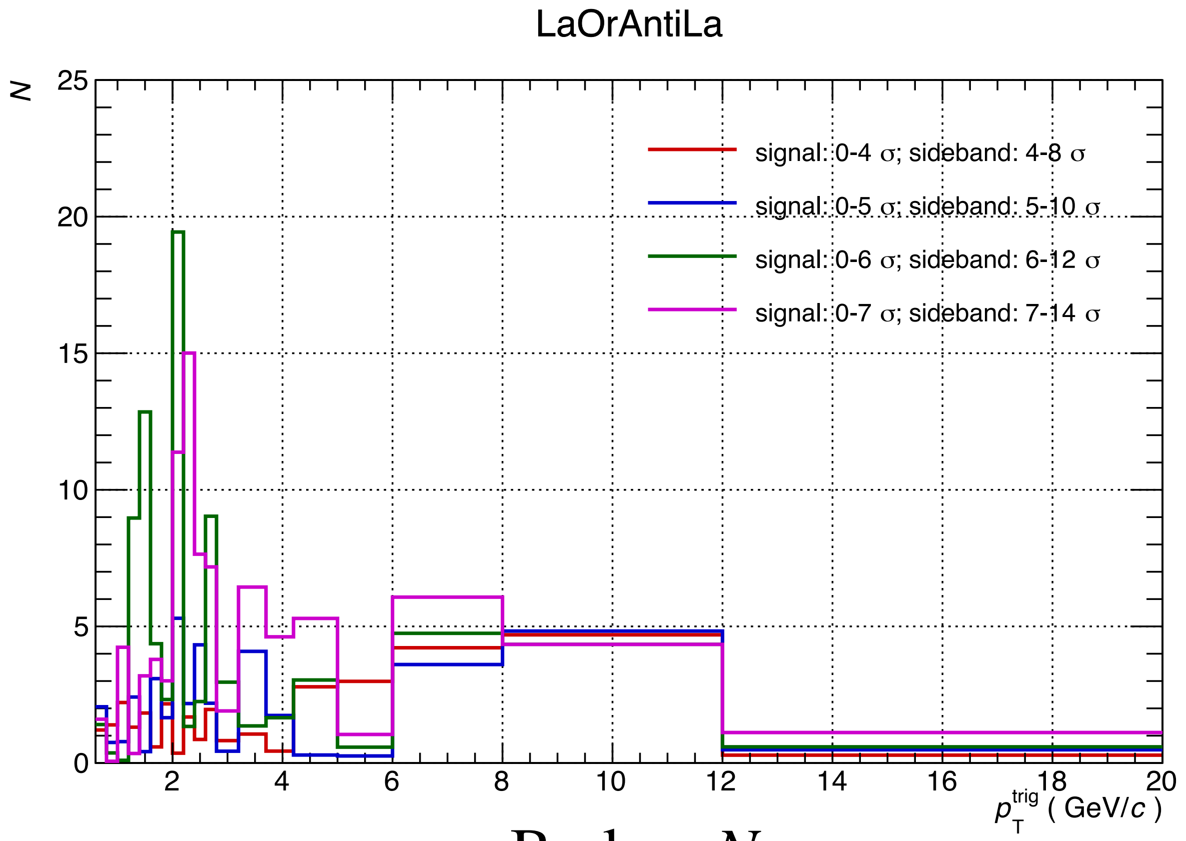


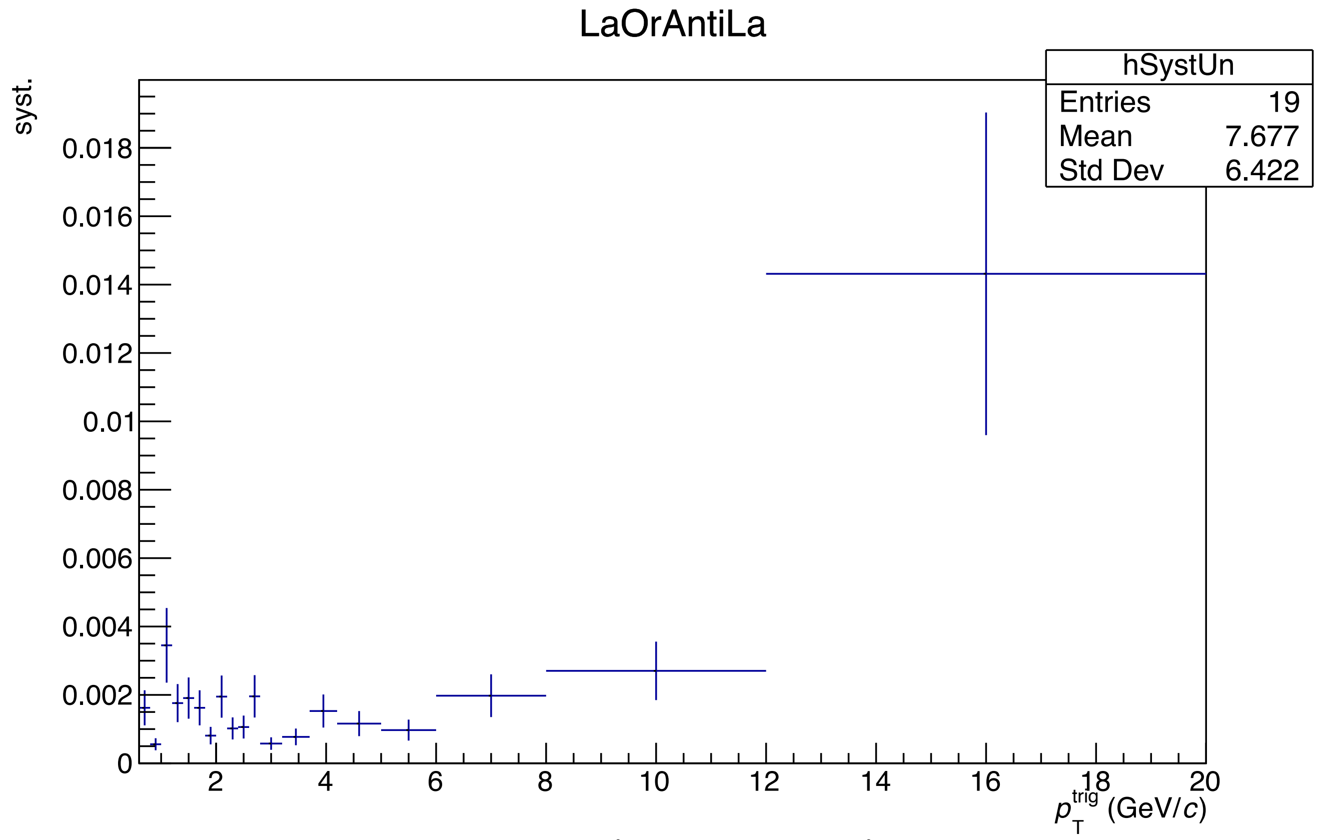




$\Lambda(\overline{\Lambda})$



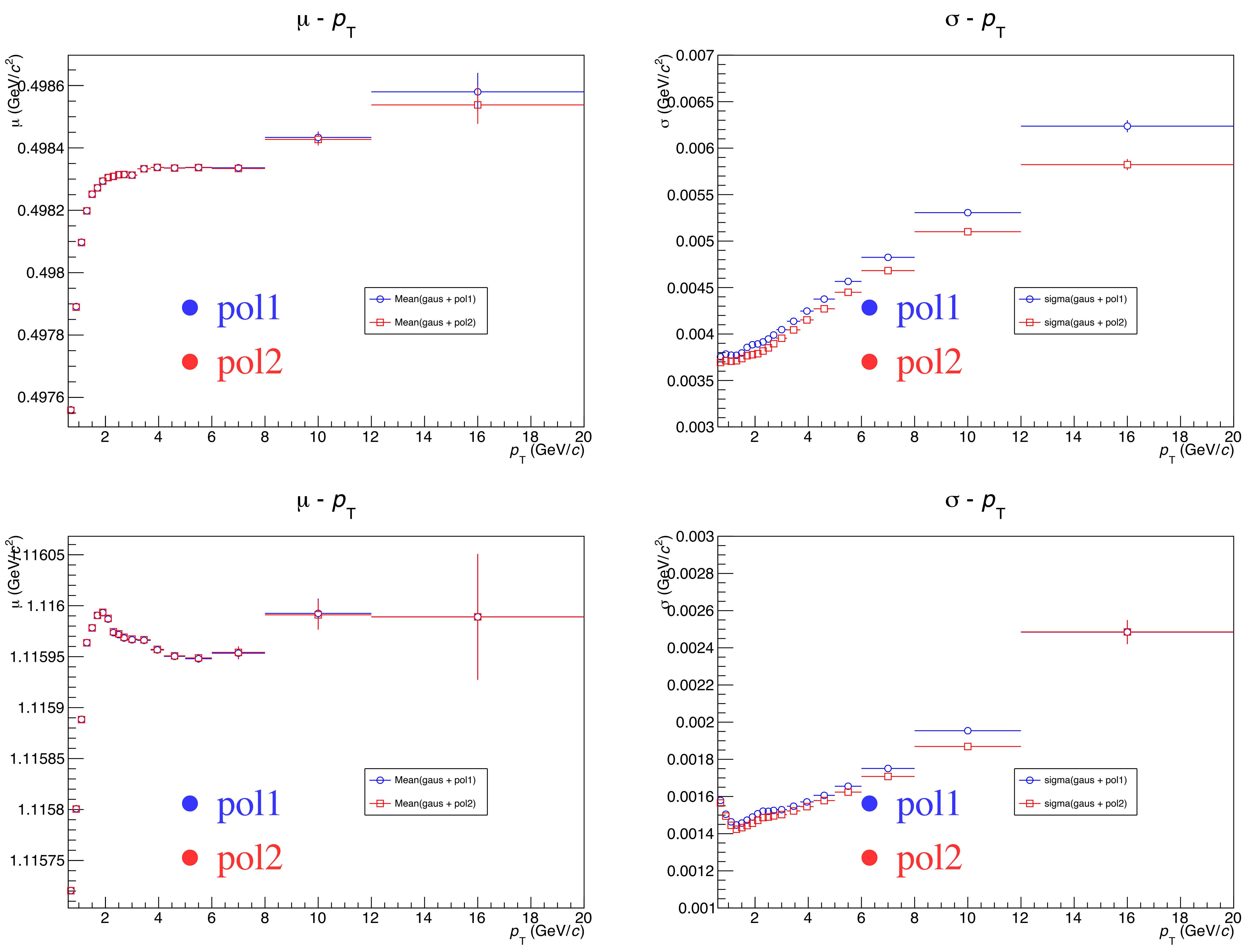

ratio to default — Barlow $N$ — systematic uncertainty

- For this source, the systematic uncertainty is assigned as the RMS (standard deviation) of the $< z >$ results for each $p_{\mathrm{T,\,trig}}$ intervals as shown in the right plot

# Uncertainty - Inv.M fit function

- Change the background fit function when fit the Inv.M:
  1. pol1 (**default**)
  2. pol2

- Mean ($\mu$) is almost not changing
- Resulted width varied at the order of $1\sigma$
  - ➡ End up with changing the signal and side band region
- Proposal: not take this source into account




$K^0_S$

$\Lambda(\overline{\Lambda})$

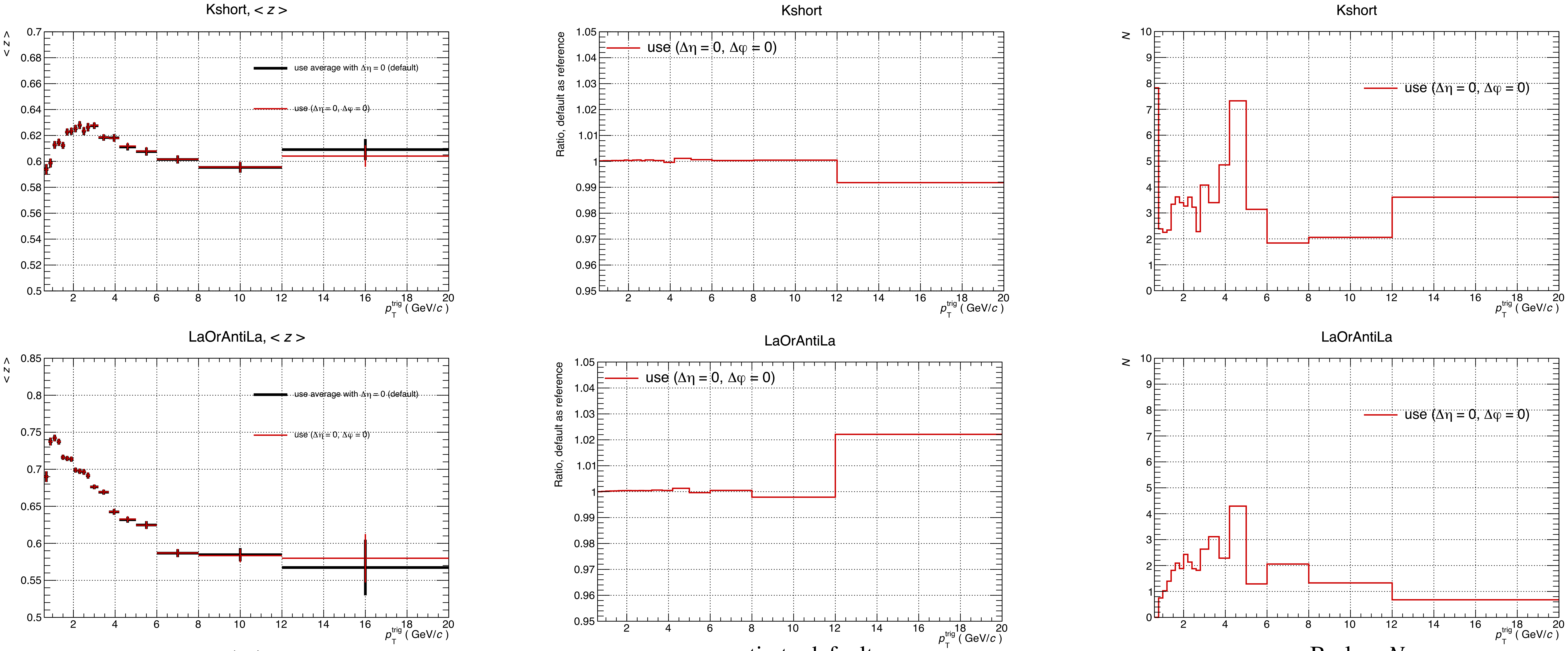
Mean ($\mu$, left) and sigma ($\sigma$, right) as a function of $p_{T,\,trig}$
The upper plots are for leading $K^0_S$, and the bottom plots are for leading $\Lambda(\overline{\Lambda})$

# Uncertainty - mix event normalization

- Mix correlation function normalization:
  1. Use the average with $\Delta\eta = 0$ (**default**)
  2. Use the value of $(\Delta\eta = 0, \Delta\varphi = 0)$

$K^0_S$

$\Lambda(\overline{\Lambda})$




$< z >$ ratio to default Barlow $N$

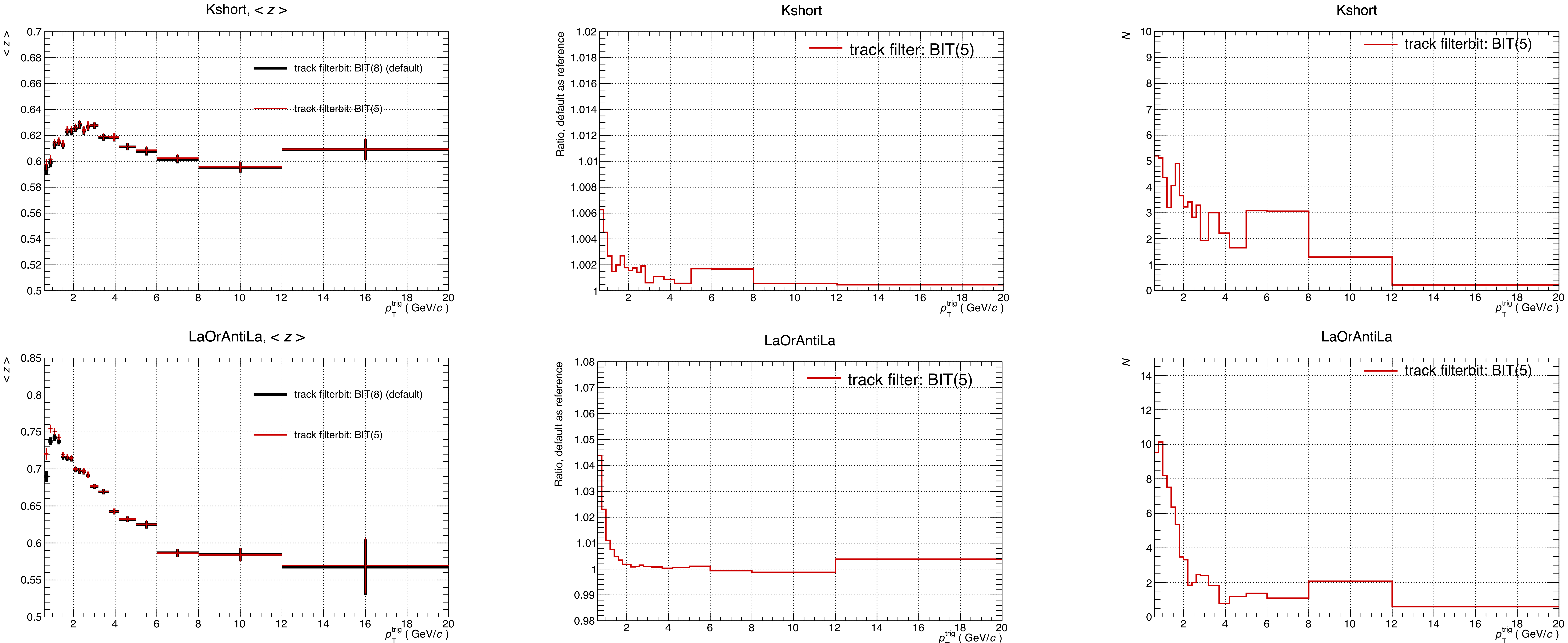
- For this source, the systematic uncertainty is assigned as the relative uncertainty

# Uncertainty - filterbit for primary tracks

- Filterbit for associates:
  1. BIT(8) (**default**) (global hybrids with $|DCA_{xy}| < 2.4$ cm and $|DCA_z| < 3.2$ cm)
  2. BIT(5) (tracks with standard cuts with tight DCA cut, $|DCA_z| < 2$ cm)

$K^0_S$

$\Lambda(\overline{\Lambda})$




$< z >$     ratio to default     Barlow $N$

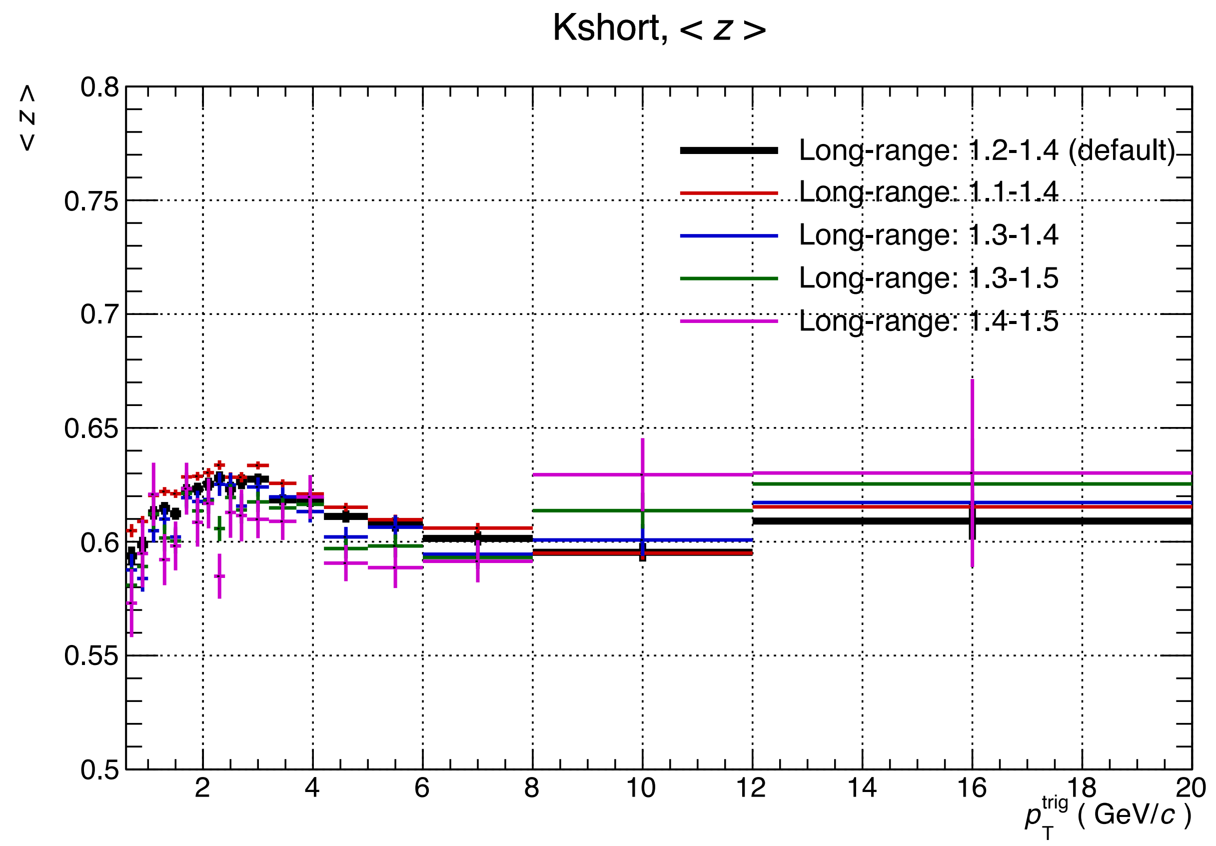
- For this source, the systematic uncertainty is assigned as the relative uncertainty

# Uncertainty - jet region and out-of-jet region

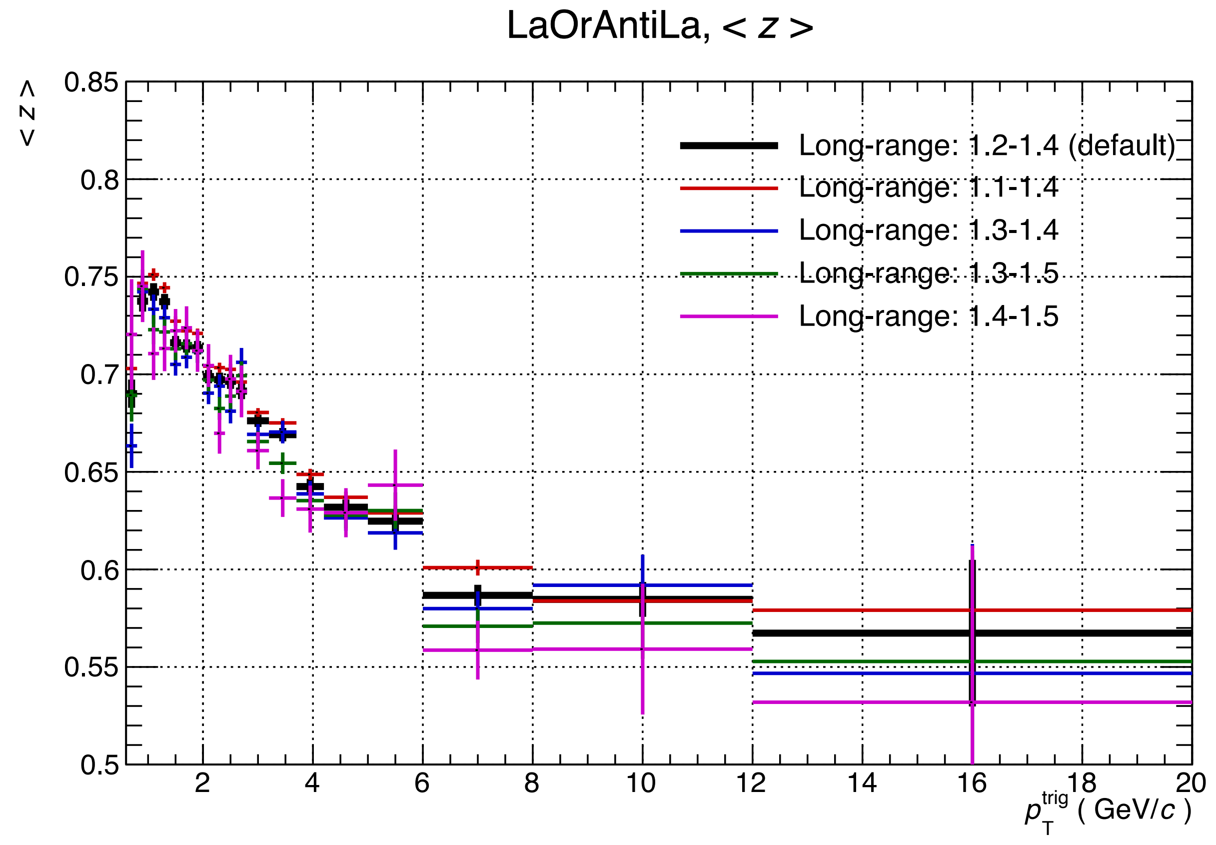
- Definition of jet and out-of-jet regions:

| | jet region ( short range) | out-of-jet region ( long range) |
|---|---|---|
| 1(**default**) | $\|\Delta\eta\| < 1.2$ | $1.2 < \|\Delta\eta\| < 1.4$ |
| 2 | $\|\Delta\eta\| < 1.1$ | $1.1 < \|\Delta\eta\| < 1.4$ |
| 3 | $\|\Delta\eta\| < 1.3$ | $1.3 < \|\Delta\eta\| < 1.4$ |
| 4 | $\|\Delta\eta\| < 1.3$ | $1.3 < \|\Delta\eta\| < 1.5$ |
| 5 | $\|\Delta\eta\| < 1.4$ | $1.4 < \|\Delta\eta\| < 1.5$ |

$K^0_S$




$\Lambda(\overline{\Lambda})$

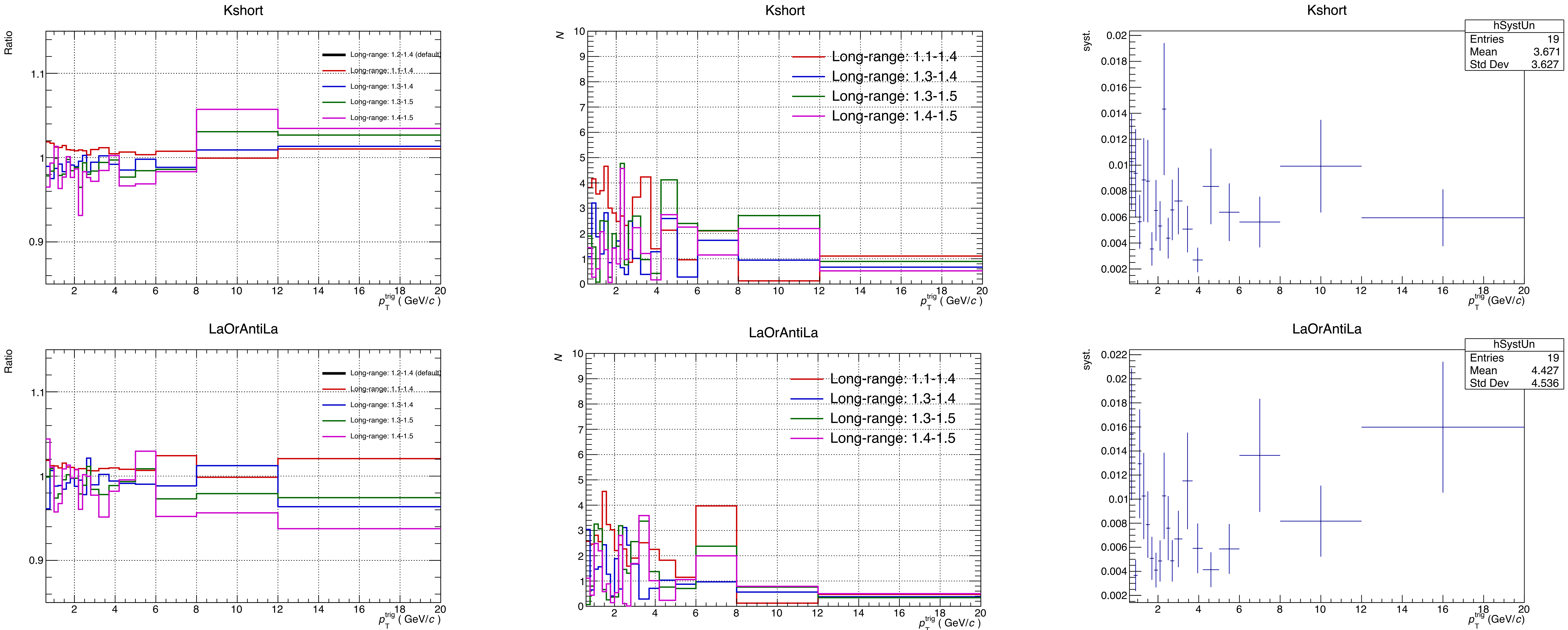



$< z >$

# Uncertainty - jet region and out-of-jet region

$K_S^0$

$\Lambda(\overline{\Lambda})$




ratio to default — Barlow $N$ — systematic uncertainty

- For this source, the systematic uncertainty is assigned as the RMS (standard deviation) of the $< z >$ results for each $p_{T,\,trig}$ intervals as shown in the right plot

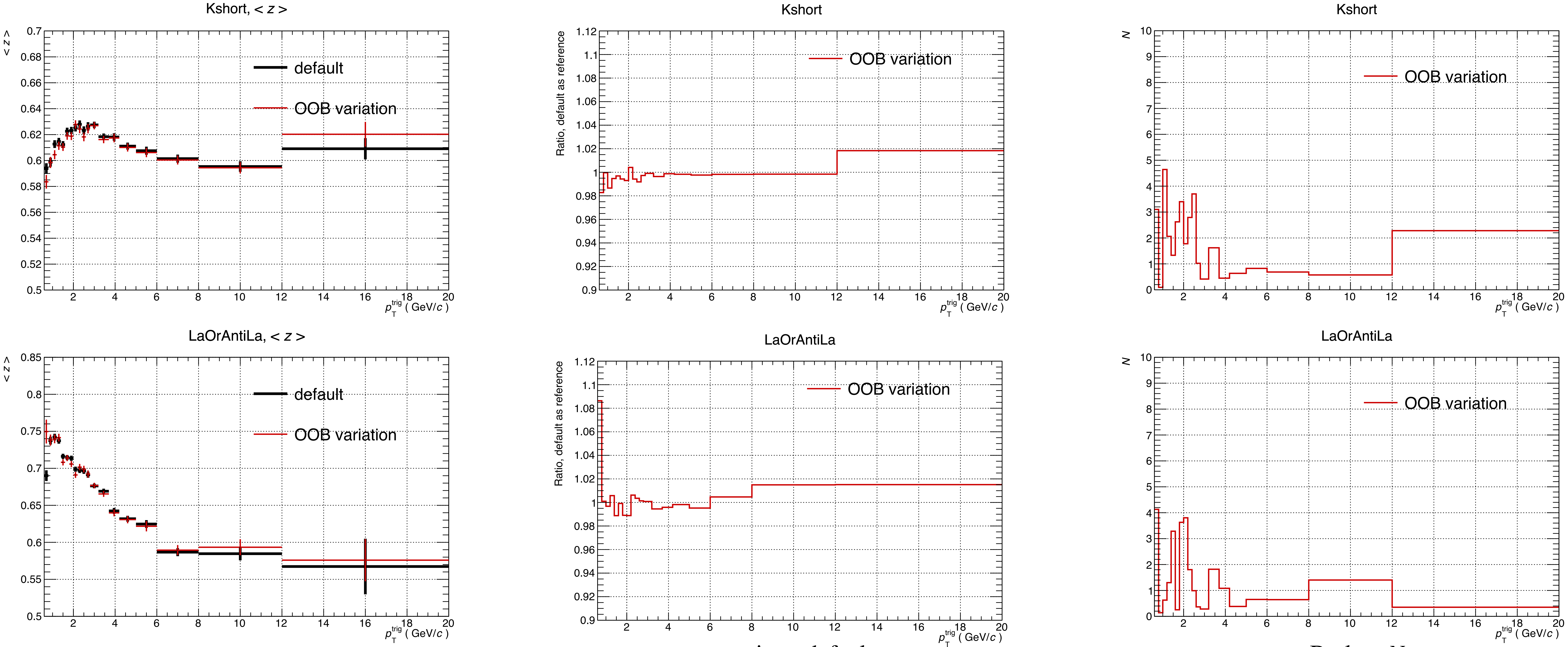
# Uncertainty - OOB PU



- OOB pileup cut for the $V^0$:
    1. (At least) one of $V^0$'s decay tracks should have ITSrefit flag (**default**)
    2. (At least) one of $V^0$'s decay tracks should have ITSrefit flag and its bunch-crossing ID in TOF connected to this track is 0

$K^0_S$

$\Lambda(\bar{\Lambda})$

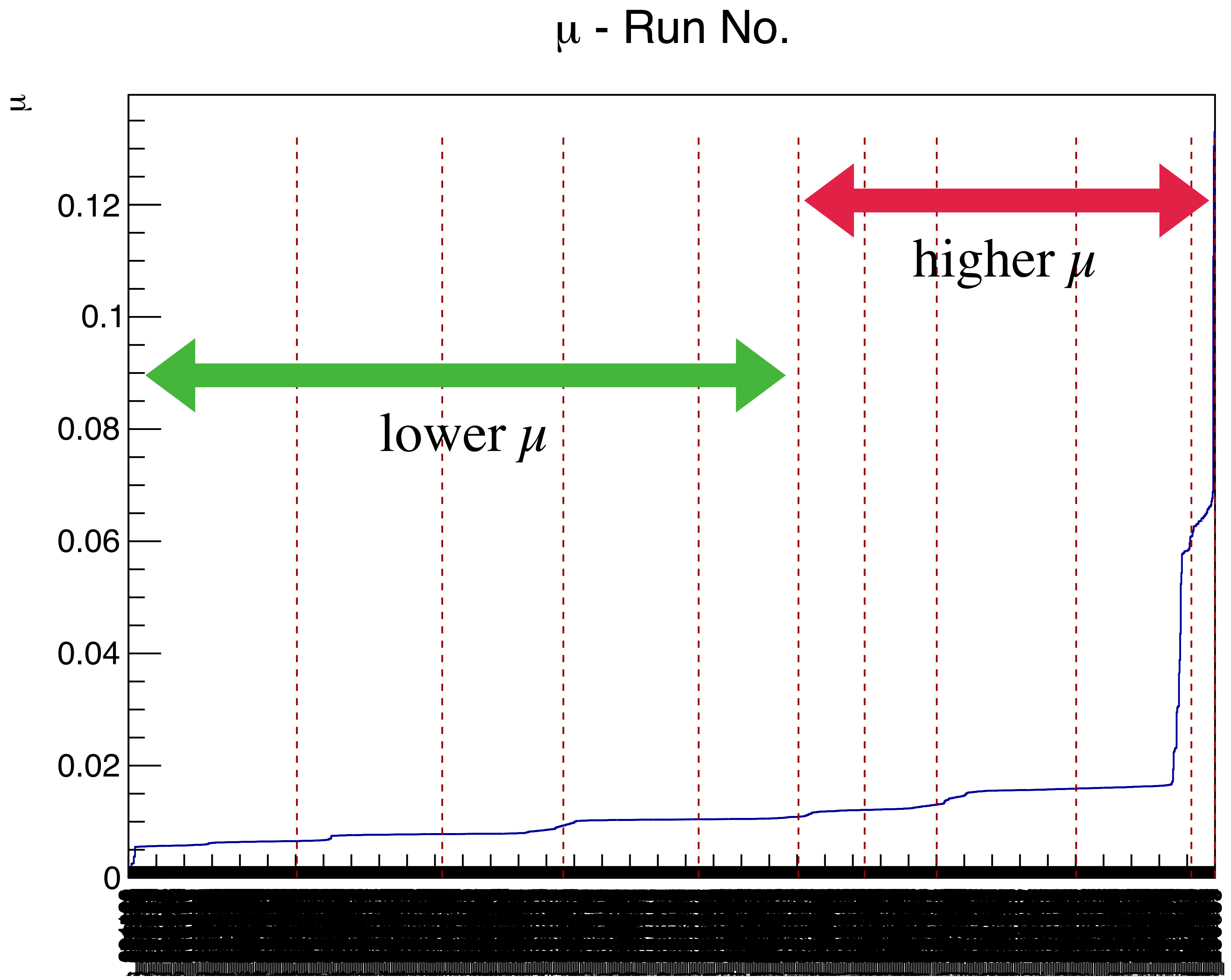



$< z >$ ratio to default Barlow $N$

- For this source, the systematic uncertainty is assigned as the relative uncertainty

# Uncertainty - IB PU

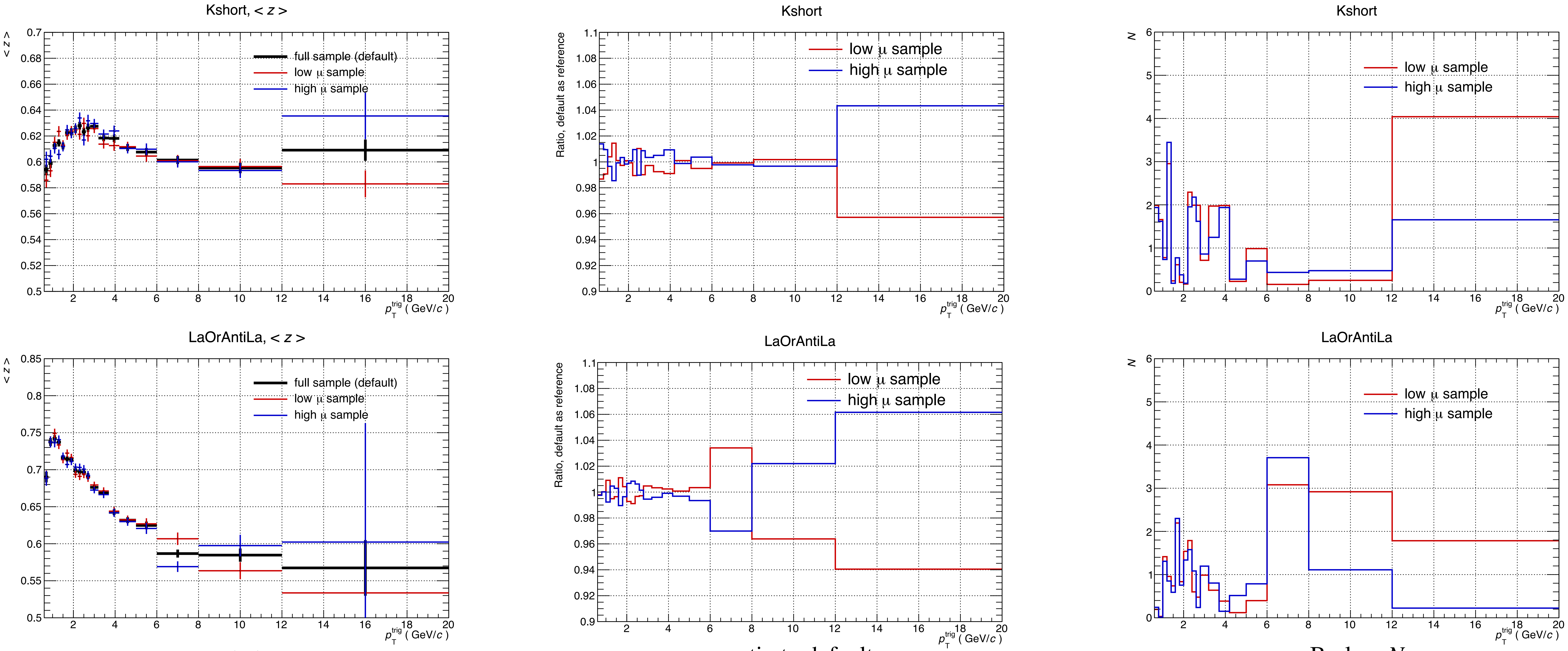
- The full sample is splited to two parts with equal # of selected events, one consists of lower $\mu$ value and the other one consists of higher $\mu$ value



# Uncertainty - IB PU

$K^0_S$

$\Lambda(\overline{\Lambda})$




$< z >$ | ratio to default | Barlow $N$

- For this source, the systematic uncertainty is assigned as the larger relative uncertainty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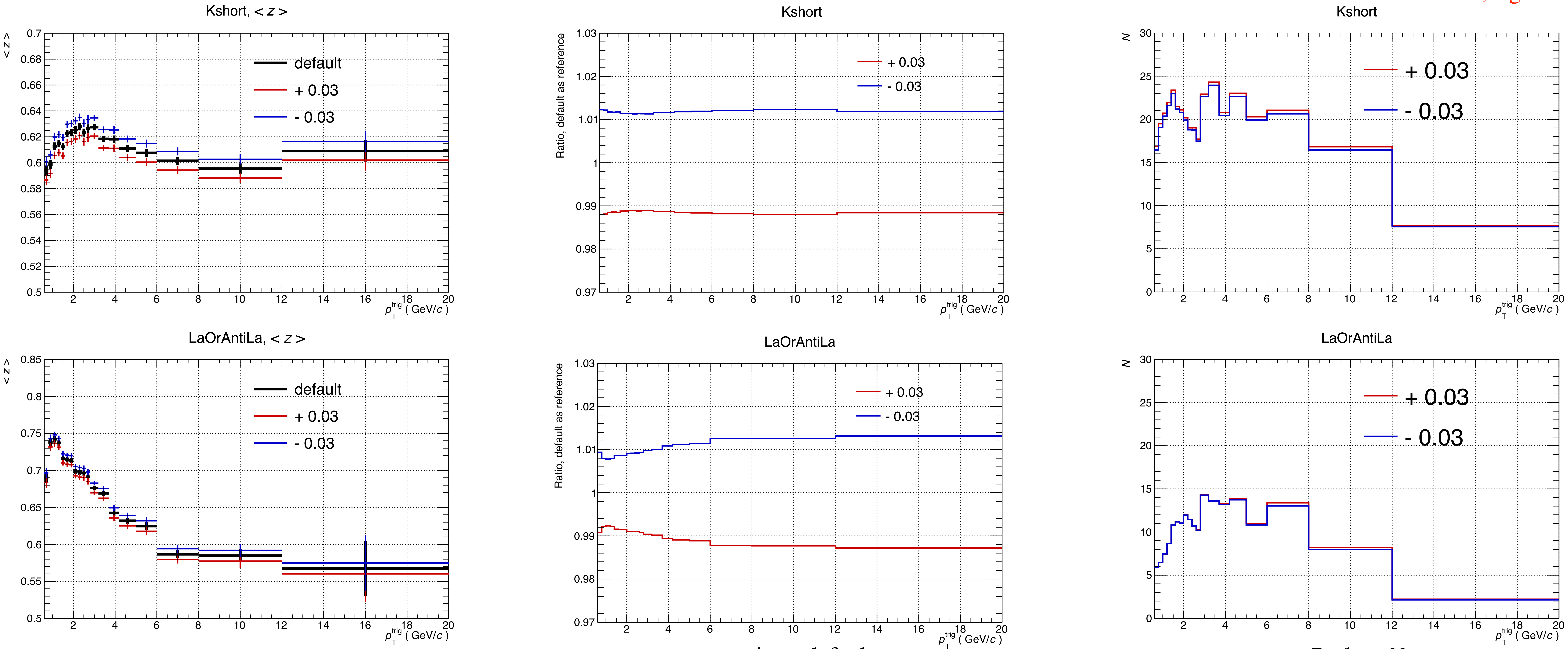
# Uncertainty - material budget

- Material budget affects on tracking efficiency and then propagates to the sum of $p_{\mathrm{T,\,assoc}}$
    1. Shift up/down the sum of $p_{\mathrm{T,\,assoc}}$ by 3%

$$z = \frac{p_{\mathrm{T,trig}}}{p_{\mathrm{T,trig}} + \sum p_{\mathrm{T,assoc}}}$$

$K^0_S$

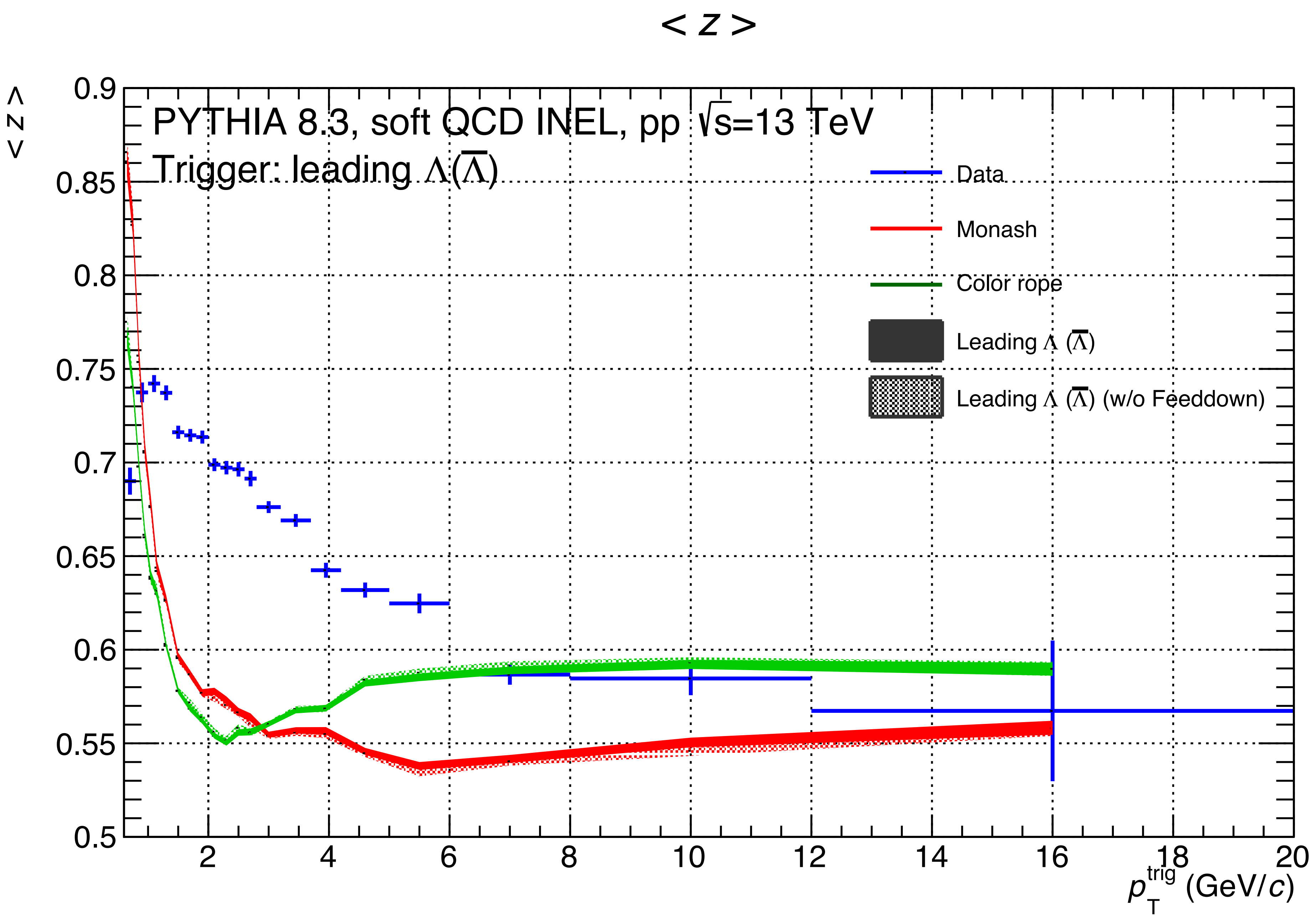
$\Lambda(\overline{\Lambda})$

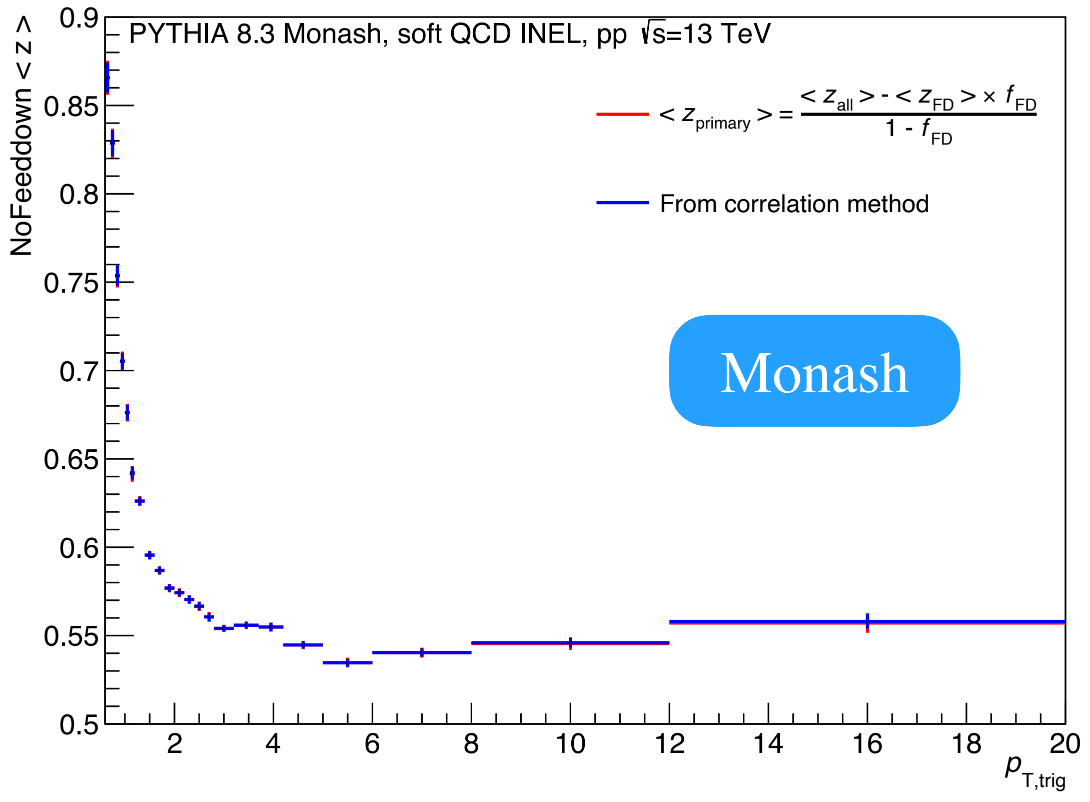


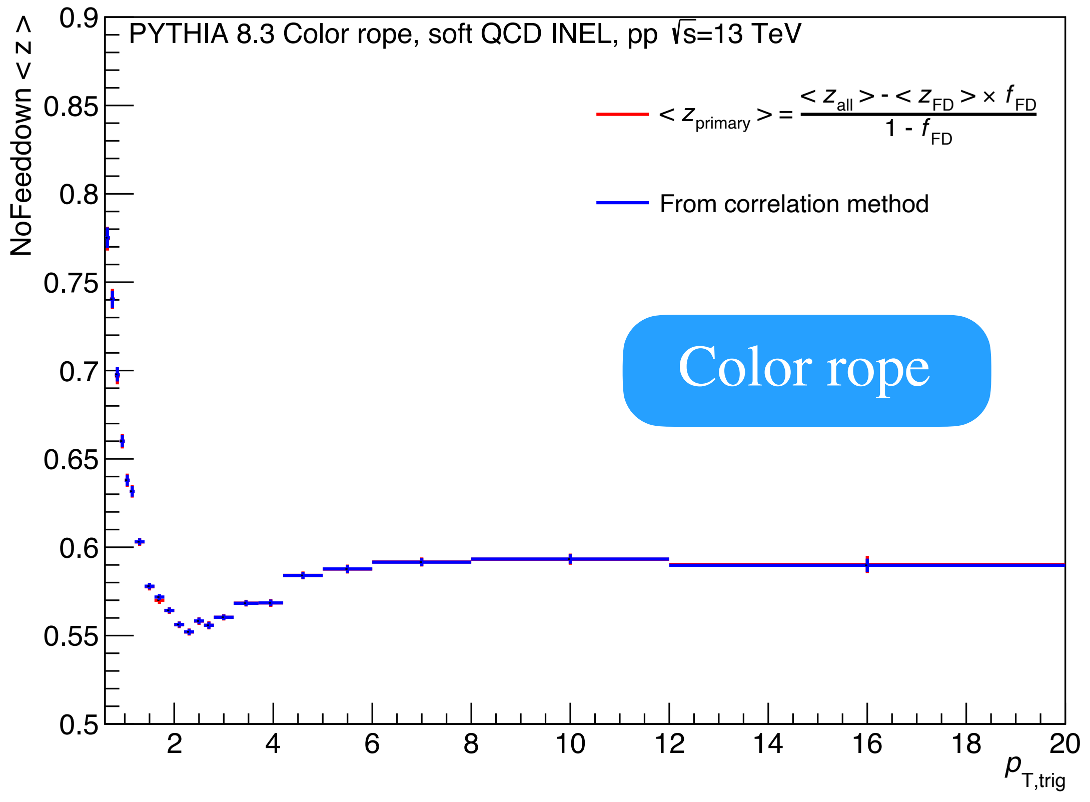

$< z >$ ratio to default Barlow $N$

- For this source, the systematic uncertainty is assigned as the larger relative uncertainty

# Uncertainty - feed down




$$\langle z \rangle = \frac{\langle z_{\text{primary}} \rangle \times N_{\text{primary}} + \langle z_{\text{feed-down}} \rangle \times N_{\text{feed-down}}}{N_{\text{primary}} + N_{\text{feed-down}}}$$

$$\langle z_{\text{primary}} \rangle = \frac{\langle z_{\text{all}} \rangle \times N_{\text{all}} - \langle z_{\text{feed-down}} \rangle \times N_{\text{feed-down}}}{N_{\text{all}} - N_{\text{feed-down}}} = \frac{\langle z_{\text{all}} \rangle - \langle z_{\text{feed-down}} \rangle \times f_{\text{feed-down}}}{1 - f_{\text{feed-down}}}$$

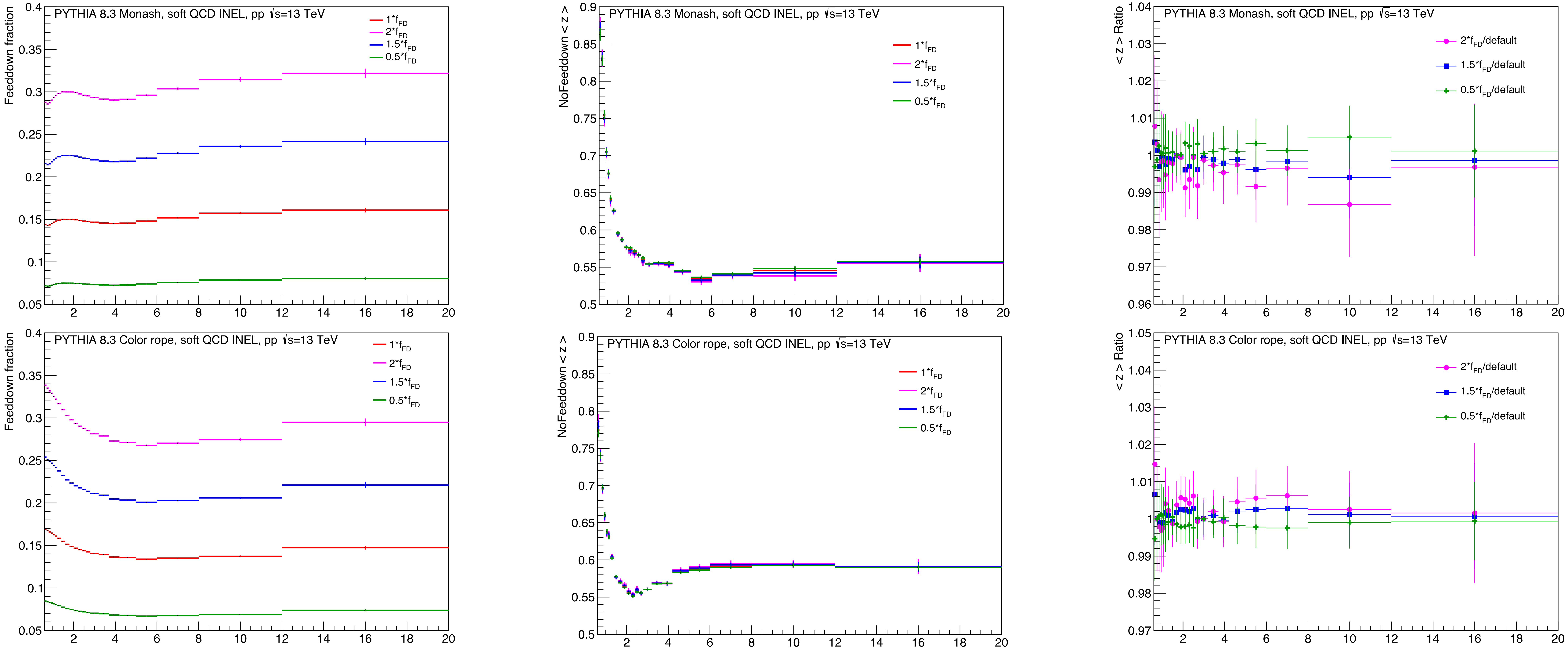
- In MC simulation, $< z >$ is not sensitive to whether $\Lambda(\overline{\Lambda})$ is come from $\Xi^{\pm}$
- However, simulations can not describe data
- If the difference is caused by feed down fraction ($f_{\text{FD}}$), $< z >$ should be sensitive to $f_{\text{FD}}$

- $< z_{\text{primary}} >$ obtained from correlation method directly in simulation is consistent with that calculated by the equation in both Monash and Color rope

# Uncertainty - feed down

Monash

Color rope




feed down fraction

$< z_{\text{primary}} >$ calculated by the equation

ratio to default

- If significantly change the $f_{\text{FD}}$, $< z_{\text{primary}} >$ has not changed significantly
- Proposal: assign a conservative 1.5% uncertainty uncorrelated with $p_{\text{T}}$ for feed down

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# Responses to ARC

# Responses to ARC



## Setups for MC studies

**Data sample:**

General-proposed MC anchored to 2018 (except the one anchored to LHC18c), # of events: ~162 M

**For MC truth (gen level)**

- Trigger (leading V0) selection:
  ➡ IsPhysicalPrimary() + !IsFromSubsidiaryEvent() + PDG code + same kinetic selection as in data
- Associate (charged particle) selection:
  ➡ IsPhysicalPrimary() + !IsFromSubsidiaryEvent() + charged + same kinetic selection as in data
- Correction:
  ➡ mixed event correction

**For MC reconstructed (rec level)**

- Trigger (leading V0) selection:
  ➡ The same as that in data
- Associate (charged particle) selection:
  ➡ BIT(8) + $|\eta|<0.8$
- Correction:
  ➡ tracking efficiency correction ($p_{\mathrm{T}}$ dependence) + side-band correction + mixed event correction


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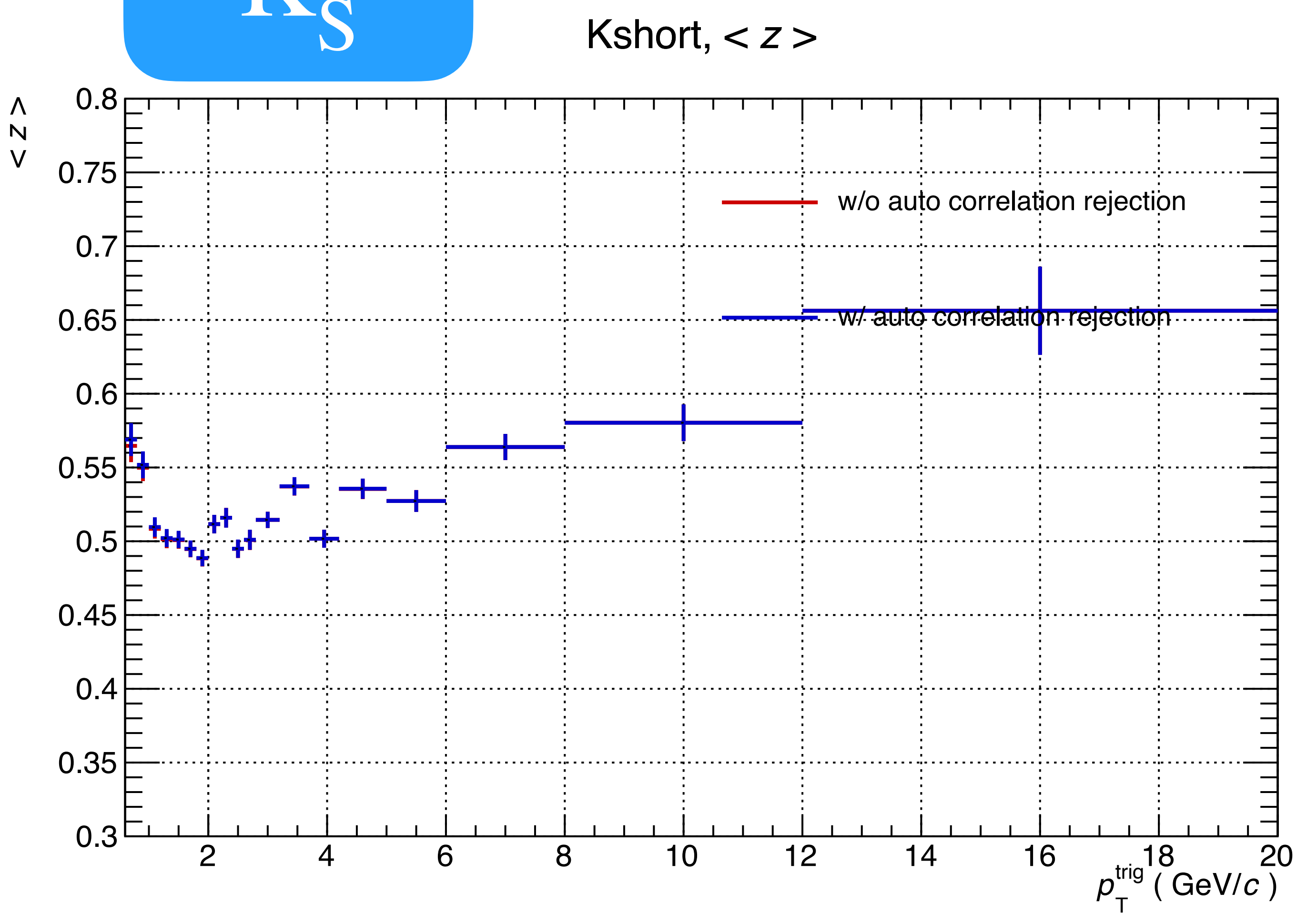
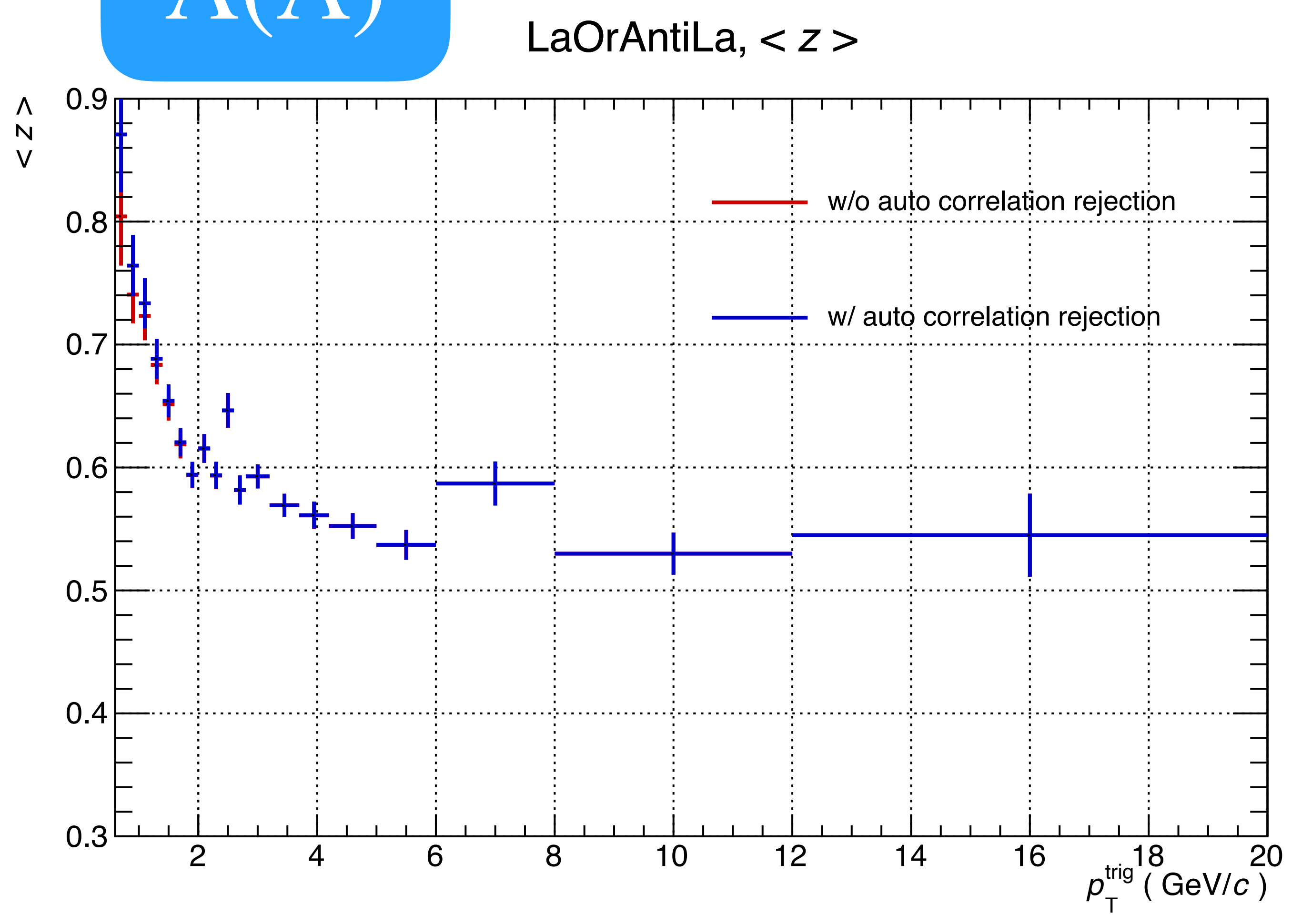
# Responses to ARC

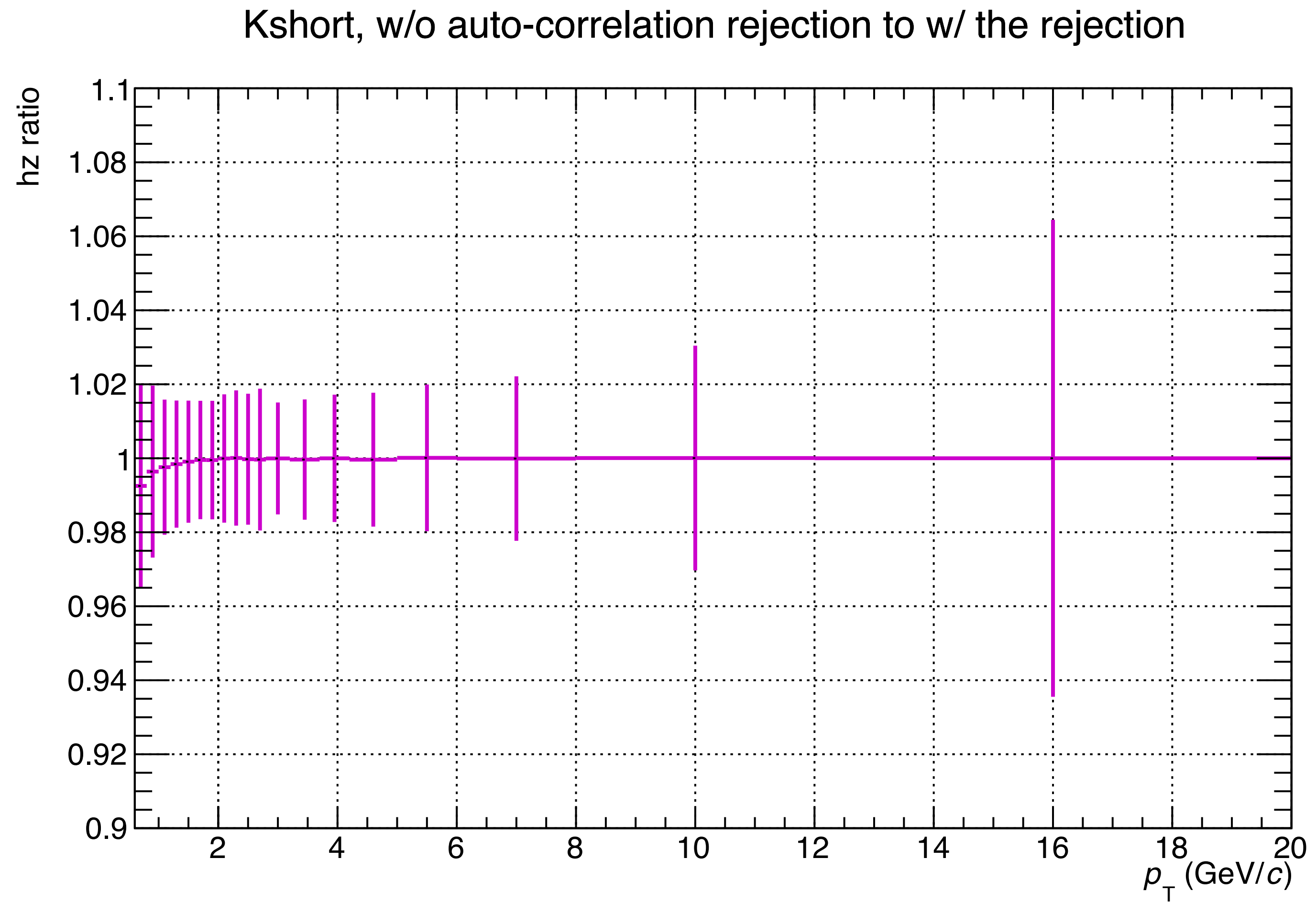
## Auto-correlation

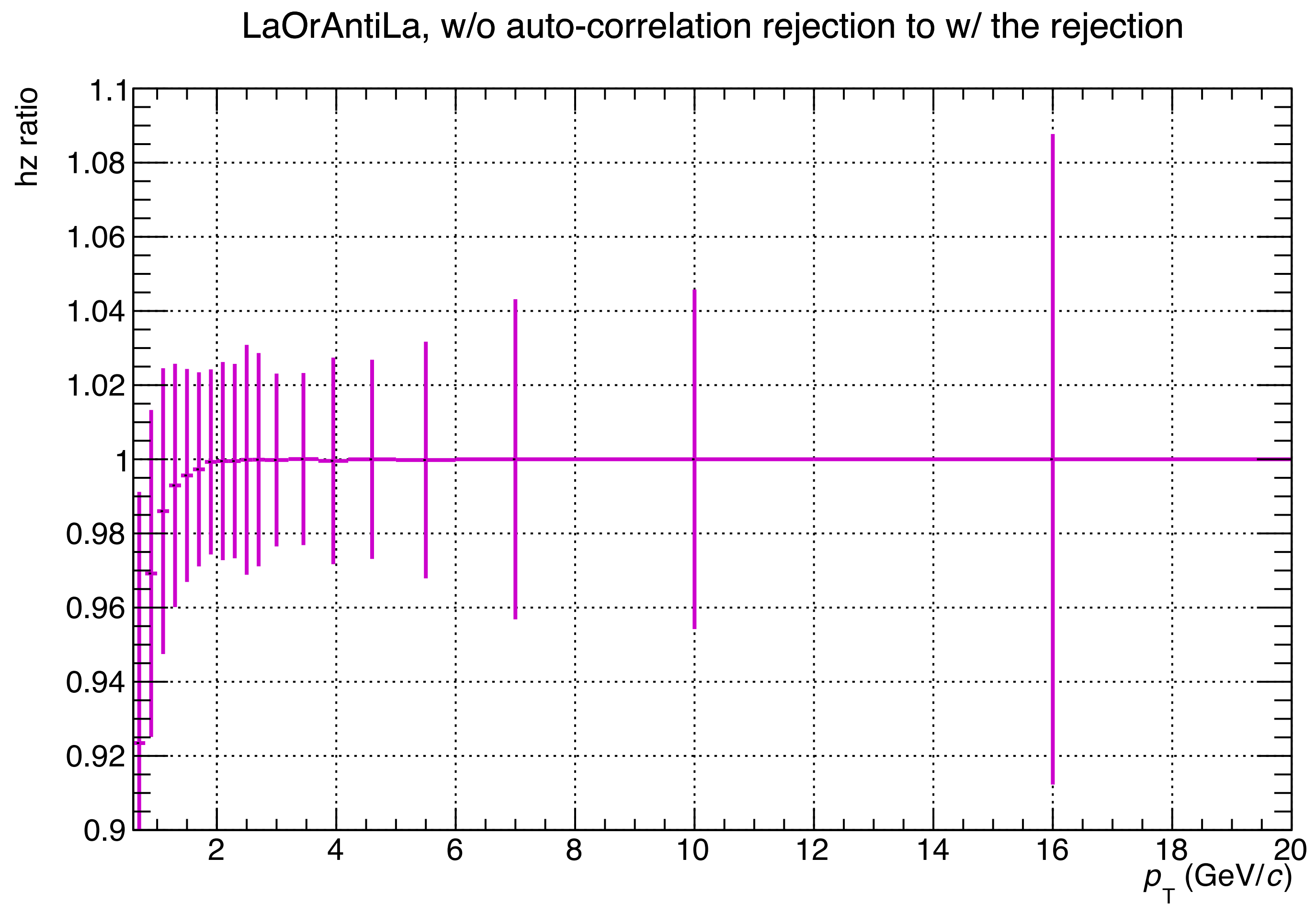
$K_S^0$




$\Lambda(\overline{\Lambda})$




- In MC, auto-correlation won't have significant impact on <*z*>
- For leading $K_S^0$ analysis, the difference is less than 1% and for leading $\Lambda(\overline{\Lambda})$ analysis, it's less than 1.5% when $p_{T,trig} > 1$ GeV/$c$
- For now, assign the difference as systematic uncertainty according to the ARC's suggestion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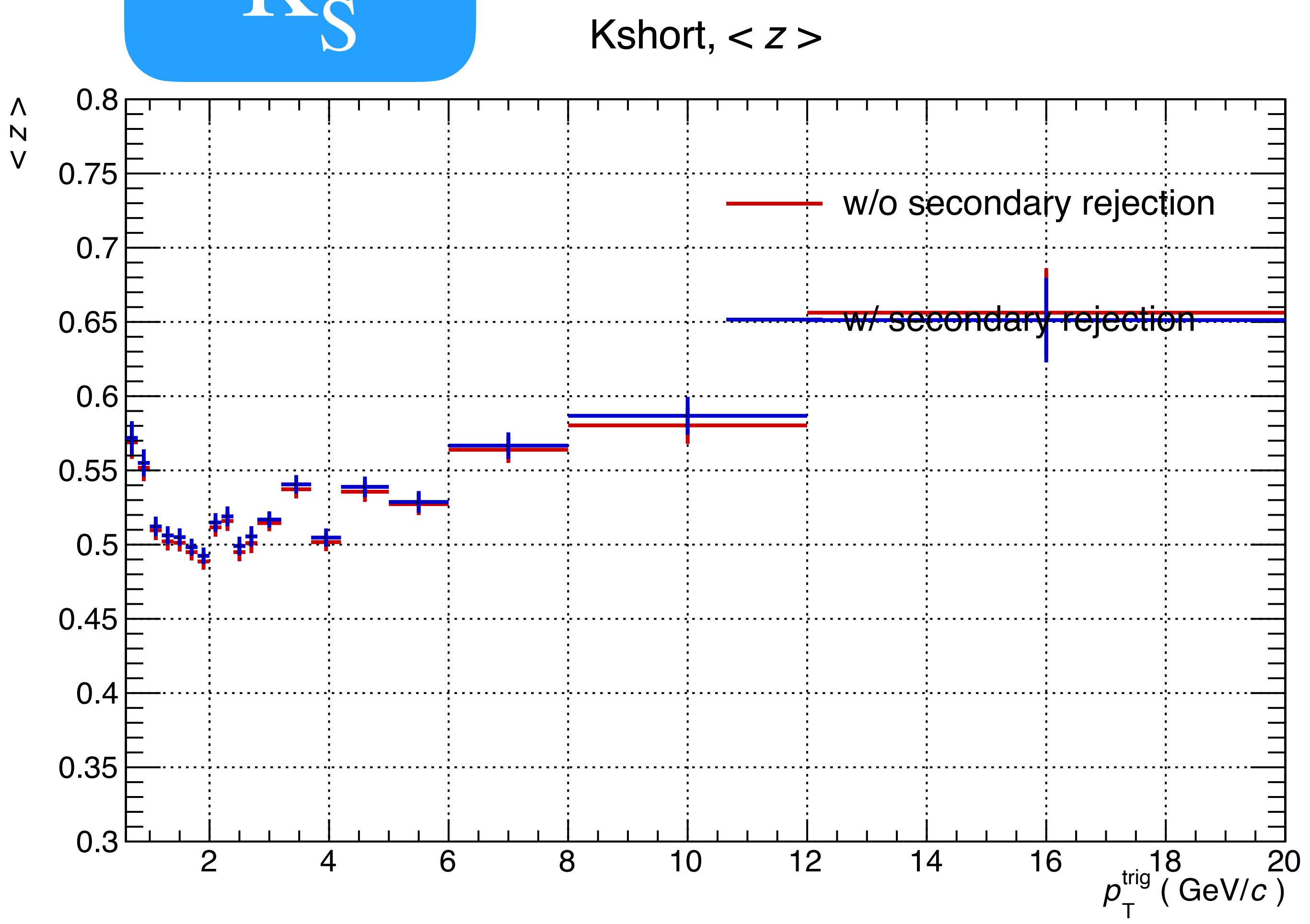
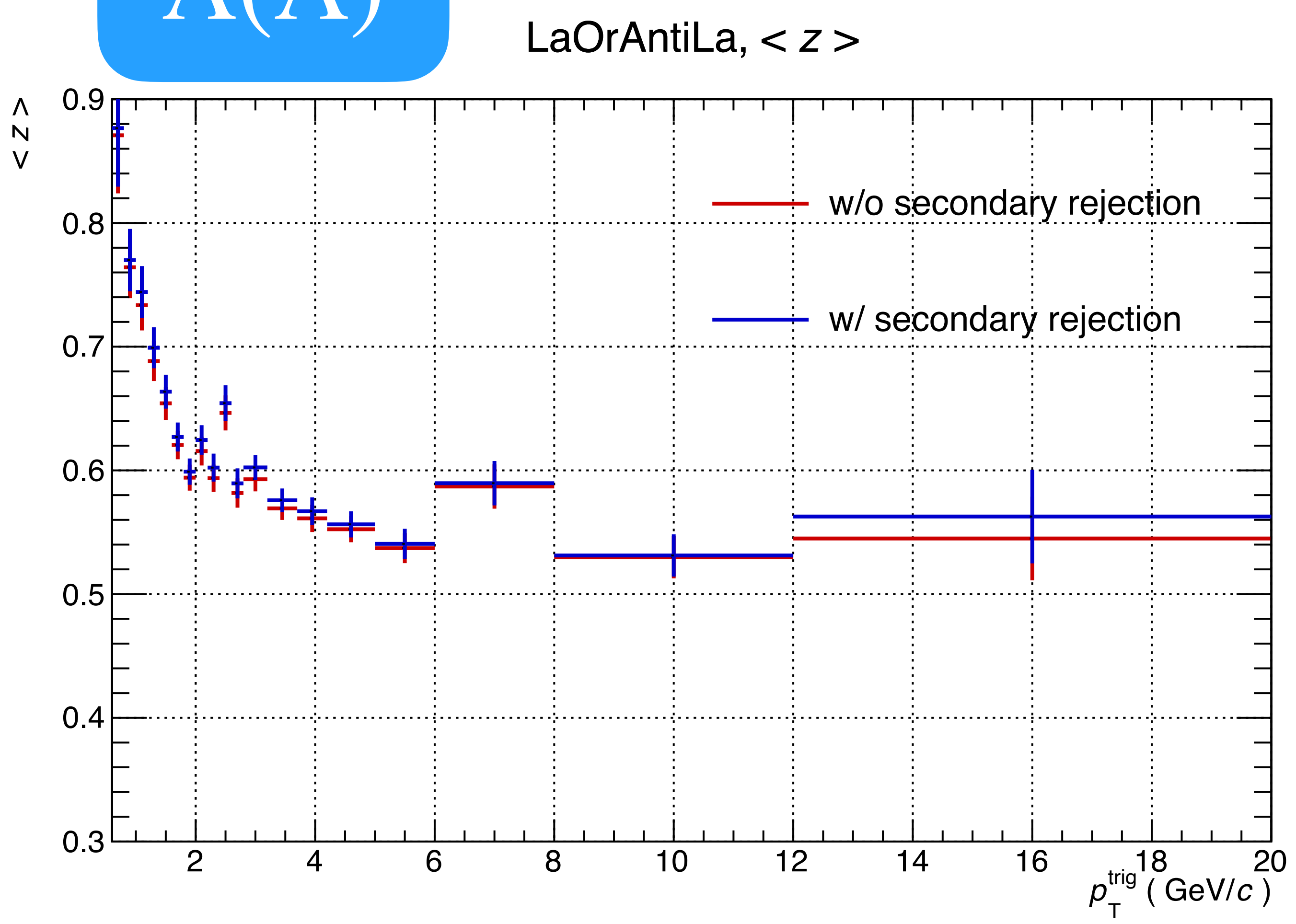
# Responses to ARC

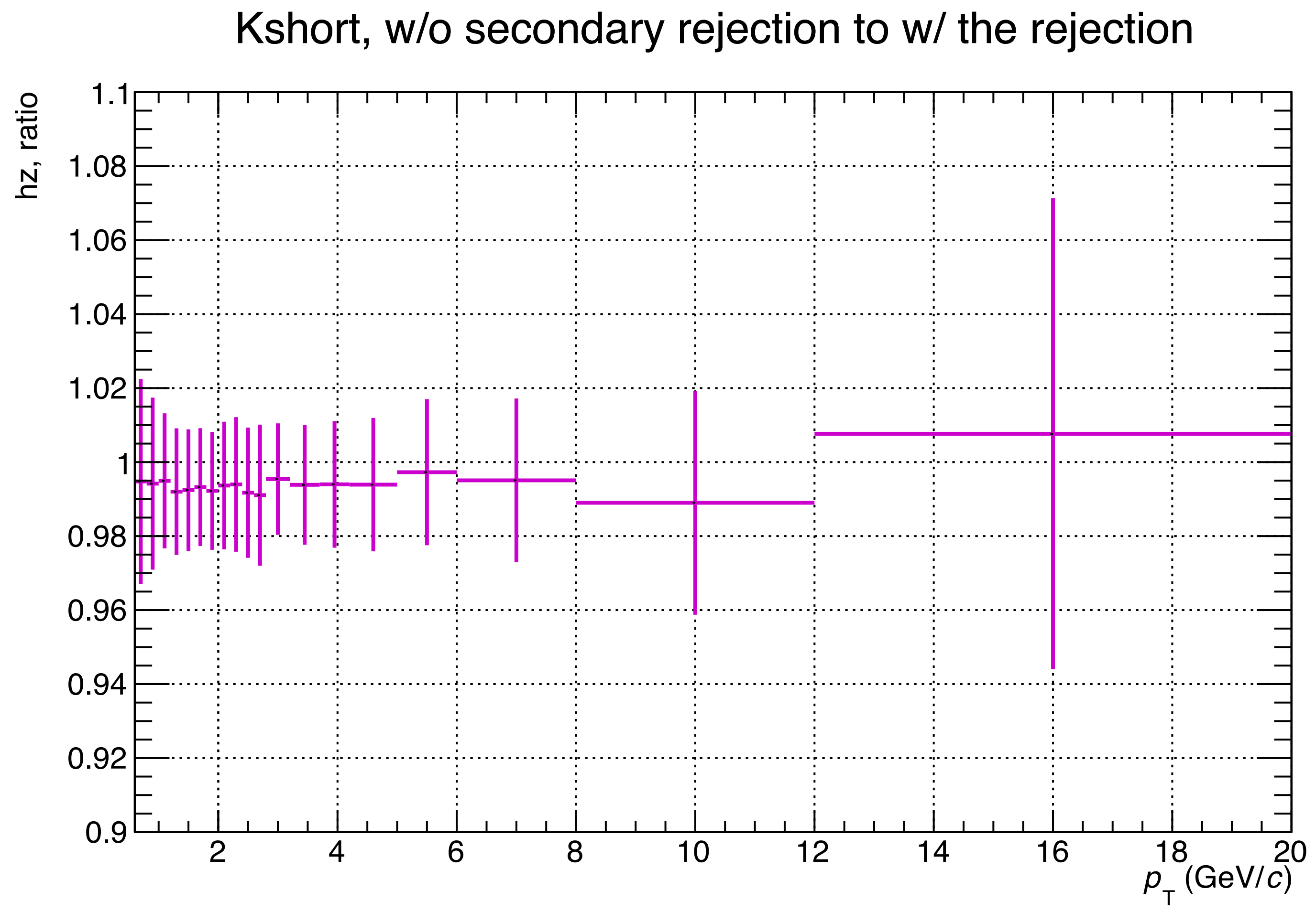
## Non-primary contamination rejection

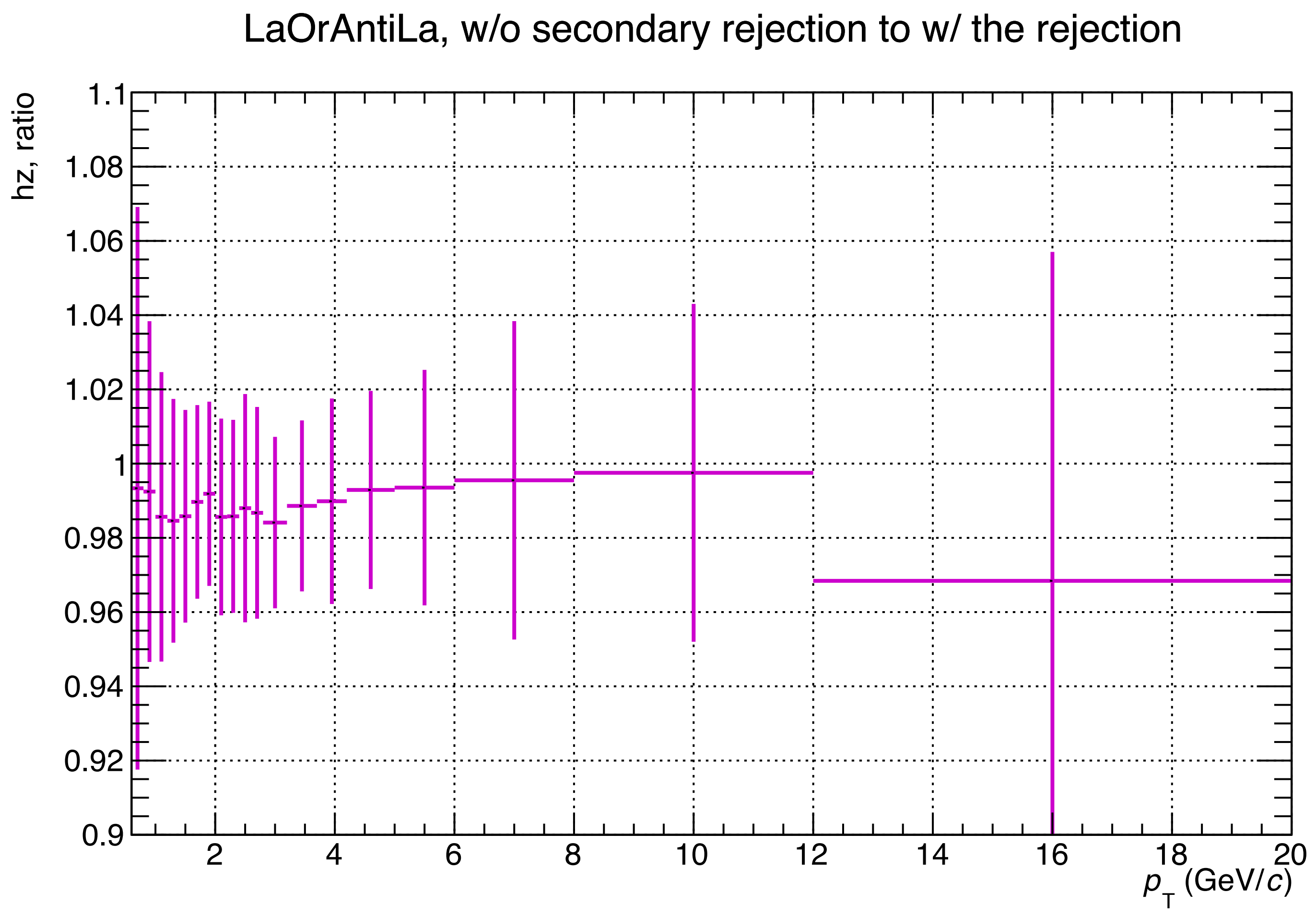
$K_S^0$




$\Lambda(\overline{\Lambda})$




- Introducing secondary particle rejection or not won't have significant influence on <z>. For most case, the difference is less than 1% (for leading $K_S^0$ analysis) and 1.5% (for leading $\Lambda(\overline{\Lambda})$)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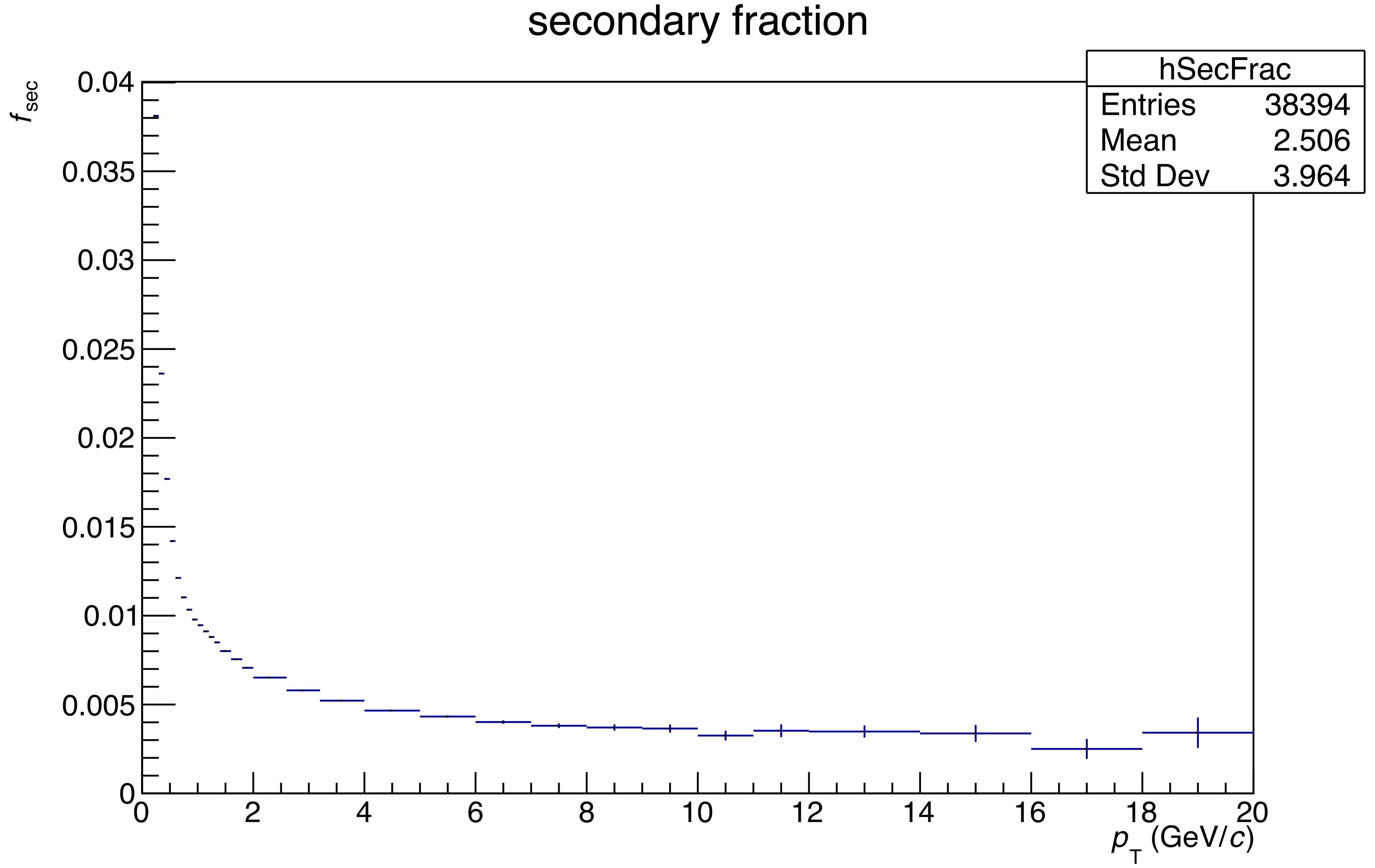
# Responses to ARC

## Non-primary particle fraction




$$f_{sec} = \frac{N^{passed}_{secondaries}}{N^{passed}_{total}}$$

- The secondary fraction is smaller than 1% when $p_T >$ 1GeV/$c$, and between 1% - 4% when $0.2 < p_T < 1$ GeV/$c$, with increasing $p_T$, the secondary fraction decreases steeply
- For now, assign the difference as systematic uncertainty on the secondary contamination source according to the ARC's suggestion

# Responses to ARC

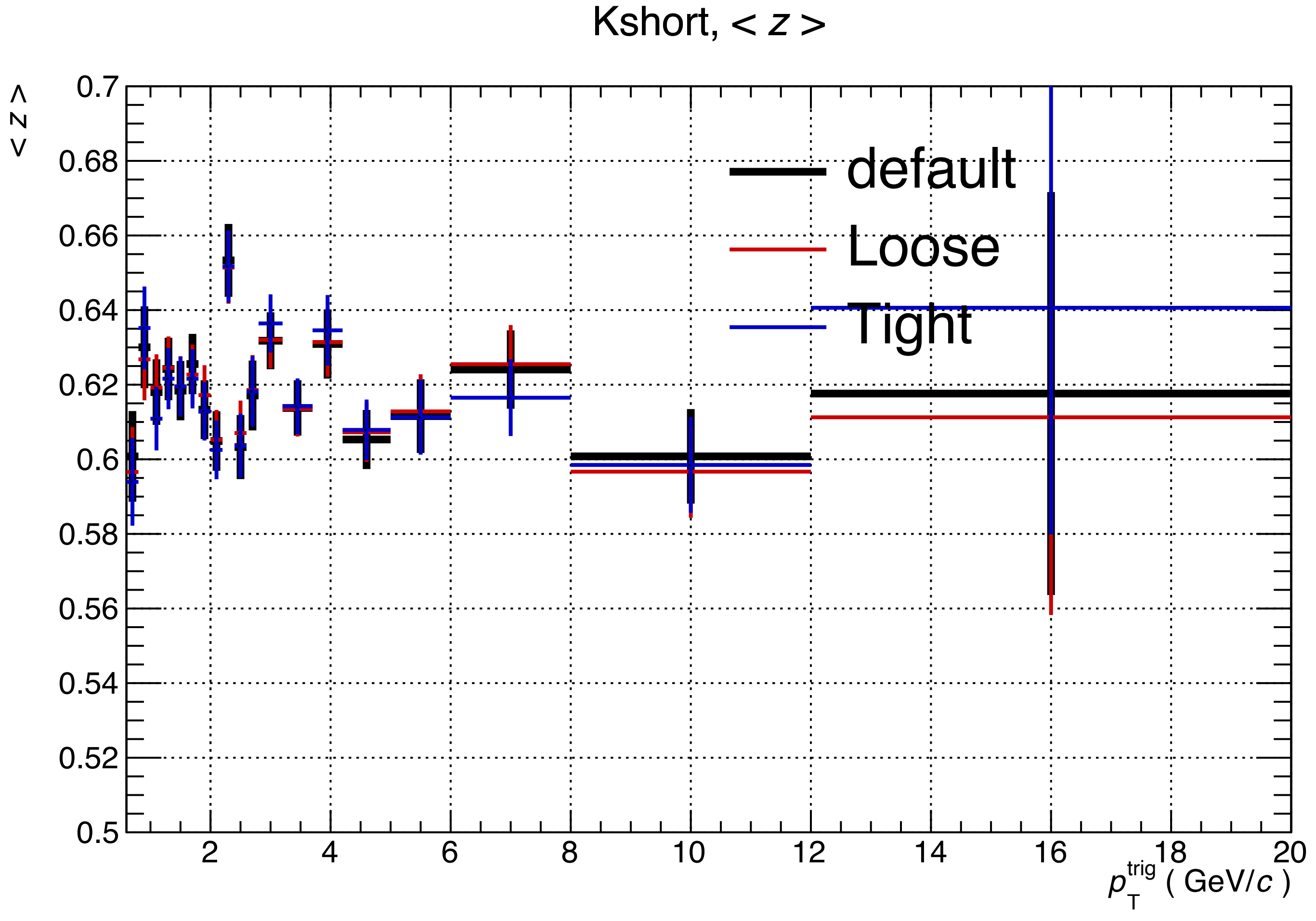


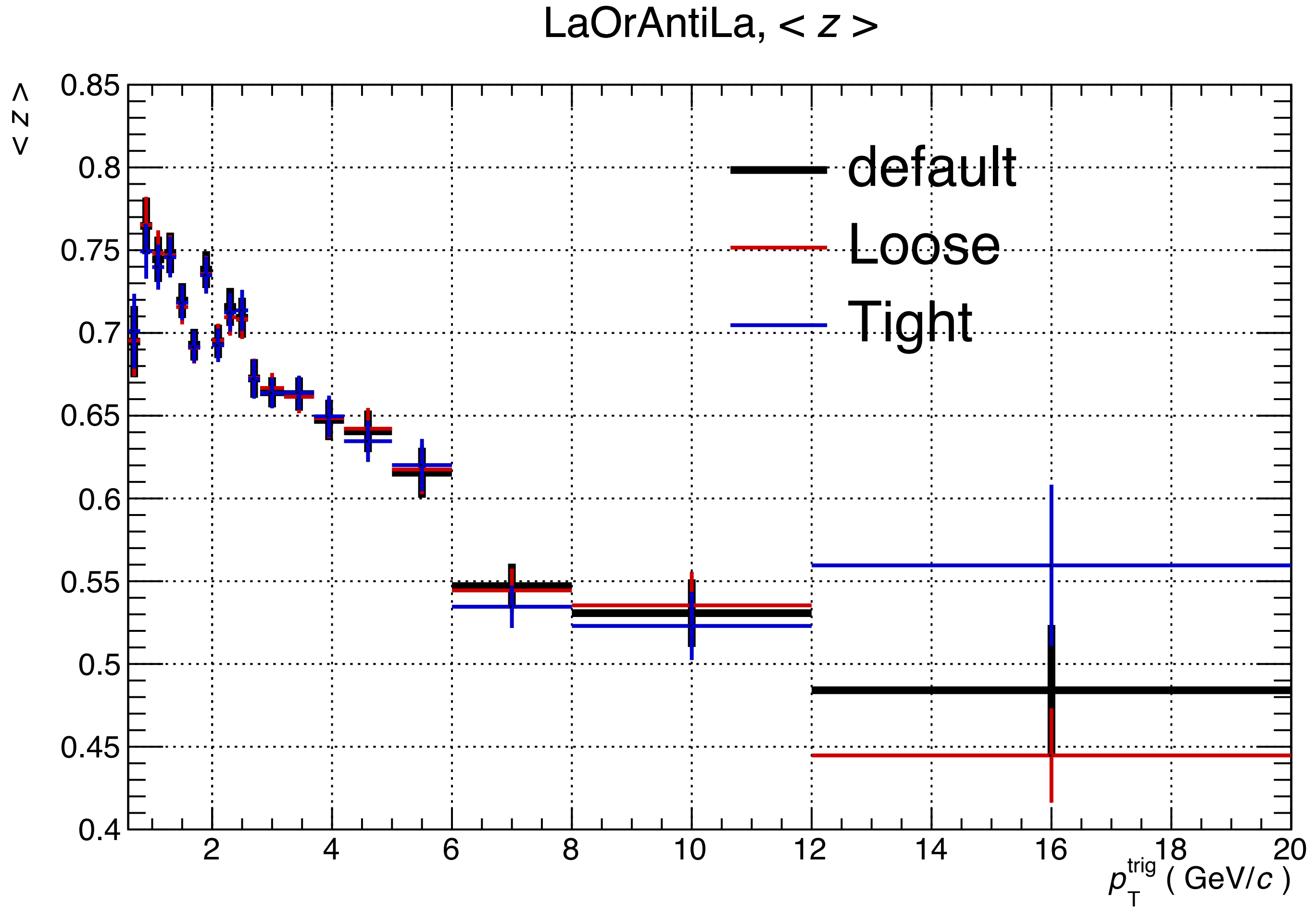
- Systematic uncertainties: do you assess any systematic uncertainty related to the topological selections of $K^0_S$ and $\Lambda(\overline{\Lambda})$? (like V0radius, CosPA, DCA of daughter tracks to PV)
  - ➡ The uncertainty on topo selection is not considered. In the regular spectrum analysis, the topo uncertainty is estimated by varying the selections in data and MC simultaneously. This is used to estimate the discrepancy between data and MC on the topo variable distributions (on top of the material budget). Since the efficiency correction is not applied to the trigger, the variation of topo selections should only change the trigger (raw) yield. For the regular V0-h correlation analysis, the uncertainty from topo is ~ 1.5% for $K^0_S$ and ~ 2% for $\Lambda$ (Eur. Phys. J. C 81 (2021) 945)
  - ➡ For now, this was checked in a very small sample of LHC18b pass2 AOD with varying loose/tight cut sets with these three variables, values were took from in JHEP 07 (2023) 136

| | Very loose | Standard | Very tight |
|---|---|---|---|
| V0radius | > 0.3 cm | > 0.5 cm | > 0.7 cm |
| CPA | > 0.95 (0.993) | > 0.97 (0.995) | > 0.99(0.997) |
| Daughter tracks DCA to PV | > 0.05 cm | > 0.06 cm | > 0.08 cm |

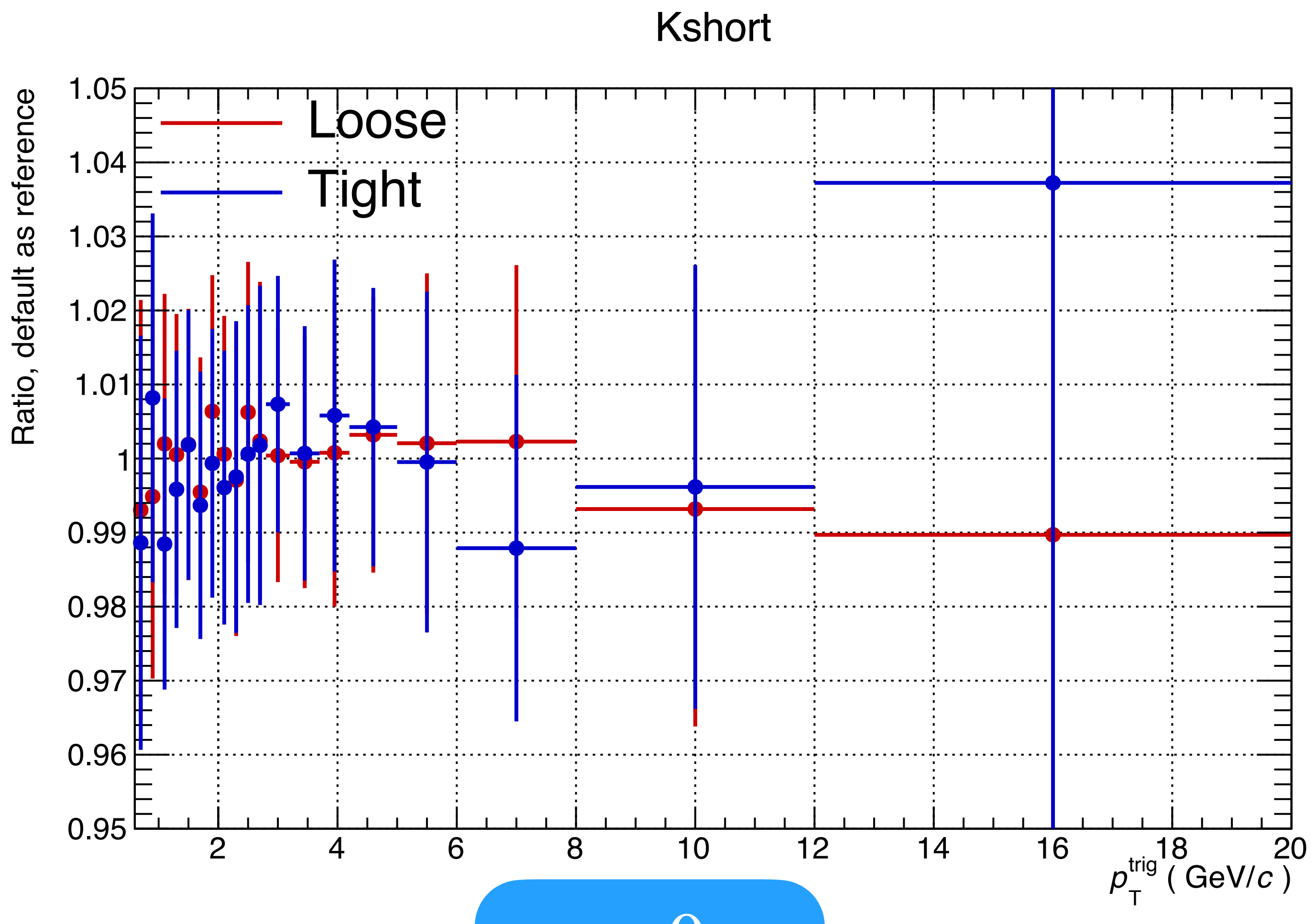
# Responses to ARC

- Systematic uncertainties: do you assess any systematic uncertainty related to the topological selections of $K_S^0$ and $\Lambda(\overline{\Lambda})$? (like V0radius, CosPA, DCA of daughter tracks to PV)



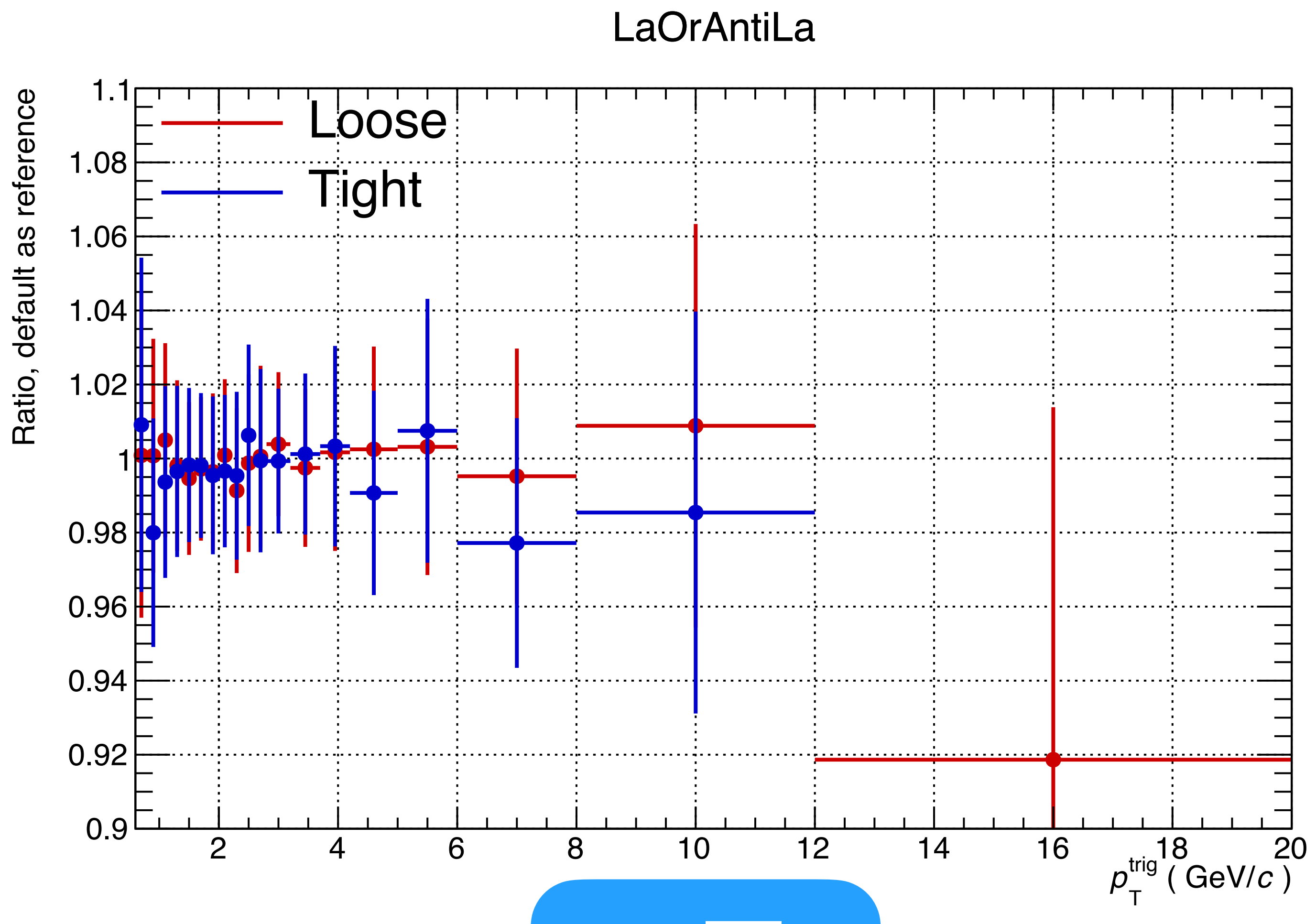




Ratio to default




$K_S^0$

Ratio to default



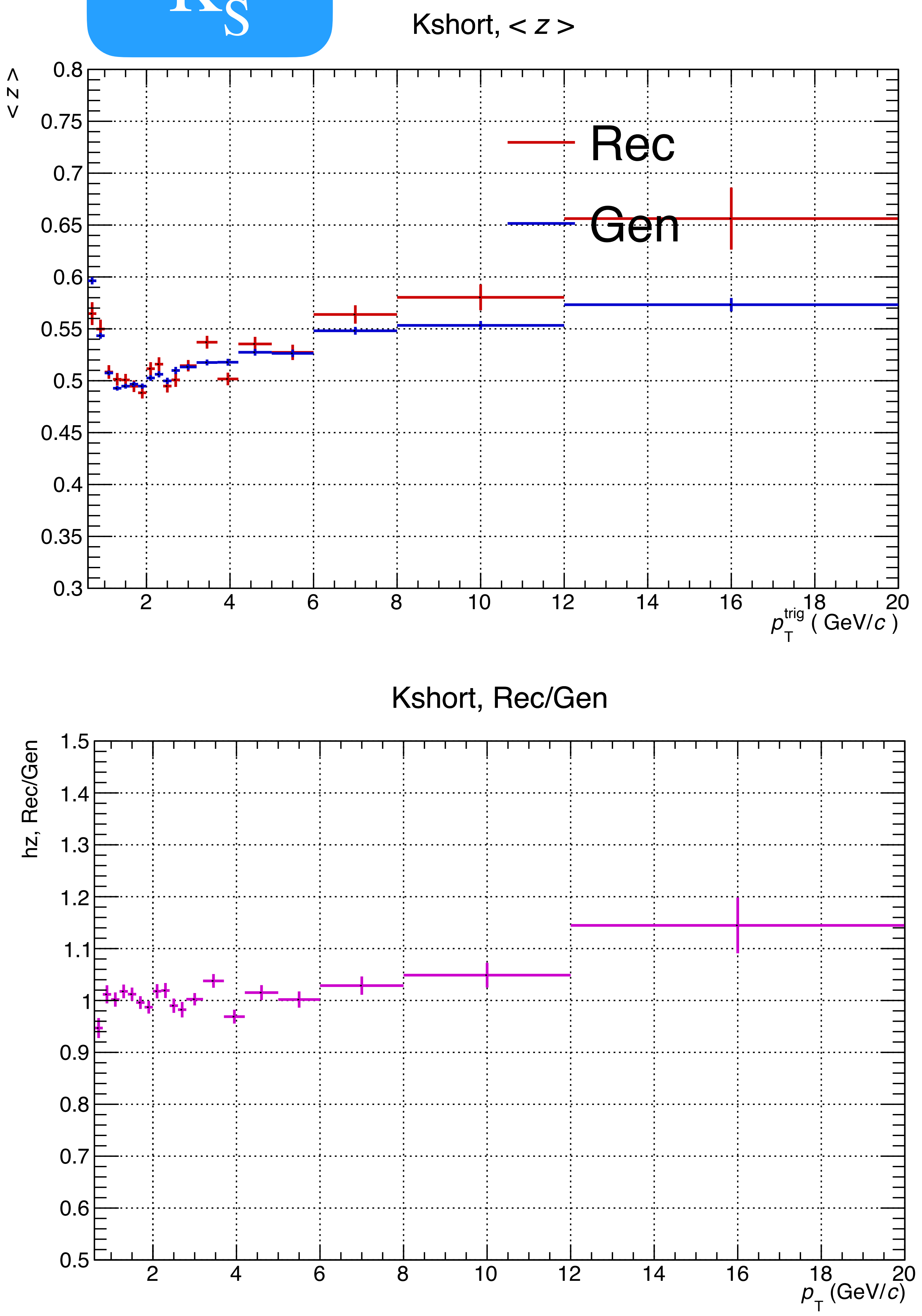

$\Lambda(\overline{\Lambda})$

- In most case, the difference is less than 1%

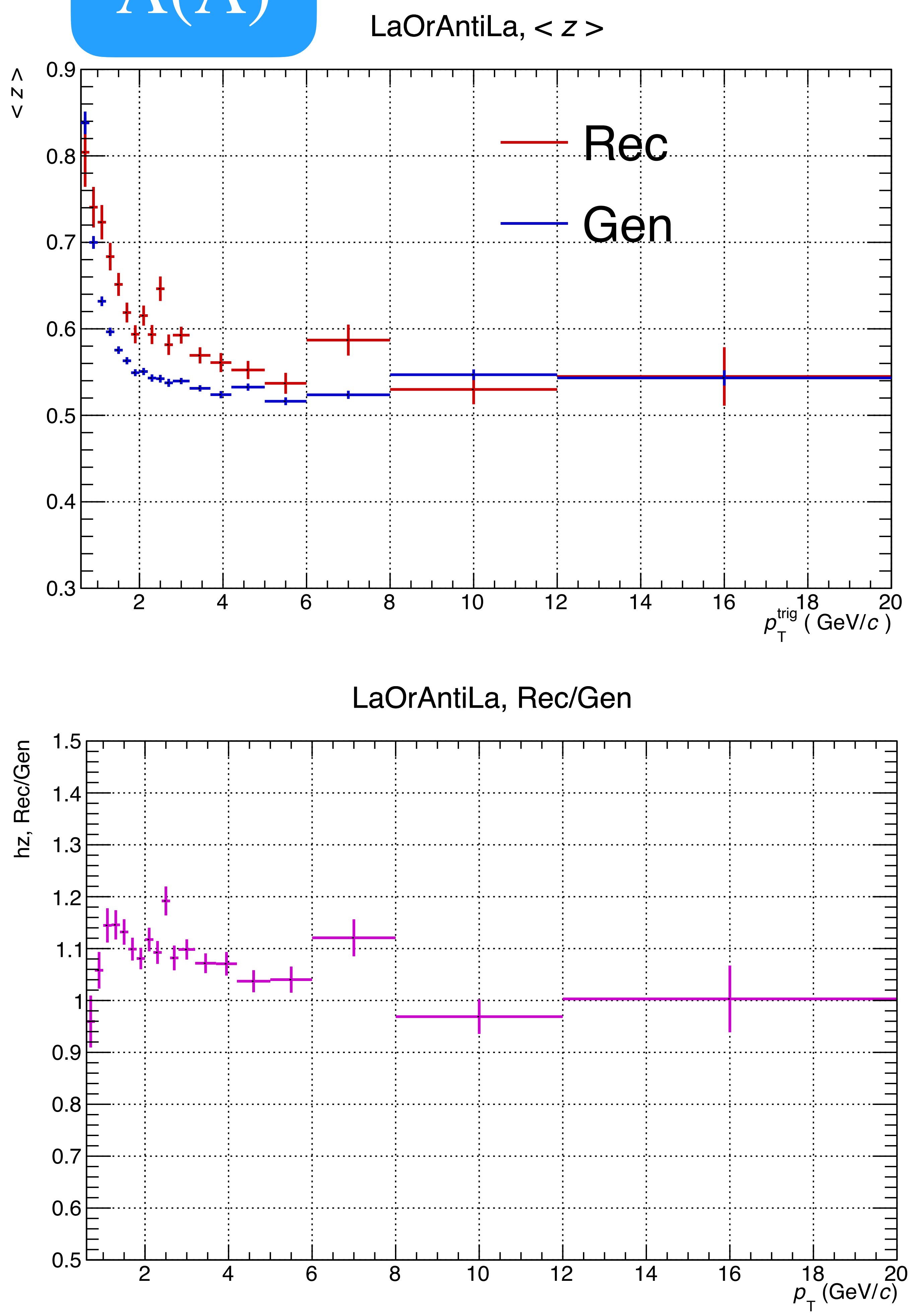
# Responses to ARC

## MC closure test

$K^0_S$




$\Lambda(\overline{\Lambda})$




- For leading $K^0_S$ analysis, the Rec level and the Gen level shows good consistency within uncertainty
- For leading $\Lambda(\overline{\Lambda})$ analysis, some points have ~ 10% deviation. This non-closure is also found in previous Λ-h correlation analysis (Eur. Phys. J. C 81 (2021) 945)
  - ➡ Last discussion in PAG: may due to track merging effect (?), perform the closure test on 2D correlation function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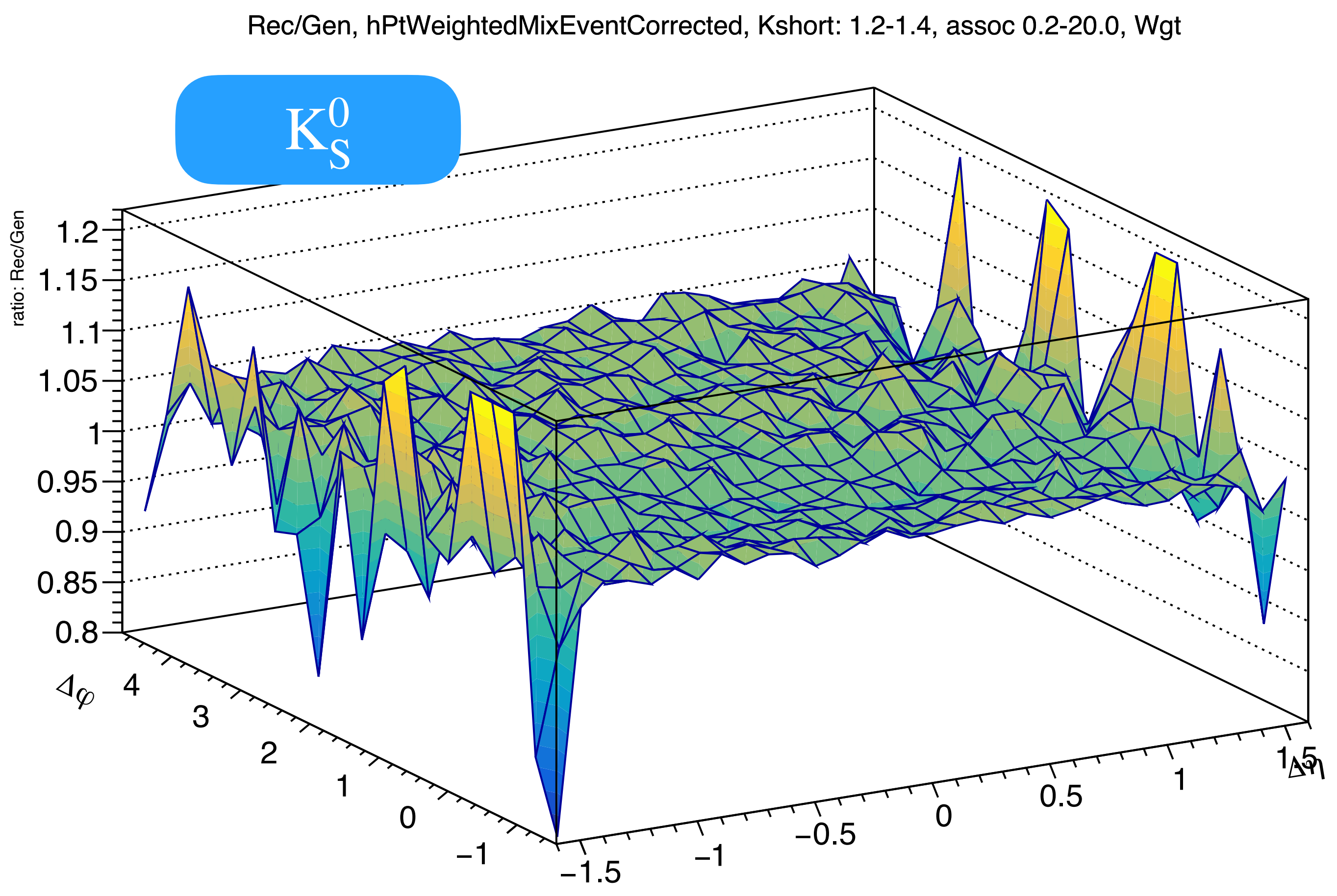
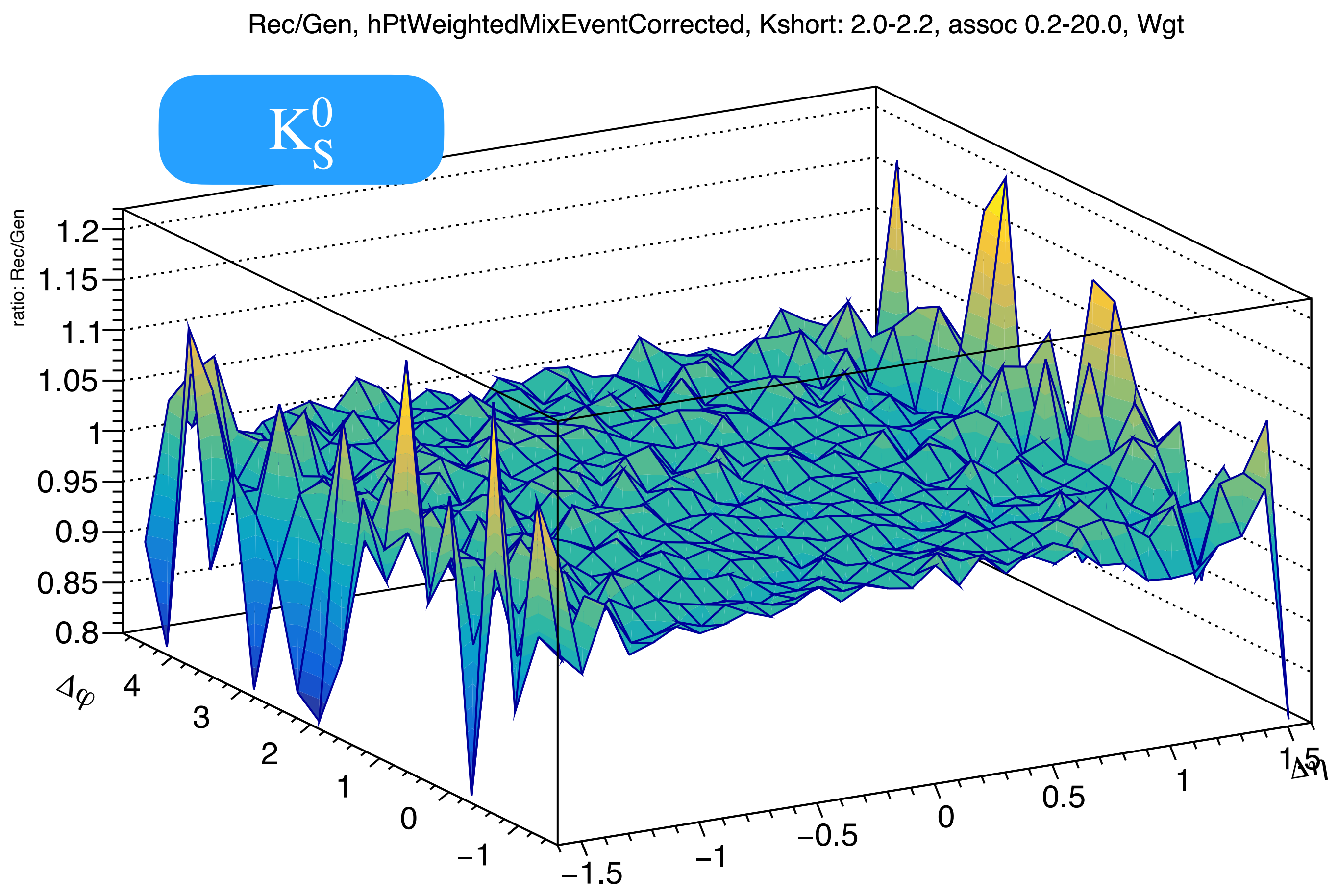
# Responses to ARC

## Proposed in PAG: MC closure test on 2D weighted CF — Rec/Gen ratio

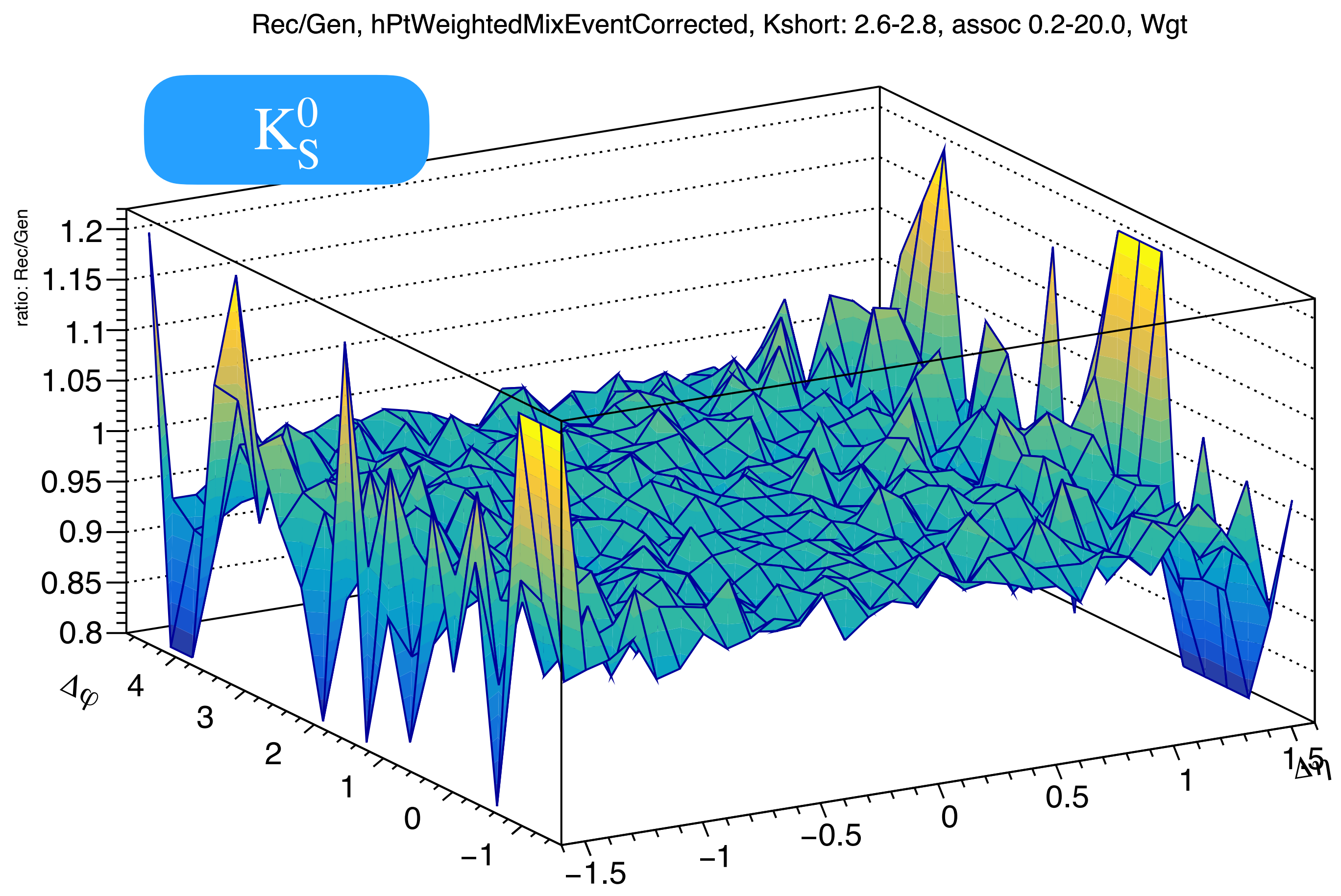
$K^0_S$



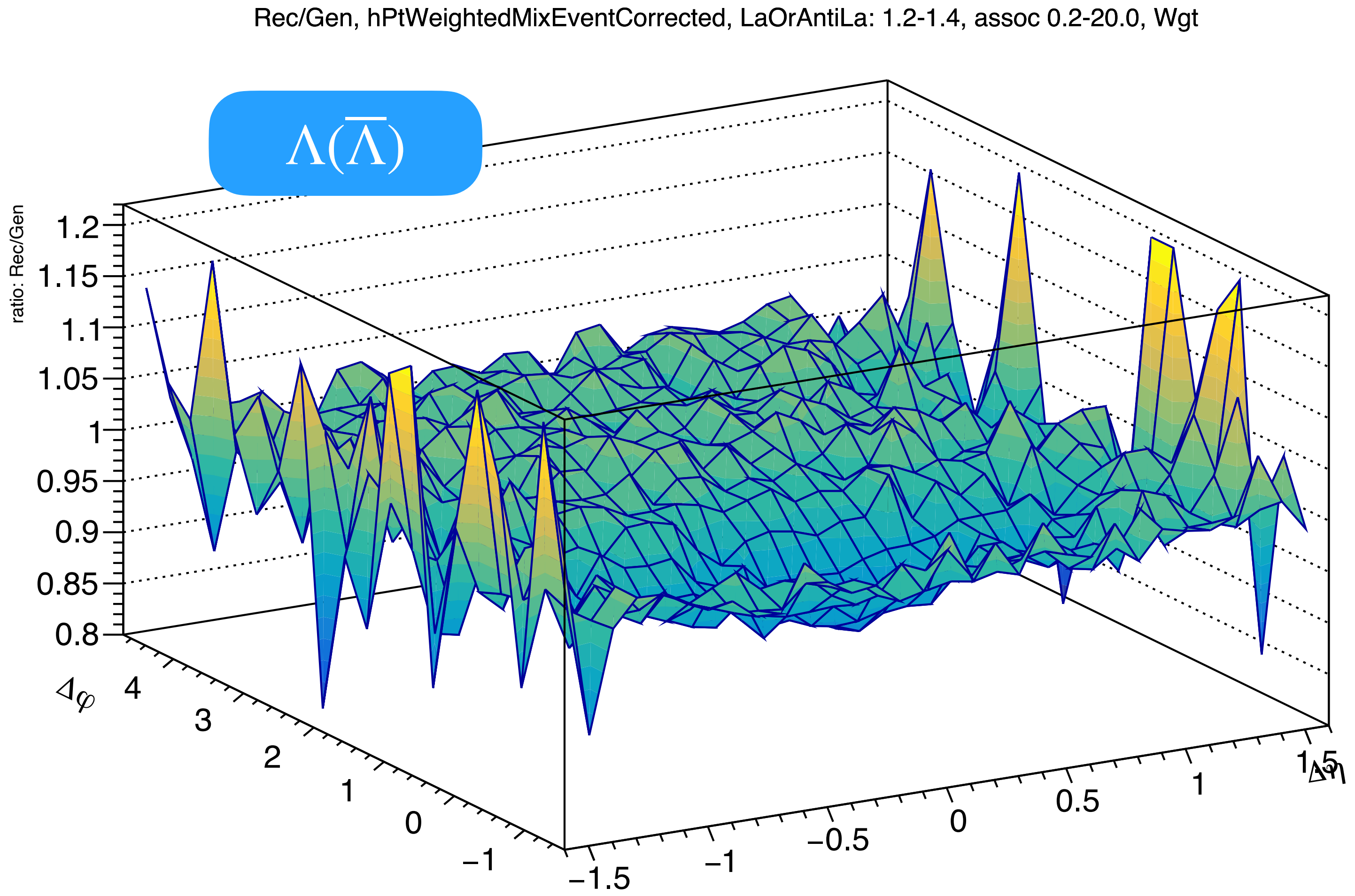

$K^0_S$



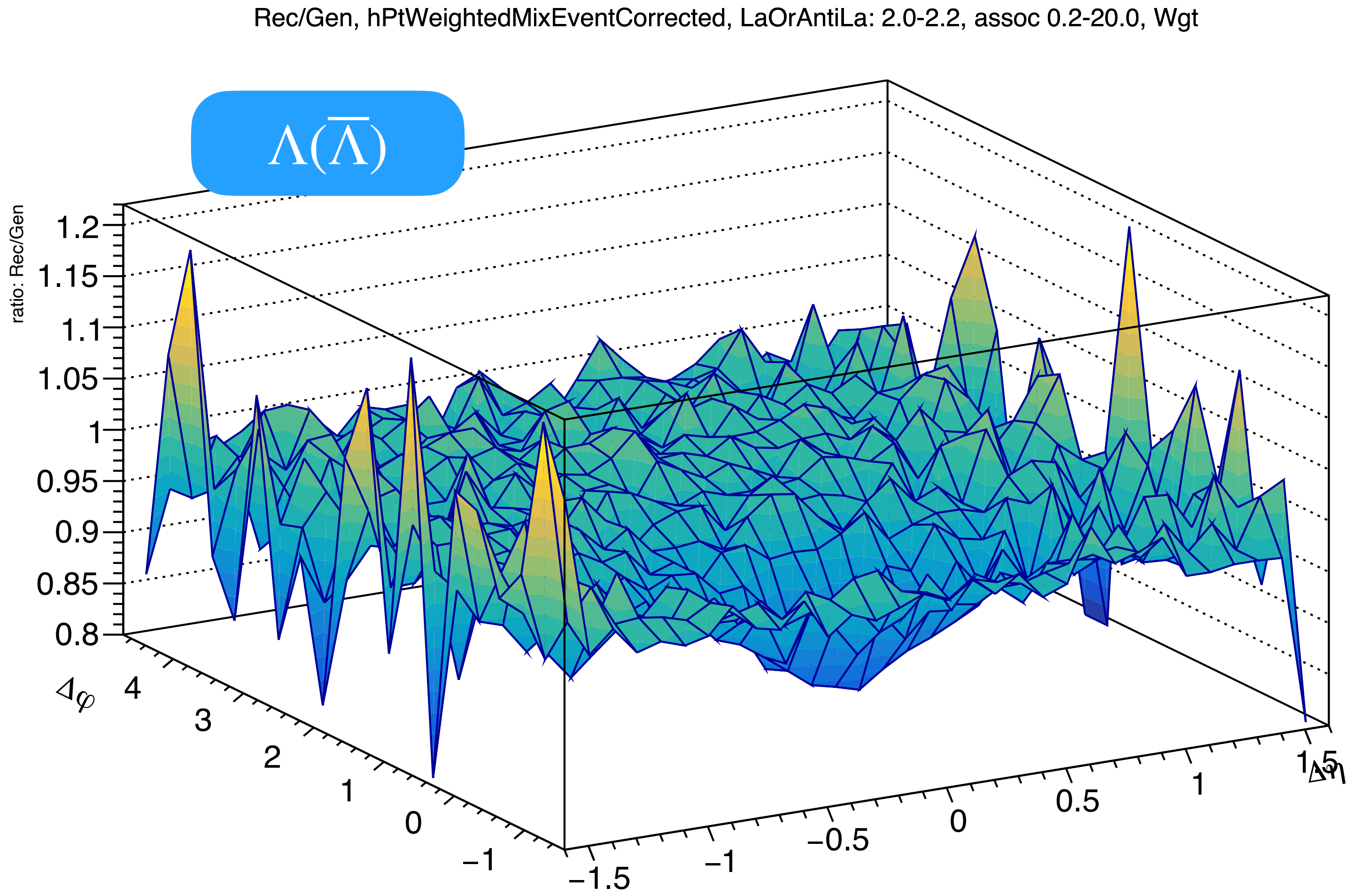

$K^0_S$



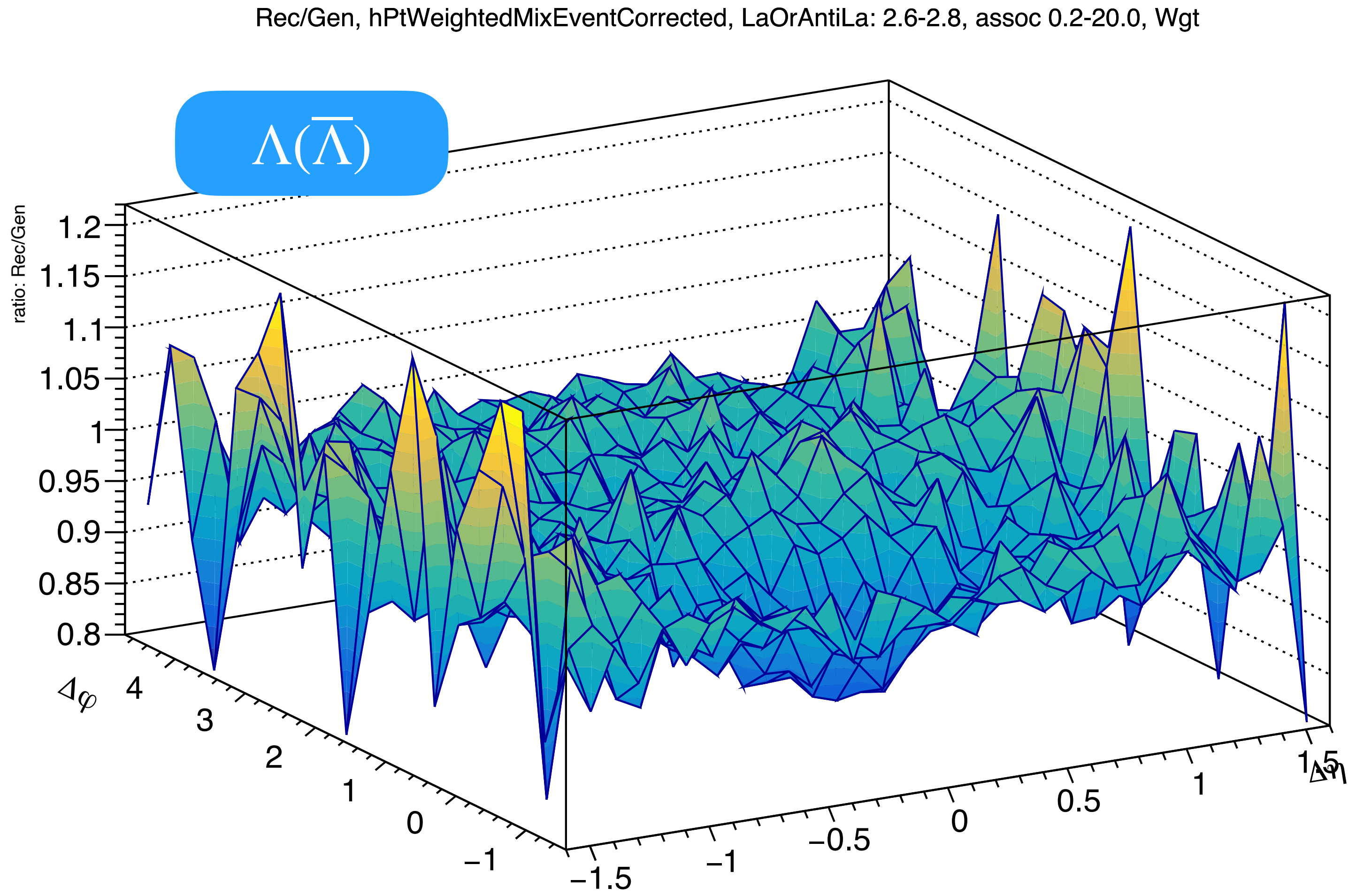

$\Lambda(\overline{\Lambda})$




$\Lambda(\overline{\Lambda})$




$\Lambda(\overline{\Lambda})$




$1.2 < p_{\mathrm{T, trig}} < 1.4$ GeV/$c$

$2.0 < p_{\mathrm{T, trig}} < 2.2$ GeV/$c$

$2.6 < p_{\mathrm{T, trig}} < 2.8$ GeV/$c$

# Responses to ARC

*Ryan' AN*

**One possible solution:**

- Make a 2D map correction on the weighted CF

$$C_{\mathrm{wgt}}^{\text{corrected for 2D map}} = C_{\mathrm{wgt}}^{\text{uncorrected for 2D map}} \times \left( \frac{C_{\mathrm{wgt}}^{\text{Rec Truth}}}{C_{wgt}^{\mathrm{Gen}}} \right)^{-1}$$

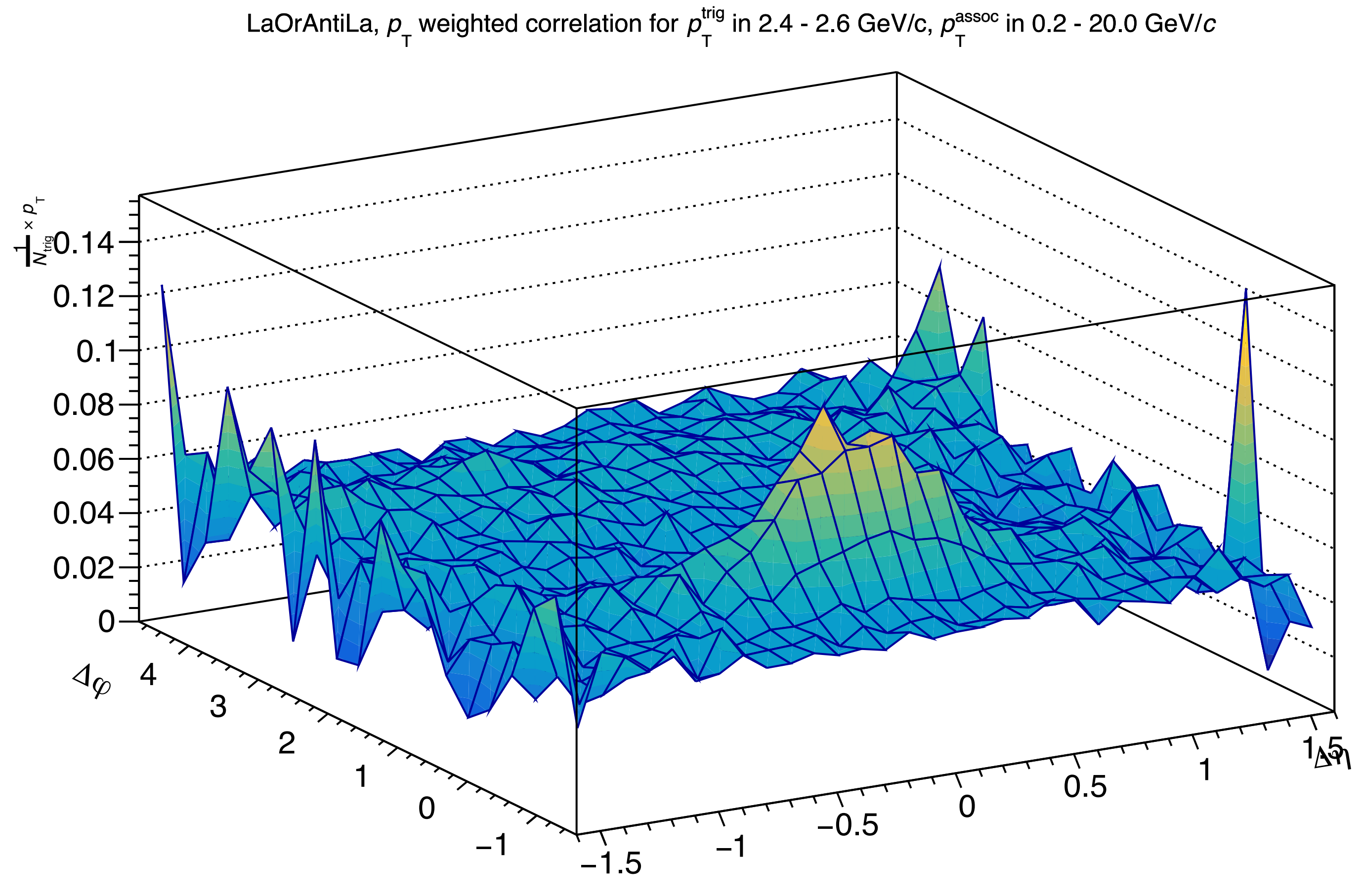
- "Rec Truth" means the results using the reconstructed $\Lambda(\overline{\Lambda})$ with their true kinematics
- Using LHC20f2b2 (the general proposed MC anchored to LHC16d) as a test, # of event: ~27 M

# Responses to ARC

- "Rec Truth" means the results using the reconstructed $\Lambda(\overline{\Lambda})$ with their true kinematics
- LHC20f2b2 (the general proposed MC anchored to LHC16d), # of event: ~27 M

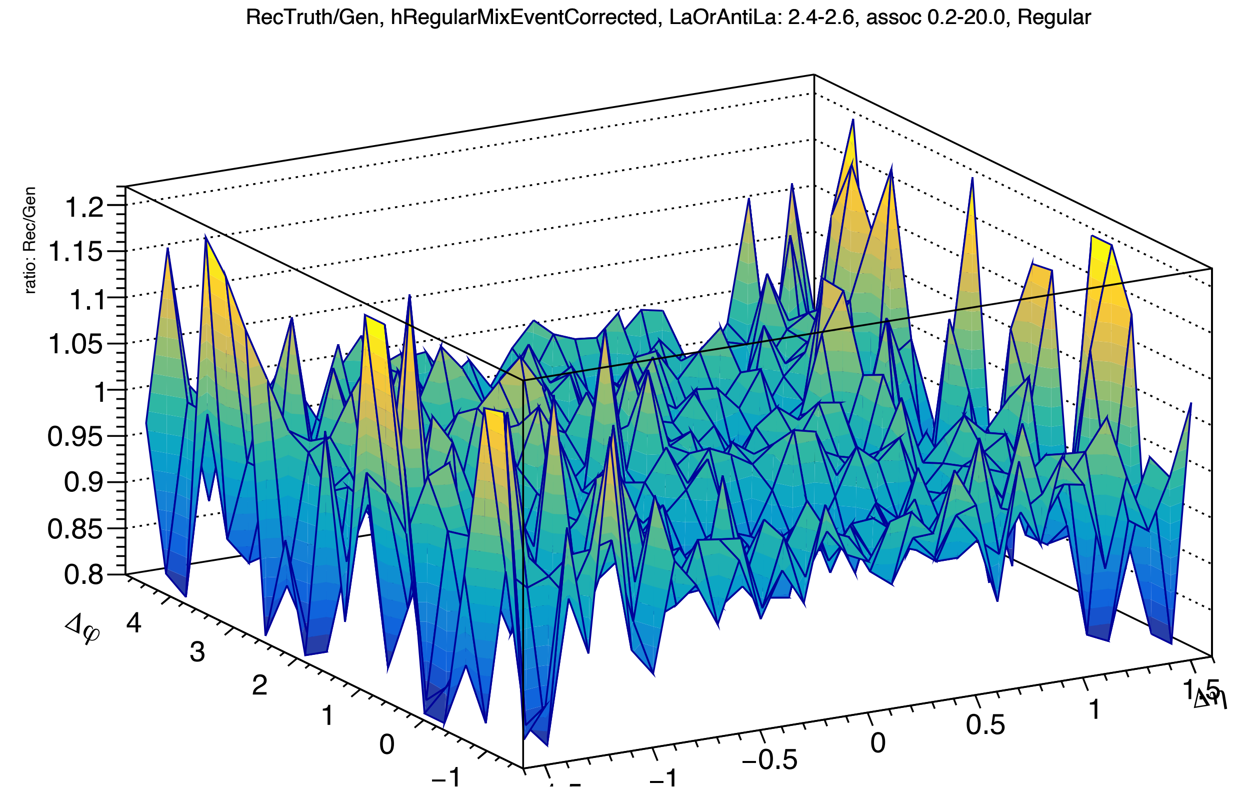
*Ryan' AN*

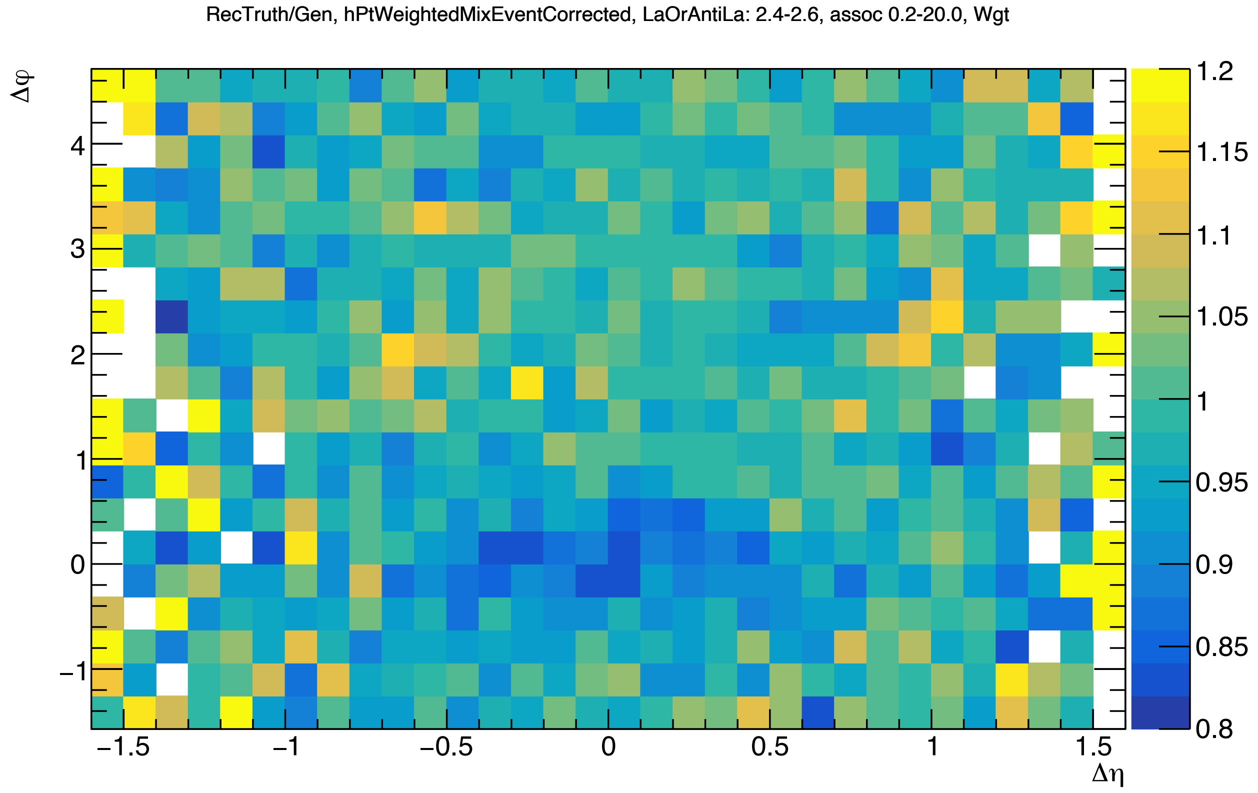
$$C_{\text{wgt}}^{\text{uncorrected for 2D map}} \times \left(\frac{C_{\text{wgt}}^{\text{Rec Truth}}}{C_{wgt}^{\text{Gen}}}\right)^{-1} = C_{\text{wgt}}^{\text{corrected for 2D map}}$$




rec

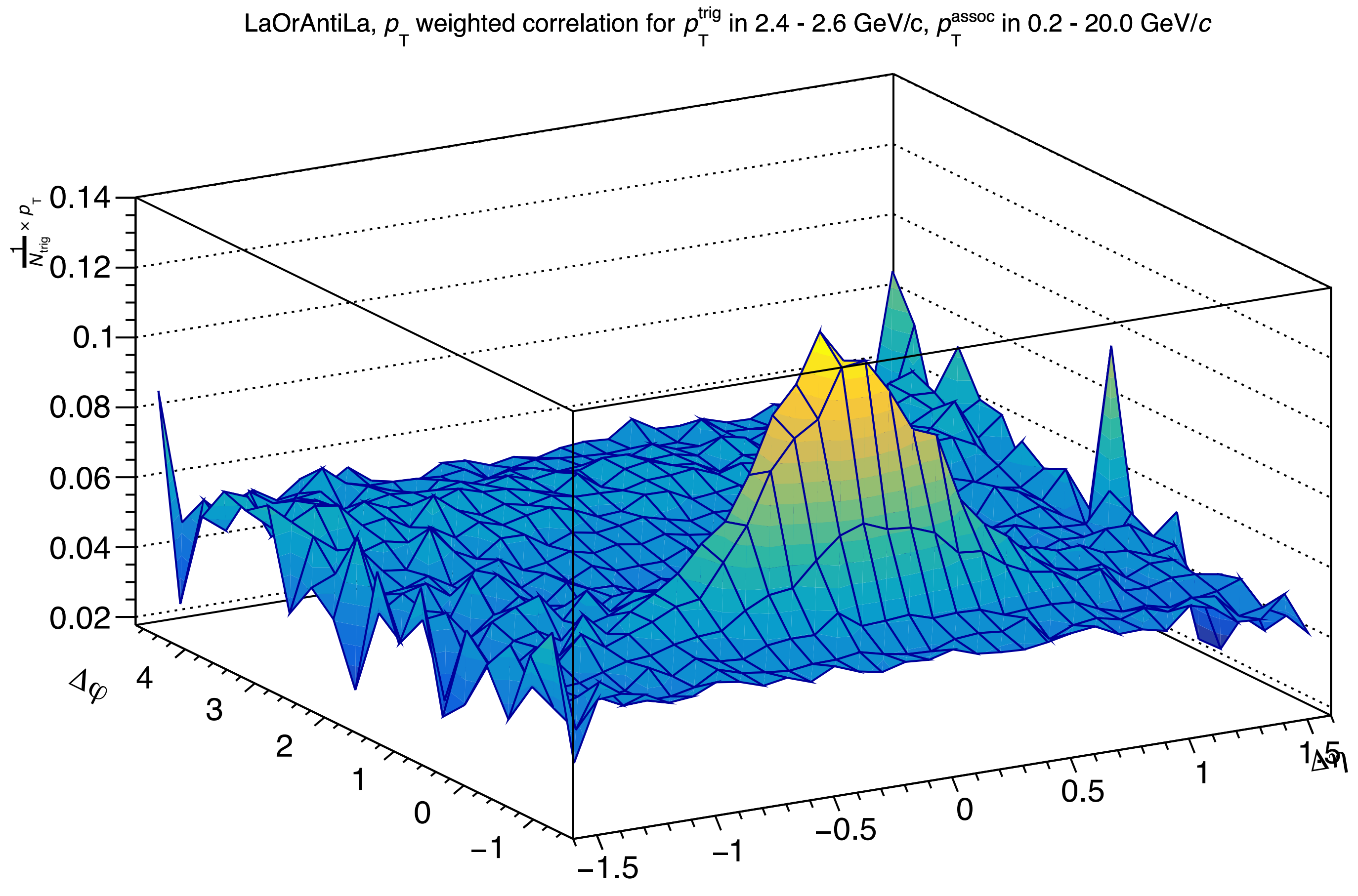
÷




2D Map

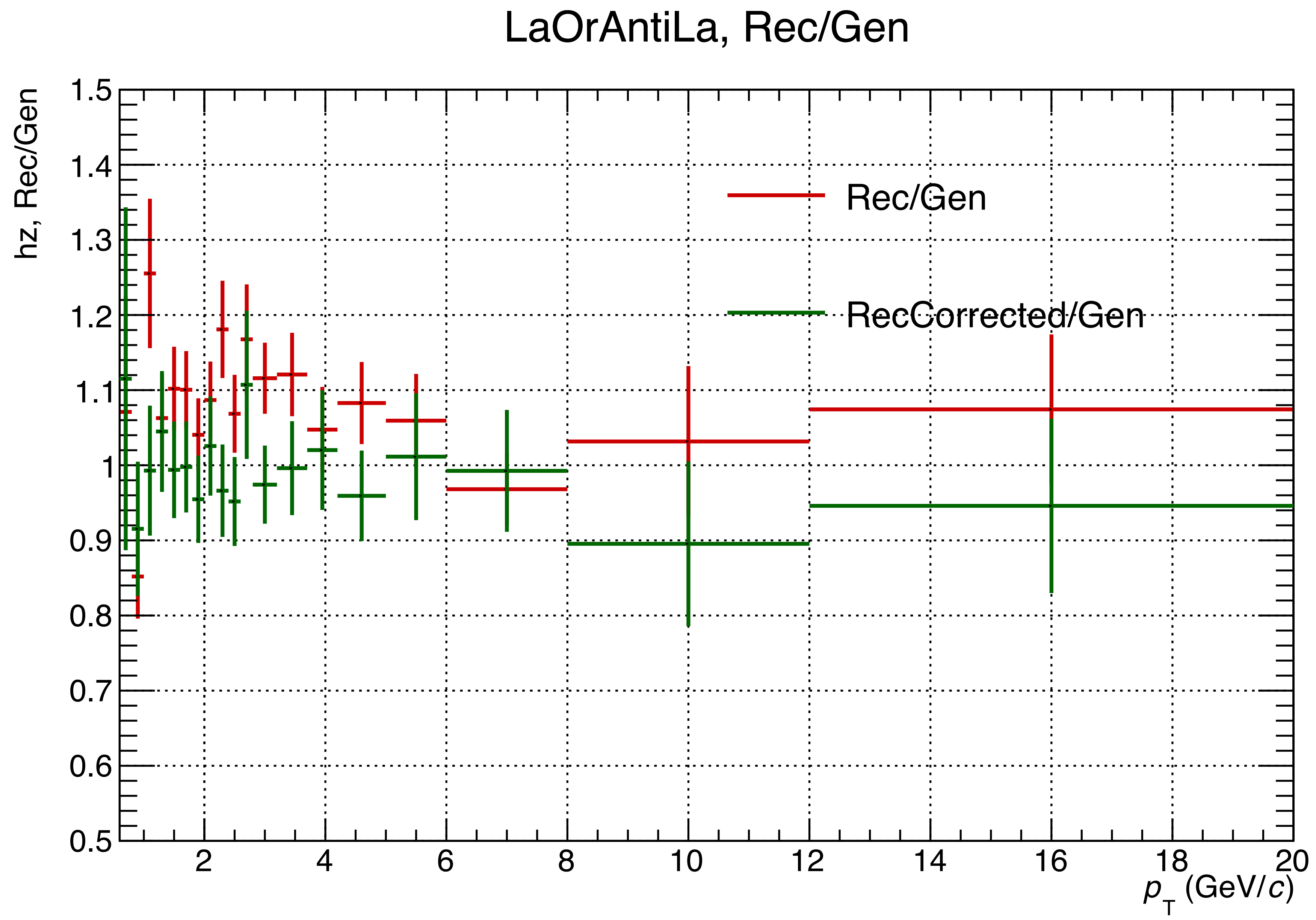
=




rec corrected

- "Rec Truth" means the results using the reconstructed $\Lambda(\overline{\Lambda})$ with their true kinematics *Ryan' AN*
- LHC20f2b2 (the general proposed MC anchored to LHC16d), # of event: ~27 M

$$C_{\text{wgt}}^{\text{uncorrected for 2D map}} \times \left( \frac{C_{\text{wgt}}^{\text{Rec Truth}}}{C_{wgt}^{\text{Gen}}} \right)^{-1} = C_{\text{wgt}}^{\text{corrected for 2D map}}$$




- After the 2D map correction, the MC closure test for $\Lambda(\overline{\Lambda})$ looks better

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# Responses to ARC



- If you find an associated particle with $p_{\mathrm{T}} > p_{\mathrm{T,trig}}$, do you consider it for the analysis?
  - ➡ Yes, it's considered. The idea of this analysis is to collect $p_{\mathrm{T}}$ of particles from the same (mini-)jet hadronization/fragmentation as the trigger.
- Do you correct <$z$> for the unmeasured associated particles with $p_{\mathrm{T}} < 0.2$ GeV/$c$?
  - ➡ We did not correct that. At very low $p_{\mathrm{T}}$, the tracking efficiency should introduce addtional uncertainty to the analysis. The observable in current analysis can be labeled as <$z$> w/ $p_{\mathrm{T,assoc}} > 0.2$ GeV/$c$. And it should be a "well-defined" observable for which the analysis condition can be reproduced in MC simulations or theoretical calculations, validating a direct comparison

# Data Sample

| Data | *LHC16d* | *LHC16e* | *LHC16g* | *LHC16h* | *LHC16i* | *LHC16j* | *LHC16k* | *LHC16l* | *LHC16o* | *LHC16p* | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Number of MB Events* (M)** | ***~ 34*** | ***~ 58*** | ***~ 25*** | ***~ 68*** | ***~ 30*** | ***~ 46*** | ***~ 114*** | ***~ 31*** | ***~ 34*** | ***~ 20*** | ***~ 460*** |
| **MC** | LHC20f2b2 | LHC21d4a | LHC21d4a | LHC21d5a | LHC21d4a | LHC21d8a | LHC21d8a/ LHC21d8a_extra | LHC18f1/ LHC18f1_extra | LHC21e1a | LHC21e2a | **Total** |
| ***Number of MC Events* (M)** | ~ 34 | ~ 15 | ~ 7 | ~ 18 | ~ 8 | ~ 12 | ~ 118 | ~ 30 | ~ 9 | ~ 5 | ~ 256 |

| Data | *LHC17c* | *LHC17e* | *LHC17f* | ~~*LHC17g (rejected)*~~ | *LHC17h* | *LHC17i* | *LHC17j* | *LHC17k* | *LHC17l* | *LHC17m* | *LHC17o* | *LHC17r* | **Total** (w/o LHC17g) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Number of MB Events* (M)** | ***~ 9*** | ***~ 10*** | ***~ 9*** | ~~*~ 101*~~ | ***~ 125*** | ***~ 44*** | ***~ 38*** | ***~ 79*** | ***~ 66*** | ***~ 72*** | ***~ 96*** | ***~ 24*** | ***~ 572*** |
| **MC** | LHC21g4a | LHC21g4a | LHC21g4a | ~~LHC21g3a~~ | LHC21g1a | LHC21g2a | LHC21g4a | LHC21i4a | LHC21h1a | LHC21i5a | LHC21i6a | LHC21h2a | **Total** (w/o LHC17g) |
| ***Number of MC Events* (M)** | ~ 2 | ~ 2 | ~ 2 | ~~~ 23~~ | ~ 32 | ~ 13 | ~ 9 | ~ 27 | ~ 16 | ~ 22 | ~ 26 | ~ 7 | ~ 158 |

| Data | *LHC18b* | ~~*LHC18c (rejected)*~~ | *LHC18d* | *LHC18e* | *LHC18f* | *LHC18g* | *LHC18h* | *LHC18i* | *LHC18j* | *LHC18k* | *LHC18l* | *LHC18m* | *LHC18o* | *LHC18p* | **Total** (w/o LHC18c) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Number of MB Events* (M)** | ***~ 170*** | ~~*~ 208*~~ | ***~ 37*** | ***~ 47*** | ***~ 51*** | ***~ 8*** | ***~ 3*** | ***~ 51*** | ***~ 0.07*** | ***~ 9*** | ***~ 65*** | ***~ 181*** | ***~ 27*** | ***~ 63*** | ***~ 712*** |
| **MC** | LHC21c6a | ~~LHC21a6a_cent~~ | LHC21c7a | LHC21c8a | LHC21b5a | LHC21d3a | LHC21d3a | LHC21d3a | LHC21d3a | LHC21d3a | LHC21a4a | LHC21a5a | LHC21b4a | LHC21b3a | **Total** (w/o LHC18c) |
| ***Number of MC Events*** | ~ 44 | ~~~ 59~~ | ~ 10 | ~ 13 | ~ 13 | ~ 2 | ~ 0.9 | ~ 13 | ~ 0.02 | ~ 2 | ~ 18 | ~ 7 | ~ 50 | ~ 17 | ~ 190 |

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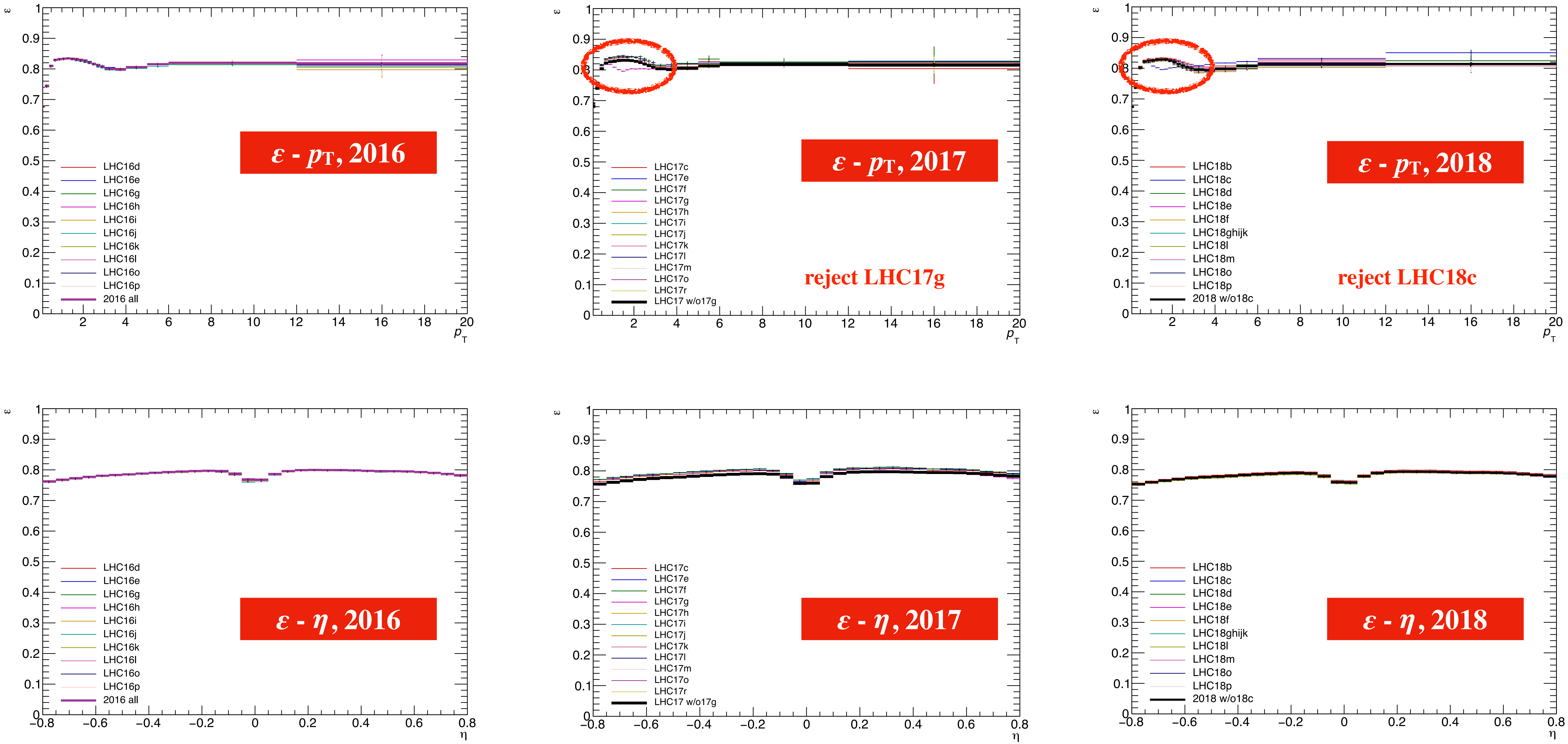
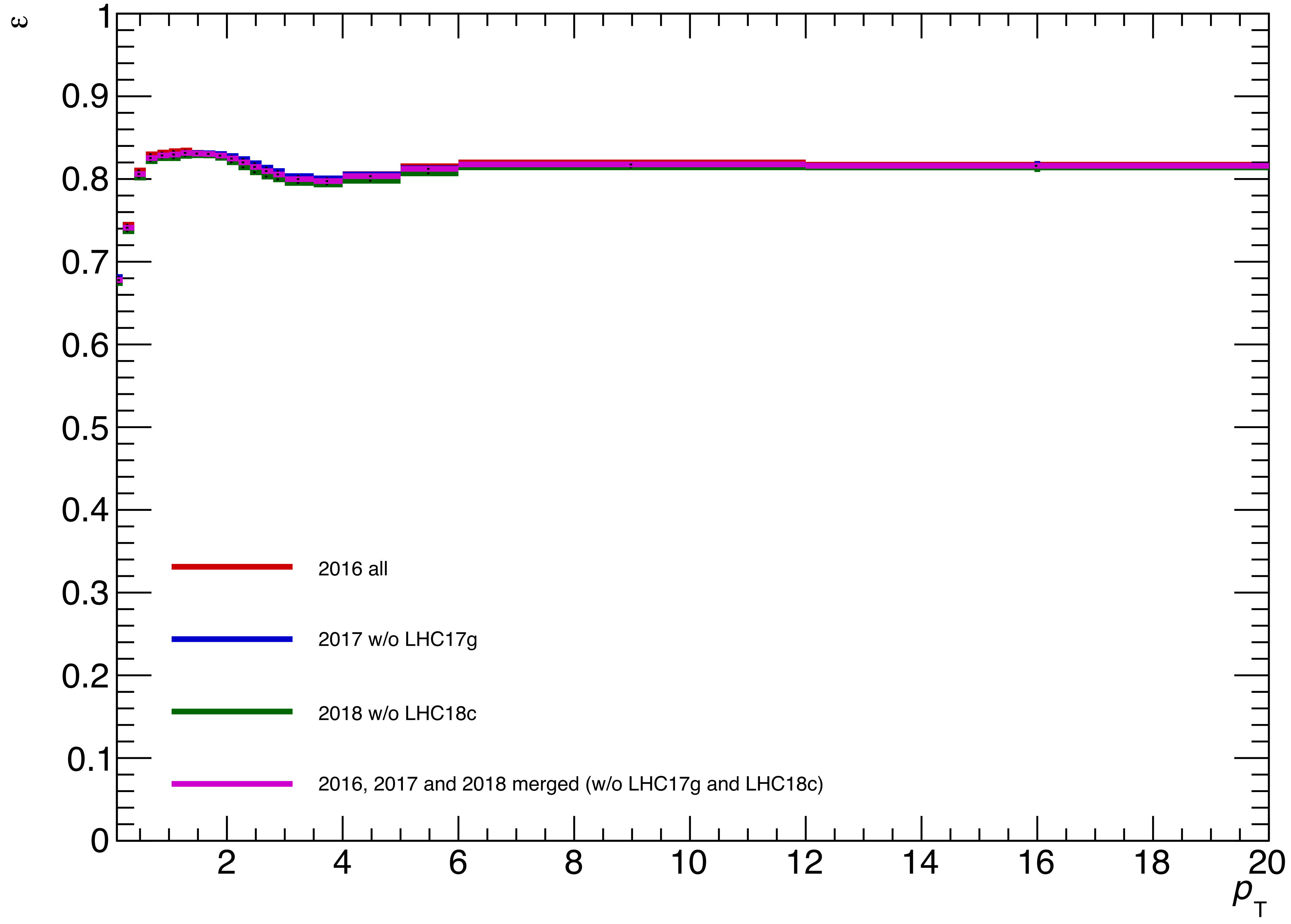
# Tracking efficiency

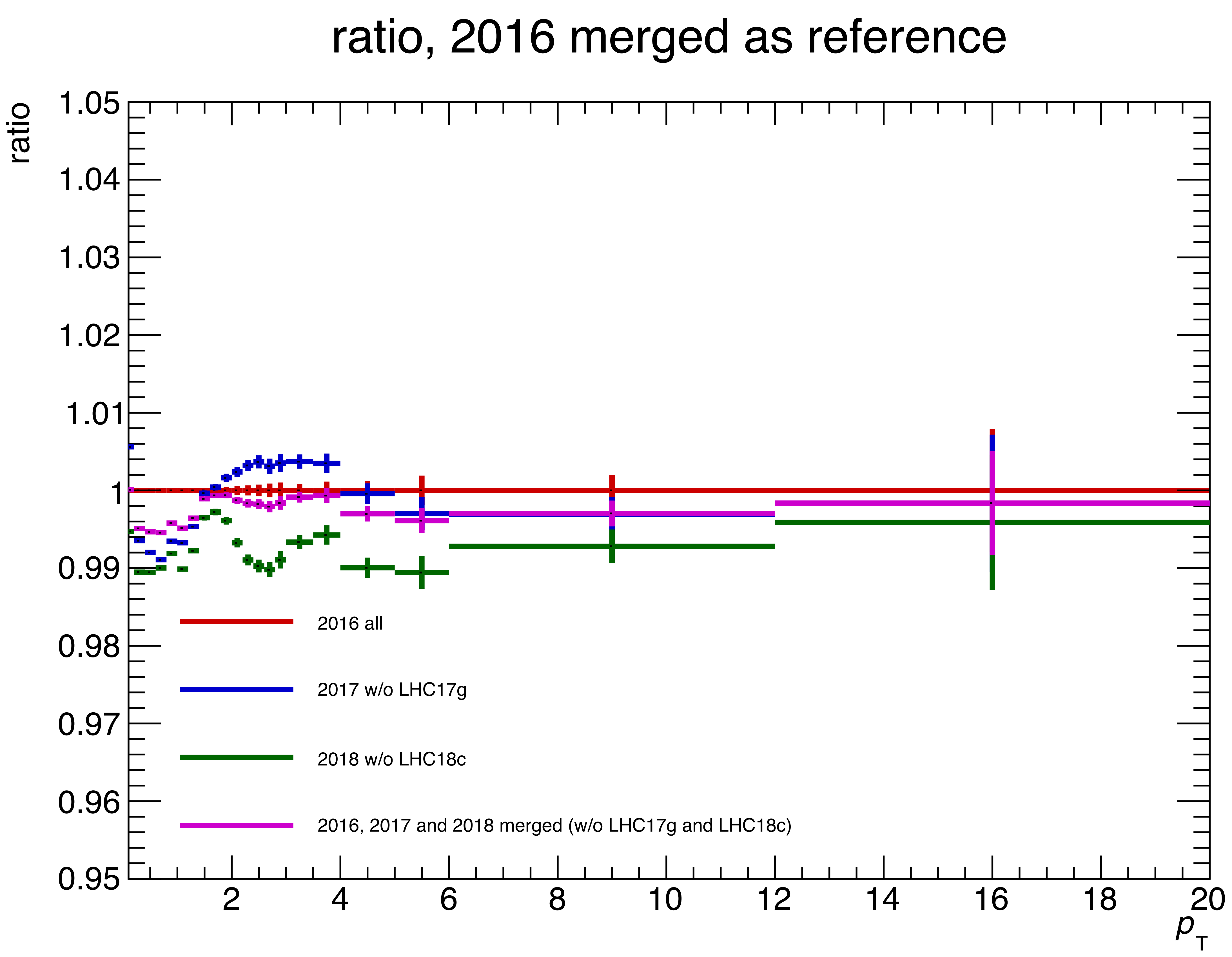





Tracking efficiency for different periods

# Tracking efficiency




- Selected data can be merged
  - ➡ For 2016 data —> include all
  - ➡ For 2017 data —> exclude LHC17g
  - ➡ For 2018 data —> exclude LHC18c

# Analysis details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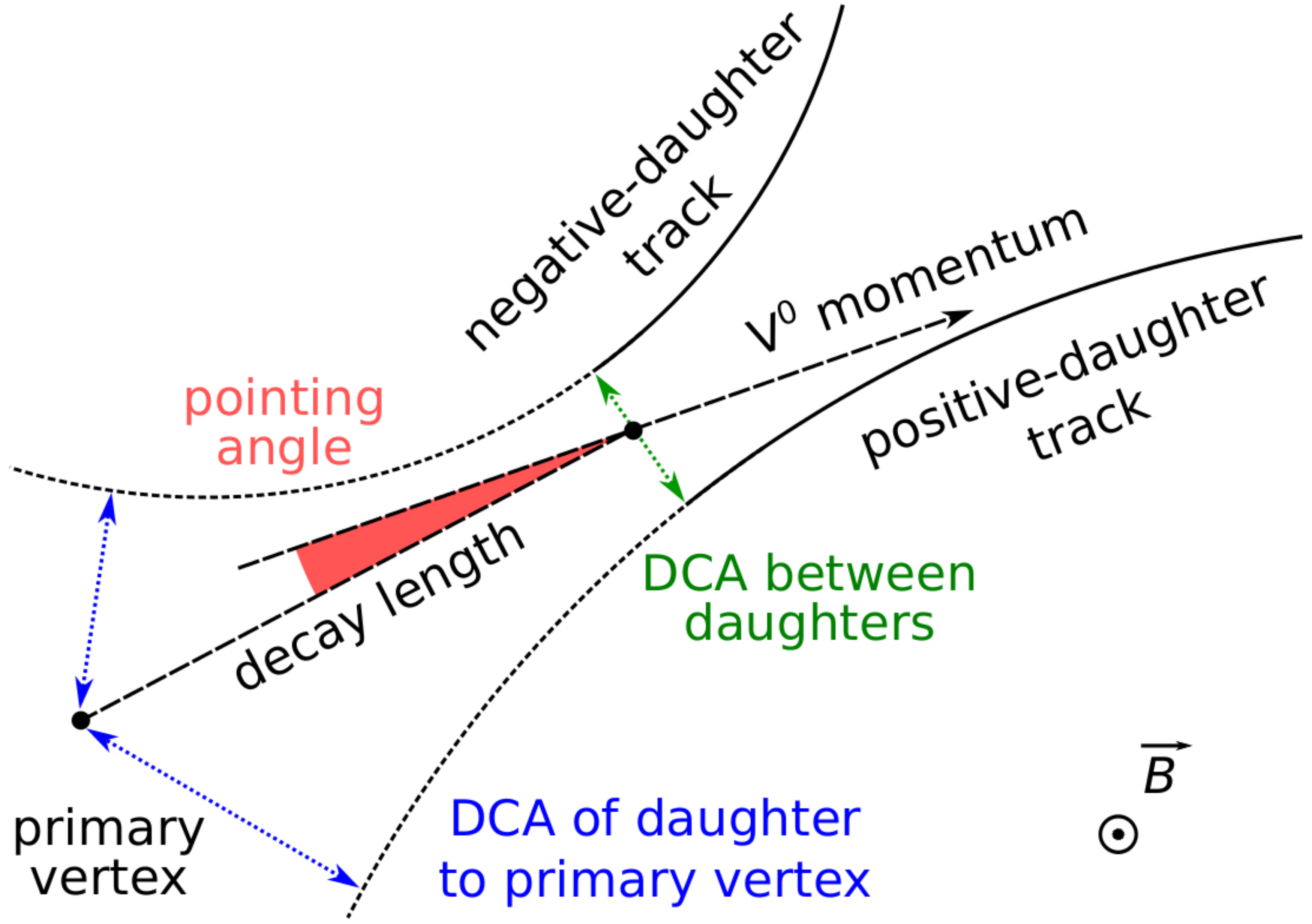
# Trigger topology selection

| *variables* | $K^0_S$ **cut** | $\Lambda(\overline{\Lambda})$ **cut** |
|---|---|---|
| *\|η\| for trigger* | $< 0.75$ | $< 0.75$ |
| *2D decay radius* | $> 0.5$ cm | $> 0.5$ cm |
| *Cosine Pointing Angle* | $> 0.97$ | $> 0.995$ |
| *Proper lifetime(mL/p)* | $< 30$ cm | $< 30$ cm |
| *Competing mass* | $\lvert M_\Lambda - 1.11568 \rvert > 0.005\ \mathrm{GeV}/c^2$ | $\lvert M_{K^0_S} - 0.497614 \rvert > 0.010\ \mathrm{GeV}/c^2$ |
| *Daughter tracks DCA to PV* | $> 0.06$ cm | $> 0.06$ cm |
| *DCA between daughter tracks* | $< 1\sigma$ | $< 1\sigma$ |
| *\|η\| for daughter tracks* | $< 0.8$ | $< 0.8$ |
| *TPC dE/dx* | $< 5\sigma$ | $< 5\sigma$ |

Trigger is reconstructed via the decay products and selected using the decay topology




$$K^0_S \rightarrow \pi^+ + \pi^- \ (B.R.\ 69.2\%)$$
$$\Lambda \rightarrow p + \pi^- \ (B.R.\ 63.9\%)$$
$$\overline{\Lambda} \rightarrow \overline{p} + \pi^+ \ (B.R.\ 63.9\%)$$

A link to strange particle in jet production analysis
**arXiv:2211.08936**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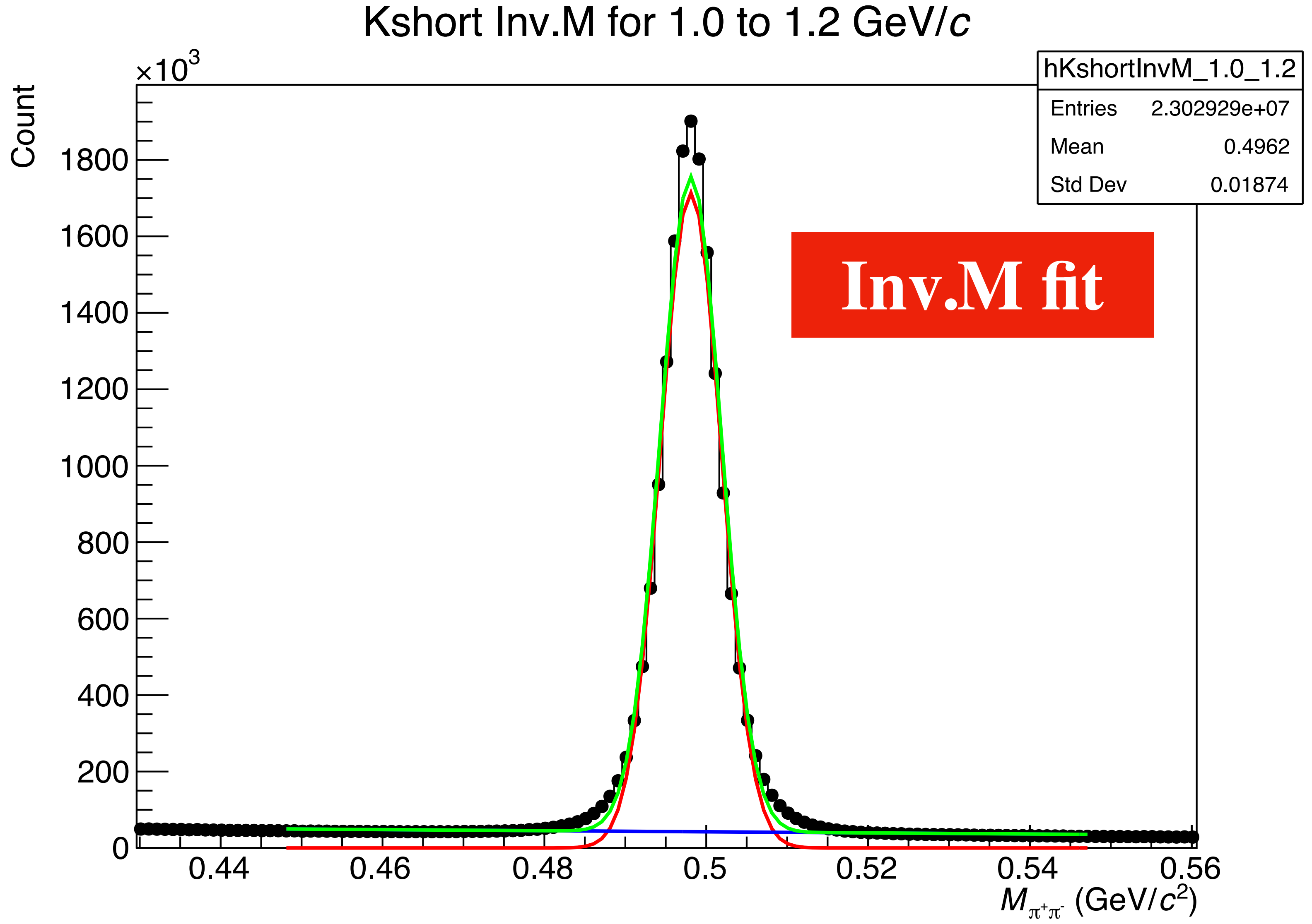
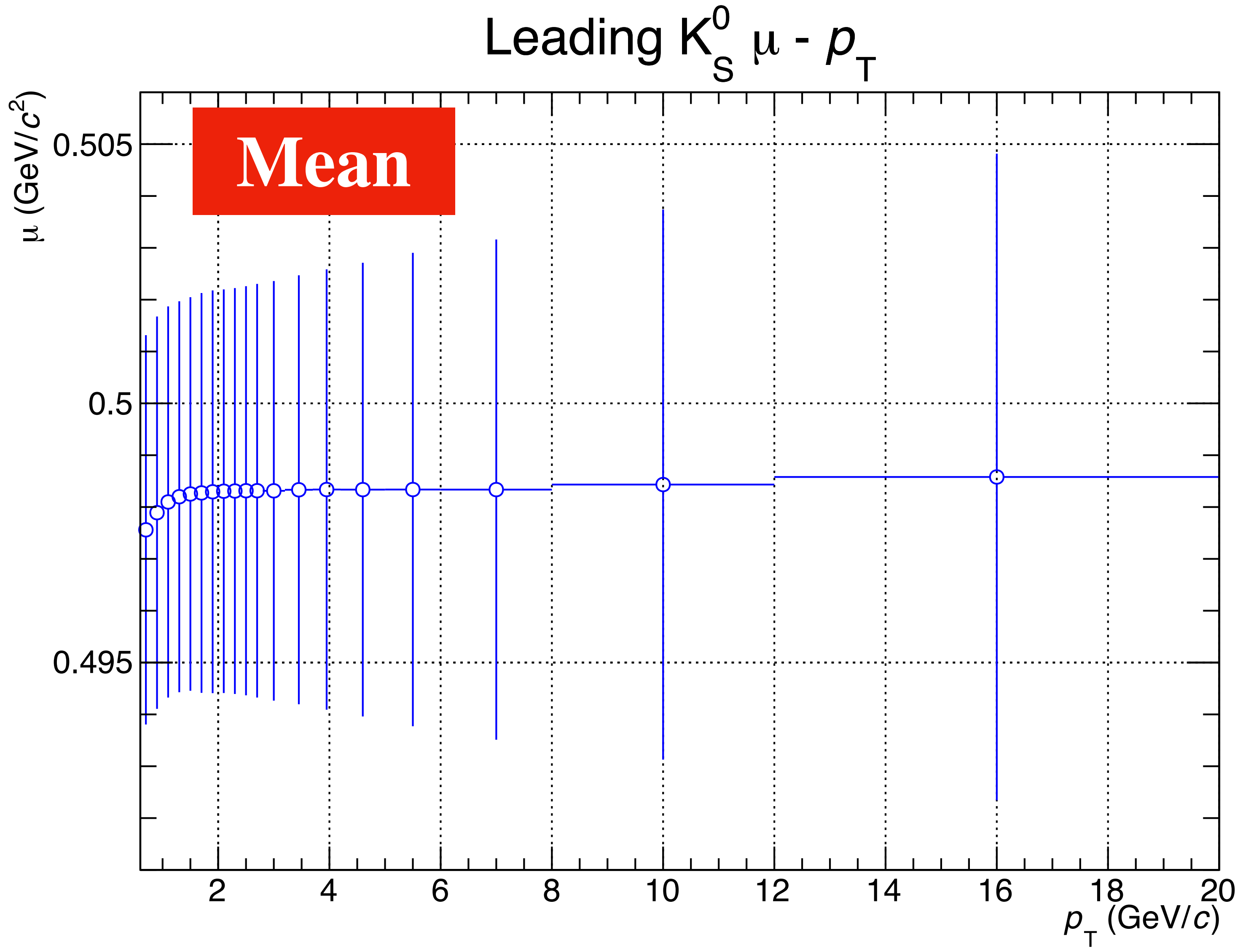
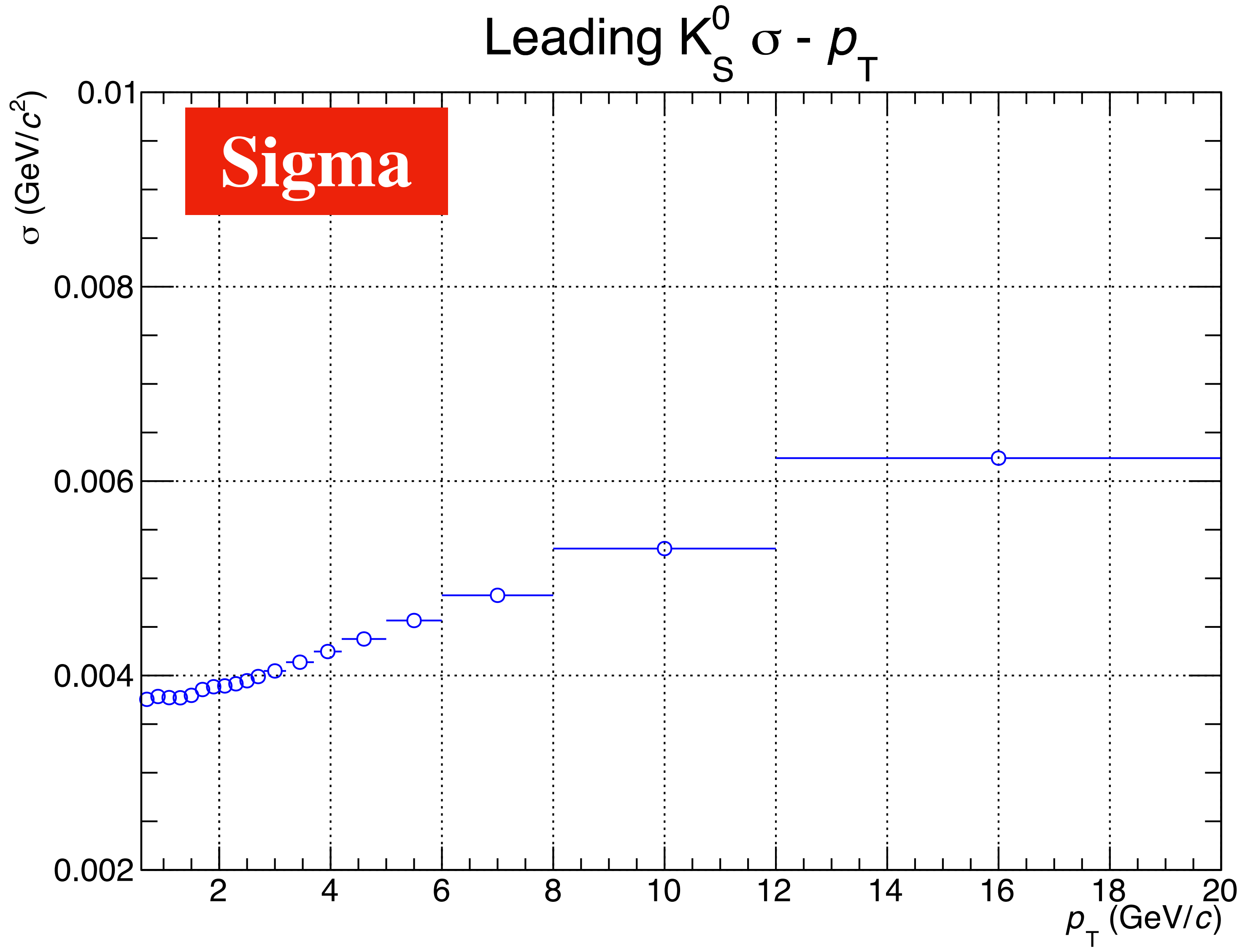
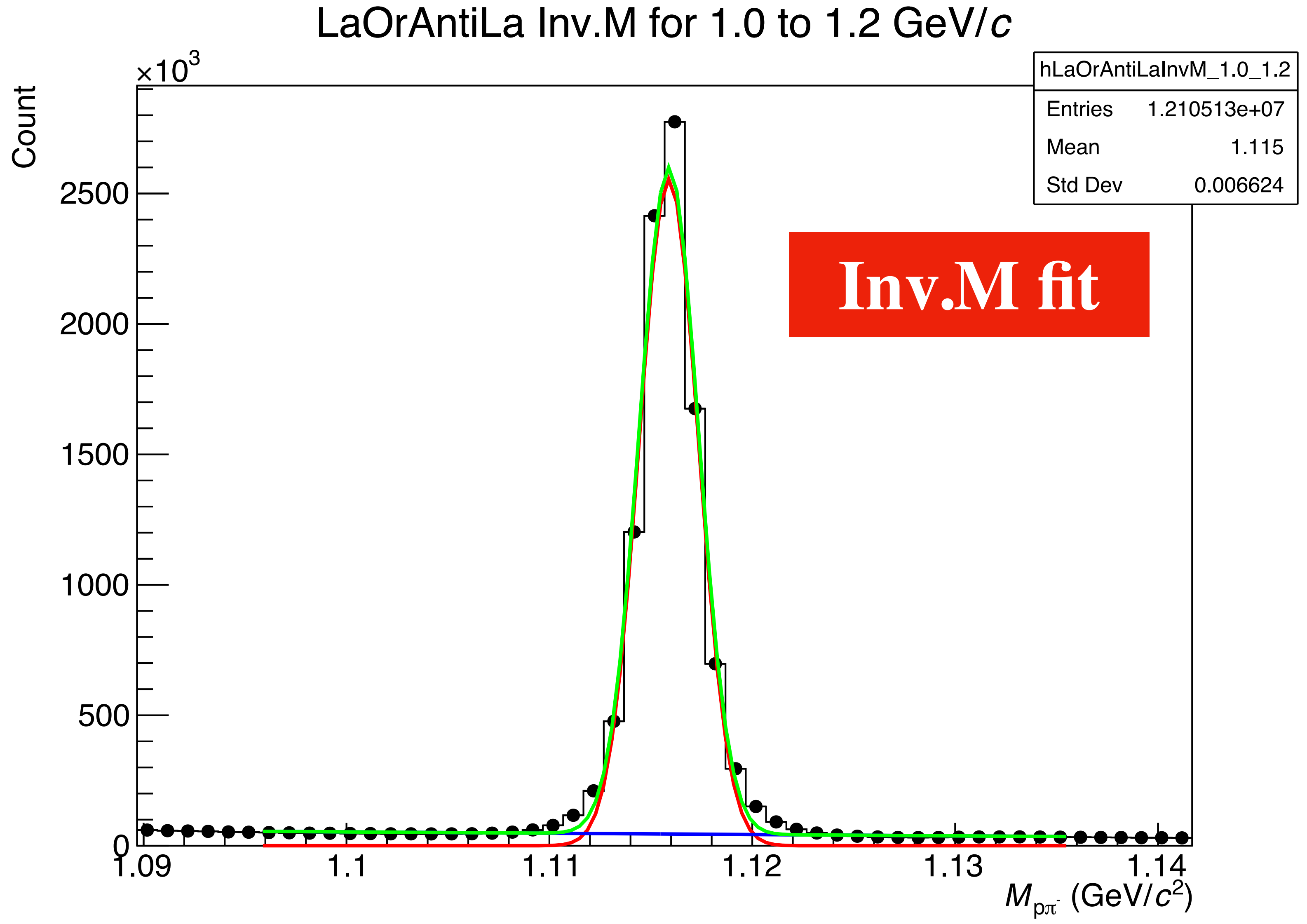
# Trigger selection

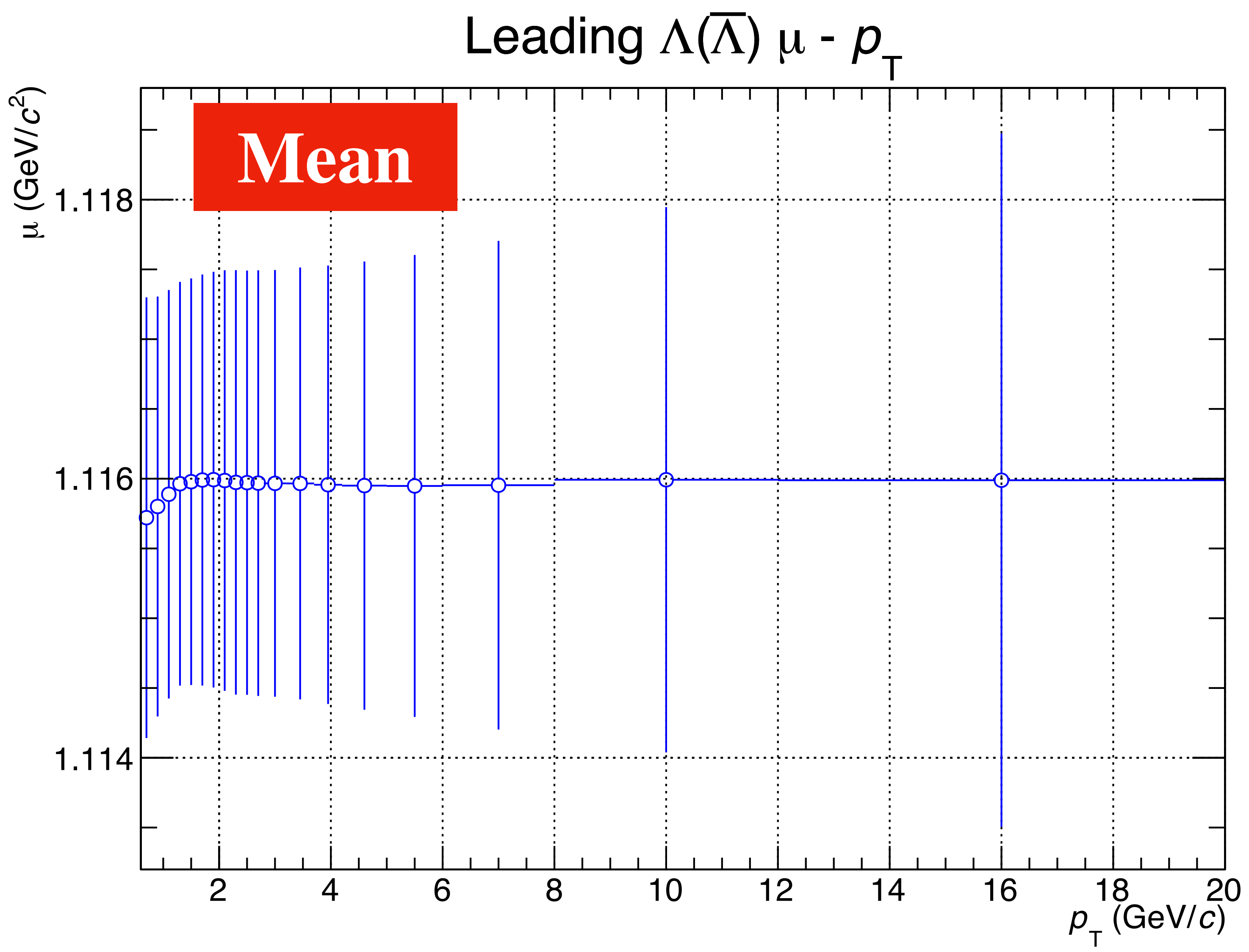


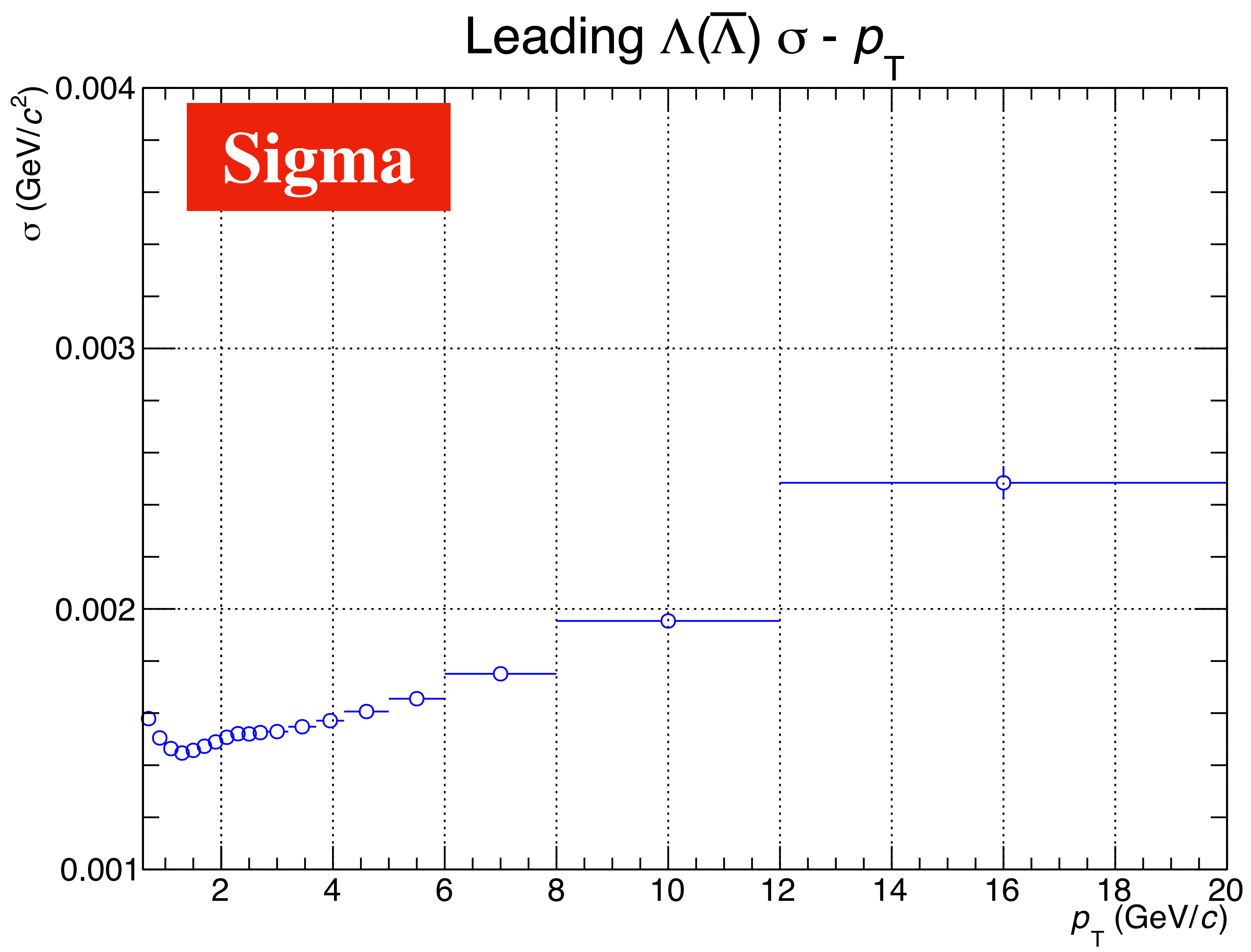



- Signal region: $0 < \left| M_{\text{inv}} - M_{\text{mean}} \right| < 3\sigma$; Sideband regions: $6\sigma < \left| M_{\text{inv}} - M_{\text{mean}} \right| < 9\sigma$

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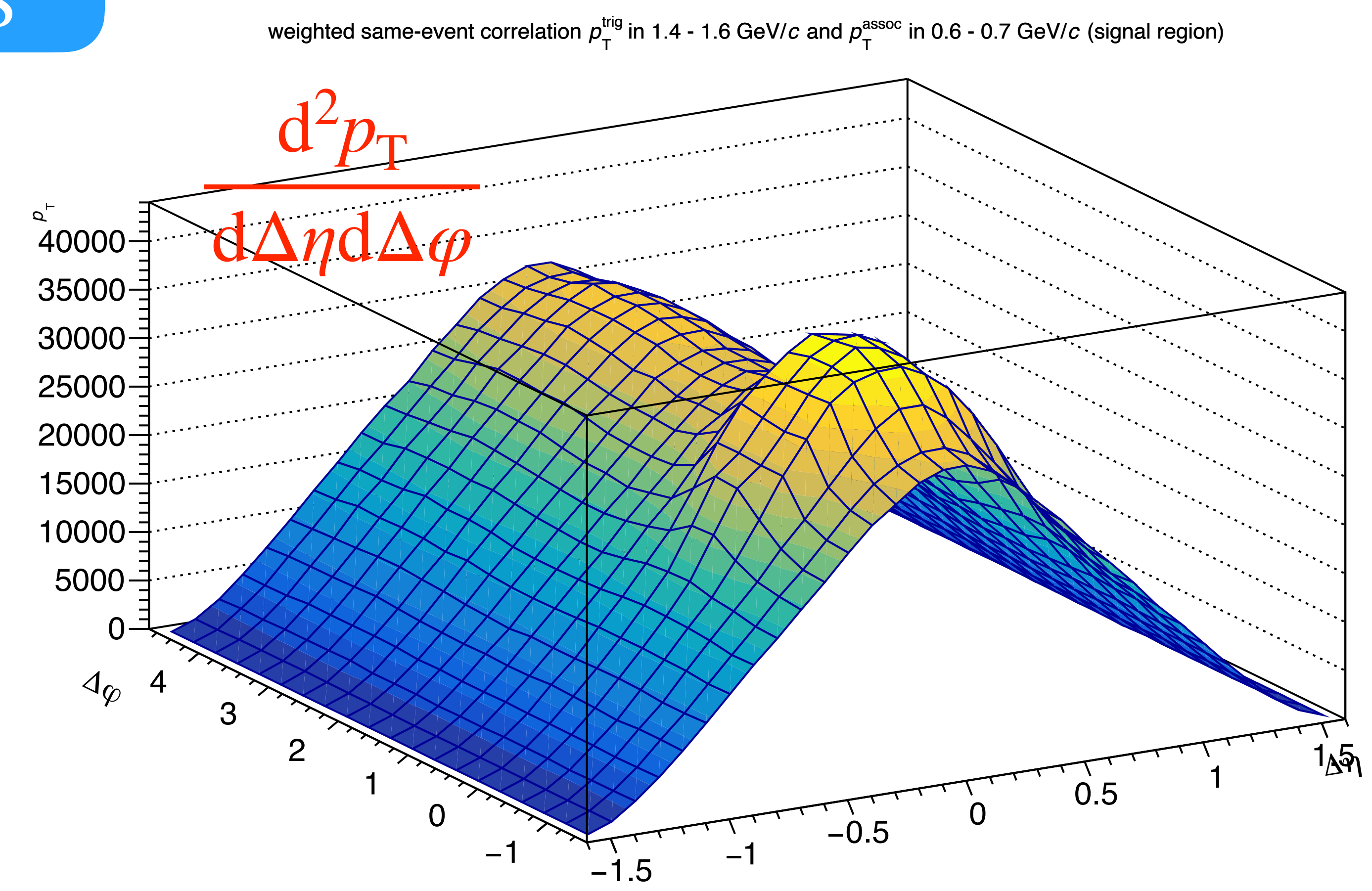
# $p_T$ weighted correlation analysis

$K_S^0$

same event

signal region

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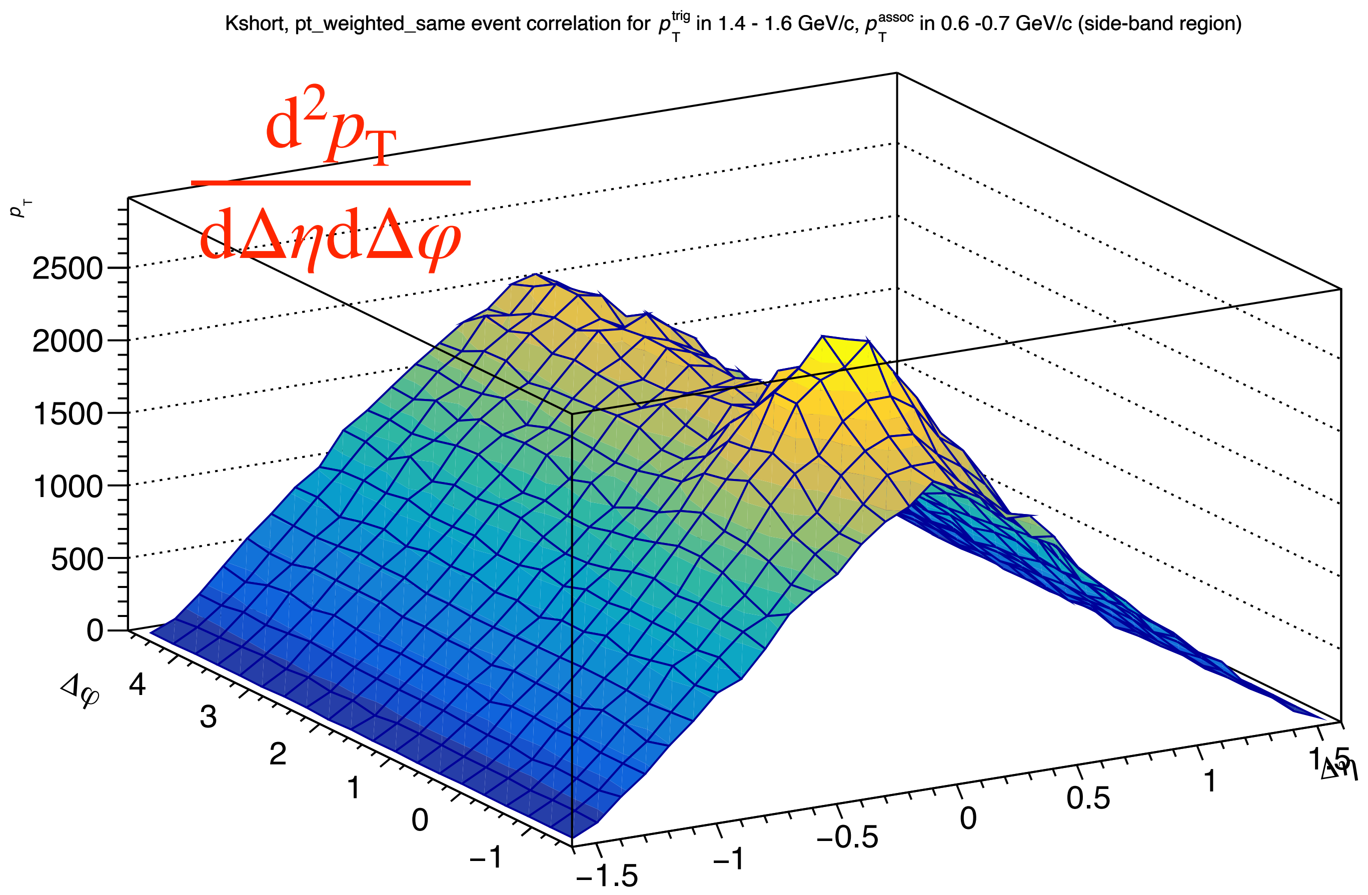
sideband region

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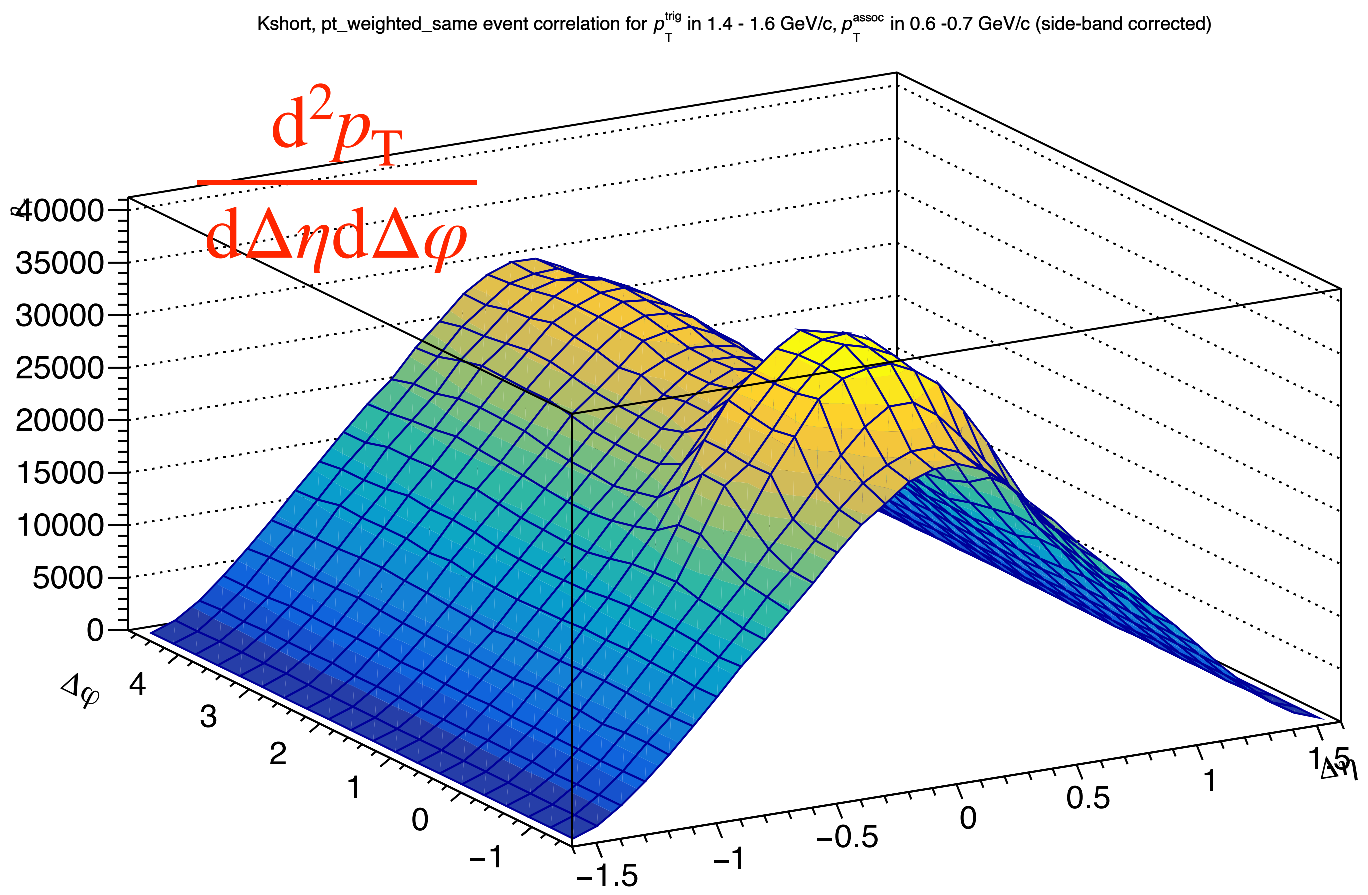
sideband corrected




Example: $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ and $0.6\ \mathrm{GeV}/c < p_T^{assoc} < 0.7\ \mathrm{GeV}/c$, tracking efficiency is considered

## Same event

- $p_{T,\,assoc}$ is used as the weight, weight = $p_{T,\,assoc}$ / $\varepsilon$, where $\varepsilon$ is the tracking efficiency
- Sideband subtraction from Inv.M peak region

# $p_T$ weighted correlation analysis

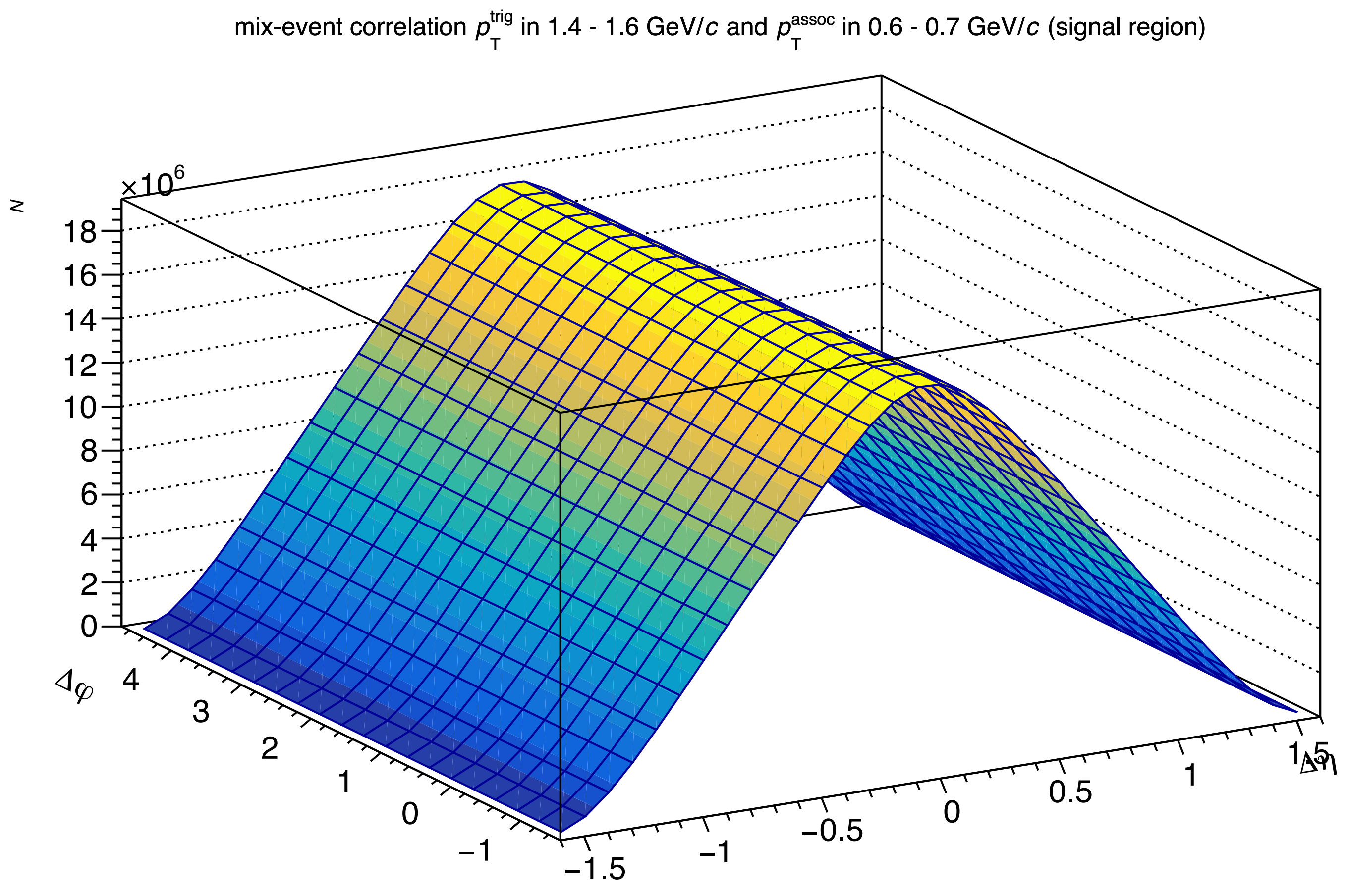
$K_S^0$

**Mix event**

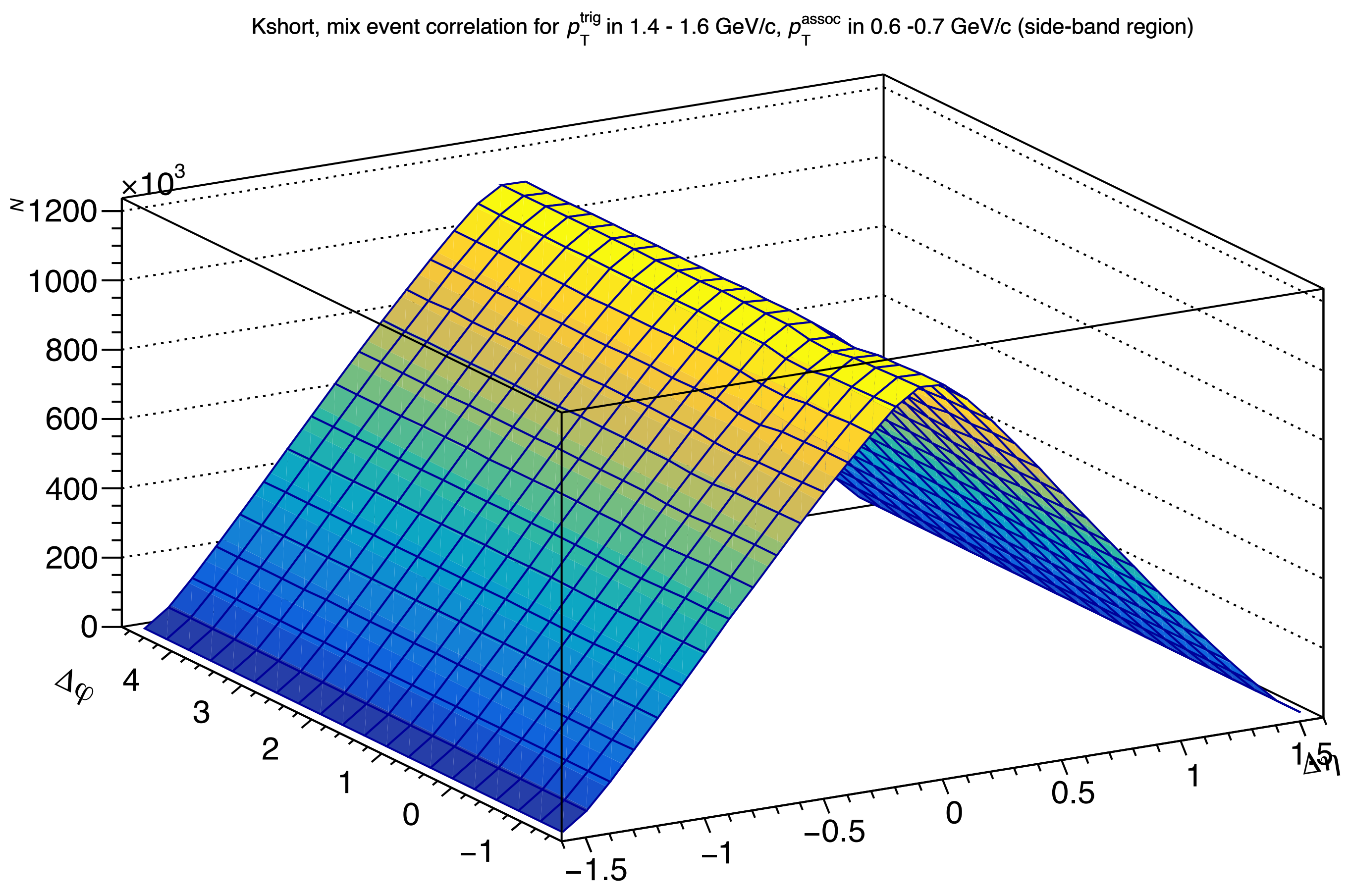
- ME grid: $\Delta z_{vtx} < 2$ cm, no multiplicity dependence is considered
- Same procedures as in the same event, but w/o weight

mix event

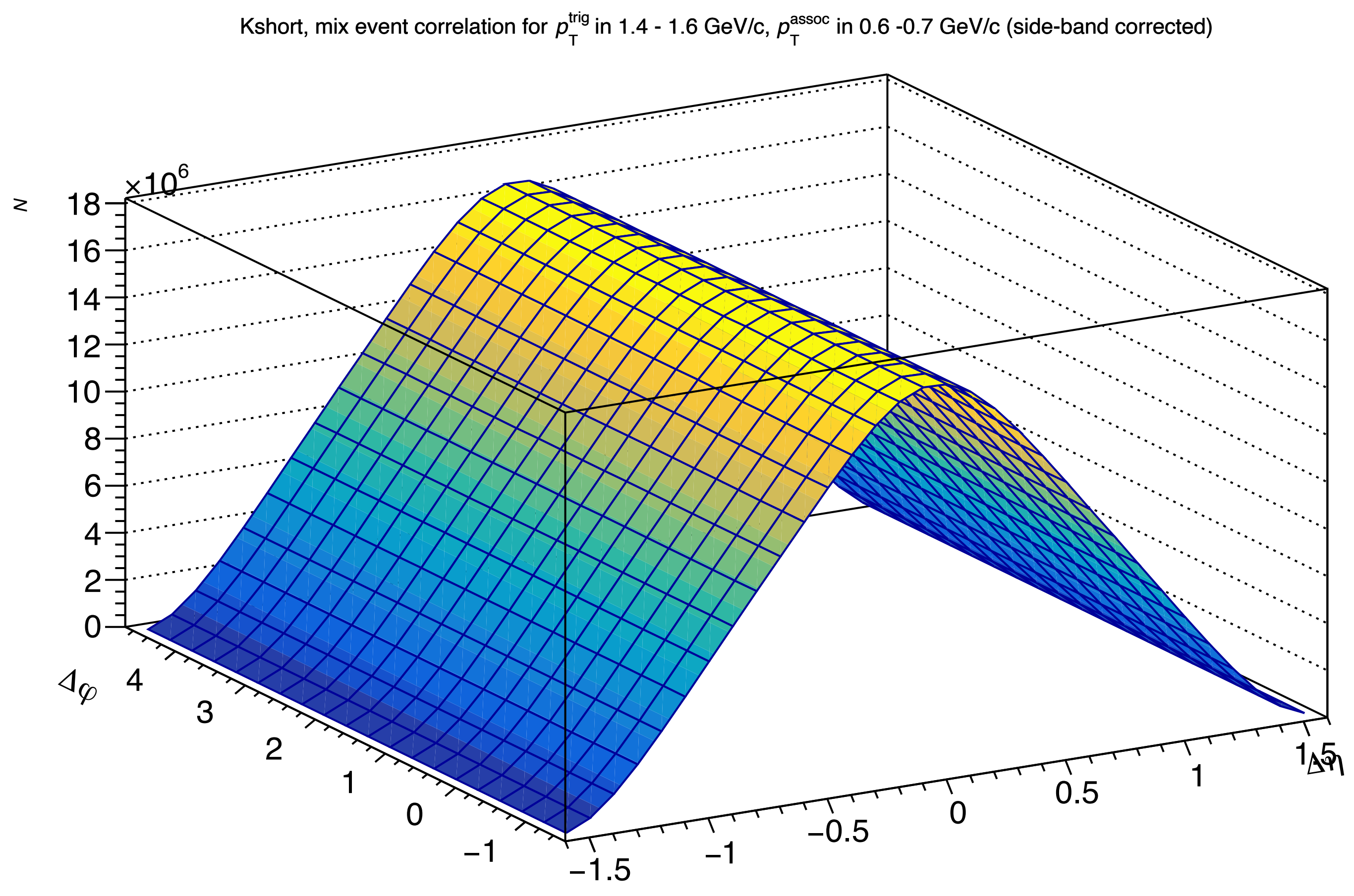
signal region




sideband region




sideband corrected




Example: $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ and $0.6\ \mathrm{GeV}/c < p_T^{assoc} < 0.7\ \mathrm{GeV}/c$

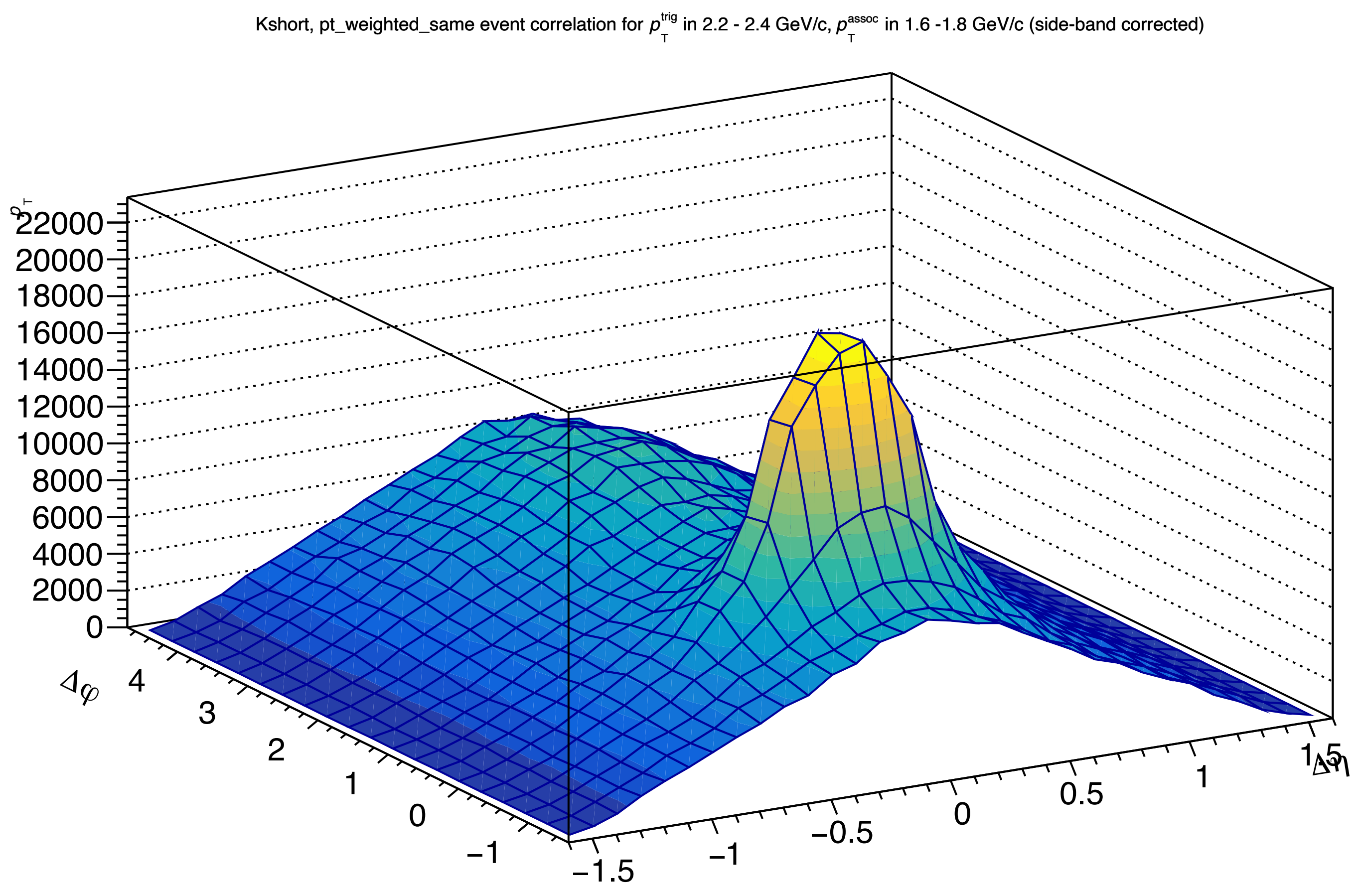
# $p_T$ weighted correlation analysis



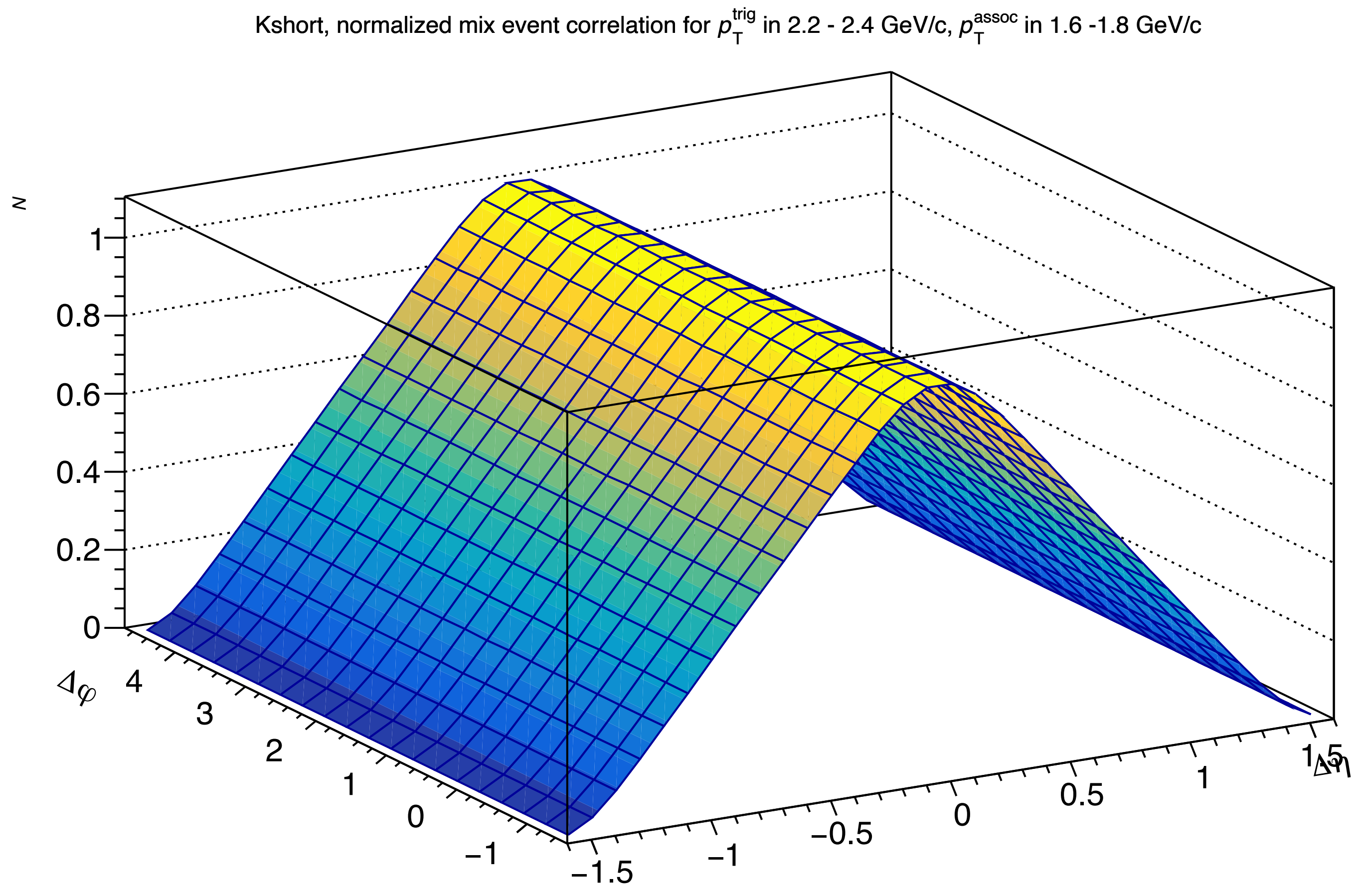
$K_S^0$

$$C = \frac{S}{\frac{1}{\alpha}M}, \text{ where } \alpha \text{ is the average over bins with } \Delta\eta = 0$$

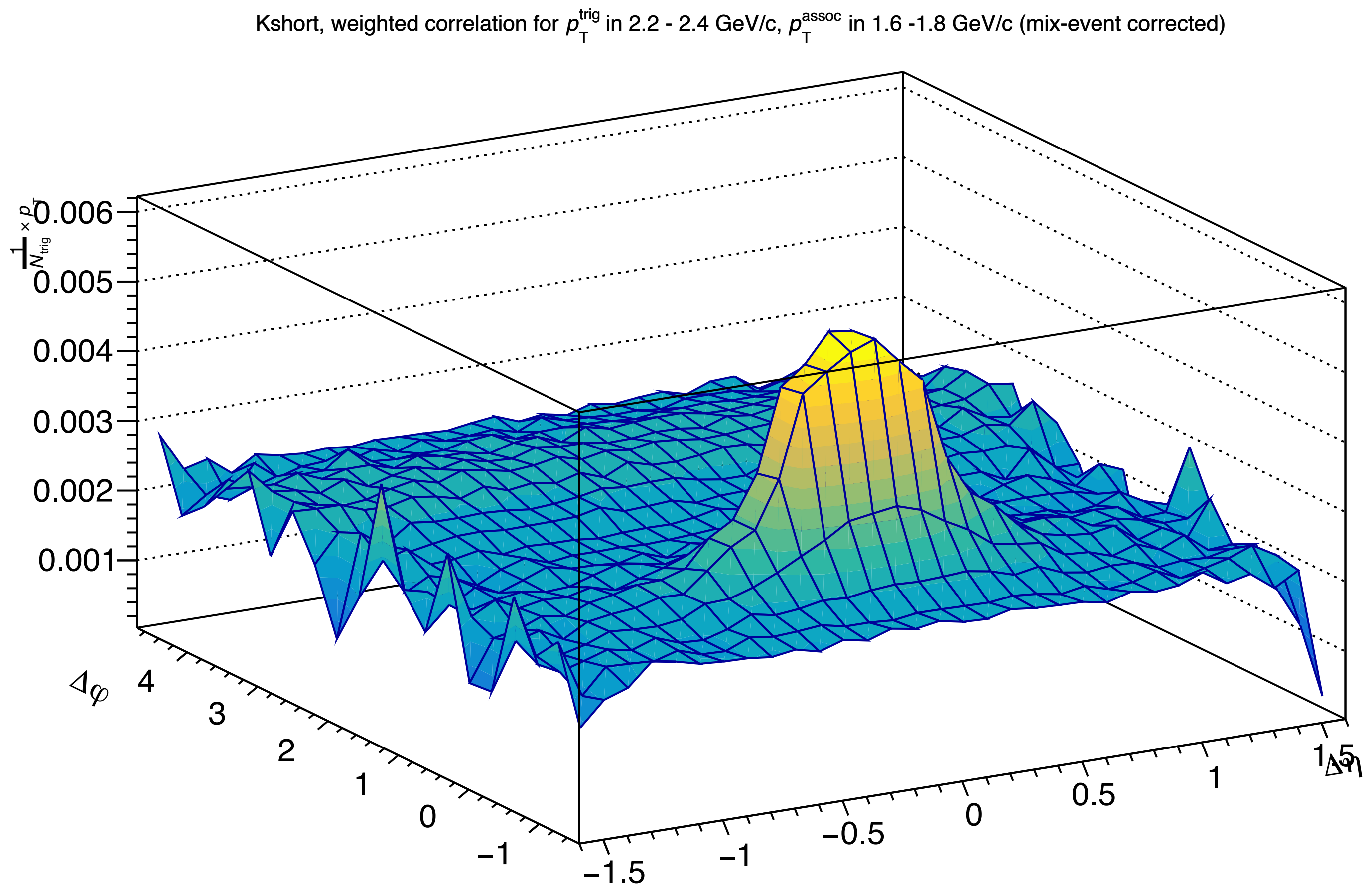
same event (side band corrected)




mix event (side band corrected, normalized)




mix event corrected



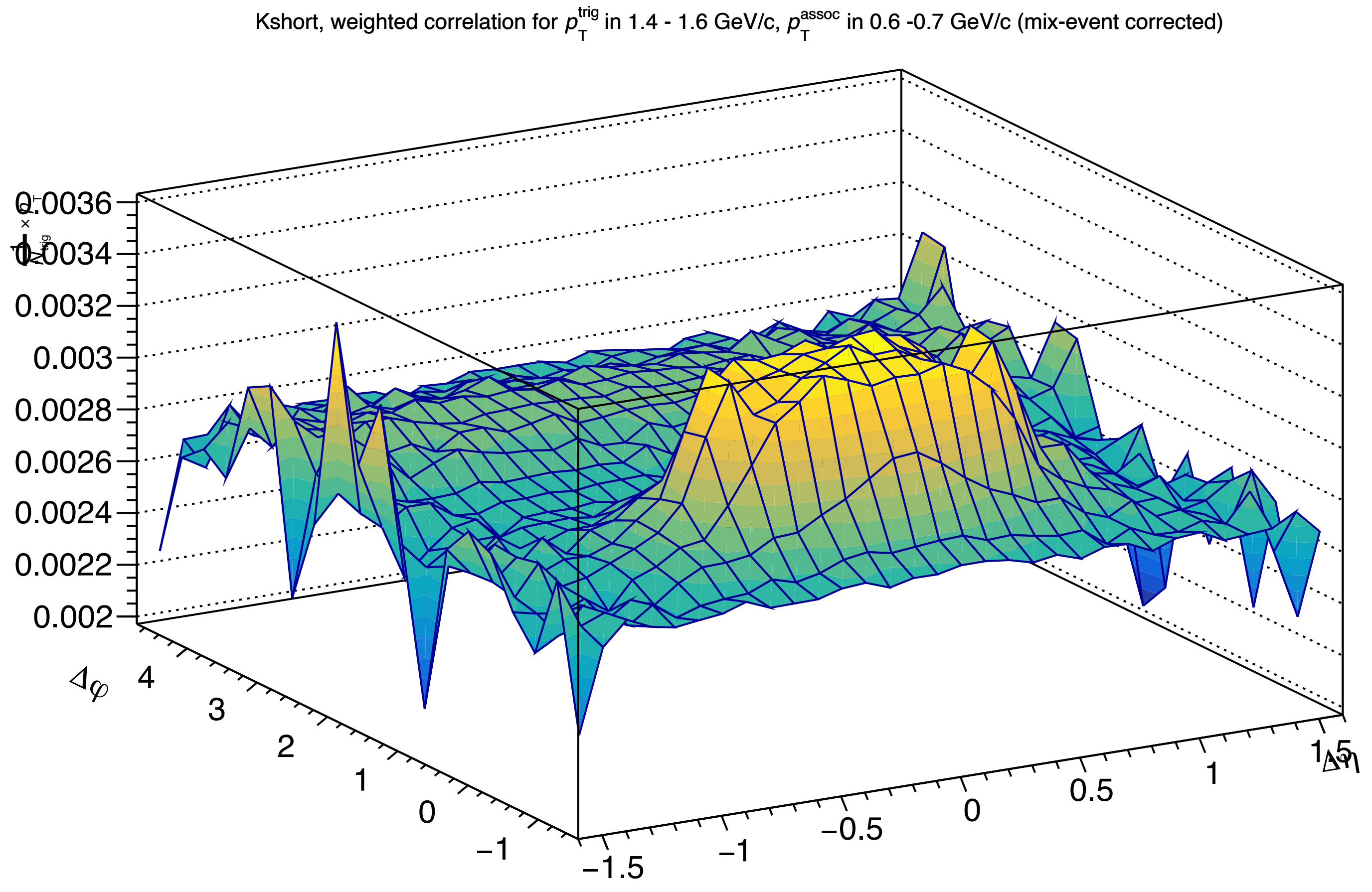

Example: $2.2\ \mathrm{GeV}/c < p_T^{trig} < 2.4\ \mathrm{GeV}/c$ and $1.6\ \mathrm{GeV}/c < p_T^{assoc} < 1.8\ \mathrm{GeV}/c$

# Mix event corrected

$K_S^0$

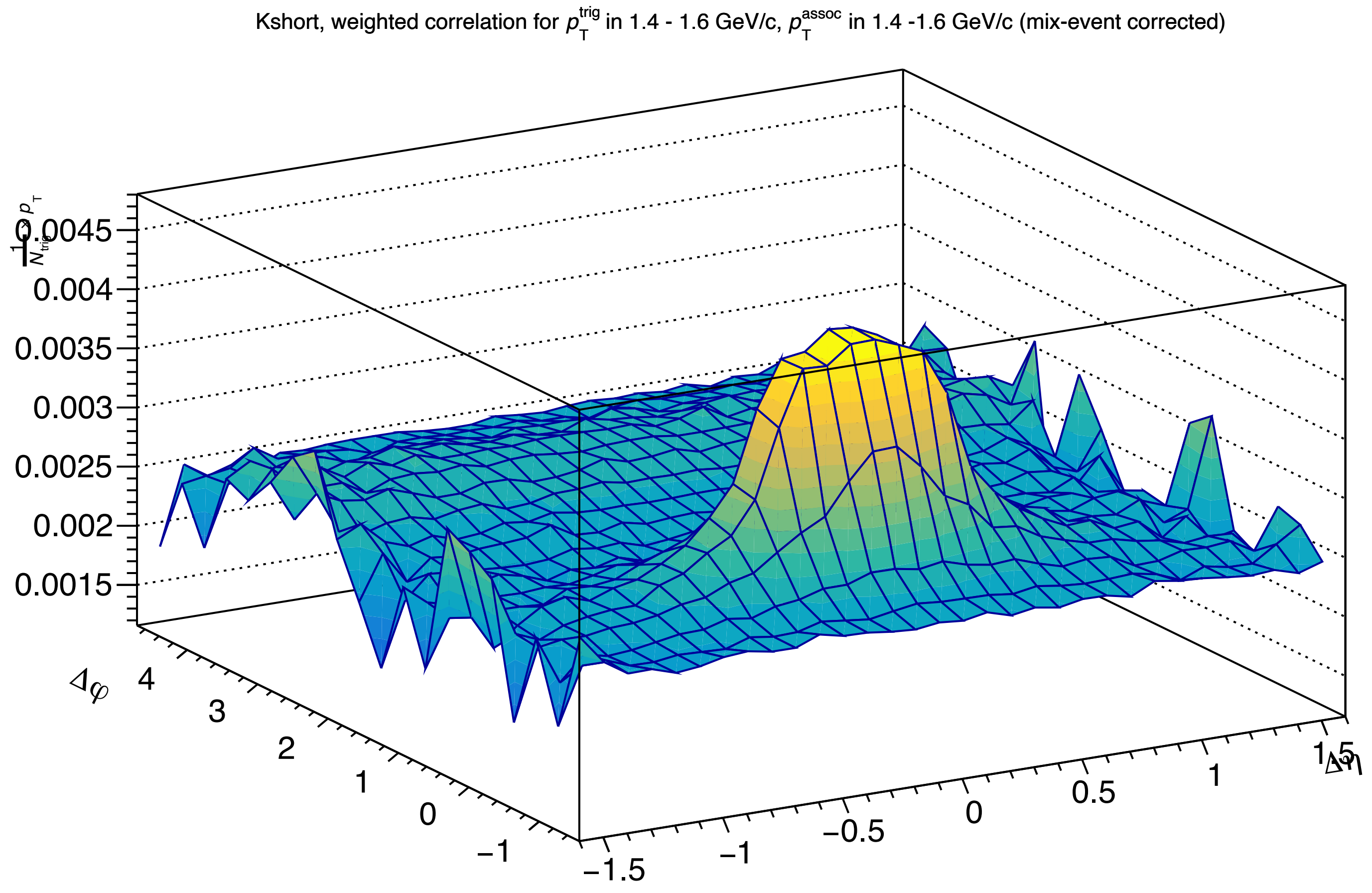
Example: mix-event corrected correlation results for $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ with different $p_T^{assoc}$ bins

$0.6 < p_{T,assoc} < 0.7\ \mathrm{GeV}/c$



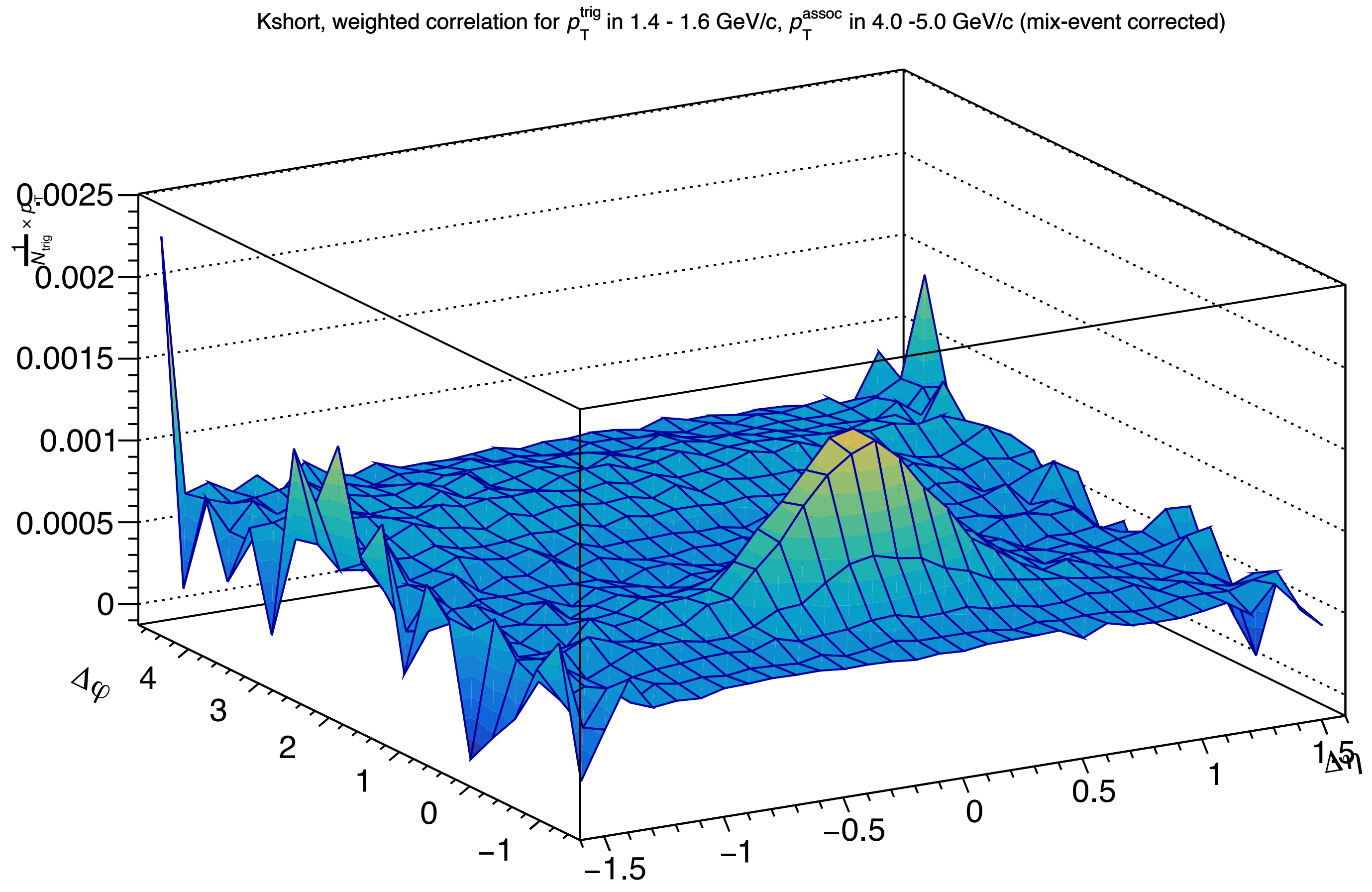

+

$1.4 < p_{T,assoc} < 1.6\ \mathrm{GeV}/c$




+

$4.0 < p_{T,assoc} < 5.0\ \mathrm{GeV}/c$

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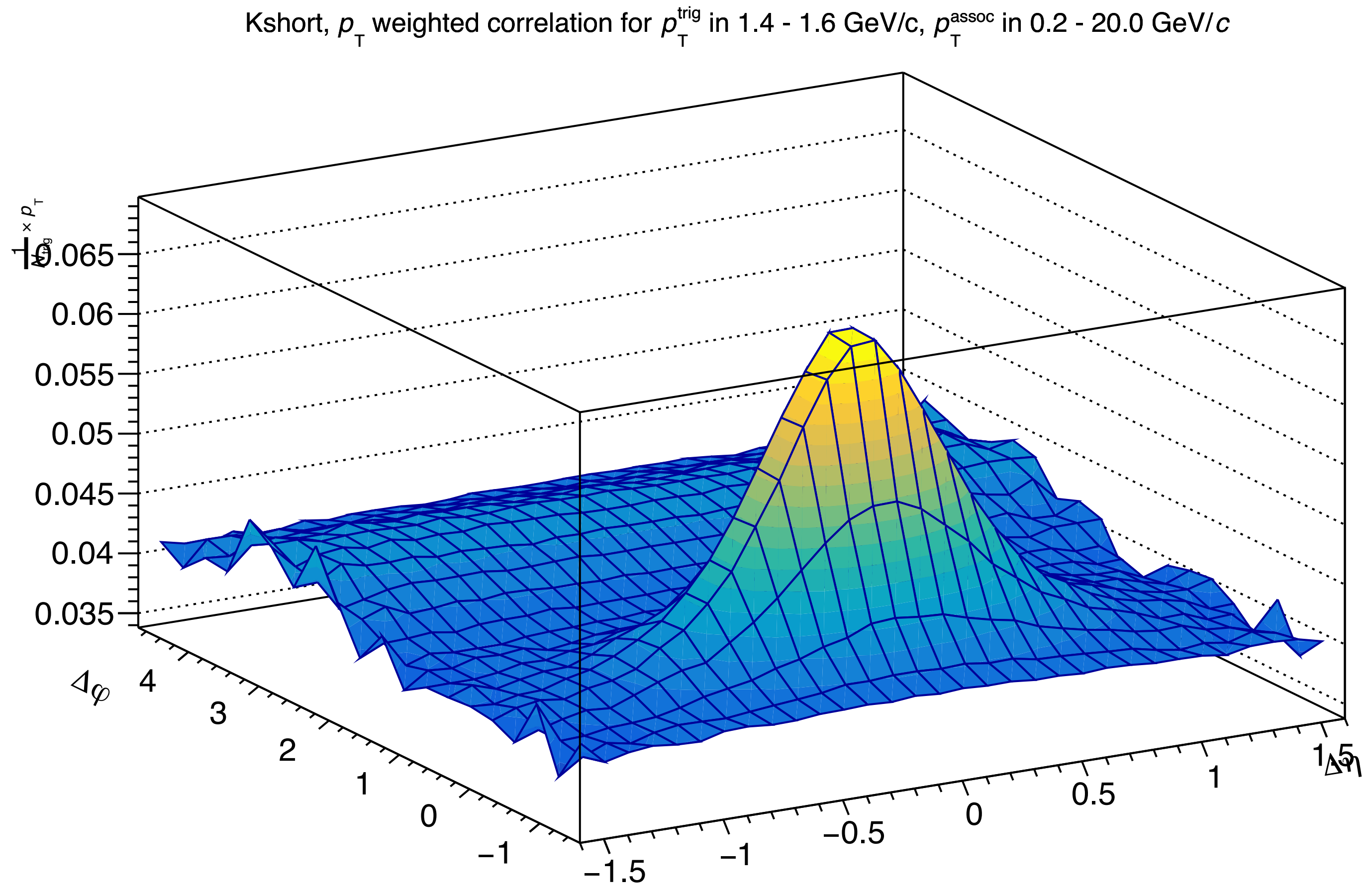
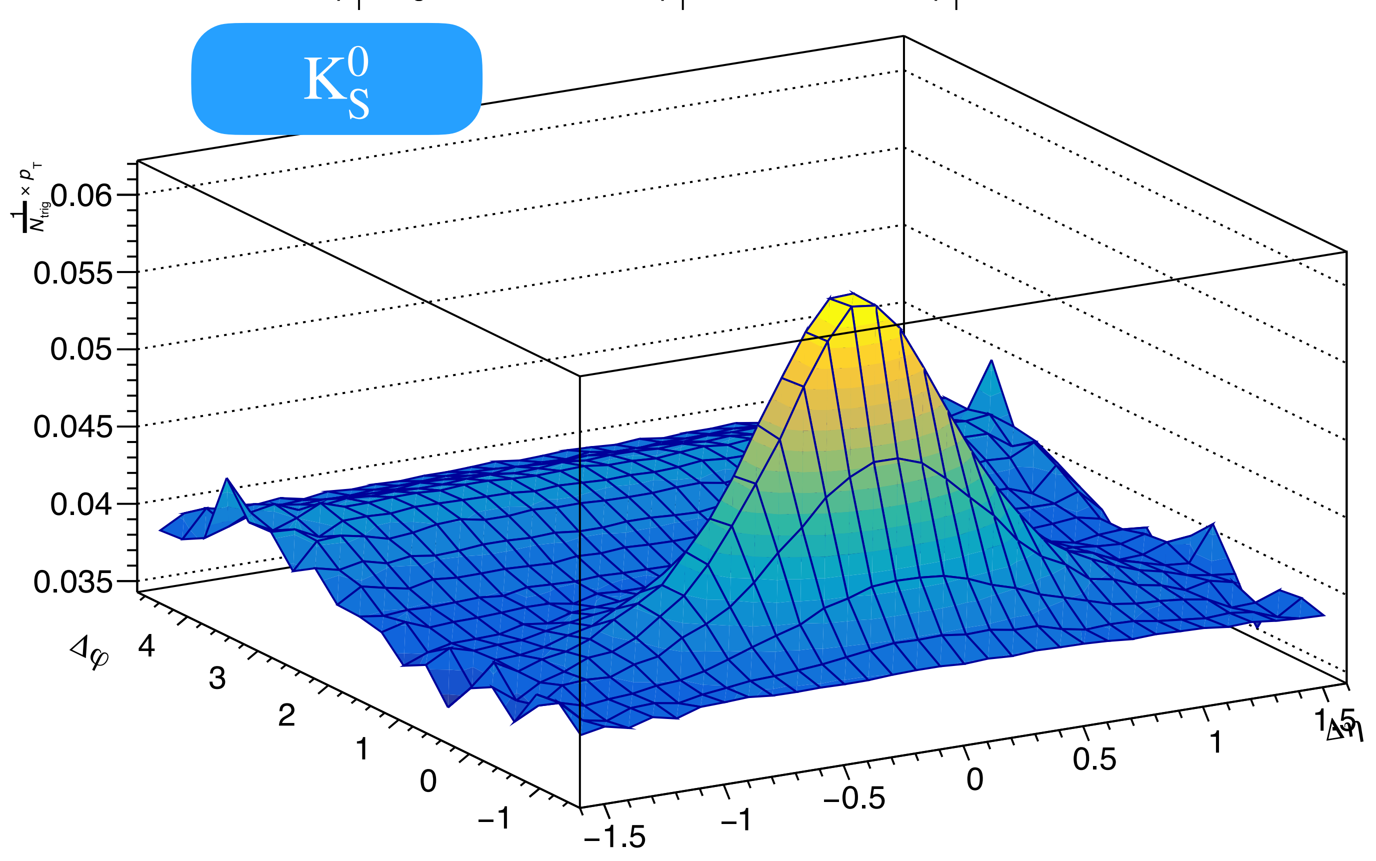
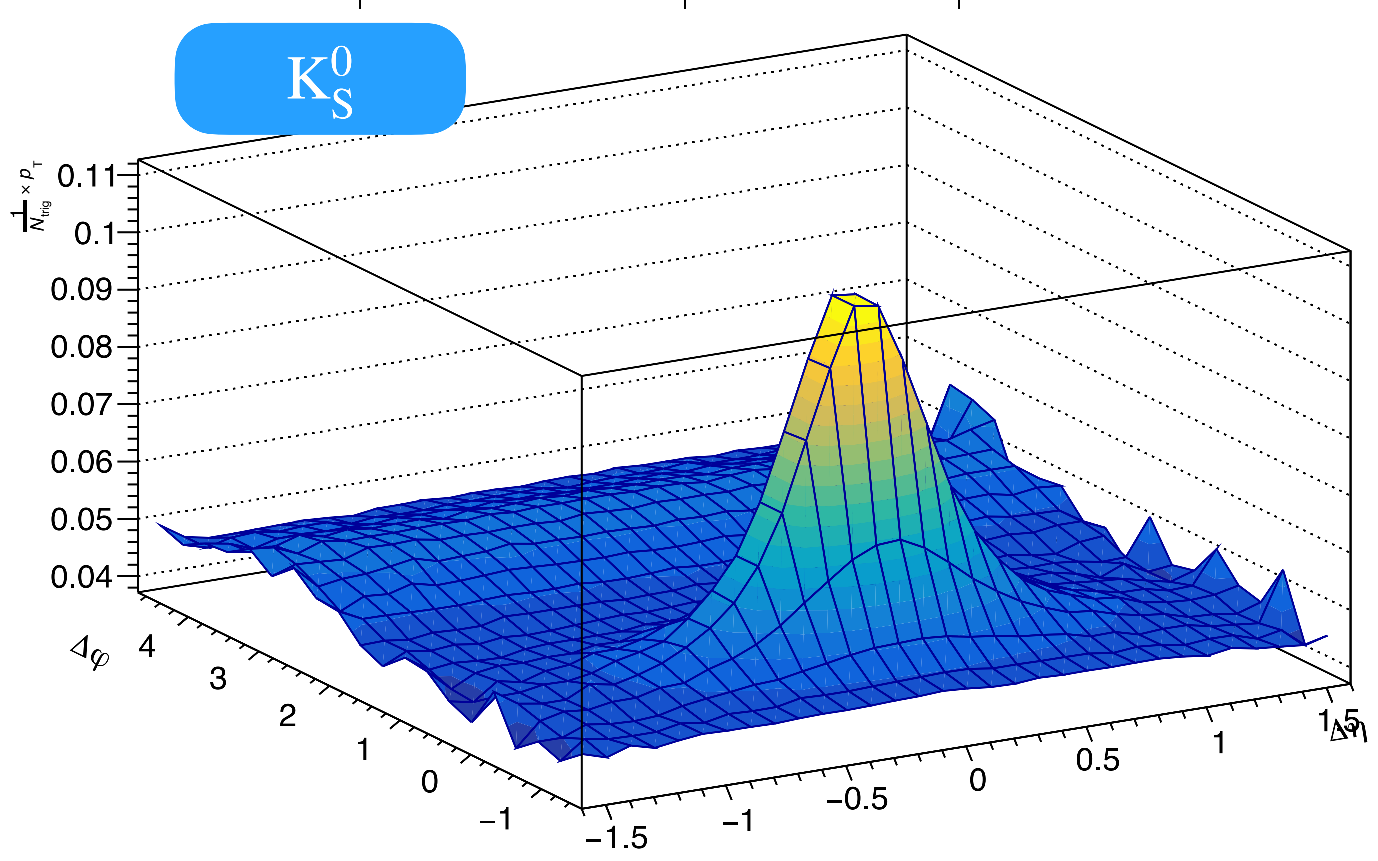


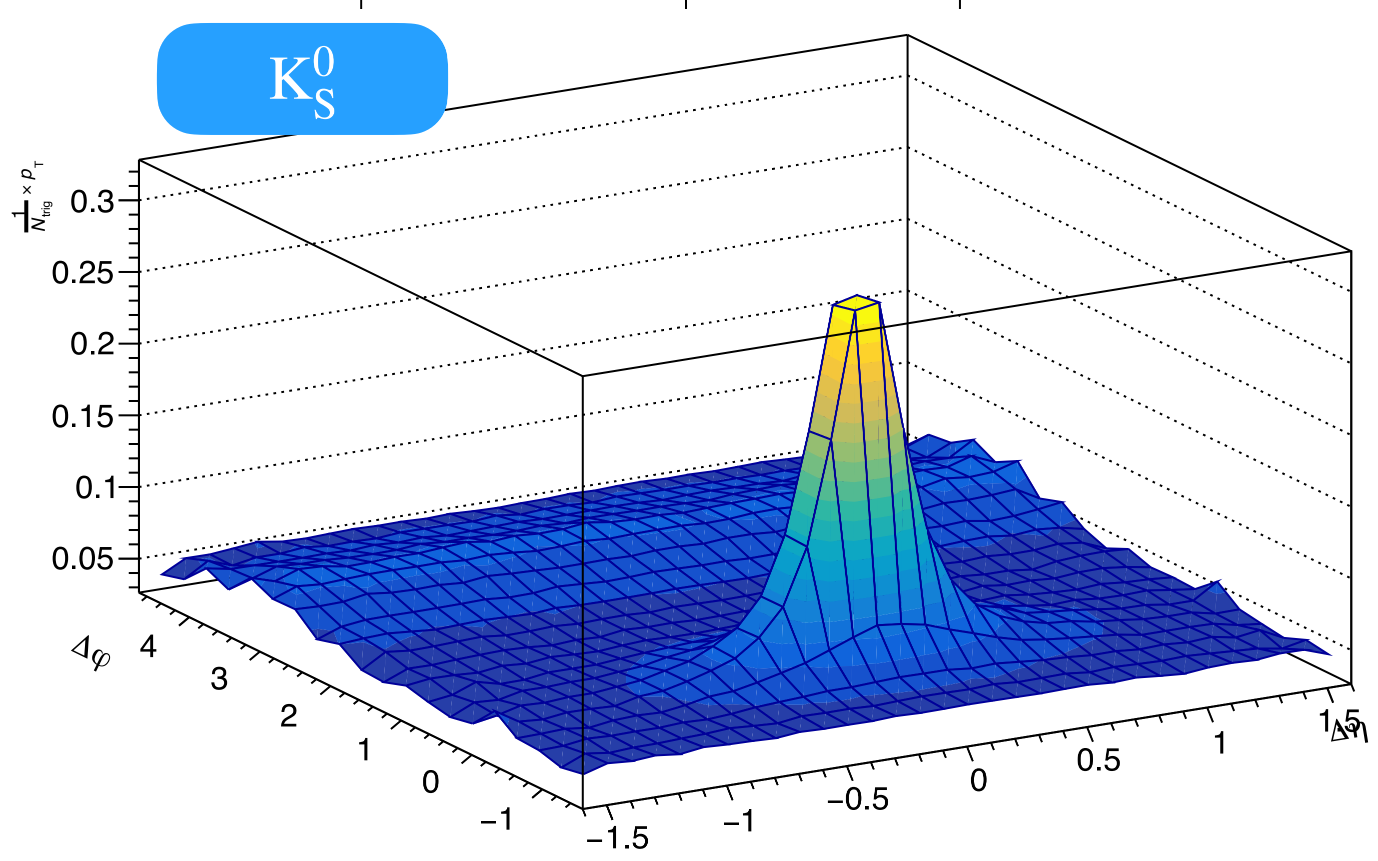

- With different $p_{T,assoc}$ bins, we will introduce a bias on the $p_{T,assoc}$
  - ➡ Combine $p_{T,\,assoc}$ bins in each $p_{T,\,trig}$ interval

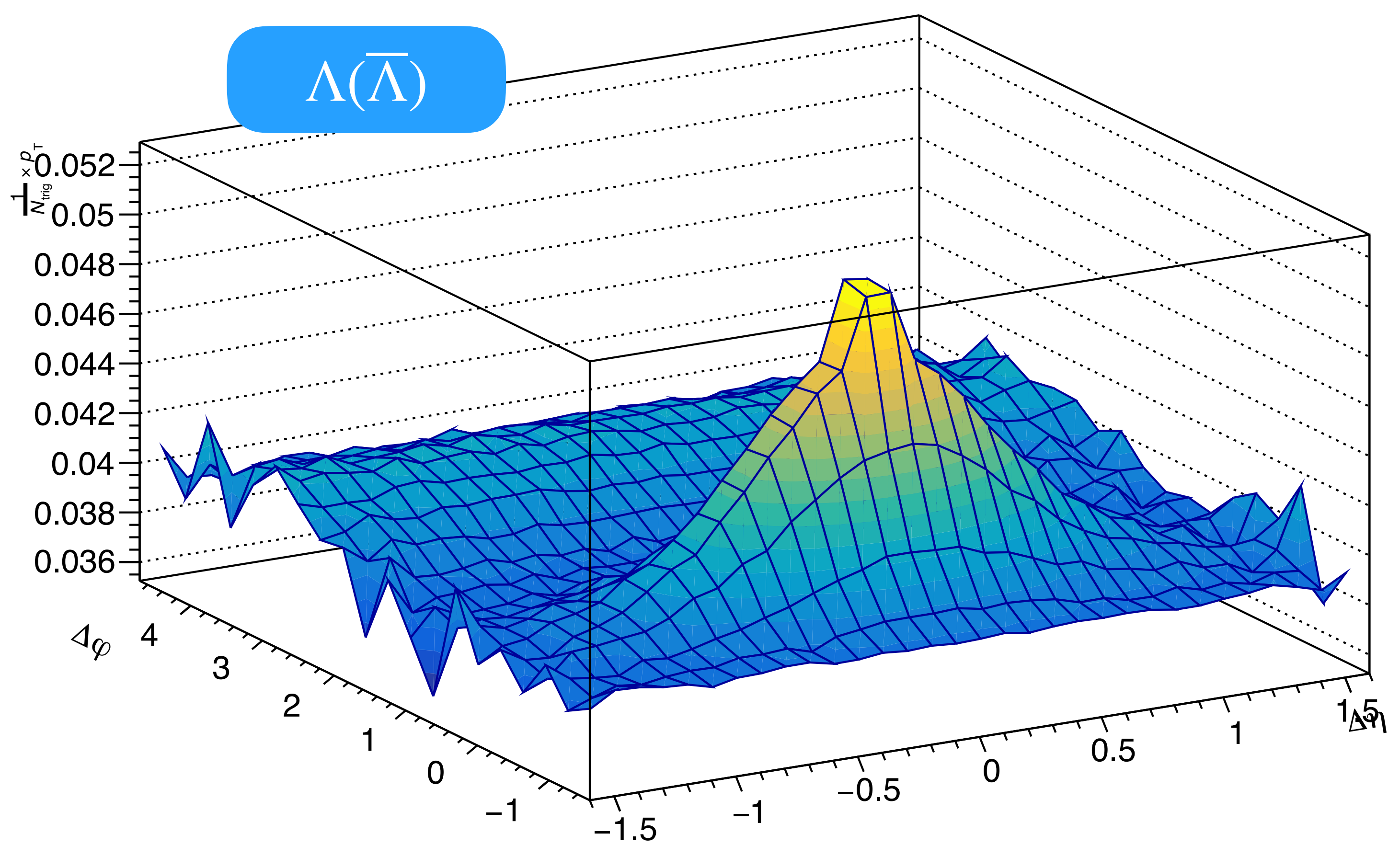
# Combined correlation function

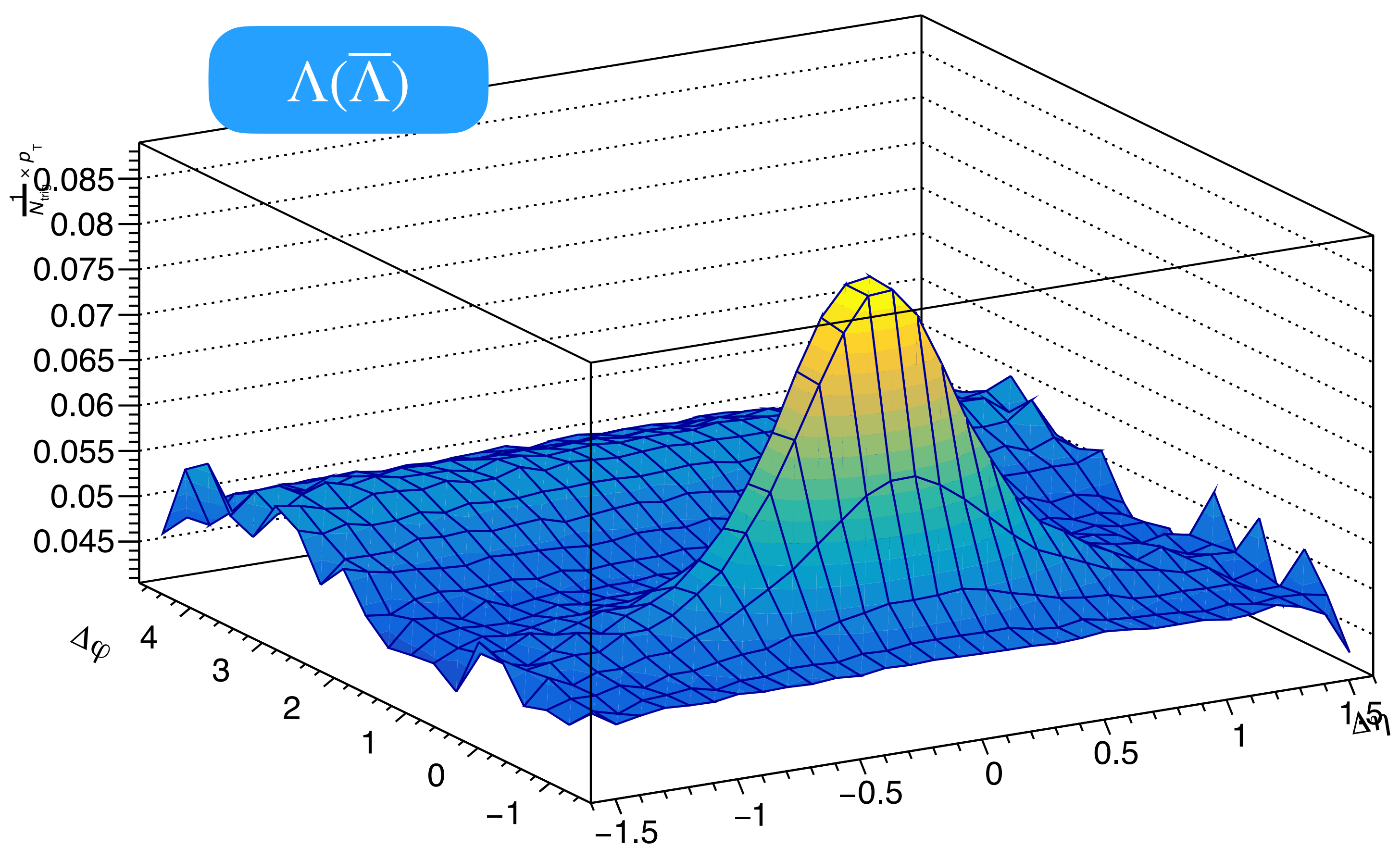
| $1.2 < p_{T,\,trig} < 1.4$ GeV/$c$ | $2.4 < p_{T,\,trig} < 2.6$ GeV/$c$ | $5.0 < p_{T,\,trig} < 6.0$ GeV/$c$ |
| --- | --- | --- |

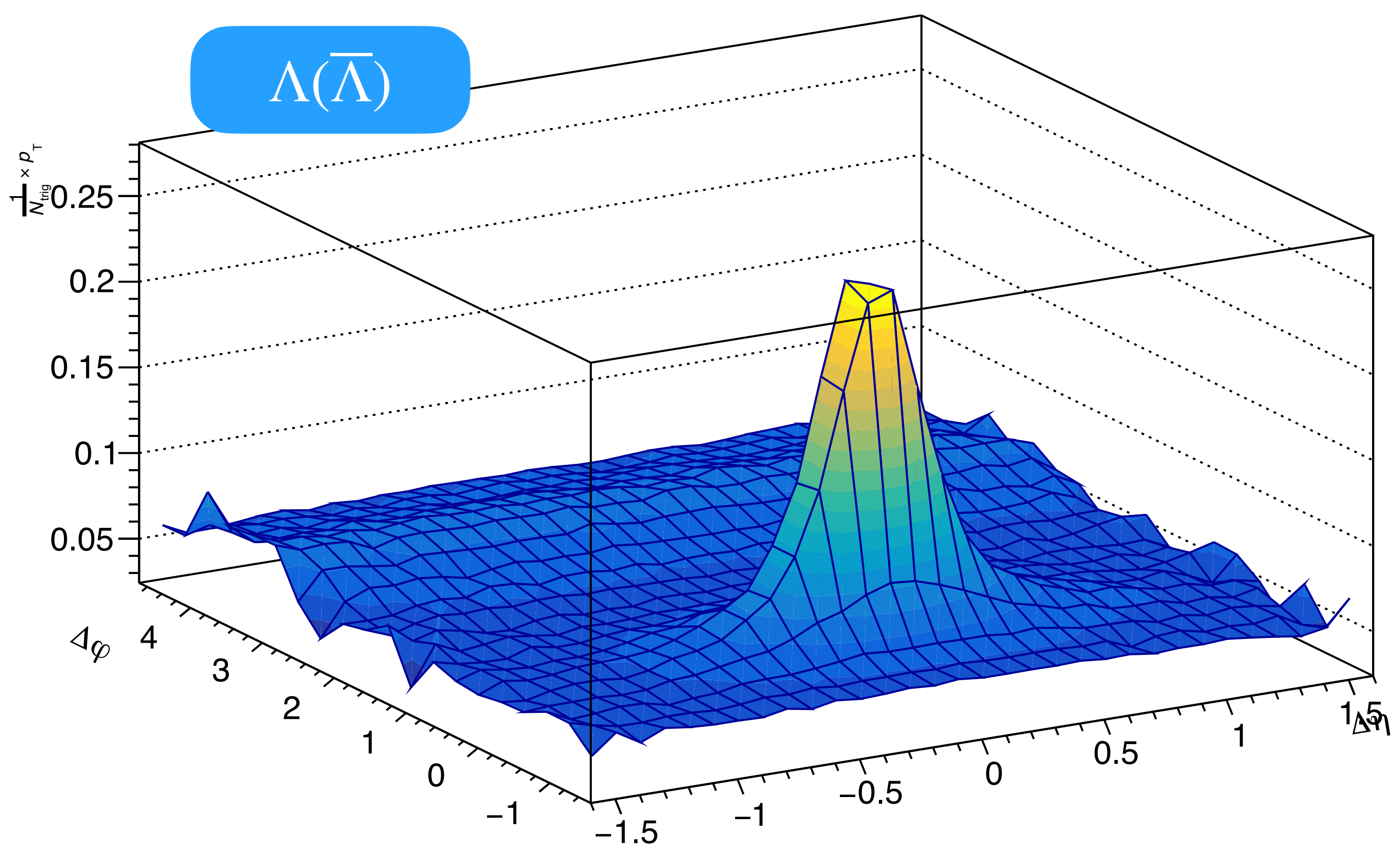



Analysis details are in backup slides

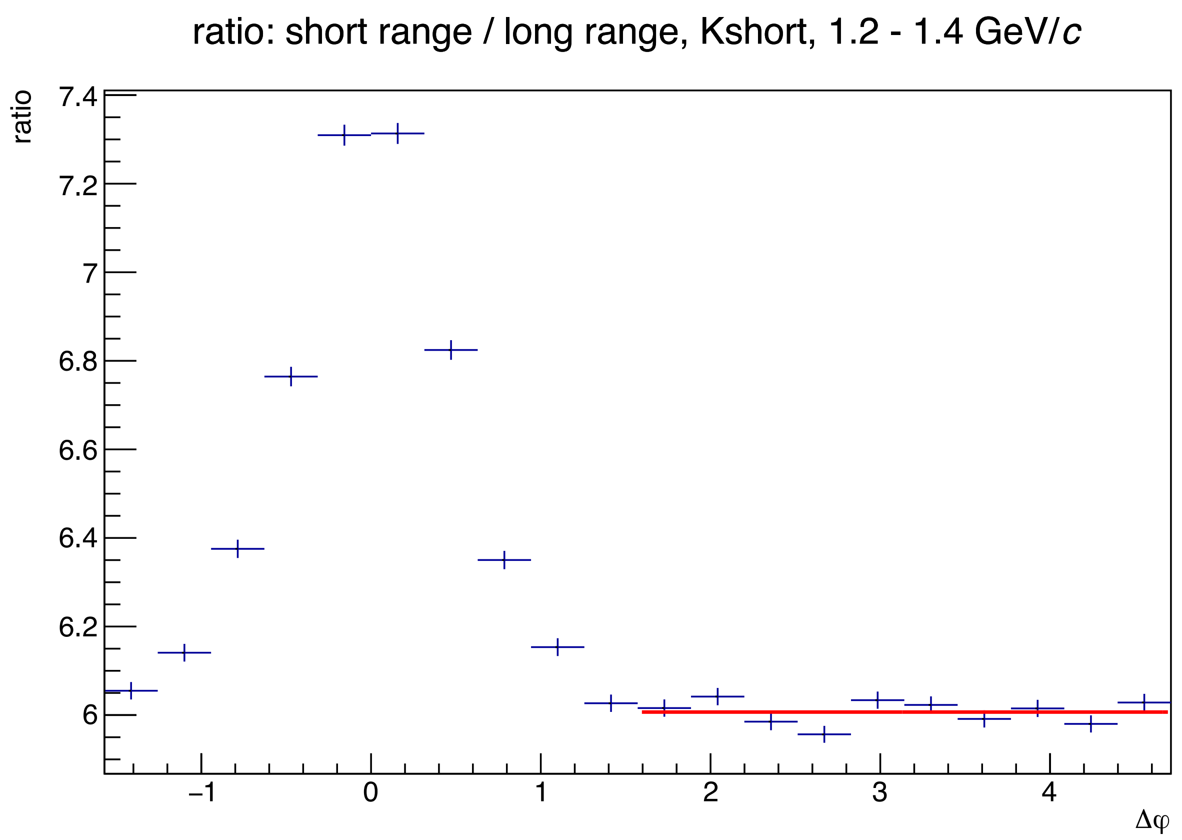
# Uncorrelated bkg subtraction

## $\eta$ gap method

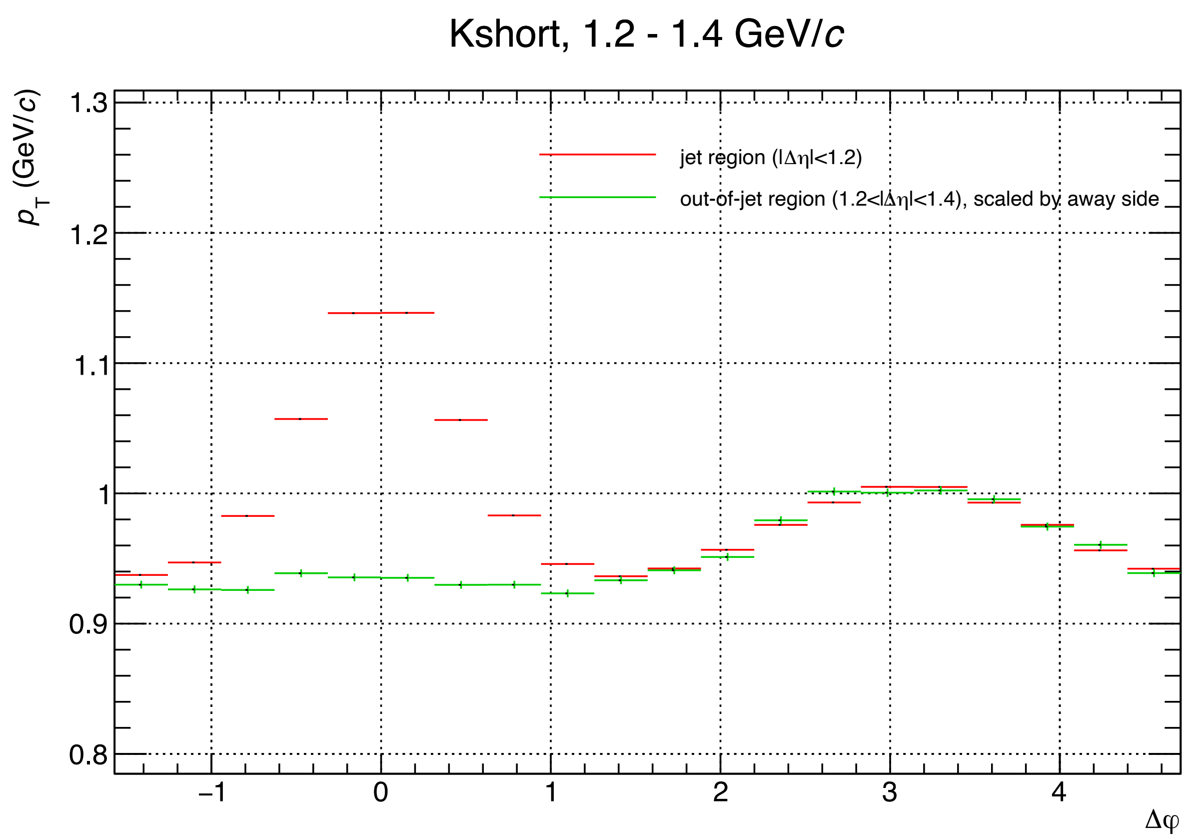
- Jet region: $|\Delta\eta| < 1.2$, out-of-jet (OOJ) region: $1.2 < |\Delta\eta| < 1.4$
- Make $\Delta\varphi$ projections within the jet and OOJ region, respectively
- Make ratio of the $\Delta\varphi$ projections and fit the away side with a constant, fitting range: $(1.58, 4.71)$
- Scale the $\Delta\varphi$ projections associated to the OOJ region by the fit results
- Subtract the scale plot from the $\Delta\varphi$ projections associated to the jet region

$$z = \frac{p_{\mathrm{T,trig}}}{p_{\mathrm{T,trig}} + \sum p_{\mathrm{T,assoc}}}$$

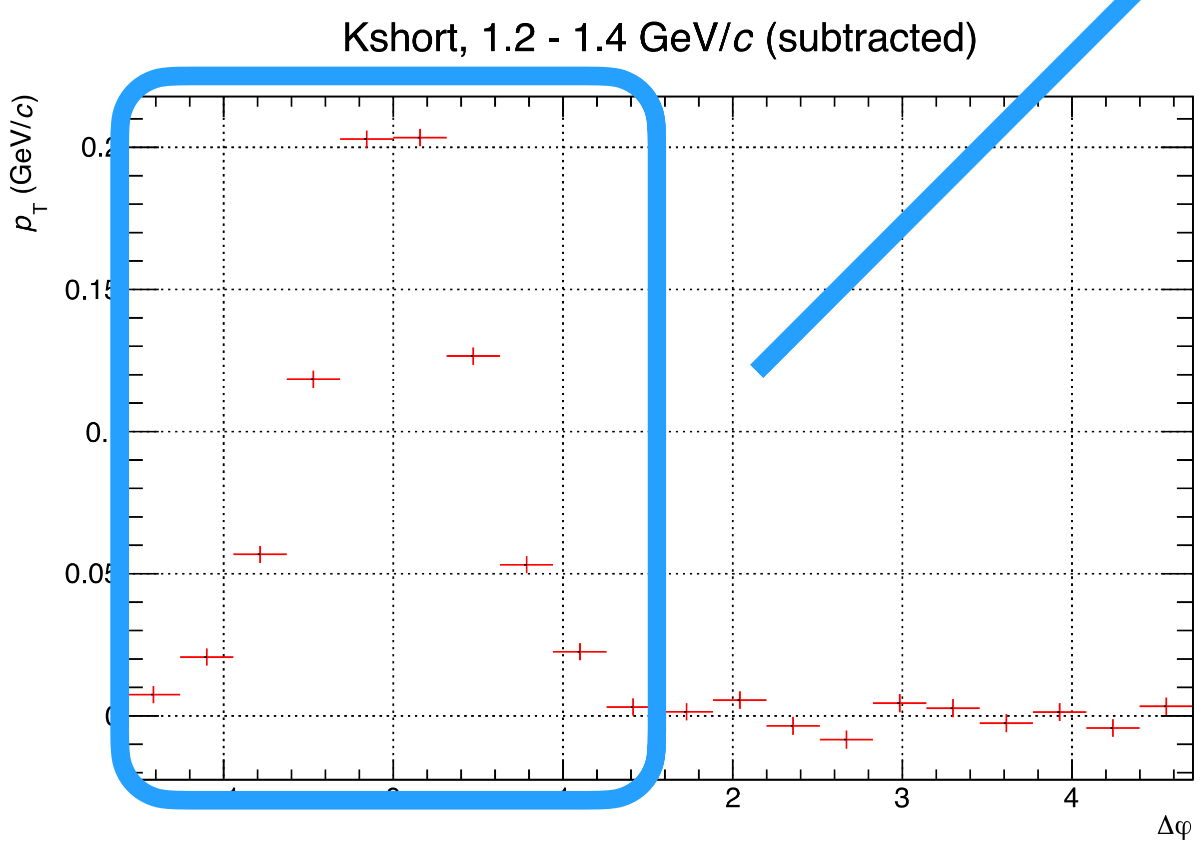
**Example: leading $K^0_S$ as trigger**, $1.2 < p_{\mathrm{T,\,trig}} < 1.4$ GeV/$c$




$\Delta\varphi$ projection ratio: jet region to OOJ region, and fit the AS




$\Delta\varphi$ projections: jet region and scaled OOJ region




Uncorrelated bkg subtracted