ALICE

PhD Days

Study of strange particle production in mini-jets with ALICE at the LHC

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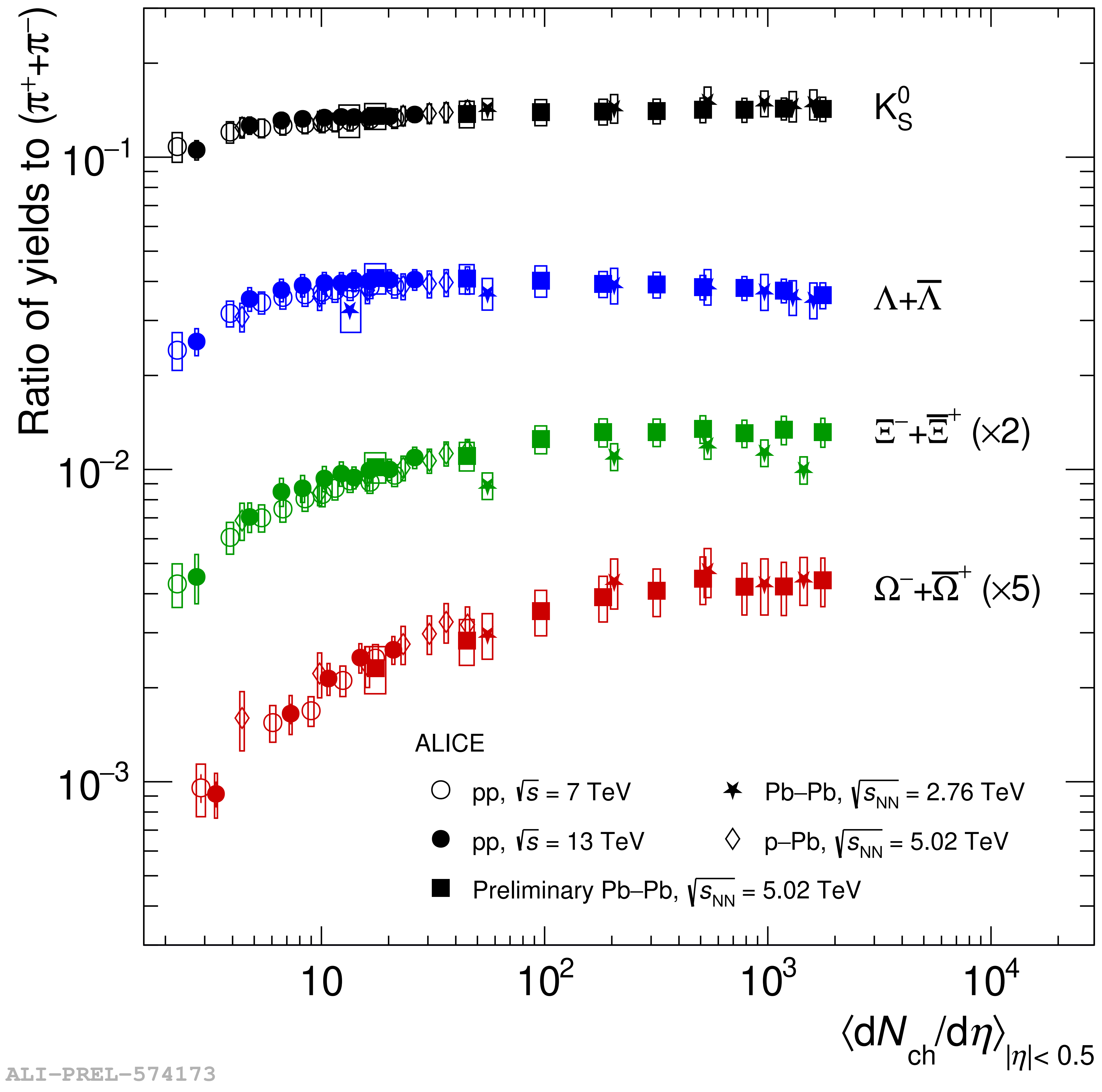
- Motivation
- Data sample and analysis strategies
- Systematic uncertainty
- Results and outlook

2025/04/17

Motivation



【*Nature Physics 13 (2017) 535-539*】

- Smooth increasing yield ratio (strange particle to pion) vs multiplicity observed
- Stronger increasing with more strangeness content
- Reaching the values in Pb-Pb collisions where the system is thermalized
- The origin of this enhancement is still an open question

➡Study the strange particle production in jets

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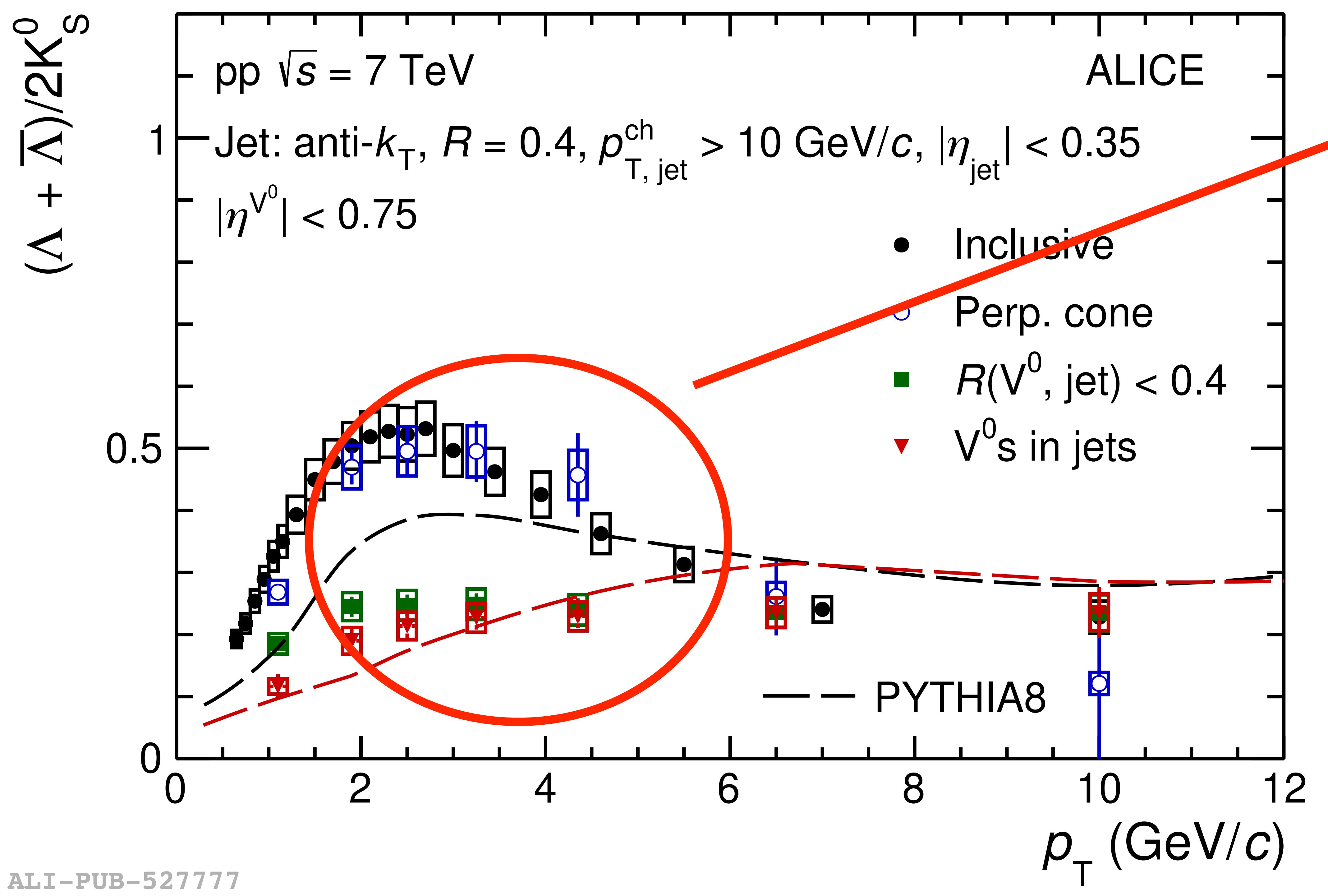
Motivation

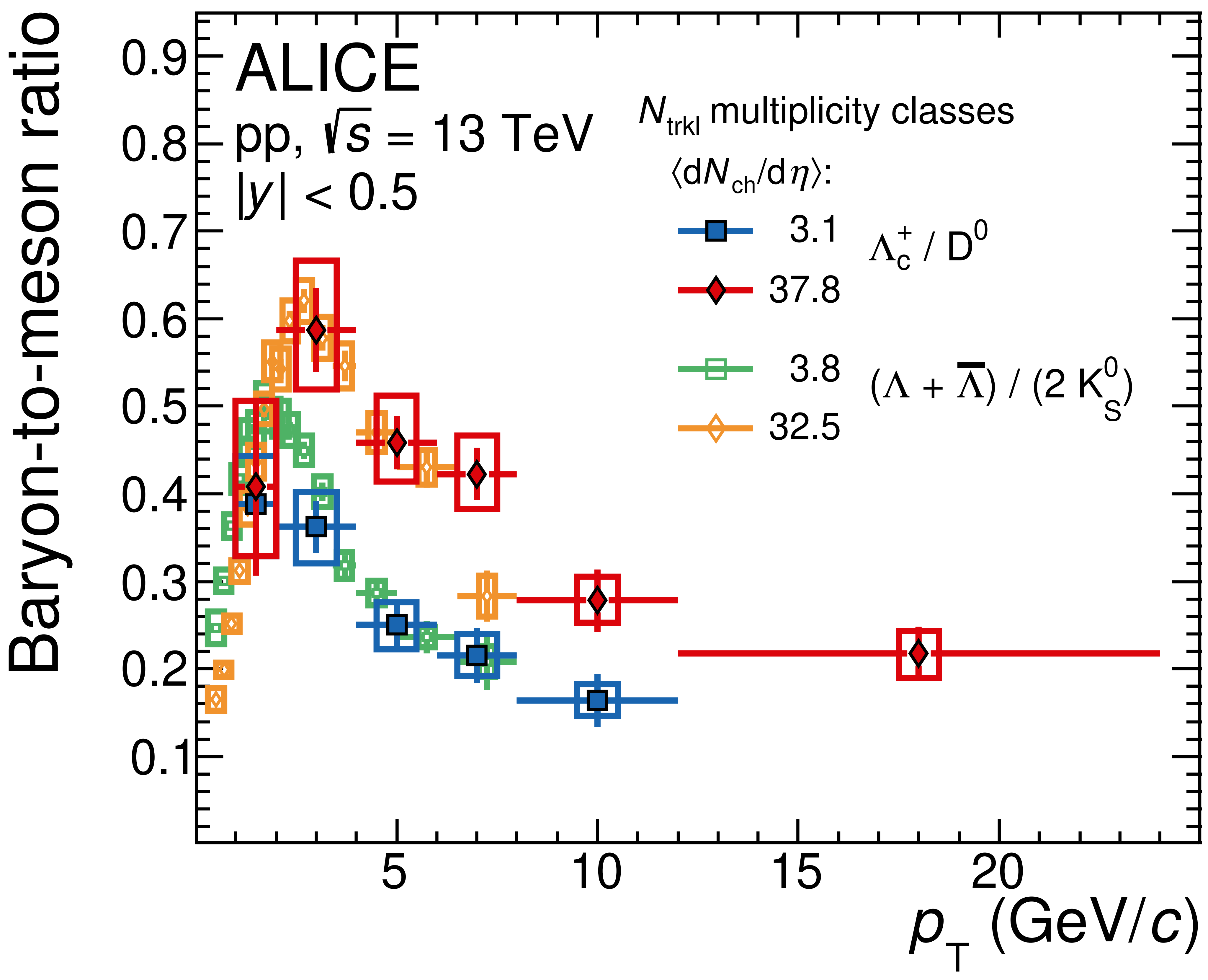
Phys. Lett. B 827 (2022) 136984



- Strange baryon-to-meson ratio enhancement in the underlying event (compared to in jet production) observed in p_T at 2–4 GeV/c in pp (and p–Pb)
  - ➡ Suggests the enhancement is not attribute 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

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: $z = p_{\mathrm{T,trigger}} / p_{\mathrm{T,jet}}$
  - ➡ Choosing strange particle as trigger, charged primary particles as associated particles

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Event & Track selection

Data sample

a full sample list is in the backup

- ***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 strange particle (candidata) 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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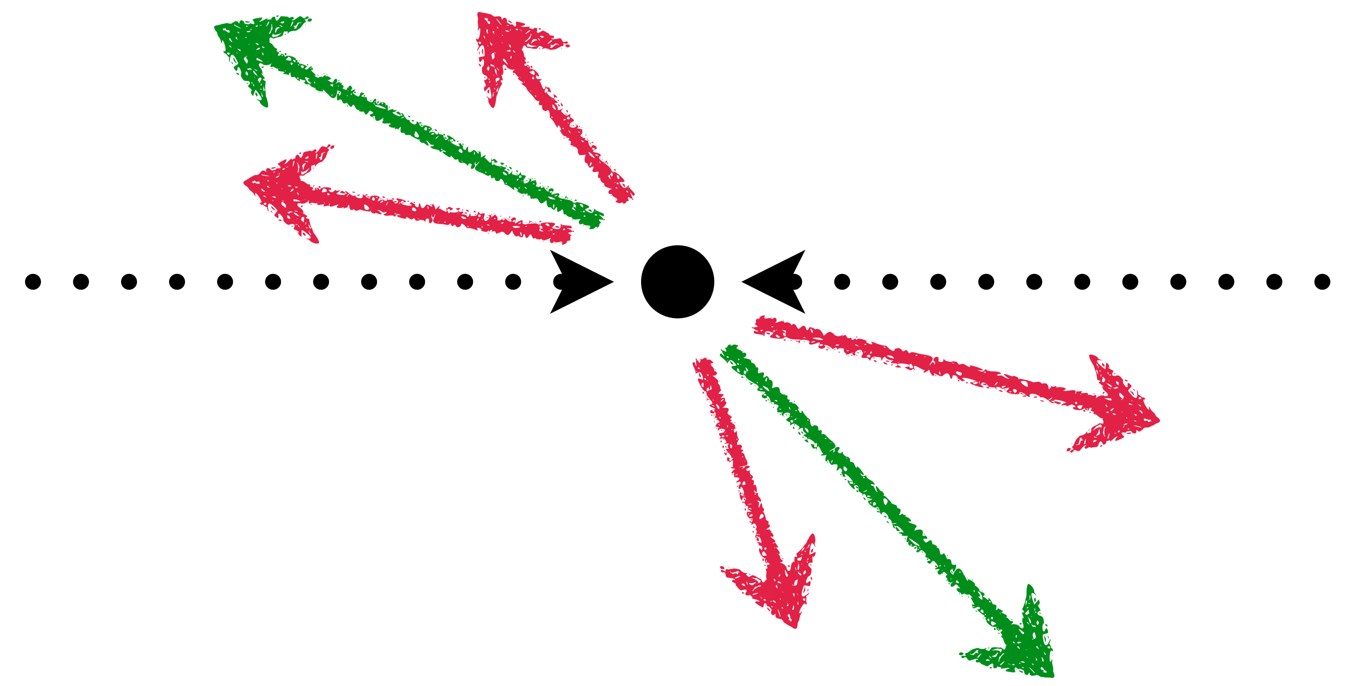
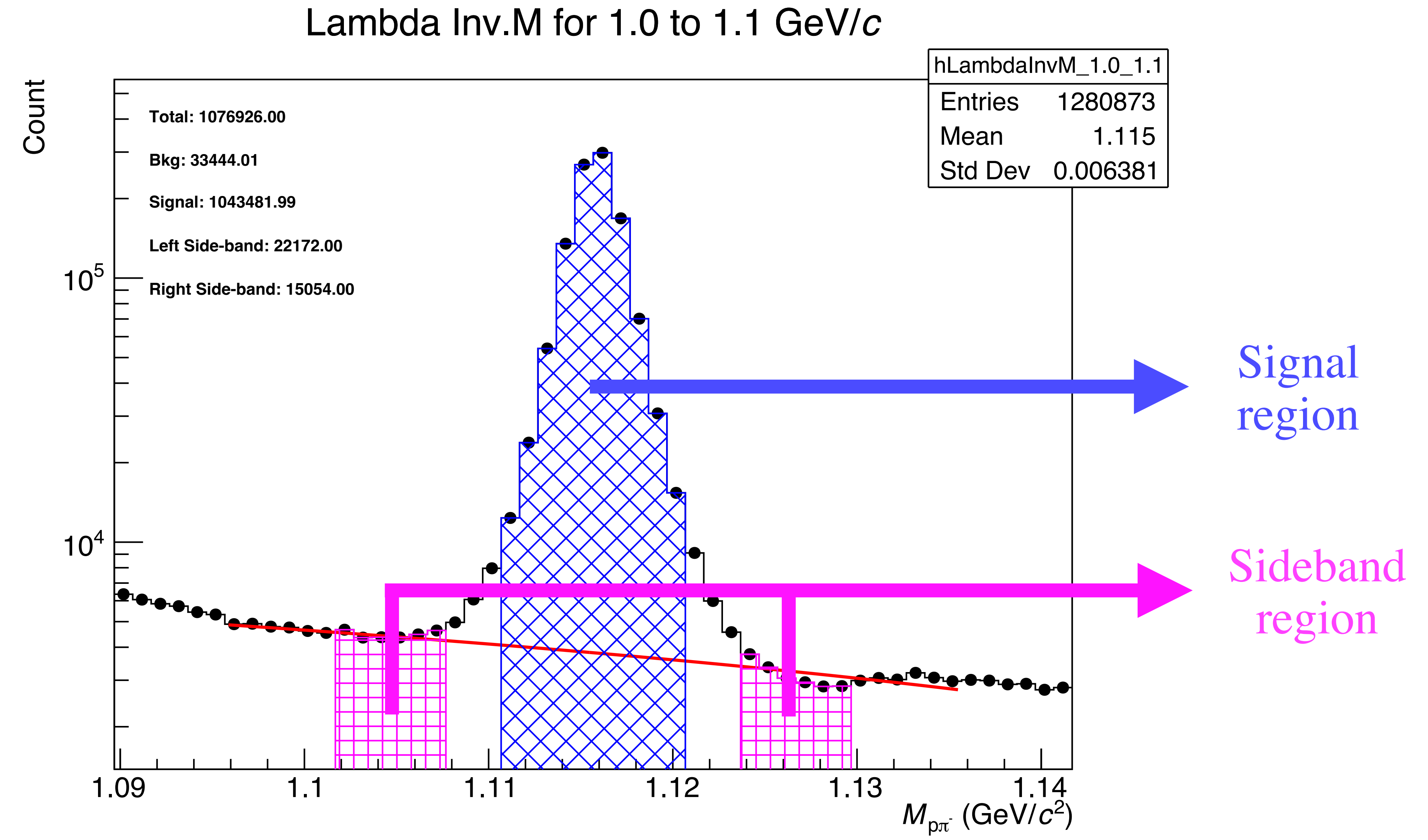
Correlation function



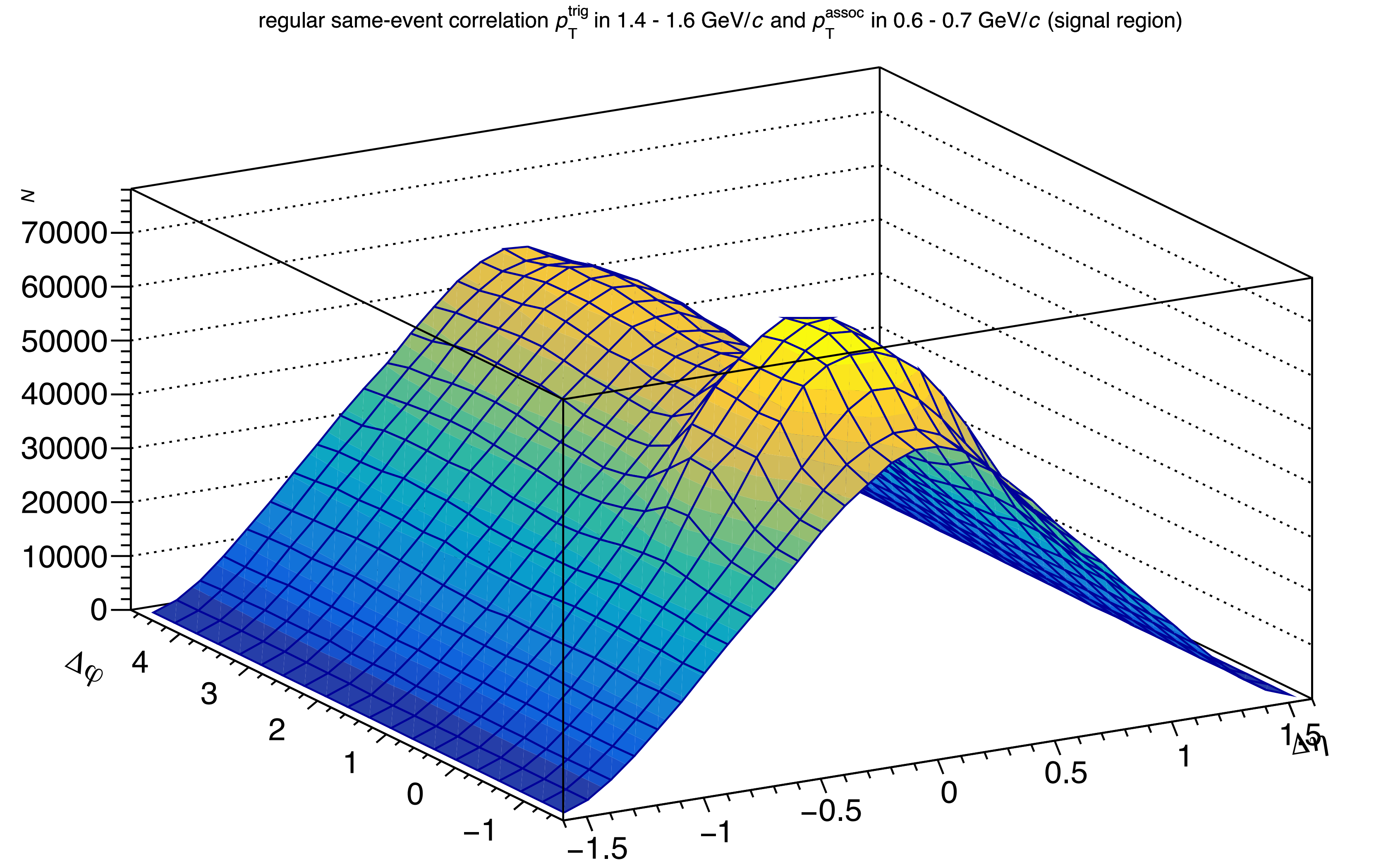
- **Correlation function**

$$C\left(\Delta\eta,\ \Delta\varphi\right)=\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N}{\mathrm{d}\Delta\varphi\mathrm{d}\Delta\eta}$$

- **To build up correlation function**
  ① Select triggers and associated particles
  ② Calculate the differences of azimuthal φ and pseudorapidity η
  ③ Fill the histogram in the $\Delta\eta - \Delta\varphi$



reconstructed trigger Inv.M distribution



an example of the two-particle correlation function

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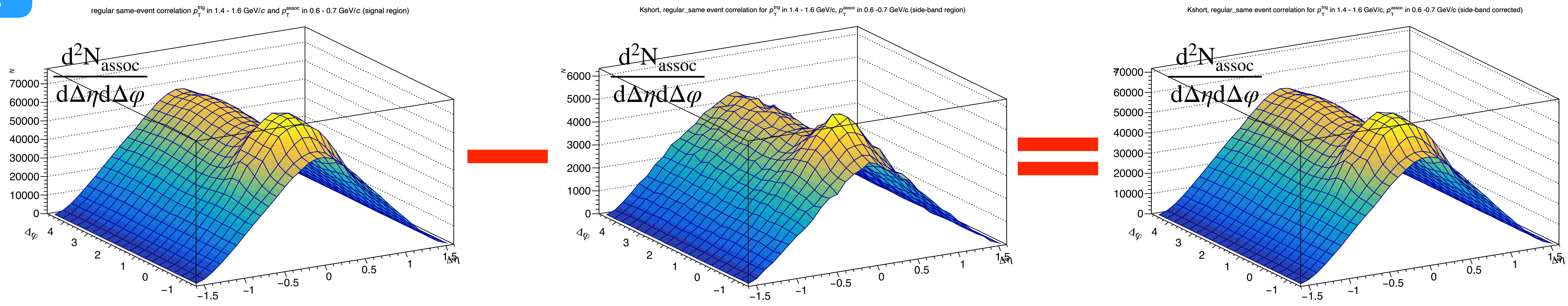
Regular correlation analysis

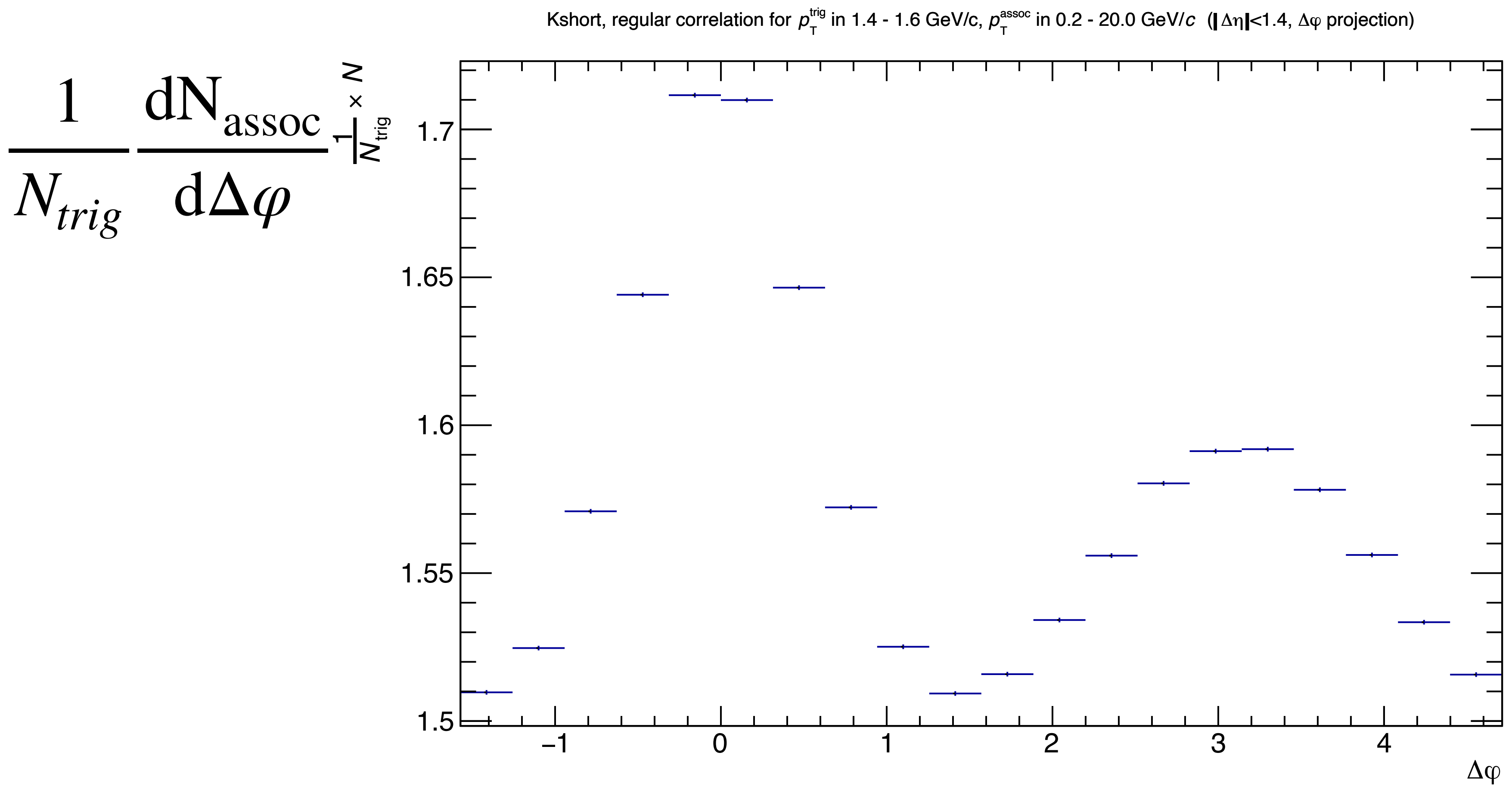
K_S^0

signal region | sideband region | sideband corrected

same event



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



- Raw correlation function
  - ➡ Jet yield can be obtained by applying acceptance (mixed event correction) and inefficiency (efficiency correction) corrections, and baseline subtraction

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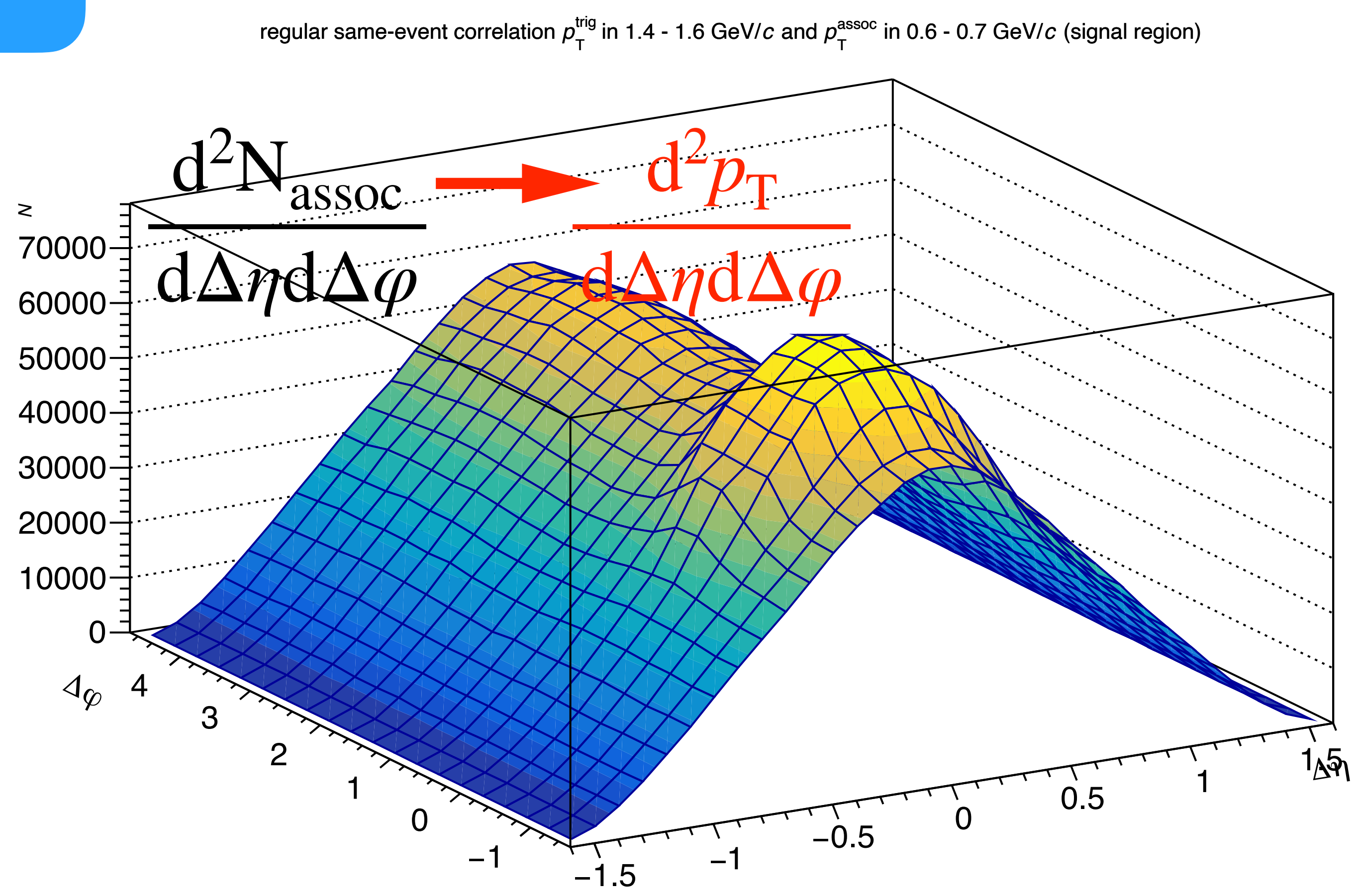
p_T weighted correlation analysis

K^0_S

signal region



same event

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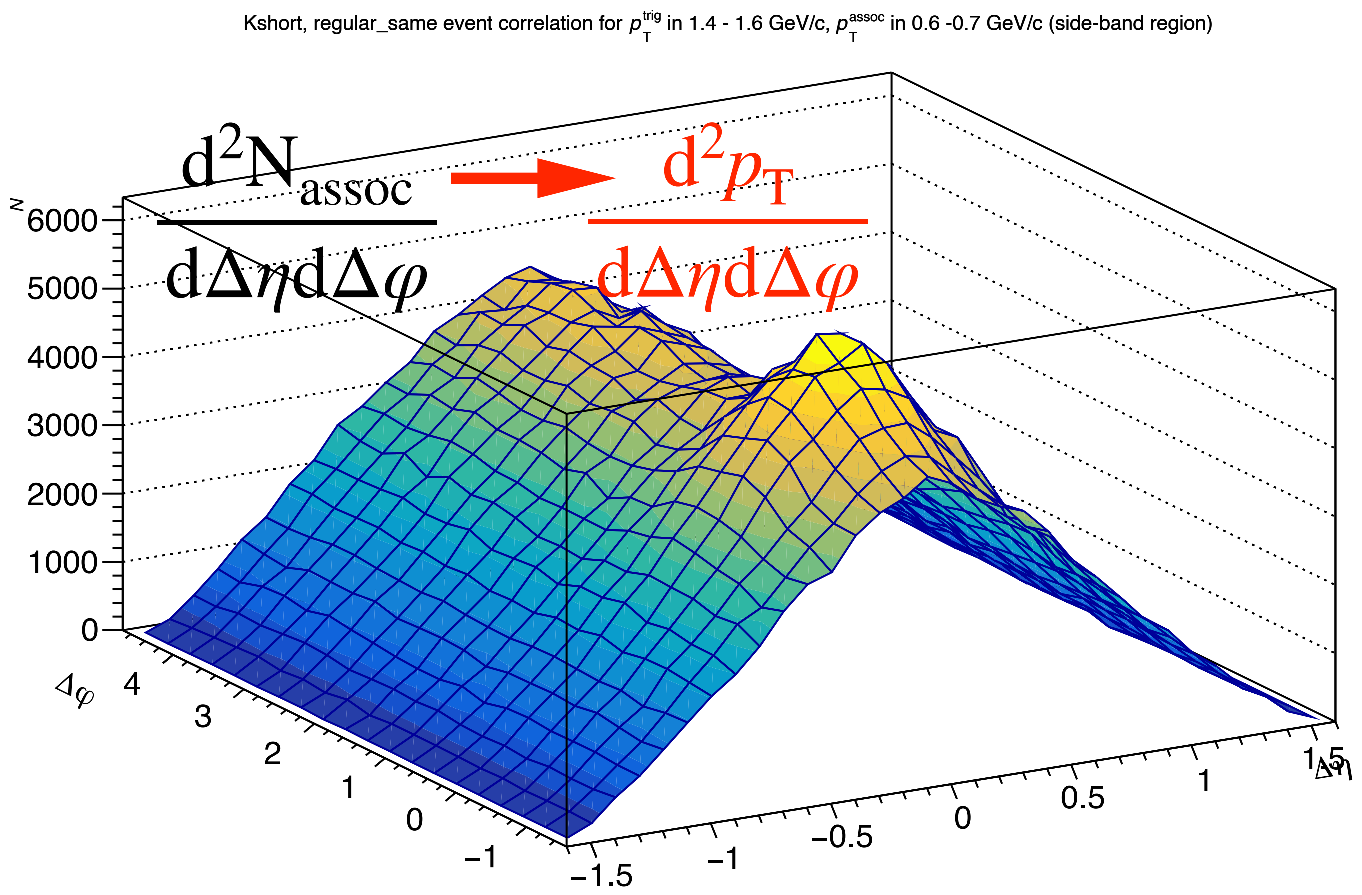
sideband region



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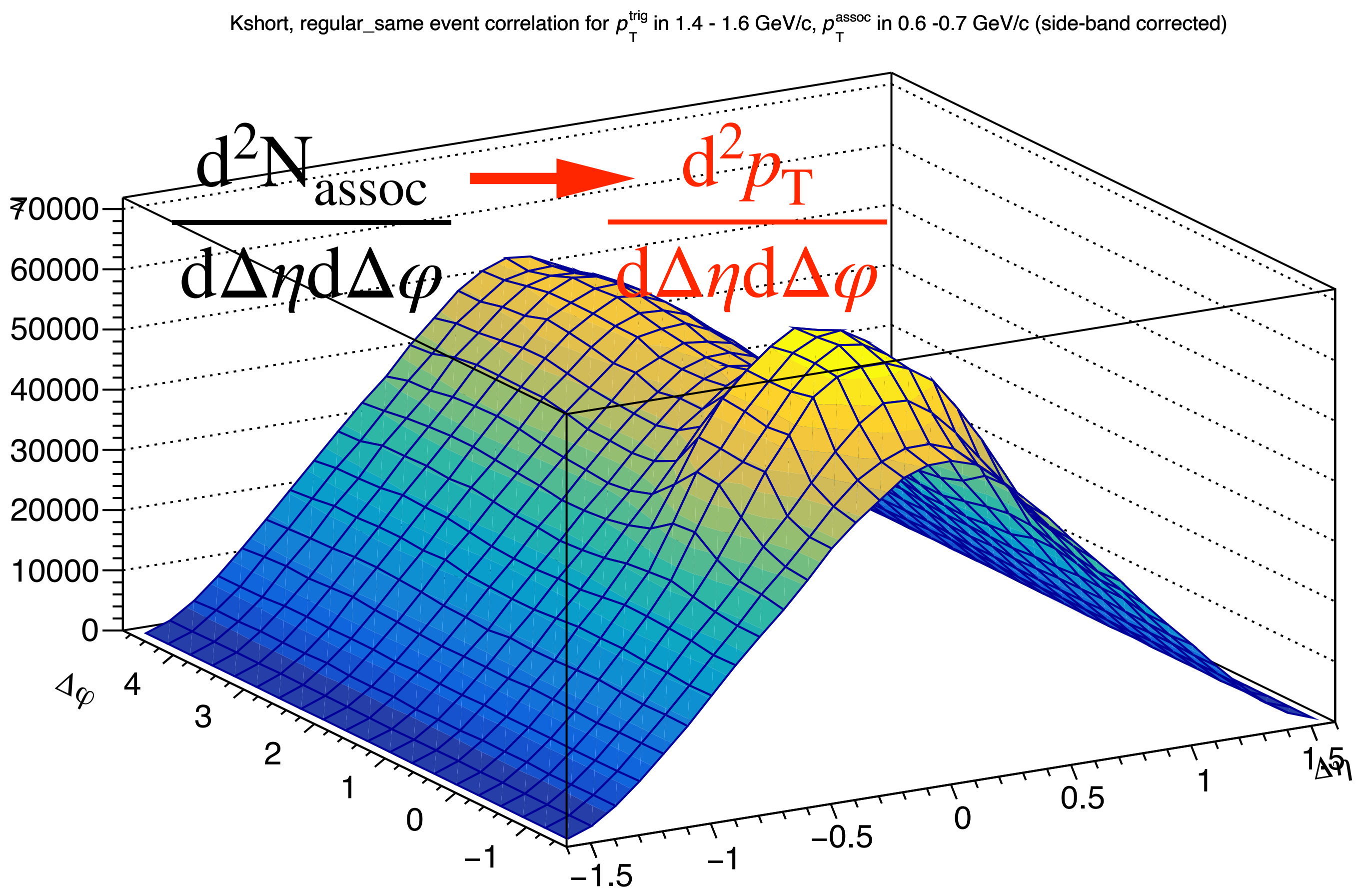
sideband corrected

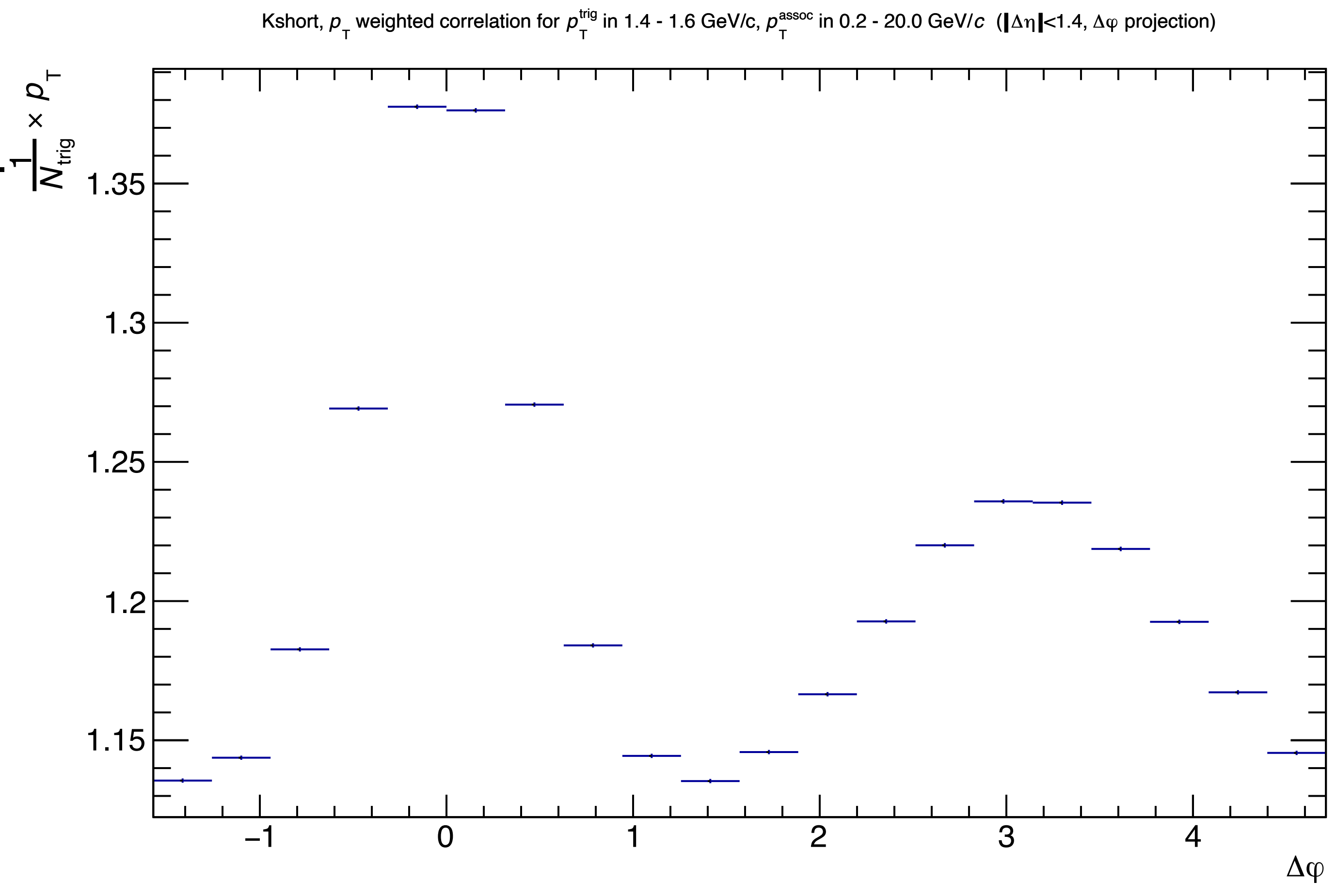


Example: a regular analysis results for $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ and $0.6\ \mathrm{GeV}/c < p_T^{assoc} < 0.7\ \mathrm{GeV}/c$, inefficiency is considered

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

↓

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



example

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

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

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

➡ Introduce a p_T weight

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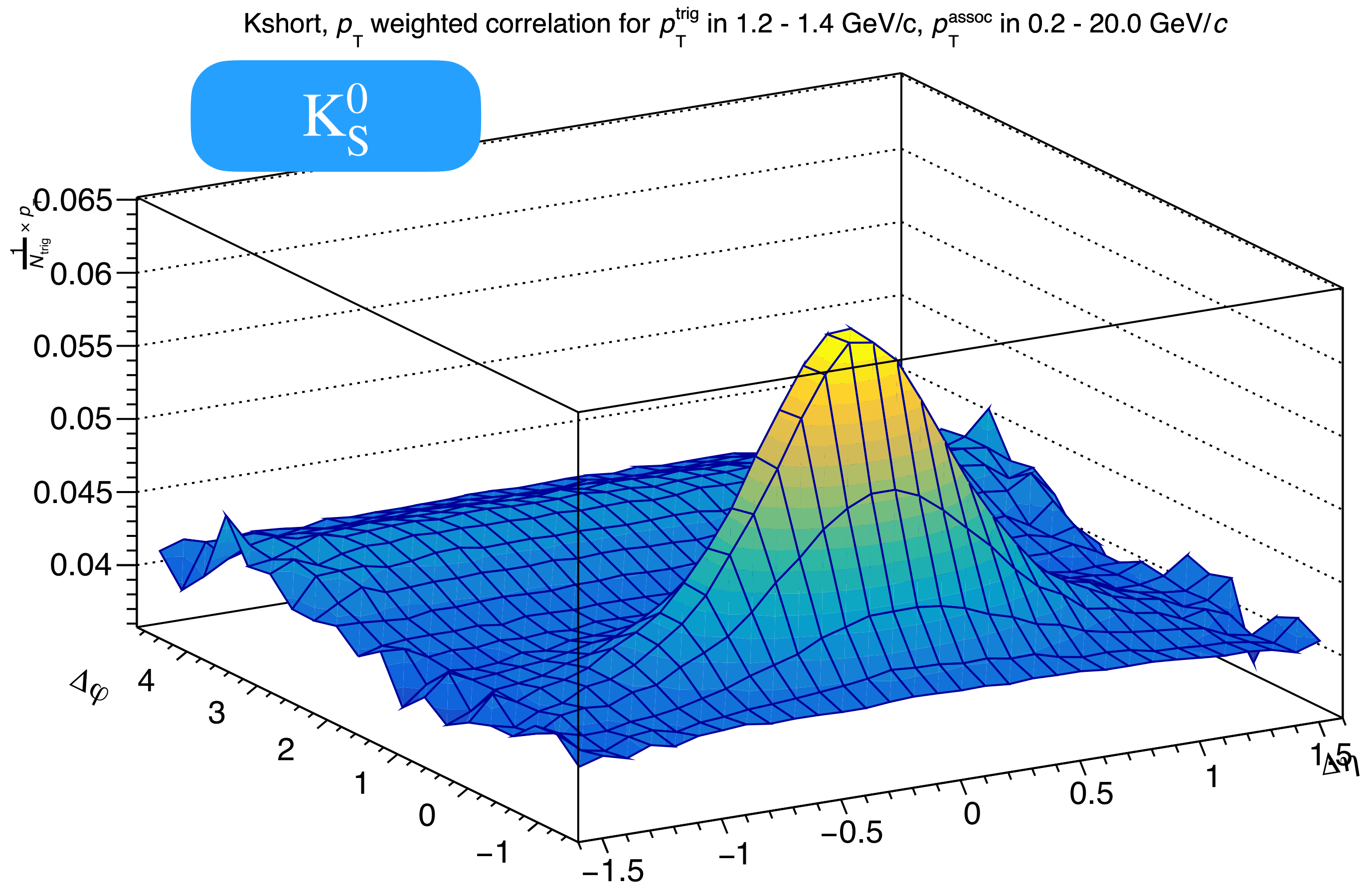
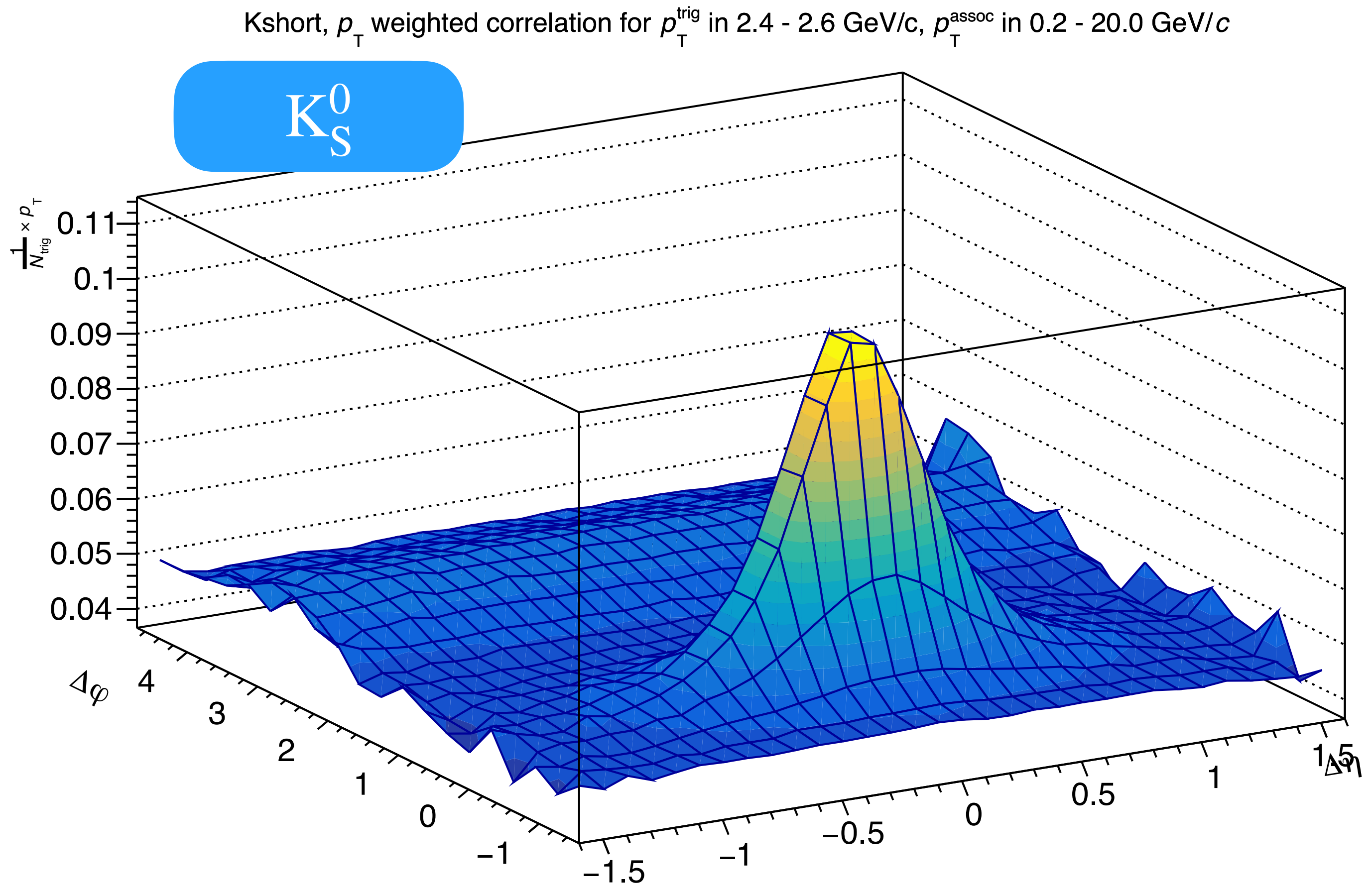
Combined correlation function

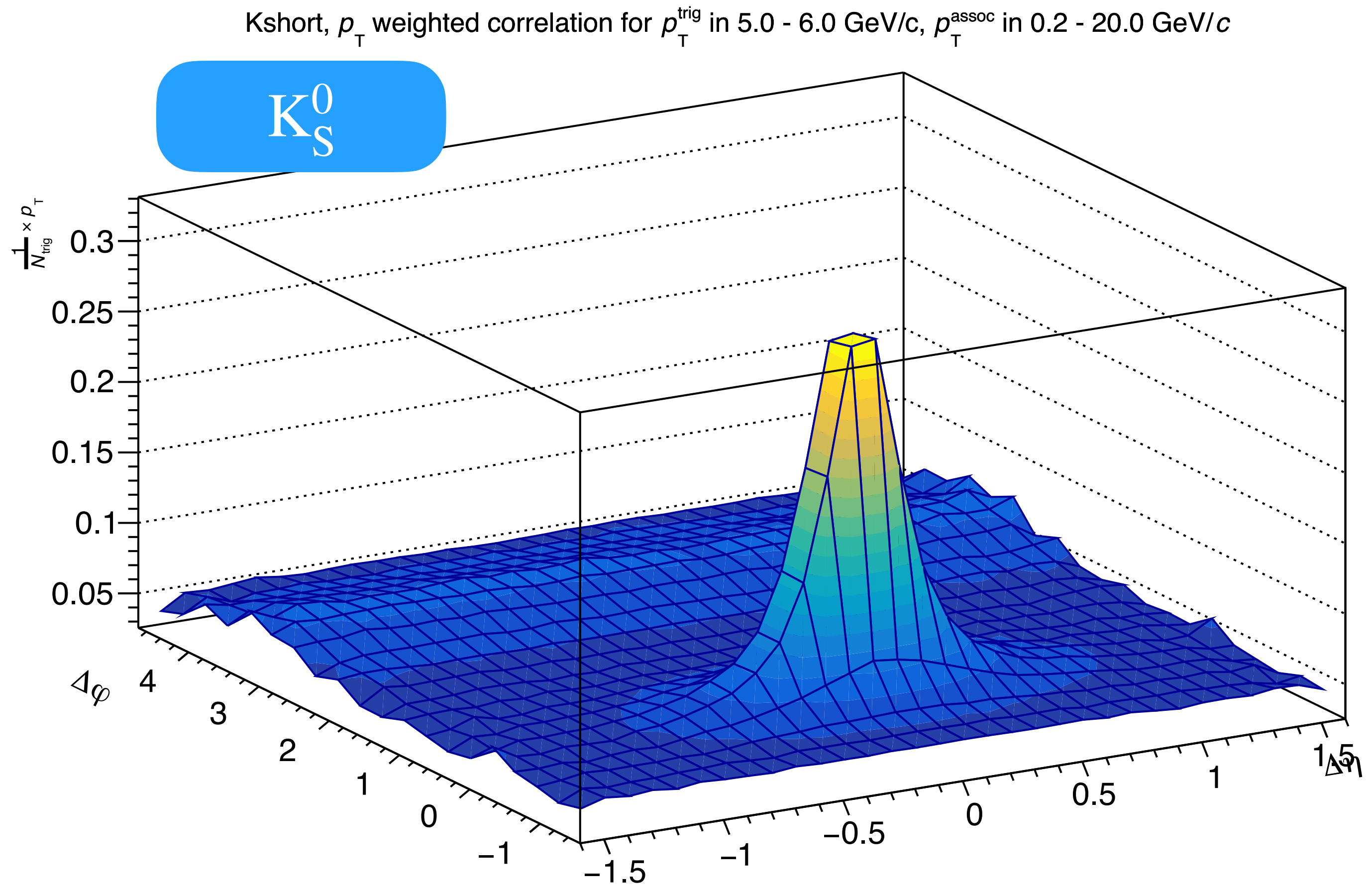
$1.2 < p_{T,\,trig} < 1.4$ GeV/c

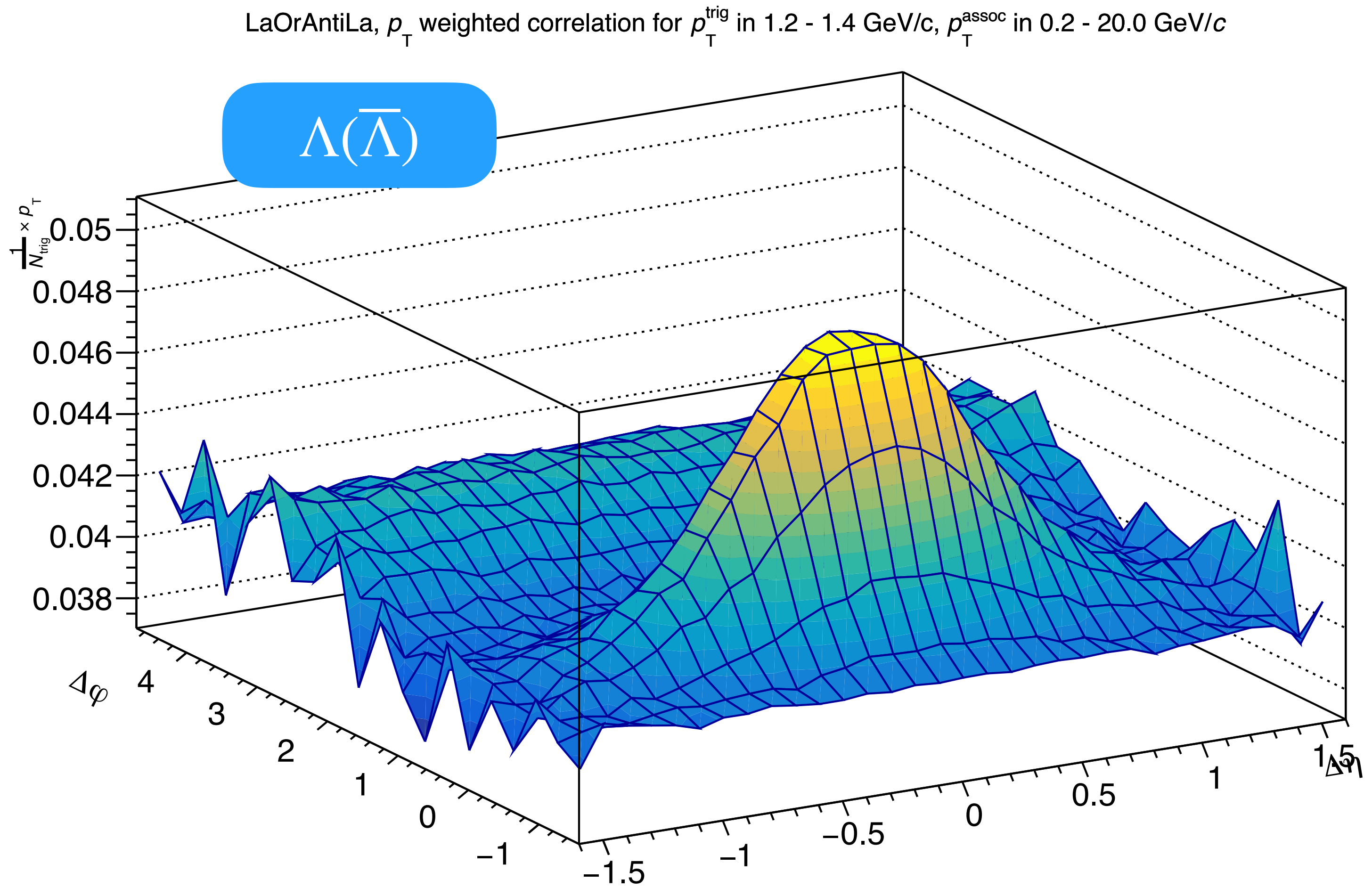
$2.4 < p_{T,\,trig} < 2.6$ GeV/c

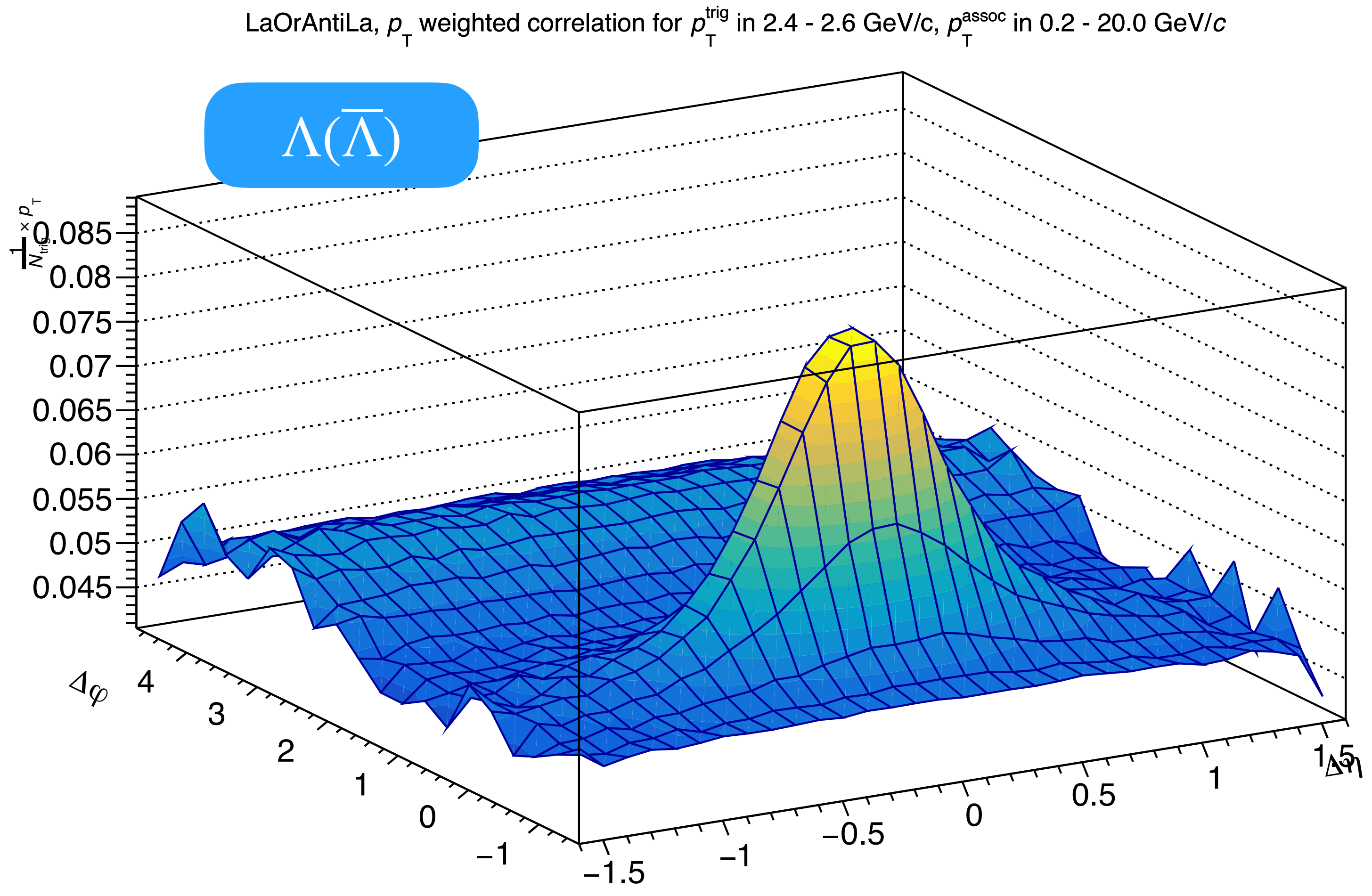
$5.0 < p_{T,\,trig} < 6.0$ GeV/c

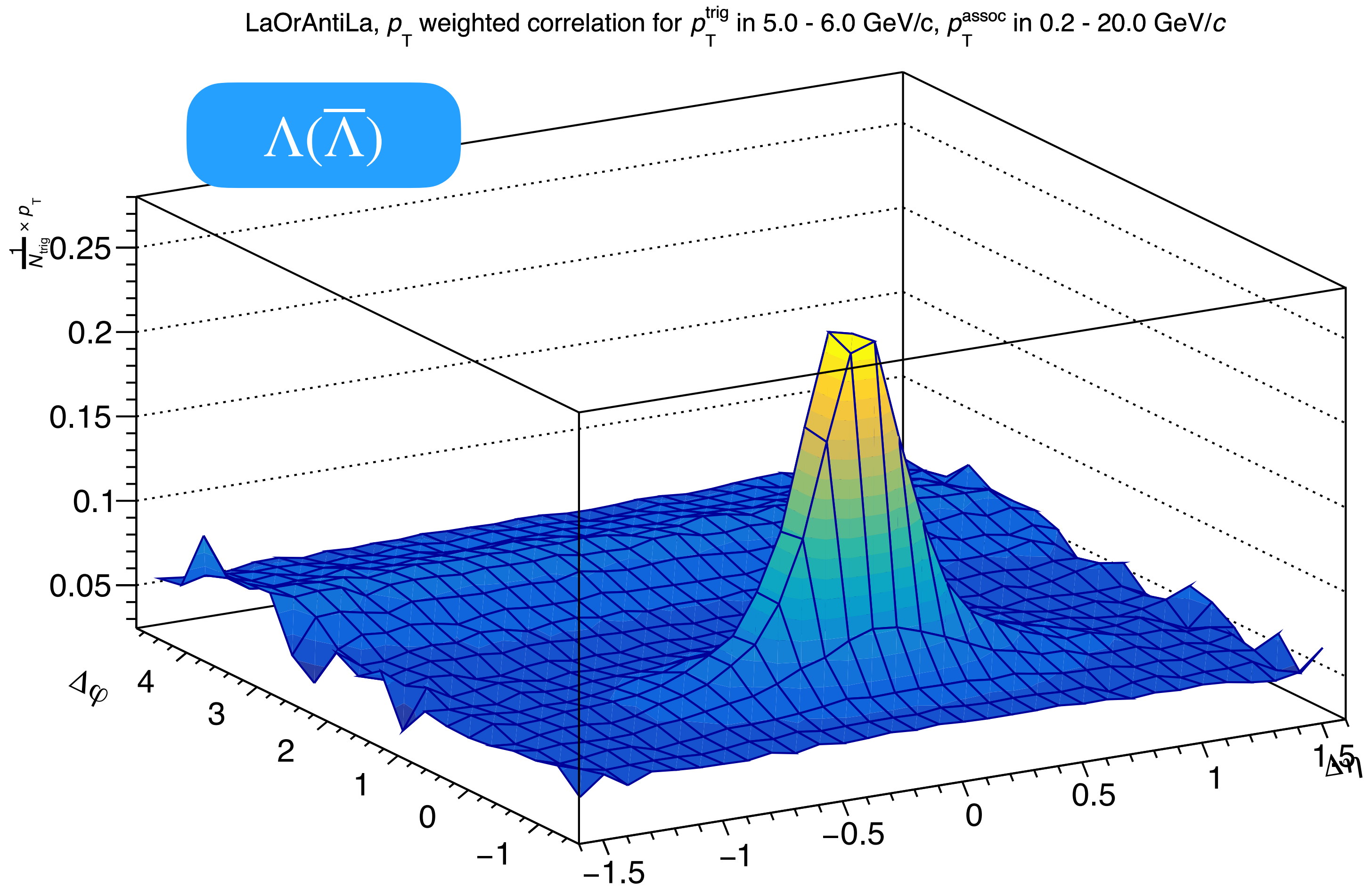












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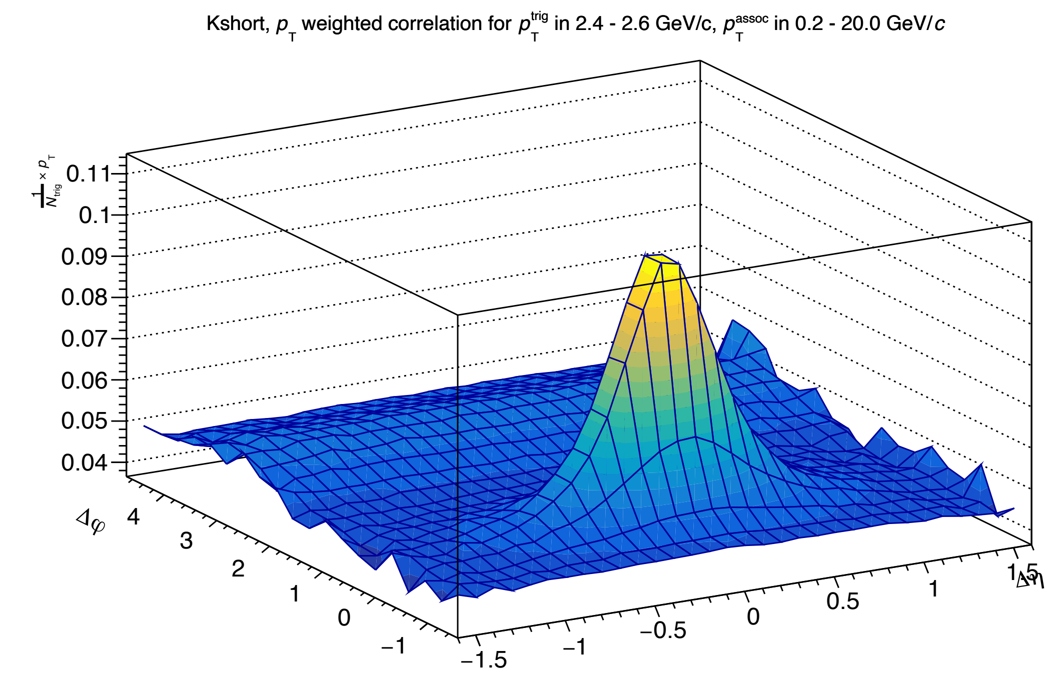
Uncorrelated bkg subtraction

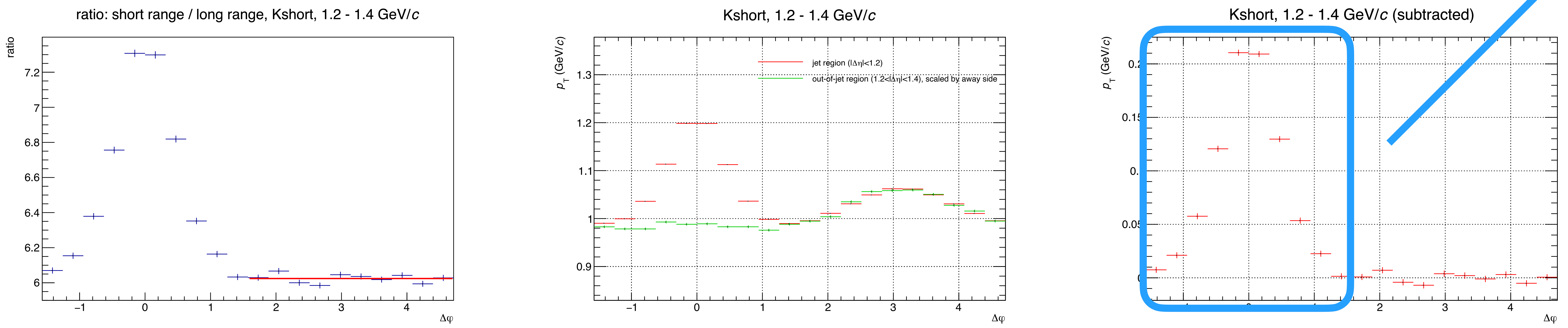


η gap method

- 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

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

Example: K^0_S as trigger, $1.2 < p_{T,\,trig} < 1.4$ 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

2D correction for $\Lambda(\overline{\Lambda})$

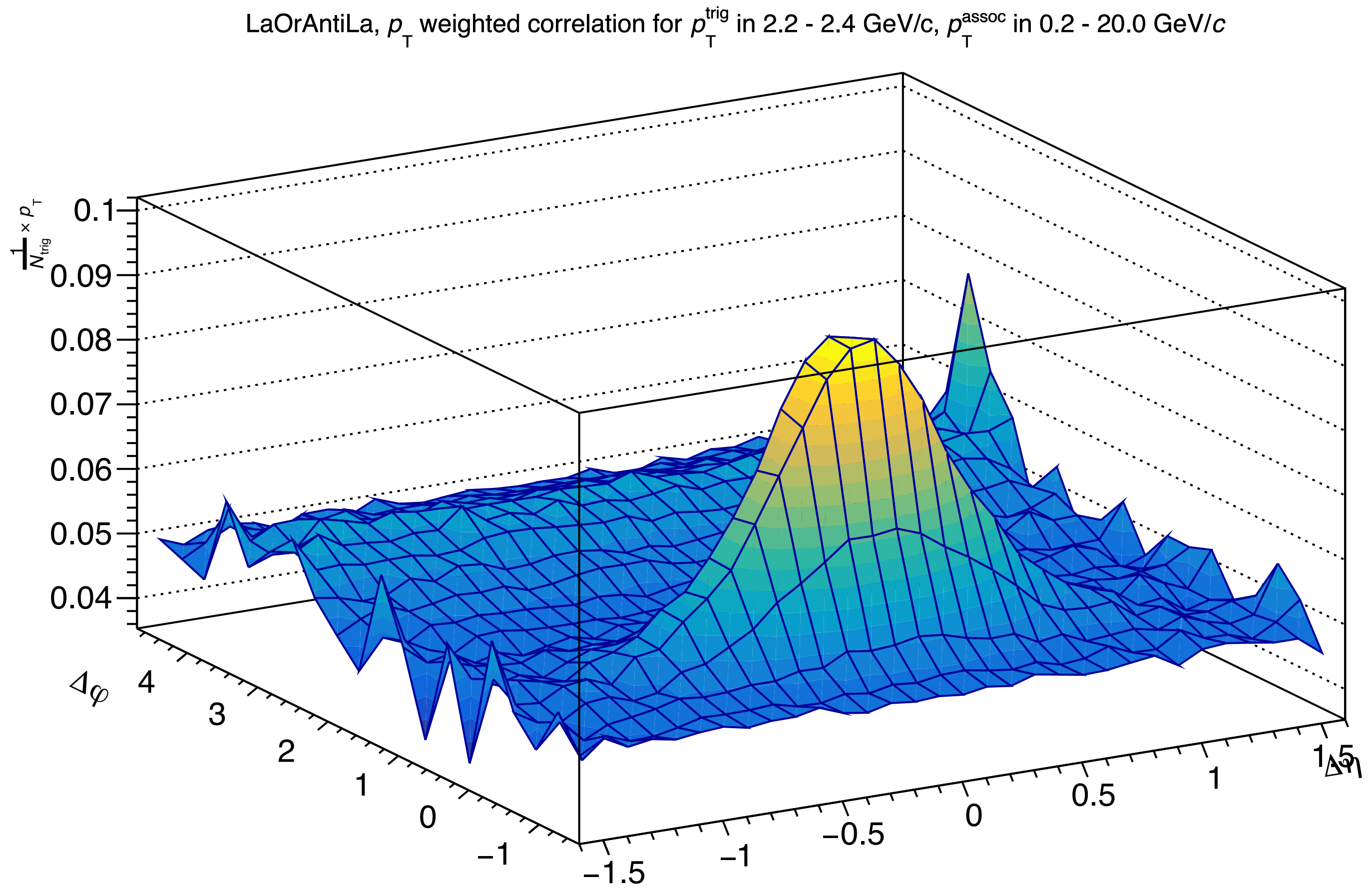
- Make a 2D template correction on the weighted CF

Phys. Rev. C 111 (2025) 015201

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

The 2D map

- "Rec Truth" means the results using the reconstructed $\Lambda(\overline{\Lambda})$ with their true kinematics



Rec

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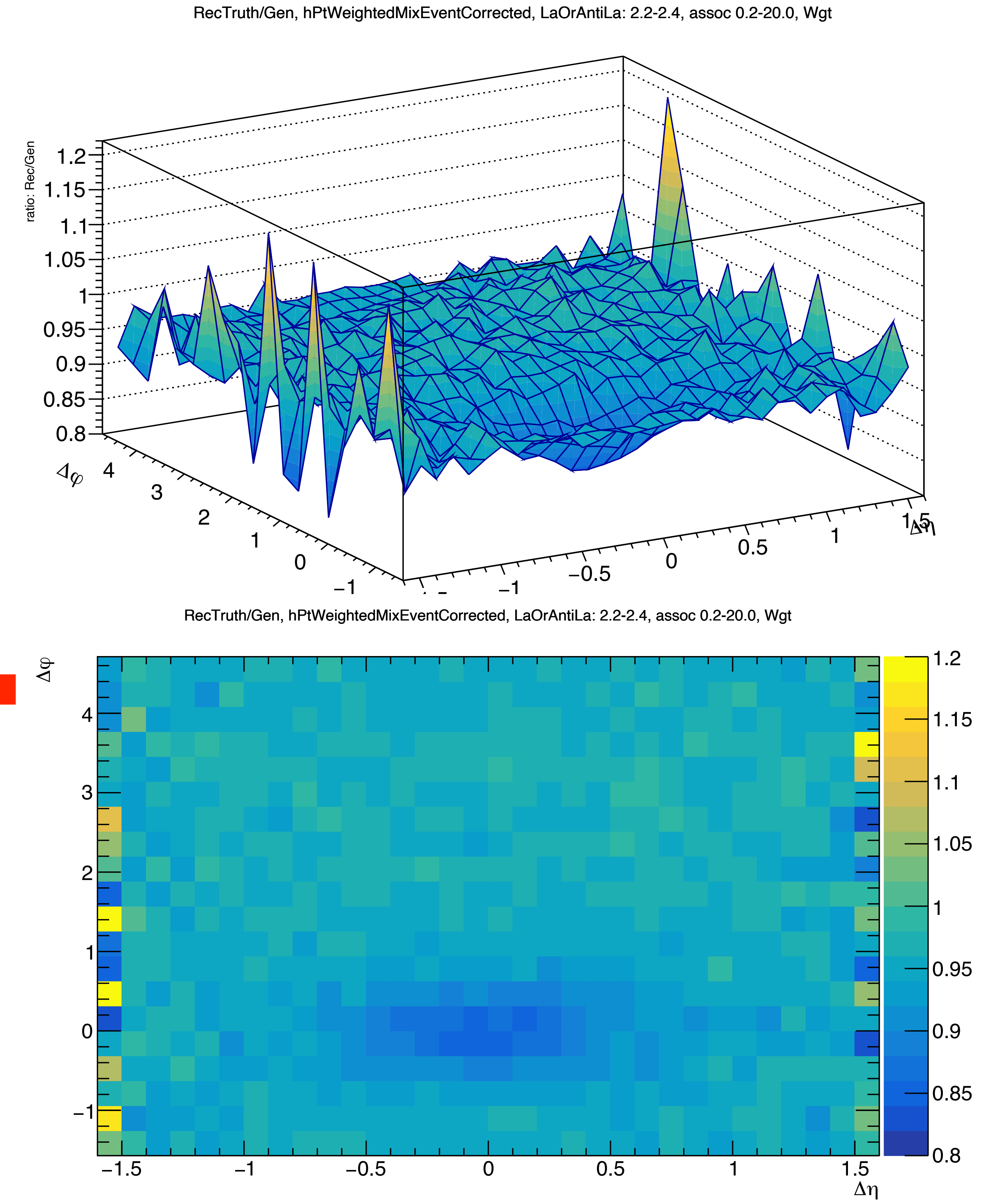

2D map: Rec Truth/Gen

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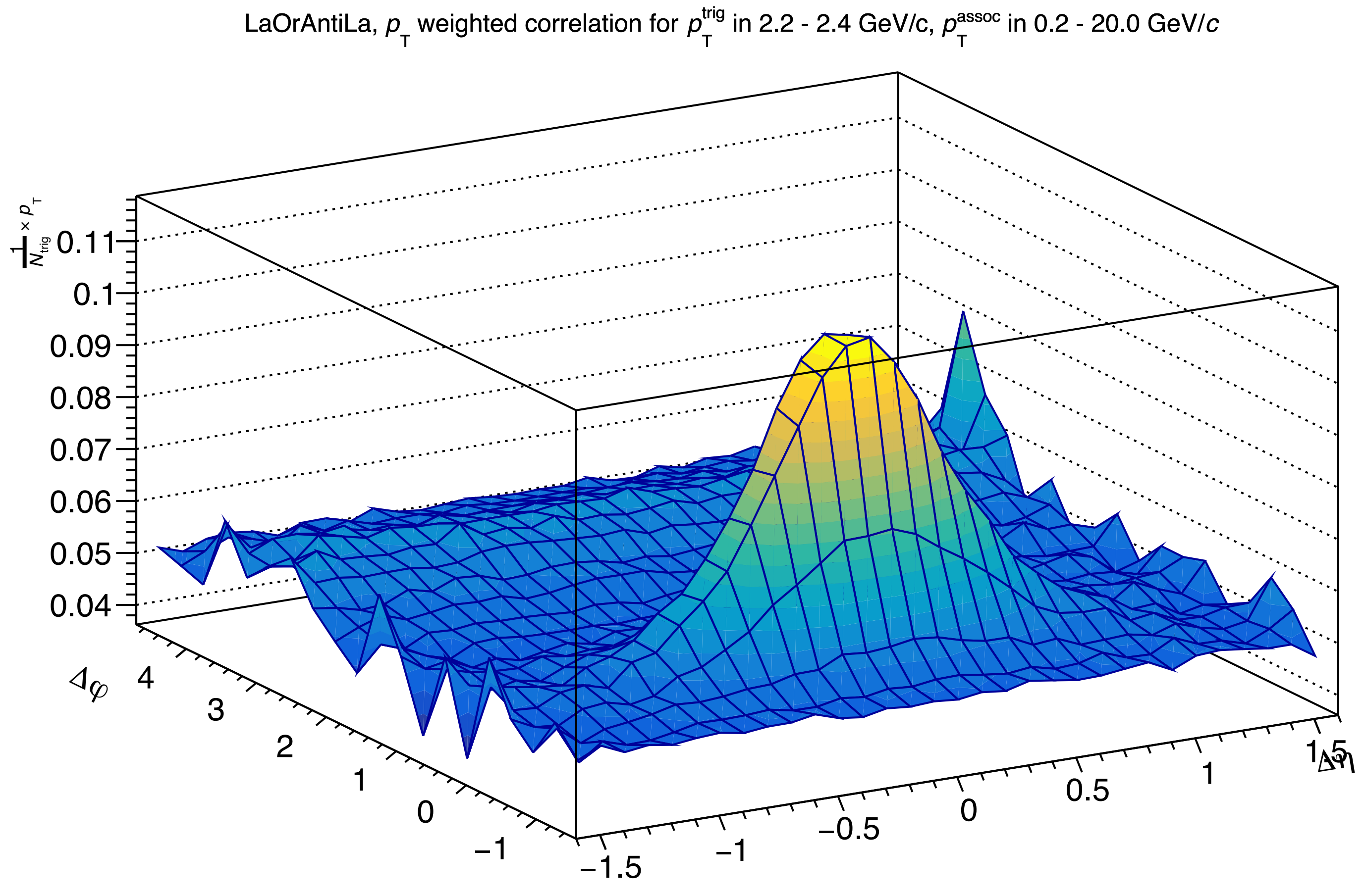


Corrected

2D correction for $\Lambda(\overline{\Lambda})$

Fitting function:

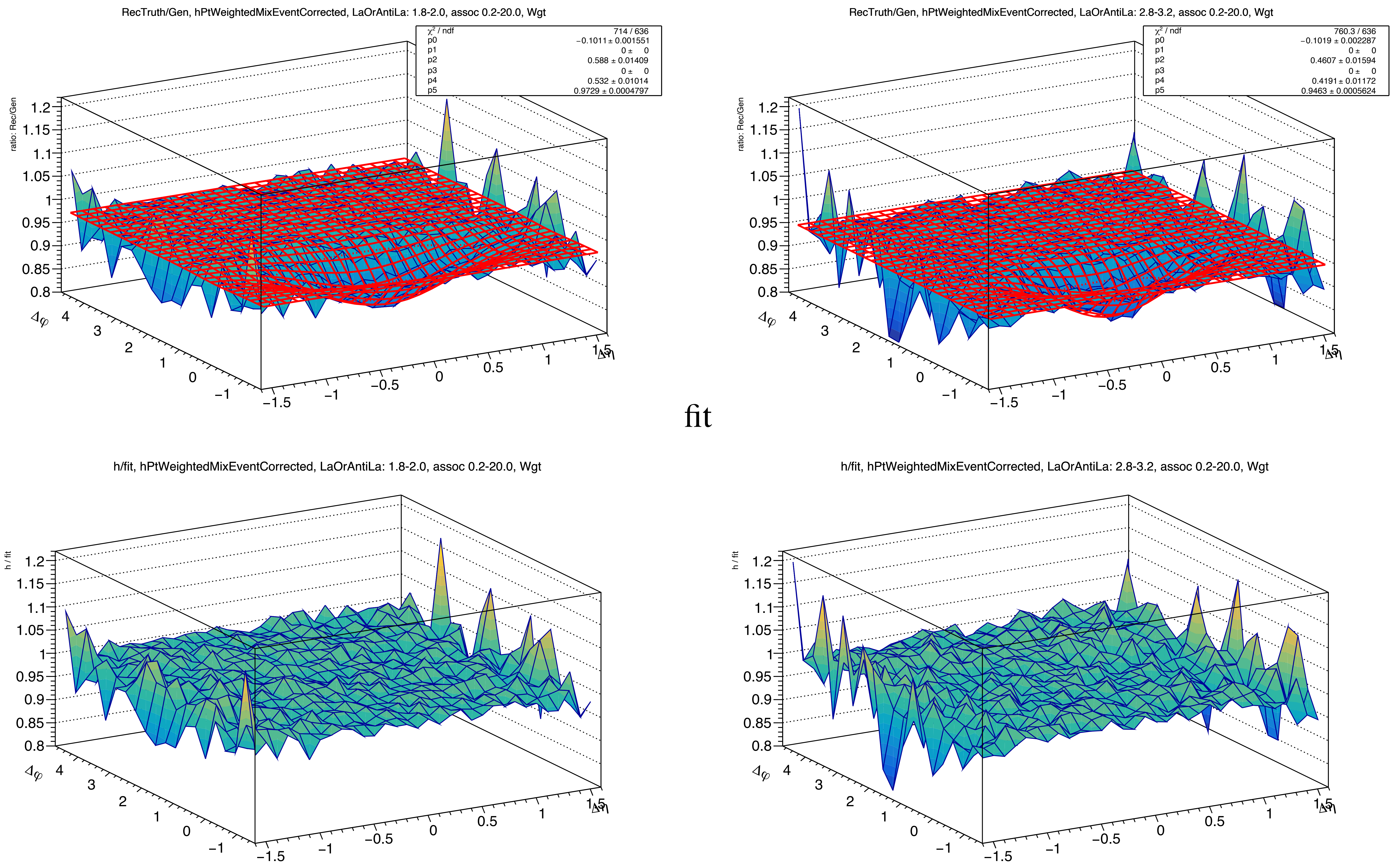
$$f(x,y) = Ae^{-\frac{(x-\mu_x)^2}{2\sigma_x^2}-\frac{(y-\mu_y)^2}{2\sigma_y^2}} + C$$

Parameter initialization:

$$\mu_x = \mu_y = 0 \text{ (fixed)};$$
$$\sigma_x = 0.4 \text{ (0.1 for the first interval)};$$
$$\sigma_y = 0.2;$$
$$C = 1.0$$

- Overall, the fit results well-describe the 2D maps for $p_{\mathrm{T}} < 6$ GeV/c

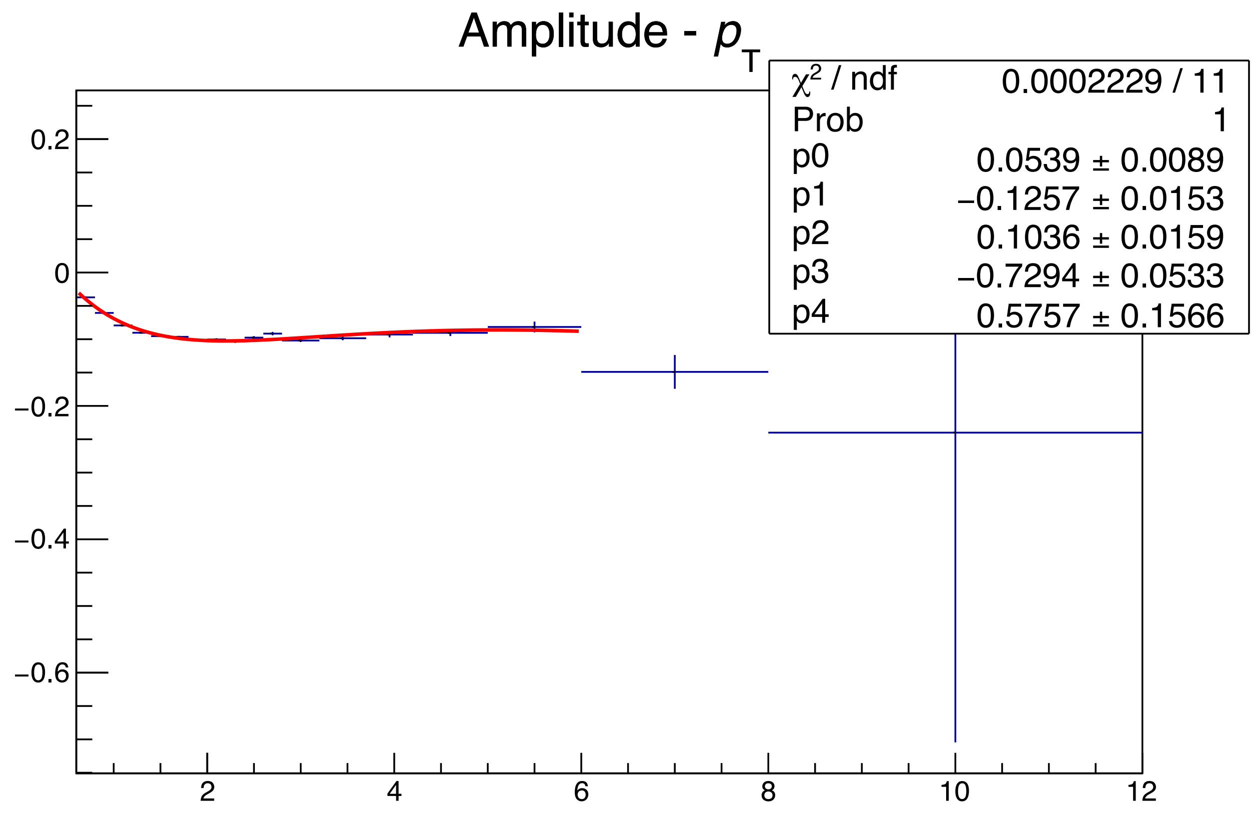
1.8-2.0 GeV/c 2.8-3.2 GeV/c

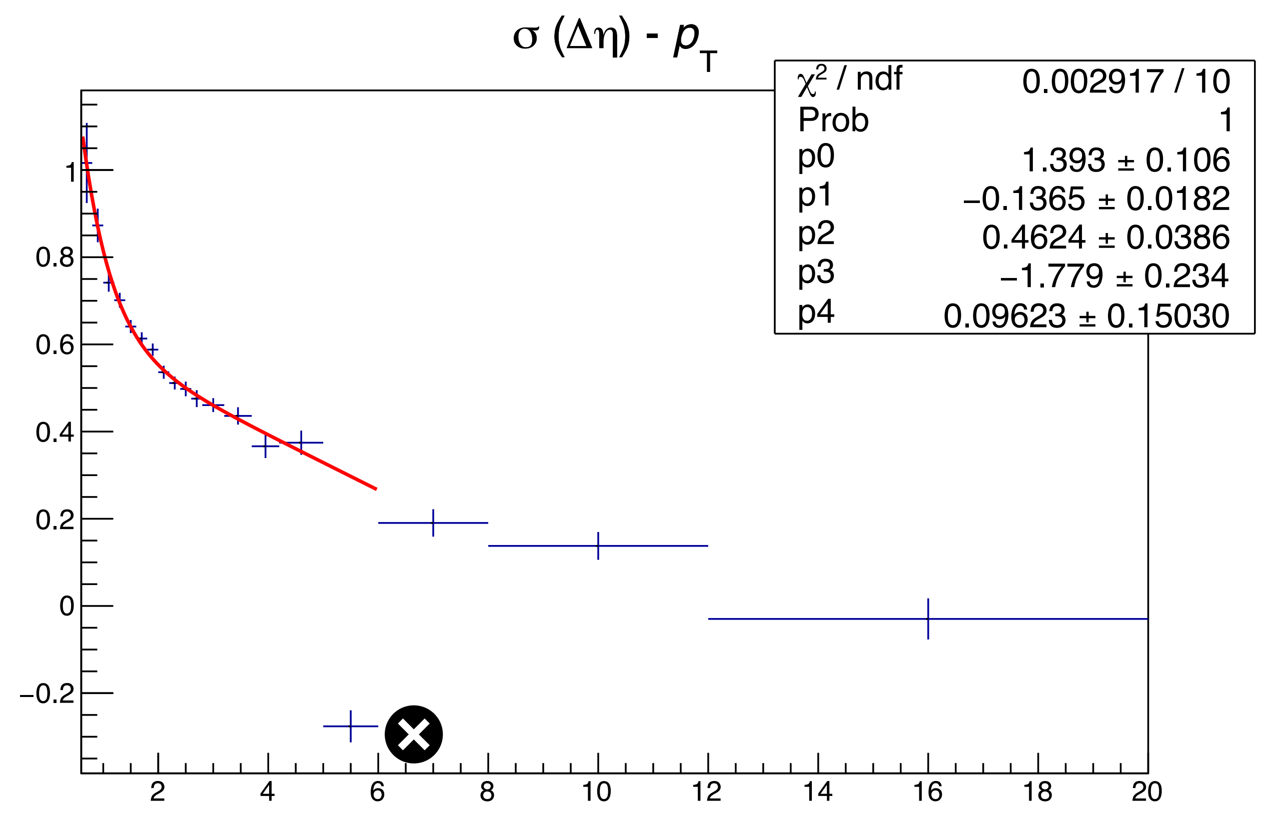


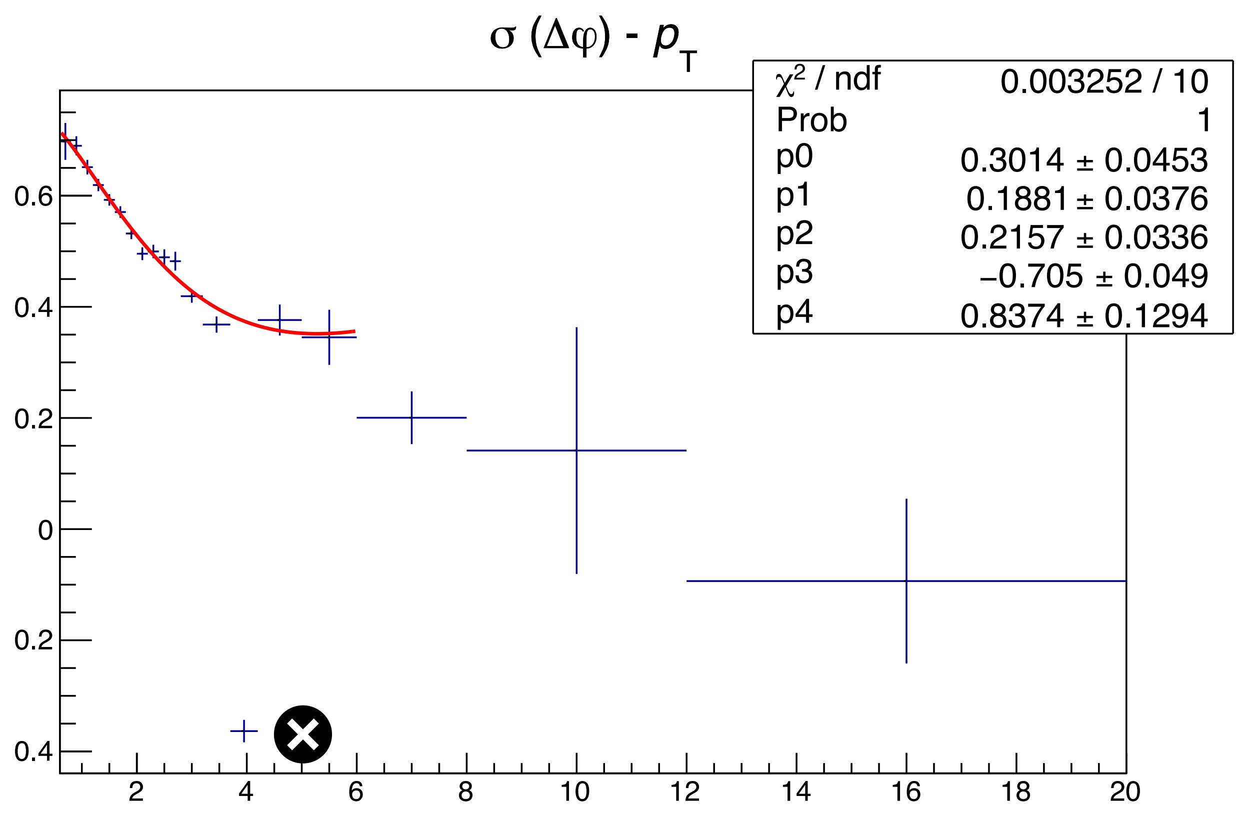
fit

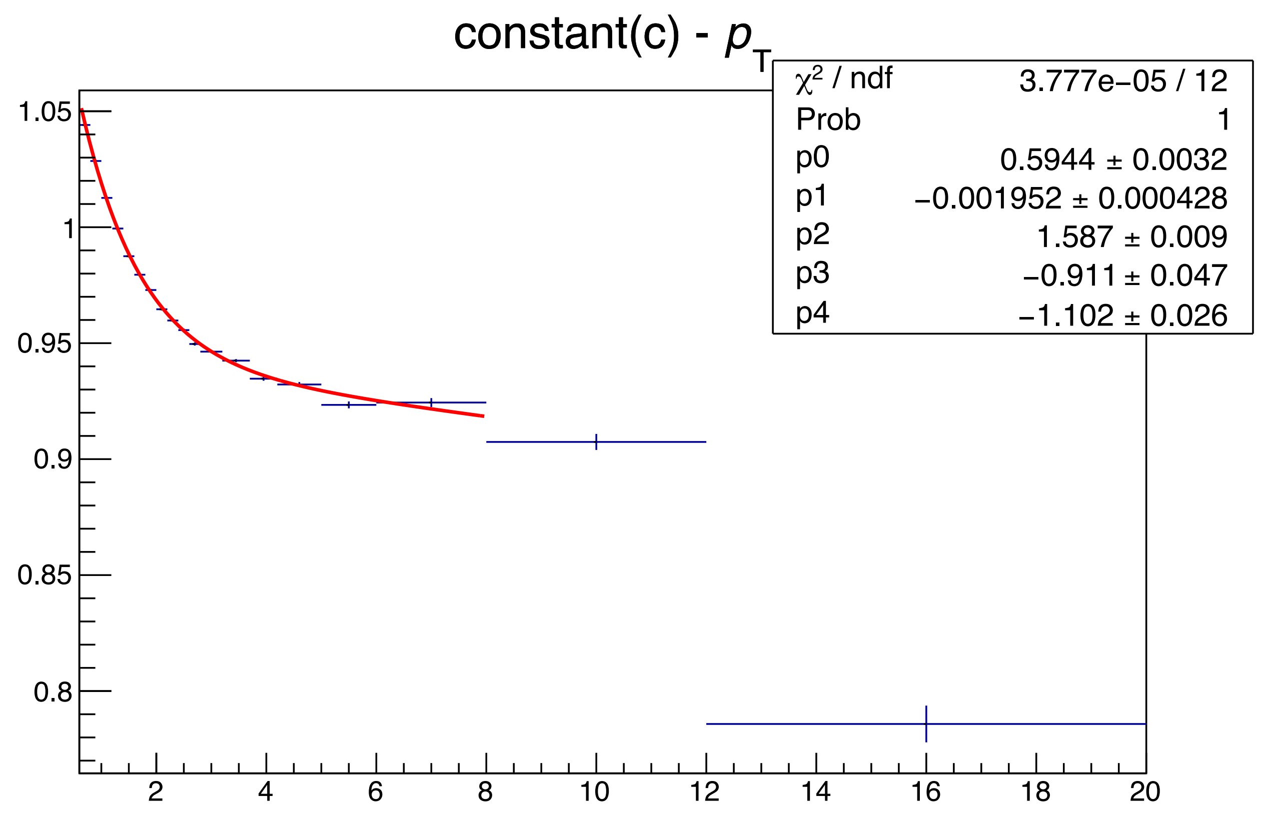
h / fit

2D correction for $\Lambda(\overline{\Lambda})$









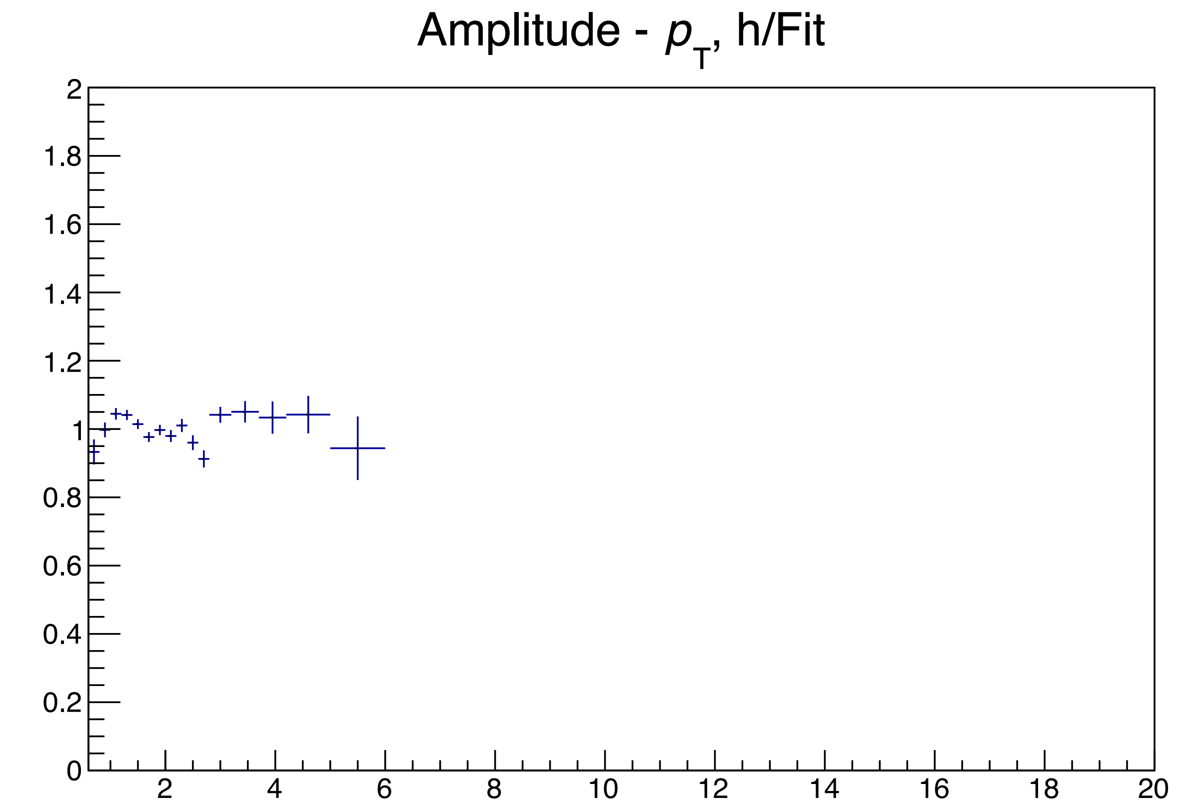
fit

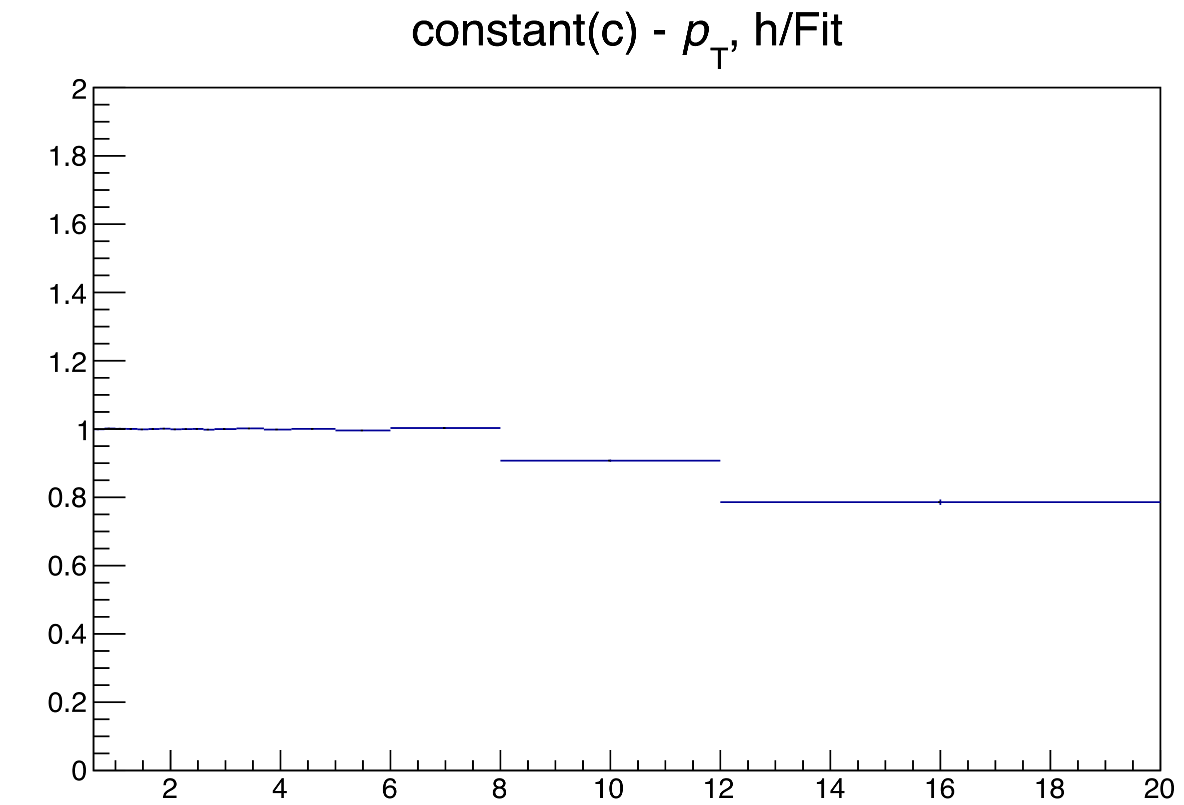
Function: pol1 * exp
Fit range: 0.6-6 GeV/c

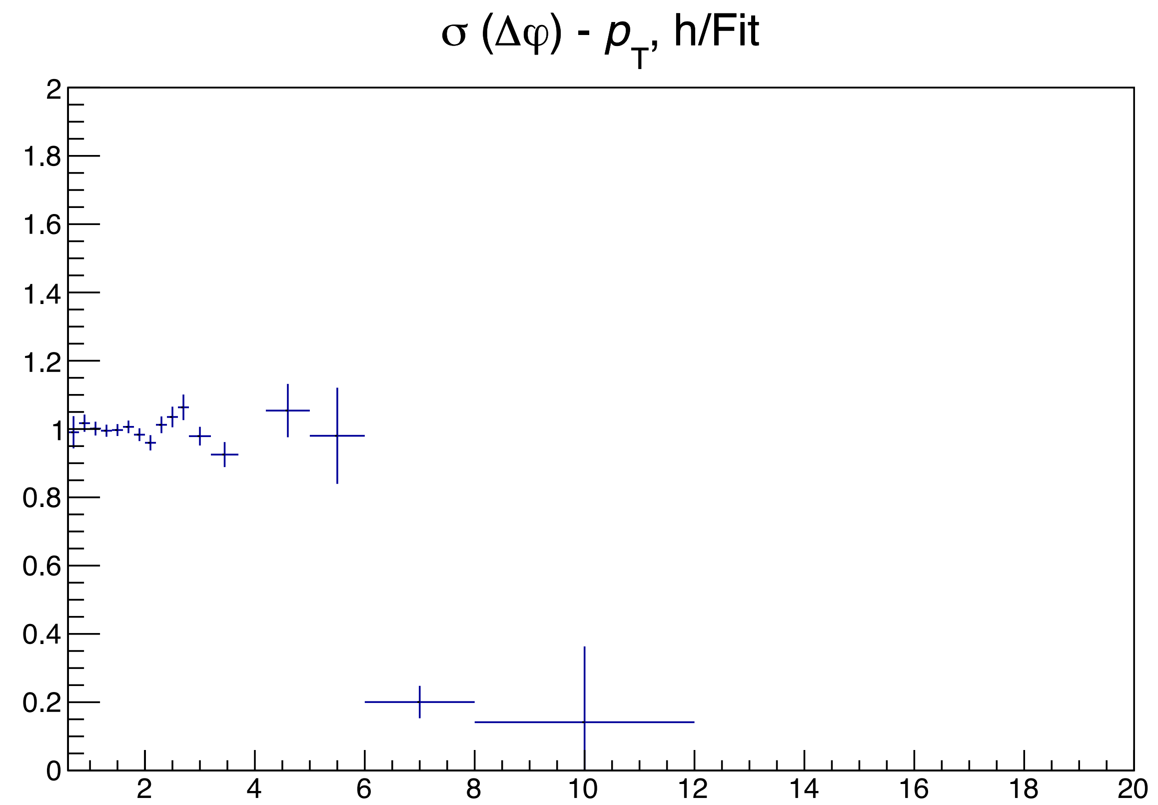
Function: pol1 * exp
Fit range: 0.6-6 GeV/c

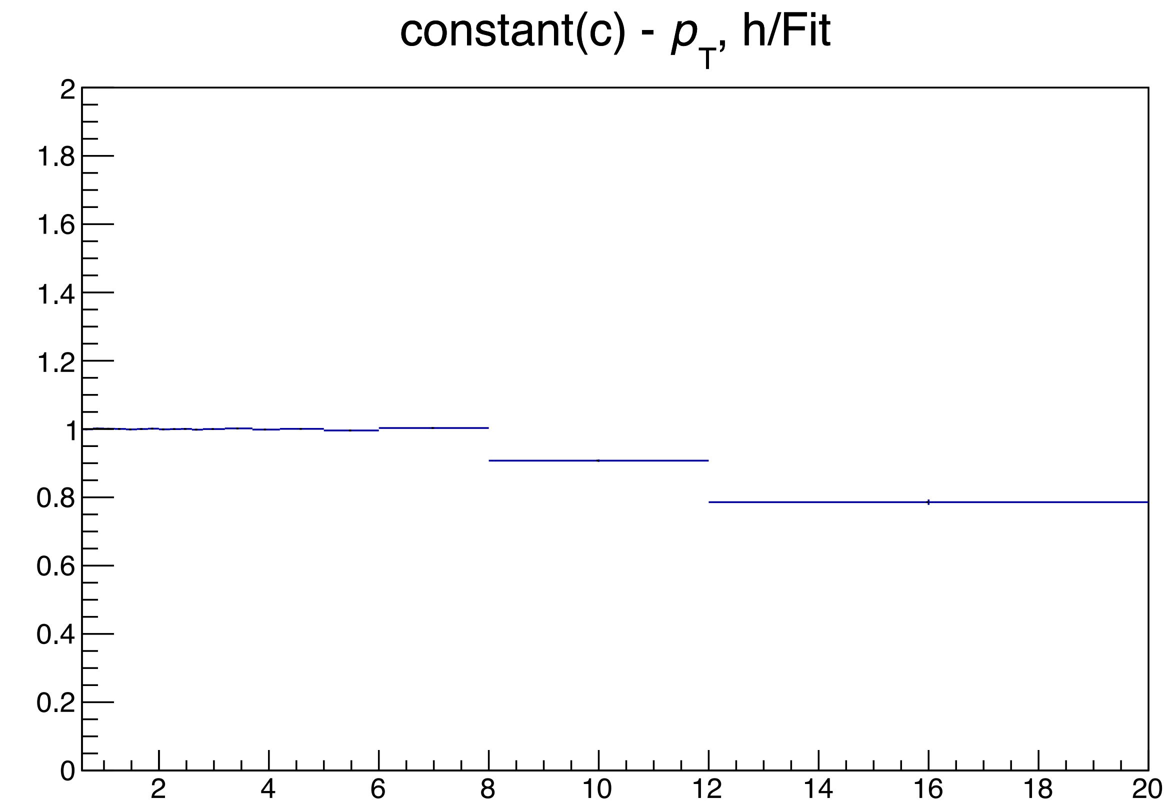
Function: pol1 * exp
Fit range: 0.6-3.7 & 4.2-6 GeV/c

Function: pol1 * exp
Fit range: 0.6-8 GeV/c









h / fit

$p_{\mathrm{T,trig}} \leq$ 6 GeV/c: based on the fit of parameters, reconstruct the 2D function to do the correction

$p_{\mathrm{T,trig}} >$ 6 GeV/c: ?

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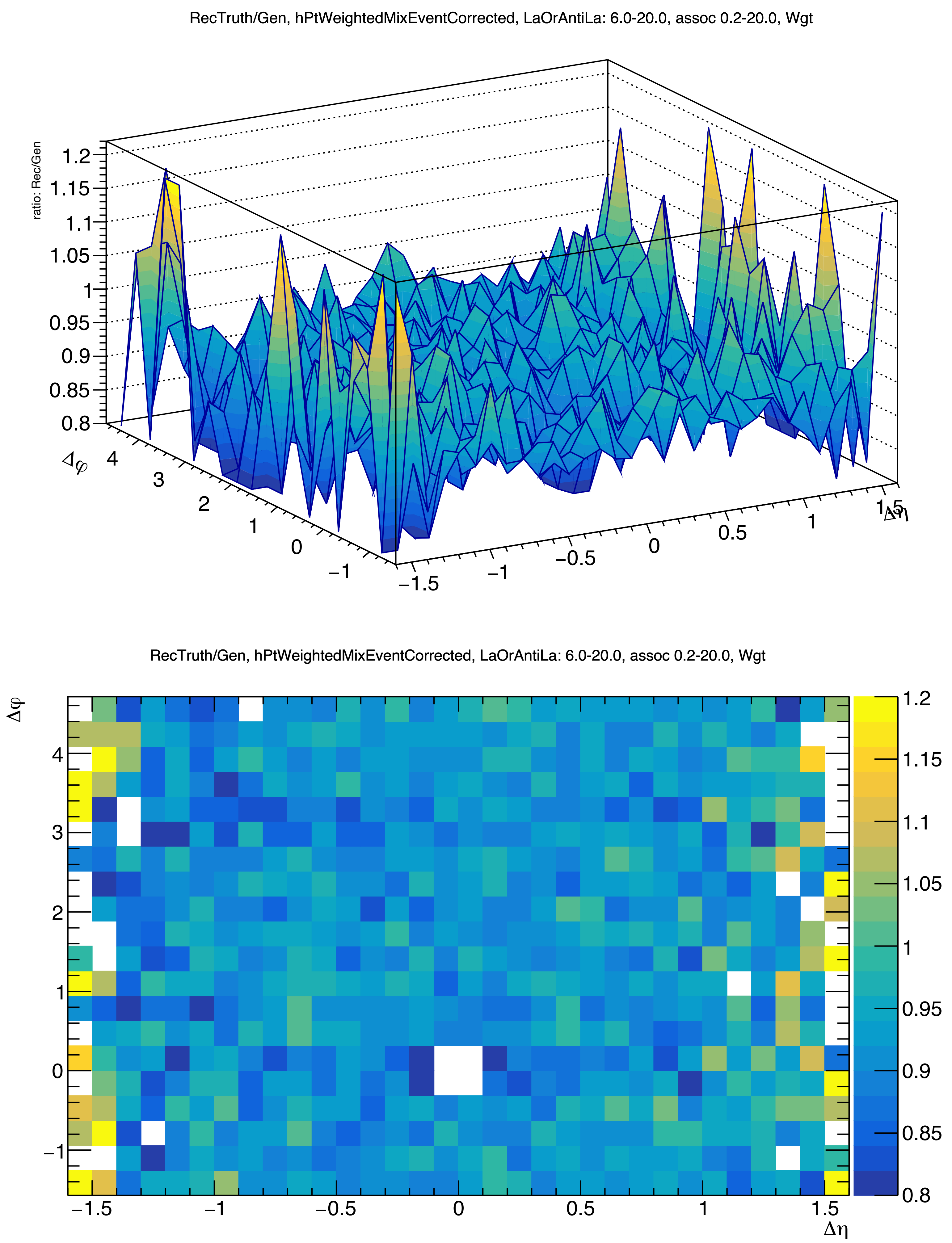
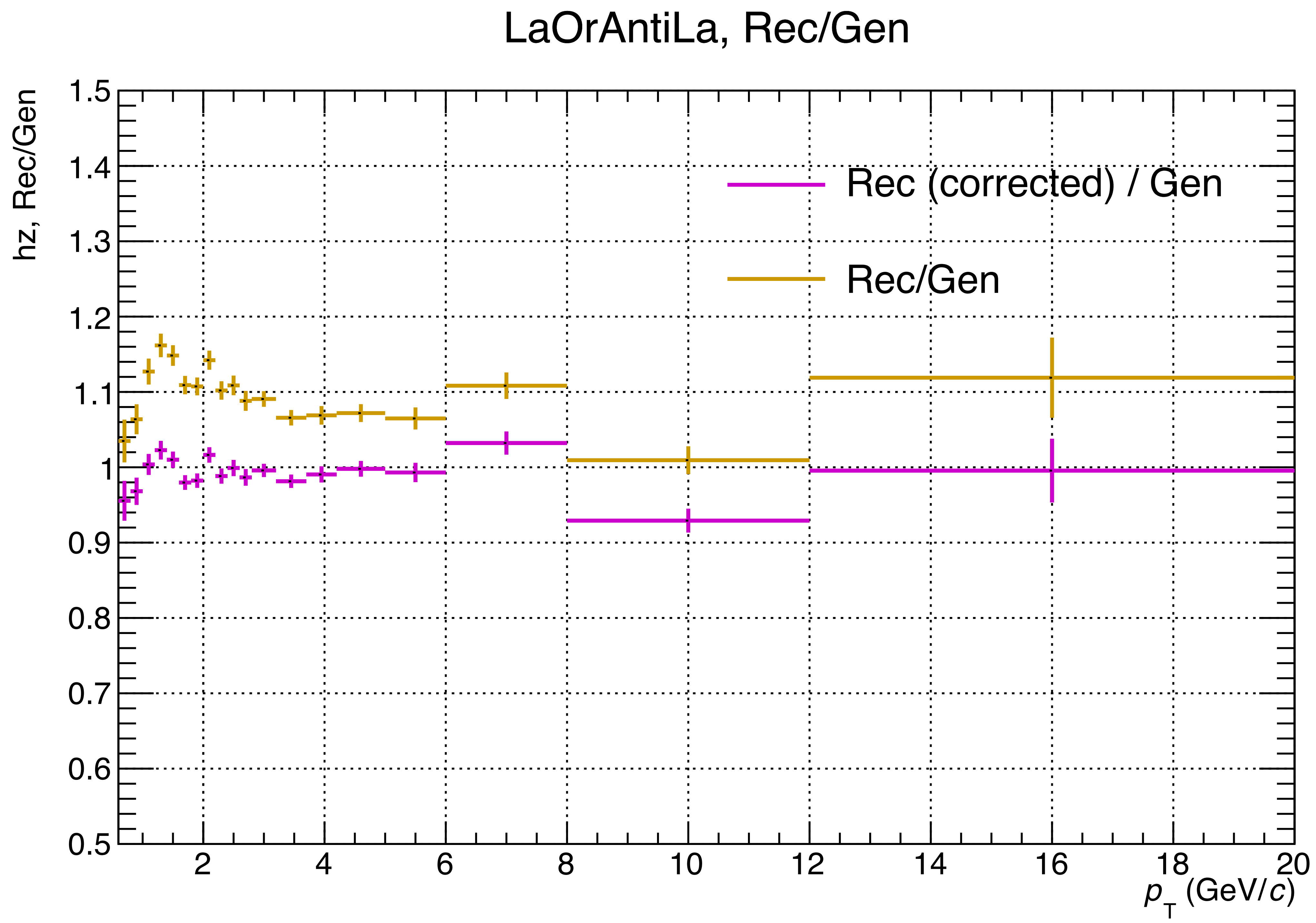
2D correction for $\Lambda(\overline{\Lambda})$



The 2D map for 6-20 GeV/c

For the last three bins, using the same 2D map (6-20 GeV/c, left) for correction



Yellow points: Rec/Gen before 2D correction
Magenta points: Rec/Gen after 2D correction

For > 6 GeV/c, an uncertainty is given by:

$$\sigma^2_{\text{syst. non-closure}} = \sigma^2_{\text{stat. corrected by 2Dmap w/ uncertainty}} - \sigma^2_{\text{stat. corrected by 2Dmap w/o uncertainty}}$$

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 (*Not taken in the end*)
④ Method to normalize the mix event correlation function
⑤ Selections on primary tracks: FB256 —> FB32
⑥ Choice of the jet region and out-of-jet region
⑦ OOB/IB PU
⑧ Material budget
⑨ Feed-down for $\Lambda(\overline{\Lambda})$
⑩ Non-closure for $\Lambda(\overline{\Lambda})$

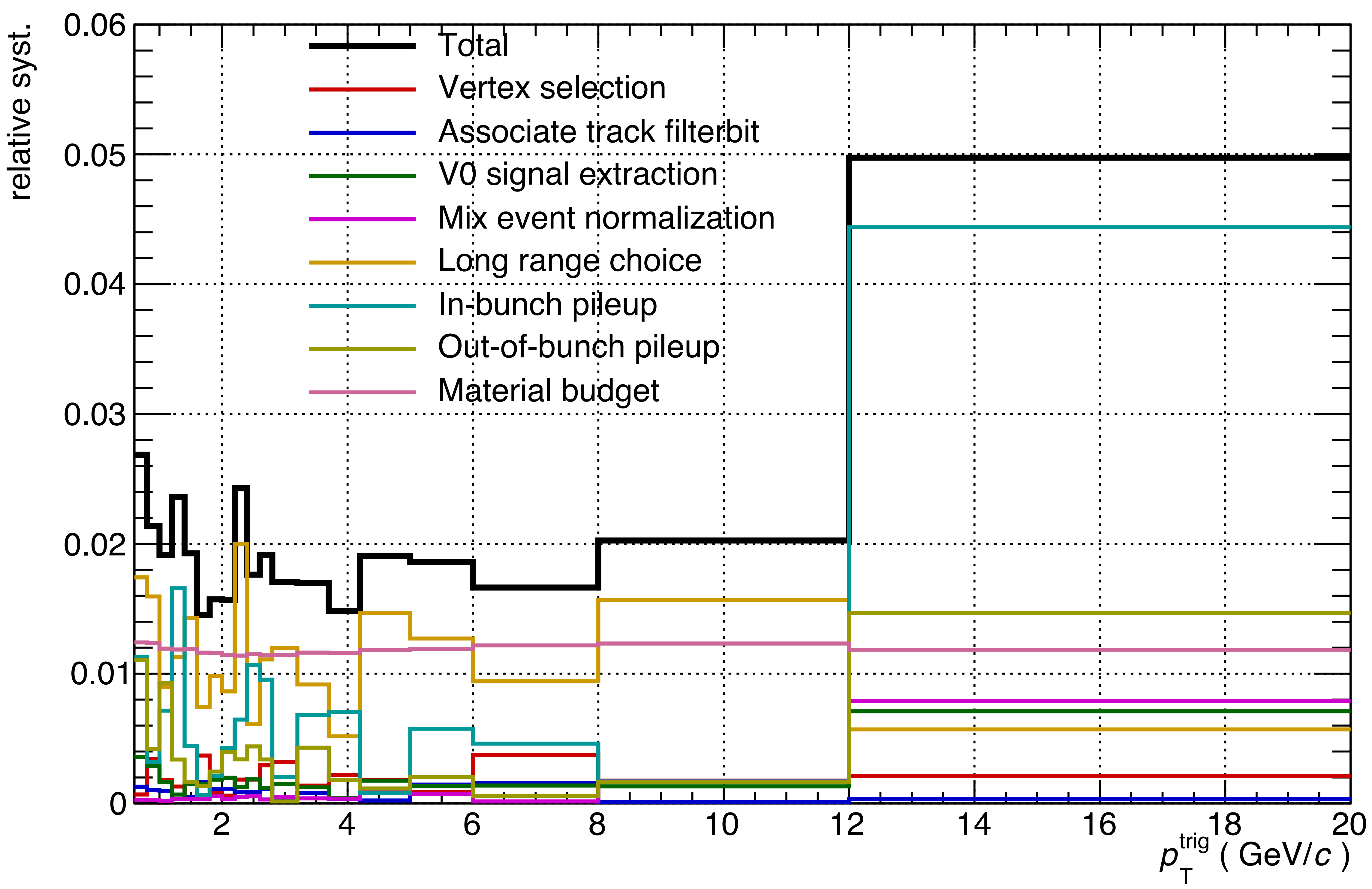
All sources are examined by the Barlow check

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

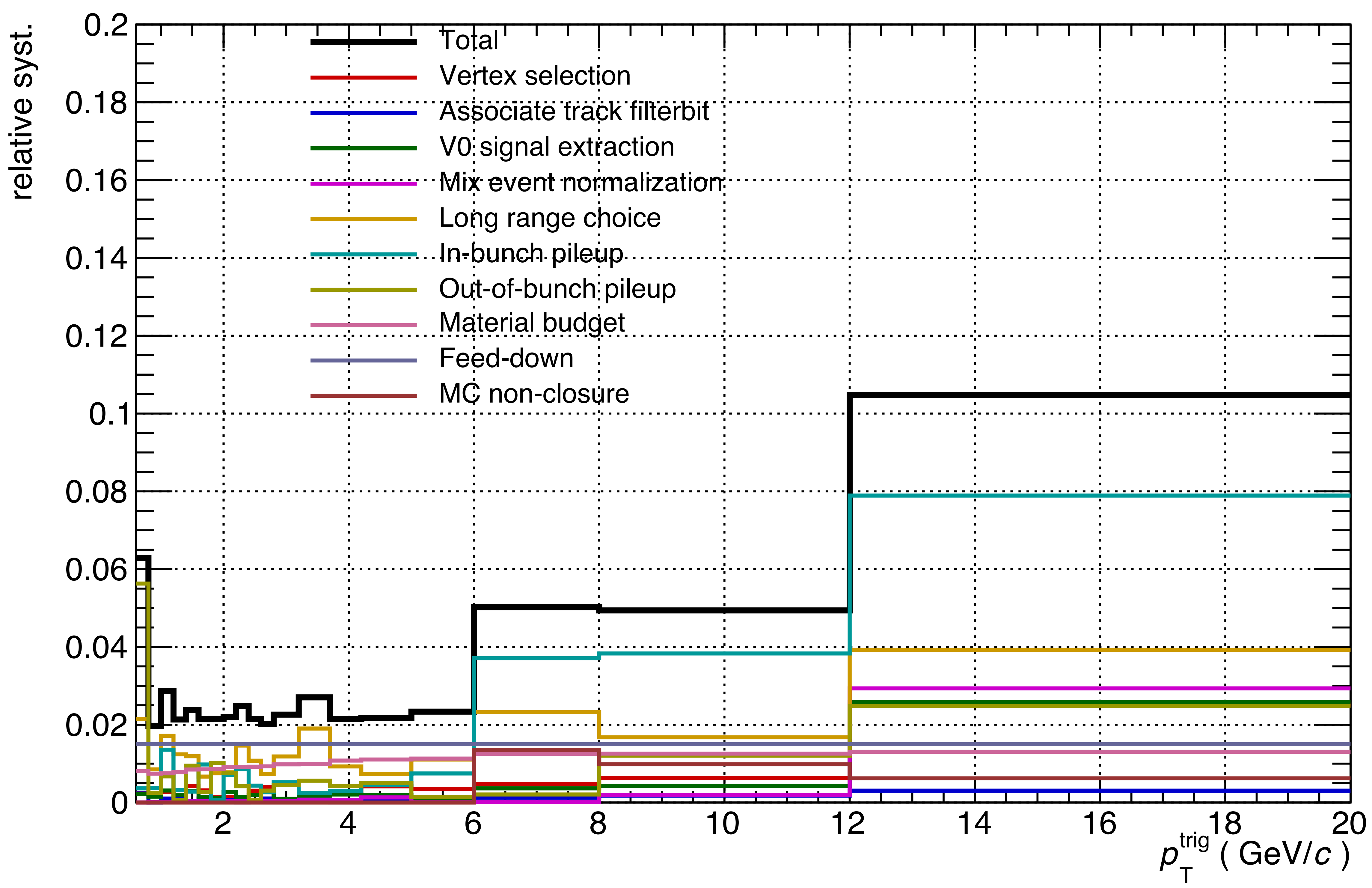
Systematic uncertainty details are in backup slides

Systematic uncertainty

K^0_S



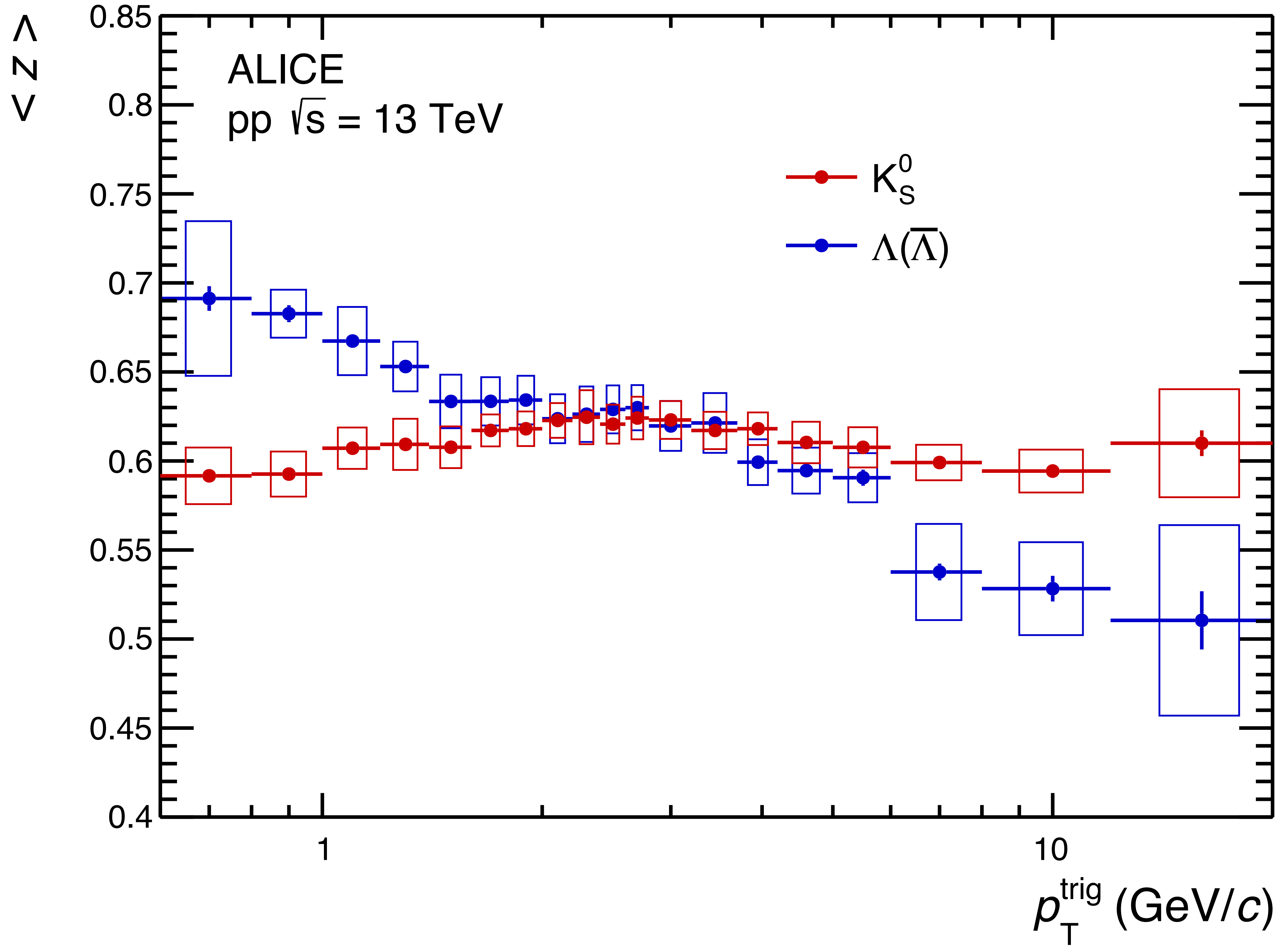
$\Lambda(\overline{\Lambda})$

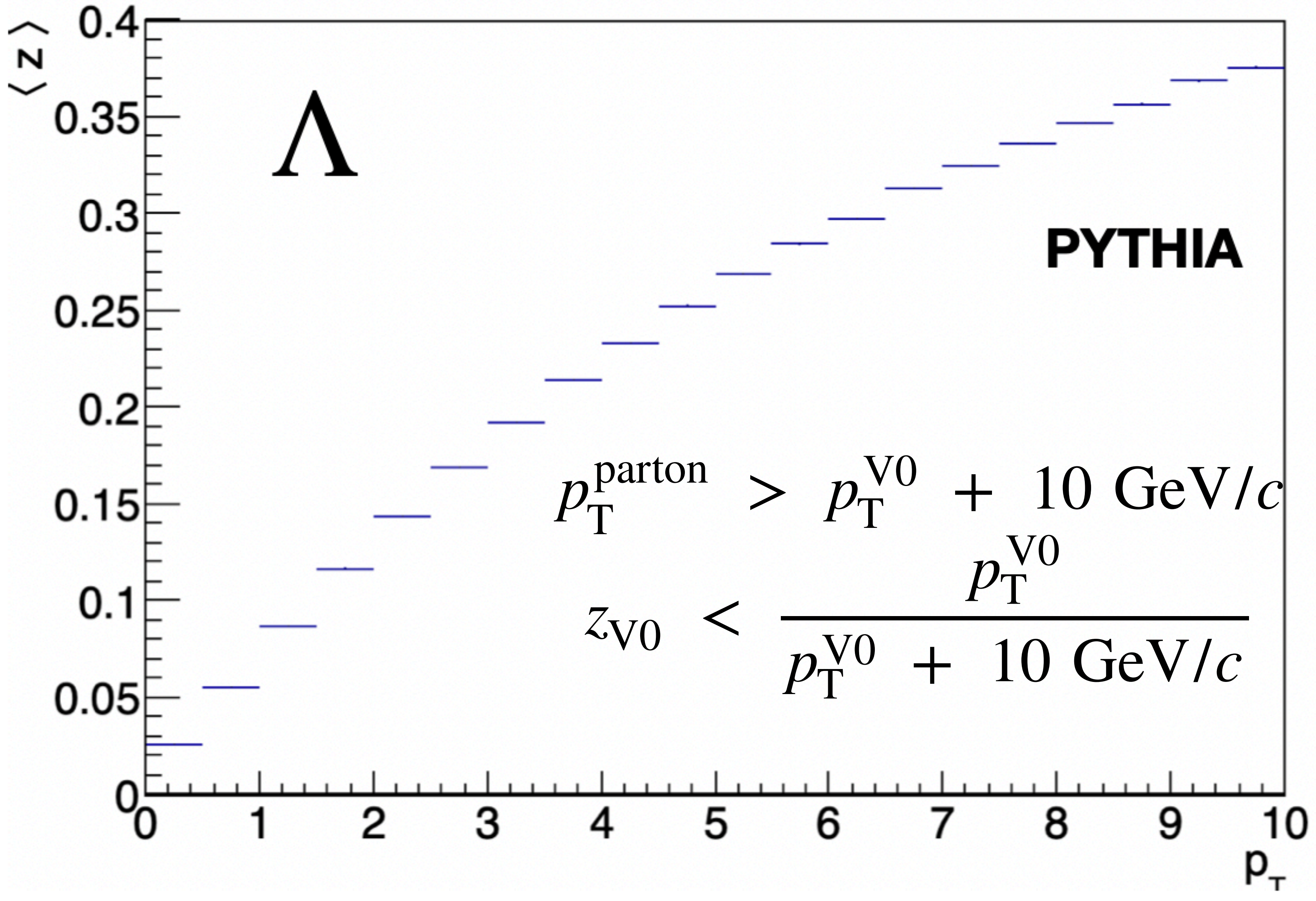


$$\sigma_{\text{total}} = \sqrt{\sum_i \left(\sigma_i^2\right)}$$

Systematic uncertainty details are in backup slides

Results - <z>

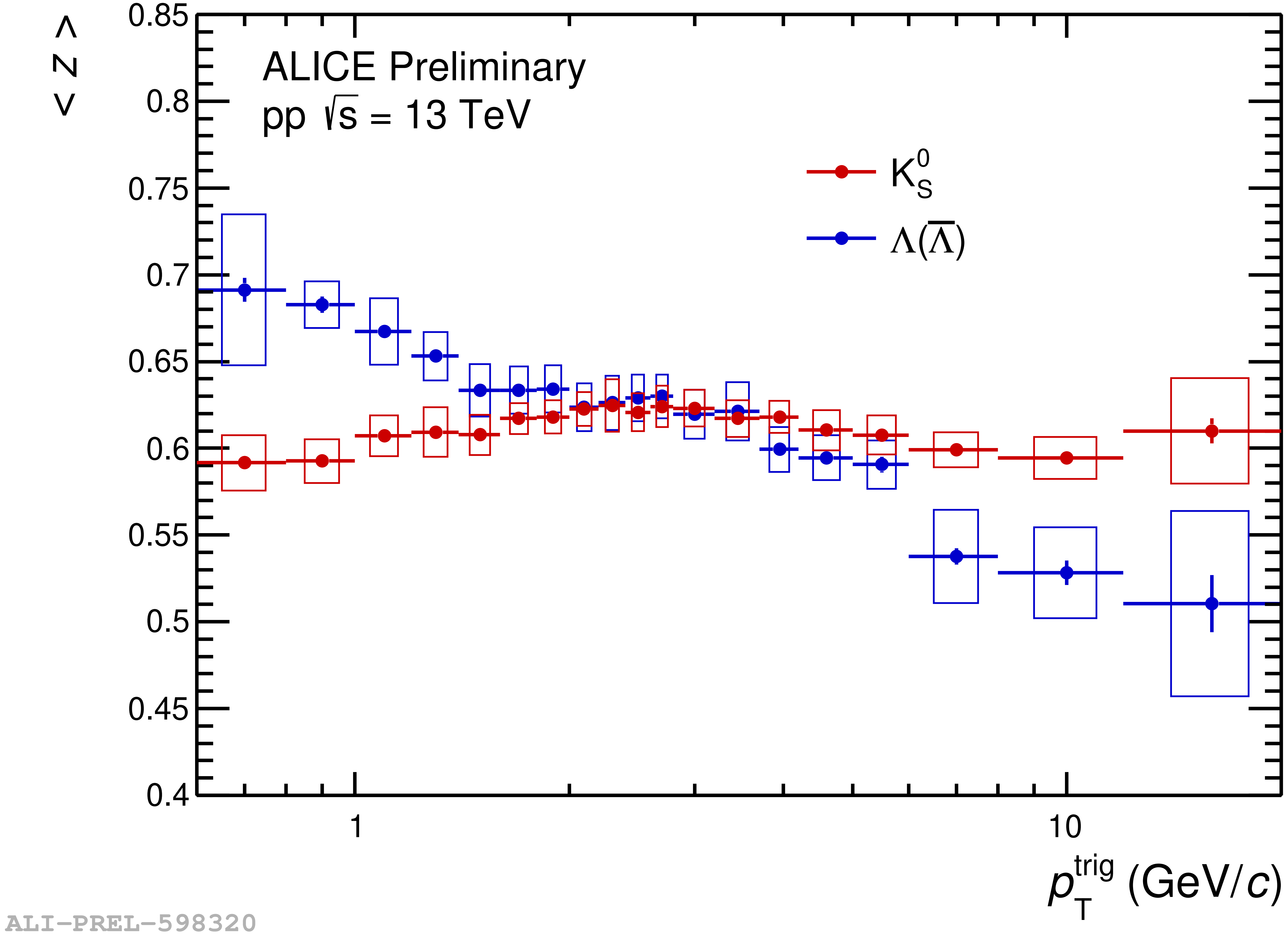




Inside-jet Λ momentum fraction z

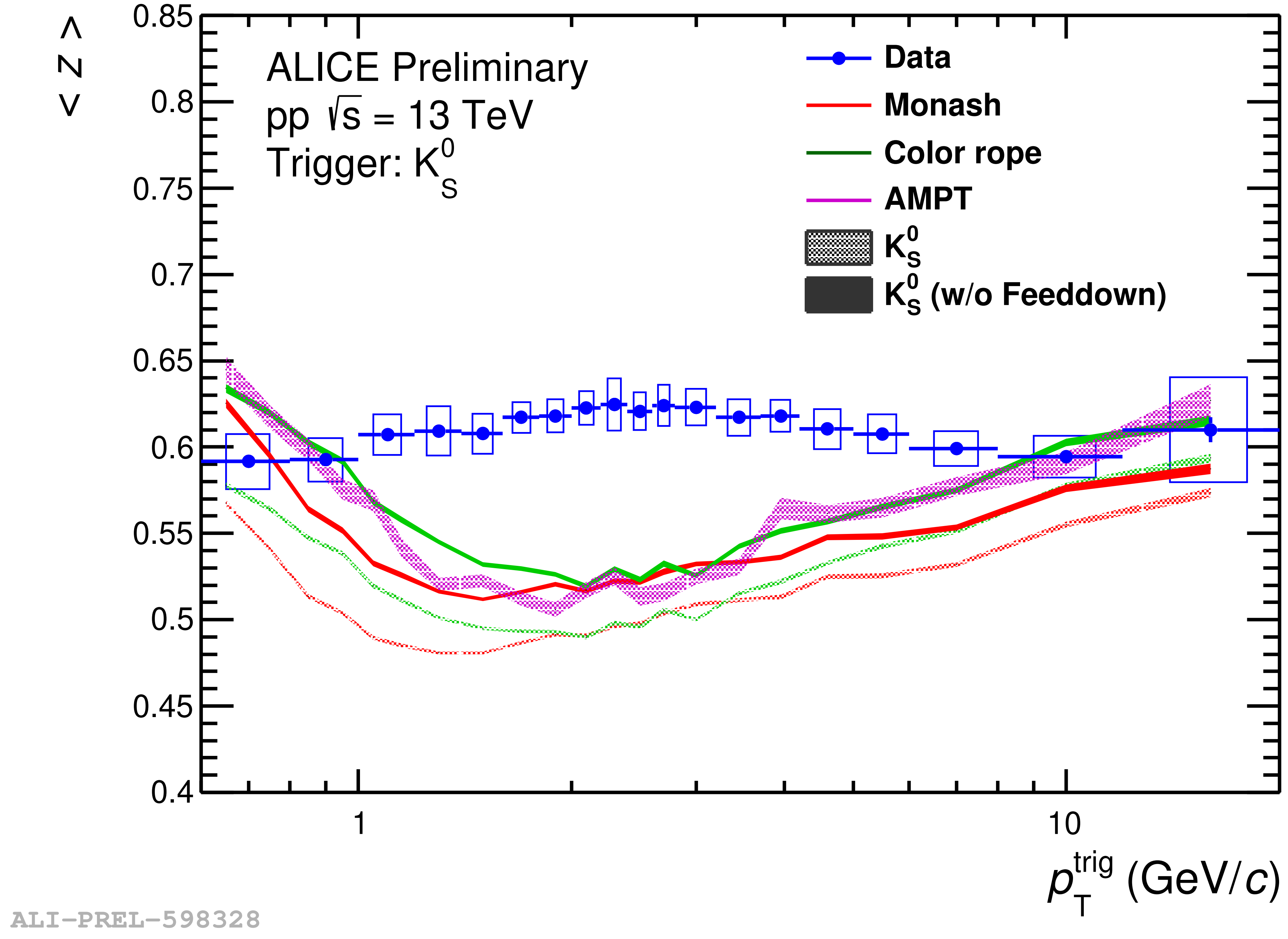
- Results suggests that the fragmentation of the strange particles is (relative) low energy partons with high <*z*> type
  - When compare the in-jet and out-of-jet strange particles production, we are actually measuring particles with different <*z*>

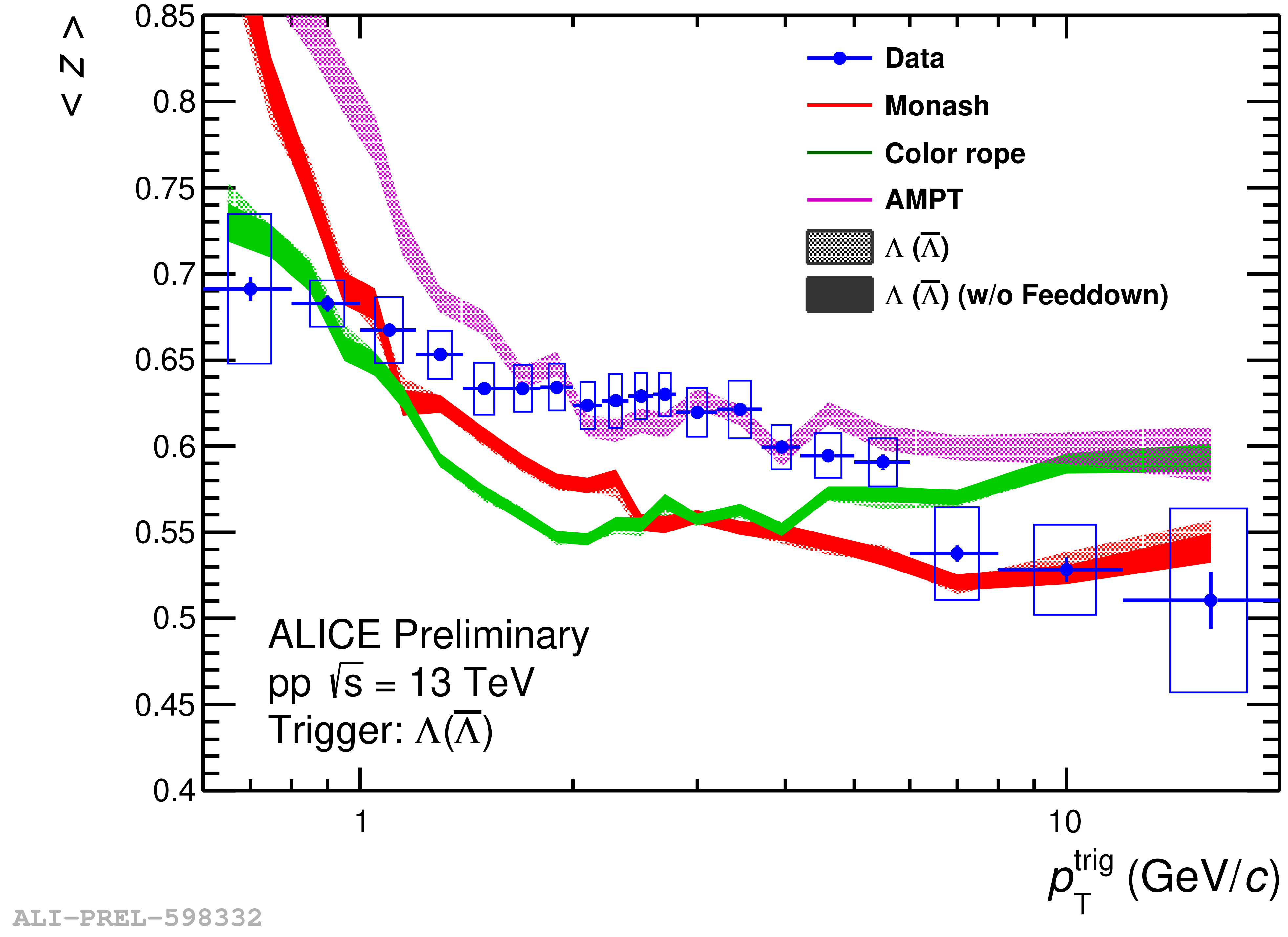
Results - <z>



- At high p_T, these relatively high values for these two particle species are expected to due to the leading particle effect
- $<z>$ is nearly flat and consistent for two particle species in 2-6 GeV/c shows no indication of a significant change of production mechanism in this region
- At low p_T (< 1.5 GeV/c), the increasing (from intermediate p_T to low p_T) due to either the fragmentation is harder for $\Lambda(\bar{\Lambda})$ at this region, or more isolated $\Lambda(\bar{\Lambda})$ production contribution in this region

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 can not well-reproduce data
- K^0_S: predictions provide a minimum instead of a maximum

Prediction results are partly provided by Qiuyue Zhang

Summary and outlook

Summary:

- The first measurement of the strange particle's $p_{\rm T}$ fraction in mini-jets in pp collisions at $\sqrt{s}$ = 13 TeV is almost finished using the novel weighted correlation method, systematic uncertainty study is also performed
- Paper proposal within the ALICE Collaboration has been approved and the first paper draft is almost ready for the review inside collaboration

Outlook:

- Extend the study to multi-strange particles, investigate the dependence of $\langle z \rangle$ on charged-particle multiplicity

Thank you!

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Backup

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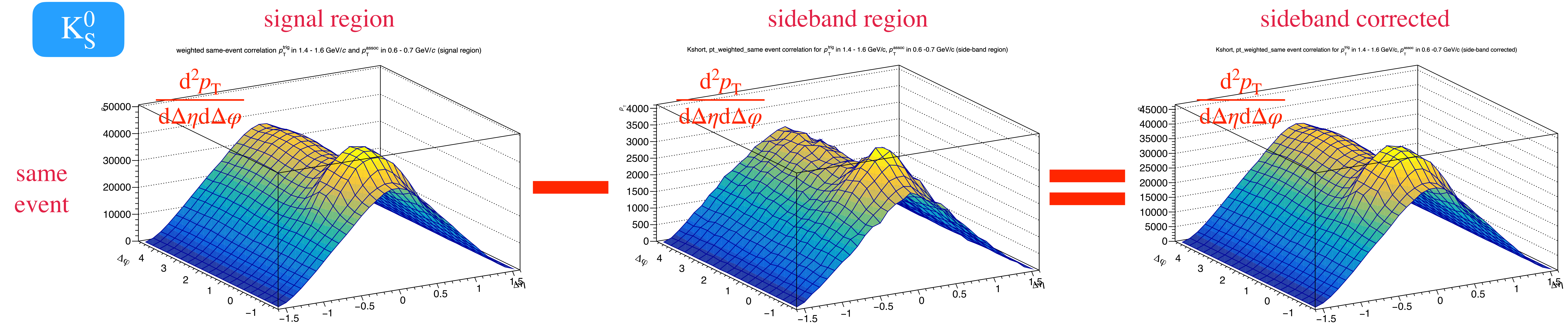
p_T weighted correlation analysis

K^0_S



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

Same event

- $p_{T,\,assoc}$ is used as the weight, weight = $p_{T,\,assoc}$ * (1 - C) / ε, where C and ε are the secondary fraction and tracking efficiency
- Sideband subtraction from the signal region

p_T weighted correlation analysis

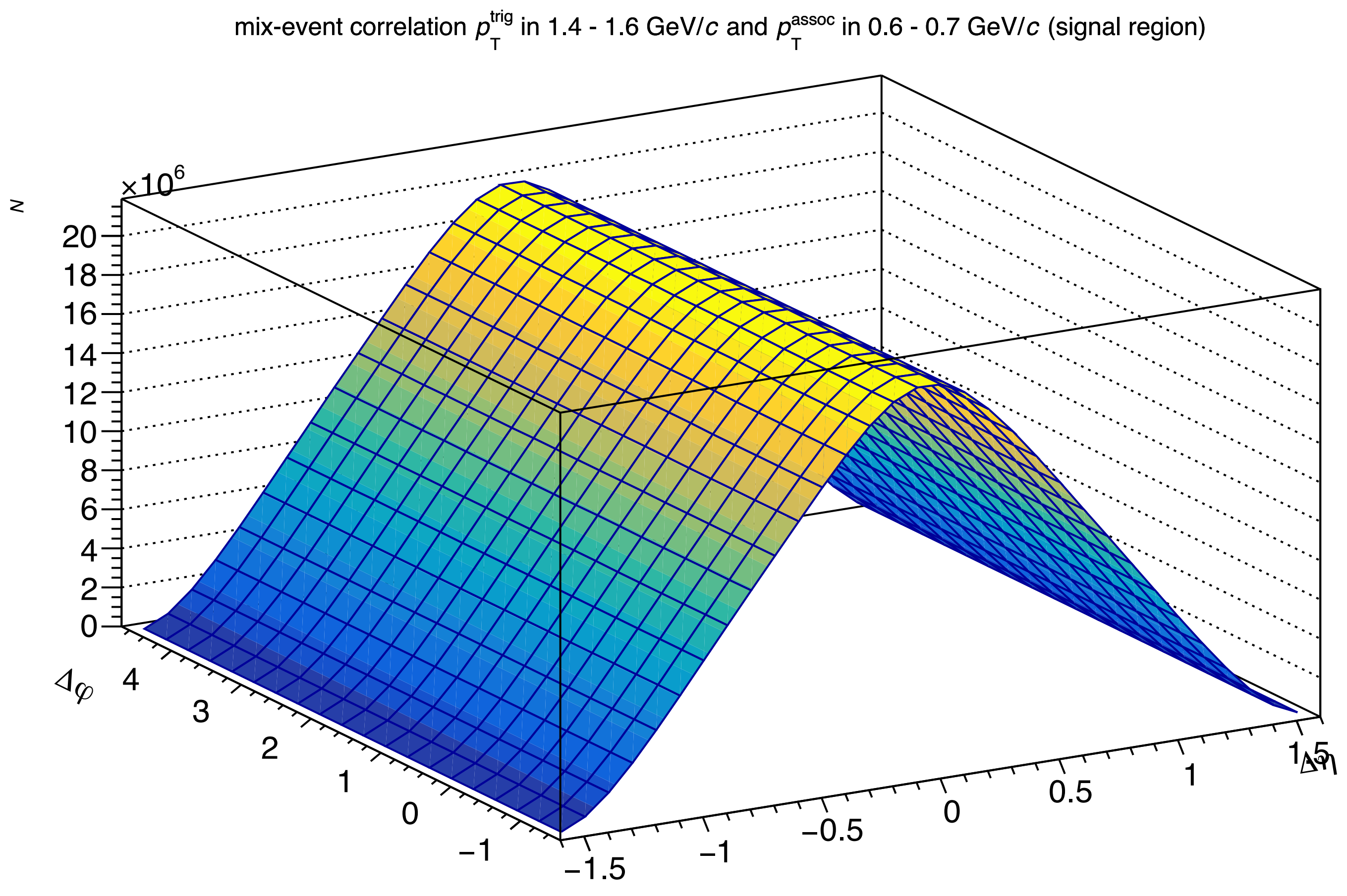
K^0_S

Mix event

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

mix event

signal region



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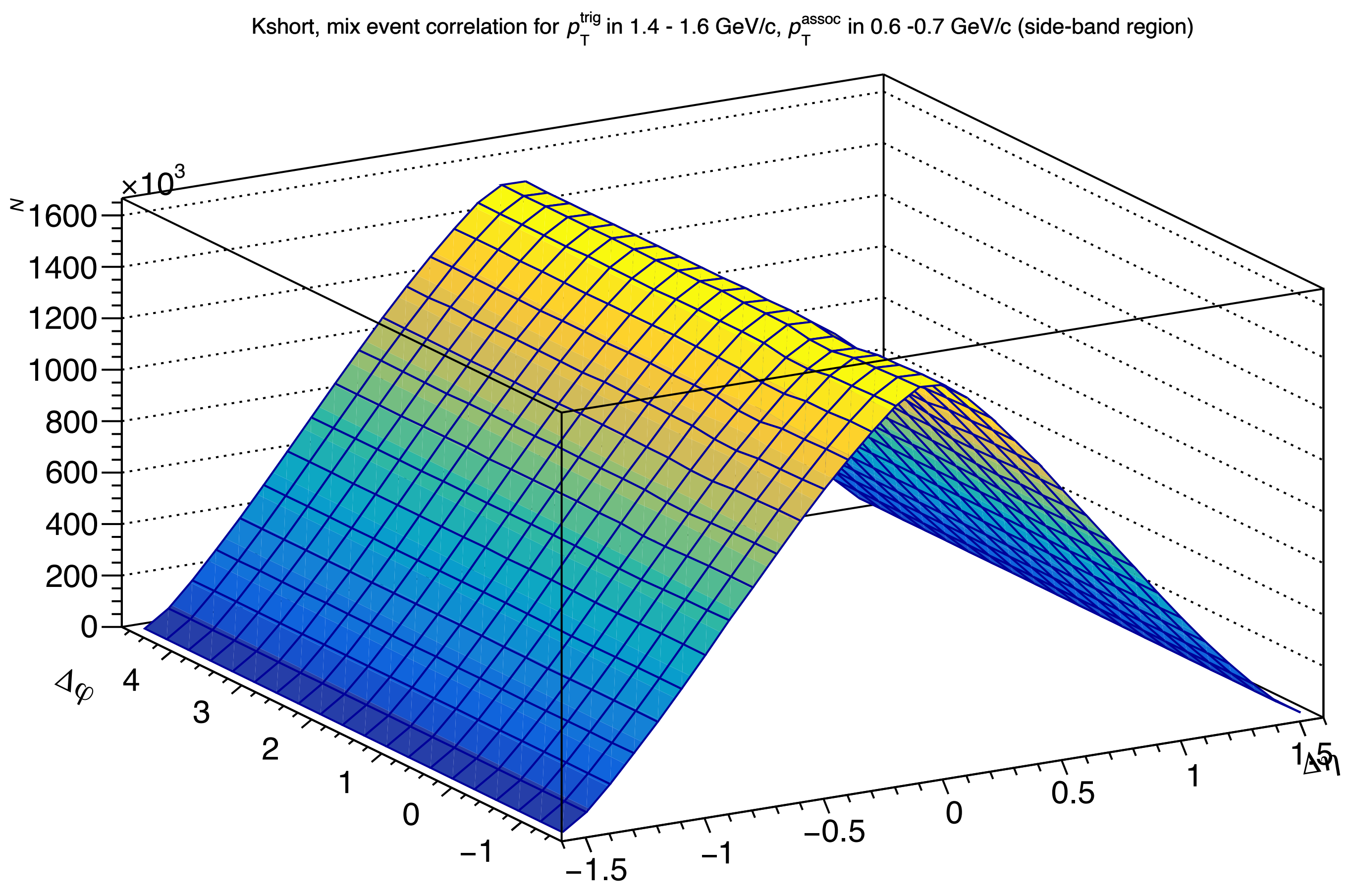
sideband region



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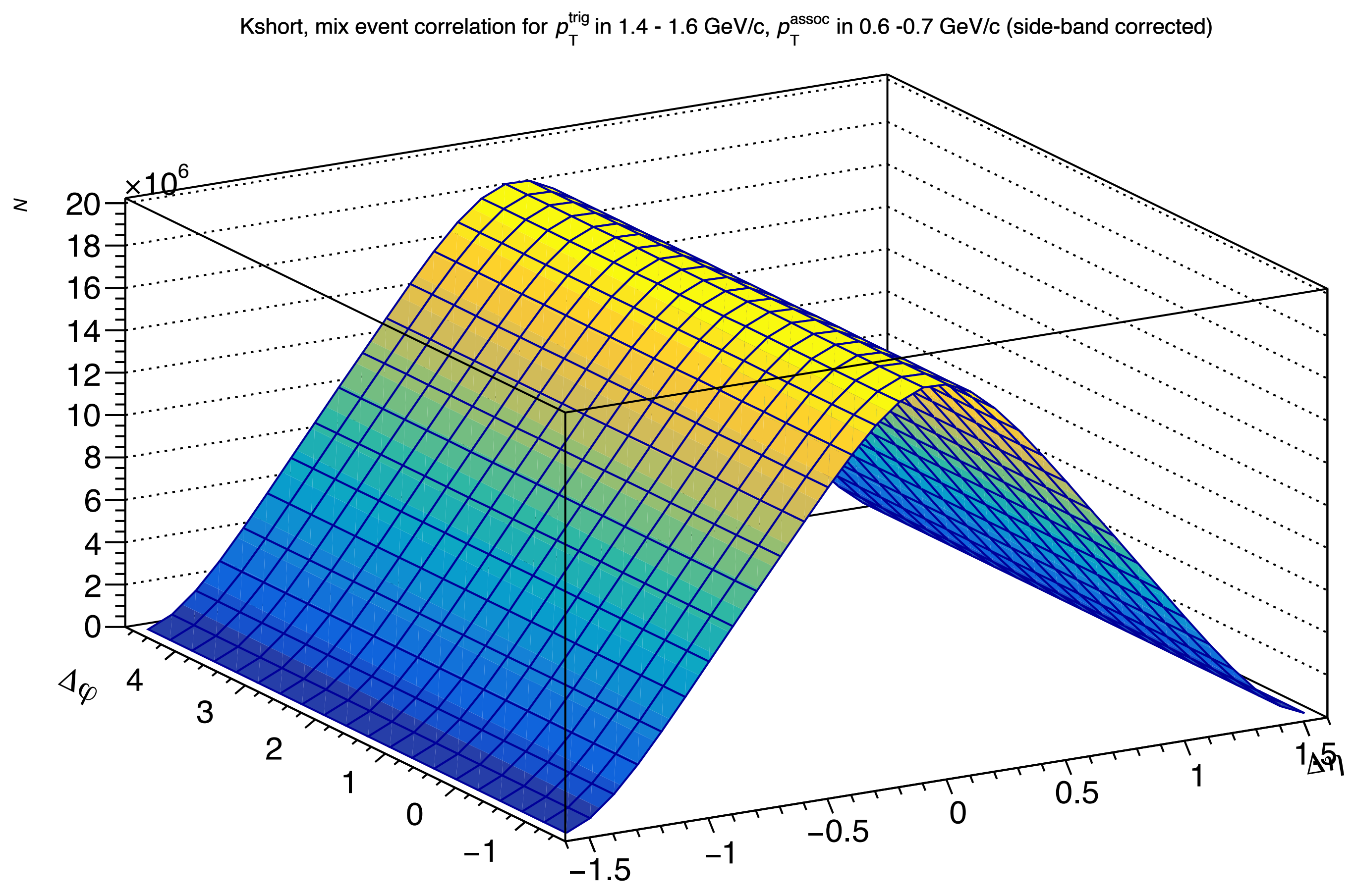
sideband corrected



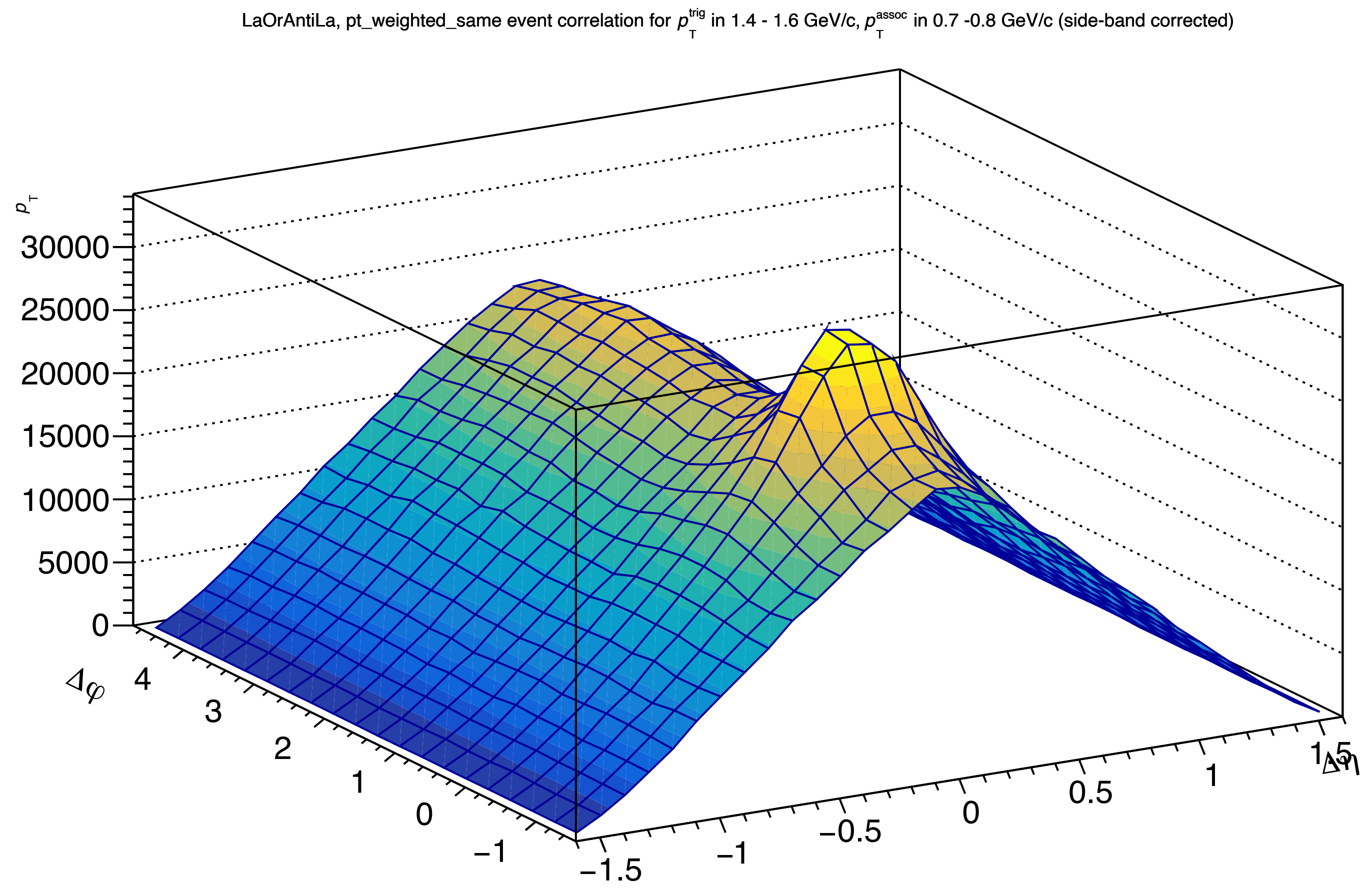
Example: $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ and $0.6\ \mathrm{GeV}/c < p_T^{assoc} < 0.7\ \mathrm{GeV}/c$

p_T weighted correlation analysis

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

$$C = \frac{S}{M}$$, where M is the normalized mixed event correlation function

same event (side band corrected)



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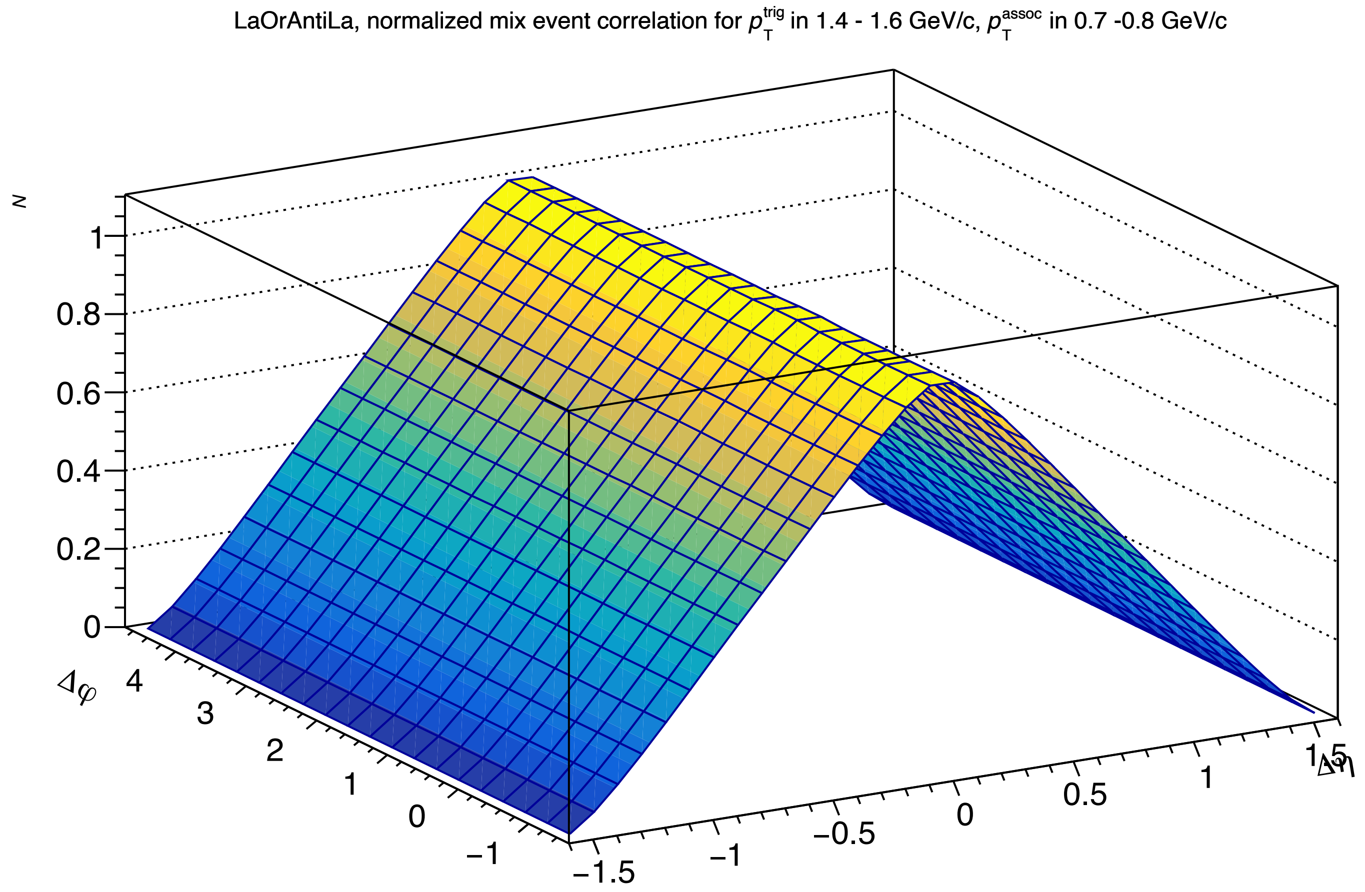
mix event (side band corrected, normalized)



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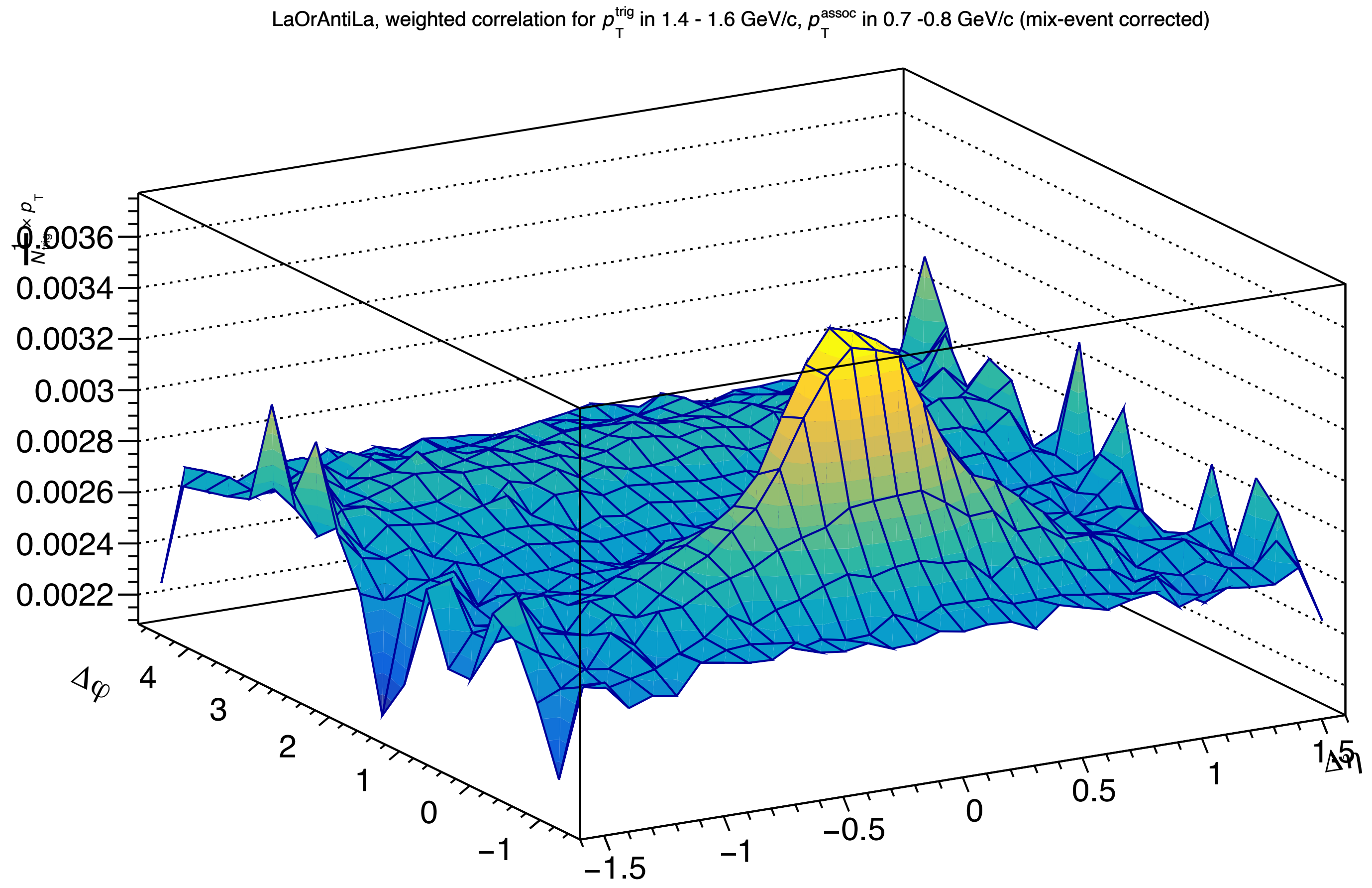
mix event corrected



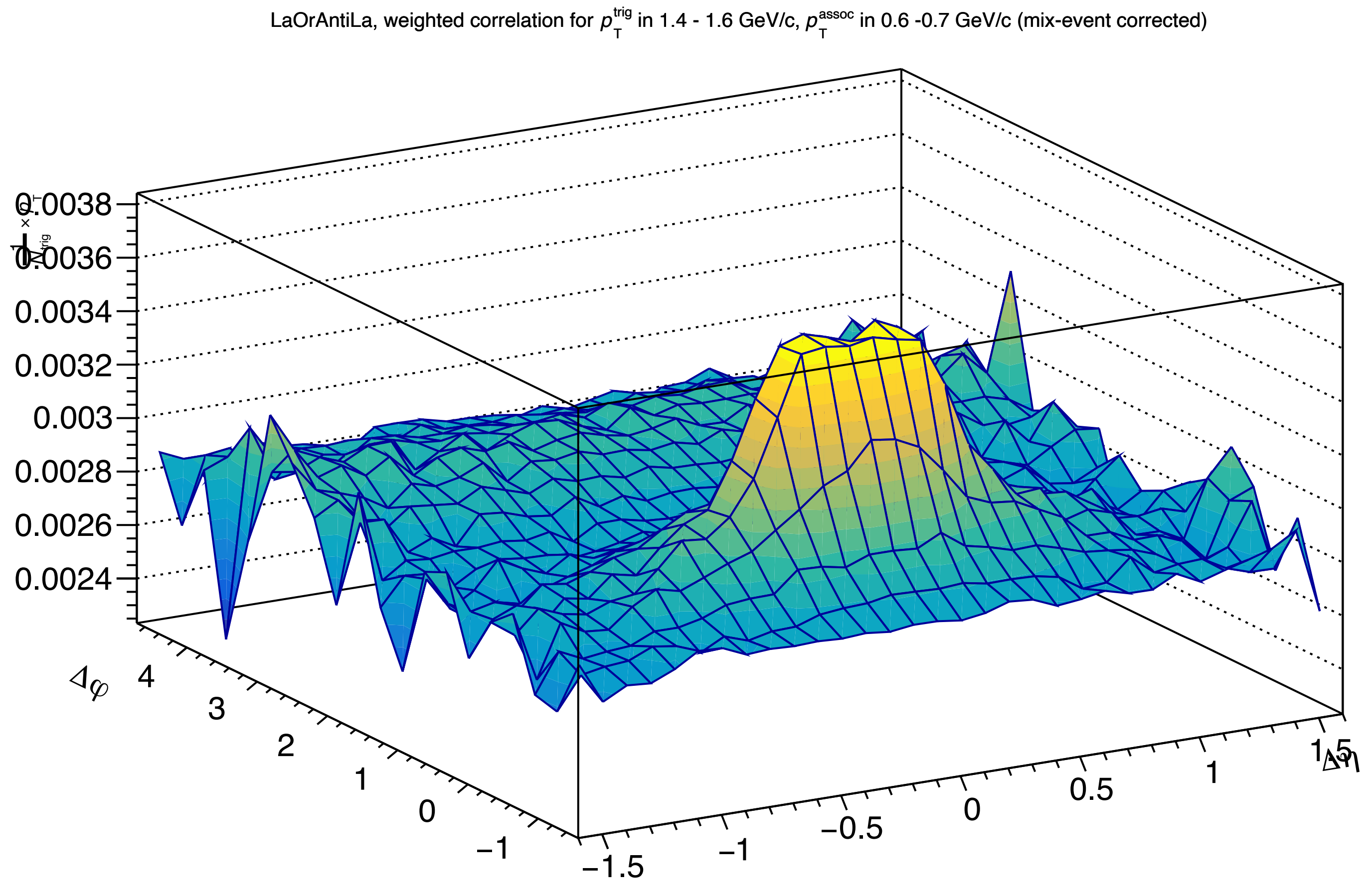
Example: $1.4\ \mathrm{GeV}/c < p_T^{trig} < 1.6\ \mathrm{GeV}/c$ and $0.7\ \mathrm{GeV}/c < p_T^{assoc} < 0.8\ \mathrm{GeV}/c$

Mix event corrected

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

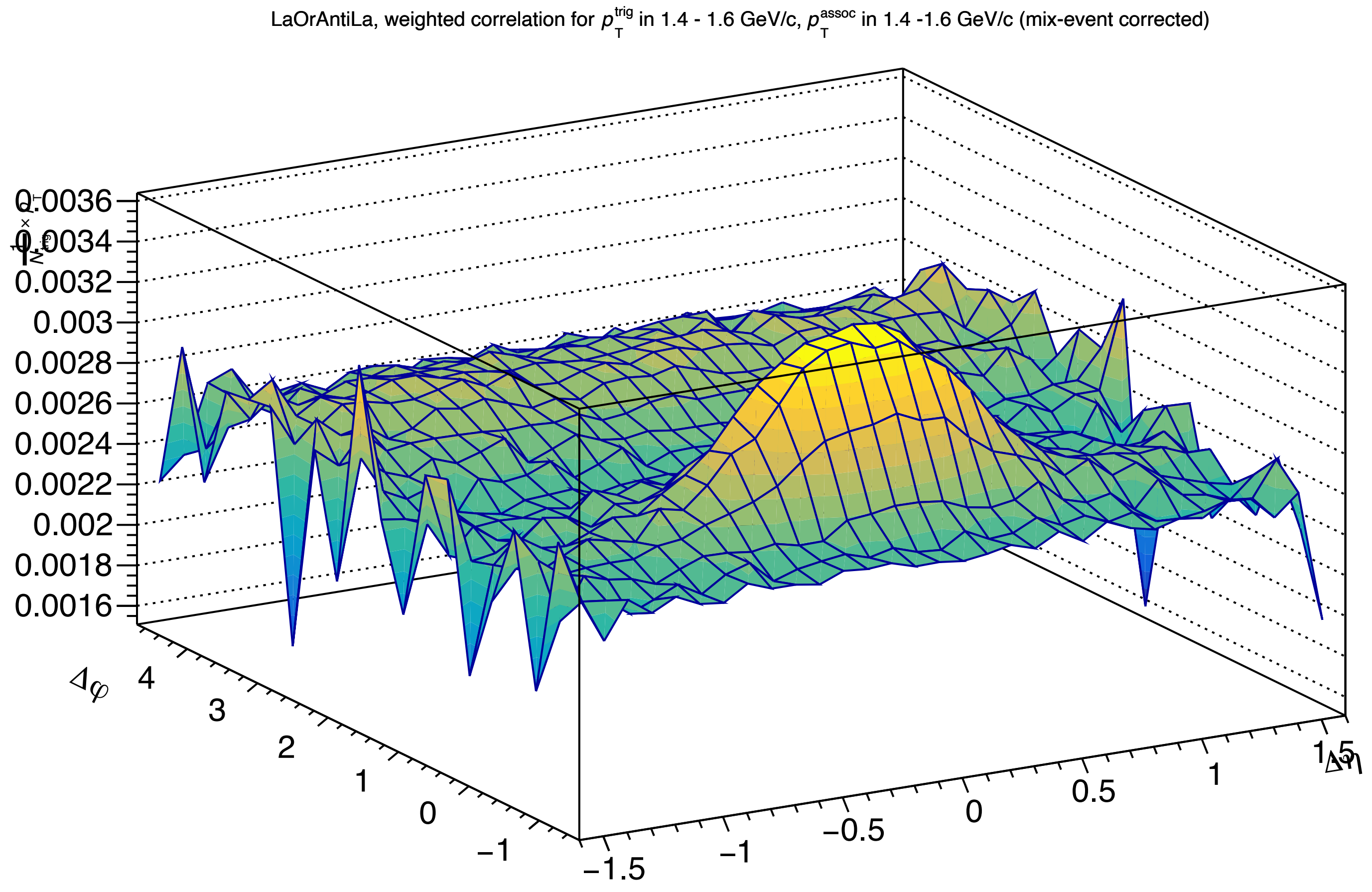
Example: mix-event corrected correlation results for $1.4\ \mathrm{GeV}/c < p_{\mathrm{T}}^{trig} < 1.6\ \mathrm{GeV}/c$ with different p_{T}^{assoc} bins

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



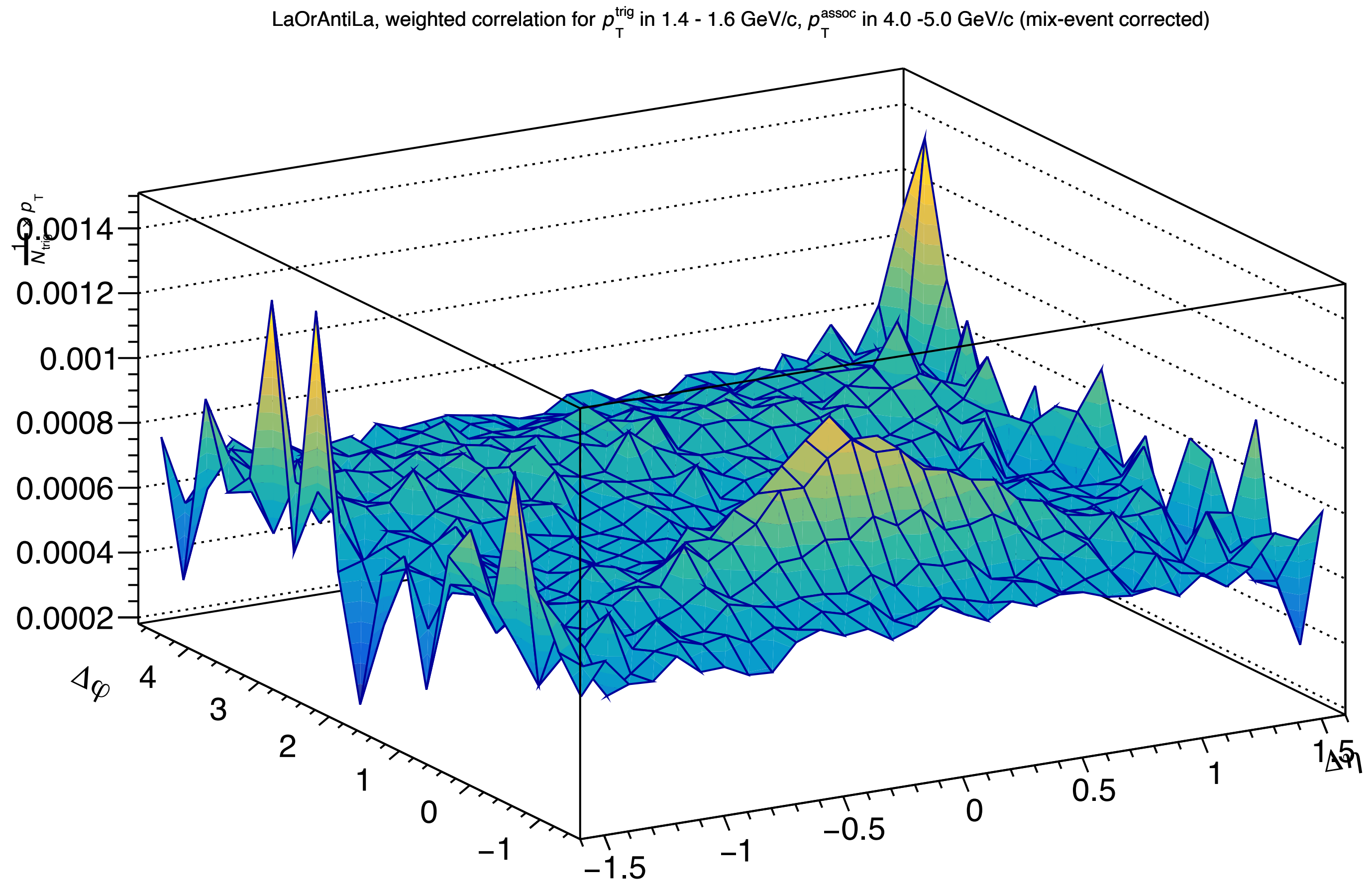
+

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



+

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



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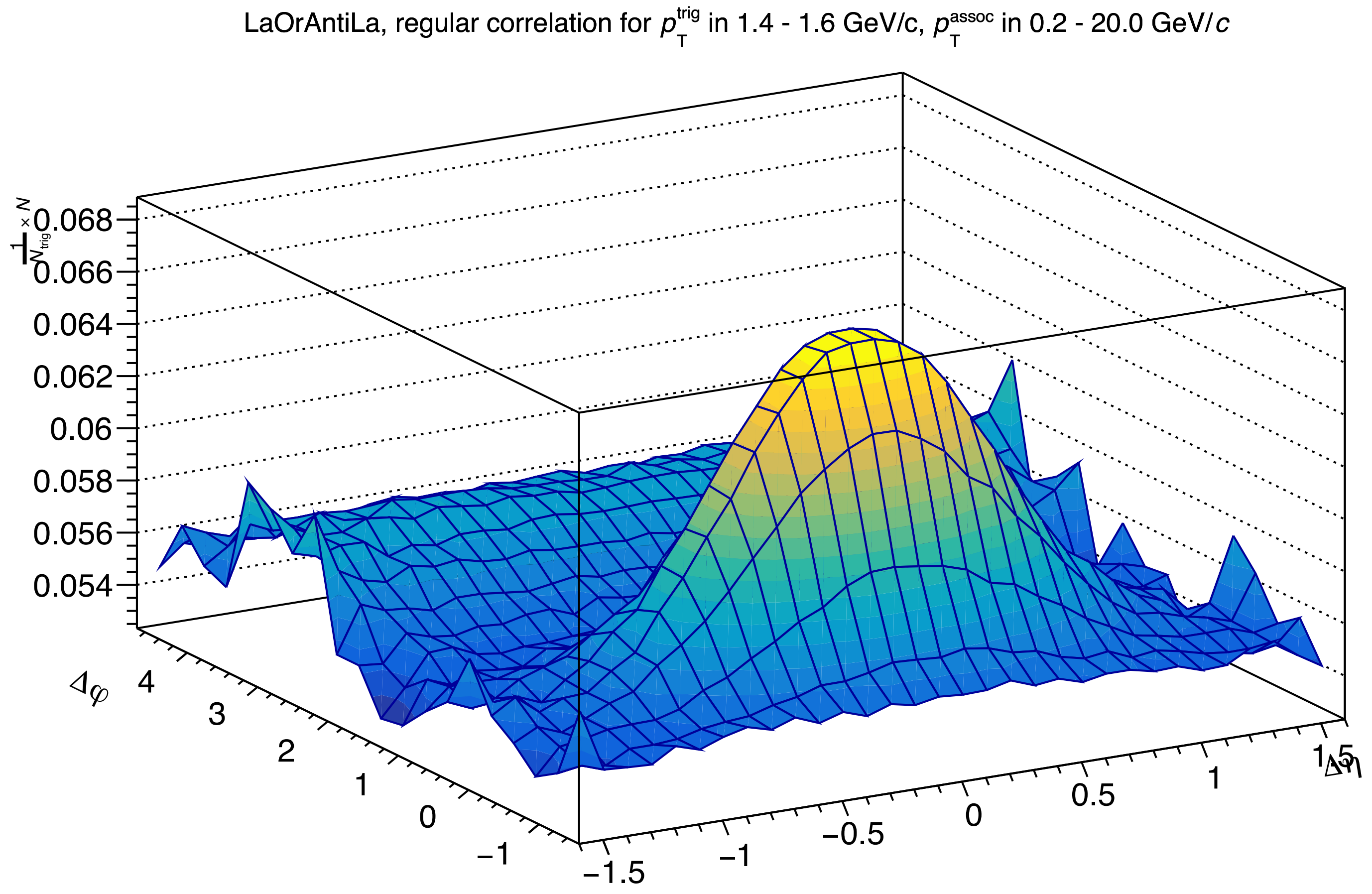

- Combine $p_{\mathrm{T,\,assoc}}$ bins in each $p_{\mathrm{T,\,trig}}$ intervals

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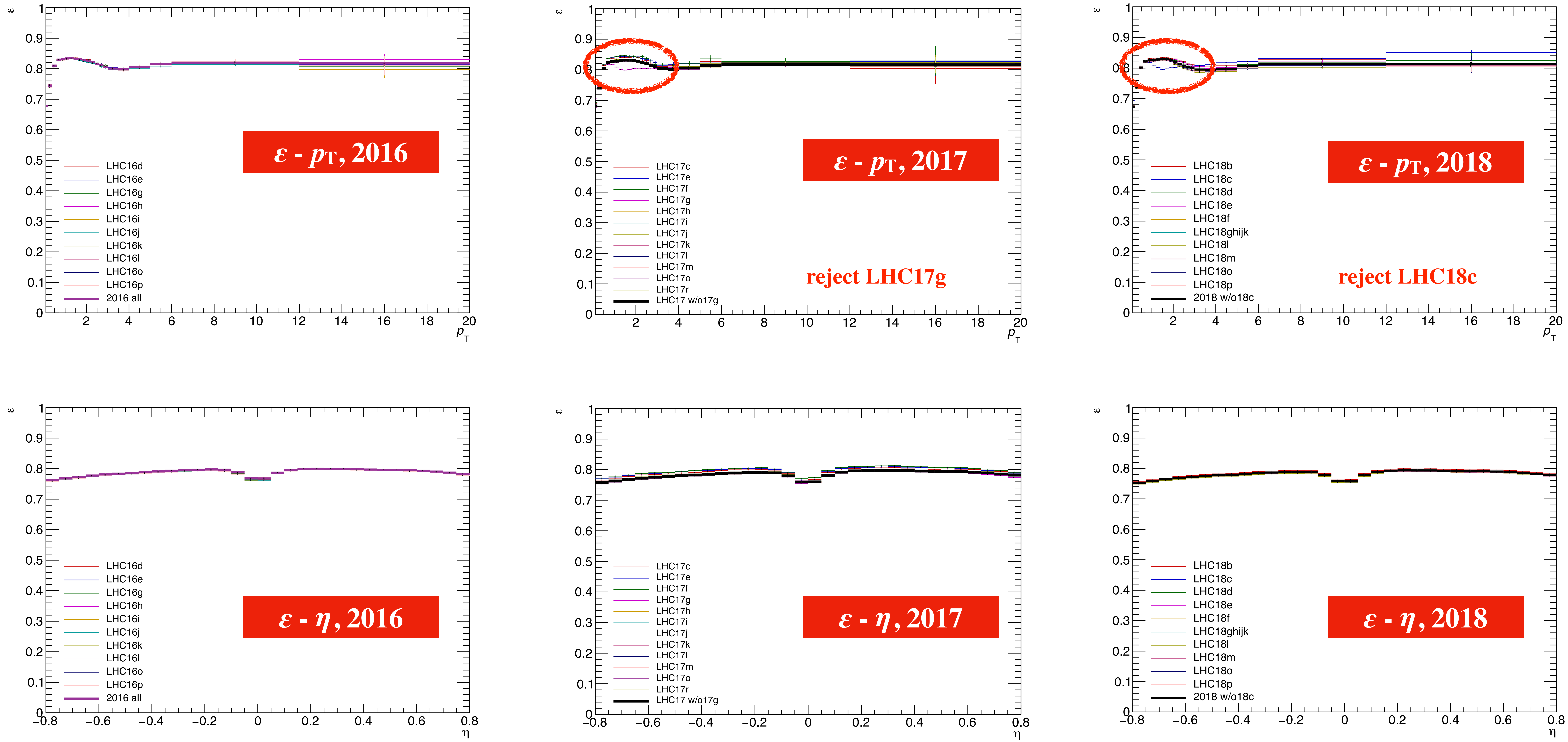
Data Sample

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

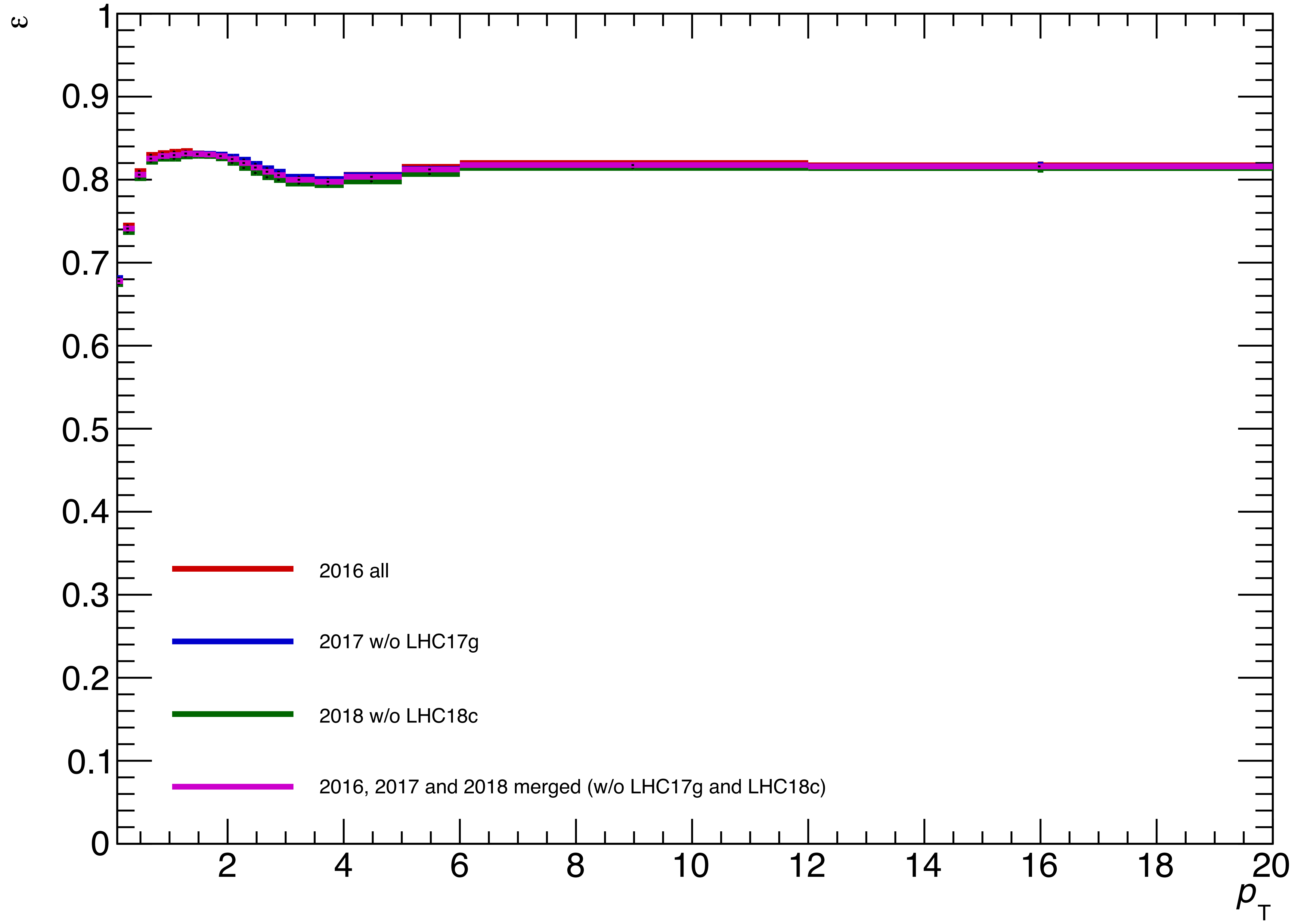
Data	*LHC18b*	~~*LHC18c (rejected)*~~	*LHC18d*	*LHC18e*	*LHC18f*	*LHC18g*	*LHC18h*	*LHC18i*	*LHC18j*	*LHC18k*	*LHC18l*	*LHC18m*	*LHC18o*	*LHC18p*	**Total** (w/o LHC18c)
Number of MB Events (M)	*~ 170*	~~*~ 208*~~	*~ 37*	*~ 47*	*~ 51*	*~ 8*	*~ 3*	*~ 51*	*~ 0.07*	*~ 9*	*~ 65*	*~ 181*	*~ 27*	*~ 63*	*~ 712*
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

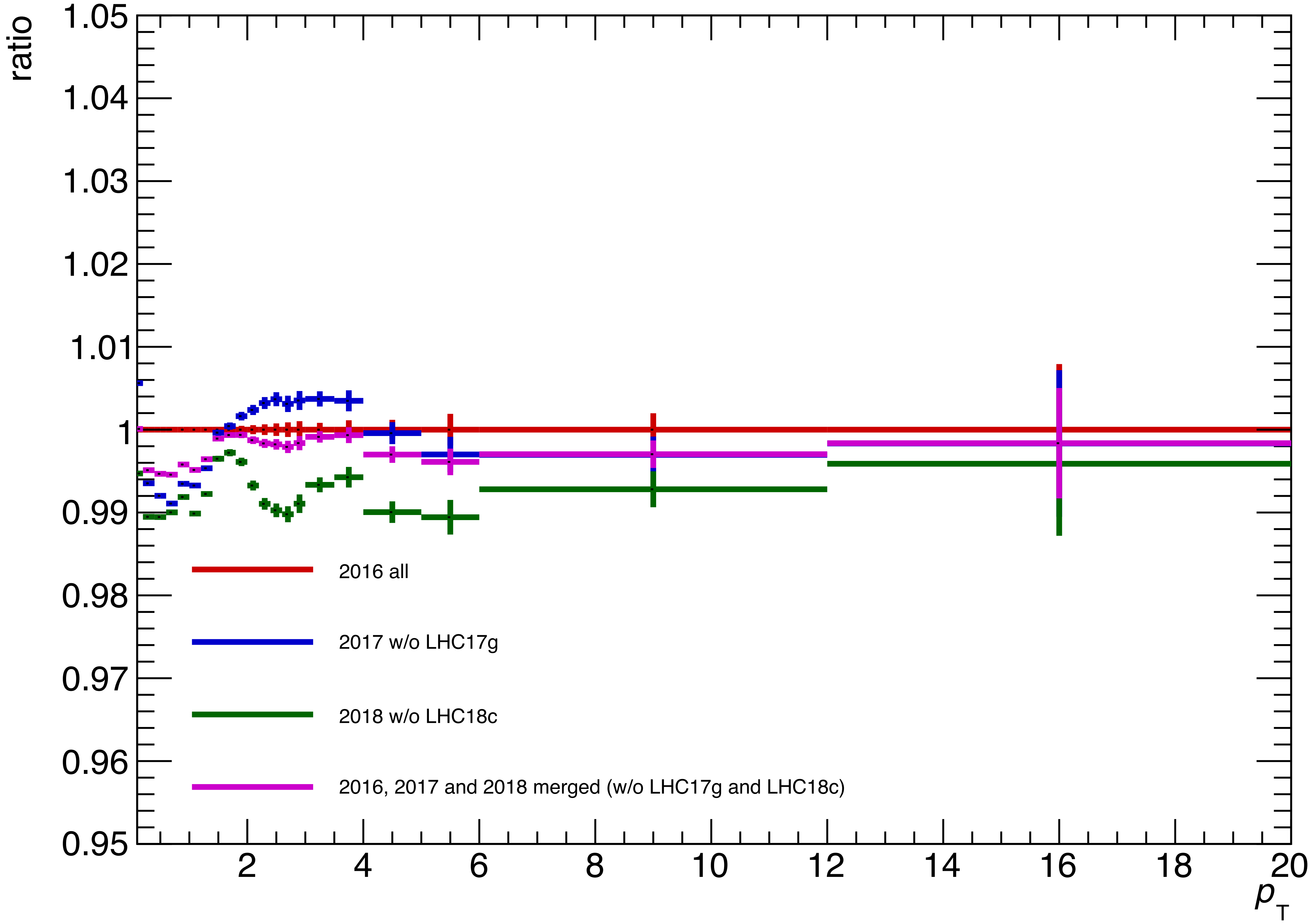
Tracking efficiency



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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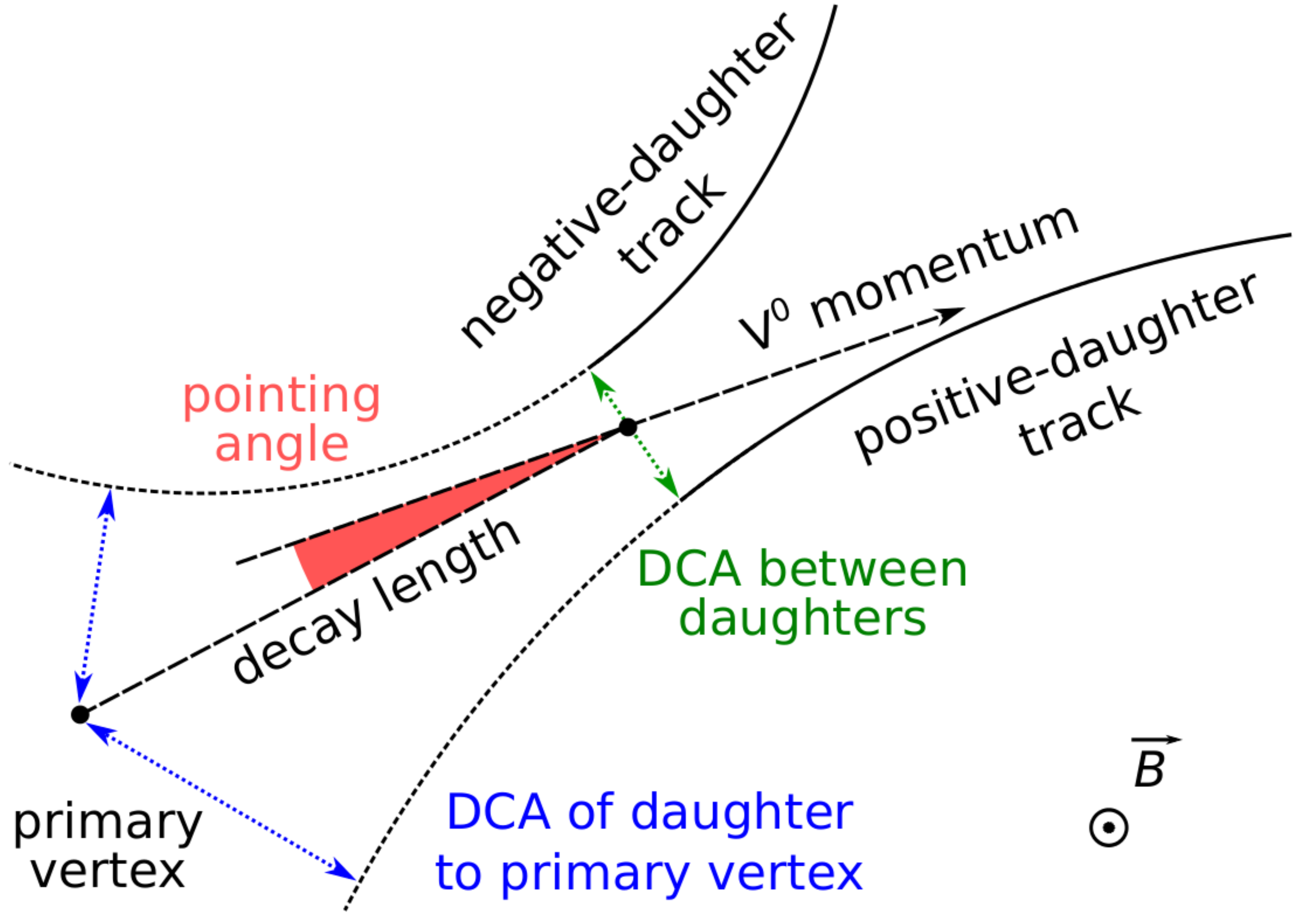
Trigger topology selection

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)	< 20 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	< 1σ	< 1σ
|η| for daughter tracks	< 0.8	< 0.8
TPC dE/dx	< 5σ	< 5σ

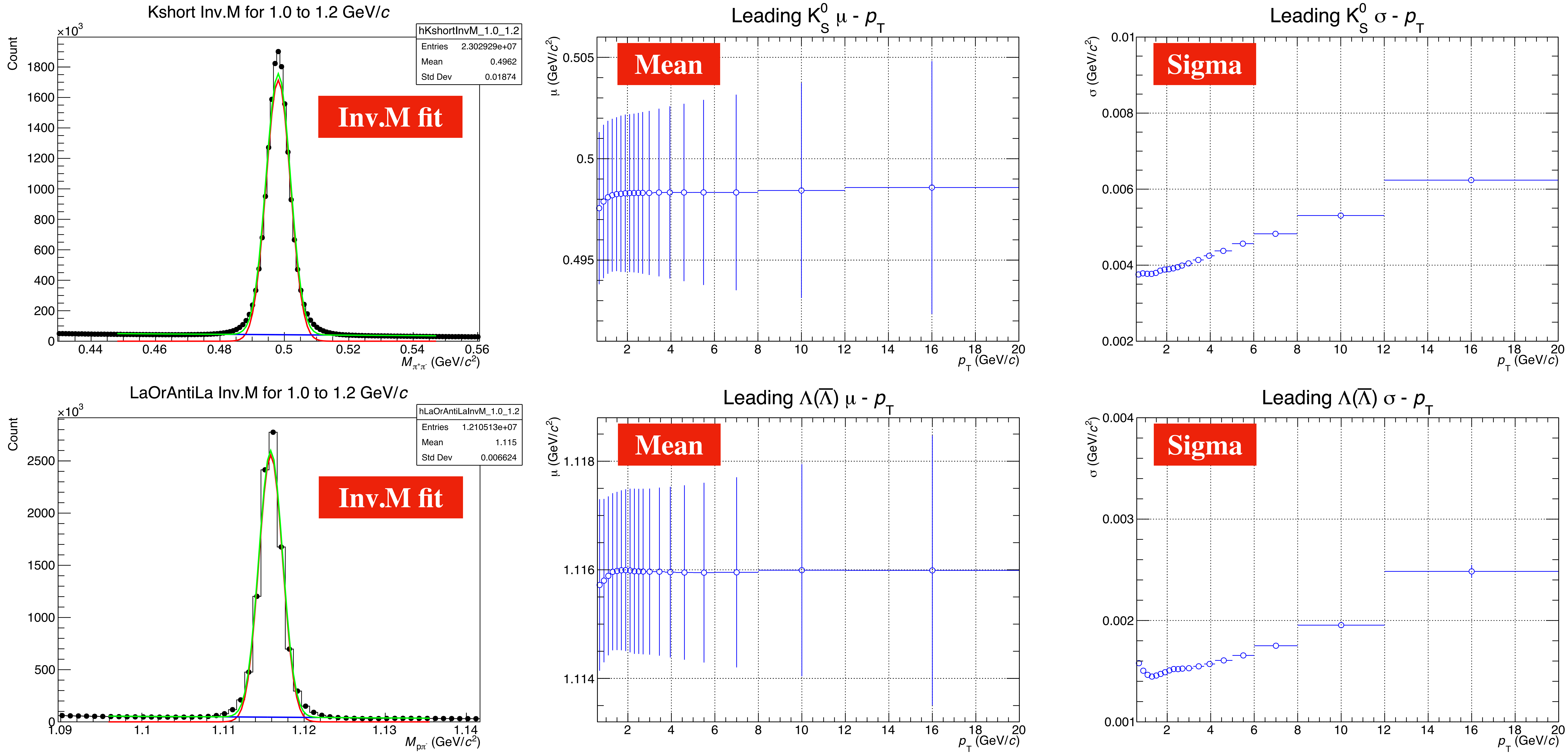
Trigger is reconstructed via the decay products and selected using the decay topology



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

A link to strange particle in jet production analysis
arXiv:2211.08936

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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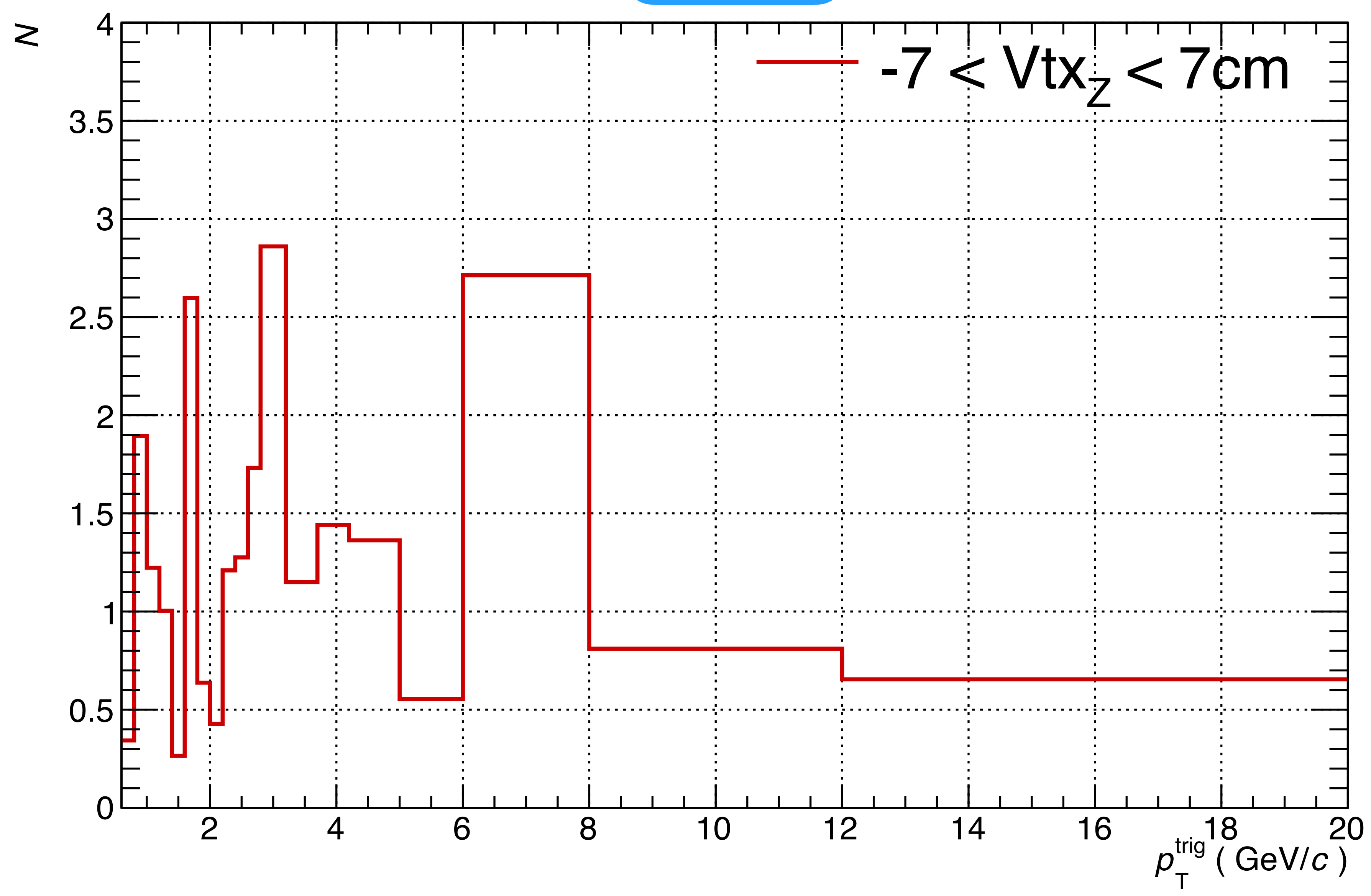
Systematic uncertainty details

Uncertainty - event vertex acceptance region

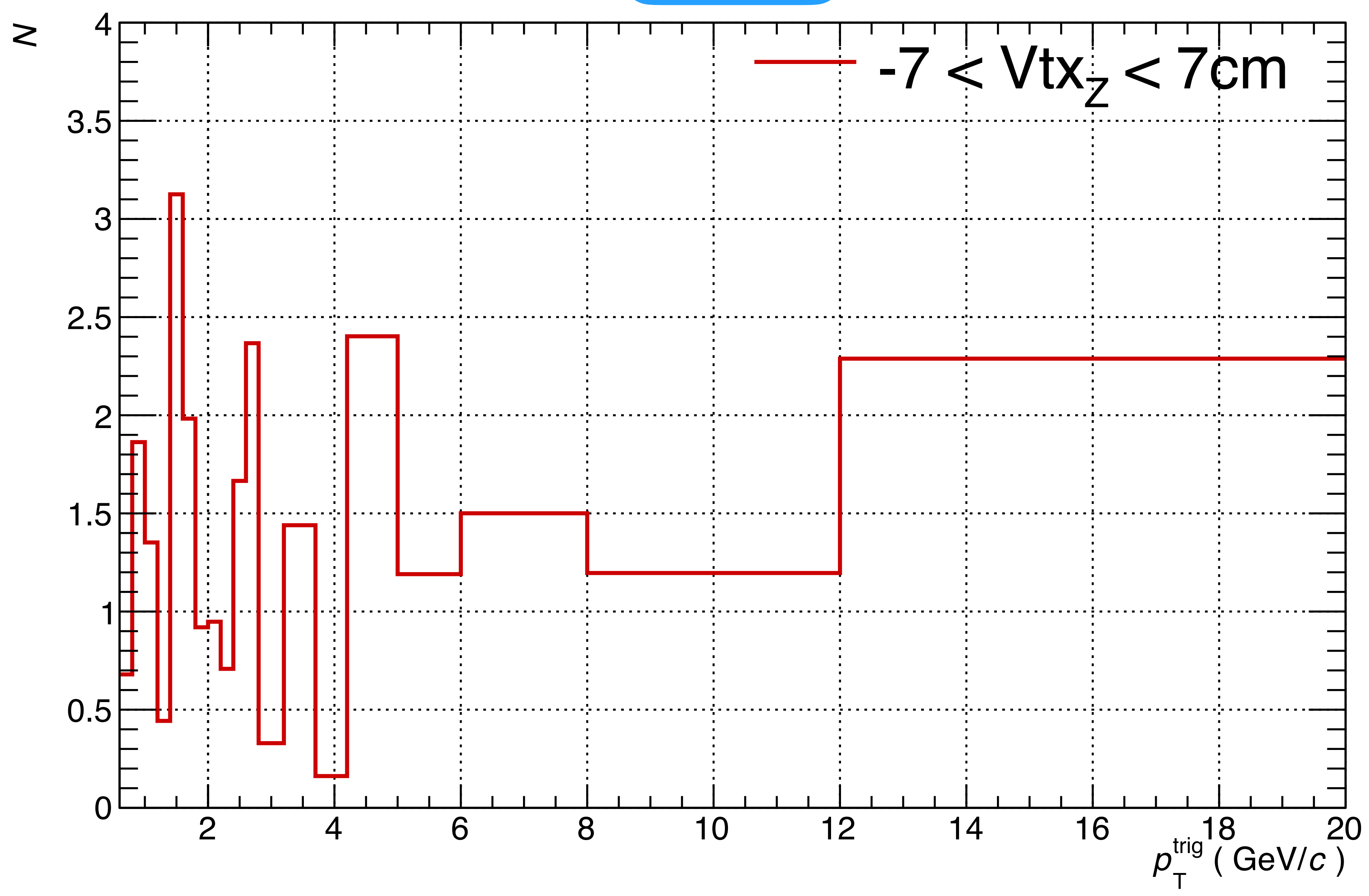
- Selections on vertex z position:
  1. $-10 < Vtx_z < 10$ cm (**default**)
  2. $-7 < Vtx_z < 7$ cm

K^0_S



Barlow N

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



Barlow N

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

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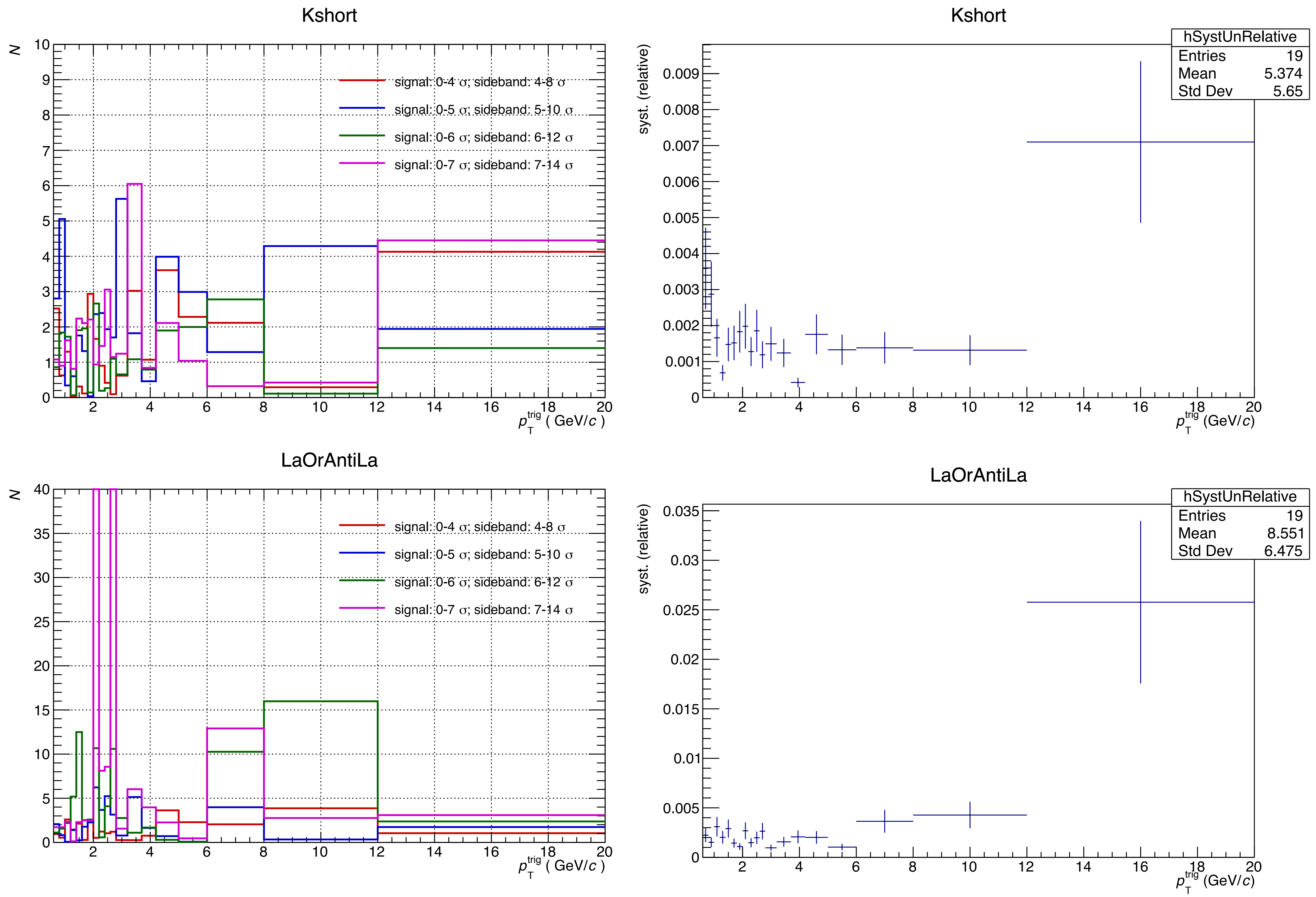
Uncertainty - signal extraction

- 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

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



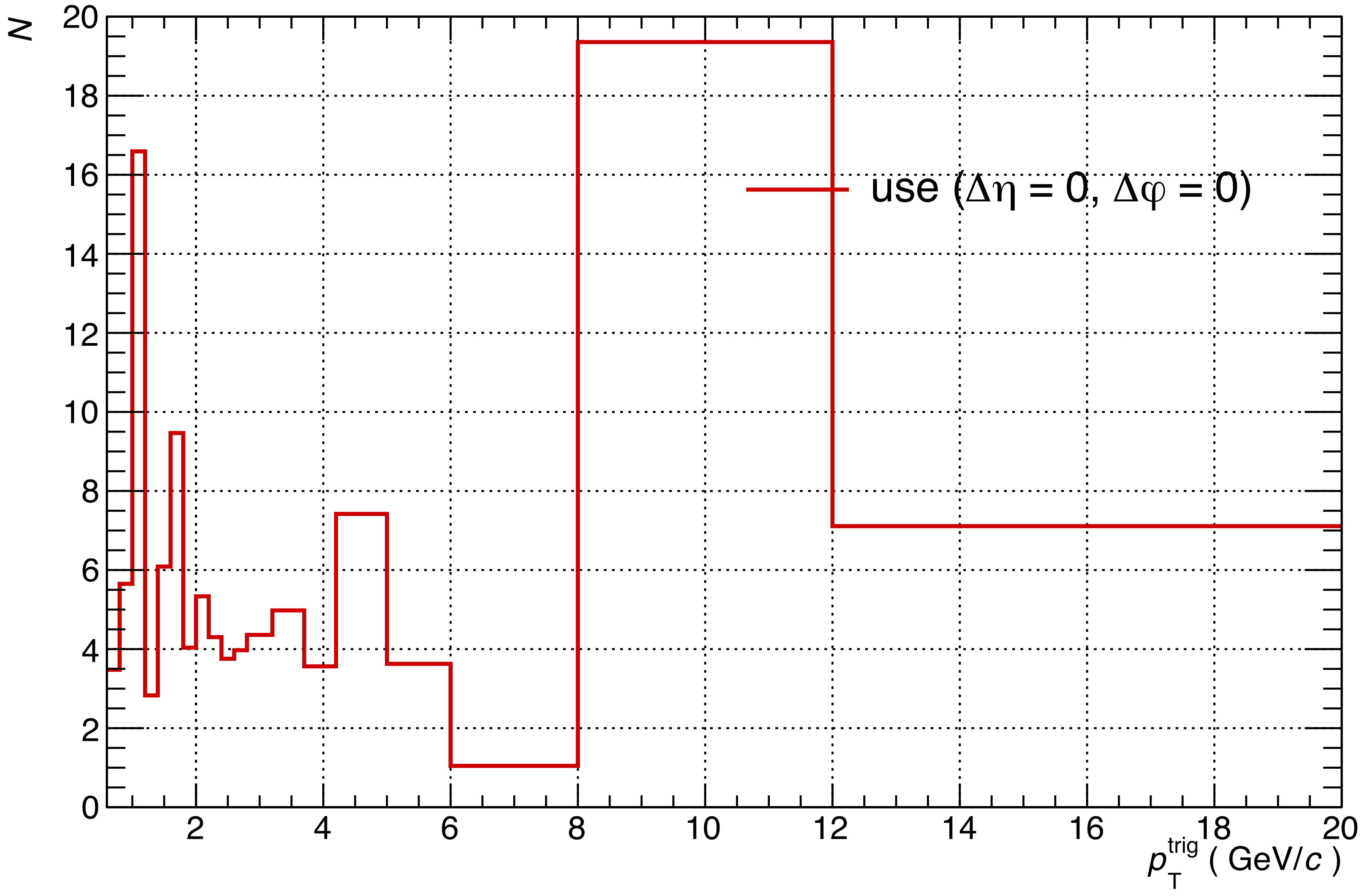
Barlow N RMS

- 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

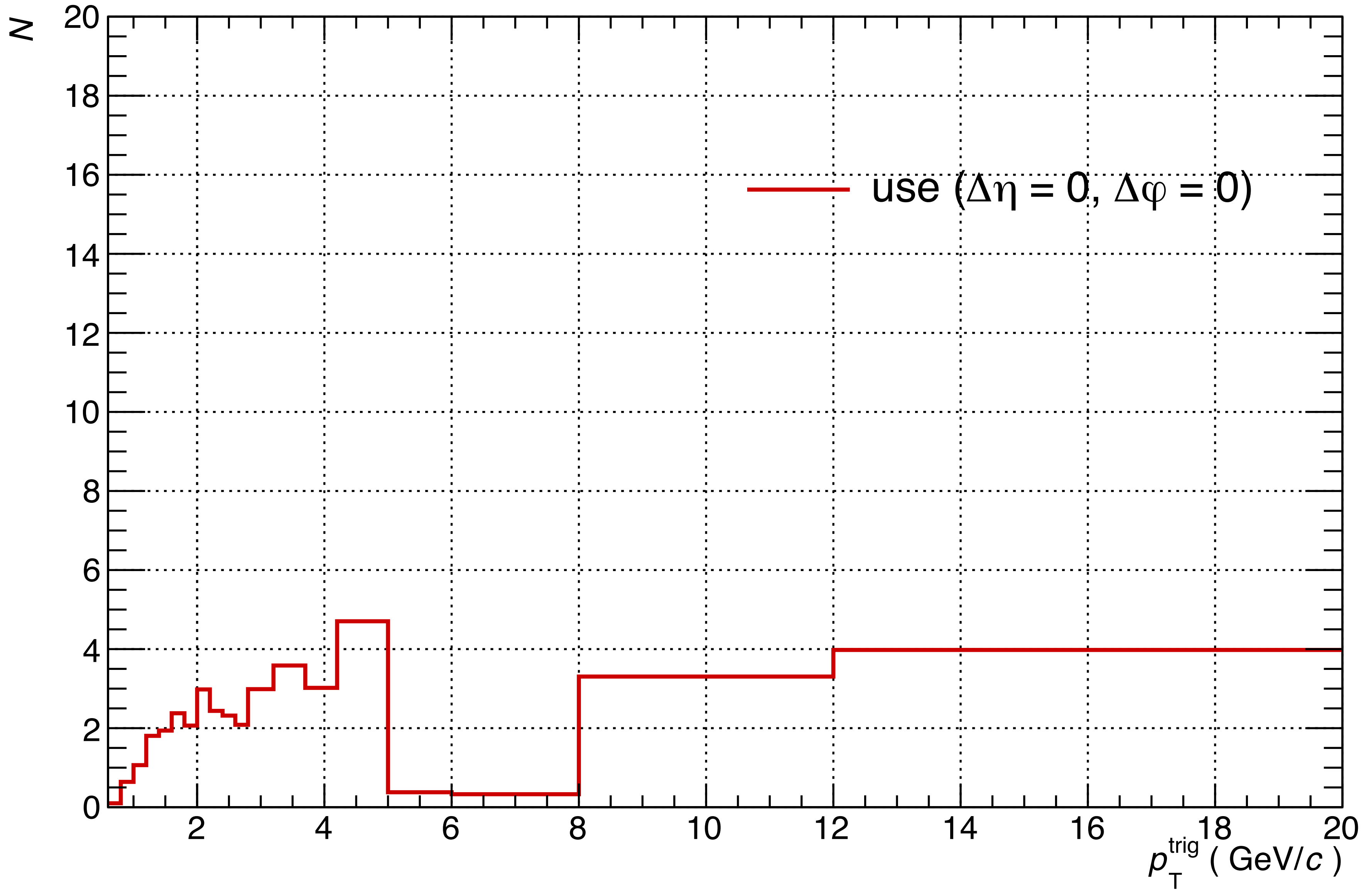
Uncertainty - mix event normalization

- 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



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



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

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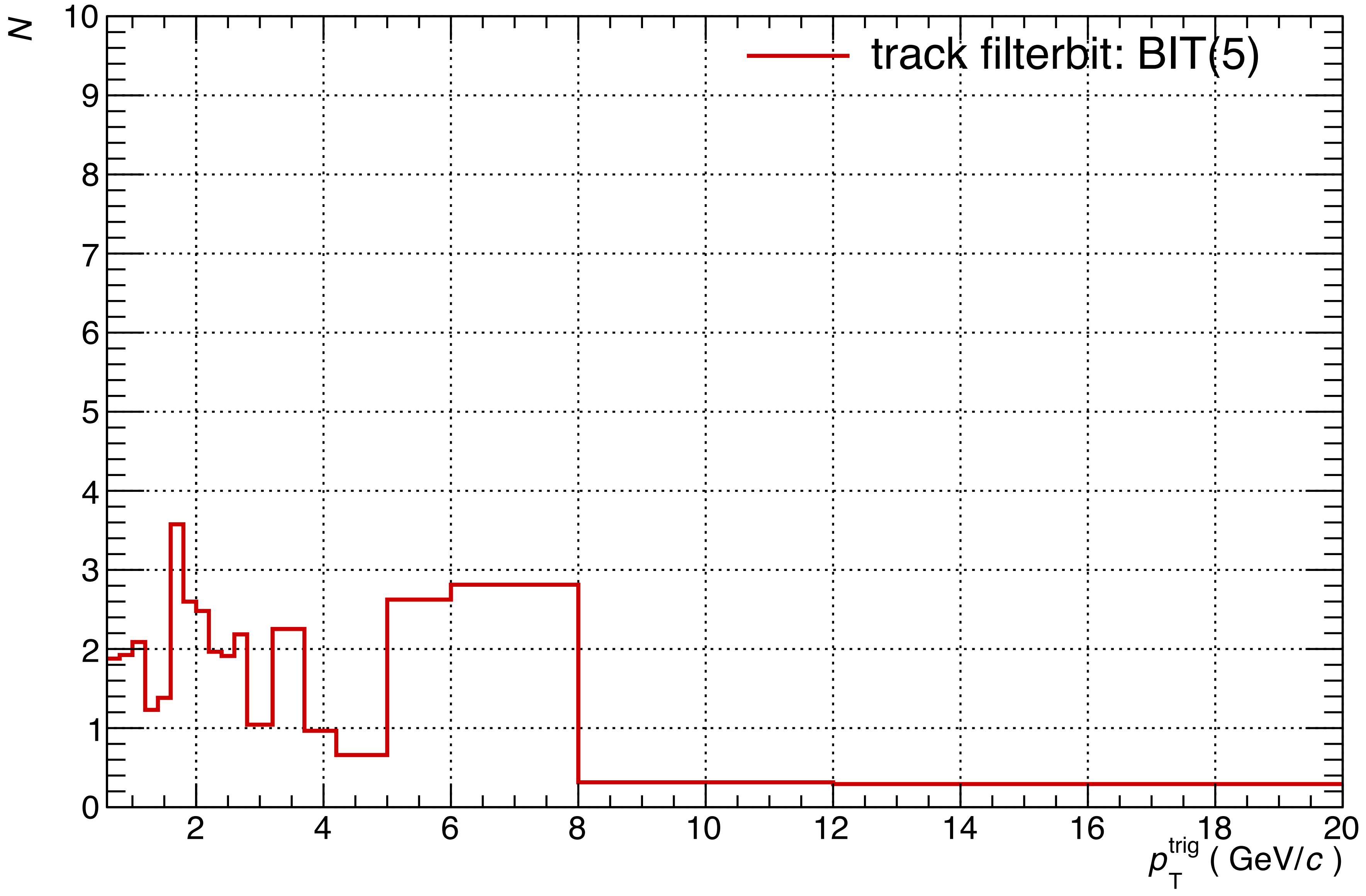
Uncertainty - filterbit for primary tracks

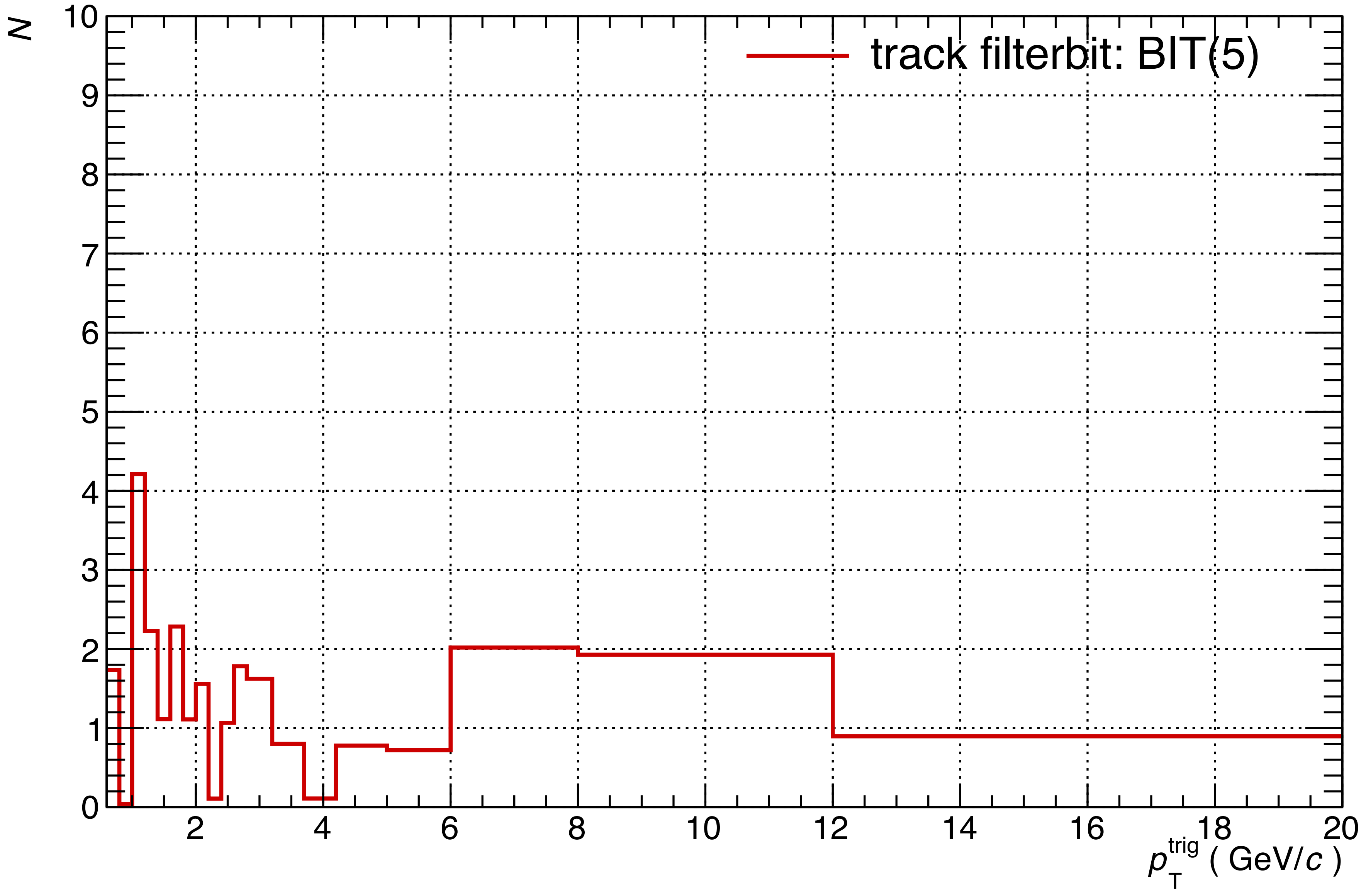
- Filterbit for associates:
    1. BIT(8) (**default**) (global hybrids with $|DCA_{xy}| < 2.4$ cm and $|DCA_z| < 3.2$ cm)
    2. BIT(5) (tracks with standard cuts with tight DCA cut, $|DCA_z| < 2$ cm)

K^0_S



Barlow N

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



Barlow N

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

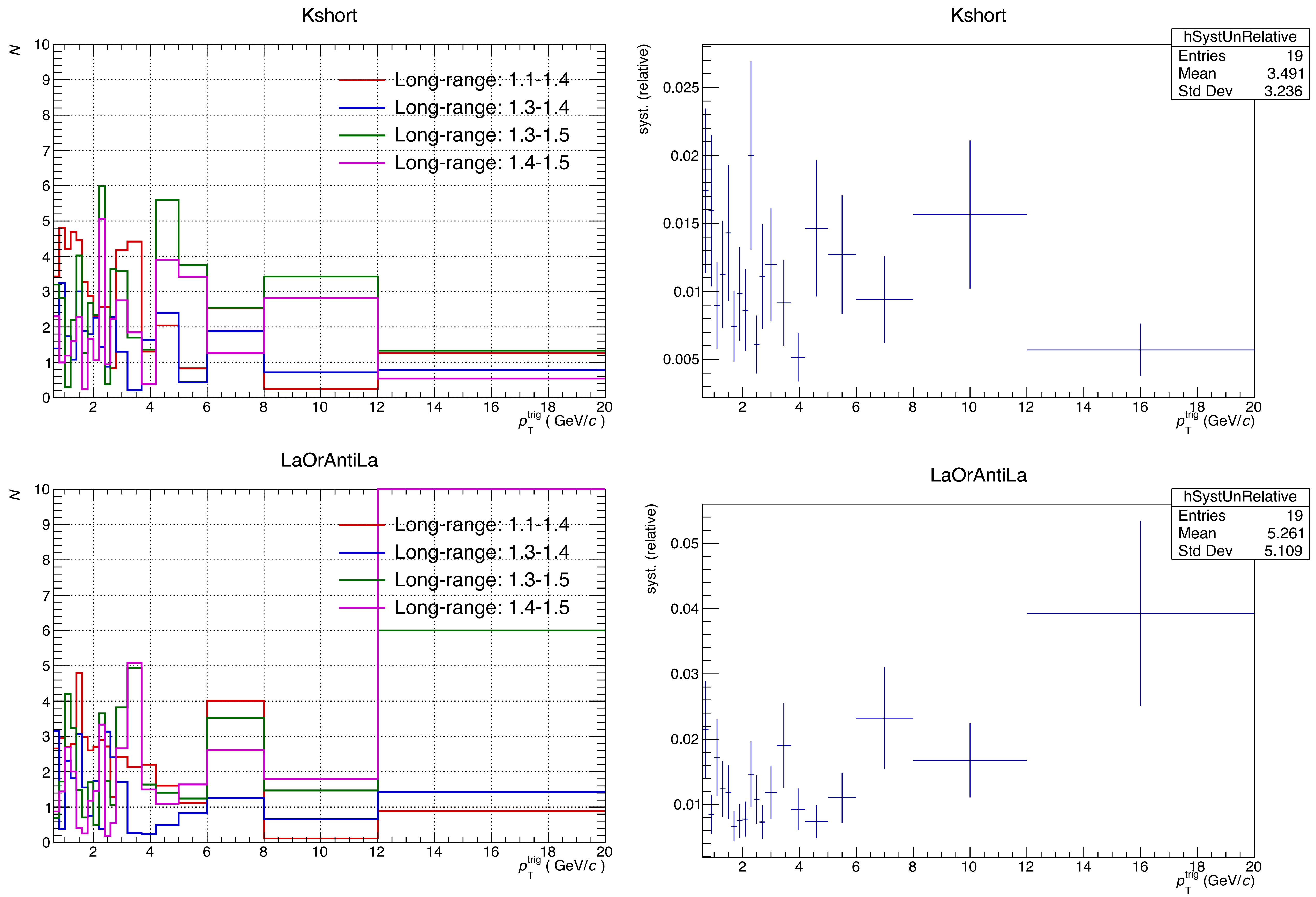
Uncertainty - jet region and out-of-jet region

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

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

K^0_S

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



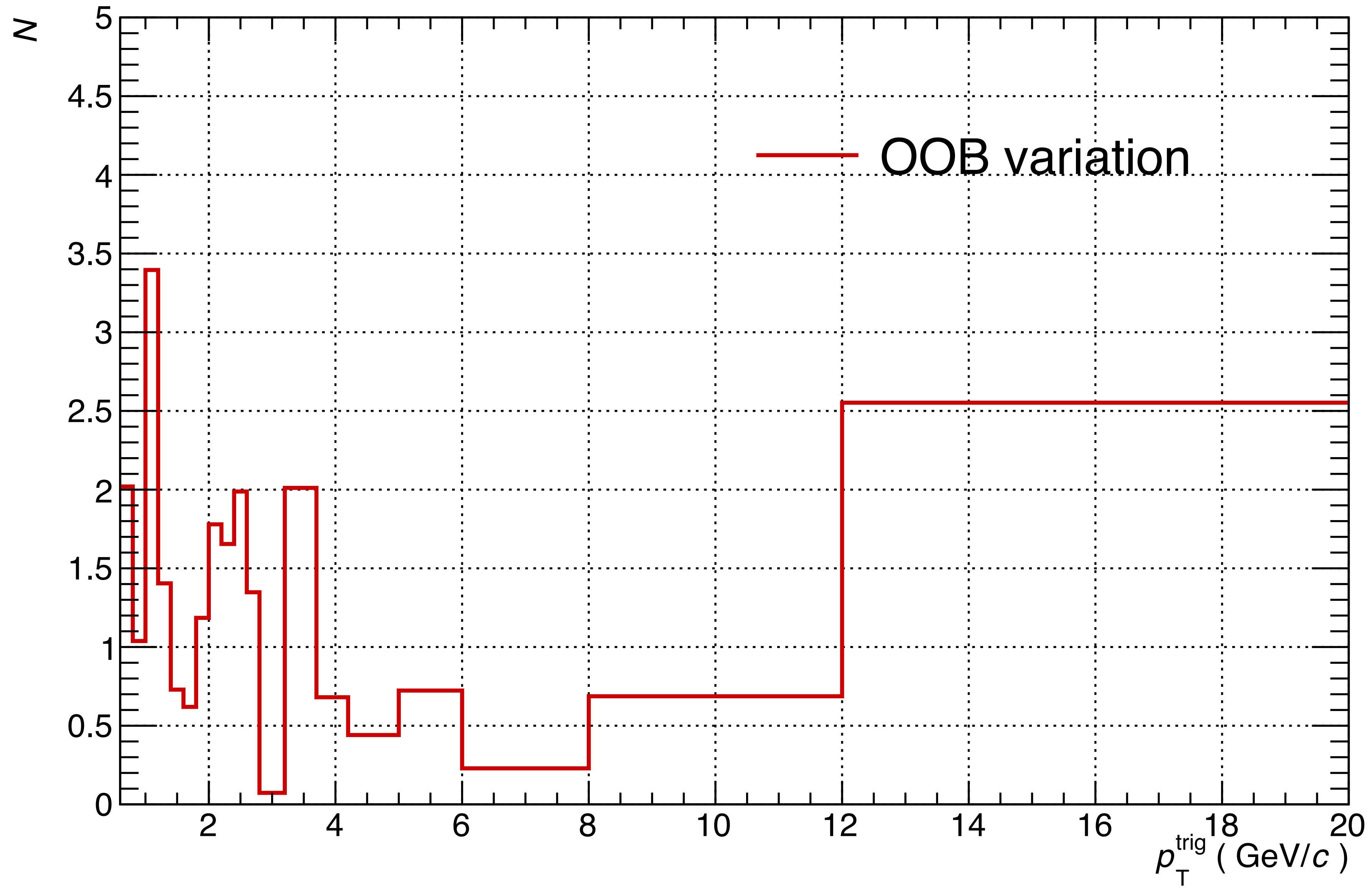
Barlow N RMS

- 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

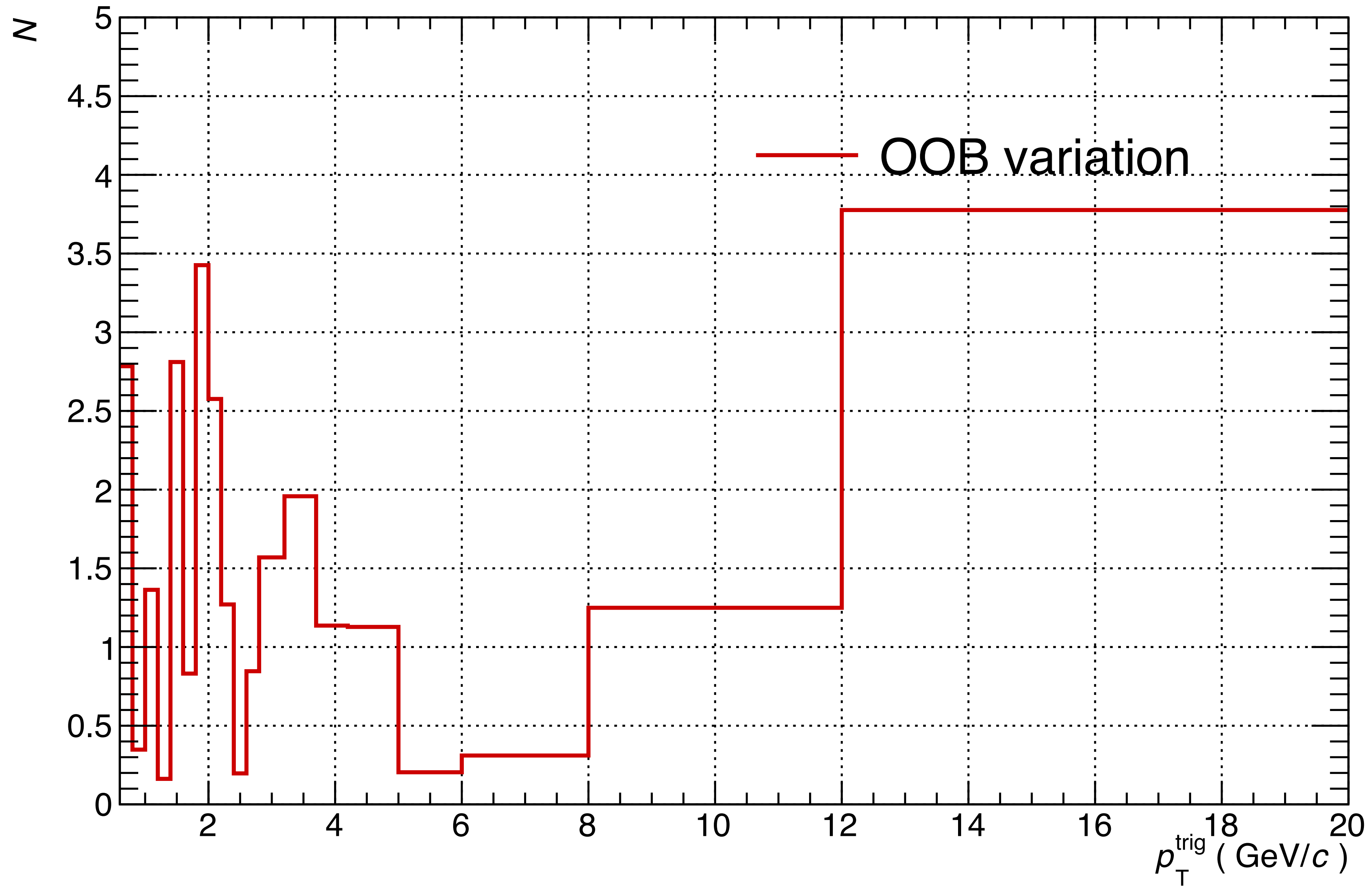
- OOB pileup cut for the V^0:
  1. (At least) one of V^0's decay tracks should have ITSrefit flag (**default**)
  2. (At least) one of V^0's decay tracks should have ITSrefit flag and its bunch-crossing ID in TOF connected to this track is 0

K^0_S



Barlow N

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



Barlow N

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

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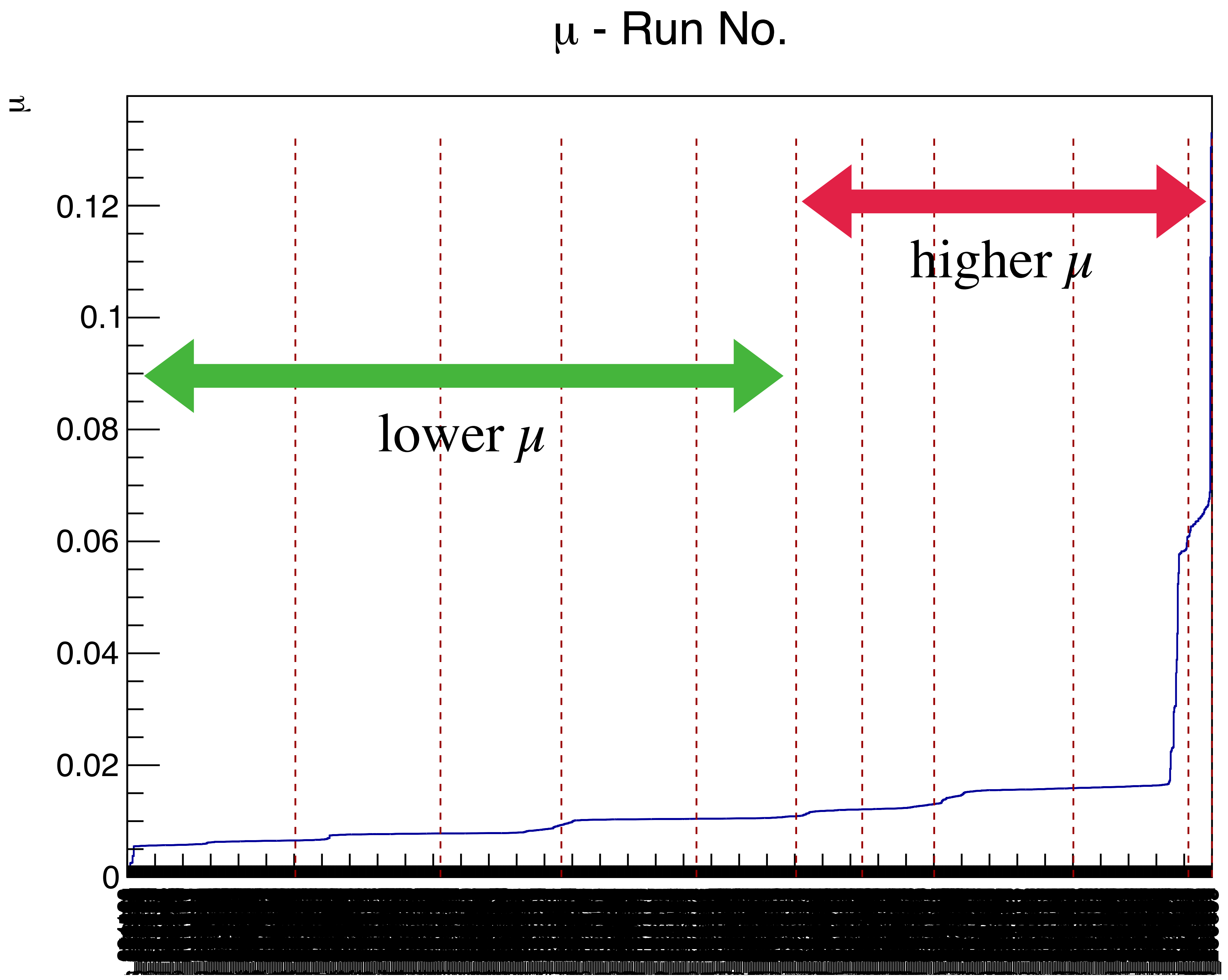
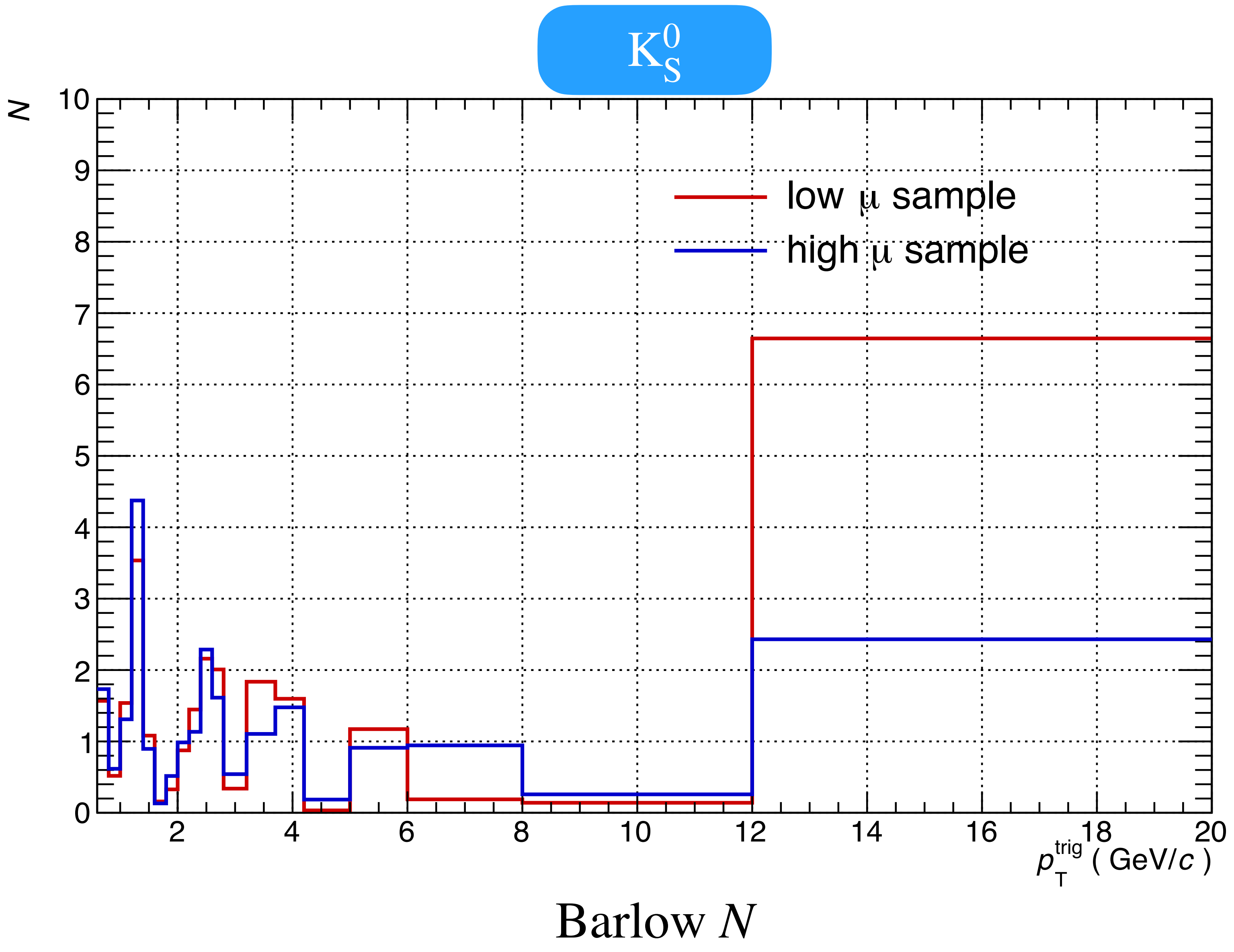
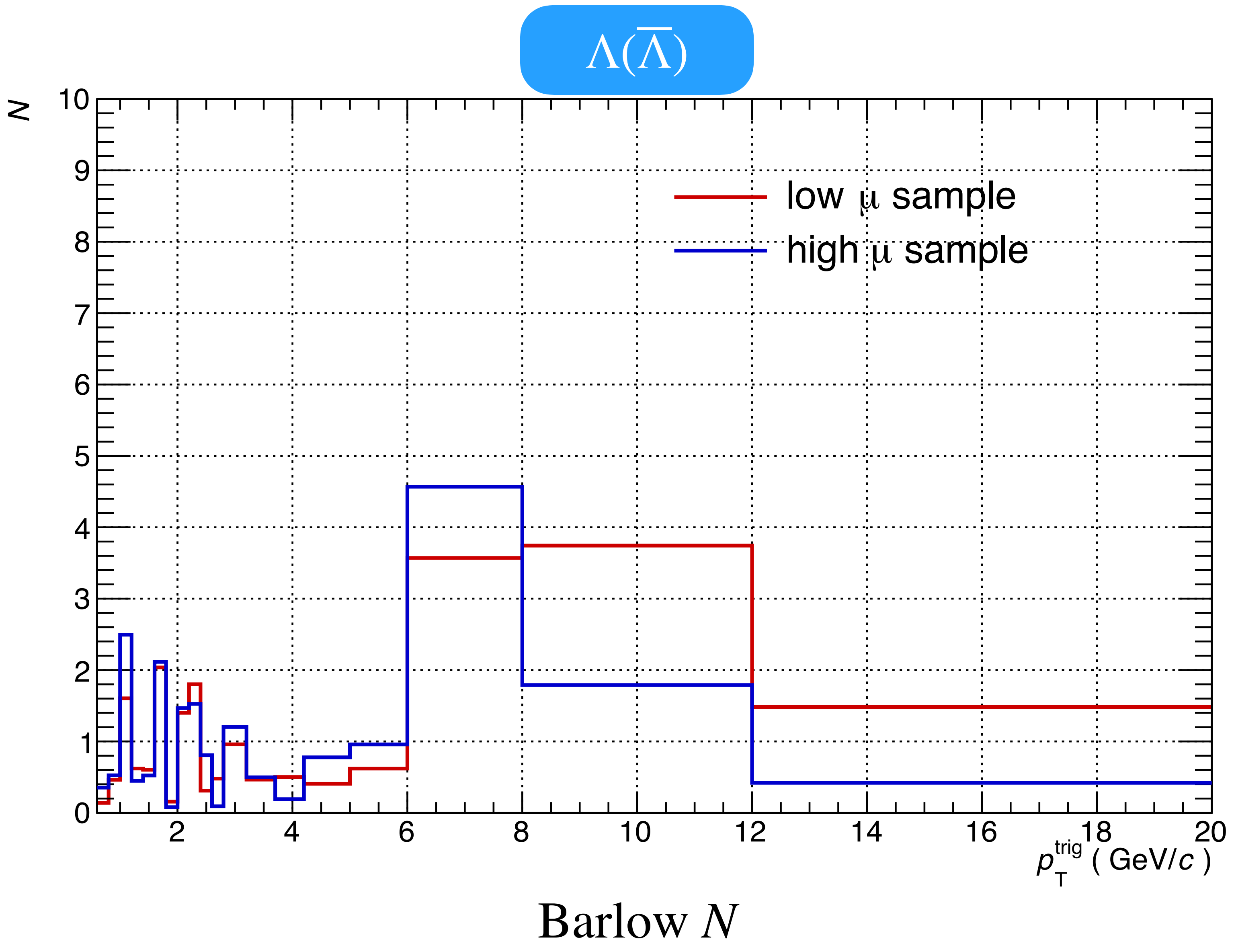
- The full sample is splited to two parts with equal # of selected events, one consists of lower μ value and the other one consists of higher μ value







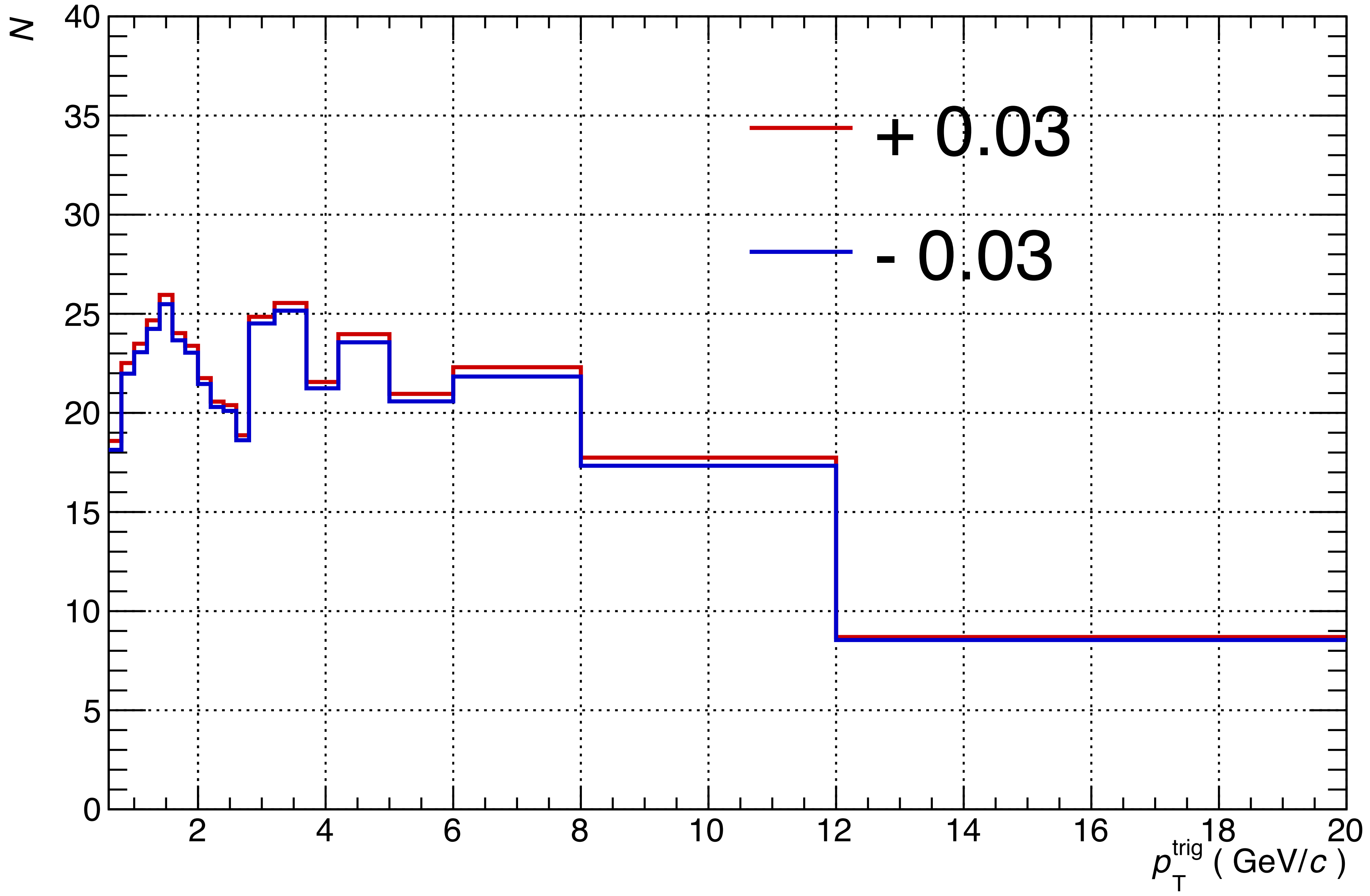
- For this source, the systematic uncertainty is assigned as the larger relative uncertainty

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%

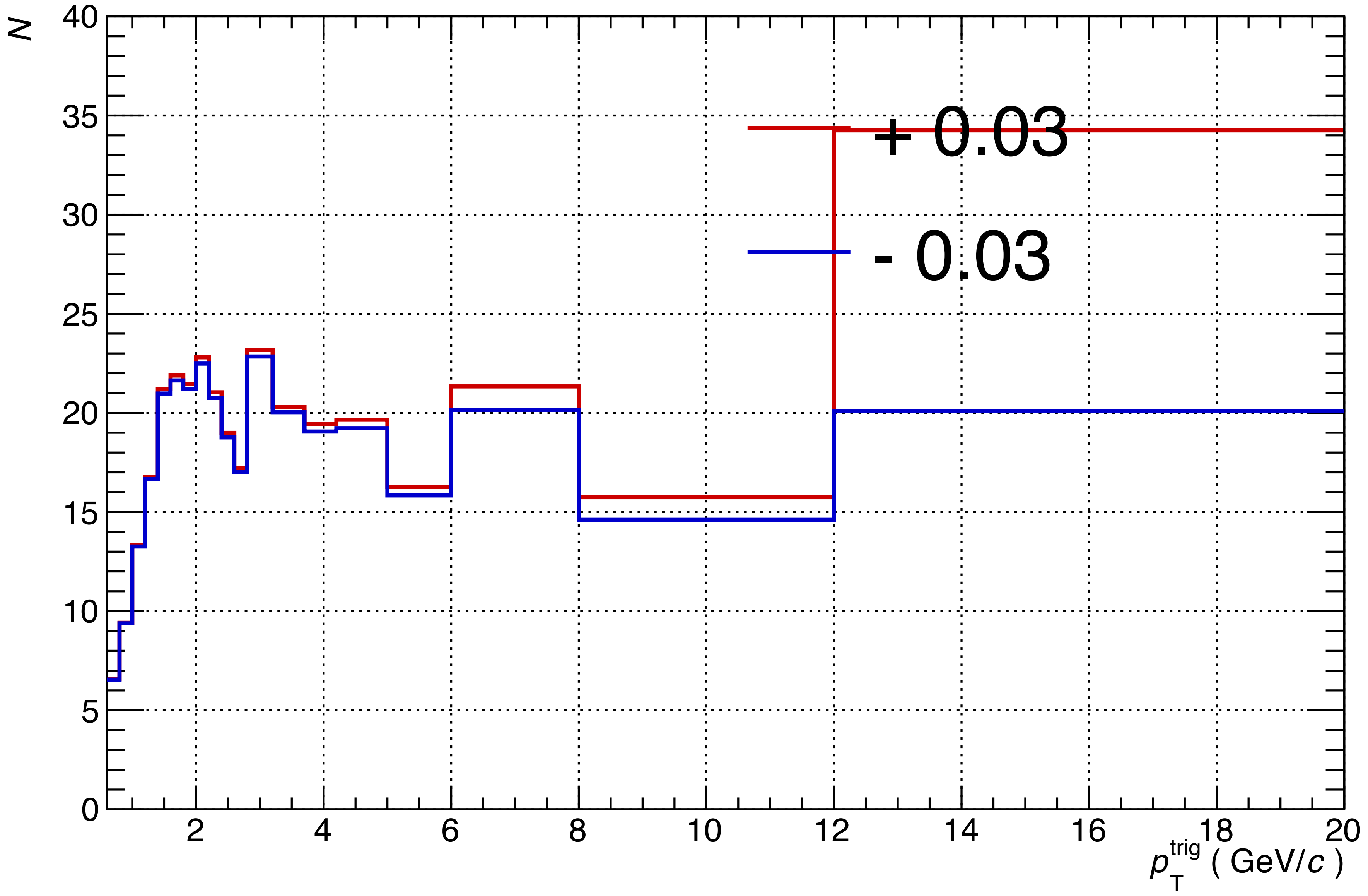
$$z = \frac{p_{\mathrm{T,trig}}}{p_{\mathrm{T,trig}} + \sum p_{\mathrm{T,assoc}}}$$

K^0_S



Barlow N

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



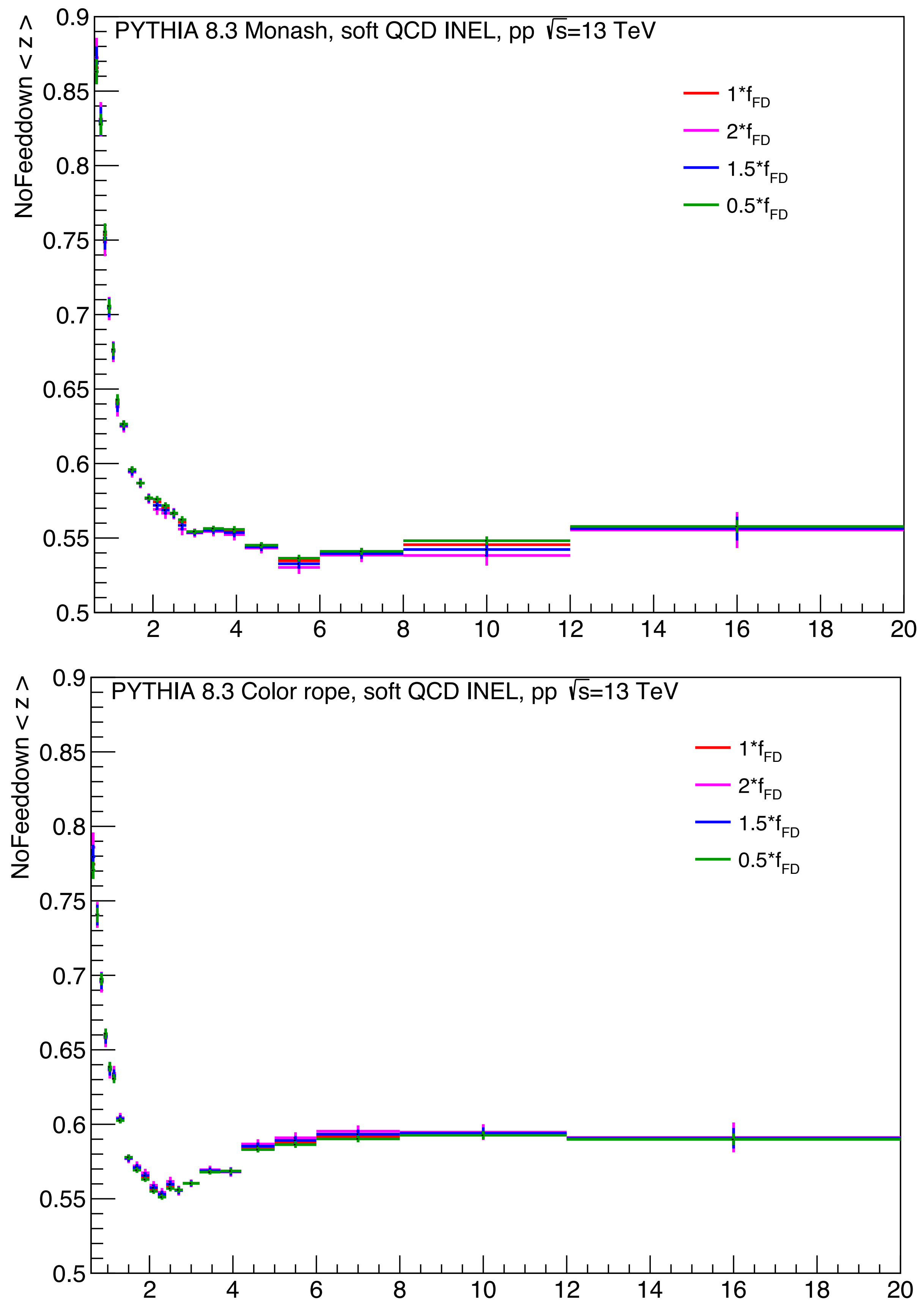
Barlow N

- For this source
  - K^0_S: the systematic uncertainty is assigned as the larger relative uncertainty
  - $\Lambda(\overline{\Lambda})$: the systematic uncertainty is assigned as the larger relative uncertainty

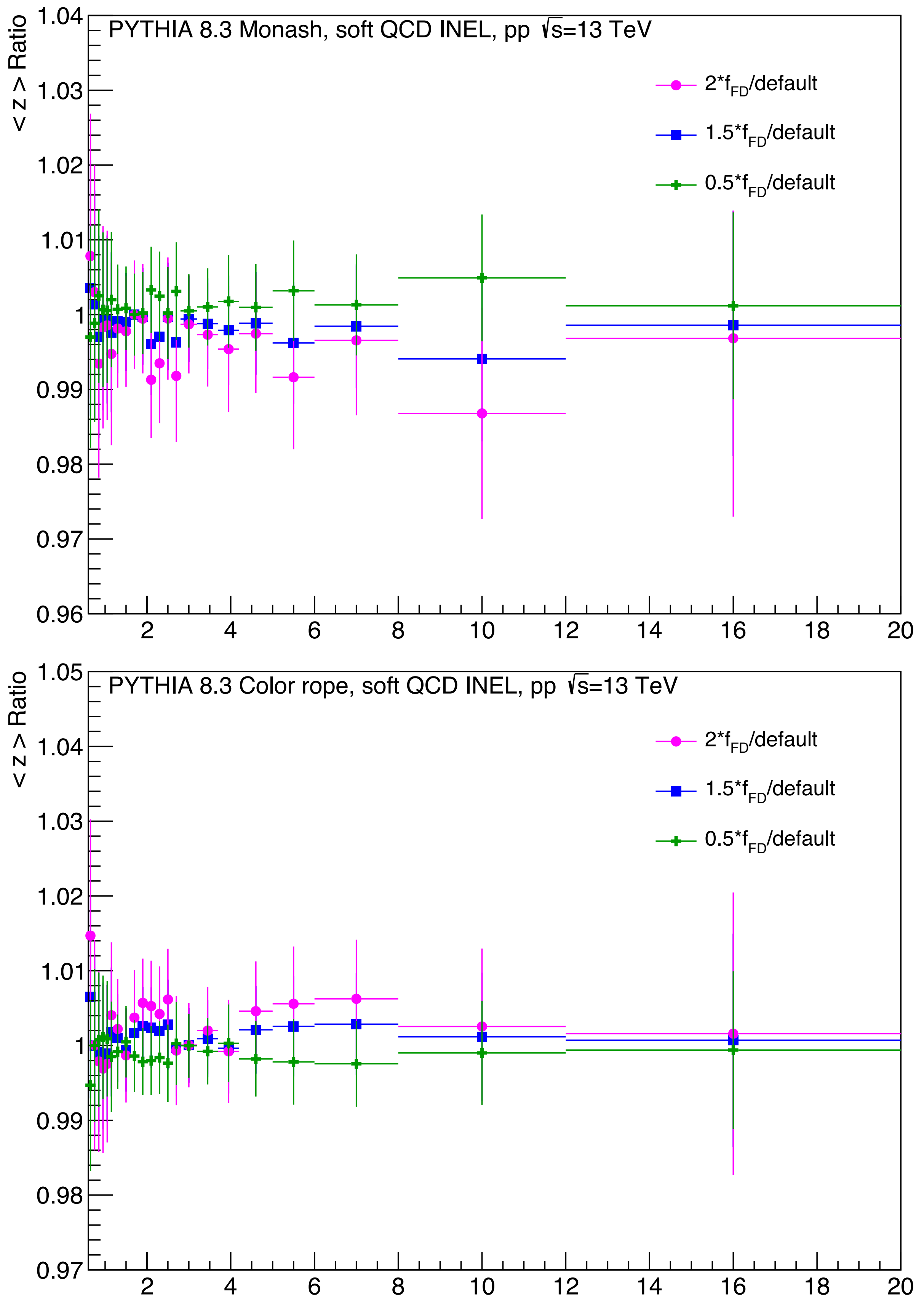
Uncertainty - feed down

Monash

Color rope



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



ratio to default

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

- The strategy for this source is to investigate how $<z>$ changes with the feed down fraction
- Assign a conservative 1.5% uncertainty uncorrelated with p_T for feed down

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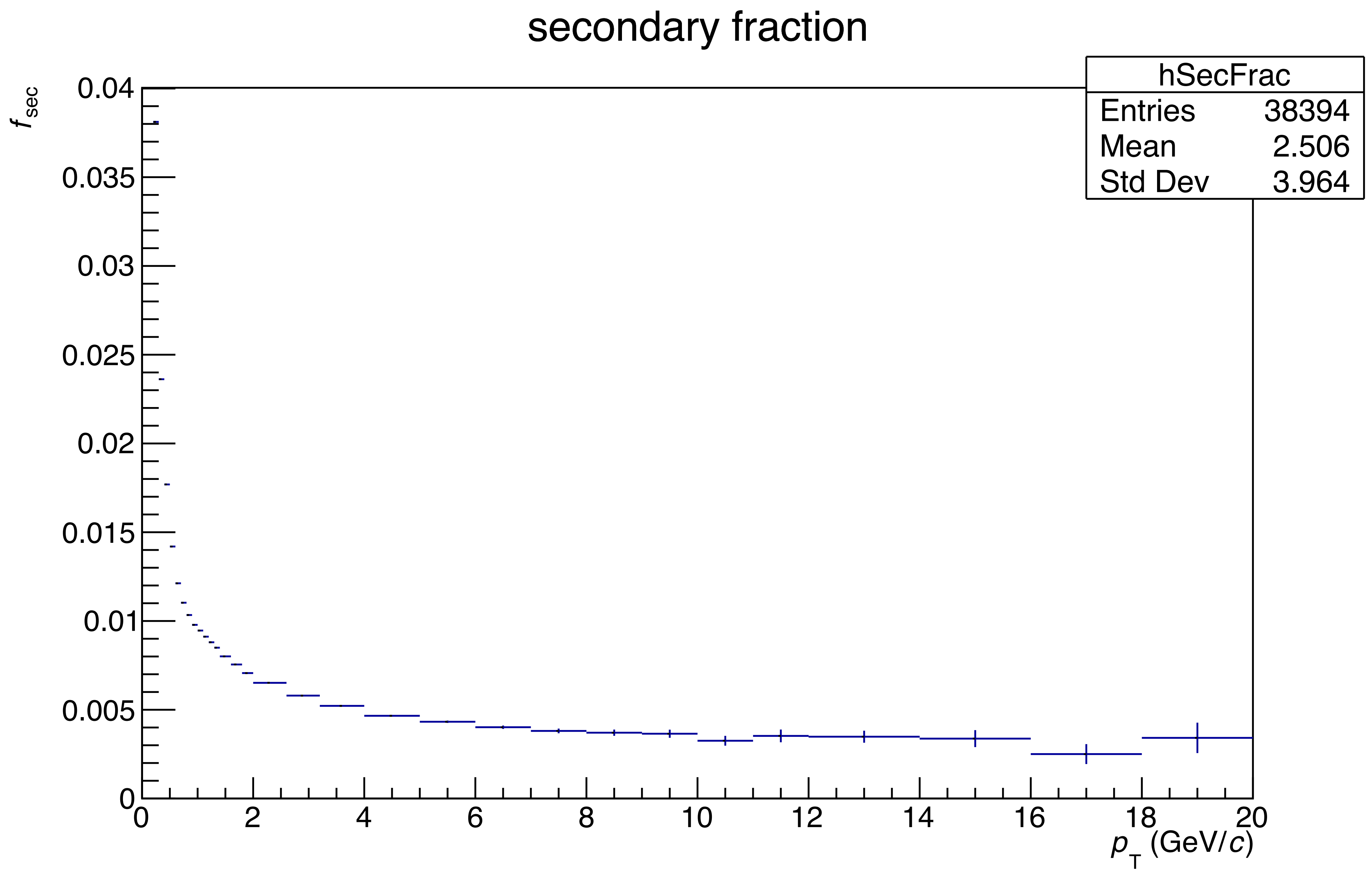
Secondary fraction



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

- 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

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