Energy Dependence of Underlying-Event Observables Measured with ALICE at the LHC

Feng Fan (CCNU)

with Antonio Ortiz and Daicui Zhou

AN: https://alice-notes.web.cern.ch/node/1261

ARC: Peter Christiansen & Beomkyu Kim

華中師範大學
CENTRAL CHINA NORMAL UNIVERSITY

Instituto de Ciencias Nucleares UNAM

ALICE

Introduction and motivation

- The study of pp collisions has become important because of the discovery of heavy-ion-like effects in high-multiplicity pp collisions.
- In MC event generators like PYTHIA 8, multiparton interactions (MPI) and color reconnection (CR) can mimic collective effects, therefore, it is pertinent to study observables sensitive to MPI.
- The activity in the transverse region of the di-hadron correlations is the most sensitive to the underlying event, which compromises particles from MPI and beam-beam remnants, but it also has contributions from initial- and final-state radiation (ISR-FSR). In order to better understand the particle production in the transverse region, this region can be further divided into trans-max and trans-min regions which are sensitive to ISR-FSR and UE, respectively.

- In this work, a study of the multiplicity distributions for pp collisions at $\sqrt{s} = 2.76$, 5.02, 7 and 13 TeV with ALICE is reported for transverse, trans-max and trans-min regions.

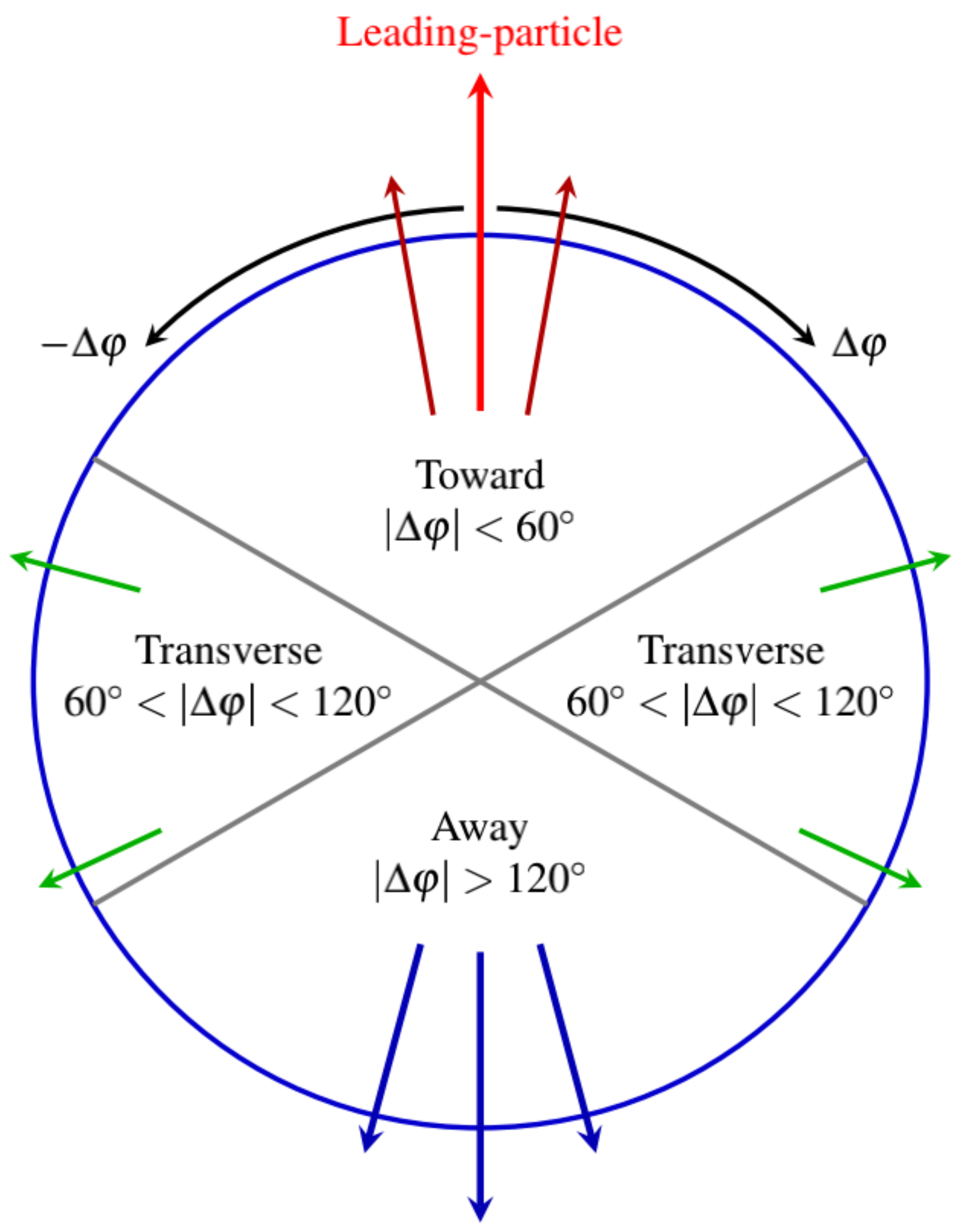


figure from JHEP 04, 192 (2020)

transverse I : $\pi/3 < \Delta\varphi < 2\pi/3$

transverse II: $\pi/3 < -\Delta\varphi < 2\pi/3$

trans-max (trans-min) refers to the transverse region (I or II) with the largest (smallest) number of charged particles.

Analysis Details

Data sample, event and track selection

ALICE

Data sample

pp, 2.76 TeV	Data: LHC11a_pass4_with_SDD MC: LHC12f1a_wSDD
pp, 5.02 TeV	Data: LHC15n_pass4 MC: LHC17e2
pp, 7 TeV	Data: LHC10d_pass4 MC: LHC14j4d
pp, 13 TeV	Data: LHC16l_pass2 MC: LHC18d8_extra (PYTHIA8, Monash 2013 tune) LHC17d20b2 (EPOS LHC) evaluating the systematic uncertainty due to MC model dependence

Event and track selection

event selection	track selection $\|\eta\| < 0.8,\ p_T \geq 0.5$ GeV/c
Standard Physics Selection • Minimum Bias trigger: kINT7(run 2 data) or kMB(run 1 data) • $\|V_z\| < 10$ cm • $5 \leq p_T^{trig} \leq 40$ GeV/c, $\|\eta\| < 0.8$ • rejection of pile-up events and DAQ incomplete events vertex (SPD/track vertex) reconstruction, vertex quality	• Leading track GetStandardITSTPCTrckCuts2015PbPb() SetMaxFractionSharedTPCClusters(0.4) SetCutGeoNcrNcl(3.0, 130.0, 1.5, 0.85, 0.7) SetMaxDCAToVertexXYPtDep("0.0182+0.0350/pt^1.01") • N_{ch} in transverse, trans-max and trans-min regions GetStandardTPConlyTrackCuts() ITS & TPC refit

Analysis strategy —— 1D Bayesian unfolding

The goal is to get back the true multiplicity distribution (N_{ch}) from the measured one (N_{acc})

$$P(N_{ch}) = \sum_{N_{acc}} P(N_{ch}|N_{acc})P(N_{acc})$$

if ($\chi_i^2 < 1$) → $P(N_{ch})$

else ↓

$P^0(N_{ch})$ *initial guess* →

$$P(N_{ch}|N_{acc}) = \frac{P(N_{acc}|N_{ch})P(N_{ch})}{\sum_{N_{ch'}} P(N_{acc}|N_{ch'})P(N_{ch'})}$$

This strategy has been implemented in several works

ANA-1193 (Omar, Peter, et. al.)
ANA-1031 (Sushanta, Antonio)
ANA-896 (Mario Kruger)

N_{ch} : number of charged particles produced in a event

N_{acc}: number of tracks detected in the device

$P(N_{ch})$: probability of finding events with true multiplicity N_{ch}

$P(N_{acc})$: probability of finding events with measured multiplicity N_{acc}

$P(N_{acc} | N_{ch})$: **response matrix** given by MC including the detector response

$P(N_{ch} | N_{acc})$: **un-smearing matrix** calculated by **Bayes' Theorem**

$$P(N_{ch}|N_{acc}) = \frac{P(N_{acc}|N_{ch})P(N_{ch})}{P(N_{acc})}$$

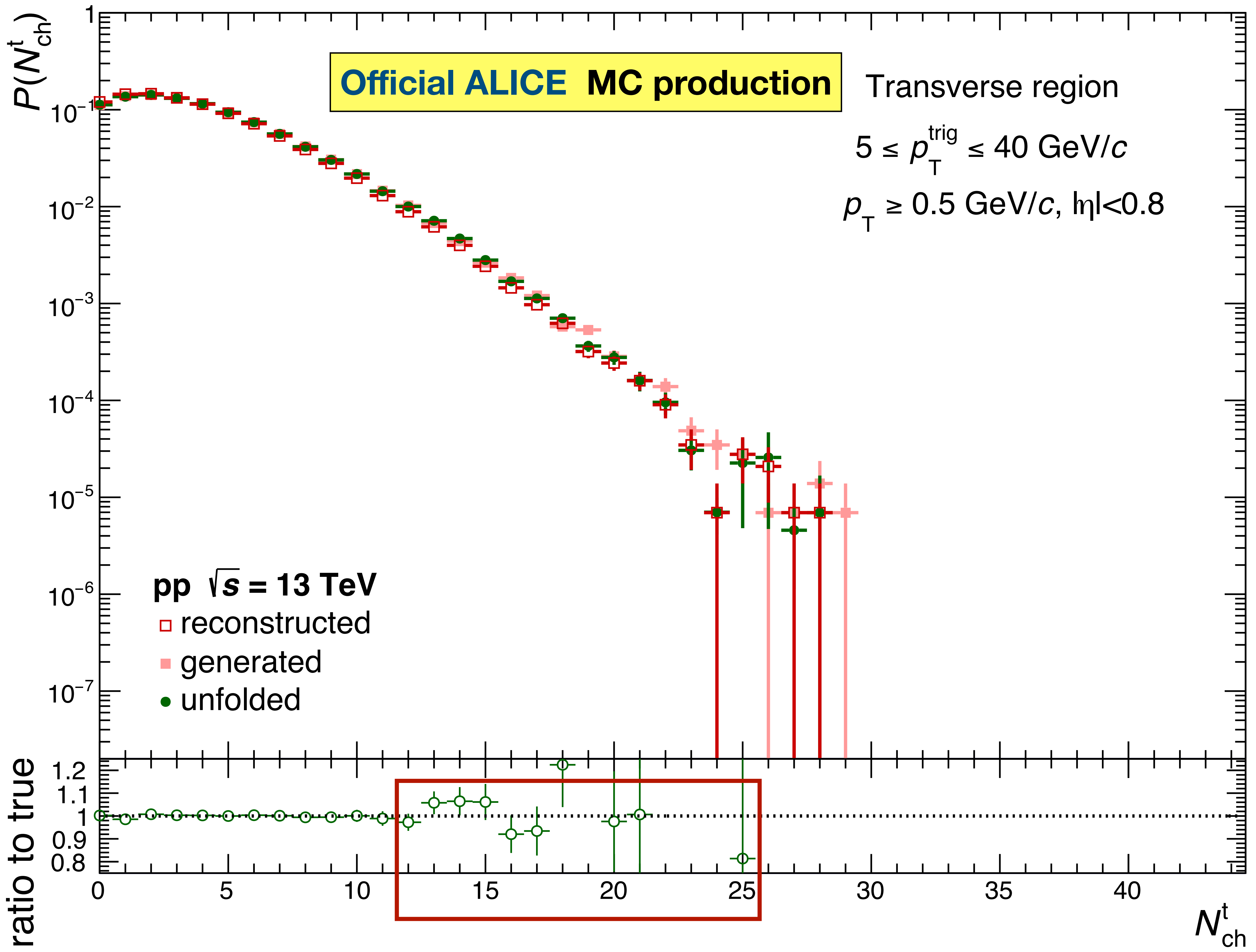
- $P(N_{ch})$ is gotten by iteratively applying Bayes' theorem.
- χ_i^2 is calculated by the formula,

$$\chi_i^2 = \frac{1}{N-1}\sum_{j=1}^{N}\left(\frac{n_i^j - n_{i-1}^j}{\sigma_i^j}\right)^2 \qquad (i \geq 1)$$

where n_i^j is the entry and σ_i^j is the statistic error in the 'j' bin of $P(N_{ch})$ histogram in the 'i' iteration, and 'N' is number of points in that histogram.

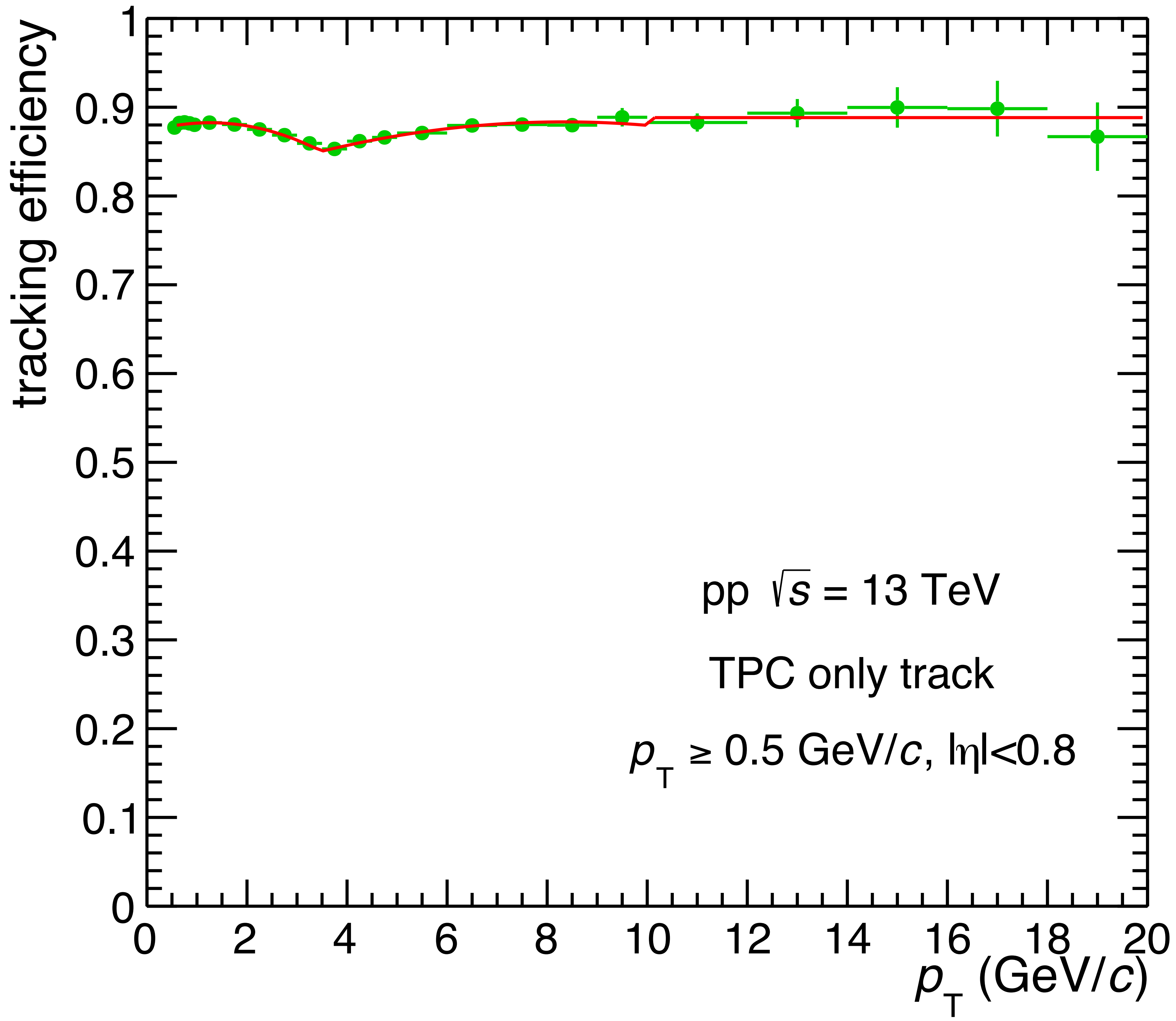
Check of Unfolding Procedure

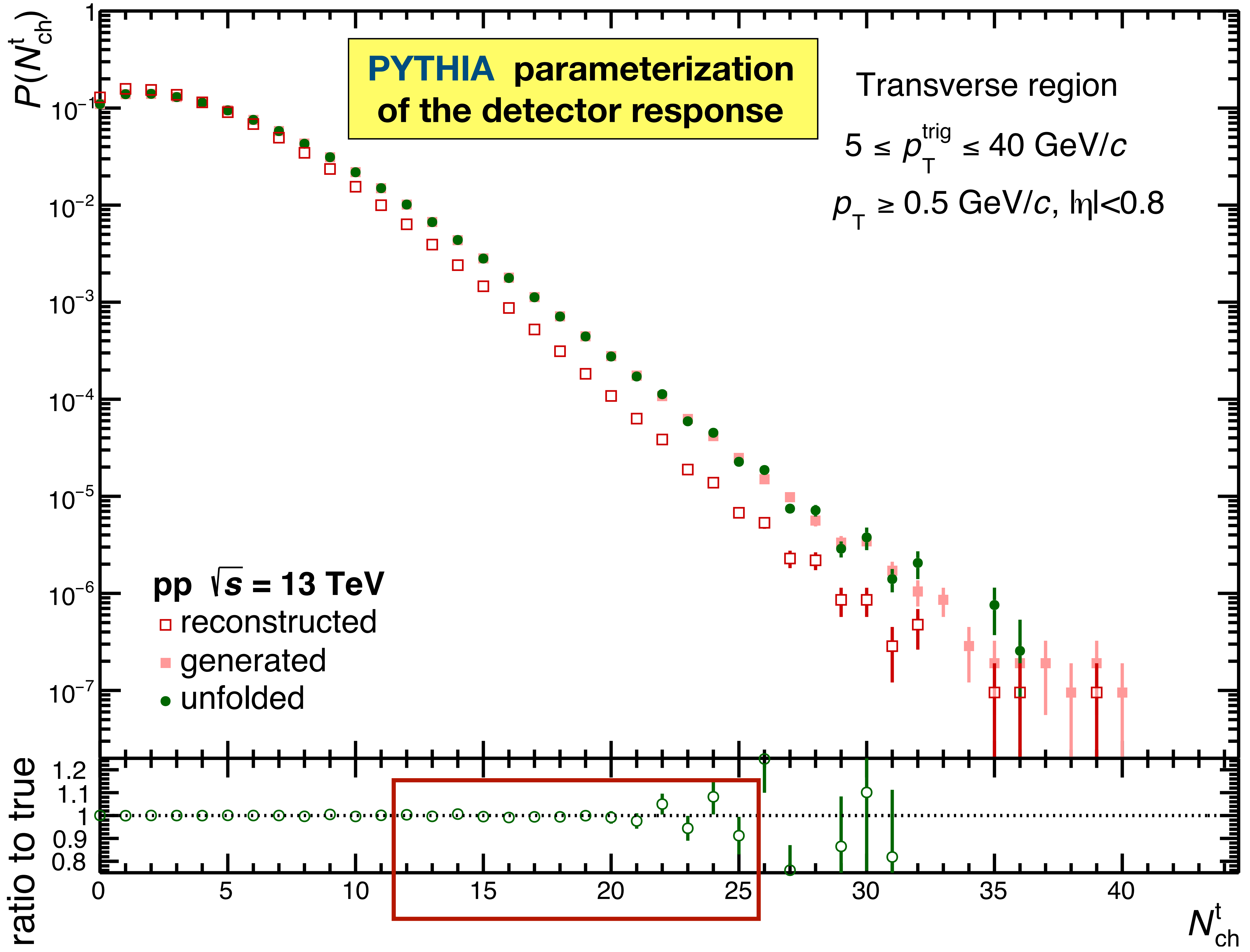
MC closure test



- MC closure was checked using the official MC production (LHC18d8_extra, PYTHIA 8 Monash)
- To test the unfolding technique at very high multiplicities, PYTHIA 8 (Monash) standalone simulations were used

MC closure test at high multiplicity





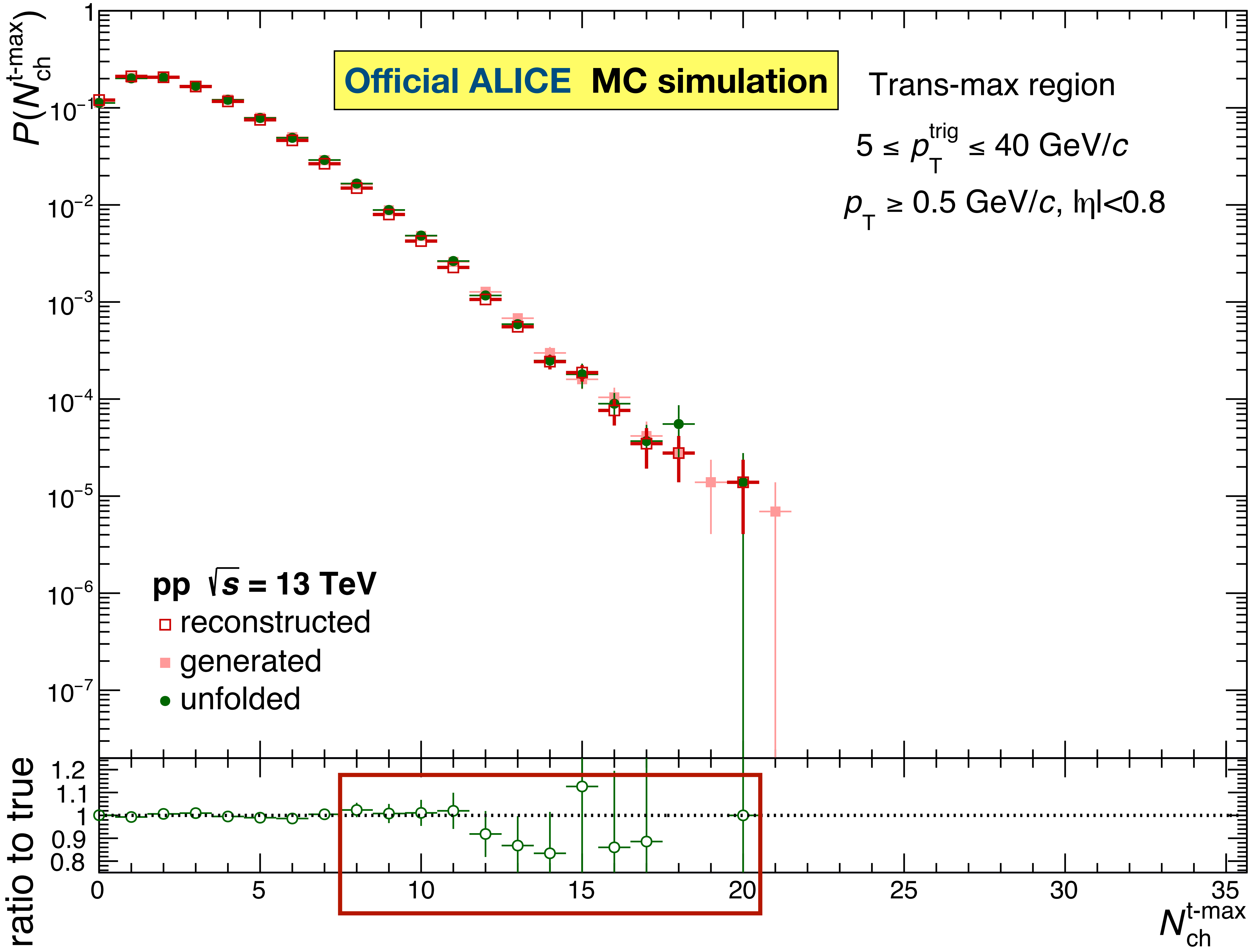
Using Pythia standalone simulations

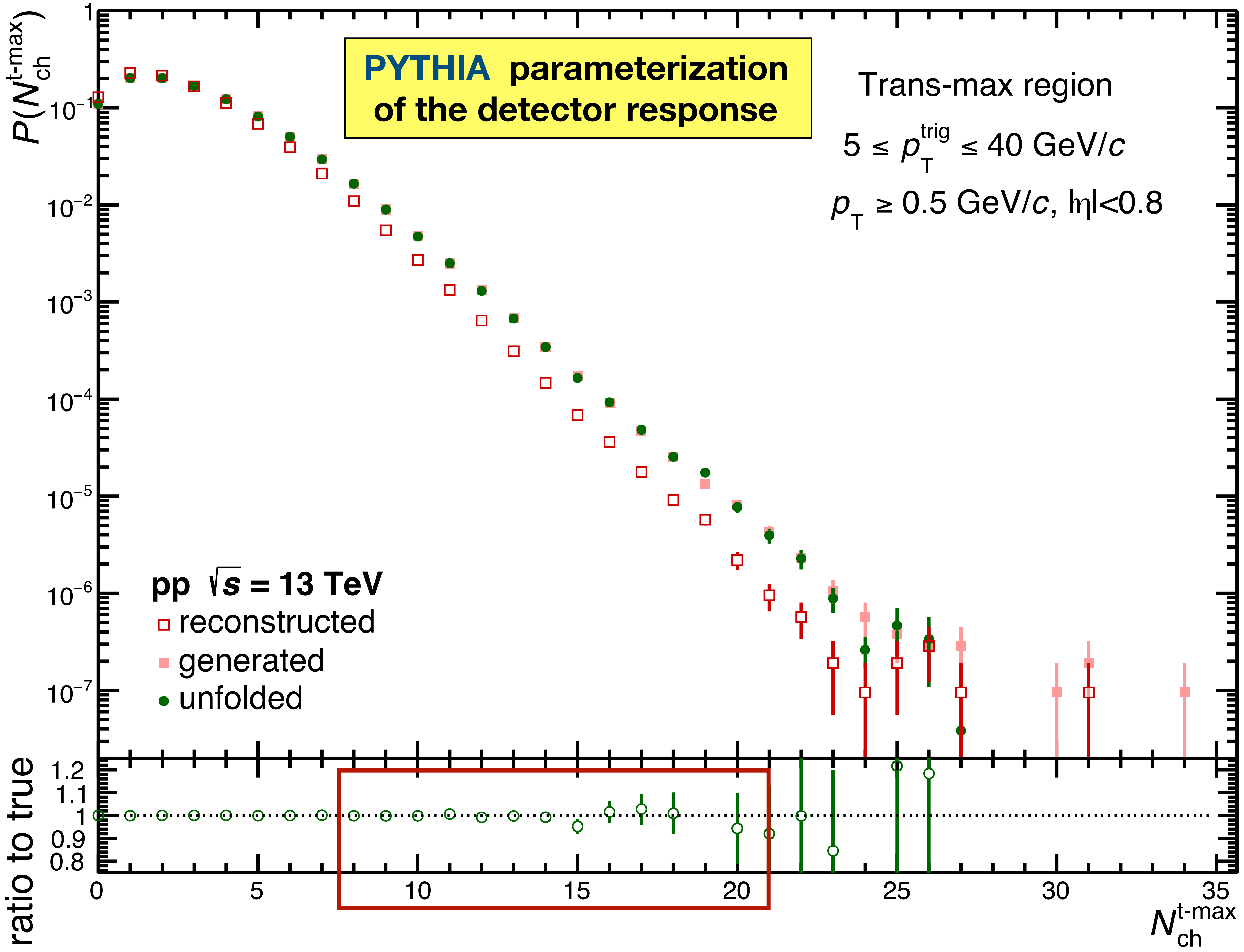
- "Reconstructed events" were simulated, the tracking efficiency was applied to primary charged particles
  - ➡ 600 M events were used to get the "correction factors"
  - ➡ 600 M events were used to test the unfolding technique

(A similar study was suggested by ARC)

The unfolding technique works very well at very high multiplicity.

MC closure test at high multiplicity (trans max)





- In the trans-max region, it can reach to very high multiplicity by implementing the parameterization of the detector response.
- The unfolding technique works very well at very high multiplicity.

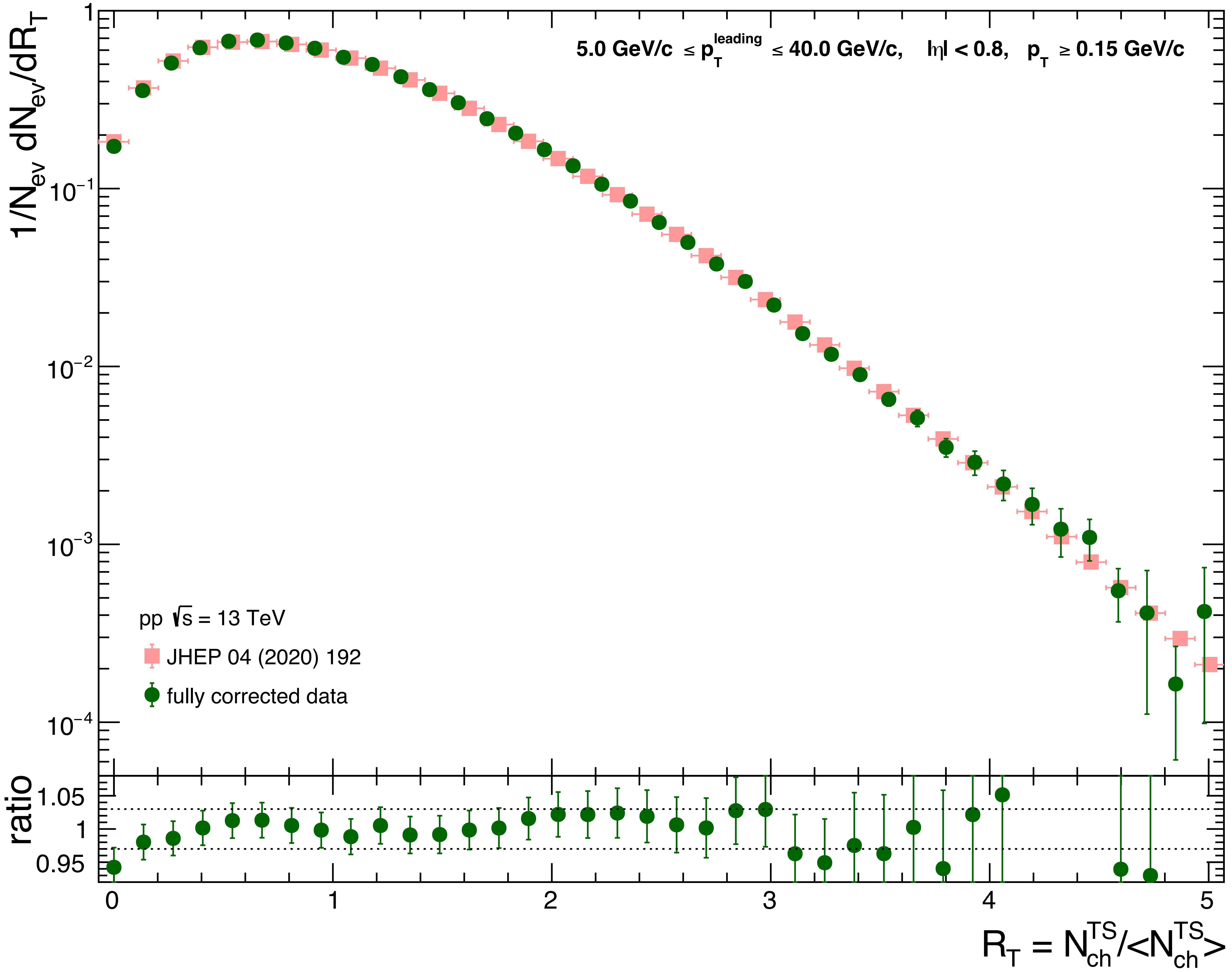
MC closure test at high multiplicity (trans min)

ALICE

- In the trans-min region, it can reach to very high multiplicity by implementing the parameterization of the detector response.
- The unfolding technique works very well at very high multiplicity.

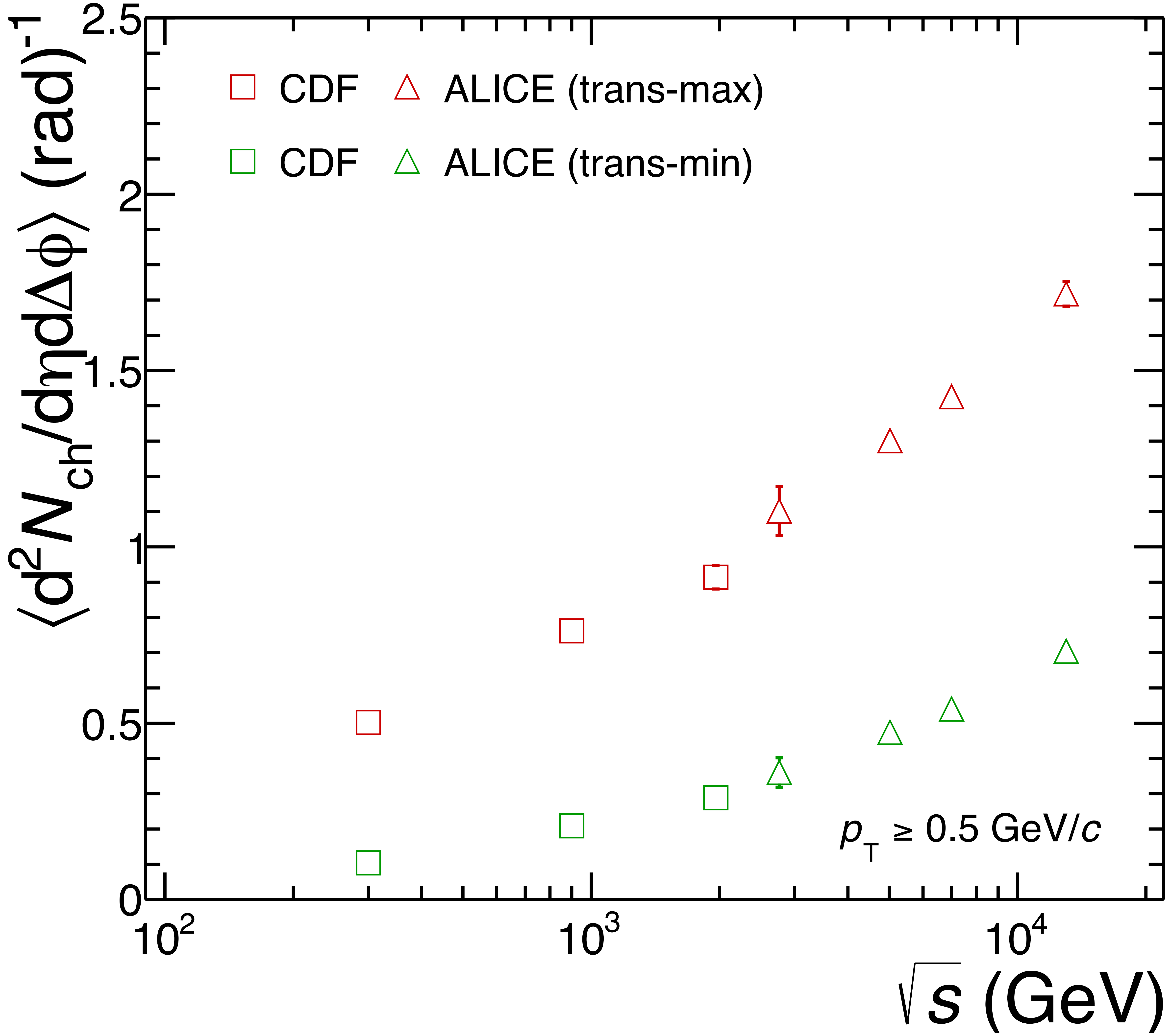
Sanity Check

Consistency with R_T



- We use a smaller sample than that used in the publication, different unfolding method
- Within 4%, our data is consistent with the published result in pp collisions at 13 TeV.

Consistency with $N_{ch}^{trans-max}$, $N_{ch}^{trans-min}$



- Our results are consistent with the trend of existing results from CDF in the trans-max and trans-min regions.

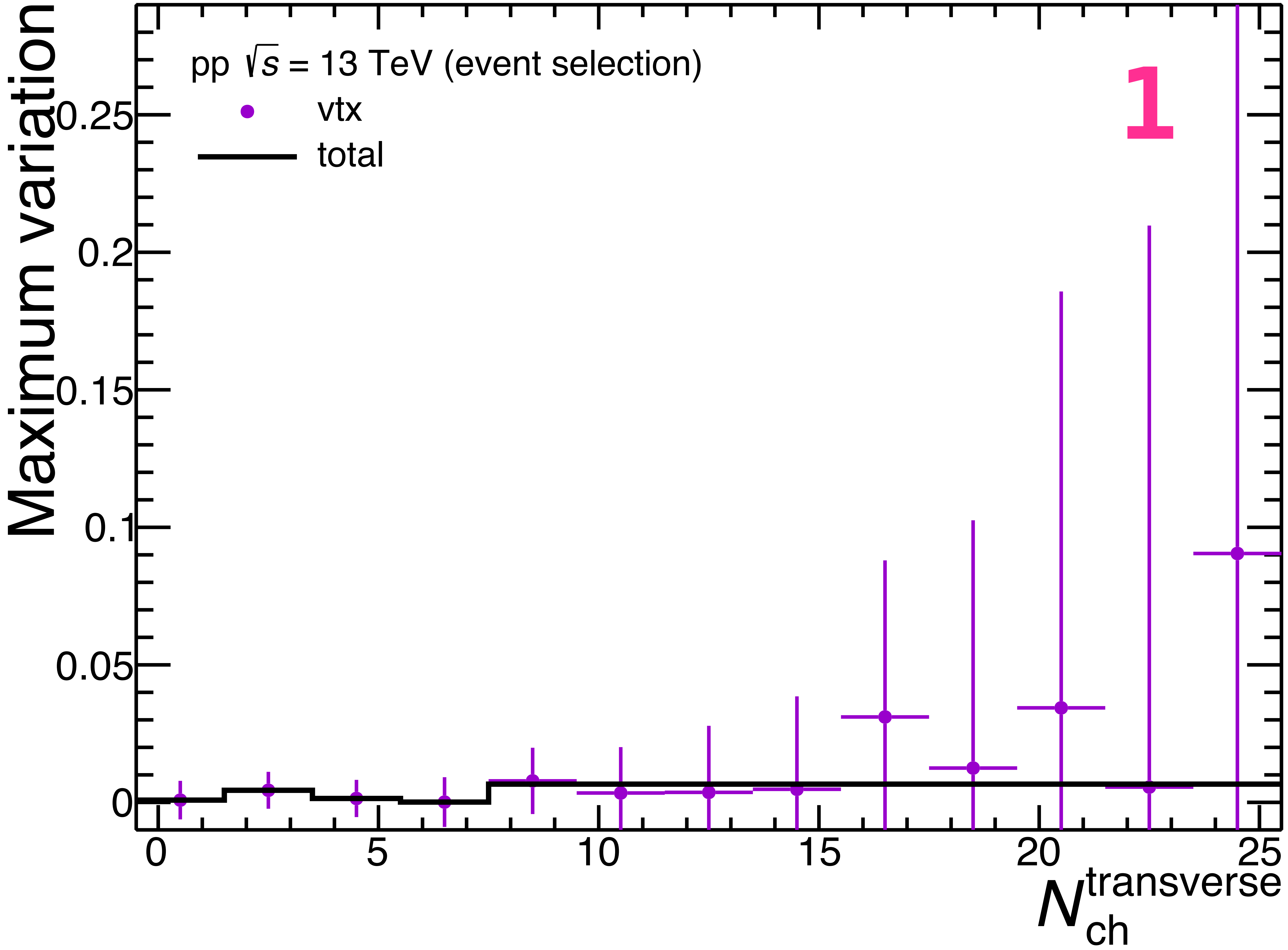
Average multiplicity

ALICE

	$\langle N_{\mathrm{ch}}^{\mathrm{trans-min}} \rangle$	$\langle N_{\mathrm{ch}}^{\mathrm{trans-max}} \rangle$	Sum	$\langle N_{\mathrm{ch}}^{\mathrm{transverse}} \rangle$
pp $\sqrt{s} = 2.76$ TeV	0.603657	1.84547	2.449127	2.44242
pp $\sqrt{s} = 5.02$ TeV	0.794141	2.17986	2.974001	2.97027
pp $\sqrt{s} = 7$ TeV	0.904969	2.38866	3.293629	3.29331
pp $\sqrt{s} = 13$ TeV	1.17942	2.87749	4.05691	4.05631

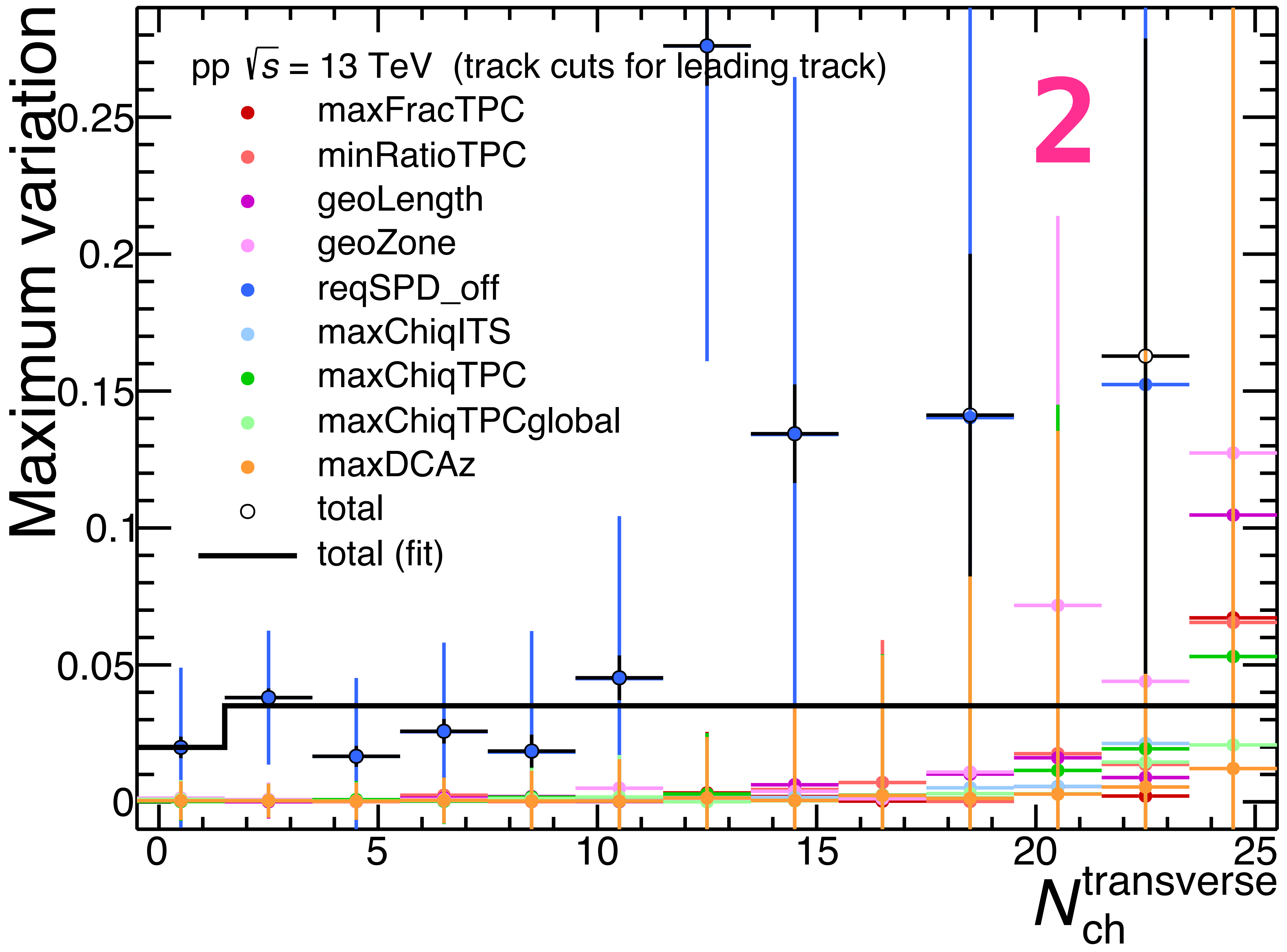
Systematic Uncertainties (Multiplicity Distributions)

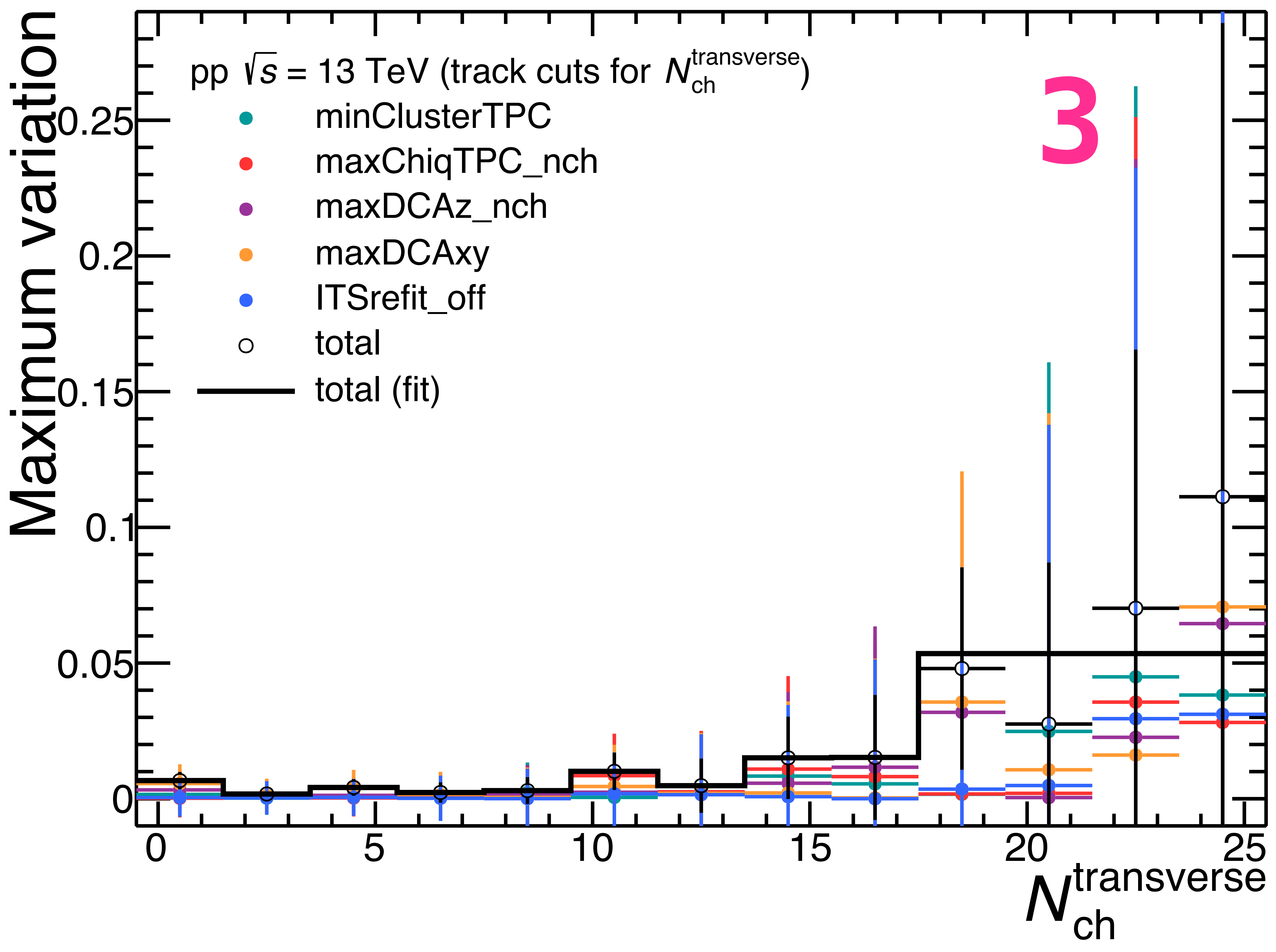
Event selection



- |Vz| < 5 cm (15 cm), the nominal value is 10 cm.
- A constant fit to data is used to estimate the systematic uncertainty at high multiplicity, this allows to reduce the effects of statistical fluctuations.

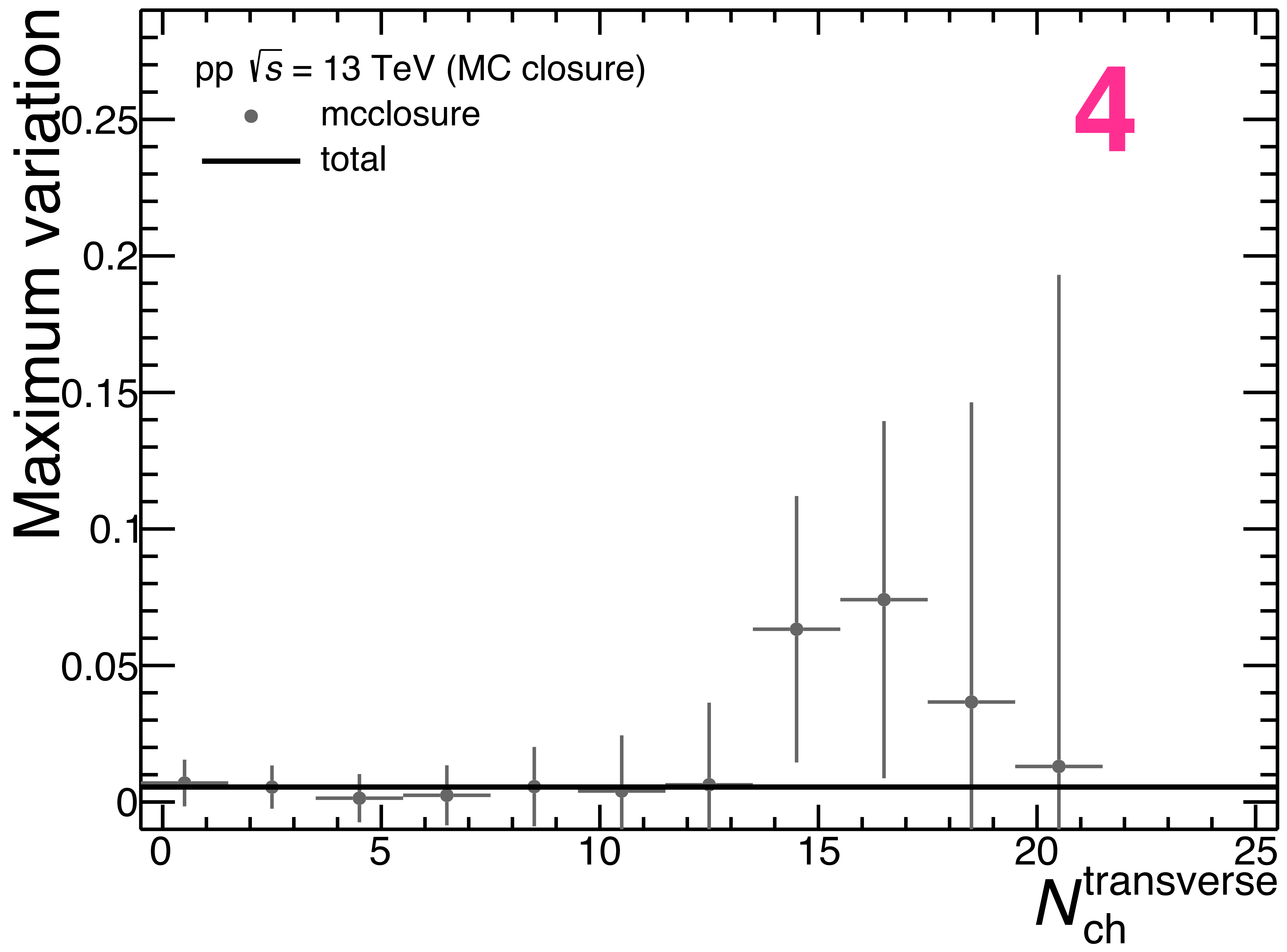
Track selection

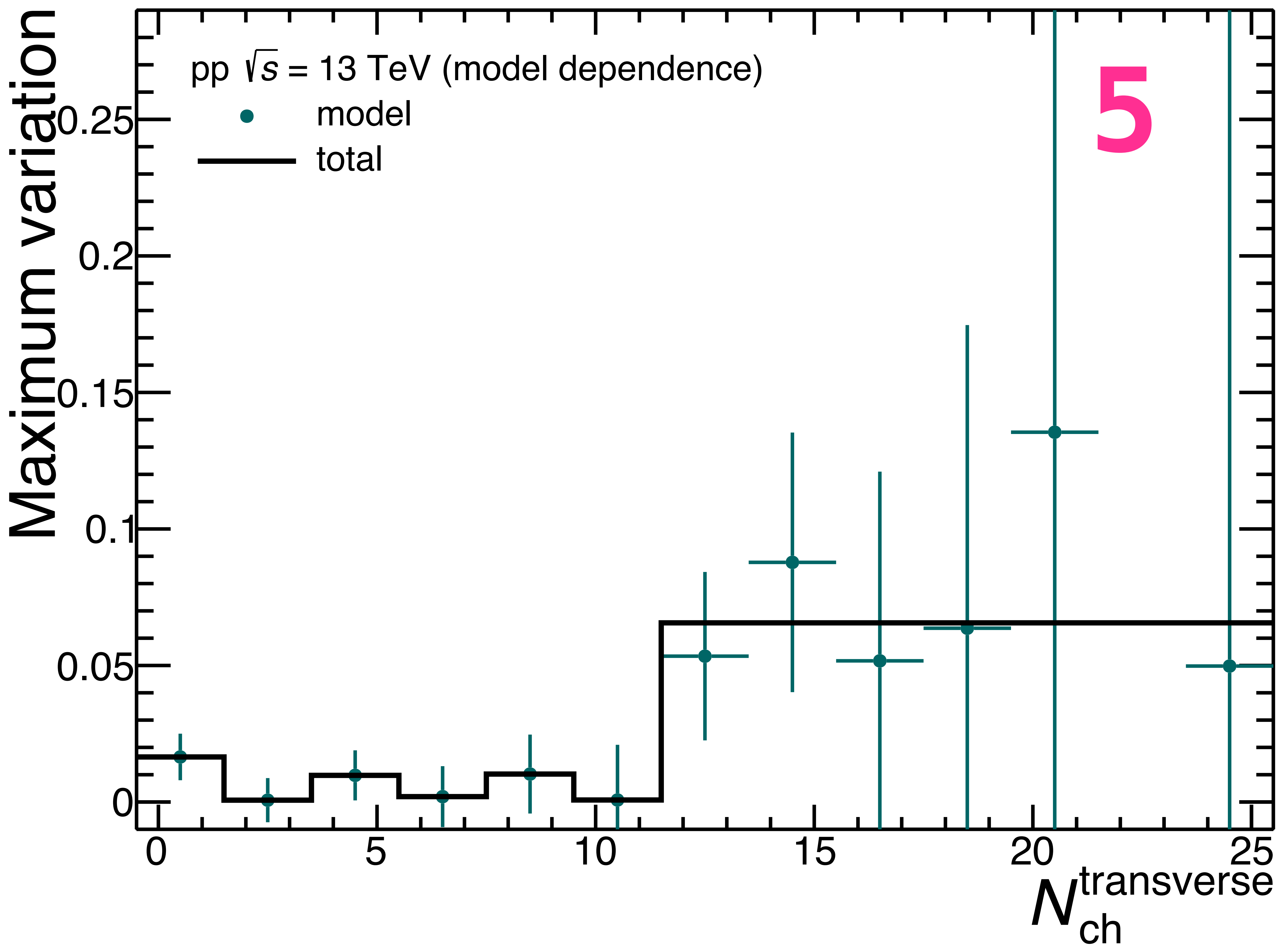




- The total systematic uncertainties are obtained by the quadrature sum of maximum variation of each track cut.

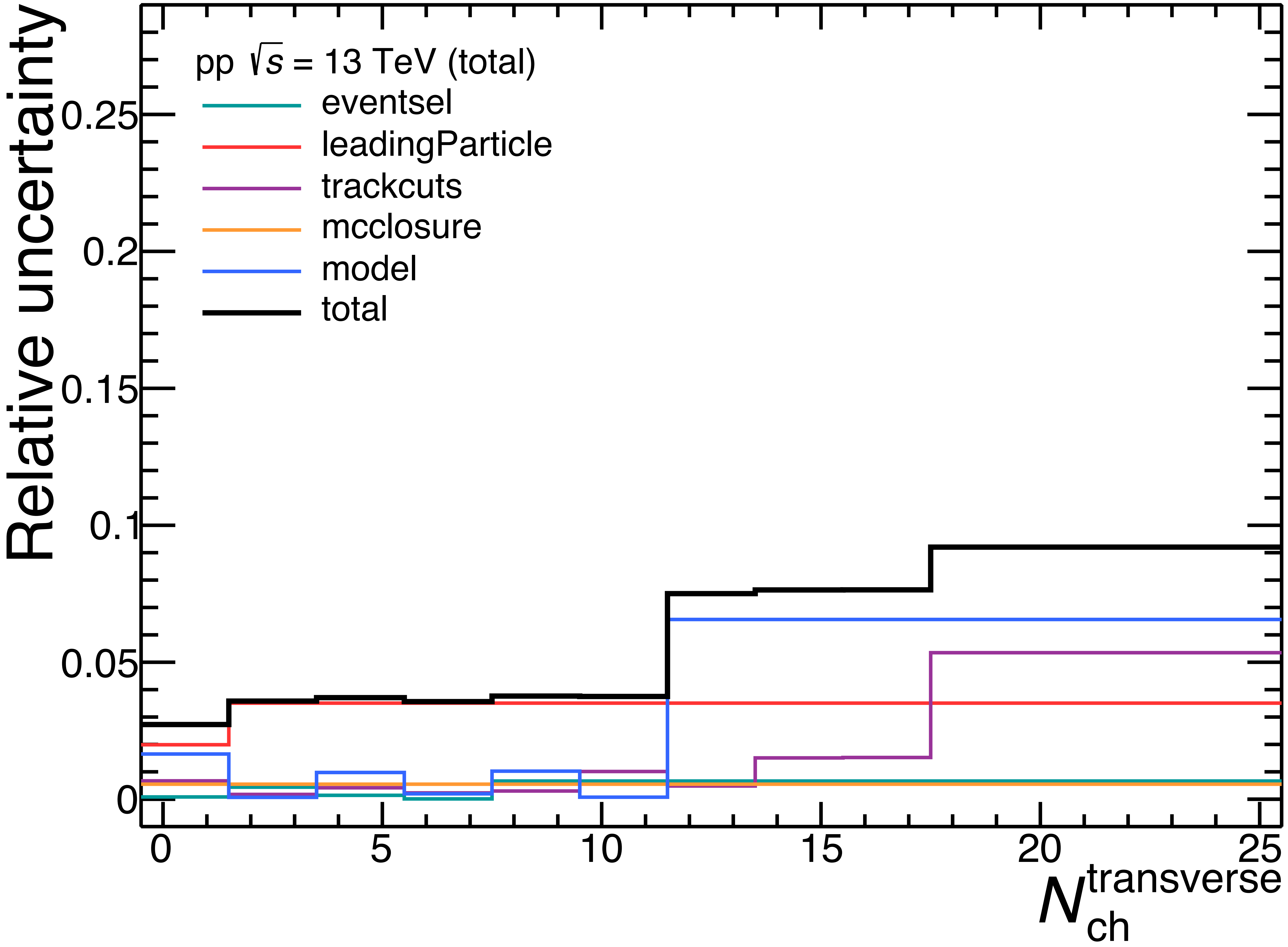
MC closure test & model dependence





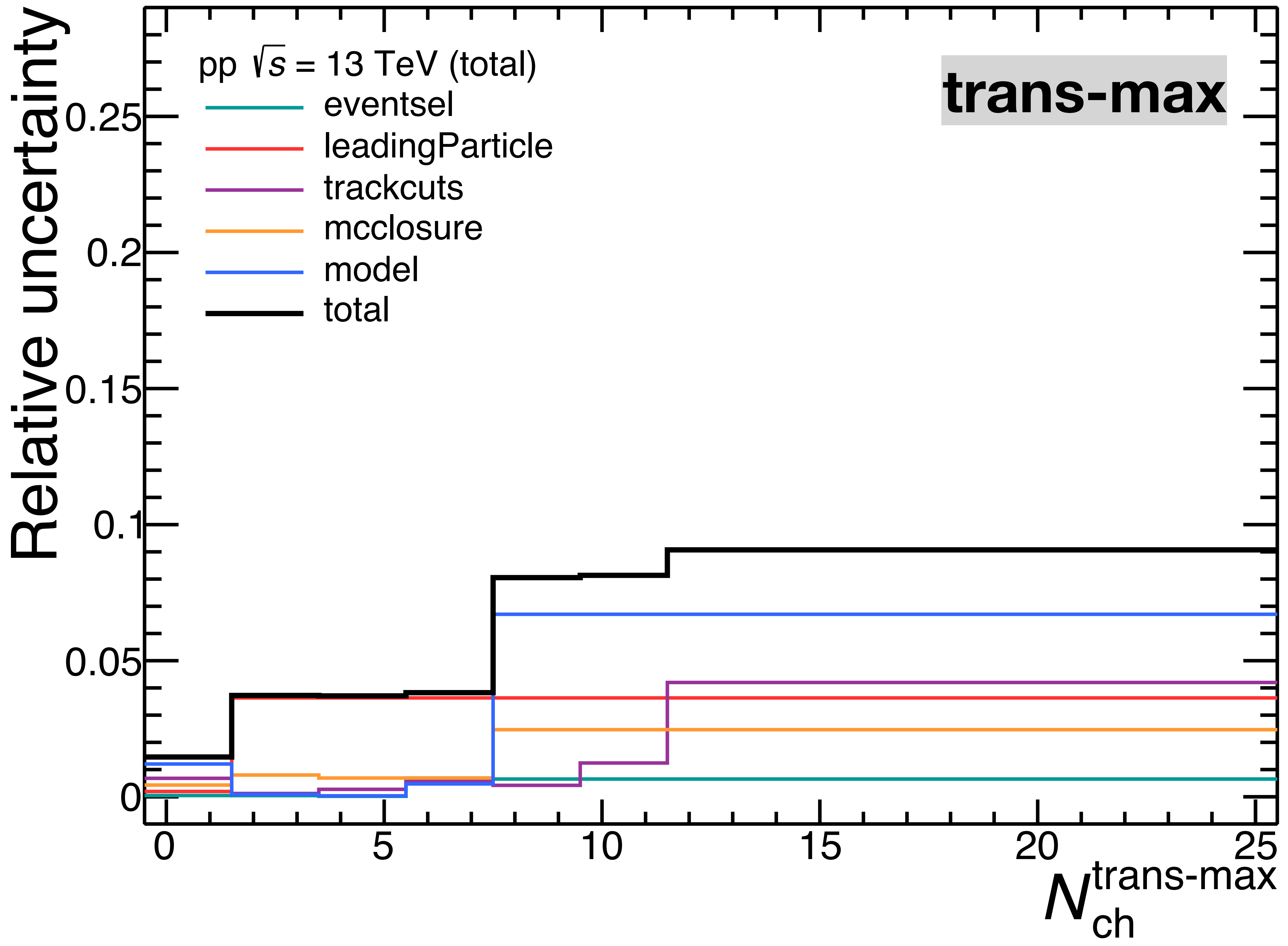
- The model dependence was only tested for 13 TeV and we assume the same uncertainty for lower energies.

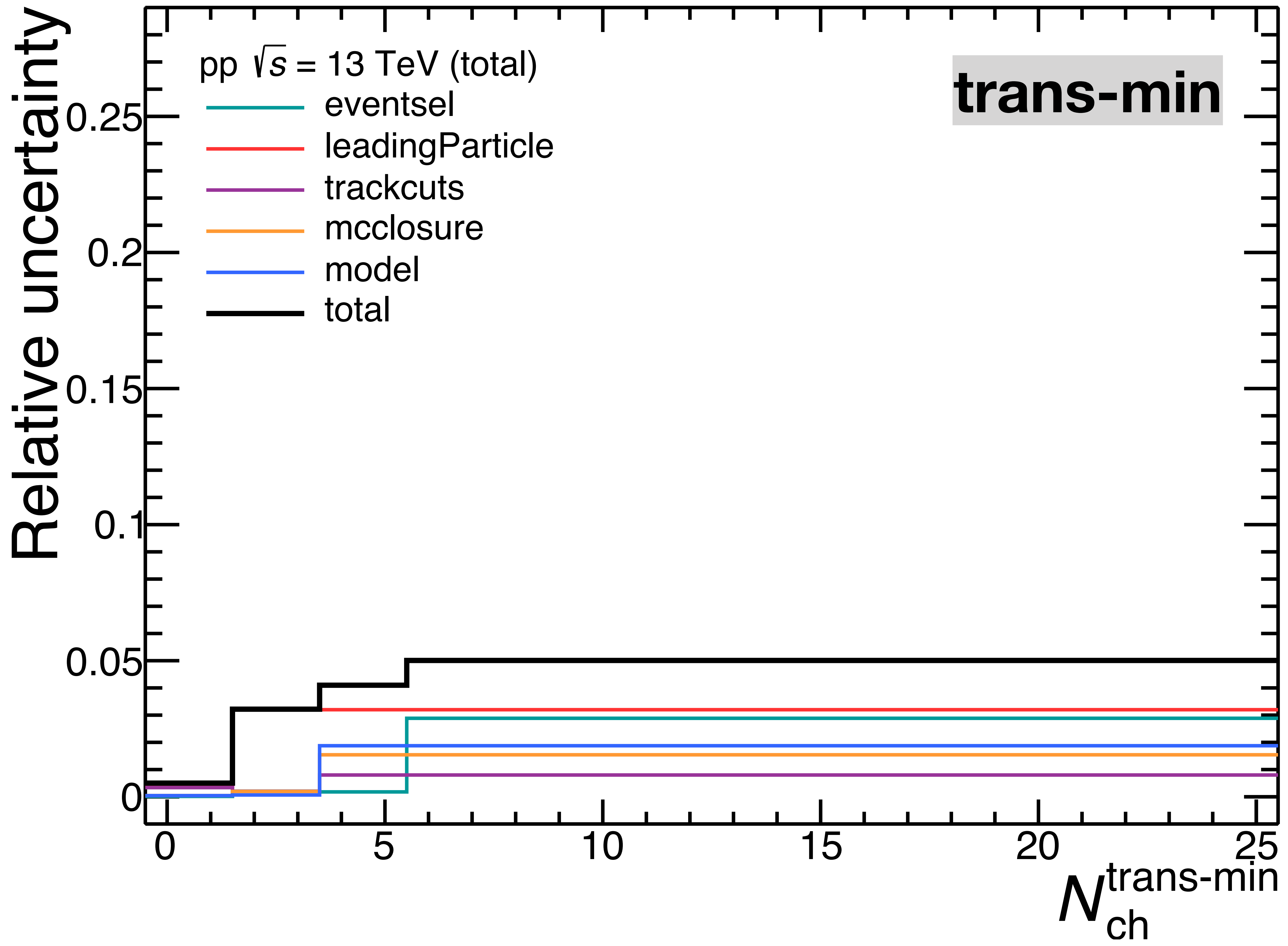
Systematic uncertainties



- The total systematic uncertainties are obtained by the quadrature sum of the five sources of systematic uncertainty.

Systematic uncertainties





- The total systematic uncertainties in trans-max and trans-min regions have a similar behavior to the transverse region.

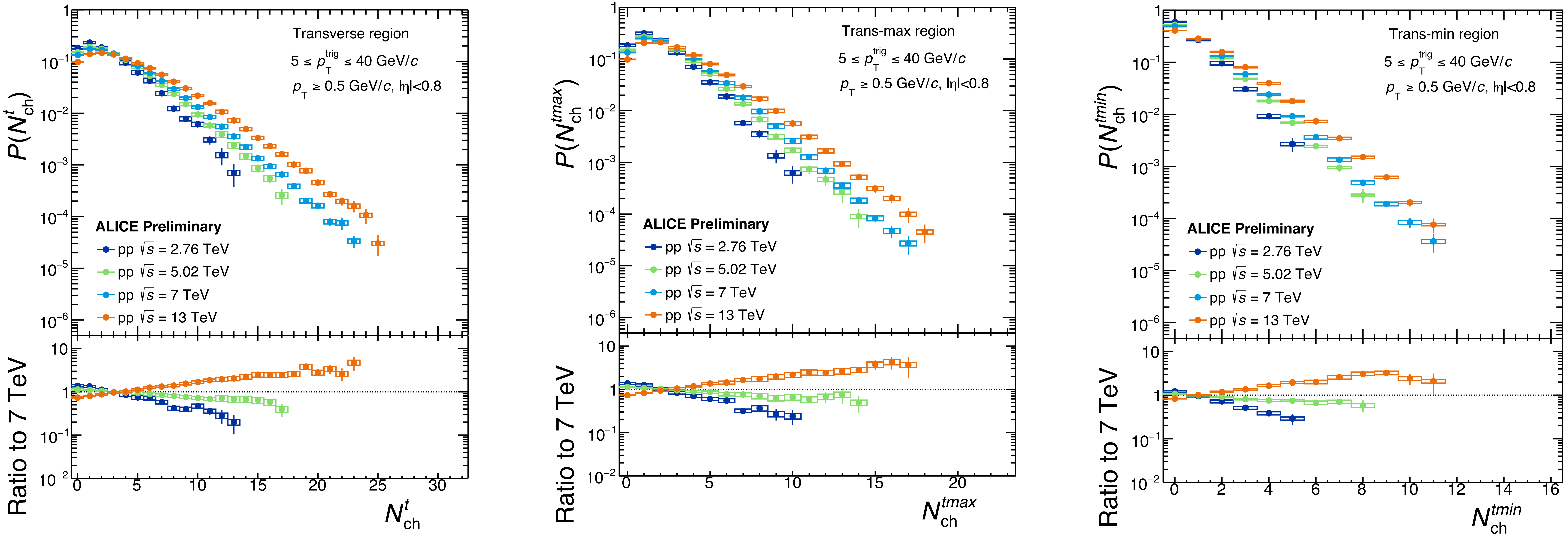
Systematic Uncertainties (Average Multiplicity)

Systematic uncertainties

source	pp $\sqrt{s} = 13$ TeV $\langle N_{ch}^{transverse} \rangle$	$\langle N_{ch}^{trans-max} \rangle$	$\langle N_{ch}^{trans-min} \rangle$
event selection	0.1%	0.1%	0.3%
track selection for leading track	1.7%	1.7%	1.8%
track selection for N_{ch}	0.2%	0.2%	0.3%
MC closure test	negl.	0.1%	0.1%
MC model dependence	0.8%	1.1%	0.1%
total	1.9%	2.0%	1.9%

Results

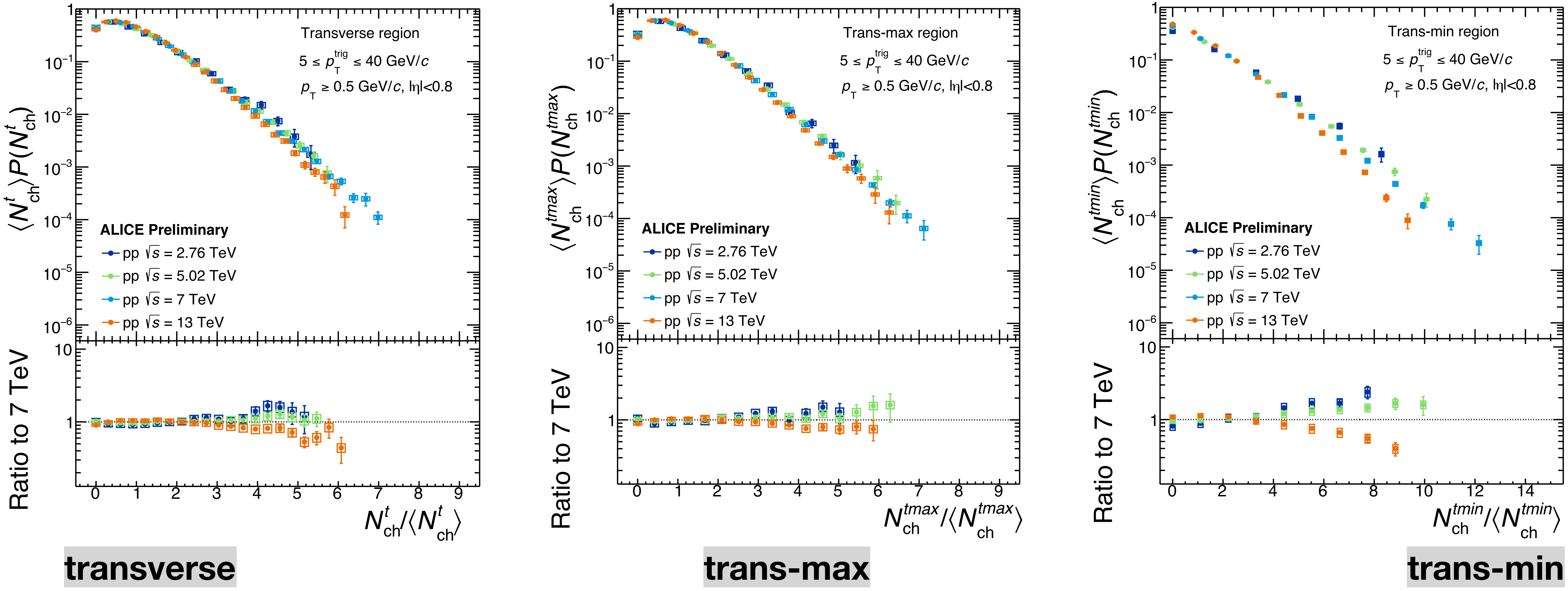
Candidate for preliminary (N_{ch} distributions)



transverse **trans-max** **trans-min**

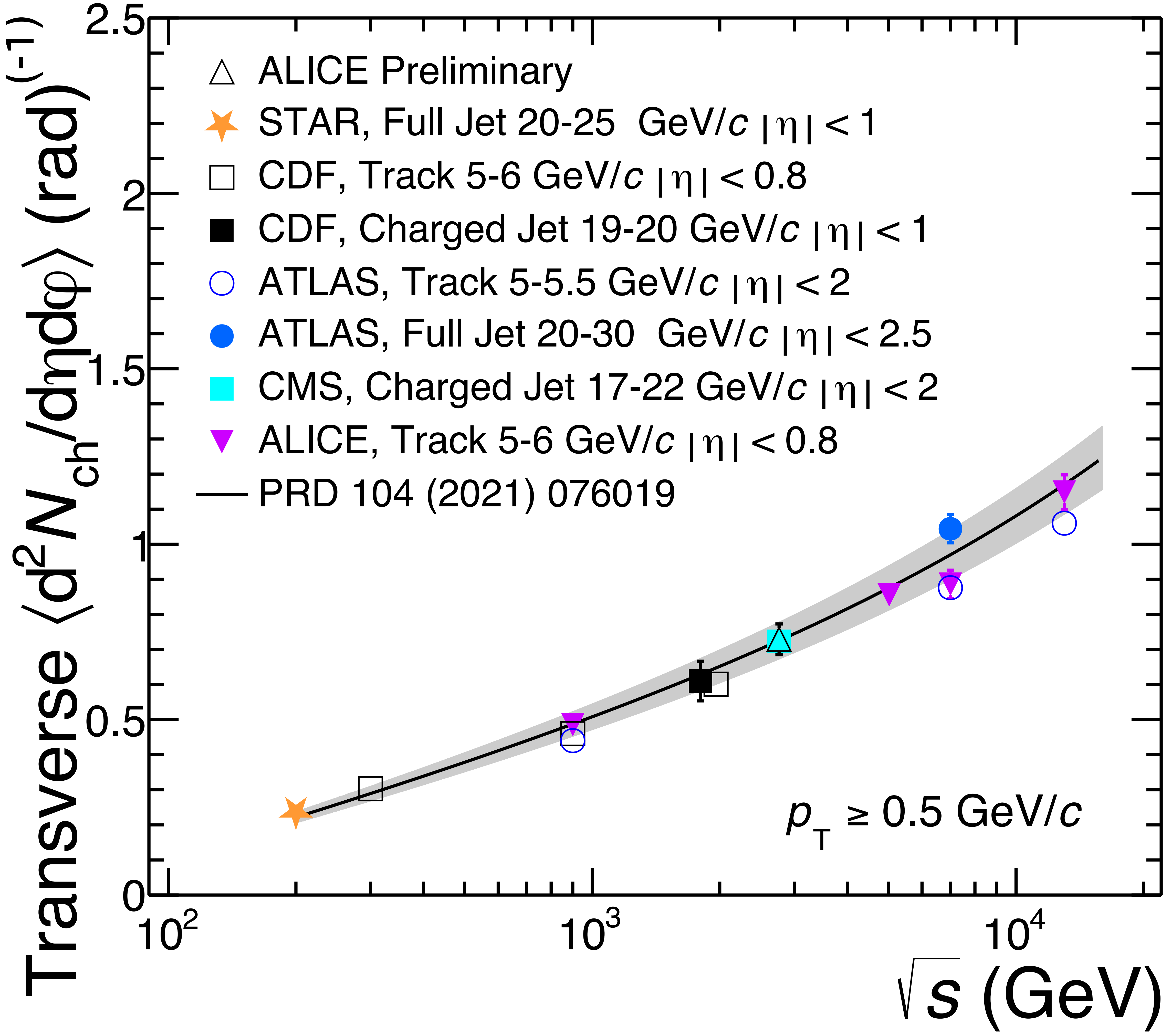
- The charged particle multiplicity distributions are energy dependent in three topological regions.
- Similar behavior is seen in minimum-bias pp collisions

Candidate for preliminary (KNO variables)



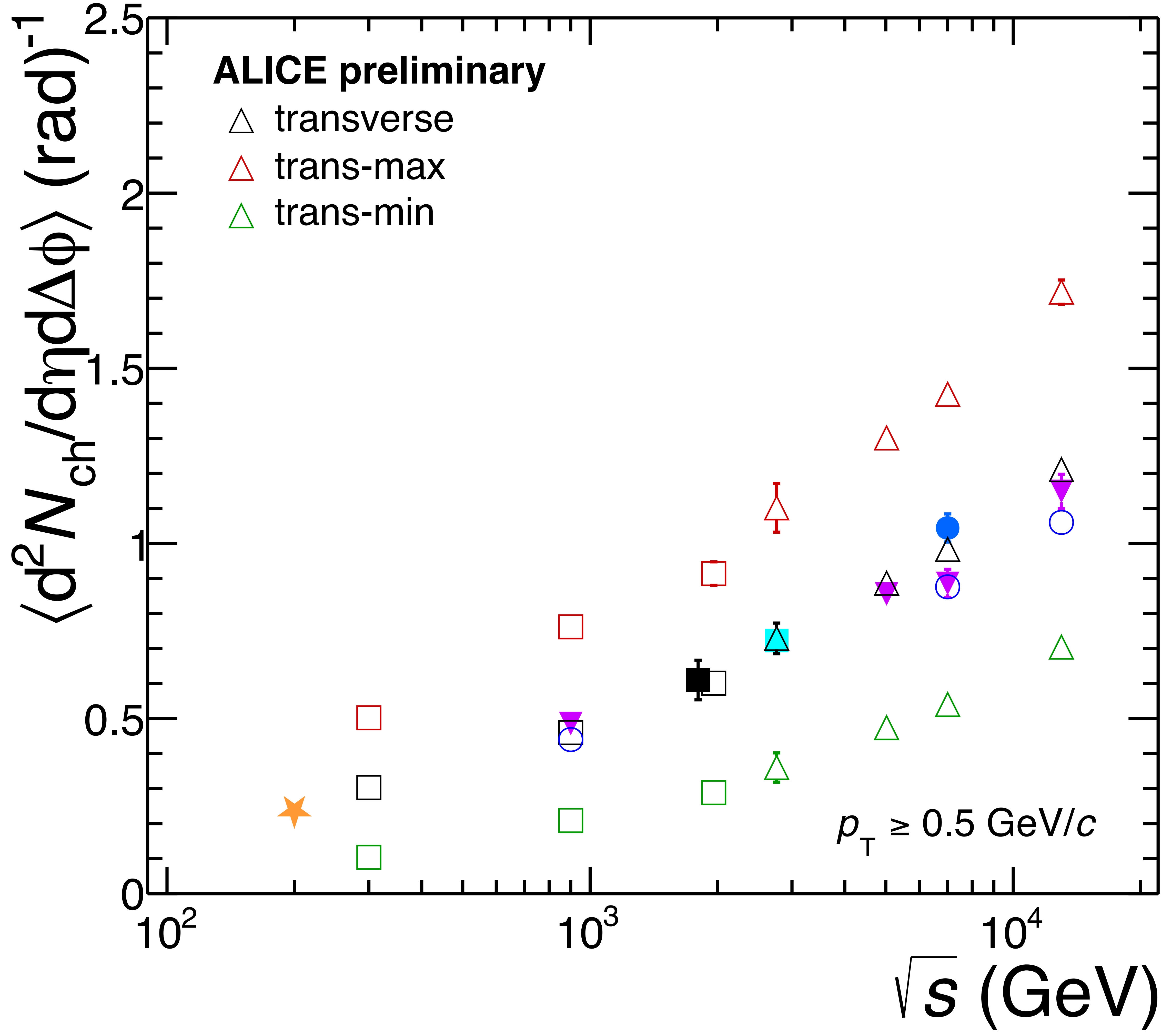
- In three topological regions the KNO-like scaling holds for $0 < z(= N_{ch}/\langle N_{ch}\rangle) < 3.5$
  - ➡ This scaling suggests that a single pp collision results from the superposition of a given number of elementary partonic collisions emitting independently. Therefore, MPI can produce such an effect.
- At higher multiplicities the scaling is broken in particular for trans min, high multiplicity mini jets?

Candidate for preliminary ($\sqrt{s}$ dependence of UE)



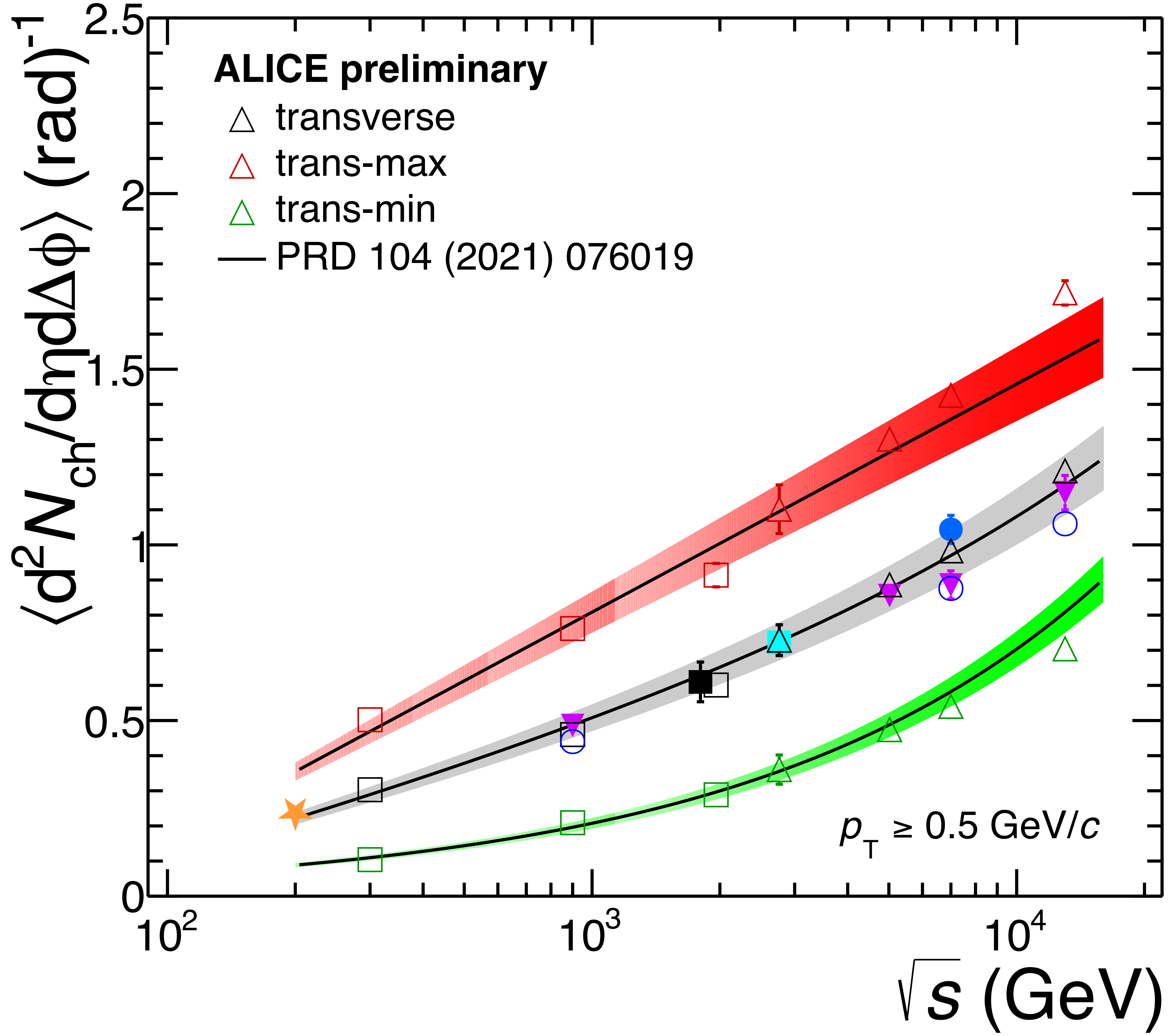
- Our data is consistent with the trend of existing results

Candidate for preliminary ($\sqrt{s}$ dependence of uE)



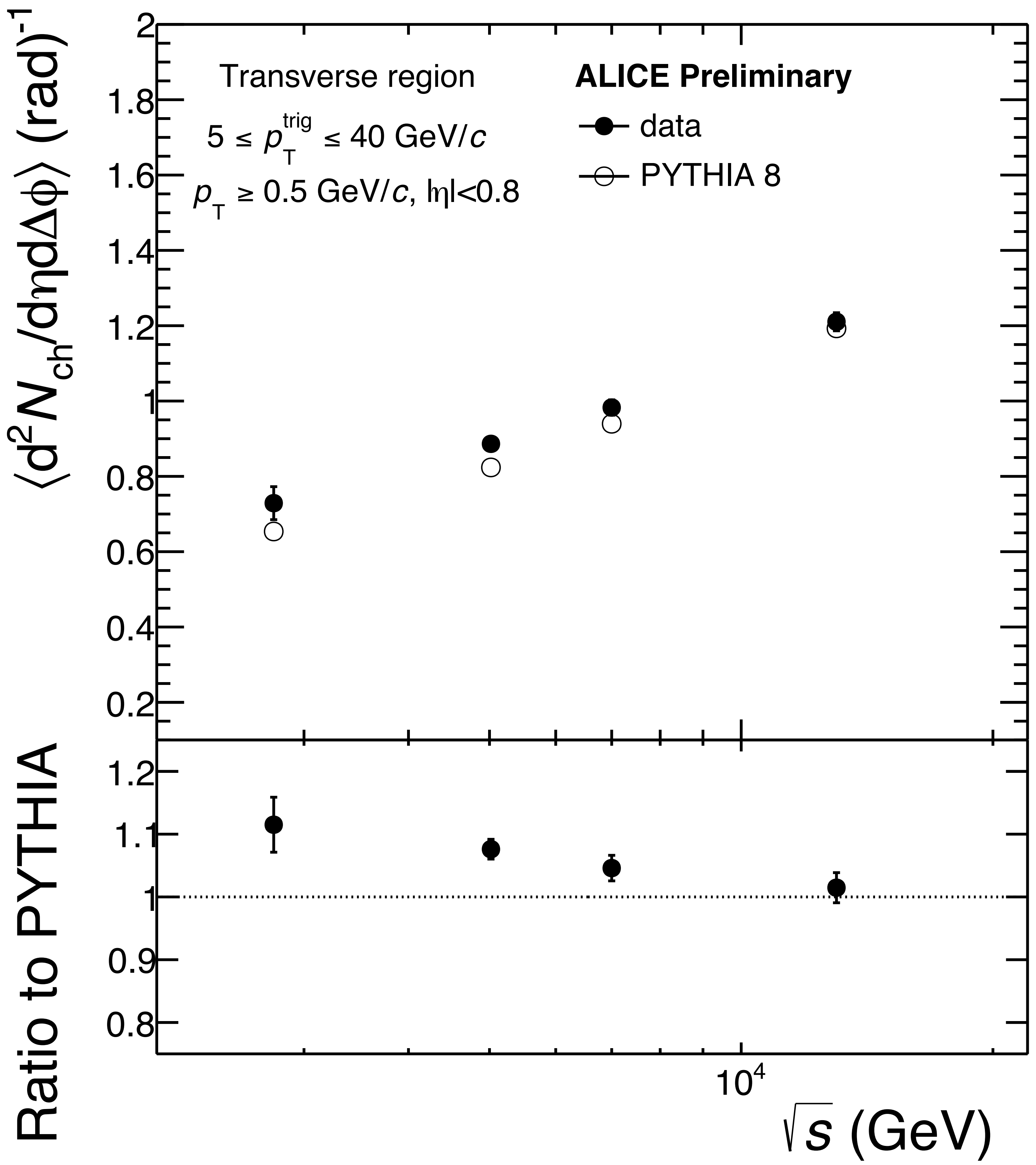
- Our results are consistent with the trend of existing results from CDF in trans-max and trans-min regions.

Candidate for Preliminary ($\sqrt{s}$ dependence of uE)

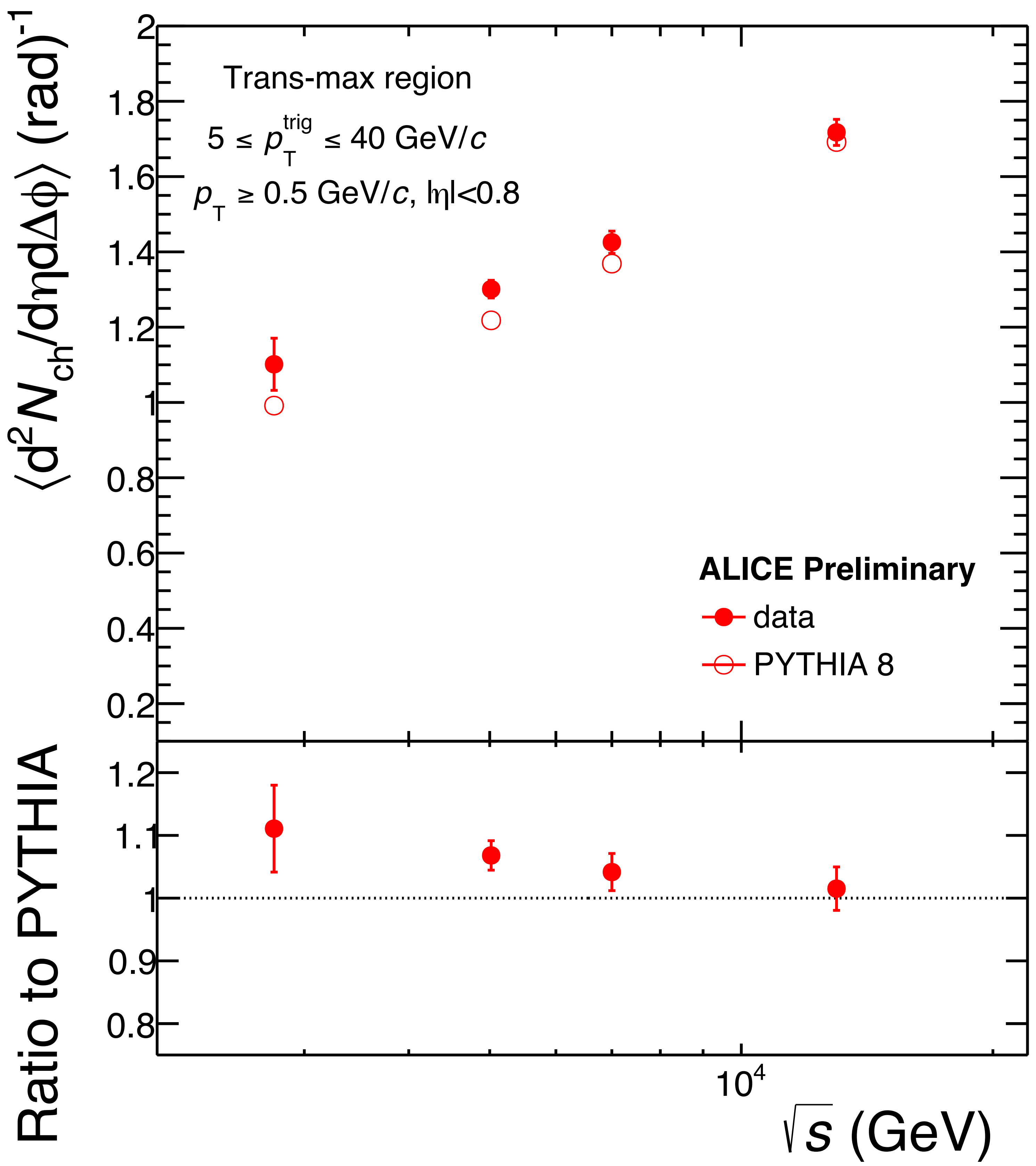


- The UE component is found to increase like a power of the center-of-mass energy, while the ISR-FSR component increases logarithmically. The power-law behavior of the UE contribution is similar to the energy dependence of the parameter that regulates Multiparton Interactions in PYTHIA 8.

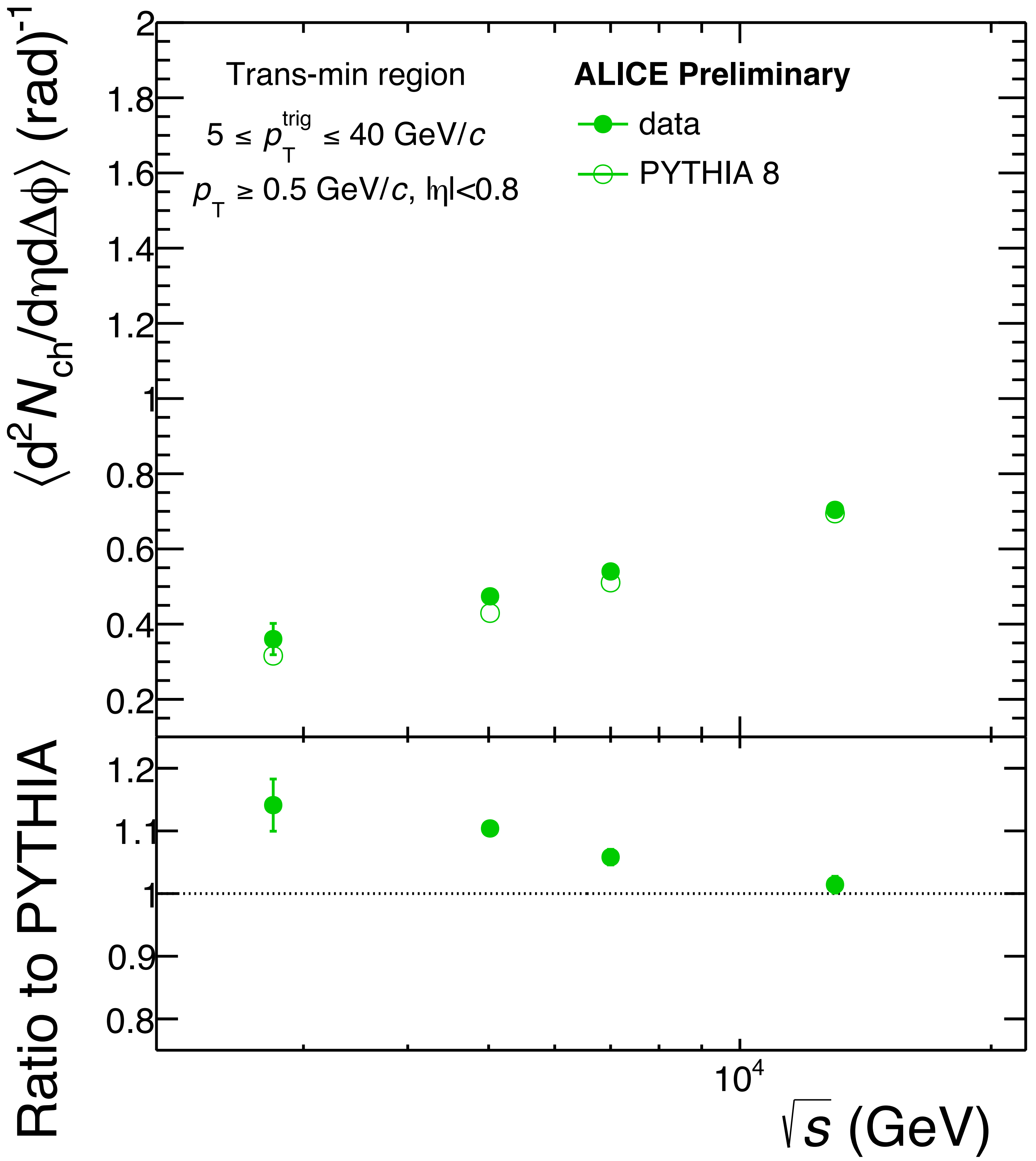
Candidate for preliminary (PYTHIA 8 vs DATA)



transverse



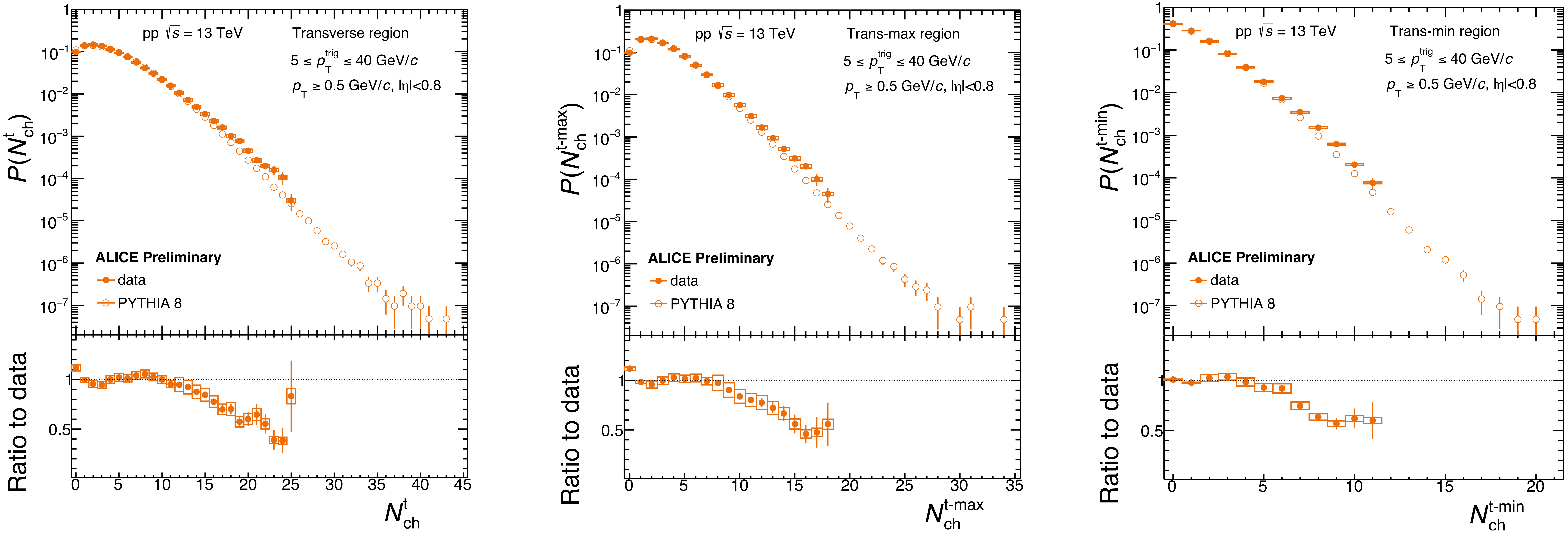
trans-max



trans-min

- Within around 10%, PYTHIA 8 is consistent with data and a better agreement is reached at higher energies.

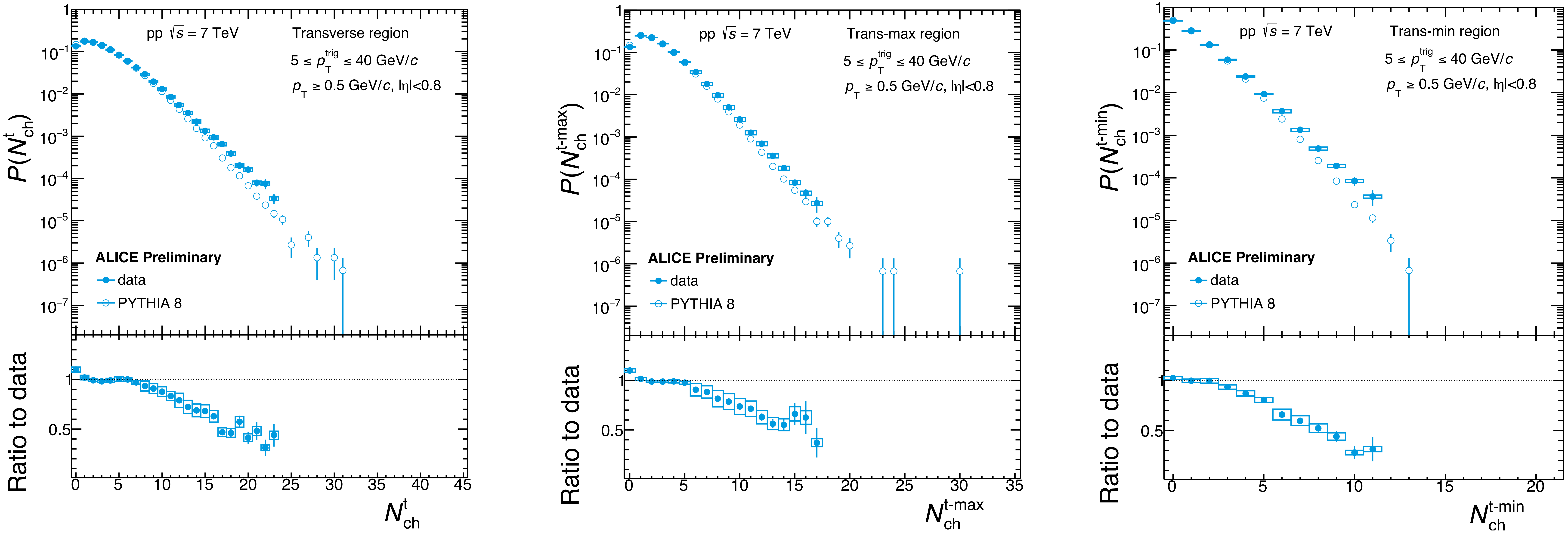
Candidate for preliminary (PYTHIA 8 vs DATA)



transverse **trans-max** **trans-min**

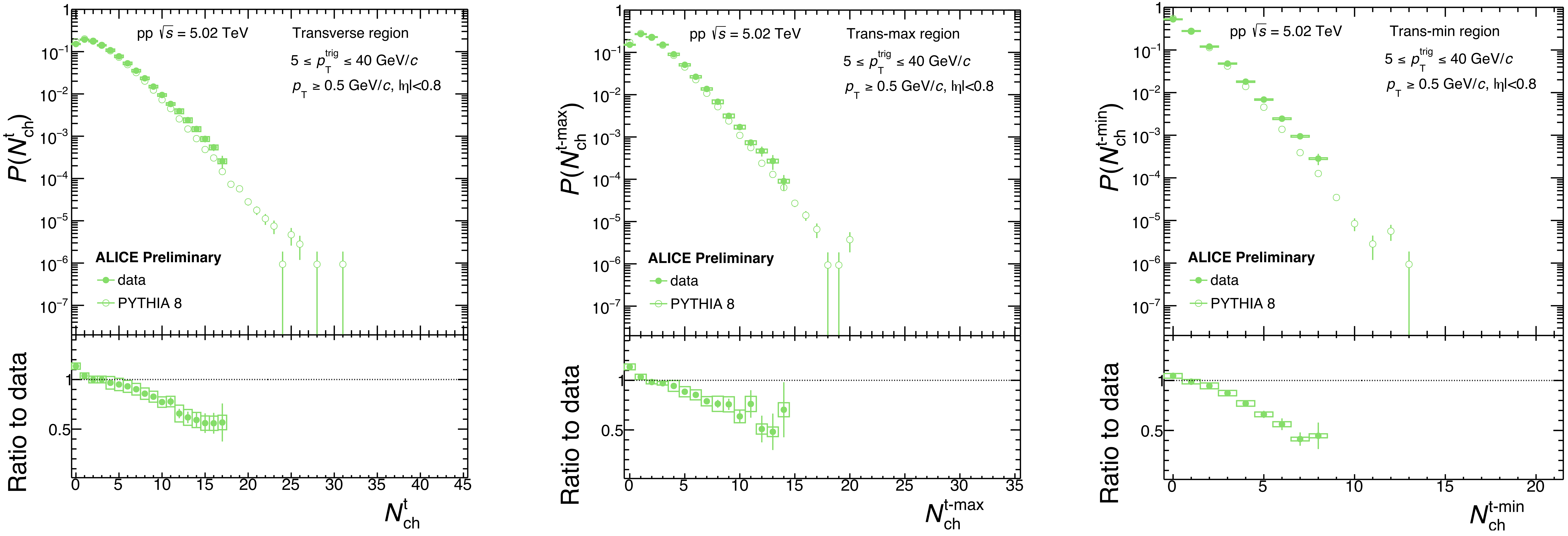
- At low multiplicities, within 10% PYTHIA 8 is consistent with data
- At high multiplicities, PYTHIA 8 underestimates the data. A similar behavior was reported in the ALICE paper on UE observables in pp collisions at 13 TeV

Candidate for preliminary (PYTHIA 8 vs DATA)



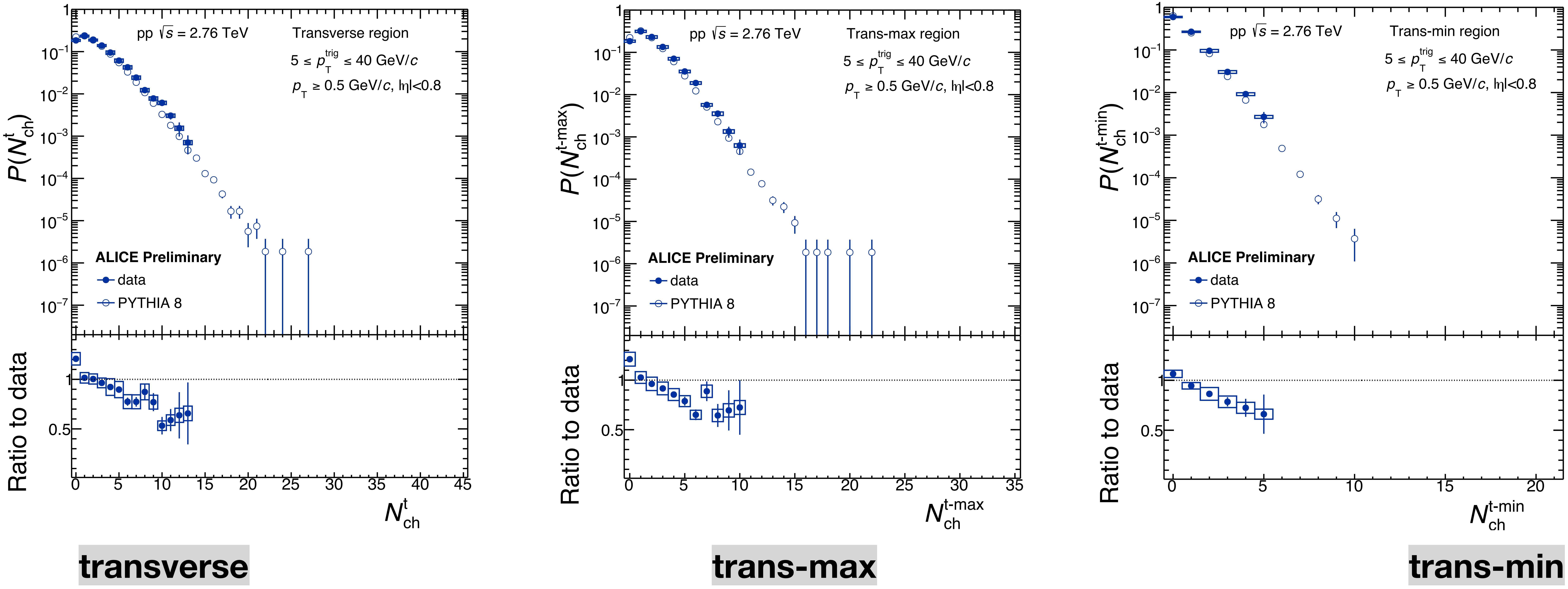
transverse **trans-max** **trans-min**

Candidate for preliminary (PYTHIA 8 vs DATA)



transverse **trans-max** **trans-min**

Candidate for preliminary (PYTHIA 8 vs DATA)



- Comparison between data and PYTHIA 8 for KNO variables will be added.

Summary

ALICE

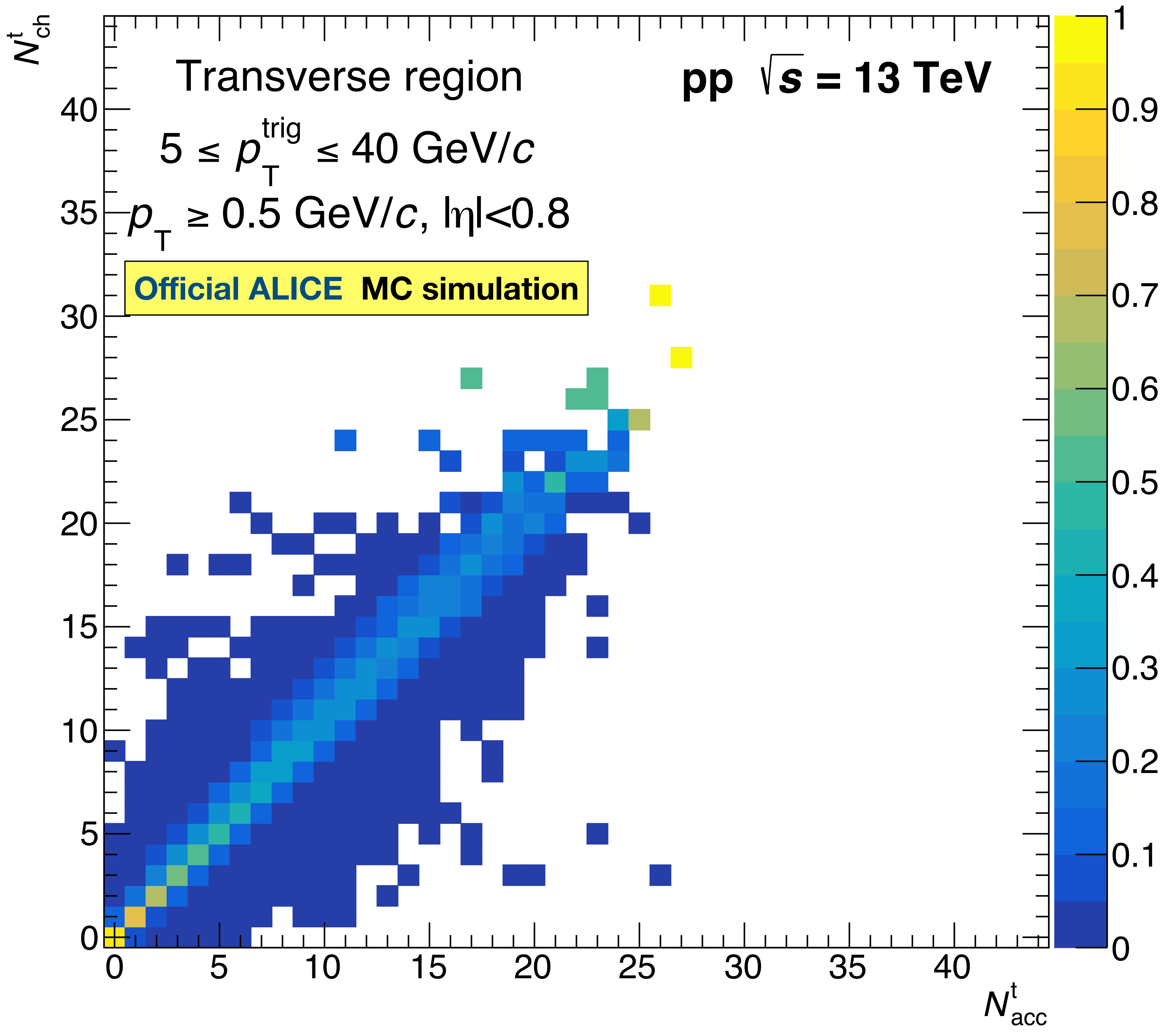
- The average charged particles densities are consistent with the trend of existing results. Compared with a parameterization, the UE component was found to increase like a power of the center-of-mass energy, while the ISR-FSR component increased logarithmically. The power-law behavior of the UE contribution is similar to the energy dependence of the parameter that regulates Multiparton Interactions in PYTHIA 8.
  ➡ Within around 10%, PYTHIA 8 is consistent with data and a better agreement is reached at higher energies.

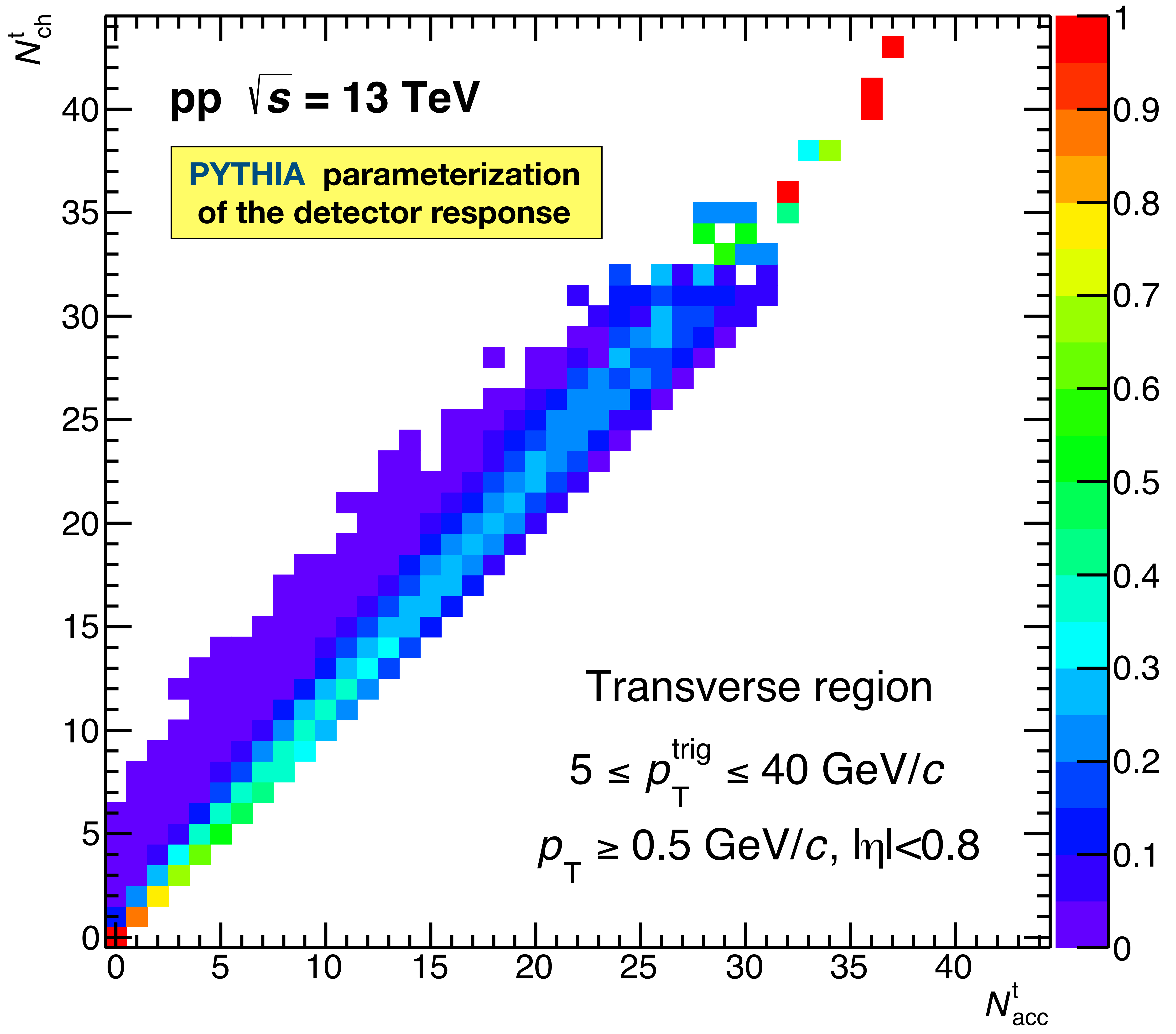
- The charged particle multiplicity is energy dependent in three topological regions. Higher multiplicities are reached for higher energies, a similar behavior is observed in minimum bias pp collisions.
  ➡ Within around 10%, PYTHIA 8 reproduces the low multiplicity part of the distribution, and for higher multiplicities it underestimates the data.

- The KNO-like scaling holds for $0 < z(=N_{\rm ch}/\langle N_{\rm ch}\rangle) < 3.5$ and it is broken above 3.5. Especially, in the trans-min region, there is a bigger violation.

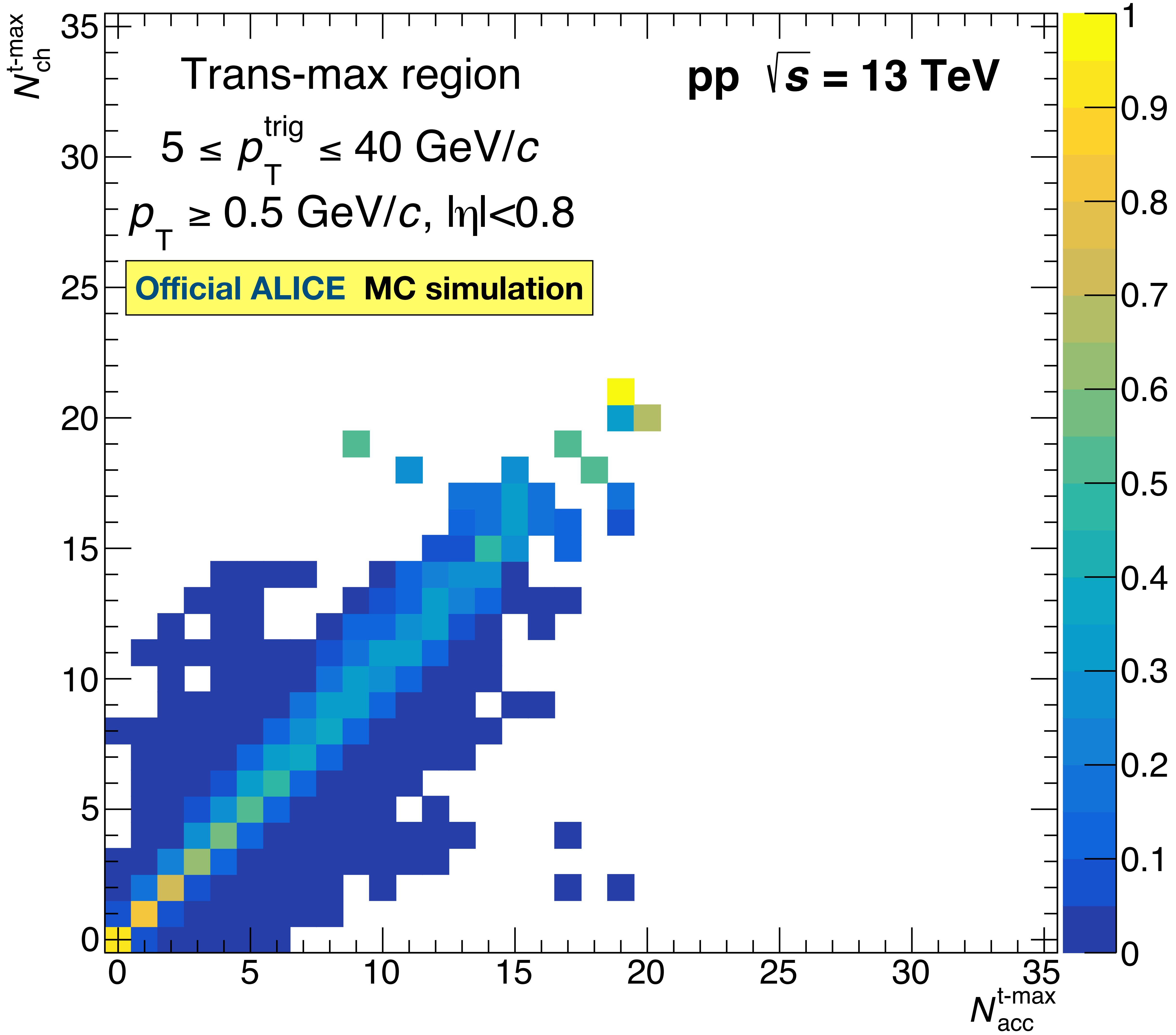
BACKUP

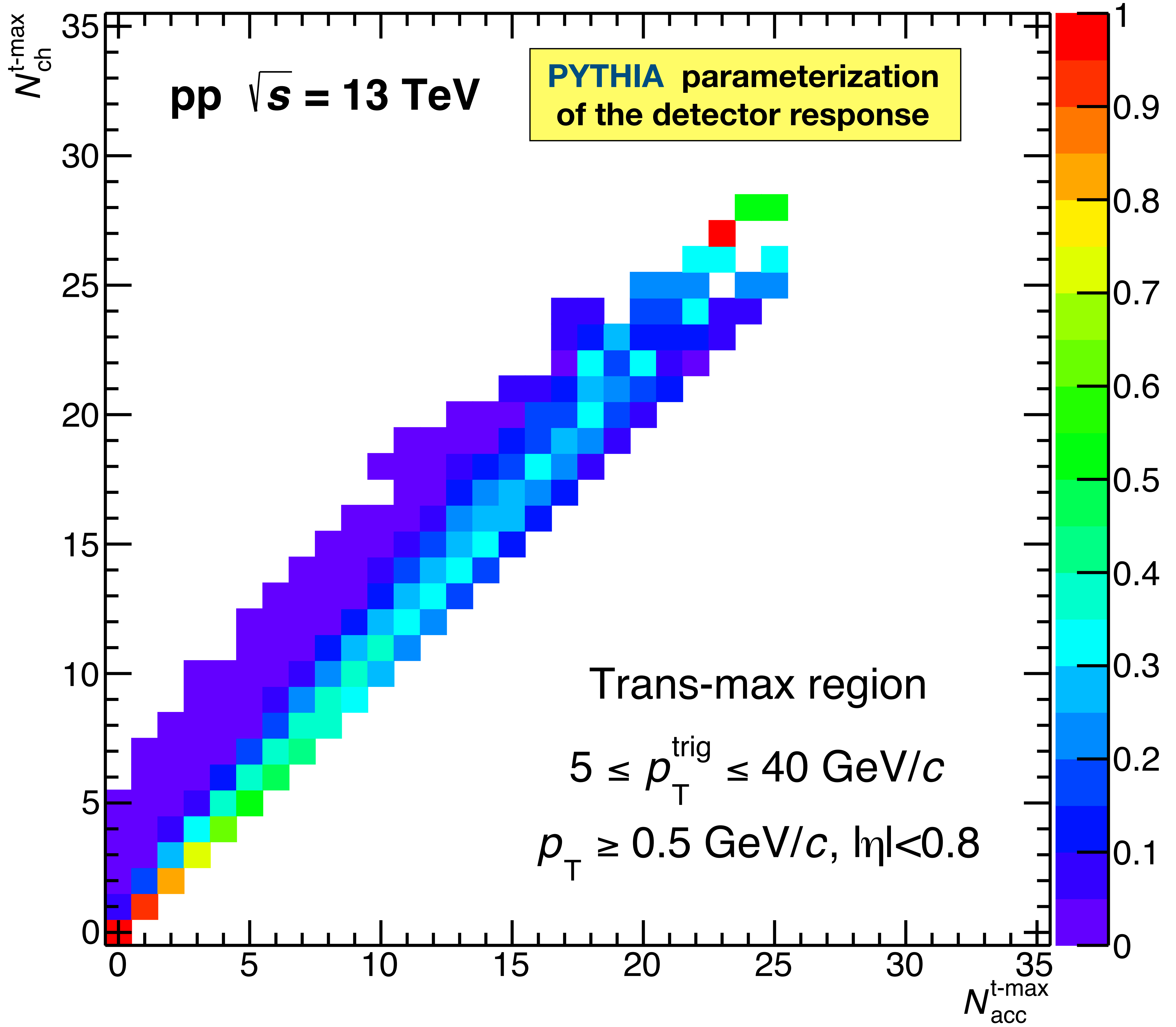
Response Matrix (13 TeV)



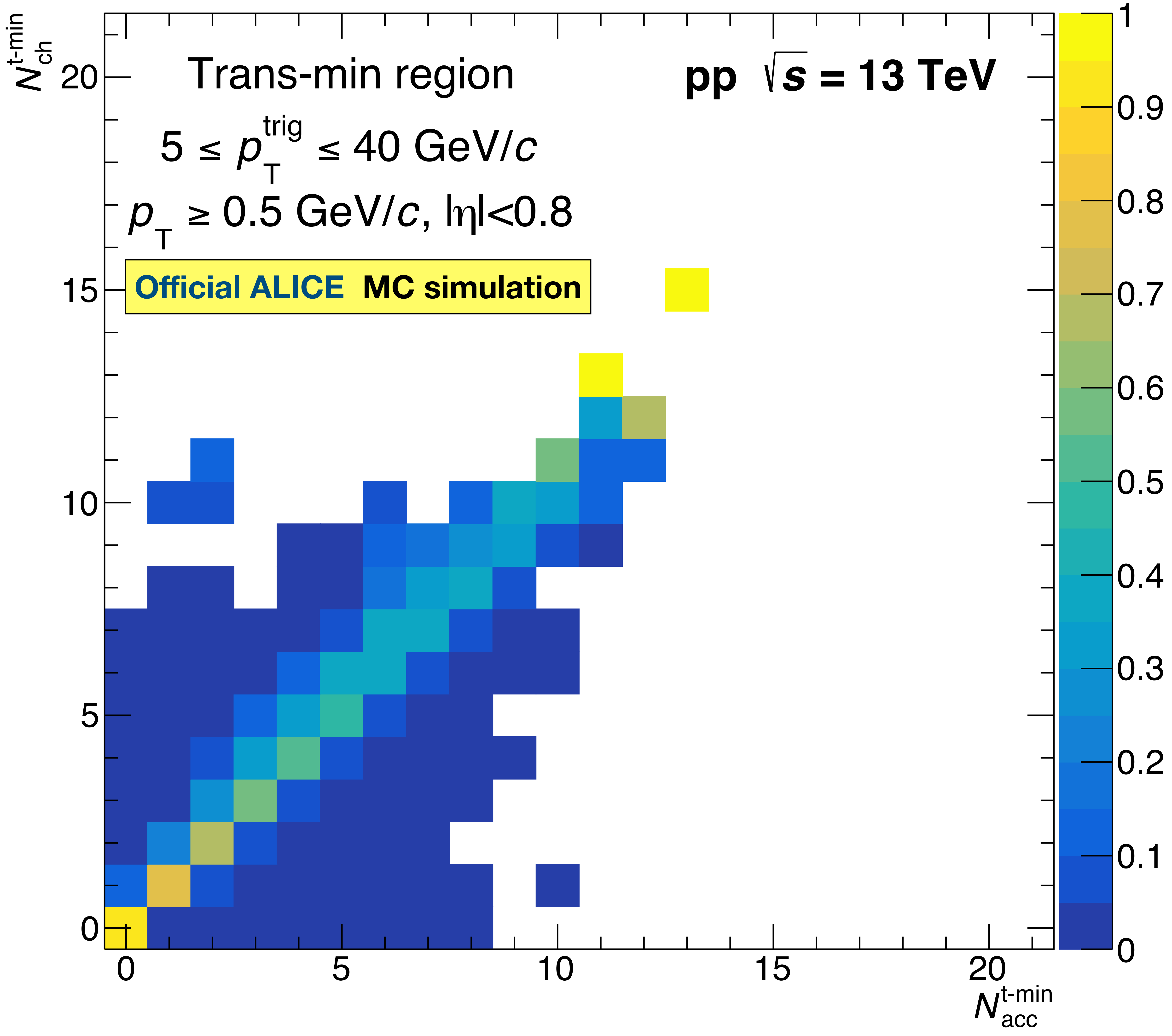


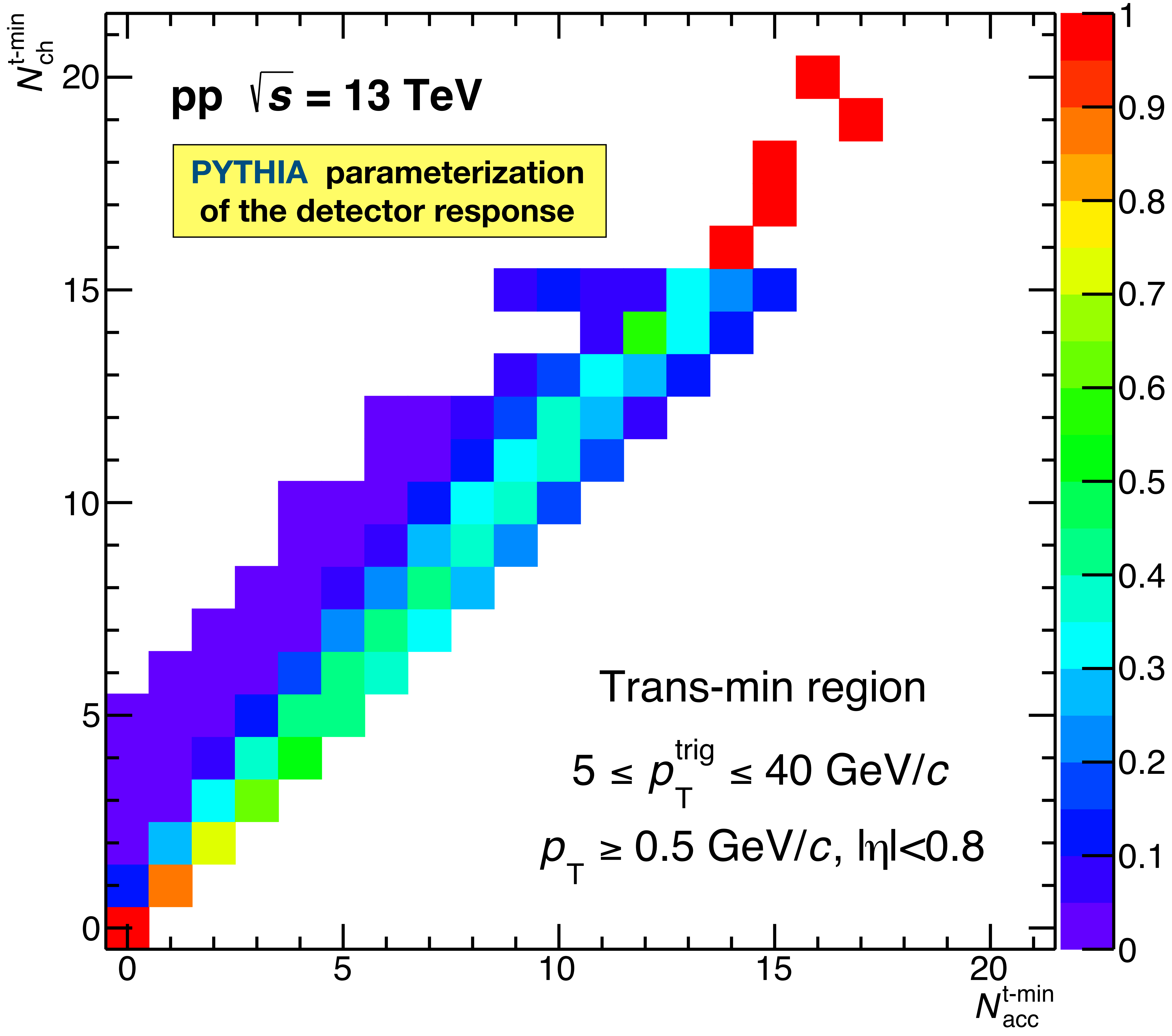
Response Matrix (13 TeV)



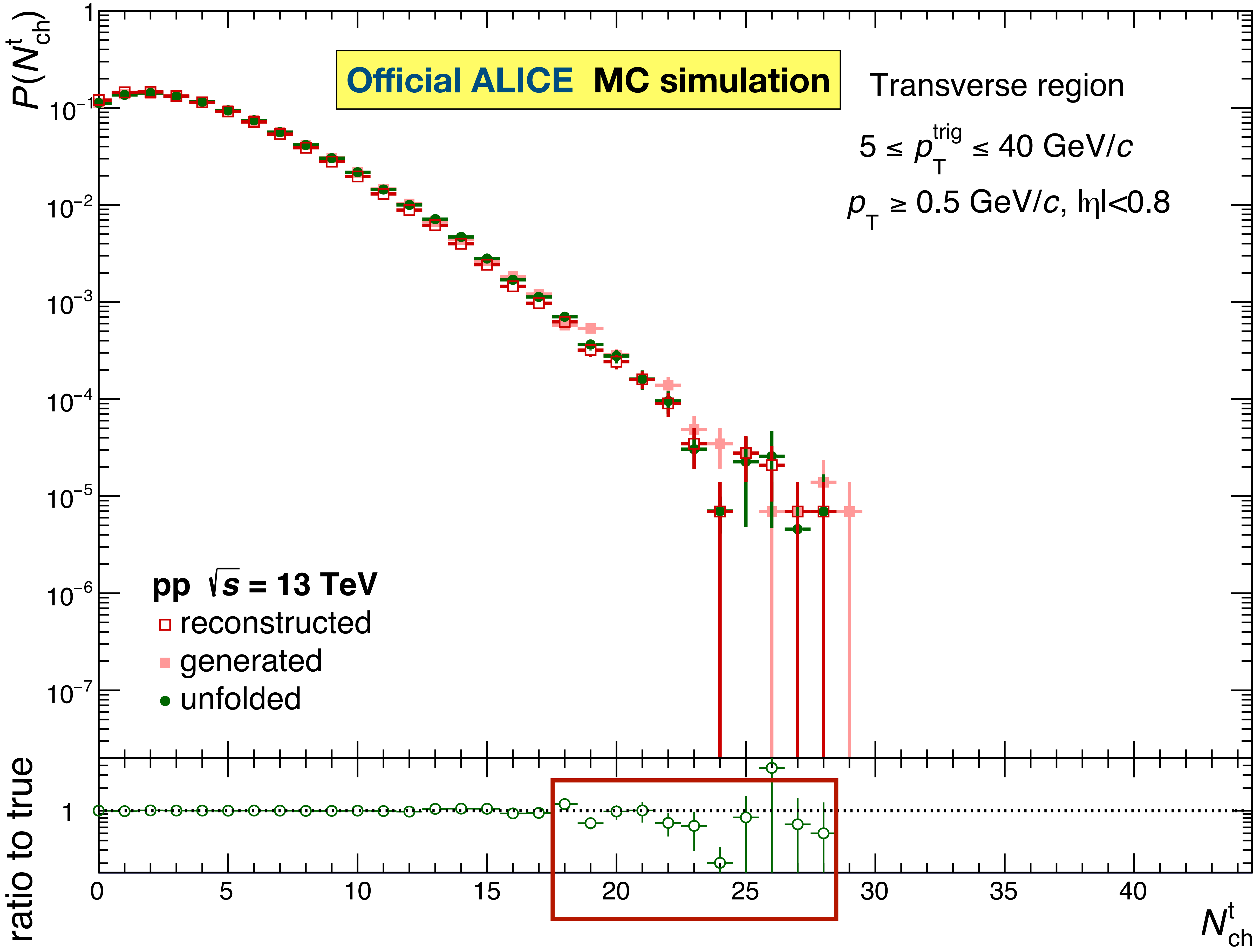


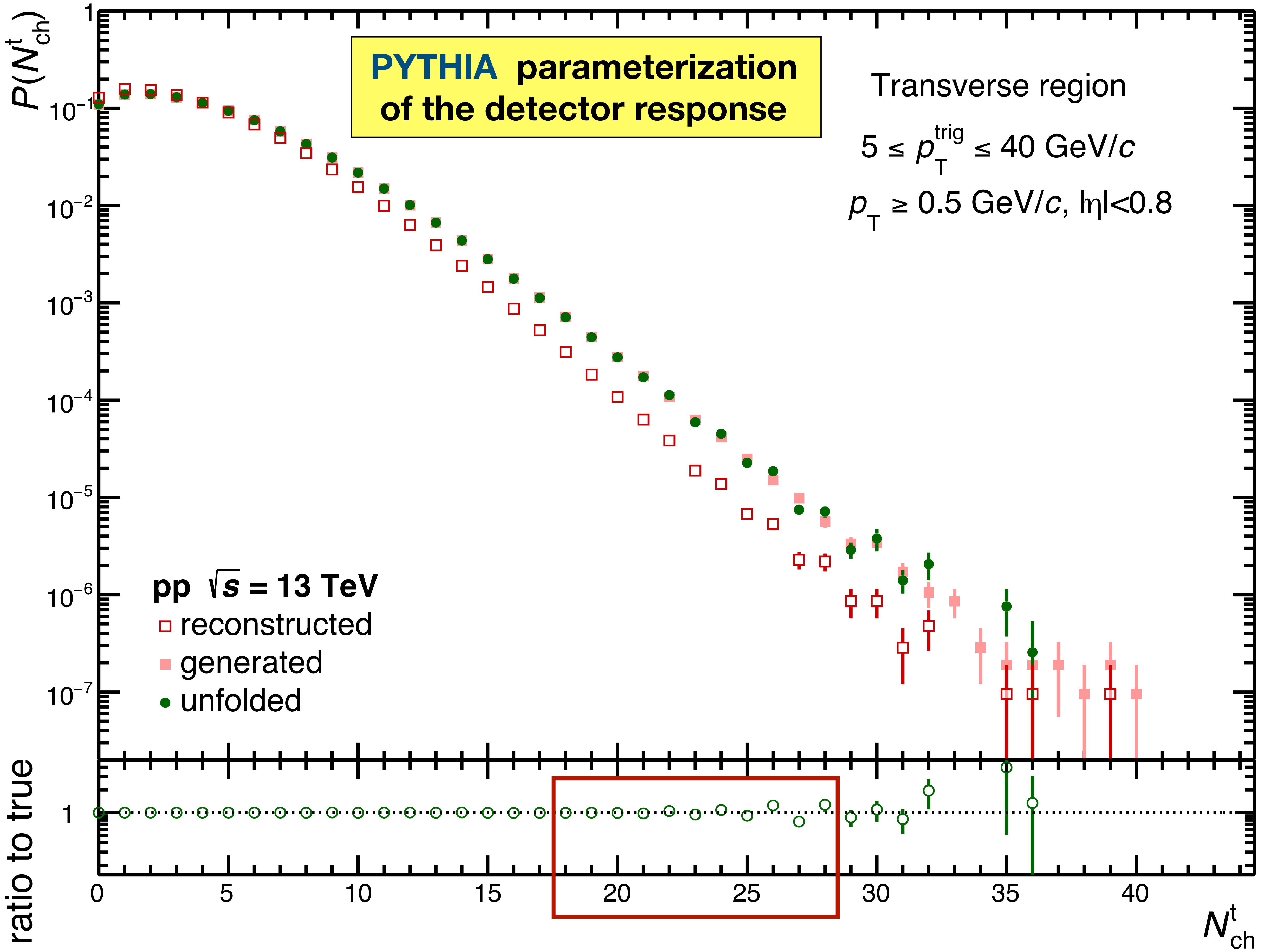
Response Matrix (13 TeV)



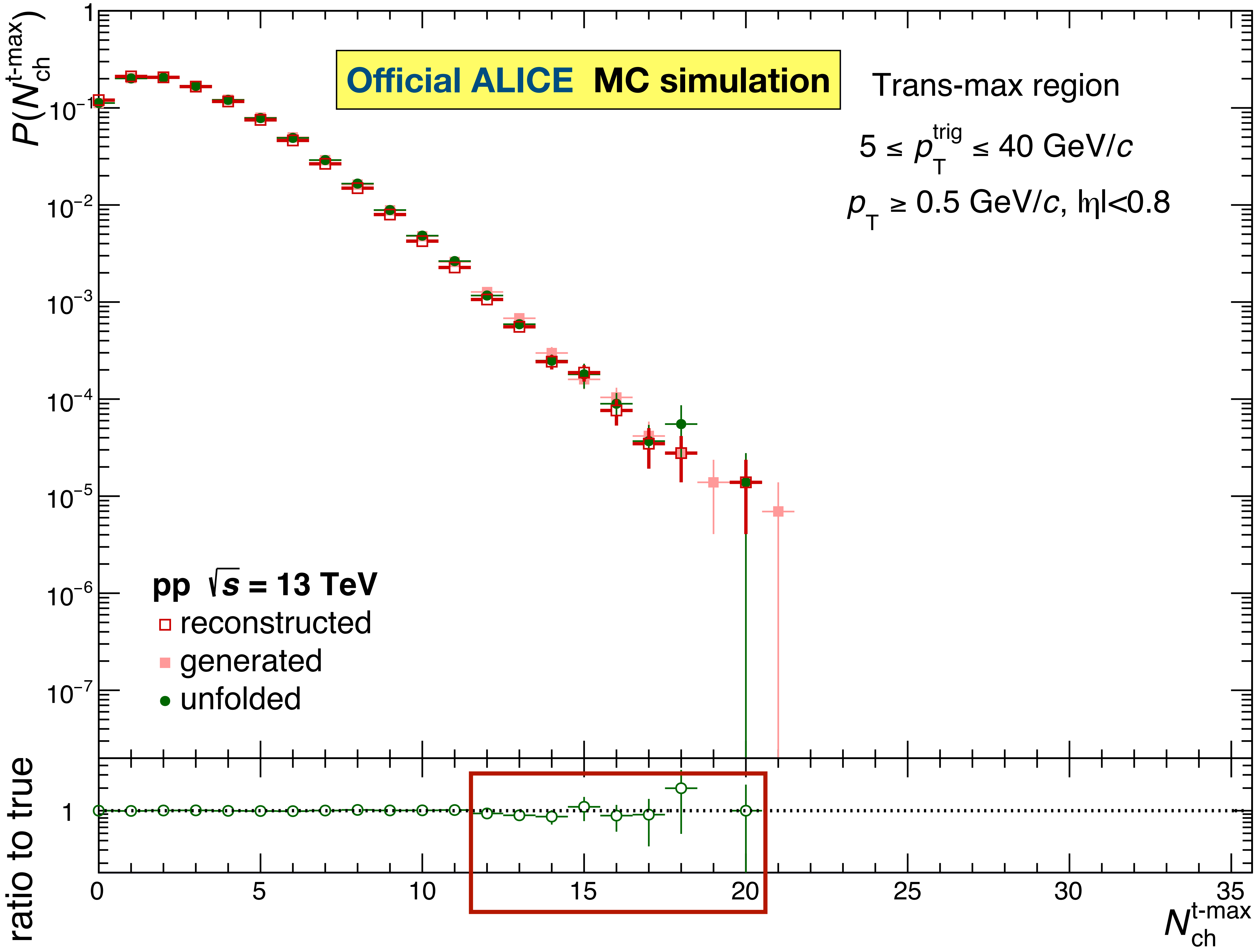


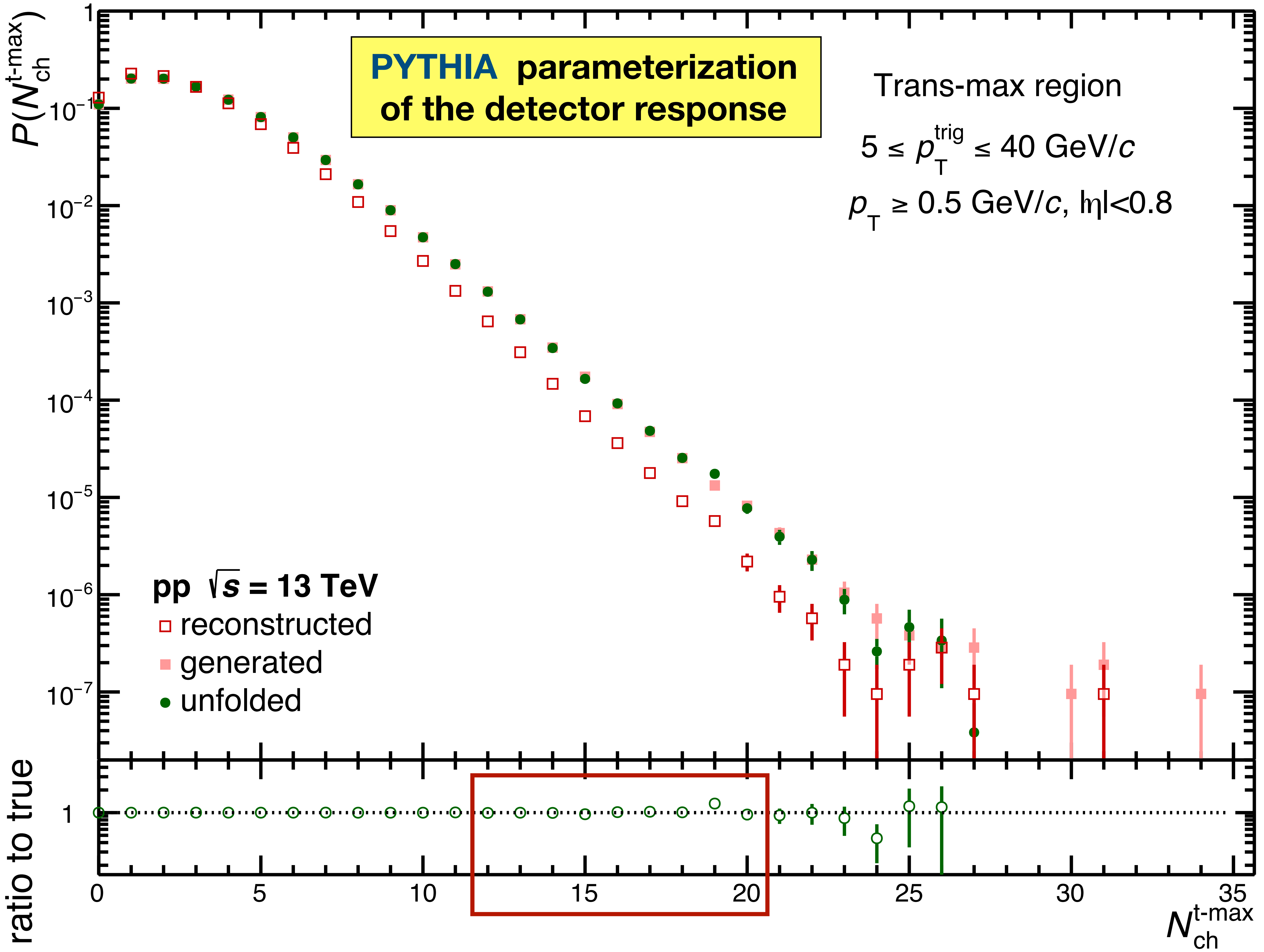
MC closure test at high multiplicity (13 TeV)



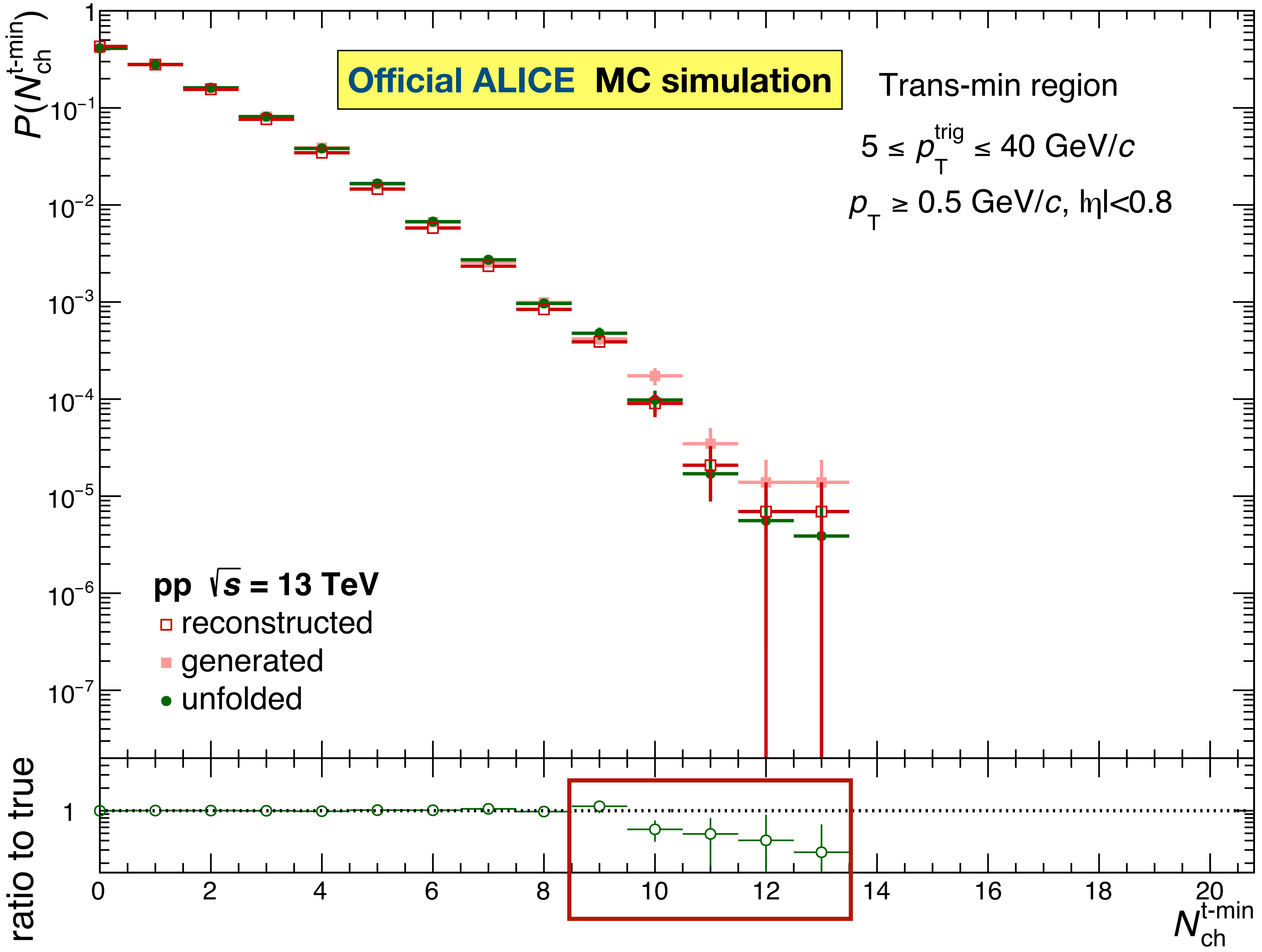


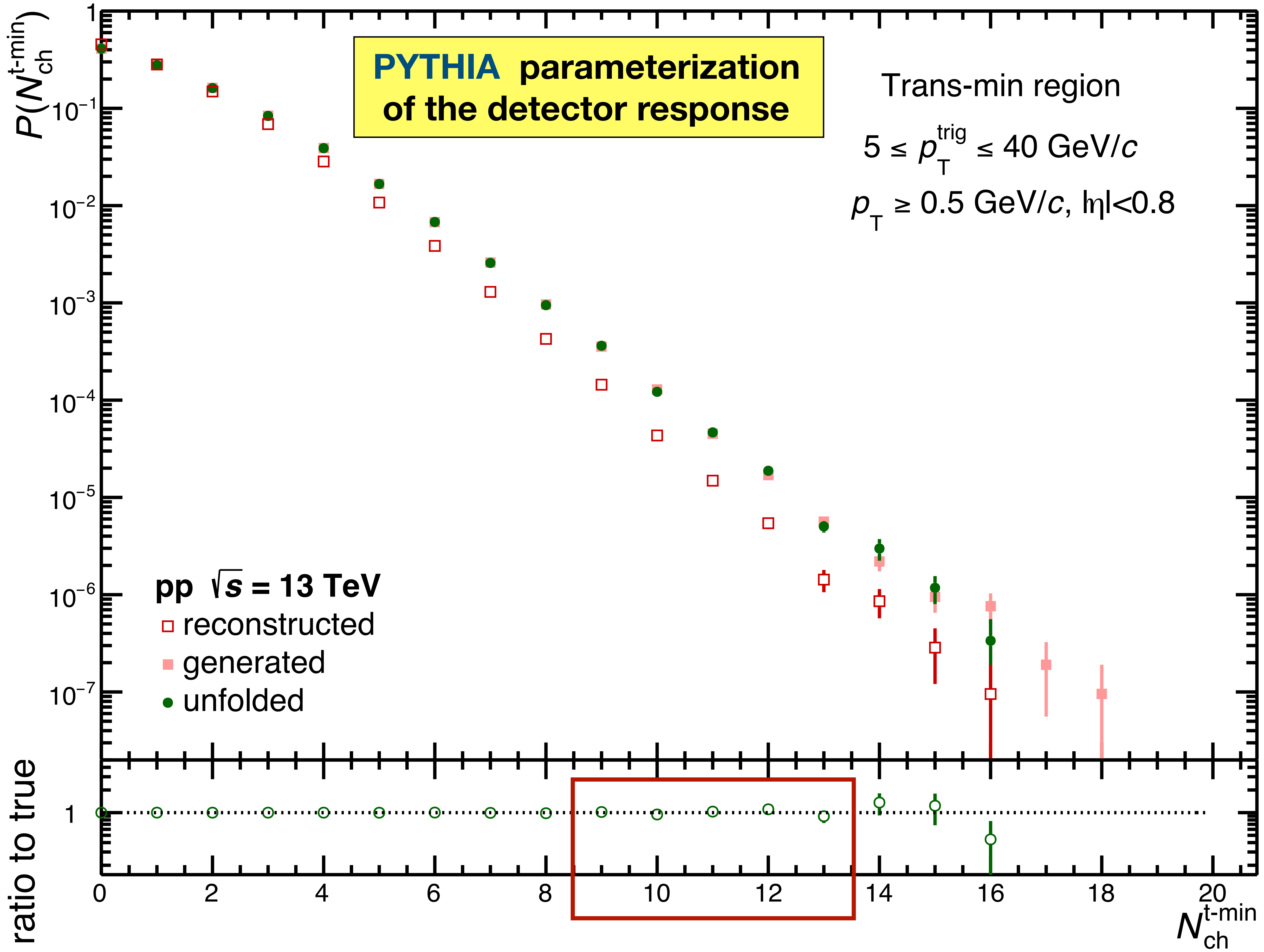
MC closure test at high multiplicity (13 TeV)





MC closure test at high multiplicity (13 TeV)





MC closure test (7 TeV)

MC closure test (5.02 TeV)

MC closure test (7 TeV)

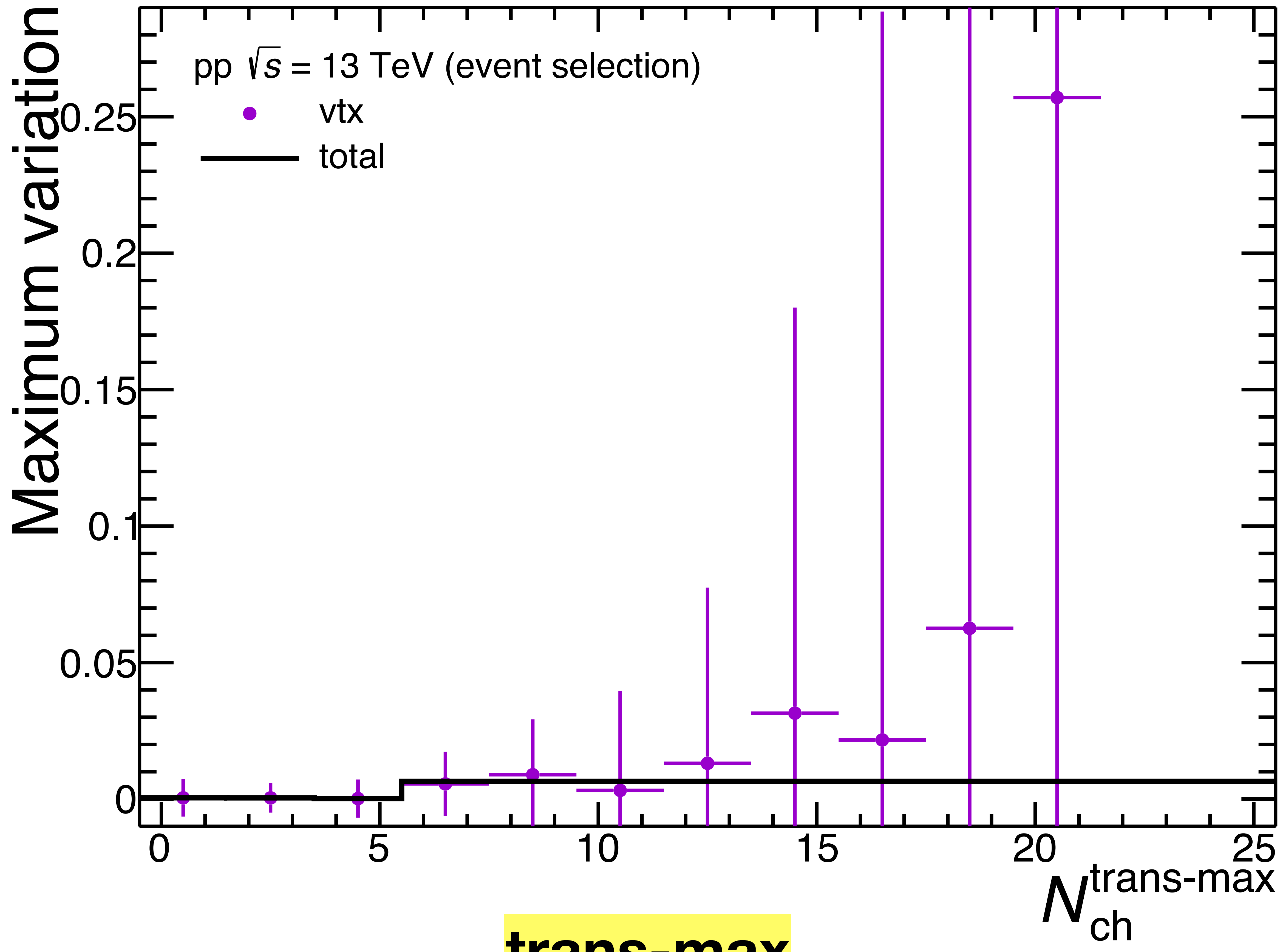
Systematic Uncertainties ~ $\langle N_{ch}^{transverse} \rangle, \langle N_{ch}^{trans-max} \rangle, \langle N_{ch}^{trans-min} \rangle$

ALICE

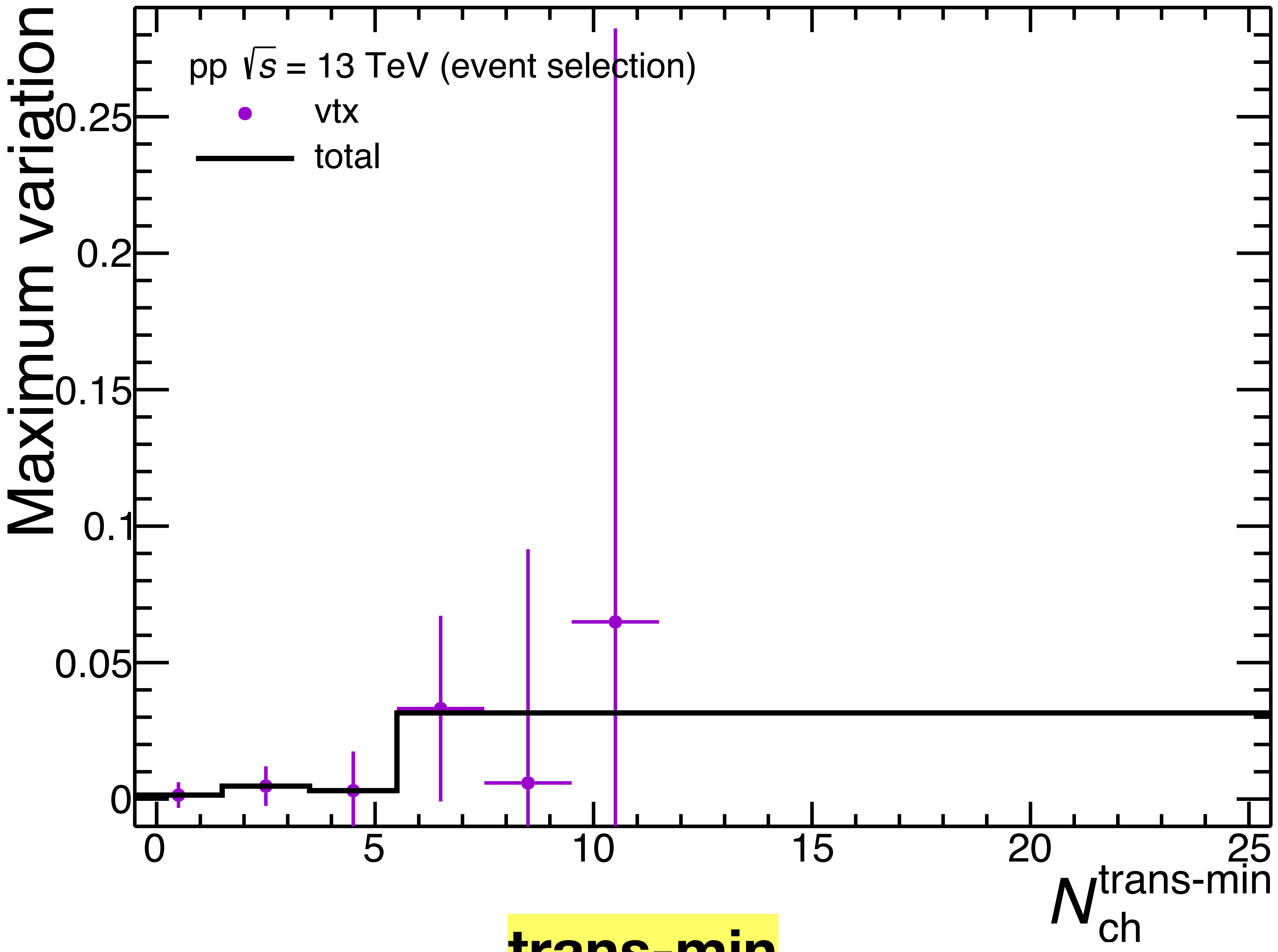
source	pp $\sqrt{s}$ = 2.76 TeV			pp $\sqrt{s}$ = 5.02 TeV			pp $\sqrt{s}$ = 7 TeV		
	$\langle N_{ch}^{transverse} \rangle$	$\langle N_{ch}^{trans-max} \rangle$	$\langle N_{ch}^{trans-min} \rangle$	$\langle N_{ch}^{transverse} \rangle$	$\langle N_{ch}^{trans-max} \rangle$	$\langle N_{ch}^{trans-min} \rangle$	$\langle N_{ch}^{transverse} \rangle$	$\langle N_{ch}^{trans-max} \rangle$	$\langle N_{ch}^{trans-min} \rangle$
event selection	1.2%	0.8%	2.9%	negl.	negl.	negl.	negl.	negl.	0.1%
track selection for leading track	2.4%	4.3%	6.4%	1.1%	1.3%	1.2%	1.6%	1.6%	1.9%
track selection for N_{ch}	4.4%	4.1%	8.8%	0.2%	0.2%	0.6%	0.9%	0.9%	1.3%
MC closure test	0.7%	0.2%	1.5%	negl.	0.3%	0.7%	negl.	negl.	negl.
MC model dependence	0.8%	1.1%	0.1%	0.8%	1.1%	0.1%	0.8%	1.1%	0.1%
total	5.3%	6.1%	11.4%	1.4%	1.7%	1.5%	2.0%	2.1%	2.3%

Systematic Uncertainties ~ $N_{ch}^{trans-max}$, $N_{ch}^{trans-min}$ (pp, 13 TeV)

ALICE



trans-max

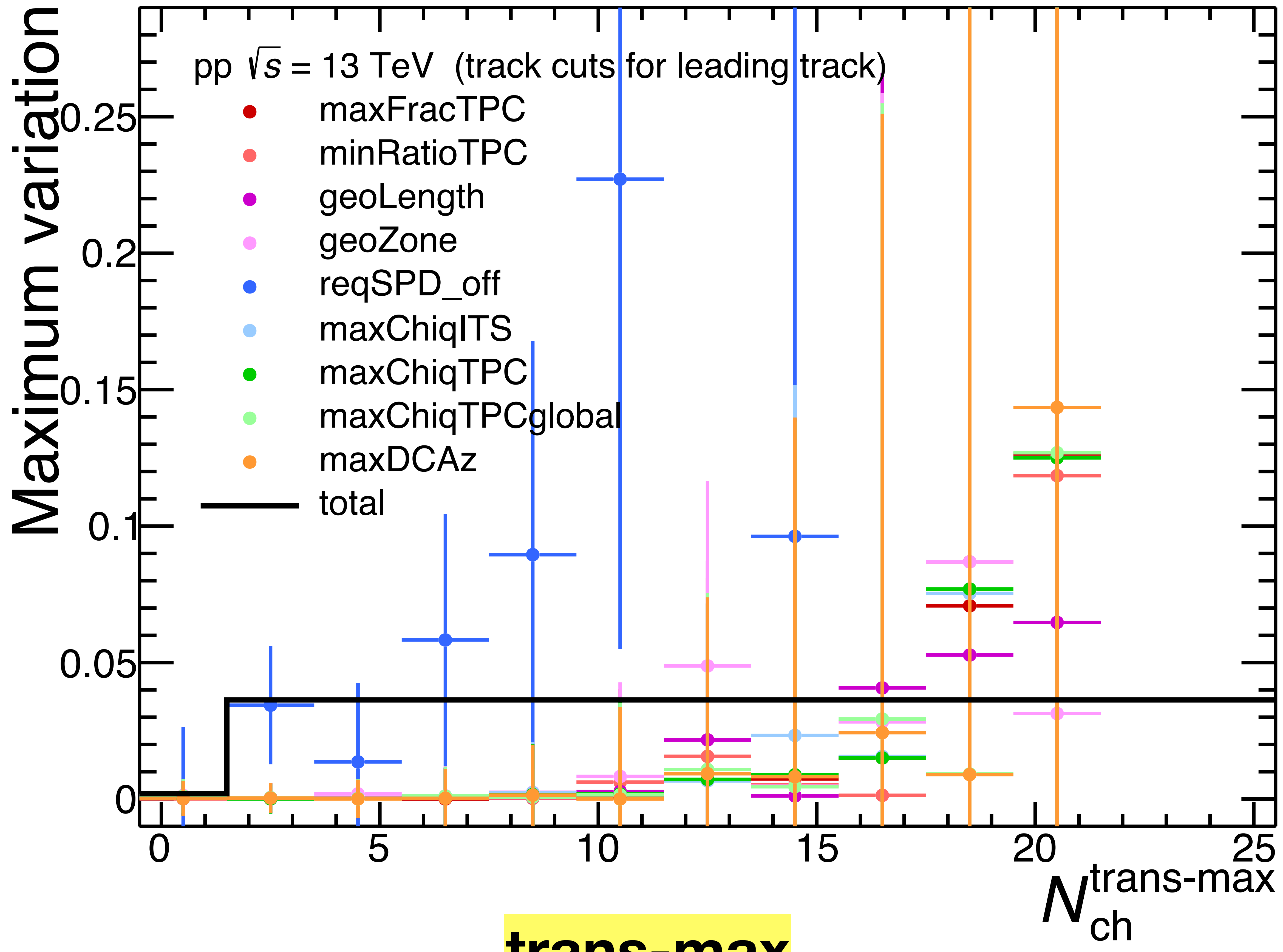


trans-min

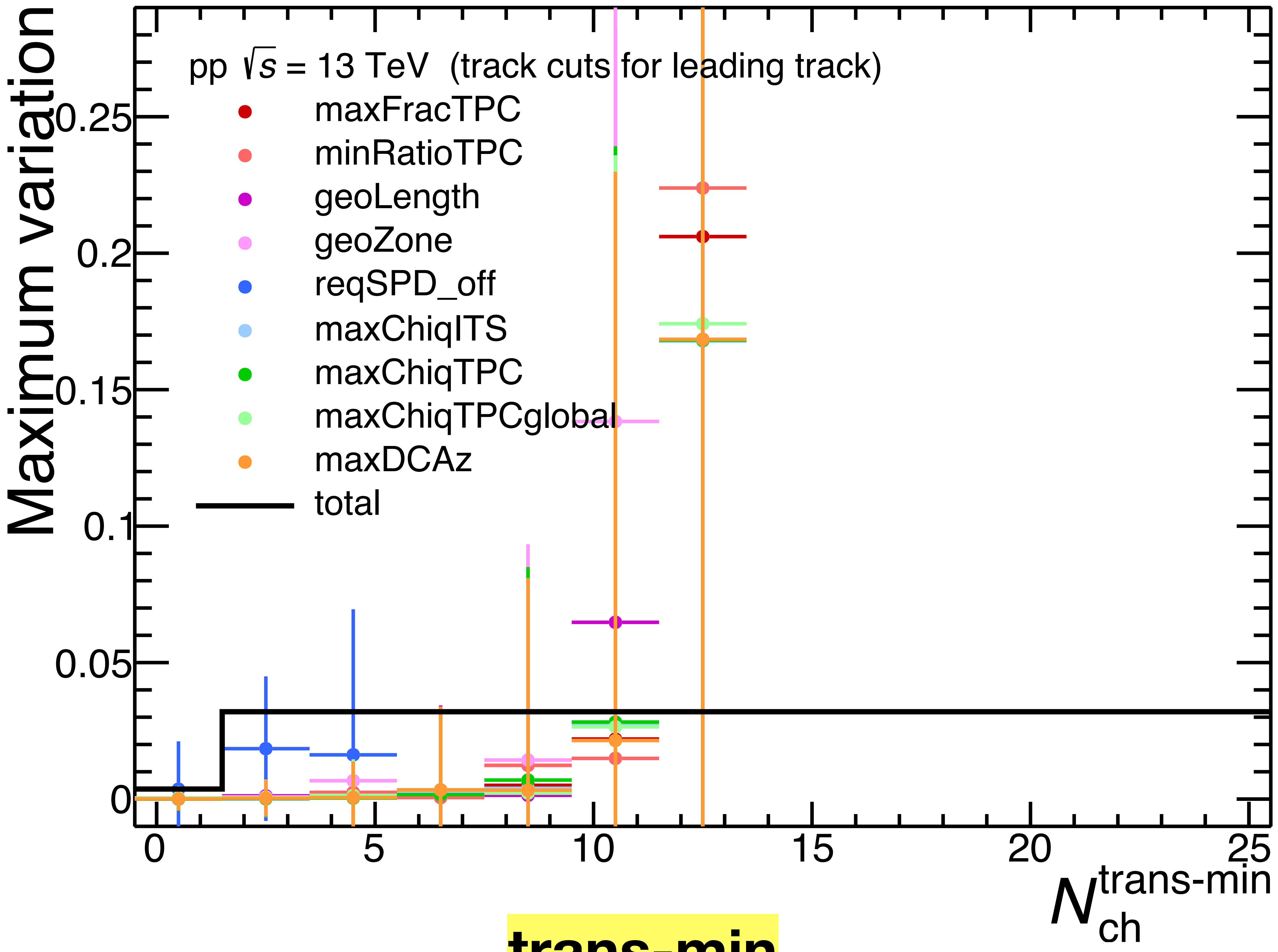
- In trans-max region, the systematic uncertainty is less than 1%
- In trans-min region, the systematic uncertainty is up to around 3% at high multiplicity

Systematic Uncertainties ~ $N_{ch}^{trans-max}$, $N_{ch}^{trans-min}$ (pp, 13 TeV)

ALICE



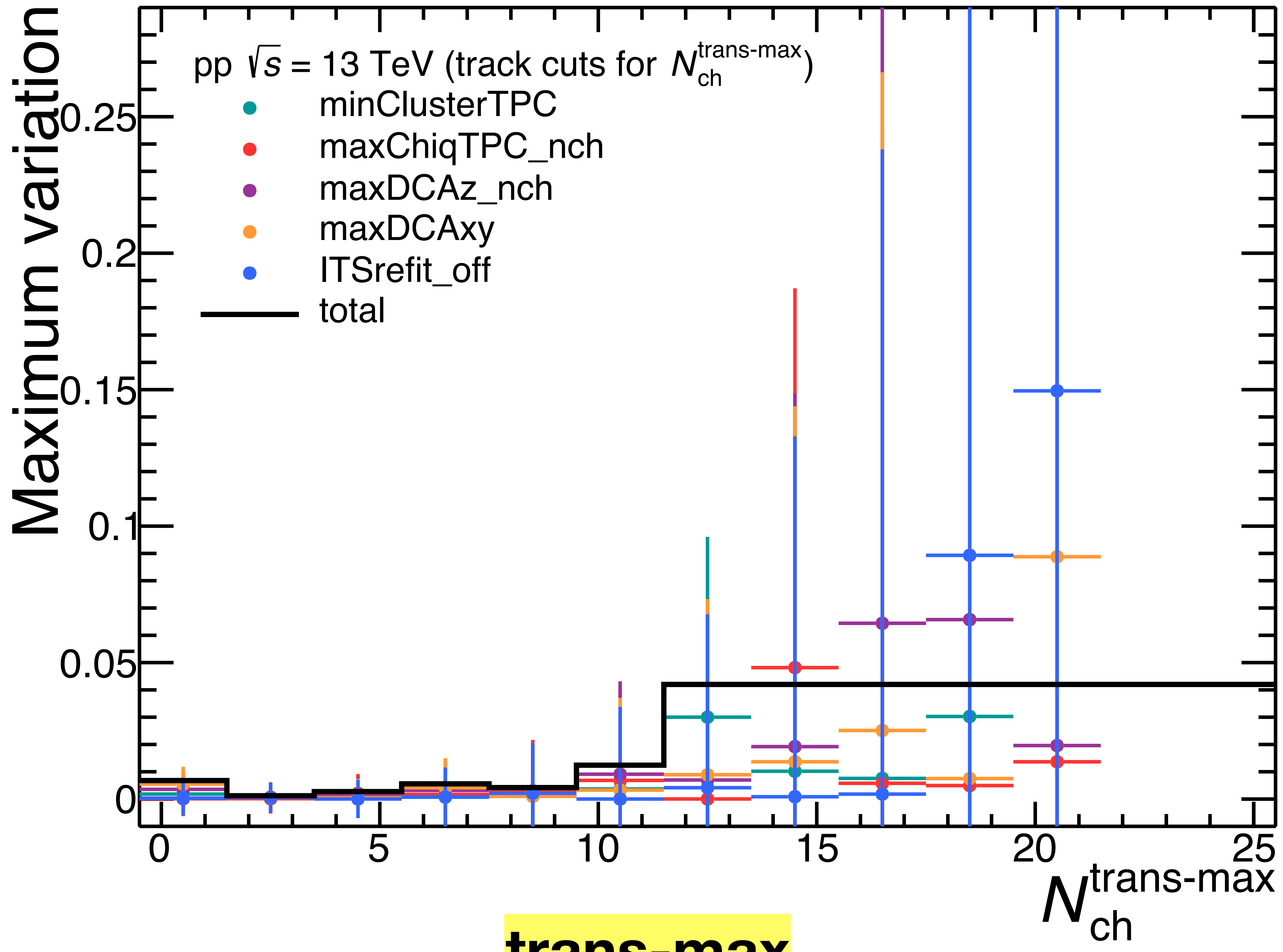
trans-max



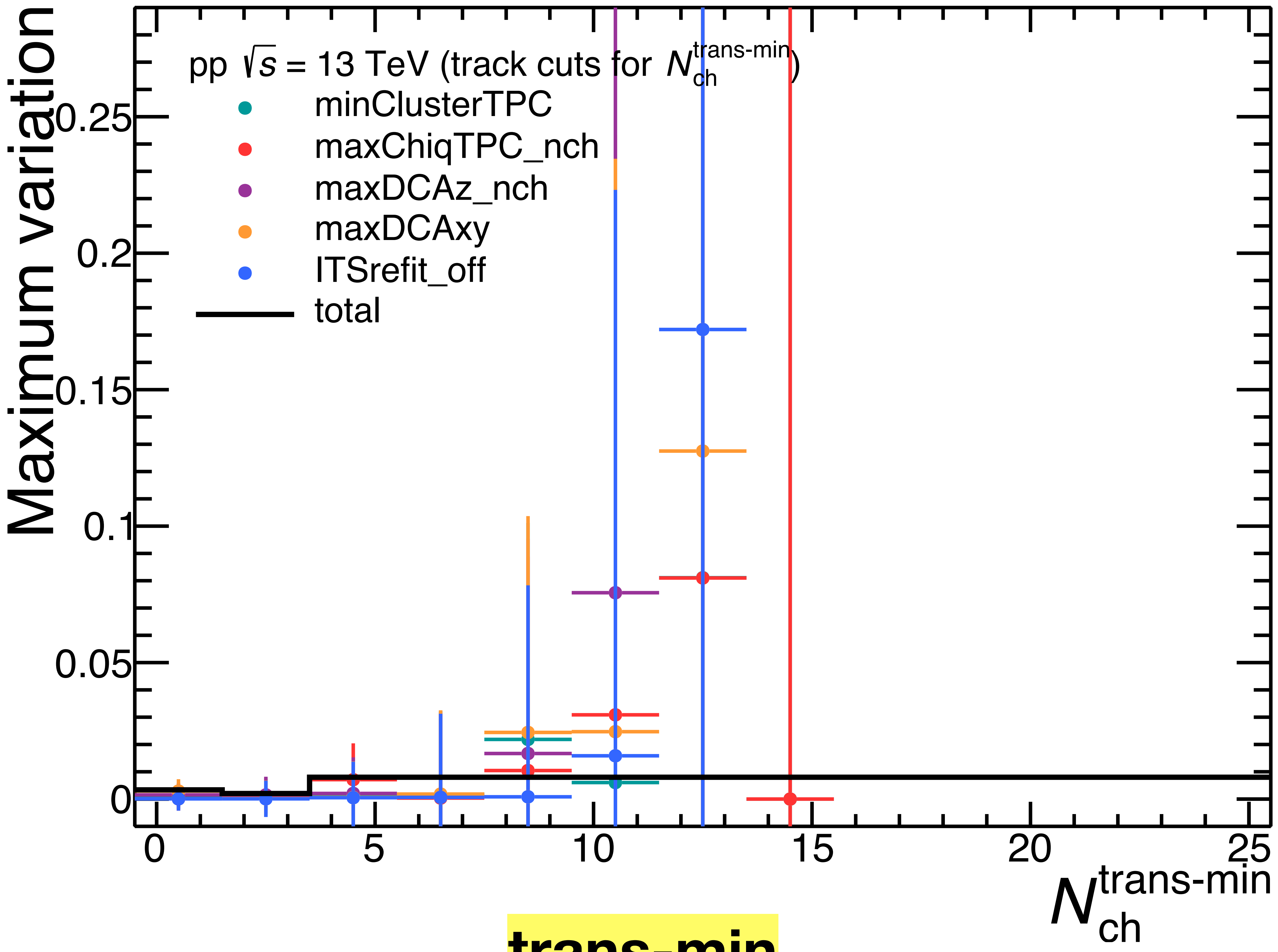
trans-min

- The systematic uncertainty due to track selection on leading track is nearly multiplicity independent.
- The systematic uncertainties are up to around 4% and 3% in trans-max and trans-min region, respectively.

Systematic Uncertainties ~ $N_{ch}^{trans-max}$, $N_{ch}^{trans-min}$ (pp, 13 TeV)



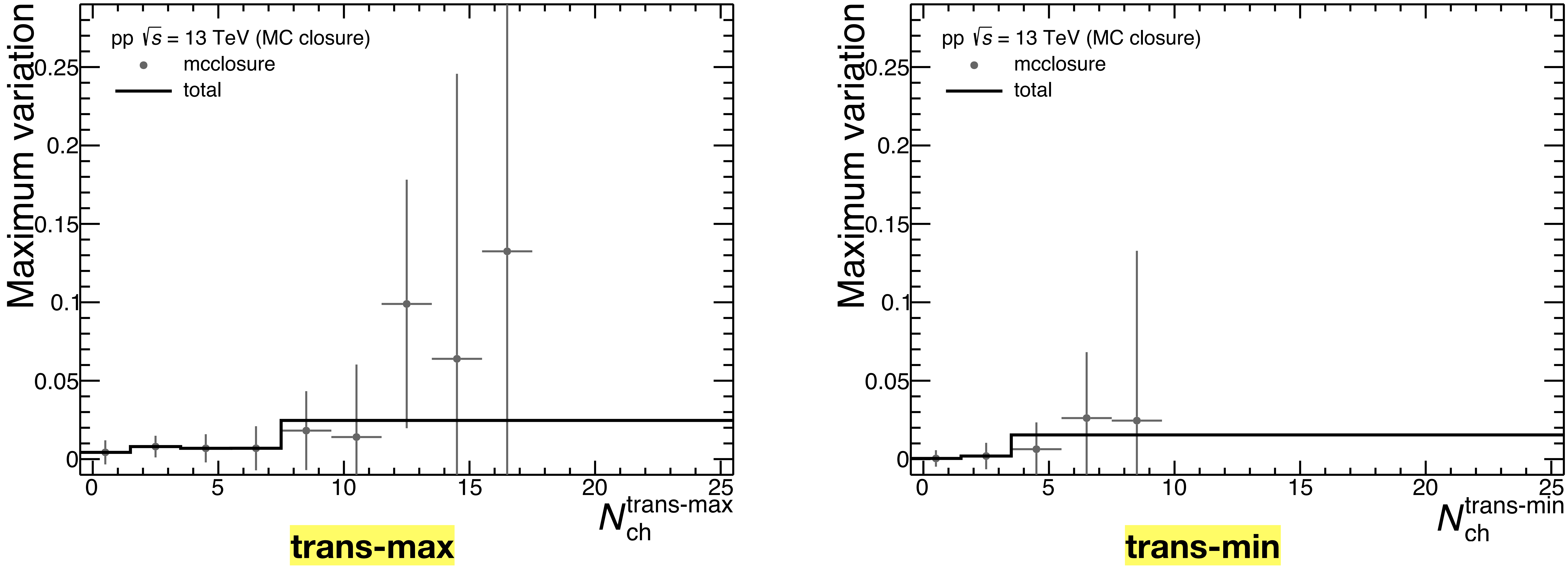
trans-max



trans-min

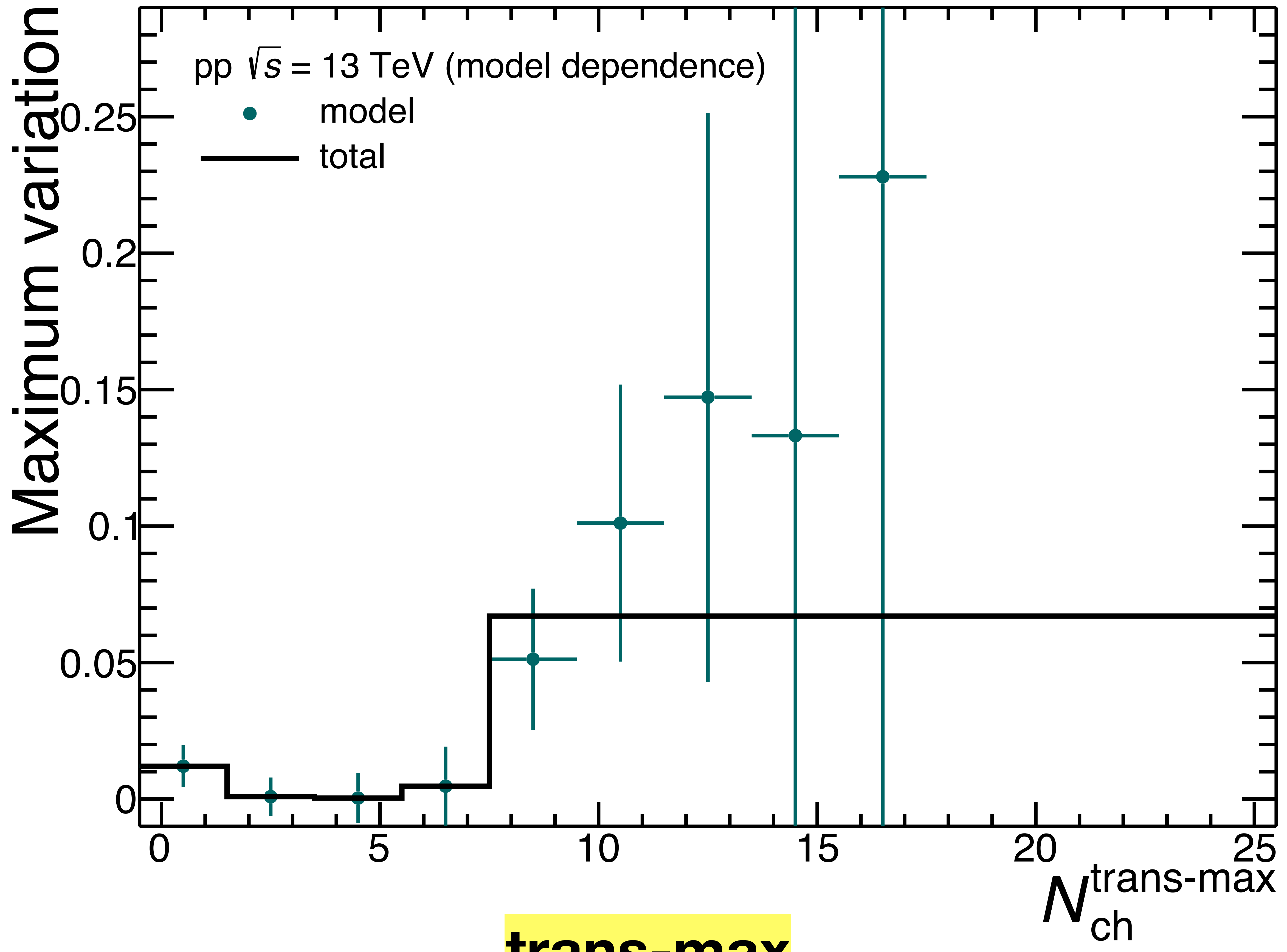
- In trans-max region, the systematic uncertainty is up to around 4% at high multiplicity.
- In trans-min region, the systematic uncertainty is less than 1%.

Systematic Uncertainties ~ $N_{ch}^{trans-max}$, $N_{ch}^{trans-min}$ (pp, 13 TeV)

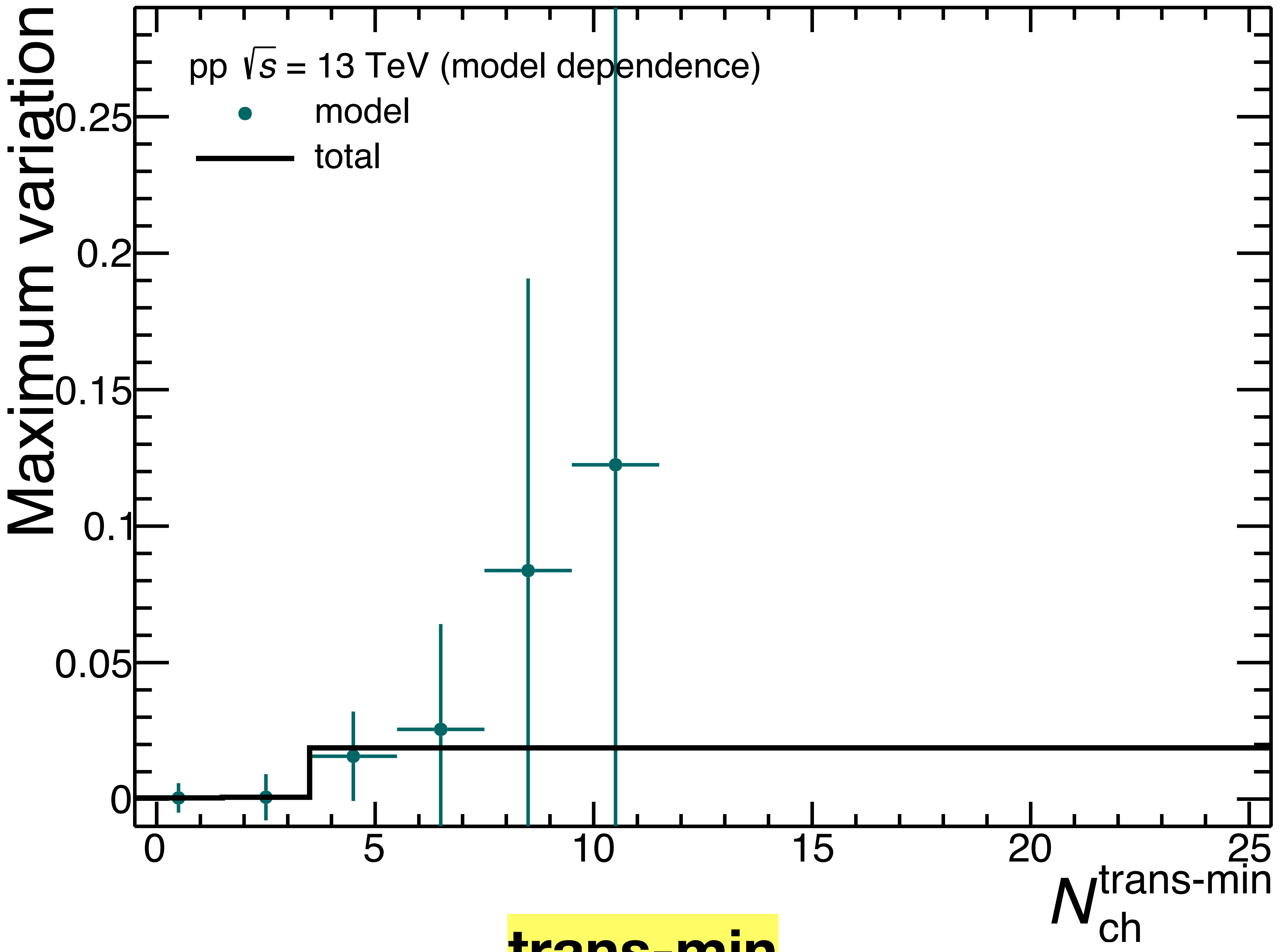


- In trans-max region, the systematic uncertainty is up to around 3% at high multiplicity.
- In trans-min region, the systematic uncertainty is up to around 2% at high multiplicity.

Systematic Uncertainties ~ $N_{ch}^{trans-max}$, $N_{ch}^{trans-min}$ (pp, 13 TeV)



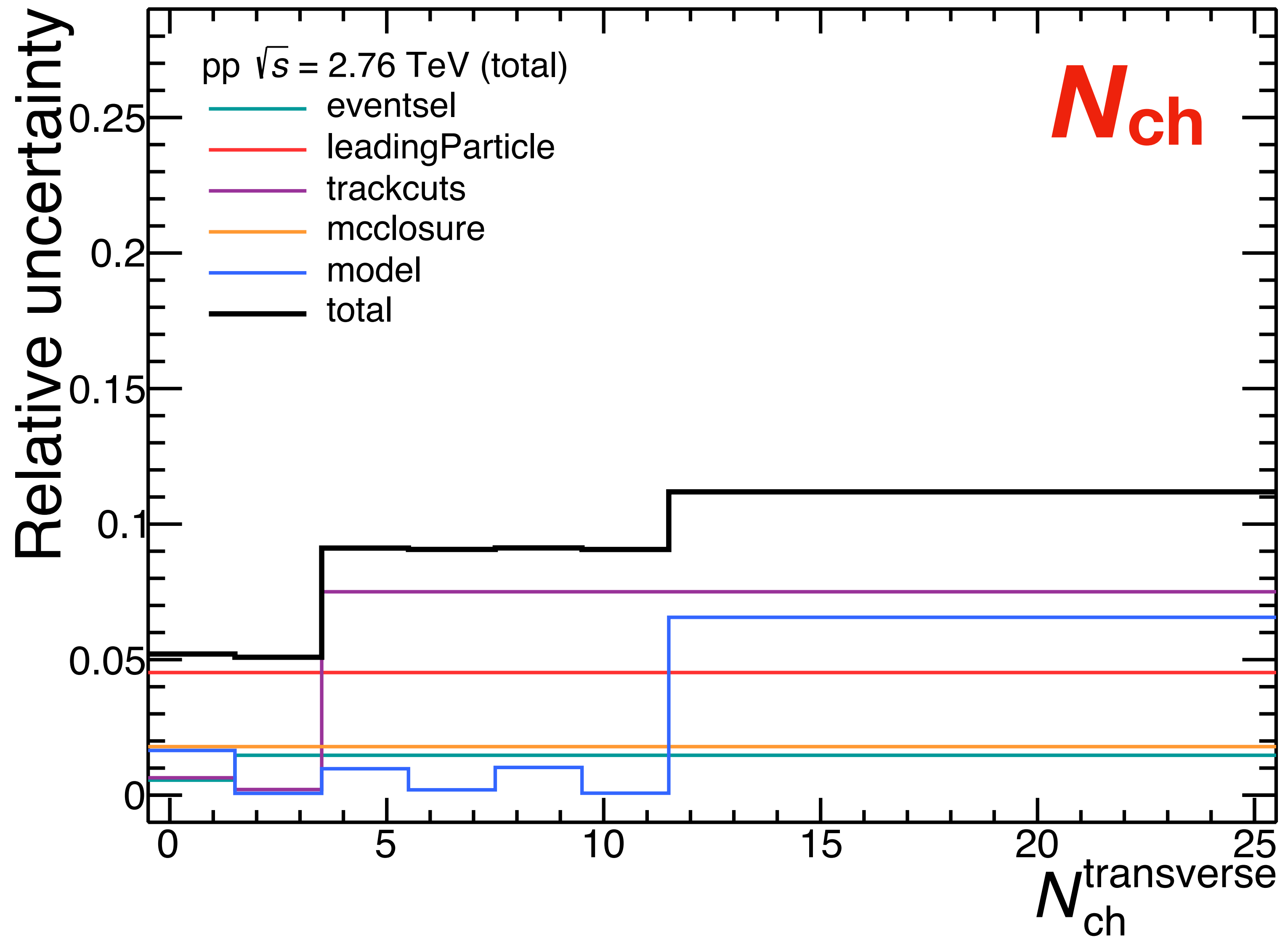
trans-max

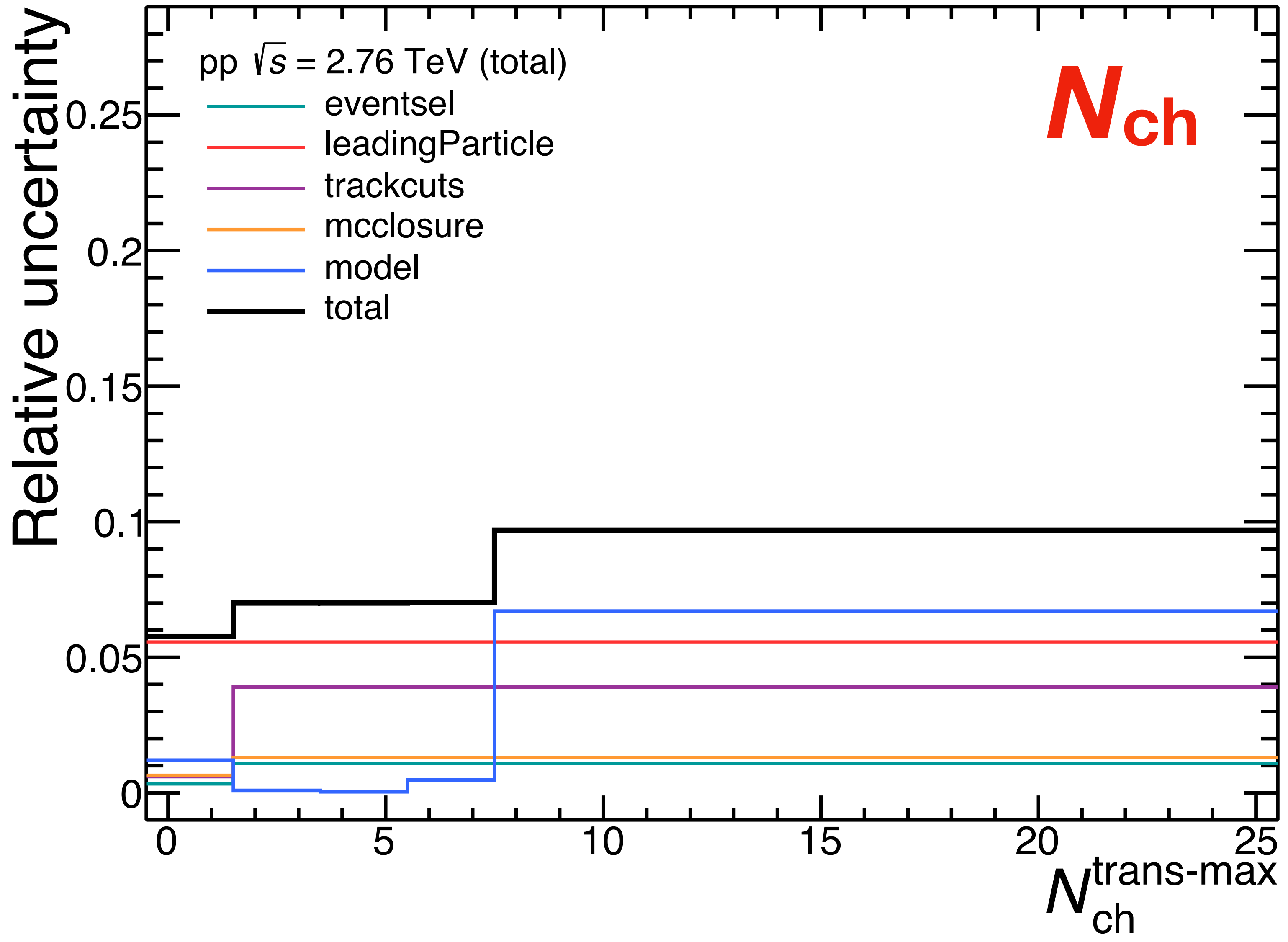


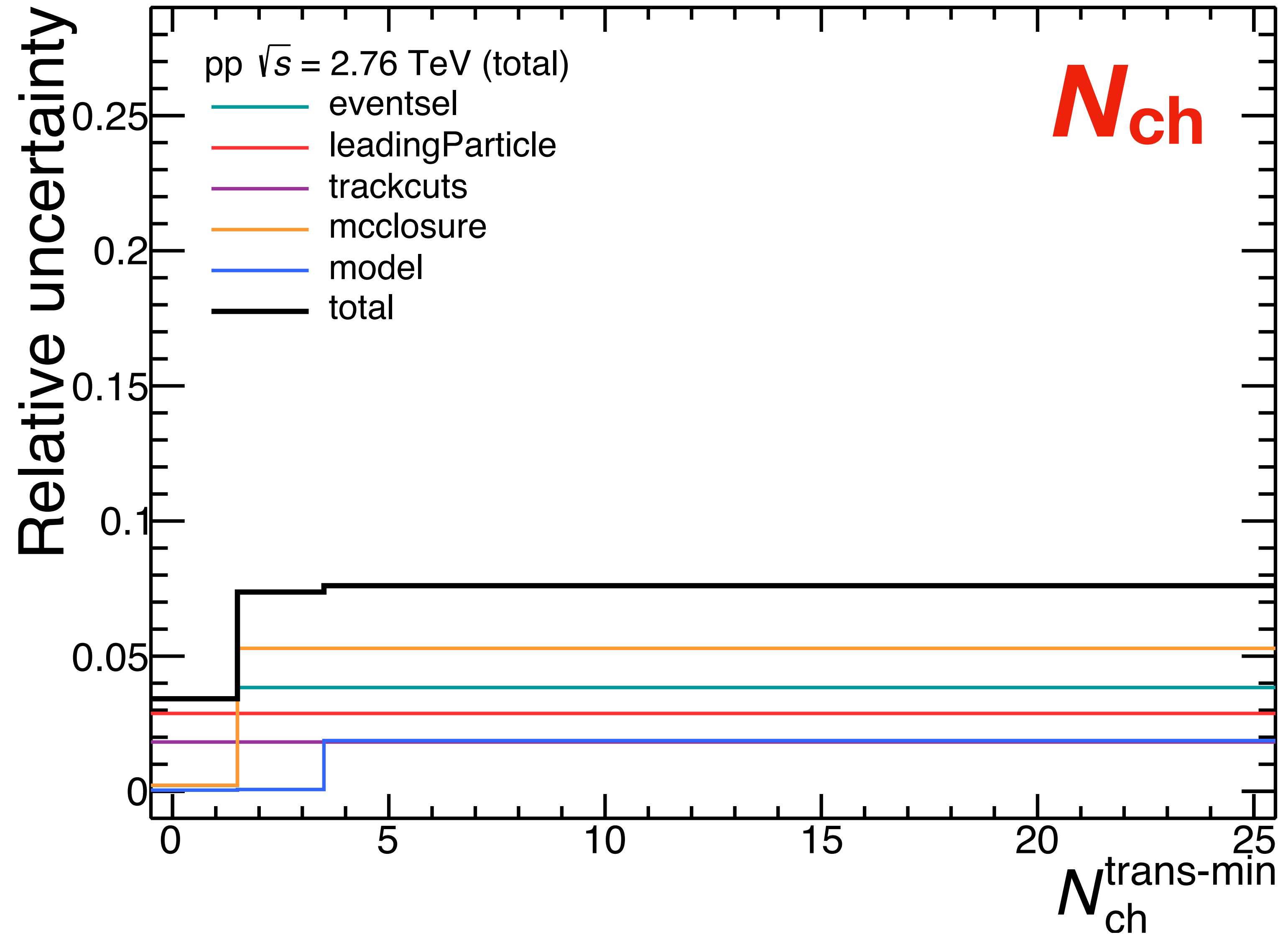
trans-min

- In trans-max region, the systematic uncertainty is up to around 7% at high multiplicity.
- In trans-min region, the systematic uncertainty is up to around 2% at high multiplicity.

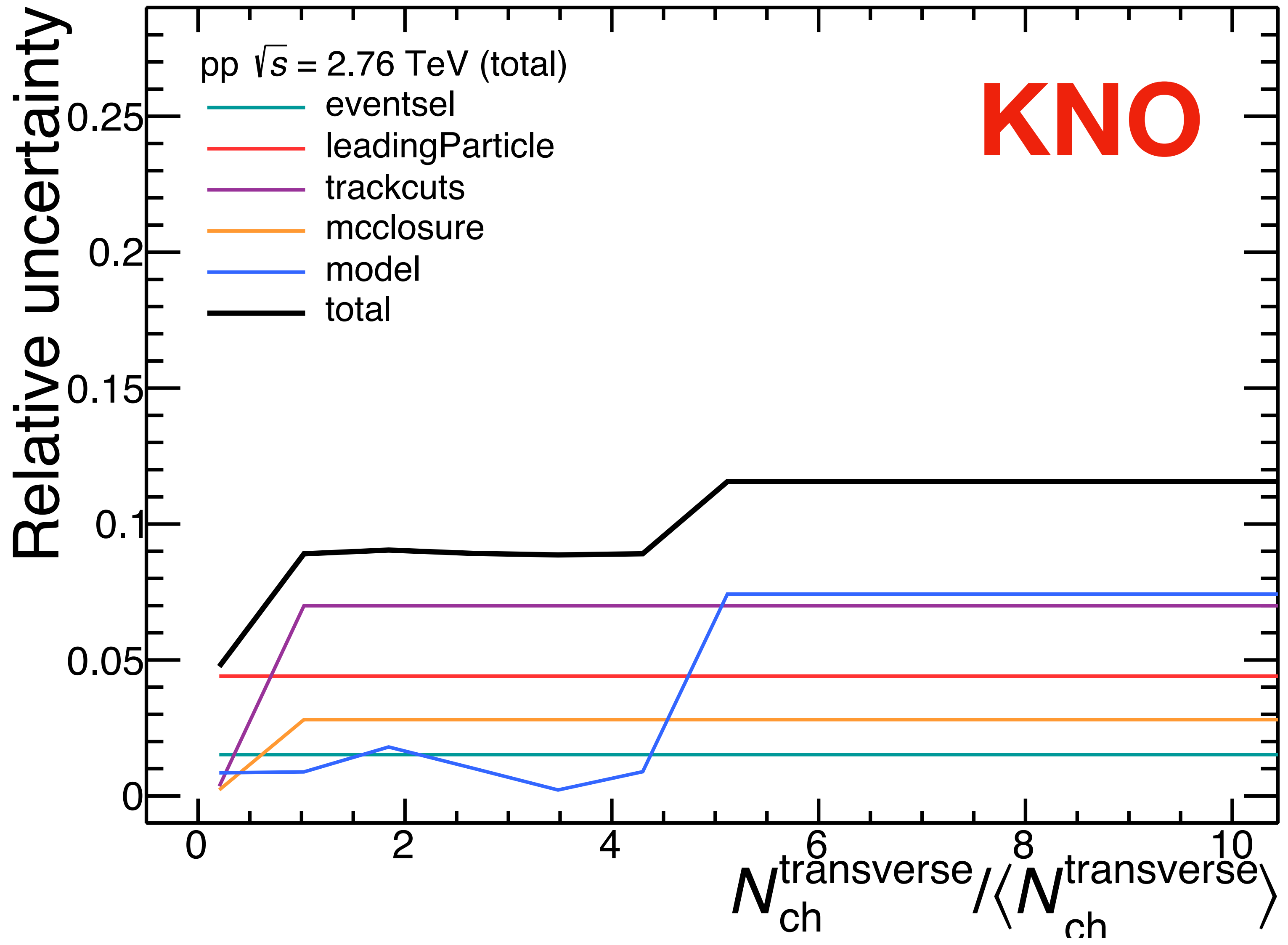
Systematic Uncertainties (pp, 2.76 TeV)

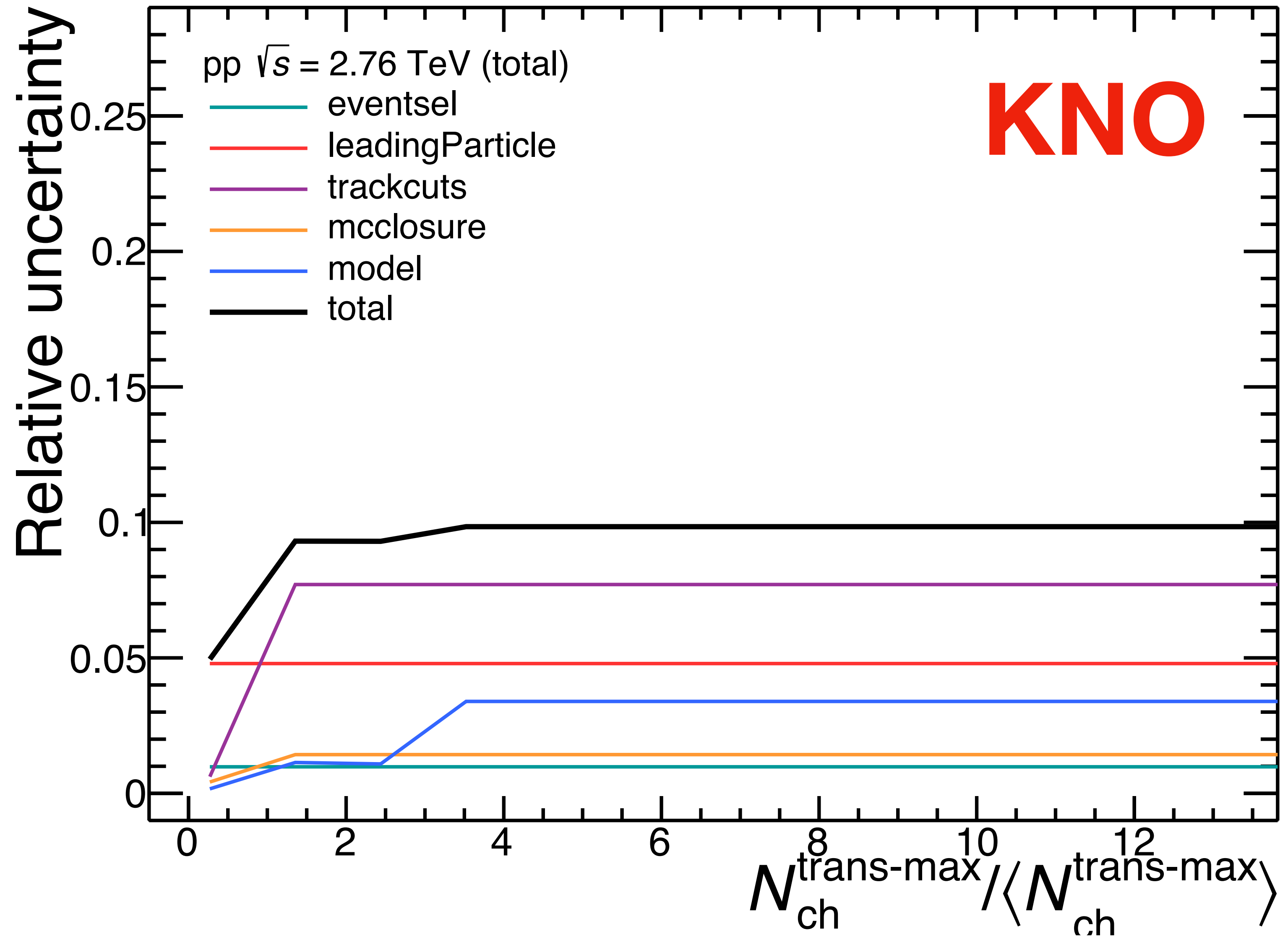


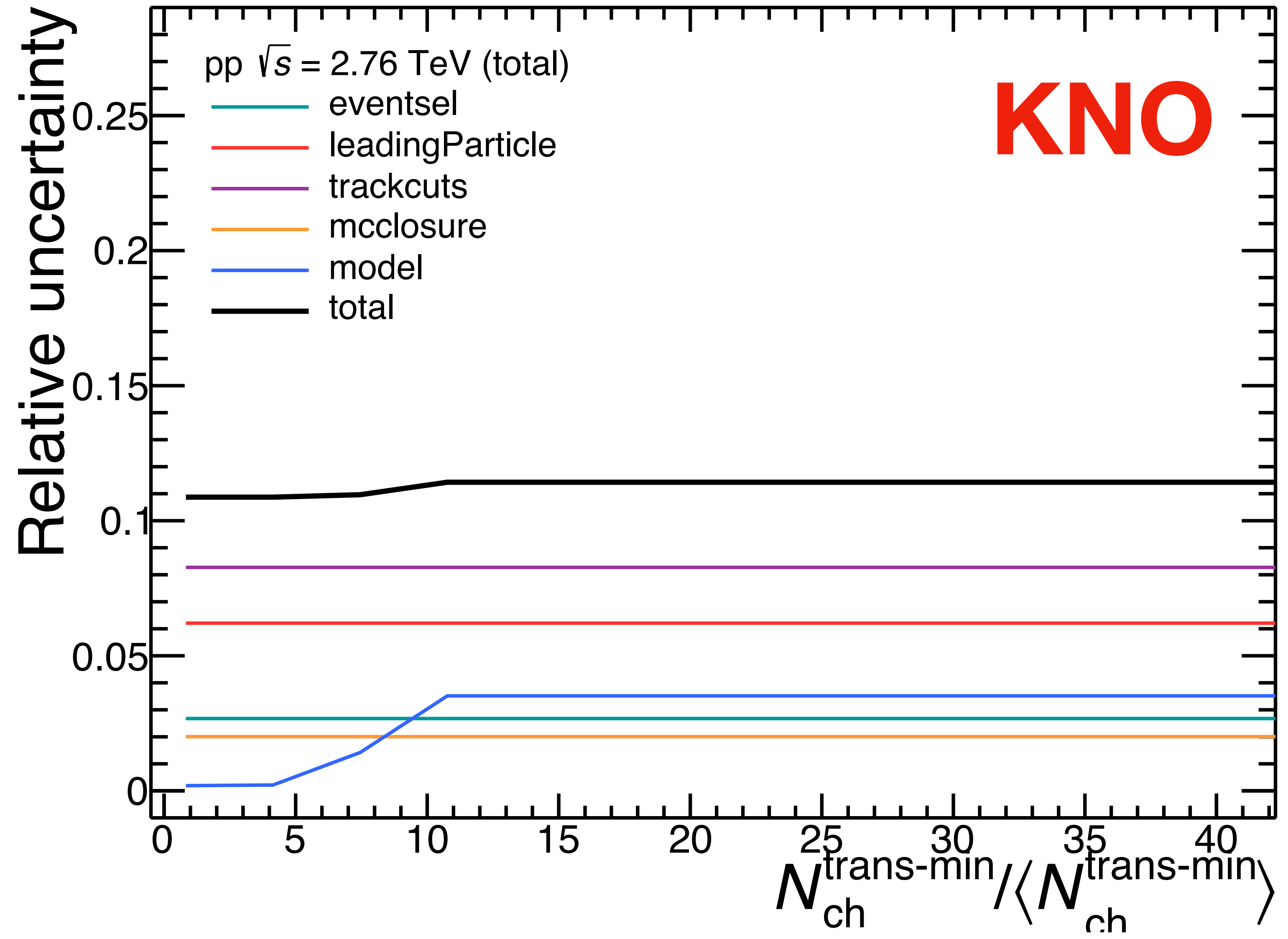




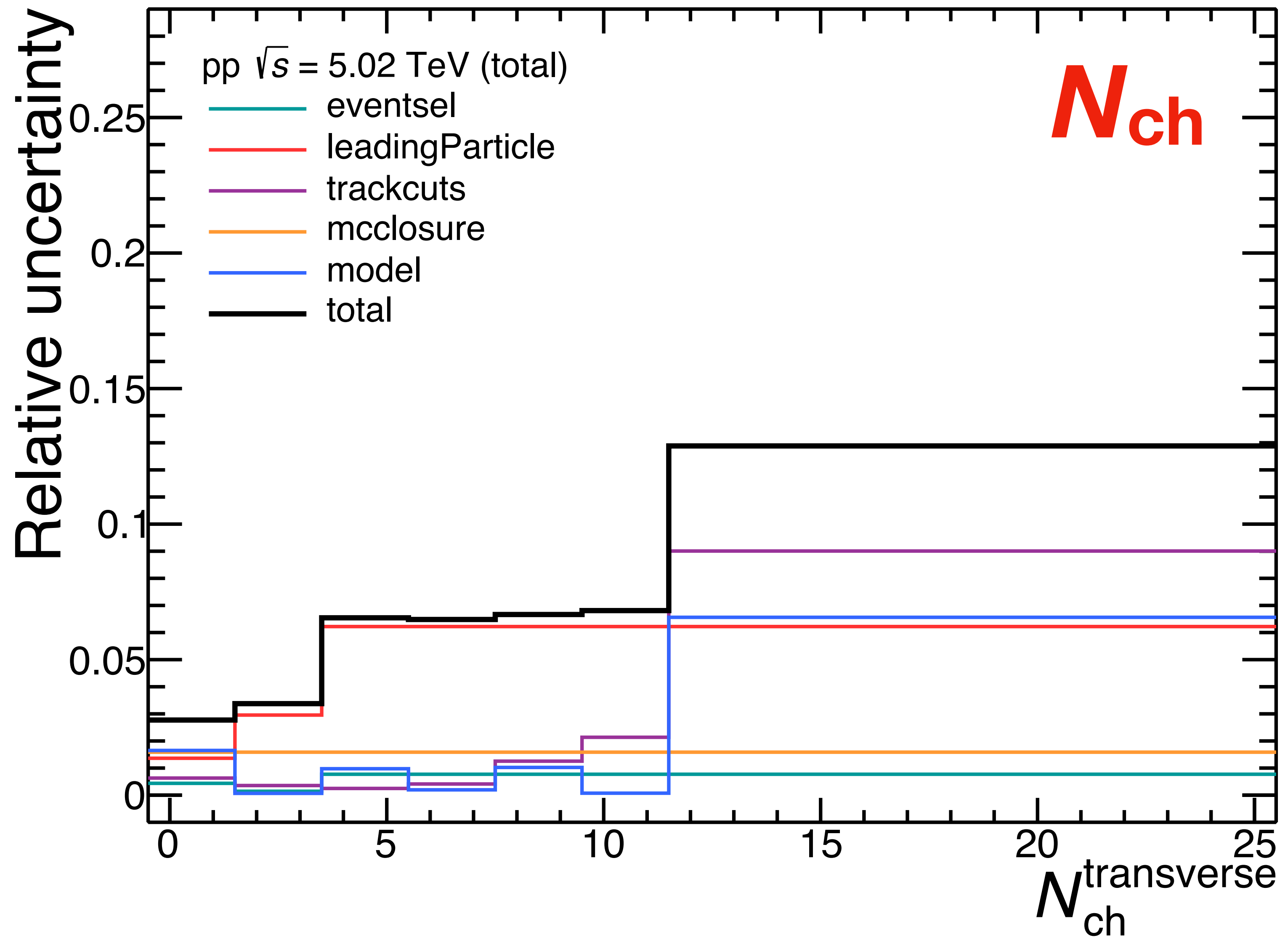
transverse **trans-max** **trans-min**

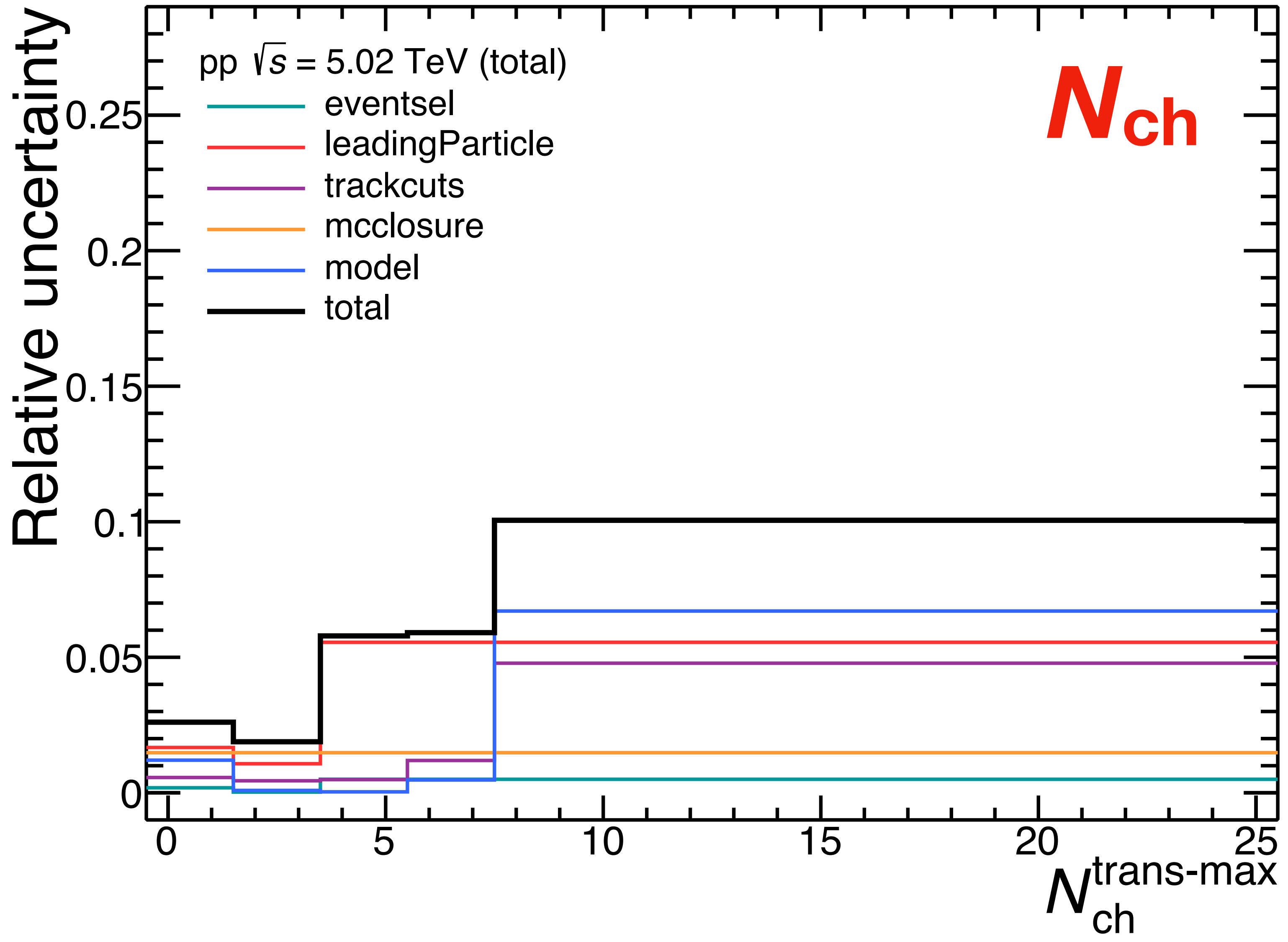


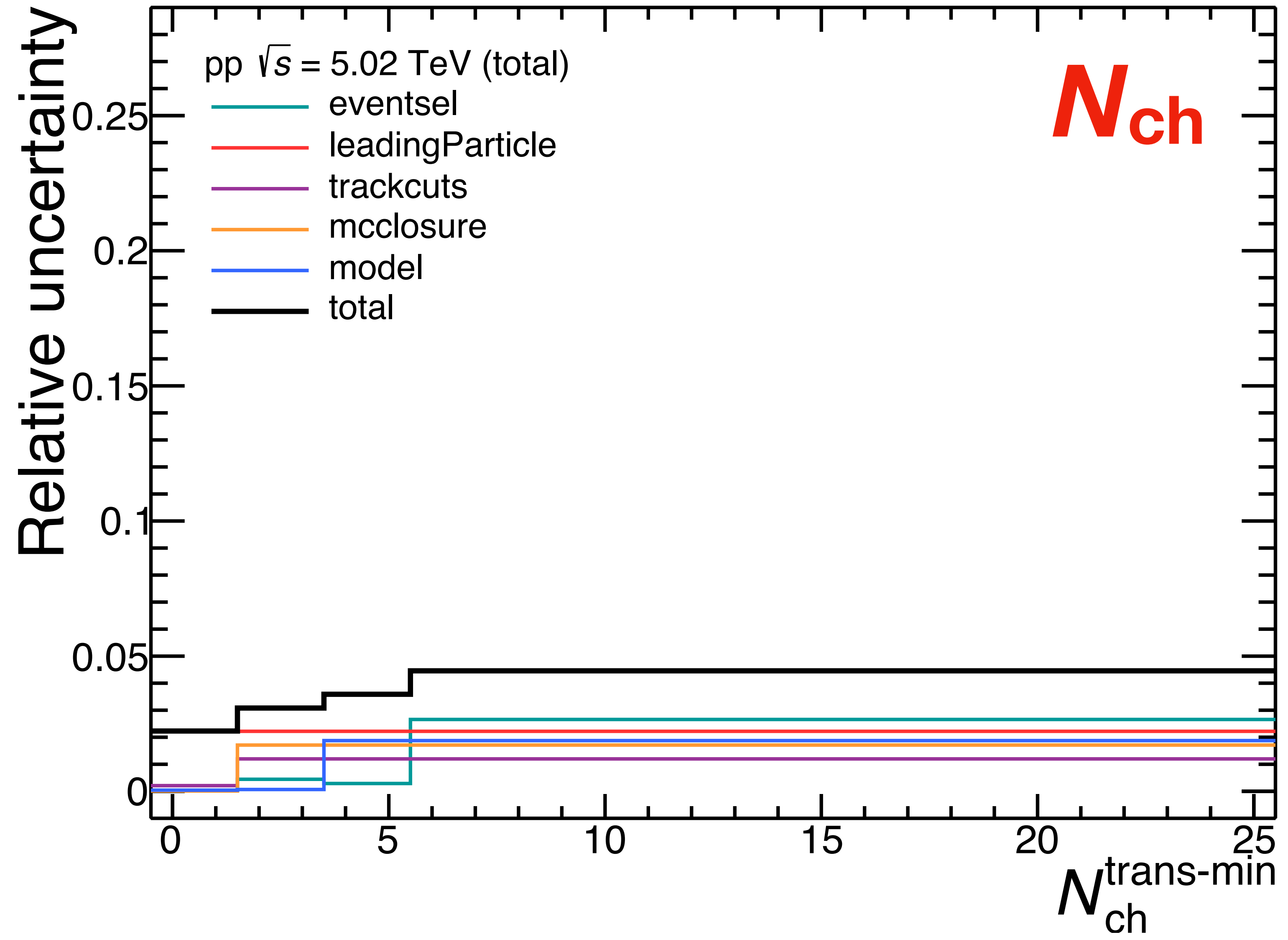




Systematic Uncertainties (pp, 5.02 TeV)



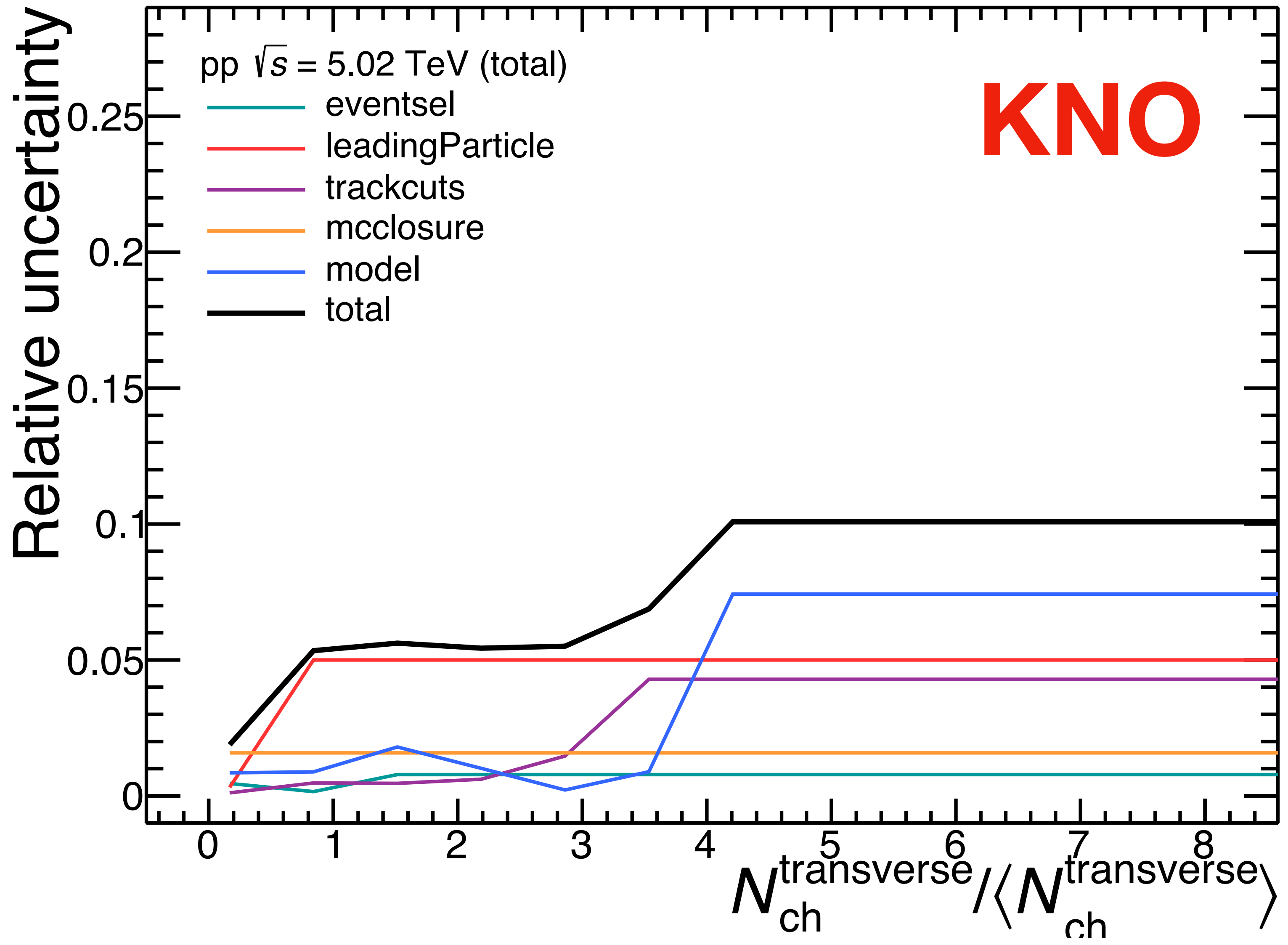


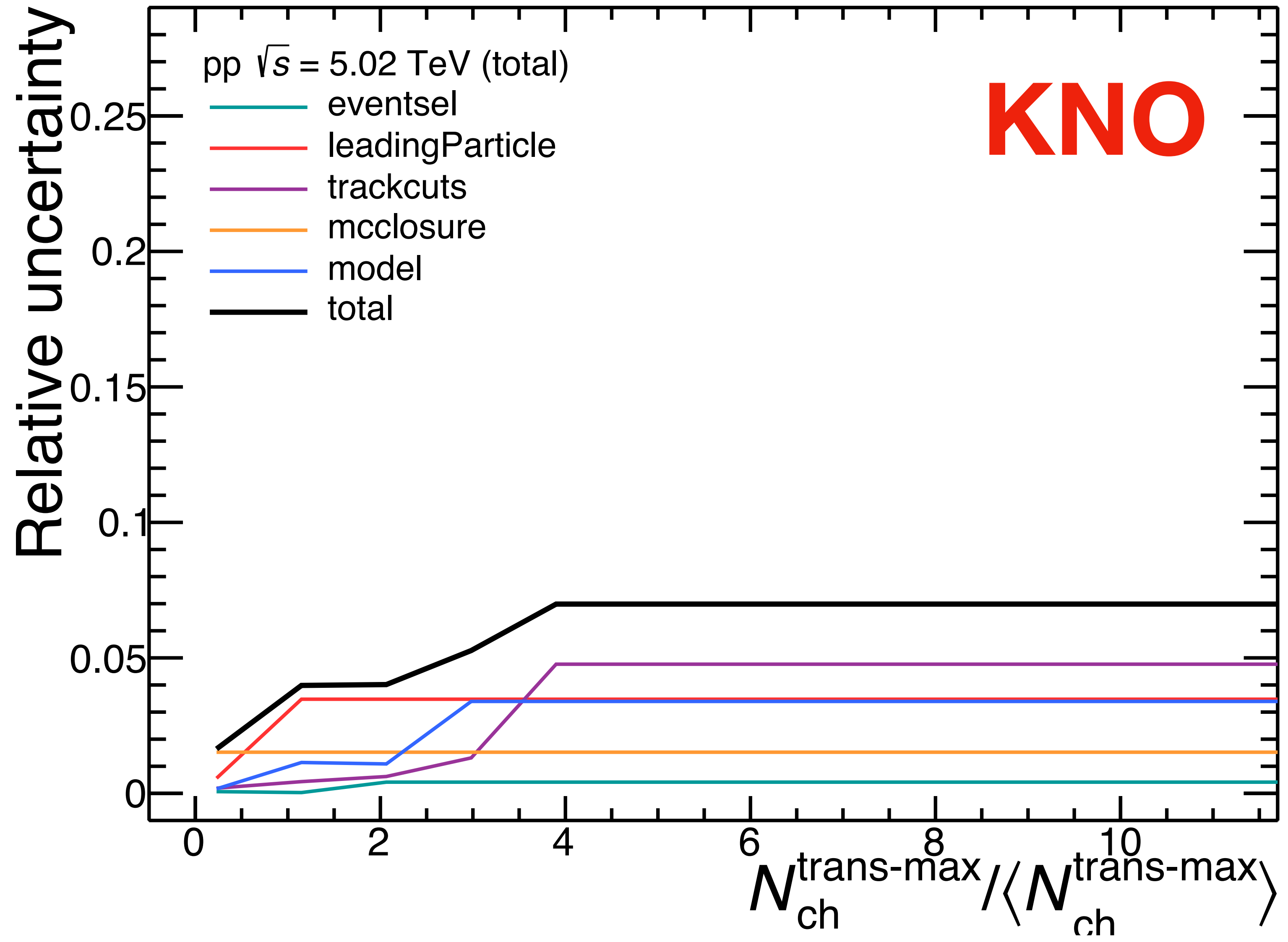


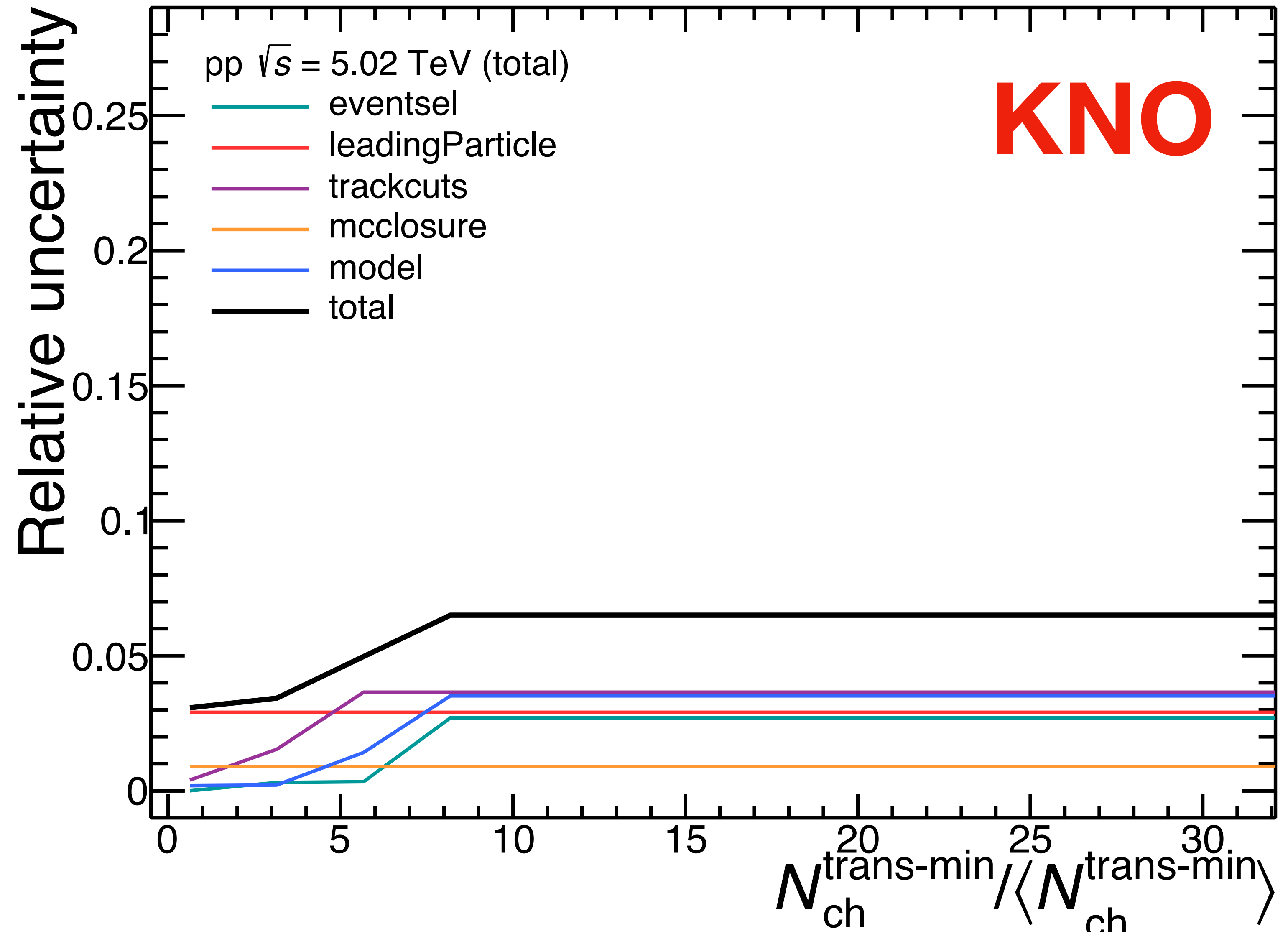
transverse

trans-max

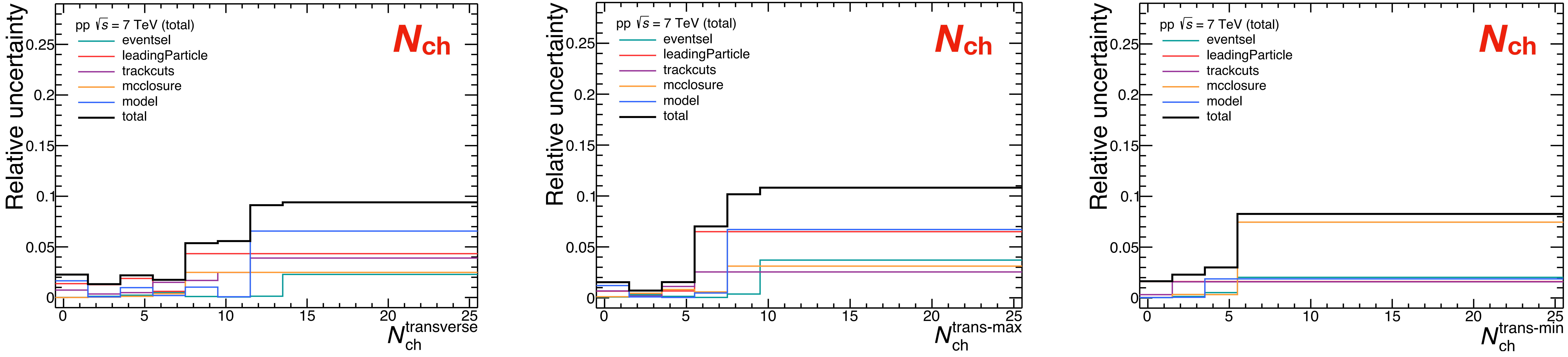
trans-min



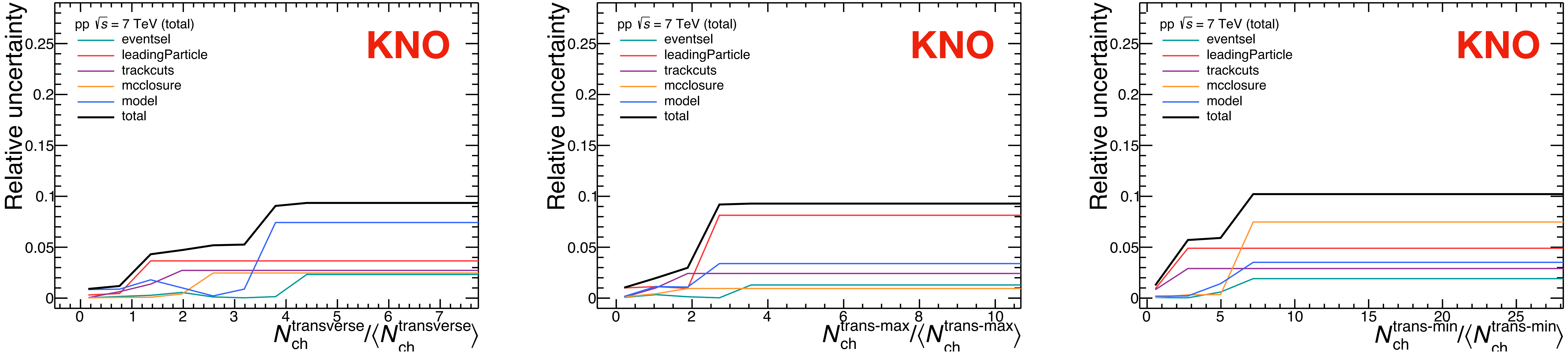




Systematic Uncertainties (pp, 7 TeV)

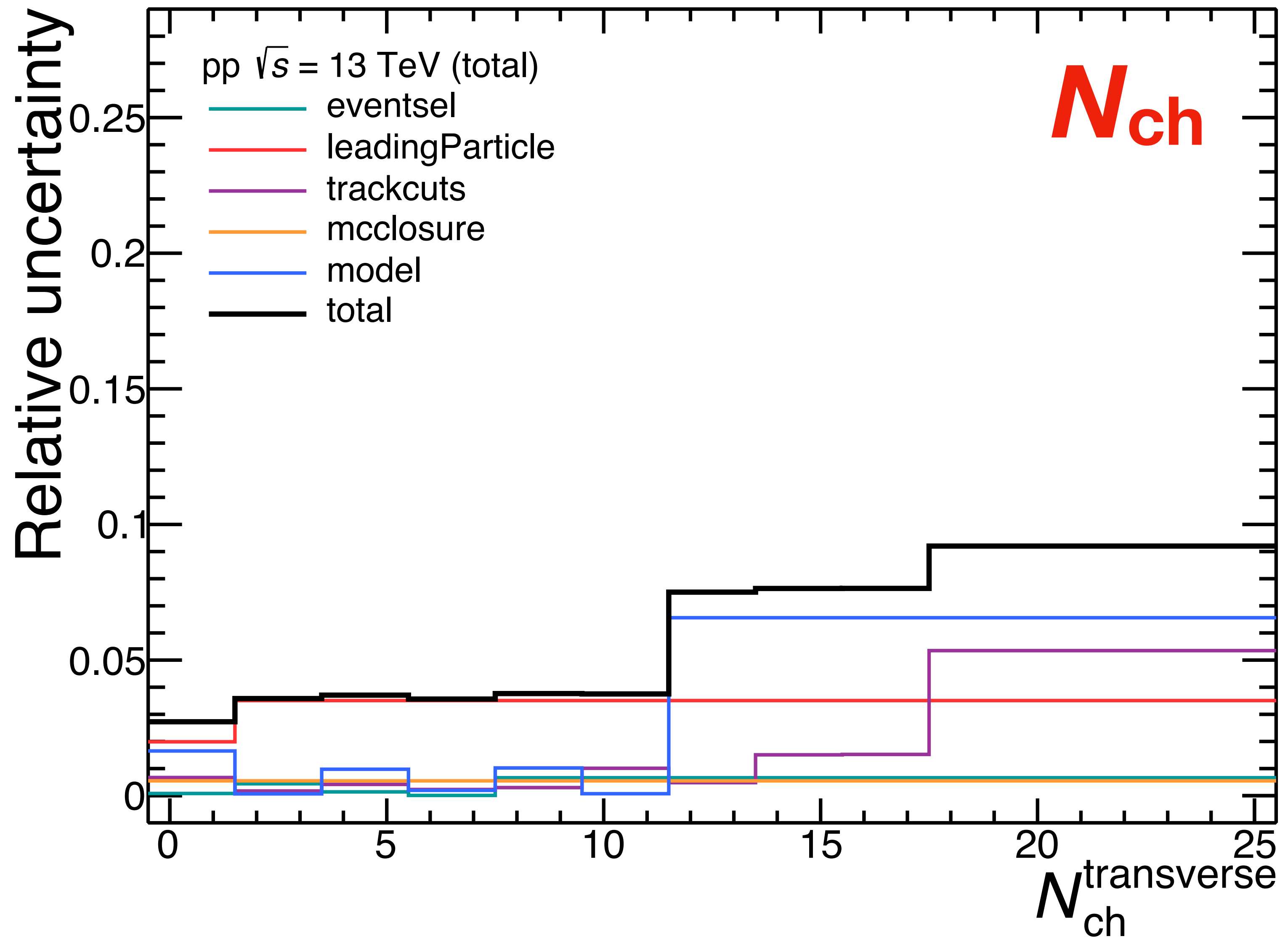


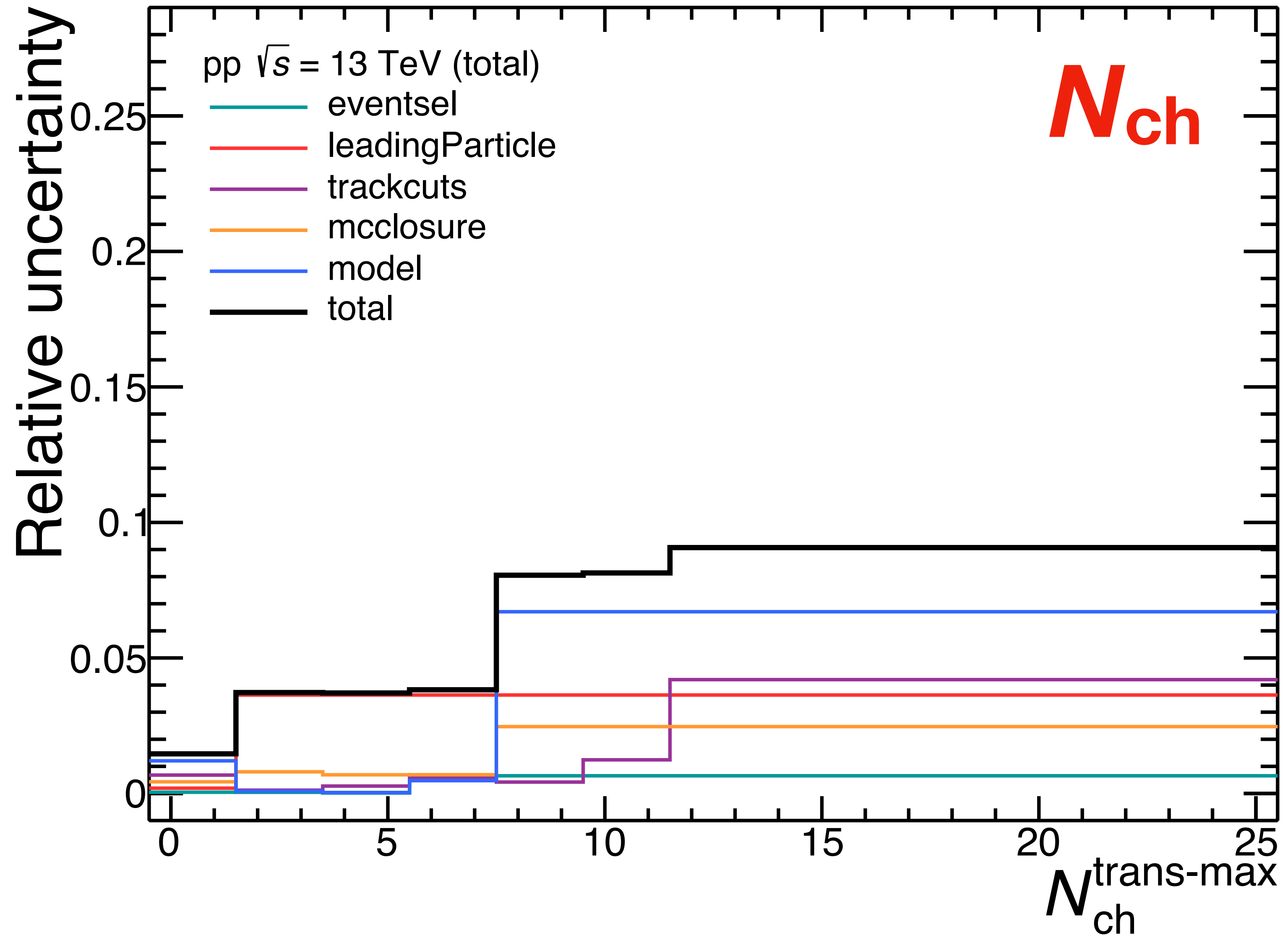
transverse trans-max trans-min

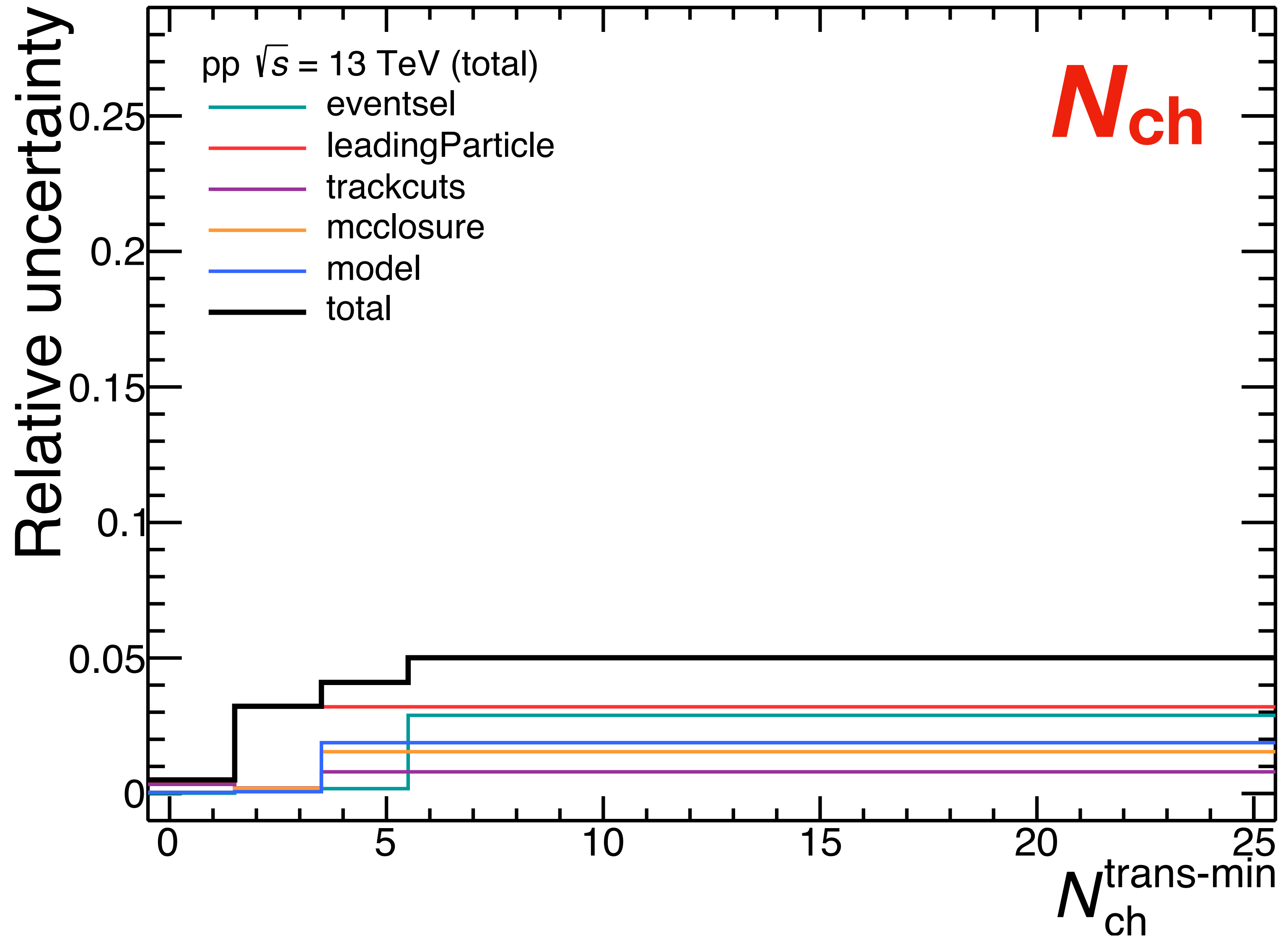


Systematic Uncertainties (pp, 13 TeV)

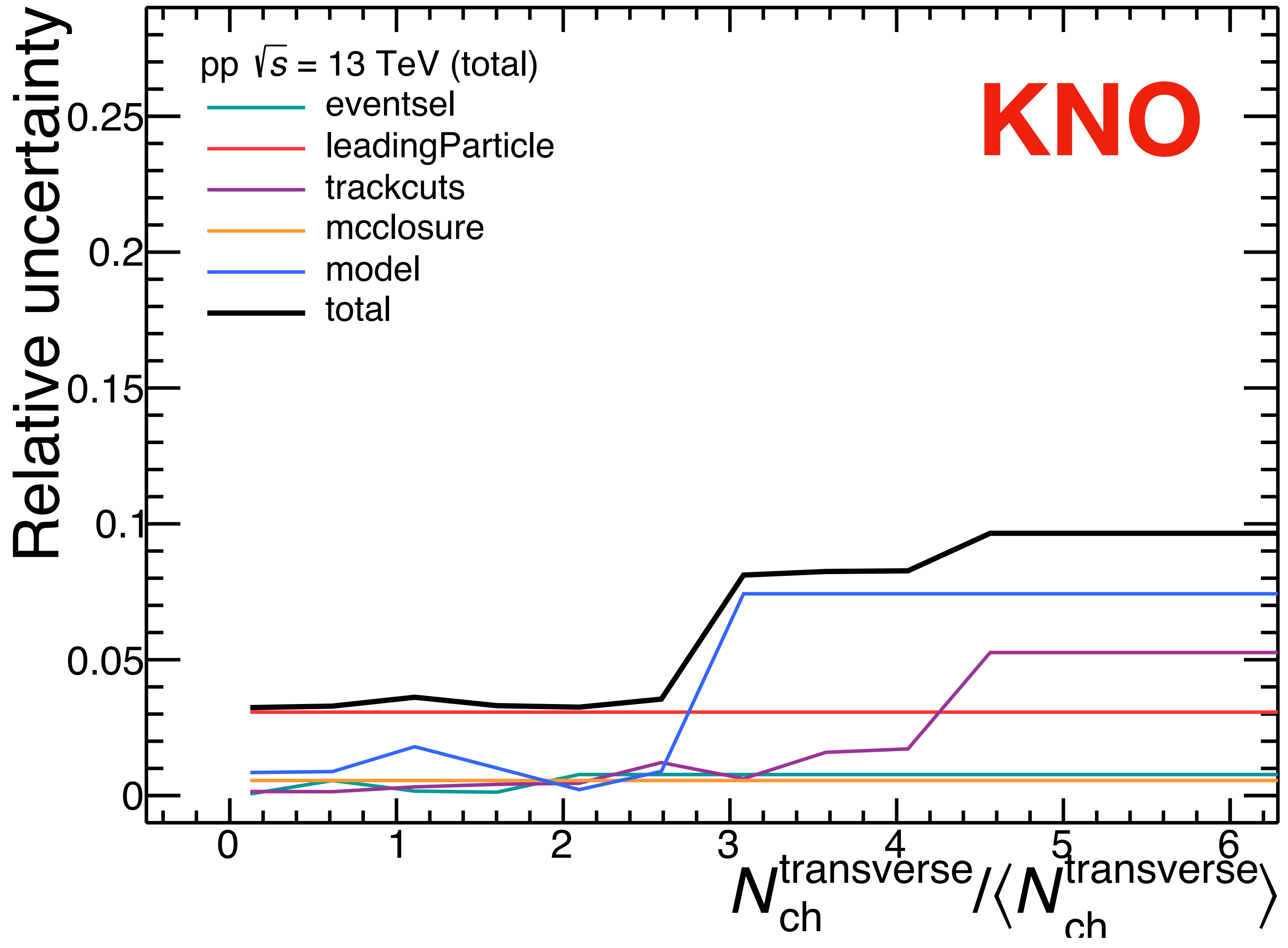
ALICE

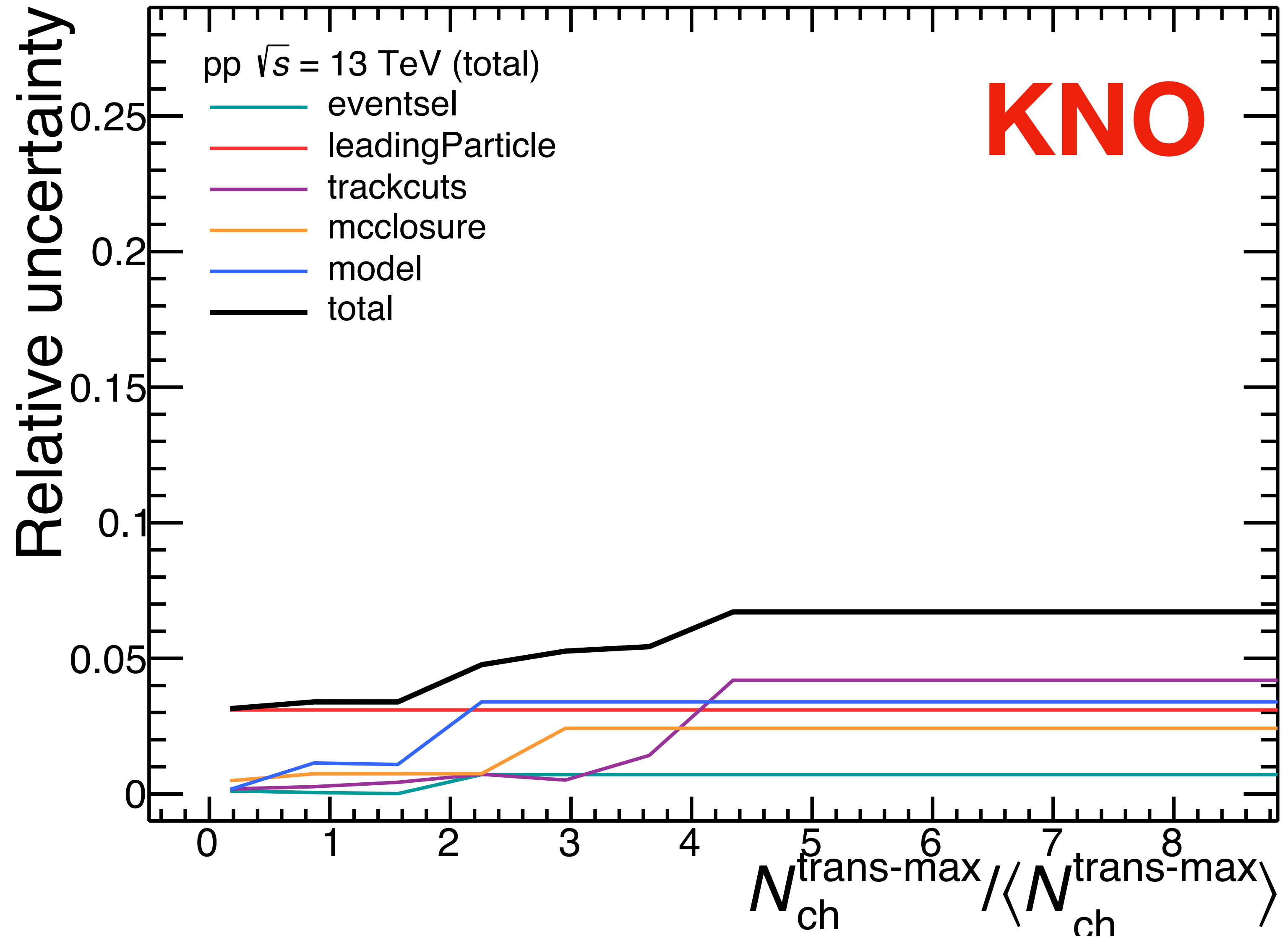


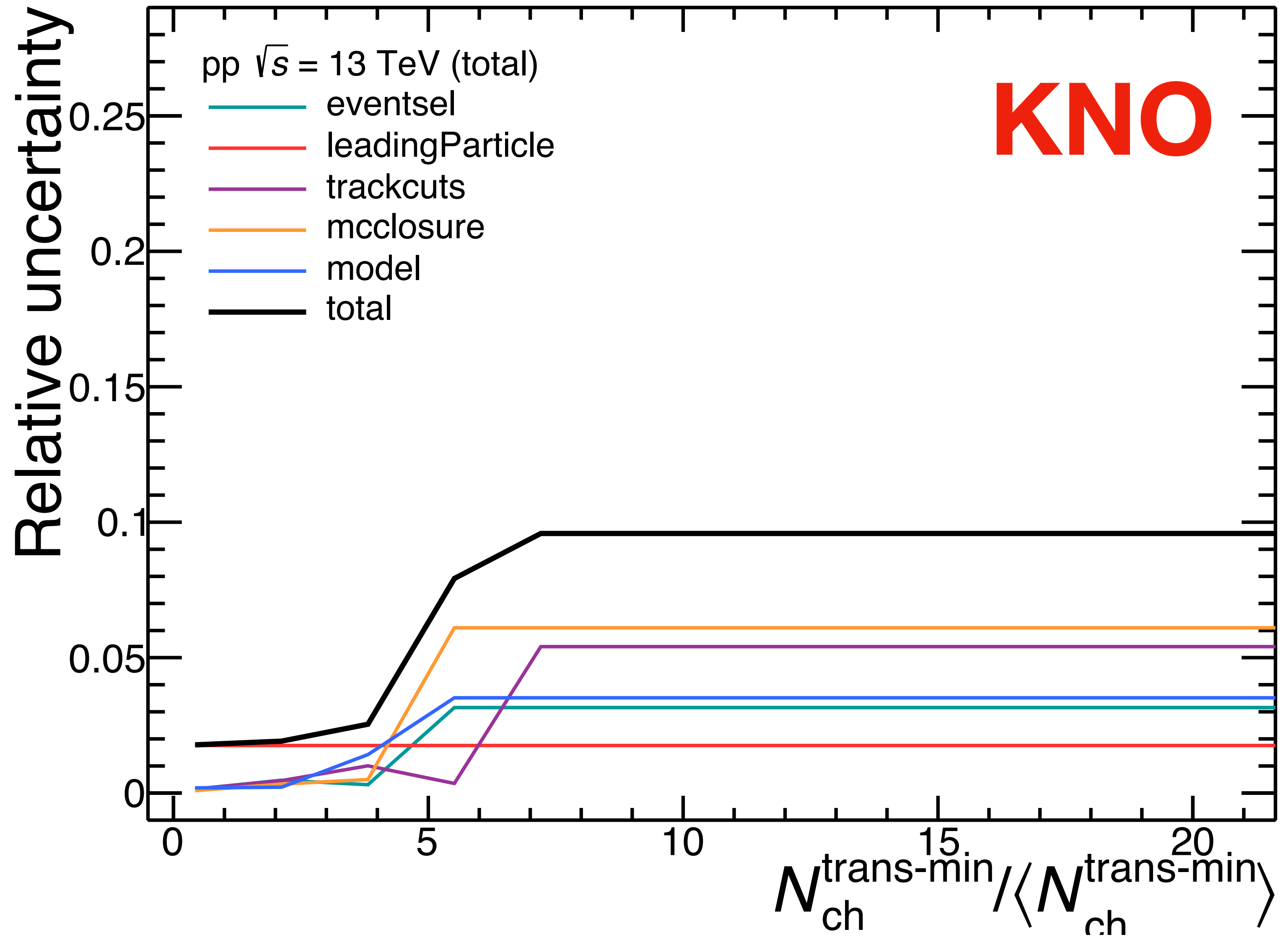




transverse **trans-max** **trans-min**







Systematic Uncertainties

ALICE

track selection for leading track GetStandardITSTPCTrackcuts2015PbPb()	nominal	low	high
max. fraction of shared clusters in TPC	0.4	0.2	1
min. ratio of crossed rows to findable clusters in TPC	0.8	0.7	0.9
width of dead zone in TPC	3	2	4
geometric track length	130	120	140
min. number of hits in SPD	1	0	0
max. χ^2 per cluster in ITS	36	25	49
max. χ^2 per cluster in TPC	4	3	5
max. χ^2 between TPC track and global track	36	25	49
max. DCA_z	2	1	5

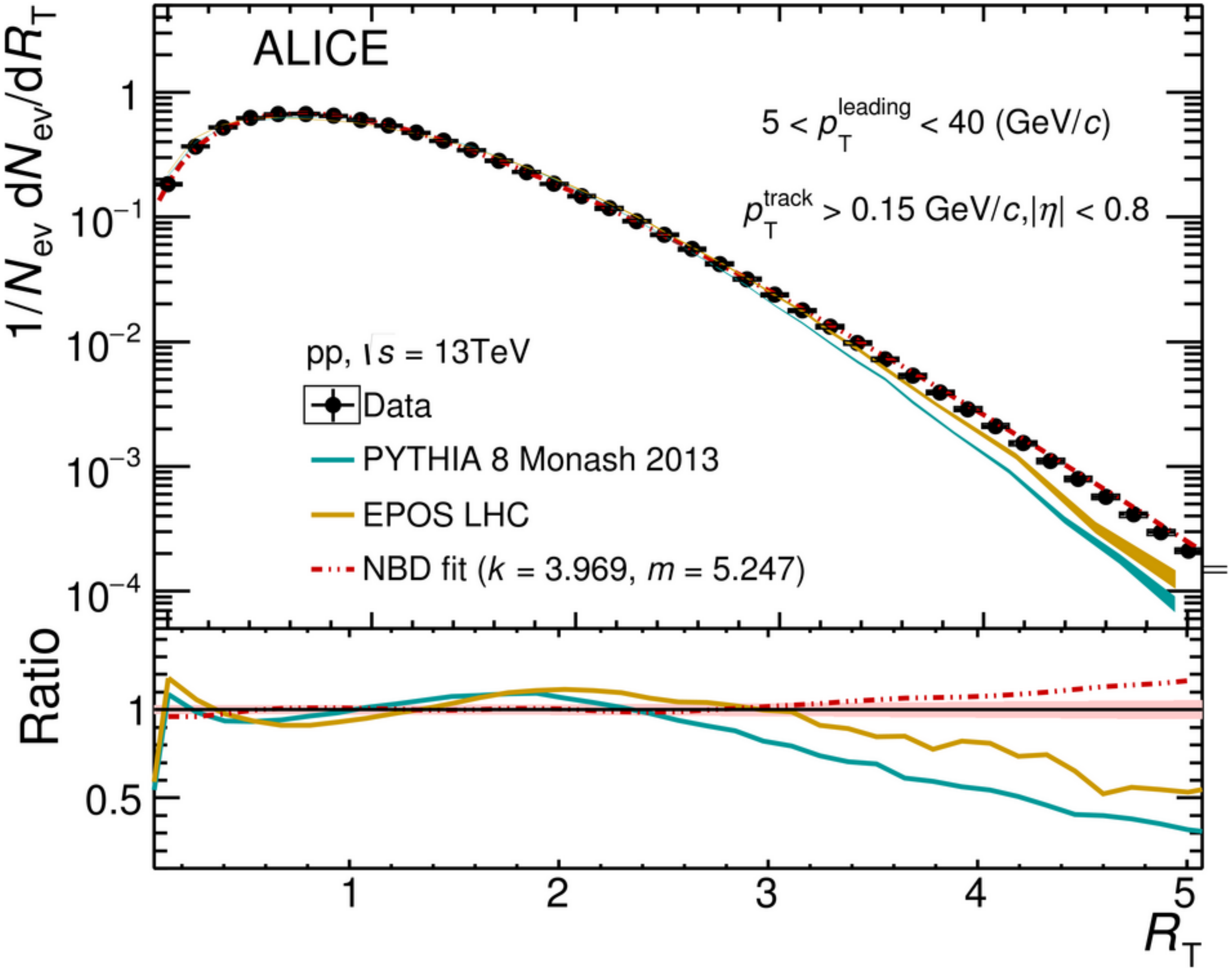
track selection for N_{ch} in transverse, trans- max and trans-min region GetStandardTPConlyTrackcuts()	nominal	low	high
min. number of clusters in TPC	50	30	70
max. per clusters in TPC	4	3	5
max. DCAz	3.2	2	4
max.DCAxy	2.4	1	4
requirement of ITS refit	required	not required	

Track Selection

	track selection for leading track GetStandardITSTPCTrackcuts2015PbPb()	nominal
1	max. fraction of shared clusters in TPC (additional track cut)	0.4
2	min. ratio of crossed rows to findable clusters in TPC	0.8
3	width of dead zone in TPC (new parameters)	3
4	geometric track length (new parameters)	130
5	min. number of hits in SPD	1
6	max. χ^2 per cluster in ITS	36
7	max. χ^2 per cluster in TPC	4
8	max. χ^2 between TPC track and global track	36
9	max. DCA_z	2
10	p_T dependent cut on DCA_{xy}: $\lvert DCA_{xy}\rvert < 0.0182 + 0.035 p_T^{-0.01}$	
11	reject kink daughters	
12	require ITS refit	
13	require TPC refit	
14	accept track even if sigma from track-to-vertex could not be calculated	
15	without a two dimensional DCA cut to cut tracks	
16	$\lvert\eta\rvert < 0.8,\ p_T \geq 0.5$ GeV/c	

track selection for N_{ch} in transverse, trans- max and trans-min region GetStandardTPConlyTrackcuts()	nominal
min. number of clusters in TPC	50
max. per clusters in TPC	4
max. DCA_z	3.2
max. DCA_{xy}	2.4
require ITS refit (additional track cut)	
require TPC refit (additional track cut)	
reject kink daughters	
accept track according to a two dimensional DCA cut	
$\lvert\eta\rvert < 0.8,\ p_T \geq 0.5$ GeV/c	

Existing ALICE result



- Within 1%, unfolded multiplicity is consistent with the true multiplicity.