Higher-order diagonal cumulants of (Λ+K)-multiplicity distributions: Au+Au 27 GeV (Run18)

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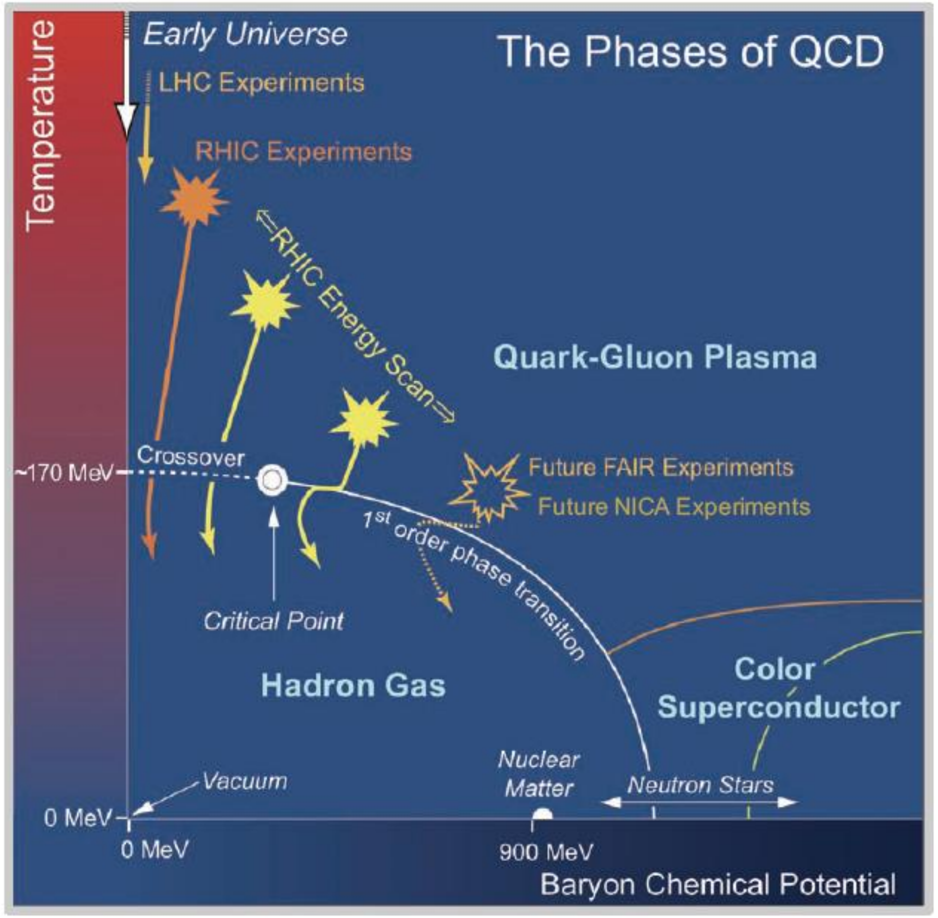
Motivation

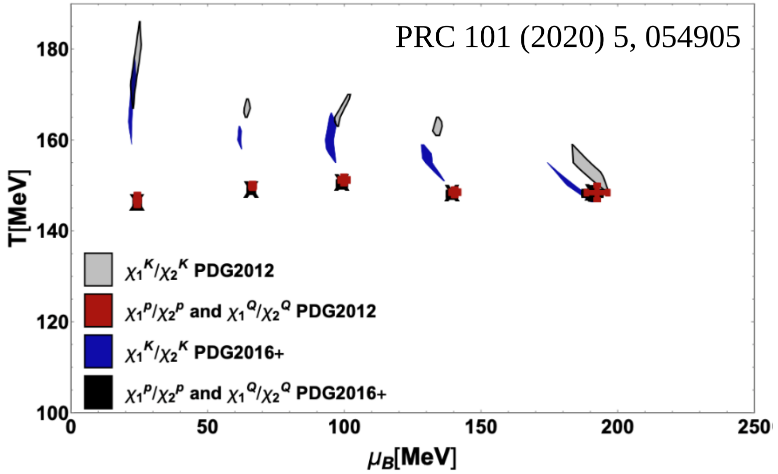


- Goal of the RHIC BES program

  To explore the QCD Phase diagram and search for the QCD Critical Point

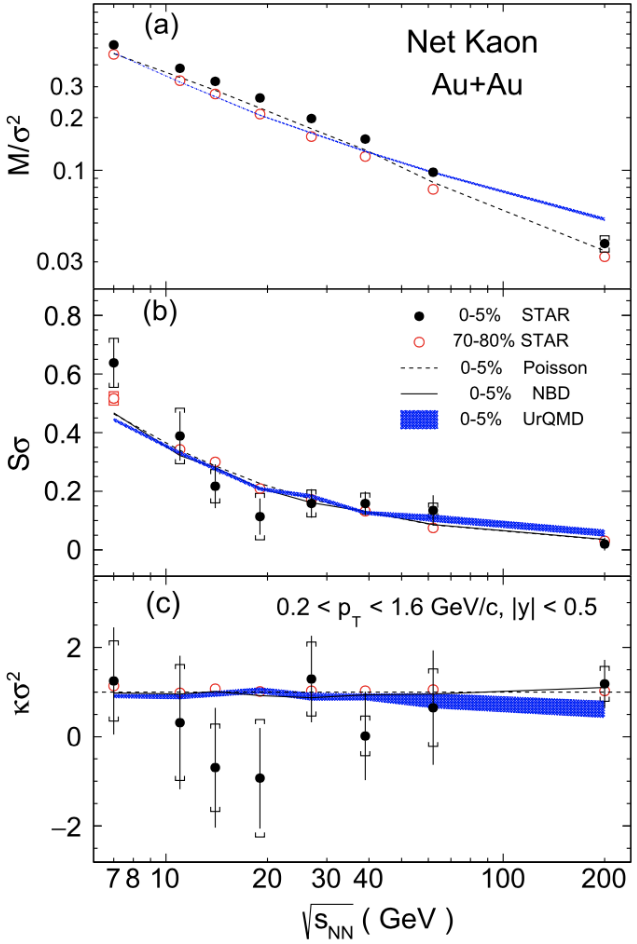
- Recently, many theoretical attempts have been made to extract freezeout (FO) parameters using higher order cumulants measurements

- And to understand strangeness dependent chemical FO parameters

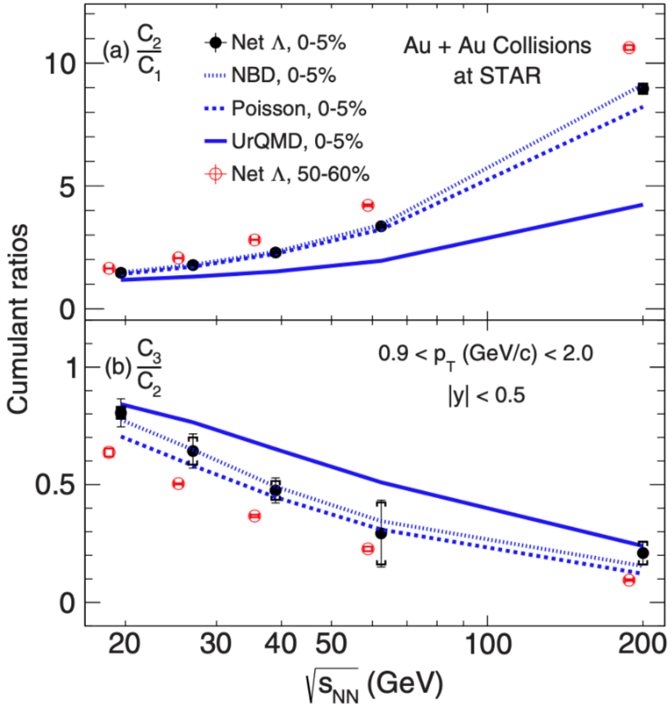


STAR BES-I Net-Kaon and Net-Lambda results

Net-Kaon: PLB 785 (2018) 551



Net-Lambda: PRC 102 (2020) 2, 024903



- We plan to measure net-(Kaon+Lambda) multiplicity distributions for BES program.
- Net-(Kaon+Lambda) can be approximately considered as net-strangeness.
- Differential and precision measurements of net-K, net-Λ, and net-(K+ Λ) are needed to understand the critical fluctuations and strangeness chemical freeze-out parameters at the BES energies

Thermodynamic susceptibilities and cumulants

$$C_X^m = VT^3 \chi_X^m (T, \mu)$$

- X is conserved charge such as net-electric charge(Q) net-baryon number(B) and net-strangeness(S)
- C_X^m is cumulant
- V is volume of the system.
- We can hardly know the volume or sometimes we want to compare thermodynamic susceptibilities of different system, so we use the ratio of susceptibilities to remove the volume term

Different order of cumulants

$$C_1 = \langle N \rangle$$

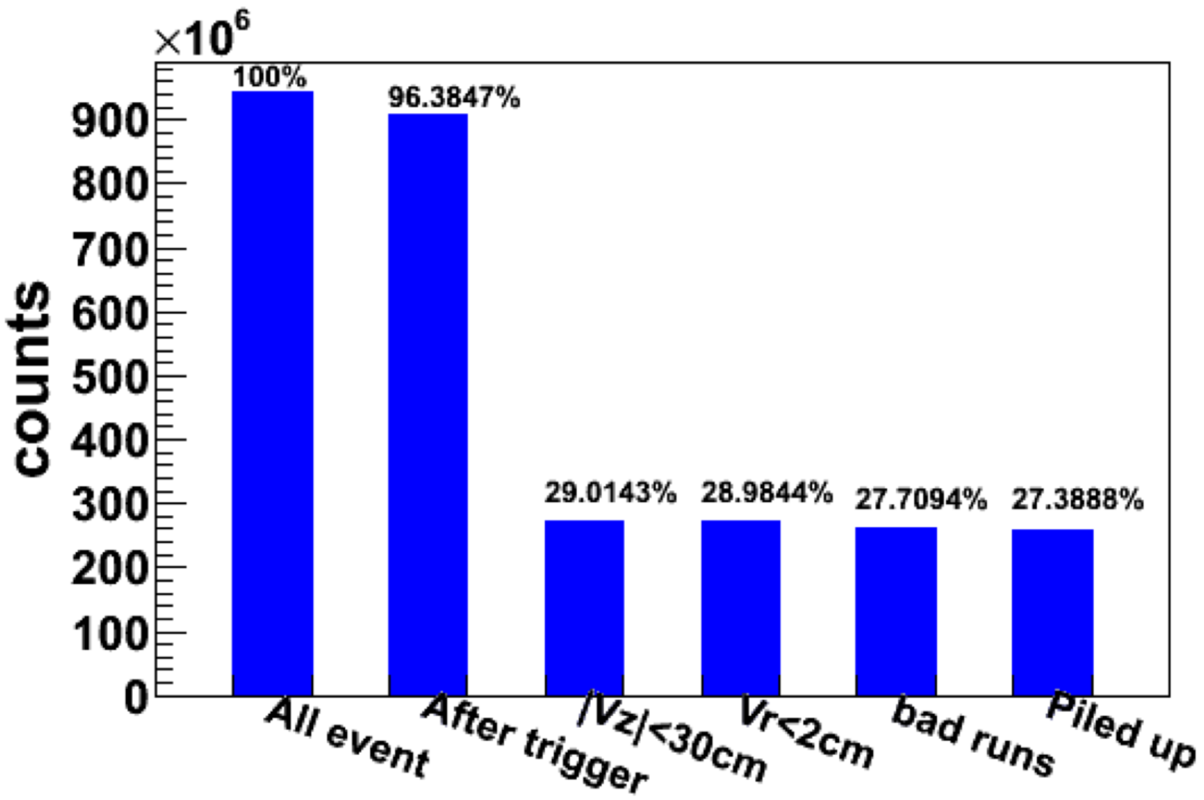
$$C_2 = \langle (\delta N)^2 \rangle$$

$$C_3 = \langle (\delta N)^3 \rangle$$

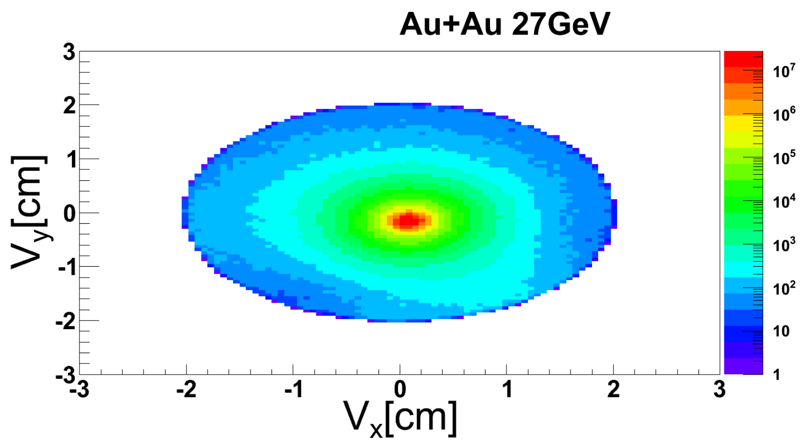
$$C_4 = \langle (\delta N)^4 \rangle - 3\langle (\delta N)^2 \rangle^2$$

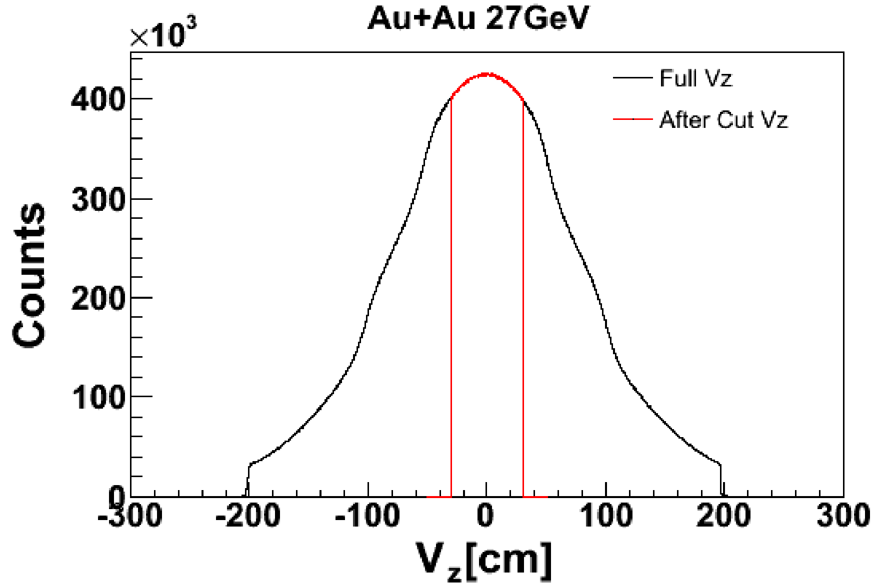
New 27 GeV (Run18) dataset

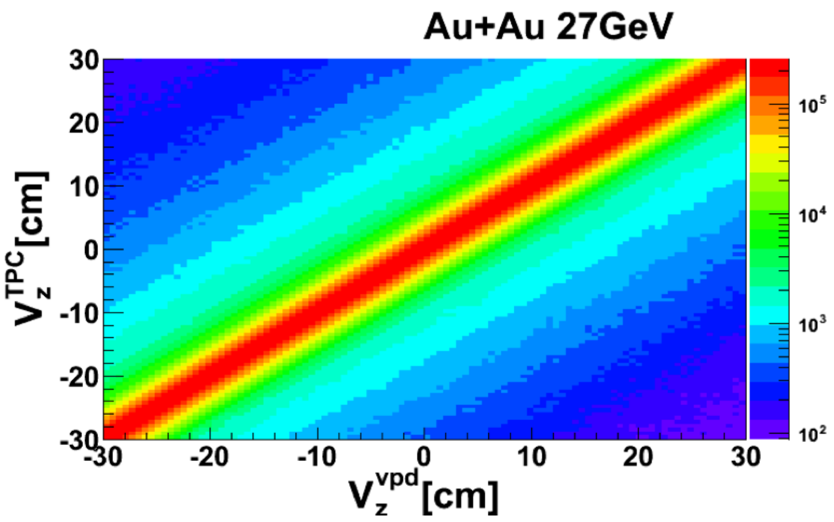
- Triggersetupname= 27GeV_production_2018
- Production=P19ib
- Trigger Ids = 610001, 610011, 610021, 610031,610041, 610051
- |Vz| < 30 cm
- Vr < 2 cm

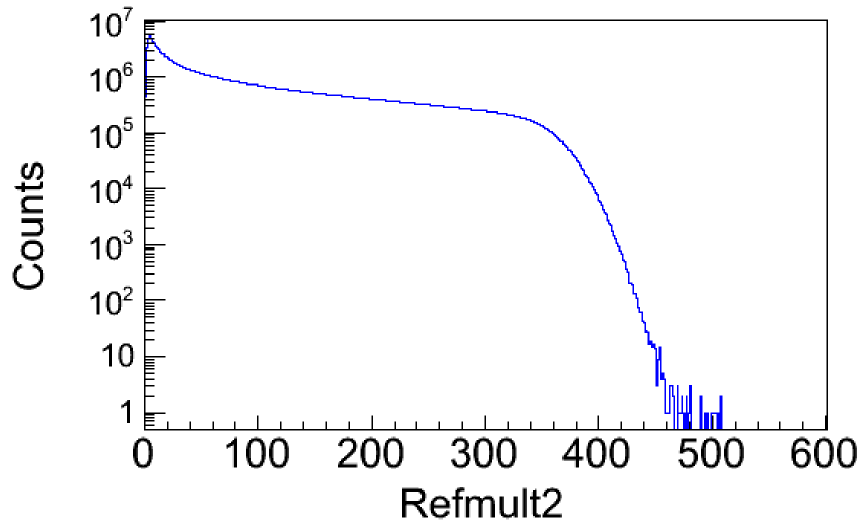


Event QA


Au+Au 27GeV
V_y[cm]
V_x[cm]
-3
-2
-1
0
1
2
3
10^7
10^6
10^5
10^4
10^3
10^2
10
1


Au+Au 27GeV
×10^3
Full Vz
After Cut Vz
Counts
V_z[cm]
-300
-200
-100
0
100
200
300
400


Au+Au 27GeV
V_z^TPC[cm]
V_z^vpd[cm]
-30
-20
-10
0
10
20
30
10^5
10^4
10^3
10^2


Counts
Refmult2
0
100
200
300
400
500
600
10^7
10^6
10^5
10^4
10^3
10^2
10
1

QA: Bad run rejection and Pileup events removal

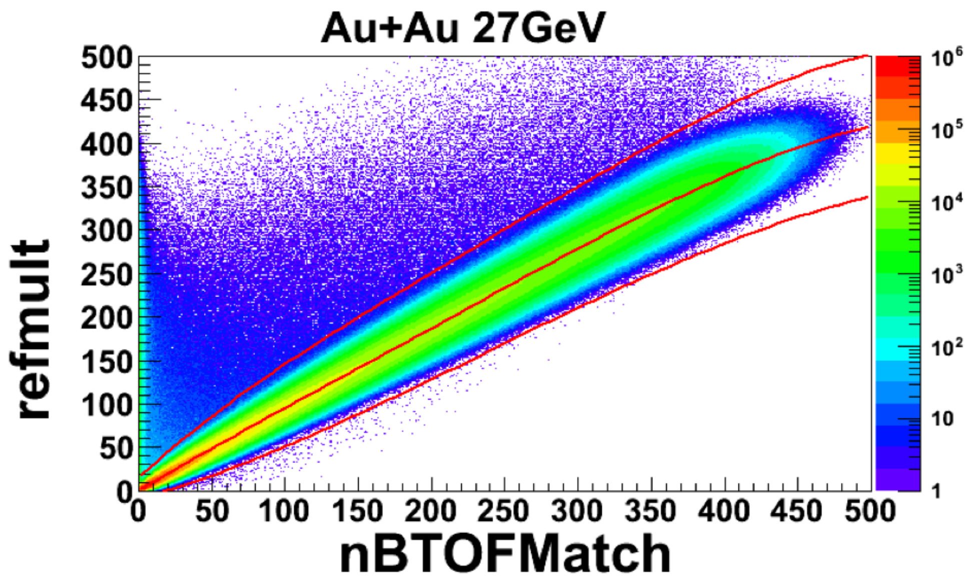
- Bad runs are selected based on the run-by-run check on <eta>, <pT>, <Refmult>, <Tofmult>, <TofMatch>, etc.
- Outliers are selected those are 5σ away from the local mean

Bad run list:

19130085	19131009	19131010	19131012	19131016	19131037	19131039	19131040
19131041	19131042	19131045	19131050	19131057	19132006	19132016	19132029
19132031	19132038	19132048	19132063	19133018	19133023	19134011	19134017
19134044	19135011	19135038	19135039	19135040	19136001	19136005	19136009
19136012	19136013	19136014	19137001	19137003	19137004	19137008	19137011
19137013	19137020	19137022	19137028	19137029	19137050	19137051	19137052
19137056	19137057	19138004	19138008	19138010	19139022	19139026	19139032
19140014	19140016	19140040	19141004	19141008	19141019	19141029	19142005
19143008	19143009	19143010	19143011	19143012	19143013	19143014	19143015
19143016	19143017	19144019	19144038	19146007	19146016	19147008	19147009
19147010	19147014	19147015	19147016	19149035	19156032	19156041	19156044
19156045	19157013	19158009	19158013	19159025	19160018	19161019	19162002
19162005	19165018	19165020	19167026	19167042	19147007	19147029	

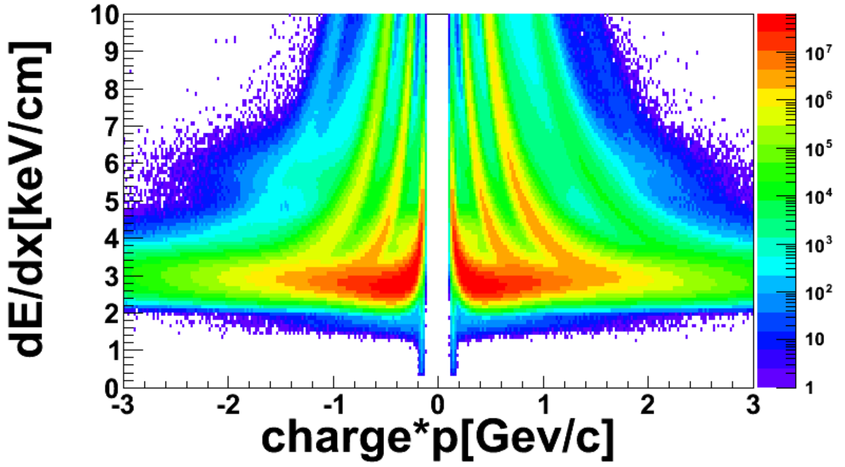
Refmult vs. TofMatch is used to reject the pileup events.

Refmult vs. TofMatch is used to reject the pileup events.

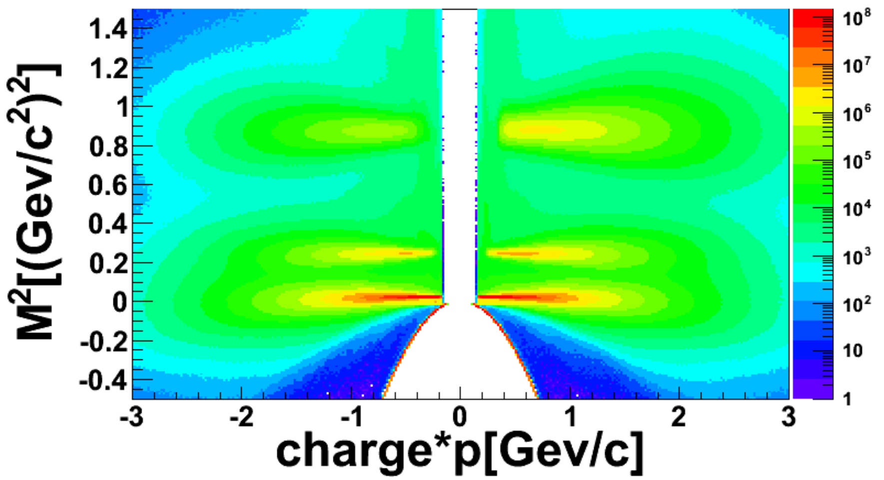


Track cuts and K^+ and K^- identification using TPC and TOF

TPC



TPC + TOF



Track cuts:

- p_T range: 0.4 to 1.6 GeV/c
- $|y| < 0.5$
- nHitsFit >=15
- nHitsFit/nHitMax >= 0.52
- nHitdedx > 5
- DCA < 1 cm

- TPC: $|n\sigma_{Kaon}| < 2$ and $|n\sigma_{\pi}| > 2$
- TOF: $0.15 < m^2 < 0.4\ GeV^2/c^4$
- $0.4 < p_T < 1.6$ GeV/c

Track cuts to reconstruct Λ

In this analysis, we measure both K^+, K^-, Λ, and anti-Λ for Net-(K+ Λ) multiplicity distribution:

- Kaons (K^+ and K^-) are identified using TPC and TOF within $0.4 < p_T < 1.6$ GeV/c
- Proton and pion are used for Λ/anti-Λ reconstruction

Track cut:

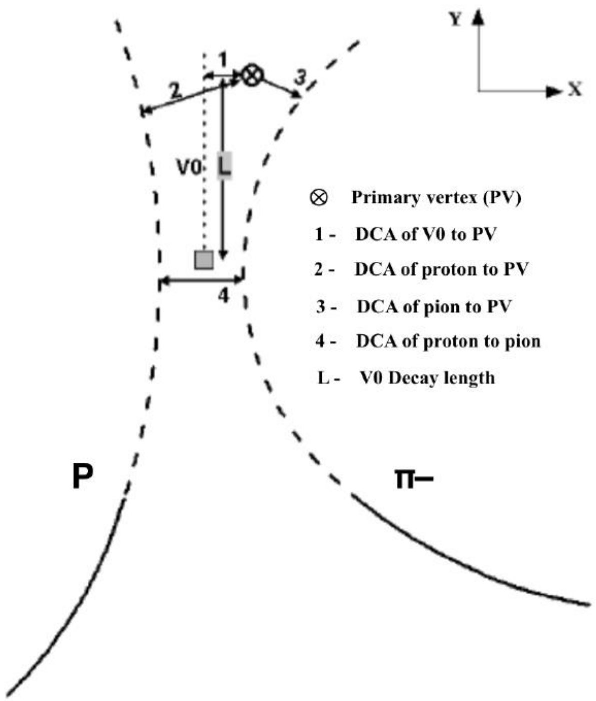
- Pt > 0.05 GeV/c
- |Eta|<1.0
- nHitsFit>15
- nHitsFit/nHitsMax>0.52
- Nsigma<2.0

(Based on net-Λ published results)

Topological cuts for Λ reconstruction

1. DCA of V0 to Primary Vertex (PV)
2. DCA of proton to PV
3. DCA of pion to PV
4. DCA of proton to pion
5. Decay Length (L)

DCA (P to PV)	**>0.5cm**
DCA (π to PV)	>1.5cm
DCA (P to π)	<0.6cm
DCA (V0 to PV)	<0.5cm
Decay Length (L)	>3.0cm
Pointing away from PV r.p	>0
Pt	0.4<Pt(GeV/c)<1.6
Eta	|rap|<0.5
LambdaMass	1.112<LambdaMass <1.12



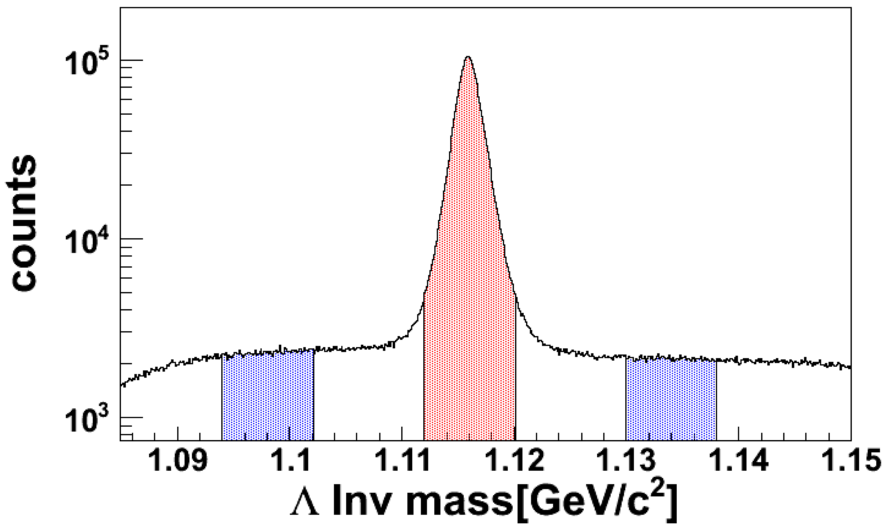
Λ and anti-Λ reconstruction: Invariant Mass

Signal mass window: 1.112 - 1.12 GeV/c^2

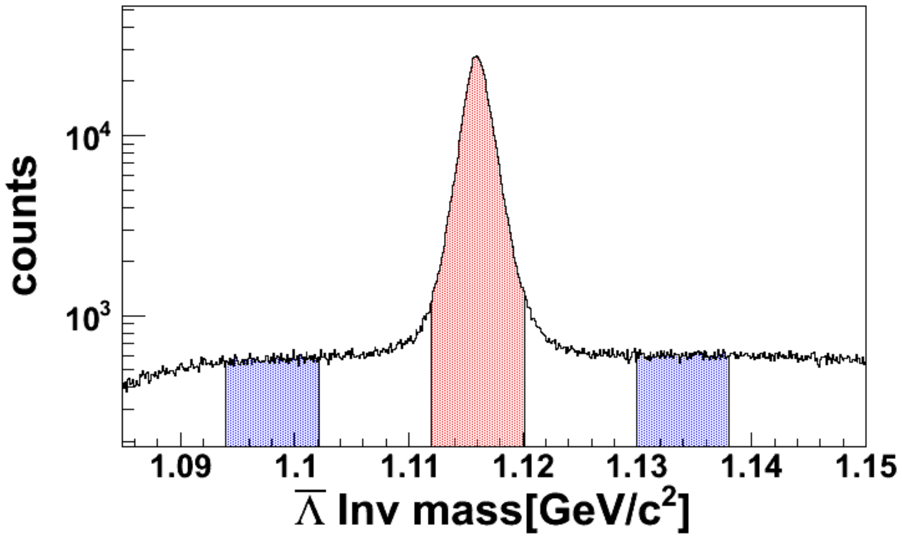
left side: 1.094 - 1.102 GeV/c^2

right side:1.13 - 1.138 GeV/c^2

Centrality 0-5%



Centrality 0-5%



Net-K Net-Λ and Net-(K+Λ) definition

K^+	contains	$u\bar{s}$	strangeness is +1
K^-	contains	$\bar{u}s$	strangeness is -1
Λ	contains	uds	strangeness is -1
anti-Λ	contains	$\bar{u}\bar{d}\bar{s}$	strangeness is +1

We plan to calculate net $\bar{s}$

Net-K=$\Delta N_K = N_{K+} - N_{K-}$

Net- Λ =$\Delta N = N_{anti\text{-}\Lambda} - N_\Lambda$

Net-(K+Λ) = $\Delta N_{(K+\Lambda)}$

$= (N_{K+} + N_{anti\text{-}\Lambda}) - (N_{K-} + N_\Lambda)$

N_{K+} = Total number of K^+

N_{K-} = Total number of K^-

N_Λ =Total number of Λ

$N_{anti\text{-}\Lambda}$ =Total number of anti-Λ

Track by track efficiency correction

$$\langle Q\rangle_c = \langle q_{(1,1)}\rangle_c$$

$$\langle Q^2\rangle_c = \langle q_{(1,1)}^2\rangle_c + \langle q_{(2,1)}\rangle_c - \langle q_{(2,2)}\rangle_c$$

$$\langle Q^3\rangle_c = \langle q_{(1,1)}^3\rangle_c + 3\langle q_{(1,1)}q_{(2,1)}\rangle_c - 3\langle q_{(1,1)}q_{(2,2)}\rangle_c + \langle q_{(3,1)}\rangle_c - 3\langle q_{(3,2)}\rangle_c + 2\langle q_{(3,3)}\rangle_c$$

$$\langle Q^4\rangle_c = \langle q_{(1,1)}^4\rangle_c + 6\langle q_{(1,1)}^2 q_{(2,1)}\rangle_c - 6\langle q_{(1,1)}^2 q_{(2,2)}\rangle_c + 4\langle q_{(1,1)}q_{(3,1)}\rangle_c + 3\langle q_{(2,1)}^2\rangle_c$$
$$+3\langle q_{(2,2)}^2\rangle_c - 12\langle q_{(1,1)}q_{(3,2)}\rangle_c + 8\langle q_{(1,1)}q_{(3,3)}\rangle_c - 6\langle q_{(2,1)}q_{(2,2)}\rangle_c$$
$$+\langle q_{(4,1)}\rangle_c - 7\langle q_{(4,2)}\rangle_c + 12\langle q_{(4,3)}\rangle_c - 6\langle q_{(4,4)}\rangle_c$$

where $$q_{(r,s)} = q_{(a^r/p^s)} = \sum_{i=1}^{M}\left(a_i^r / p_i^s\right) n_i$$

We use n_i=1,
a_i equal to 1 or -1
p_i is efficiency
M is track number of one event

For detail you can read this paper:
https://journals.aps.org/prc/abstract/10.1103/PhysRevC.95.064912

QM2022 Results

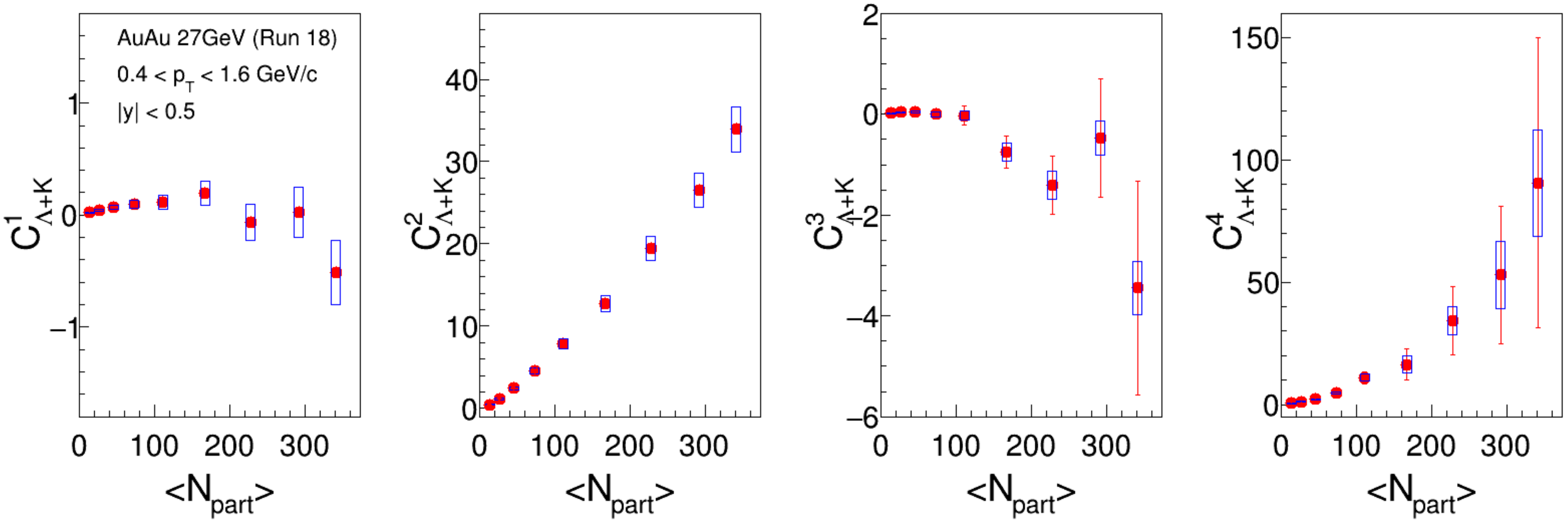
Cumulants of Net-(K+ Λ) multiplicity distributions

Net-(Λ+K) ≡ $\Delta N_{(\Lambda+K)} = (N_{\text{anti-}\Lambda} + N_{K^+}) - (N_{\Lambda} - N_{K^-})$

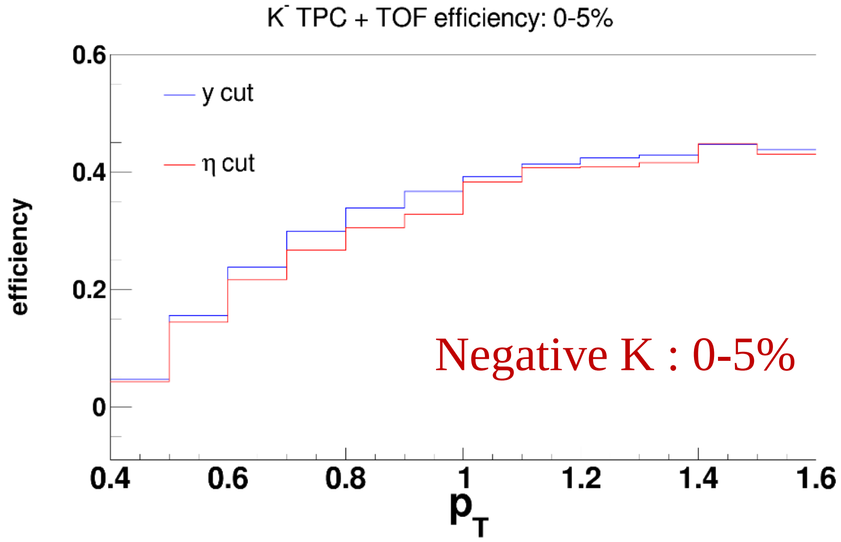
I used pseudorapidity(η) to calculate TPC efficiency of kaon, but analysis was done with |y|<0.5

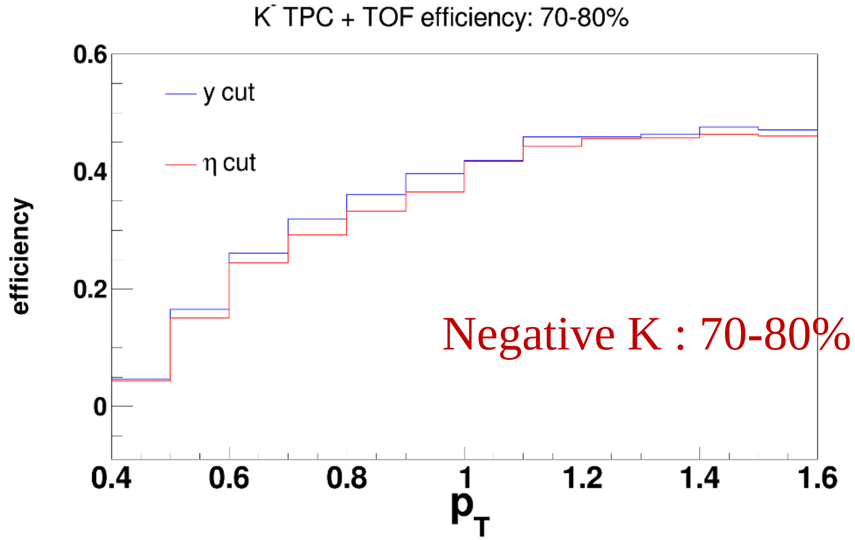
Phase-space window:

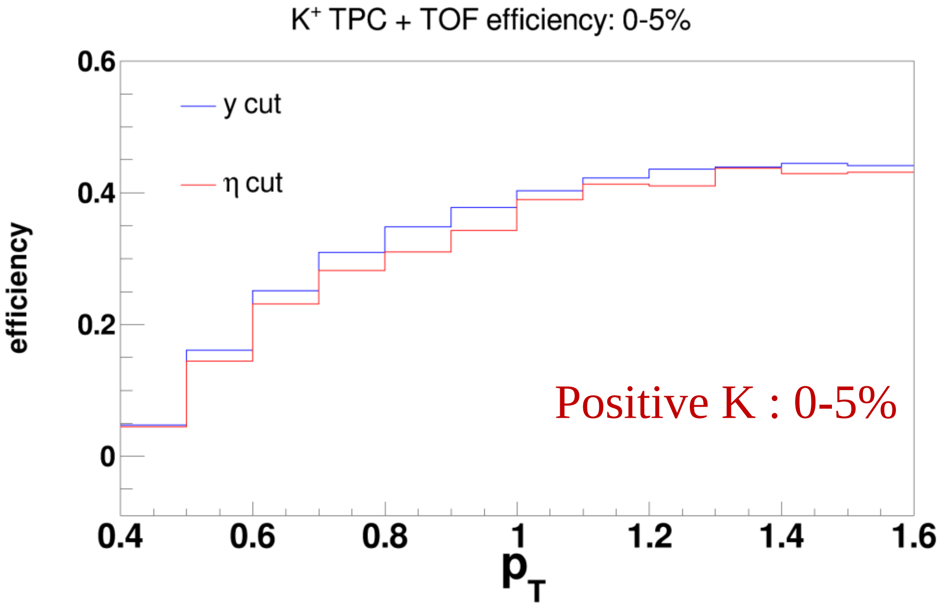
- $0.4 < p_T < 1.6$ GeV/c
- $|y| < 0.5$
- Track by track efficiency correction
- Centrality definition with Refmult2

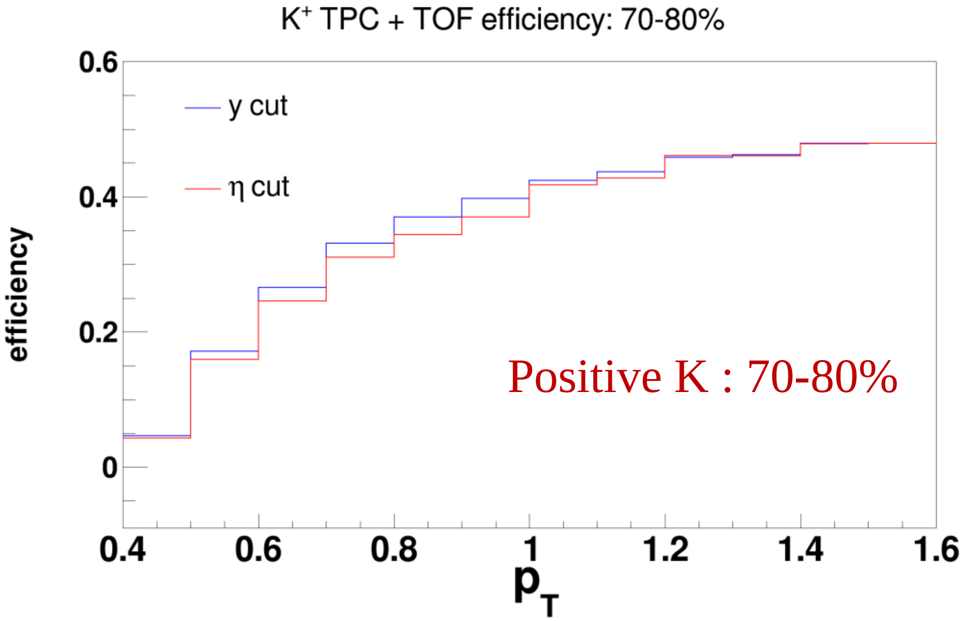


Comparison of kaon efficiency between |η|<0.5 and |y|<0.5 cut







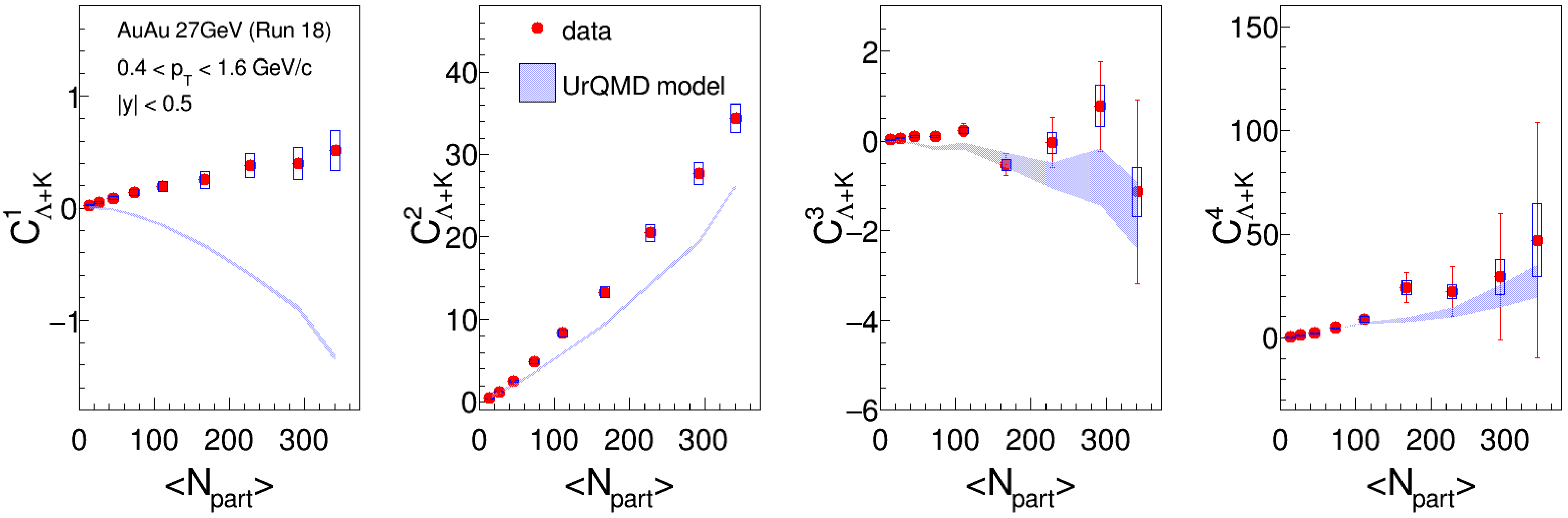


Cumulants of Net-(K+ Λ) multiplicity distributions

$$\text{Net-}(\Lambda+K) \equiv \Delta N_{(\Lambda+K)} = (N_{\text{anti-}\Lambda} + N_{K^+}) - (N_{\Lambda} - N_{K^-})$$

Phase-space window:

- $0.4 < p_T < 1.6$ GeV/c
- $|y| < 0.5$
- Track by track efficiency correction
- Centrality definition with Refmult2



Cumulants ratio of Net-(K+ Λ) multiplicity distributions

Net-(Λ+K) ≡ $\Delta N_{(\Lambda+K)} = (N_{anti\text{-}\Lambda} + N_{K^+}) - (N_{\Lambda} - N_{K^-})$

Phase-space window:

- $0.4 < p_T < 1.6$ GeV/c
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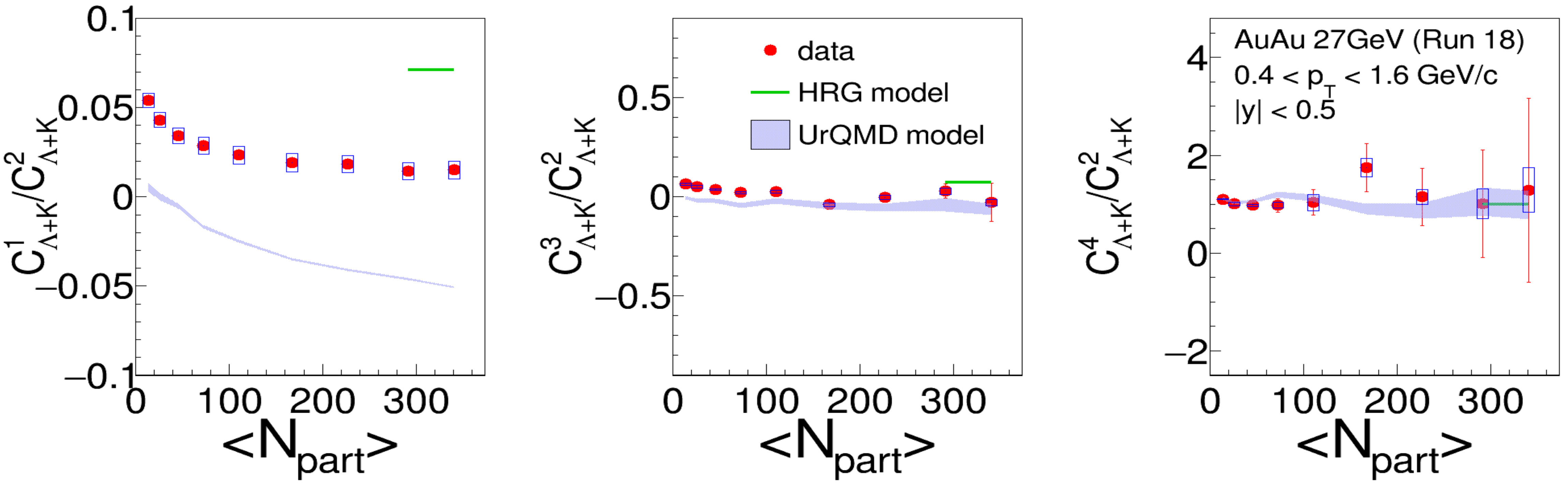
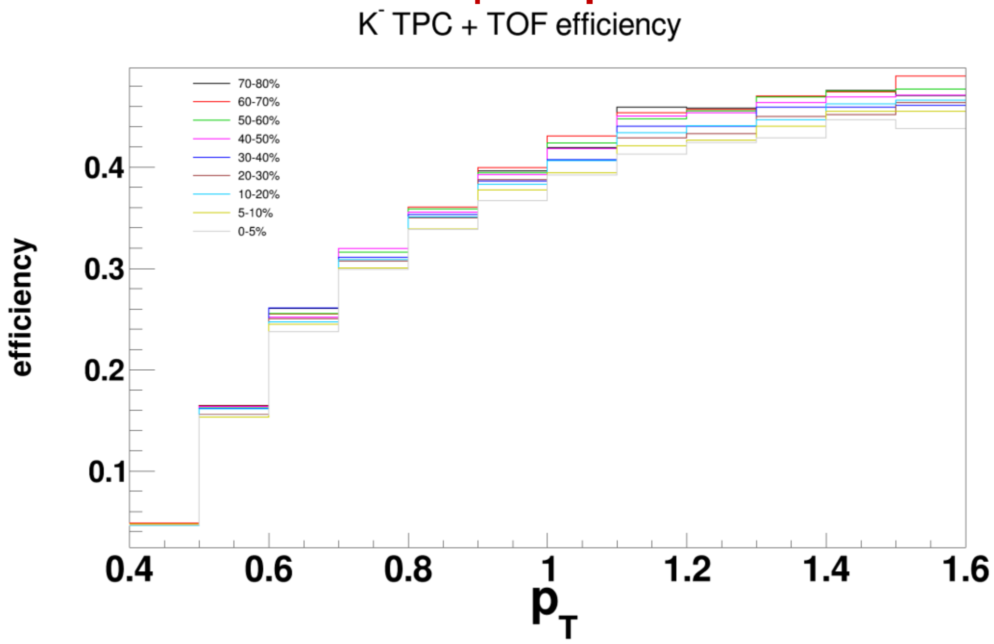


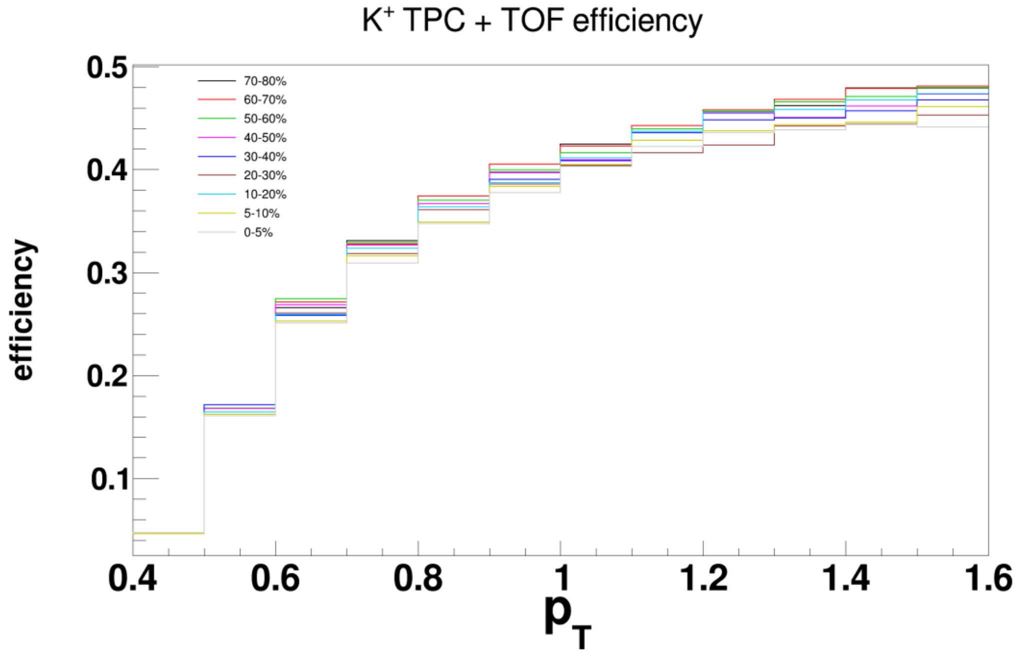
Summary and Outlook

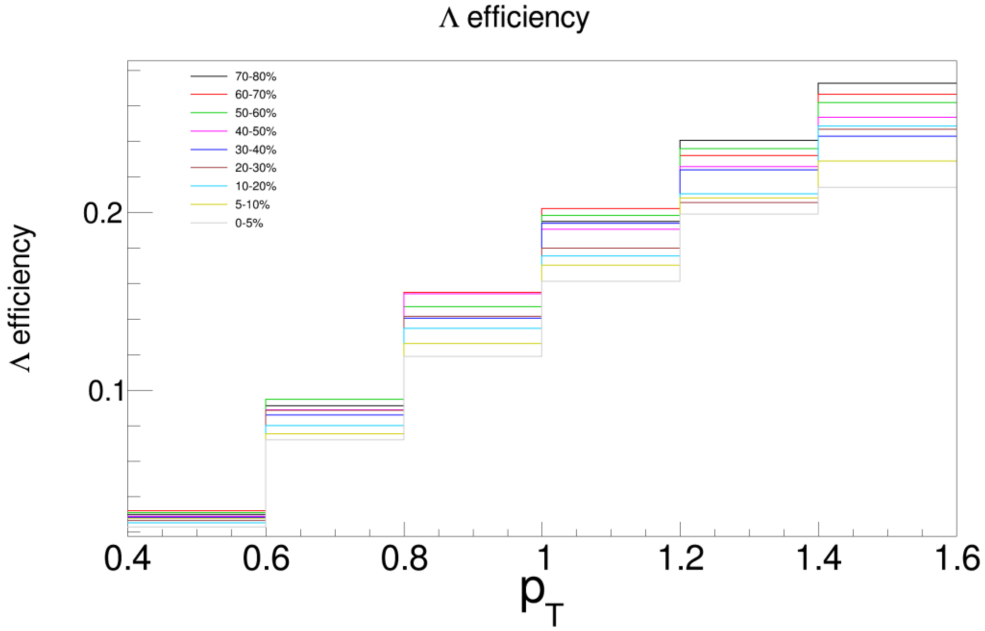
- First attempt to measure cumulants of net-(K+Λ) multiplicity distributions using Run18 27 GeV
- HRG and UrQMD results are compared with the data
- C_1/C_2 deviates from the HRG and UrQMD calculations, whereas C_3/C_2 and C_4/C_2 agrees with both the models.

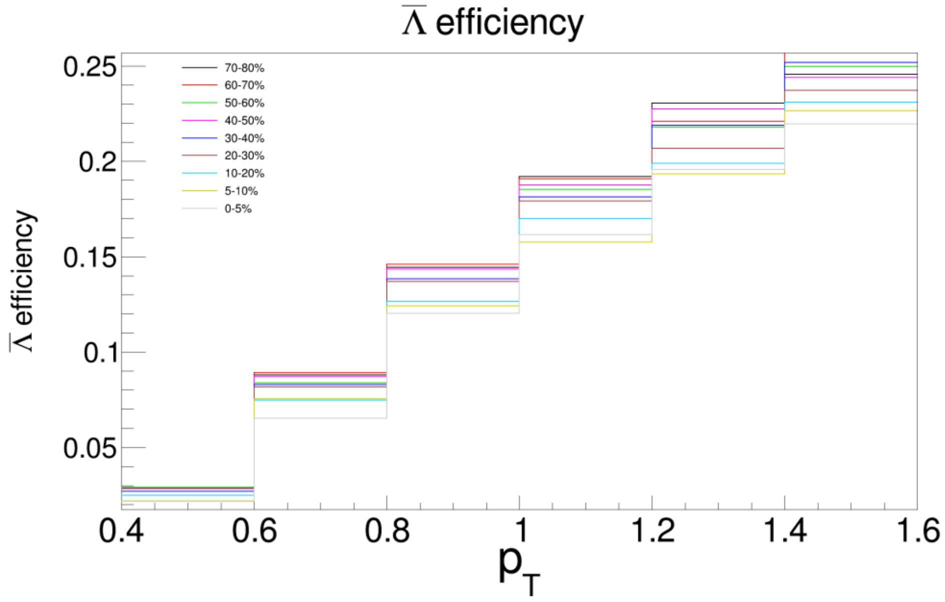
Backup

P_T dependent kaon and lambda efficiency

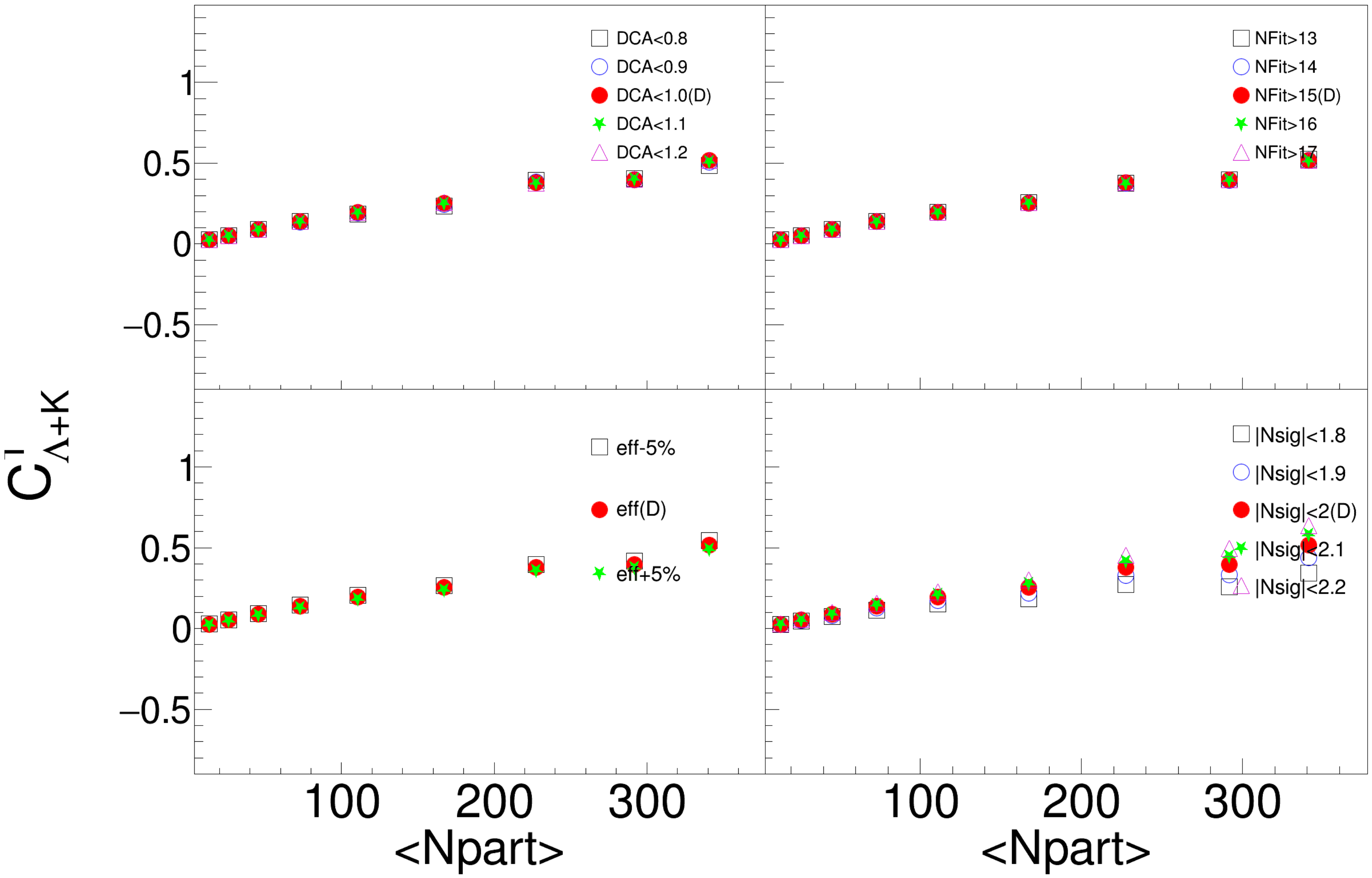


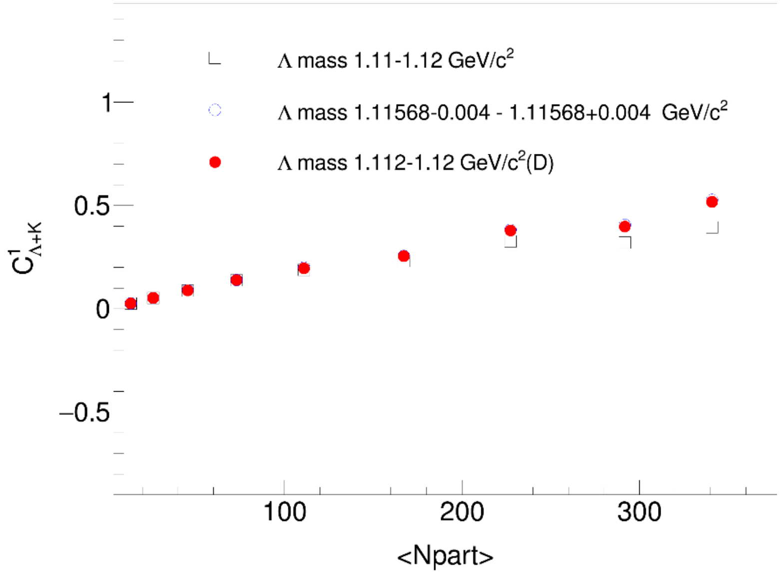






Systematic uncertainty estimation: DCA, nHits, efficiency, $|n\sigma_{PID}|$ and lambda mass window variations





$$\sigma_{sys} = Y_{def}\sqrt{\sum_j R_j^2}$$

$$R_j = \sqrt{\frac{1}{n}\sum_i \left(\frac{Y_{i,j} - Y_{def}}{Y_{def}}\right)^2}$$

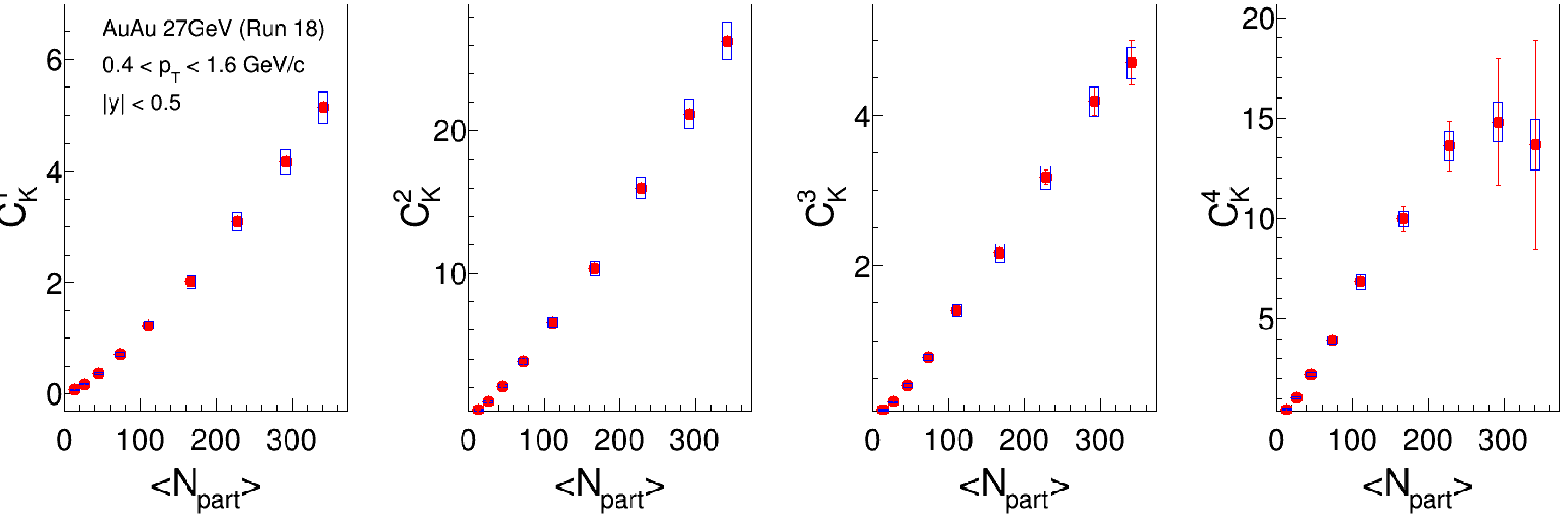
Y_i represents *i*th change of the cut on jth variable

Cumulants of Net-Kaon multiplicity distributions

Net-K $\equiv$ ΔN_K = $N_K^+ - N_K^-$

Phase-space window:

- $0.4 < p_T < 1.6$ GeV/c
- $|y| < 0.5$
- Track by track efficiency correction
- Centrality definition with Refmult2

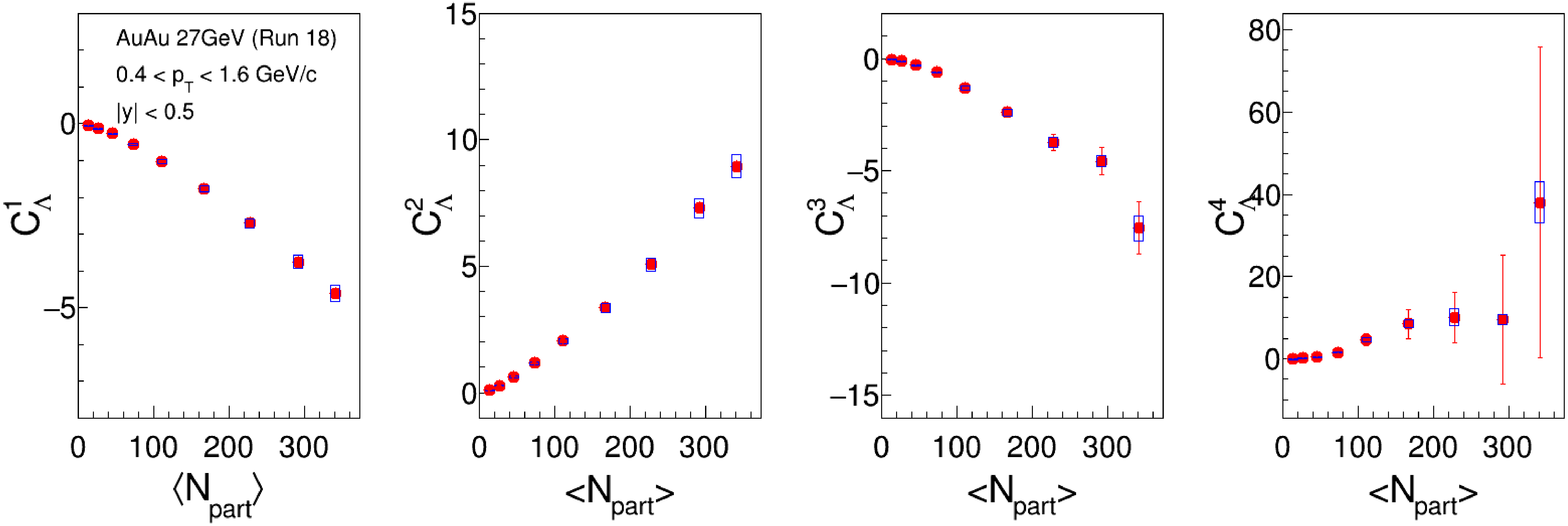


Cumulants of Net-Λ multiplicity distributions

$\text{Net-}\Lambda \equiv \Delta N_\Lambda = N_{\text{anti-}\Lambda} - N_\Lambda$

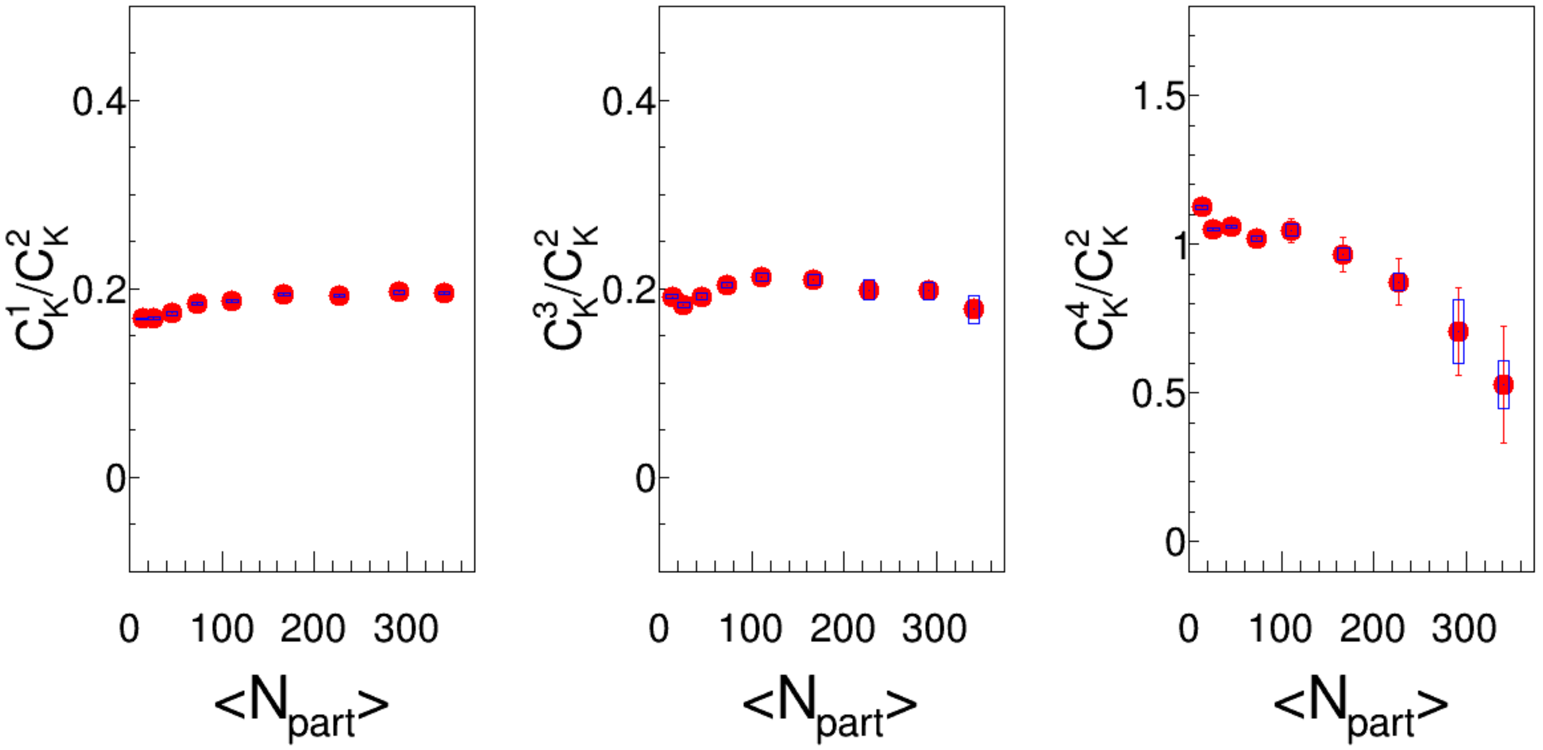
Phase-space window:

- $0.4 < p_T < 1.6$ GeV/c
- $|y| < 0.5$
- Track by track efficiency correction
- Centrality definition with Refmult2



Cumulants ratio of Net-Kaon multiplicity distributions

Net-K ≡ ΔN_K = $N_K^+ - N_K^-$



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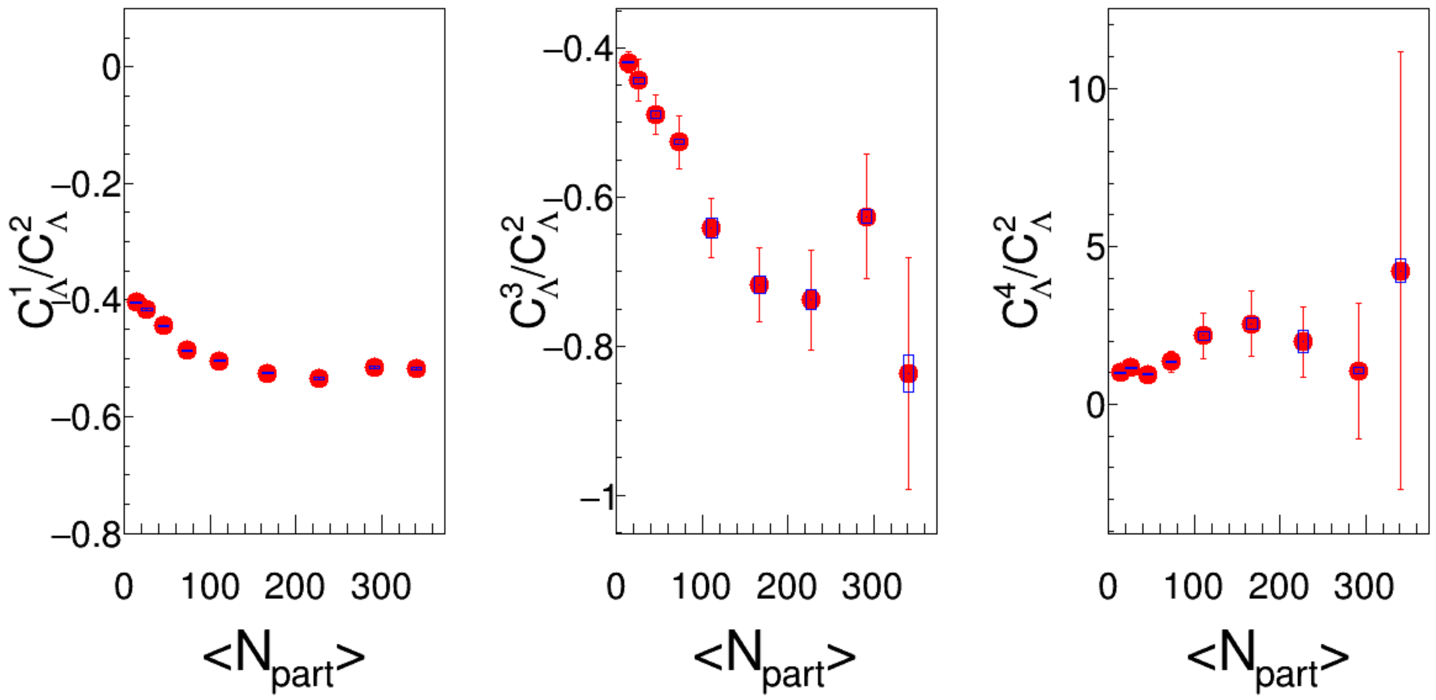
Cumulants ratio of Net-Λ multiplicity distributions

$\text{Net-}\Lambda \equiv \Delta N_{\Lambda} = N_{\text{anti-}\Lambda} - N_{\Lambda}$



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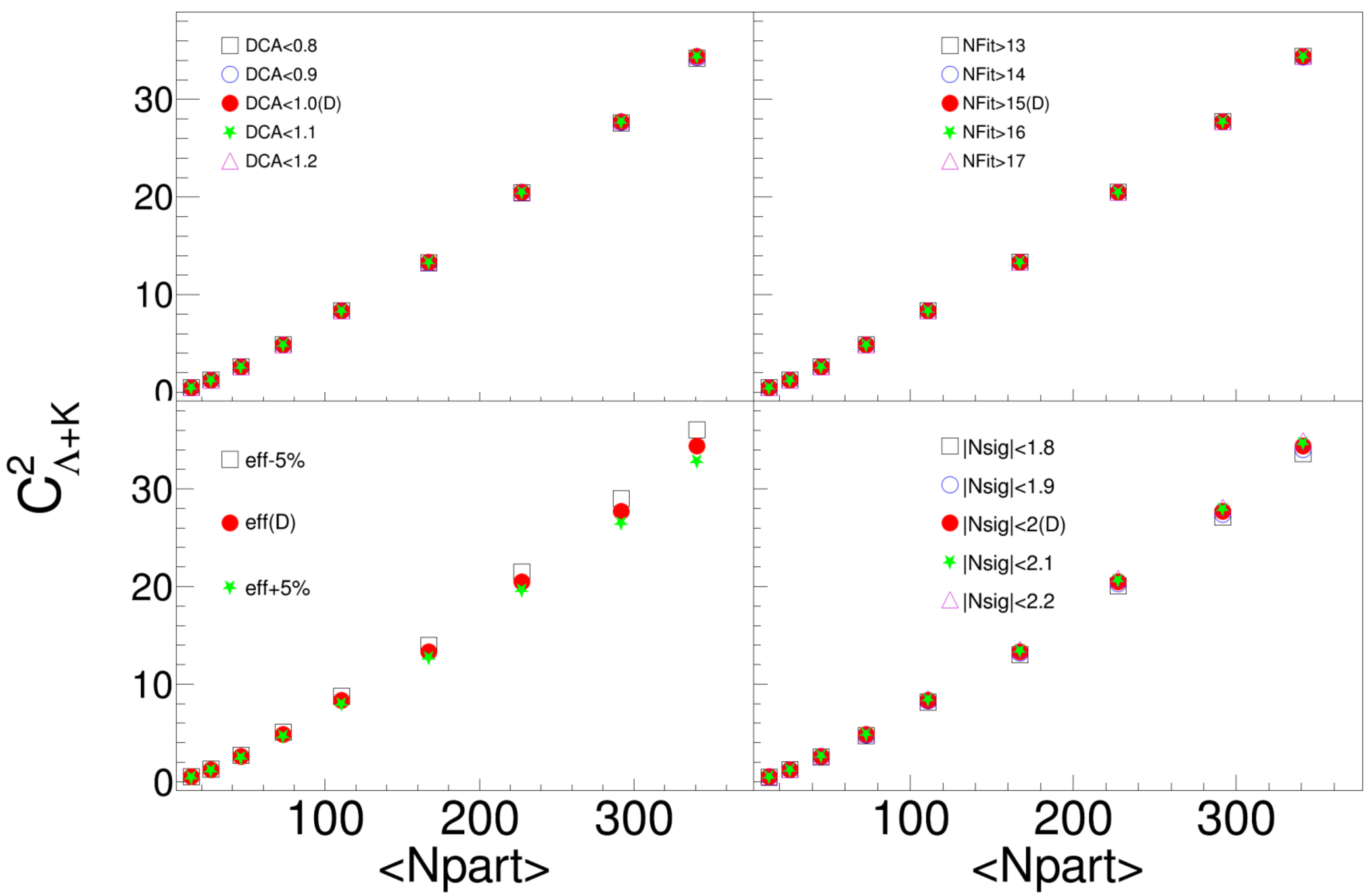
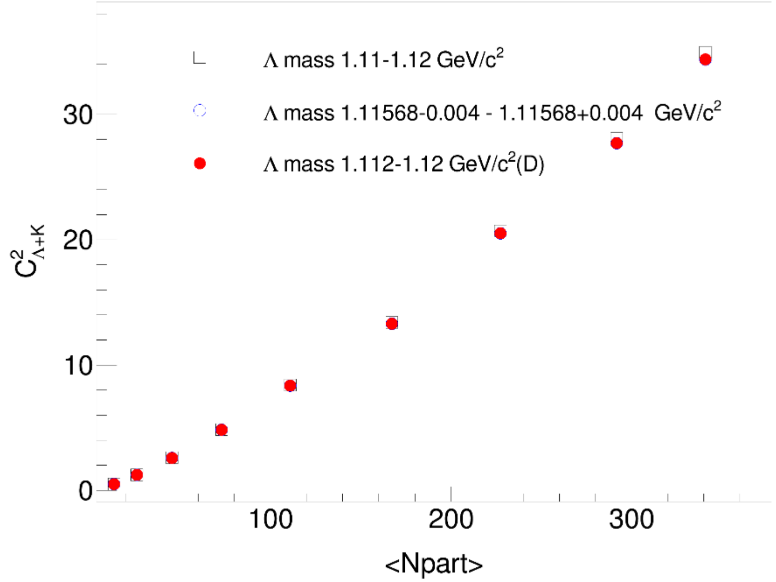
Systematic uncertainty estimation: DCA, nHits, efficiency, $|n\sigma_{PID}|$ and lambda mass window variations



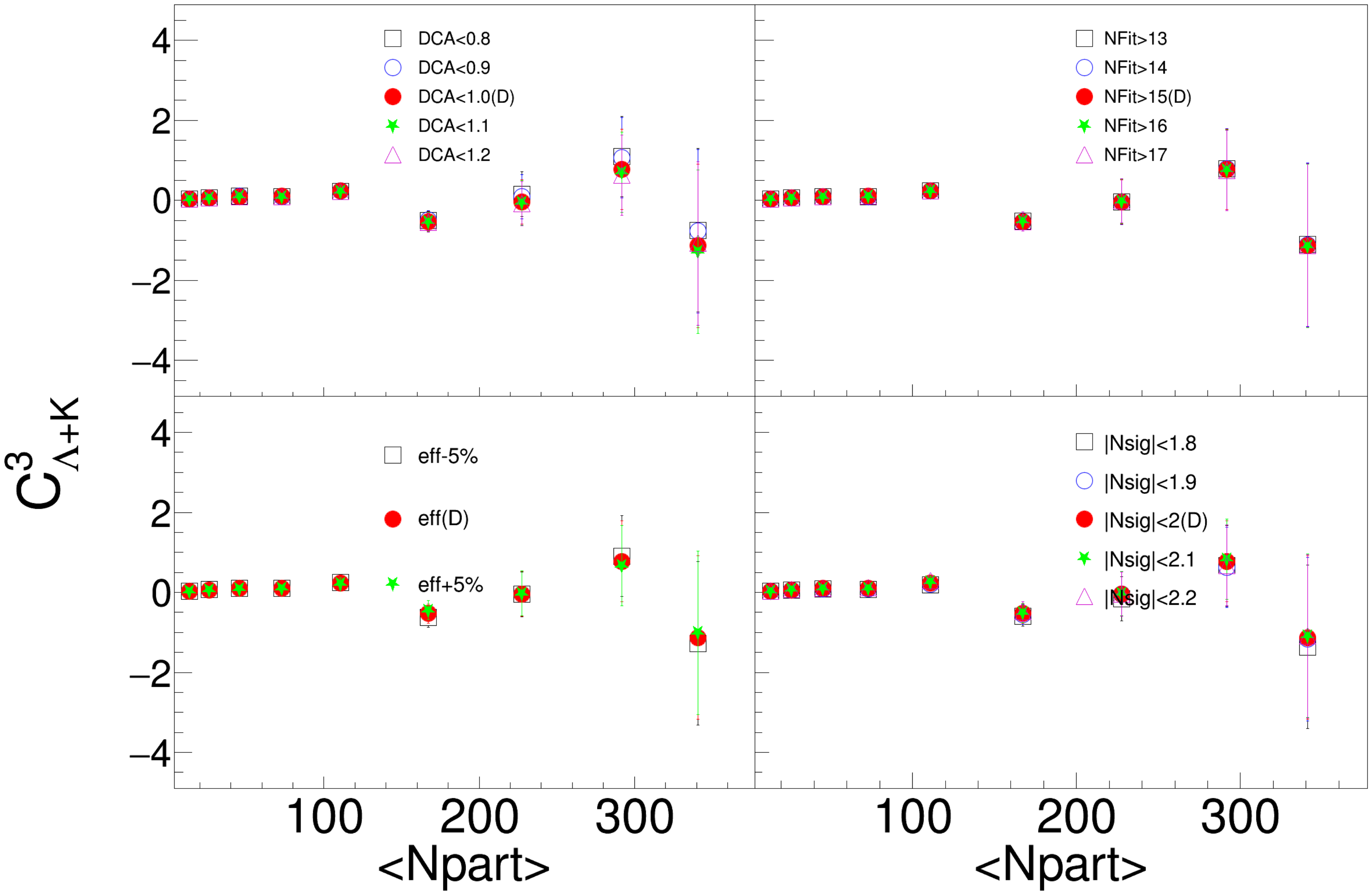


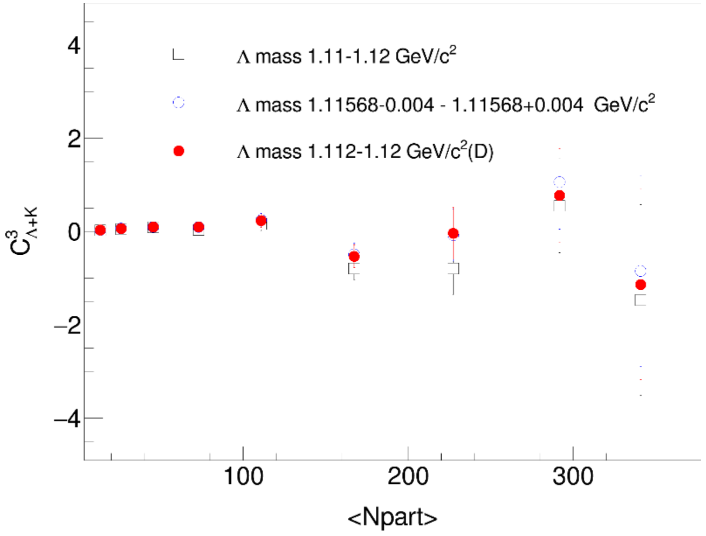
$$\sigma_{sys} = Y_{def} \sqrt{\sum_j R_j^2}$$

$$R_j = \sqrt{\frac{1}{n} \sum_i \left(\frac{Y_{i,j} - Y_{def}}{Y_{def}} \right)^2}$$

Y_i represents *i*th change of the cut on jth variable

Systematic uncertainty estimation: DCA, nHits, efficiency, $|n\sigma_{PID}|$ and lambda mass window variations





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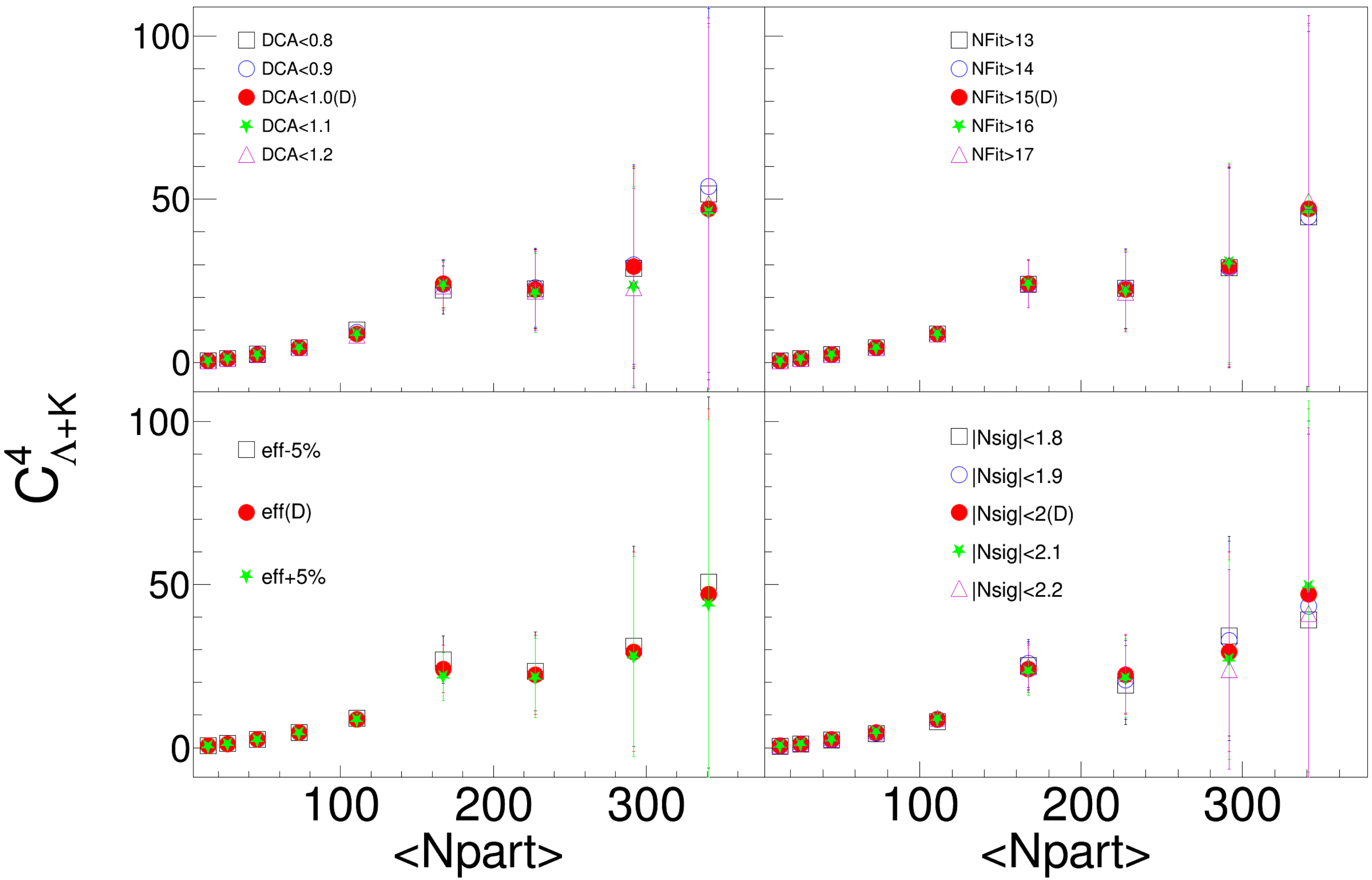

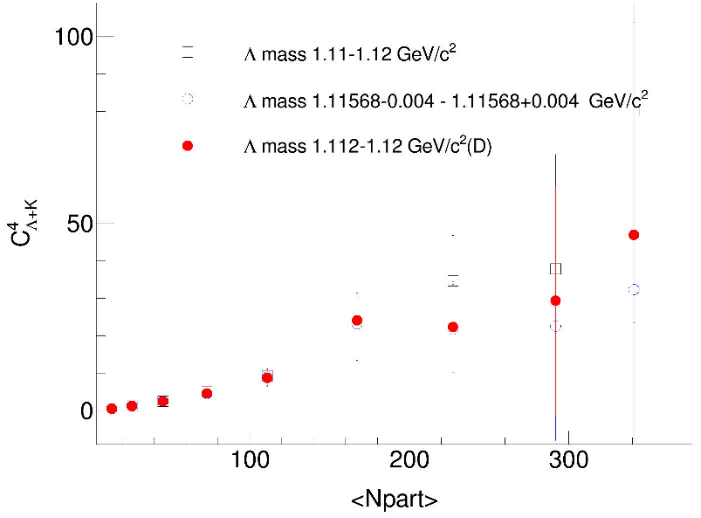

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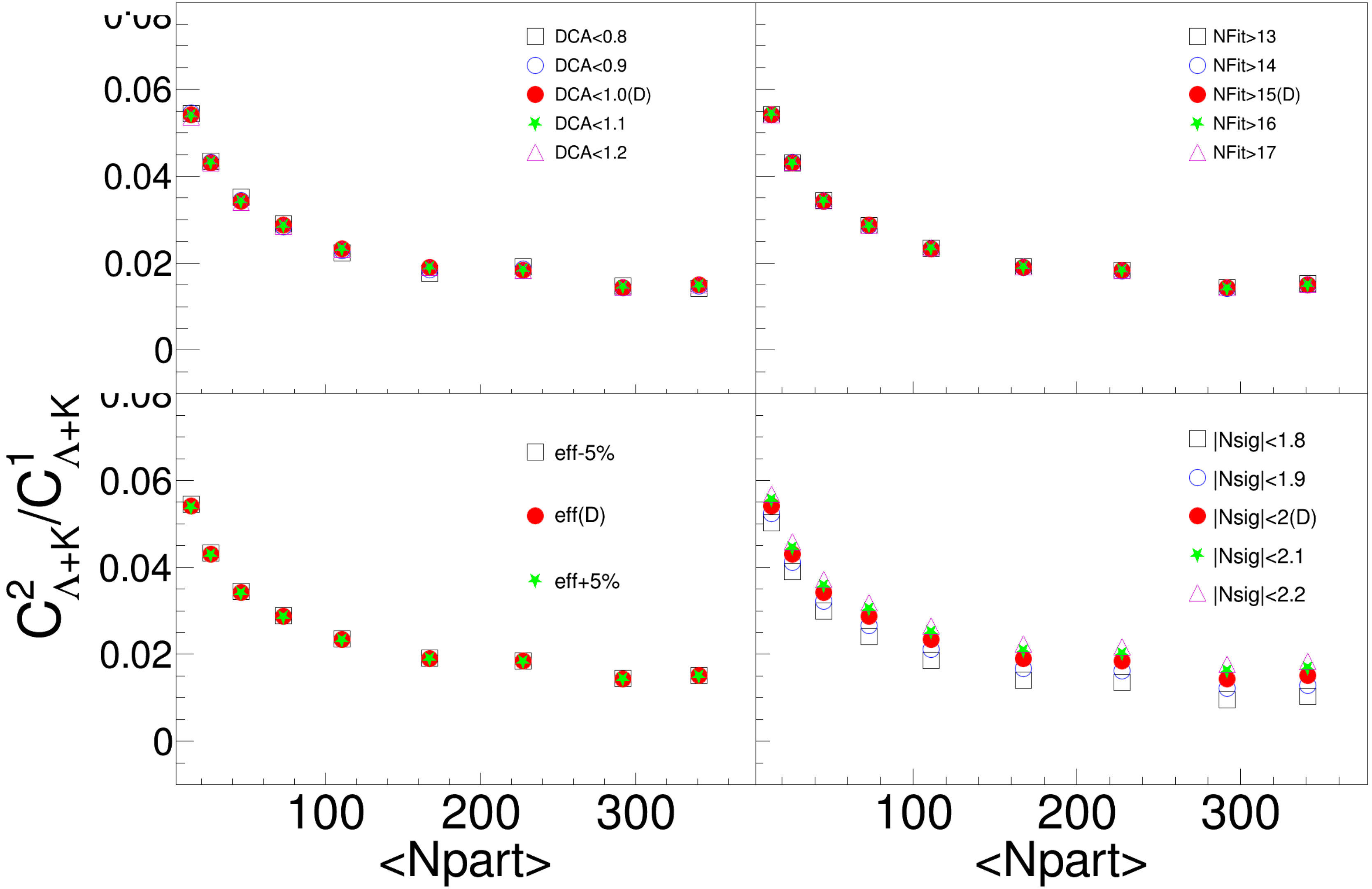
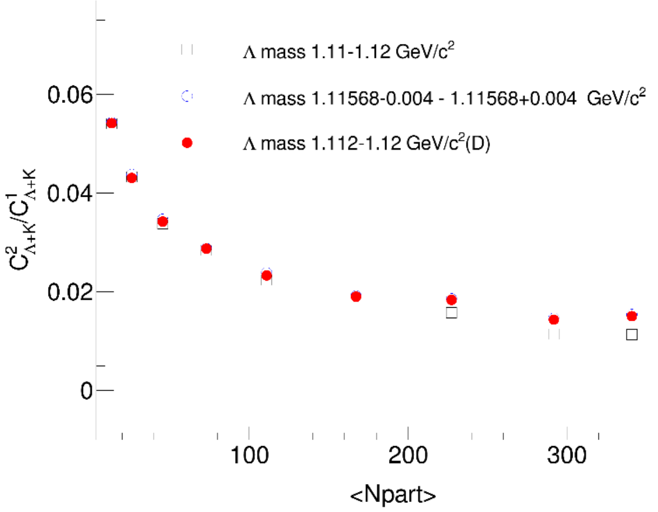
Y_i represents *i*th change of the cut on jth variable

Systematic uncertainty estimation: DCA, nHits, efficiency, $|n\sigma_{PID}|$ and lambda mass window variations





$$\sigma_{sys} = Y_{def}\sqrt{\sum_j R_j^2}$$

$$R_j = \sqrt{\frac{1}{n}\sum_i\left(\frac{Y_{i,j} - Y_{def}}{Y_{def}}\right)^2}$$

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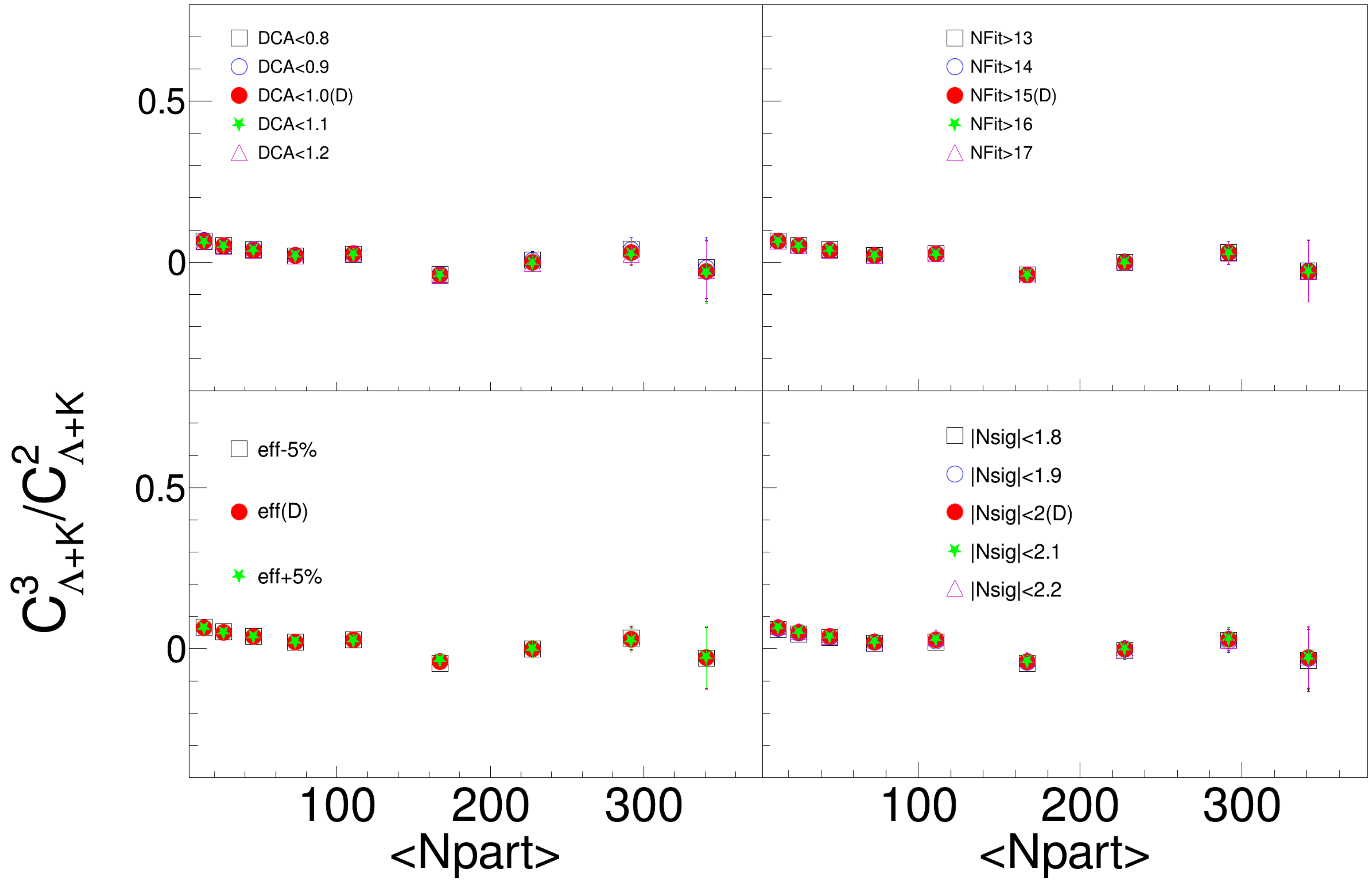

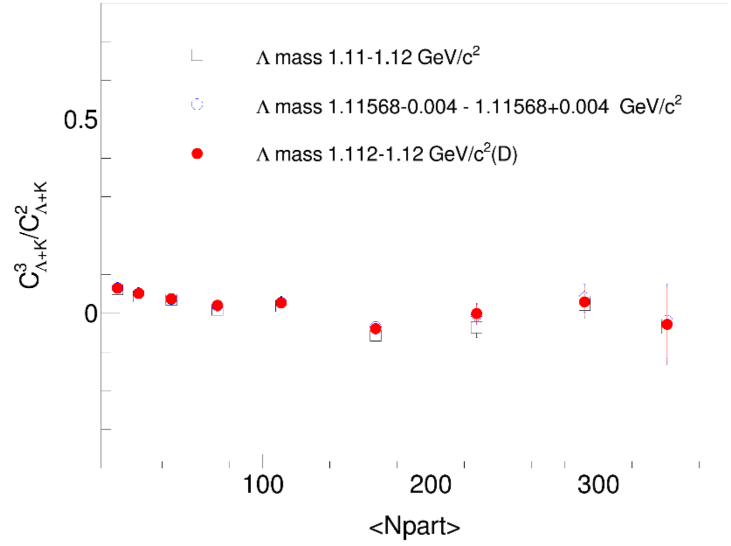

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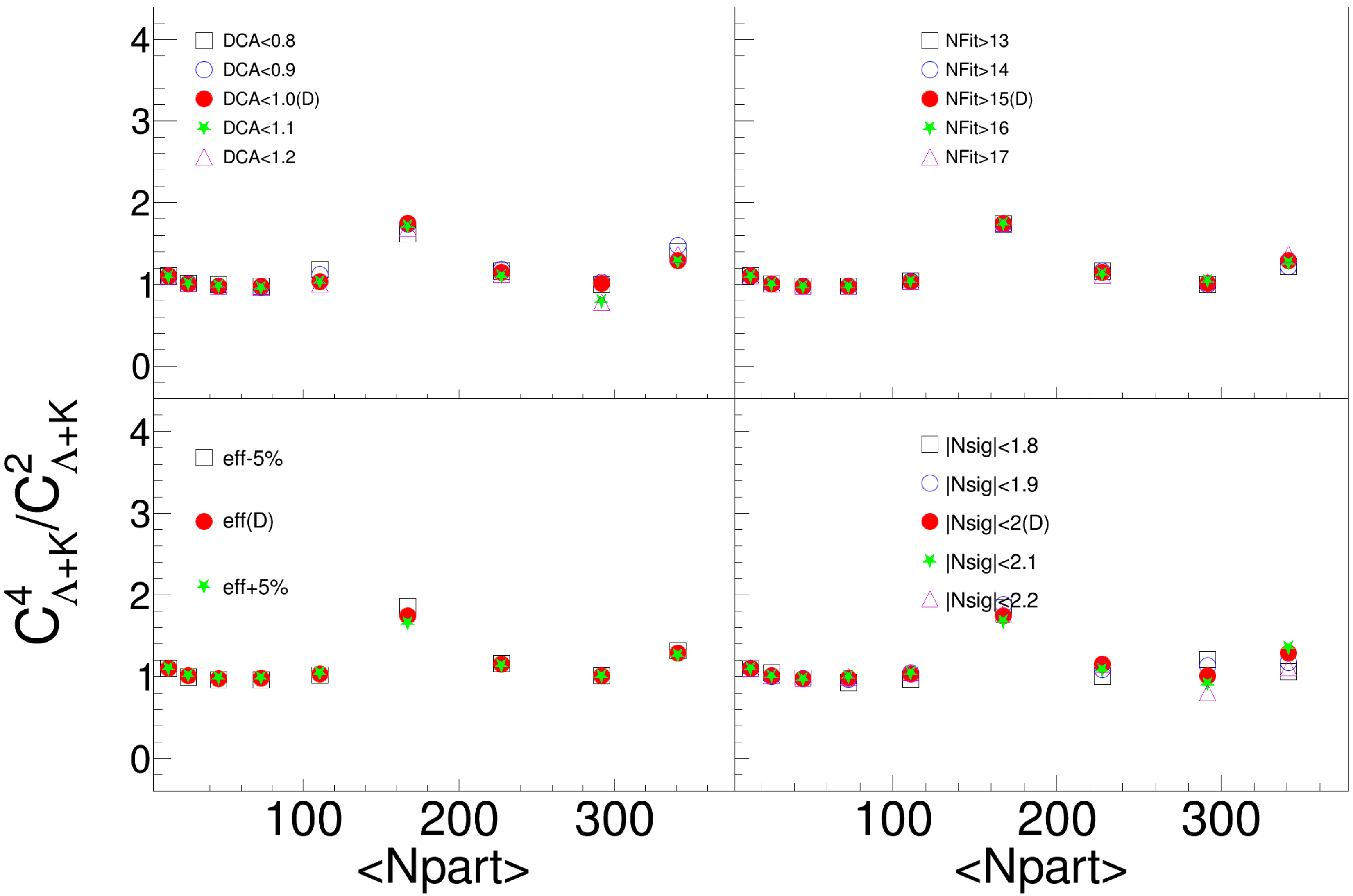
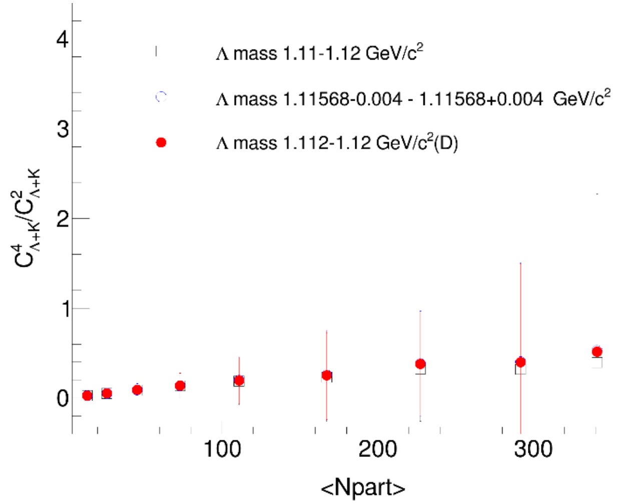
Systematic uncertainty estimation: DCA, nHits, efficiency, $|n\sigma_{PID}|$ and lambda mass window variations





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Y_i represents *i*th change of the cut on jth variable

P_T dependent kaon efficiency

I use the pseudorapidity cut when I calculate TPC efficiency of kaon