Energy Dependence of Higher Moments of Net-Kaon Multiplicity Distributions at STAR

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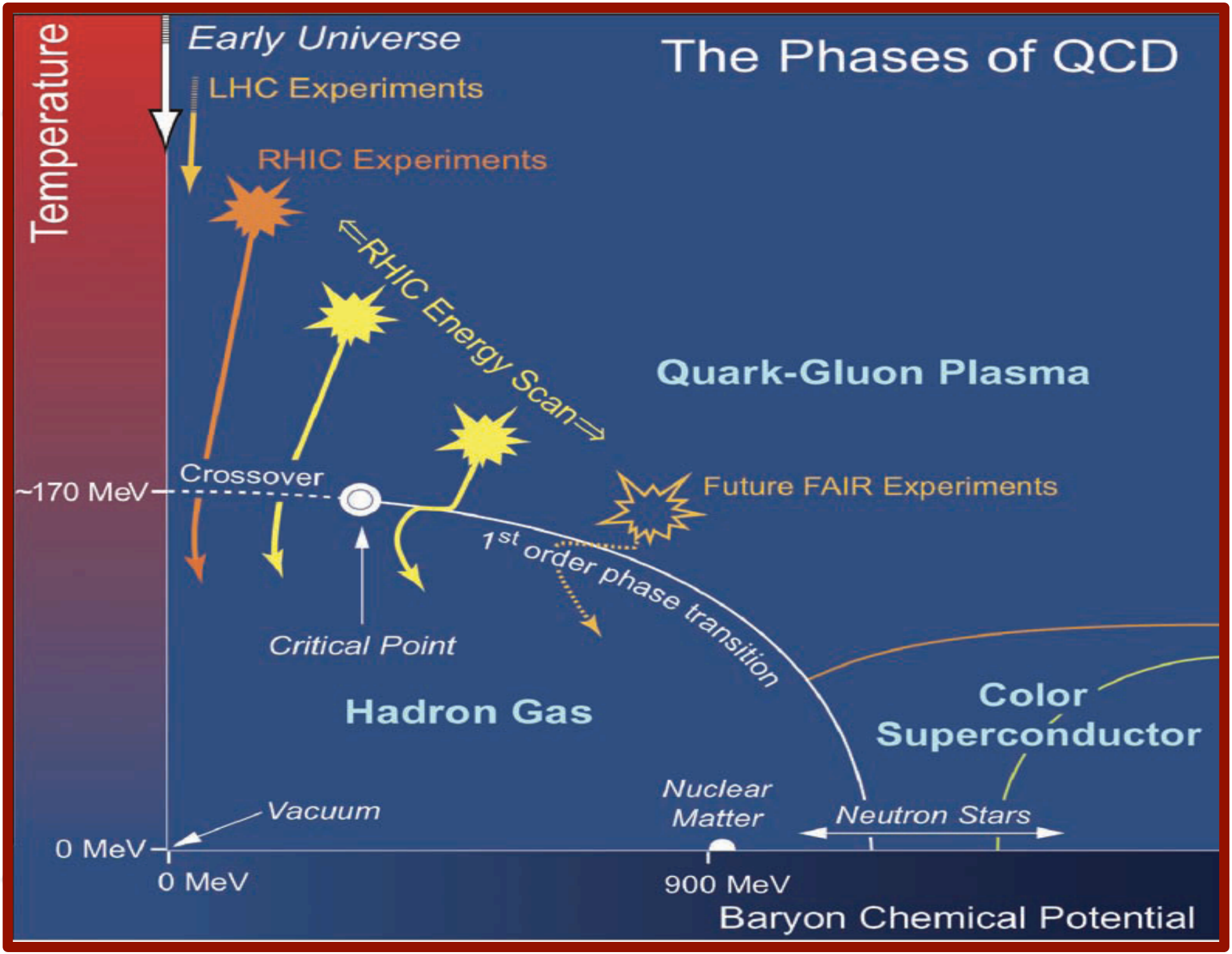
Outline:

1) Status of the Net-Kaon Analysis at STAR

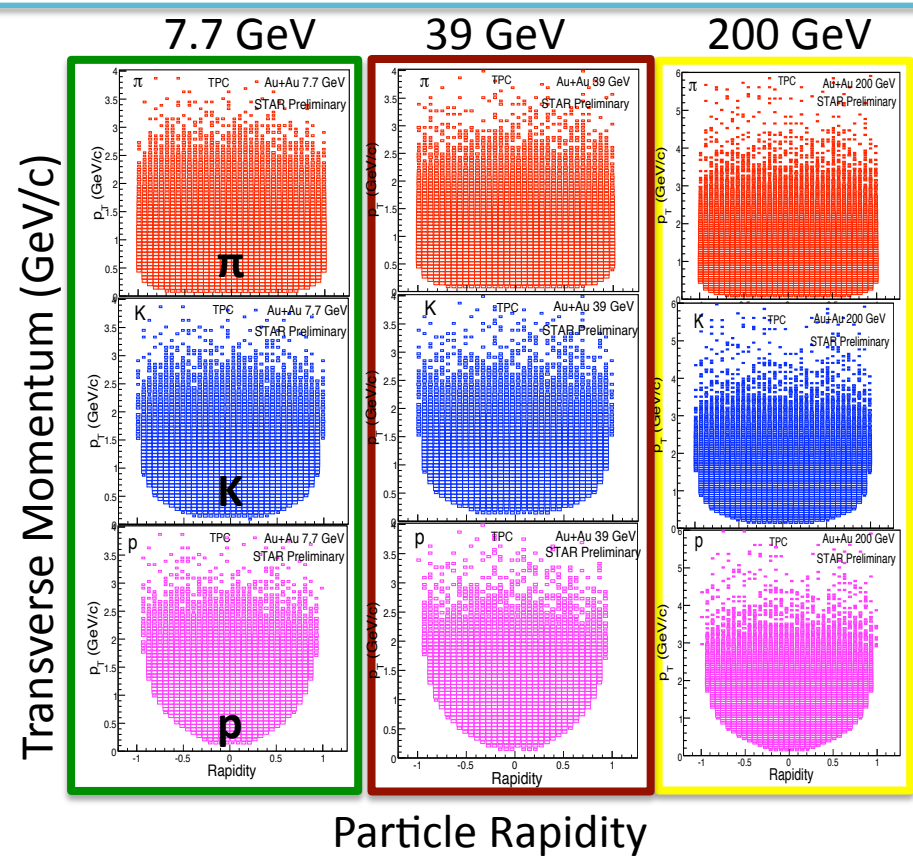
(Based on QM2015 Poster by Ji Xu)

2) Future Plan


The Phases of QCD
Temperature
Early Universe
LHC Experiments
RHIC Experiments
RHIC Energy Scan
Quark-Gluon Plasma
Crossover
~170 MeV
Future FAIR Experiments
1st order phase transition
Critical Point
Hadron Gas
Color Superconductor
Nuclear Matter
Neutron Stars
Vacuum
0 MeV
0 MeV
900 MeV
Baryon Chemical Potential

Data Sets at STAR

$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	Year	*μ_B (MeV)	*T_{CH} (MeV)
200	350	2010	25	166
62.4	67	2010	73	165
39	39	2010	112	164
27	70	2011	156	162
19.6	36	2011	206	160
14.5	20	2014	264	156
11.5	12	2010	316	152
7.7	4	2010	422	140

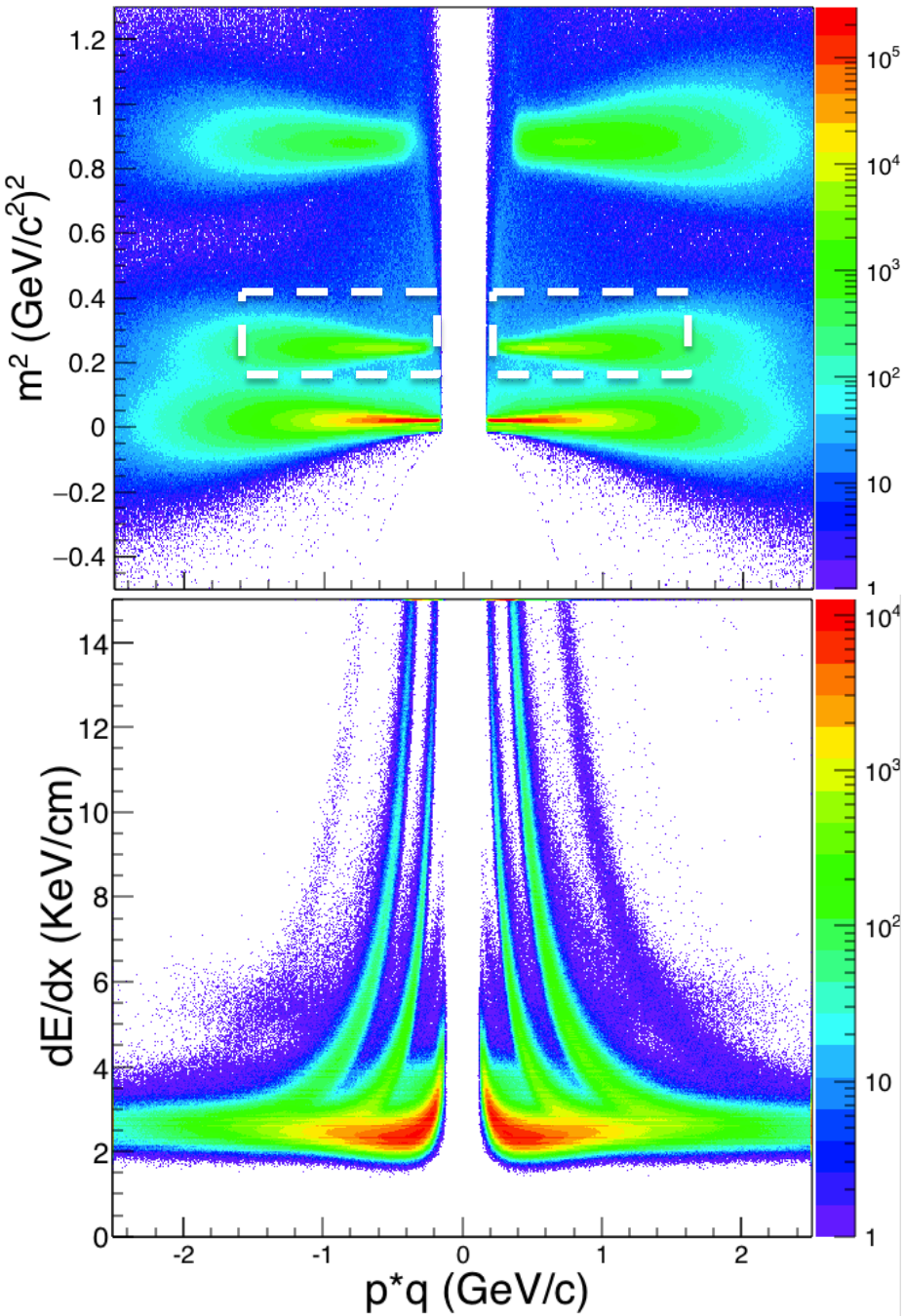


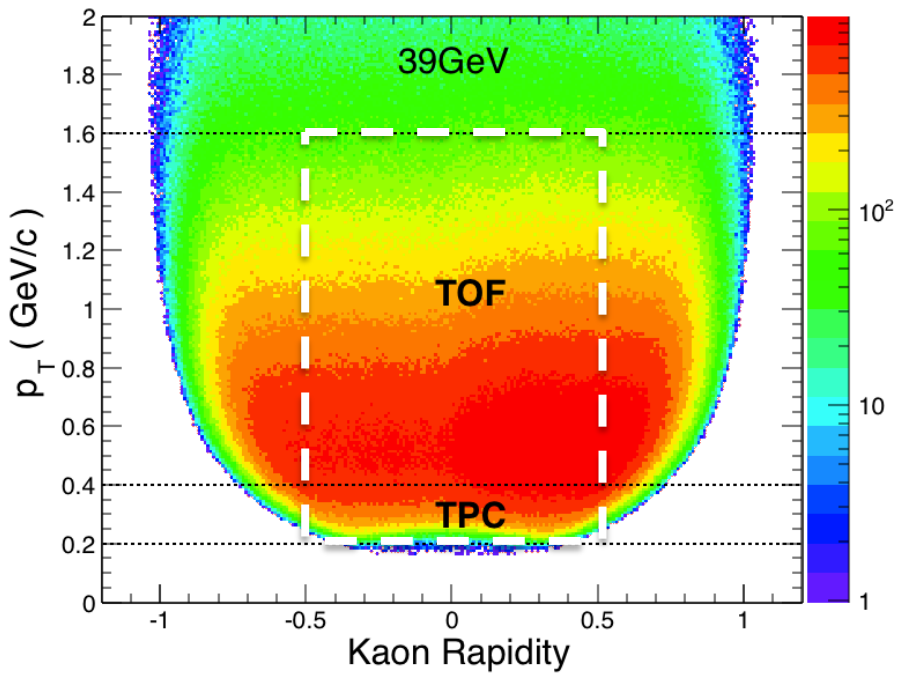
1) Largest data sets versus collision energy: **Many thanks to RHIC operation!**
2) STAR: Large and homogeneous acceptance, excellent particle identification capabilities. Important for fluctuation analysis!

*(μ_B, T_{CH}) : J. Cleymans et al., PRC 73, 034905 (2006)
Talk by J. Thäder, at QM2015

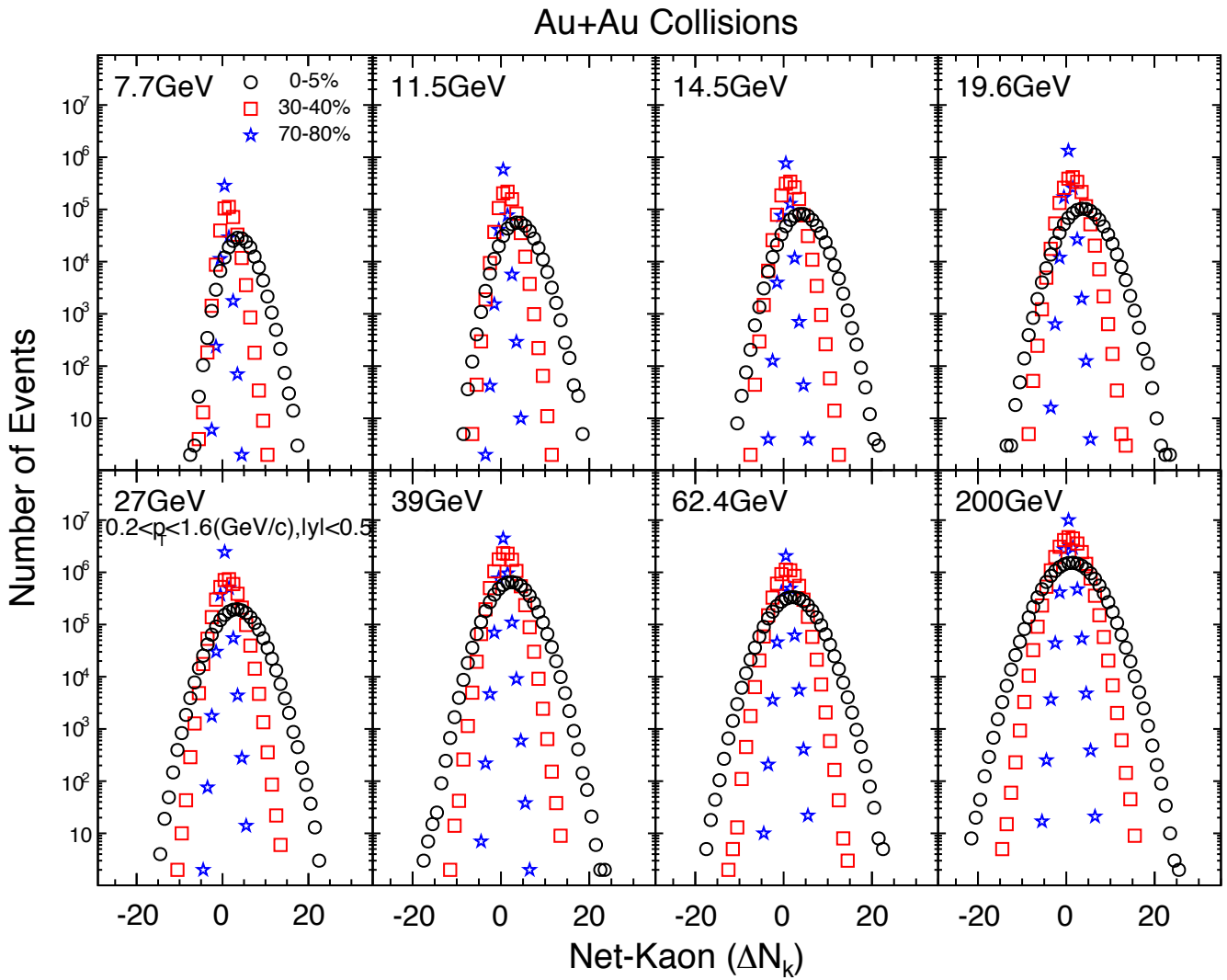
$K^{\pm}$ Identifications

- **BES-I**: $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5 19.6, 27, 39 GeV
- **Kaon PID**: within $0.2 < p_T < 1.6$ (GeV/c) $|y_{Kaon}| < 0.5$
- **Kaon Purity:** > 98%





Raw Net-Kaon Distributions

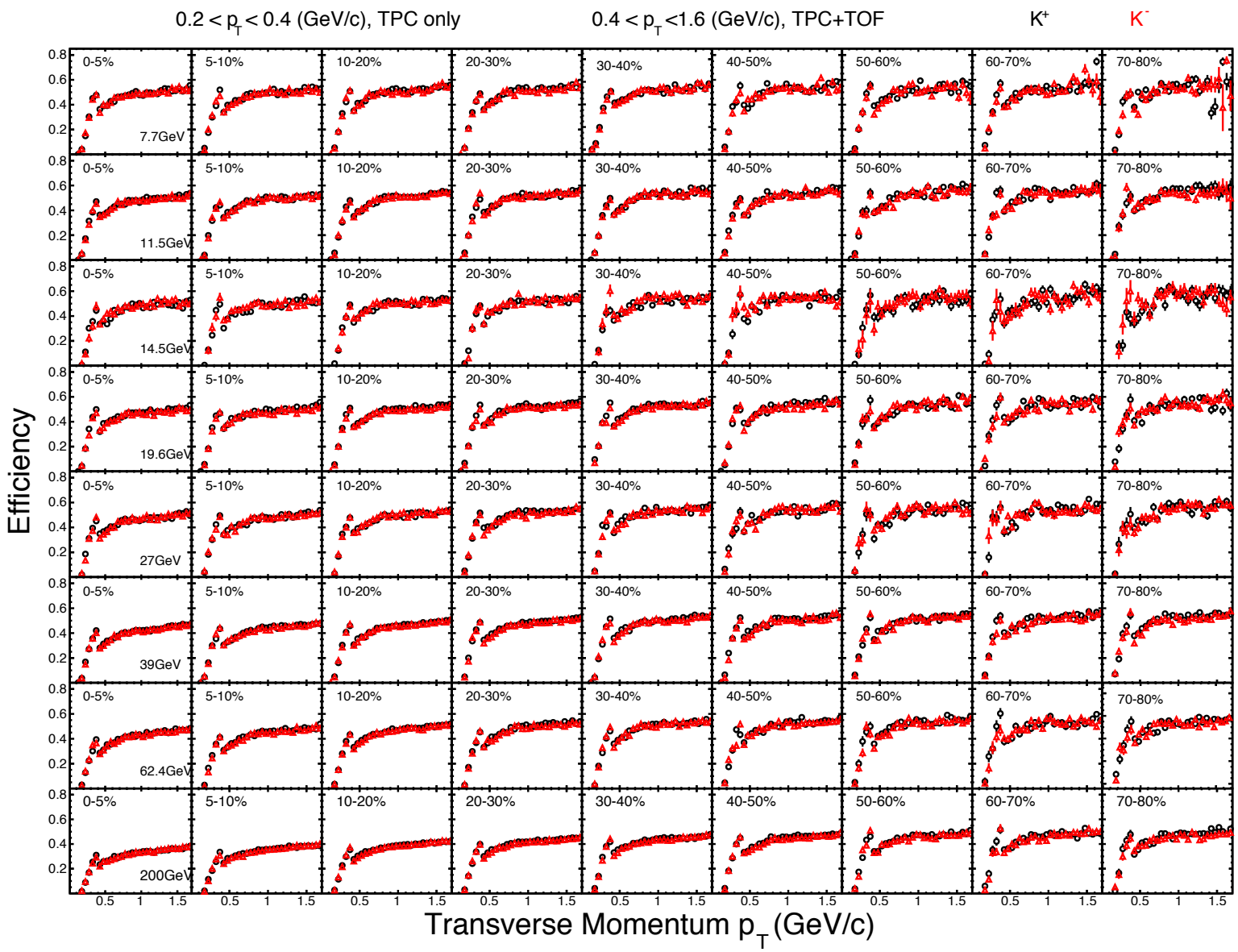


Corrections:

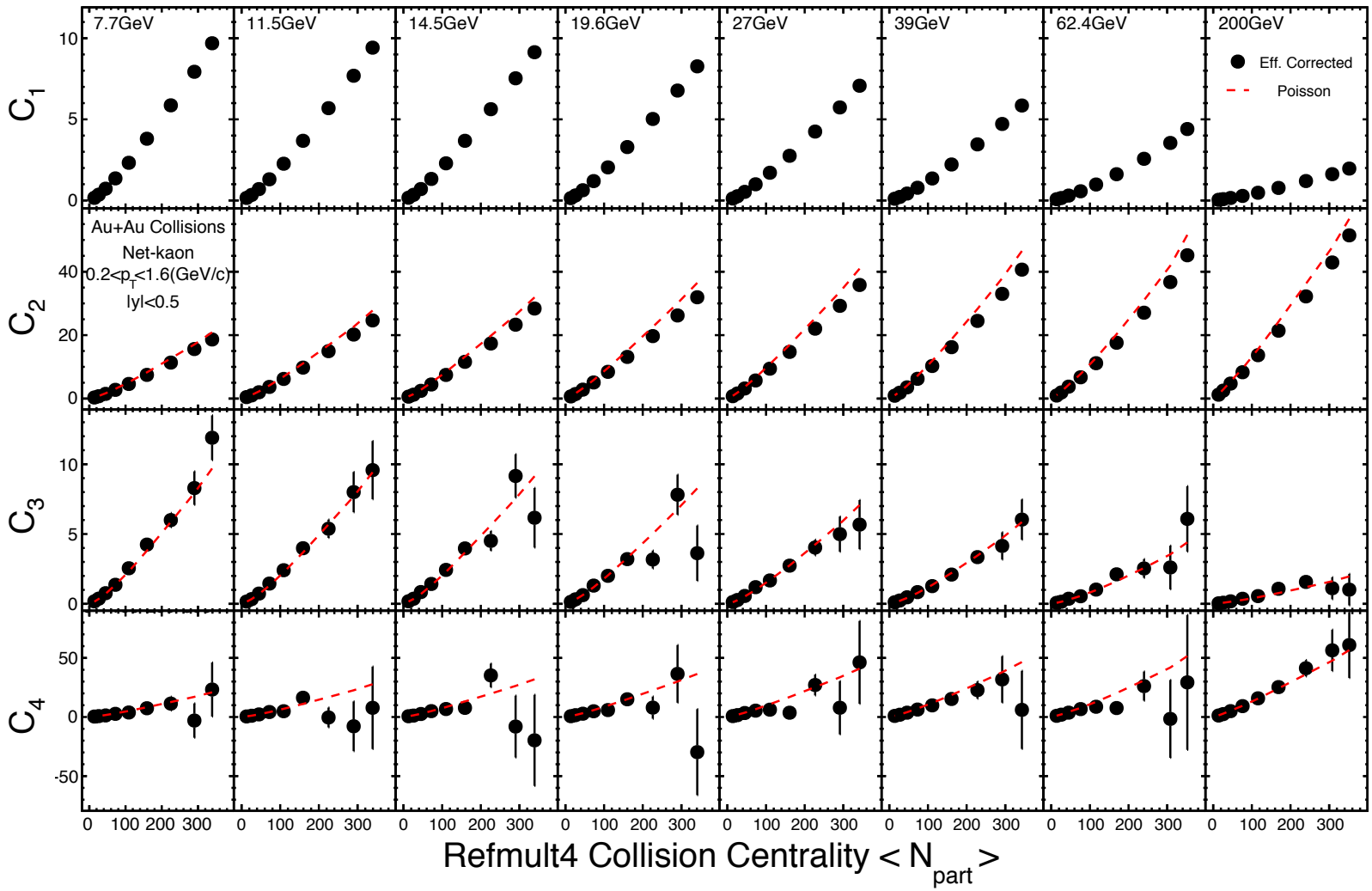
1. Auto-correlation in event selection
2. Volume fluctuations
3. Detector efficiency

X. Luo, PRC91, 034907 (15)
X. Luo, et al. JPG40,105104(13)

Kaon PID Efficiencies



Centrality Dependence of Cumulants



Systematic Errors Estimation

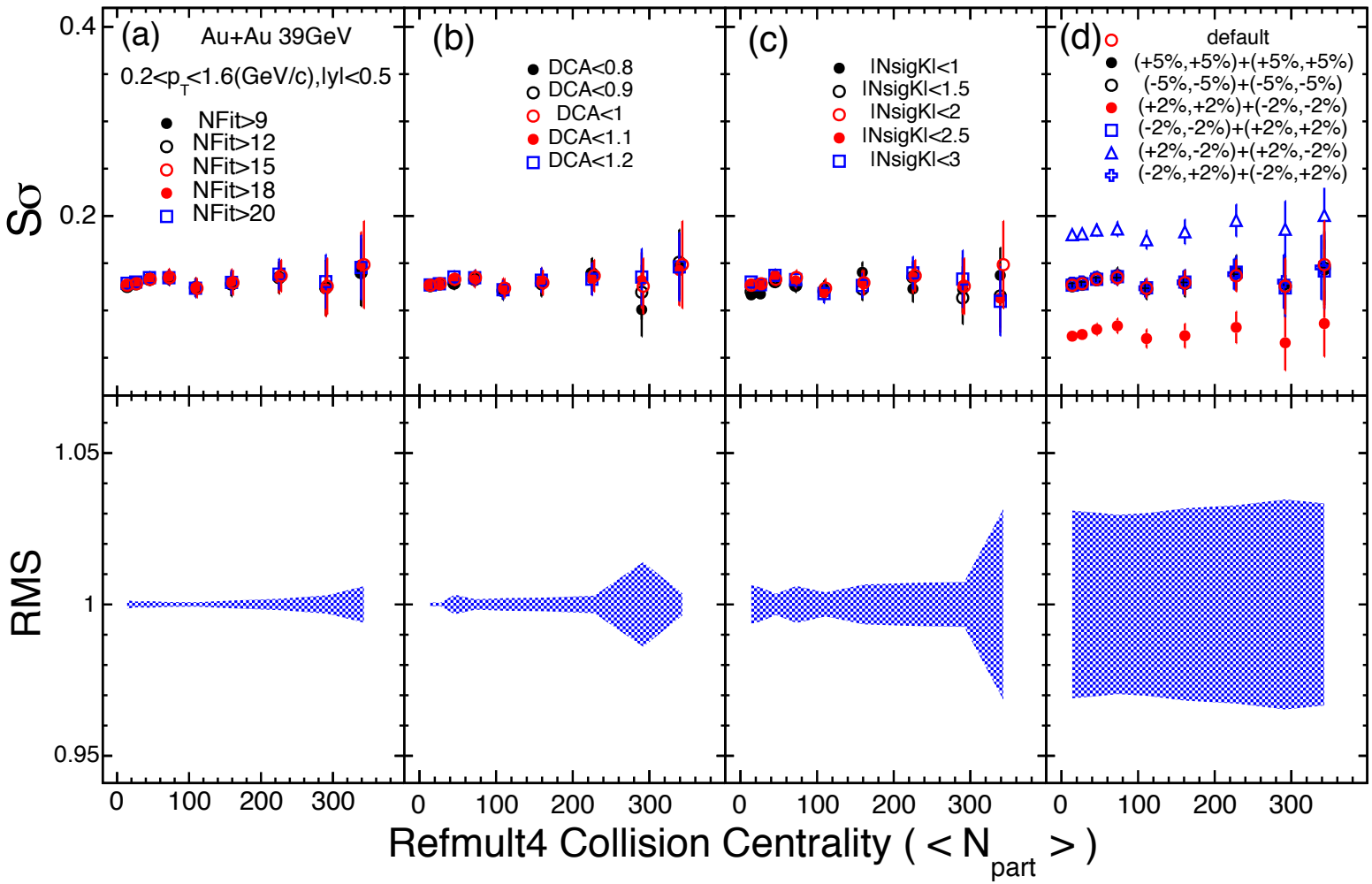
- Varying PID, DCA, Nfit cuts and efficiencies to study the systematic errors, for all the energies .

  1) NFitPoint > {9, 12, **15**, 18, 20}
  2) DCA (cm) < {0.8, 0.9, **1.0**, 1.1, 1.2}
  3) |nSigmaKaon| < {1, 1.5, **2**, 2.5, 3}
  4) Efficiency: (+5%, +5%)+(+5%, +5%); (-5%, -5%)+(-5%, -5%)
     (+2%, +2%)+(-2%, -2%); (-2%, -2%)+(+2%, +2%)
     (+2%, -2%)+(+2%, -2%); (-2%, +2%)+(-2%, +2%)

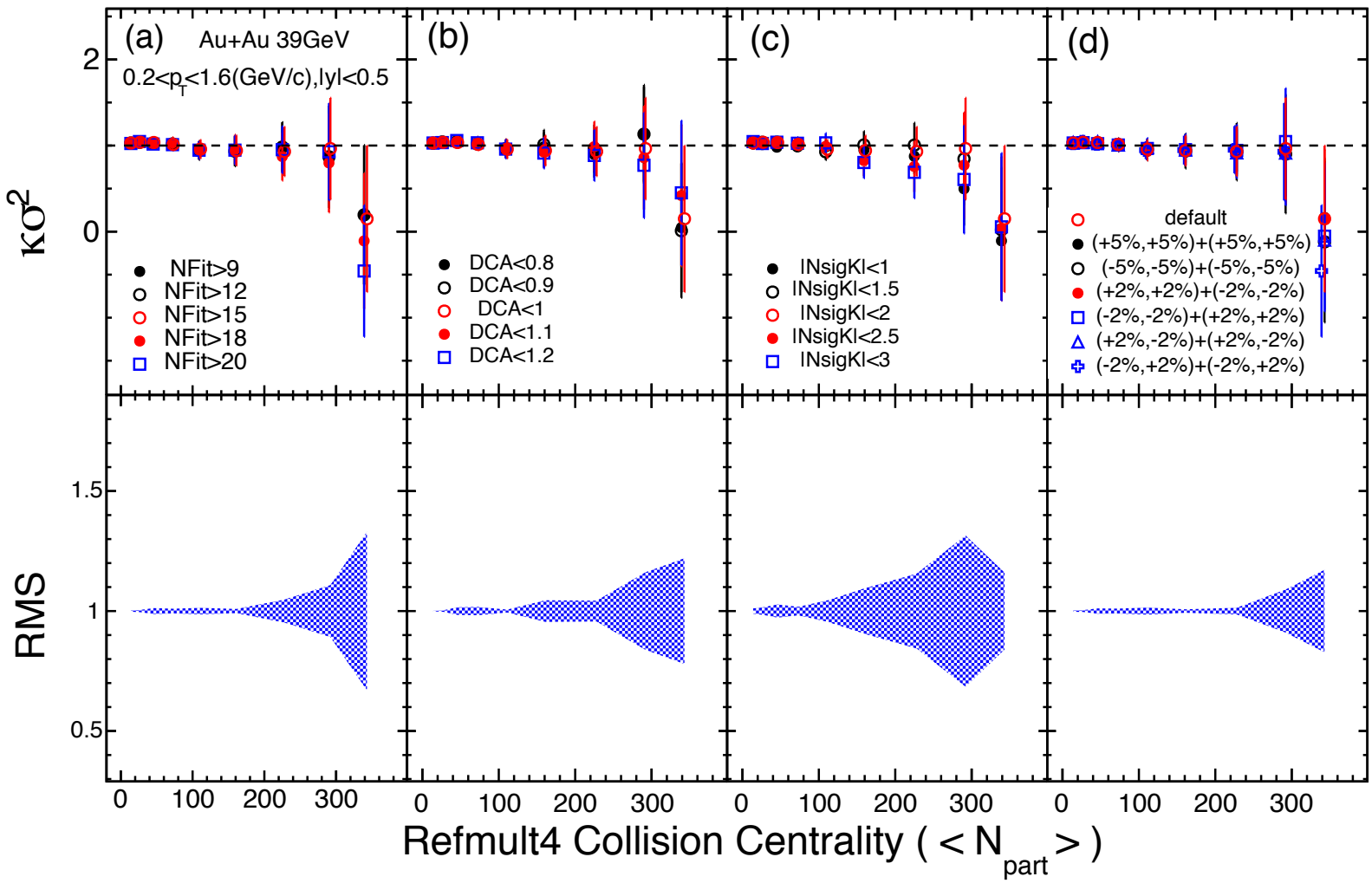
- X : Values with varying cuts ,Y: Values with default cut:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - Y)^2} \qquad Systematic \quad Error = \sqrt{\sum_j RMS_j^2}$$

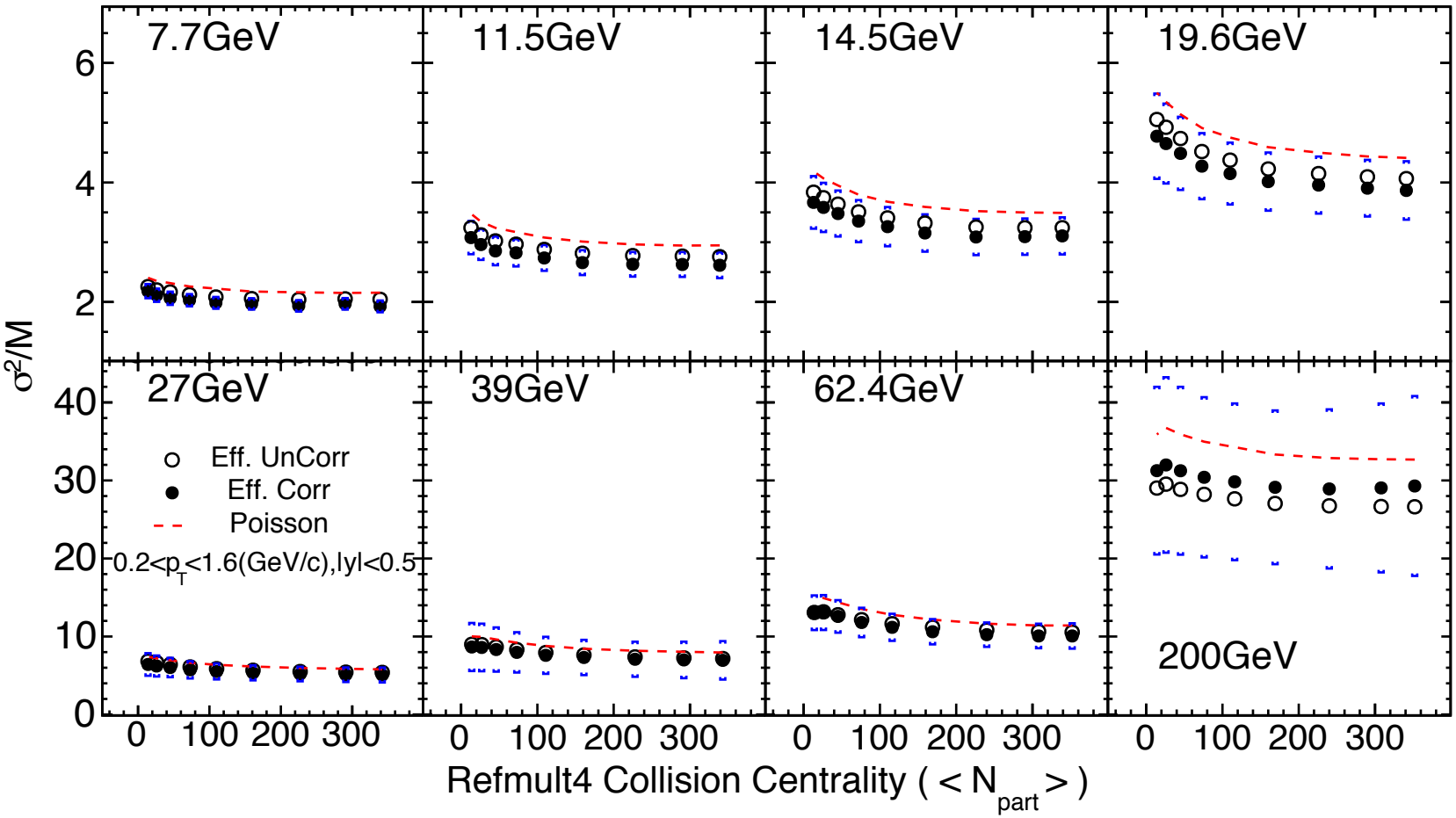
e.g.: Au+Au Collisions at 39GeV



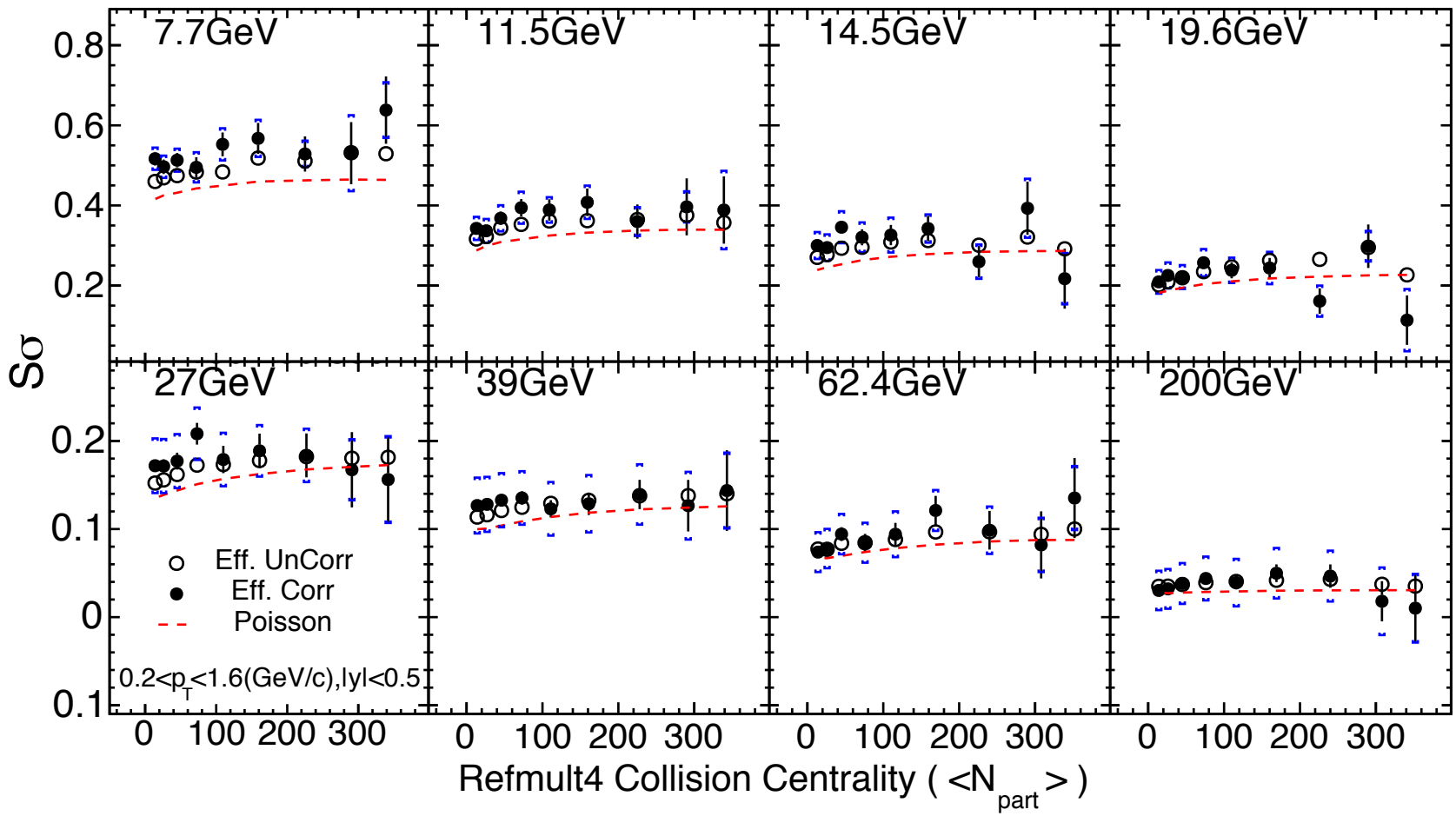
e.g.: Au+Au Collisions at 39GeV



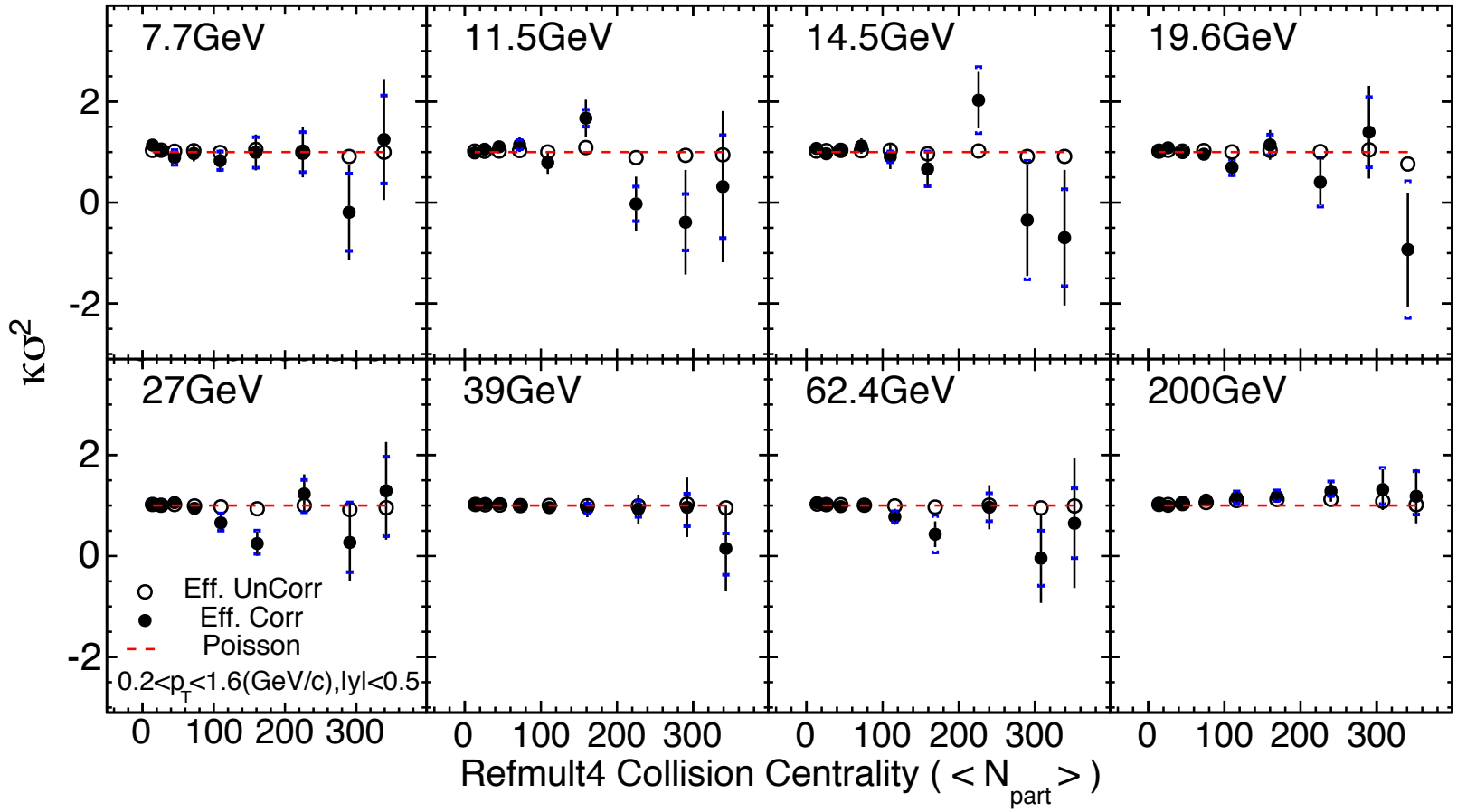
Net-Kaon Cumulant Ratios: of C2/C1



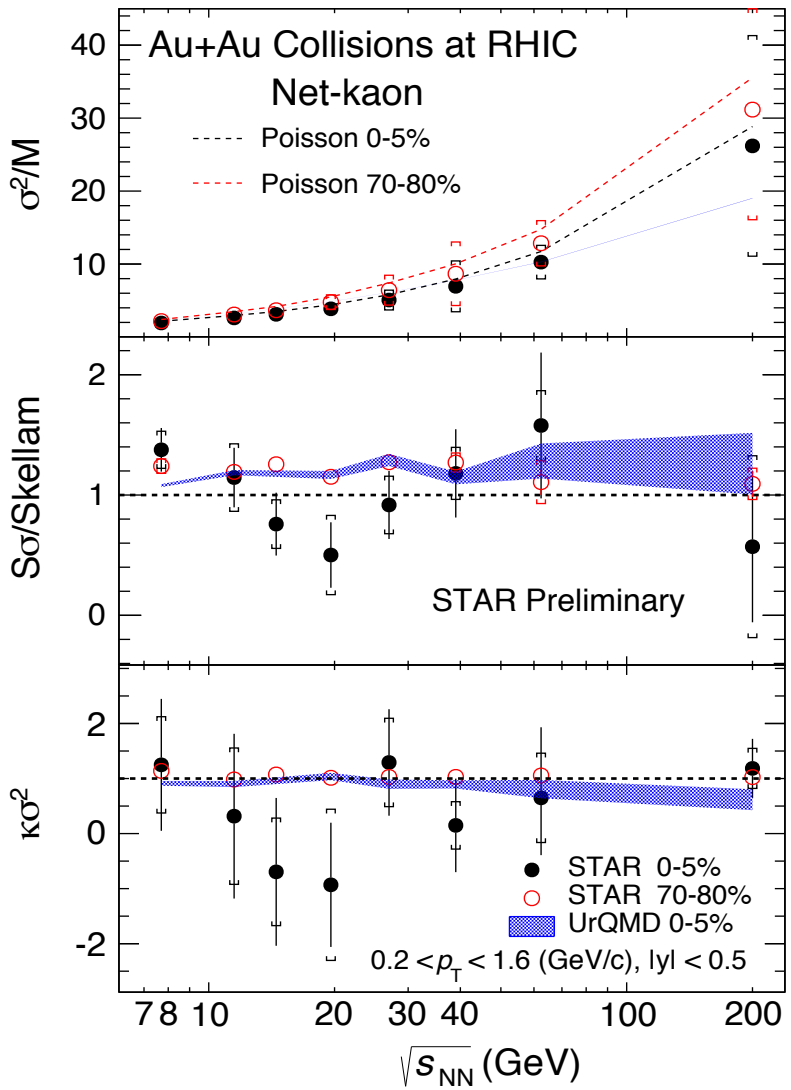
Net-Kaon Cumulant Ratios: of C3/C2



Net-Kaon Cumulant Ratios: of C4/C2

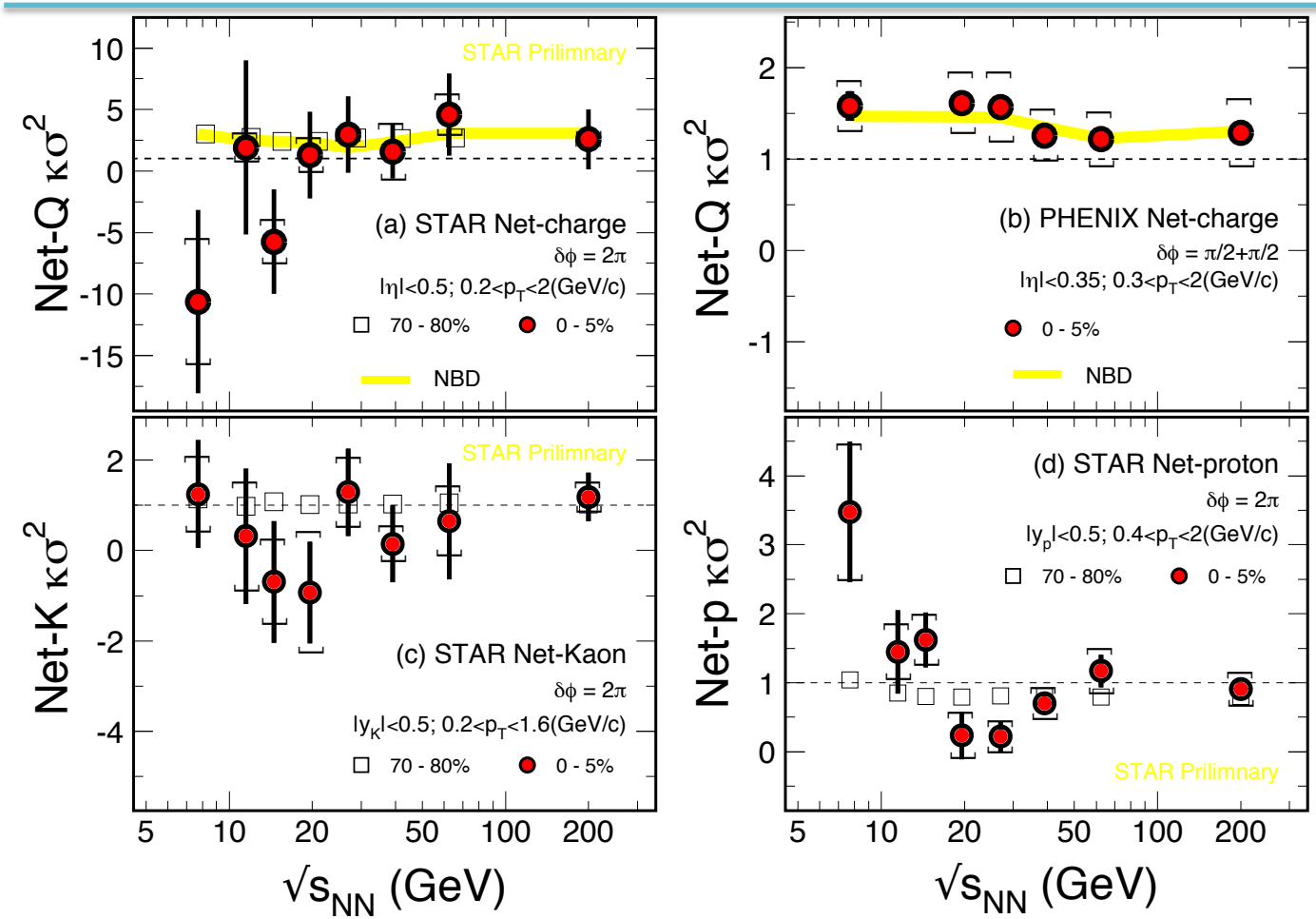


Energy Dependence of the Ratios



- The values of σ^2/M increase as the energy increases
- The values of $S\sigma$/Skellam are consistent with unity with large uncertainties
- For the most central collisions (0-5%), the values of $\kappa\sigma^2$ are consistent with unity with large errors.
- UrQMD (no QCD CP) shows no energy dependence for the most central collisions

Higher Moment of Net -Q, -K, -p



$$error(\kappa * \sigma^2) \propto \frac{1}{\sqrt{N}} \frac{\sigma^2}{\varepsilon^2}$$

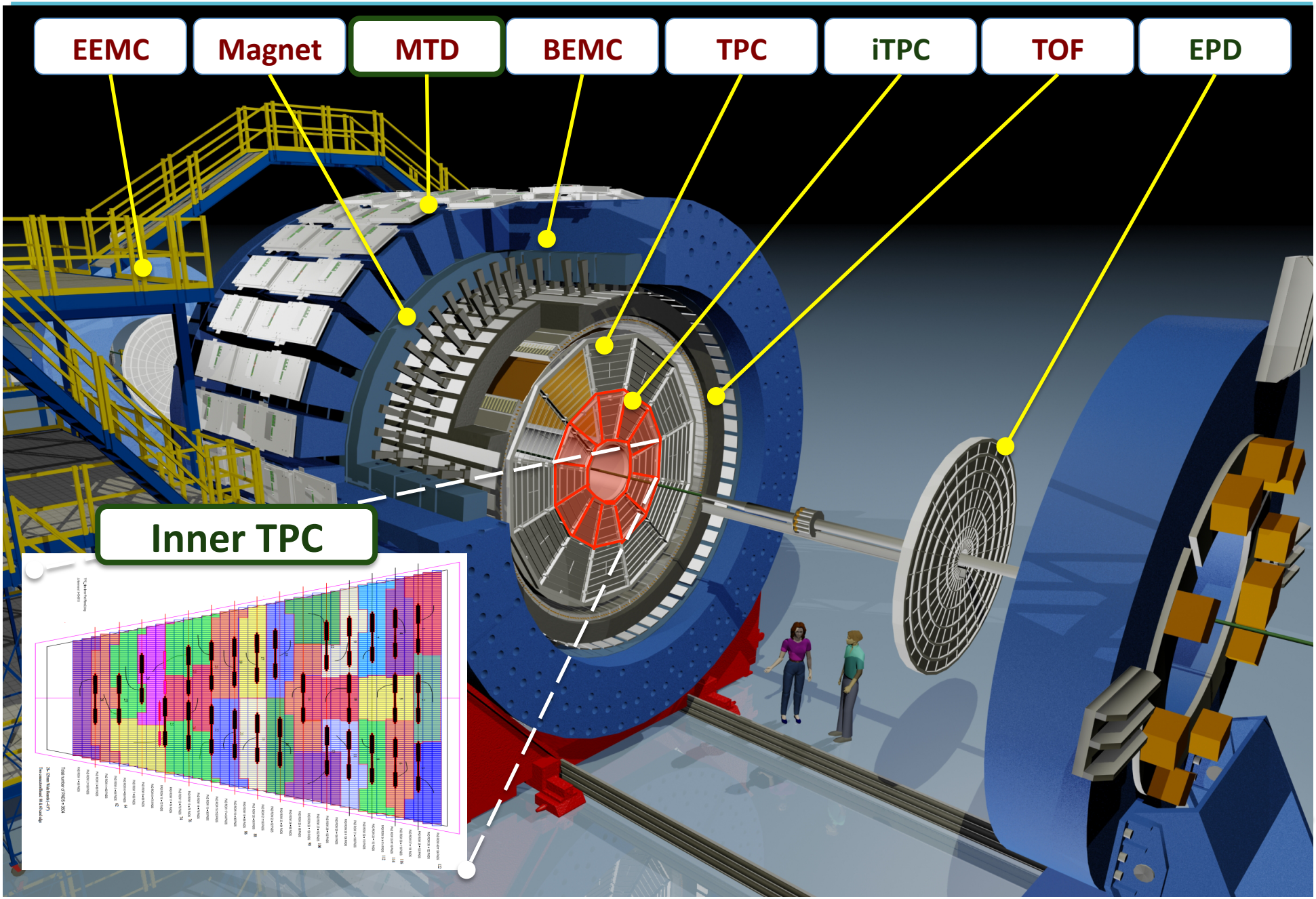
In STAR:

$\sigma(Q) > \sigma(K) > \sigma(p)$

1) Higher moment of net-Q, net-Kaon, and net-proton measured at RHIC BES-I
2) Net-p shows **non-monotonic energy dependence** in the most central Au+Au collisions at $\sqrt{s_{NN}}$ < 27 GeV!

PHENIX: talk by P. Garg at QM2015; STAR: talk by J. Thäder and poster by J. Xu at QM2015

STAR Detector System

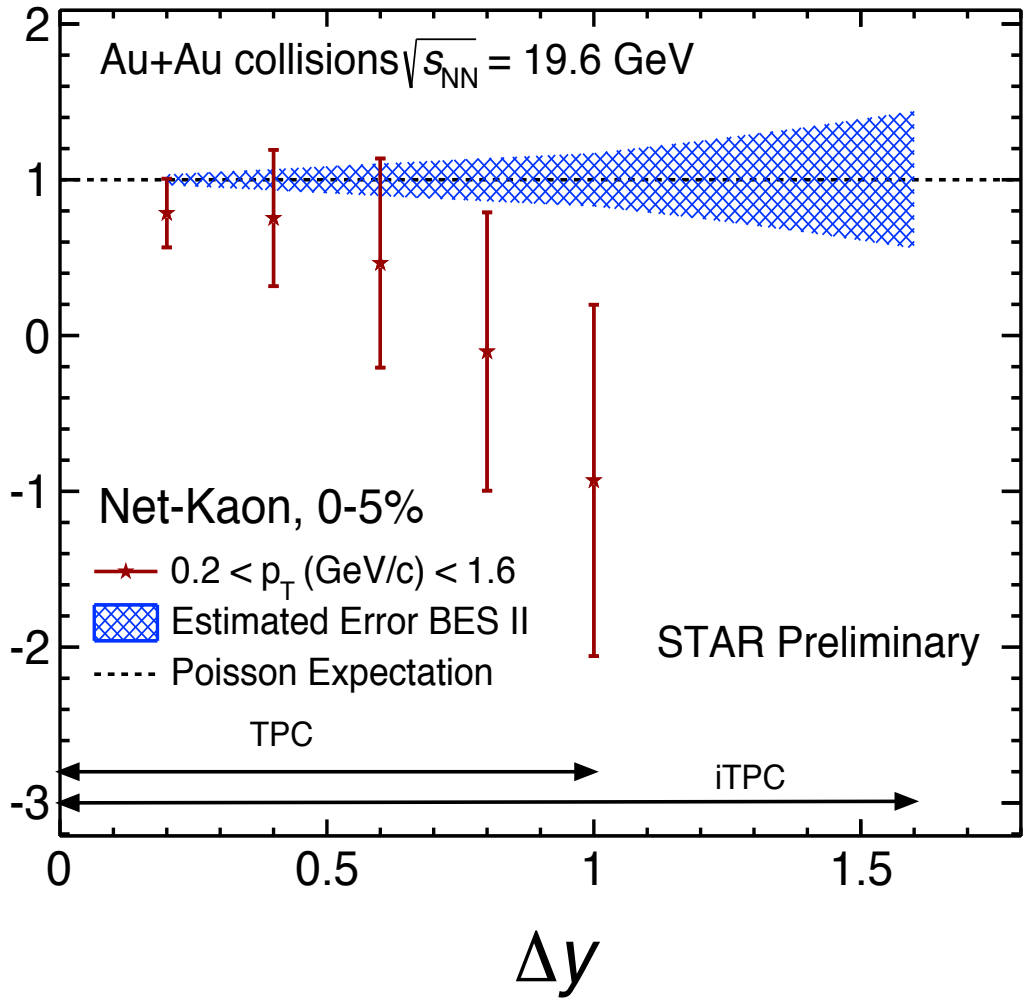


Event Statistics for BES II at RHIC

$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	BES II / BES I	Weeks	μ_B (MeV)	T_{CH} (MeV)
200	350	2010		25	166
62.4	67	2010		73	165
39	39	2010		112	164
27	70	2011		156	162
19.6	**400** / 36	**2019-20** / 2011	**3**	206	160
14.5	**300** / 20	**2019-20** / 2014	**2.5**	264	156
11.5	**230** / 12	**2019-20** / 2010	**5**	315	152
9.2	**160** / 0.3	**2019-20** / 2008	**9.5**	355	140
7.7	**100** / 4	**2019-20** / 2010	**14**	420	140

1) Event statistics driven by QCD CP search and di-electron measurements

Beam Energy Scan II



STAR iTPC Upgrade:

- Wider rapidity and p_T coverage
  $|y_{Kaon}| < 1.6$
  $p_T > 60$ MeV/c

- Higher efficiency and purity for Kaons

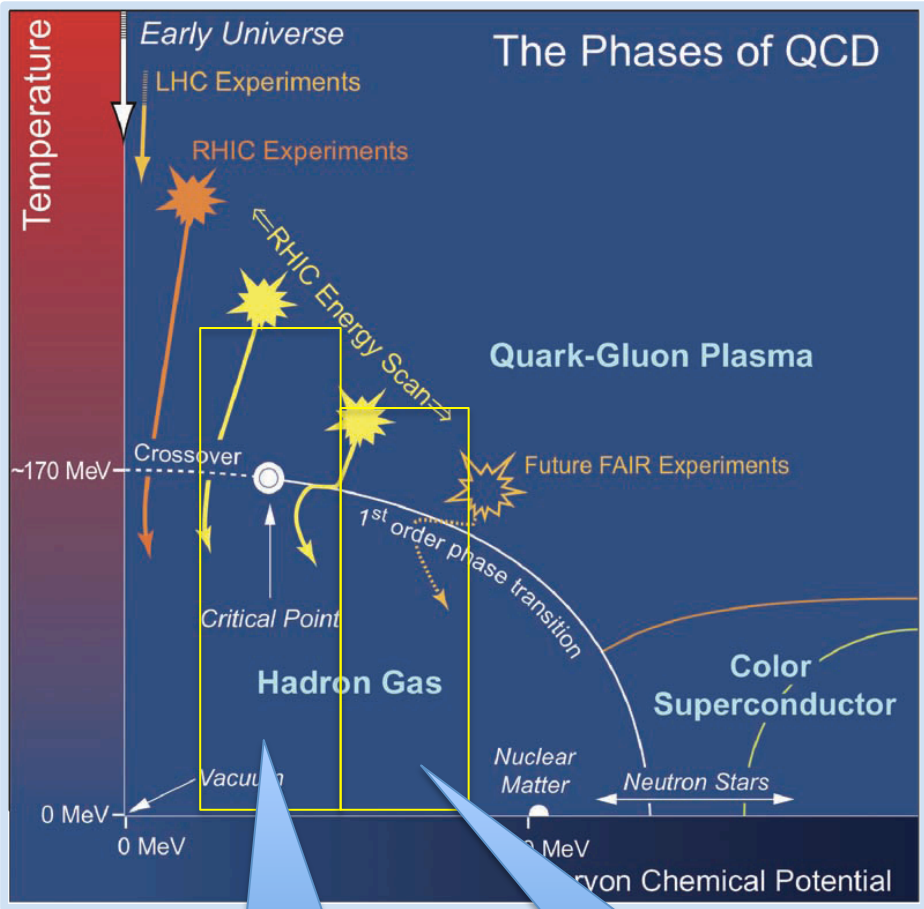
Summary

- Energy and centrality dependence of cumulants and ratios for net-Kaons. Kaons are identified within [$|y| < 0.5$, $0.2 < p_T < 1.6$ (GeV/c)] for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4 and 200 GeV

- Statistical errors are dominant. Within errors, the values of $\kappa\sigma^2$ and $S\sigma$/Skellam are consistent with unity and no energy dependence

- Detector upgrades in BES-II will improve the efficiency and purity for Kaon identification and kinematic coverage

Outlook



RHIC BESII collider mode
$200 < \mu_B < 420$ MeV

Fixed-target BES-III
$350 < \mu_B < 750$ MeV

RHIC e-cooling and iTPC upgrades bring BES-II a **new era** for studying the QCD phase structure at high net-baryon region ($200 < \mu_B < 420$ MeV) with unprecedented precision and coverage. Possible new discovers are:

1) The QCD critical point (region) and phase boundary
2) Properties with Chiral symmetry

Longer Future: fixed-target experiment at extreme large net-baryon density, $350 < \mu_B < 750$ MeV ($8 < \sqrt{s_{NN}} < 2$ GeV)