Higher moments of Net Kaon multiplicity distributions at RHIC energies for the search of QCD Critical Point (CP) at STAR

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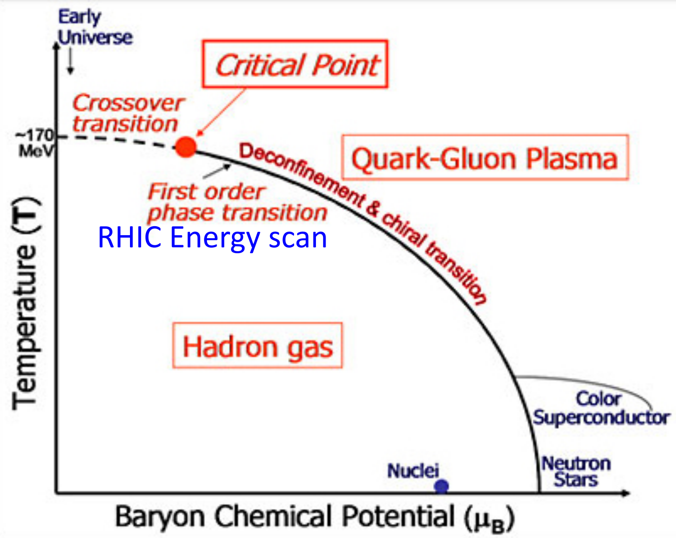
Motivation

QCD phase diagram & Critical Point

The **critical point (CP)** is the end point of the first order phase transition line in the QCD phase diagram where hadronic degrees of freedom changes to color degrees of freedom . STAR Collaboration, Phys. Rev. Lett 105, 022302 (2010), M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009) M. A. Stephanov, Phys. Rev. Lett. 107, 052301(2011), F. Karsch et all., Phys. Lett. B 695 (2011).



1. Lattice QCD finds a smooth crossover at large T and μ_B~0.
Y. Aoki, et al., arXiv:1007.2613 (2010), M. Cheng, et al., Phys. Rev. D 79 (2009) 074505

2. Various models find a strong 1st order transition at large μ_B.
S. Ejiri, Phys. Rev. D 78,074507 (2008); E.S. Bowmanand J. I. Kapusta, Phys. Rev. C 79, 015202 (2009)

3. Lattice calculation shows : CP range ~ 160 < μ_B <500 MeV. Y. Aoki, et al., arXiv:1007.2613 (2010)

4. M. Stephanov's sigma model predict that the higher moments of the multiplicity distribution of conserved quantities like the net-charge, net-baryon and net-strangeness are related to the corresponding susceptibilities and the correlation length of the system. M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009) M. A. Stephanov, Phys. Rev. Lett. 107, 052301(2011

5. These moments should show deviation from monotonic behavior at critical point when looking at the same quantity with the collision energy.

STAR Collaboration, Phys. Rev. Lett 105, 022302 (2010), M. A. Stephanov, Phys. Rev. Lett. 102, 032301 (2009), M. A. Stephanov, Phys. Rev. Lett. 107, 052301(2011),C. Athanasiou, etal, Phys. Rev. D 82, 074008 (2010)

Higher moments
Non-Gaussian Fluctuation Measurement

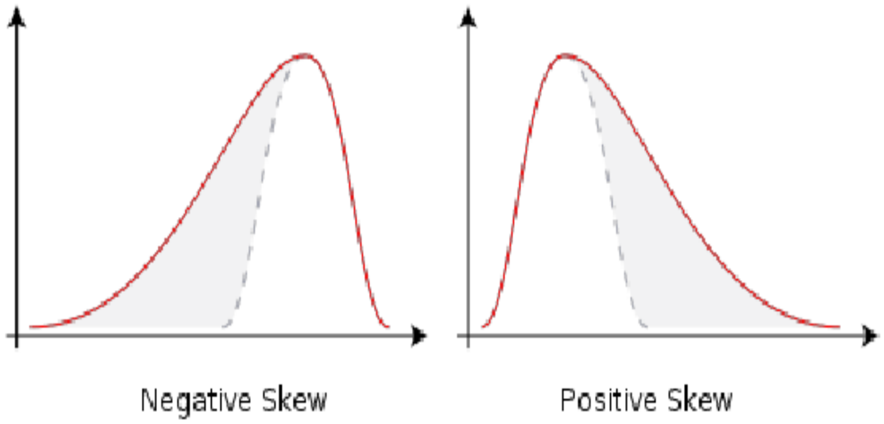
Mean (M) = < N >

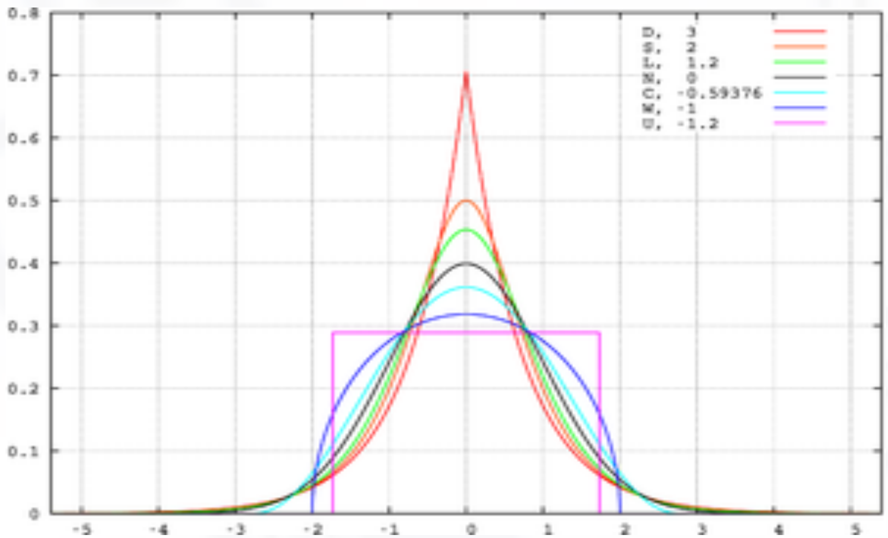
Standard Deviation (σ) = $\sqrt{\langle (N - \langle N \rangle)^2 \rangle}$

Skewness (S) = $\langle (N - \langle N \rangle)^3 \rangle / \sigma^3$

Kurtosis (κ) = $\langle (N - \langle N \rangle)^4 \rangle / \sigma^4 - 3$

Where, **N**: Event by Event Multiplicity Distribution





Skewness represents the asymmetry of the distribution and kurtosis represent the sharpness of the distribution. For Gaussian distribution, the Skewness and Kurtosis values are equal to zero. Higher moments are ideal probe to measure non-Gaussian fluctuation. htttp://en.wikipedia.org/wiki/Skewness & /Kurtosis.

Higher moments

Relation with the Correlation length

In a static, infinite medium, the correlation length (ξ) diverges at the CP. ξ is related to various moments of the distributions of conserved quantities such as net baryons, net charge, and net strangeness STAR Collaboration, Phys. Rev. Lett 105, 022302 (2010), F. Karsch et all., Phys. Lett. B 695 (2011).

$\sigma^2 = \langle(\Delta N)^2\rangle \sim \xi^2$ ξ = Correlation length

$S = \langle(\Delta N)^3\rangle \sim \xi^{4.5}$ and $\kappa = \langle(\Delta N)^4\rangle - 3\langle(\Delta N)^2\rangle^2 \sim \xi^7$

The moments of the net distribution contains a system volume dependence. To cancel out these volume dependency we construct moment products like $S\sigma$ and $\kappa\sigma^2$.

These volume independent moment product having sensitivity to the correlation length (ξ) as

$$S\sigma \propto \xi^{2.5}$$

and

$$\kappa\sigma^2 \propto \xi^5$$

S. Gupta, arXiv:0909.4630v1

Net-Kaons as a proxy for Net-Strangeness in Higher moments calculation

Experimentally, event-by-event net strangeness is very difficult to calculate.

Net-Kaon → **As a proxy of net-strangeness.**

There are other measurements ongoing in STAR in the same spirit to search for the QCD critical point.

Net-Charge → **For net-Charge.**

STAR collaboration, QM2012

Net-Proton → **As a proxy of net-Baryon.**

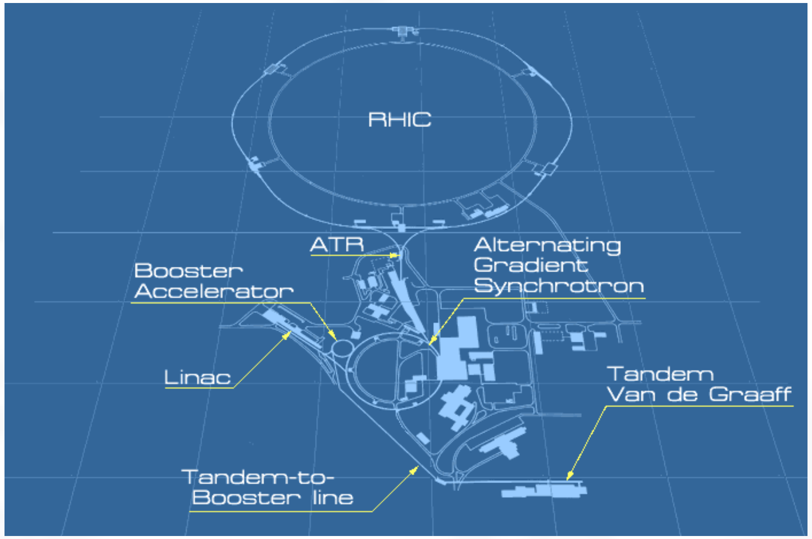
STAR collaboration, QM2012

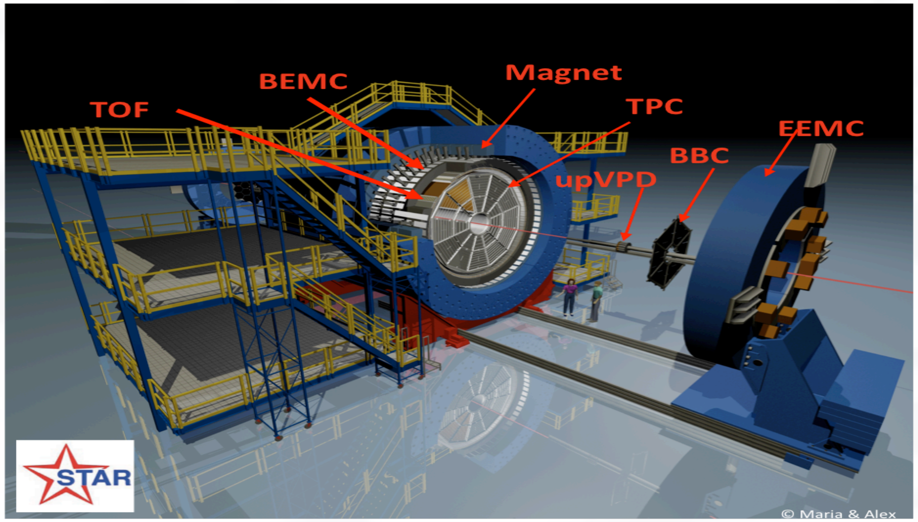
Experimental Setup

STAR at The Relativistic Heavy Ion collider (RHIC)

At the critical point the first order transition becomes continuous, resulting in long range correlations and fluctuations at all length scales. Such properties of state open possibilities for distinct experimental signatures which can be used to discover the critical point.

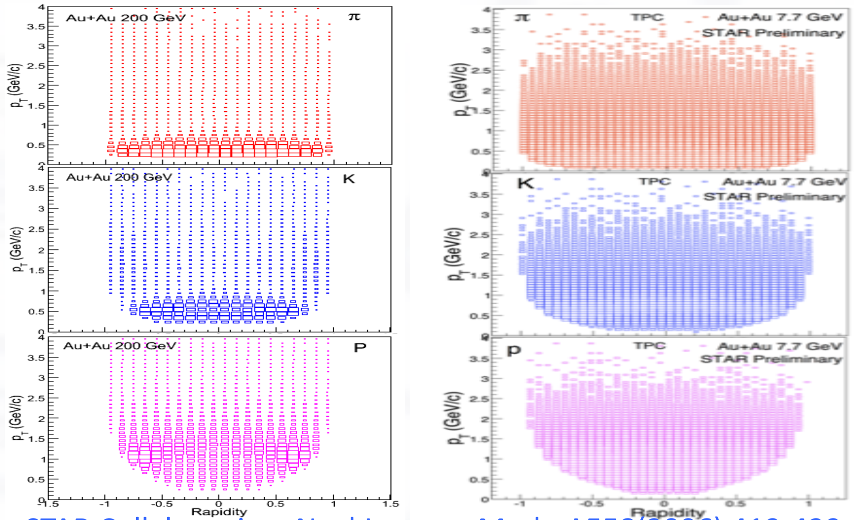
The Relativistic Heavy-Ion Collider (RHIC), at BNL, has started its beam energy scan program to locate the QCD critical point which is also one of the main aims of the STAR experiment.





STAR detector has full 2π coverage and uniform acceptance at mid-rapidity.

200 GeV 7.7 GeV



STAR Collaboration, Nucl.Instrum.Meth. A558(2006) 419-429., STAR Collaboration, Nuclear Physics A – NUCL PHYS A, (vol. 774, pp. 956-958,2006).

Analysis

Data analysed

Energy (in GeV)	Number of Events (in M)	Year
7.7	~ 2.4	2010
11.5	~ 7.5	2010
19.6	~ 17	2011
27.0	~ 34	2011
39.0	~ 40	2010
62.4	~ 44	2010
200	~ 200	2010

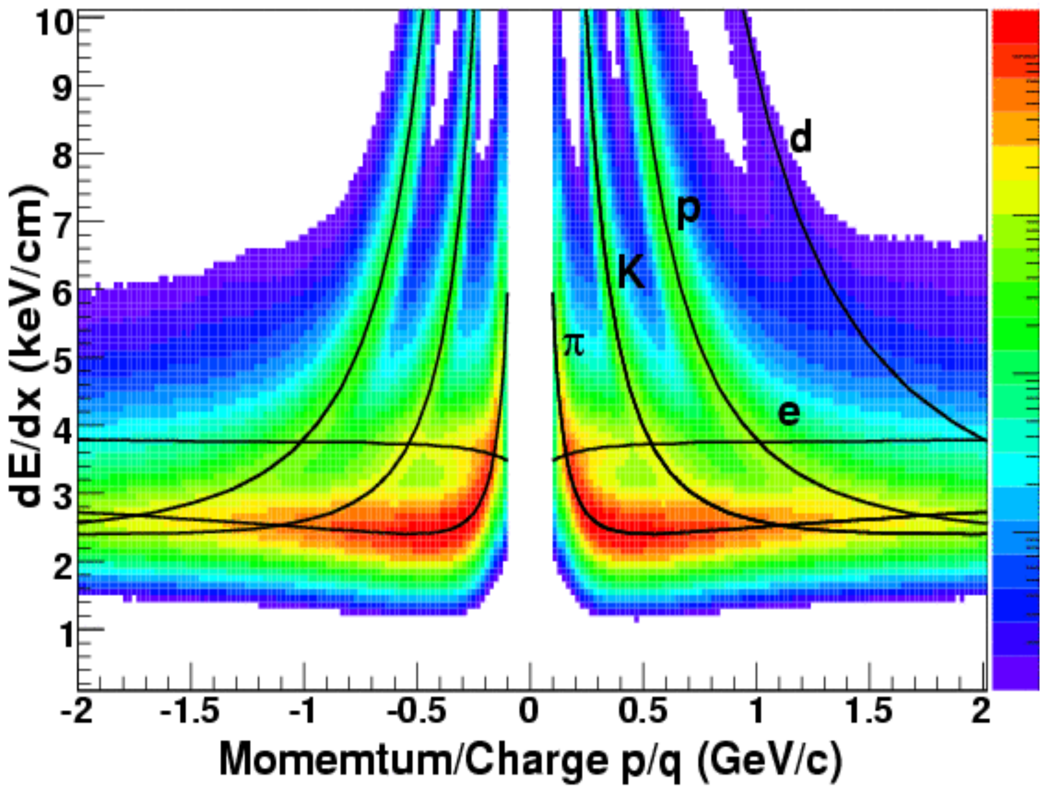
Basic cuts used:
DCA ≤ 1 cm, 0.2< p (GeV/c) < 1.6,
Number of Fit Points ≥ 15, $|\eta| \leq 0.5$
$|V_Z| \leq 30$ cm, $|n\sigma_{kaon}| < 2.0$,
where,

$$n\sigma_X = \frac{1}{R}\log\frac{< dE/dx > |_{measured}}{< dE/dx >_X |_{expected}}$$

A cut has been applied on the mass square, $0.22 < m^2 < 0.265$, using ToF
For more details see the backup slides.

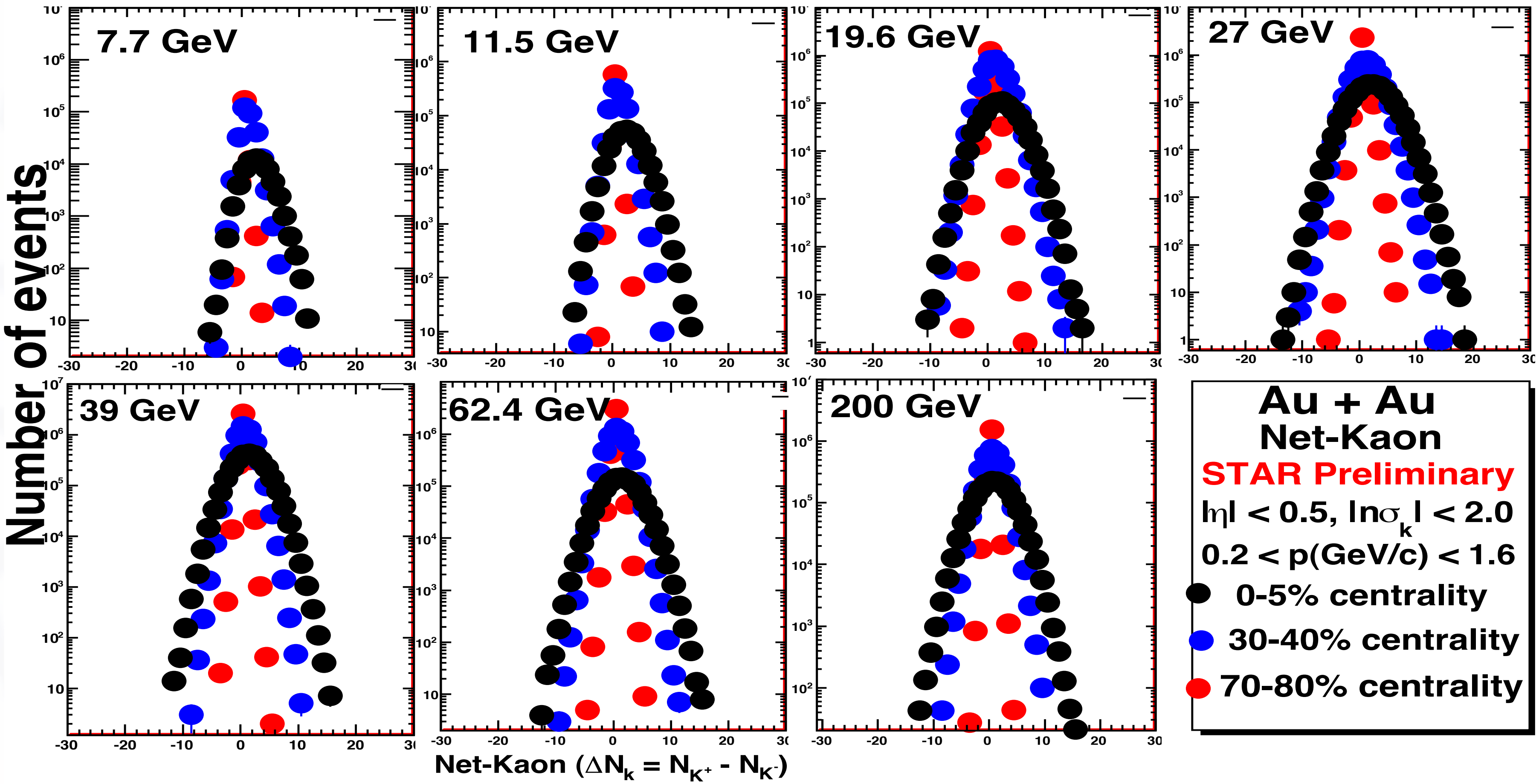
Particle Identification

Ionization energy loss (dE/dx) of charged particles in the STAR TPC was used to identify the inclusive particles by comparing it to the theoretical (parameterized) expectation. STAR Collaboration, Nucl.Instrum.Meth. A558(2006) 419-429, STAR Collaboration, Nuclear Physics A – NUCL PHYS A, (vol. 774, pp. 956-958,2006)



Results : Net-Kaon distribution

The raw net-Kaon (ΔN_K) multiplicity distribution in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 - 200 GeV for various collision centralities at mid-rapidity (|η|<0.5), shown in the figure.

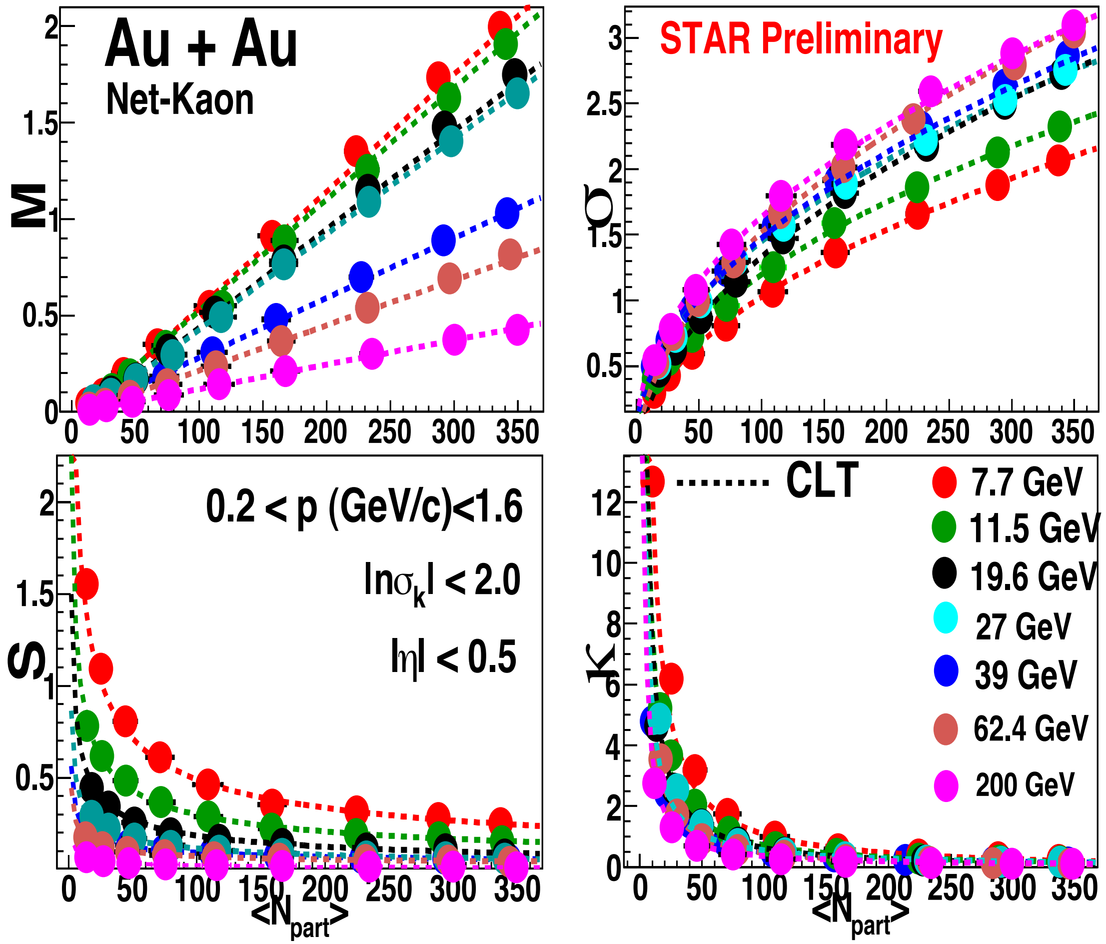


The mean of net-Kaon (ΔN_K) distribution shifts towards zero from low to high energies. The centrality selection utilized the uncorrected charged particle multiplicity within the pseudo rapidity 0.5< |η|<1.0, measured by the TPC.

Results: Centrality dependence of the higher moments of the ΔN_K multiplicity distribution

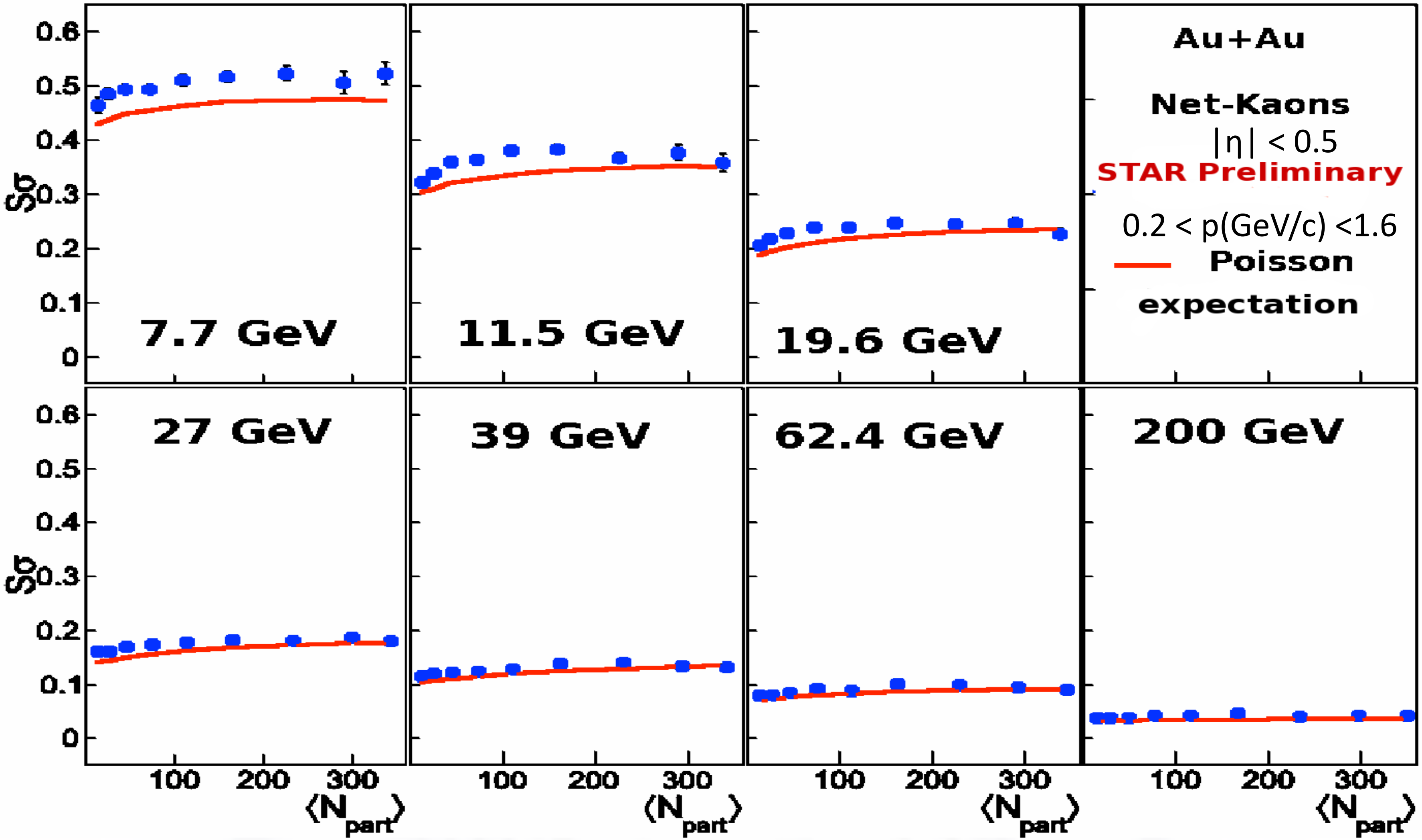
The four moments (M, σ, S, and k) which describe the shape of the ΔN_K distributions at various collision energies are plotted as a function of average number of participants $< N_{part} >$. The results are corrected for the finite centrality bin width effects. X. Luo [STAR Collaboration], J. Phys. Conf. Ser.316, 445 012003 (2011).

Moments fitted with it's predicted dependence function from Central Limit Theorem (CLT), goes as it's volume's x, √x, 1/√x and 1/x respectively (the dotted lines).



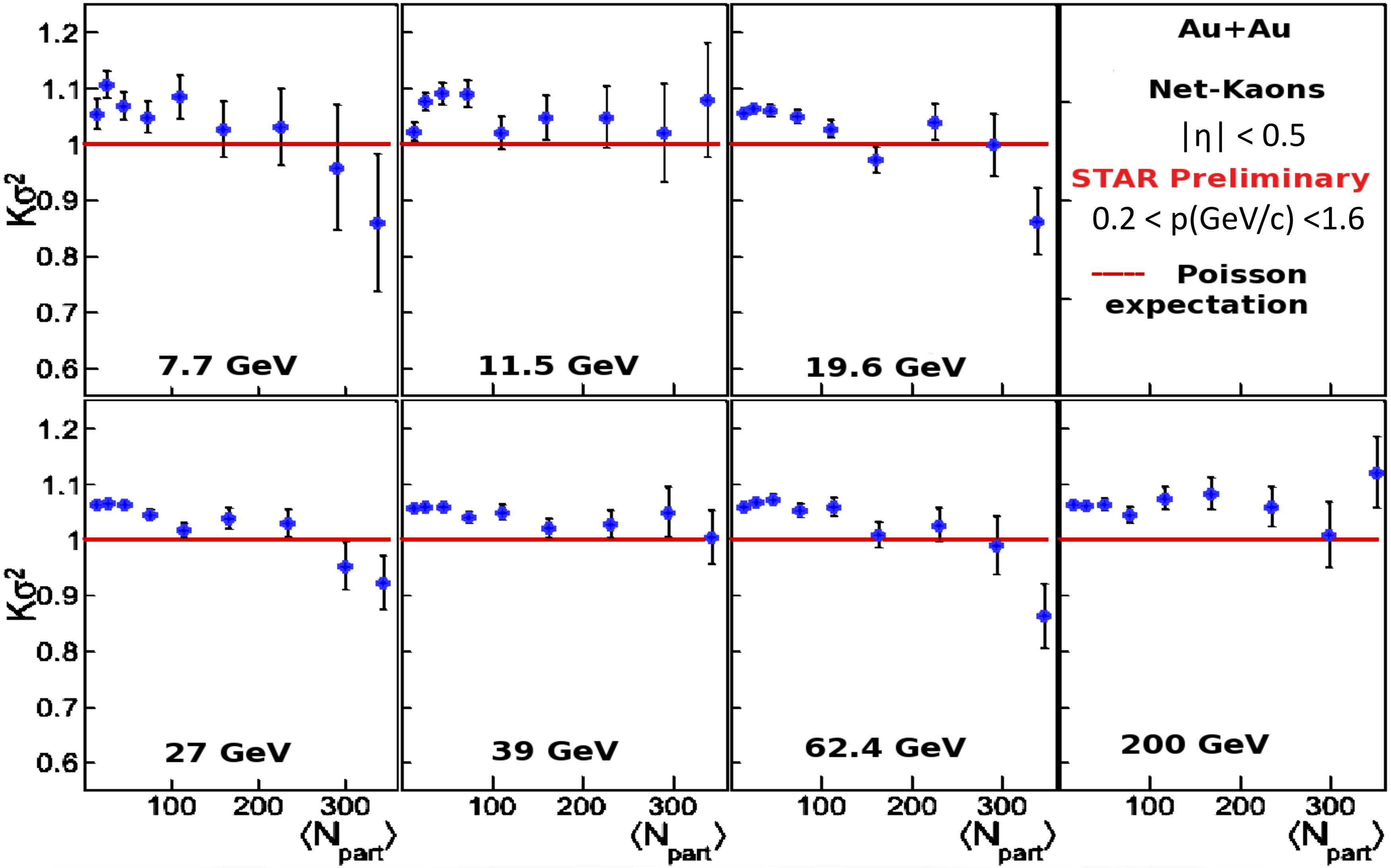
Delta Theorem has been used for error estimation X. Luo, J. Phys. G 39, 025008 (2012)[arXiv: 1109.0593].

Results : Centrality dependence of Sσ



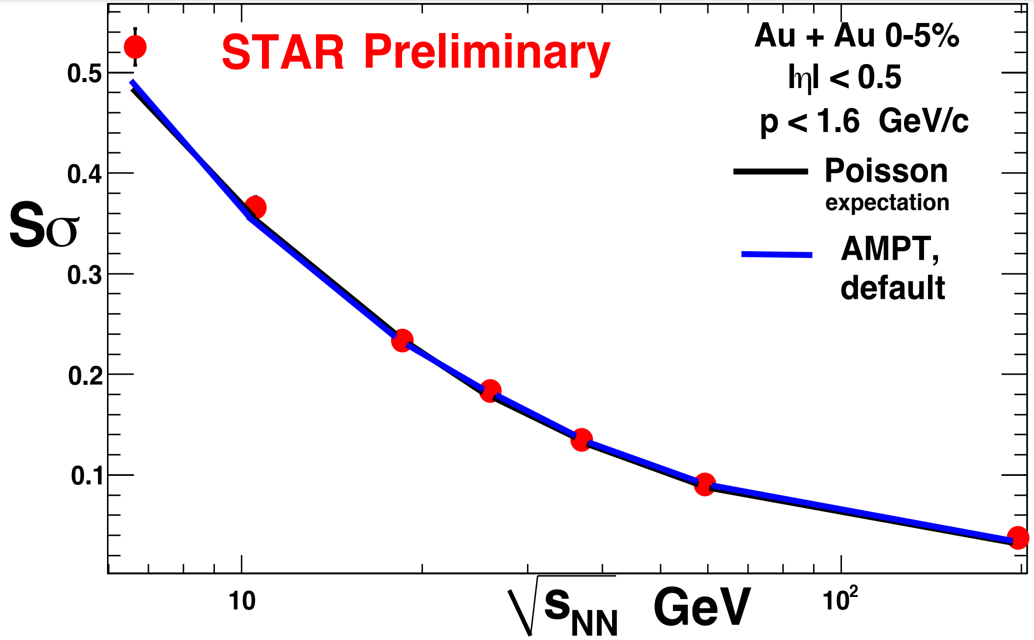
There is a very small increasing centrality dependency in Sσ value towards most central collision which is within 15%. Sσ value is greater than Poisson baseline for beam energy below 200 GeV. Sσ increase with decreasing collision energies.

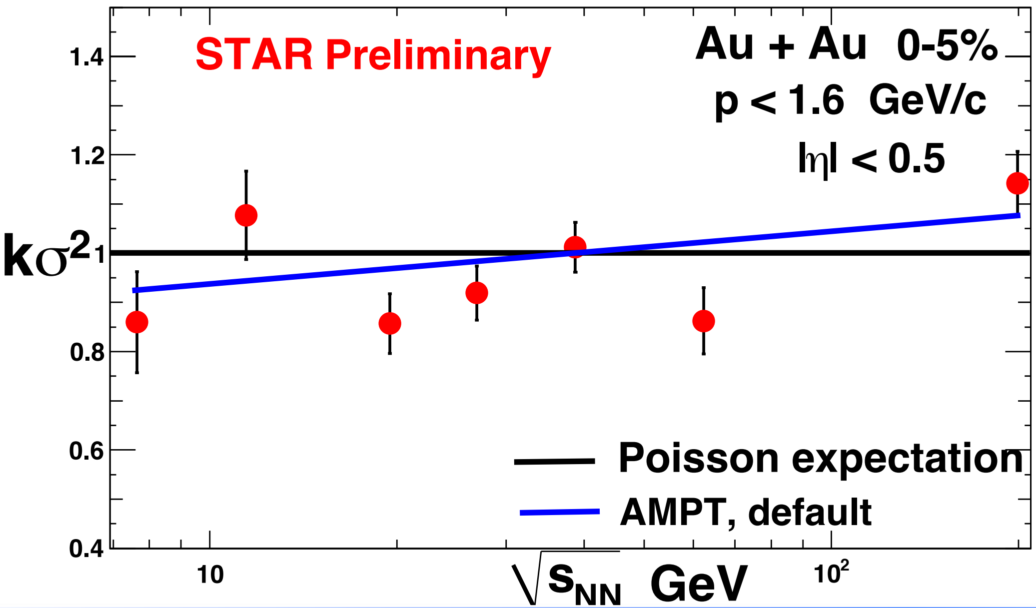
Results : Centrality dependence of kσ²



Within the statistical uncertainty volume independent product kσ² value is independent of centrality within 10%.

Results : Energy dependence of Sσ and kσ²





Sσ value matches with Poisson expectation value and AMPT default value, in 0-5% most central collision.

Within the statistical uncertainty, $k\sigma^2$ value matches with AMPT default value for the top 0-5% central collision.

$k\sigma^2$ value matches with Poisson baseline for the top 0-5% central collision.

Summary

1. The Net-Kaon (ΔN_K) distribution showing that, as we are going lower to higher energy, the mean shifted towards zero.

2. There is a very small increasing centrality dependency in $S\sigma$ value towards most central collision which is within 15%. $S\sigma$ value is greater than Poisson baseline for beam energy below 200 GeV. $S\sigma$ increase with decreasing collision energies.

3. Within the statistical uncertainty volume independent product $\kappa\sigma^2$ value is independent of centrality within 10%.

4. $S\sigma$ value matches with Poisson expectation and AMPT default (string melting off) value, in 0-5% most central collision.

5. $\kappa\sigma^2$ value matches with Poisson expectation and AMPT default (string melting off) value for the top 0-5% central collision.

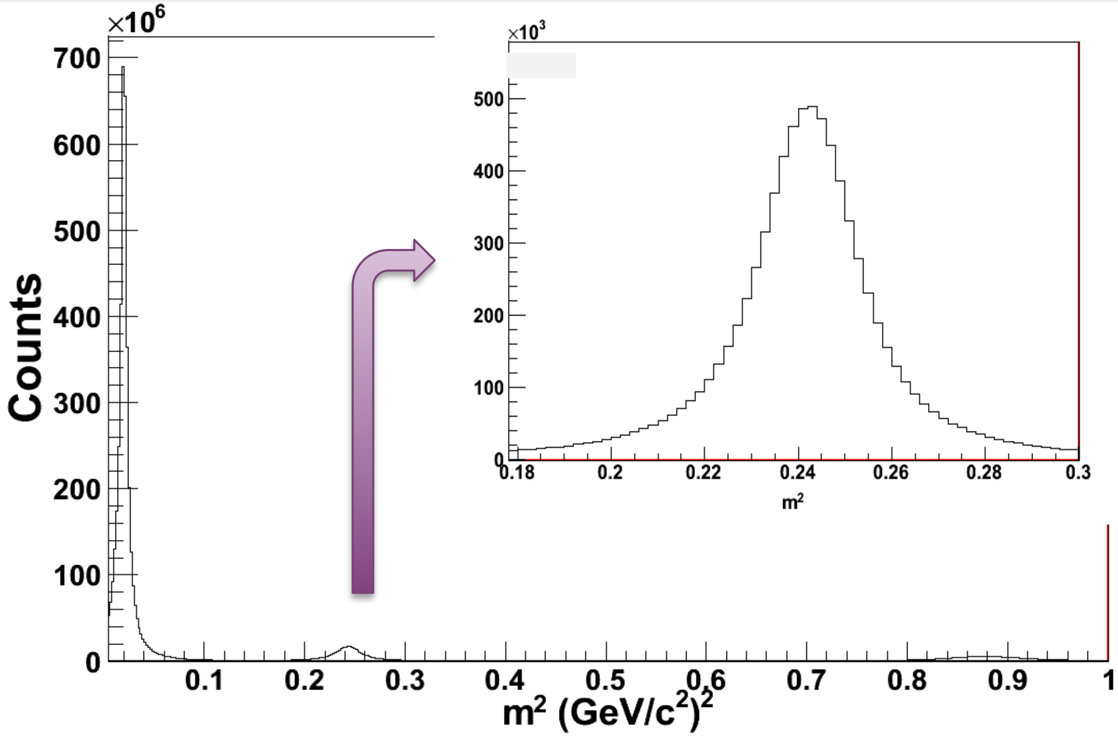
6. No significant enhancement of moment products was observed compare to the Poisson baseline at presently available energies.

7. No non-monotonic behavior is observed in net-Kaon higher moments analysis.

Thanks for your attention …

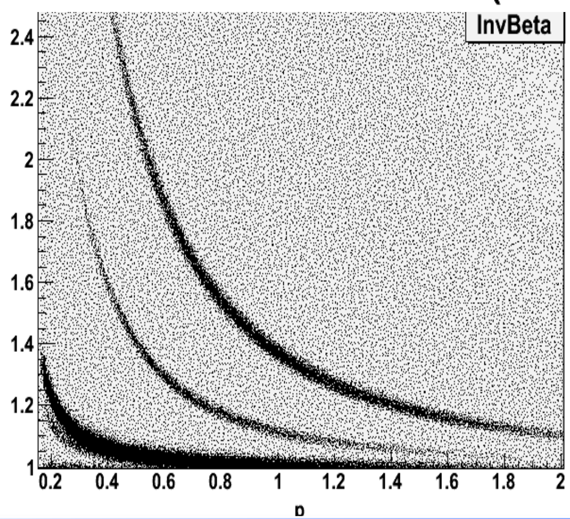
Back Up

TOF cuts



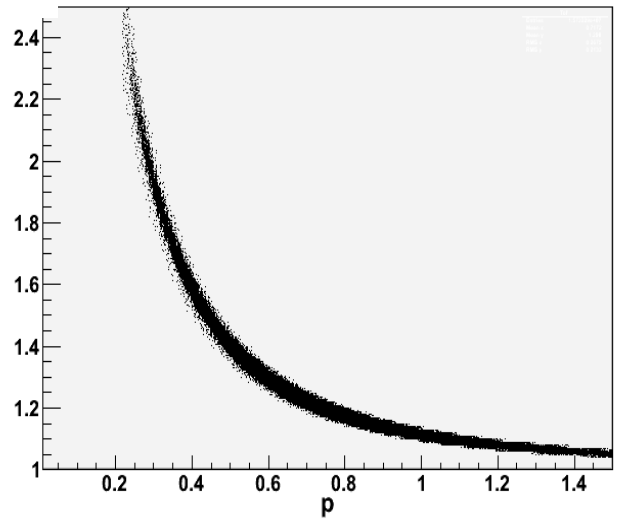
$$m^2 = p^2\left(\frac{c^2t^2}{L^2} - 1\right)$$

p = momentum
t = time-of-flight
c = velocity of light
L = path length



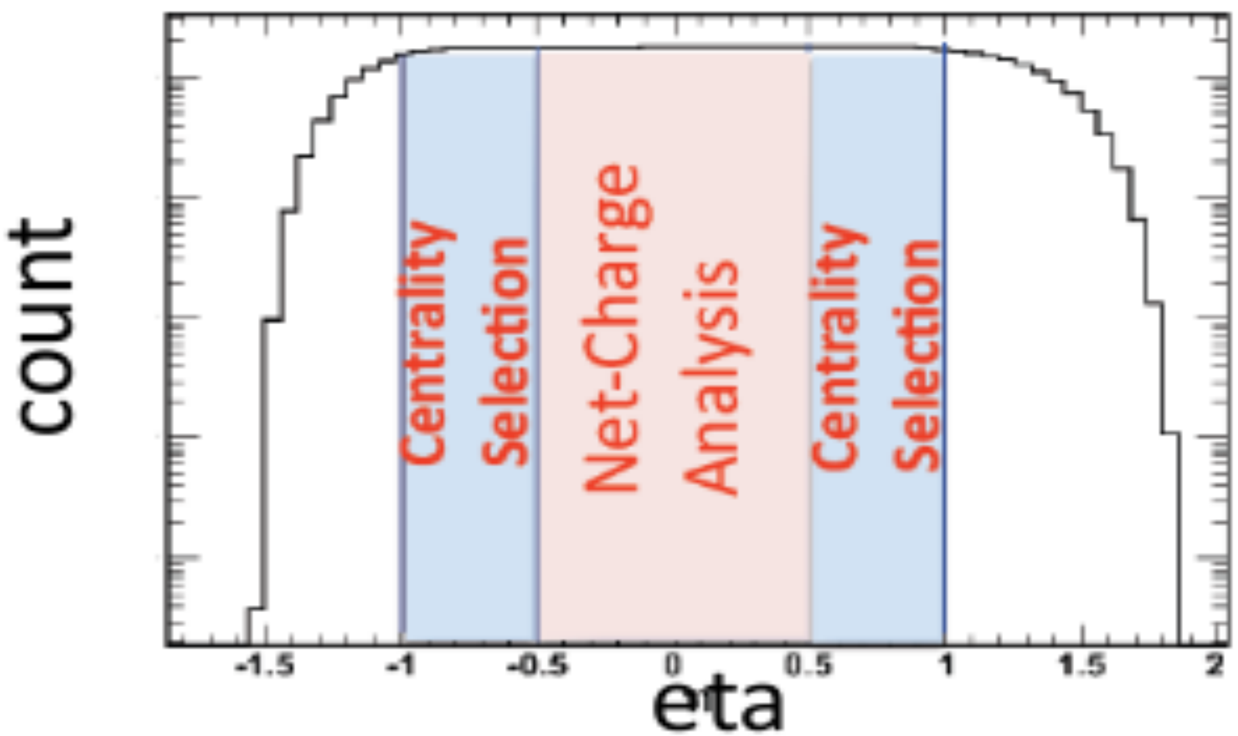
$0.22 < m^2 < 0.265$

$0.01 < P < 1.6$



New Reference multiplicity

Using Refmult2 to remove the auto correlation



DCA < 3
Vz <=30 cm
0.5<|eta|<1.0
NFitPoints > 10

Centrality bin-width effect

Centrality bin-width effect correction done by the Direct Weighted method :

For each centrality, various moments are calculated reference multiplicity by reference multiplicity and weighted by the number of events of that reference multiplicity.

$$(1): \sigma = \frac{\sum_r n_r \sigma_r}{\sum_r n_r} = \sum_r \omega_r \sigma_r$$

$$(2): S = \frac{\sum_r n_r S_r}{\sum_r n_r} = \sum_r \omega_r S_r$$

$$(3): \kappa = \frac{\sum_r n_r \kappa_r}{\sum_r n_r} = \sum_r \omega_r \kappa_r$$

$$\left(\frac{\sum_r n_r}{\sum_r n_r} = \sum_r \omega_r\right)$$

X. Luo arXiv: 1106.2926 [nucl-ex]

Back Up

The Poisson baseline has been calculated from the mean value of the $N_K^{+(}$ (μ_1) and N_K^- (μ_2) distribution.

$$\text{Mean (M)} = \mu_1 - \mu_2$$

$$\text{Variance } (\sigma^2) = \mu_1 + \mu_2$$

$$\text{Skewness (S)} = (\mu_1 - \mu_2)/(\mu_1 + \mu_2)^{3/2}$$

and

$$\text{kurtosis } (\kappa) = 1/(\mu_1 + \mu_2)$$

And the volume independent moment products,

$$S\sigma = (\mu_1 - \mu_2)/(\mu_1 + \mu_2)$$

and

$$\kappa\sigma^2 = 1$$