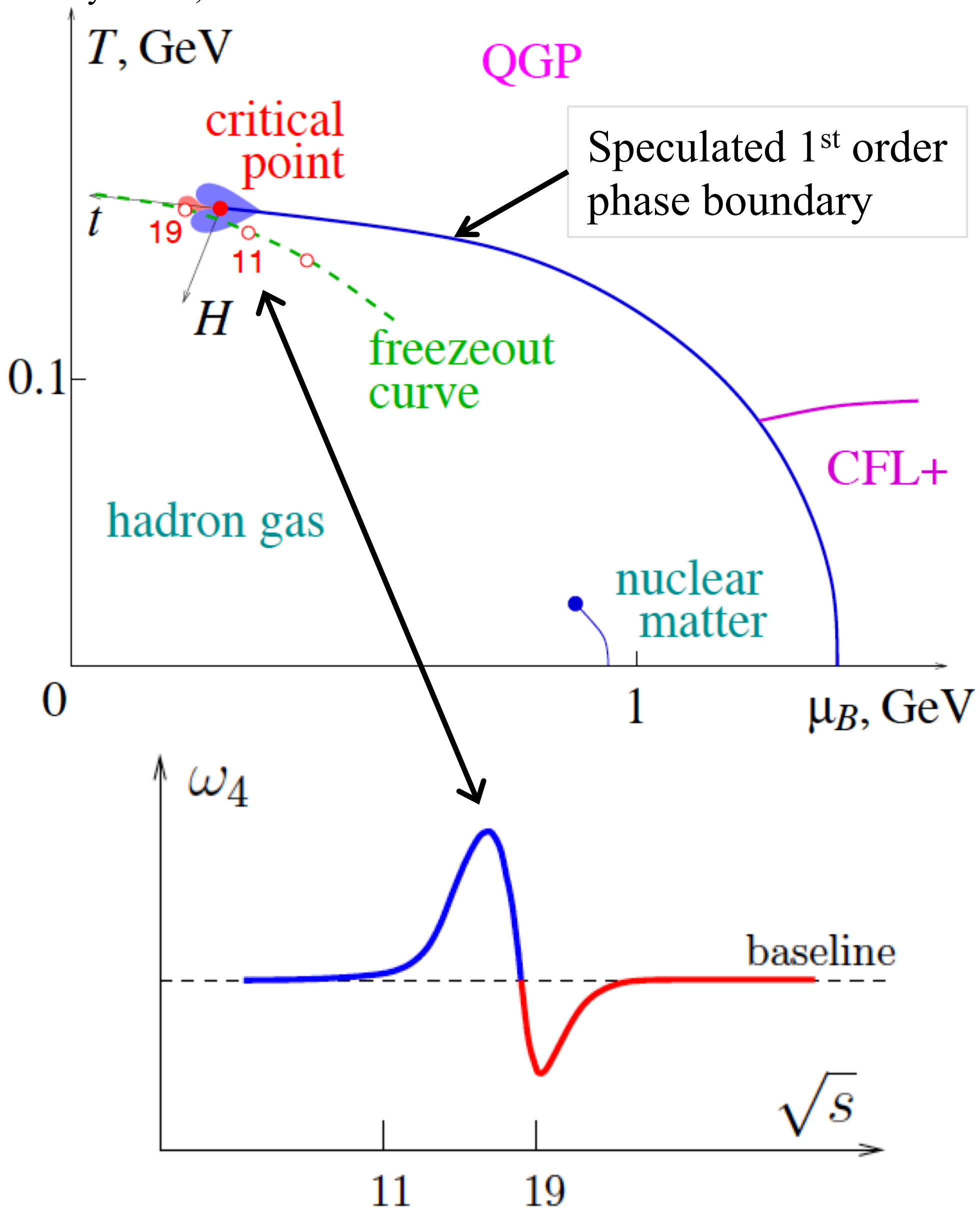
Intra-event correlations and the statistical moments of the identified particle multiplicity distributions in the RHIC beam energy scan data collected by STAR

W.J. Llope for the STAR Collaboration
Rice University

M. Stephanov, Rice Workshop, May 23-25, 2012



Measured "net-proton" and "net-charge" multiplicity distributions may provide insight on the conserved B and Q quantum numbers.

Measure the shapes of multiplicity distributions as quantified by the moments: **μ, σ^2, S, K**

S = skewness, K = kurtosis

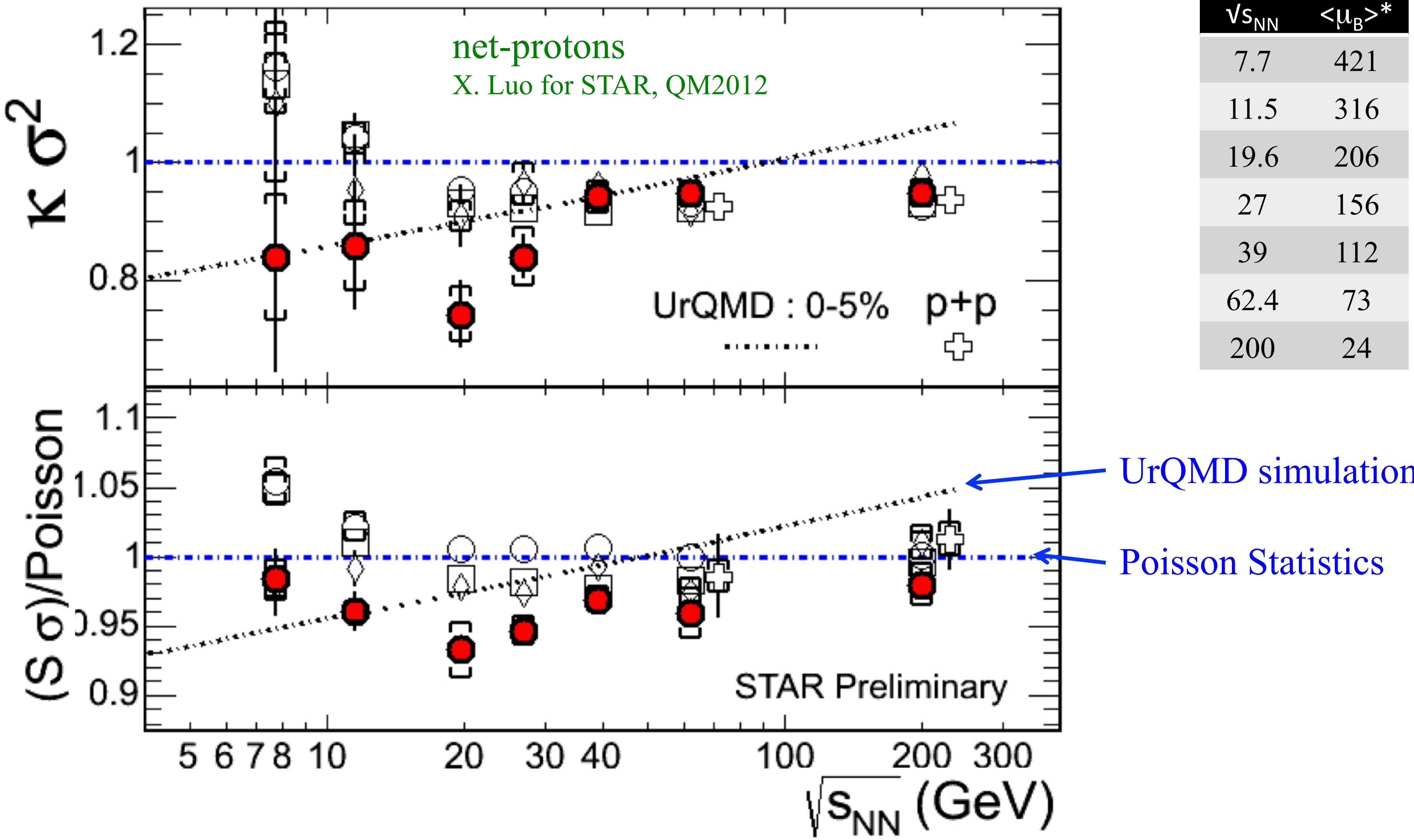
The products Sσ & Kσ^2 are less volume dependent

Experimentally-measured moments products may be directly related to the susceptibility ratios (QCD order parameters) from the lattice theory.
Values may relate to HG vs QGP phases…

In the NLSM, experimentally-measured moments products may also be proportional to powers of the correlation length. (critical opalescence)
Divergent values may indicate the Critical Point…

STAR net-p Results at QM2012

http://indico.cern.ch/getFile.py/access?contribId=158&sessionId=57&resId=0&materialId=slides&confId=181055



$\sqrt{s_{NN}}$	$\langle\mu_B\rangle$*
7.7	421
11.5	316
19.6	206
27	156
39	112
62.4	73
200	24

* Cleymans *et al.* PRC **73**, 034905 (2006)

No strong non-monotonicity seen, but there is an apparent dip at ~19.6-27 GeV

Baselines

In this presentation, I will describe the comparison of the net-p and net-Q data to two data-driven techniques that explicitly break the intra-event correlations between N_{pos} and N_{neg}.

- Do intra-event correlations between N_{pos} and N_{neg} affect the measured net-X moments?
- Can the net-X moments be understood from the N_{pos} and N_{neg} distributions alone?

"Independent Random Variable (IRV) Cumulant Arithmetic"

A feature of cumulants is their additivity for pairs of independent random variables.

$$C_k(u+v) = C_k(u) + C_k(v)$$

for **net-X**, *i.e.* "u-v" with $u=N_{pos}$ and $v=N_{neg}$,

$$C_k(u-v) = C_k(u) + (-1)^k \times C_k(v)$$

$S\sigma = C_3/C_2$ and $K\sigma^2 = C_4/C_2$ (C_1=mean, C_2=variance)

"Sampled Singles"

Stochastically sample from the N_{pos} and N_{neg} distributions, forming N_{net} distributions from which one can calculate $S\sigma$ and $K\sigma^2$

Sampled Singles and IRV approach give the same results if former "oversampled" with weights …both/either can be called an "Independent Production" expectation

Other important "baselines" include

Poisson (Skellam) – uncorrelated HG emission, calcuable from $\langle N_{pos} \rangle$ and $\langle N_{neg} \rangle$ only

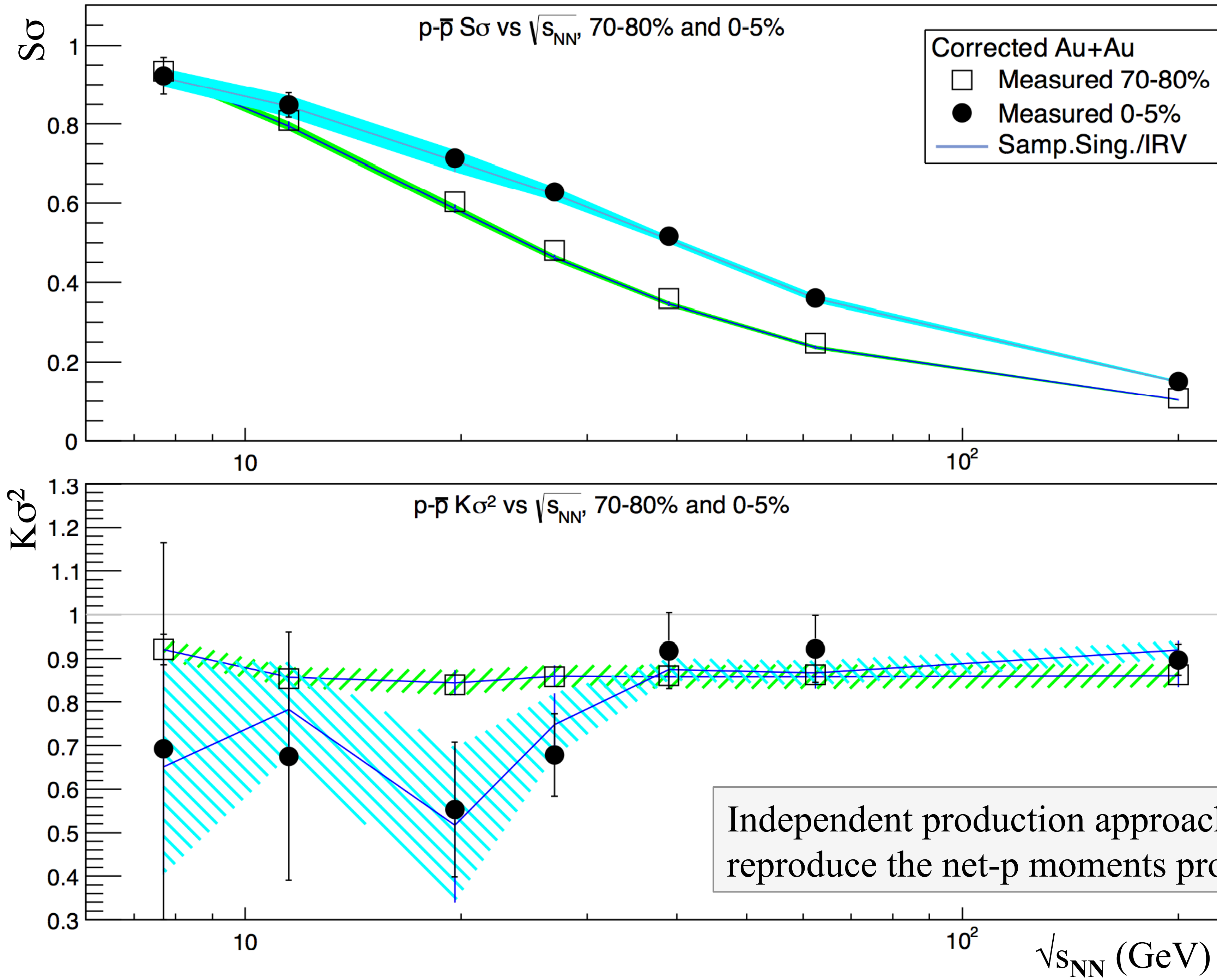
S. Jeon and V. Koch, arXiv:hep-ph/0304012

(N)BD – sister functions to Poisson for which $\mu<\sigma^2$ (Neg. binomial) or $\mu>\sigma^2$ (binomial)

T..J. Tarnowsky & G. Westfall, arXiv:nucl-ex/1210.8102v1

Corrected net-p $S\sigma$ and $K\sigma^2$ vs $\sqrt{s_{NN}}$ for 0-5% and 70-80% centrality

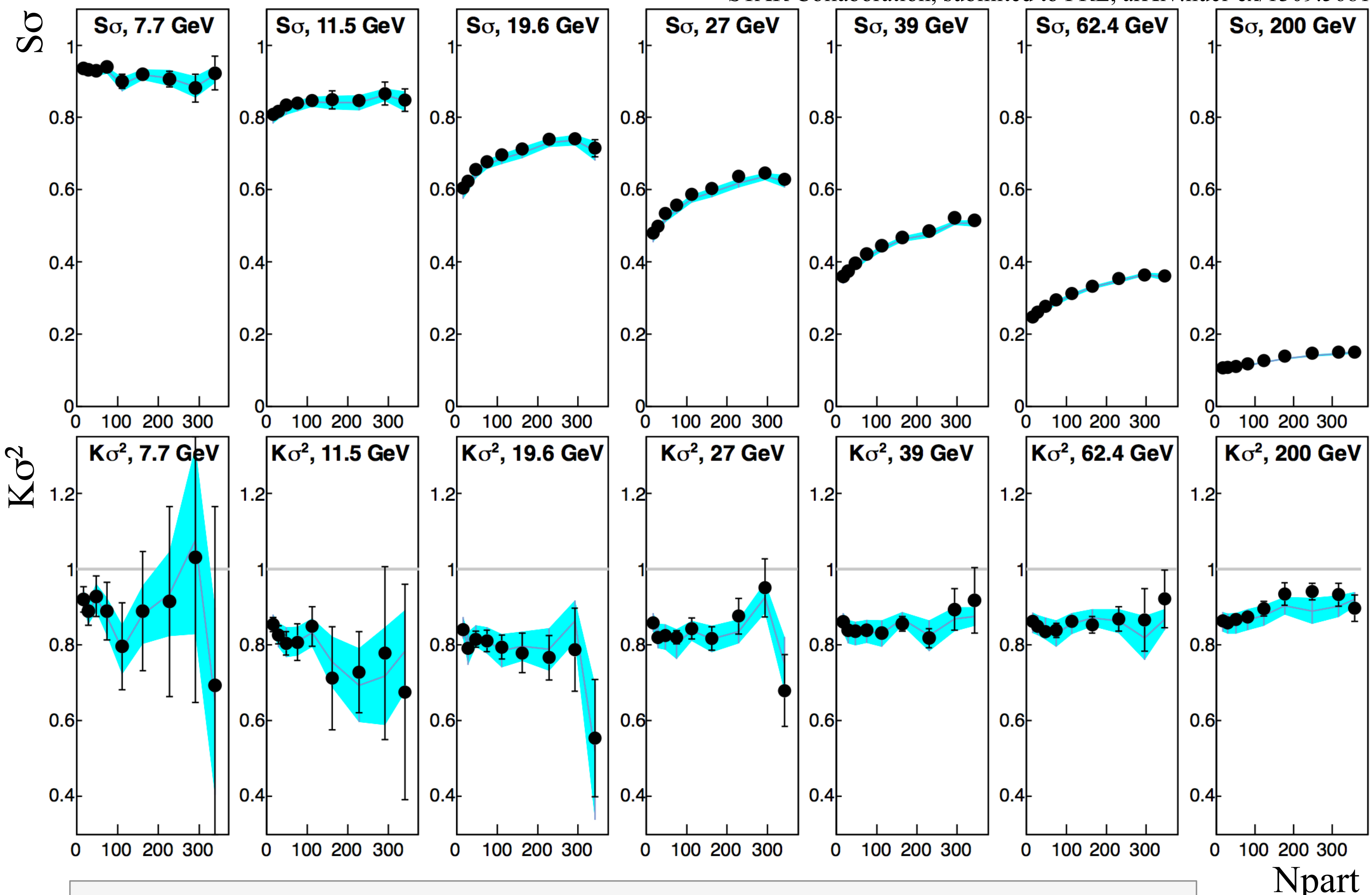
STAR Collaboration, submited to PRL, arXiv:nucl-ex/1309.5681



Independent production approaches reproduce the net-p moments products

Efficiency-corrected net-p $K\sigma^2$ vs centrality by $\sqrt{s_{NN}}$

STAR Collaboration, submited to PRL, arXiv:nucl-ex/1309.5681



IRV and sampled singles approaches (cyan) quantitatively reproduce the net-proton moments products at all beam energies and centralities…

Further exploring the moments products by deconstructing them…

The net-proton moments products can be understood using the p and pbar multiplicity distributions separately…

Intra-event correlations of N_p and N_{pbar} do not measurably affect the net-p moments products

That is…

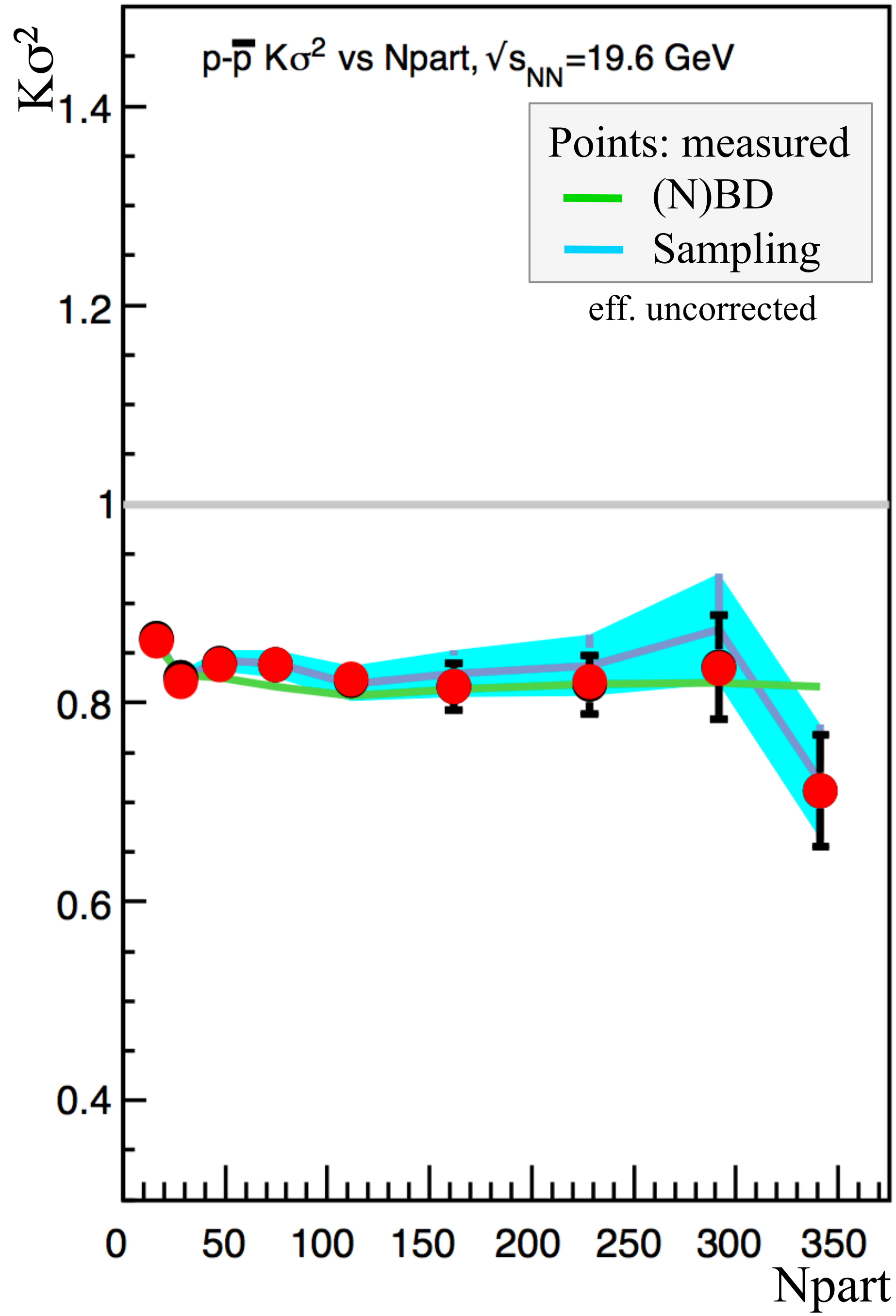
$K\sigma^2$(net-p)

$= C_4$ (net-p)/C_2(net-p)

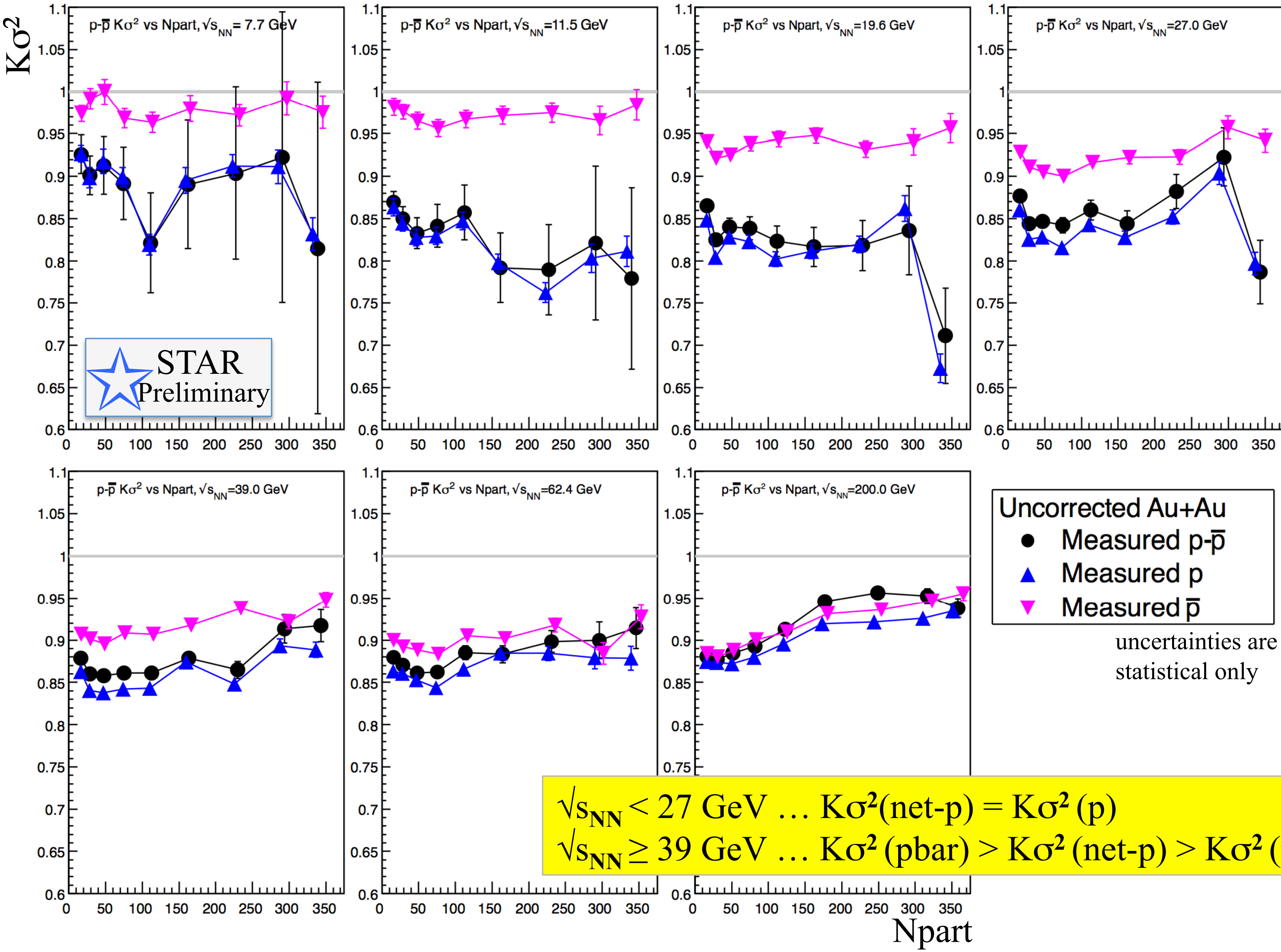
$= [C_4(p)+C_4(pbar)] / [C_2(p)+C_2(pbar)]$

Four quantities there.

Are the experimental values of $K\sigma^2$(net-p) driven by all four quantities equally?
Or does one of these dominate?



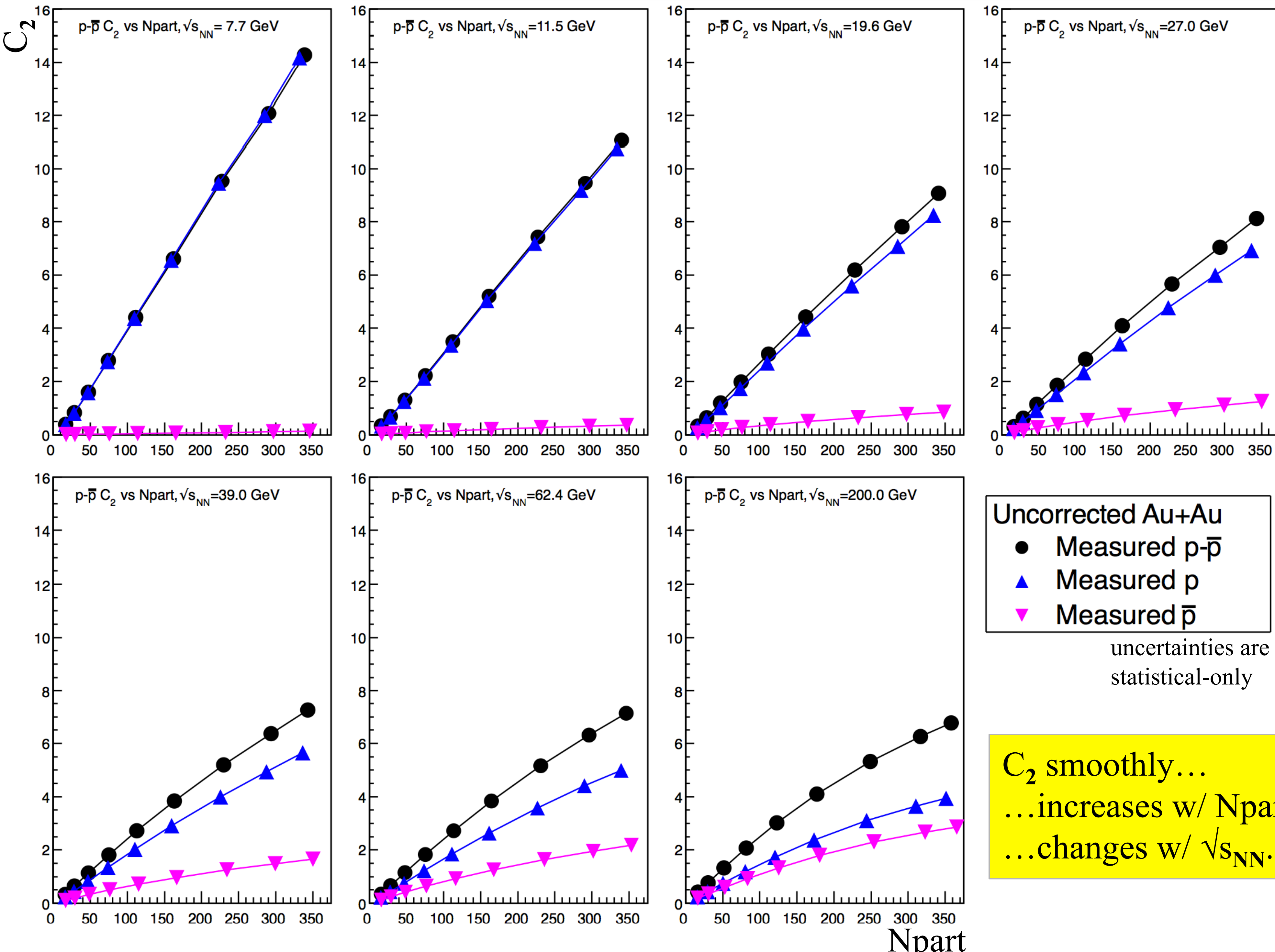
Charge-separated uncorrected $K\sigma^2$ *vs.* centrality by $\sqrt{s_{NN}}$



$\sqrt{s_{NN}} < 27$ GeV … $K\sigma^2$(net-p) = $K\sigma^2$ (p)

$\sqrt{s_{NN}} \geq 39$ GeV … $K\sigma^2$ (pbar) > $K\sigma^2$ (net-p) > $K\sigma^2$ (p)

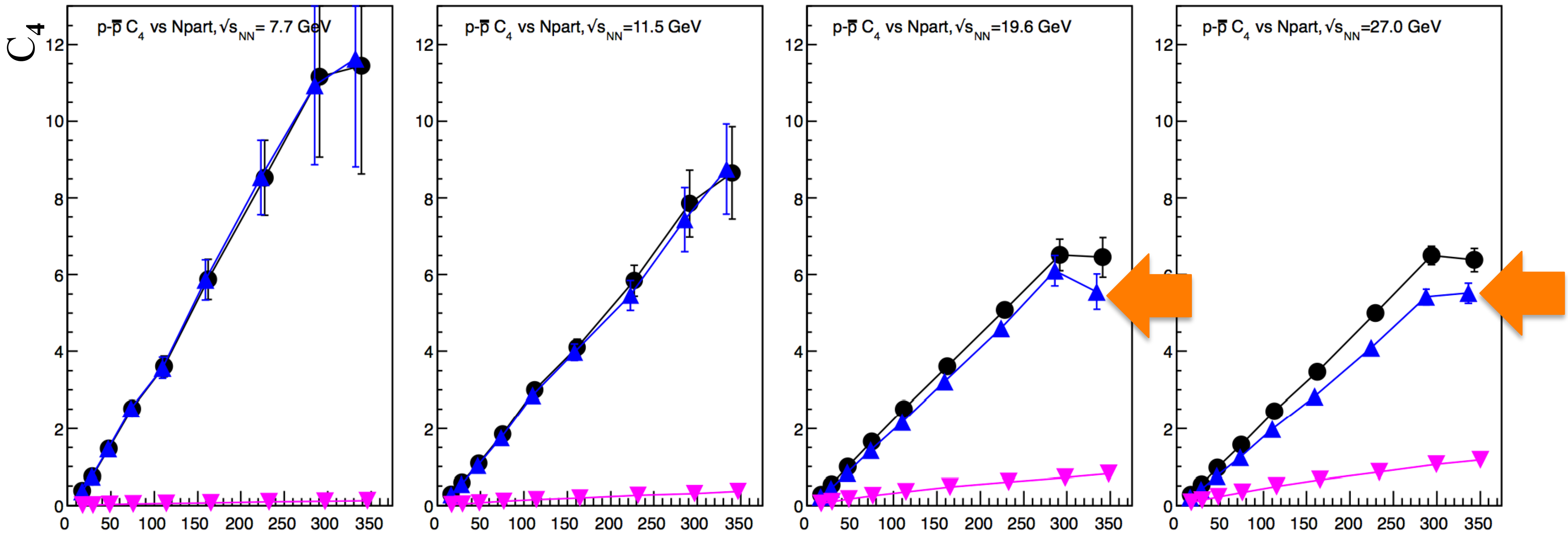
Uncorrected net-proton C_2 (variance) *vs.* centrality by $\sqrt{s_{NN}}$

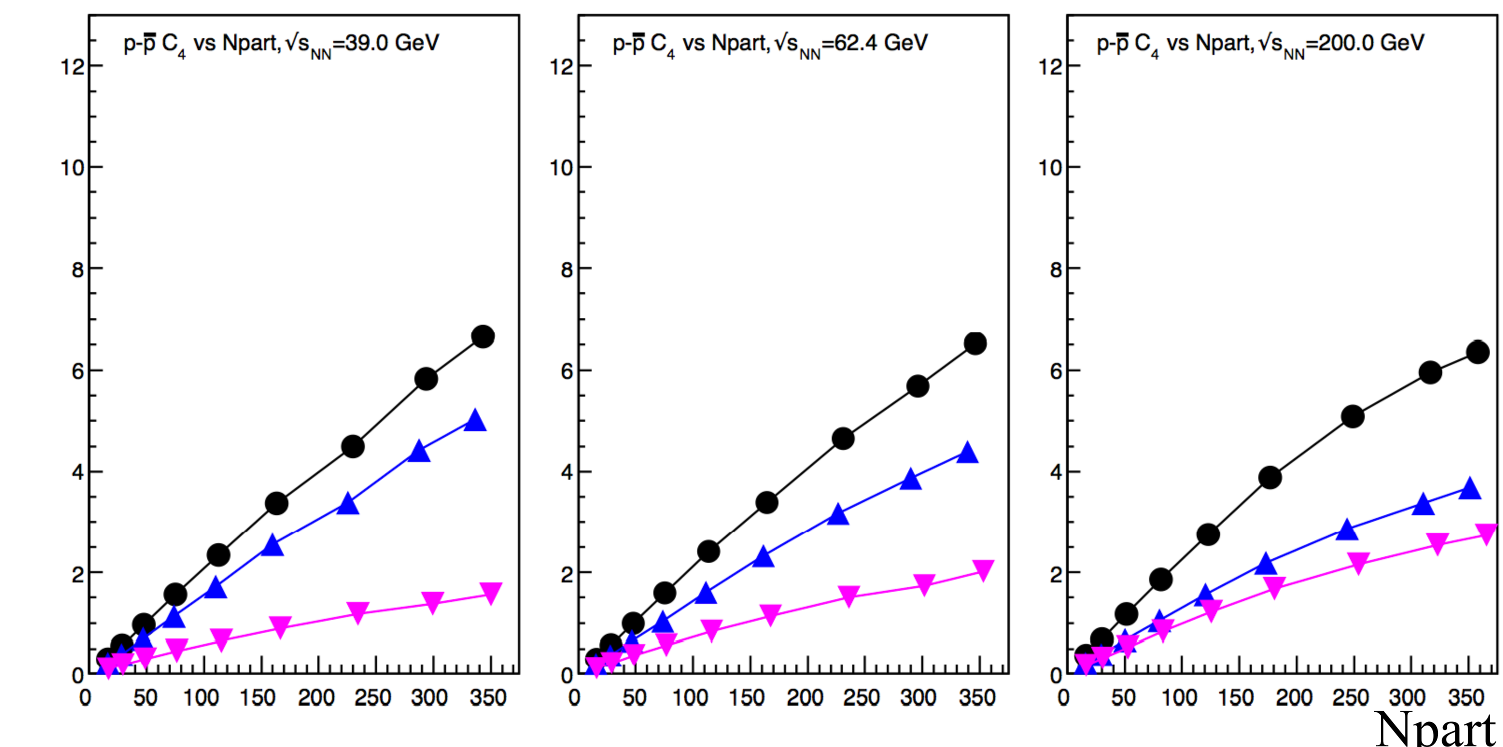


uncertainties are statistical-only

C_2 smoothly…
…increases w/ Npart.
…changes w/ $\sqrt{s_{NN}}$.

Uncorrected net-proton C_4 *vs.* centrality by $\sqrt{s_{NN}}$





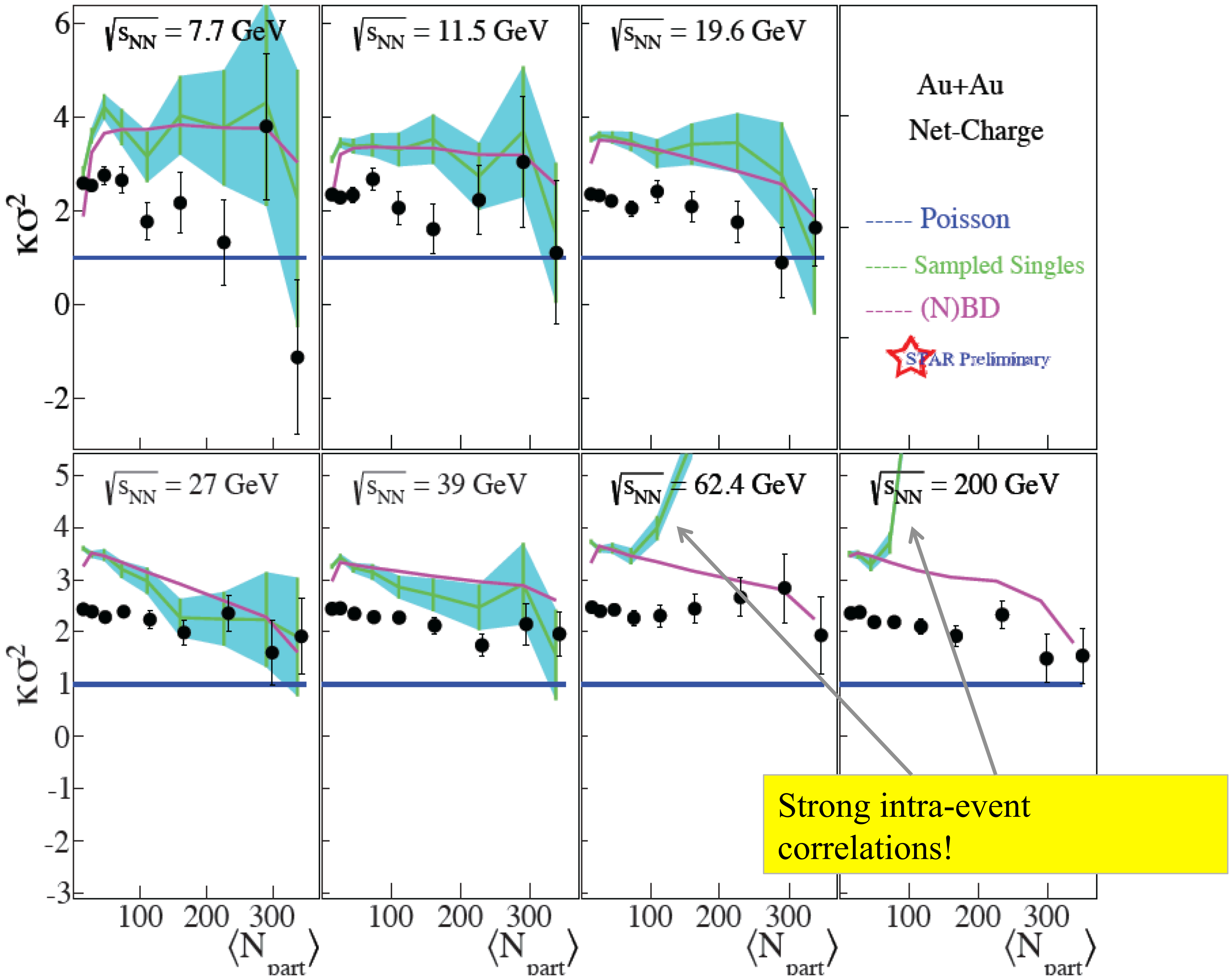
Uncorrected Au+Au
● Measured p-p̄
▲ Measured p
▼ Measured p̄

uncertainties are statistical-only

proton C_4 sags for 0-5% @ 19&27…

pbar C_4 increases smoothly…

Net-Charge (results from AGS-RHIC Users Meeting 2013, D. McDonald)



Summary

Net-proton moments products

Independent random variable cumulant arithmetic and the “sampled singles” approaches reproduce the experimentally-measured net-proton moments products nearly exactly…

- Implies intra-event correlations of N_p and N_{pbar} do not have a measurable effect on the measured net-p moments products.
- Agreement is almost as good if one simply ignores the antiprotons.
- The dip with respect to Poisson near ~19.6 GeV is driven by the proton C_4 values… …proton C_2 smoothly increases with centrality and beam energy

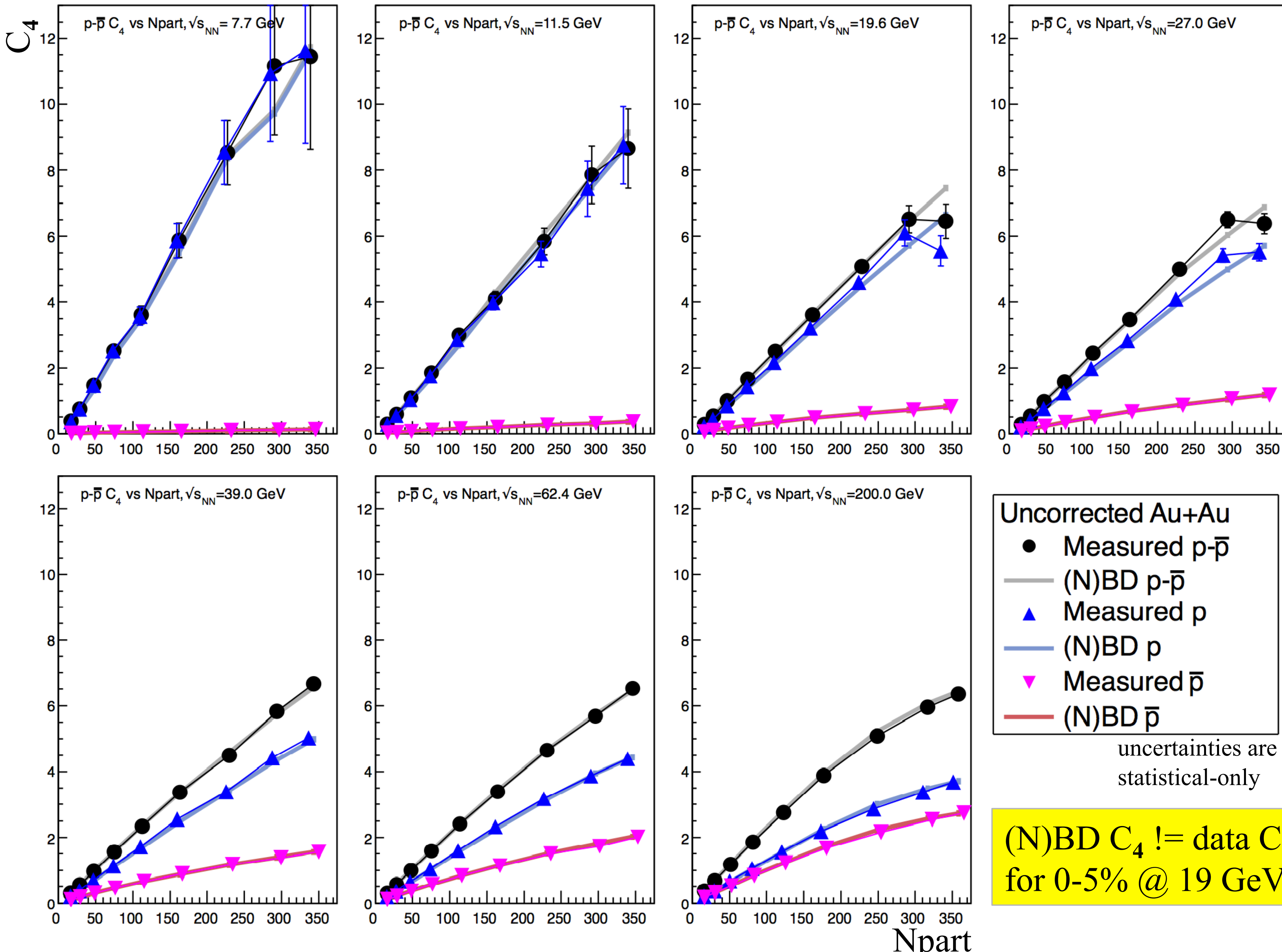
$$K\sigma^2(\text{net-p}) = C_4(\text{net-p}) / C_2(\text{net-p})$$
$$= [\mathbf{C_4(p)}+C_4(\text{pbar})] / [C_2(p)+C_2(\text{pbar})]$$

Net-charge moments products

- Net-charge moments products deviate slightly from all baselines in general.
- Independent production approaches deviate strongly from the experimental data for ~central collisions in the 62.4 and 200 GeV data sets.

BACKUP SLIDES

Comparison of (N)BD to uncorrected net-proton C_4 *vs.* centrality by $\sqrt{s_{NN}}$

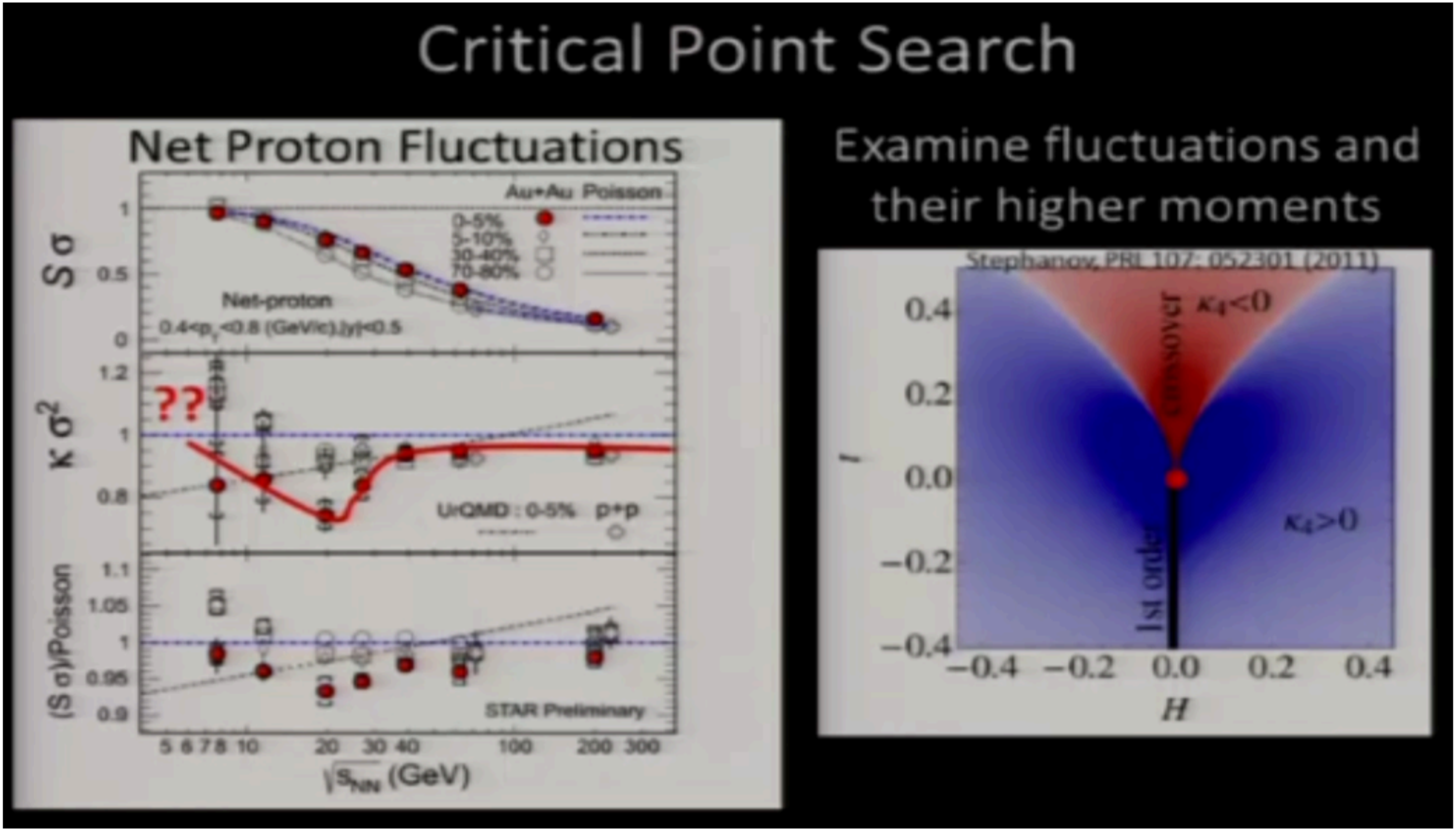


uncertainties are statistical-only

(N)BD C_4 != data C4 for 0-5% @ 19 GeV…

On the apparent net-p dip near 19.6 GeV

J. Nagle, last talk at QM2012

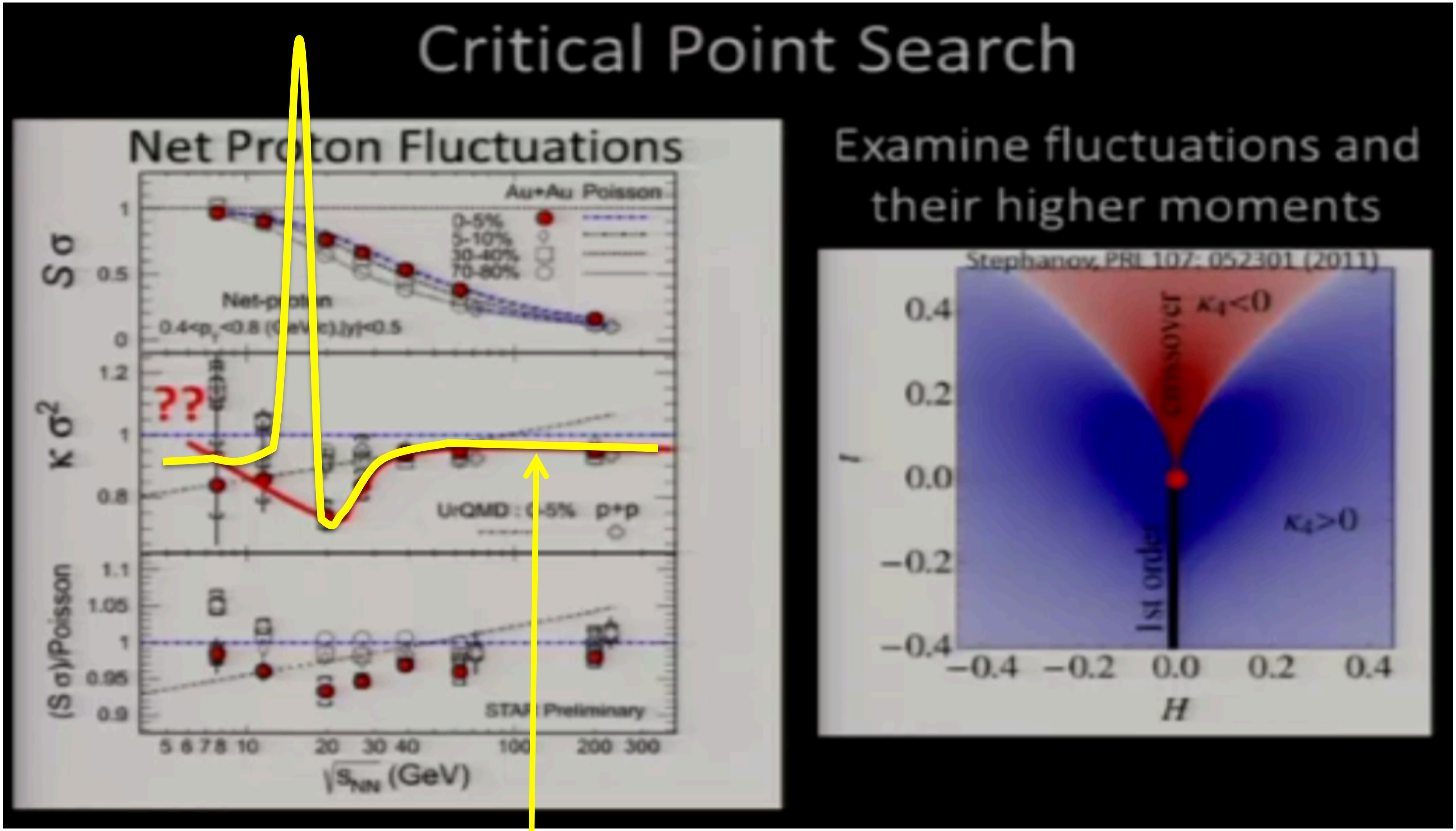


Kurtosis < Poisson for $\sqrt{s_{NN}}$ just above CP?

M.A. Stephanov, Phys. Rev. Lett. 107, 052301 (2011)

On the apparent net-p dip near 19.6 GeV

J. Nagle, last talk at QM2012



what the NLSM would *actually* expect for a CP at $\sqrt{s_{NN}}$~15 GeV
(15 GeV data on the way in upcoming Run 14!)

Negative Binomial / Poisson / Binomial

T..J. Tarnowsky & G. Westfall, Oct. 2012 `http://arxiv.org/pdf/1210.8102v1.pdf`

Functional form describes the (particle identified) multiplicity distributions ranging from NA22 & UA5 to PHENIX

Inputs:
mean (μ) &
variance (σ^2)

Then, the values of C_k , $S\sigma$, & $K\sigma^2$ are predicted.

$\mu<\sigma^2$ …NBD
$\mu=\sigma^2$ …Poisson
$\mu>\sigma^2$ …BD

If the mean is equal to the variance, a Poisson Distribution is used. The BD baseline for the moments products $S\sigma$ and $K\sigma^2$ uses the parameter p, defined as p=1-σ^2/μ, where μ is the mean and σ^2 is the variance. Then, the BD baseline for $S\sigma$ is given by

$$(S\sigma)^{BD} = 1 - 2p \ (\mu > \sigma^2), \tag{2.19}$$

and the BD calculation of the moments product $K\sigma^2$ is

$$(K\sigma^2)^{BD} = 1 - 6p + 6p^2 \ (\mu > \sigma^2). \tag{2.20}$$

For the NBD baselines of the moments products $S\sigma$ and $K\sigma^2$ the parameter p is defined as p=μ/σ^2. Then, the NBD baseline for $S\sigma$ is given by

$$(S\sigma)^{NBD} = (2 - p)/p \ (\mu < \sigma^2), \tag{2.21}$$

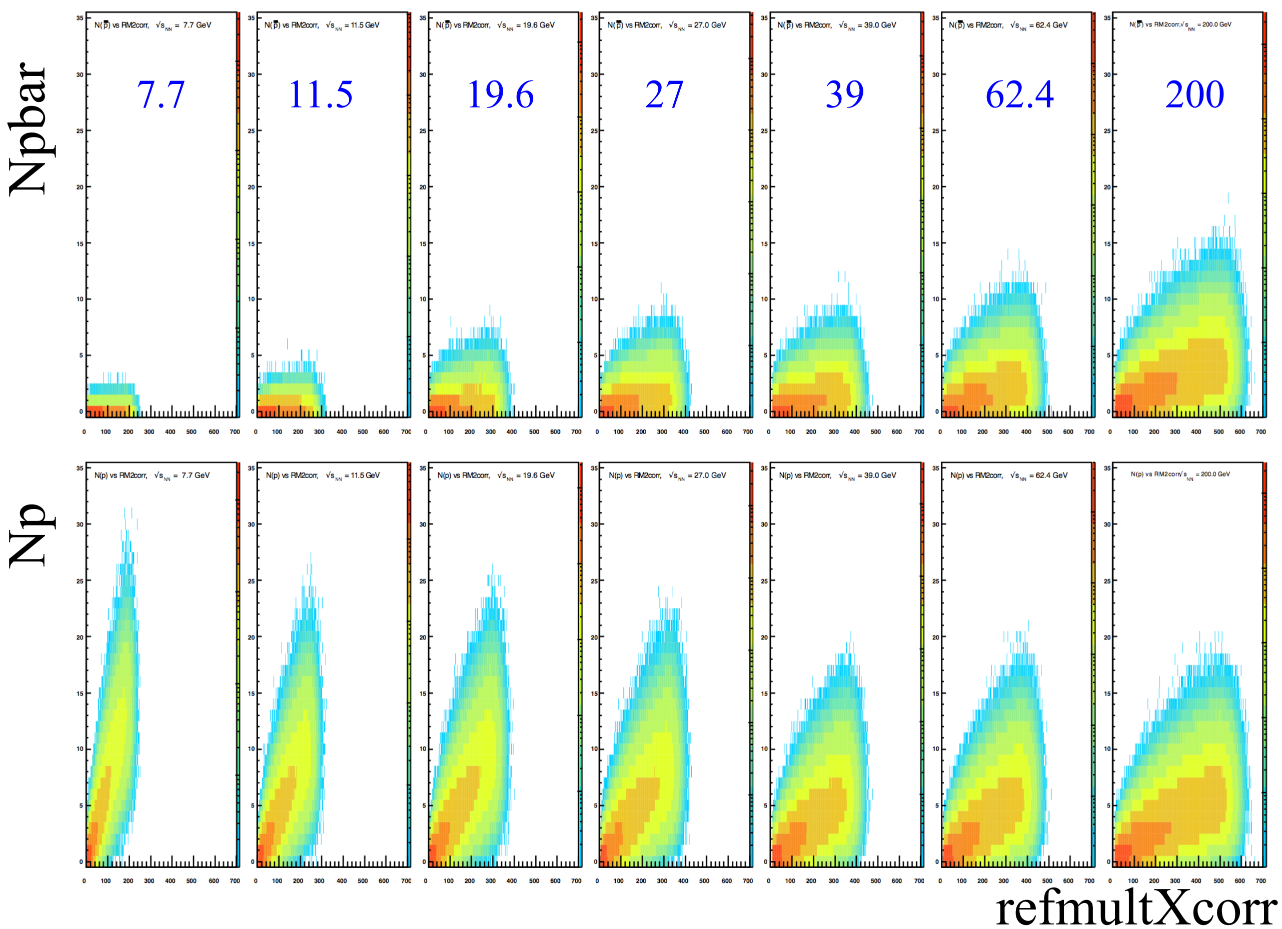
and the NBD calculation of the moments product $K\sigma^2$ is

$$(K\sigma^2)^{NBD} = (6 - 6p + p^2)/p^2 \ (\mu < \sigma^2). \tag{2.22}$$

Sampled Singles

The only input is the 2D distributions of Npos *vs.* centrality and Nneg *vs.* centrality.
where pos = p, K^+, q^+ & neg = pbar, K^-, q^-

With Nnet and Ntot *vs.* centrality I can also independently produce the experimental results, with delta theorem error bars, efficiency corrections, etc…



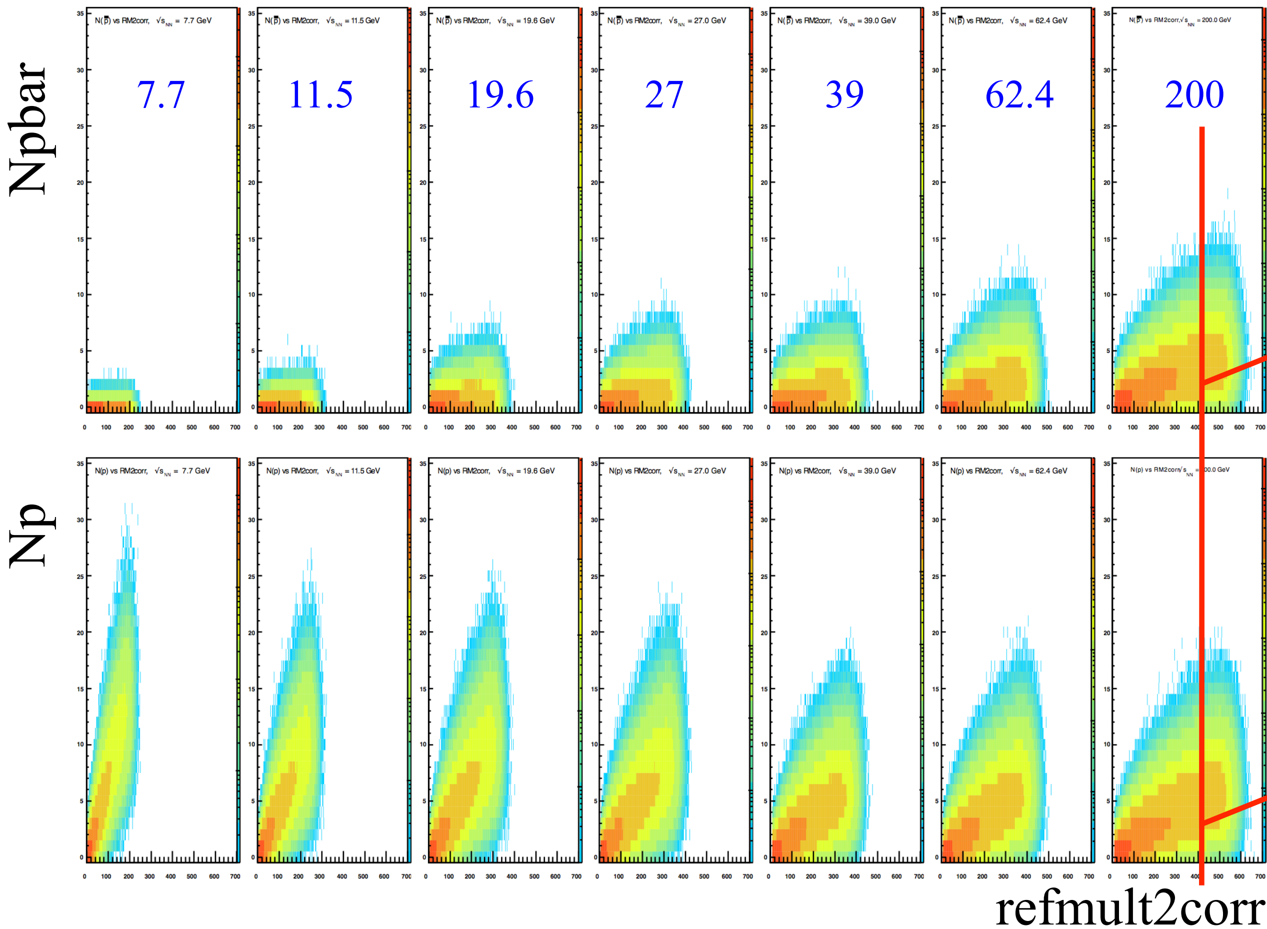
similar plots for $K^{\pm}$, $q^{\pm}$…

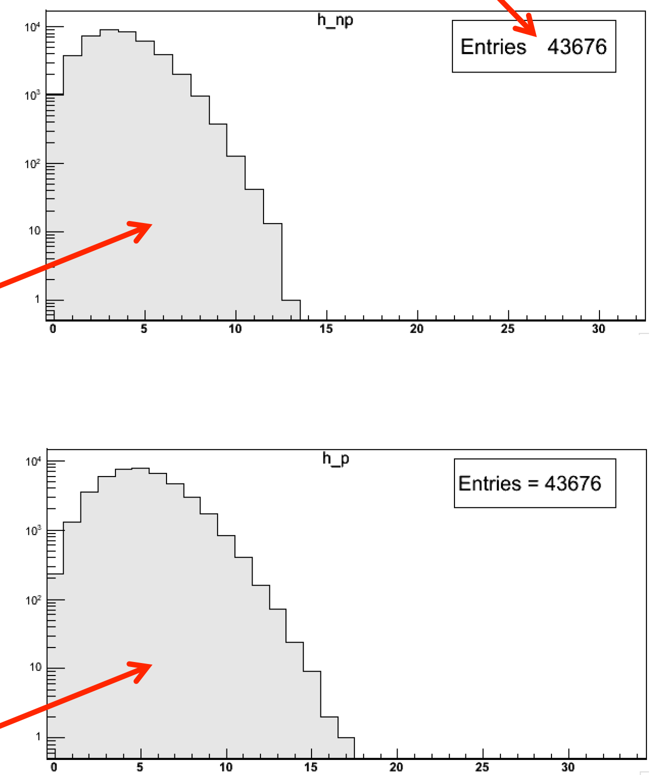
Filled at exactly the same spot in the analysis codes where the deviates are saved

i.e. TH2Ds include the same track cuts, PID, and run&evt QA as the local analysis…

Sampled Singles method

In every slice of rmXcorr, sample one value of Npos and one value of Nneg, Nevt times.





cf. G. Torrieri *et al.*,
J. Phys. G, **37**, 094016 (2010)

In each sample at a given rmXcorr, one then has a value for Npos and Nneg

Then form Nnet = Npos-Nneg and Ntot = Npos+Nneg

Fill similar 2D plots of Nnet and Ntot *vs.* centrality

And then extract the moments (products) and do the CBW corrections as usual…

Destroys all intra-event correlations between Npos and Nneg, reproduces singles distributions, & has the same statistical certainty as the data by construction…