STAR Detector Upgrades for BES-II

W.J. Llope for the STAR Collaboration
Wayne State University

Why (do a) Beam Energy Scan (BES)?

#1. Search for the disappearance of QGP signatures
#2. Search for the existence of a QCD critical point

Where & Who? ☆ at BNL

What (was seen in) BES-I?

Why (do it again in) BES-II?

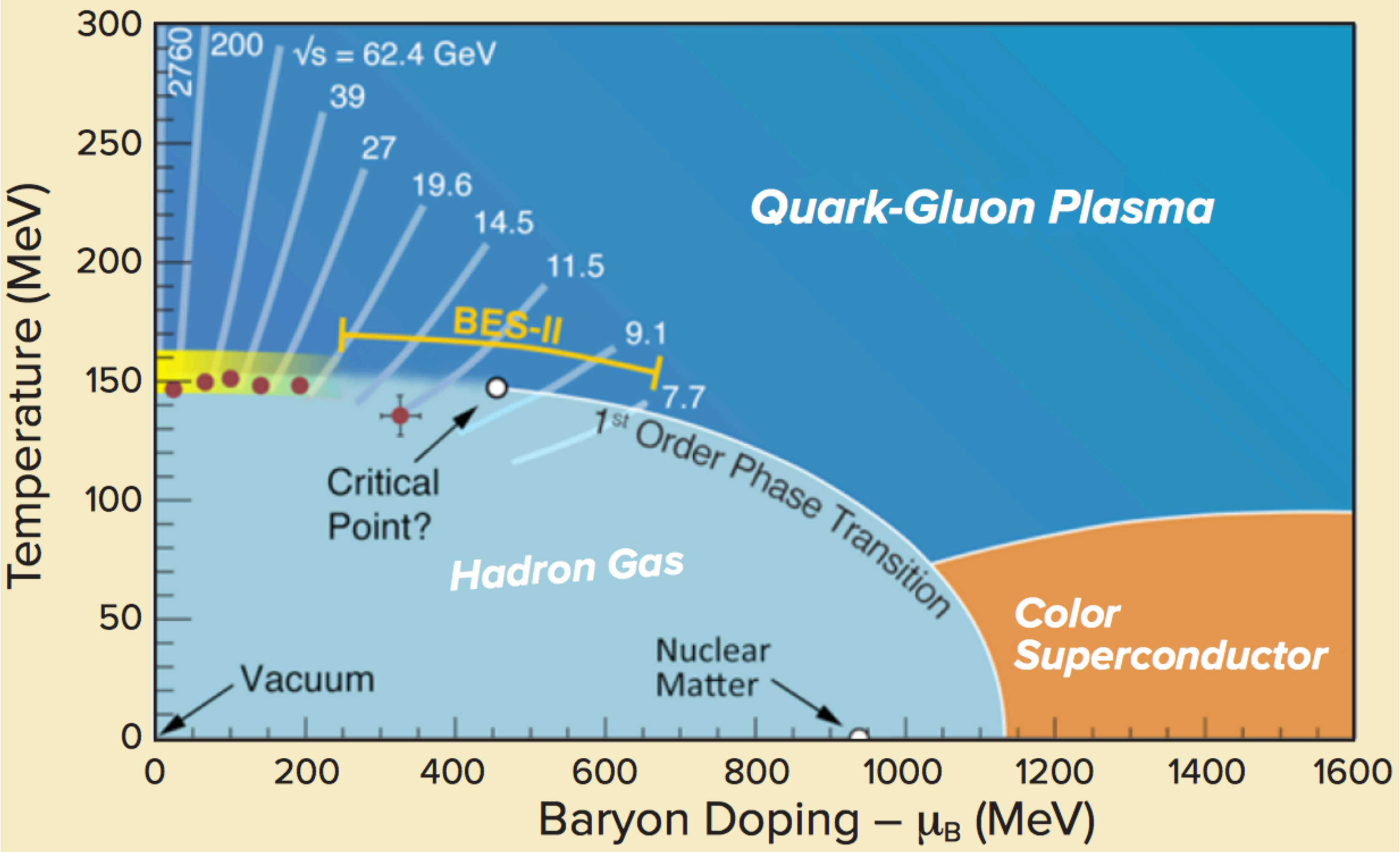
How (to optimize ☆ for) BES-II?

This talk will discuss these questions while focussed on motivation #2.
See Rosi Reed's talk Thursday morning: same topic but different spin!

Why BES? Our map of the world is mostly dragons at the moment...

Top beam energy at RHIC (200 GeV): crossover transition from QGP to HG.

Decreasing the beam energy increases the baryochemical potential



Systematic study of the data as a function of the beam energy allows a “scan” in streaks across the phase diagram...

Why BES? Search for critical opalescence...

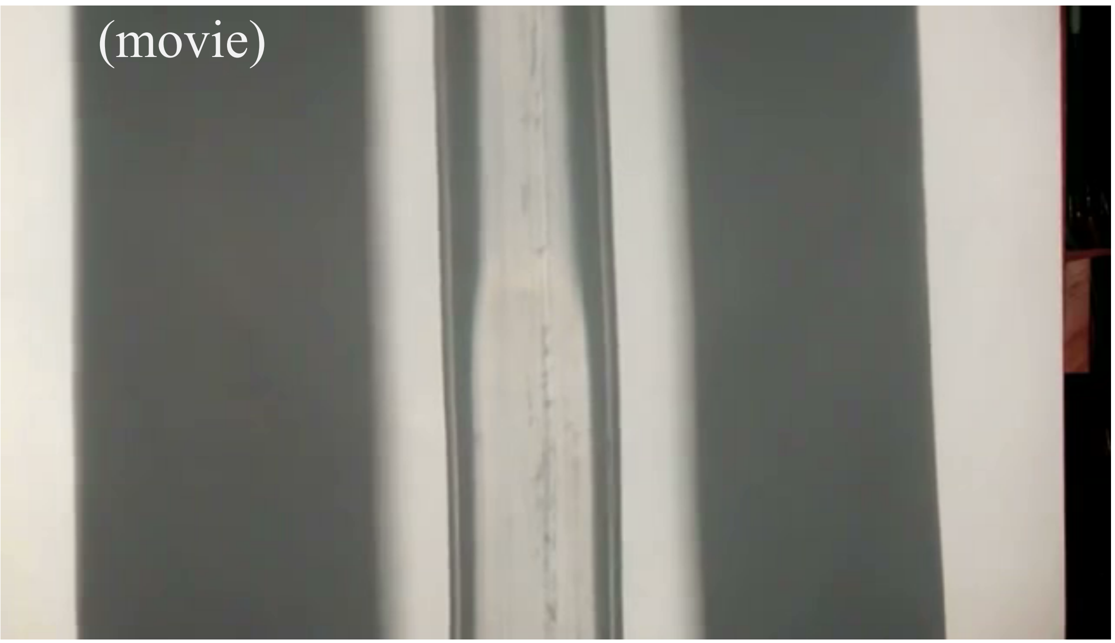
So how could we find a Critical Point if it exists?

Assume that it's going to have the same basic features of other CPs

divergence of the susceptibilities, χ… *e.g.* magnetism transitions 0801.4256v2

divergence of the correlation lengths, ξ… *e.g.* critical opalescence

liquid SF_6 at 37atm heated to ~43.9 C, then cooled



CO_2 near its liquid-gas transition

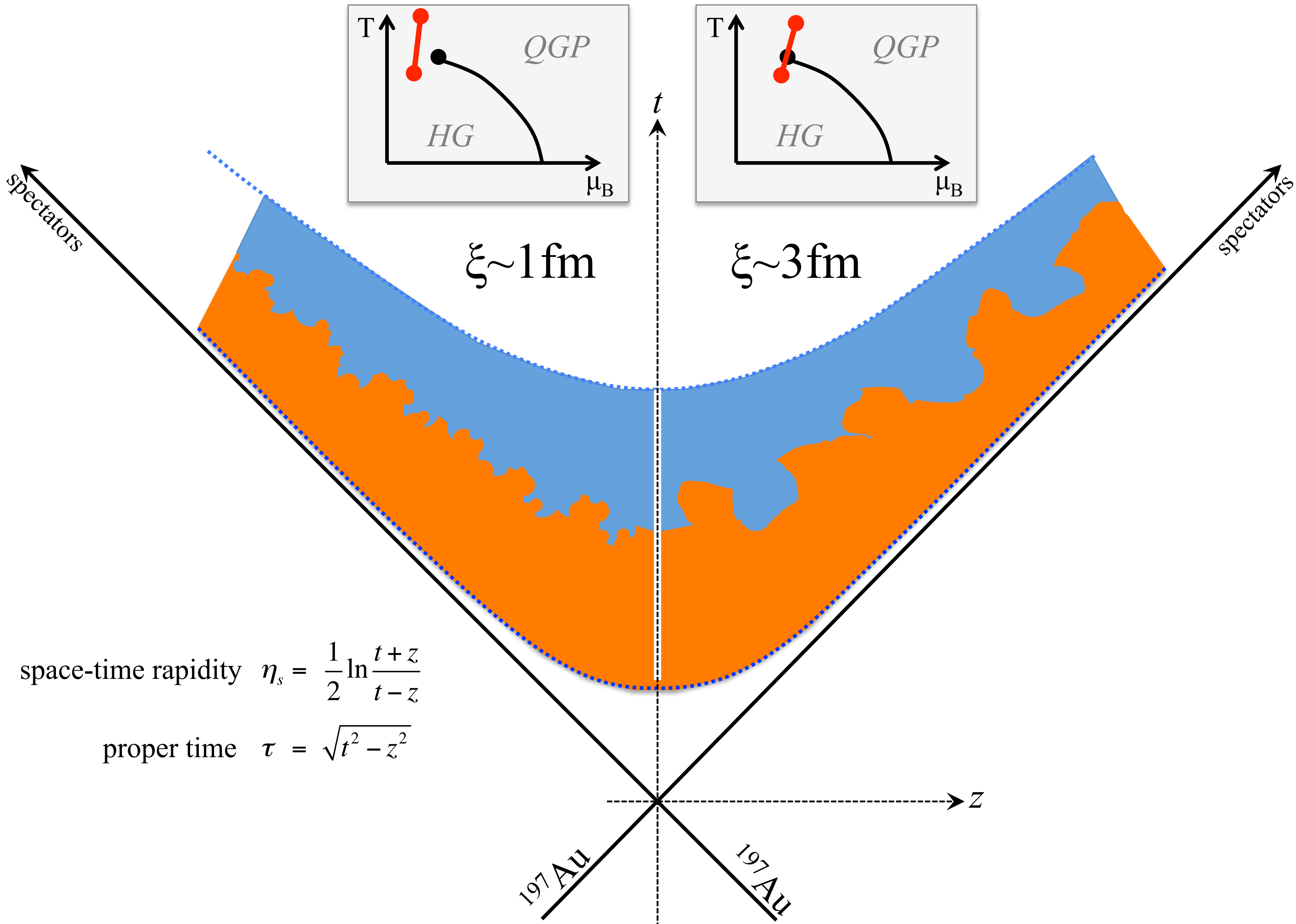
$T > T_C$ $T \sim T_C$ $T < T_C$

T. Andrews. Phil. Trans. Royal Soc., 159:575, 1869
M. Smoluchowski, *Annalen der Physik, 25 (1908) 205 - 226*
A. Einstein, *Annalen der Physik, 33 (1910) 1275-1298*

Formation of large domains of the two phases (hadronic, QGP)

Large domains mean large correlation length, ξ – canonical signature of a critical point

Why BES? Search for critical opalescence...



space-time rapidity $\eta_s = \frac{1}{2}\ln\frac{t+z}{t-z}$

proper time $\tau = \sqrt{t^2 - z^2}$

Why BES? Search for critical opalescence via multiplicity cumulants...

The ratios of cumulants of the net-particle multiplicity distributions, *e.g.* C_4/C_2, should diverge if the correlation length diverges...

No. of particles in a single event...

Average No. of particles in all "similar" events...

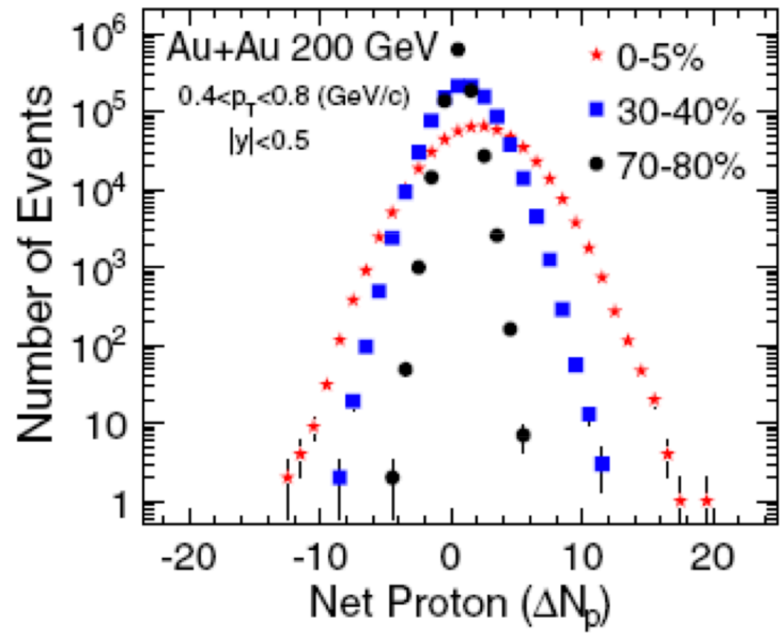
$$\delta x \equiv x - \langle x \rangle$$

C_2 $$\kappa_{2x} \equiv \langle\langle x^2 \rangle\rangle \equiv \langle (\delta x)^2 \rangle$$

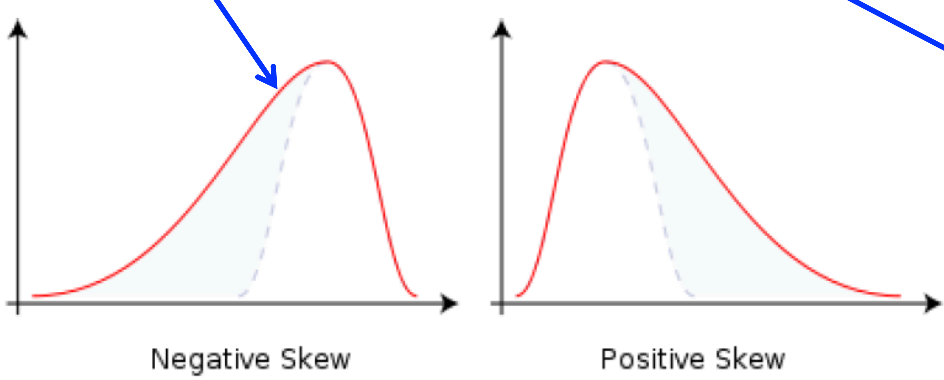
C_3 $$\kappa_{3x} \equiv \langle\langle x^3 \rangle\rangle \equiv \langle (\delta x)^3 \rangle$$

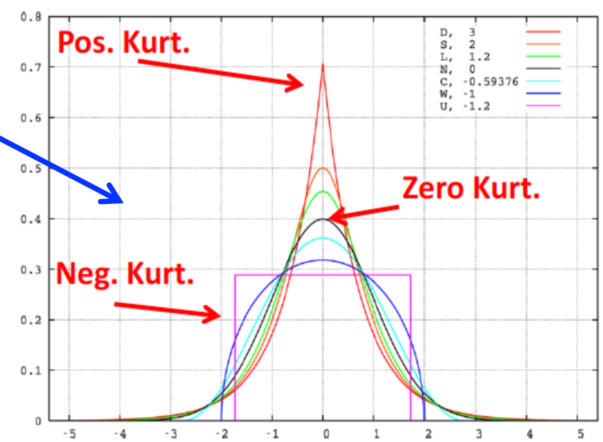
C_4 $$\kappa_{4x} \equiv \langle\langle x^4 \rangle\rangle \equiv \langle (\delta x)^4 \rangle - 3 \langle (\delta x)^2 \rangle^2$$

$$\text{skewness} = \frac{\kappa_3}{\kappa_2^{3/2}}, \quad \text{kurtosis} = \frac{\kappa_4}{\kappa_2^2}$$



STAR, Phys. Rev. Lett. 105 (2010) 022302





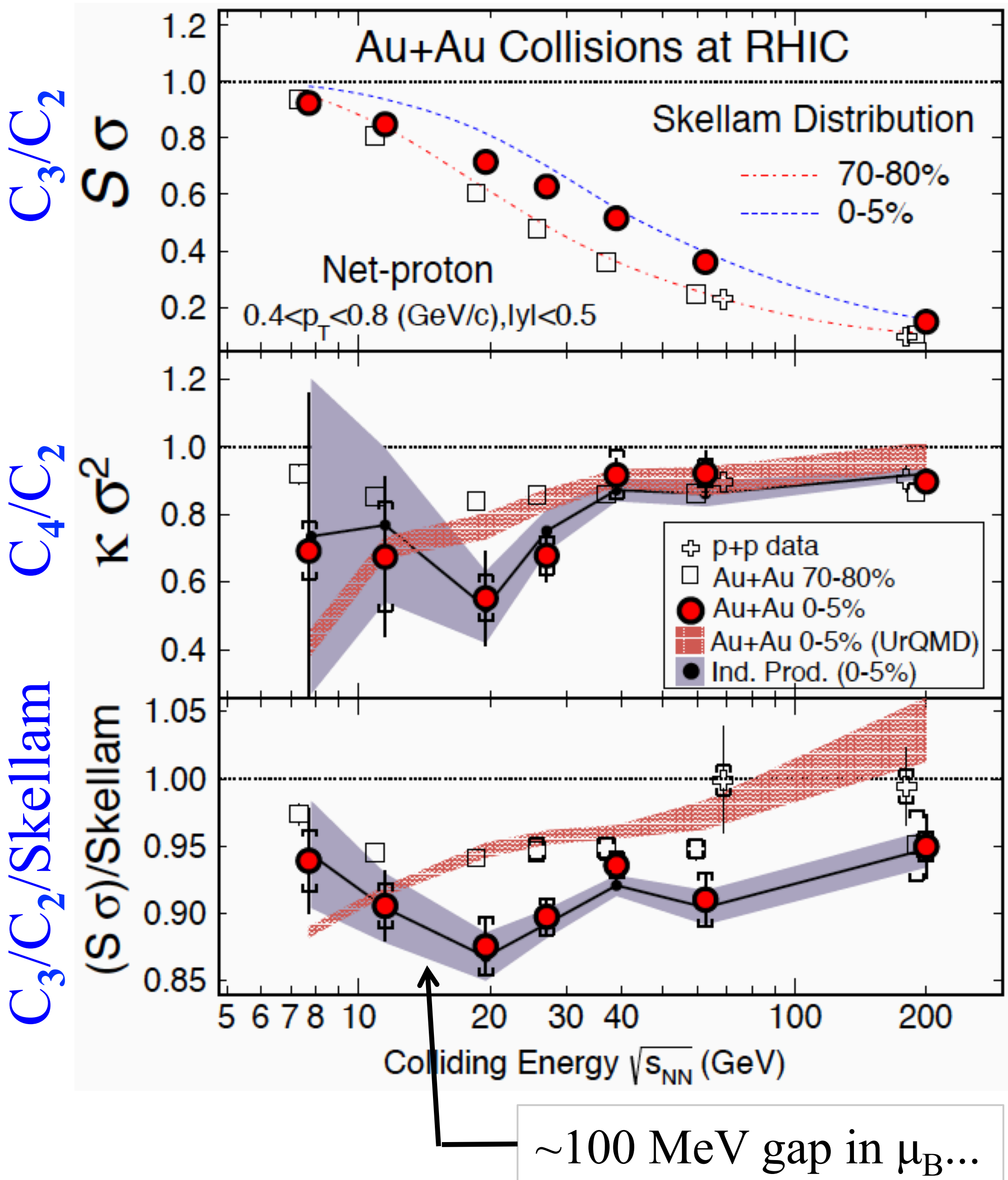
Deviations of the cumulant ratios from Poisson expectations is "interesting"

What (was learned in) BES-I? Net-proton multiplicity cumulant ratios...

$0.4<P_T<0.8$ GeV/c

STAR net-p PRL

L. Adamczyk, et al., [STAR Collaboration], Phys. Rev. Lett. 112 (2014) 032302.



Poisson expectation is effectively that obtained from the Skellam distribution (difference of two Poissons)

There do seem to be 2-3σ deviations from the Poisson...
but with large uncertainties...

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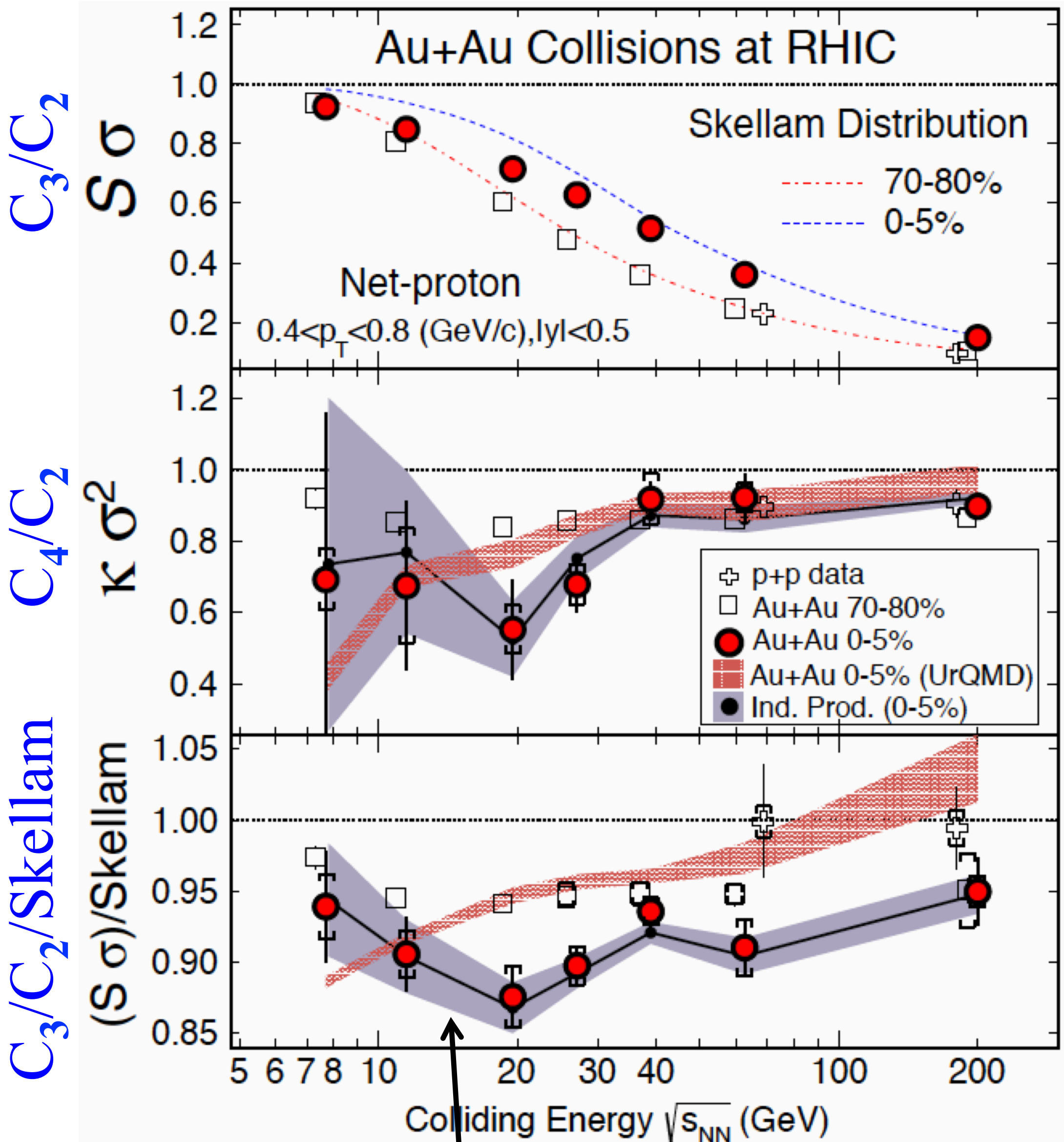
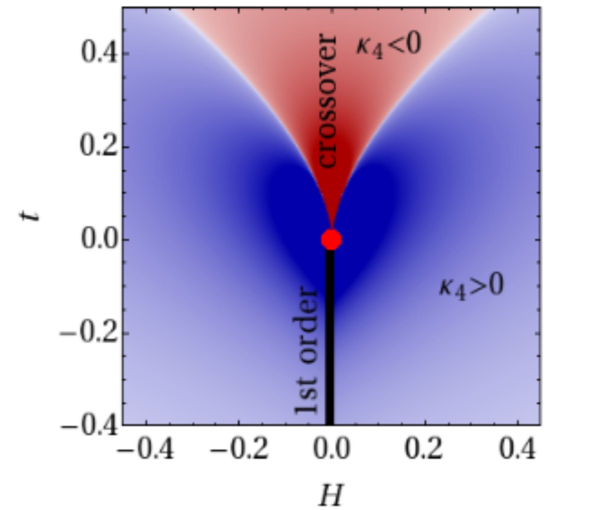
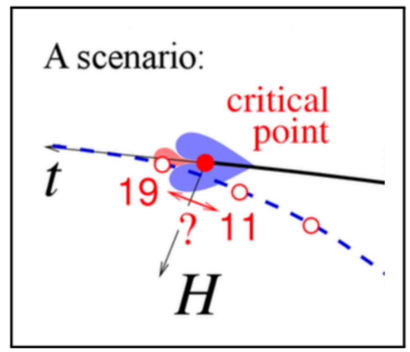


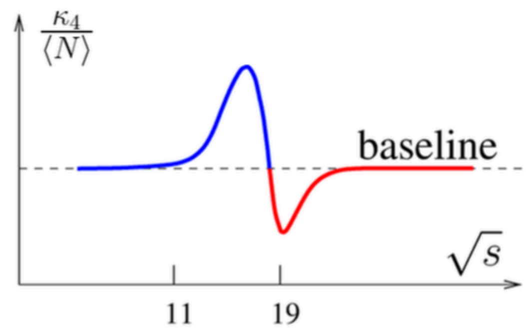
~100 MeV gap in μ_B...

C. Athanasiou et al., **PRD** 82, 074008 (2010)
M.A. Stephanov, PRL **107**, 052301 (2011)

Non-linear σ model:







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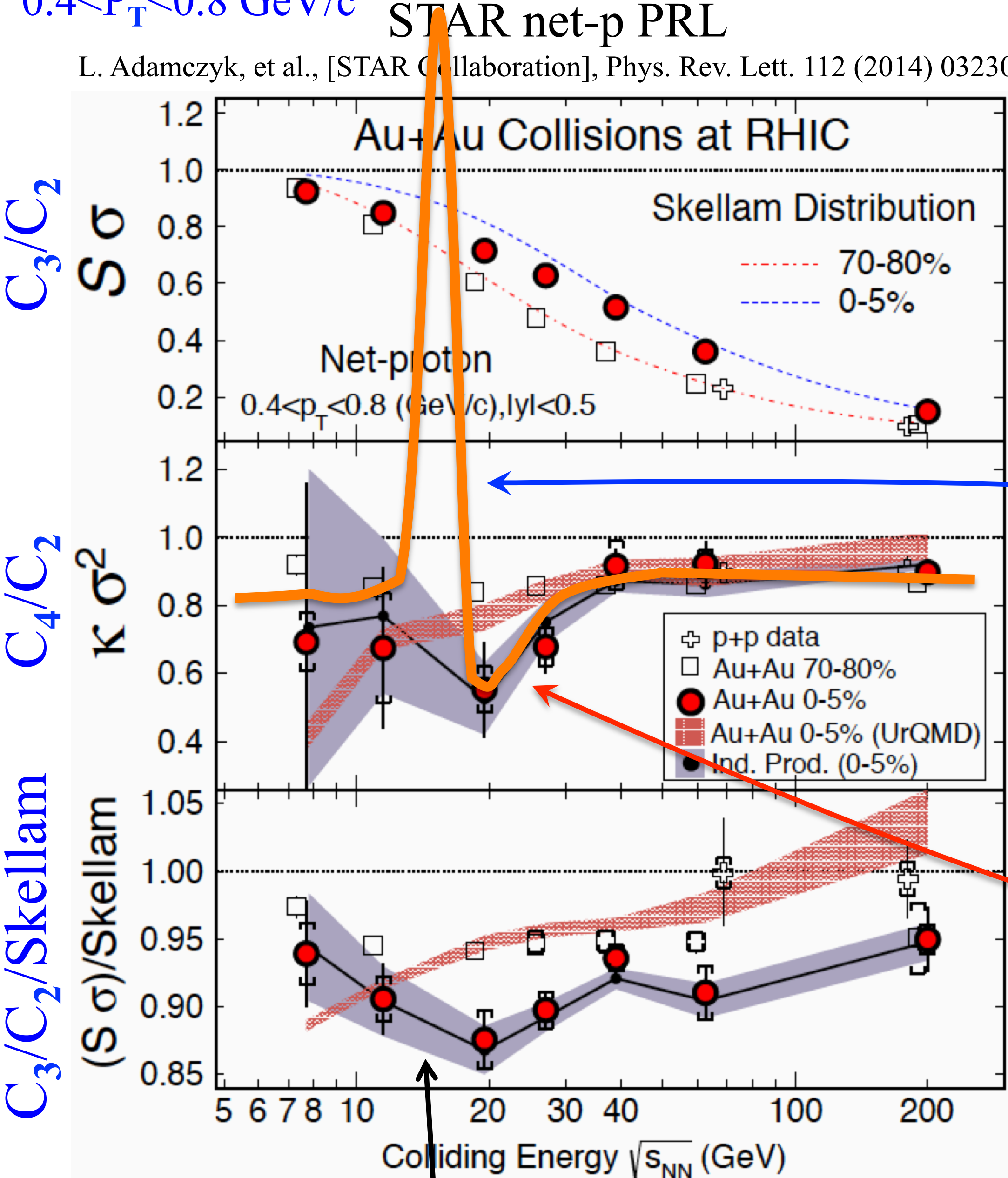

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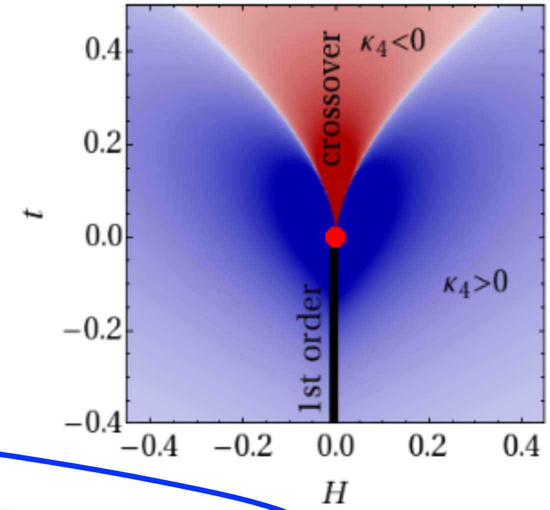
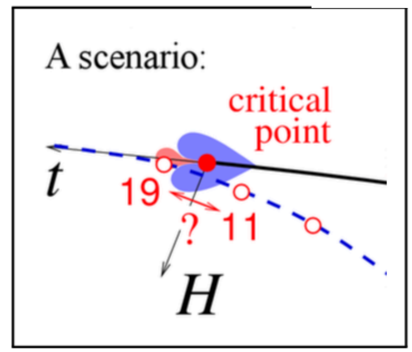
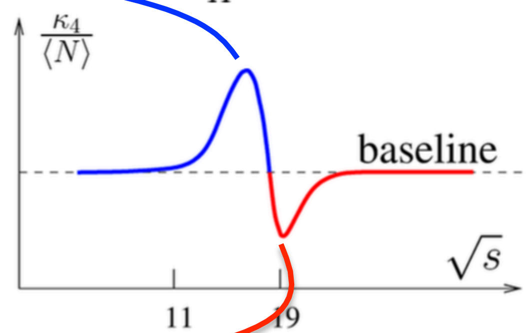




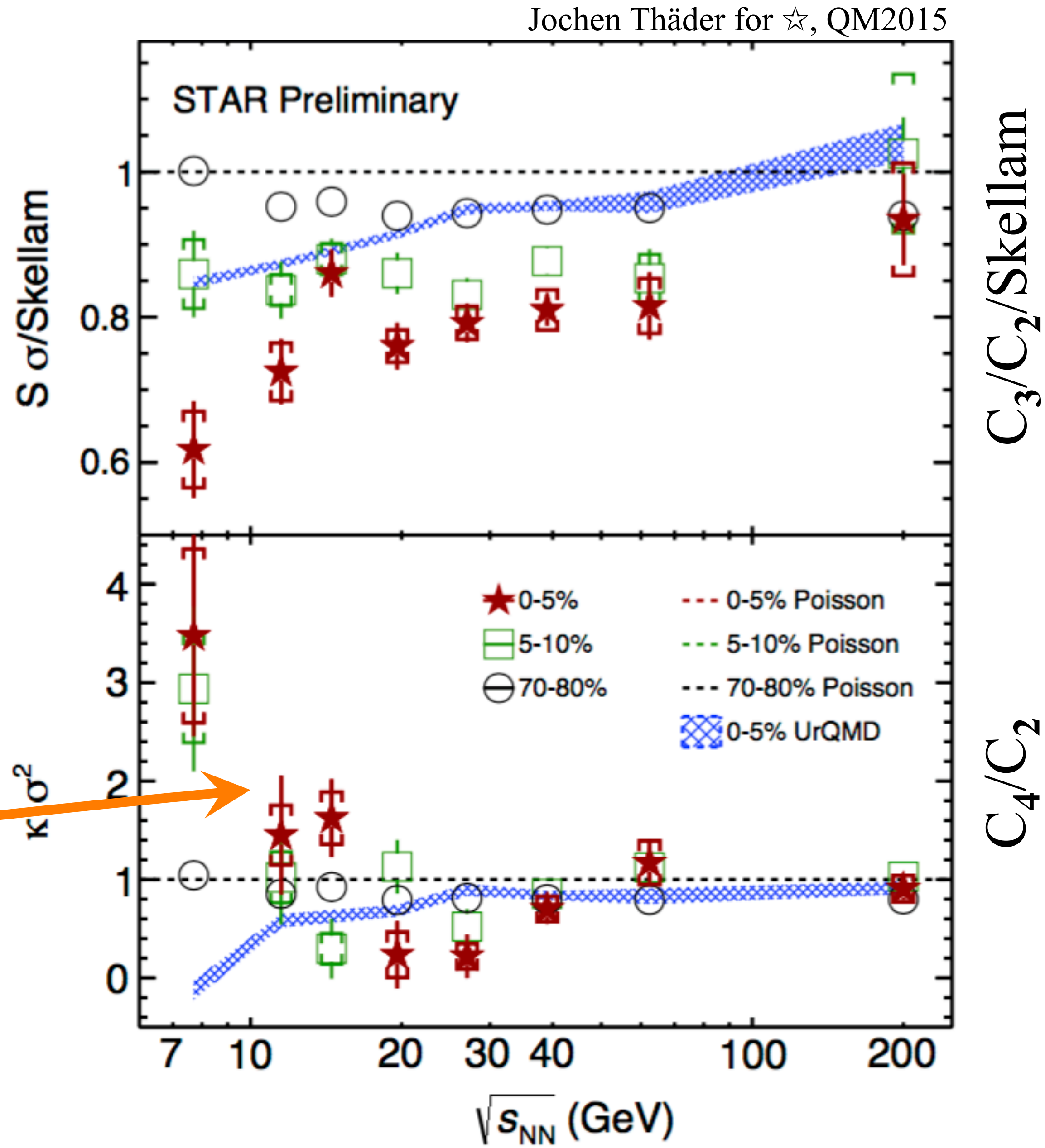


~100 MeV gap in μ_B... Data at 14.5 GeV was collected in 2014!

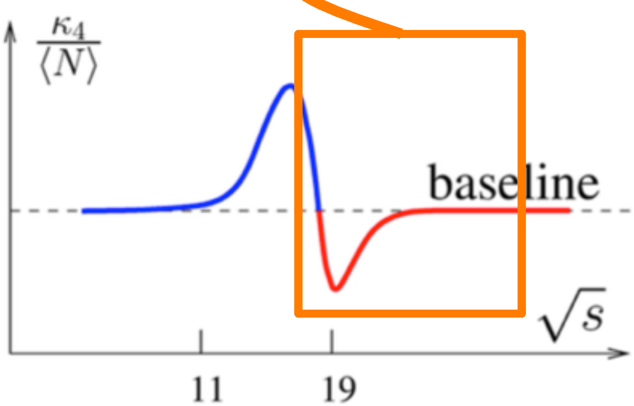
What (was learned in) BES-I? Net-proton multiplicity cumulant ratios...

Widen the acceptance!

from $0.4<P_T<0.8$ to $0.4<P_T<2.0$...



critical opalescence?



A wider P_T acceptance made the deviations from Poisson much larger!

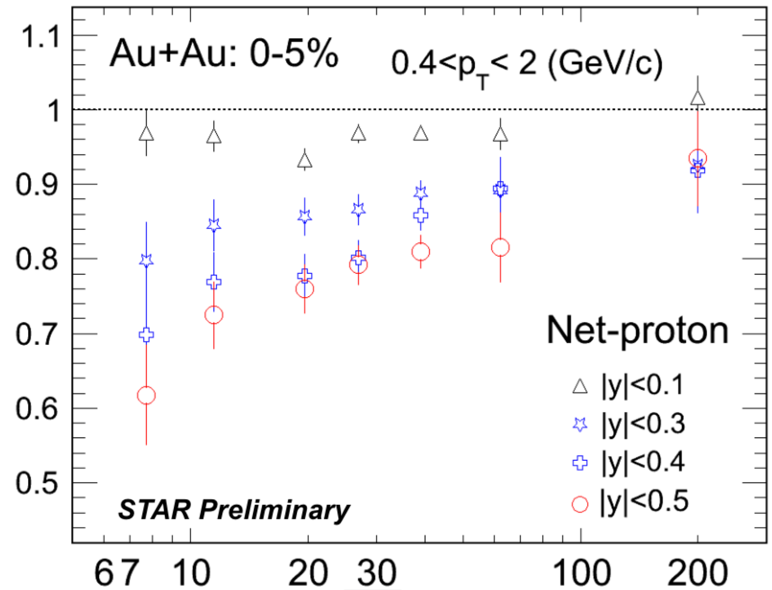
What (was learned in) BES-I? Net-proton multiplicity cumulant ratios...

In a small acceptance, you will see Poissonian cumulant ratios, CP or not....

V. Koch, RIKEN BNL Research Center Workshop on Fluctuations, Correlations and RHIC Low Energy Runs, October 3-5, 2011
http://quark.phy.bnl.gov/~htding/fcrworkshop/Koch.pdf

decreasing rapidity acceptance in the analysis also drives the C_4/C_2 values to Poisson:

see also D. Mahapatra *et al.*, arXiv nucl-ex/0108011v2



X. Luo, QM2014

Net-baryon Acceptance:

0% — 100%

Poisson fluctuations — Zero fluctuations (baryon # conservation)

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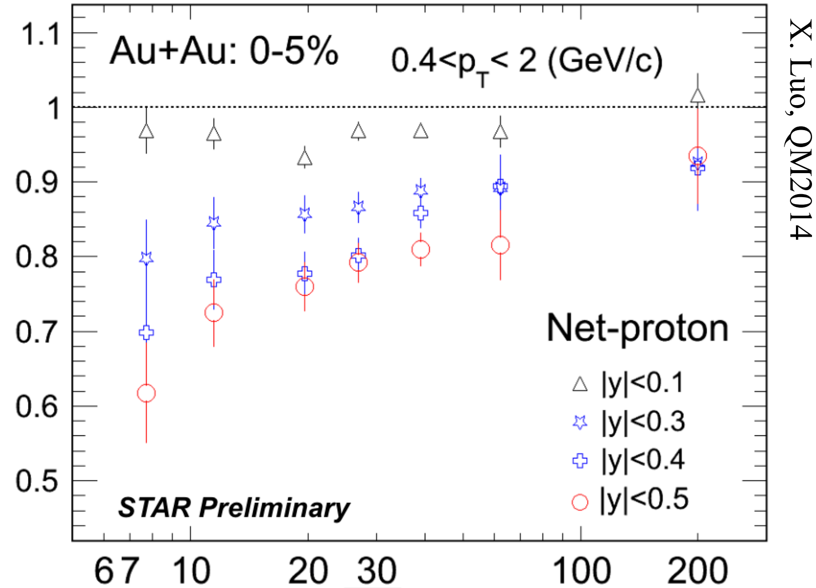

Net-baryon Acceptance:

0%		100%
Poisson fluctuations	Maximum signal?	Zero fluctuations (baryon # conservation)
No signal!	B. Ling & M. Stephanov, arXiv 1512.09125	No signal!

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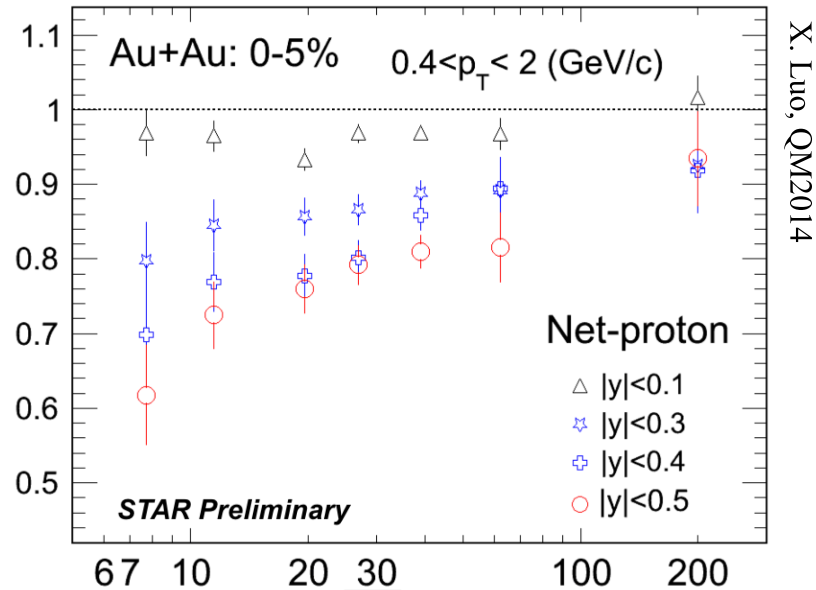


Net-baryon Acceptance:

0% 5% 14% 100%

Poisson fluctuations

Zero fluctuations (baryon # conservation)

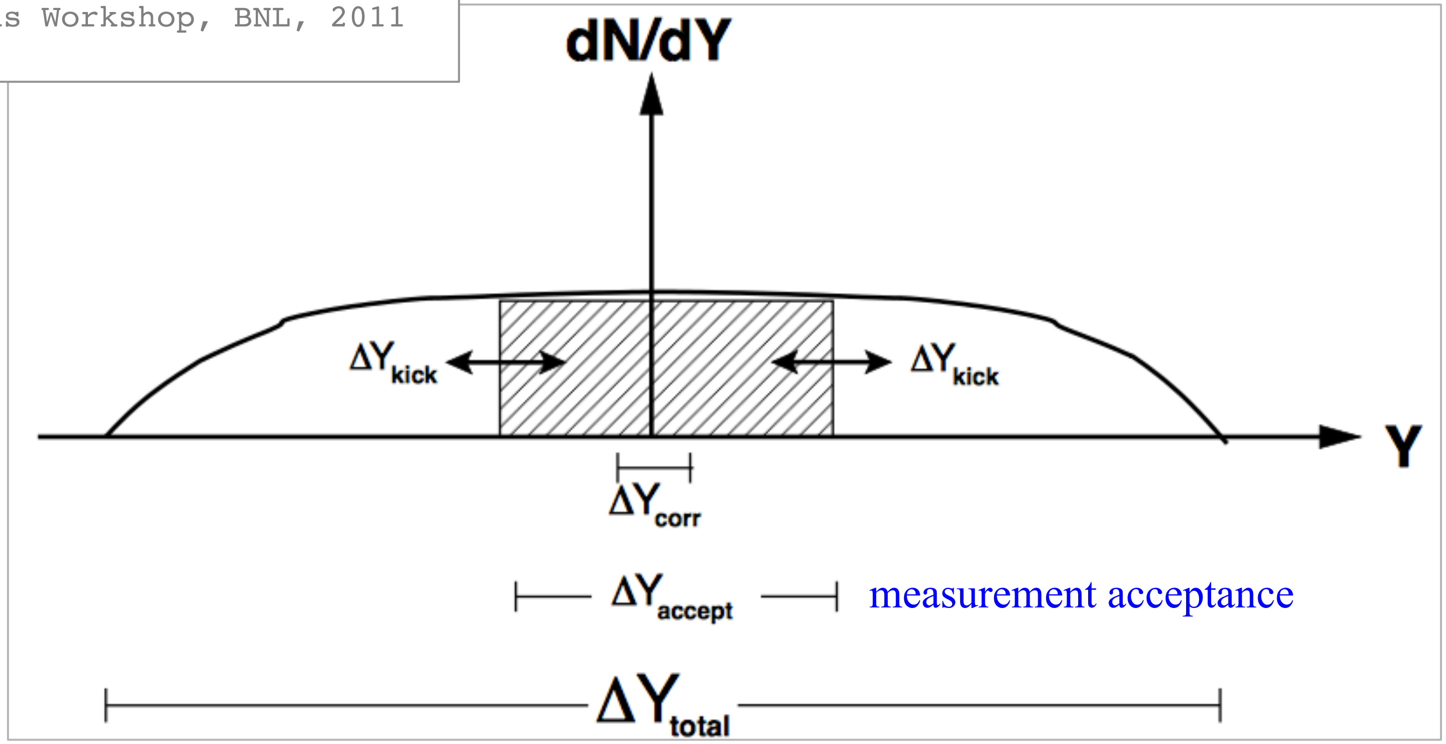
net-protons
$0.4<P_T<0.8$, $|y|<0.5$
$C_1 \sim 8$ @ 19.6GeV

net-protons
$0.4<P_T<2.0$, $|y|<0.5$
$C_1 \sim 22$ @ 19.6GeV

STAR's acceptance is actually still quite small for net-protons!

Fluctuations of conserved quantities and rapidity scales

V. Koch, BNL Riken Fluctuations Workshop, BNL, 2011
and arXiv:0810.2520v1



In a perfect acceptance, conserved quantities do not fluctuate.

But the observation of an appropriately-sized subsystem, then the fluctuations are interesting.

Here, the subsystem can exchange conserved quanta with the rest of the system.
Similar to assumptions governing a thermal system in the grand canonical ensemble, & LQCD

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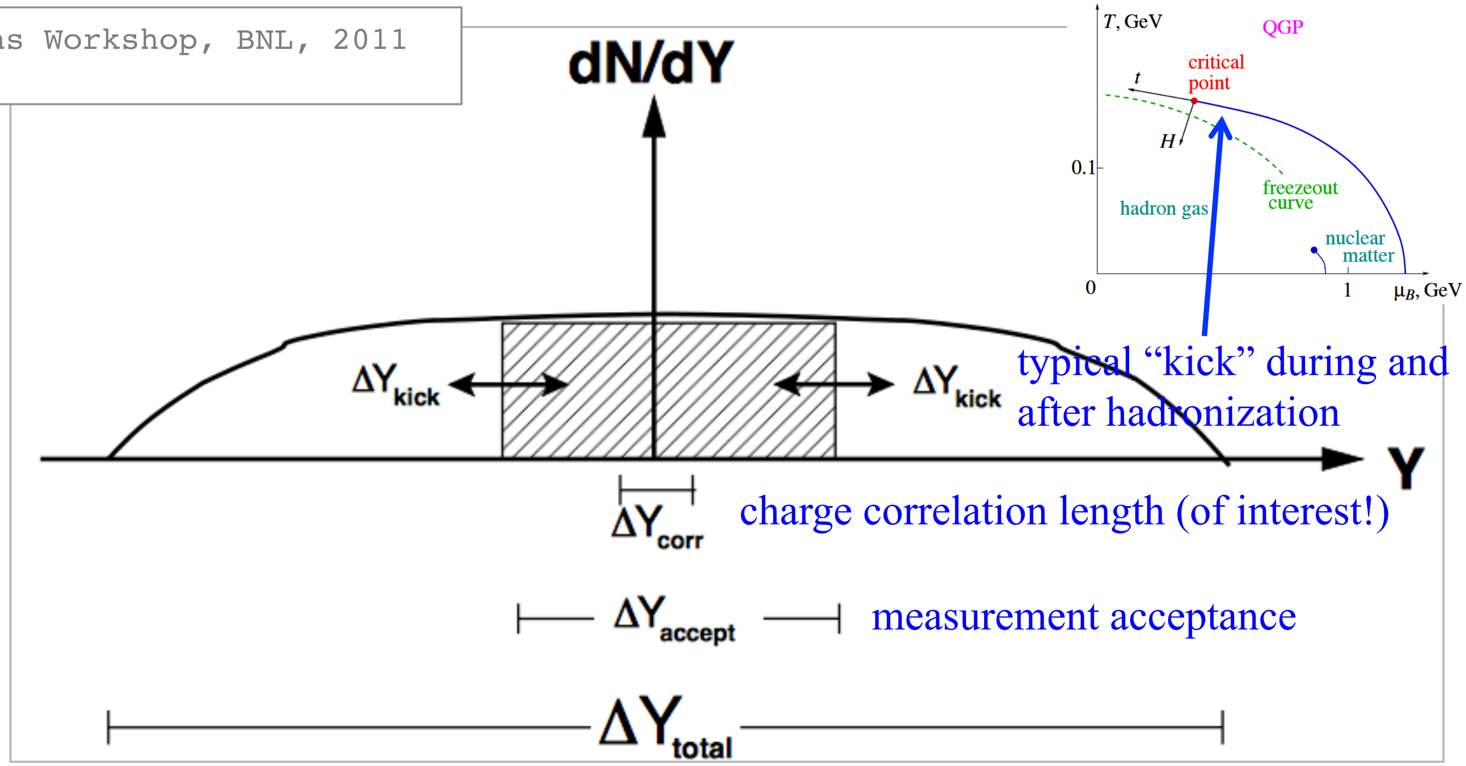

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For fluctuations of conserved charges to be meaningful, these scales need to be well-separated:

$$\Delta Y_{accept} \gg \Delta Y_{corr}$$ ensures measurement is sensitive to the physics

$$\Delta Y_{total} \gg \Delta Y_{accept} \gg \Delta Y_{kick}$$ ensures that charge conservation does not suppress the signal, and that it survives hadronization

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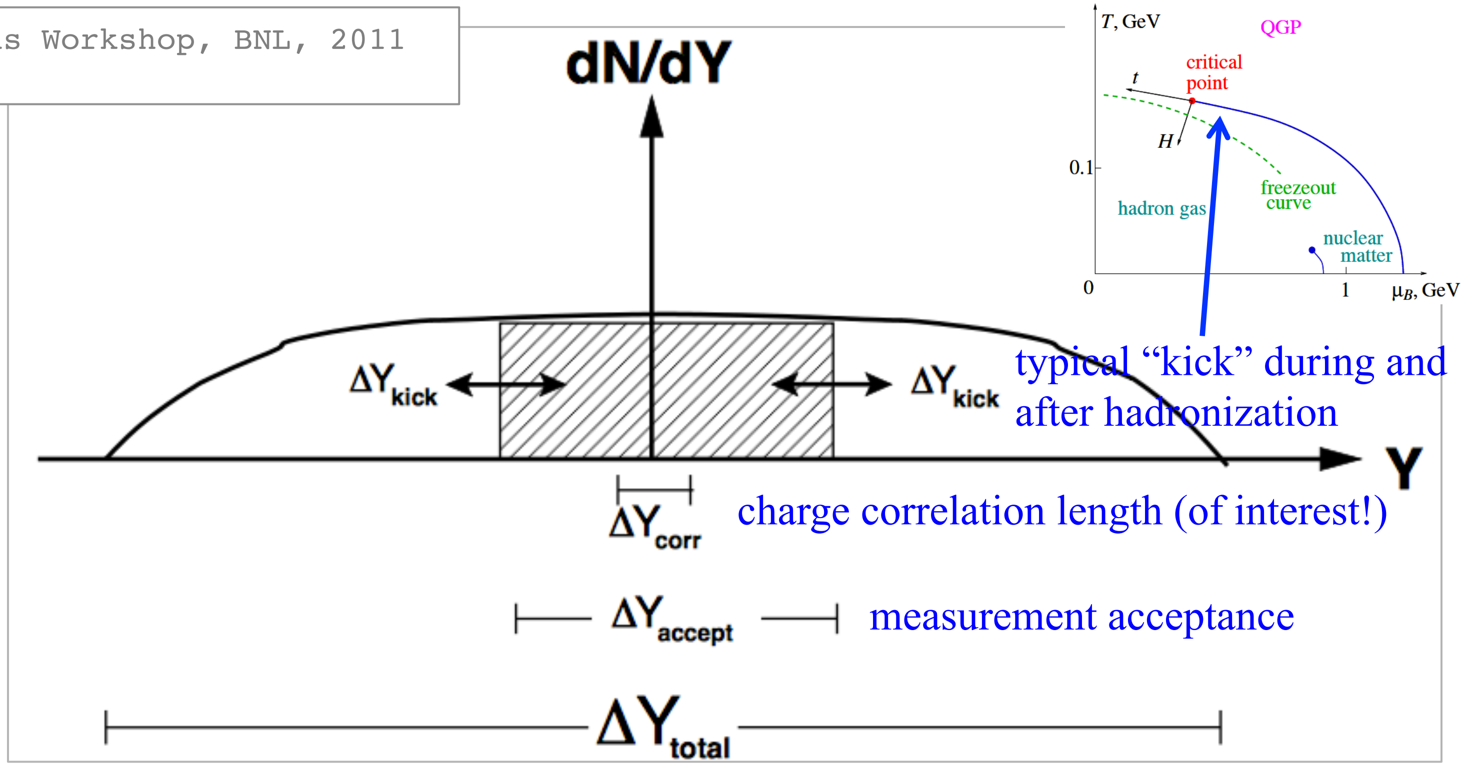

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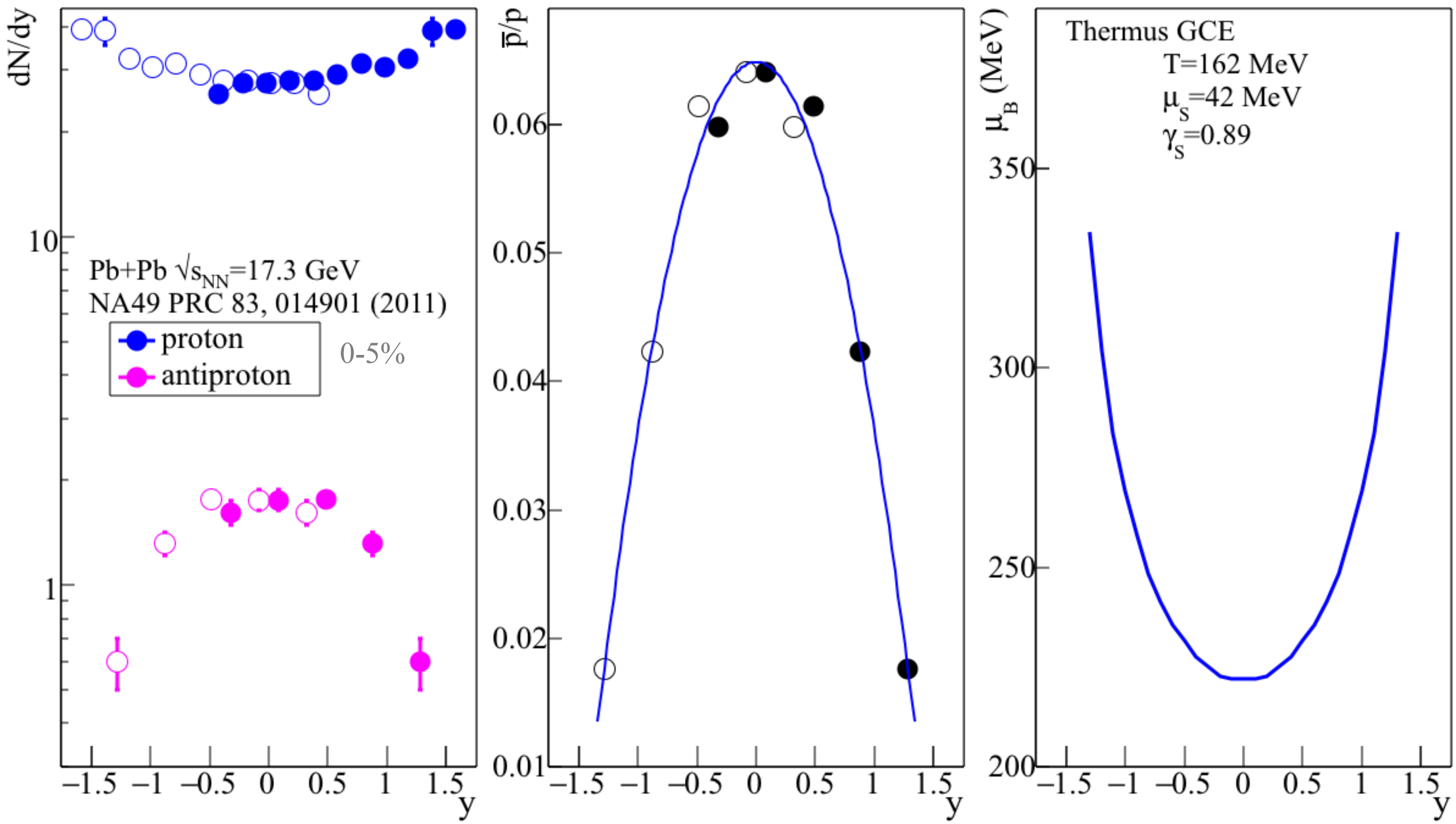
At low $\sqrt{s_{NN}}$: $\Delta Y_{total} \approx \Delta Y_{kick} \sim 1.5$
There's also "thermal blurring"
M Asakawa, QM2015
Ling & Stephanov arXiv 1512.09125

need a wider rapidity acceptance!

STAR needs a wider rapidity acceptance.
Expanding in y has another benefit: Varying μ_B either by |y| or $\sqrt{s_{NN}}$



Variation in μ_B via the rapidity out to |y|~1.3 at fixed $\sqrt{s_{NN}}$ is as large as the variation in μ_B from the different $\sqrt{s_{NN}}$ values...

Allows disentangling of (μ_B,T) dependence from quark transport to y~0.

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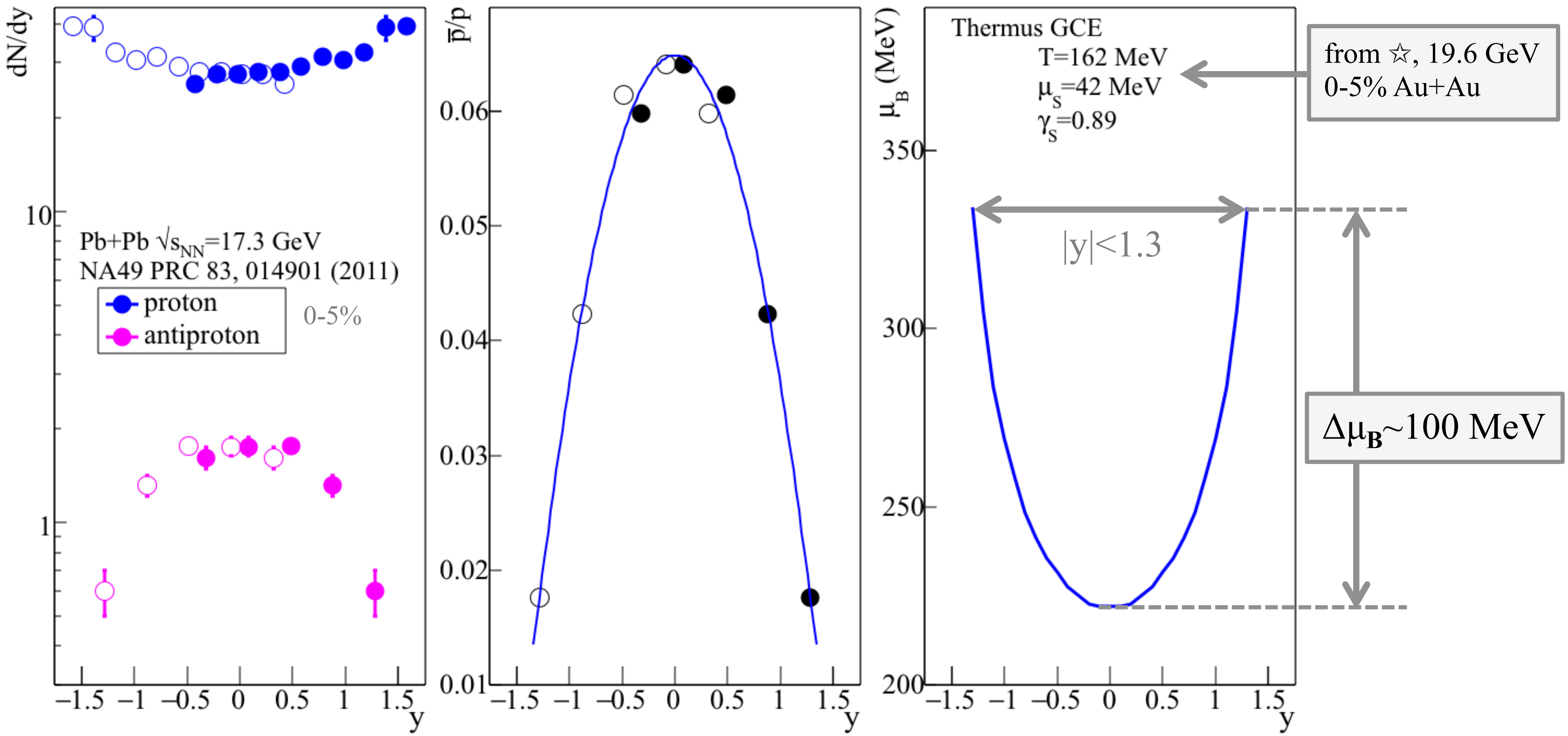


Variation in μ_B via the rapidity out to |y|~1.3 at fixed $\sqrt{s_{NN}}$ is as large as the variation in μ_B from the different $\sqrt{s_{NN}}$ values...

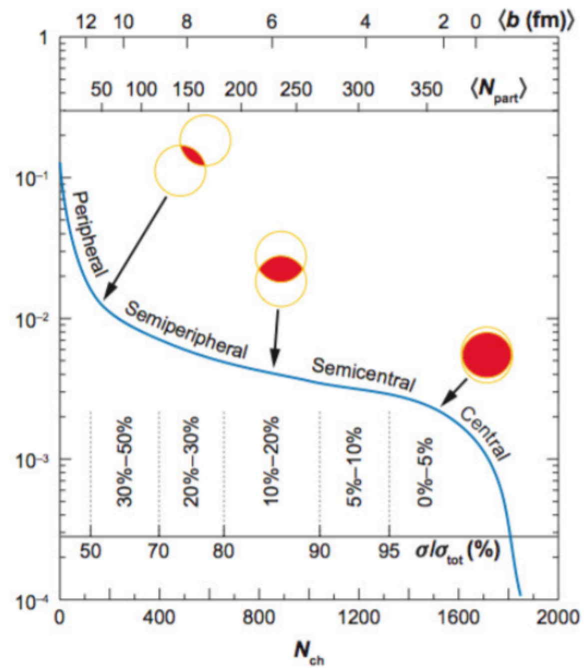
Allows disentangling of (μ_B,T) dependence from baryon # transport *etc*.

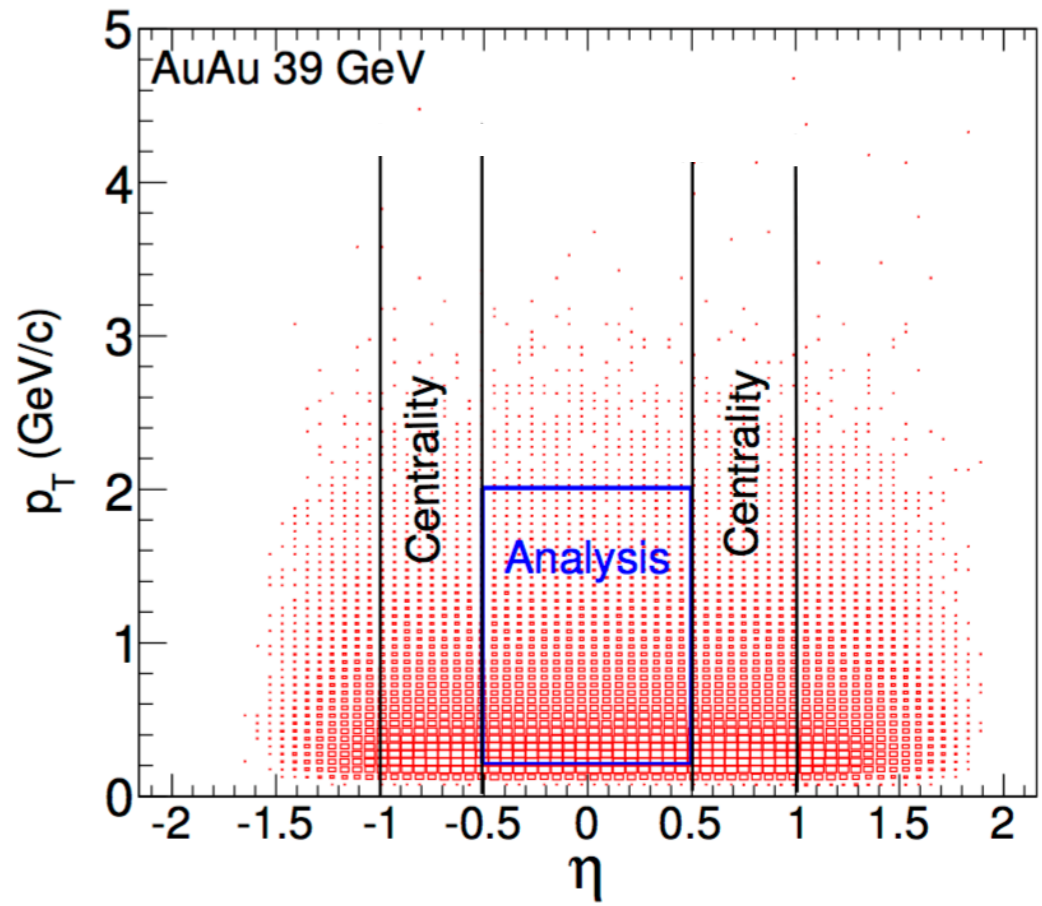
Why do all ☆ net-p, net-K, & net-h multiplicity cumulant results only use $|y|<0.5$ or $|\eta|<0.5$?

Doesn't the TPC cover all the way out to $|\eta|<1.0$ *?!?*

Yes, it does, but we had to sacrifice some of the TPC acceptance to define the centrality!

There are ***bad*** autocorrelations when studying multiplicity cumulants while cutting on the multiplicity for centrality*!*



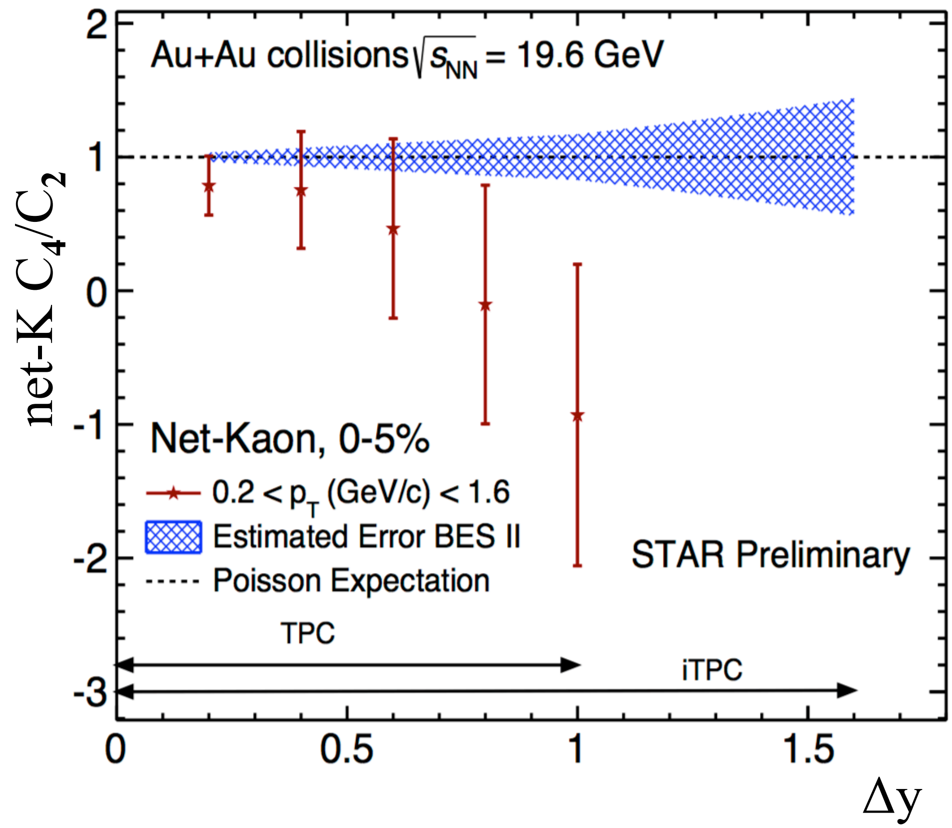


The ability to define the centrality using tracks with $|\eta| \gtrsim 1.5$ would allow the use of the full acceptance of the TPC for the physics analyses...

BES-II as envisioned now:

2019: Au+Au at 19.6, 14.5, 11.5 GeV
& commission electron cooling

2020: Au+Au at 9.1 and 7.7 GeV



What's different w.r.t. BES-I?

1. Take advantage of excellent C-AD experience from BES-I to deliver higher luminosity beams for $\sqrt{s_{NN}} < 20$ GeV

   Collect more events in roughly the same real-time

2. Upgraded STAR detectors!

   improved track reconstruction in TPC, extend tracking reach to $|\eta|<1.7$...

   new charged hadron PID capabilities for $1.1<|\eta|<1.6$

   improved centrality definition (and event plane resolution) with $|\eta|>1.7$

Why BES-II?

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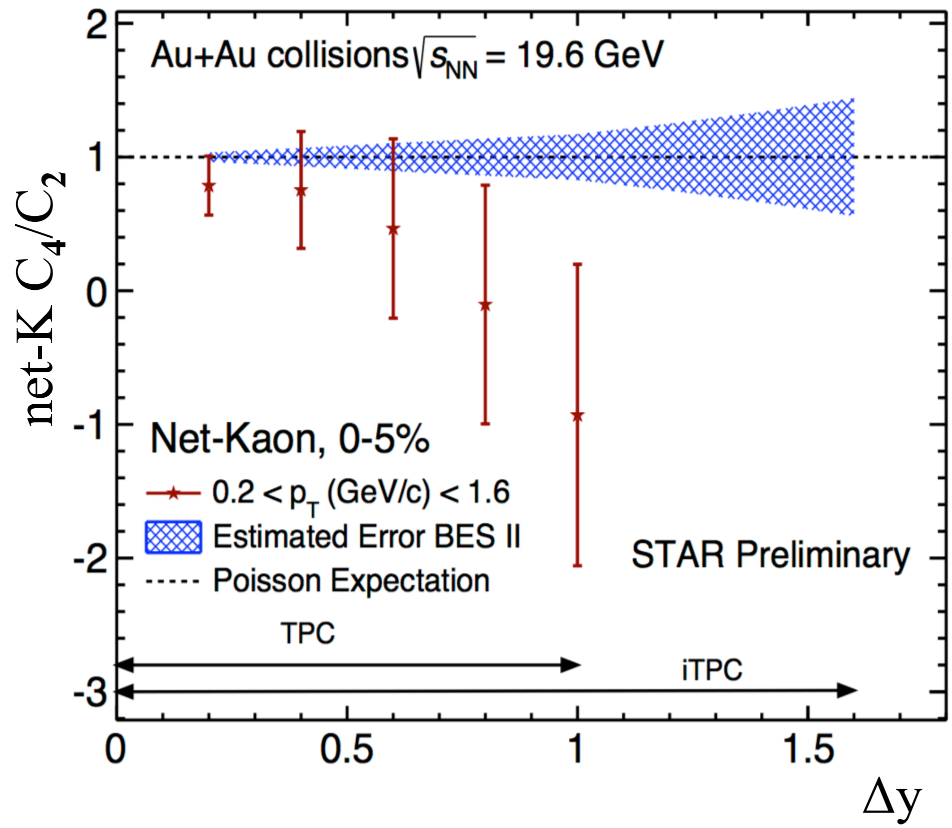

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iTPC improved track reconstruction in TPC, extend tracking reach to |η|<1.7...

ETOF new charged hadron PID capabilities for 1.1<|η|<1.6

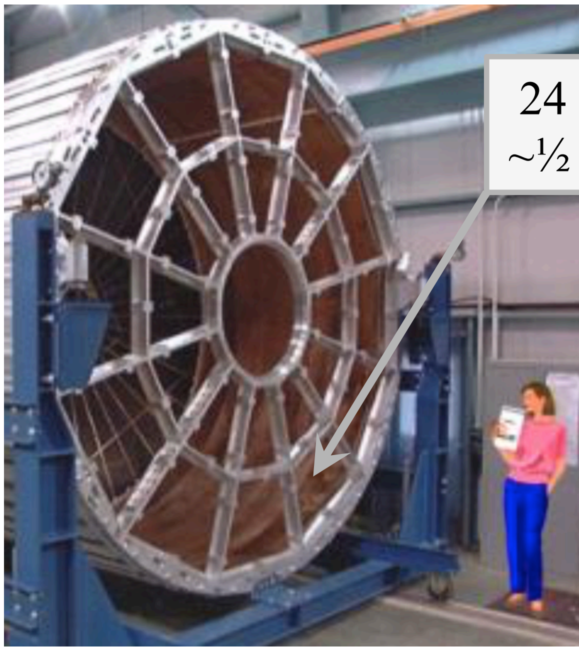
EPD improved centrality definition (and event plane resolution) with |η|>1.7

iTPC – fully instrumented the inner padrows of the Time Projection Chamber

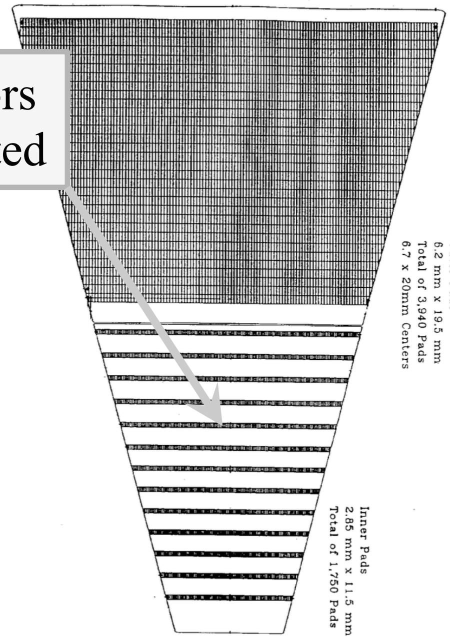
will extend pseudorapidity acceptance from $|\eta|<1$ to $|\eta|<1.5$

& transverse momentum acceptance from $P_T>125$ MeV to $P_T>60$ MeV/c

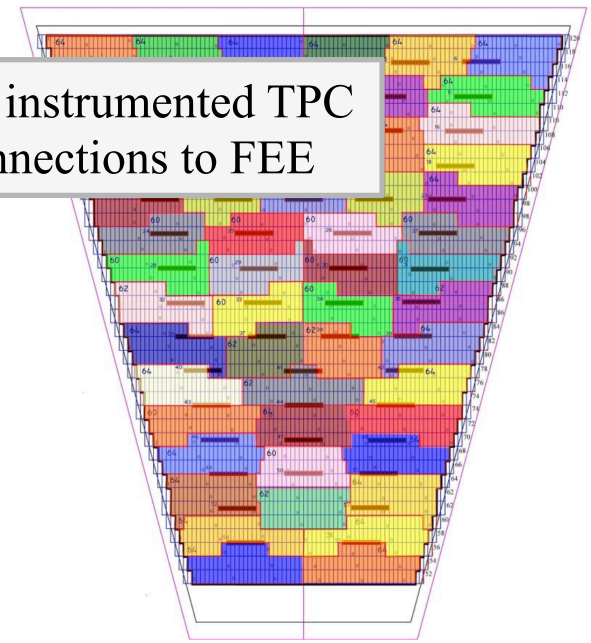
while improving track dE/dx resolution from 7.5% to 6.2%

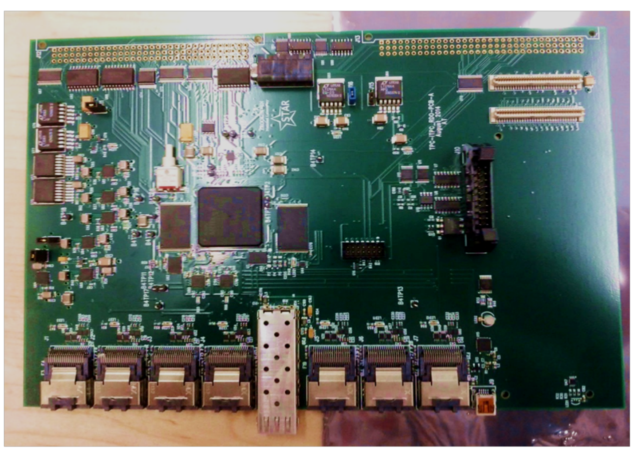


24 inner sectors
~½ instrumented



fully instrumented TPC
connections to FEE

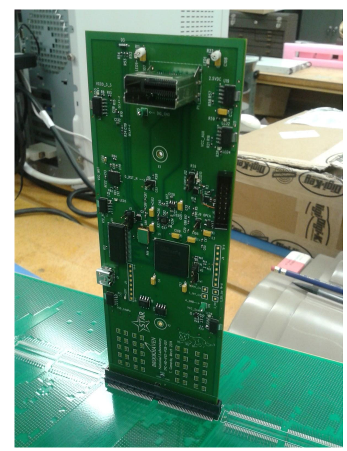


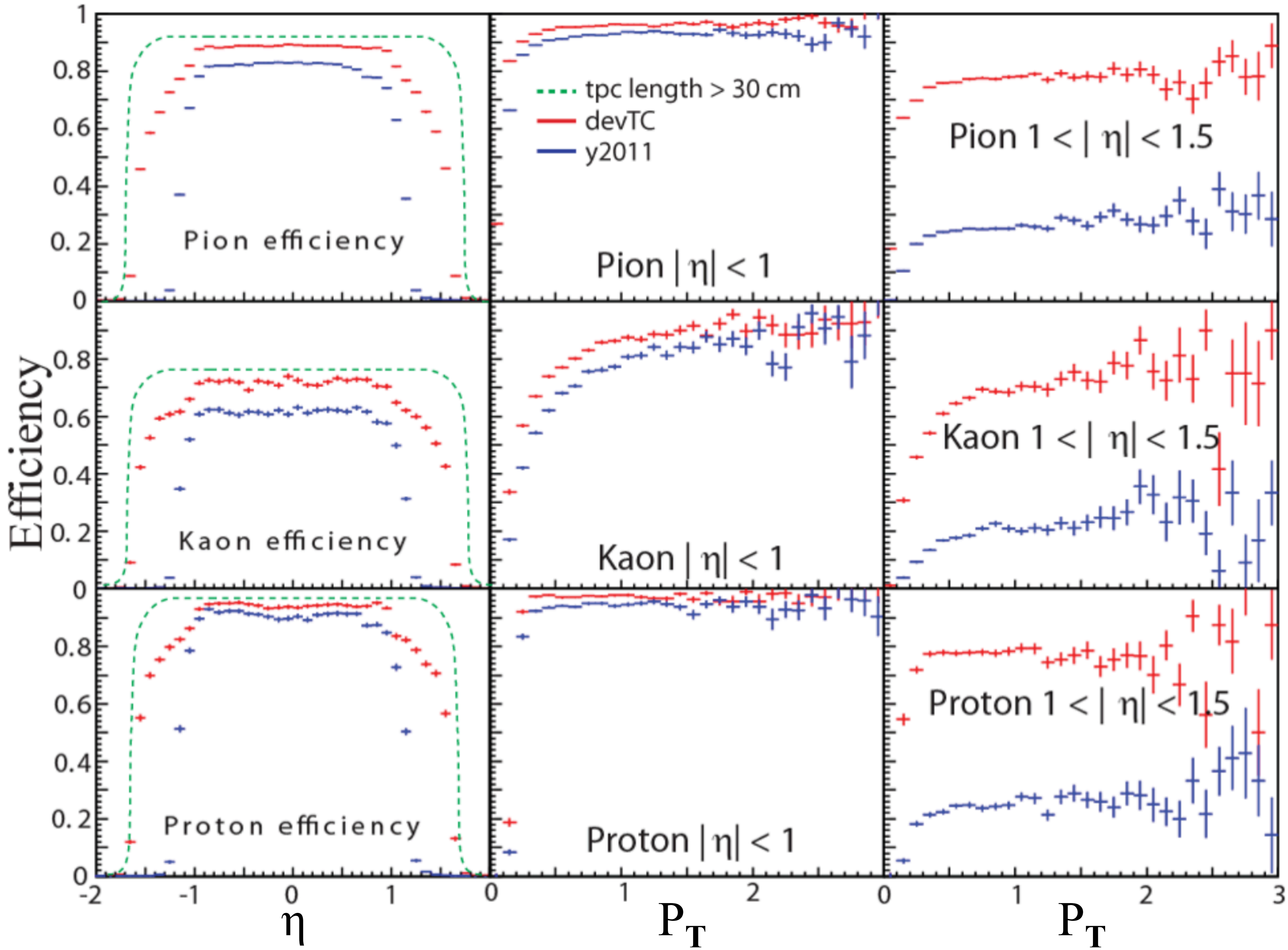


RDO

FEE &
Pad Plane

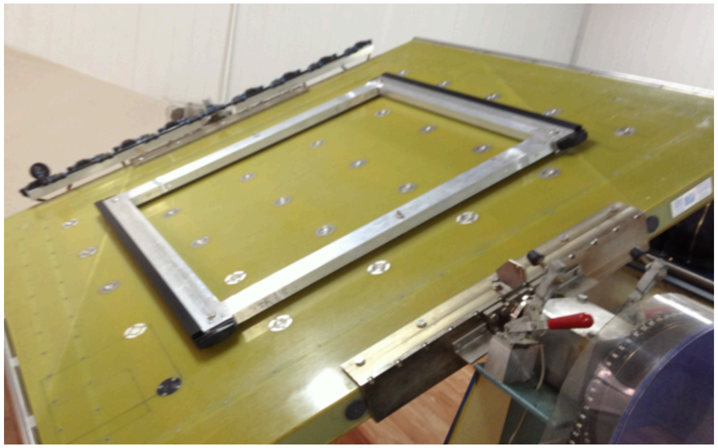
iFEE based on current FEE,
but uses ALICE SAMPA chip…
Twice the # of channels per card…





>50% efficient for π, K, p tracking at |η|=1.5

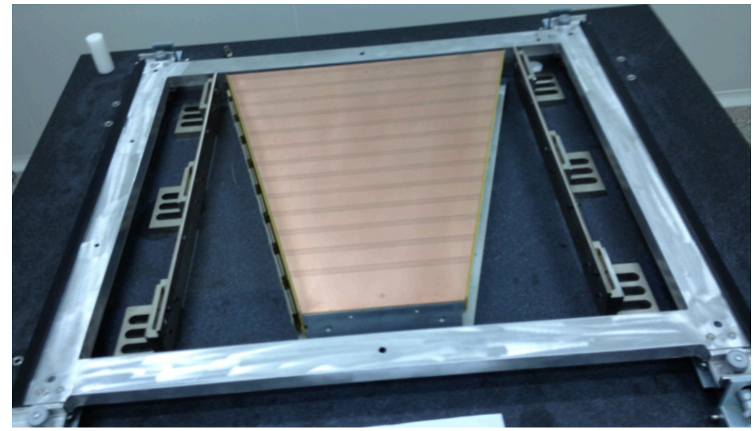
MWPC prototyping underway at Shandong University – ~1M$ contribution from China with USTC (Hefei) & SINAP (Shanghai)



Wire winding

wire tension determined via laser system that measures the vibration frequency…

Wire plane and pad plane



Director’s review at BNL Jan 25, 2016…

https://indico.bnl.gov/conferenceDisplay.py?confId=1711

From the ALD’s Desk
A Quarterly RHIC News Bulletin
March 2016

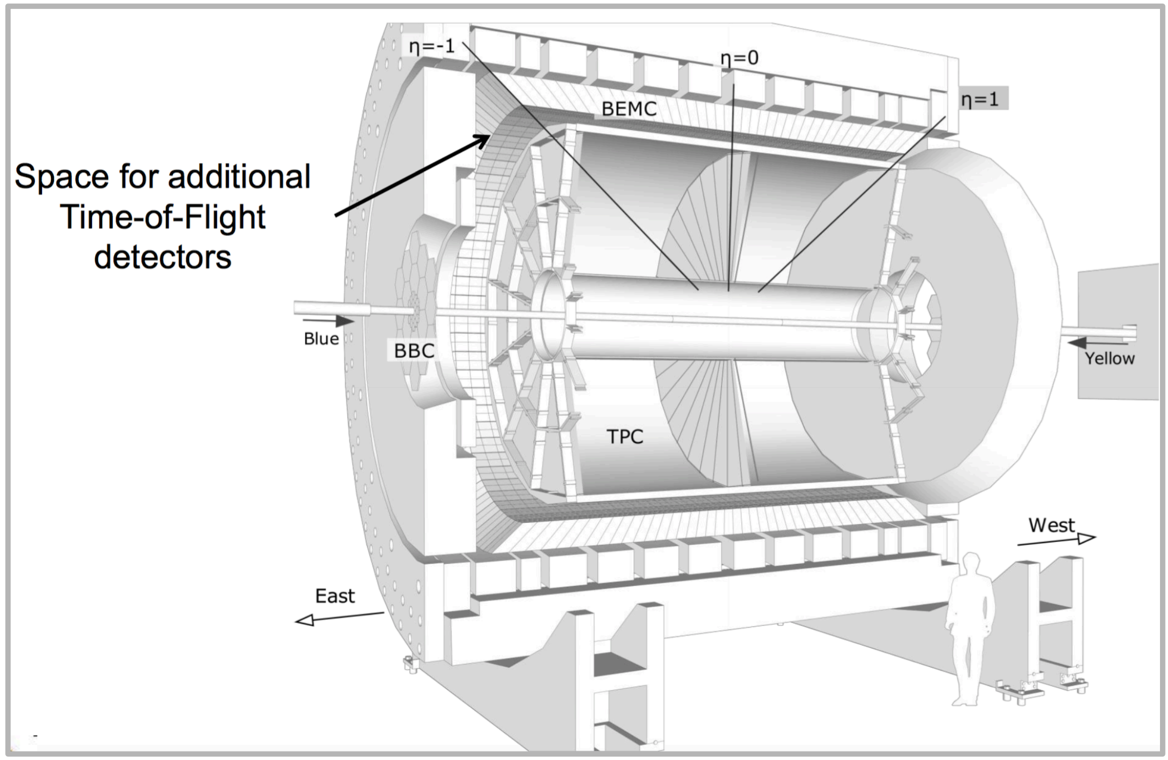
Berndt Müller

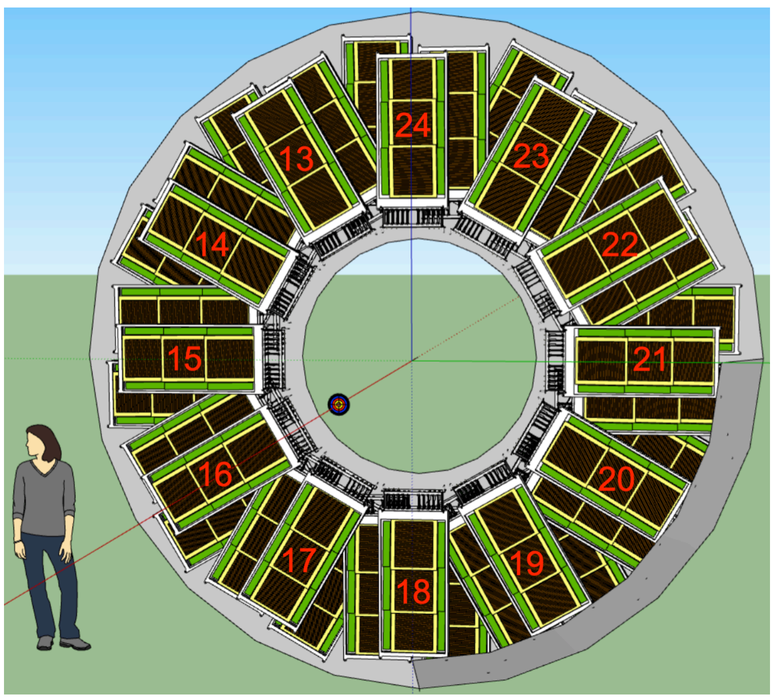
STAR iTPC Upgrade: Following a successful cost, schedule, and risk review in January, the DOE Office of Nuclear Physics approved our request to begin with the STAR iTPC upgrade. The first components have been ordered, and the project team led by Flemming Videbaek expects to complete the upgrade on schedule for the planned 2019 low energy RHIC run.

How to optimize ☆ for BES-II... ETOF

☆ and CBM institutions proposed installing CBM TOF modules inside East pole-tip.

- Would provide TOF PID for eastern iTPC tracks in 1.09<|η|<1.62
- Brings low-$\sqrt{s_{NN}}$ experts into RHIC physics program (GSI SIS, CERN SPS)
- Provides important detector operations experience to CBM effort





36 Modules in 3 layers, 6912 channels…
Modules arranged to match 12 TPC sectors…

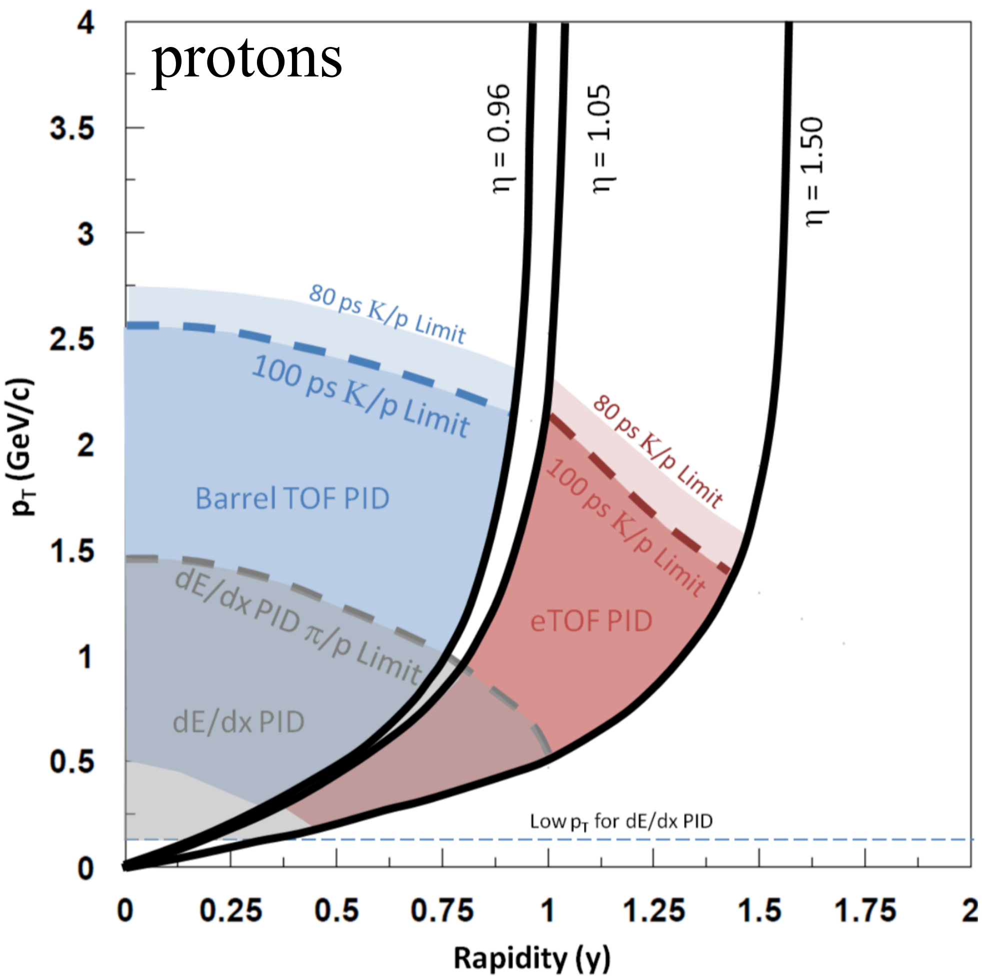
Each module is long-strip MRPC read-out at both ends. Similar to existing STAR MTD.
Considerable MRPC expertise already in ☆

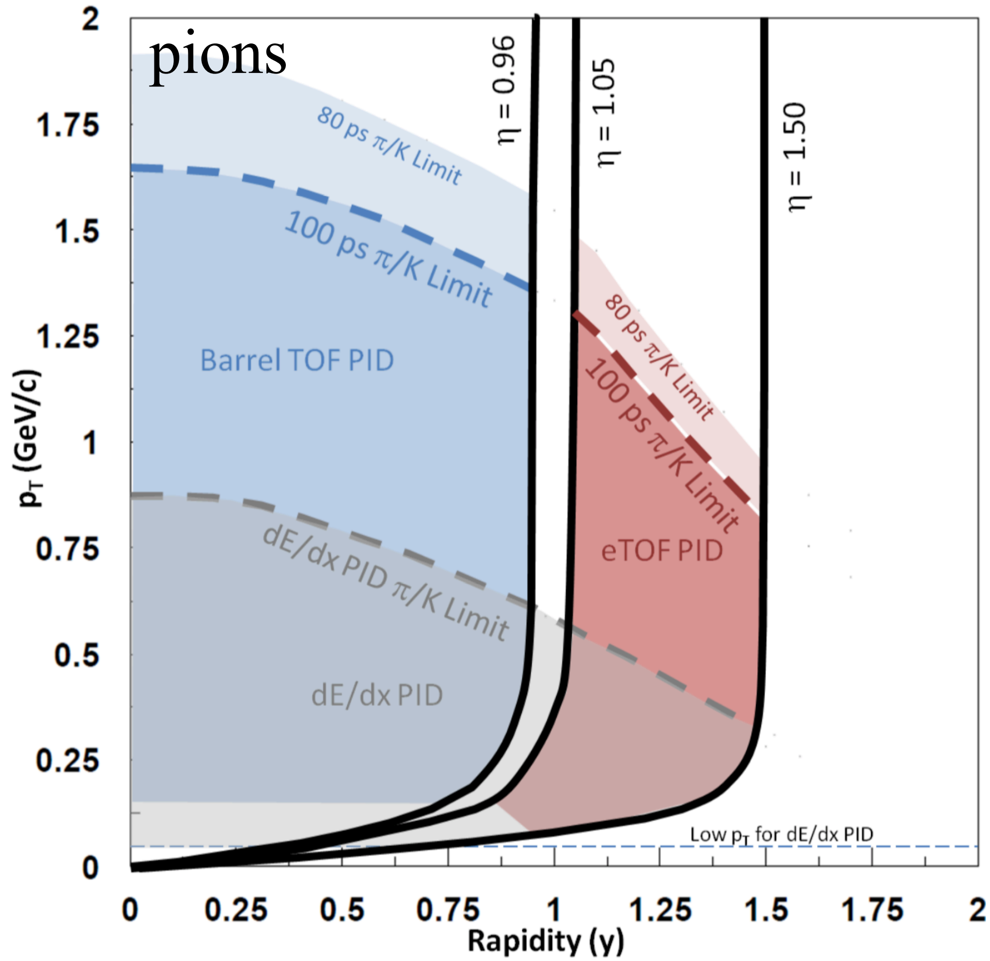
Multiple hit probability per strip <7.4%

Prototypes installed during 2017 & 2018 RHIC runs.

How to optimize ☆ for BES-II... ETOF

Significant extension of TOF PID acceptance beyond the barrel TOF (|η|<0.94)



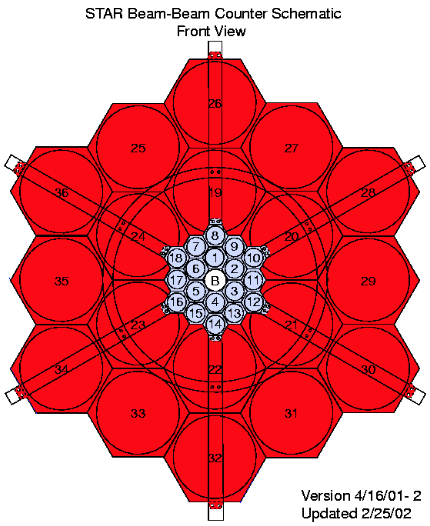


Detectors and electronics loaned from CBM

Installation and facilities from ☆
~100k$ support requested

Successful STAR internal review March 2016.

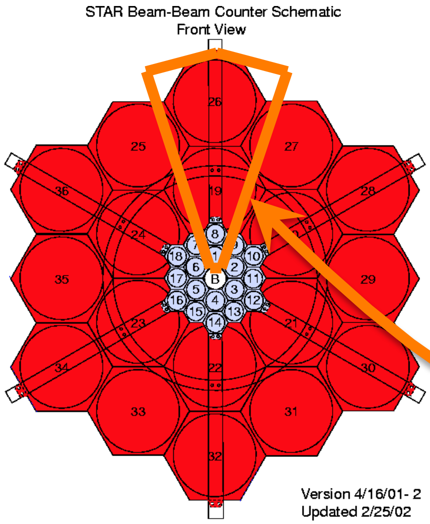
How to optimize ☆ for BES-II... EPD



Replace the Beam-Beam Counter (BBC)…

- 2 × 36 channels, small & large (3.3<|η|<5) hexagonal tiles
- PMT read-out over long fibers
- timing resolution ~2ns, poor centrality resolution

How to optimize ☆ for BES-II... EPD



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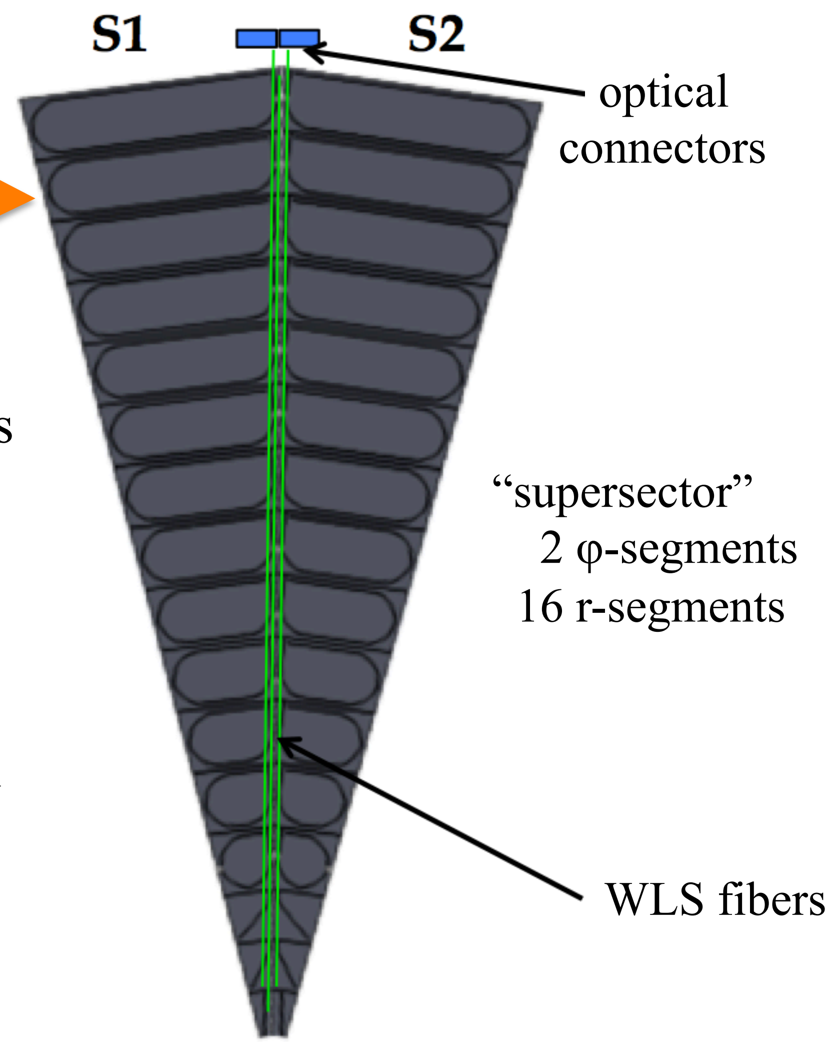
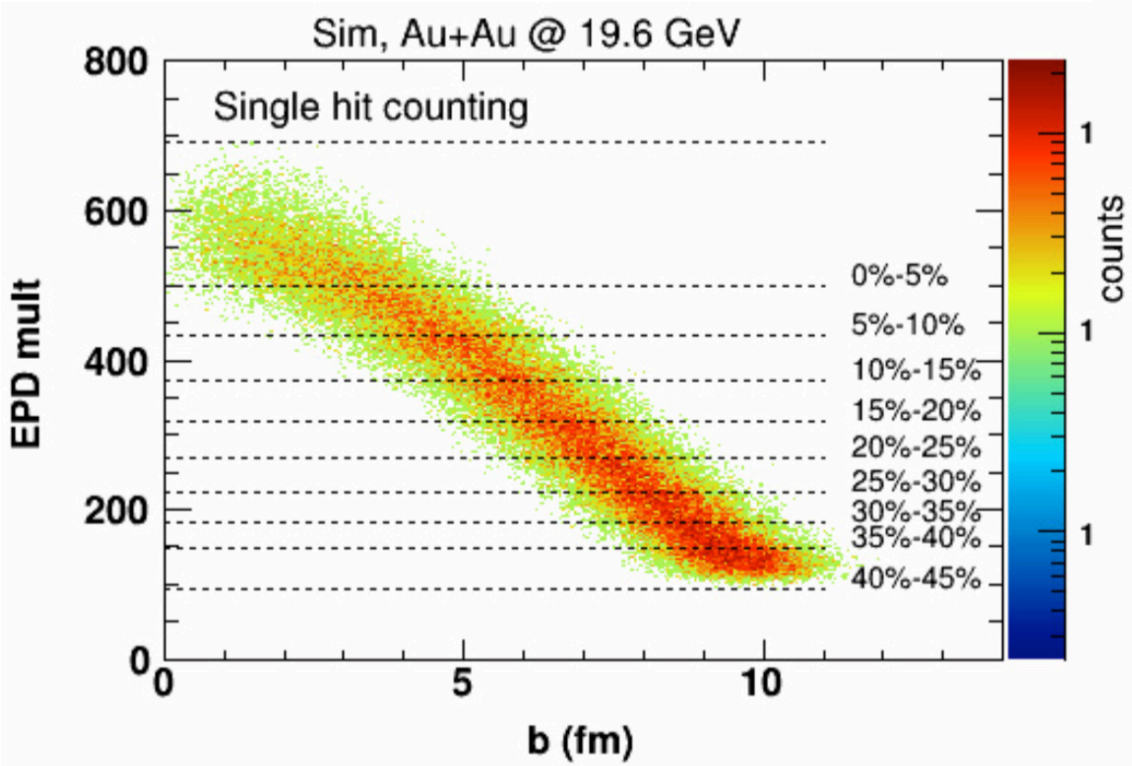
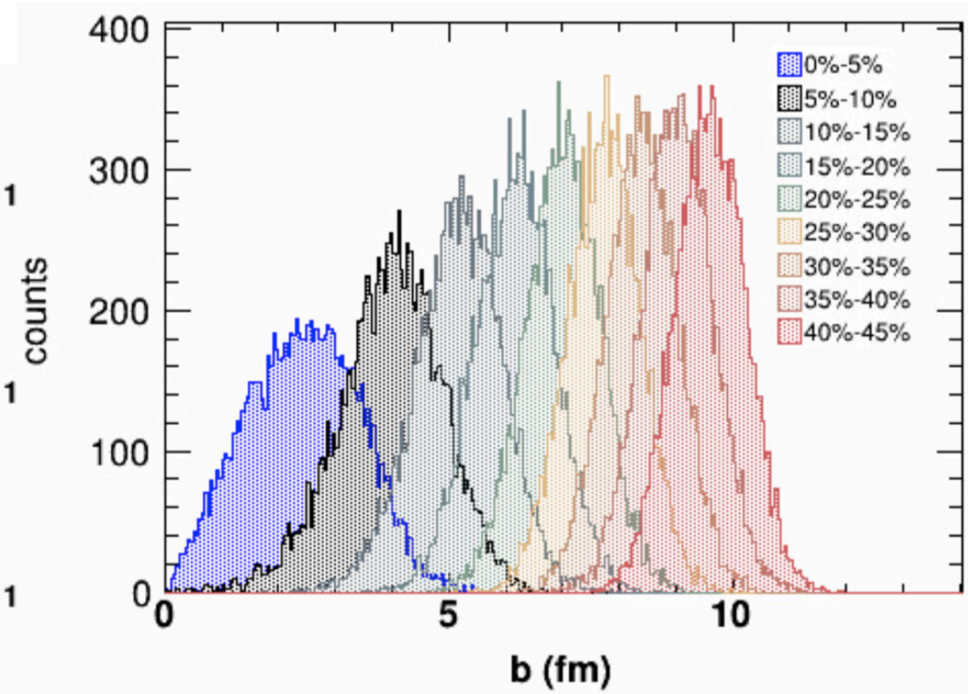


…with the Event Plane Detector (EPD)

- 2×384 channels, trapezoidal tiles of various sizes
  - 16 radial sections, 24 azimuthal sections
  - arranged as 2×12 supersectors
- $4.5<r<90$ cm, $|Z| = 375$ cm, $2.1<|\eta|<5$
- SiPM readout over shorter fibers
- timing resolution <1ns, good centrality resolution
- <10% multi-hit probability at 19.6 GeV
- to optimize centrality resolution
  - & event plane determination

EPD centrality resolution

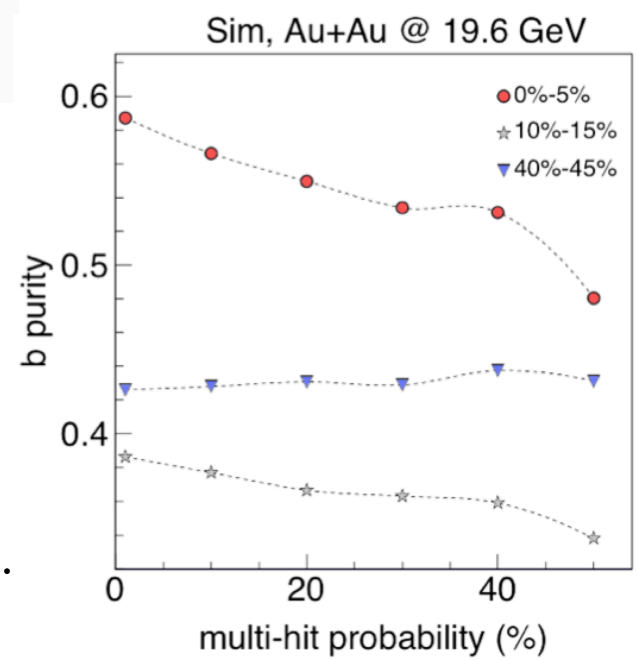




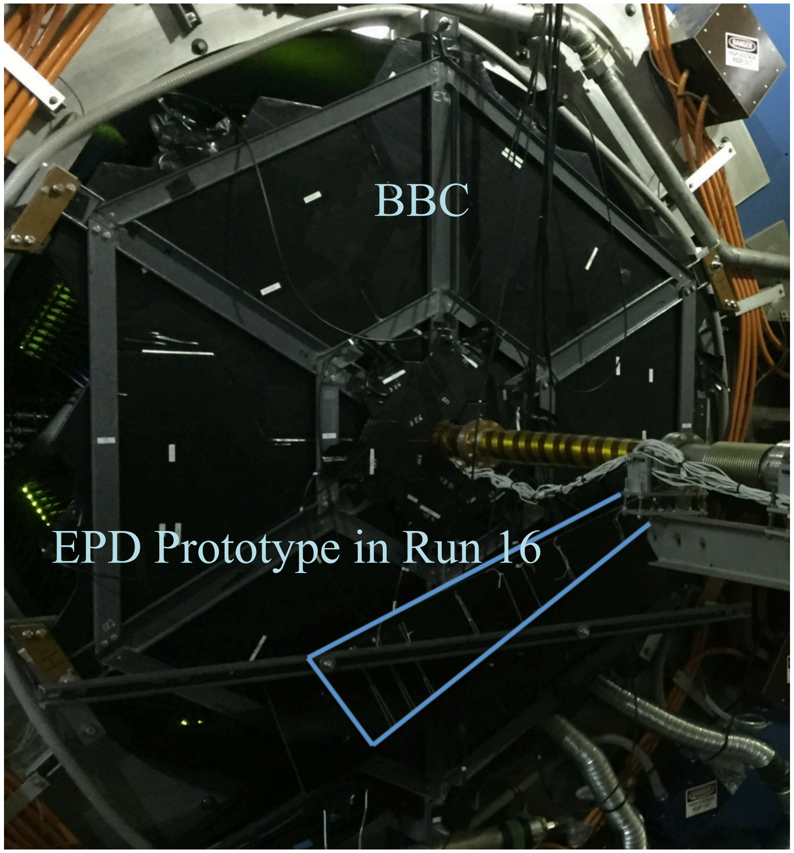
Impact parameter resolution looks good even when simply counting lit detectors…

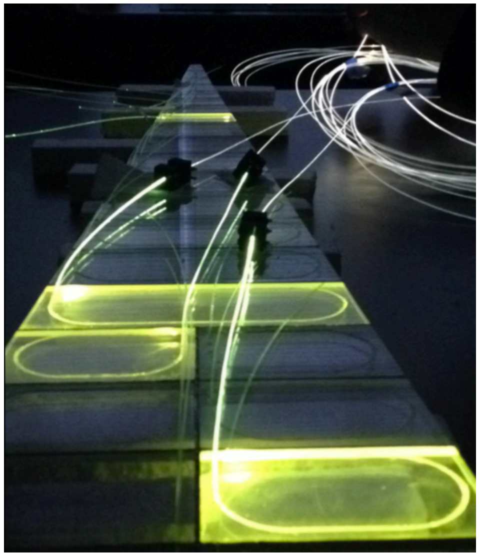
degrades significantly for more peripheral collisions...

Possible additional improvement if pulse size (ADC) information is used instead..



How to optimize ☆ for BES-II... EPD



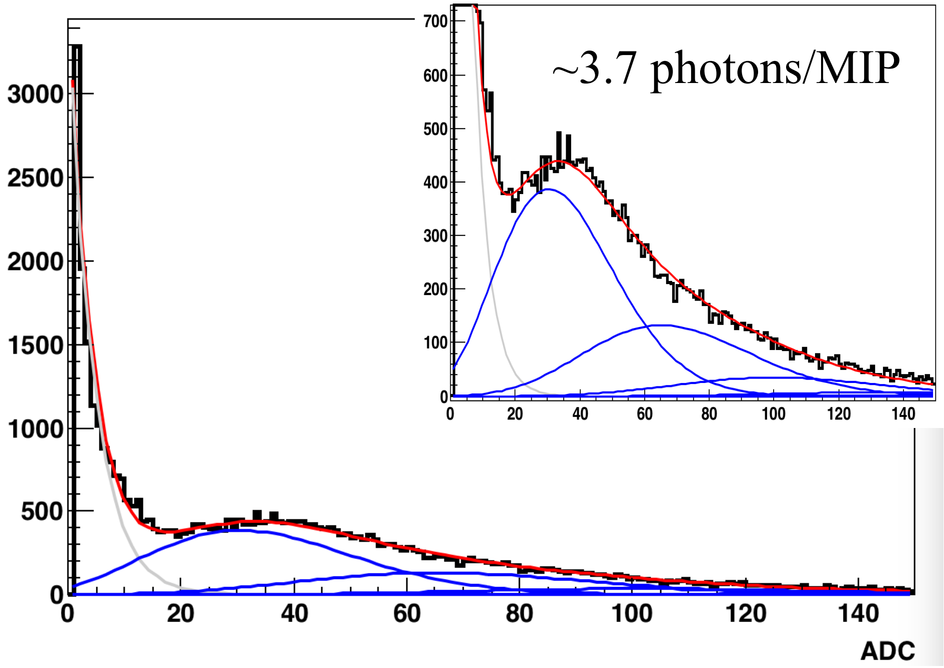


Single φ-section installed in Run 16

operated throughout entire run…

24 channels (8 with timing information)…

sub-1ns timing resolution shown...



Successful STAR internal review April 2016

Seeking ~330 k$

242 k$ for EPD, 90k$ for digitizer boards "QT"

Full quadrant installed for 2017 run (1/8th of full detector)

Summary and conclusions...

The iTPC, ETOF, and EPD detectors will significantly extend the acceptance of ☆ in both P_T and y directions, making possible signatures of a 1st order phase transition and critical point more apparent.

With the expected higher beam luminosities from C-AD, we expect to make strong statements on the phase diagram using the BES-II data.

We thank C-AD for their usual excellent machine performance and we very much look forward to BES-II in 2019-2020!

What (was learned in) BES? The devil in the details: thermal blurring

We look for increased correlation length, ξ, from ~1 to 2-3fm

This translates to space-time rapidity correlation length of $\Delta\eta_s = \xi/\tau_f$

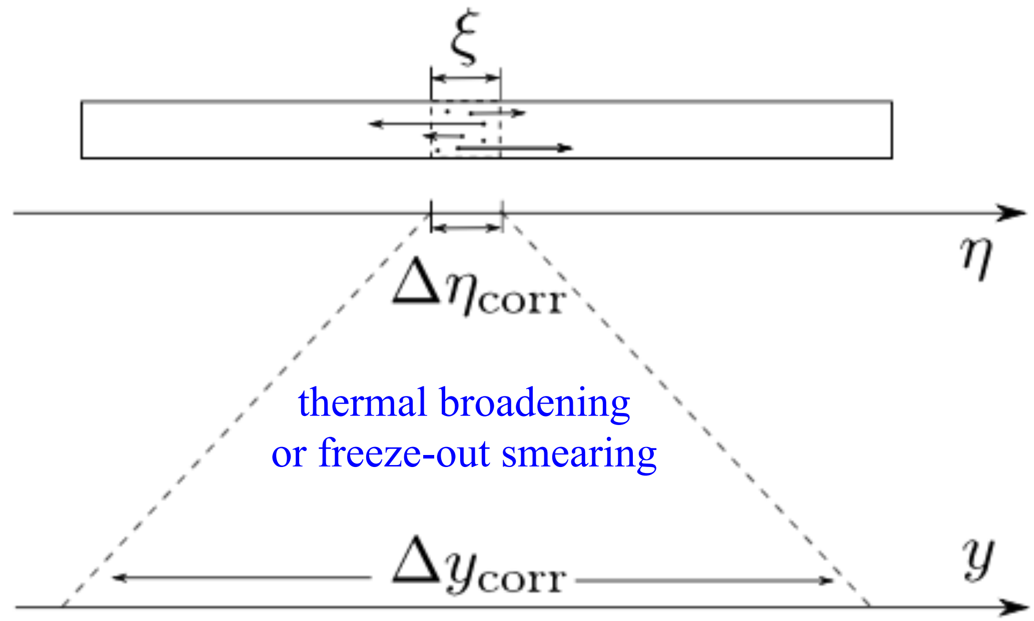
and if τ_f is 10 fm/c, then the critical space-time rapidity correlation length $\Delta\eta_s$ is 0.2-0.3

B. Ling & M. Stephanov
http://arxiv.org/pdf/1512.09125.pdf

But, we cannot measure η_s

And there is a smearing of order 1 unit of rapidity in what we *can* measure...

Bjorken scaling broken. $y \neq \eta_s$



M. Asakawa, QM2015