Studying the Phase Diagram of QCD Matter

Beam Energy Scan White Paper Committee

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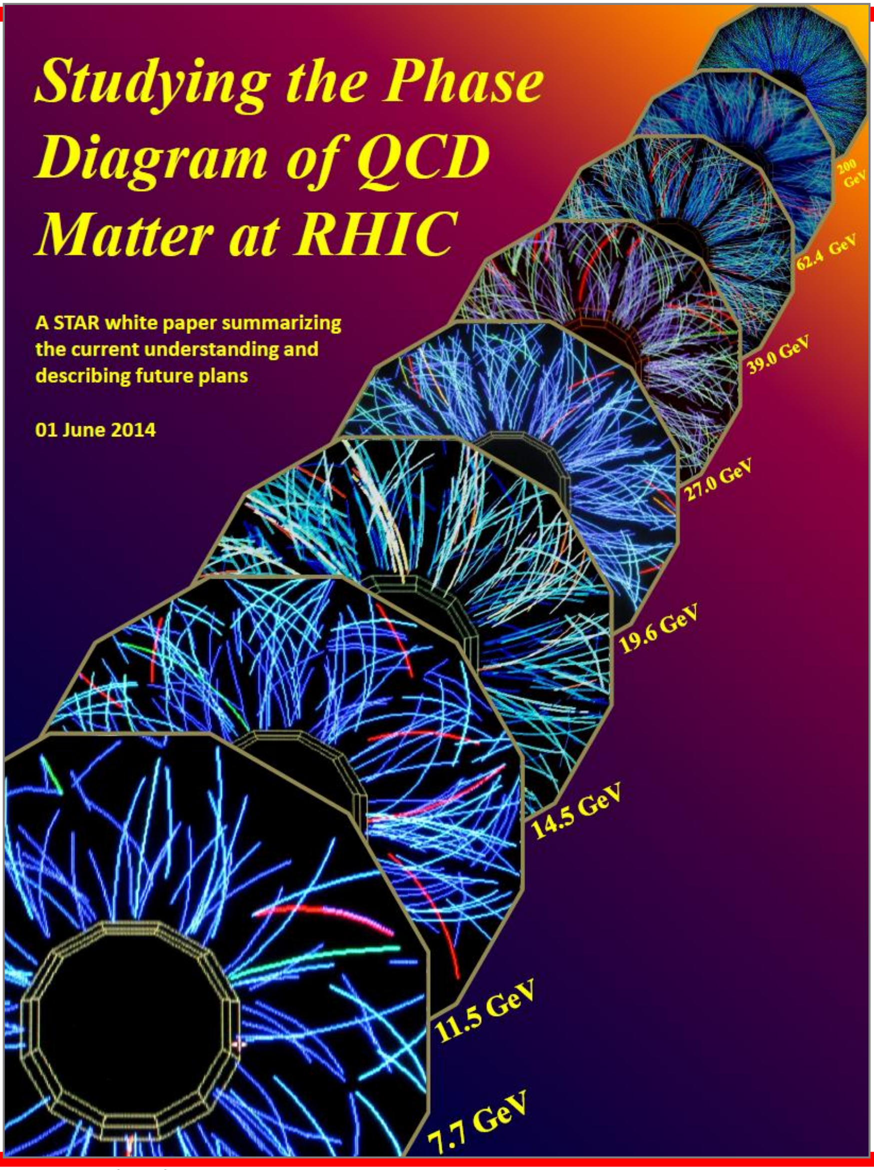
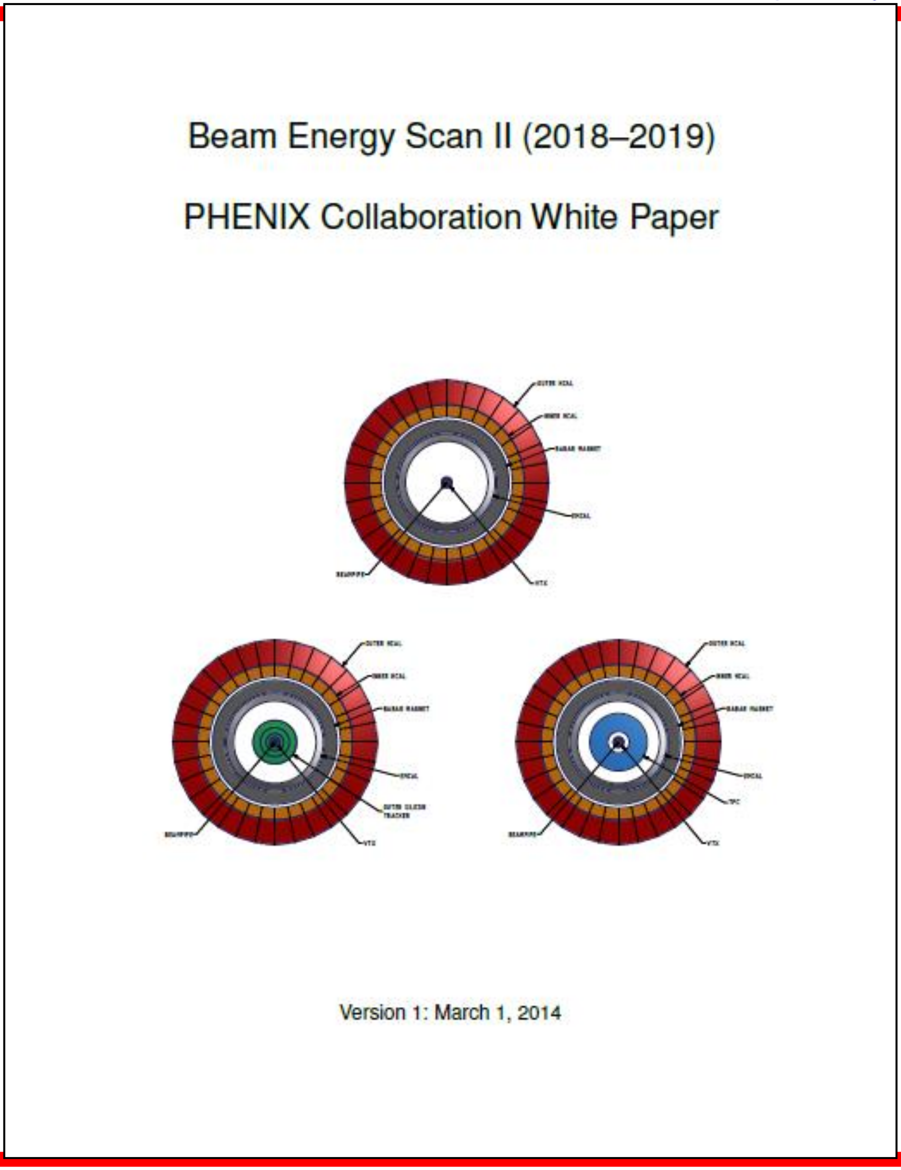
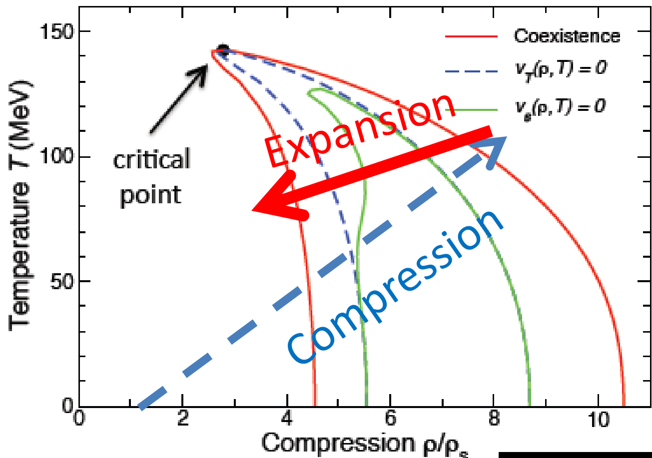
STAR and PHENIX BES-II White Papers





Exploring the Phase Diagram

By varying the beam energy, we can change the pre-equilibrium compression.



$v_T = 0$: isothermal spinodal

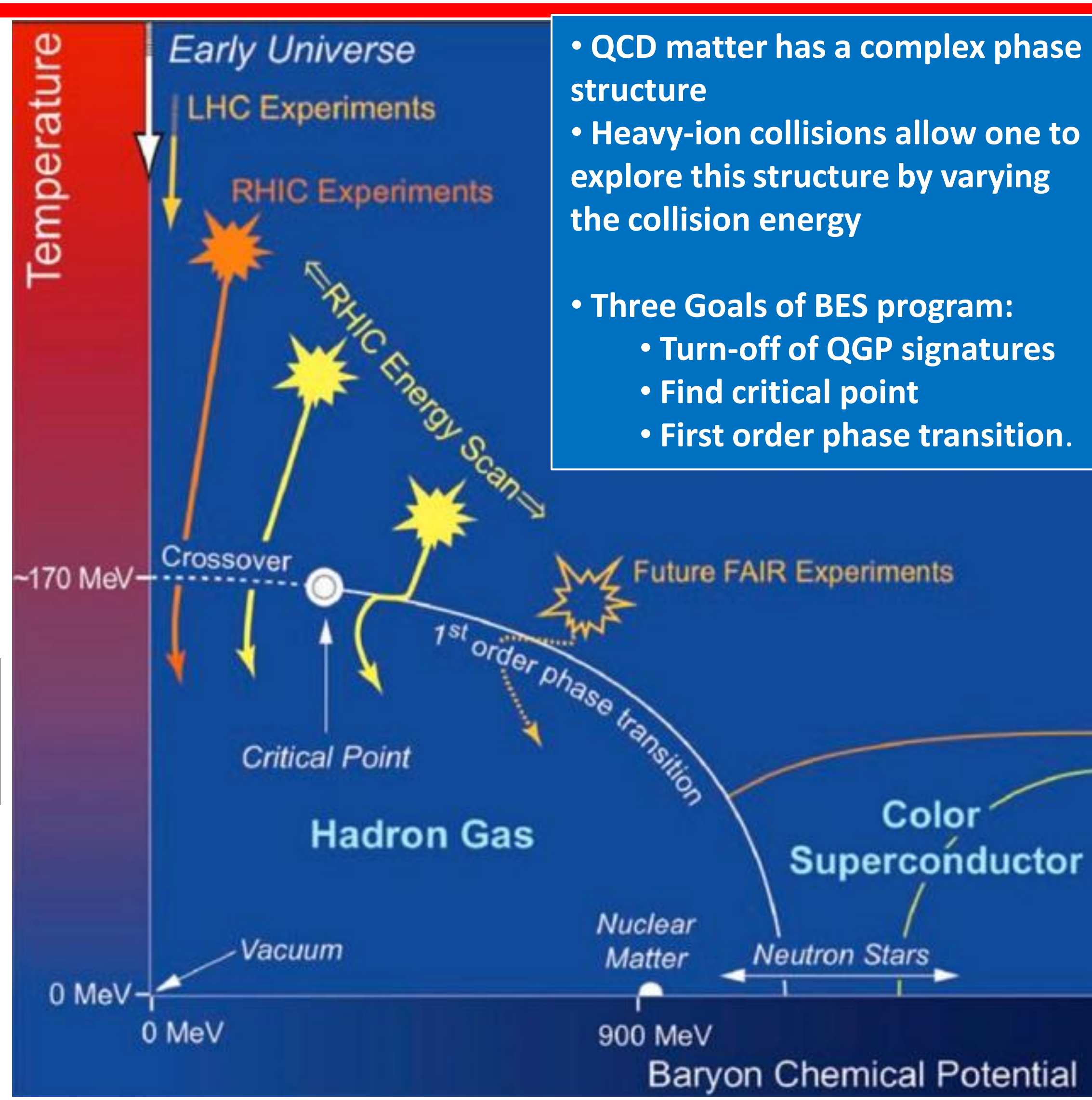
$v_s = 0$: isentropic spinodal

$$\mu = \frac{\partial U}{\partial N}$$

With careful planning and the kindness of nature, we will create reaction trajectories the probe the interesting features of the phase diagram.

- QCD matter has a complex phase structure
- Heavy-ion collisions allow one to explore this structure by varying the collision energy

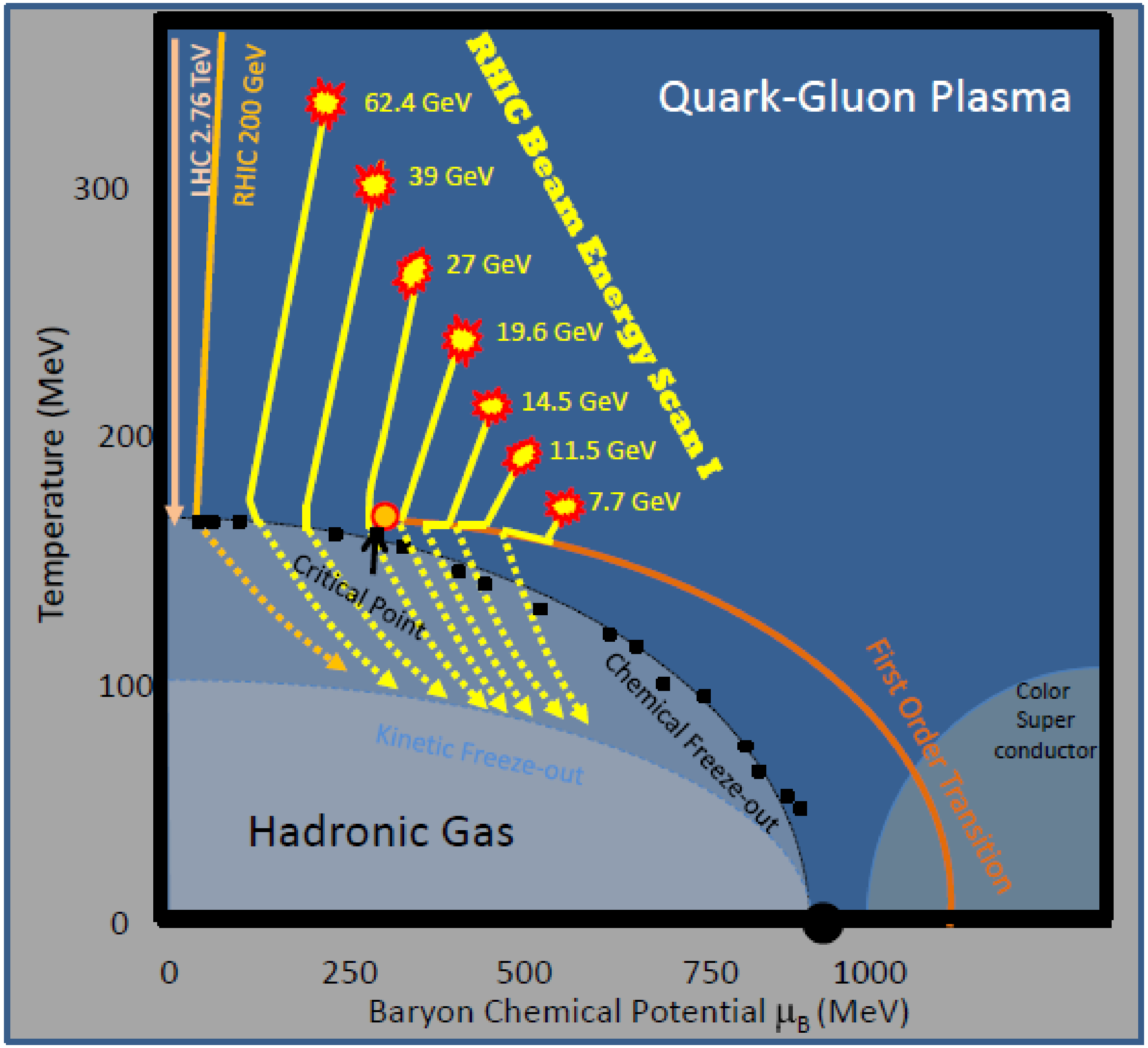
- Three Goals of BES program:
  - Turn-off of QGP signatures
  - Find critical point
  - First order phase transition.



RHIC Beam Energy Scan Phase 1

In the first phase of the RHIC Beam Energy Scan, seven energies were surveyed in 2010, 2011, and 2014

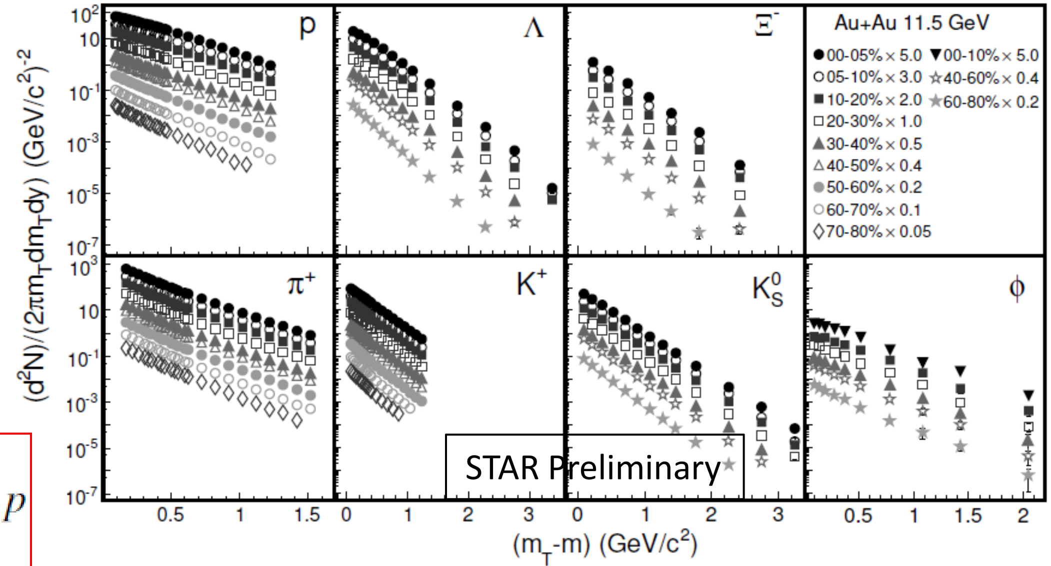
Energy (GeV)	Events (Million)	Time (Weeks)
200	350	11
62.4	67	1.5
39.0	130	2
27.0	70	1
19.6	36	1.5
14.5	20	3
11.5	12	2
7.7	4	4



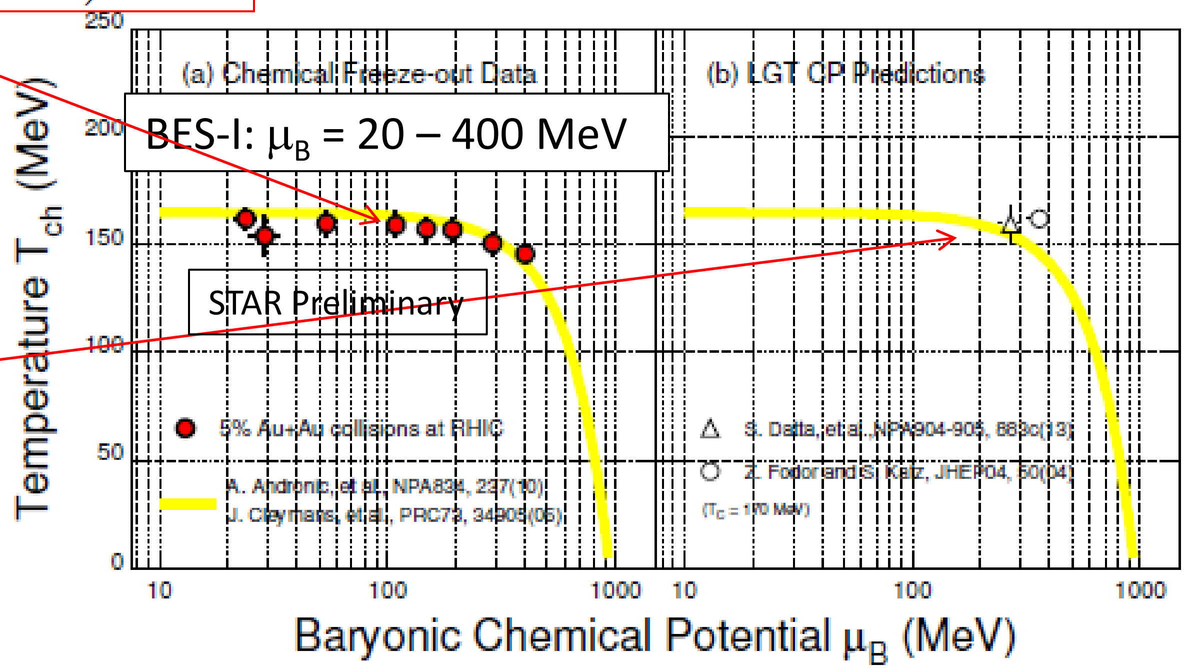
Setting the Scene

Using a statistical equilibrium model and the measured particle yields, one can estimate the location in the phase diagram.

$$N_i/V = \frac{g_i}{(2\pi)^3}\gamma_S^{S_i}\int \frac{1}{\exp\left(\frac{E_i-\mu_B B_i-\mu_S S_i}{T_{\rm ch}}\right)\pm 1}d^3p$$

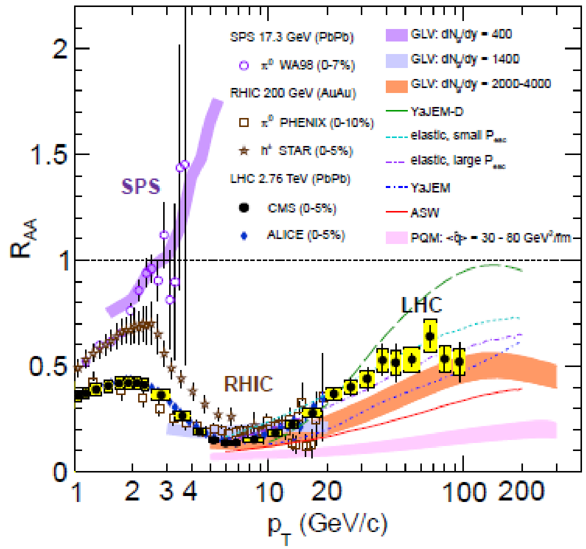


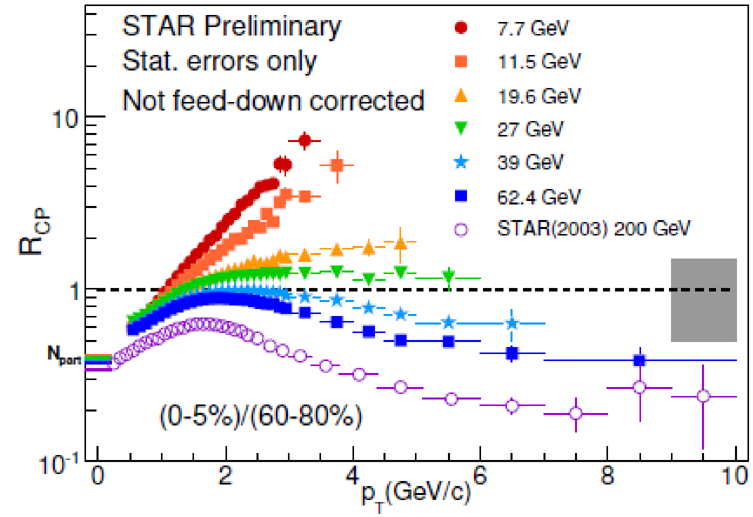
Although it is now understood that the phase transition is a crossover at the lowest μ_B, Lattice Gauge Theory predictions suggest that the low end of the BES-I may find the critical point



Disappearance of QGP Signatures - R_{CP}

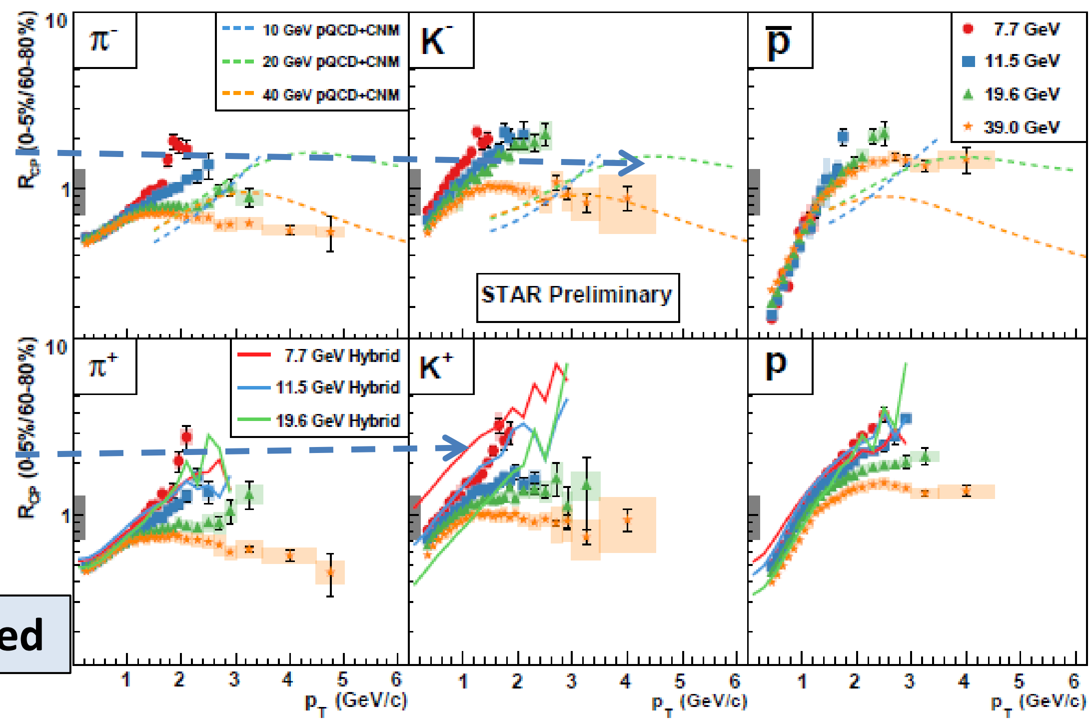
- R_{CP} for hadrons and for identified particles can provide a measure of partonic energy loss in the medium.
- Not sufficient reach to search for evidence of high p_T suppression below 19.6 GeV
- Stopped Baryons complicate inclusive R_{CP} measurements
- pQCD calculations show high p_T suppression
- Hybrid calculations describe the low p_T behavior





pQCD calculations

Hybrid calculations



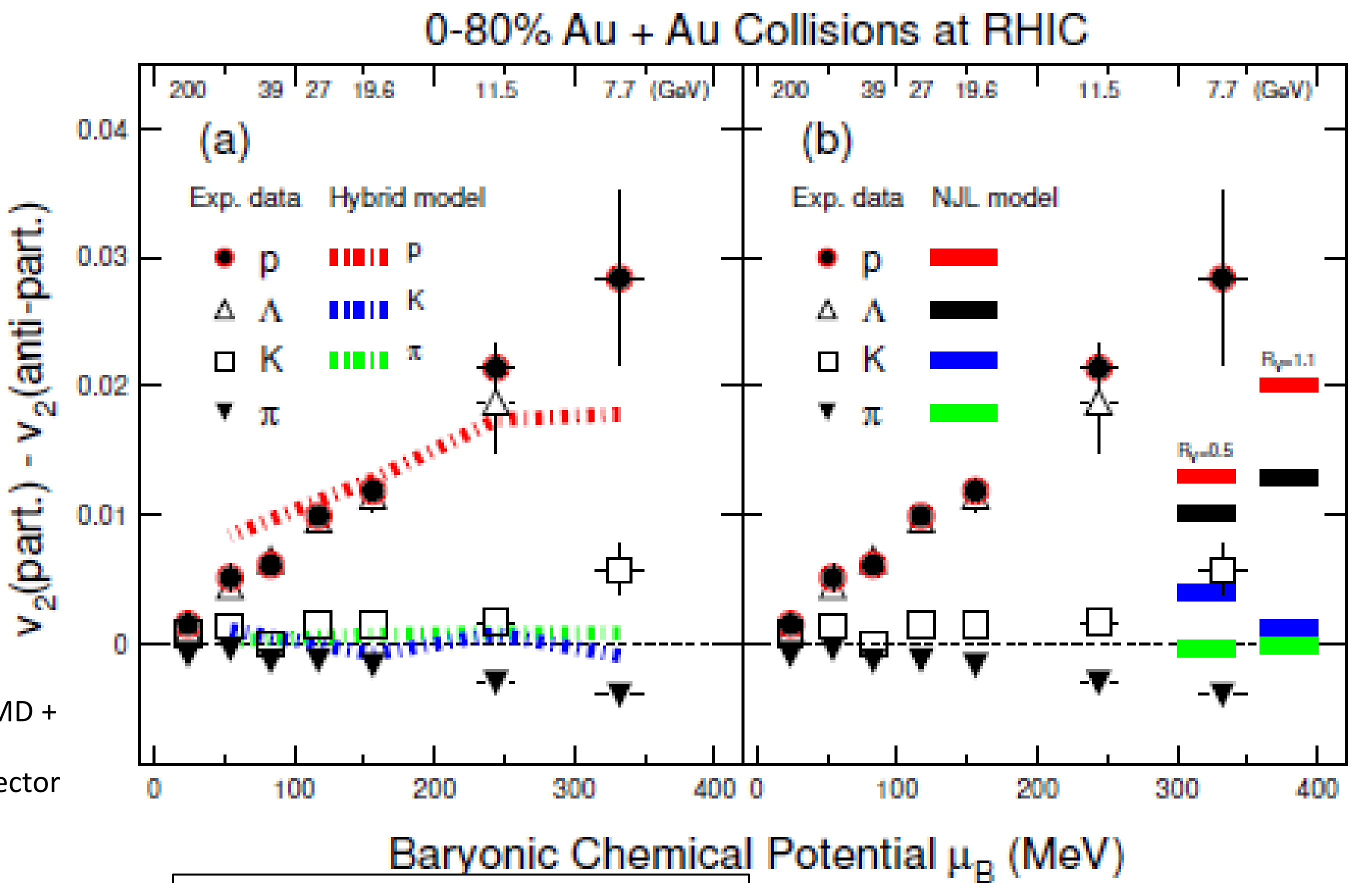
More p_T reach is needed

Disappearance of QGP Signatures – Δv_2

• There is a remarkable difference between particles and their anti-particles, especially for the lowest energies in the range.

•Difference between particles and their anti-particle decreases with increasing beam energy

• The difference seems to track with chemical potential



- Hybrid model: Hybrid model (UrQMD + hydro) with baryon stopping
- Nambu-Jona-Lasinio (NJL): Using vector mean-field potential, repulsive or quarks, attractive for anti-quarks

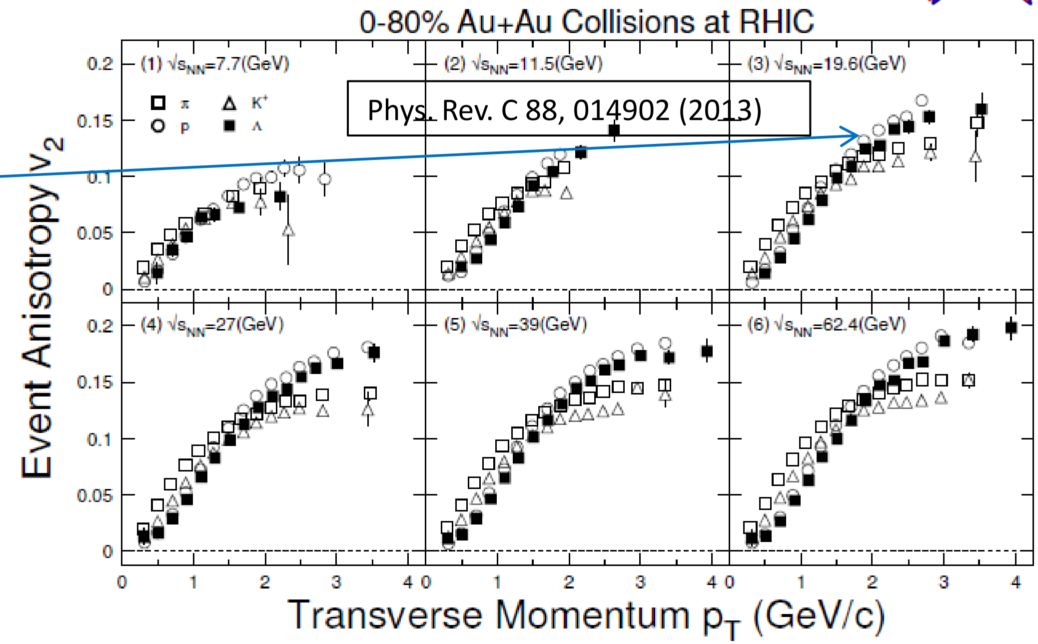
Data: Phys. Rev. Lett. 110, 142301 (2013)

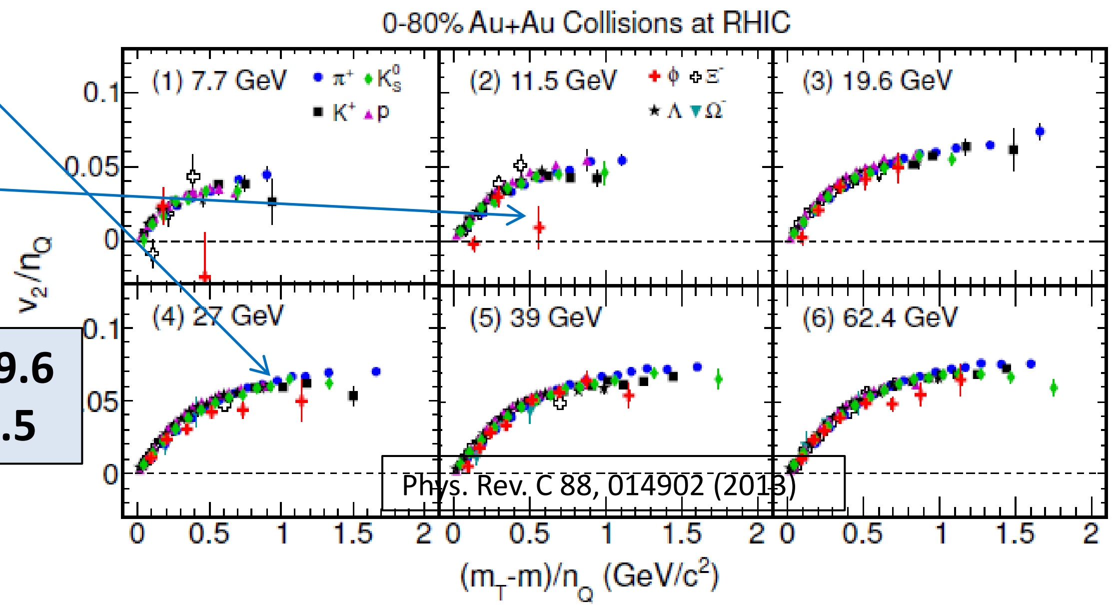
Hybrid: Phys. Rev. C 86, 044903 (2012)

NJL: Acta Phys.Polon.Supp. 7 (2014) 1, 183

Disappearance of QGP Signatures – v_2

- Baryon/Meson Splitting is seen at the higher energies (19.6 and higher)
- Constituent quark scaling is seen as an indication of partonic behavior
- n_Q scaling seen for particles for higher energies
- The ϕ meson may not follow the trends are 11.5 or 7.7 GeV, but



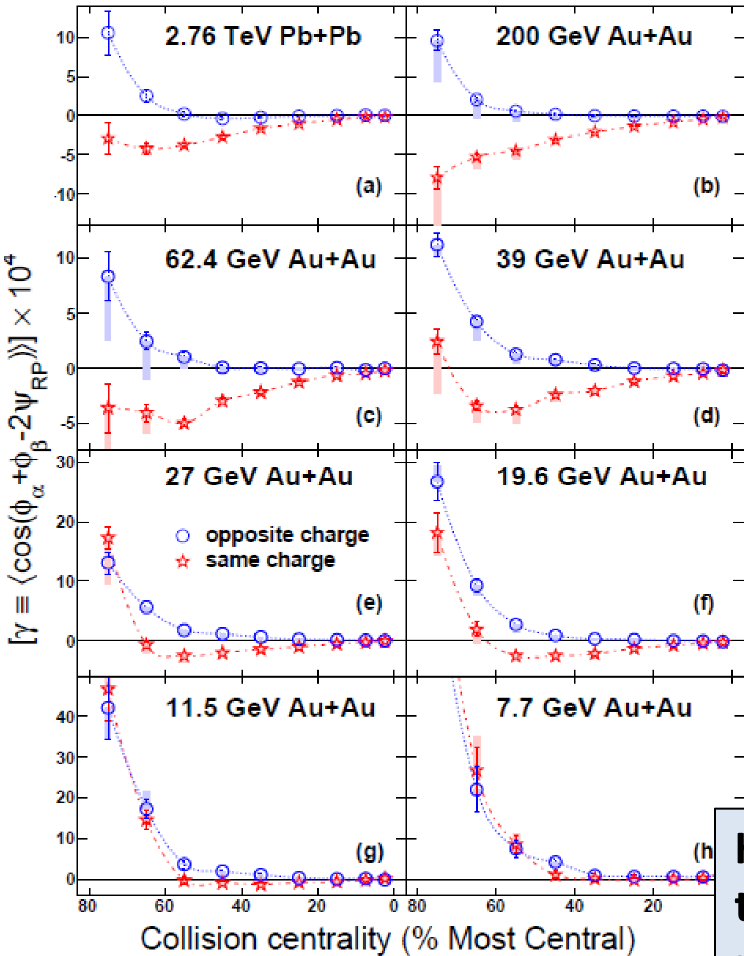


Need more p_T reach at 7.7, 11.5, and 19.6
Need more statistics for f at 7.7 and 11.5

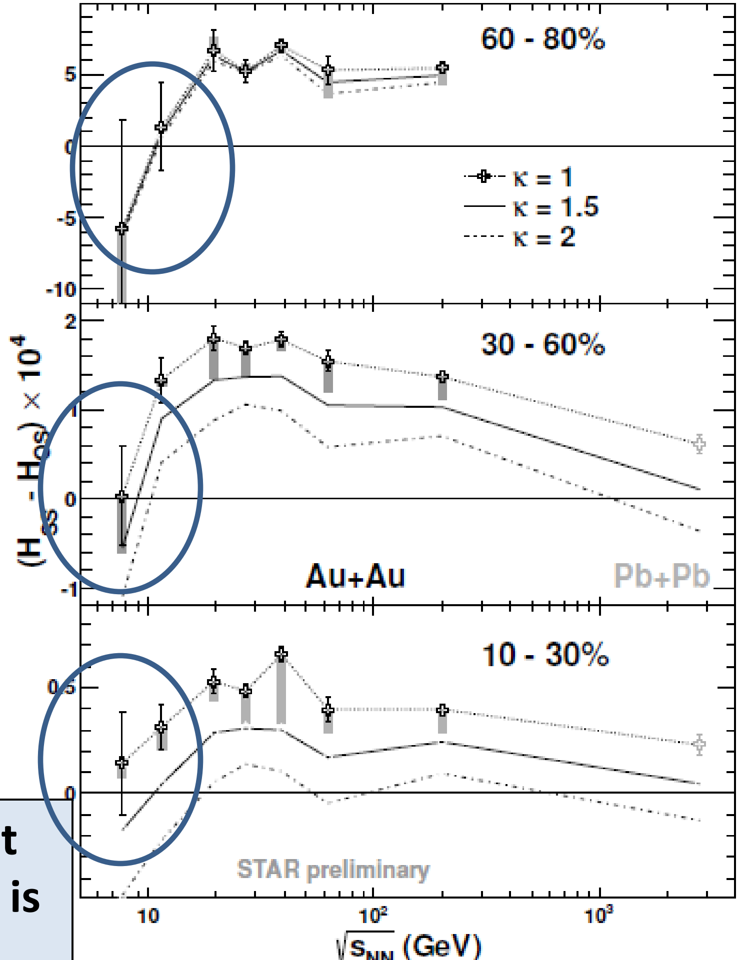
Disappearance of QGP Signatures -- CME

Same-charge and opposite charge are shown separately, while the signal is opposite-same

Here signal minus background is shown. Background is other physics coupled to v_2



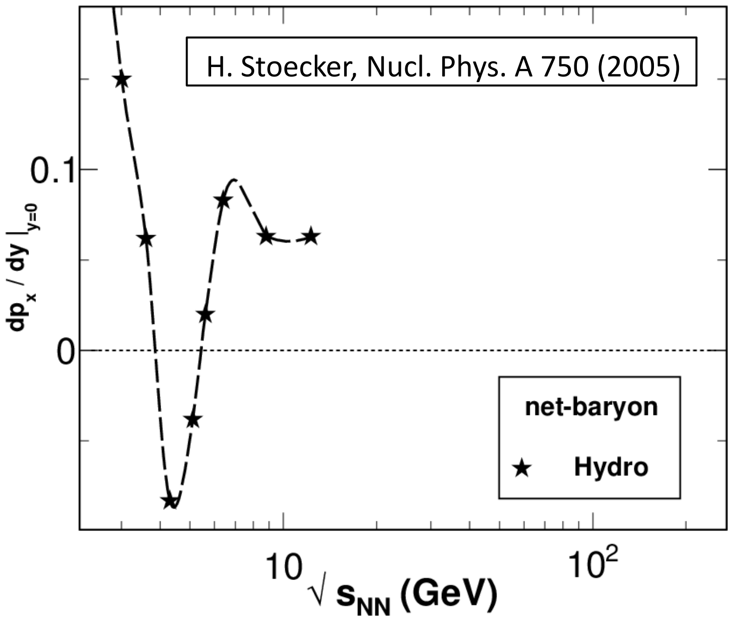
- Three particle correlators show an effect which may be CME
- This effect disappears at the lowest beam energies.

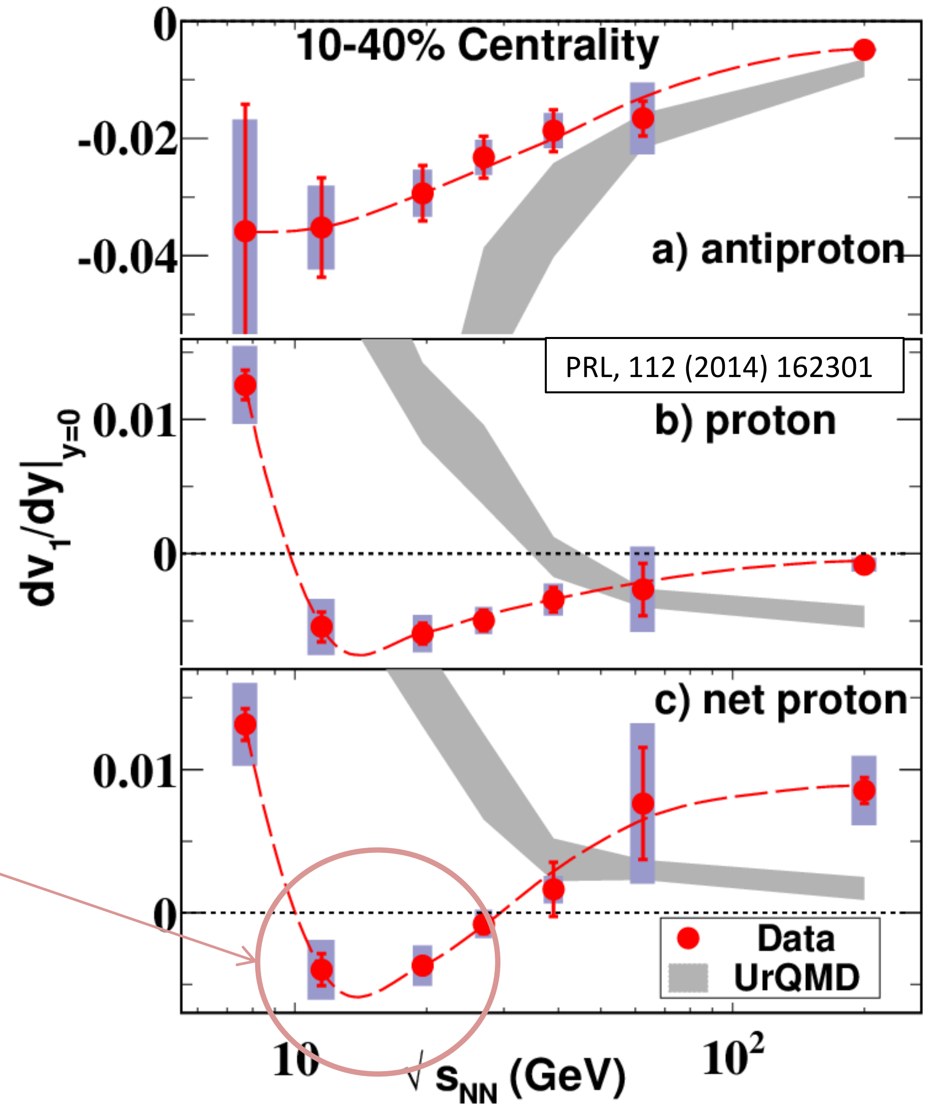


Higher Resolution at the lowest energies is needed

CME = Chiral Magnetic Effect

Search for 1st Order Phase Transition – v_1

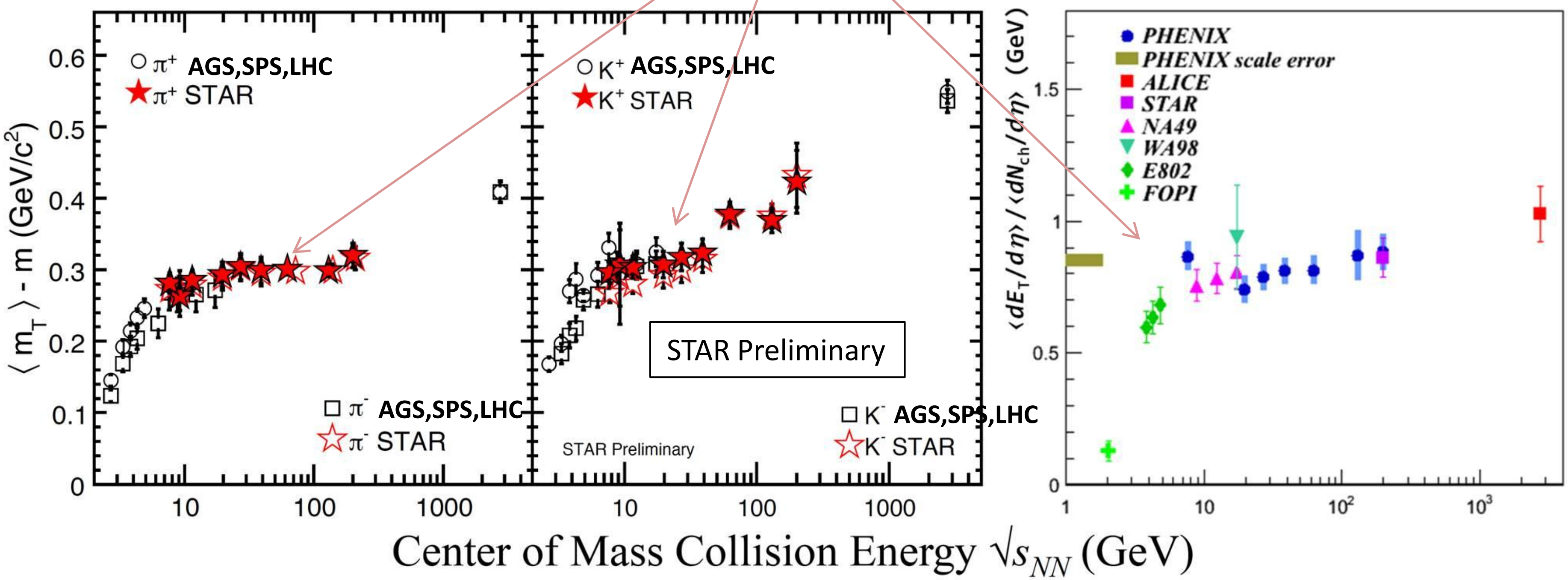




- First order phase transition is characterized by unstable coexistence region. This spinodal region will have the lowest compressibility
- v_1 is a manifestation of early pressure in the system

Search for 1st Order Phase Transition - <m$_T$>

- <m$_T$> - m is a measure of the thermal excitation, i.e. temperature
- dN/dy ~ ln($\sqrt{s_{NN}}$) may represent the entropy
- The observed saturation of <m$_T$> is characteristic of a 1st order phase transition
- E_T includes mass and is associated with the energy density

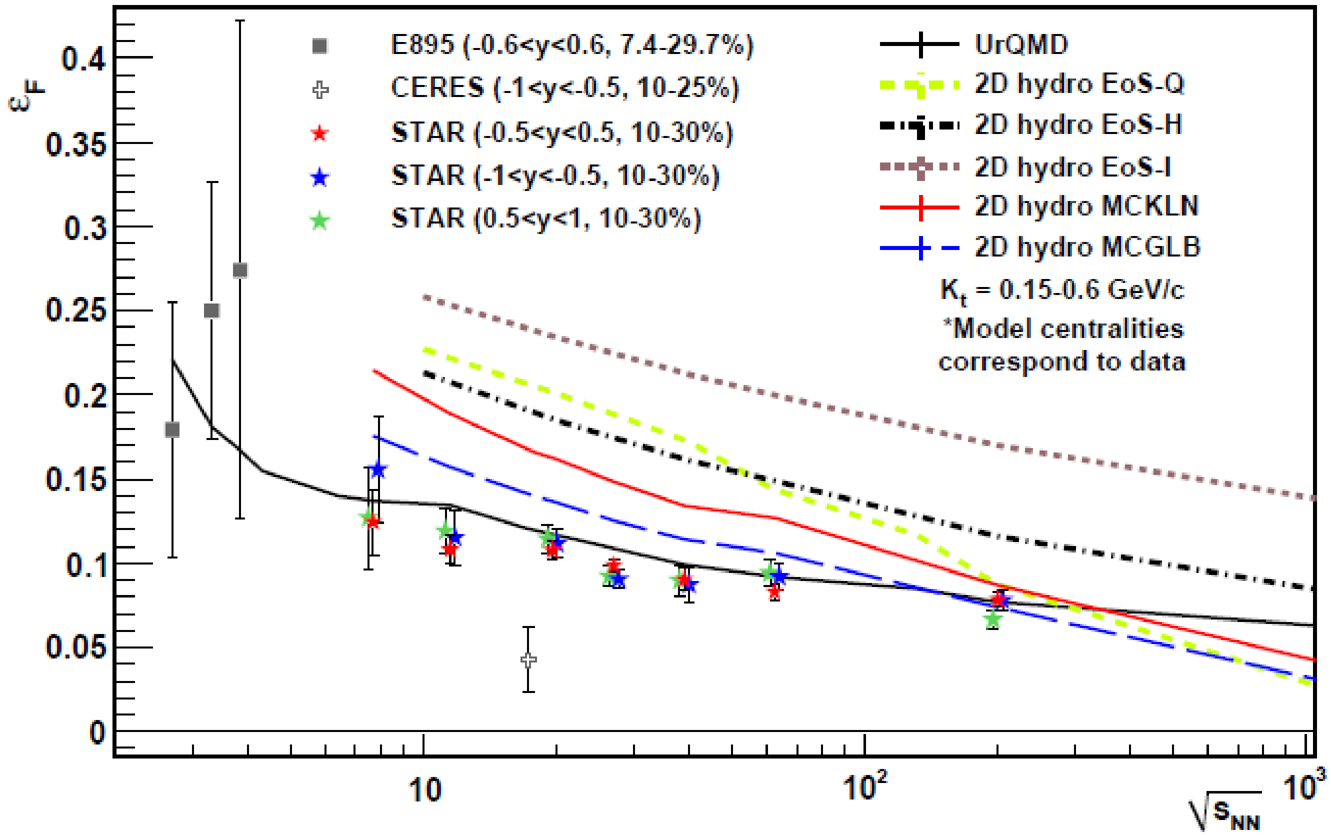


Search for 1st Order Phase Transition - asHBT

- Pion asHBT allows a study of the coordinate space "almond shape" (ε_F) after expansion

- The expansion in coordinate space slows above 7.7 GeV. But no strong minimum is observed.

- Late signature, therefore may not have sufficient sensitivity

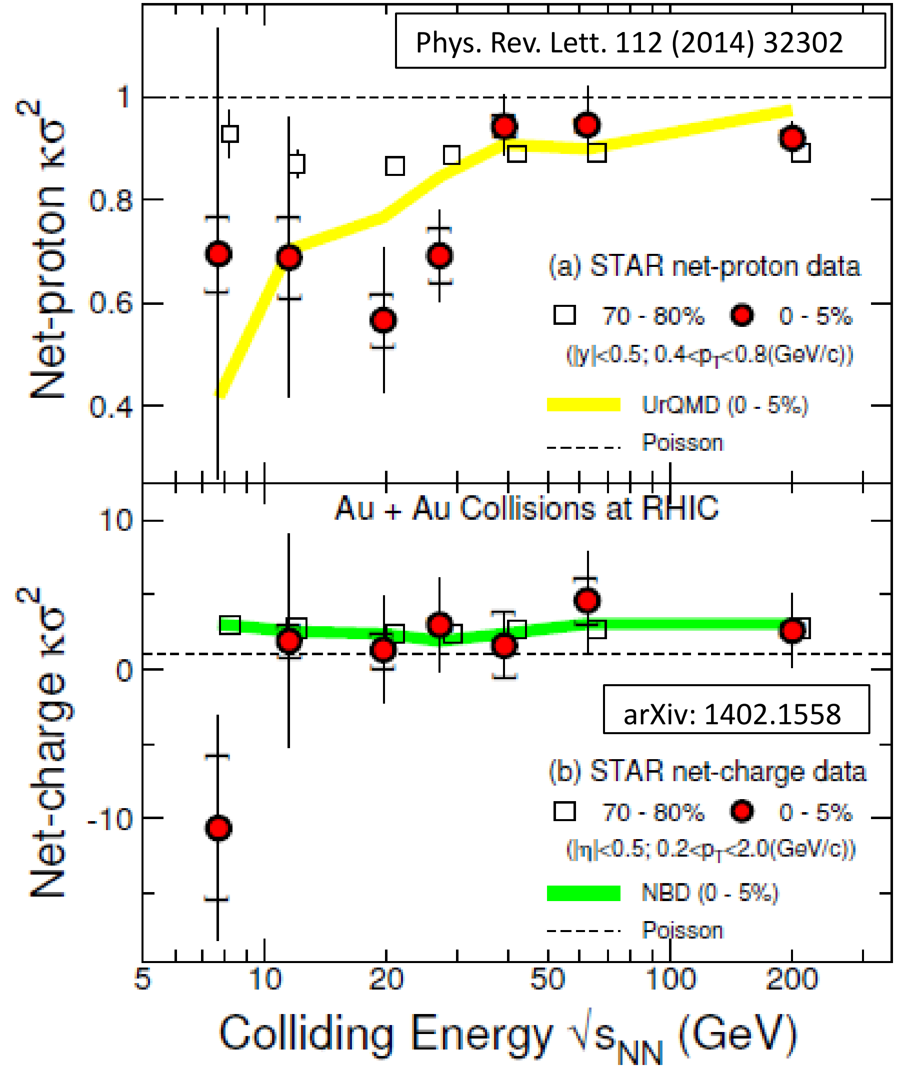


- Fluctuations of conserved quantities are the best observables to use to search for the critical point
- The variances of these quantities are proportional to the square of the correlation length
- Skew and Kurtosis are even more sensitive
- Some features seen in net-proton $\kappa\sigma^2$
- Difference between signal and baselines is less than the uncertainty in net charge measurements

Volumes cancel

$$\chi_B^{(n)} = \left.\frac{\partial^n (P/T^4)}{\partial(\mu_B/T)^n}\right|_T \Rightarrow \begin{array}{l}\chi_B{}^4 / \chi_B{}^2 = (\kappa\sigma^2)_B \\ \chi_B{}^3 / \chi_B{}^2 = (S\sigma)_B\end{array}$$

F. Karsch, PoS (CPOD07) 026, PoS (Lattice 2007) 015



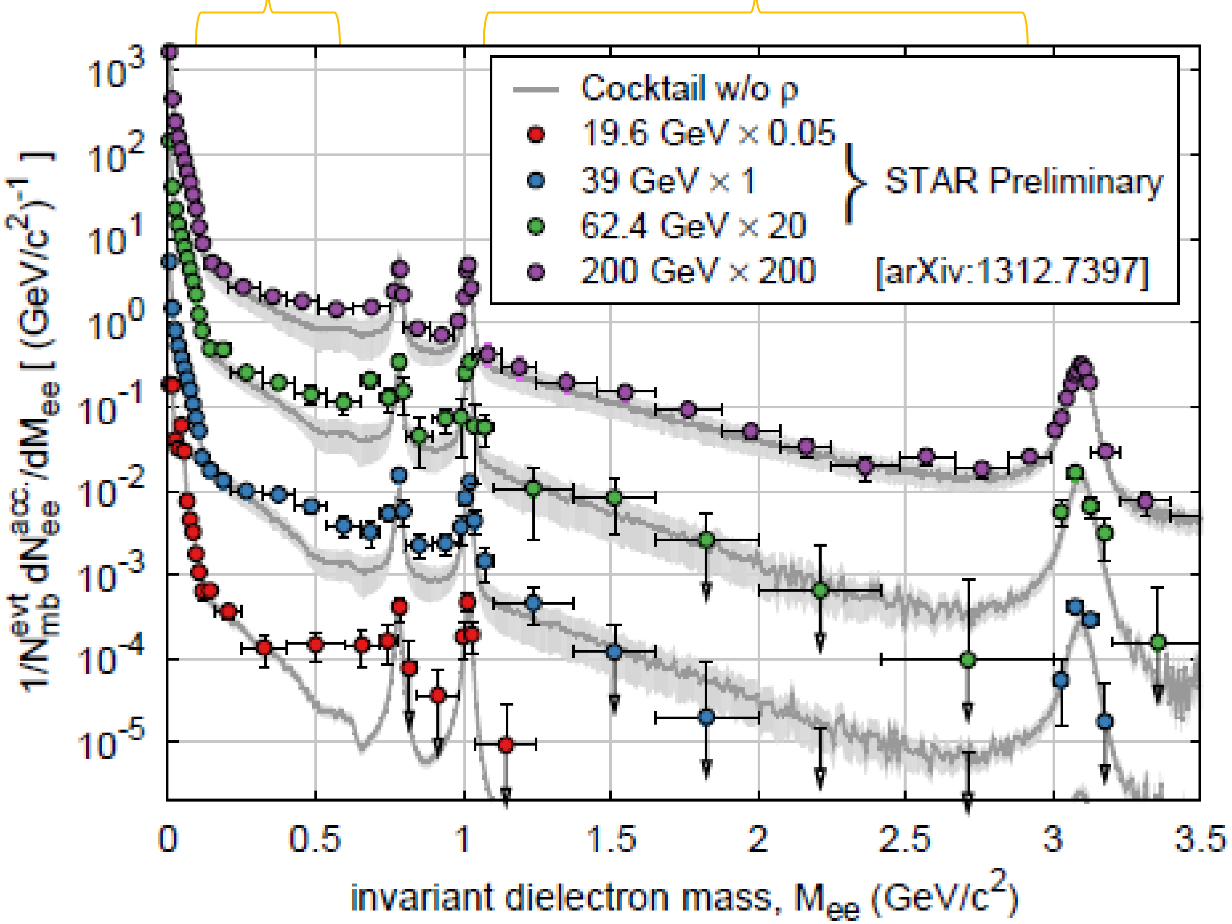
More data are needed

Bulk Penetrating EM Probes

Low Mass Region:
ρ in medium modification tied to chiral symmetry restoration

Intermediate Mass Region:
QGP Thermal Radiation

- No strong √s dependence of LMR excess yield
- Constant Baryon density (ρ) from 200 GeV down to 19.6 GeV
- Not enough statistics in IMR
- No handle on charm continuum (in IMR)



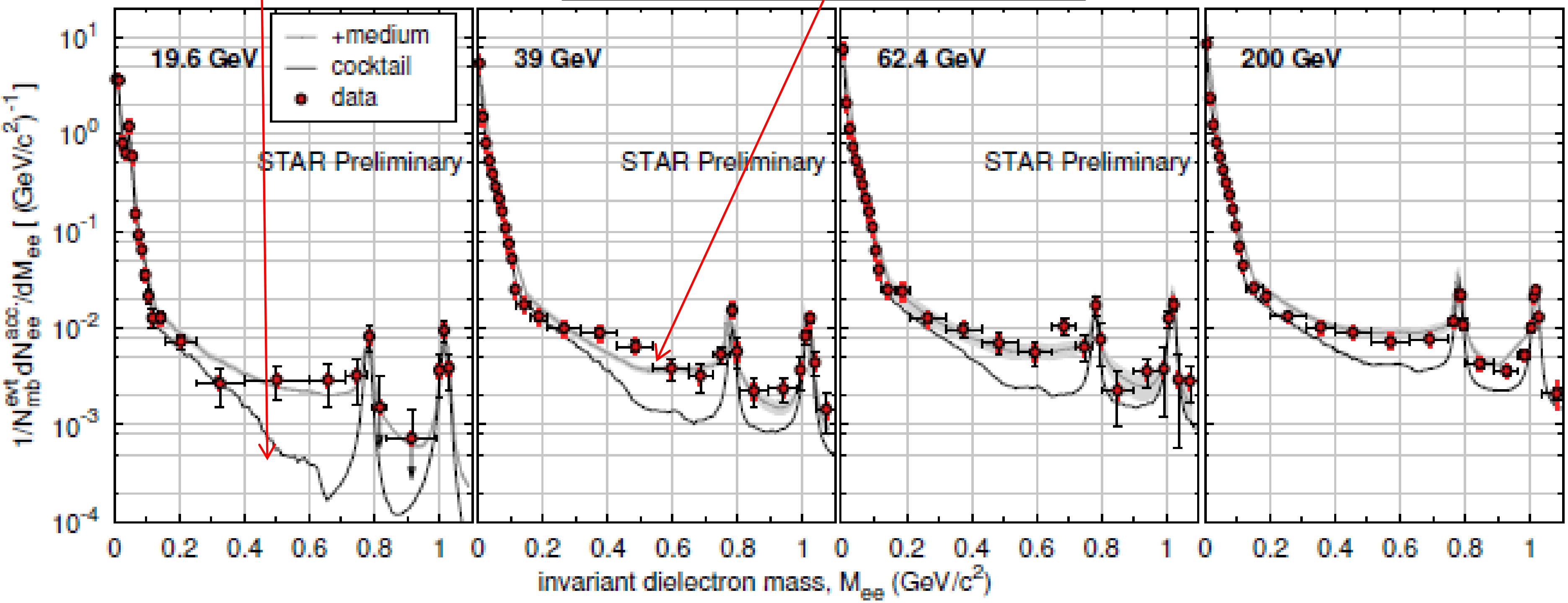
Bulk Penetrating EM Probes

R. Rapp, private communication,
R. Rapp Adv. Nucl. Phys. 25,1 (2000)

Low Mass Region:
Black lines are the Cocktail (excluding the ρ meson)

Grey lines are in medium calculations from R. Rapp which include both HG and QGP components (including medium broadened ρ meson). Model is able to match the data

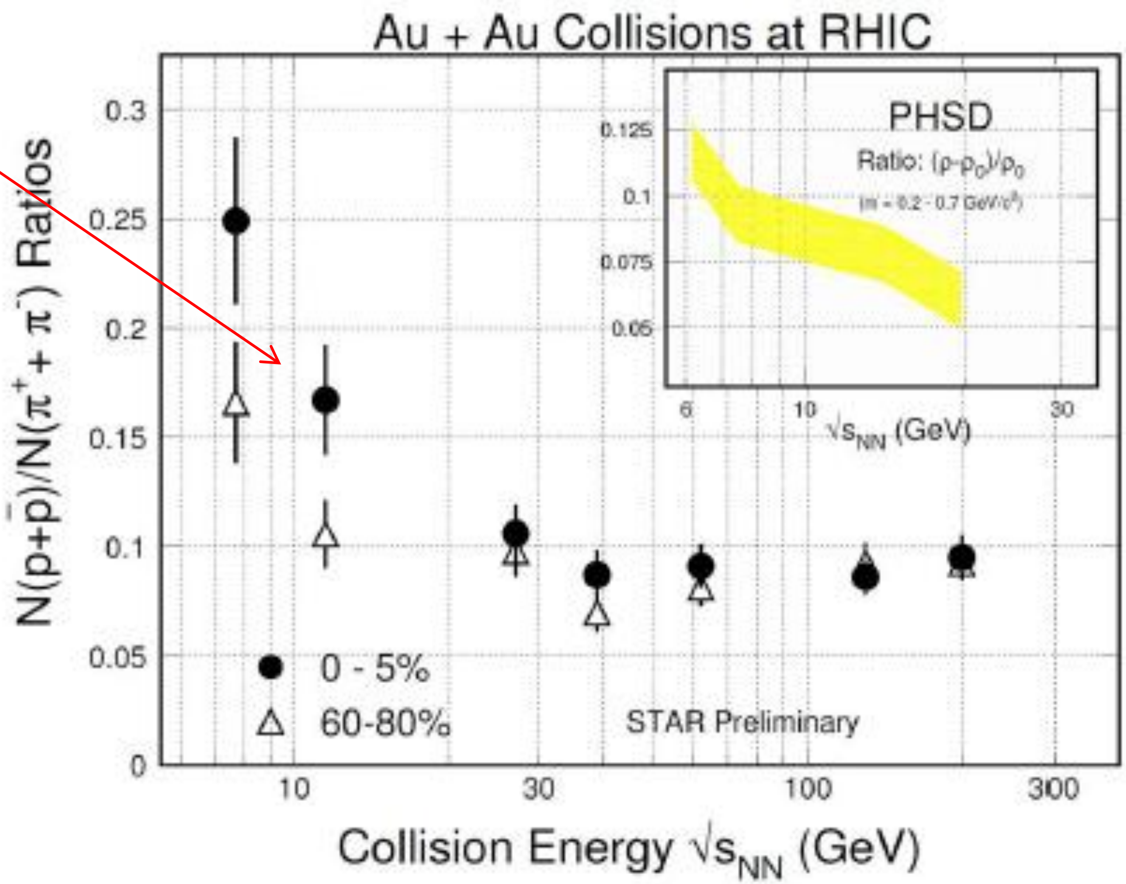
The uncertainty is purely from the cocktail



Bulk Penetrating EM Probes

Ratio of Baryons to Mesons: Total Baryon density increases at low energies

- N(p+p-bar)/N($\pi^+ + \pi^-$) is our proxy for total baryon density
- Increases by factor of two at lower energies
- Inset is a PHSD model calculation of the excess in the region of interest
- Measure LMR excess for increasing total baryon density (ρ) at lower √s



BES Phase I – What have We Learned

• The BES at RHIC spans a range of μ_B that could contain feature of the QCD phase diagram

• Several signatures demonstrate that the high energy range of the BES shows features that are consistent with a parton dominated regime

• These signatures either disappear, lose significance, or lose sufficient reach at the low energy region of the scan.

• There are indicators pointing towards a softening of the equation of state which could be indicative of a first order phase transition

• The critical phenomena expected as one passes near a critical point would present compelling evidence, but these analyses are quite sensitive and place stringent demands on the statistics in order to characterize the tails of the distributions

• EM probes offer a unique way to study chiral symmetry restoration (spectral function changes – really need both ρ and a1) and QGP thermal radiation, but intermediate mass dileptons are rare and require high statistics data sets.

Beam Energy Scan Phase II

- Physics goals
- Accelerator upgrade – electron cooling
- Internal fixed-target program
- Detector upgrades – iTPC, EPD, end cap TOF

Proposed Goals of BES Phase-II

- Measurement of the R_{CP} of identified hadrons up to a p_T = 5 GeV/c (not 7 GeV, maybe 9)

- Consolidate the observation of a non-monotonic variation of the slope of net-proton $v_1(y)$ around midrapidity.

- Quantitatively address the issue of current qualitative observation of absence of partonic collectivity below $\sqrt{s_{NN}}$ = 19.6 GeV, through measurement of v_2 of ϕ mesons.

- Consolidate the observation of turn-off of CME/LPV like effect at lower beam energies of 7.7 GeV.

- Quantitatively establish the suggestive non-monotonic variation of net-proton $\kappa\sigma^2$ with beam energy.

- Characterize the orientation and the eccentricity of the coordinate space anisotropy of the baryon distribution of the medium using two proton correlations

- Unique opportunity to carry out a systematic study of dilepton production in high total-baryon density environment. Chiral symmetry and thermal radiation can be explored.

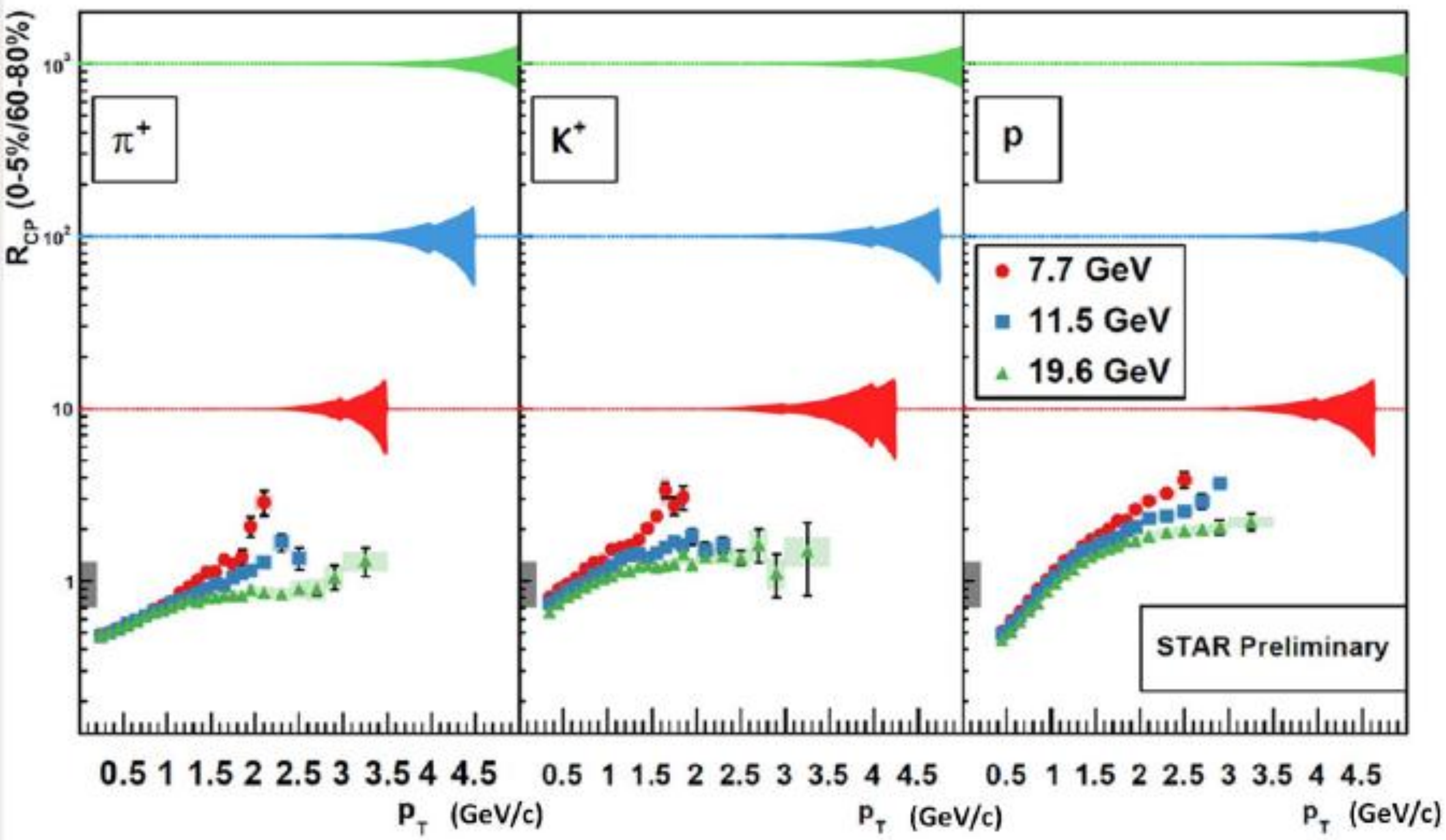
Statistics Needed in BES phase II

Collision Energies (GeV):	**7.7**	**9.1**	**11.5**	**14.5**	**19.6**
Chemical Potential (MeV):	**420**	**370**	**315**	**260**	**205**
Observables	Millions of Events Needed				
QGP: R_{CP} up to p_T 4.5 GeV	NA	NA	160	92	22
QGP: Elliptic Flow of ϕ meson (v_2)	100	150	200	300	400
QGP: Local Parity Violation (CME)	50	50	50	50	50
1st P.T.: Directed Flow studies (v_1)	50	75	100	100	200
1st P.T.: asHBT (proton-proton)	35	40	50	65	80
C.P.: net-proton kurtosis ($\kappa\sigma^2$)	80	100	120	200	400
EM Probes: Dileptons	100	160	230	300	400
Proposed Number of Events:	**100**	**160**	**230**	**300**	**400**

Disappearance of QGP Signatures -- R_{CP}

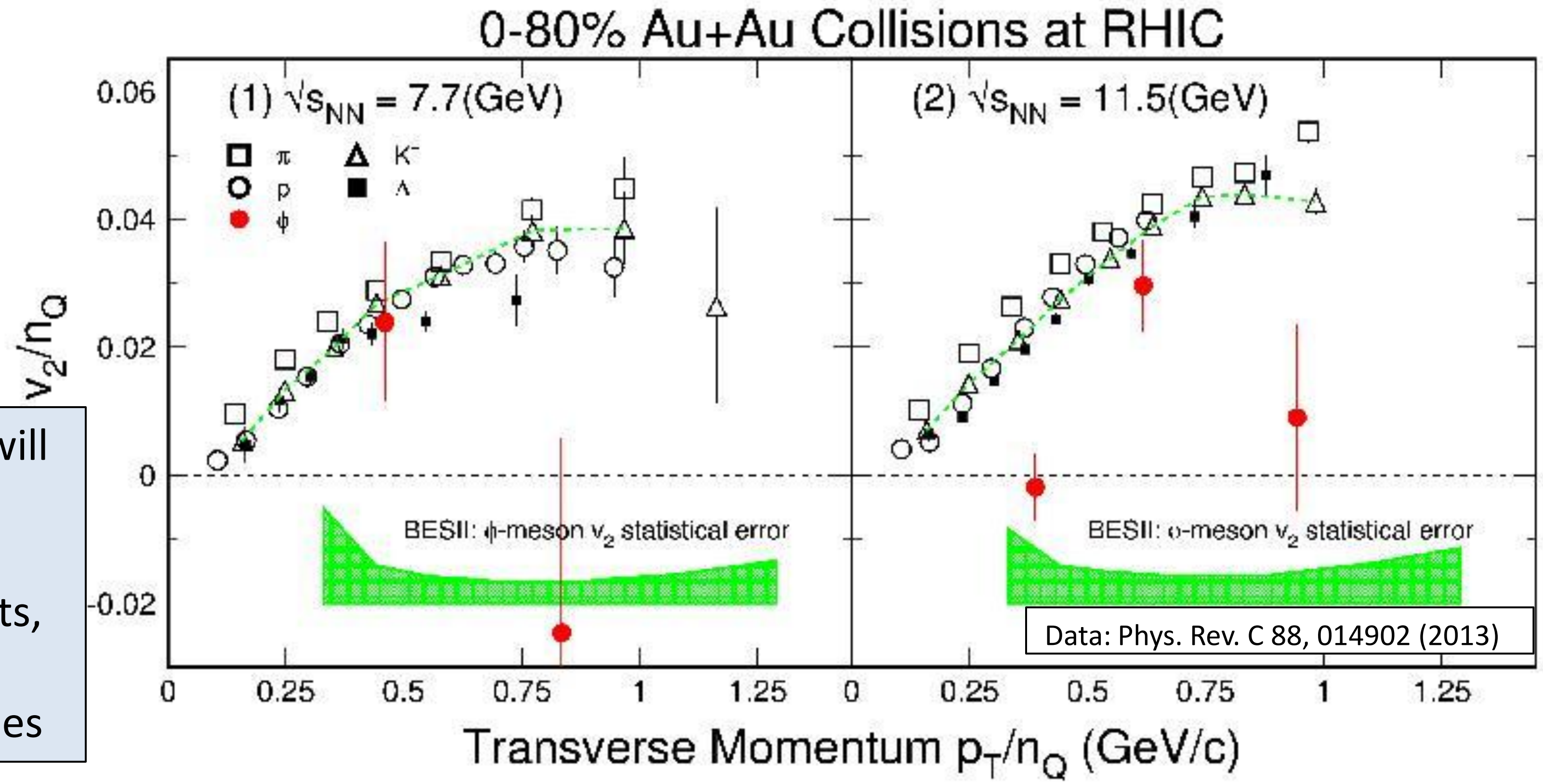
The key to characterizing the parton energy loss in a colored medum is to reach to a high enough p_T where hard scattering processes dominate. Soft physics dominates the cross section for p_T less than 2 GeV/c

From the measured spectra at lower p_T, we can extrapolate the yields to higher p_T, and then estimate the expected uncertainties



Disappearance of QGP Signatures – v_2 of ϕ

The ϕ meson is a promising probe of partonic media, however the current data do not allow an unambiguous measure of v_2, especially at high p_T where the scaling is most indicative



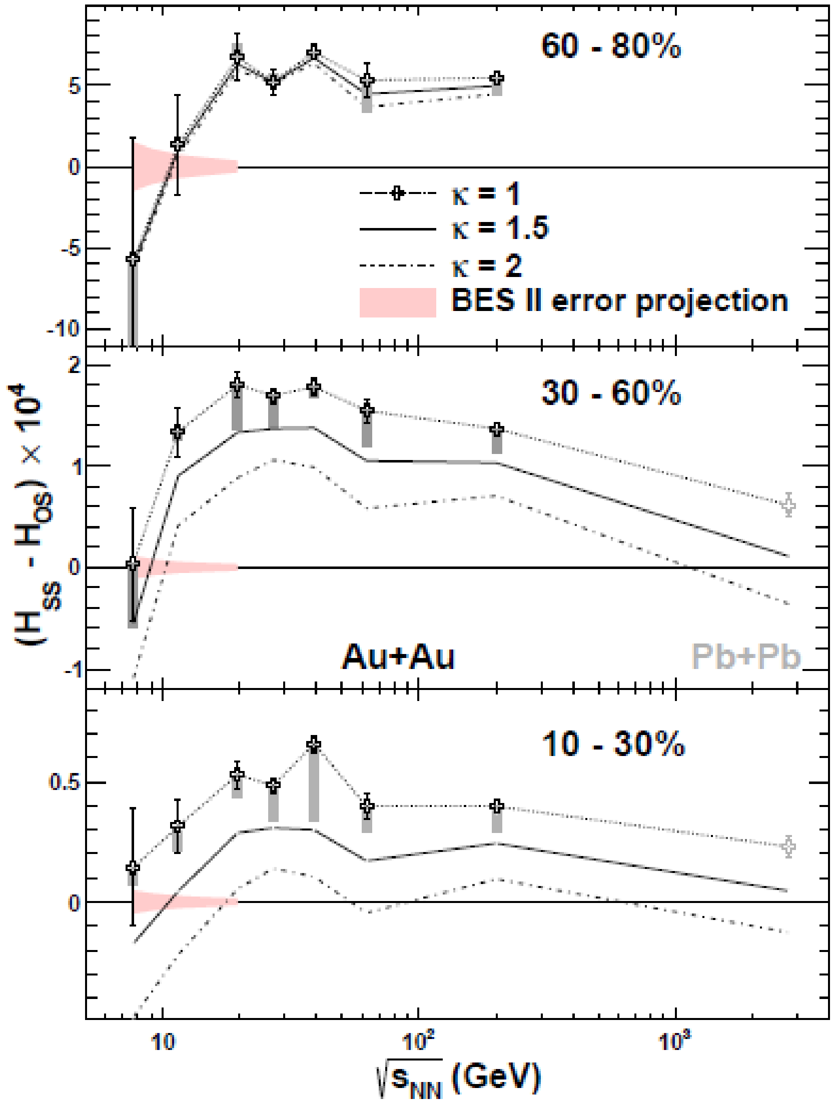
Data: Phys. Rev. C 88, 014902 (2013)

BES Phase II will provide conclusive measurements, even at the lowest energies

Disappearance of QGP Signatures -- CME

The CME signature seems to disappear at 7.7 GeV, however the uncertainties of the measurement make it hard to reach definitive conclusions.

BES Phase II measurements will allow a quantitative measurement of energy where the CME signature disappears



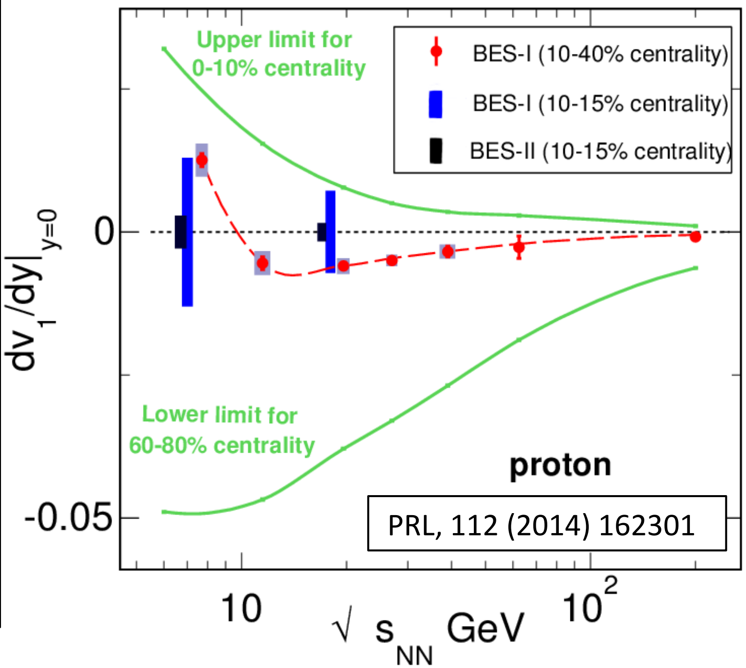
Search for 1st Order Phase Transition – v_1

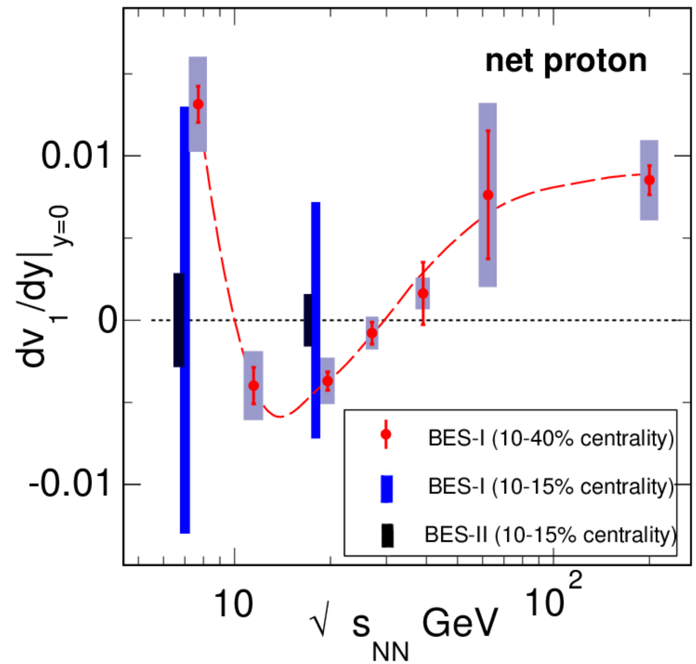
• Study of the directed flow as a function of centrality and of particle type will help us to relate this observable to models which incorporate a phase transition.

• As the directed flow signal is sensitive to the early phase of a collision, the initial impact parameter (centrality) should have a big effect on the measured flow.

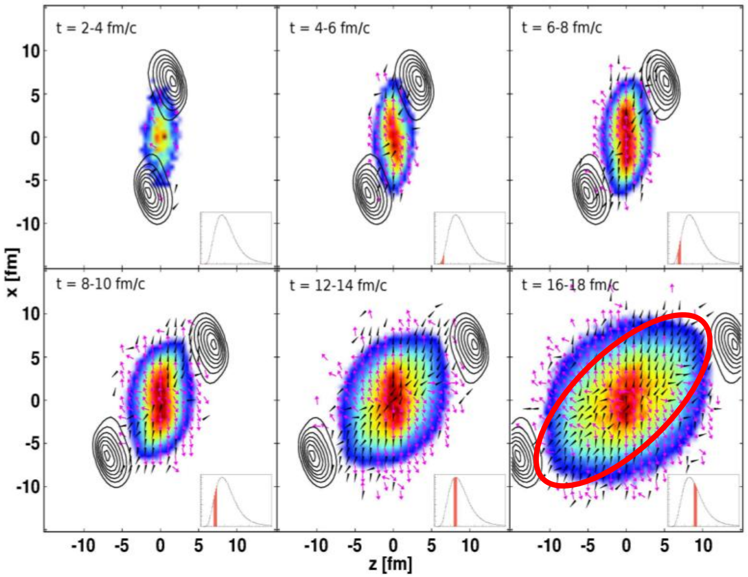
• BES Phase-II data will allow for a definitive test of the relationship of directed flow and compressibility

• Best opportunity to determine the softest point in the EoS



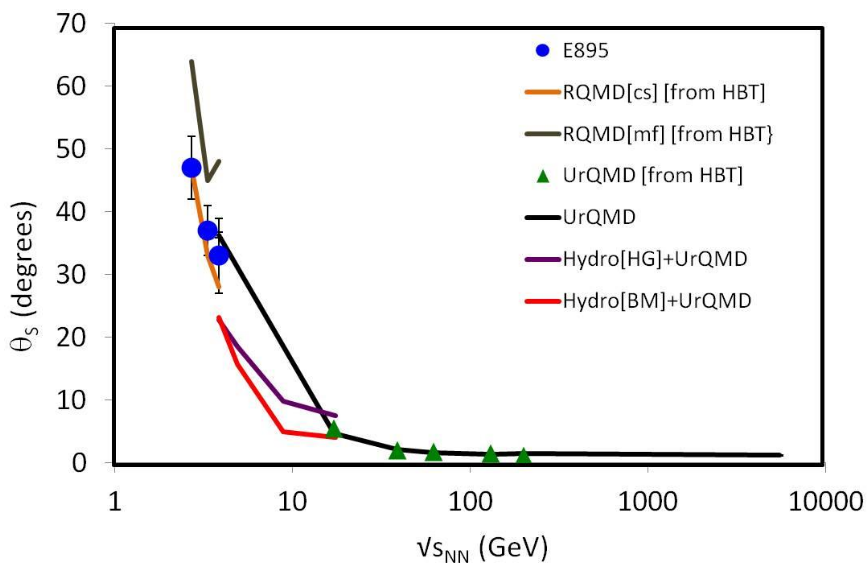


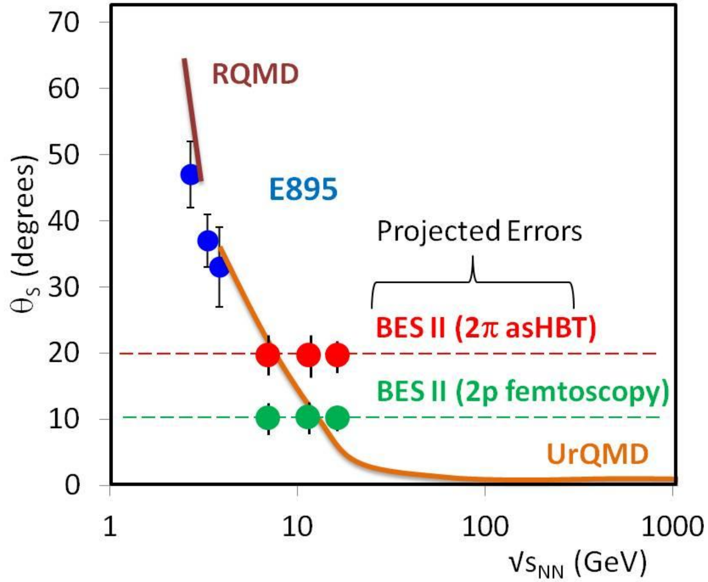
Search for 1st Order Phase Transition -- HBT



Just as the directed flow is a measure of the early compression, an azimuthally sensitive femtoscopy measurement of the longitudinal tilt of the source will provide a measure of the stiffness of the equation of state

This measurement was not possible with the limited statistics of BES I

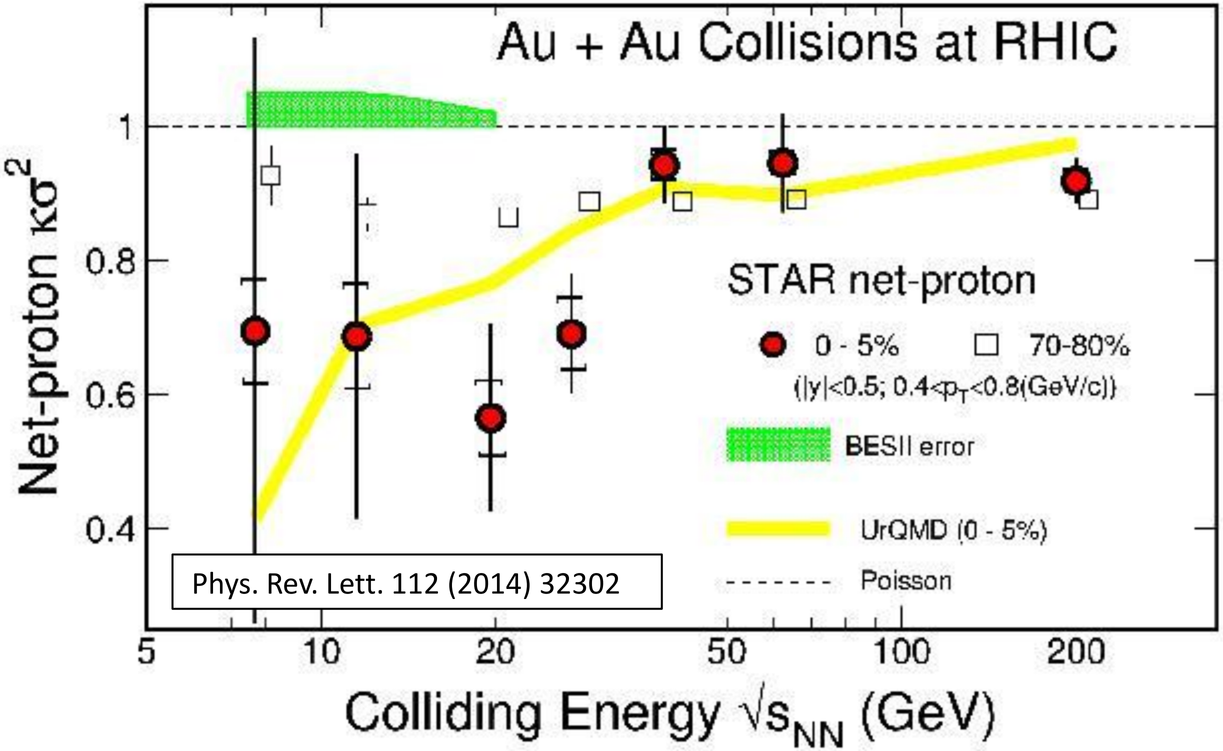




Search for the Critical Point – $\kappa\sigma^2$

•The higher moments are the most promising signature for critical behavior, however the limited statistics of BES-I make conclusions difficult

•With the errors projected for BES Phase-II, it will become clear whether the trends at 19.6 and 27 are a manifestation of criticality

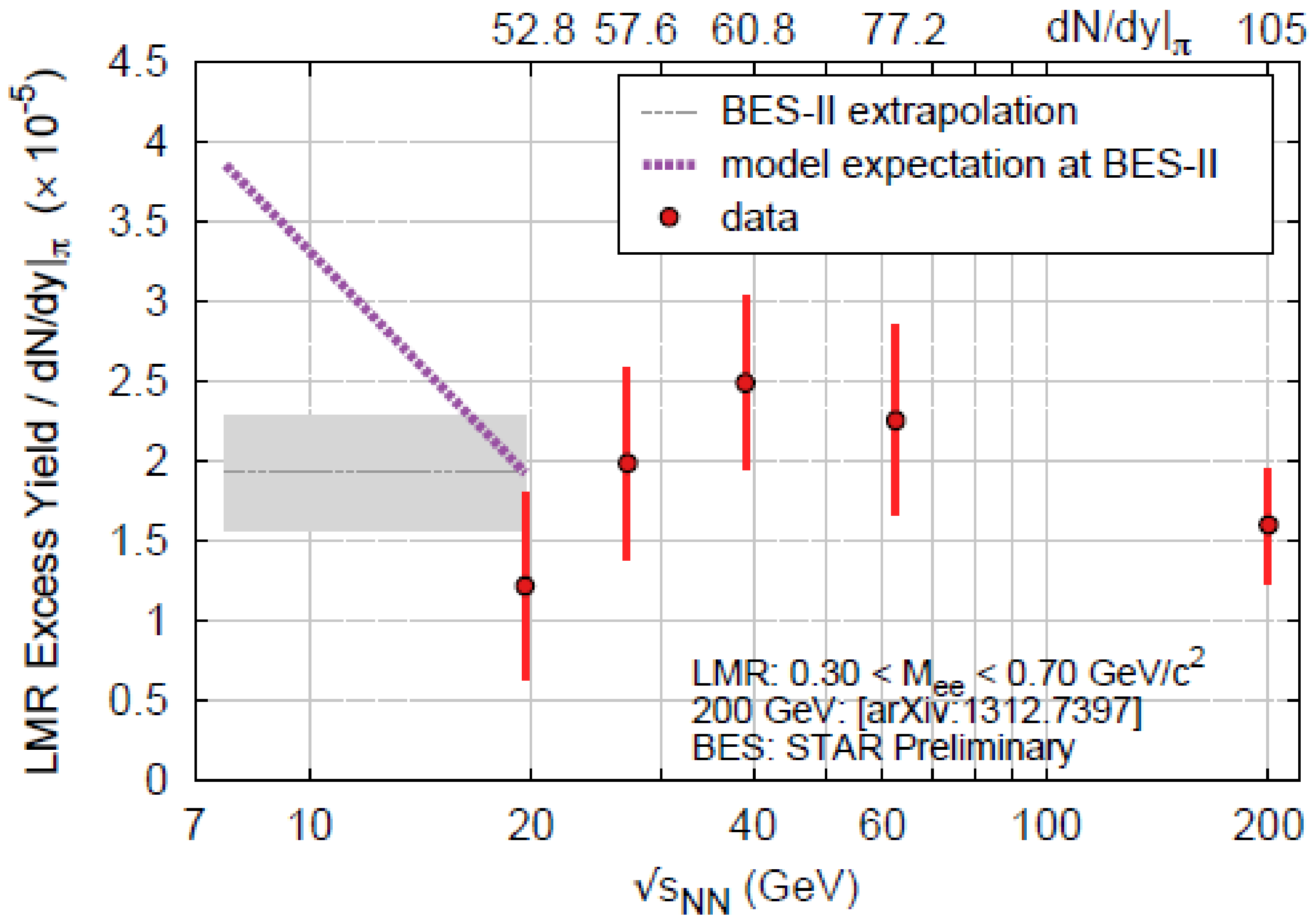


Phys. Rev. Lett. 112 (2014) 32302

Bulk Penetrating EM Probes

BES-II:

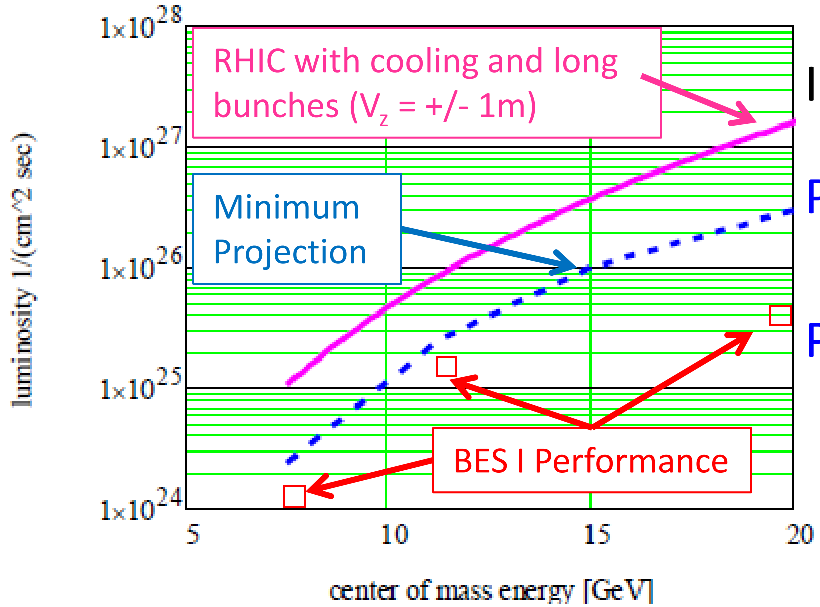
- Measure LMR excess for increasing total baryon density (ρ) at lower √s
- Measure QGP thermal radiation (IMR)
- Possible medium modifications of charm in the IMR
- Include di-muon spectra
- Improved ePID and acceptance with iTPC



Low Energy Electron Cooling at RHIC

Electron Cooling can raise the luminosity by a factor of 3-10 in the range from 5 – 20 GeV

Long Bunches increase luminosity by factor of 2-5

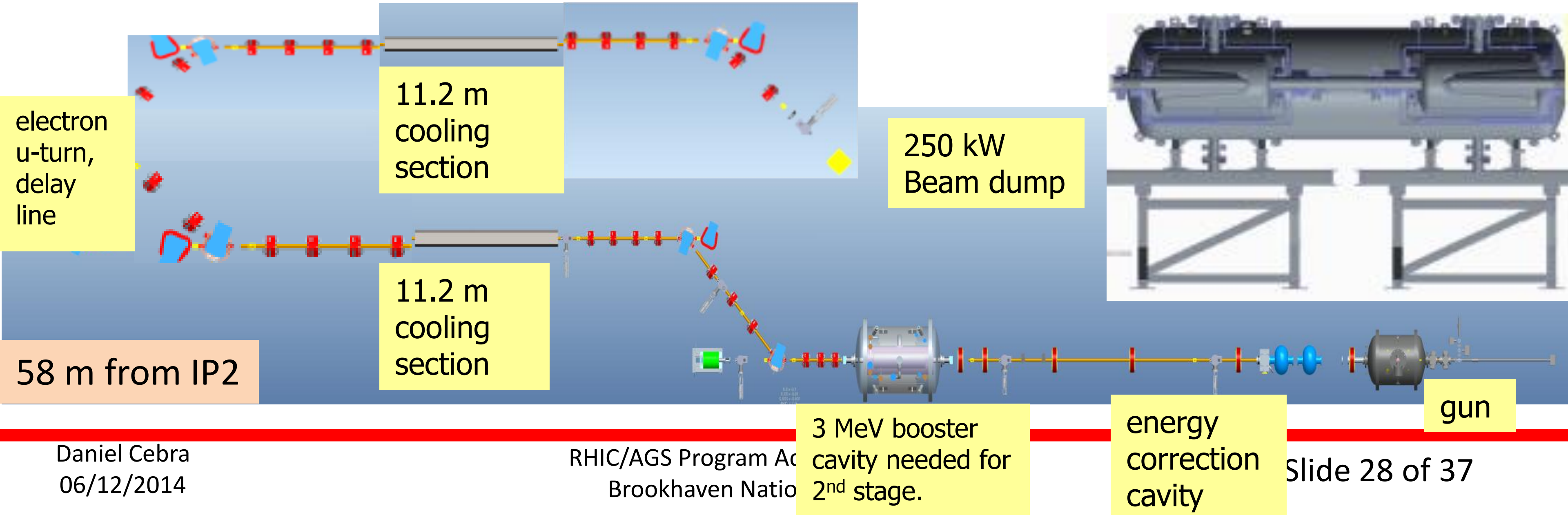


Implementation in phases:

Phase I (2018)
$\sqrt{s_{NN}}$ = 5-9 GeV

Phase II (2019) [additional 3 MeV booster cavity]
$\sqrt{s_{NN}}$ = 9-20 GeV

100 MHz SRF Gun



BES Phase II Proposal

BES Phase II is planned for two 22 cryo-week runs in 2018 and 2019

$\sqrt{S_{NN}}$ (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV)	420	370	315	250	205
BES I (MEvts)	4.3	---	11.7	24	36
Rate(MEvts/day)	0.25*	0.6%	1.7*	2.4%	4.5*
BES I $\mathcal{L}$ (1×10^{25}/cm^{2}sec)	0.13	0.5%	1.5	2.1%	4.0
BES II (MEvts)	100	160	230	300	400
eCooling (Factor)	4	4	4	8	15(4)
Required Beam (weeks)	**14**	**9.5**	**5.0**	**2.5**	**3.0+**

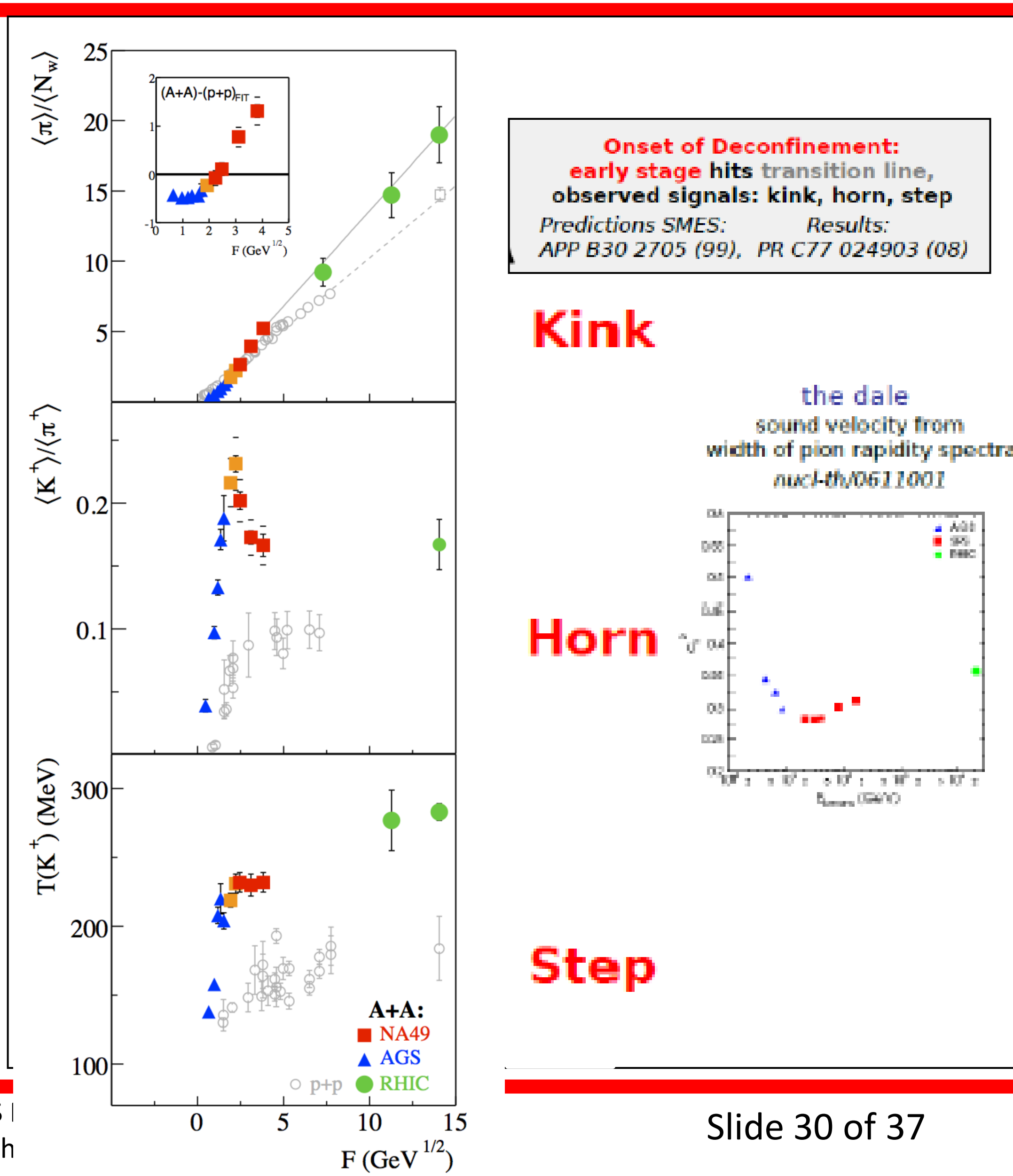
* Average performance in final week of BES-I operations ($|V_z|$< 70 cm)

% Interpolated between adjacent energy points

+ Assuming triggering on only good events – saturates DAQ 1000

What if the Onset of Deconfinement is Below 7.7 GeV?

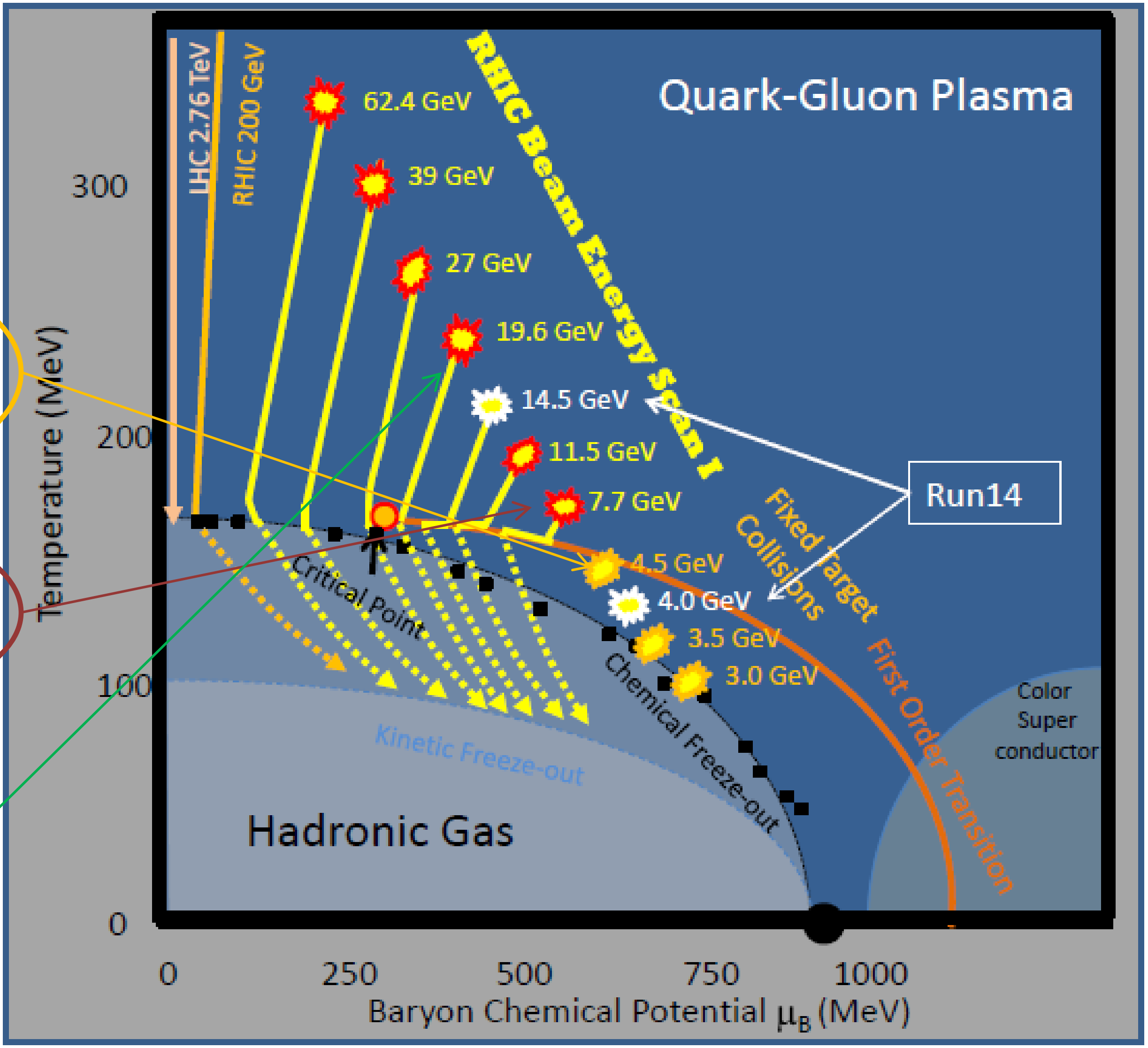
- NA49 has completed a scan at the SPS and claimed observation of the *onset of deconfinement* at 7.7 GeV.
- The disappearance of a given QGP signature does not conclusively demonstrate the absence of the QGP, it could also mean that this signature loses sensitivity.
- It is therefore critical to study collision energies below 7.7 GeV.
- This is a challenge with the collider, although much progress has been made.



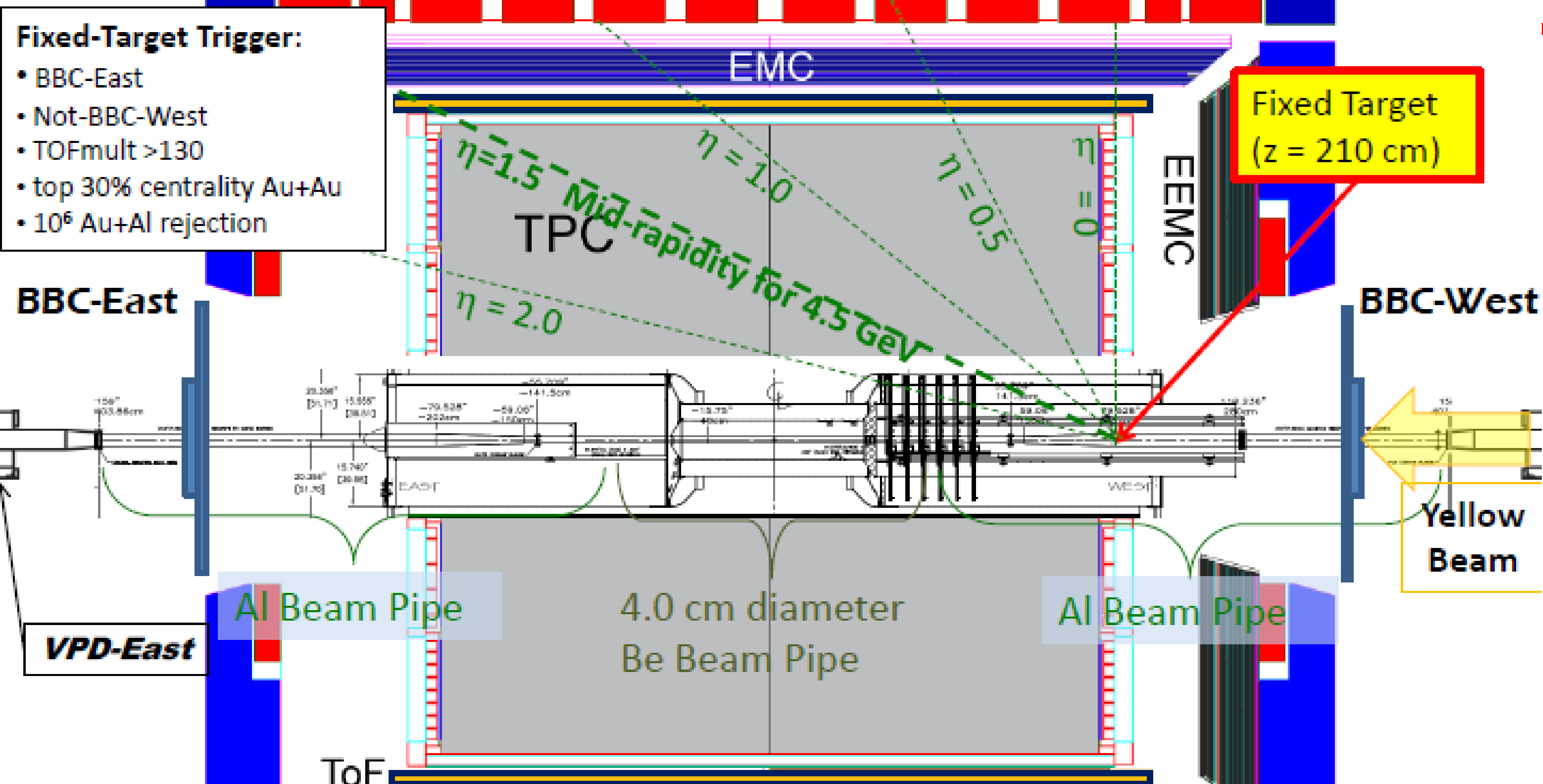
Goals for the Fixed-Target Program

When considering heavy-ion reaction trajectories on the QCD phase diagram, there are three key points:

1) At what energy does the interaction region first achieve enough energy density to reach the mixed-phase?
2) At what energy does it pass out of the mixed phase and reach the QGP (Onset of deconfinement)?
3) At what energy does an expanding system pass through the critical point as it cools?

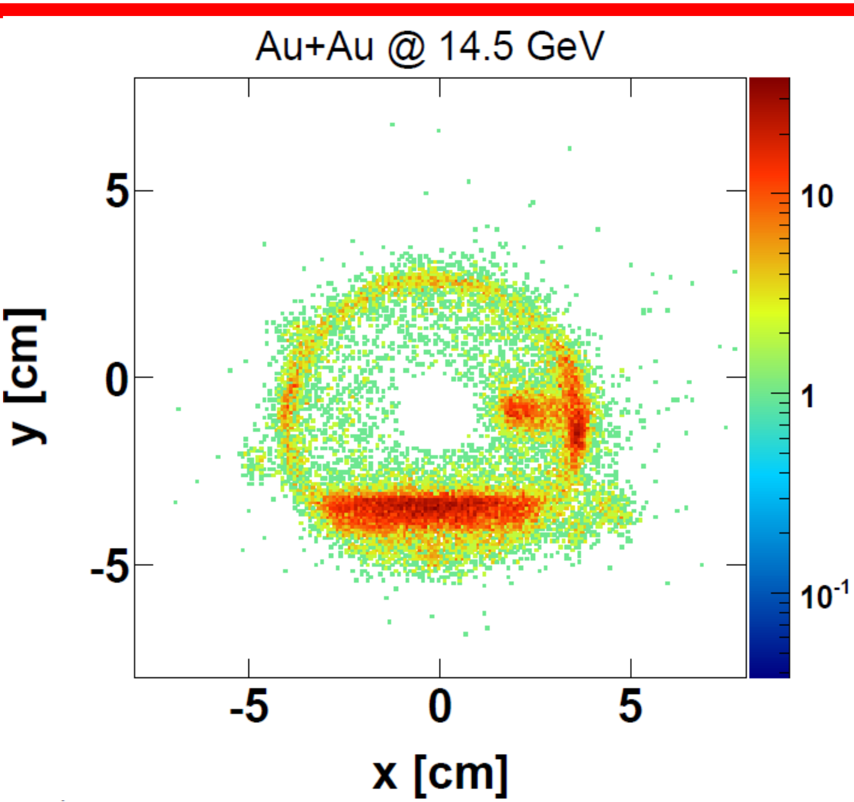


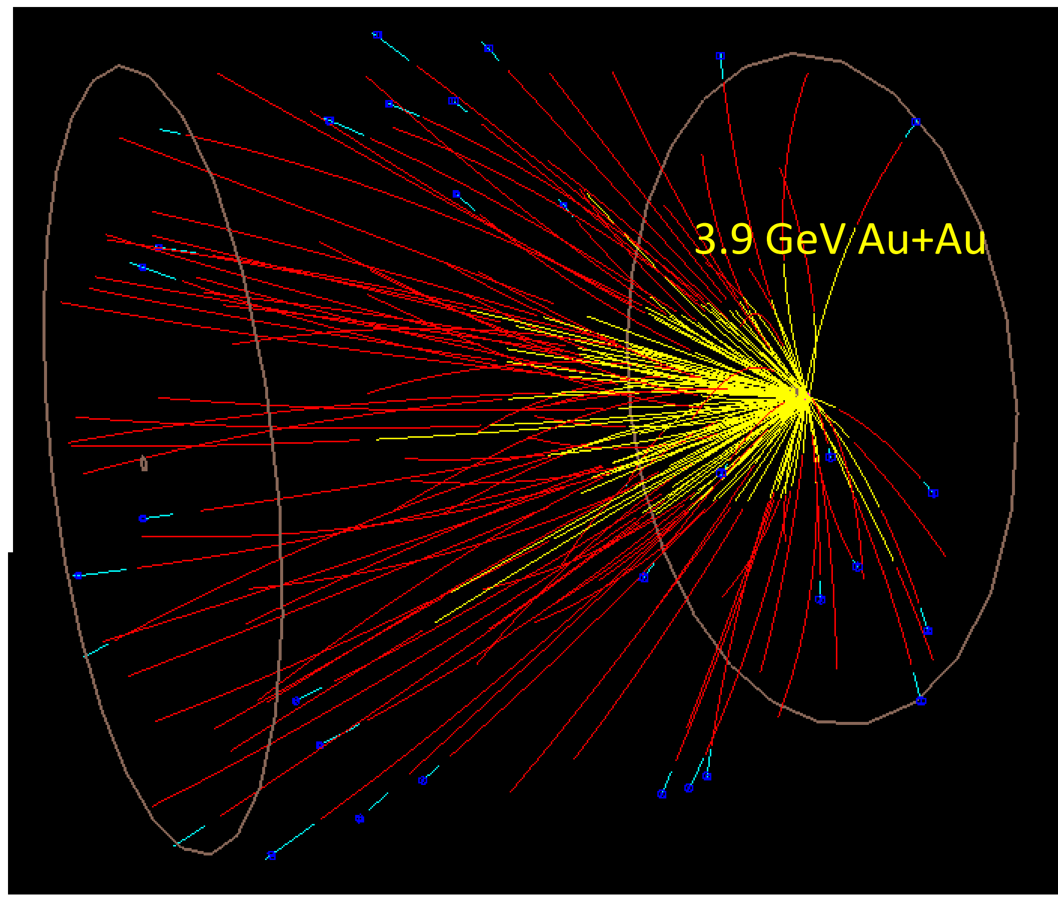
STAR Fixed-Target Run14 Set-up



Collider mode Energies (GeV)	7.7	11.5	***14.5***	19.6
Fixed Target $\sqrt{s_{NN}}$ (GeV)	*3.0*	*3.5*	***3.9***	*4.5*
Fixed Target μ_B (MeV)	*720*	*670*	***633***	*585*
Fixed Target y_{CM}	*1.05*	*1.25*	***1.37***	*1.52*

3.9 GeV Au+Au Fixed-Target Events in STAR



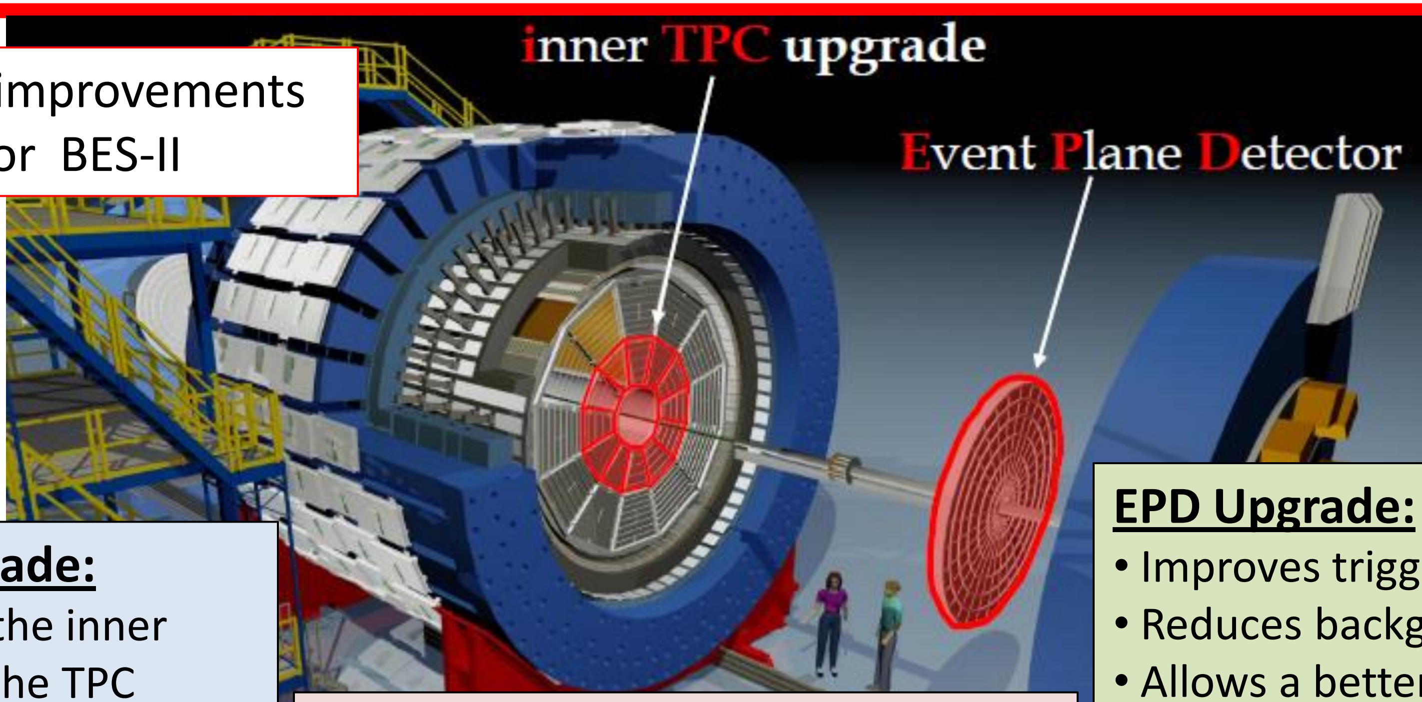


We are able to select events originating on the gold target.

The TPC has good acceptance for these lower energy events.

The STAR Upgrades and BES Phase II

Major improvements for BES-II

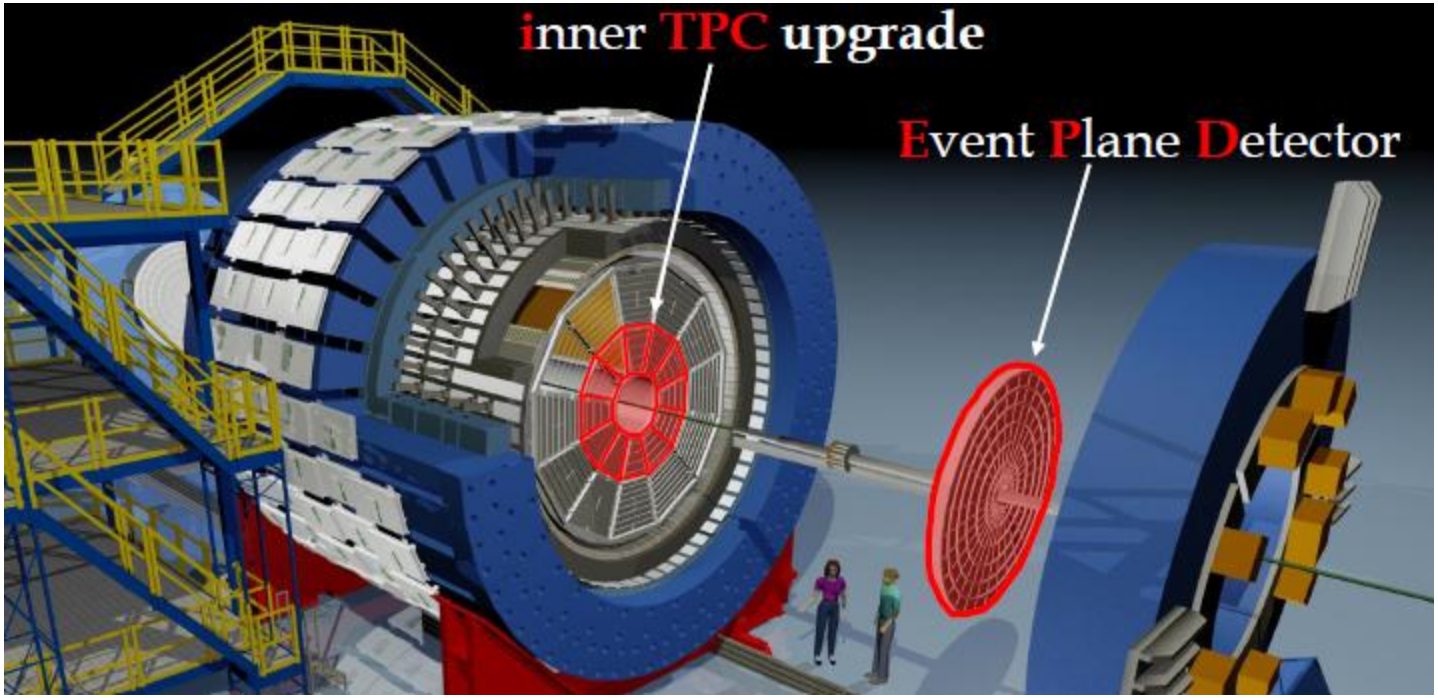


iTPC Upgrade:
- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.7
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

EndCap TOF Upgrade:
- Rapidity coverage is critical for several proposed BES Phase II measurements
- Particle Identification at forward rapidity is only possible with an end-cap TOF
- Prototype modules will be available

EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

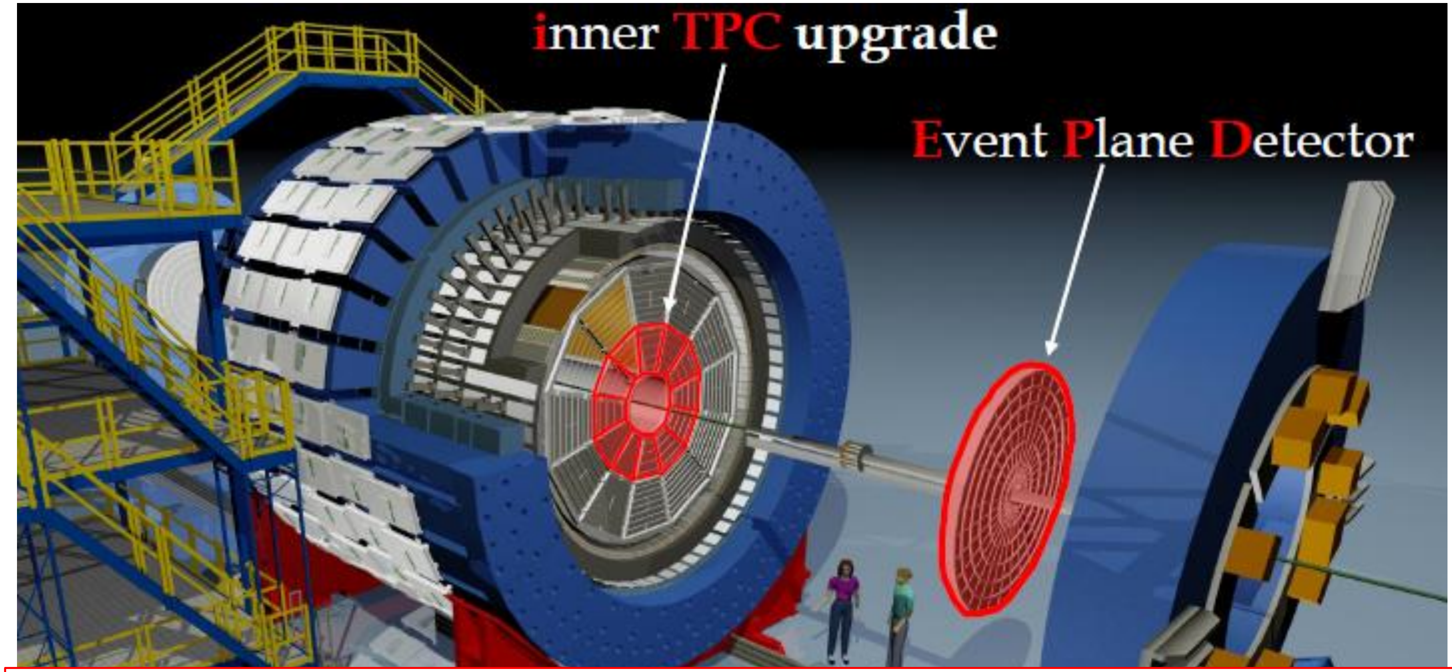
The STAR Upgrades -- iTPC



Several key physics analyses are improved by the additional capabilities of the iTPC:

- The directed flow measurements greatly improved with the extended η coverage
- The kurtosis studies are strongly dependent of acceptance and improved by more η coverage, the lower p_T cut, and the improved dE/dx
- The R_{CP} and ϕ meson studies benefit from the improved dE/dx
- Additional η dependent analysis (longitudinal studies are made possible)

The STAR Upgrades – Event Plane Detector



Several key physics analyses are improved by the additional capabilities of the EPD:

- The directed and elliptic flow studies are improved using a quality reaction definition using detectors well separated in η from the region of interest (analysis)
- For all studies, triggering on good events is essential
- Background was a significant issue for STAR in BES-I. For example, 95% of all triggers were background for the 7.7 GeV system. STAR can only fully utilize the improved luminosity of BES Phase-II with this improvement to the trigger

BES phase II - Outlook

- BES Phase I told us where to search – Lattice QCD suggests this is the region in which there are interesting features

- Machine improvements allow for a precision search

- Detector upgrades allow for more refined searches

The focused, precise, and refined studies of BES phase II will help to answer several key questions which will allow us to better understand the phases and transitions of QCD matter.

EXTRA SLIDES

7.7 GeV Au+ Au (2010)

Goals: 5 M mb (no need for central trigger – trigger peaks at a few hundred Hz

Final Estimate 4.3 M StRefMultCorr Events/19 days

Rate Estimate: 0.25 MEvts/day

Typical trigger rate at start of fill: 80 Hz

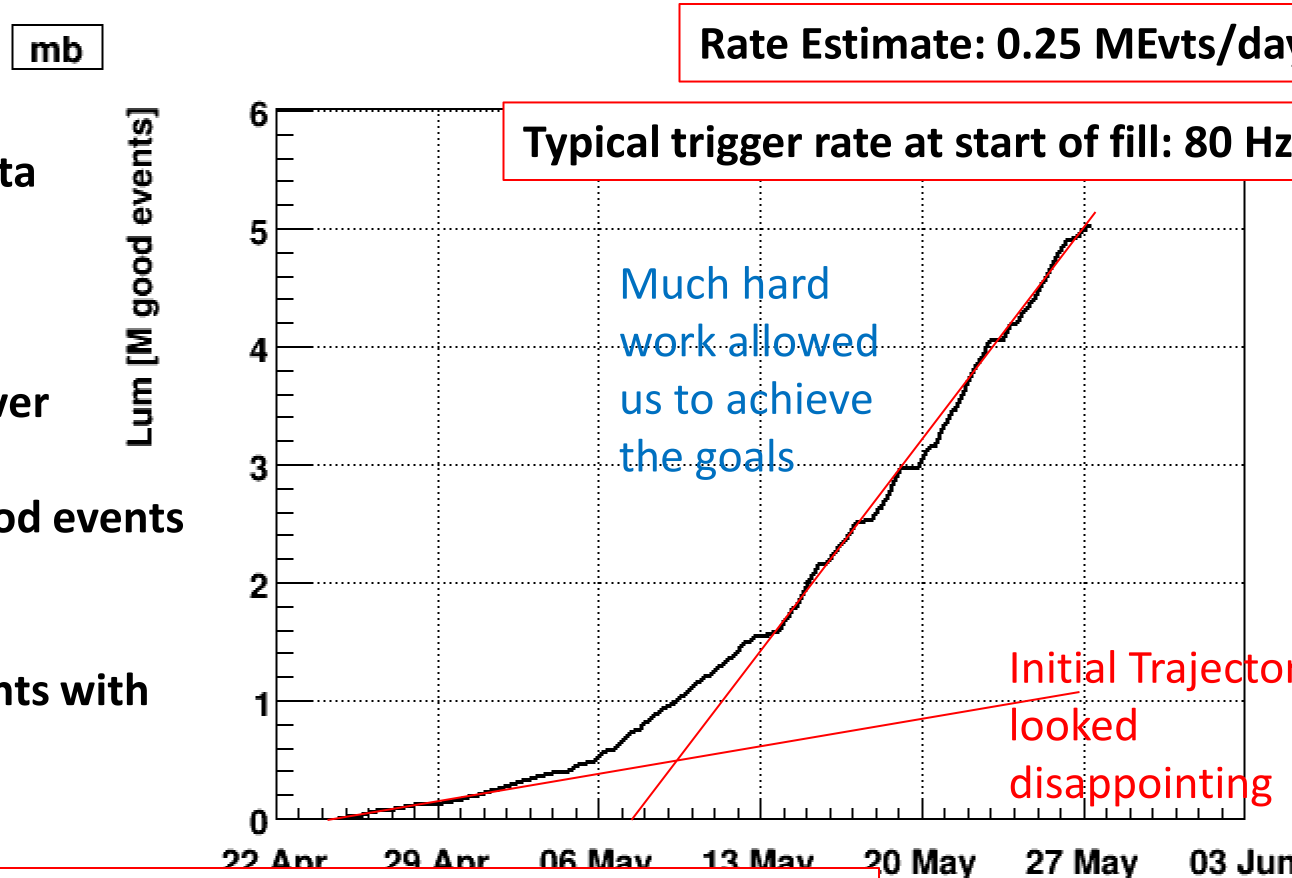
Apr 23rd: First Collisions
Apr 24th: Start Taking Data

May 27th: met mb Goals

May 27th: 7.7 GeV run over

Acquired: 5.01 M mb good events with $|V_z| < 75$ cm

Acquired: 4.3 M mb events with $|V_z| < 70$ cm (StRefMultCorr)



No Scale Up the Rate Estimate: 0.25 MEvts/day
No change in |Vz|

11.5 GeV Au+ Au (2010)

Goals: 5 M mb (no need for central trigger – trigger peaks at a few hundred Hz

mb

May 27th: First Collisions
May 28th: Start Taking Data

Jun 04th: met mb Goals

Jun 07th: 11.5 GeV run over

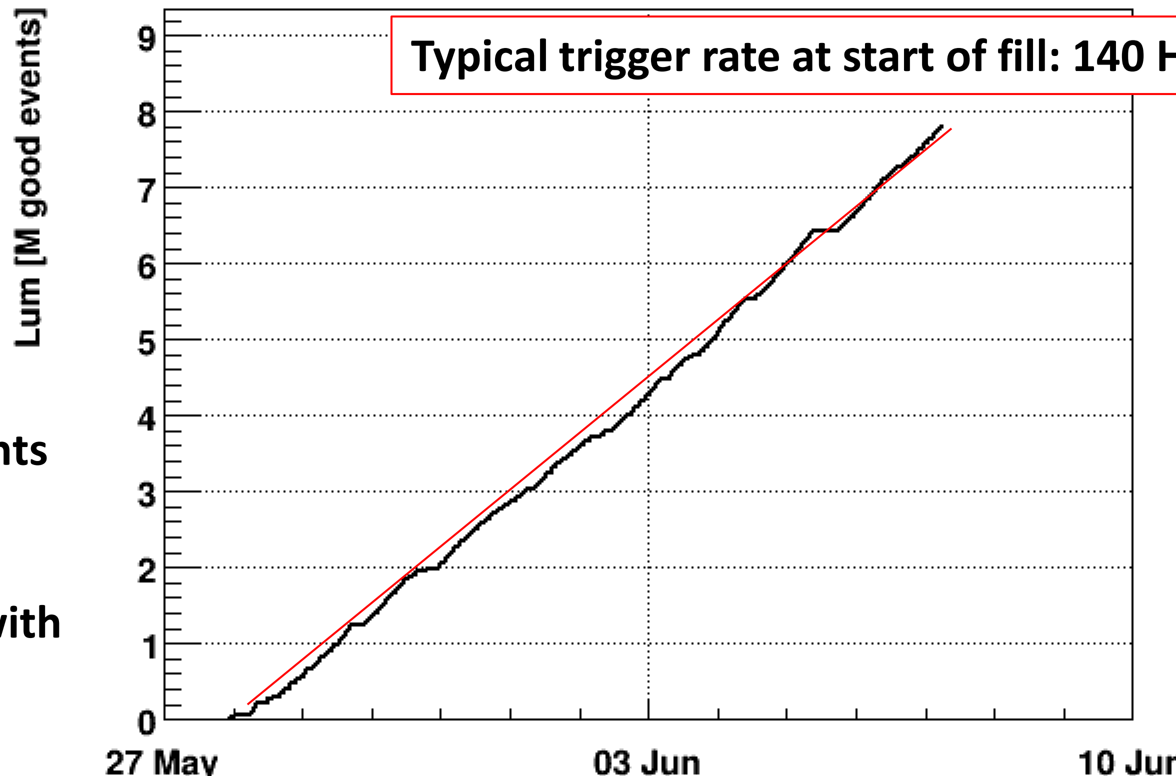
Acquired: 7.2 M mb good events with $|V_z| < 30$ cm

Acquired: 11.7 M mb events with $|Vz| < 50$ cm (StRefMultCorr

Final Estimate 11.7 M StRefMultCorr Events/10 days

Rate Estimate: 1.2 MEvts/day

Typical trigger rate at start of fill: 140 Hz



Wed Jun 9 10:00:12 2010

Scale Up the Rate Estimate: 1.7 MEvts/day
To account for the change in |Vz|

14.5 GeV Au+ Au (2014)

Goals: 150 M triggers (BUR14-15)

Final Estimate 12.6 M Q/A good evts Events/21days

Rate Estimate: 0.6 MEvts/day

Typical trigger rate at start of fill: 300 Hz

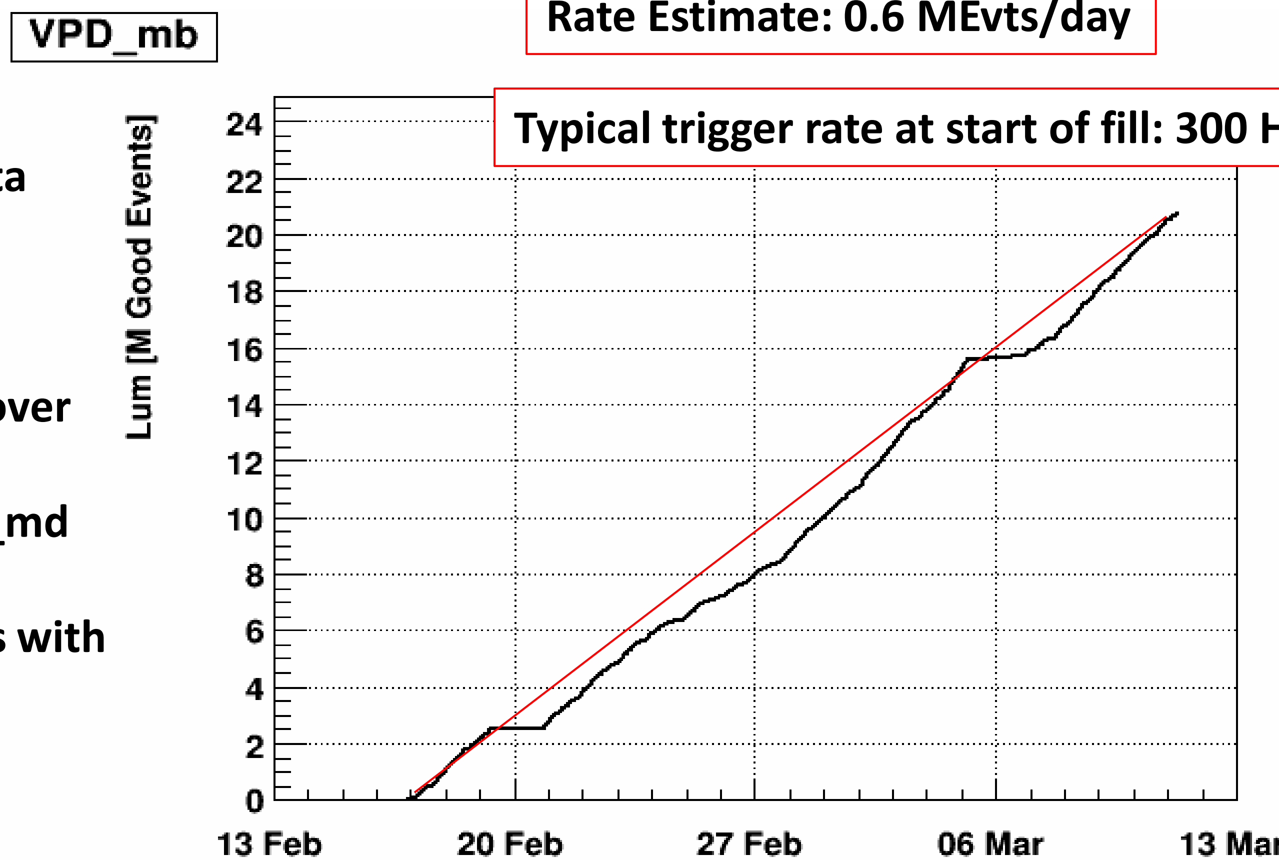
Feb 13th: First Collisions
Feb 17th: Start Taking Data

Mar 11th: met mb Goals

Mar 11th: 14.5 GeV run over

Acquired: 21 M mb VPD_md

After Q/A: 12.6 M events with |Vz| < 30 cm



Scale Up the Rate Estimate: 1.4 MEvts/day
To account for the change in |Vz|

19.6 GeV Au+ Au (2011)

2011

Final Estimate 36 M StRefMultCorr Events/9days

Goals: 5 M mb

Rate Estimate: 4.0 MEvts/day

Typical trigger rate at start of fill: 500 Hz

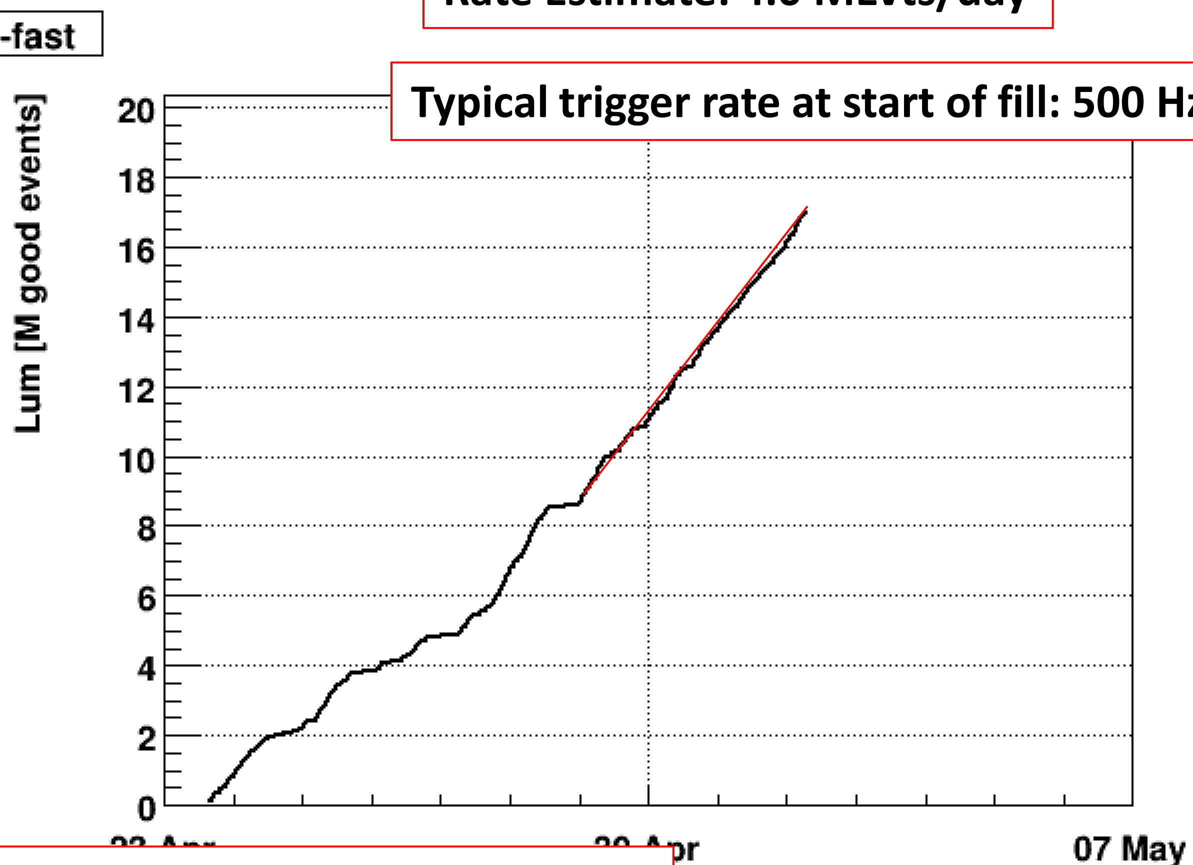
Apr 21st : First Collisions
Apr 24th: Start Taking Data

Apr 28th met mb Goals

May 02nd: 19.6 GeV run over

Acquired: 17M good events defined with $|V_z| < 30$ cm

Acquired: 36 M mb events with $|V_z| < 70$ cm (StRefMultCorr)



Scale Up the Rate Estimate: 4.0 MEvts/day
To account for the change in |Vz|

27.0 GeV Au+ Au (2011)

2011

Final Estimate 70 M StRefMultCorr Events/7 days

Goals: 5 M mb

mb1-fast

Rate Estimate: 10 MEvts/day

Typical trigger rate at start of fill: 1200 Hz

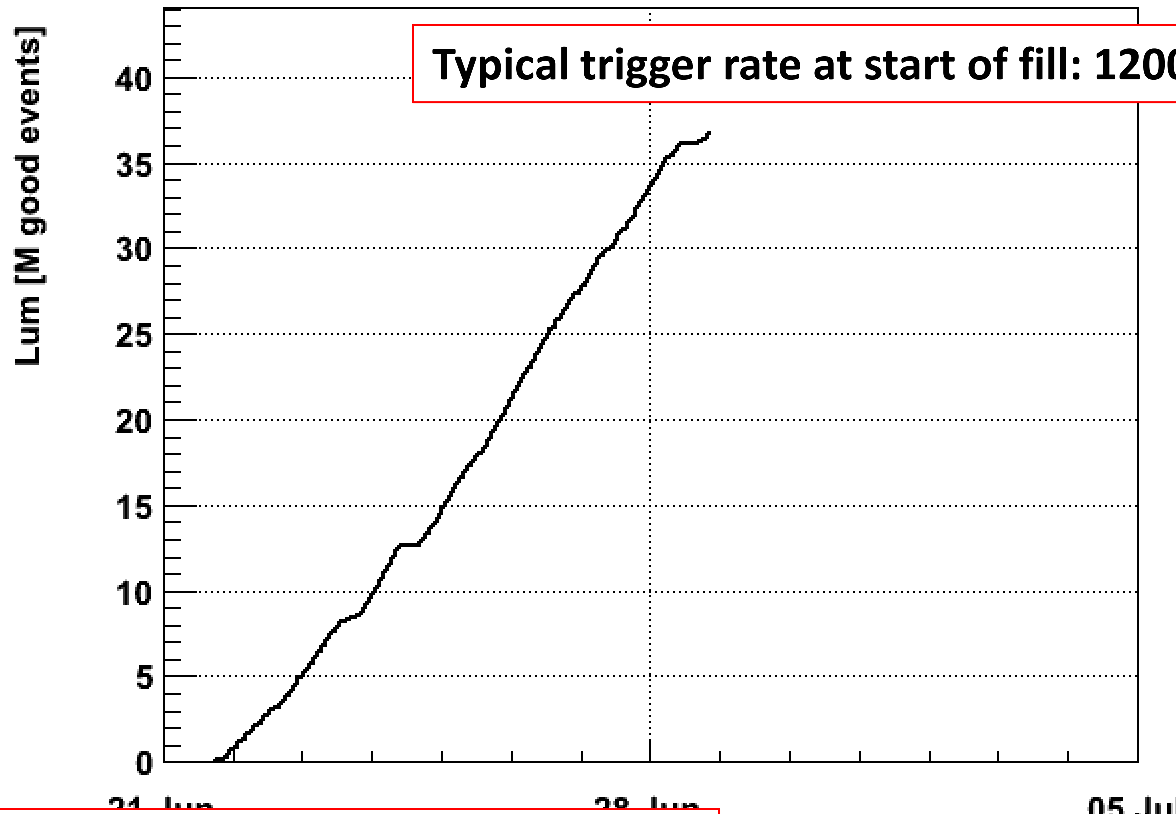
Jun 21st : First Collisions
Jun 21st: Start Taking Data

Jun 23st met mb Goals

Jun 27th: 27.0 GeV run over

Acquired: 37M good events defined with $|V_z| < 30$ cm

Acquired: 70 M mb analysis events with $|V_z| < 70$ cm (StRefMultCorr)



Scale Up the Rate Estimate: 10.0 MEvts/day
To account for the change in |Vz|

39 GeV Au+ Au (2010)

Goals: 24 M mb

Apr 8th: First Collisions
Apr 10th: Start Taking Data

Apr 11th: met mb Goals

Apr 22nd: 39 GeV run over

Acquired: 250 M triggers → 169 M good mb events (13.5 M with mb-slow)

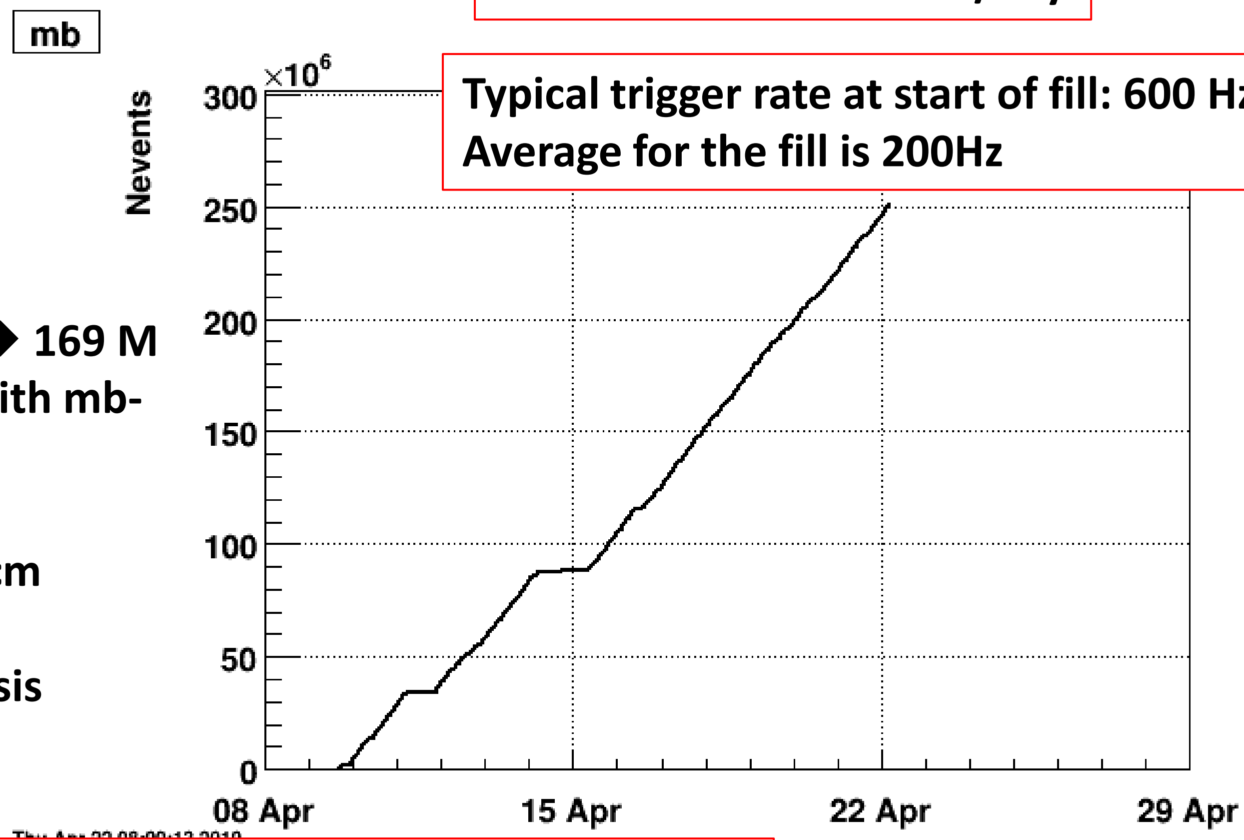
Trigger selected $|V_z| < 50$ cm

Acquired: 130 M mb analysis events with $|V_z| < 40$ cm (StRefMultCorr)

Final Estimate 130 M StRefMultCorr Events/12 days

Rate Estimate: 11 MEvts/day

Typical trigger rate at start of fill: 600 Hz
Average for the fill is 200Hz



Scale Up the Rate Estimate: 19.25 MEvts/day
To account for the change in |Vz|

62.3 GeV Au+ Au (2010)

Goals: 100 M mb, 20 M central

Final Estimate 67 M StRefMultCorr Events/12 days

Mar 18th: First Collisions
Mar 23rd: Start Taking Data

Rate Estimate: 5.6 MEvts/day

Mar 29th: met mb Goals
Apr 03rd: met central Goals

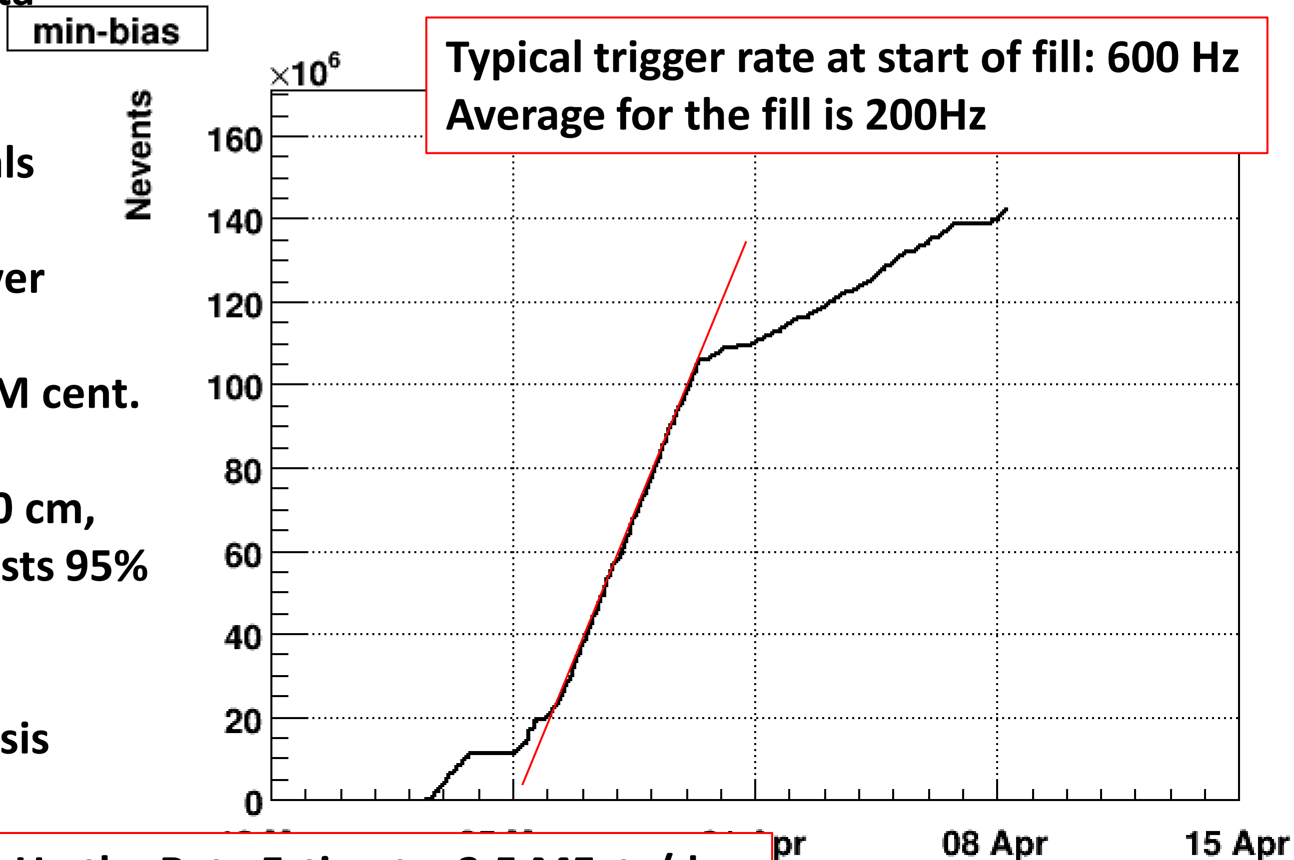
Typical trigger rate at start of fill: 600 Hz
Average for the fill is 200Hz

Apr 08th: 62.3 GeV run over

Acquired: 140 M mb, 33 M cent.

(trigger selected $|V_z| < 50$ cm, online HLT analysis suggests 95% are good events)

Acquired: 67 M mb analysis events with $|V_z| < 40$ cm (StRefMultCorr)

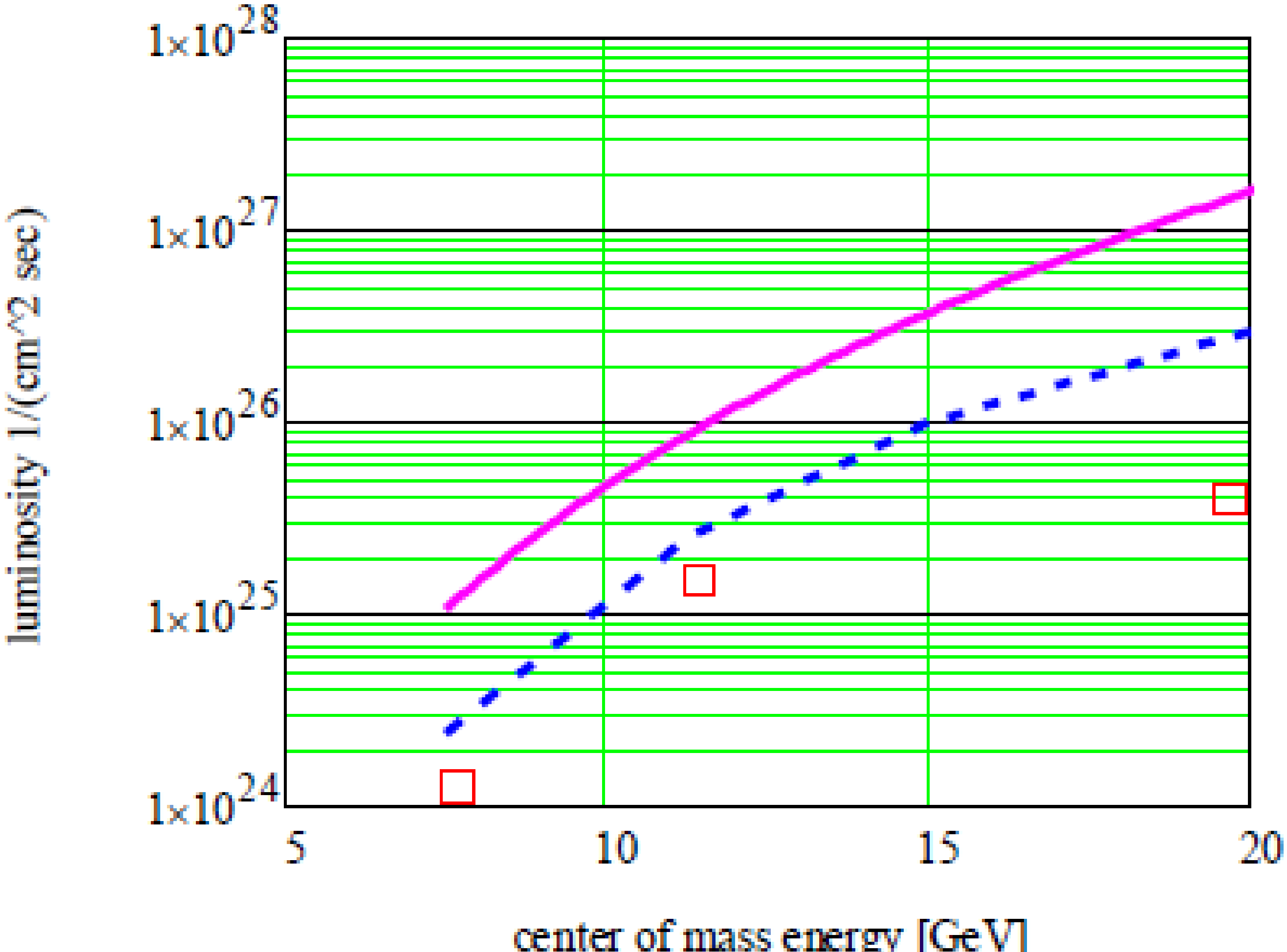


Scale Up the Rate Estimate: 3.5 MEvts/day
To account for the change in |Vz|

Analysis |Vz| cuts Energy by Energy

GeV	|Vz| (cm)
7.7	70
11.5	50
19.6	70
27	70
39	40
62.4	40

Larger View of RHIC Projections



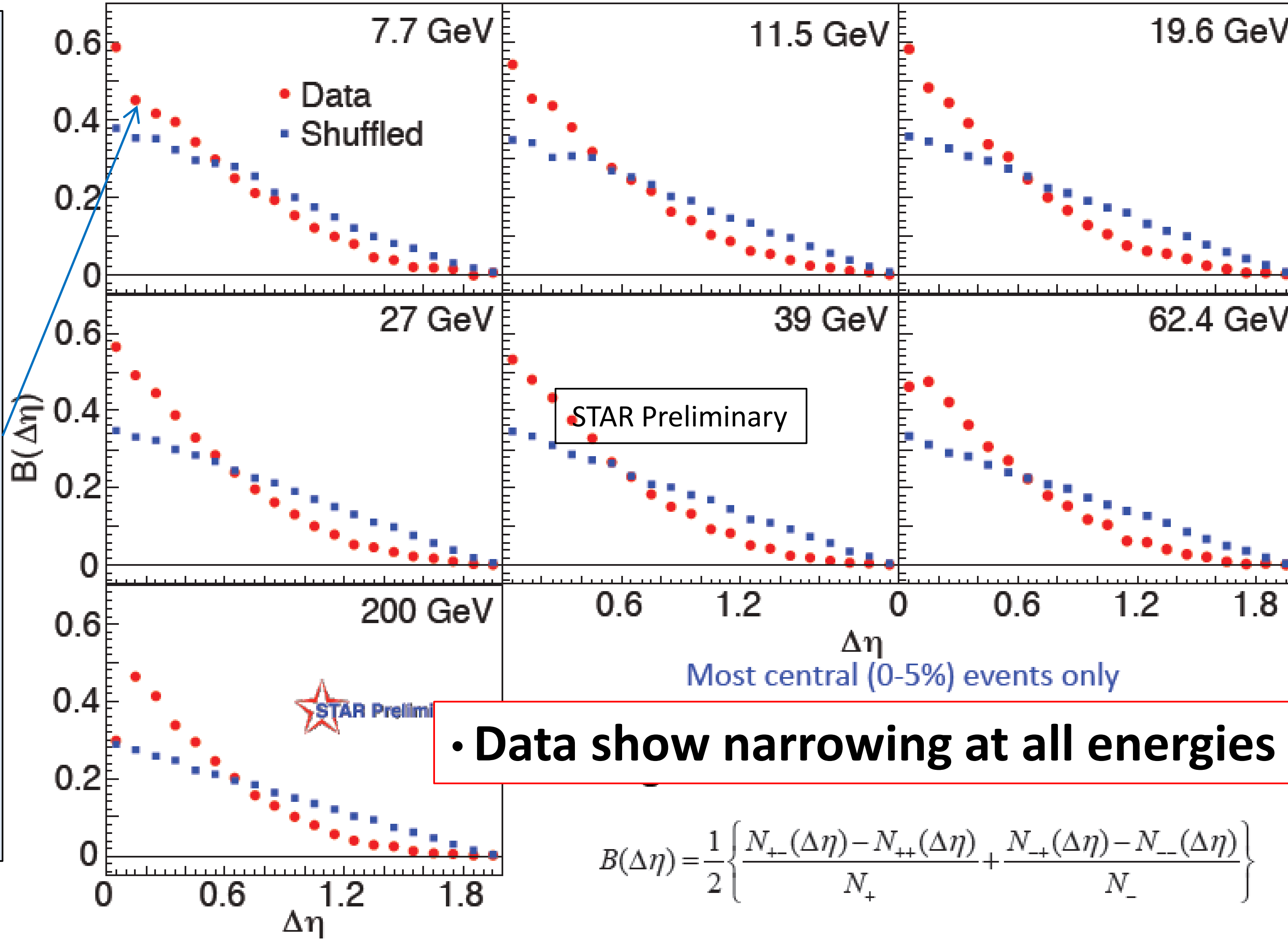
Projections for a finer step size in μ_B

Collision Energy (GeV)	Chemical Potential μ_B (GeV)	$\Delta\mu_B$ (GeV)	BES I Luminosity (10^{25}/cm^{2}sec)	BESI Rate Million evts/day	BESI Rate Projected (Mevt/day)	BES II Luminosity	BES II Projected (Mevt/day)	Days for BESI Survey	BES II Request (Mevts)	Days for BESII Data Set	Weeks for BESII Data Set
19.6	0.206		4.00	**1.89**	1.90	70.0	33.3	0.8	**400**	5	1*
16.8	0.234	0.028	2.52		1.20	32.4	15.4	1.1	322	9	
14.5	0.264	0.030	1.62	**0.60**	0.77	15.5	7.37	1.5	**262**	15	2
13.0	0.288	0.024	1.17		0.55	9.0	4.27	1.8	225	23	
11.5	0.316	0.028	0.81	**0.72**	0.38	4.9	2.31	2.3	**190**	35	5
10.3	0.343	0.027	0.58		0.28	2.8	1.33	2.9	163	52	
9.3	0.370	0.026	0.43		0.20	1.7	0.80	3.6	**141**	76	10
8.4	0.397	0.028	0.31		0.15	1.0	0.48	4.4	122	109	
7.7	0.422	0.024	0.24	**0.095**	0.12	0.7	0.31	5.2	**108**	149	20
7.0	0.449	0.028	0.18		0.09	0.4	0.19	6.3	95	210	
6.4	0.476	0.027	0.14		0.07	0.3	0.12	7.5	83	290	
5.8	0.506	0.030	0.10		0.05	0.2	0.08	9.1	73	414	

|Vz|< 30 cm |Vz|< 30 cm |Vz|< 70 cm

Disappearance of QGP Signatures -- BF

- Narrowing of the balance functions is seen as a signature of partonic behavior.
- This signature is still present at 7.7 GeV, which could be a sign of the onset of deconfinement.
- **Points to the need to explore lower energies.**

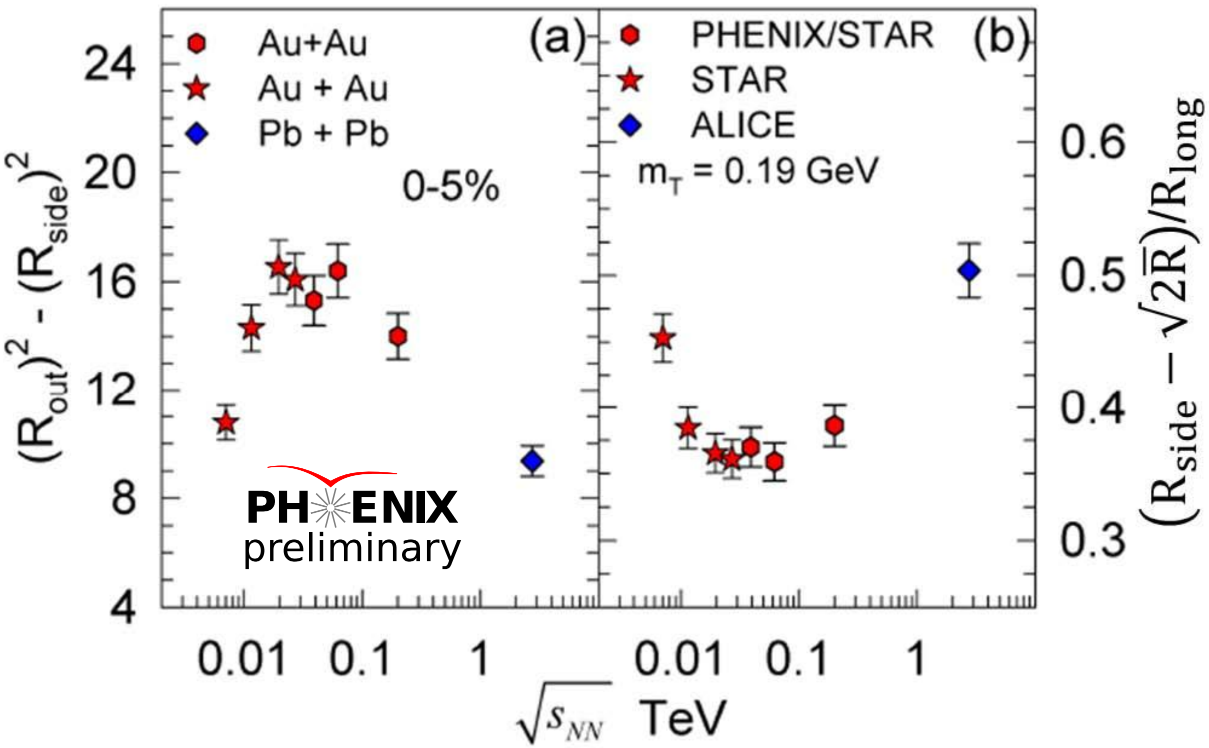


- **Data show narrowing at all energies**

$$B(\Delta\eta) = \frac{1}{2}\left\{\frac{N_{+-}(\Delta\eta) - N_{++}(\Delta\eta)}{N_+} + \frac{N_{-+}(\Delta\eta) - N_{--}(\Delta\eta)}{N_-}\right\}$$

BF = Balance Functions

Search for 1st Order Phase Transition



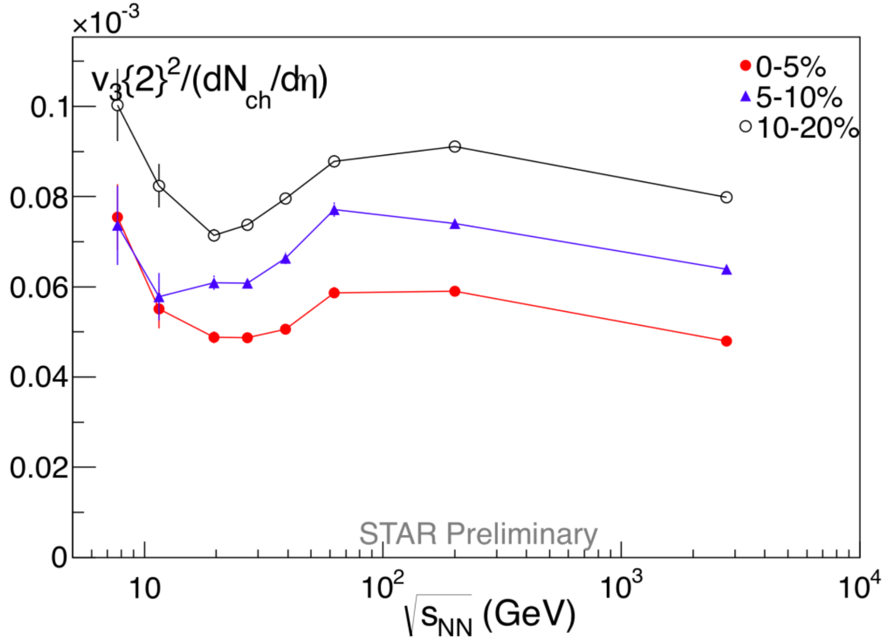
$R_{long} \propto \tau$

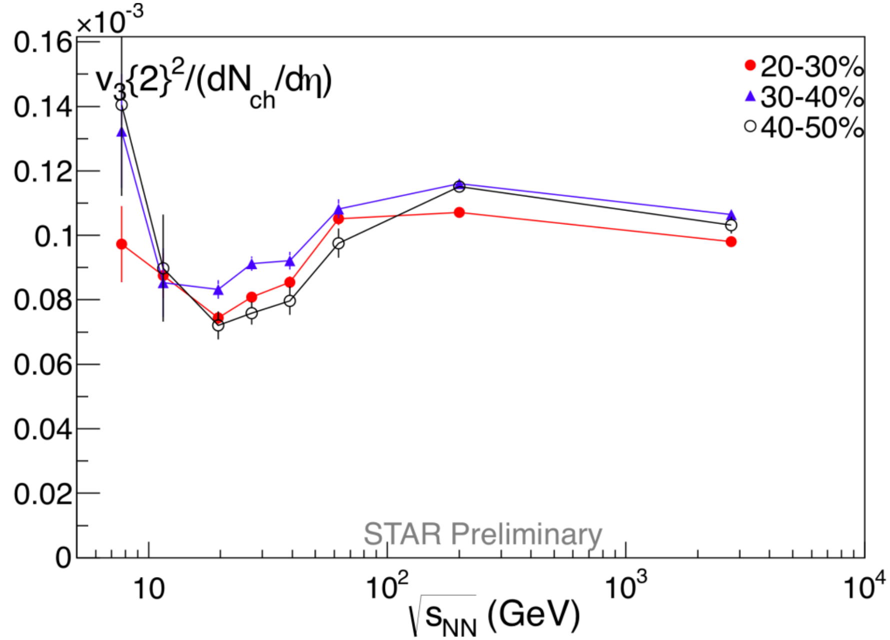
$R_{out}^2 - R_{side}^2 \propto \Delta\tau$

$R - R_i \;/\; R_{long} \propto u$

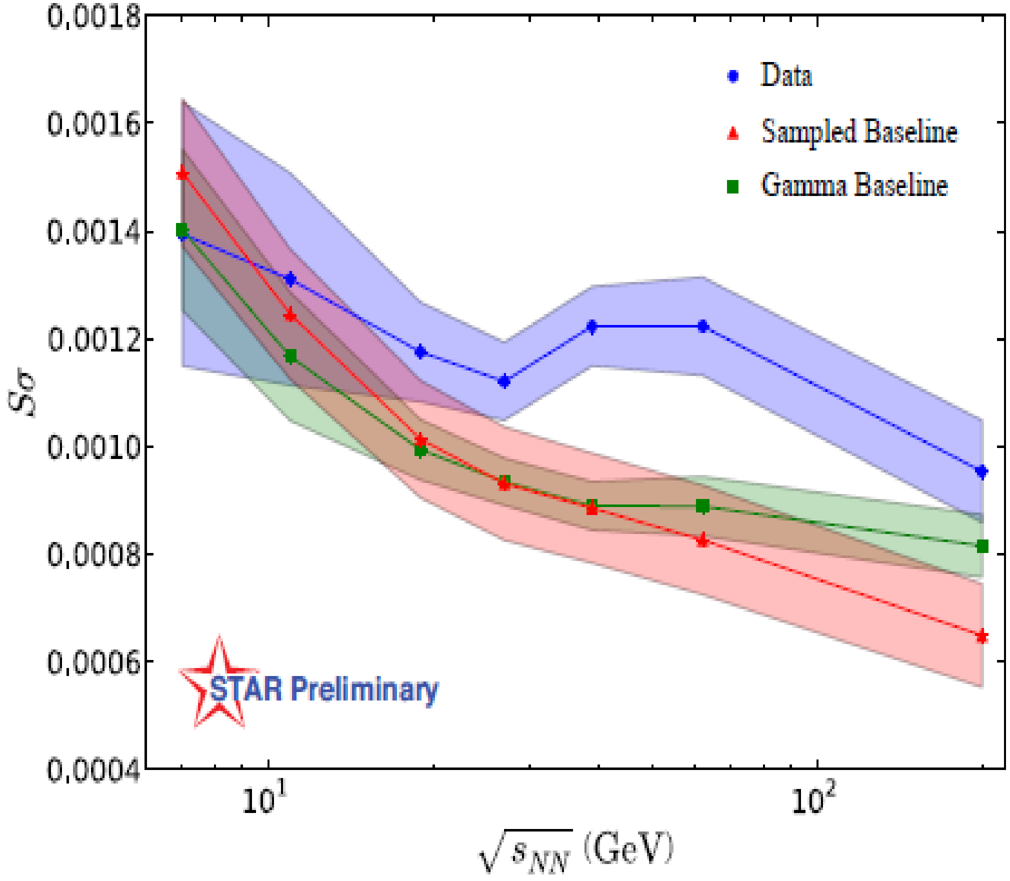
$R_i = \sqrt{2}\bar{R}$

Search for 1st Order Phase Transition

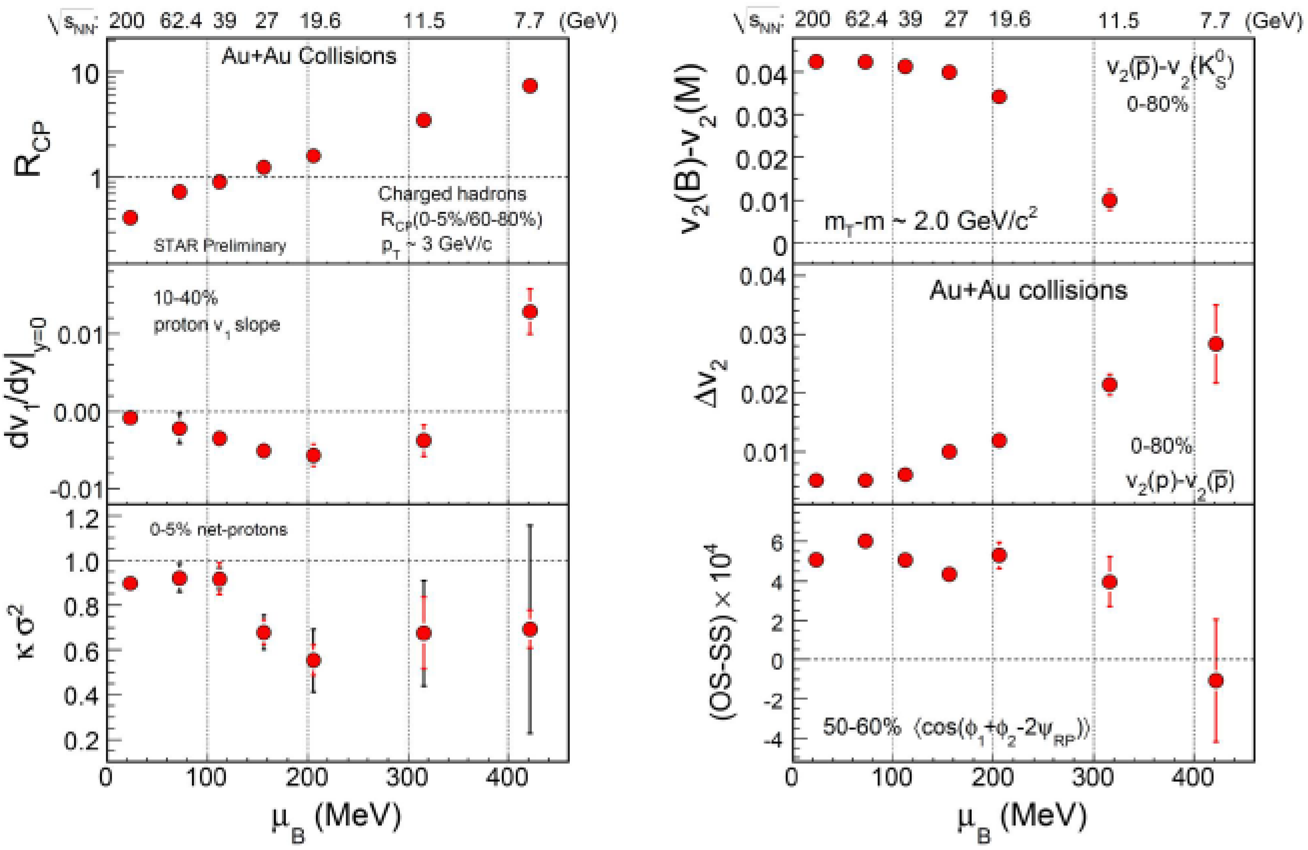




Search for the Critical Point – p_T $S\sigma$



A Summary of BES-I Results



Directed Flow Predictions and Published Data