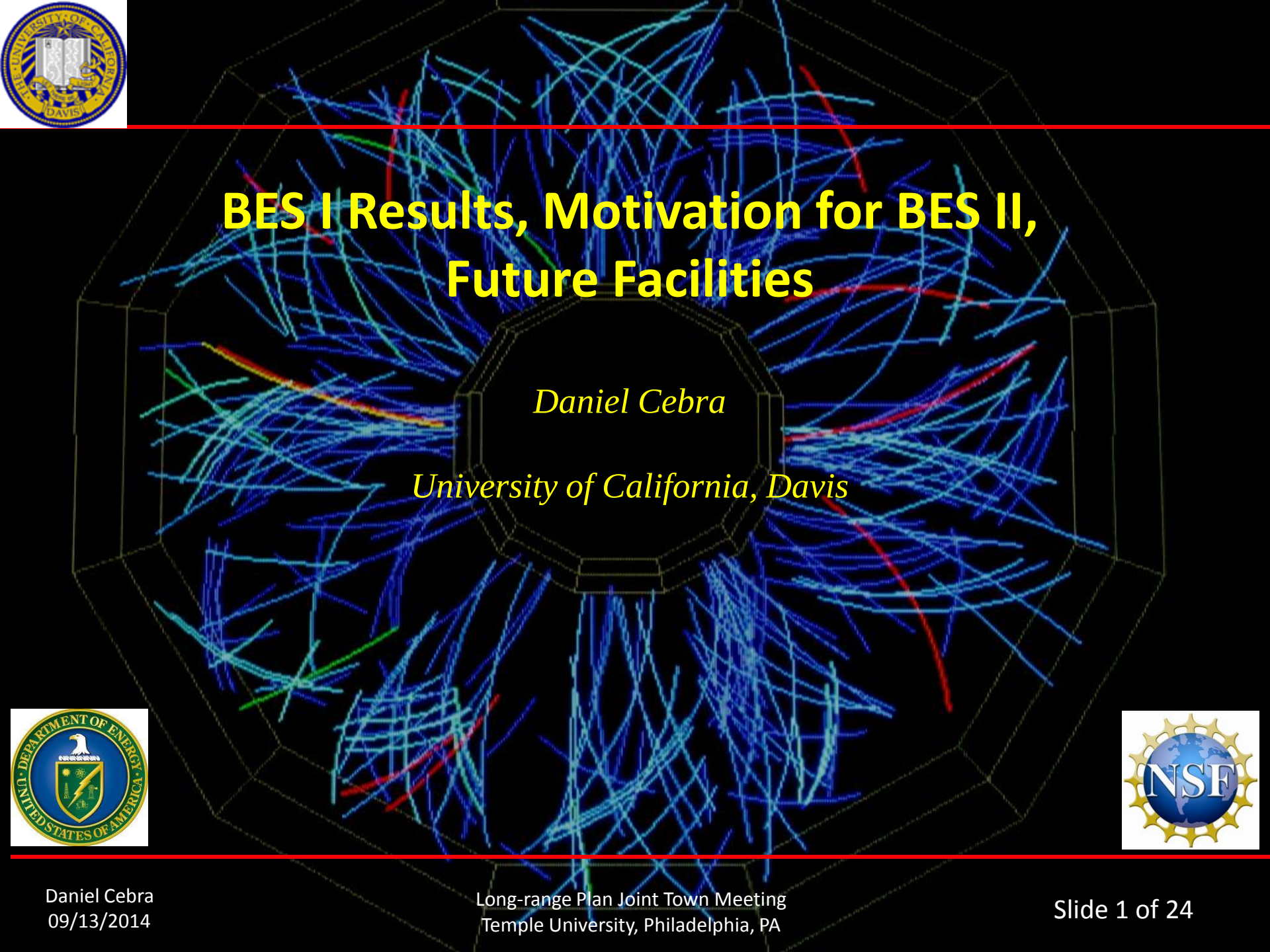


BES I Results, Motivation for BES II, Future Facilities

Daniel Cebra

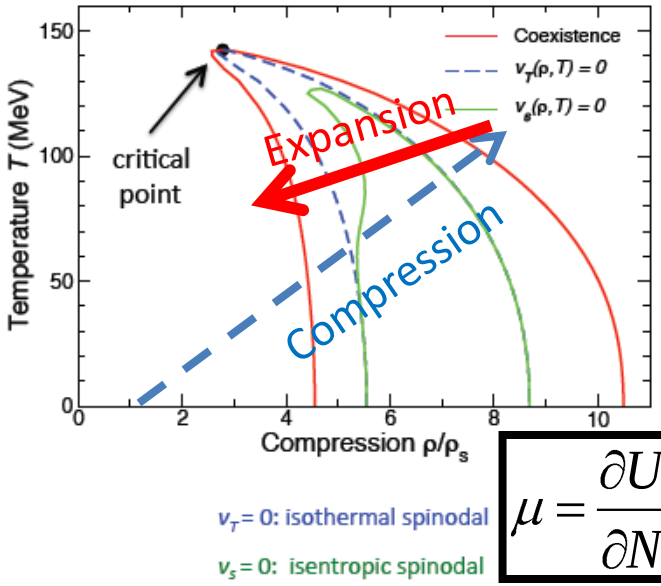
University of California, Davis

Exploring the Phase Diagram

What was known?

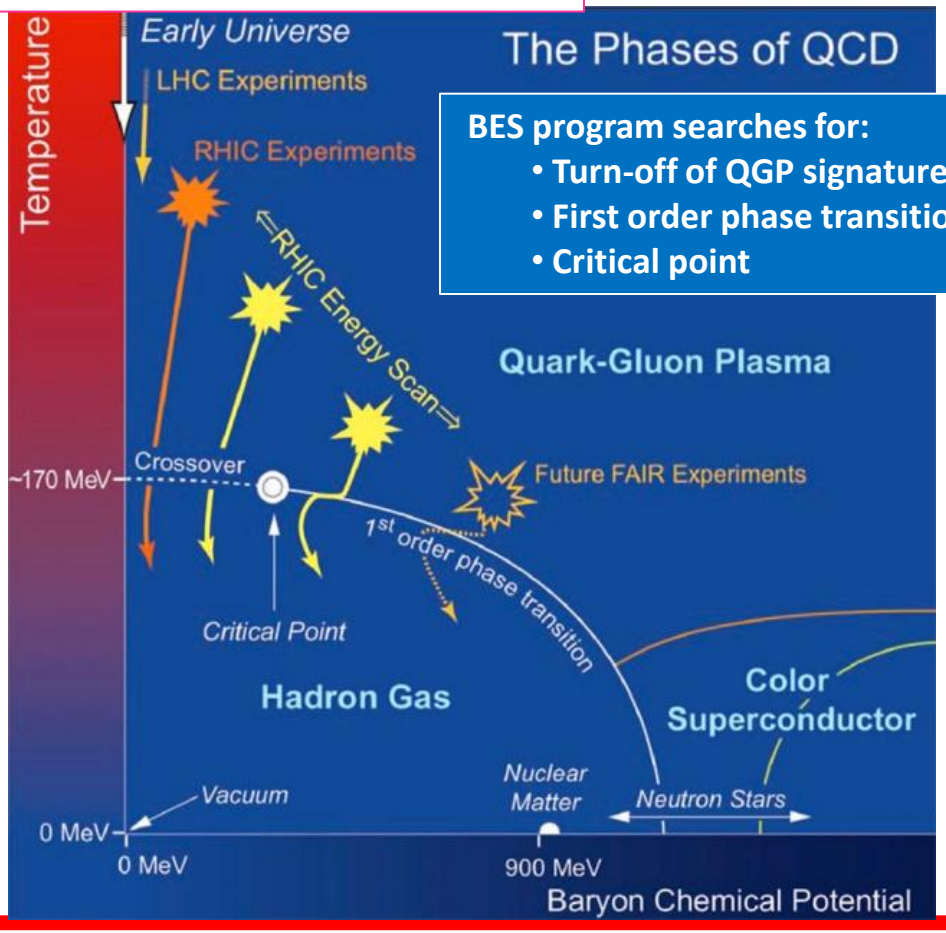
1) High Energy Heavy-ion Collisions ➔ partonic matter
2) Highest energies ➔ transition is a cross over
3) At increased μ_B, there might be a first-order phase transition
4) And if so, there should be a critical point

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

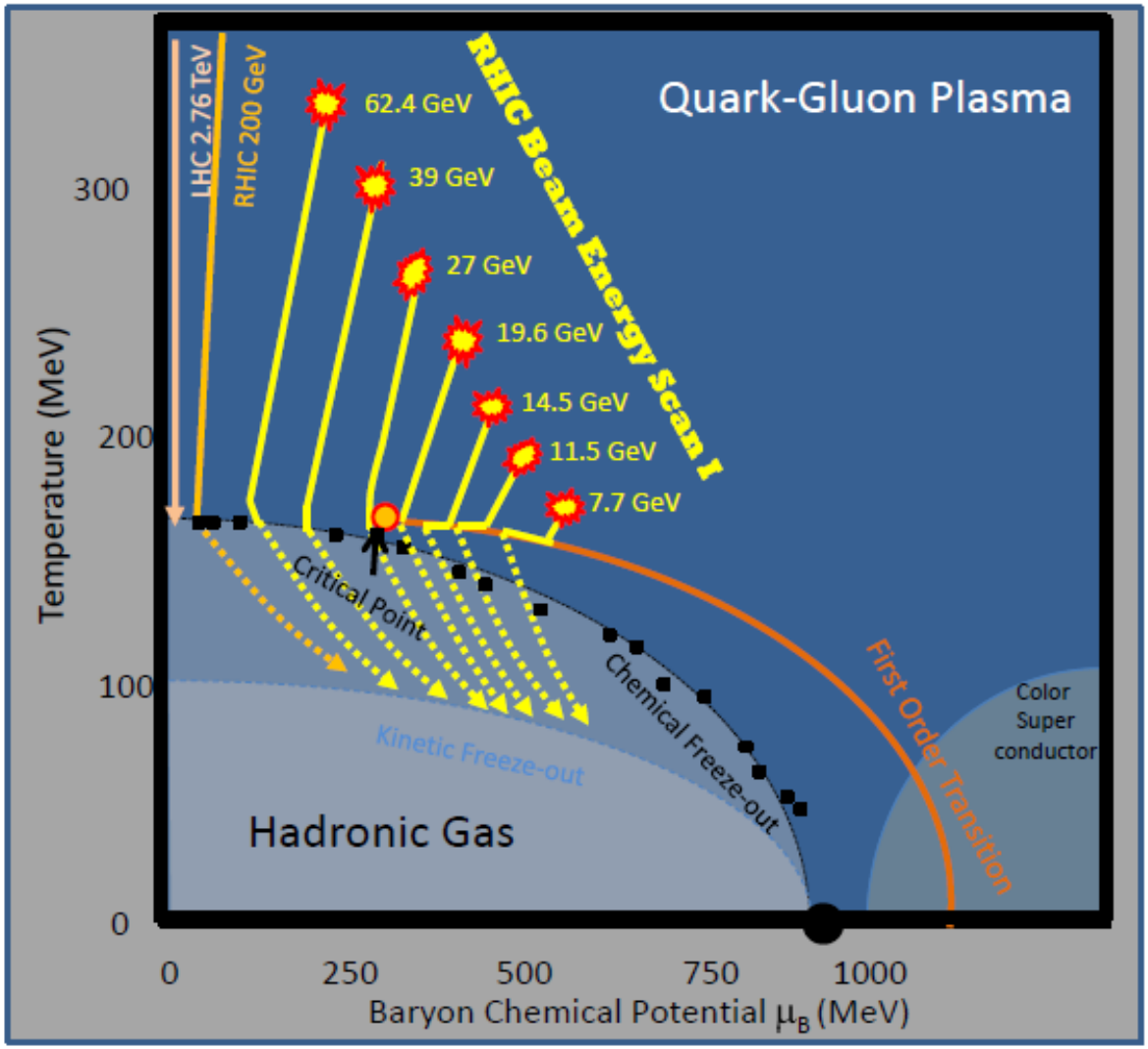


$$\mu = \frac{\partial U}{\partial N}$$

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



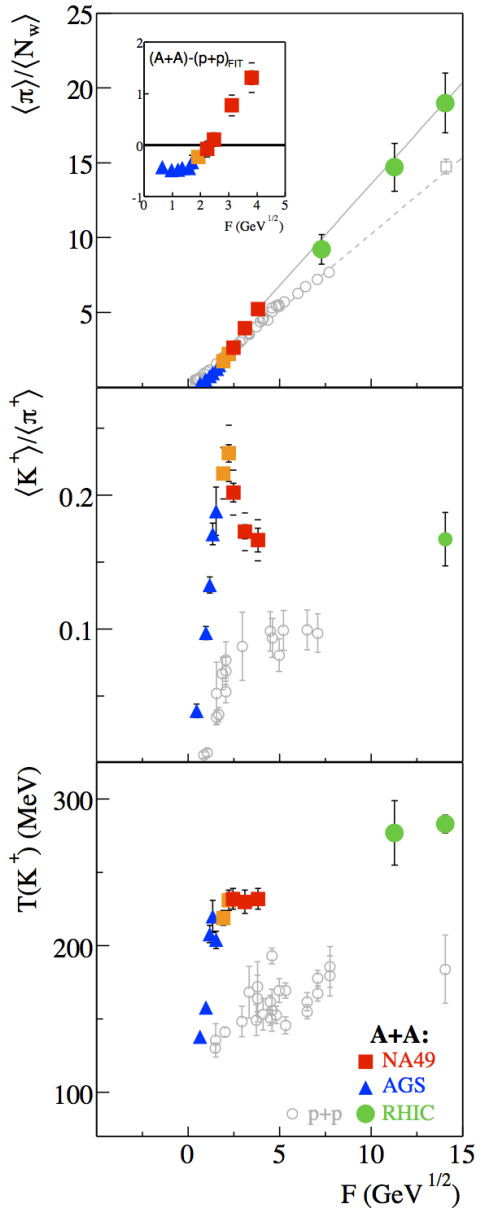
Phase Diagram of QCD Matter



	Energy (GeV)	Chemical Potential μ_B	Pred. Temp. (MeV)
LHC	2760.0	2	166.0
RHIC	200.0	24	165.9
RHIC	130.0	36	165.8
RHIC	62.4	73	165.3
RHIC	39.0	112	164.2
RHIC	27.0	156	162.6
RHIC	19.6	206	160.0
SPS	17.3	229	158.6
RHIC	14.6	262	156.2
SPS	12.4	299	153.1
RHIC	11.5	316	151.6
SPS	8.8	383	144.4
RHIC	7.7	422	139.6
SPS	7.7	422	139.6
SPS	6.4	476	131.7
AGS	4.7	573	114.6
AGS	4.3	602	108.8
AGS	3.8	638	100.6
AGS	3.3	686	88.9
AGS	2.7	752	70.4
SIS	2.3	799	55.8

What Was Learned in the Earlier Scans?

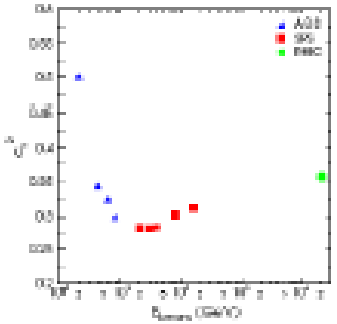
- Summary of AGS, SPS, and early RHIC Results
- Inclusive observables ➔ *onset of deconfinement* at 7-8 GeV.
- The observables suggest a change in the nature of the system.
- More discriminating studies were needed to understand the nature of the phase transition and to search for critical behavior.
- It is best to study regions above and below the possible onset energy.



Onset of Deconfinement:
early stage hits transition line,
observed signals: kink, horn, step
Predictions SMES: APP B30 2705 (99), Results: PR C77 024903 (08)

Kink

the dale
sound velocity from
width of pion rapidity spectra
nucl-th/0611001



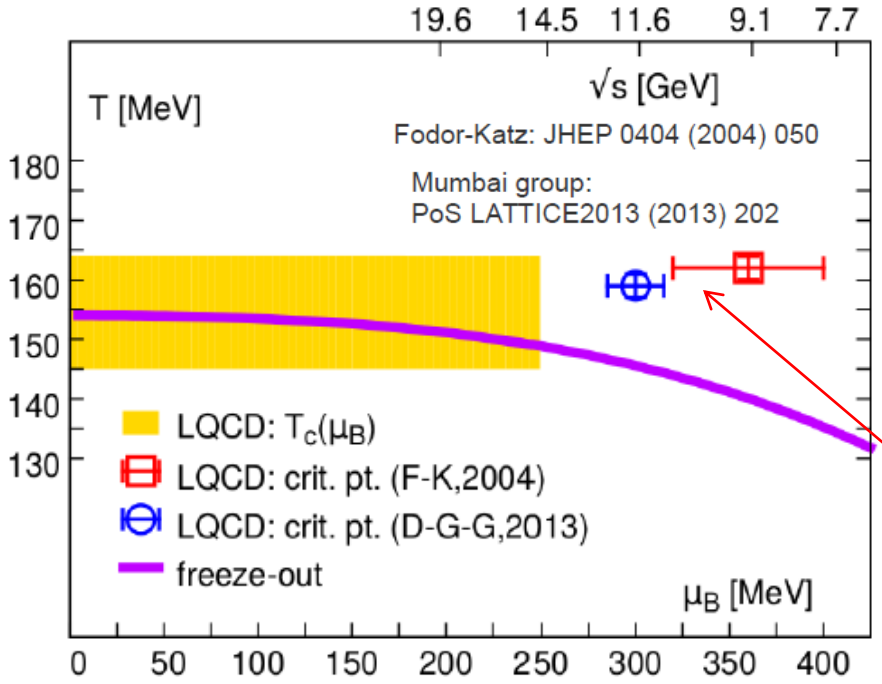
Horn

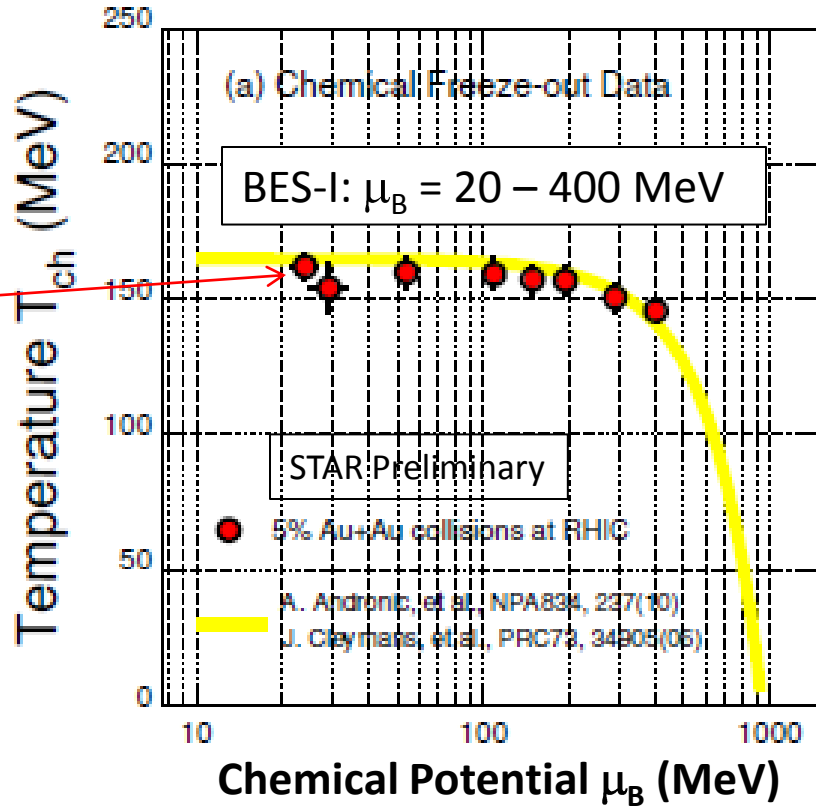
Step

Setting the Scene

Using a statistical equilibrium model and the measured particle yields (π, K, p, Λ, Ξ, ϕ, Ω), one can estimate the location in the phase diagram.

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



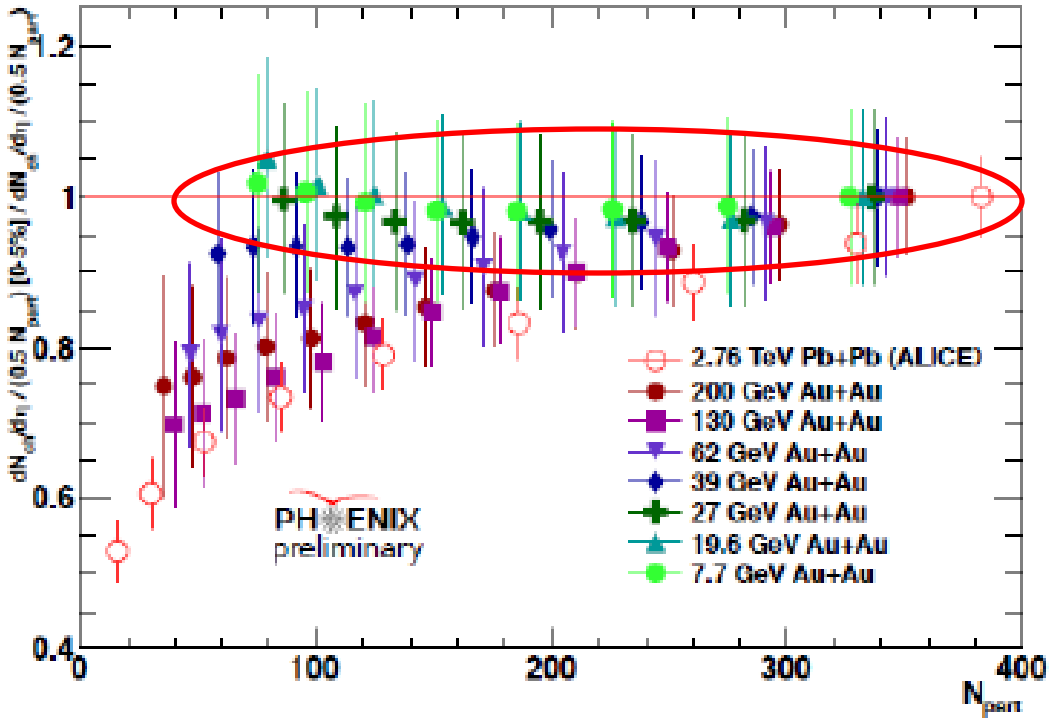


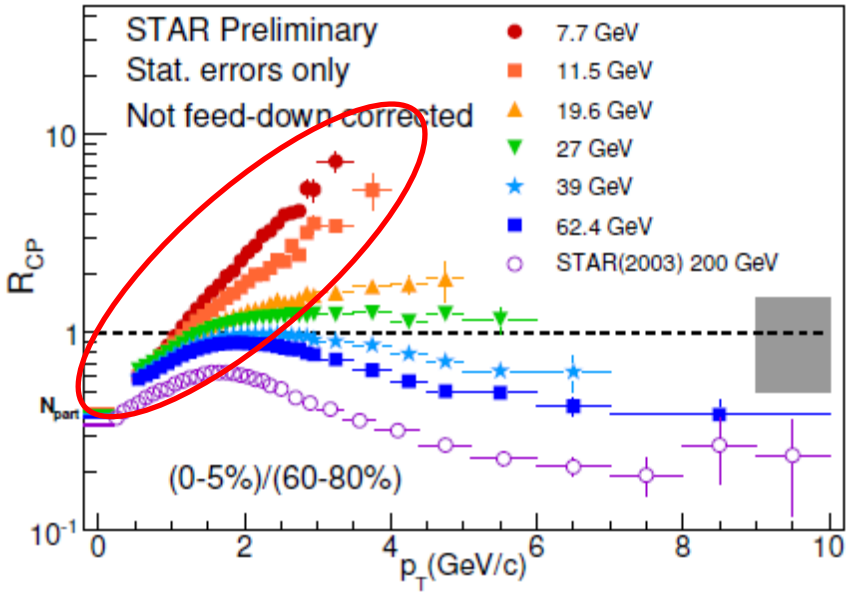
Some Lattice Gauge Theory predictions suggest that the low end of the BES-I may find the critical point

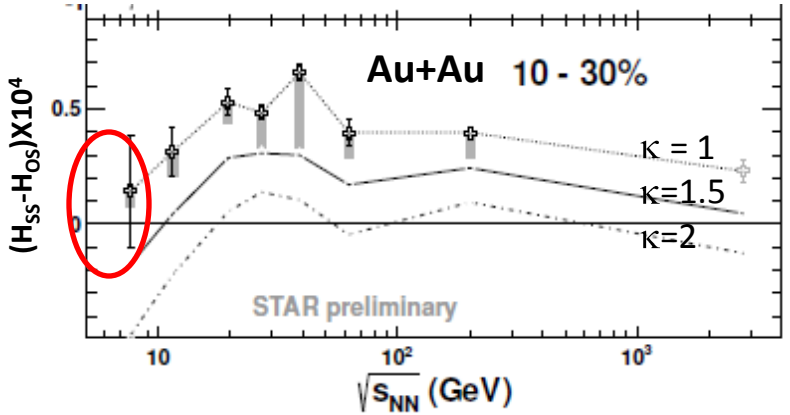
Disappearance of QGP Signatures

Several QGP signatures are seen to evolve across the energy range:

1) Participant nucleon scaling of multiplicity
2) High p_T suppression (R_{CP})
3) Particle Correlations WRT reaction plane (Chiral Magnetic Effect)

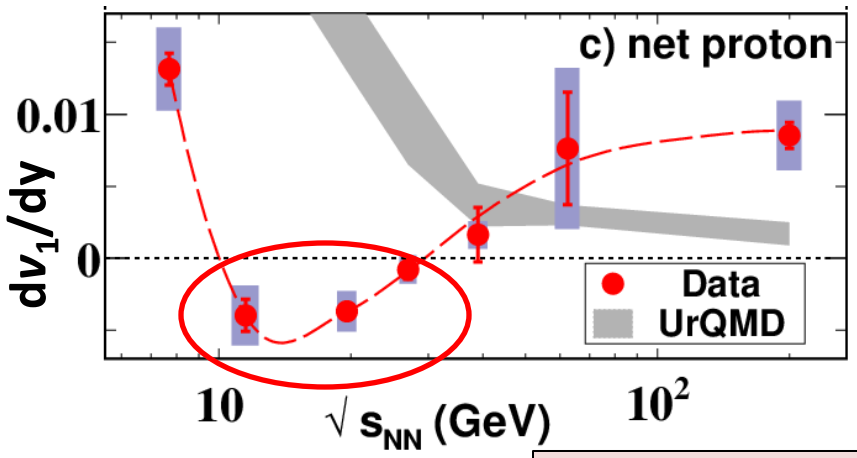


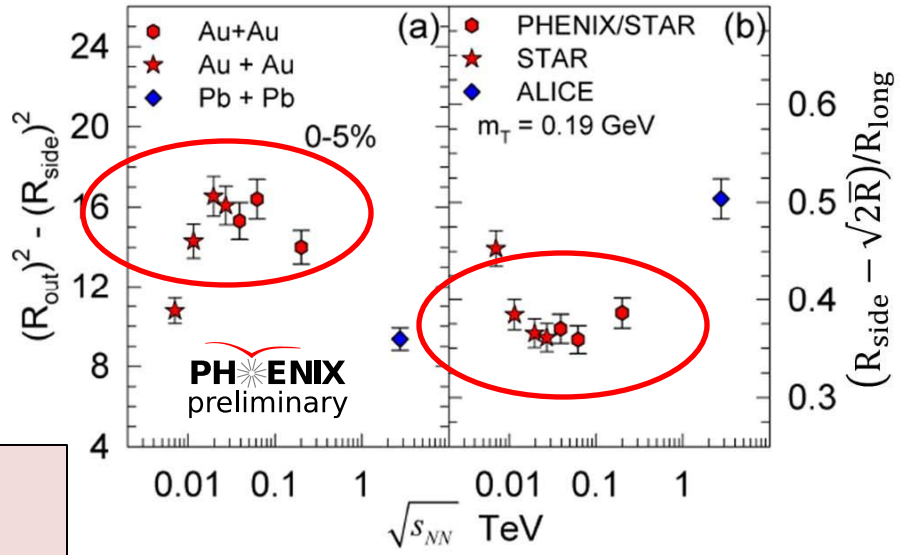




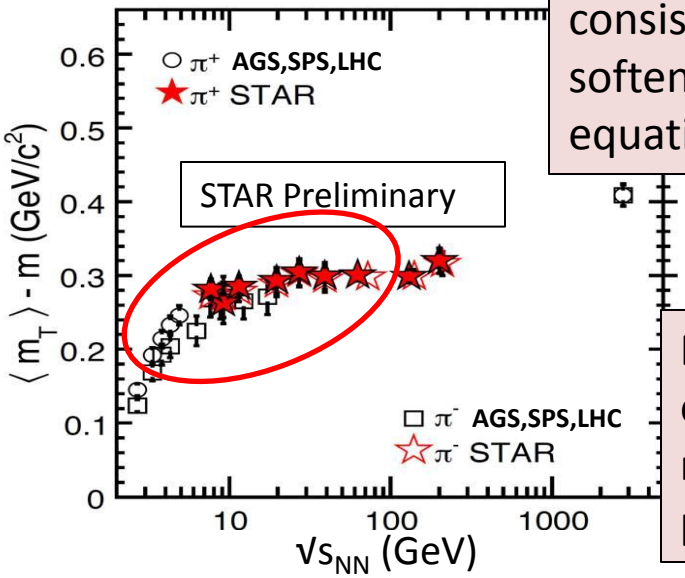
➔ **QGP Signatures disappear**

Search for 1st Order Phase Transition

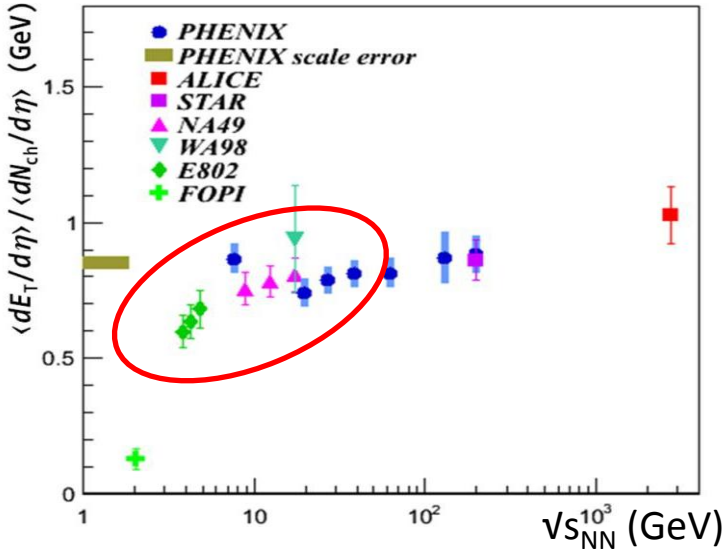




Several features are consistent with a softening of the equation of state



Need model comparisons to relate to first order phase transition



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

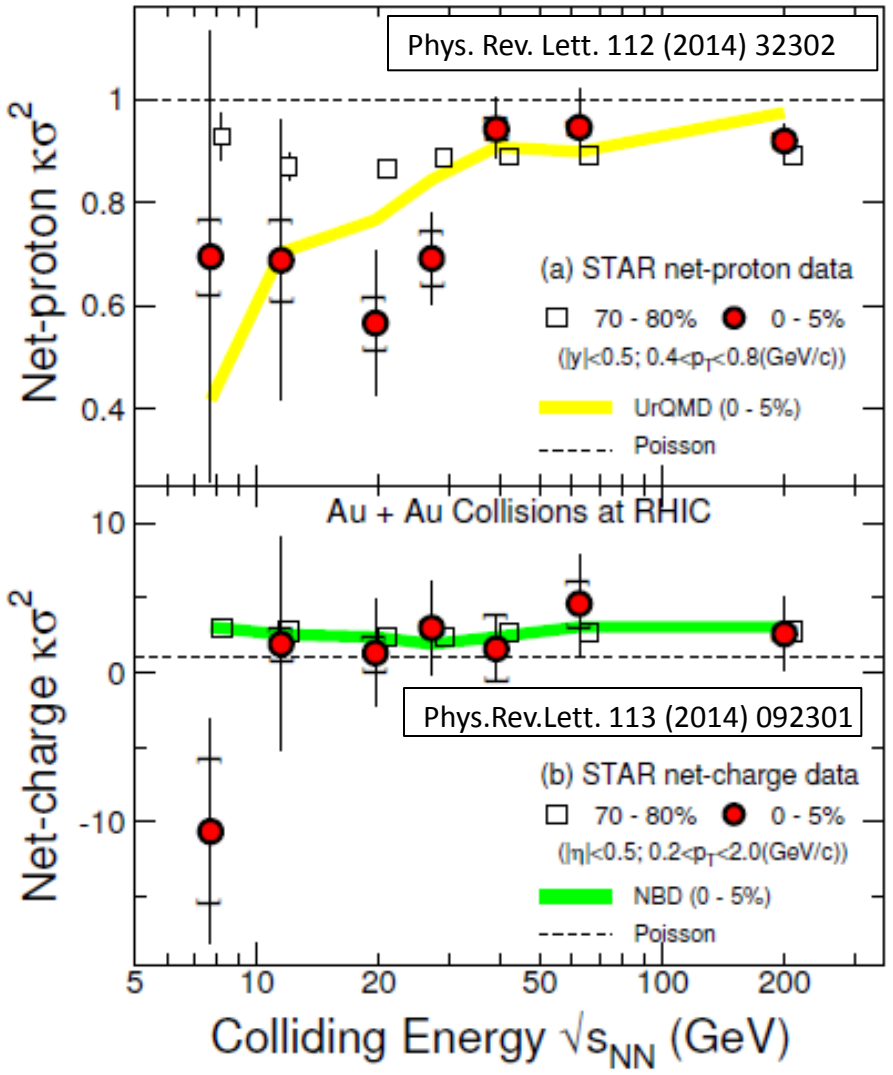
- Fluctuations of conserved quantities in a region of limited acceptance are the best observables to use to search for the critical point
- Some differences are seen between the $\kappa\sigma^2$ signals and baselines.
- These may be significant, however the uncertainties are quite large.

Volumes cancel

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

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

More data are needed



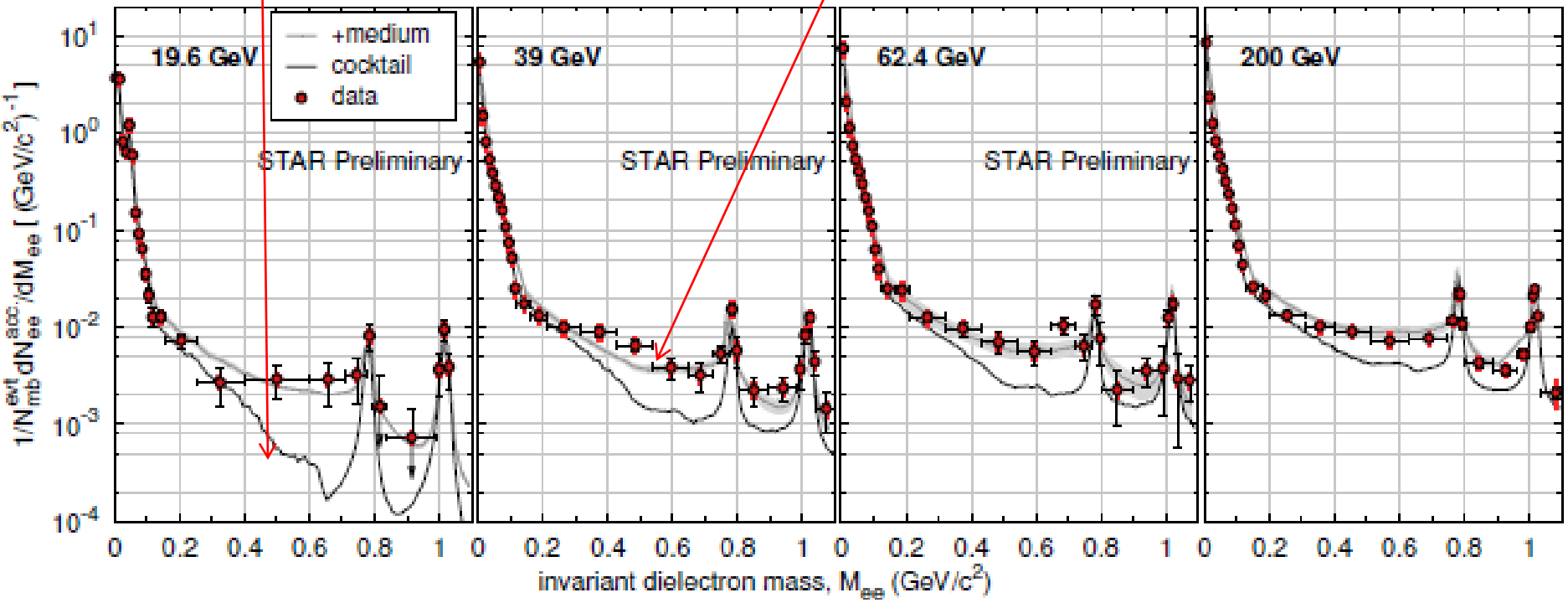
Bulk Penetrating EM Probes

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

Low Mass Region:
Emission depends on T, total baryon density, and lifetime



BES Phase I – What have We Learned

- The BES at RHIC spans a range of μ_B that could contain features of the QCD phase diagram.

- Signatures consistent with a parton dominated regime either disappear, lose significance, or lose sufficient reach at the low energy region of the scan.

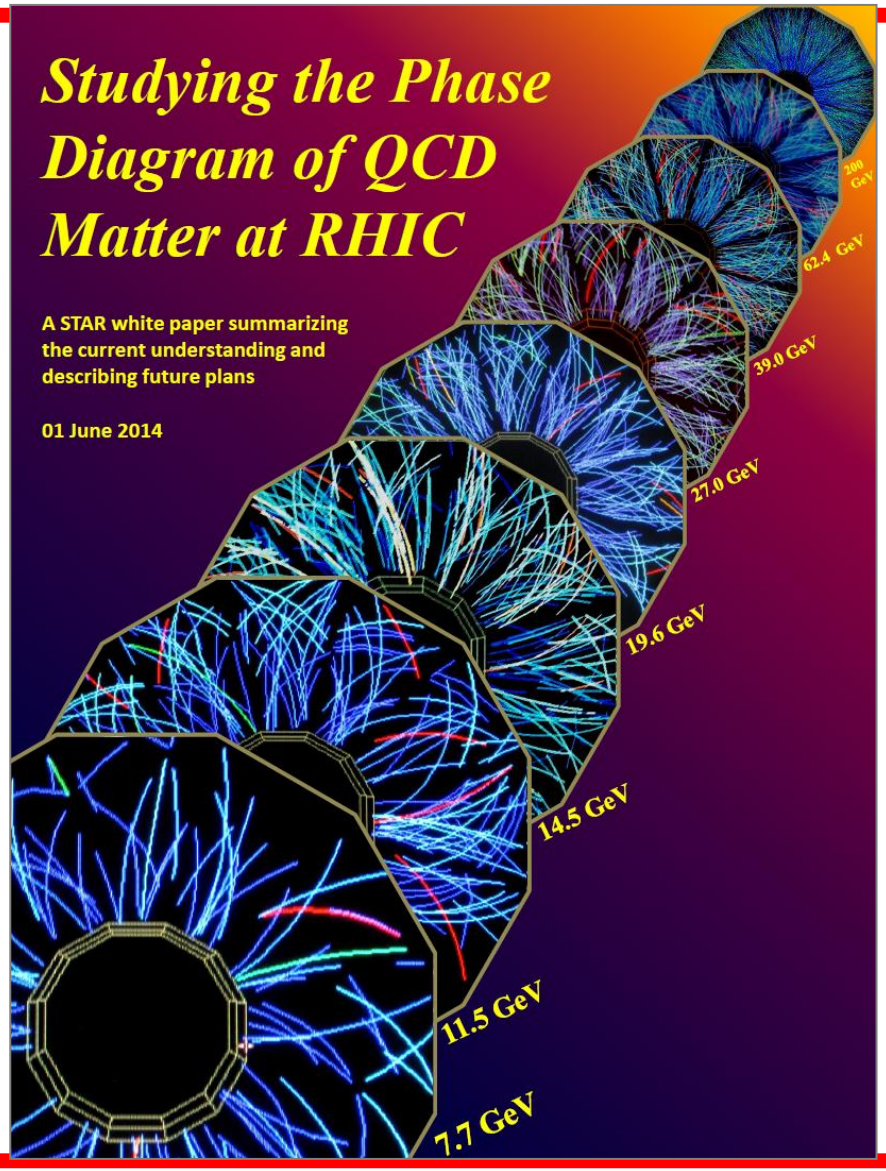
- There are indicators pointing towards a softening of the equation of state which can be interpreted as evidence for a first order phase transition.

- The higher moment fluctuation is sensitive to critical phenomena, but these analyses place stringent demands on the statistics.

- Dilepton mass spectra show a broadening consistent with models including hadron gas and quark-gluon plasma components.

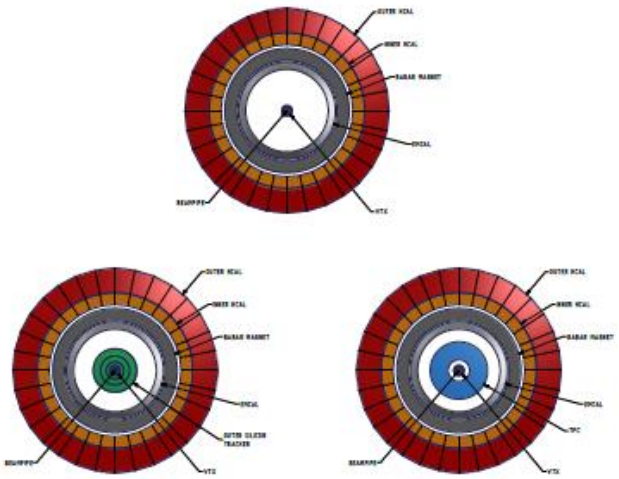
Beam Energy Scan Phase II

STAR and PHENIX BES-II White Papers



Beam Energy Scan II (2018–2019)

PHENIX Collaboration White Paper

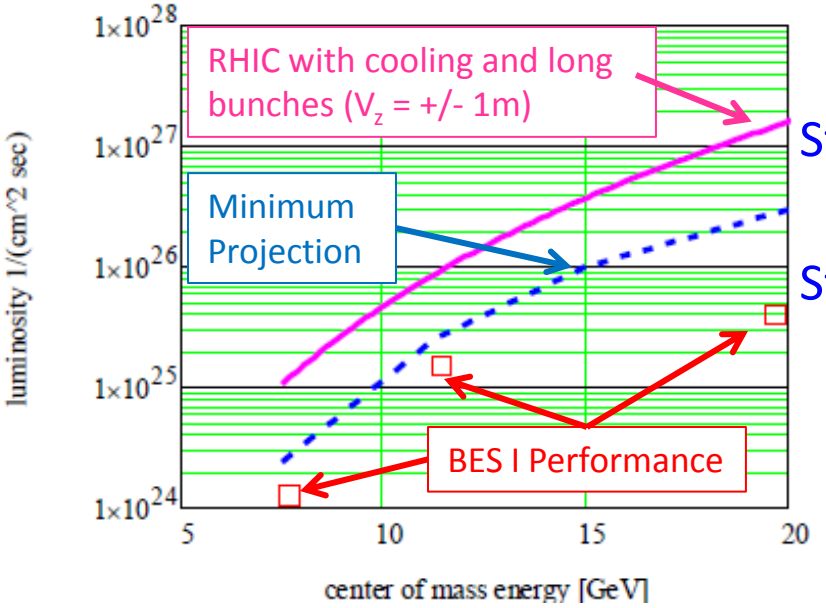


Version 1: March 1, 2014

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

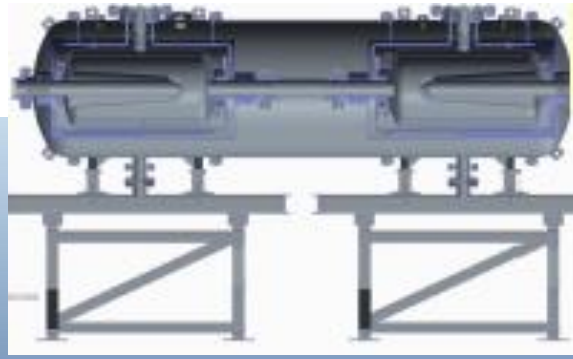
Long Bunches increase luminosity by factor of 2-5



Stage I
$\sqrt{s_{NN}}$ = 5-9 GeV

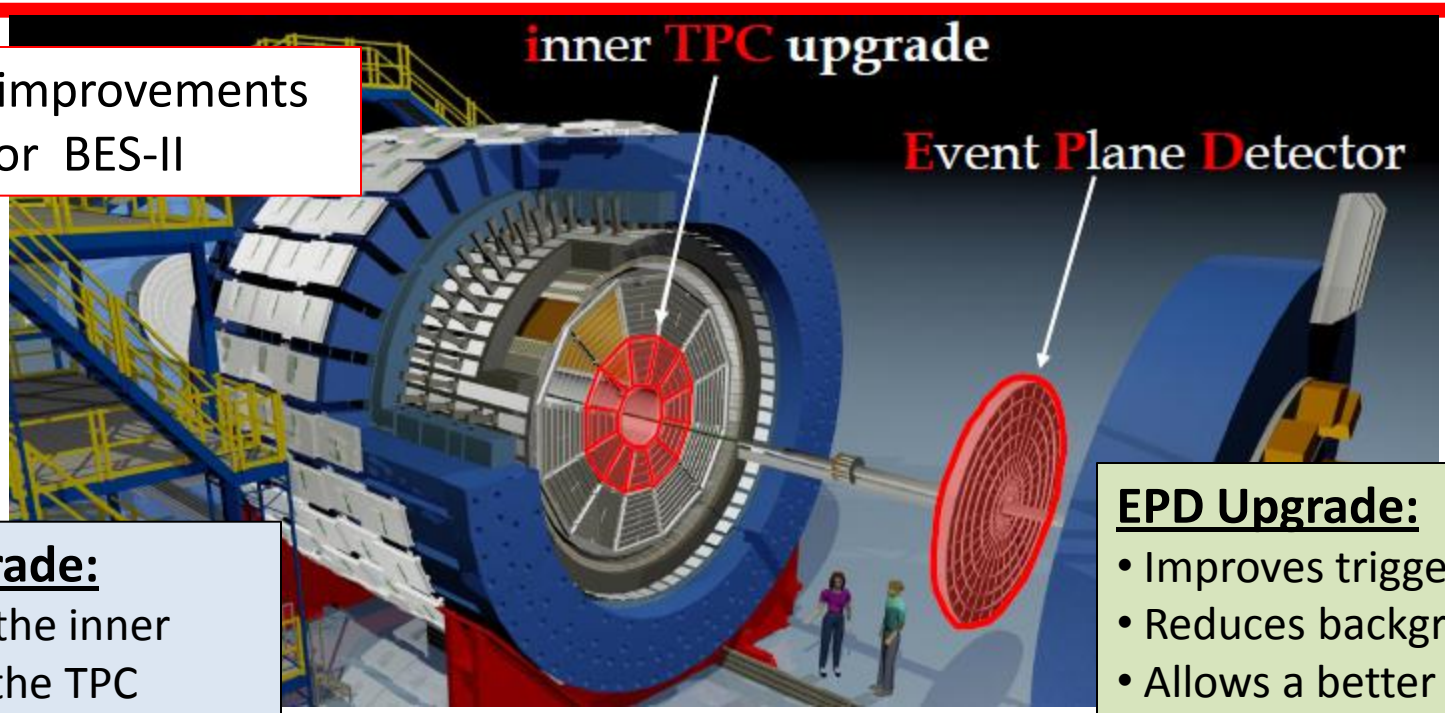
Stage II -- 3 MeV booster cavity
$\sqrt{s_{NN}}$ = 9-20 GeV

100 MHz SRF Gun



The STAR Upgrades and BES Phase II

Major improvements for BES-II

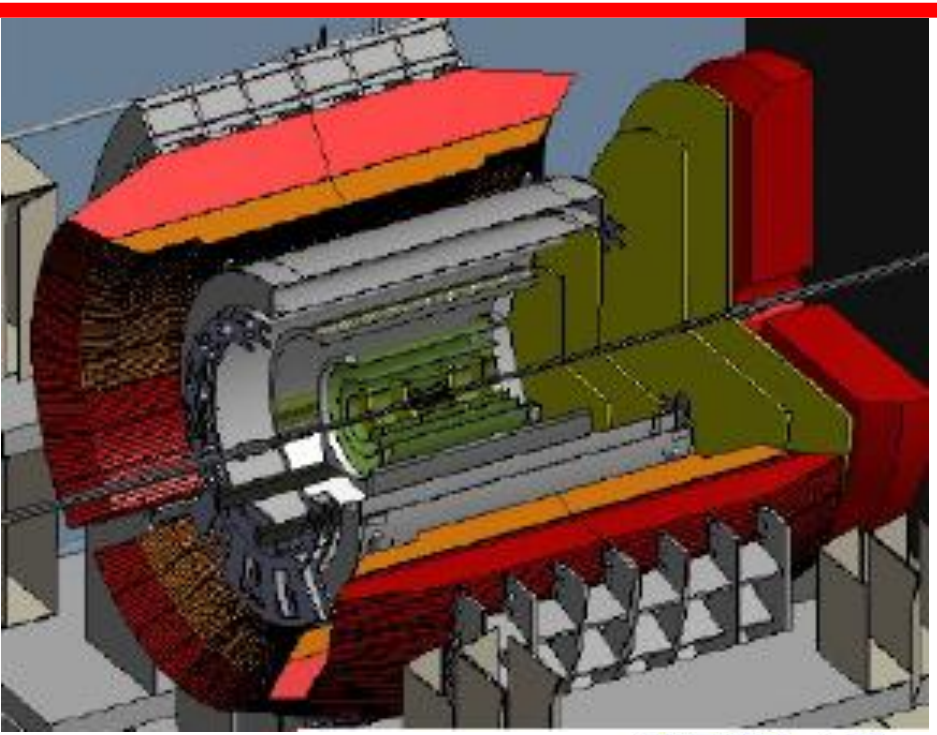


iTPC Upgrade:
- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.7
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

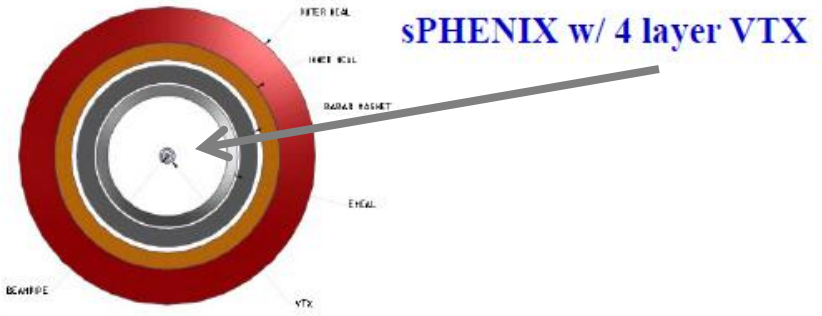
EndCap TOF Upgrade:
- Rapidity coverage is critical
- PID at forward rapidity

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

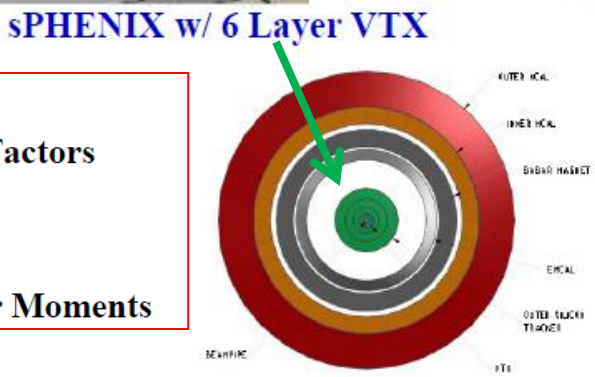
The sPHENIX Upgrades and BES Phase II

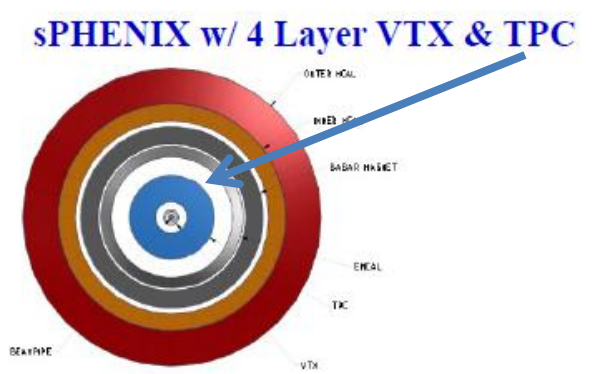


sPHENIX for BES II:
- **BABAR Solenoid**
- **HCal**
- **Ecal (partial)**
- **Tracking**



- **Global Variables**
- **Spectra and Nuclear Modification Factors**
- **HBT and Flow**
- **Chiral Magnetic Effect**
- **Fluctuations and Analysis of Higher Moments**





BES Phase II Proposal

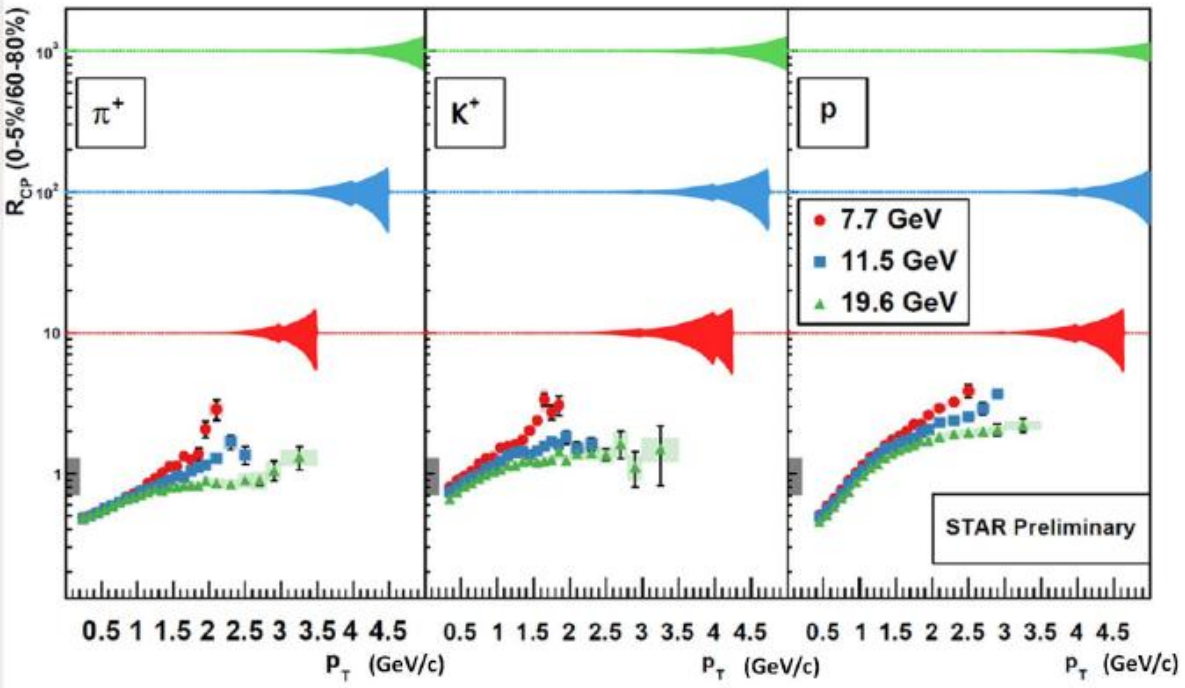
BES Phase II is planned for two 22 cryo-week runs in 2018 and 2019

$\sqrt{s_{NN}}$ (GeV)	5.0	7.7	9.1	11.5	13.0	14.5	19.6
μ_B (MeV)	550	420	370	315	290	250	205
BES I (MEvts)	---	4.3	---	11.7	---	24	36
Rate(MEvts/day)		0.25		1.7		2.4	4.5
BES I $\mathcal{L}$ (1×10^{25}/cm^{2}sec)		0.13		1.5		2.1	4.0
BES II (MEvts)		100	160	230	250	300	400
eCooling (Factor)	2	3	4	6	8	11	15
Beam Time (weeks)		**14**	**9.5**	**5.0**	**3.0**	**2.5**	**3.0**

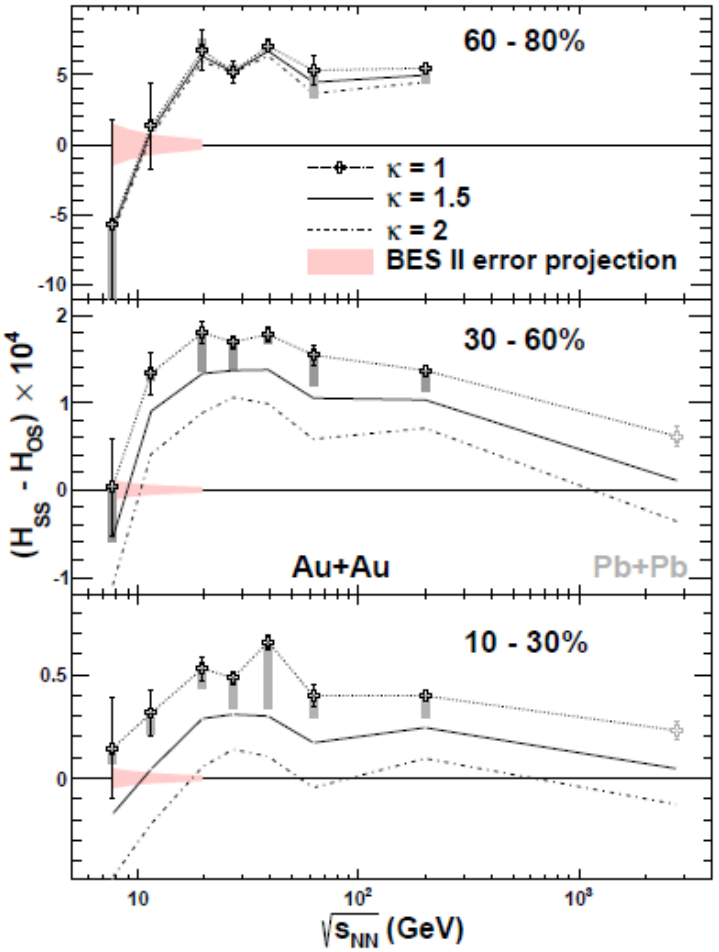
Disappearance of QGP Signatures

From the BES I data sets and the expected statistics for BES II, we can estimate the expected uncertainties. Signatures will define the energy of the onset of deconfinement.

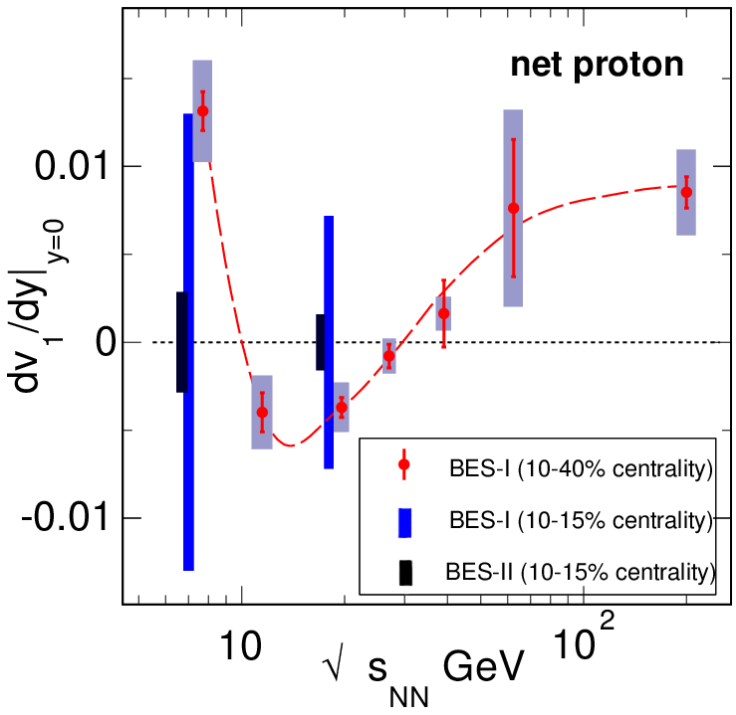
High p_T Suppression



Chiral Magnetic Effect



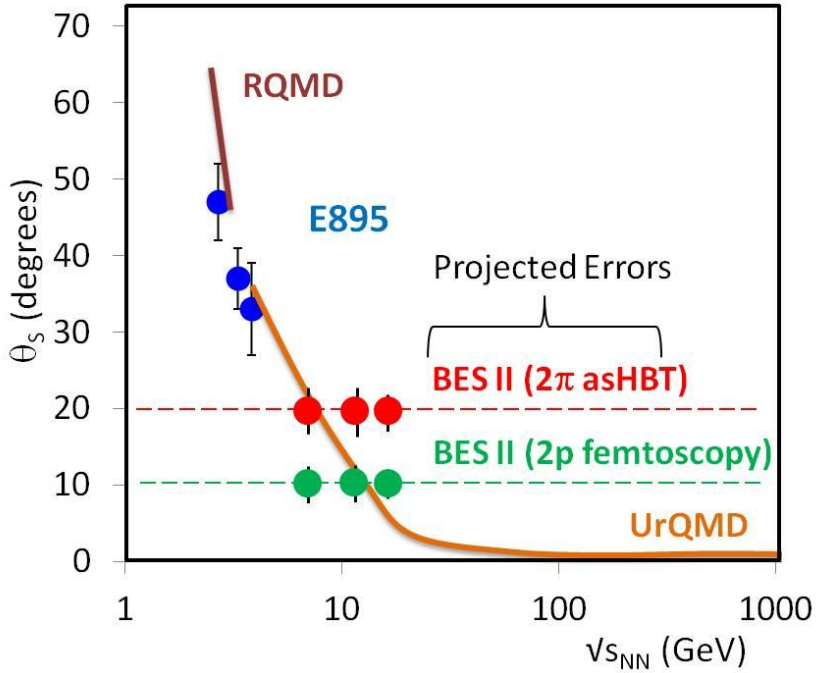
Search for 1st Order Phase Transition



- 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 and constrain the EOS

Azimuthally sensitive femtoscopy allows measurement of the longitudinal tilt of the source (θ_s) ➔ the stiffness of the equation of state

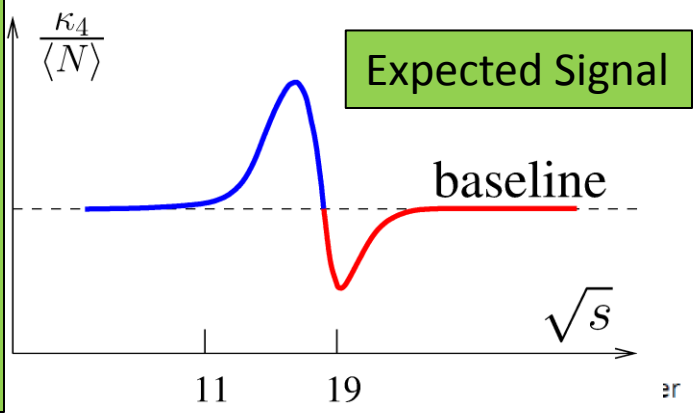
This measurement was not possible with the limited statistics of BES I

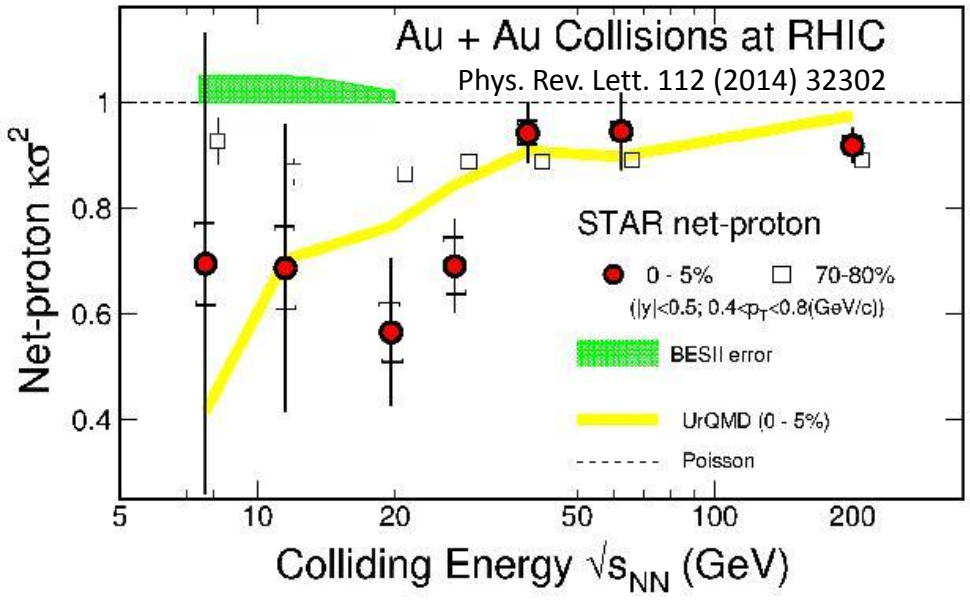


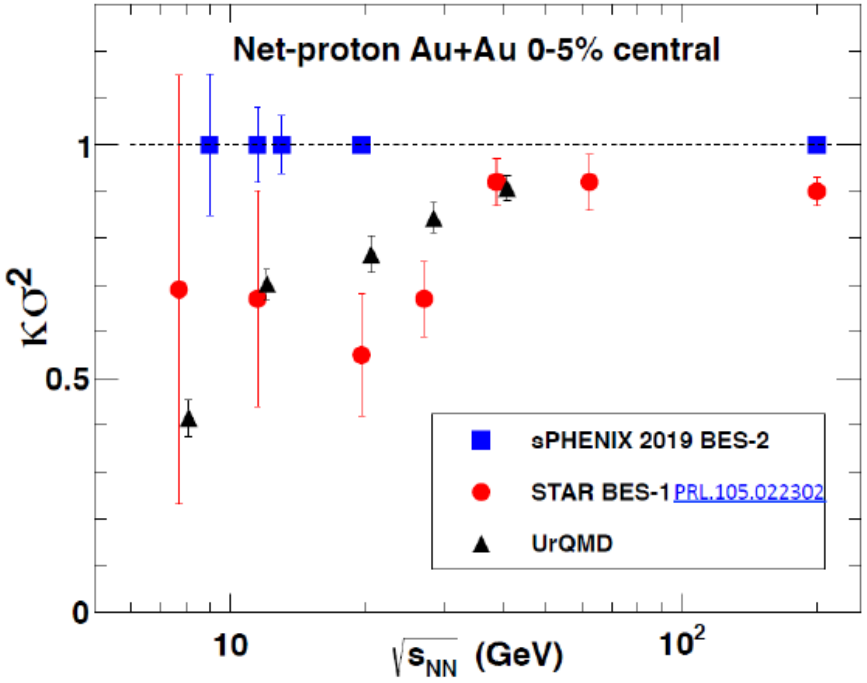
Search for the Critical Point – $\kappa\sigma^2$

- 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 27 GeV and below are a manifestation of criticality



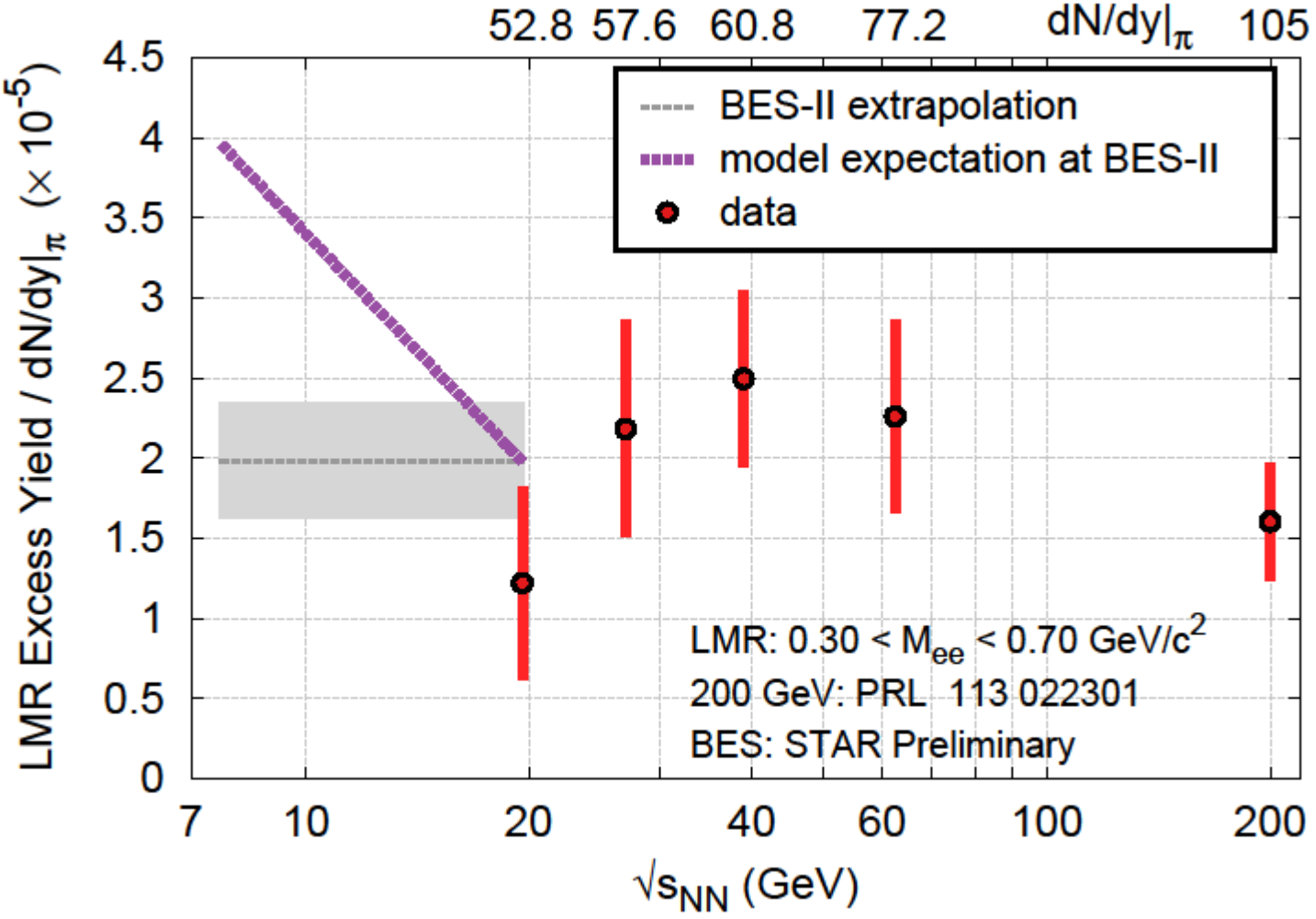




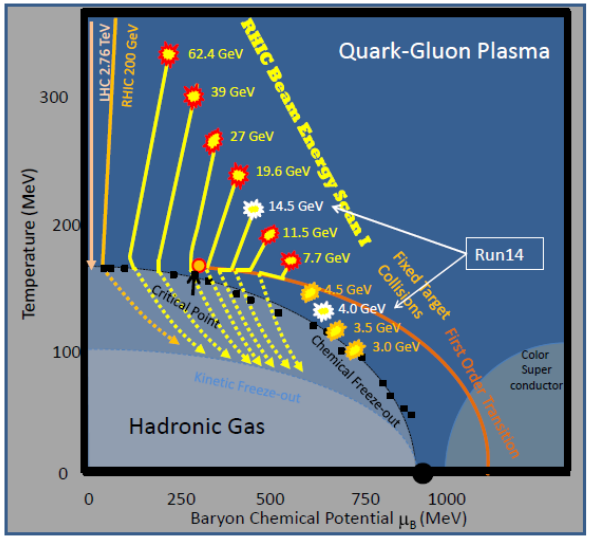
Bulk Penetrating EM Probes

BES-II:

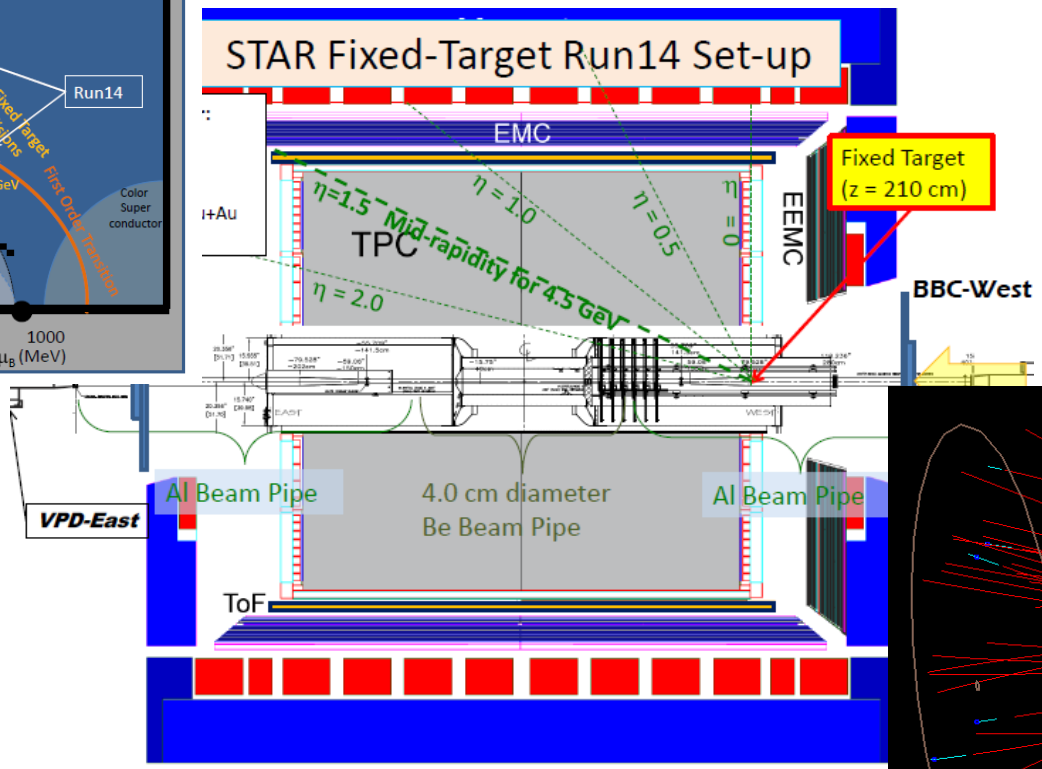
- Measure LMR excess ➔ probes total baryon density (ρ) and lifetime dependence at lower √s
- Measure QGP thermal radiation (IMR) ➔ probes early temperature
- Possible medium modifications of charm in the IMR

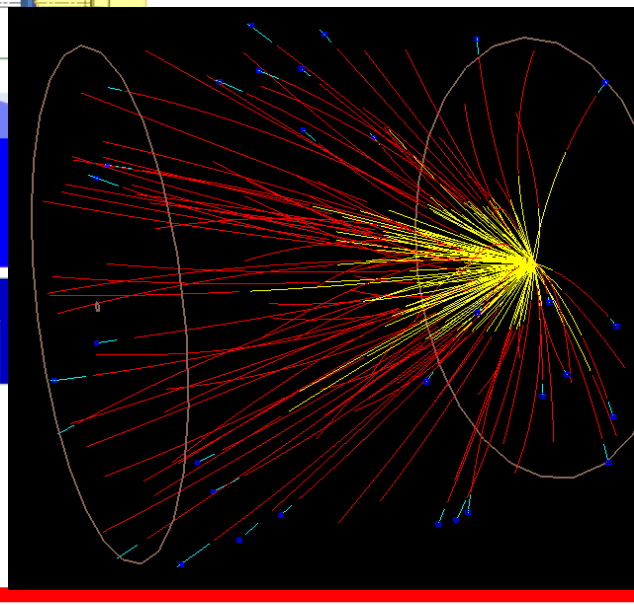


RHIC Fixed-Target Program



Should measurements below 7 GeV prove essential, a fixed target program is being developed





Au+Au event at 3.9 GeV from a test in Run 14

BES phase II - Outlook

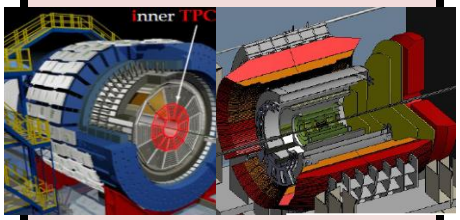
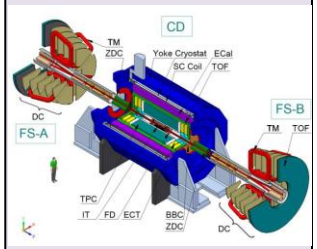
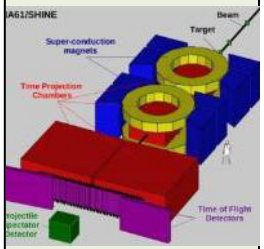
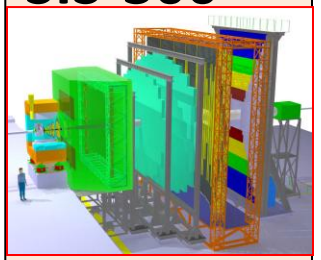
- BES Phase I told us where to search – Lattice QCD suggests this could be an interesting region.

- Machine improvements allow for a precision search

- Detector upgrades allow for more refined searches

The focused and improved studies of BES phase II will allow us to define the energy of the onset of deconfinement and allow us to characterize the phases and transitions of QCD matter.

Comparison of Facilities

Facilty	RHIC BESII	NICA	SPS	SIS-300
Exp.:				
Start:	2018	>2018?	2009	?
Au+Au Energy: $\sqrt{s_{NN}}$ (GeV)	3.0 – 19.6+	2.7 - 11	4.9-17.3	2.7-8.2
Event Rate: At 8 GeV	10-100 HZ	<10 kHz	100 HZ	<10 MHZ
Physics:	CP,OD,DHM	OD&DHM	CP&OD	OD&DHM

CP = Critical Point
OD = Onset of Deconfinement
DHM = Dense Hadronic Matter

Conclusion: RHIC is the best option

Fixed Target
Lighter ion collisions

Fixed Target

Conclusions

There are scenarios that would see a limited time to termination of RHIC operations.

- A BESII program in 2018 would not be run
- A shorter run without eCooling would not have the statistics needed

What would be lost?

- RHIC is optimally suited to find the critical point, and define the PT

➔ "*If RHIC did not exist, someone would have to build it*" *Berndt Mueller*

- NICA and FAIR are **too low** in energy for CP searches
- NA61 is a **fixed-target** experiment and is running lighter ions
- ➔ **Without RHIC, the QCD phase diagram will not be understood**

- **Study of the phase diagram needs RHIC with eCooling!**