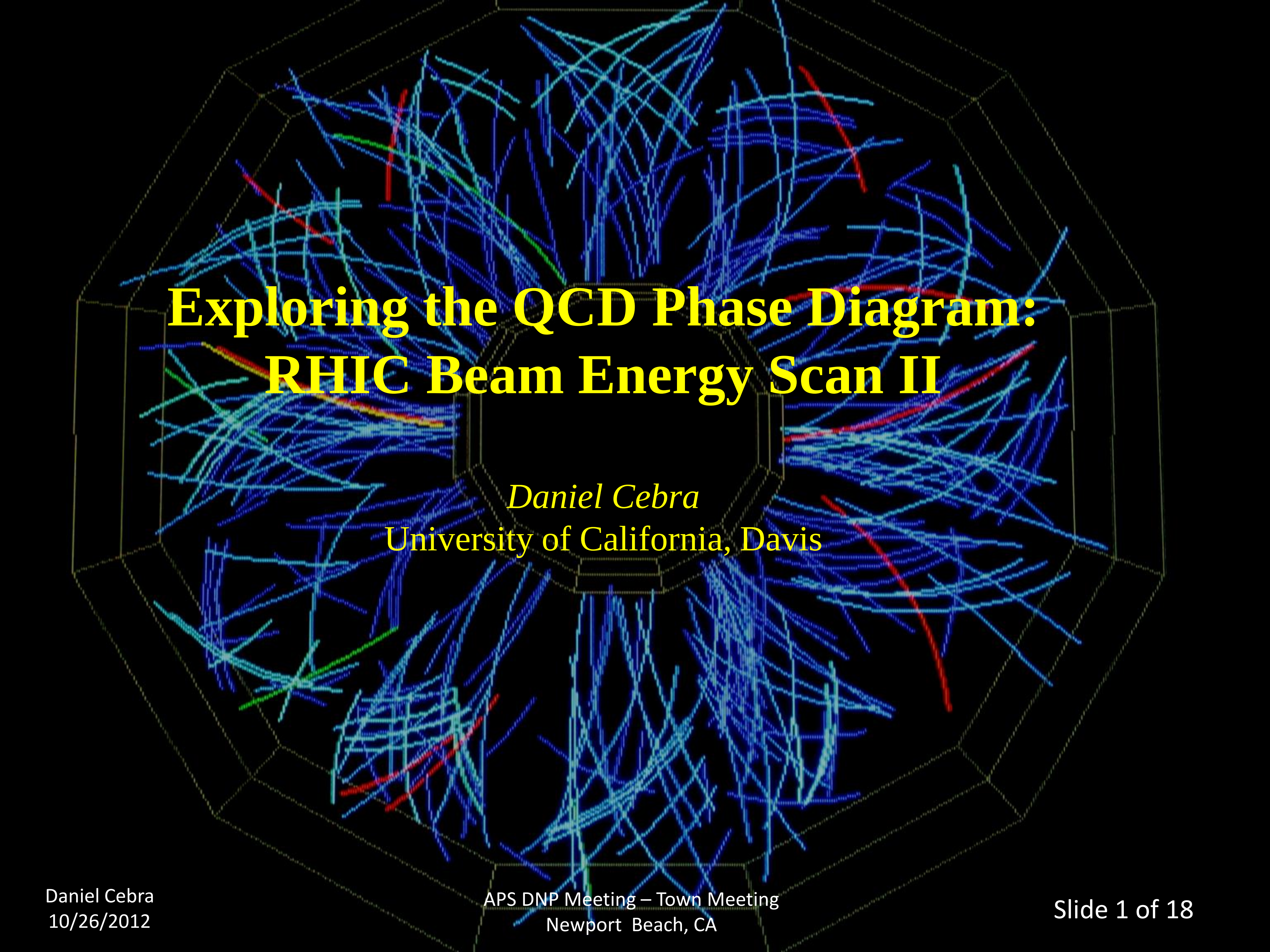

Exploring the QCD Phase Diagram: RHIC Beam Energy Scan II

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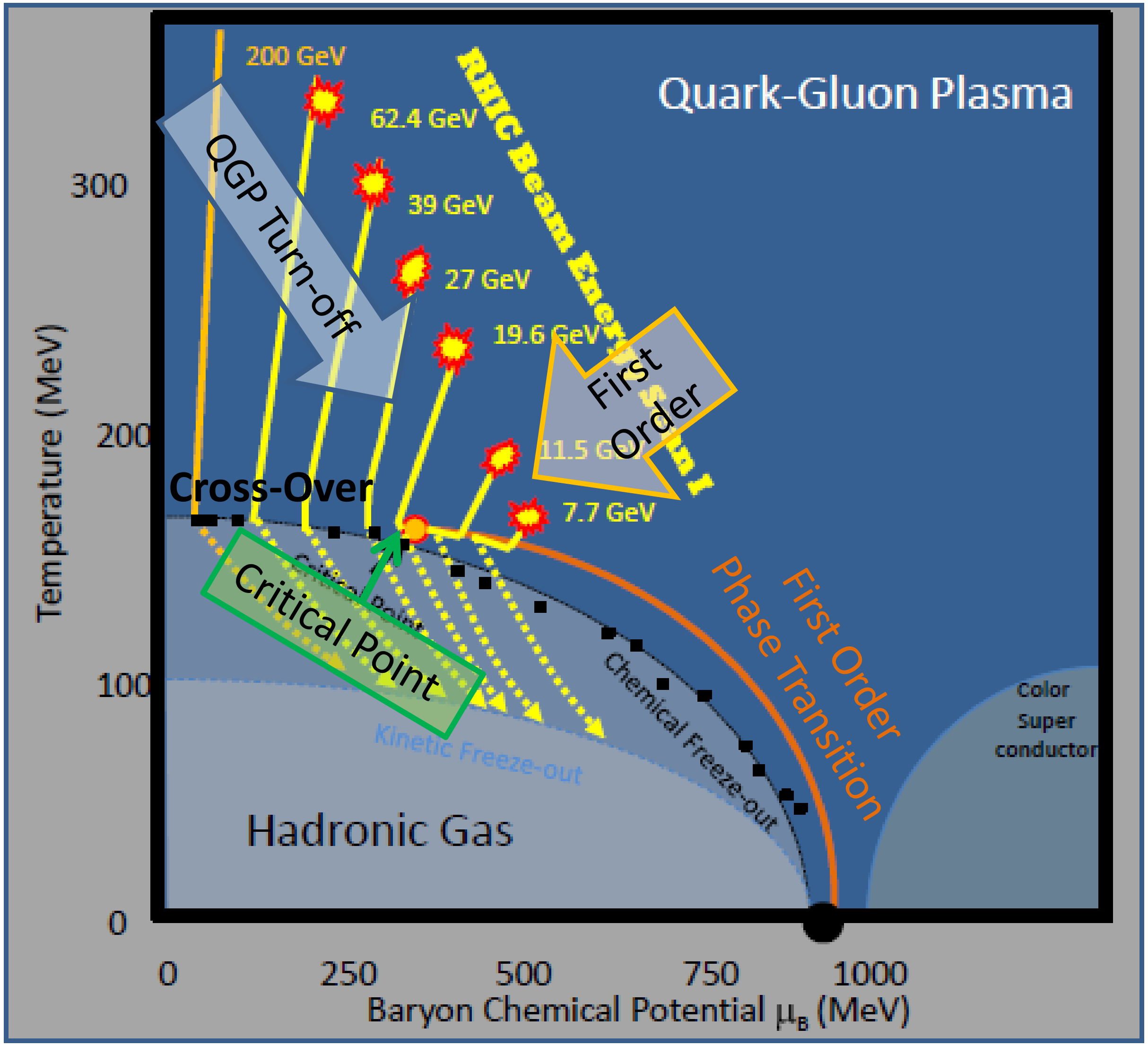
The RHIC Beam Energy Scan I

- We built RHIC to find the QGP.
  And we did it!

- But QGP is a new and complicated phase of matter. We have made huge progress in understanding its nature. At high energy, we expect a **cross-over** transition. At lower energy there should be a **first order** transition and a **critical point**.

- The structure of the QCD matter phase diagram is **fundamental**. This will be in textbooks in future decades

- **Three Goals:**
  - **Turn-off of QGP signatures**
  - **Critical Point**
  - **First order phase transition.**



Overview of the Beam Energy Scan I Results

1. **Turn-off of QGP signatures:**
   - **NCQ breaks down below 19.6 GeV**
   - **High p_t suppression not seen below 19.6 GeV**
   - **LPV effect not seen below 11.5 GeV**

Clear Evidence

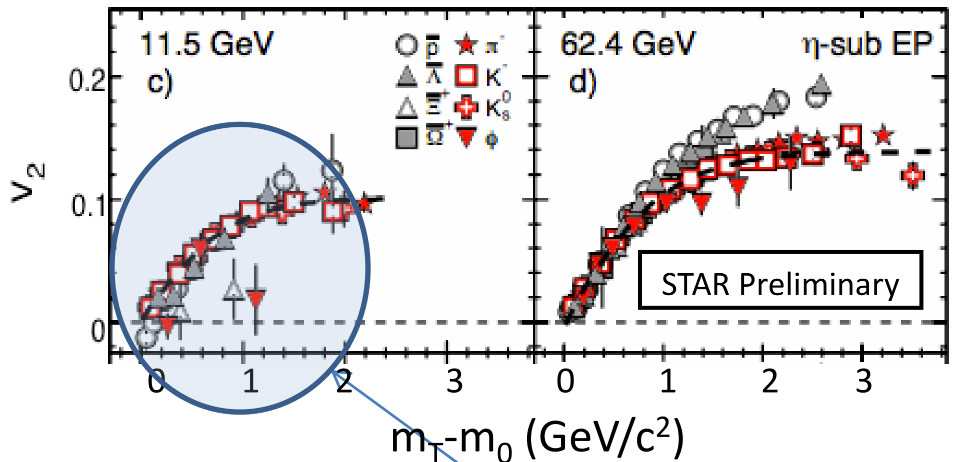
2. **Evidence of the first order phase transition.**
   - **v_1 sign change above 7.7**
   - **Inflection in v_2 and $dE_T/d\eta$ at 7.7**
   - Azimuthal HBT signal inconclusive

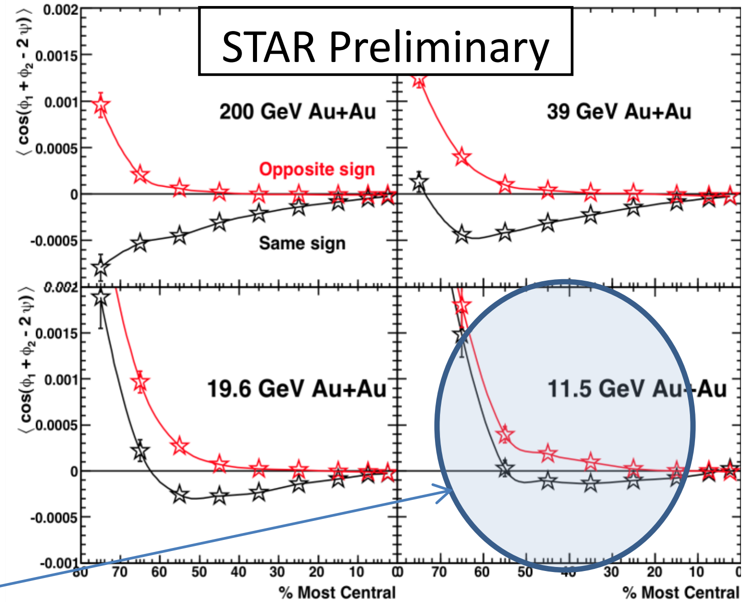
Strong Hints

3. **Search for the critical point.**
   - K/π, K/p, or p/π fluctuations are not conclusive.
   - **Higher moments of the proton distributions**

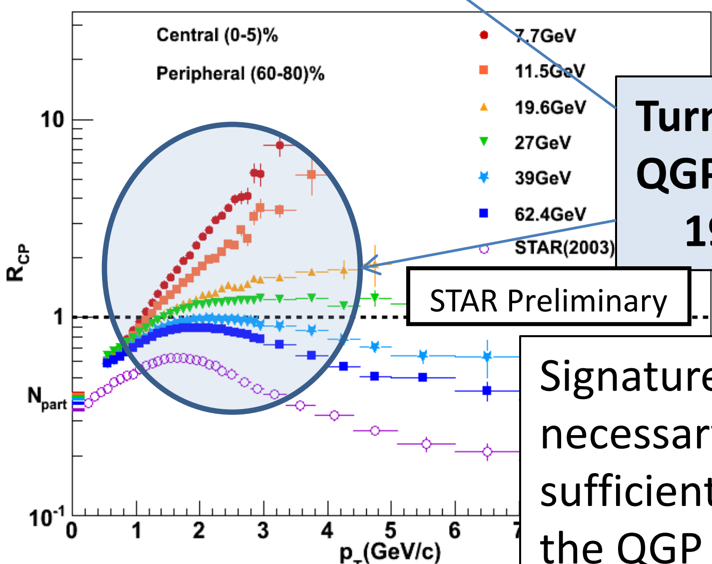
Hints

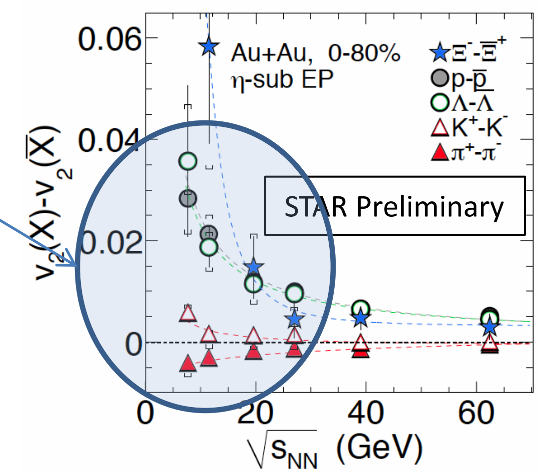
Turn-off of QGP Signatures





Turn-off of key QGP signatures 19.6 – 11.5

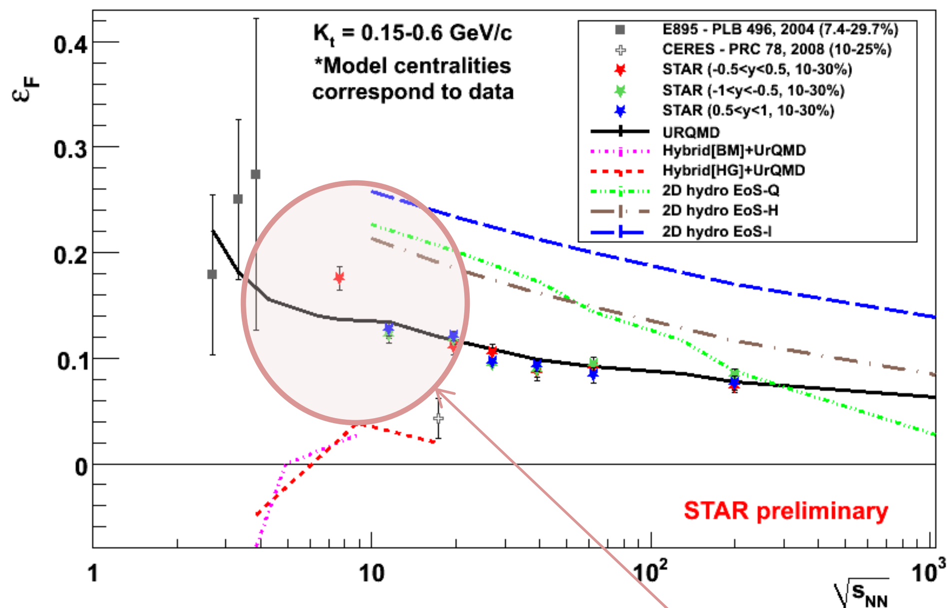


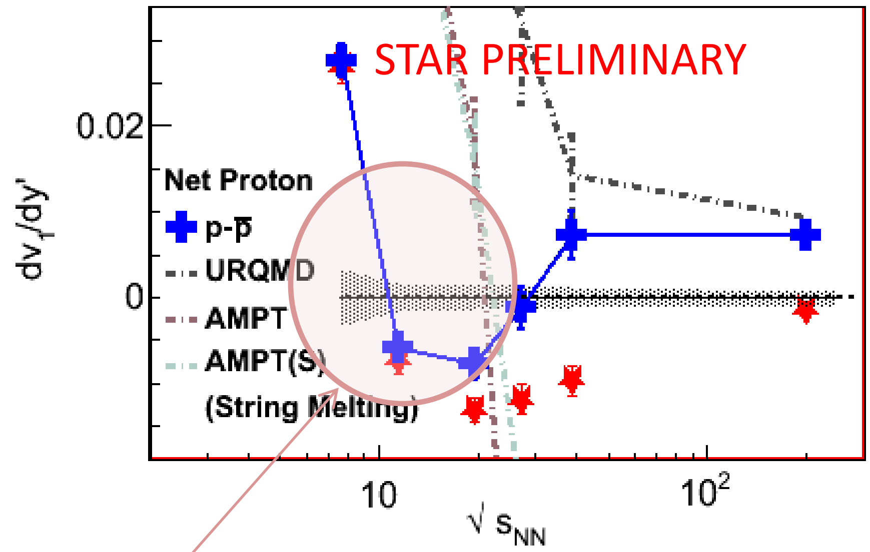


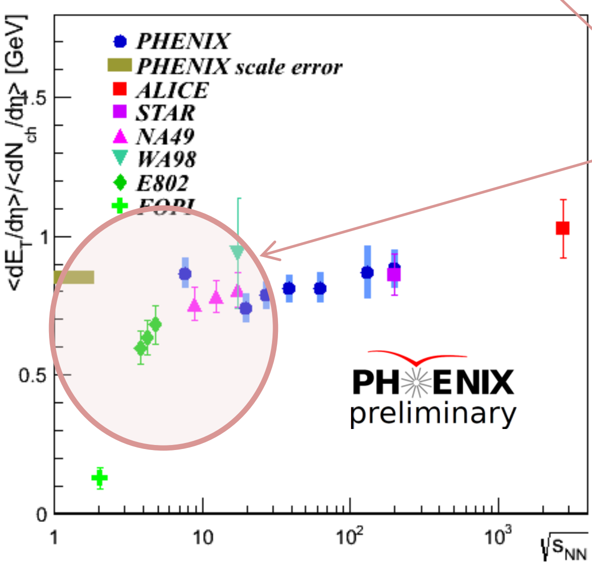
Signature turn-off is necessary but not sufficient to demonstrate the QGP is not reached

Search for 1st Order PhaseTransition

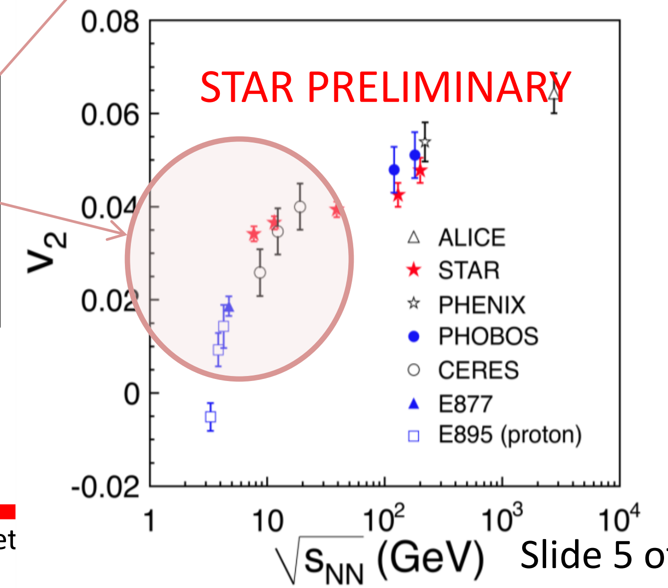
Excitation function for freeze-out eccentricity, ε_F







Hints of change in behavior at the low end of the energy range

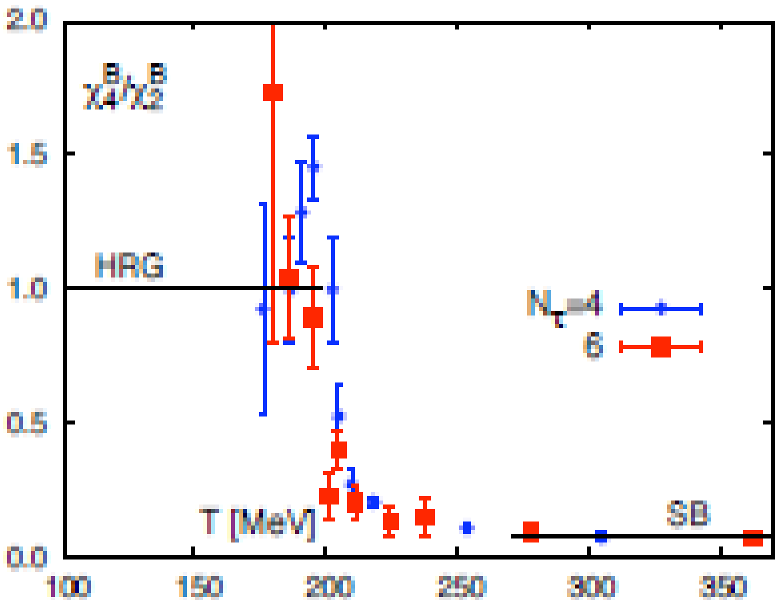


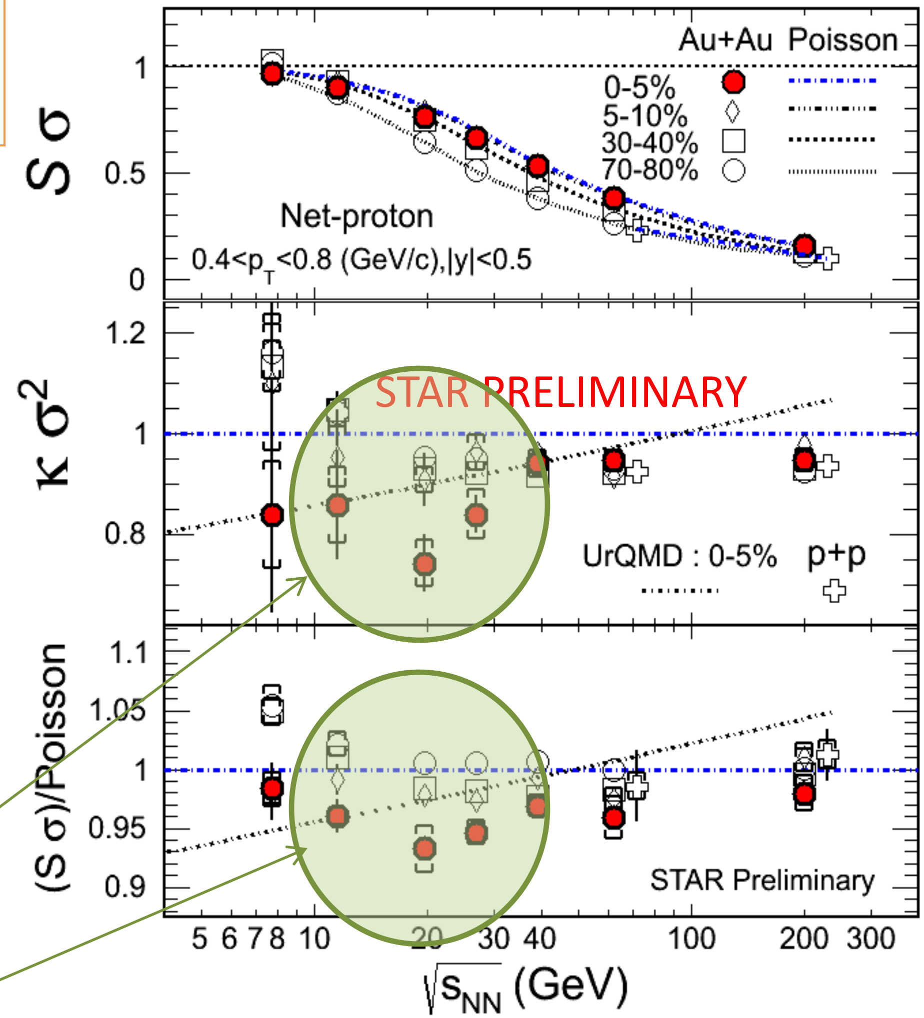
Search for the Critical Point

Volumes cancel

$$\chi_B^{(n)} = \left.\frac{\partial^n (P/T^4)}{\partial(\mu_B/T)^n}\right|_T$$

$$\chi_B^4 / \chi_B^2 = (\kappa\sigma^2)_B$$
$$\chi_B^3 / \chi_B^2 = (S\sigma)_B$$





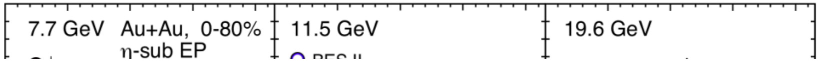
Deviations from Poisson in the lower half of the BES energy range

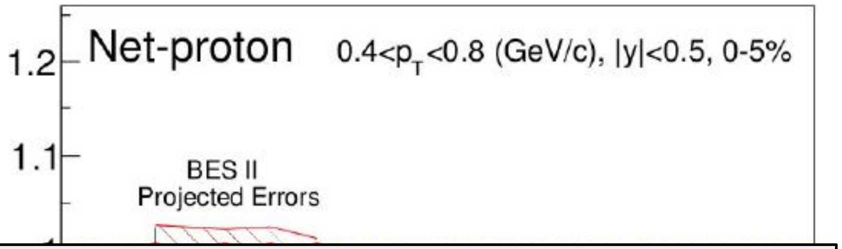
Need more statistics or finer energy steps

What Have We Learned? What Needs to be Done?

1) The key QGP *signatures* disappear, no need to search above 19.6

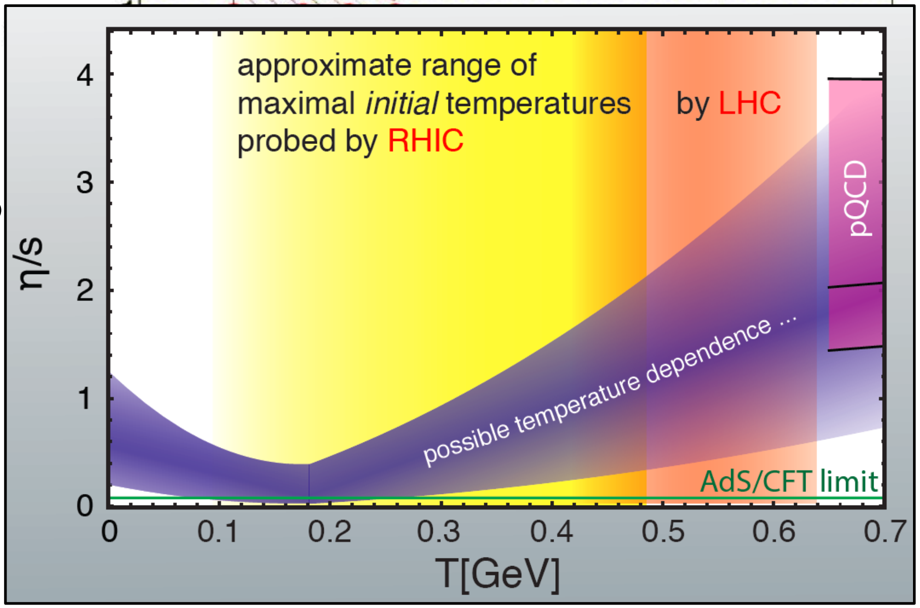
2) First order phase transition or Onset of deconfinement *likely* at the lower end of the range
   - *low energy performance is critical*





3) Critical Point will need more statistics
   - Do we need finer steps? Over 100 MeV Gap in μ_B between 11.5 and 19.8

4) Determination of the temperature dependence of transport properties



Beam Energy Scan II: Answering the remaining questions

$\sqrt{s_{NN}}$ (GeV)	19.6	15	11.5	7.7
μ_B (GeV)	205	250	315	420
BES I (MEvts)	36	---	11.7	4.3
BES II (MEvts)	**400**	**100**	**120**	**80**

- Finer steps in μ_B
- High Statistics

Critical Point

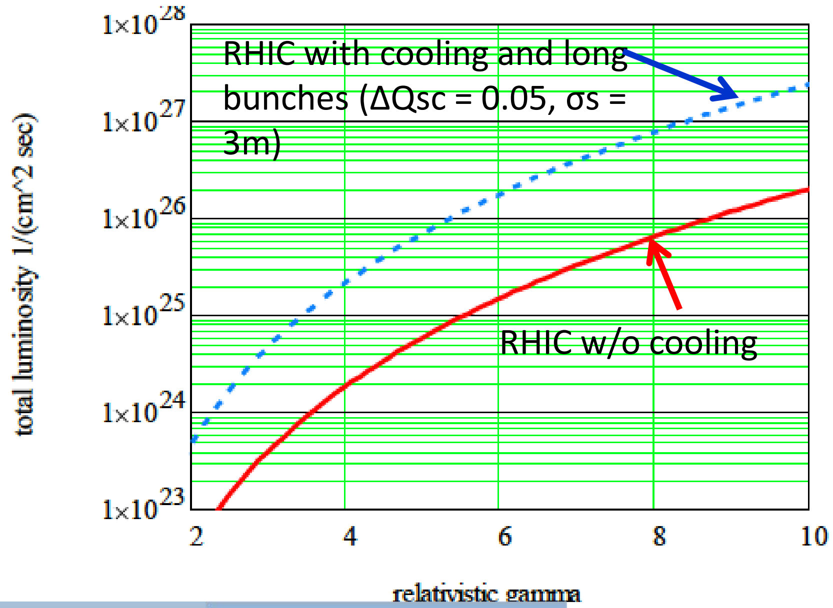
Onset of Deconfinement

But that's a lot of data… at current rates, this would take ~70 weeks of RHIC operations!
Isn't there a better way? ➔ Yes! We can cool the beams!

Low Energy Electron Cooling at RHIC

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

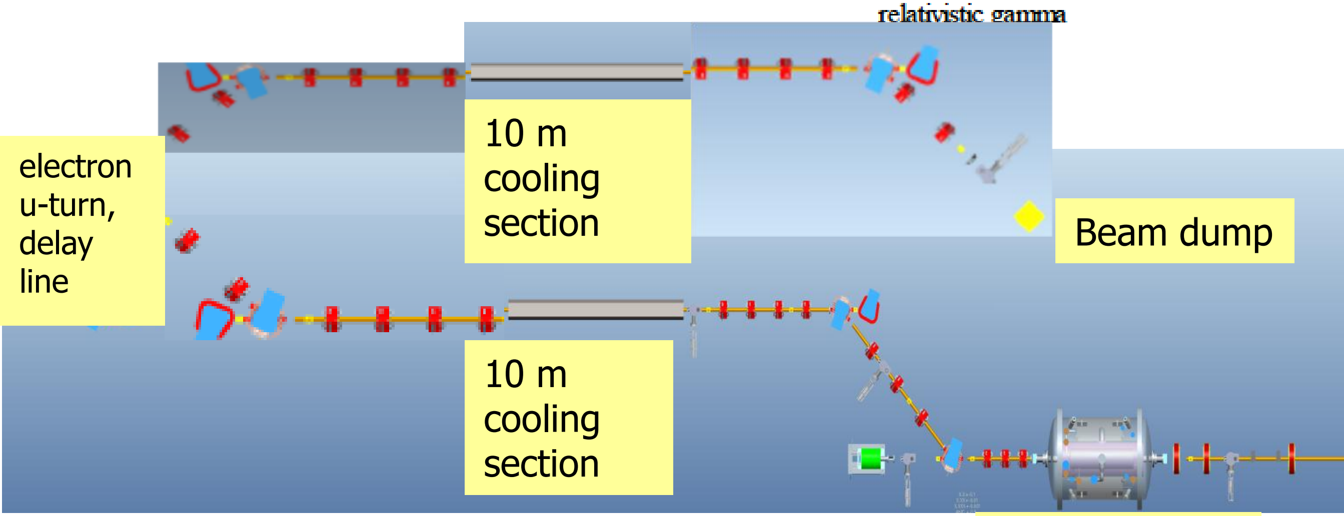
Long Bunches increase luminosity by factor of 2-5

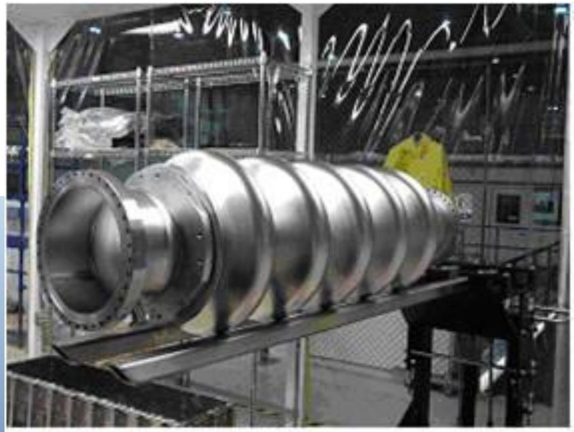


Implementation in phases:

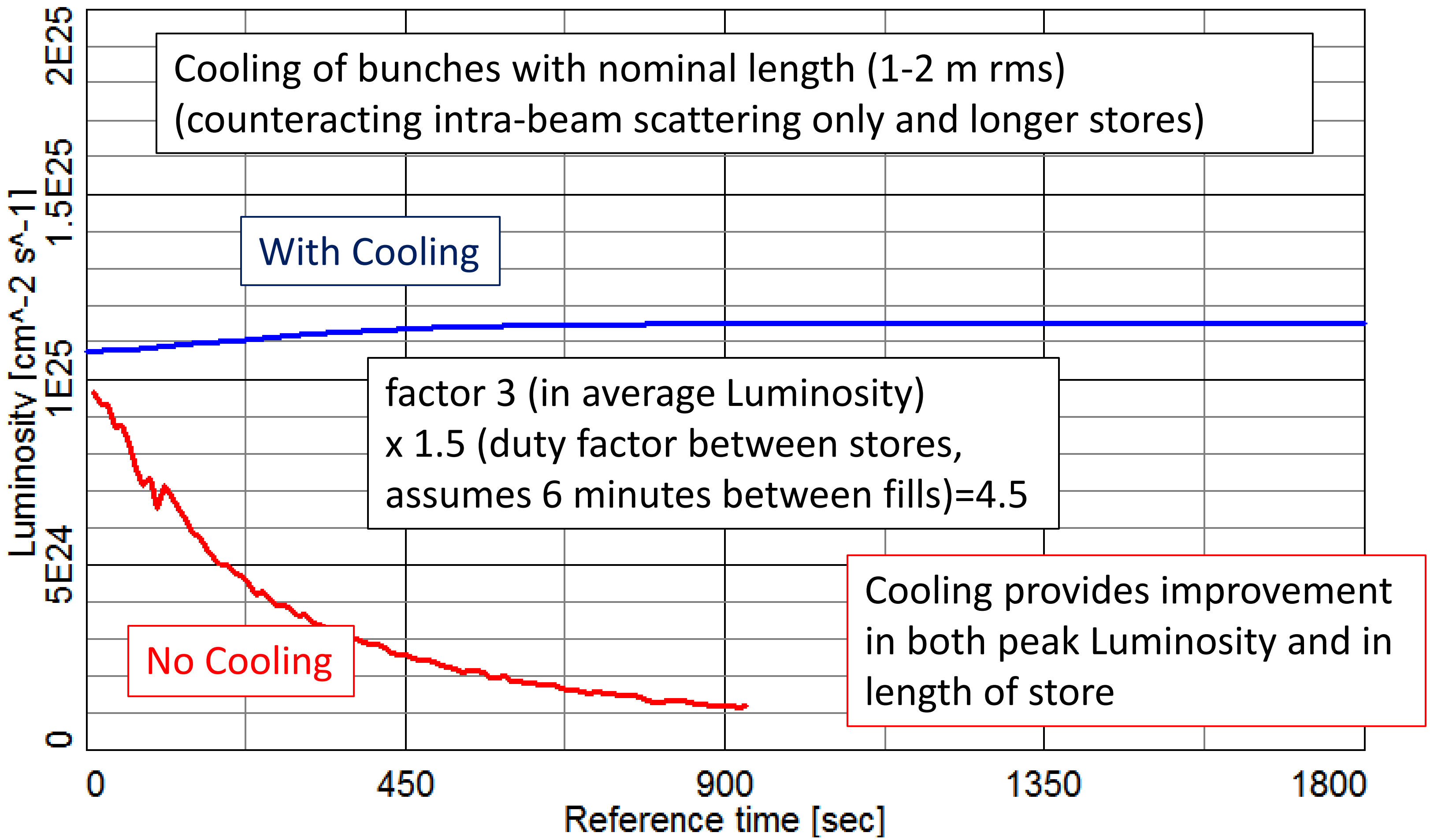
Phase I (2017)
$\sqrt{s_{NN}}$ = 5-9 GeV

Phase II (2018+)
[additional 3 MeV booster cavity]
$\sqrt{s_{NN}}$ = 9-20 GeV





Simulation of luminosity with electron cooling at beam energy of 3.85 GeV/n ($\sqrt{s_{NN}}$ =7.7 GeV).



Timeline for RHIC's Next Decade

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 500 GeV $\vec{p}+\vec{p}$ • 15 GeV Au+Au	• Sea antiquark and gluon polarization • QCD critical point search	• Electron lenses • upgraded pol'd source • STAR HFT
2014	• 200 GeV Au+Au and baseline data via 200 … eeded for … bsystems)	• Heavy flavor flow, energy loss, thermalization, etc. • quarkonium studies	• 56 MHz SRF • full HFT • STAR Muon Telescope Detector • PHENIX Muon Piston Calorimeter Extension (MPC-EX)
2015-2017	• High stat. Au+Au at 200 and ~40 GeV • U+U/Cu+Au at 1-2 energies • 200 GeV p+A • 500 GeV $\vec{p}+\vec{p}$	• Extract $\eta/s(T_{min})$ + constrain initial quantum fluctuations • further heavy flavor studies • sphaleron tests @ $\mu_B \neq 0$ • gluon densities & saturation • finish p+p W prod'n	• Coherent Electron Cooling (CeC) test • Low-energy electron cooling • STAR inner TPC pad row upgrade
2018-2021	• 5-20 GeV Au+Au (E scan phase 2) • long 200 GeV + 1-2 lower $\sqrt{s}$ Au+Au w/ upgraded dets. • baseline data @ 200 GeV and lower $\sqrt{s}$ • 500 GeV $\vec{p}+\vec{p}$ • 200 GeV $\vec{p}+A$	• x10 sens. increase to QCD critical point and deconfinement onset • jet, di-jet, γ-jet quenching probes of E-loss mechanism • color screening for different qq states • transverse spin asyms. Drell-Yan & gluon saturation	• sPHENIX • forward physics upgrades

Note: This will be a 3 week run, without cooling,
➔lower statistics (30-40M)
Still need to come back to this energy later

The BES II program needs electron cooling

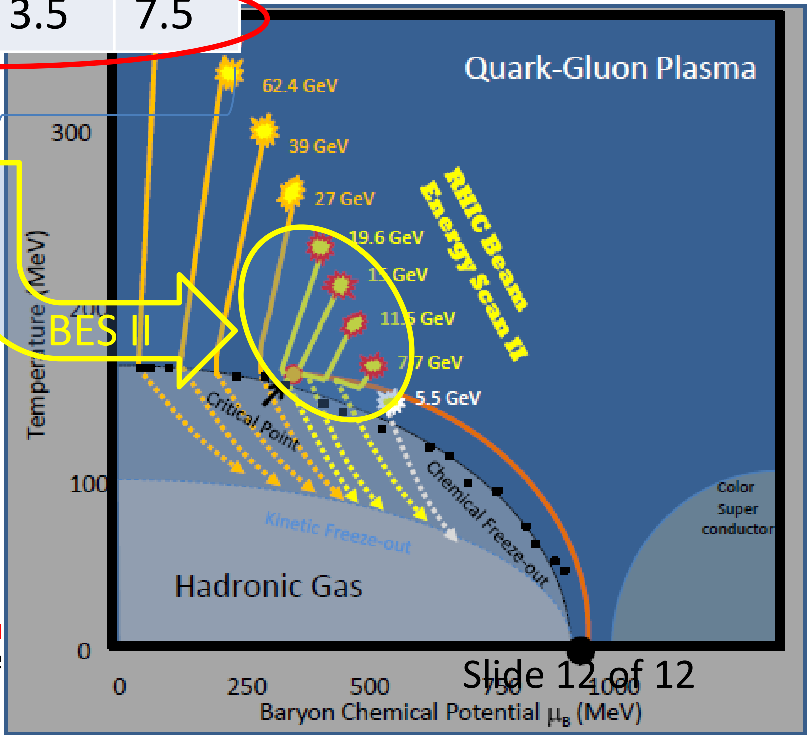
Beam Energy Scan II

$\sqrt{S_{NN}}$ (GeV)	62.4	39	27	19.6	15	11.5	7.7
μ_B (GeV)	70	115	155	205	250	315	420
BES I (MEvts)	67	130	70	36	---	11.7	4.3
Rate(MEvts/day)	20	20	9	3.6	1.6	1.1	0.5
BES II (MEvts)	---	---	---	**400**	**100**	**120**	**80**
eCooling factor	---	---	---	8	6	4.5	3
Beam (weeks)	---	---	---	2.0	1.5	3.5	7.5

Add a week between each energy, and BES II program will take about **17 weeks**

•BES II will focus on the most interesting regions of the phase diagram

•Electron cooling is key to the feasibility of this program; without cooling, BES II would take ~**70 weeks**



Is there another way?

Can another facility do this faster?

Or better?

Super Proton Synchrotron (SPS)

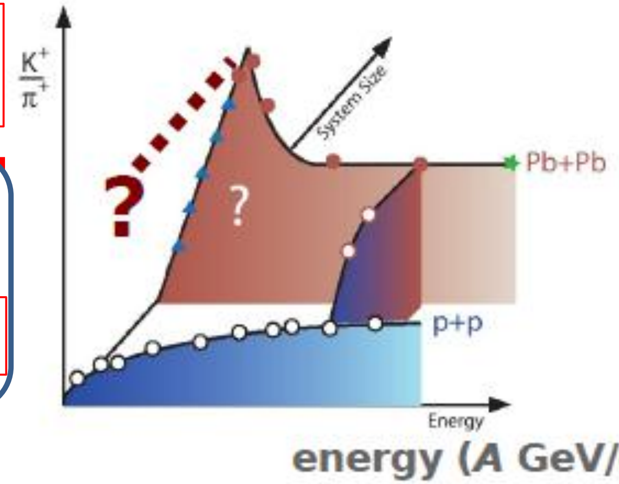
SHINE NA61

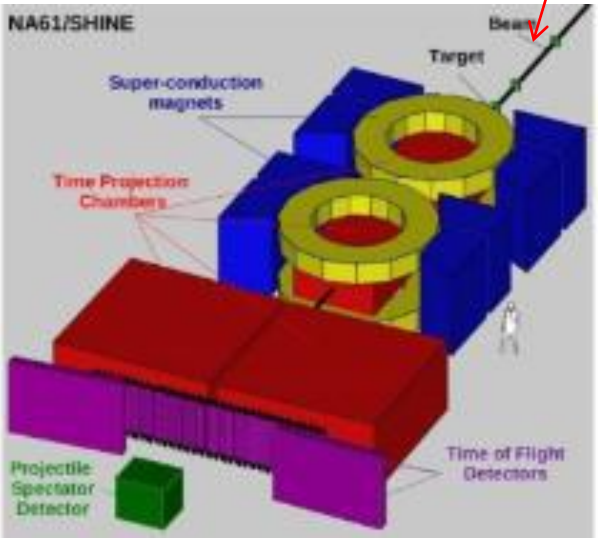
+ Running now, that's good
+ Energy range is good
- But fixed-target
- And light ions

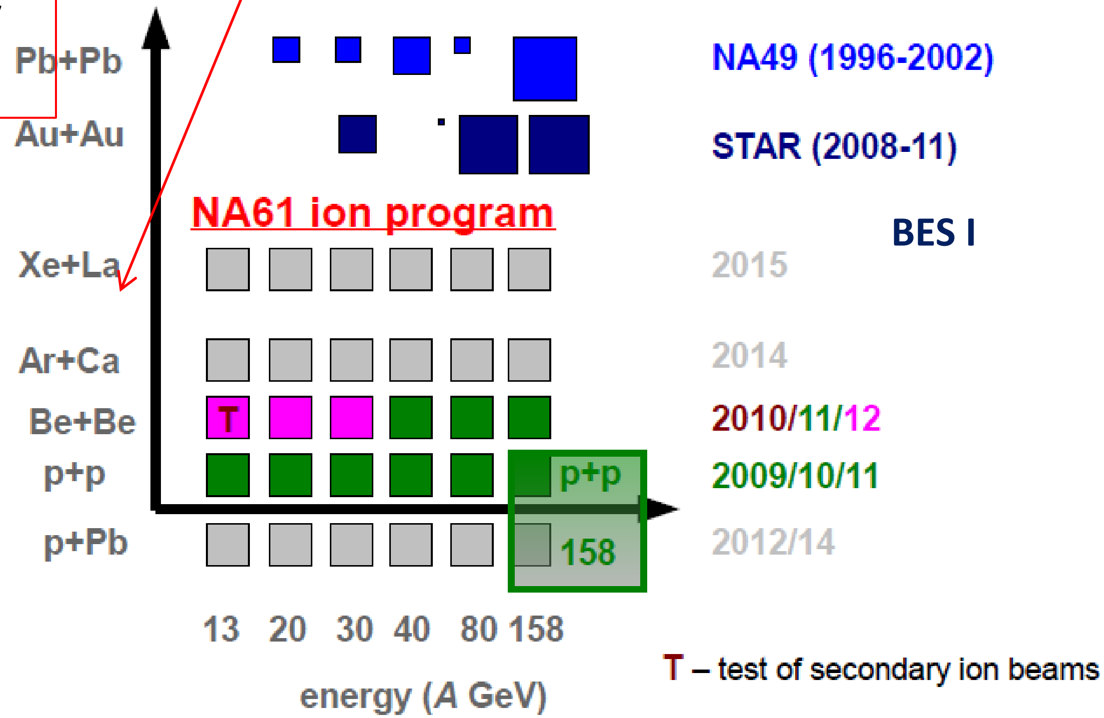
Not Ideal

- **Time Line:** 2009-2015
- **Energy Range:** $\sqrt{s_{NN}}$ = **4.9 to 17.3** GeV

μ_B = 0.560 to 0.230 GeV





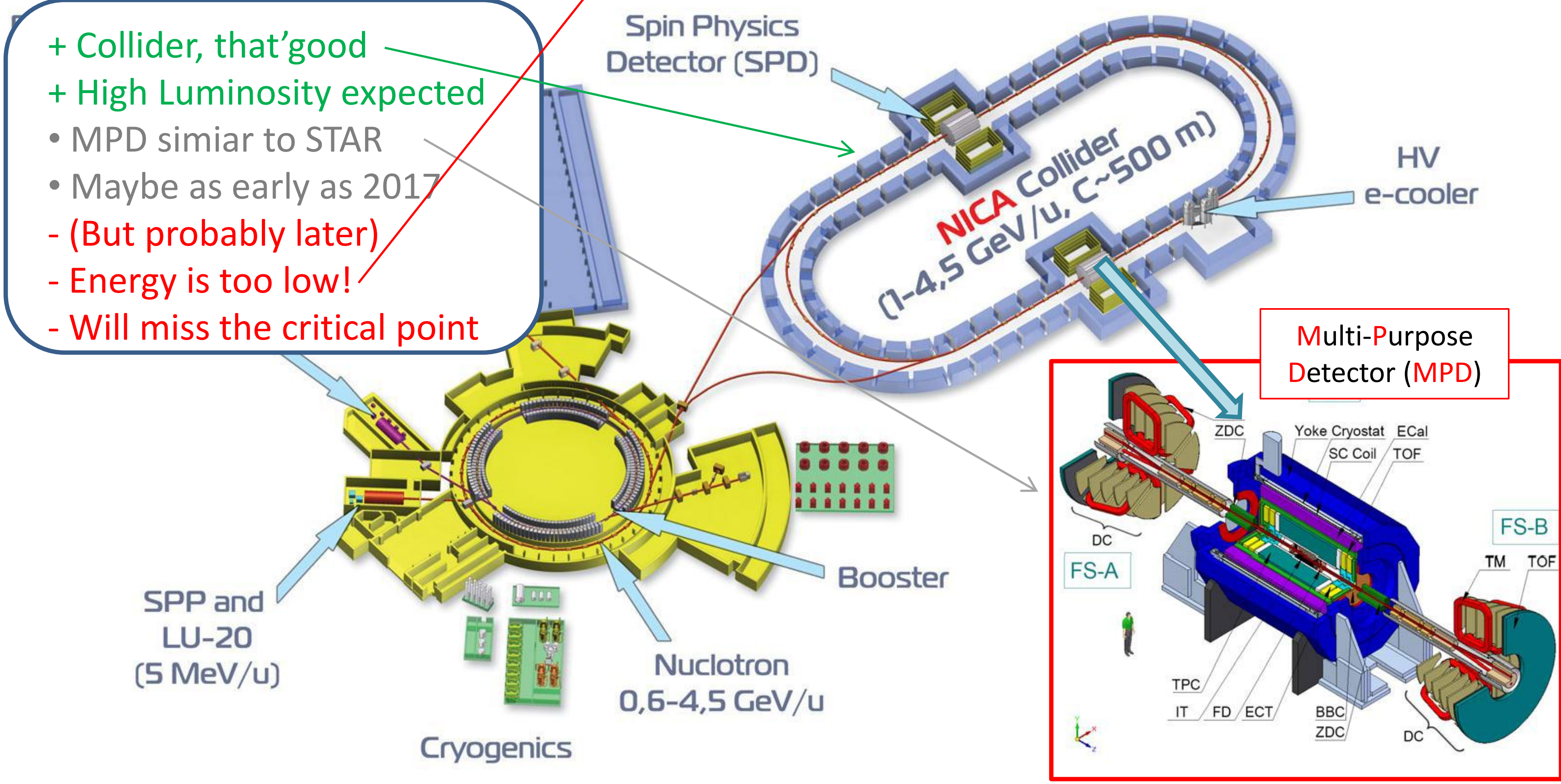


Nuclotron based Ion Collider fAcility (NICA)

•**Time Line:** Not yet funded. Plan is to submit documents by end of 2012.
Operations could not begin before 2017 (probably much later)

•**Energy Range:** $\sqrt{s_{NN}}$ from **3.9 - 11 GeV** for Au+Au; μ_B from 0.630 - 0.325 GeV.

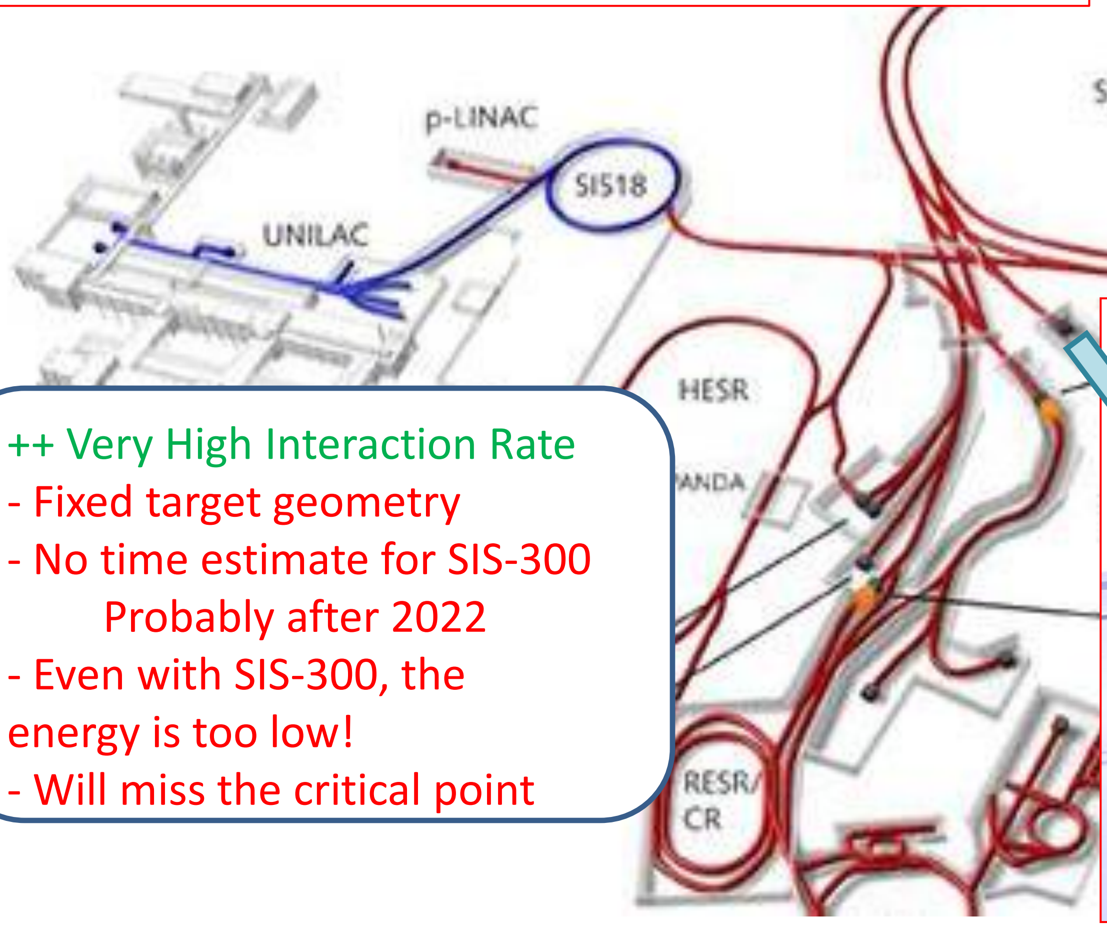
+ Collider, that'good
+ High Luminosity expected
• MPD simiar to STAR
• Maybe as early as 2017
- (But probably later)
- Energy is too low!
- Will miss the critical point



Facility for Antiproton and Ion Research (FAIR)

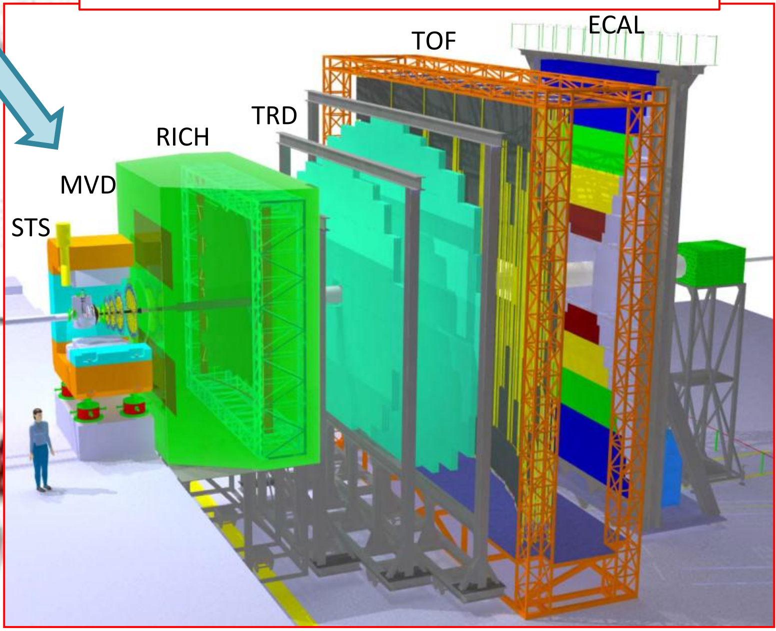
Time Line:
SIS-100 is funded and will be complete by 2018
SIS-300 will need additional funding (**no time estimate**)

Energy Range:
SIS-100: Au+Au @ 2.9 GeV
SIS-300: Au+Au from **2.7 to 8.2** GeV
μ_B from 0.730 to 0.410 GeV



++ Very High Interaction Rate
- Fixed target geometry
- No time estimate for SIS-300
  Probably after 2022
- Even with SIS-300, the energy is too low!
- Will miss the critical point

Compressed Baryonic Matter (CBM)



Comparison of Facilities

Facilty	RHIC BESII	SPS	NICA	SIS-300
Exp.:	STAR PHENIX	NA61	MPD	CBM
Start:	2017	2009	>2017?	>2022?
Au+Au Energy: $\sqrt{s_{NN}}$ (GeV)	7.7– 19.6+	4.9-17.3	2.7 - 11	2.7-8.2
Event Rate: At 8 GeV	100 HZ	100 HZ	<10 kHz	<10 MHZ
Physics:	CP&OD	CP&OD	OD&DHM	OD&DHM
		Fixed Target Lighter ion collisions		Fixed Target

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

Conclusion:
RHIC is the best option

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
- 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**

- Currently, the US is the leader in the field. Without RHIC, that leadership moves overseas.

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