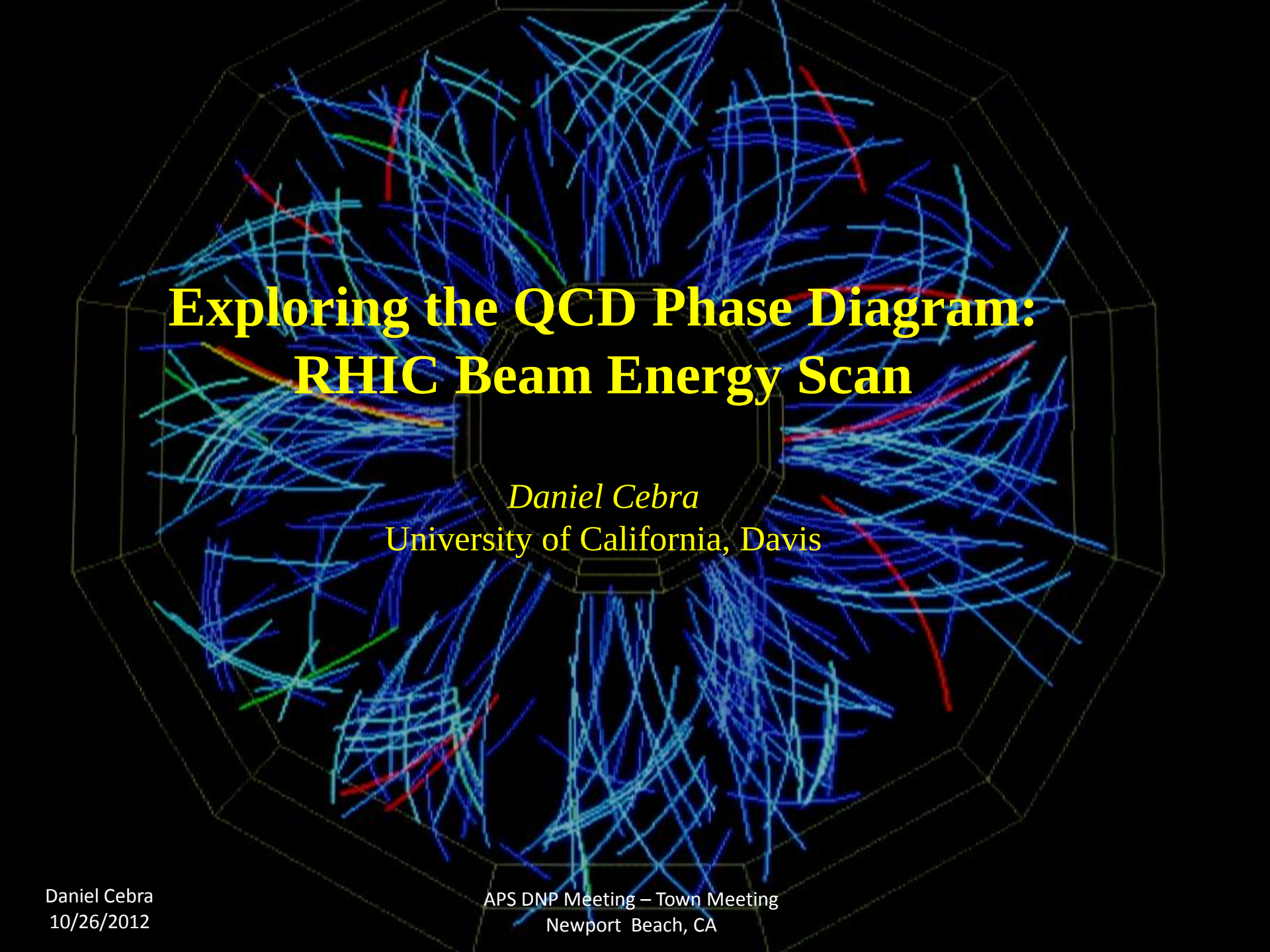


Exploring the QCD Phase Diagram: RHIC Beam Energy Scan

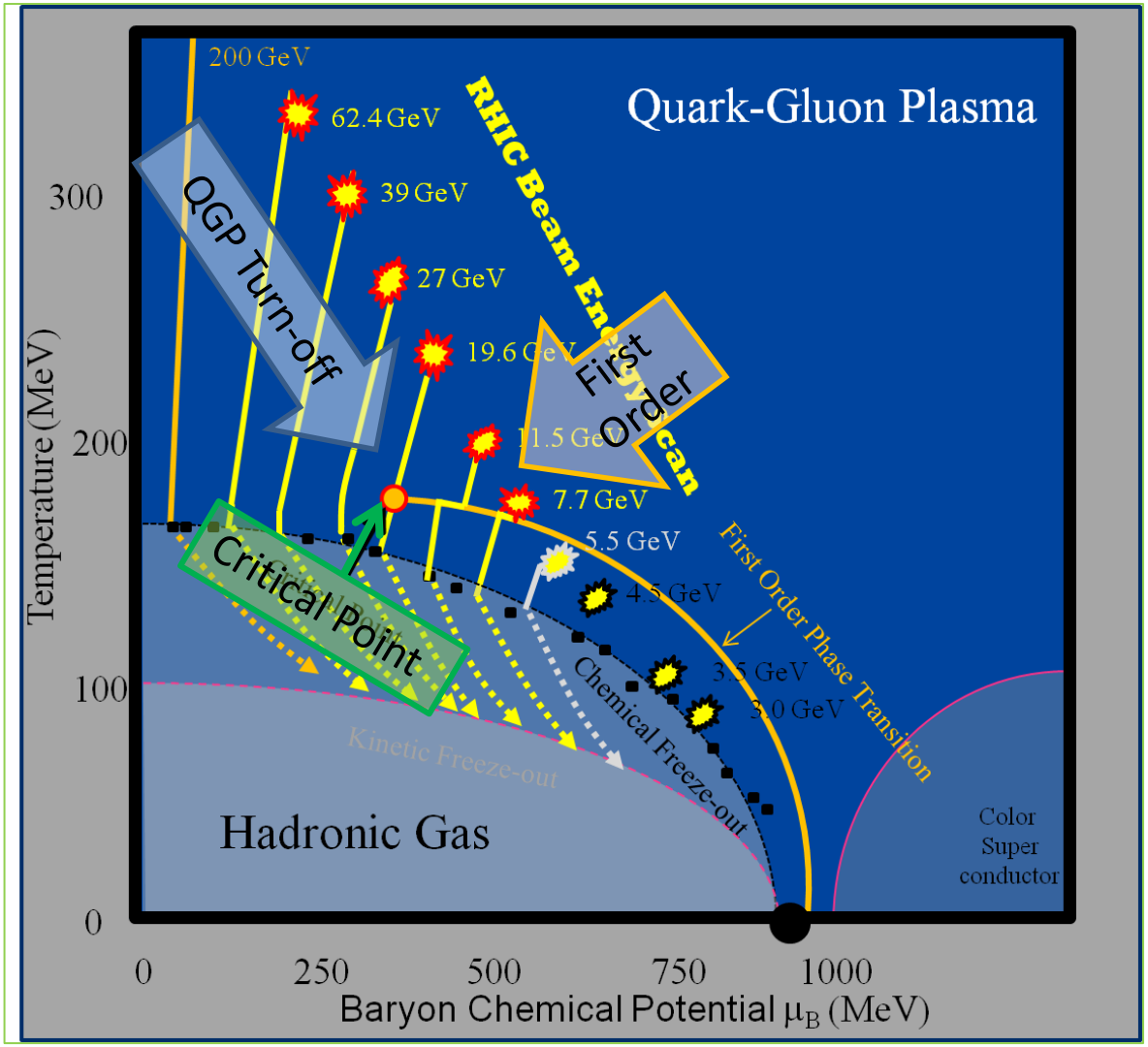
Daniel Cebra
University of California, Davis

The RHIC Beam Energy Scan

- Much progress has been made in understanding the phase diagram of QCD matter. We expect a cross-over at high energy. At lower energy there should be a first order transition.

- Mapping the features of the QCD matter phase diagram is key to our understanding dense matter.

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



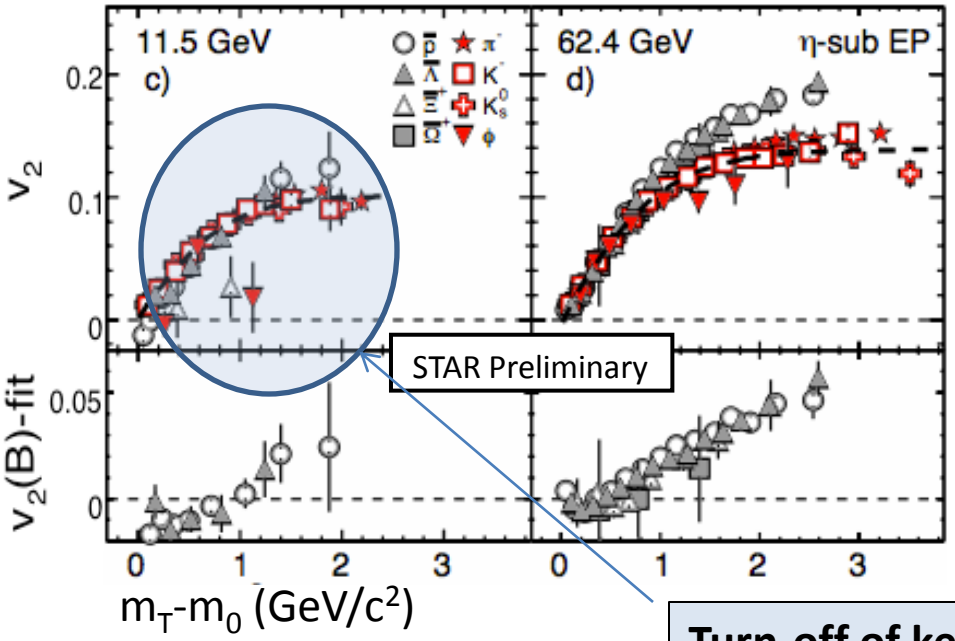
Overview of the Beam Energy Scan Goals

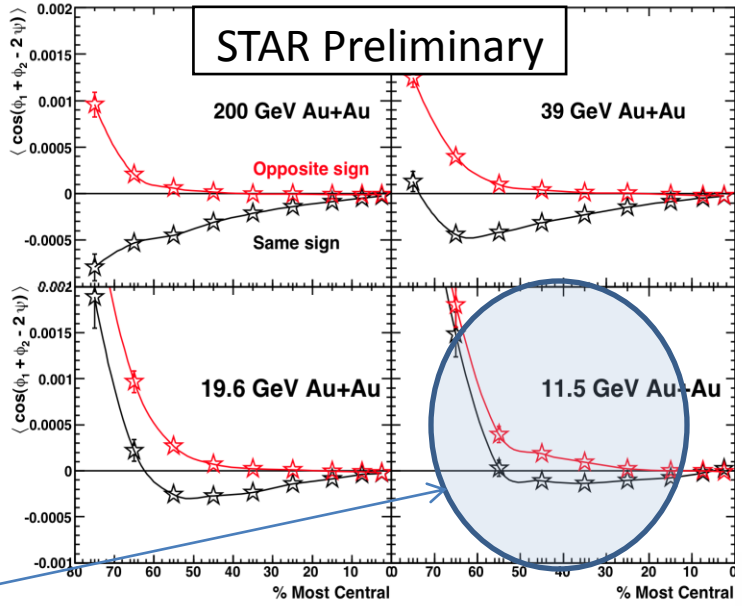
1. **Turn-off of QGP signatures:**
   - **NCQ breaks down below 19.6 GeV**
   - **High p_t suppression not seen below 19.6 GeV**
   - **LPV effect not seen below 11.5 GeV**

2. **Evidence of the first order phase transition.**
   - **Inflection in v_2 at 7.7**
   - **v_1 sign change at 7.7**
   - Large Azimuthal HBT signal at 7.7

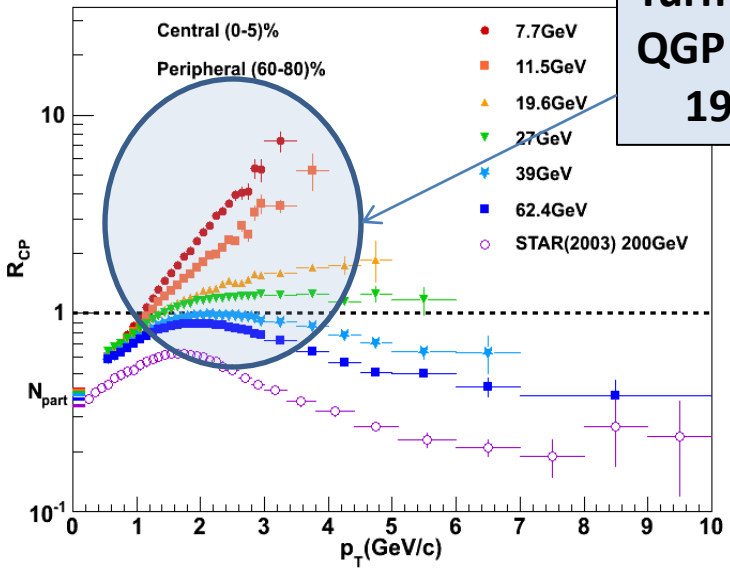
3. **Search for the critical point.**
   - K/π, K/p, or p/π fluctuations are not conclusive.
   - **Higher moments of the proton distributions – hints.**

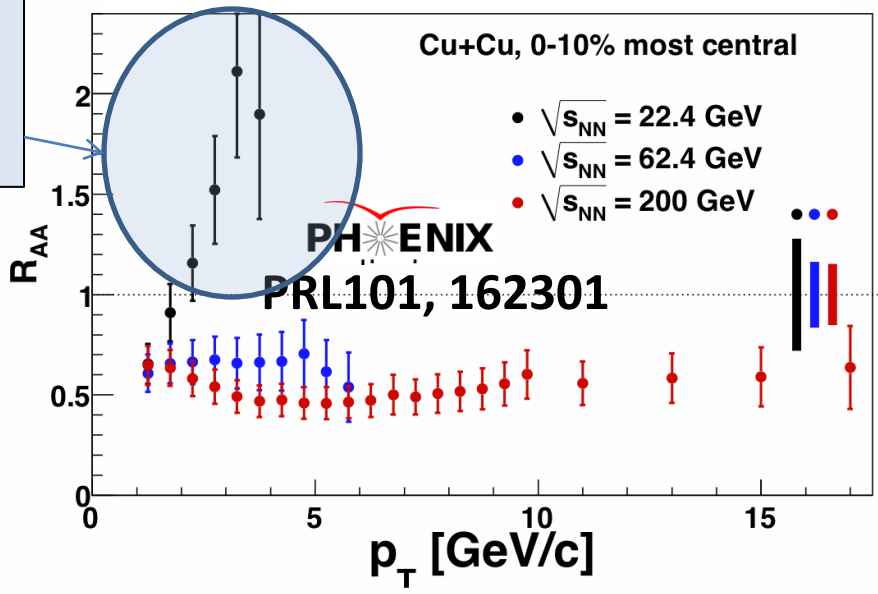
Turn-off of QGP Signatures





Turn-off of key QGP signatures 19.6 – 11.5

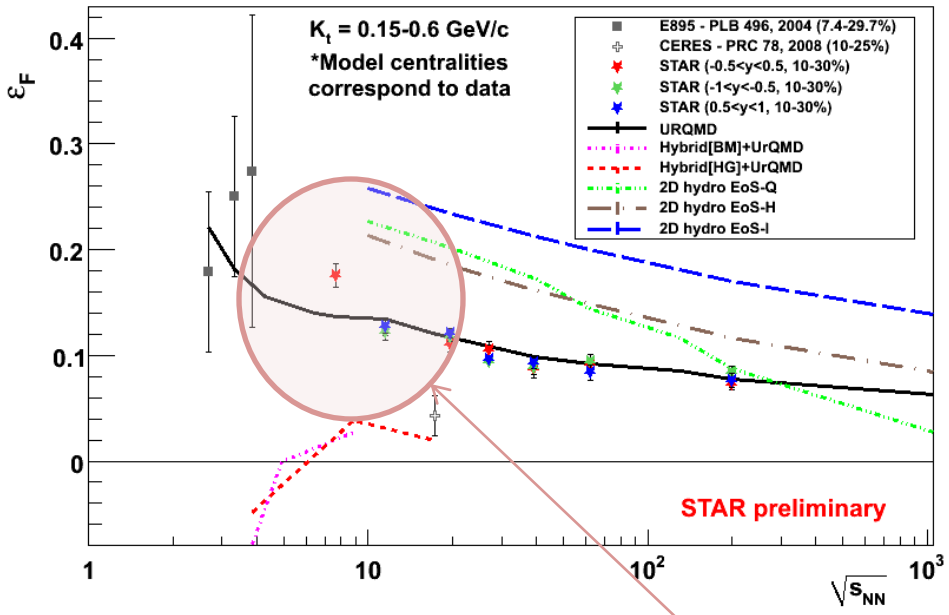


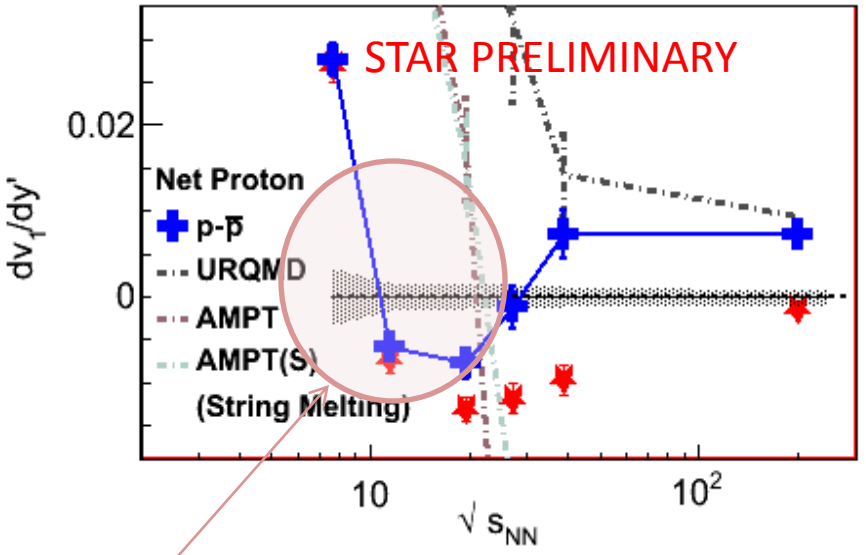


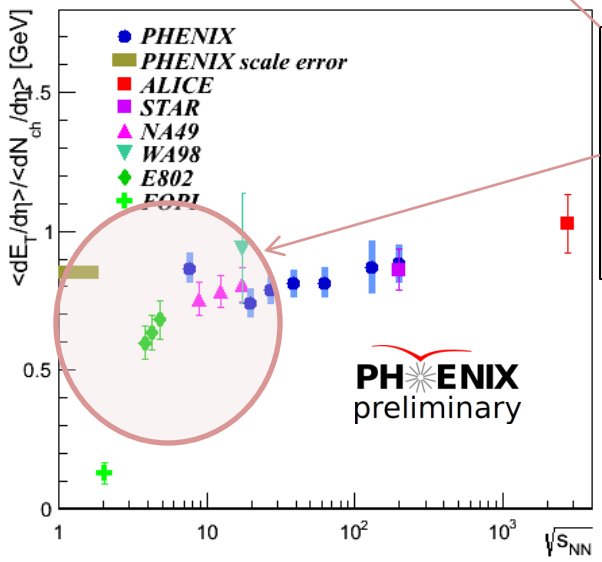
Meeting
ewport I

Search for 1st Order PhaseTransition

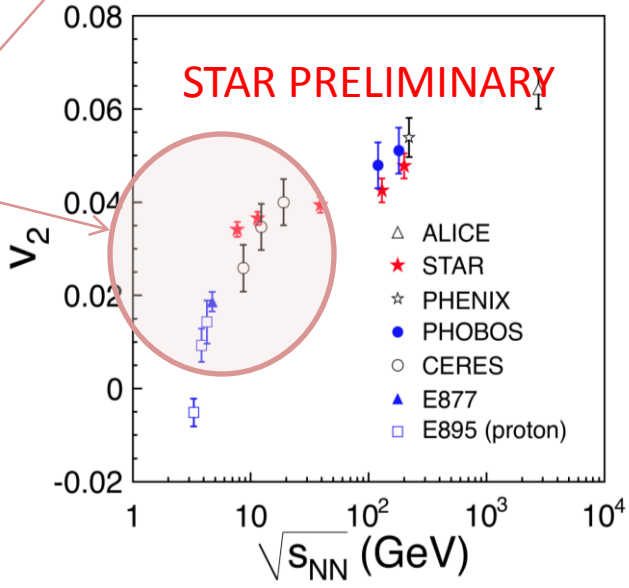
Excitation function for freeze-out eccentricity, ε_F







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

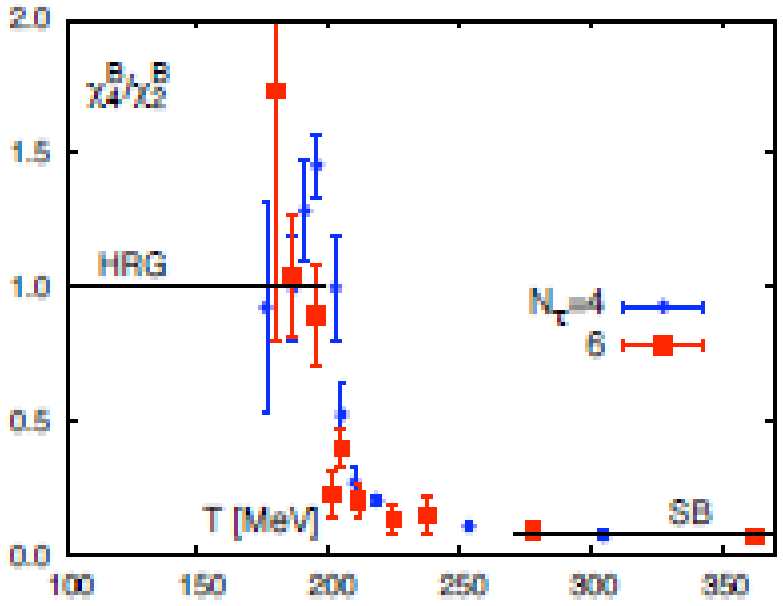


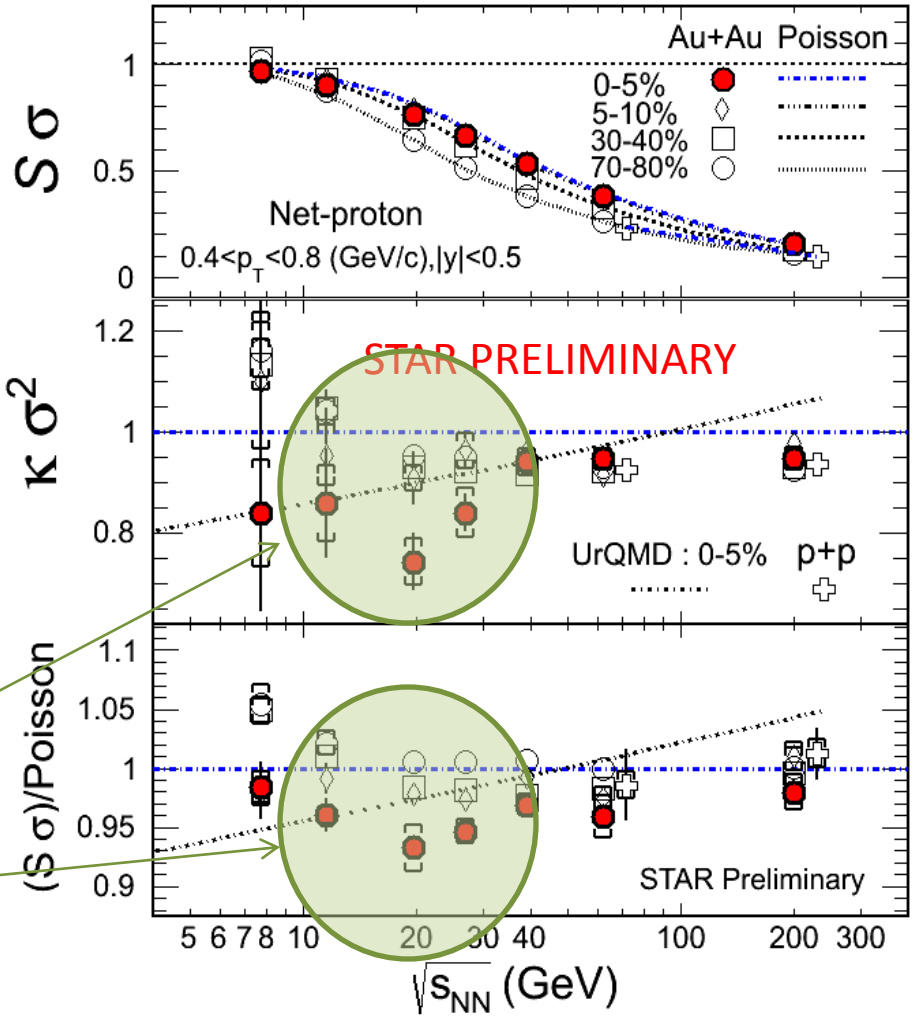
Search for the Critical Point

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 HRG model in the middle energies of the BES range

Need more statistics or finer energy steps

What Have We Learned?

The key QGP *signatures* disappear between 19.6 and 11.5 GeV

- Necessary, but not sufficient to say that QGP has gone

- First Order phase transition/Onset of deconfinement *likely* at the low end of the BES Range
  - *low energy performance is critical*

- Critical Point is challenging to find, will need more statistics
  - Do we need finer steps or more statistics?

How should we answer the remaining questions?

RHIC Beam Energy Scan II:

$\sqrt{s_{NN}}$ (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

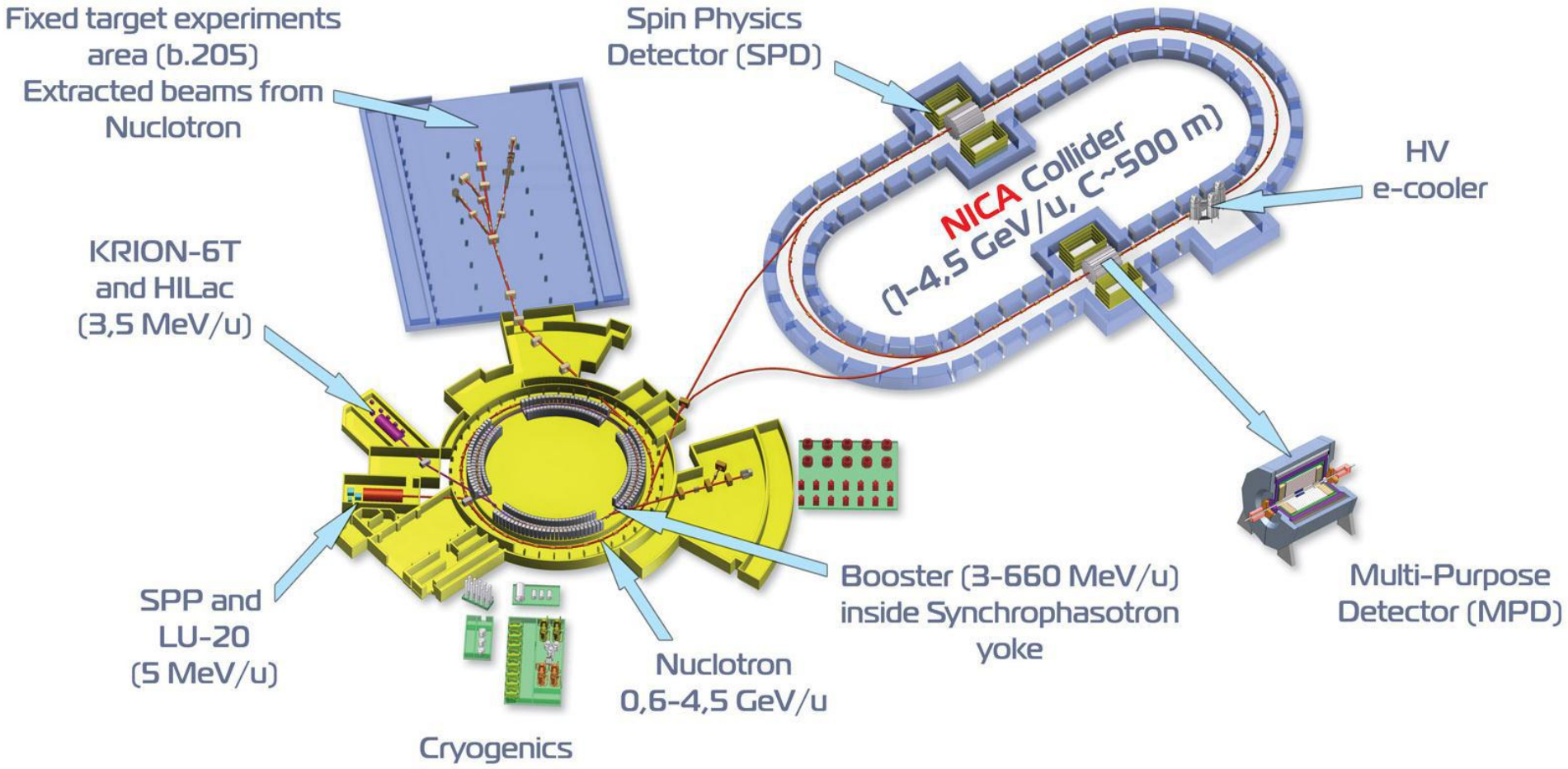
Critical Point

Onset of Deconfinement

Complementary to the NICA, FAIR, CERN experimental programs

Nuclotron based Ion Collider fAcility (NICA)

Collider
Operations to begin ~2016
$\sqrt{s_{NN}}$ from **3.9 - 11 GeV** for Au+Au; μ_B from 0.630 - 0.325 GeV.

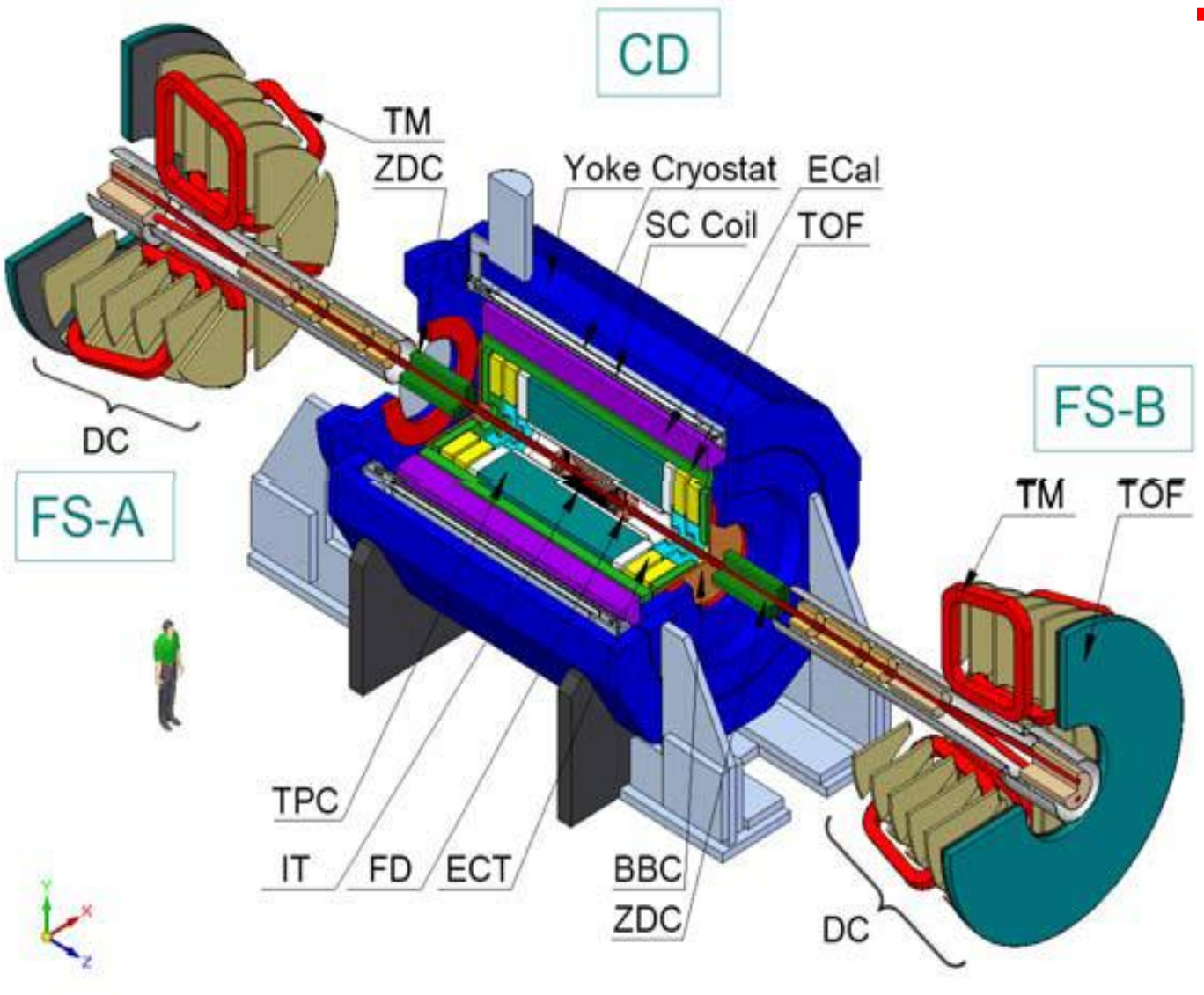


MPD Experiment: *Multi-Purpose Detector*

Capabilities will be very similar to STAR.

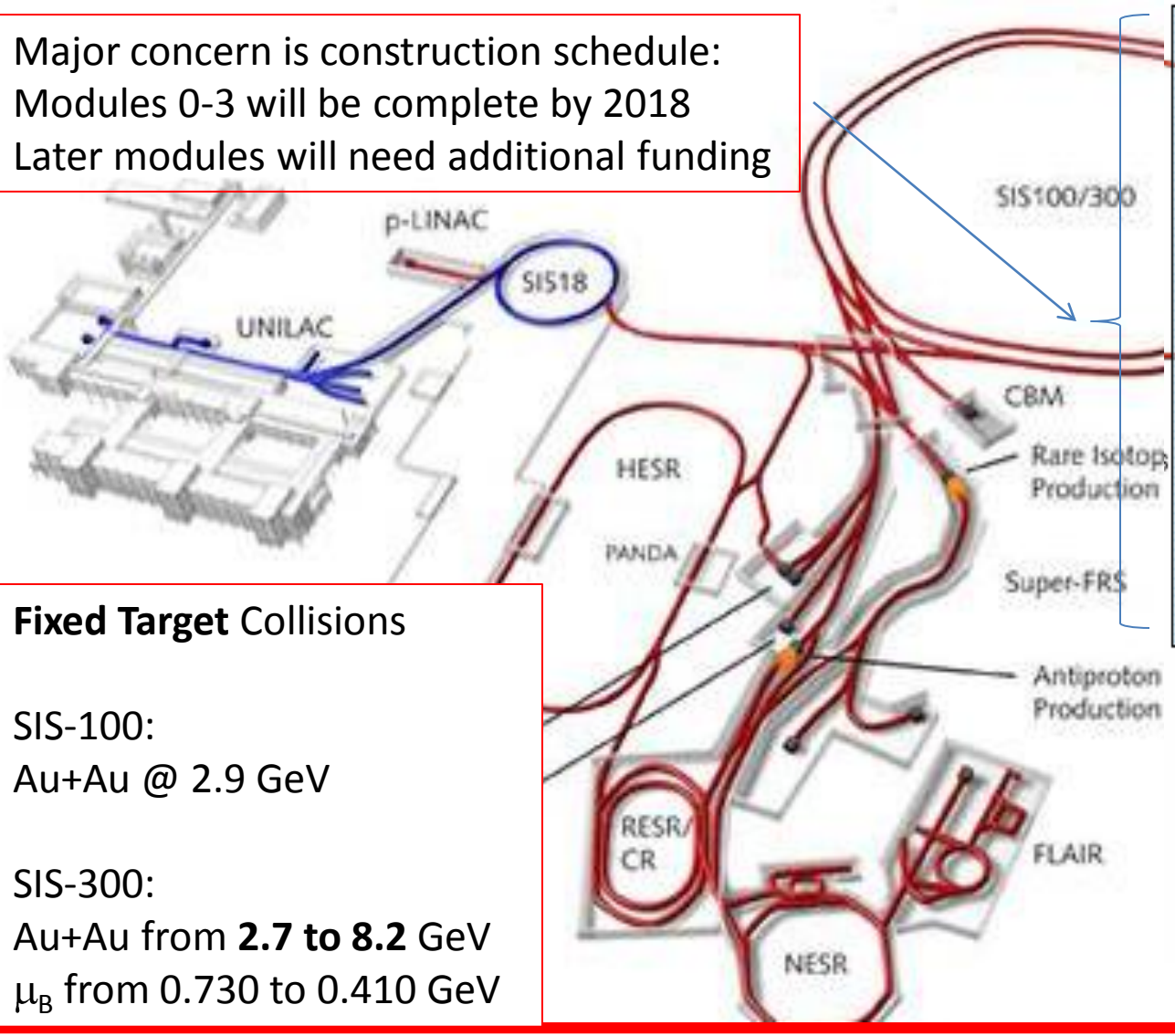
Luminosities of NICA will be higher than RHIC

Collision rates of < 10 kHz



Facility for Antiproton and Ion Research (FAIR)

Major concern is construction schedule:
Modules 0-3 will be complete by 2018
Later modules will need additional funding



Module 0:
SIS100 and connection to existing GSI facility

Module 1:
Experimental areas

Module 2:
Super-Fragment separator

Module 3:
High-energy antiprotons (p-linac, pbar-target, CR, HESR)

Module 4:
NESR, low energy RIB and low energy antiprotons

Module 5:
RESR storage ring

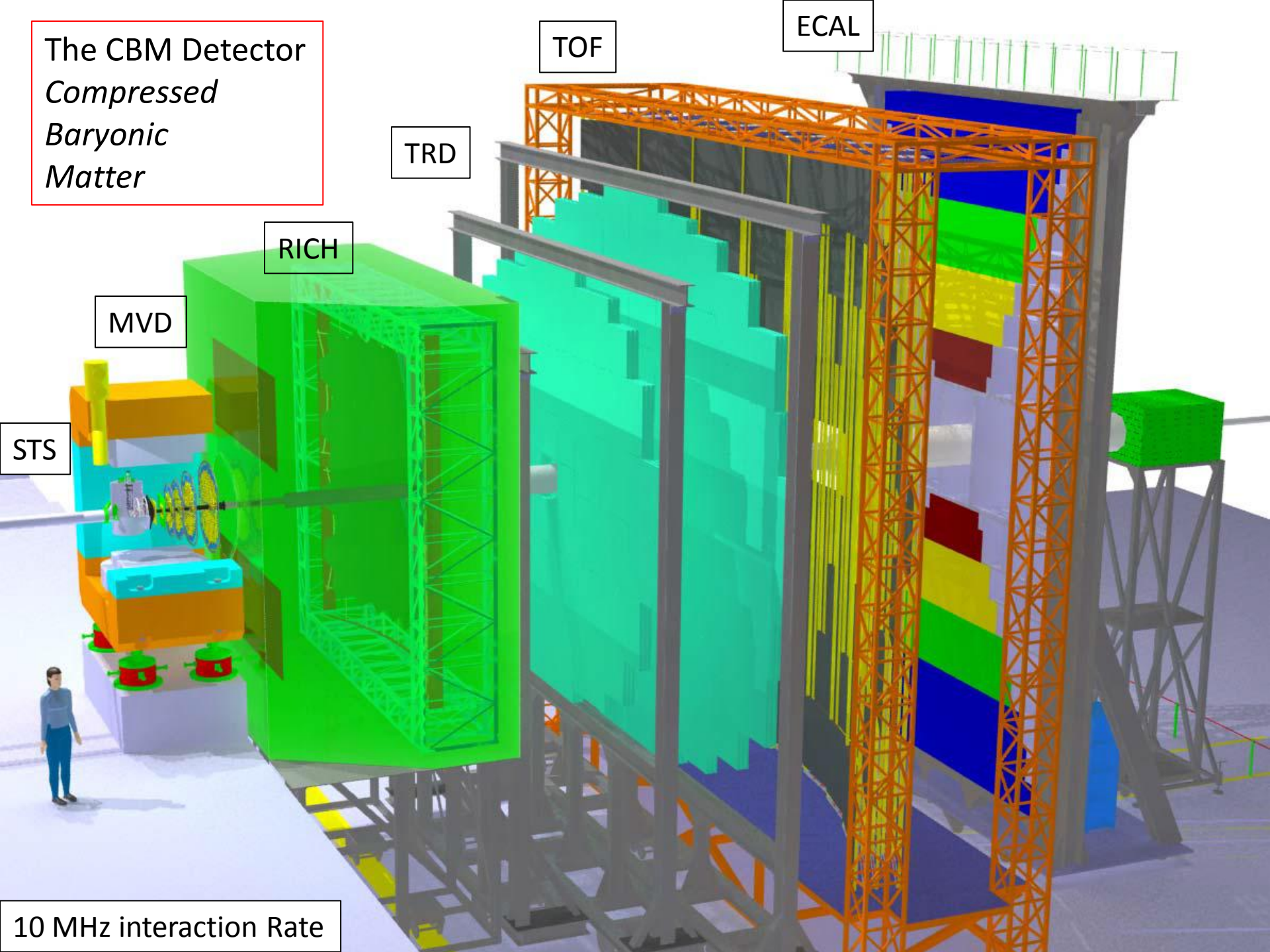
Module 6: SIS-300

Fixed Target Collisions

SIS-100:
Au+Au @ 2.9 GeV

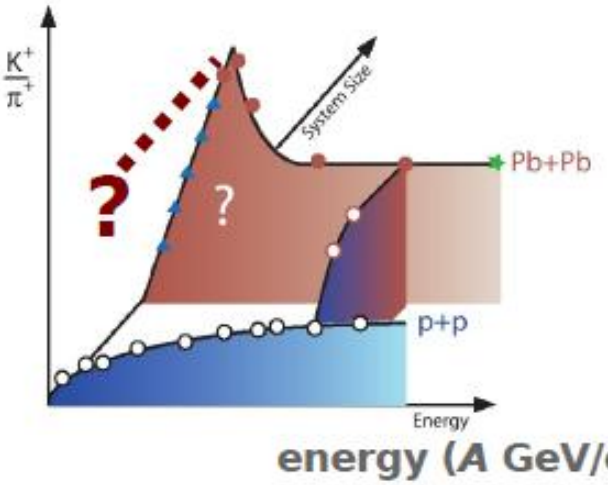
SIS-300:
Au+Au from **2.7 to 8.2** GeV
μ_B from 0.730 to 0.410 GeV

The CBM Detector
Compressed Baryonic Matter

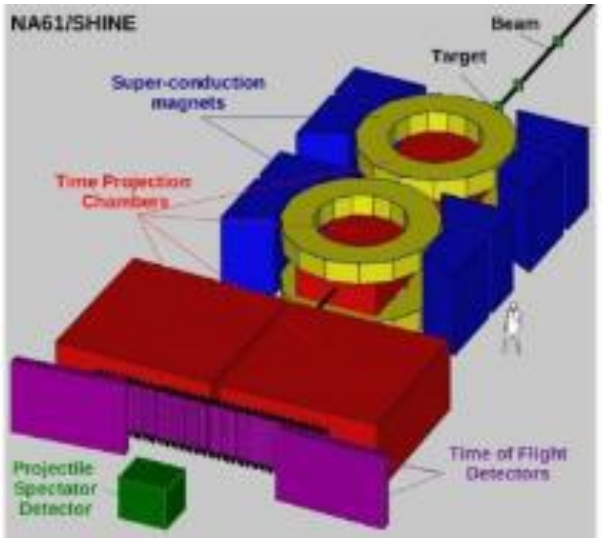


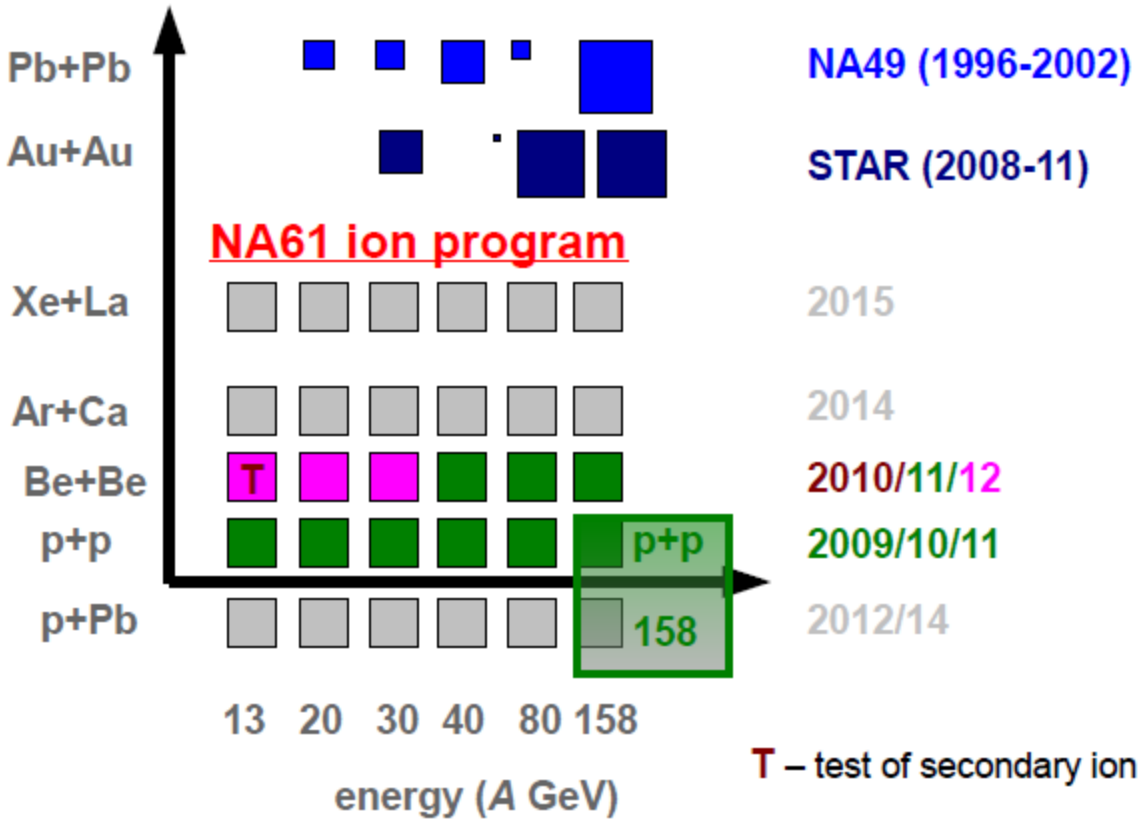
10 MHz interaction Rate

SHINE
NA61



Fixed Target Collisions
$\sqrt{s_{NN}}$ = **4.9 to 17.3** GeV
μ_B = 0.560 to 0.230 GeV

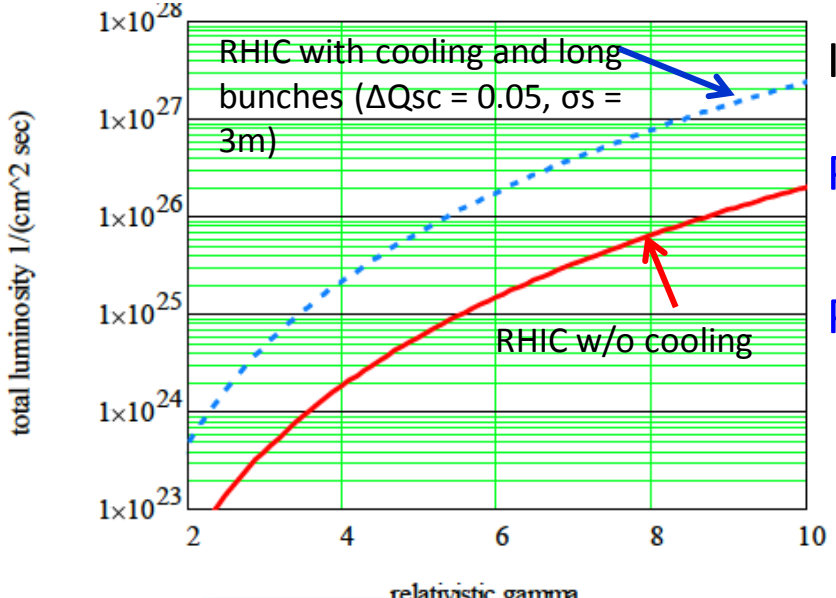




Low Energy Electron Cooling at RHIC

Electron Cooling can raise the luminosity by a factor a 3-10 in the range from3 – 10 GeV

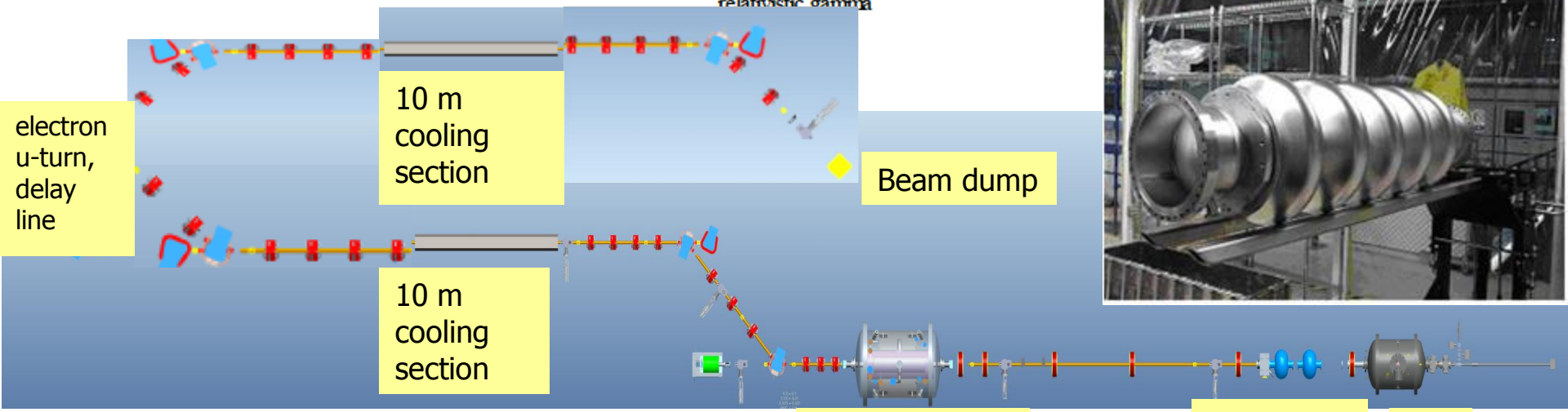
Long Bunches increase luminosity by factor of 2-5



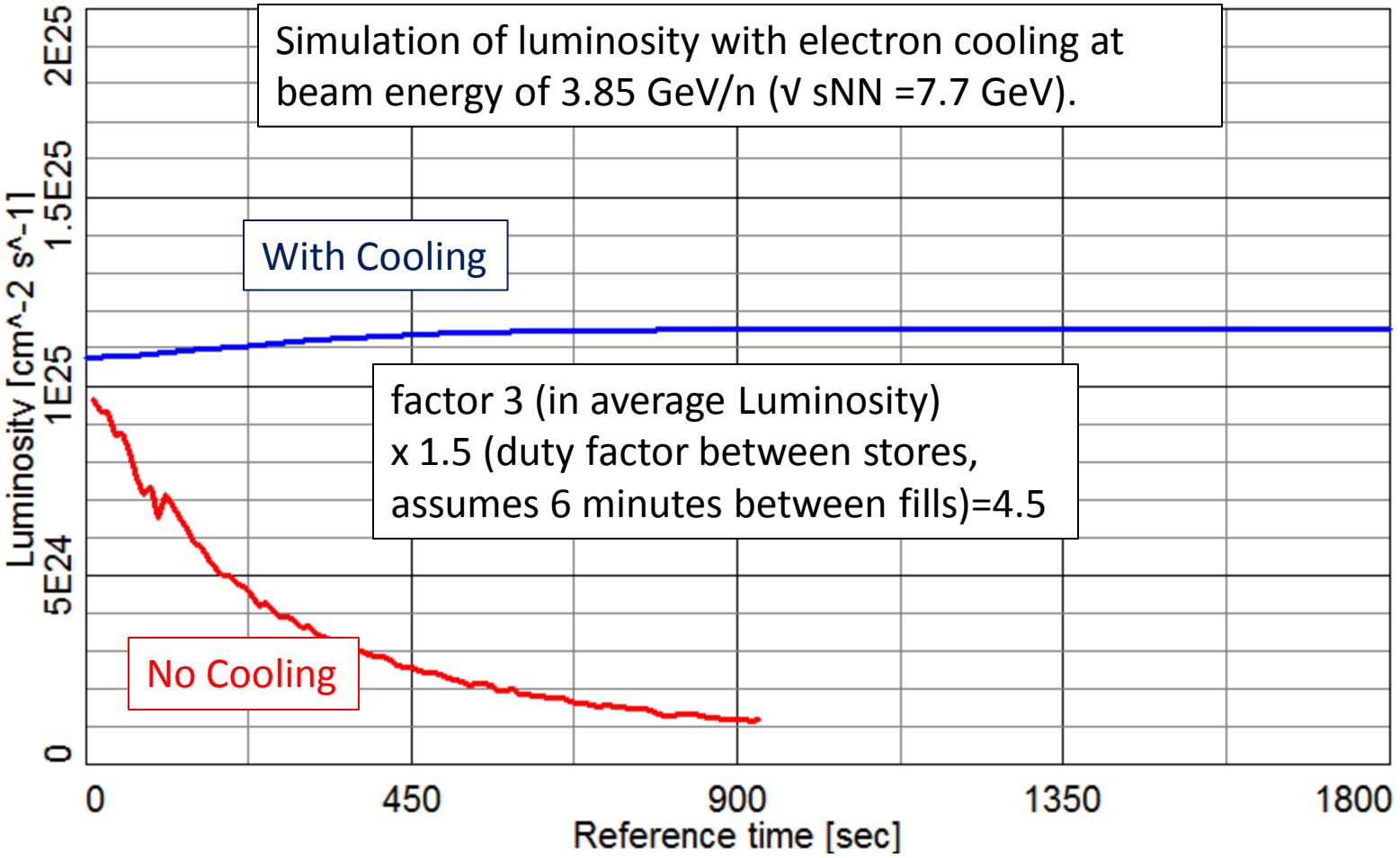
Implementation in phases:

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

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



Cooling of bunches with nominal length (1-2 m rms)
(counteracting IBS only and longer stores)



Comparison of Facilities

Facilty	RHIC	NICA	SIS-300	SPS
Exp.:	STAR PHENIX	MPD	CBM	NA61
Start:	2010	2017	>2018	2009
Au+Au Energy: √sNN (GeV)	7.7-- 50	2.7 - 11	2.7-8.2	4.9-17.3
Event Rate: At 8 GeV	100 HZ	<10 kHz	<10 MZ	100 HZ
Physics:	CP&OD	OD&DHM	OD&DHM	CP&OD

Lighter ion collisions

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

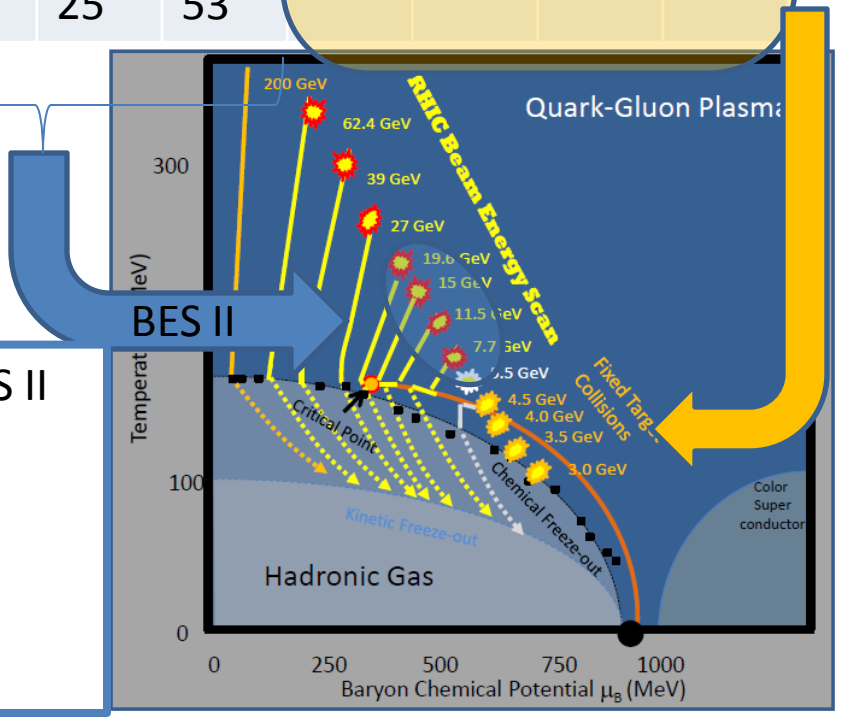
Fixed Target

Beam Energy Scan II

$\sqrt{s_{NN}}$ (GeV)	62.4	39	27	19.6	15	11.5	7.7	4.5	4.0	3.5	3.0
μ_B (GeV)	70	115	155	205	250	315	420	585	620	670	720
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**	5	5	5	5
eCooling	---	---	---	8	6	4.5	3				
Beam (days)	---	---	---	14	10	25	53				

Fixed Target Collisions

- We have now put forward a BES II proposal to focus on the most interesting region
- Electron cooling is key to the feasibility of this proposal



What would be lost?

- RHIC is optimally suited to find the critical point.
- NICA and FAIR are probably too low in energy
- NA61 is a fixed target experiment and is running lighter ions