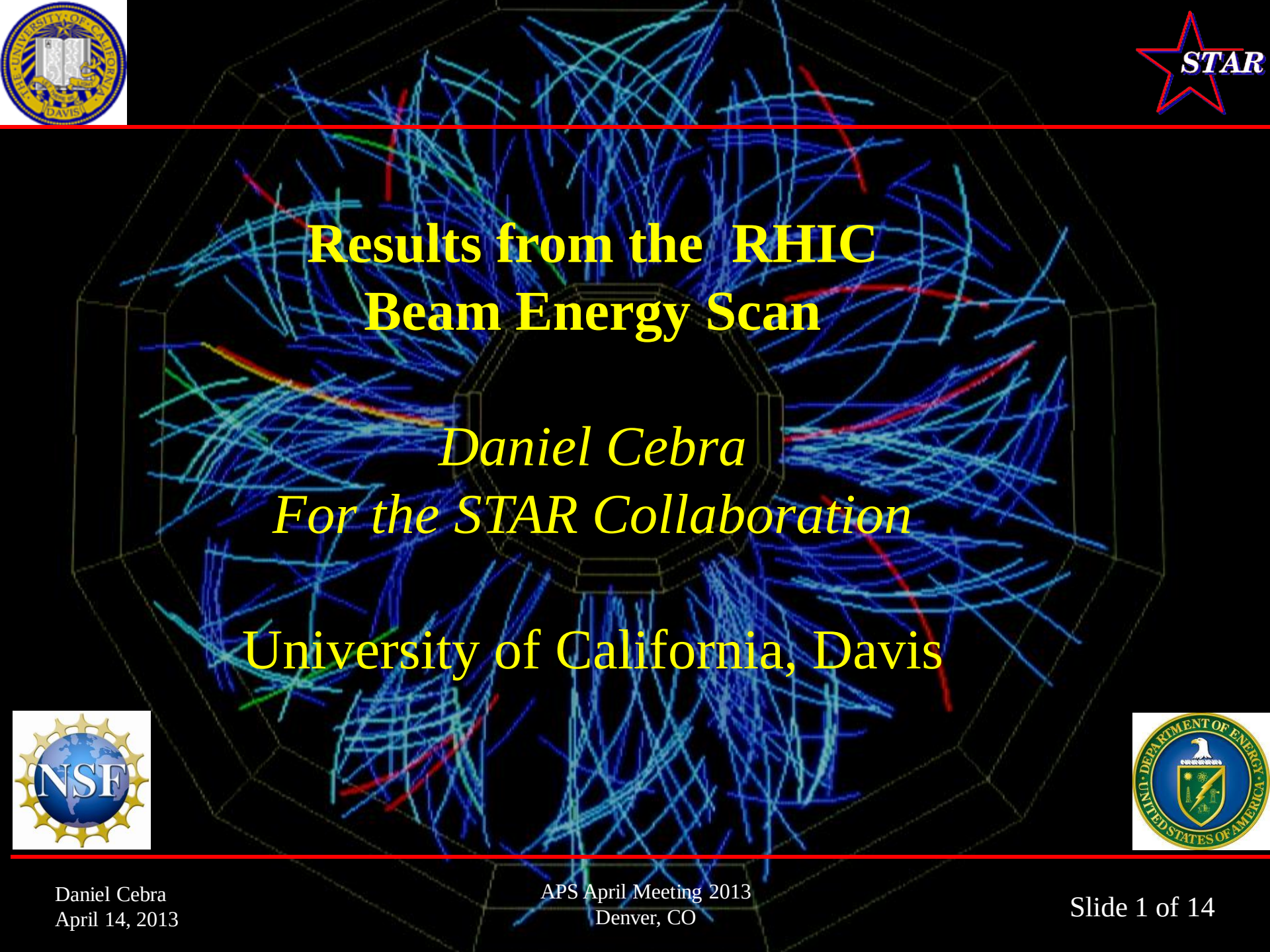


Results from the RHIC Beam Energy Scan

Daniel Cebra
For the STAR Collaboration

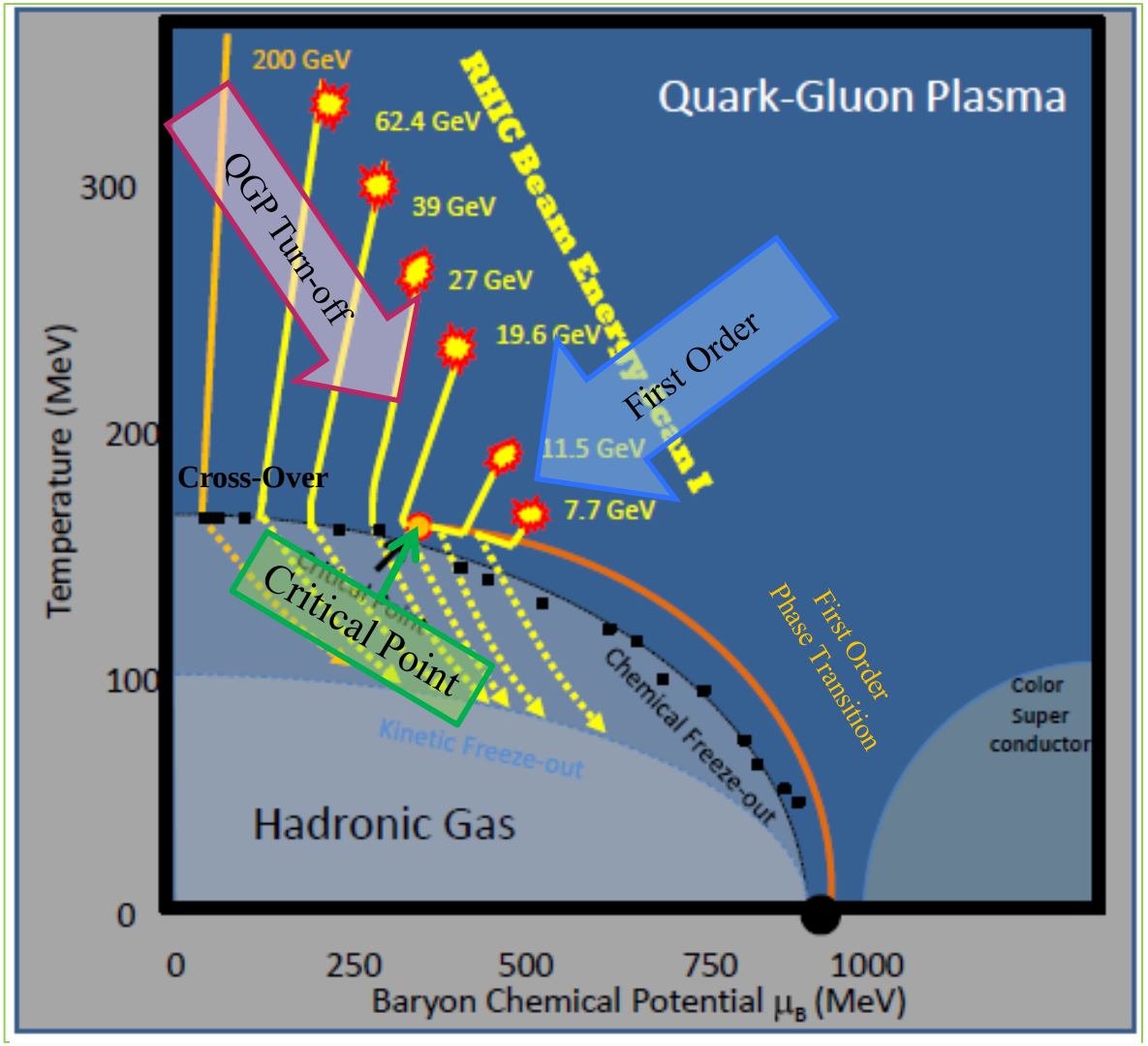
University of California, Davis

The RHIC Beam Energy Scan

- Much progress has been made in understanding the phase diagram of QCD matter. We expect a cross-over at low μ_B/T. At higher μ_B/T there could be a first order transition.

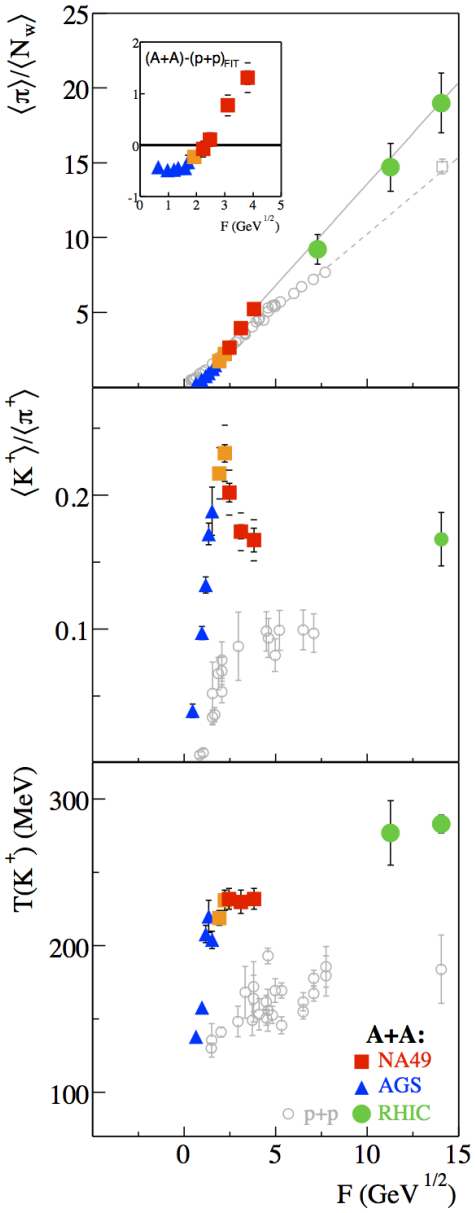
- Mapping the features of the QCD matter phase diagram is key to our understanding dense matter.

- In 2009 the RHIC PAC approved a series of six energies to search for the **turn-off of QGP signatures**, the **critical point**, and evidence of a **first order phase transition**.



What Determined the Range of Energies?

1) RHIC had already run Au+Au at 200 and 62.4 GeV.
2) NA49 had completed a scan at the SPS and claimed observation of the *onset of deconfinement* at 7.7 GeV.
3) The μ_B size between steps needed to be small enough so that we would not miss the critical point.
4) The total request needed to be less than 10 weeks of collider time.
5) Adequate statistics would be needed at all energies, even for rare signals (ϕ, Ω).
6) Certain energies could not be run by the collider (others energies not STAR and PHENIX simultaneous)
7) Some p+p energies had been run at Fermilab and ISR.



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

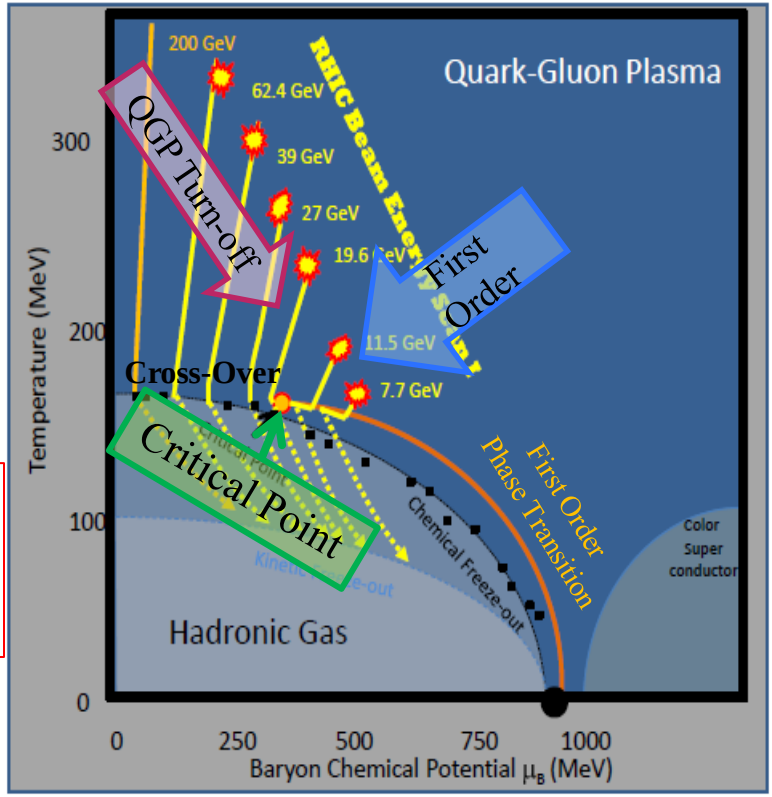
Step

Overview of the Beam Energy Scan Goals

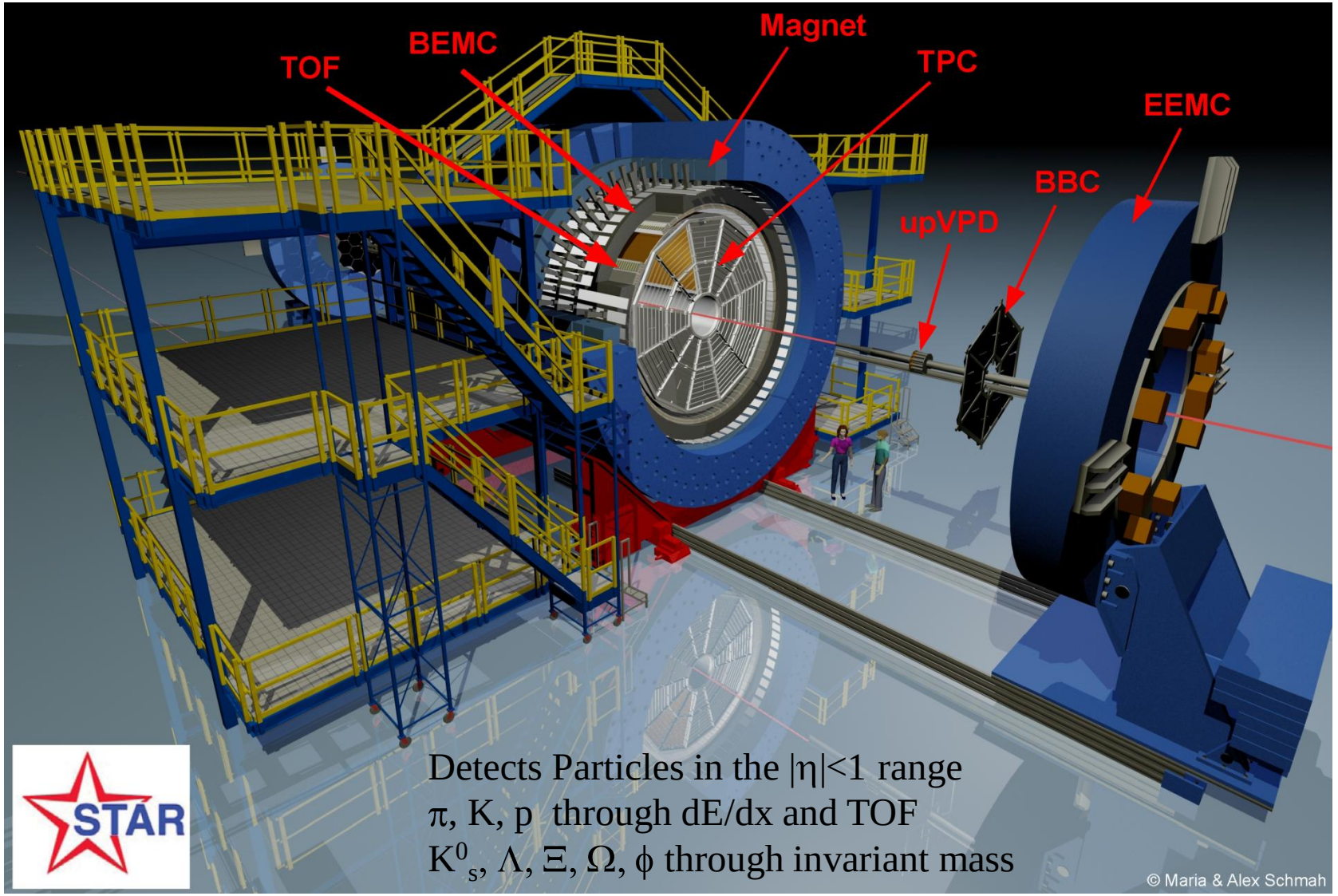
• The RHIC facility has successfully completed a *phase I* beam energy scan (BES-I).

- **Evidence of turn-off of QGP signatures**
  - Constituent quark scaling of flow
  - **High p_T suppression**
  - Chiral magnetic effect anisotropies
- **Evidence for first order phase transition**
  - The magnitude of the elliptic flow
  - **The directed flow**
  - The azimuthal HBT
- **Searches for critical point signatures**
  - Particle ratio fluctuations (K/π etc.)
  - **Skewness and Kurtosis of conserved quantities**

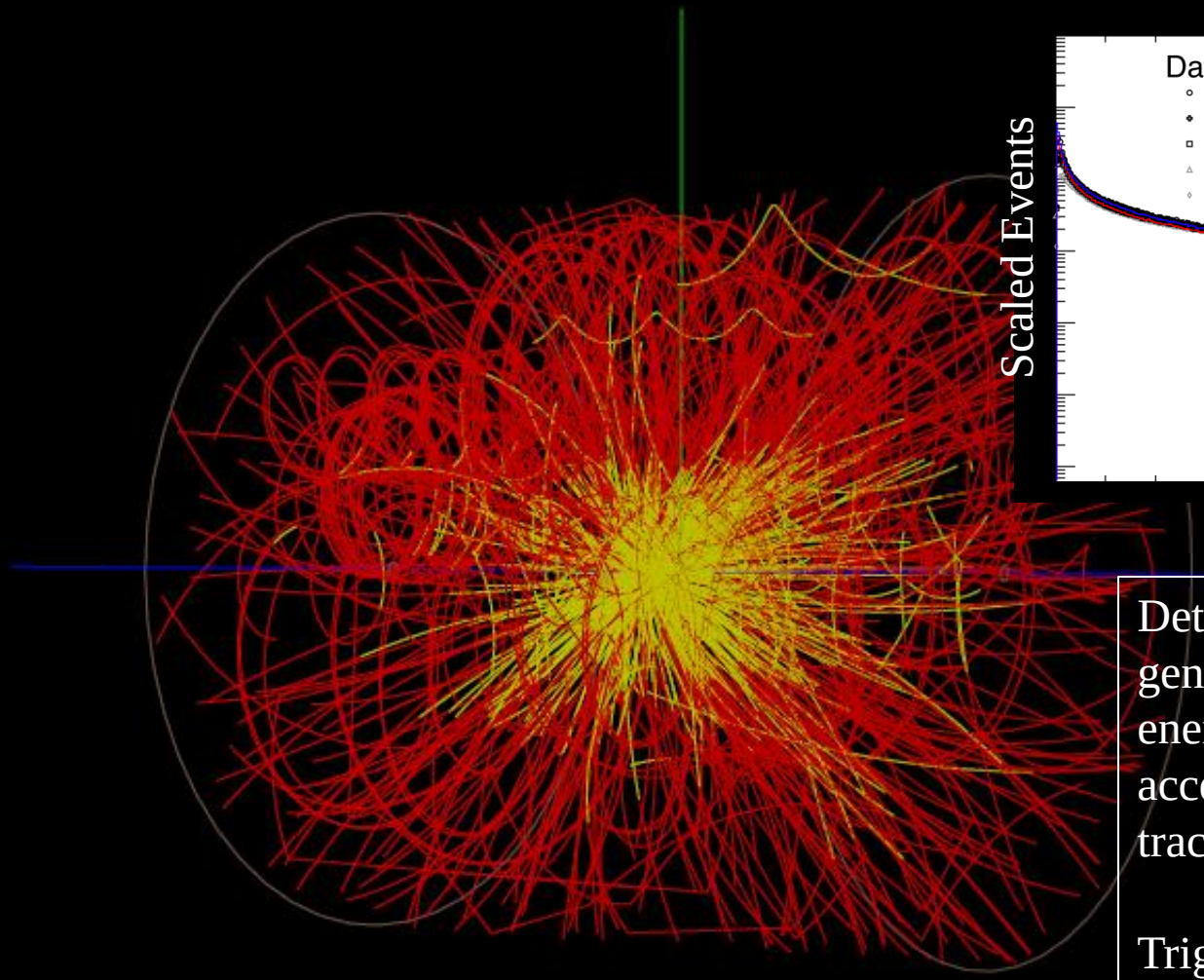
Only have time to mention the signals in bold

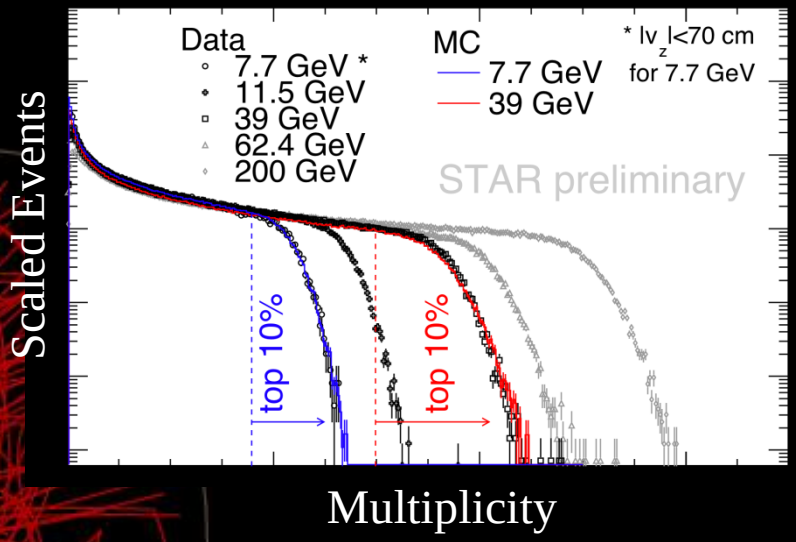


The STAR Detector for the Beam Energy Scan



Central Au+Au at 7.7 GeV



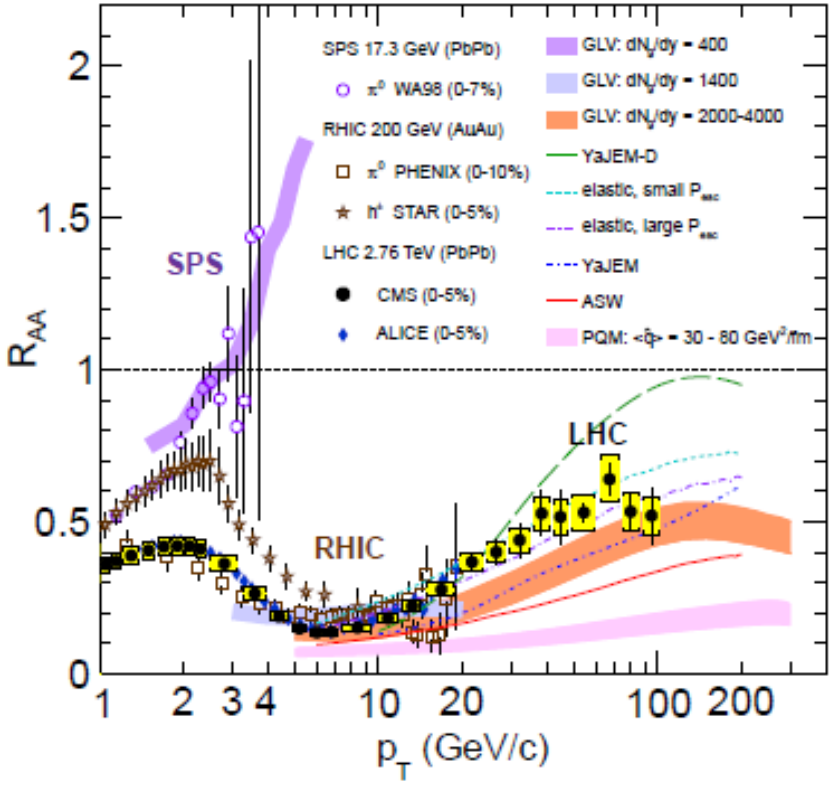


Detector performance generally improves with lower energies. Geometric acceptance remains the same, track density gets lower.

Triggering required effort, but was a solvable problem.

Turn-off of QGP Signatures

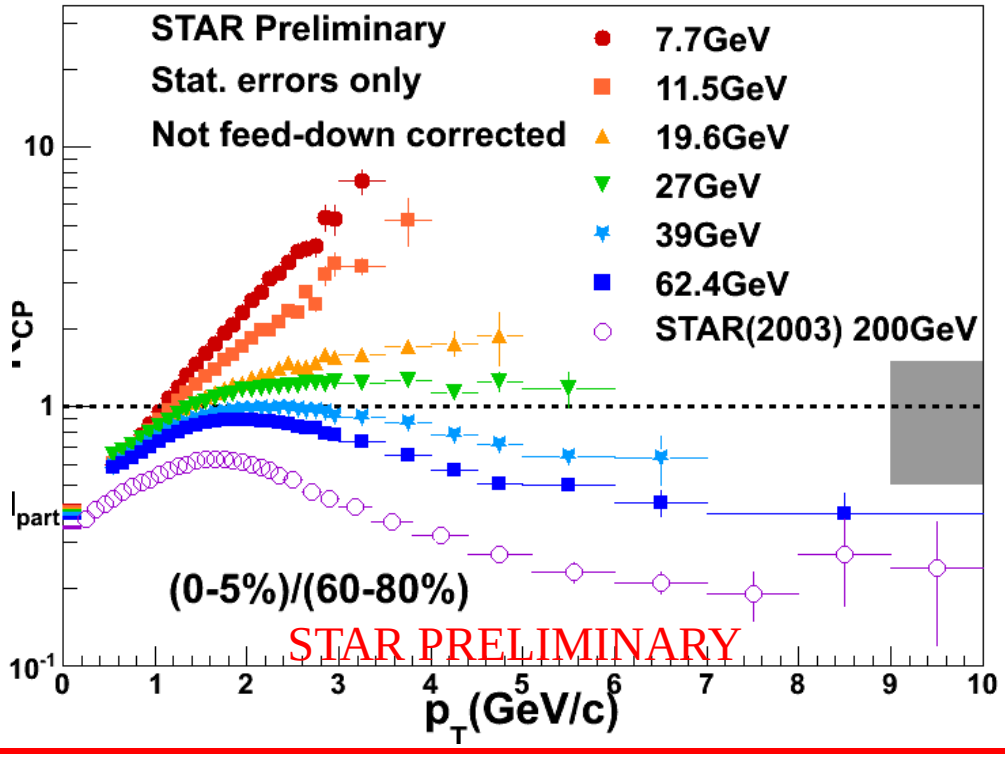
High p_T suppression has been seen as a clear manifestation of energy loss by color objects (quarks) in a color medium (QGP)



Eur.Phys.J. C72 (2012) 1945

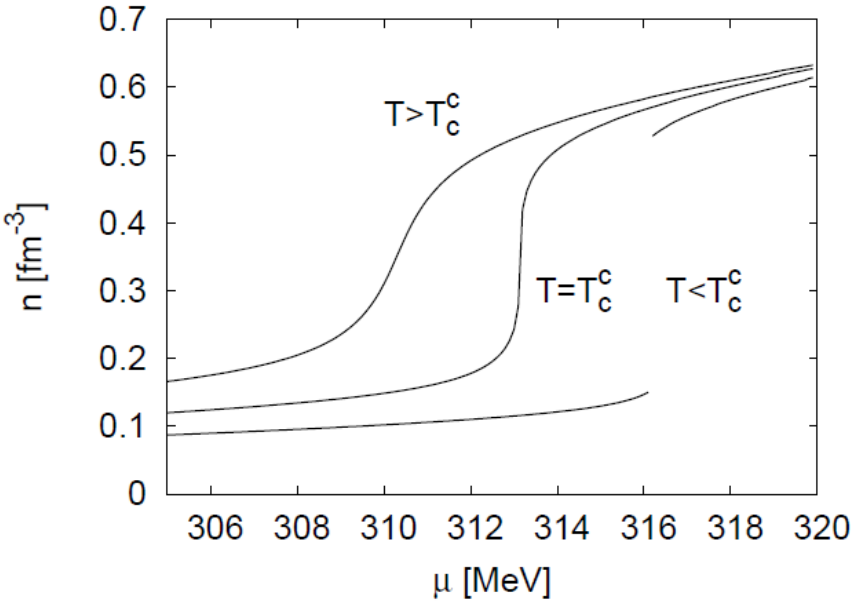
- R_{cp} suppression NOT seen at lower energies!

➔**The QGP signature is turned off.**

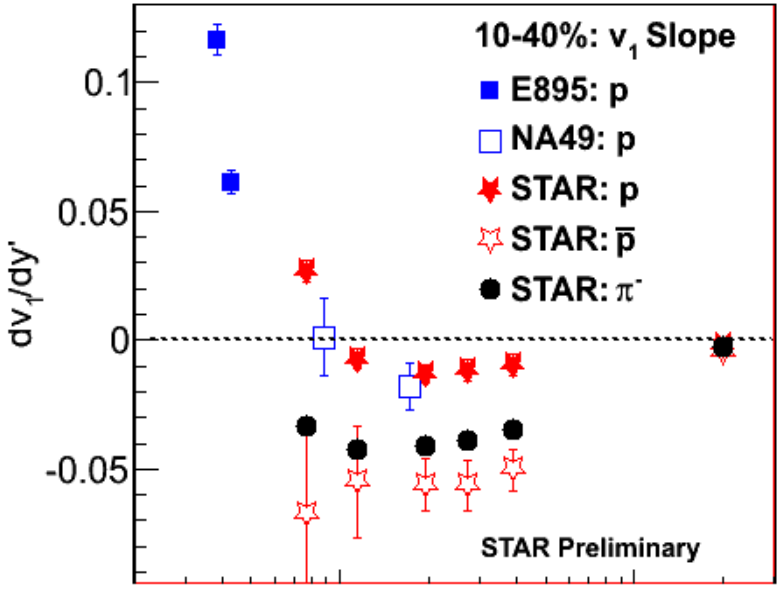


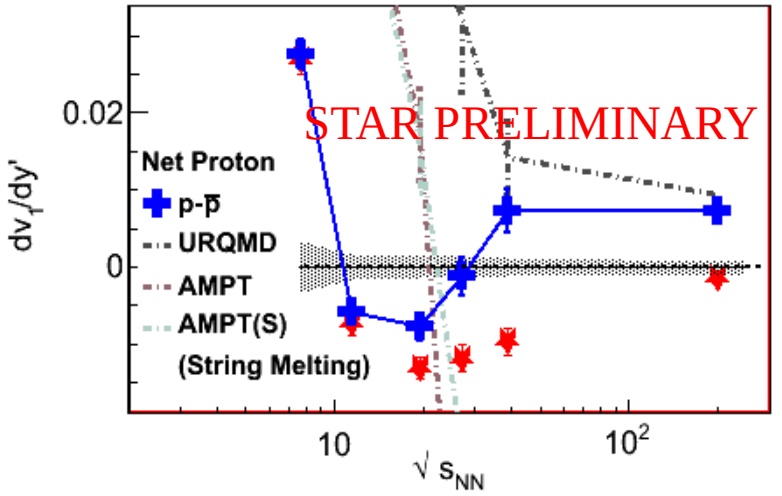
Search for 1st Order PhaseTransition

B. Schaefer and J. Wambach Phys.Rev. D75 (2007) 085015



- Lattice QCD calculations predict a first order phase transition, seen as a discontinuity in the density.
- 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
- We see a minimum of the v_1 signal. ➔ ***Suggestive***



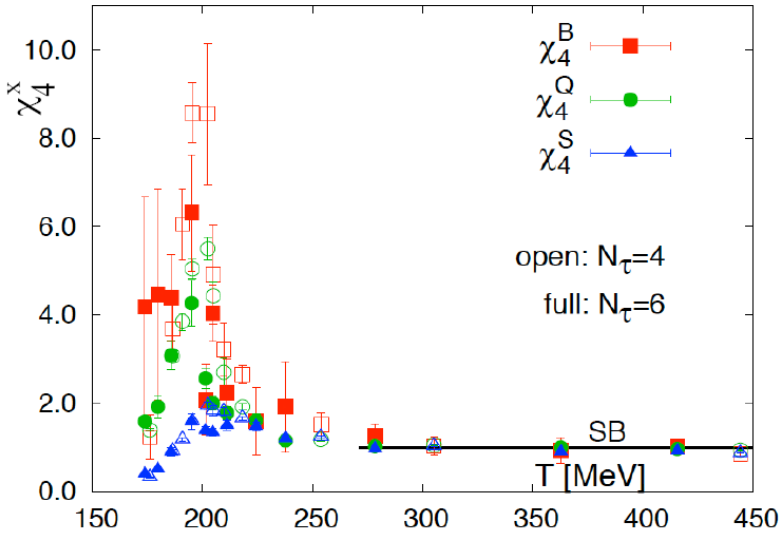


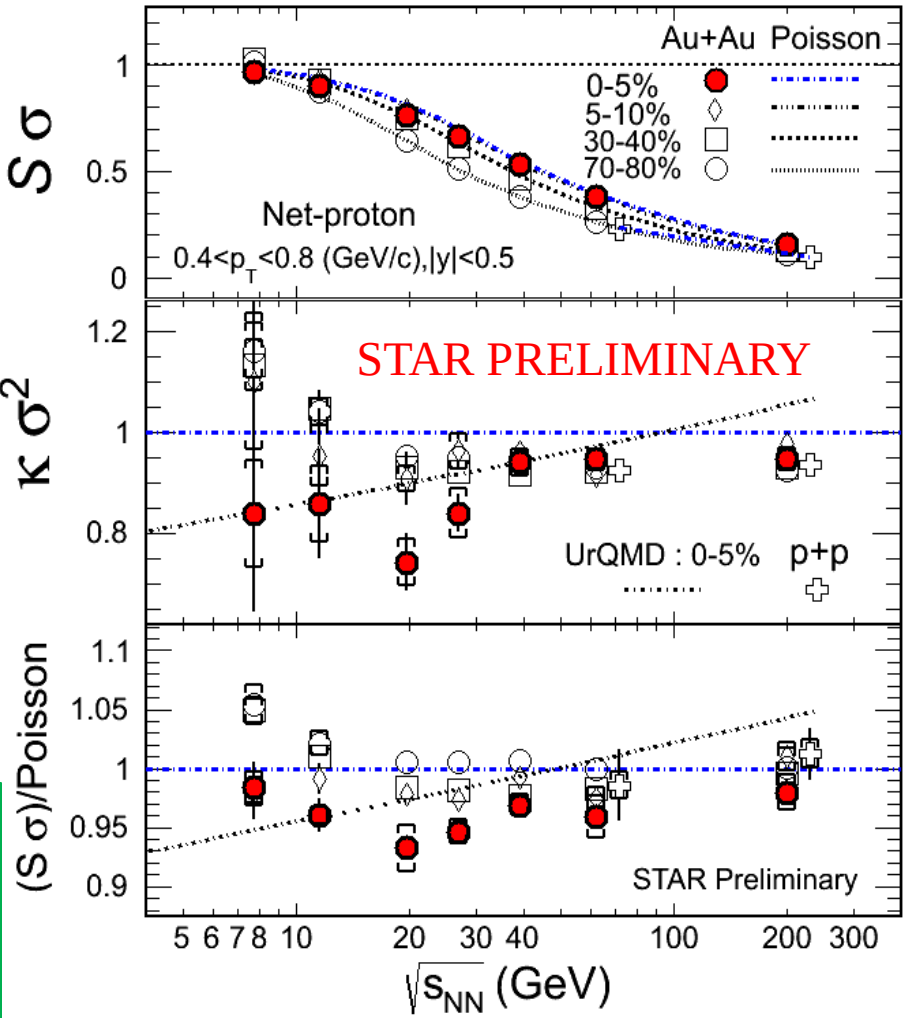
Search for the Critical Point

Volumes cancel

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

M. Cheng et al., Phys. Rev. D 79, 074505(2009)





- Data are consistent with Poisson baseline at high energy.
- Deviations from Poisson at low energy.
- Inconclusive ➔ **More data are needed**

Conclusions –BES-I

1. **Turn-off of QGP signatures:**
   - NCQ scaling 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.**
   - Inflection in v_2 at 7.7 GeV
   - **v_1 slope (dv_1/dy)sign change at 7.7 GeV**
   - Large Azimuthal HBT signal inconclusive

Strong Hints

Only had time to mention the signals in bold

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

More Data

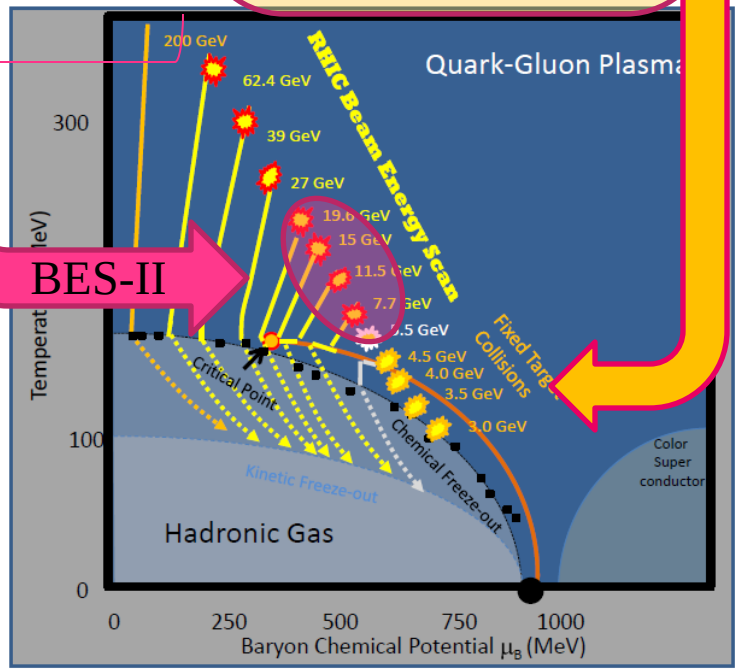
Outlook – BES-II

$\sqrt{S_{NN}}$ (GeV)	62.4	39	27	19.6	15	11.5	7.7	5.0	4.5	3.5	3.0
μ_B (MeV)*	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 (weeks)	---	---	---	2	1.5	3.5	7.5				

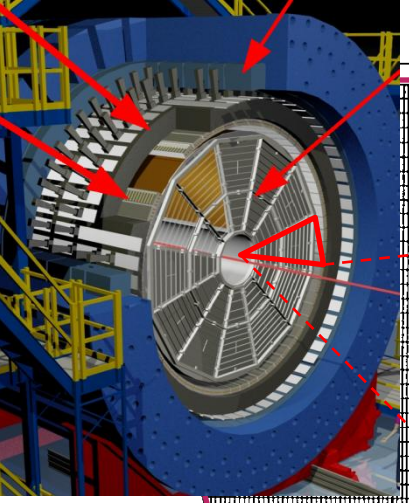
Fixed Target Collisions

* J. Cleymans, H. Oeschler, K. Redlich, S. Wheaton, PR C73, 034905 (2006).

- 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
- eCooling will take a few years
- Expect BES-II in 2017-2019



The STAR iTPC Upgrade



190 cm

32 Rows
6.2 X 19.5 mm

Old Inner Sector

13 Rows
2.85 X 11.5 mm

60 cm

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

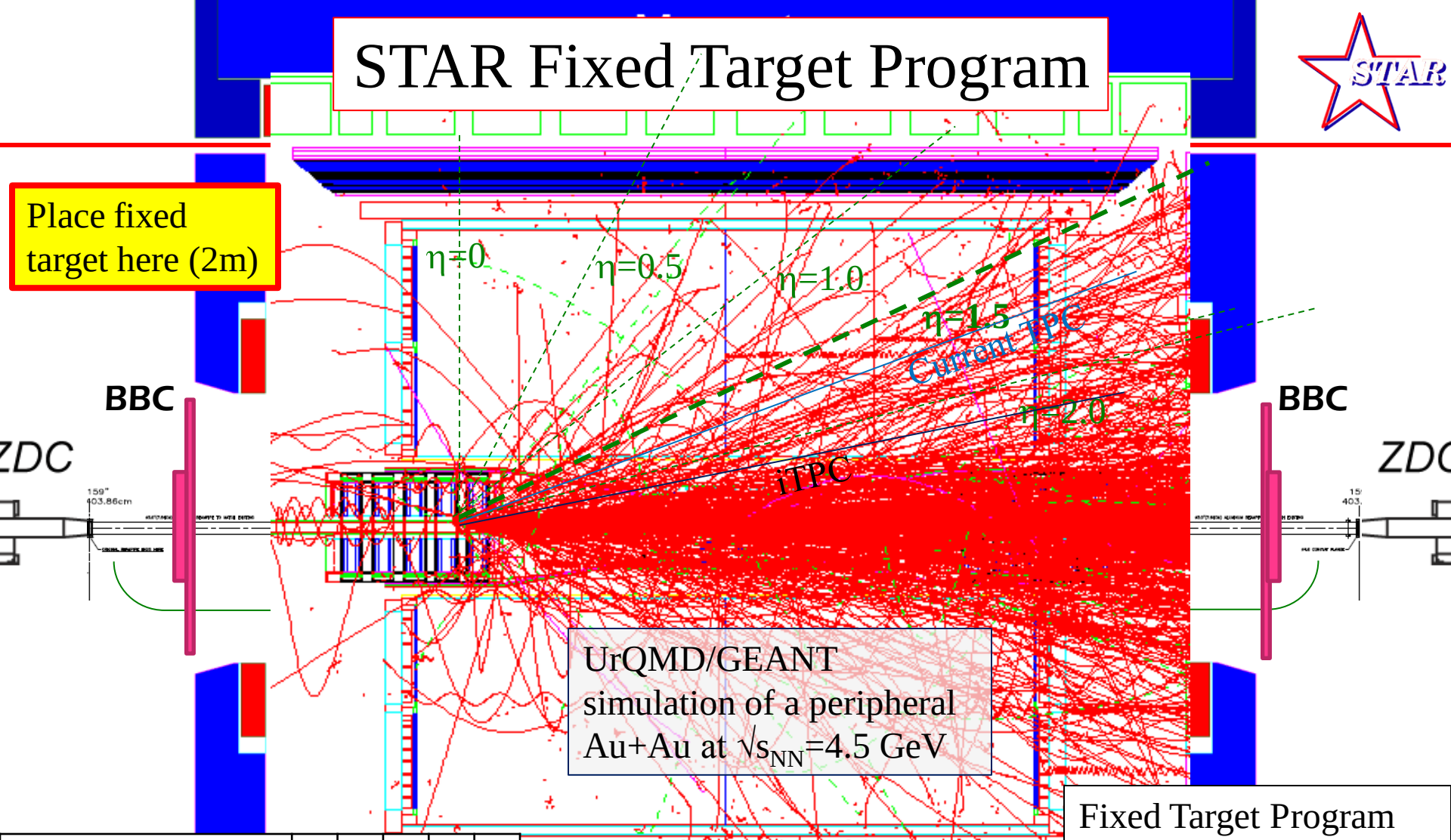
iTPC

40 Rows
6.2 X 19.5 mm
(one possible configuration)

Timeline: 2017

Major improvements for BES-II

STAR Fixed Target Program



Collider mode Energies (GeV)	5	7.7	11.5	15	19.6
Fixed Target $\sqrt{s_{NN}}$ (GeV)	2.5	3.0	3.5	4.0	4.5
Fixed Target μ_B (MeV)	775	720	670	625	585
Fixed Target y_{CM}	0.82	1.05	1.25	1.39	1.52

Fixed Target Program extends STAR's physics reach to region of compressed baryonic matter

Conclusions -- Future

Although several questions have been answered by data from BES-I, there are still some important open questions that we need more data to answer conclusively.

•Therefore we have proposed BES-II with 10-20 times better statistics.

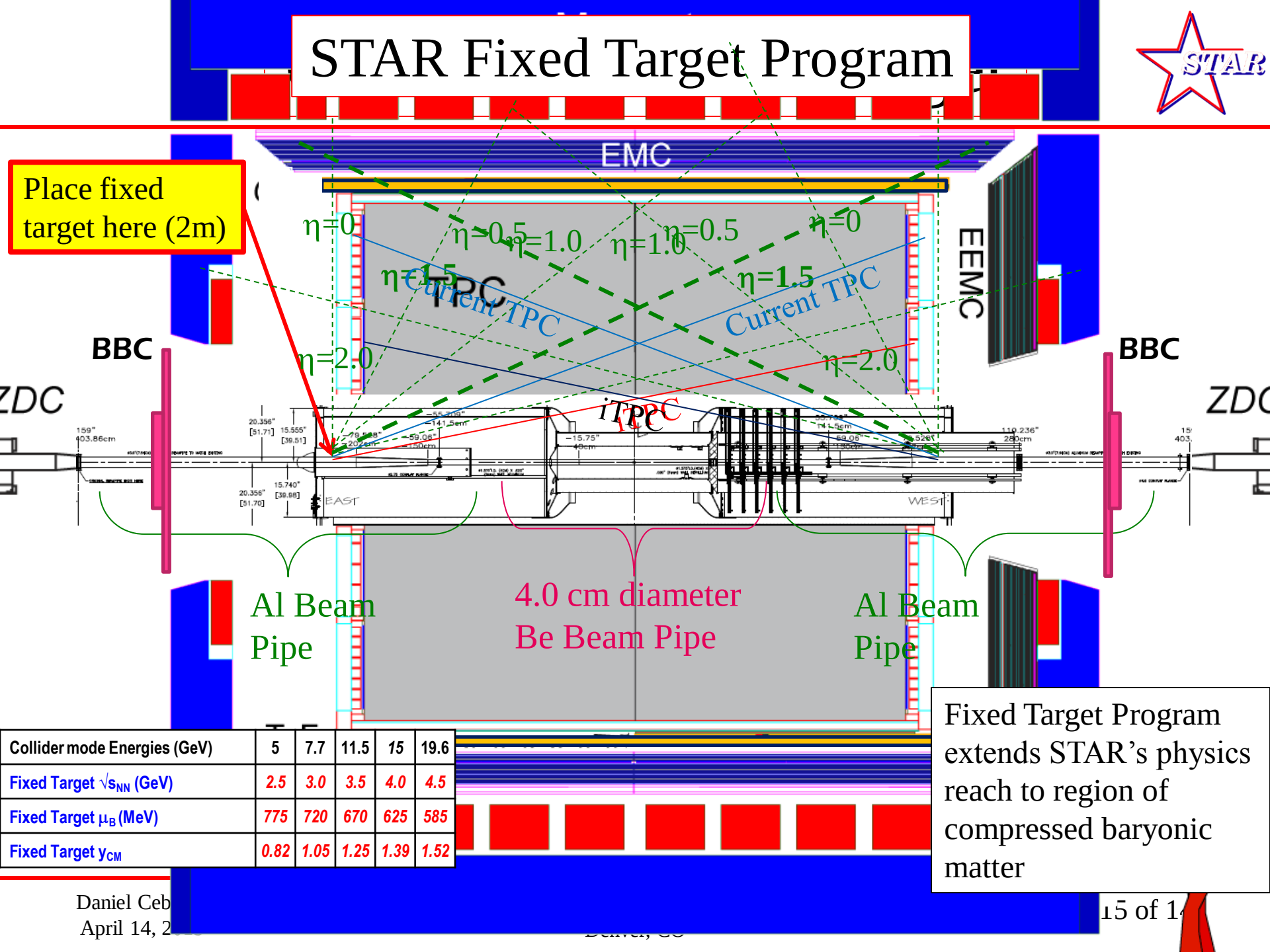
•This will need electron cooling, which is being developed by the Collider.

•The iTPC upgrades will provide extended η coverage and low p_T cut-ins.

•The Fixed target program will extend BES-II physics reach to the region below the onset of deconfinement.

• All these developments will be ready for a second low energy run at RHIC in the time frame from 2017-2020.

STAR Fixed Target Program



Collider mode Energies (GeV)	5	7.7	11.5	15	19.6
Fixed Target $\sqrt{s_{NN}}$ (GeV)	2.5	3.0	3.5	4.0	4.5
Fixed Target μ_B (MeV)	775	720	670	625	585
Fixed Target y_{CM}	0.82	1.05	1.25	1.39	1.52

Fixed Target Program extends STAR's physics reach to region of compressed baryonic matter