



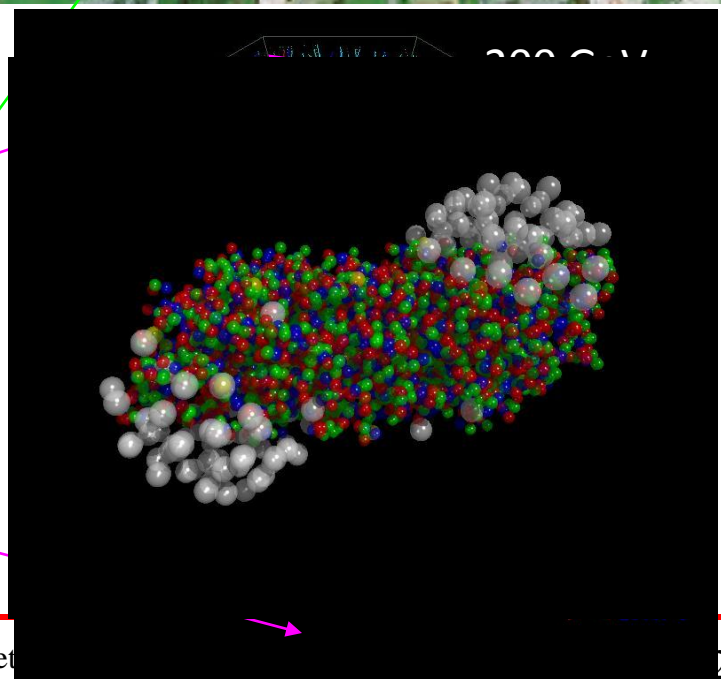
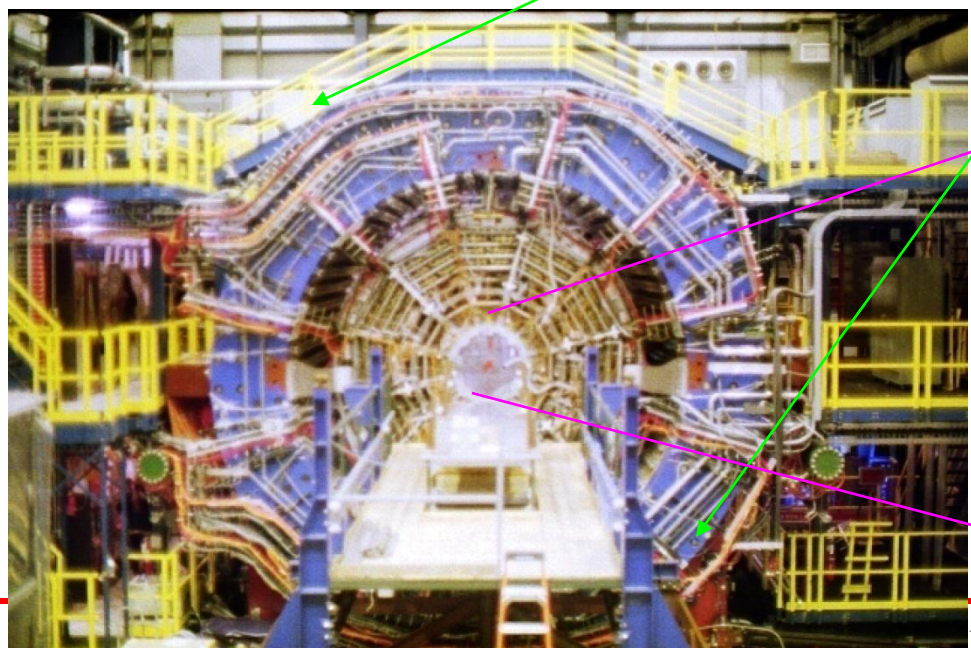
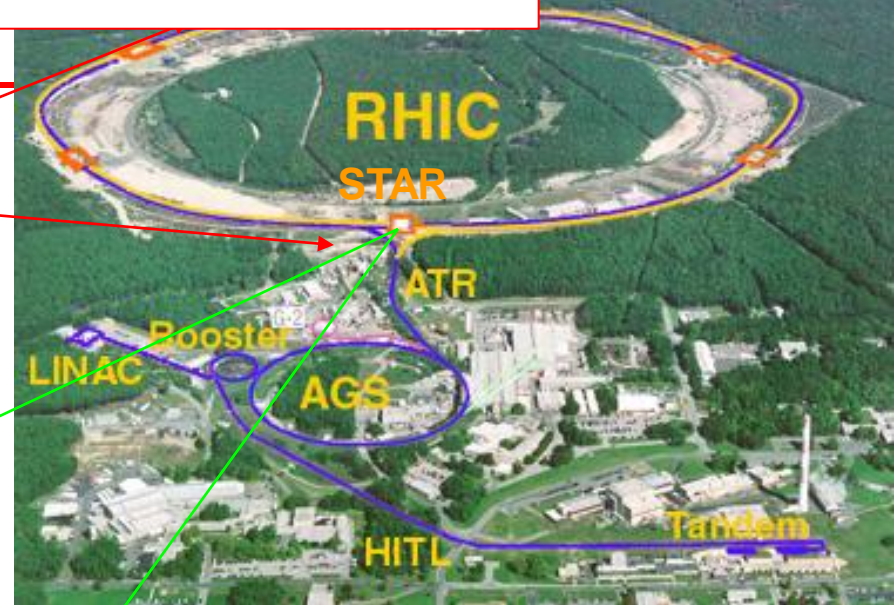
What We Have Learned from the RHIC Beam Energy Scan

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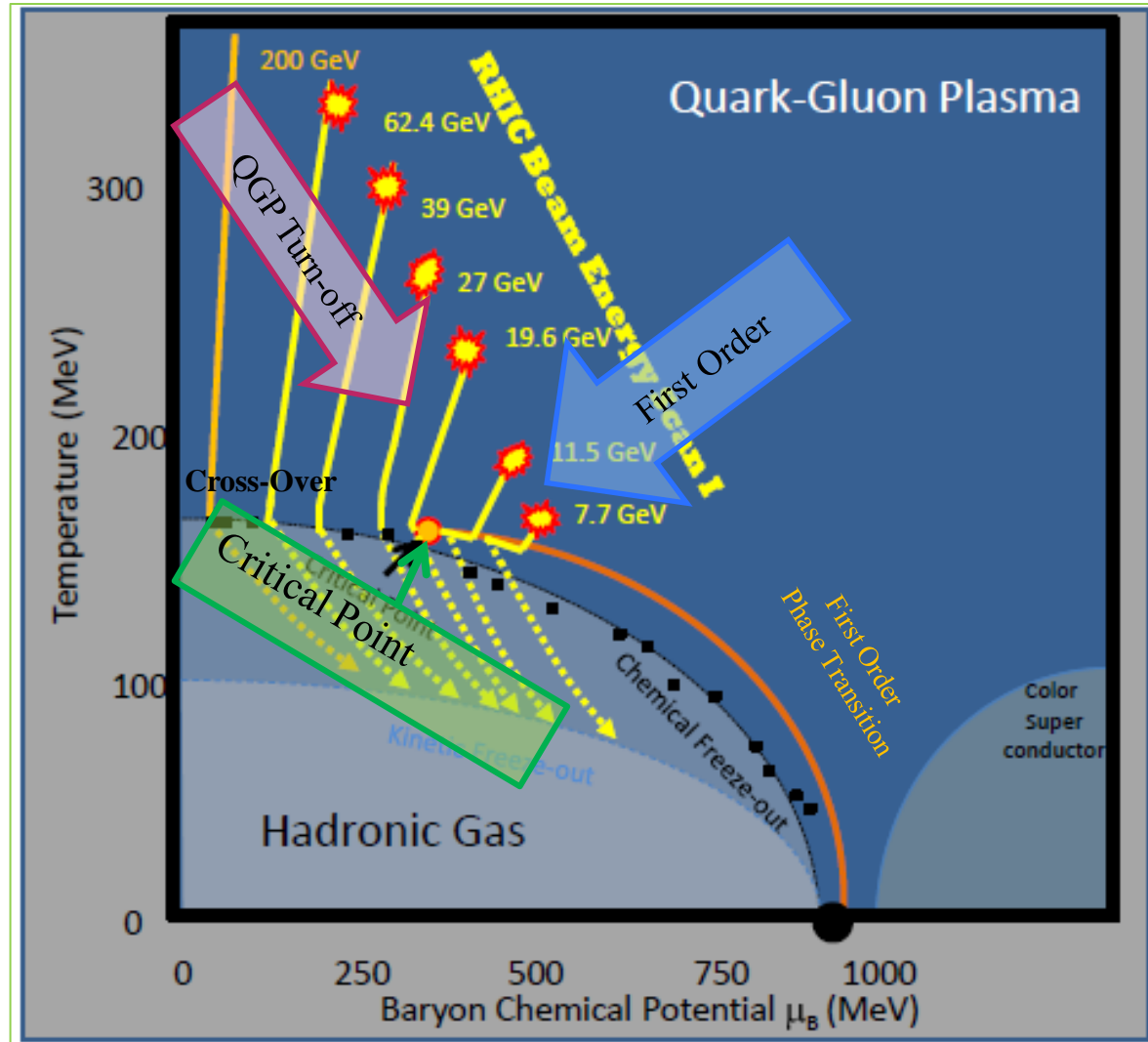
Creating Quark-Gluon Matter



The RHIC Beam Energy Scan



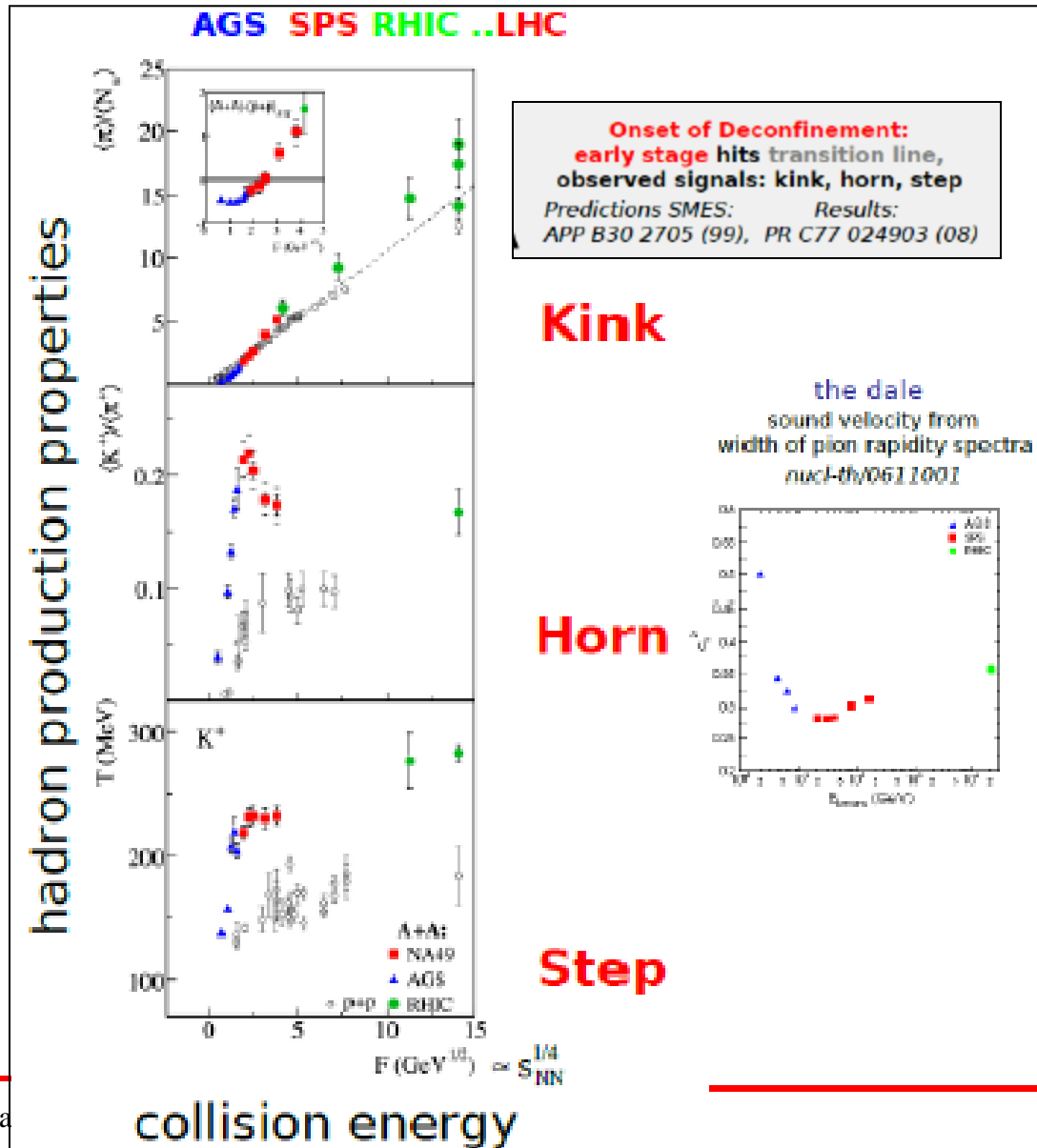
- Much progress has been made in understanding the phase diagram of QCD matter. We expect a cross-over at high energy. At lower energy there should be a first order transition.
- Mapping the features of the QCD matter phase diagram is key to our understanding dense matter.
- In 2009 the RHIC PAC approved 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 not STAR and PHENIX)
- 7) Some p+p energies had been run at Fermilab and ISR.



Overview of the Beam Energy Scan Goals



- The RHIC facility has successfully completed a *phase I* beam energy scan.

• Evidence of turn-off of QGP signatures

- Constituent quark scaling of flow
- **High p_T suppression**
- Chiral magnetic effect anisotropies

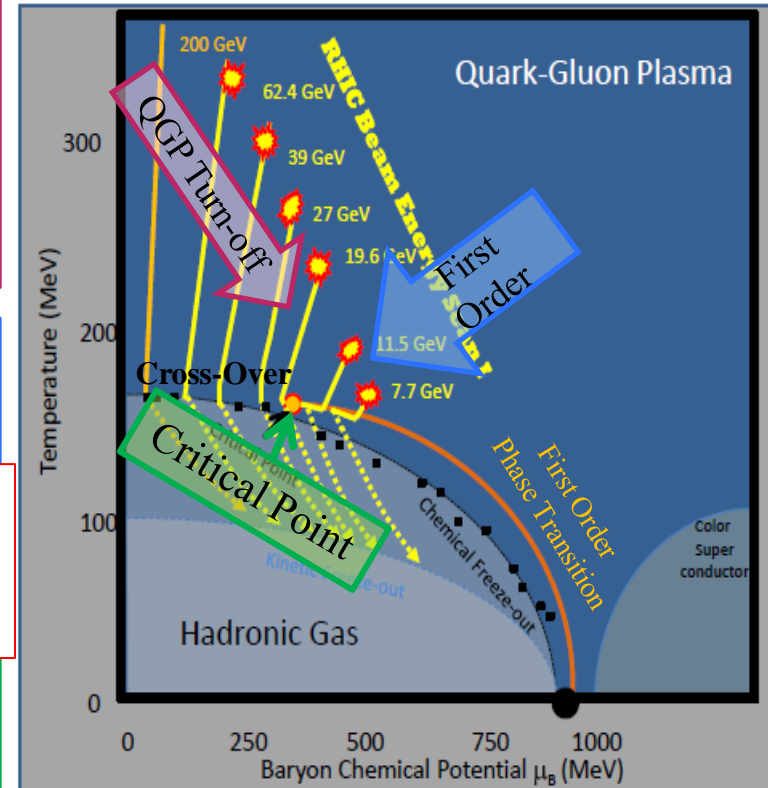
• Evidence for first order phase transition

- The magnitude of the elliptic flow
- **The directed flow**
- The azimuthal HBT

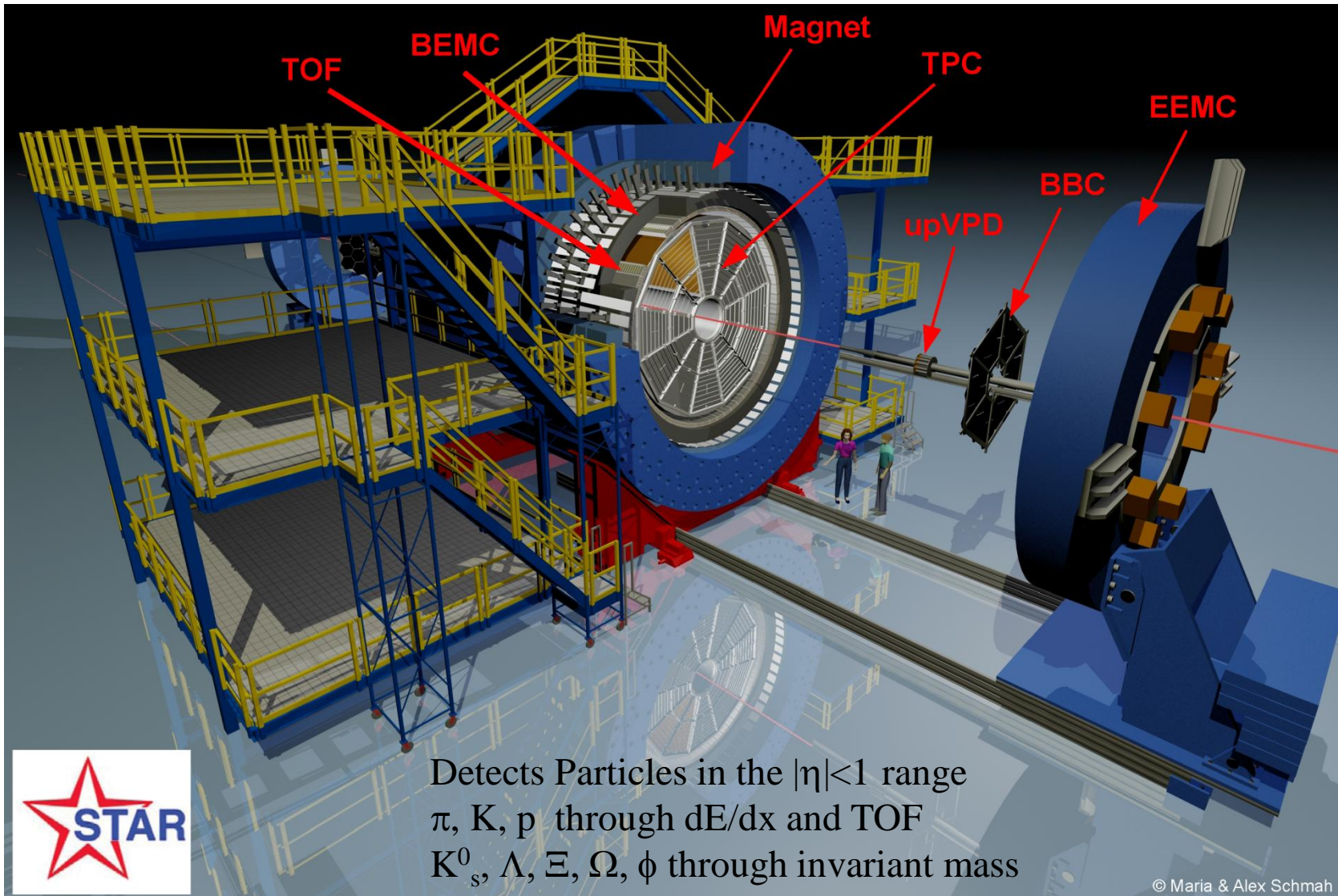
*Only have time
to mention the
signals in bold*

• Searches for critical point signatures

- Particle ratio fluctuations (K/ π etc.)
- **Skew and Kurtosis of conserved quantities**



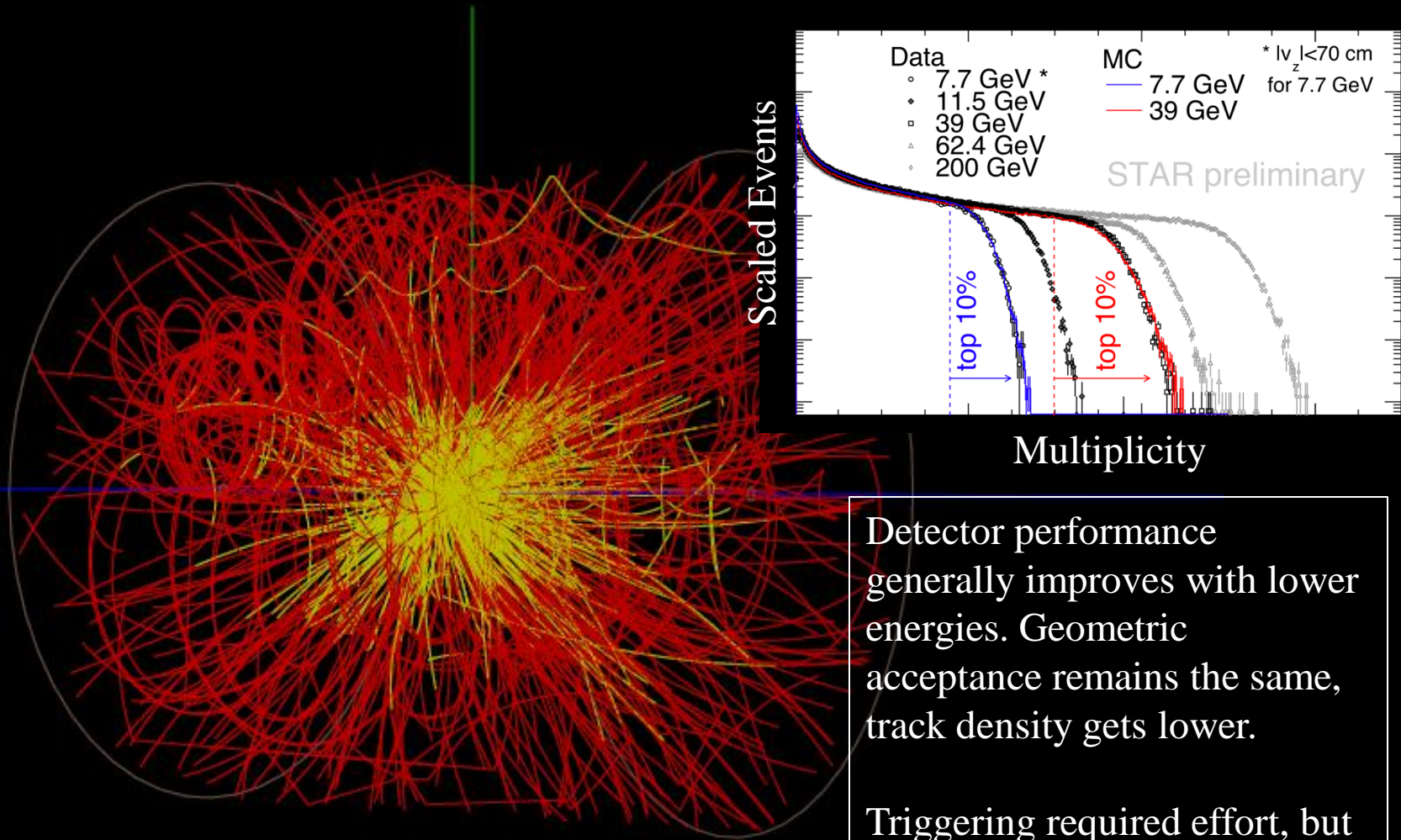
The STAR Detector for the Beam Energy Scan



Detects Particles in the $|\eta| < 1$ range
 π , K , p through dE/dx and TOF
 K_s^0 , Λ , Ξ , Ω , ϕ through invariant mass

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Central Au+Au at 7.7 GeV



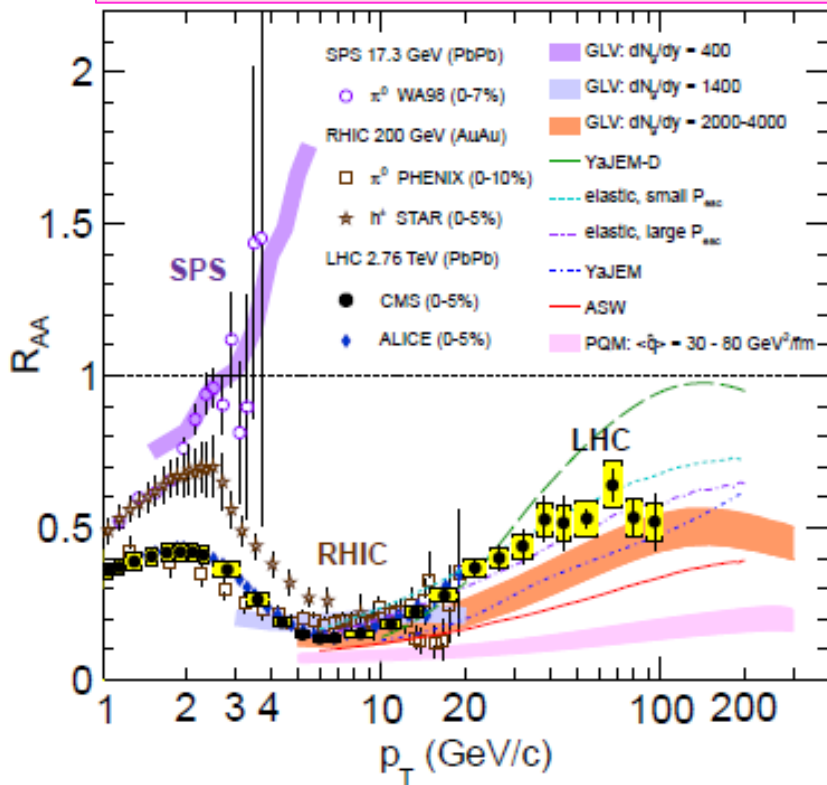
Detector performance generally improves with lower energies. Geometric acceptance remains the same, track density gets lower.

Triggering required effort, but was a solvable problem.

Turn-off of QGP Signatures

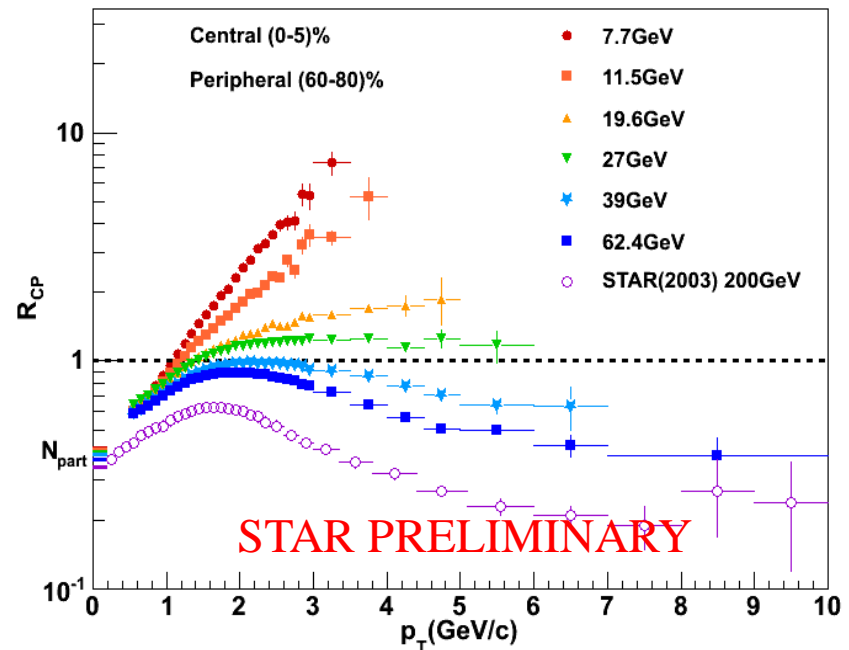


High p_T suppression has been seen as a clear manifestation of energy loss by color objects (quarks) in a color medium (QGP)



Eur.Phys.J. C72 (2012) 1945

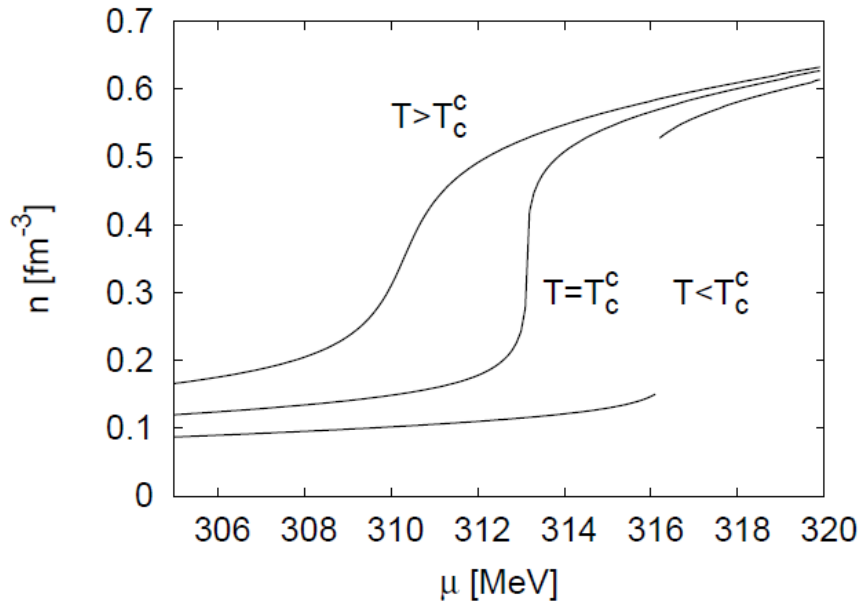
• R_{cp} suppression NOT seen at lower energies!
 → The QGP signature is turned off.



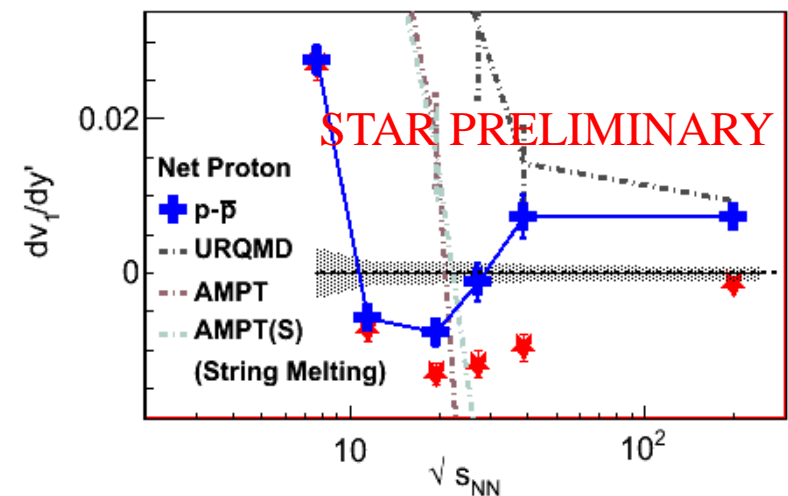
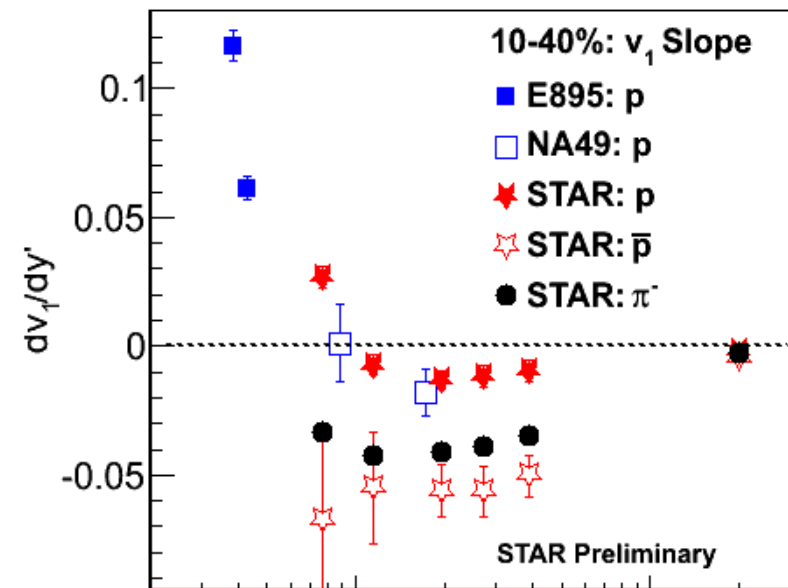
STAR PRELIMINARY

Search for 1st Order Phase Transition

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



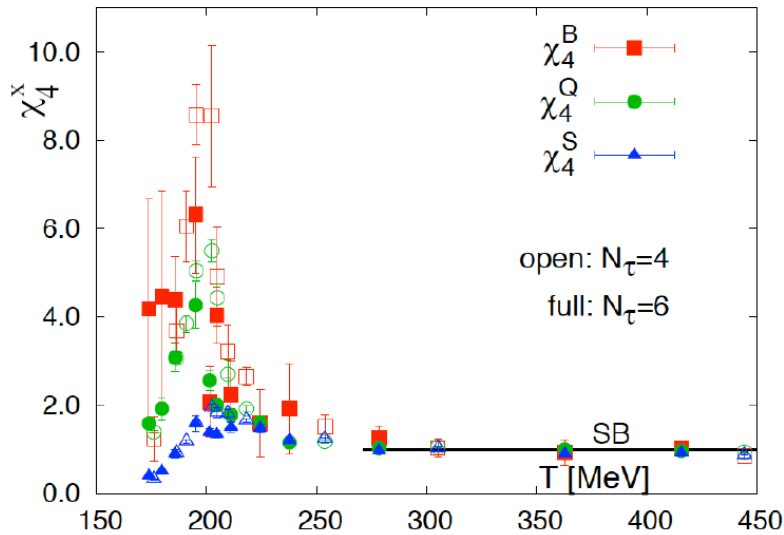
Volumes cancel

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

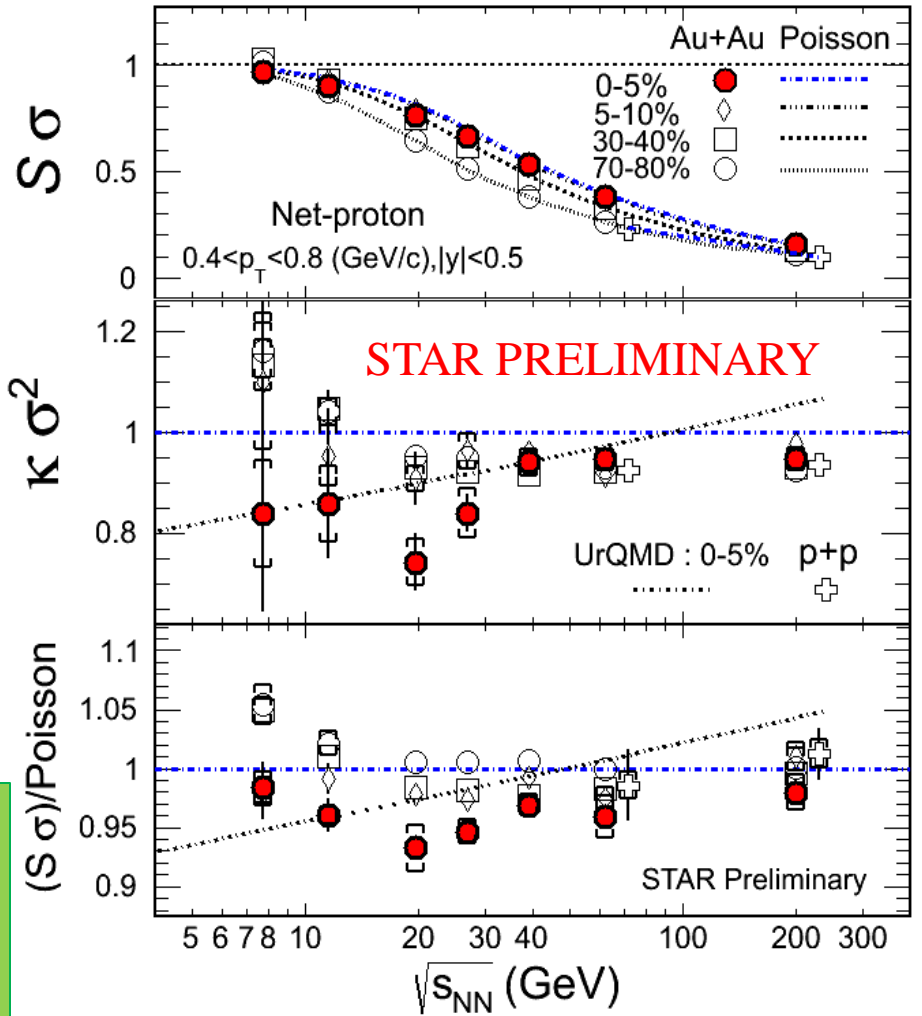


$$\begin{aligned} \chi_B^4 / \chi_B^2 &= (\kappa\sigma^2)_B \\ \chi_B^3 / \chi_B^2 &= (S\sigma)_B \end{aligned}$$

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



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



Conclusions



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



$\sqrt{s_{NN}}$ (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

