Exploring the Phase Diagram of Strongly interacting Matter
-
News from SPS and RHIC

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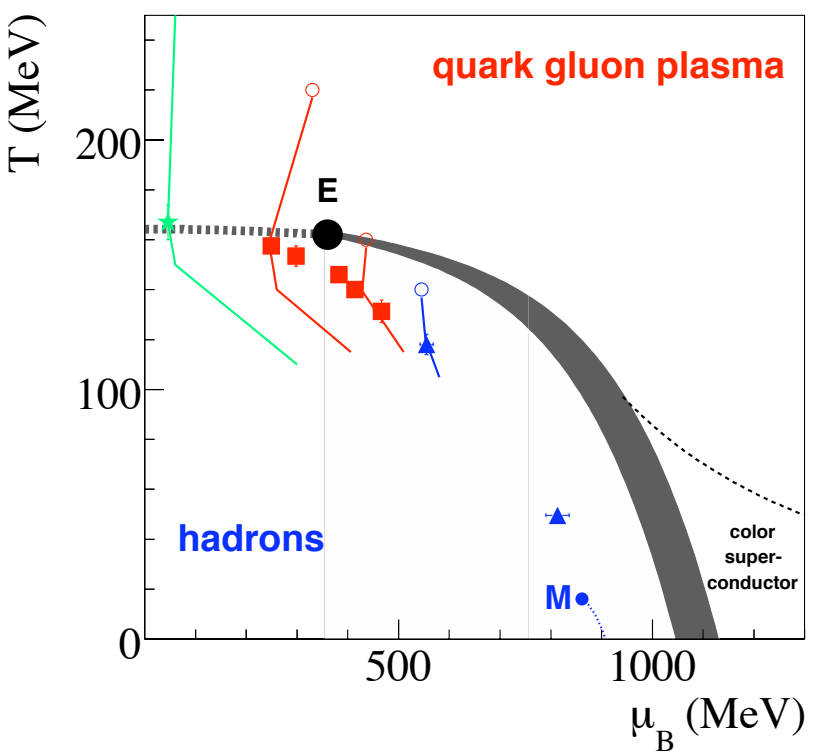
GOETHE UNIVERSITÄT FRANKFURT AM MAIN

30th International School of Nuclear Physics, Erice, 16 - 24 September 2008

Outline



Critical point and crossover:
Fodor et. al.: JHEP 0404 (2004) 050

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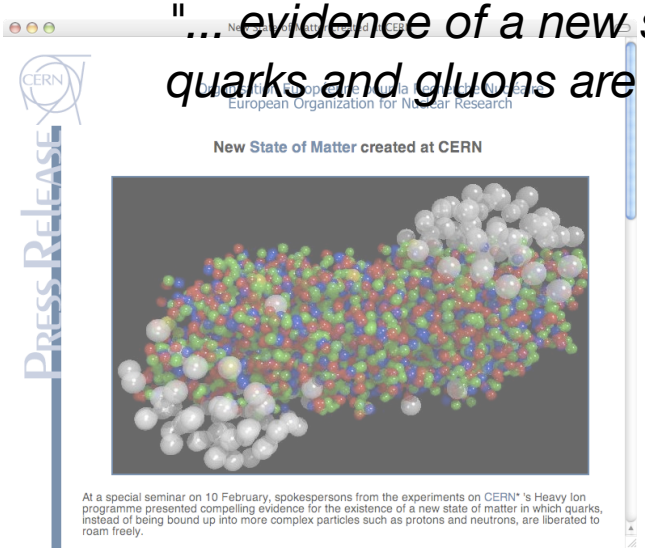
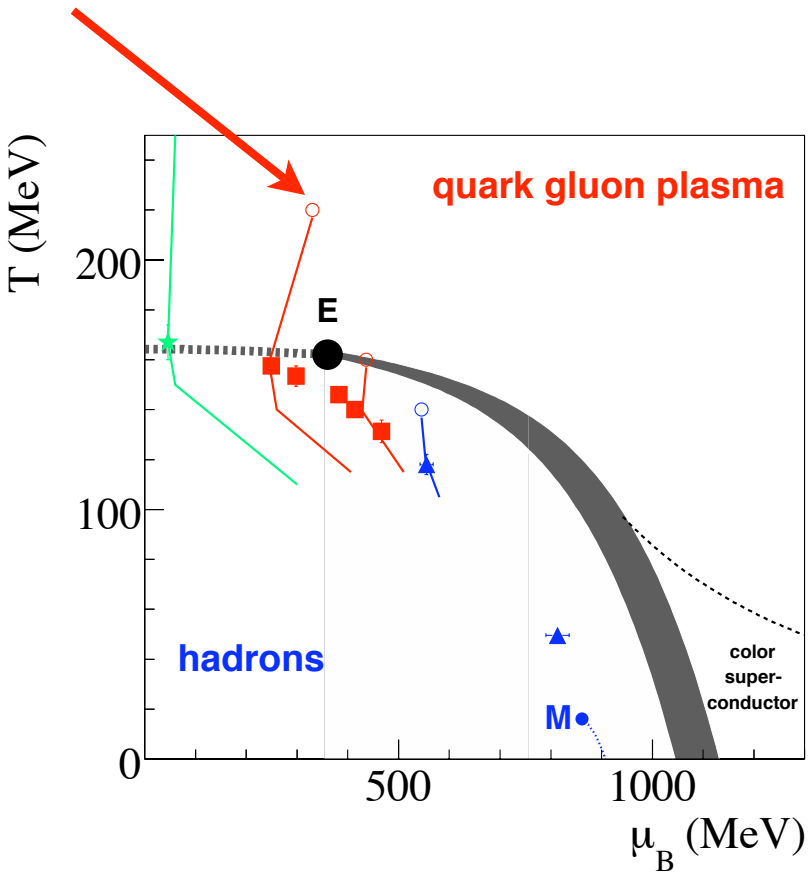
"*...evidence of a new state of matter where quarks and gluons are not confined...*" (L. Maiani)





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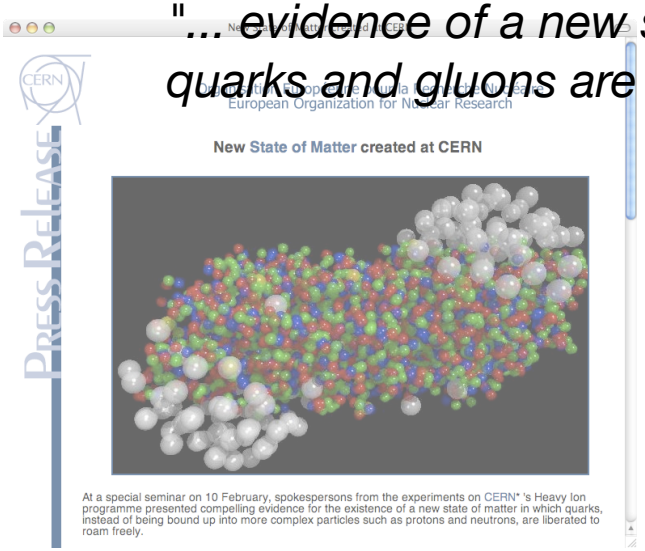
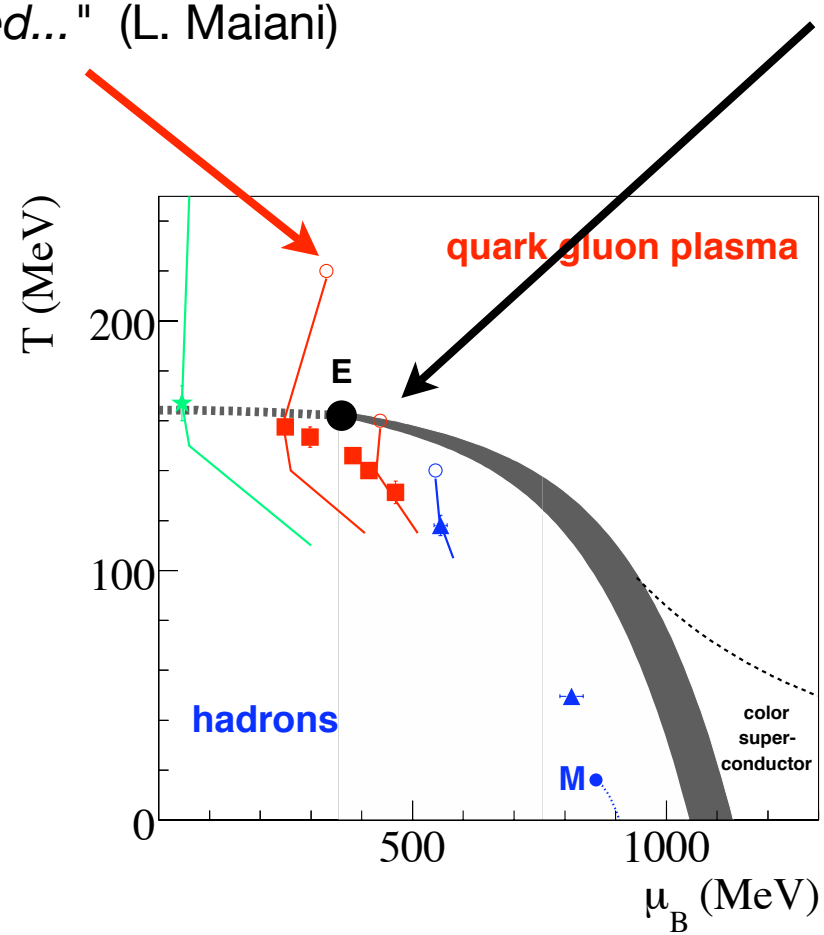


Onset of Deconfinement at lower SPS energies



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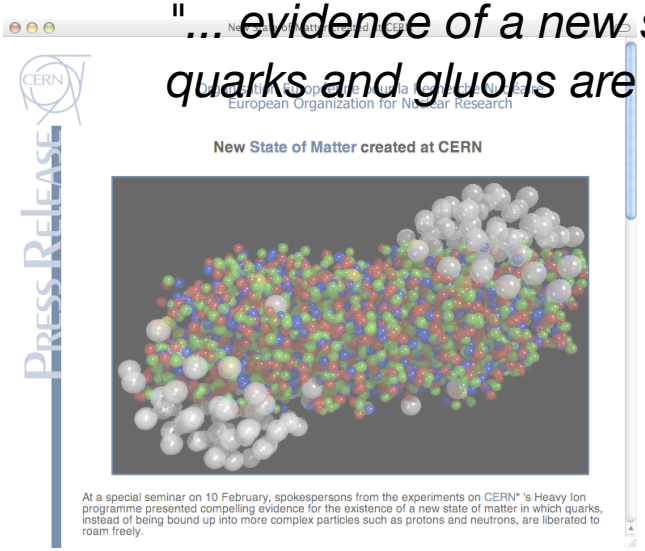

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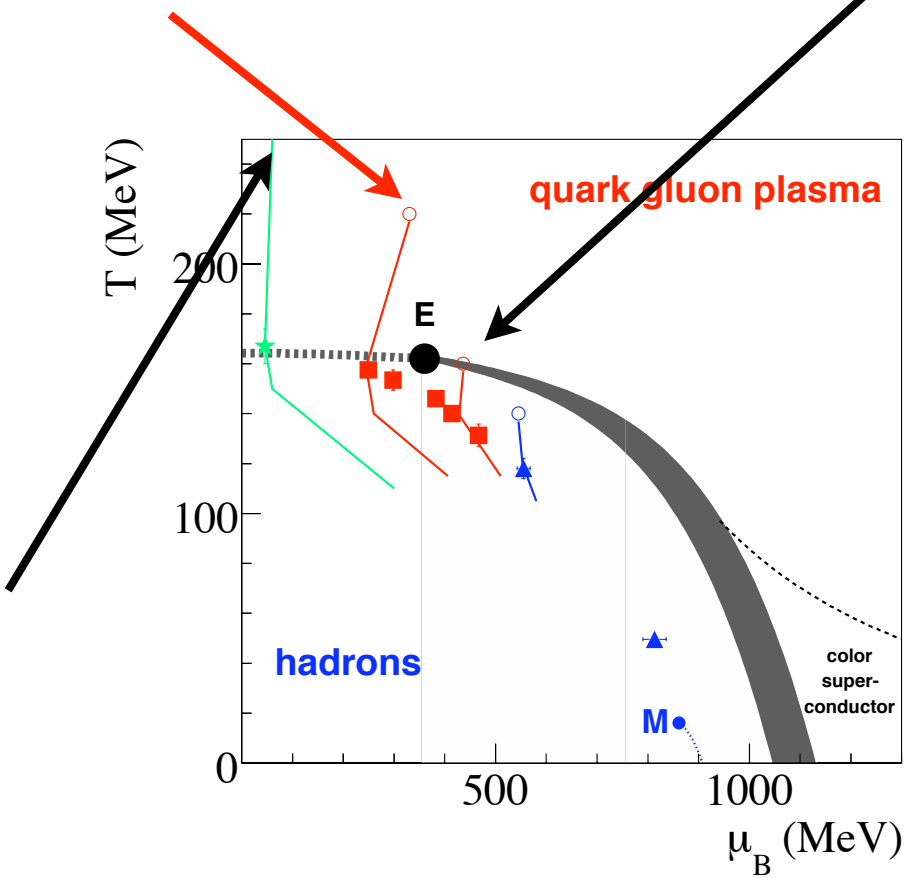

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Properties of deconfined matter studied at RHIC

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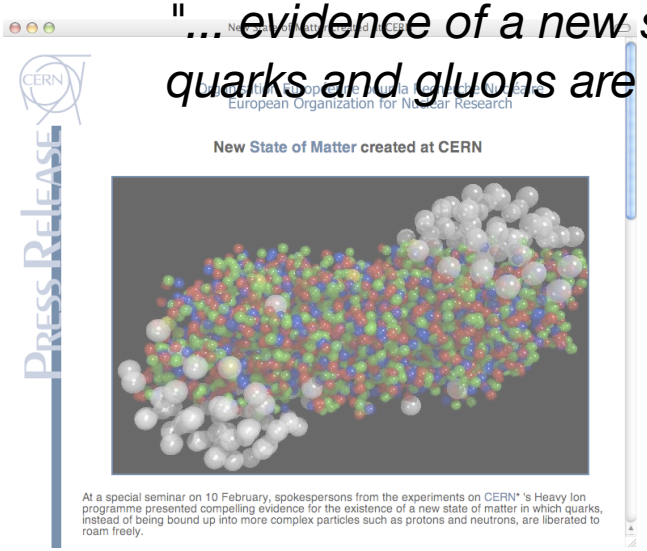

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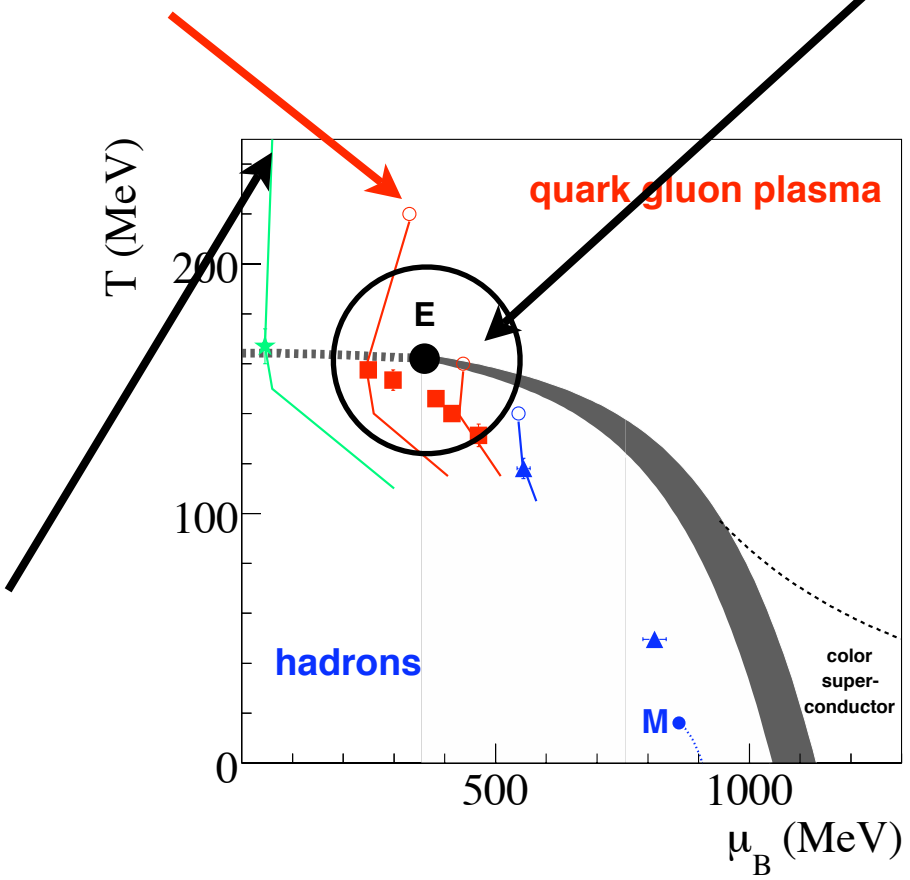

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Properties of deconfined matter studied at RHIC

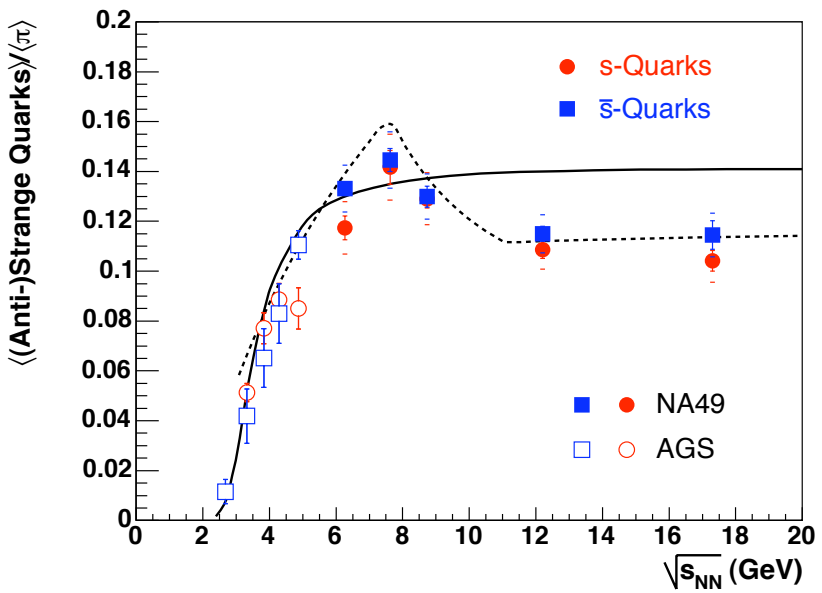
Study properties of the Onset of Deconfinement and search for the Critical Point at energies $5 < \sqrt{s_{NN}} < 20$ GeV

Outline

- Indications for a phase transition
  - Onset of deconfinement at SPS energies
  - Signatures of deconfined matter at RHIC energies
- Experimental programs to probe the phase diagram
  - NA61/SHINE, fixed-target experiment at CERN-SPS
  - STAR, collider detector at RHIC-BNL
- Physics program and capabilities to
  - Study the onset of deconfinement
  - Search for the QCD critical point

Onset of Deconfinement

- Maximum seen in strangeness to pion ratio at low SPS energies:

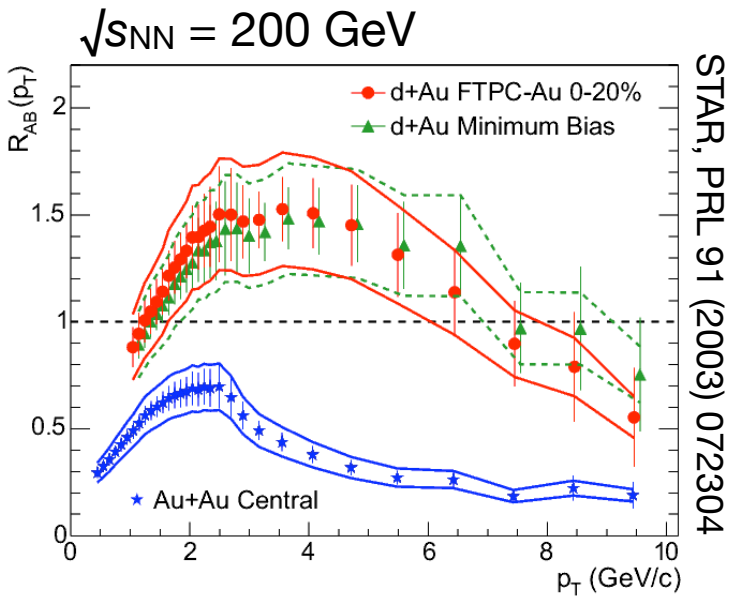


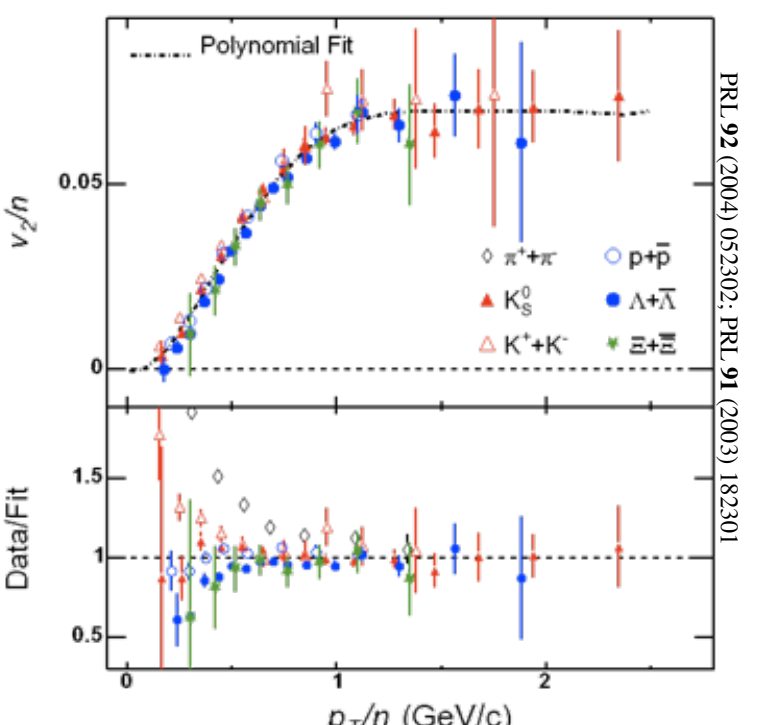
- Difficult to model in hadronic scenarios
  (e.g. —— HGM: Cleymans et al., PRC 60 (1999) 054908)

- Predicted as signal for the onset of deconfinement
  (····· SMES, APP B30 (1999) 2705)

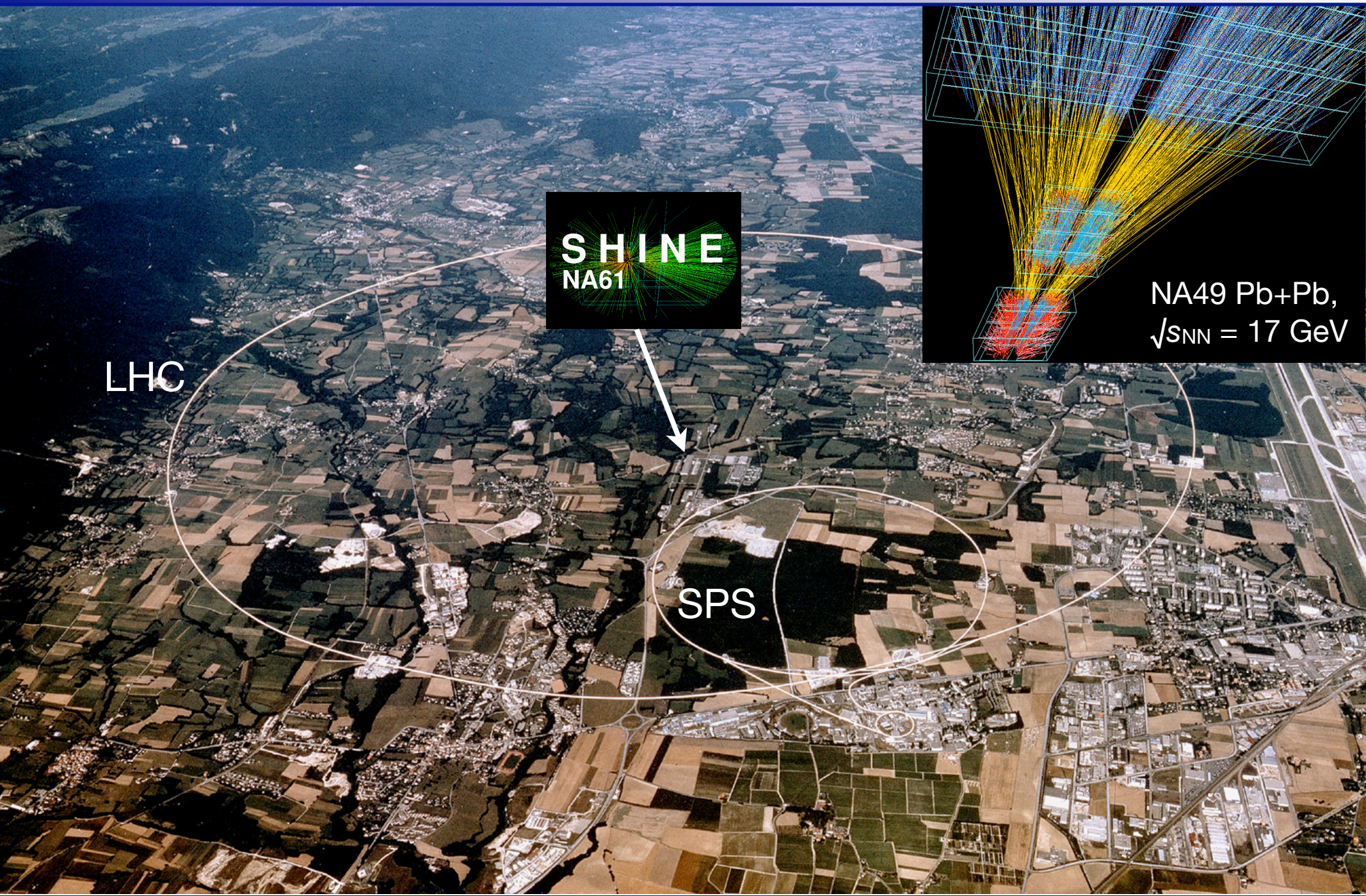
Properties of deconfined matter

- Observations in RHIC data indicating the formation of a hot partonic medium:
  - Jet energy loss
  - Strong collective flow
  - Quark number scaling
- Can we turn off these signatures when going down in energy?

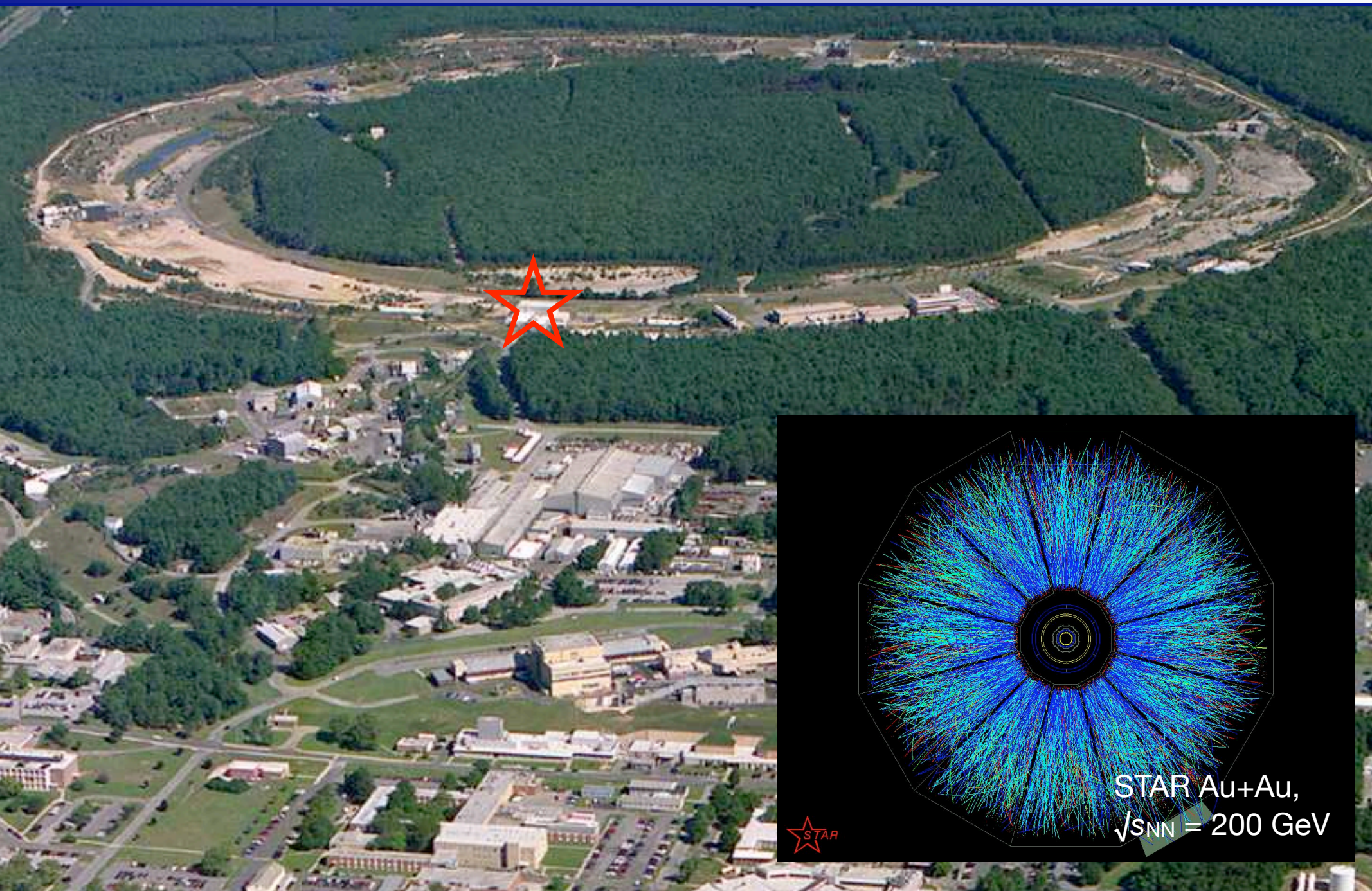




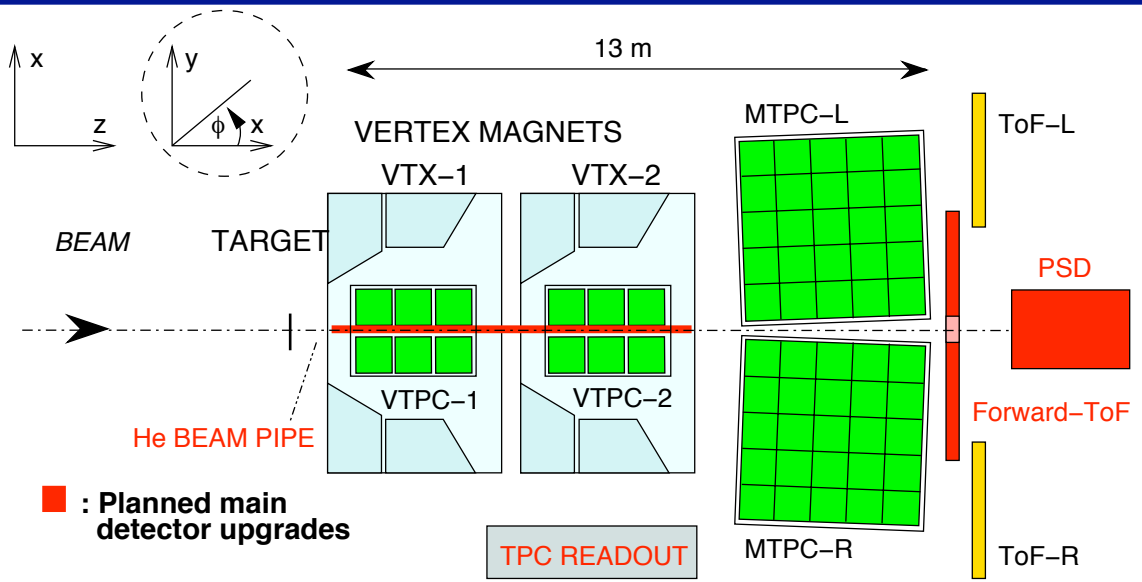
NA61/SHINE at CERN-SPS

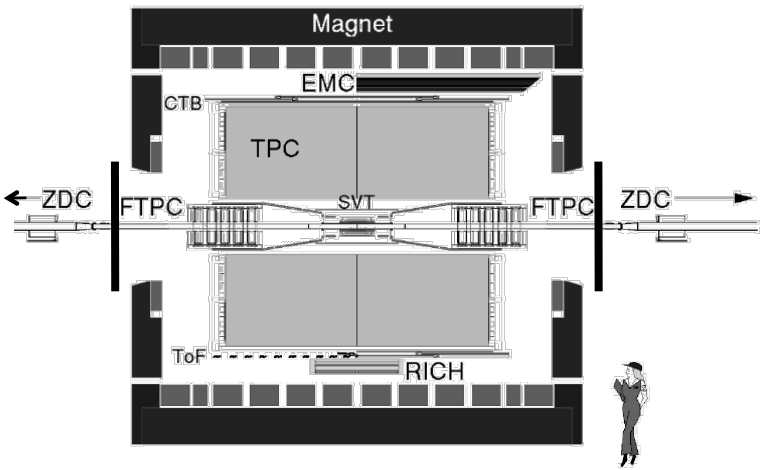


STAR at BNL-RHIC



Comparison NA61 - STAR





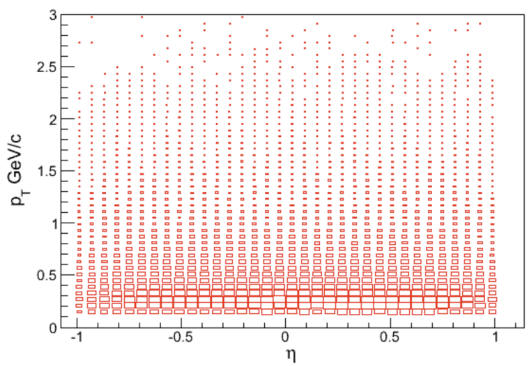
- Large acceptance hadron spectrometers
  - TPC: Q, $\boldsymbol{x}$, $\boldsymbol{p}$, dE/dx
  - Particle identification in the TPCs:
    - pions, kaons, protons via dE/dx
    - K^0_S, Λ, Ξ, Ω: decay topology + inv. mass. + dE/dx
    - φ, K^*, Λ^*: inv. mass. + dE/dx
  - plus further detectors: TOF, EMC, ...

Collider vs. Fixed-target

Advantages of a collider detector in an energy scan:

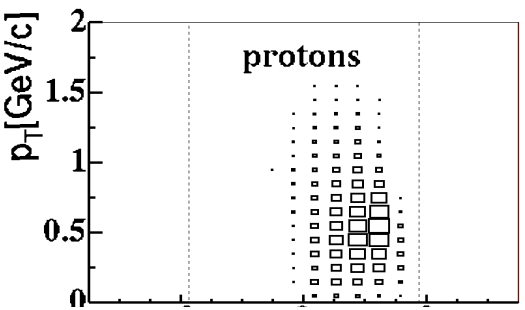
- Acceptance stays constant with energy, full azimuth

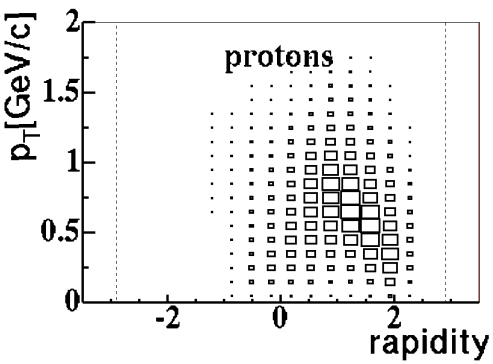
STAR



H. Caines

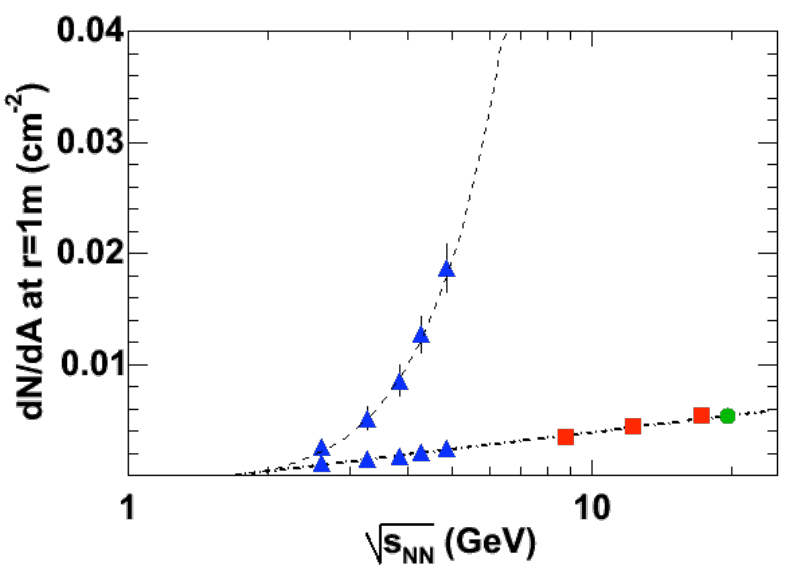
NA49





C. Roland

- Spatial track density rises slower

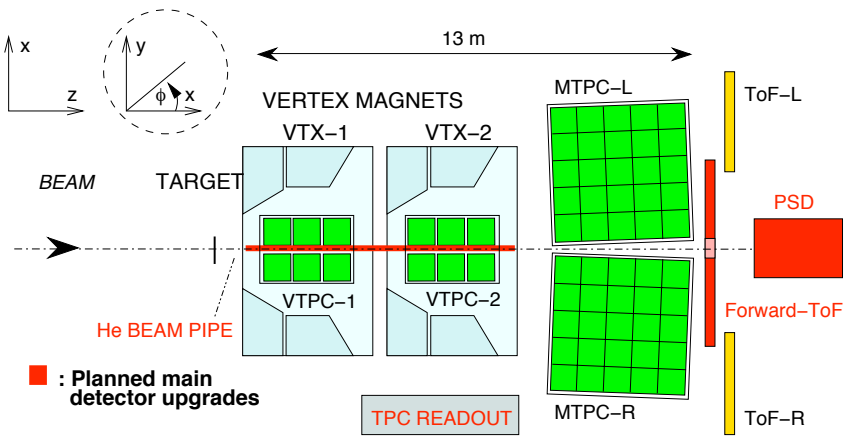


G. Roland

Collider vs. Fixed-target

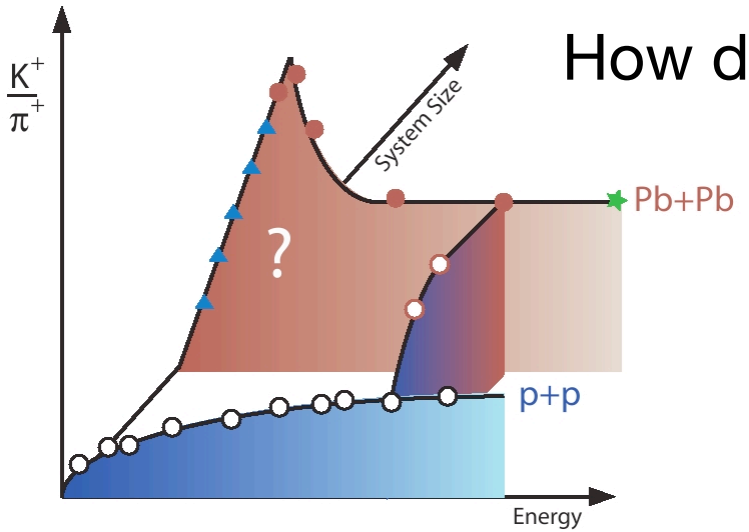
Advantages of a fixed-target experiment in an energy scan:

- Large acceptance for all spectator nucleons and fragments: Precise centrality determination



- Beam/target nucleus species can be changed quickly
  - NA61/SHINE will run in parallel with LHC-ion
  - Fragmentation beam from the primary Pb beam

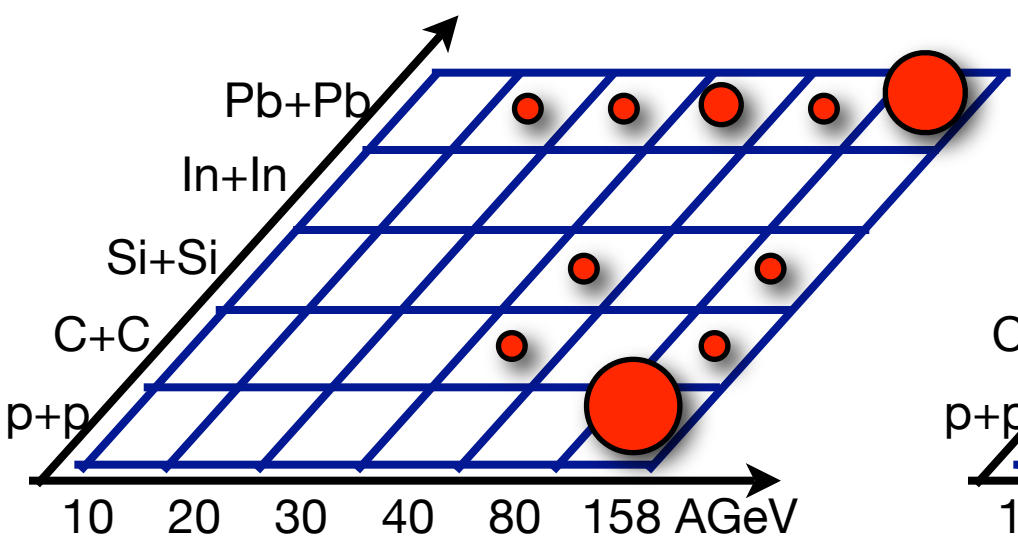
Onset of Deconfinement



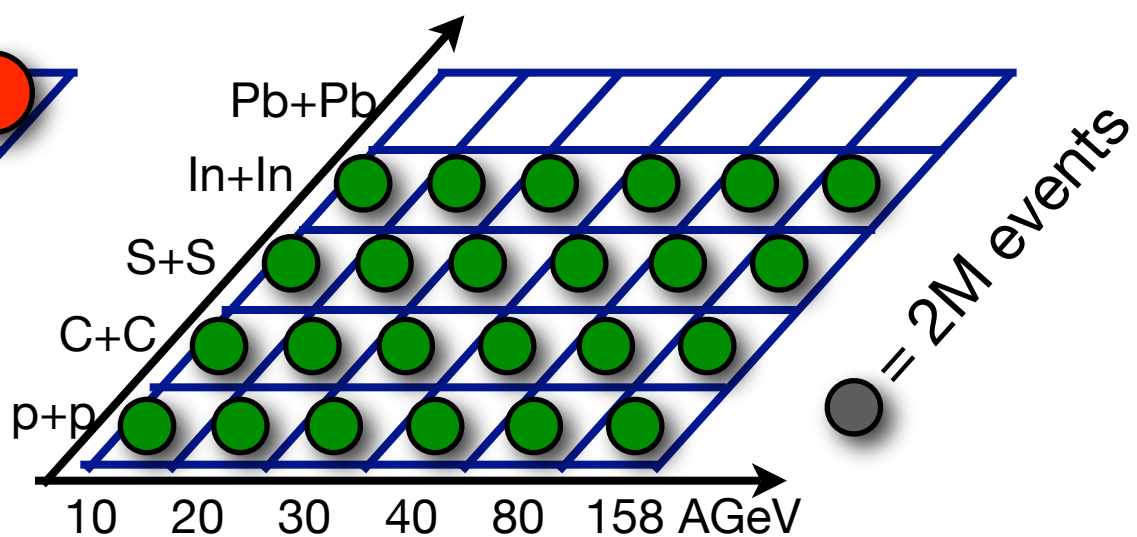
How do “horn” position and amplitude vary with system size?

→ NA61/SHINE will extend the NA49 energy and system size scan

NA49 energy and system size scan



NA61/SHINE plan



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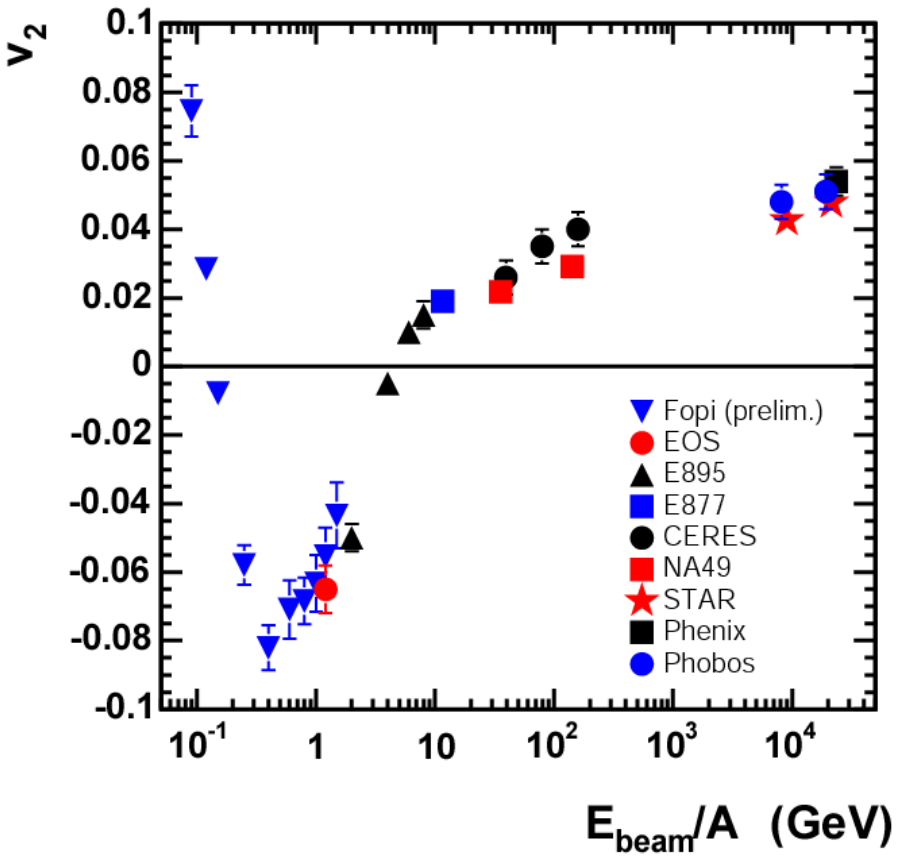
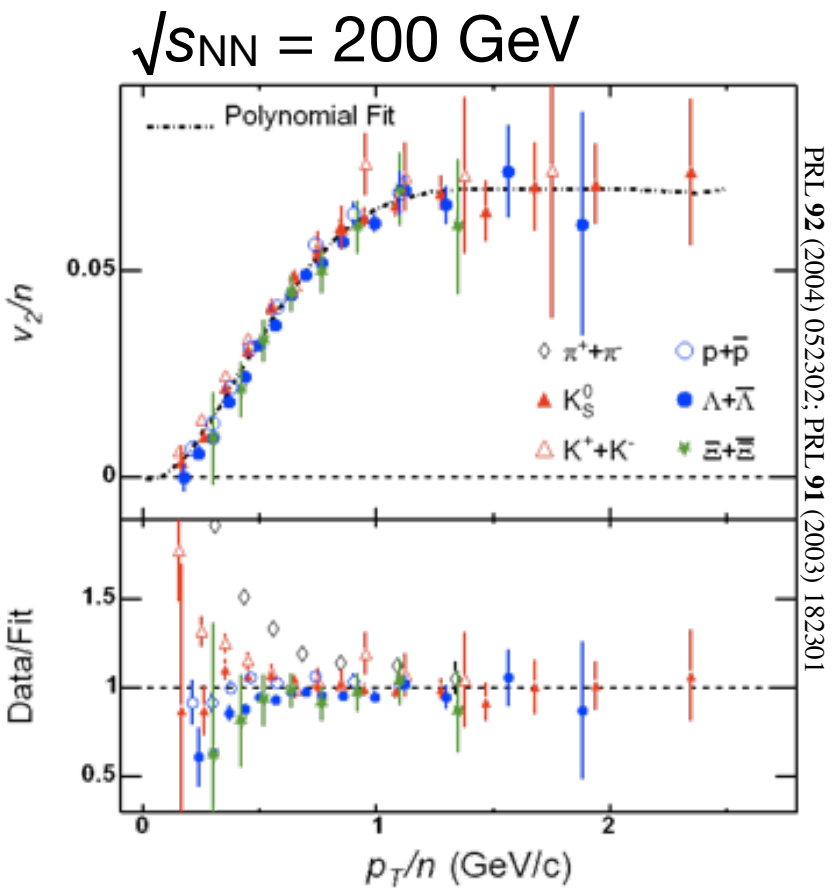
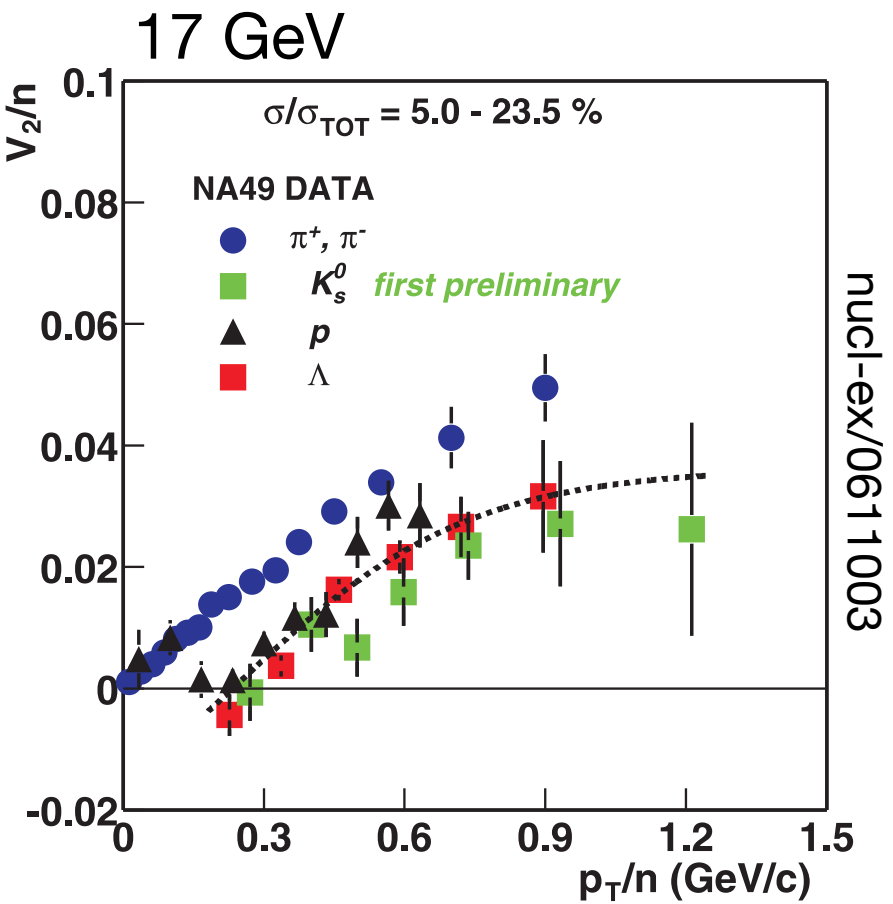


- Elliptic flow v_2
  - Probes the early stage of the collision
  - Test for initial pressure and degrees of freedom
  - Measured over a wide range of energy for pions

Onset of Deconfinement

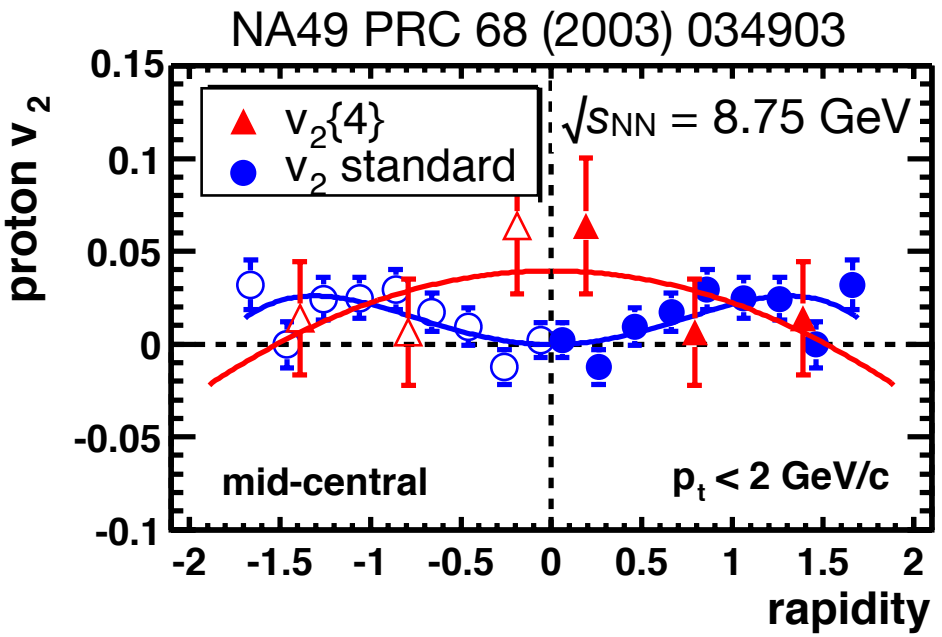
- To test the scaling, identified hadron v_2 must be measured up to large p_T

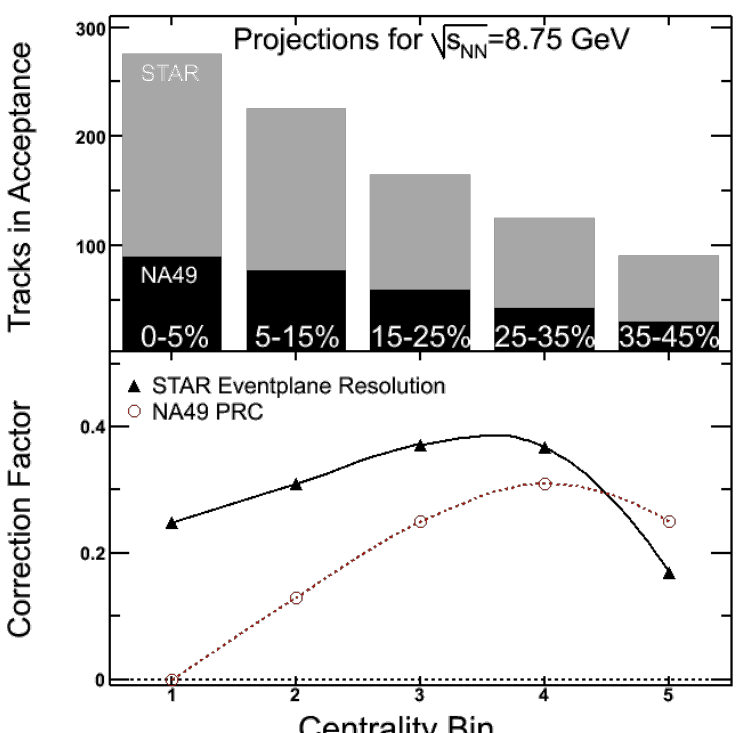




Onset of Deconfinement

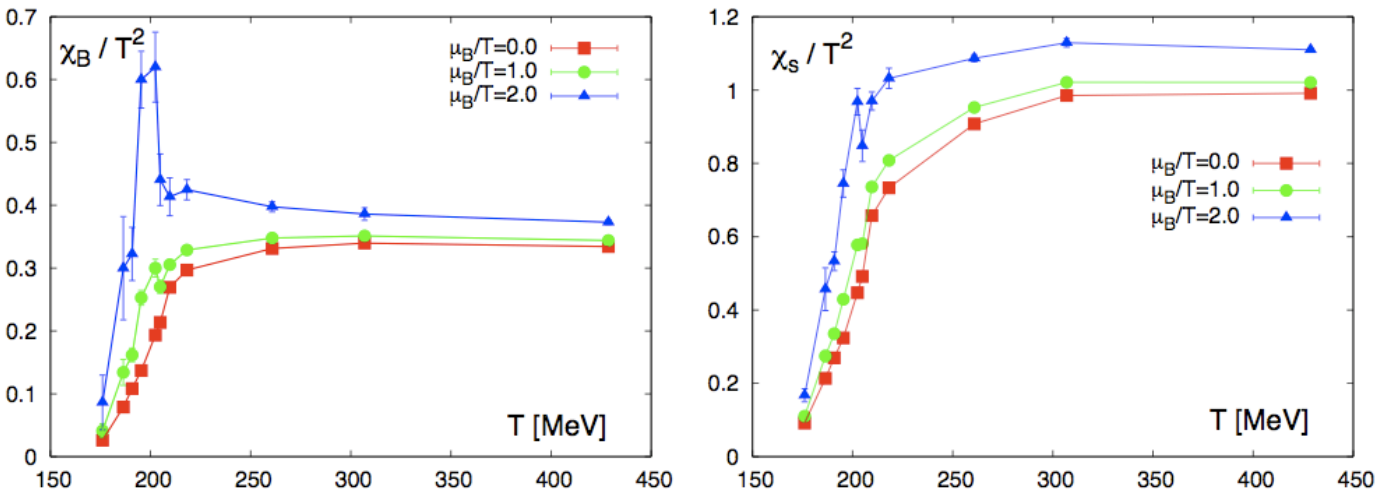
- Proton v_2 collapse predicted as signal for deconfinement
  (H. Stöcker: NPA 750 (2005) 121)
  - NA49: Difference between methods: Depends on v_2 fluctuations and non-flow contributions
  - Azimuthally symmetric detector STAR can measure event-by-event flow vector
  - STAR event plane resolution makes measurement with smaller error possible
  - Event plane detector as upgrade under discussion





Critical Point

- Lattice calculations show change in quark number susceptibilities
  - For light and strange quarks
  - Smooth transition at $\mu_B = 0$
  - Divergence at the critical point

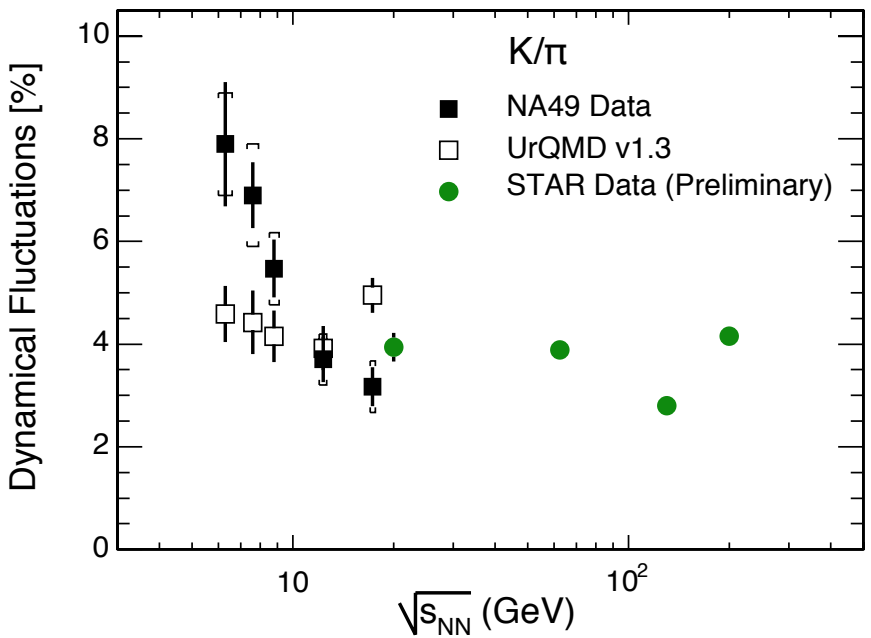


F. Karsch, PoS (CPOD07) 026

- Look for structures in the excitation function of fluctuations!
  - net-proton Kurtosis as a function of beam energy
  - two proton correlation functions
  - deuteron over proton

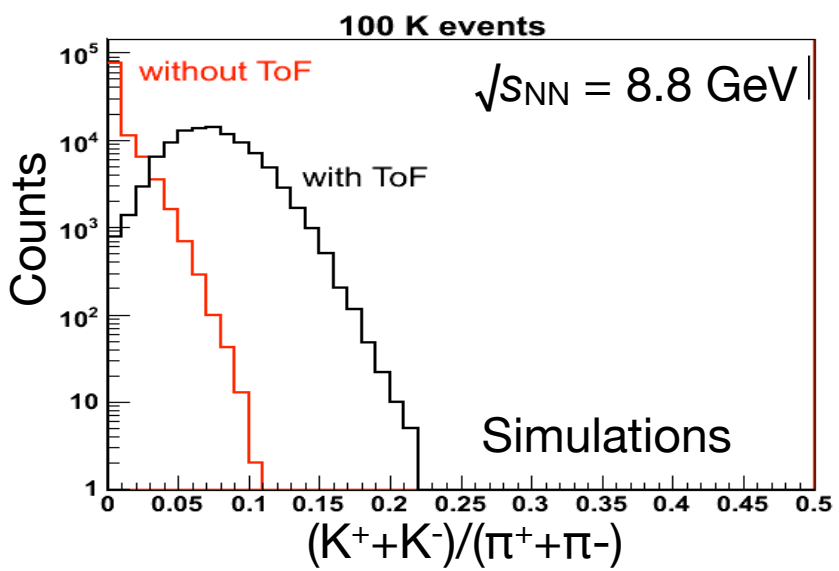
Critical Point

- Dynamical fluctuations of the K/π ratio rise steeply towards low SPS energies
  - Cannot be reproduced in hadronic model (UrQMD)
  - However, no quantitive prediction for critical point



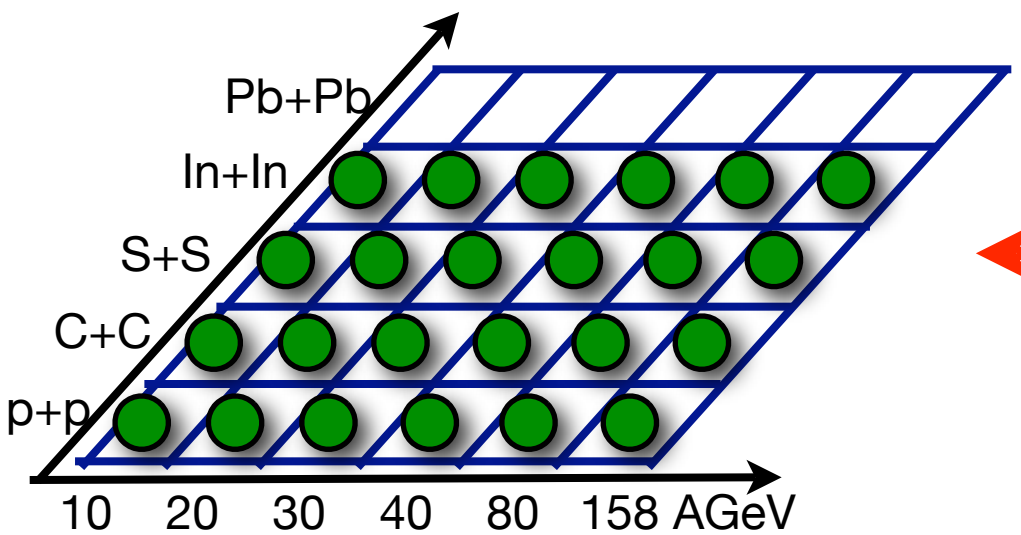
NA49: arXiv:0808.1237 [nucl-ex]
Submitted to Phys. Rev. C
STAR data: S. Das, J. Phys. G32 S541

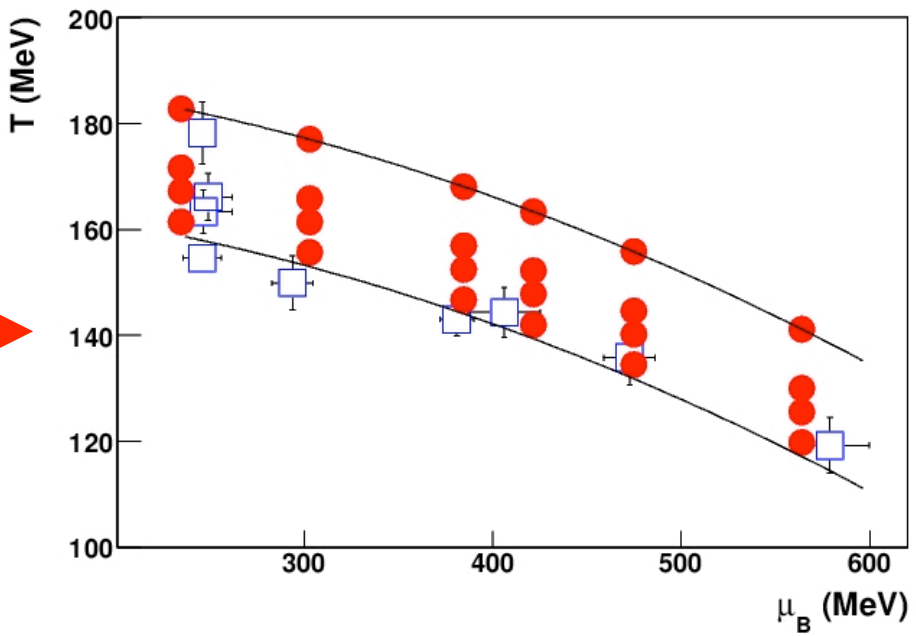
- STAR TOF will improve unambiguous kaon identification at low energies
  - Systematic measurement over wide energy range possible with smaller error



Critical Point

- Other fluctuation measures (N, $\langle p_T \rangle$) show no significant energy dependence for central Pb+Pb collisions at SPS energies
  - Are critical point signatures washed out in the hadronic phase?
  - Small systems freeze out at higher temperatures:
    A 2-D scan (T,μ_B) is possible by varying (A,$\sqrt{s}$)





Becattini et al., Phys. Rev. C 73, 044905

2006	p+Pb	Test run
2007	p+C	Neutrino physics detector R&D

1 month p beam successfully completed, positive evaluation of results

2008	p+C, p+p	high p_T, cosmic ray & neutrino physics

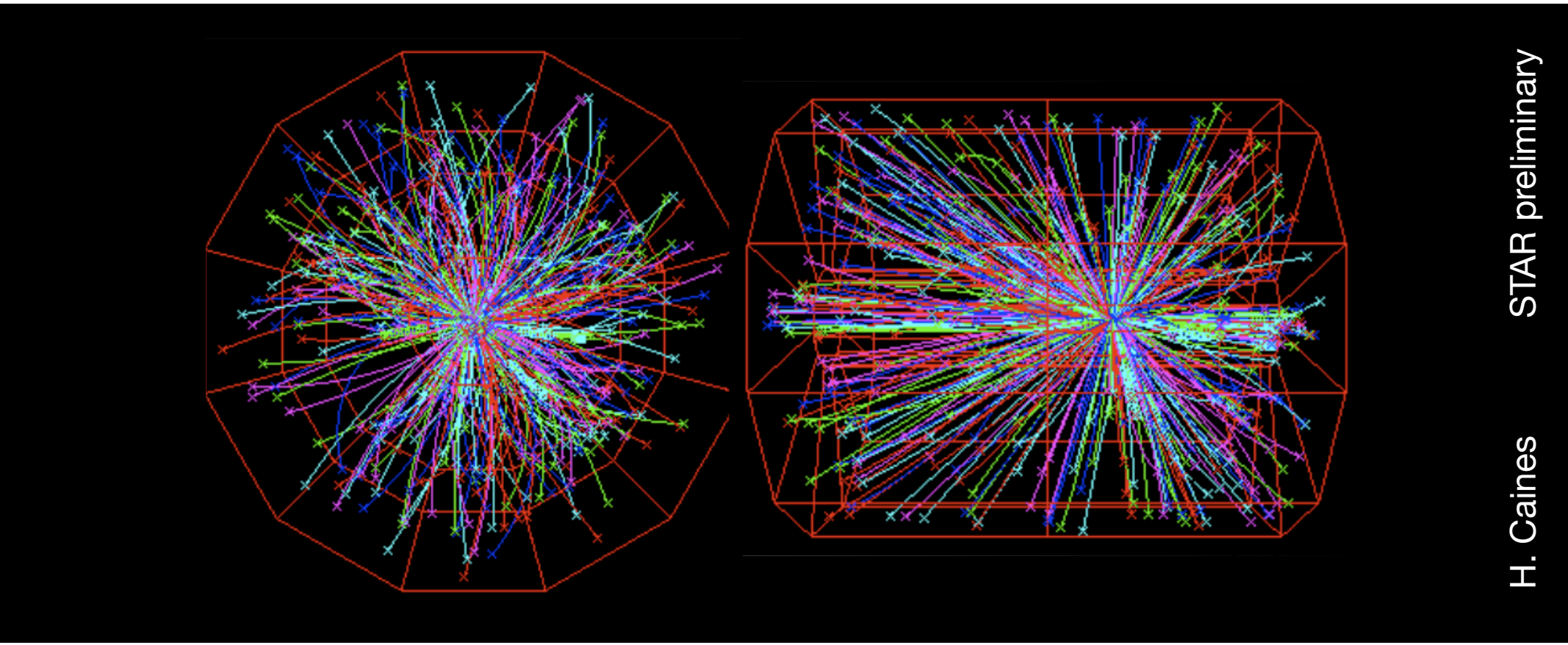
Currently successfully running!

proposed future runs:

2009	p+Pb at 158A GeV	high p_T
	p+p at 6 energies	
2010	p+Pb at 6 energies	
2011	S+S at 6 energies	
2012	C+C at 6 energies	
2013	In+In at 6 energies	

Energy and system size scan for onset of deconfinement and critical point

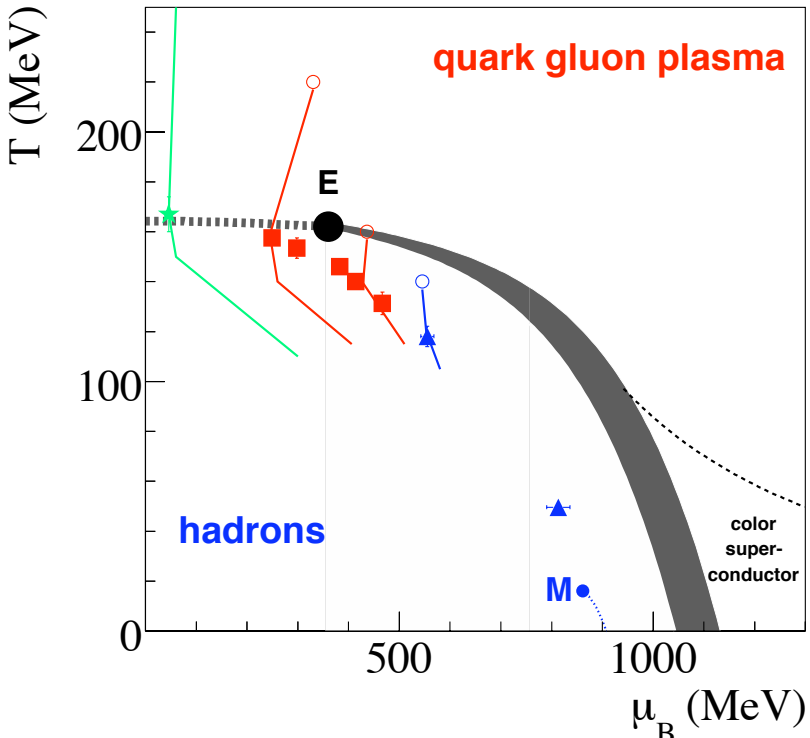
- 2008: Successful test run at $\sqrt{s_{NN}}$ = 9.2 GeV:



- 2010: 8-10 weeks exploratory run proposed
- 2012: Focussed run in region of interest exposed in exploratory run

Summary

- Explore the phase diagram of strongly interacting matter in A+A collisions at $5 < \sqrt{s_{NN}} < 20$ GeV:
  - Study the properties of the onset of deconfinement
  - Search for the critical point



- Worldwide efforts to scan the phase diagram:
  - RHIC energy scan: Au+Au at $5 < \sqrt{s_{NN}} < 200$ GeV
    Systematic study with energy independent acceptance over a wide energy range
  - NA61 at SPS: Various A+A species at $5 < \sqrt{s_{NN}} < 17$ GeV
    Adds a complementary system size scan and larger rapidity coverage
  - CBM at FAIR, MPD at NICA: $\sqrt{s_{NN}} < 9$ GeV
    High rate: Measurement of rare probes at lower energies