Explore the QCD Phase Diagram

- Partonic Equation of State at RHIC

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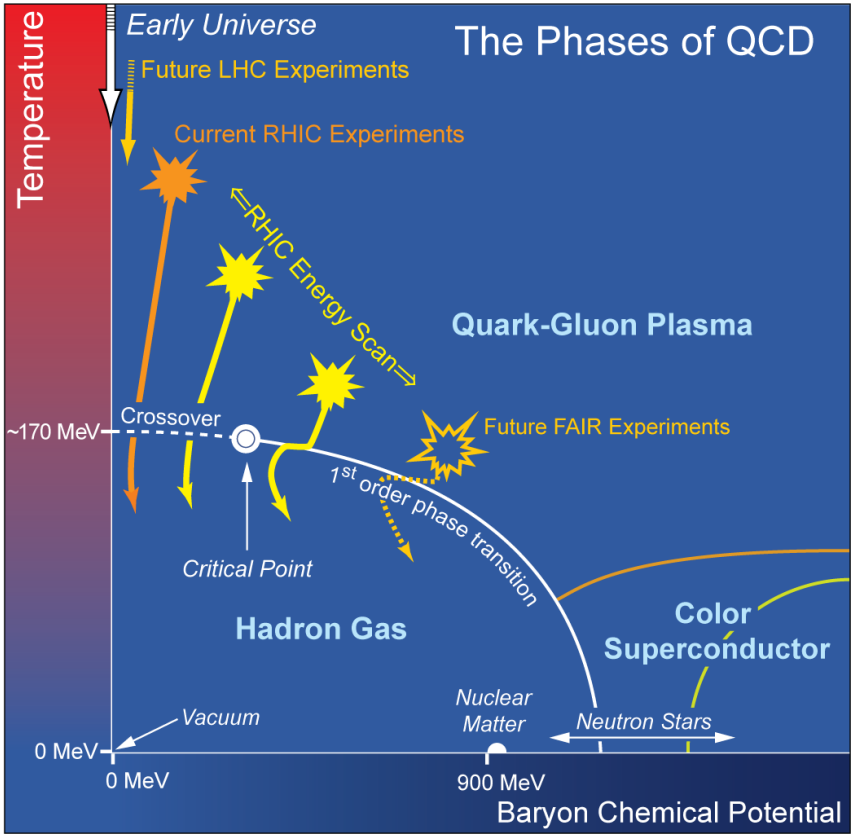
Physics Goals at RHIC

- Identify and study the properties of the matter (EOS) with partonic degrees of freedom.

- Explore the QCD phase diagram. It is our obligation!

The QCD Critical Point



2010: RHIC Beam Energy Scan
2011: Heavy Quark measurements

- LGT prediction on the transition temperature T_C is robust.

- LGT calculation, universality, and models hinted the existence of the critical point on the QCD phase diagram* at finite baryon chemical potential.

- Experimental evidence for either the critical point or 1st order transition is important for our knowledge of the QCD phase diagram*.

*** Thermalization has been assumed**

*M. Stephanov, K. Rajagopal, and E. Shuryak, PRL **81**, 4816(98)*
*K. Rajagopal, PR **D61**, 105017 (00)*

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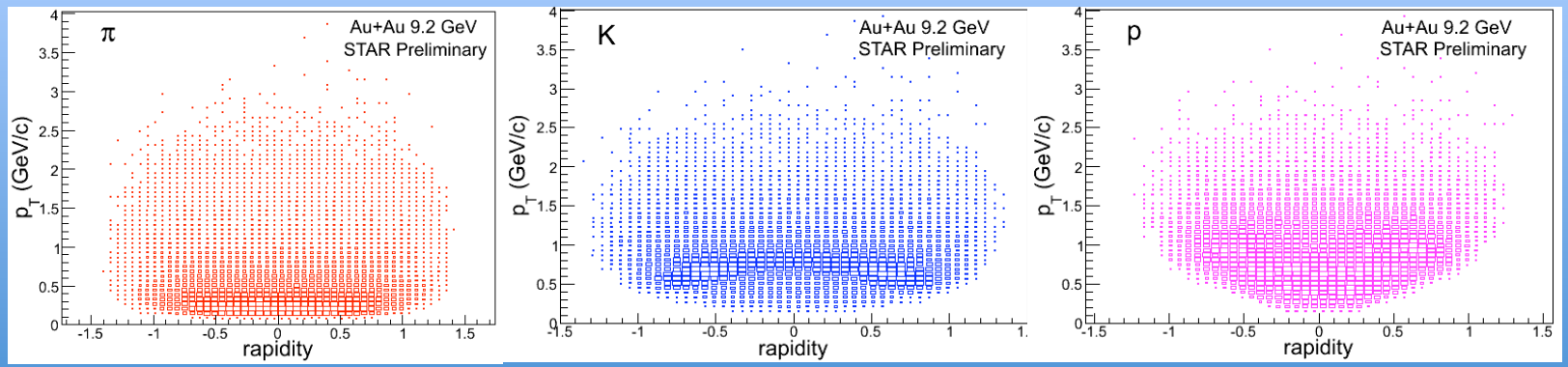
http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf

Collider Acceptance

Collider Mode STAR

$\sqrt{s_{NN}}$ = 9.2 GeV Au+Au Collisions at RHIC

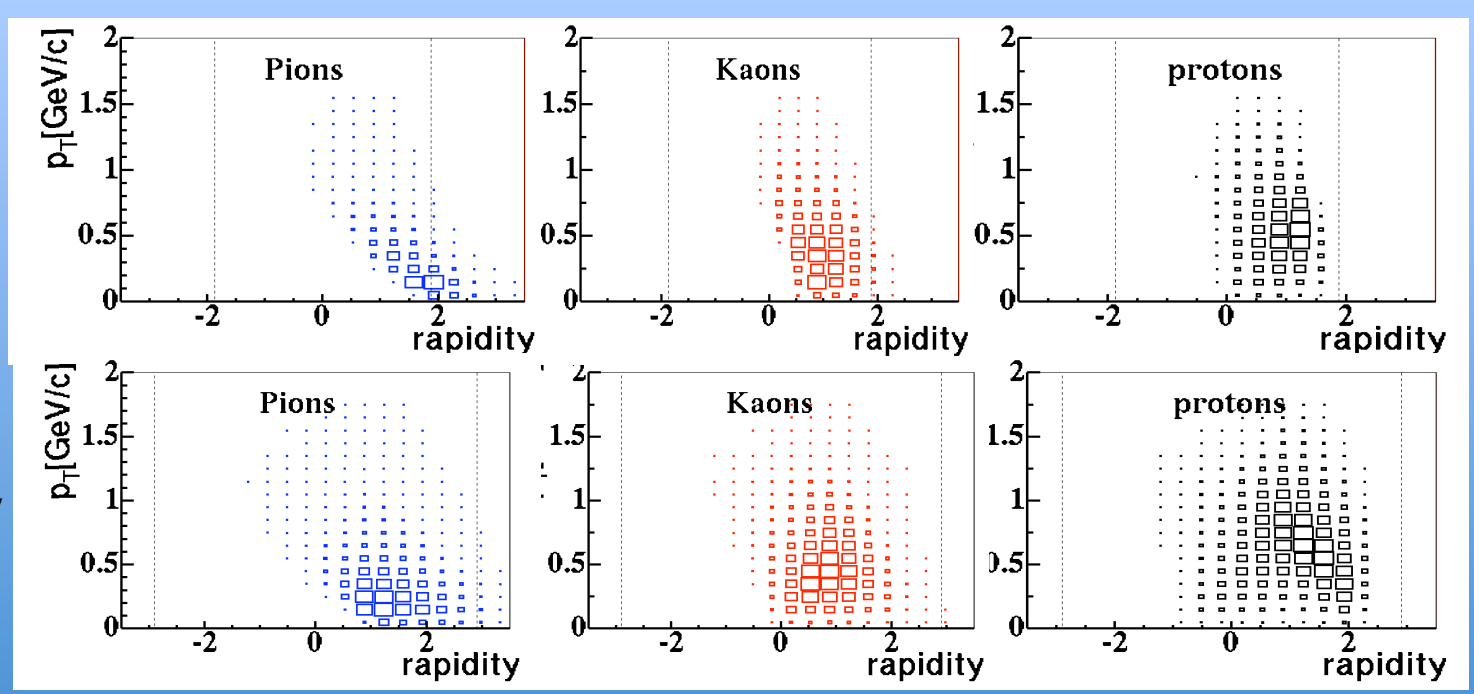


Fix-target Mode NA49

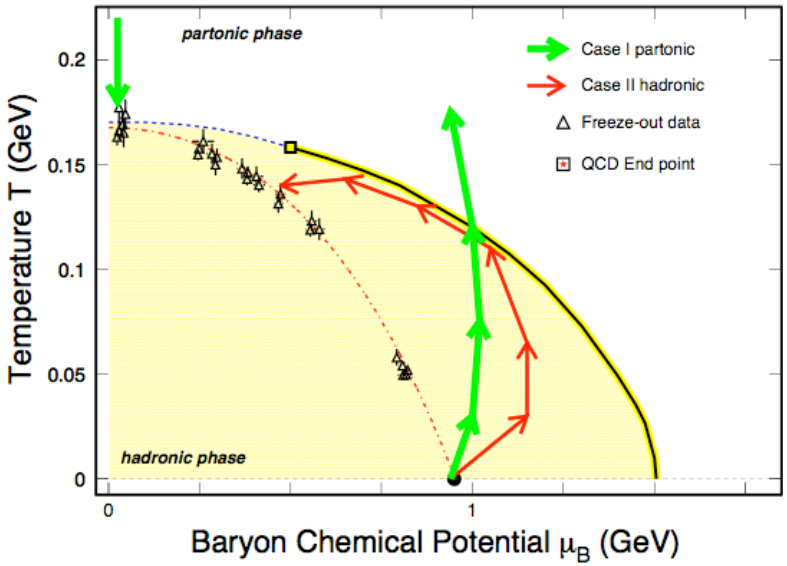
$\sqrt{s_{NN}}$

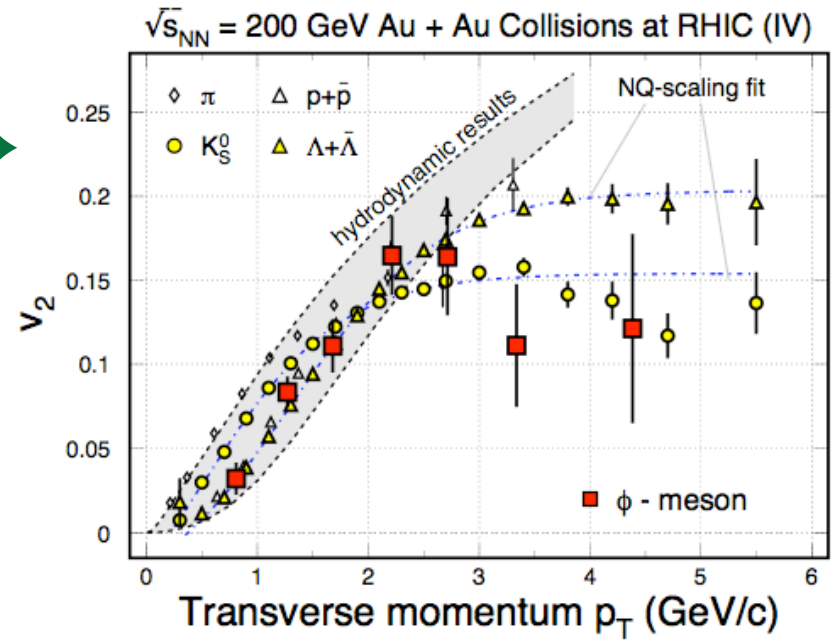
6 GeV

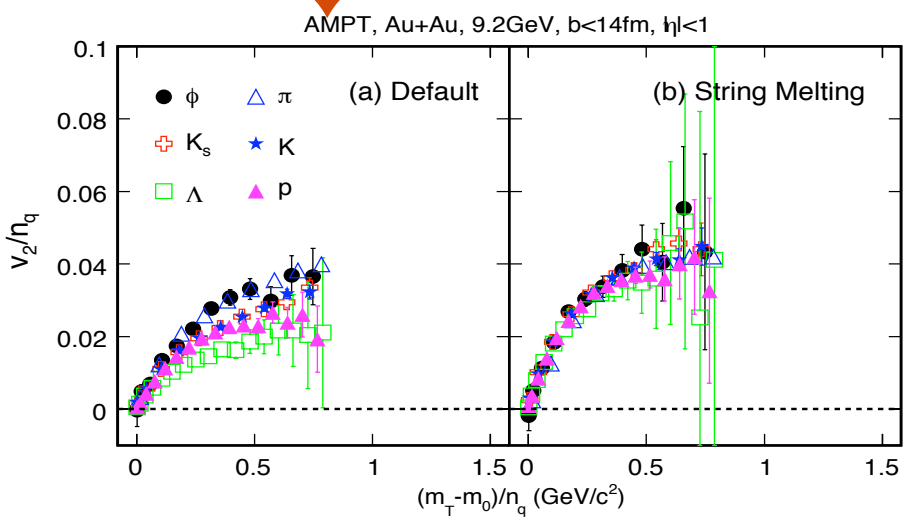
17 GeV



Observable I: Quark Scaling



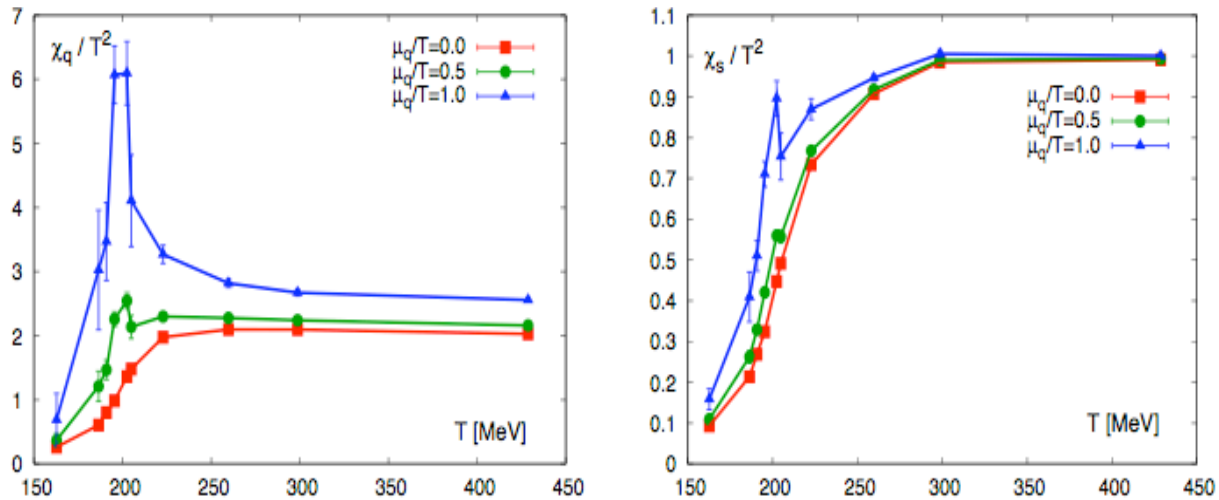




- $m_\phi \sim m_p \sim 1$ GeV
- ss ⇨ φ not K^+K^- ⇨ φ
- $\sigma_{\phi h} << \sigma_{p\pi,\ \pi\pi}$

In the hadronic case, no number of quark scaling and the value of v_2 of ϕ will be small.

Observable II: χ_q, χ_S



F. Karsch, 2008.

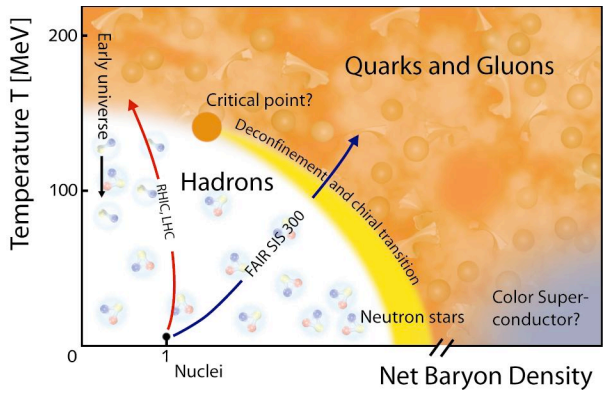
Event by event:

$$K_p = \frac{\langle N_p^4 \rangle - 3\langle N_p^2 \rangle^2}{\langle N_p^2 \rangle}$$

1. net-proton Kurtosis $K_p(E_{beam})$
2. two proton correlation functions $C_2(E_{beam})$
3. ratio of the d/p (E_{beam})
4. ratio of K/p (E_{beam})

Direct mapping from LGT (c.s.) to experiment (m.s.). ***first time!***
Tri-critical point on QCD phase diagram. ***first time!***

STAR Physics Focus

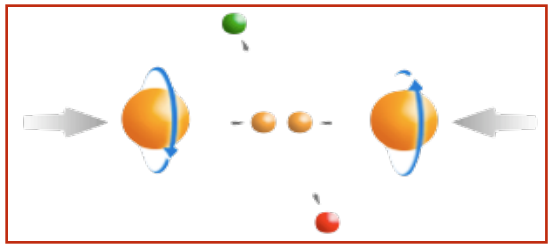


1) Heavy-ion program

- Study ***medium properties, EoS***
- pQCD in hot and dense medium

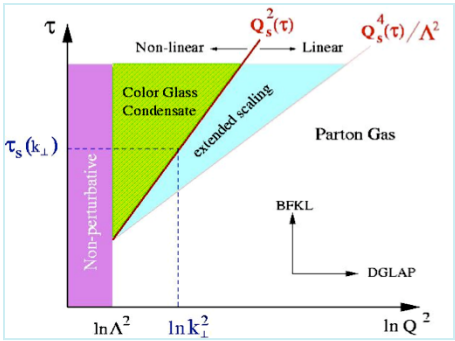
2) RHIC beam energy scan

- Search for ***critical point***
- Chiral symmetry restoration



Polarized spin program

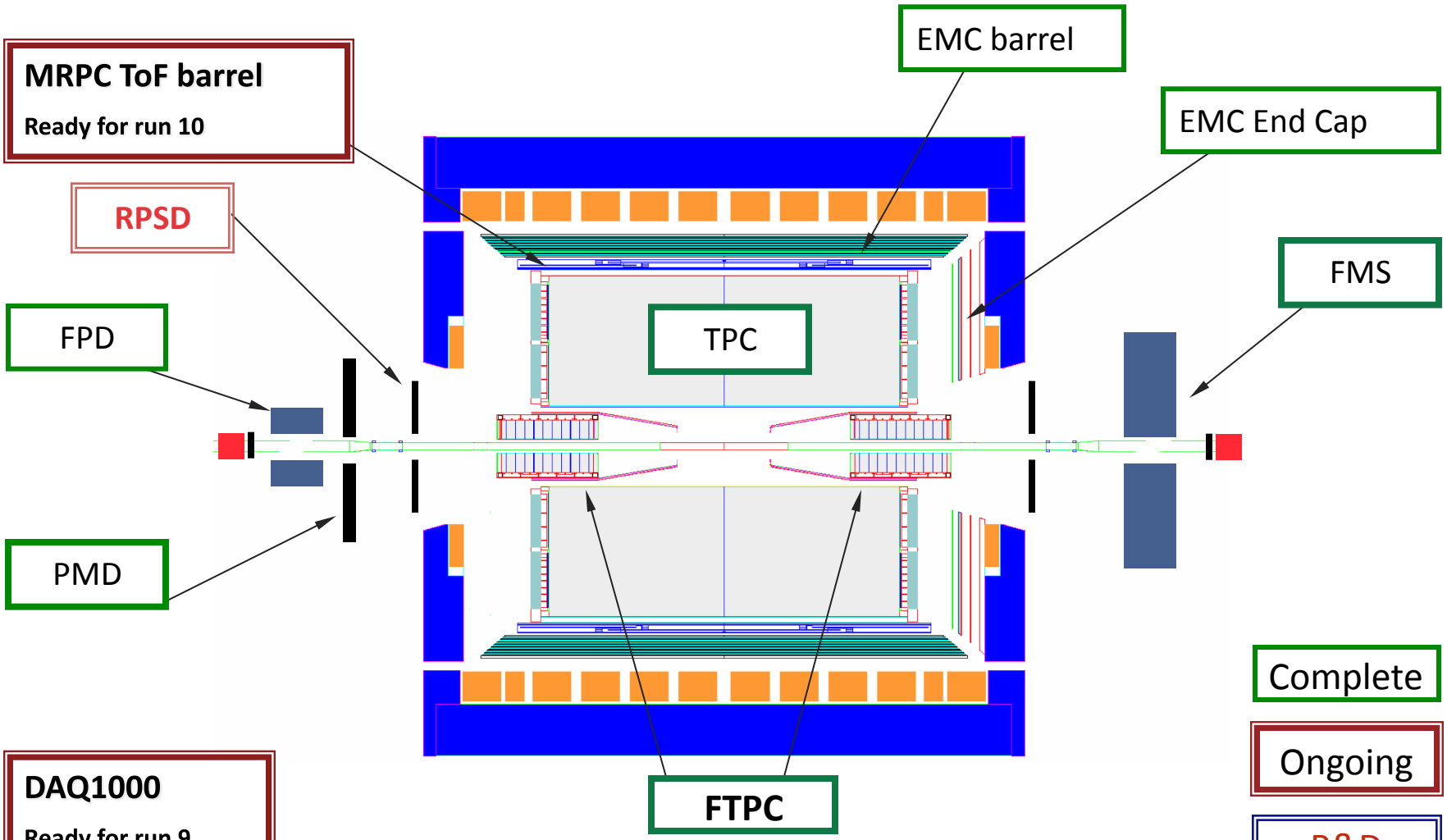
- Study ***proton intrinsic properties***



Forward program

- Study low-x properties, search for ***CGC***
- Study elastic (inelastic) processes (pp2pp)
- Investigate ***gluonic exchanges***

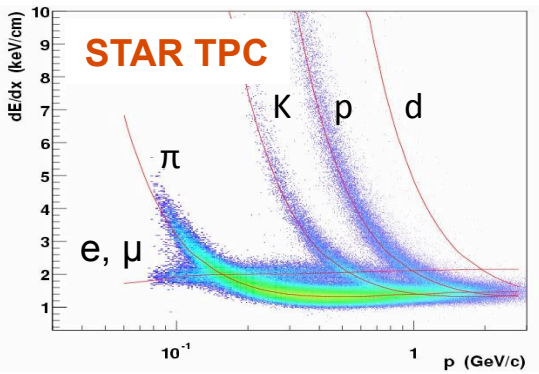
STAR Detector

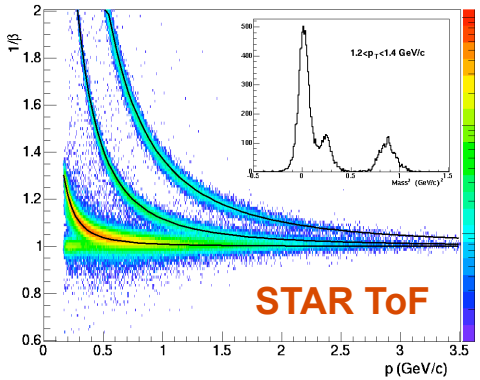


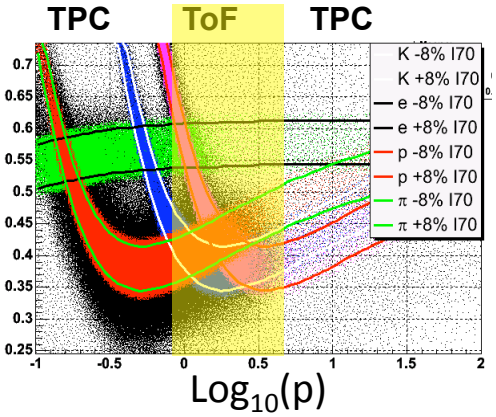
Full azimuthal particle identification!

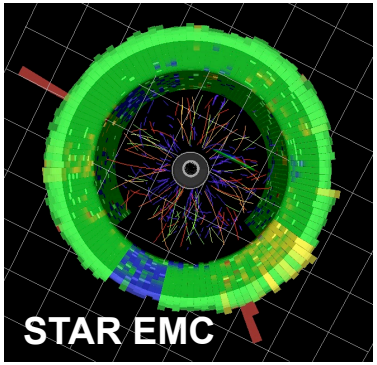
*e, π, **ρ**, K, **K***, p, **φ**, Λ, Δ, Ξ, Ω, D, Λ_C, **J/ψ**, **Υ** …*

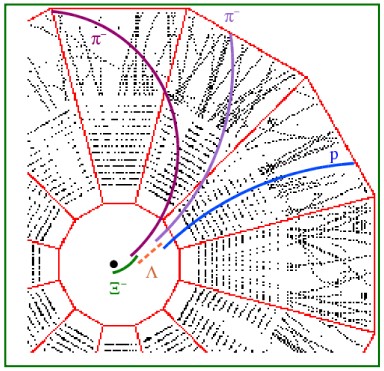
Particle Identification at STAR

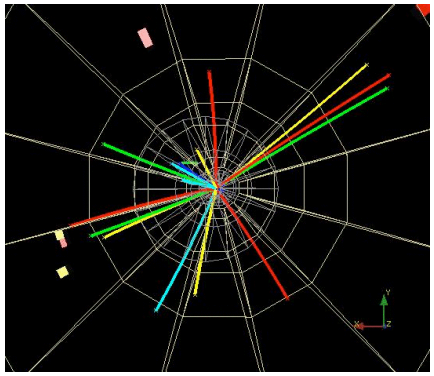


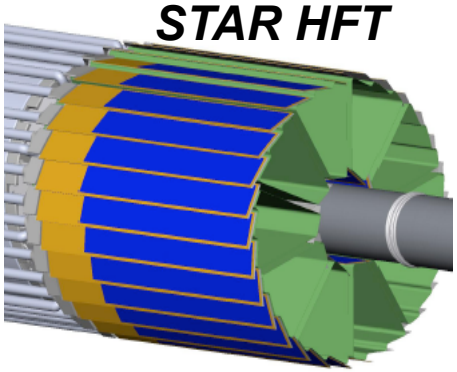












Neutral particles **Strange hyperons** **Jets** **Heavy Quark Hadrons**

Collisions Energy, Time

5 GeV	7.7 GeV	11.5 GeV	17.3 GeV	27 GeV	38 GeV
0.1 M	5 M	10 M	20 M	20 M	20 M
0.5 w	2.5 w	1.5 w	1 w	1.5 w	1.5 w

STAR Observables:

(1) K/pion, K/p, p/pion, charge, <pt> … fluctuations
(2) Net-proton Kurtosis, proton correlation functions
(3) HBT (reaction plane)
(4) PID v1, v2 (L. Csernai; CM Ko)
(5) Parity violation (+-), (--, ++)
(6) Jet-quenching of charged hadrons
(7) F-B correlations
(8) $\Delta\varphi - \Delta\eta$ (number and <pt>)
(9) v2 fluctuations (q-dist and cumulants)

η/s extraction

<pt> fluctuations (2-D); v2(b); v2(pt, pid); charm?

Onset of opacity and phase boundary

Raa; ridge (2-D imaging); di-hadrons; F-B correlations;

Softening of the EOS

Azimuthal HBT; v1 inflection points; Collapse of flow;

Critical point, 1st order phase transition

particle ratio fluctuations; PID Kurtosis;