From AA, pA to eA
-- a personal view mostly from STAR's perspective

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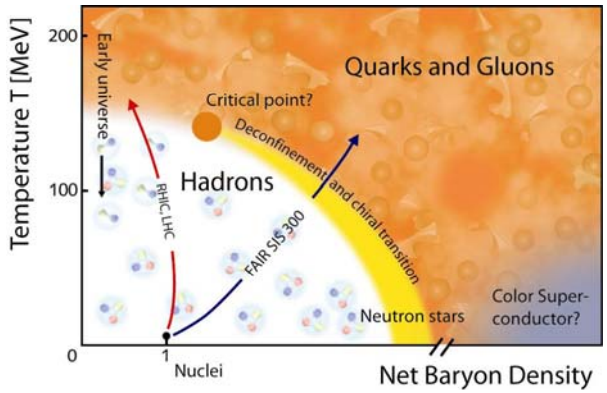
POETIC, Aug 20-22, 2012 @ Indiana

RHIC/STAR Physics Focus

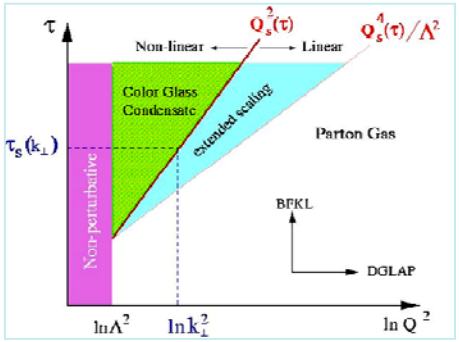


1) At 200 GeV top energy

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

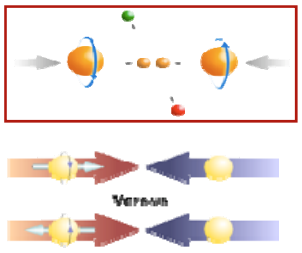
2) RHIC Beam Energy Scan (BES)

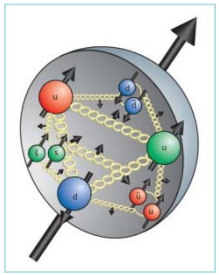
- Search for the ***QCD critical point***
- Chiral symmetry restoration



Forward program

- Study low-x properties, initial condition, search for ***CGC***
- Study elastic and inelastic processes in pp2pp



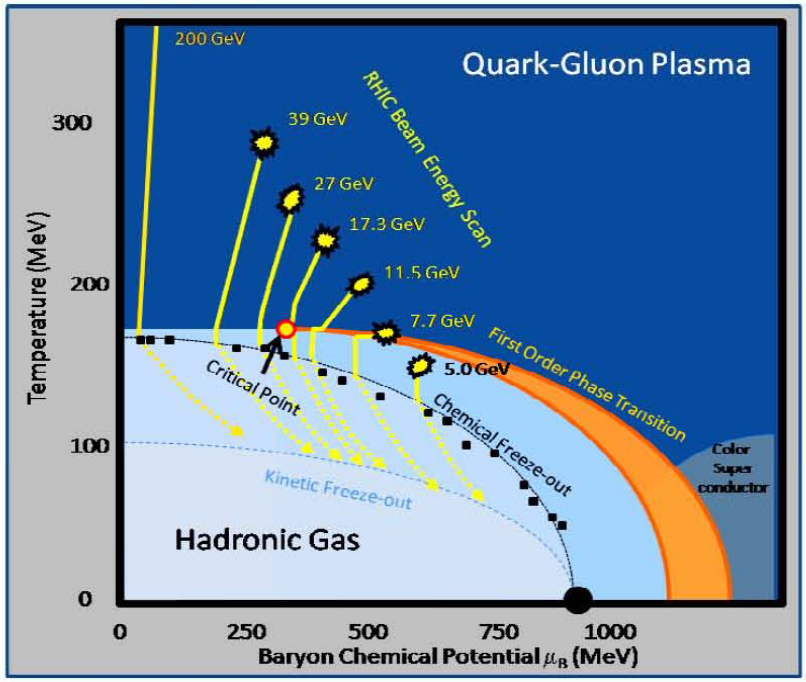


Polarized *p+p* program

- Study ***proton intrinsic properties***

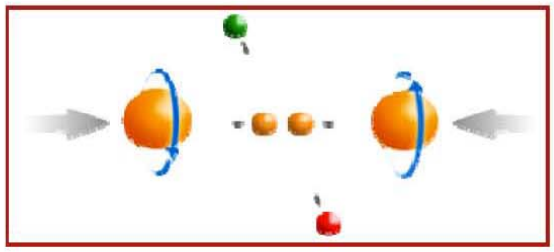
Very Exciting Scientific Program and Detector Upgrades for the coming decade

Hot QCD Matter

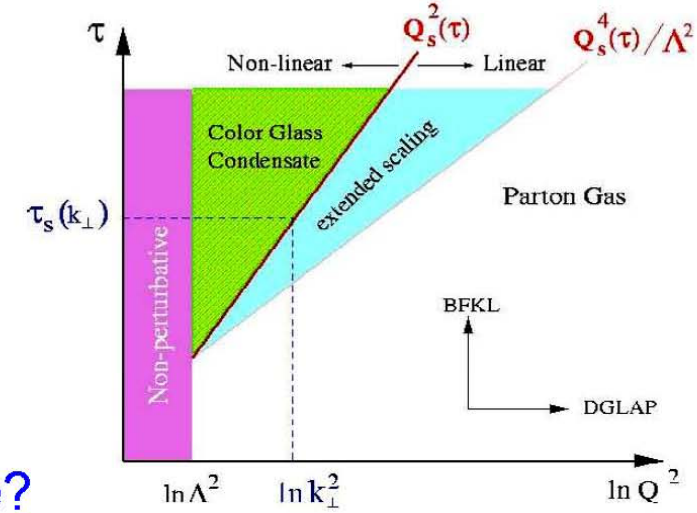


1: Properties of the sQGP
2: Mechanism of energy loss:
weak or strong coupling?
3: Is there a critical point, and if so, where?
4: Novel symmetry properties
5: Exotic particles

Partonic structure



6: Spin structure of the nucleon
7: How to go beyond leading twist and collinear factorization?



8: What are the properties of cold nuclear matter?

Outline

A+A Program

1) QCD Phase Boundary and Possible Critical Point
2) sQGP Properties
3) Chiral Symmetry and Di-lepton Probes
4) QCD Vacuum Excitation, Symmetry and Exotics

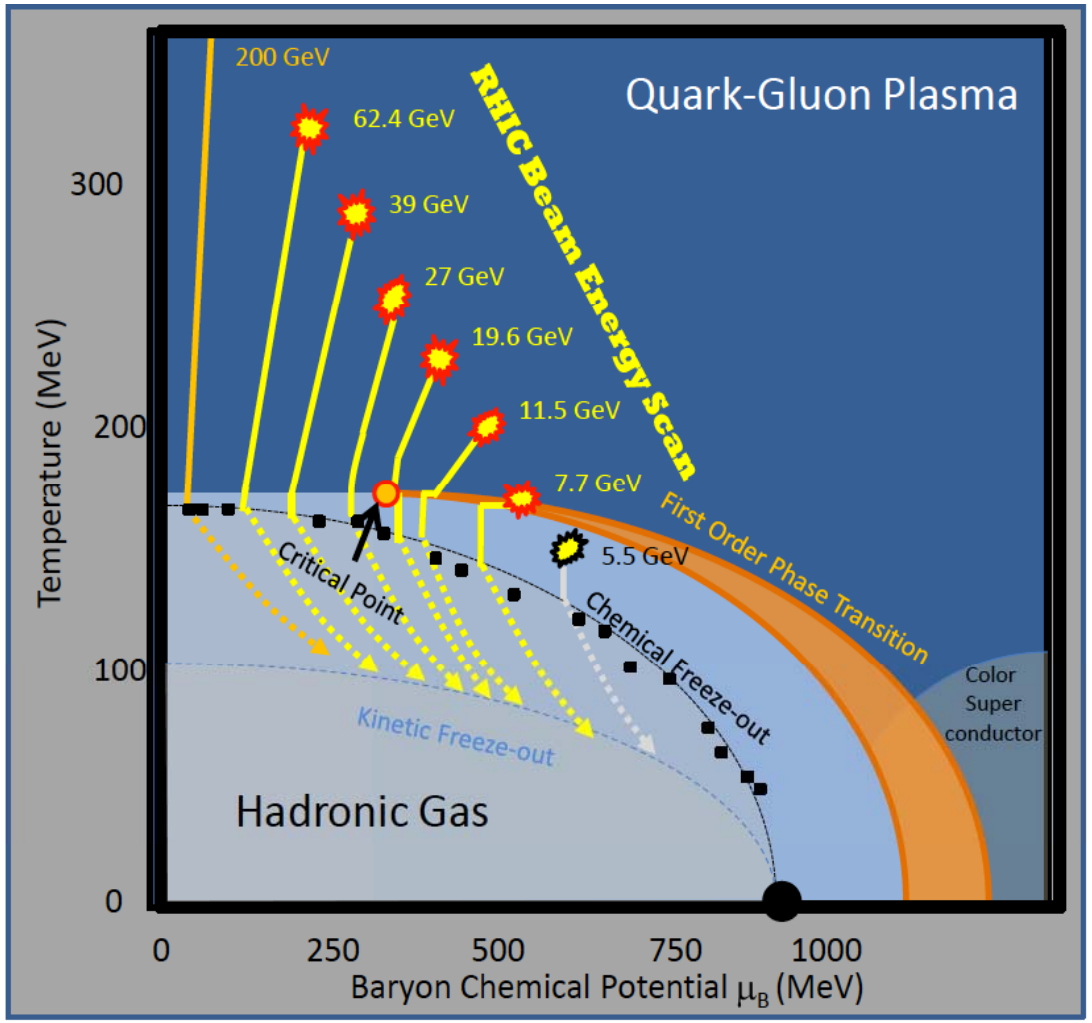
p+A Program

1) Gluon Saturation at Low x Region
2) Forward Instrumentation Upgrade

Towards eA Program

1) R&D Efforts
2) Day-1 Physics Capability (Zhangbu Xu)

QCD Phase Diagram and RHIC BES-I

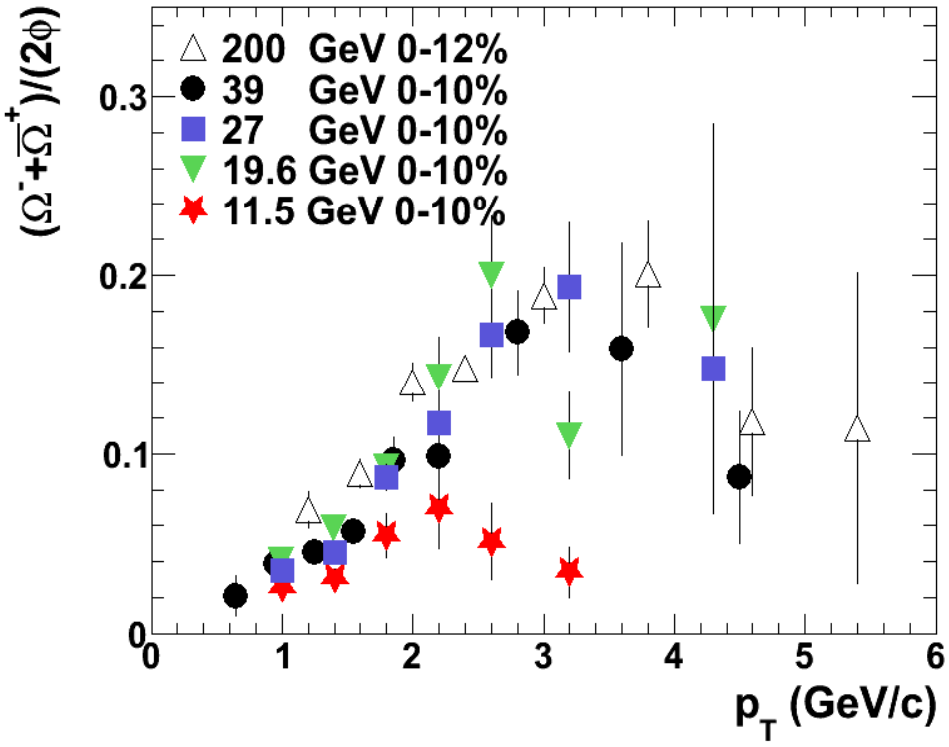


Year	En (GeV)	# Event (10^6)
2010	39	130
2010	11.5	12
2010	7.7	5
2011	27	70
2011	19.6	36

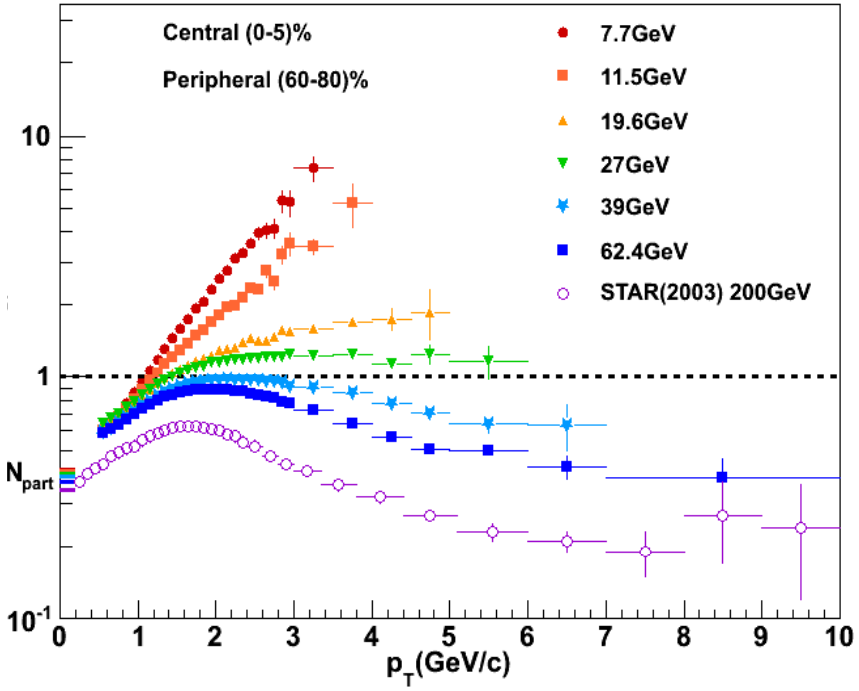
RHIC can deliver low energy beams
STAR has almost uniform acceptance independent of beam energy
Luminosity/Data-taking efficiency !!

Key Results from RHIC BES-I

Ω/ϕ Ratio



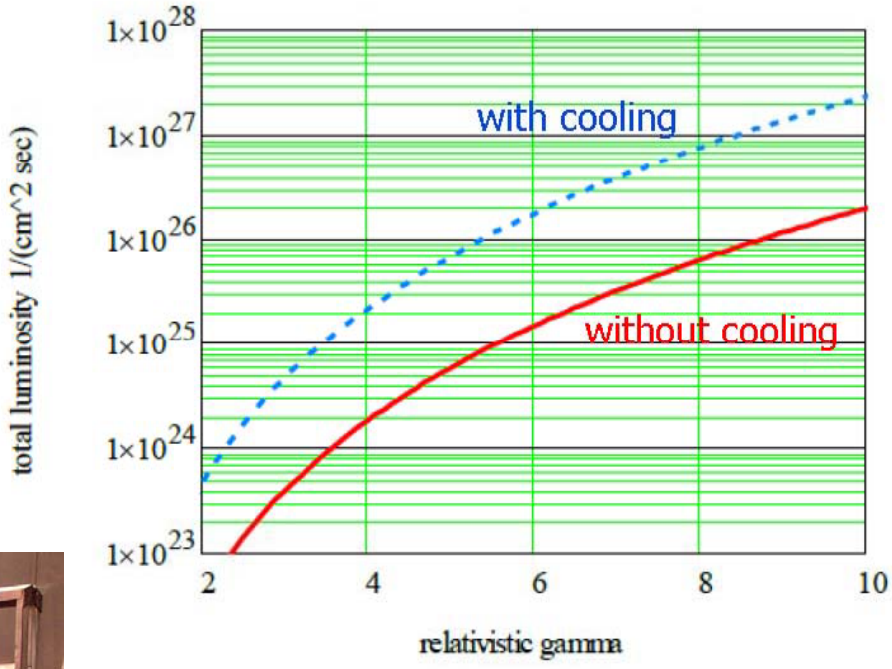
Nuclear Modification Factor R_{CP}

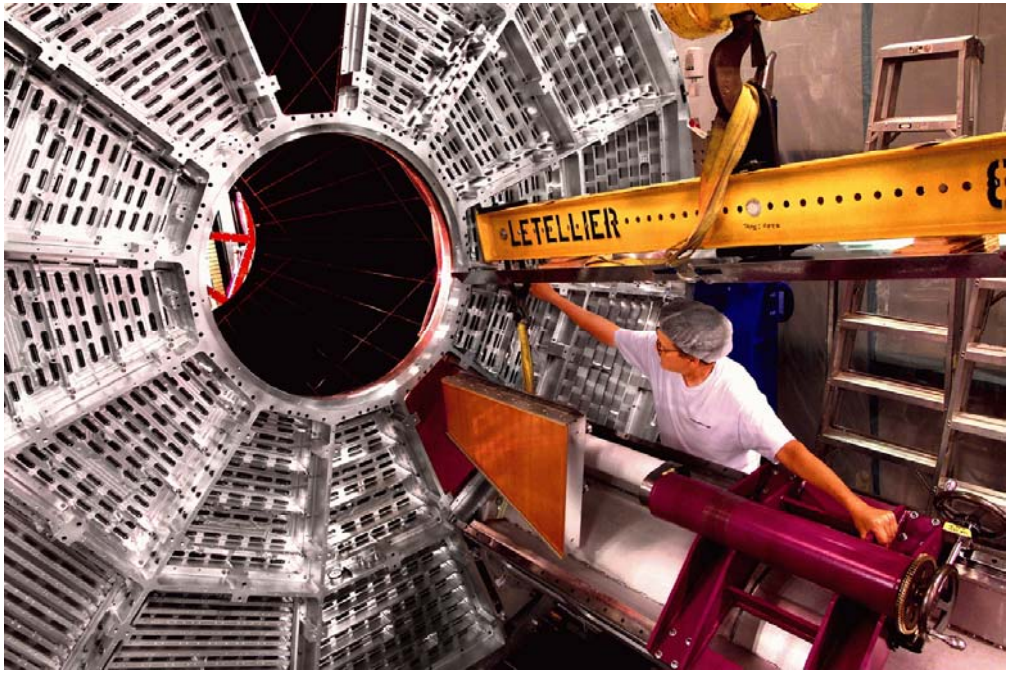


1) Likely a transition from partonic matter to hadronic DOF dominated collision dynamics between 20-10 GeV
2) No definitive observation of critical fluctuations

Road to Beam Energy Scan II

1) Need electron cooling to be more efficient !





2) STAR TPC Inner Sector readout upgrade
-- enhance tracking and PID in η 1-1.7 region

BES II Starting 2016+

Strongly Coupled Quark-Gluon Plasma

Jet Quenching

Volcanic high p_T -- Strombolian eruption

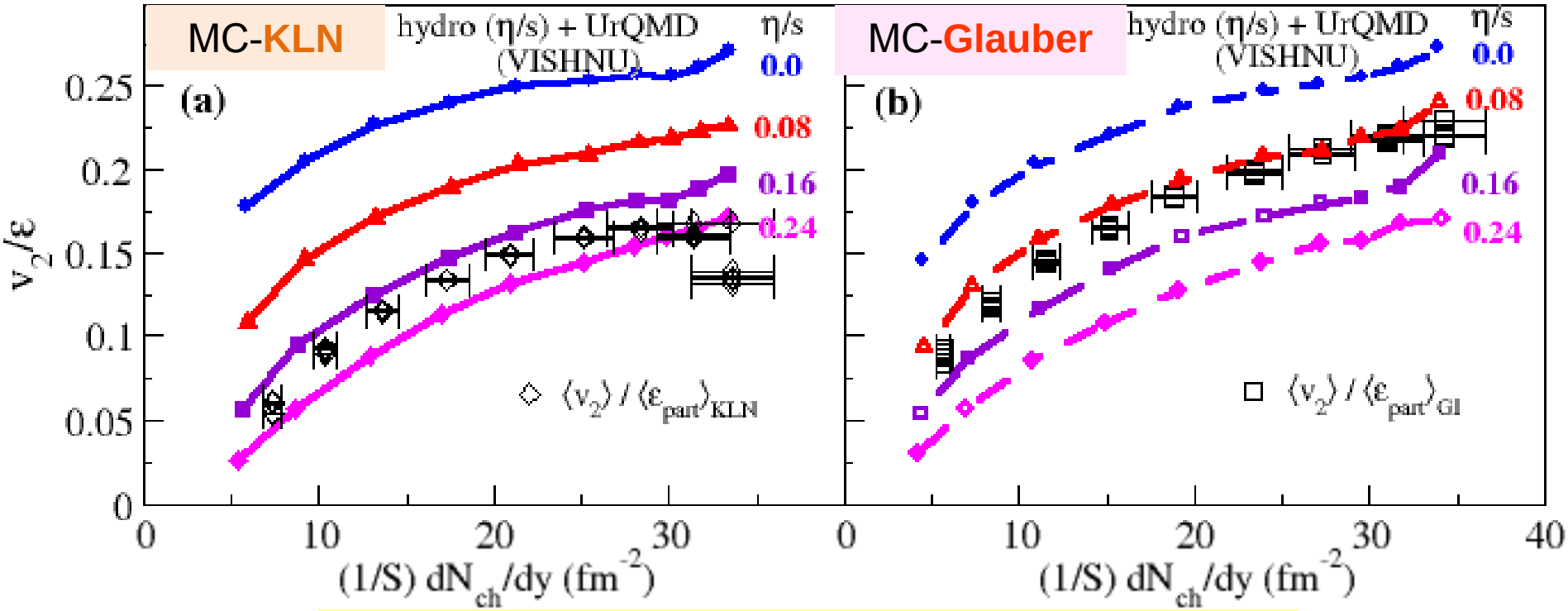
Coalescence-Clustering

Hydrodynamic Flow

Volcanic low p_T – Bulk matter flows

Quantitative Properties of sQGP

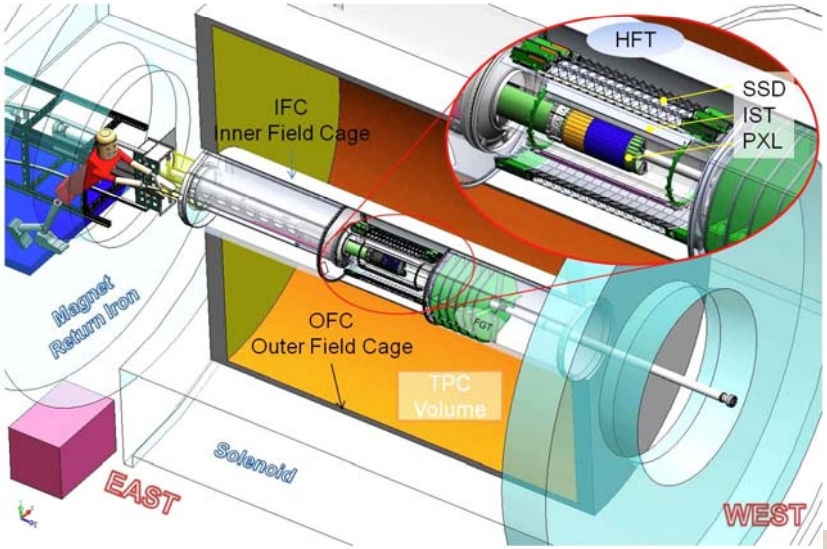
H. Song, S. Bass, U. Heinz, T. Hirano, and C. Shen, PRL2011

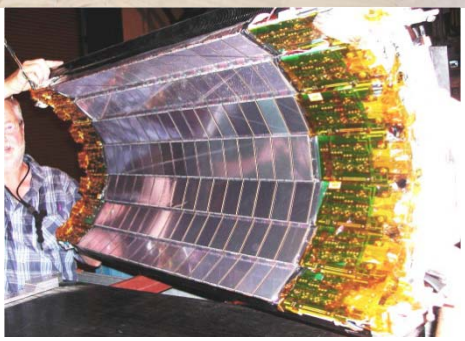


$$1\times(1/4\pi) \le (\eta/s)_{QGP} \le 2.5\times(1/4\pi)$$

Major uncertainties due to theoretical/experimental understanding of the initial conditions!

Heavy Quarks Are Better Probes





3 detector systems;

- PXL 2 layers of CMOS
- IST 1 layer at 14 cm
- SSD 1 layer

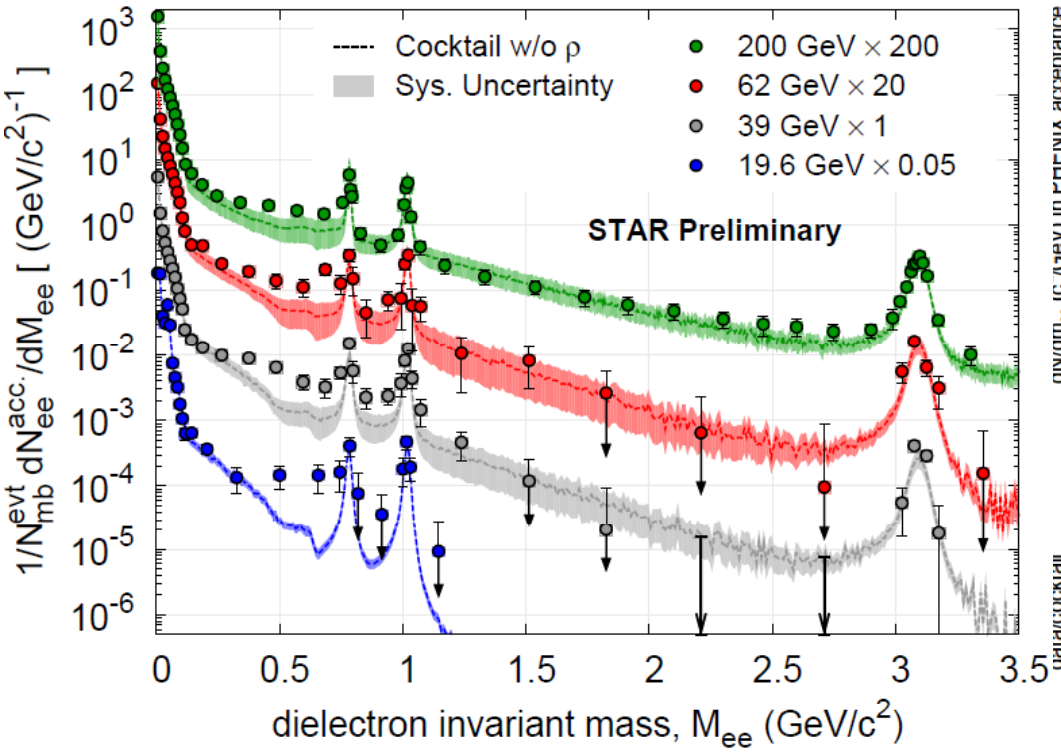
Engineering run 2013

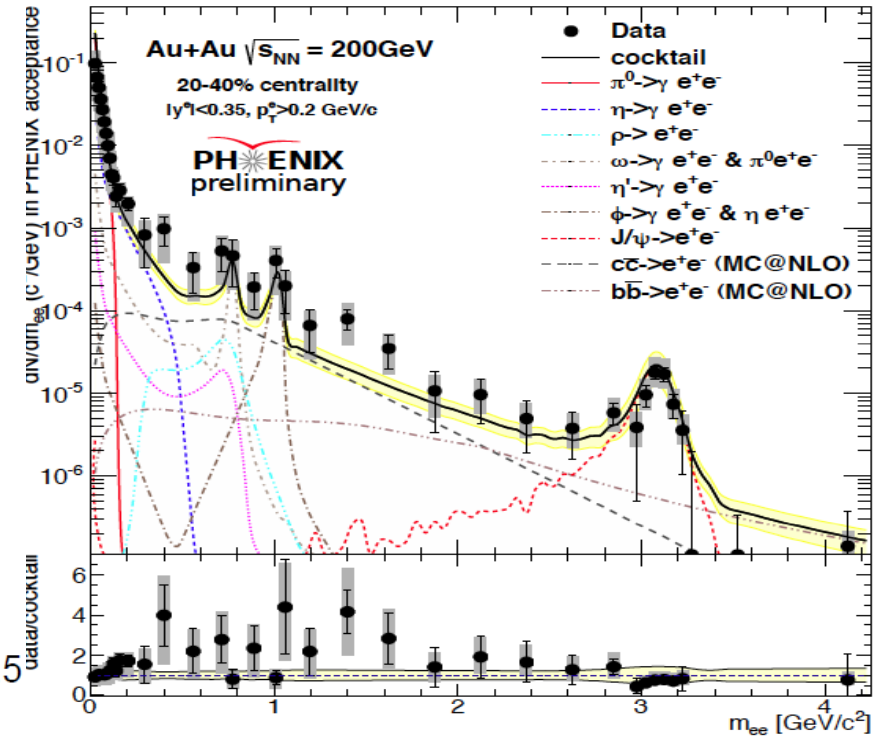
Full system installed in 2014

Charm/Bottom Diffusion Through the QCD Color Medium

Charm/Bottom Energy Loss

Chiral Symmetry and Di-electrons





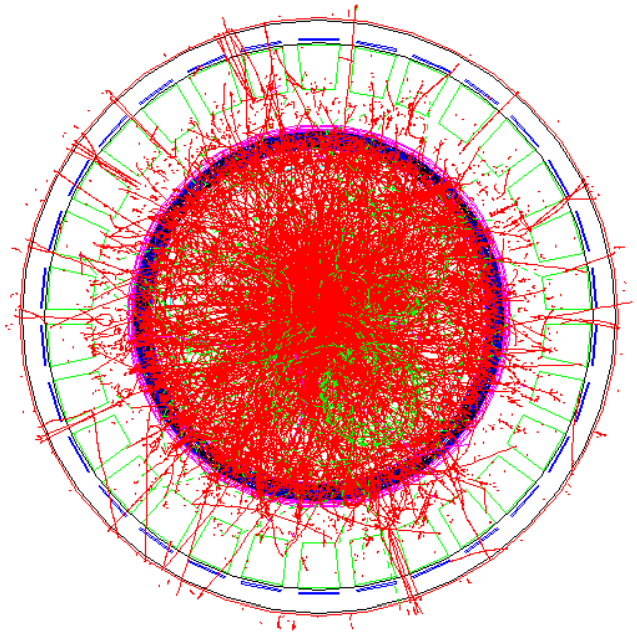
Low mass region (<1.0 GeV) – vector meson properties in the QCD medium

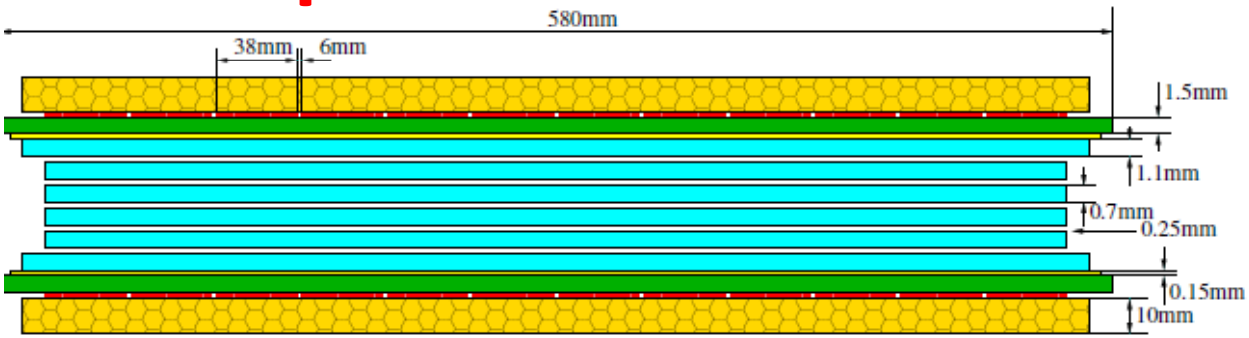
Intermediate mass region (1-3 GeV) – QGP radiation and heavy quark decays (depends on heavy quark evolution in the QCD medium)

Very difficulty experimental measurements!

lessons from SPS – need 5-10 years to understand the signal and background!

Muon Telescope Detector -- 2014





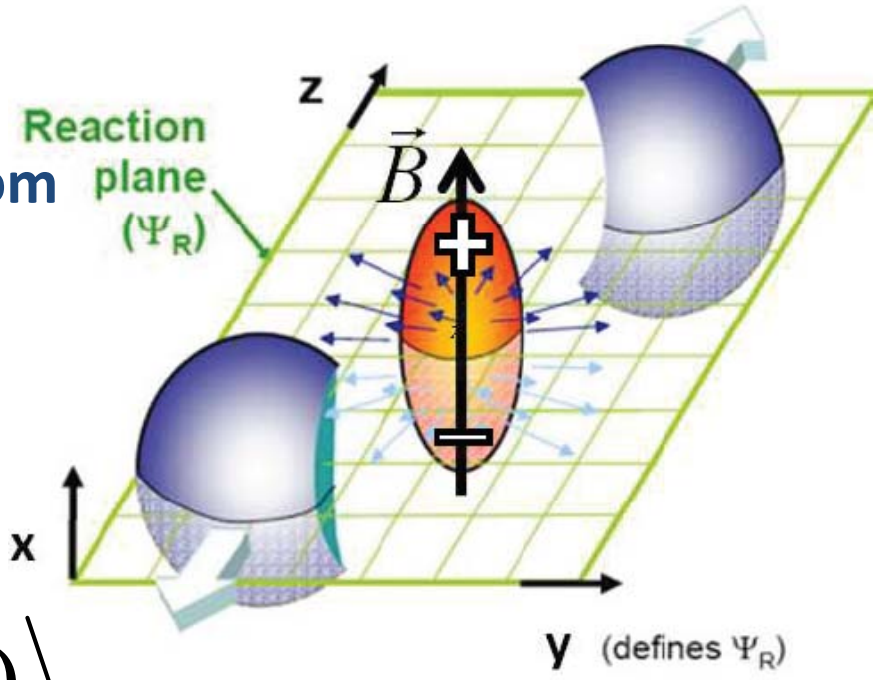
Multi-gap Resistive Plate Chamber (MRPC): gas detector, avalanche mode

Run 2012 -- 10%; 2013 – 43%+; 2014 – 100%
Successful commissioning run in 2012

Upsilon (1S, 2S/3S) States
e-μ Correlations

QCD Exotic Phenomena

QCD Vacuum Sphaleron excitation coupled to strong magnetic field from spectator protons
-- charge separation across the reaction plane
parity violating in strong interaction



Kharzeev et al NP A803, 227 (2008)

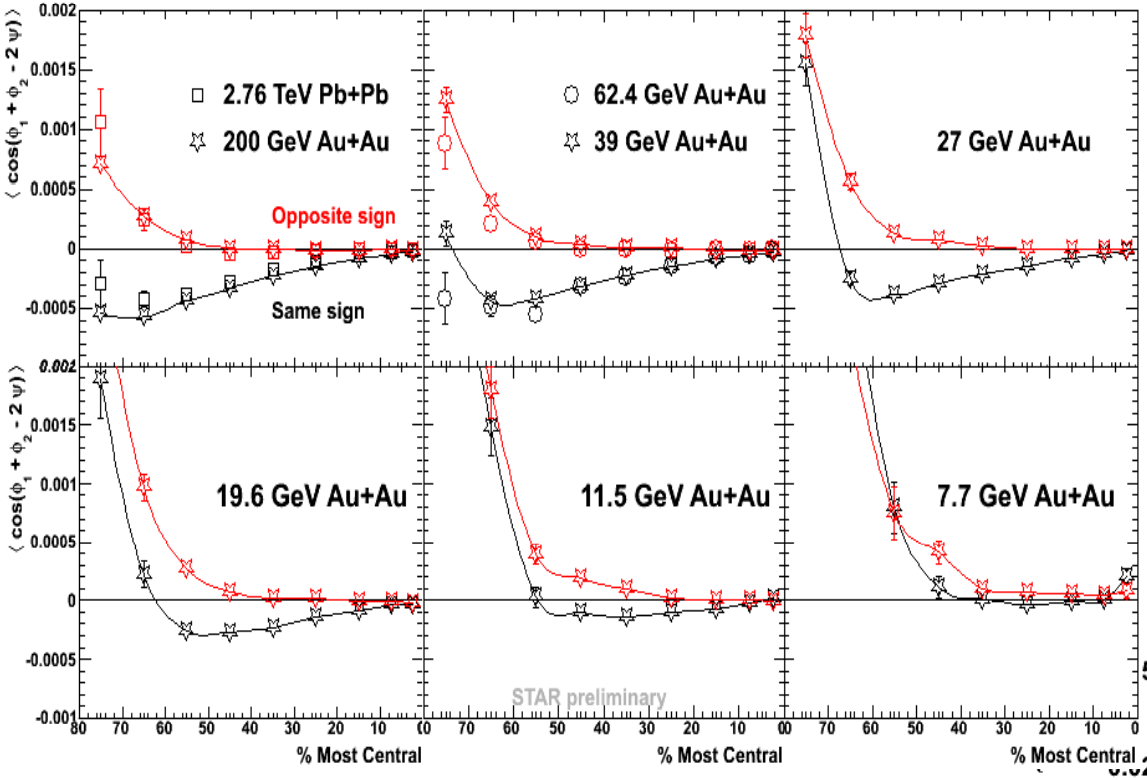
$$\gamma = \left\langle \cos(\phi_\alpha + \phi_\beta - \psi_{RP}) \right\rangle$$

$$= \left[\left\langle v_{1,\alpha} v_{1,\beta} \right\rangle + B_{in} \right] - \left[\left\langle a_\alpha a_\beta \right\rangle + B_{out} \right]$$

Voloshin, PRC70, 057901 (2004)

charge dependent – same sign (++,--) and opposite sign(+-, -+) sensitive to charge separation

Recent STAR Progress on the Charge Separation Measurement

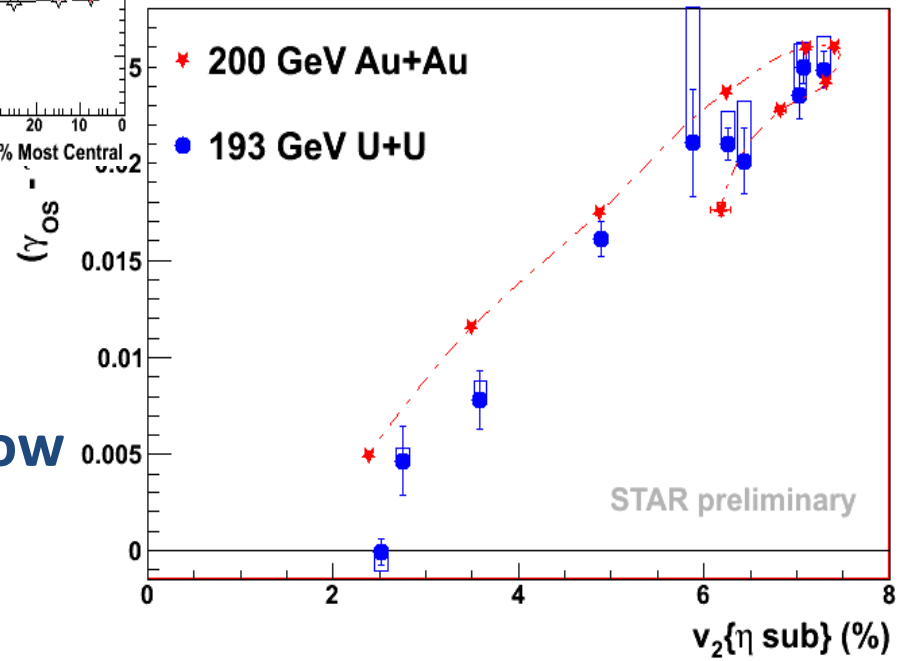


Charge separation

-- disappears at low energy where QGP presumably cannot be formed and/or live long enough!

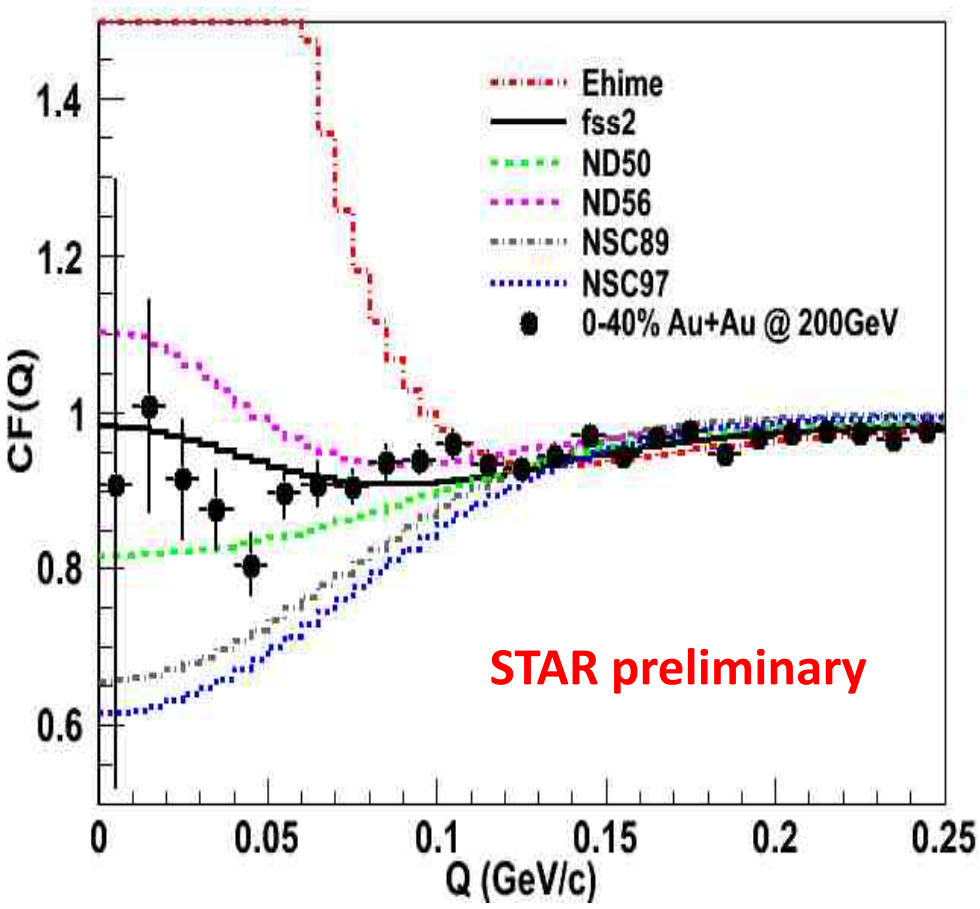
Charge separation

-- disappears in very central collisions when magnetic field approaches zero, but elliptic flow is finite !



Searches for Exotic Particles

Λ-Λ Correlation
-- sensitive to ΛΛ interaction
H (uuddss) bound state
-- depletion of ΛΛ pairs

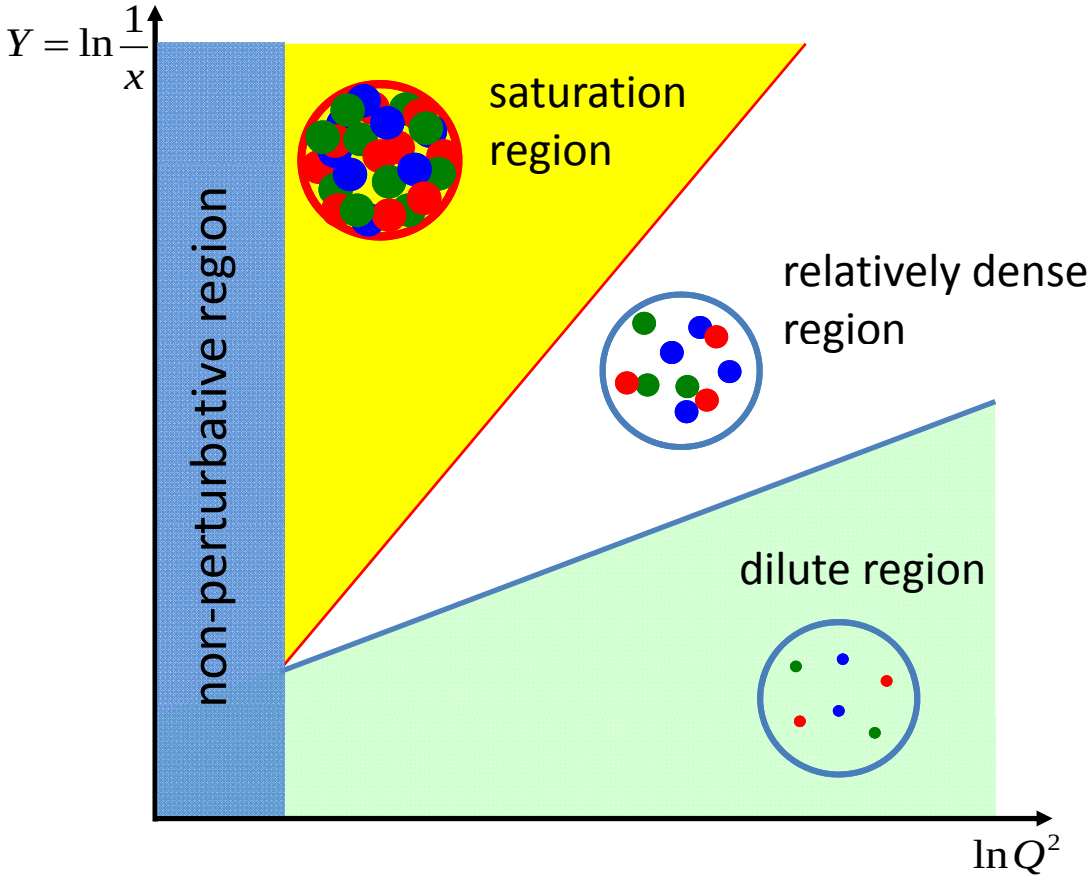


Theoretical models fit to STAR preliminary data:
ΛΛ – attractive interaction
no bound state !

Other di-hyperons ? ΞΞ or ΩΩ
Other exotic particles?

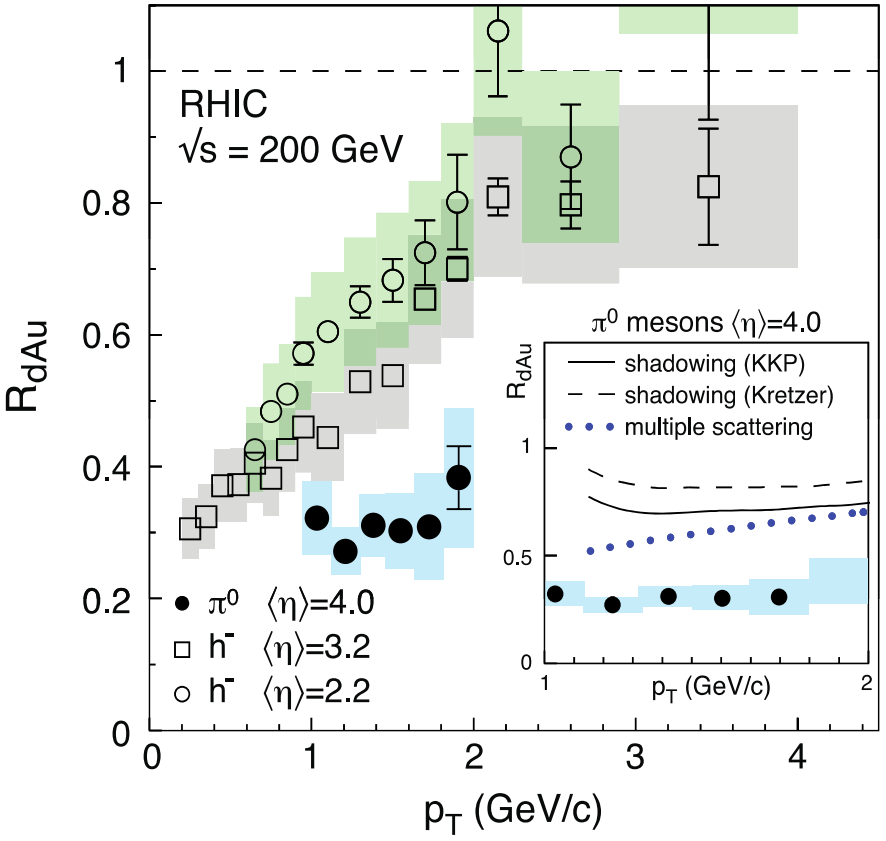
p+A Program – Parton Saturation at Low x

The quantum nature of the partons must manifest through saturations ! At what Q_S and x scales and to what extent?

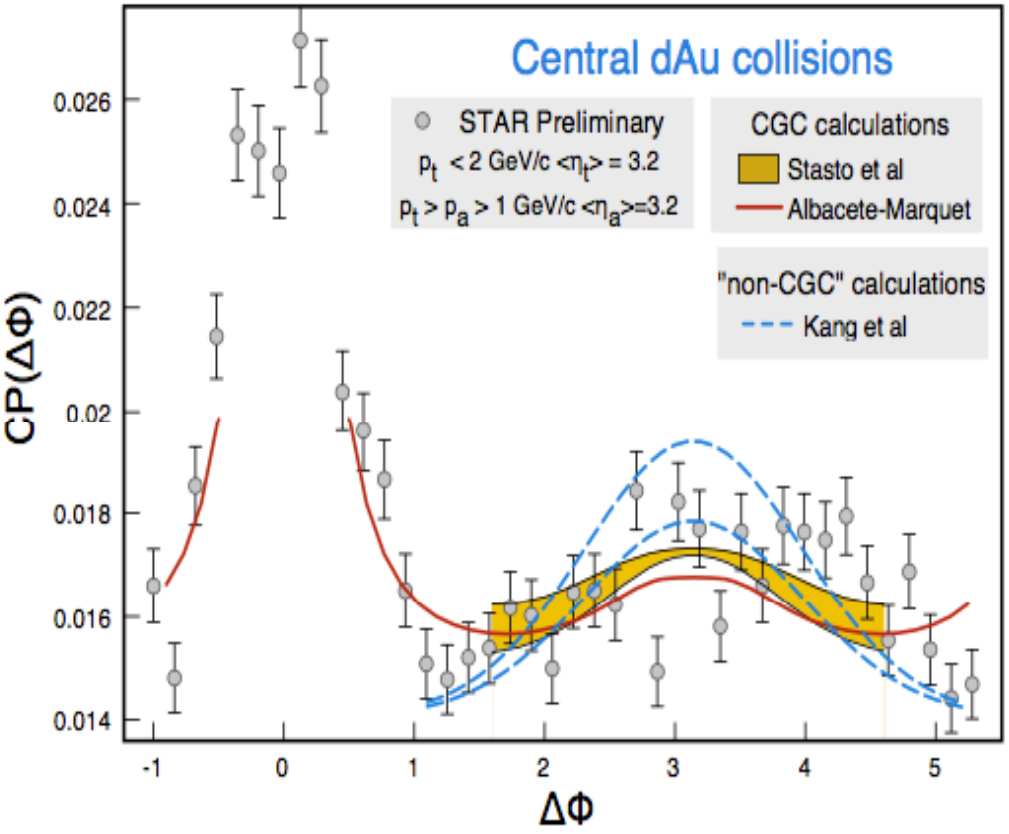


Intriguing Hints @ RHIC d+Au Collisions

Suppression at forward direction

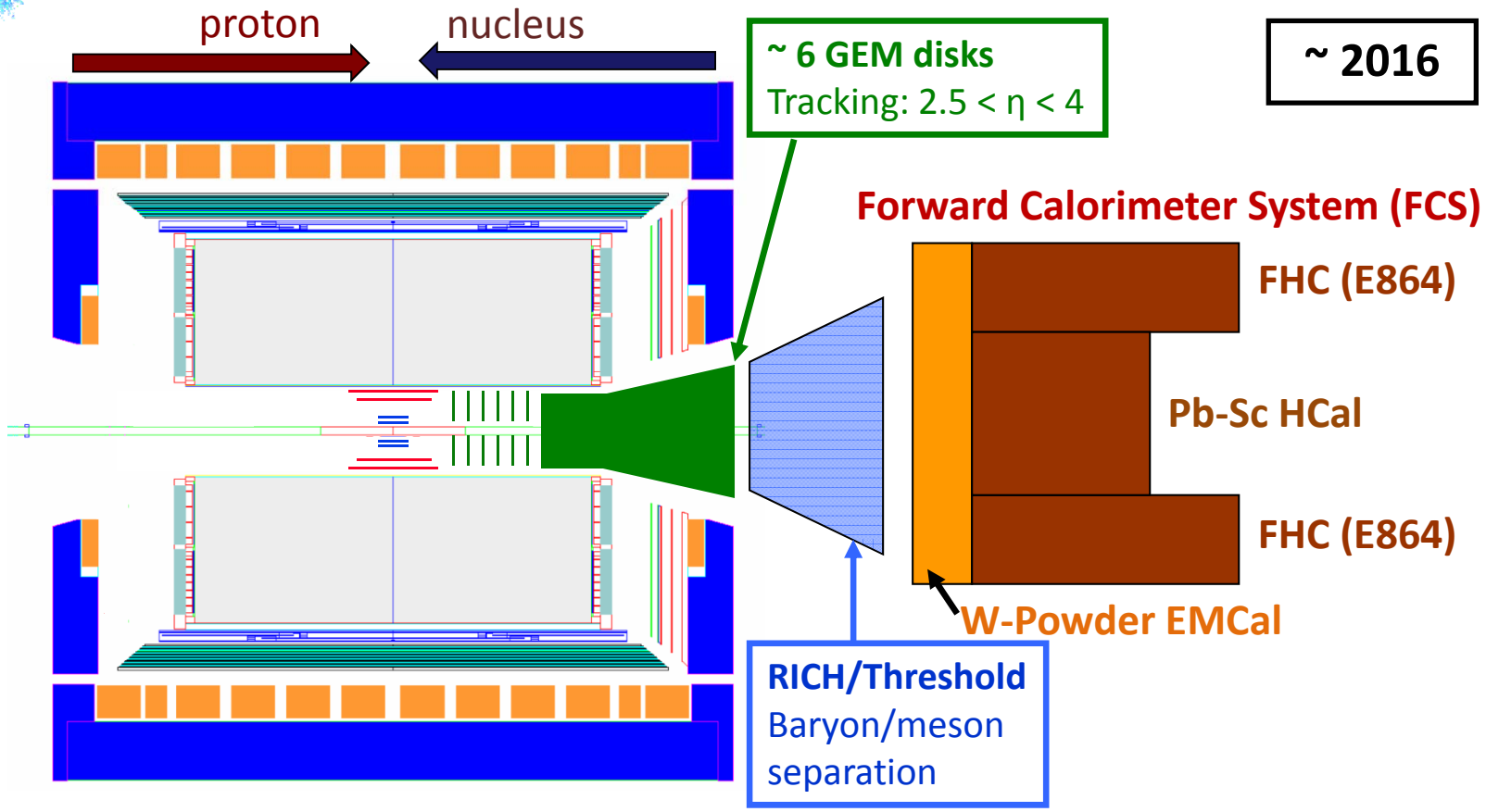


Broadening of away-side peak In $\pi^0\pi^0$ correlations



Next: full azimuthal coverage for photon, hadron and jet @ forward h-h, γ-jet and jet-jet correlations!
systematic scan of A in p(d)+A collisions !

STAR forward instrumentation upgrade



- Forward instrumentation optimized for **p+A** and **transverse spin** physics
  - Charged-particle tracking
  - *e*/*h* and γ/π^0 discrimination
  - Possibly Baryon/meson separation

STAR Forward Upgrade

Physics Focuses:

Forward photon/electron/jet(leading hadron)

p+p -- transverse spin dynamics

(transversity function and Collins frag.

QCD twist-3 processes)

pp/pA -- Drell-Yan, h-h, gamma-h correlations

(initial conditions and CGC)

AA -- Forward HQ NPE R_{AA} and eta dependence

STAR Plan for the Forward Upgrades

1) The Forward Calorimeter System (FCS) benefited from an EIC detector R&D project for constructing W-powder EMC modules. Current R&D effort focuses on compact read-out scheme and mechanical properties. We plan to build a full-scale prototype FCS module.
2) The Very Forward GEM Tracker (VFGT) detector is likely to be GEM based. Details of the design depends on our experiences with the FGT project.
3) RICH detector in STAR forward direction has not been demonstrated. Threshold Cerenkov detector is also under consideration. This detector will not be included in the initial phase of the upgrade project.
4) Schedule: Develop CD documents and Proposals aiming at VFGT/FCS construction starting 2015+

STAR Upgrade Path Towards eSTAR

Future eSTAR Option -- Detector R&D:

- **EMC – Compact W-powder SPACAL**
- **Crystals – PWO and BSO testing**
- **ETTIE – electron PID and tracking in the forward Simulations**

STAR will be ready with a detector coverage to explore eA physics during the initial phase of the eRHIC development !

RHIC – a Dedicated QCD Facility

QCD – Fundamental Corner Stone of the Standard Model !!

-Dynamics of QCD in bulk matter, vacuum structure and hadrons?

Condensed Matter Physics with Underlying QCD Interactions !

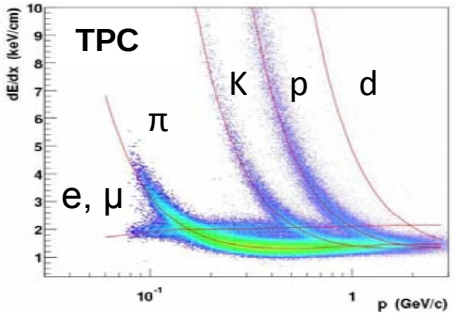
We are beyond the QGP discovery phase already !

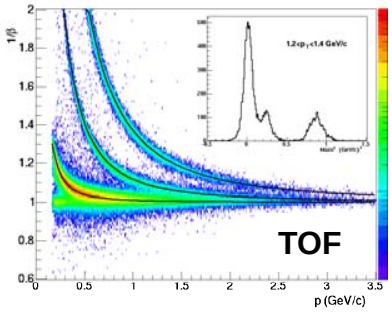
LHC -- Energy/Temperature Frontier

RHIC – New Horizons in QCD Phase Structure, Vacuum Excitation, Initial State Color Charge Dynamics, Hadron Structure and Exotics

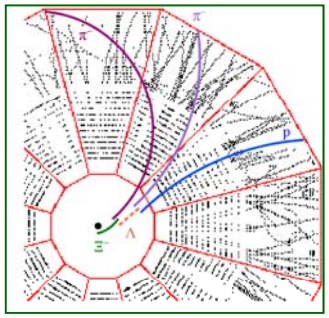
RHIC continues to explore new QCD horizons with planned detector upgrades and vigorous scientific programs in the coming decade !

Particle Identification at STAR

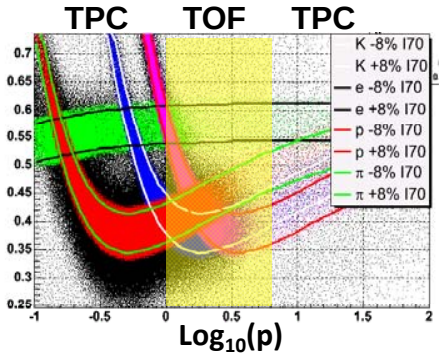


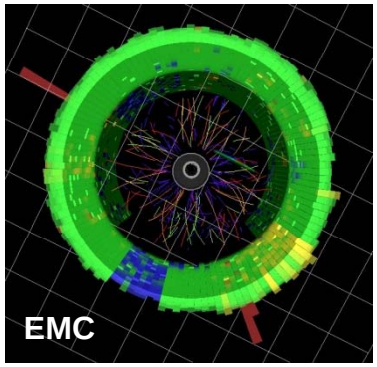


Charged hadrons

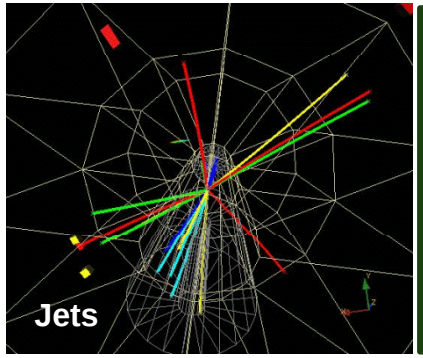


Hyperons & Hyper-nuclei

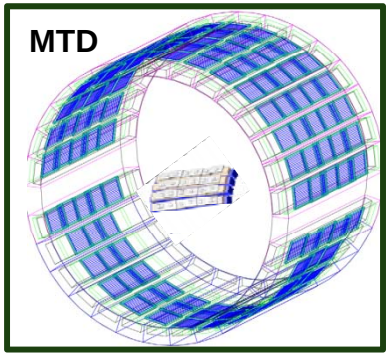




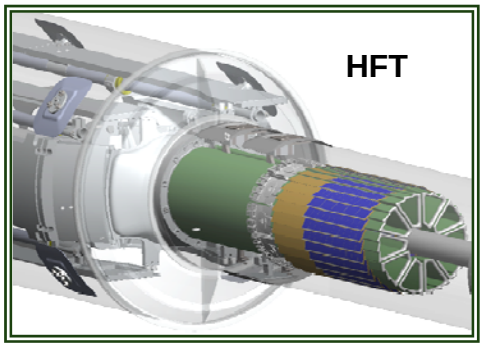
Neutral particles



Jets & Correlations



High p_T muons



Heavy-flavor hadrons

Multiple-fold correlations among the identified particles!
Nearly perfect coverage at mid-rapidity

Backup

STAR Upgrade Path

Ongoing and Near Term

- FGT 14/24 quadrants in 2012 and complete for 2013 run
- HFT engineering run 2013 and complete in FY14
- MTD 13/118 in 2012, 50-75/118 run 13 and complete 14
- Roman Pots Phase II – pp2pp

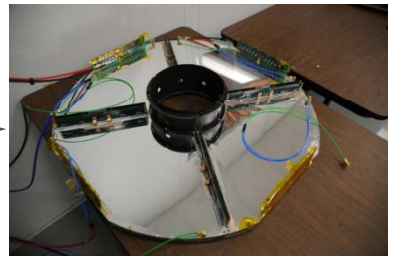
Physics Focuses:

- FGT – W program from polarized p+p collisions
- HFT – Heavy quark collectivity and separating Charm and Bottom energy loss
- MTD – Upsilon states and e-μ correlations

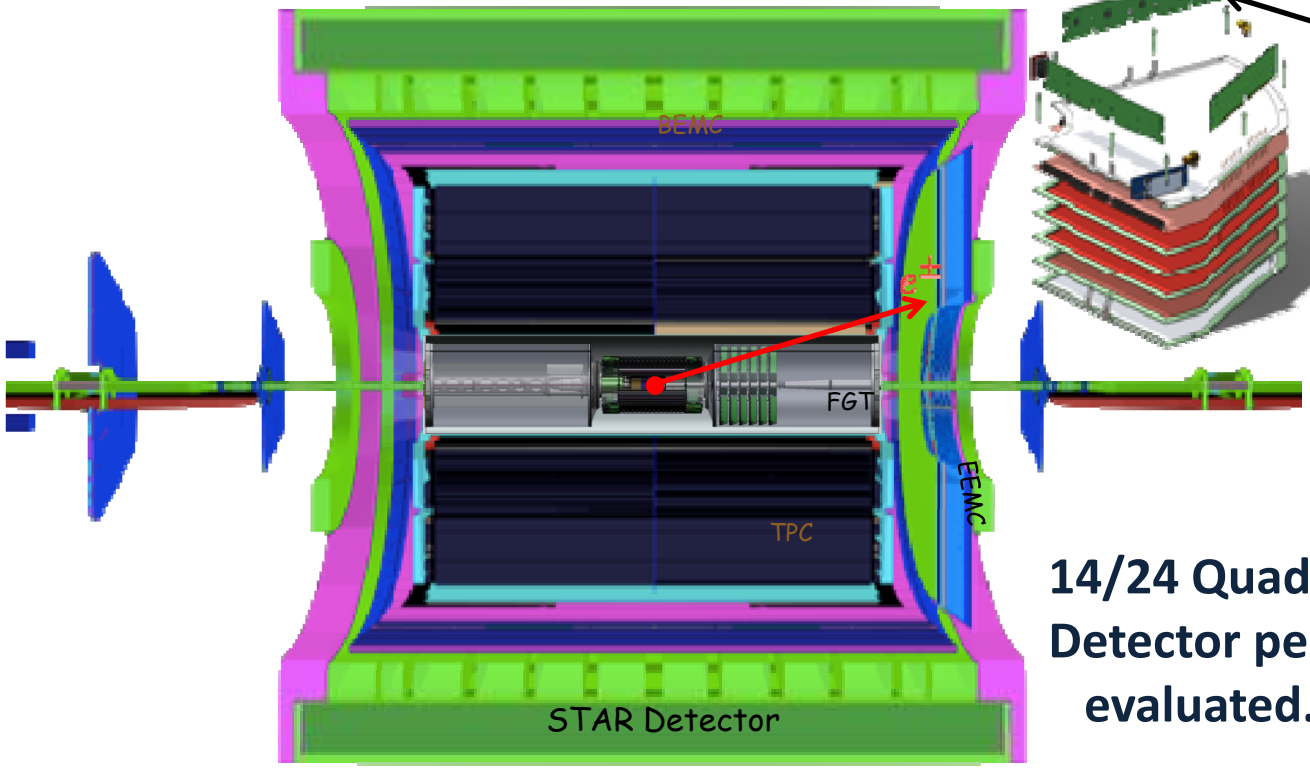
Forward GEM Tracker -- 2013

Layout

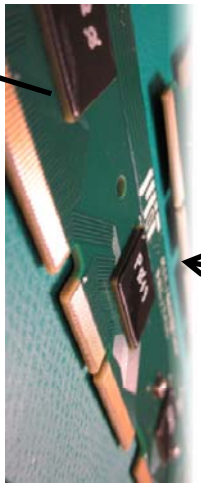

Quarter section


Disk


Quarter section



APV module



Packaged APV chip

14/24 Quads installed for run 2012 !
Detector performance is being evaluated.

STAR Vision for BES II Program

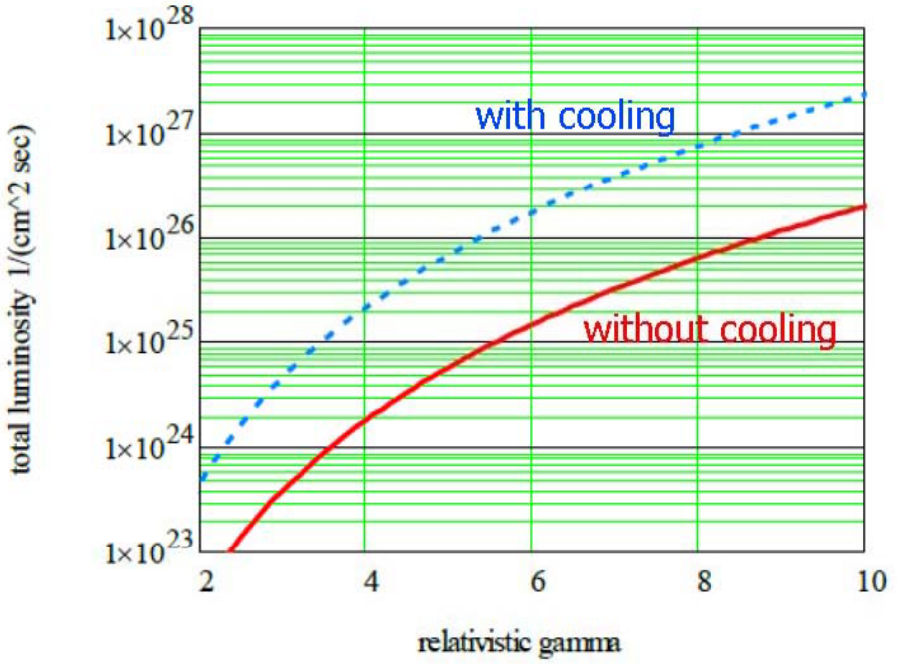
Likely beam energies below 25 GeV with improved statistics particularly for the lower end of the beam energies !

-- need electron cooling from CAD to be more efficient

-- match iTPC upgrade schedule for better detector coverage

Electron cooling necessary !!
Use RF Gun Cooler OR
Use Fermi Lab Pelletron ?

A. Fedotov – RHIC-AGS User Meeting 2012



RHIC CAD installation of the e-cooling device

~ 4 years !

BES-II takes data in 2016 +

STAR FCS R&D Status

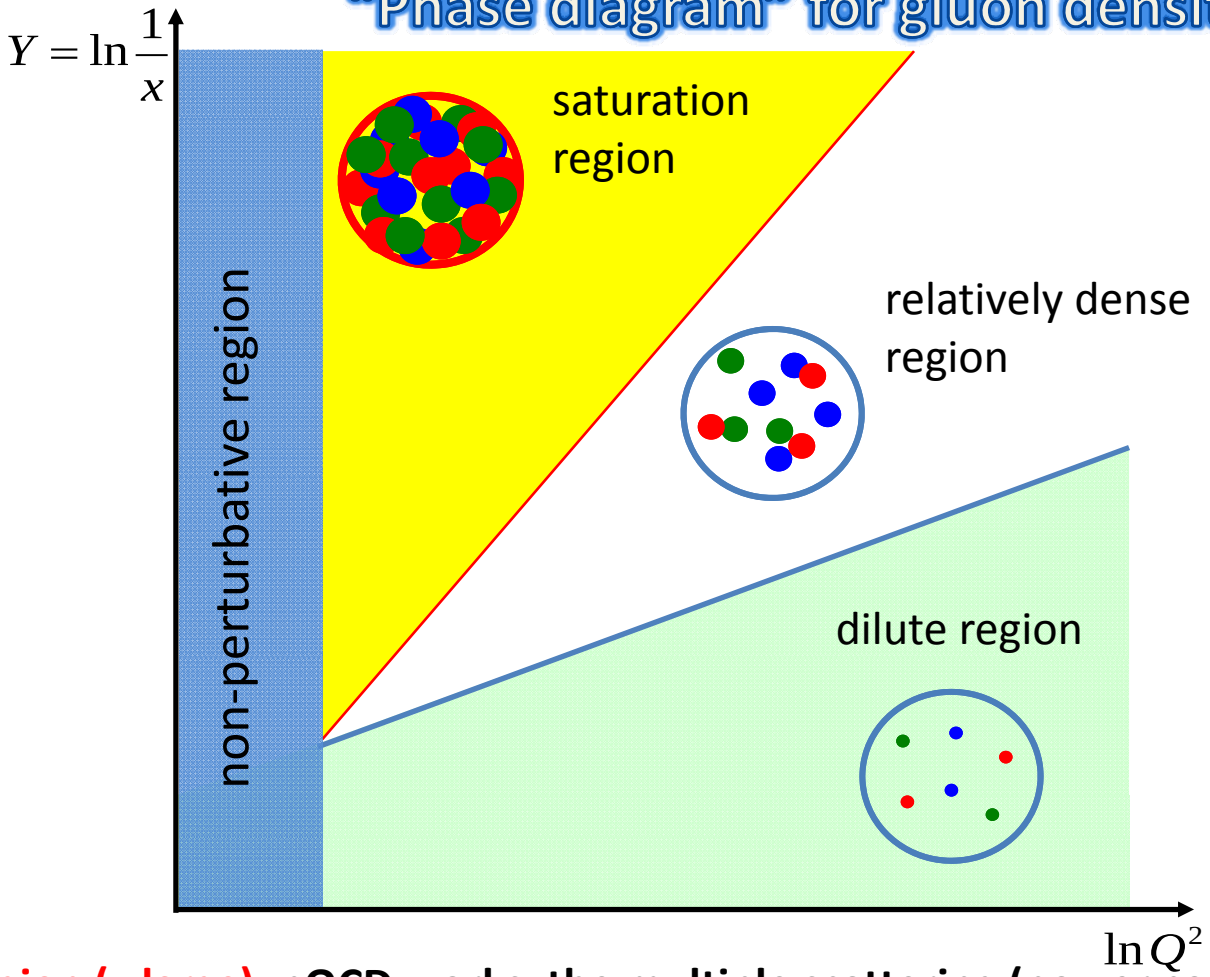
- MC, stand alone GEANT4, done.
- Pi0 reconstruction – 80% eff. At 100 GeV
- Energy resolution EM – 12/sqrt(E), constant term ~2%
- Energy resolution for hadrons 50%-60%/sqrt(E), range 10-80 GeV
- e/h rejection few*1000 @ 80 GeV

We plan to build a full scale prototype module !

What are the Physics Capability for this Detector?

Possible optimization of detector configuration with re-use of the E864 SPACAL?

"Phase diagram" for gluon density

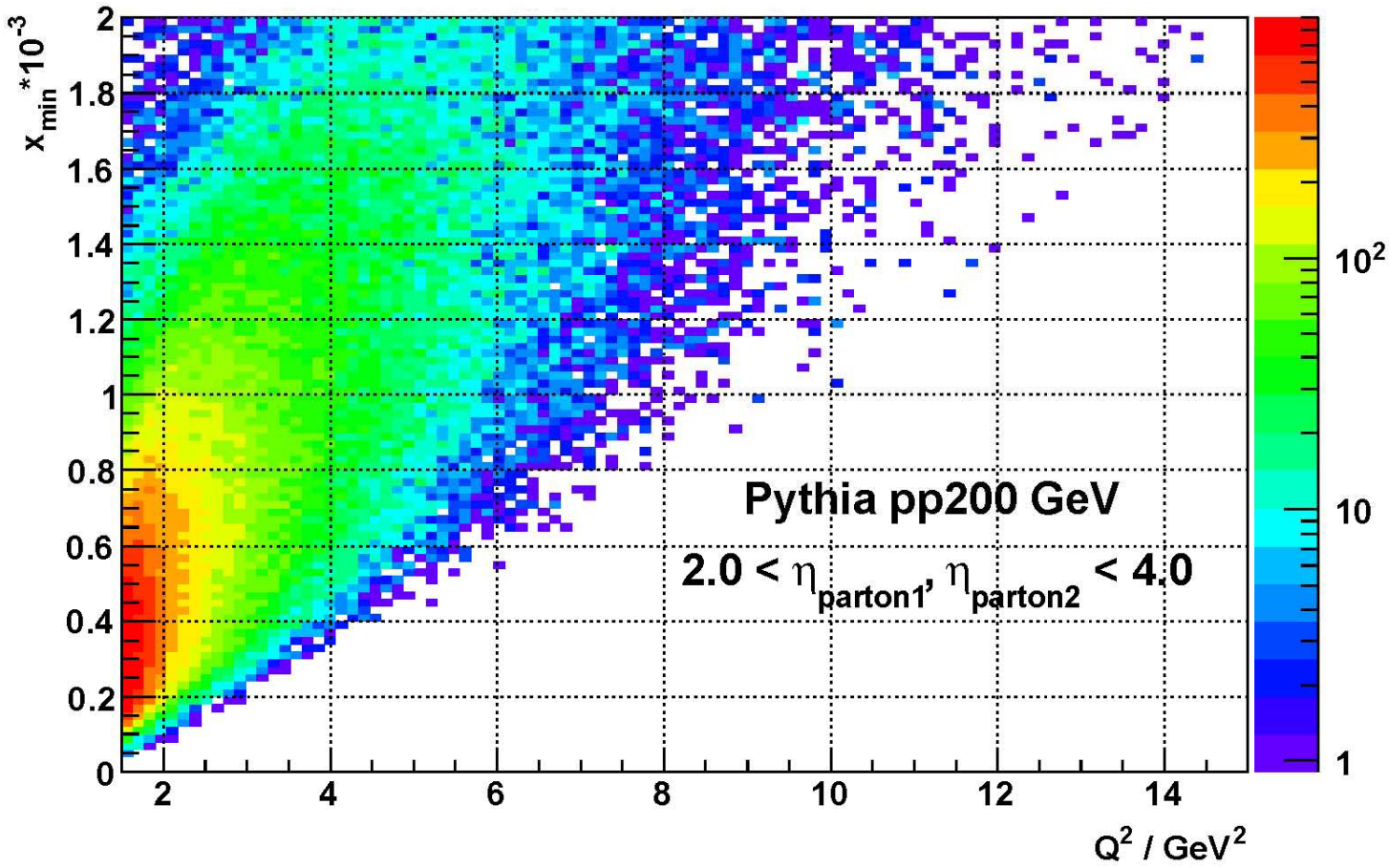


Dilute region (x large): pQCD works, the multiple scattering (power corrections) are not important

Relatively dense region (x relatively small): multiple scattering starts to become important, any additional scattering is power suppressed by Q_s^2/Q^2

Saturation region (x extremely small): all the additional scattering becomes equally important, all power terms $(Q_s^2/Q^2)^n$ have to be resummed

Accessible x-Q^2 phase space from h-h correlations in the forward direction



STAR Detectors *Fast and Full azimuthal particle identification*