The sPHENIX Upgrade
(and ePHENIX)

High Energy Scattering at Zero Degree

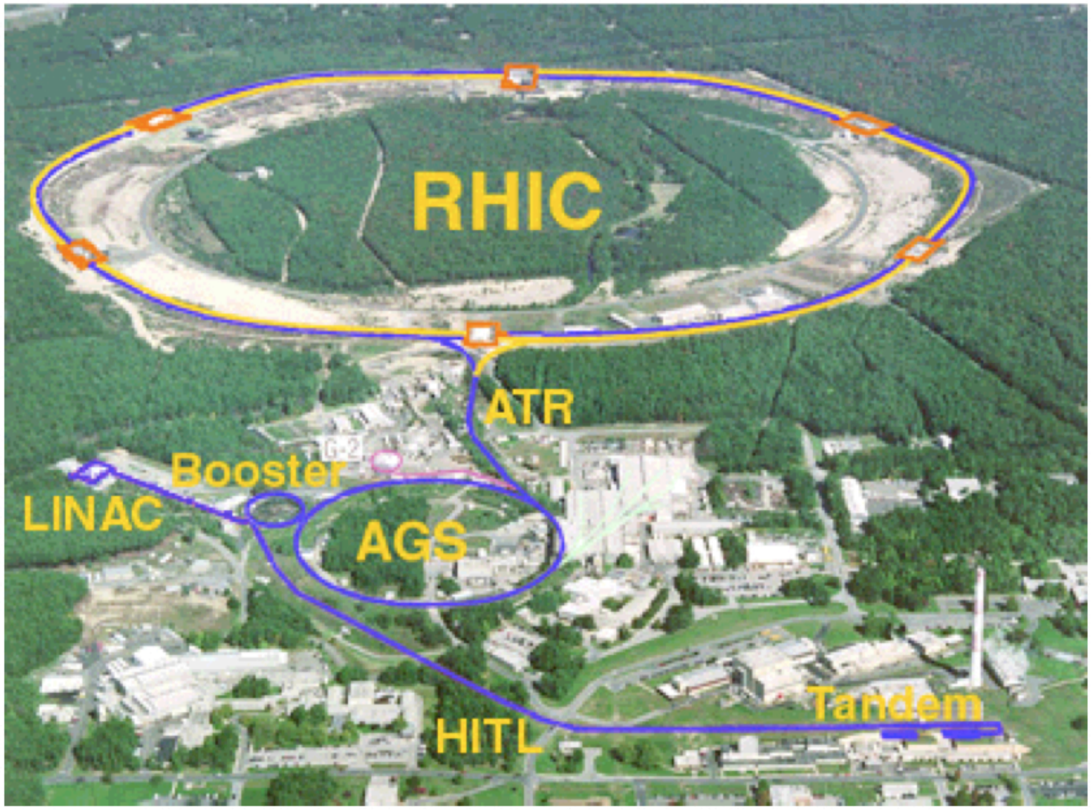
(3/4/2013)

Joe Seele

(RIKEN BNL Research Center)

- Central Upgrade
- Forward Upgrade and Physics
- Towards ePHENIX

RHIC – A QCD Machine



One of the most flexible machines!

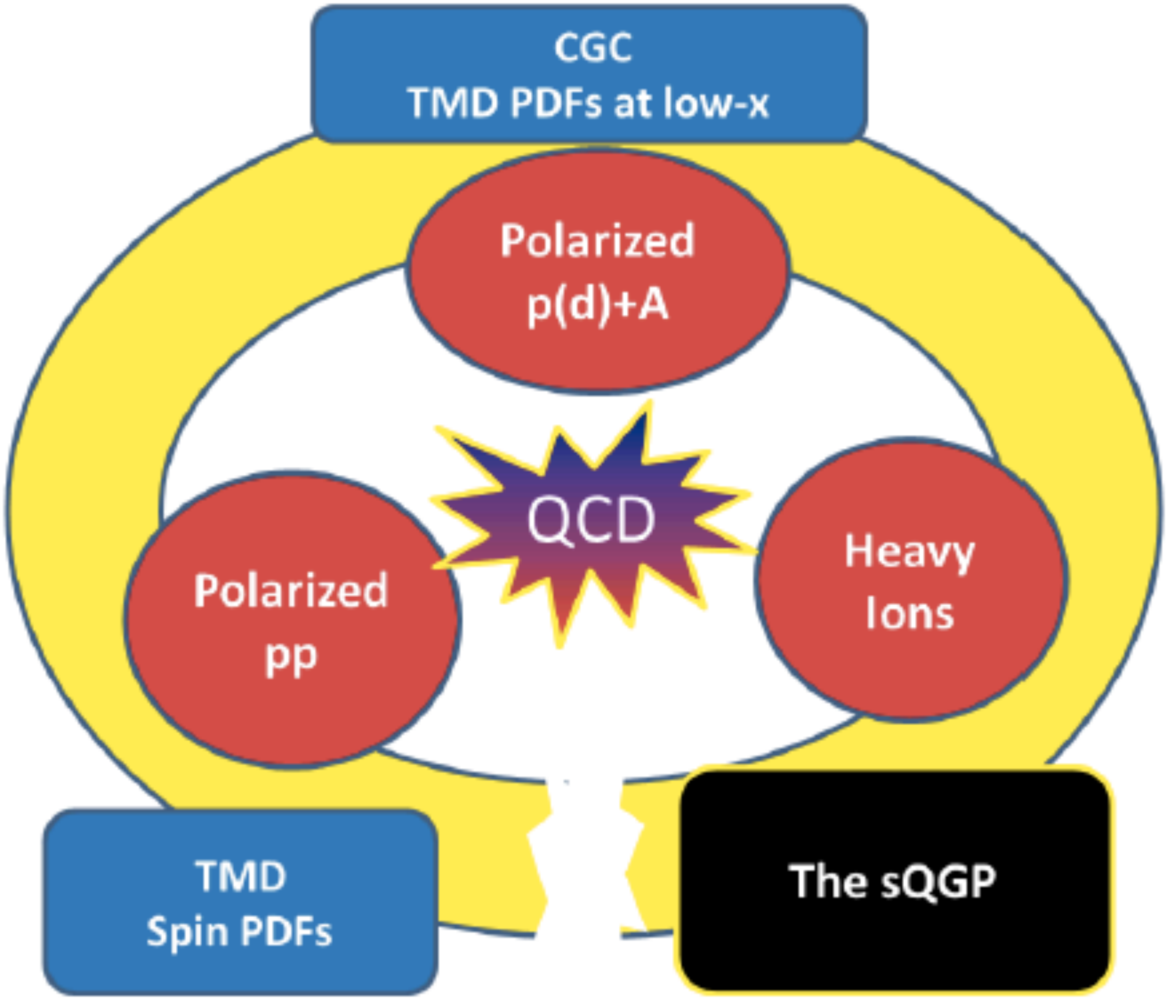
Able to collide polarized protons from sqrt(s) = 62GeV to 510 GeV

Collide heavy ions from sqrt(s) ~5GeV to 200GeV

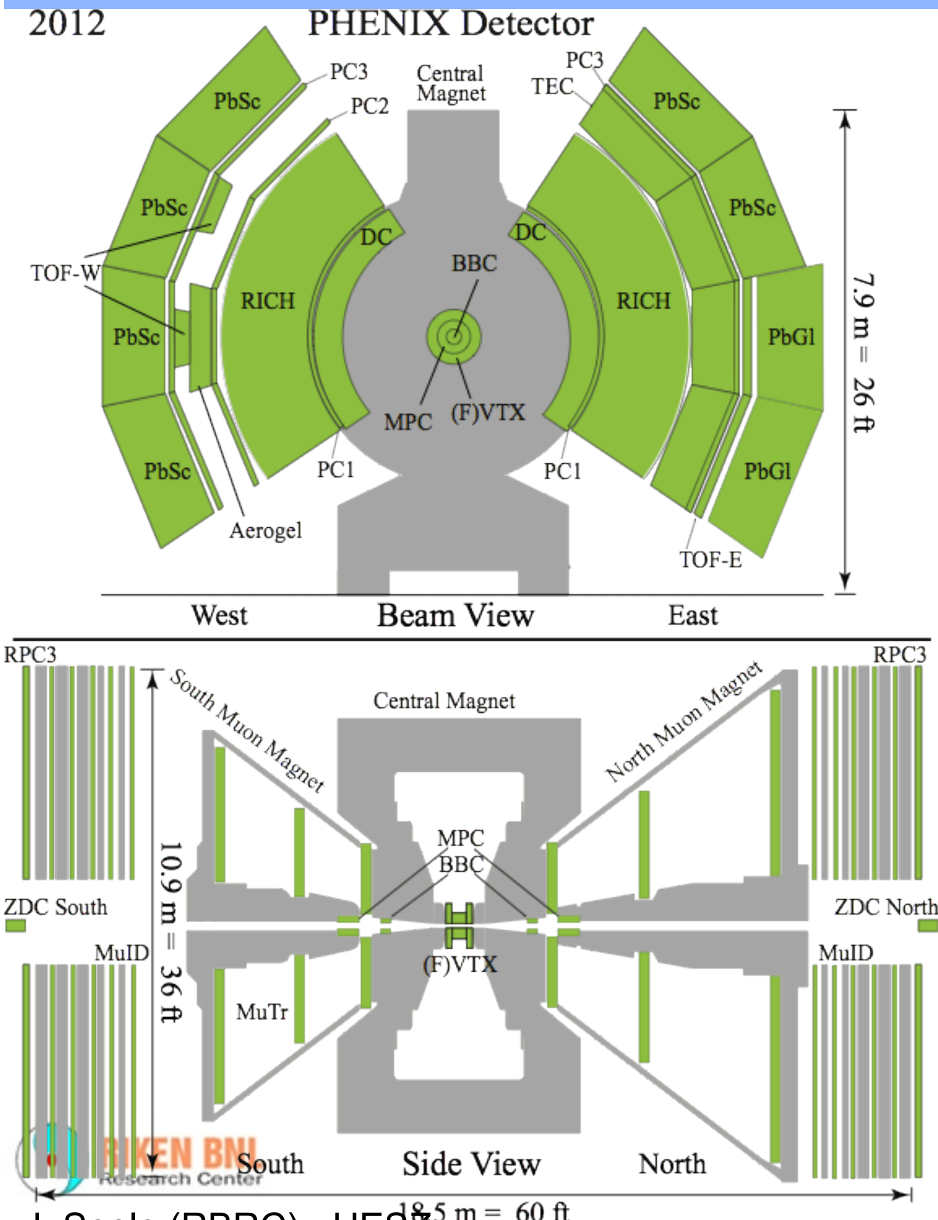
Asymmetric species : Cu+Au, d+Au, p+Au (soon!)

Many species run to date : p, d, Cu, Au, U (many more possible with new source!)

Physics at RHIC



PHENIX



Central Arms:

- $\gamma/\pi^0/\eta$ detection
  - Electromagnetic Calorimeter ($-0.35 < \eta < 0.35$)
  - PC3 - Charge Veto

Muon Arms: ($1.2<|\eta|<2.4$ + 2π)

- Large aborber in front
- Separate magnet (radial field)
- Tracking and high-p triggering

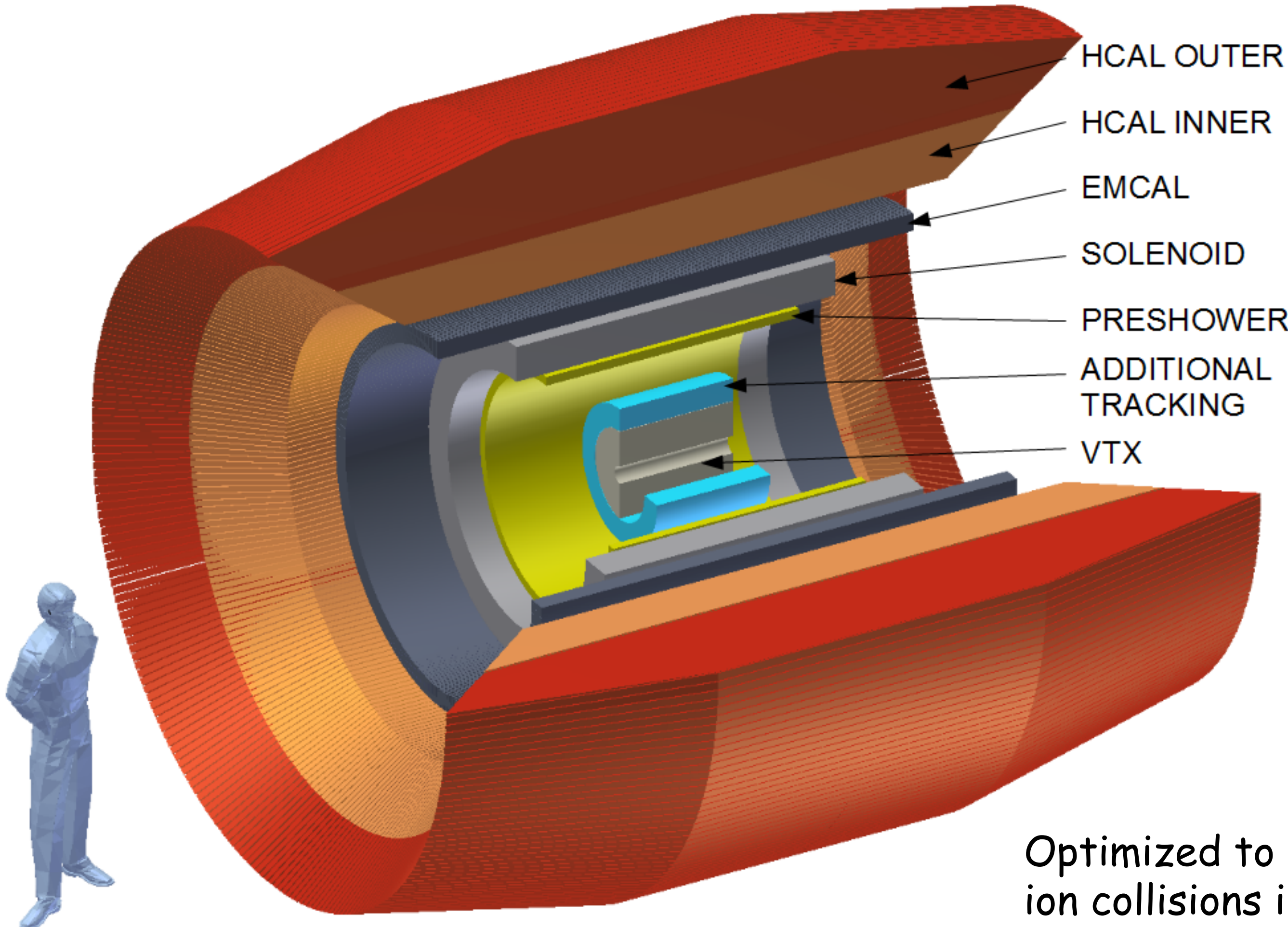
MPC

- Electromagnetic Calorimeter ($3.1<|\eta|<3.9$ + 2π)

Global Detectors:

- Relative Luminosity
  - Beam-Beam Counter (BBC) (+- 3.1 < η < 4.0)
  - Zero-Degree Calorimeter (ZDC) (+- 6.9 < η < infinity)
- Local Polarimetry - ZDC

Central sPHENIX Upgrade

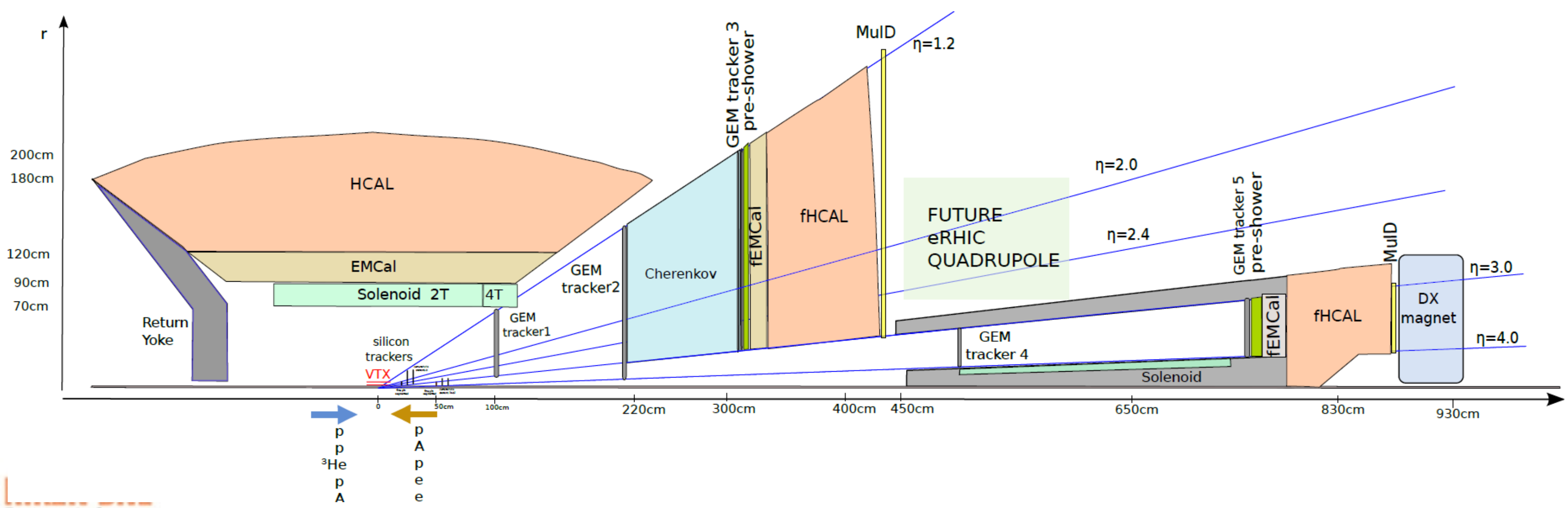


Optimized to measure jets in heavy ion collisions in order to study the coupling of the QGP

Forward sPHENIX Upgrade

Optimized for jets and photons/DY over a large range in rapidity ($1<\eta<4$)

- Extension/modification of the central solenoid for B field
- GEM based tracking
- Diamond pixel for heavy flavor tagging
- Restack of current PHENIX EMCal
- RICH based PID (pi/K/p)
- HCal for jet energy reco



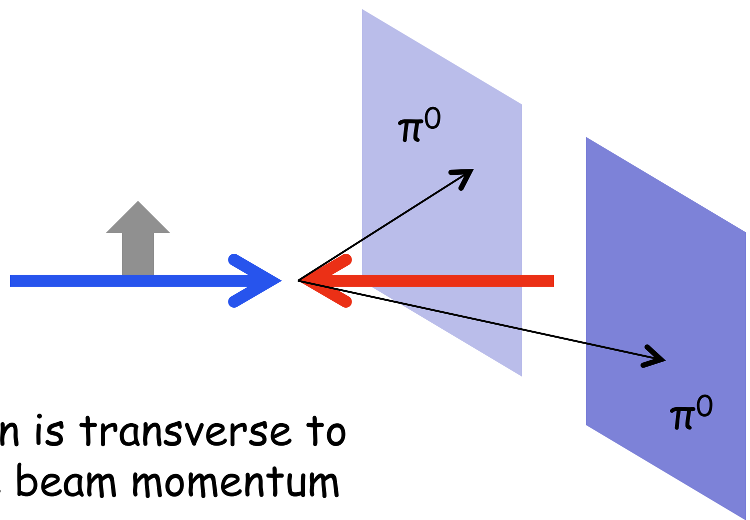
Research Center

For the uninitiated…

$$A_N^h = \frac{\sigma_L^h - \sigma_R^h}{\sigma_L^h + \sigma_R^h}$$

A_N (analyzing power) is a left-right (about the spin) asymmetry in particle production

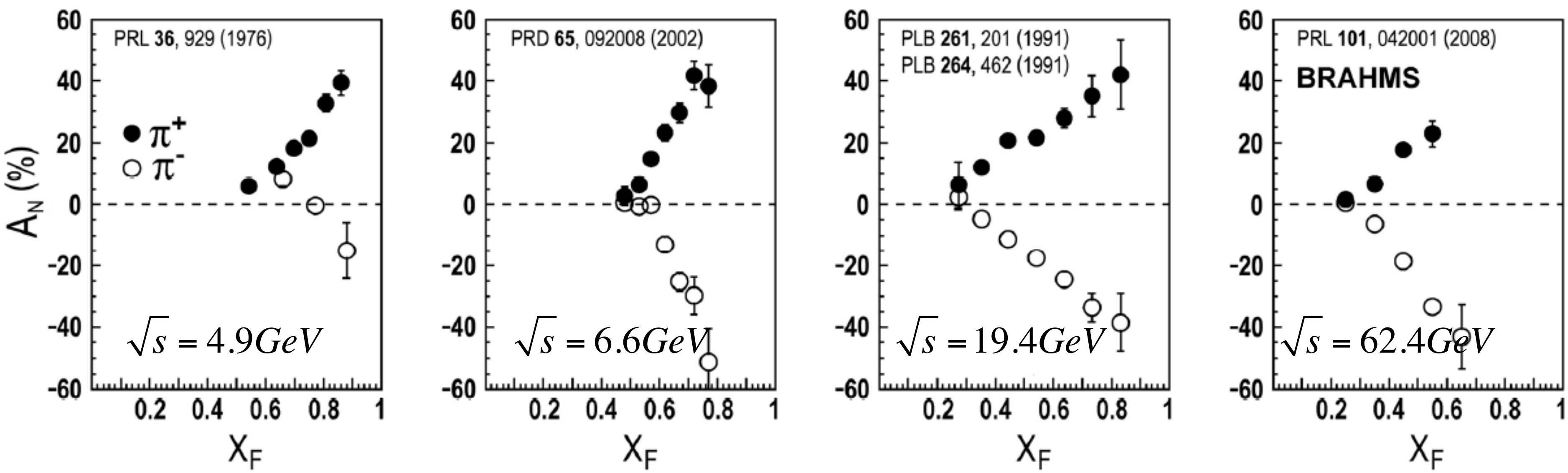
Occurs in processes where one beam is transversely polarized and the other is unpolarized



Spin is transverse to the beam momentum

Forward Spin Physics - I

Large, forward A_Ns in hadron production in p+p (p+A) have been measured since the mid 70's



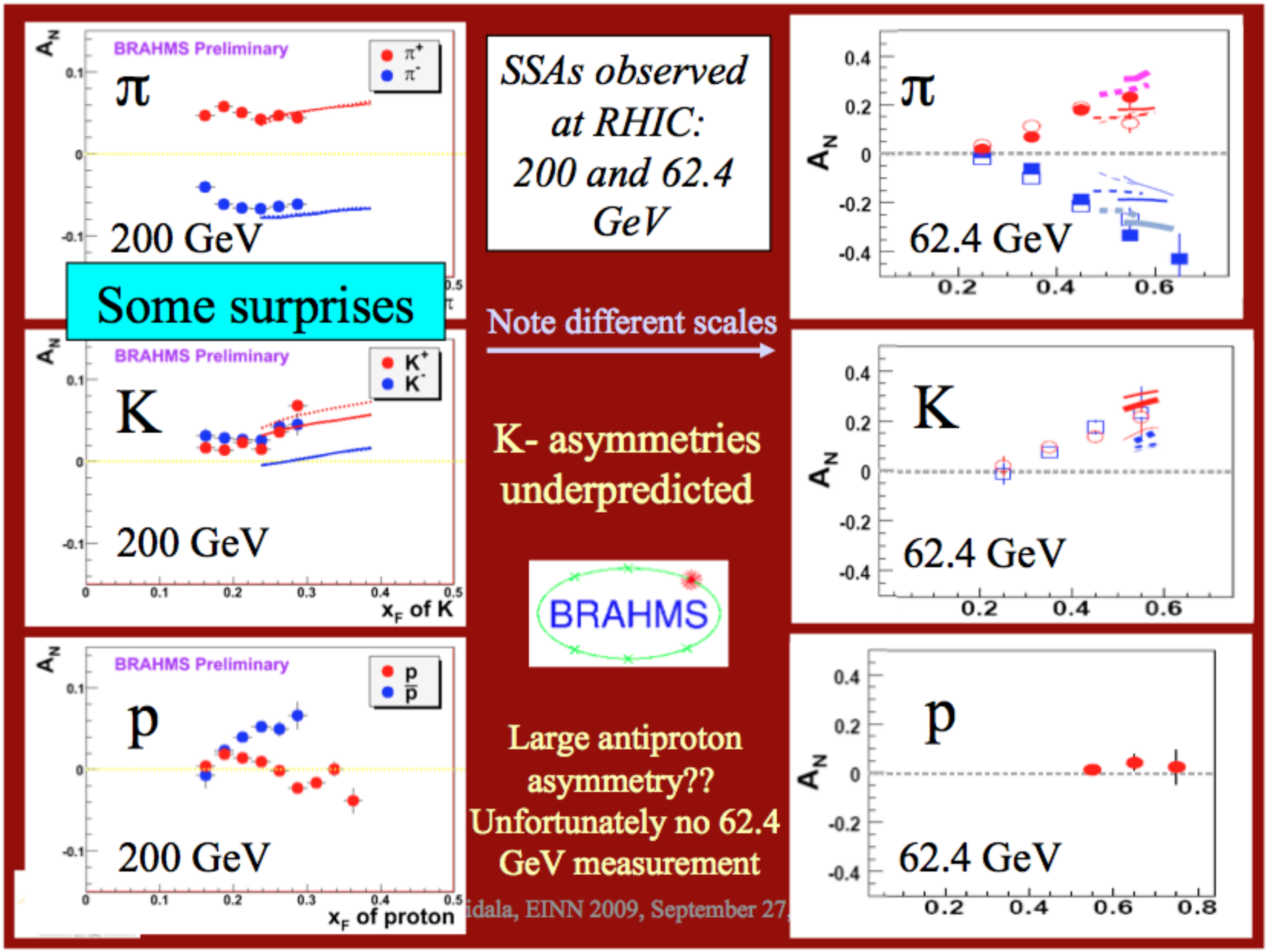
The asymmetries persist from low CM energies to high CM energies.

$$x_F = \frac{2p_L}{\sqrt{s}}$$

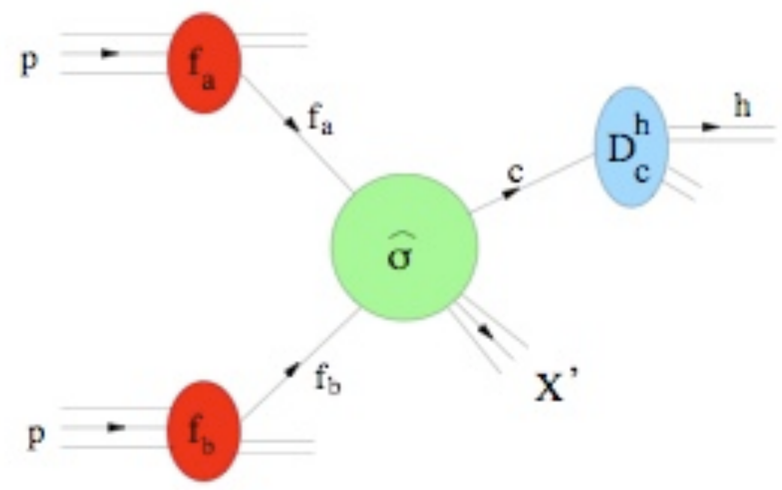
A simple (collinear) pQCD calculation tells us that an A_N can exist, but that it should scale like

$$A_N \approx \frac{m_q \alpha_S}{p_T}$$

Forward Spin Physics - II



Forward Spin Physics - III



Since the mid to late 90's new extended factorization schemes (TMD and Twist-3) have provided a new mechanism to generate single spin asymmetries in these collisions.

1. Initial-state (Sivers-type) spin-momentum correlations – Considers intrinsic transverse momentum in the nucleon and initial-state interactions
2. Final-state (Collins-type) spin-momentum correlations – Considers transverse momentum inside a jet and final-state interactions
3. Other Higher Order Correlations

$$A_N \sim \text{(Initial State Piece)} + \text{(Final State Piece)} + \text{(h.o.t.)}$$

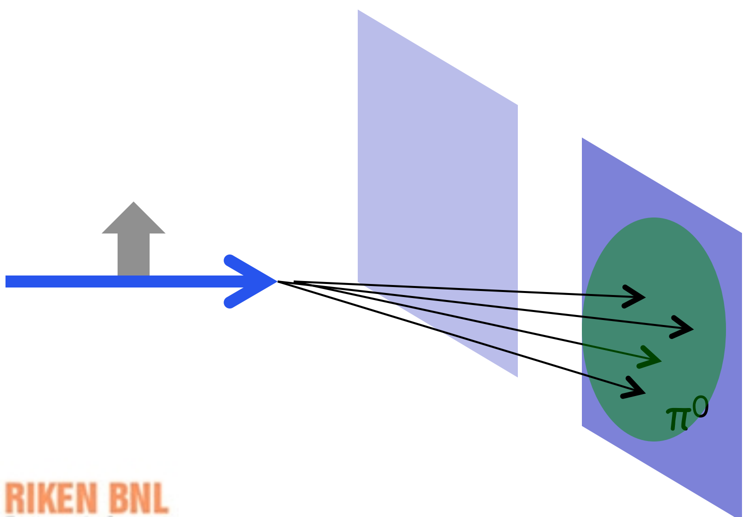
Forward Spin Physics - IV

With a good enough jet detector, we can unambiguously separate these pieces

Initial State Piece

Jets with identified hadrons (measure A_N for jets)

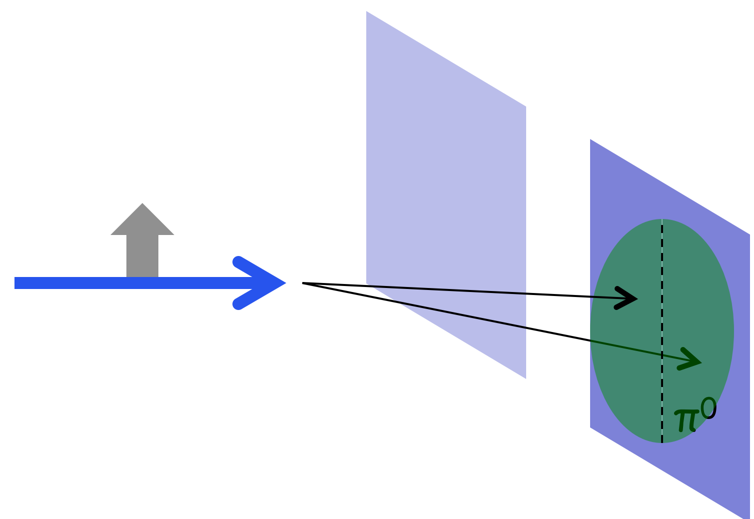
Do jets from certain quarks prefer to go left or right?



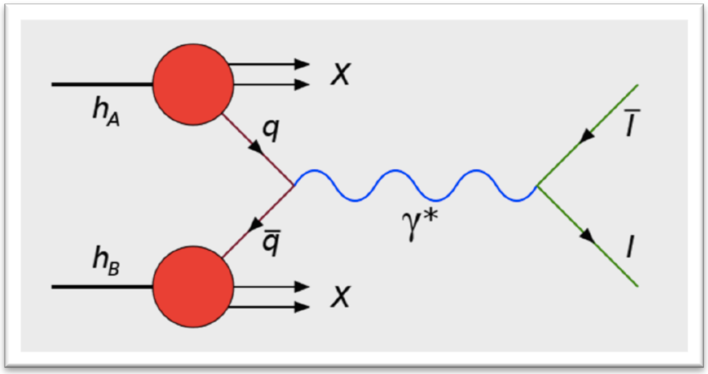
Final State Piece

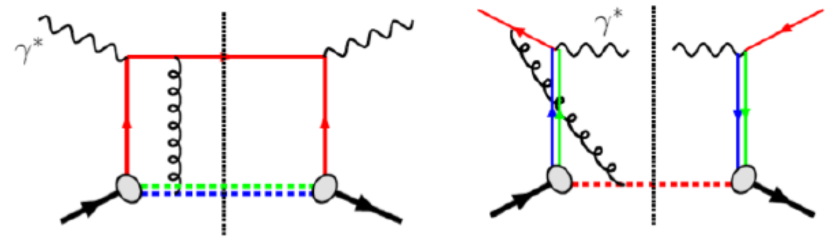
Left-right asymmetry of identified particle inside a jet

Do certain hadrons fragment from certain quarks to the left or right of the jet axis?



Forward Spin Physics - V





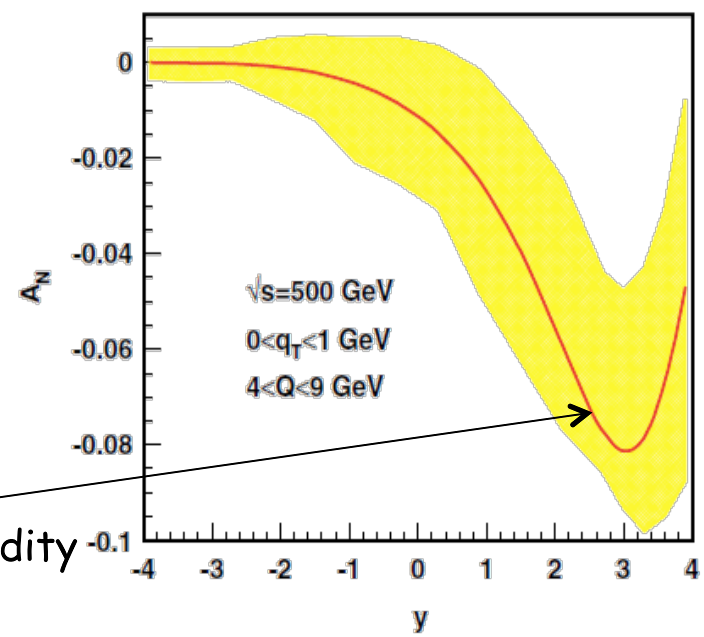
DIS DY

There is a prediction that the Sivers function measured in DY should be opposite that measured in SIDIS.

$$(\text{Sivers})_{SIDIS} = -(\text{Sivers})_{DY}$$

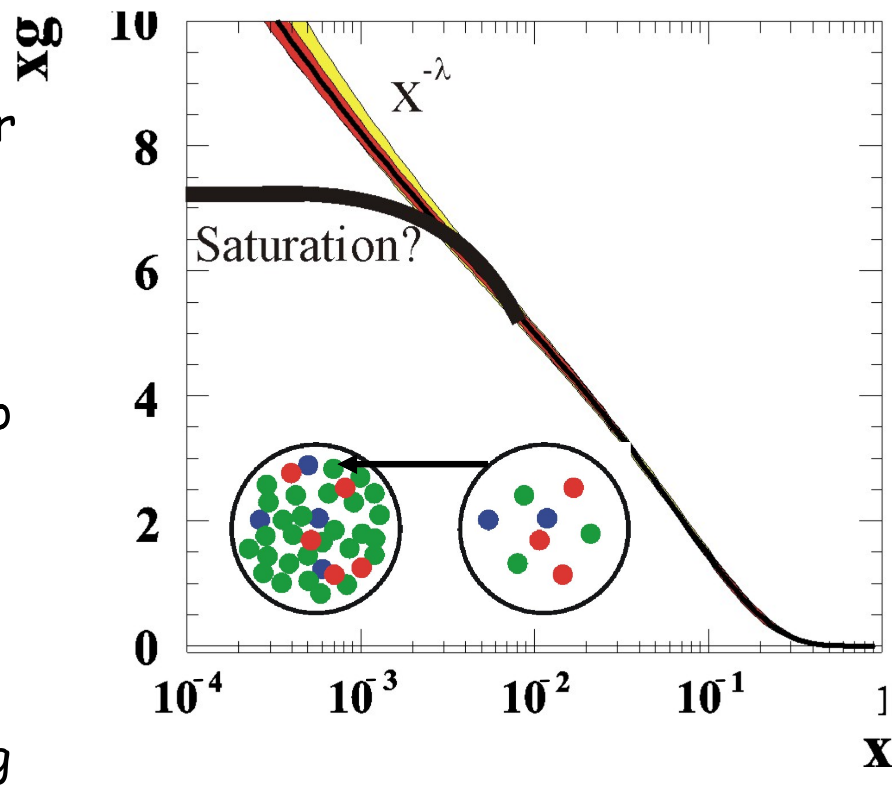
DY is a very clean process. The A_N is directly related to the Sivers function as there is no uncertainty/smearing due to fragmentation.

BUT, all the interesting asymmetry is at large rapidity



Forward CNM Physics - I

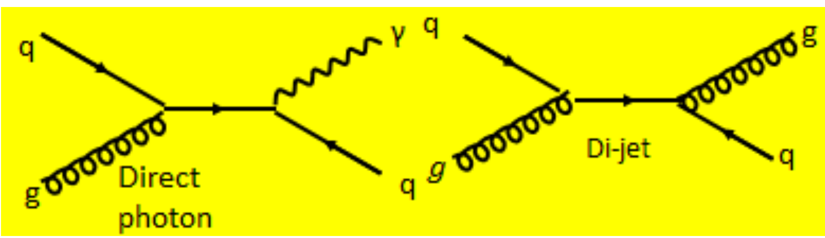
- The forward region also corresponds to the low-x region where saturation is expected (below a scale Q_S) and/or a CGC description of the data is relevant
- As in other QCD related phenomena, many measurements will be needed to substantiate and understand the validity of a CGC as the description of gluons in the nucleus as well as correlated structures
- Other theoretical tools are beginning to help elucidate the low-x region in hadrons and nuclei (TMDs)

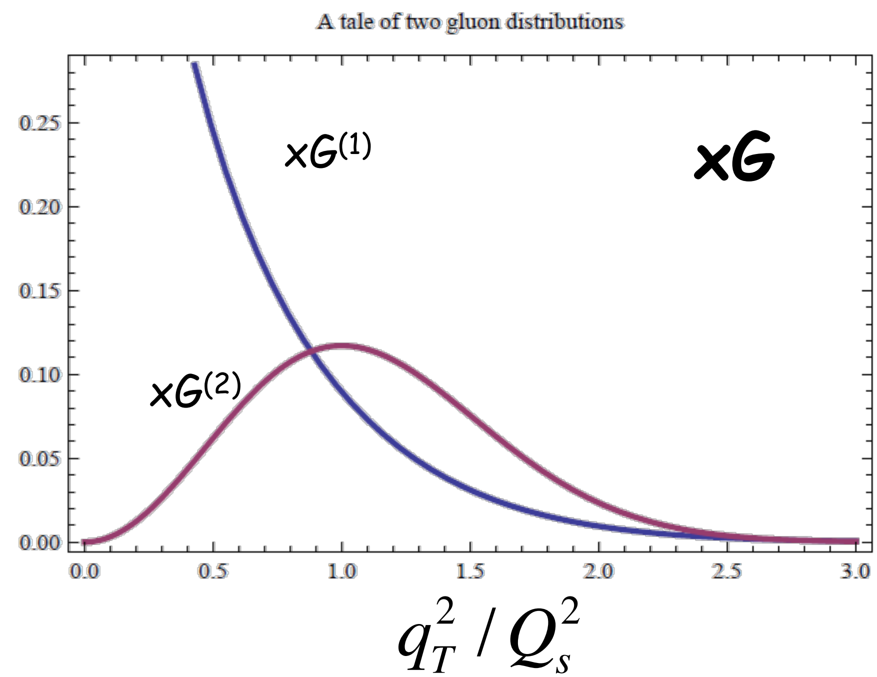


A major push is to observe saturation experimentally, and understand and map out the x and saturation scale, Q_S, dependencies

Forward CNM Physics - II

- G now comes in two flavors $G^{(1)}$ and $G^{(2)}$ in the low-x limit
- All CS described using $G^{(1)}$ and $G^{(2)}$
- Measure G's via γ-jet, dijet





PRD 49, 2233, 3352
NPB 529, 451

	DIS and DY	SIDIS	hadron in pA	photon-jet in pA	Dijet in DIS	Dijet in pA
$G^{(1)}$ (WW)	×	×	×	×	√	√
$G^{(2)}$ (dipole)	√	√	√	√	×	√

Both real and virtual (DY) photons

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A Link Between CNM and Spin

RHIC is unique in its ability to collide polarized protons with nuclei

Exploiting the link between the TMD and CGC framework, it has been shown that transverse single spin asymmetries in polarized p+A collisions are sensitive to the saturation scale in the nucleus

$$\frac{A_N^{pA\to hX}}{A_N^{pp\to hX}} \underset{p_T^h \ll Q_s^2}{\approx} \frac{Q_{s,p}^2}{Q_{s,A}^2} f(p_T^h) \qquad \frac{A_N^{pA\to hX}}{A_N^{pp\to hX}} \underset{p_T^h \gg Q_s^2}{\approx} 1$$

[Kang, Yuan, PRD84 034019]

A_N measures the azimuthal modulation of particle/jet production with respect to the proton's spin

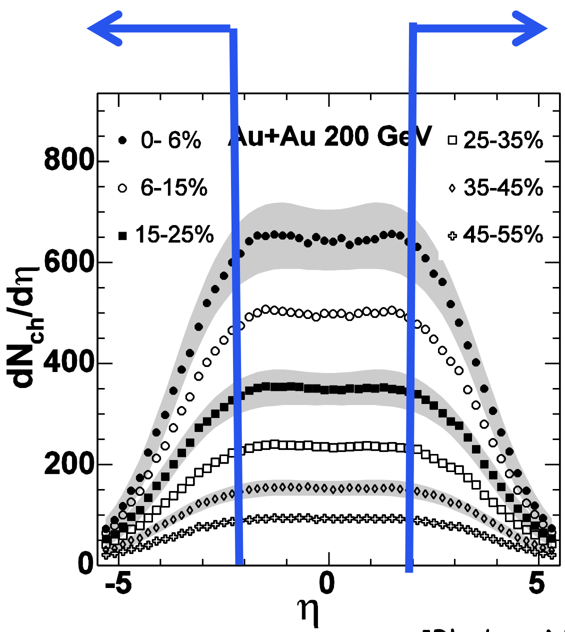
These spin effects are expected to be large. Spin "R_{AA}" could be ~O(0.5)

Forward Heavy Ion Physics

An area largely pioneered by PHOBOS and BRAHMS. We hope to expand upon their measurements (away from Bjorken plateau)

At forward rapidities

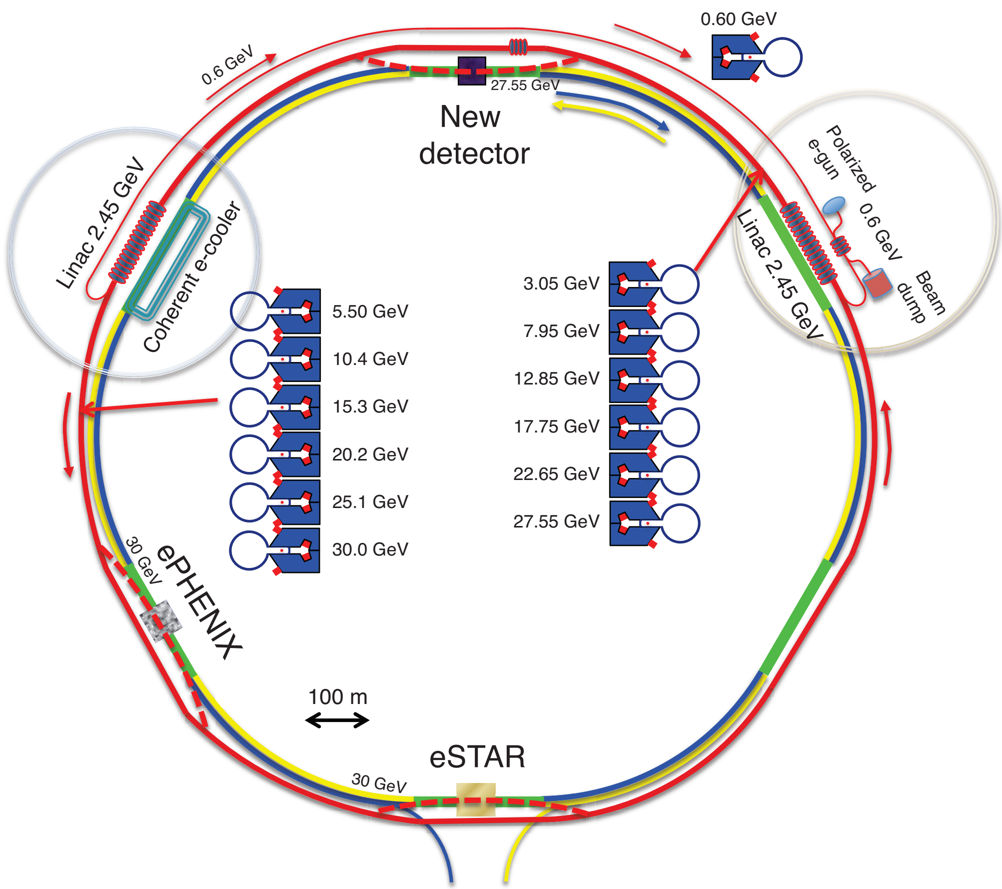
- Direct photons can give information about the expansion of the medium
- Correlation measurements can test models of longitudinal expansion (3d hydro)
- Extended (di-)jet coverage to study jet energy loss in the medium



[Phobos NPA 757]

Currently it is question of how far forward the measurements will be able to be made

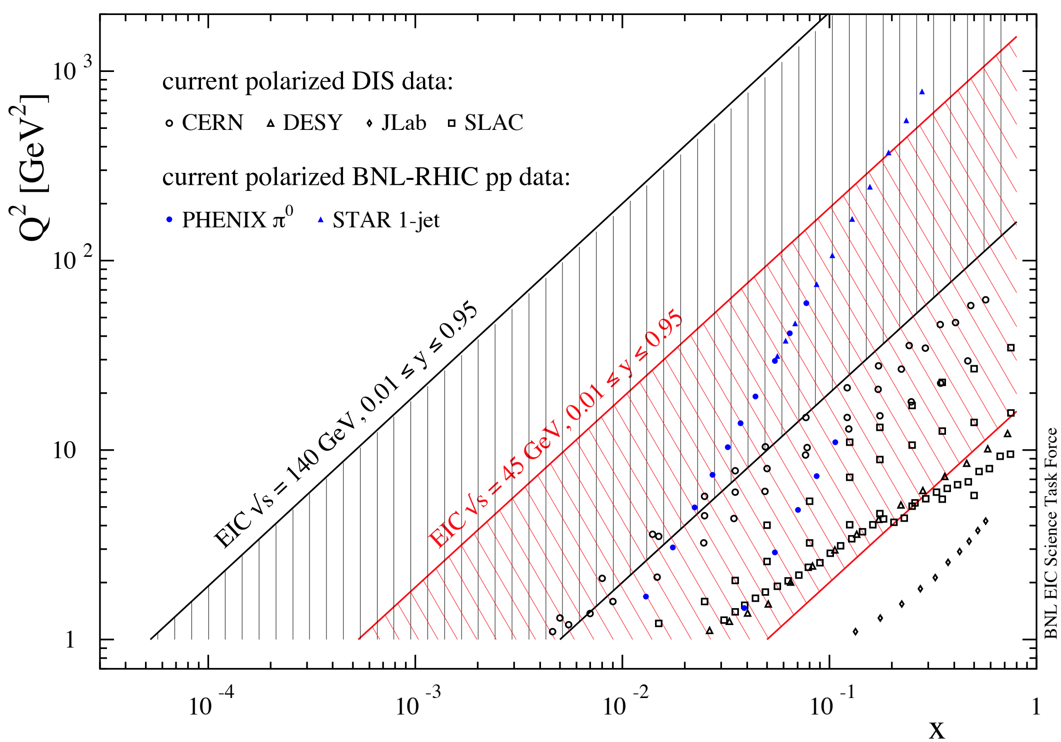
EIC and eRHIC

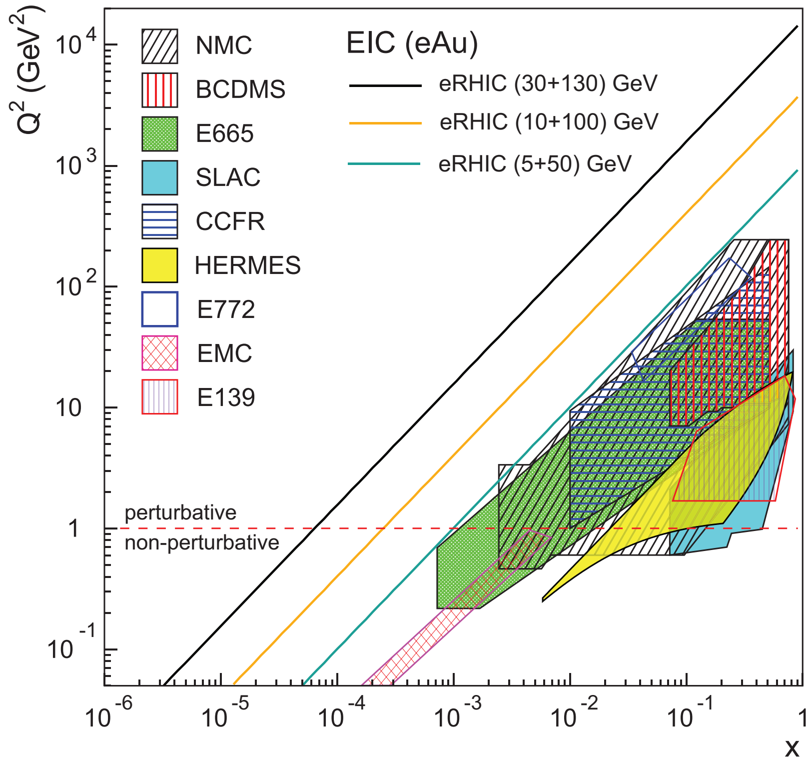


- One possible manifestation of EIC is eRHIC
- eRHIC will add electron accelerations capabilities to RHIC
- eRHIC is thought to happen in two stages (the difference being the electron beam momentum)
- Through the sPHENIX/decadal plan exercise, BNL charged the RHIC collaborations to imagine how their upgrades could lead to detectors for phase I of eRHIC

eRHIC I Physics

- A major purpose of eRHIC is to measure the 3d structure of the nucleon and nuclei over a large kinematical range





- ePHENIX needs to measure the scattered electron and complete and exclusive final states

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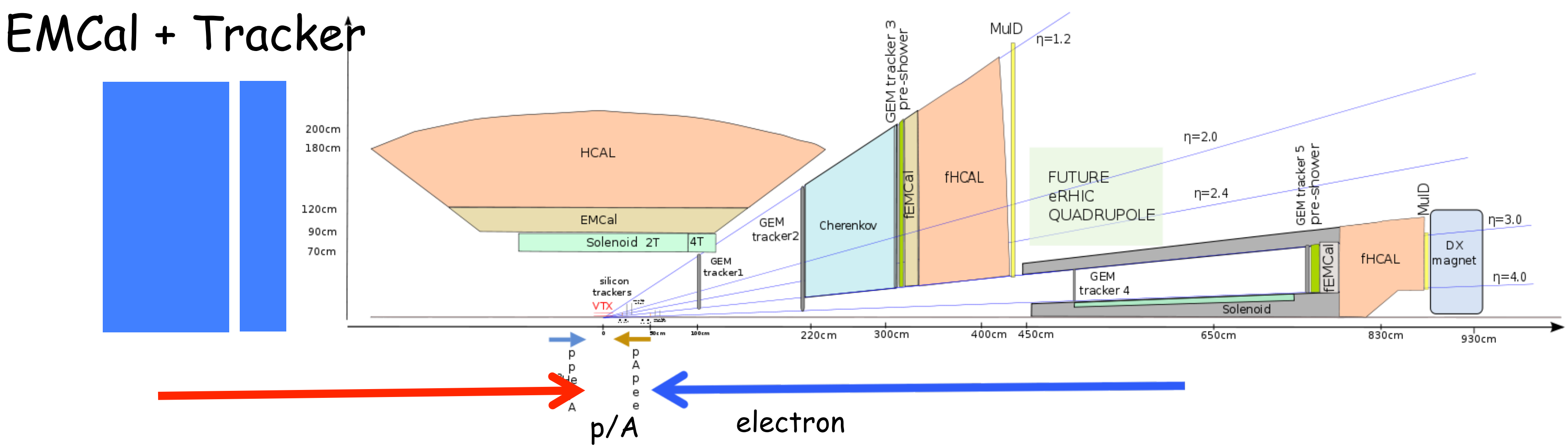
sPHENIX to ePHENIX

- Many studies were done to test the central barrel design for the phase I of eRHIC (electron beam momentum <= 10 GeV) [arXiv:1207.6378] and the current designs appears to be good enough



- Forward sPHENIX is being designed with ePHENIX in mind
- A forward EMCal + tracker on the opposite side will need to be added for ePHENIX

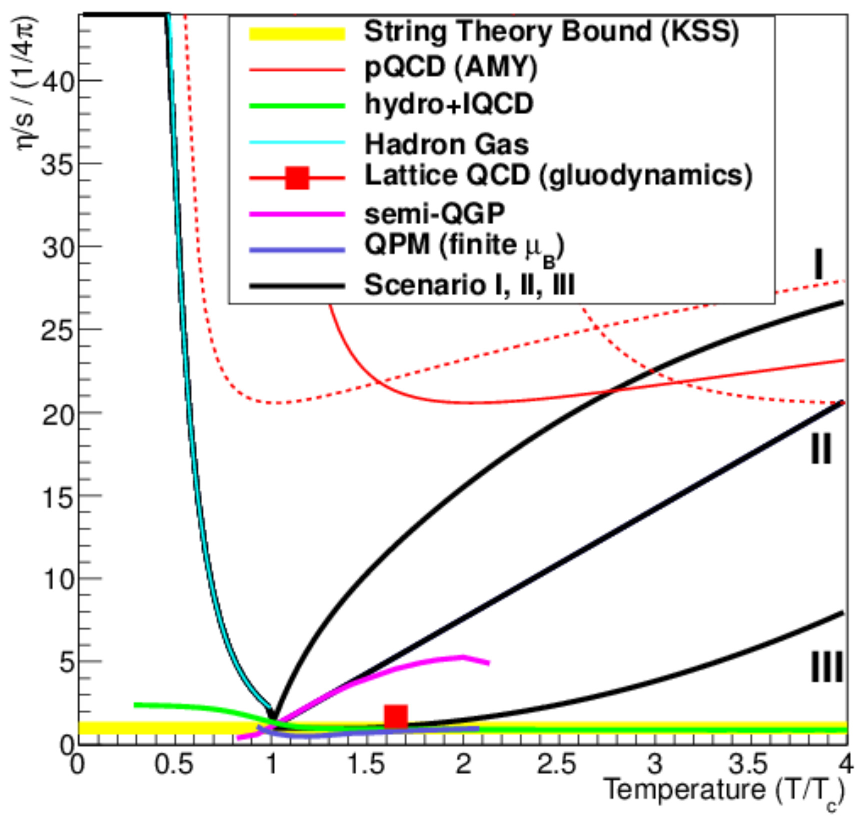
Conclusions

- PHENIX is planning upgrade programs aimed at both central and forward rapidity measurements.
- The central rapidity upgrade aims to understand jet-medium interactions as a tool to understand the QGP
- Forward sPHENIX is being designed and optimized to study forward jets, photons and DY for understanding all major facets of the RHIC program
- Sensitivity studies are ongoing
- An evolution of sPHENIX to ePHENIX is being planned for in the design of sPHENIX
- Lots of opportunity for new ideas and new collaborators!

Backups

η/s

- How does η/s go from being nearly as small as possible near T_c to the weakly coupled limit?
- The figure shows several state-of-the-art calculations and three generic scenarios approaching T_c

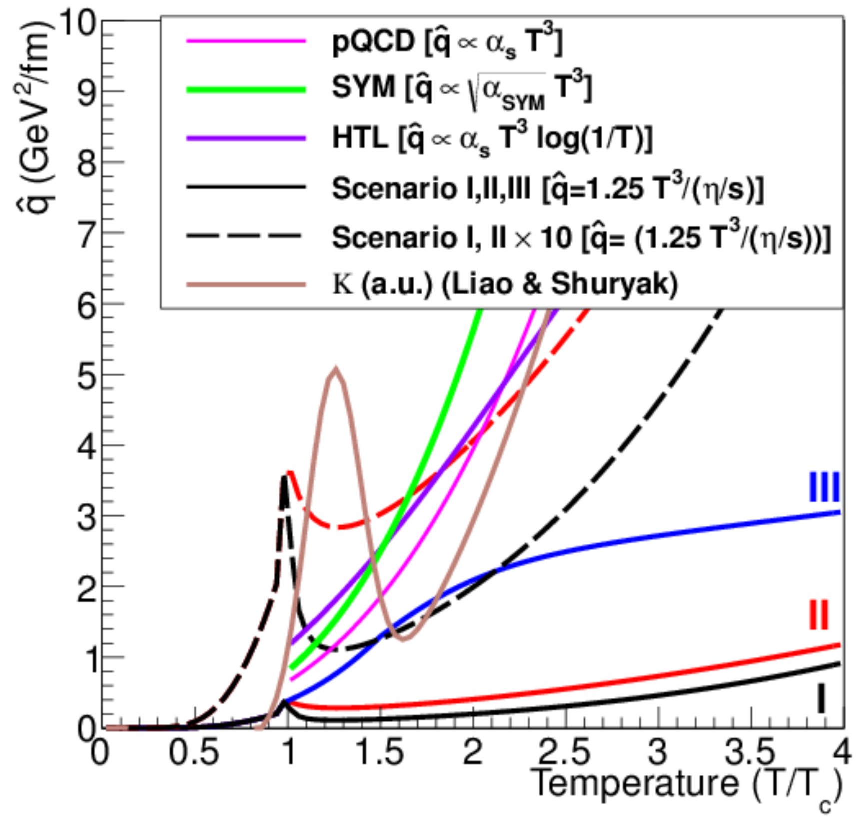


Jet observables

- A parton traversing the medium accumulates transverse momentum characterized by

$$\hat{q} = d(\Delta p_T)/dx$$

- Coupling parameters like qhat are scale dependent and must approach weak coupling at high energies and strong coupling at thermal energies



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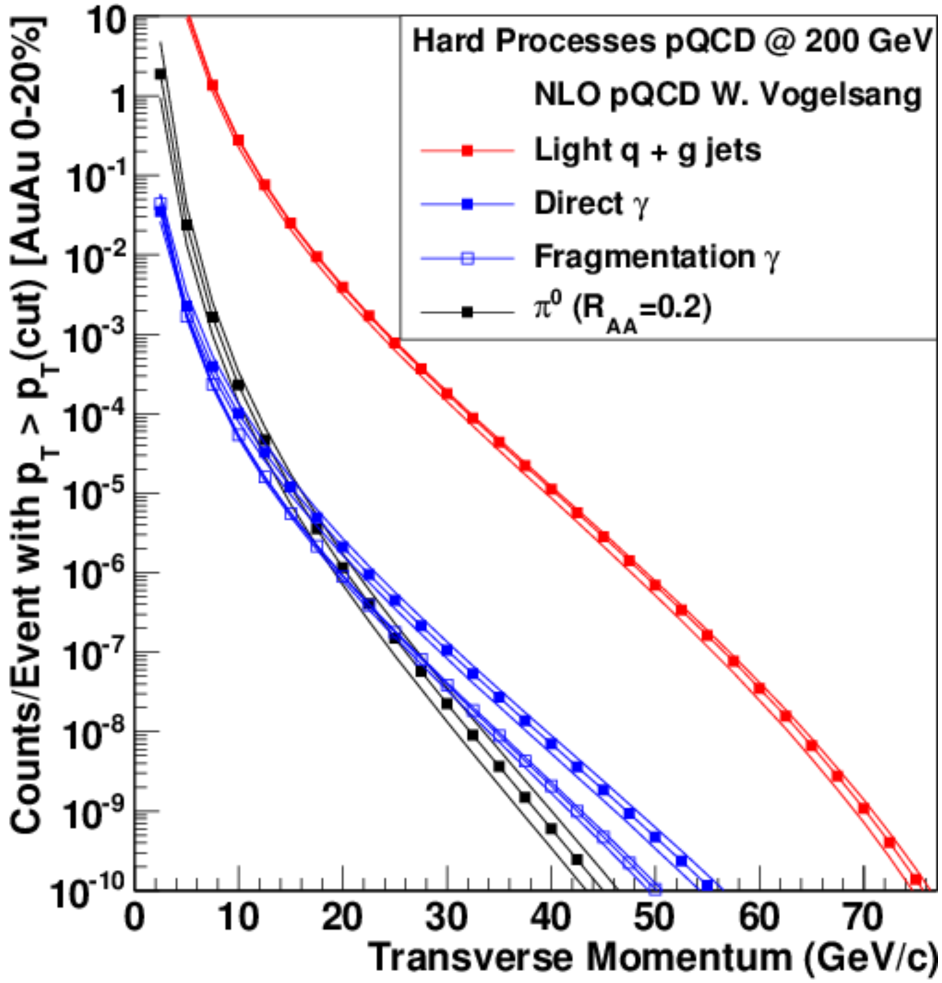
Jet rates at RHIC

- At present RHIC luminosity, in a 20 week Au+Au run we would have 10^6 jets above 30 GeV in 0-20% centrality



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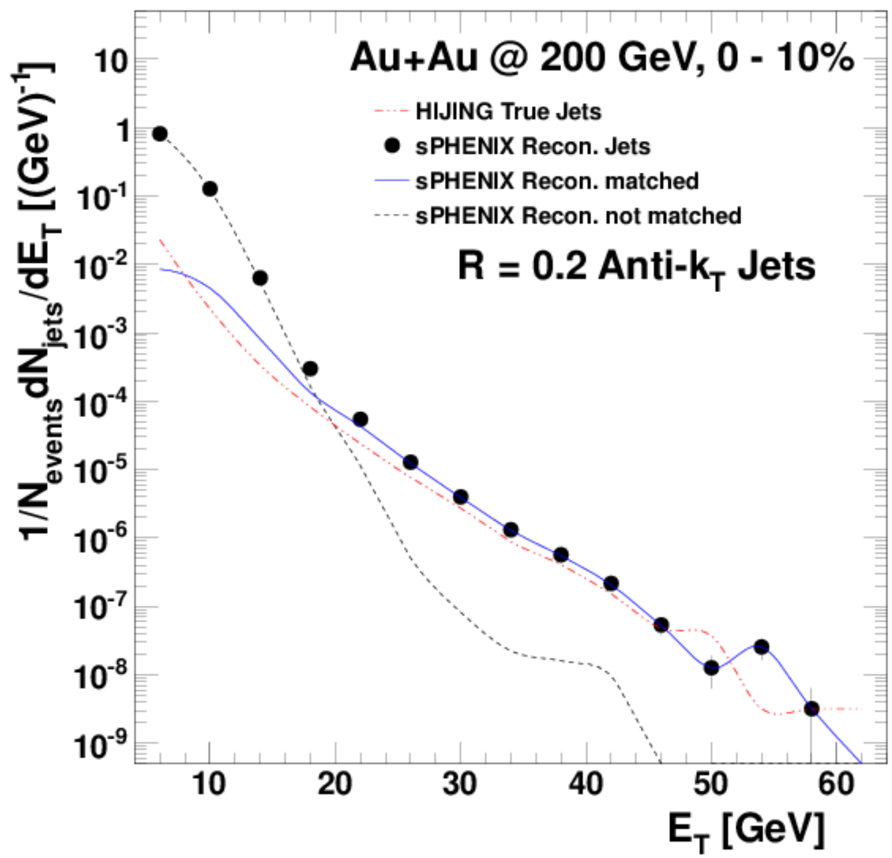
Fake jets

- Using 750M minimum bias HIJING events
- True jets outnumber fake jets for p_T > 20 GeV/c
- Details published as Hanks et al., arXiv:1203.1353, published in PRC August 10



Design Goals for a Jet Detector

- Full azimuthal coverage in a fiducial region $|\eta|<1$
- 2T solenoid to ultimately allow high resolution tracking in a small volume
- Electromagnetic and hadronic calorimetry
  - Electromagnetic
    - $\Delta\eta \times \Delta\varphi \approx 0.02 \times 0.02$
    - $\sigma_E/E \approx 15\%/\sqrt{E}$
  - Hadronic
    - $\Delta\eta \times \Delta\varphi \approx 0.1 \times 0.1$
    - $\sigma_E/E \approx 100\%/\sqrt{E}$
- Data acquisition capable of recording >10 kHz