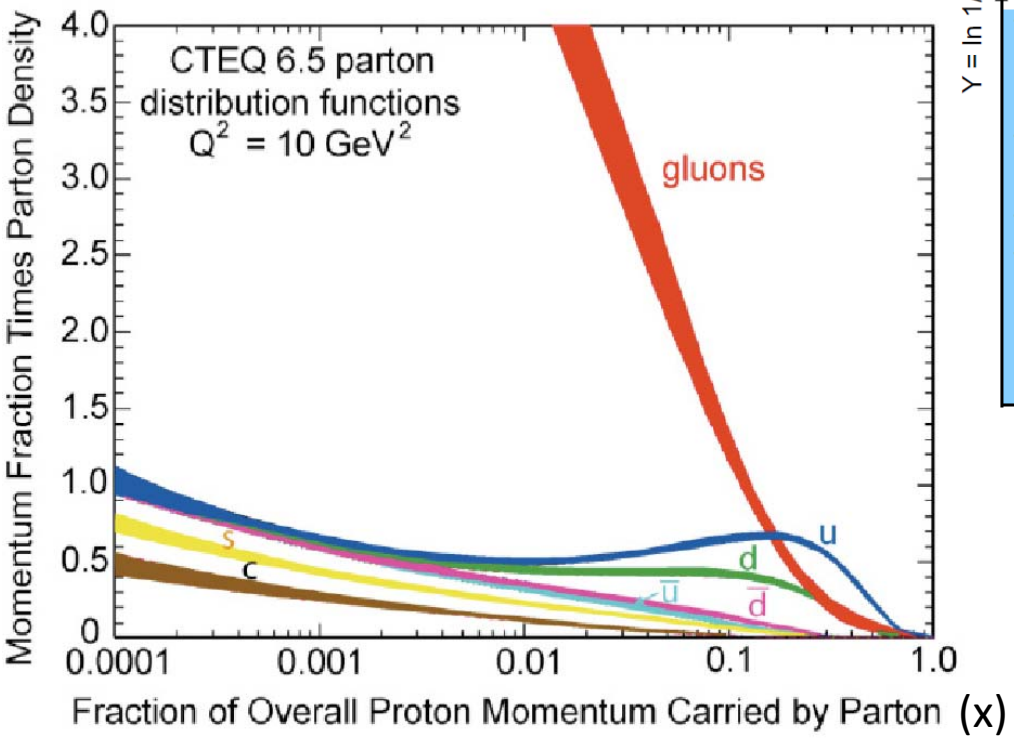
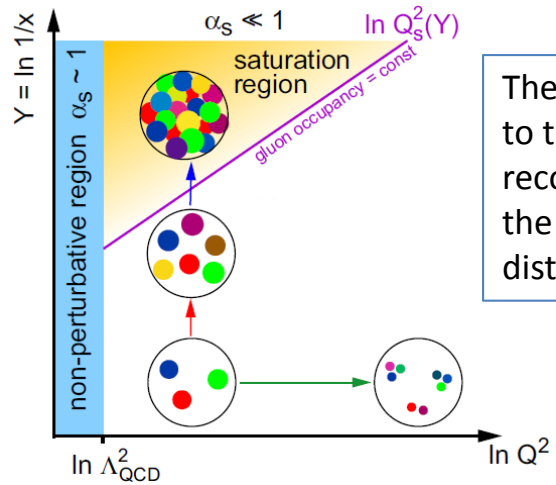
The p+A Program and Future Studies of Gluon Saturation at RHIC

John Lajoie

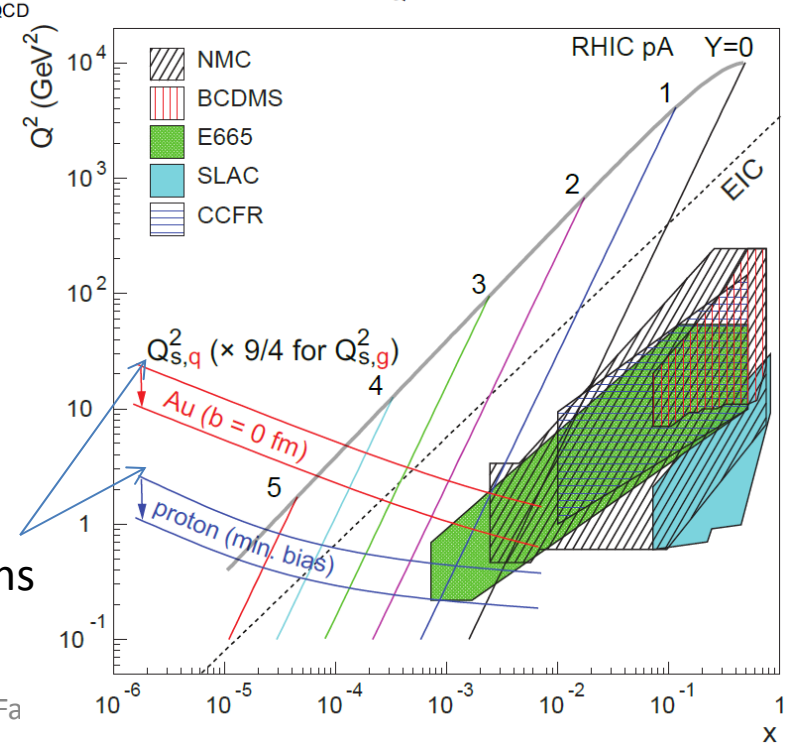
Iowa State University

Gluon Saturation





The gluon density grows to the point where recombination tames the growth of the gluon distribution at small x.



The nucleus is an *amplifier* of high gluon densities.

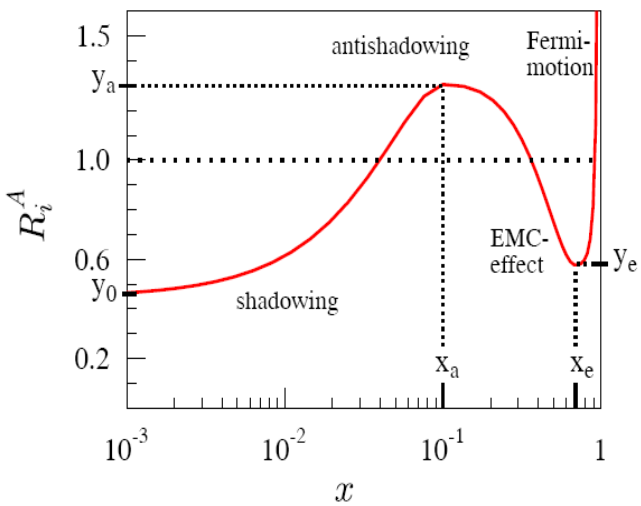
$$\left(Q_S^A\right)^2 \approx cQ_0^2\left(\frac{A}{x}\right)^{1/3}$$

gluons

Gluons in Nuclei

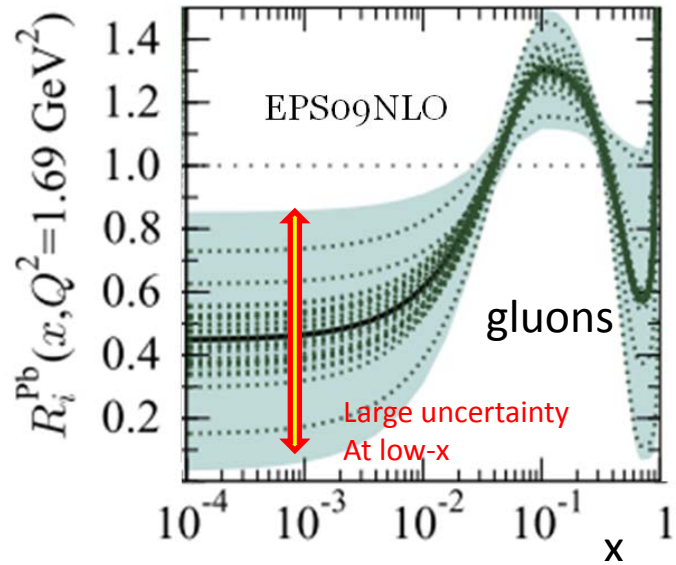
$$R_G^{Pb}(x,Q^2) = \frac{xG_A(x,Q^2)}{AxG_p(x,Q^2)}$$

shadowing/saturation in nuclei



Fit data on nuclei:
SLAC, NMC, EMC
DIS+DY+PHENIX
midrapidty π^0

Lack of data
⇨large uncertainly
in gluon pdf
at low-x



Eskola , Paukkunen, Salgado, JHP04 (2009)065

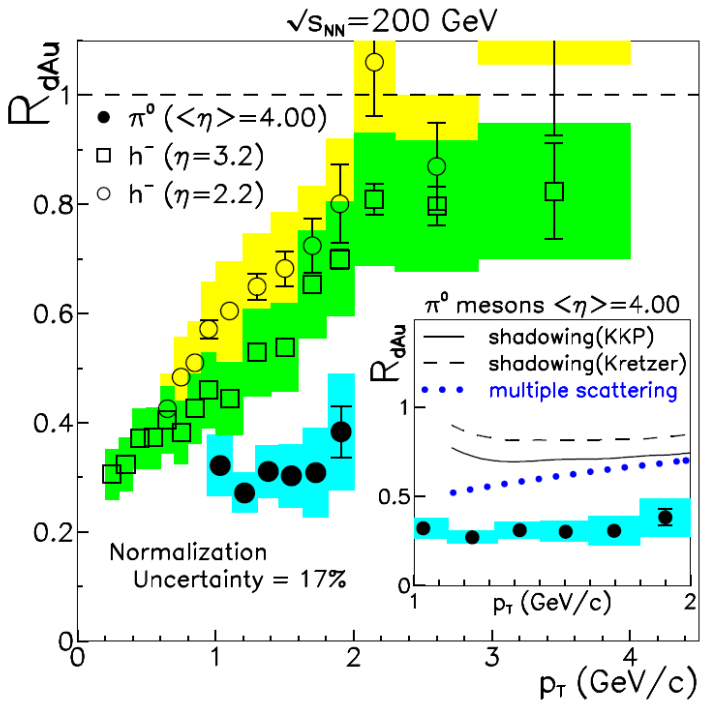
Large uncertainties in the nuclear gluon PDF at low-x: many important effects to disentangle – *shadowing, antishadowing, nonlinear QCD, saturation*, etc.

Important for fundamental understand of partonic processes in nuclei, *as well as* for the initial conditions at RHIC and the LHC.

The Big Questions

- What is the gluon density in heavy nuclei in the RHIC kinematic range?
- What role does saturation play in determining this gluon density?
- What is the saturation scale Q_s, and how does it depend on A and x?

What do we know from d+Au?

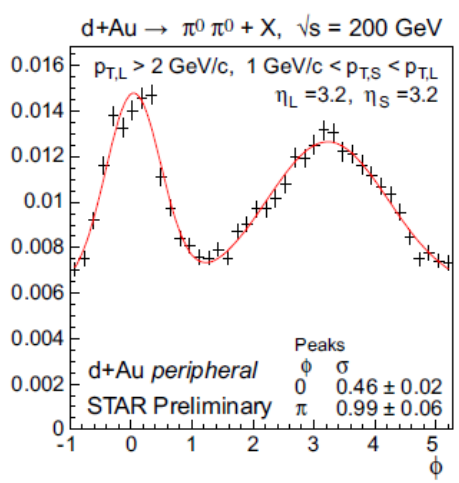


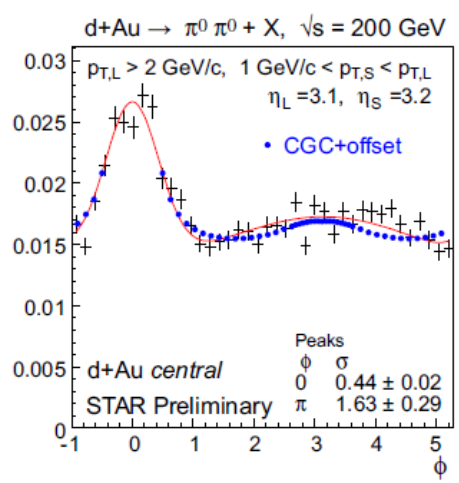
PHENIX/BRAHMS/STAR R_{dAu}

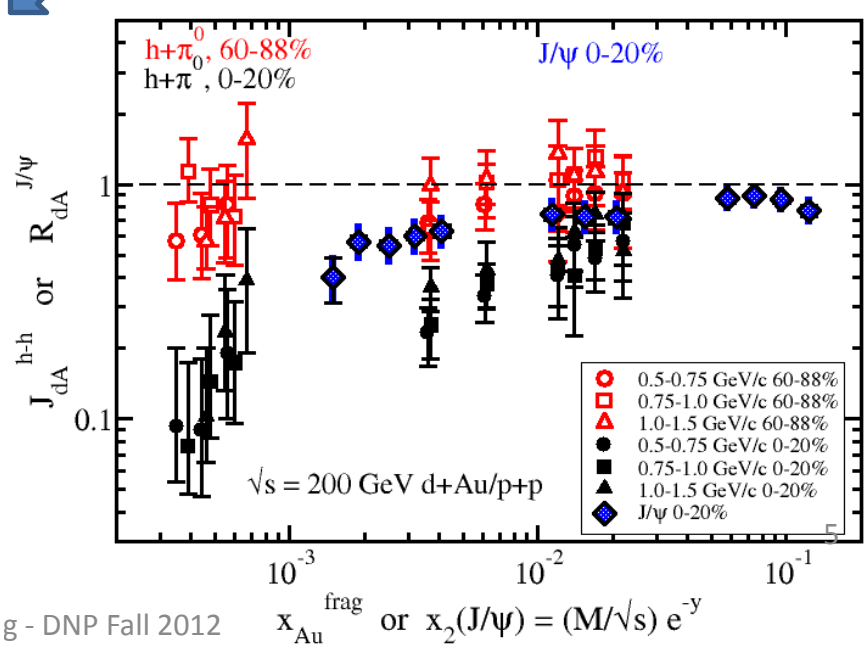
Forward R_{dAu} shows higher suppression

$$R_{dAu} = \frac{d^2\sigma/dydp_T\big|_{dAu}}{\langle N_{coll}\rangle d^2\sigma/dydp_T\big|_{pp}}$$

PHENIX/STAR forward π^0 correlations and J/Ψ suppressed

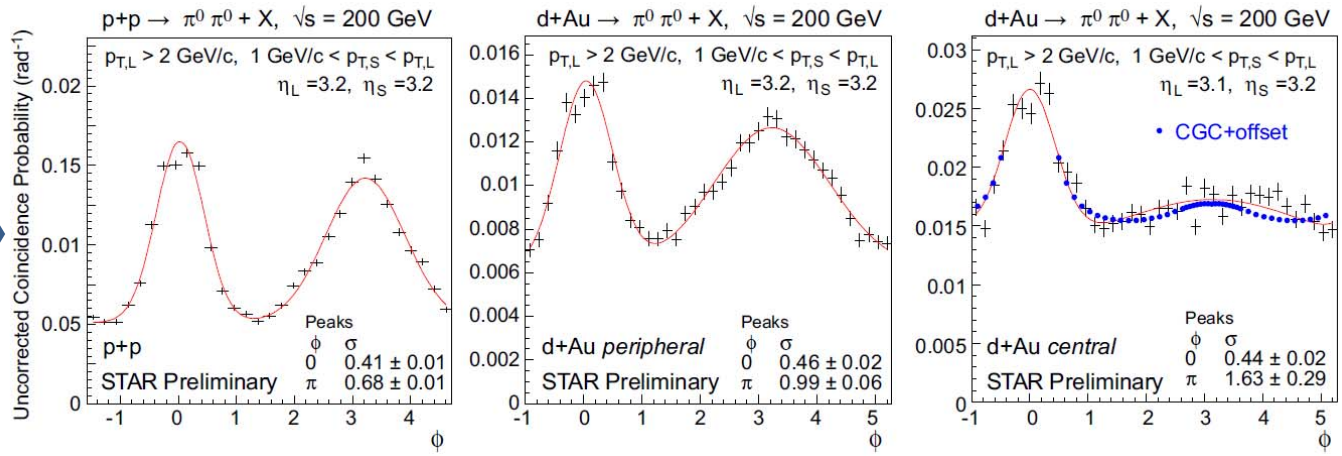


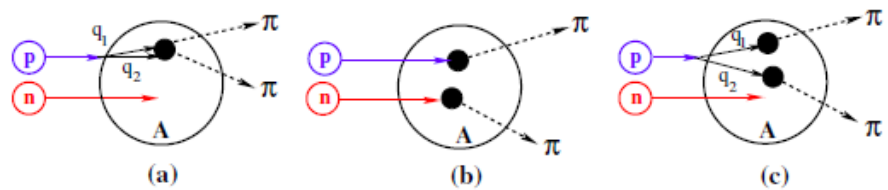




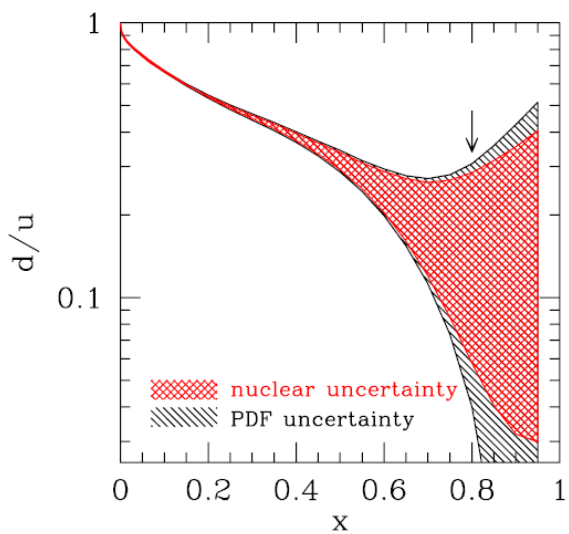
Why p+A instead of d+A?

Multi-parton interactions can contribute to the suppression of the away-side correlation strength.





Phys. Rev. D 84 014008 (2011)



Forward rapidity corresponds to *high-x* in the projectile nucleon (d or p). Nuclear corrections at high-x are large for the deuteron, which may necessitate d+p running for proper comparison.

…and you can't polarize the deuteron at RHIC…

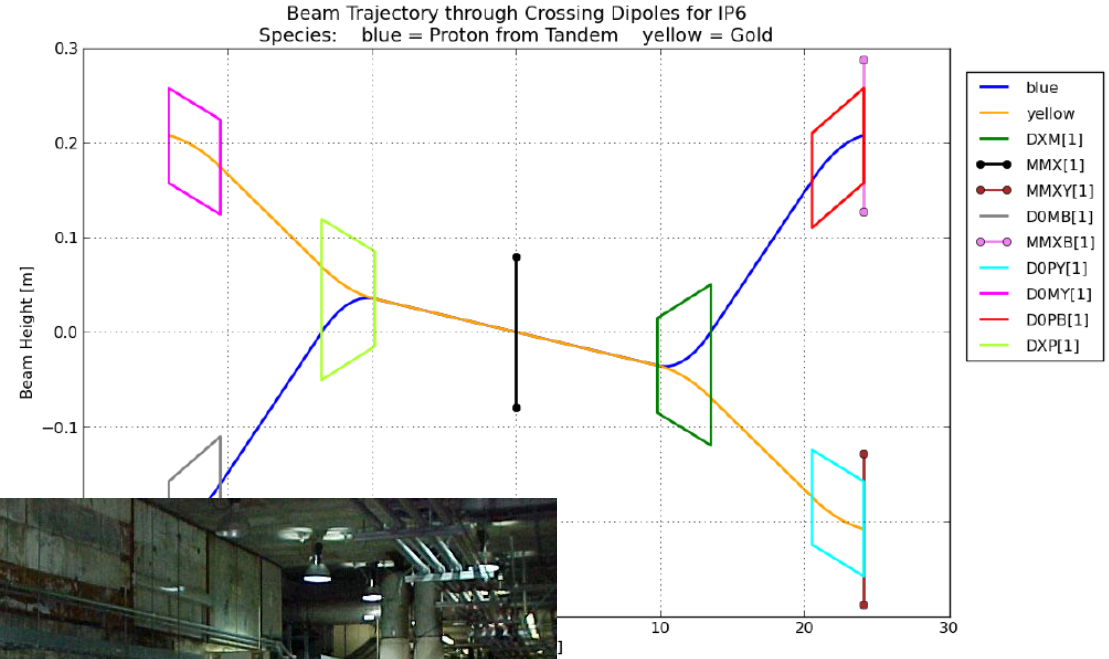
RHIC can do p+A!

New CAD study: C-A/AP/#447

p+A made easier by stochastic cooling!

Issue is aperture of the DX magnets at IP6,8 (beams in collision).

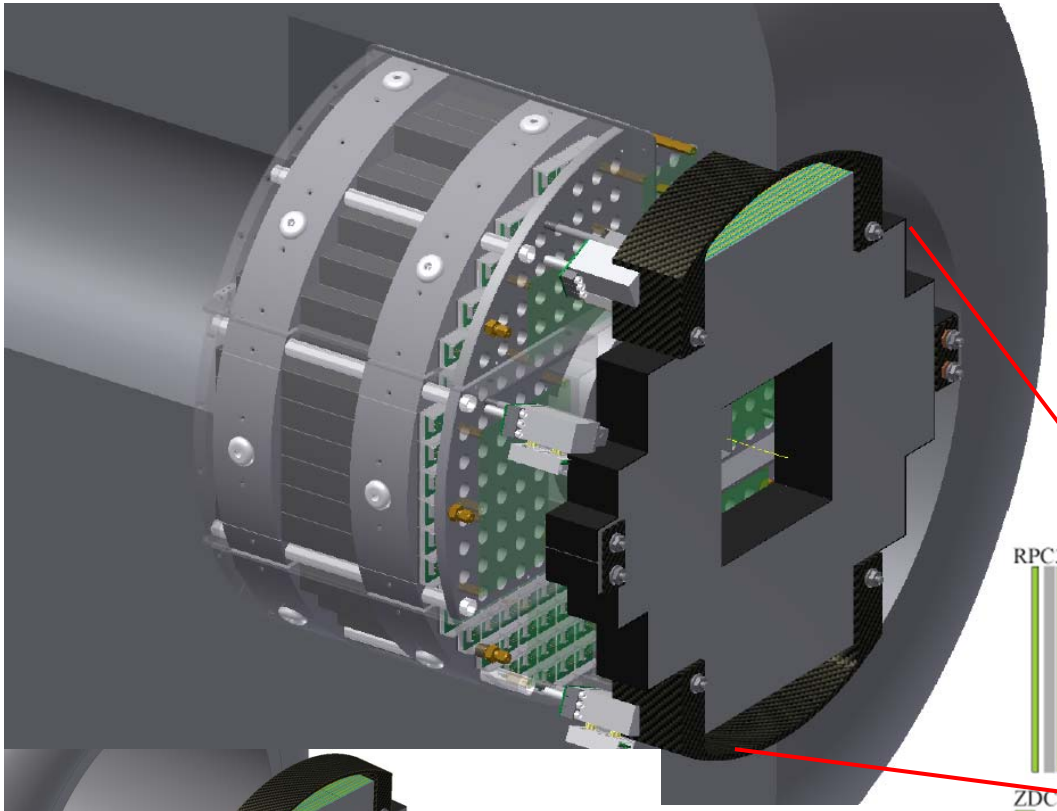
Allowing proper clearance for Au beam (3σ + 2mm) requires DX magnets at IP6,8 be moved by ~**1cm**.



CAD study by S. Tepikian and D. Trbojevic

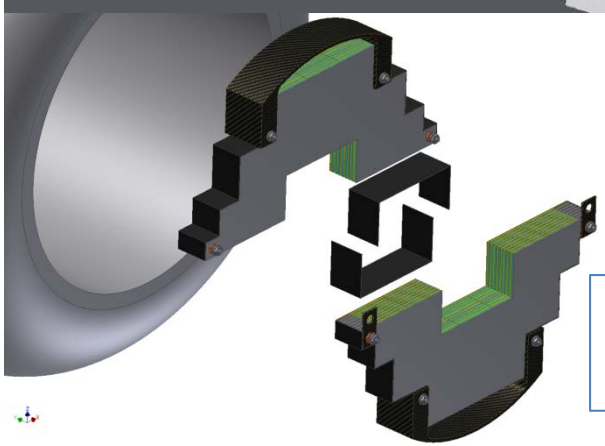
DX dipole D0, Q1-Q3

The PHENIX MPC-EX Detector

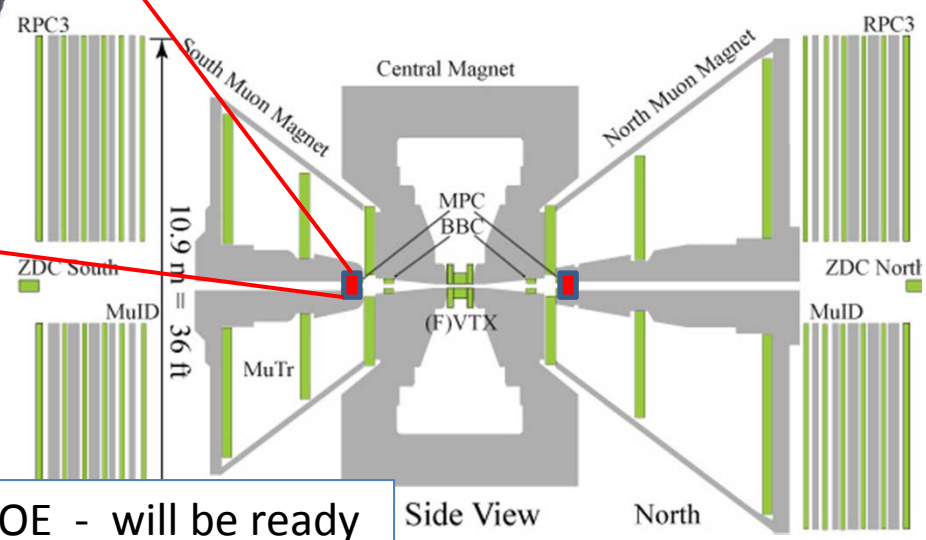


A combined charged particle tracker and EM preshower detector – dual gain readout allows sensitivity to MIPs and full energy EM showers.

- π^0 rejection (direct photons)
- π^0 reconstruction out to >80GeV
- Charged track identification



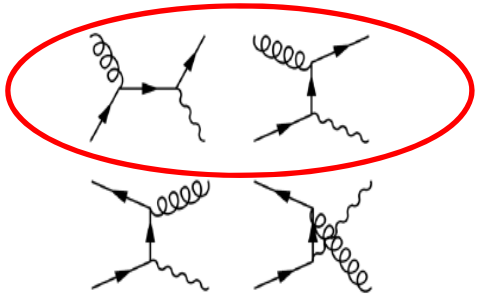
3.1<η<3.8

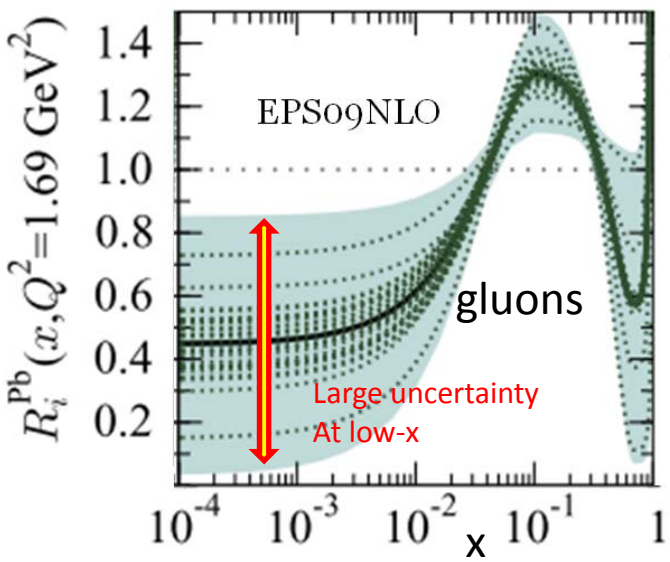


Approved by BNL/DOE - will be ready for Run-15 (earliest p+Au run)

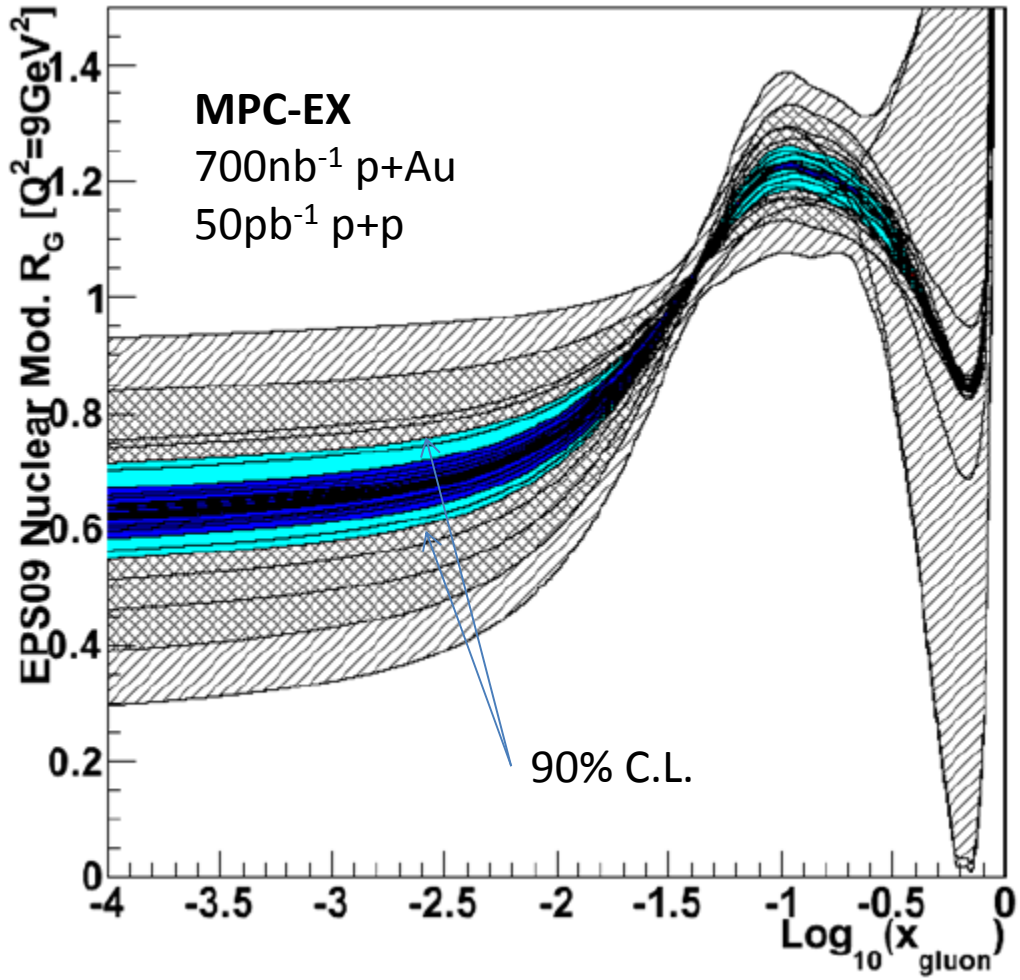
EPS09 Limits from Prompt Photons

LO Direct Photon Diagrams:





Eskola , Paukkunen, Salgado, JHP04 (2009)065



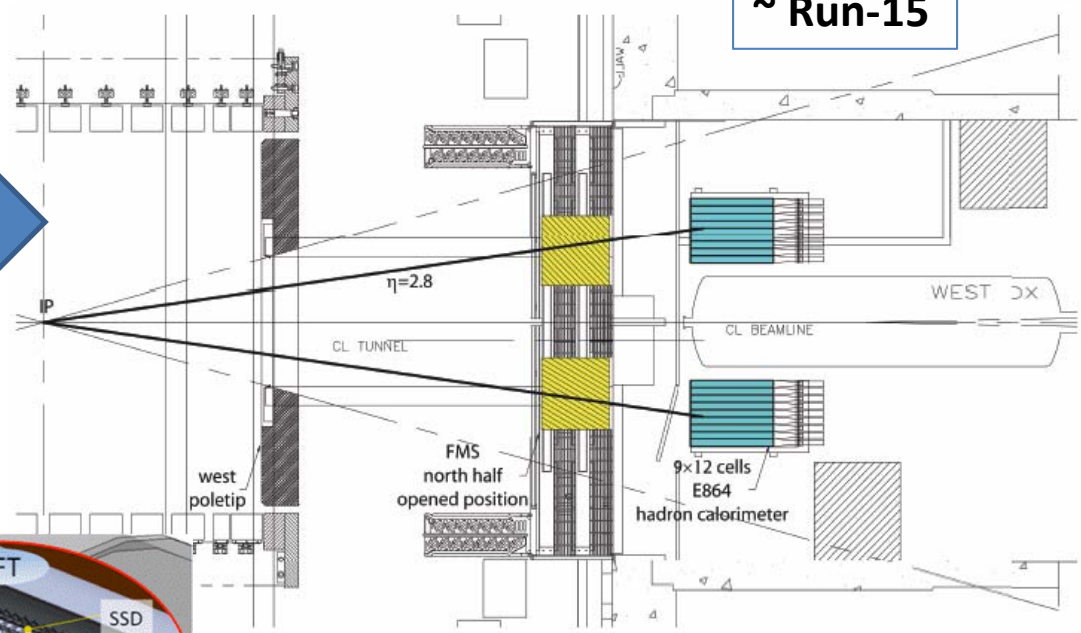
Prompt photons in MPC-EX -> Precise Measurement of Gluons at Low-x

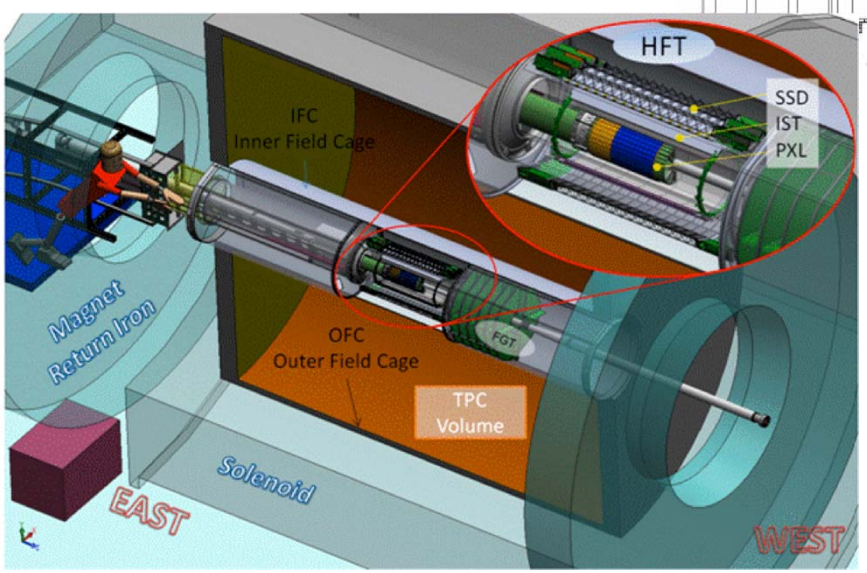
STAR Near-Term Efforts

Addition of E864 calorimeters behind FMS – full calorimetric jets!

Combined study of hadron-hadron, hadron-photon, and jet-jet correlations.

~ Run-15

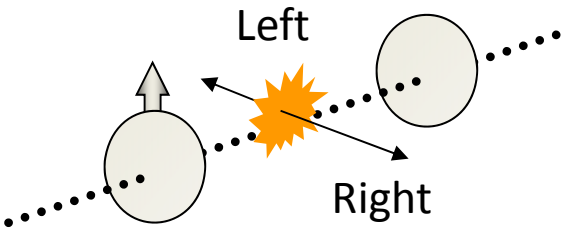




Heavy Flavor Tracker (HFT) will make possible studies of correlated charm production (gg fusion) – also EEMC and MTD

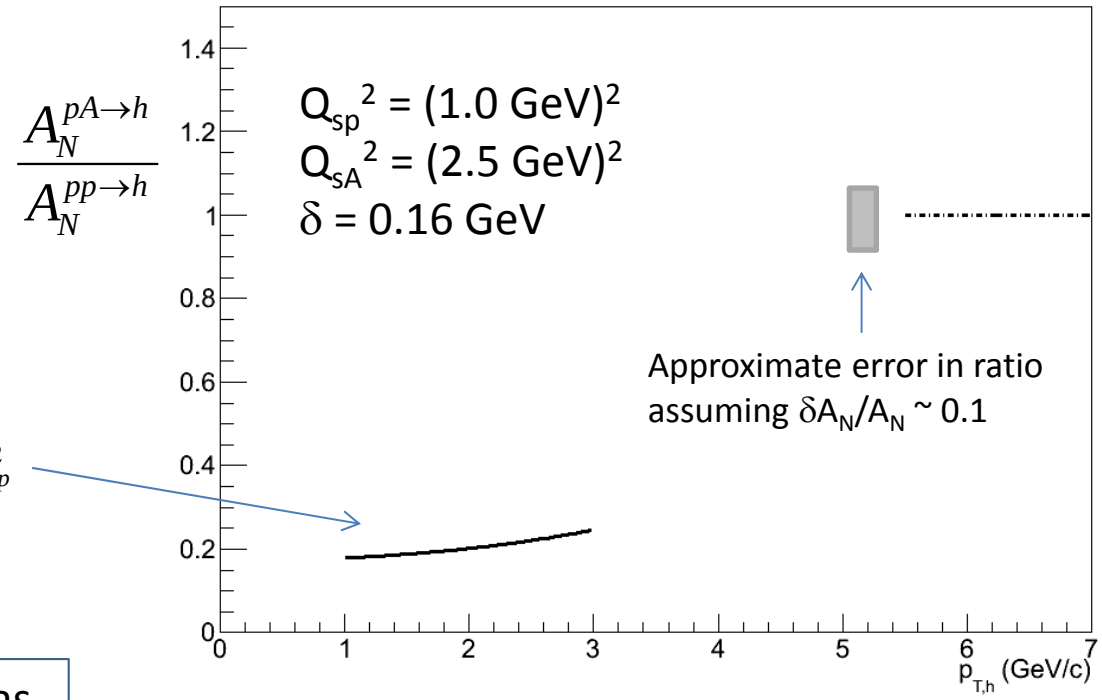
Polarized p+A Collisions

$$A_N = \frac{1}{P}\frac{\sigma_L^\pi - \sigma_R^\pi}{\sigma_L^\pi + \sigma_R^\pi}$$



$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 << Q_{sA}^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{P_{h\perp}^2 \delta^2 / Q_{sp}^2}$$

Kang, Yuan: PRD 84, 034019 (2011)

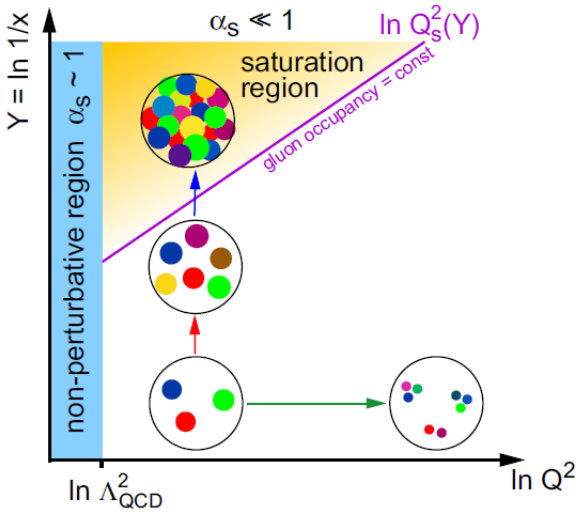


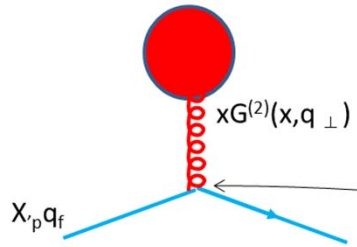
Single spin asymmetries can act as a probe of the saturation scale.

A unique capability of RHIC!

- Dependence of Q_{sA} on A
- Combined with other measurements this can estimate Q_{sp}

TMD Gluon Distributions





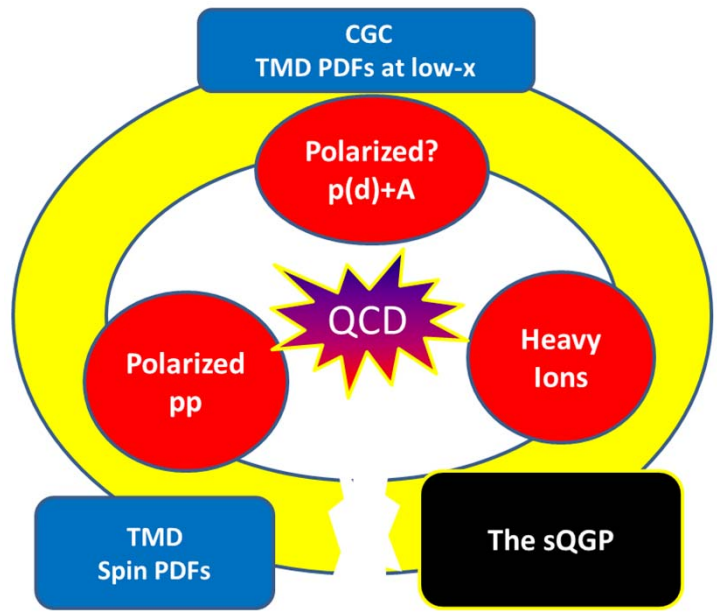
$$\frac{d\sigma^{(pA\to\gamma q+X)}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \sum_f x_p q_f(x_p)\, x_g G^{(2)}(x_g, q_\perp) H_{qg\to\gamma q}$$

Dominguez, Marquet, Xiao, Yuan: Phys Rev. D 83: 105005 (2011)

Transverse Momentum Dependent (TMD) factorization is ***recovered*** in low-x limit in p+A, consequence is <u>two</u> gluon distributions!

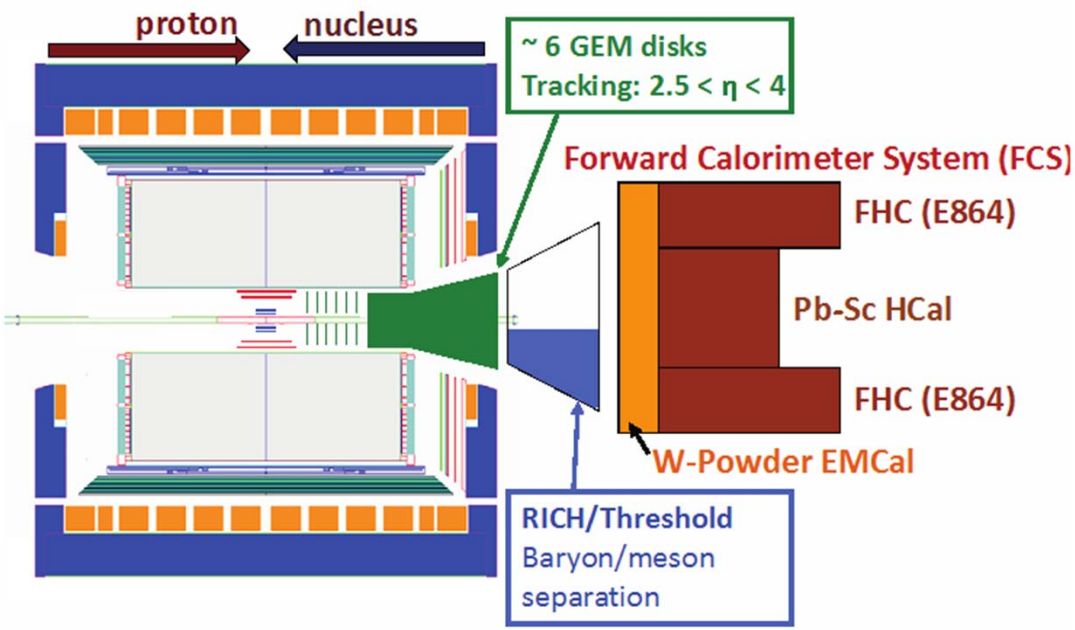
TMD PDF's at low-x are equivalent to those obtained in the Color Glass Condensate framework!

The TMD framework is important in attempts to understand single-spin asymmetries!



Strong synergies between RHIC programs!

STAR/PHENIX Forward Upgrades

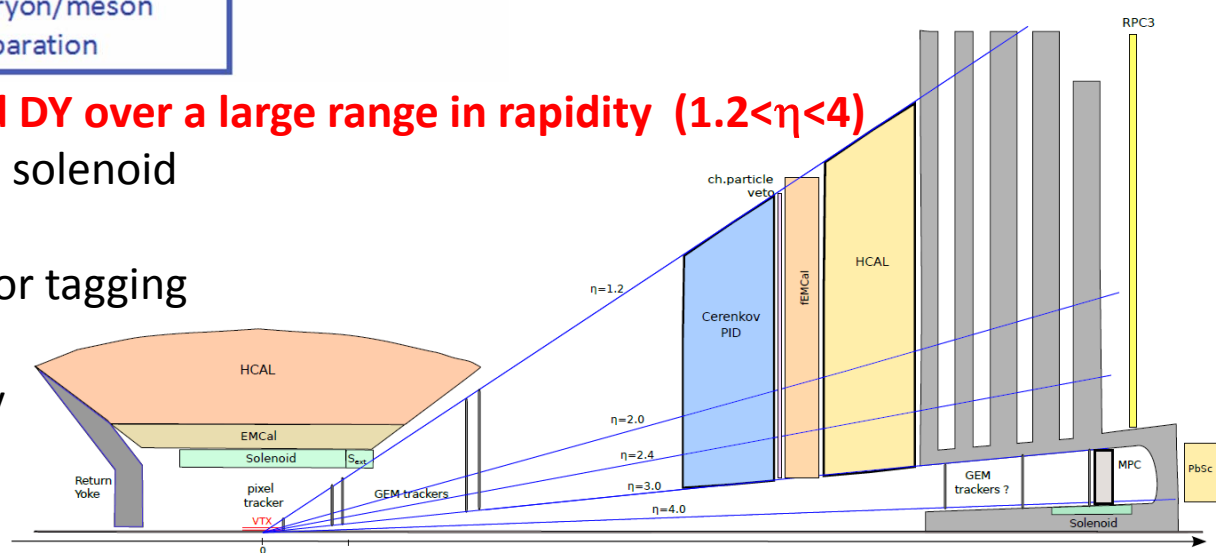


STAR Staged Approach:

Calorimeters: 2015-2017
GEM Trackers: ~2017
Cerenkov: 2018-2019

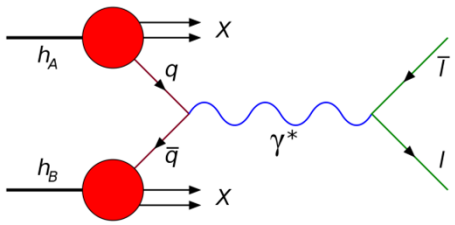
Optimized for jets, photons and DY over a large range in rapidity (1.2<η<4)

- Extension of sPHENIX central solenoid
- GEM based tracking
- Diamond pixel for heavy flavor tagging
- RICH based PID (π/K/p)
- EM and hadronic calorimetry
- Muon identification



Future Saturation Measurements

- **Forward-forward correlations:**
  - h-h and π^0-π^0 are straightforward experimentally
  - γ-h and γ-π^0 are easier to interpret
  - jet-jet, γ-jet gives access to complete kinematics at LO
- **J/Ψ Production at forward rapidity:**
  - Complimentary measurement (gg fusion)



- **Drell-Yan:**
  - Complete kinematics: x_1, x_2, Q^2
  - True 2->1 process yields access to x<0.001
  - Requires high luminosity (end of decade)

Why RHIC?

- **RHIC "straddles" Q_{sA}**
  - RHIC can make measurements both above and below the saturation scale (rapidity and centrality)
- **RHIC can explore the dependence of the saturation scale on nuclear size**
  - Flexibility of RHIC collider to run p+A with multiple *A* species
- **Polarized p+A collisions offer a unique, fundamentally new observable**
- **Measurements at RHIC and the LHC and *complementary!***

Summary

- **The study of gluon saturation offers a window into the structure of matter:**
  - Important to understand partonic processes on nuclei
  - Sets the initial conditions for HI collisions
  - Tantalizing hints in current RHIC data!
- **Near-term detector upgrades will continue the success and open new approaches:**
  - Prompt photons in the PHENIX MPC-EX
  - Jet correlations with STAR FMS+FHC
  - Polarized p+A collisions a unique opportunity
- **PHENIX/STAR forward upgrades will enable critical new observables**

BACKUP

Outline

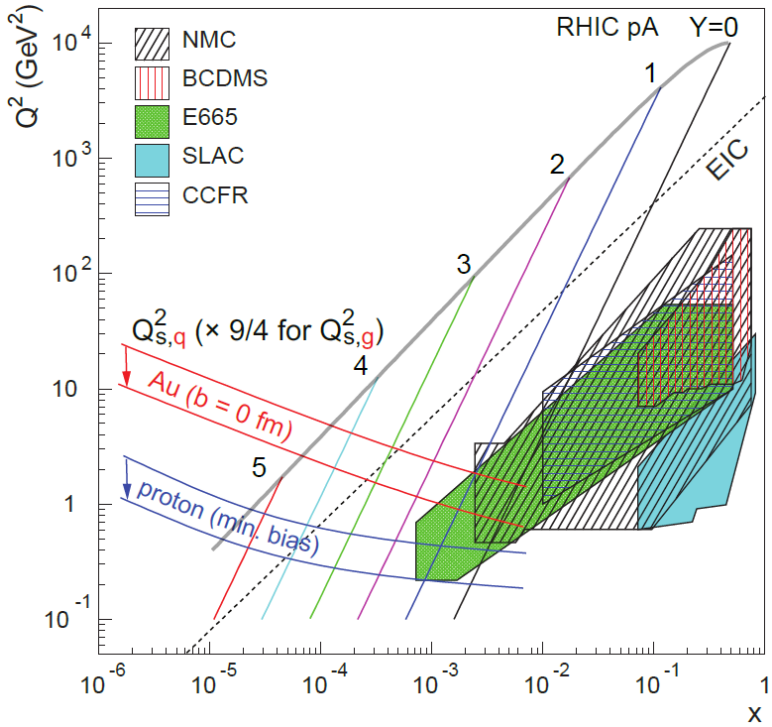
- **Gluon Saturation**
  - Why is it interesting?
- **What do we know from d+Au?**
  - Sampling of results from PHENIX and STAR (and BRAHMS)
- **Why p+A instead of d+A?**
- **Near Term Efforts**
  - PHENIX MPC-EX
  - STAR (FMS and FHC)
  - Polarized p+A: a unique capability
- **The PHENIX and STAR Forward Upgrades**
  - Physics opportunities with upgrades
- **Summary**

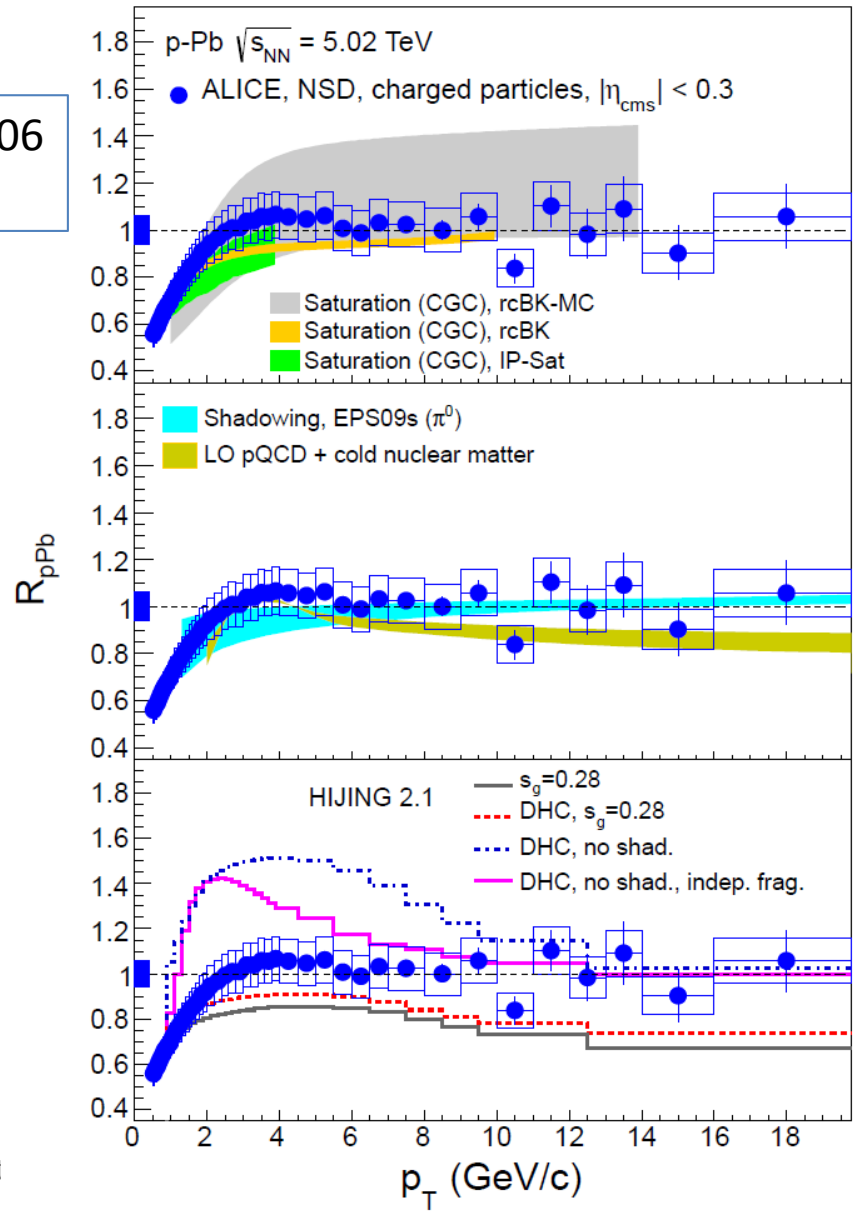
Recent Results from the LHC

ALICE results from pPb engineering run.

CERN-PH-EP-2012-306
11 October 2012

Interesting…..
but the LHC may not be fully in the saturated regime at y=0.

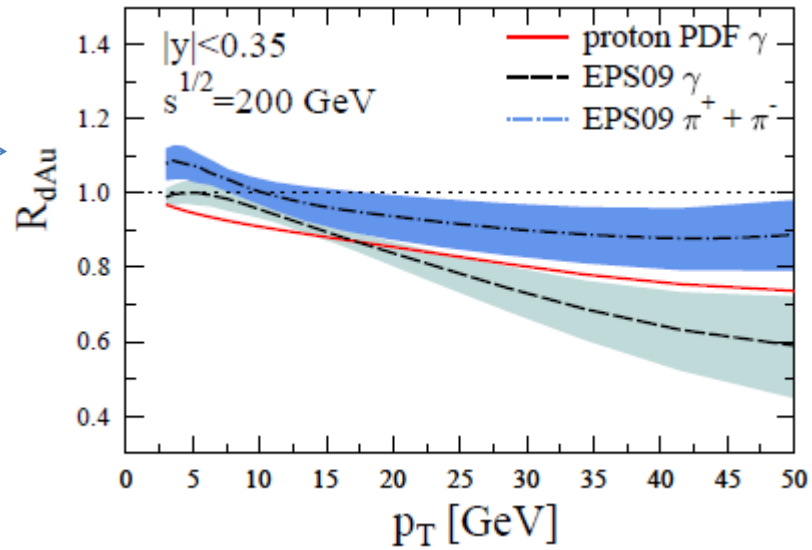




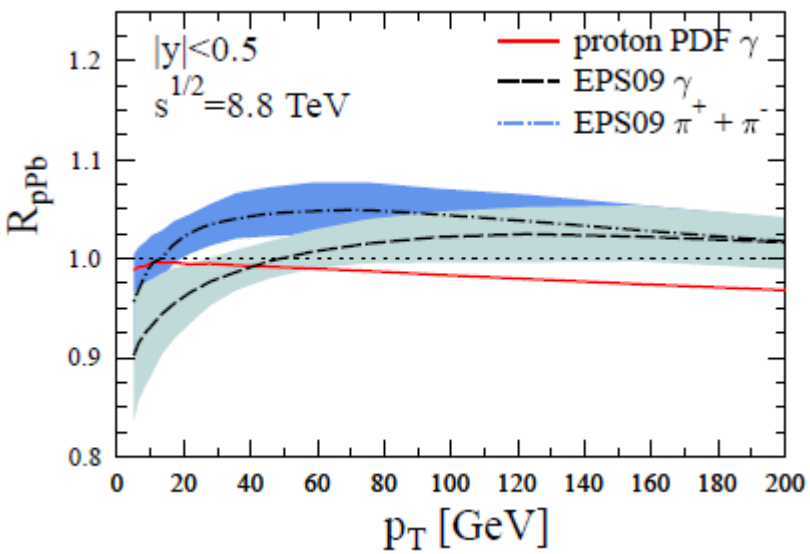
Prompt Photon Predictions

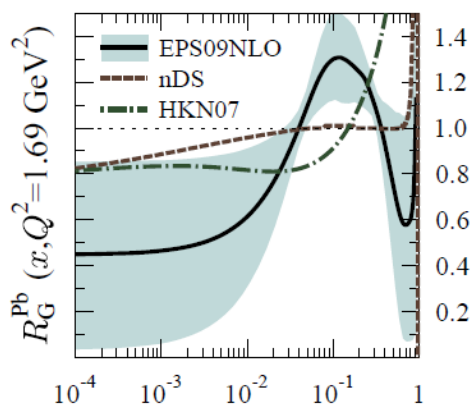
arXiv:1103.1471v2

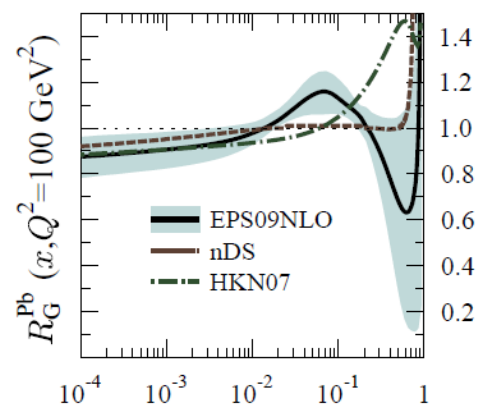
RHIC



LHC







PHENIX Forward Upgrade

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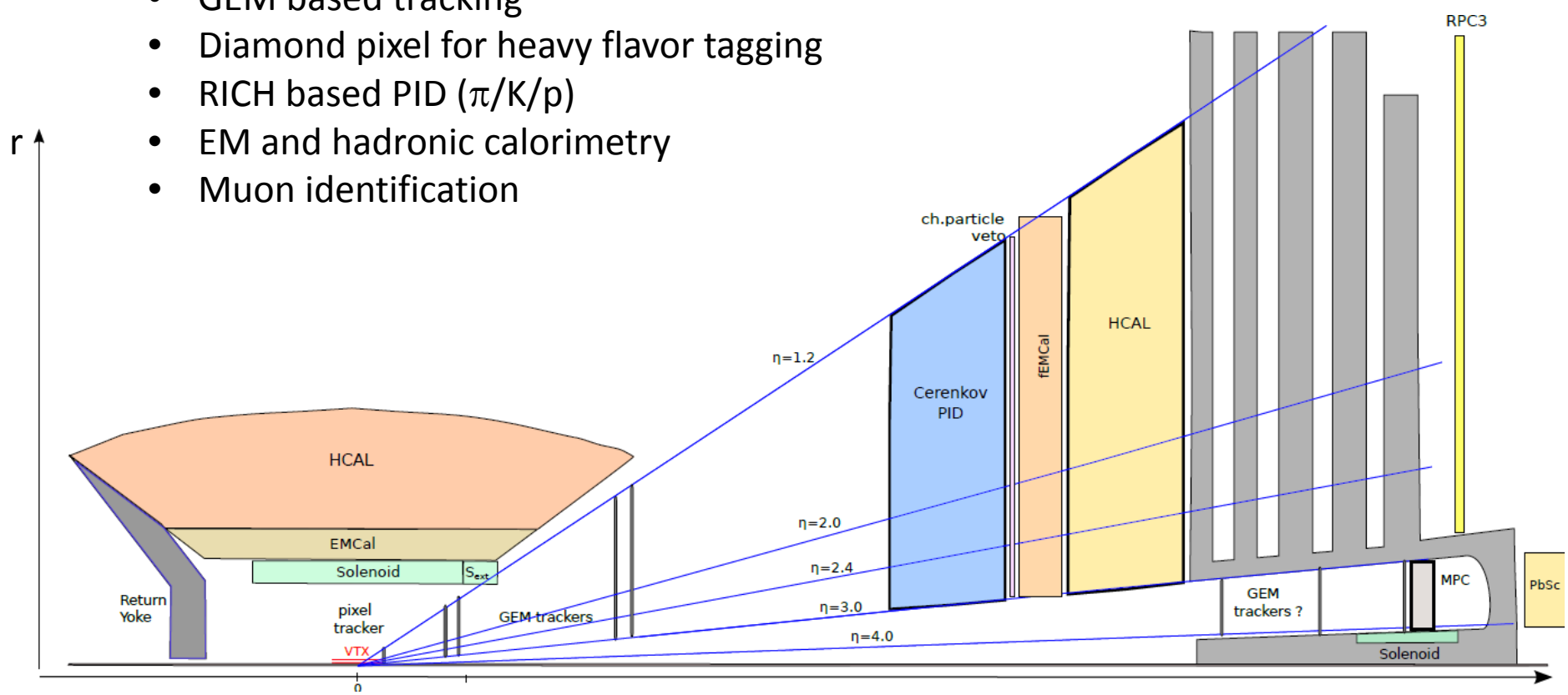

STAR Forward Upgrade

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~2017

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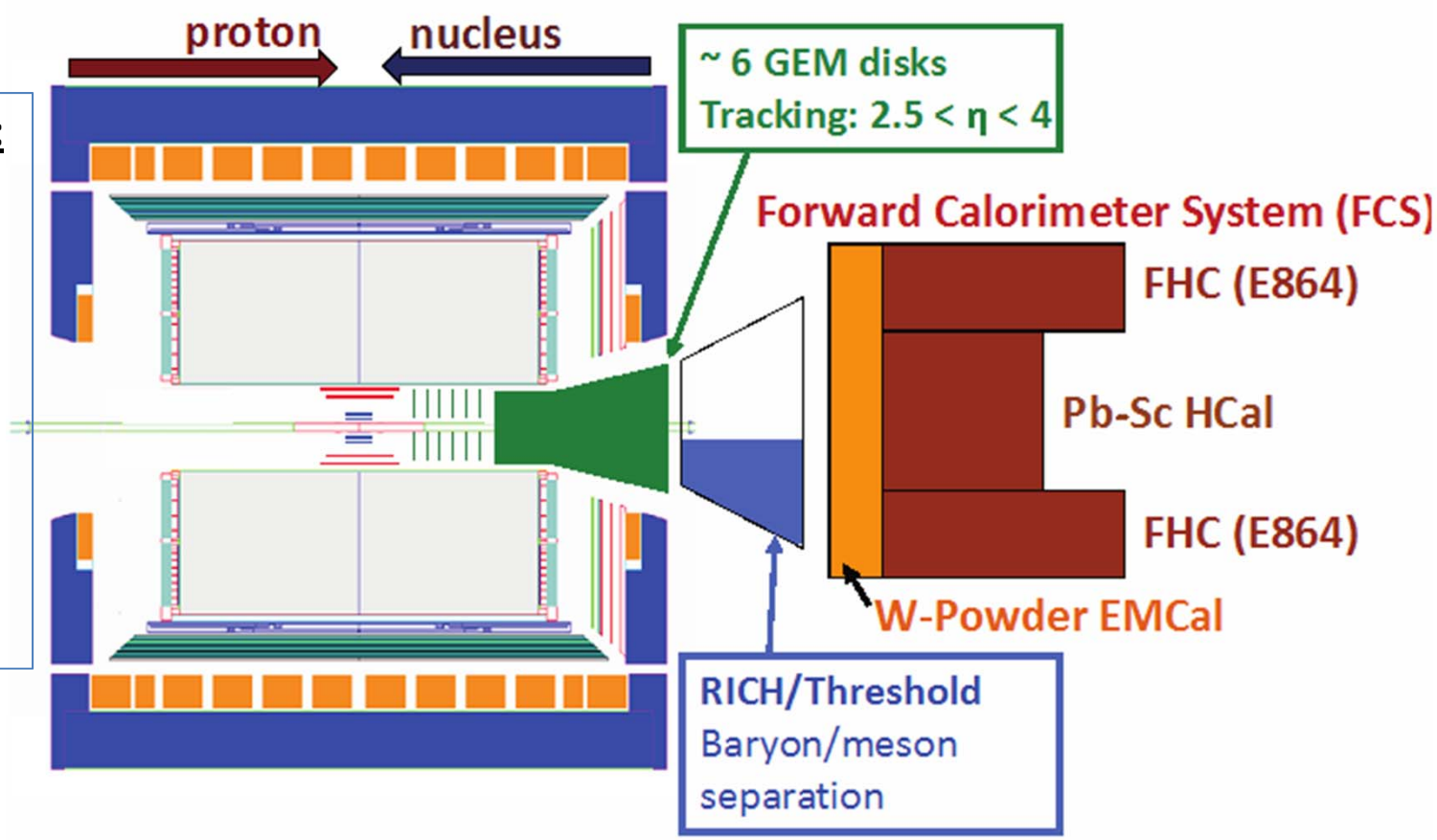
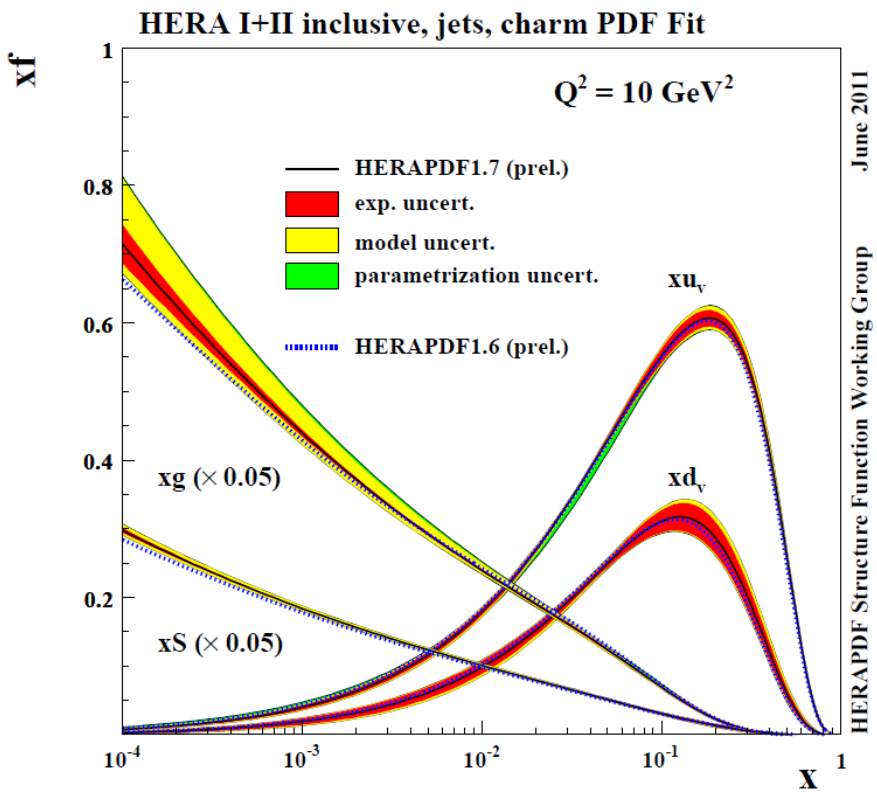
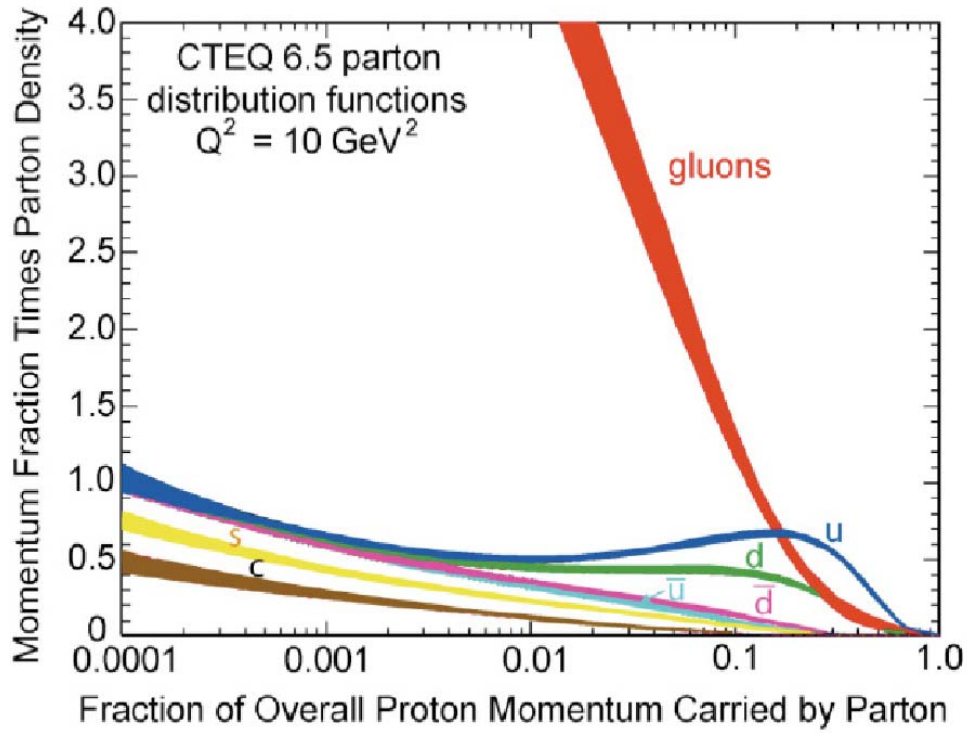


PDF's


HERA I+II inclusive, jets, charm PDF Fit
xf
$Q^2 = 10\ GeV^2$
HERAPDF1.7 (prel.)
exp. uncert.
model uncert.
parametrization uncert.
HERAPDF1.6 (prel.)
xu_v
xd_v
xg (× 0.05)
xS (× 0.05)
x
June 2011
HERAPDF Structure Function Working Group


CTEQ 6.5 parton
distribution functions
$Q^2 = 10\ GeV^2$
gluons
u
d
s
c
$\bar{u}$
$\bar{d}$
Momentum Fraction Times Parton Density
Fraction of Overall Proton Momentum Carried by Parton