The Future RHIC Spin and Cold QCD Program

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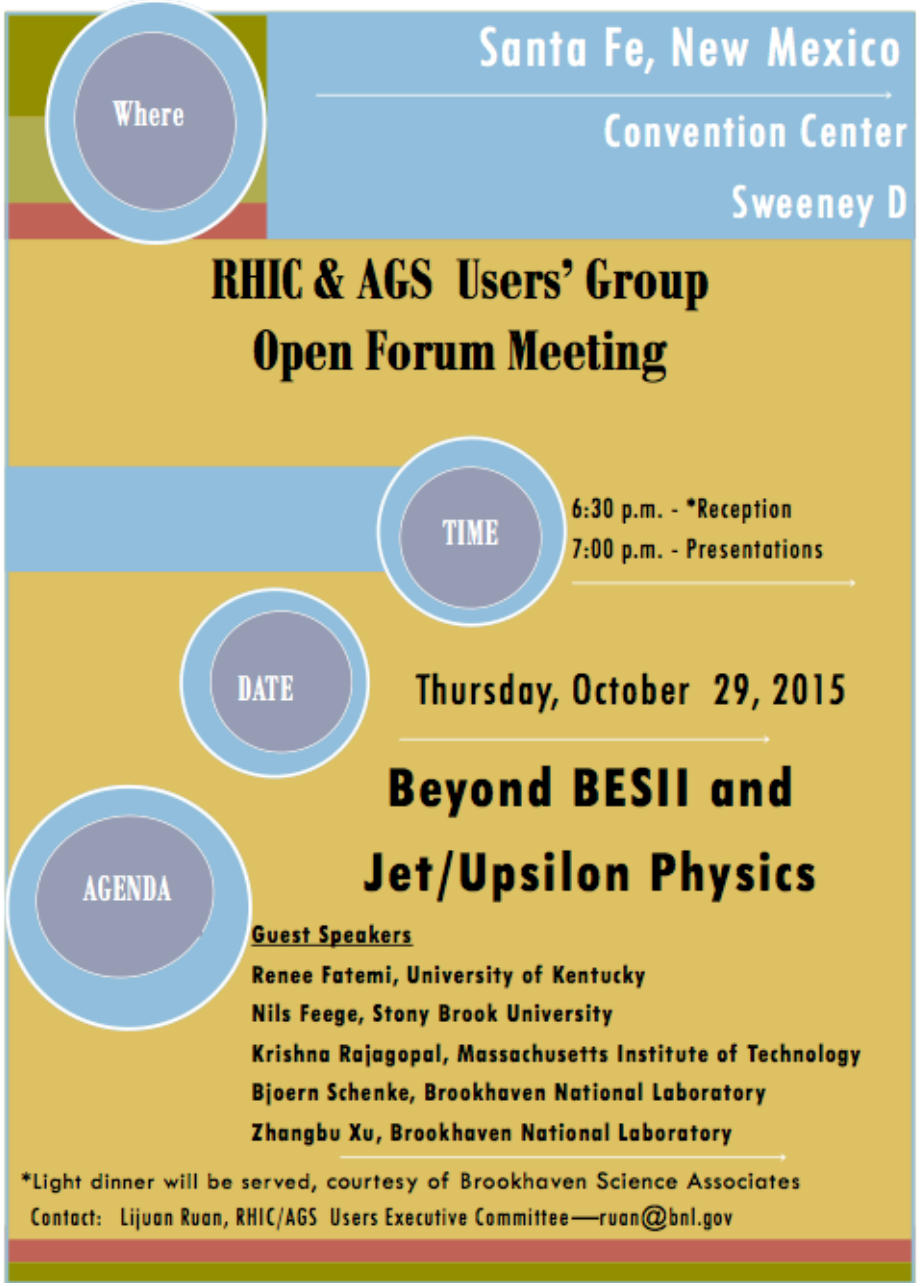
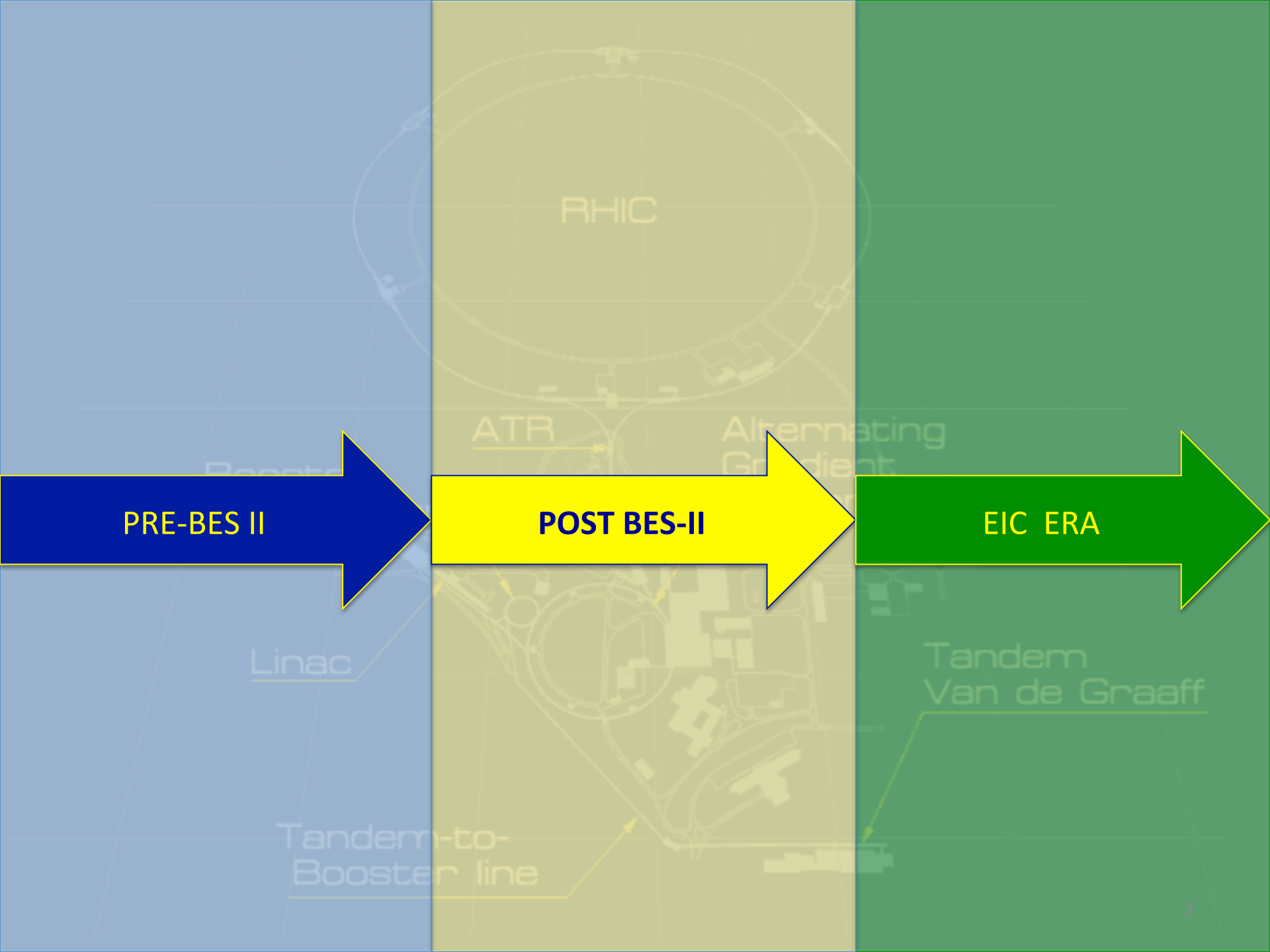
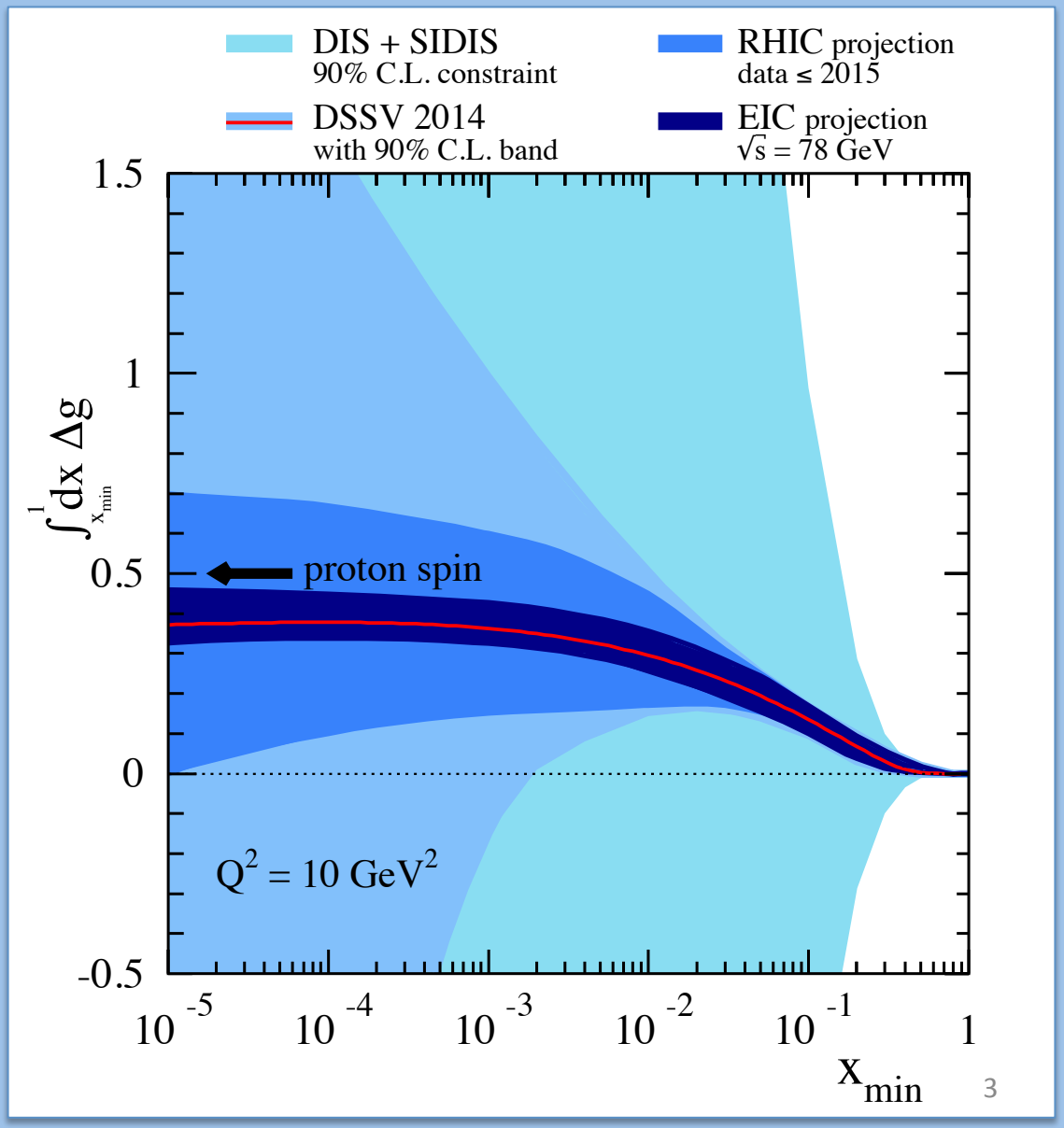



RHIC
ATR
Alternating
Linac
Tandem
Van de Graaff
Tandem-to-
Booster line
PRE-BES II
POST BES-II
EIC ERA

PRE-BES II

Extremely productive time for RHIC!

First indication of a non-zero gluon spin in the Proton!



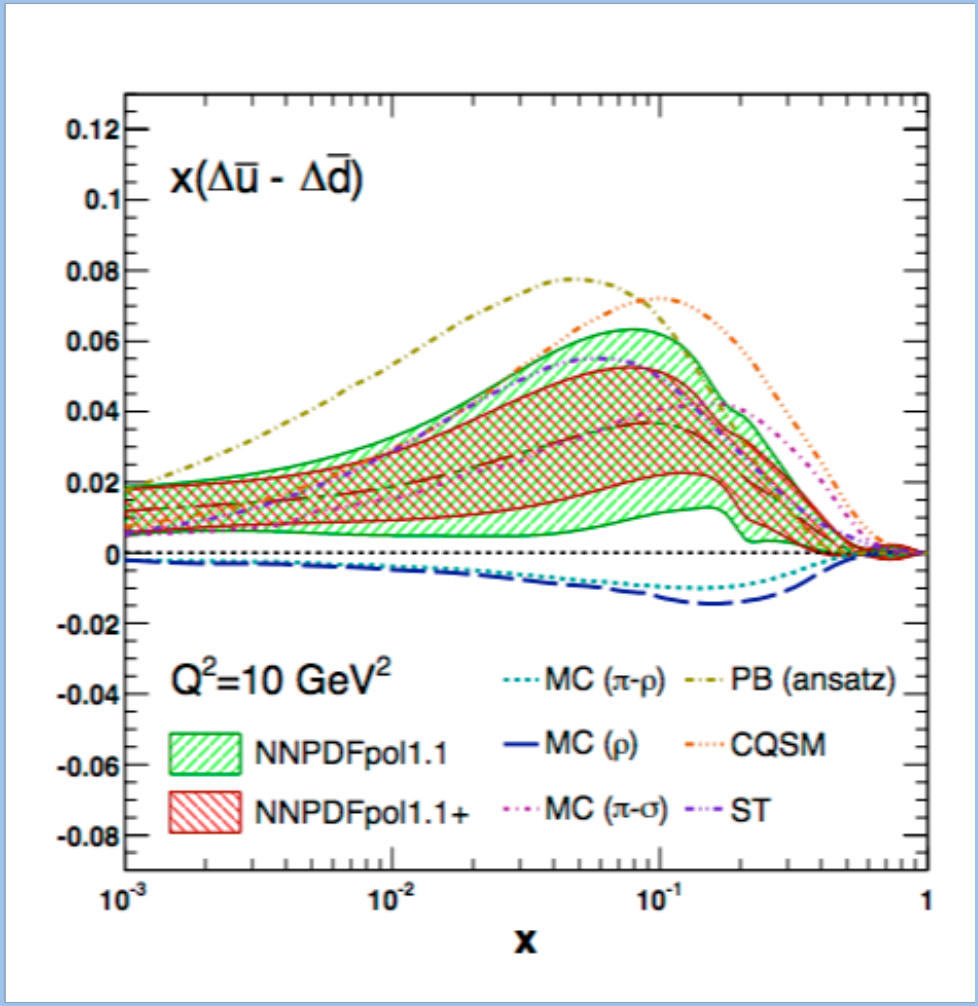
Special thanks to DSSV for this plot!

PRL 113 1, 012001 (2014)
arXiv:1509.06489v1

PRE-BES II

Extremely productive time for RHIC!

First significant indication of flavor symmetry breaking in the light polarized sea.

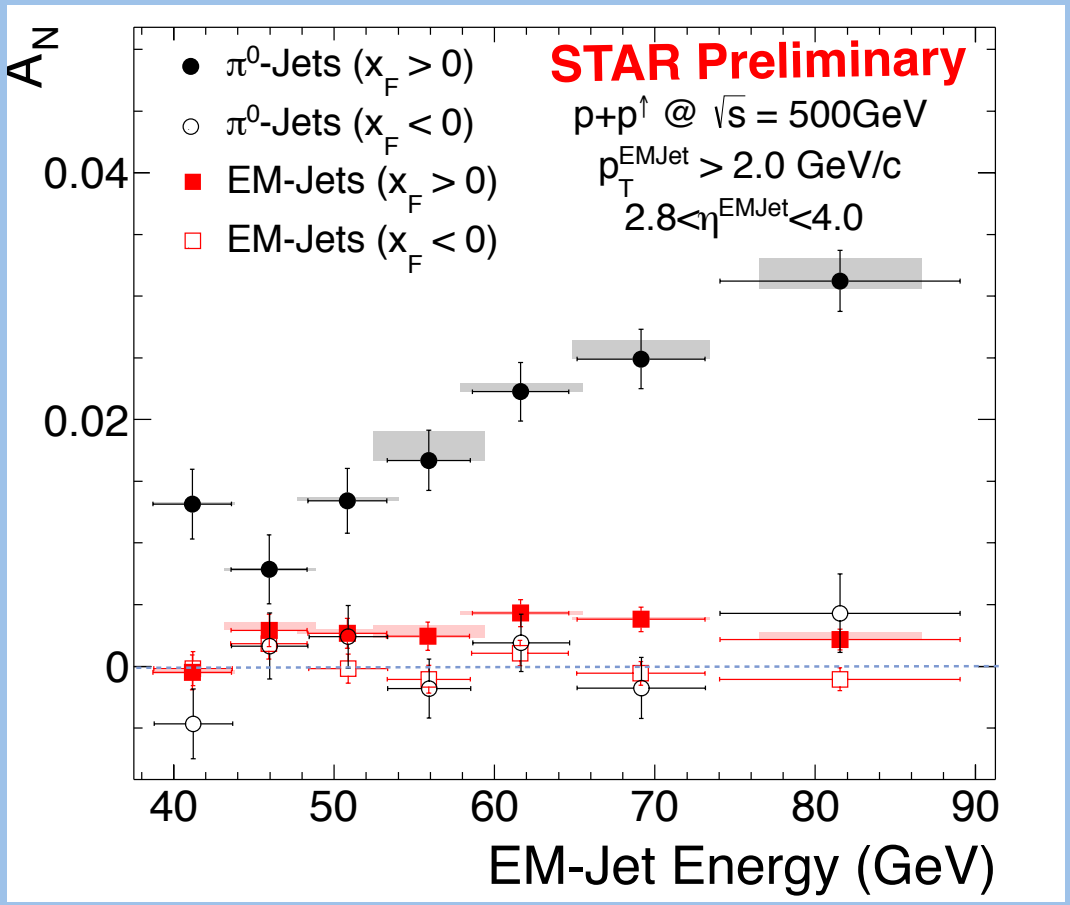


NNPDF Collaboration, Nucl. Phys. B887 276 (2014)

PRE-BES II

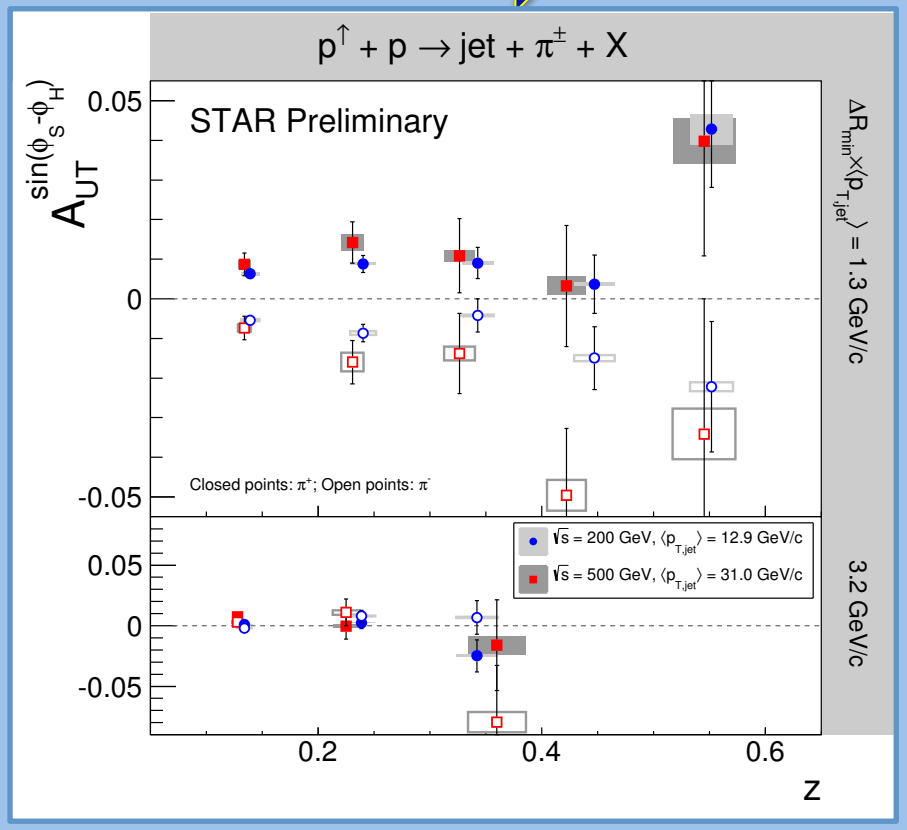
Extremely productive time for RHIC!

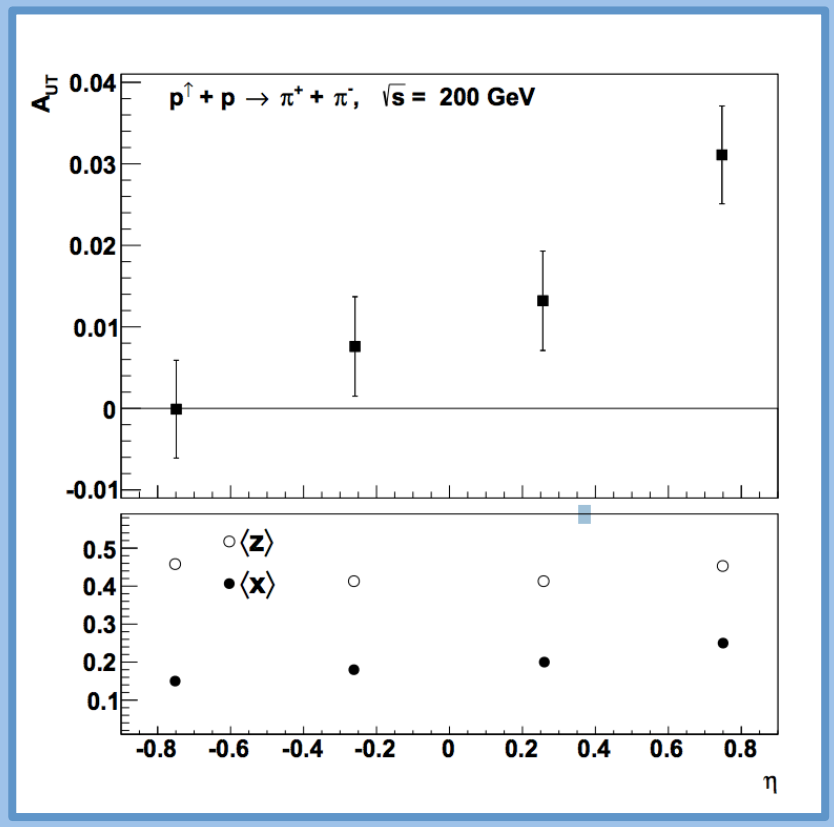
First indication that the large, and unexplained, forward π^0 transverse single spin asymmetries do not arise from 2-2 scattering.



PRE-BES II

Extremely productive time for RHIC!



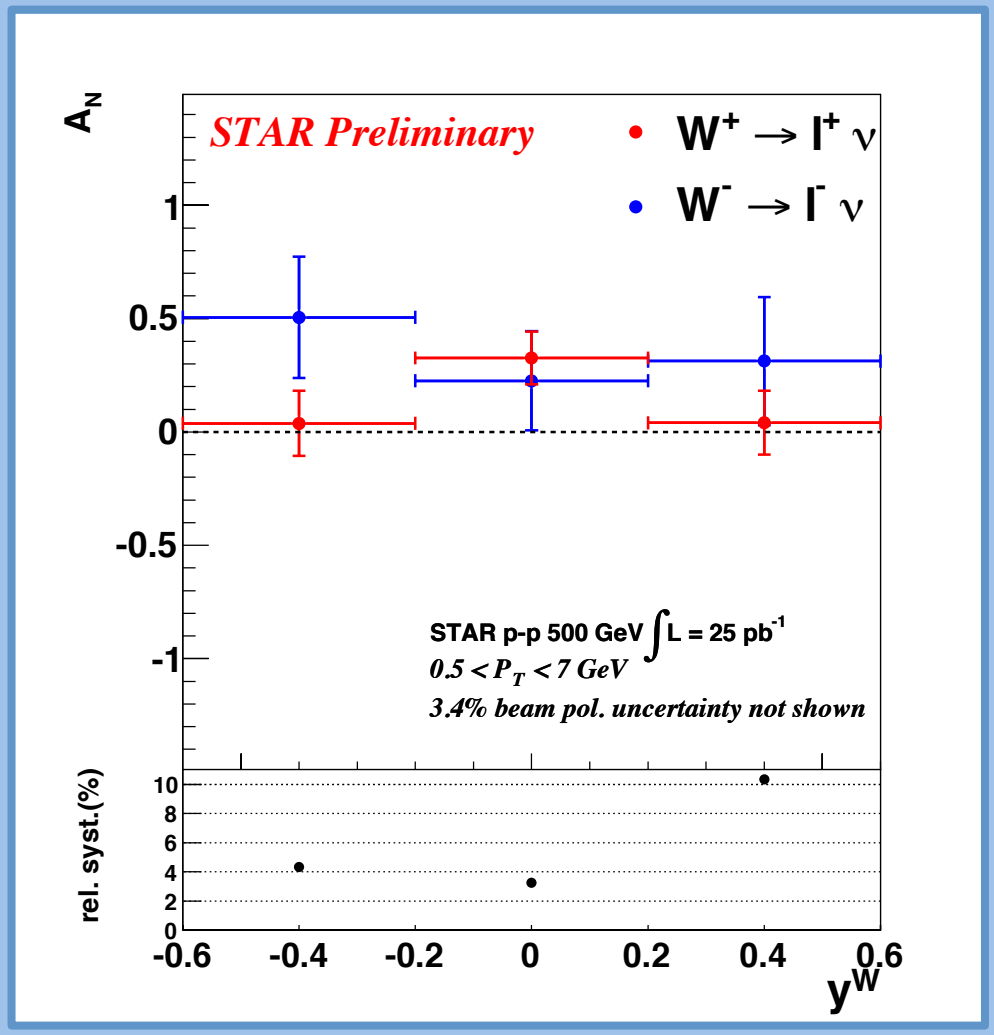


First significant asymmetries sensitive to transversity measured in hadronic collisions!

PRE-BES II

Extremely productive time for RHIC!

Run 17 will provide STAR the opportunity to be the first to measure the predicted Sivers' sign change in W and direct γ asymmetries.



PRE-BES II

- **Non-zero ΔG**
- **Evidence of $\Delta\bar{u} > \Delta\bar{d}$**
- **Evidence that large forward transverse SSA may not come from 2-2 processes!**
- **First asymmetries sensitive to transversity measured in hadronic collisions.**
- **Opportunity to measure Sivers sign change via W and direct γ production**

POST BES-II

EIC ERA

"We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."

- *LRP recommendation III*

PRE-BES II

- **Non-zero ΔG**
- **Evidence of Δū > Δd**
- **Evidence that large forward transverse SSA may not come from 2-2 processes!**
- **First asymmetries sensitive to transversity measured in hadronic collisions.**
- **Opportunity to measure Sivers sign change via W and direct γ production**

POST BES-II

The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.

- LRP recommendation I

EIC ERA

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

- LRP recommendation III

POST BES-II

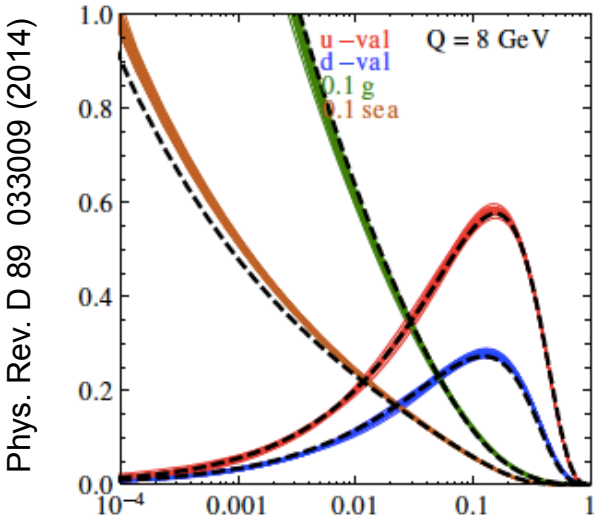
Unique opportunities for RHIC!

Current RHIC Run Plan

2021 : 20 weeks Au+Au
2022 : 10 weeks p+p
10 weeks p+A

- How does cold nuclear matter modify the parton distributions and fragmentation functions we extract from the proton?
- What role does diffraction play in the large forward pion single spin asymmetries we see at RHIC? Can we leverage RHIC's polarized proton beams to discover new gluonic states, such as the odderon, in these diffractive signals?

Nuclear Parton Distribution Functions

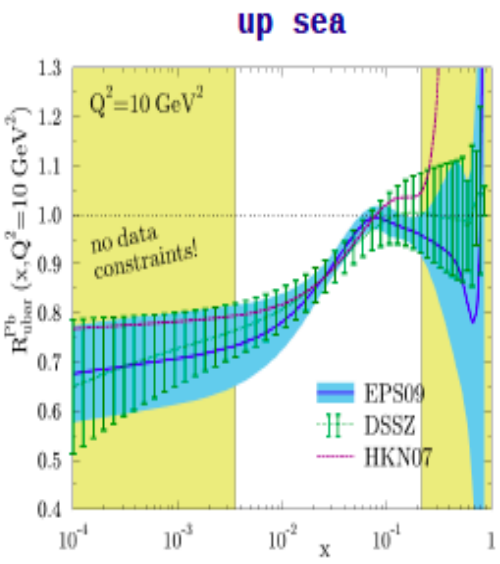


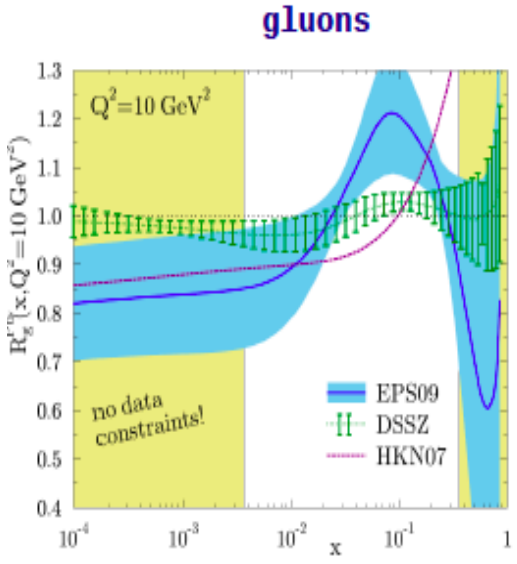
Decades of DIS data serve as input to the quark and gluon momentum distributions in proton.

Limited data indicates that these PDFs change when the proton resides inside nuclear matter.

DGLAP equations cannot predict A dependence. Saturation models predict Q^2 dependence over very limited range.

Need an **A –Scan** and large **Q^2 lever arm** for fixed x in order to reduce existing errors on nPDFs and test saturation models. **RHIC plays pivotal role in both of these areas!**





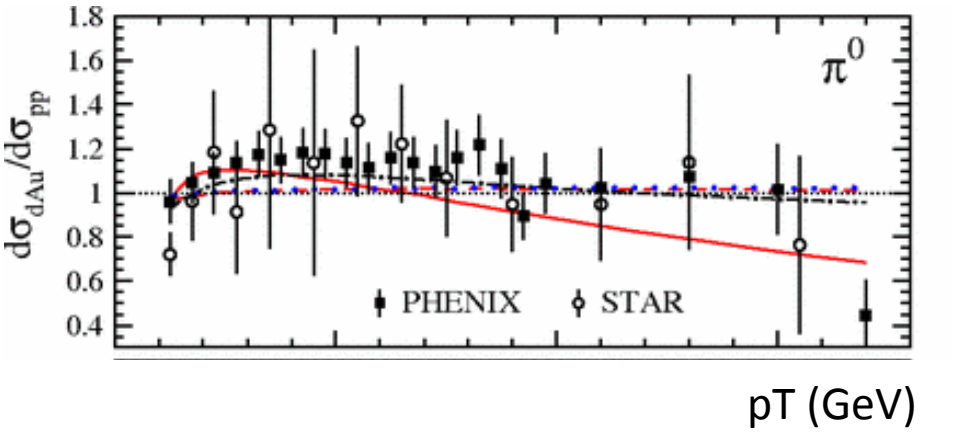
H. Paukkunen, DIS-2014

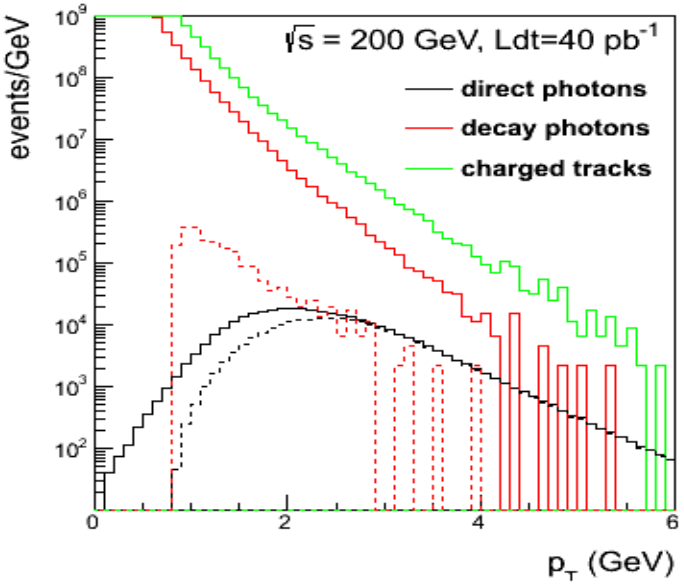
Gluon nPDFs

Access low-x gluon nPDFs with the following channels:

I. R_{pA} for inclusive π^0 and di-hadron correlations
   - Also sensitive to final state effects. Better for studying gluon saturation models.
   - Only needs forward calorimeter

Phys.Rev.D 85 074028





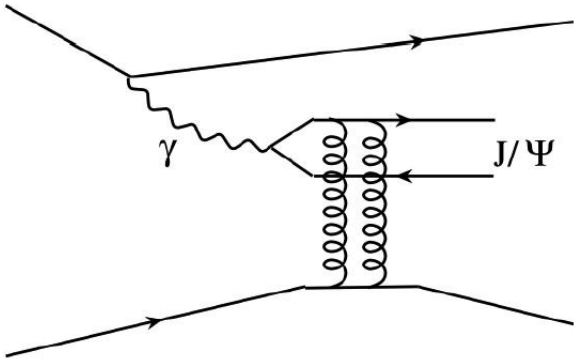
II. R_{pA} Direct photon
   - Insensitive to final state effects
   - Only needs forward calorimeter + Pre-shower

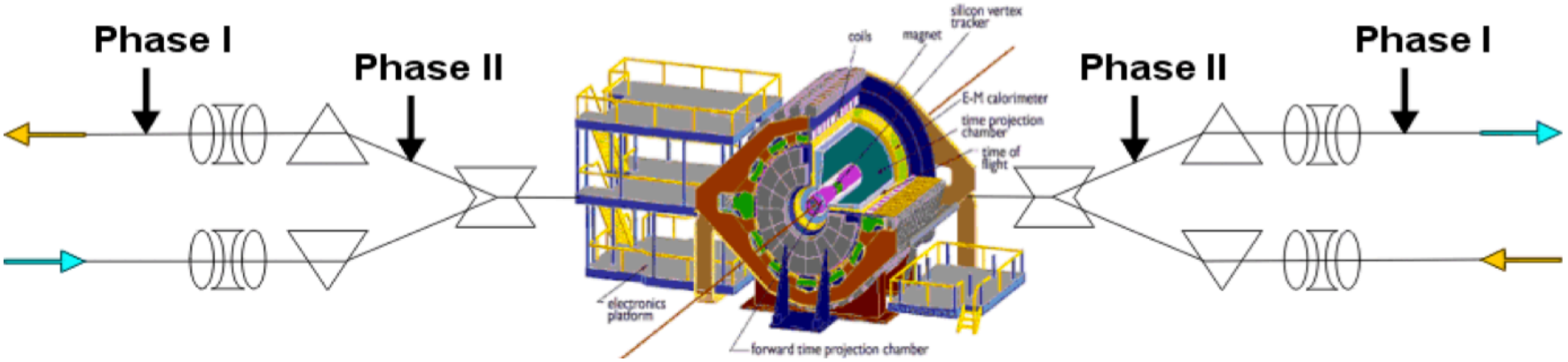
Data from 2015 p+A provides first look at all of these signals and provides future guidance for species requests in 2020+

Gluon nPDFs

III. dσ/dt for J/ψ in ultra-peripheral collisions

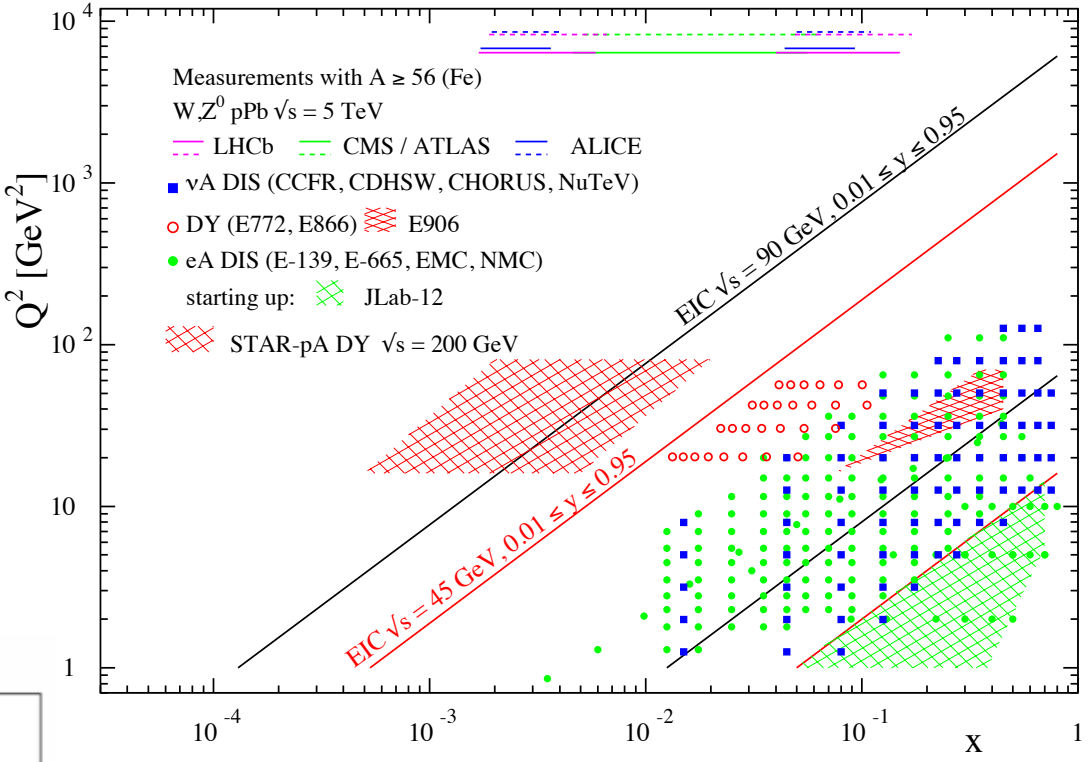
- Accesses spatial distribution $g(x,Q^2,b_T)$
- Needs mid to forward rapidity e+e- reconstruction + Roman Pots to detect two protons in final state
- Requires high lumi and expanded acceptance from final piece of RP-II upgrade

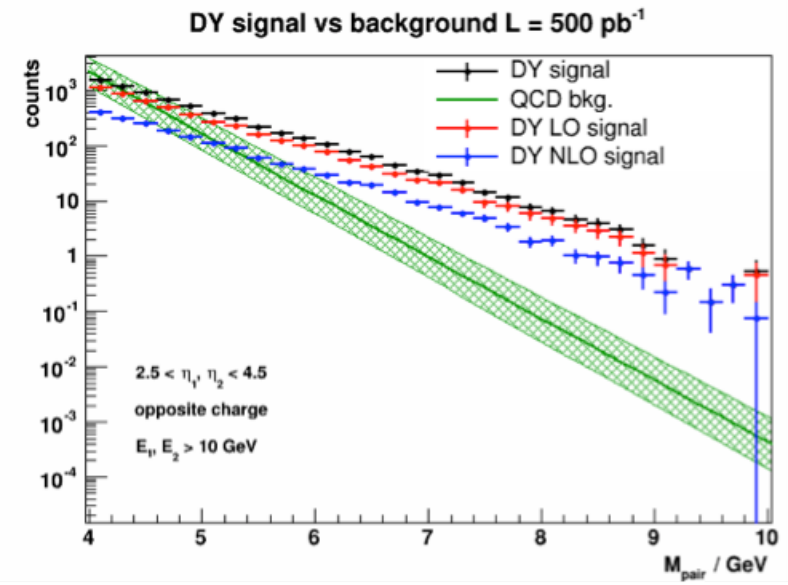




Sea quark nPDFs

- Use Drell-Yan to cleanly access initial state sea quark nuclear PDFs.
- Forward reconstruction pushes to lower x
- RHIC accesses this regime at lower Q^2 than the LHC, where effects are larger.

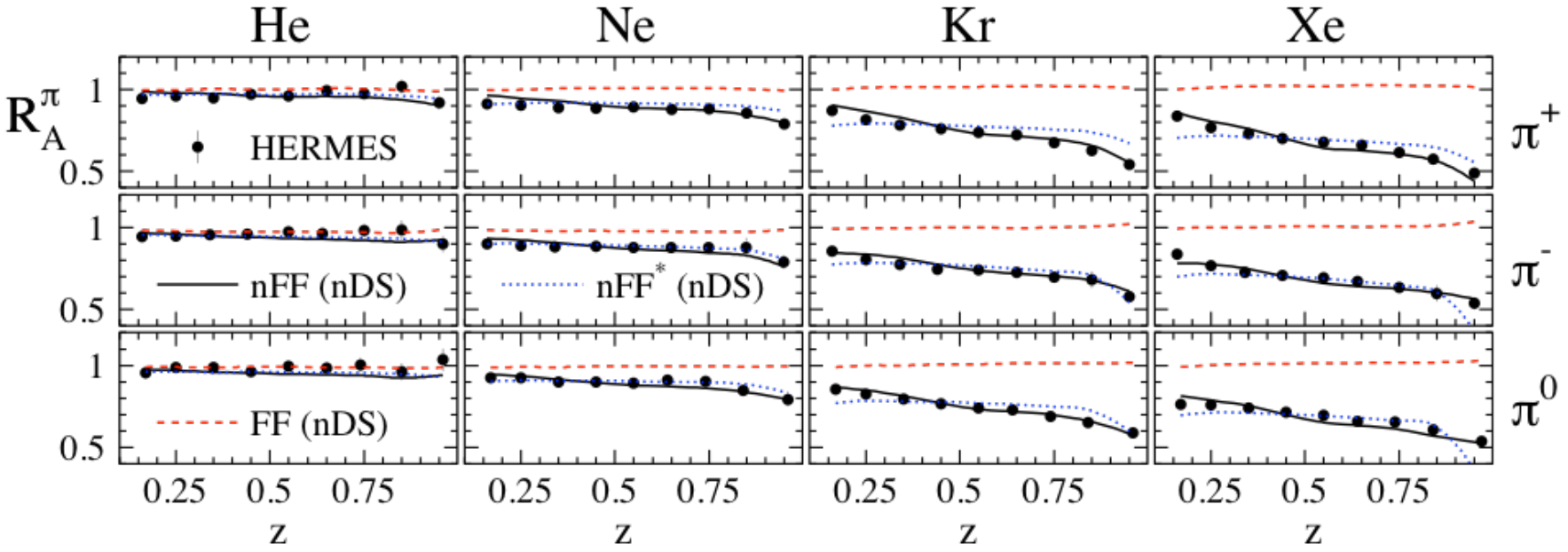




- Forward Hadron + Electromagnetic Calorimeter upgrade is required to reduce hadronic backgrounds and extract suppressed DY signal.

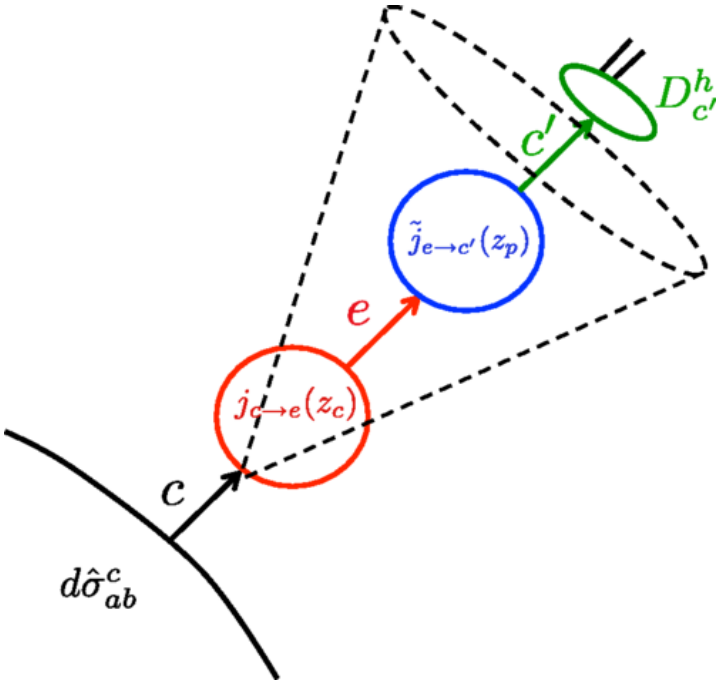
Hadronization effects in nuclear matter

Phys. Lett. B577, 37 (2003)
Phys. Lett. B684, 114 (2010)



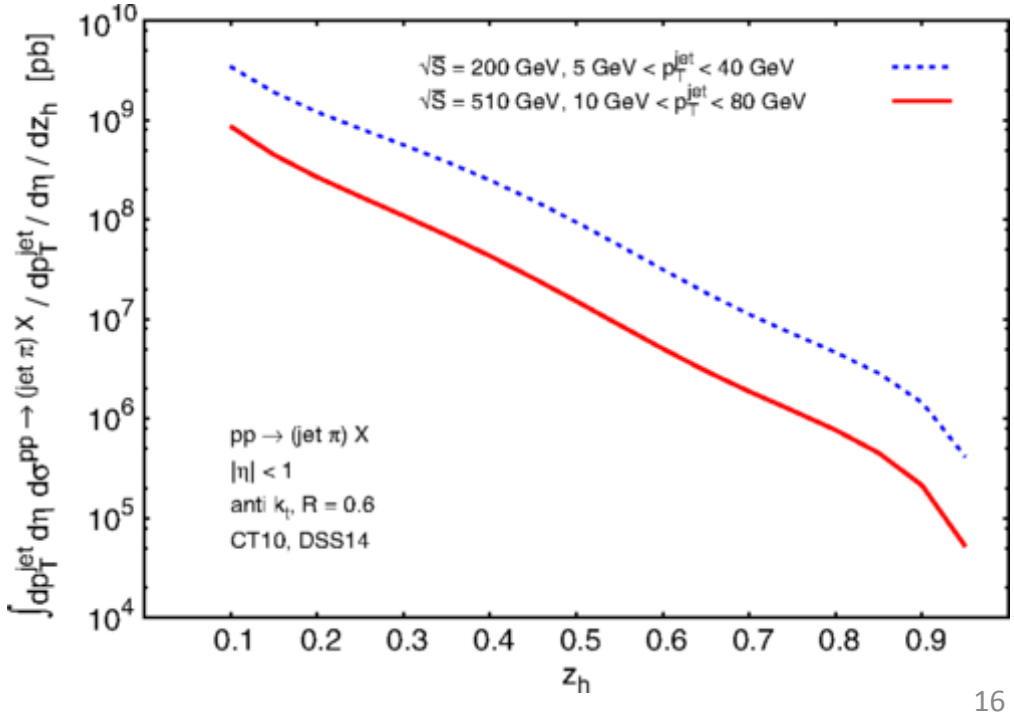
- HERMES data shows that hadron production in e+A collisions is suppressed compared to e+p collisions.
- Is this an initial state effect? A final state effect? Or both?
- Current nPDF's alone are not sufficient to explain the size of the effects.

Hadronization effects in nuclear matter



Recent work by Kaufmann, Mukherjee and Vogelsang proposes to access fragmentation functions (FF) by taking the ratio of jets yields with identified hadrons to inclusive jet yields. Technique is already being pursued at the LHC.

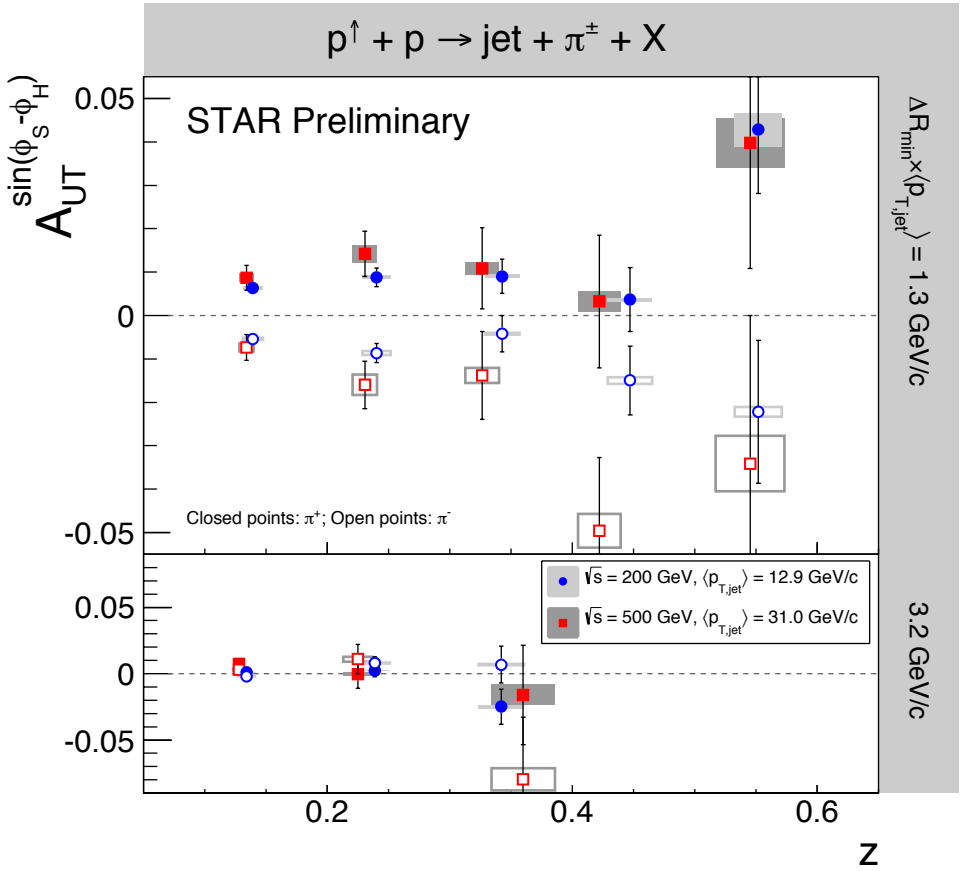
These techniques can be exploited to study how these fragmentation functions change with inside nuclear matter.



Phys.Rev.D 92 5, 054015

Polarized FF effects in nuclear matter

- STAR has demonstrated the ability to study hadron distributions within jets.
- STAR sees significant spin asymmetries associated with the azimuthal distribution of pions inside of jets.
- This expertise can be used to study both unpolarized and spin dependent effects in cold nuclear matter.

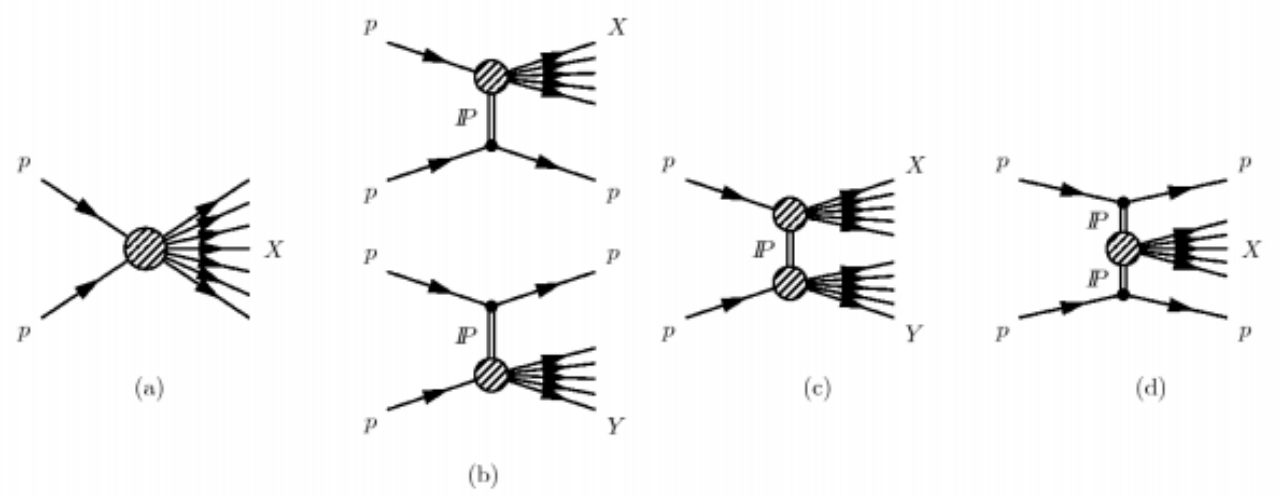


The study of spin dependent polarized FF is UNIQUE to RHIC. 2015 p+Au data will provide a first look and provide guidance for species in 2020+.

Spin Effects in Diffractive Physics

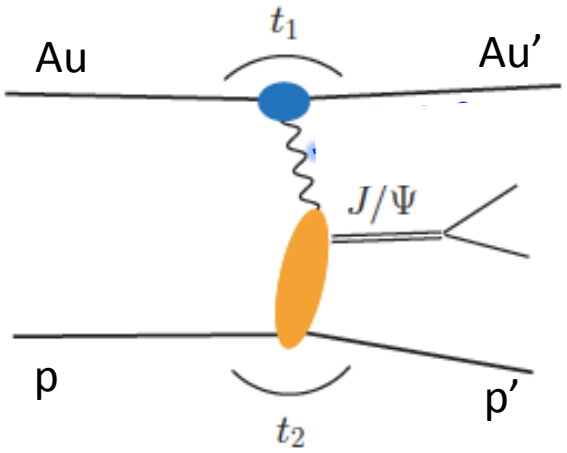
- Diffraction is defined as an interaction that is mediated by the exchange of the quantum numbers of the vacuum.

- Originally developed in Regge Theory, in QCD these exchanges are interpreted as two (Pomeron) or three (Odderon) gluon states.



- Experimentally characterized by the detection of very forward scattered protons plus one or two jets separated by a large rapidity gap.

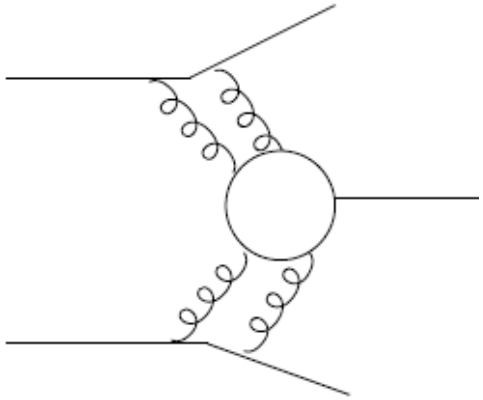
Spin Effects in Diffractive Physics in 2020+



$$A_{UT}(\tau,t) \sim \frac{\sqrt{t_0 - t}}{m_p} \frac{\mathrm{Im}(E * H)}{|H|} \qquad t = \frac{M_{J/\Psi}^2}{s}$$

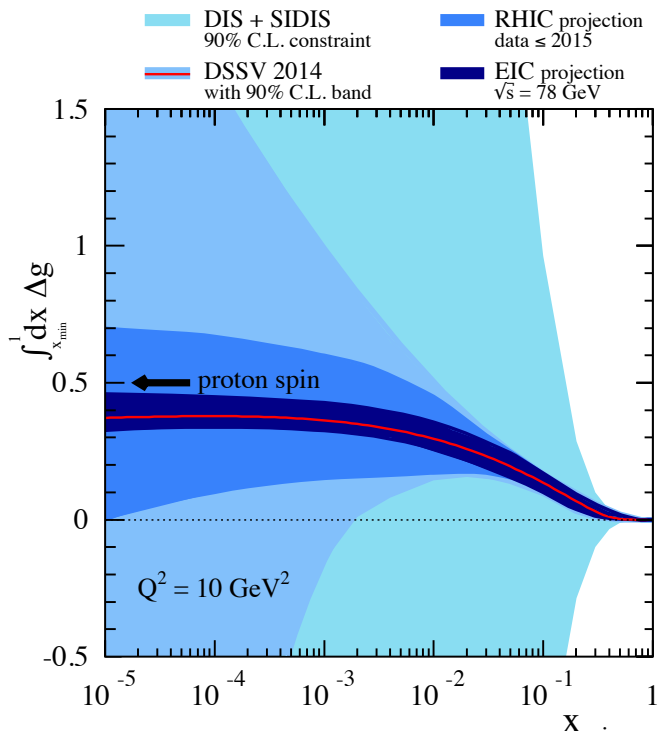
- As with unpolarized case, can utilize J/ψ production in ultra-peripheral polarized p+p collisions to access gluon helicity flip Generalized Parton Distribution (GPD) E_g.
- GPD E encapsulates gluon orbital angular momentum contributions

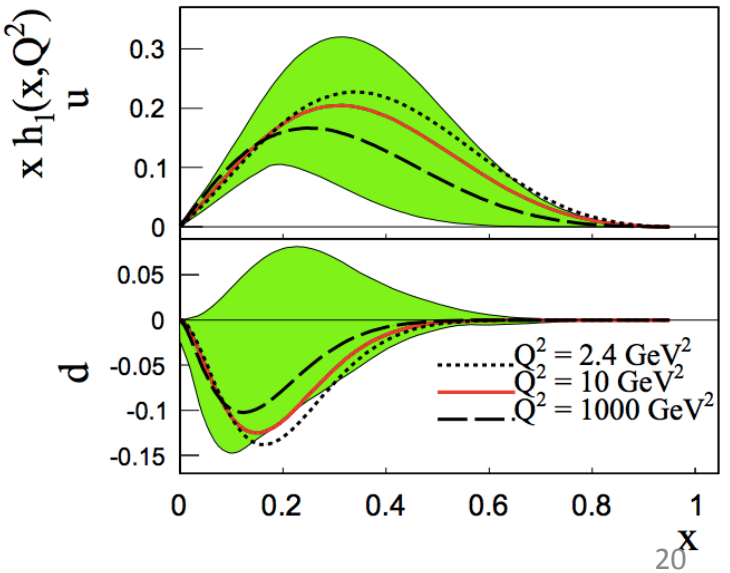
Data taken in 2015 will allow STAR to investigate possible contributions from diffractive physics to the unexplained large neutral pion single spin asymmetries in the forward direction. Depending on the size of the contribution, may open new window to study spin dependence of pomeron and possibly discover the odderon.



IF the opportunity for additional √s=500 GeV running should arise…

- ΔG needs constraints for $x < 2 \times 10^{-2}$
- Access low-x gluons (down to 10^{-3}) in the forward region in 500 GeV p+p collisions
- Dijets and photon+jet provide ability to "select" desired x region
- Same region provides access to high x (up to x = 0.6) quark transversity distributions.
- Requires hadronic and EM calorimetry upgrade as well as tracking to associate jet with correct vertex

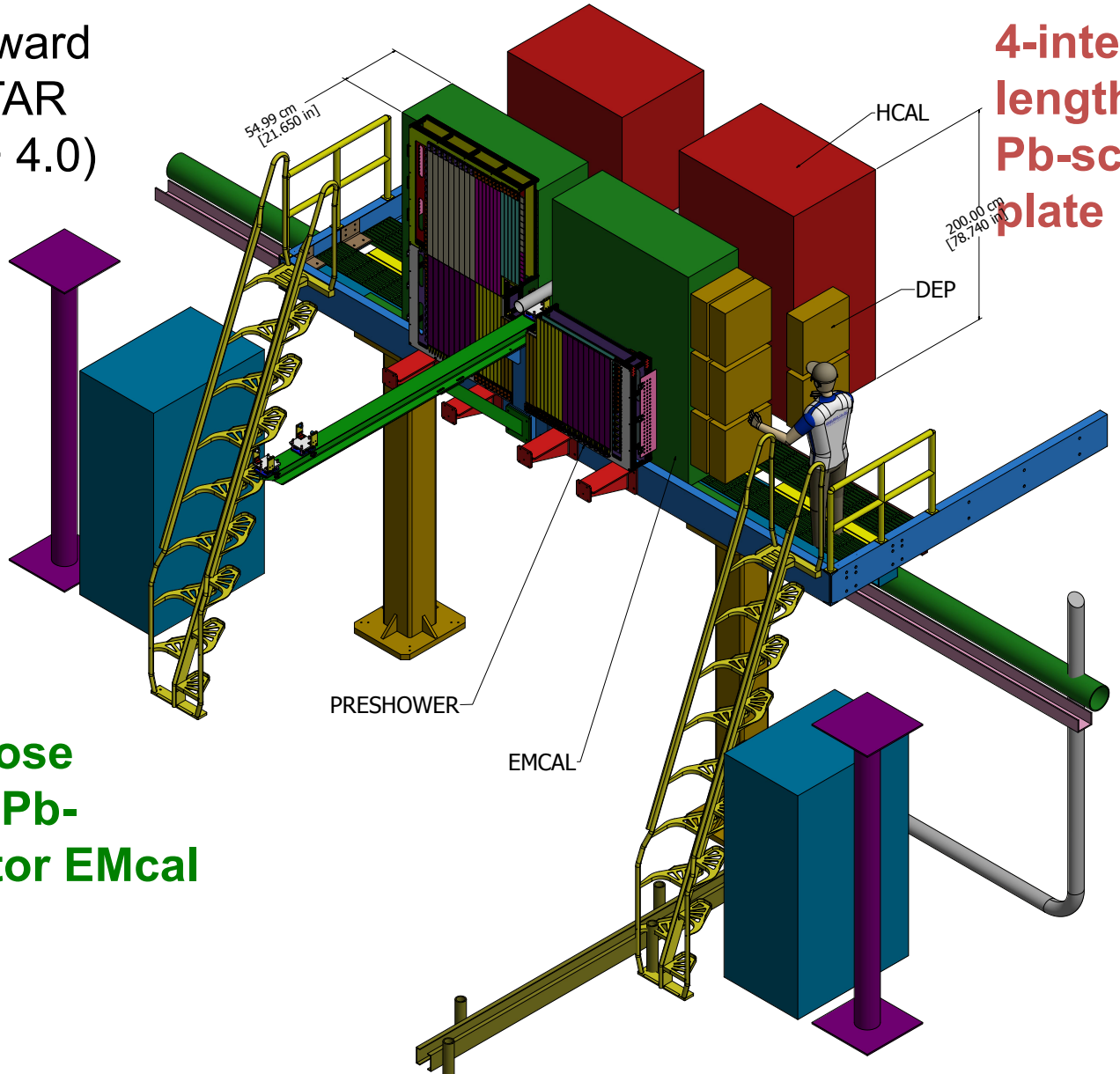




arXiv: 1505.05589

Forward Calorimeter System Upgrade

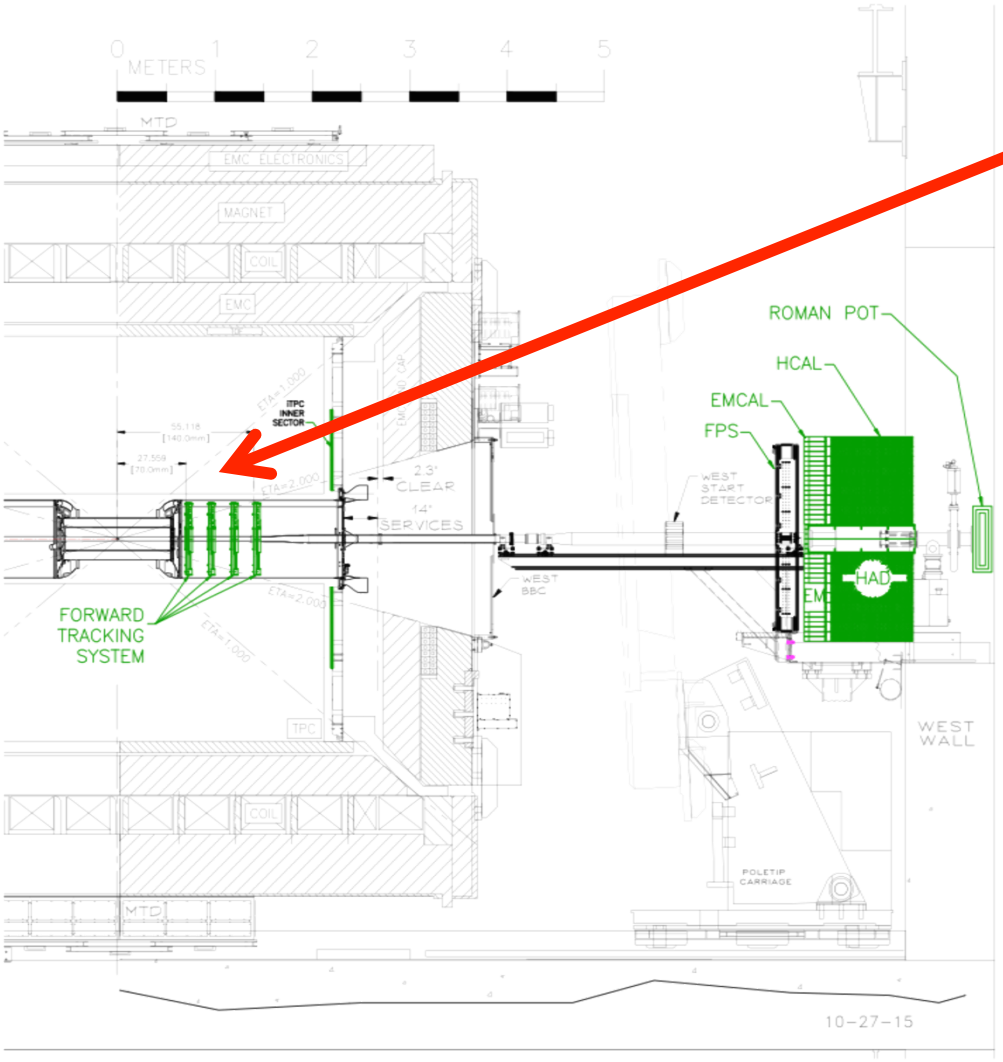
Install in forward region at STAR (2.3 > eta > 4.0)



4-interaction length thick Pb-scintillator plate HCAL

Re-purpose PHENIX Pb-scintillator EMcal

Forward Tracking System Upgrade



- Four planes of silicon strip detectors comprised of 12 wedges each.
- Designed to provide charge-sign discrimination
- Provide z vertex determination to separate particles from different interactions within the same bunch crossing

Spin and Cold QCD Outlook

- The post BES-II period is a critical time for RHIC.
- This period provides the opportunity to make a suite of unique measurements that can only be done with a (polarized) p+p, p+A collider at center of mass energies below 500 GeV.
- These measurements will explore these questions:
  - How do low and high x PDFs change in cold nuclear matter?
  - How does cold nuclear matter modify polarized and unpolarized FF?
  - How much do diffractive effects contribute to the forward pion single spin asymmetries? Can we use these spin effects to discover new states such as the odderon?

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0640