Plans and Prospects for STAR and eSTAR

Oleg Eyser

for the STAR Collaboration

RHIC & AGS Users' Meeting 2014

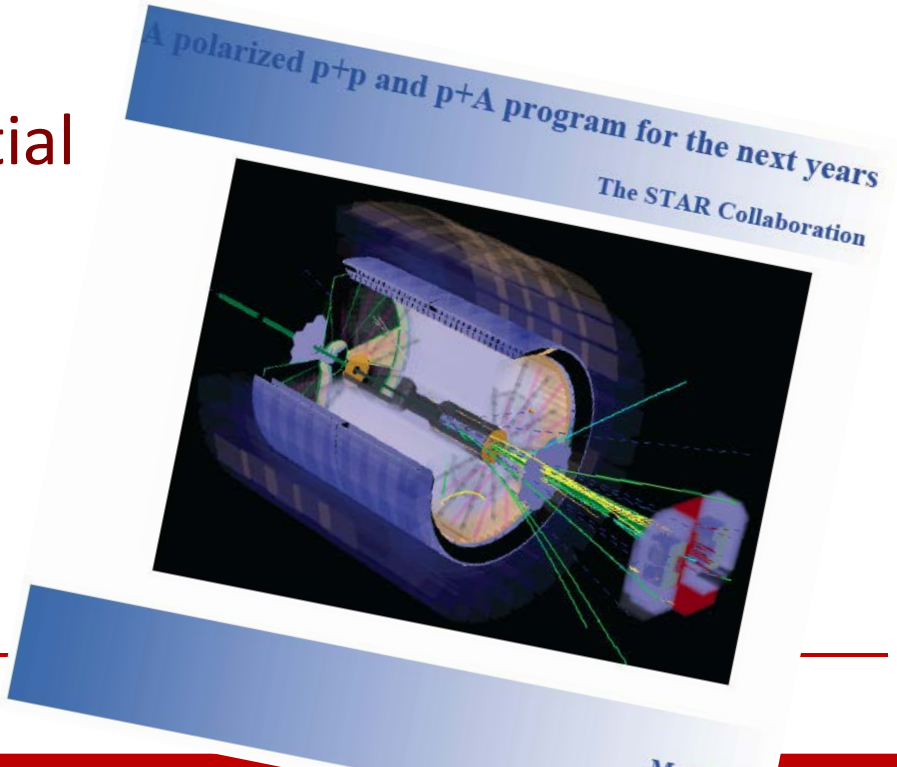
BNL

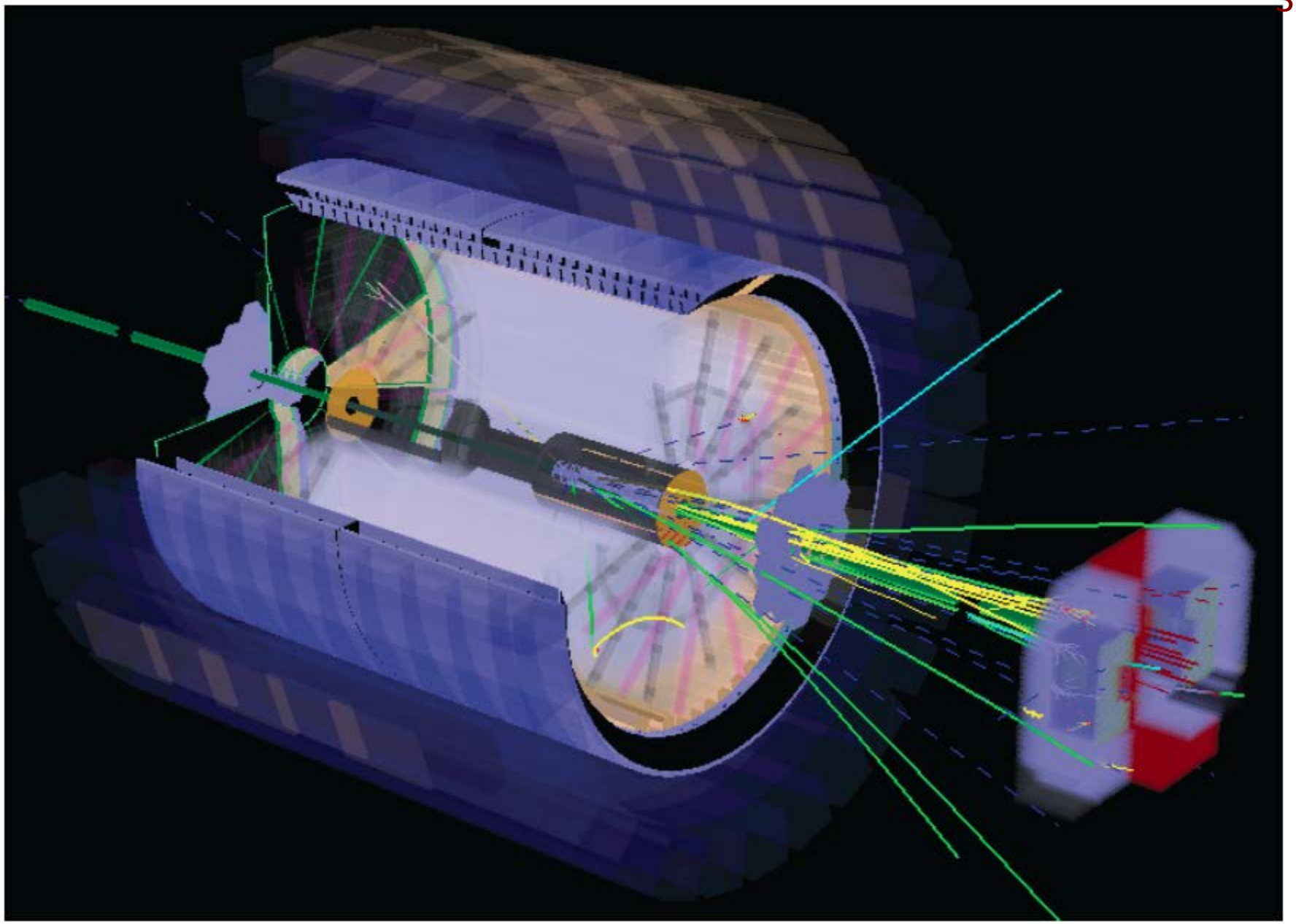
BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Looking Forward

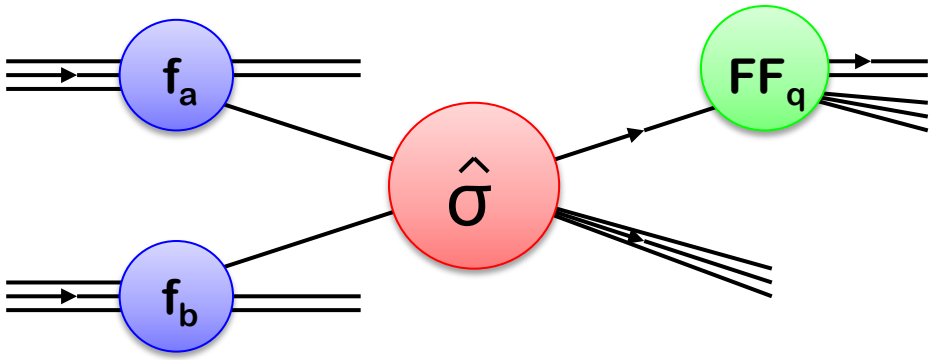
- What is the nature of the spin of the proton?
- How do quarks and gluons hadronize into final state particles?
- How can we describe the multidimensional landscape of nucleons and nuclei?
- What is the nature of the initial state in nuclear collisions?



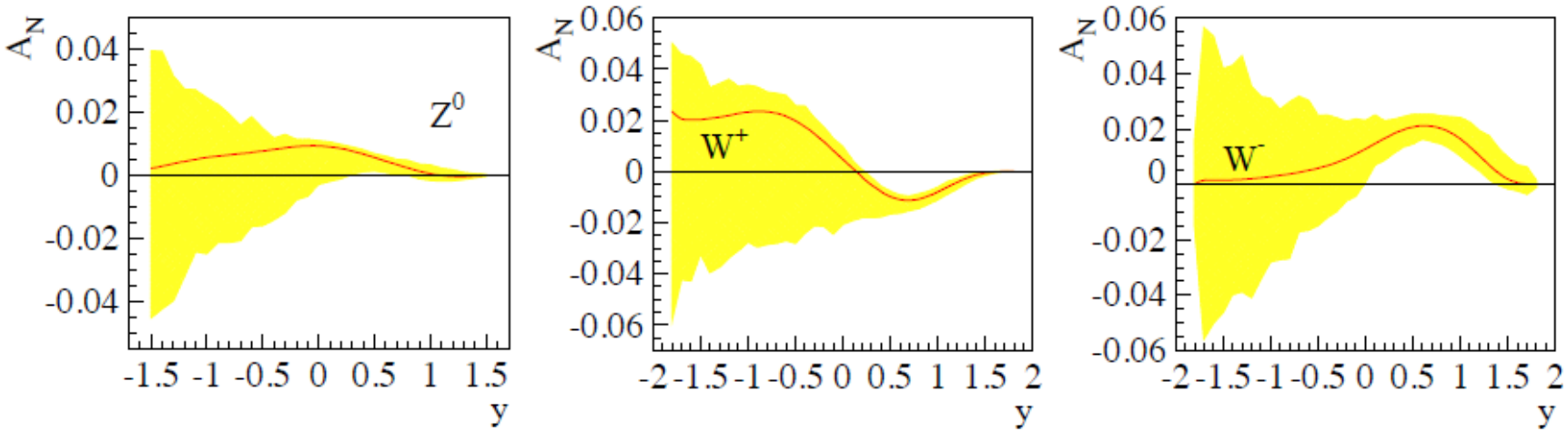


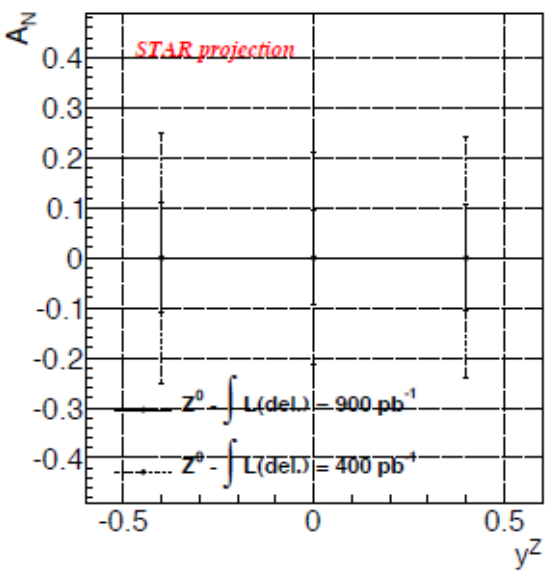
Confined Partons in the Nucleon

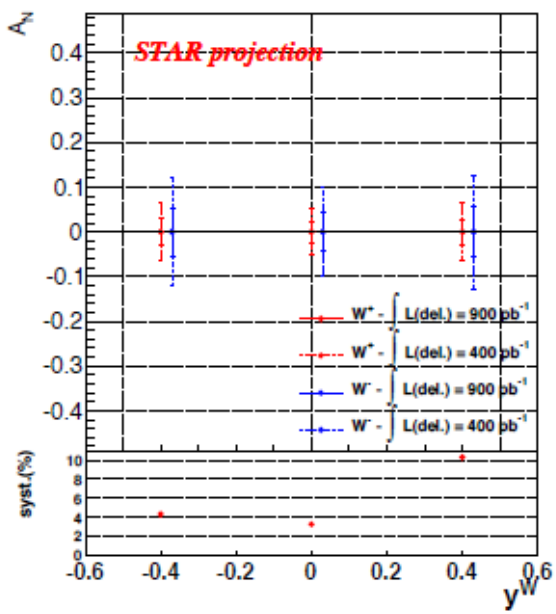
- Do the large transverse single spin asymmetries survive at high center-of-mass energies?
- Can the sub-process responsible for A_N be uniquely identified?
- Is the observed p_T-dependence of A_N consistent with theory expectations in pQCD?
- Can the TMD evolution, which is different from the well-known DGLAP evolution, be seen in the RHIC data?



Transverse Spin with $W^{\pm}, Z^0$ Bosons





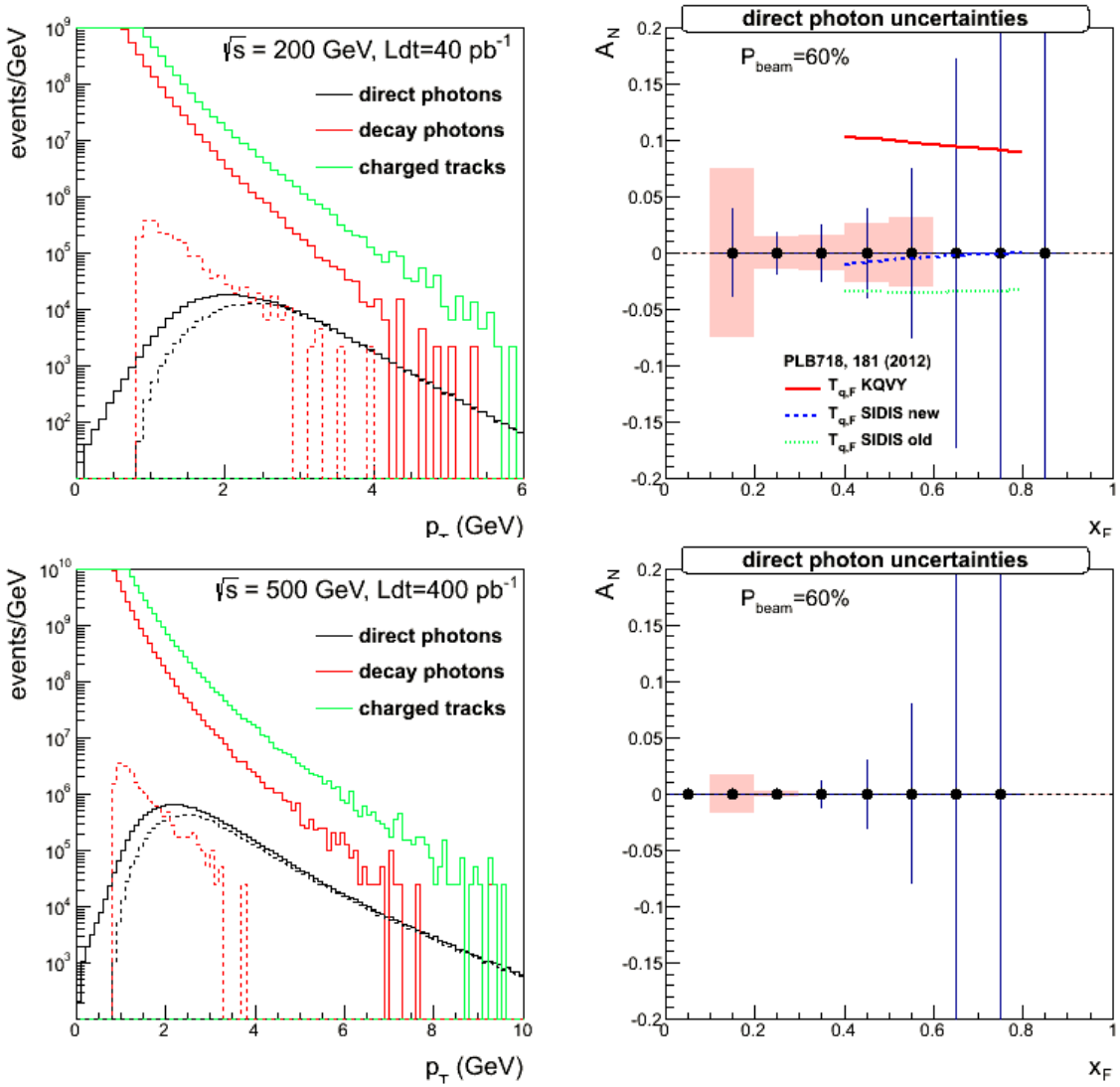


<u>Similar to Drell-Yan γ^*</u>

test the sign change of Sivers TMD in the $p^{\uparrow} + p$ initial state

Forward Direct Photons

- FMS and new preshower
- $2.5 < \eta < 4.0$
- Photon background $A_N(\pi^0, \eta) \approx \max(A_N(\pi^0))$
- No fragmentation: relates to sign-change in twist-3 framework
- At 500 GeV: compare Drell-Yan, γ_{dir}, and π^0 at same x_F



Jets & Correlations

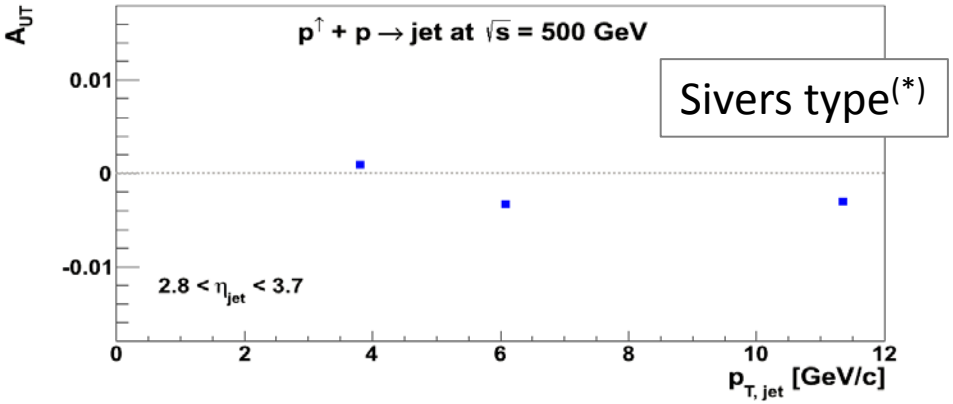
$\sqrt{s} = 500$ GeV

$2.8 < \eta < 3.7$

$p_T > 3$ GeV/c

$\mathcal{L}_{int} = 1$ fb^{-1}

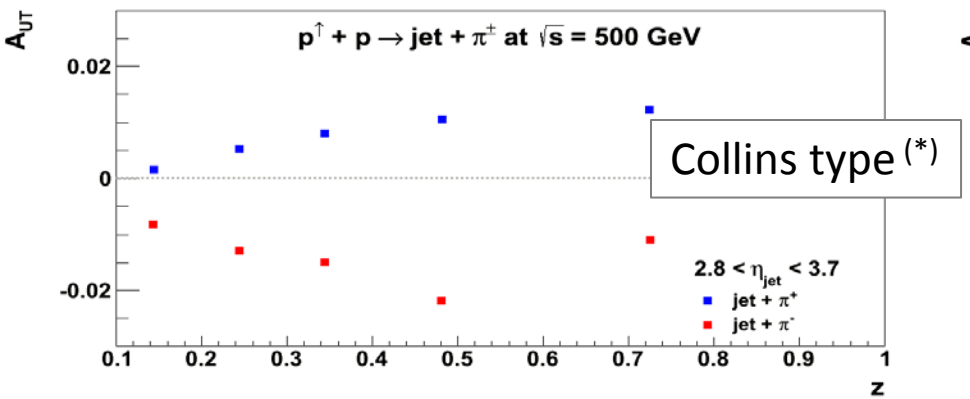
$P = 60\%$

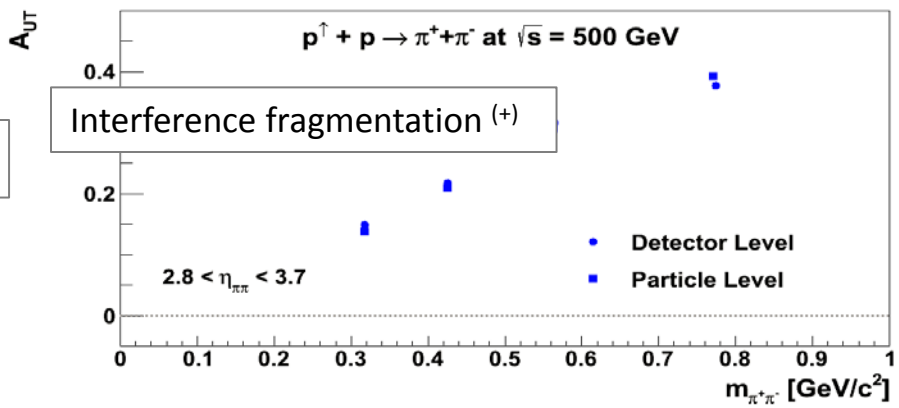


Disentangle initial and final state effects

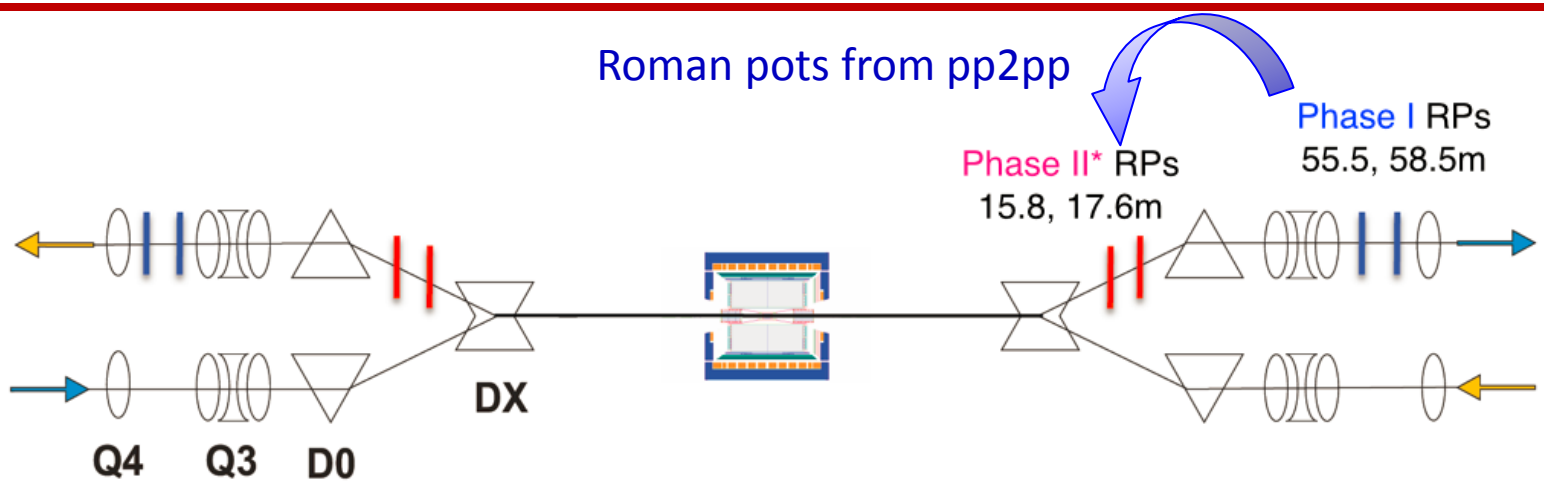
- $\Lambda_{QCD} < p_T \ll Q^2$ (or j_T)
- IFF needs input from e^+e^- (BELLE)

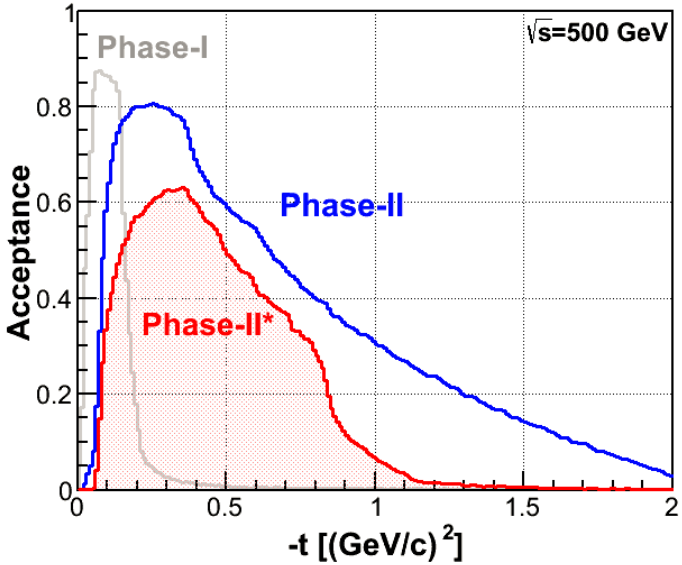
(*) based on parametrization from Alsemino et al.
(+) base don arbitrary parametrization linear in m, x, and z

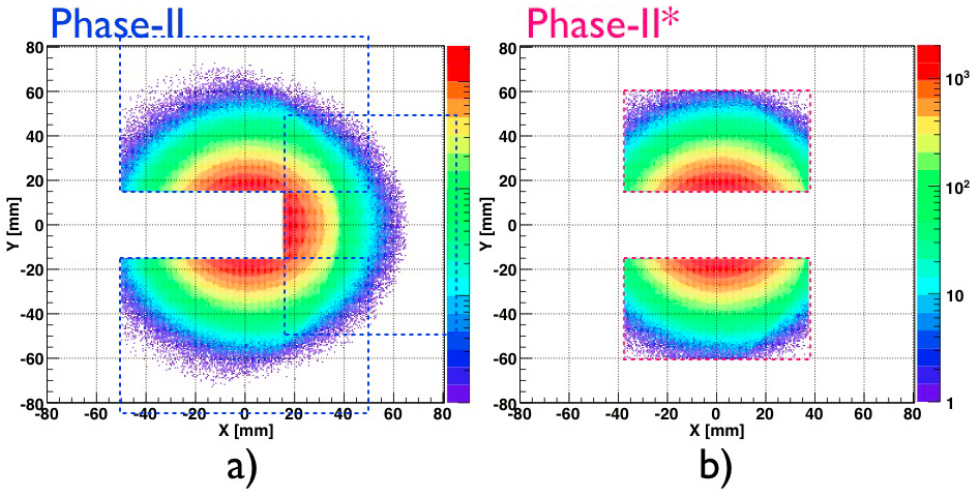




Tagging Forward Protons





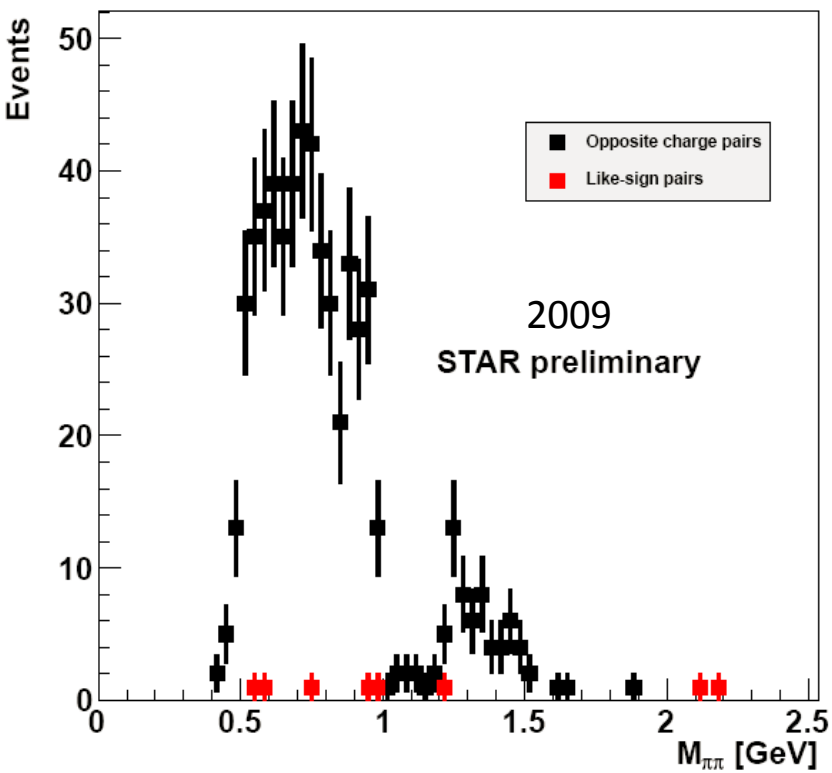


Exclusive Measurements

$$p + p \rightarrow p + M_X(\pi^+\pi^-) + p$$

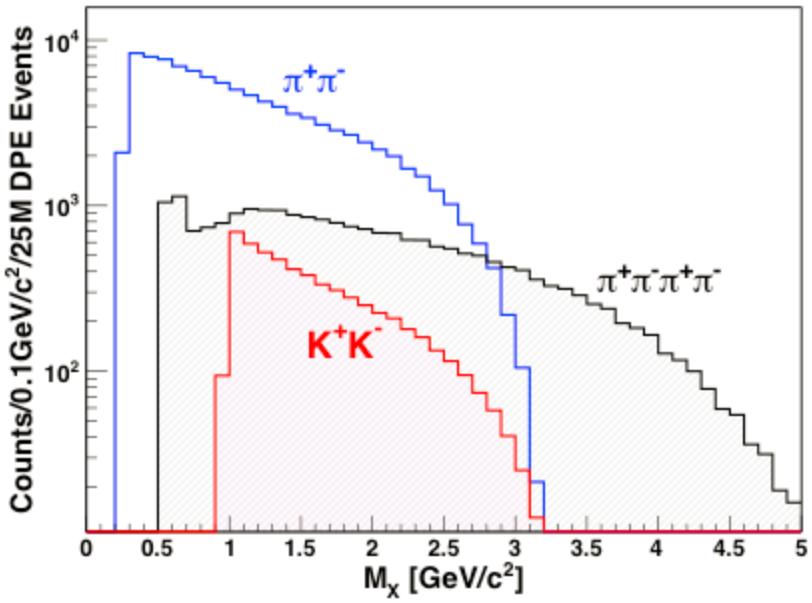
$$\sqrt{s} = 200 \text{ GeV}$$

$$\mathcal{L}_{int} = 40 \text{ pb}^{-1}$$

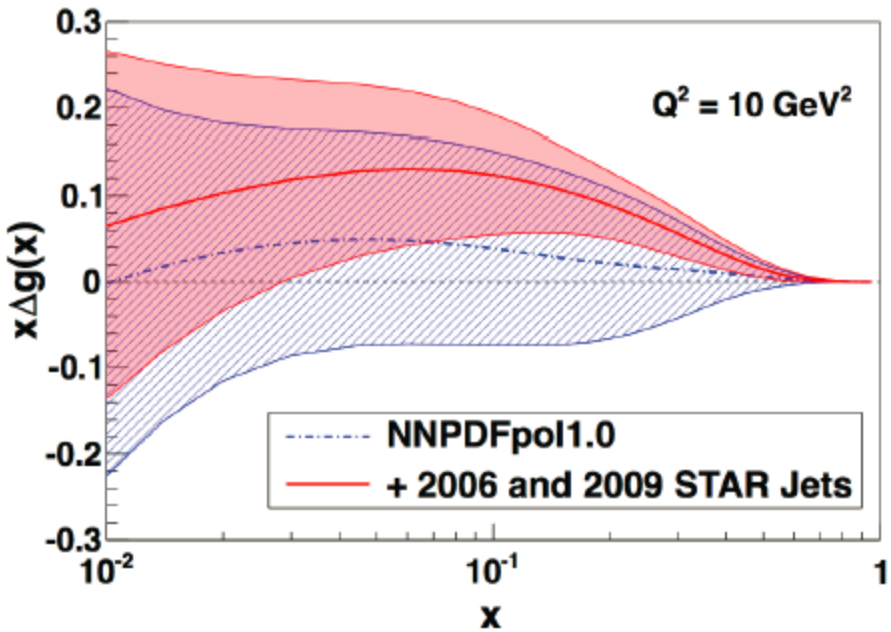


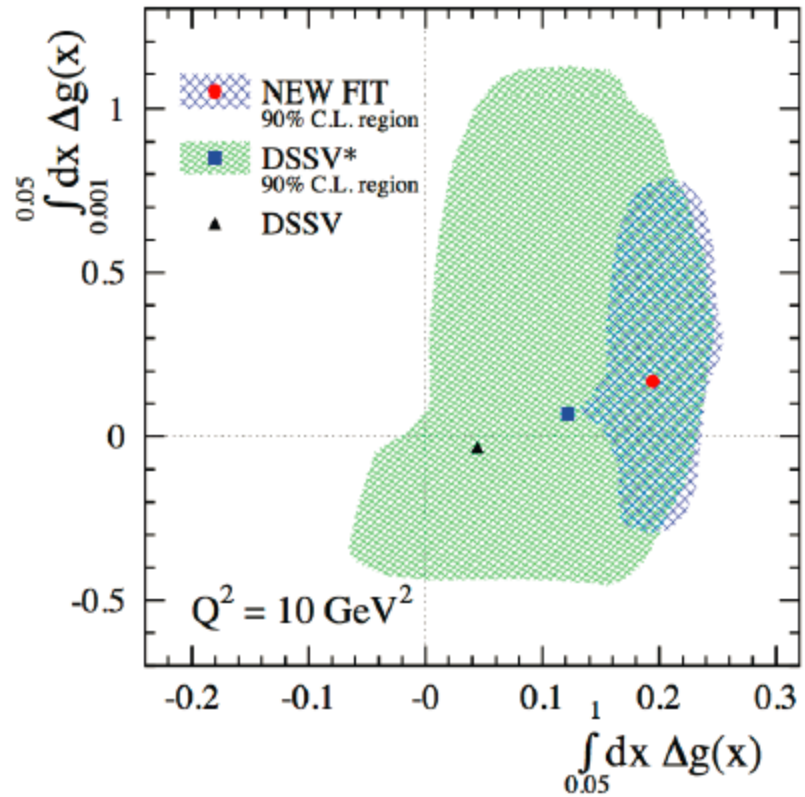
Phase Space @ $\sqrt{s} = 500$ GeV

with full RP-II



Gluon Polarization





Inclusion of STAR jet data from 2006 and 2009 help decrease uncertainties
More data on tape already
Need to reach lower x for further improvement

Di-Jet Kinematics from QCD 2 → 2

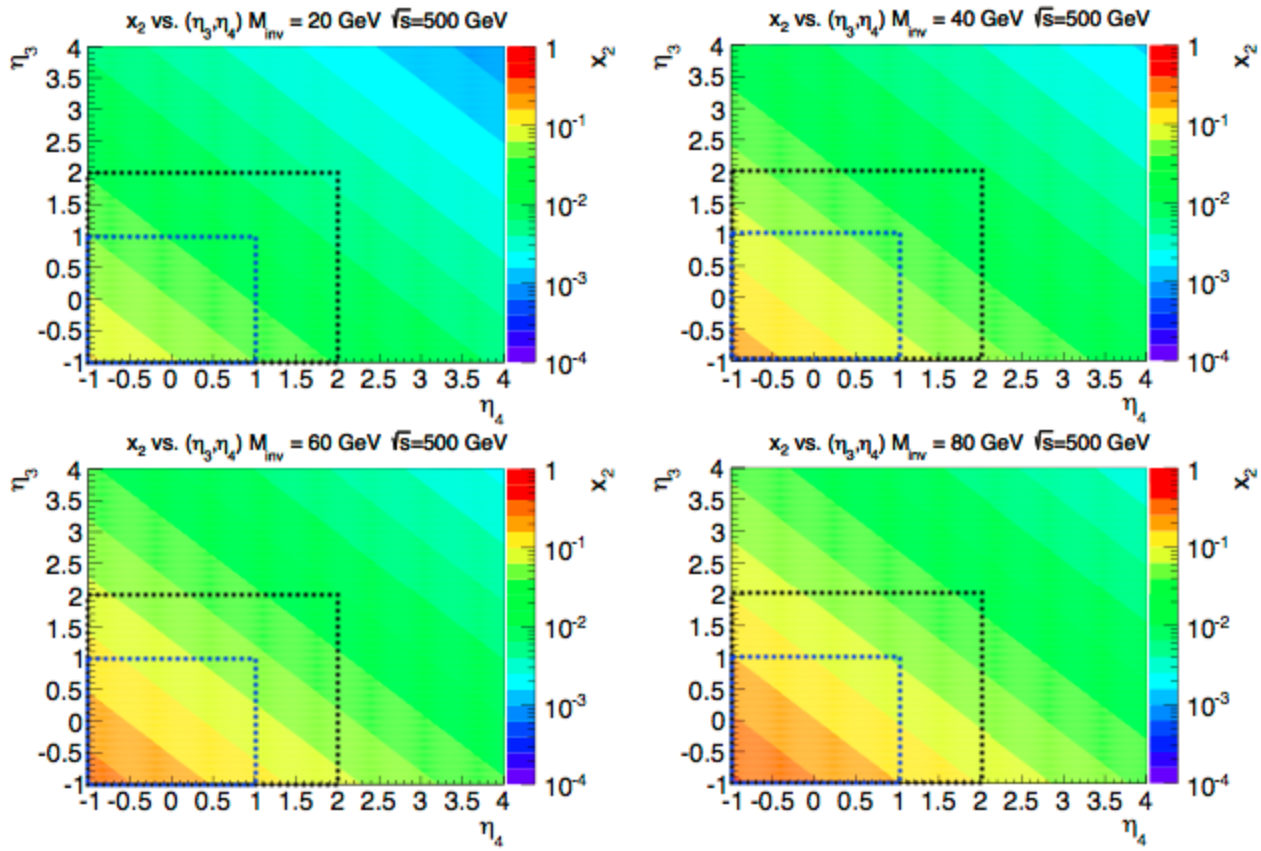
x_2

Recorded data

Published data

$$M^2 = s \cdot x_1 \cdot x_2$$

$$\eta_3 + \eta_4 = \ln \frac{x_1}{x_2}$$



Di-Jets with additional FCS

$\sqrt{s} = 500$ GeV

$-1 < \eta < 2$

$2.8 < \eta < 3.7$

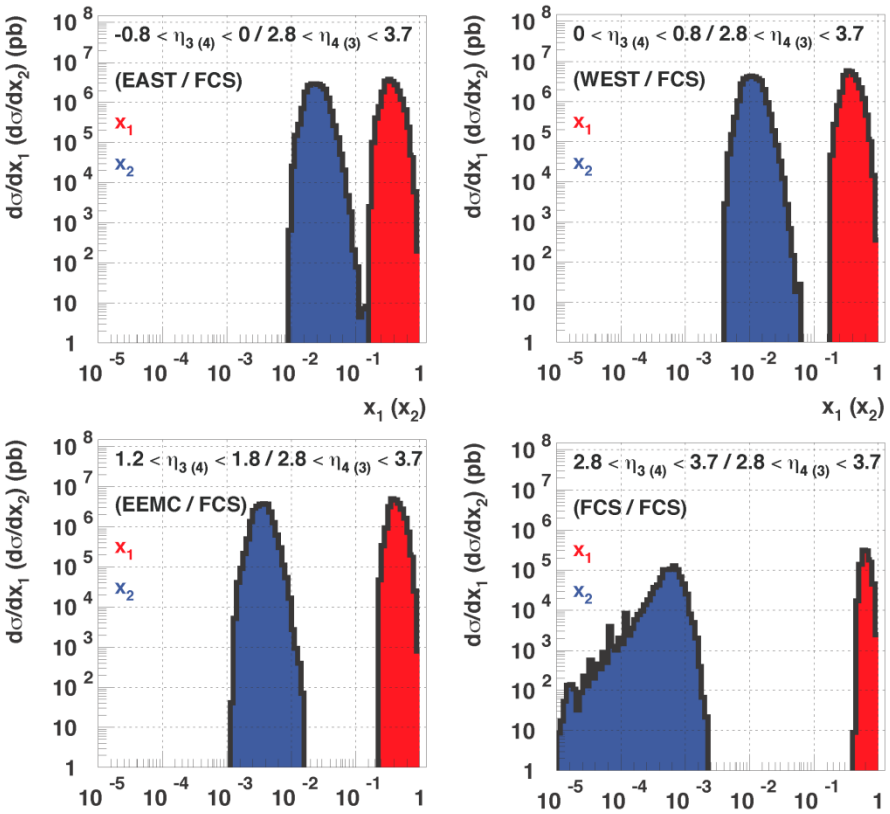
$R_{cone} = 0.7$

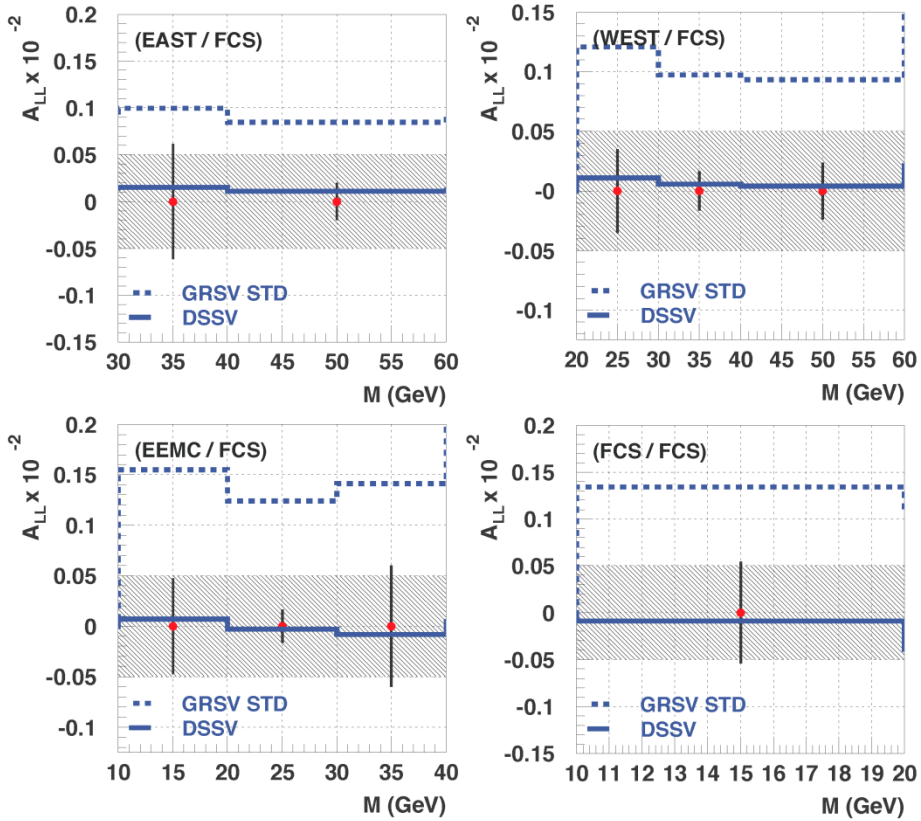
$E_{T3} > 5$ GeV

$E_{T4} > 8$ GeV

$\mathcal{L}_{int} = 1\ \mathrm{fb}^{-1}$

$P = 60\%$

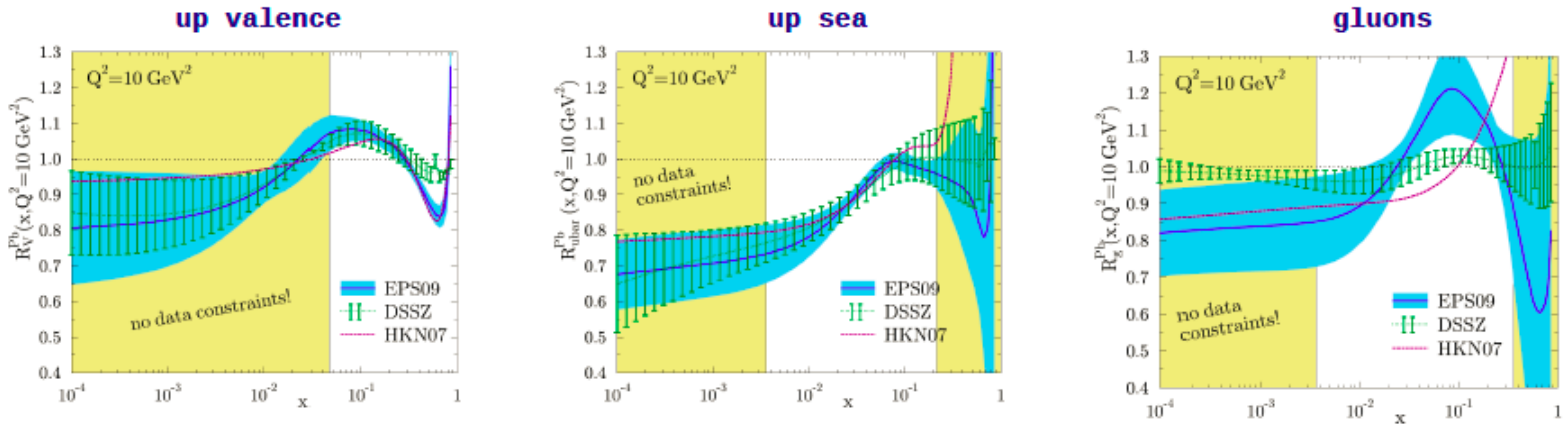


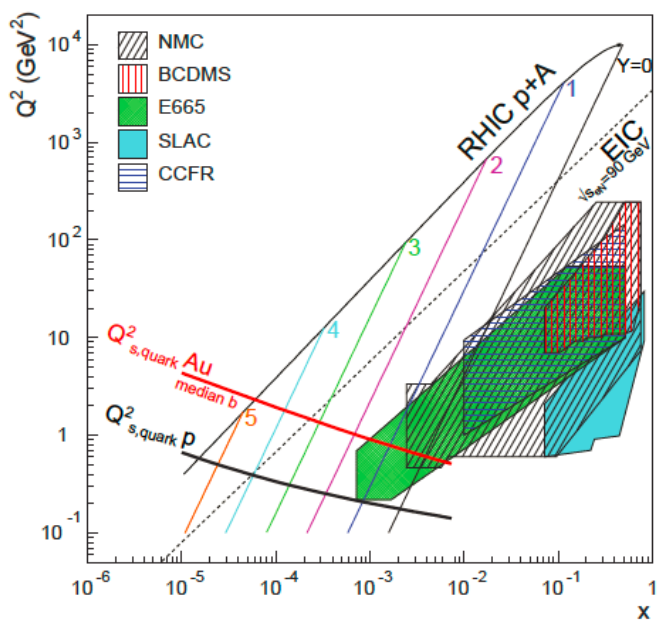


Cold Nuclear Matter

- What are the dynamics of partons at very small and very large momentum fraction (x) in nuclei, and at high gluon-density. What are the nonlinear evolution effects (i.e. saturation)?
- What are the pQCD mechanisms that cause energy loss of partons in cold nuclear matter, and is this intimately related to transverse momentum broadening?
- What are the detailed hadronization mechanisms and time scales and how are they modified in the nuclear environment?

Low-x and High Gluon Densities





- Golden Channel for saturation: di-hadron correlations
- Combination of initial and final state strong interactions in $d + A$ and $p + A$
- Remove strong interaction from the final state
- Other observables

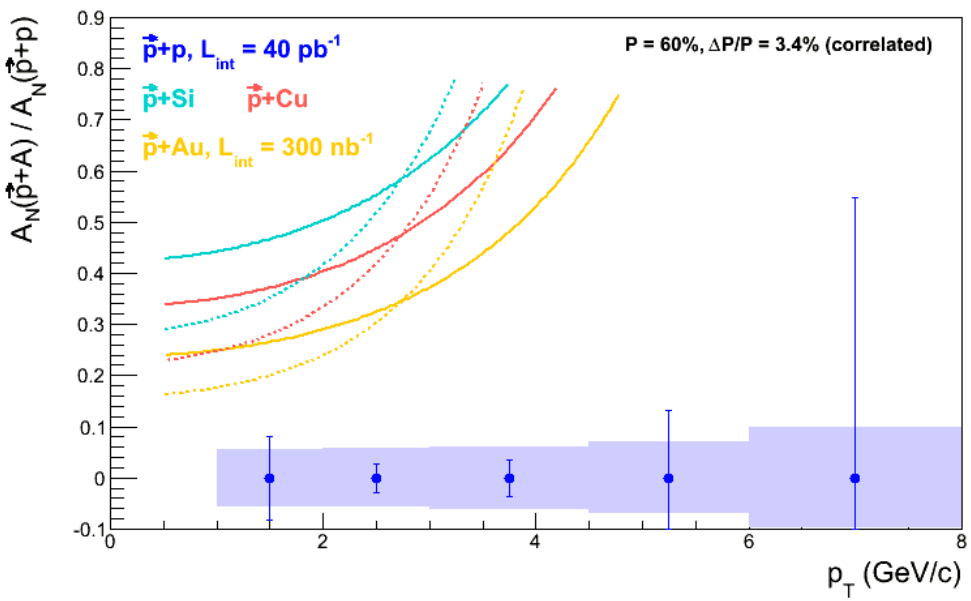
Saturation Signatures

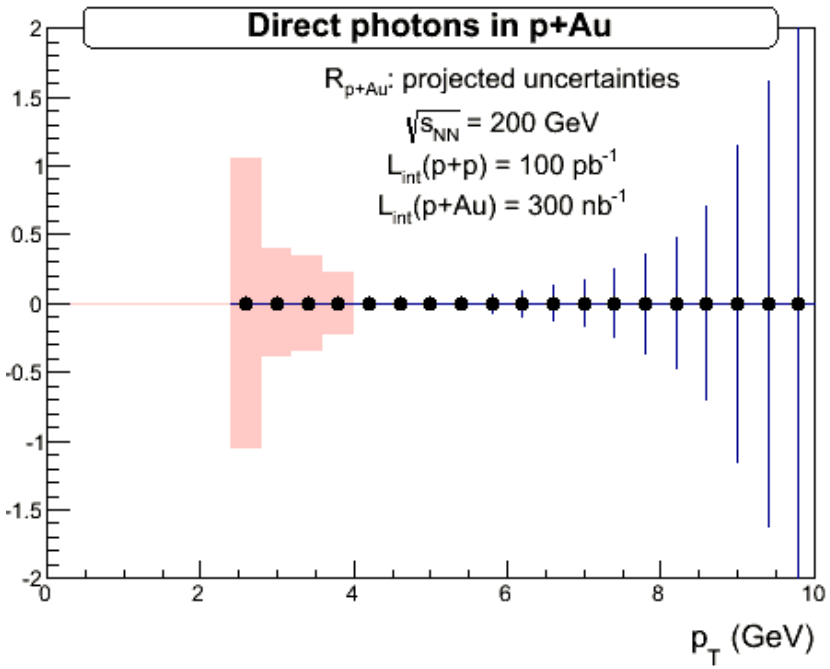
Transverse single-spin asymmetries:

- Very sizable amplitude in $\vec{p} + p \rightarrow \pi^0$
- Expected to be suppressed in $\vec{p} + A$
- Onset of saturation for different ion species

Suppression of direct photons:

- Unpolarized
- Background at low p_T
- Needs quantitative theory comparison



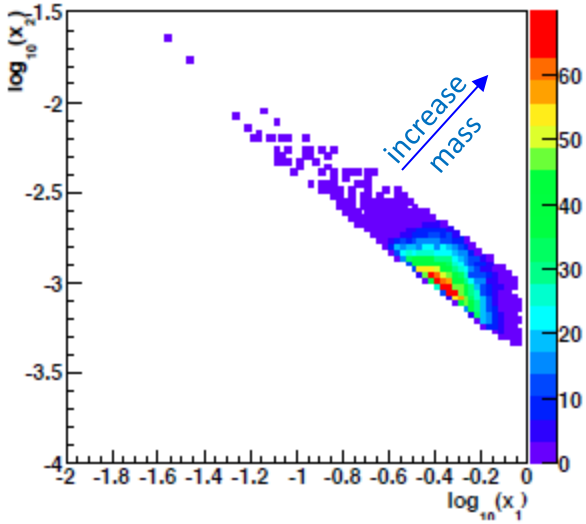


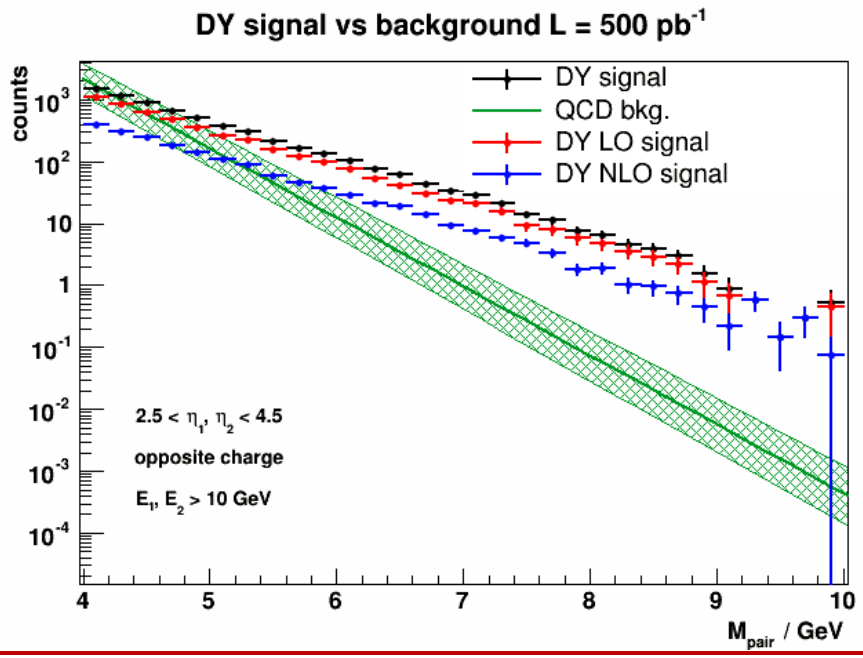
Drell-Yan Measurement

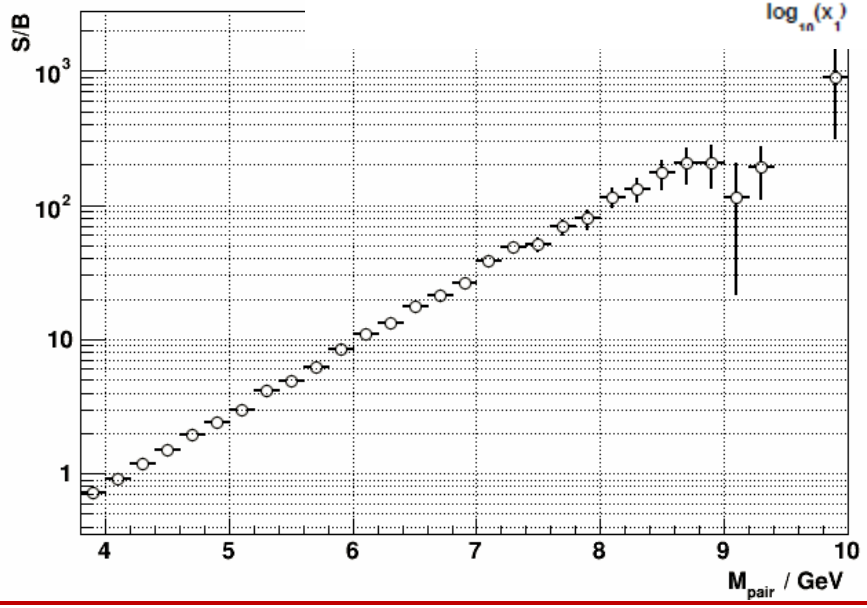
- Well defined kinematics
- No fragmentation
- Small cross section
- Needs very good background suppression

$2.5 < \eta < 4.0$

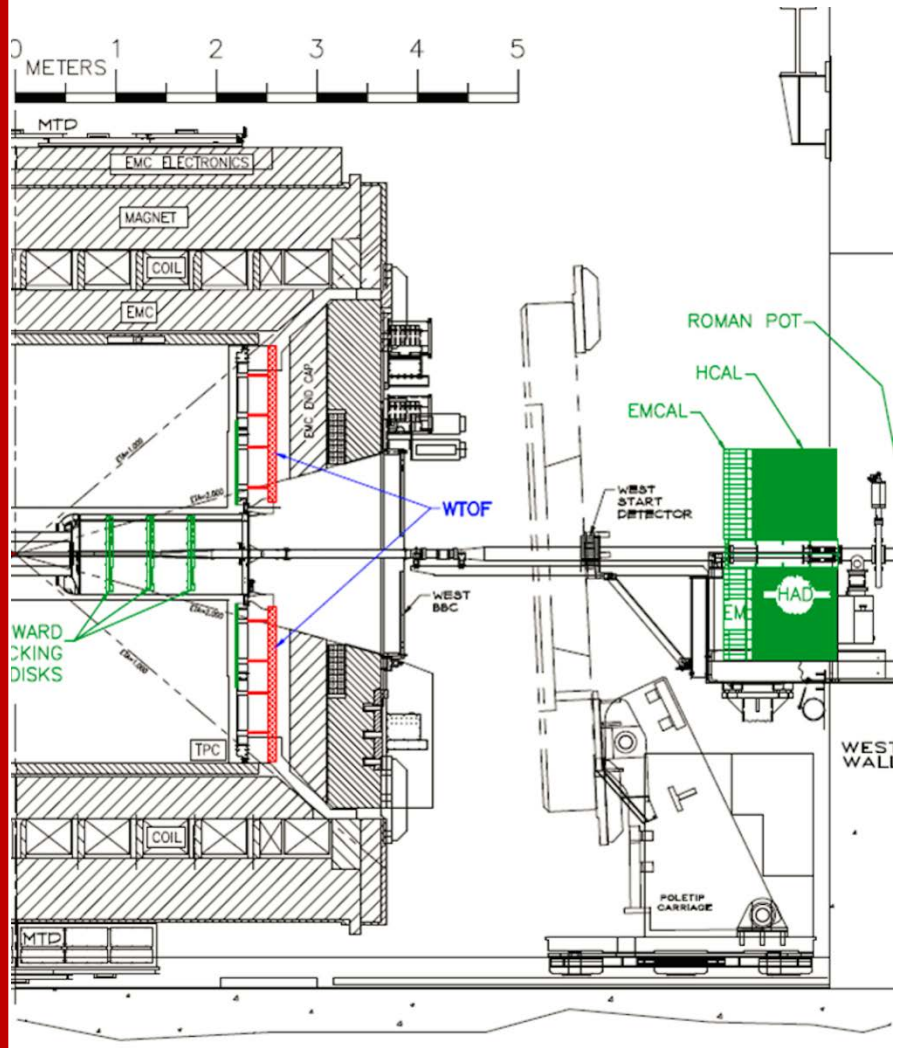
$4.0 < m_{DY} < 6.0\ \mathrm{GeV}/c^2$



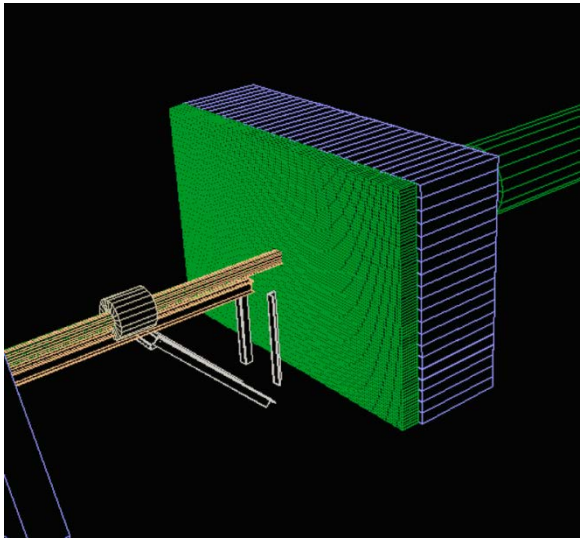


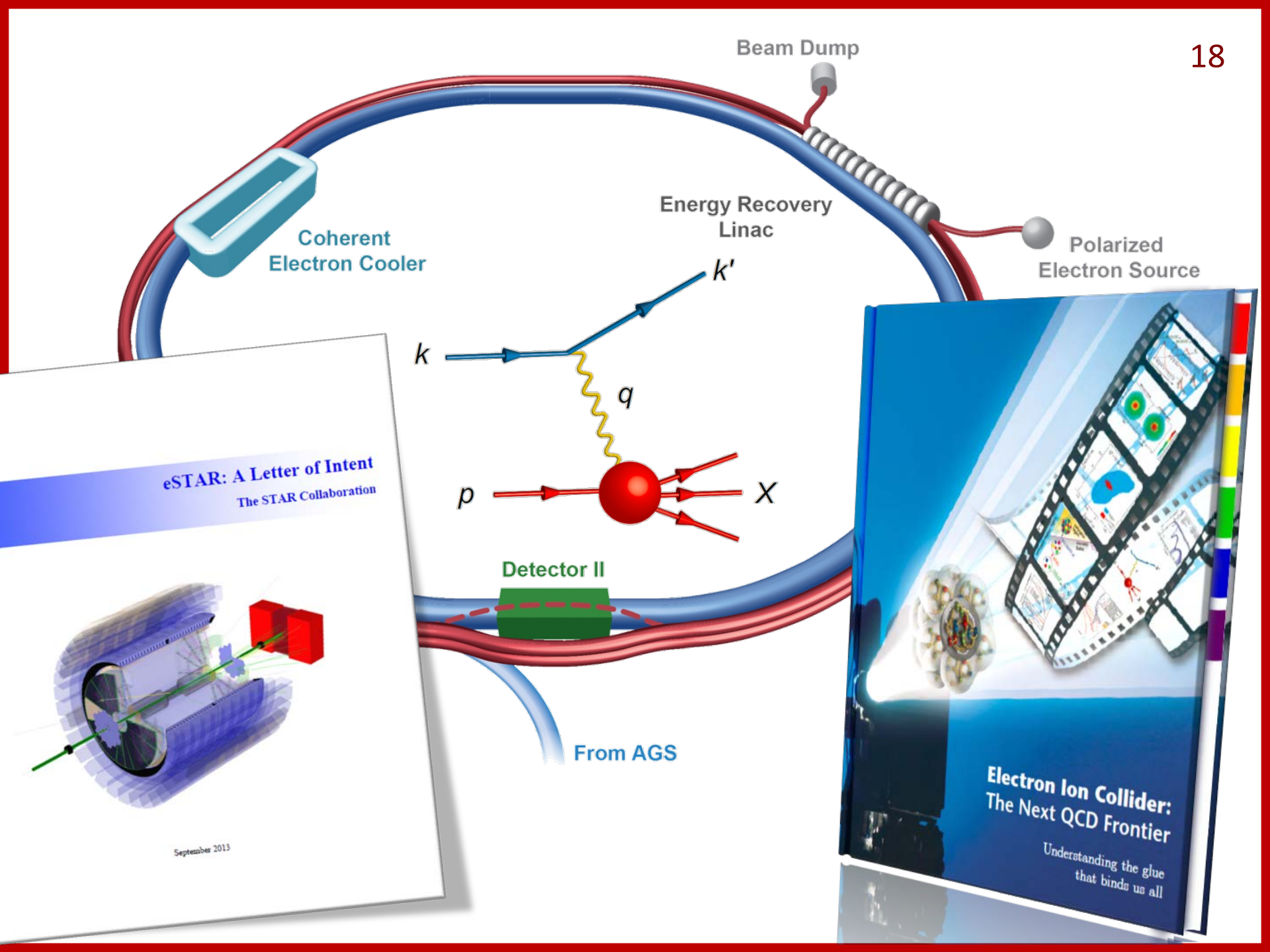


Detector Upgrades

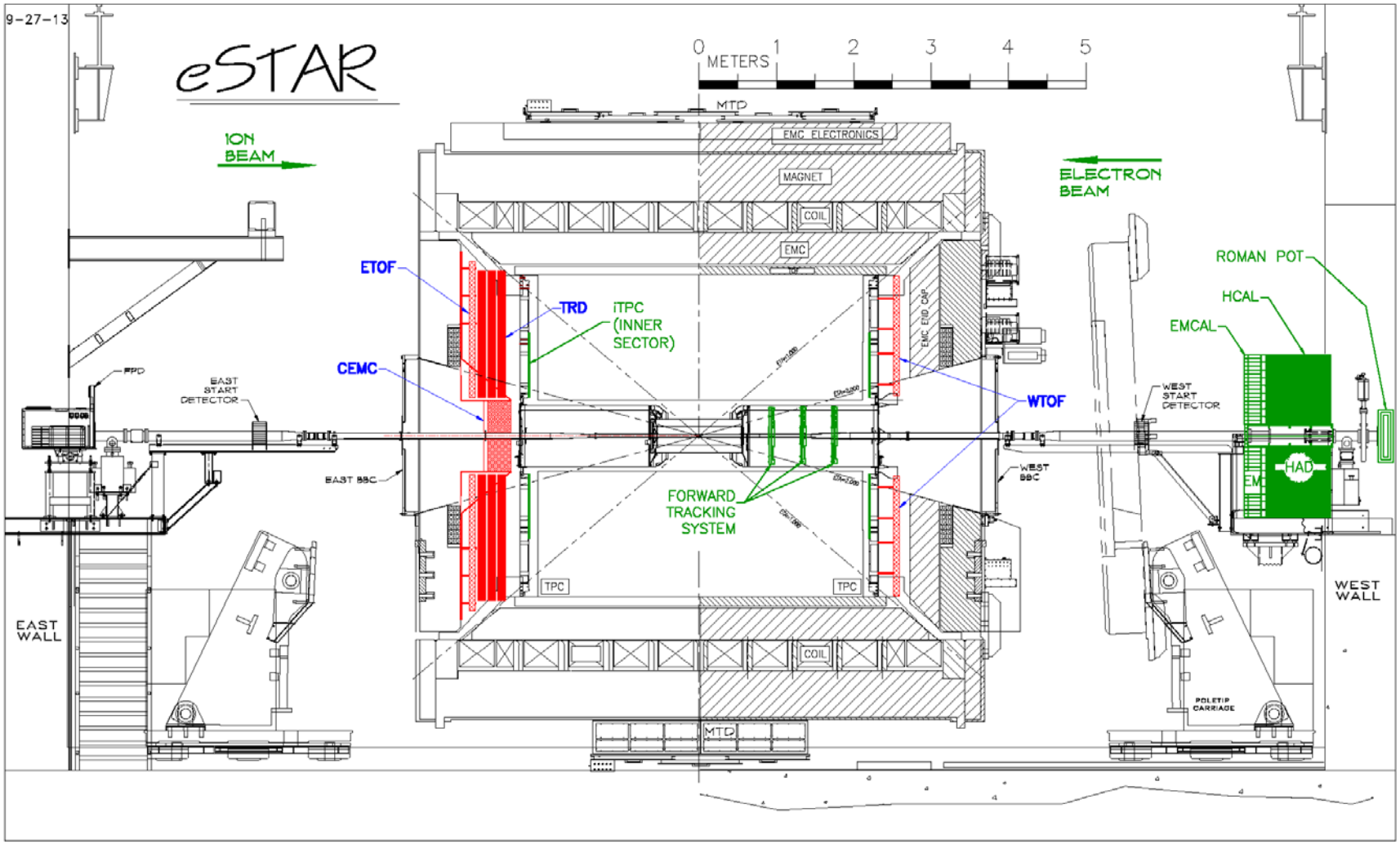


- $2.5 < \eta < 4.0$
- Forward Calorimeter System
  - SPACal + HCal
- Forward Tracking System
  - Inside solenoid 0.5 T
  - Silicon or GEM based



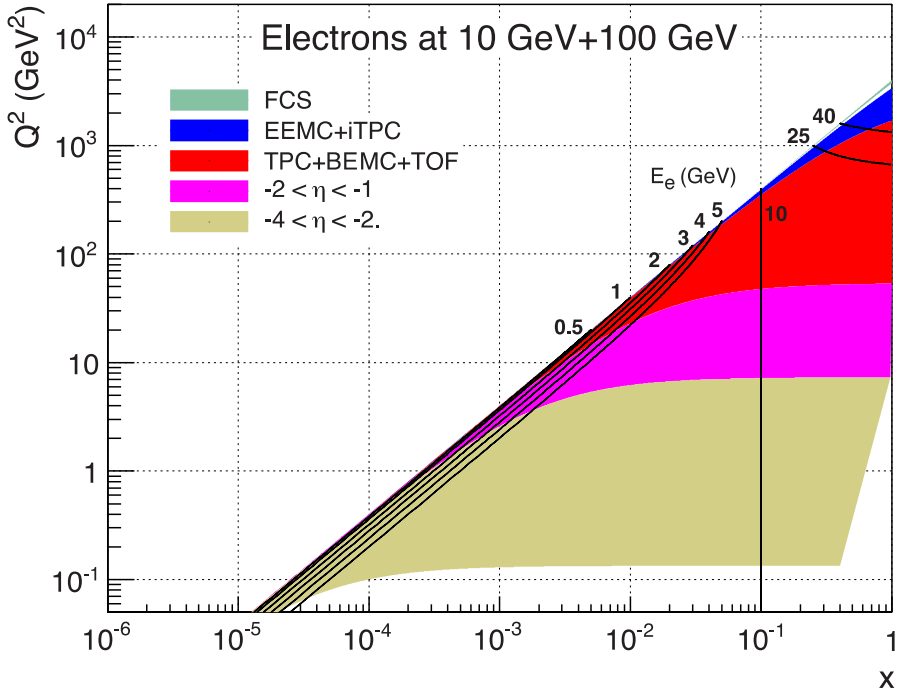

Beam Dump
Energy Recovery Linac
Coherent Electron Cooler
Polarized Electron Source
k'
k
q
p
X
Detector II
From AGS
eSTAR: A Letter of Intent
The STAR Collaboration
September 2013
Electron Ion Collider:
The Next QCD Frontier
Understanding the glue
that binds us all

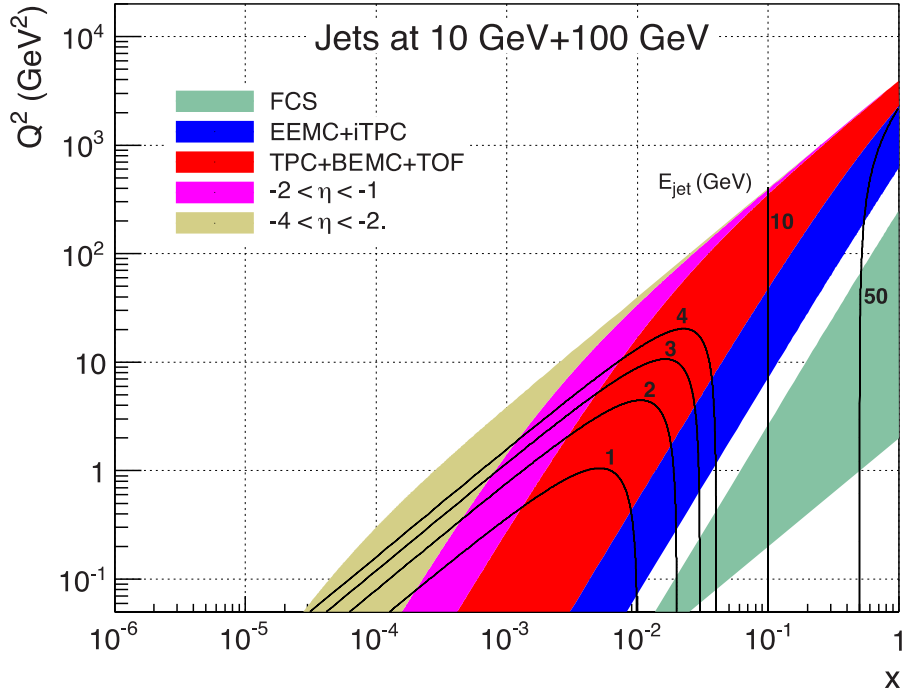
eSTAR Baseline Configuration



Kinematic Coverage

$$\sigma_r = \frac{d^2\sigma}{dxdQ^2}\frac{x\,Q^4}{2\pi\alpha^2[1+(1-y)^2]} = F_2(x,Q^2) - \frac{y}{1+(1-y)^2}F_L(x,Q^2)$$





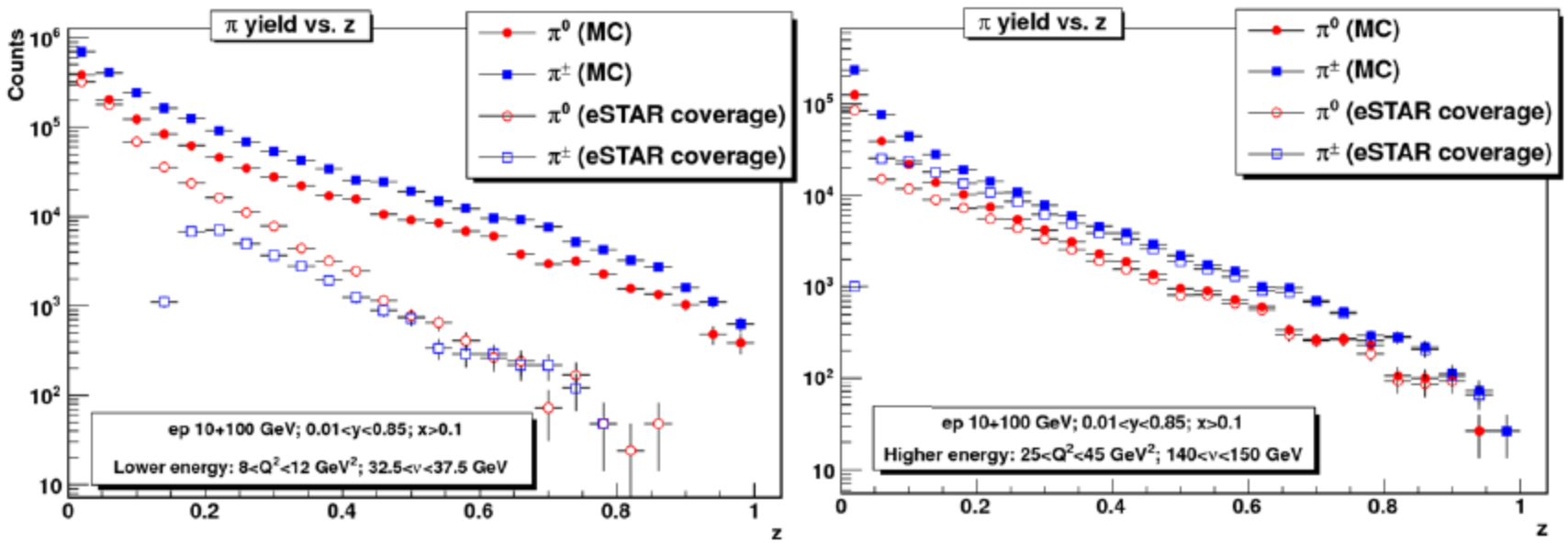
eSTAR SIDIS Acceptance

PYTHIA based fast Monte Carlo studies

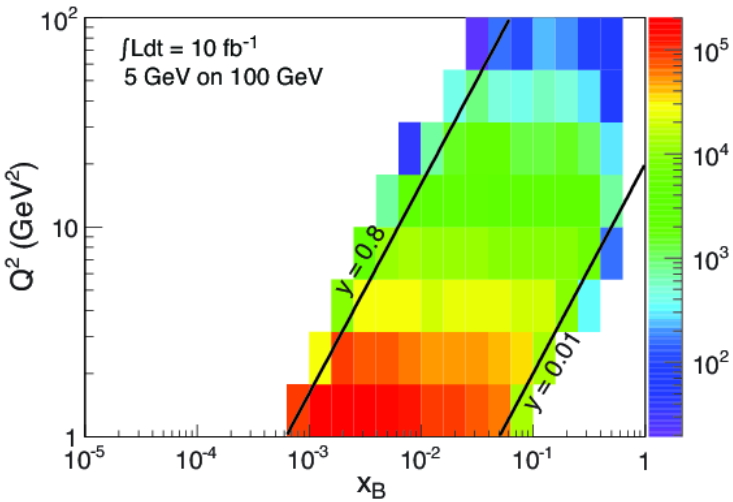
$$E_e = 10\ \text{GeV}, E_p = 100\ \text{GeV}, 0.01 < y < 0.85$$

$8 < Q^2 < 12\ \text{GeV}^2$
$32.5 < \nu < 37.5\ \text{GeV}$

$25 < Q^2 < 45\ \text{GeV}^2$
$140 < \nu < 150\ \text{GeV}$



Exclusive Processes: DVCS



GPD

$H(x,\xi,t)$

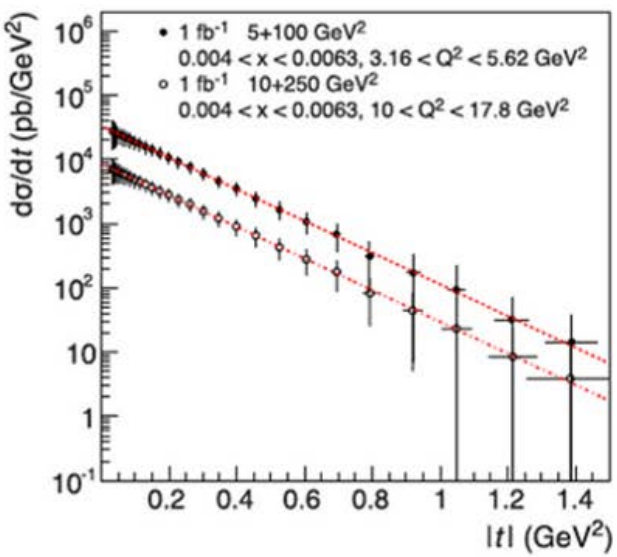
$E(x,\xi,t)$

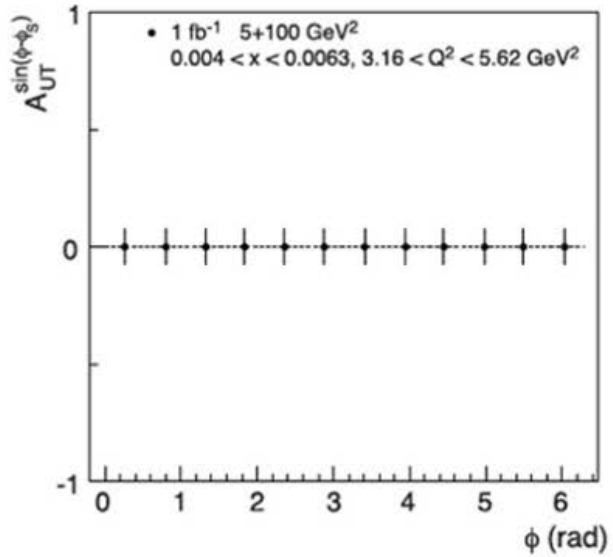
Fourier transform →

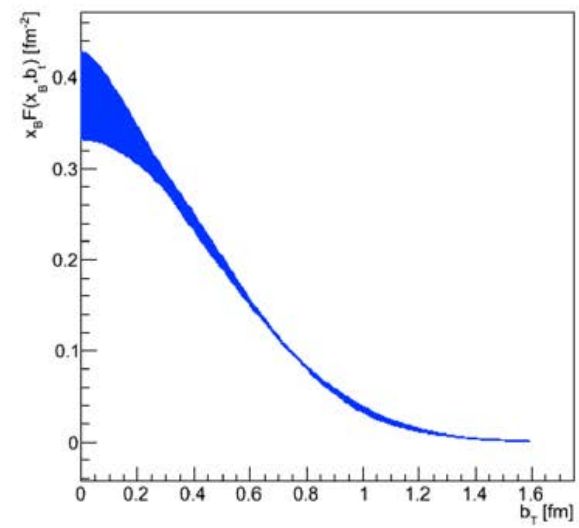
Spatial distribution

$f(x,b_T^2)$

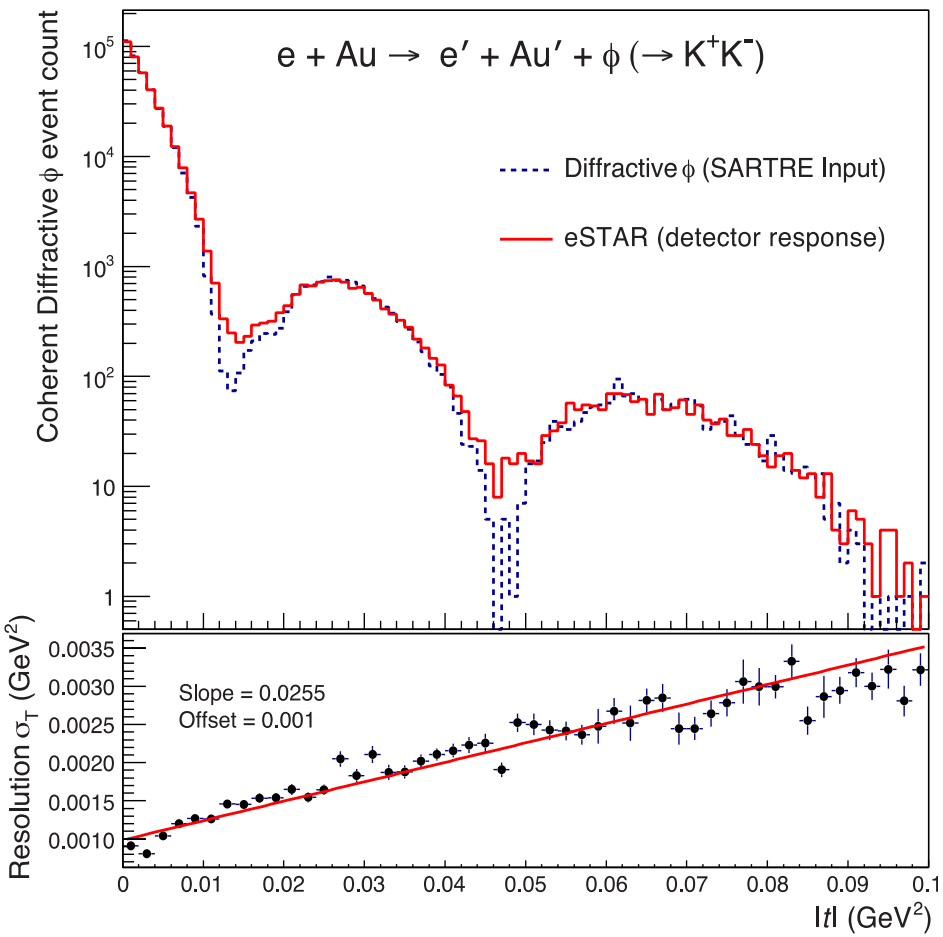
$e(x,b_T^2)$

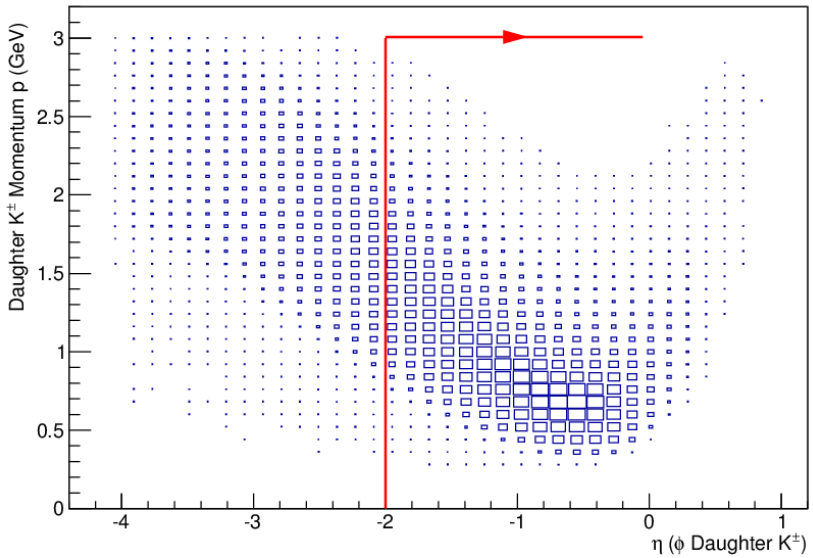


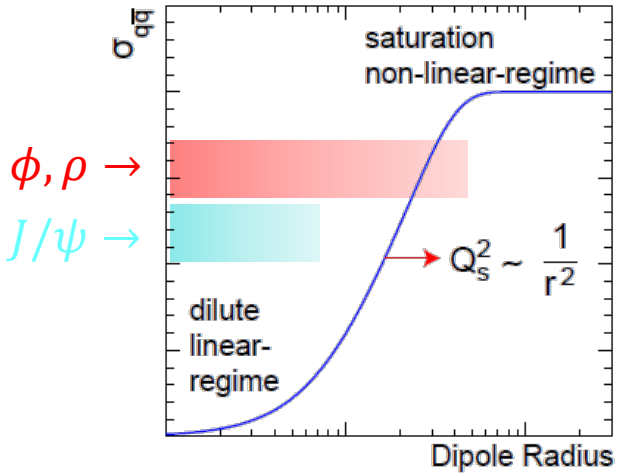




Exclusive Vector Meson Production







Summary

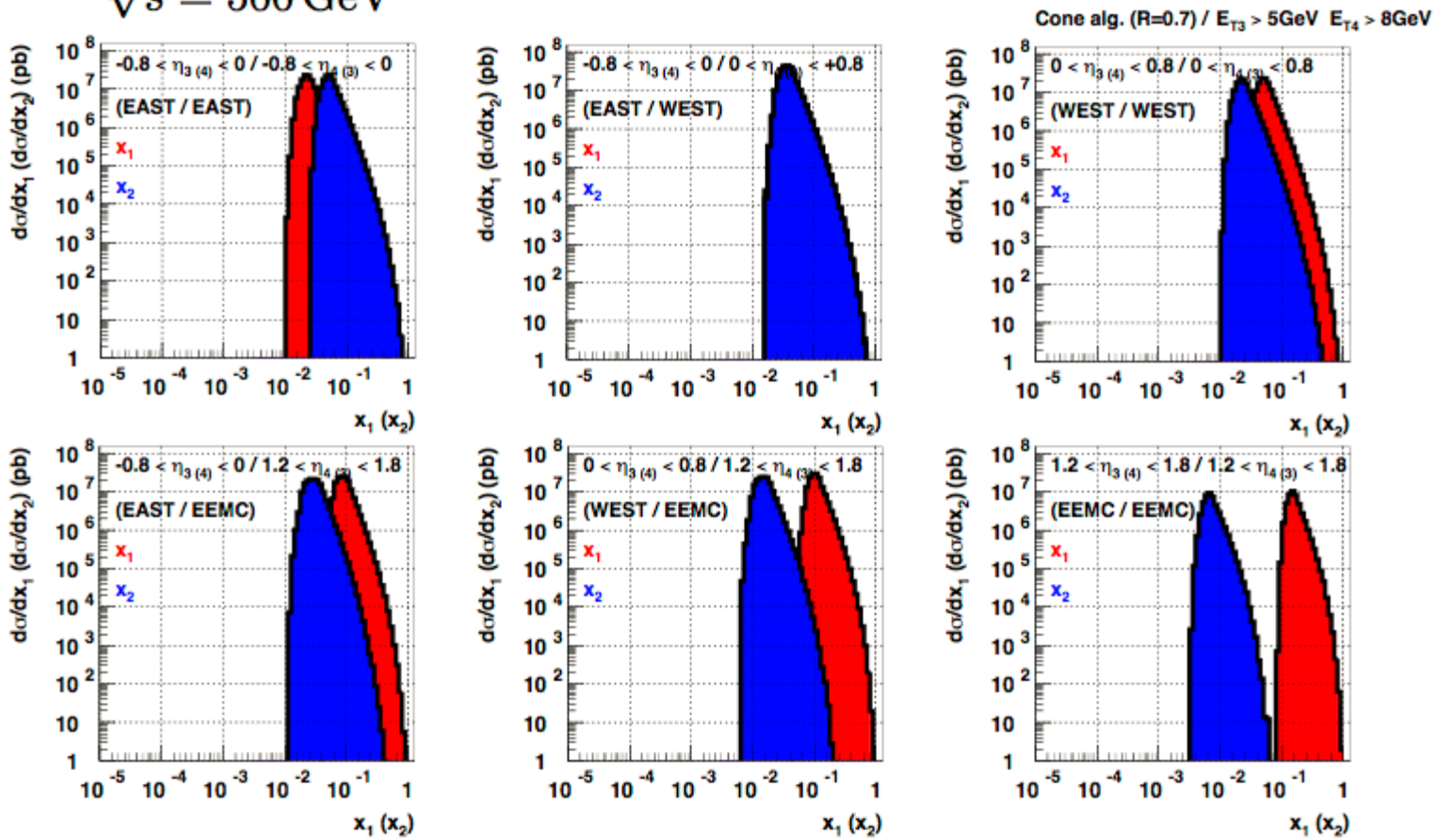
- STAR has presented a scientific program for future polarized $p^{\uparrow} + p$ and $p + A$ collisions at RHIC which can transition into an eSTAR/eRHIC era
- Upgrades are focused on the forward kinematic region with a calorimeter system and tracking
- Projections have been shown for $p + p$ collisions of $100\ \mathrm{pb}^{-1}$ ($1\ \mathrm{fb}^{-1}$) at $\sqrt{s} = 200\ \mathrm{GeV}$ ($500\ \mathrm{GeV}$) with a beam polarization of $P = 60\%$ and additional $2.5\ \mathrm{pb}^{-1}$ of $p + A$ collisions
- Measurements will help improve our understanding of nucleons and nuclei and address fundamental aspects of the partonic structure, especially at very small and very large x
- eSTAR can deliver on a broad range of key measurements that have been identified as flagship cases in the EIC community white paper

BACK UP

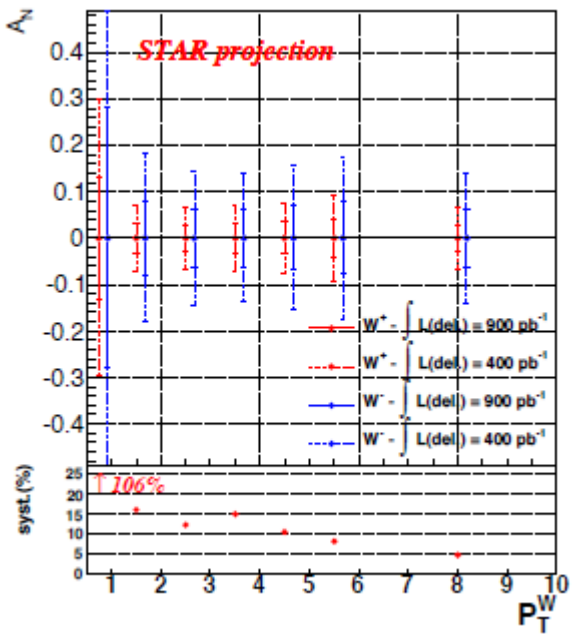
Di-Jets with Barrel & Endcap

$$-1 < \eta < 2$$

$$\sqrt{s} = 500\,\mathrm{GeV}$$



$A_N(W^{\pm}, p_T)$


A_N
STAR projection
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
W+ - ∫ L(dell) = 900 pb-1
W+ - ∫ L(dell) = 400 pb-1
W- - ∫ L(dell) = 900 pb-1
W- - ∫ L(dell) = 400 pb-1
syst.(%)
106%
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
P_T^W