The RHIC Experiments:
what can they do (forward)?

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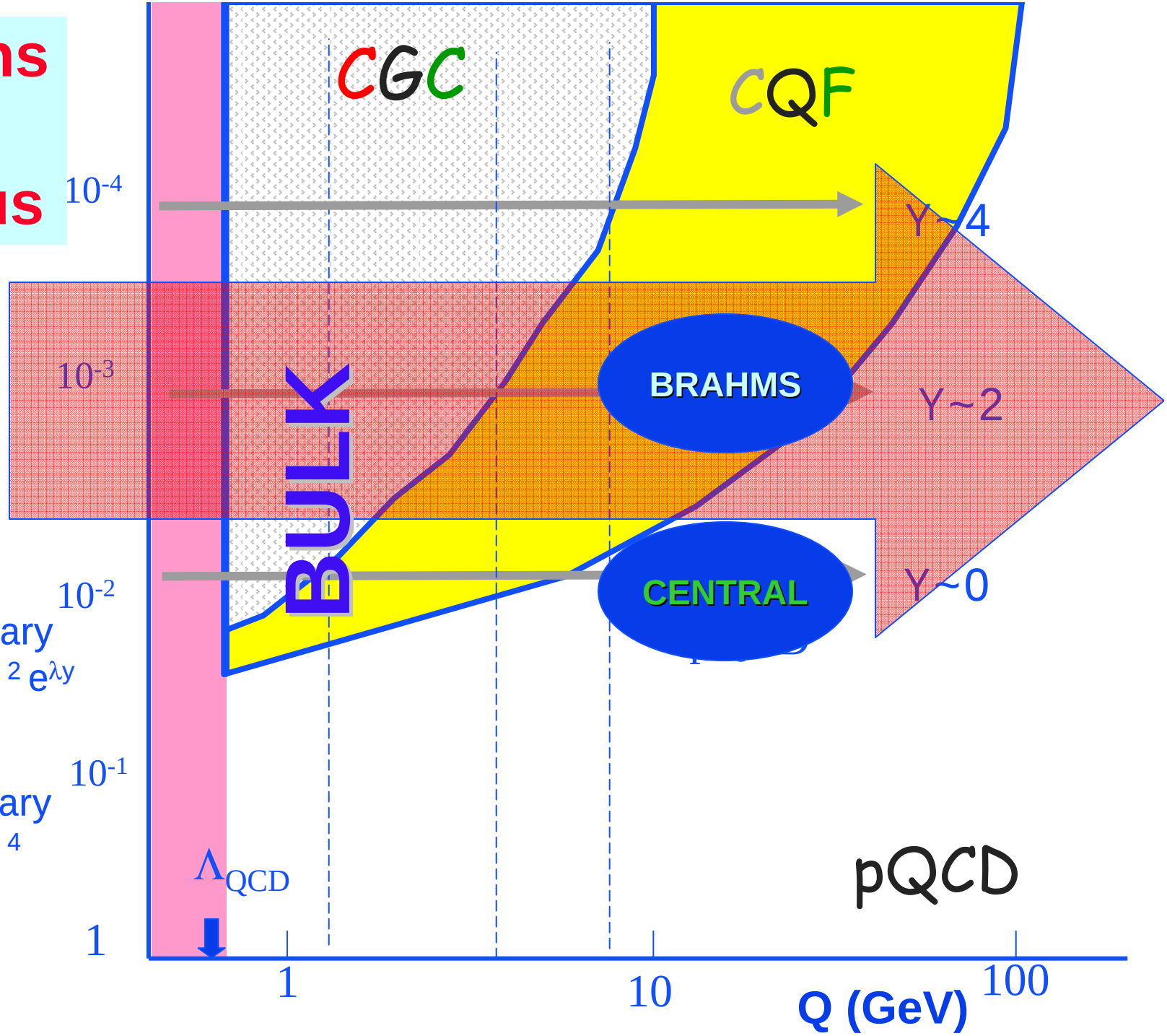
UC Riverside

Forward physics at RHIC workshop
2004 RHIC/AGS Users Meeting, BNL
14 May, 2004

Regions of a nucleus



X

CGC boundary

$Q_S^2 = Q_{S(y=0)}^2 e^{\lambda y}$

$\lambda \sim 0.3$

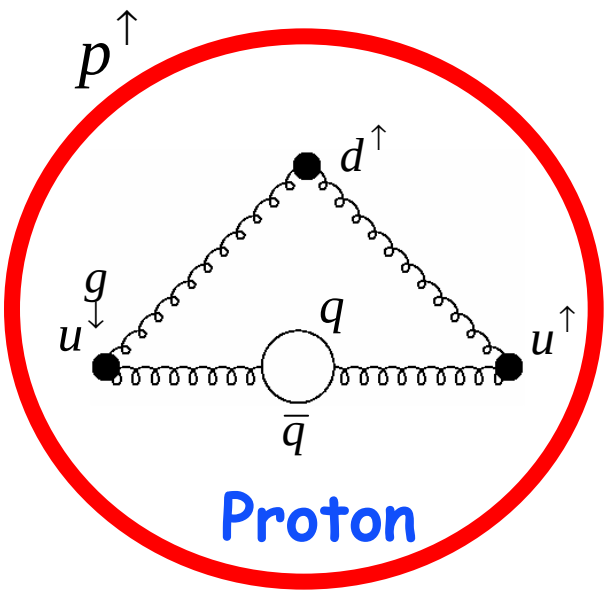
CQF boundary

$Q_S^2 = Q_{S(y=0)}^4$

Understanding proton spin structure

- Need to understand dynamics of the nucleon spin:
  - Contribution of gluons to proton spin (ΔG)
  - Gluon feed-down to quark sea (measure $\Delta\bar{q}/q$ and $\Delta q/q$)
    - W production unique in providing theoretically clean access

- A_N possibly gives us access to the transversity distribution, orbital angular momentum, and higher twist effects



Spin

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

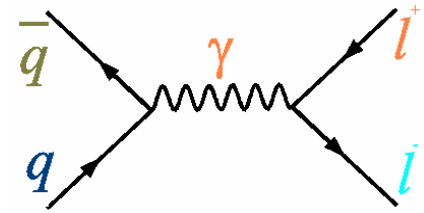
Quark Spin

Gluon Spin

Orbital Angular Momentum

Flavor decomposition

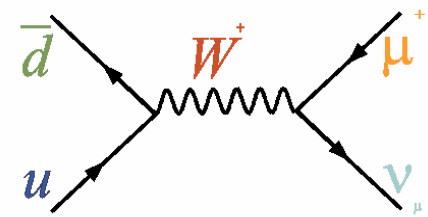
Drell-Yan production of lepton pairs



- » Maximal parton level asymmetry: $a_{LL} = -1$
- » Possible severe background from semi-leptonic decays of open charm productions – can be improved with forward silicon tracking.

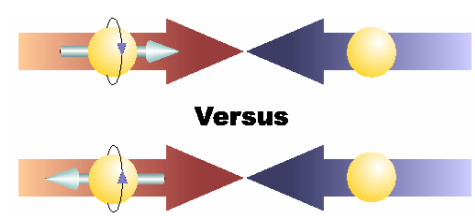
$$A_{LL}^{q\bar{q}\to\ell\bar{\ell}} = \frac{\Delta q(x_A)}{q(x_A)} \otimes \frac{\Delta\bar{q}(x_B)}{\bar{q}(x_B)} \otimes \hat{a}_{LL}^{q\bar{q}\to\ell\bar{\ell}}$$

W production

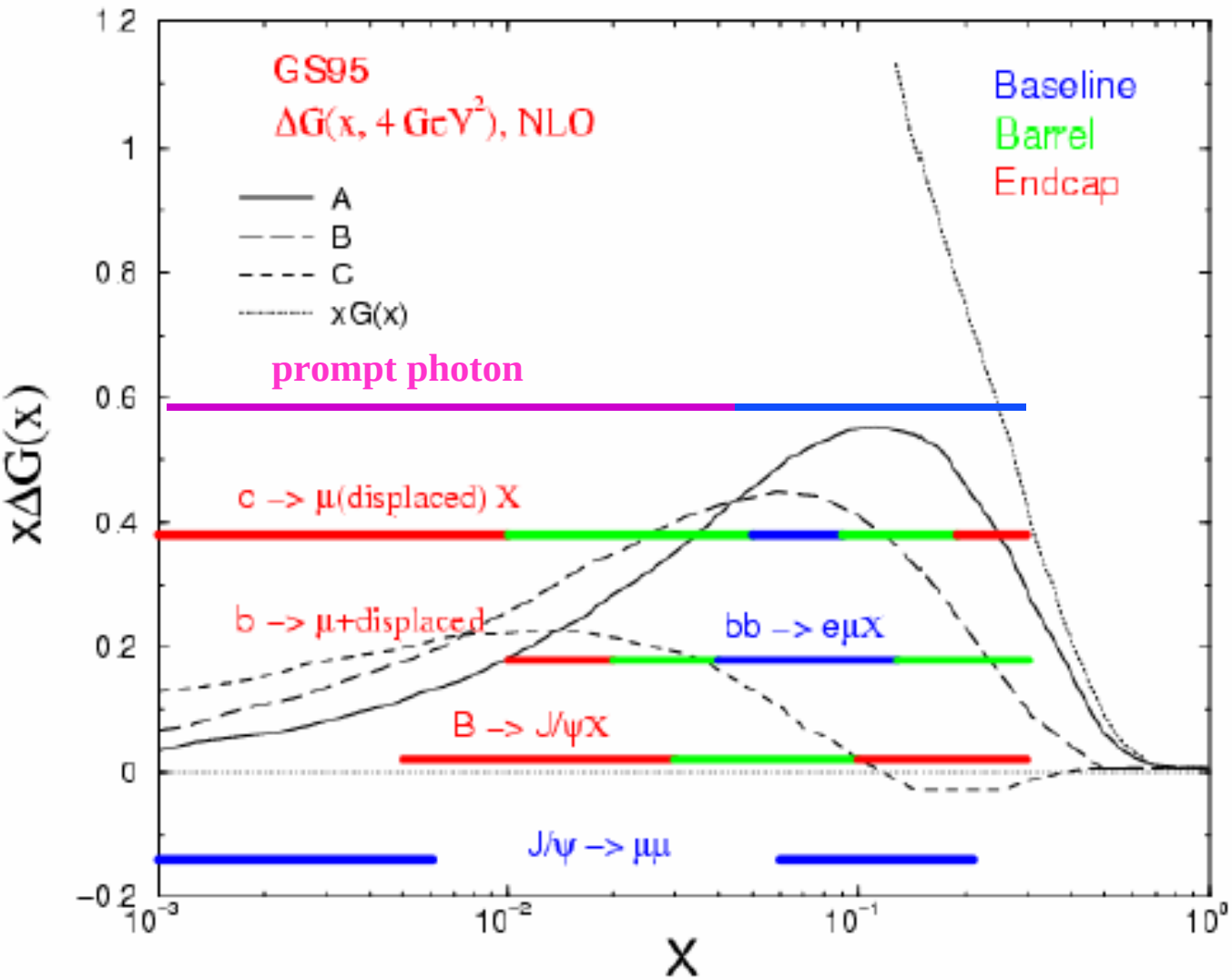


- » Produced in parity violating *V-A* process
  - — Chirality / helicity of quarks defined
- » Couples to weak charge
  - — Flavor almost fixed: flavor analysis possible
  - — Flavor ID reduces uncertainty in current pol-PDF models.
- » E.g., PHENIX-Muon Arms

$$A_L^{W^+\to\mu^+\upsilon_\mu} = \frac{\Delta u(x_a)\bar{d}(x_b) - \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$



ΔG and forward detectors

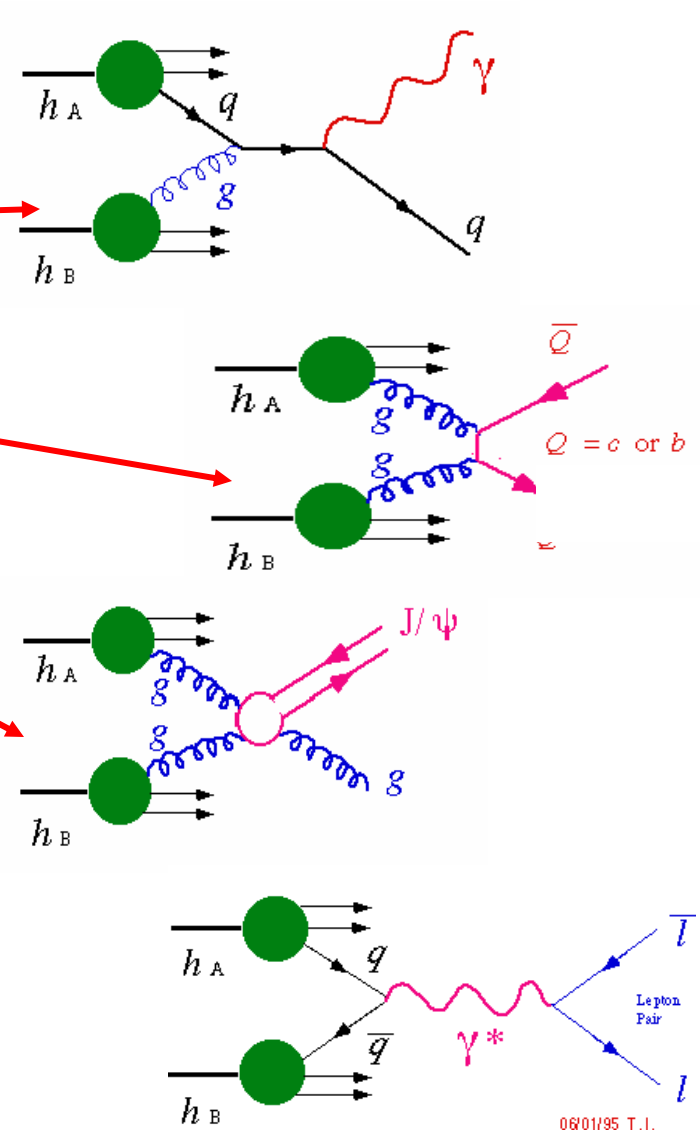


Experimental access to low-x gluons

Gluons at low-x

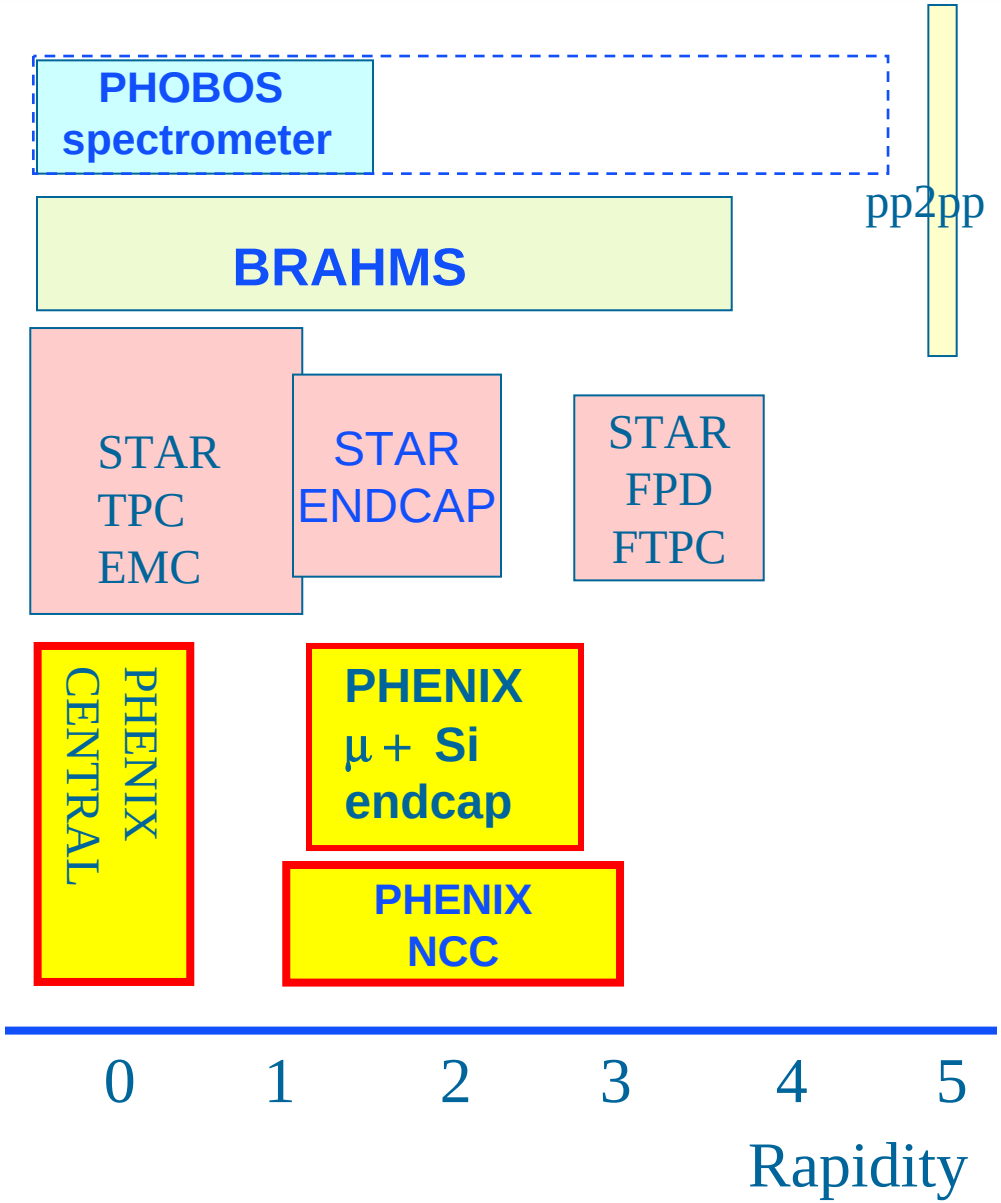
» pp & pA

- $\gamma^* \rightarrow \mu\mu$, ee
- Prompt photons
- Open Charm
- Hadrons
- J/ψ production
- correlations



Map out previous diagrams

Coverage of experiments



charged hadrons

A_N

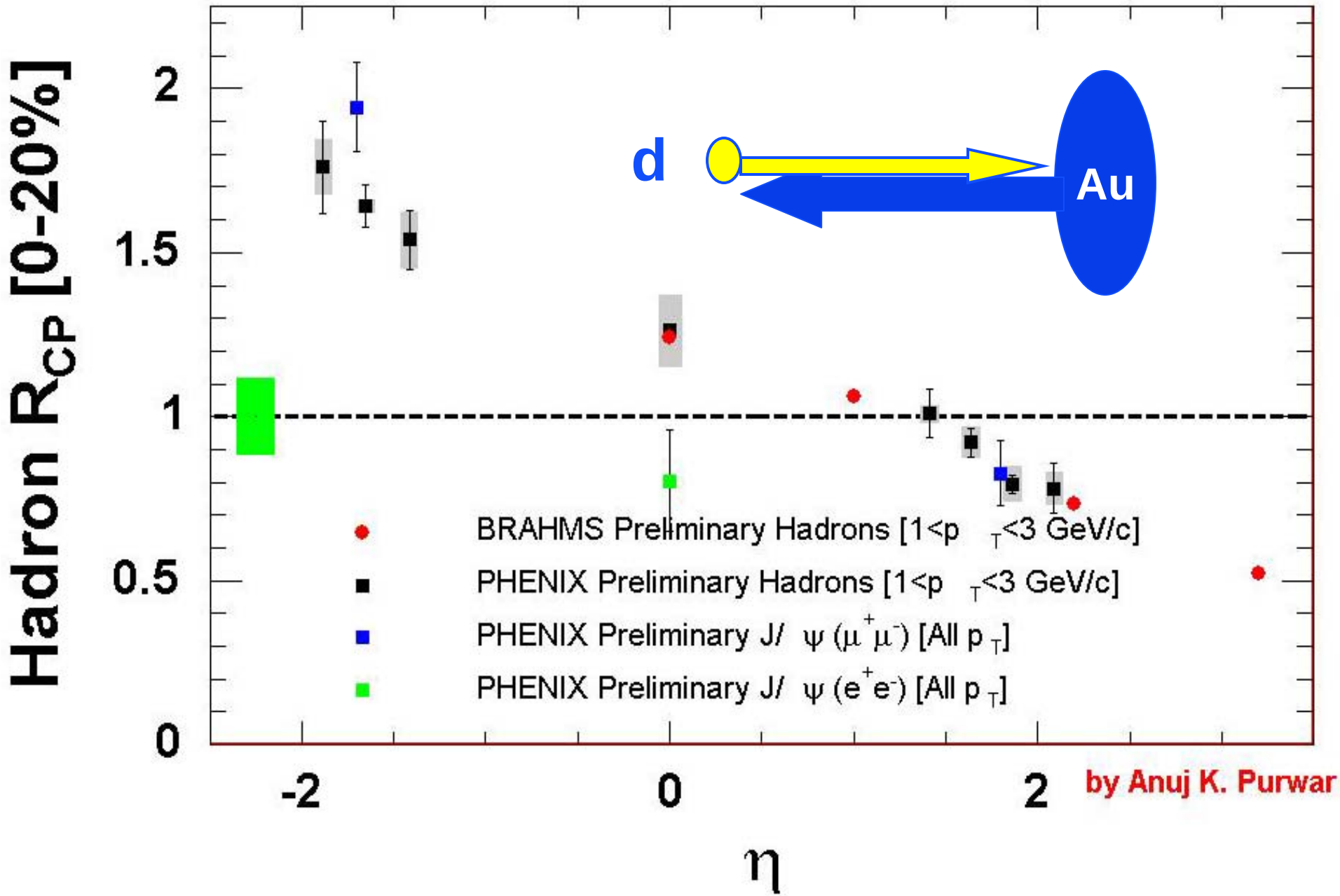
γ, π^0, jets, charm/beauty

A_N, A_L, A_{LL}

γ, π^0, jets, e, μ, $\mu\mu$, charm/beauty, eμ

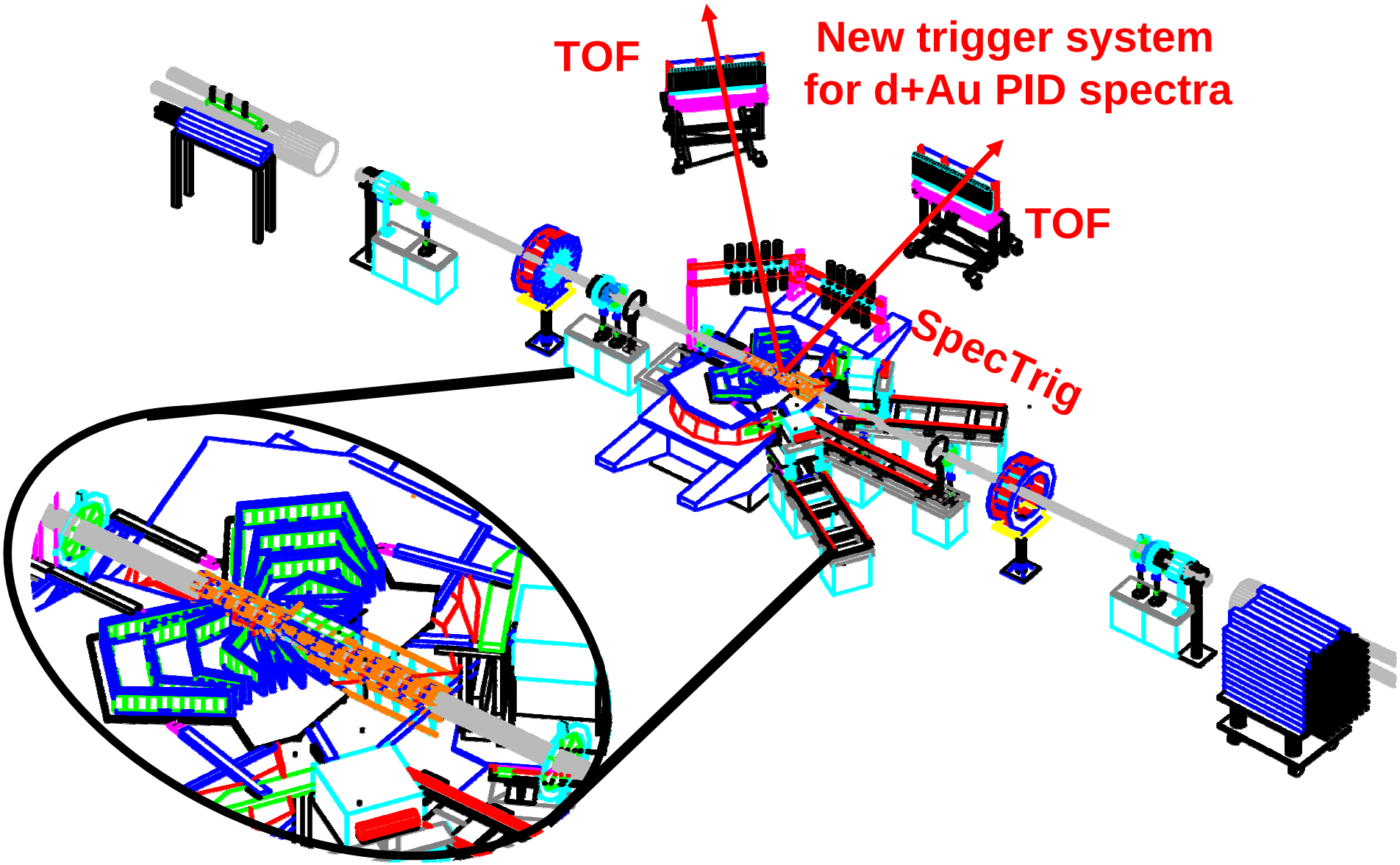
A_N, A_L, A_{LL}

Large η coverage is needed



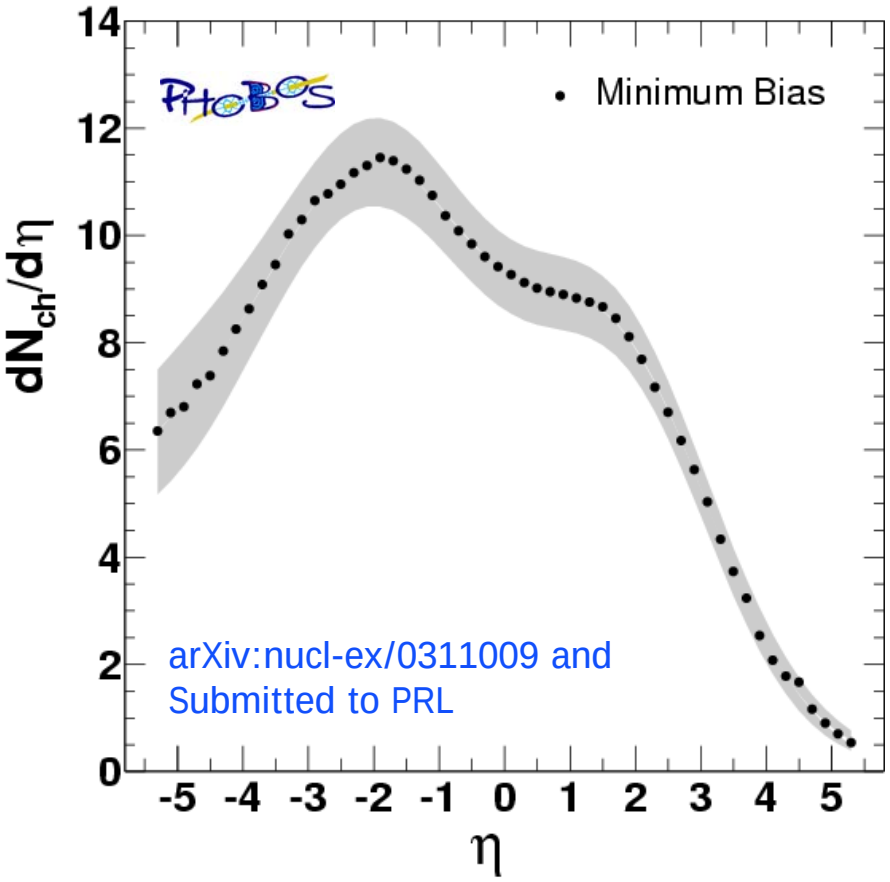
by Anuj K. Purwar

PHOBOS Detector System

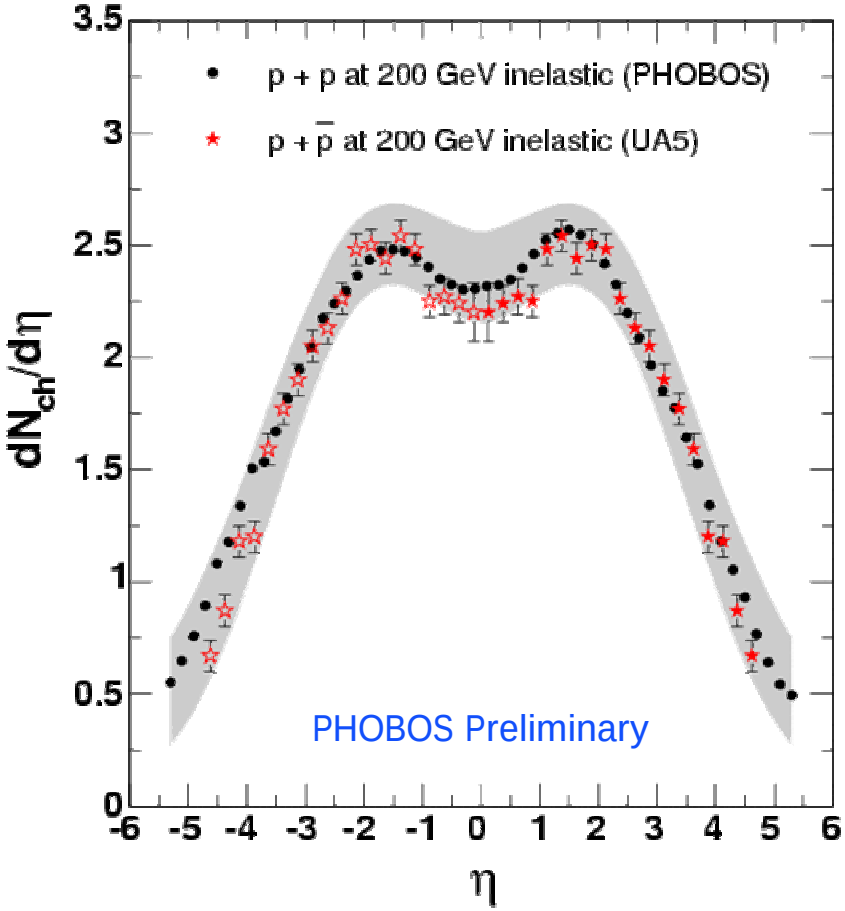


Pseudorapidity Distributions at 200 GeV

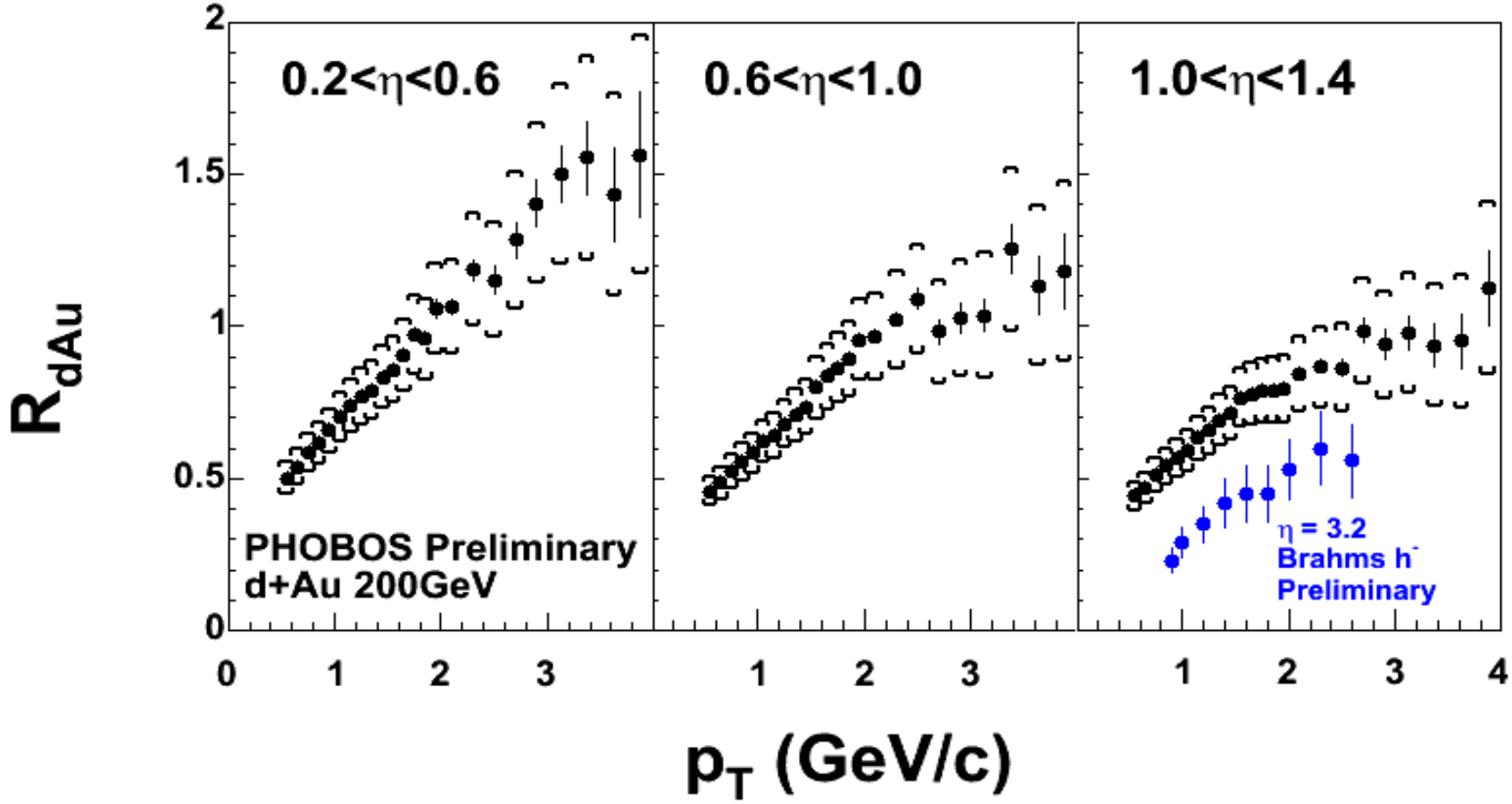
- d + Au at 200 GeV Min-Bias

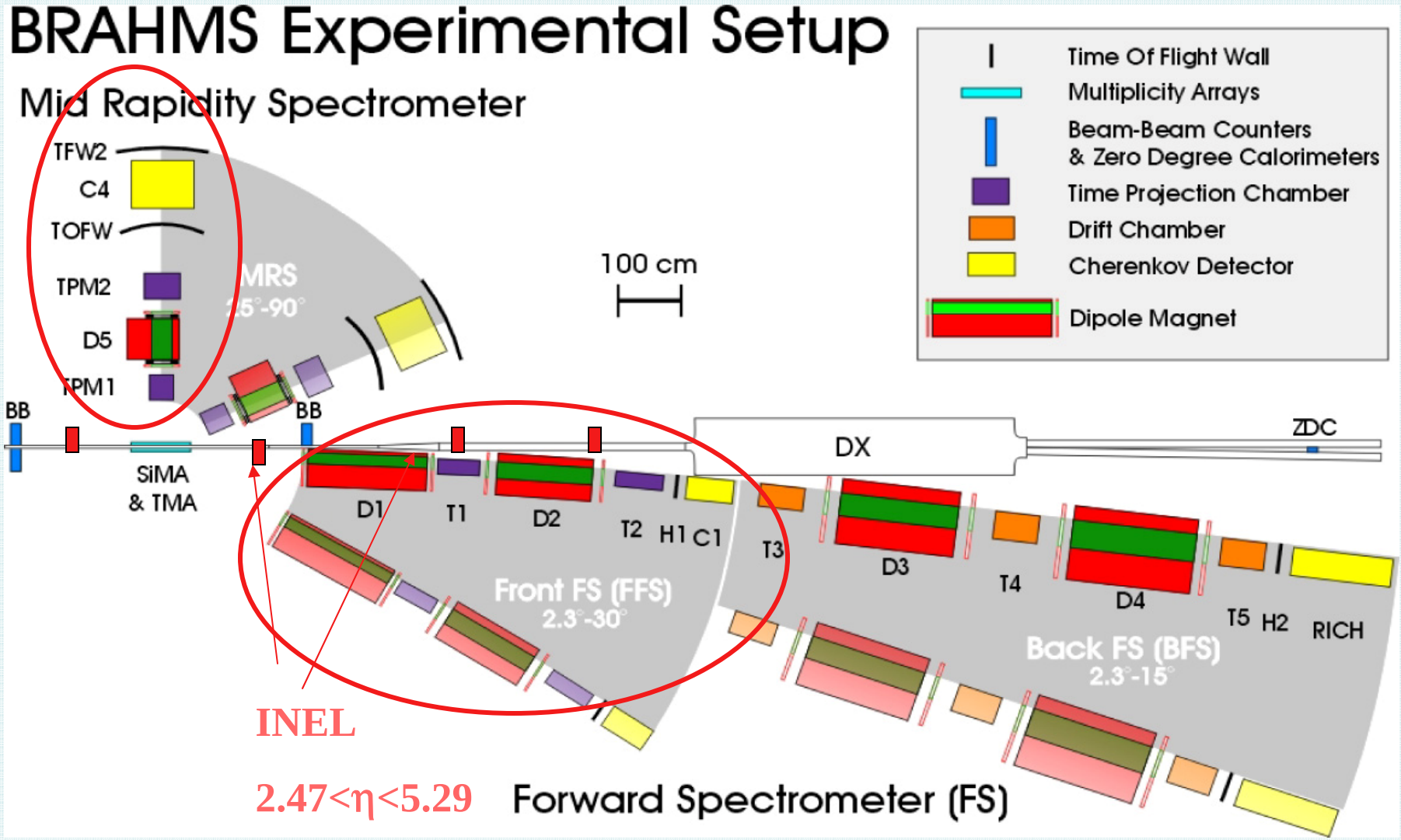


- p + p at 200 GeV



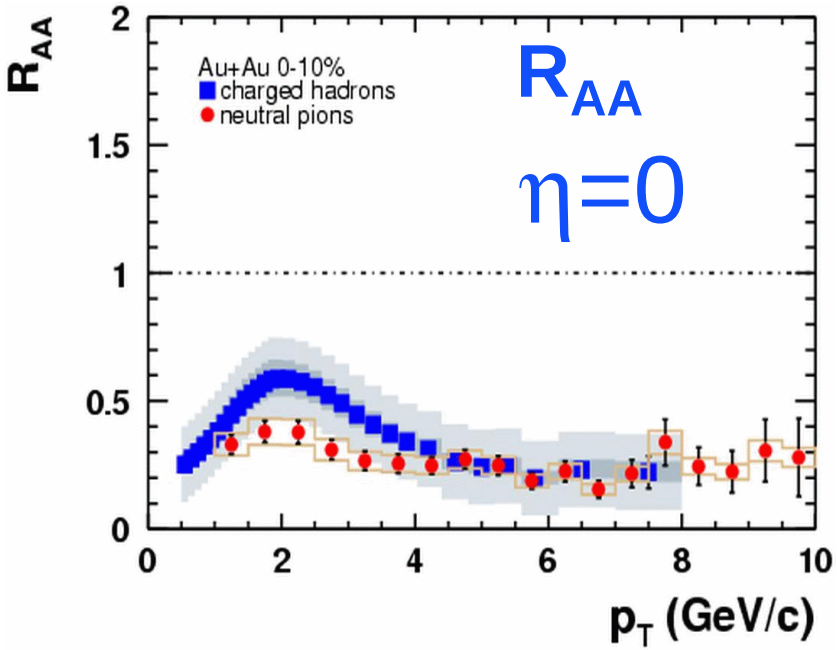
Cronin Effect as a Function of η (d+Au)

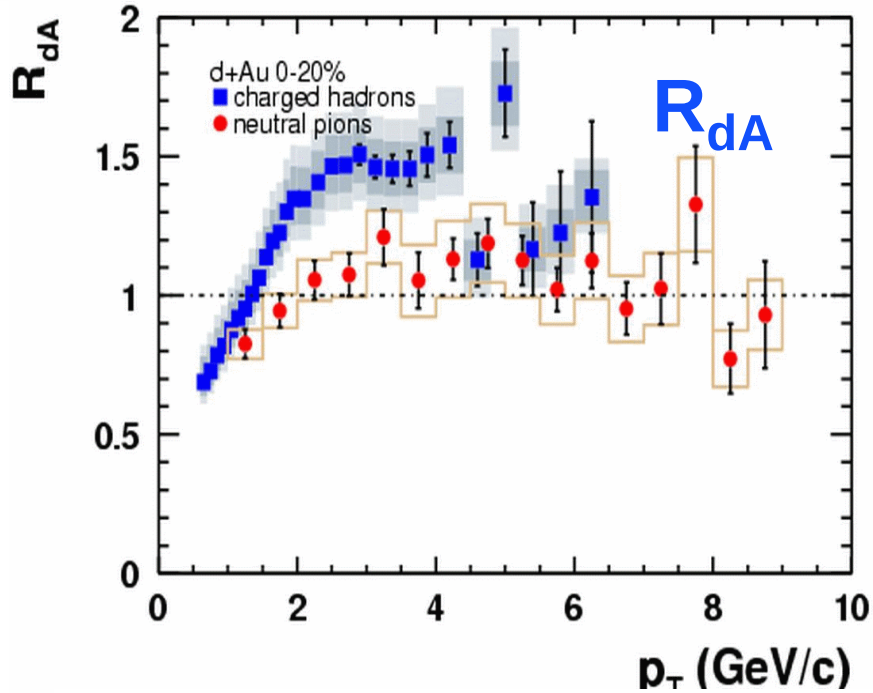


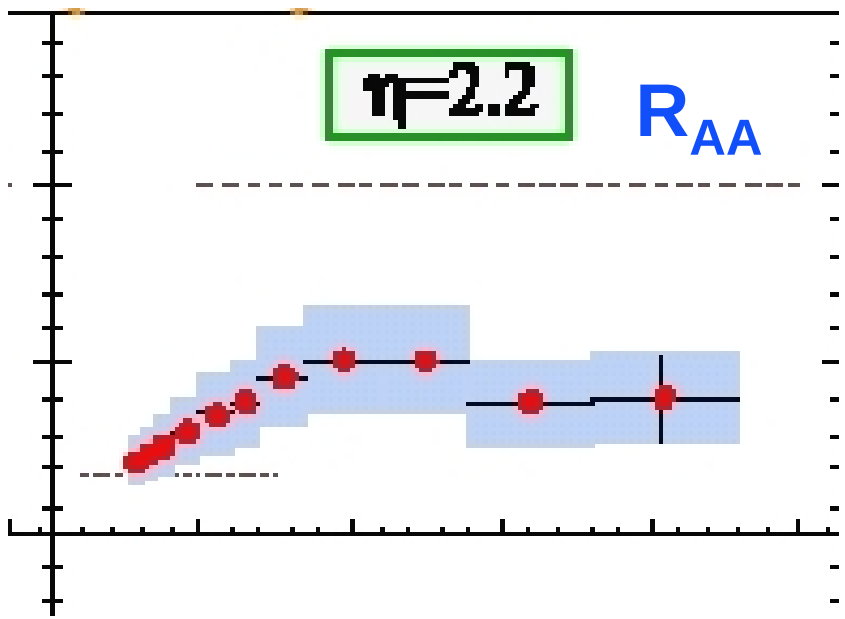


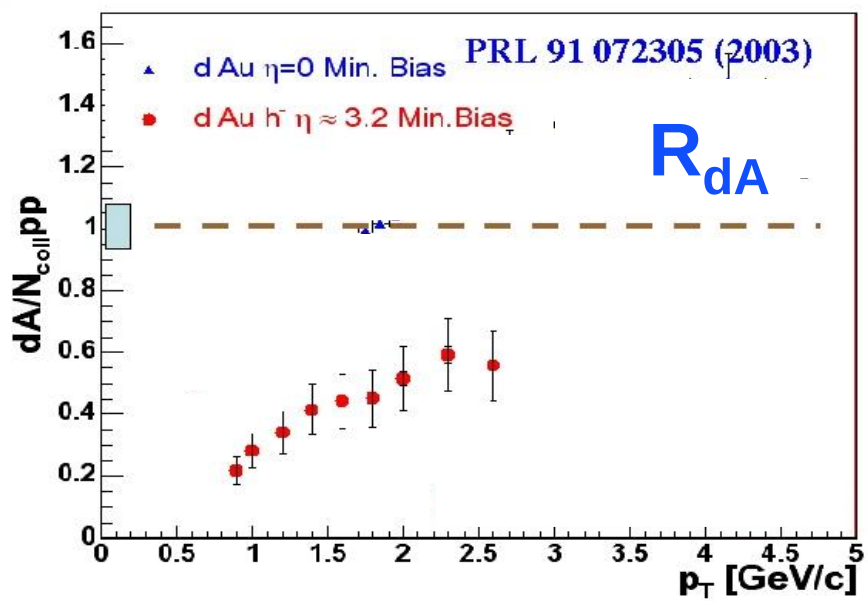
The data at forward rapidities was collected with FFS at 4º (η ~3) and 12º (η~2)

High p_T suppression for different η's

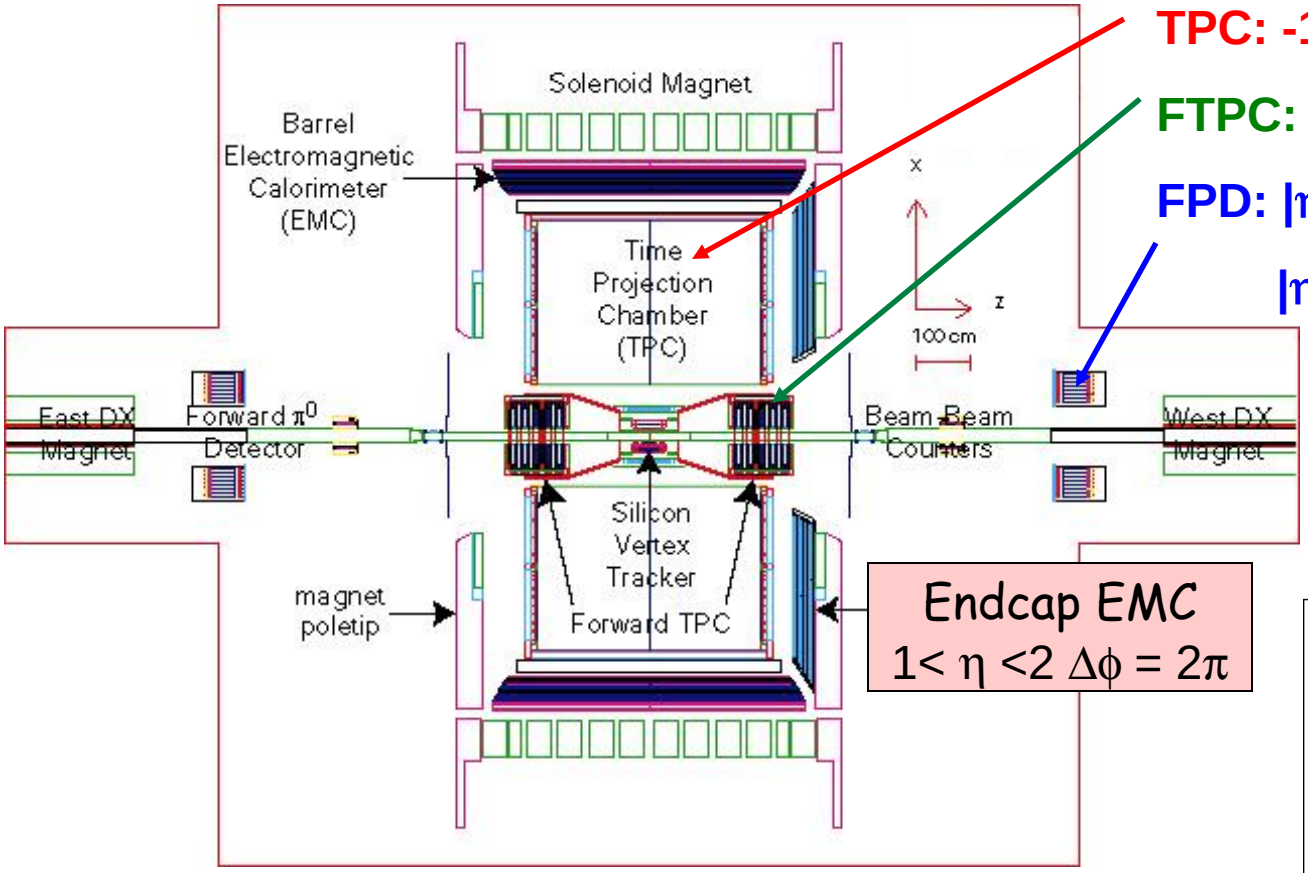








STAR Detector



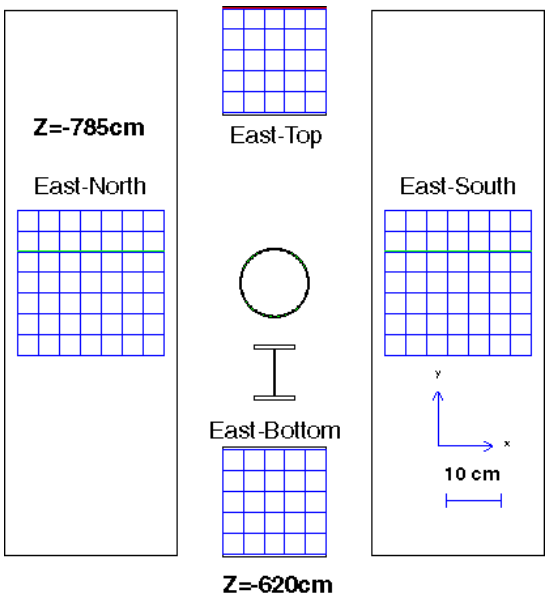
TPC: $-1.0 < \eta < 1.0$

FTPC: $2.8 < |\eta| < 3.8$

FPD: $|\eta| \sim 3.8$ (p + p)

$|\eta| \sim 4.0$ (p + p and d + Au)

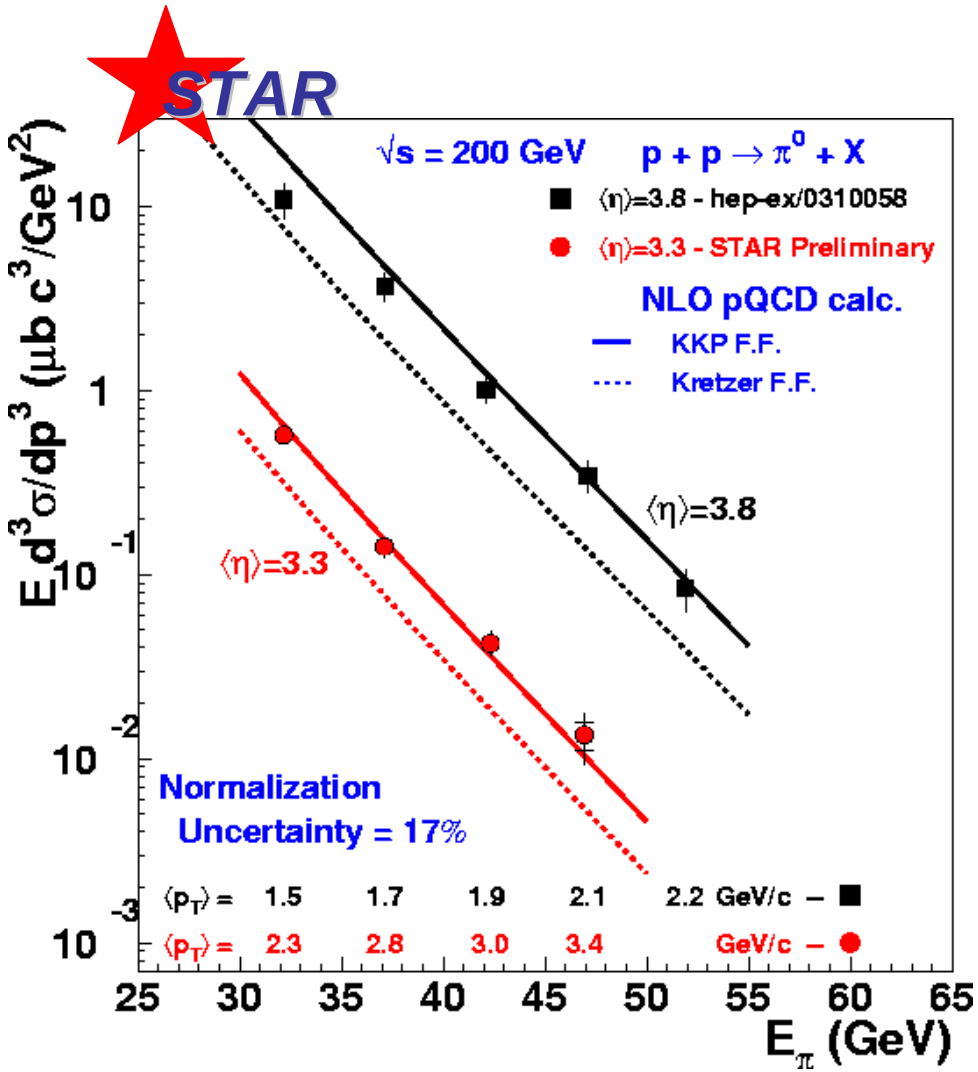
Endcap EMC
$1 < \eta < 2$ $\Delta\phi = 2\pi$



Forward π^0 Detector (FPD)

- **Pb-glass EM calorimeter**
- **Shower-Maximum Detector (SMD)**
- **Preshower**

Forward π^0 Inclusive Cross Section



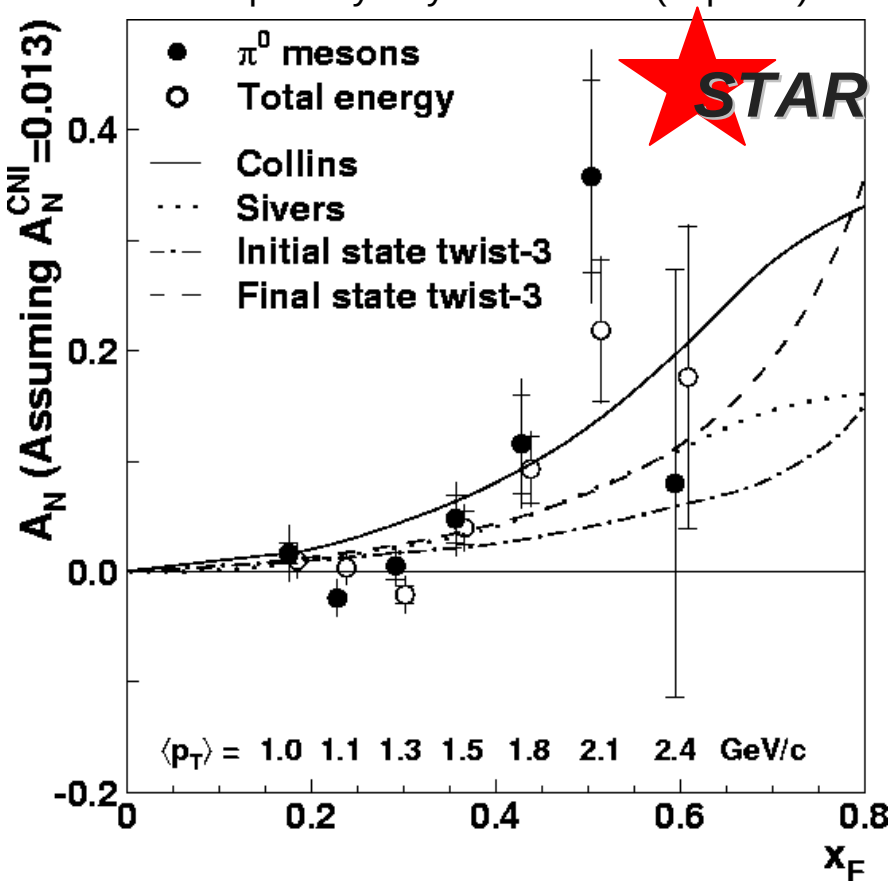
- STAR data at
  - $\langle\eta\rangle$= 3.8 (hep-ex/0310058, accepted to PRL, in press)
  - $\langle\eta\rangle$= 3.3 (hep-ex/0403012, Preliminary)
- NLO pQCD calculations at fixed η with equal factorization and renormalization scales = p_T
- Solid and dashed curves differ primarily in the $g \rightarrow \pi$ fragmentation function

STAR data consistent with Next-to-Leading Order pQCD calculations

in contrast to data at lower √s (Bourelly and Soffer, hep-ph/0311110)

A_N for forward π^0 production at $\sqrt{s}$=200GeV

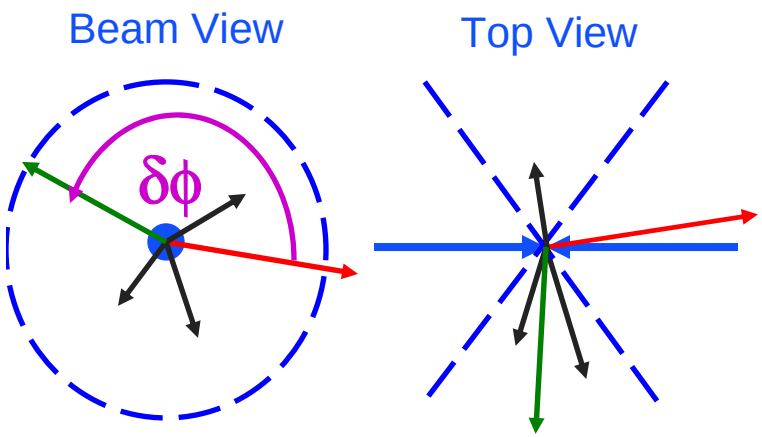
STAR collaboration, hep-ex/0310058, accepted by Phys. Rev. Lett. (in press)



In agreement with several models including different dynamics:

- Sivers: spin and $k_\perp$ correlation in initial state (related to orbital angular momentum?)
- Collins: Transversity distribution function & spin-dependent fragmentation function
- Qiu and Sterman (initial-state) / Koike (final-state) twist-3 pQCD calculations

- p_T dependence?
- x_F<0?
- A_N with mid-rapidity correlation?
- Spin dependence in jet?
- Heavy flavors??
- Related to "gluon saturation"???



Trigger by forward π^0

- $E_p > 25$ GeV
- $\langle \eta_\pi \rangle = 4$

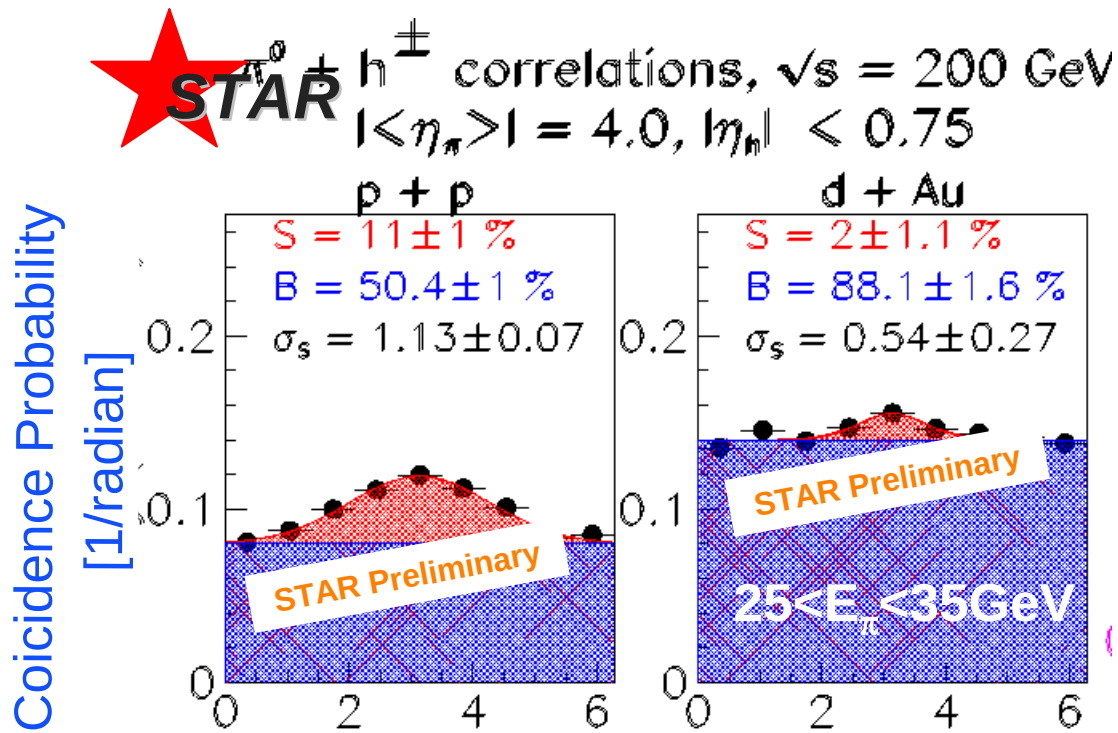
STAR

Large rapidity gap π^0+$h^\pm$ correlation data

Midrapidity $h^\pm$ tracks in TPC

- $-0.75 < \eta < +0.75$

Large rapidity gap π^0 +h correlation data are suppressed in d+Au relative to p+p at small <xF> and <pT,p>
Consistent with CGC picture



Coverage 1<η<3

Jets direction and energy

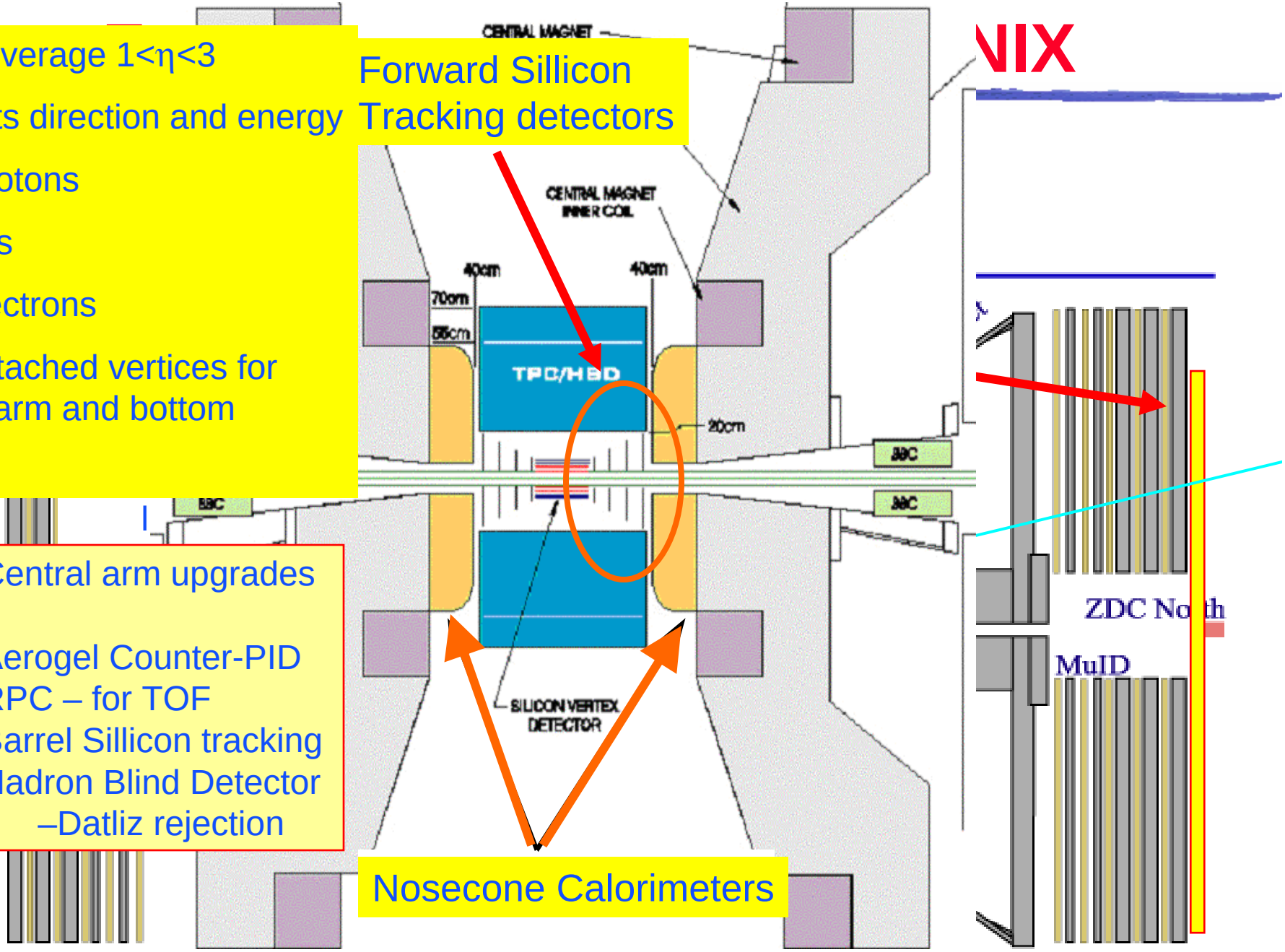
photons

π^0's

electrons

detached vertices for charm and bottom

Forward Sillicon Tracking detectors



Central arm upgrades

Aerogel Counter-PID
RPC – for TOF
Barrel Sillicon tracking
Hadron Blind Detector
–Datliz rejection

Nosecone Calorimeters

PHENIX Forward Upgrade Components

Endcap Vertex Tracker

» silicon pixel detectors

Nosecone Calorimeter

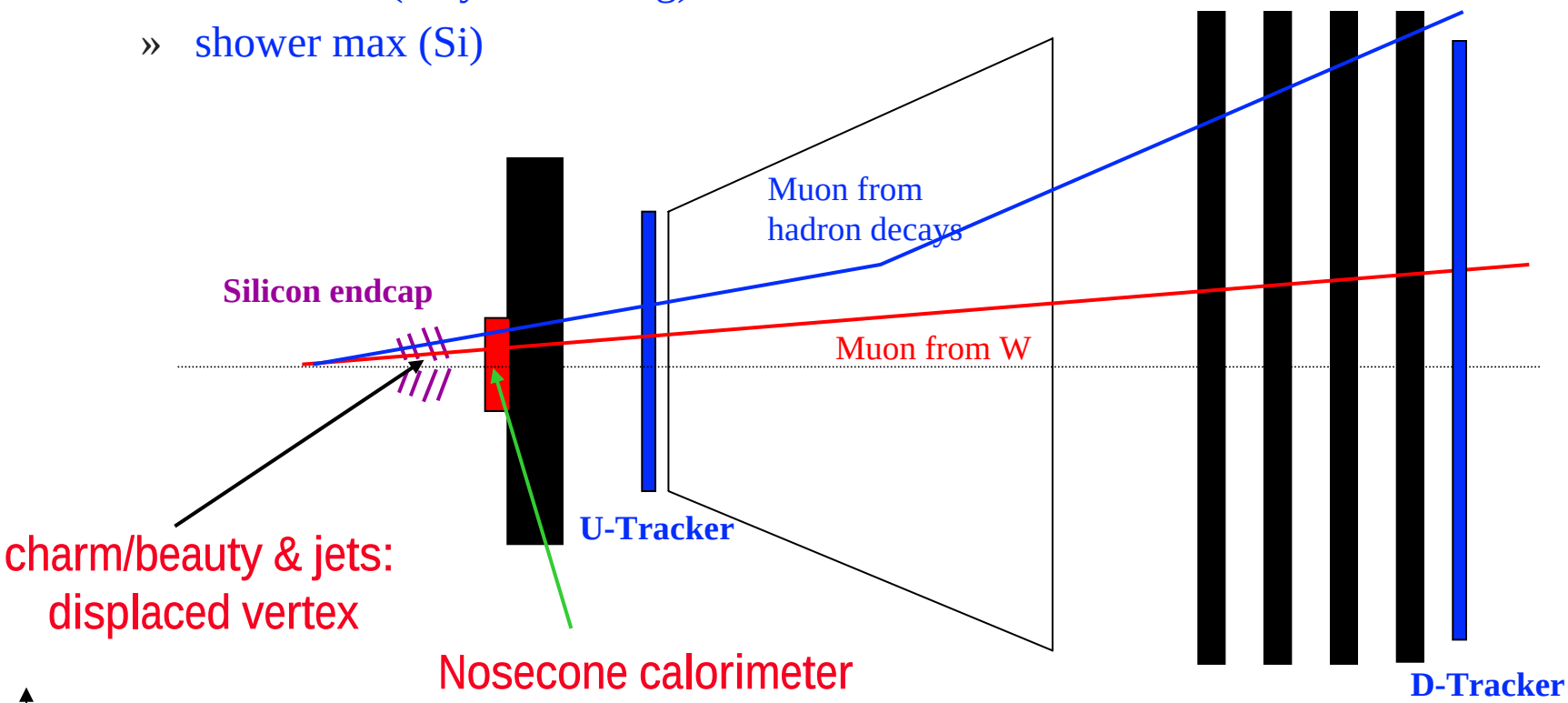
» W-silicon (only 20cm long)

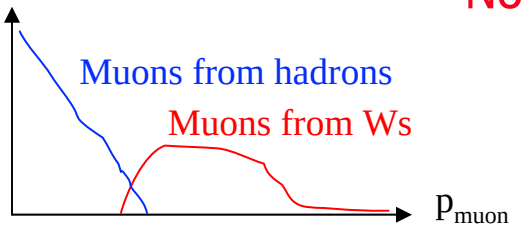
» shower max (Si)

Muon trigger

» U-tracker (RPC or MuTr)

» D-tracker (RPC's)

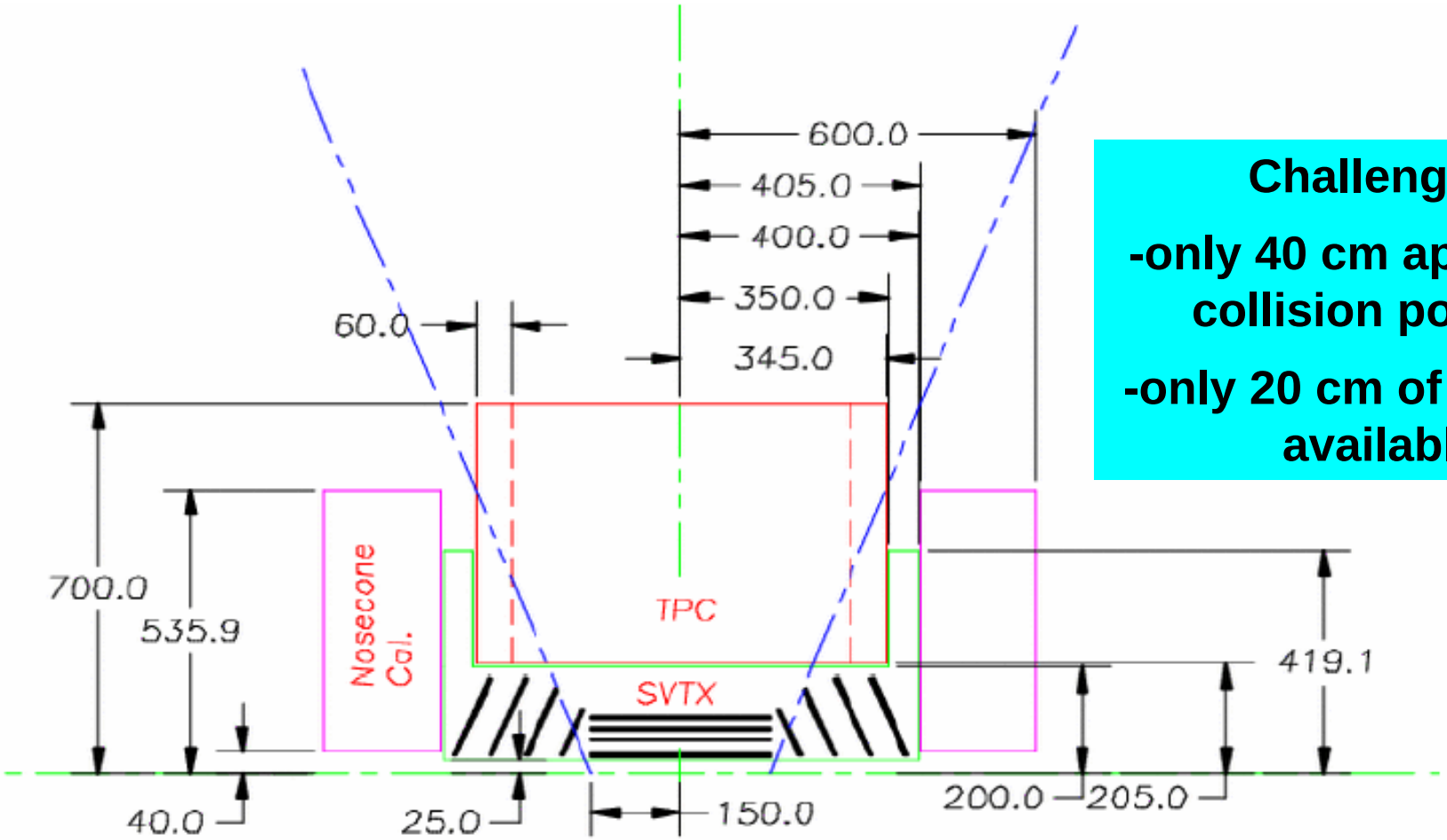




W and quarkonium:
improved μ-trigger rejection

K. Barish

Space is tight …



Challenges:

-only 40 cm apart from collision point …

-only 20 cm of space is available

Design thoughts

PHENIX preliminary design:

14 cm of W absorber

+

6 cm Si readout

Calorimeter: ~	**40 L_{rad} / 1.6 L_{abs}**
Lateral seg.	**1.5 x 1.5 cm^2**
EM section:	**10 Lrad**
γ/π^0 identifier:	**at a depth ~ 5Lrad (two layers of ~2x60 mm^2 silicon strips)**

- Good γ/π^0 separation
- Good position resolution
- e/h separation
- Reasonable jet measurements
- Triggering capability

Notes:.

» AuAu is challenging

» Shower max layers required

» Need upstream tracking to recover J/Ψ resolution in AuAu

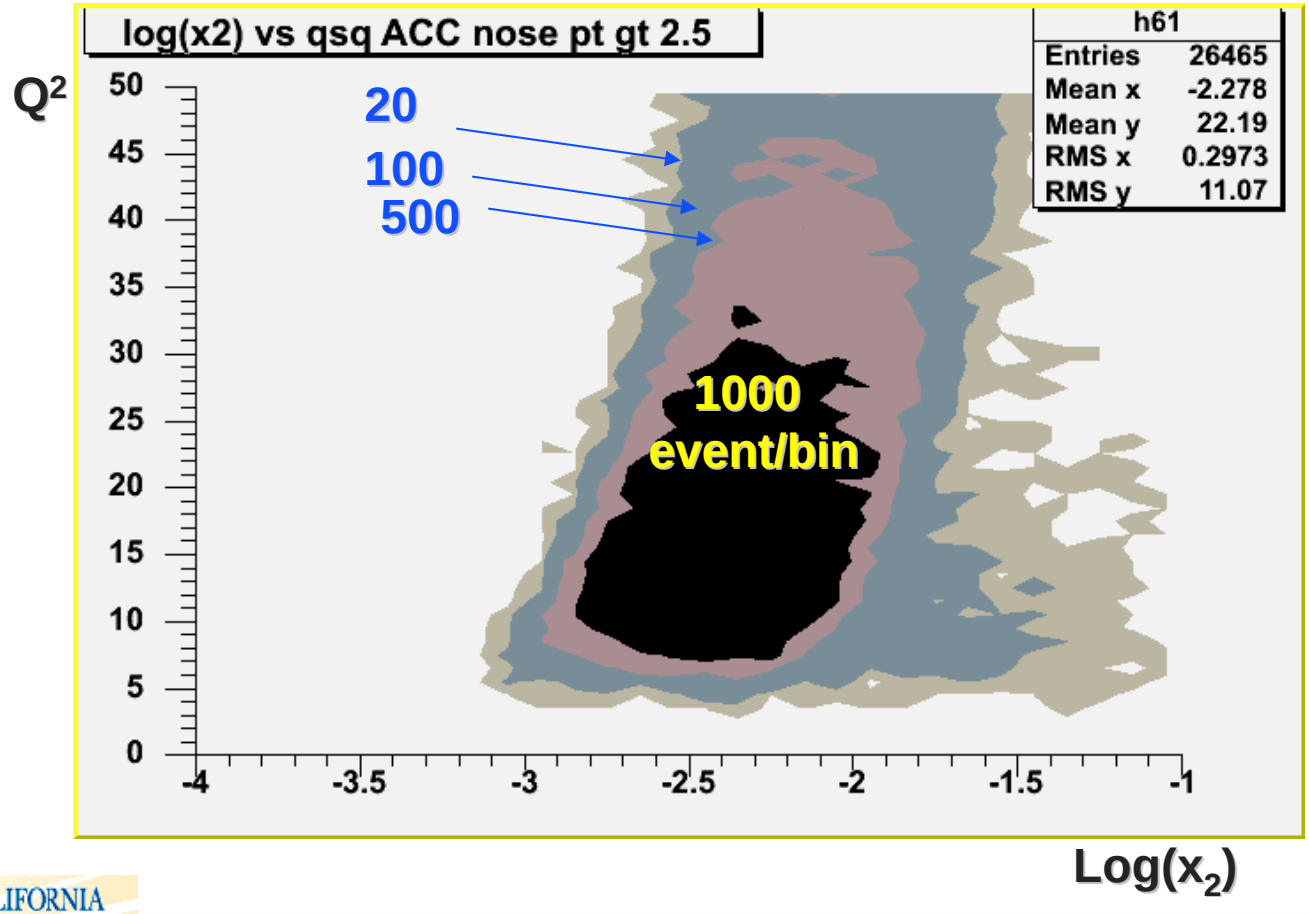
This is a huge challenge, but not completely crazy!!

Coverage of NCC at 200 GeV

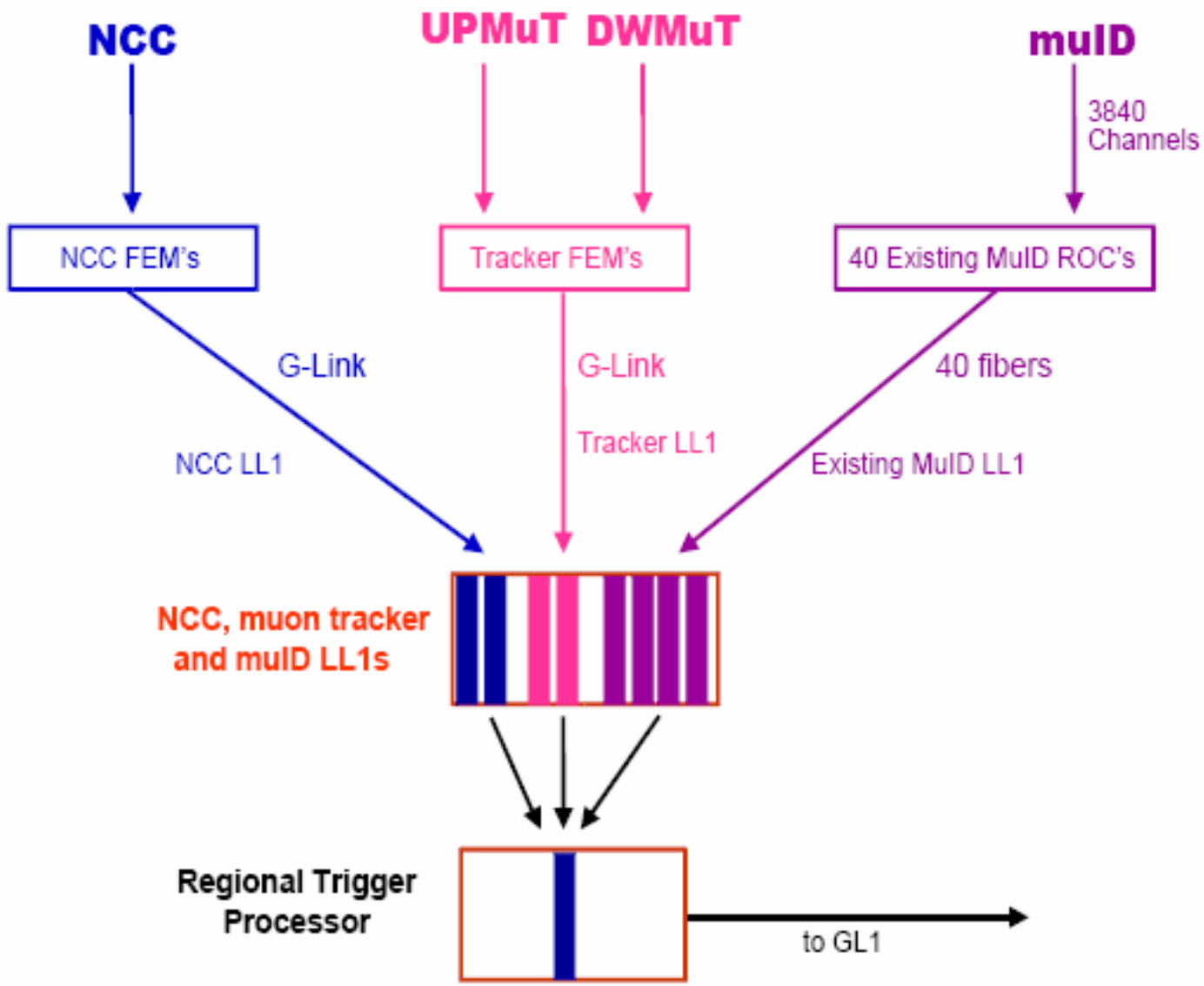
0.5 pb^{-1} pAu (run 12)

$\Delta\log(x_2)\ \Delta Q^2$=0.1x1 GeV^2

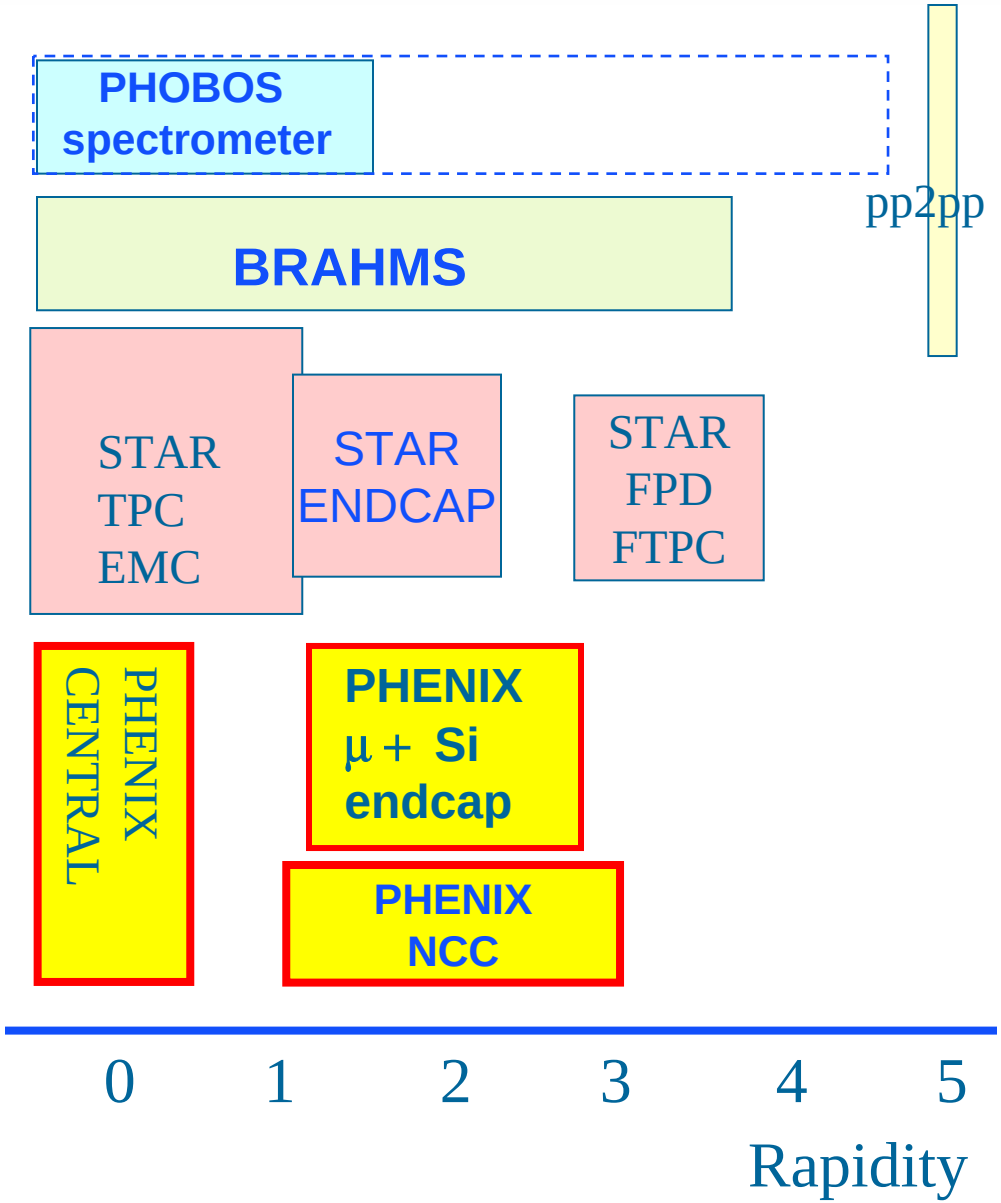
Direct photon



Level-1 triggering scheme



Summary



charged hadrons
A_N

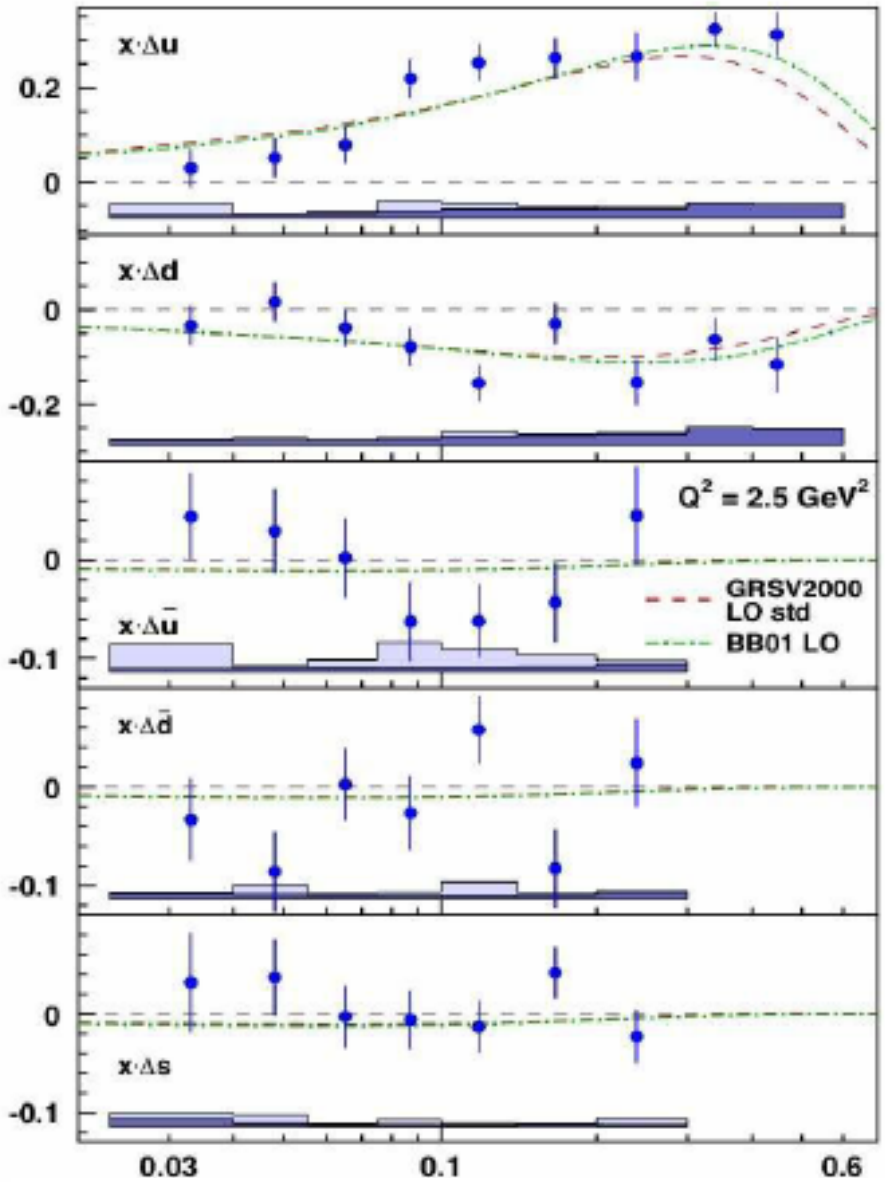
γ, π^0, jets, charm/beauty
A_N, A_L, A_{LL}

γ, π^0, jets, μ, $\mu\mu$, charm/beauty, eμ

A_N, A_L, A_{LL}

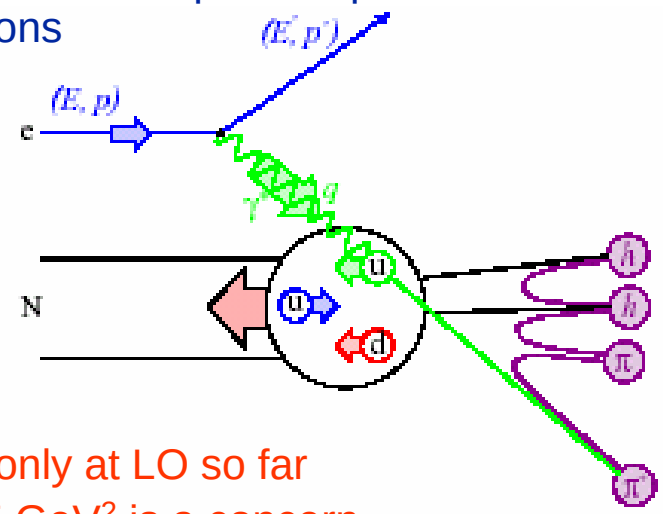
Extra slides …

Semi-inclusive DIS



- Hermes: Phys.Rev.Lett 92 (2004) 012005

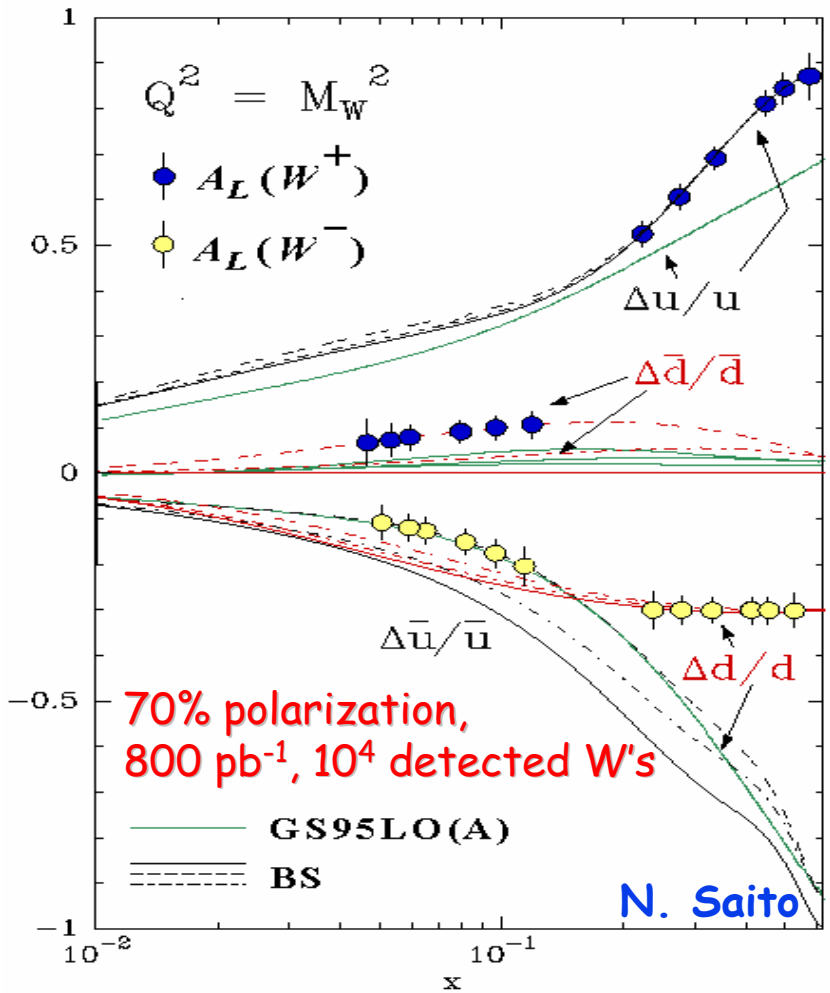
- In addition to the scattered electron, one measures in addition, the hadronic final state(s) – leading K's and π's
- Access to flavor separated parton distributions



Comments:

- Treated only at LO so far
- Q^2 of 2.5 GeV^2 is a concern
- Higher twist effects not included
- u-quark "dominance" limits precision of d and s-quark (and anti-quark) polarized distributions.
- "Hadron taging" technique relies on knowledge of fragmentation functions
- **Measurements at the highest Q^2 (RHIC) are important.**
- **W production (at RHIC) is an independent and eloquent technique**

Sensitivity goal: flavor decomposition



$A_L(W^+) \rightarrow \Delta u/u(x_1)$ @$x_1 \gg x_2$

$A_L(W^+) \rightarrow -\Delta d/d(x_1)$ @$x_2 \gg x_1$

(W^+ and W^- have a different acceptance)

- The measurement of inclusive single spin muon asymmetries is the least biased way to probe $\Delta q/q$, $\Delta \bar{q}/\bar{q}$.
  - Complete theoretical treatment from first principles by Nadolsky and Yuan using re-summation and NLO techniques [NuclPhysB 666(2003) 31].
  - PHENIX is in the process of re-evaluating their sensitivities using their NLO code.
- Measurement requires a trigger with rejection ~10,000.
  - Present muon trigger has a rejection of 250 (run 3).
  - Upgrade needed … requires momentum determination at level-1 to reject background due to hadron-decay's into μ's and beam related backgrounds.
- Nose-cone calorimeter important to help reject hadron jets off-line