Exploring Transverse Spin Physics at SeaQuest

Ming Liu

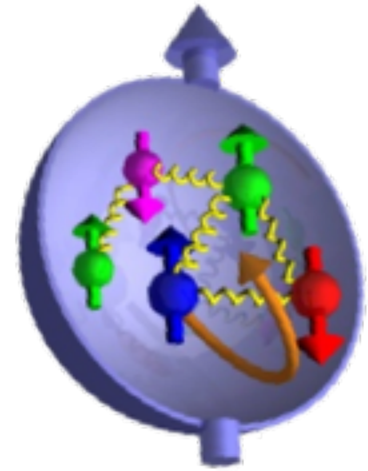
LANL

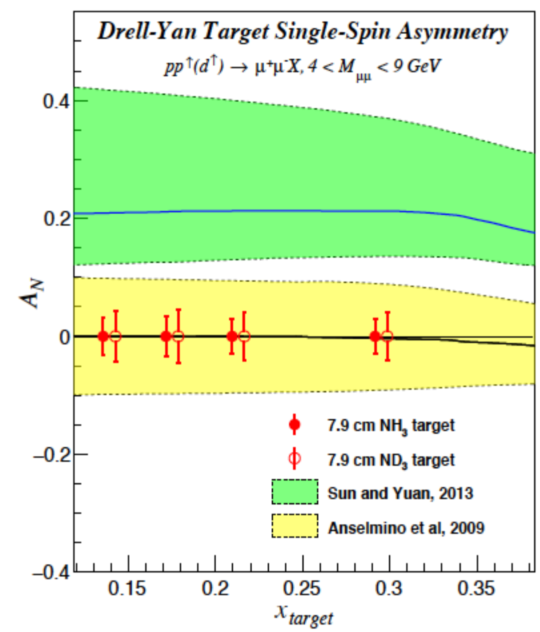
6/15/2018

SeaQuest/E1039 Collaboration Meeting

Outline

- Overview of latest TMD physics
  - Recent highlights and global fits
    - RHIC/W, charged hadrons, J/Psi, Charm
    - COMPASS DY, JLab
- SeaQuest opportunities
  - Sea quark Sivers,
    - ubar & dbar
  - Gluon Sivers at valence region
  - Transversity distributions
  - Experimental observables
    - J/Psi
    - Open charm
- Day-1 physics
  - Positive signal confirmation
  - Target and dump separation
  - Trigger optimization

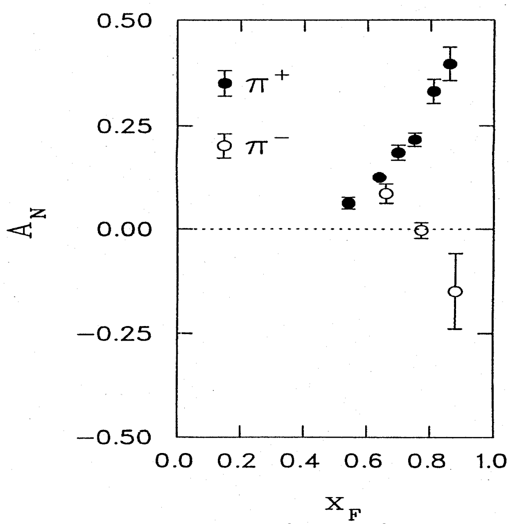




Four Decades of Transverse Spin Measurements
- Do we understand the physics?

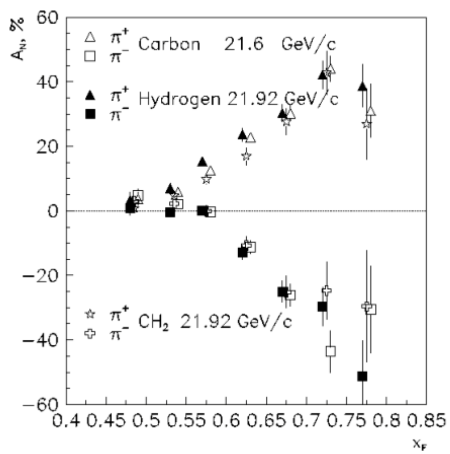
Large Transverse Single Spin Asymmetry (TSSA) in forward hadron production persists up to top RHIC energy.

ZGS 12 GeV beam



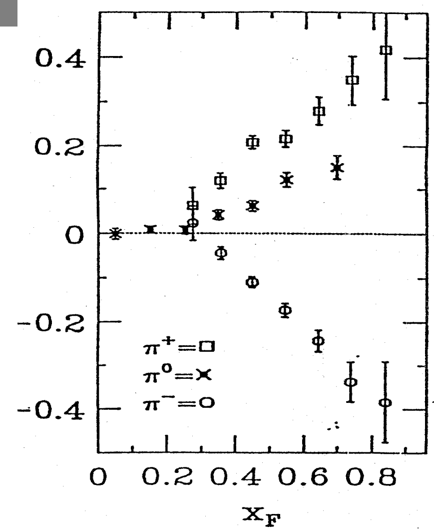
PRL36, 929 (1976)

AGS 22 GeV beam



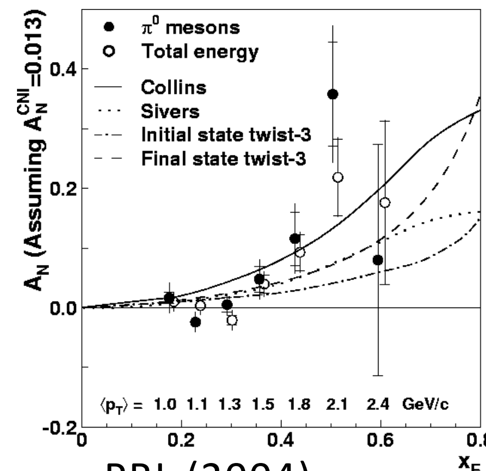
PRD65, 092008 (2002)

FNAL 200 GeV beam

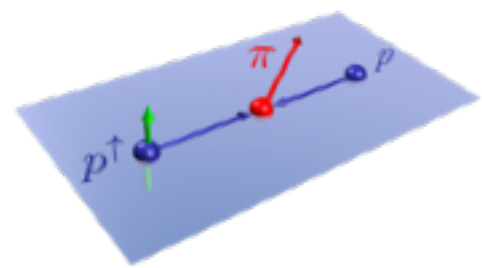


PLB261, 201 (1991)
PLB264, 462 (1991)

RHIC 200 GeV CMS



PRL (2004)

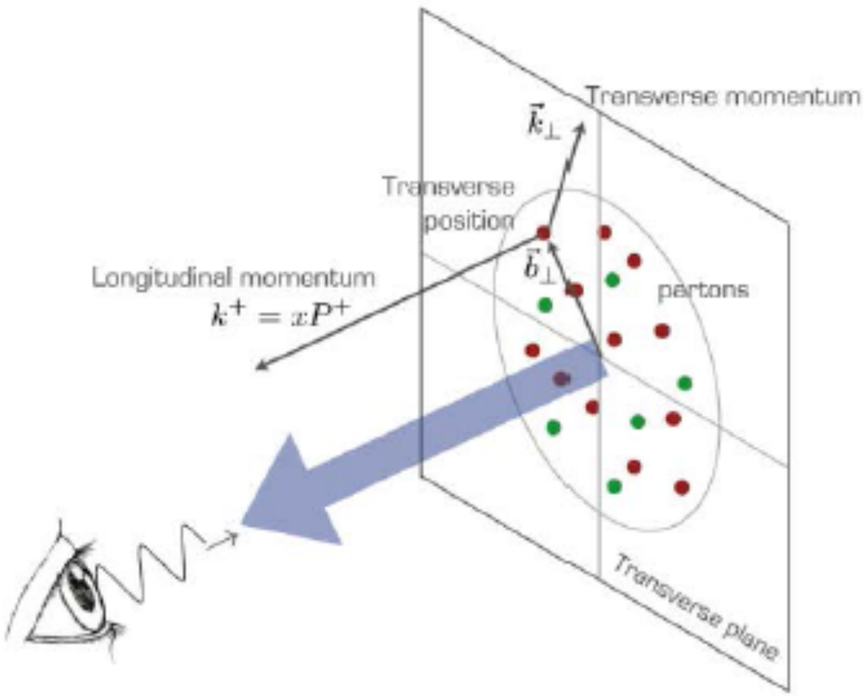


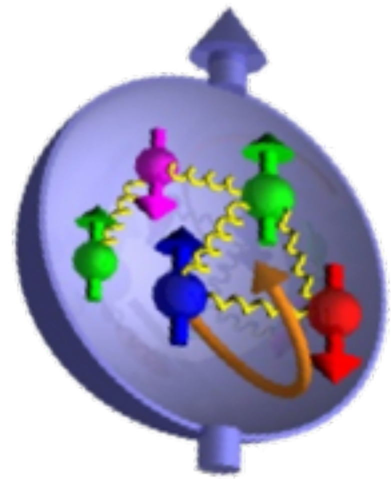
Sivers, Collins, Twist-3 ….

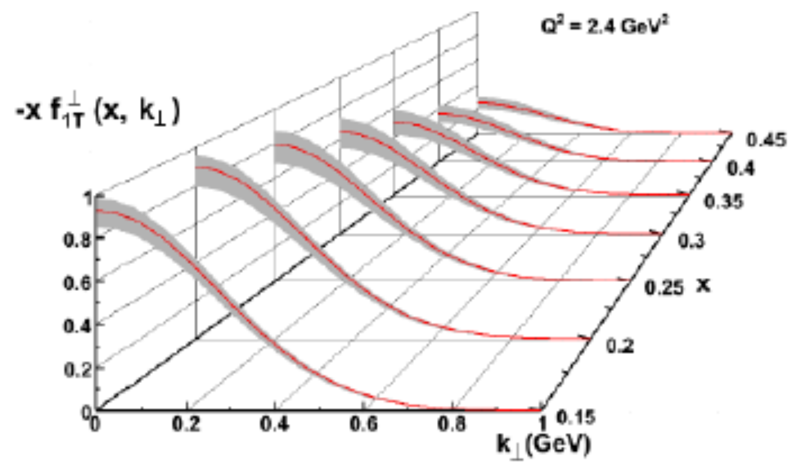
Non-Perturbative cross section → Perturbative cross section

Nucleon Structure and TMD

from Alessandro Bacchetta





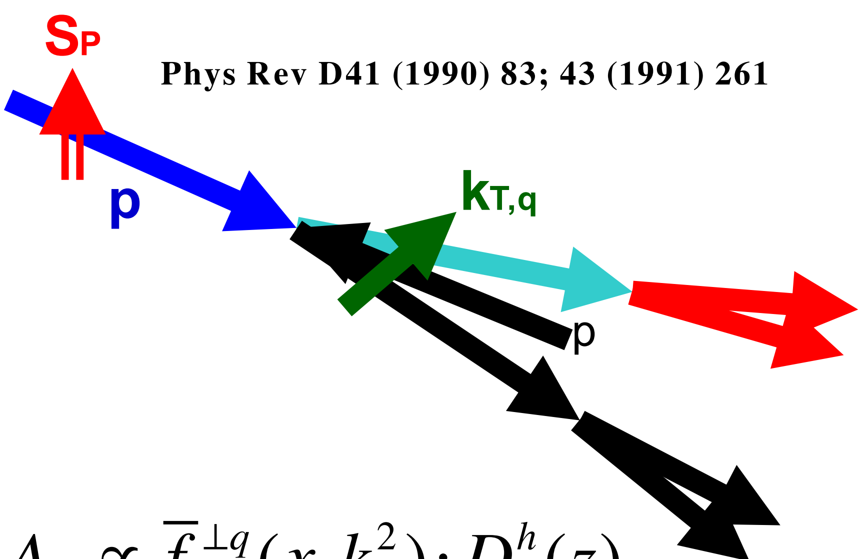


TMD: $f(x, k_T)$,

Sivers functions, quark transversity etc.

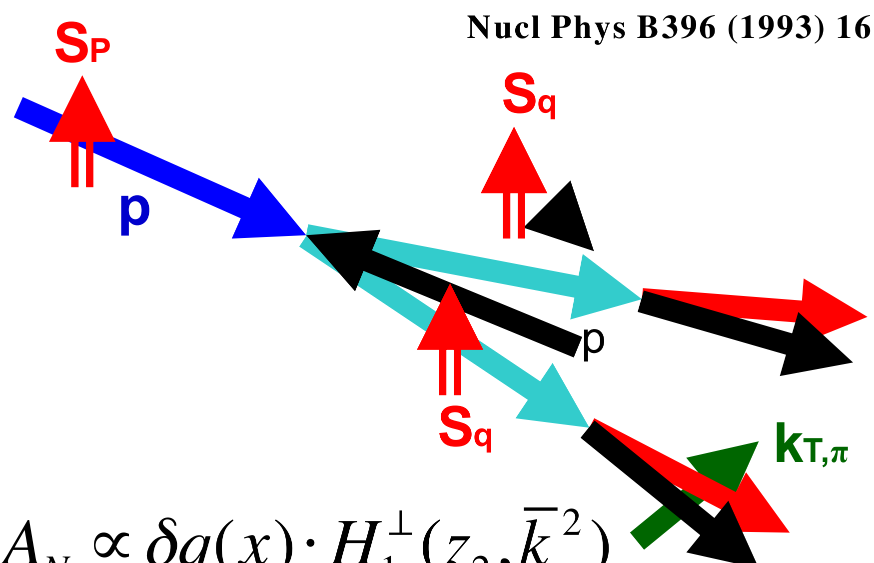
Probe the Underlying Physics via Hard Scatterings
TMD vs Collinear Twist-3 Factorizations

(i) Sivers mechanism:
correlation proton spin & parton k_T



$$A_N \propto \overline{f}_{1T}^{\perp q}(x,k_\perp^2)\cdot D_q^h(z)$$

(ii) Collins mechanism:
Transversity × spin-dep fragmentation



$$A_N \propto \delta q(x)\cdot H_1^\perp(z_2,\overline{k}_\perp^2)$$

Collinear Twist-3 (RHIC, Fermilab):

quark-gluon/gluon-gluon correlation

Hadron TSSA in p+p in Twist-3 Framework

Qiu & Sterman PRD 59 (1998)

$$\Delta\sigma_{A+B\to\pi}(\vec{s}_T) = \sum_{abc} \phi^{(3)}_{a/A}(x_1, x_2, \vec{s}_T) \otimes \phi_{b/B}(x') \otimes H_{a+b\to c}(\vec{s}_T) \otimes D_{c\to\pi}(z)$$

$$+ \sum_{abc} \delta q^{(2)}_{a/A}(x, \vec{s}_T) \otimes \phi^{(3)}_{b/B}(x'_1, x'_2) \otimes H''_{a+b\to c}(\vec{s}_T) \otimes D_{c\to\pi}(z)$$

$$+ \sum_{abc} \delta q^{(2)}_{a/A}(x, \vec{s}_T) \otimes \phi_{b/B}(x') \otimes H'_{a+b\to c}(\vec{s}_T) \otimes D^{(3)}_{c\to\pi}(z_1, z_2)$$

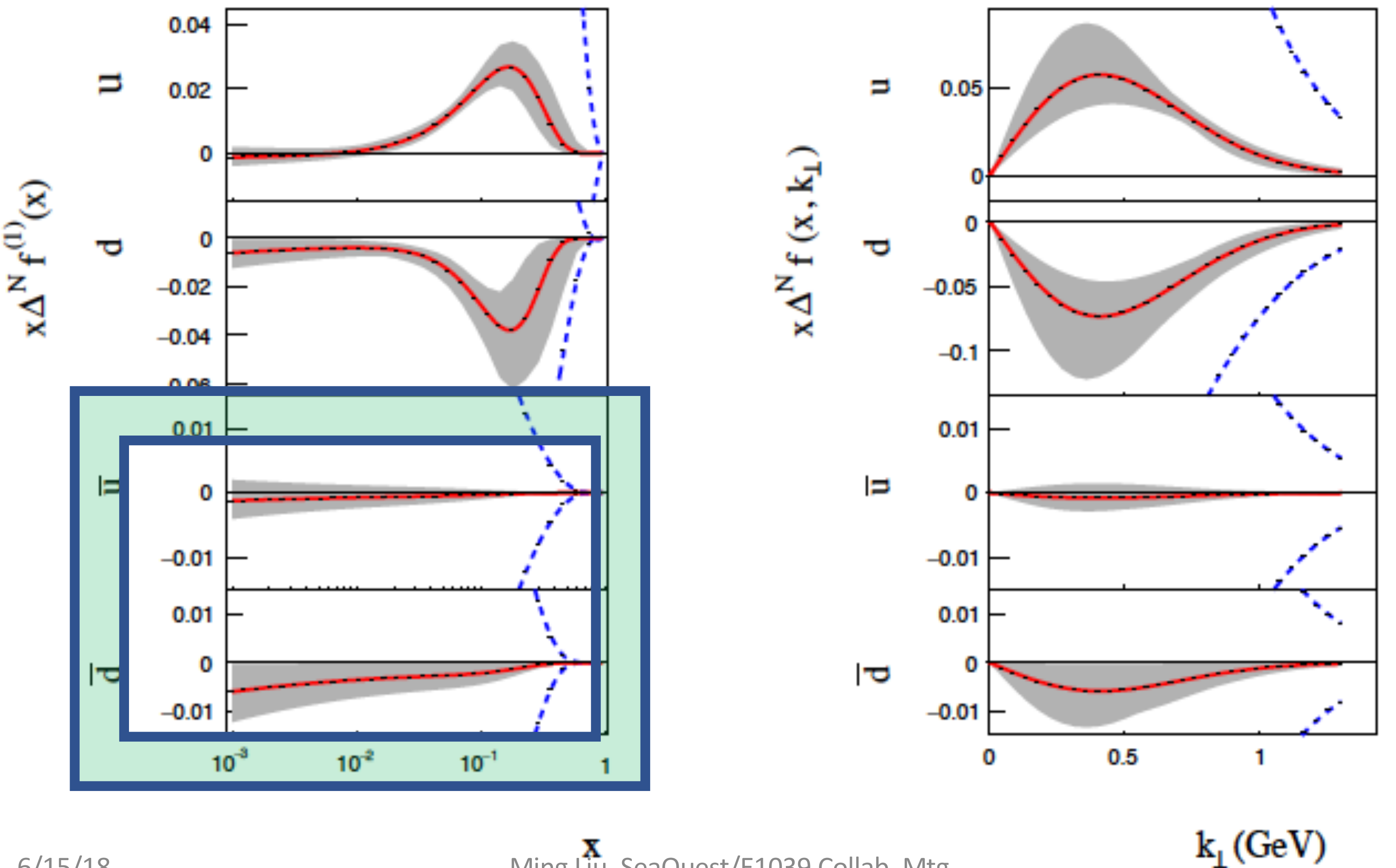
$$+ \text{higher power corrections},$$

1st term: twsit-3 correlation functions, "Sivers"
2nd term: twist-2 transversity * twist-3 from unpol beam (expected small)
3rd term: twist-2 transversity * twist-3 FF, "Collins"

Sivers Functions from Global Fits – Quarks

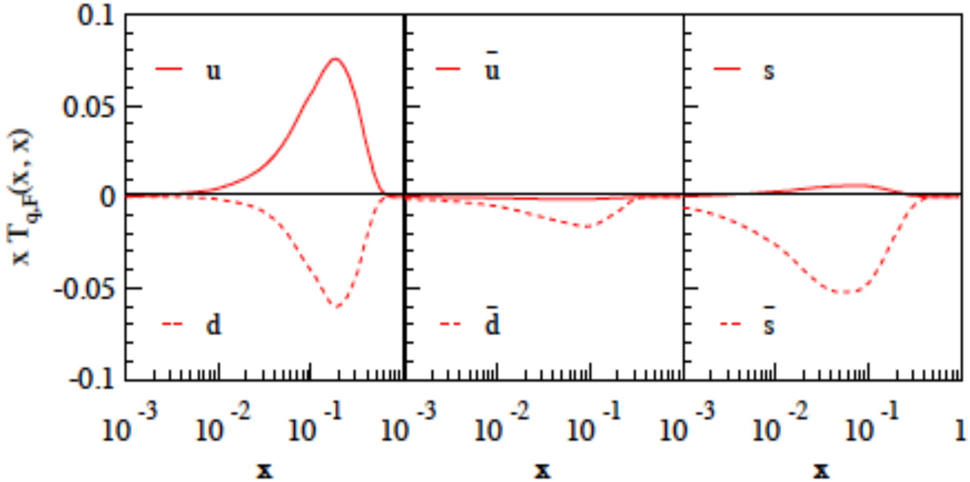
- Sea Quark Sivers poorly constrained, but seem small

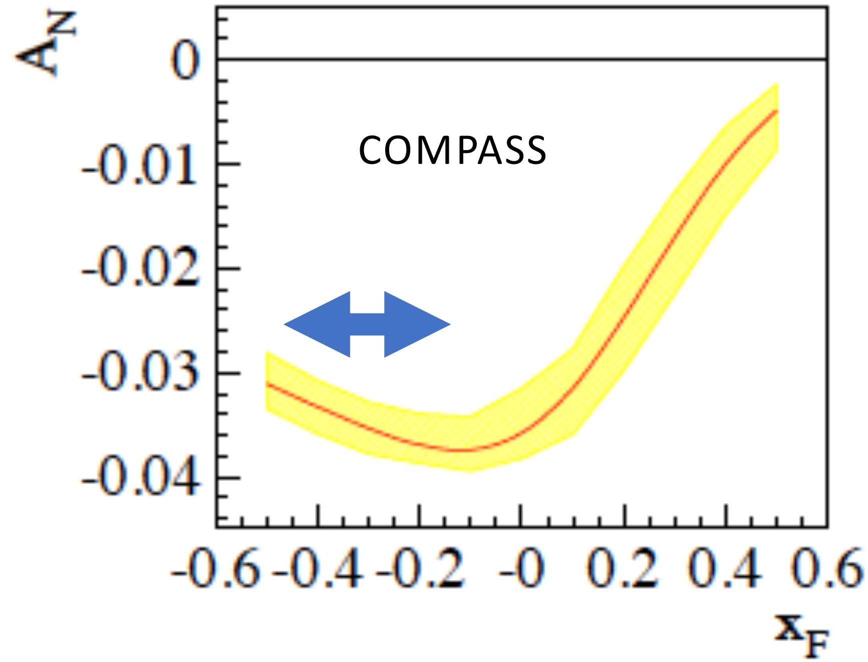
1612.06413, M. Anselmino et al

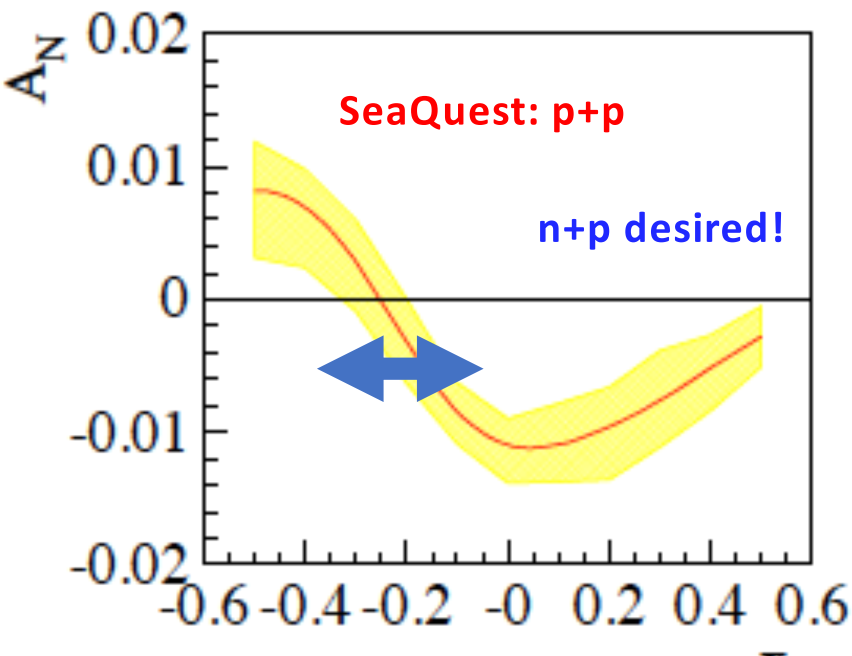


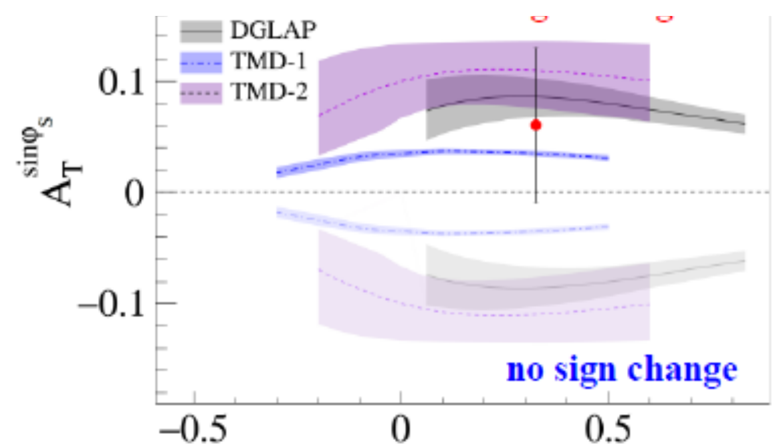
Drell-Yan Sivers Asymmetries

Kang et al, 1401.5078

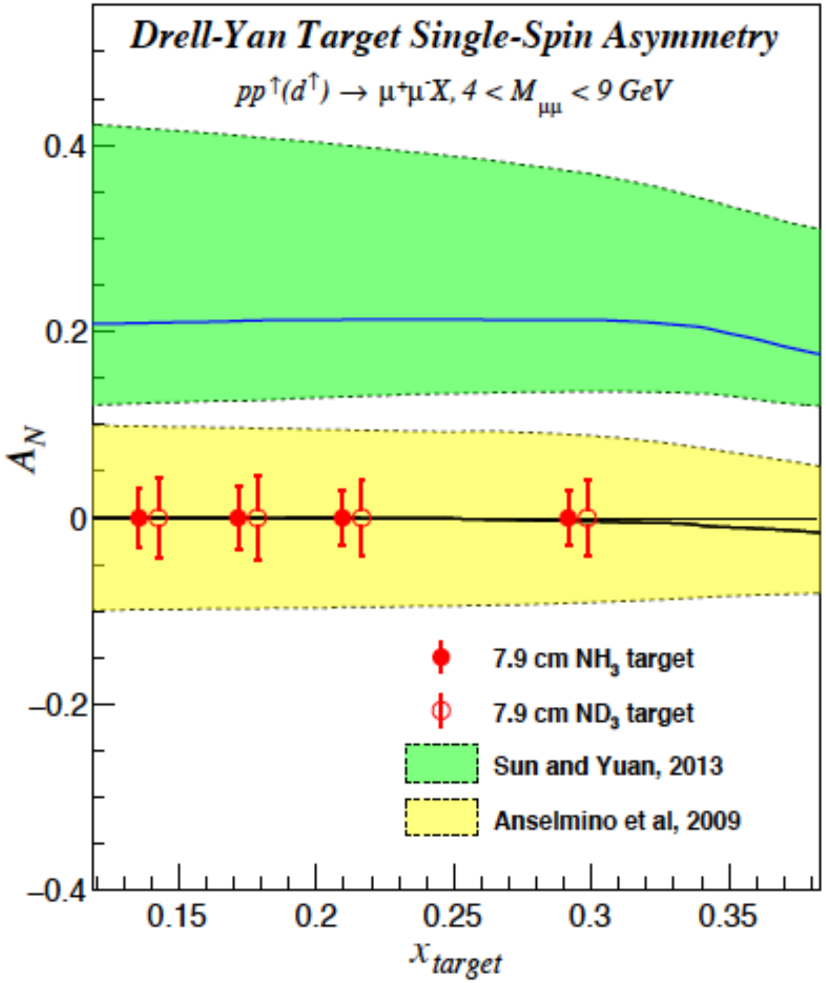




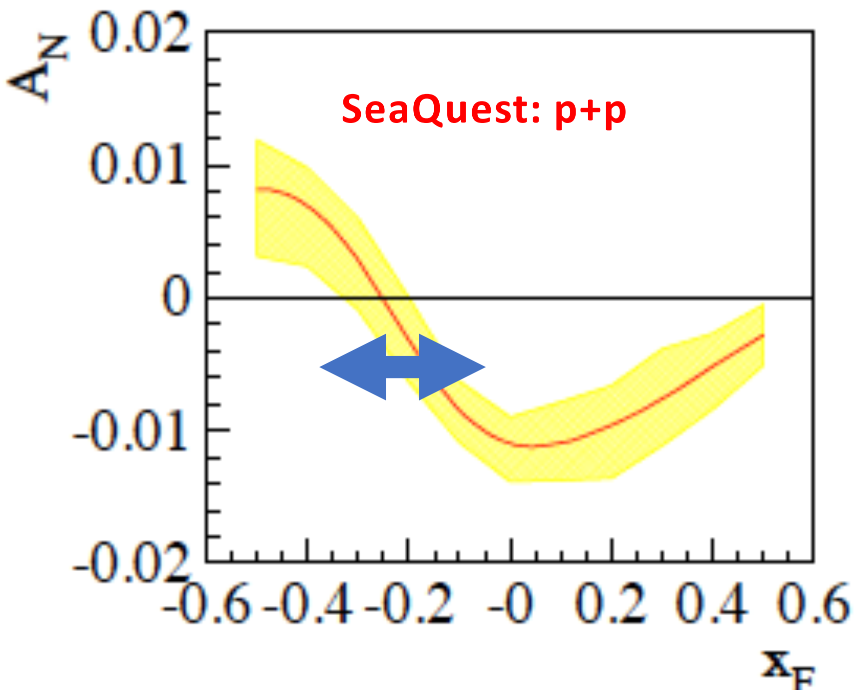




E1039 DY A_N Sensitivity

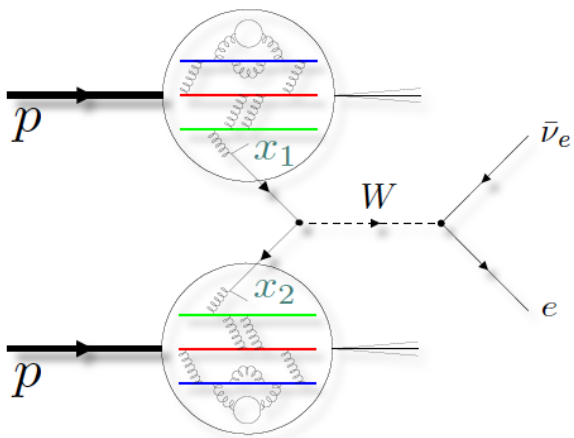


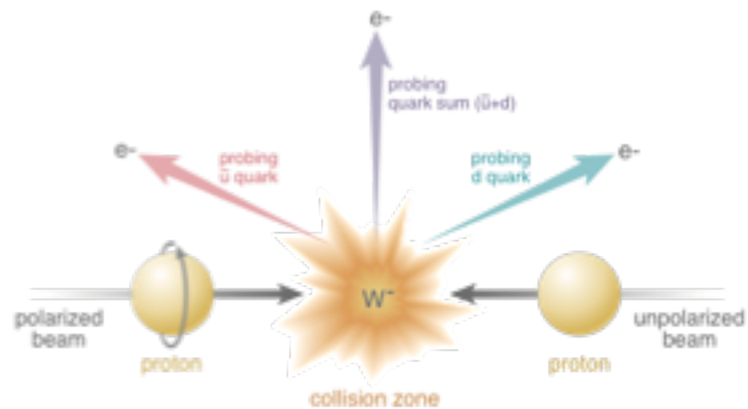
It is critical to control of systematic errors for high precision measurements



Electroweak Probe for Sea Quarks at High Energy at RHIC

$$q(x_1) + \bar{q}'(x_2) \rightarrow W^{\pm} \rightarrow e^{\pm} + \nu(\bar{\nu})$$





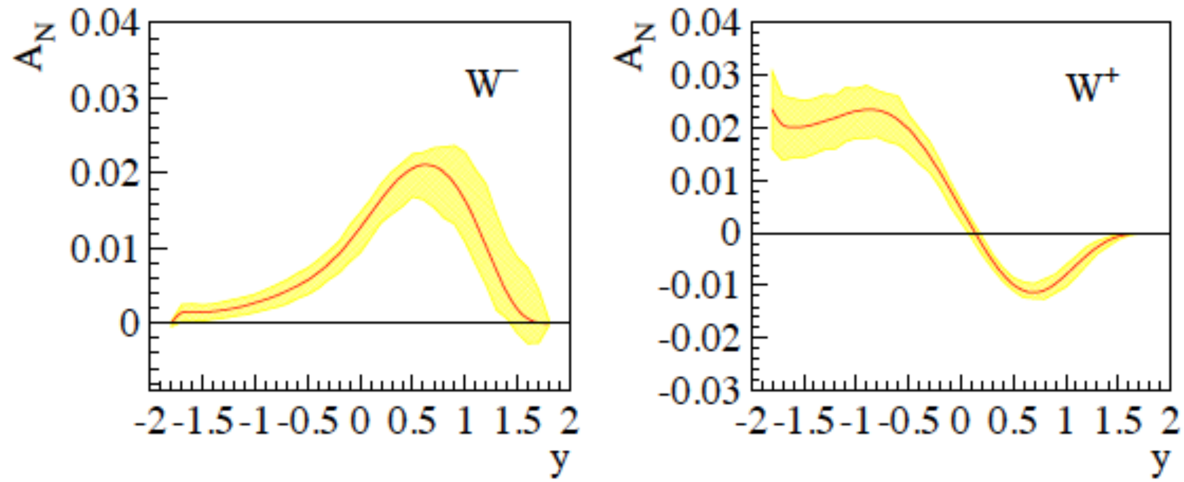
$A_N(W^+) \sim \left(\Delta^N f_{u/p^\uparrow} \otimes f_{\bar{d}/p} + \underline{\Delta^N f_{\bar{d}/p^\uparrow}} \otimes f_{u/p}\right)$

$A_N(W^-) \sim \left(\underline{\Delta^N f_{\bar{u}/p^\uparrow}} \otimes f_{d/p} + \Delta^N f_{d/p^\uparrow} \otimes f_{\bar{u}/p}\right)$

Sensitive to flavor identified (sea)quarks' Sivers functions

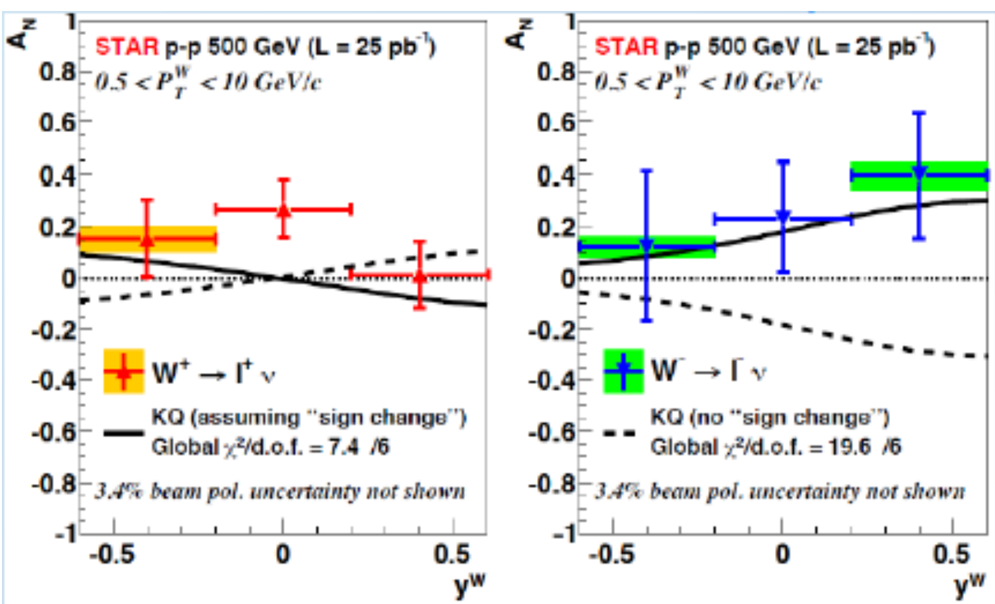
RHIC $W^{+/-}$ TSSA: Sea Quark Sivers

QCD Evolution included, Kang et al, 2014



QCD evolution:
reduces the amplitude

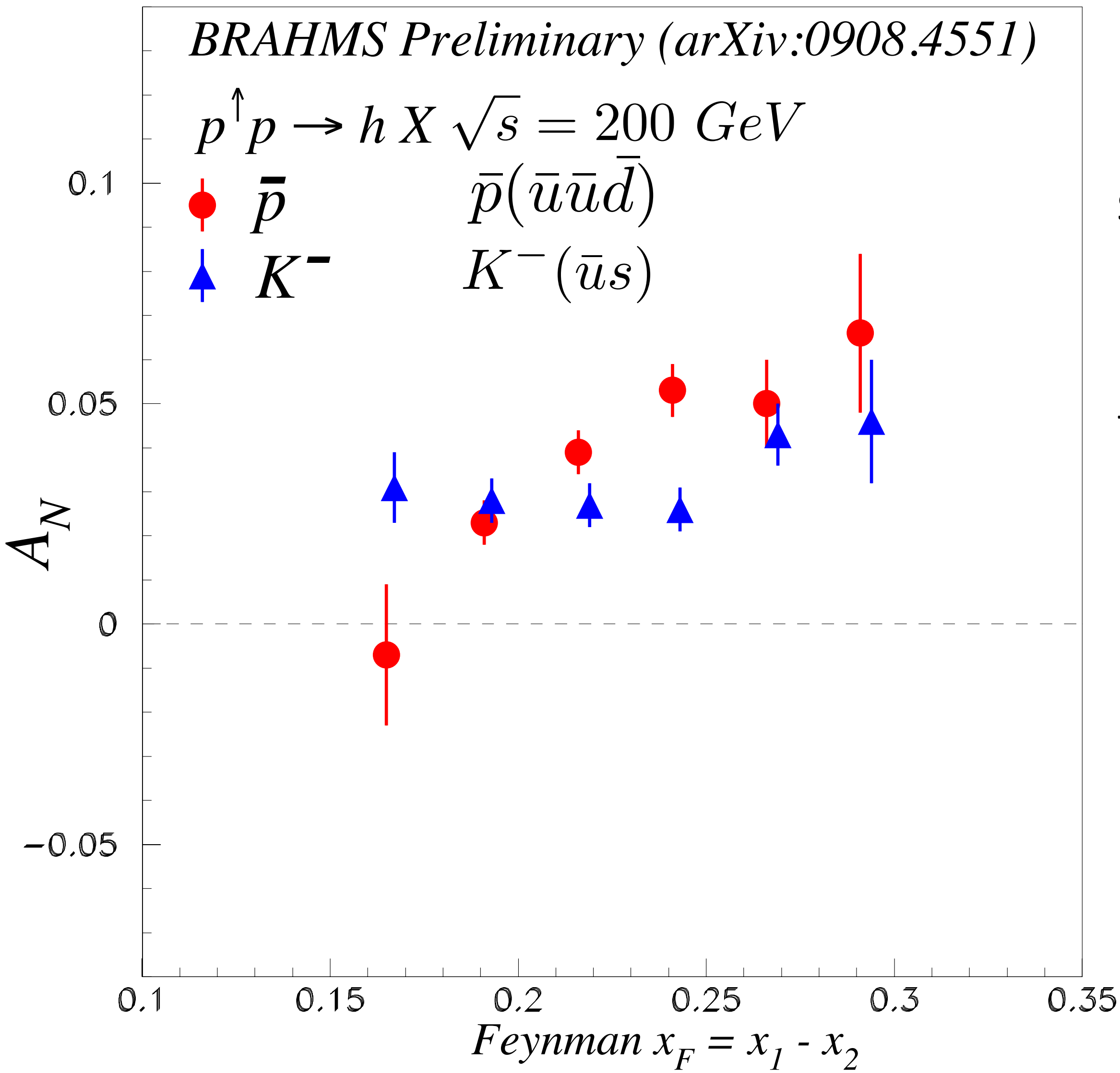
Anselmino et al 2016



RHIC data:
Statistically limited, ~0(10%)

E1039:
- lower Q^2
- Better statistics, ~O(1%)

Non-Vanishing Sea Quark Sivers Distribution ?

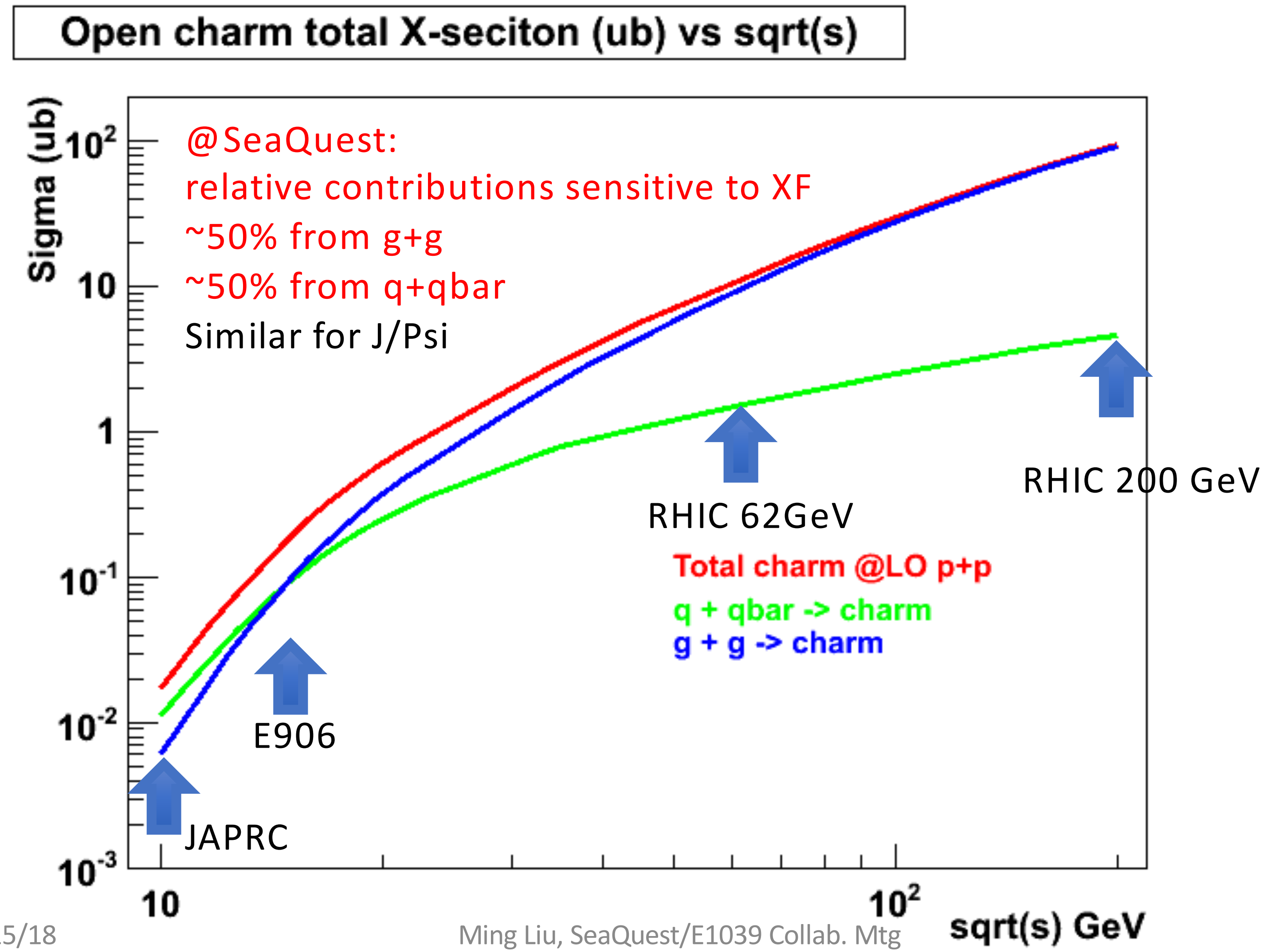


Sea quark generates left-right bias ?

Left-right bias generated through fragmentation process ?

But the asymmetry from sea-quark could not be very large

Open Charm Production in p+p at LO - access gluon distribution

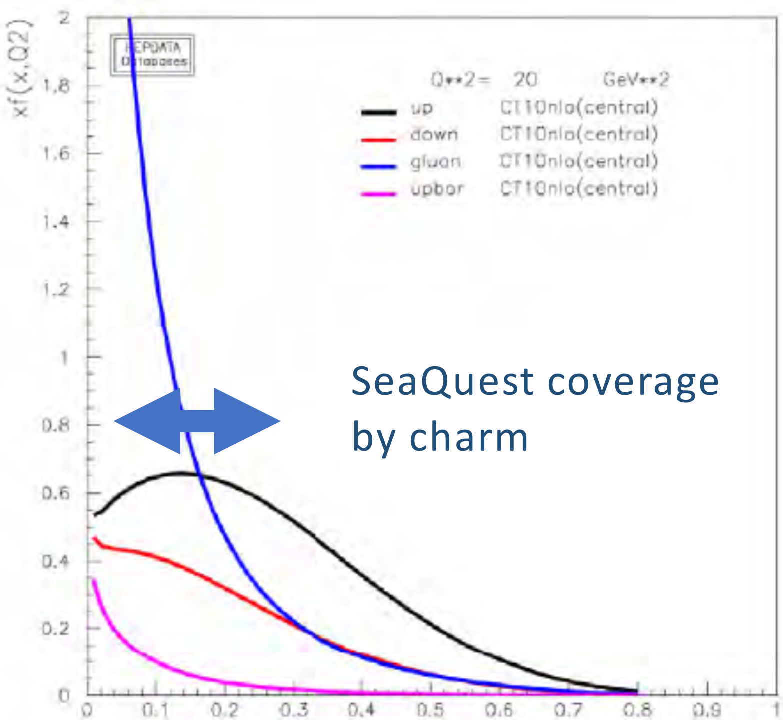


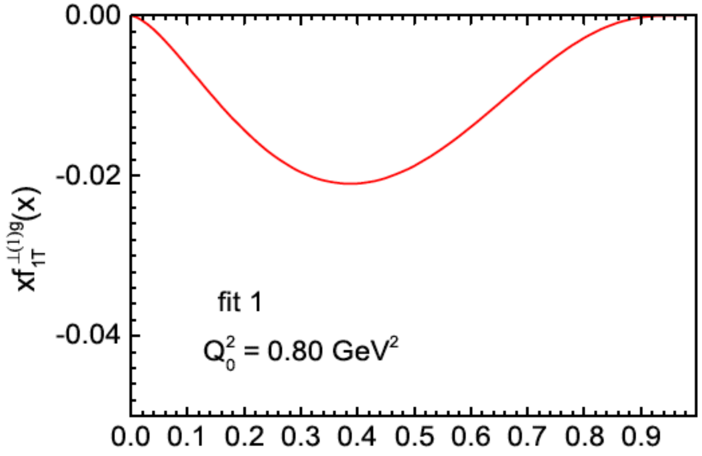
Gluon Sivers in the Valence Region
- a lot of gluons at high x!

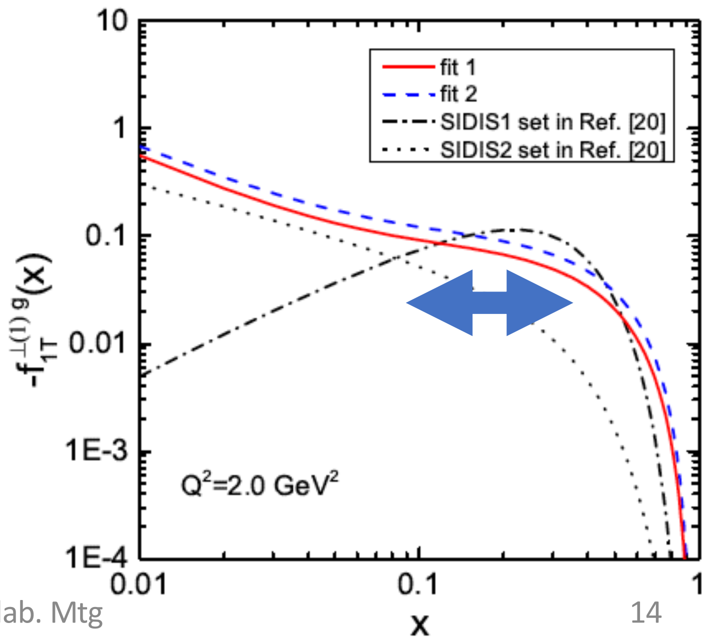
1611.00125 Z. Lu & B.Q. Ma

- Gluon Sivers poorly known

Unpolarized PDF:
Glons dominate at x < 0.2



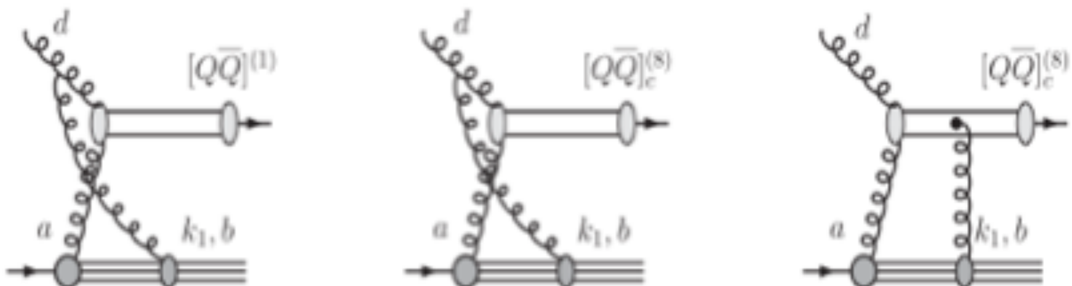




J/ψ A_N

- ❑ J/ψ A_N is sensitive to the production mechanisms
  - Assuming a non-zero gluon Sivers function, in pp scattering, J/ψ A_N vanishes if the pair are produced in a color-octet model but survives in the color-singlet model

F. Yuan, PRD 78, 014024(2008)



One color-singlet diagram
— no cancellation, asymmetry generated by the initial state interaction, $A_N \neq 0$

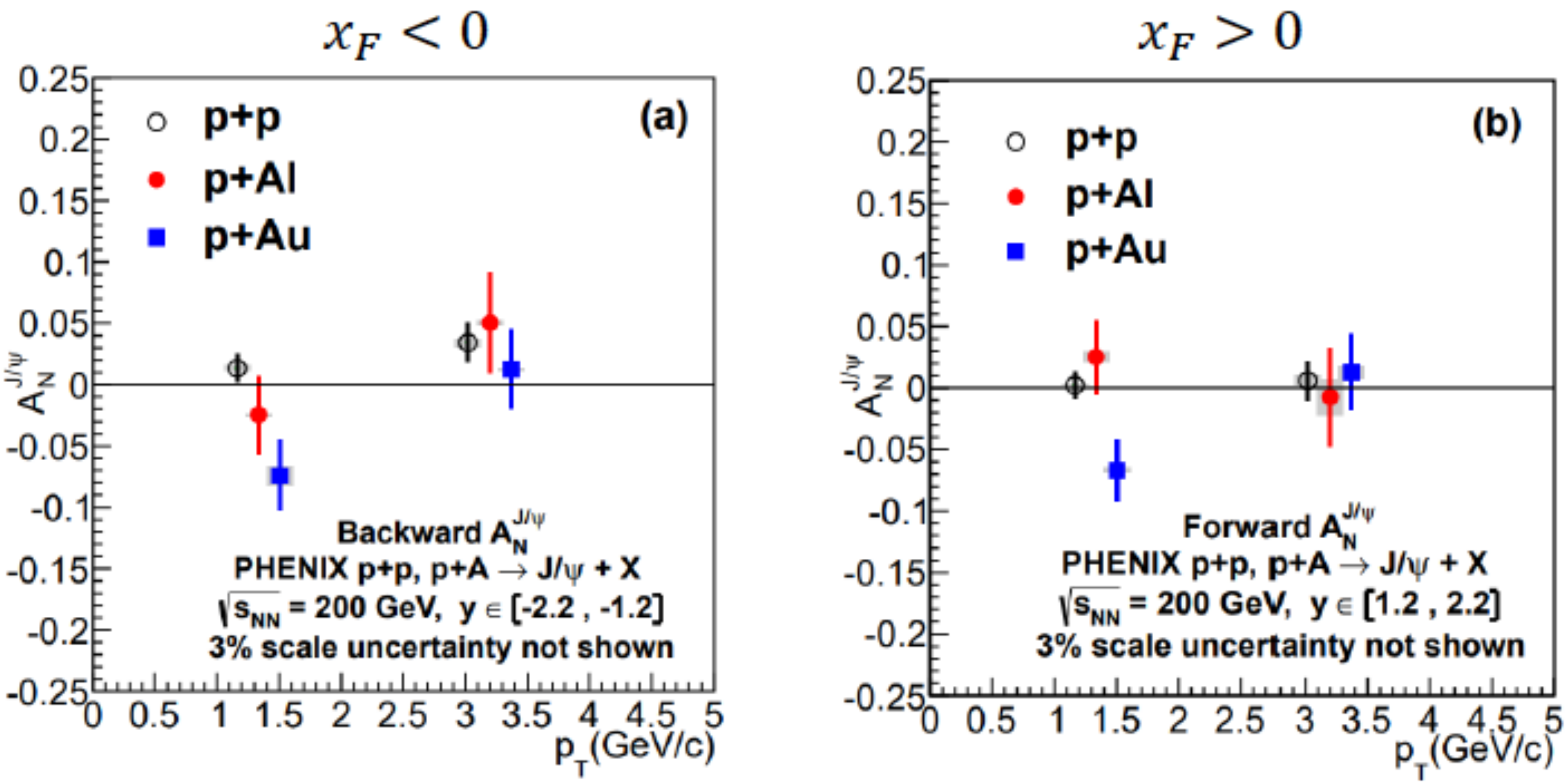
Two color-octet diagrams
— cancellation between initial and final state interactions, no asymmetry $A_N=0$

Heavy Flavor: J/ψ A_N

Some nuclear final state effects?

$$J/\Psi \rightarrow \mu^{+}\mu^{-}$$

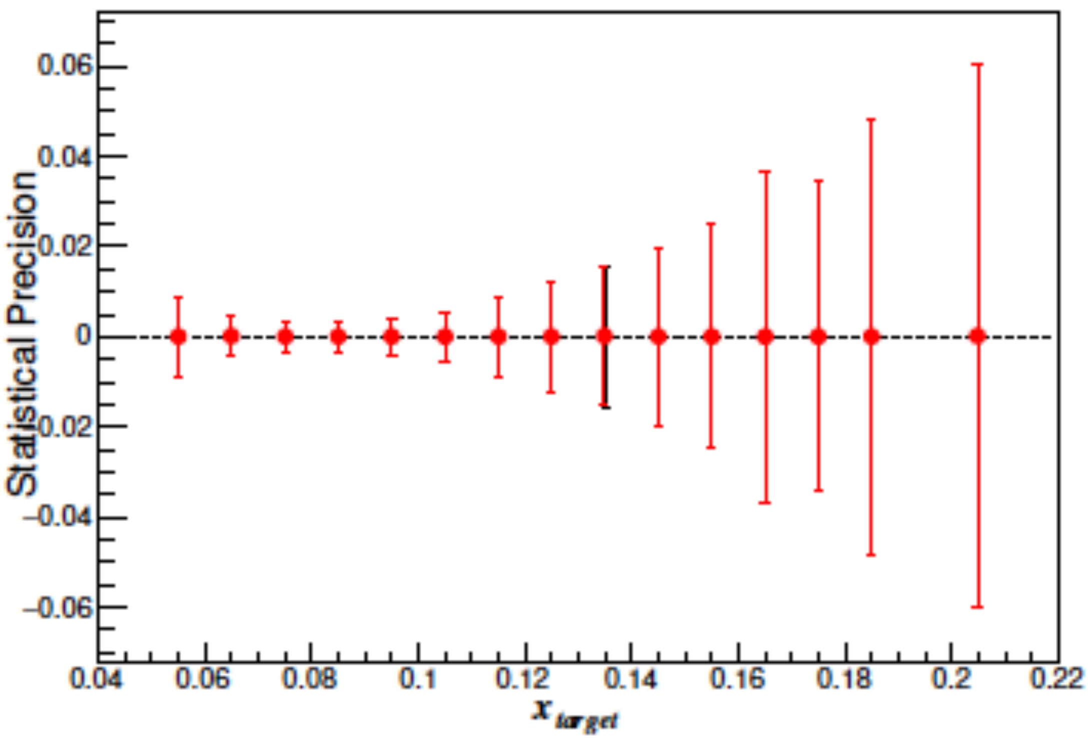
PHENIX: 1805.01491



High Precision A_N Measurements @SeaQuest

Cross section contributions:
- gluon+gluon
- u + ubar
- d + dbar, could be significant

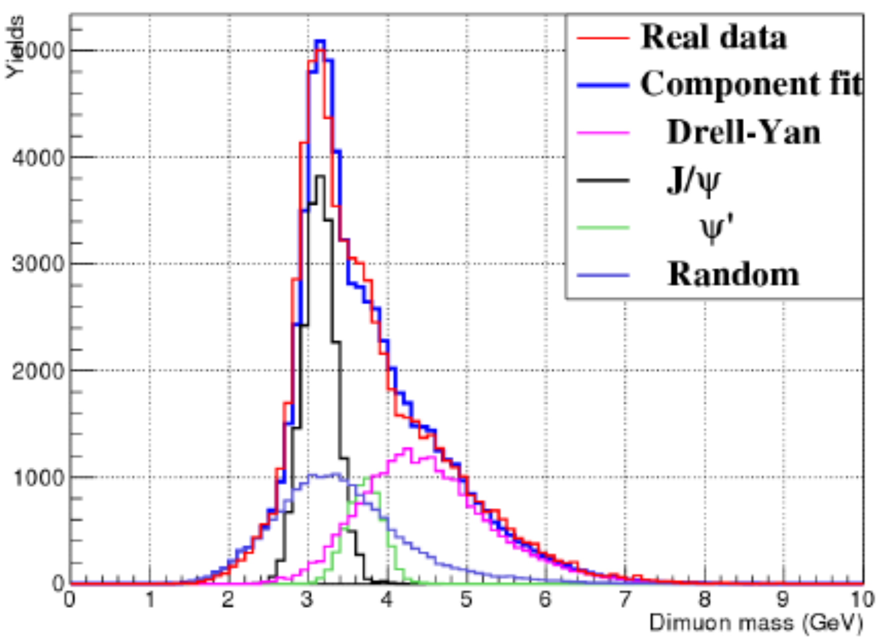
- Sivers functions:
  - Gluon
  - ubar
  - dbar



Polarized targets:
- NH3
- ND3

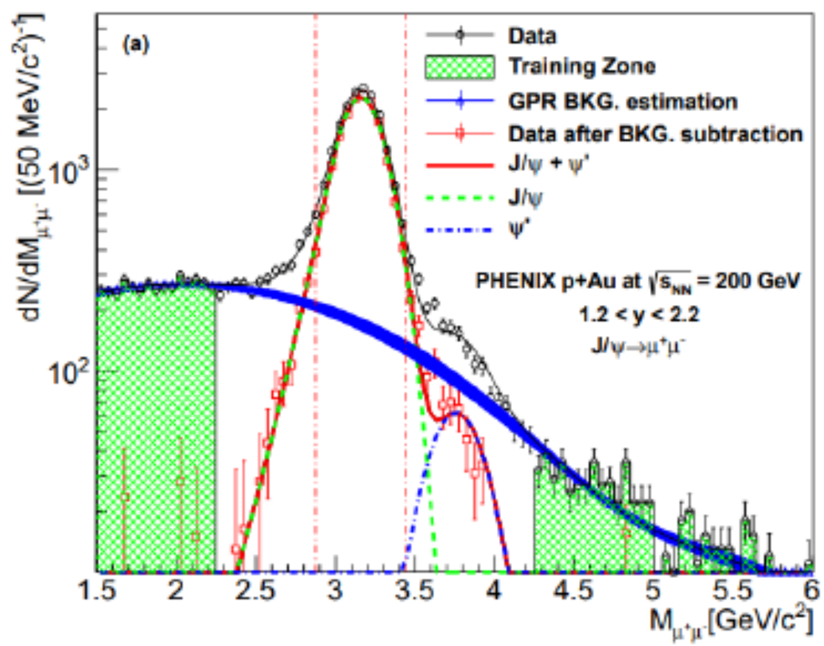
SeaQuest Dimuons:
Improve acceptance for low mass dimuons

Open up dimuon acceptance at trigger level:
- Possible with the dark photon triggers
- Improved DAQ
- Better background determination



E906 preliminary

PHENIX dimuons



Open Charm TSSA in Twist-3 Approach

Factorized formula for D-meson production

Qiu, 2010

- Same factorized formula for both subprocesses:

$$E_{P_h}\frac{d\Delta\sigma}{d^3P_h}\bigg|_{q\bar{q}\to c\bar{c}} = \frac{\alpha_s^2}{S}\sum_q\int\frac{dz}{z^2}D_{c\to h}(z)\int\frac{dx'}{x'}\phi_{\bar{q}/B}(x')\int\frac{dx}{x}\sqrt{4\pi\alpha_s}\left(\frac{\epsilon^{P_h s_T n\bar{n}}}{z\tilde{u}}\right)\delta\left(\tilde{s}+\tilde{t}+\tilde{u}\right)$$
$$\times\left[\left(T_{q,F}(x,x)-x\frac{d}{dx}T_{q,F}(x,x)\right)H_{q\bar{q}\to c}(\tilde{s},\tilde{t},\tilde{u})+T_{q,F}(x,x)\mathcal{H}_{q\bar{q}\to c}(\tilde{s},\tilde{t},\tilde{u})\right],$$

$$E_{P_h}\frac{d\Delta\sigma}{d^3P_h}\bigg|_{gg\to c\bar{c}} = \frac{\alpha_s^2}{S}\sum_{i=f,d}\int\frac{dz}{z^2}D_{c\to h}(z)\int\frac{dx'}{x'}\phi_{g/B}(x')\int\frac{dx}{x}\sqrt{4\pi\alpha_s}\left(\frac{\epsilon^{P_h s_T n\bar{n}}}{z\tilde{u}}\right)\delta\left(\tilde{s}+\tilde{t}+\tilde{u}\right)$$
$$\times\left[\left(T_G^{(i)}(x,x)-x\frac{d}{dx}T_G^{(i)}(x,x)\right)H_{gg\to c}^{(i)}(\tilde{s},\tilde{t},\tilde{u})+T_G^{(i)}(x,x)\mathcal{H}_{gg\to c}^{(i)}(\tilde{s},\tilde{t},\tilde{u})\right],$$

- Hard parts:

$$H_{q\bar{q}\to c}=H_{q\bar{q}\to c}^{I}+H_{q\bar{q}\to c}^{F}\left(1+\frac{\tilde{u}}{\tilde{t}}\right) \qquad H_{gg\to c}^{(i)}=H_{gg\to c}^{I(i)}+H_{gg\to c}^{F(i)}\left(1+\frac{\tilde{u}}{\tilde{t}}\right)$$

All $\mathcal{H}_{q\bar{q}\to c}$ and $\mathcal{H}_{gg\to c}^{I(i)}$ and $\mathcal{H}_{gg\to c}^{F(i)}$ vanish as $m_c^2\to 0$

- Hard parts change sign for $T_G^{(d)}(x,x)$ when $c\to\bar{c}$

$$H_{gg\to\bar{c}}^{(f)}=H_{gg\to c}^{(f)}, \qquad H_{gg\to\bar{c}}^{(d)}=-H_{gg\to c}^{(d)},$$
$$\mathcal{H}_{gg\to\bar{c}}^{(f)}=\mathcal{H}_{gg\to c}^{(f)}, \qquad \mathcal{H}_{gg\to\bar{c}}^{(d)}=-\mathcal{H}_{gg\to c}^{(d)}.$$

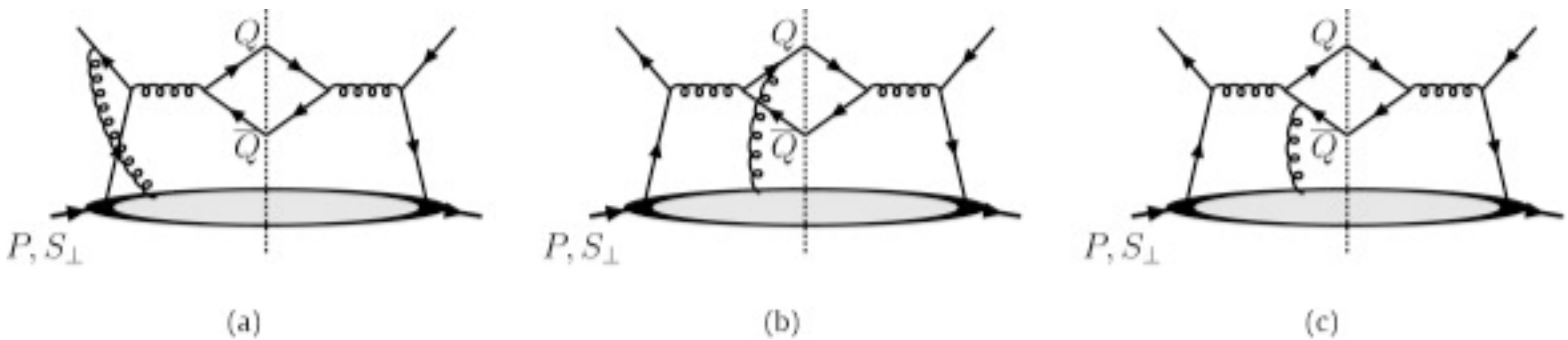
Heavy Quark TSSA @Fermilab

Twist-3 quark-gluon correlation functions

- Different color factors for charm and anti-charm A_N

$$q+\bar{q}\rightarrow c\bar{c}$$

F. Yuan and J. Zhou PLB 668 (2008) 216-220

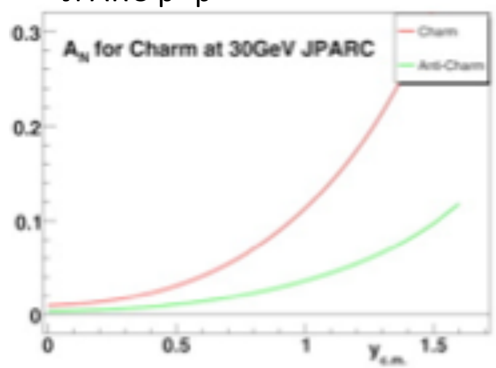


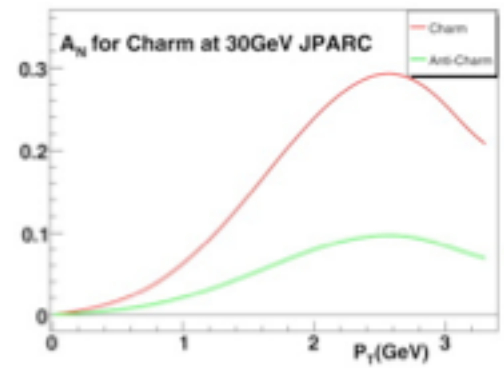
Initial state	Charm	anti-Charm
$\sim\frac{1}{2N_C^2}$	$\sim\frac{N_C^2-2}{2N_C^2}$	$\sim\frac{2}{2N_C^2}$

Open Charm TSSA at Low Energy

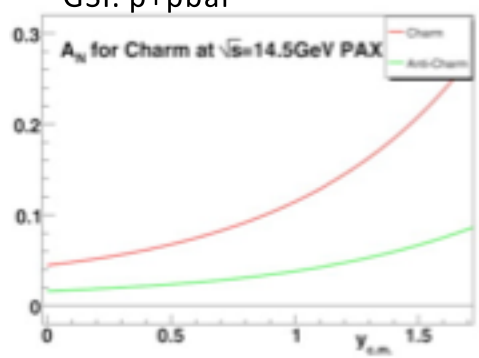
$$A_N : q + \bar{q} \rightarrow c(\bar{c}) + X$$

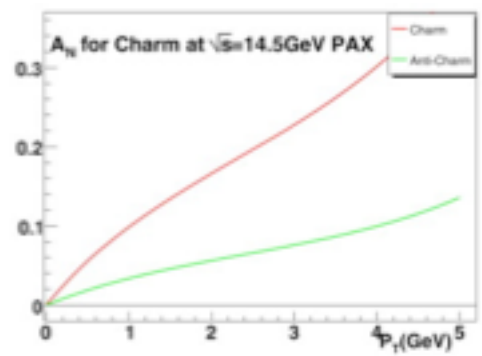
JPARC p+p





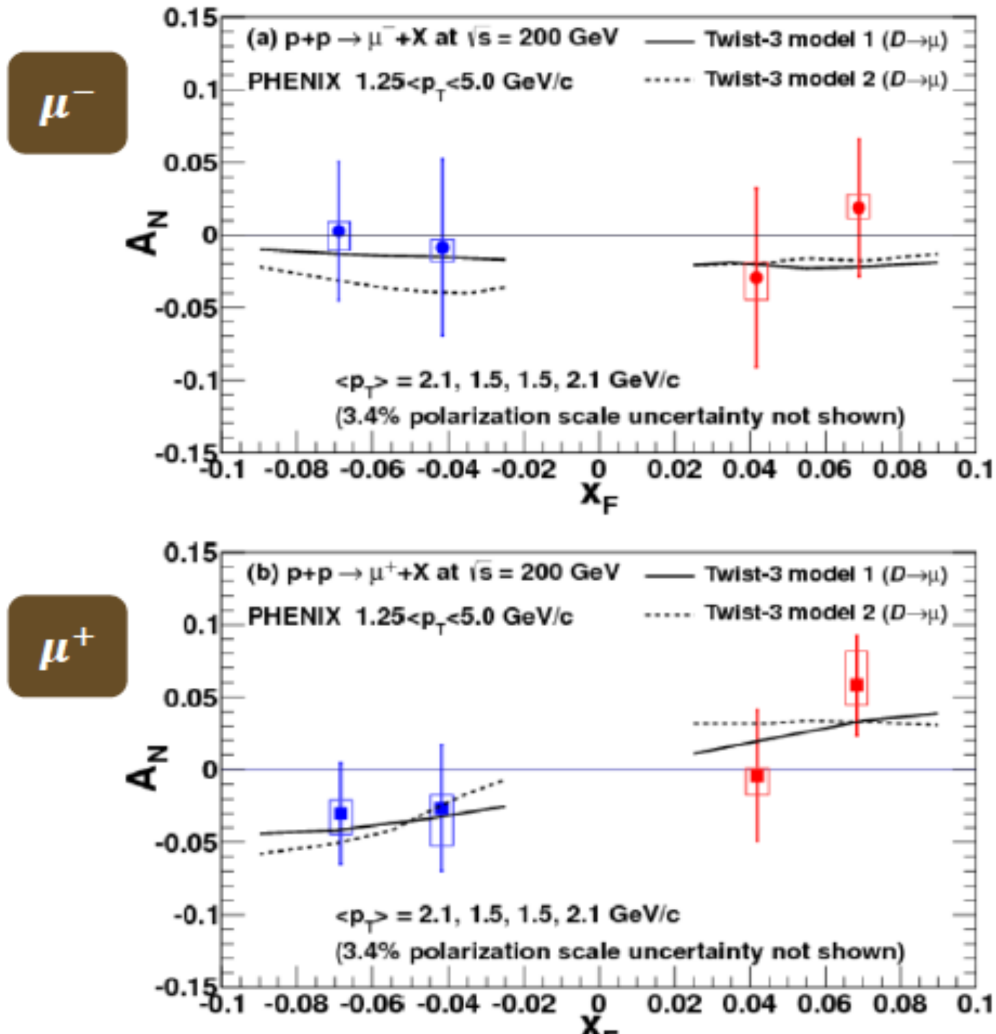
GSI: p+pbar





First Precision Open HF A_N from PHENIX

Phys.Rev. D95, 112001 (2017)

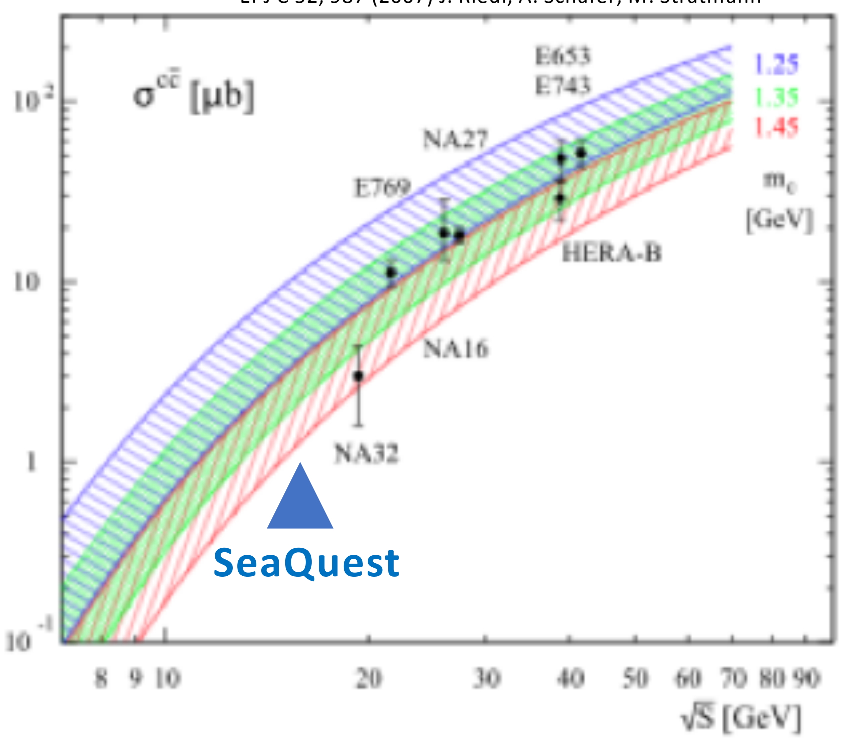


$$x_F = 2p_L/\sqrt{s}$$

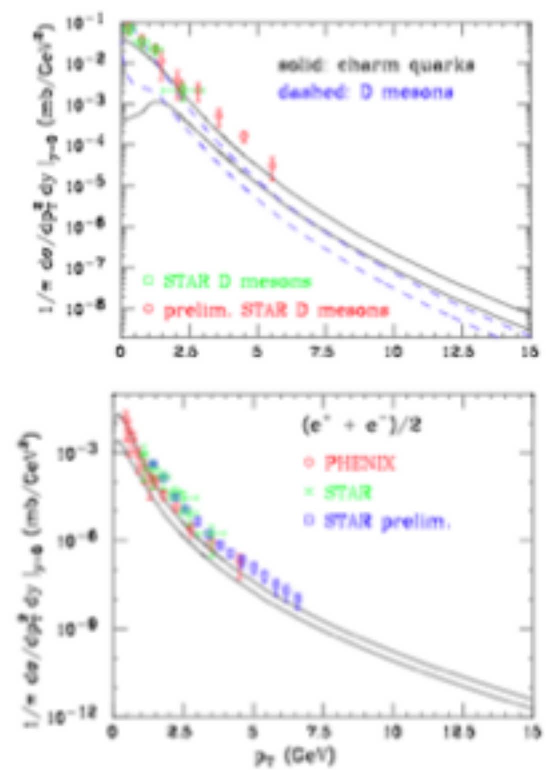
More on Open Charm Production

- Fixed targets vs NLO
- Collider mode @RHIC

EPJ C 52, 987 (2007) J. Riedl, A. Schafer, M. Stratmann



PRL 95, 122001 (2005) M. Cacciari, P. Nason, R. Vogt



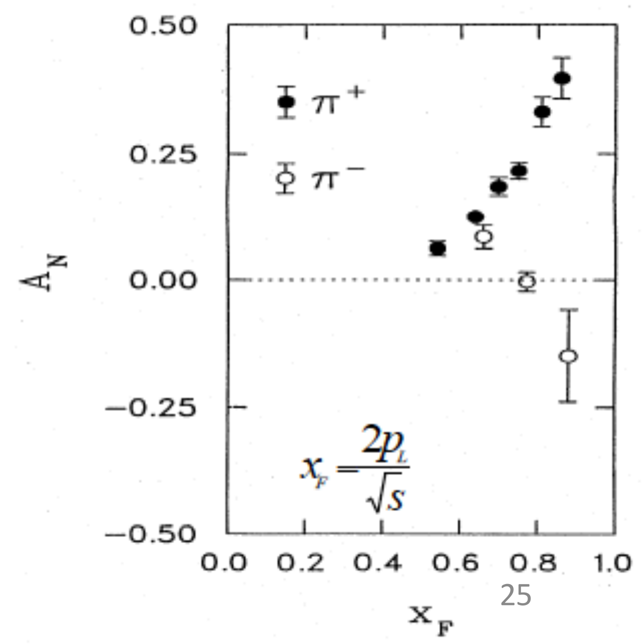
Open Charm via high pT Single muons?

- Open charm cross section
  - Test NLO pQCD framework
- Open charm TSSA
  - test pQCD twist-3 framework

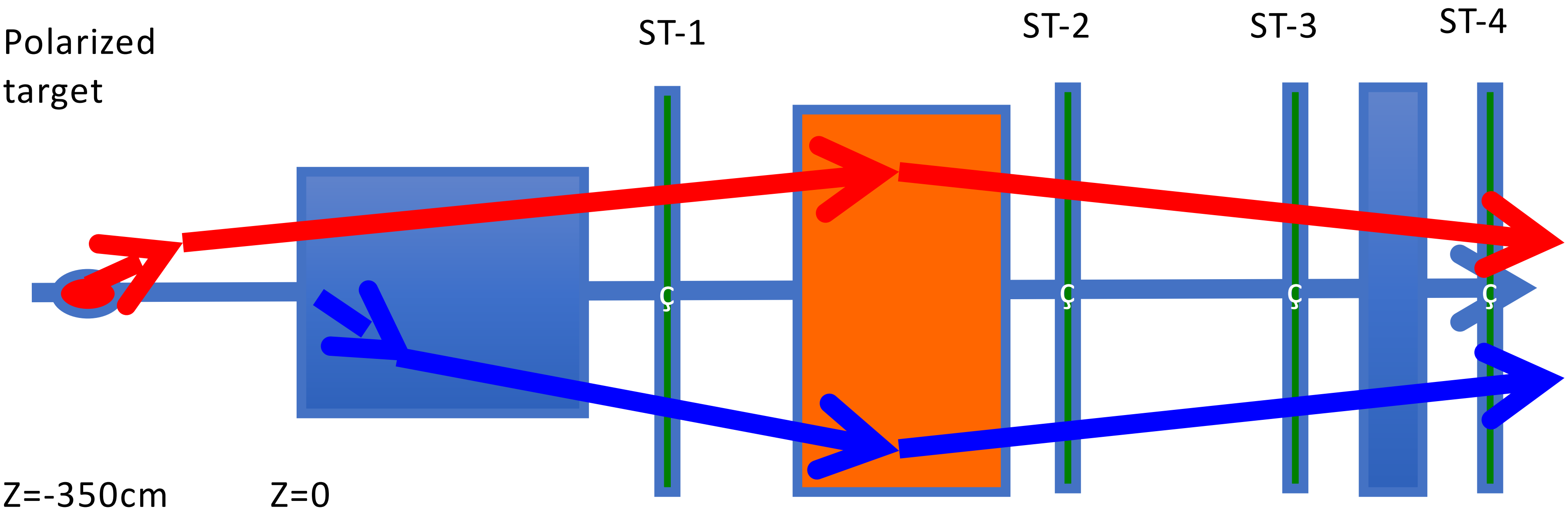
- High pT single muon trigger
- Target and dump separation

Day-1 Physics:
Can we confirm positive TSSA from day-1?

- Large TSSA observed in charged hadron production
- Help to understand the polarized target and detector performance
- Control the systematics
- Requires trigger optimization for
  - Target vs dump events



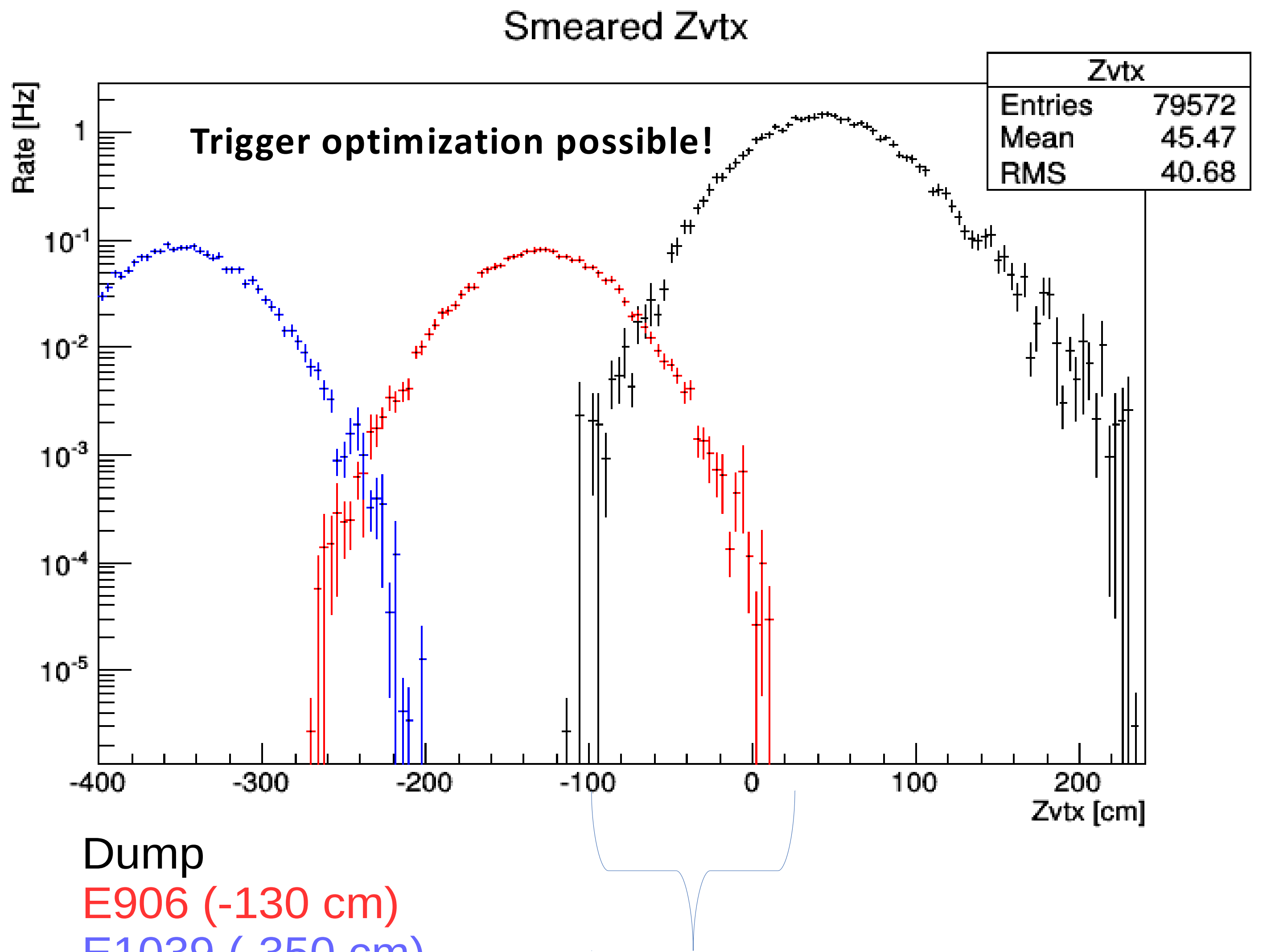
Experimental Layout for Single Muon Positive Signal Confirmation



1. Tag: single muons from pi/K decays
   - from target and beam dump
2. Trigger: single muons
   - high statistic single muons to provide positive A_N signals

- Low pZ events preferred (more "valence origin" hadrons), trigger optimization required;
- High pZ events are more sensitive to gluon and sea-quark Sivers

Target and Beam Dump Event Separation
target at upstream: Z=-3.5m



Dump
E906 (-130 cm)
E1039 (-350 cm)

Confirm positive signals from muons from charged hadrons $h^{+/-}$ decays

- Target @ Z= -350cm, long decay length
- Decay muons from charged $pi^{+/-}$ and $K^{+/-}$
  - K+/- decay could be very important
- Confirm positive signal from mu^{+} and mu^{-}

- Asy (phi) = S(phi)/Ref(phi)

- Need to rum full MC to simulate
  - Single $mu^{+/-}$ from pi/K decays
  - Kinematics and single muon trigger optimization

The Measured Raw Asymmetry:

$$A_{\mathrm{meas}} = \underbrace{f \cdot P_{\mathrm{T}}}_{\sim 0.1} \cdot A_{\mathrm{phy}}$$

P_T=0.8 target polarization

for pure NH_3 dilution factor: $f = \frac{\text{polarized protons}}{^{14}\mathrm{NH}_3} = \frac{3}{17} = 0.176$

In reality, need count all unpolarized material in beam's path, f=0.12~0.14.

In JLab Hall B, deep-inelastic scattering data, **f=0.14** (eg1-dvcs).

$$\text{dilution factor } f = \frac{\text{polarized protons}}{\text{Al.+Kapton+}^4\text{He+}^{14}\text{NH}_3\text{+NMR Coil} + \ldots}$$

➔ Need to control systematic uncertainty on measured asymmetry to **$\delta(A)_{meas} \approx 0.1\%$ for DY (1% for $h^{+/-}$)**

Challenging !!!

The Normal Approach in "collider-mode": RHIC, JLab etc.

Spin UP(1) and DOWN(2):

A = <pol>*physics asymmetry, ~O(1%)

$$dN_1(\phi) = N_1 \times (1 + A \times cos(\phi))$$

$$dN_2(\phi) = N_2 \times (1 - A \times cos(\phi))$$

$$R = N_1/N_2$$

Relative luminosity,
for E1039, this is the luminosity of beam on target, which is very hard to measure to <<(0.1%)!

$$A_{raw}(\phi) = (dN_1 - R \times dN_2)/(dN_1 + R \times dN_2) = A \times cos(\phi)$$

Need precision measurements of relative luminosity, better than ~O(0.1%)

$$\delta A_{raw} \sim (\delta R + X ...)$$

How to Measure Drell-Yan(Single Muon) TSSA Raw Asymmetry at 10^-3 Level with a polarized proton target?

- The challenges of precision TSSA measurements
  - Detector acceptance * efficiency varies >>1% level over a few hours of operation under a given "target polarization" configuration
  - Very difficult to measure the relative beam on target(NH3) luminosity at ~10^-3 level
    - Large beam x-y profile
    - small target size
    - Beam position/direction jitter (dX ~ 1-2mm),
      - see https://p25ext.lanl.gov/elog/Hardware/12
    - non-uniform DC responses to large beam intensity fluctuations (~O(10%))
    - NH3 packing factor variation >~1% from target to target
    - Target polarization known to ~O(3-4%) level through NMR
    - Other variations, including target changes etc, ~O(1%)
  - Frequent spin flip is hard/impossible
    - can't do what we are doing at RHIC and Jlab
    - Takes time to reach a stable polarization
    -
  - We must be able to measure raw TSSA at 10^-3 level for a given target polarization configuration
- A new approach needed

False Detector Asymmetry Study

- Run-2 data dimuons (Roadset 57)

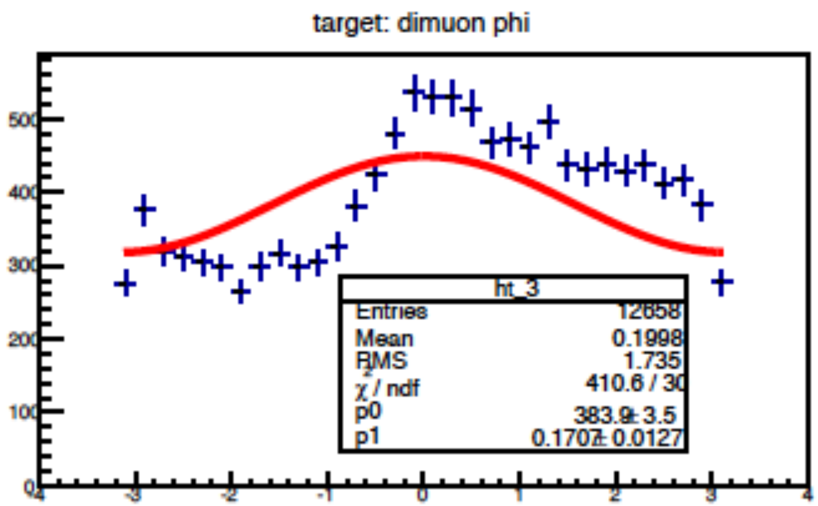
- Event selection:
  - 4< mass < 7
  - Target events: -250 < z0 < -50cm
  - Beam dump events: -50 < z0 < 200 cm
  - Track quality cuts

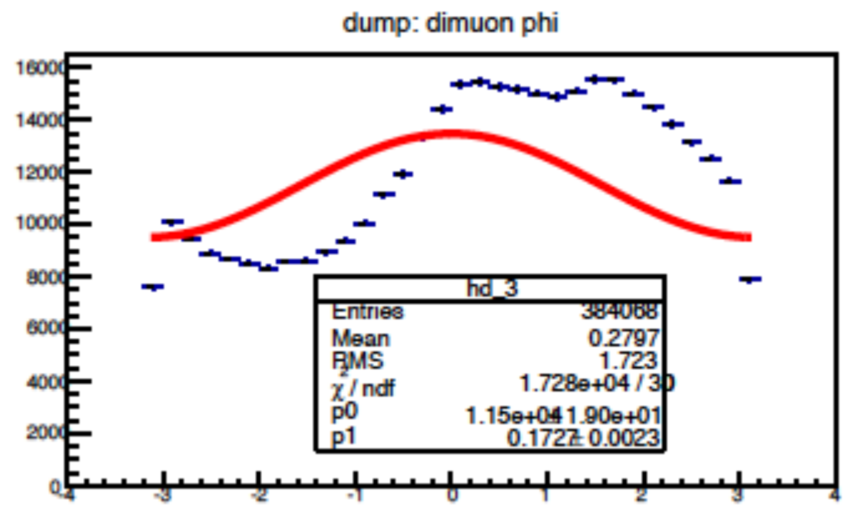
- Detector (relative) acceptance for DY events
  - Raw "spin" asymmetries
  - MC study need to correct target/beam dump acceptance difference
    - Trigger road bias
    - Detector acceptance corrections
  - Further reduce raw asymmetry via target spin-flip and Fmag/kMag field directions
    - Keep the same "target dipole field", only change RF frequency to flip the direction of target polarization
    - Change the FMag and kMag field directions
    - Impact of Relative beam on target beam luminosity

Run-2: Close Look of DY Phi Distributions

We need to get the false asymmetry << 0.1% ~ expected raw spin asymmetry

$$y(\phi) = N \times (1 + A \times cos(\phi))$$



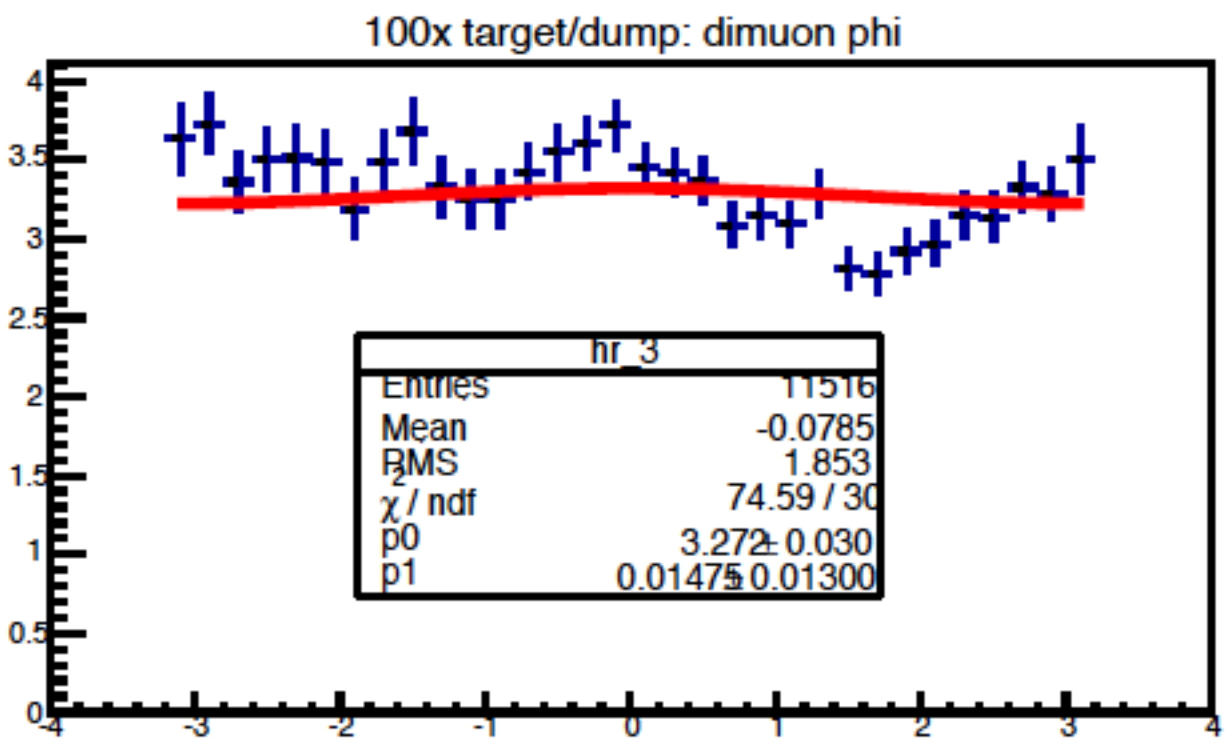


A = 0.171 +/- 0.013 --→ 100x too large!

Huge false asymmetry: >> X10 sigma

A New Approach

- Using the same DY(or $h^{+/-}$) events from beam dump to normalize the detector acceptance effects
  - Beam dump events, 100x statistics, similar muon acceptance
    - the stat_err from reference << signal stat_err
  - the beam dump asymmetry = 0
    - Known physics
  - normalize the beam intensity
    - Can achieve O(1%) on relative luminosity of beam on target, with dedicated telescopes
  - Identical timing and spatial variation of detector acceptance and efficiency for signal and background
    - Can achieve O(0.1%) on raw asymmetry



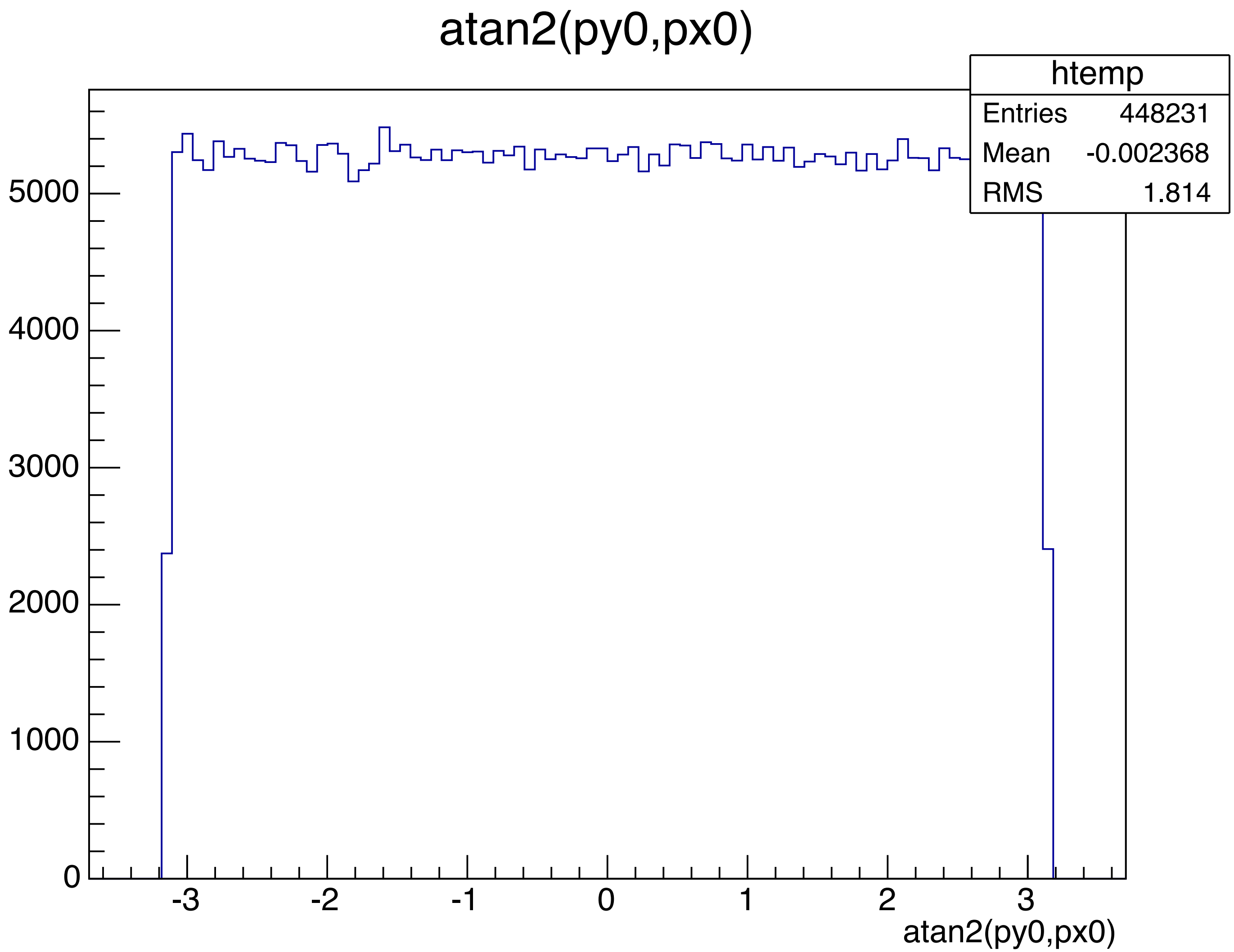
False asymmetry after normalization:

~ 1 sigma, good!

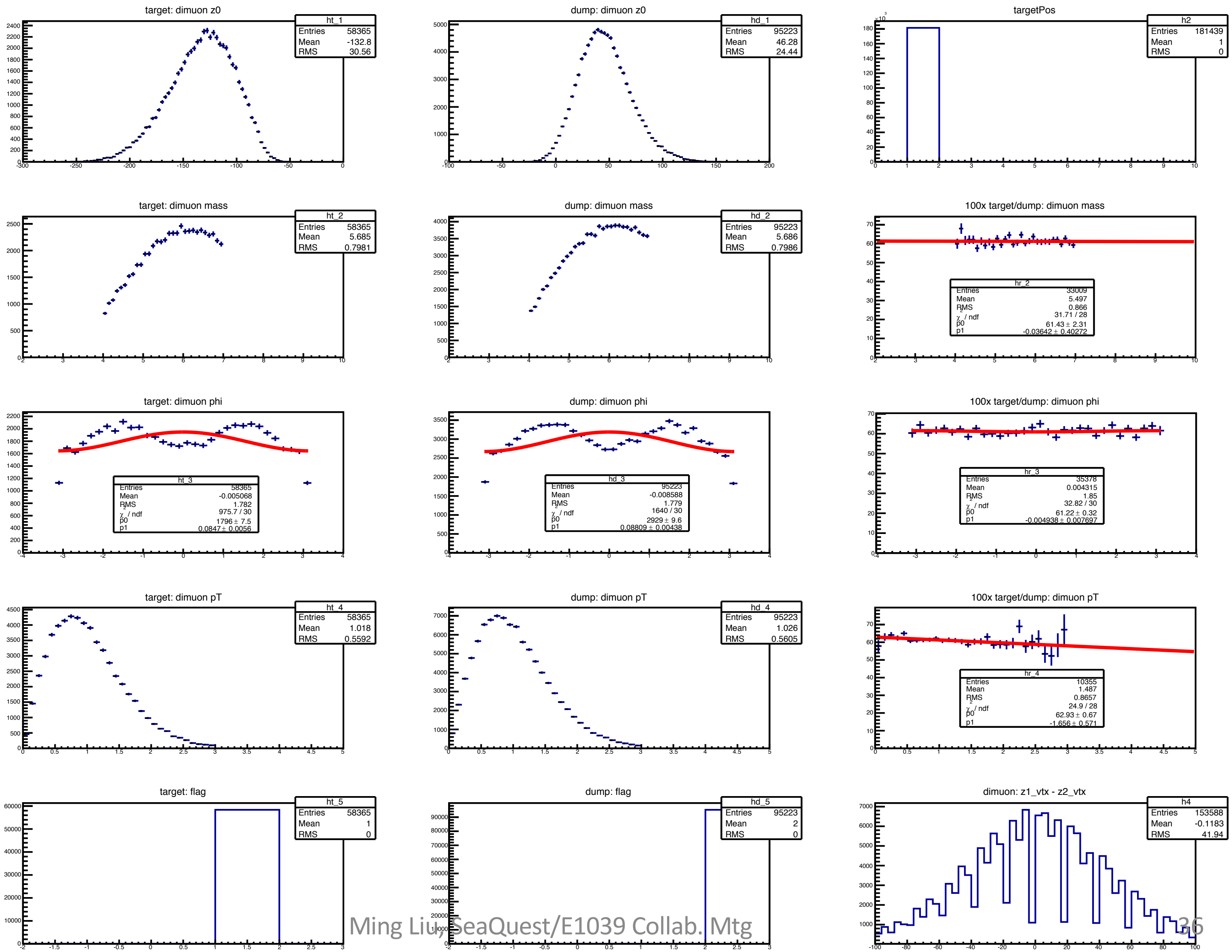
Need to run ~100x more MC or data to prove we can reach 0.001 level!

$$A = 0.015 \pm 0.013$$

J/Psi MC at Production: Phi



Drell-Yan MC: Target and Dump Distributions



Future Work for Improvements

- Detailed MC simulation with the new polarized target position
  - Prove the systematic error can be controlled to O(0.1%)
  - Target/Dump DY acceptance correction study
  - 100x more MC events to reach O(0.1%) level precision
- Real data analysis to understand and correct the large false asymmetry
  - Beam axis, directions
  - Detector response to instant beam fluctuations
  - Systematic reduction of the false asymmetry
- New beam position/direction monitoring instruments?
  - Summer shutdown work 2018?
- Beam on target luminosity telescope
  - Summer shutdown work 2018?

Summary: New Physics Topics for E1039

- Gluons Sivers functions in “valence region”
  - Xg = 0.1~0.3
  - Gluon Sivers functinos can be best determined in E1039
  - Large A_N observed from valance quark in this x-range, it would be very interesting to explore the gluon sector in this kinematic region.
  - Could be probed by charm, J/Psi and high pZ hadrons(q-g scattering)

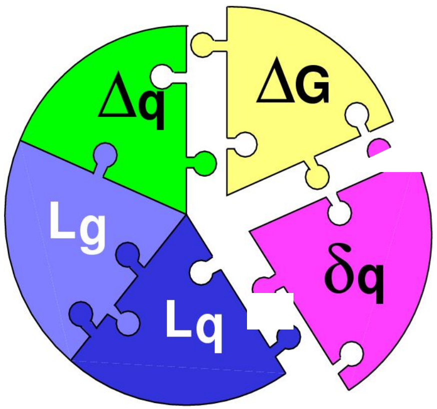
- Open charm and anti-Charm A_N
  - Single muon A_N for mu^+ and mu^- from charm decay
  - Reveals the underlying physics of color interaction
  - Test pQCD Twist-3 framework

- J/Psi and Psi’
  - Study the J/Psi production mechanisms with A_N.
  - Early theoretical work shows J/Psi A_N is sensitive to production processes
- **Light hadron A_N using decay muons: day-1 physics**
  - This is the one we plan to use to calibrate the Drell-Yan A_N measurements

Backup slides

Three Decades of the Proton Spin Puzzle

- Early expectation: large gluon polarization



$$\Delta\Sigma' = \Delta\Sigma - \frac{\alpha_s}{2\pi}\cdot\Delta G$$

$$\frac{\alpha_s}{2\pi}\cdot\Delta G = 0.3 \pm 0.1$$

Axial anomaly
Cheng & Li, PRL (1989)

EMC, 1980s

$$\frac{1}{2} = \frac{1}{2}\Delta q + L_q^z + \Delta G + L_g^z$$

$$\Delta q \sim 30\% \quad (SIDIS/DIS)$$

$$\Delta G \sim 40\% \quad (RHIC)$$

$$L \sim ? \quad (RHIC, FNAL?)$$

	Quark Spin	Gluon Spin
SLAC -> 2000	E80 – E155	
CERN ongoing	EMC, SMC, COMPASS	
DESY ->2007	HERMES	
JLab ongoing	Hall A,B,C	
RHIC ongoing	(BRAHMS), (PHENIX), STAR	

SIDIS/DIS

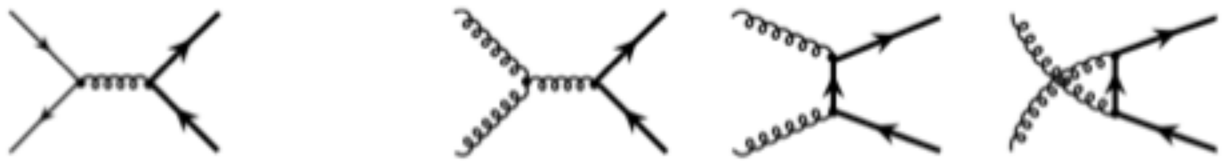
Polarized p+p

TSSA in Heavy Quark Production in p+p

Kang, Qiu, Vogelsang, Yuan, PRD 2008

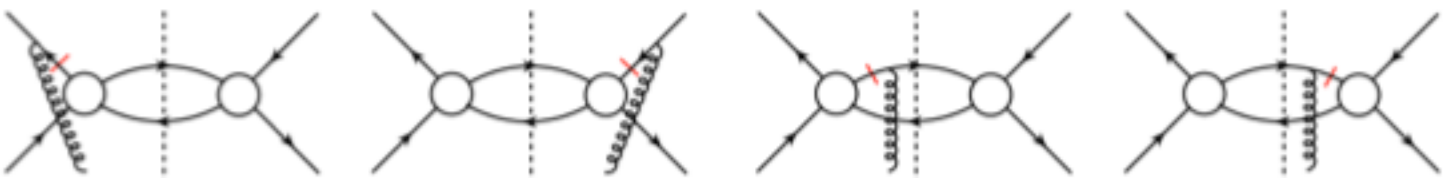
D-meson production in hadronic collisions

- Two partonic subprocesses:



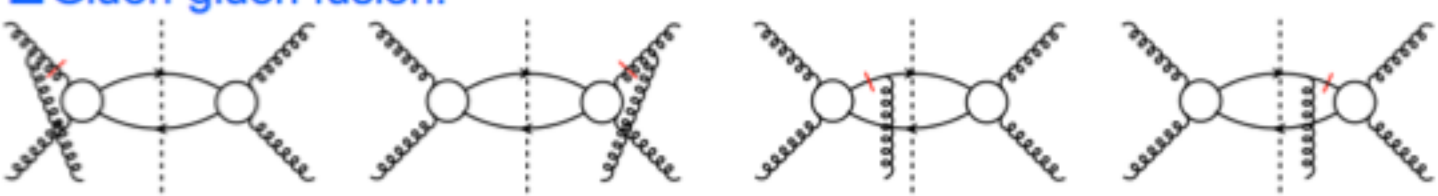
(a) (b)

- Quark-antiquark annihilation:



(a) (b) (c) (d)

- Gluon-gluon fusion:



(a) (b) (c) (d)

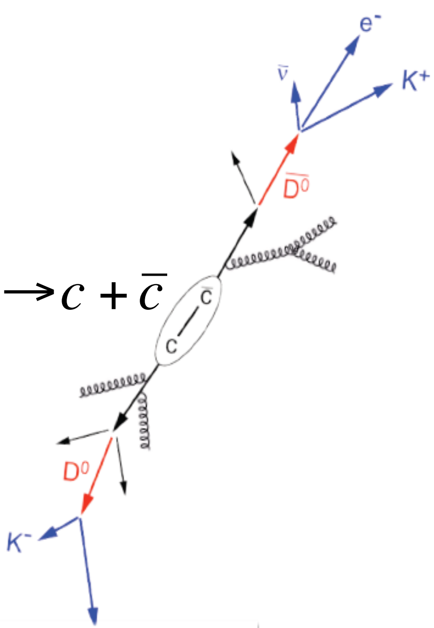
Open Charm TSSA at High Energy at RHIC

Twist-3 tri-gluon correlation Functions

$$P_h^0 \frac{d\sigma^{3\text{gluon}}}{d^3P_h} \simeq \frac{\alpha_s^2 M_N \pi}{S} \epsilon^{P_h p n S_\perp} \sum_{f=c\bar{c}} \int \frac{dx'}{x'} G(x') \int \frac{dz}{z^3} D_a(z) \int \frac{dx}{x} \delta\left(\tilde{s}+\tilde{t}+\tilde{u}\right) \frac{1}{\tilde{u}} \left[\delta_f \left(\frac{d}{dx}O(x) - \frac{2O(x)}{x}\right)\hat{\sigma}^{O1} + \left(\frac{d}{dx}N(x) - \frac{2N(x)}{x}\right)\hat{\sigma}^{N1}\right].$$

where $O(x) \equiv O(x,x) + O(x,0)$, $N(x) \equiv N(x,x) - N(x,0)$.

$g + g \rightarrow c + \bar{c}$

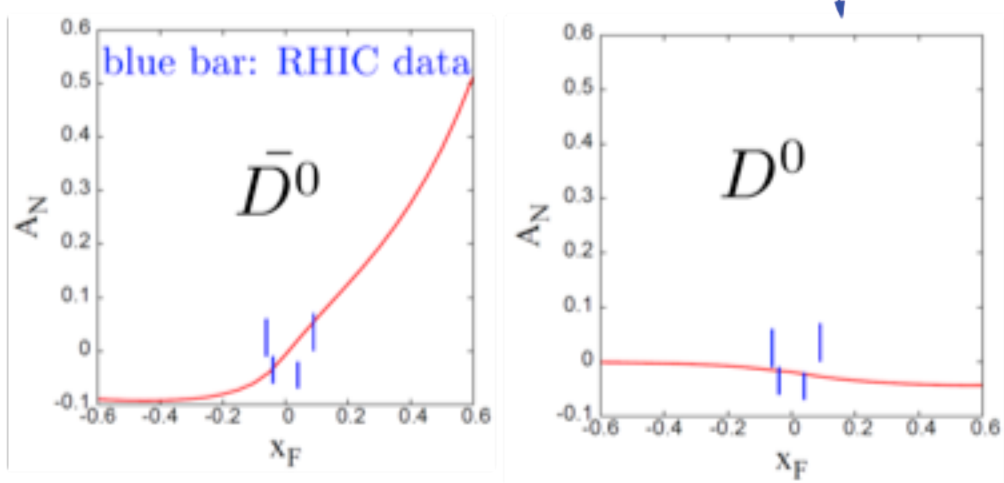


$\delta_f = +1(c);\ \ -1(\bar{c})$

$$A_N(D) \overset{?}{\neq} A_N(\bar{D})$$

Model 1:
$O(x) = 0.004xG(x)$

Koike *et. al.* (2011)
Kang, Qiu, Vogelsang, Yuan (2008)



Drell-Yan Asymmetry (II) 05/27/2015

- Use beam-dump events as reference, R(phi)
- Use target events as signal, S(phi)

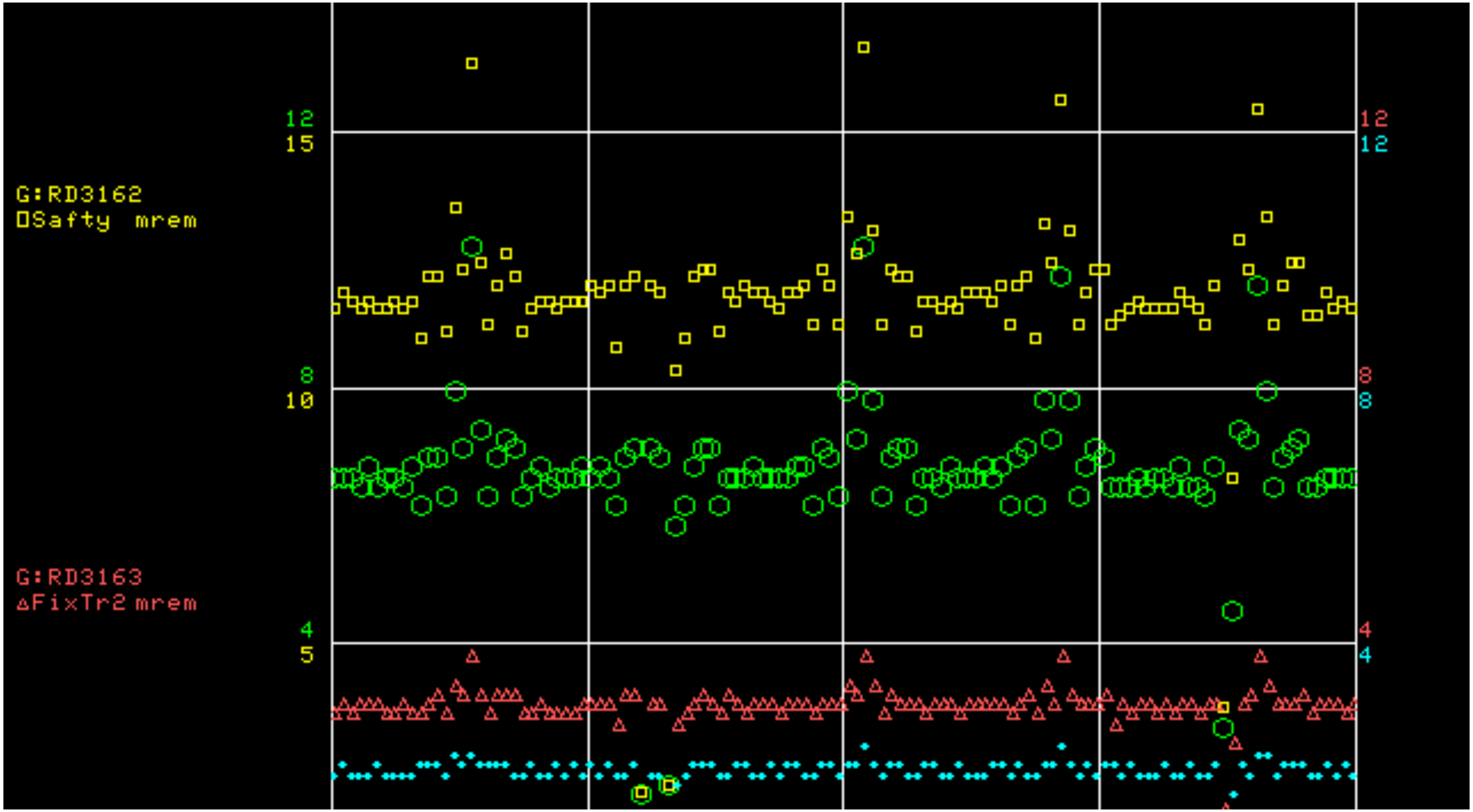
- Asymmetry(phi) = S(phi)/Ref(Phi)

- This is a follow up of previous discussions about DY spin asymmetry measurements

https://p25ext.lanl.gov/elog/Drell-Yan/29
https://www.phenix.bnl.gov/WWW/publish/mxliu/E906/LDRD-Pol-DY-Work-2015-Ming.pdf (pptx)

Bean Profile Study

Chuck suggested to scan W-target and monitor radiation rates outside of the building (Yellow)
Can do at ~2 sigma level (~5%), but hard to reach 0.1% for beam halo study…



Telescope

- 4 units of 2”x2” telescope rates:
  - 3+4: 349k counts/spill
  - 1+2+3+4: 339K counts/spill
  - Background rate < 1 Hz
- Location
  - ~5m from the instrumentation package (~1%)
  - ~45 degree
- Polarized target:
  - Small tunnels at ~90 degree on both L/R sides to provide service lines (Cryo and Microwave)
  - Scattering rate at ~90? Must by very low
  -

Beam on Target: 4-sigma coverage

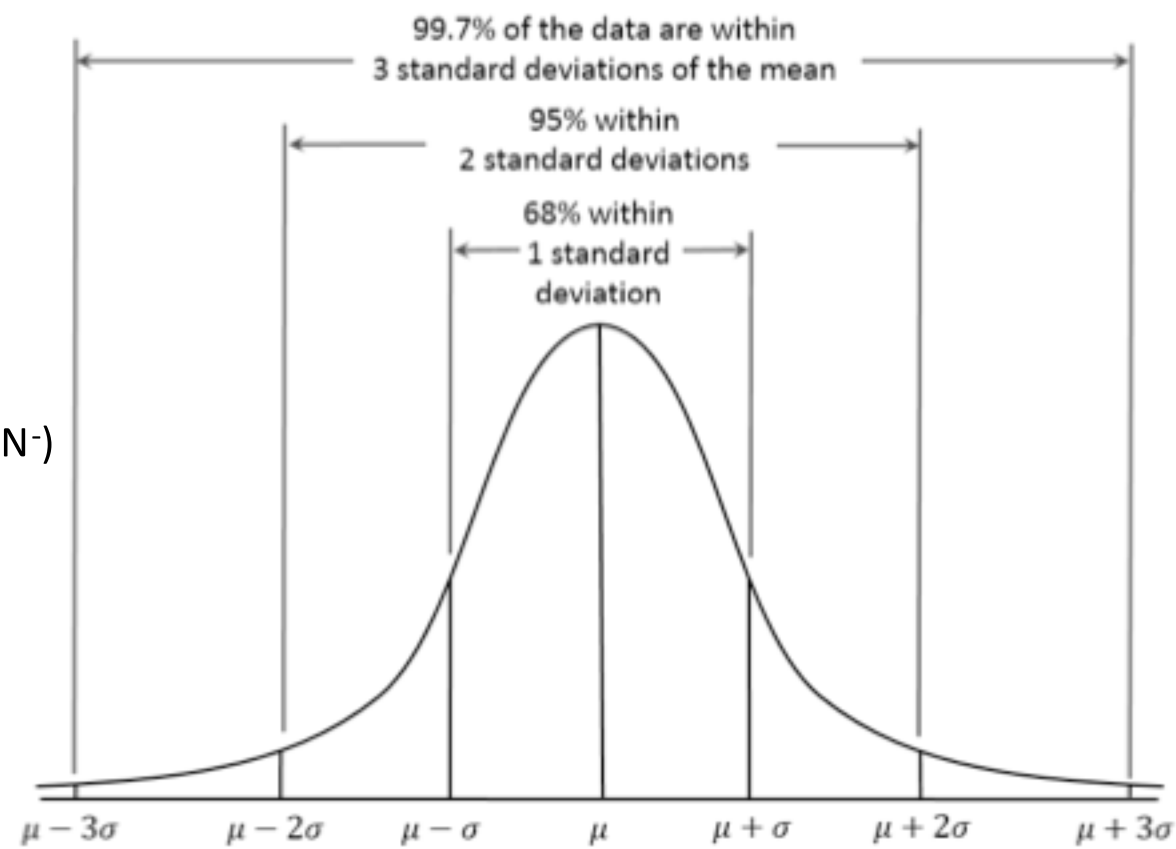
relative luminosity measurement better than $2x10^{-4}$

Expected Raw Asymmetry:

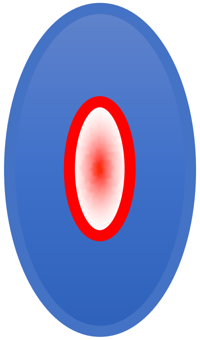
~ 1%/10~20 = 5 x 10^{-4}

Asymetry = $(N^+/R - N^-)/(N^+/R + N^-)$

R = spin-dependent
relative luminosity
dR <~ $2x10^{-4}$



New Beam Collimator, Focusing Q3 and Target



Target cross section: 18 x 28 mm^2

Beam cross section:

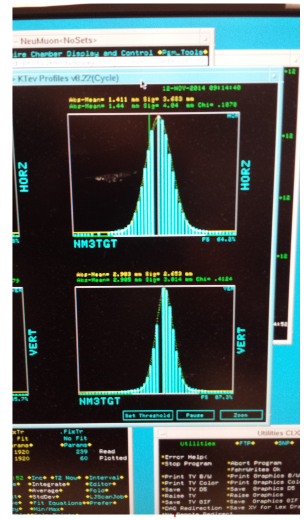
Need be well contained within 4 sigma, required by $dR < 2 \times 10^{-4}$

sigX = 18/2/4 = 2.2 mm

sigY = 28/2/4 = 3.5 mm

Beam jitter: dX=dY ~ 1mm

1 sig = 0.68269
2 sig = 0.95450
3 sig = 0.99730
4 sig = 0.99994



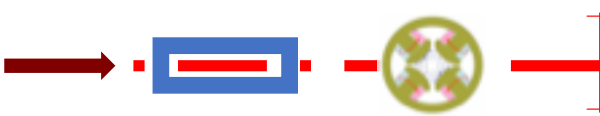
E906 beam profile:

SigX = 4.0mm

SigY = 3.0mm

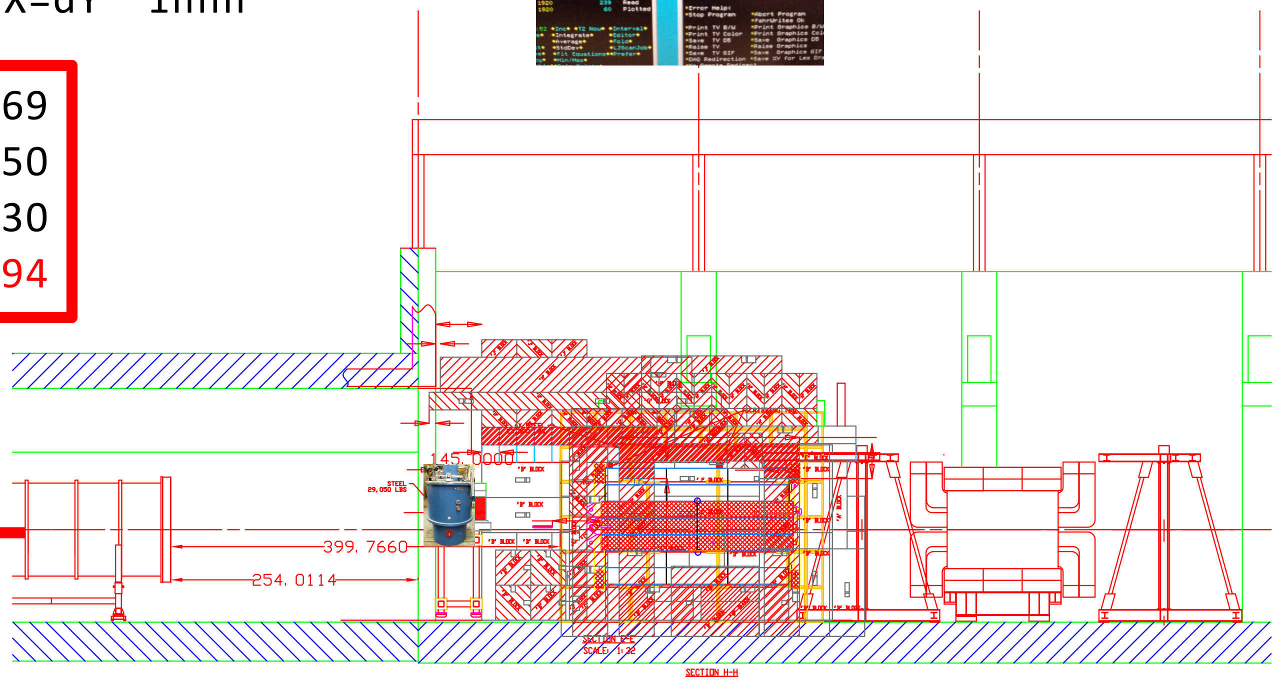
$$f(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Beam collimator



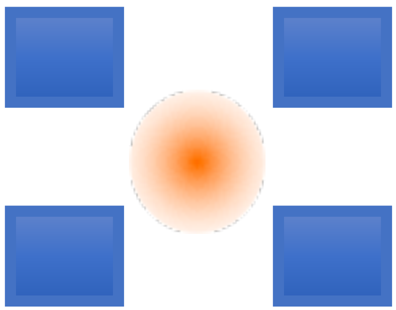
120GeV beam

Final focusing Q3



Beam position and angular direction measurements 4/1/2015

- Two sets of “position-sensitive diamond detector” ~2cm apart, better than 1mm spatial resolution
- Quadrant Pattern
  - (X,Y) and sigma
- MC PYTHIA Sim
  - MB to check rates
  - Optimal detector locations



Reality: Not So Perfect Detector and Beam Controls

- Not so perfect detectors (dt ~ minutes) without fast spin flip (dT << minutes)
  - Polarized target spin-flip period ~ several hours
- Acceptance varies within the time of a fixed “target spin config.”
  - Time dependence
  - Dead and hot space points
  - Impossible to get to << O(0.1%)

$$dN_{Targte}(\phi) = N^0_{Target}(1 + P \times A \times cos(\phi)) \times \epsilon_{target}(\phi, t)$$

- If target is not a pure proton, for e.g. NH_3, another background fraction “f_B”, including all other supporting materials,

$$dN_{Target} = [N_1 + N_2 \times (1 + p \times A \times cos(\phi))] \times \epsilon(\phi, t)$$

Background fraction:

Varies target to target

$$f_B = \frac{N_1}{N_1 + N2}$$

Target and time-dependent

$$dN_{Target}(\phi) = N^0_{Target}(f_B + (1 - f_B)(1 + P \times A \times cos(\phi))) \times \epsilon(\phi, t)$$

DY events produced in “Target”

Target variation

(space,time) variation

How it works?

$$dN_{Target}(\phi) = N_1 + N_2(1 + P \cdot A \cdot \cos(\phi))$$
$$= N^0_{Target}(f_B + (1 - f_B)(1 + P \cdot A \cdot \cos(\phi))) \times \varepsilon(\phi, t)$$

$$dN_{Dump}(\phi) = N^0_{Dump} \times \varepsilon(\phi, t)$$

$$f_B \equiv \frac{N_1}{N_1 + N_2}$$

If we use the same DY dimuon events (mass, pT,xF etc) from Target and Dump:

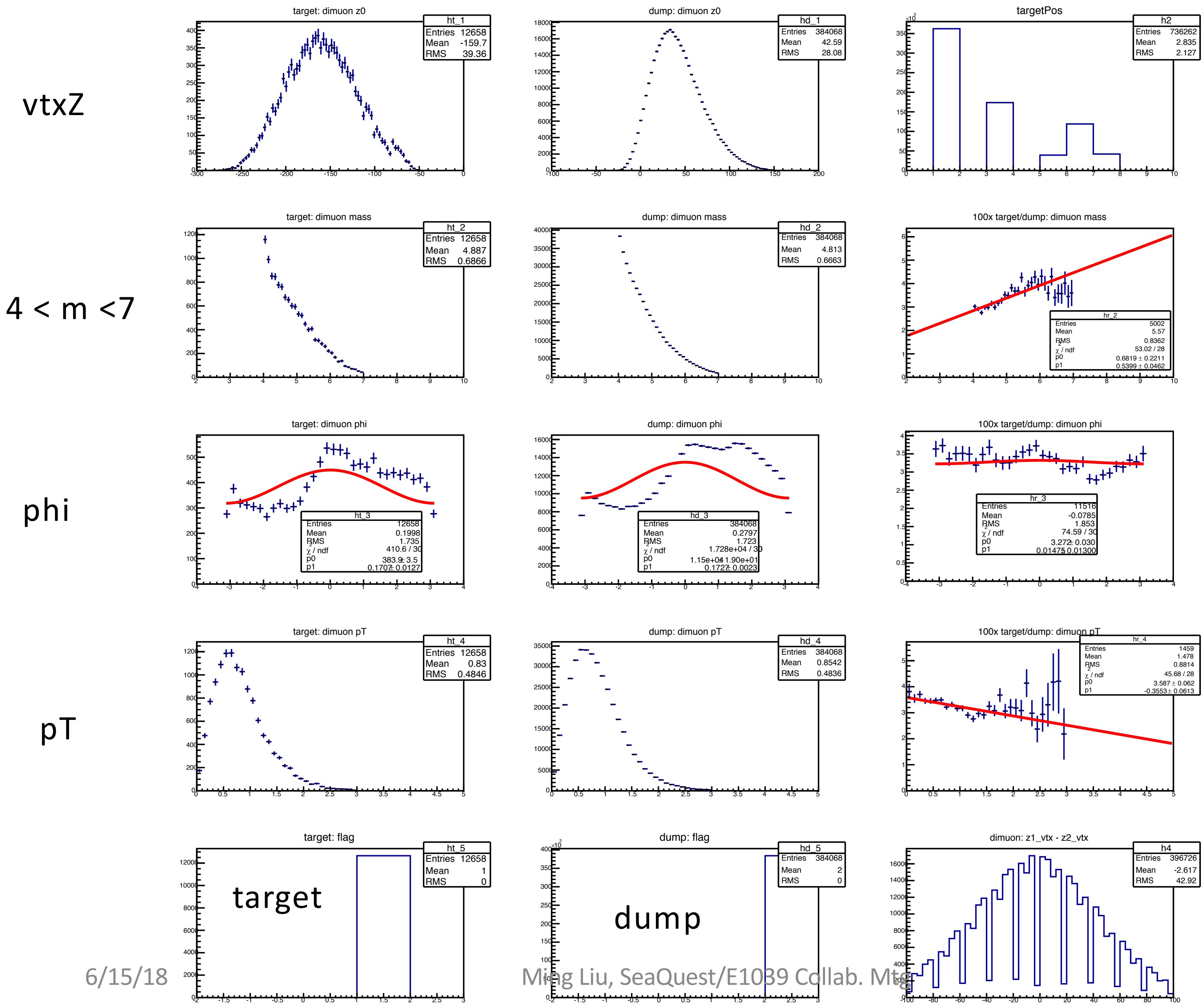
- the time-dependent detector acceptance variations are mostly canceled out
- The small difference can be corrected with MC and data by using the muons measured in the same phase space
- Much reduced requirements on relative lumi, background fraction, target polarization measurements
    - sufficient at O(1%) level.

$$\Delta R(\phi) = dN_{Target}(\phi)/dN_{Dump}(\phi)$$

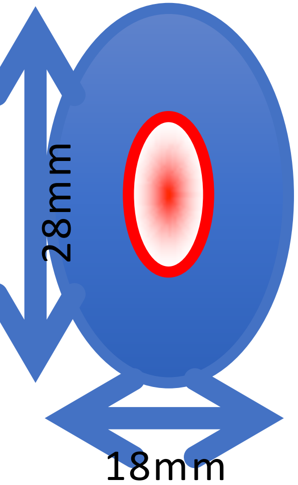
$$\Delta R(\phi) = \frac{N^0_{Target}}{N^0_{Dump}}(f_B + (1 - f_B)(1 + P \times A \times cos(\phi))) \times (\epsilon_{target}(\phi, t)/\epsilon_{dump}(\phi, t))$$

$$\Delta R(\phi) = \frac{N^0_{Target}}{N^0_{Dump}}(f_B + (1 - f_B)(1 + P \times A \times cos(\phi)))$$

Run-2 DY Dimuon (Roadset 57): all targets



New Beam Collimator, Focusing Q3 and Target



Target cross section: 18 x 28 mm^2

Beam cross section:

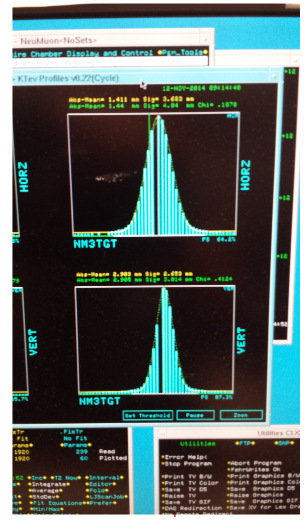
Need be well contained within 4 sigma, required by dR< 2x10^{-4}

sigX = 18/2/4 = 2.2 mm

sigY = 28/2/4 = 3.5 mm

Beam jitter: dX=dY ~ 2mm

1 sig = 0.68269
2 sig = 0.95450
3 sig = 0.99730
4 sig = 0.99994

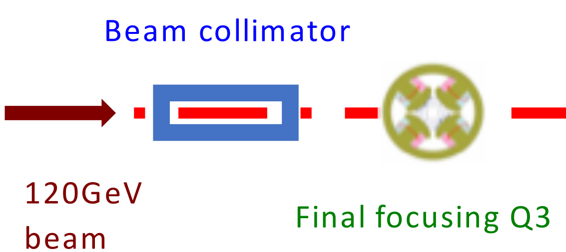


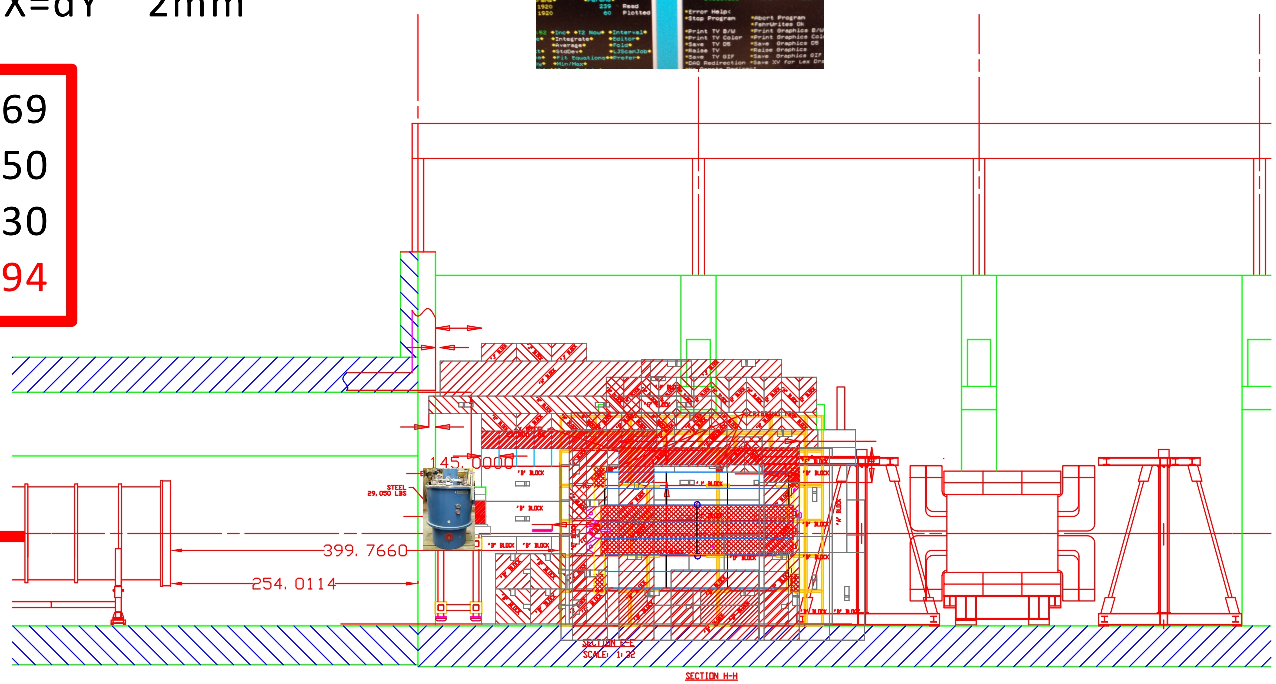
E906 beam profile:

SigX = 5.0mm

SigY = 3.5mm

$$f(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$





Run-3 Beam X Position Stability vs Spill_ID

Run = 13360, M3TGHM/HS; VM/VS