1) Nuclear effects of Drell-Yan, quarkonium, and charm production in p-A and π-A collisions

2) Sign of TMD functions (transversity, Boer-Mulders function, Sivers function)

Nuclear effects of Drell-Yan, quarkonium, and charm production in p-A collisions

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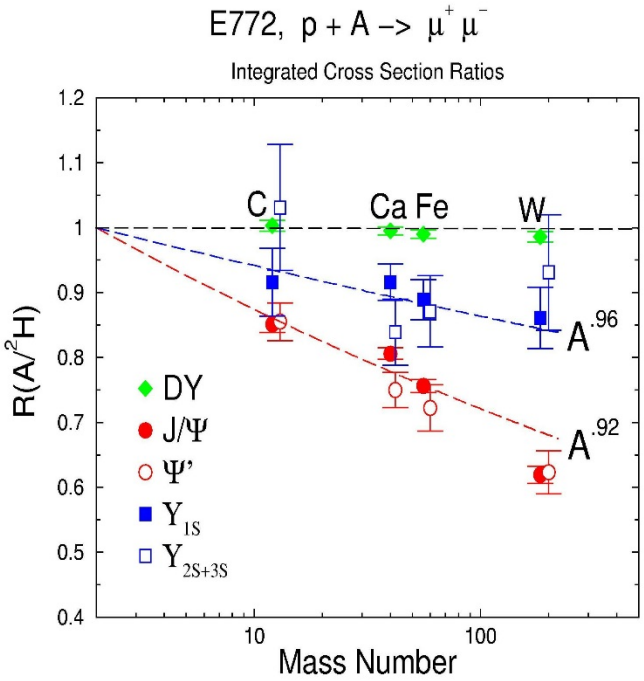
ECT Workshop, June 3-7, 2008, Trento, Italy

- A-dependence results from Fermilab E772, E789 and E866 dimuon experiments
  - What have we learned?
  - Results from E866
- Future prospects of Fermilab E906 and J-PARC dimuon experiments
  - What do we hope to learn?

Nuclear effects of Quarkonium productions

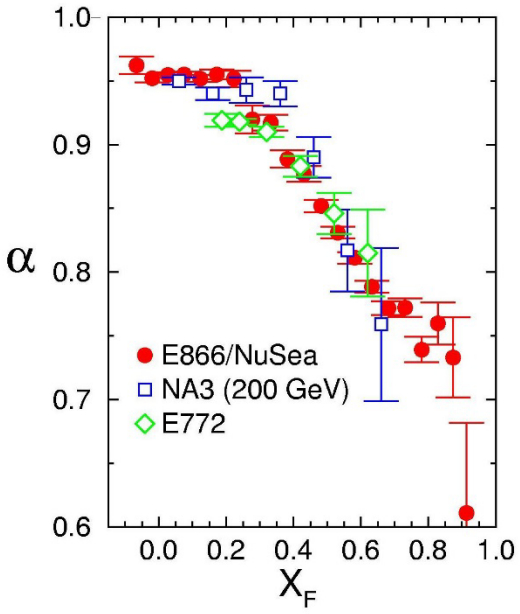
$p + A$ at $s^{1/2} = 38.8$ GeV

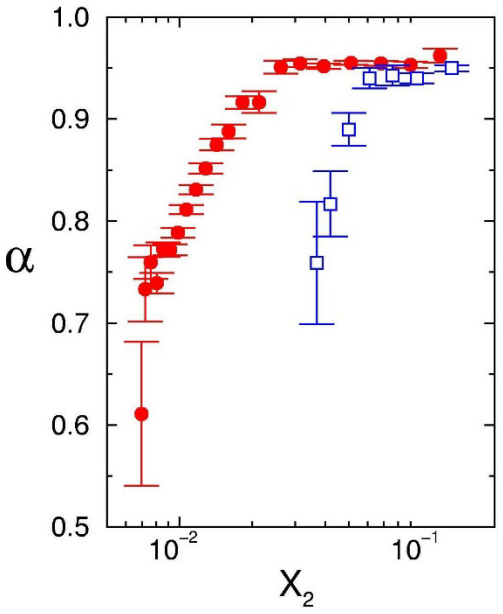
E772 data



$\sigma(p+A) = A^{\alpha}\sigma(p+N)$

Strong x_F - dependence



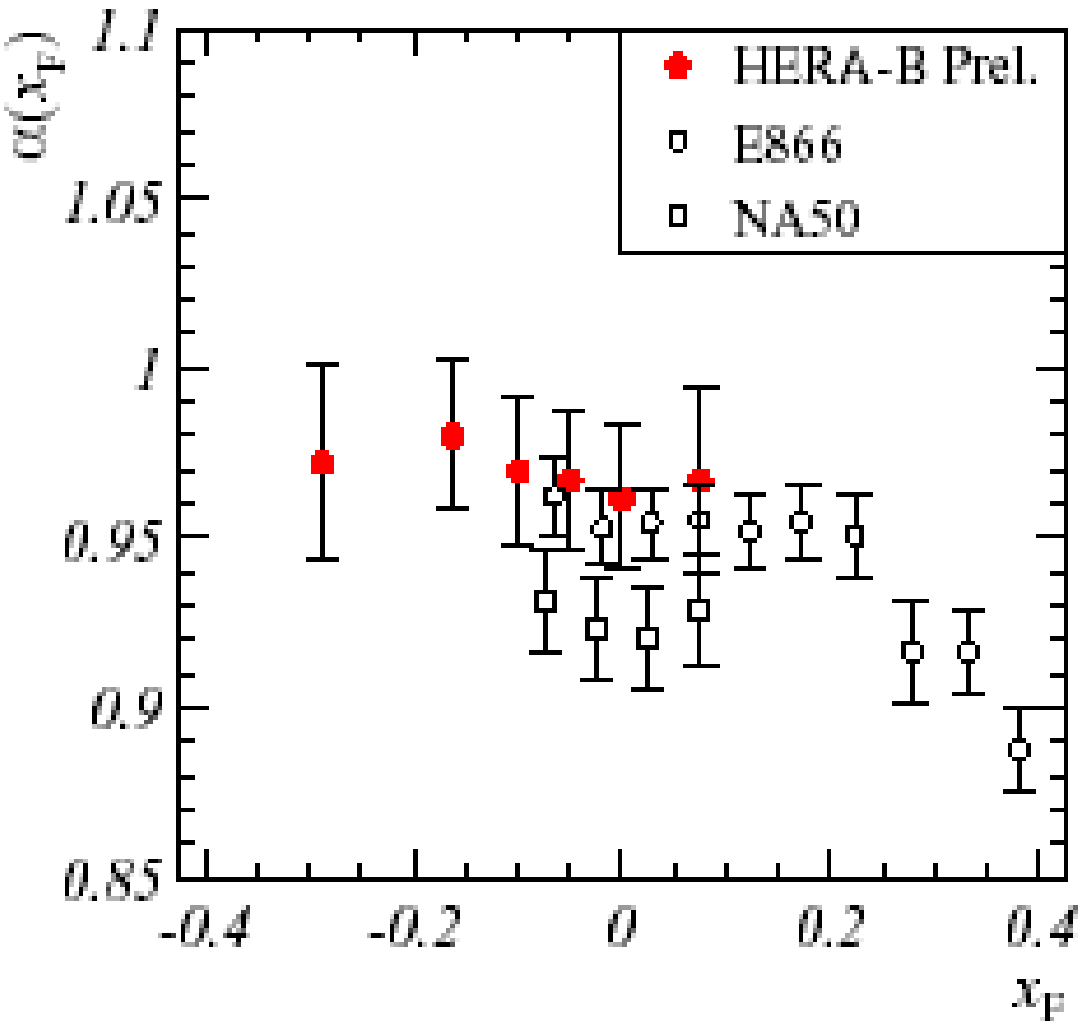


Nuclear effects scale with x_F, not x_2

What about negative x_F?

Nuclear dependence of J/Ψ production at negative X_F

HERA-B 920 GeV p+W and p+C

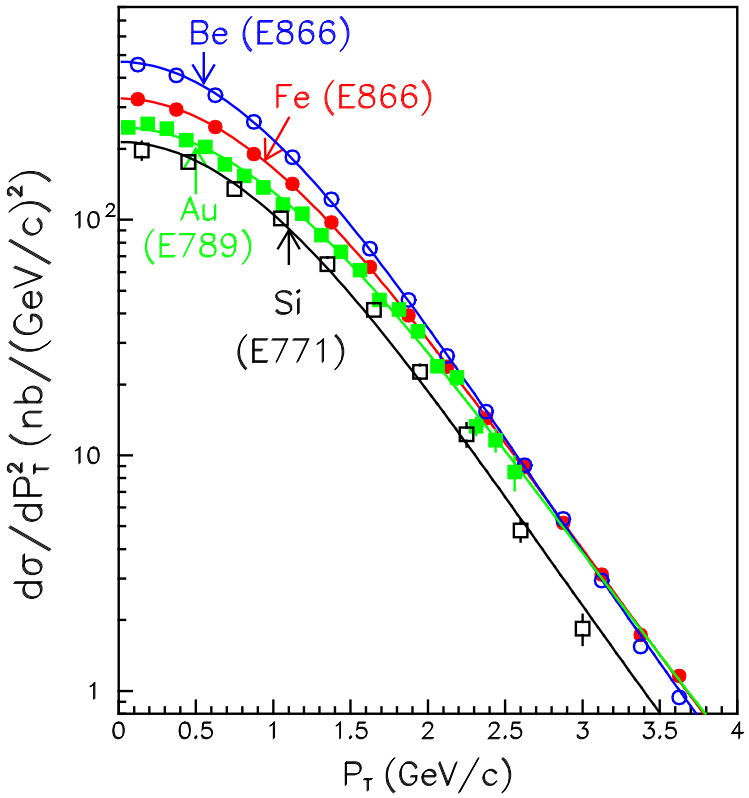


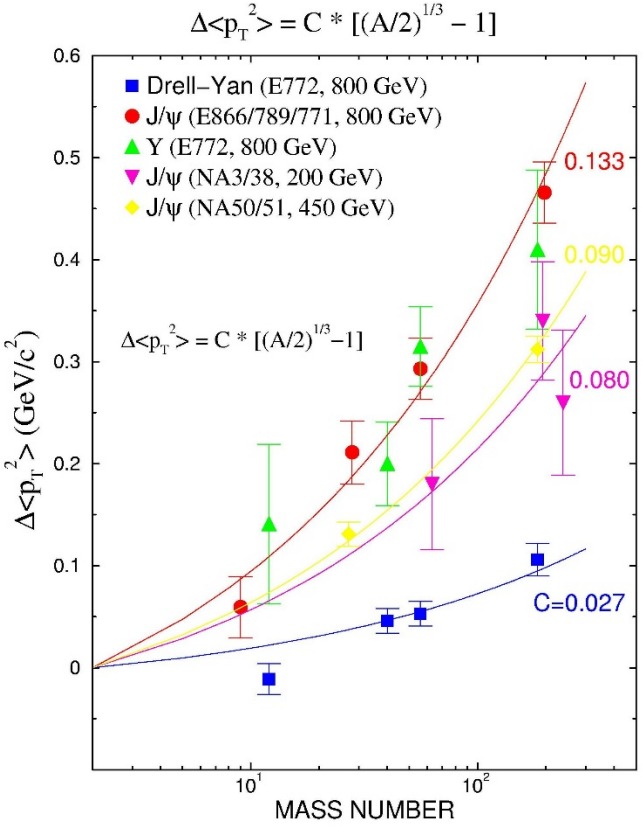
hep/ex/0506071

P_T - broadening for D-Y, J/Ψ and Y

Extract $\langle P_T^2 \rangle$ from fits to data

800 GeV P + A –> J/Ψ

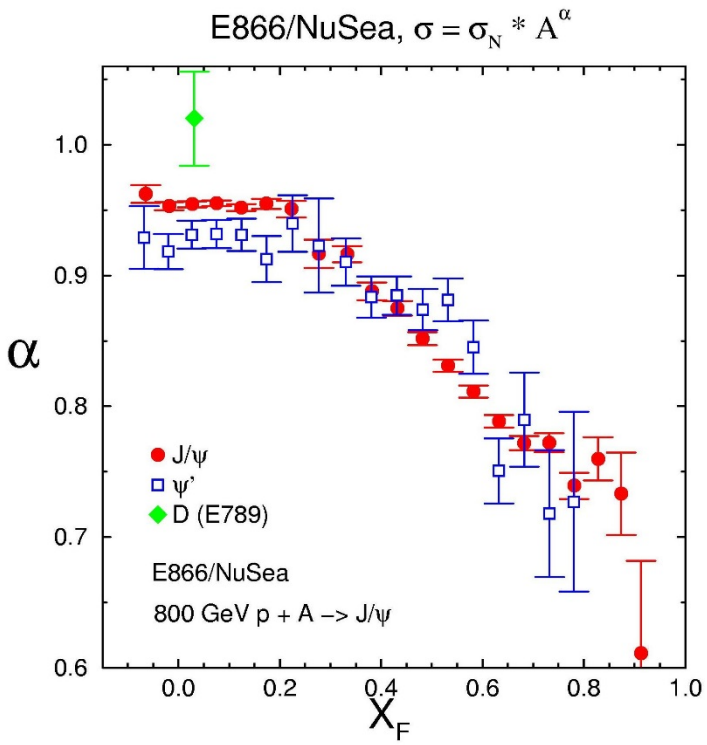


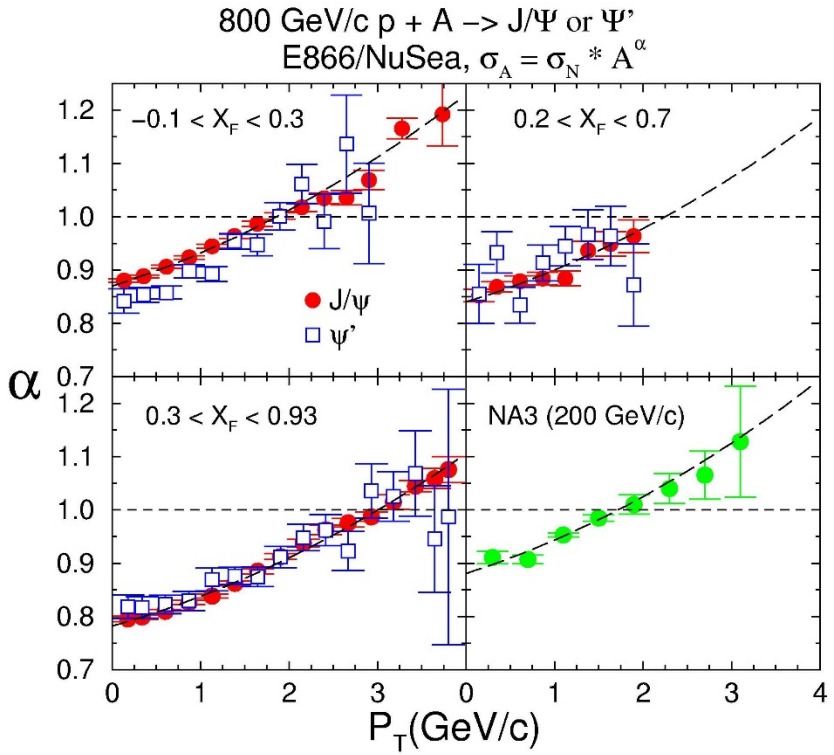


- $\Delta\langle P_T^2 \rangle$ for J/Ψ is larger than for D-Y
- Similar behavior for J/Ψ and Y

Comparison between the J/Ψ and Ψ' nuclear effects

p + A → J/Ψ or Ψ' at $s^{1/2}$ = 38.8 GeV





α(x_F) is largely the same for J/Ψ and Ψ' (except at x_F ~ 0 region)

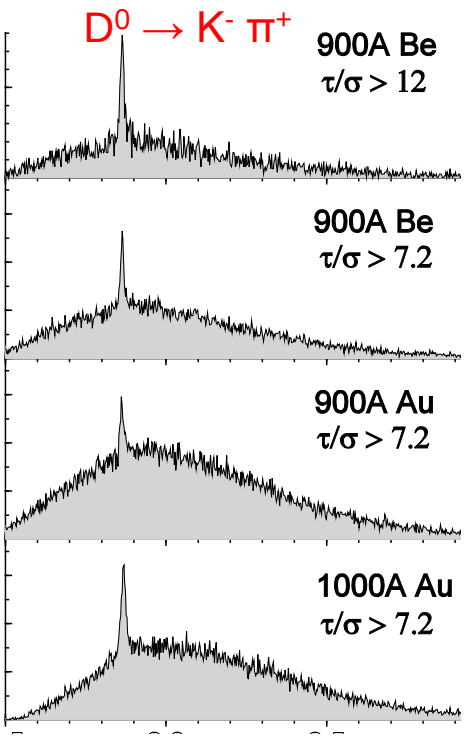
'Universal' behavior for α(p_T) (similar for J/Ψ, Ψ'; weak $s^{1/2}$ dependence)

Nuclear effects of open-charm production

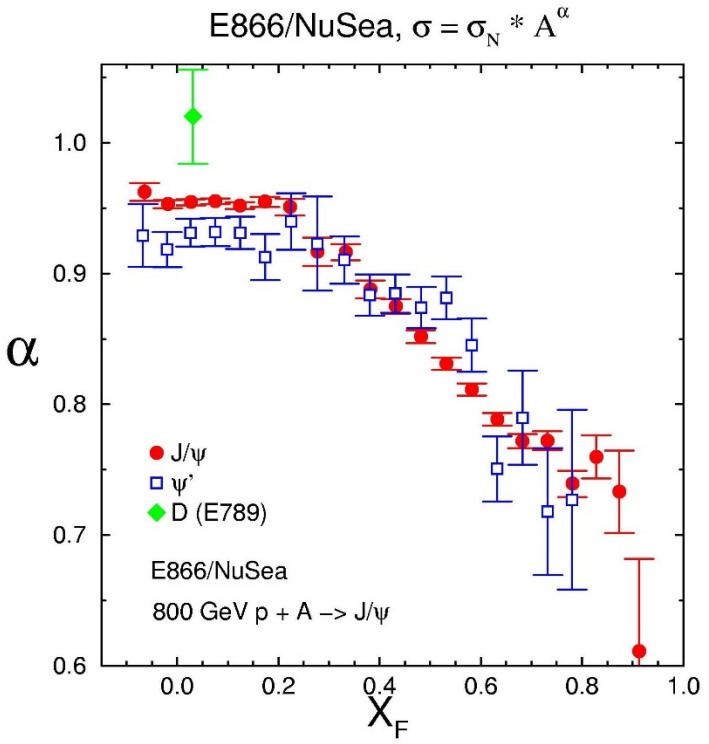
$p + A \rightarrow D + x$ at $s^{1/2} = 38.8$ GeV

E789 open-aperture, silicon vertex + dihadron detection

h^+h^- mass spectrum (after vertex cut)



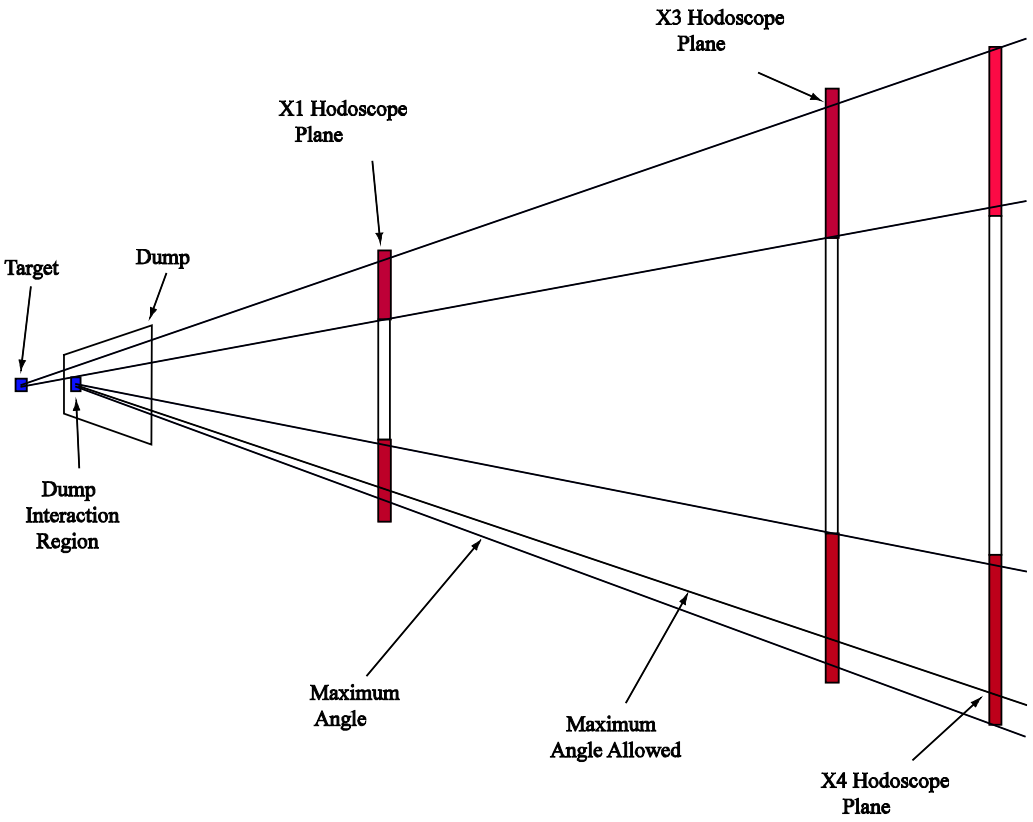
No nuclear effect for D production (at xF ~ 0)



Need to extend the measurements to large x_F region

Single muon measurement in E866 p+A

Thesis of Stephen Klinksiek

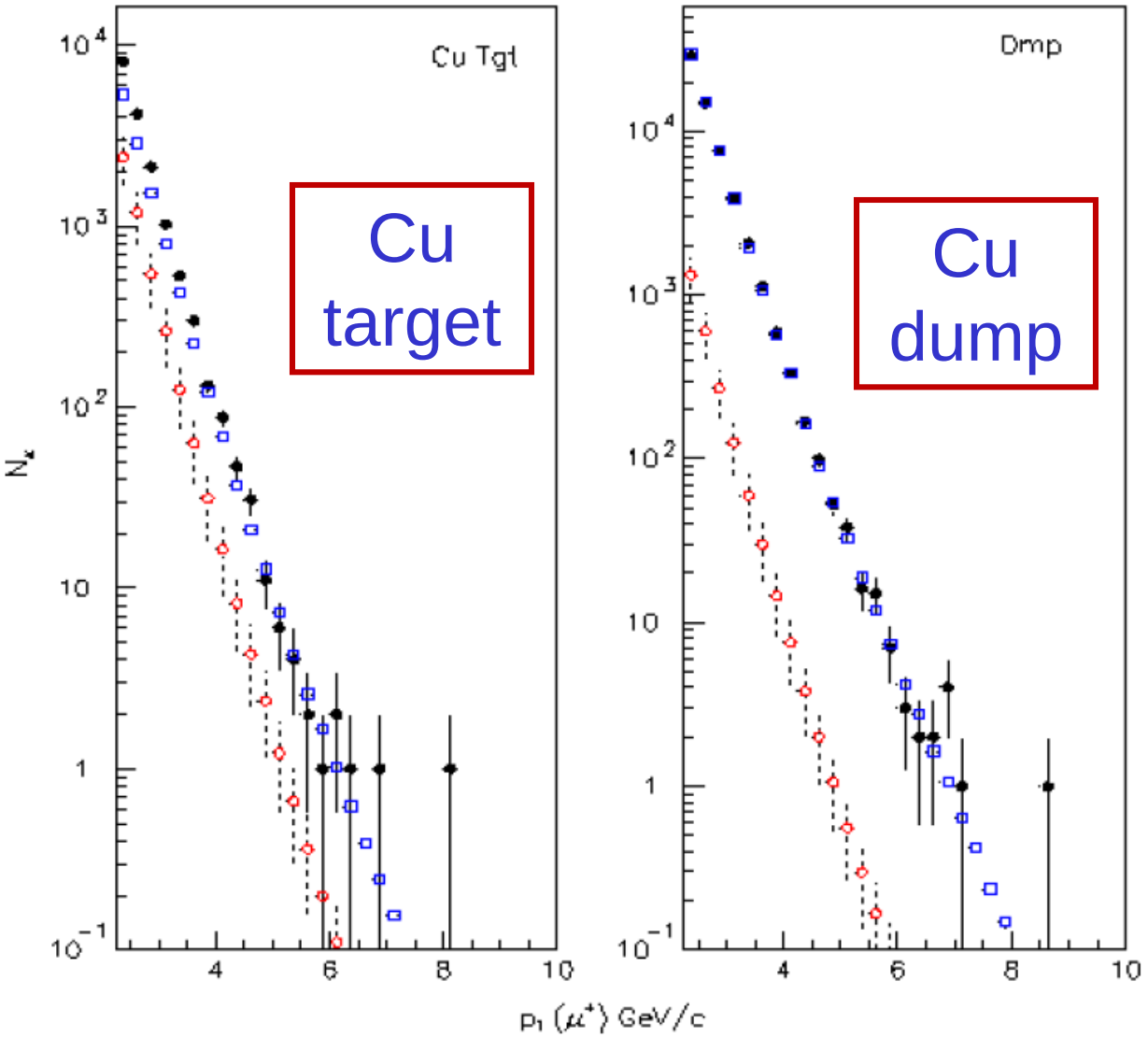


Targets (Z = -24.0")
0 = Empty
1 = 0.502 " Copper
2 = 2.036 " Beryllium
3 = 1.004 " Copper

Single Muon Trigger

Light hadron background is greatly reduced for beam-dump events !

Single muon measurement in E866 p+A

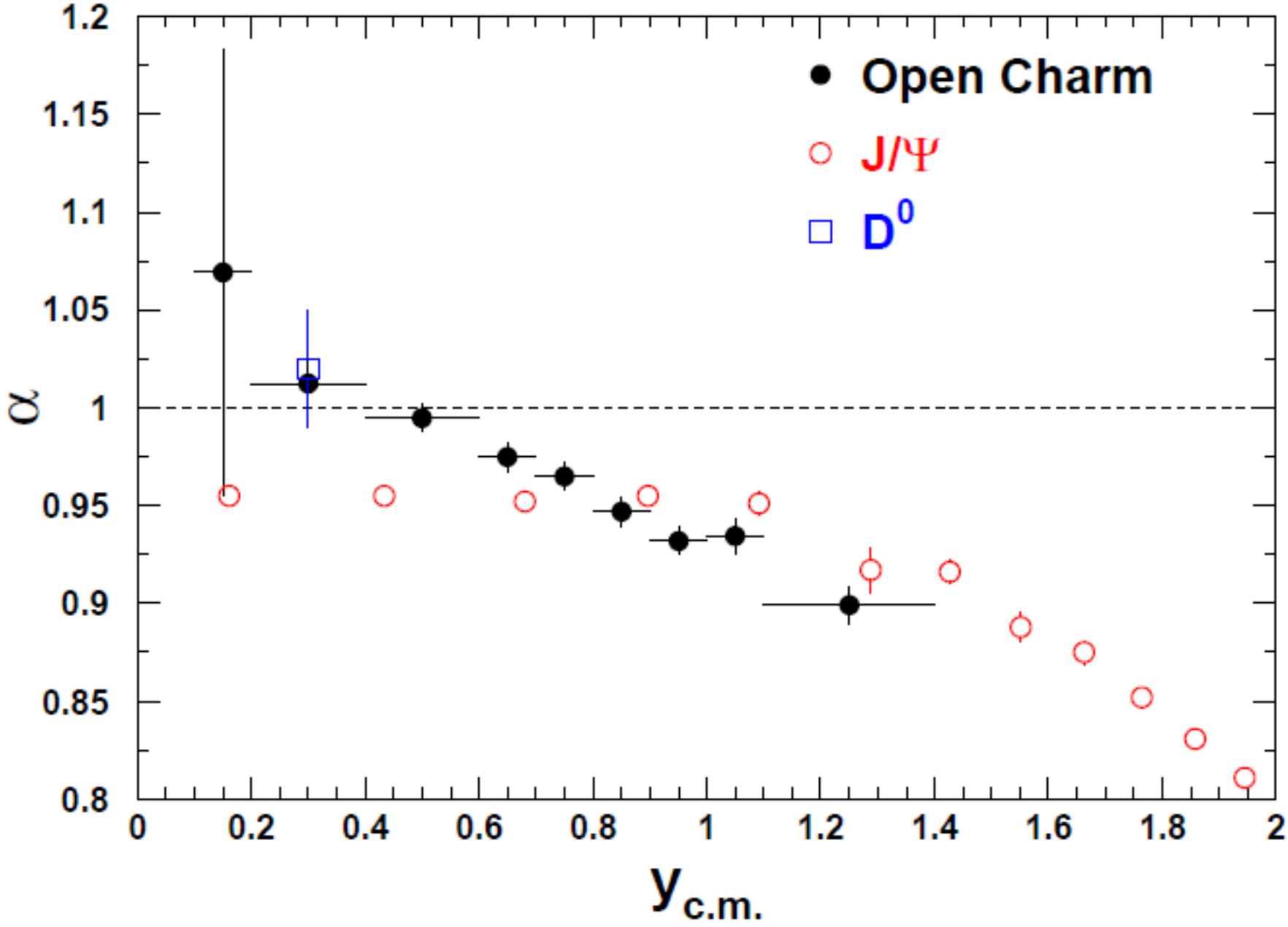


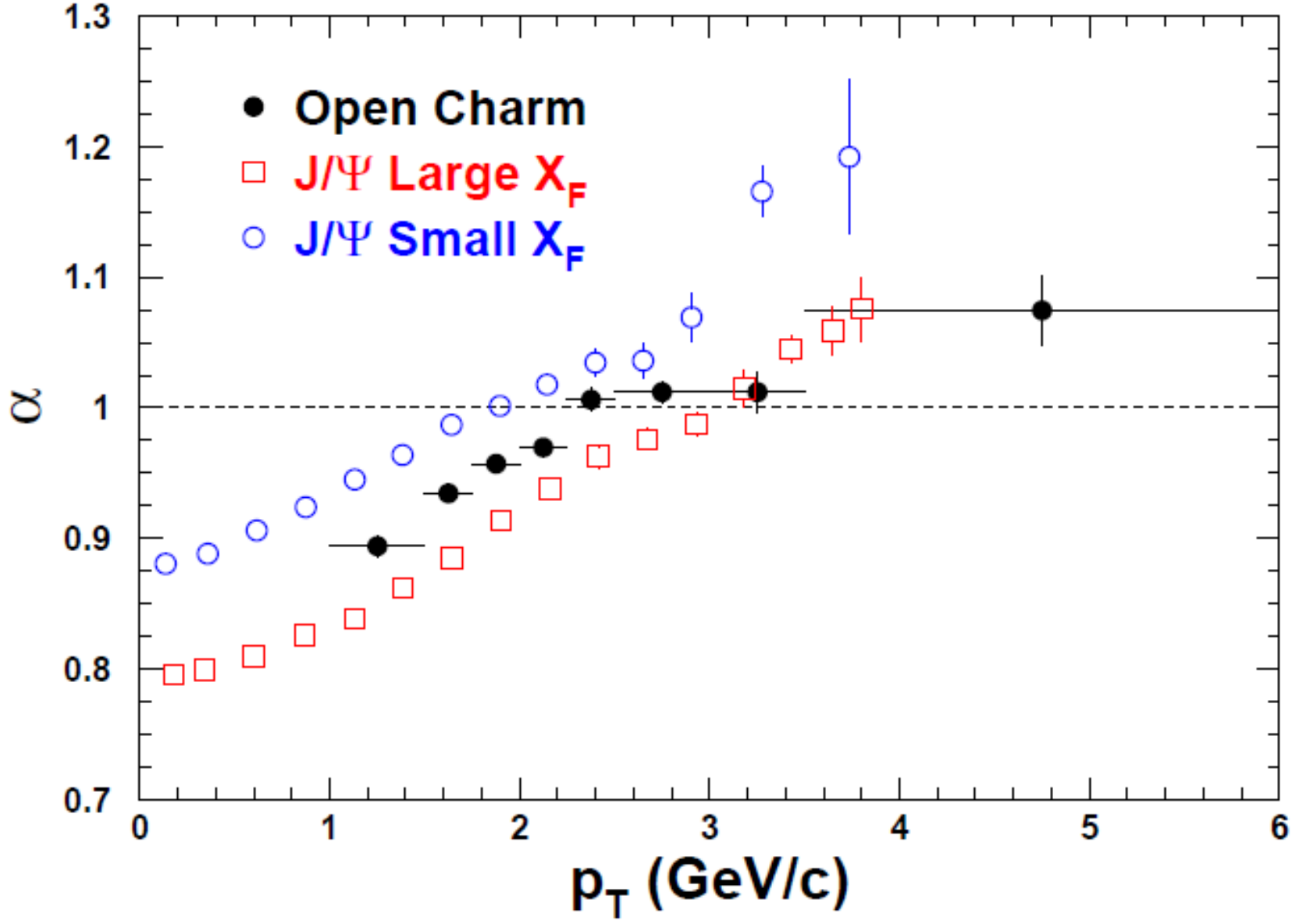
800 GeV proton beam

Black points: data

Red points: background from pi and K decays

Blue points: muons from charm decay


Open Charm
J/Ψ
D0
α
y c.m.
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


Open Charm
J/Ψ Large X_F
J/Ψ Small X_F
α
p_T (GeV/c)
1.3
1.2
1.1
1
0.9
0.8
0.7
0
1
2
3
4
5
6

Signs of TMDs
(Transversity, Sivers, Boer-Mulders)

Three parton distributions describing quark's transverse momentum and/or transverse spin

Three transverse quantities:

1) Nucleon transverse spin

$\vec{S}_\perp^{\,N}$

2) Quark transverse spin

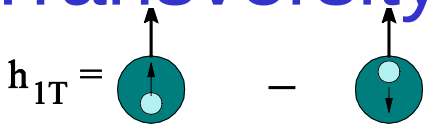
$\vec{s}_\perp^{\,q}$

3) Qaurk transverse momentum

$\vec{k}_\perp^{\,q}$

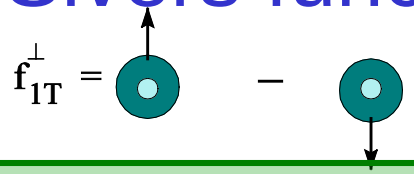
$\Rightarrow$ Three different correlations

1) Transversity



Correlation between $\vec{s}_\perp^{\,q}$ and $\vec{S}_\perp^{\,N}$

2) Sivers function



Correlation between $\vec{S}_\perp^{\,N}$ and $\vec{k}_\perp^{\,q}$

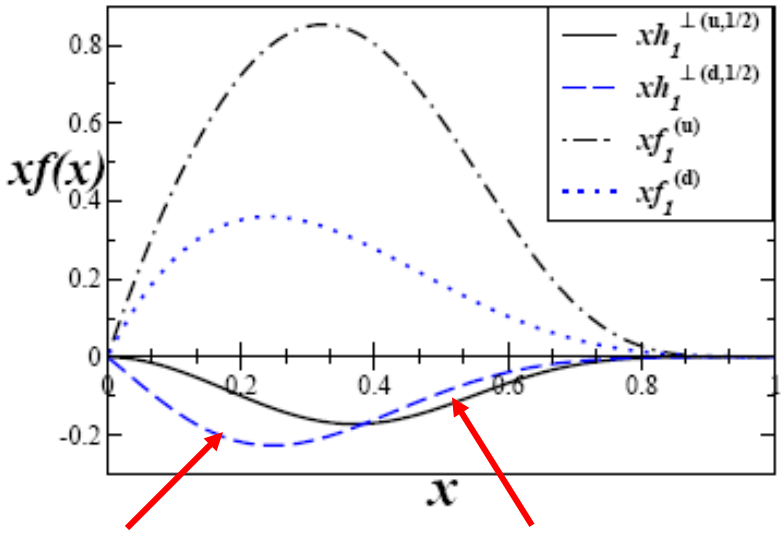
3) Boer-Mulders function

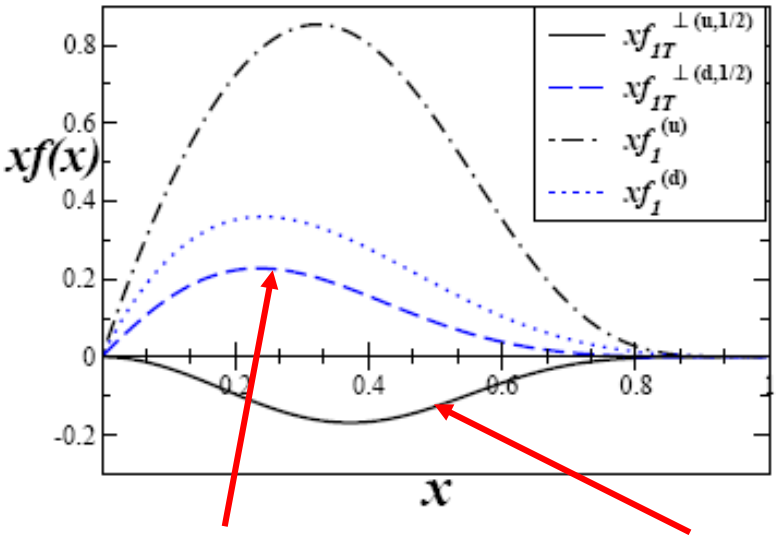
Correlation between $\vec{s}_\perp^{\,q}$ and $\vec{k}_\perp^{\,q}$

Quark-diquark Models for Boer-Mulders Function $h_1^{\perp}$

Quark-diquark model including axial-diquarks

Gamberg, Goldstein & Schlegel, arXiv:0708.0324.





B-M d-quark | B-M u-quark | Sivers d-quark | Sivers u-quark

Opposite sign for the u and d quarks Sivers functions

Same sign for the u and d quarks B-M functions

A simple "explanation" for the signs of the up- and down-quark Boer-Mulders functions

From fits to SIDIS data,

we know that

1) transversity

$h_1(u) > 0 \qquad h_1(d) < 0$

2) Sivers function

$f_{1T}^{\perp}(u) < 0 \qquad f_{1T}^{\perp}(d) > 0$

3) Boer-Mulders function

One expects

$h_1^{\perp}(u) < 0 \qquad h_1^{\perp}(d) < 0$

1) Transversity

Correlation between $\vec{s}_{\perp}^{\,q}$ and $\vec{S}_{\perp}^{\,N}$

2) Sivers function

Correlation between $\vec{S}_{\perp}^{\,N}$ and $\vec{k}_{\perp}^{\,q}$

3) Boer-Mulders function

Correlation between $\vec{s}_{\perp}^{\,q}$ and $\vec{k}_{\perp}^{\,q}$

Can one test the predicted sign-change from DIS to D-Y for pion's B-M function?

1) From NA10 pion Drell-Yan data, one deduces that the product of the pion valence quark B-M function and the proton valence quark B-M function is positive. Using *u*-quark dominance, we have:

$$h_{1,u}^{\perp,DY}(p) * h_{1,u}^{\perp,DY}(\pi) > 0$$

Therefore, either a) $h_{1,u}^{\perp,DY}(p) > 0;\ h_{1,u}^{\perp,DY}(\pi) > 0 \quad (sign-change)$

or b) $h_{1,u}^{\perp,DY}(p) < 0;\ h_{1,u}^{\perp,DY}(\pi) < 0 \quad (no\ sign-change)$

2) In polarized $\pi - p$ D-Y, the $\sin(2\phi - \phi_S)$ modulation is sensitive to the sign of $h_{1,u}^{\perp,DY}(\pi)$ (being measured at COMPASS)

3) Need to measure the sign of pion's B-M function in DIS (or rely on theory)

How to measure pion B-M function in SIDIS ?

SIDIS on the meson cloud of proton at EIC

TSIDIS (Tagged Semi-Inclusive DIS)

TSIDIS

$$e^- + p \to e^{-\prime} + n + \pi^{\pm} + x$$

underlying process:

$$e^- + \pi^+ \to e^{-\prime} + \pi^{\pm} + x$$

1) An independent check of pion's PDF

2) Could allow valence-sea flavor separation

Detected π^- is most likely from $\bar{u}$ (or d) sea in π^+

Detected π^+ is most likely from valence u (or $\bar{d}$) in π^+

3) Pion B-M function is extracted from $\cos 2\phi$ modulation

Nuclear modification of spin-dependent PDF?

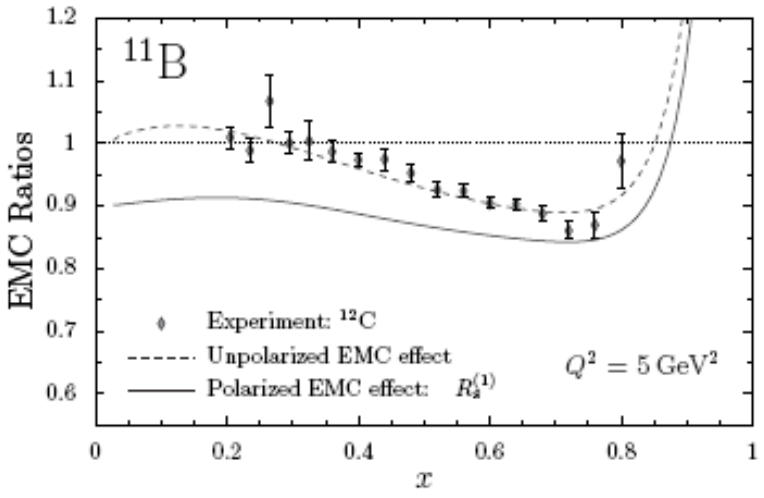


Figure 7: EMC ratios for ^{11}B. The experimental data refer to ^{12}C.

EMC effect for $g_1(x)$

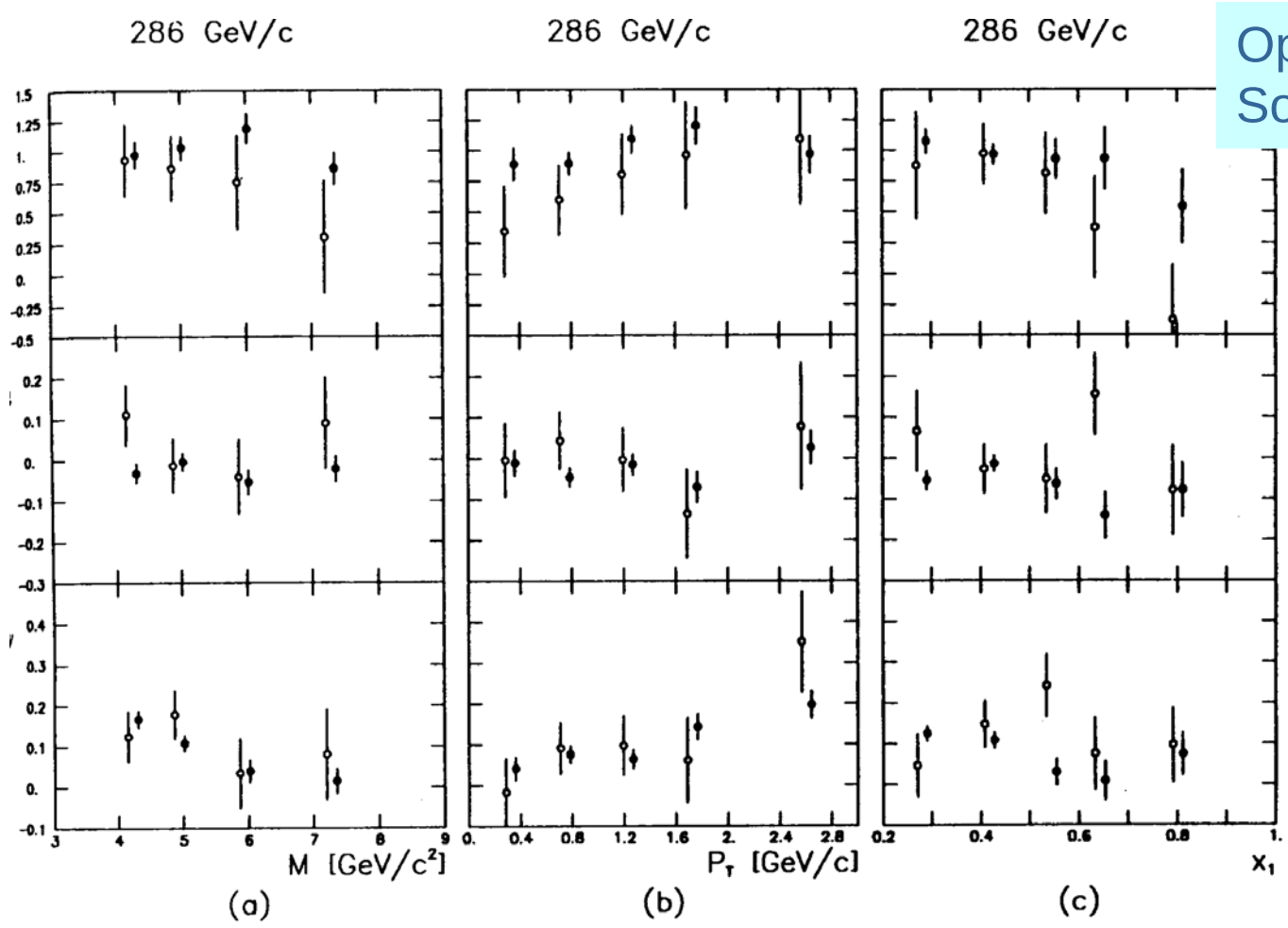
Bentz, Cloet et al., arXiv:0711.0392

Very difficult to measure !

Easier to measure the nuclear modification of Boer-Mulders functions (only unpolarized targets are required)?

(See Bianconi and Radici, J. Phys. G31 (2005) 645)

Nuclear modification of the B-M function?



Open: Deuterium
Solid: Tungsten

NA10 results

Can be measured at COMPASS