Polarized pA Physics

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Contents

- Introduction
  - Our primary goal in the original plan
- What the machine can provide ?
- Single Spin Physics with large Nucleus
- Double Spin Physics with small Nucleus
- Summary (How significant the outcome will be ?)

Spin Physics at RHIC

RHIC = polarized parton collider

- Spin Structure of Nucleon
  - $1/2=(1/2)\Delta\Sigma+\Delta G+L_q+L_g$
    - ΔG: gluon polarization
    - $\Delta\bar{q}$: Anti-quark polarization
  - New Structures
    - h_1: transversity

$gq \rightarrow \gamma q$ direct γ
$gg \rightarrow b\bar{b}$ gluon fusion
$u\bar{u} \rightarrow \gamma^*$ Drell Yan
$u\bar{d} \rightarrow W$

- Test of pQCD
  - Use asymmetries sensitive ONLY to the higher orders (A_N at high P_T etc.)

- NEW TOOL to study hadronic processes
  - W,Z @500GeV
    - flavor sensitive studies on the structure functions
  - $c\bar{c}/\overline{bb}$
    - Production mechanism
  - Spin in the fragmentation

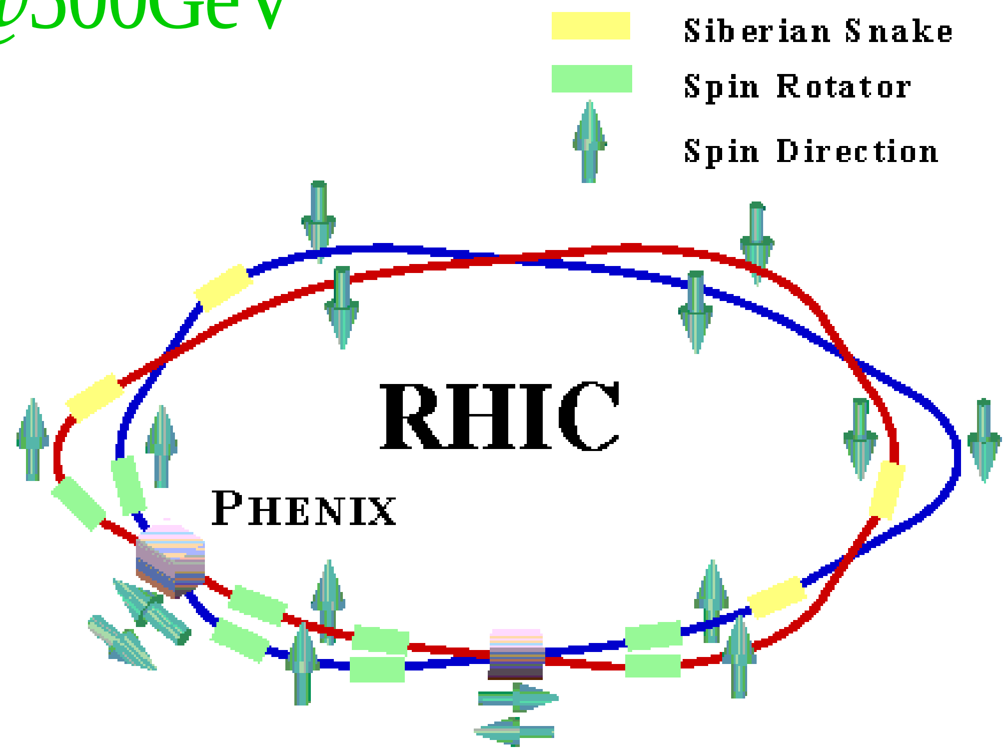
?QCD triumph? or ?beyond ?

Polarized beam acceleration

$$50 \leq \sqrt{s} \leq 500\text{GeV};\ P_B \approx 70\%$$
$$L \approx 2.0 \times 10^{32}\,\text{cm}^{-2}\,\text{sec}^{-1} @500\text{GeV}$$

Full Snake
kill the resonances
twisted dipole in RHIC

Partial Snake
complete spin flip at resonances
solenoid in AGS



Polarized Ions in RHIC

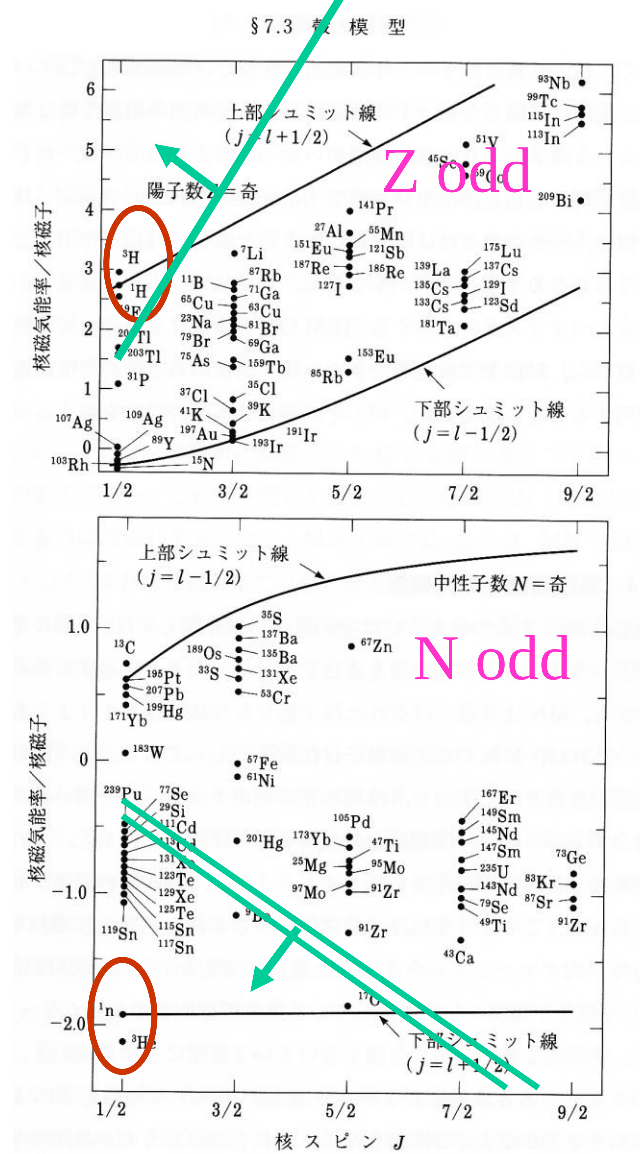
If Snake is twice strong

$BL(\pi) = 10.48\, A/Z \,/\, (\mu\, A/(2ZS) - 1) < 6\,\mathrm{Tm}$

Magnetic Moment Anomaly

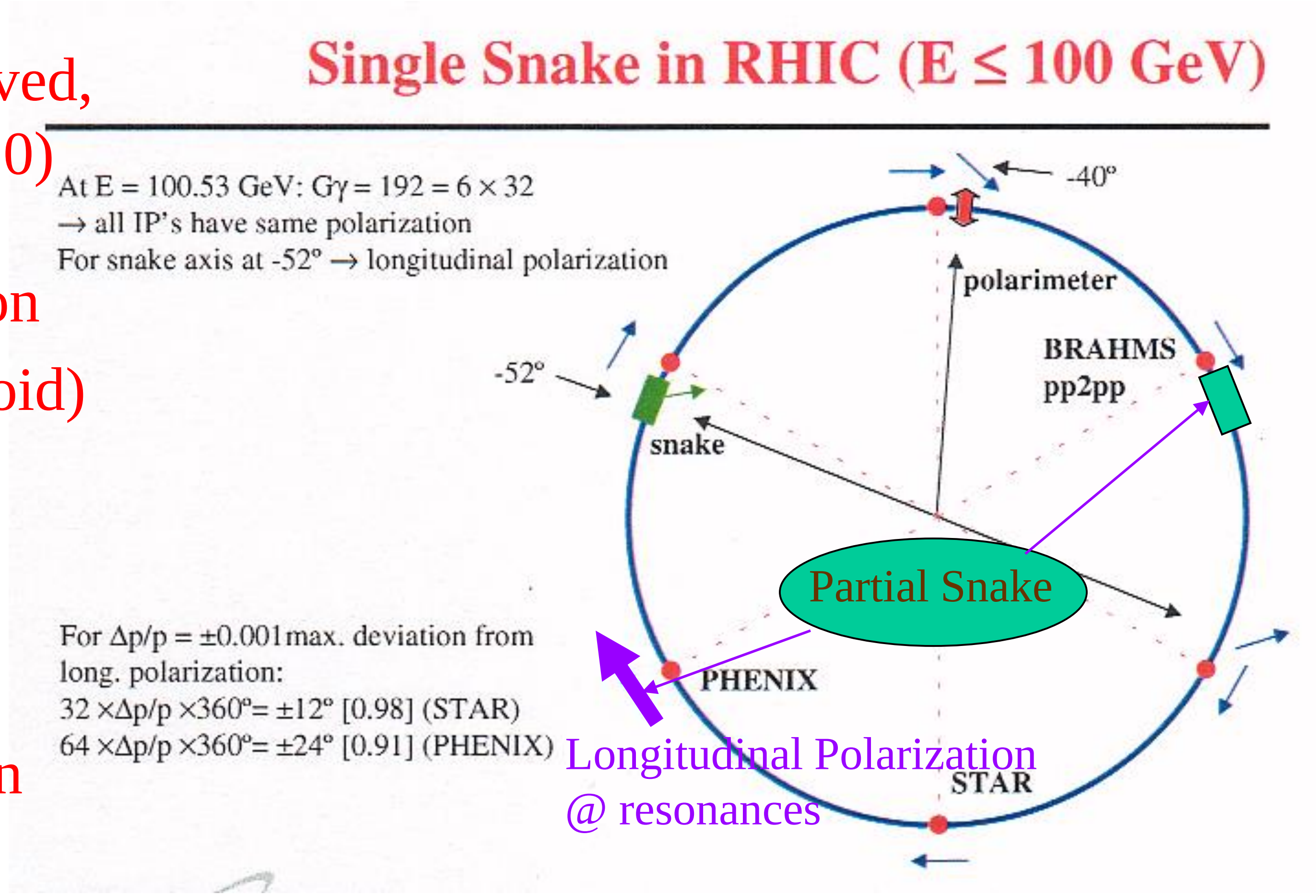
Present Snake Power

	A	Z	S	μ	G	BL(180°)
p	1	1	1/2	2.793	1.793	5.845
d	2	1	2/2	0.857	−0.143	−146.985
^{3}H	3	1	1/2	2.979	7.937	3.961
3He	3	2	1/2	−2.127	−4.191	−3.751
7Li	7	3	3/2	3.256	1.532	15.957
9Be	9	4	3/2	2.450	0.838	28.155
17O	17	8	5/2	−1.893	−1.805	−12.341
19F	19	9	1/2	2.627	4.547	4.866
205Tl	205	81	1/2	1.700	3.302	8.031
119Sn	119	50	1/2	−1.100	−3.618	−6.894



Deuteron and Others ?

- If Pol.d can be achieved, Most of Ions (spin ≠ 0) can be accelerated without depolarization
- Partial Snake (Solenoid) can work to kill the resonances (twice stronger than AGS snake)
- Single Snake for Spin manupilation ?
- Spin Flip ?



Luminosity & Energy

Ions	Goal in RHIC	Achieved in RHIC	Goal in Source	Achieved in Source
Au	$1*10^9$	$1*10^9$	–	–
P	$2*10^{11}$ P=70%	$1*10^{11}$ P=20%	$9*10^{11}$ P>80%	$6*10\wedge^{11}$ P=72%
$2D^-$	–	–	–	$1*10^{13}$ P=80%
$3He^{++}$	–	–	–	10^{10}~10^{11} P=70~80%

$2*10^{11}$ N/bunch

$\mathcal{L}_{\mathbf{pA}} \sim \mathcal{L}_{\mathbf{pp}}$

Working Assumptions

$\mathcal{L}_{pA} \sim \mathcal{L}_{pp}$

500GeV pp → 200GeV pA

→ 333GeV p^{3}He

650GeV pp → 260GeV pA

Asymmetric(important to have W)

→325+230(530) p^{3}He

→325+130(410) pA

$\vec{A}\vec{A}$ is not "Best-Buy"

due to "dilution"

$^3\vec{H}$ = "$\vec{p}$" with 1/3 Pol.

$^3\vec{He}$= "$\vec{n}$" with 1/3 Pol.

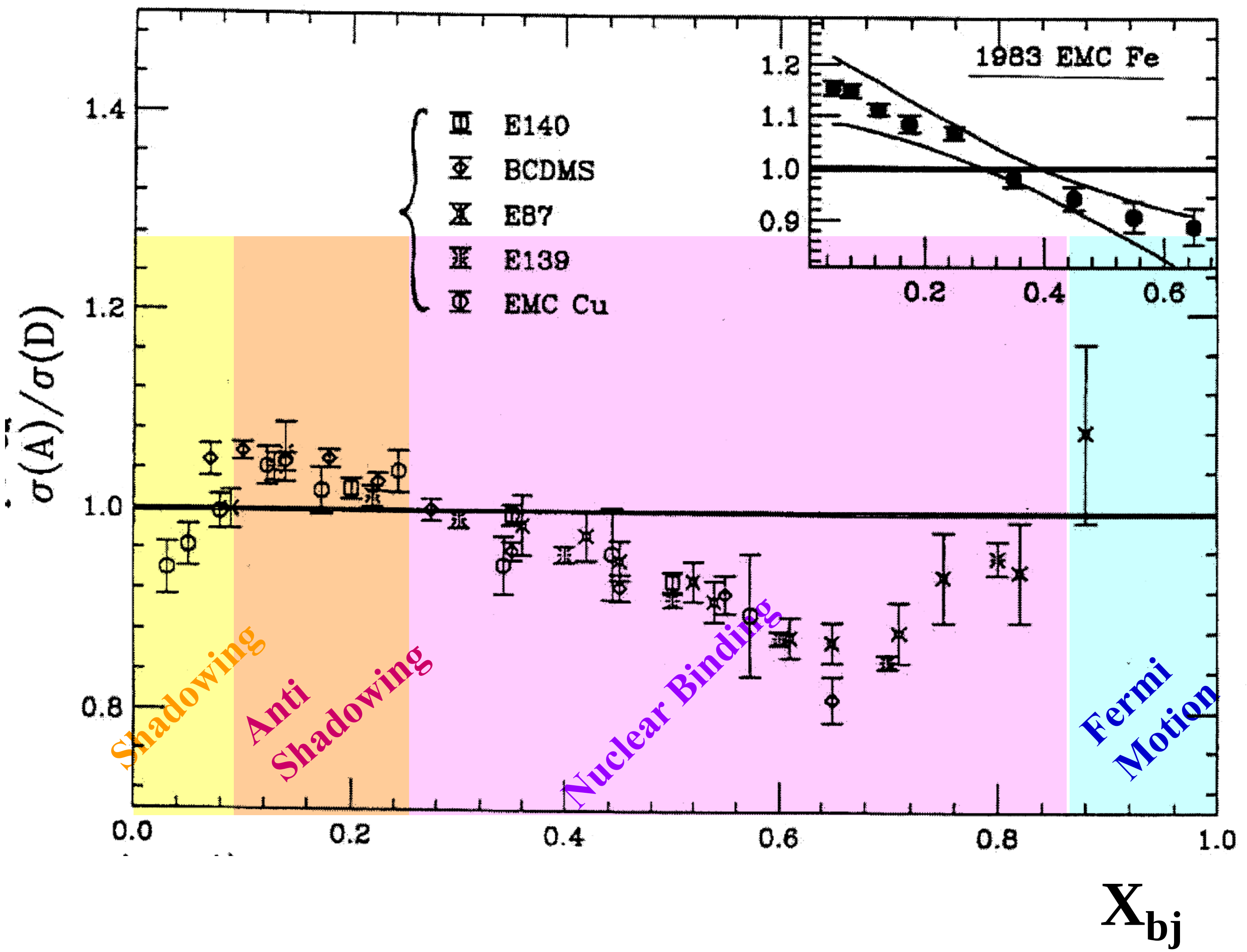
	p	^{3}H	^{3}He	d	F	A
p	⇄	⇄	⇄	⇄	⇄	→
^{3}H	⇄					
^{3}He	⇄					
d	⇄					
F	⇄					
A	→					

Our Surprises (Past)

- Gluons' momentum fraction
- Iso spin Structure of Sea
- **Spin** Fraction of Quarks
- EMC effect !?

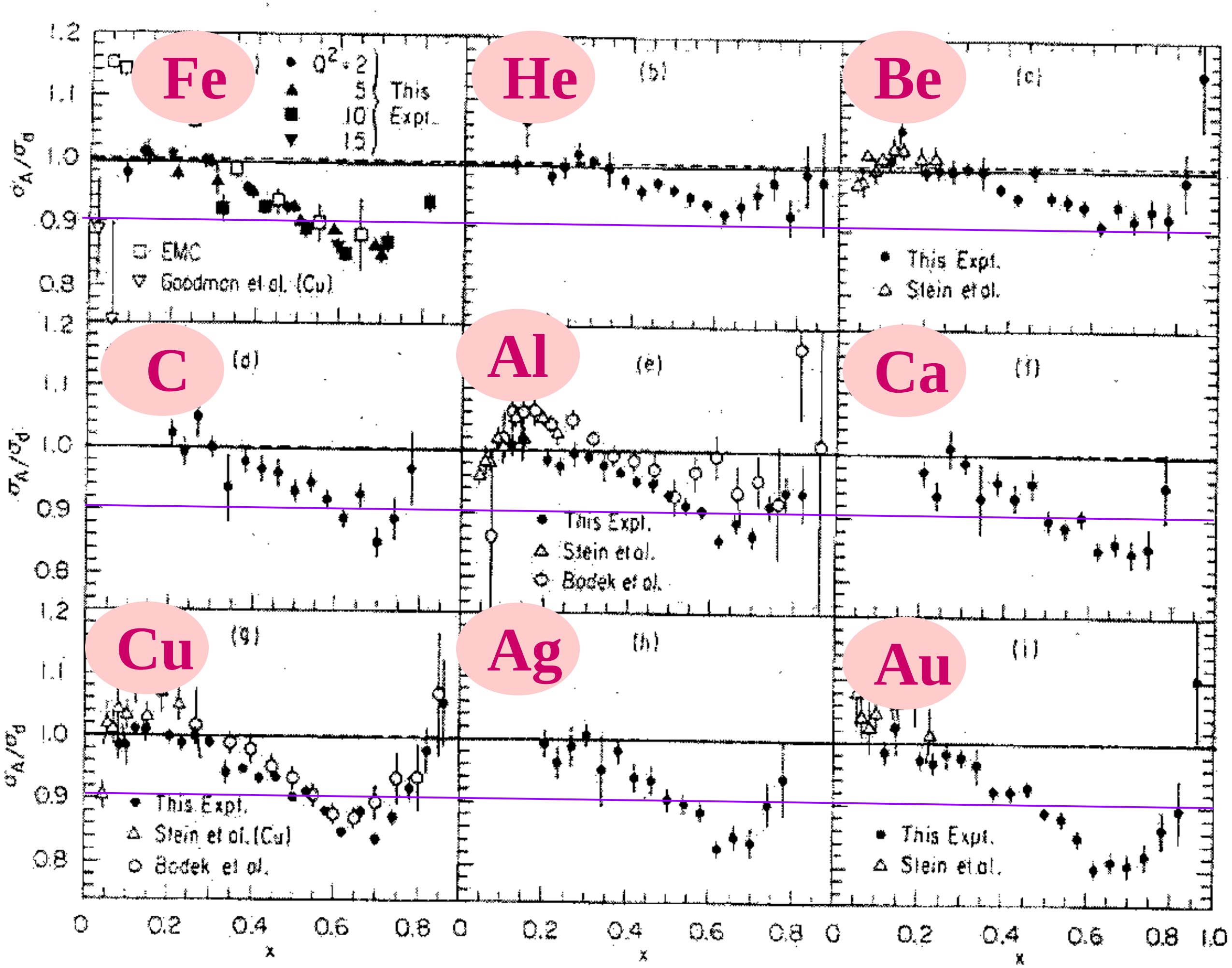
Future ? (QCD perfect?)

EMC effect

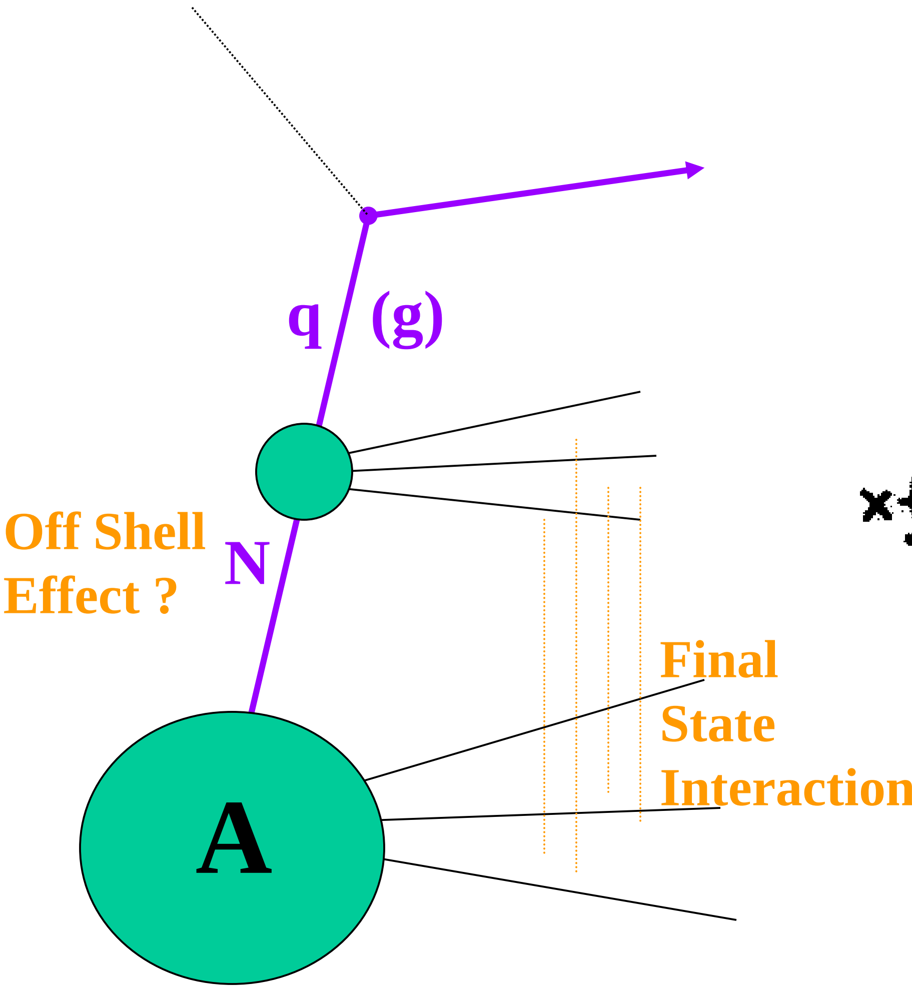


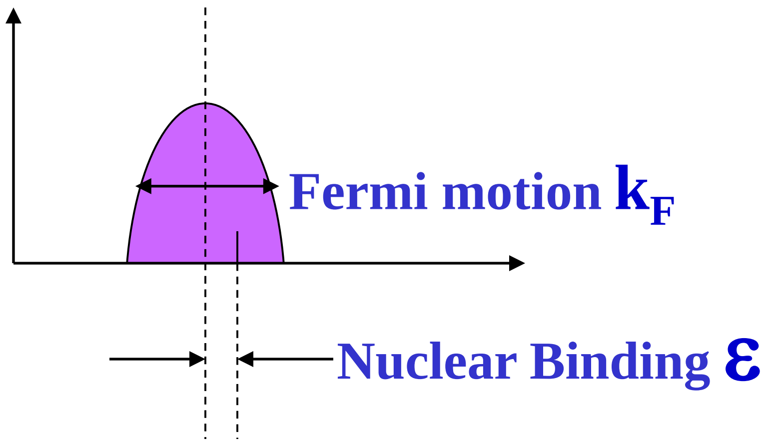
1983 EMC Fe
1.2
1.1
1.0
0.9
0.2
0.4
0.6
E140
BCDMS
E87
E139
EMC Cu
1.4
1.2
1.0
0.8
$\sigma(A)/\sigma(D)$
0.0
0.2
0.4
0.6
0.8
1.0
Shadowing
Anti
Shadowing
Nuclear Binding
Fermi
Motion
X_{bj}

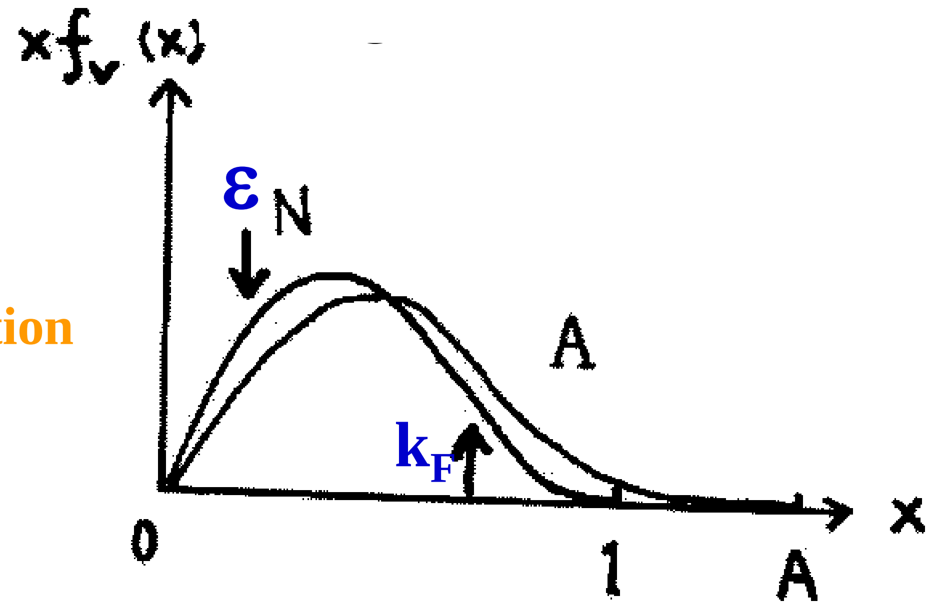
EMC effect is seen any nucleus



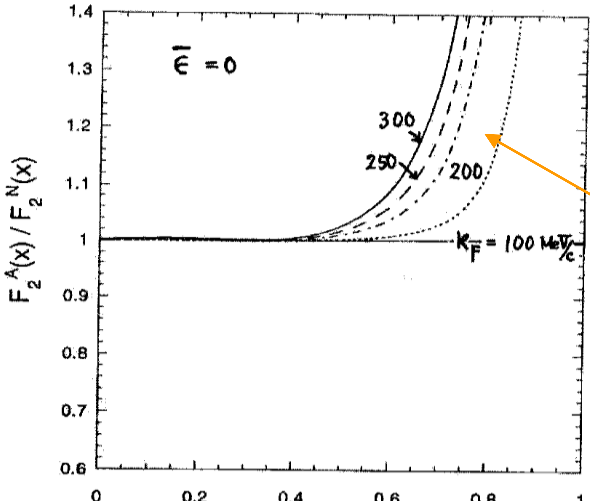
EMC effect, Not Fundamental?

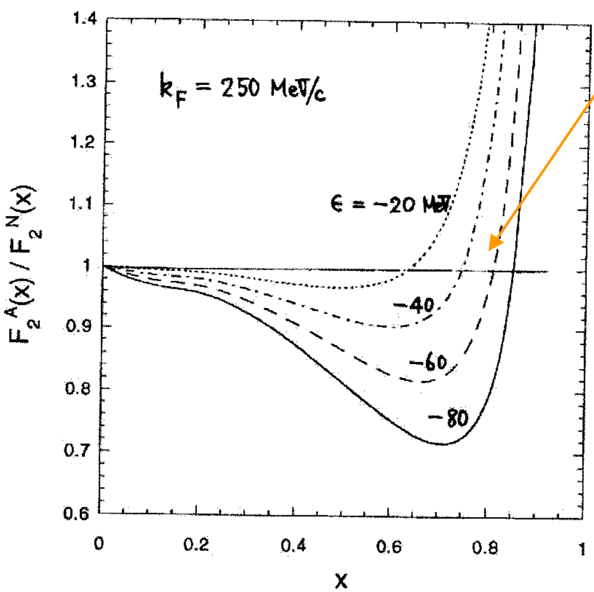






EMC effect, Not definitive answer





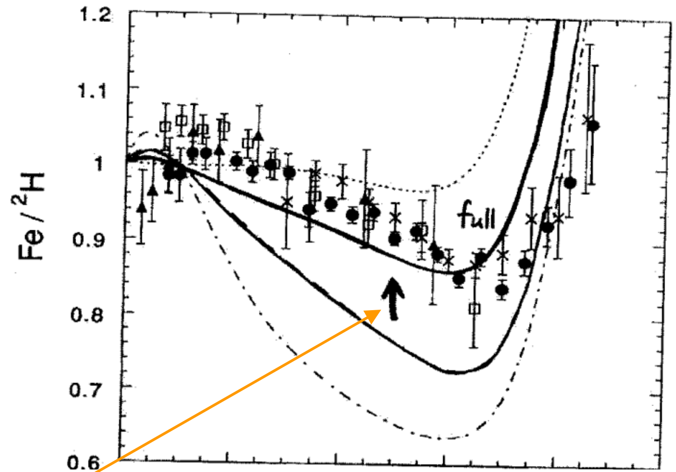
Fermi momentum

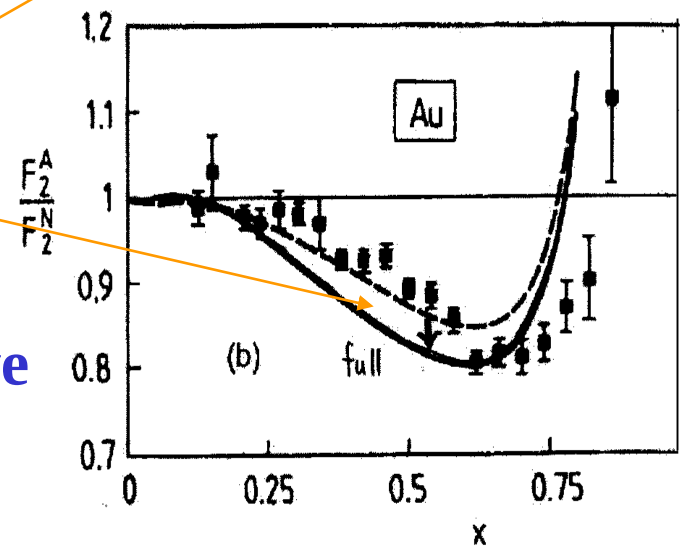
Binding Energy

Final State Int.

Off Shell Effect

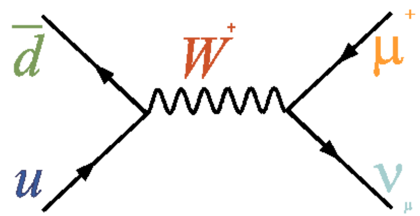
MN: Not definitive
QPM: Worse





Weak Boson Detection at PHENIX @500GeV

- W production is
  - Flavor sensitive
  - helicity fixed (V-A)



Yield in 1-RHIC year at 500GeV

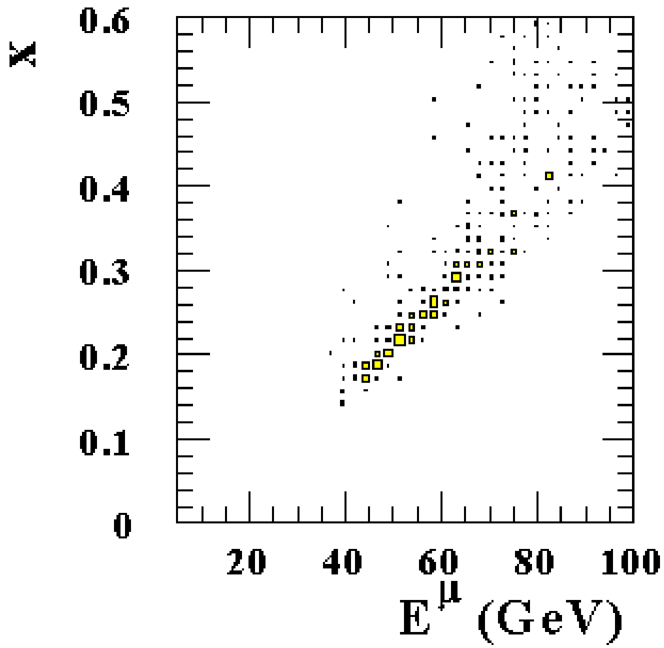
	W^-	W^+
acceptance for muon w/ $p_T > 20$ GeV/c	14%	4%
yield (both muon arms)	5100	5600
ΔA_L (statistical only)	2%	2%
rapidity average	0.78±0.34	0.71±0.41
background from Z-decay	1095(21.5%)	984(17.6%)

20% Less

30% MORE

Kinematics (realized by N.Saito)

- power of the polarized collider with Muon Endcaps



A/Z ratio in Large Nucleus
If $\bar{d}_p=\bar{d}_n$ &
$\bar{u}_p=\bar{u}_n$

LHC^{--} pA (reachable in RHIC^{++}) for Flavor Sensitive EMC effect

- $W^{+} = \bar{d}_A(x_A)u_p(x_p) + \bar{d}_p(x_p)u_A(x_A)$
- $W^{-} = d_A(x_A)\bar{u}_p(x_p) + d_p(x_p)\bar{u}_A(x_A)$

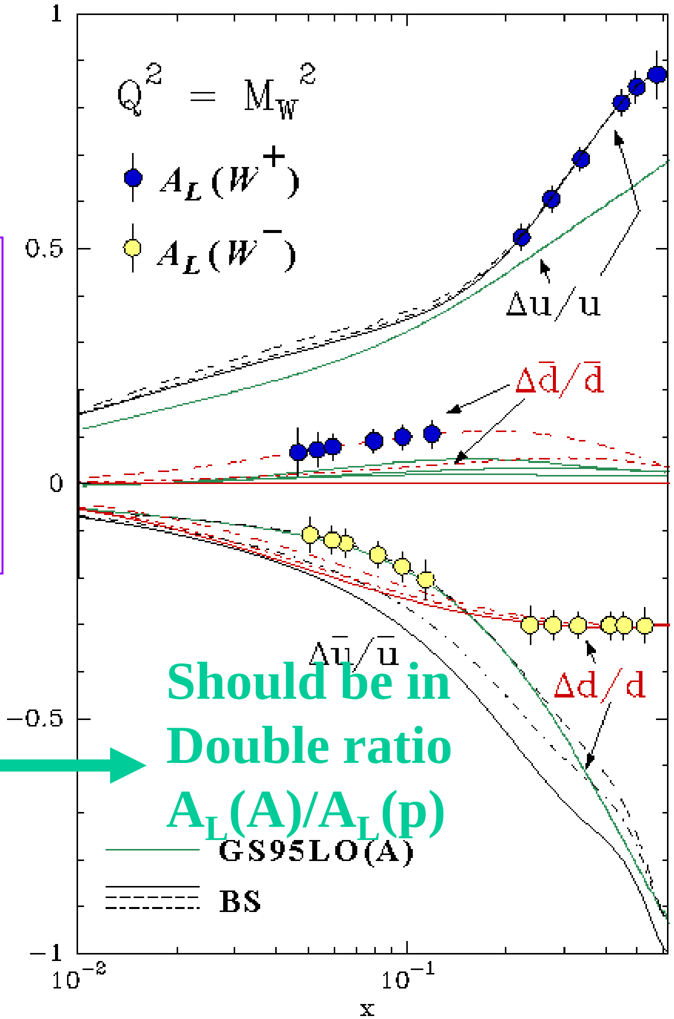
EMC Effect with flavor

- $R(W^{+}{}_A/W^{+}{}_p) = \bar{d}_A(x_A)/\bar{d}_p(x_{p*})$ $\quad (x_p >> 0)$
  $u_A(x_A)/u_p(x_{p*})$ $\quad (x_A >> 0)$
- $R(W^{-}{}_A/W^{-}{}_p) = d_A(x_A)/d_p(x_{p*})$ $\quad (x_p >> 0)$
  $\bar{u}_A(x_A)/\bar{u}_p(x_{p*})$ $\quad (x_A >> 0)$

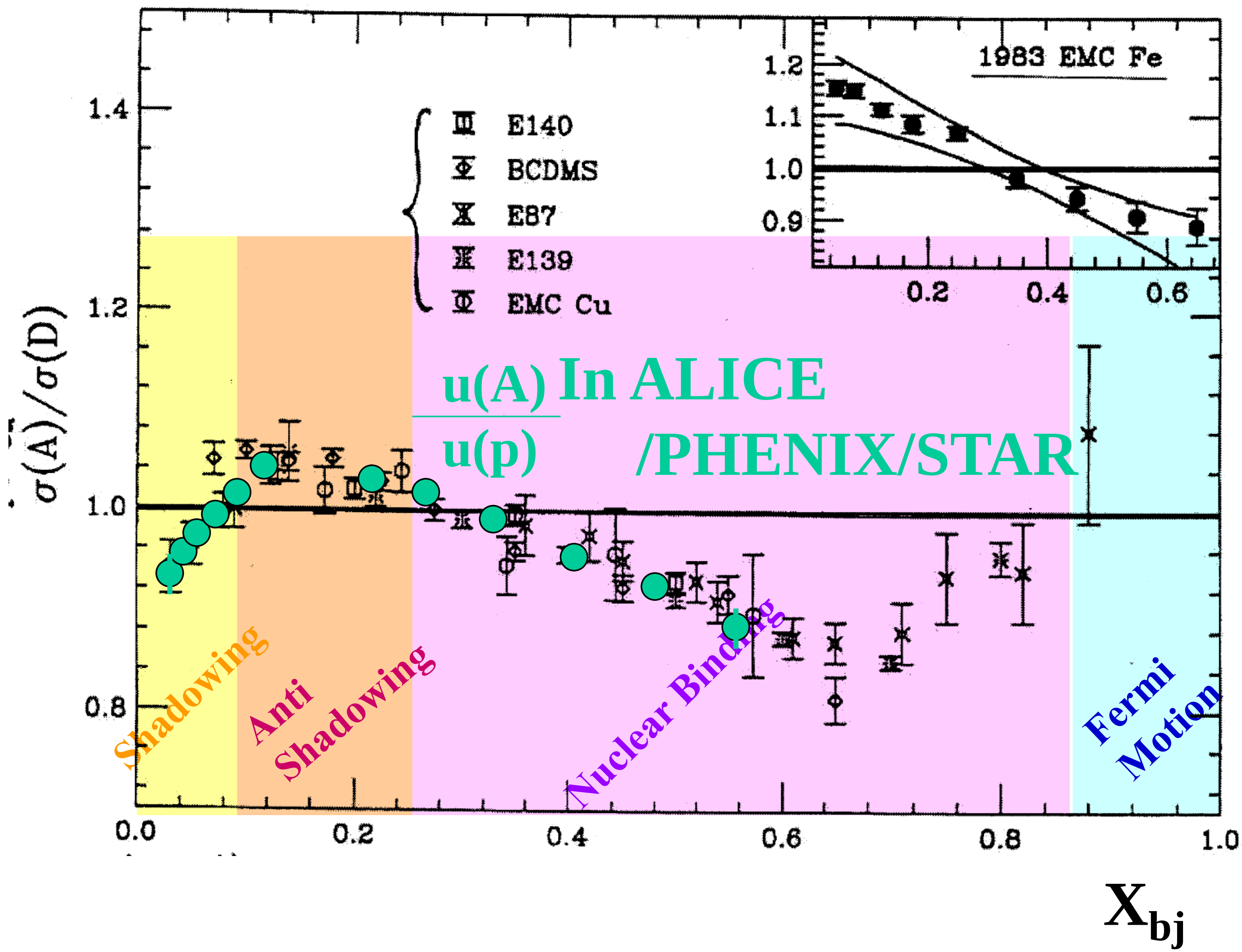
EMC Effect with spin (requires polarized proton)

- $A_L(W^{+}{}_A) = \Delta\bar{d}_A(x_A)/\bar{d}_A(x_A)$ $\quad (x_p >> 0)$
  $\Delta u_A(x_A)/u_A(x_A)$ $\quad (x_A >> 0)$
- $A_L(W^{-}{}_A) = \Delta d_A(x_A)/d_A(x_A)$ $\quad (x_p >> 0)$
  $\Delta\bar{u}_A(x_A)/\bar{u}_A(x_A)$ $\quad (x_A >> 0)$

Should be in Double ratio $A_L(A)/A_L(p)$



Quark Structure Function in A



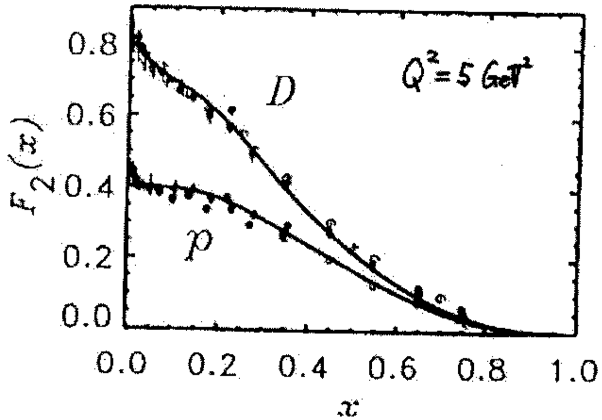
Q2 evolution
Neglected

Why not $\Delta G(A)$ In RHIC @200GeV

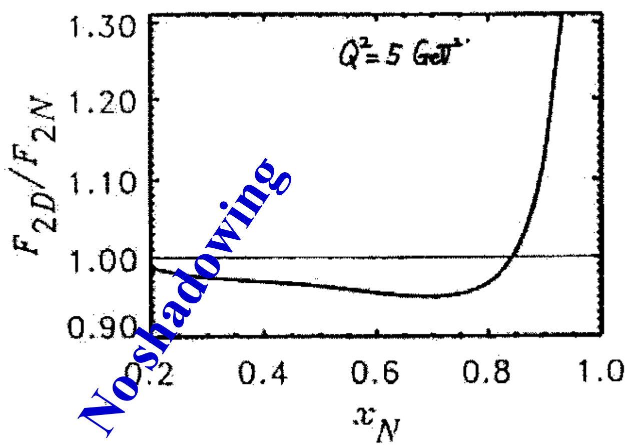
- must be interesting (the other side of EMC effect)
- All the ΔG channel can be applied, but x determination is crucial. STAR γ+Jet or PHENIX + Jet detection upgrade will be suitable for q+g channel
- Channel like $g+g \rightarrow b\bar{b}$ is feasible & interesting, but x is not well determined in open bb channel.
  - No real measurements so far ?
- Not easy to get $\Delta G(A)/G(A)$ with large Nucleus

  A_{LL} required. ^{19}F can be tried. ^{19}F is a pure proton hole state of $^{20}Ne(N=Z=10)$. $\rightarrow$ polarized structure function of proton hole. But dilution is large (1/19)

With light Nuclei: $^3H, ^3He, d$



d/(2p)



- A_{LL} A_{TT} possible
- EMC effect exist.

  Almost under control
- ***$^3He/^3H$: mirror nuclei***

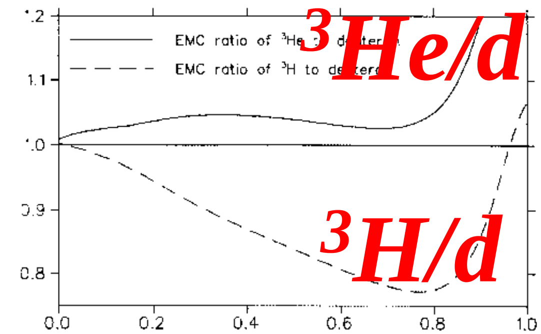


Fig. 1. The ratio of the F_2 structure functions of ^{3}He and ^{3}H to that of the deuteron (at 1 GeV^2).

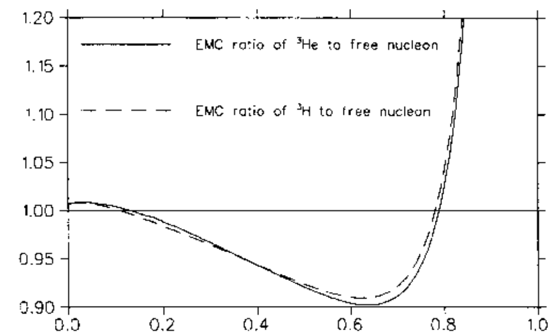
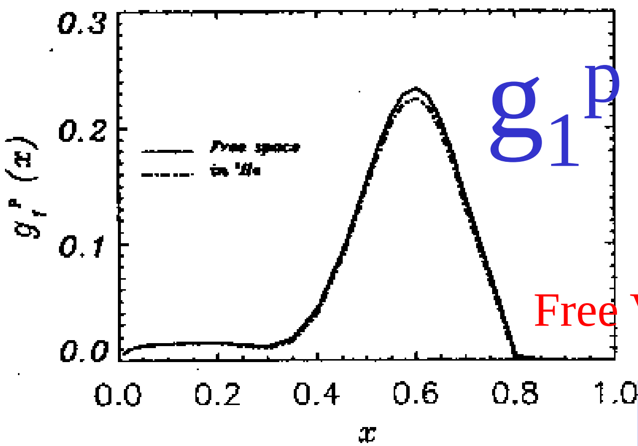


Fig. 2. Theoretical calculations of the nuclear corrections in ^{3}He and ^{3}H (at 1 GeV^2) – the theoretical EMC ratio is defined through Eq. (1).

$^3He/(2p+n), ^3H/(p+2n)$

Nuclear Effect to g_1 is not large (3He)
- model calculations -

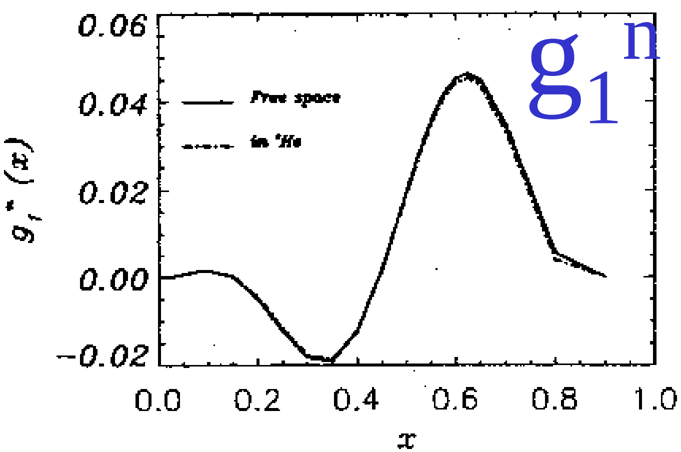


g_1^p

Free VS 3He

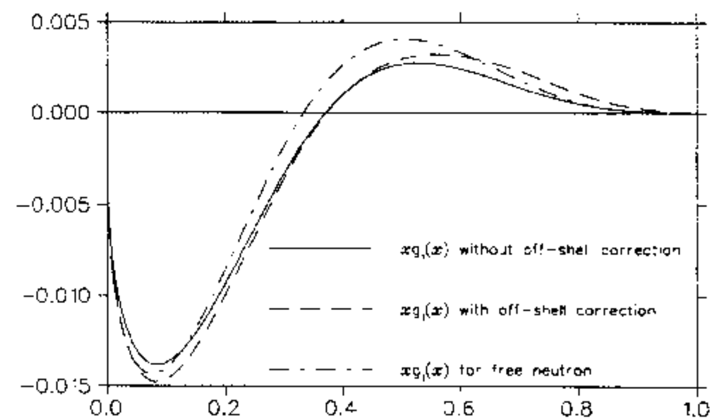
This is why we can assume that polarized 3He is a polarized **neutron**

Offshell Effect ?

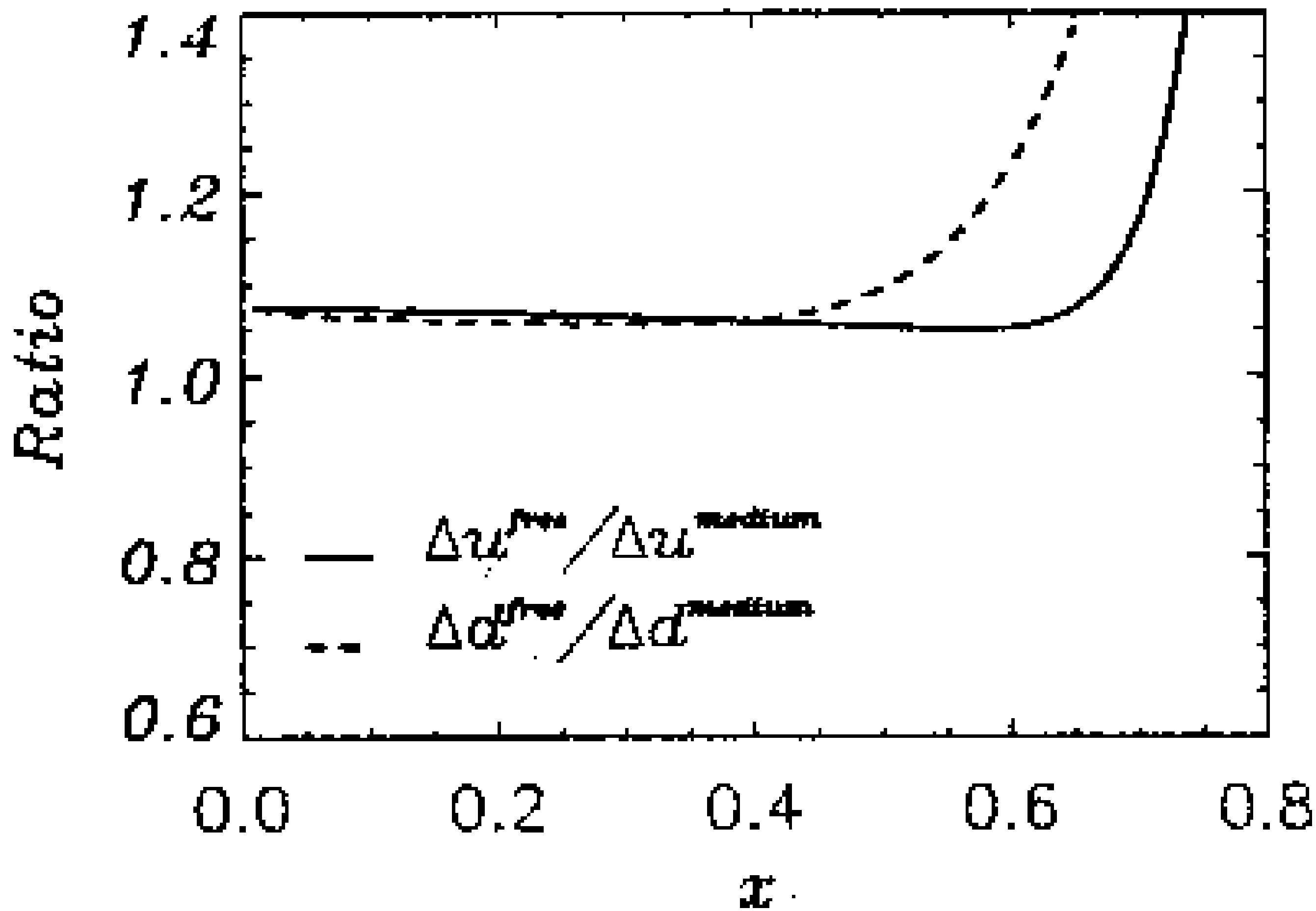


g_1^n

Different Model



But in detail there may be …



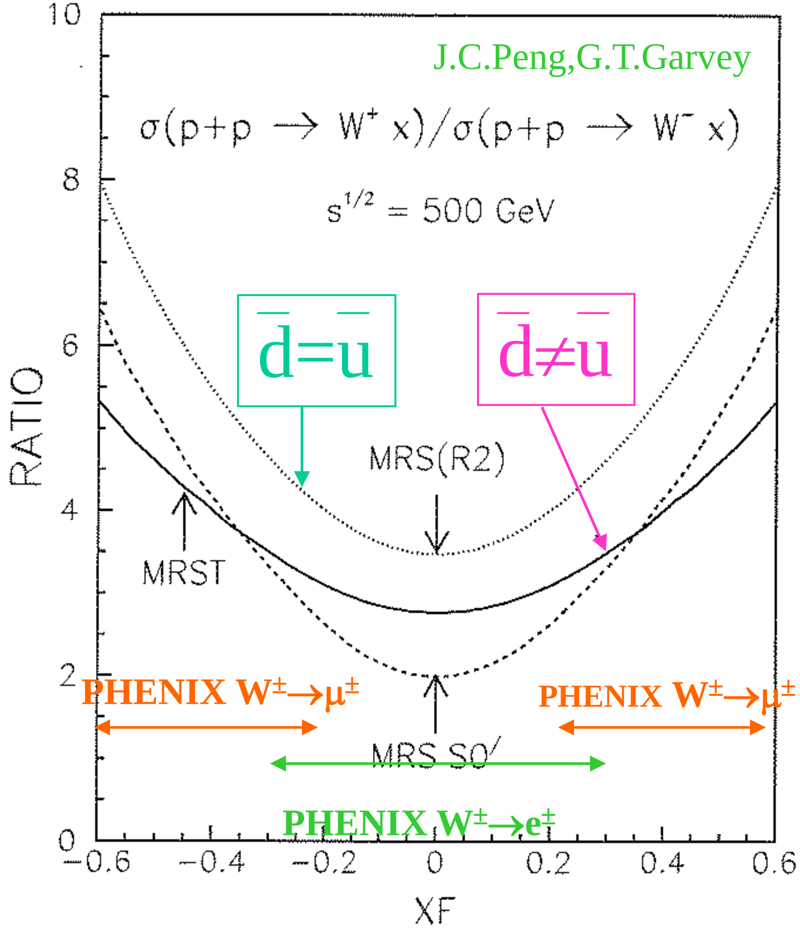
So….

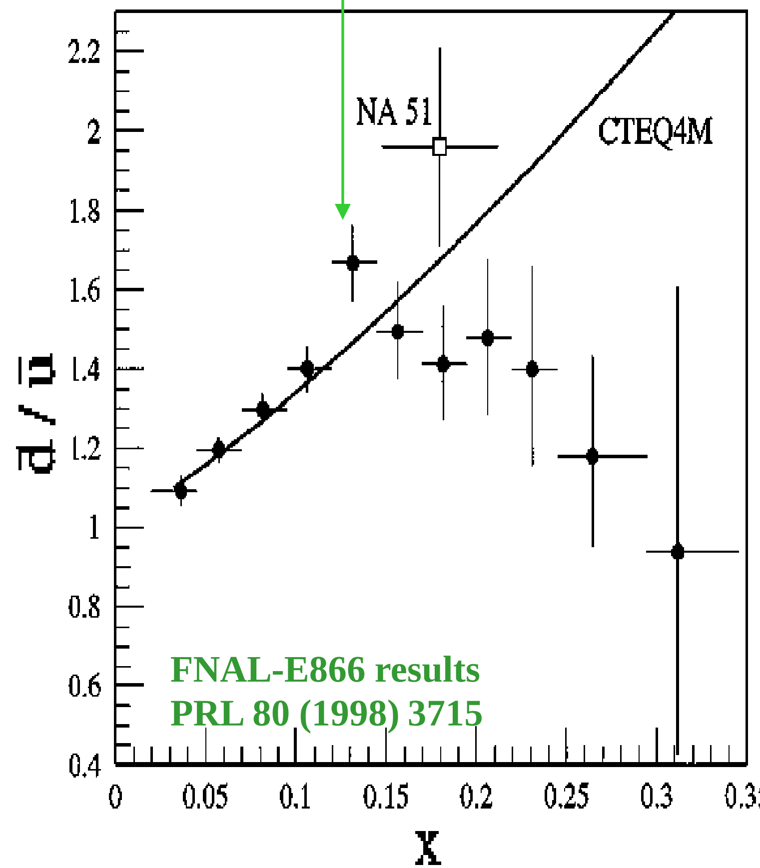
- We can safely repeat the same measurements in p+"n" as p+p.
  - Note that the effective luminosity is 1/3 lower (dilution)
- We believe Isospin Symmetry
  - u in p = d in n
  - d in p = u in n
  - g in p = g in n , Δg in p = Δg in n (RHIC specialty).
- With 3H we can study " $\vec{p}$ " in nuclear matter, but the effect may not be large.
- Diagnostics type measurements (but always SURPRIZE can happen)

Flavor Structure of Nucleon

- No reason to assume $\bar{d} = \bar{u}$ in nucleon
  - $\Delta\bar{d} \neq \Delta\bar{u}$ is natural
- RHIC@500GeV
  - W^+/W^- Yield comparison

Recent FNAL Data shows ≤50% difference in $p+p/p+d \rightarrow \mu^+\mu^-$(D.Y.)





p+3He / p+3H for sea quark

- Gottfried sum

  $I_G = \int dx(\, F_2^p - F_2^n)$

  $= 1/3 + 2/3 \int dx(\, u^p - d^p)$

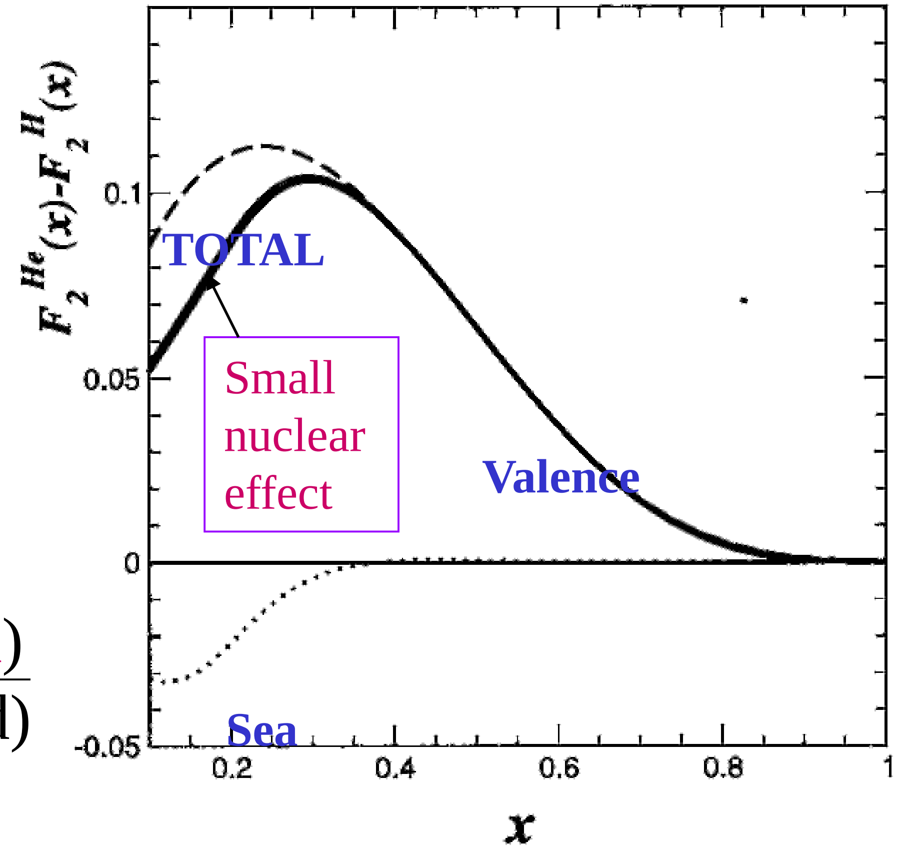
  $= 0.235$ (exp.)

- For mirror nucleus
- $I_G = \int dx(\, F_2^{p3He} - F_2^{3H})$

  $= 1/3 + 2/3 \int dx(\, u^p - d^p)$

- Cancel nuclear effects
- Easy Spin handling

$$\frac{\sigma\,(p^3He) - \sigma\,(p^3H)}{\sigma\,(p^3He) + \sigma\,(p^3H)} = \frac{1(4u-d)(u-d)}{3(4u+d)(u+d)}$$

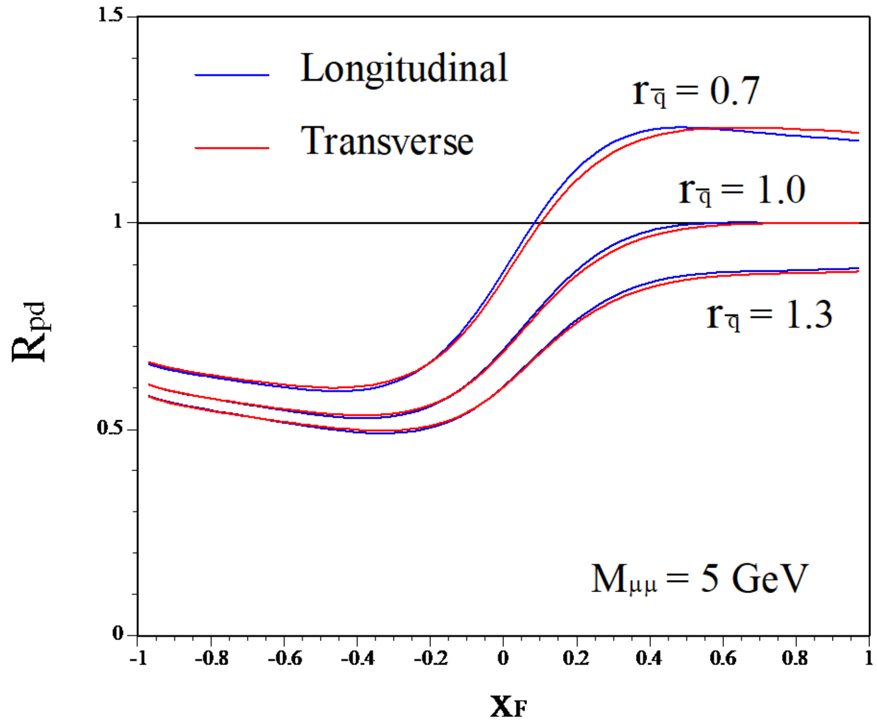


$$\frac{A_{LL}^{p3He}\,\sigma\,(p^3He) - A_{LL}^{p3H}\,\sigma\,(p^3H)}{\sigma\,(p^3He) + \sigma\,(p^3H)} = \frac{1(4u-d)(\Delta u-\Delta d)}{3(4u+d)(u+d)}$$

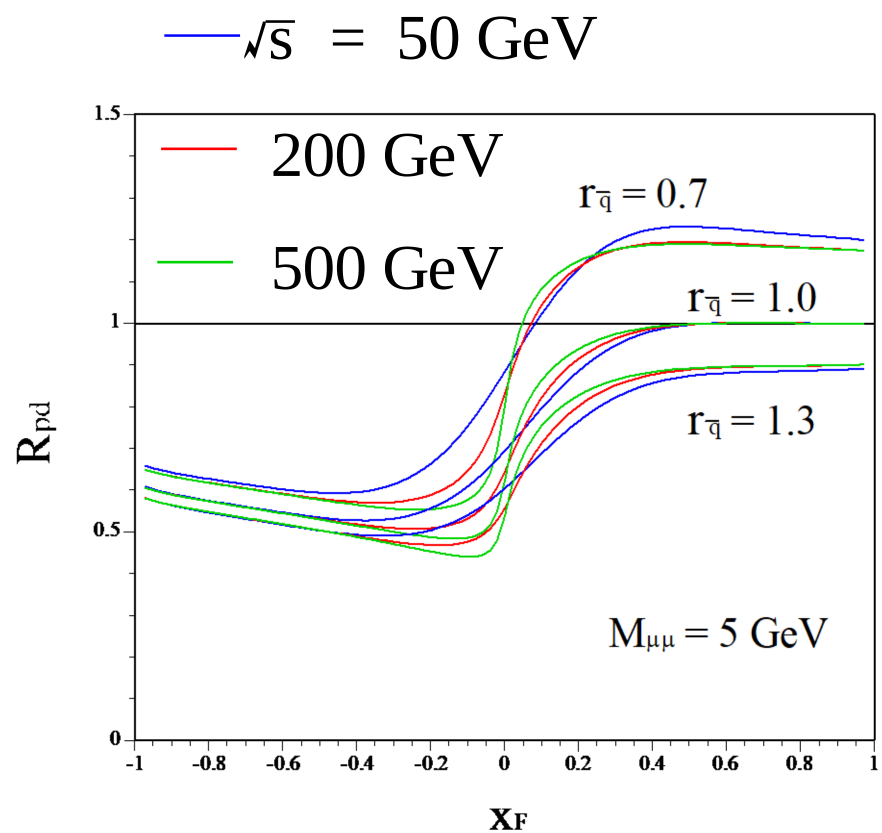
p＋d

- D↑＝p↑＋n↑(spin 1)
  - $A_{LL}=\Delta q^{d}$ helicity
  - $A_{TT}=\Delta_T q^{d}$ transversity
  - $A_{UQ}=\delta q^{d}$ tensor
- As a “n” beam vs ^{3}He
  - d is less attractive since A_{LL}^{pd} arise also from “p”
  - d is more attractive since Nuclear effect is better known
  - d is less attractive from a view point of spin handling
- □ $\Delta\bar{u} \neq \Delta\bar{d}$ physics
  - $R_{pd} = \Delta\sigma_{pd}/2\Delta\sigma_{pp}$ in D.Y. (Kumano et al.)
    $=1/2(1+\Delta\bar{d}/\Delta\bar{u})$

p+d



Longitudinal
Transverse
$r_{\bar{q}} = 0.7$
$r_{\bar{q}} = 1.0$
$r_{\bar{q}} = 1.3$
$M_{\mu\mu} = 5$ GeV
R_{pd}
x_F



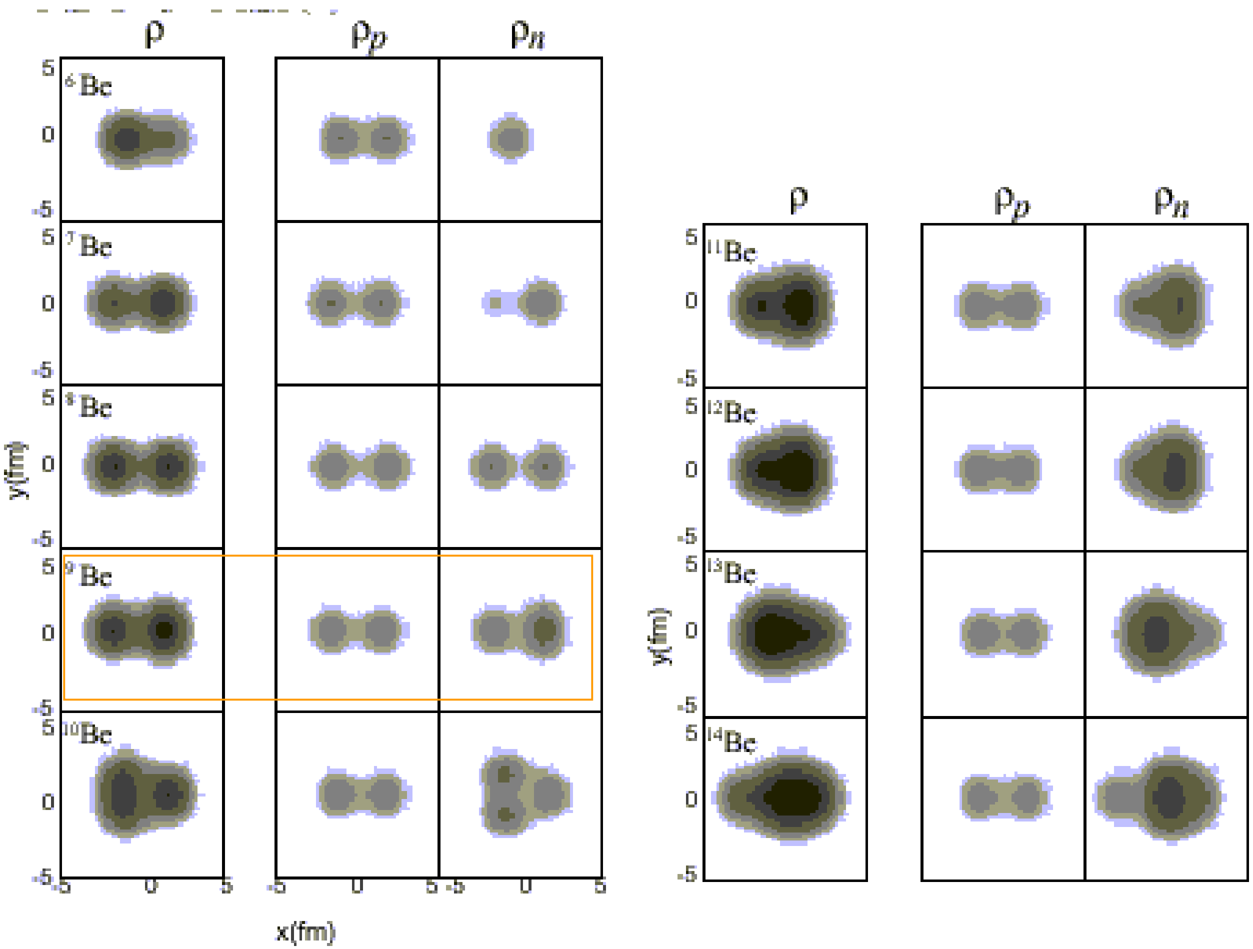
$\sqrt{s}$ = 50 GeV
200 GeV
500 GeV
$r_{\bar{q}} = 0.7$
$r_{\bar{q}} = 1.0$
$r_{\bar{q}} = 1.3$
$M_{\mu\mu} = 5$ GeV
R_{pd}
x_F

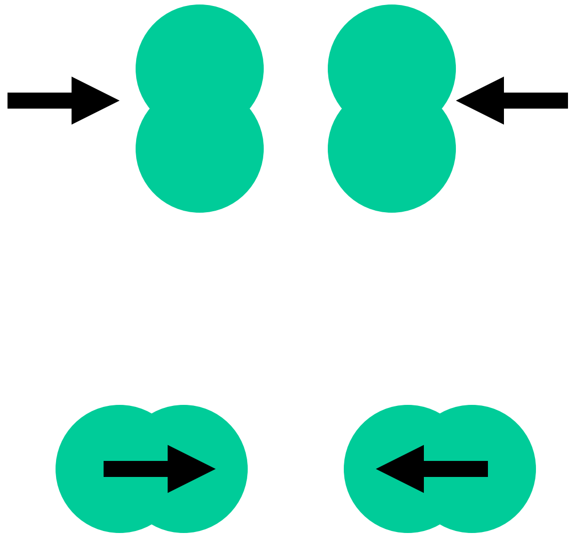
Summary

- Two categories are feasible in polarized pA physics
  - Single spin pA
  - Double spin p(d, 3H, 3He,19F)
- Reachable in RHIC++, pA @ >500 GeV can provide unique measurements which can address FLAVOR sensitive EMC effect (LHC?).
  - A kind of measurements we have to do it at least once.
- G(A)/G(p) can be addressed in RHIC. With 19F $\Delta G(A)/G(A)$ can be measured (with 1/19 dilution).

- With 3He, polarized p + polarized "n" can be studied. If Isospin Symmetry holds, this is a kind of diagnostics measurements. (very important, but less interesting)
- $\Delta\bar{u} = \Delta\bar{d}$, $\bar{u}=\bar{d}$ can be studied with 3He,3H,d Drell-Yan, complementary to $pp \rightarrow W$
- Clearly we need more study on this matter.
  - A_N type measurements (single spin pA) should also be considered
    - Higher order QCD, can be a lot different in A

Spin manipulation is collision geometry change in AA





The biggest UPGRADE issue
in Spin Community is

NEW DETECTOR
FOR SPIN

or not