News on the nuclear EMC effect

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Argonne National Laboratory

Gordon Research Conferences

PHOTONUCLEAR REACTIONS

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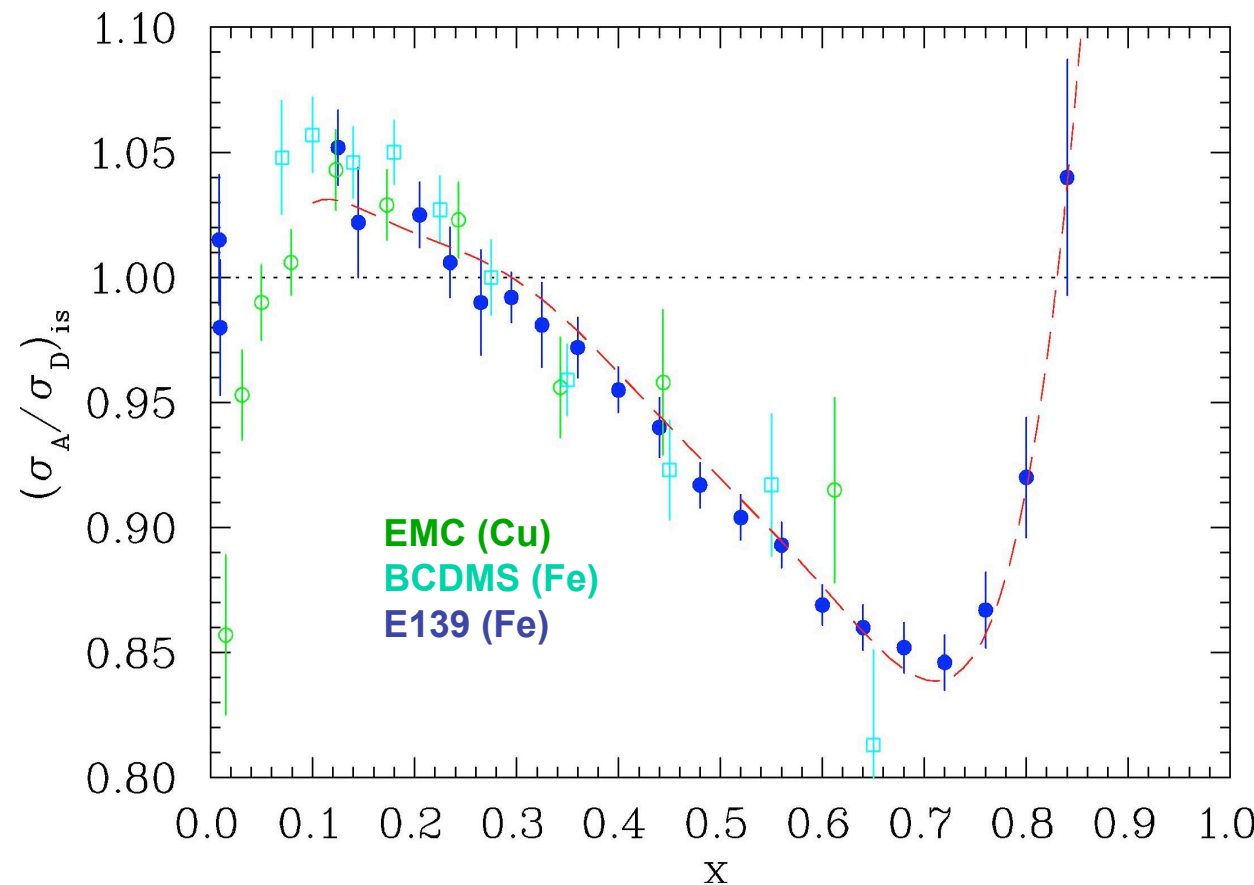# Nuclear structure functions and the EMC effect

❖ **Nuclear structure: $\sigma_A \neq Z \cdot \sigma_p + N \cdot \sigma_n$**

◆ Effects found in several experiments at CERN, SLAC, DESY

❖ **Same *x*-dependence in all nuclei**

◆ Shadowing: $x < 0.1$
◆ Anti-shadowing: $0.1 < x < 0.3$
◆ EMC effect: $x > 0.3$

❖ **The size of the effect is a function of A**

EMC (Cu)
BCDMS (Fe)
E139 (Fe)

$(\sigma_A / \sigma_D)_{is}$

x

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Mapping the EMC Effect

Models should include conventional effects:
- ➢ Fermi motion and binding dominate at high x
- ➢ Binding also affects quark distribution at all x

Benhar, Pandharipande, and Sick
Phys. Lett. B410, 79 (1997)
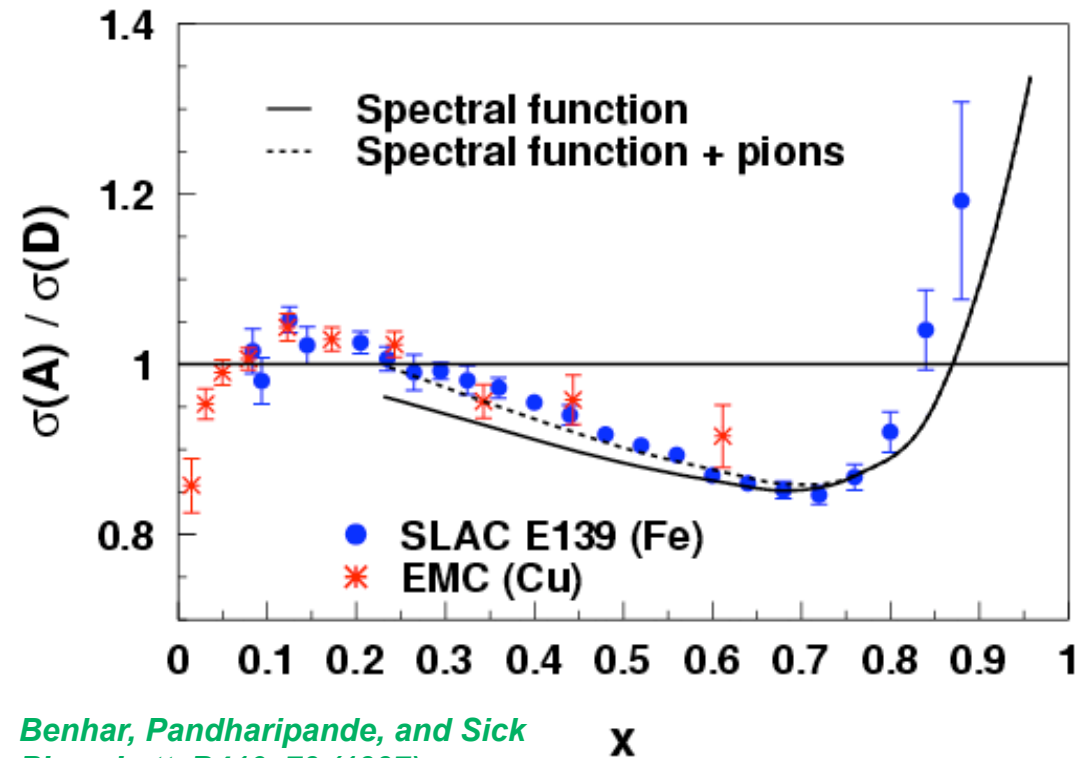
Then more "exotic" explanations may be added if these effects are not enough to describe the data like:

- ➢ Nuclear pions
- ➢ Multiquark clusters
- ➢ Dynamical rescaling

Many of these models can reproduce the large x region but failed in other x-regions or for other data (Drell-Yan) or didn't include conventional effects.

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Existing EMC Data
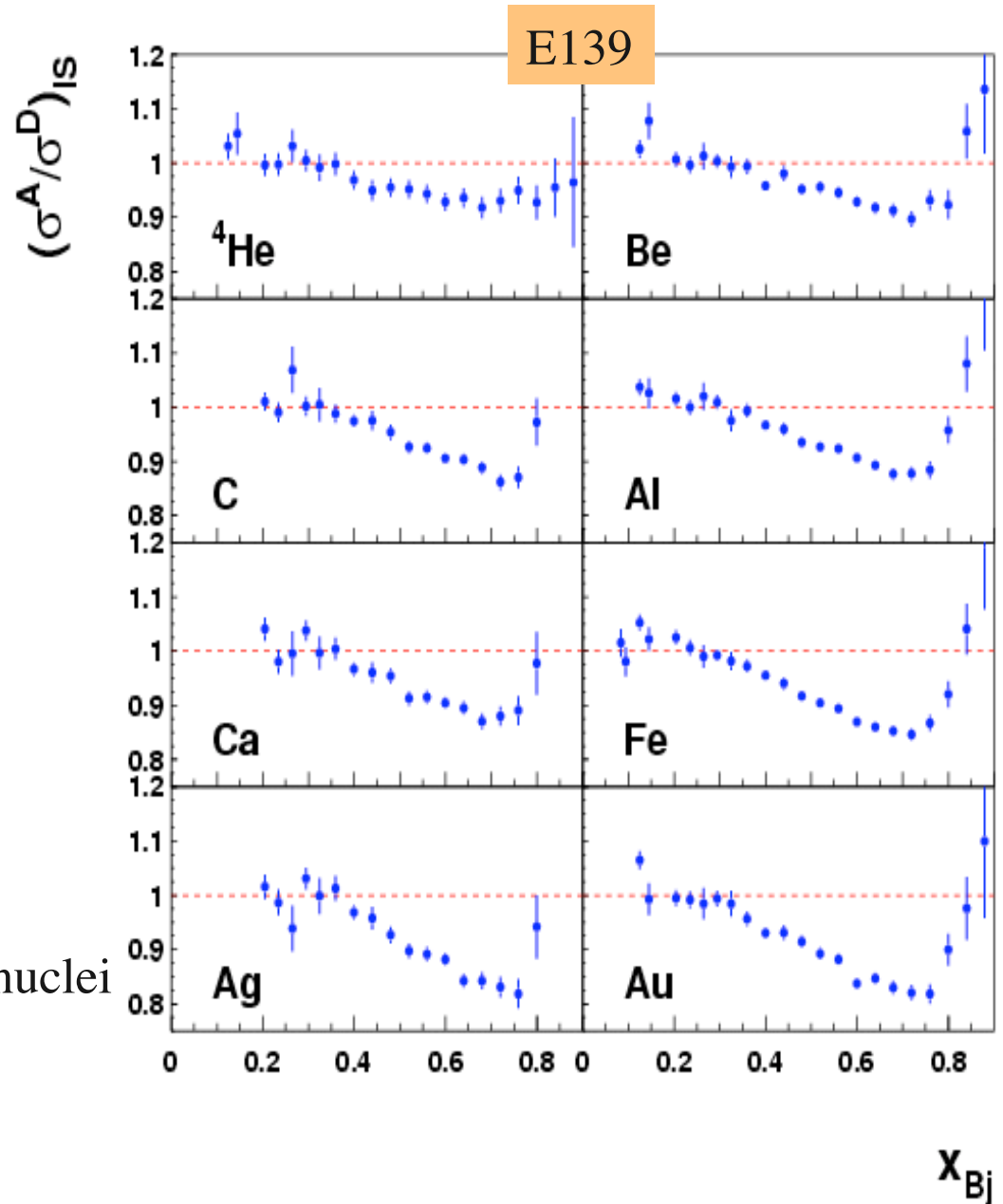
❖ **SLAC E139**

 ◆ Most complete data set: A=4 to 197

 ◆ Most precise at large *x*

  → Q^2-independent

  → universal shape

  → magnitude dependent on A

❖ **E03-103 will improve with**

 ◆ Higher precision data for ^{4}He

 ◆ Addition of ^{3}He data

 ◆ Precision data at large *x* and on heavy nuclei

⇨ **Lowering Q^2 to reach high *x* region**

E139

$(\sigma^A/\sigma^D)_{IS}$

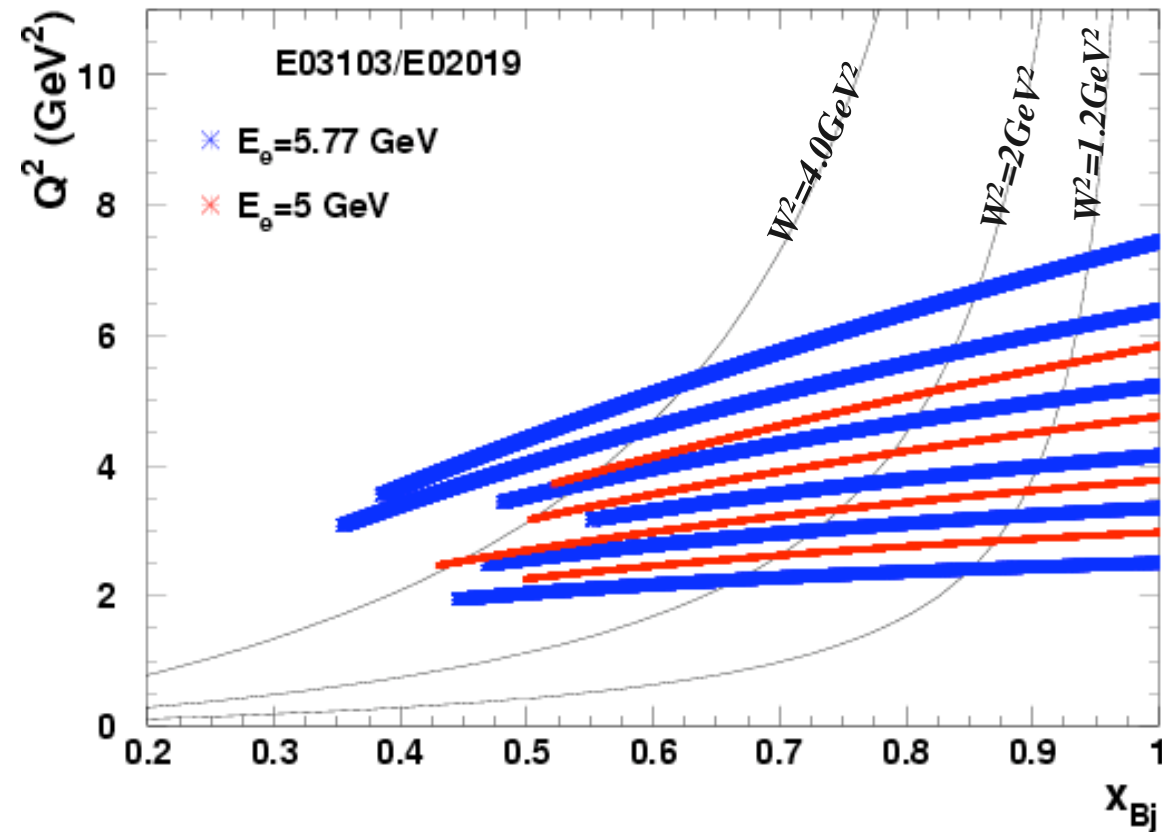^{4}He Be C Al Ca Fe Ag Au

X_{Bj}

JLab Experiment E03-103

Spokespersons: D. Gaskell and J. Arrington
Post-doc: P. Solvignon
Graduate students: J. Seely and A. Daniel

A(e,e') at 5.0 and 5.8 GeV in Hall C

- Targets:
  H, ^{2}H, ^{3}He, ^{4}He,
  Be, C, Al,
  Cu, Au

- 10 angles to measure
  Q^2-dependence

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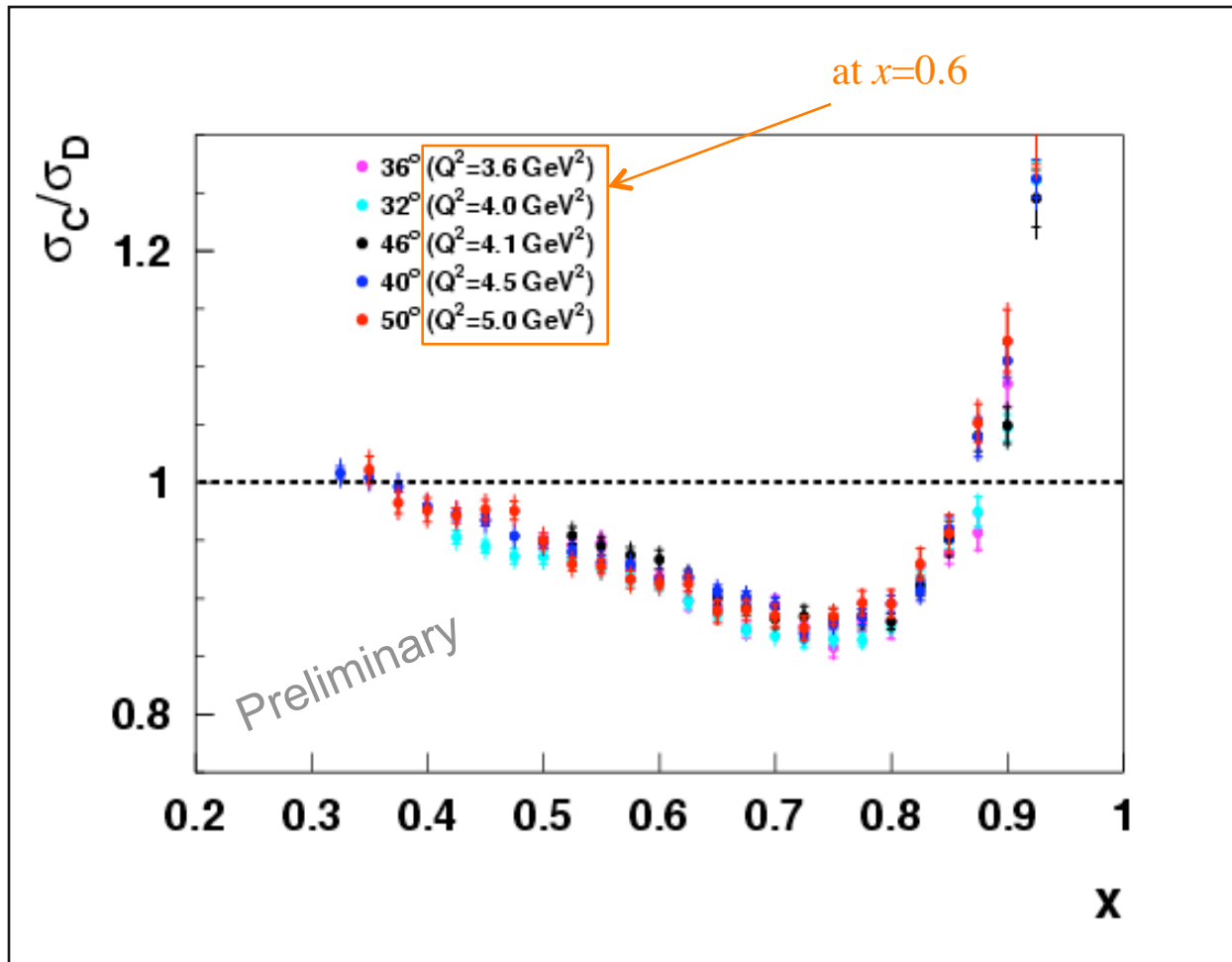Graduate students: J. Seely and A. Daniel

A(e,e') at 5.0 and 5.8 GeV in Hall C

- Targets:
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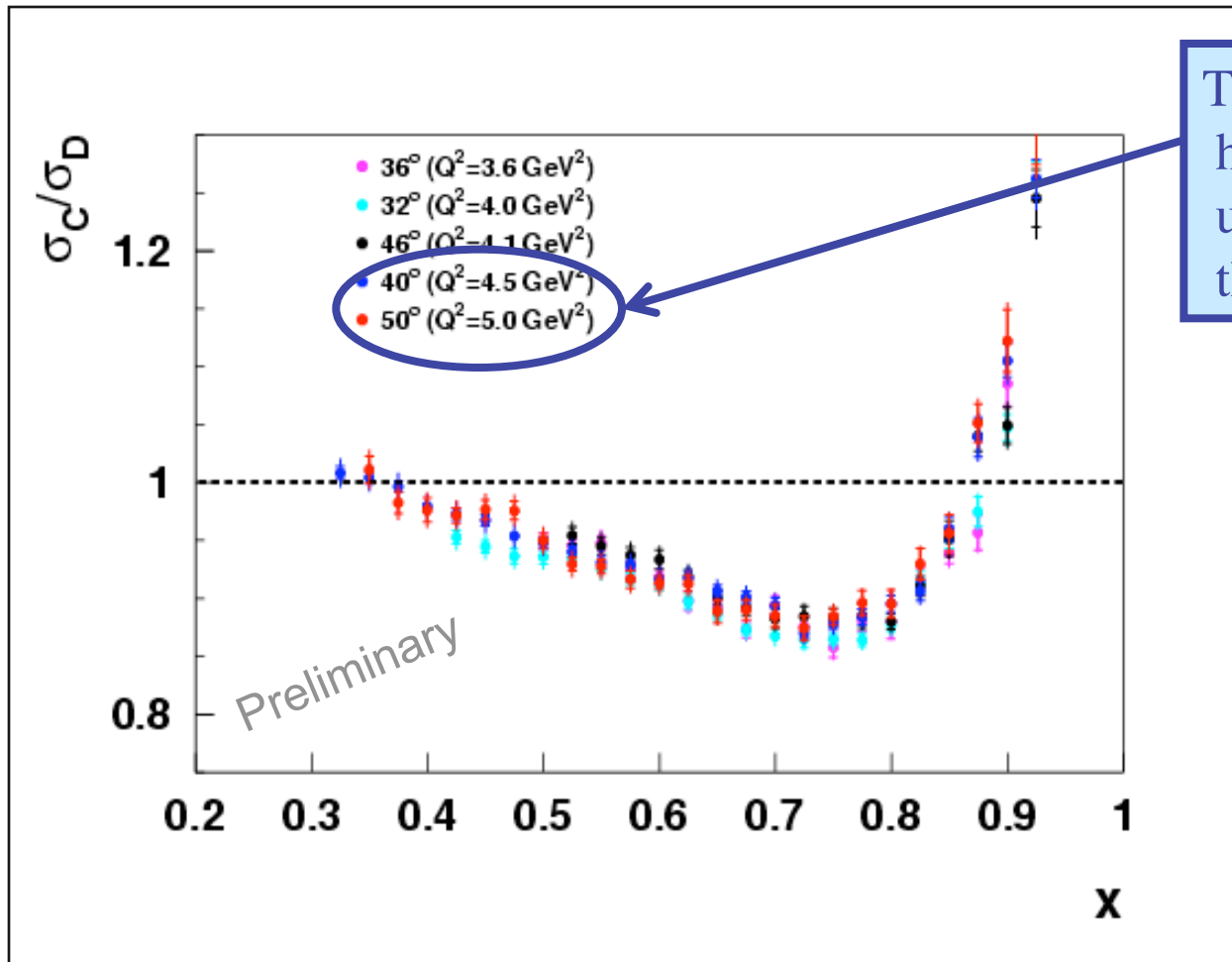 Cu, Au

- 10 angles to measure
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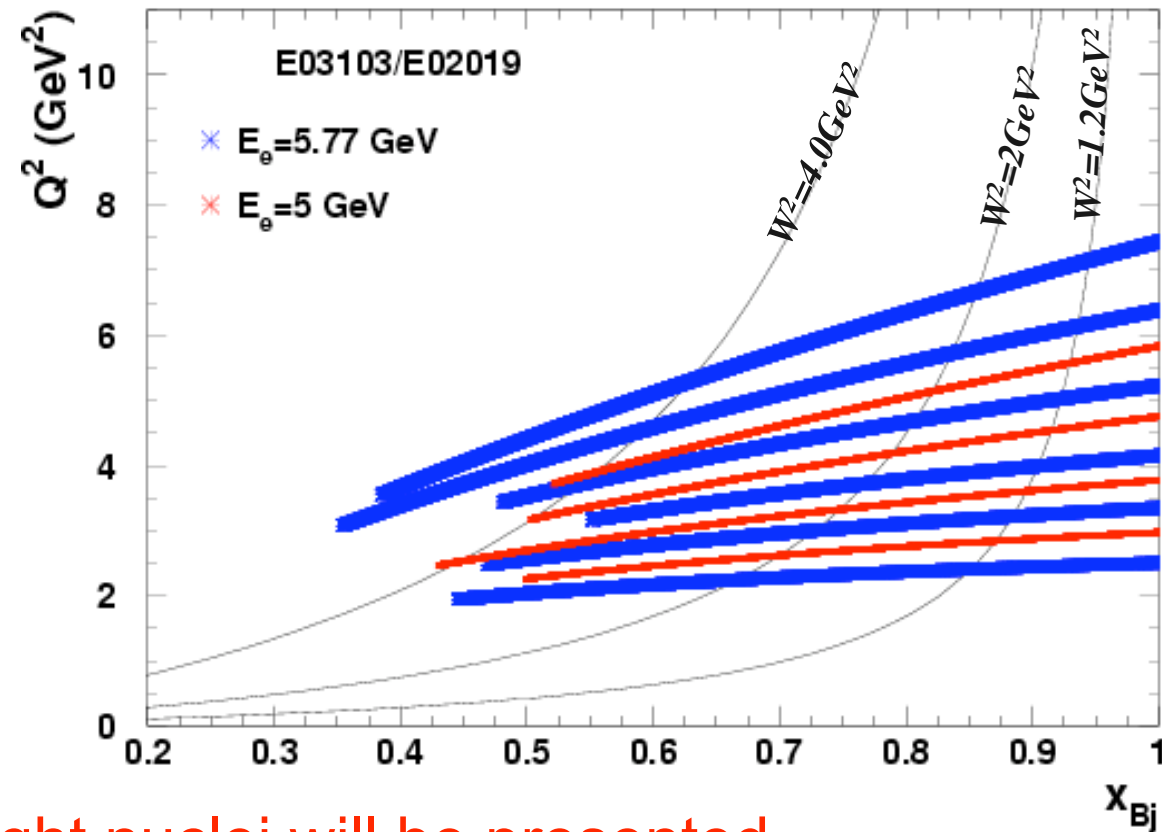
In this talk, only results on light nuclei will be presented

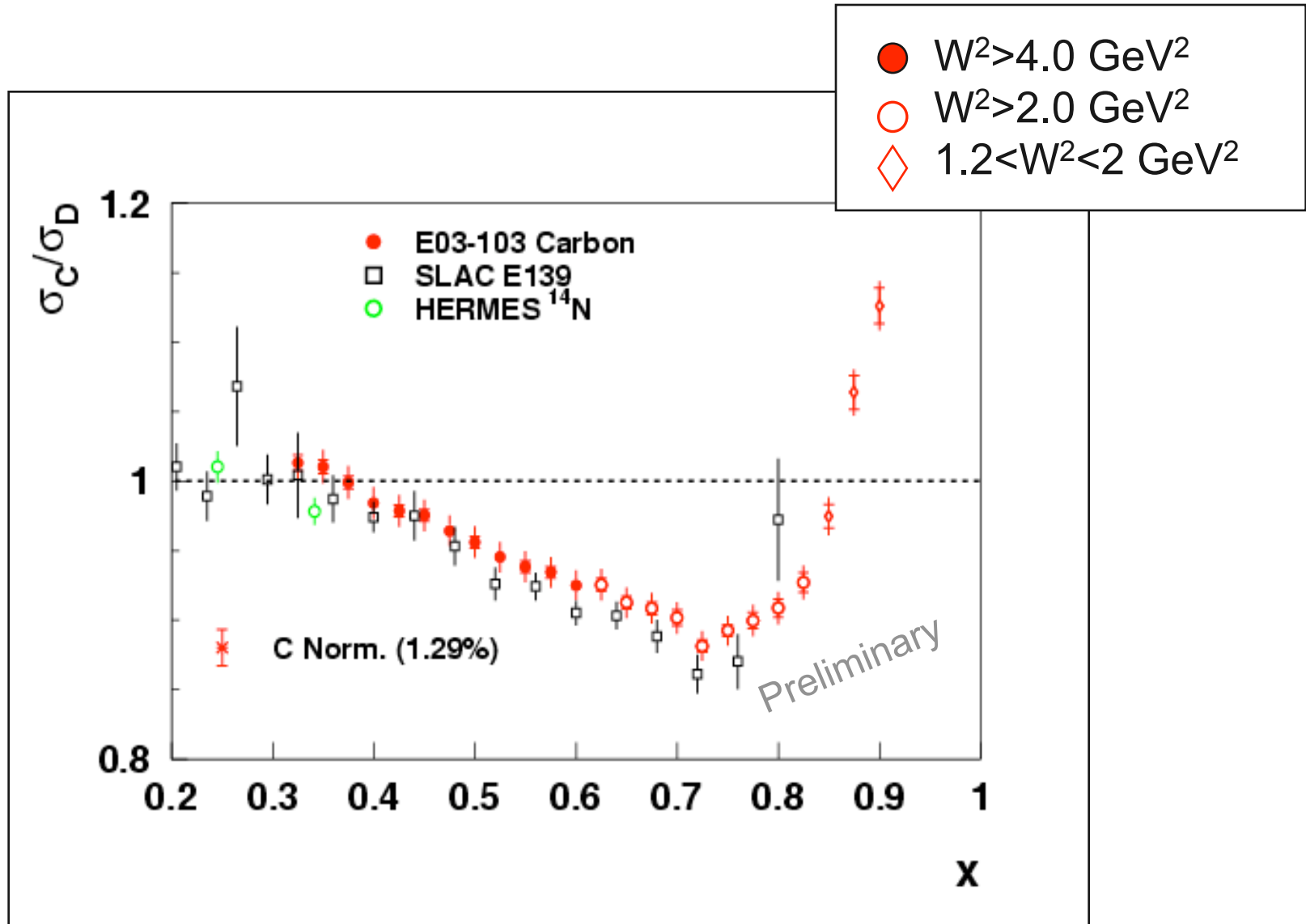# E03-103: Carbon EMC ratio and Q^2-dependence

➔ indication of scaling to very large x

E03-103: Carbon EMC ratio and Q^2-dependence

The combined two highest Q^2 are used in the rest of the talk

Legend within the plot:
- 36° ($Q^2=3.6\,\text{GeV}^2$)
- 32° ($Q^2=4.0\,\text{GeV}^2$)
- 46° ($Q^2=4.1\,\text{GeV}^2$)
- 40° ($Q^2=4.5\,\text{GeV}^2$)
- 50° ($Q^2=5.0\,\text{GeV}^2$)

Preliminary

Axes: σ_C/σ_D versus x

E03-103: Carbon EMC ratio

Legend:
- ● $W^2 > 4.0$ GeV^2
- ○ $W^2 > 2.0$ GeV^2
- ◇ $1.2 < W^2 < 2$ GeV^2

Plot axes: σ_C / σ_D versus x

In-plot legend:
- ● E03-103 Carbon
- □ SLAC E139
- ○ HERMES ^{14}N

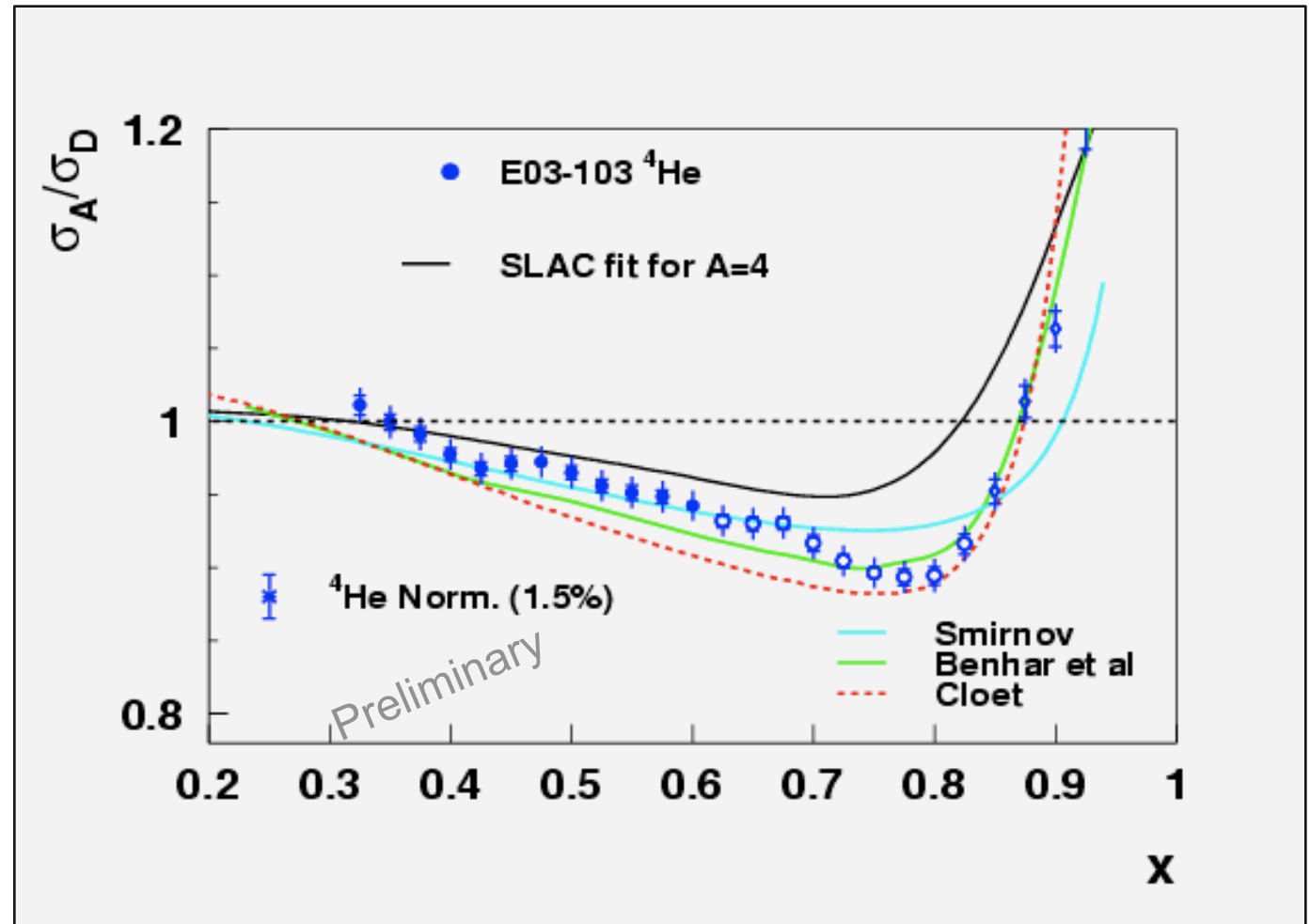C Norm. (1.29%)

Preliminary

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E03-103: ^{4}He

JLab results consistent with
SLAC E139
→Improved statistics and
systematic errors
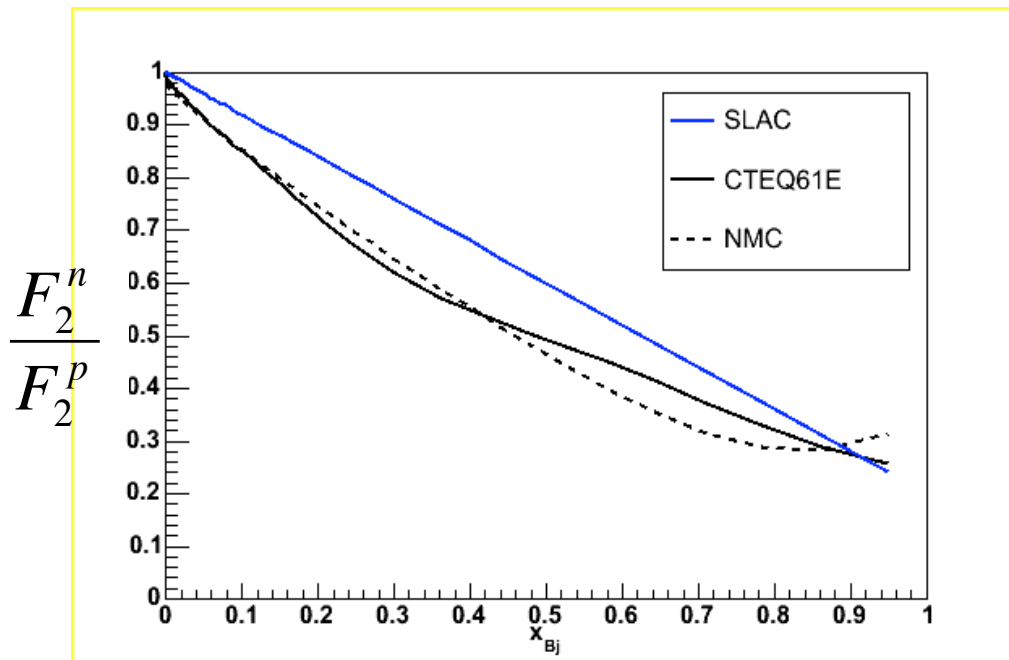
Large *x* shape more clearly
consistent with heavier
nuclei
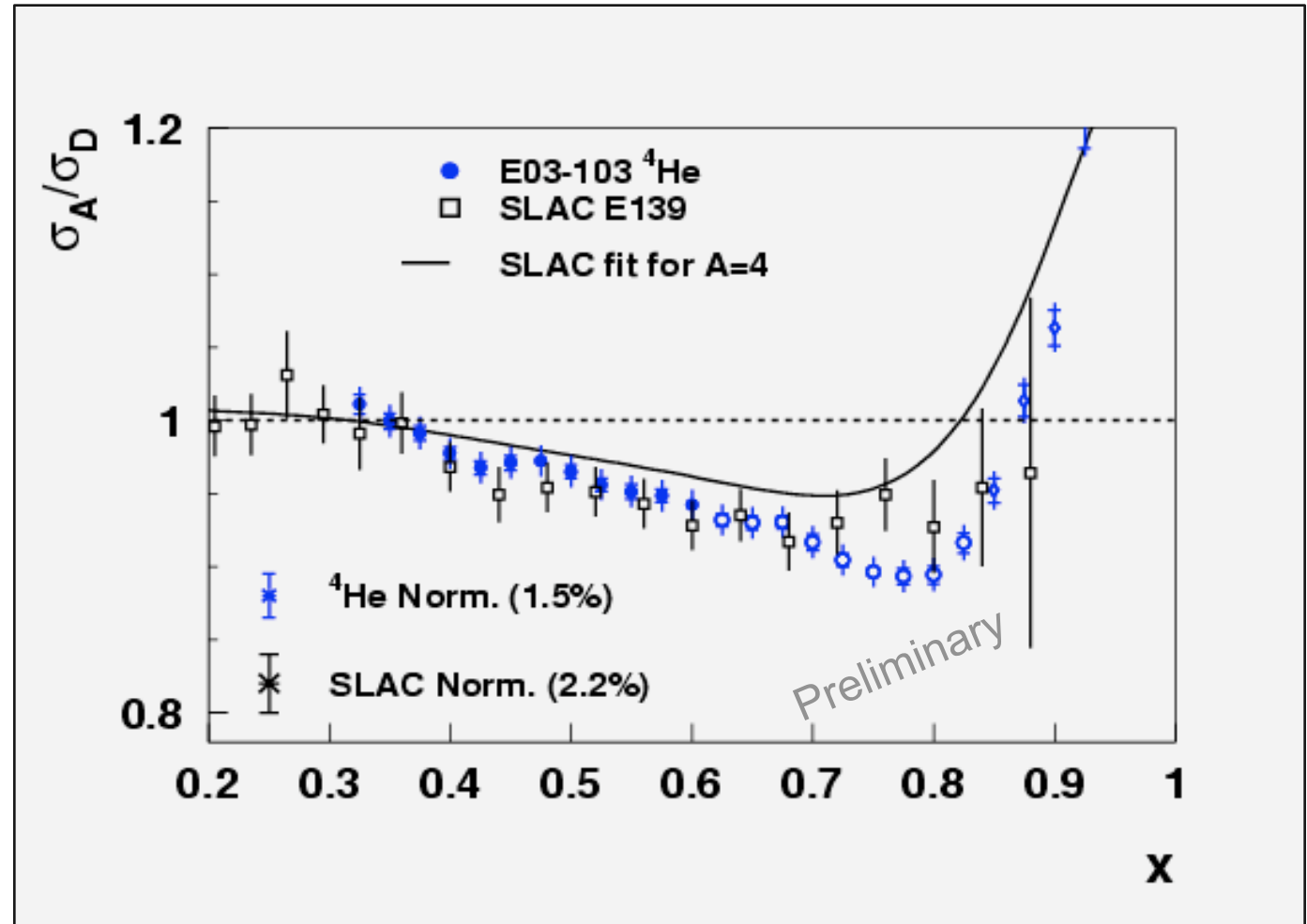
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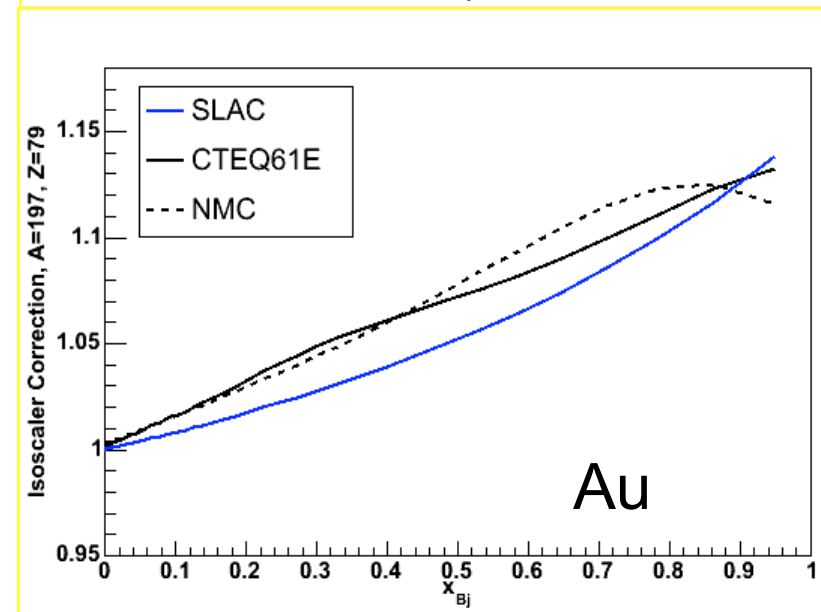
Models shown do a reasonable job describing the data

Isoscalar correction

$$R_{EMC} = \frac{\sigma_2^A/A}{\sigma_2^D/2} \cdot \left(\frac{1 + F_2^n/F_2^p}{Z + N F_2^n/F_2^p} \right)$$

Isoscalar correction

$$\frac{F_2^n}{F_2^p}$$

Legend:
- SLAC
- CTEQ61E
- NMC

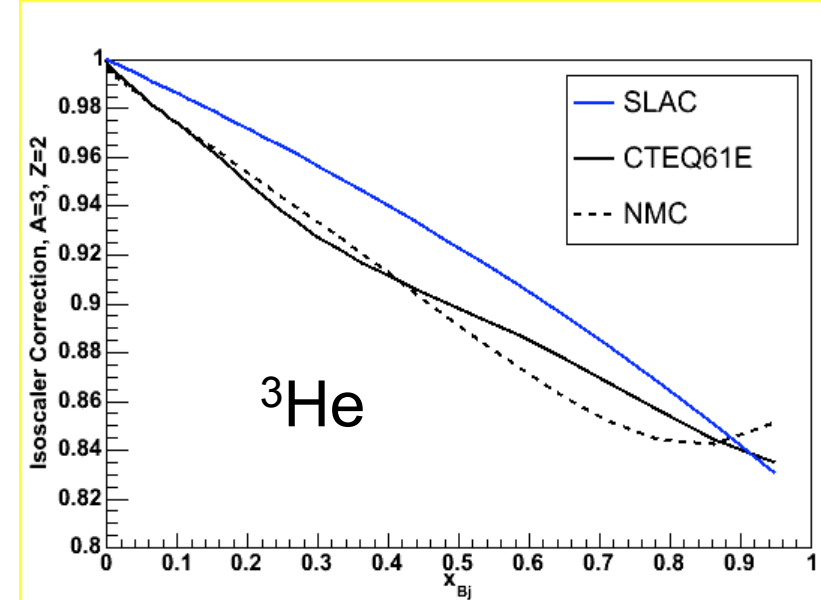*SLAC fit: (1-0.8x)*

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Isoscalar correction

$$R_{EMC} = \frac{\sigma_2^A / A}{\sigma_2^D / 2} \cdot \left(\frac{1 + F_2^n / F_2^p}{Z + N F_2^n / F_2^p} \right)$$
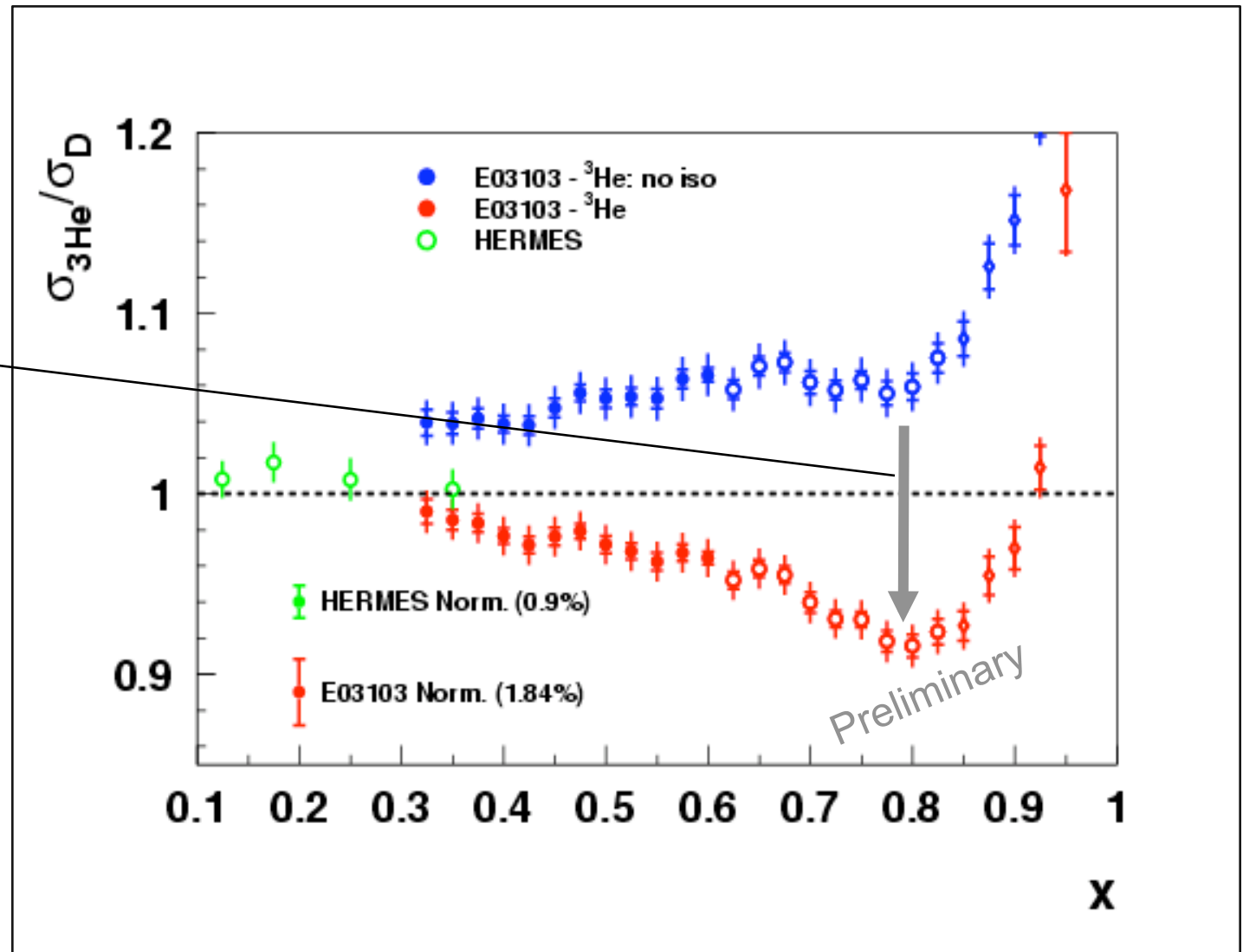
Isoscalar correction

SLAC
CTEQ61E
NMC

^{3}He

$\dfrac{F_2^n}{F_2^p}$

SLAC
CTEQ61E
NMC

SLAC fit: (1-0.8x)
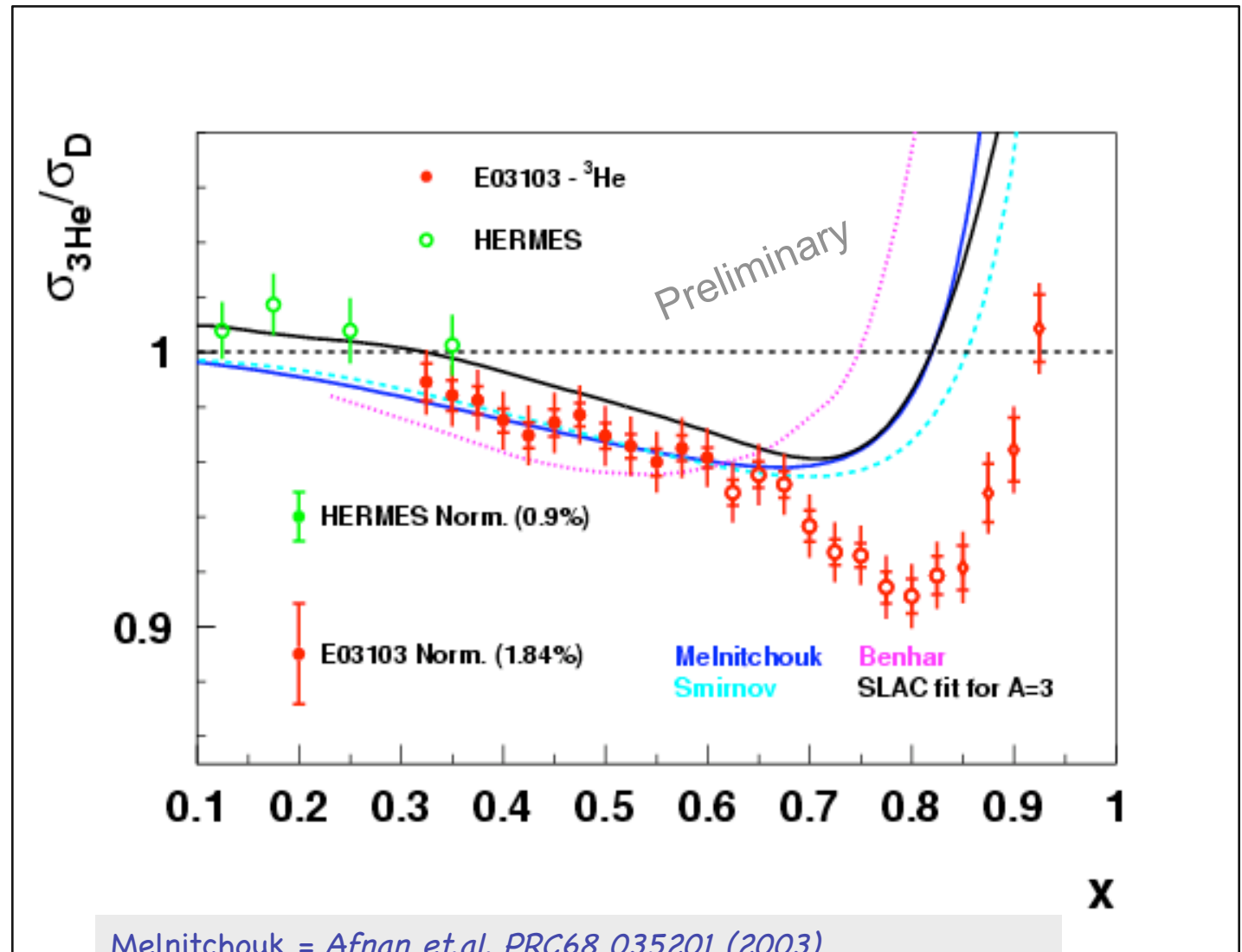
SLAC
CTEQ61E
NMC

Au

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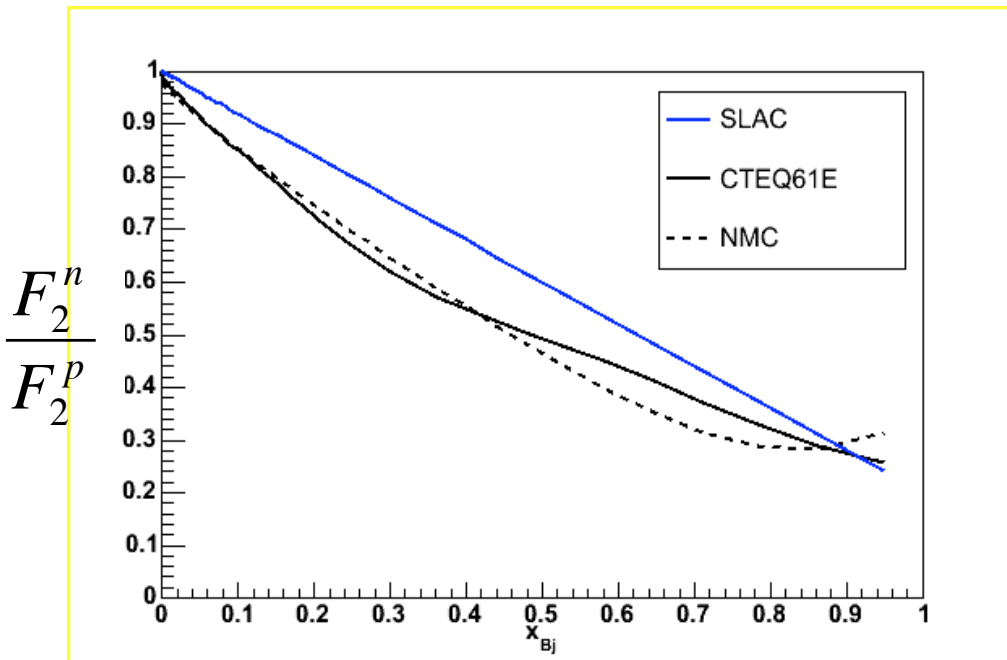
E03-103: Preliminary ³He EMC ratio

Large proton excess correction

E03-103: Preliminary ³He EMC ratio

Melnitchouk = Afnan et.al. PRC68 035201 (2003)
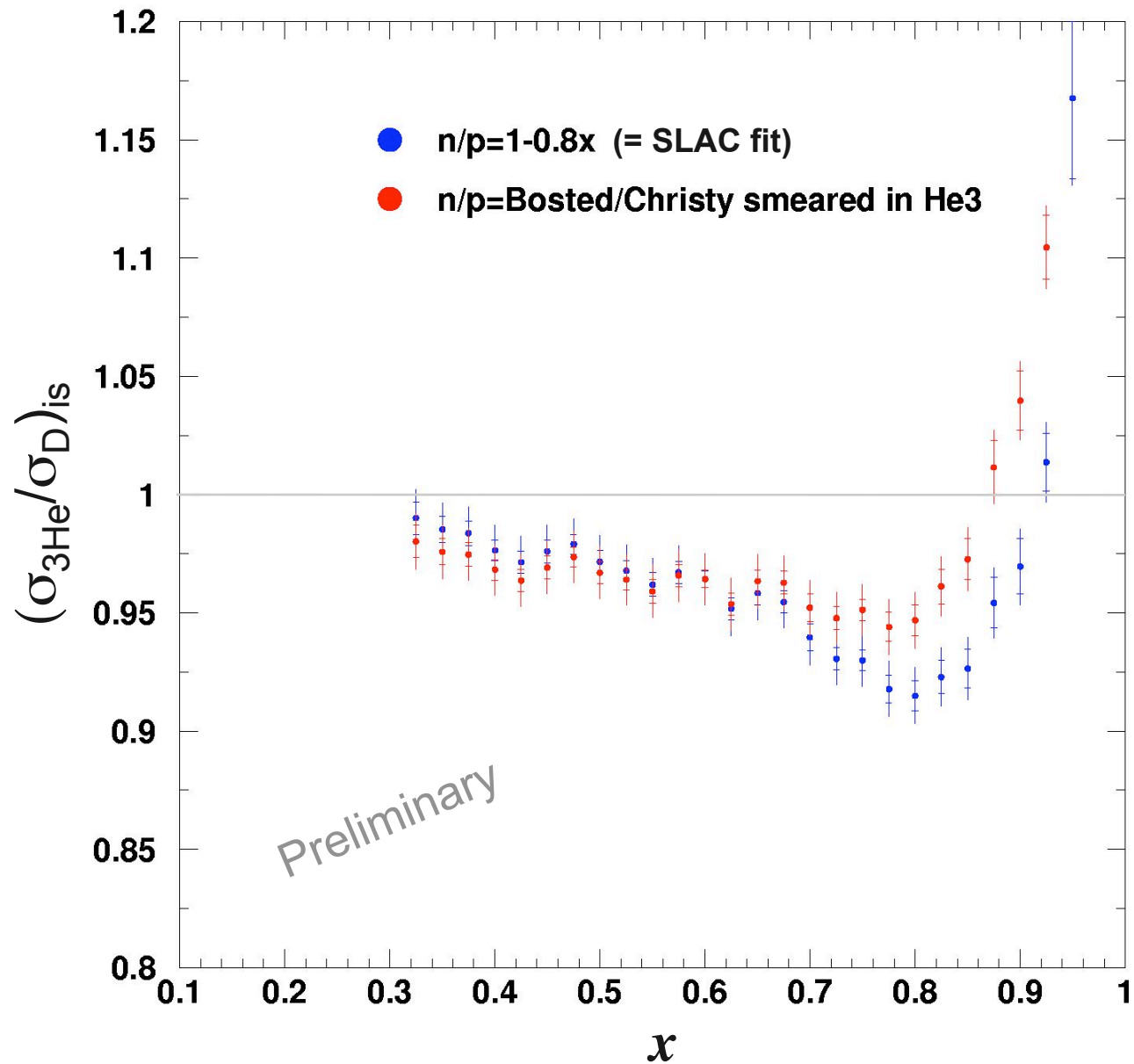Smirnov = Molochkov and Smirnov Phys. Lett. B 466, 1 (1999)
Benhar = private communication (Hannover SF, Paris potential)

E03-103: New isoscalar correction

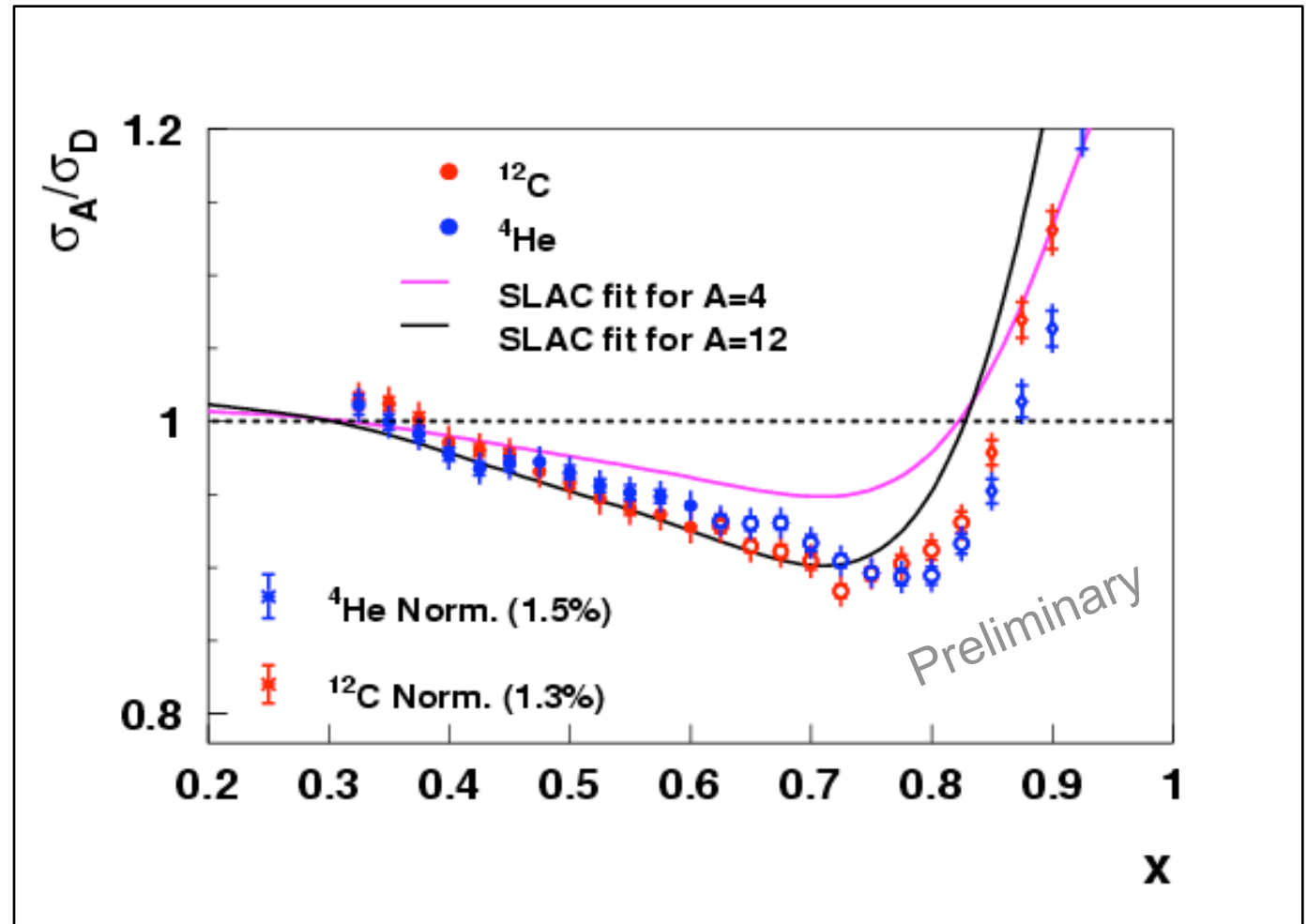Used fit of the cross section
data at our kinematics

Performed our own
convolution of n/p in ^{3}He

A or density dependence ?

Magnitude of the
EMC effect for C
and ^{4}He very similar

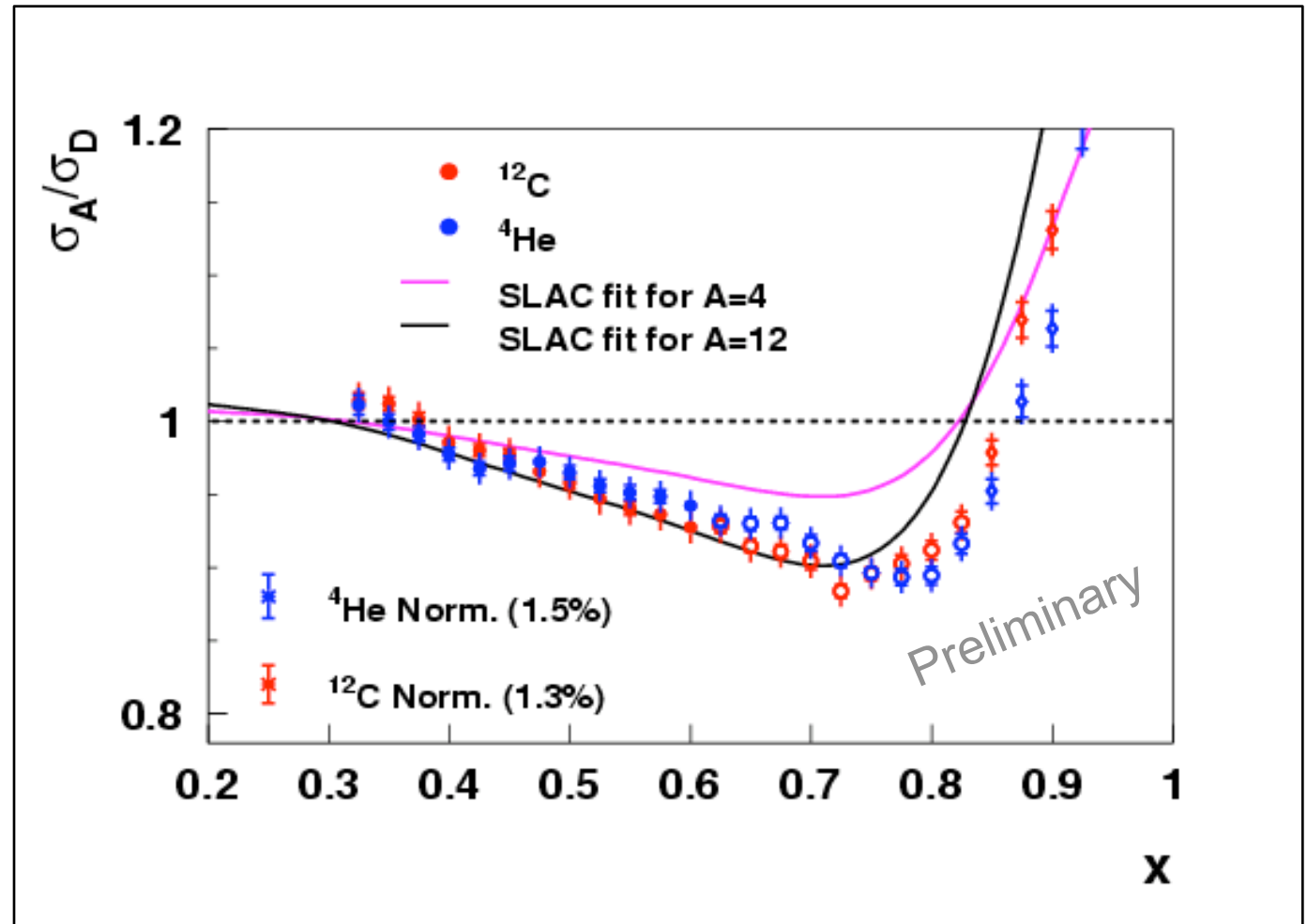^{4}He more consistent
with SLAC A=12 fit
than A=4

A or density dependence ?

Magnitude of the
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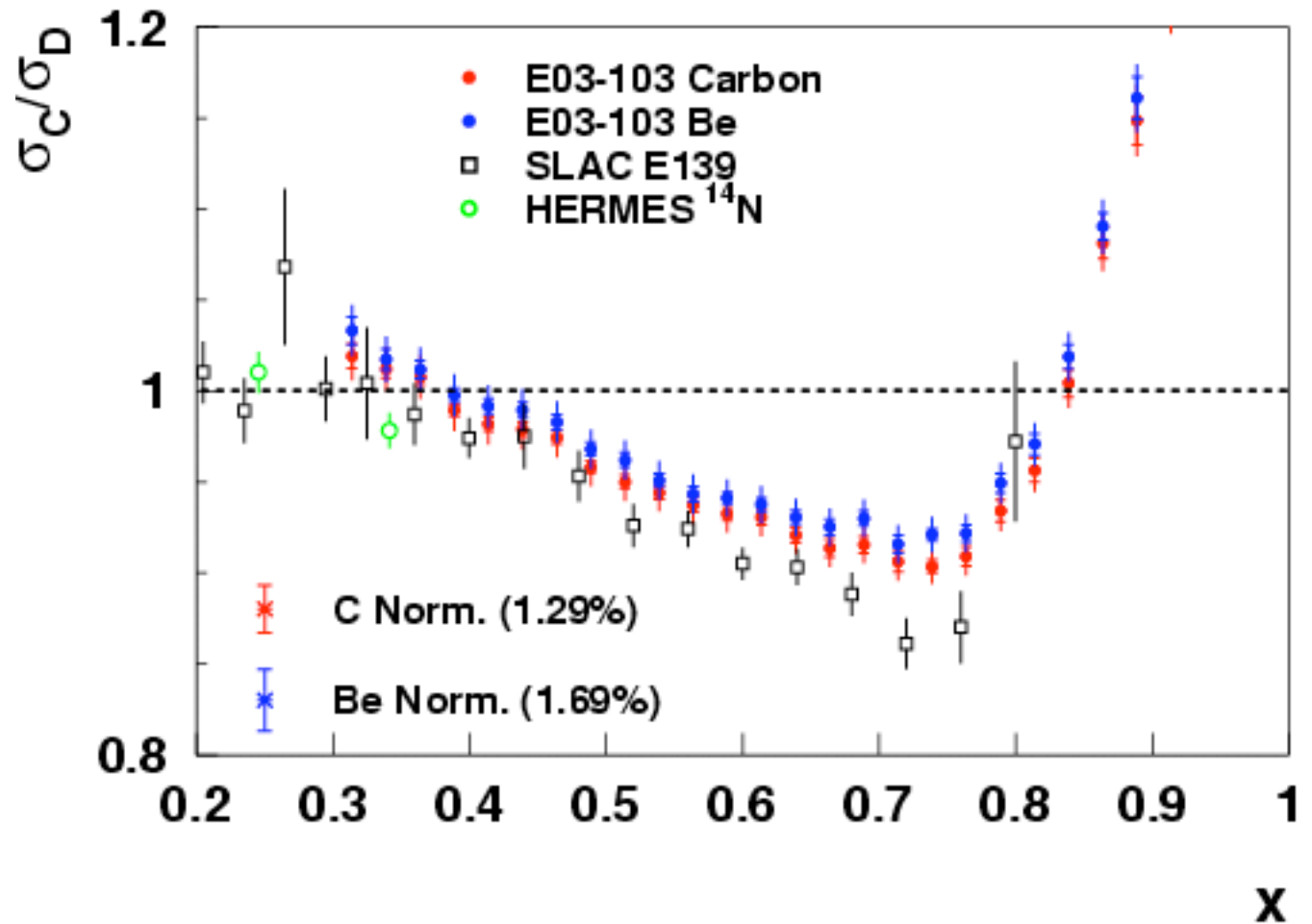^{4}He more consistent
 with SLAC A=12 fit
 than A=4

$\rho(^4\text{He}) \sim \rho(^{12}\text{C})$

EMC effect: ρ−dependent

A or density dependence ?

Magnitude of the
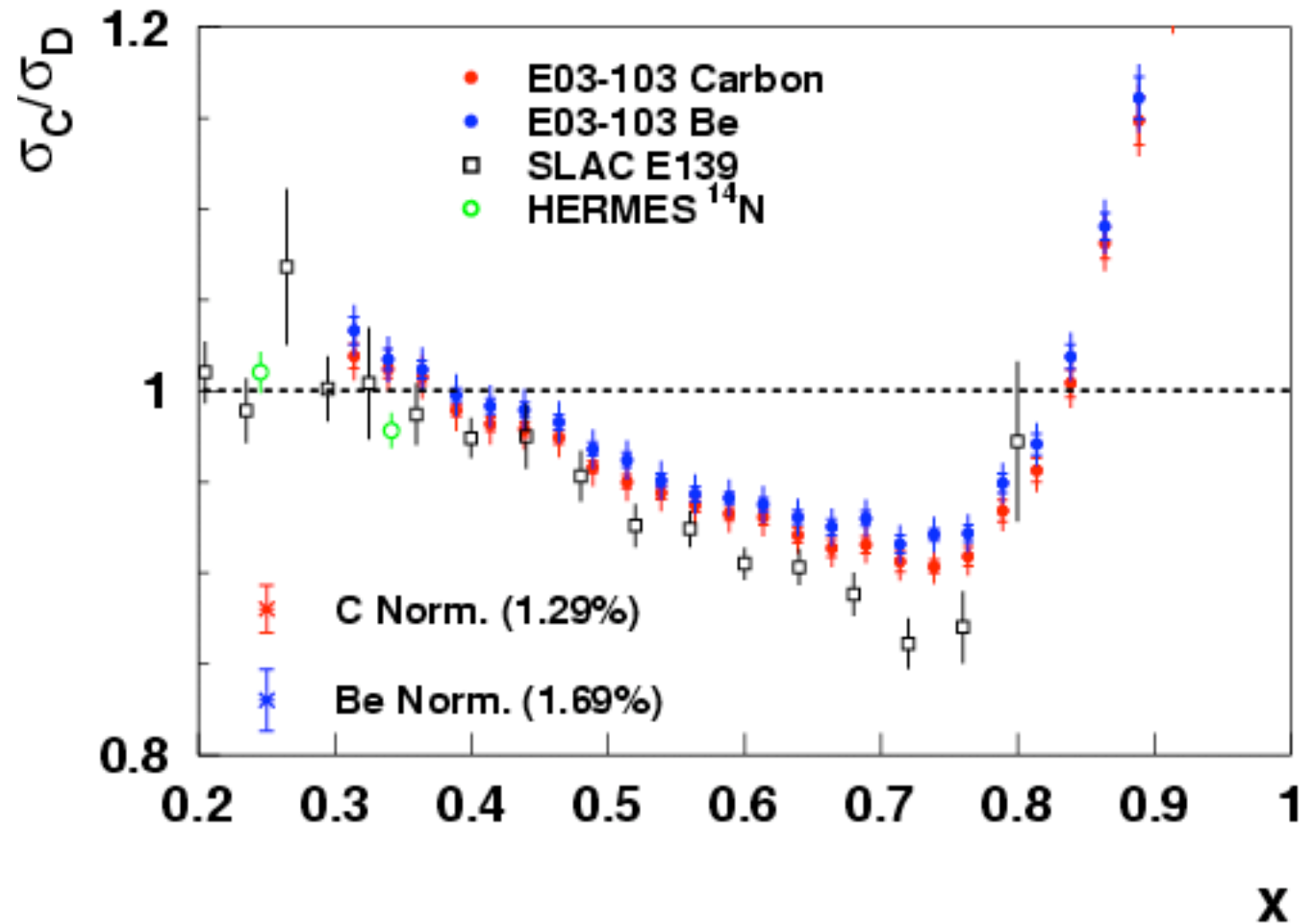EMC effect for C
and ^{9}Be very similar

A or density dependence ?

Magnitude of the
EMC effect for C
and ^{9}Be very similar

But:

$\rho(^9\text{Be}) << \rho(^{12}\text{C})$

EMC effect: A-dependent

Summary

❖ JLab E03-103 provides:
  - Precision nuclear structure ratios for light nuclei
  - Access to large x EMC region for $^3\text{He} \rightarrow {}^{197}\text{Au}$

❖ Observations:
  - Scaling of the structure function ratios for $W < 2$ GeV down to low Q^2
  - (Large) EMC effect in ^3He
  - Similar large x shape of the structure function ratios for A>3
  - EMC effect dependence: A or ρ ?

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EMC effect versus overlap density
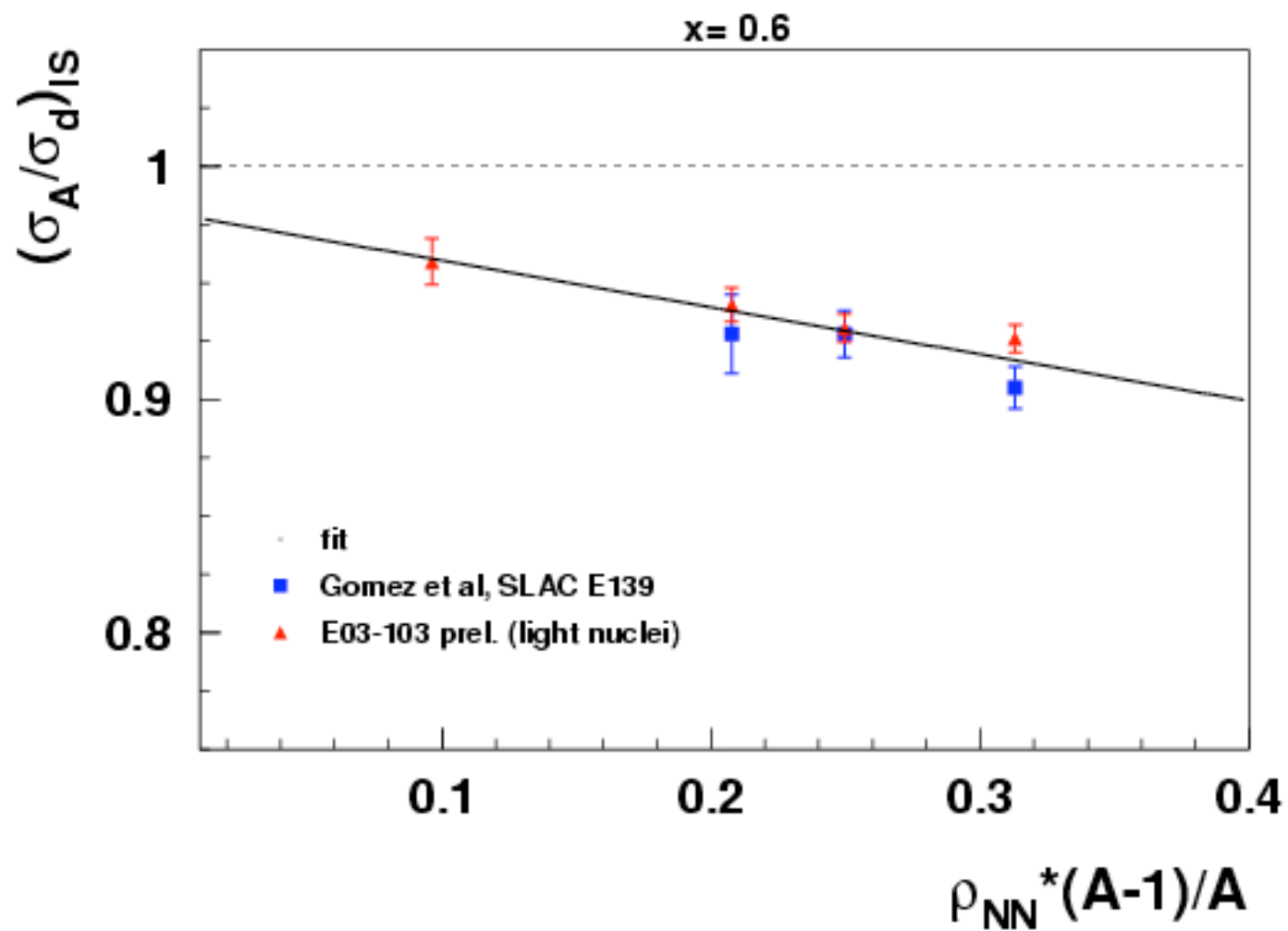
More detailed look at scaling

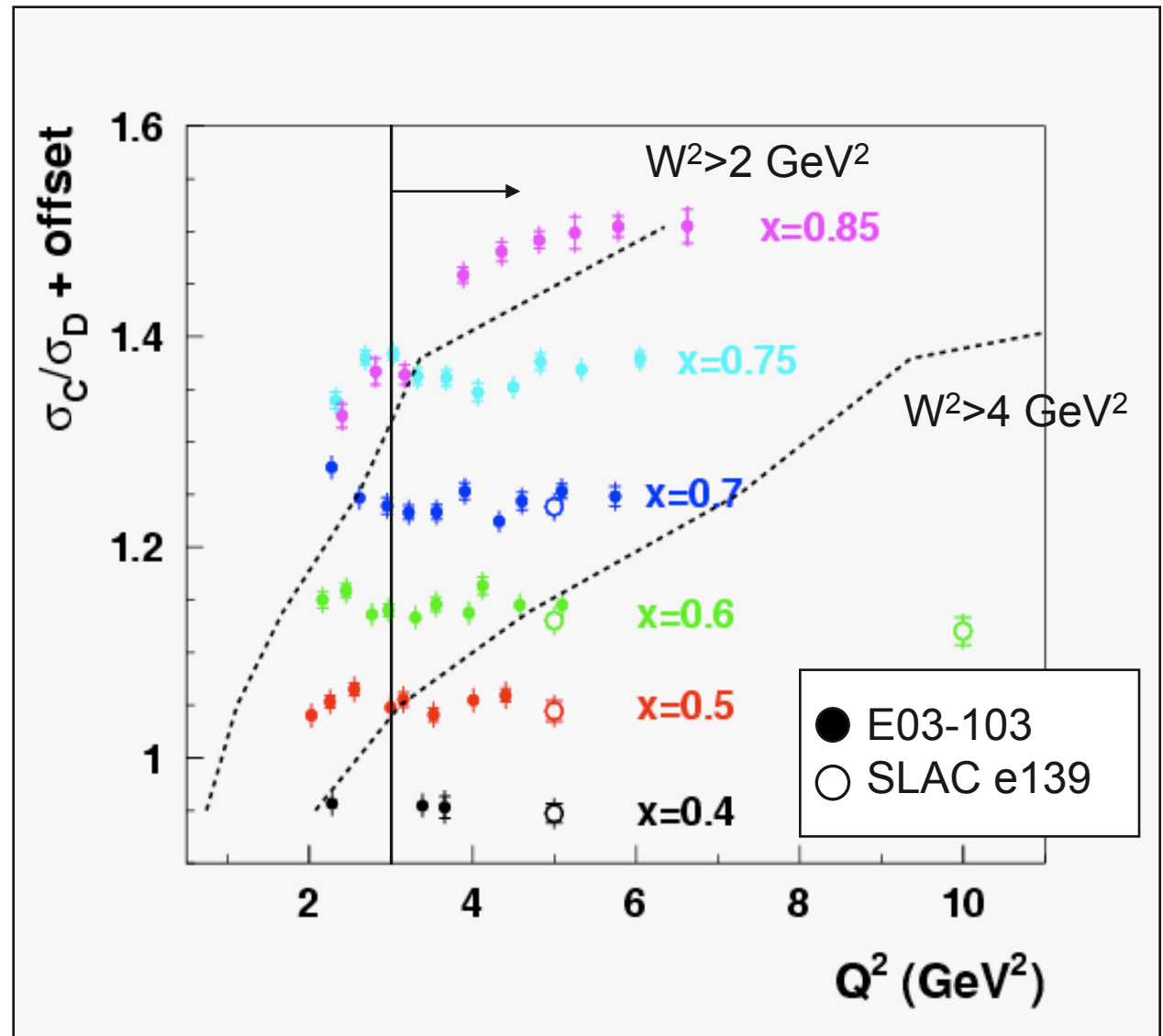C/D ratios at fixed x are Q^2 independent for:

$W^2 > 2$ GeV^2
and
$Q^2 > 3$ GeV^2

limits E03-103 coverage to $x=0.85$

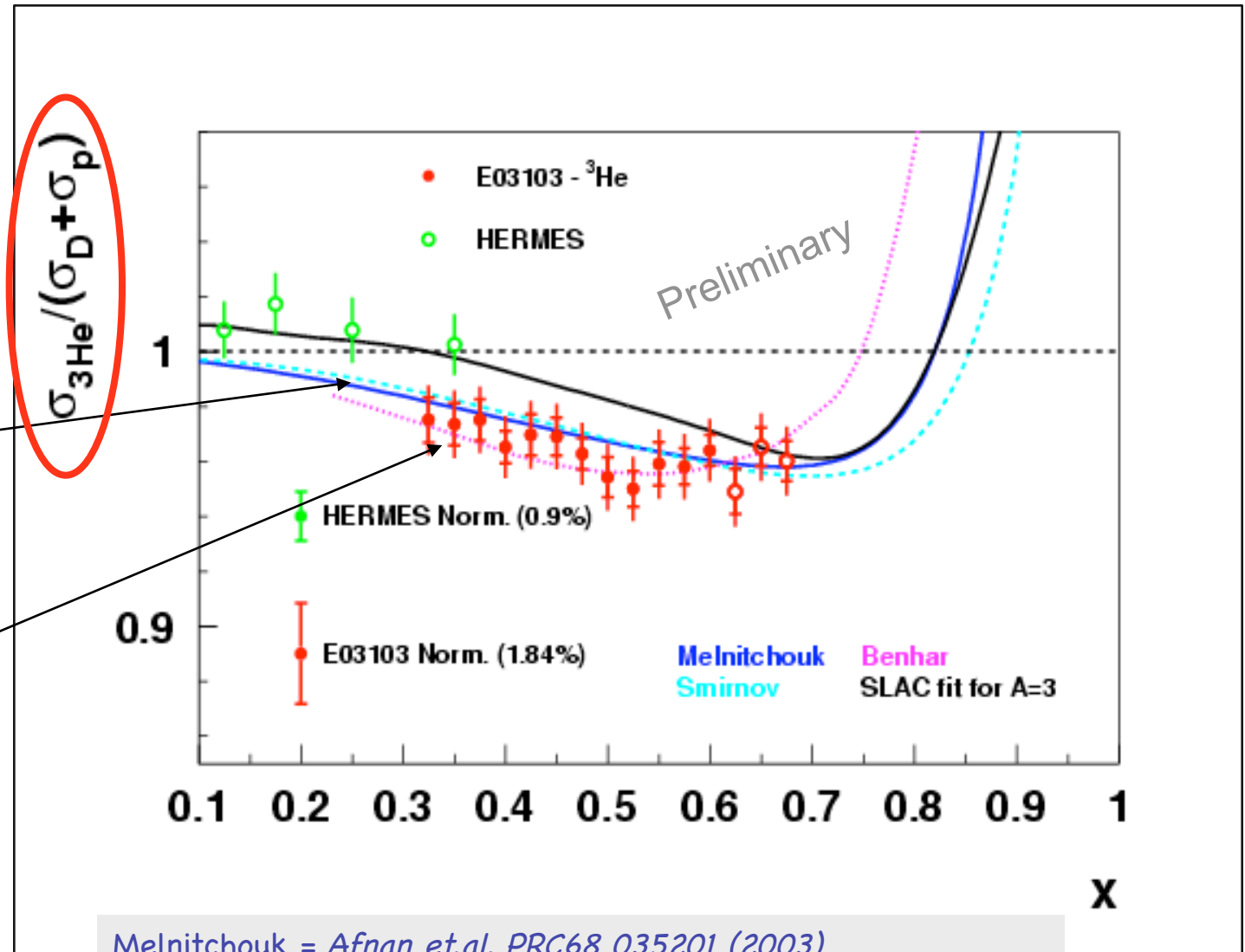Note: Ratios at larger x will be shown, but should be taken cautiously

E03-103: Preliminary ³He EMC ratio

All calculations shown
use convolution
formalism at some level

$$\frac{F_2^{3He}}{(F_2^D + F_2^p)}$$

$$\frac{F_2^{3He}}{(2F_2^p + F_2^n)}$$

- E03103 - ³He
- HERMES

Preliminary

$\sigma_{3He}/(\sigma_D + \sigma_p)$

HERMES Norm. (0.9%)

E03103 Norm. (1.84%)

Melnitchouk   Benhar
Smirnov   SLAC fit for A=3

X

Melnitchouk = Afnan et.al. PRC68 035201 (2003)
Smirnov = Molochkov and Smirnov Phys. Lett. B 466, 1 (1999)
Benhar = private communication (Hannover SF, Paris potential)

Coulomb distortions on heavy nuclei

Initial (scattered) electrons are accelerated (decelerated) in Coulomb field of nucleus with *Z* protons

– Not accounted for in typical radiative corrections

– Usually, not a large effect at high energy machines – *not true at JLab (6 GeV!)*

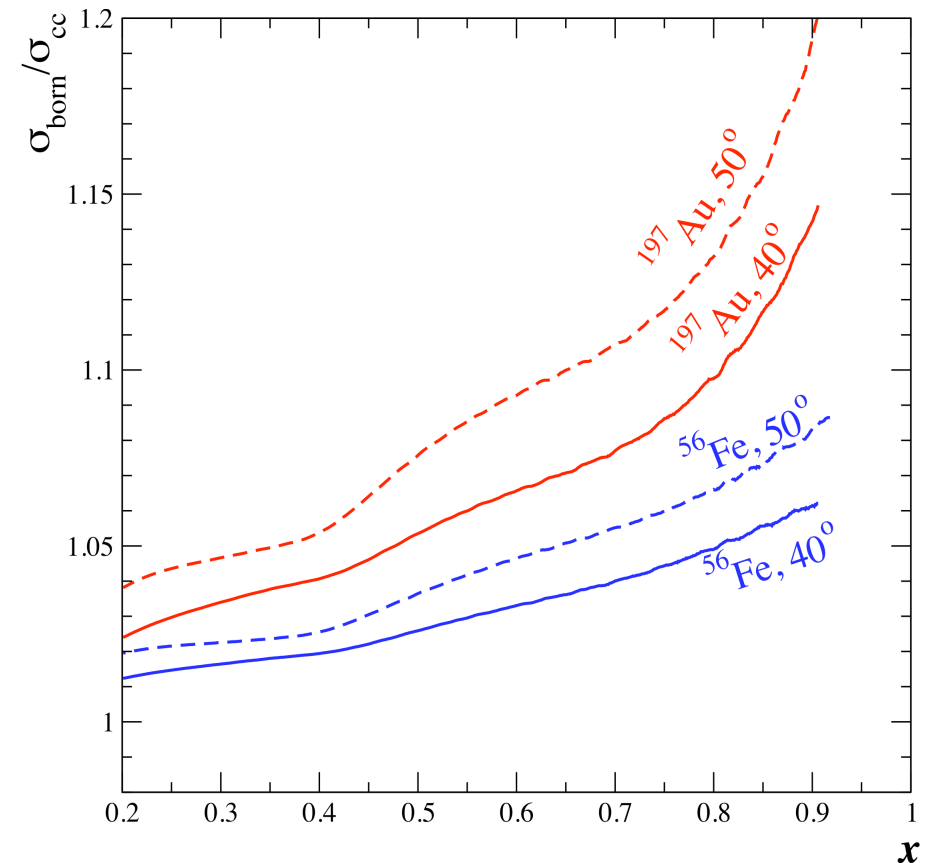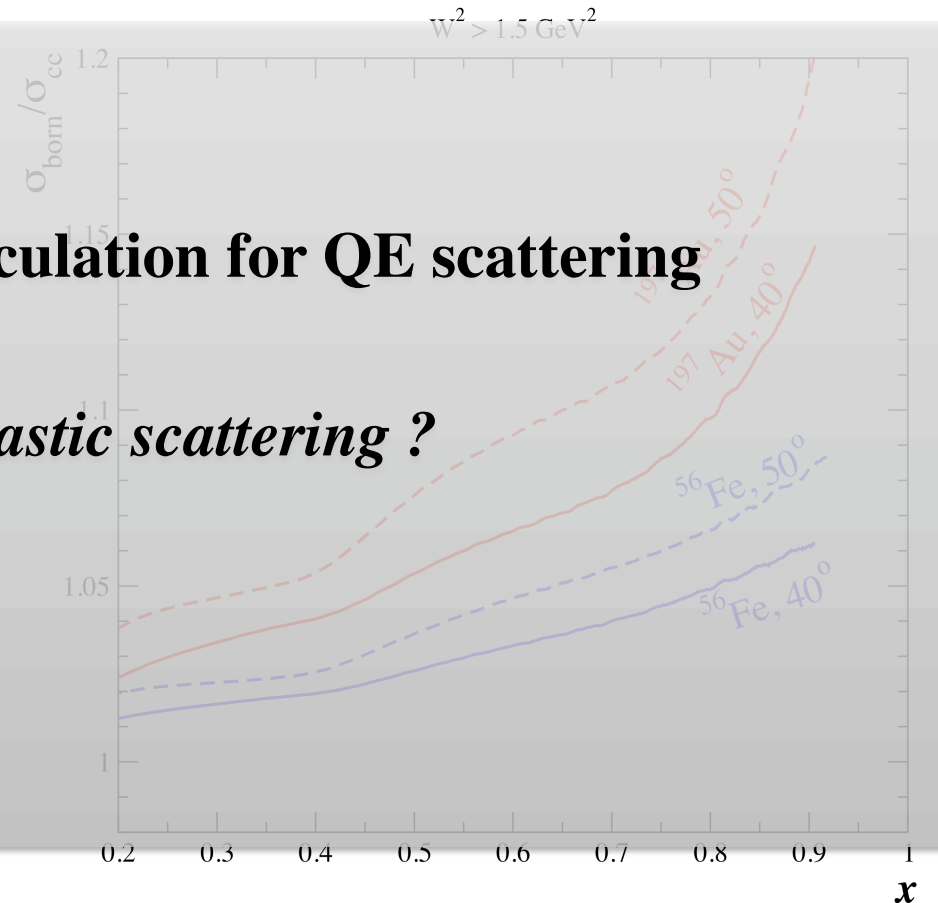**E03-103 uses modified Effective Momentum Approximation (EMA)**

Aste and Trautmann, Eur, Phys. J. A26, 167-178(2005)

$$E \rightarrow E+\Delta$$
$$E' \rightarrow E'+\Delta$$

$with \quad \Delta = -\frac{3}{4} V_0$
$$V_0 = 3\alpha(Z-1)/(2r_c)$$

Coulomb distortions on heavy nuclei

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E03-103 uses modified Effective Momentum
Approximation (EMA)

Aste and Trautmann

$E \rightarrow E+\Delta$

$E' \rightarrow E'+\Delta$

$\Delta = -\frac{3}{4} V_0, V_0 = 3\alpha(Z-1)/(2r_c)|$

EMA tested against DWBA calculation for QE scattering

➔ *application to inelastic scattering ?*

$W^2 > 1.5\ \text{GeV}^2$

$\sigma_{born}/\sigma_{cc}$

1.2

1.15

1.1

1.05

1

197 Au, 50°

197 Au, 40°

56 Fe, 50°

56 Fe, 40°

0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

x

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Effect of the coulomb distortion on E03-103 data

Before coulomb corrections

Gold

E03-103

preliminary

- ● 40°
- ■ 50°
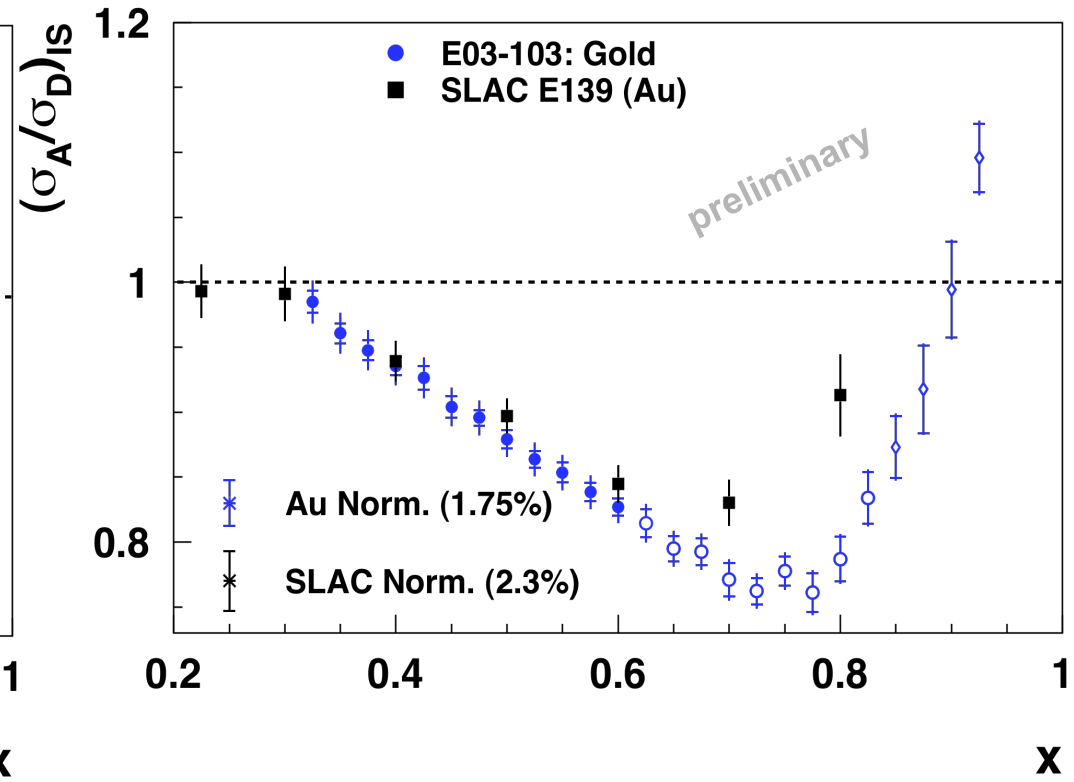
y-axis: $(\sigma_A/\sigma_D)_{is}$

x-axis: x
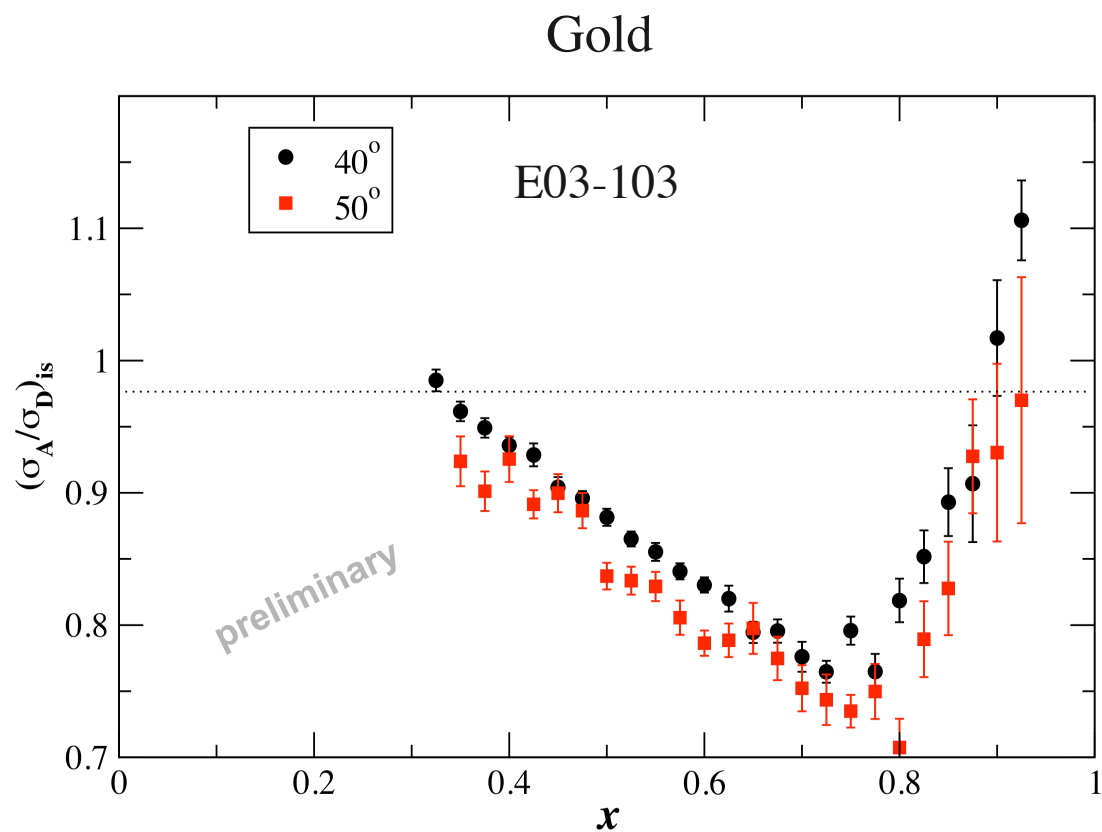
Effect of the coulomb distortion on E03-103 data

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E03-103

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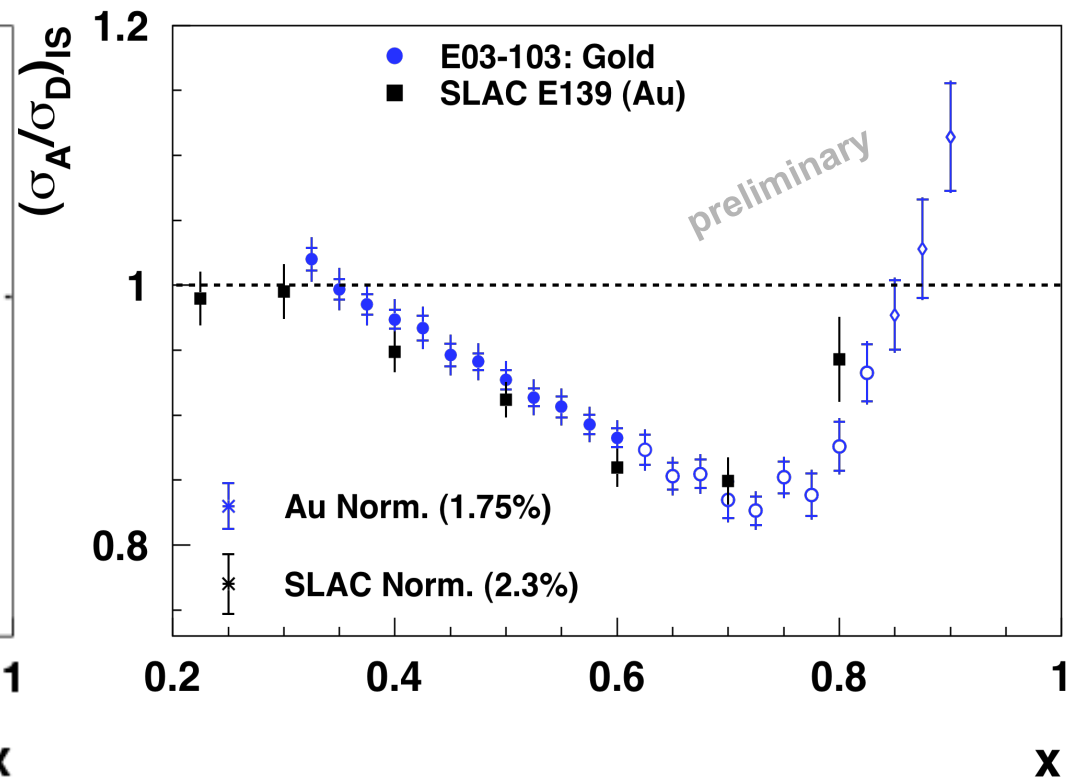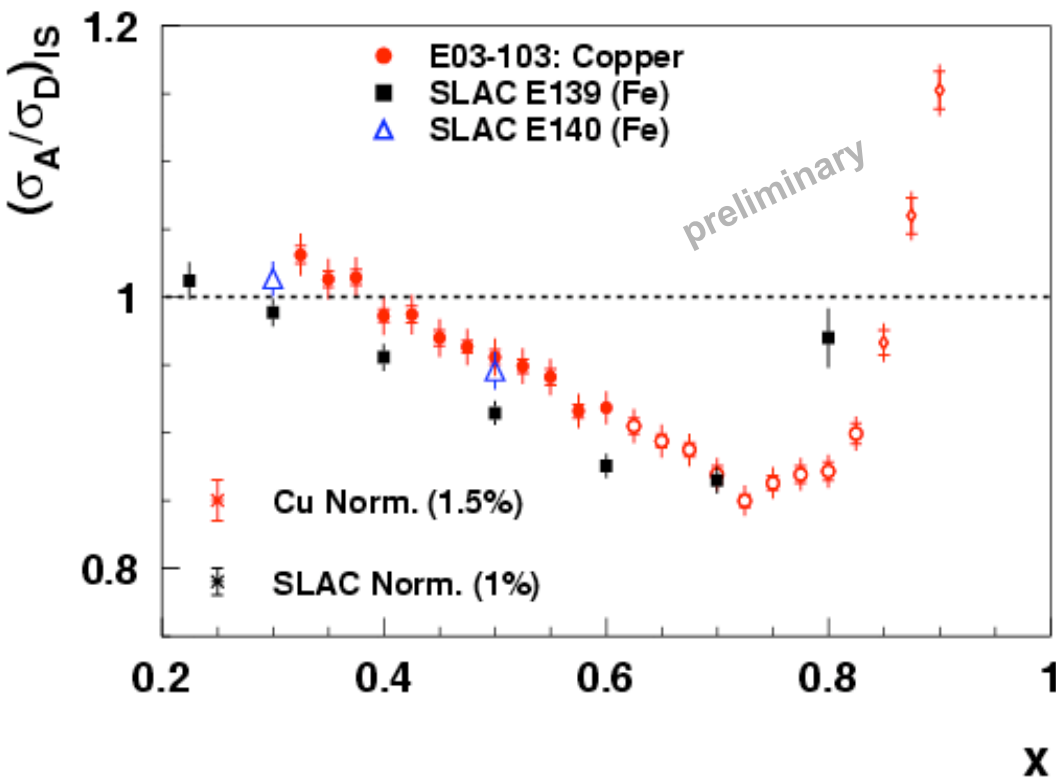- ■ 50°

preliminary

$(\sigma_A/\sigma_D)_{is}$

x
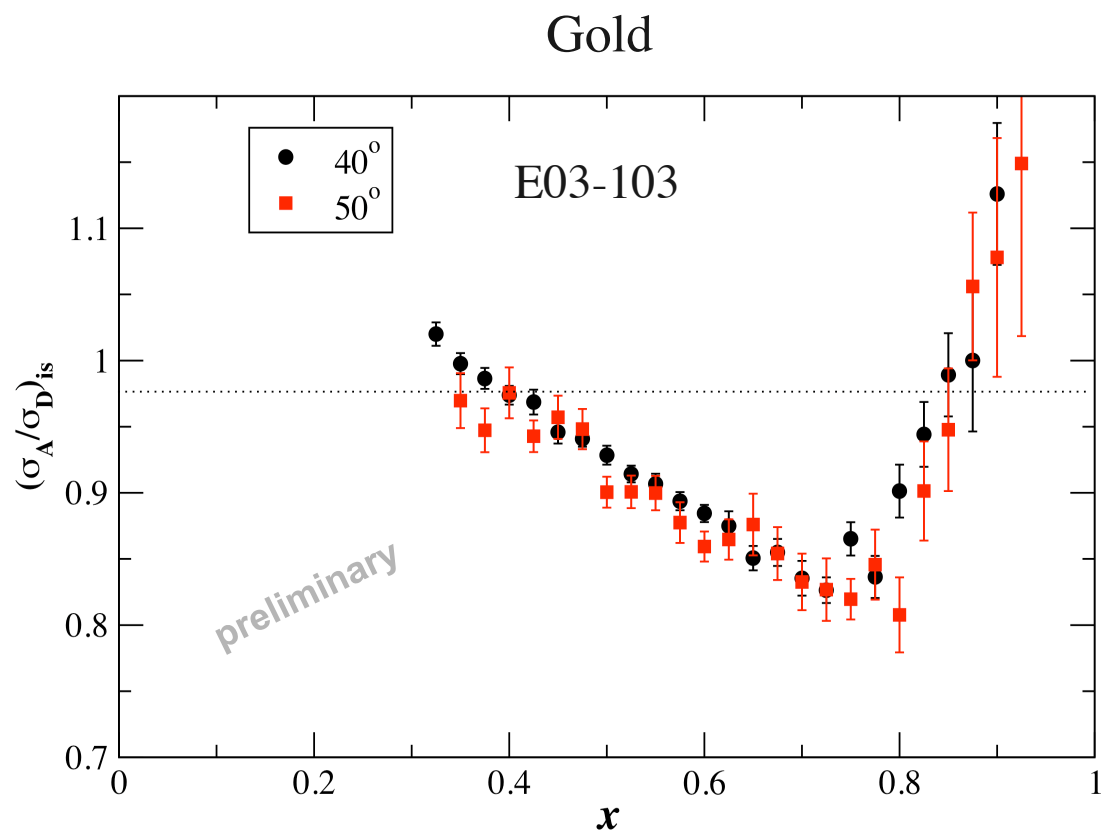
E03-013 heavy target results and world data

Before coulomb corrections
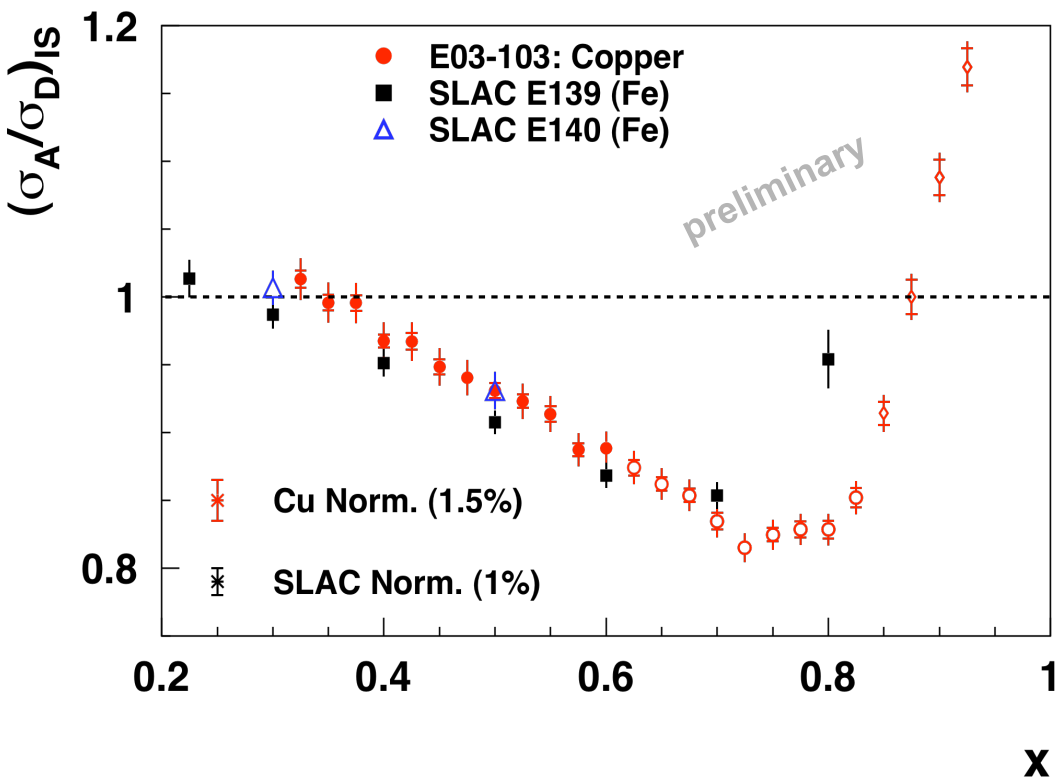
E03-013 heavy target results and world data

After coulomb corrections on all data
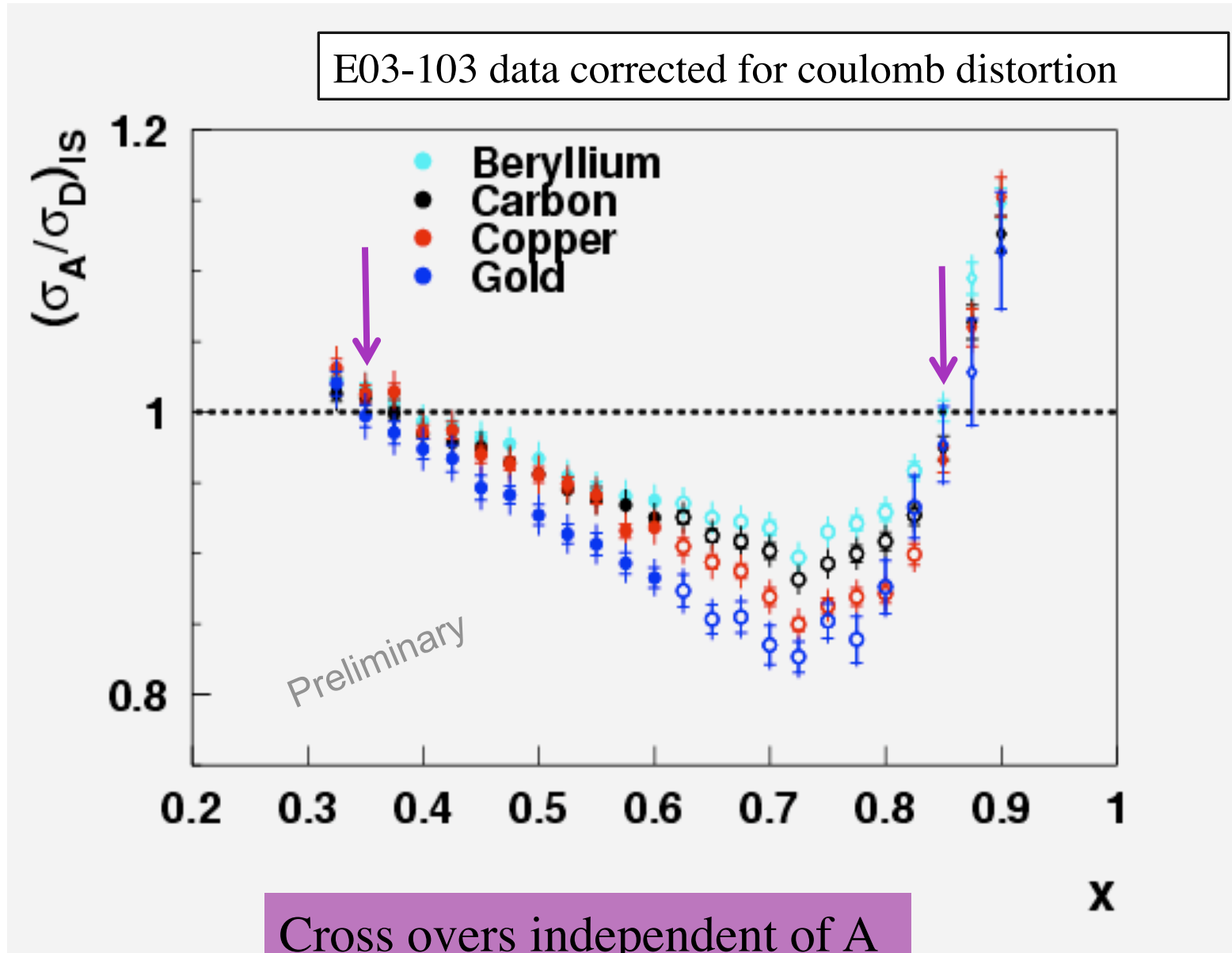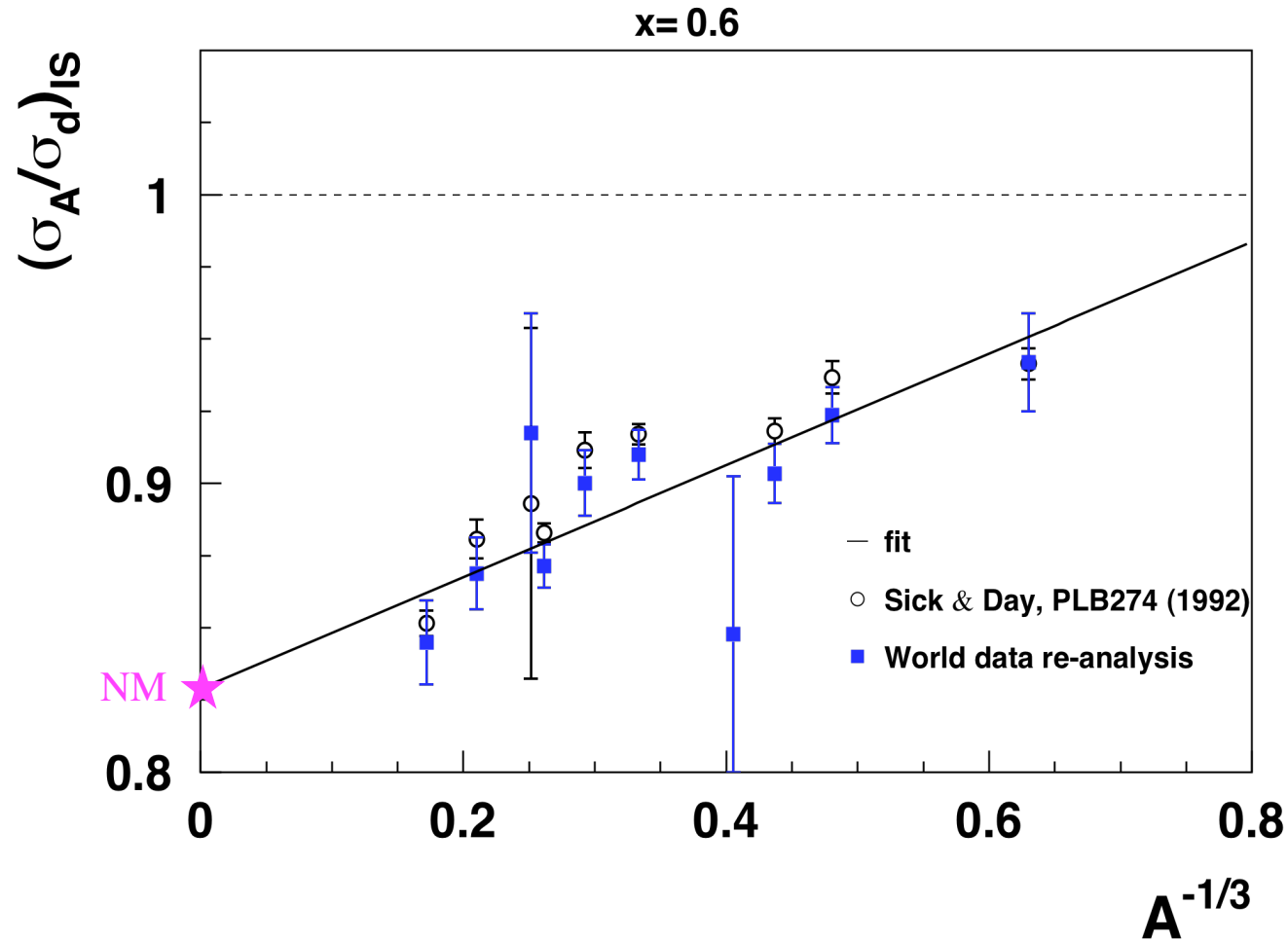
E03-103: EMC effect in heavy nuclei

E03-103 data corrected for coulomb distortion

E03-103: EMC effect in heavy nuclei

E03-103 data corrected for coulomb distortion

Cross overs independent of A
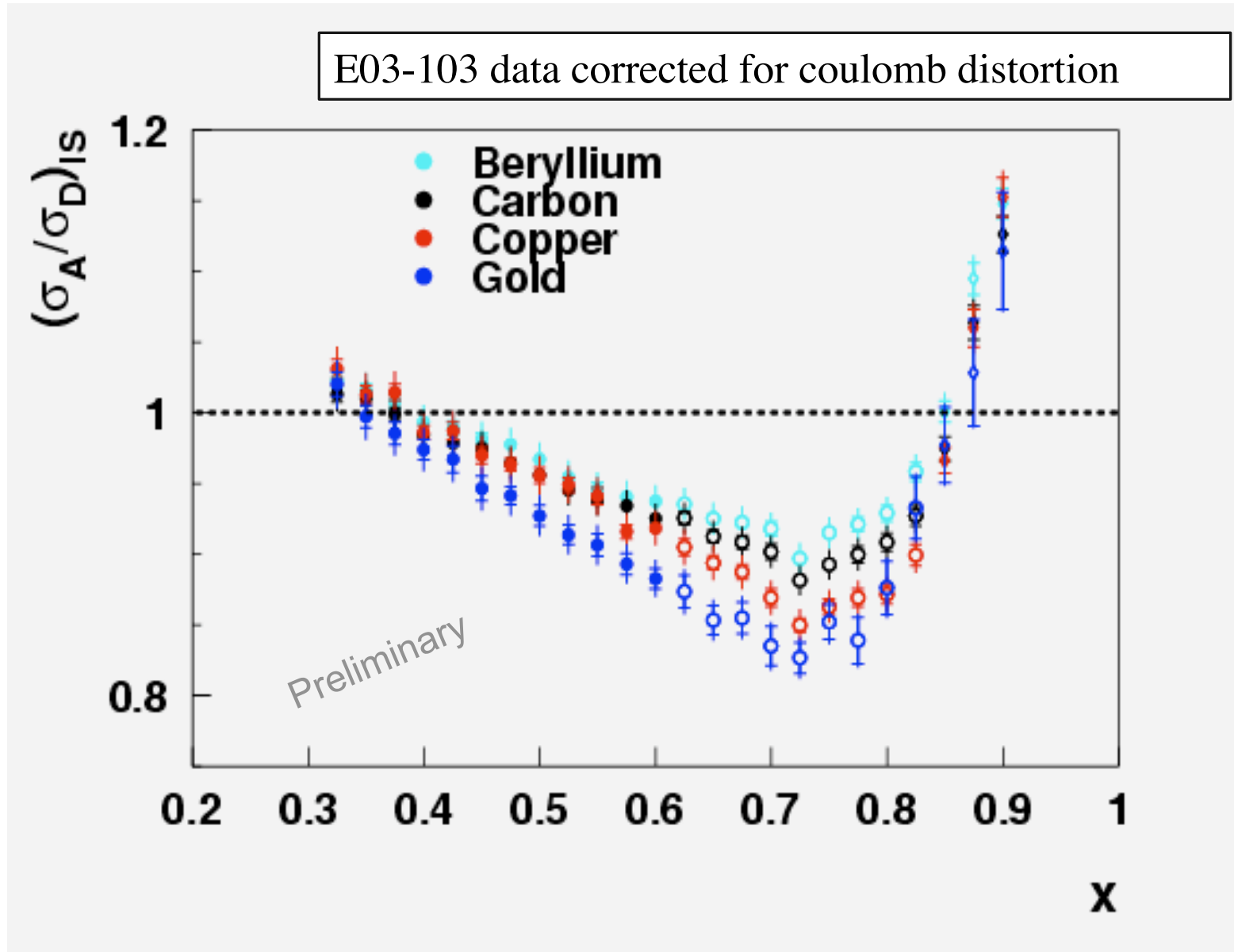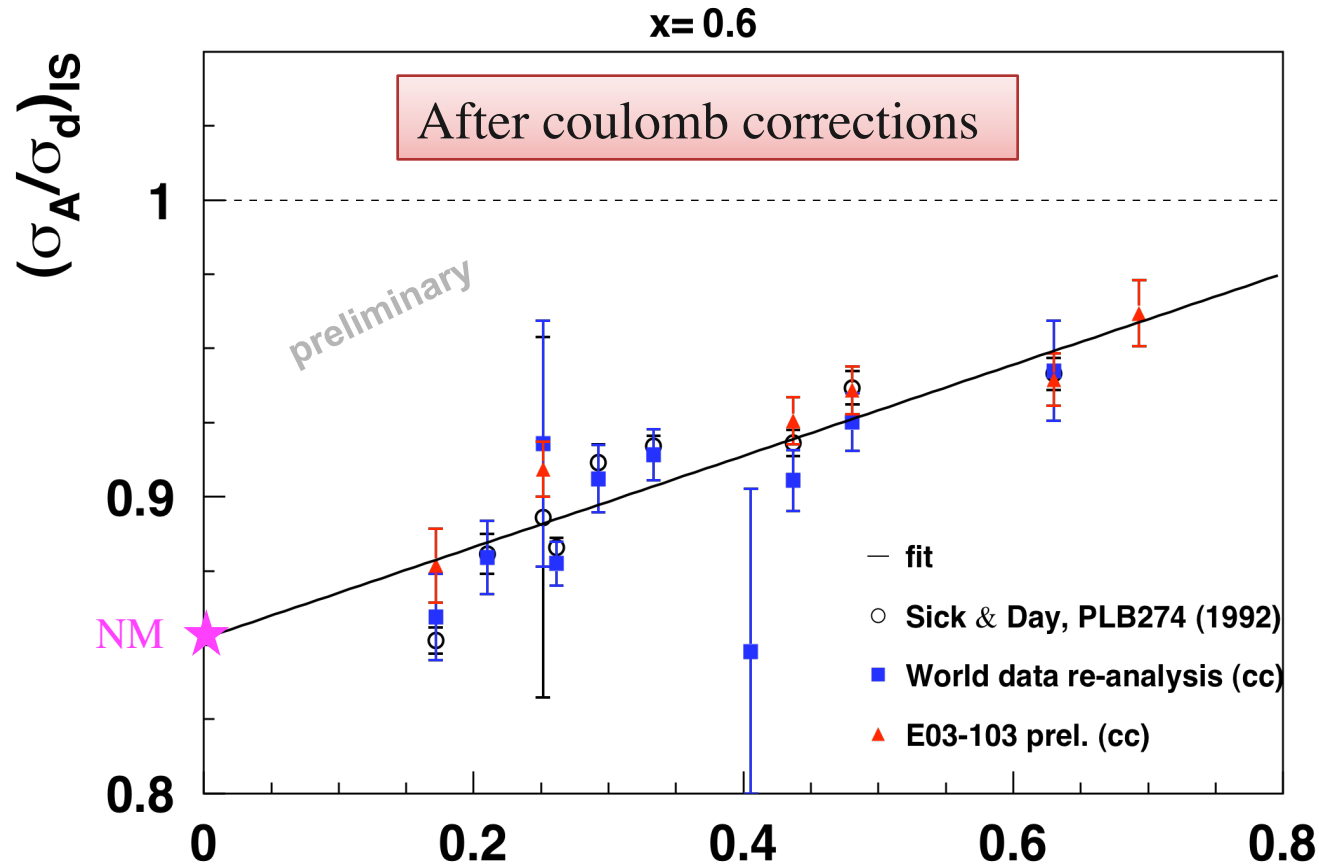
Nuclear dependence of the EMC effect

Main difference due to E139 data sets used:
- Sick & Day used E139 Q^2-avg tables
- we used E139 constant Q^2 to be able to apply CC

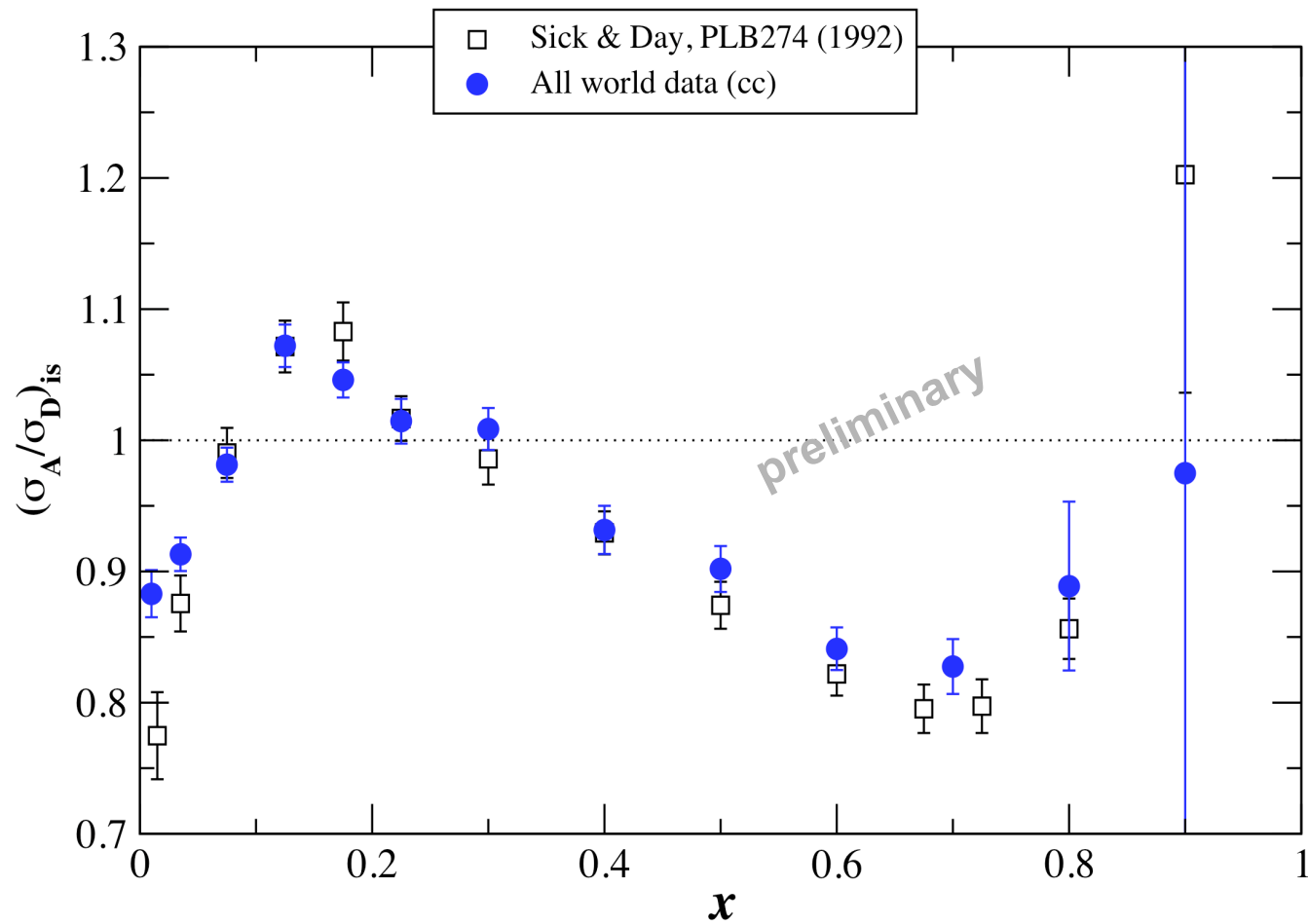# Nuclear dependence of the EMC effect
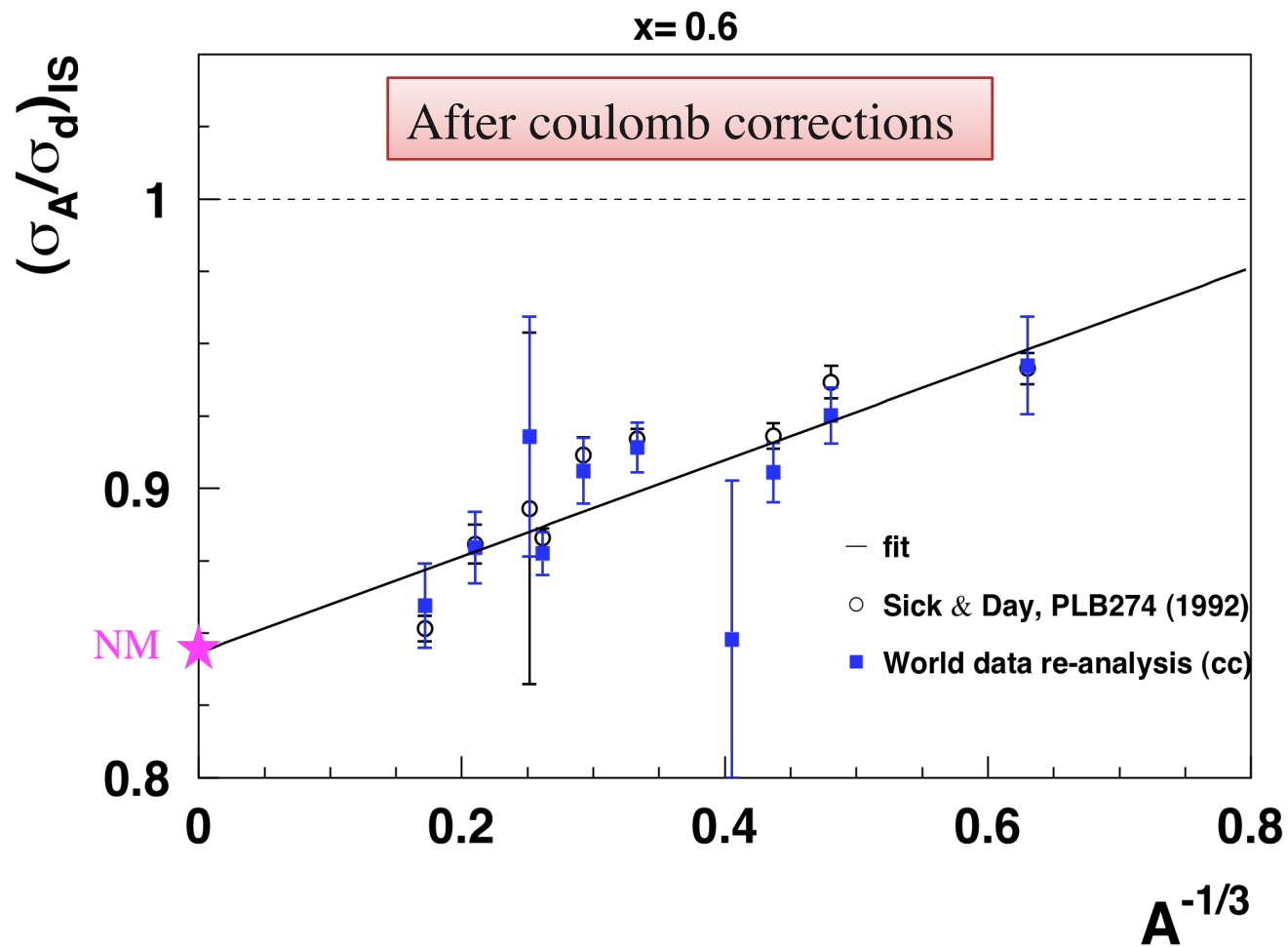
Nuclear dependence of the EMC effect

➤ Good agreement between E03-103 and SLAC E139 data after Coulomb corrections.

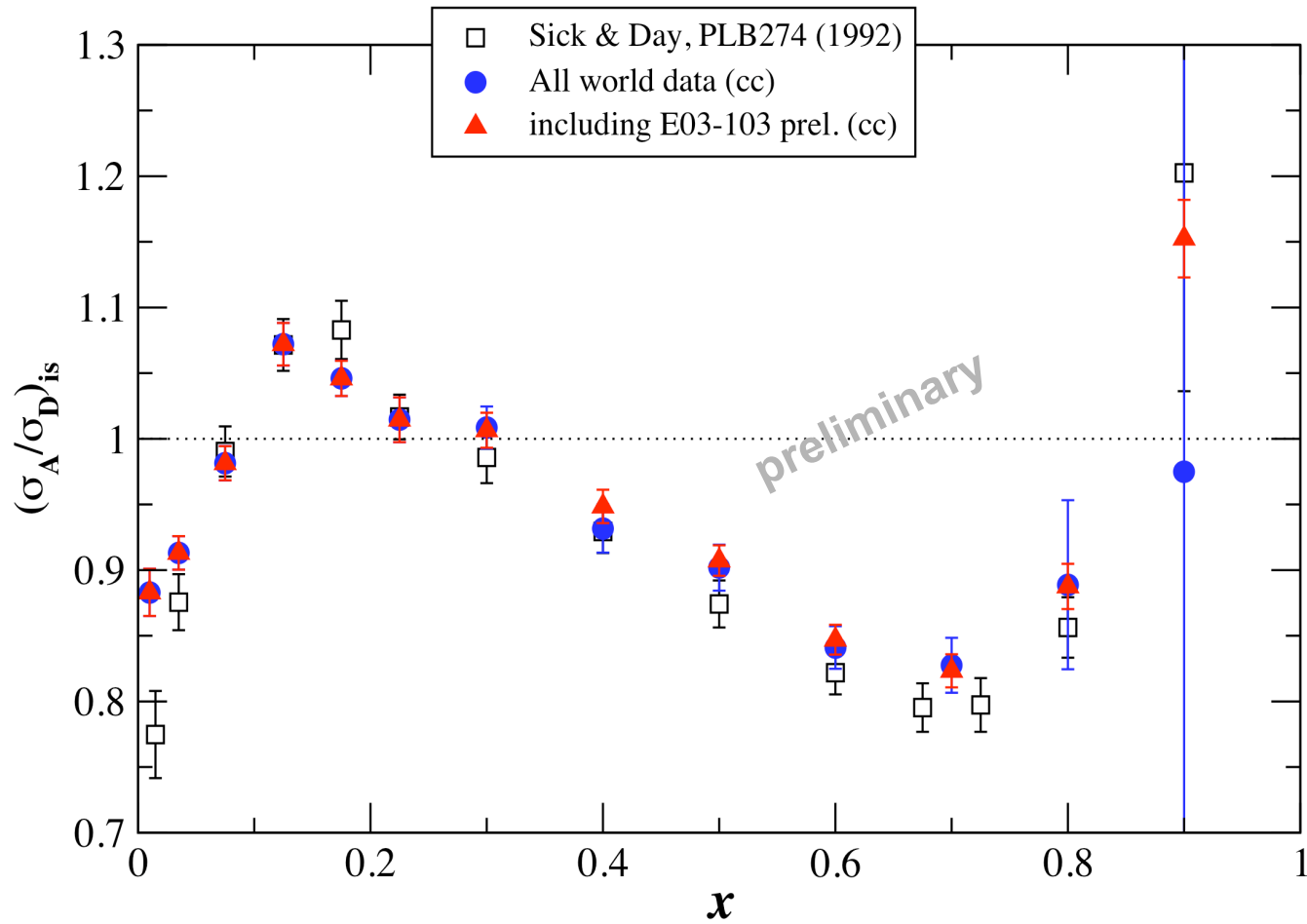➤ Preliminary E03-103 results confirm A-dependence of the EMC effect.

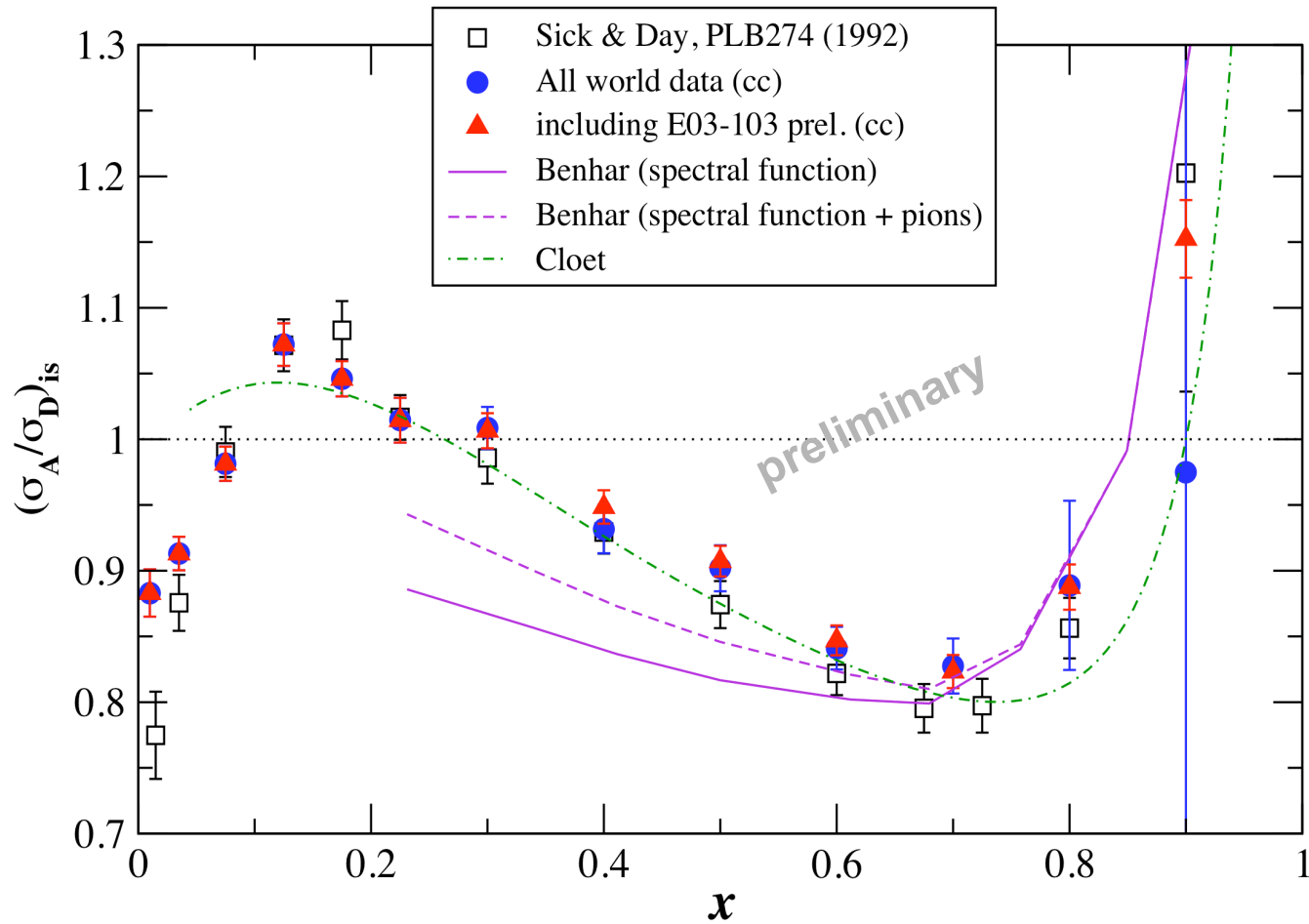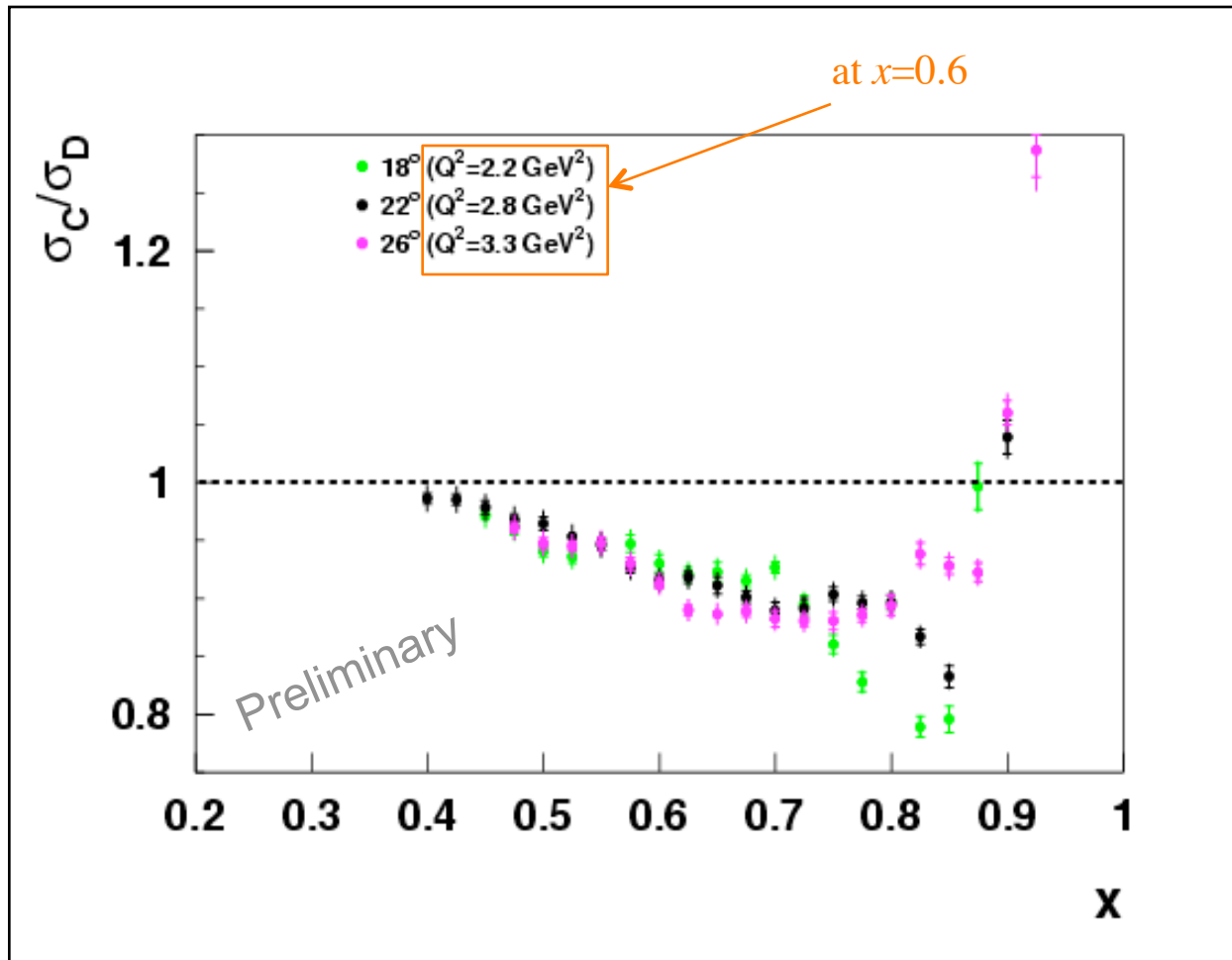Note: n/p correction is also A-dependent !

Nuclear matter

Nuclear matter

Nuclear matter

E03-103: Carbon EMC ratio and Q^2-dependence

Small angle, low Q^2 ➜ clear scaling violations for $x>0.7$,
but surprisingly good agreement at lower x