INT Workshop INT-13-52W February 11 -22, 2013

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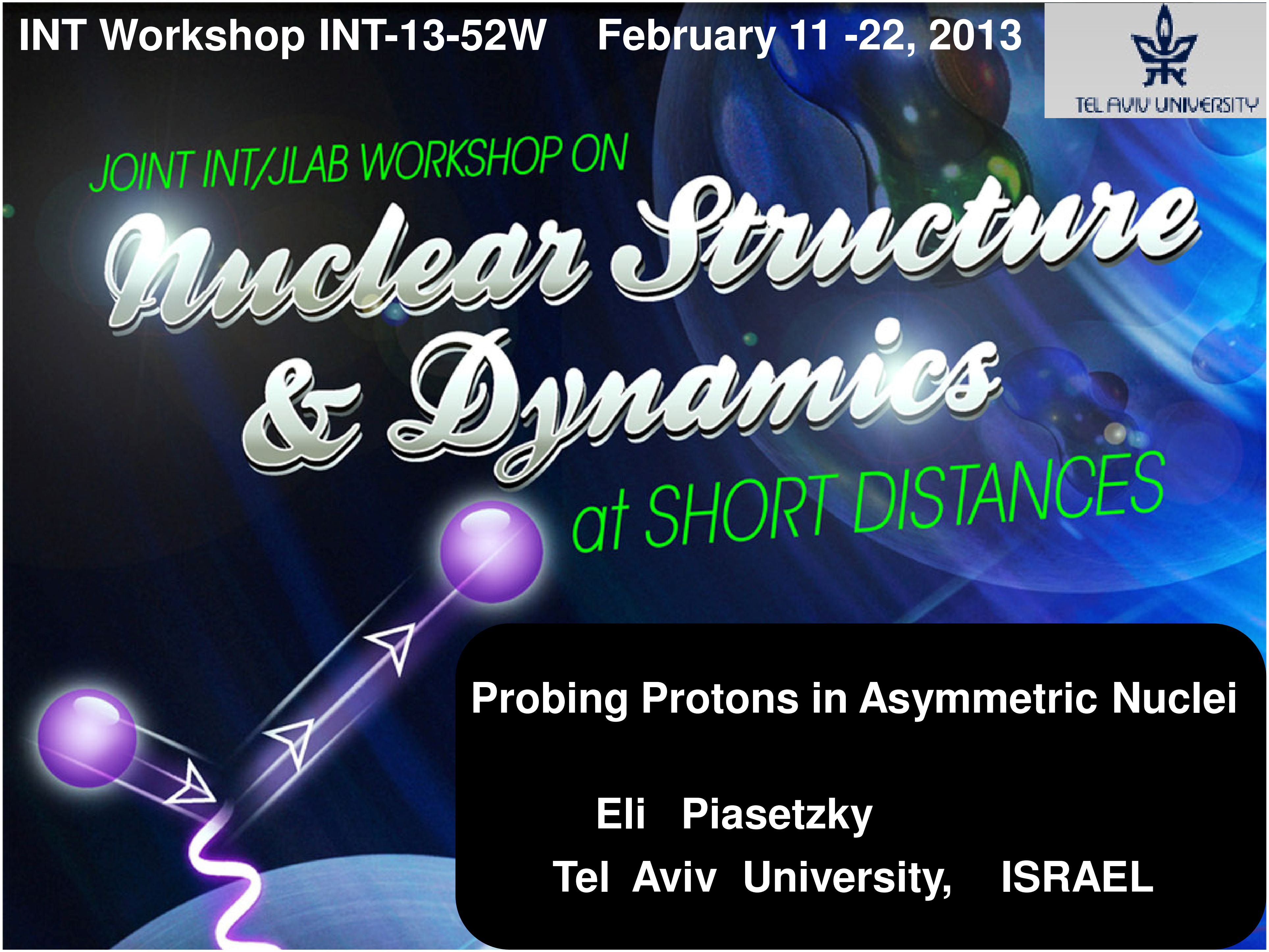
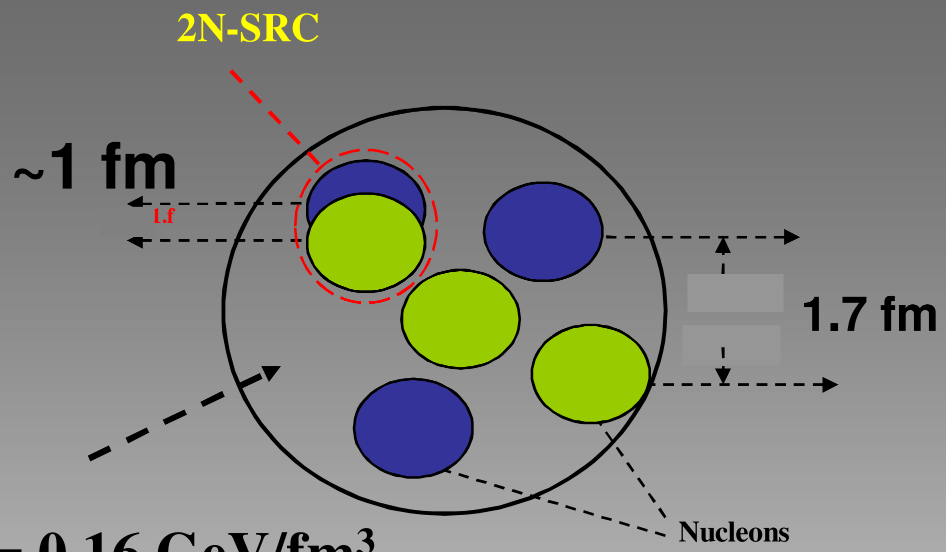


Probing Protons in Asymmetric Nuclei

Eli Piasetzky
Tel Aviv University, ISRAEL

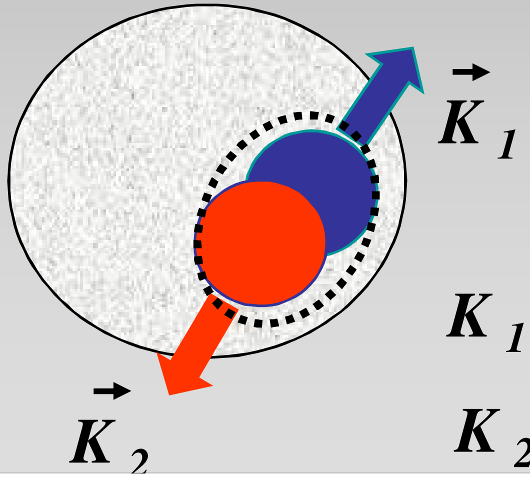
What are 2N-SRC in nuclei ?

In coordinate space:



$\rho_o = 0.16\ \mathrm{GeV/fm^3}$

In momentum space:



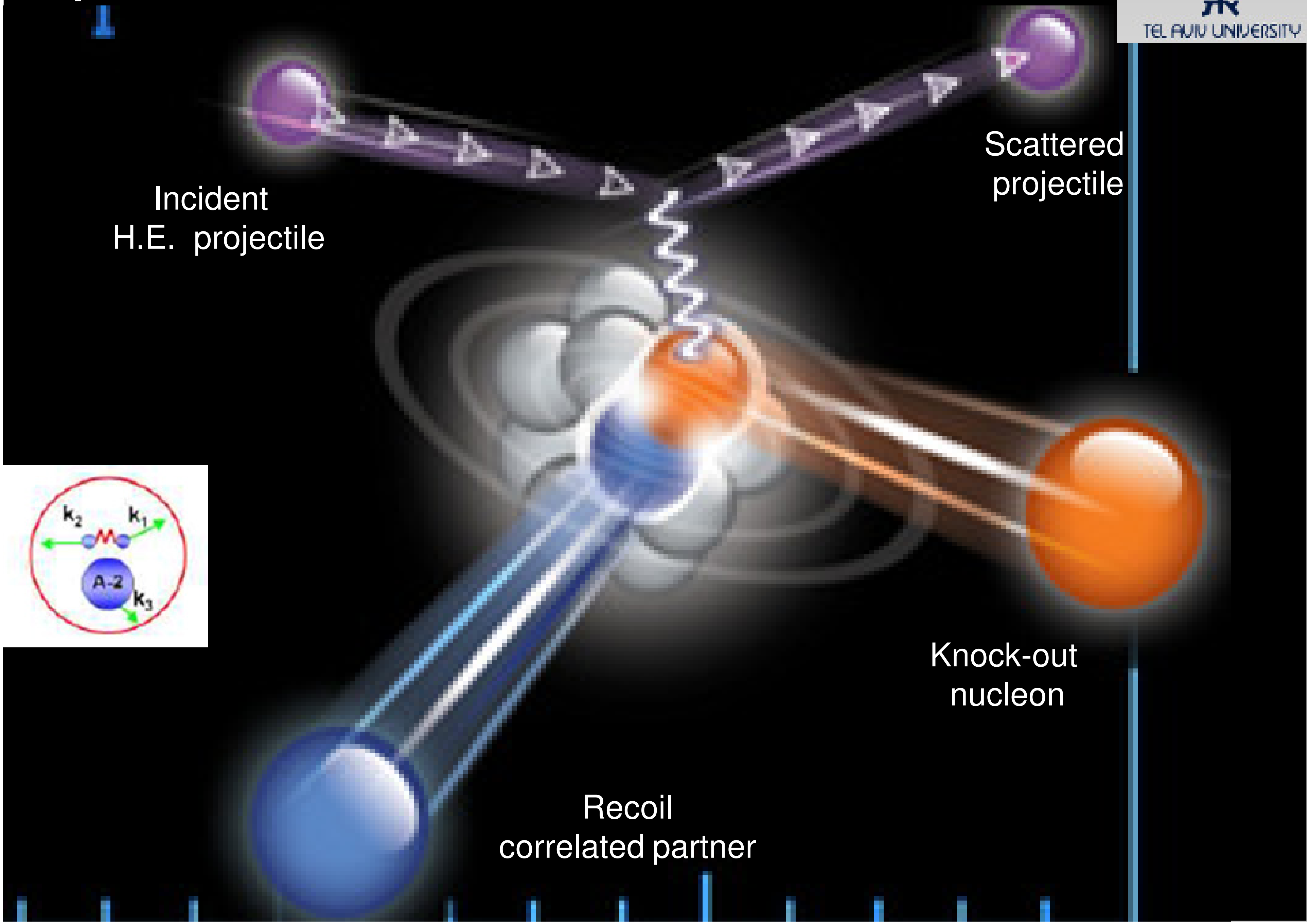
large relative momentum
small CM momentum.

$\vec{K}_1 \cong \vec{K}_2$

$K_1 > K_F ,$

$K_2 > K_F \quad K_F \sim 250\ MeV/c$

Triple – coincidence measurements:



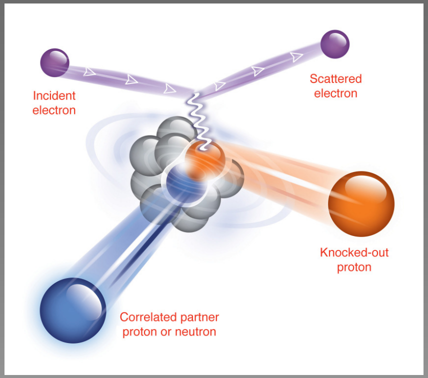
Incident
H.E. projectile

Scattered
projectile

Knock-out
nucleon

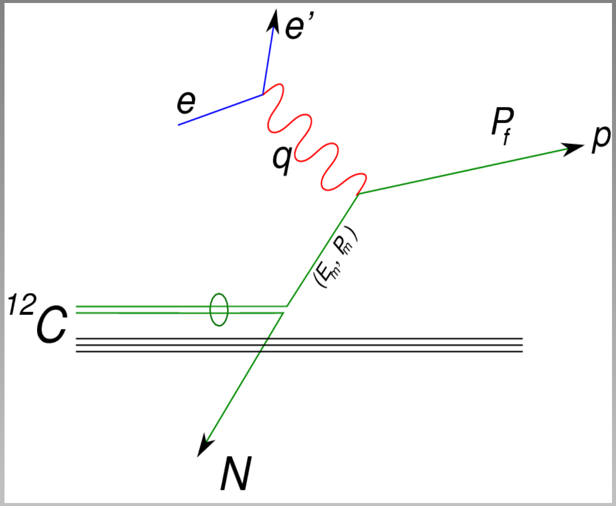
Recoil
correlated partner

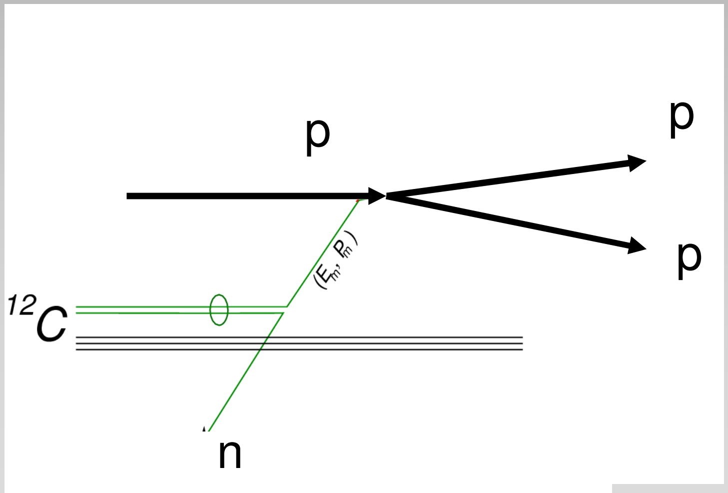
Triple – coincidence measurements:



JLab

(4-5 GeV electron)





EVA / BNL

(6-10 GeV/c protons)

Triple Coincident ^{12}C(p,ppn), ^{12}C(e,e'pp), ^{12}C(e,e'pn)

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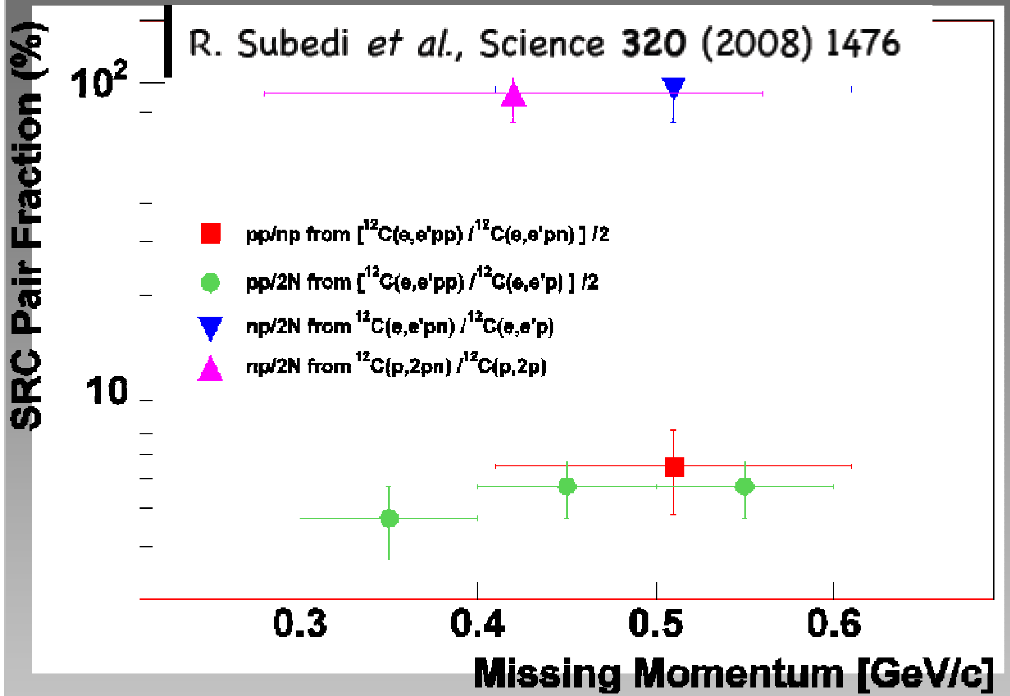
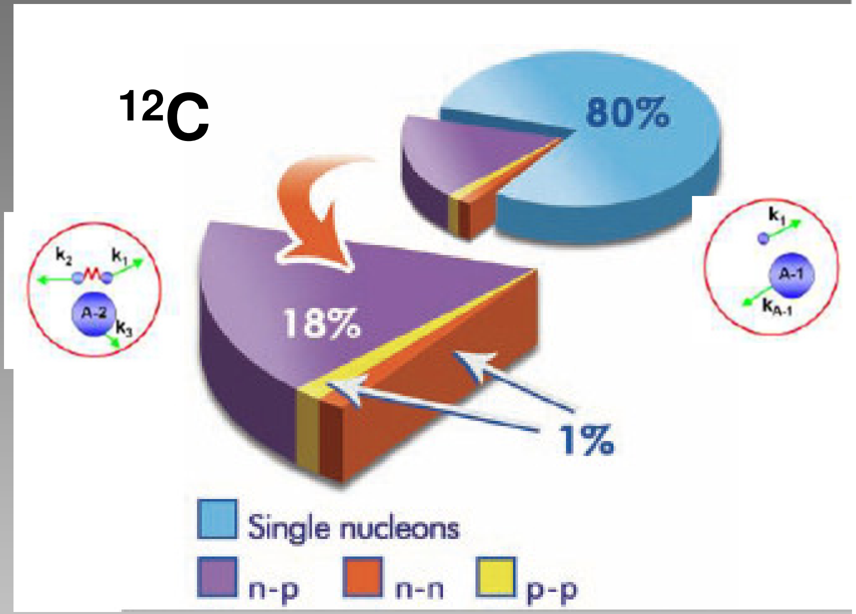
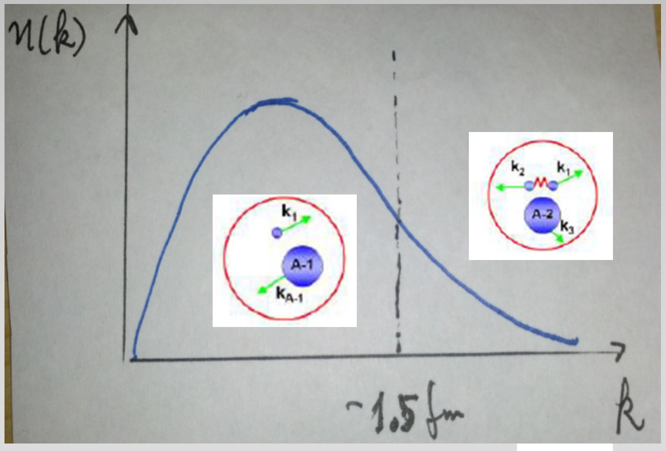

R. Subedi *et al.*, Science **320** (2008) 1476

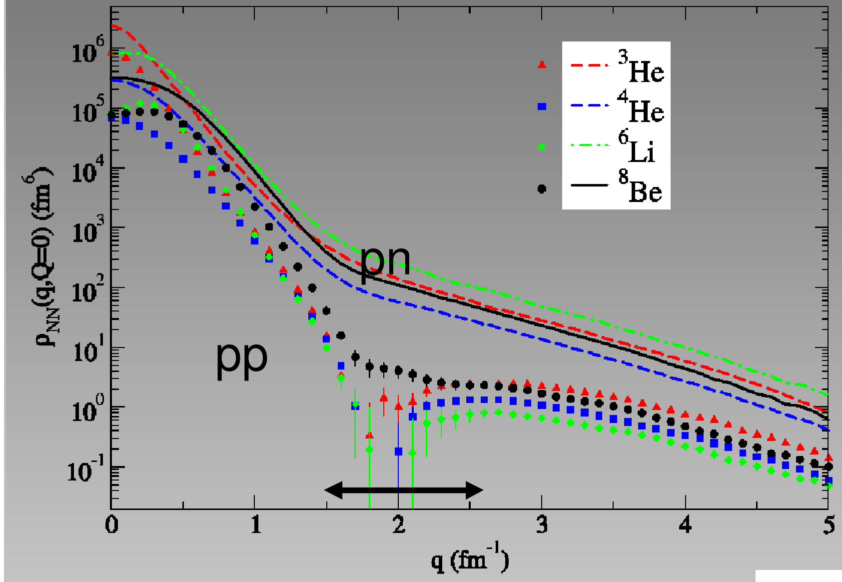




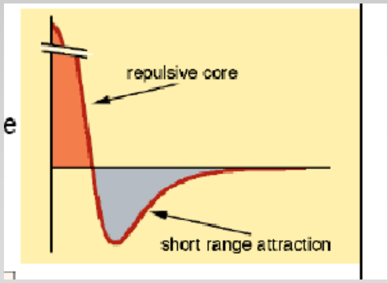
More than ~90% of all nucleons with momentum ≥ 300 MeV / c belong to 2N-SRC.

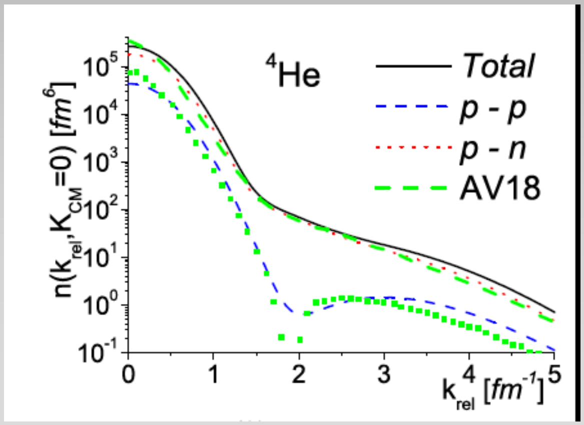
Probability for a nucleon with momentum 300-600 MeV / c to belong to np-SRC is ~18 times larger than to belong to pp-SRC.

At 300-600 MeV/c there is an excess strength in the np momentum distribution due to the strong correlations induced by the tensor NN potential.

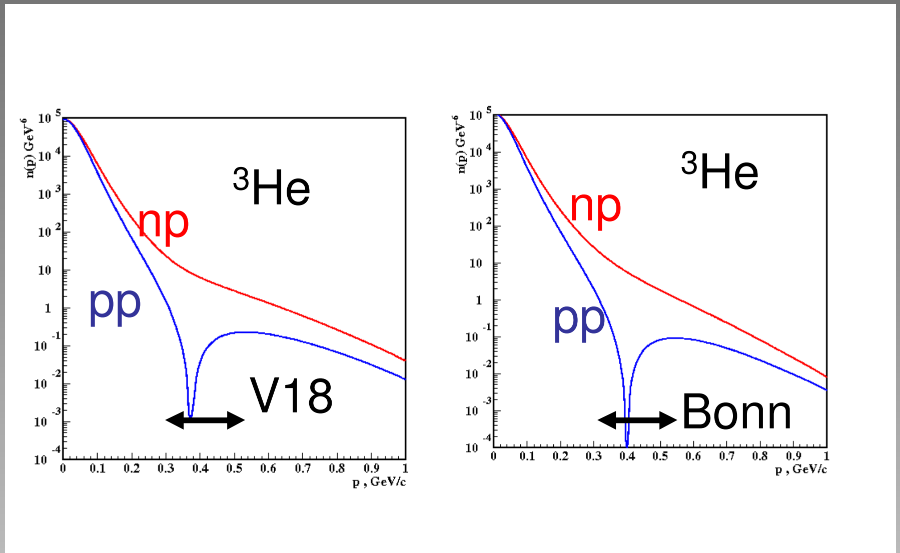


Schiavilla, Wiringa, Pieper,
Carson, PRL 98,132501 (2007).

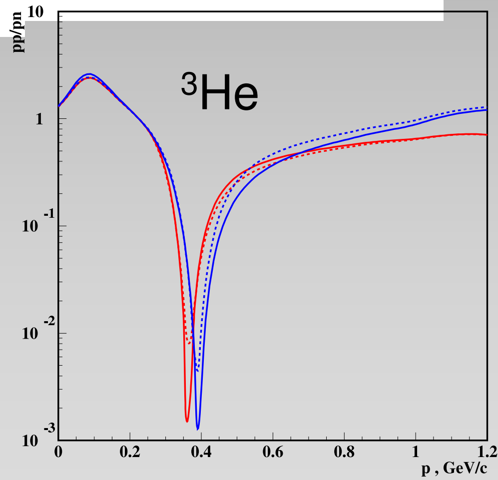




Ciofi and Alvioli
PRL 100, 162503 (2008).

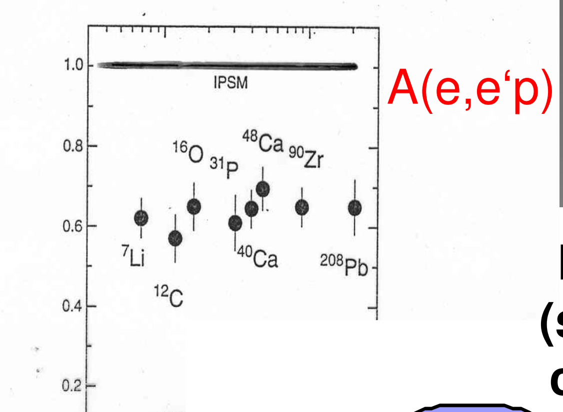


pp/np

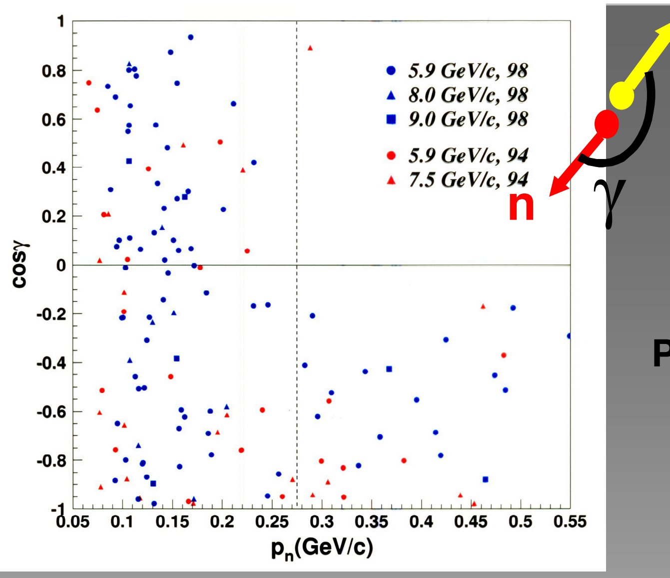


Sargsian, Abrahamyan, Strikman,
Frankfurt PR C71 044615 (2005).

Summary of Results



A(e,e‘p)



^{12}C(p,2p n)

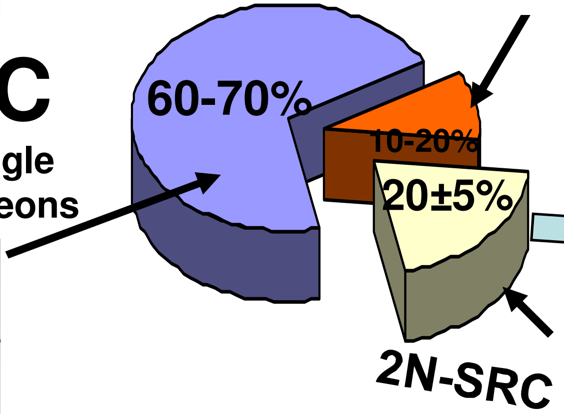
Tang et al.
PRL 042301 (2003)

Piasetzky, Sargsian, Frankfurt, Strikman, Watson
PRL 162504(2006).

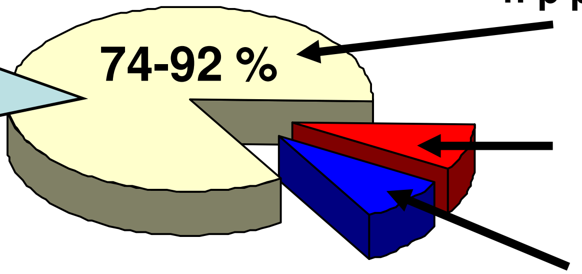
^{12}C

Single nucleons

Long range (shell model) correlations



2N-SRC

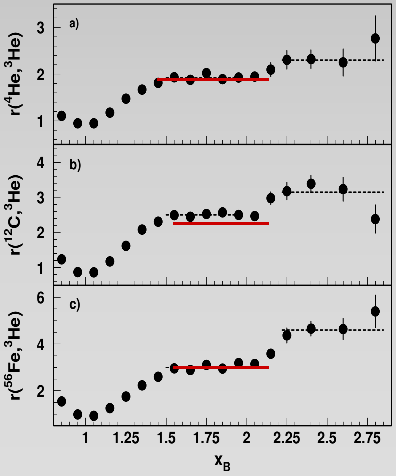


n-p pairs

4.75±1%
p-p pairs

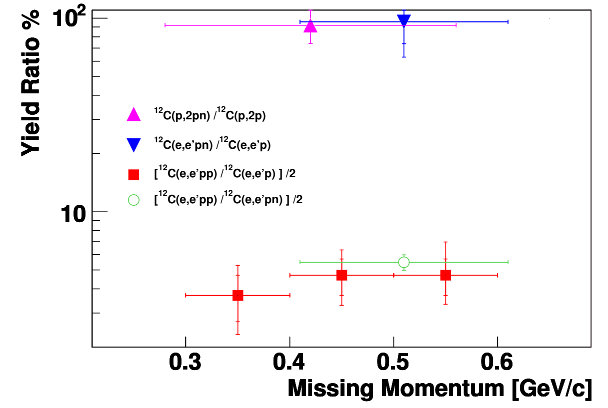
4.75±1%
n-n pairs

A(e,e‘pN)



A(e,e‘)

R. Subedi et al., Science 320, 1476 (2008).



Egiyan et al. **PRC 68, 014313.**
Egiyan et al. **PRL. 96, 082501 (2006)**

JLab / CLAS, Data Mining, EG2 data set

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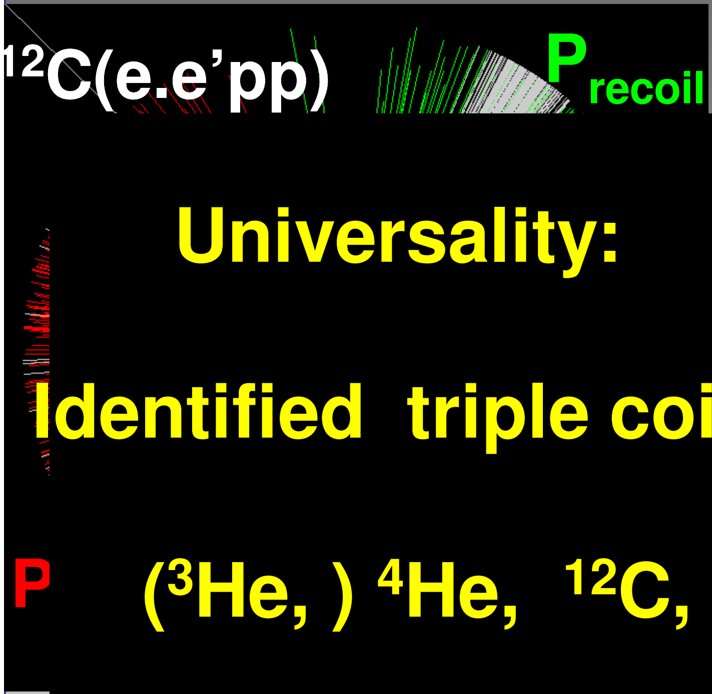
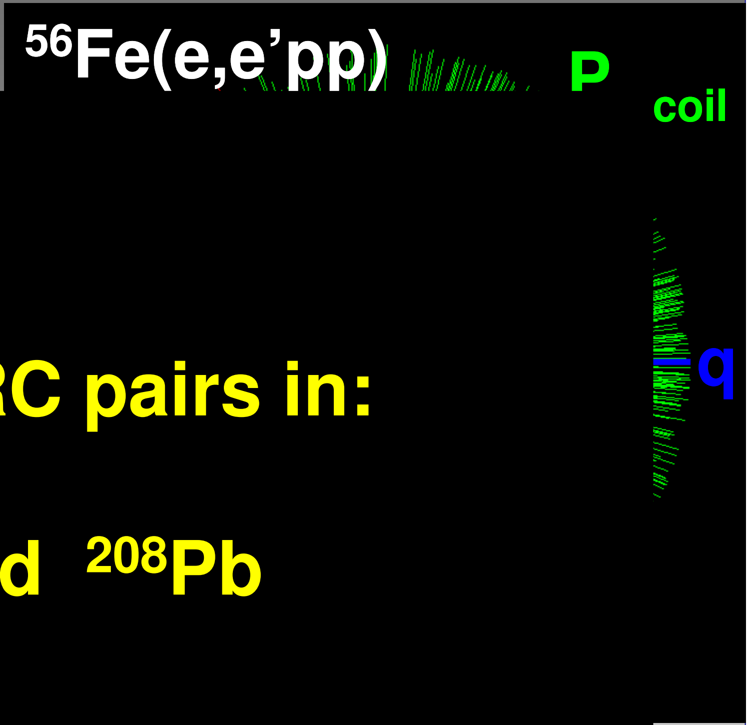
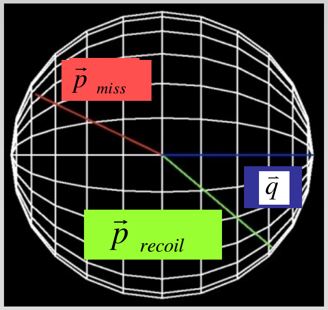


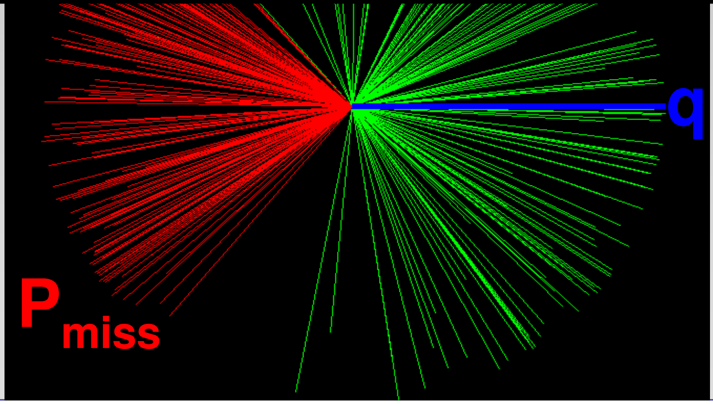


Universality:

Identified triple coincidence SRC pairs in:

(^{3}He,) ^{4}He, ^{12}C, ^{27}Al, ^{56}Fe, and ^{208}Pb





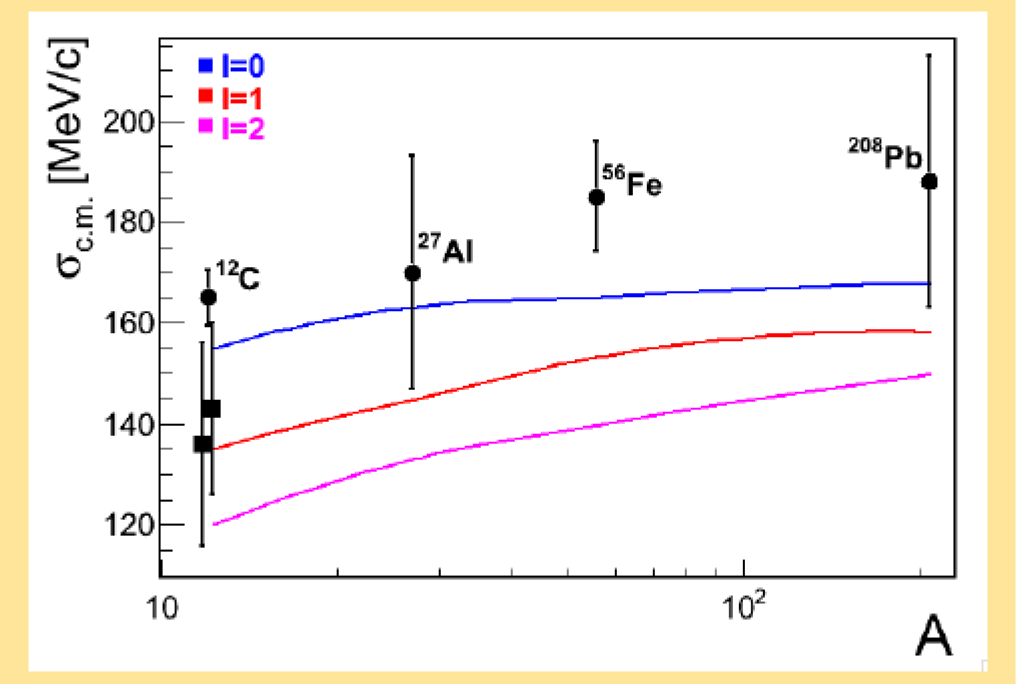
pp-SRC events

Ein =5.014 GeV

$Q^2>1.5 GeV/c^2$ X>1.2

C.m. motion of correlated pp pairs

DATA IS PRELIMINARY! (COURTESY OF O. HEN AND E. PIASETZKY)



- analysis of exclusive $A(e,e'pp)$ for ^{12}C, ^{27}Al, ^{56}Fe, ^{208}Pb
- distribution of events against P is fairly Gaussian
- $\sigma_{c.m.}$: Gaussian widths from a fit to measured c.m. distributions
- theory lines: Gaussian fits to computed c.m. distributions for $I = 0, 1, 2$

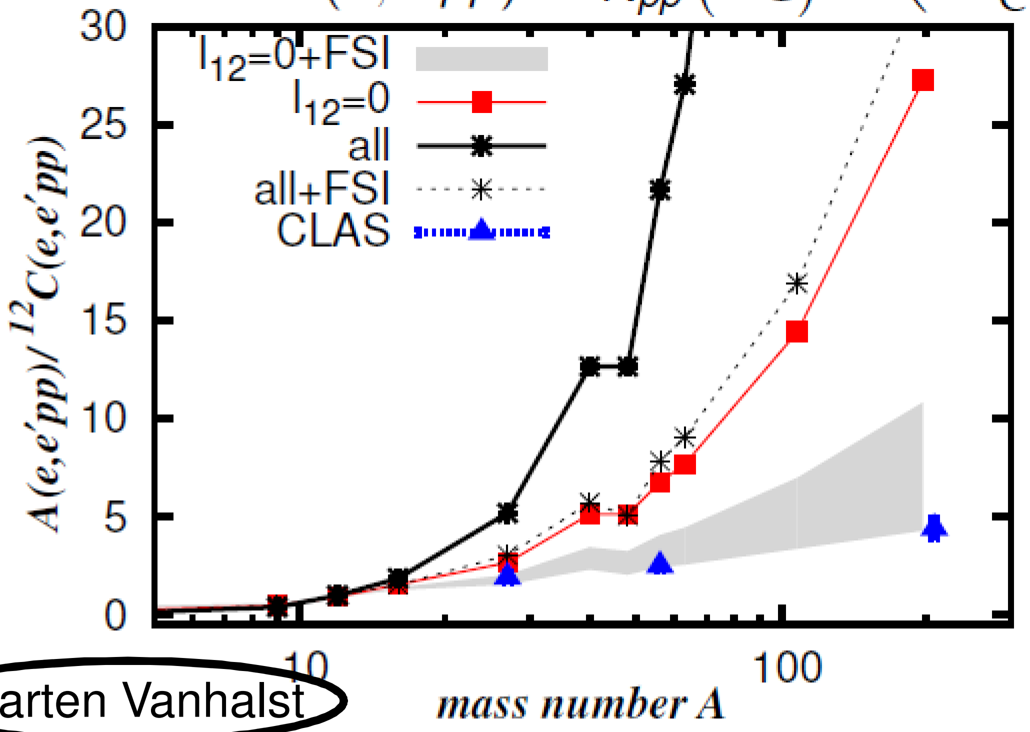
More on the $A(e,e'pp)$ results from CLAS Data Mining: O. Hen (Expt), M. Vanhalst (MC simulations) (Wed, Feb. 20)

Mass dependence of the $A(e,e'pp)$ cross sections

PREDICTION: A dependence of $A(e,e'pp)$ c.s. is soft

(much softer than predicted by naive $Z(Z-1)$ counting)

$$\frac{A(e,e'pp)}{^{12}\mathrm{C}(e,e'pp)} \approx \frac{N_{pp}(A)}{N_{pp}\,(^{12}\mathrm{C})} \times \left(\frac{T_A(e,e'p)}{T_{^{12}\mathrm{C}}(e,e'p)}\right)^{1-2}$$



PRELIMINARY DATA (COURTESY OF O. HEN AND E. PIASETZKY) COMPATIBLE WITH ABSORPTION ON $l_{12}=0$ PAIRS!

Maarten Vanhalst

For asymmetric (N>Z) nuclei:

A direct consequence of np-dominance

Protons move faster than neutrons

Lead, N=126, Z=82

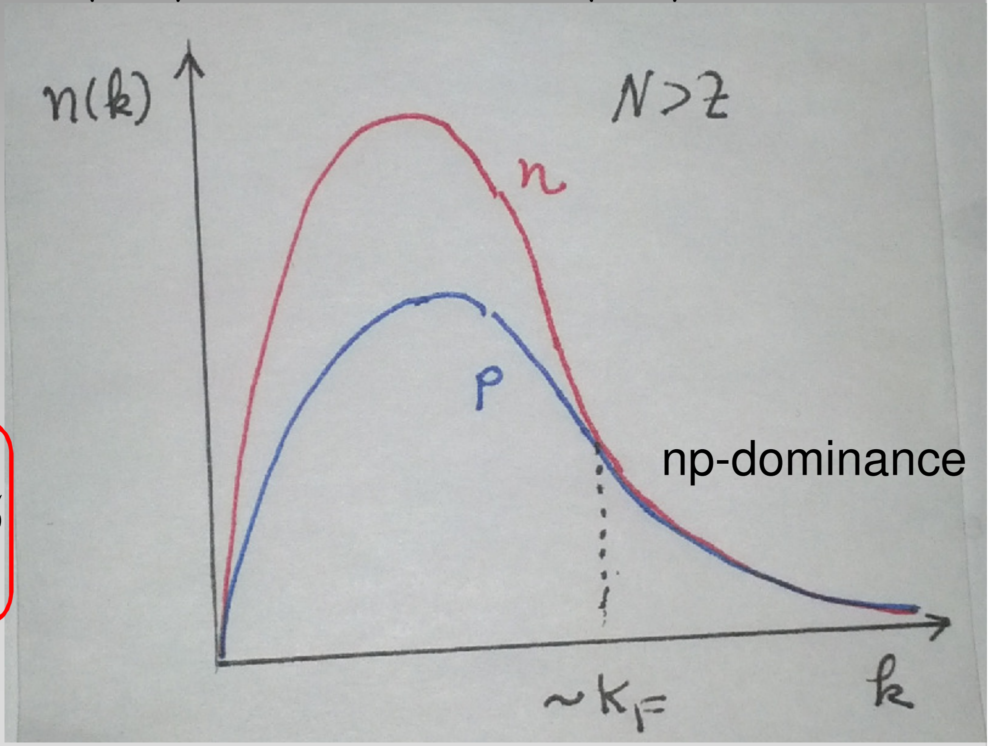
$$\langle k_p \rangle > \langle k_n \rangle \qquad \langle T_p \rangle > \langle T_n \rangle$$

Assuming about (20-25)% of the protons above **k=K$_F$**

$$R_p \equiv \frac{\#\, protons\, \|_{k>K_F}}{\#\, protons\, |_{k<K_F}} \approx \frac{16}{82-16} \approx 0.25$$

$$R_n \equiv \frac{\#\, neutrons\, \|_{k>K_F}}{\#\, neutrons\, |_{k<K_F}} \approx \frac{16}{126-16} \approx 0.15$$

$$\frac{R_p}{R_n} \approx \frac{0.25}{0.15} \approx 1.7$$



See talk by Misak Sargsian

How to check this hypothesis experimentally ?

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Problem: One body momentum distributions are not observables.

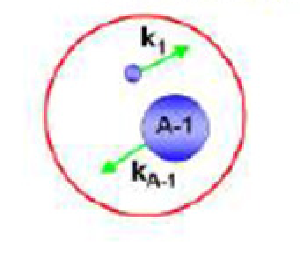
1) Define proxy which is :

Reflect well the difference between proton and neutron momentum distributions .

Can be well determined experimentally

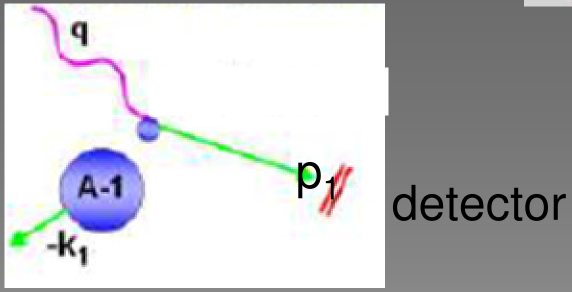
2) Compare the experimental observable to calculation.

Semi exclusive one-body knockout reaction A(e,e'p)

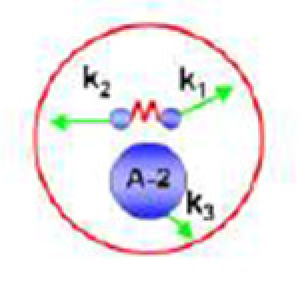


Mean Field:

$k_1 + k_{A-1} = 0$



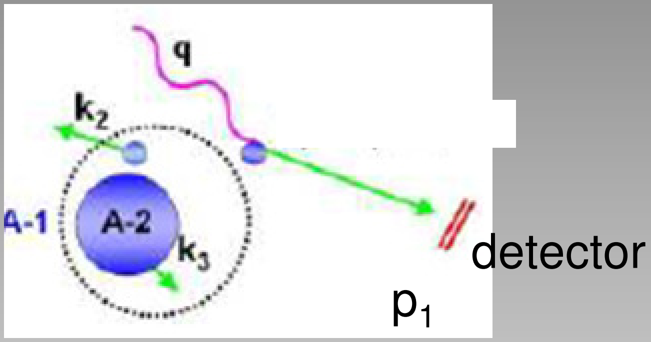
$$p_{miss} \equiv p_1 - q \cong k_1$$



Correlations:

$k_1 + k_2 + k_3 = 0$

$k_2 \simeq -k_1 \quad k_3 \simeq 0$



$$\frac{\#events(e,e'p)\,\big|_{p_{miss}>k_2}\big|_A}{\#events(e,e'p)\,\big|_{p_{miss}<k_1}\big|_A}$$

$$\sigma(e,e'p) = K \cdot \sigma_{ep} \cdot S(E_{miss}, \vec{p}_{miss}) \cdot T$$

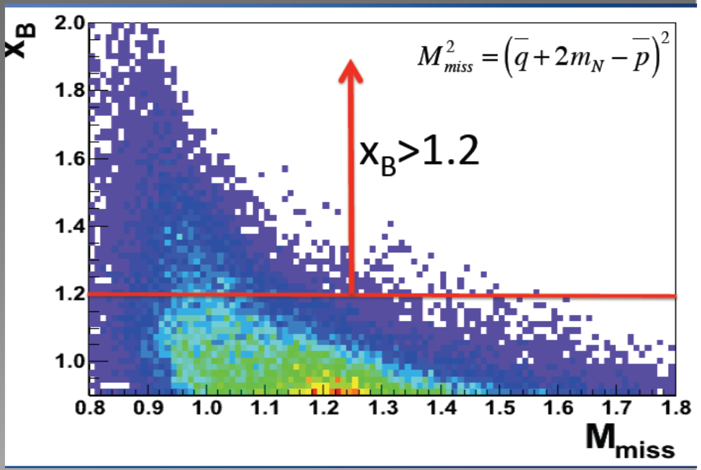
$$k_1 \le k_F \le k_2$$

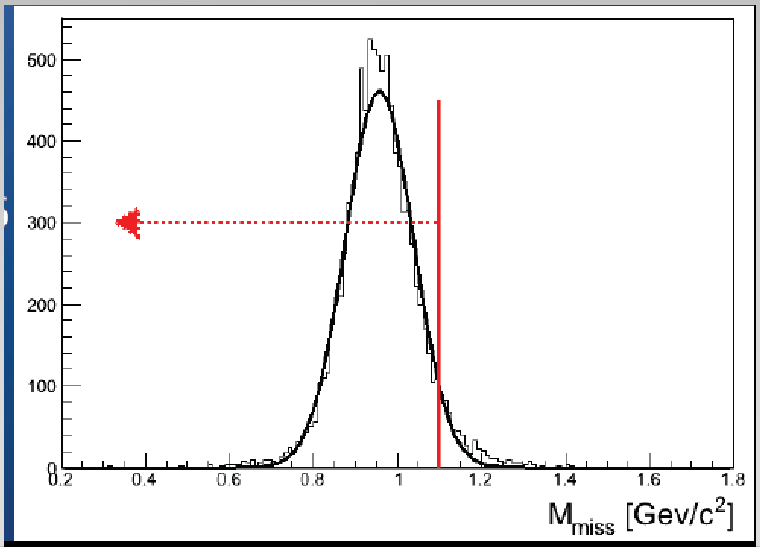
Or even better experimentally:

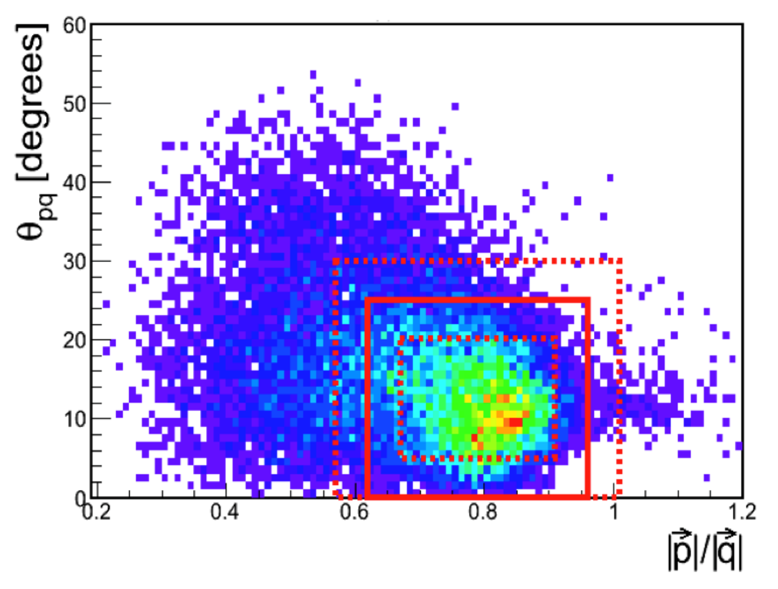
$$\frac{\#events(e,e'p)\,\big|_{p_{miss}>k_2}\big|_A}{\#events(e,e'p)\,\big|_{p_{miss}<k_1}\big|_A} \Bigg/ \frac{\#events(e,e'p)\,\big|_{p_{miss}>k_2}\big|_{^{12}C}}{\#events(e,e'p)\,\big|_{p_{miss}<k_1}\big|_{^{12}C}}$$

(e, e’ p) SRC event selection

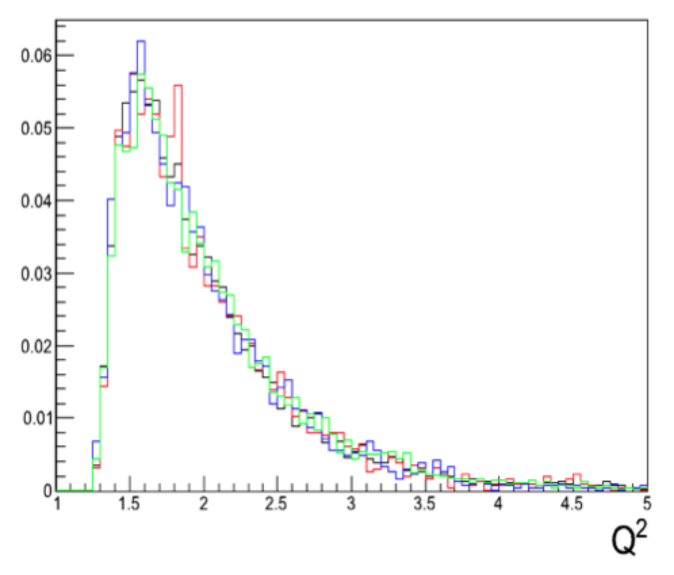
- $x_B > 1.2$
- $300 < |P_{miss}| < 600$ MeV/c
- $\Theta_{pq} < 25^o$
- $0.62 < |P|/|q| < 0.96$
- $M_{miss} < 1.1$ GeV/c^2

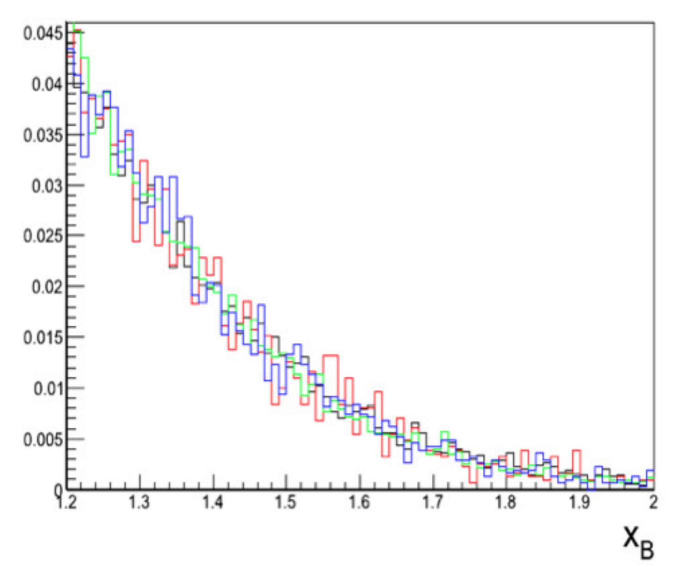




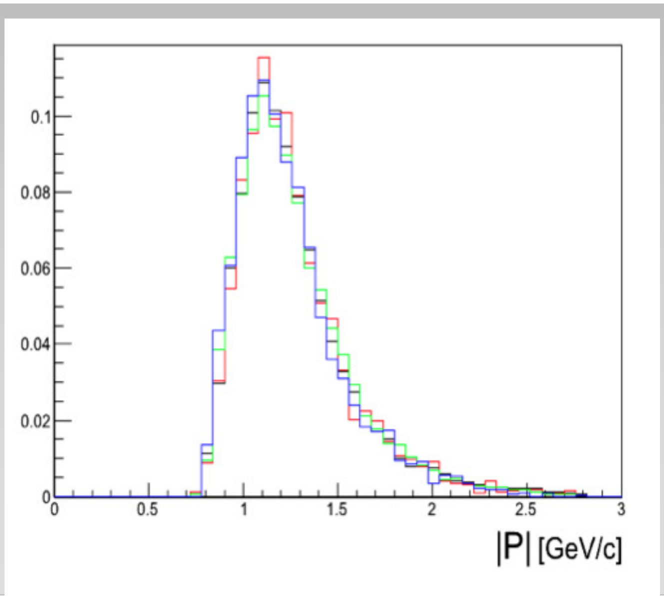


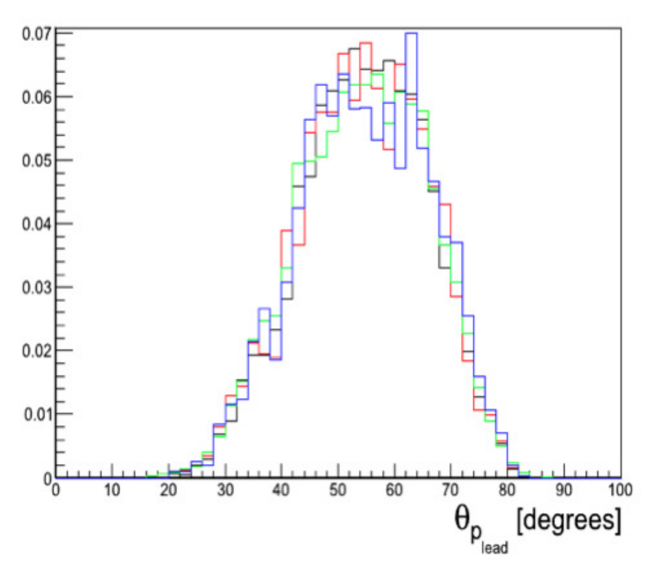
No acceptance correction is required in the supper ratio of A / C





electrons

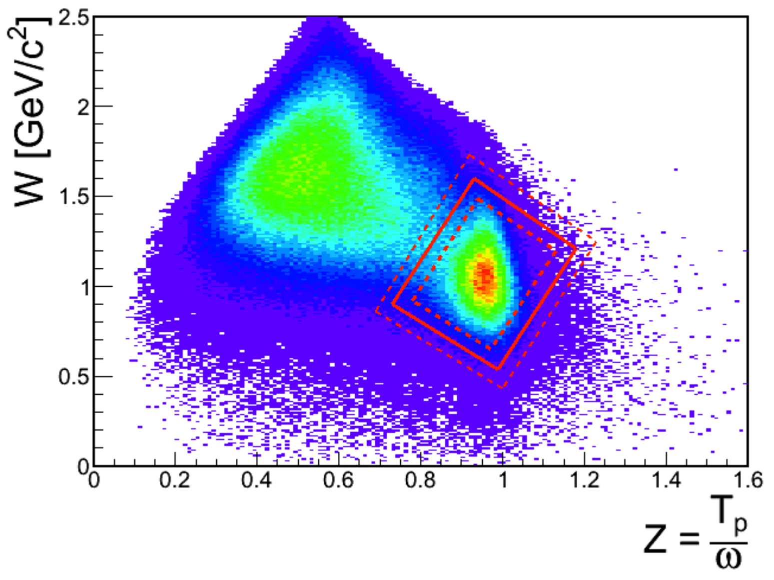




protons

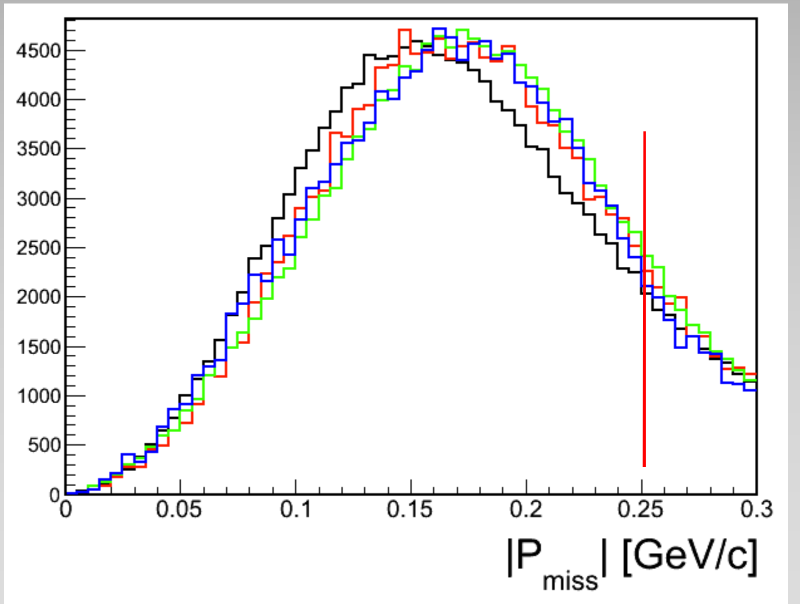
Different color – different nuclei –same acceptance

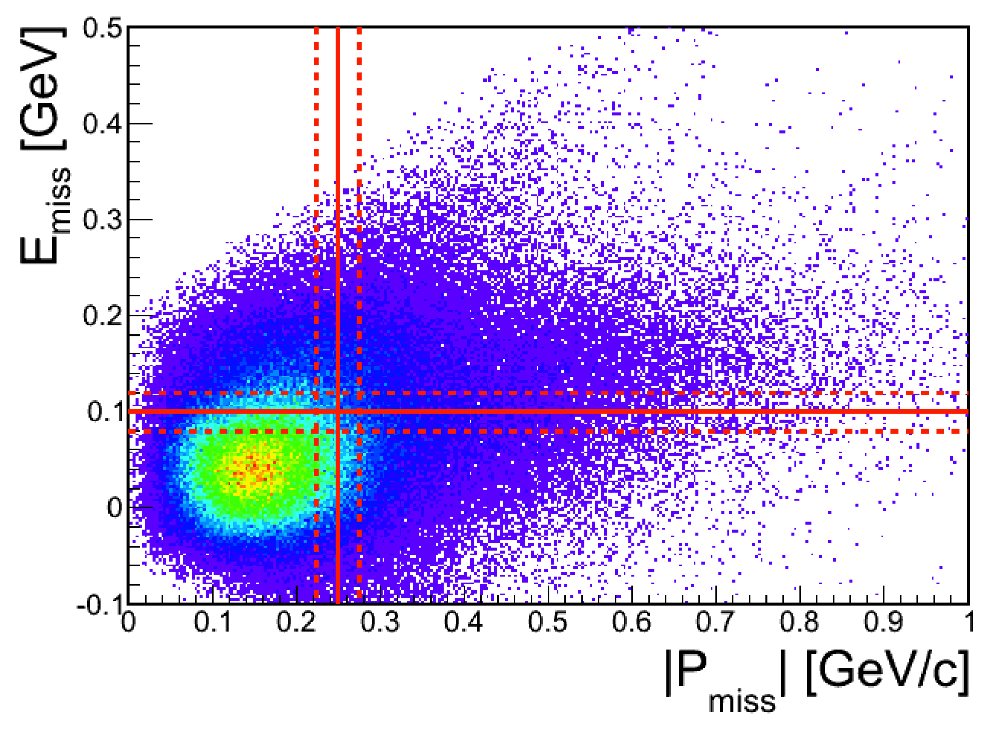
Mean Field (MF) Event selection



W vs. Z

E_{miss} vs. P_{miss}





Compare the experimental observable to calculations

$$n_p(k) = \begin{cases} \eta \cdot n_{MF}(k) & k \leq k_0 \\ \dfrac{a2(A) \cdot n_d(k)}{2 \cdot Z/A} & k \geq k_0 \end{cases}$$

$$n_n(k) = \begin{cases} \eta \cdot n_{MF}(k) & k \leq k_0 \\ \dfrac{a2(A) \cdot n_d(k)}{2 \cdot N/A} & k \geq k_0 \end{cases}$$

η is determined by requesting: $\int_0^\infty n(k) k^2 dk = 1$

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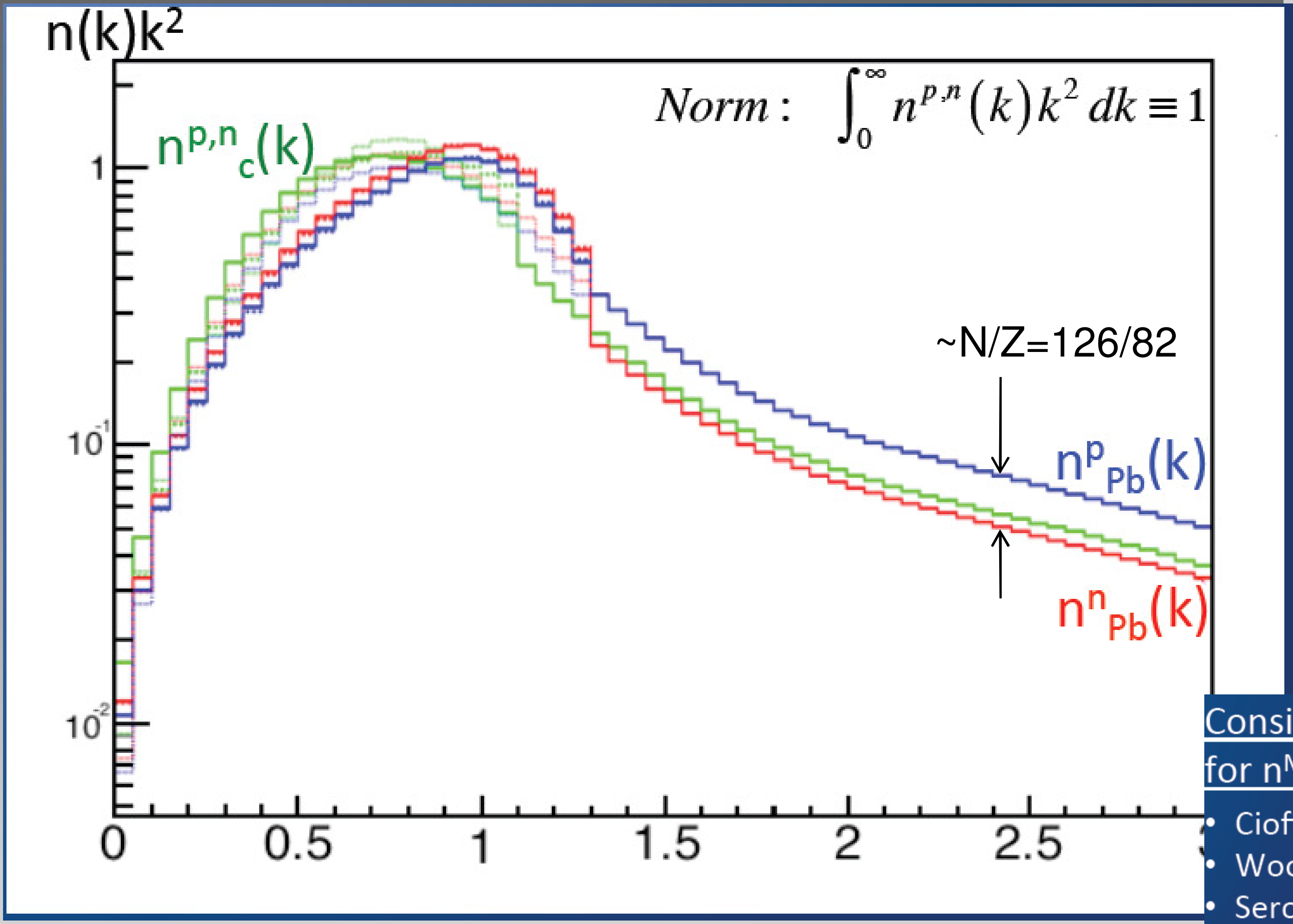


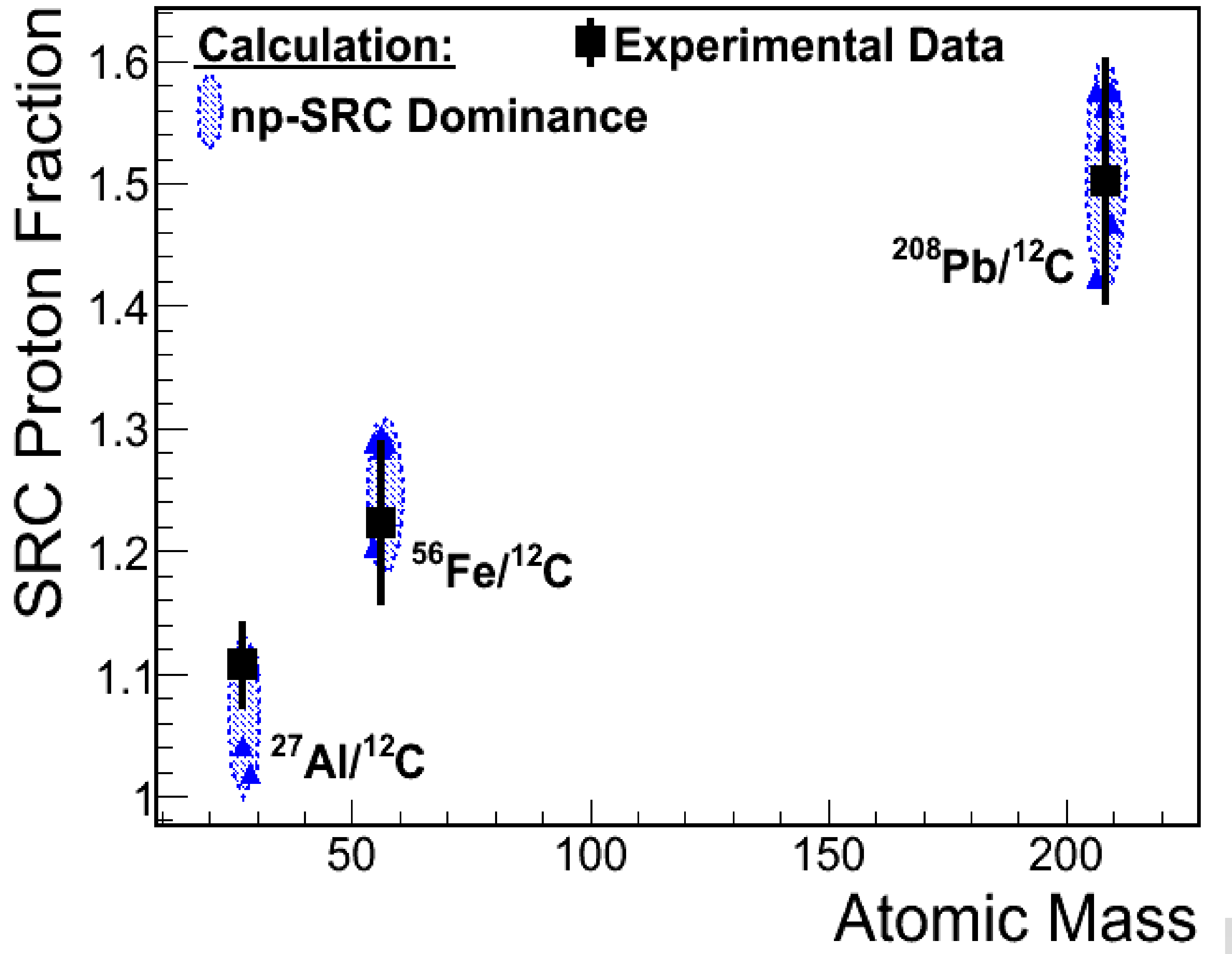
Consider 3 models for $n^{M.F.}(k)$:

- Ciofi and Simula
- Wood-Saxon
- Serot-Walecka

Consider 2 values for k_0:

- k_F
- 300 MeV/c

3 models for $n(k)_{MF}$ X 2 SRC / MF change over points



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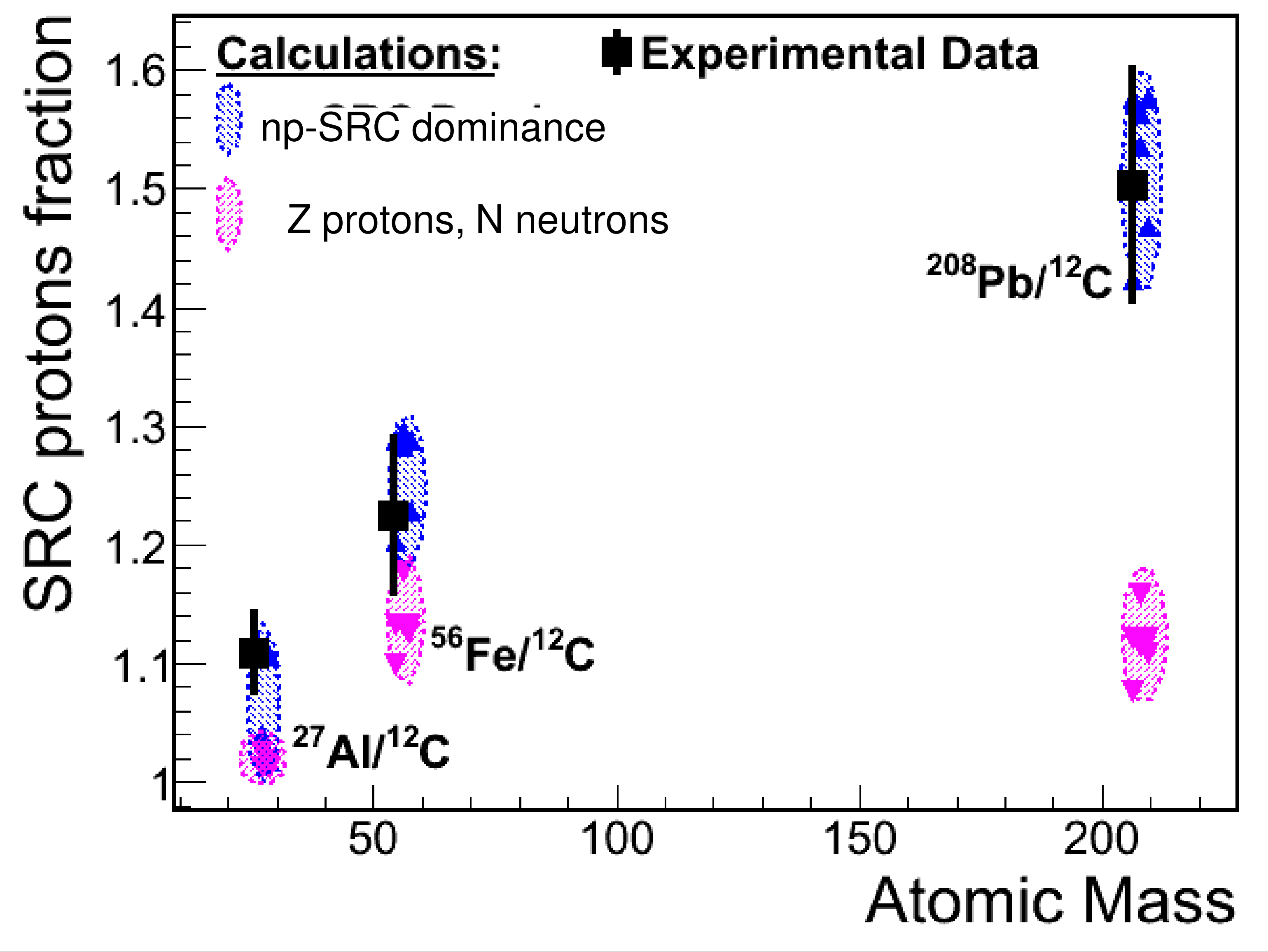

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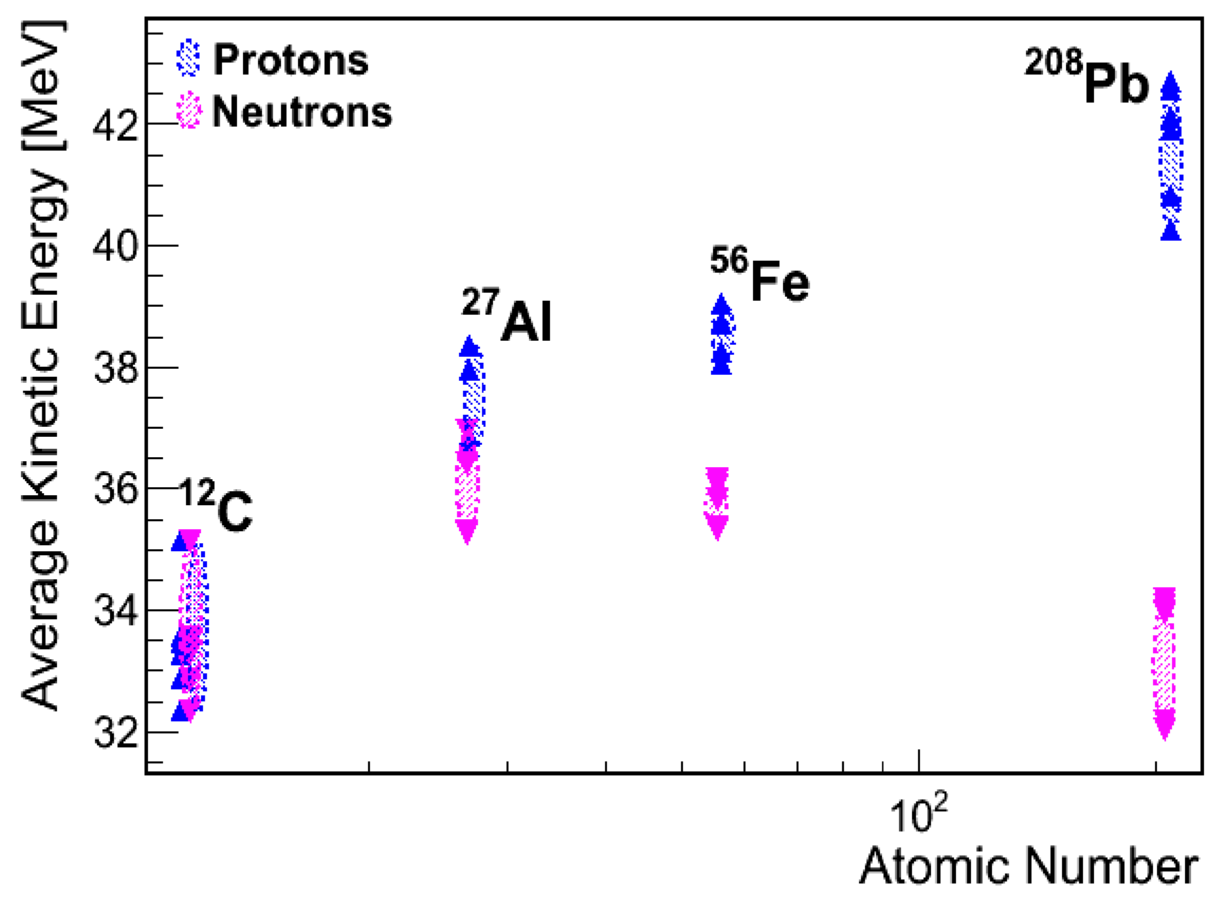

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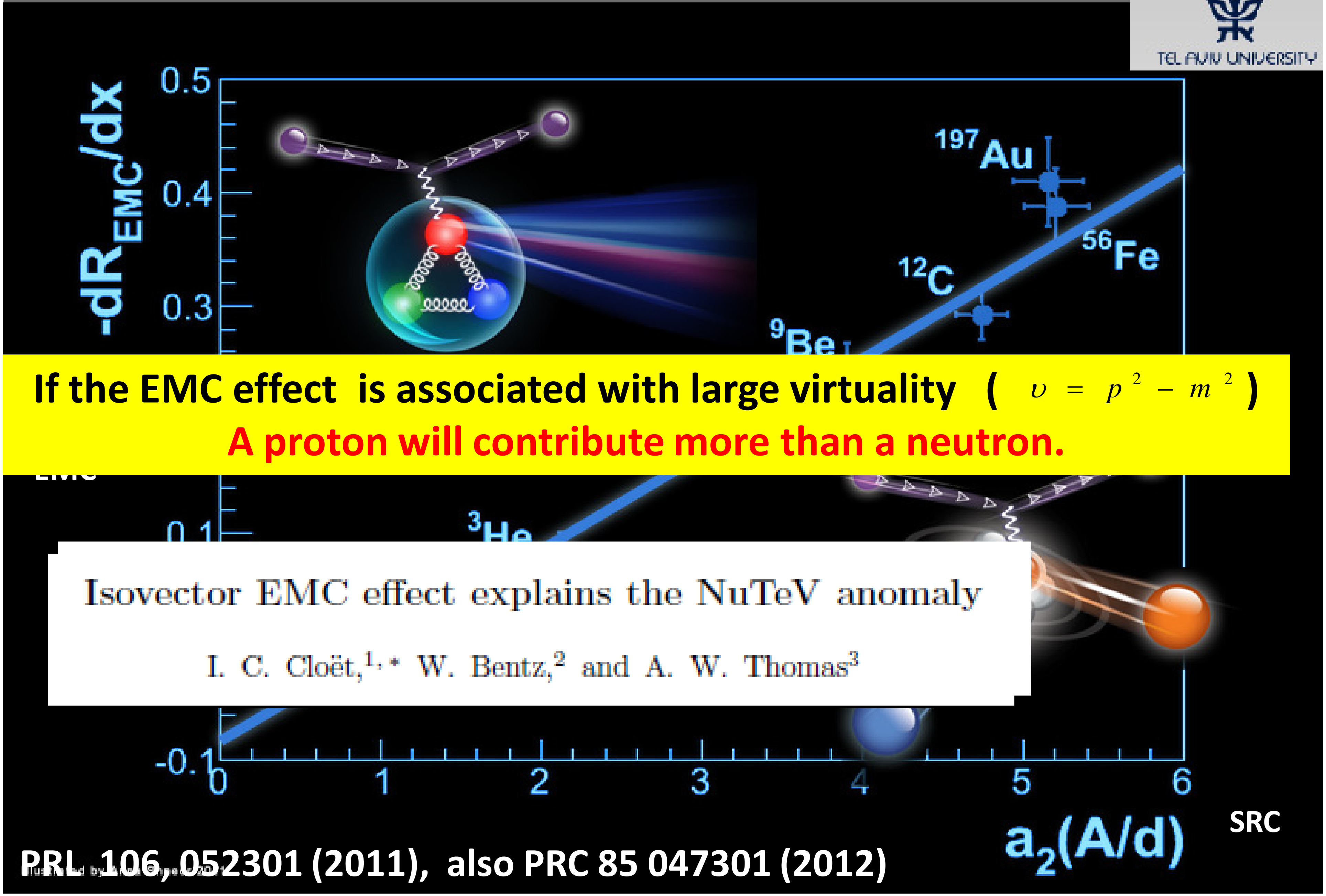
consequences: isospin dependence of the EMC effect



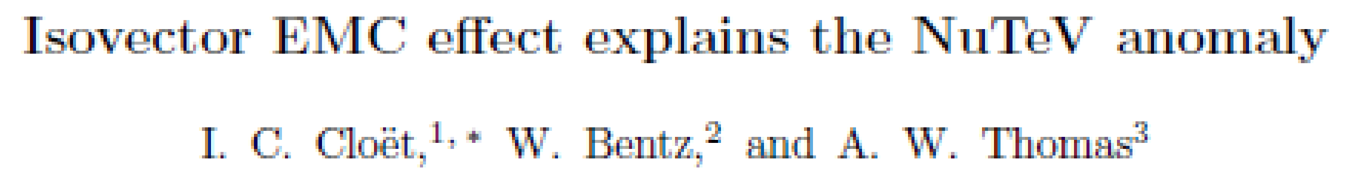
If the EMC effect is associated with large virtuality ($\upsilon = p^2 - m^2$)

A proton will contribute more than a neutron.

Isovector EMC effect explains the NuTeV anomaly

I. C. Cloët,[1,*] W. Bentz,[2] and A. W. Thomas[3]

PRL 106, 052301 (2011), also PRC 85 047301 (2012)



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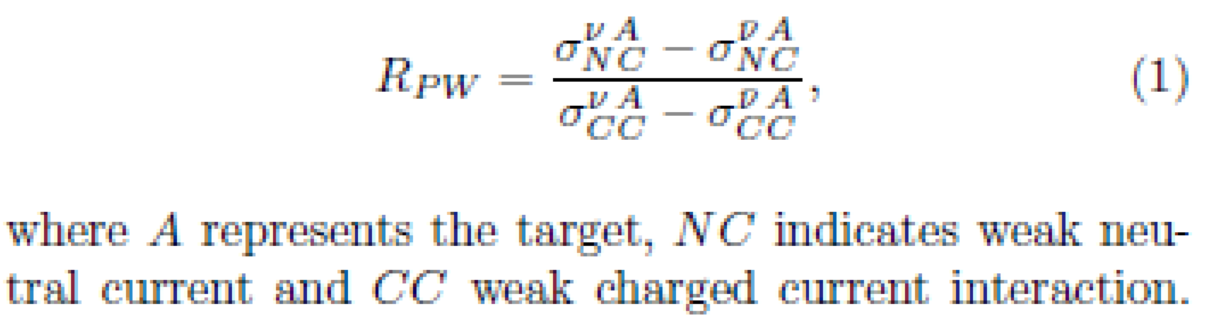
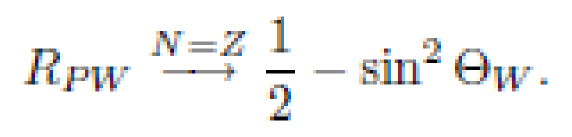


$$R_{PW} = \frac{\sigma_{NC}^{\nu A} - \sigma_{NC}^{\bar\nu A}}{\sigma_{CC}^{\nu A} - \sigma_{CC}^{\bar\nu A}}, \qquad (1)$$

where A represents the target, NC indicates weak neutral current and CC weak charged current interaction.



$$R_{PW} \xrightarrow{N=Z} \frac{1}{2} - \sin^2\Theta_W.$$

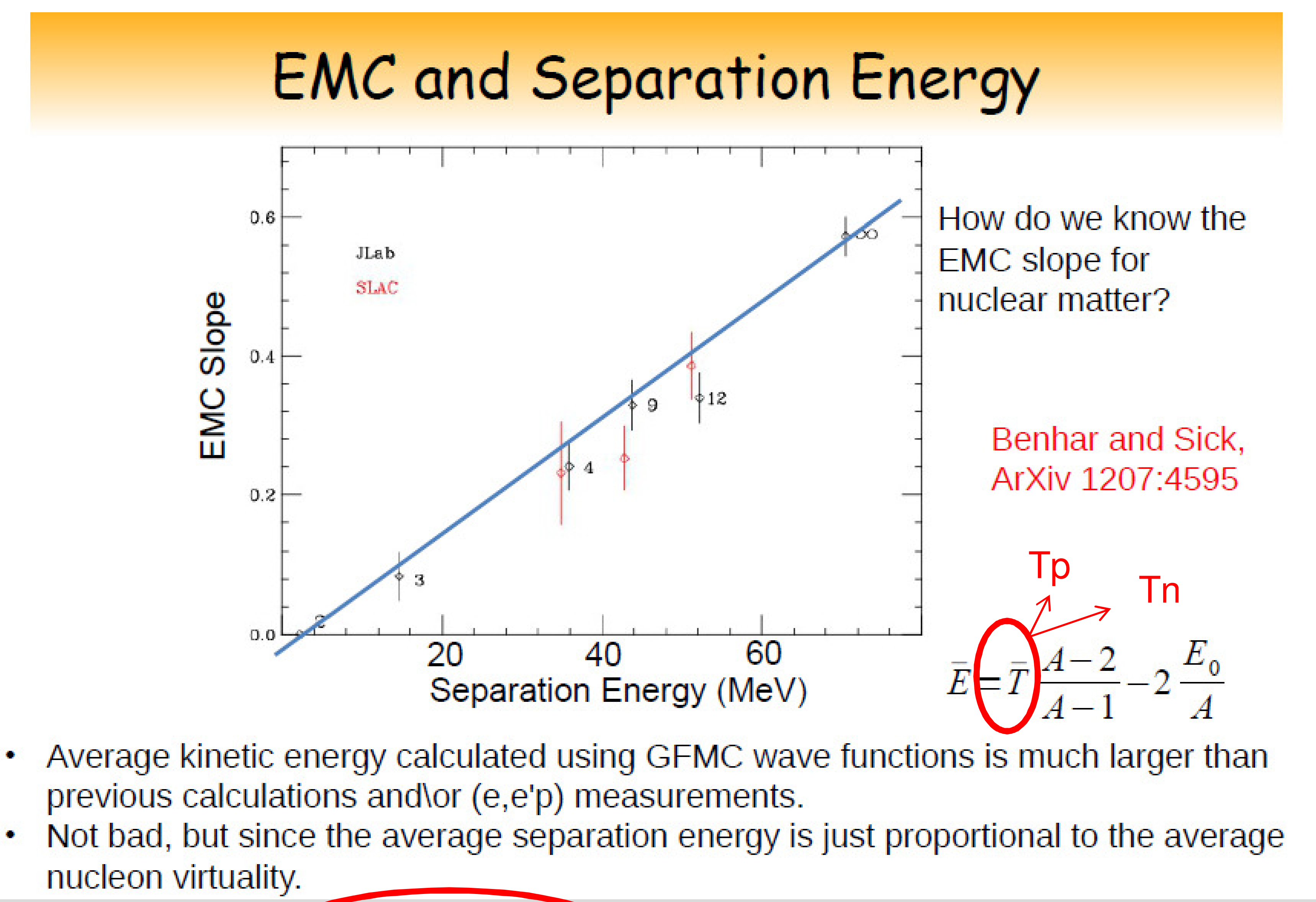
NuTev collaboration extracted fro iron:

$$\sin^2\Theta_W = 0.2277 \pm 0.0013(\text{stat.}) \pm 0.0009(\text{syst.}).$$

Which is 3 σ different from the word average.

Work above claimed that an isospin-dependent EMC effect, larger for u-quark than for d-quark can solve this discrepancy.

consequences: isospin dependence of the EMC effect



EMC and Separation Energy

How do we know the EMC slope for nuclear matter?

Benhar and Sick, ArXiv 1207:4595

$$\bar{E} = \bar{T}\,\frac{A-2}{A-1} - 2\,\frac{E_0}{A}$$

- Average kinetic energy calculated using GFMC wave functions is much larger than previous calculations and\or (e,e'p) measurements.
- Not bad, but since the average separation energy is just proportional to the average nucleon virtuality.

Protons ≠ neutrons

consequences: implication for neutron stars

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- **At the core of neutron stars, most accepted models assume :**

~95% neutrons, ~5% protons and ~5% electrons (β-stability).

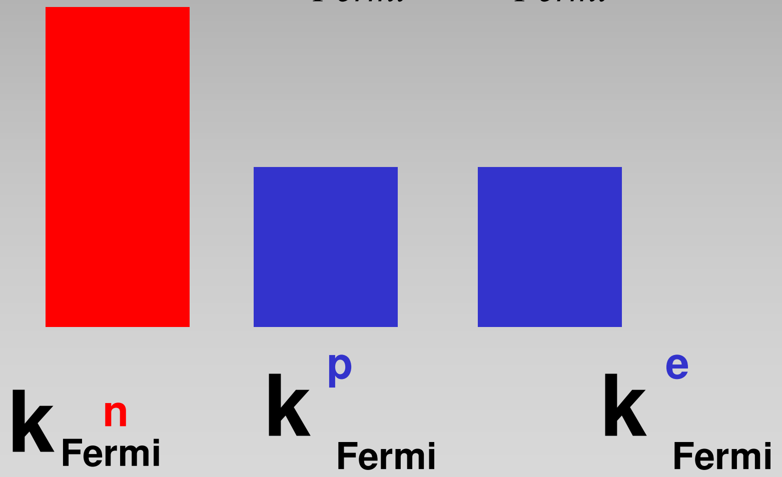
- **Neglecting the np-SRC interactions, one can assume three separate Fermi gases (n p and e).**

At T=0 $$k^n_{Fermi} = k^p_{Fermi} + k^e_{Fermi}$$ $$k^p_{Fermi} = k^e_{Fermi} = (\frac{N_p}{N_n})^{1/3} k^n_{Fermi}$$

For $$\rho = 5\rho_{0,}\ \ k^n_{Fermi} \approx 500\,\mathrm{MeV/c},\ \ k^p_{Fermi} = k^e_{Fermi} \approx 250\,\mathrm{MeV/c}$$

Pauli blocking prevent
direct n decay

$$n \to p + \mathrm{e} + \overline{\nu}_{\mathrm{e}}$$



What happen at T≠0 with a strong SR np interaction ?

consequences: Asymmetric ultracold Fermi gas mixtures in traps

Allow "quantum simulation" of asymmetric nuclei and neutron stars With a control over the asymmetry level ,and the interaction strength.

What are the properties of a spin polarized unitary Fermi gas?
Aurel Bulgac

I thanks the organizers for a great workshop at a wonderful location

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