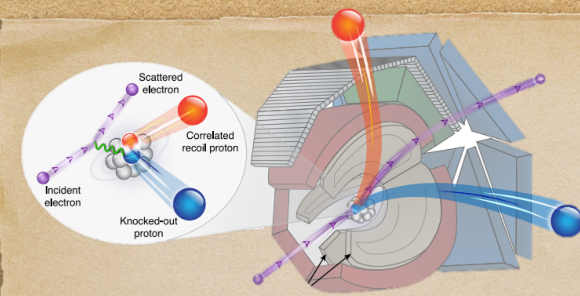
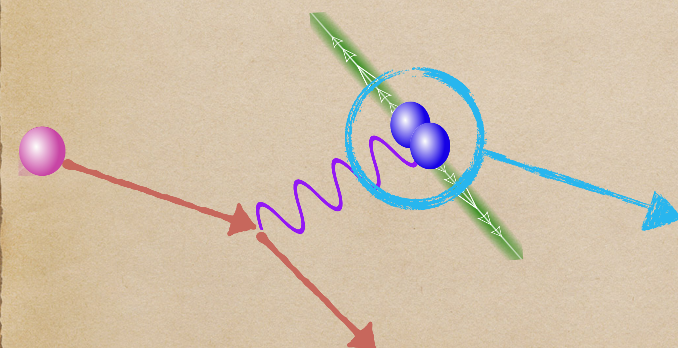



# pp-SRC c.m. motion

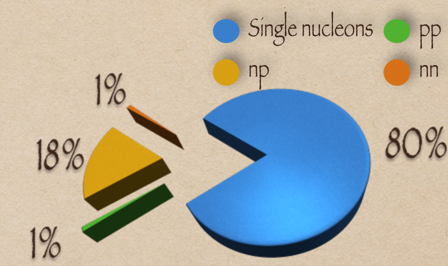


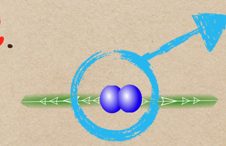
Erez. O. Cohen,
Or Hen,
Eli Piasetzky,
Meytal Duer,
Igor Korover
Tel Aviv University

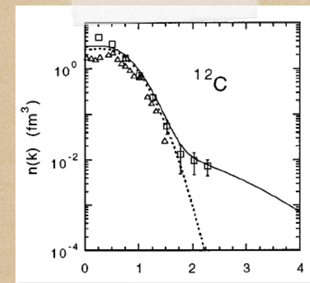
Int. Workshop on Exp. and Theo. topics in CLAS Data-Mining
Buffalo (NY), July-28, 2015

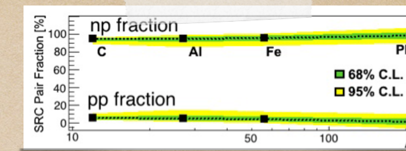
# OUTLINE

- Motivation
  - 2N-SRC.
  - Exclusive 2N-SRC study
  - The ground state picture of pp-SRC.
- EG2 analysis of pp-SRC.
- Acceptance correction and work under way.

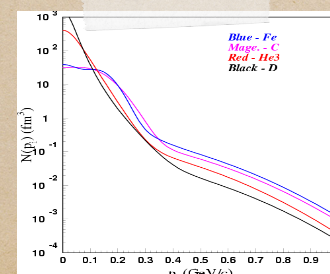


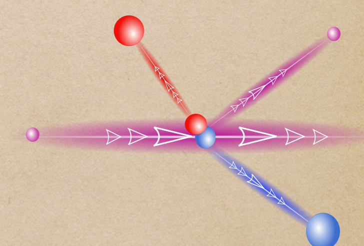




$^{12}$C
n(k) (fm$^3$)
10$^0$
10$^{-2}$
10$^{-4}$
0 1 2 3 4


np fraction
pp fraction
SRC Pair Fraction [%]
C
Al
Fe
Pb
68% C.L.
95% C.L.
10 50 100
A

# Motivation


Blue - Fe
Mage. - C
Red - He3
Black - D
N(p) (fm$^3$)
p (GeV/c)

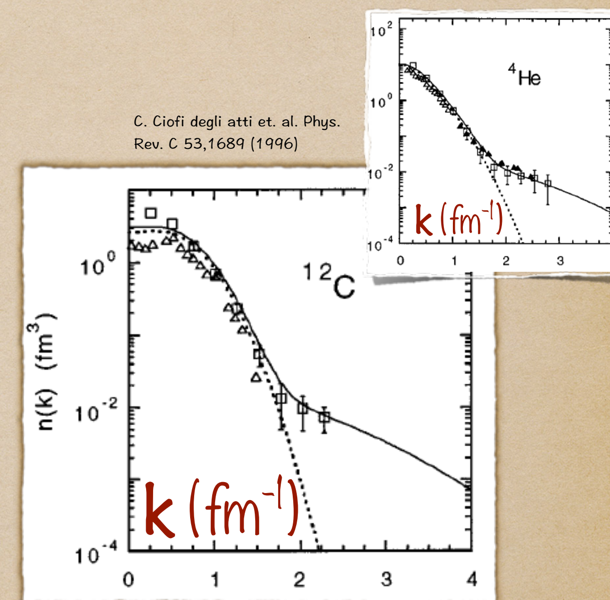


# Nucleon momentum distributions

- IPM do not produce enough high-momentum nucleons.
- Including correlations shifts strength from low to high momentum.

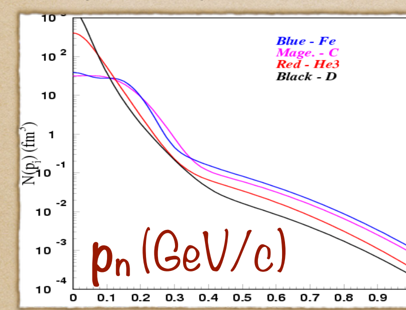
☞ **correlations build high-momentum tail.**

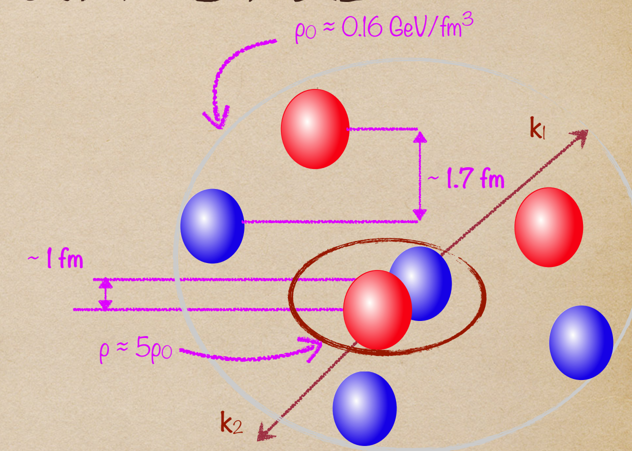
C. Ciofi degli atti et. al. Phys. Rev. C 53,1689 (1996)



# What is 2N-SRC

C. Ciofi degli atti et. al. Phys. Rev. C 53,1689 (1996)




- Large relative & Small c.m. momentum(w.r.t Fermi).
- High momentum part has the same shape for all nuclei (Scaling)

$$n_A(k) = a_2(A,Z) \cdot n_2(k), \quad for\ k > k_F$$

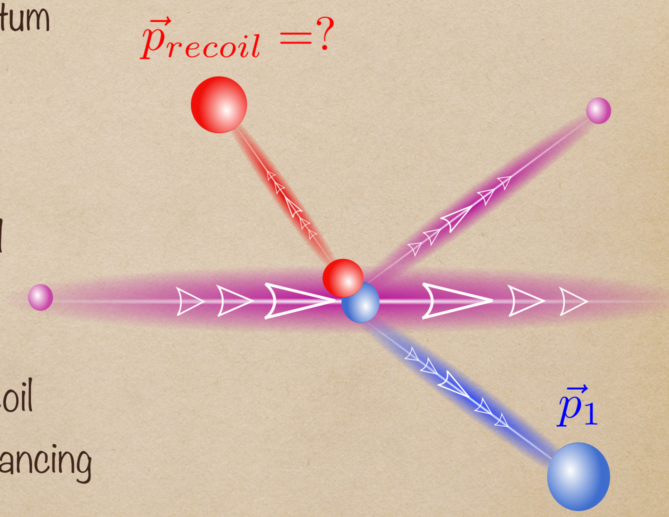
$$|\vec{k}_1 + \vec{k}_2| < k_F$$

$$|\vec{k}_1|, |\vec{k}_2| > k_F$$

$$\vec{k}_1 \simeq -\vec{k}_2$$

# Exclusive 2N-SRC studies

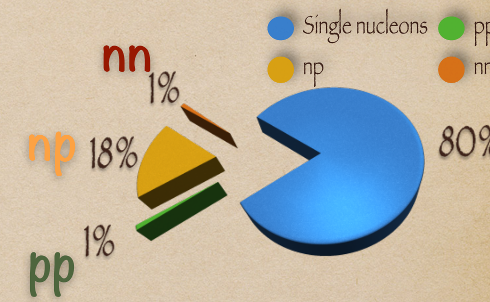
- Knock out of high-momentum proton.
- Reconstruct the initial momentum of the knocked proton.
- Look for emission of a recoil proton with momentum balancing the struck proton.

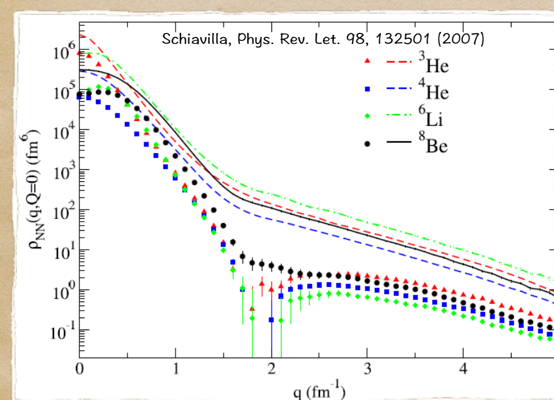



$$\vec{p}_{miss} = \vec{p}_1 - \vec{q}$$

# Previous results

- Exclusive $^{12}C(p,p'pn)$ and $^{12}C(e,e'pN)$ measurements probed the high-momentum tail of the nuclear wave-function.

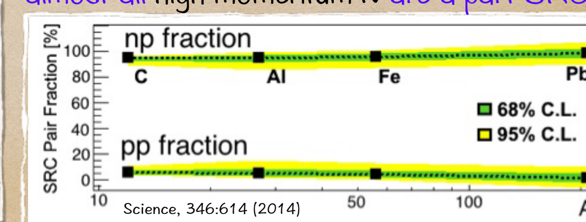


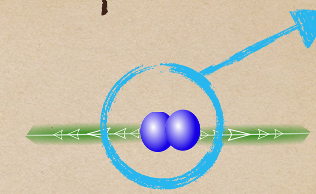

- Results show that for

$$0.3 < |p_{miss}| < 0.6 \text{ GeV/c}$$

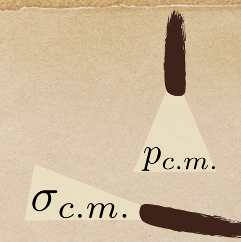
almost all high momentum N are a part SRC.



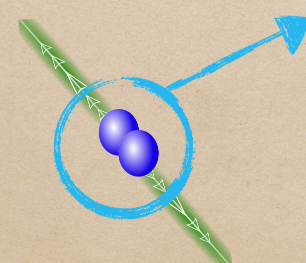
# c.m. motion of the 2N-SRC pair - Properties



- We expect c.m. momentum to be:
  - smaller than the typical momentum of a nucleon in a nucleus,
  - That it will depend on the quantum numbers of the pair,
  - That small c.m. is an important criterion to distinguish 2N- from 3N- SRC.
- Goal of this work: extract the c.m. momentum of the pp-SRC pair.

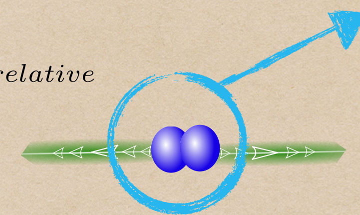



# The ground state picture of pp-SRC



# The g.s. picture of pp-SRC

$$\vec{p}_{miss} = \frac{\vec{p}_{c.m.}}{2} + \vec{p}_{relative}$$



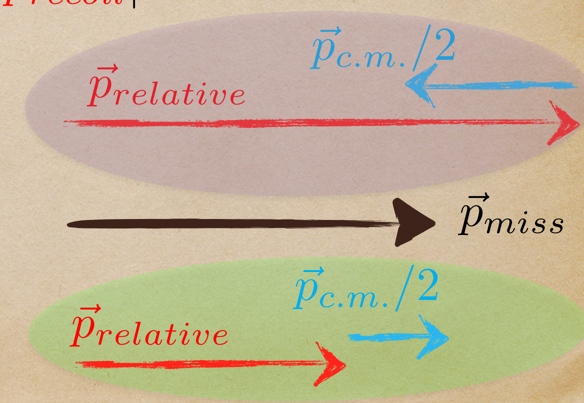
$$\vec{p}_{recoil} = \frac{\vec{p}_{c.m.}}{2} - \vec{p}_{relative}$$

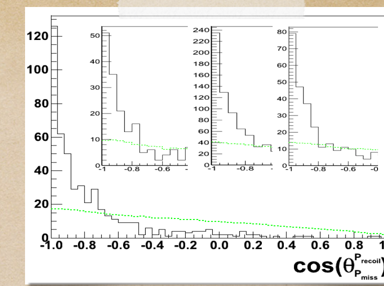
(Due to the **c.m. motion** of the pair)

$$|\vec{p}_{miss}| \neq |\vec{p}_{recoil}|$$

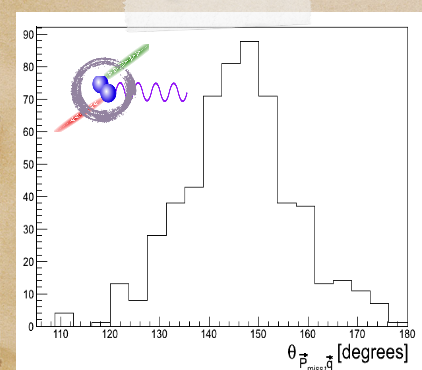
More likely to find a high $p_{miss}$ nucleon with

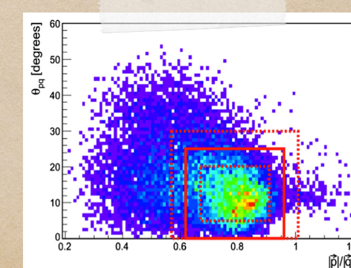
- $p_{relative}$ < | $\mathbf{p}_{miss}$ |.
- $\mathbf{p}_{c.m.}$ aligned in $\mathbf{p}_{miss}$ direction.






# EG2 Analysis of pp-SRC



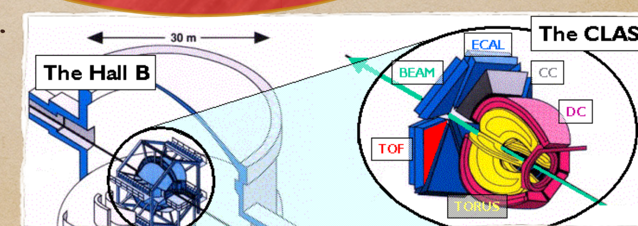



# EG2 experiment

- 2004 at Hall-B, JLAB.
- 5 GeV e-beam.
- Target - D + solid foils (simultaneously):

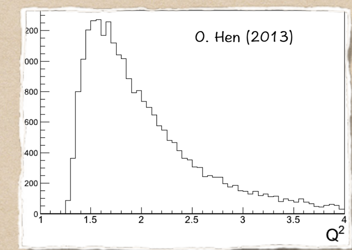
$^{2}H$ + $^{12}C$/$^{27}Al$/$^{56}Fe$/$^{208}Pb$.

Q: Was the beam energy 5.009 GeV at EG2 experiment?



# (e,e'p) SRC event selection

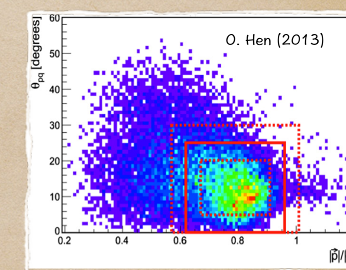
- Kinematics

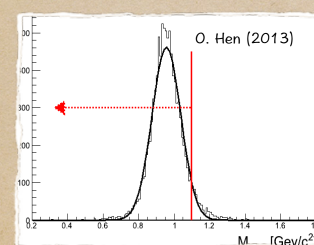



  - $x_B > 1.2$
  - $1000 > |\mathbf{p}_{miss}| > 300$ MeV/c

[ $Q^2 > 1.5$ (GeV/c)$^2$ ]

- Leading proton
  - $\theta_{pq} < 25^0$
  - $0.62 < |\mathbf{p}|/|\mathbf{q}| < 0.96$



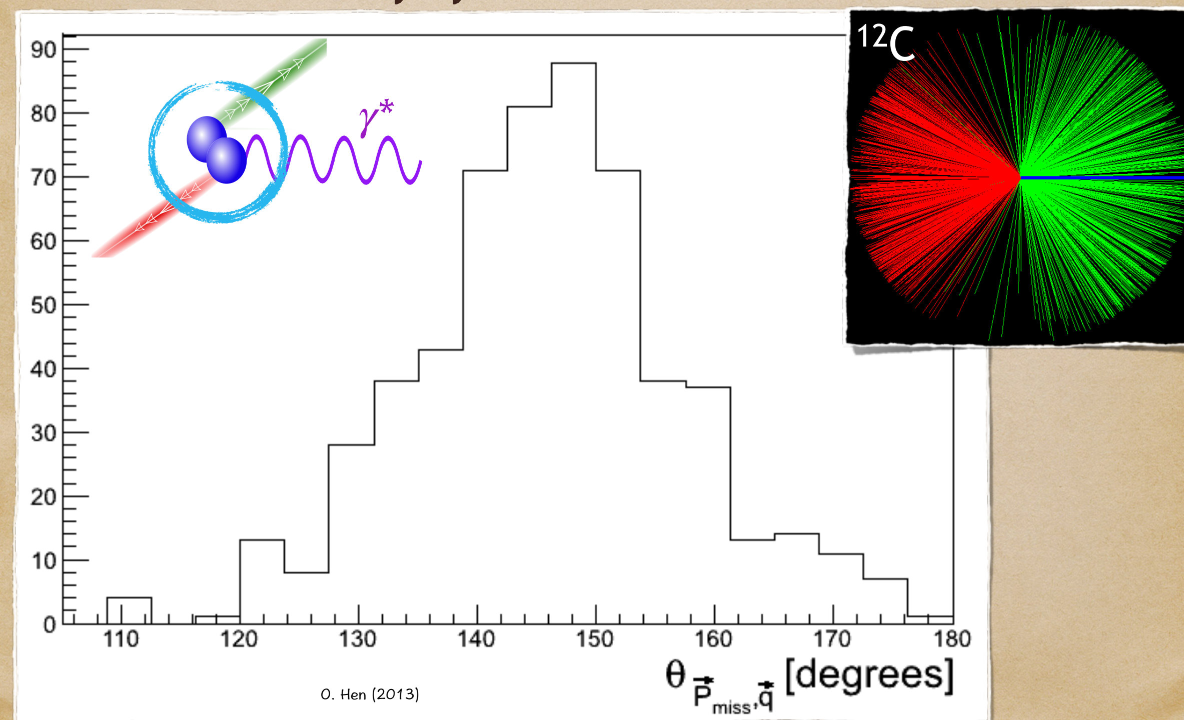




- Missing Mass
  - $M(miss) < M(N) + M(\pi)$

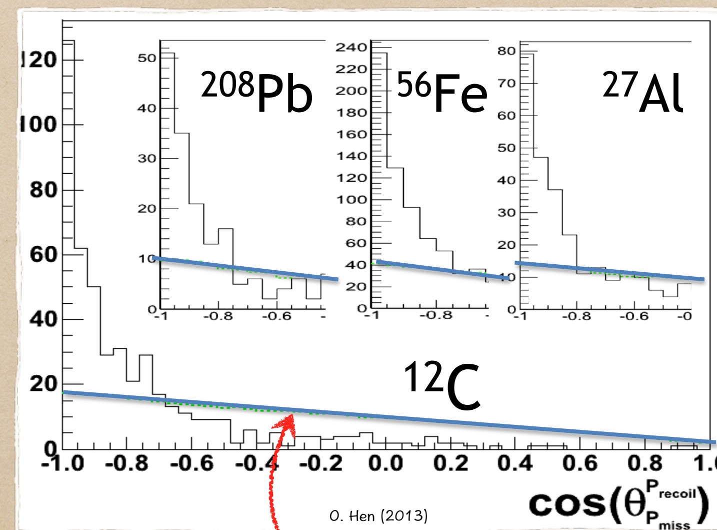
# (e,e'pp) event selection

- (e,e'p) events, in which a recoil proton is detected with momentum > 350 MeV/c

# (e,e'pp) kinematics

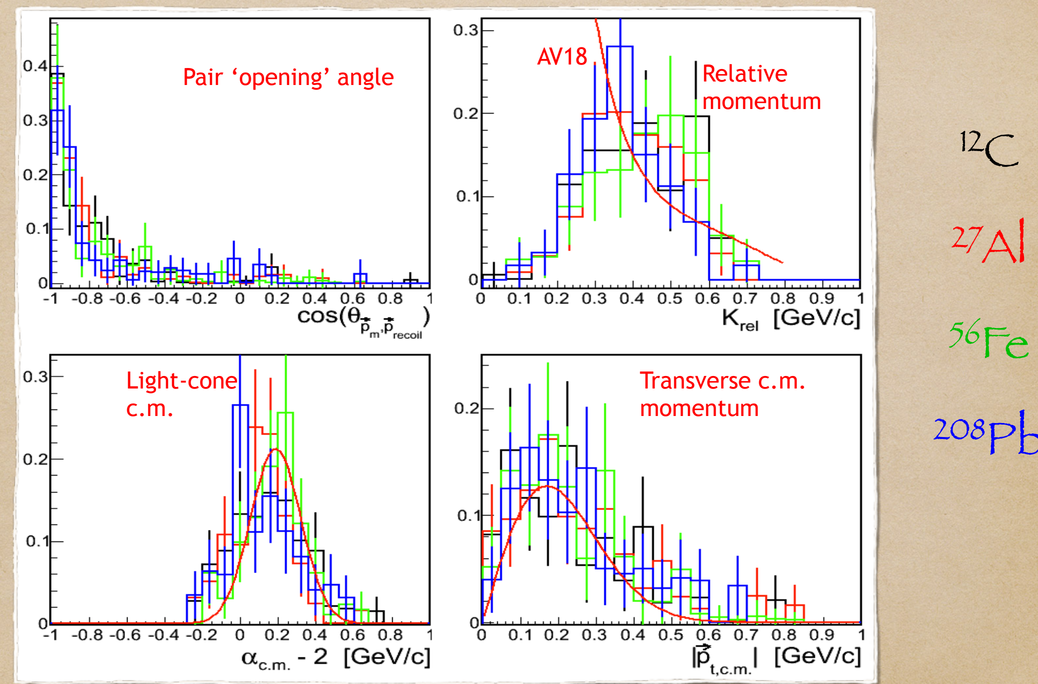


# Opening angle




Mixed Events "phase-space"

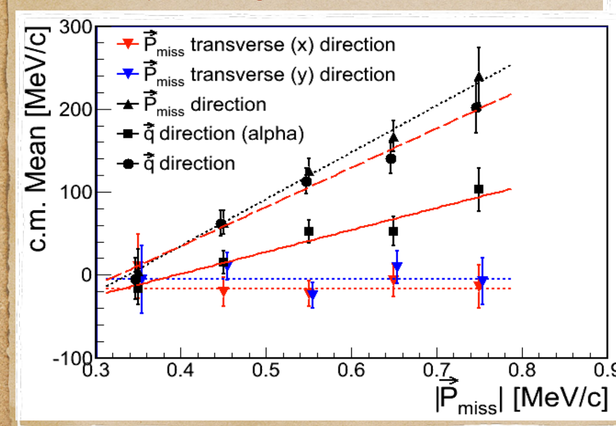
# LC analysis - pp-pair motion

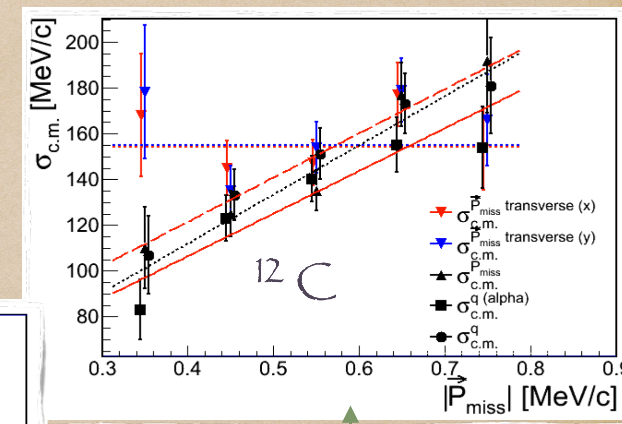


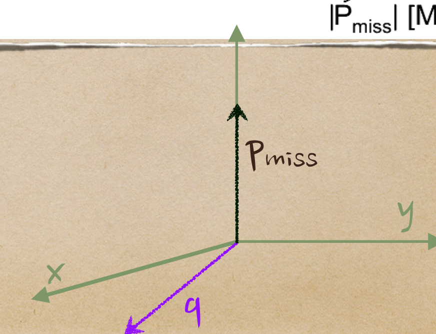

**NOT CORRECTED FOR ACCEPTANCE YET**

# EG2 Analysis results

- width of $|\mathbf{p}_{c.m.}|$.
- shift along $\mathbf{p}_{miss}$ / $\mathbf{q}$ direction.

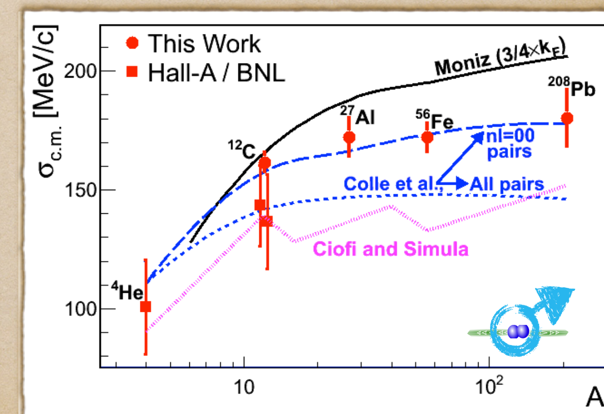


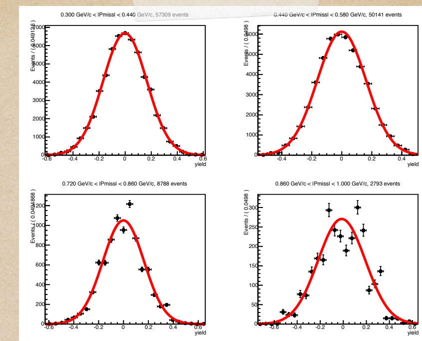



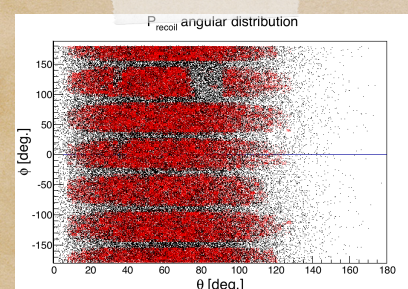
# Conclusions from the results

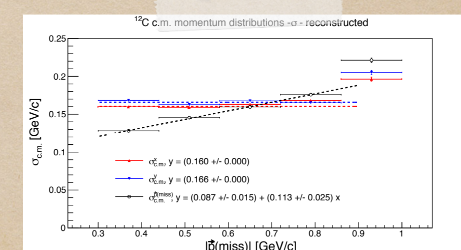
- The c.m. motion is smaller than the momentum of a typical nucleon in the nucleus .
- The c.m. motion corresponds with the assumption that the pair is from the same shell with relative quantum numbers **n=0 and l=0**.






# Acceptance correction



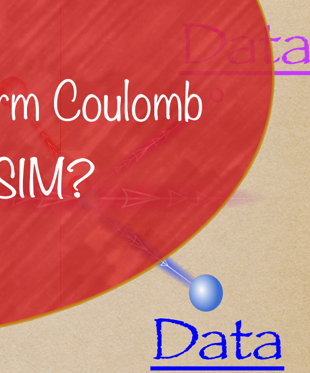



# Aiming for pair momentum dist.

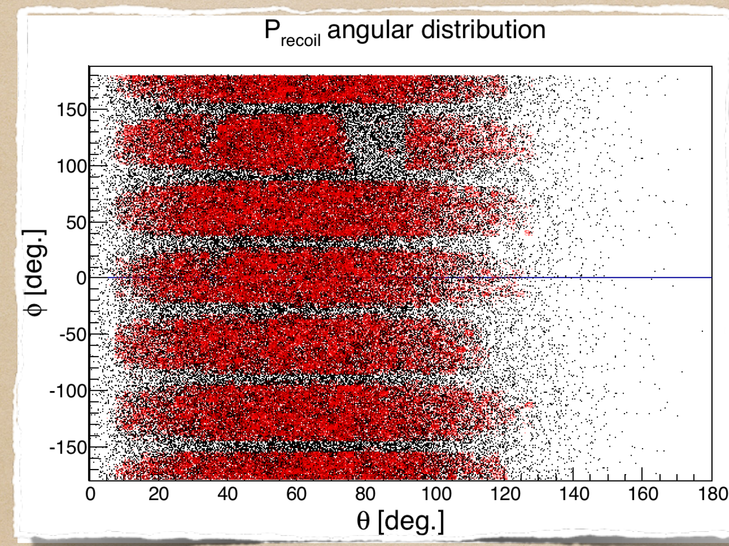
- To get the momentum distribution we need to correct for CLAS phase-space and cuts biasing
- Strategy:
  - Take SRC (e,e'p) data.
  - Move to q-frame and generate c.m. motion.
  - Generate a recoil proton according to this c.m.
  - Run GSIM with the (e,e'pp) events.

😷

Q: Do We need to perform Coulomb correction post GSIM?



# Generated recoil proton falls mostly in the fiducial region due the back-to-back correlation



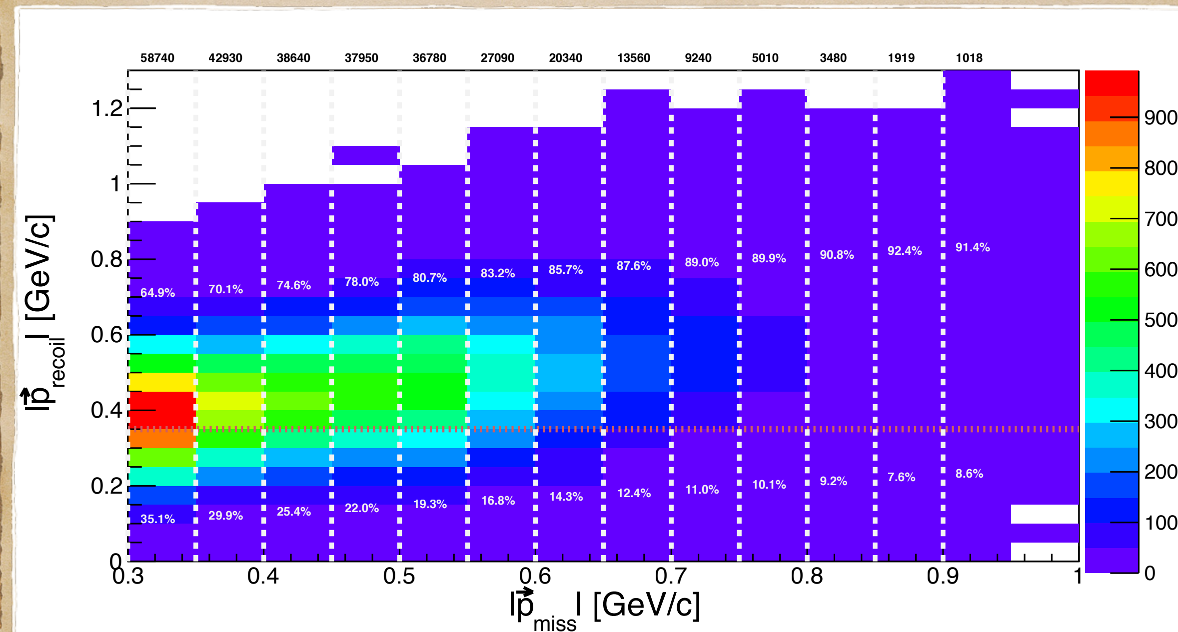

Generated

Accepted

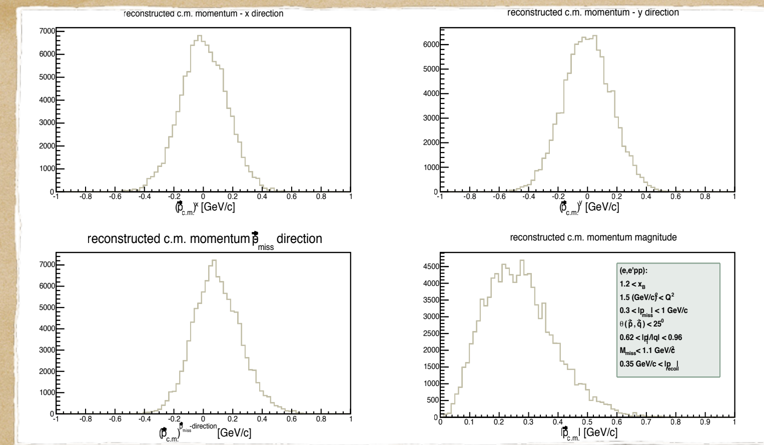
SRC(e,e'p) already does selection for the recoil:

$\mathbf{p}_{lead}$ is accepted - and so $\mathbf{p}_{recoil}$ is accepted

# $p_{miss}$ - $p_{recoil}$ relation in the EG

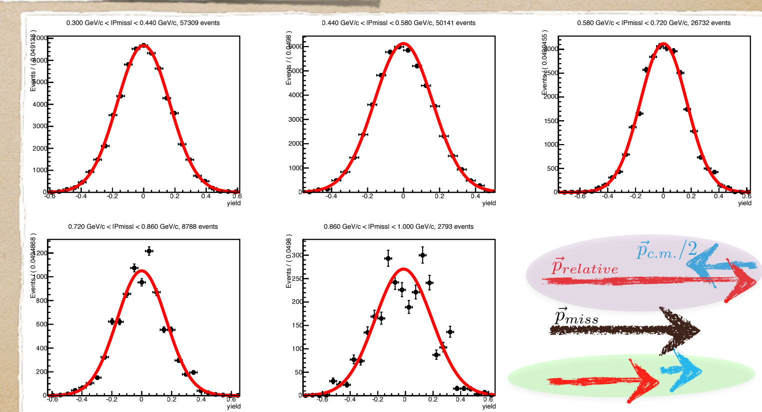



The effect of $p_{recoil}$ > 0.35 GeV/c cut will have more impact at the low $p_{miss}$

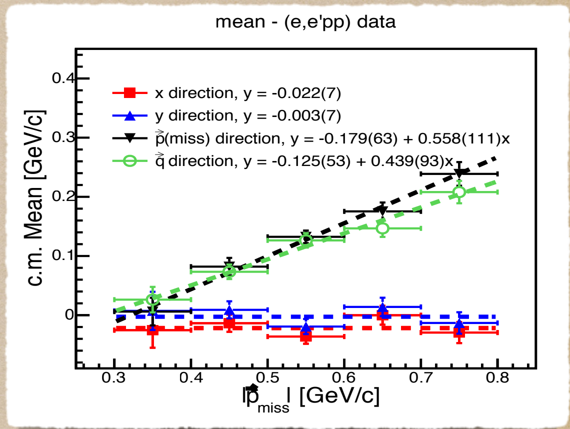


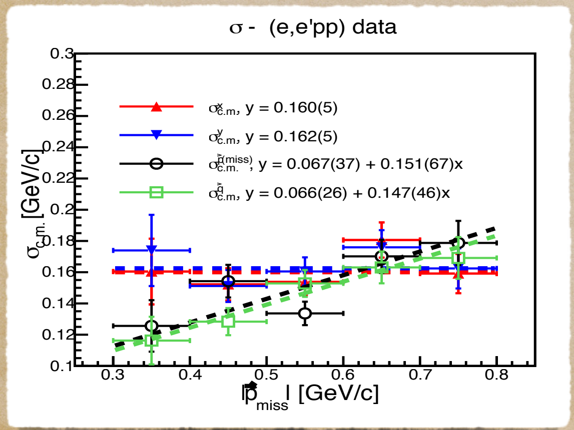

Match pp-SRC kinematical cuts in simulated data.

Divide the data into bins in $|p_{miss}|$

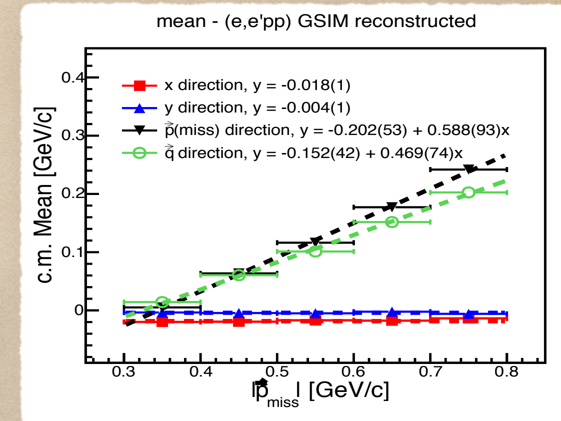


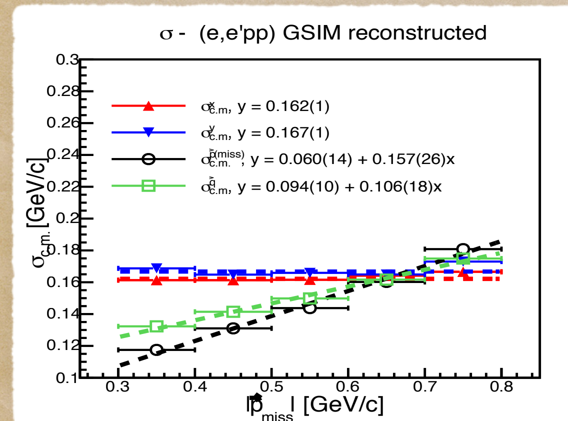
# (e,e'pp) data in bins of |$\mathbf{p}_{miss}$|



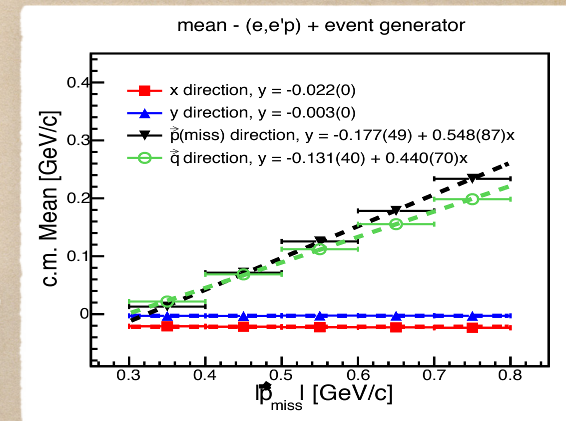
# GSIM (e,e'pp) reconstructed vs. $|p_{miss}|$

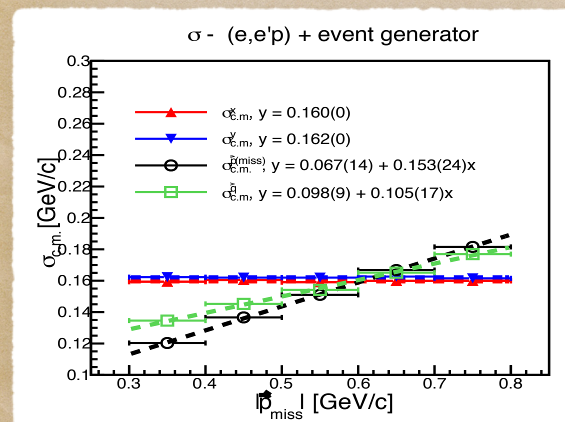



GSIMulation I do is reasonable

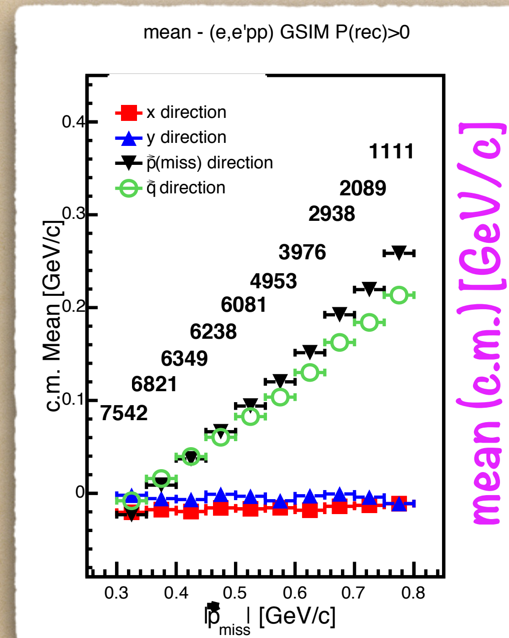
# GSIM (e,e'pp) genereted vs. |p$_{miss}$|



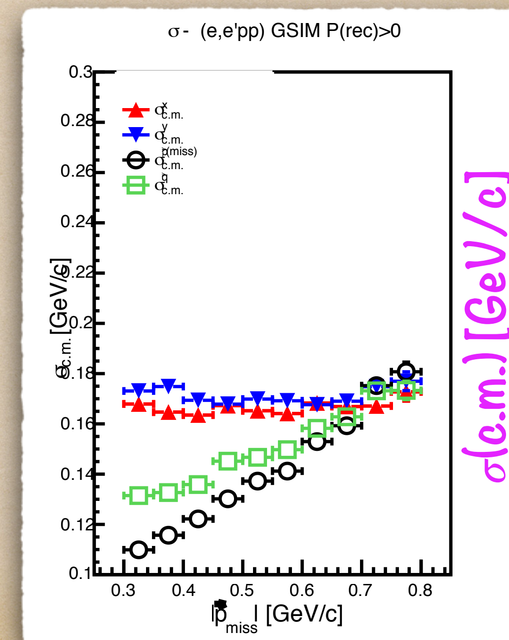




Acceptance has little effect

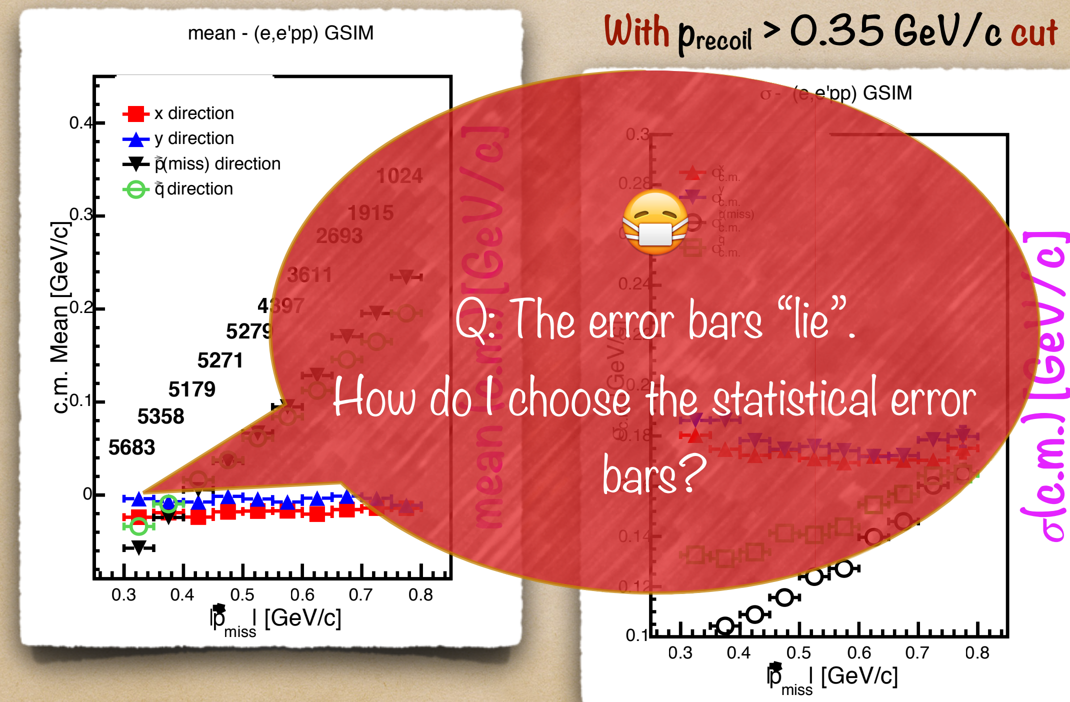
# However, there is acceptance effect




Without $p_{recoil}$ > 0.35 GeV/c cut

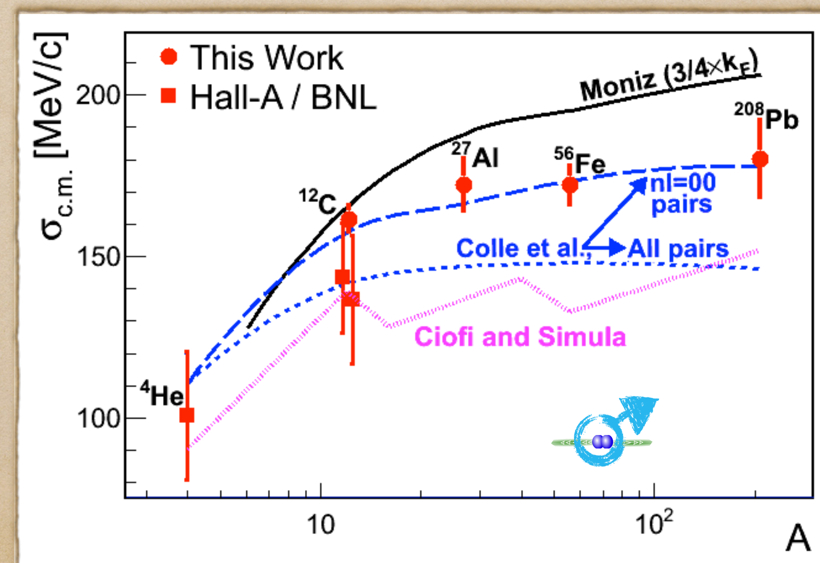


# However, there is acceptance effect



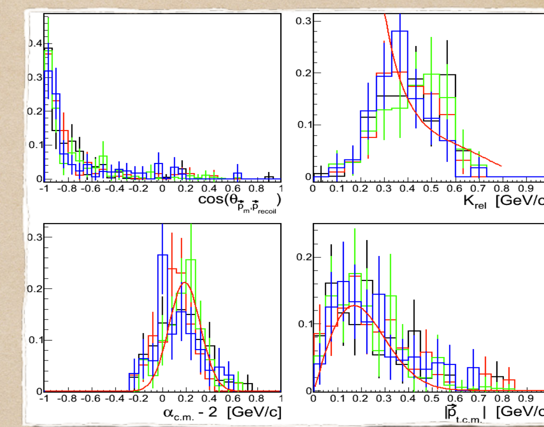
# Generated vs. GSIM reconstructed

We now need to get back to our results and apply the acceptance correction, but conclusions will be the same since the correction is small.



# Next steps

- pp-SRC pair distributions:
  - events Mott weighting.
  - Flux factor corrections.



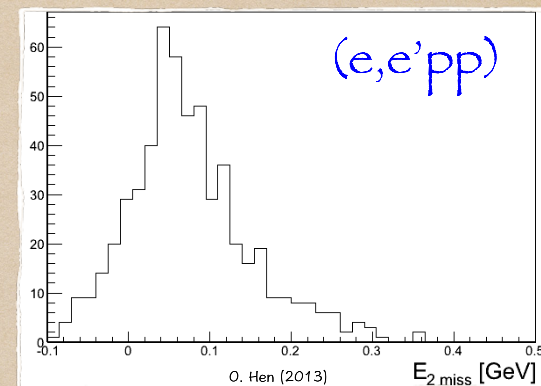

- Study the ratio of (e,e'pp)/(e,e'p) as a function of $p_{miss}$ is SRC kinematics (GSIMulation).

# Thank you for your time...

Comments/Suggestions/Questions:
cohen.erez7@gmail.com

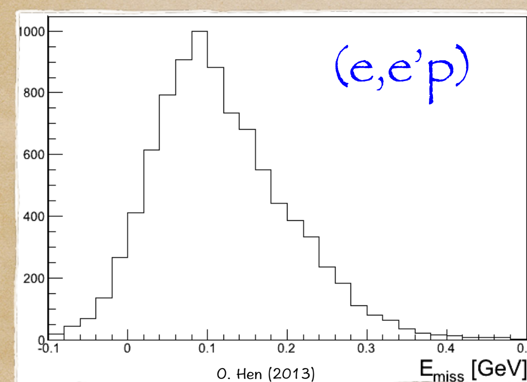
# Extra-slides

# Excitation energies



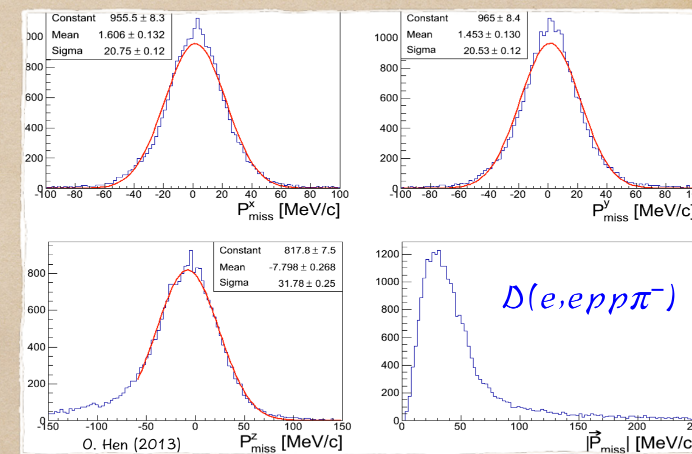

$$E_{2-miss} = \omega - T_{lead} - T_{recoil} - T_{A-2}$$

$$E_{miss} = \omega - T_p - T_{A-1}$$



# CLAS resolution contribution to width of c.m.

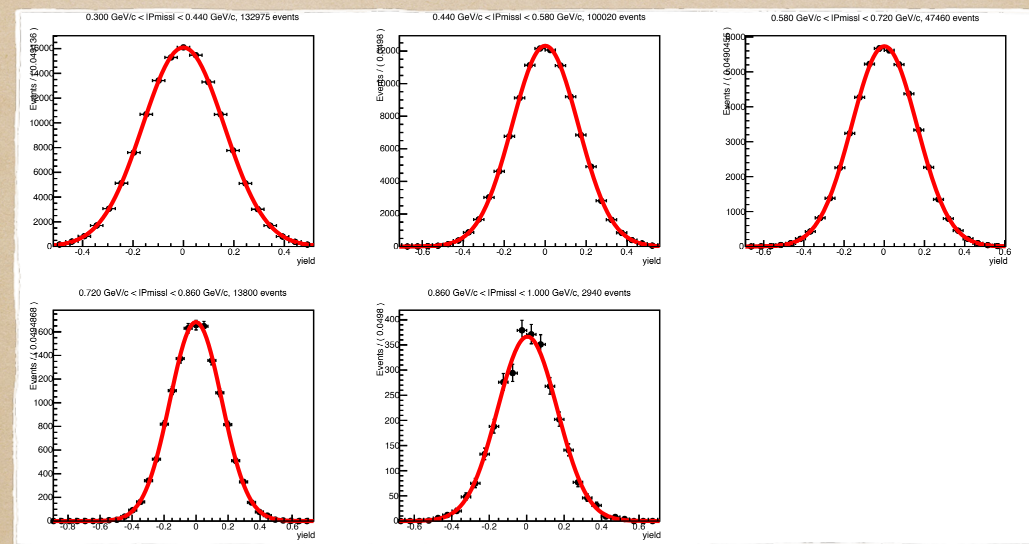
$$\sigma_{c.m.} = \sqrt{\sigma_{exp}^2 - \sigma_{res}^2}$$



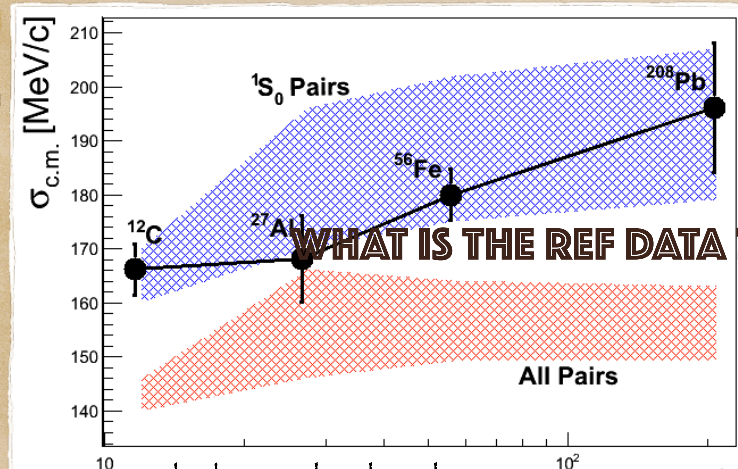

$\sigma_{res}$ ~ 20 MeV/c

☞ Correction ~ 3 MeV/c for $\sigma_{exp}$ ~ 160 MeV/c

# Using RooFit for un-binned fitting

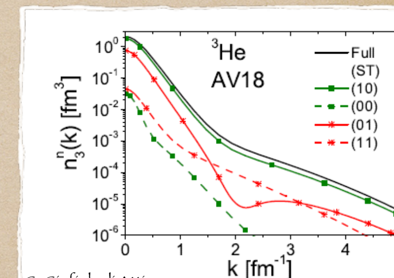


# C.M. motion width




calculations by the Ghent group

WHAT IS THE REF DATA ? PRELIMINARY BY OR?




C. Ciofi degli Atti

| nucleus | $\sigma_x$ [MeV/c] | $\sigma_y$ [MeV/c] |
|---|---|---|
| $^{12}$C | 169±7 | 164±6 |
| $^{27}$Al | 162±10 | 180±13 |
| $^{56}$Fe | 179±6 | 182±7 |
| $^{208}$Pb | 208±18 | 186±16 |

The spin-Isospin contribution to the momentum distribution

# Light cone

# Light-cone fraction study

$$\alpha = A\frac{E_p - p_z}{m_A}$$

- The Light-Cone fraction has less sensitivity to FSI.
- Goes together with the transverse momentum

flux calculated for the moving nucleon

$$\frac{d\sigma}{dE'_e d\Omega'_e d^3p_f d^3p_{rec}} = \frac{j_N}{j_A} A \sum_N \sigma_{eN}(p_f, k_e, k'_e) D^N(\vec{p}_m, E_m, \vec{p}_{rec})$$

Sargsian, Abrahamyan, Strikman and Frankfurt), Phys. Rev. C 71, 044615

electron - off-shell eN scattering

# 2N-SRC Decay function formalism

$$\frac{d\sigma}{dE'_e d\Omega'_e d^3p_f d^3p_{rec}} = \frac{j_N}{j_A} A \sum_N \sigma_{eN}(p_f, k_e, k' \ldots , E_m, \vec{p}_{rec})$$


The decay function is a convolution of two density matrices representing the relative and c.m. momentum distribution

$$D = \rho_{rel} \cdot \rho_{c.m.} \frac{\alpha_{rec}}{\alpha_{c.m.}} \times \delta\left(P_{R+} - \frac{m^2 - (p_{rec})_T^2}{m\alpha_{rec}} - \frac{M_{A-2}^2 + (p_{c.m.})_T^2)}{m(A - \alpha_{c.m.})}\right)$$

E. Piasetzky et al., Phys.Rev.Lett. 97 (2006) 162504

LC componenet of the residual A-1 nuclear state

# Light-cone fraction study

$$\alpha = A\frac{E_p - p_z}{m_A}$$

- Define the equivalents of detected, missing, c.m. and recoil light cone fraction of momenta

$$\alpha_{miss} = \alpha_{initial} = \alpha_{lead} - \alpha_q$$
$$\alpha_{c.m.} = \alpha_{miss} + \alpha_{rec}$$

Where $\alpha_q = \frac{\omega - |q|}{m}$

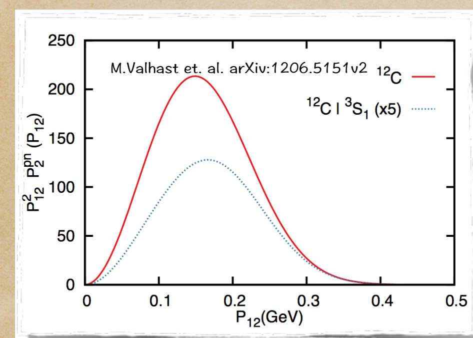
$$(p_{c.m.})_T = (p_{miss})_T + (p_{rec})_T$$
$$(p_{rel})_T = (p_{rec})_T - \frac{\alpha_{rec}}{\alpha_{c.m.}}(p_{c.m.})_T$$

# 2N-SRC Decay function formalism

$$\frac{d\sigma}{dE'_e d\Omega'_e d^3p_f d^3p_{rec}} = \frac{j_N}{j_A} A \sum_N \sigma_{eN}(p_f, k_e, k \ldots D^N \ldots E_m, \vec{p}_{rec})$$

E. Piasetzky et al., Phys.Rev.Lett. 97 (2006) 162504

$$D = \rho_{c.m.} \cdot \ldots \times \delta\left(P_{R+} - \frac{m^2 - (p_{rec})_T^2}{m\alpha_{rec}} - \frac{M_{A-2}^2 + (p_{c.m.})_T^2}{m(A - \alpha_{c.m.})}\right)$$




- The 2-body c.m. momentum distribution can be parametrized in terms of Gaussian distribution.

$$\rho_{rel}(\alpha_{rel}, (p_{rel})_T) = a_2(A/d)\frac{\psi_D^2(k_{rel})}{2 - \alpha_{rel}}\sqrt{m^2 + k_{rel}^2}$$

$$\rho_{c.m.}(\alpha_{c.m.}, (p_{c.m.})_T) = \frac{2m}{(2\pi\sigma_{c.m.}^2)} e^{-\frac{m^2(2-\alpha_{c.m.})^2 + (p_{c.m.})_T^2}{2\sigma_{c.m.}^2}}$$