Experimental Study of Short Range Correlation in ^4He

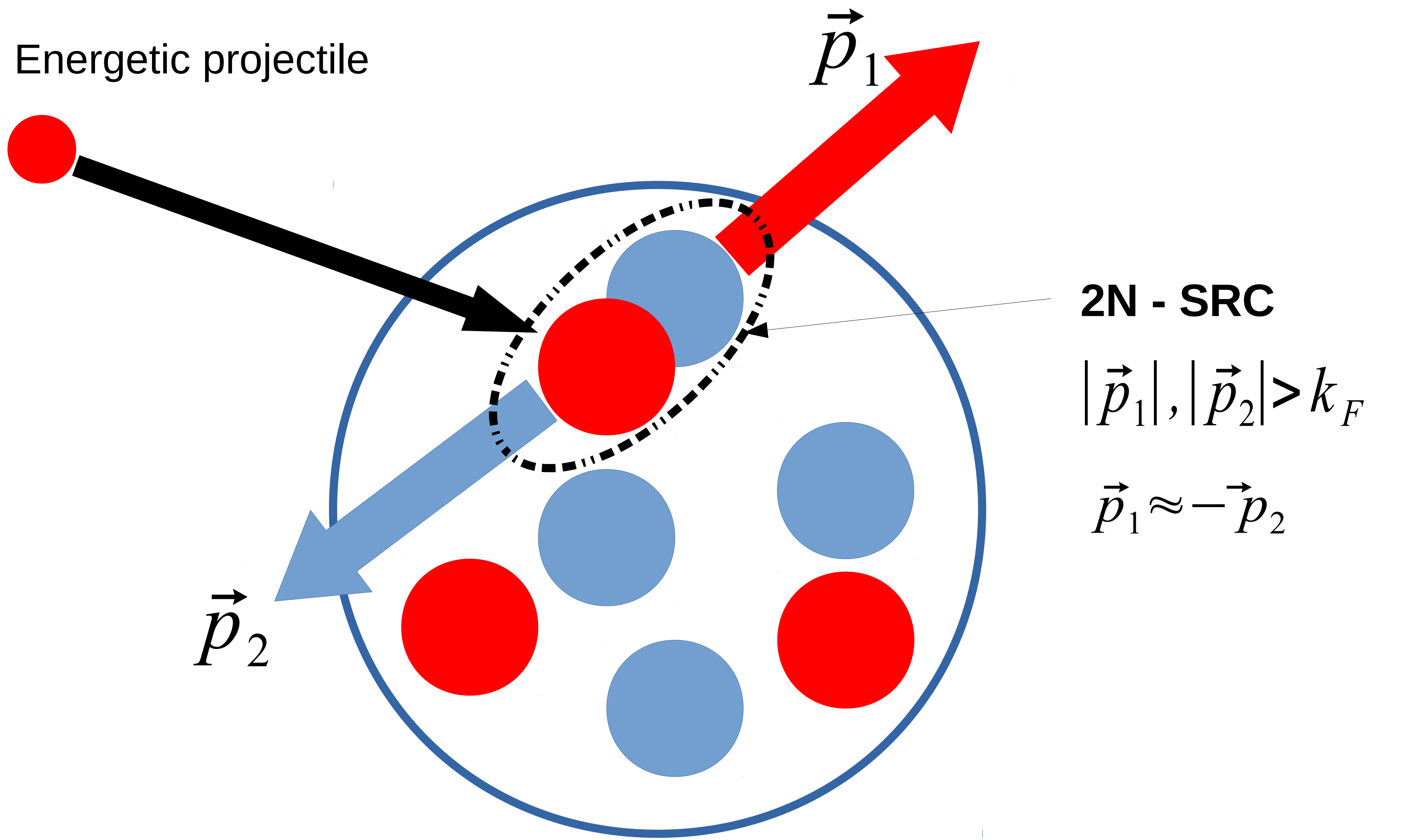
$^4He(e,e'pN)$

Igor Korover

EMMI Workshop: Cold dense matter:
from short-range nuclear correlations to neutron stars

October 16, 2015.
GSI, Germany

Triple coincidence measurement of Short Range Correlation

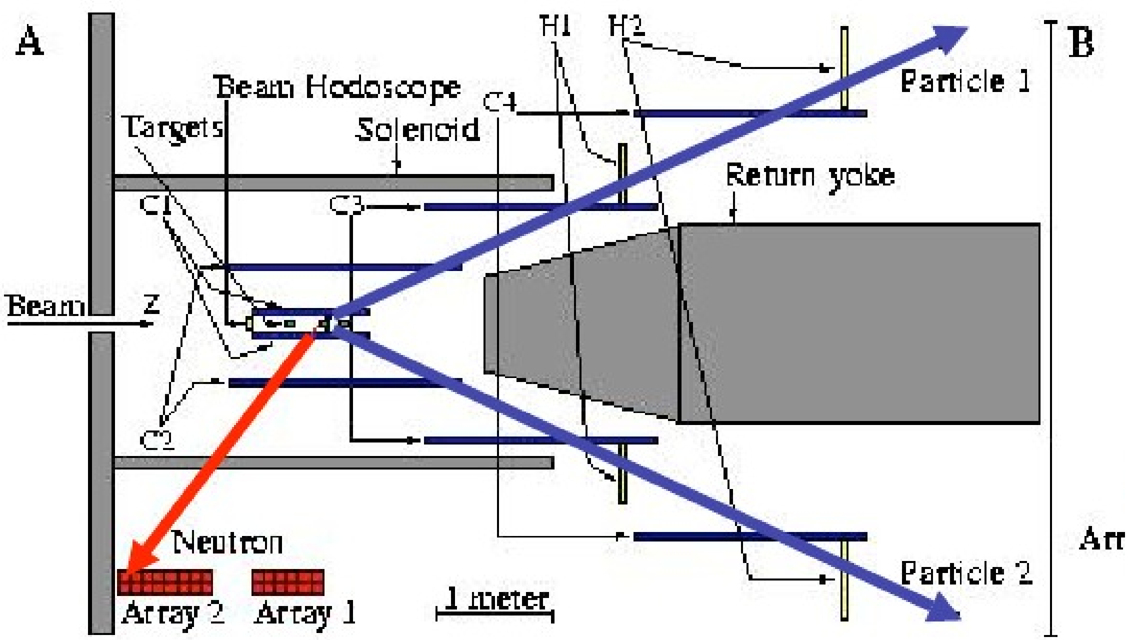


High energetic projectile probe small distances and disintegrate the SRC pair

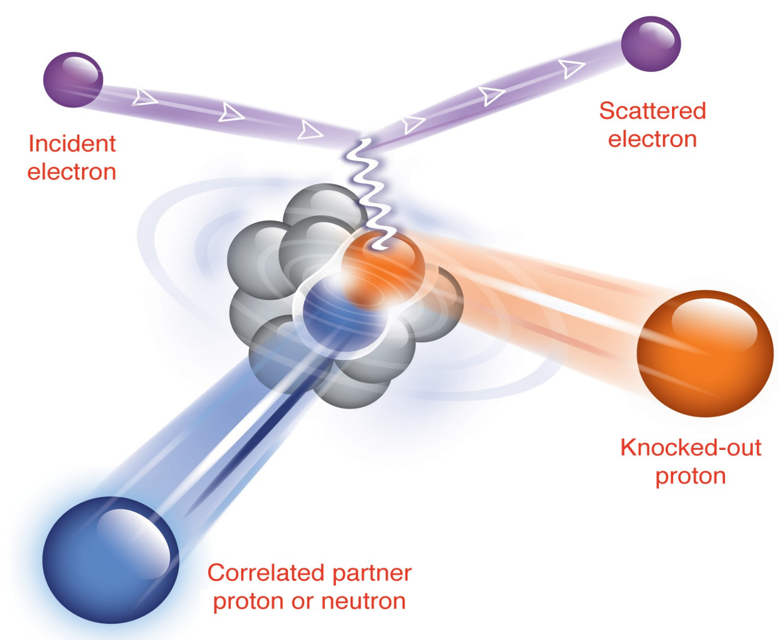
Previous triple coincidence experiments on ^{12}C target:

BNL (~1999) and Jefferson Lab (2004)

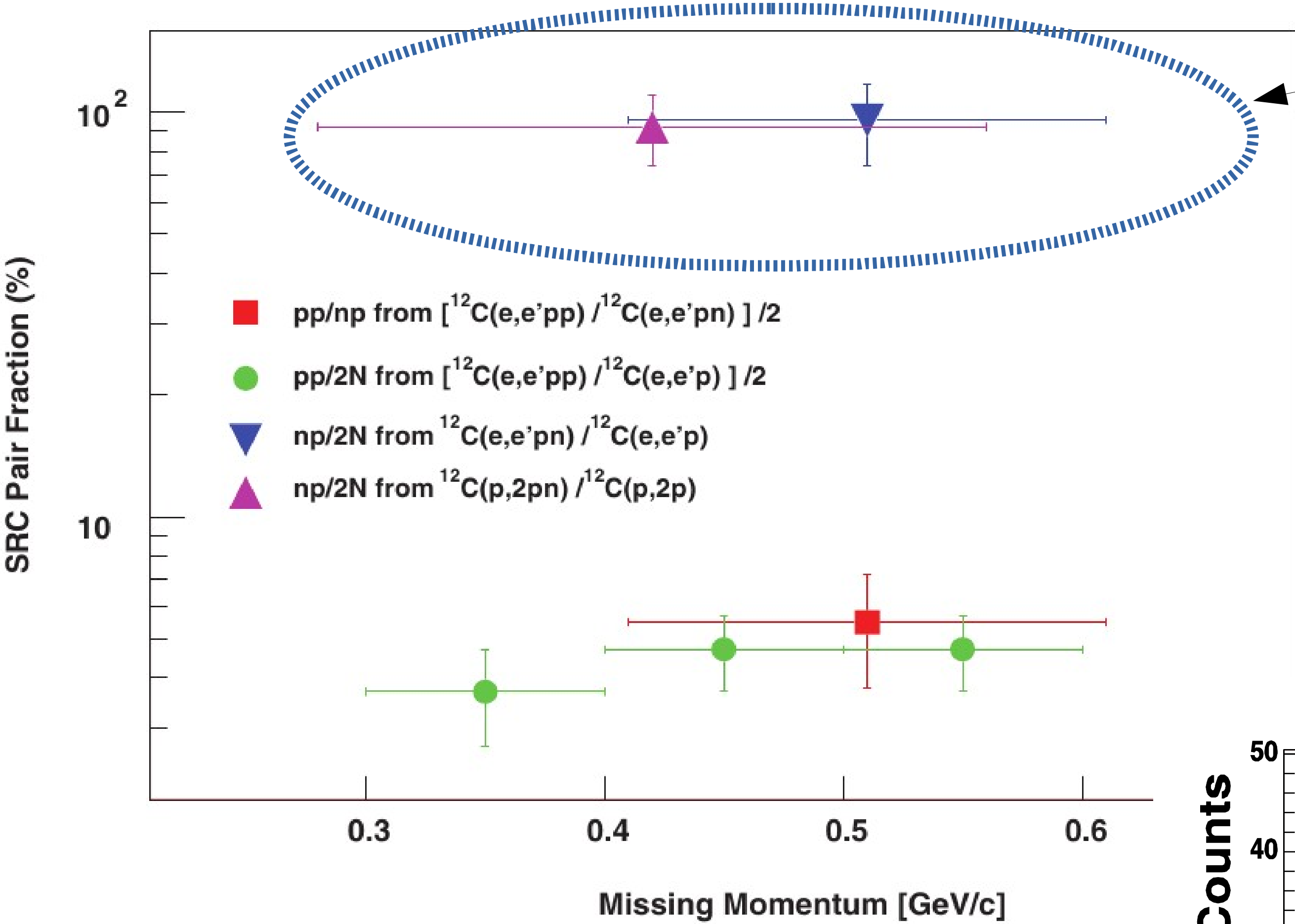
$^{12}C(p, 2pn)$



$^{12}C(e, e'pn)$



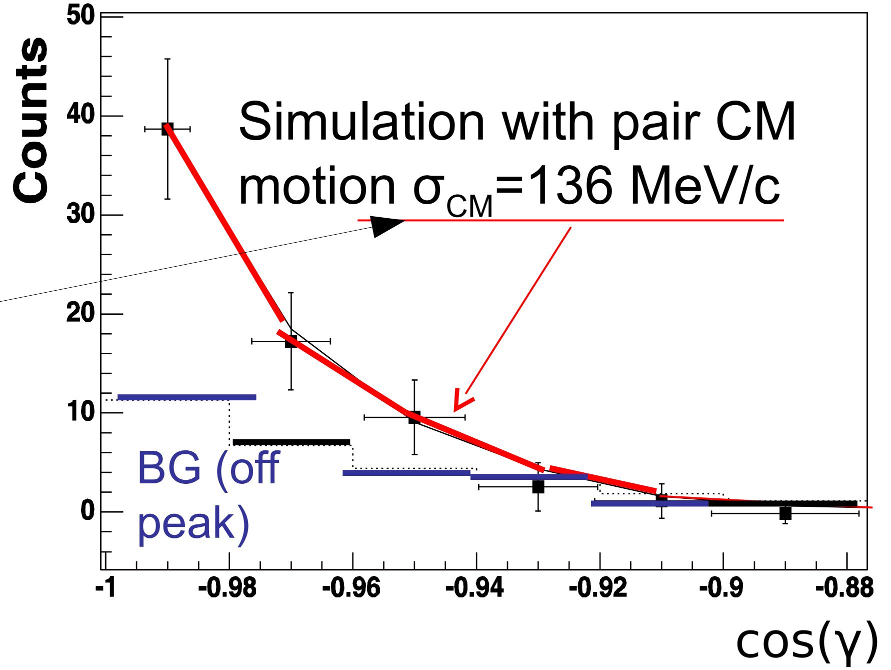
What is measured so far:



np – dominance

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

~20 times more np pairs than pp(nn) pairs



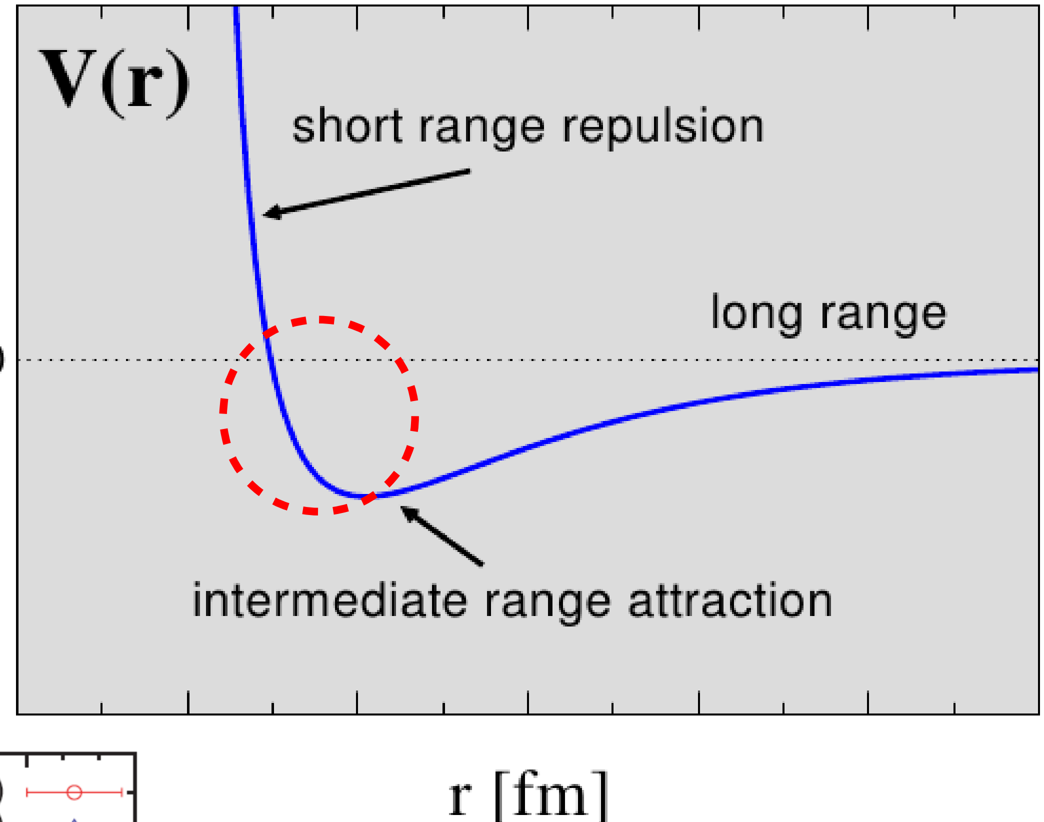
Low CM momentum of the pair

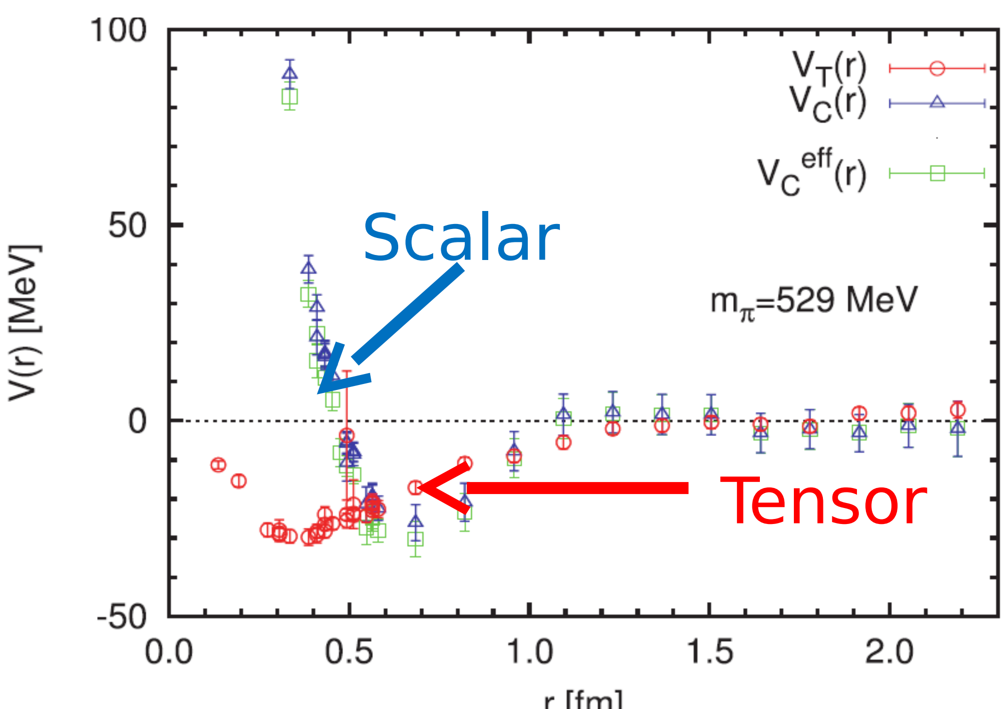
R. Shneor et al., Phys. Rev. Lett. **99**, 072501 (2007)

Why np dominance?

The dominant scalar part of NN potential → 0

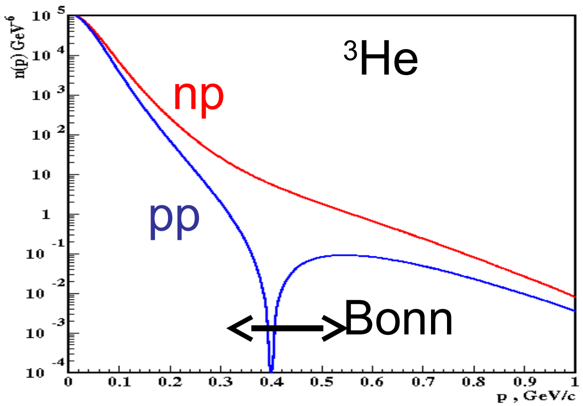
Tensor part dependent on Isospin of the 2N-SRC.



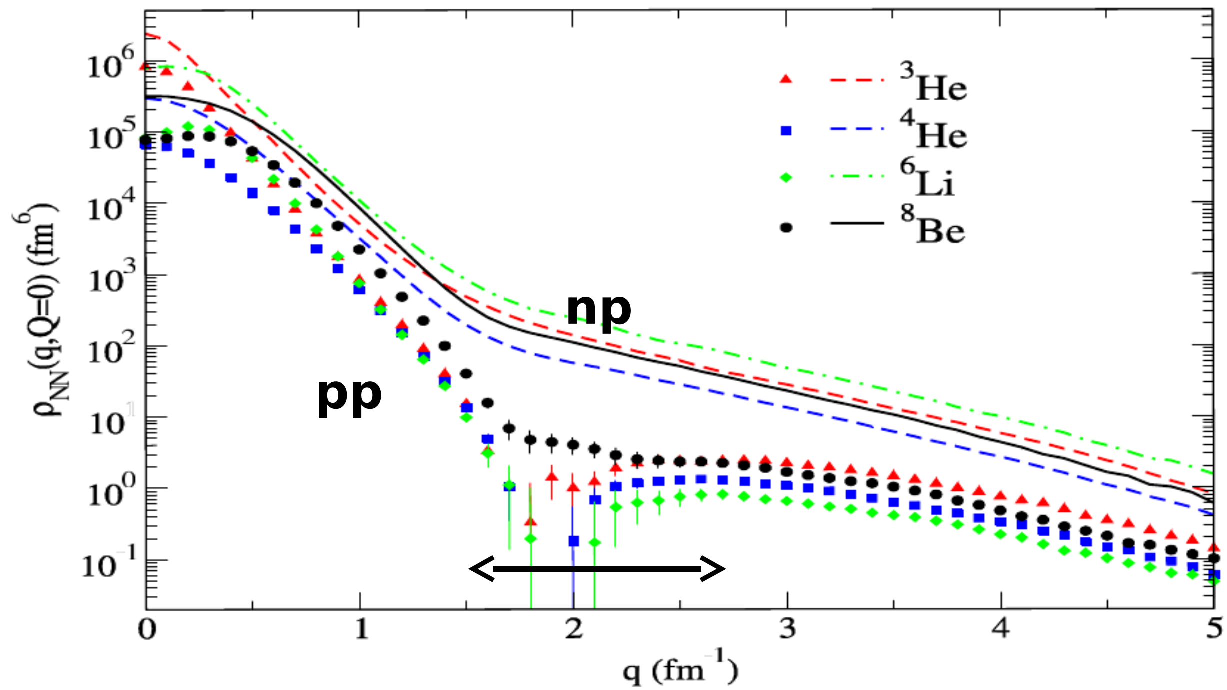


Prog. Theor. Exp. Phys. 2012, 01A105

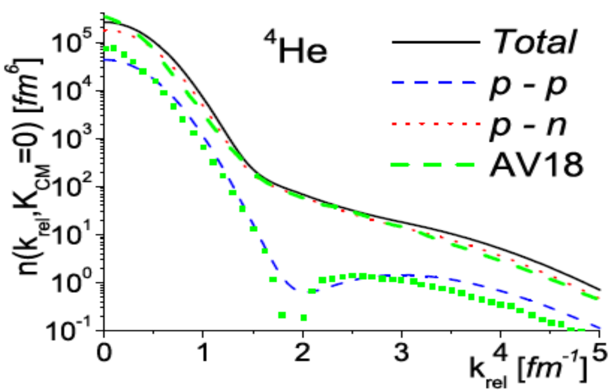
At 300-600 MeV/c there is an excess strength in the np momentum distribution due to the strong correlations induced by the tensor NN potential.



Sargsian, Abrahamyan, Strikman, Frankfurt Phys. Rev. C**71** 044615 (2005).



Schiavilla, Wiringa, Pieper, Carson, Phys. Rev. Lett. **98**,132501 (2007).



Ciofi and Alvioli
Phys. Rev. Lett. **100,** 162503 (2008).

<u>Motivation to new JLab experiment E07-006:</u>

Relative momentum, p ↑ → Expect:

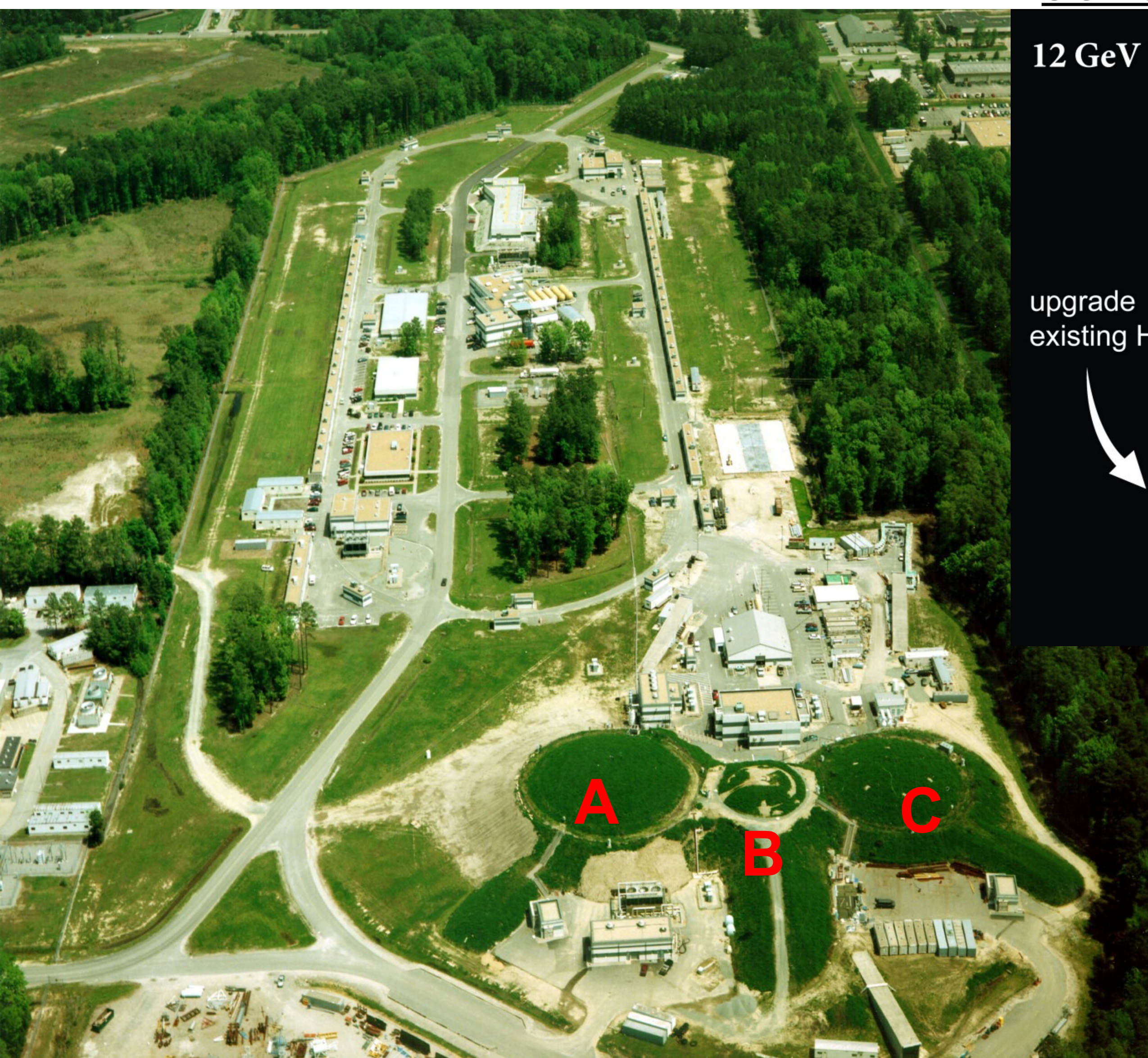
- Less np dominance
- Increase in number of pp pairs

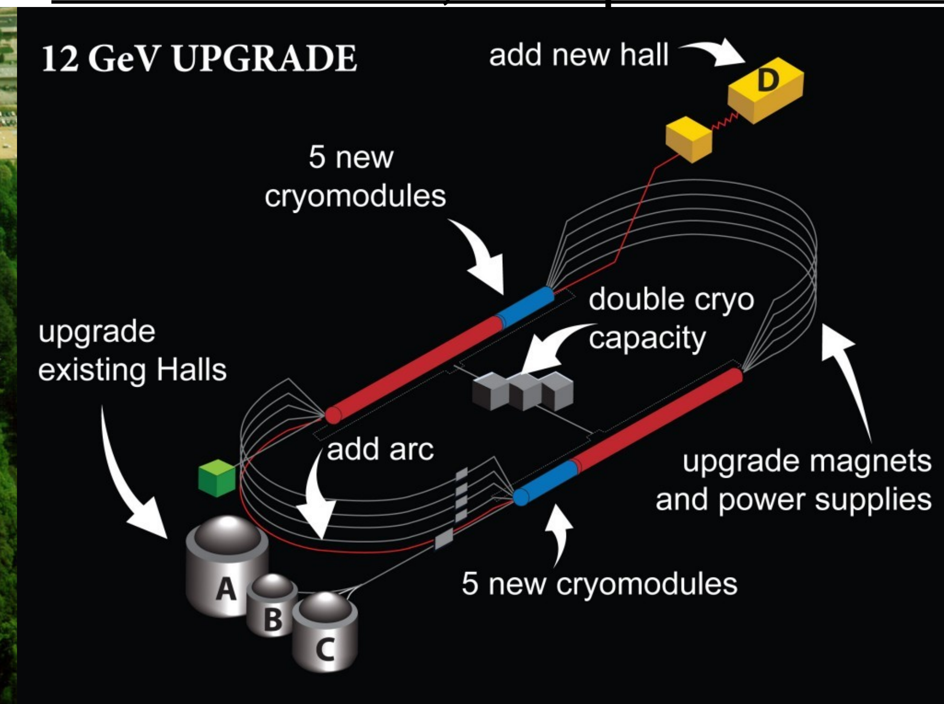
Experiment

January – May 2011.

6 GeV electron beam with maximum current of 200 µA.

Jefferson Lab, Newport News VA





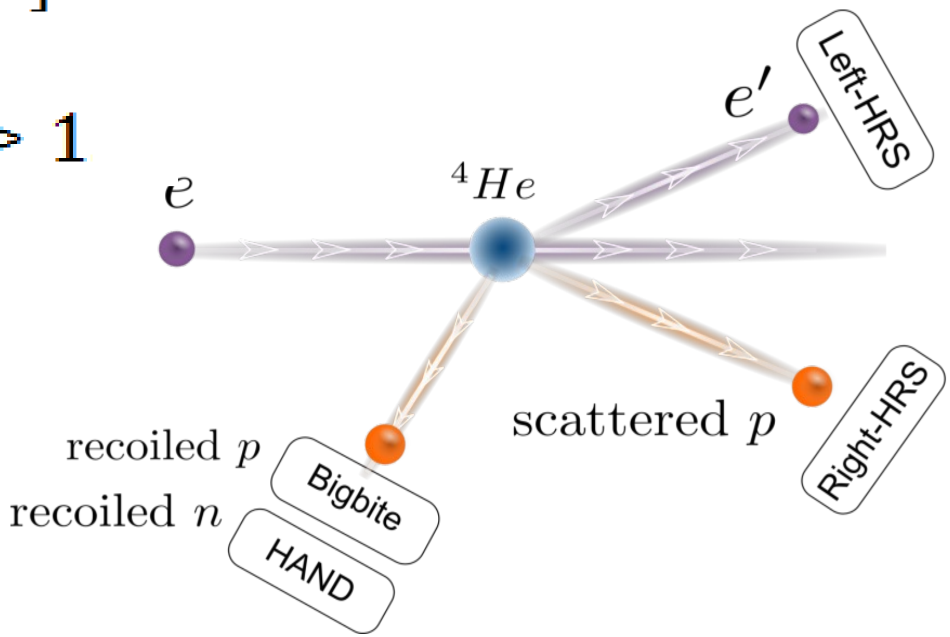
Kinematics

Incoming beam 4.457 GeV

Scattering angle of 20.3 deg (fixed during production)

$$Q^2 \approx 2 \left[{}^{GeV}/_{c}\right]^2$$

$$x_B = \frac{Q^2}{2m\omega} > 1$$



$$\vec{p}_i = \vec{p}_{miss} \equiv \vec{p}_f - \vec{q}$$

(Impulse approximation)

Detectors for recoil nucleon at 97 and 92 deg.

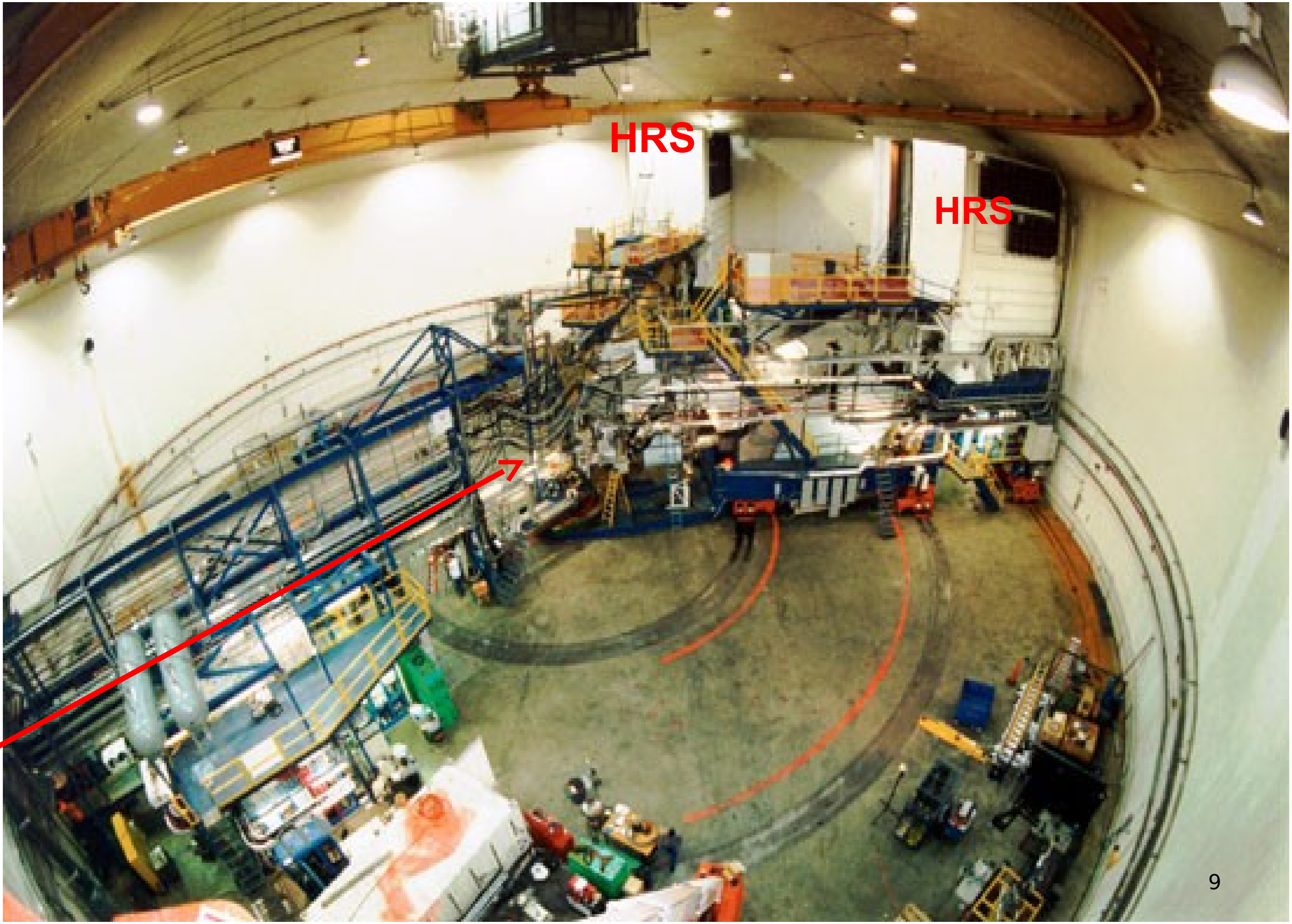
p_{miss} coverage from **400 – 850** MeV/c

By variation of the knock – out proton detector

Three kinematical settings:

"500" MeV/c, "625" MeV/c and "750" MeV/c

HRS



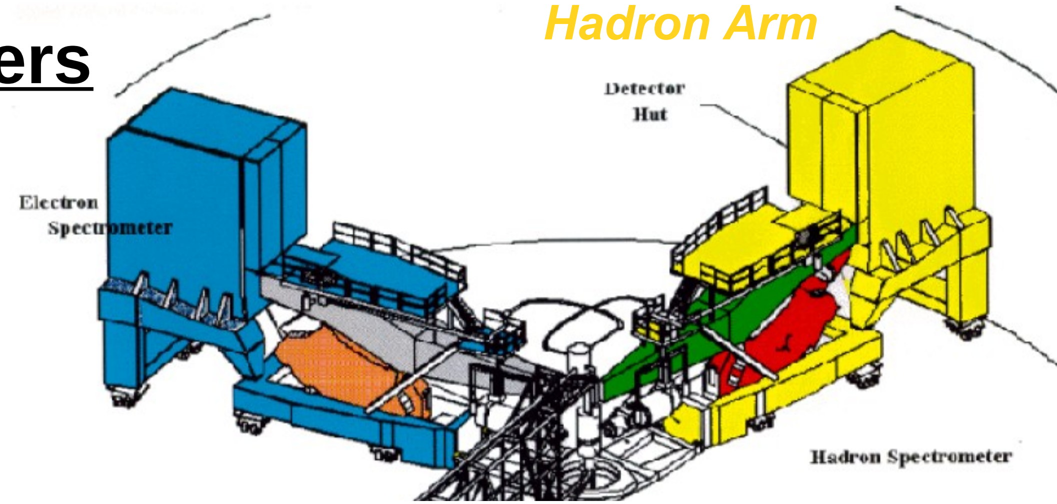
Beam

High Resolution Spectrometers

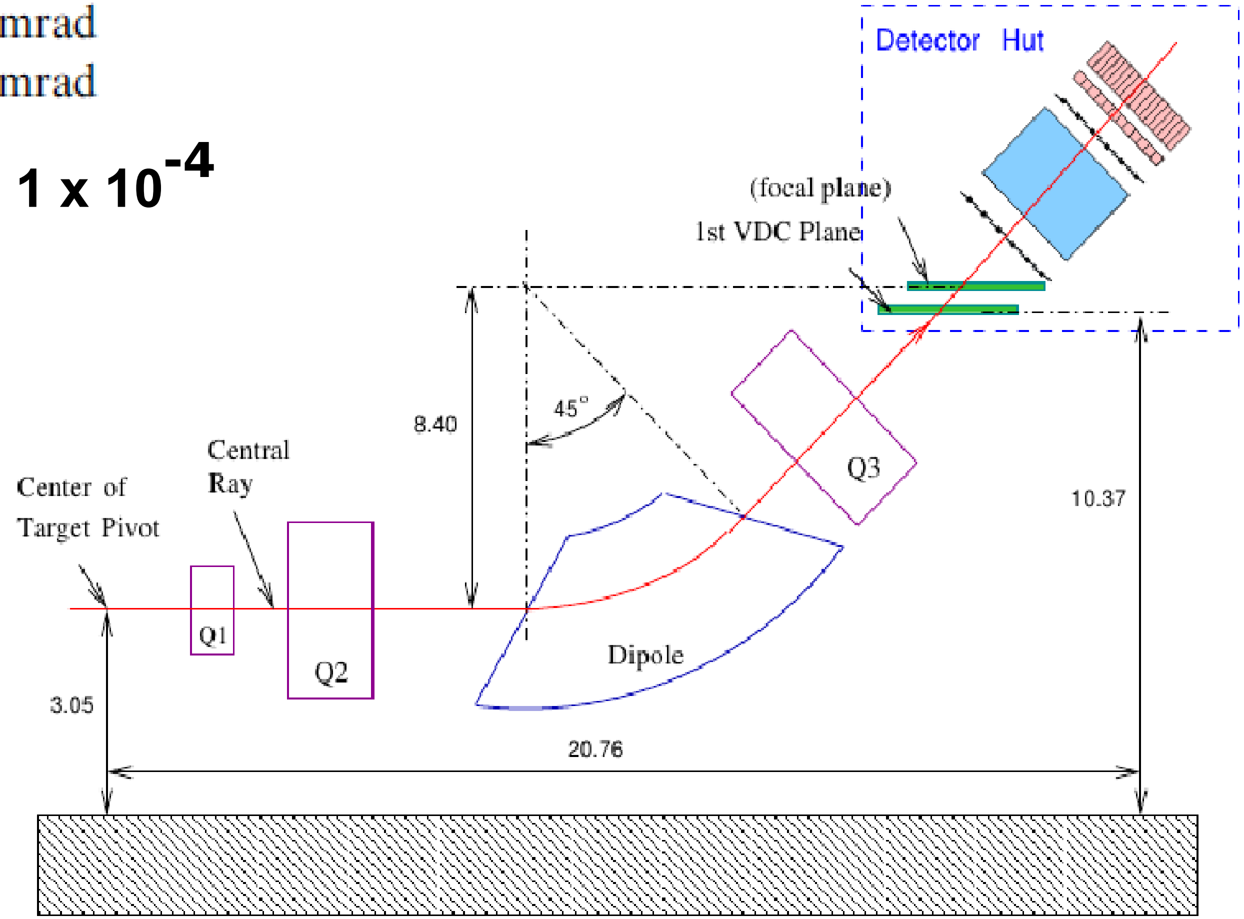
Angular range	
HRS-L	12.5–150°
HRS-R	12.5–130°
Angular acceptance	
Horizontal	±30 mrad
Vertical	±60 mrad
Angular resolution	
Horizontal	0.5 mrad
Vertical	1.0 mrad

Momentum Resolution: dp/p ~ 1 x 10^{-4}

Hadron Arm

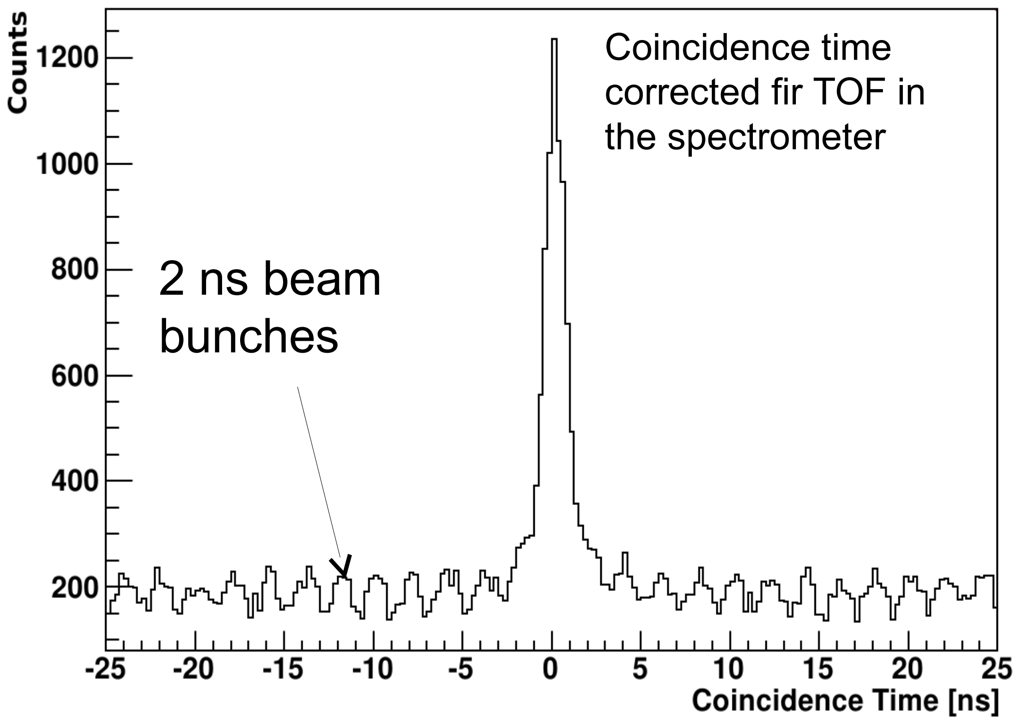


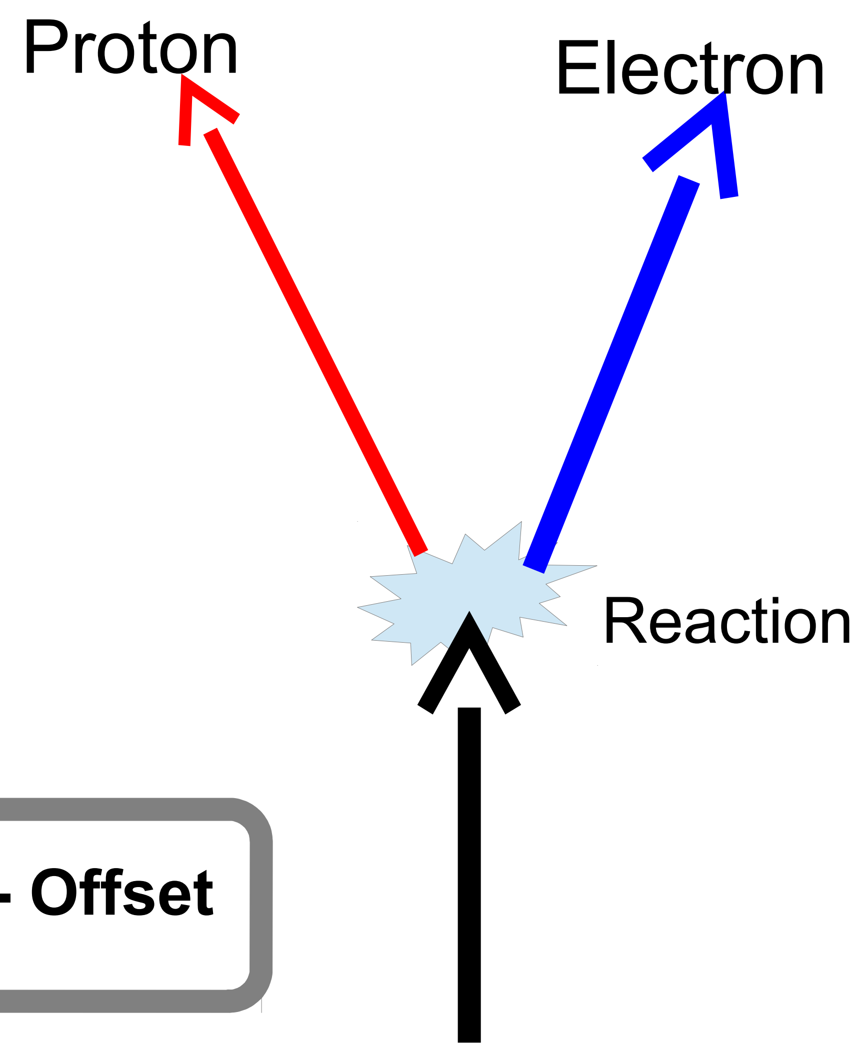
Electron Arm



Trigger formation

Coincidence time between the electron arm (Left HRS) and proton arm (Right HRS)



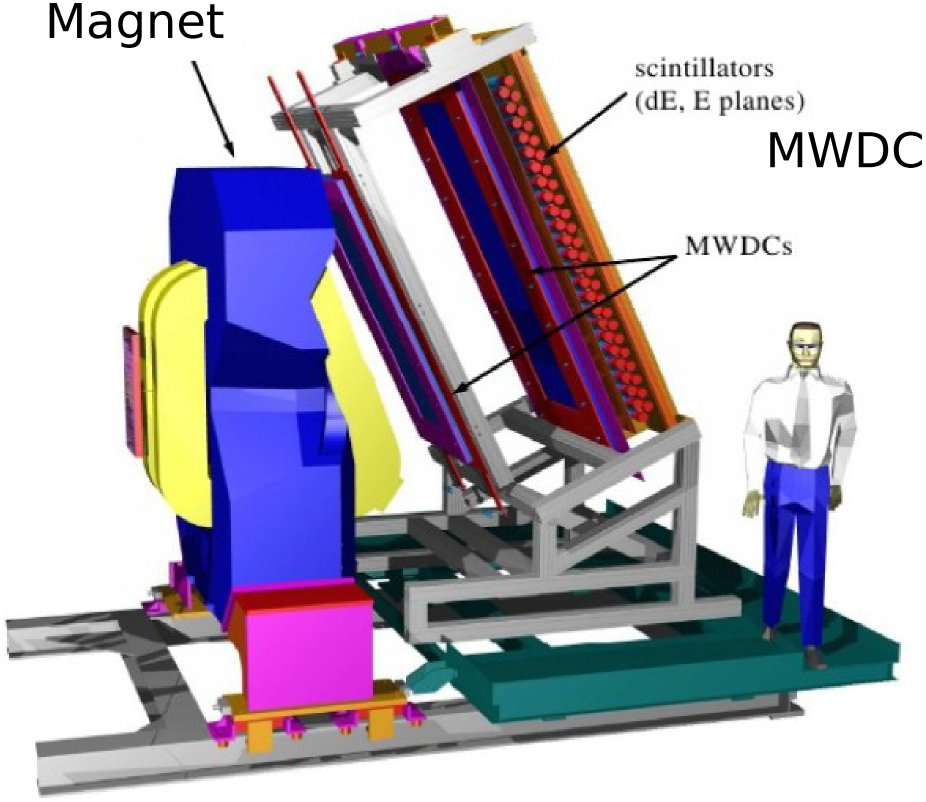


Coincidence Time = $TOF_p - TOF_e$ - Offset

Electron arrival time serve as a reference time in the experiment.

Big Bite

3D drawing of BigBite



Main Characteristics

Momentum Range: 300 – 900 MeV/c

Angular acceptance:

Horizontal: ~ 240 mrad
Vertical: ~ 500 mrad

Momentum resolution ~ 1.5%

Angular resolution
Horizontal: ~ 7 mrad
Vertical: ~ 16 mrad

~ 8 times larger
than the HRS!

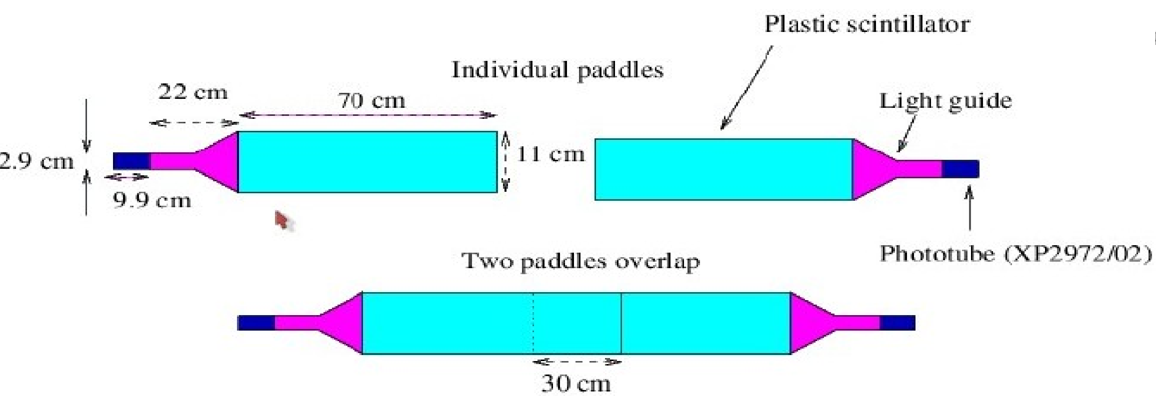
HAND

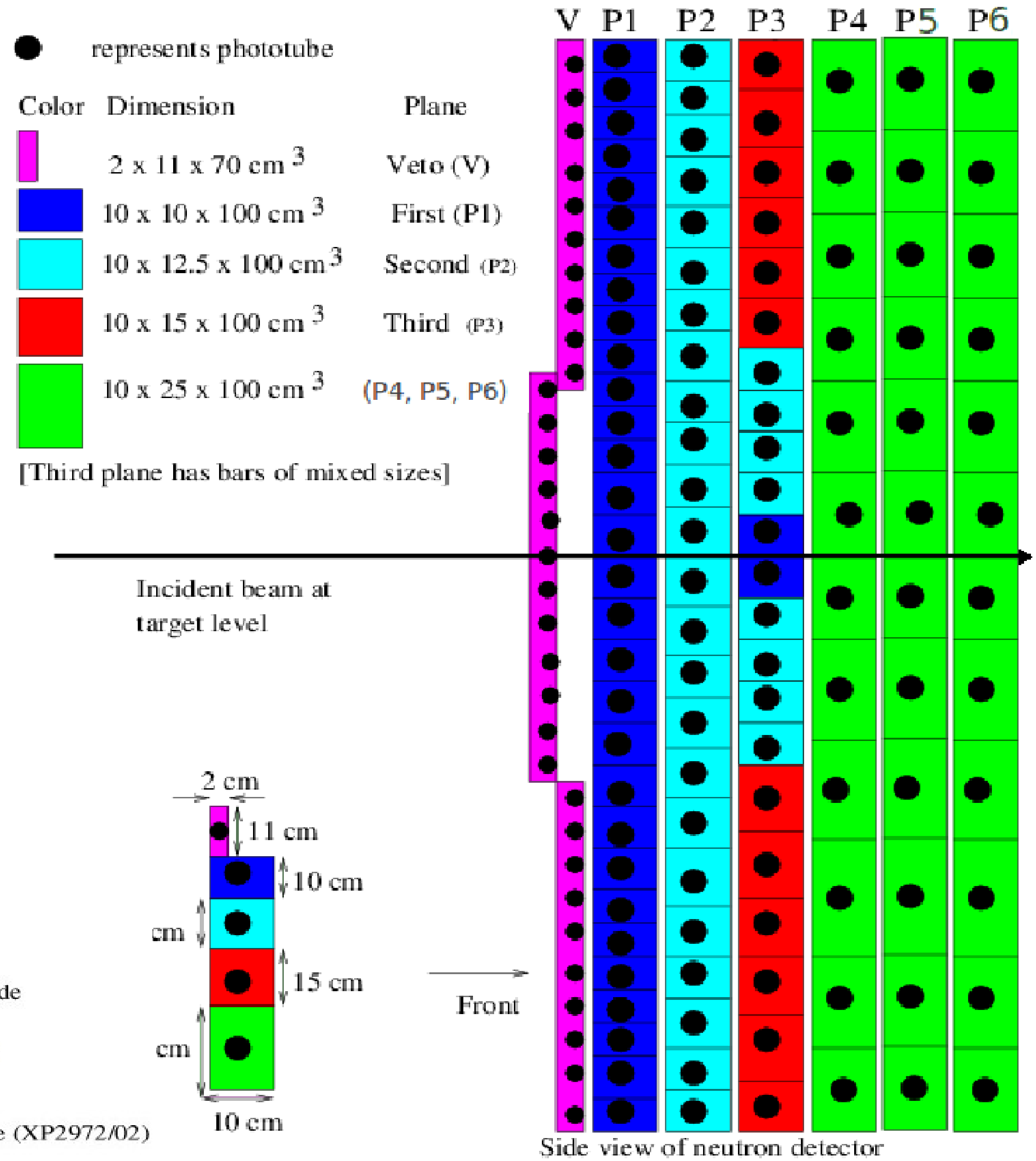
Located 6 m from the target.
Behind the BigBite spectrometer.

Array of **112** plastic scintillators divided into 6 planes.

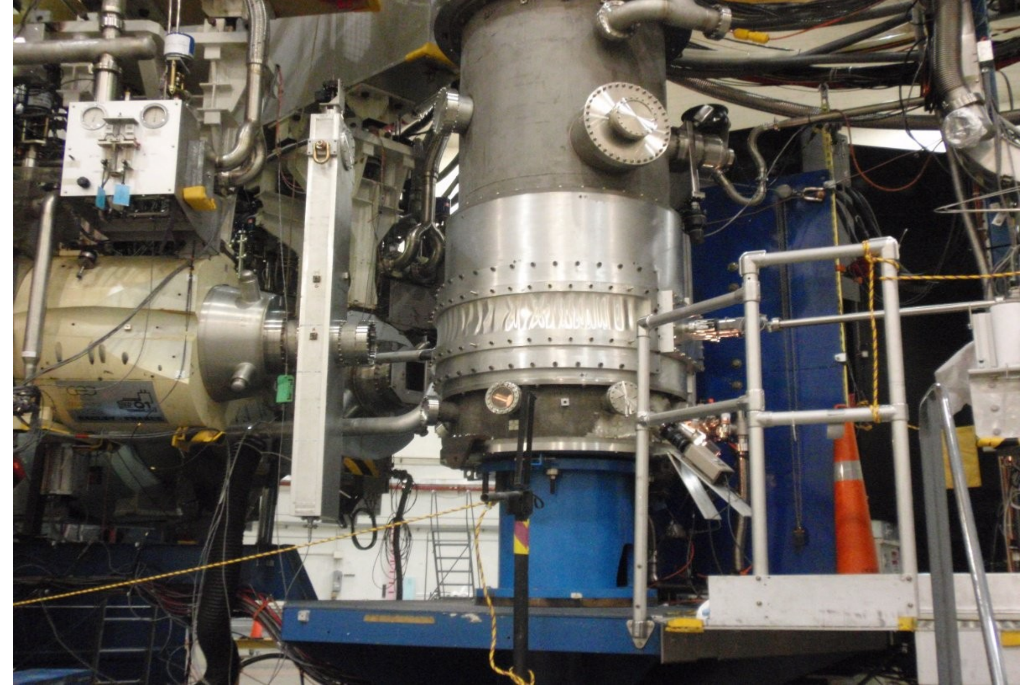
1" lead wall to absorb charged particles

64 scintillators served as a veto layer (PM on one side only)





Target chamber



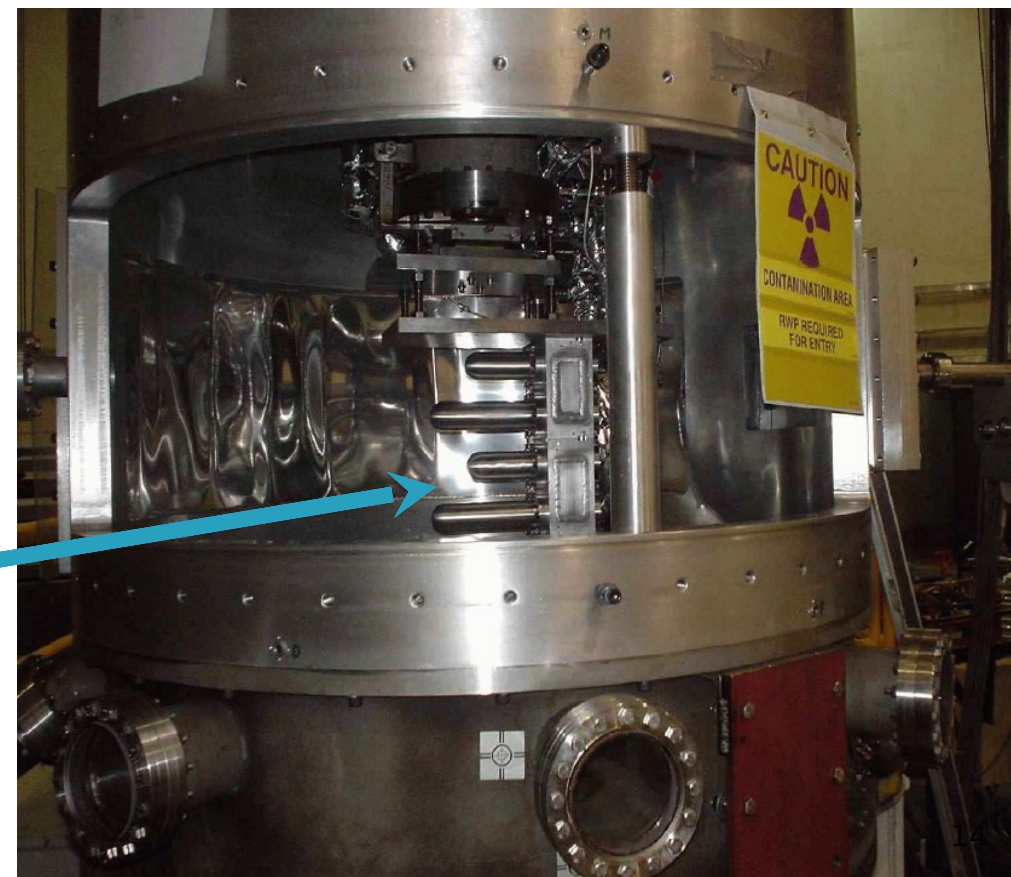
Production target:

^{4}**He** – 13 atm, 20 K

Density 0.033 g/cm^3

Calibration targets

- Hydrogen
- Deuterium
- Carbon

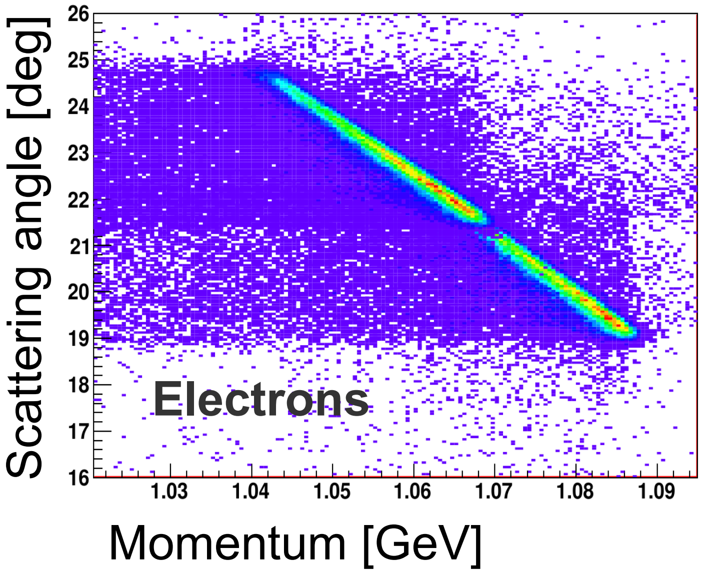


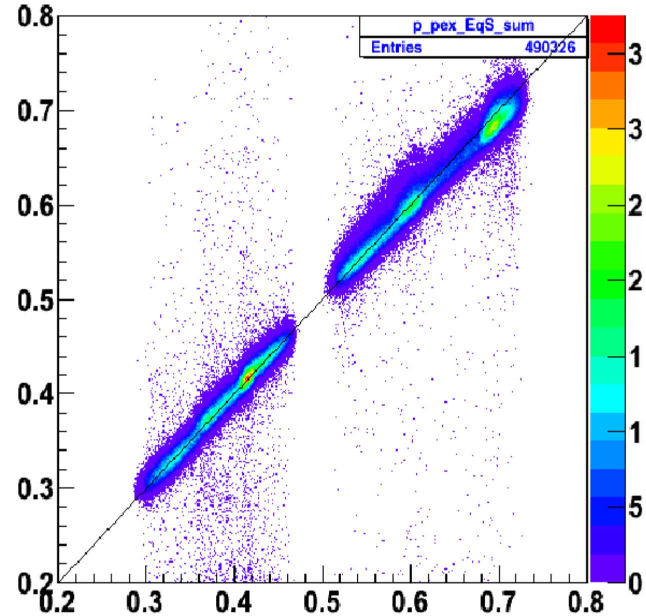
Aluminum cylinder

20 cm long
2.5 " diameter

Calibration Measurements

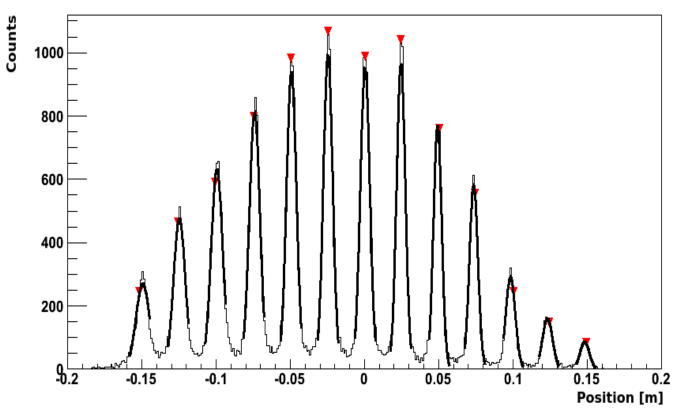
H(e,e') – well defined kinematics

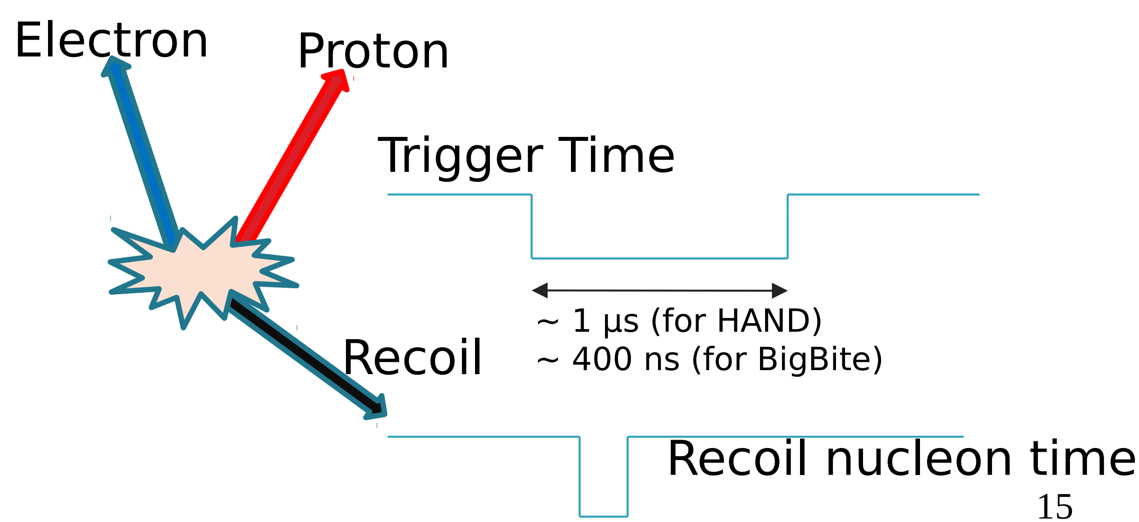




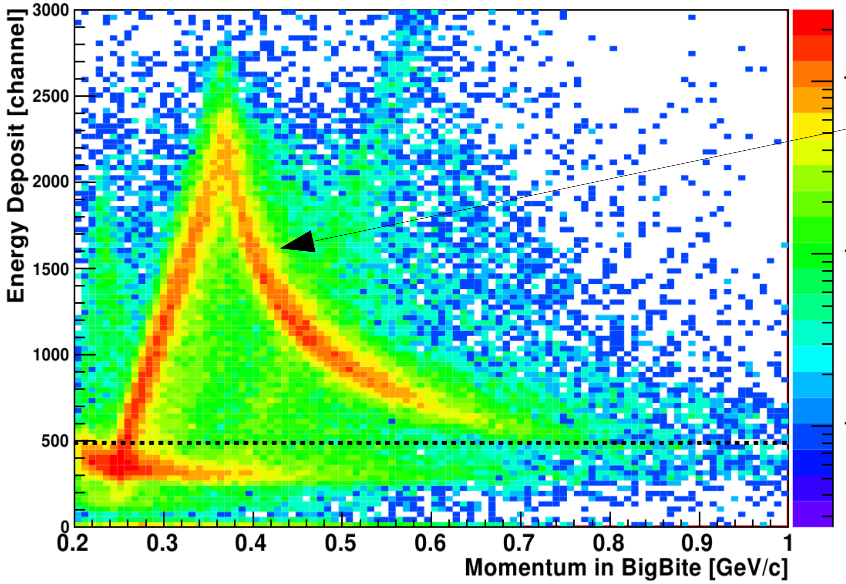
Adjusting timing gate to catch the recoil nucleon:

Carbon Multi foil target

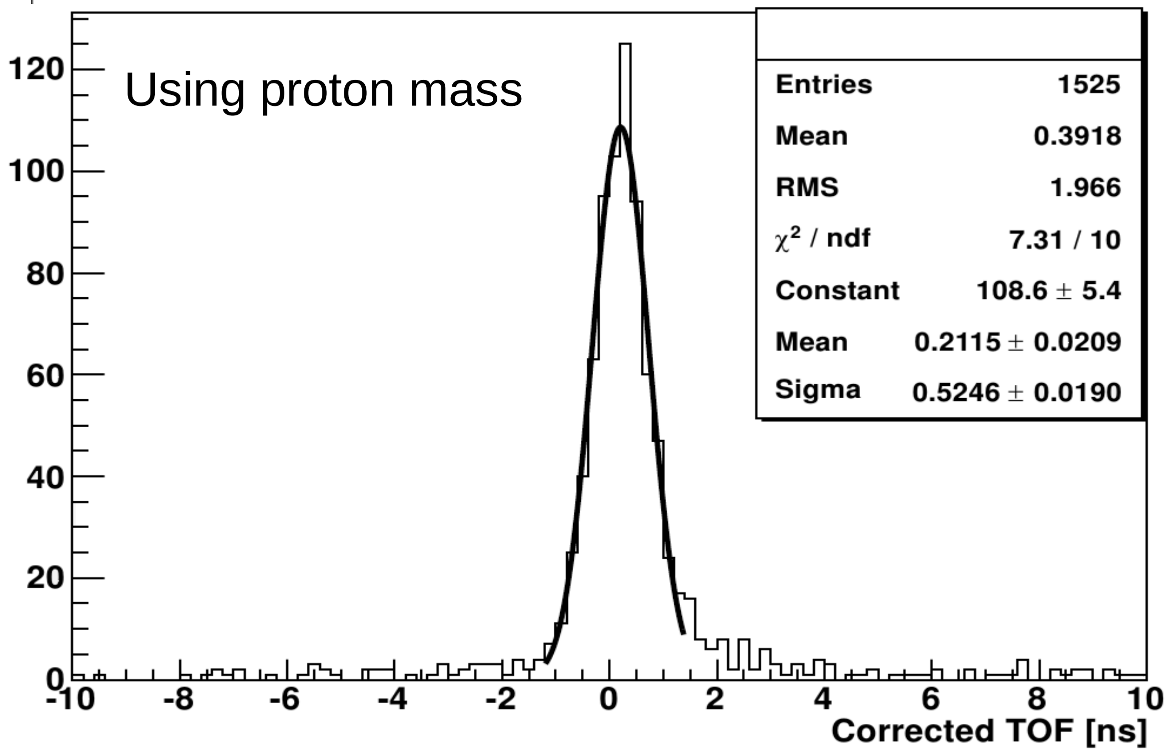




Proton ID: Energy deposit and corrected TOF



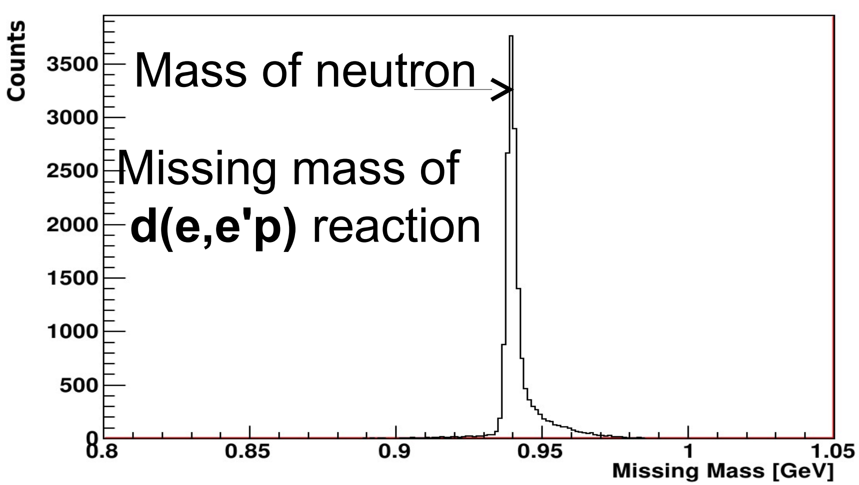
Energy deposit in trigger plane scintillators

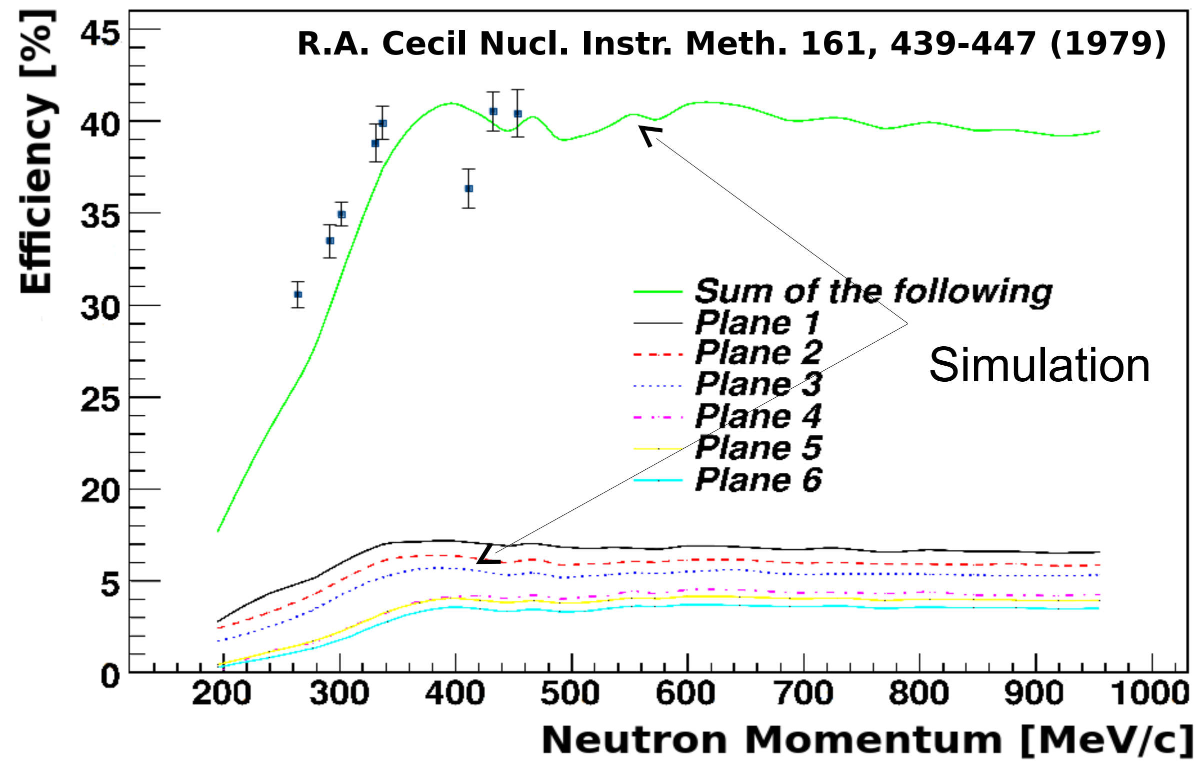


Proton detection efficiency:
~ 75%

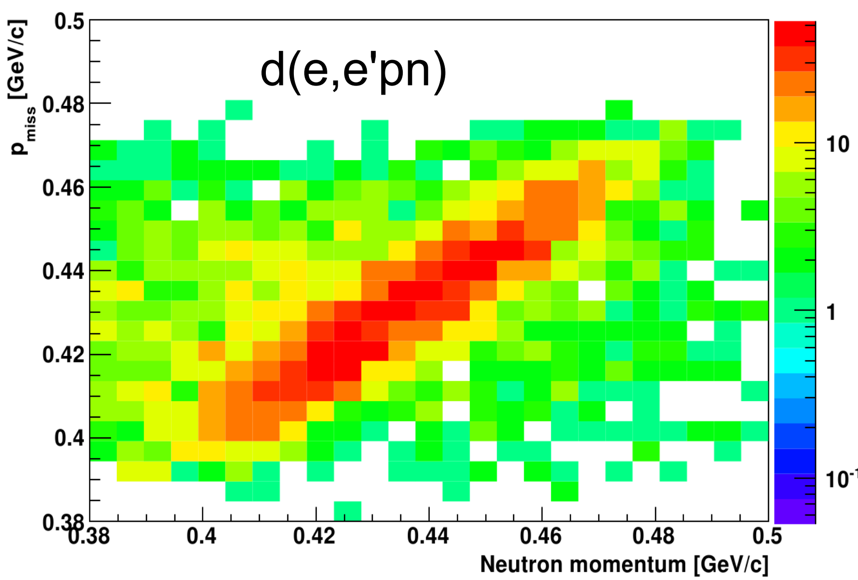
Neutron detection efficiency and absolute timing

The **absolute** neutron detection efficiency was determined by exclusive scattering from **Deuterium**





Absolute time – momentum reconstruction

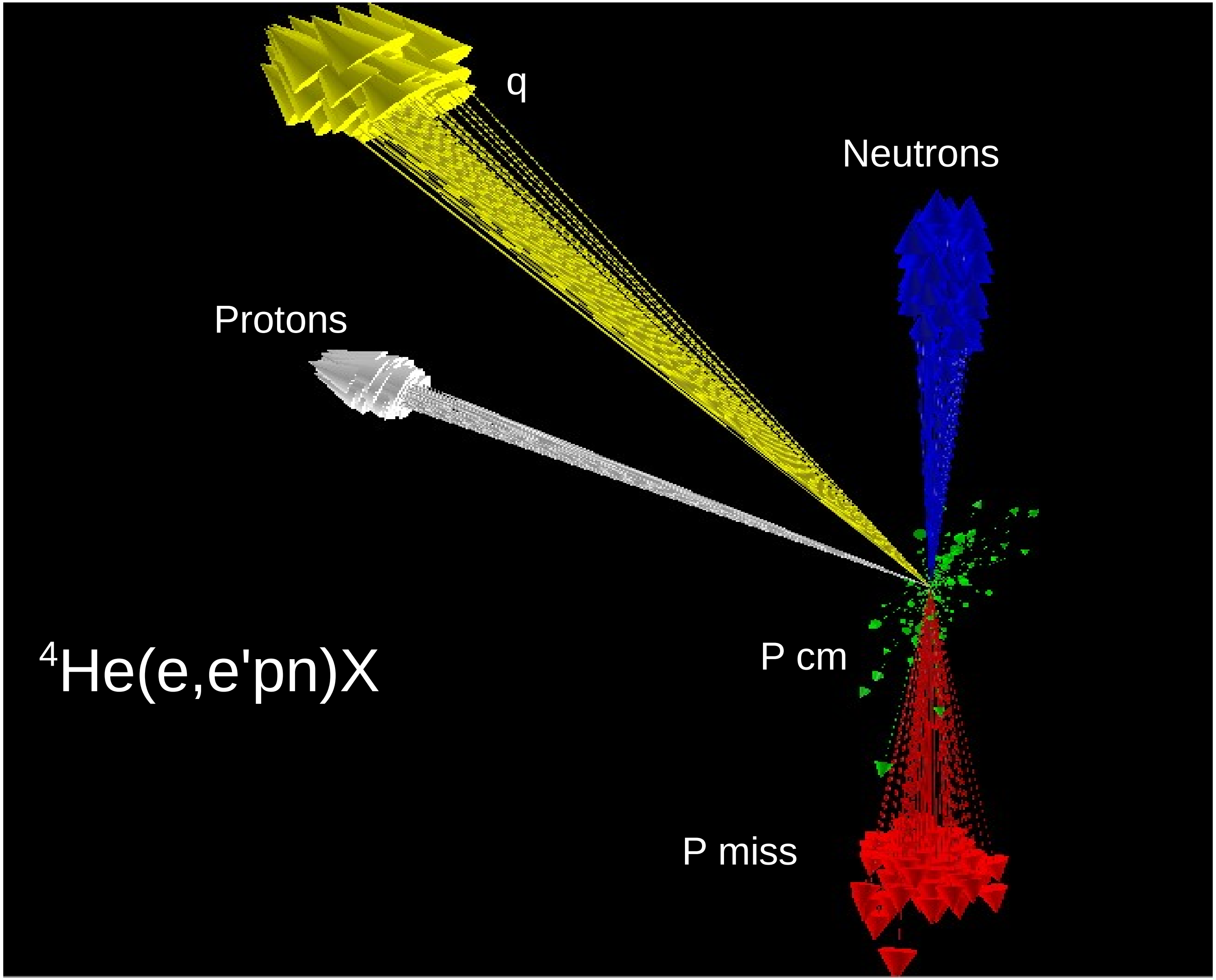


Measurement at higher momentum have very low rate.

TOF converted to momentum

$$p_n = \frac{m}{\sqrt{\left(\frac{0.3 \cdot tof}{d}\right)^2 - 1}}$$

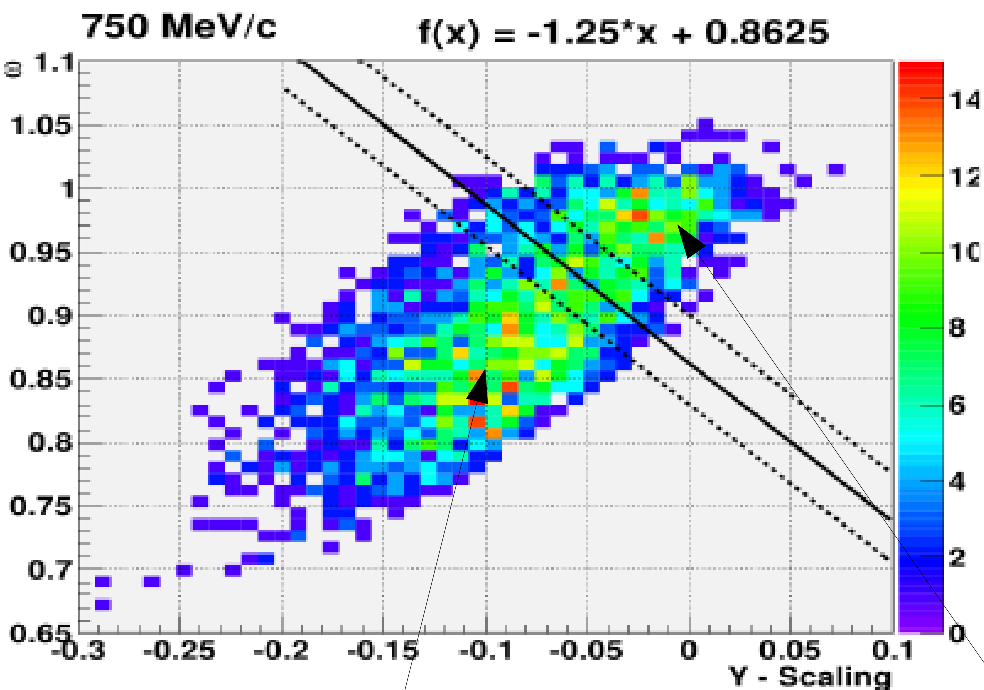
Event display:



(e,e'p) events selection

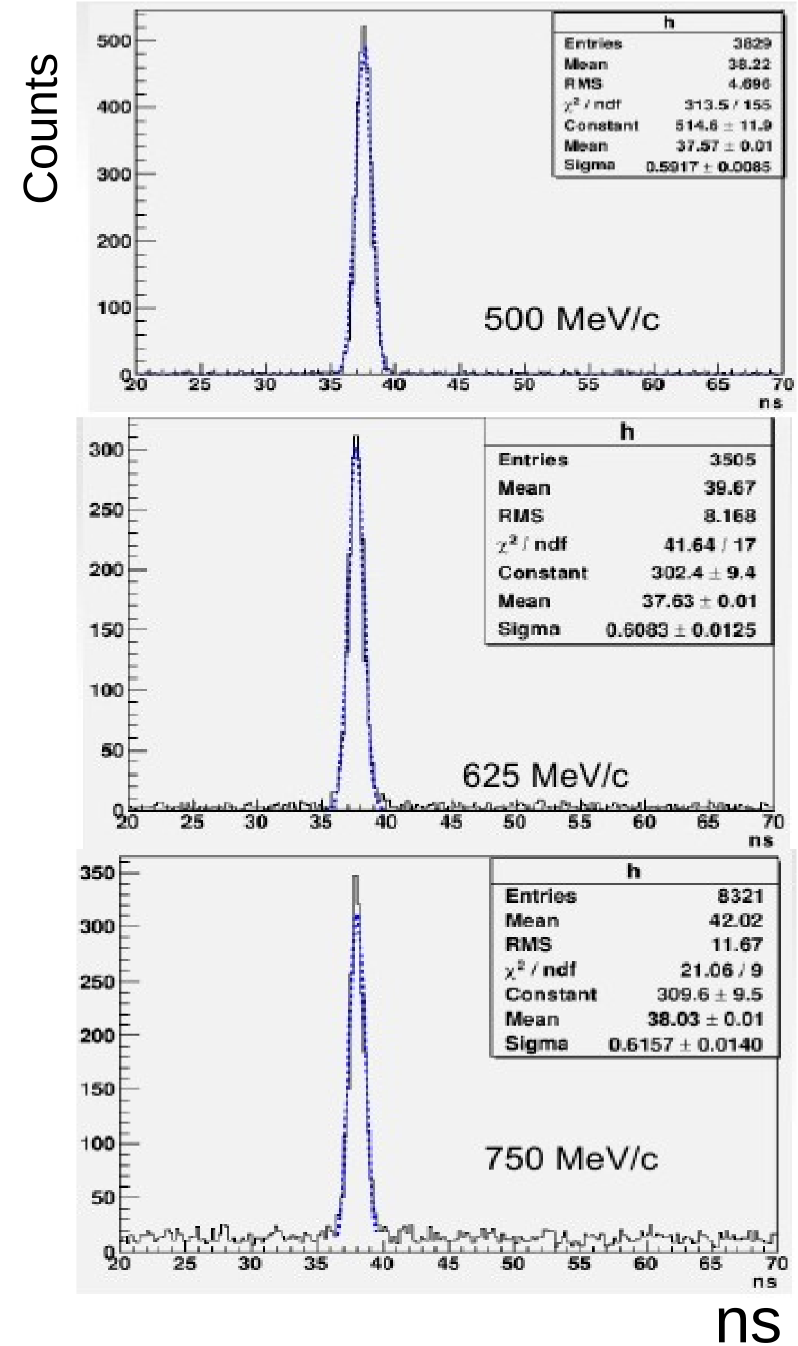
- Spatial cuts on HRSs
- Coincidence time
- Vertex reconstruction cut

Random background from 1% to 9%



Nucleon region

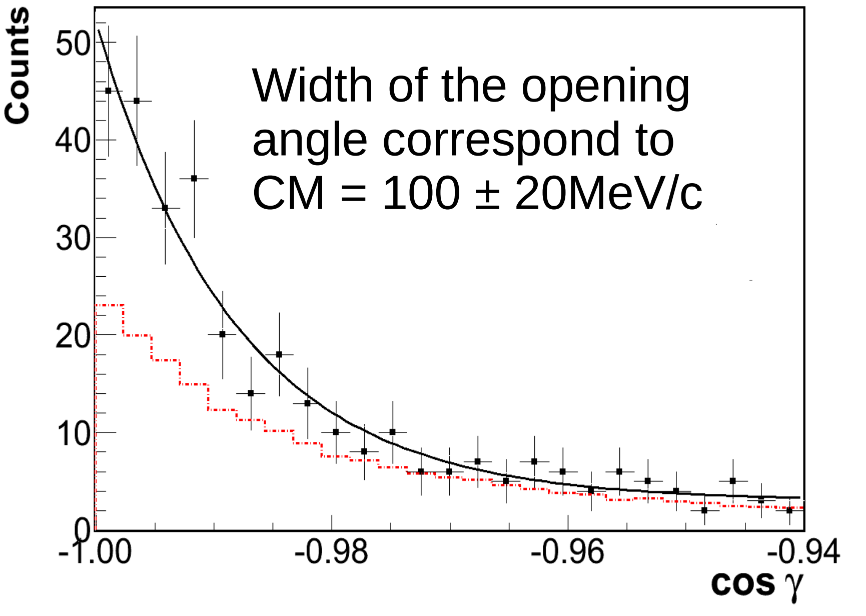
Delta production



Y – Scaling: Fraction of the nucleon's momentum in the direction of the virtual photon

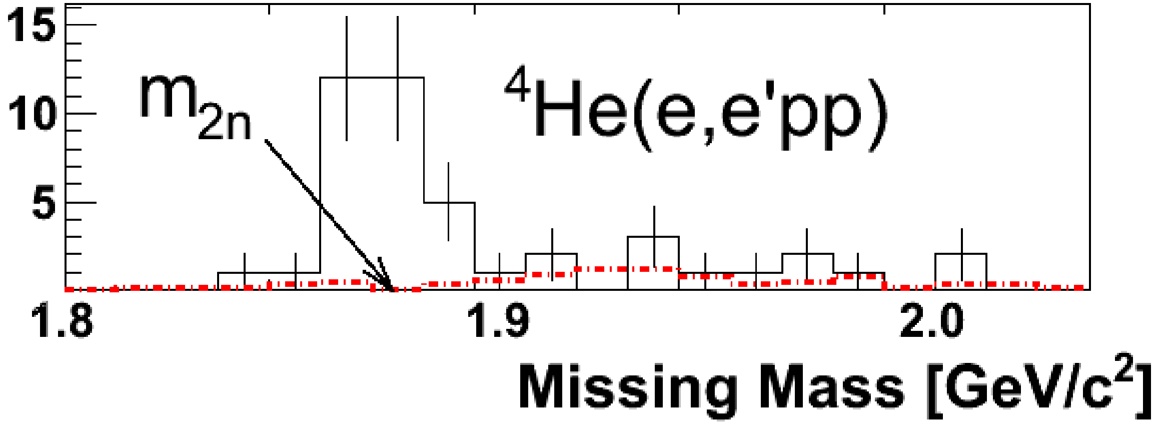
How we know that the detected protons and neutrons belong to 2N-SRC?

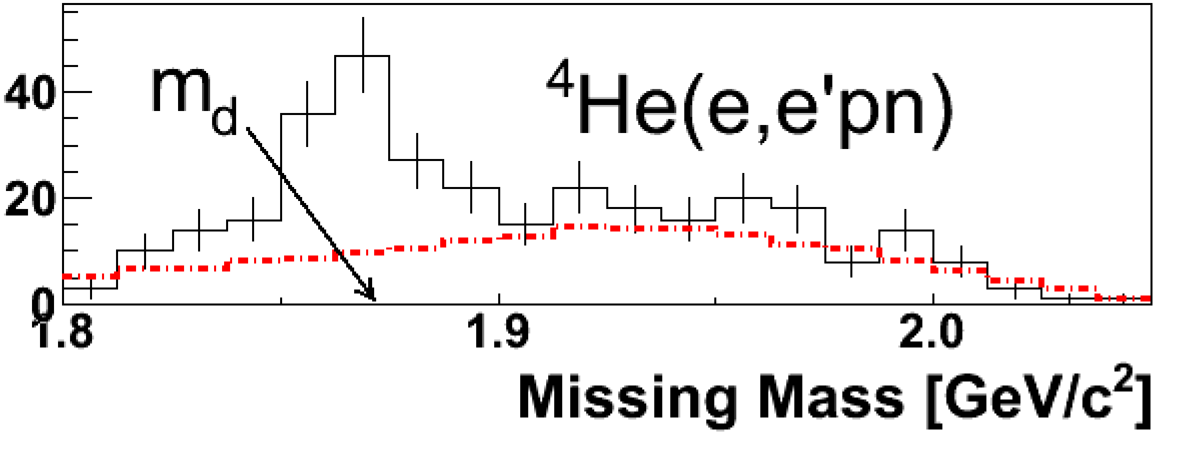
Clearly see the back to back correlation



Consistent with theoretical prediction for ^{4}He

Low excitation energy of the residual system (A-2)





With the number of the events calculate ratios

Triple to Double ratios:

$$\frac{\#^4He(e,e'pn)}{\#^4He(e,e'p)}$$

$$\frac{\#^4He(e,e'pp)/2}{\#^4He(e,e'p)}$$

Divided by two in order to prevent double counting

Triple to triple ratio

$$\frac{\#^4He(e,e'pp)/2}{\#^4He(e,e'pn)}$$

From these ratios we determine the isospin structure of the SRC in the He ground state.

FSI correction

most of the interaction are confined to SRC pair:

$$\Delta E = -q_0 - M_A + \sqrt{m^2 + (p_i + q)^2} + \sqrt{M_{A-1}^2 + p_i^2}$$

$$r \approx \frac{1}{\Delta E} v \leq 1fm \ (for \ x > 1.3)$$

(Adapted from Misak)

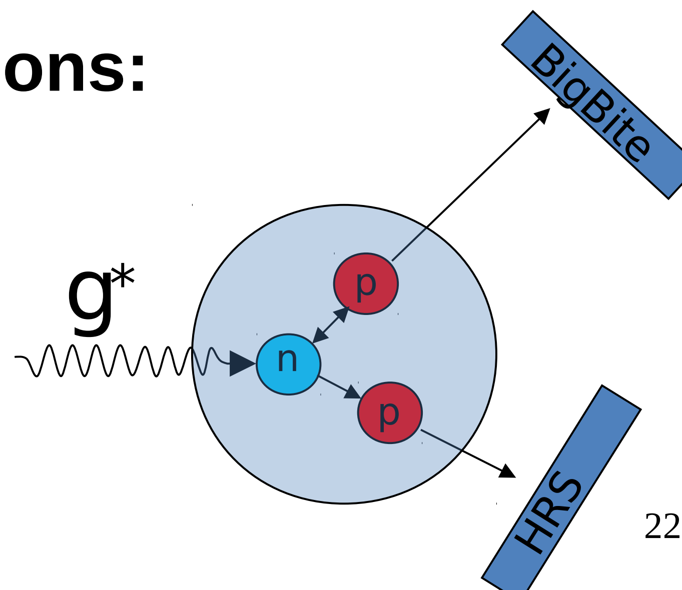
FSI in the pair

- Conserve the isospin structure of the pair .
- Conserve the CM momentum of the pair.

There are two additional FSI contributions:

Nuclear Transparency (T)

Single Charge exchange (SCX)



Correction for nuclear transparency and single charge exchange

Assuming Glauber approximation:

Transparency correction for the leading proton: $T_L = 0.75$

Transparency correction for the recoil: $T_R = 0.66 – 0.73$

J. Ryckebusch, D. Debruyne, P. Lava, S. Janssen, B. Van Overmeire, and T. Van Cauteren, Nucl. Phys. **A728**, 226 (2003); W. Cosyn, M. C. Martinez and J. Ryckebusch, Phys. Rev. C **77**, 034602 (2008); W. Cosyn and J. Ryckebusch (private communication).

Single charge exchange probability was assumed to be ~ 1.5 ± 1.5%

Based on the SCX total cross section of 1.1 ± 0.2 mb

J. L. Friedes, H. Palevsky, R. L. Stearns, and R. J. Sutter, Phys. Rev. Lett. **15**, 38 (1965).

FSI – Transparency and SCX

$$R=\frac{^4He(e,e'pp)}{^4He(e,e'pn)}=\frac{2\cdot\#pp\,\sigma_{ep}\cdot T_L\cdot T_R+\#np\,\sigma_{en}\cdot P_{scx}\cdot T_R}{\#np\,\sigma_{ep}\cdot T_L\cdot T_R+2\cdot\#nn\,\sigma_{en}\cdot P_{scx}\cdot T_R}$$

Measured

Extracted

$$\frac{\#np}{\#pp}=\frac{2\cdot T_L-2\cdot P_{scx}\cdot\frac{\sigma_{en}}{\sigma_{ep}}\cdot R}{T_L\cdot R-P_{scx}\cdot\frac{\sigma_{en}}{\sigma_{ep}}}$$

For Triple to double ratios we solve simultaneously:

$$R_1=\frac{^4He(e,e'pn)}{^4He(e,e'p)}=\frac{\#np\cdot\sigma_{ep}\cdot T_R\cdot T_L+2\cdot\#pp\cdot\sigma_{en}\cdot P_{SCX}\cdot T_L\cdot T_R}{\#p\cdot\sigma_{ep}\cdot T_L}=\frac{\#np\cdot T_R+2\cdot\#pp\cdot\frac{\sigma_{en}}{\sigma_{ep}}\cdot P_{SCX}\cdot T_R}{\#p}$$

$$R_2=\frac{^4He(e,e'pp)}{^4He(e,e'p)}=\frac{2\cdot\#pp\cdot\sigma_{ep}\cdot T_R\cdot T_L+\#np\cdot\sigma_{en}\cdot P_{SCX}\cdot T_L\cdot T_R}{\#p\cdot\sigma_{ep}\cdot T_L}=\frac{2\cdot\#pp\cdot T_R+\#np\cdot\frac{\sigma_{en}}{\sigma_{ep}}\cdot P_{SCX}\cdot T_R}{\#p}$$

Extracted $\frac{\#np}{\#p}$ and $\frac{\#pp}{\#p}$

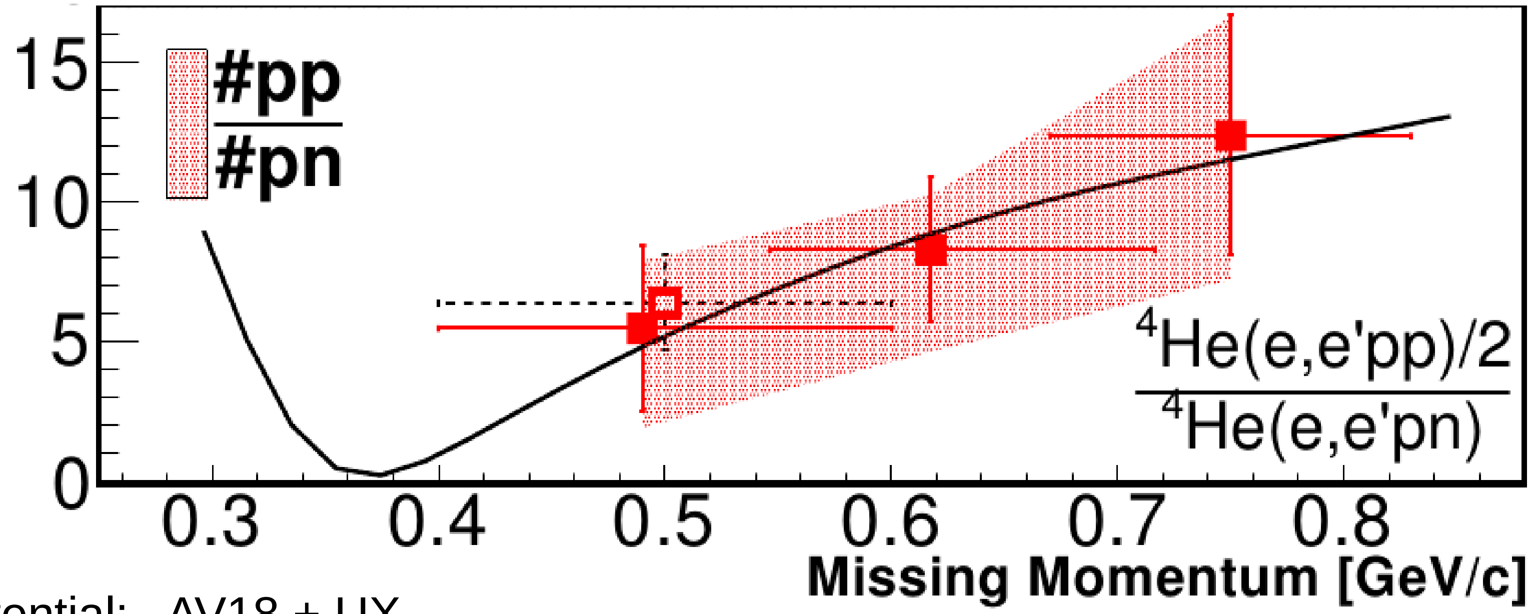
Calculation were done with help from:

Wim Cosyn, Camille Colle and Jan Ryckebusch

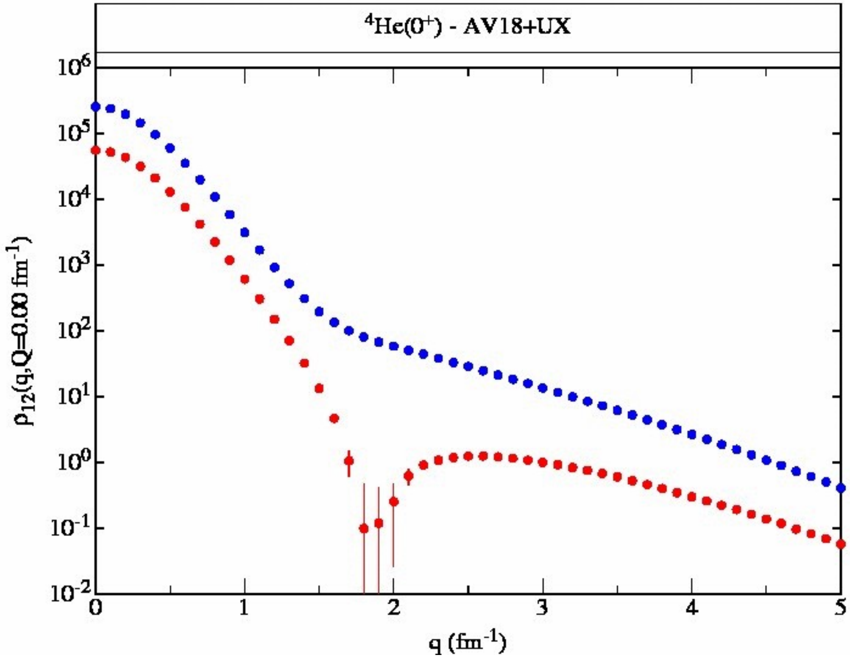
pp over pn ratio

PhysRevLett.**113**, 022501 (2014)

Band represent the extracted pair fractions
Open symbols represent experiment on Carbon

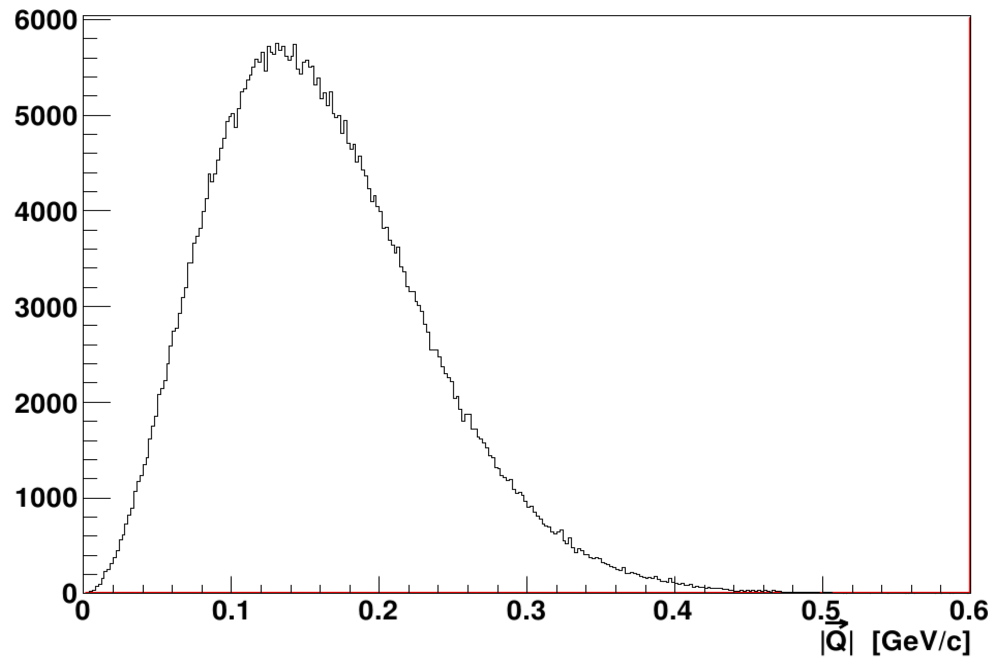


Argonne group used potential: AV18 + UX



Momentum distribution for different
CM momentum of the pairs: 0 – 400 MeV/c

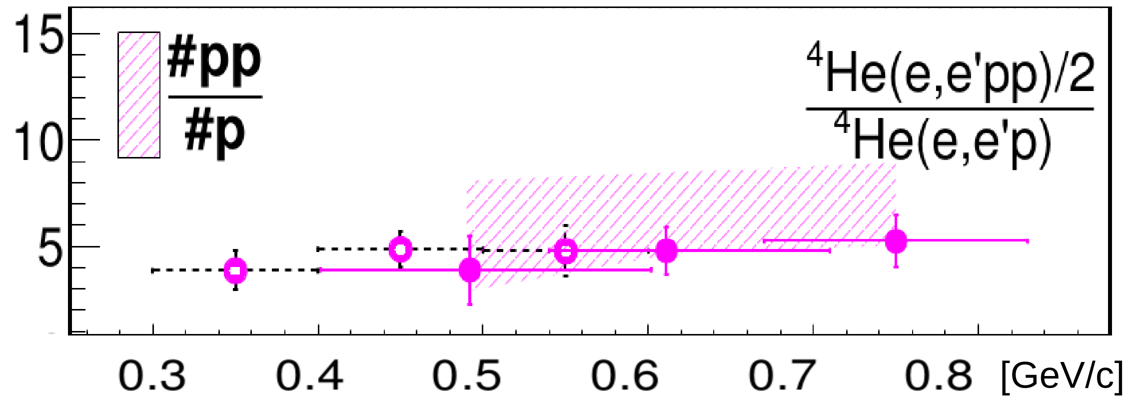
Averaged over P_{CM} distribution



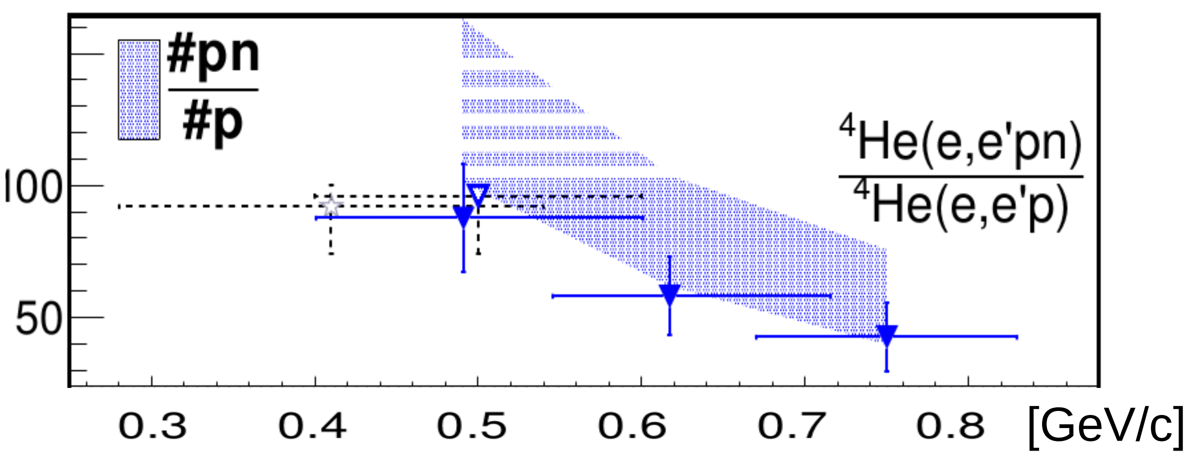
Triple to double ratios

- Fraction of the pp pairs stays constant with the increase of the missing momentum.

Band represent the extracted pair fractions
Open symbols represent experiment on Carbon



- Fraction of the np pairs strongly drops from ~100% to ~50% with increasing momentum



Can be due to contribution from 3N-SRC / FSI

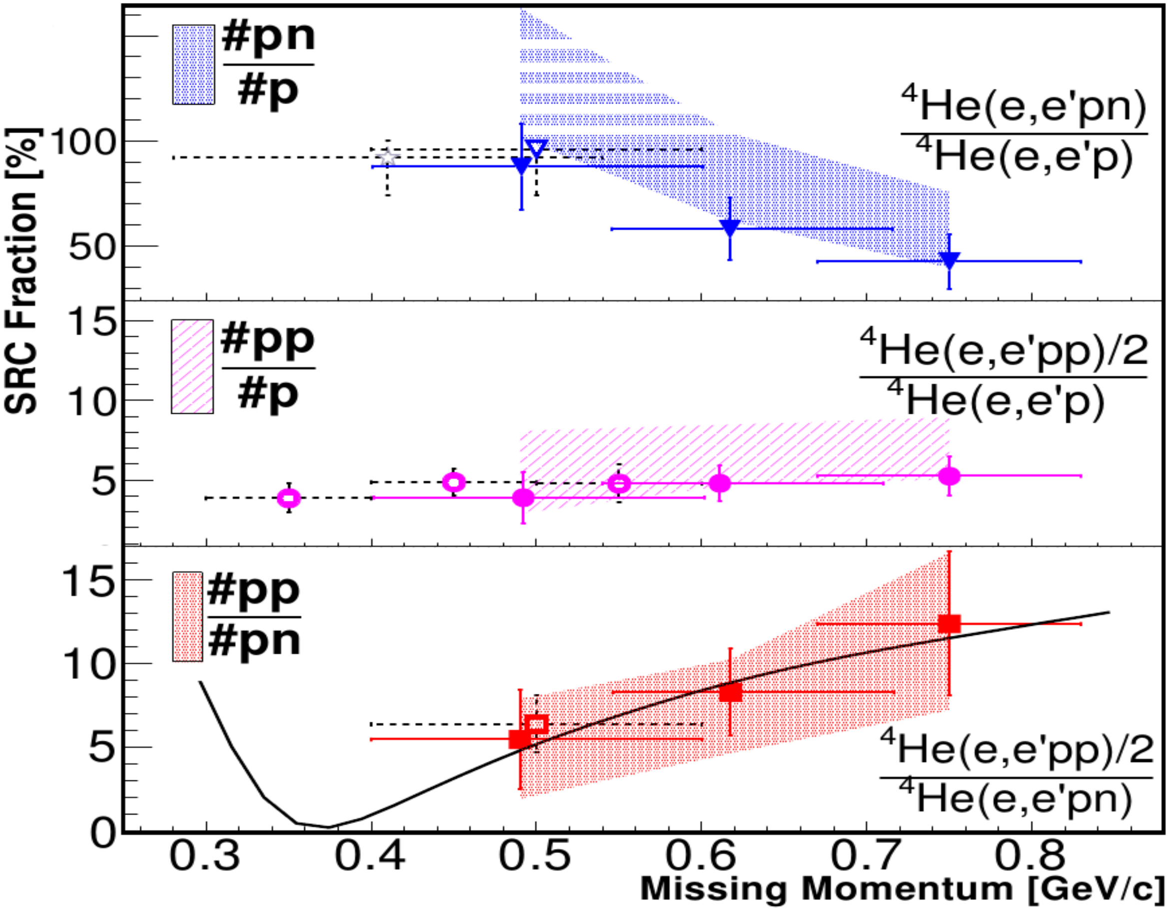
Summary:

- We observe increase in the pp/pn ratio, as expected from the theory
- We identify significant decrease in the number of pn pairs with increasing momentum, however they are still dominant
- Number of pp pairs stay constant with the increase of the momentum.

Open questions:

* Why we don't see significant increase of pp pairs?

* Total number of pairs don't sum to 100%



Thank you for your attention!