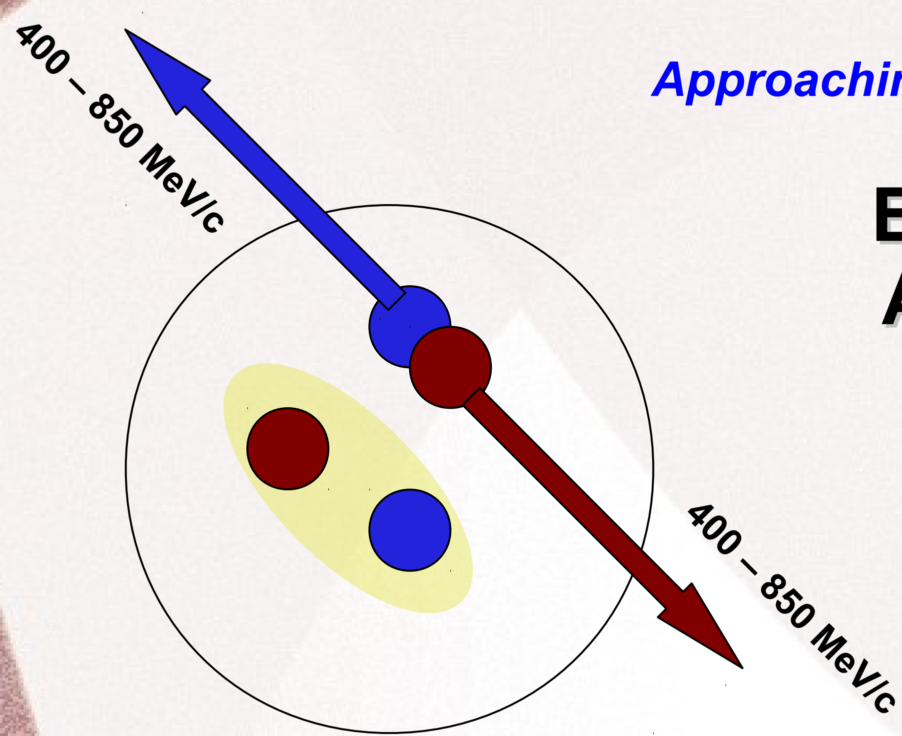
Hall A Collaboration Meeting

Approaching the NN short range repulsive core

E07 – 006 (SRC) Analysis Report



$$^{4}He(e,e'p)$$

$$^{4}He(e,e'pp)$$

$$^{4}He(e,e'pn)$$

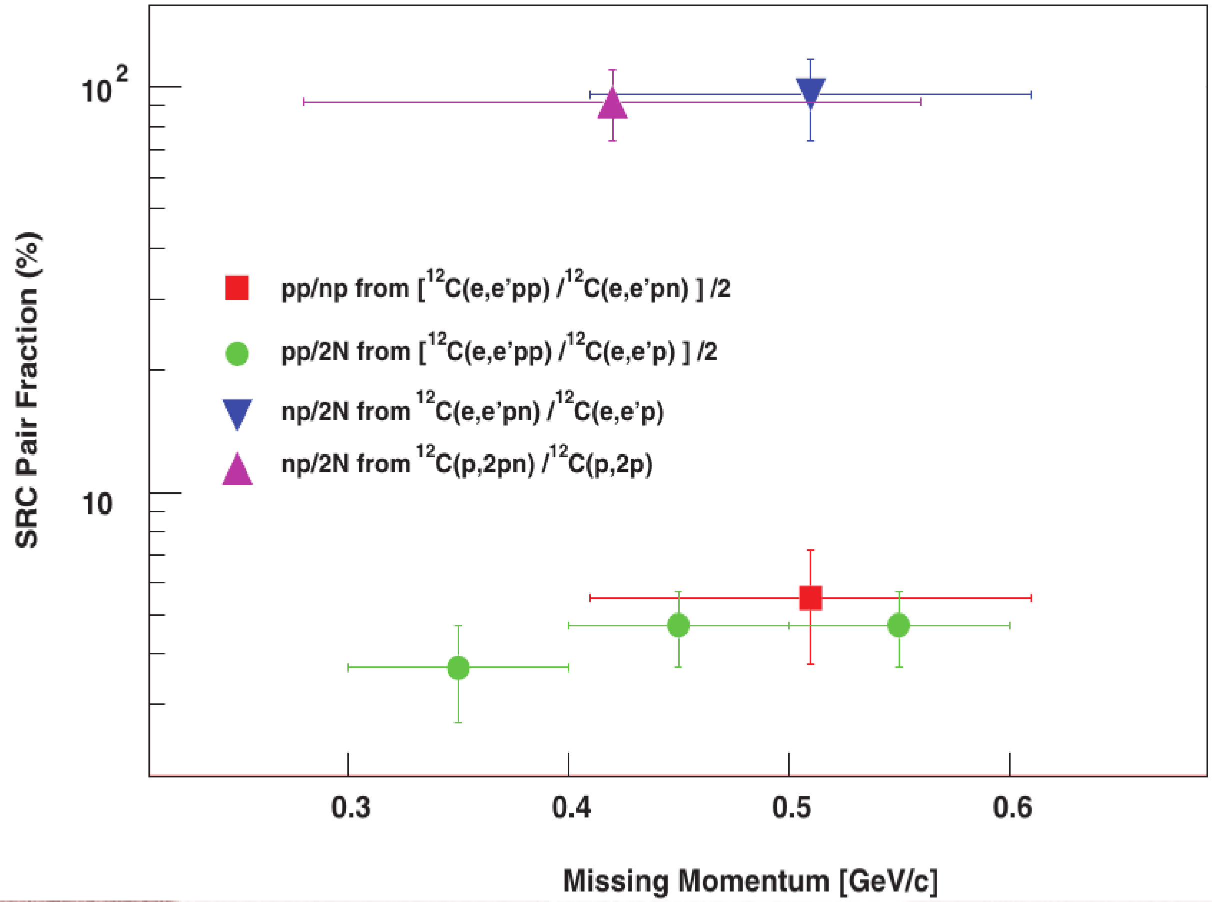
Igor Korover

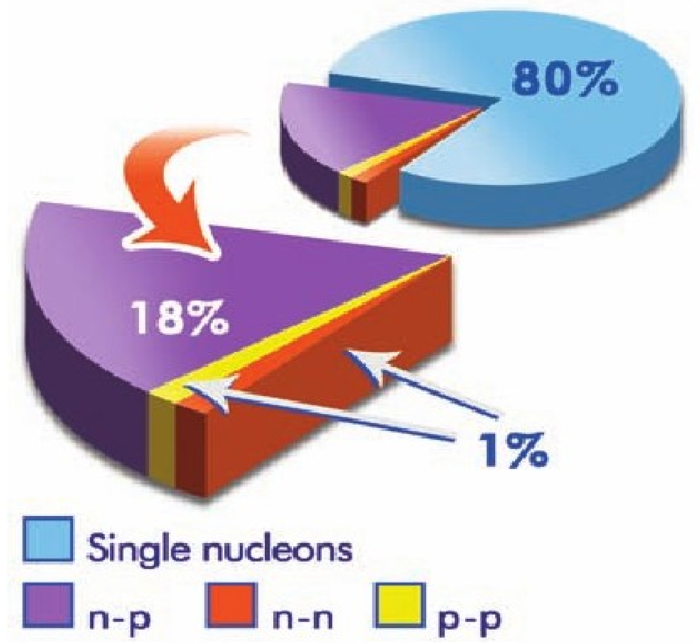
JLab

Dec 16-17, 2013

Results from E01 - 015

(2005)





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

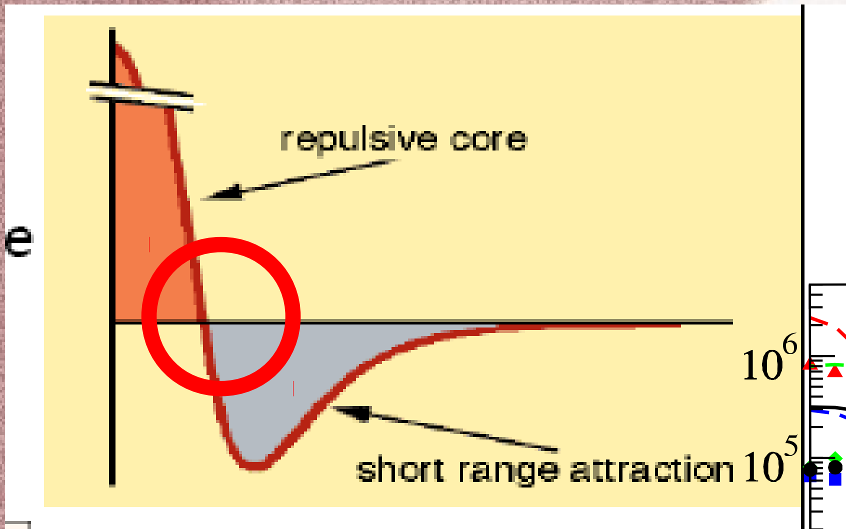
E. Piasetzky, Phys. Rev. Lett. ***97****, 162504 (2006).*

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

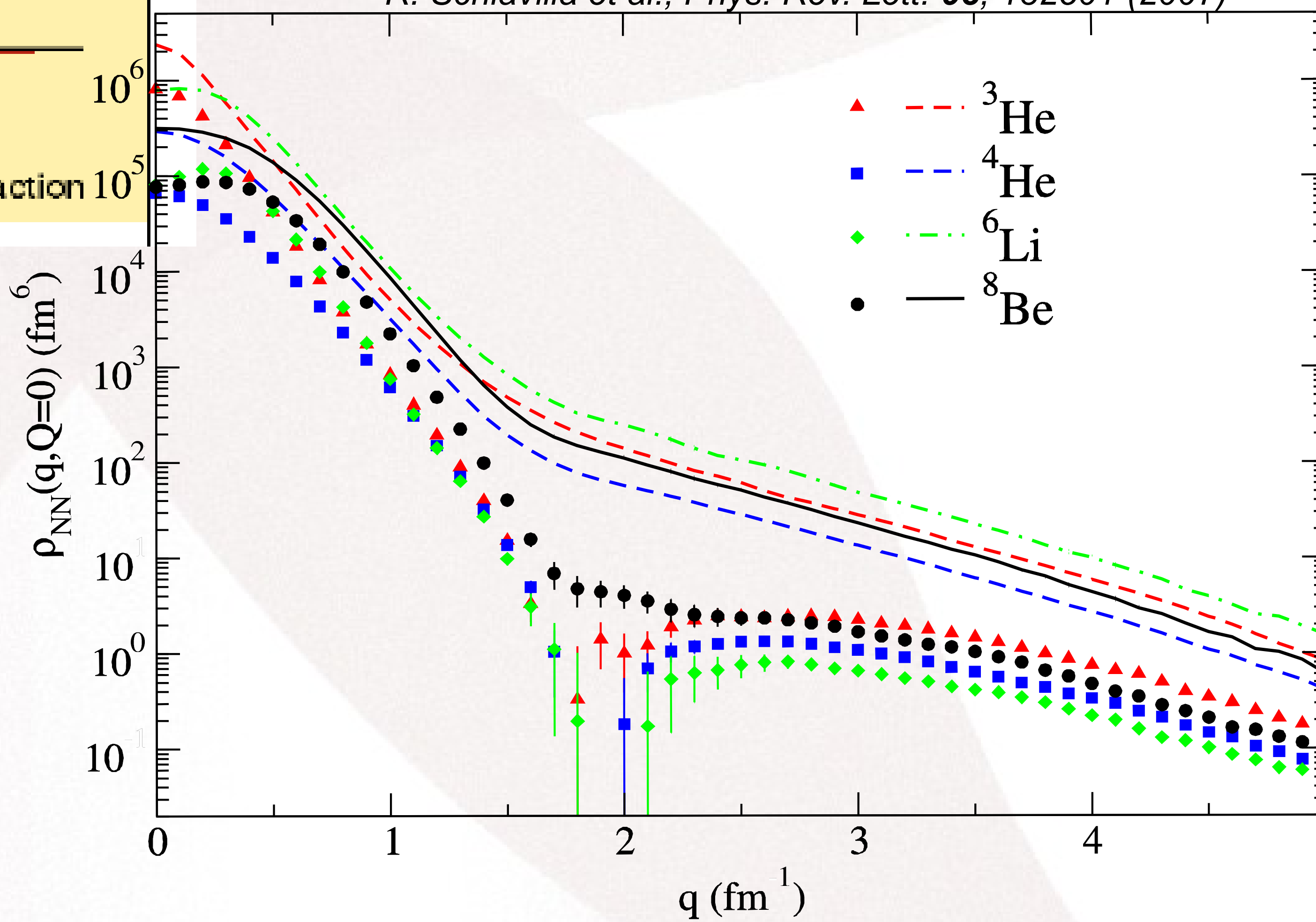
A. Tang, Phys. Rev. Lett. ***90****, 042301 (2003).*

- ~80% of all nucleons with momentum ≥ 300 MeV / c belong to 2N-SRC.
    - For 300-600 MeV/c: $\frac{\#\,\text{np-SRC}}{\#\,\text{pp-SRC}} \approx 18$

Theoretical interpretation



R. Schiavilla et al., Phys. Rev. Lett. **98**, 132501 (2007)



Similar calculations by Ciofi and Alvioli
PRL **100**, 162503 (2008)

<u>Sargasian, Abrahamyan, Strikman, Frankfurt</u>
PR **C71** 044615 (2005)

- Dominance of NN tensor force

Motivation for E07 – 006

Extend the measurement to be sensitive to the **NN tensor force** and the **repulsive force**

Repulsive core is not well know theoretically and experimentally.

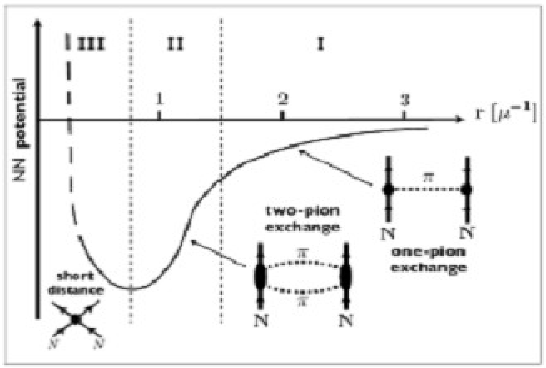
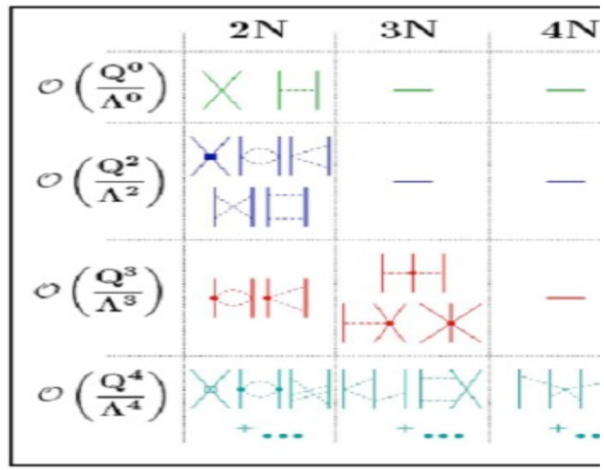
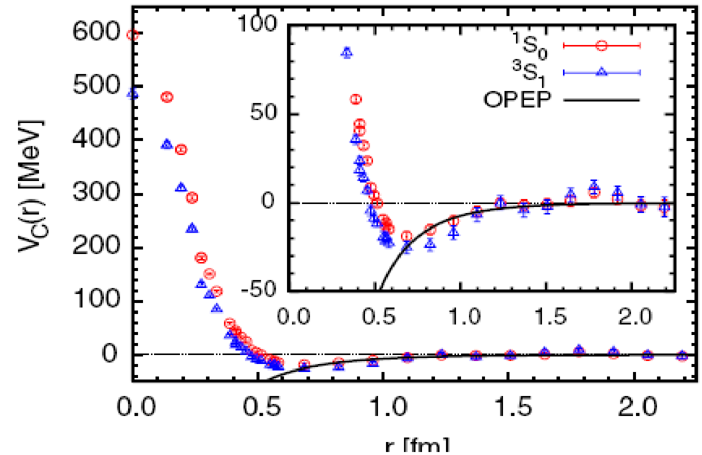


Fig. 2. Hierarchy of scales governing the nucleon-nucleon interaction (adapted from Taketani [5]). The distance r is given in units of the pion Compton wavelength, $\mu^{-1} \simeq 1.4$ fm.





PRL 99, 022001 (2007) PHYSICAL REVIEW LETTERS week ending 13 JULY 2007

Nuclear Force from Lattice QCD

N. Ishii, S. Aoki, and T. Hatsuda

We want to study isospin structure of the SRC pairs by measuring ratios:

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

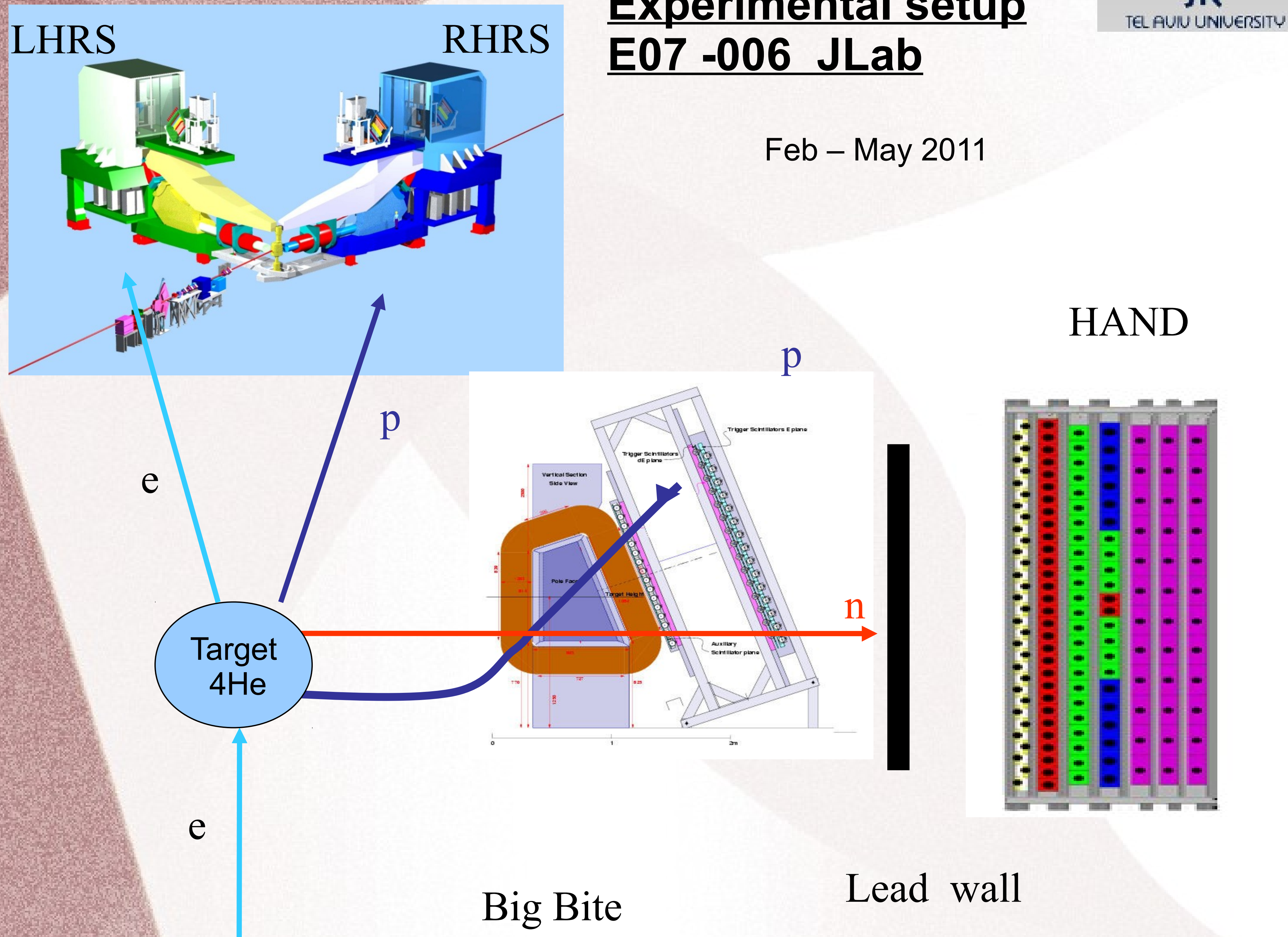
Triple to double ratios

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

Triple to triple ratio

Experimental setup E07 -006 JLab

Feb – May 2011



Experimental setup – continued

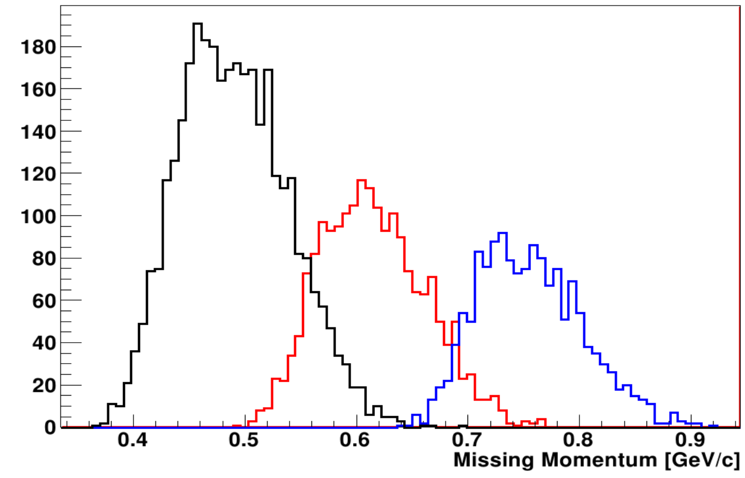
BigBite: Use of MWDC instead of auxiliary plane – Improve momentum resolution

HAND: Two additional scintillator planes
Thinner lead wall

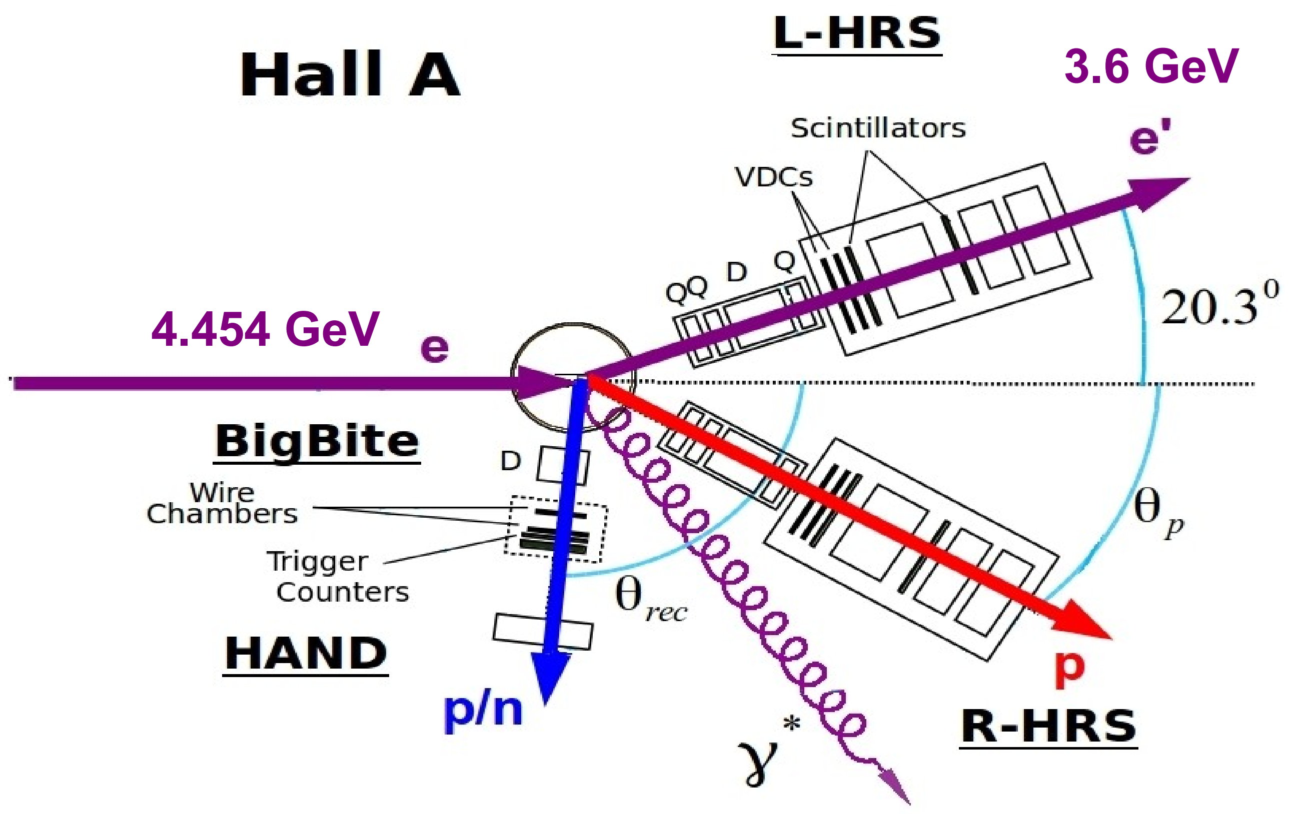
} Increase neutron detection efficiency

Target: $^{12}C \longrightarrow {}^{4}He$ Less FSI and can be treated more easily theoretically

Three Kinematic settings:

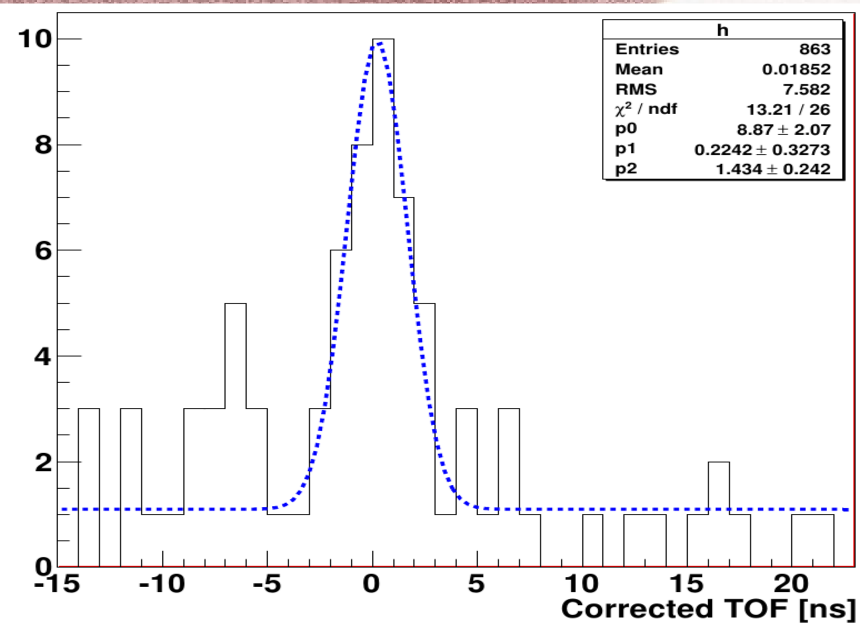


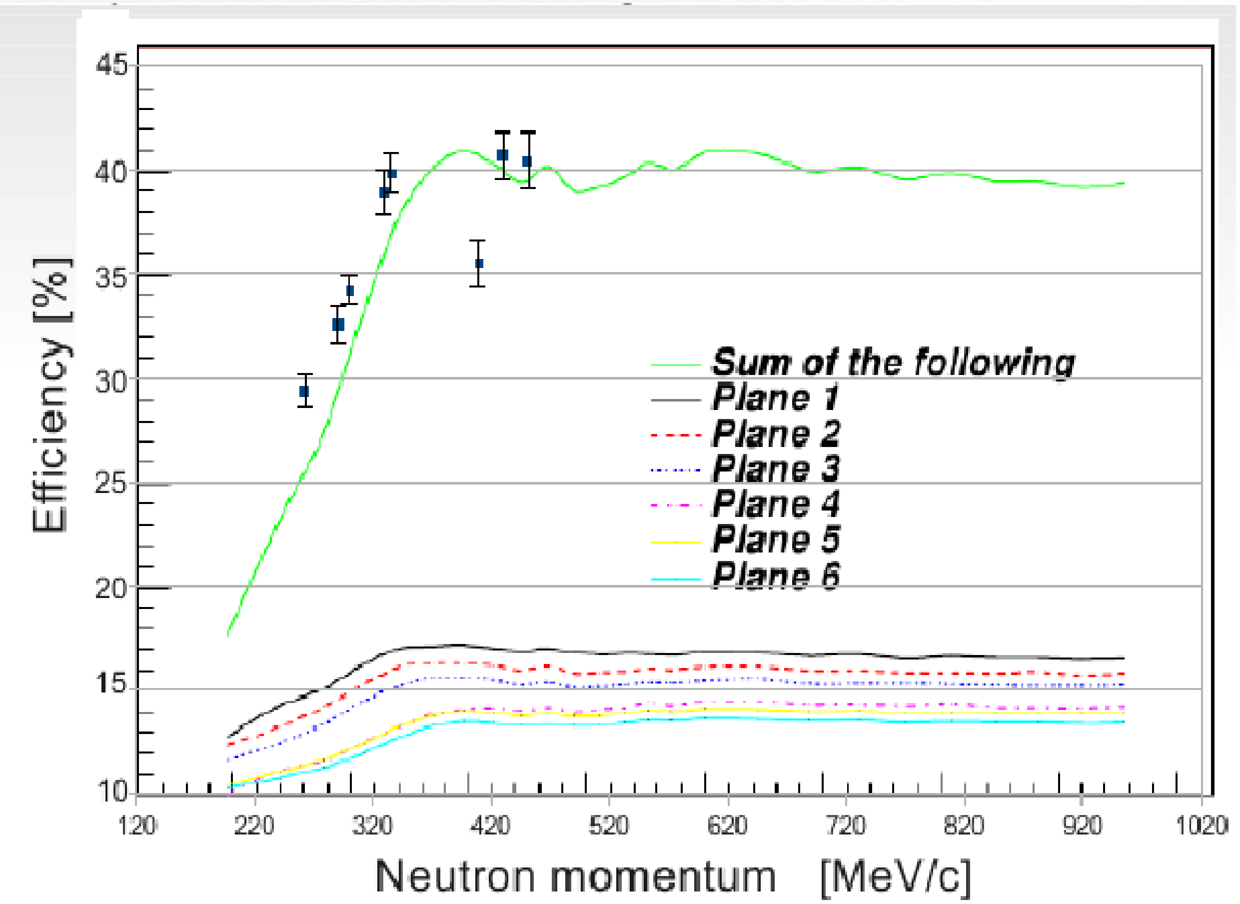
"500" MeV/c, **"625"** MeV/c
and **"750"** MeV/c



HAND analysis

d(e,e'pn)





$\sigma \approx 1.5\,ns$

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

Momentum: 400 – 850 MeV/c

Δp/p 2.5% - 5%

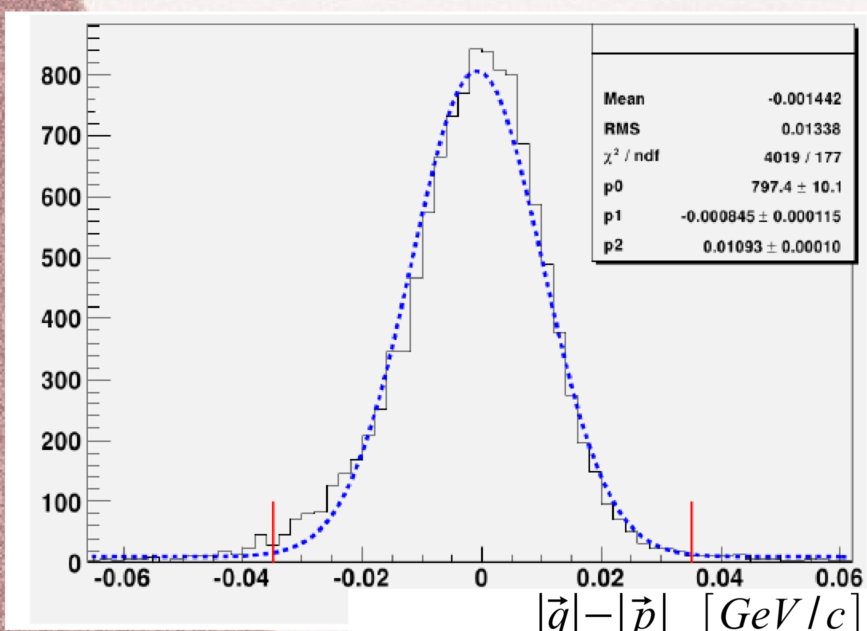
Efficiency:

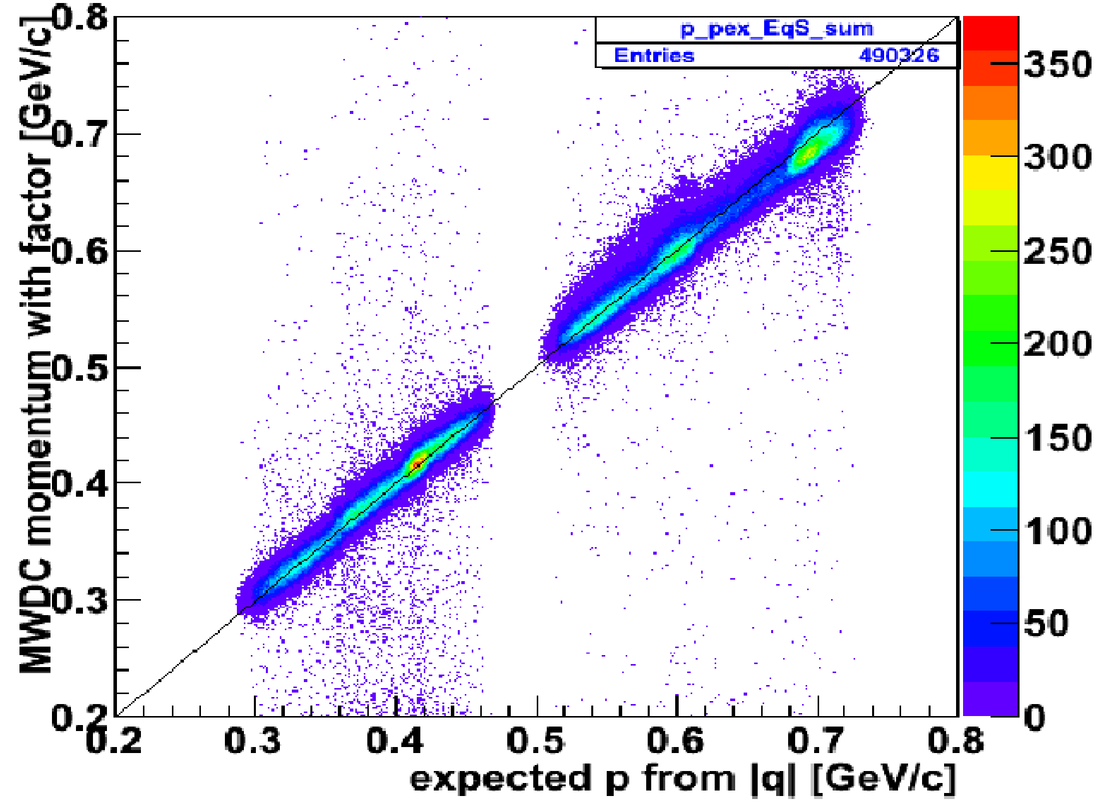
40 ± 1.4%

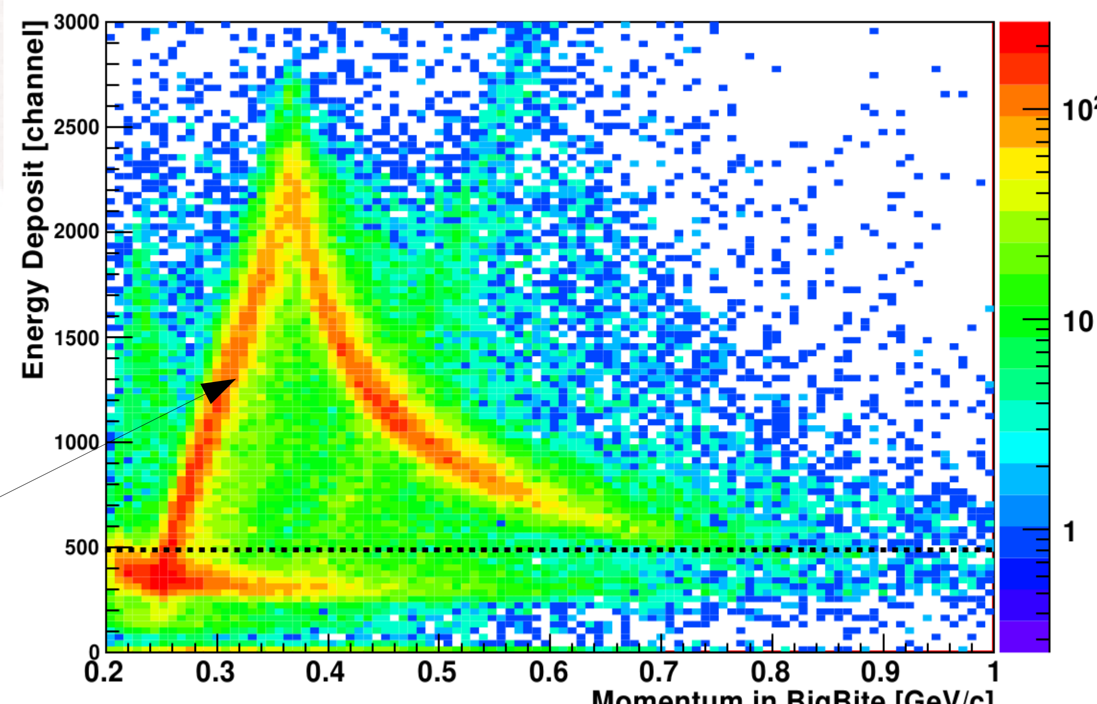
BigBite Spectrometer

Momentum determination using MWDC – curvature in the magnetic field.

$$\frac{dp}{p} \approx \frac{10}{650} \quad [MeV/c] \quad \approx 1.5\%$$







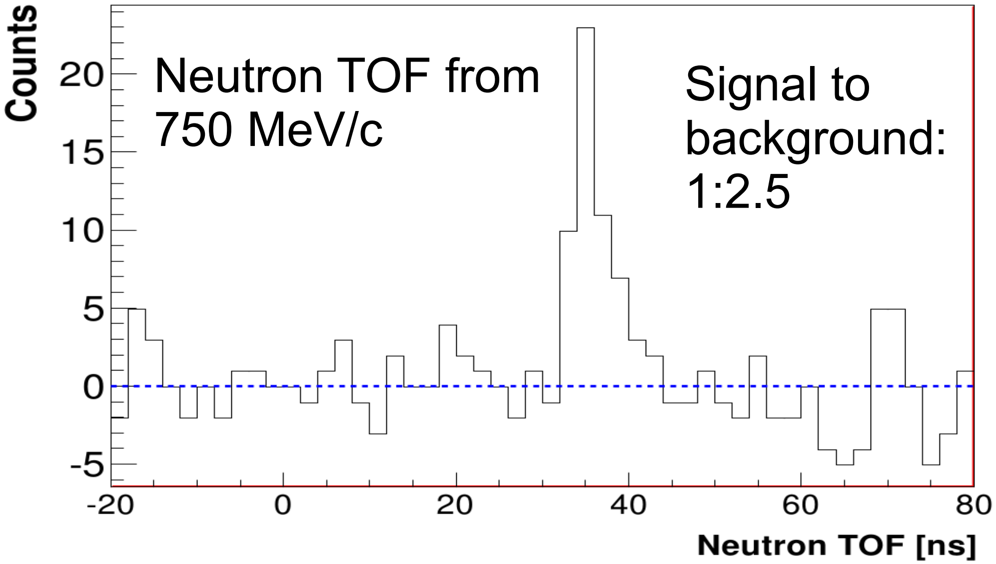
Protons

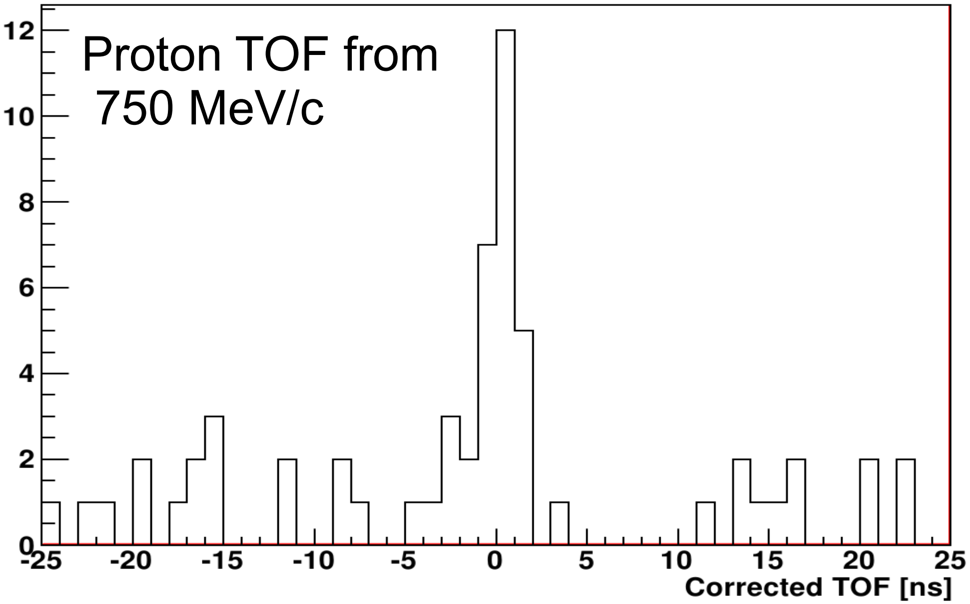
Results - Triple coincidence events

$$x_B > 1$$

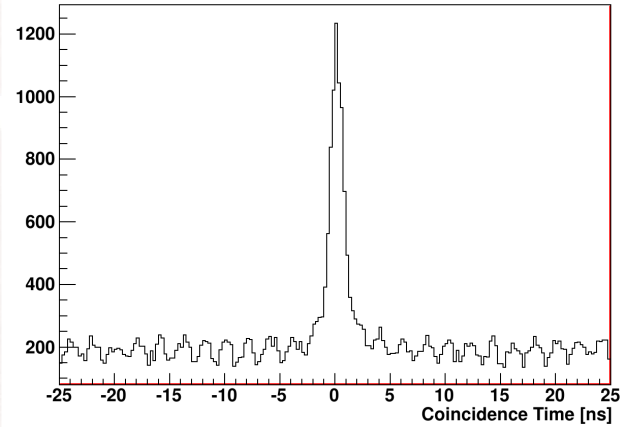
$$Q^2 \approx 2\left(GeV/c\right)^2$$

Event selection based on the TOF peak

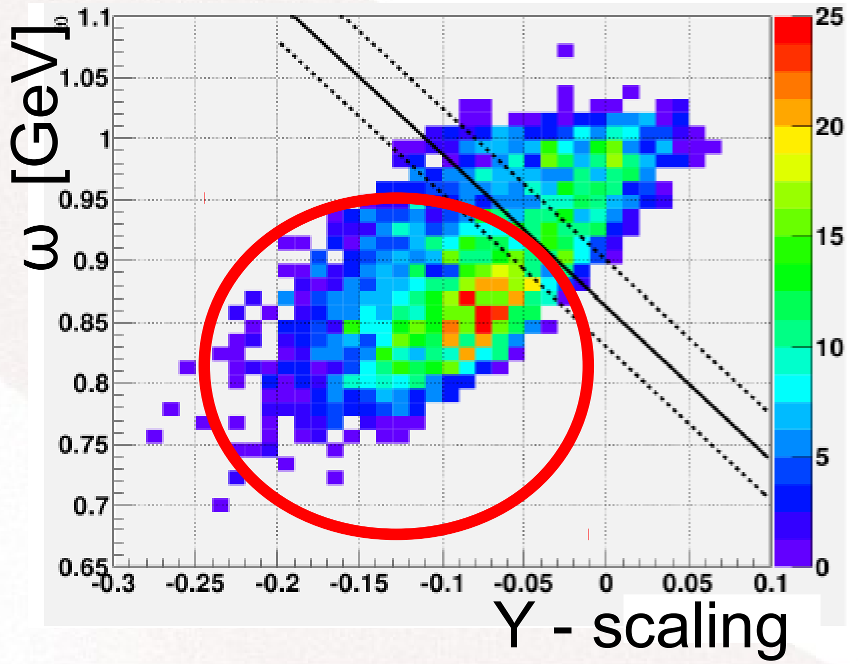




(e,e'p) coincidence time



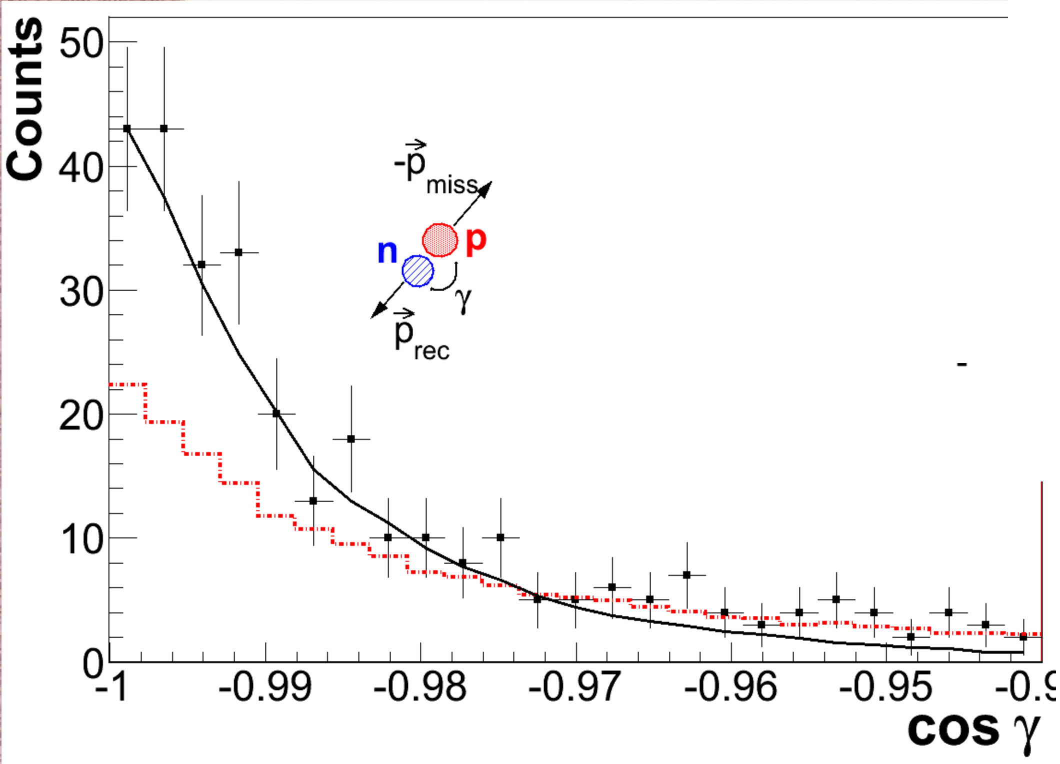
Quasi elastic (e,e'p) events selection

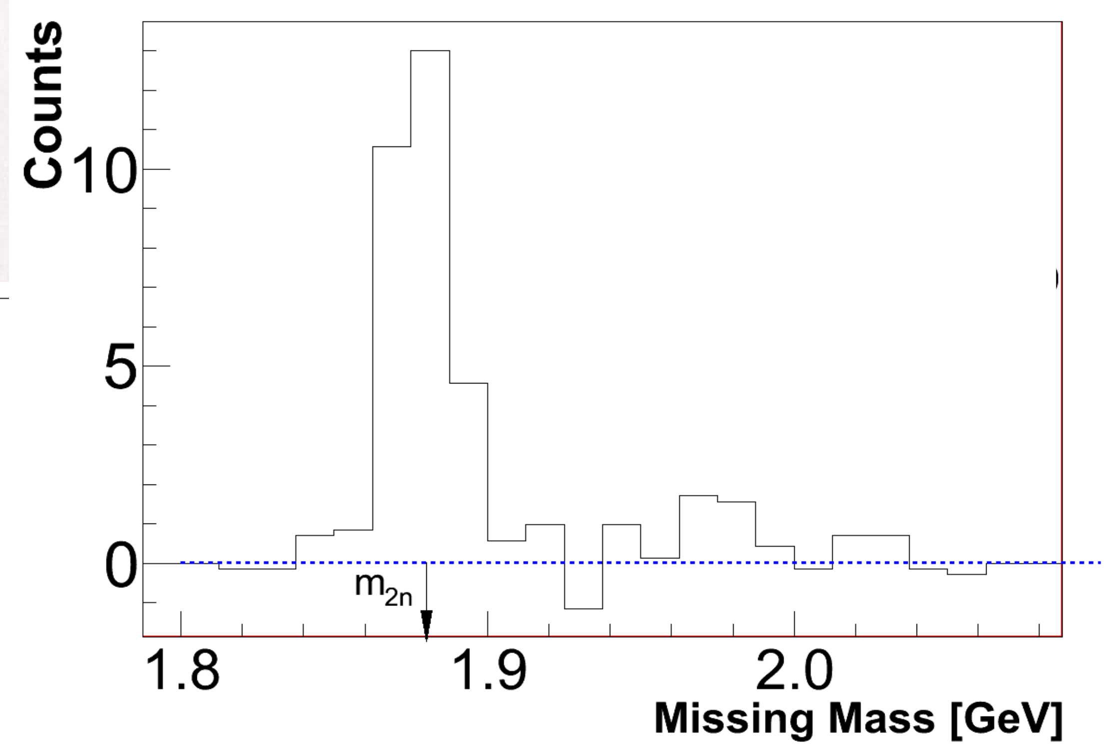


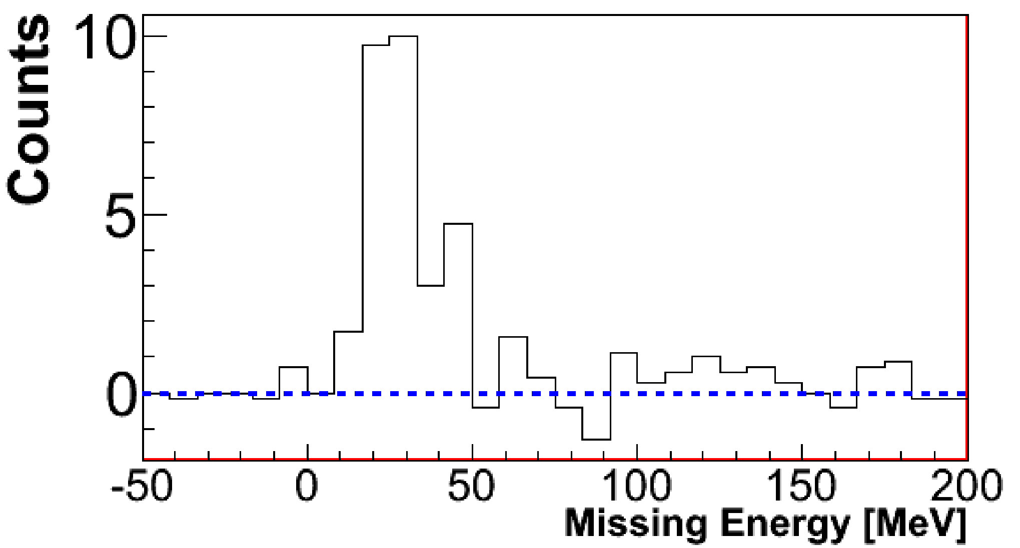
Results – Identification of SRC pairs

$$M=\sqrt{(\omega-m_{^4He}-E_f-E_{rec})^2-(\vec{q}-\vec{p}_f-\vec{p}_{rec})^2}$$

- Opening angle – Back to Back
- Missing mass – Two nucleons in FS
- Missing Energy – Low excitation energy







FSI – Transparency and SCX

TEL AVIV UNIVERSITY

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

Extracted

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

Measured

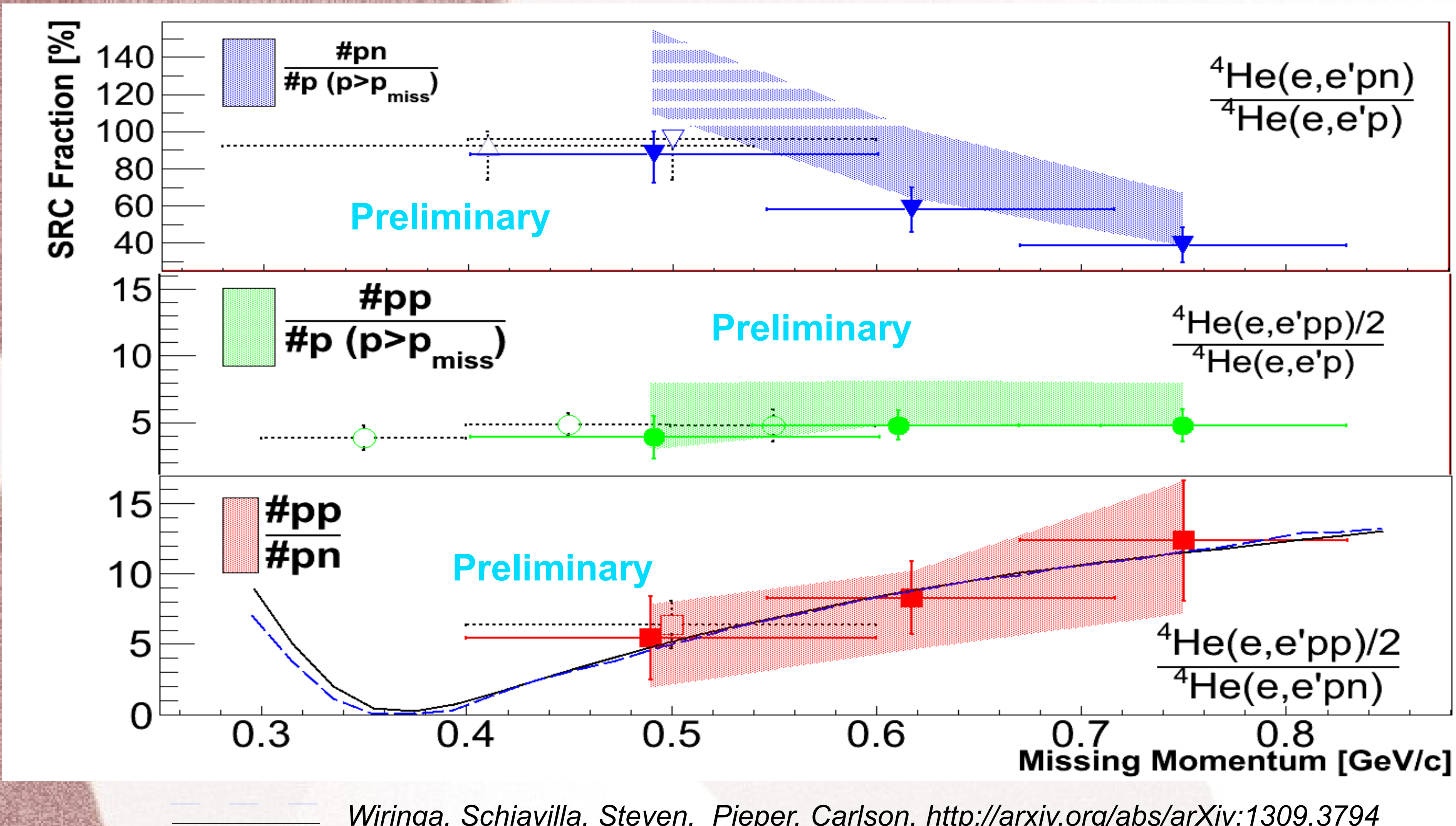
For Triple to double ratios we solve simultaneously:

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

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

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

Results



Wiringa, Schiavilla, Steven, Pieper, Carlson, http://arxiv.org/abs/arXiv:1309.3794

With increasing Pmiss

pp/ # np increase (As predicted by AV 18)
pp is constant (Dominated by the repulsive core)
np decrease (FSI and/or 3N Correlations)

Summary

We observe a change in the pp-SRC/np-SRC ratio indicating a transition from the dominate tensor NN force to the repulsive interaction

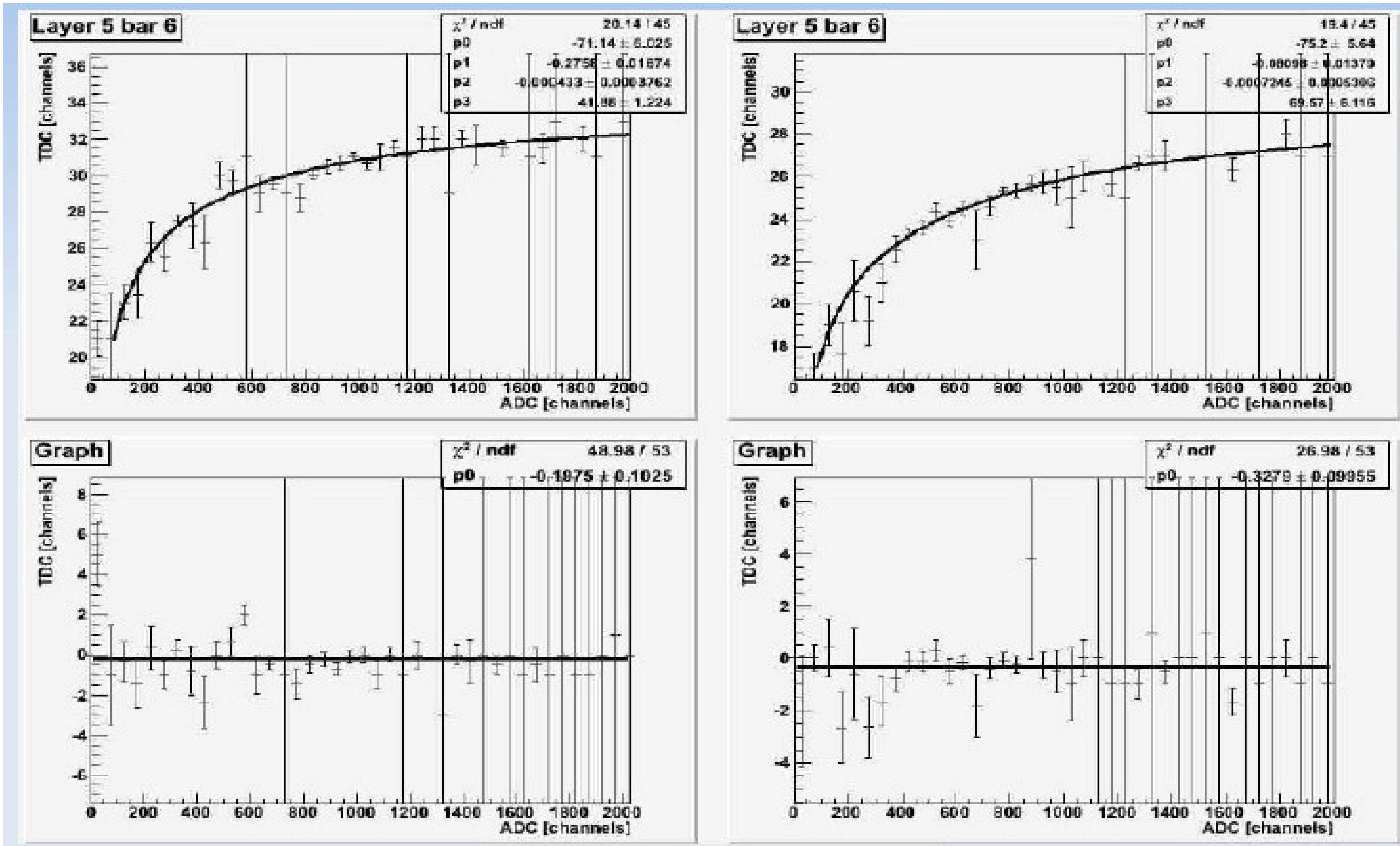
- We plan to publish the results presented here within 1-2 months
- Additional analysis on the (e,e'p_recoil) and (e,e'n_recoil) reactions is in progress (Navaphon Muangma from MIT).

Thank you!

TDC calibration

Relative time calibration using elastic protons

Time walk correction



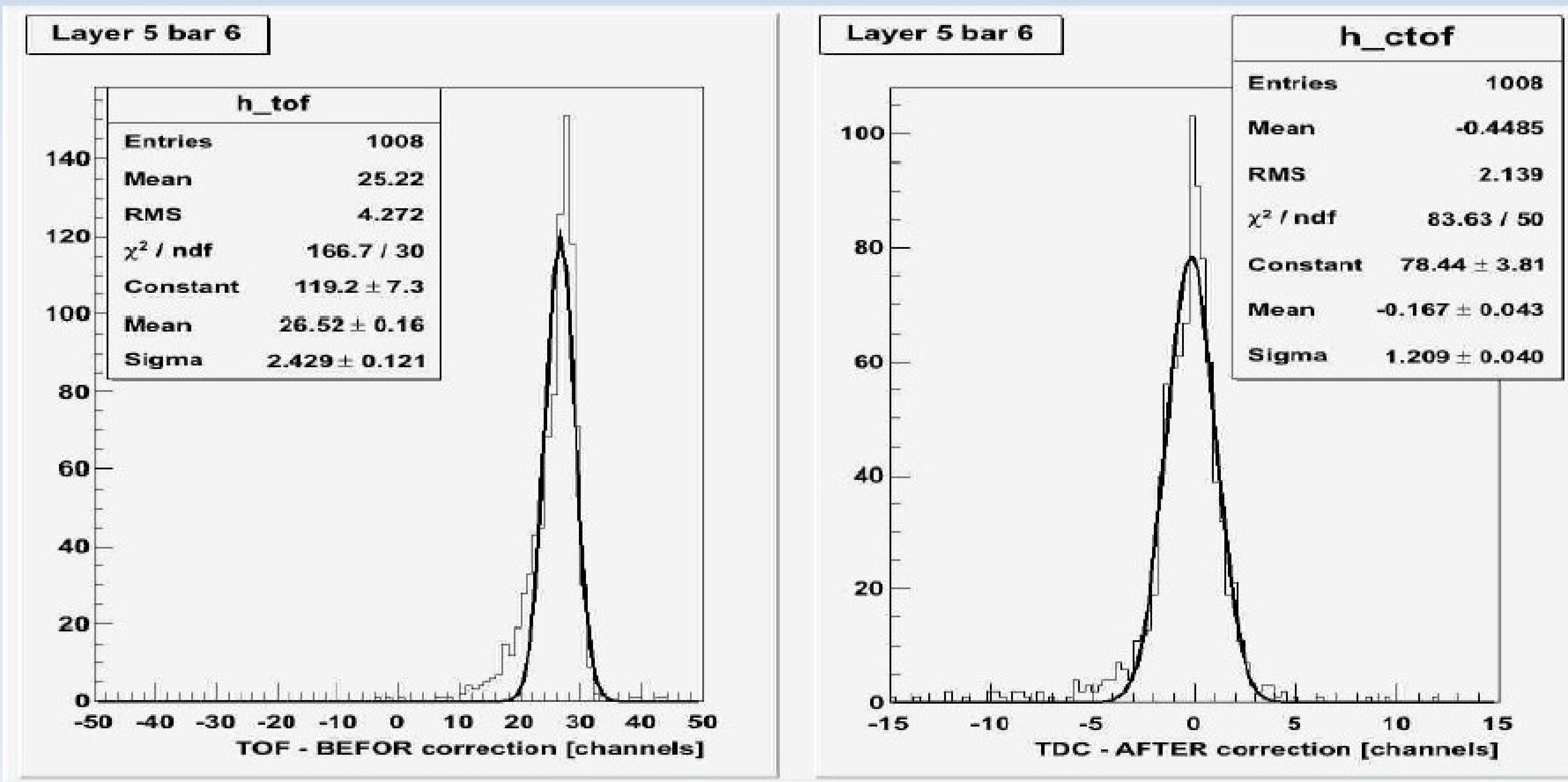
$$TDC = a * X^{b} + c * X + d$$

TDC calibration - Continue

TOF resolution for single bar before and after the correction

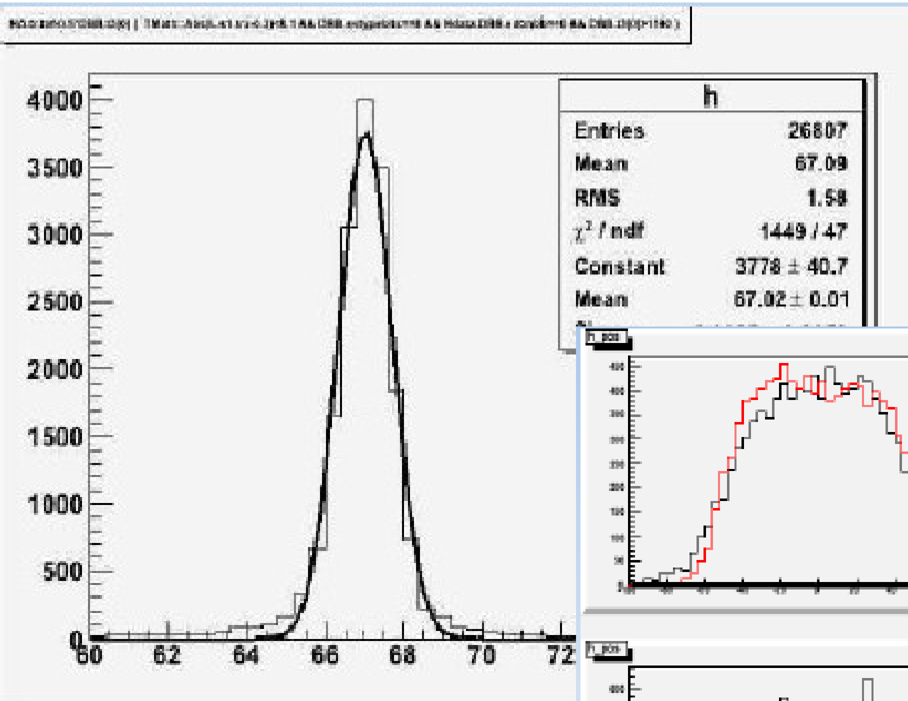
Before — After

Sigma = 1.2 [ns] — Sigma = 0.6 [ns]

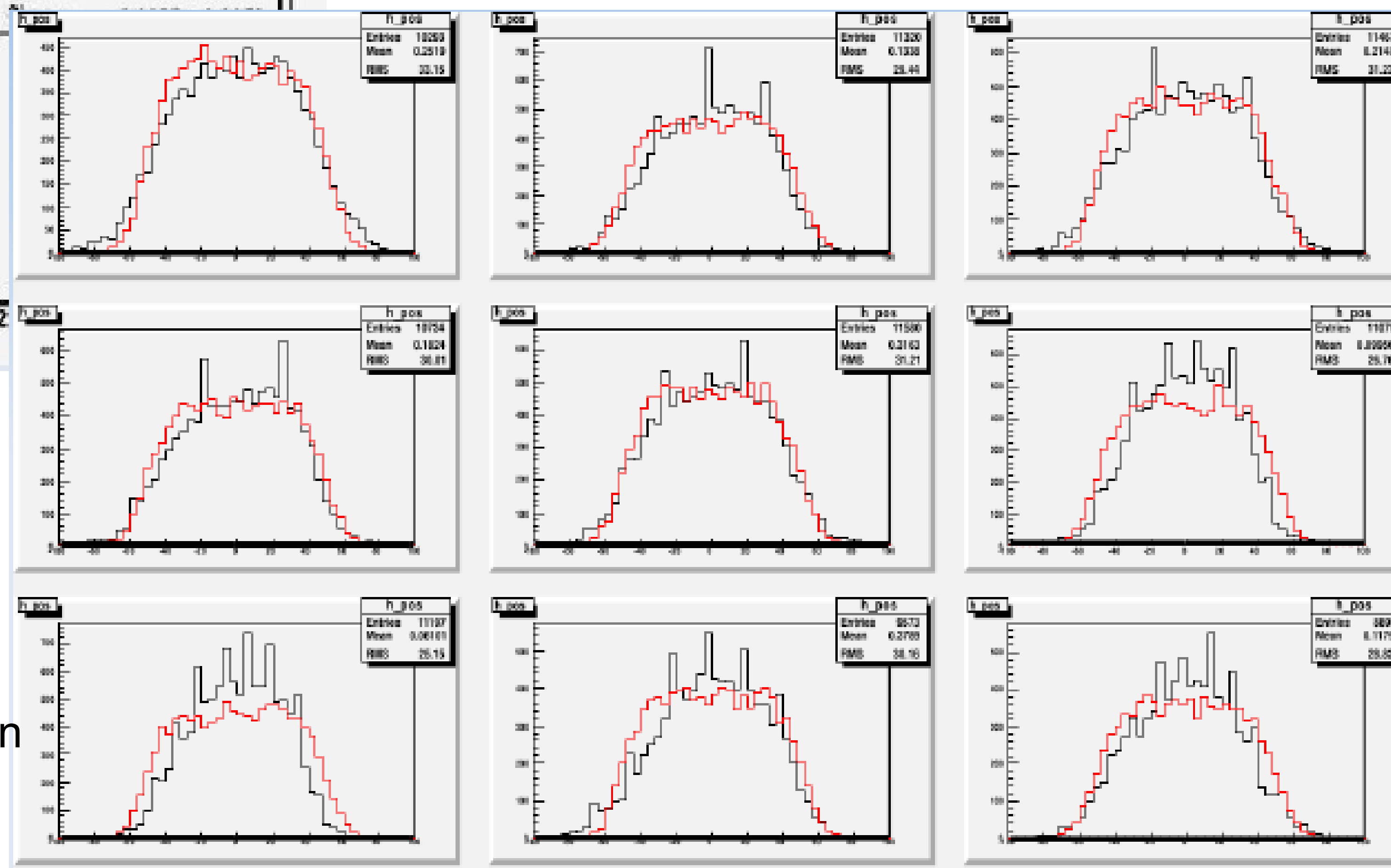


TDC calibration - Continue

Relative time calibration using elastic protons



TOF resolution after alignment of all bars: **0.68 ns**



Position distribution:

Black – Data

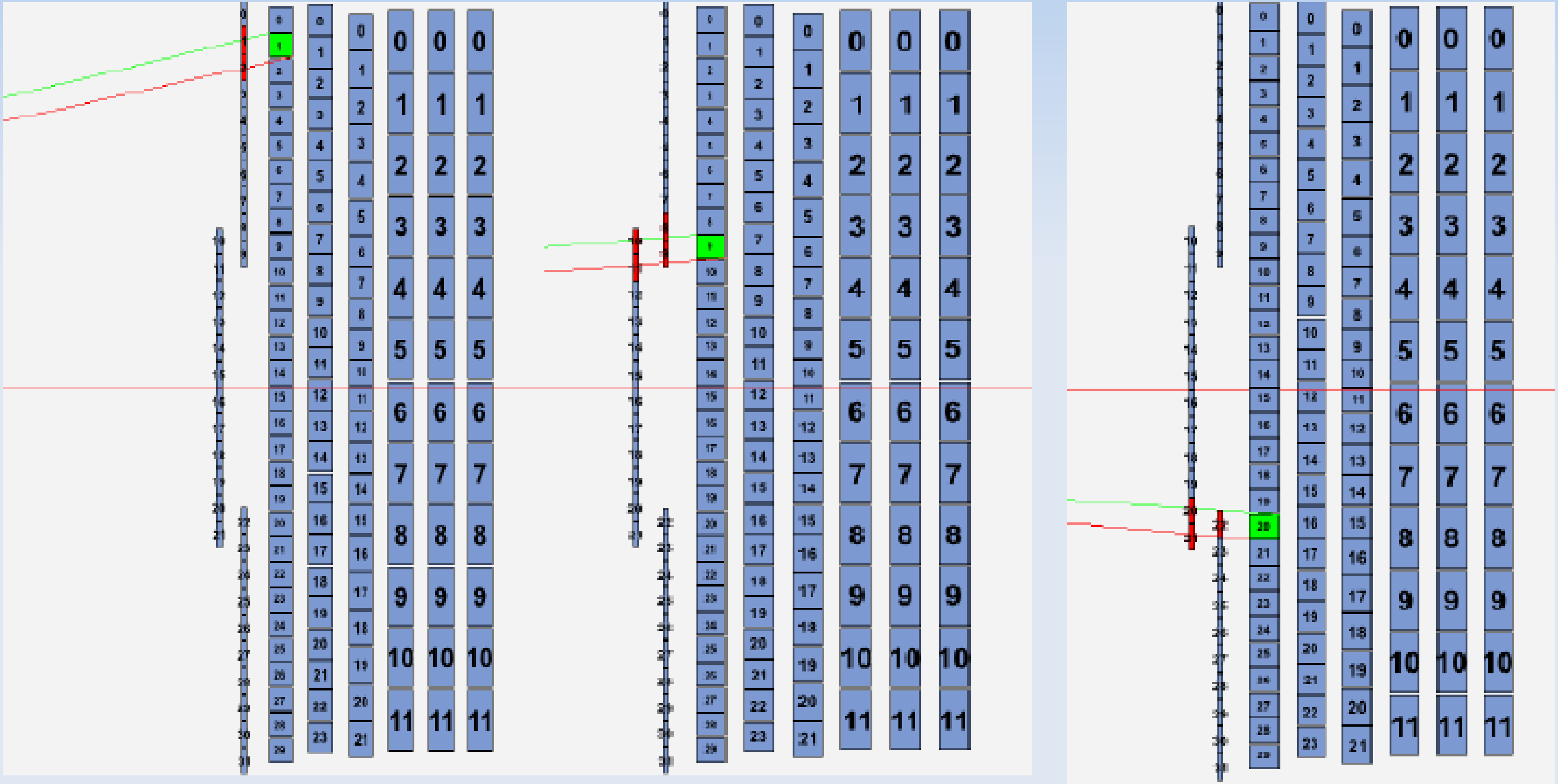
Red – Theoretical position distribution with same number of events

Neutron identification

Neutron is defined as a hit if there is no hit in space and time in the matching bar in the preceding layer (blocking bar)

Event viewer created:

Green bar: examined bar
Red bar : blocking bar



Neutron Efficiency

Efficiency measurements at two kinematical settings:

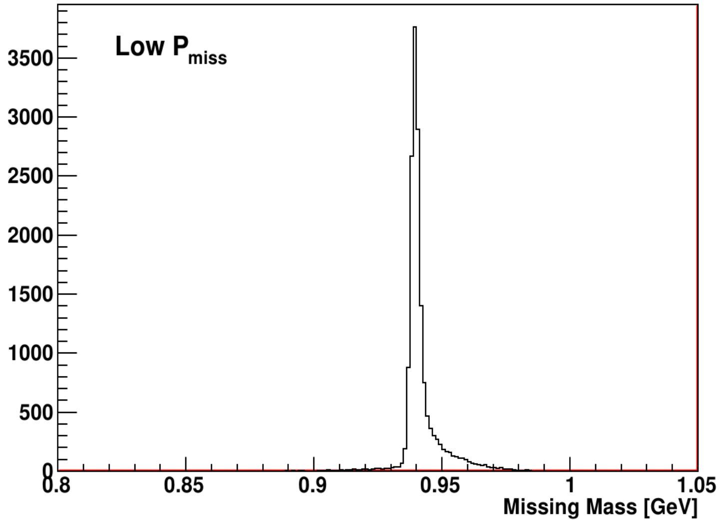
- Pmiss ~ 300 MeV/c
- Pmiss ~ 440 MeV/c

Efficiency determined by comparing the number of (e,e'p) events to (e,e'pn) events

Target: LD2
HRS-R – detected electrons (contrary to protons during the production)

In order to define a valid (e,e'p) event following cuts are used:

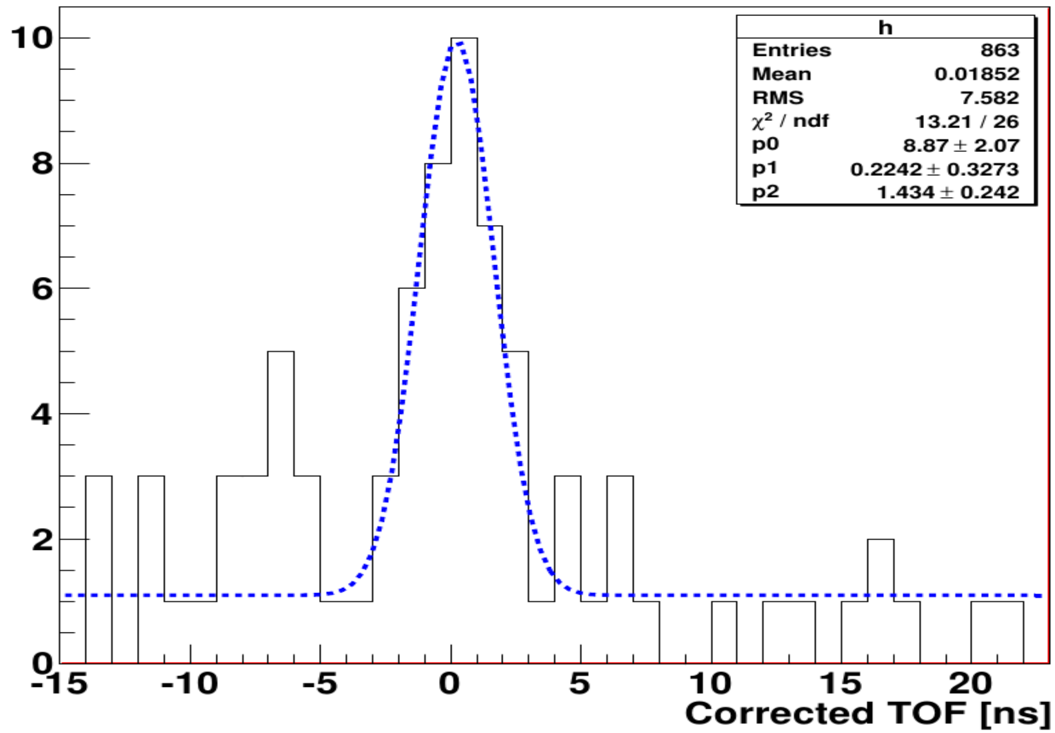
- Missing mass
- Coincidence Time (e,e'p)
- Nominal HRSs cuts
- Vertex Cuts
- Spatial direction of Pmiss

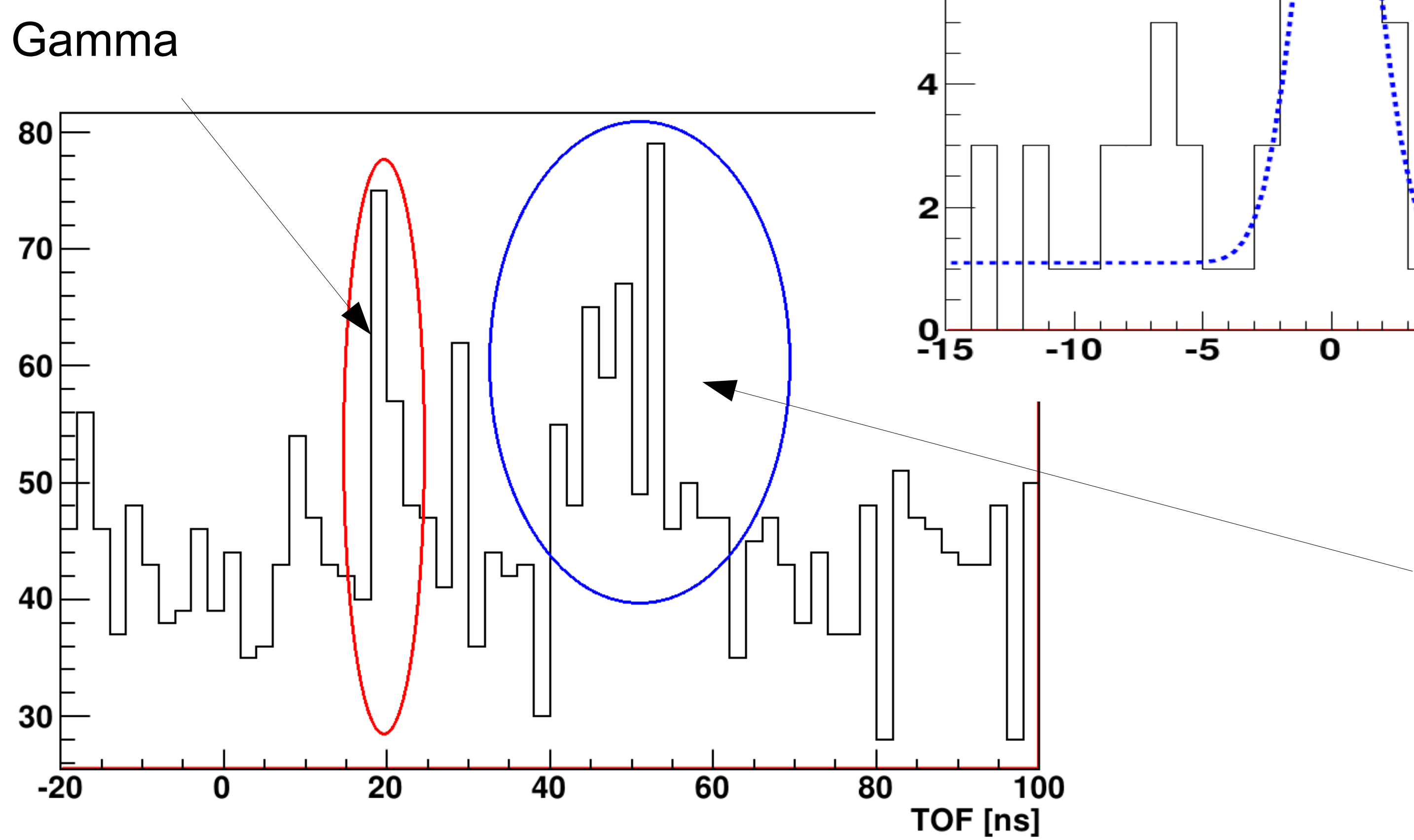


Absolute timing determined using the exclusive scattering from Deuterium when LHRS detected electrons and carried the time during the production.

HAND was already calibrated with elastic protons, so only global offset needed to determine the absolute time.

Correction using the Pmiss information





Gamma Peak

In addition to exclusive scattering. High energy photons arrive to detector at the same time during the production

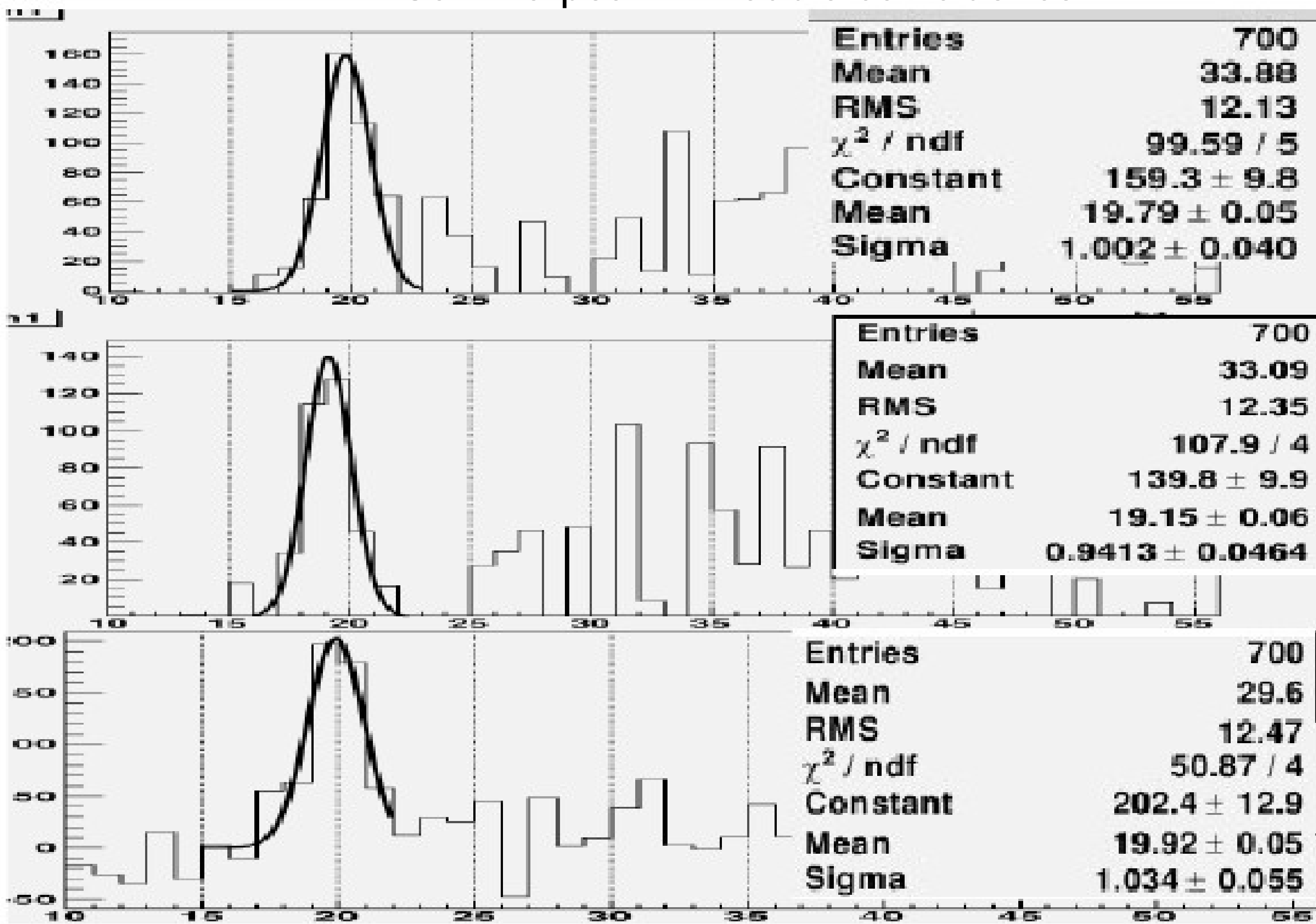
Settings

500 MeV/c

625 MeV/c

750 MeV/c

Gamma peak in Double coincidence



Hits Matching

In order to define a proton we must match the hits in MWDC to the hits in the Trigger plane

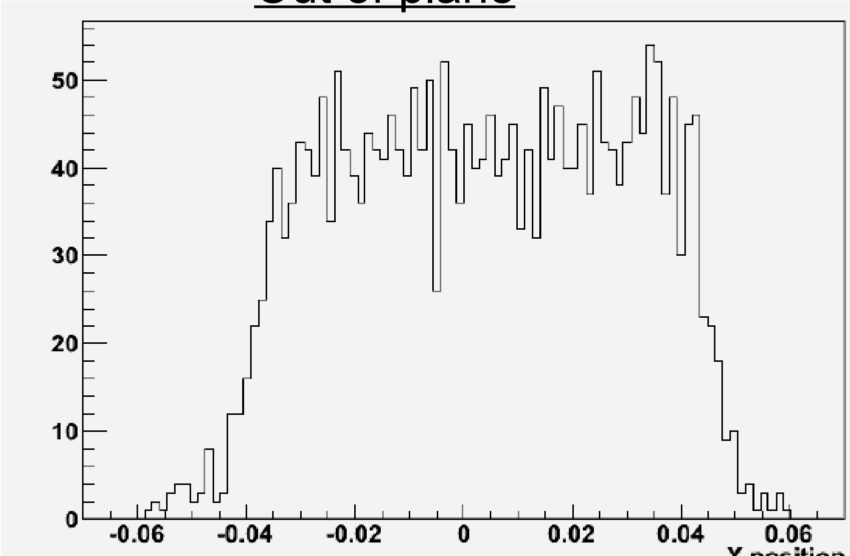
Matching algorithm:

1) for each reconstructed track check if there is a hit in E plane

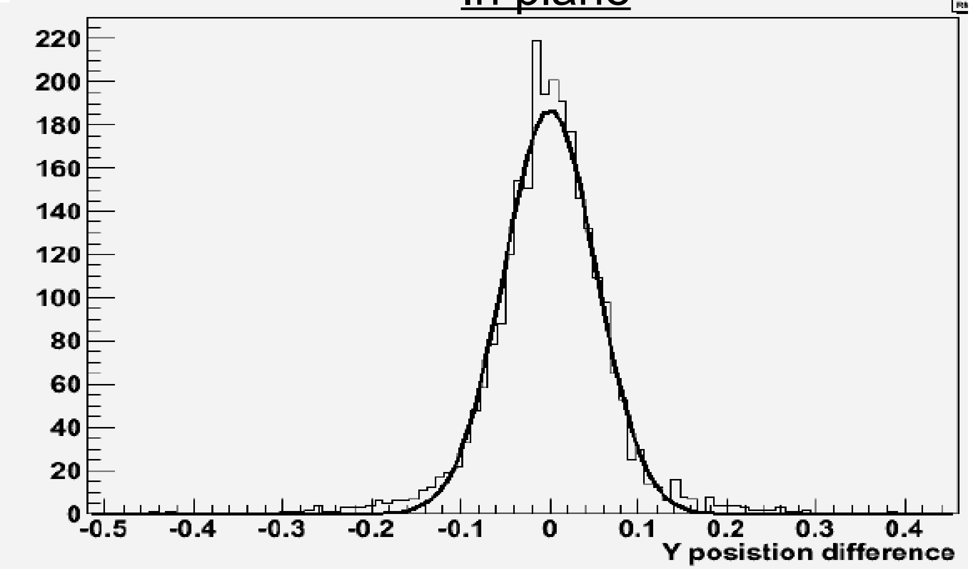
2) If there is no hit in E plane, than check if there is hit in dE plane

Matching between the track from the MWDC and Trigger plane

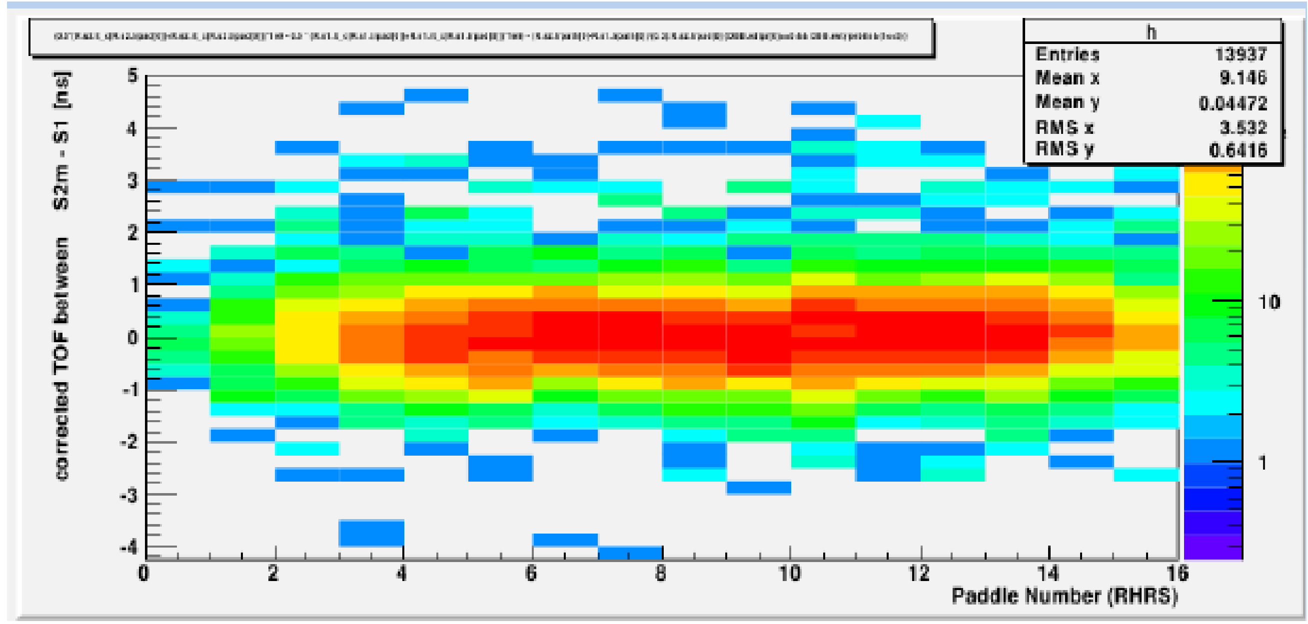
Out of plane



In plane

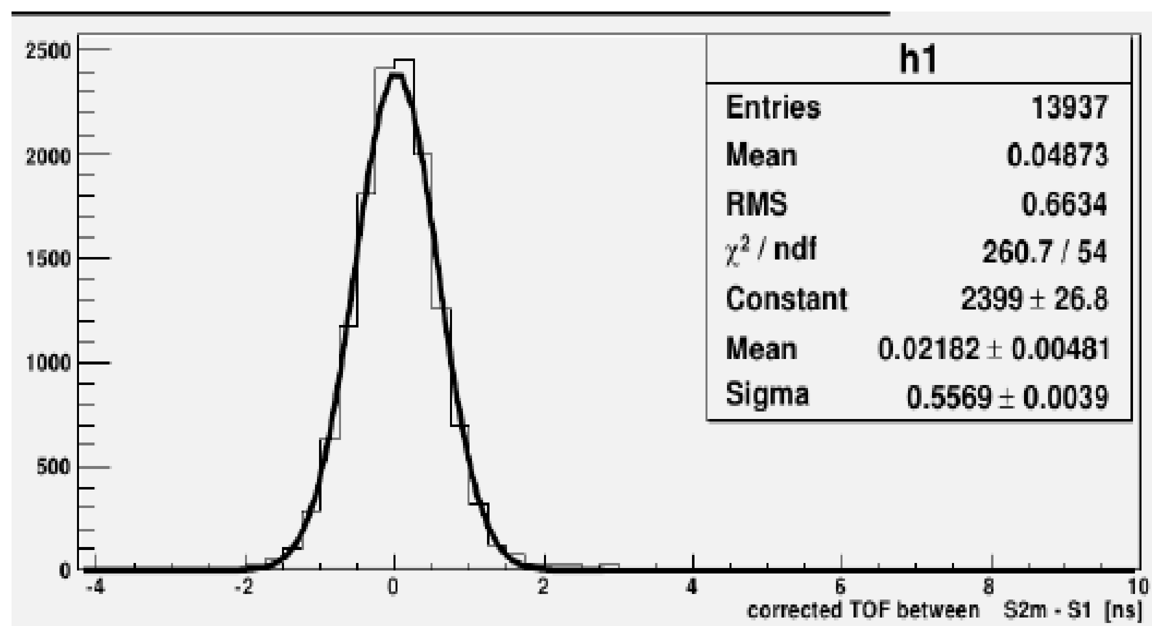


HRS – Calibrations



Alignment of all TDCs to generate signal in the same time with no dependence on the paddle that was hit.

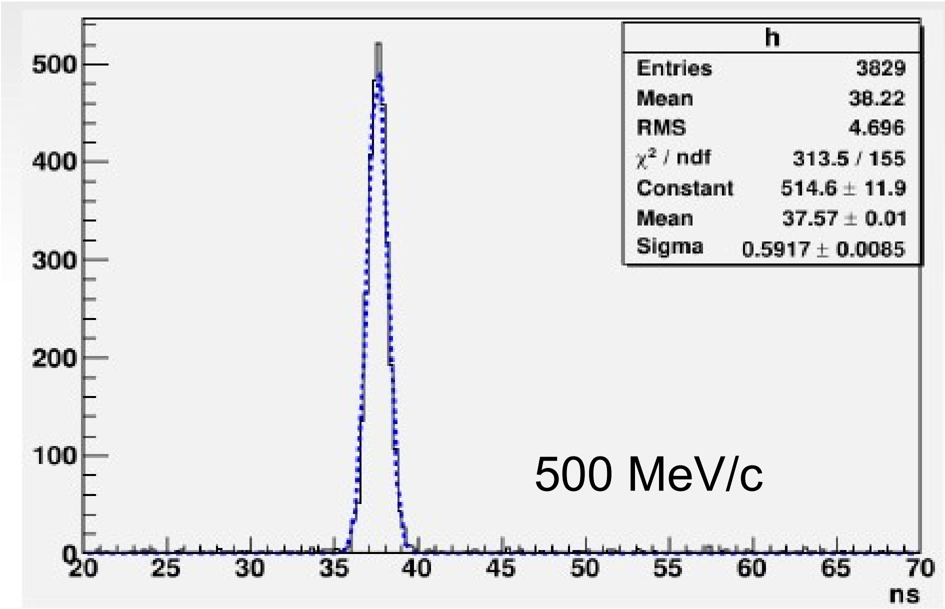
Example for RHRS

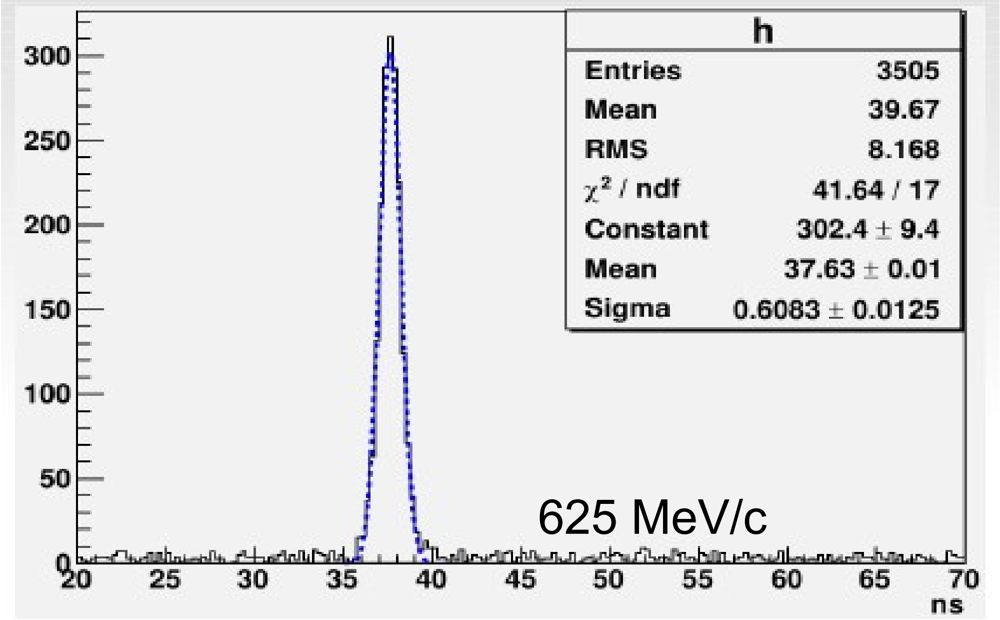


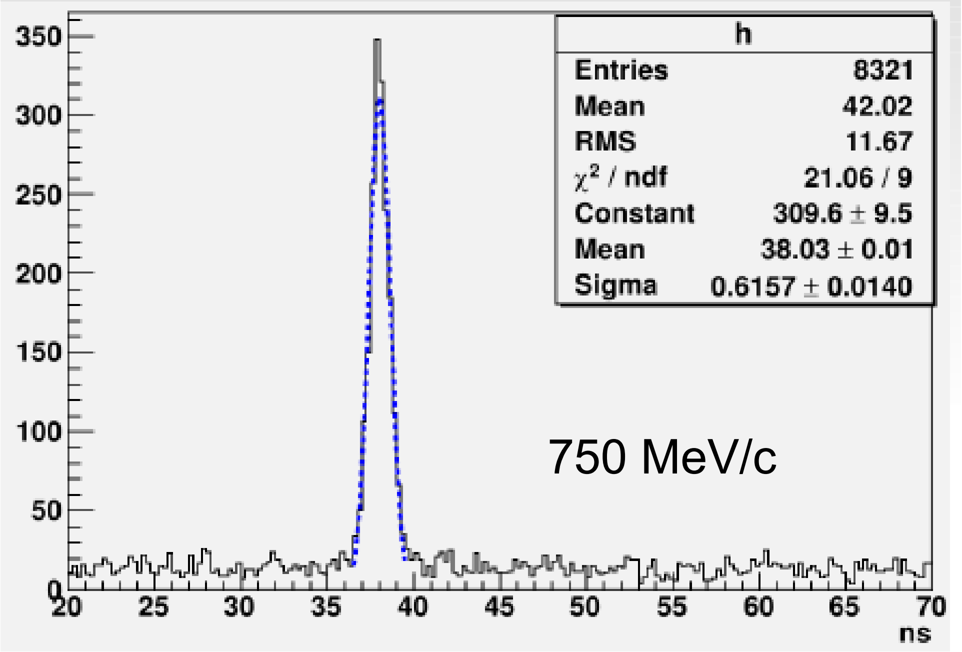
Event Selections

(e,e'p) events are the basis for the analysis. Cut that used to choose these events are:

- Nominal HRSs cuts
- Coincidence Time
- Vertex cut
- Vertex difference between L-HRS and R-HRS
- Two dimensional cut on Y scaling and omega

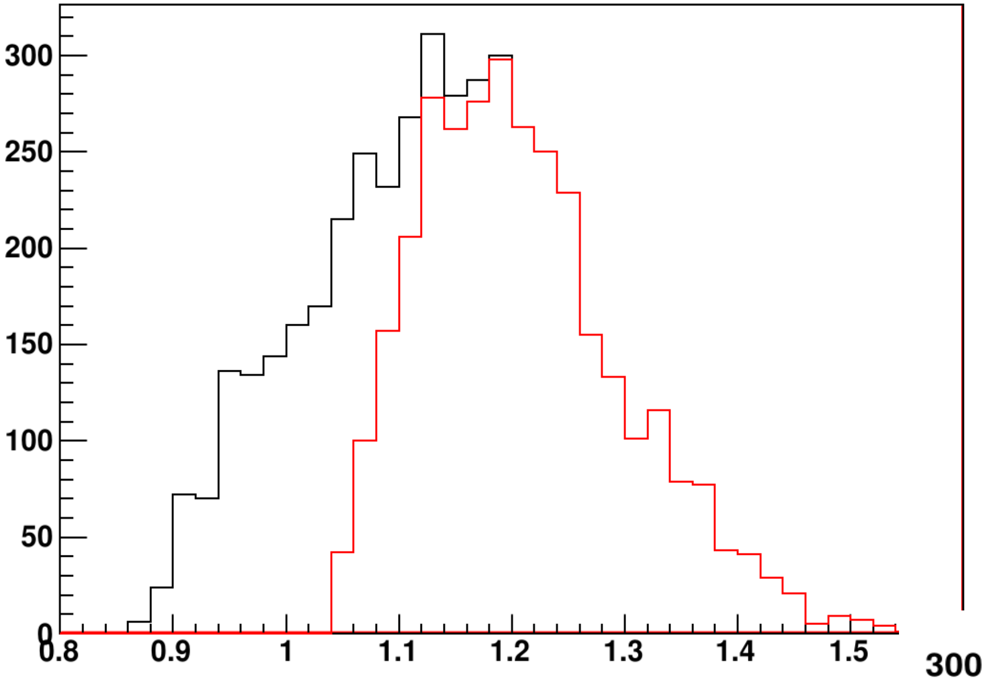






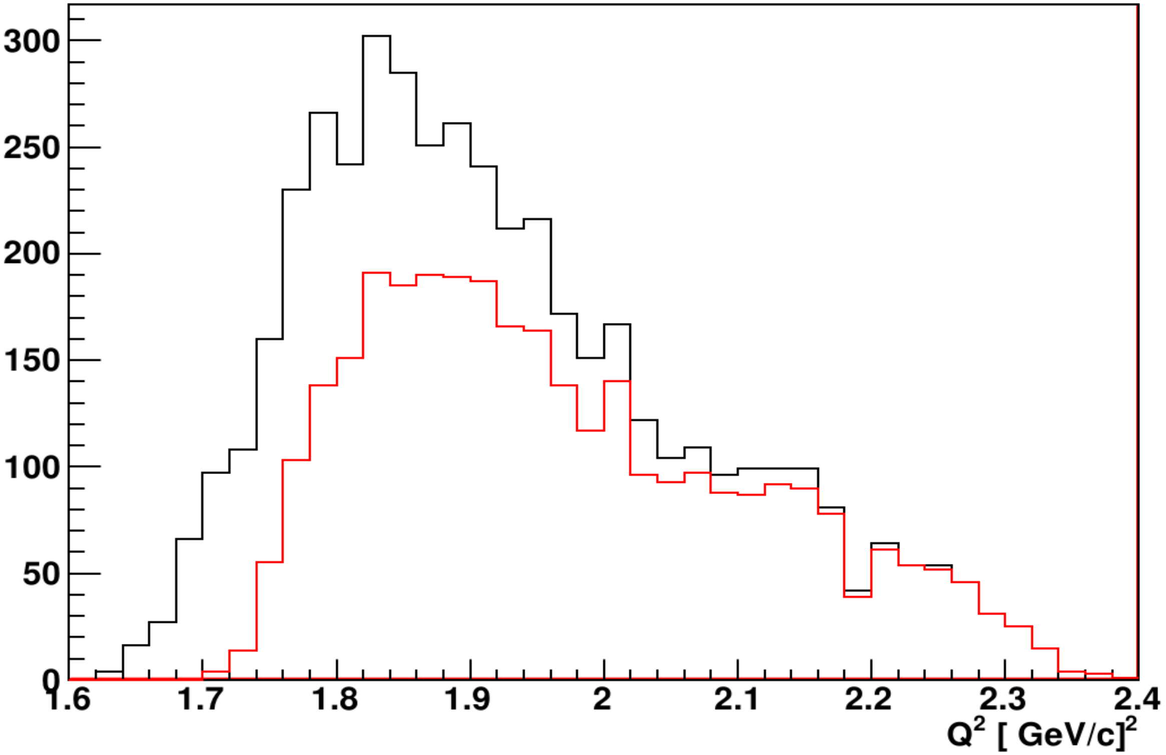
Background ~ 9%!

By applying Y scaling – Omega cut on the data



X Bjorken

Q2



Neutron TOF with background subtraction