E08-005: A_y^0 in Quasi-Elastic ^{3}He$(e,e'n)$ Scattering

Elena Long

Hall A Collaboration Meeting

December 17th, 2013

Today's Discussion

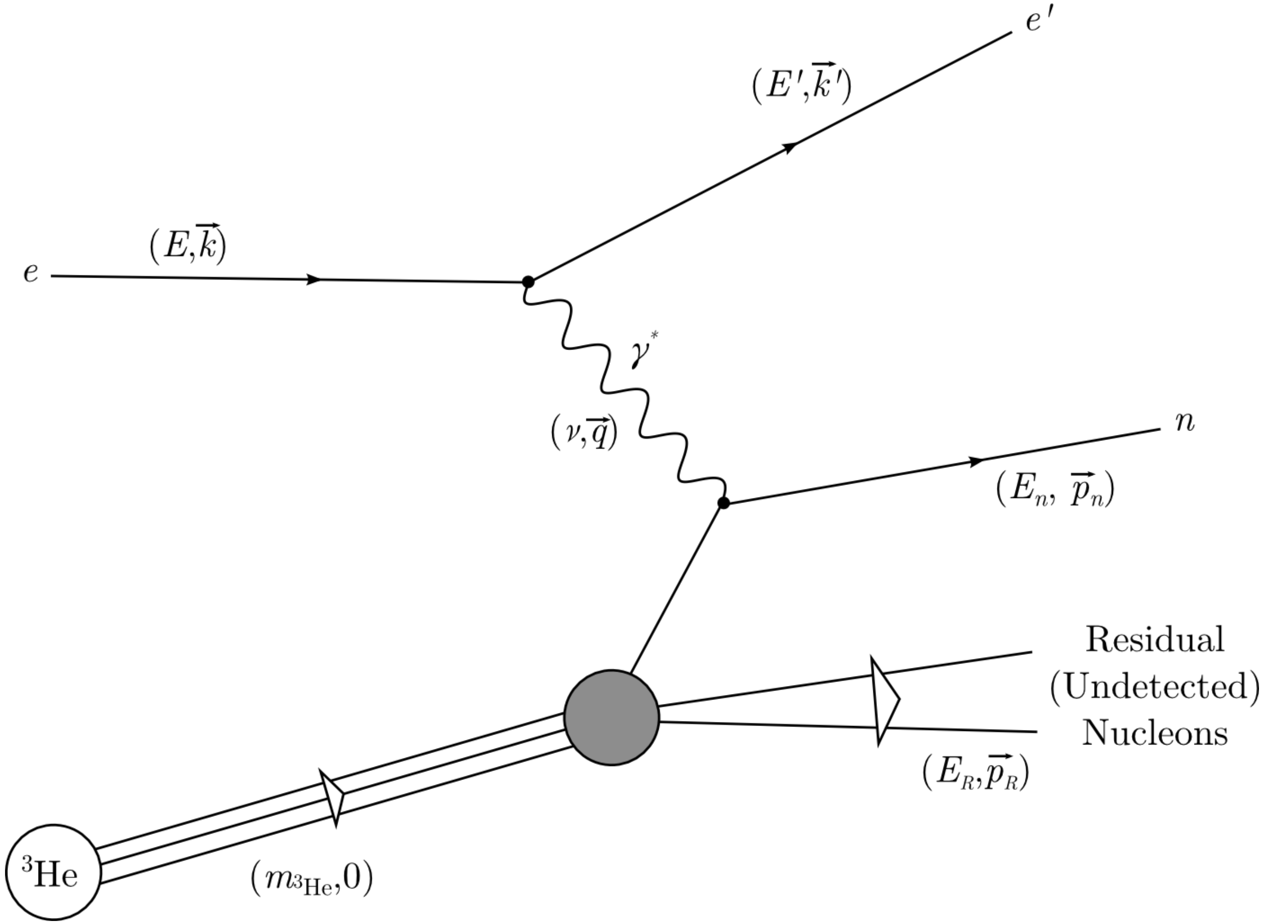
- Brief background of the physics
- Experimental method
- Summary of past analysis
- Summary of recent analysis
- Results

$$\frac{d\sigma(h,\vec{S})}{d\Omega_e dE_e d\Omega_d dp_d} = \frac{d\sigma}{d\Omega_e dE_e d\Omega_d dp_d}\left[1 + \vec{S}\cdot\vec{A}^0 + h(A_e + \vec{S}\cdot\vec{A})\right]$$

$$\vec{A}^0 = \left(\cancelto{0}{A_x^0}, A_y^0, \cancelto{0}{A_z^0}\right)$$

Simple ^{3}He(*e,e'n*) - PWIA

- Ideally, the only interaction that occurs is when the incoming electron hits the neutron
- This model is called Plane Wave Impulse Approximation (PWIA)
- PWIA predicts the single-spin target asymmetry, A_y^0, to be exactly zero

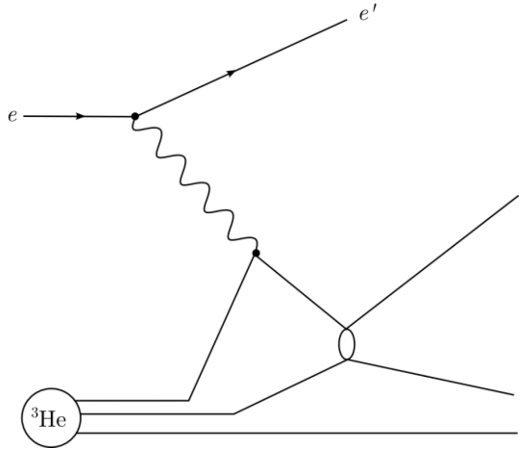


^{3}He(e,$e'n$) Complications

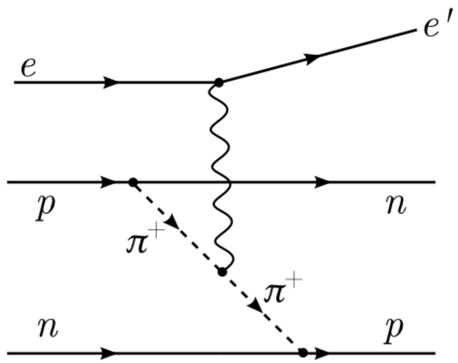
- Since other nucleons exist in the 3He nucleus, they cause secondary effects that must be taken into account

- These effects, particularly FSIs, cause A_y^0 to be non-zero

- Final State Interactions (FSI)



- Meson Exchange Currents (MEC)

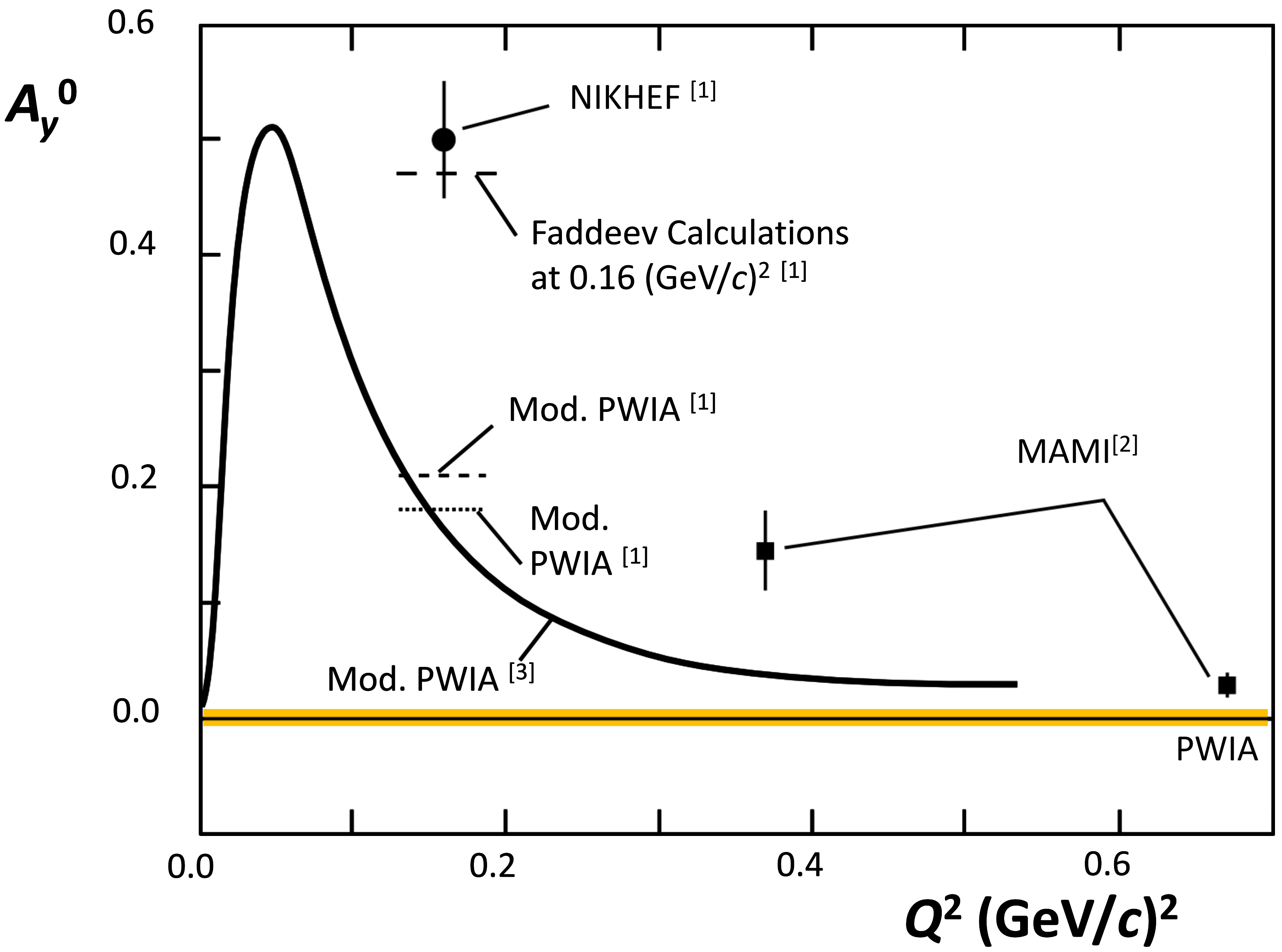


Current Measurements

- A_y^0 data will test state-of-the-art calculations at high Q^2
  - Neutron physics extracted from ^{3}He (such as EM form factors) must correctly predict this asymmetry
- Any non-zero result indicates higher order effects

Historical Data and Models

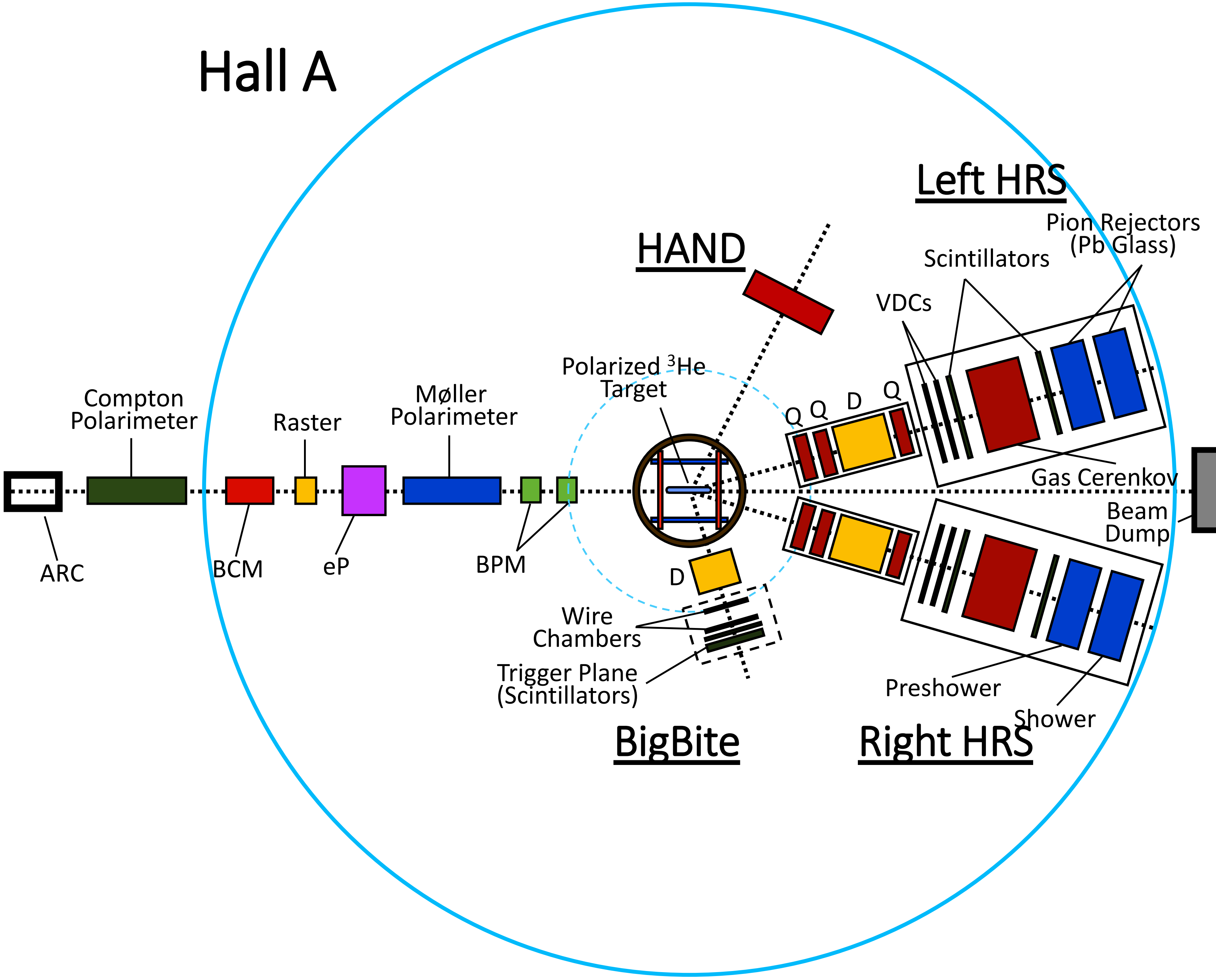
- Faddeev calculations by the Bochum group[4] correctly predicted FSI, where other groups expected a much lower value



[1] H.R. Poolman, Ph.D. Thesis, Vrije Universiteit, 1999.
[2] J. Bermuth *et al.*, Phys. Lett. **B**564, 199 (2003).
[3] J.M. Laget, Phys. Lett. **B**273, 367 (1991).
[4] J. Golak *et al.*, Phys. Rev. **C**65, 044002 (2002).

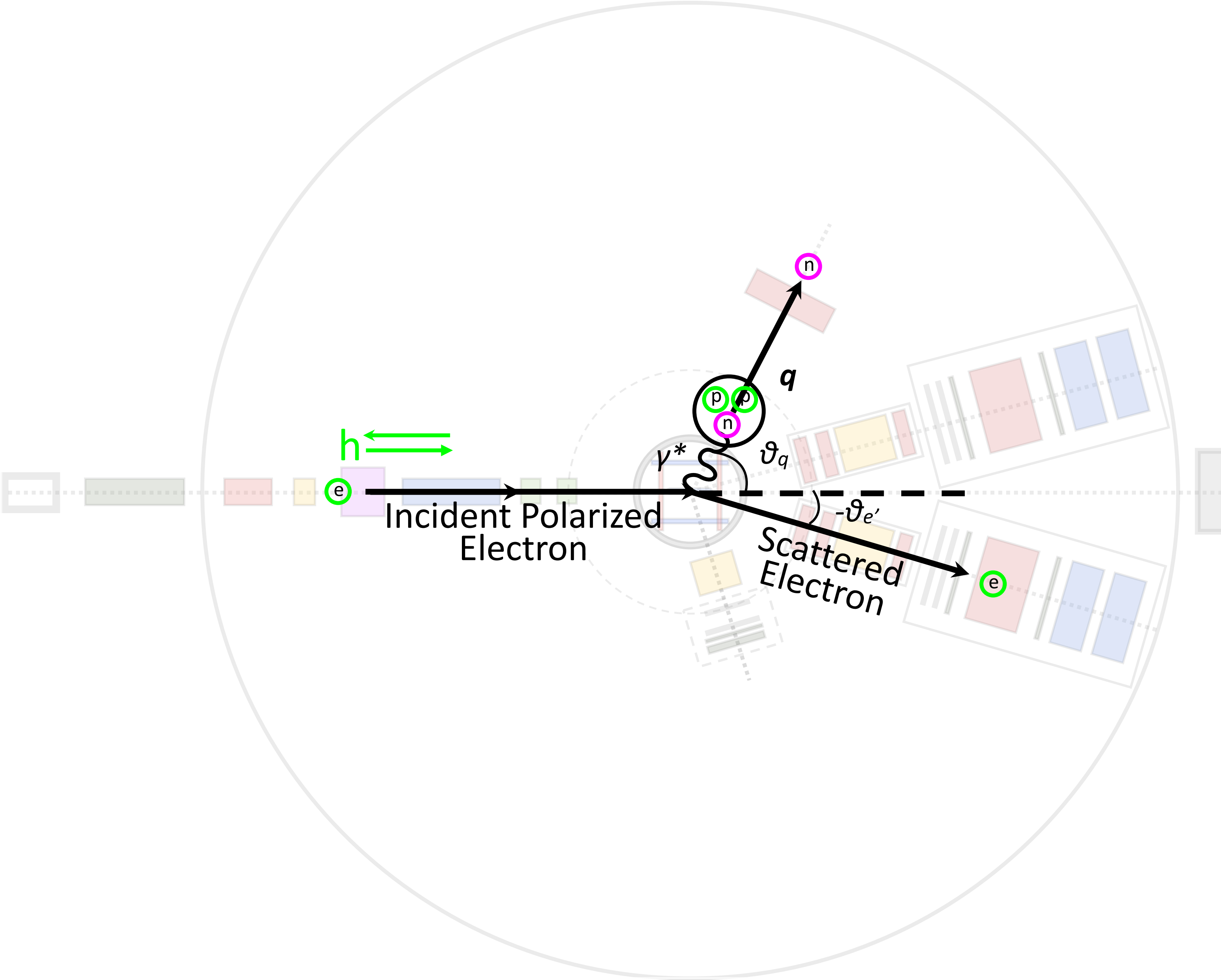
The Measurements

Hall A



The Measurements

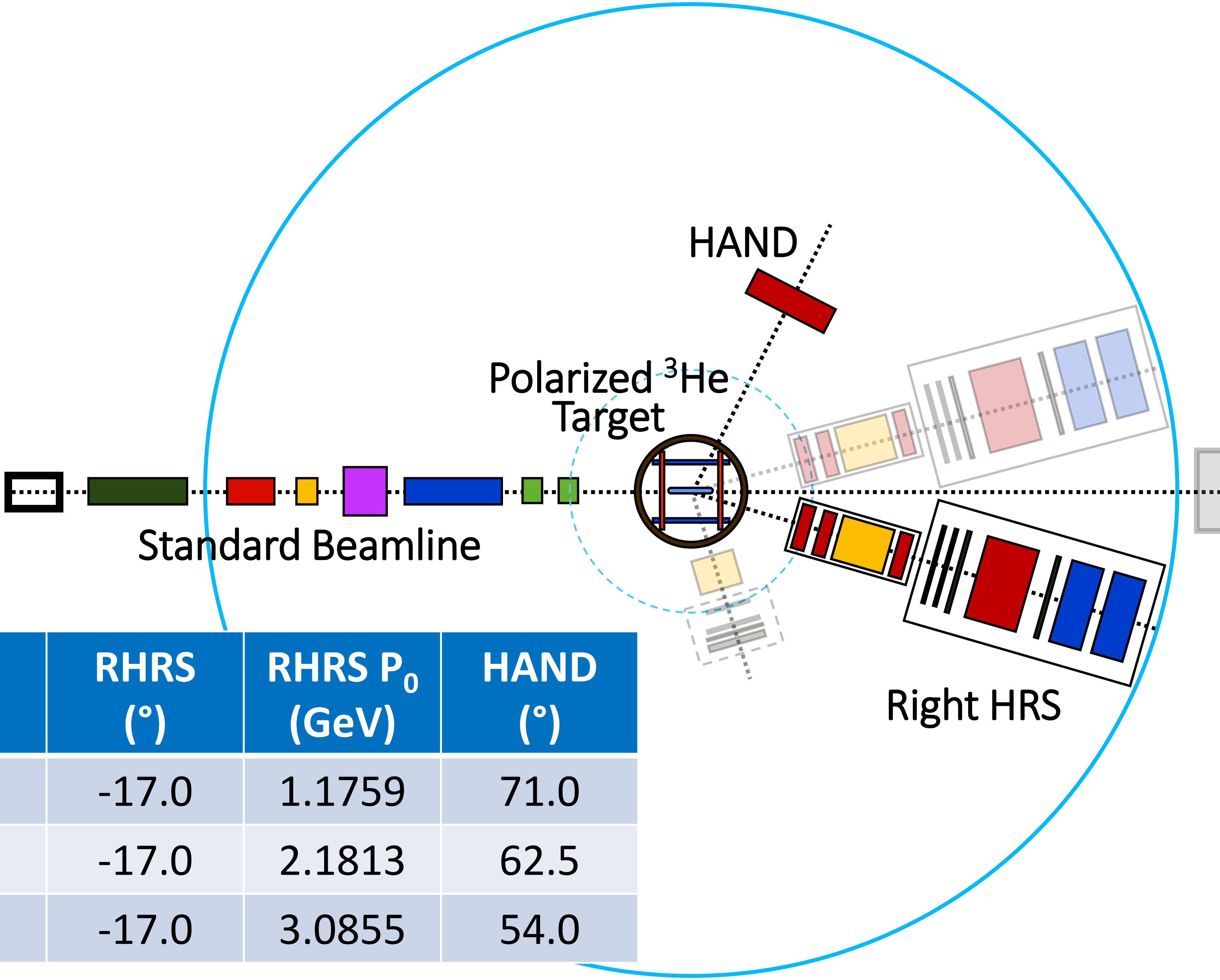
^{3}He(e,$e'n$) Channel



The Measurements

Experimental Set-up

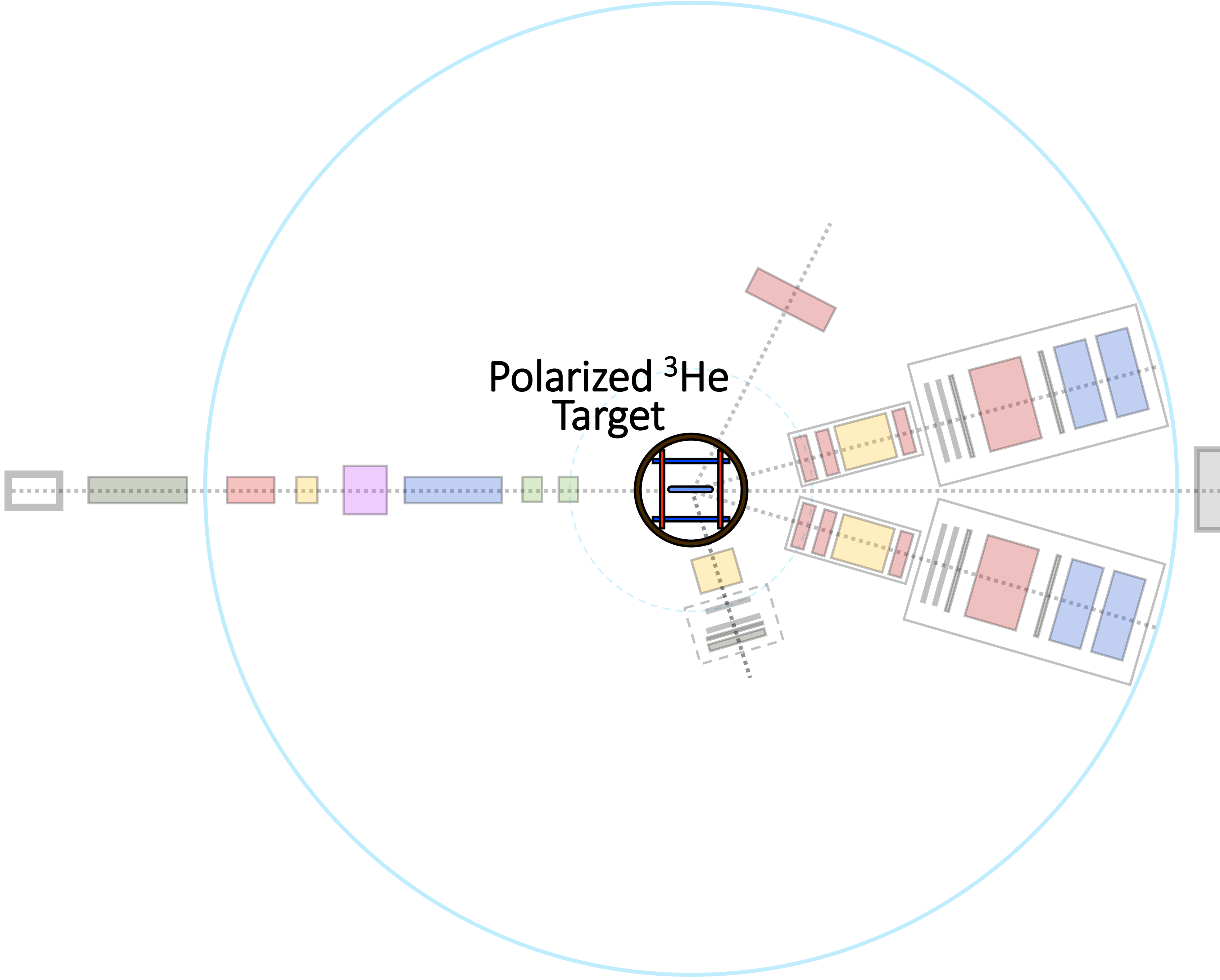
- Run period was April-June 2009



Target Pol.	Q^2 $(GeV/c)^2$	E_0 (GeV)	RHRS (°)	RHRS P_0 (GeV)	HAND (°)
Vertical	0.13	1.245	-17.0	1.1759	71.0
Vertical	0.46	2.425	-17.0	2.1813	62.5
Vertical	0.95	3.605	-17.0	3.0855	54.0

The Measurements

Polarized ^{3}He Target



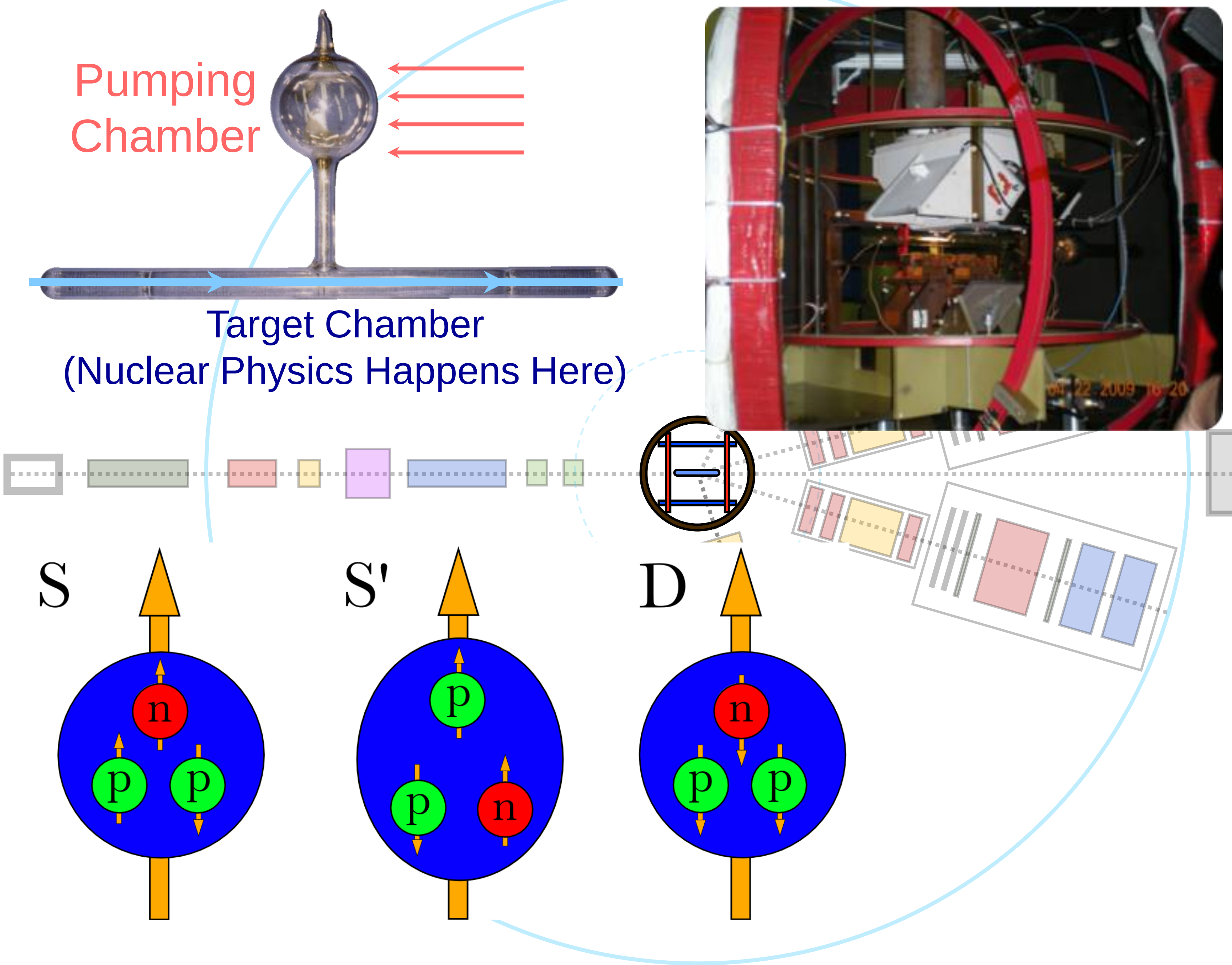
The Measurements

Polarized ^{3}He Target

- Optically pumped Rb and K vapor used to polarized ^{3}He via spin exchange (SEOP)
- NMR and EPR used to measure P_t
- N present in cell to absorb photons from spin-exchange

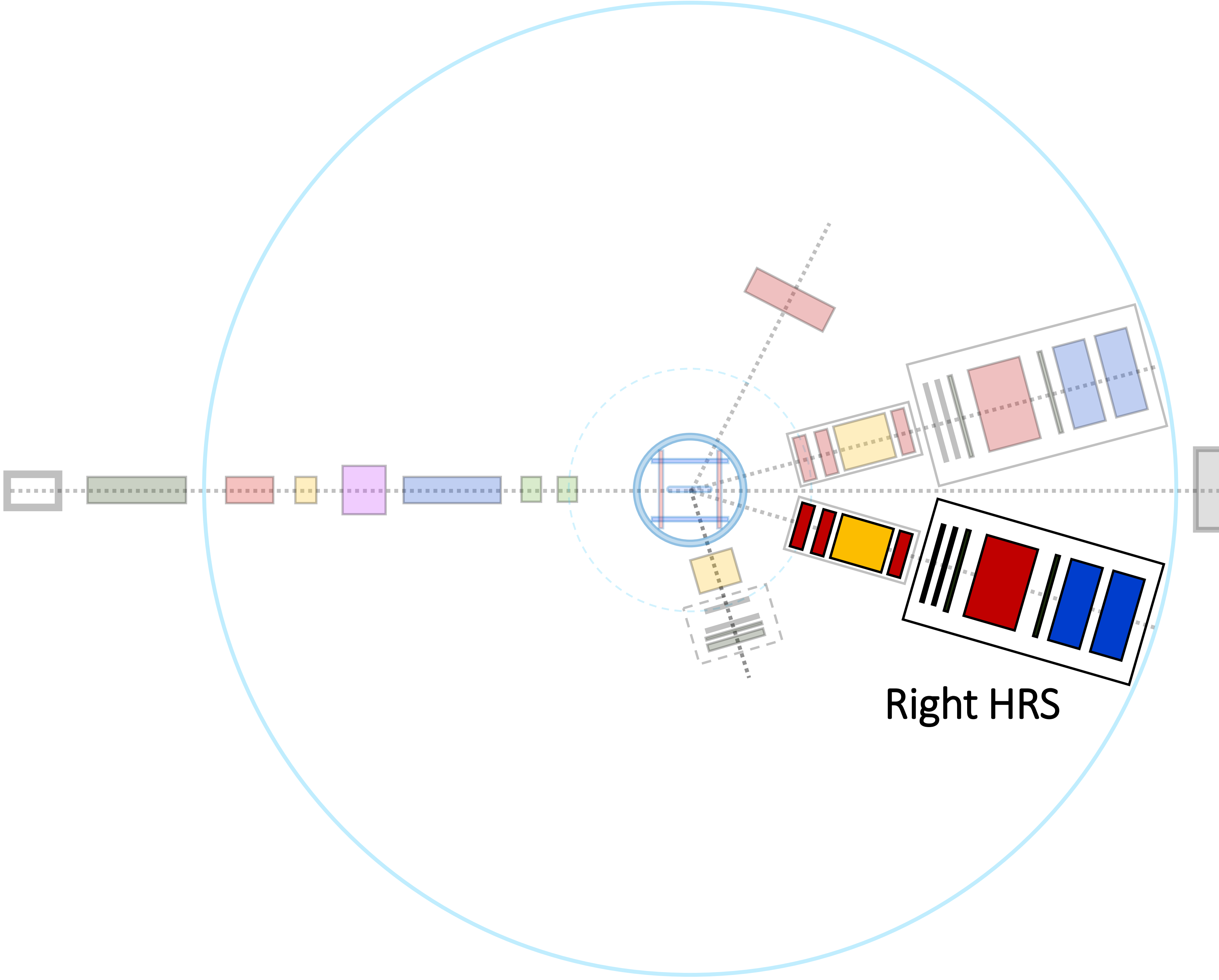
$$D_N = \begin{array}{l} 5.3 \pm 0.8\% \text{ at } Q^2 = 0.1 \\ 2.4 \pm 0.3\% \text{ at } Q^2 = 0.5 \\ 2.8 \pm 1.2\% \text{ at } Q^2 = 1.0 \end{array}$$

- Achieved P_t of $51.4 \ \pm 0.4 \pm 2.8$ %
- Details in Y. Zhang, Ph.D. Thesis, Rutgers, 2013



The Measurements

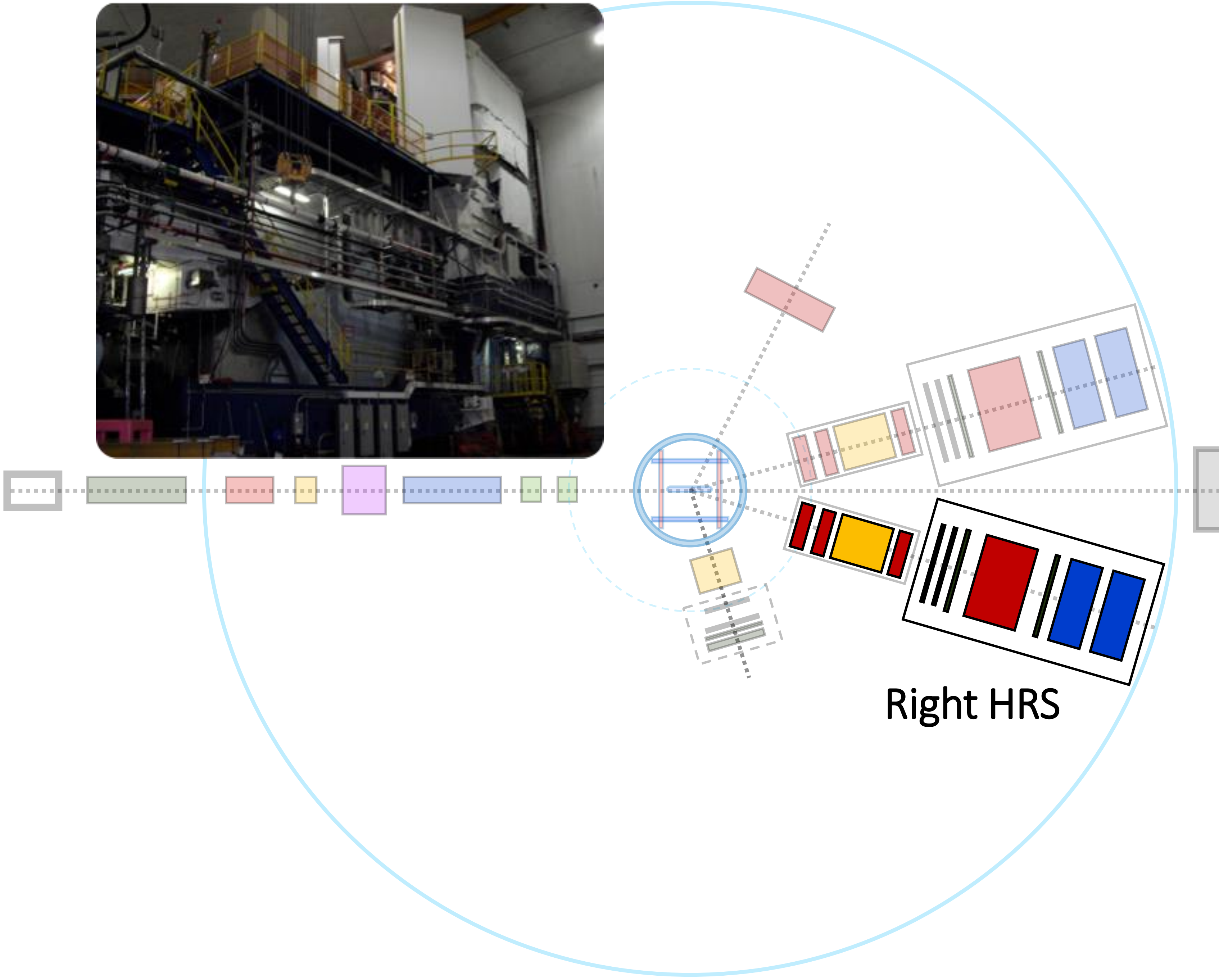
Right HRS



The Measurements

Right HRS

- Detected scattered electrons from ^{3}He(e,$e'n$) and ^{3}He(e,e')
- Provided trigger for HAND
- Detector package included VDCs, trigger scintillators, gas Cherenkov, and lead-glass calorimeters



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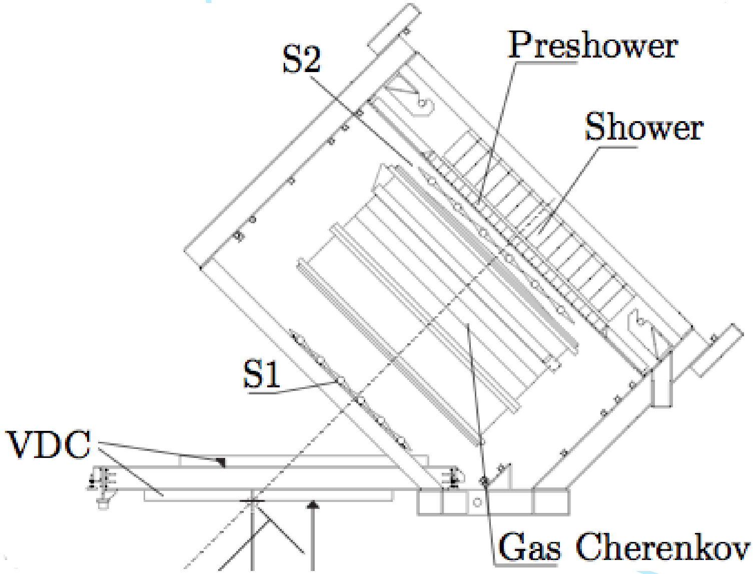
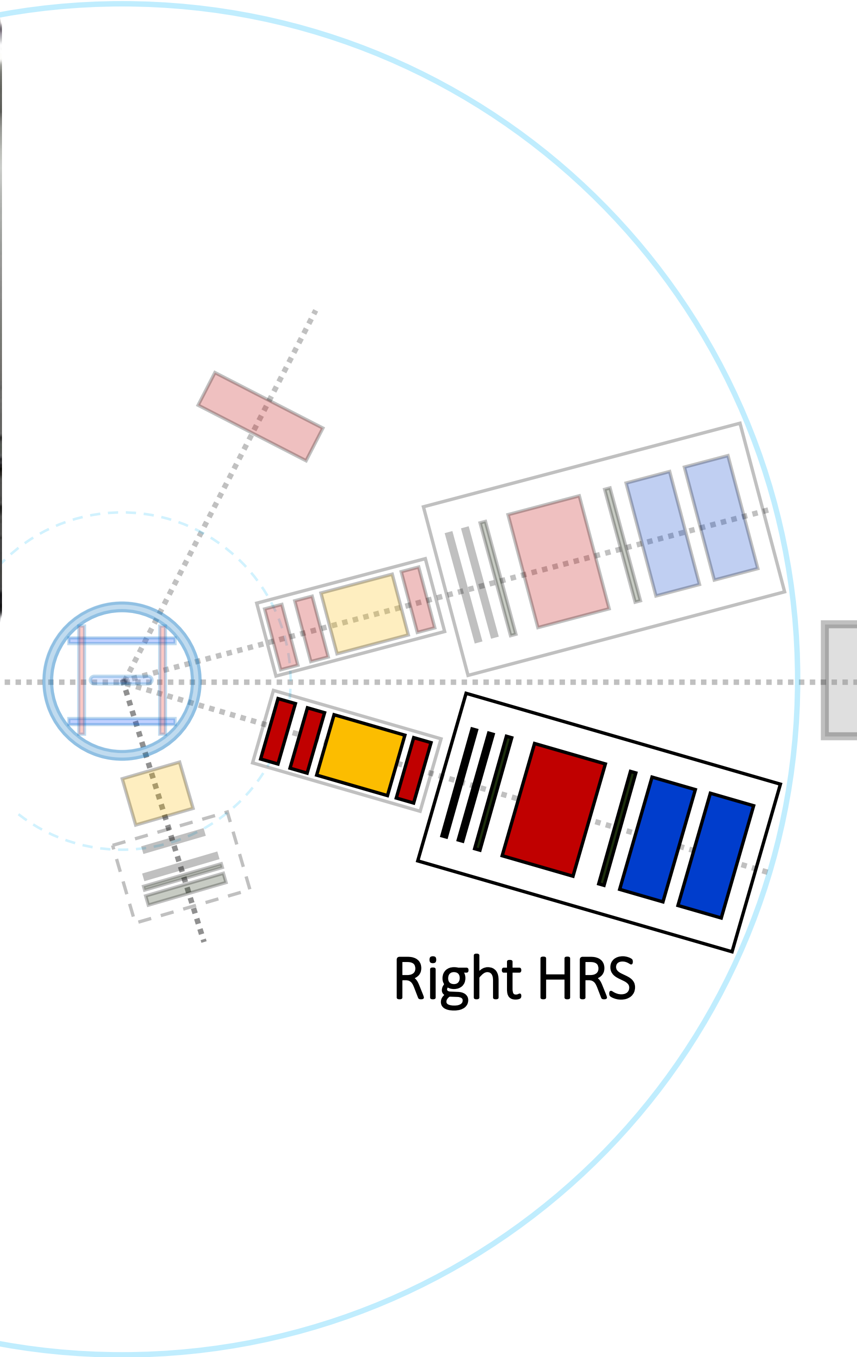
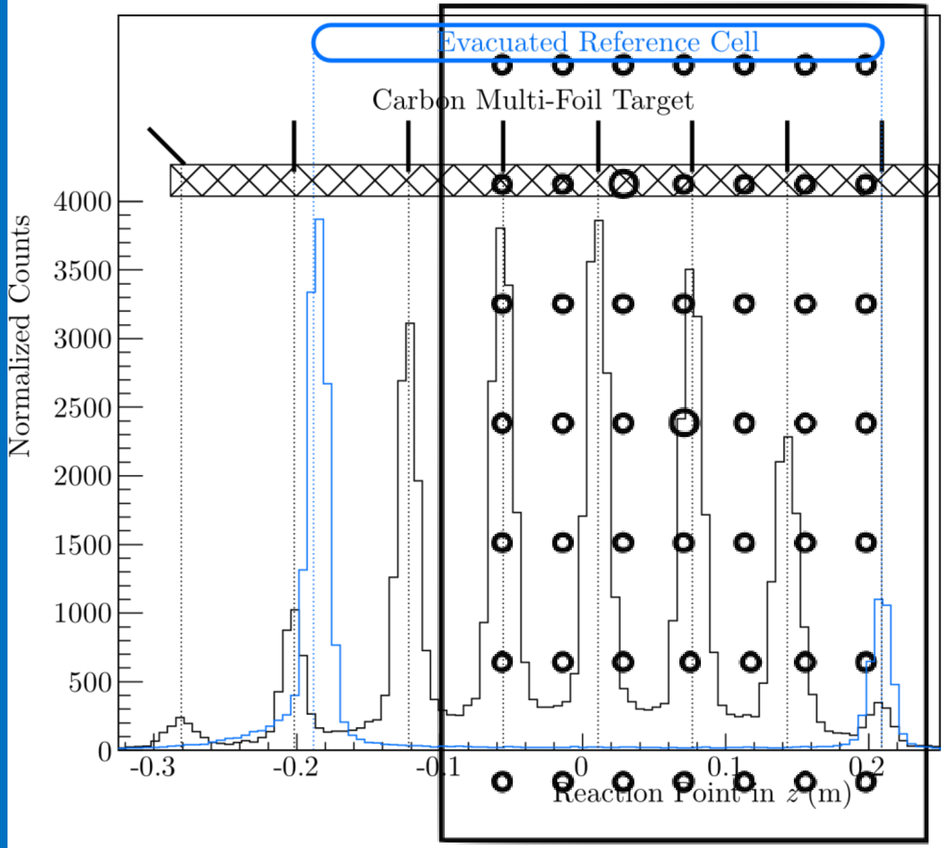


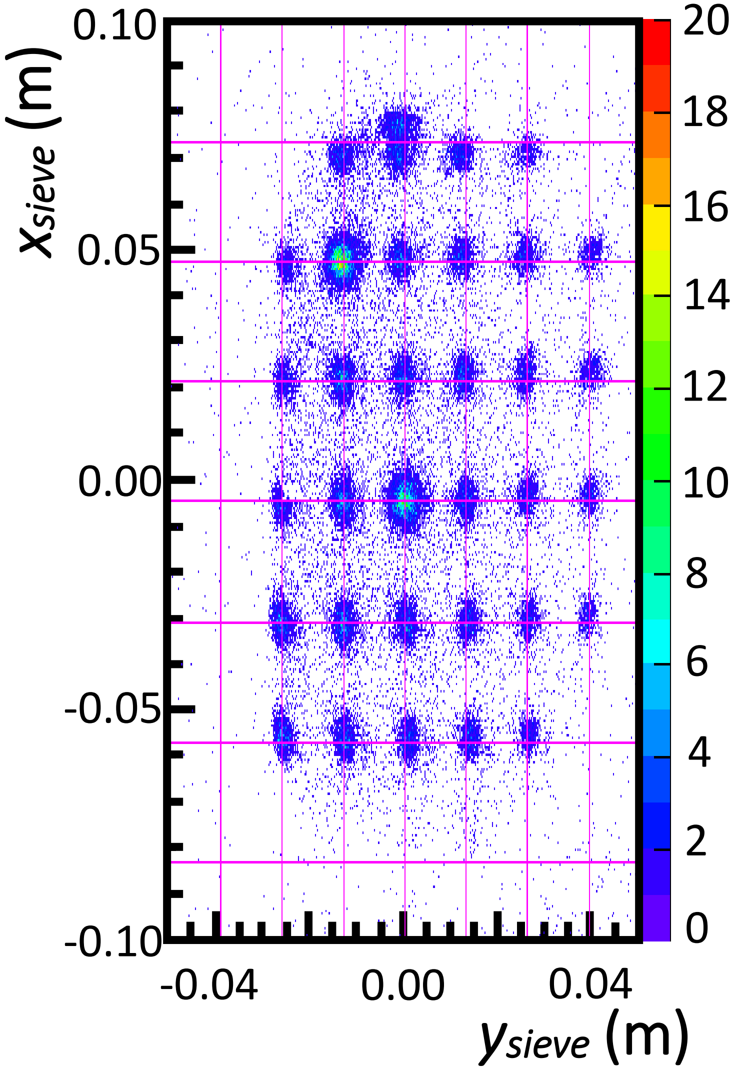


The Measurements

Right HRS

- Details in G. Jin, Ph.D. Thesis, University of Virginia, 2011



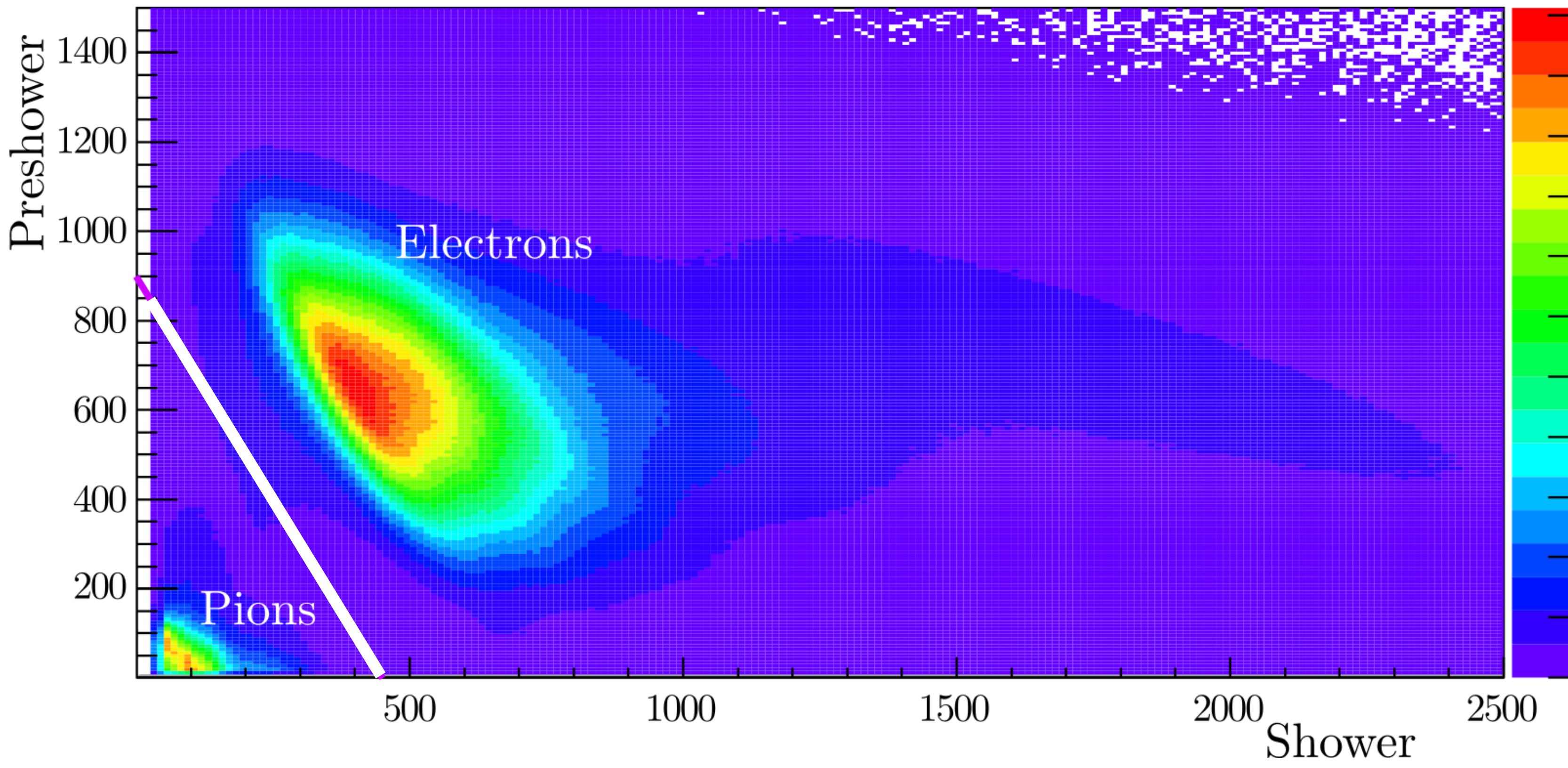


The Measurements

Right HRS

- Electron ID
- Details in E. Long, Ph.D. Thesis, Kent State University, 2012 (arXiv:1209.2739)

Preshower/Shower



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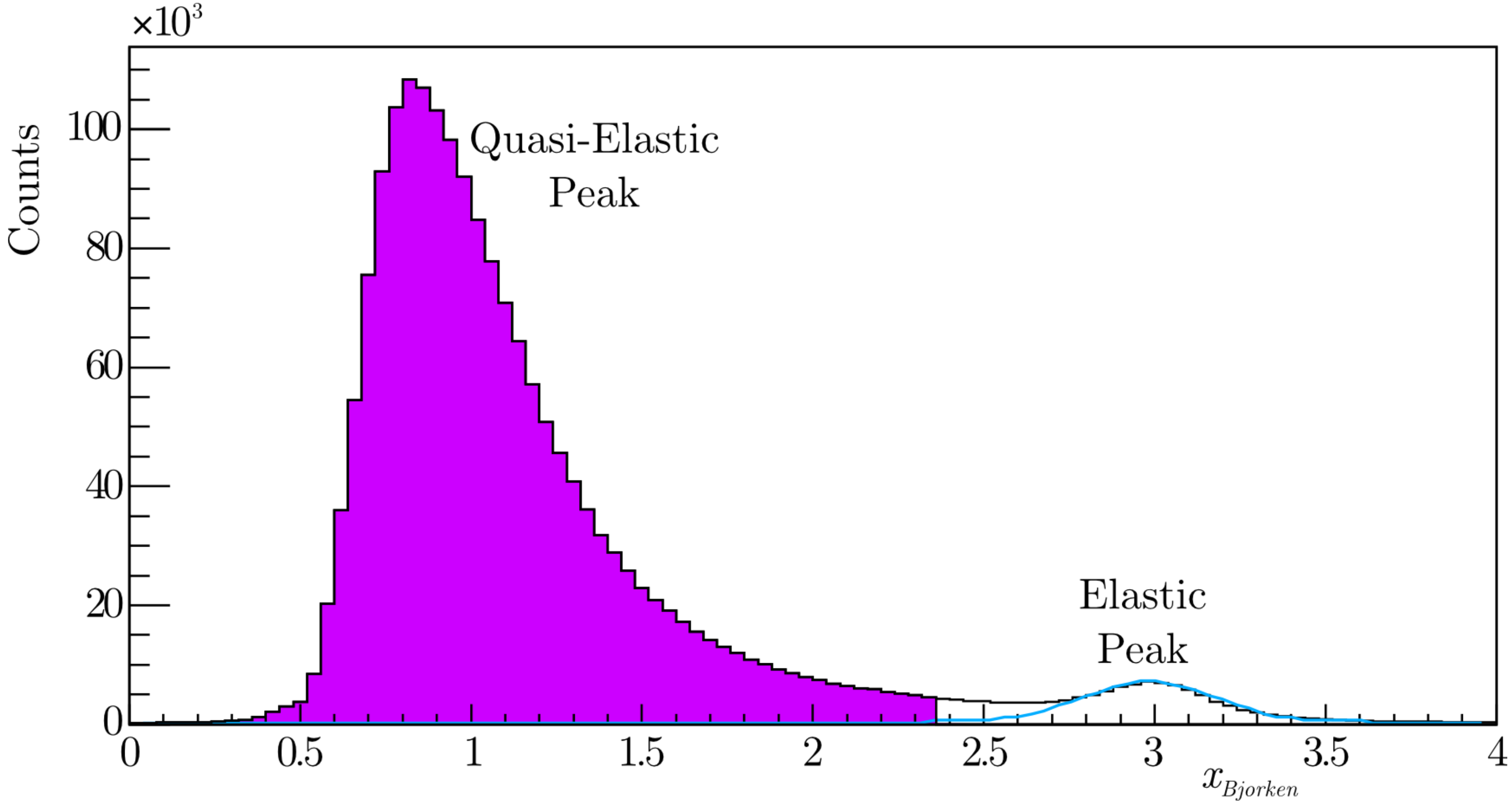
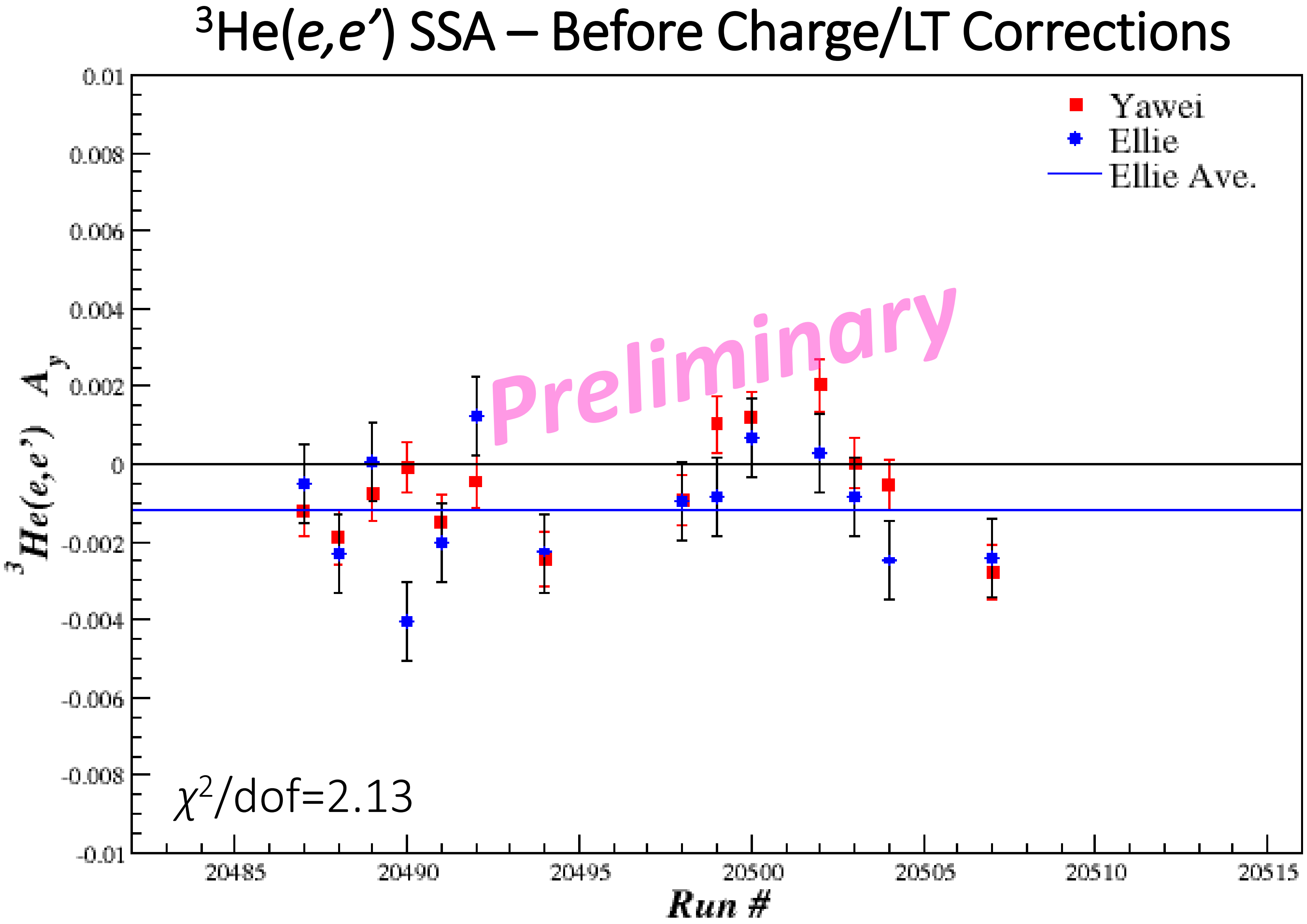
Bjorken x



The Measurements

Right HRS

- ^{3}He(*e,e'*) Single-Spin Asymmetry
- Comparison with Y. Zhang

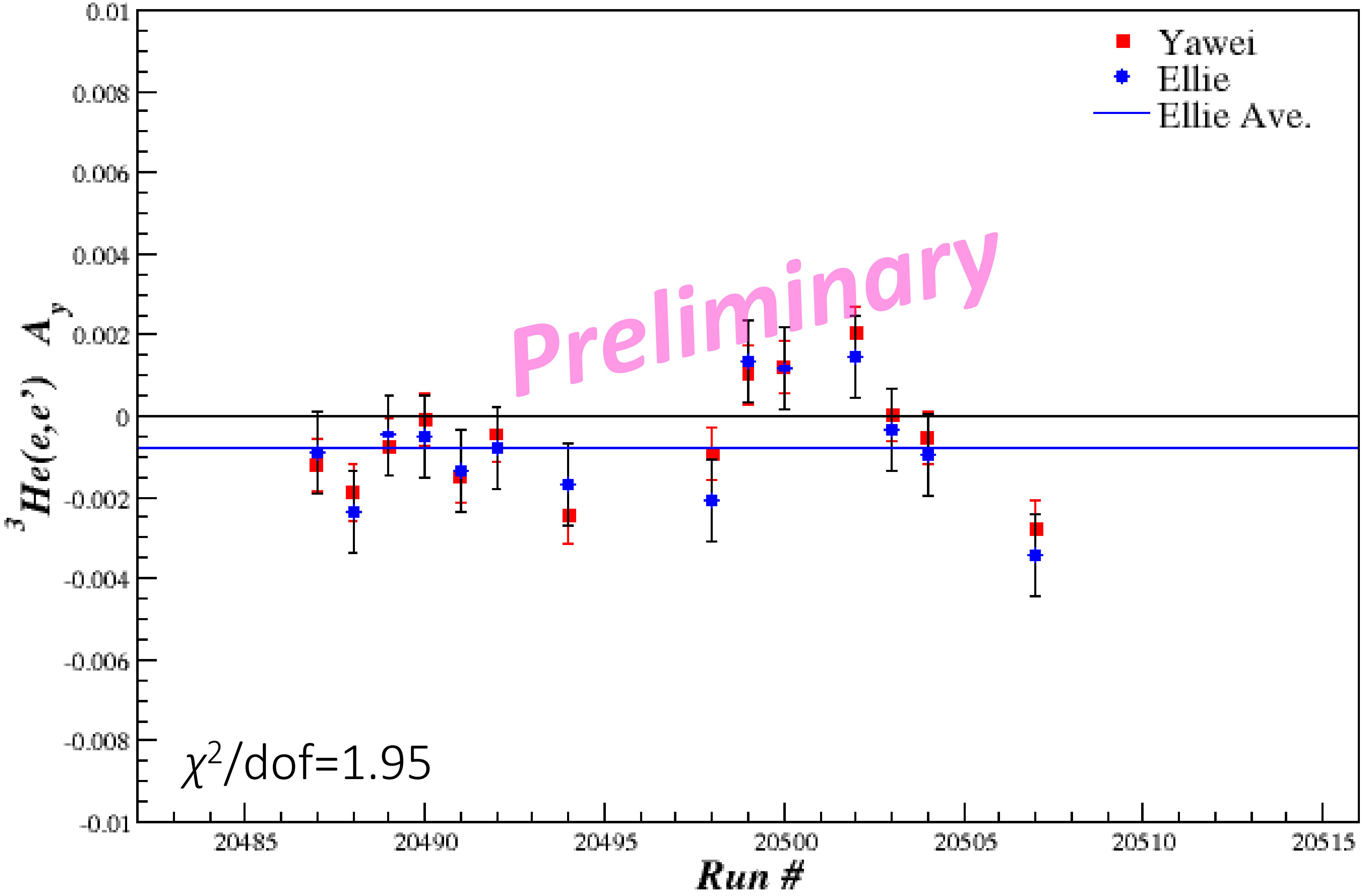


The Measurements

Right HRS

- ^{3}He(*e*,*e'*) Single-Spin Asymmetry
- Comparison with Y. Zhang

^{3}He(*e*,*e'*) SSA – After Charge/LT Corrections

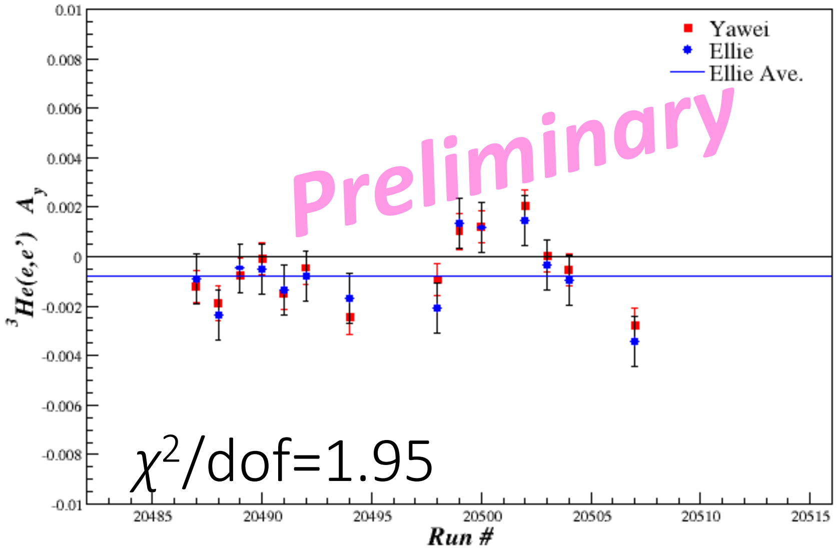


The Measurements

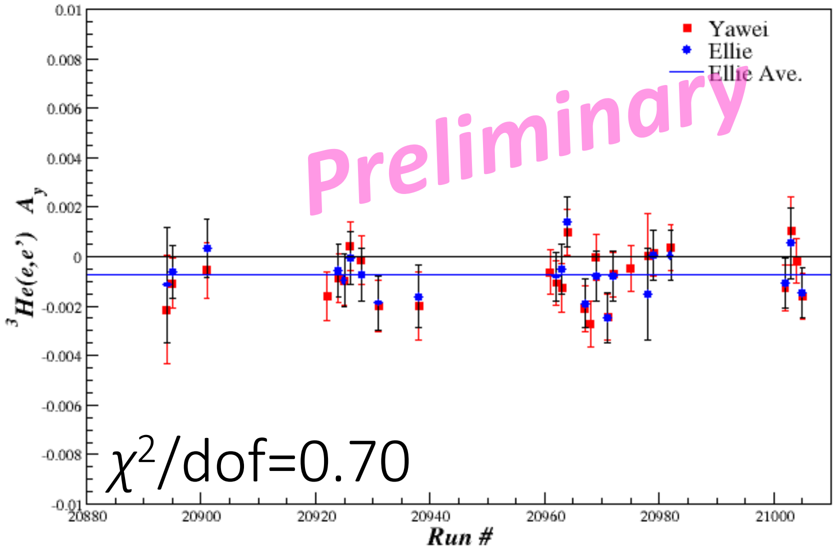
Right HRS

- ^{3}He(e,e') Single-Spin Asymmetry
- Comparison with Y. Zhang

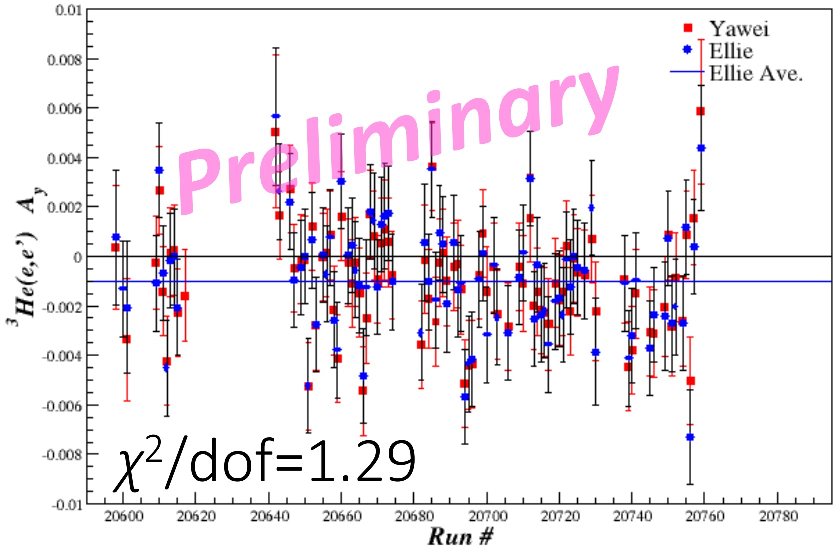
Q^2=0.1 (GeV/c)^2



Q^2=0.5 (GeV/c)^2

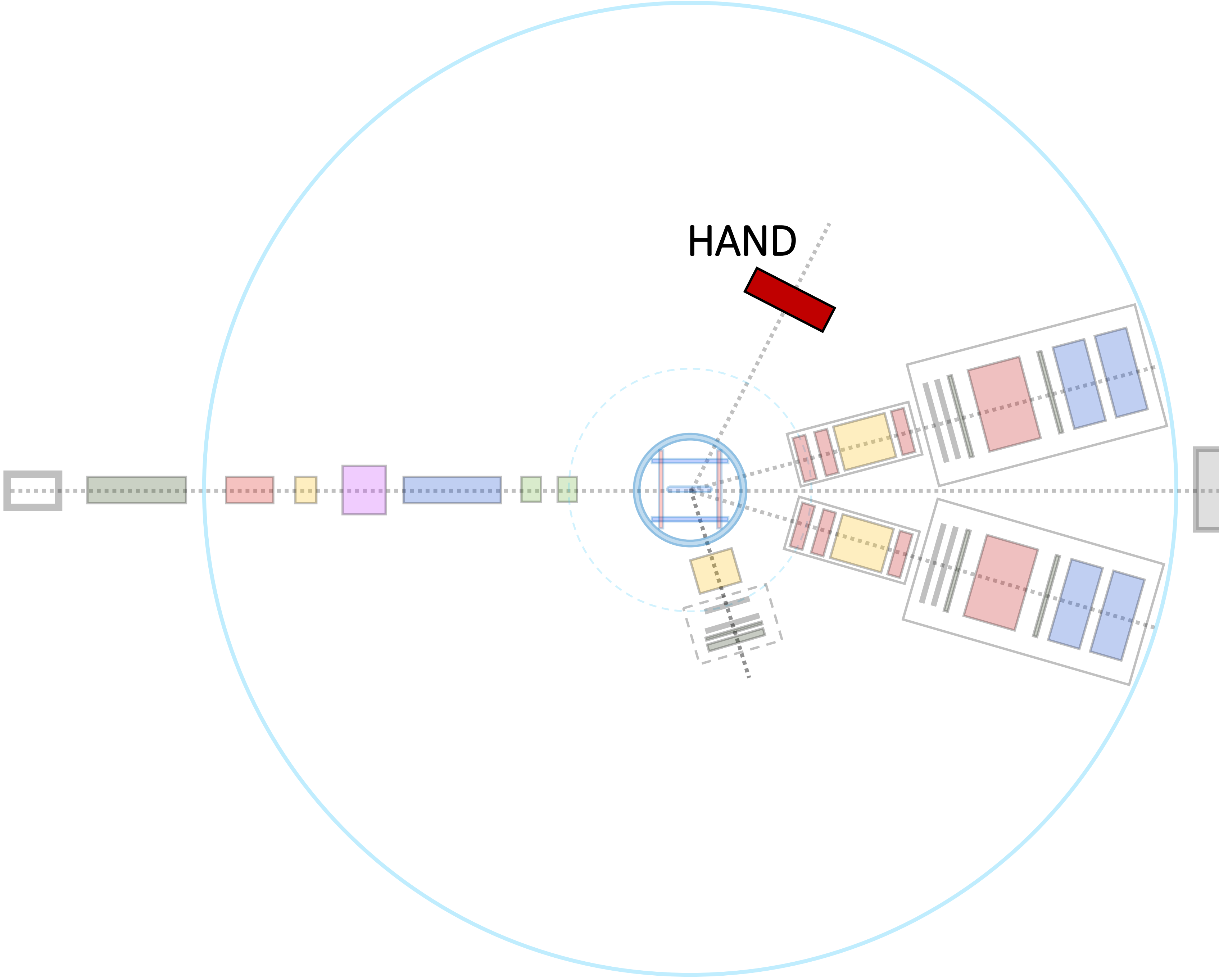


Q^2=1.0 (GeV/c)^2



The Measurements

Hall A Neutron Detector (HAND)



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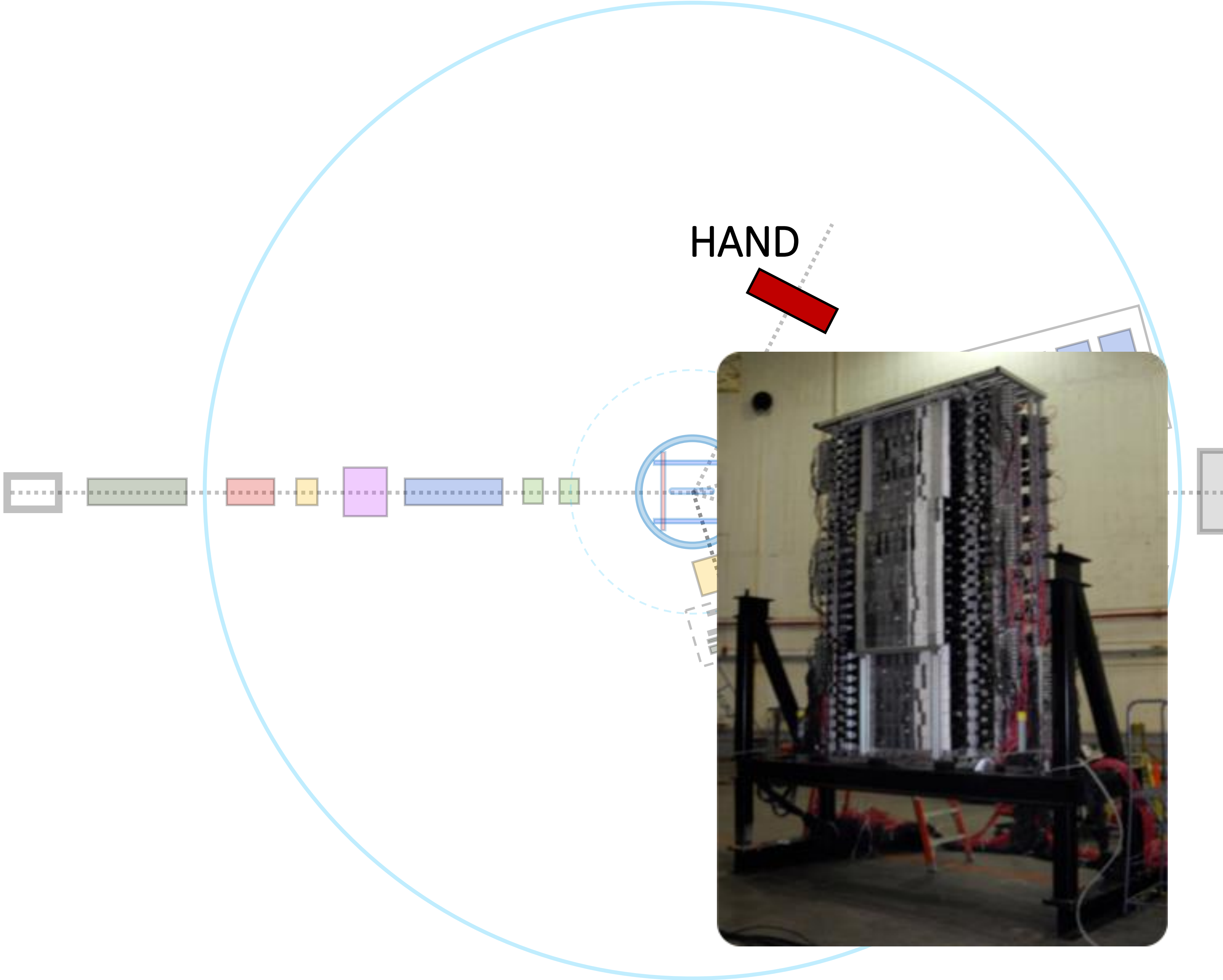
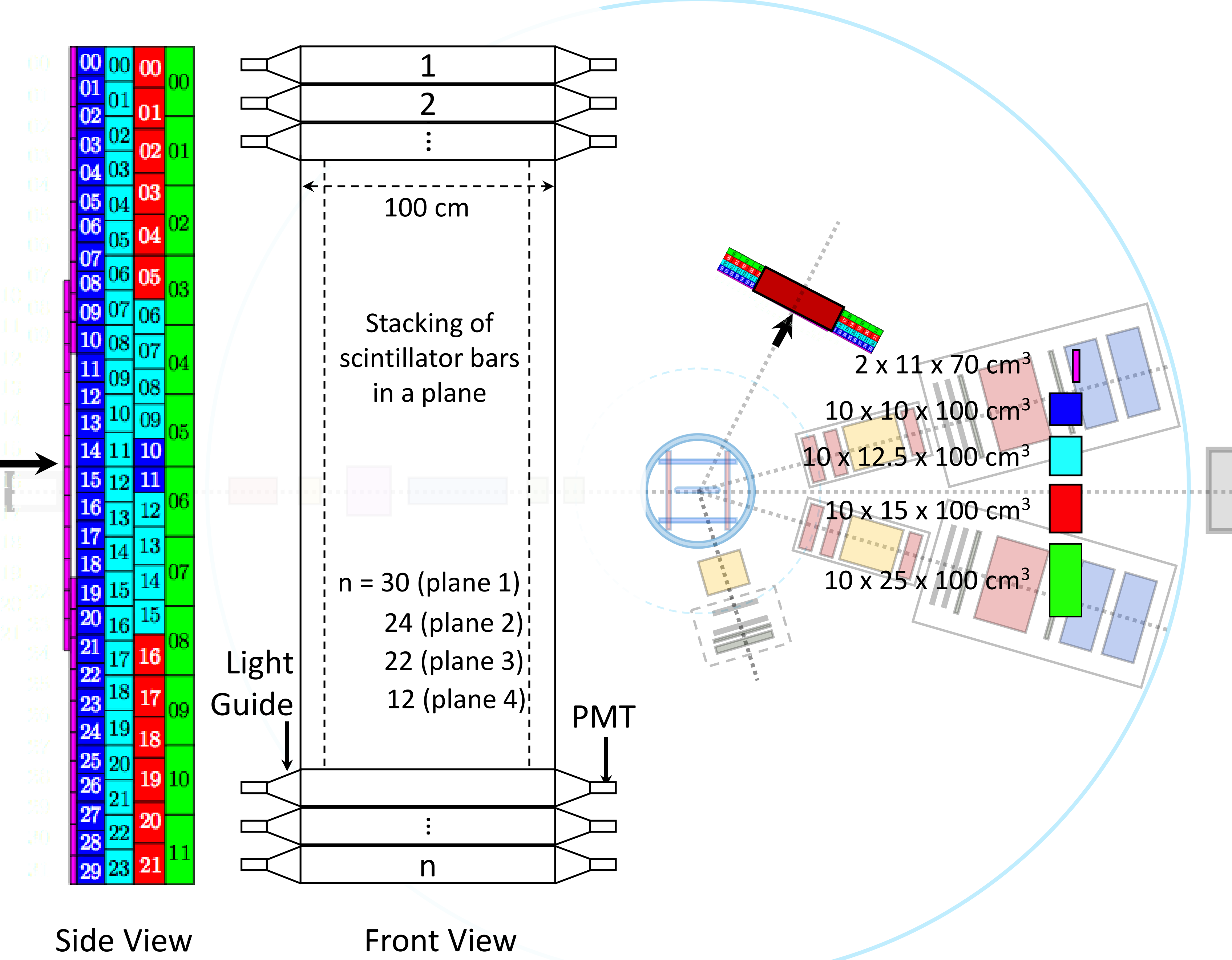


The Measurements

Hall A Neutron Detector (HAND)

- Plastic scintillator array
- Detected neutrons from ^{3}He($e,e'n$) in coincidence with the RHRS
- Details in E. Long, Ph.D. Thesis, Kent State University, 2012 (arXiv:1209.2739)



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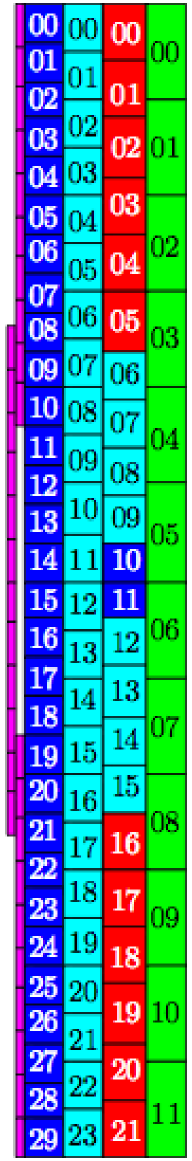

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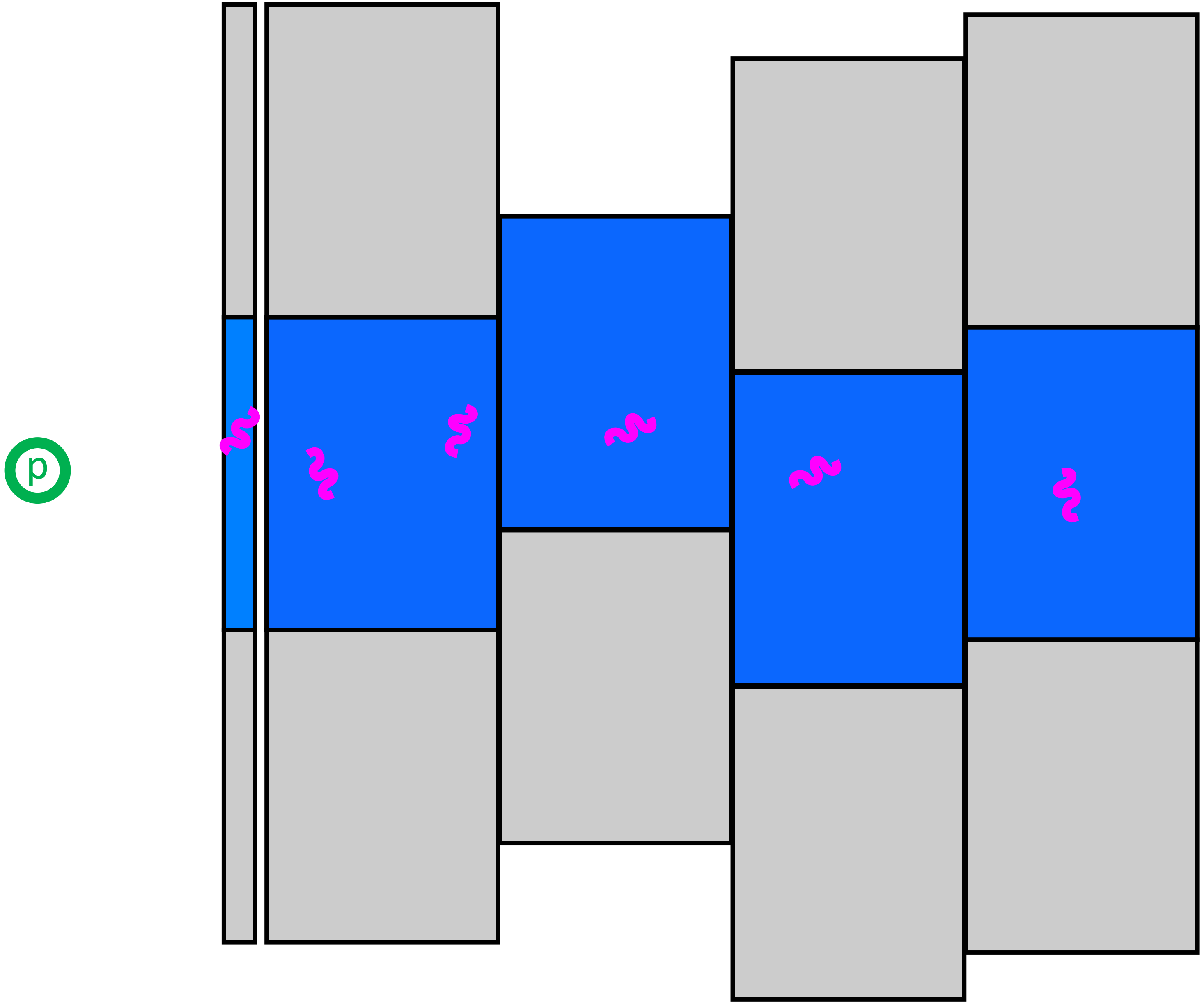

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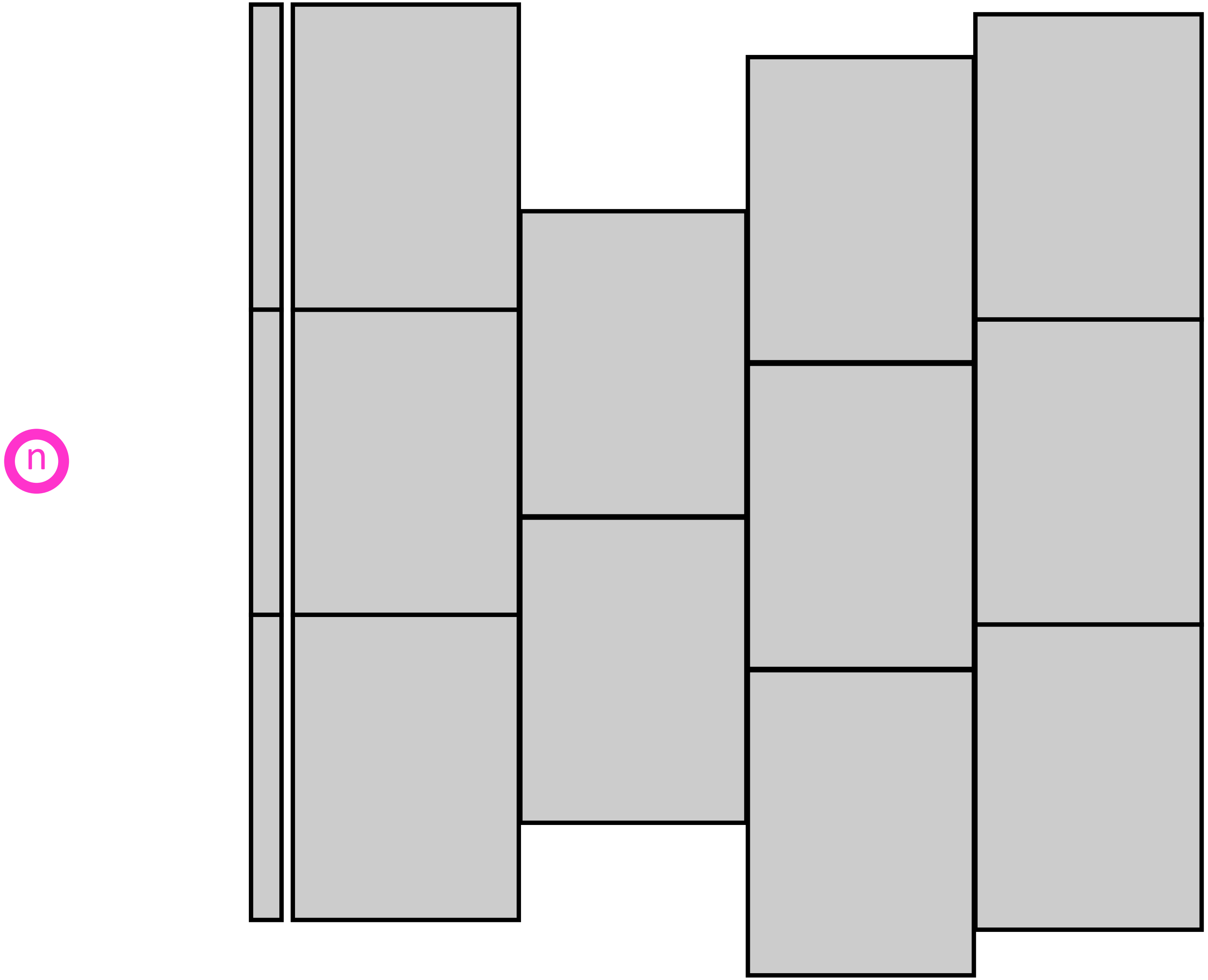

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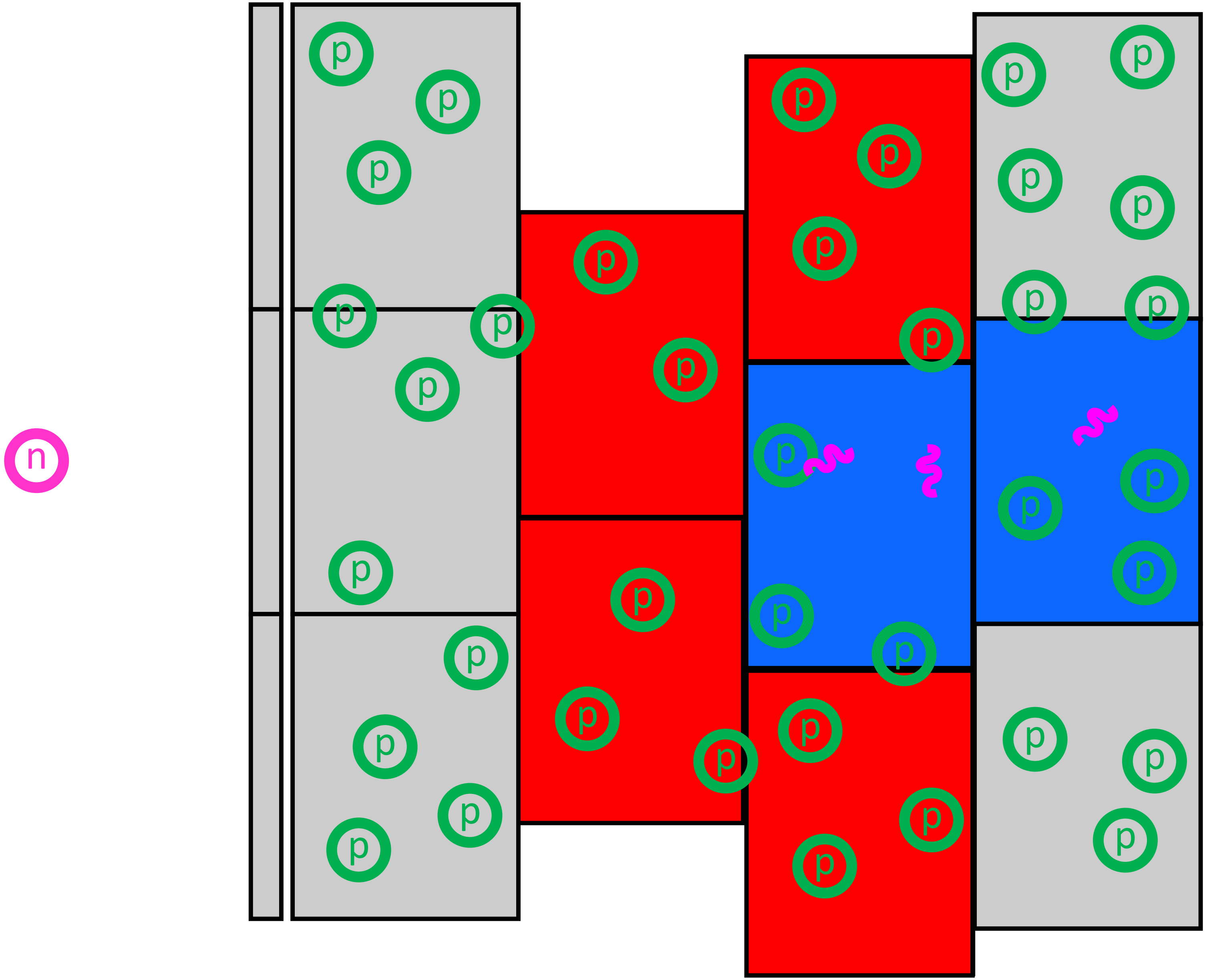

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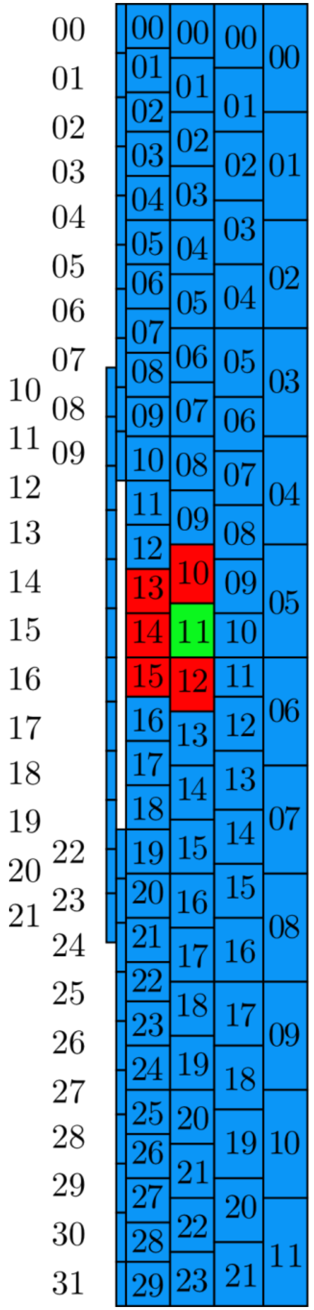
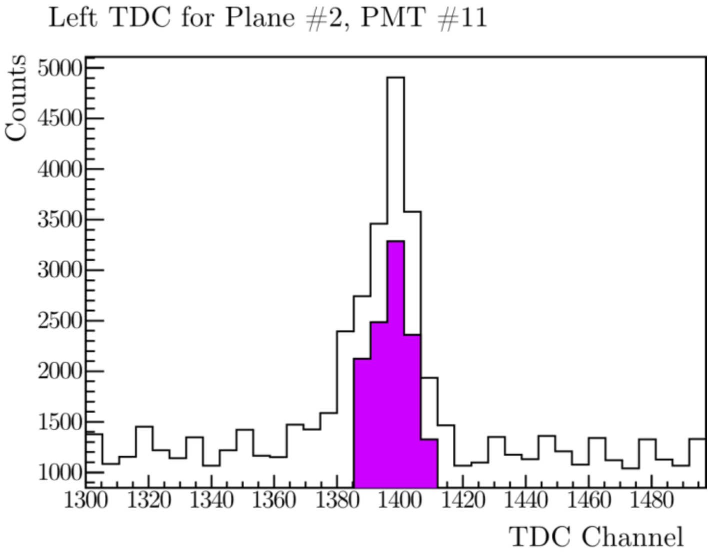
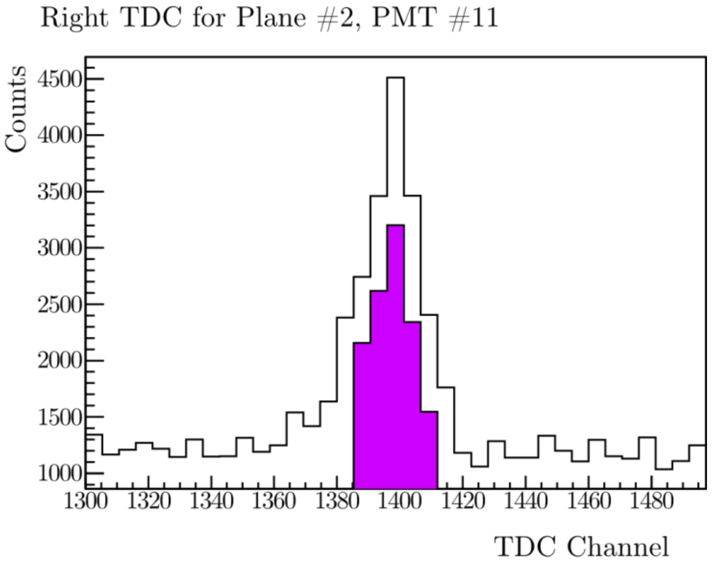




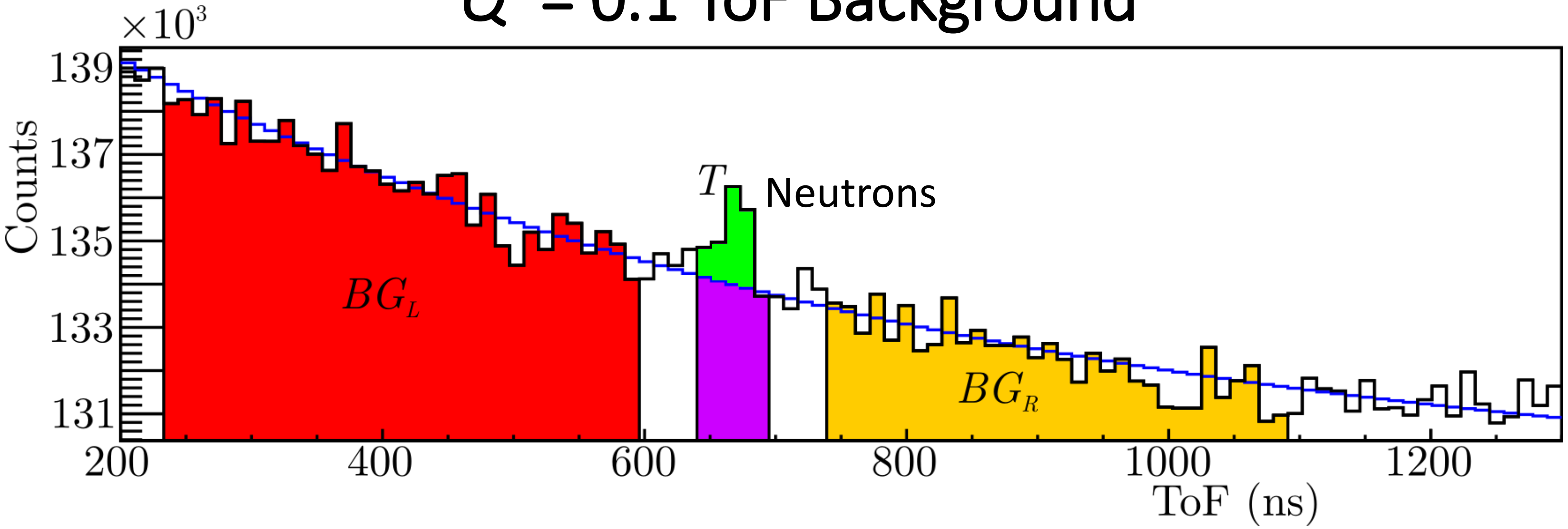


The Measurements

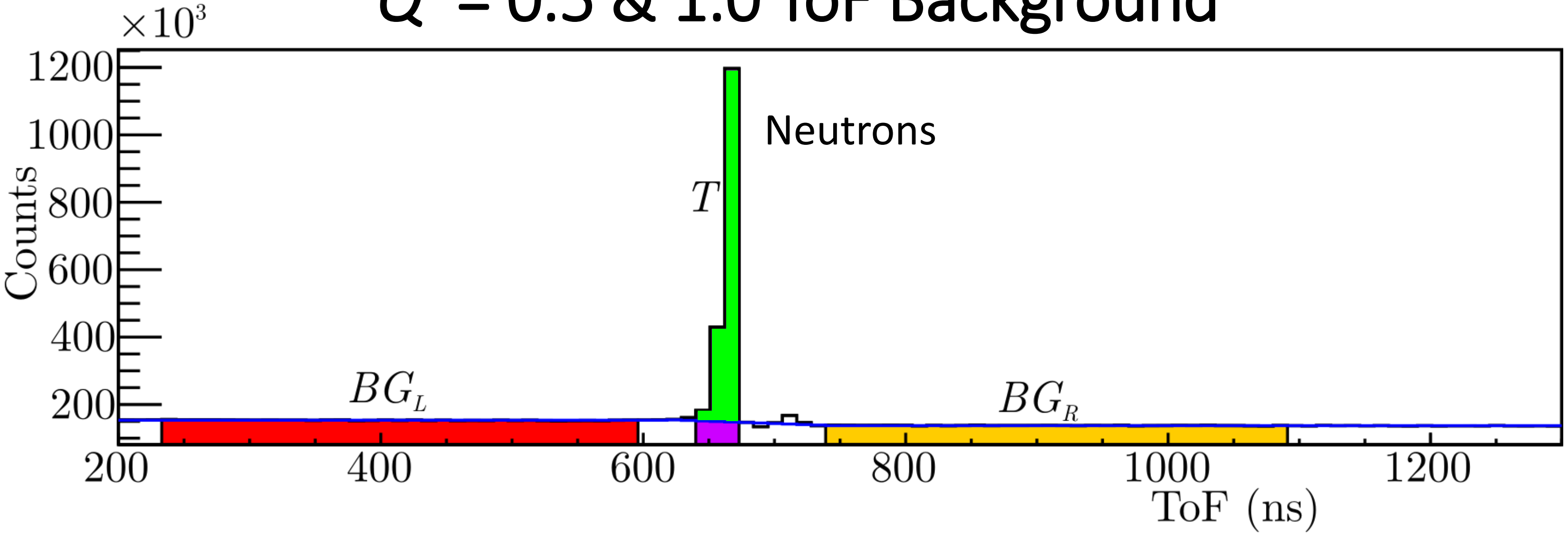
Hall A Neutron Detector (HAND)

- Time-of-Flight background subtracted from the neutron peak
- Details in E. Long, Ph.D. Thesis, Kent State University, 2012 (arXiv:1209.2739)

$Q^2 = 0.1$ ToF Background



$Q^2 = 0.5$ & 1.0 ToF Background



The Measurements

Hall A Neutron Detector (HAND)

- Proton contamination
- Details in E. Long, Ph.D. Thesis, Kent State University, 2012 (arXiv:1209.2739)

Proton Contamination

- To find misidentified protons, apply neutron cuts to H(e,e'p)
  - $r_{mis\ id} = \frac{p_{\mathrm{H}\ mis\ id}}{Tot_{\mathrm{H}\ meas}}$
- Find ratio of protons:neutrons from ^{3}He(e,e'n) and ^{3}He(*e,e'p*)
  - $\sigma = \sigma_{Mott}\left(\frac{G_E^2+\tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2\frac{\theta}{2}\right)$
  - $r_{p:n} = \frac{2\sigma_p}{\sigma_n} = \begin{array}{r} 18.9{:}\,1 \text{ at } Q^2 = 0.1\ (\mathrm{GeV}/c)^2 \\ 7.6{:}\,1 \text{ at } Q^2 = 0.5\ (\mathrm{GeV}/c)^2 \\ 5.3{:}\,1 \text{ at } Q^2 = 1.0\ (\mathrm{GeV}/c)^2 \end{array}$

The Measurements

Hall A Neutron Detector (HAND)

- Proton contamination
- Details in E. Long, Ph.D. Thesis, Kent State University, 2012 (arXiv:1209.2739)

Proton Contamination

- Using $r_{p:n}$ and total measured He events in HRS, find expected number of protons and neutrons thrown at HAND
  - $Tot_{\text{He } meas} = p_{exp} + n_{exp}$
  - $n_{exp} = \frac{Tot_{\text{He } meas}}{1+r_{p:n}}$ $\longrightarrow$ Use to find efficiency, $E_{HAND} = \frac{n_{meas}}{n_{exp}}$
  - $p_{exp} = n_{exp} r_{p:n}$
- Include $r_{mis\ id}$ to estimate number of misidentified protons in 3He
  - $p_{\text{He } mis\ id} = p_{exp} r_{mis\ id}$
- Calculate proton dilution factor
  - $D_p = 1 - \frac{p_{\text{He } mis\ id}}{n_{exp}}$

Version 1.2 as of December 12, 2013
Primary author: Elena A. Long, ellie@jlab.org
To be submitted to PRL.
Comment to `Hall A Collaboration` by the Quasi-Elastic Family Collaboration

HALL A INTERNAL DOCUMENT – NOT FOR PUBLIC DISTRIBUTION

A measurement of the single-spin asymmetry A_y^0 in quasi-elastic $^3\mathrm{He}^{\uparrow}(e,e'n)$ scattering at $0.1\ \mathrm{GeV}/c^2 > Q^2 > 1.0\ \mathrm{GeV}/c^2$

E. Long,[1,*] Y.-W. Zhang,[2] M. Mihovilovic,[3] G. Jin,[4] K. Allada,[5] B. Anderson,[6] J.R.M. Annand,[7] T. Averett,[8] W. Boeglin,[9] P. Bradshaw,[8] A. Camsonne,[5] M. Canan,[10] G. Cates,[4] C. Chen,[11] J.P. Chen,[5] E. Chudakov,[5] R. De Leo,[12] X. Deng,[4] A. Deur,[5] C. Dutta,[13] L. El Fassi,[2] D. Flay,[14] S. Frullani,[15] F. Garibaldi,[15] S. Gilad,[16] R. Gilman,[5,2] O. Glamazdin,[17] S. Golge,[10] J. Gomez,[5] O. Hansen,[5] D. Higinbotham,[5] T. Holmstrom,[18] J. Huang,[16,19] H. Ibrahim,[20] C.W. de Jager,[5] E. Jensen,[21] X. Jiang,[19] M. Jones,[5] H. Kang,[22] J. Katich,[8] H.P. Khanal,[9] P. King,[23] W. Korsch,[13] J. LeRose,[5] R. Lindgren,[4] H.-J. Lu,[24] W. Luo,[25] P. Markowitz,[9] M. Meziane,[8] R. Michaels,[5] B. Moffit,[5] P. Monaghan,[11] N. Muangma,[16] S. Nanda,[5] B.E. Norum,[4] K. Pan,[16] D. Parno,[26] E. Piasetzky,[27] M. Posik,[14] V. Punjabi,[28] A.J.R. Puckett,[16,19] X. Qian,[29] Y. Qiang,[5] X. Qui,[25] S. Riordan,[4] A. Saha,[5] B. Sawatzky,[5] M. Shabestari,[4] A. Shahinyan,[30] B. Shoenrock,[31] S. Sirca,[32,3] J. St. John,[18] R. Subedi,[33] V. Sulkosky,[16] W.A. Tobias,[4] W. Tireman,[31] G.M. Urciuoli,[15] D. Wang,[4] K. Wang,[4] Y. Wang,[34] J. Watson,[5] B. Wojtsekhowski,[5] Z. Ye,[11] X. Zhan,[16] Y. Zhang,[25] X. Zheng,[4] B. Zhao,[8] and L. Zhu[11]
(The Hall A Collaboration)

Results

Results

- Run-by-run A_y^0

$$\delta A_y^{0\prime} = \varepsilon_{stat} + \varepsilon_{sys}{}'$$

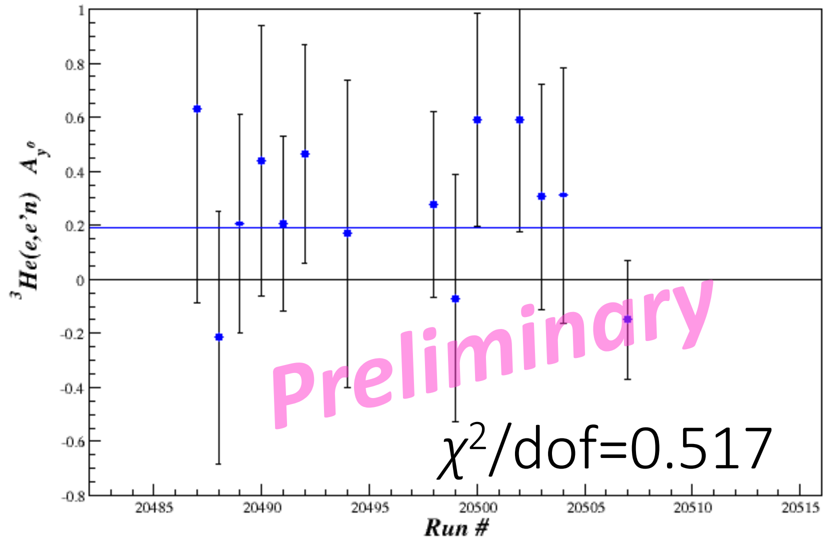
$$S = \left[\frac{\chi^2}{dof}\right]^{1/2}$$

$$\delta A_y^0 = S\delta A_y^{0\prime}$$

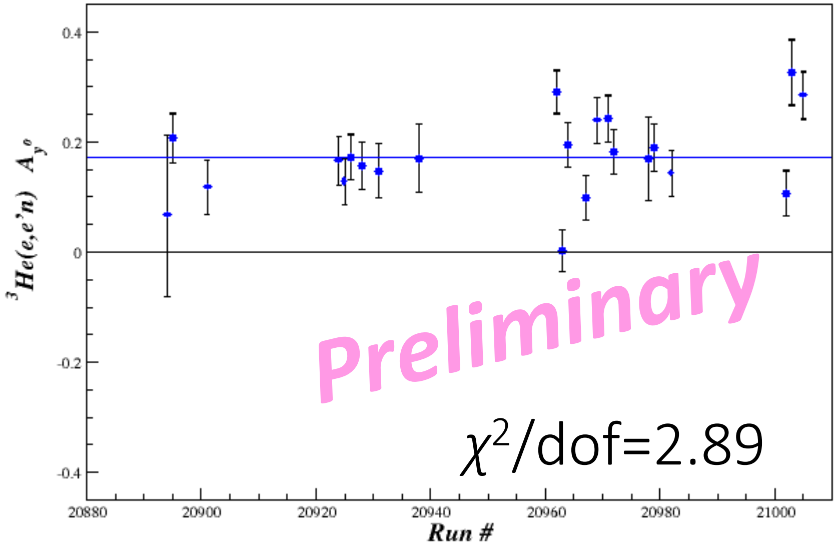
$$\varepsilon_{sys} = S\varepsilon_{sys}{}' + (S-1)\varepsilon_{stat}$$

$$\delta A_y^0 = \varepsilon_{stat} + \varepsilon_{sys}$$

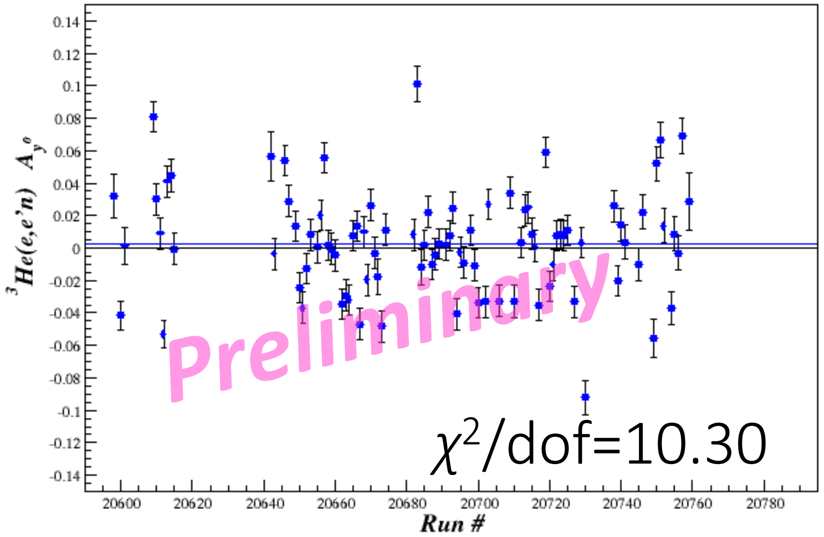
Q^2=0.1 (GeV/c)^2



Q^2=0.5 (GeV/c)^2



Q^2=1.0 (GeV/c)^2



Results

- Run-by-run $A_y{}^0$

$$\delta A_y^0{}' = \varepsilon_{stat} + \varepsilon_{sys}{}'$$

$$S = \left[\frac{\chi^2}{dof}\right]^{1/2}$$

$$\delta A_y^0 = S\delta A_y^0{}'$$

$$\varepsilon_{sys} = S\varepsilon_{sys}{}' + (S-1)\varepsilon_{stat}$$

$$\delta A_y^0 = \varepsilon_{stat} + \varepsilon_{sys}$$

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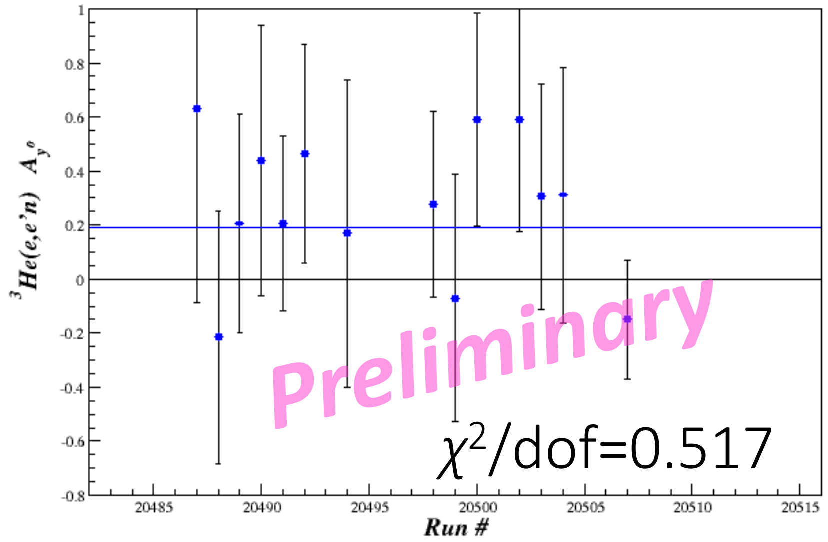
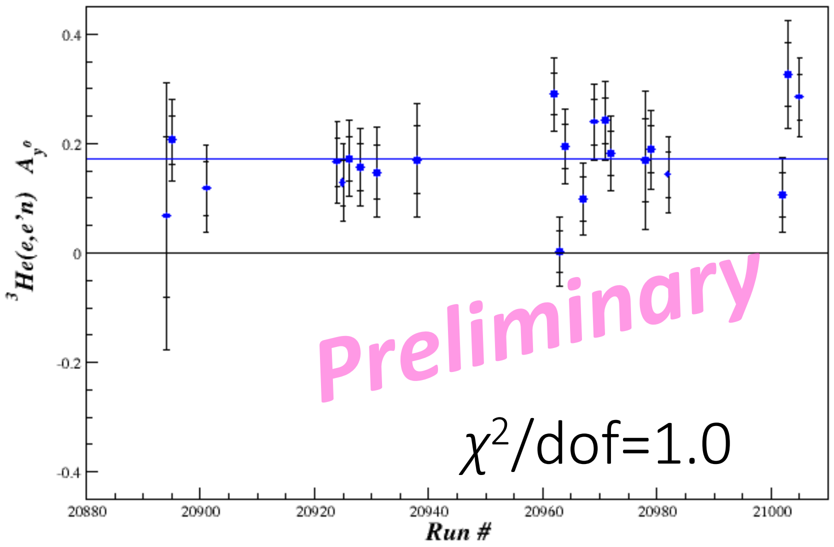
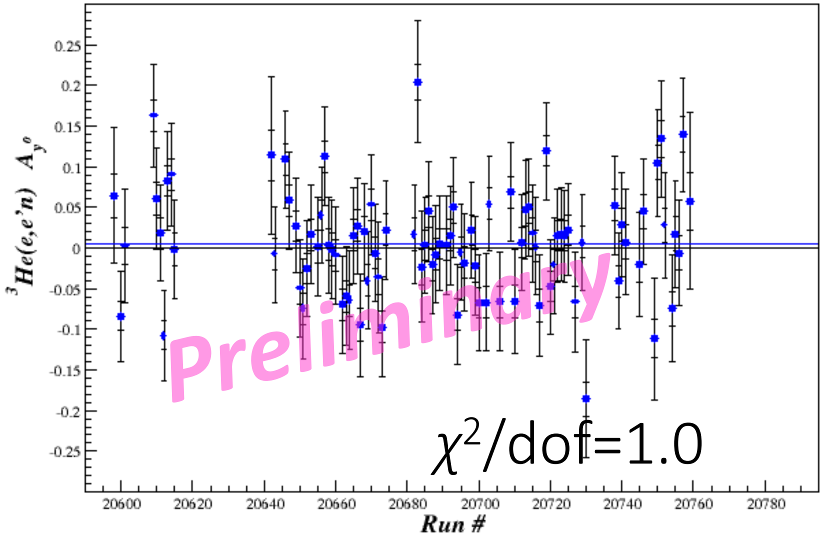


Q^2=0.5 (GeV/c)^2



Q^2=1.0 (GeV/c)^2



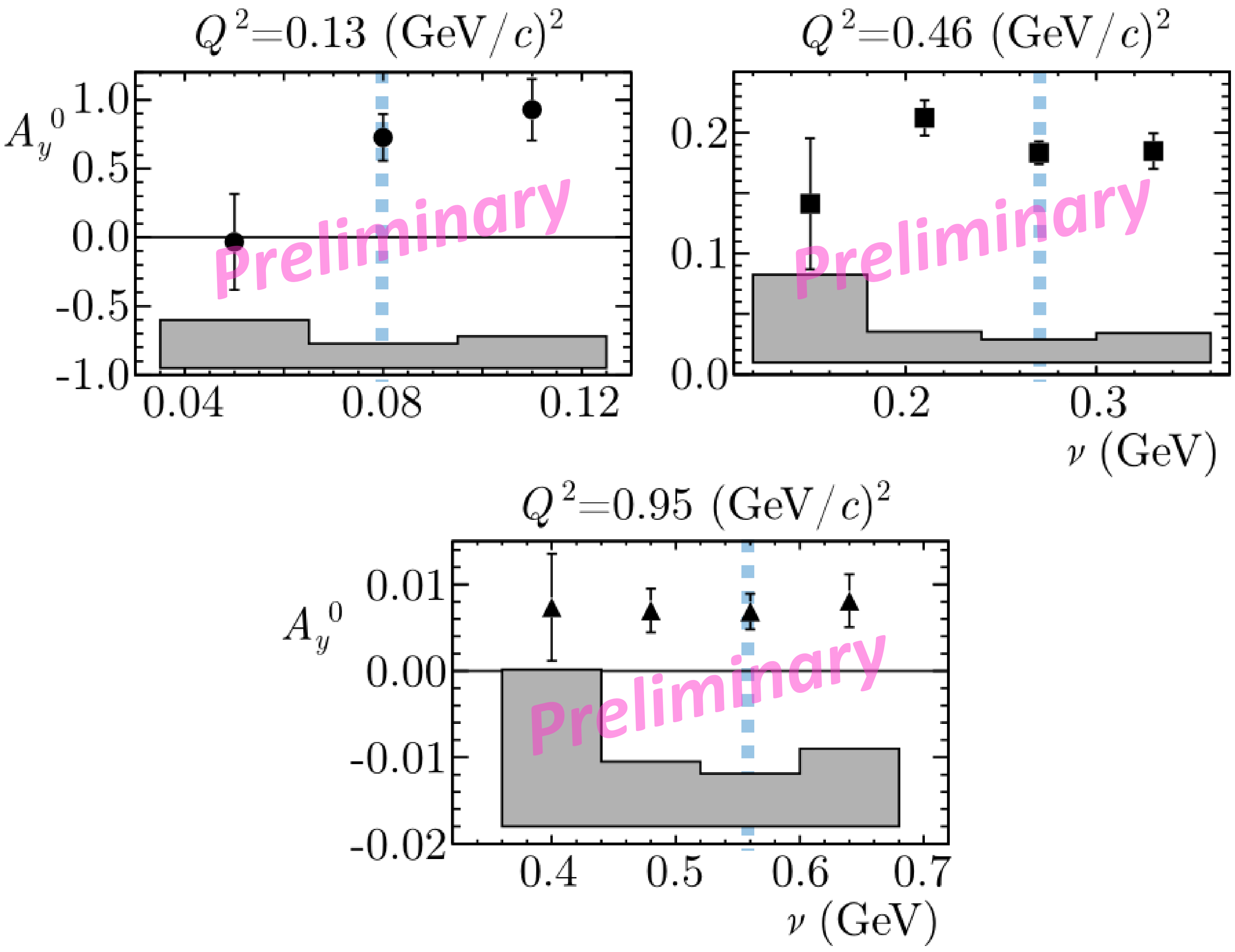
Results

- Systematic Uncertainties

$\langle Q^2 \rangle$ $(\mathrm{GeV}/c)^2$	0.13	0.46	0.95
ϵ_{eff}	0.173	0.0168	60.8×10^{-4}
ϵ_t	0.0339	0.0086	3.21×10^{-4}
$\epsilon_{\mathrm{N_2}}$	0.0054	0.00054	0.848×10^{-4}
ϵ_{p}	0.0015	0.00012	0.0067×10^{-4}
ϵ_{sys}	0.176	0.0188	60.9×10^{-4}

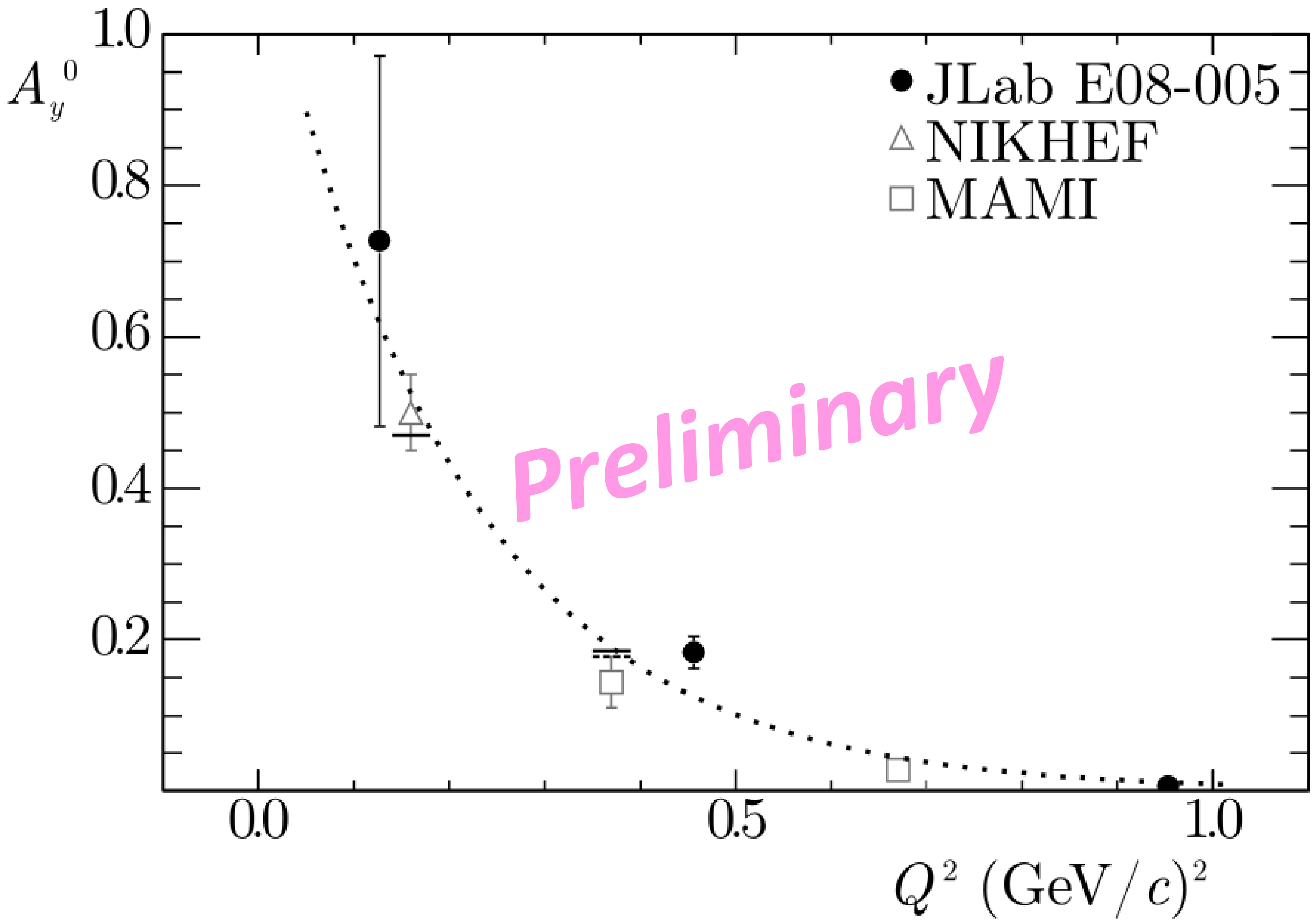
Results

- A_y^0 vs. ν



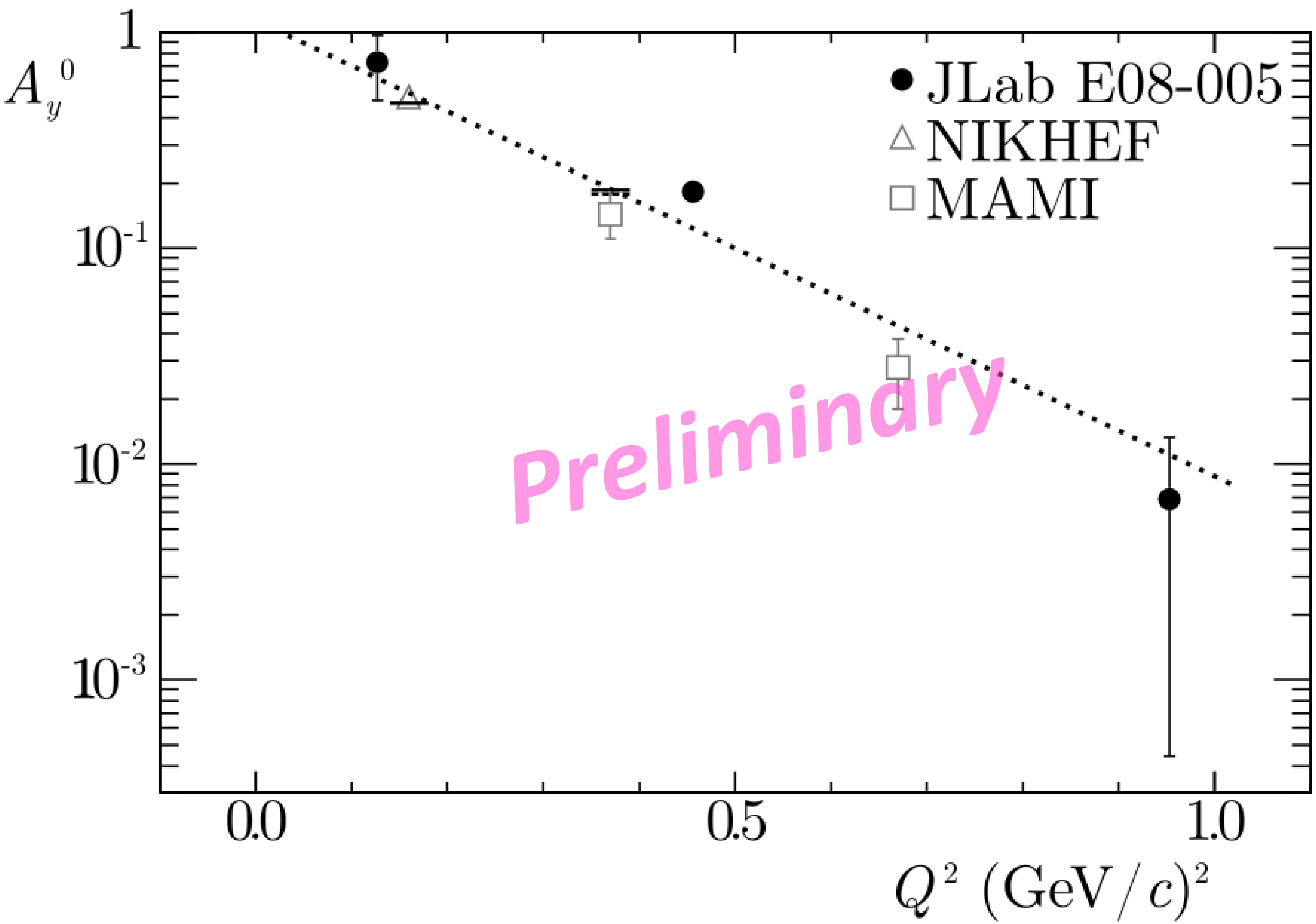
Results

- A_y^0 vs. Q^2
  - Linear



Results

- A_y^0 vs. Q^2
  - Logarithmic



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The Hall A Collaboration

Thank you!

Graduate Students

Spokespersons

Run Coordinators

Advisors

End

Backup Slides

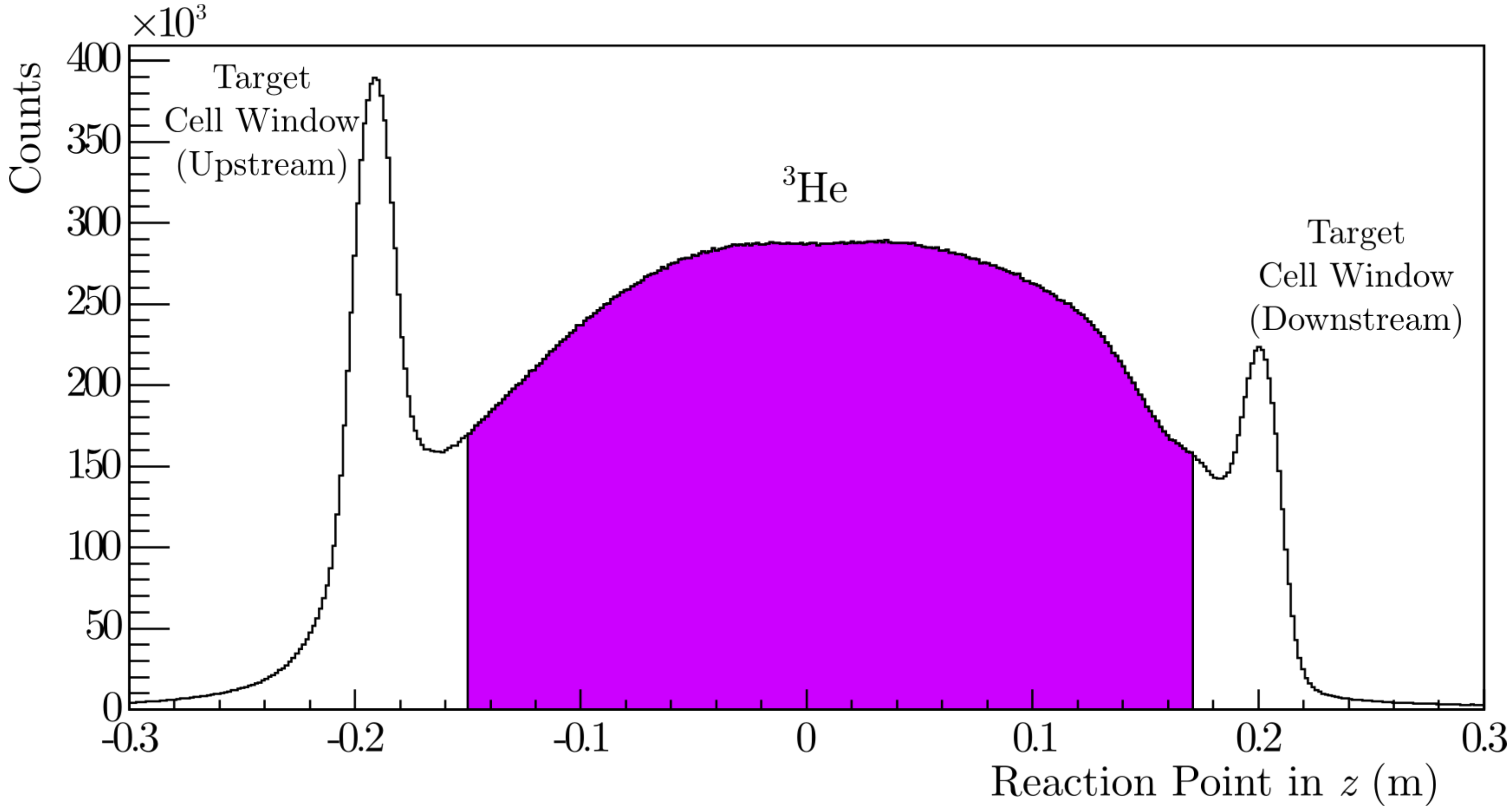
The Measurements

Right HRS

- Electron ID

[1]G. Jin, Ph.D. Thesis, University of Virginia, 2011.

Reaction Point in *z*

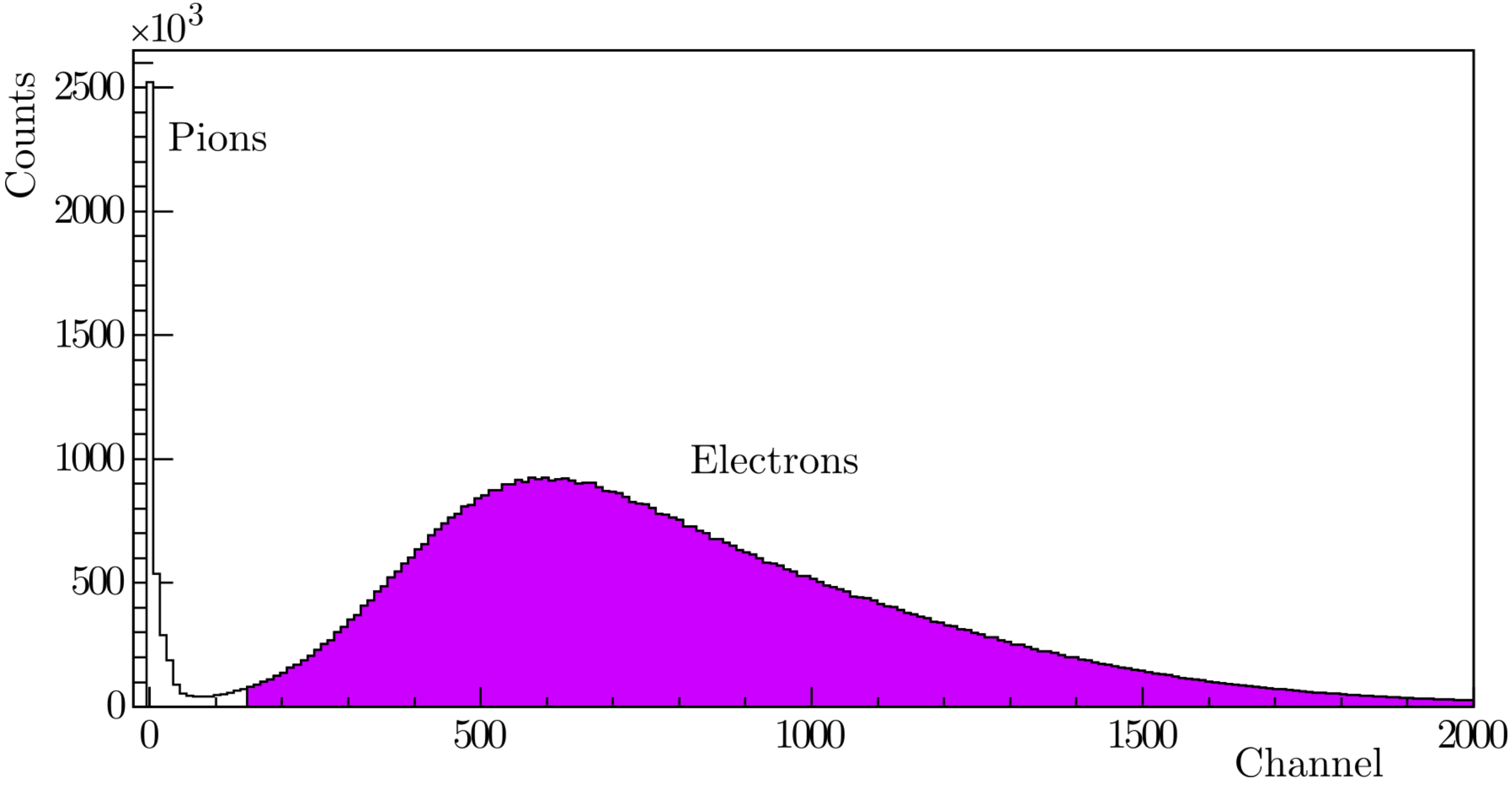


The Measurements

Right HRS

- Electron ID
- Details in E. Long, Ph.D. Thesis, Kent State University, 2012 (arXiv:1209.2739)

Cerenkov

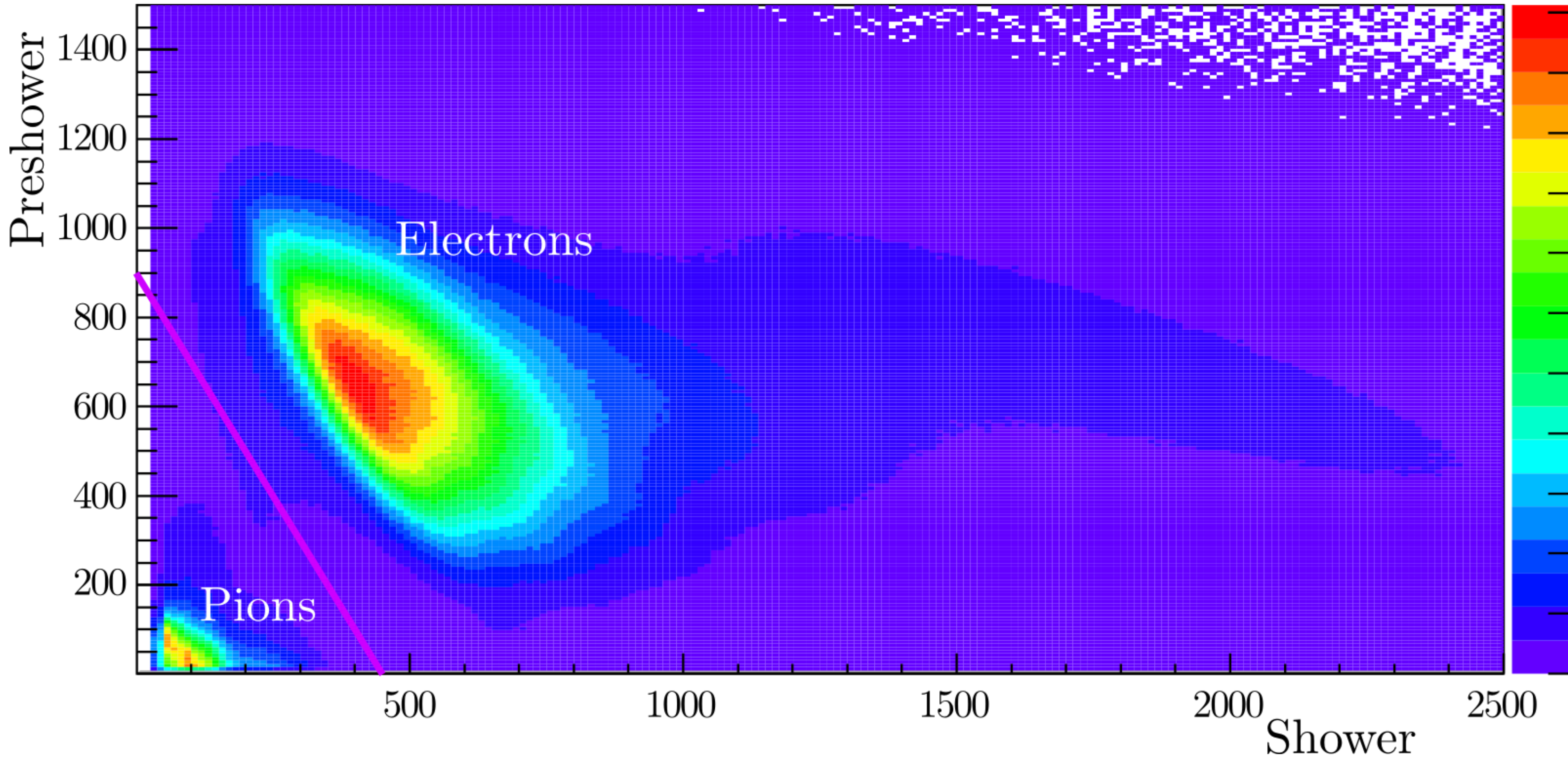


The Measurements

Right HRS

- Electron ID

Preshower/Shower



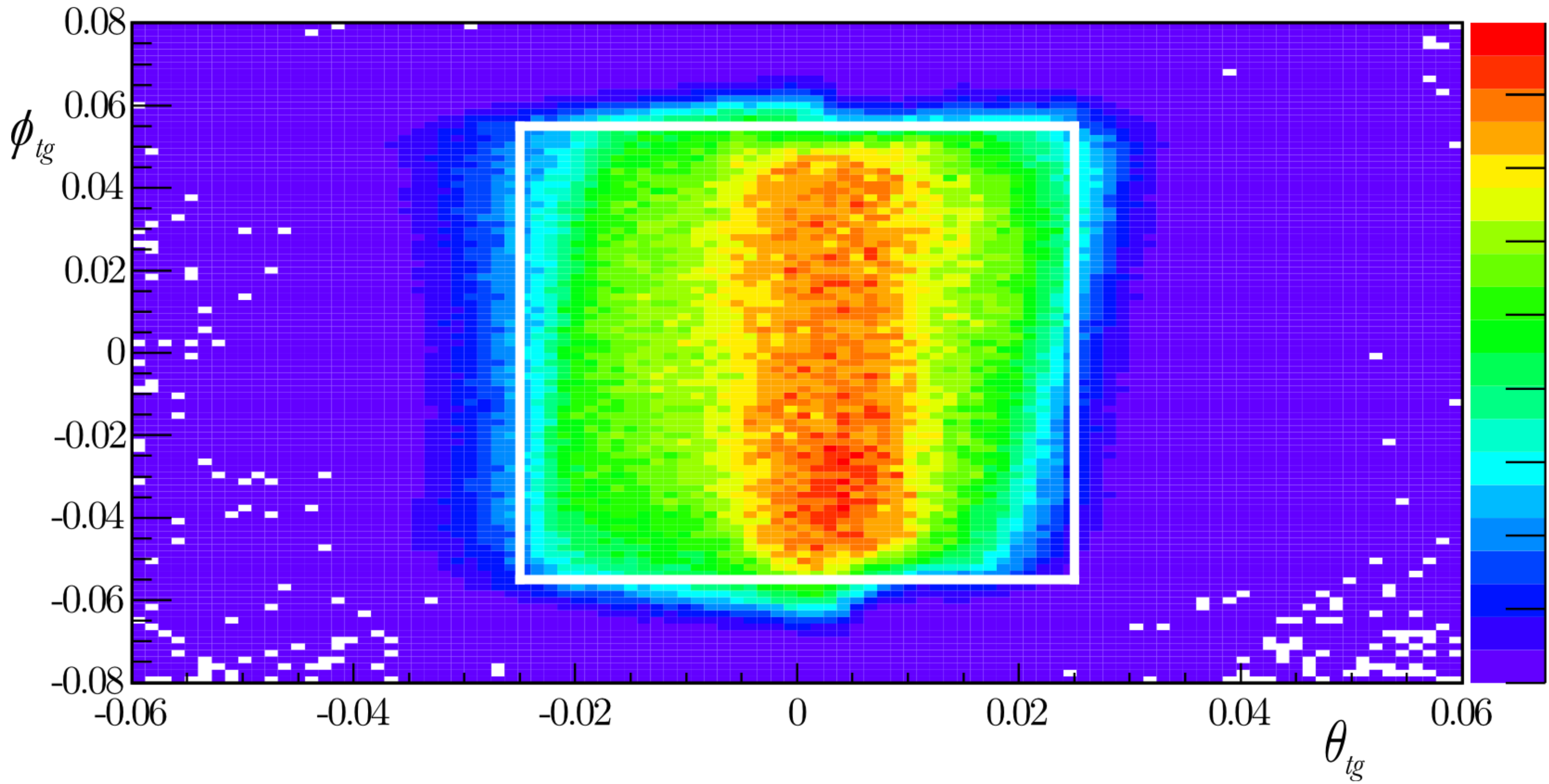
[1]G. Jin, Ph.D. Thesis, University of Virginia, 2011.

The Measurements

Right HRS

- Electron ID

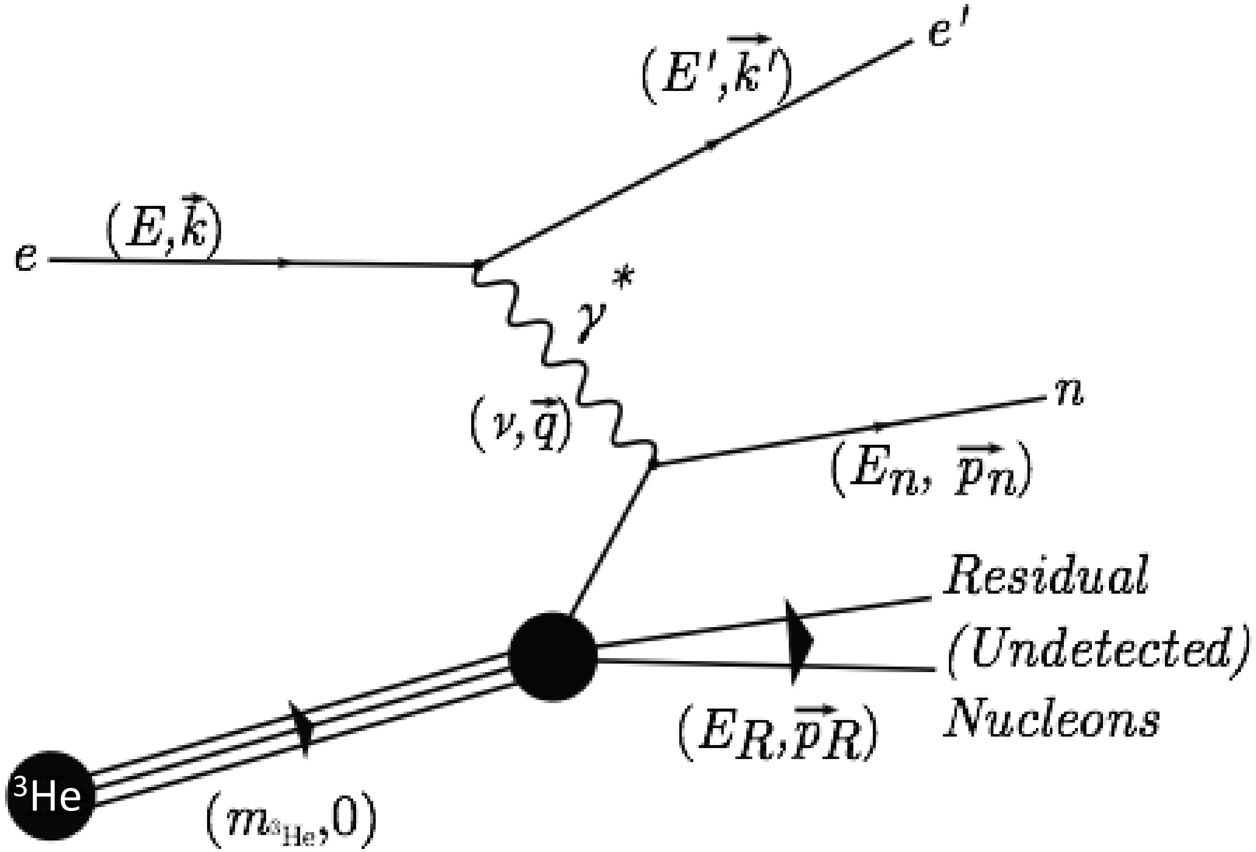
Theta/Phi



[1]G. Jin, Ph.D. Thesis, University of Virginia, 2011.

Simple ^{3}He($e,e'n$) - PWIA

- Ideally, the only interaction that occurs is when the incoming electron hits the neutron
- This model is called Plane Wave Impulse Approximation (PWIA)
- PWIA predicts the single-spin target asymmetry, A_y^0, to be exactly zero



The Measurements

Hall A Neutron Detector (HAND)

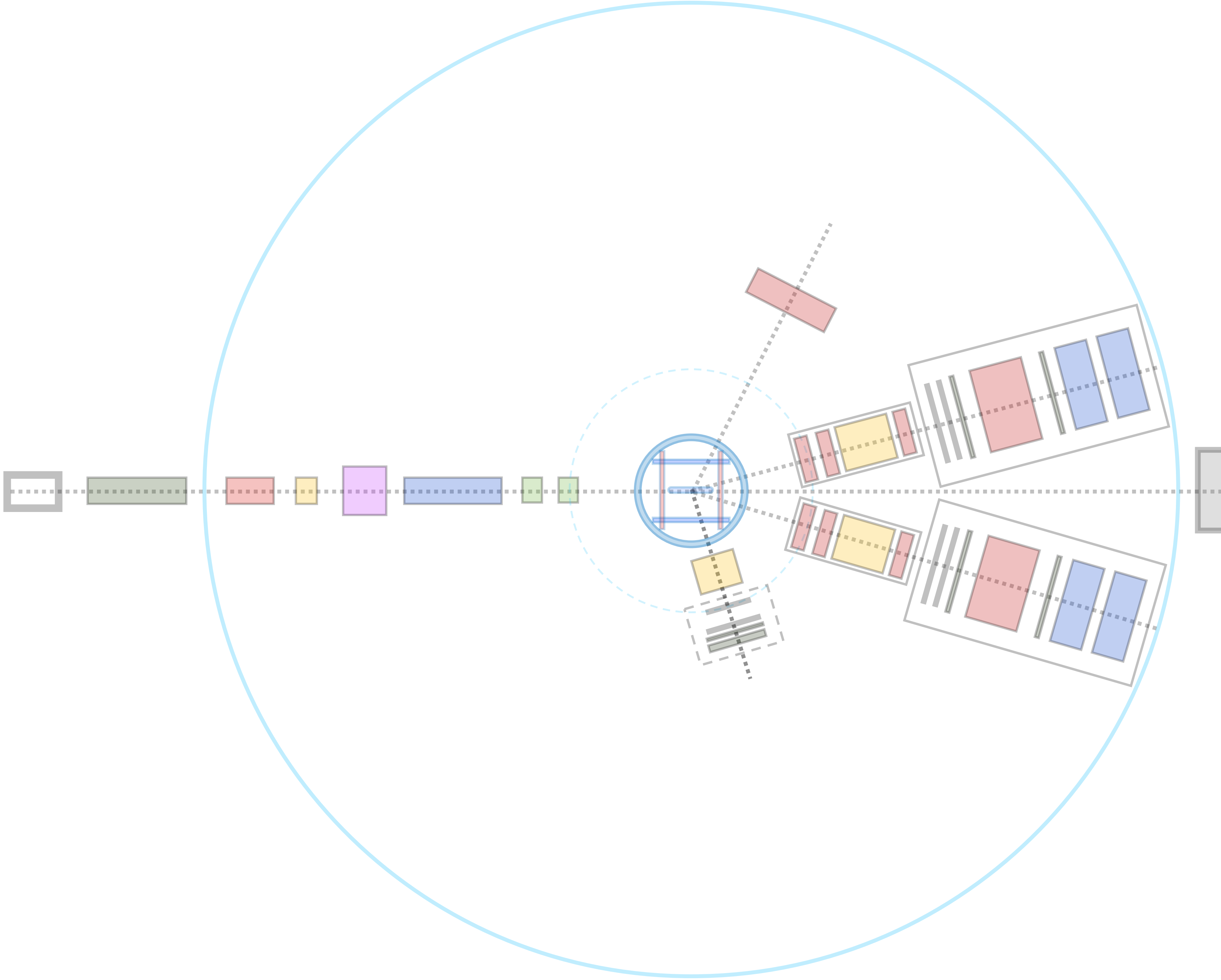
- Proton contamination
- Details in E. Long, Ph.D. Thesis, Kent State University, 2012 (arXiv:1209.2739)

- To find misidentified protons, apply neutron cuts to H(e,e'p)
  - $r_{mis\ id} = \frac{p_{\mathrm{H}\ mis\ id}}{Tot_{\mathrm{H}\ meas}}$
- Find ratio of protons:neutrons from ^{3}He(e,e'n) and ^{3}He(*e,e'p*)
  - $\sigma = \sigma_{Mott}\left(\frac{G_E^2+\tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2\frac{\theta}{2}\right)$
  - $r_{p:n} = \frac{2\sigma_p}{\sigma_n} = \begin{matrix} 18.9{:}\,1 \text{ at } Q^2 = 0.1\ (\mathrm{GeV}/c)^2 \\ 7.6{:}\,1 \text{ at } Q^2 = 0.5\ (\mathrm{GeV}/c)^2 \\ 5.3{:}\,1 \text{ at } Q^2 = 1.0\ (\mathrm{GeV}/c)^2 \end{matrix}$
- Using $r_{p:n}$ and total measured He events in HRS, find expected number of protons and neutrons thrown at HAND
  - $Tot_{\mathrm{He}\ meas} = p_{exp} + n_{exp}$
  - $n_{exp} = \frac{Tot_{\mathrm{He}\ meas}}{1+r_{p:n}}$ $\longrightarrow$ Use to find efficiency, $E_{HAND} = \frac{n_{meas}}{n_{exp}} = \begin{matrix} 1.1 \pm 0.1\% \text{ a} \\ 7.0 \pm 0.7\% \text{ a} \\ 32.2 \pm 3.2\% \end{matrix}$
  - $p_{exp} = n_{exp} r_{p:n}$
- Include $r_{mis\ id}$ to estimate number of misidentified protons in 3He
  - $p_{\mathrm{He}\ mis\ id} = p_{exp} r_{mis\ id}$
- Use to calculate proton dilution factor
  - $D_p = 1 - \frac{p_{\mathrm{He}\ mis\ id}}{n_{exp}}$

The Measurements

Reference Slide

- Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.



Results

- A_y^0 vs. Q^2
  - Linear and Logarithmic