CaFe

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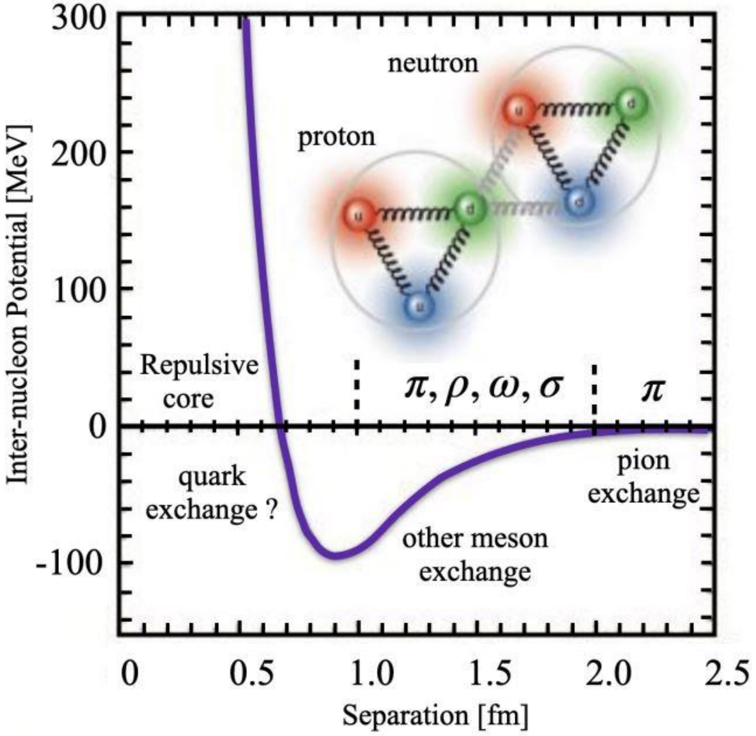
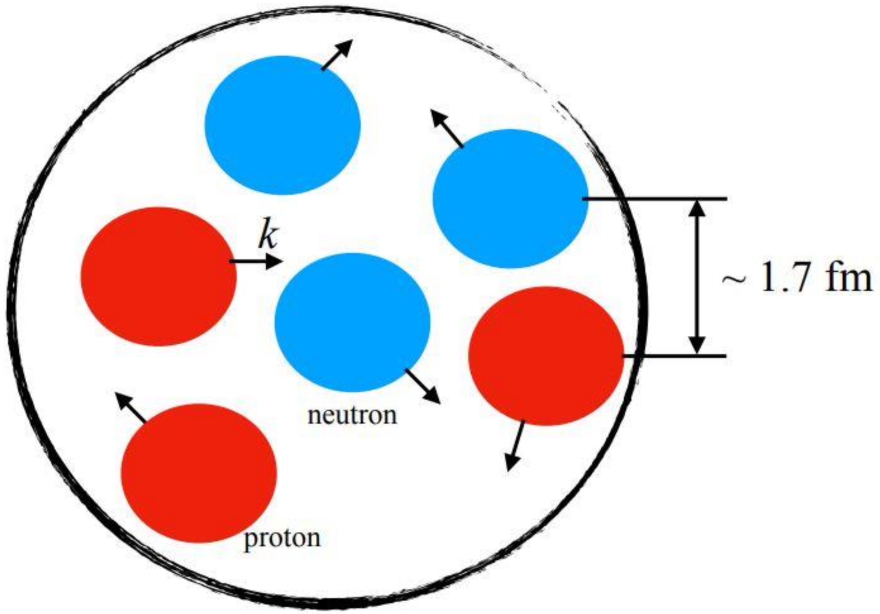
Outline

- Review the CaFe experiment
- Rate Estimates
- Data Calibration
- Data Quality Checks
- Initial Group Results

Nuclear Shell Model

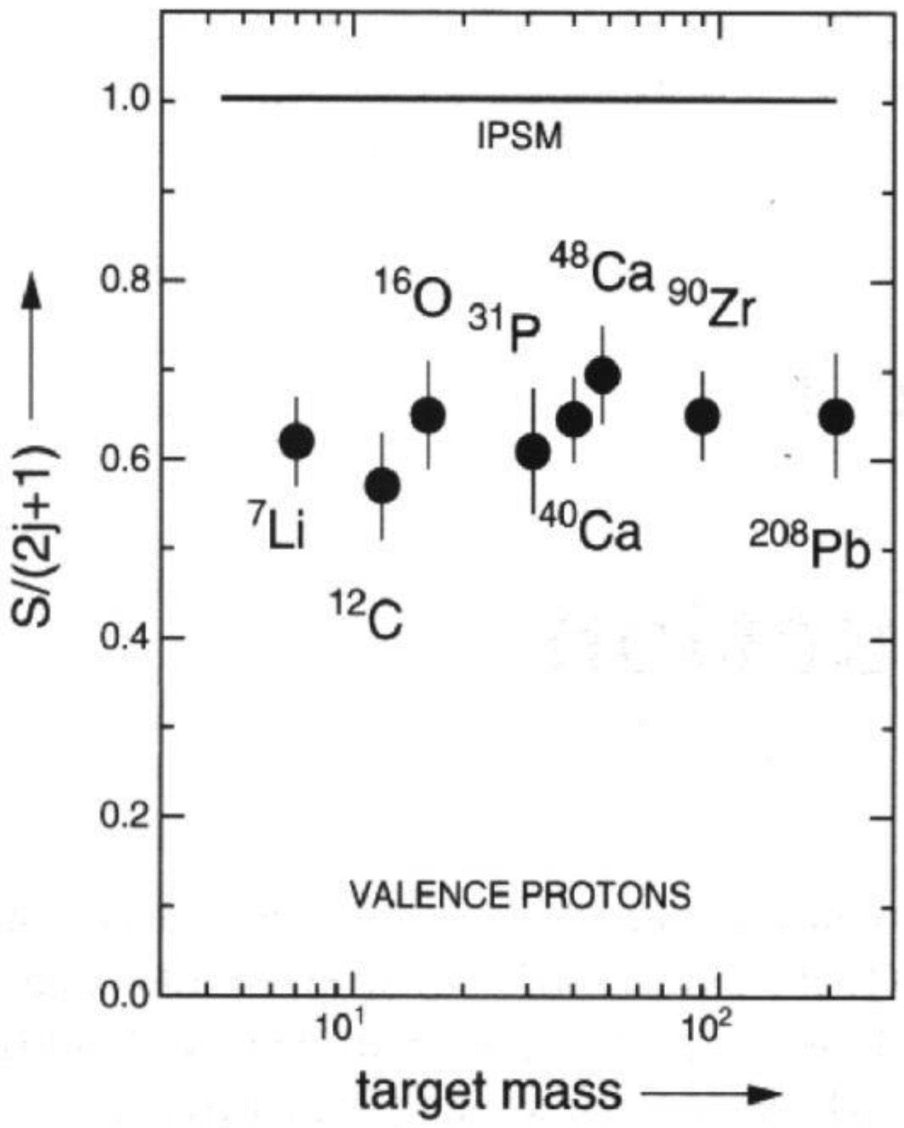
- The nucleus consists of *A* nucleons interacting via the Strong Interaction
- Nucleons move independently in a mean field generated by the other (A-1) nucleons
- Successfully describes bulk properties of nuclei
  - Shell structure
  - Excitation energies
  - Spin, parities
  - Nuclear magic numbers
- Typical momentum less than Fermi momentum, k_F~250 MeV/C





Limitations of the Nuclear Shell Model

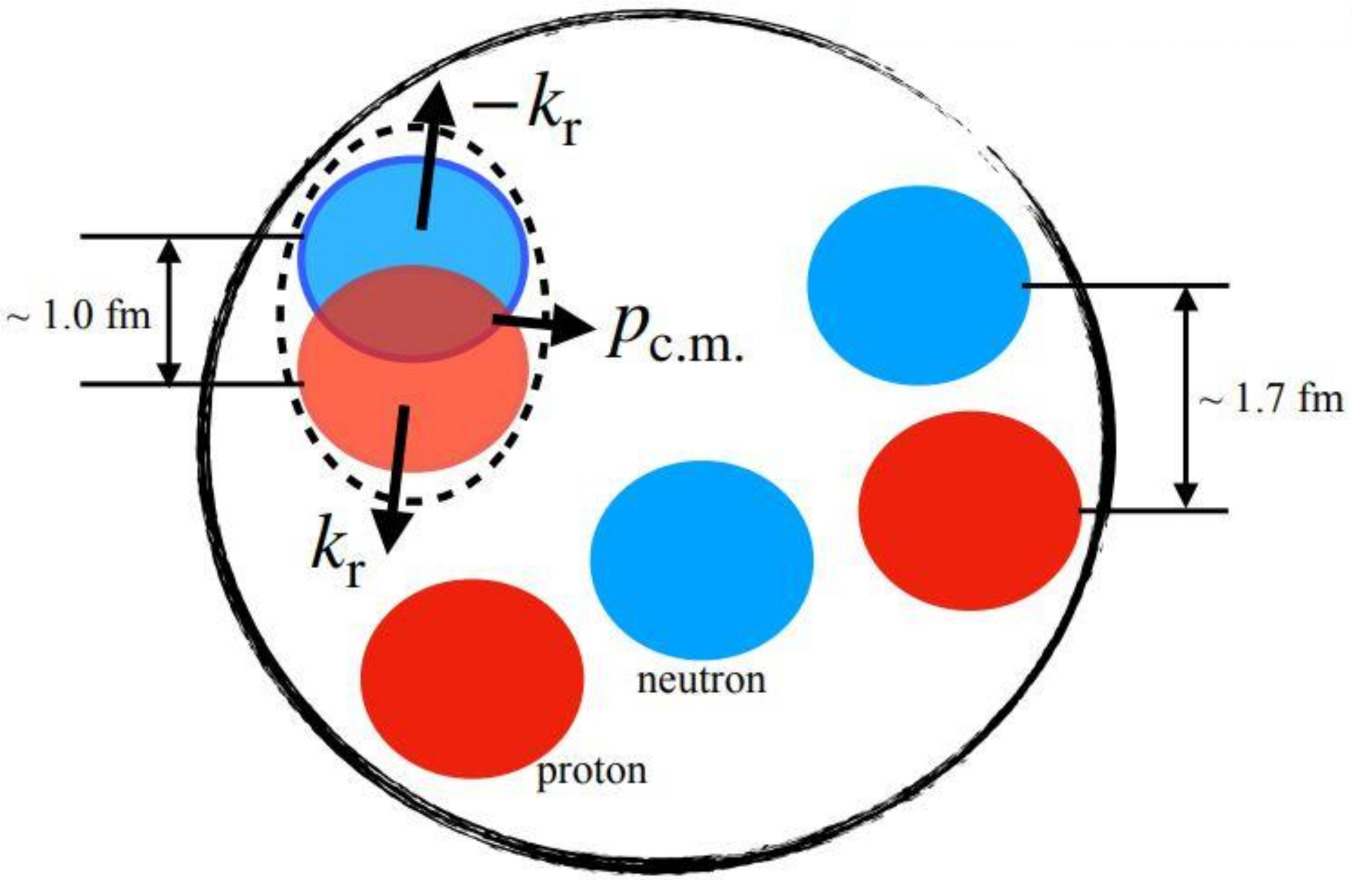
- Measured (e,e'p) proton knockout from valence shells
  - Found ~60-70% of predicted occupancy
- Corrections
  - Long range correlations
  - Short range correlations (SRCs)
    - 20-25%



O. Hen, G. A. Miller, E. Piasetzky, and L.B. Weinstein, Rev. Mod. Phys. 89, 045002 (2017). [1611.09748] Nucleon-Nucleon Correlations, Short-lived Excitations, and the Quarks Within (arxiv.org)

Short Range Correlations

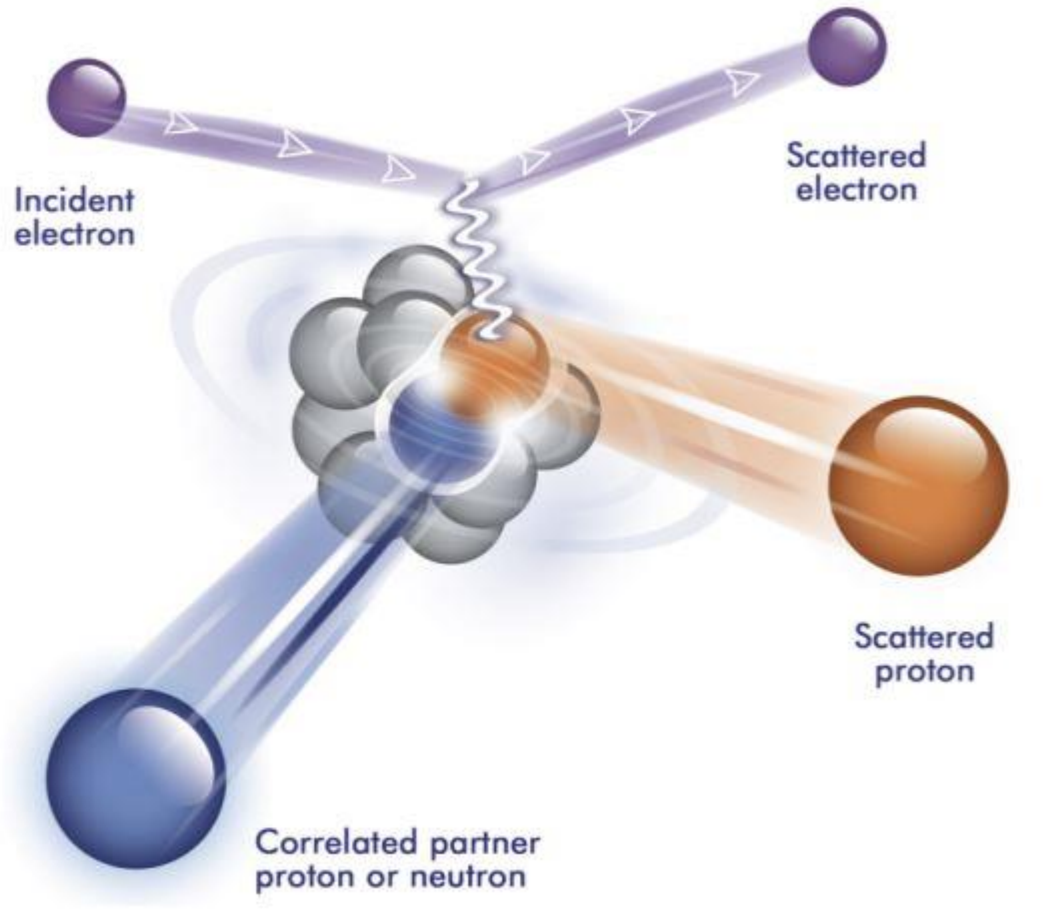
- SRCs are temporary and require close proximity between nucleons
- Interact via the strong N-N interaction
- High relative momentum ($k_r > k_F \sim 250$ MeV/c)
- Unchanged center-of-mass momentum



CaFe Motivation

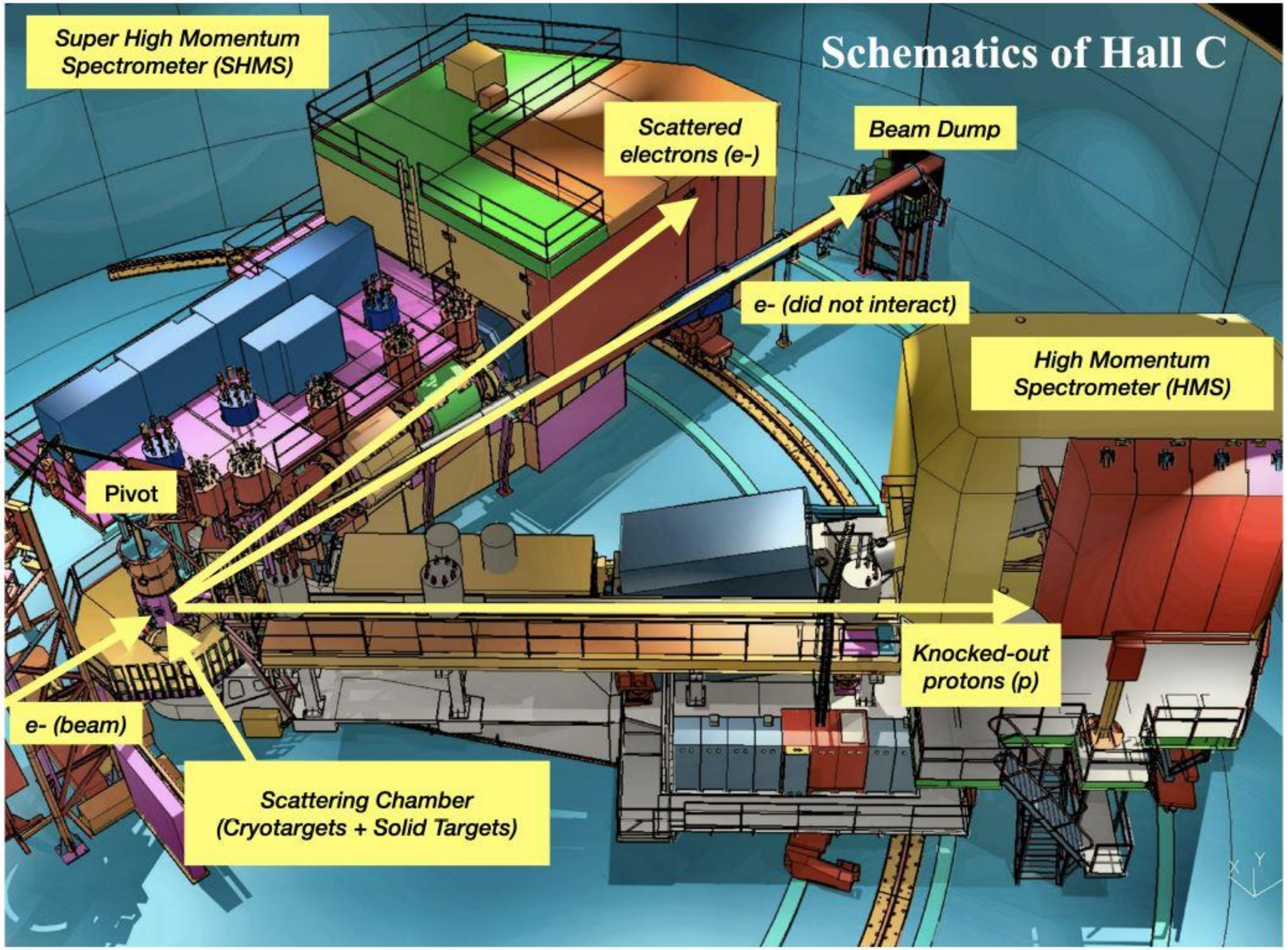
Which nucleons form pairs?

- Compare number of high momentum protons in ^{40}Ca and ^{48}Ca
  - ^{40}Ca has filled the 1s, 1p, and 2s/1d proton and neutron shells
  - How do the additional 8 $f_{7/2}$ neutrons of ^{48}Ca change the number of SRC pairs?
- Compare number of high momentum protons in ^{48}Ca and ^{54}Fe
  - How does the additional 6 $f_{7/2}$ protons of ^{54}Fe change the number of SRC pairs?
- Measure A(e,e'p) on d, ^{9}Be, ^{10,11}B, ^{12}C, ^{40,48}Ca, ^{54}Fe, and ^{197}Au at high and low missing momentum
  - ^{9}Be-^{10}B-^{11}B-^{12}C quartet and ^{40}Ca-^{48}Ca-^{54}Fe triplet



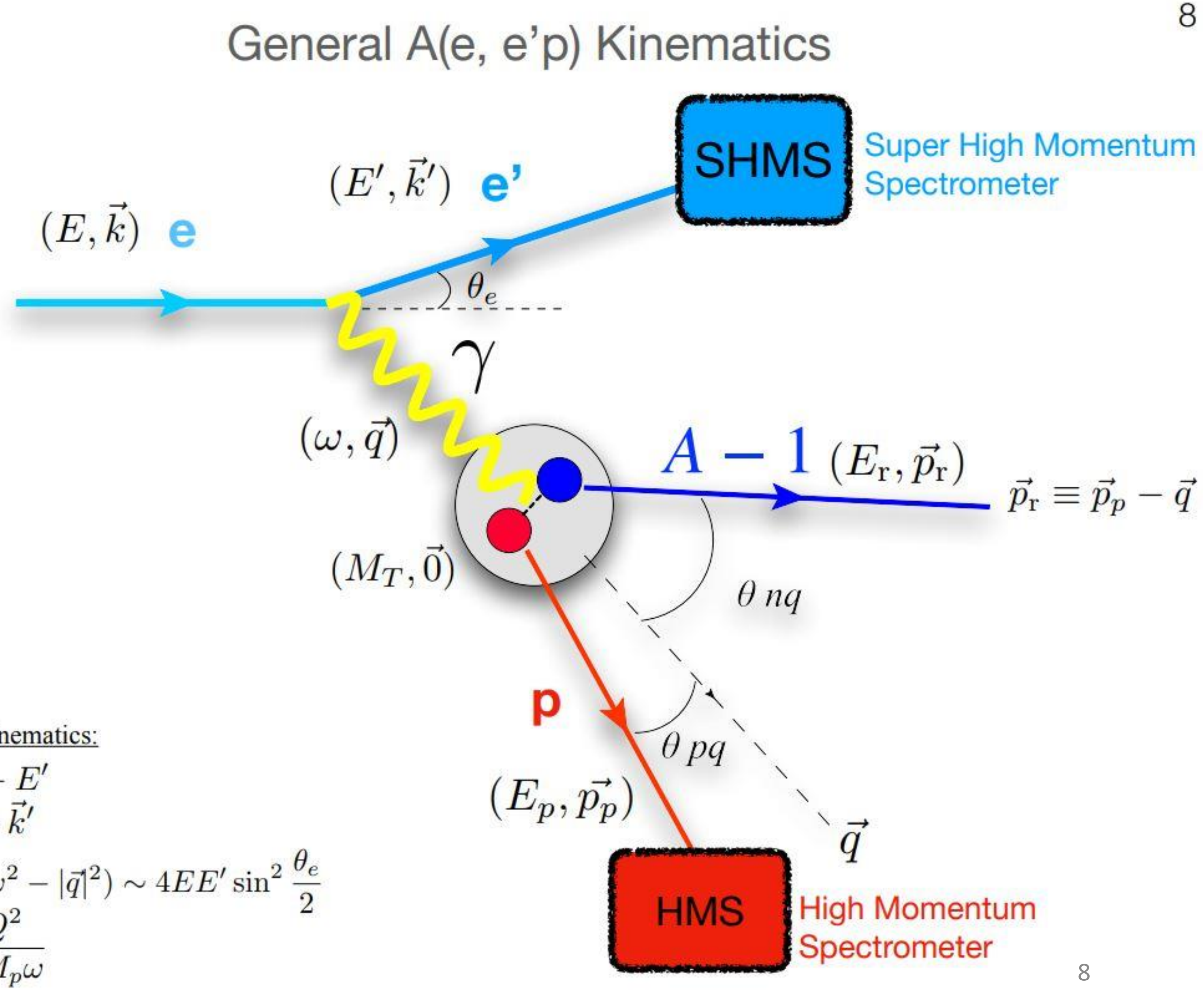
Hall C: CaFe Experimental Setup

- A(e,e'p)
- 10.6 GeV
- Detect scattered electrons in the Super High Momentum Spectrometer (SHMS)
- Detect knocked-out protons in the High Momentum Spectrometer (HMS)



Hall C: Experimental Setup Cont.

- E_o = 10.6 GeV
- E'=8.55 GeV
- Θ_e =8.3 Degrees
- Q^2 =2.1 (GeV/c)^2
- $P_{miss} \approx$ 400 MeV/c
  - $|P_p|$ = 1.325 GeV/c
  - Θ_p = 66.4°
- $P_{miss} \approx$ 150 MeV/c
  - $|P_p|$ = 1.820 GeV
  - Θ_p = 48.3 Degrees



Electron Kinematics:

$$\omega \equiv E - E'$$
$$\vec{q} \equiv \vec{k} - \vec{k}'$$
$$Q^2 \equiv -(\omega^2 - |\vec{q}|^2) \sim 4EE' \sin^2 \frac{\theta_e}{2}$$
$$x_{Bj} \equiv \frac{Q^2}{2M_p\omega}$$

Rate Estimates

- Prior to data taking
- Provide second independent rate estimates to inform run plan
- Used SIMC to simulate counts for 1 hour of
  - MF ^{12}C
  - SRC ^{2}D
  - Simulation did not account for
    - The nuclear proton transparency (PT)
    - Run Time (t)
    - A 50% safety factor
- Corrected initial MF ^{12}C and SRC ^{2}D counts by introducing a scale factor
  - #MF_C12 = #Simc_C12 * 0.5 * t * PT
- Scaled the MF ^{12}C counts to other targets
  - #MF_A = #MF_C12 * (PT_A)/(PT_C12) * (Thick_A)/(Thick_C12) * (t_A)/(t_C12)
- SRC counts treated similarly

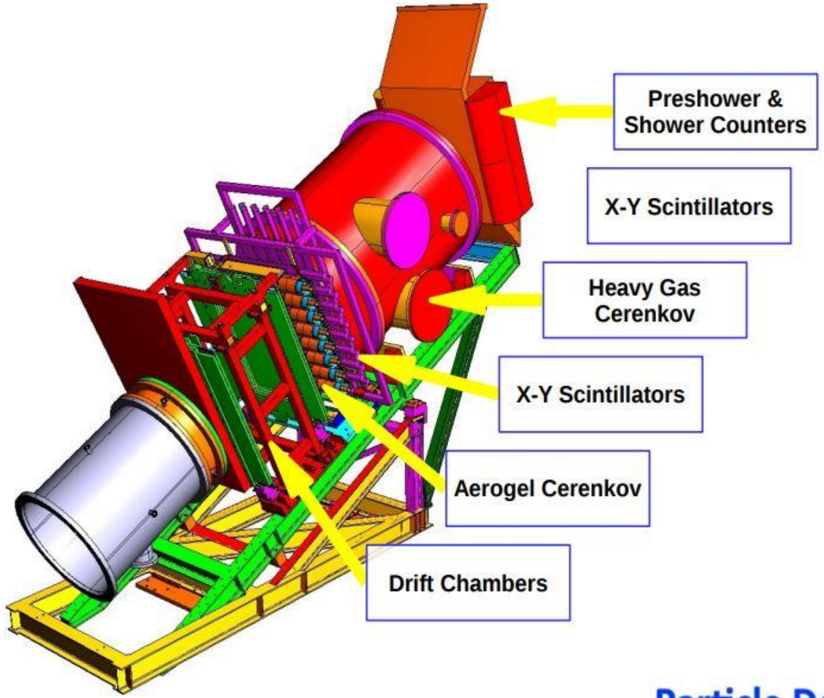
MF		
Target	Run Time (Hr)	Counts (10^5)
D2	8	26
Be9	8	10
B10	8	60
B11	8	66
C12	8	55
Ca40	8	56
Ca48	8	56
Fe54	8	29

SRC		
Target	Run Time (Hr)	Counts (10^2)
D2	8	55
Be9	8	83
B10	8	50
B11	8	55
C12	8	52
Ca40	8	52
Ca48	8	52
Fe54	8	31

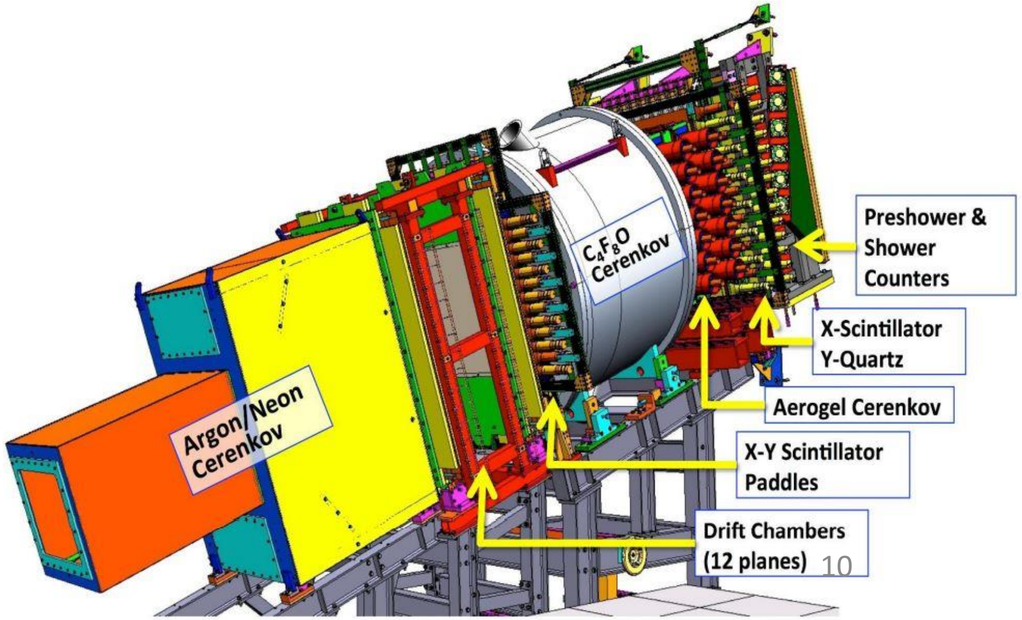
Data Calibration

- SHMS & HMS
  - SHMS Focus
- Detectors
  - Drift Chamber
  - Hodoscopes
    - (X-Y Scintillators)
  - Calorimeter
    - (Preshower & Shower Counters)

Particle Detectors inside the HMS

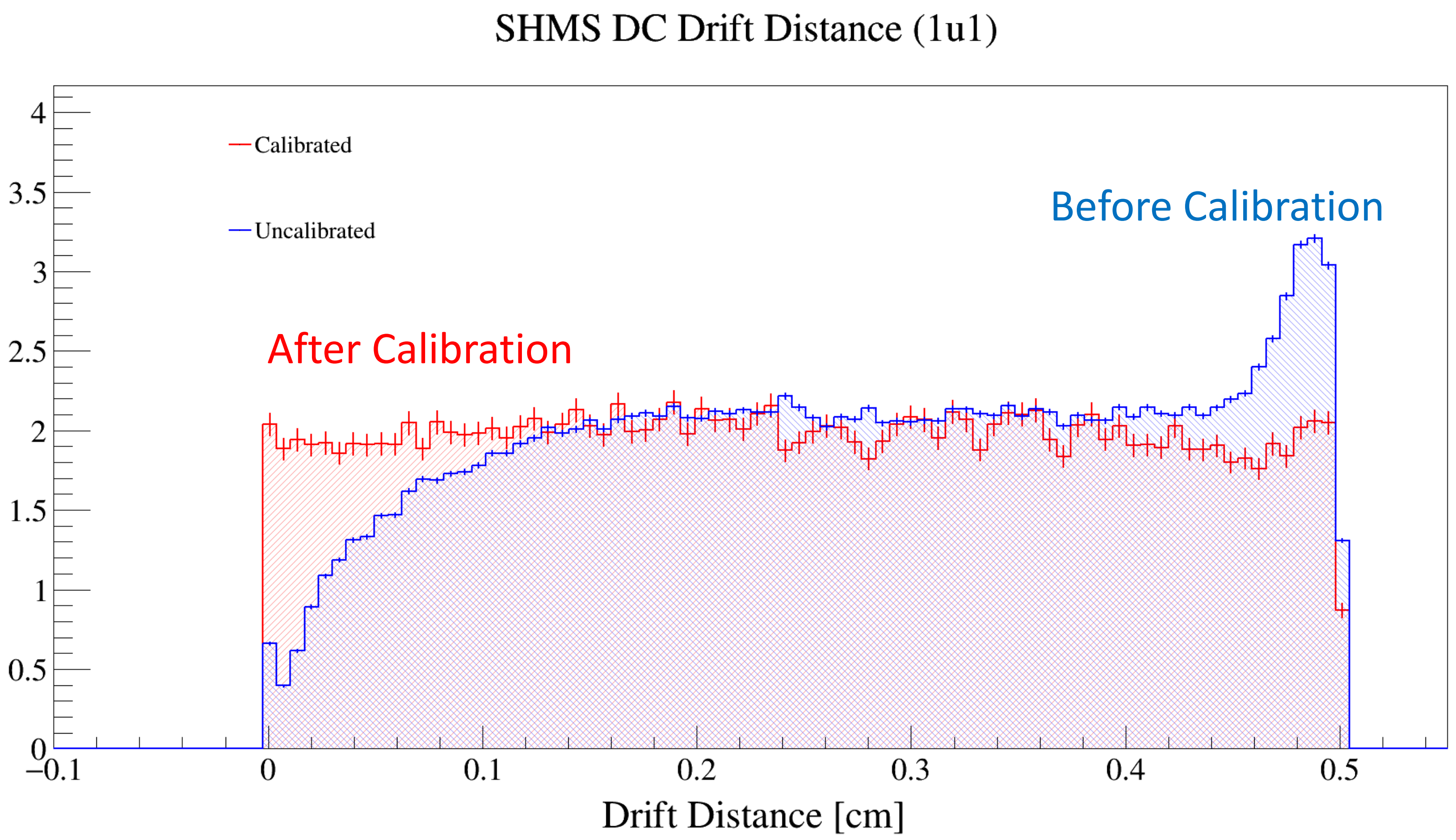


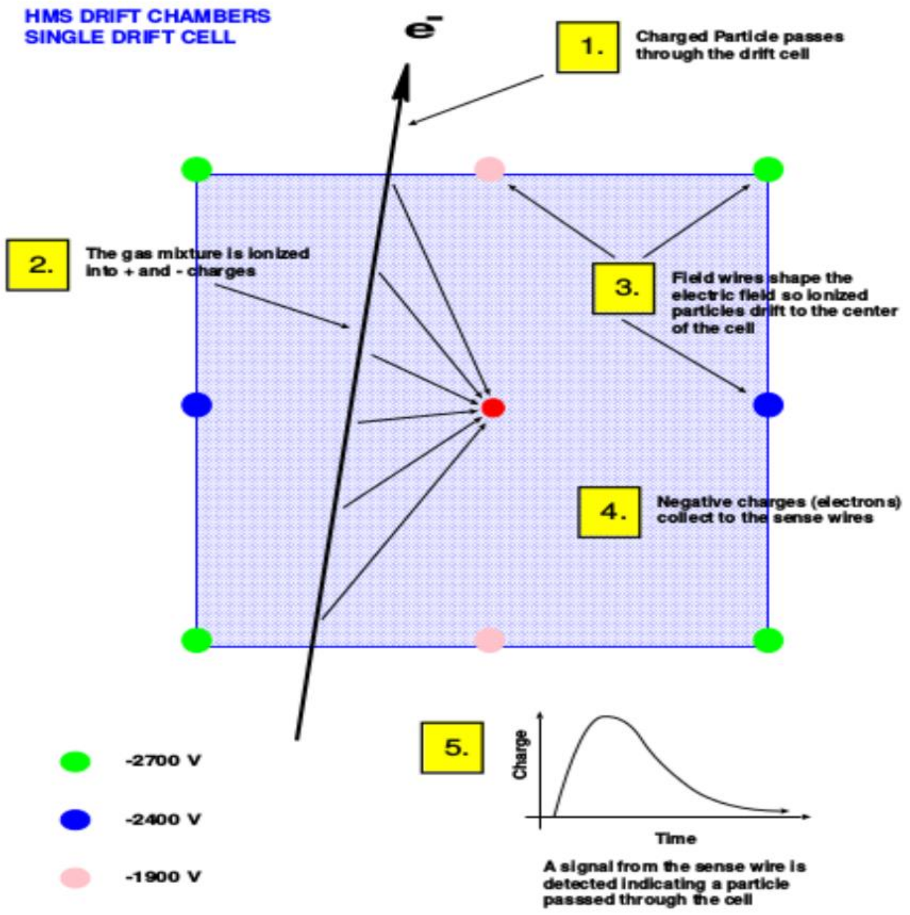
Particle Detectors inside the SHMS



SHMS Drift Chamber Drift Distance

- Multiplicity cut, nhit ==1



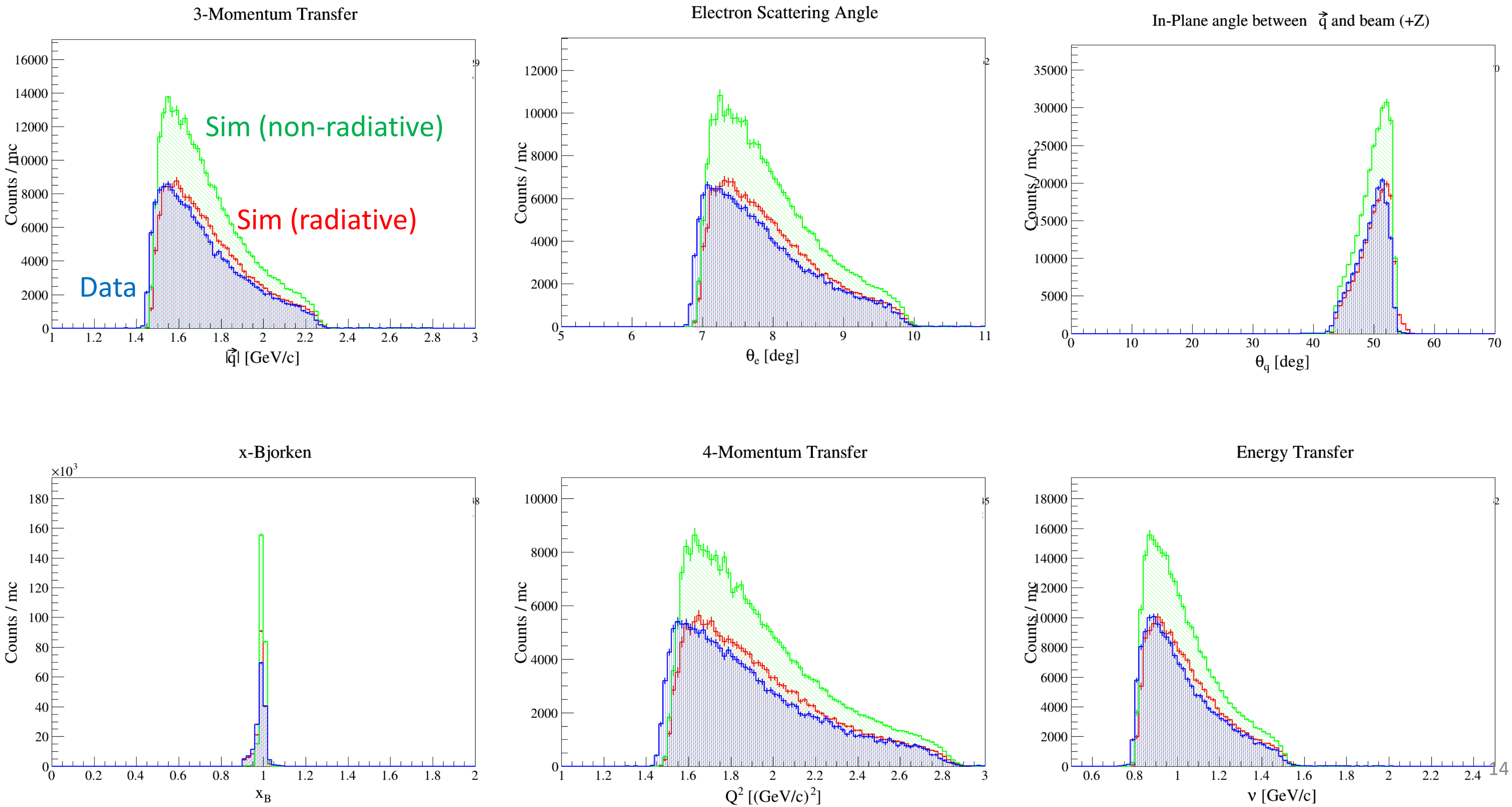


CaFe Data Quality Checks

Data vs Simulation

- Each run for every target has unique
  - Charge (charge) [mC]
  - HMS Hadron Tracking Efficiency (Ehtrk) [%]
  - SHMS Electron Tracking Efficiency (Eetrk) [%]
  - Live Time (Elt) [%]
  - All exceed 98%
- Correct raw data
  - Corrected counts = counts / ((Ehtrk * Eetrk * Elt) * (charge));

H(e,e’) elastic Data vs Sim



Preliminary Group Results

What we measured ?

"high-momentum fraction"

$$\frac{A(e,e'p)^{SRC}/A(e,e'p)^{MF}}{{}^{12}C(e,e'p)^{SRC}/{}^{12}C(e,e'p)^{MF}}$$

$$A(e,e'p) : \frac{N}{Q \cdot \epsilon_i \cdot T_N \cdot \rho_t}$$

N : $(e,e'p)$ coincidence counts

Q : total charge [mC]

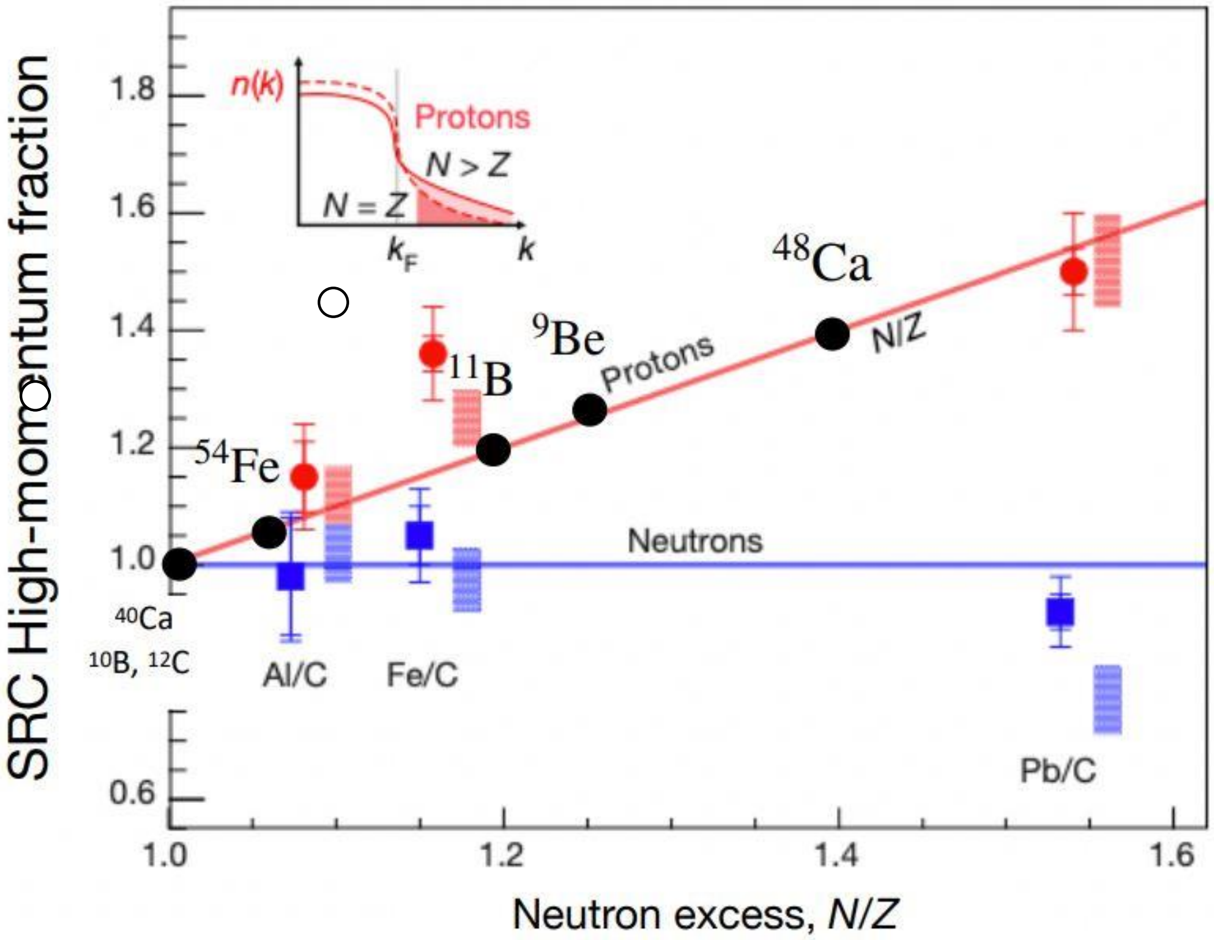
ϵ_i : detector/DAQ efficiencies

T_N : nuclear transparency

ρ_t : target thickness [g/cm^2]

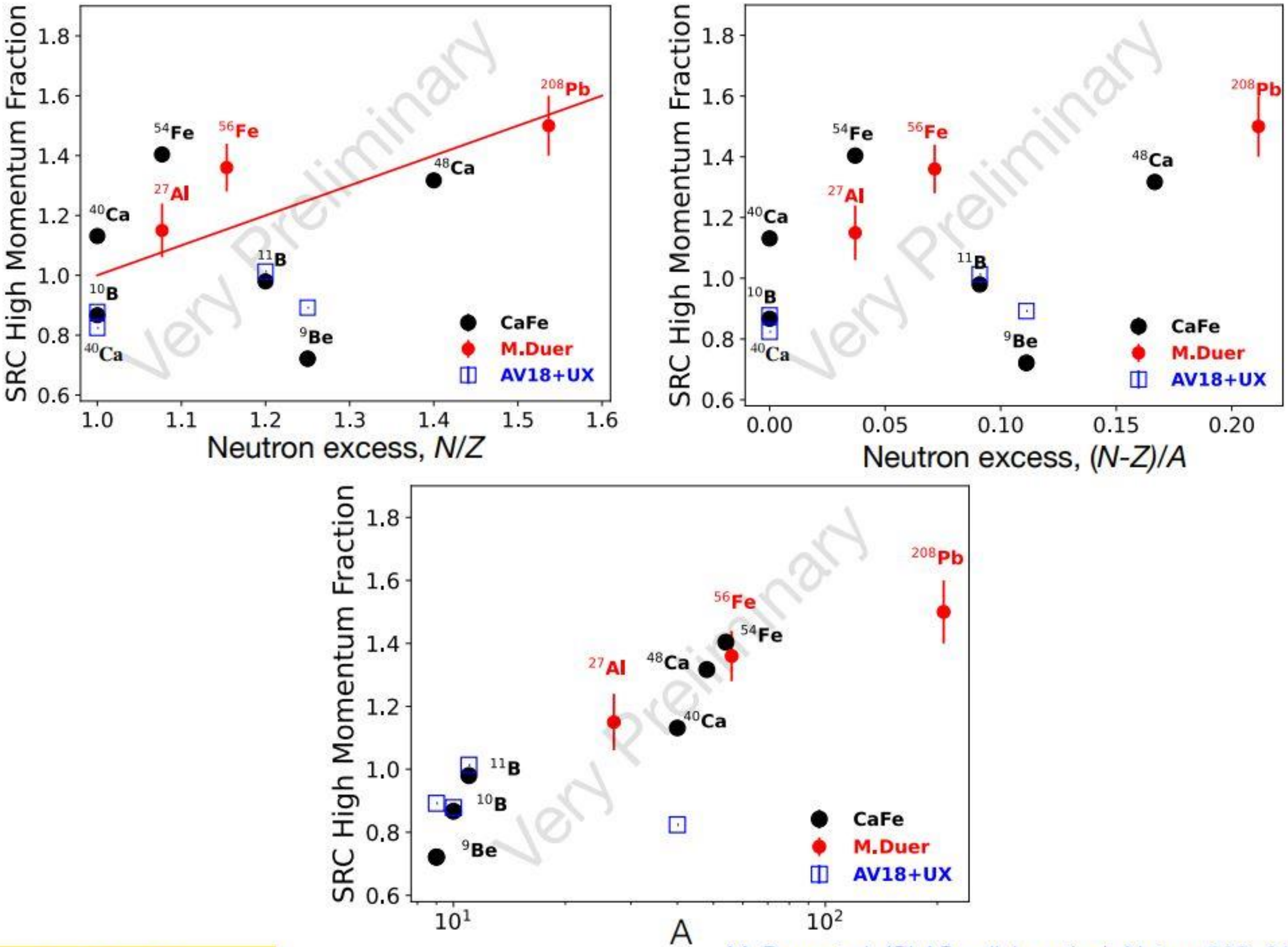
cancel in double ratio

Simple CaFe Projection



M. Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

Results



Plots by Dien Nguyen

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M. Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

Summary

- Progress
  - Rate Estimates
  - Experiment
  - Data calibration
  - Data quality checks
- Future Work
  - Further data quality checks
  - Paper on ratios in a few months
  - Work on cross section and cross section ratios
    - Determine spectrometer efficiencies and radiative corrections

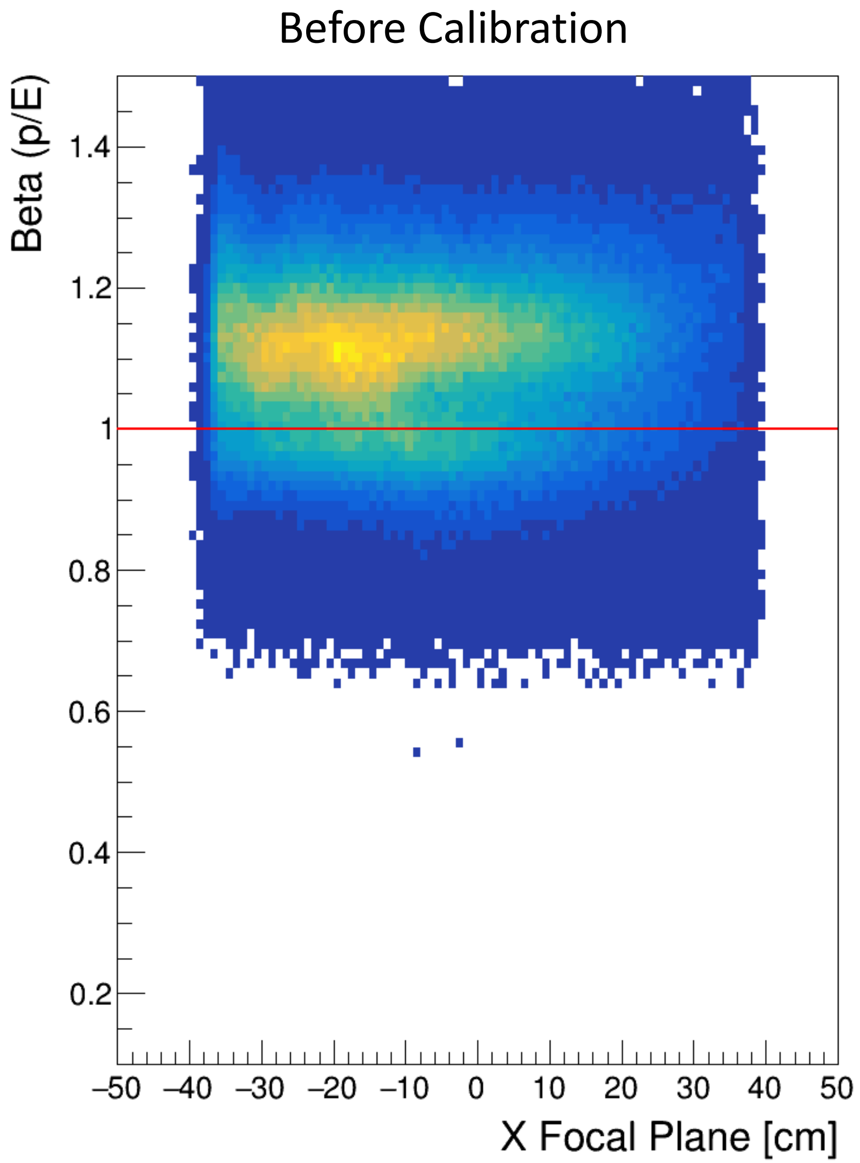
Questions?

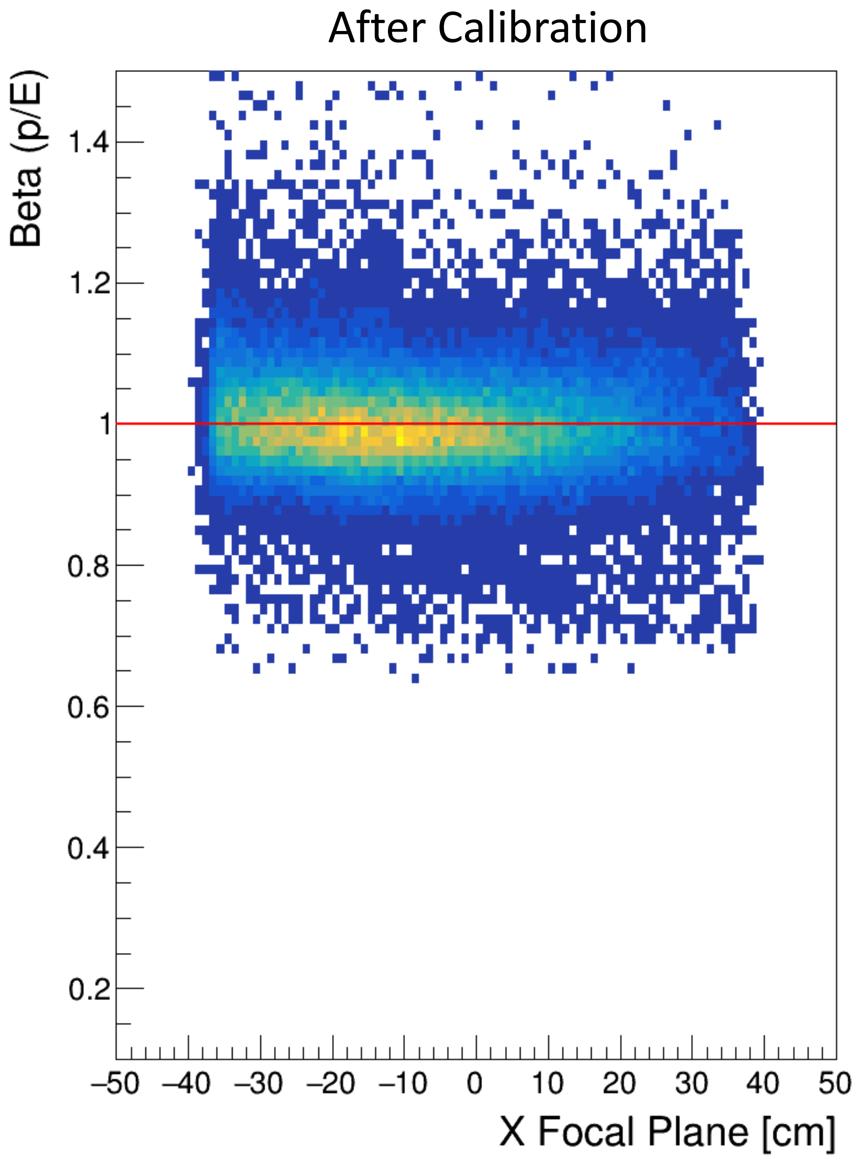
Back Up Slides

Experiment Run

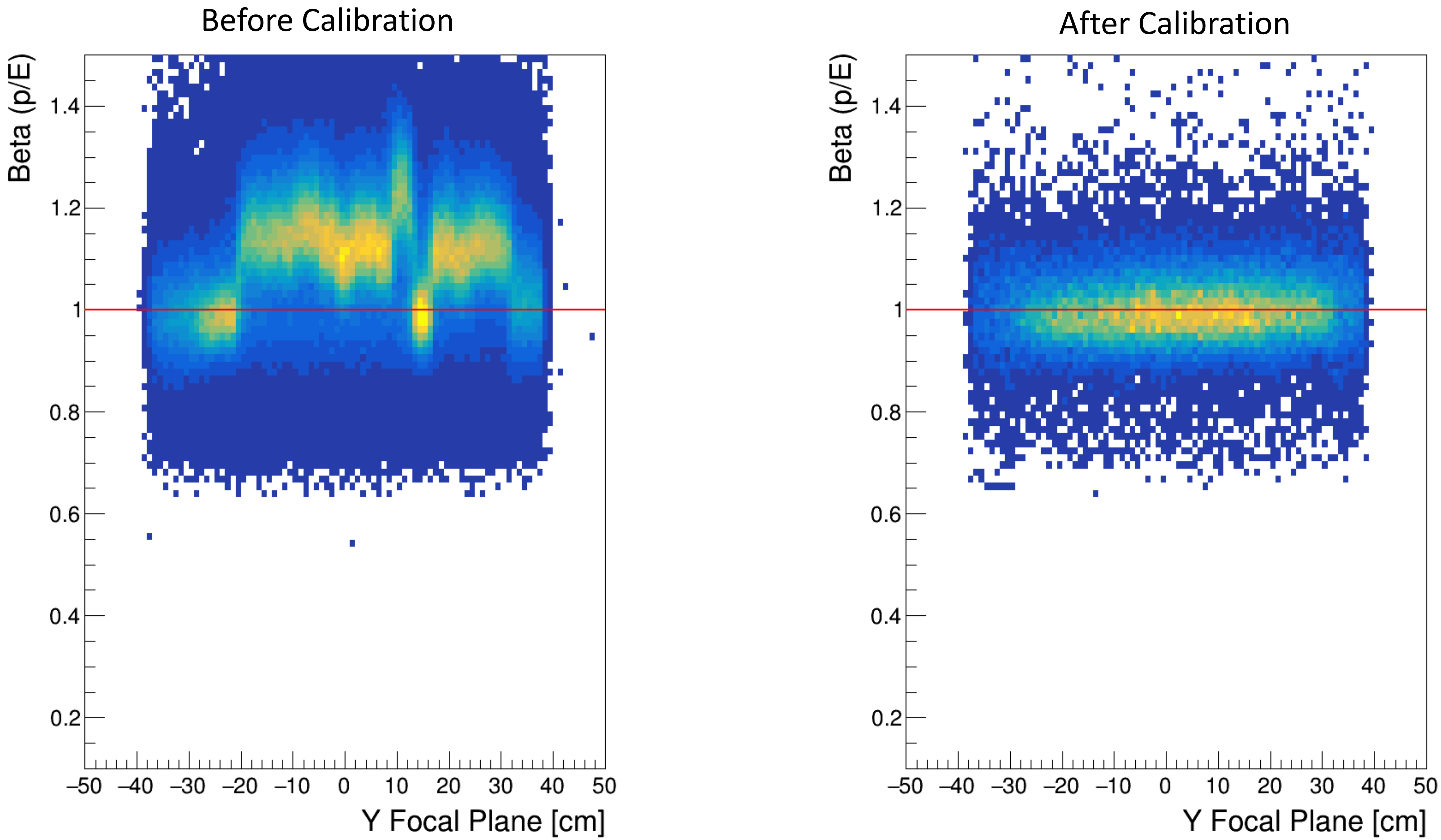
- Initial CaFe run on ^{2}D, ^{9}Be, ^{10,11}B, ^{12}C, ^{40}Ca, ^{48}Ca, ^{54}Fe
  - Sep. 16th to the 29th
  - Successfully acquired all necessary data during our run time
  - Accelerator could not provide expected 80μA
    - 40-60μA
- Second CaFe run on ^{197}Au
  - Feb 22nd-24th
- Preparation and Contribution
  - Took numerous shifts prior to CaFe to gain experience
  - Helped ensure real time data quality
  - Took 5 Target Operator owl shifts and 2 Shift Leader swing shifts

SHMS Hodoscope Beta vs X Focal Plane

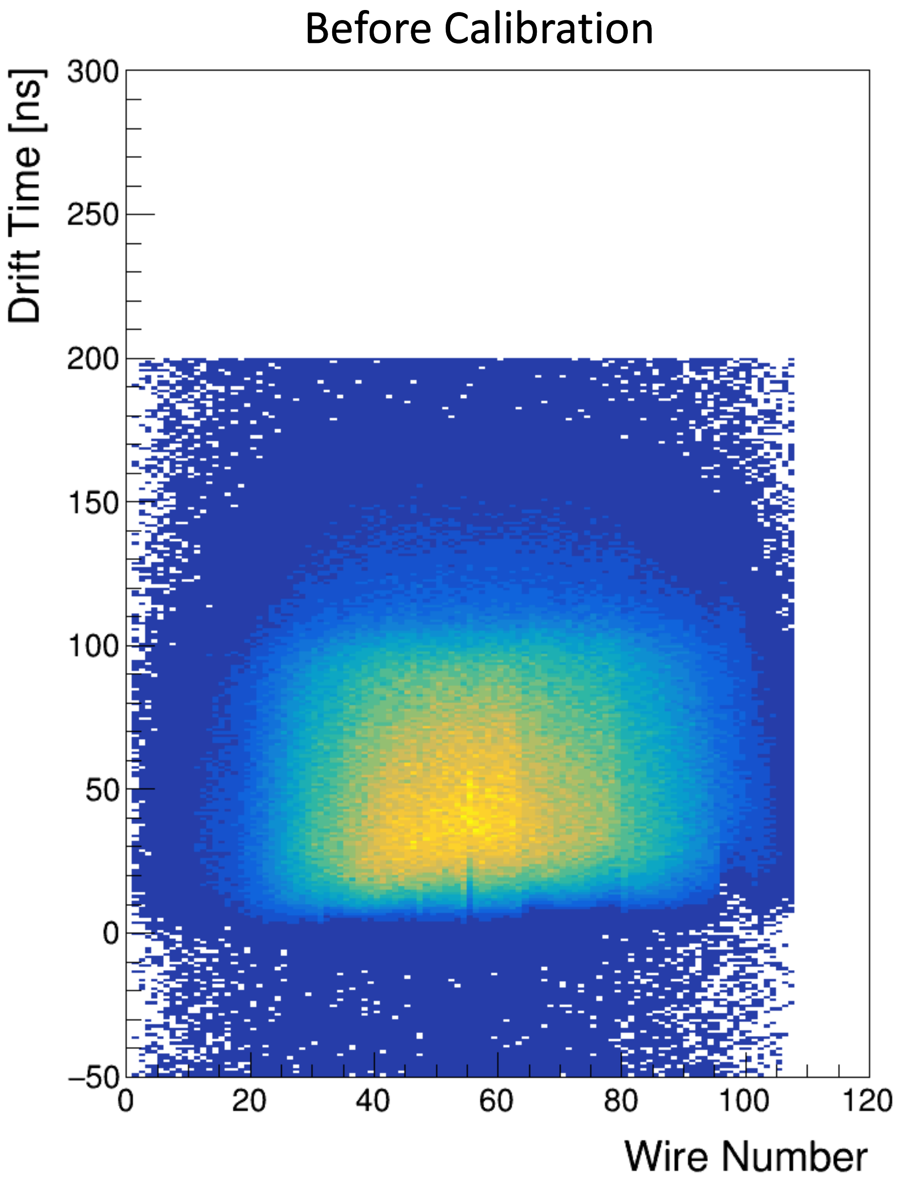


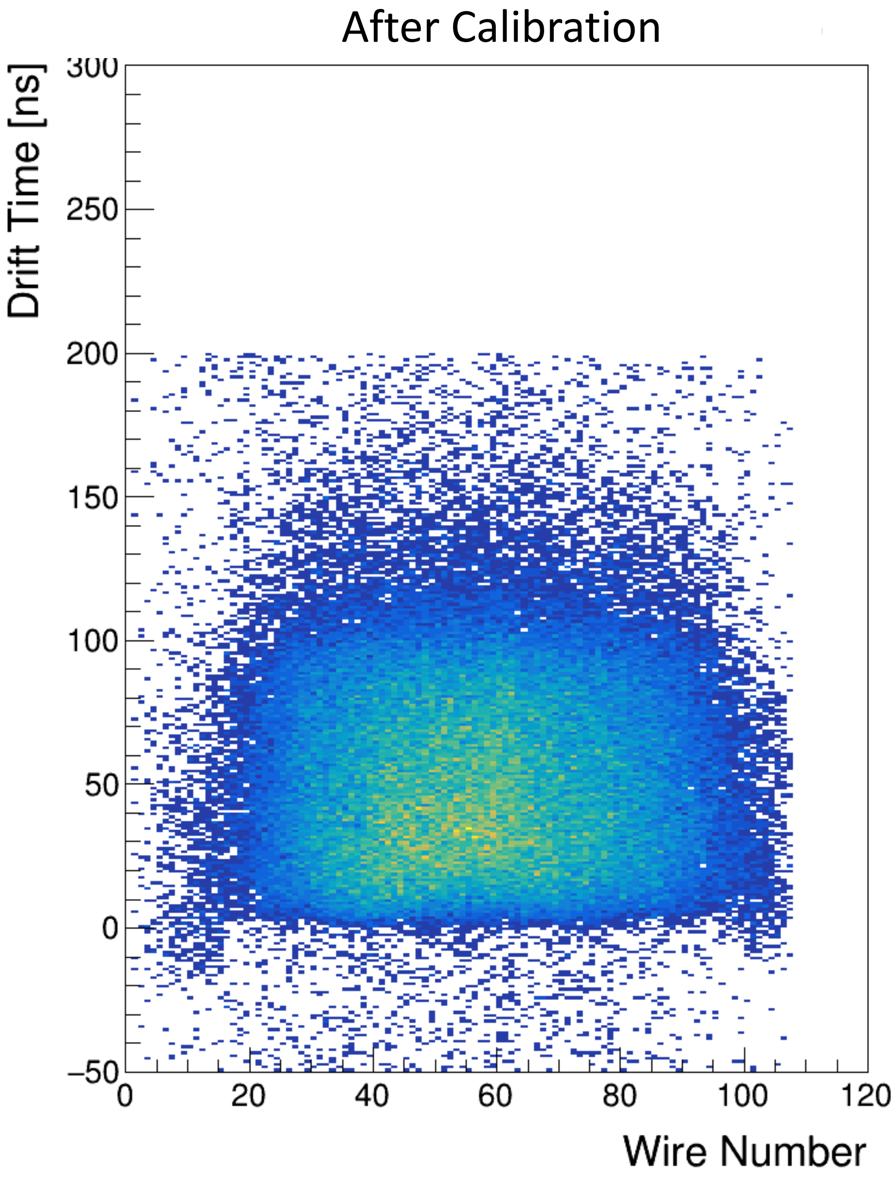


SHMS Hodoscope Beta vs Y Focal Plane

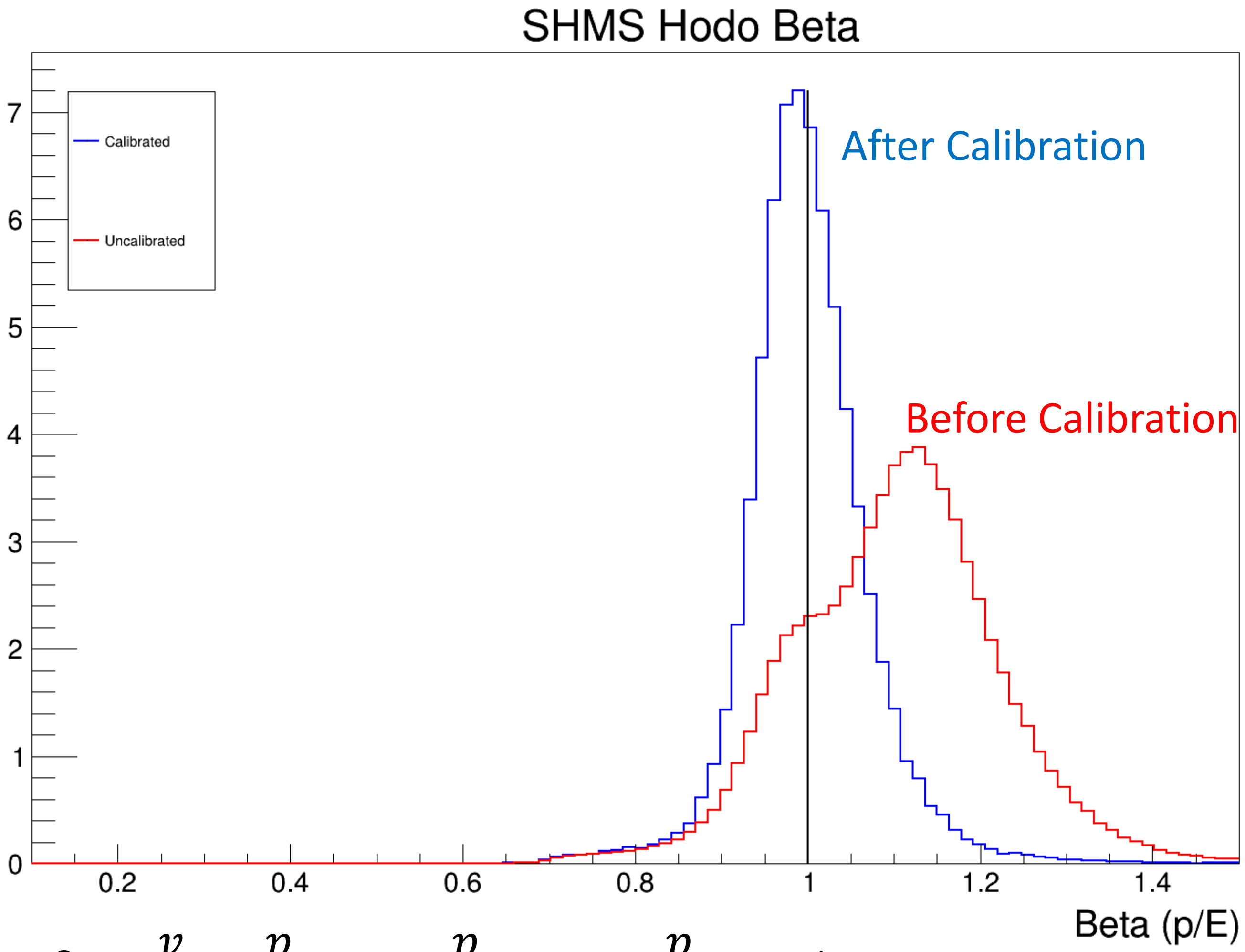


SHMS Drift Chamber Drift Time vs Wire Num

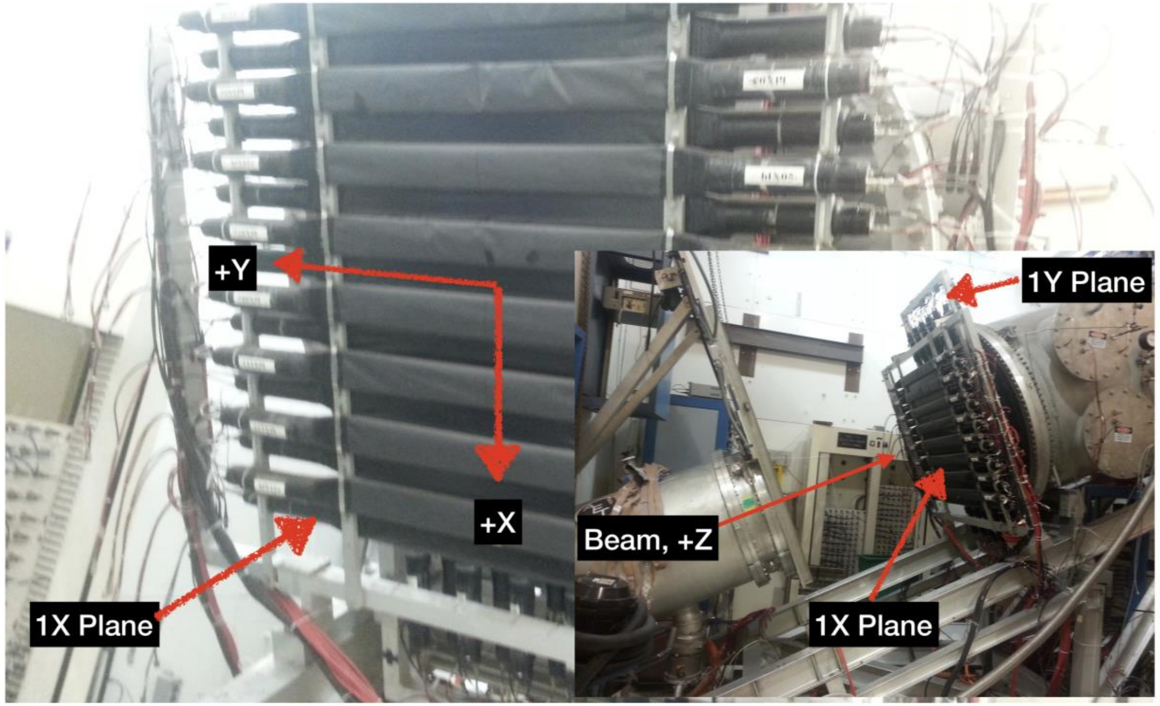




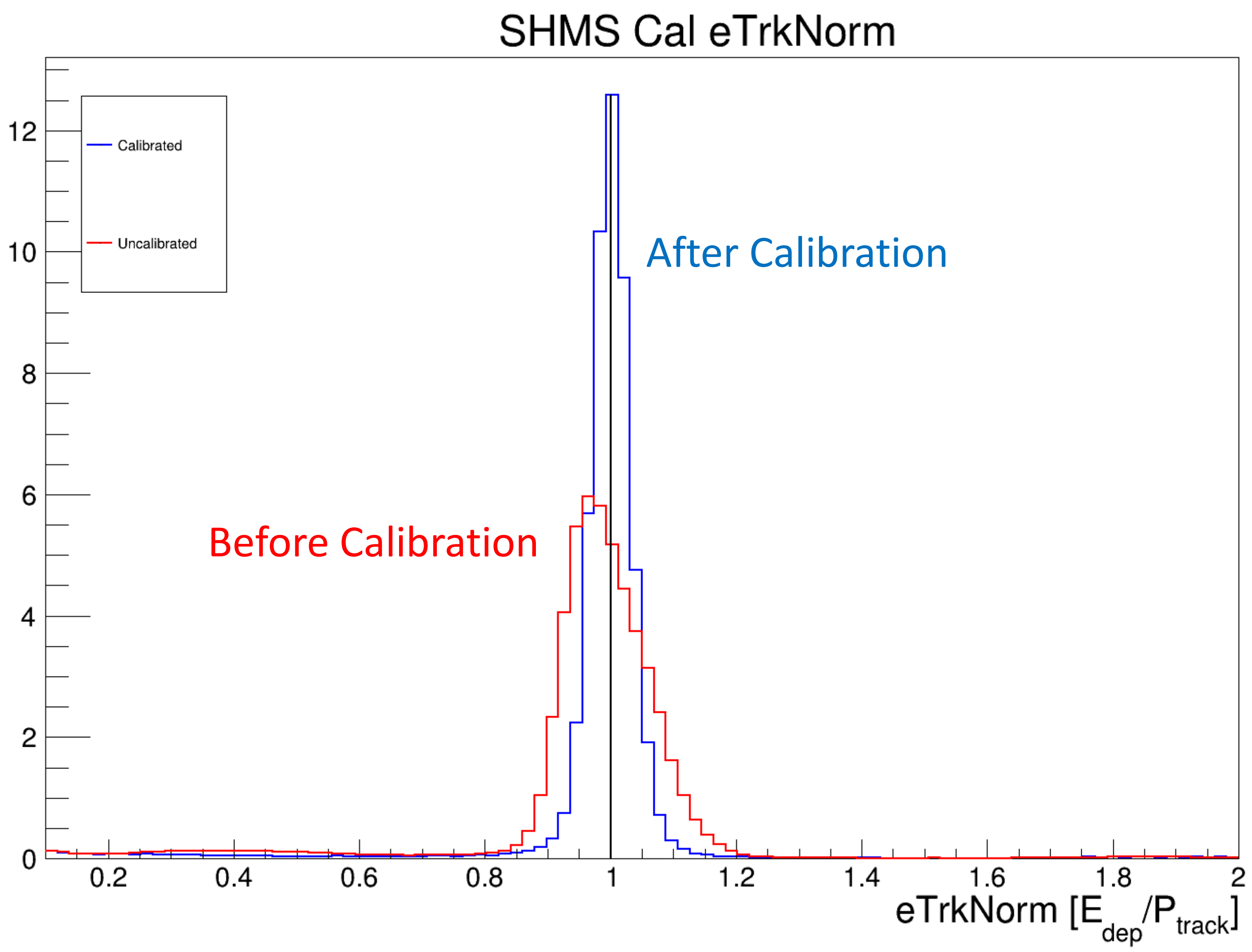
SHMS Hodoscope Beta

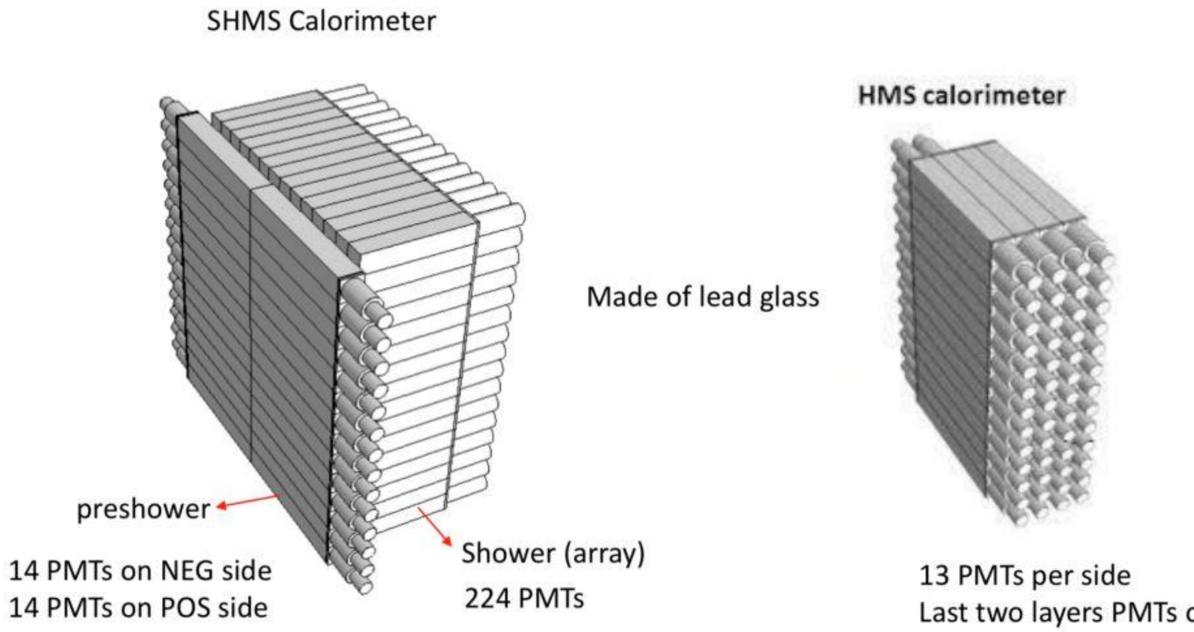


$$\beta_e = \frac{v}{c} = \frac{p}{E} = \frac{p}{\sqrt{m^2+p^2}} \approx \frac{p}{\sqrt{p^2}} = 1$$

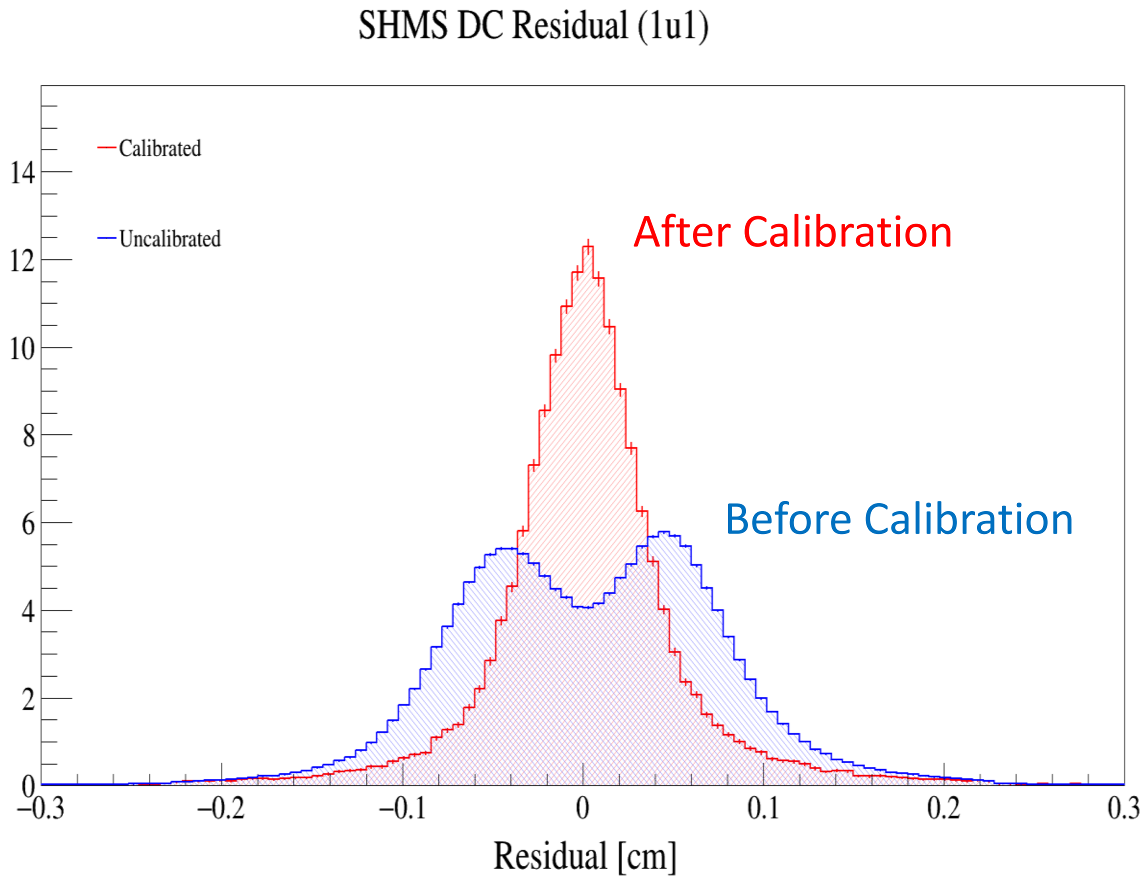


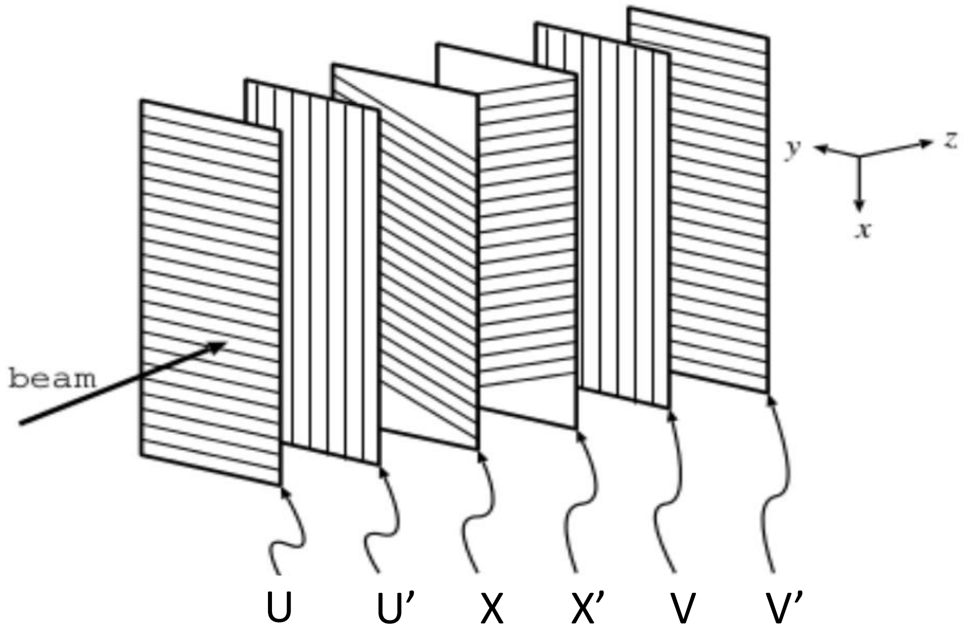
SHMS Calorimeter eTrkNorm

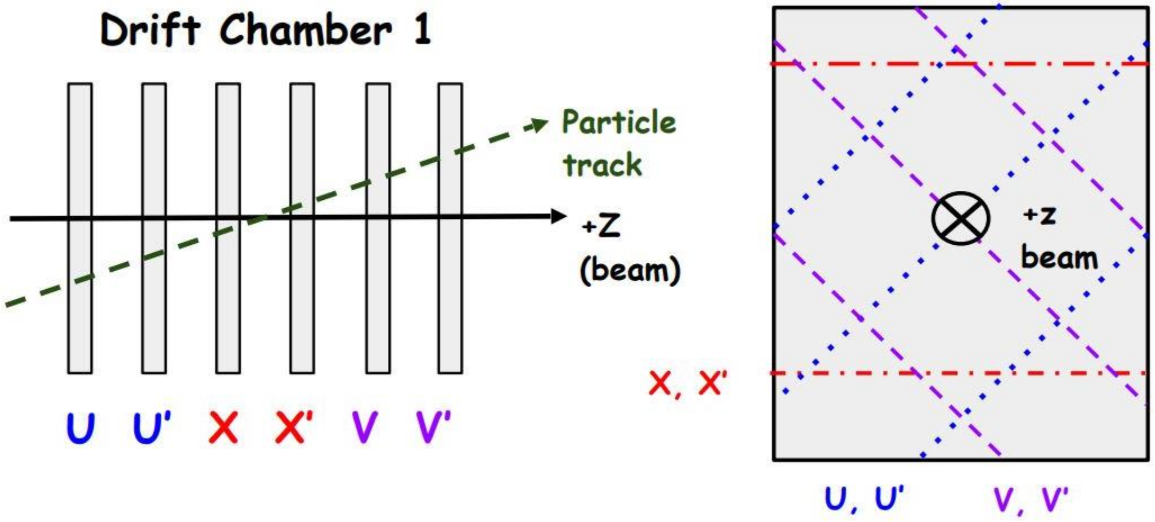




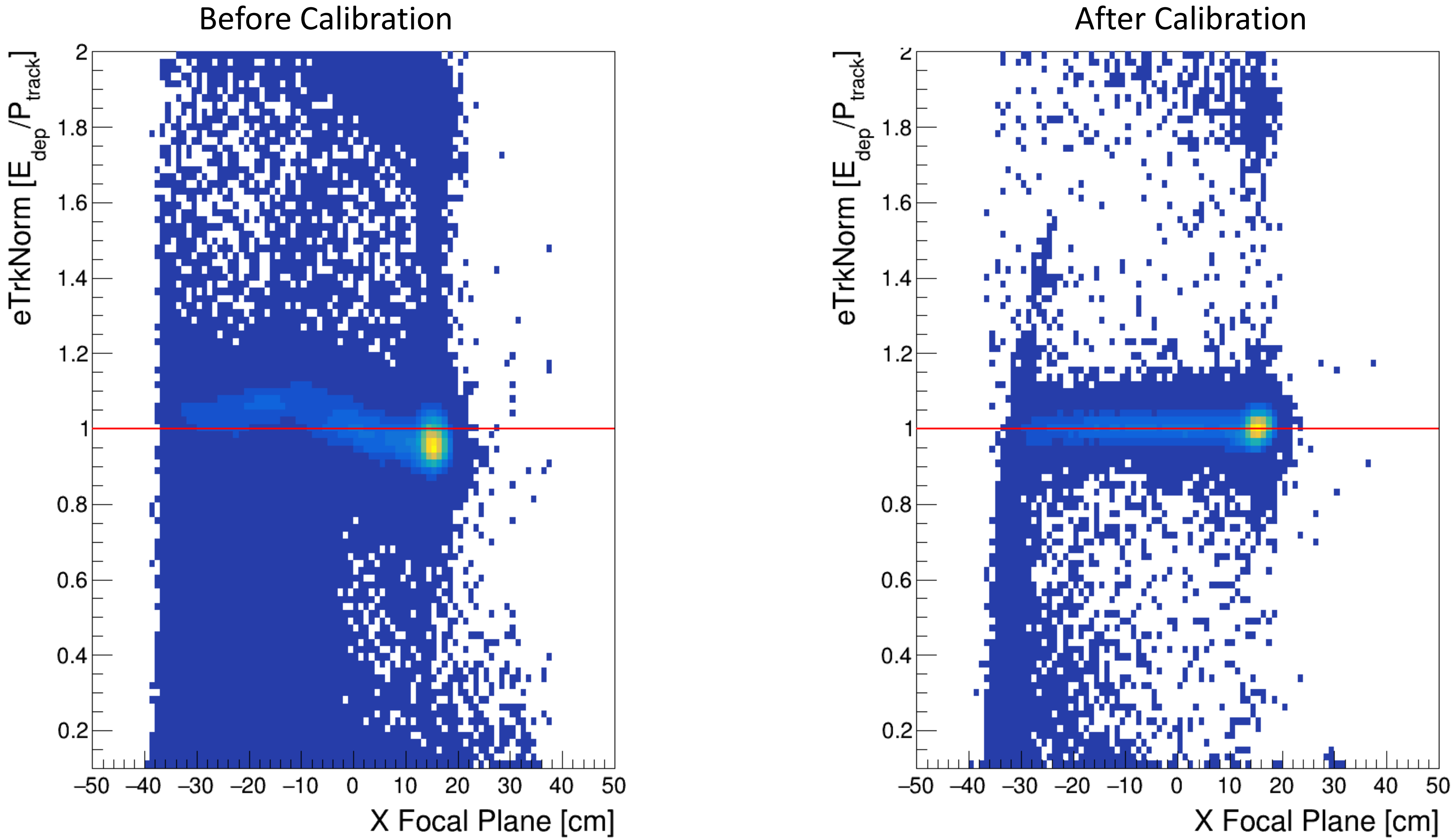
SHMS Drift Chamber Residual



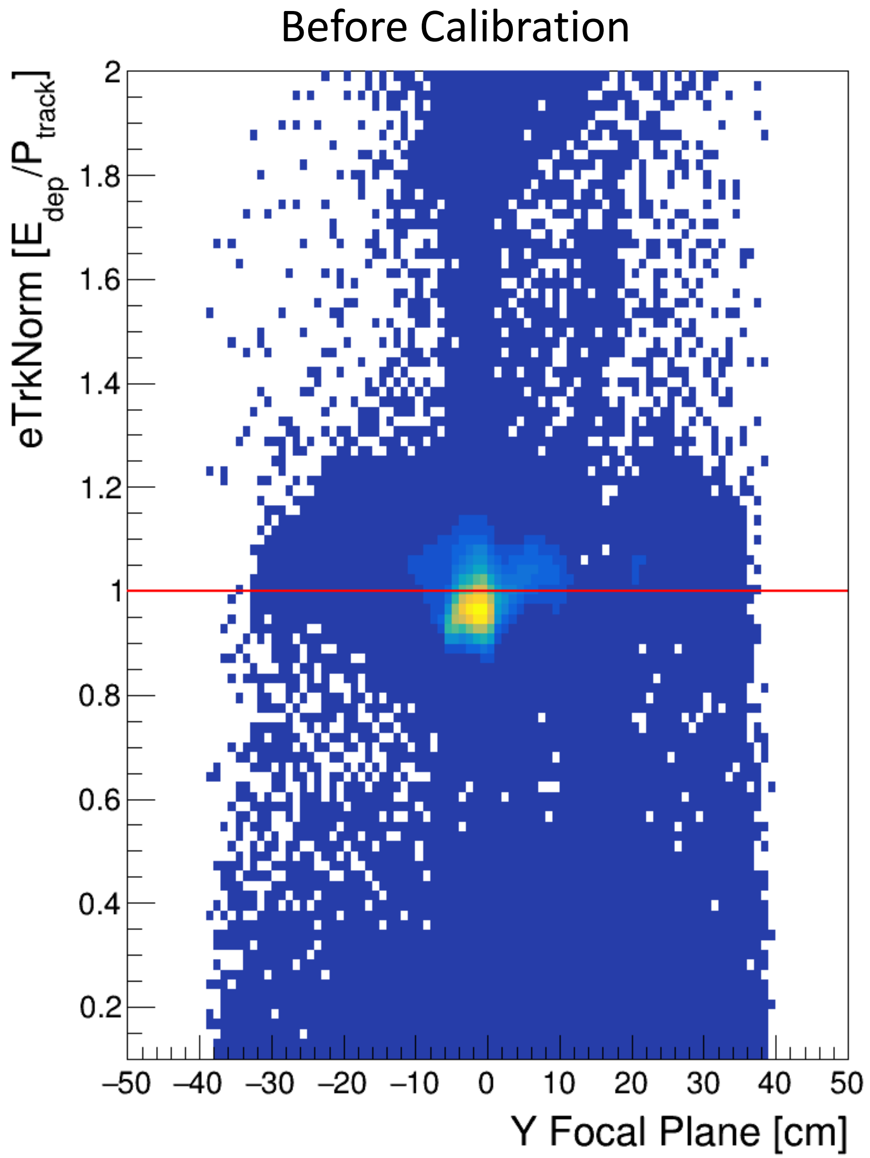


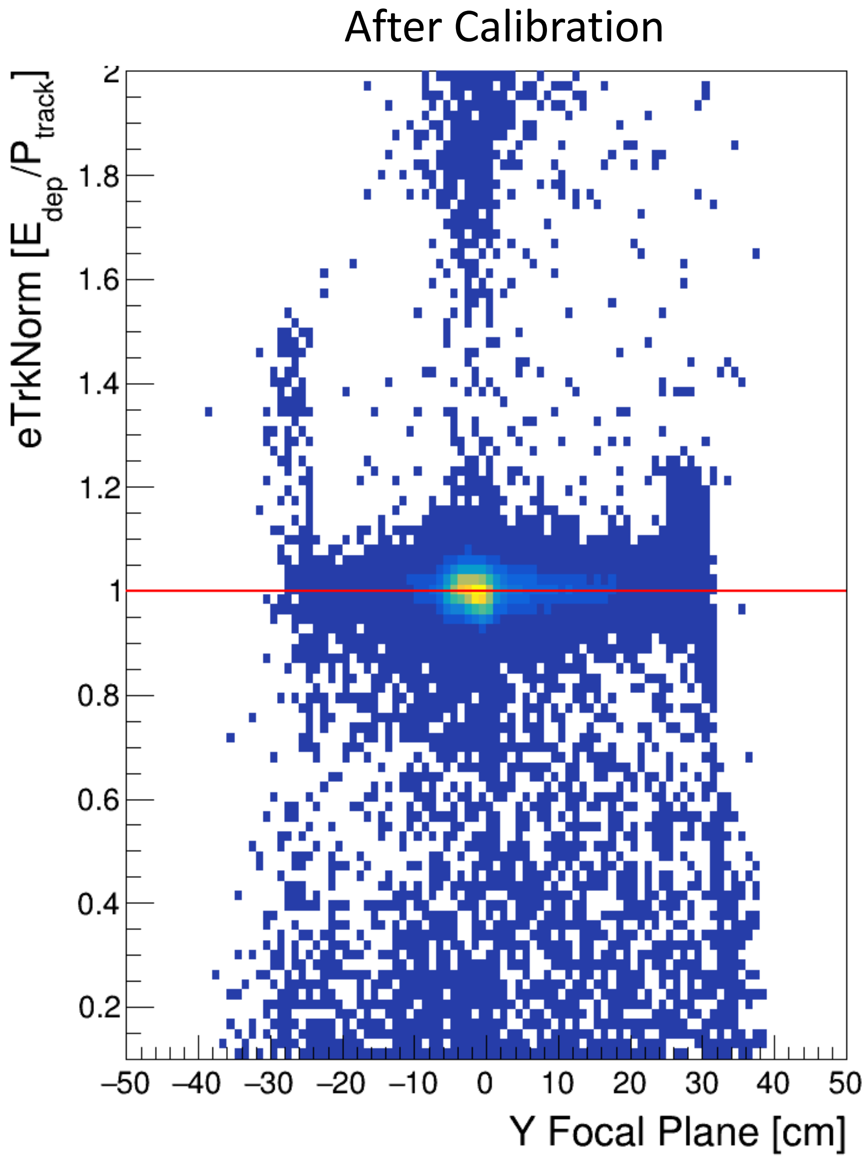


SHMS Calorimeter eTrkNorm vs X Focal Plane



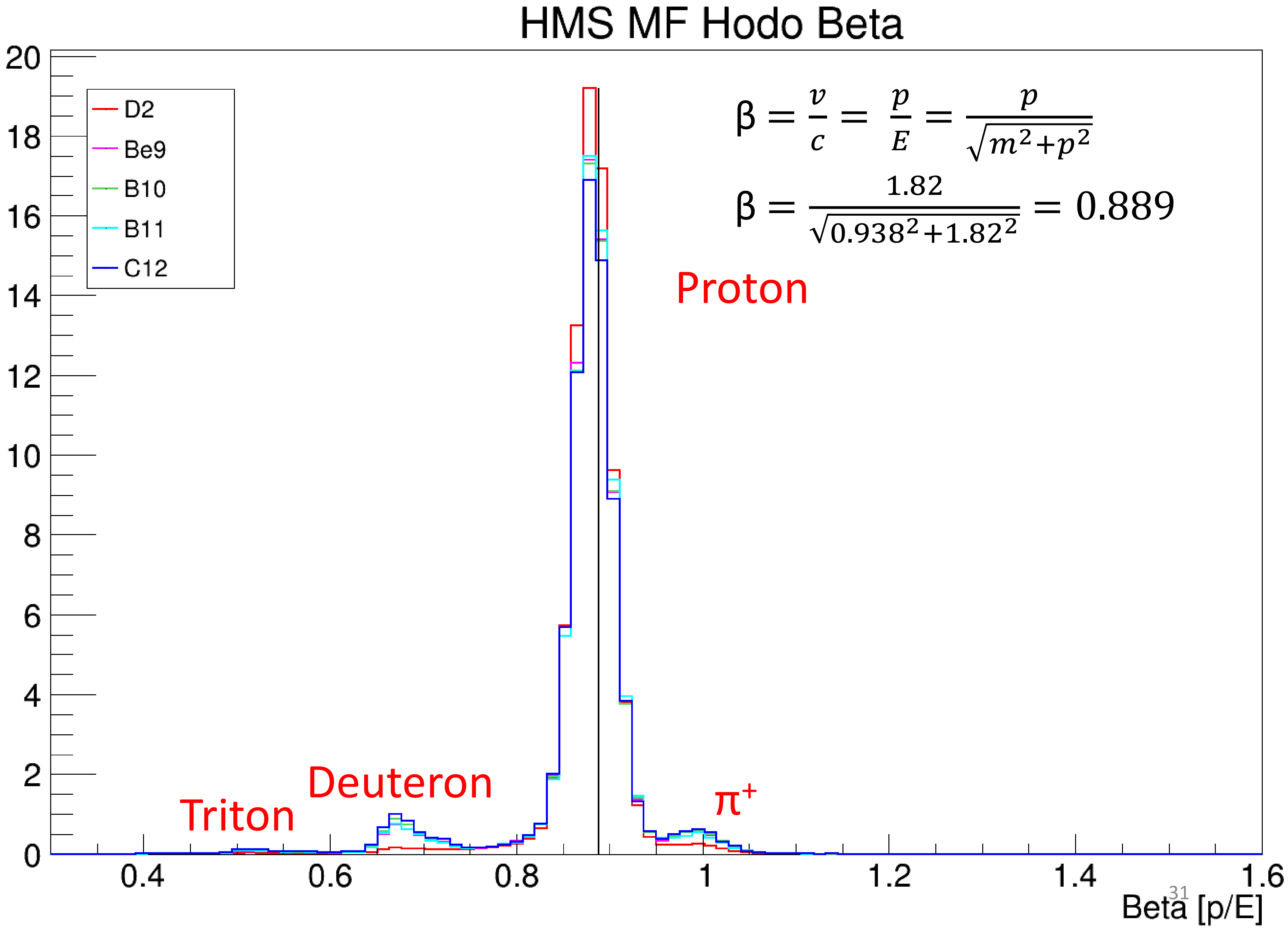
SHMS Calorimeter eTrkNorm vs Y Focal Plane



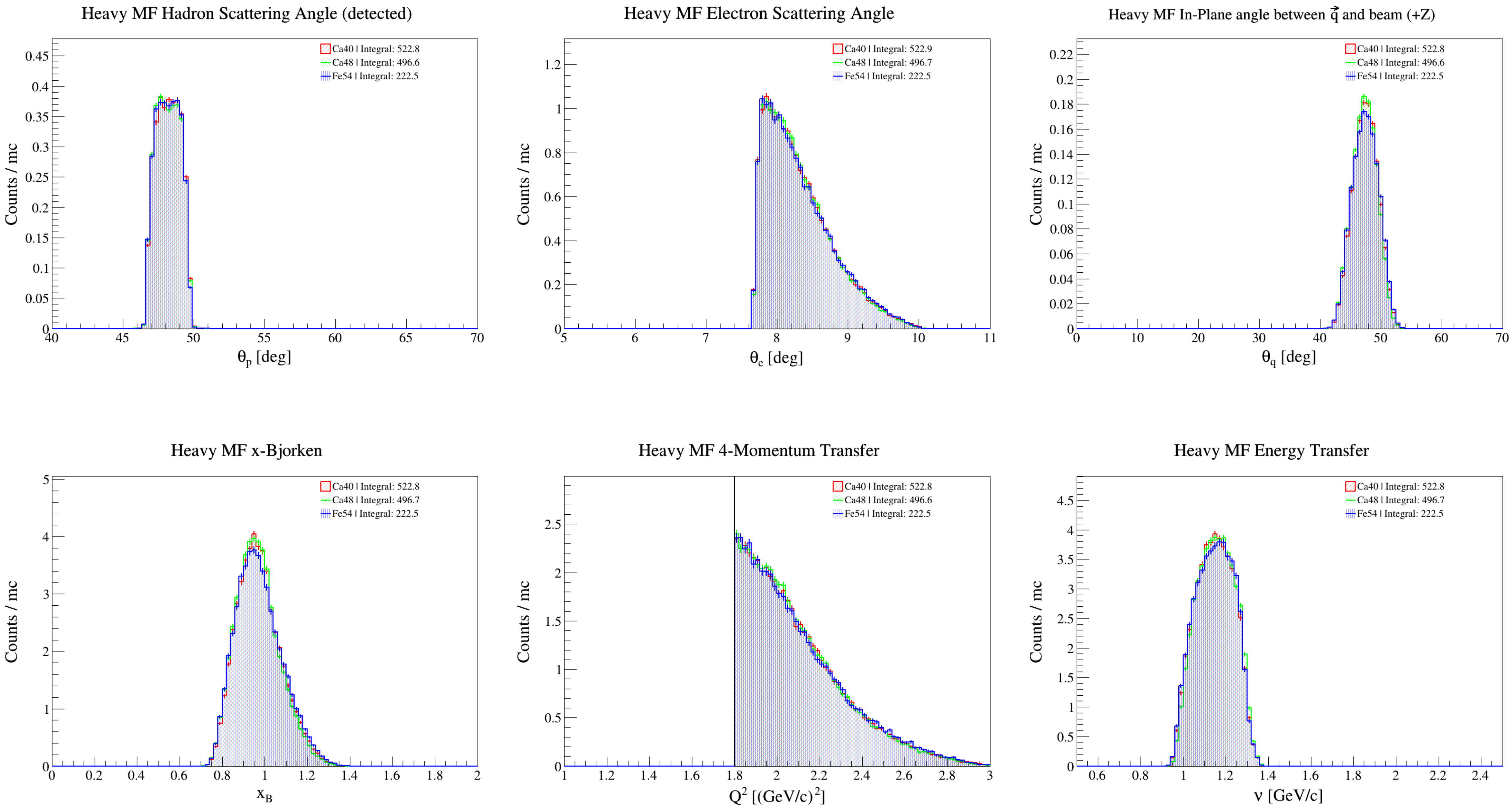


HMS Calibration Checks

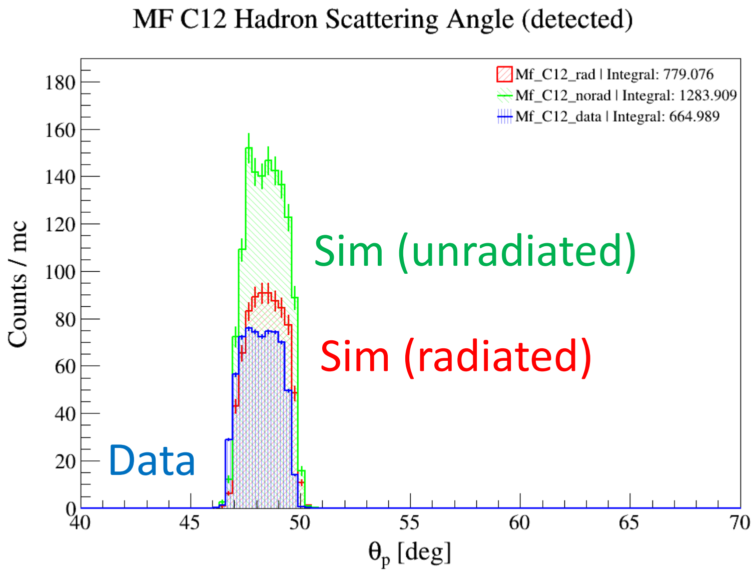
- Other HMS detectors are similar to SHMS

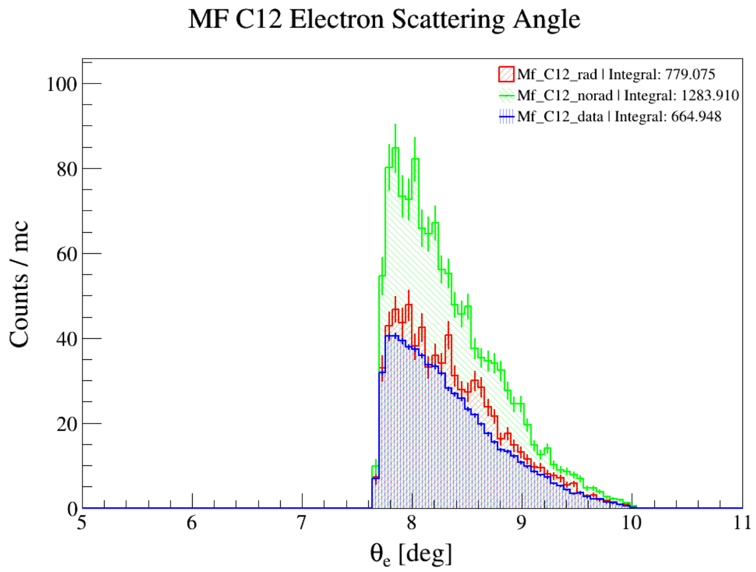


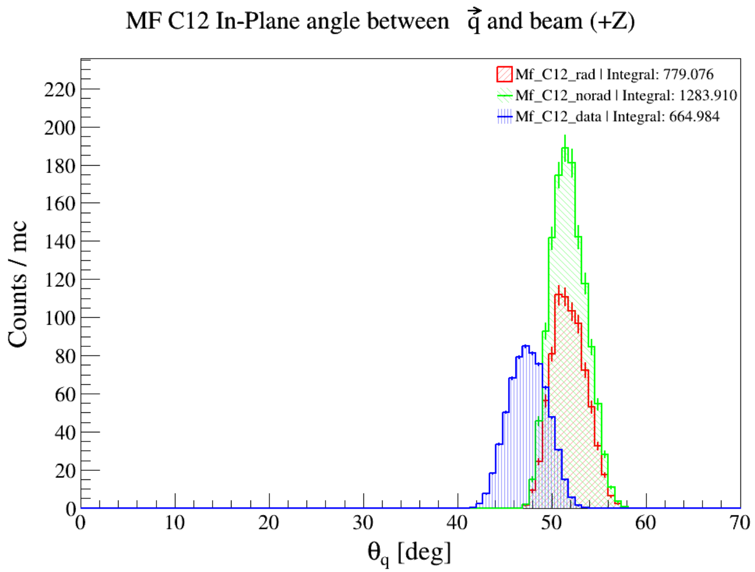
Ca40, Ca48, Fe54, MF Targets

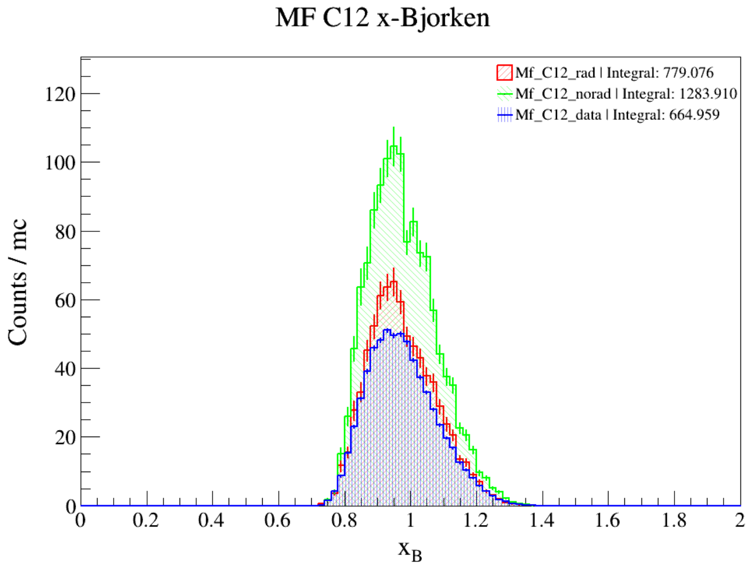


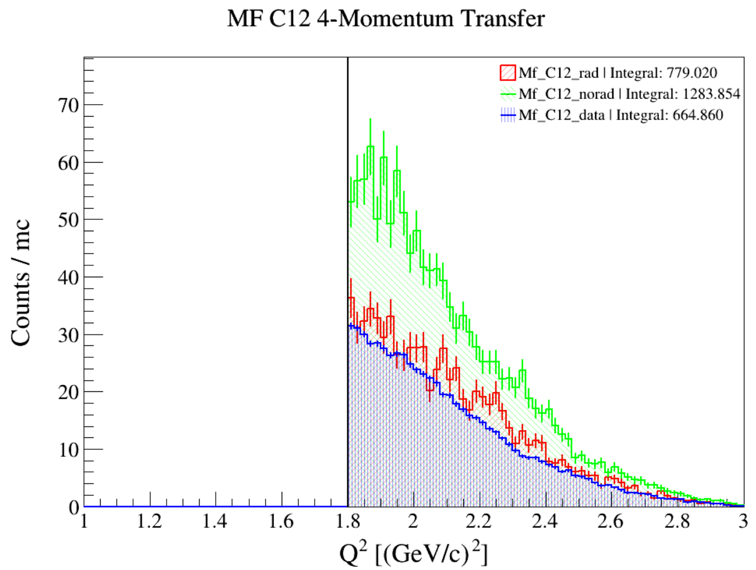
MF C12(e,e’p) Data vs Sim

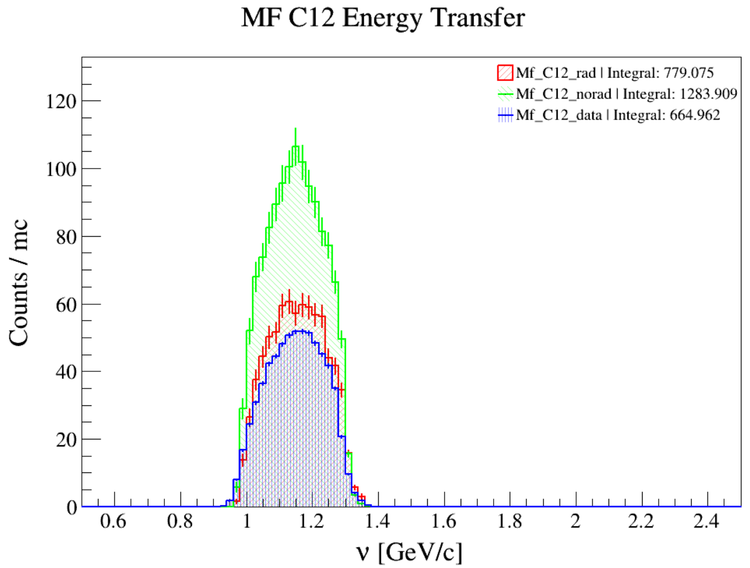




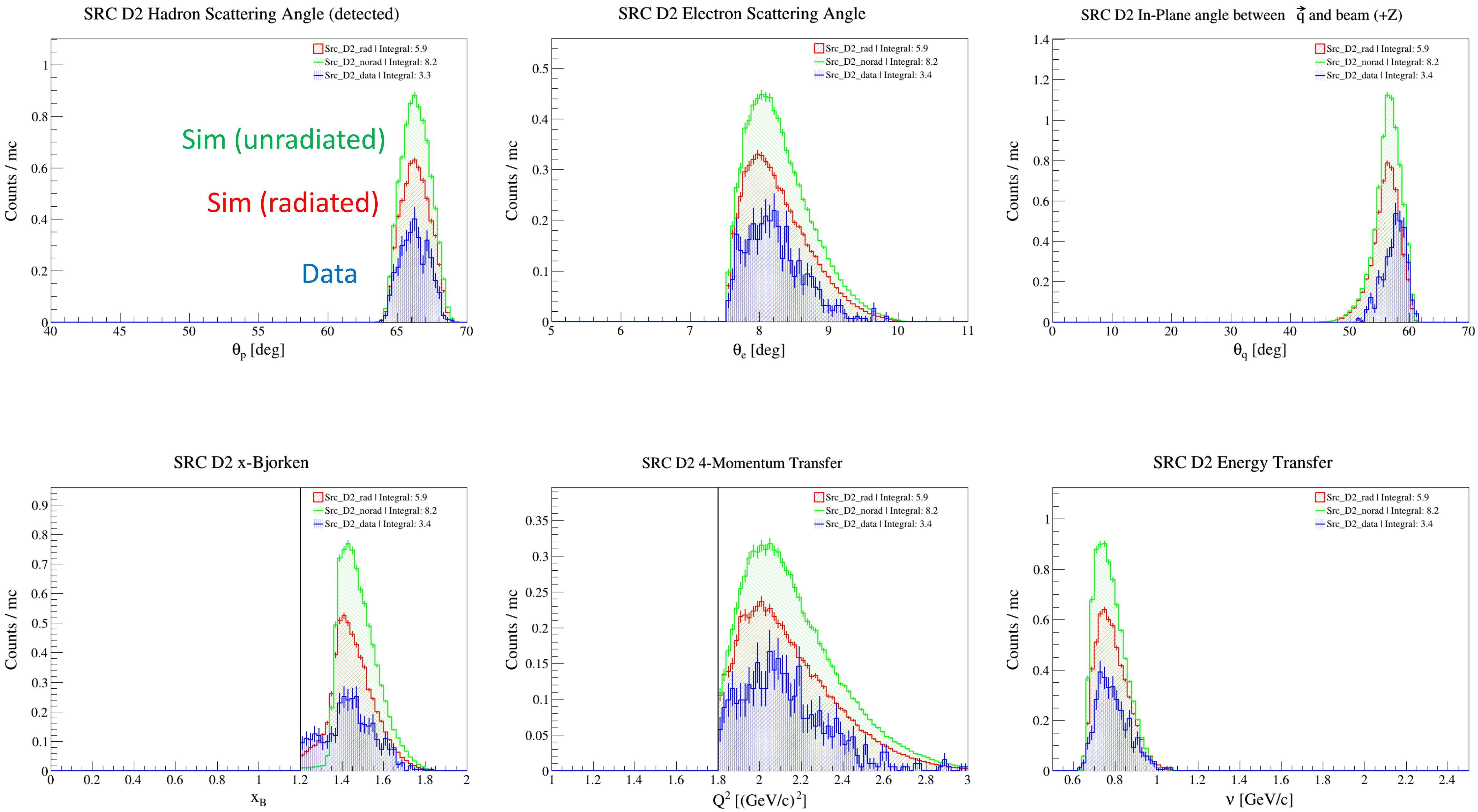




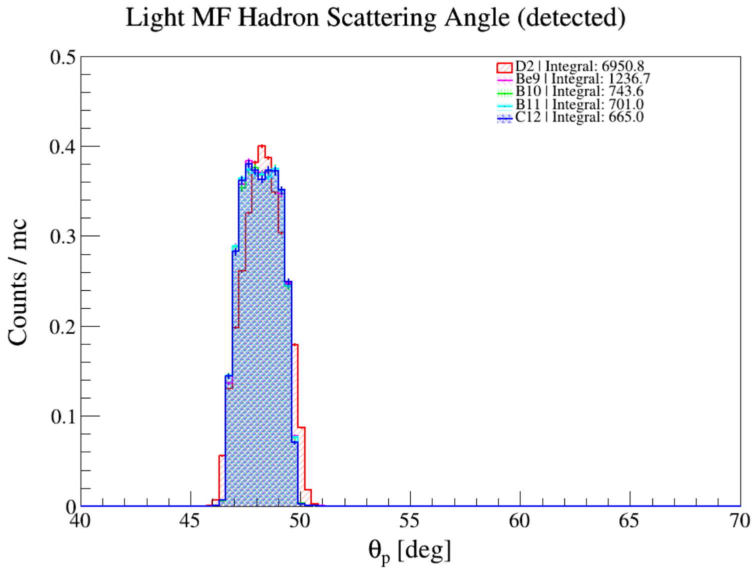


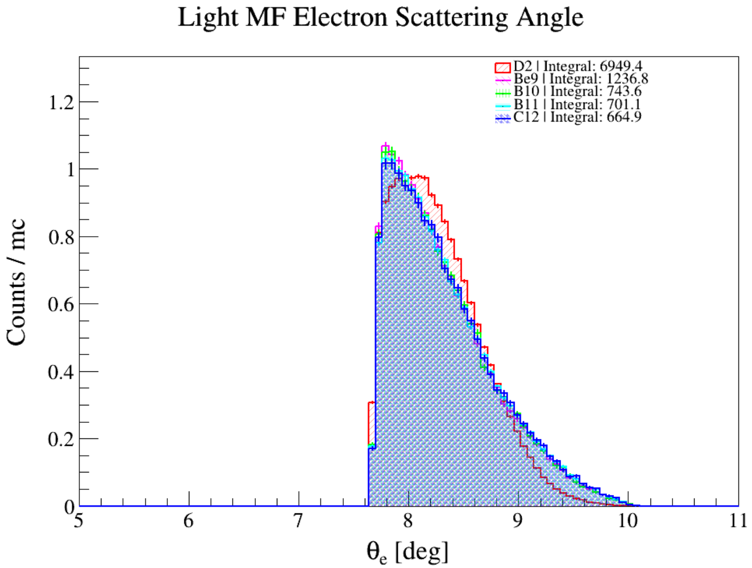


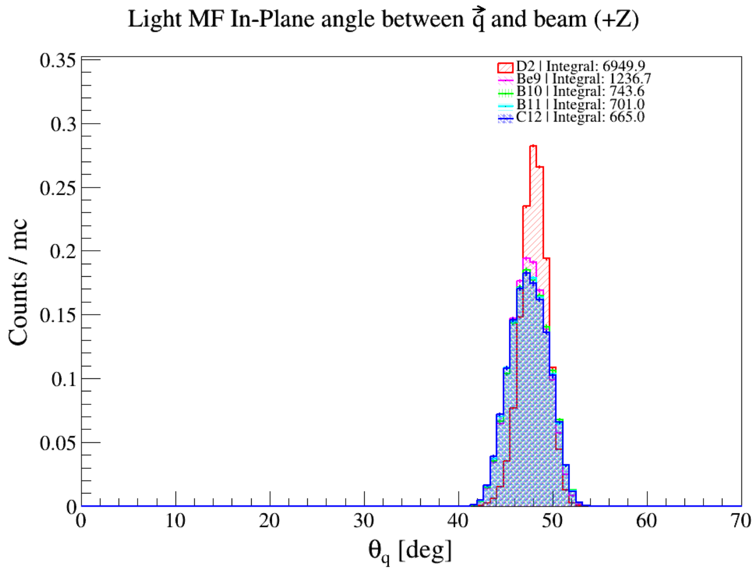
SRC D2(e,e'p) Data vs Sim

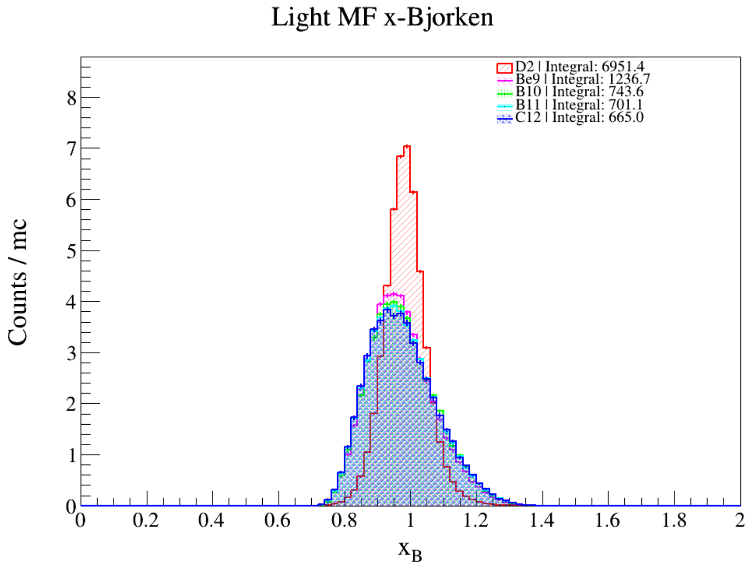


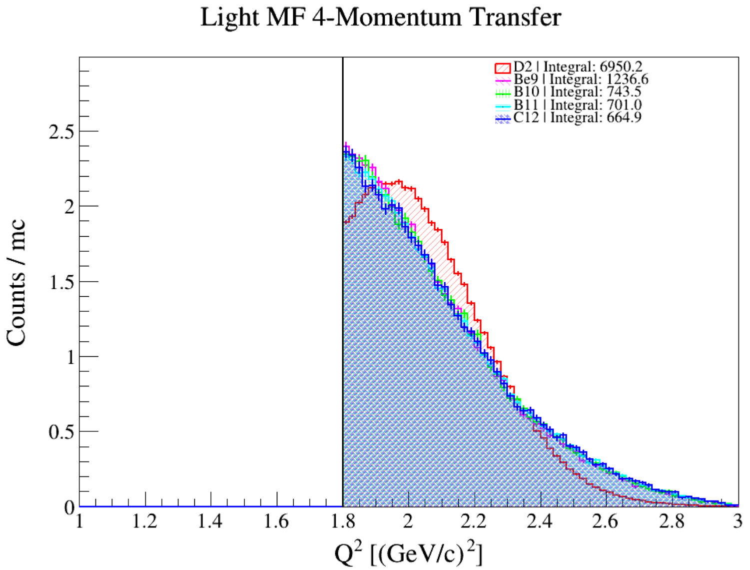
D2, Be9, B10,11, C12 MF Targets

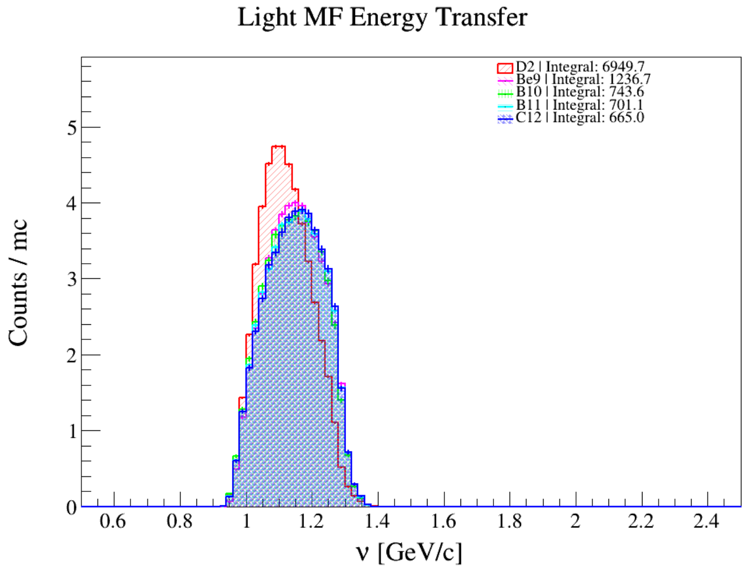




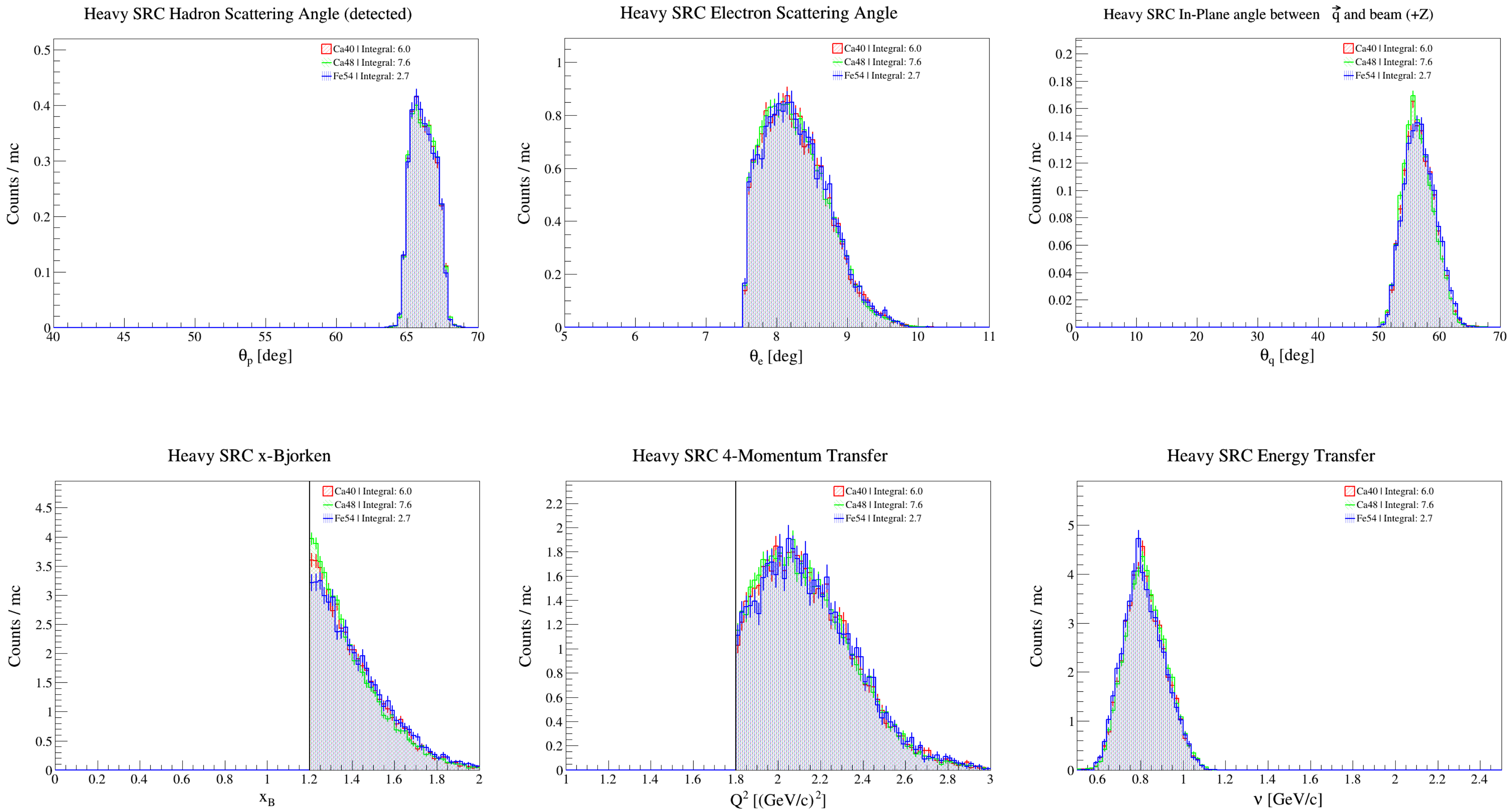




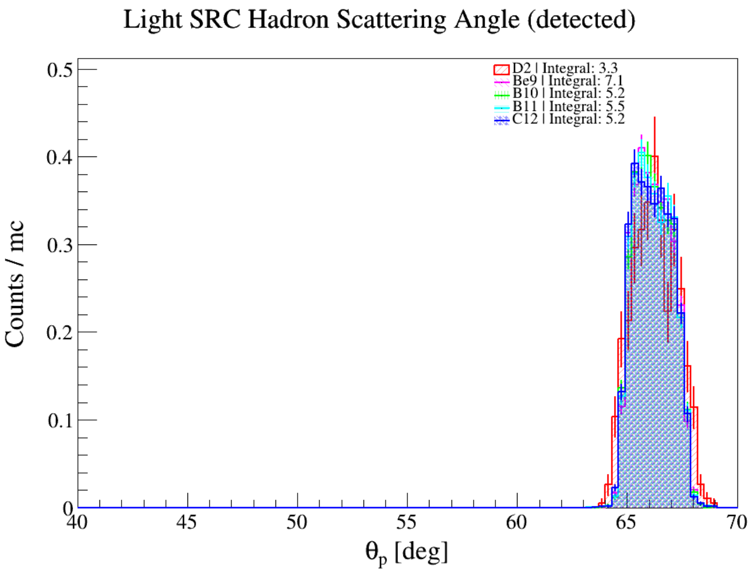


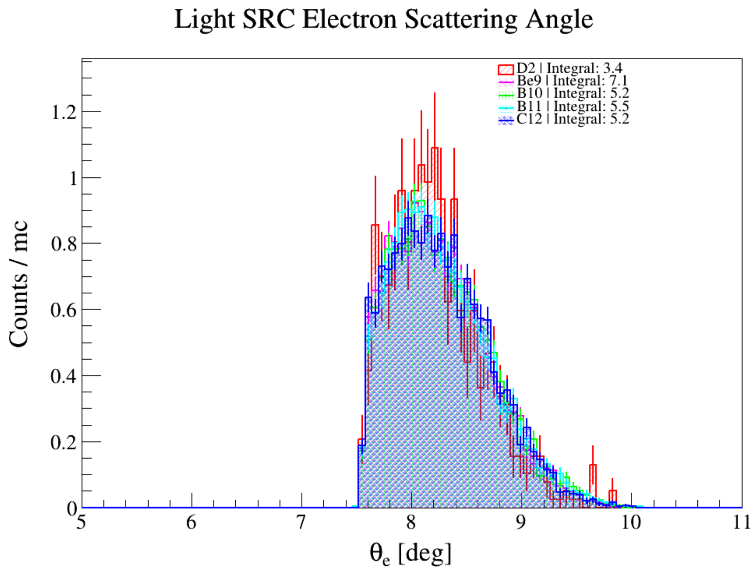


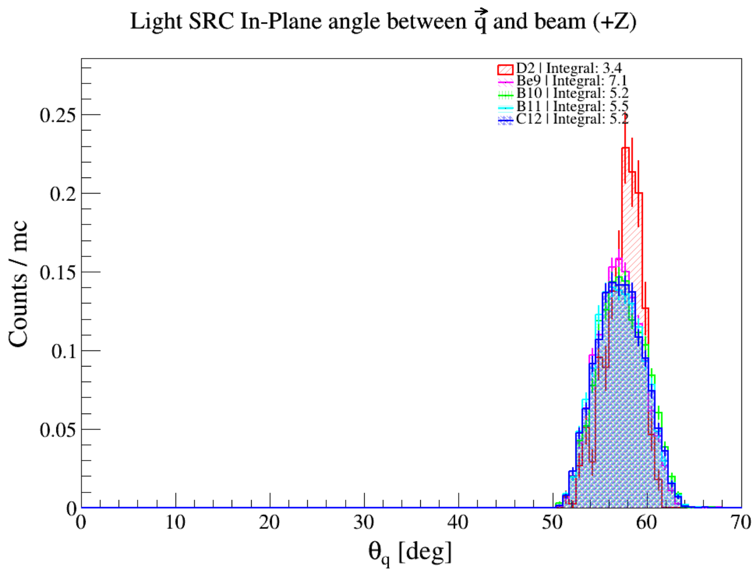
Ca40, Ca48, Fe54 SRC Targets

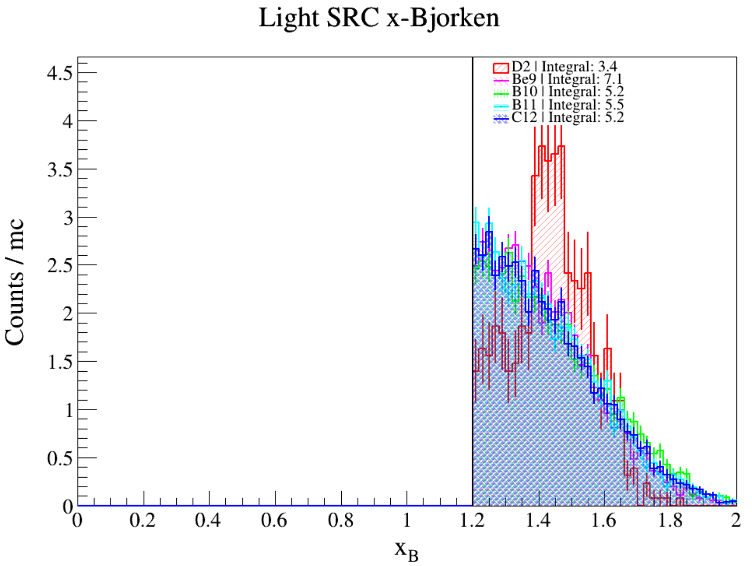


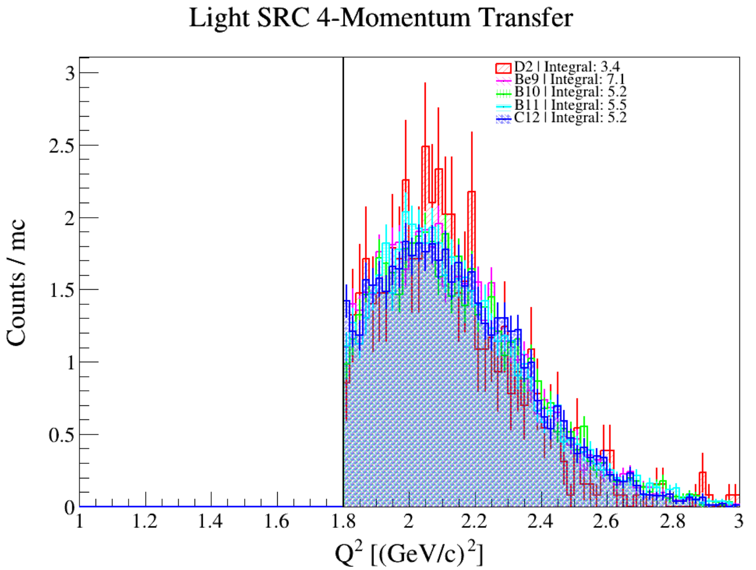
D2, Be9, B10,11, C12 SRC Targets

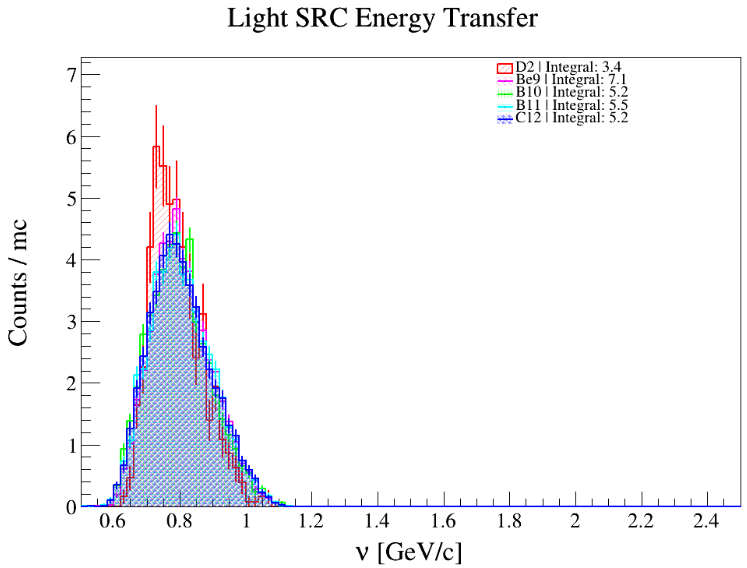




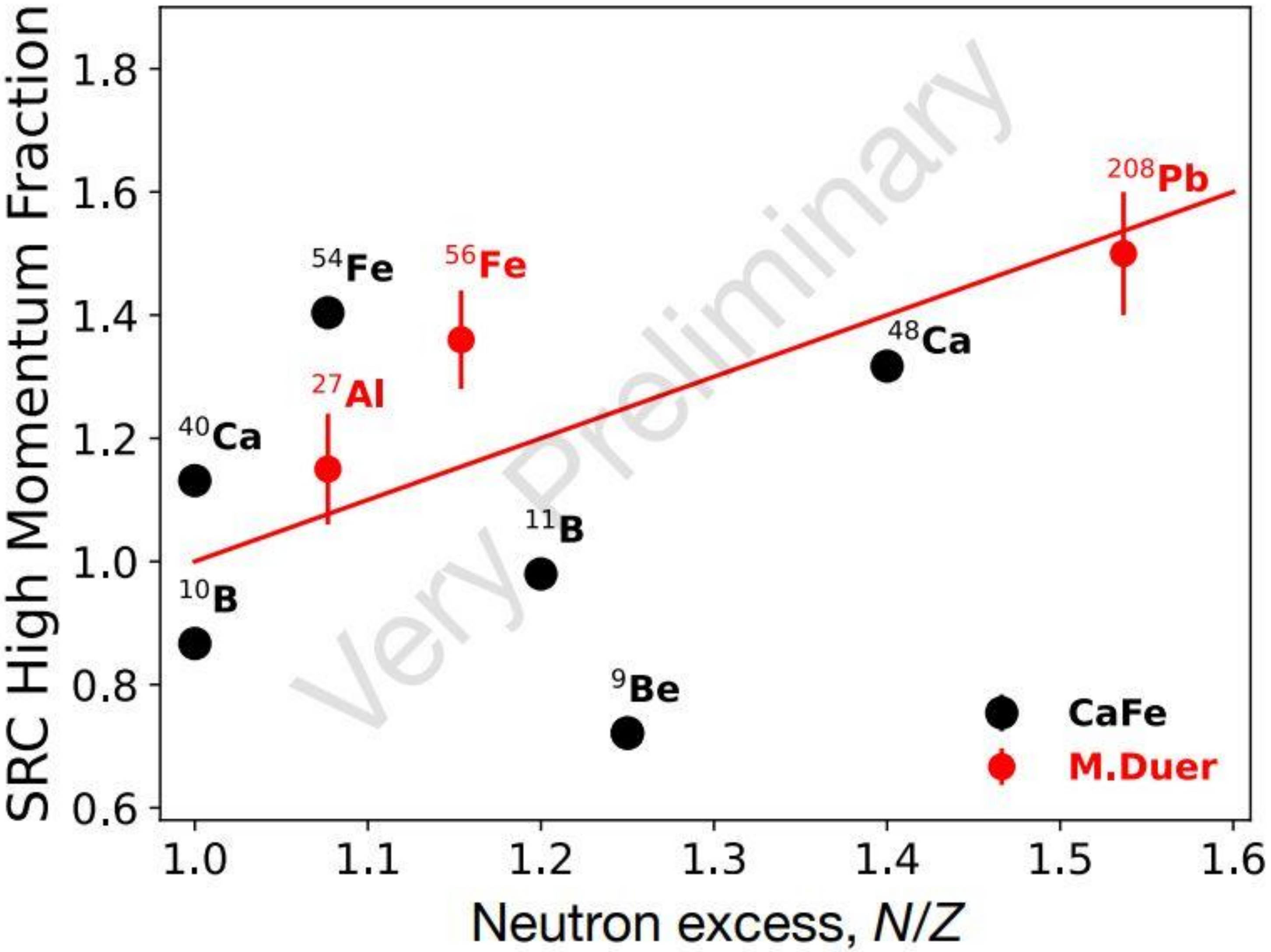








Results



M. Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

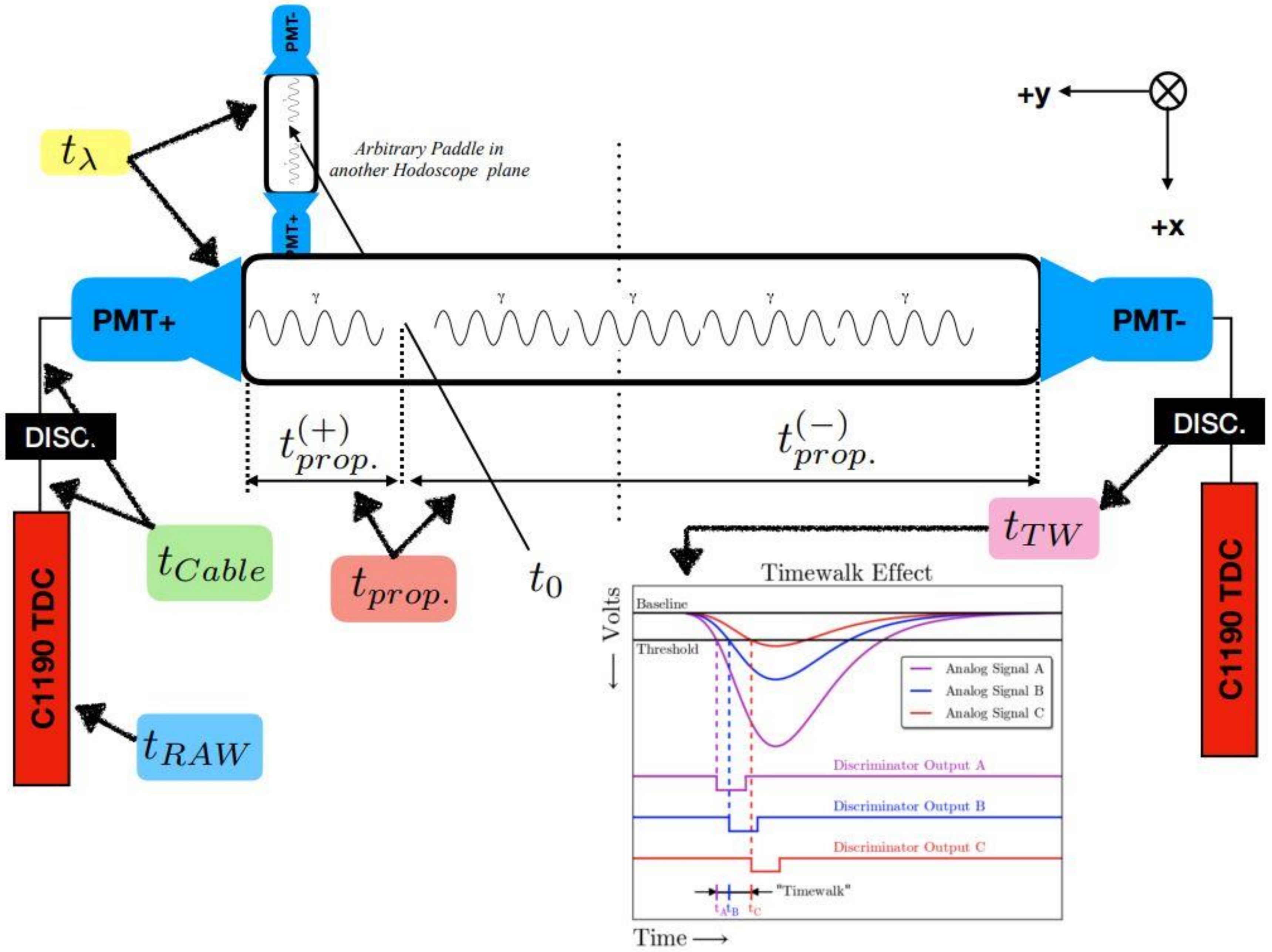
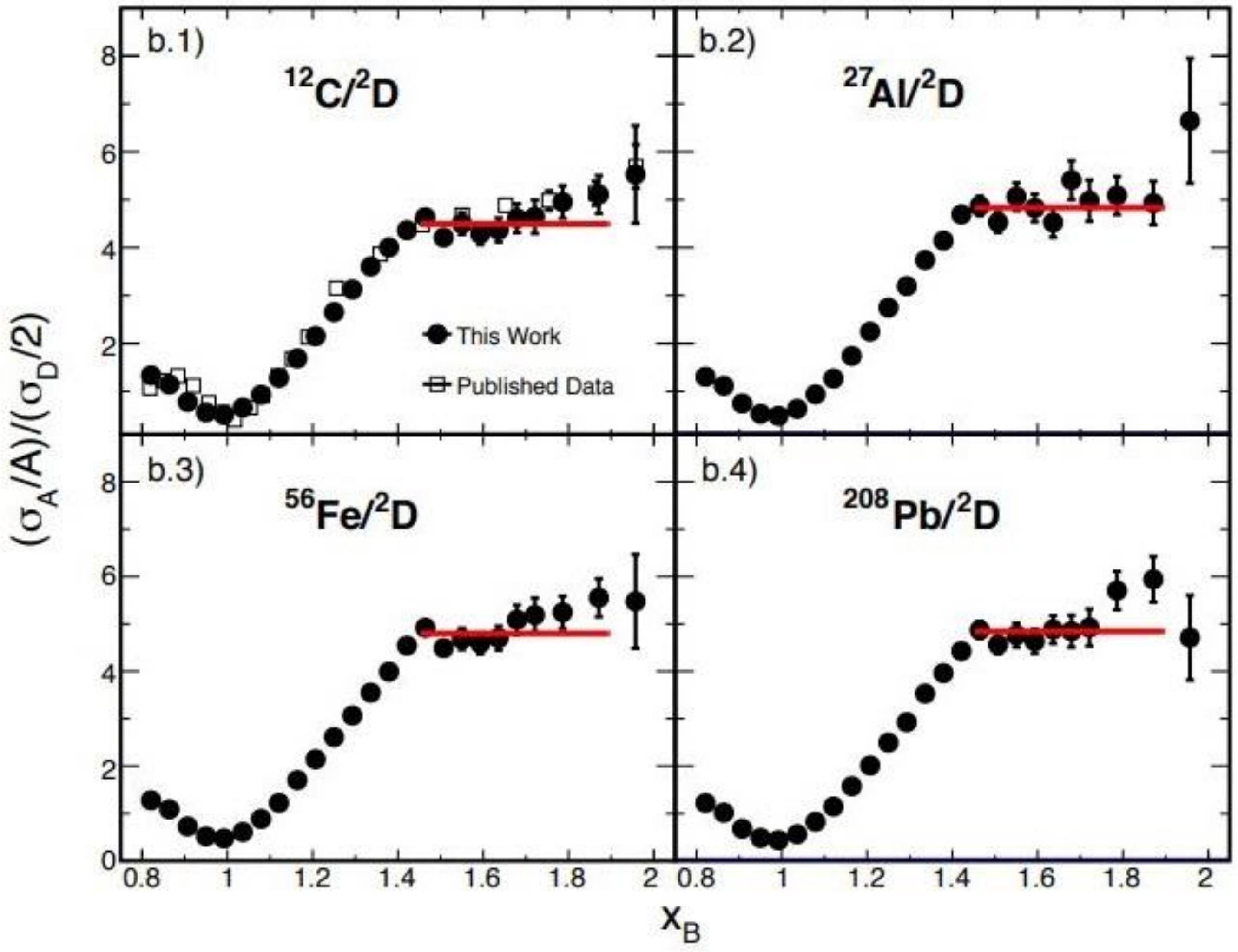


Figure 2: Cartoon of individual scintillator paddles to illustrate the various timing corrections applied.

Quasi-elastic (e,e') Cross-section Ratio

- (e,e') per nucleon cross-section ratio of nucleus A to deuterium is constant for 1.5 < x < 2
- Plateau implies Nucleon momentum distributions differ by a scale factor
- Plateau increases slowly with nuclear mass, suggesting the number of high momentum nucleons increase linearly with A



Schmookler et al. (2019) Nature, 566, 354.
https://doi.org/10.1038/s41586-019-0925-9

A(e,e’)

$$\frac{d^3\sigma}{d\Omega_e dw} = \frac{N_e[\theta_e, w]}{\left(\frac{\#tgt\ nuclei}{cm^2}\right)(\#e)d\Omega_e dw}$$

$$N_e[\theta_e, w] = \frac{Y\ [\theta_e, w]}{EDT\ CLT\ SHMS_e} * (Radiative\ Correction)$$

A(e,e’p)

$$\frac{d^6\sigma}{d\Omega_e\ dw\ dE_m\ dP_m\ d\varphi_p} = \frac{Y\ \left[P_e, P_p\right]}{EDT_e\ EDT_p\ CLT\ SHMS_e\ HMS_e} * (Radiative\ Correction)$$

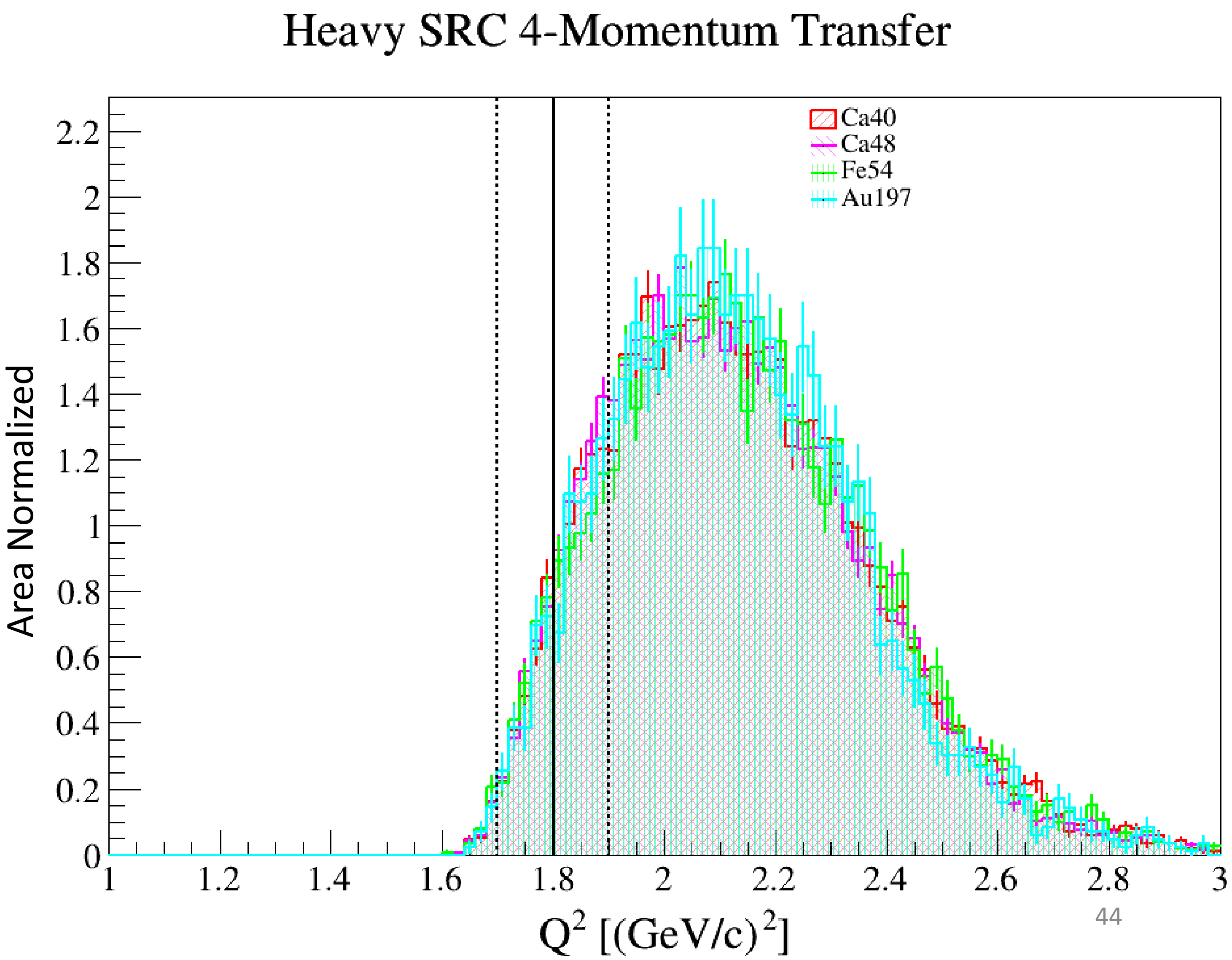
Cuts (+/-2σ)

- MF
  - Skim
    - EDTM_tdcTimeRaw == 0
    - epCoinTime < 50 (ns)
  - PID
    - 0.8 < petot_trkNorm < 1.3
  - Acceptance
    - -10 < hdelta < 10 (%)
    - 0 < edelta < 22 (%)
    - Collimator Cut +/- 8%
    - `evtyp >= 4`
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)
- SRC
  - Skim
    - EDTM_tdcTimeRaw == 0
    - epCoinTime < 50 (ns)
  - PID
    - 0.8 < petot_trkNorm < 1.3
  - Acceptance
    - -10 < hdelta < 10 (%)
    - 0 < edelta < 22 (%)
    - Collimator Cut +/- 8%
    - `evtyp >= 4`
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - 0.375 +/- 0.025 < pmiss < 0.700 +/- 0.1 (GeV/c)
    - 1.2 +/- 0.1 < xbj
    - theta_rq < 40 +/- 4 (deg)

Heavy SRC

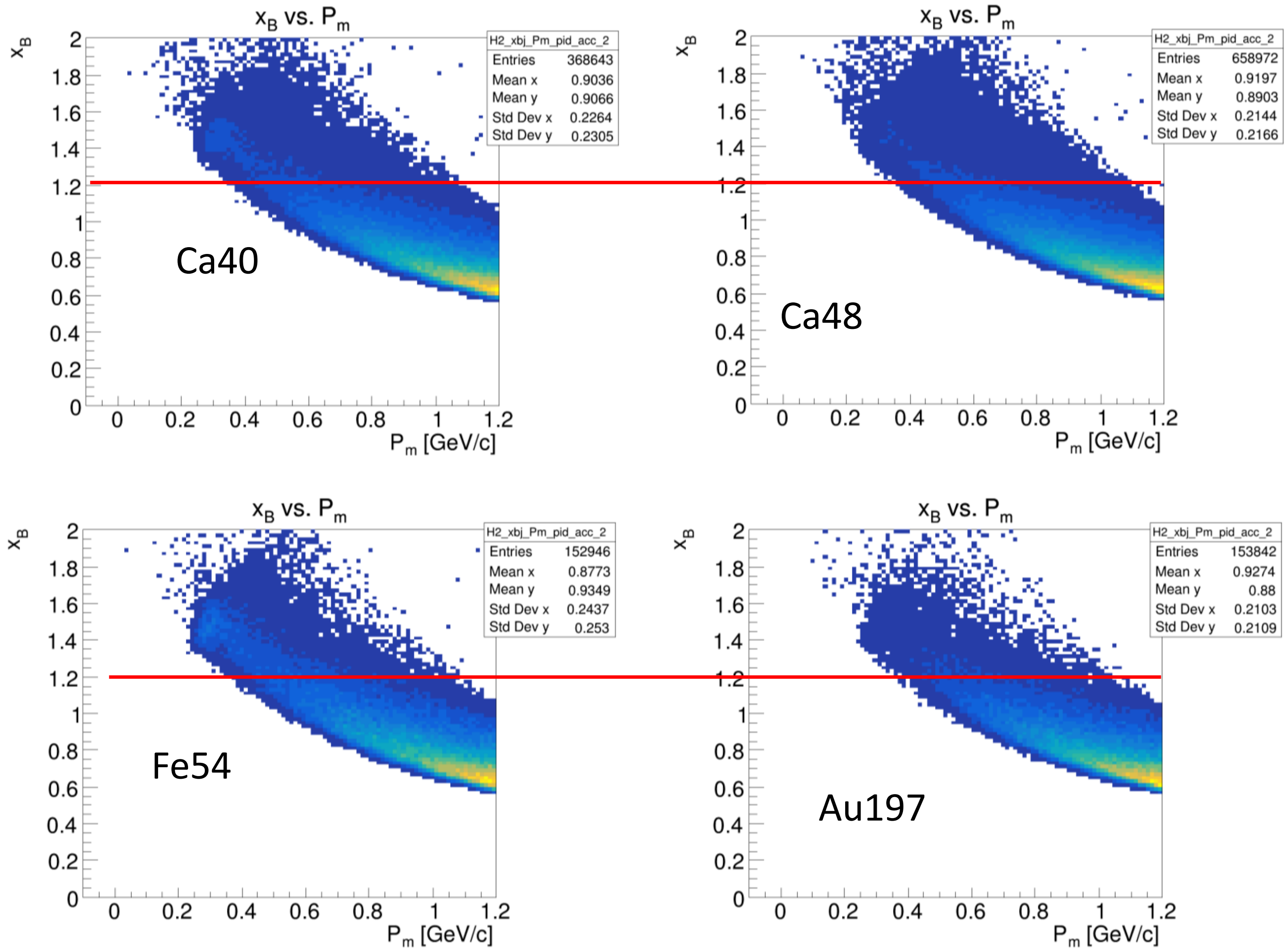
SRC Heavy: Q2

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < (deg)



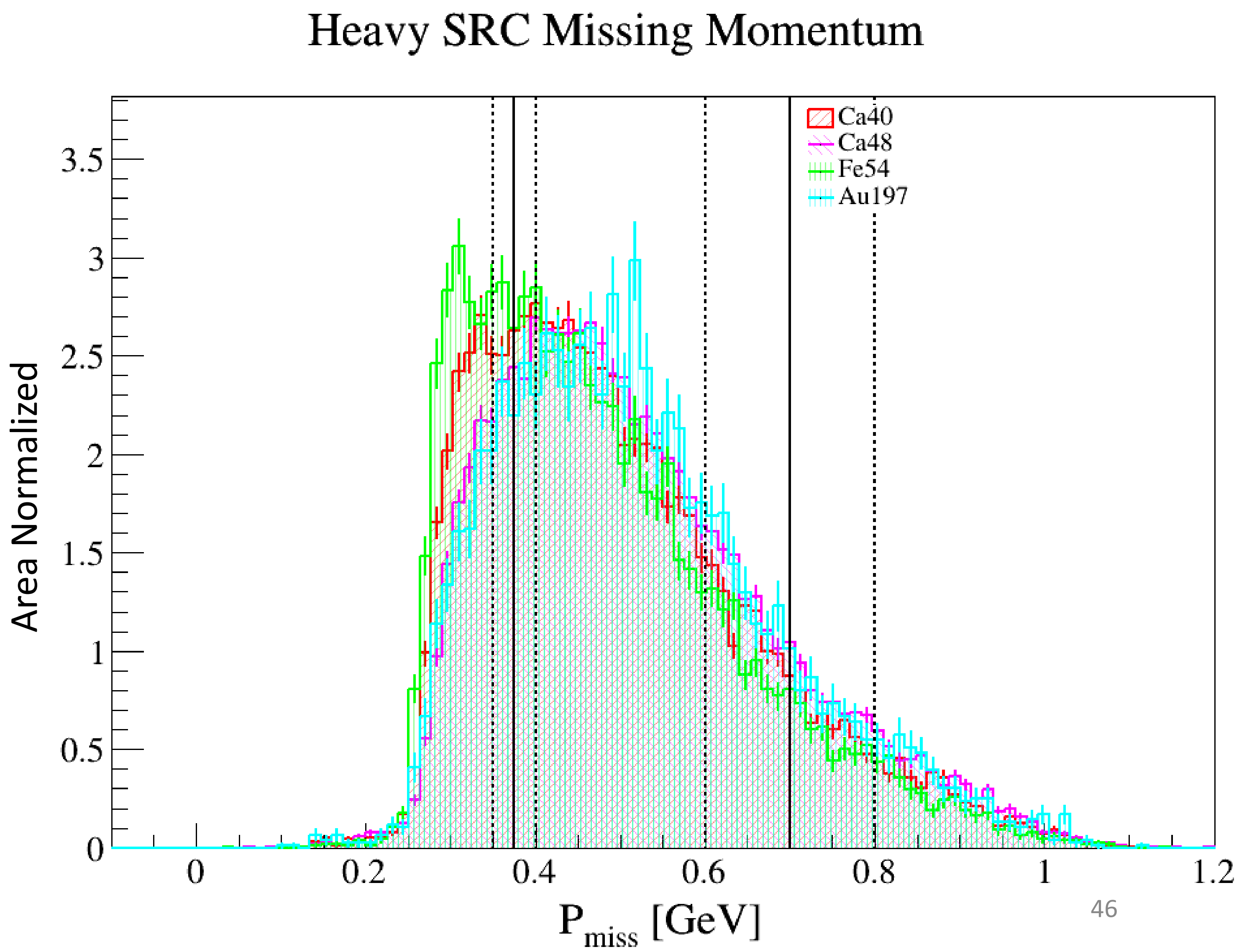
SRC Heavy: Pm vs xbj

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



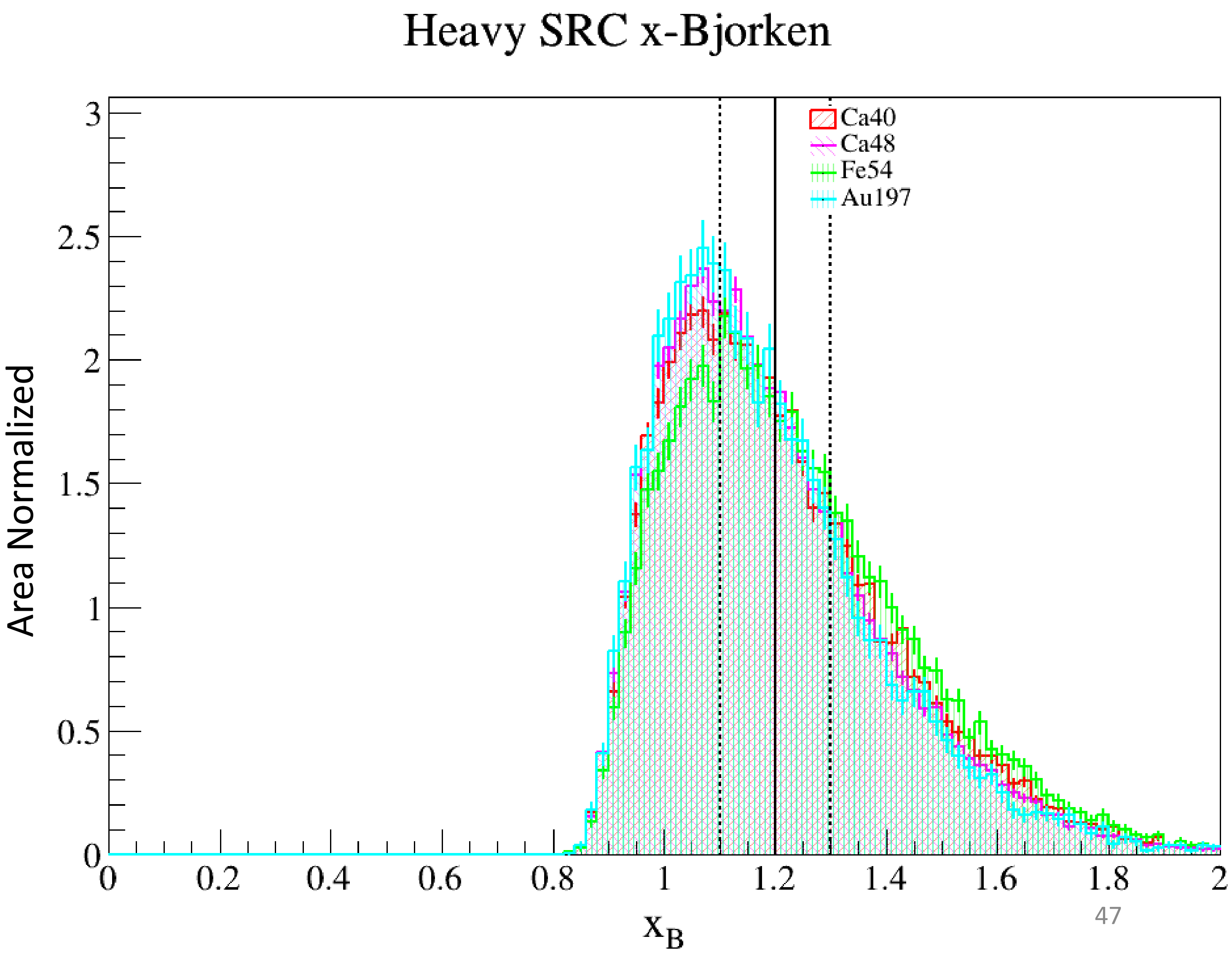
SRC Heavy: Pm

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 +/-0.025 < pmiss < 0.700 +/- 0.1 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



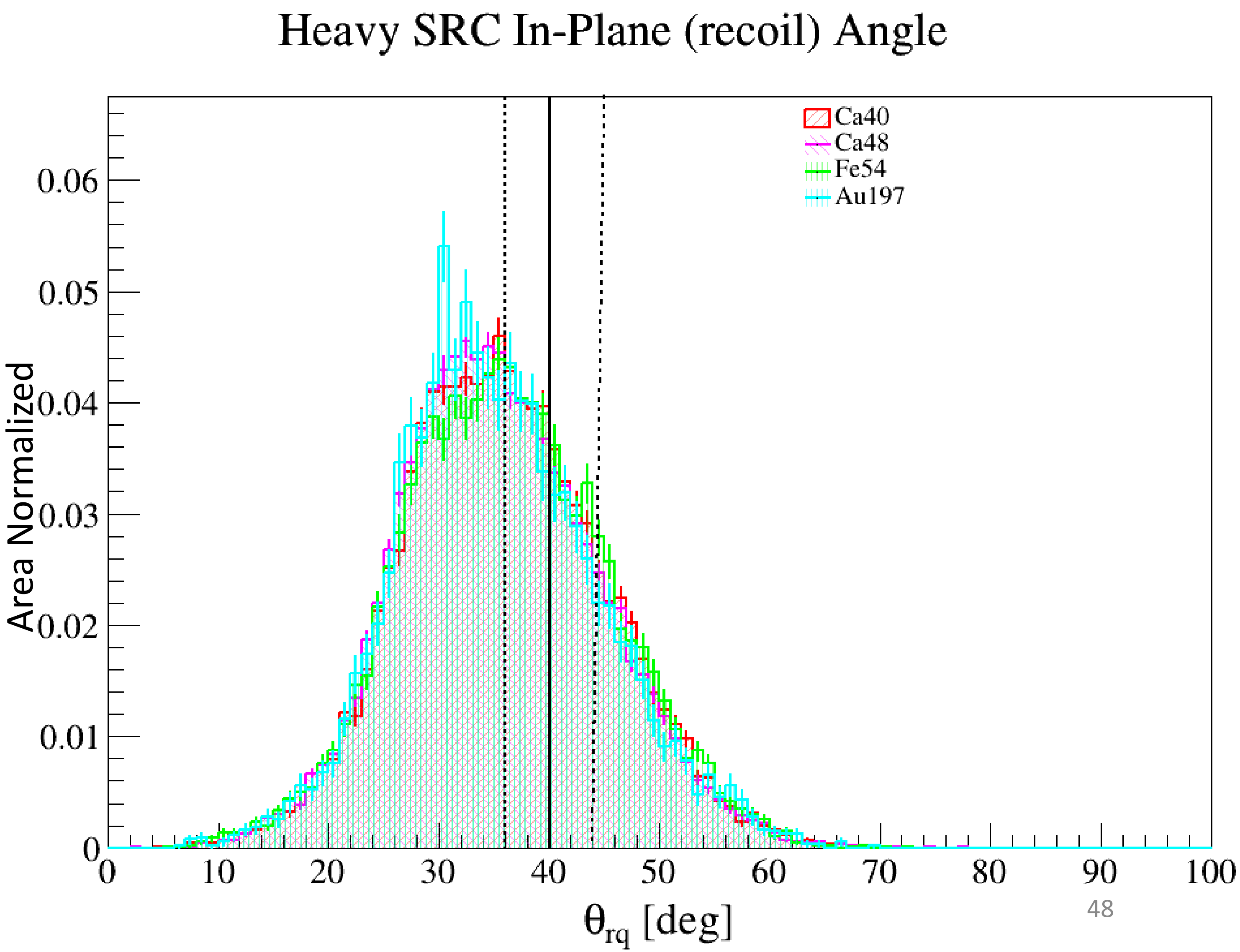
SRC Heavy: xbj

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 +/- 0.1 < xbj
    - 0 < theta_rq < 40 (deg)



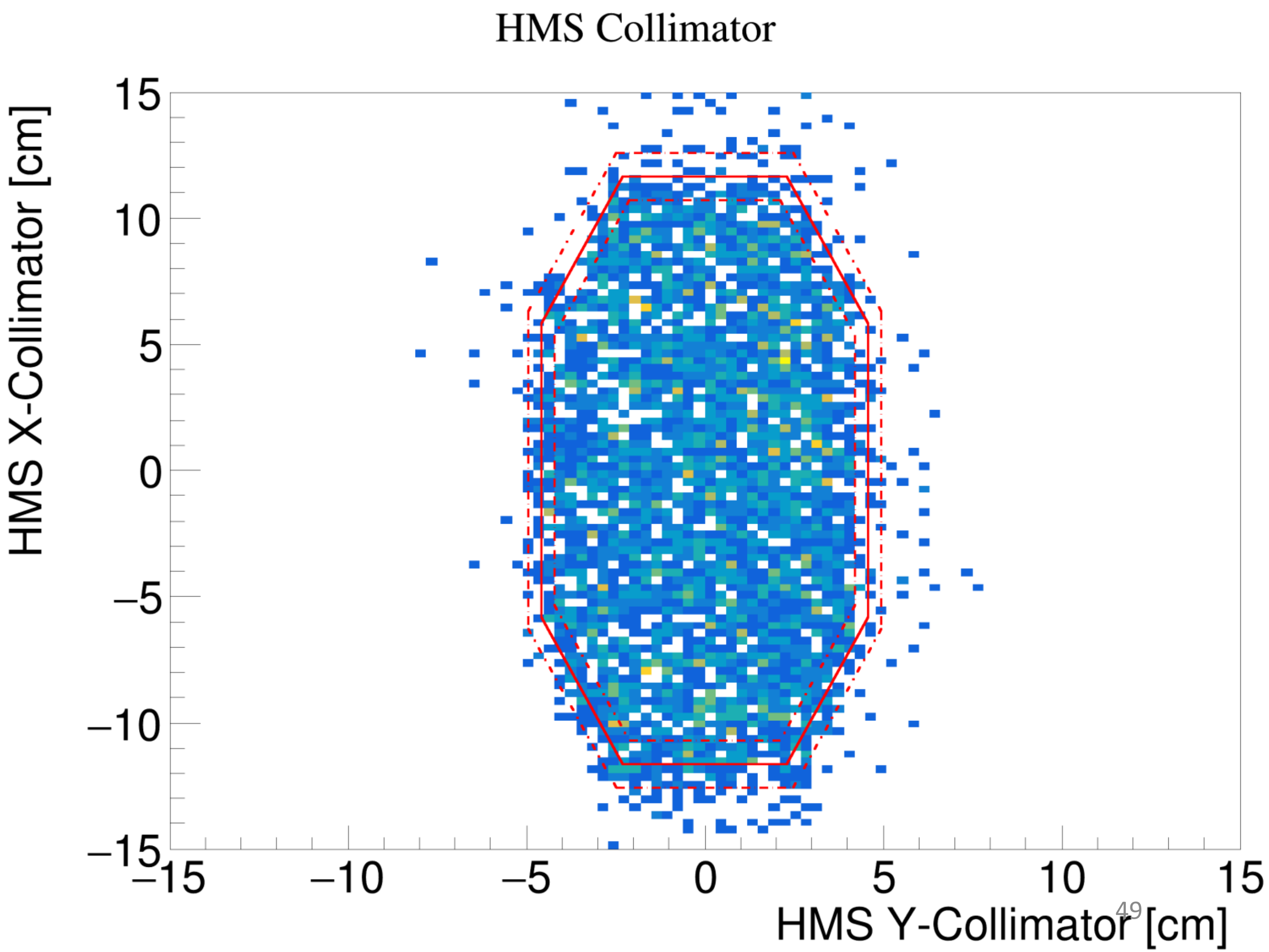
SRC Heavy: theta_rq

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 +/- 4 (deg)



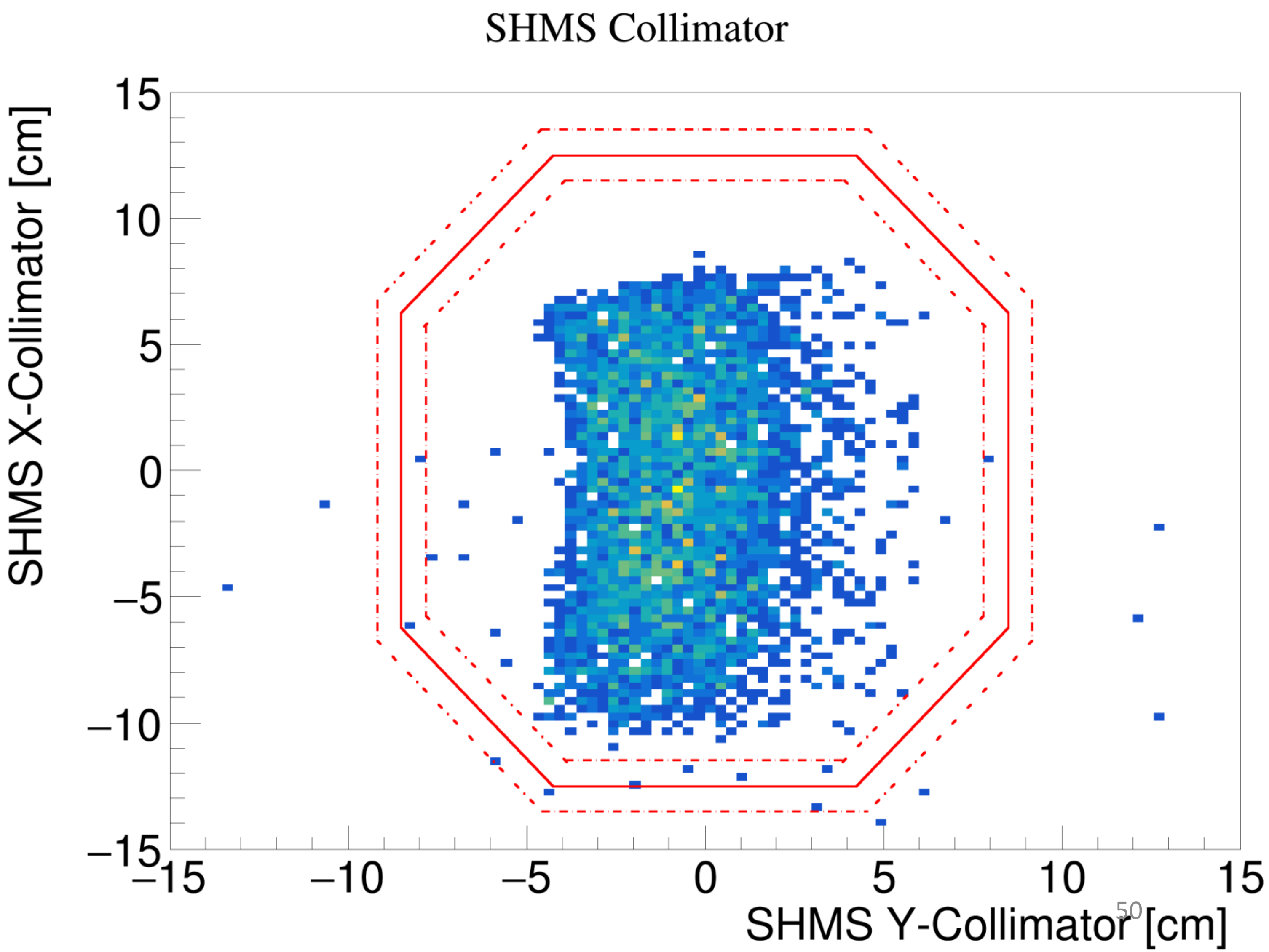
SRC Au197: HMS Collimator

- Cuts
  - Acceptance
    - Collimator Cut: scale +/- 8%
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



SRC Au197: SHMS-Collimator

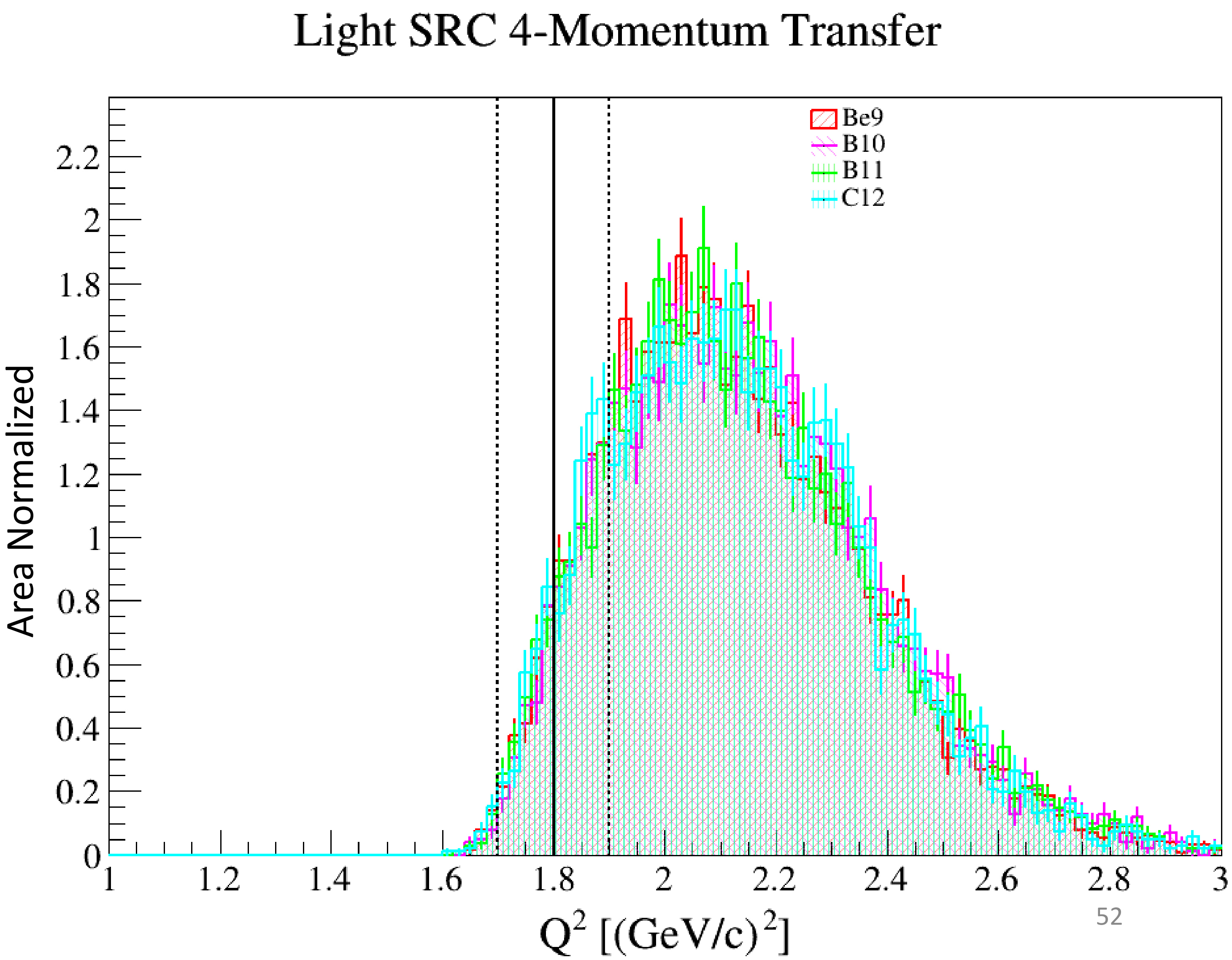
- Cuts
  - Acceptance
    - Collimator Cut: scale +/- 8%
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



Light SRC

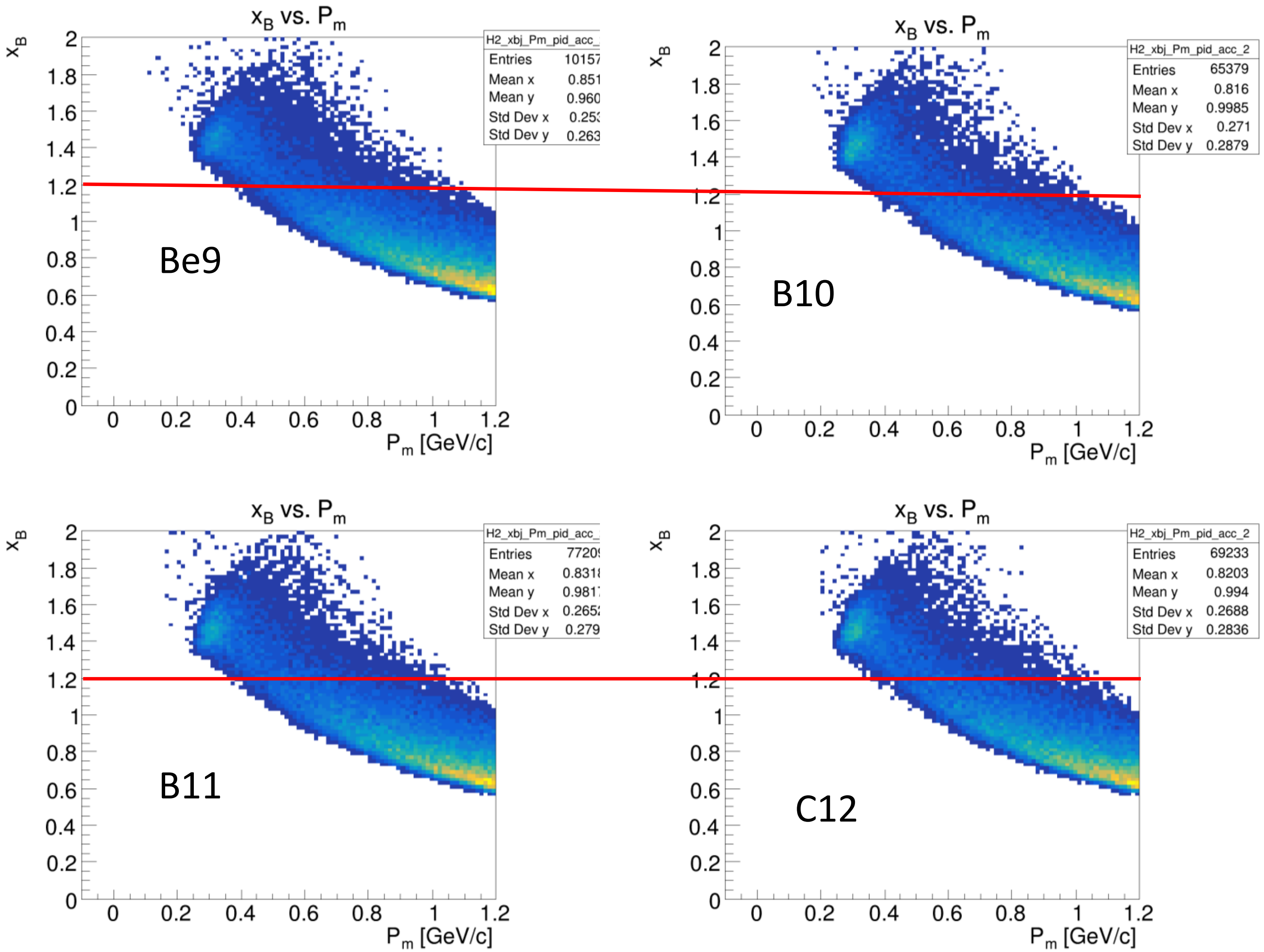
SRC Light: Q2

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



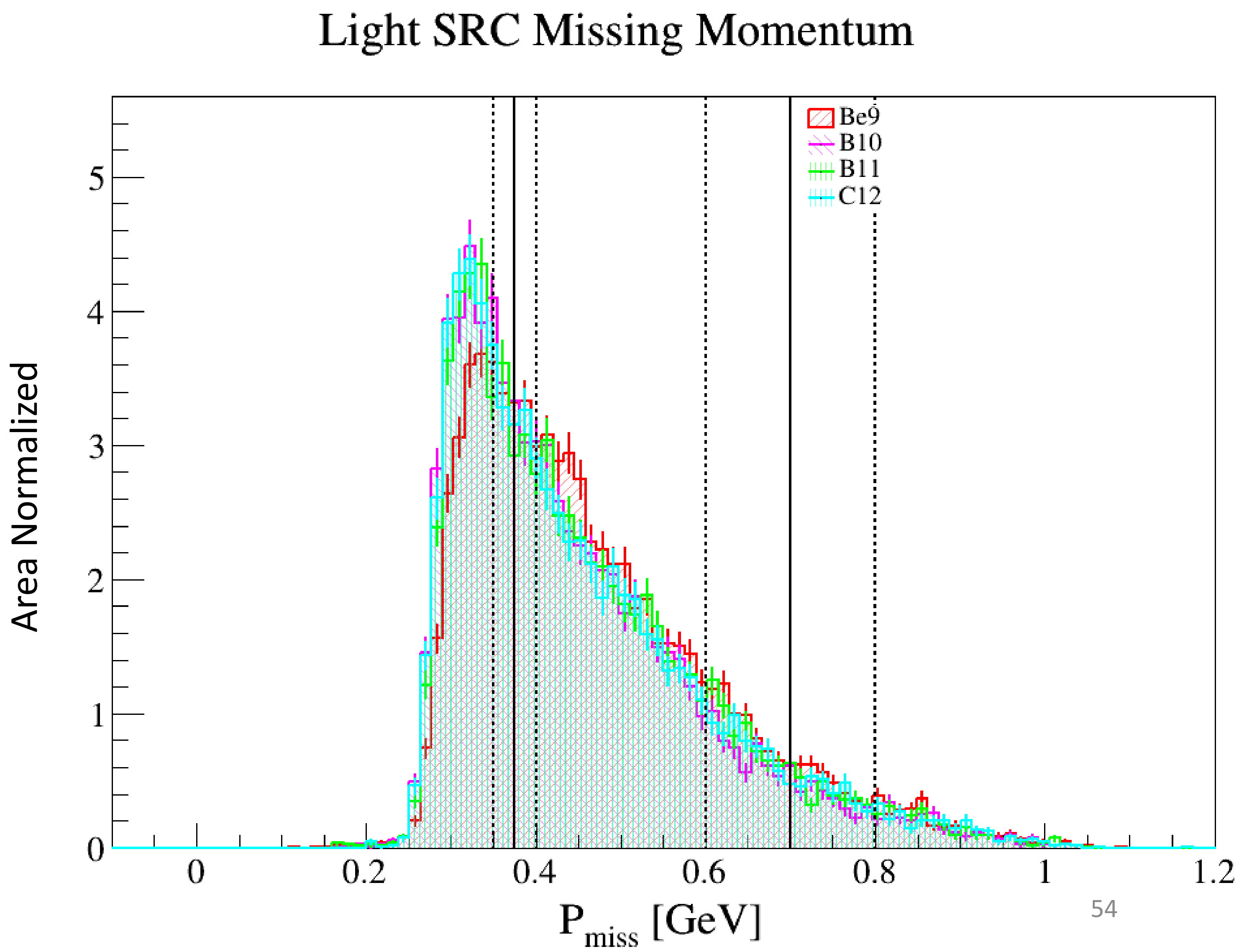
SRC Light: Pm vs xbj

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 +/-0.025 < pmiss < 0.700 +/- 0.1 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



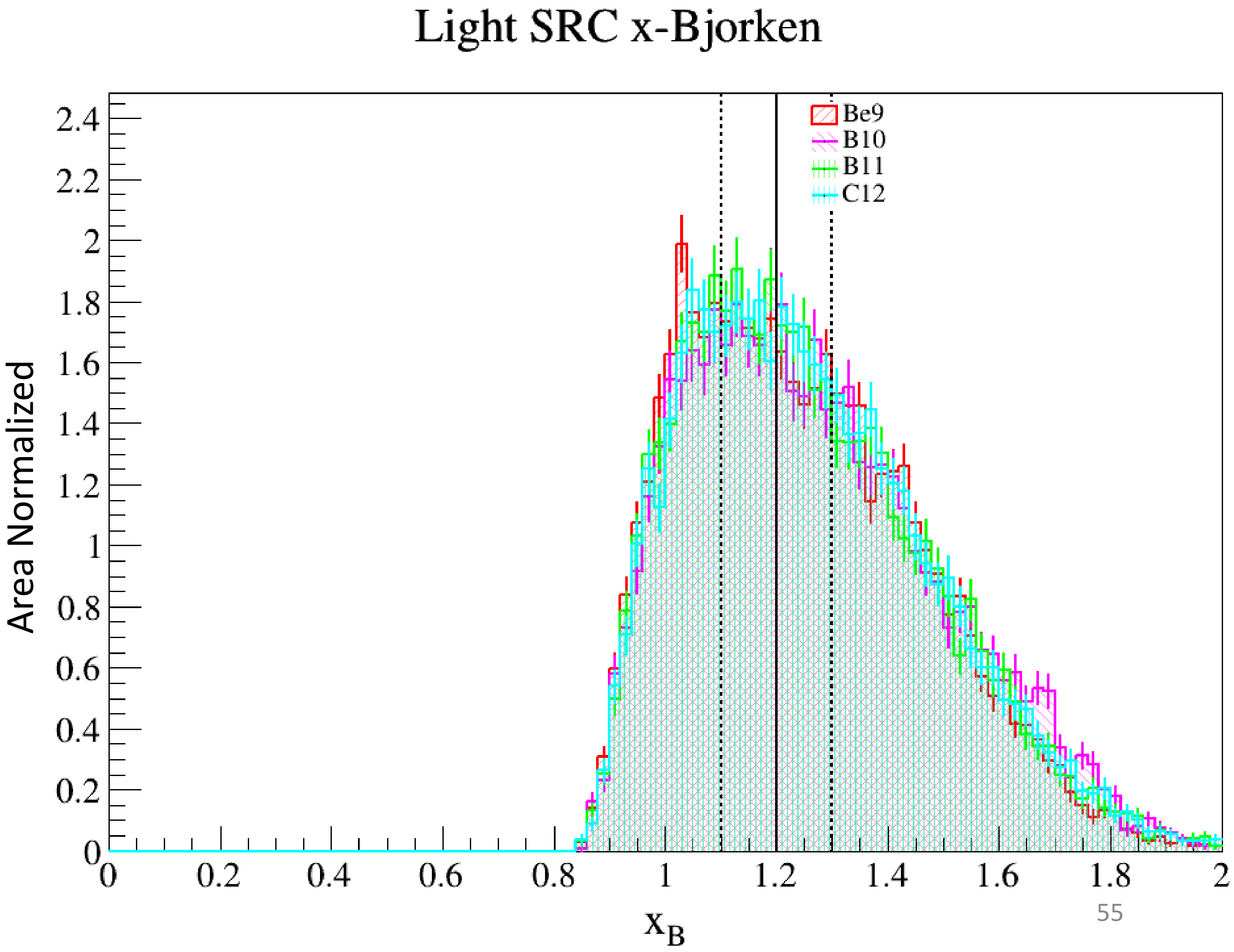
SRC Light: Pm

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 +/-0.025 < pmiss < 0.700 +/- 0.1 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



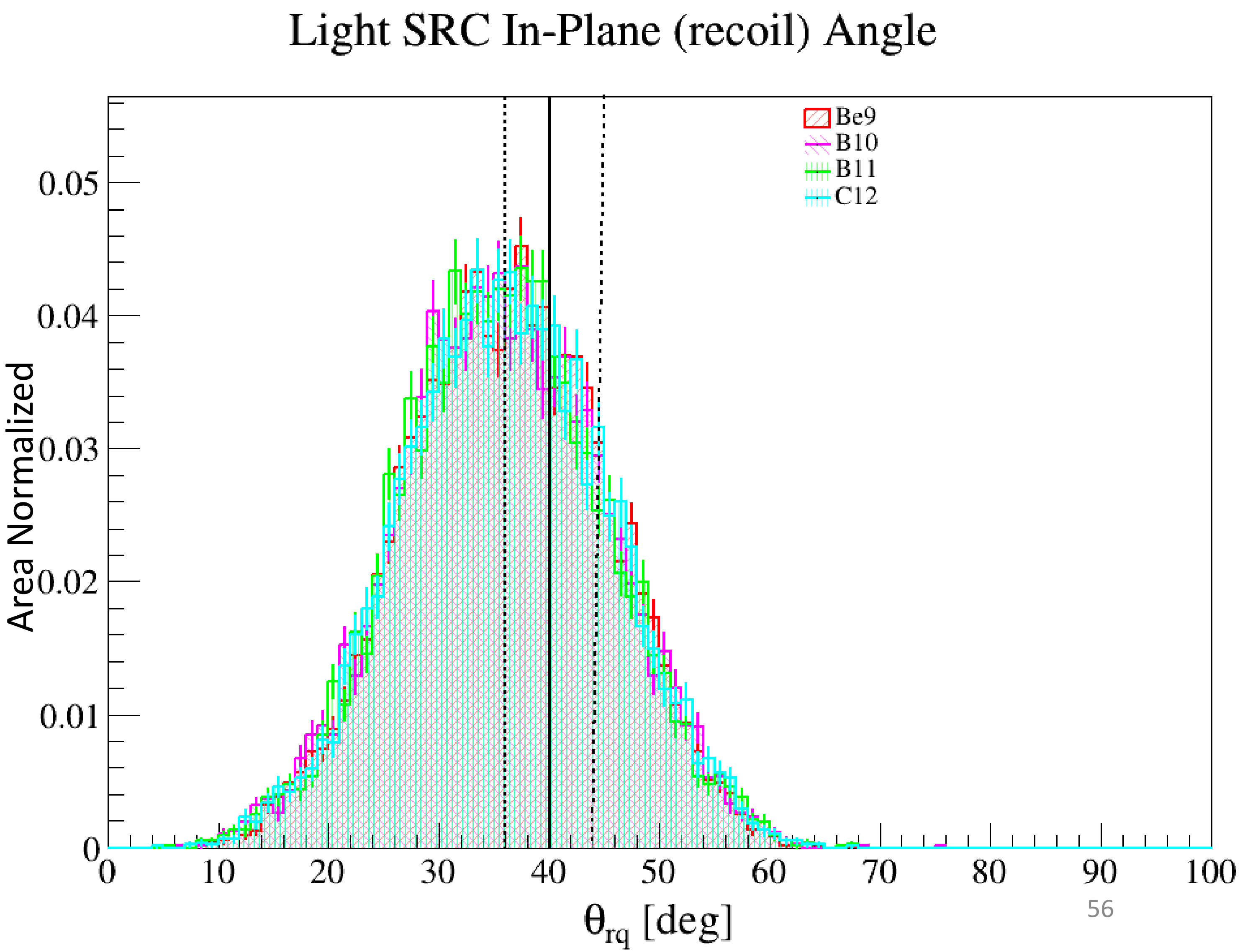
SRC Light: xbj

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 +/- 0.1 < xbj
    - 0 < theta_rq < 40 (deg)



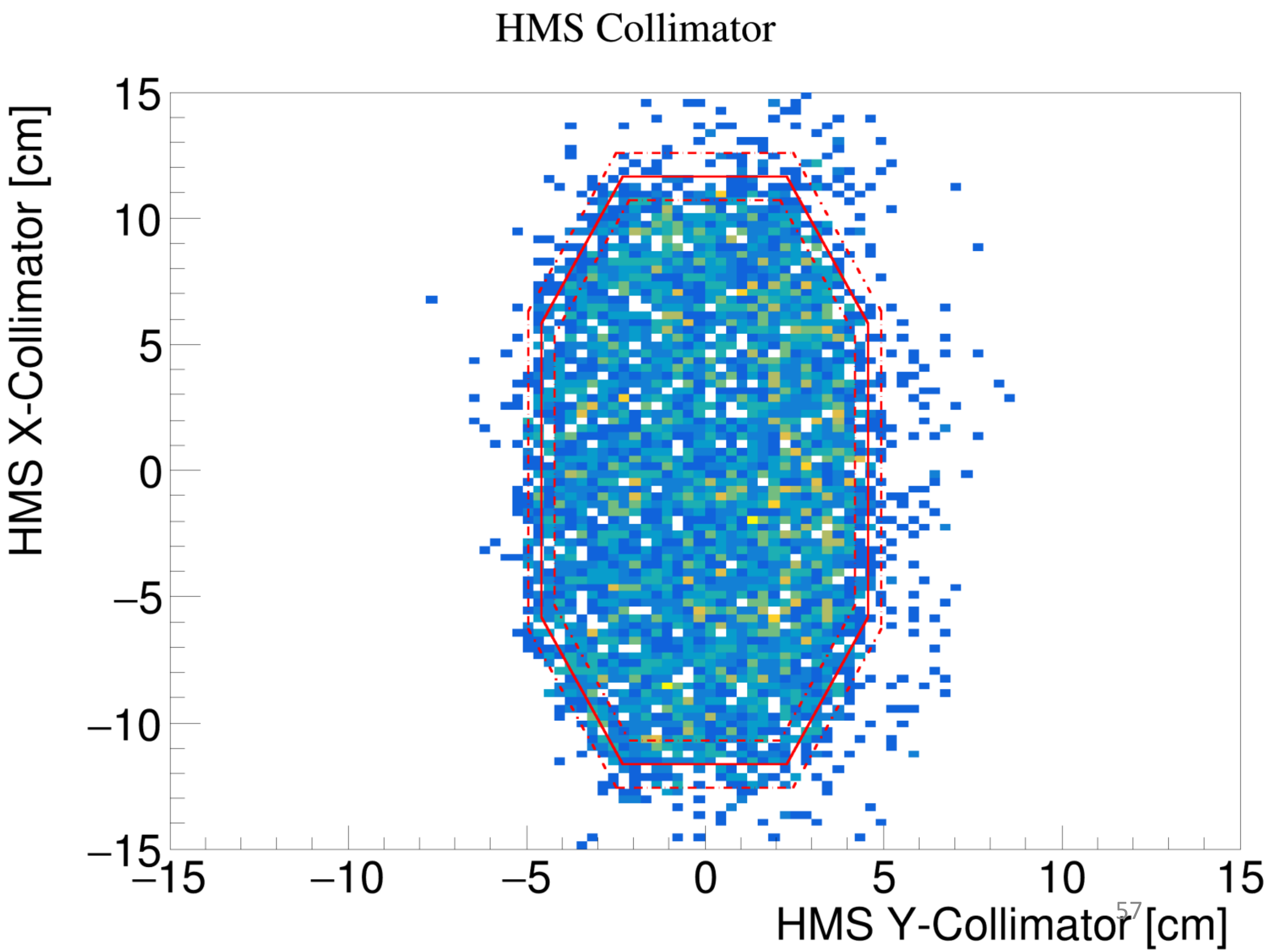
SRC Light: th_rq

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 +/- 4 (deg)



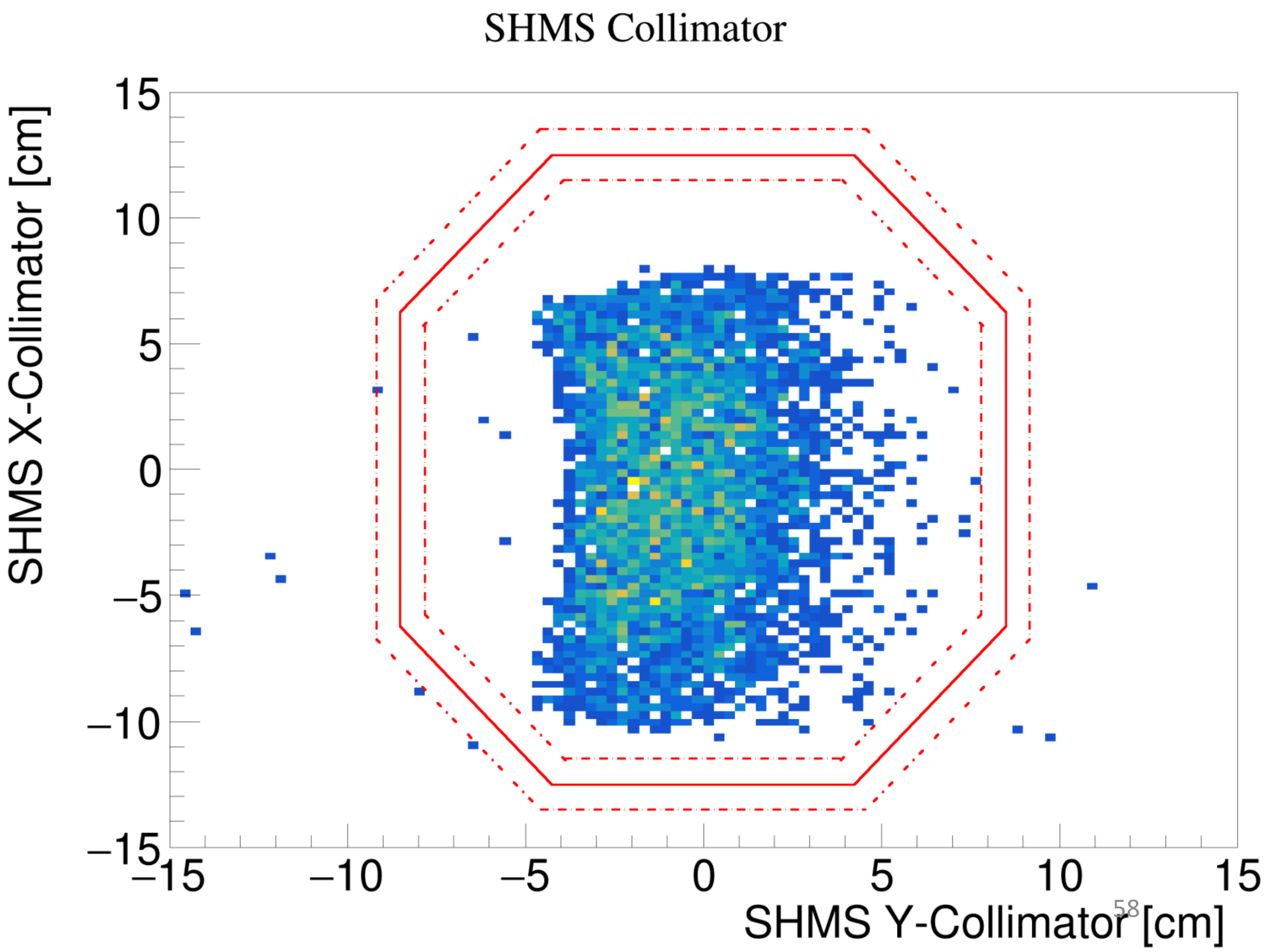
SRC C12: HMS Collimator

- Cuts
  - Acceptance
    - Collimator Cut: scale +/- 8%
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < 40 (deg)



SRC C12: SHMS-Collimator

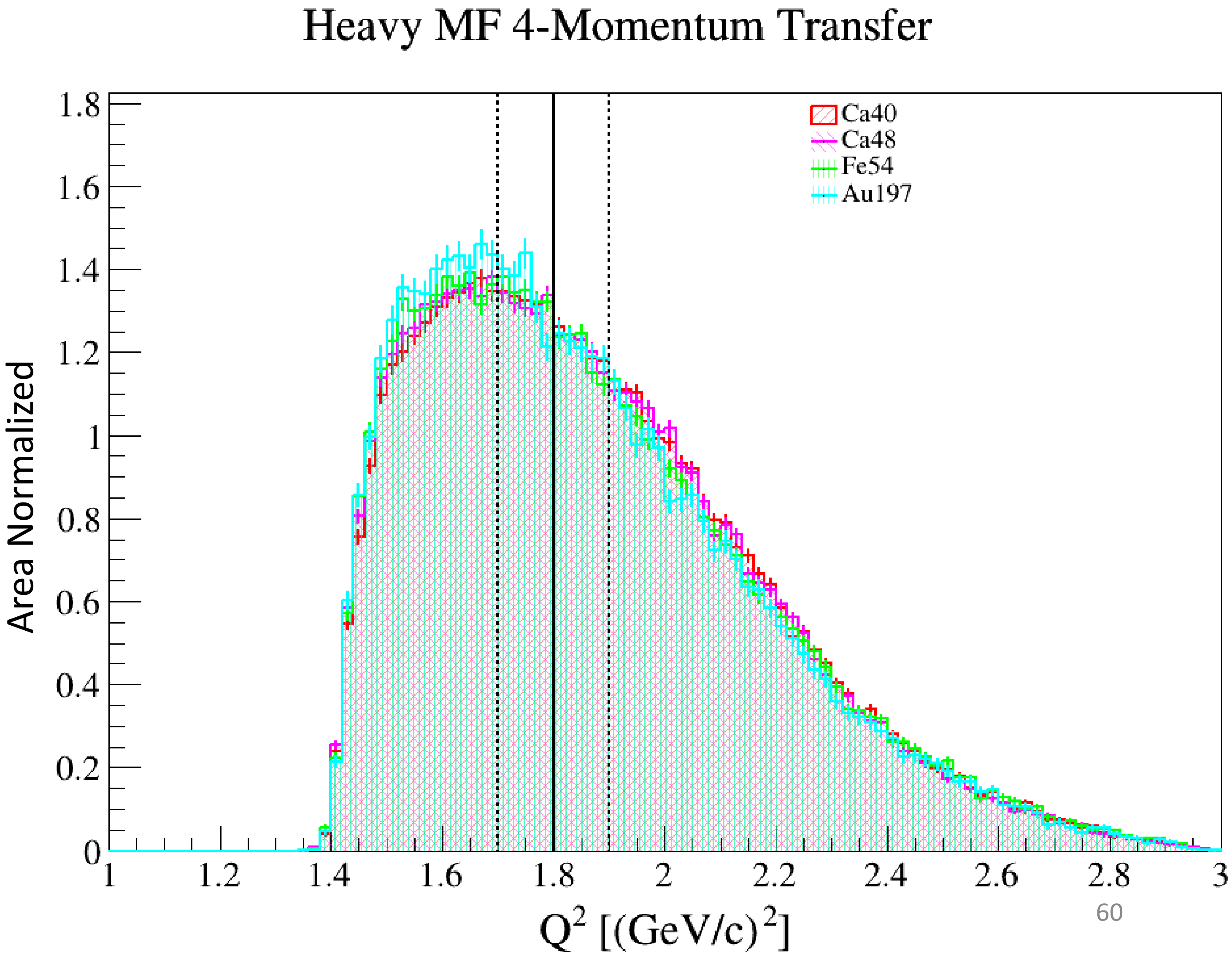
- Cuts
  - Acceptance
    - Collimator Cut: scale +/- 8%
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - 0.375 < pmiss < 0.700 (GeV/c)
    - 1.2 < xbj
    - 0 < theta_rq < (deg)



Heavy MF

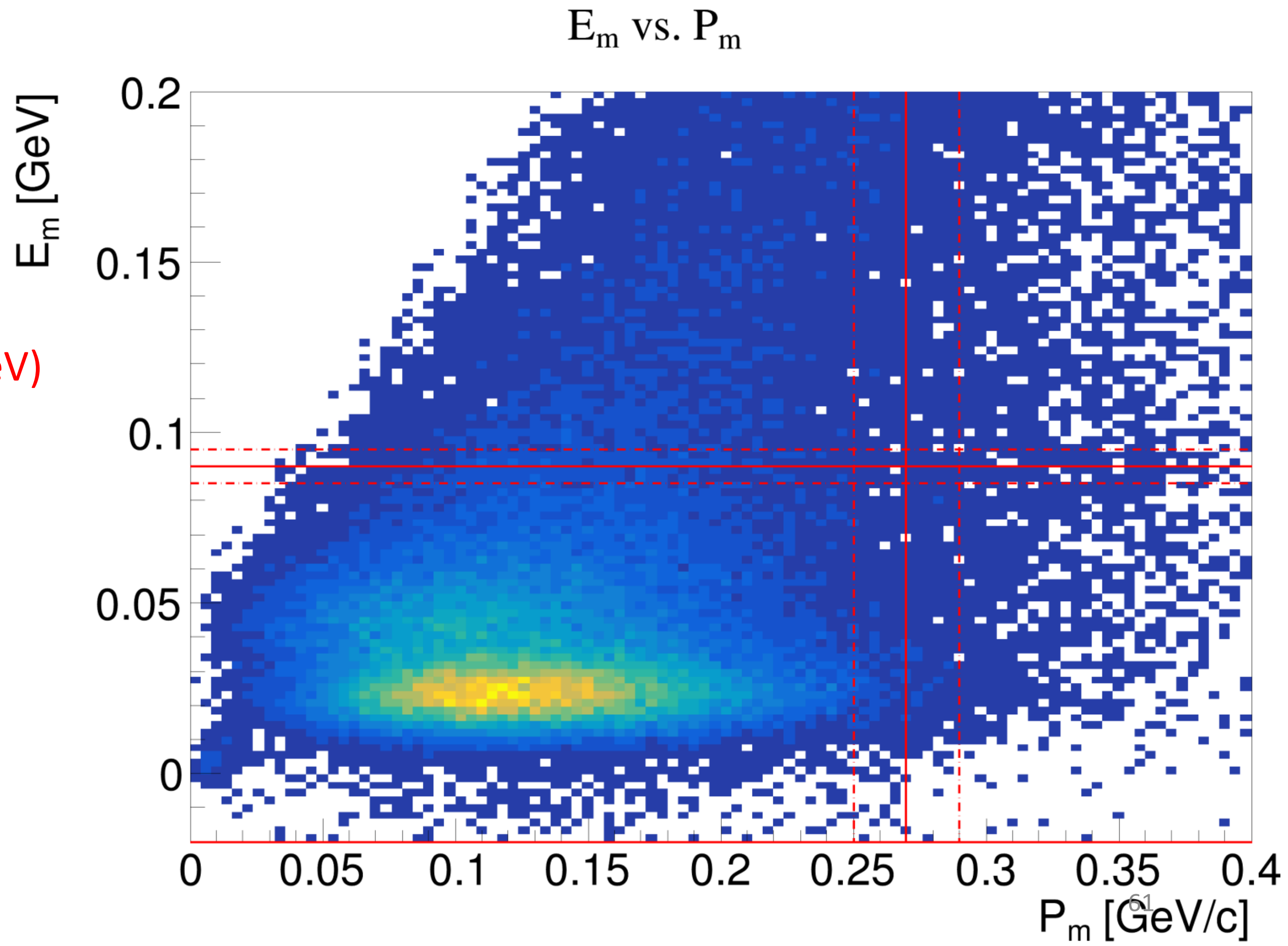
MF Heavy: Q2

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - pmiss < 0.270 (GeV/c)
    - -0.02 < emiss < 0.09 (GeV)



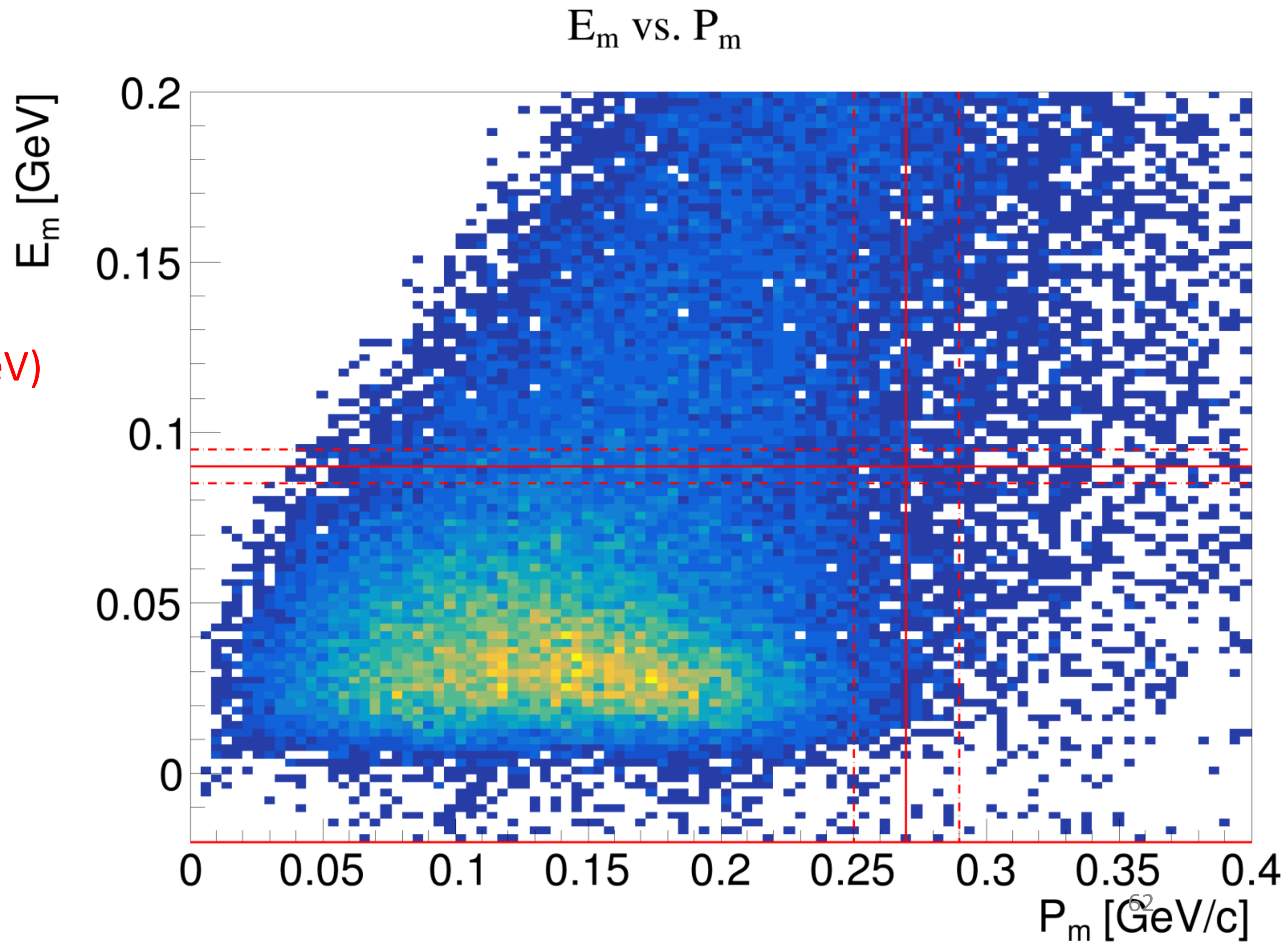
MF C12: Em & Pm

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)



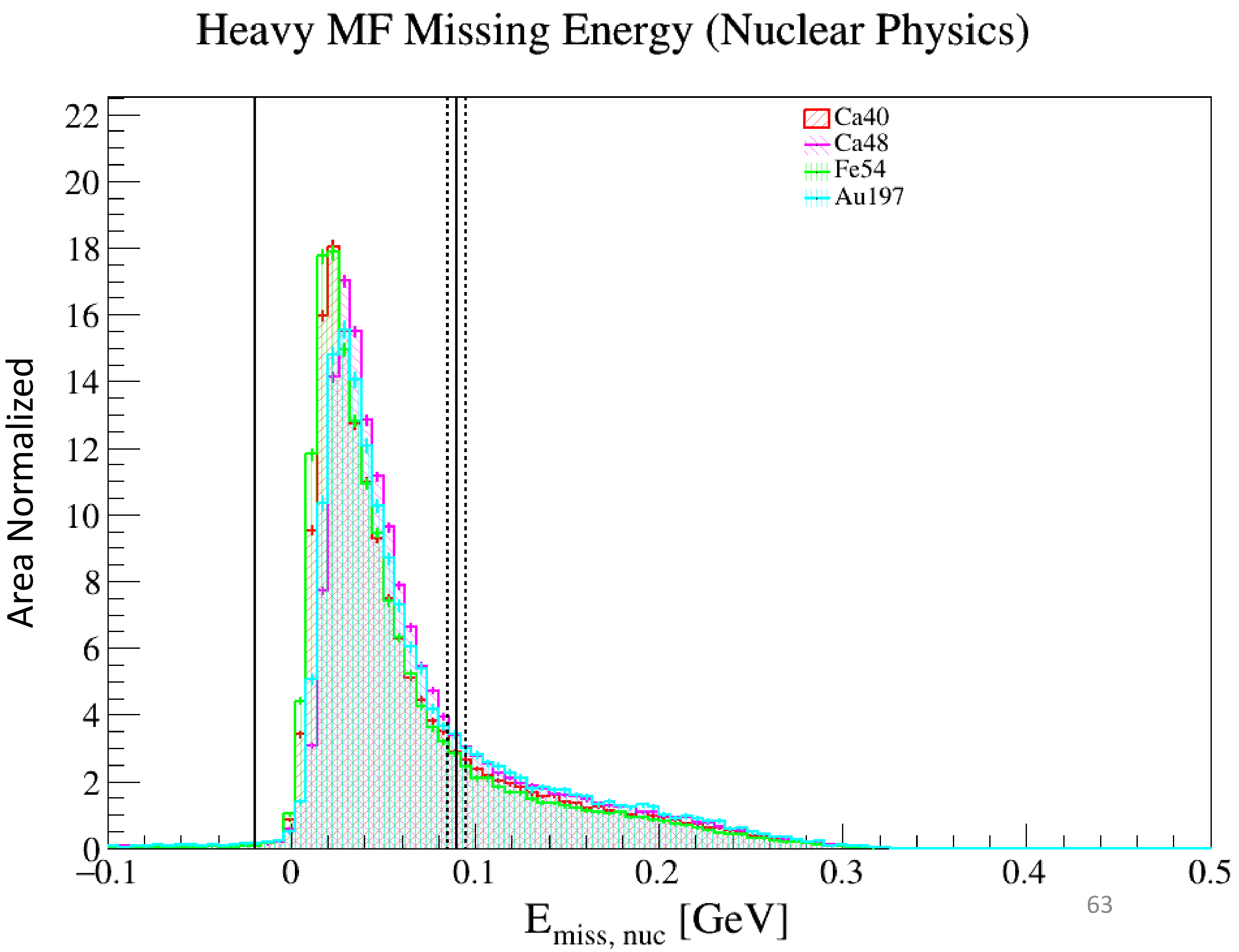
MF Au197: Em & Pm

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)



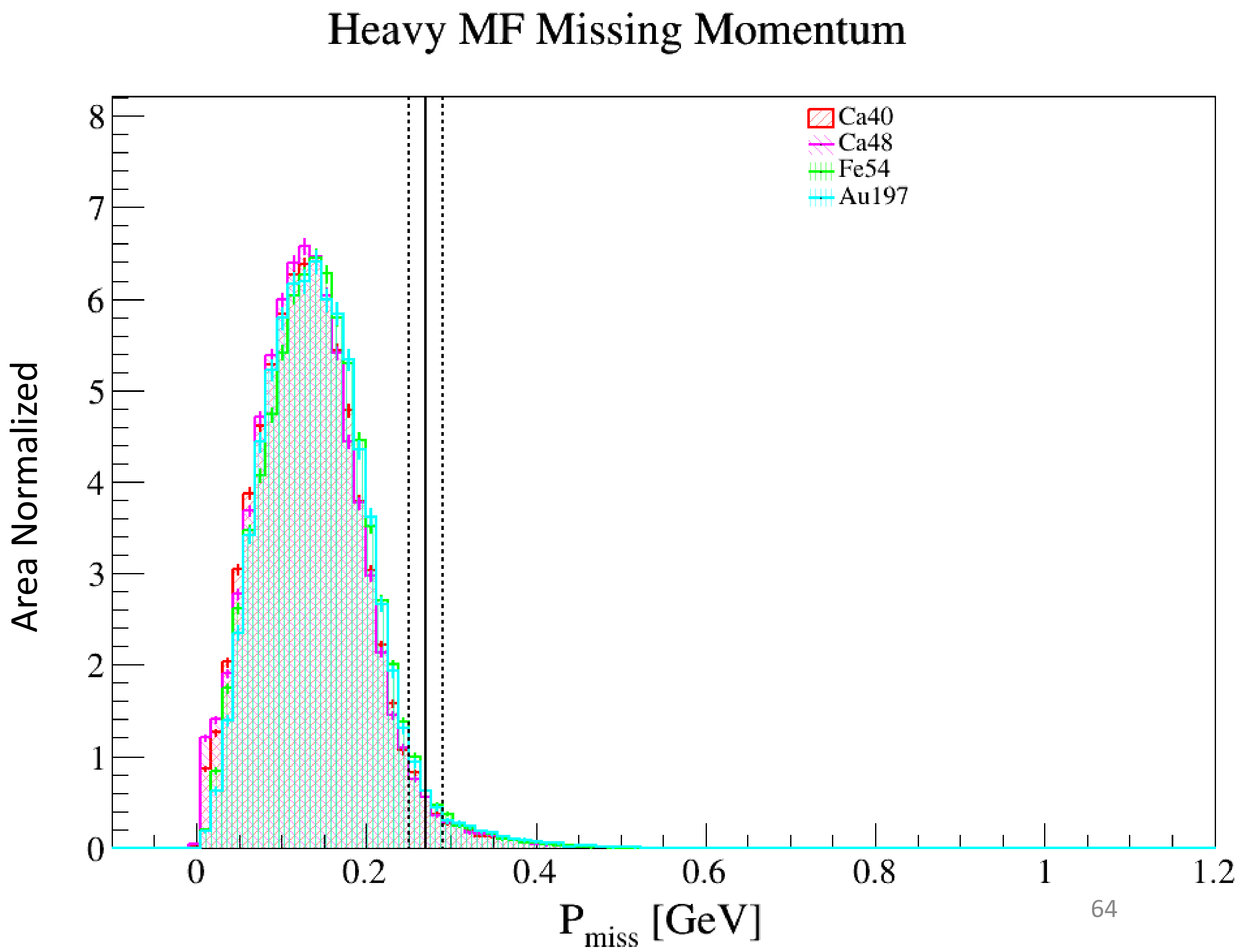
MF Heavy: Em

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - pmiss < 0.270 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)



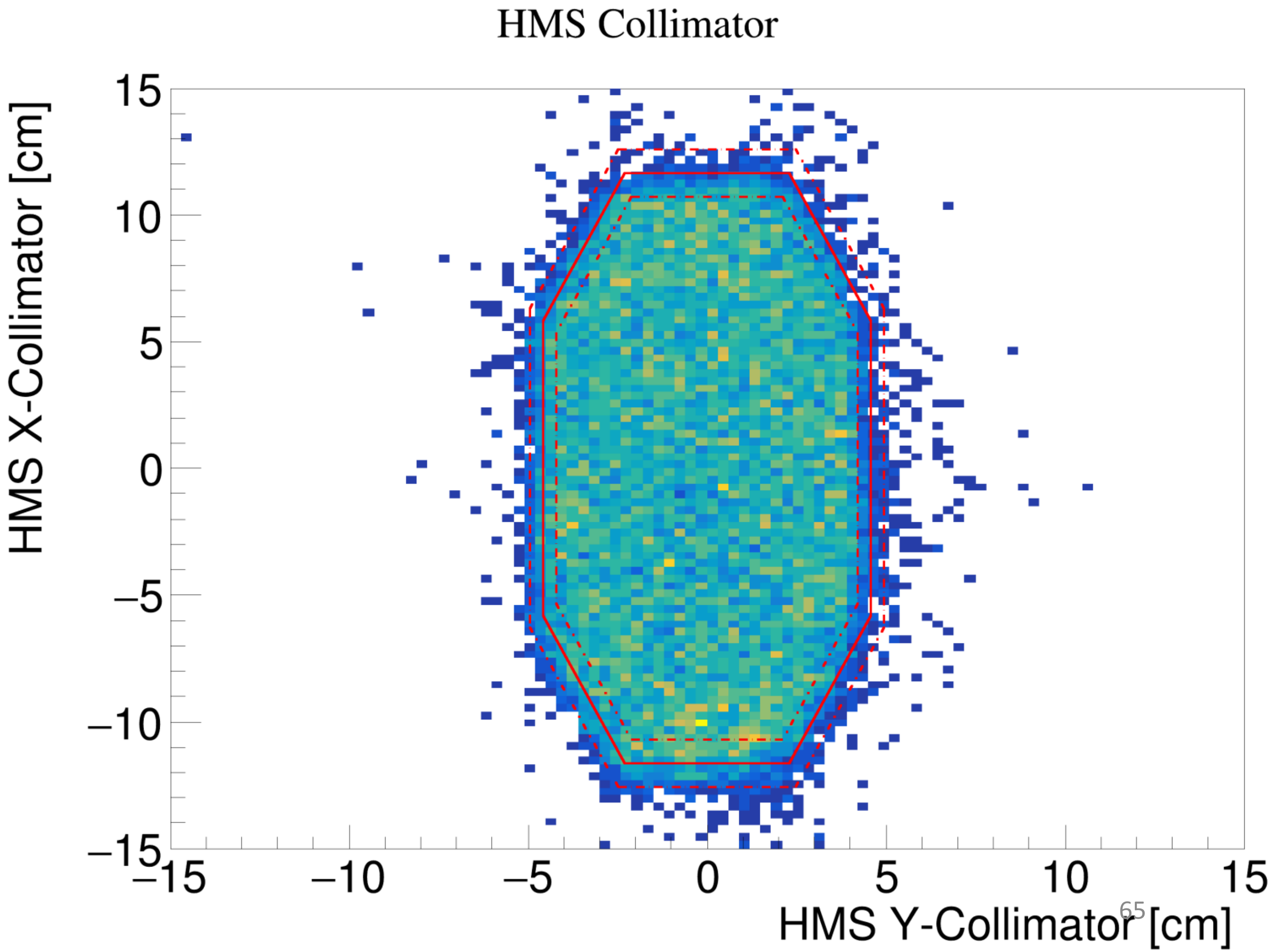
MF Heavy: Pm

- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 (GeV)



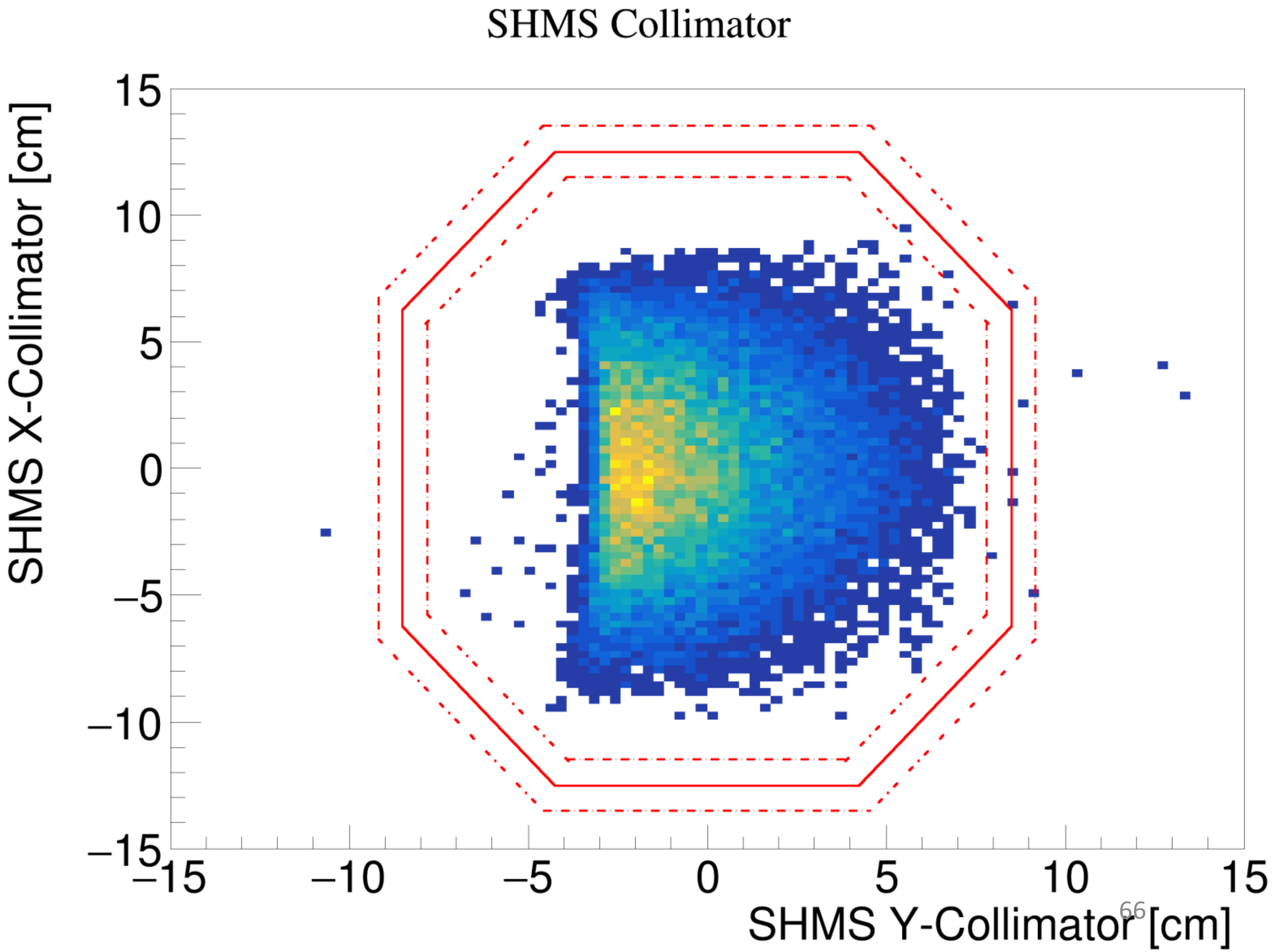
MF Au197: HMS Collimator

- Cuts
  - Acceptance
    - Collimator Cut +/- 8%
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - pmiss < 0.270 (GeV/c)
    - -0.02 < emiss < 0.09 (GeV)



MF Heavy: SHMS-Collimator

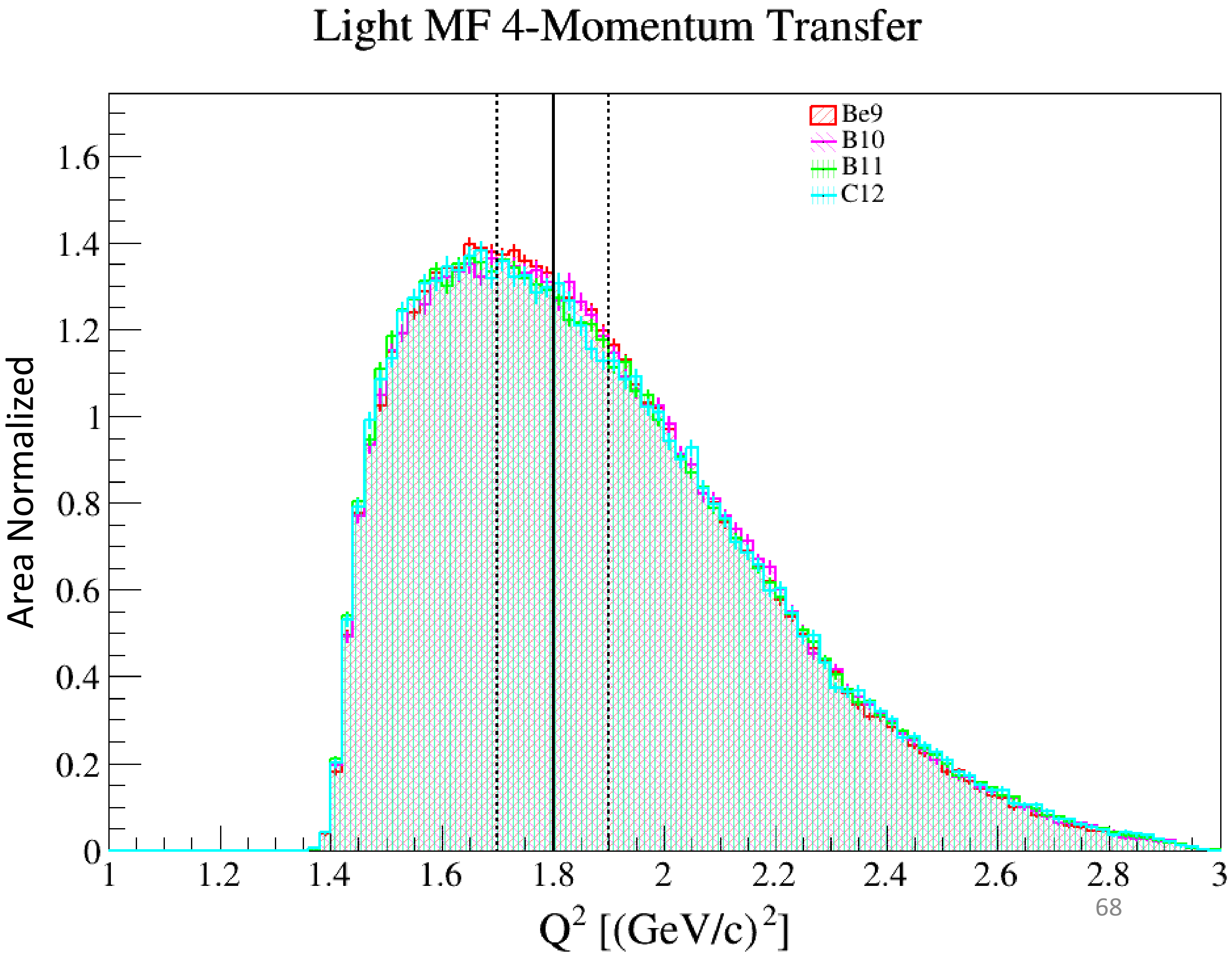
- Cuts
  - Acceptance
    - Collimator Cut
  - Kinematics
    - 1.8 < Q2 (GeV/c)^2
    - pmiss < 0.270 (GeV/c)
    - -0.02 < emiss < 0.09 (GeV)



Light MF

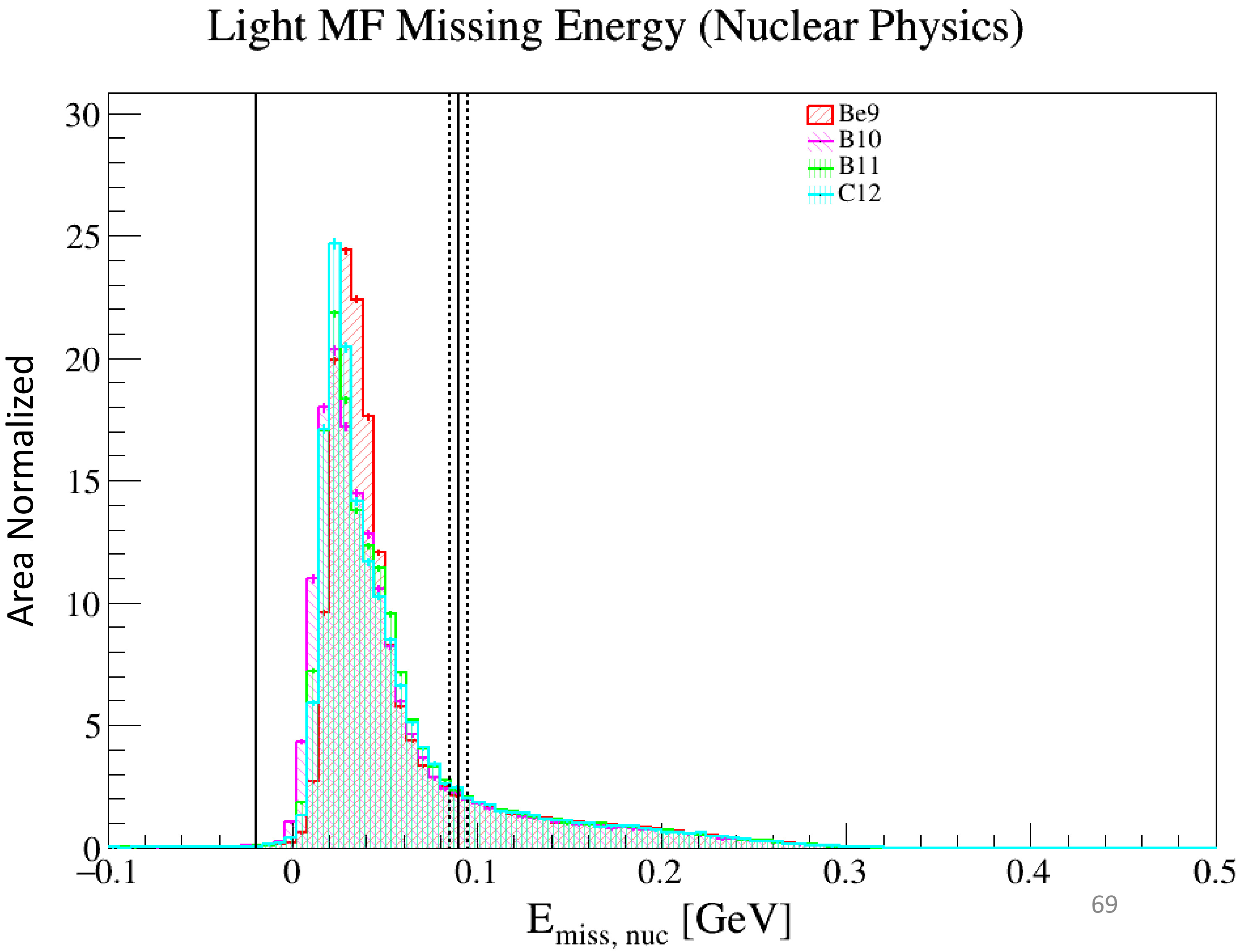
MF Light: Q2

- Cuts
  - Acceptance
    - Collimator Cut +/- 8%
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)



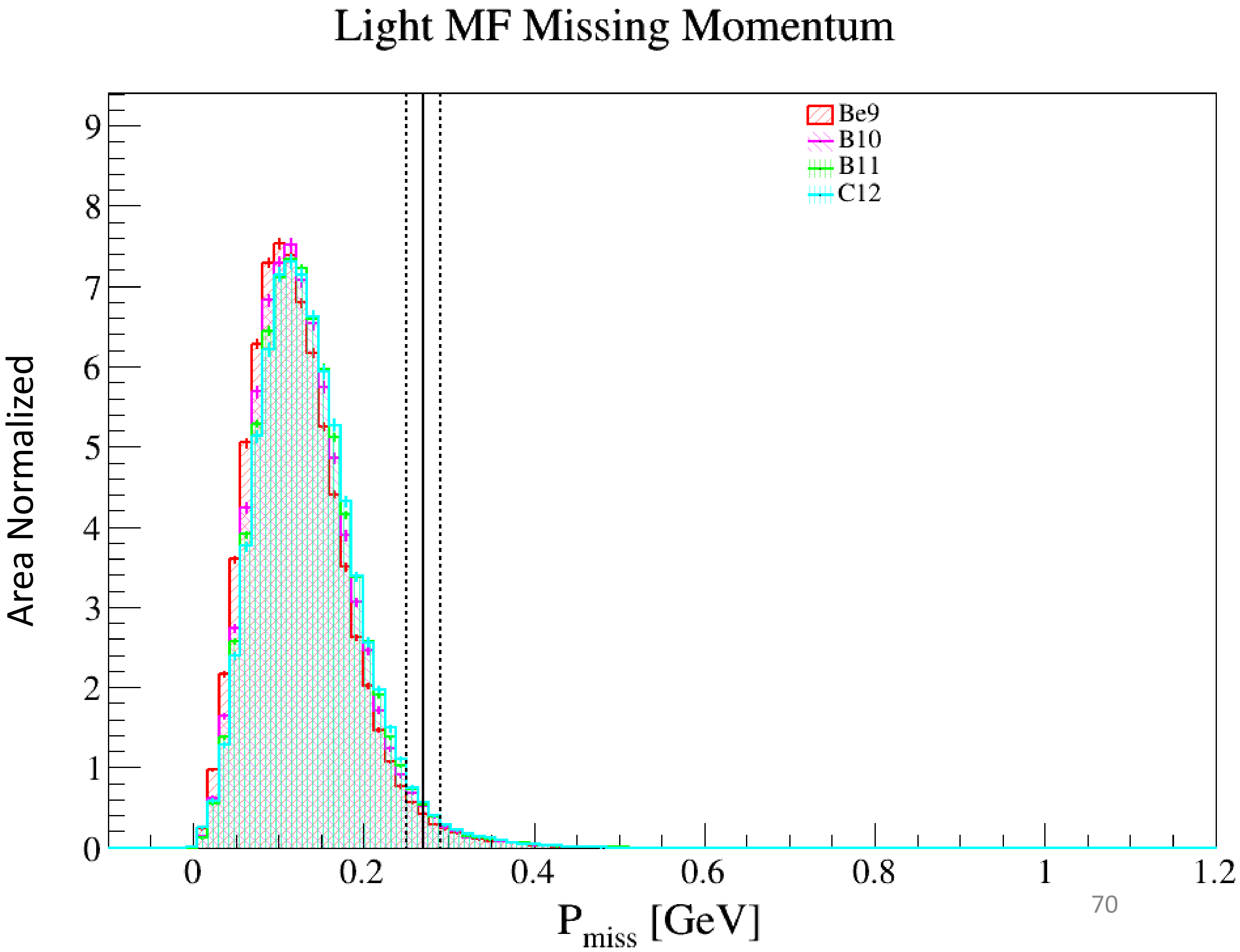
MF Light: Em

- Cuts
  - Acceptance
    - Collimator Cut +/- 8%
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)



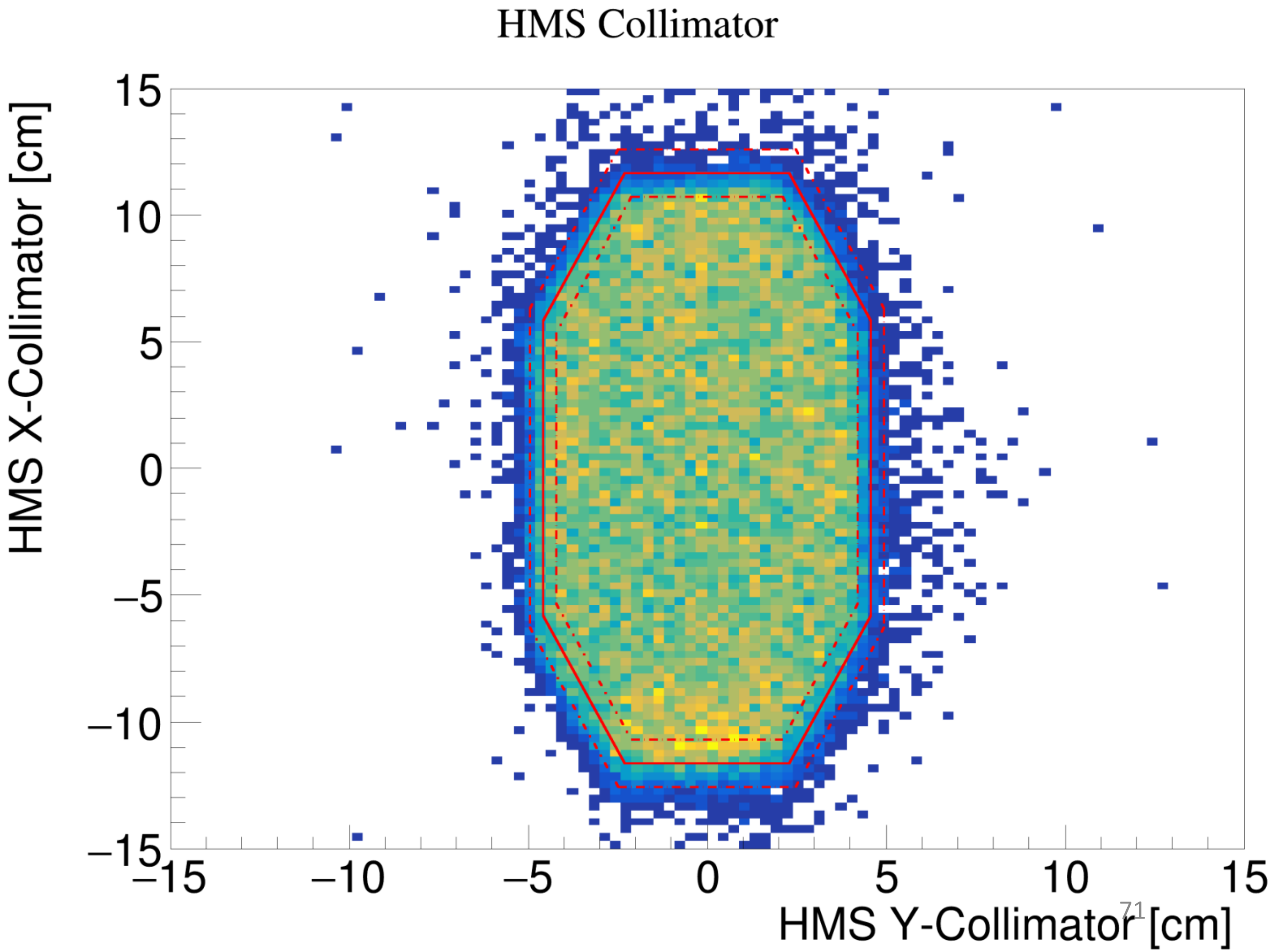
MF Light: Pm

- Cuts
  - Acceptance
    - Collimator Cut +/- 8%
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)



MF C12: HMS Collimator

- Cuts
  - Acceptance
    - Collimator Cut +/- 8%
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)



MF C12: SHMS-Collimator

- Cuts
  - Acceptance
    - Collimator Cut +/- 8%
  - Kinematics
    - 1.8 +/- 0.1 < Q2 (GeV/c)^2
    - pmiss < 0.270 +/- 0.02 (GeV/c)
    - -0.02 < emiss < 0.09 +/- 0.005 (GeV)