Update on Neutron Magnetic Form Factor (G_M^n) Measurement at High Q^2 with CLAS12

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Outline:

1. Some Background
2. DC Fiducial cuts
3. PCAL Fiducial cuts
4. Vertex cuts
5. Summary

- The elastic, electromagnetic form factors (G_M^n, G_E^n, G_M^p, and G_E^p) are fundamental quantities related to the distribution of charge and magnetization/currents in the neutron. Broad, PAC-approved effort to measure all four form factors.

- The elastic $e-n$ or $e-p$ cross section in terms of the Sachs form factors is

$$R = \frac{\frac{d\sigma}{d\Omega}\left({}^2\mathrm{H}(e,e'n)p\right)_{QE}}{\frac{d\sigma}{d\Omega}\left({}^2\mathrm{H}(e,e'p)n\right)_{QE}} = a(Q^2)\frac{\sigma^n_{mott}\left(G_E^{n\,2}+\frac{\tau_n}{\epsilon_n}G_M^{n\,2}\right)\left(\frac{1}{1+\tau_n}\right)}{\sigma^p_{mott}\left(G_E^{p\,2}+\frac{\tau_p}{\epsilon_p}G_M^{p\,2}\right)\left(\frac{1}{1+\tau_p}\right)}$$

Deuteron target

Nuclear correction

Well-known proton cross section.

where $\sigma^{p,n}_{mott}$, $\tau_{p,n}$, $\epsilon_{p,n}$, and $a(Q^2)$ are all known kinematic factors.

- Ratio (R) data on deuterium were collected in Run Group B.

- Corrections to the Ratio

$$R_{Cor} = f_{NDE} f_{PDE} f_{nuc} f_{fermi} f_{rad} R$$

- Pass 1 Corrections and Status

f_{rad}	Radiative Correction	✓
f_{PDE}	Proton Detection Efficiency	✓
f_{nuc}	Nuclear correction	✓
f_{fermi}	Fermi Correction	✓
f_{NDE}	Neutron Detection Efficiency	✓
f_{lumi}	Luminosity Correction	ongoing

- Now updating analysis code to Pass 2 - focus of this talk.

Exp. Detail	In-bending	Out-bending	In-bending
Run Period	Spring 2019	Fall 2019	Spring 2020
Run Range	6156-6399 6420-6598	11093-11283	11323-11571
Number of runs	117 runs 106 runs	97 runs	171 runs
Beam	10.6 GeV 10.2 GeV	10.4 GeV	10.4 GeV
Target	Unpolarized LD_2	Unpolarized LD_2	Unpolarized LD_2
Current	35-50 nA	40 nA	35-50 nA
Torus Field	-1	$+1/+1.008$	-1
Solenoid Field	-1	-1	-1

RGB run period conditions.

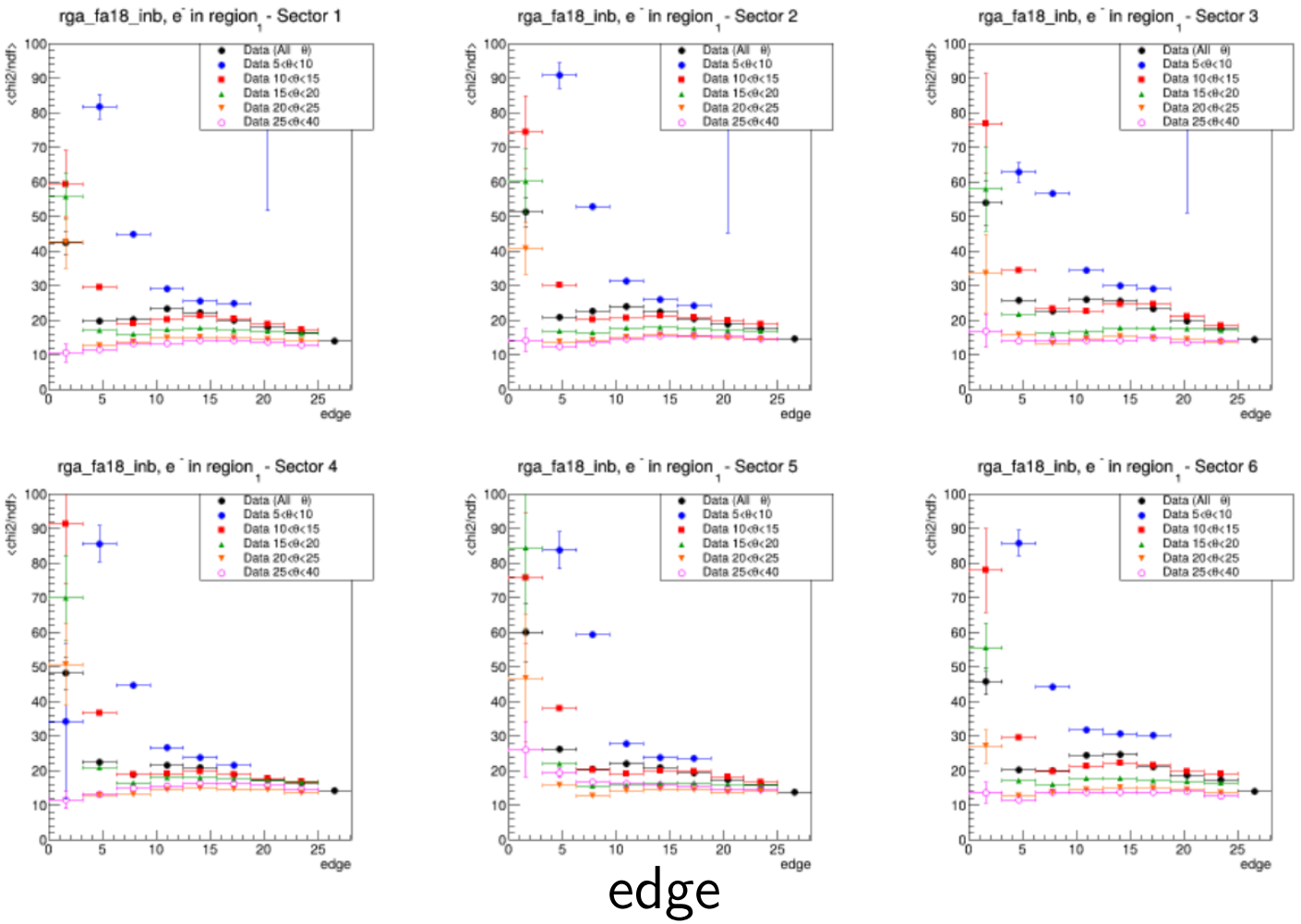
Cuts are determined by the *edge* parameter in the REC::Traj bank. It is a signed quantity defining the distance in *cm* to the closest edge of the detector. The value is determined where the chi2ndf of tracks stabilizes. Results below from the RG-A Pass 2 Analysis Note.

Inbending Tracks	
Region 1	If $\theta < 10^{\circ}$, *edge* > 10 *cm*, else *edge* > 3 *cm*
Region 2	If $\theta < 10^{\circ}$, *edge* > 3 *cm*, else *edge* > 3 *cm*
Region 3	*edge* > 10 *cm*

Outbending Tracks	
Region 1	*edge* > 3 *cm*
Region 2	*edge* > 3 *cm*
Region 3	*edge* > 10 *cm*

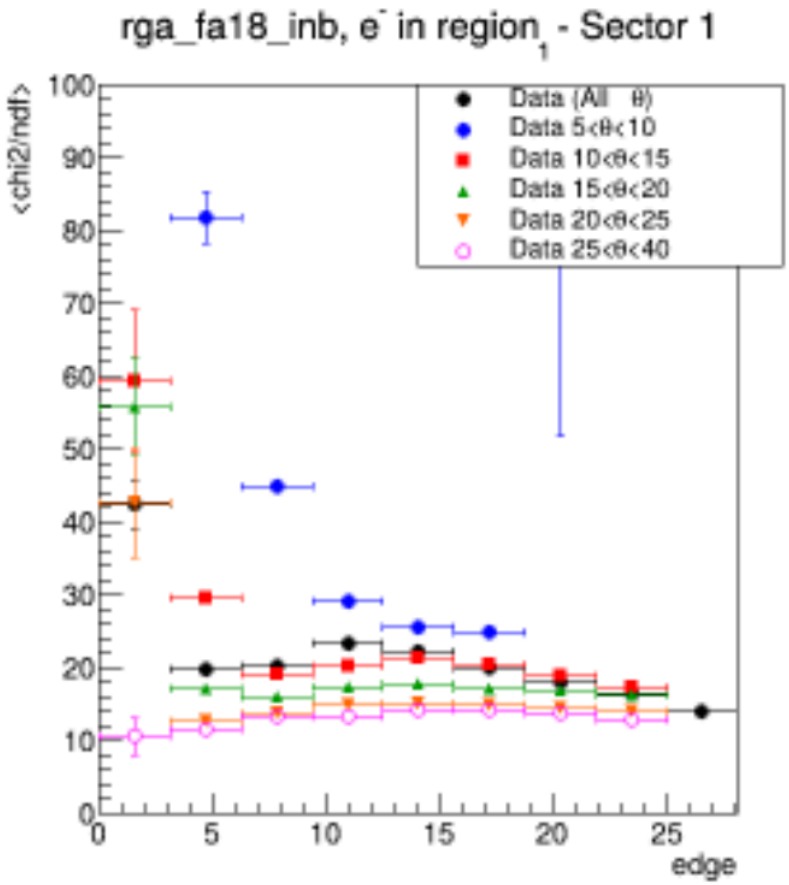
*Parameters from *RGA_Pass_2_Analysis_Overview_and_Procedures-4.pdf*.

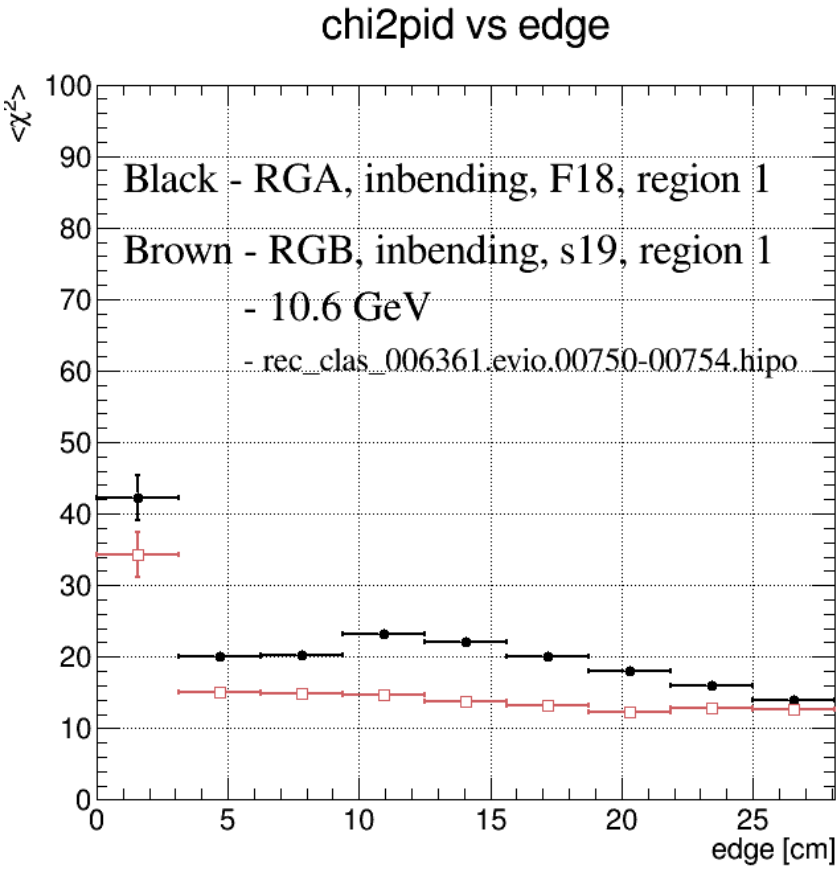
Angle cut determined by stability of ⟨chi2/ndf⟩ in each sector.*



* - RGA_Pass_2_Analysis_Overview_and_Procedures.pdf, S. Alvarado *et al.*

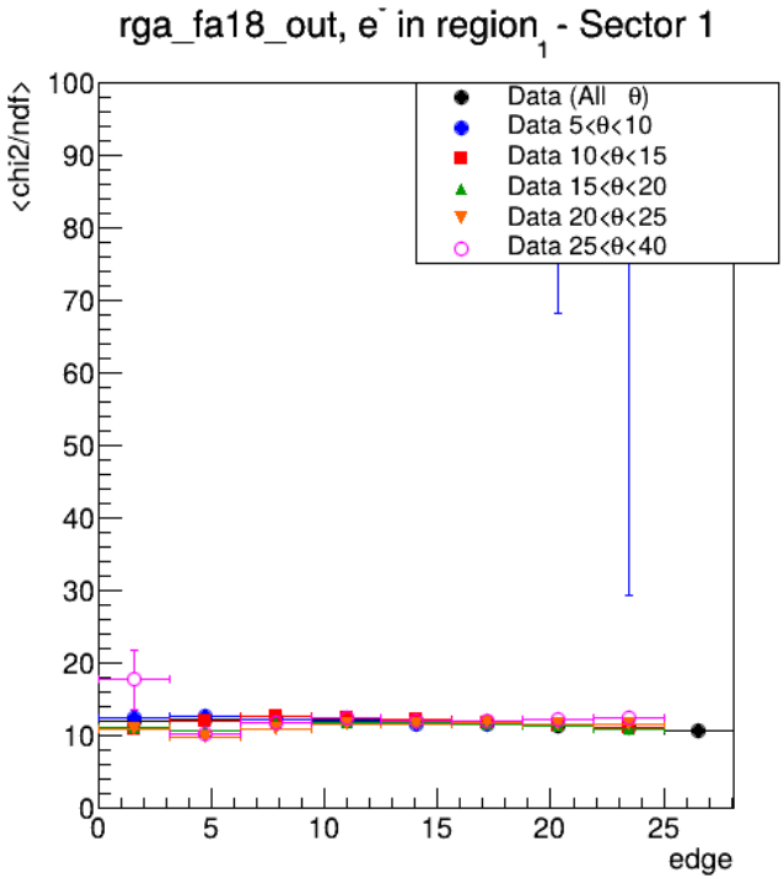
DC chi2/ndf results* - RGA/RGB Inbending electrons

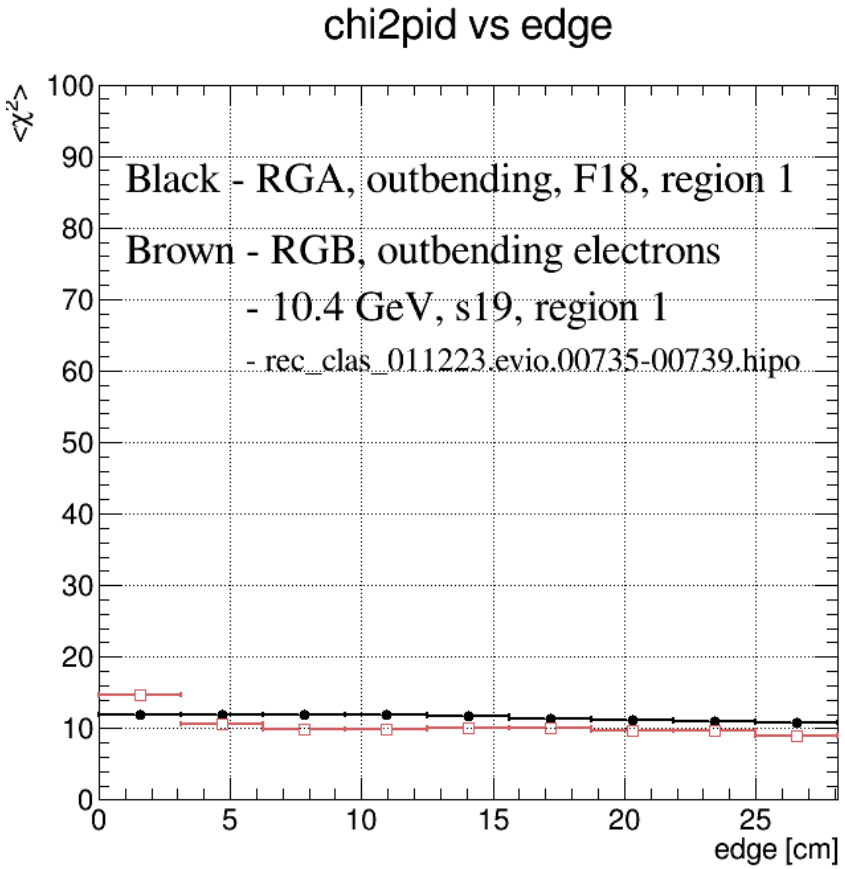




* - RGA_Pass_2_Analysis_Overview_and_Procedures.pdf, S. Alvarado *et al.*

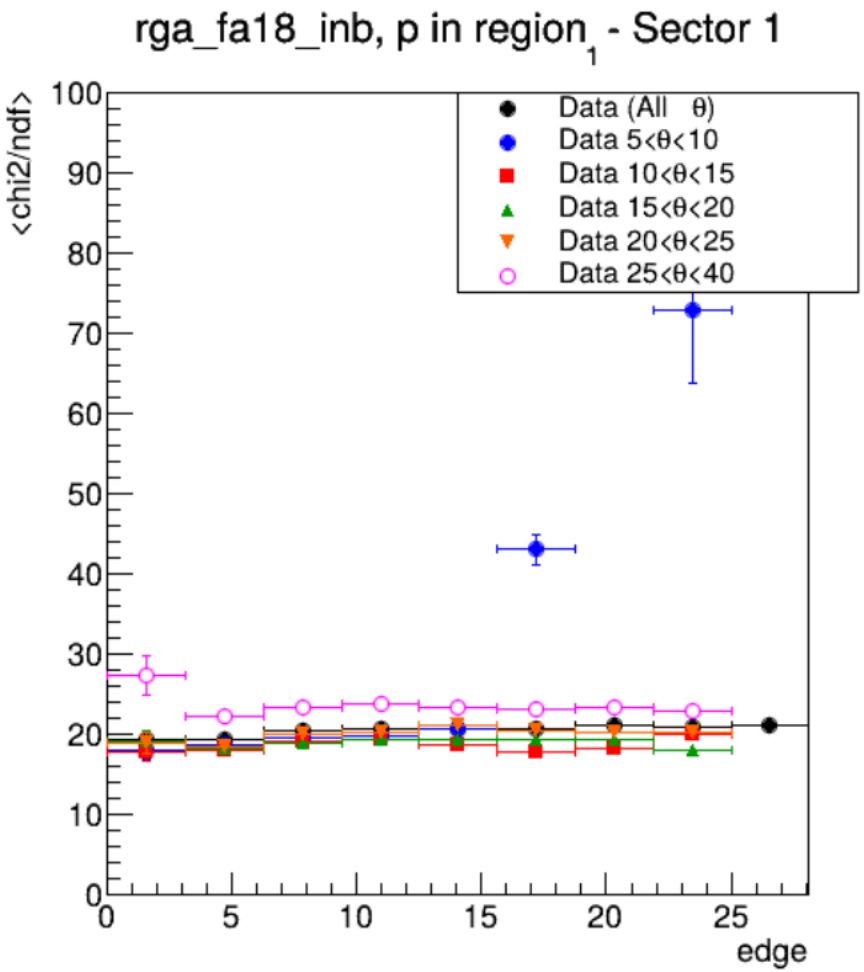
DC chi2/ndf results* - RGA/RGB Outbending electrons 8

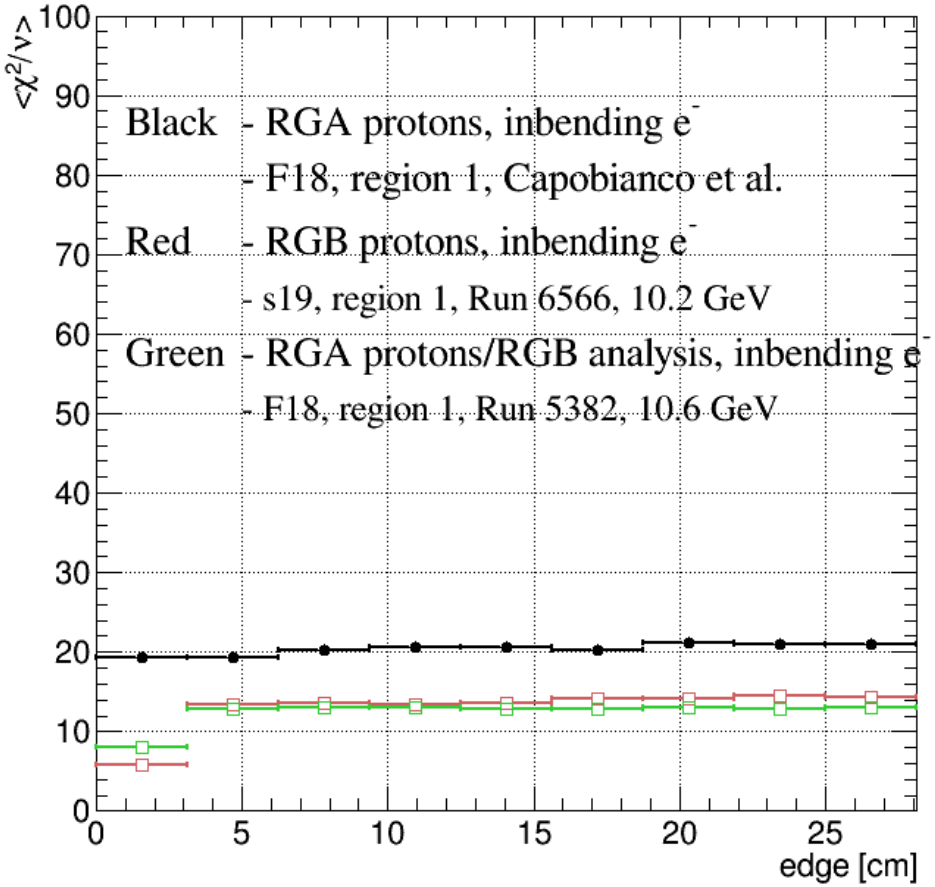




* - RGA_Pass_2_Analysis_Overview_and_Procedures.pdf, S. Alvarado *et al.*

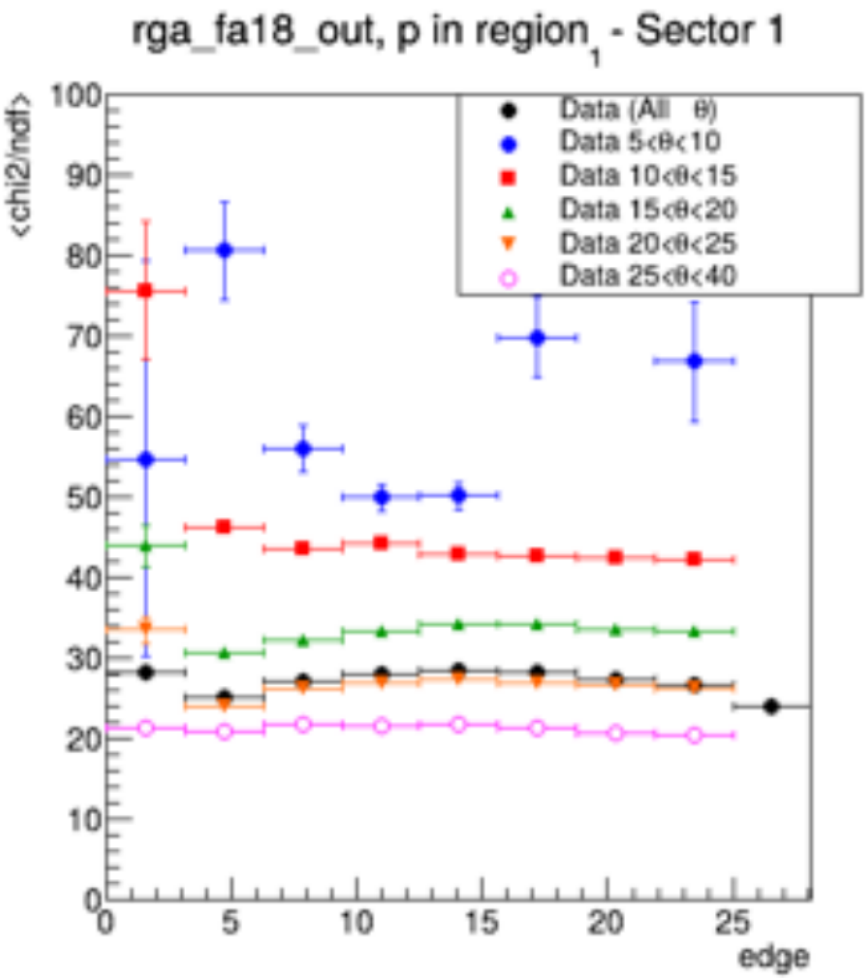
DC chi2/ndf results* - RGA protons (Inbend electrons) 9

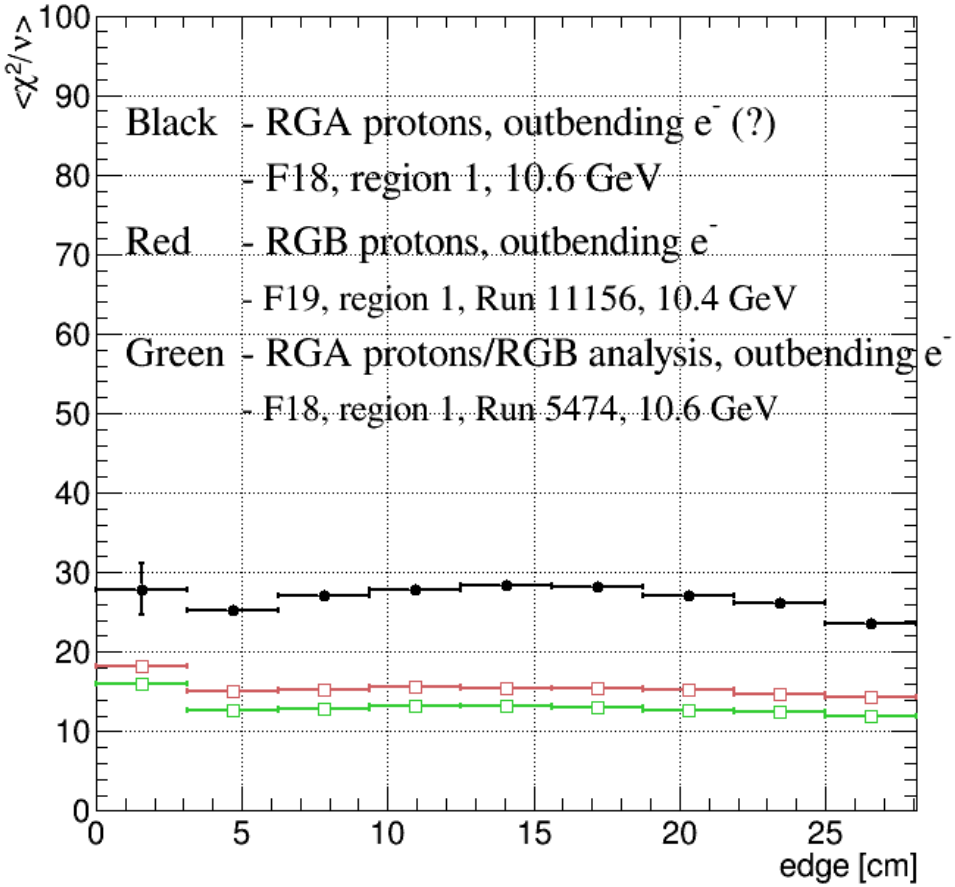




* - RGA_Pass_2_Analysis_Overview_and_Procedures.pdf, S. Alvarado *et al.*

DC chi2/ndf results* - RGA protons (outbend electrons)10

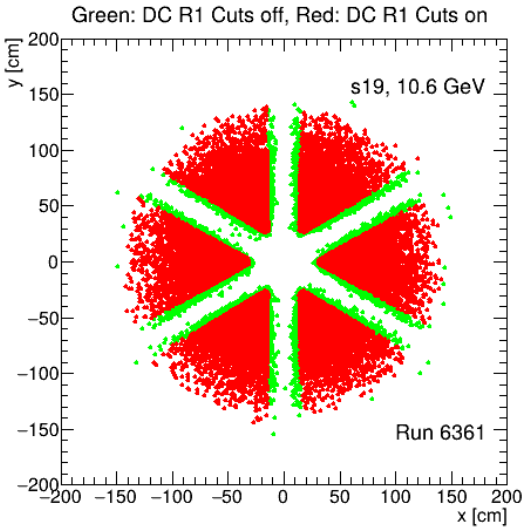


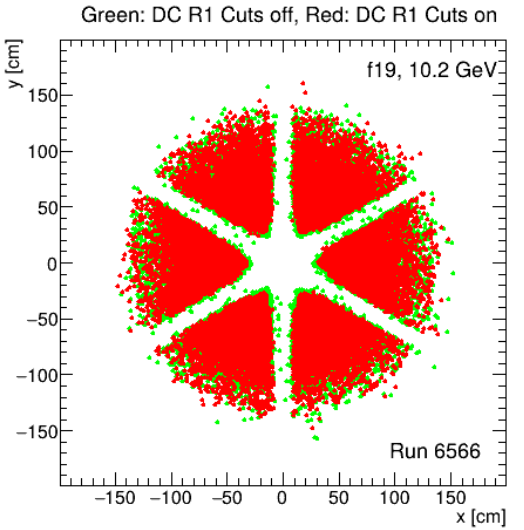


* - RGA_Pass_2_Analysis_Overview_and_Procedures.pdf, S. Alvarado *et al.*

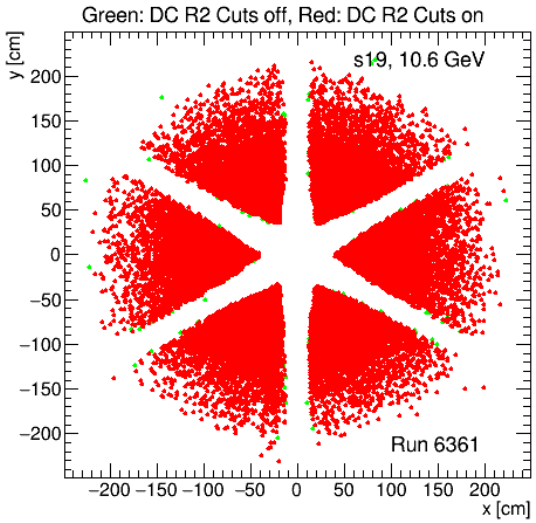
DC Fiducial Cuts - S19, 10.6 GeV and 10.2 GeV

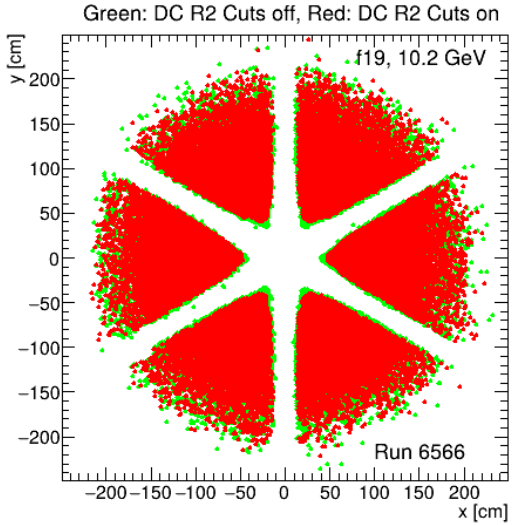
Region 1



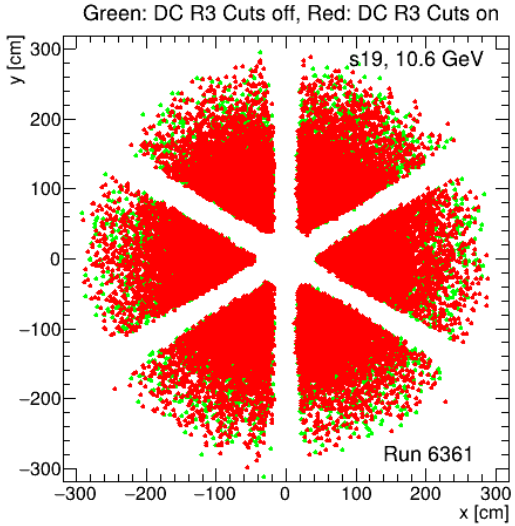


Region 2

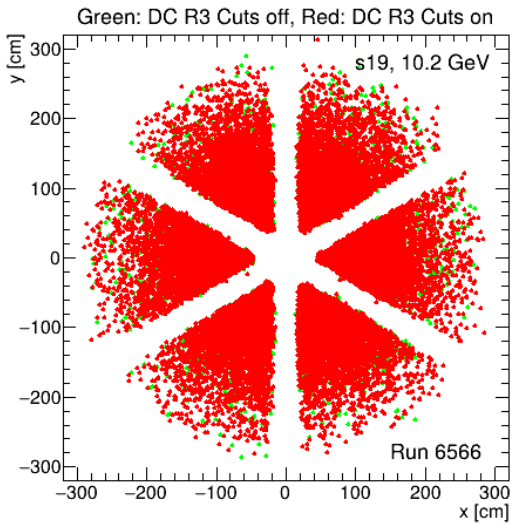




Region 3

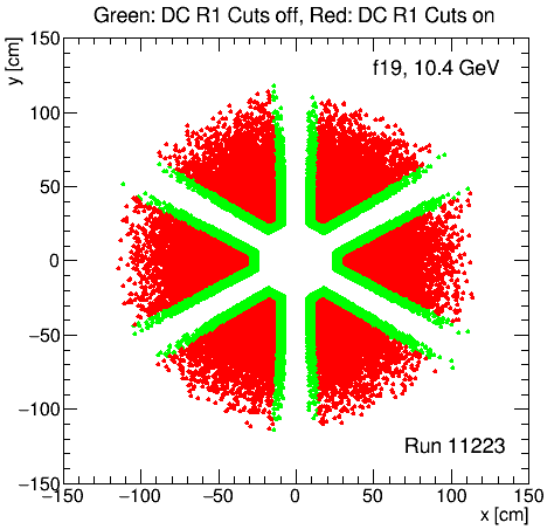


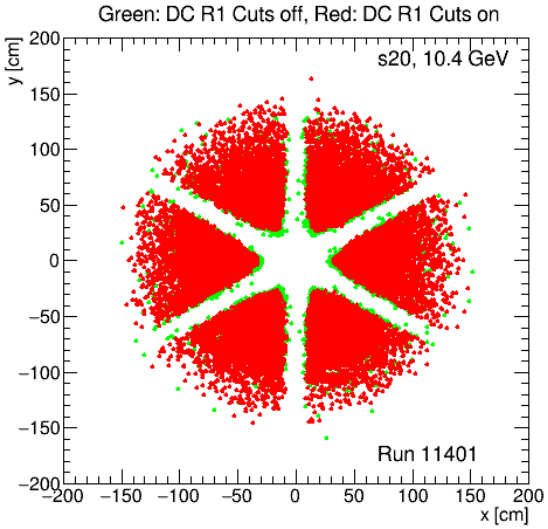
inbending



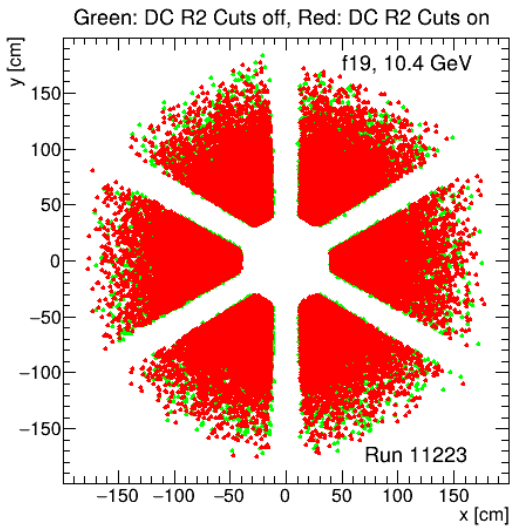
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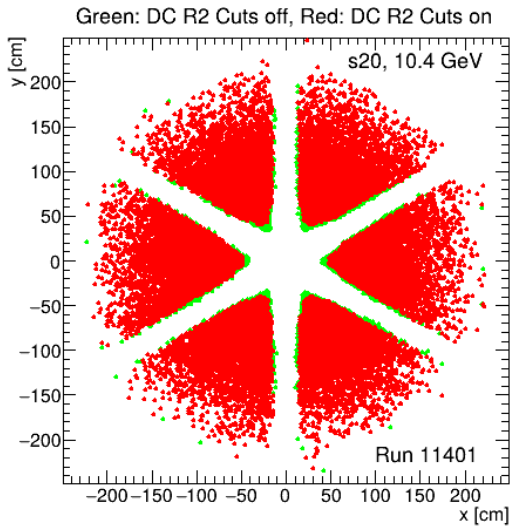
Region 1



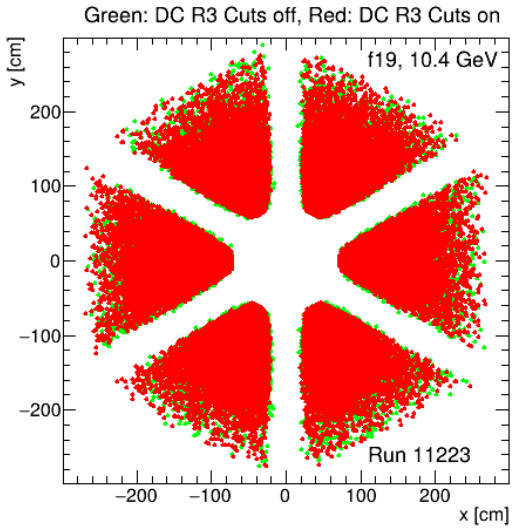


Region 2

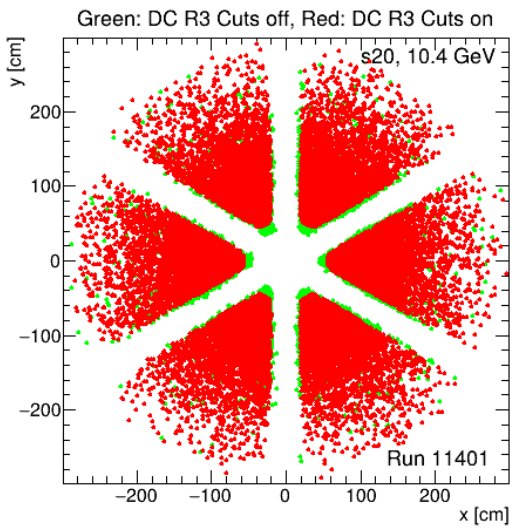




Region 3



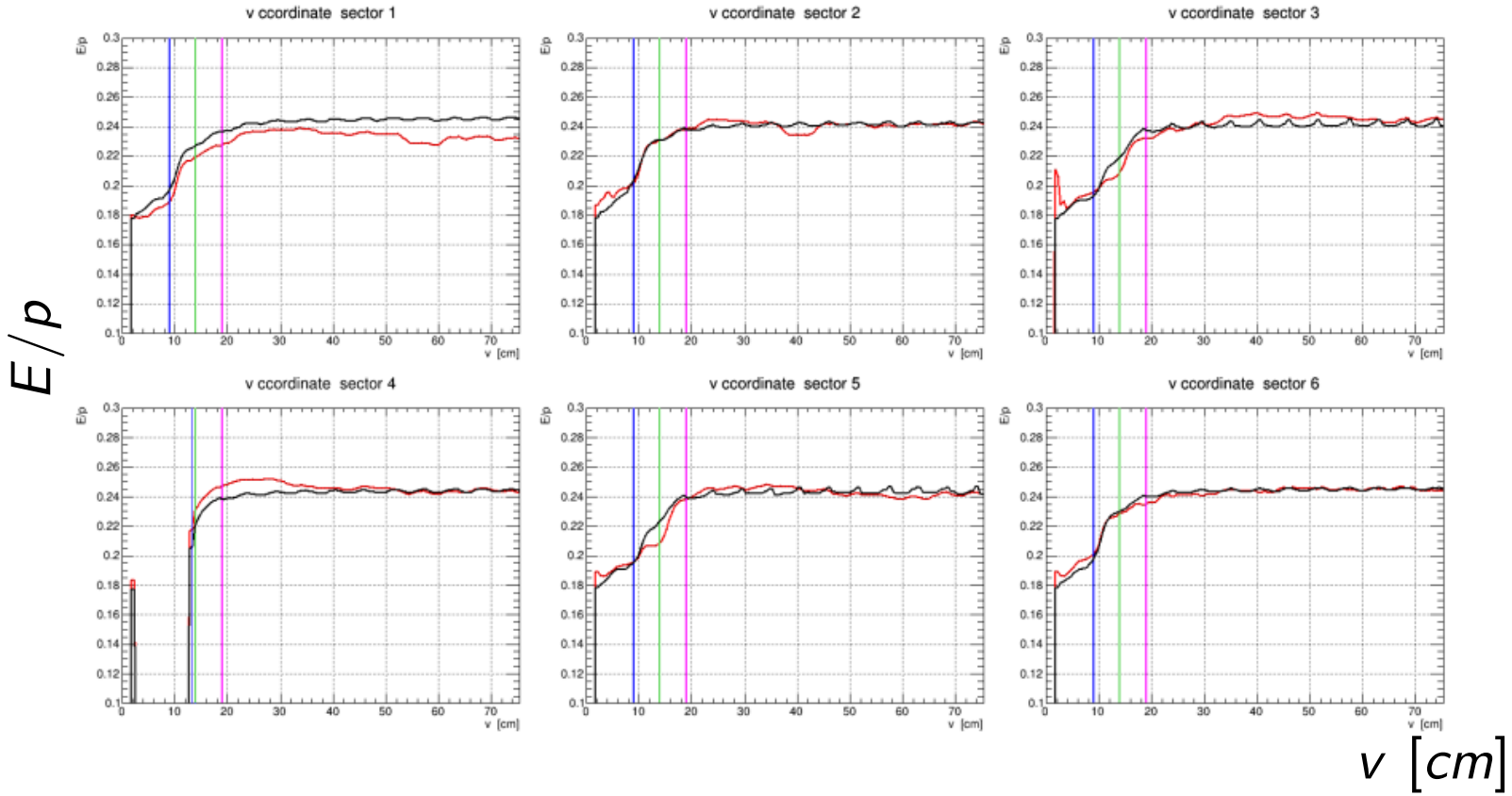
outbending



inbending

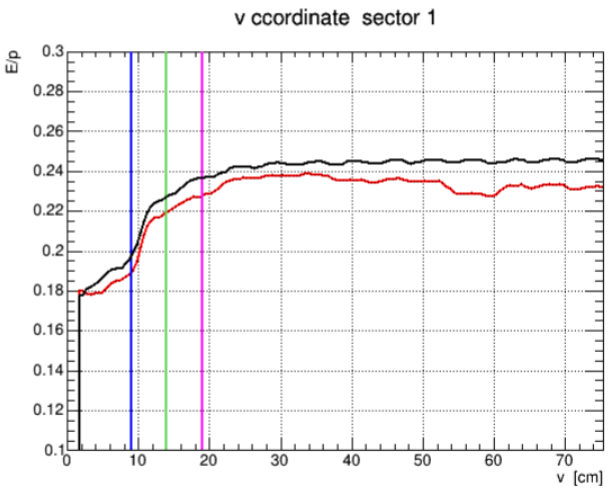
Fiducial Cuts in the PCAL.*

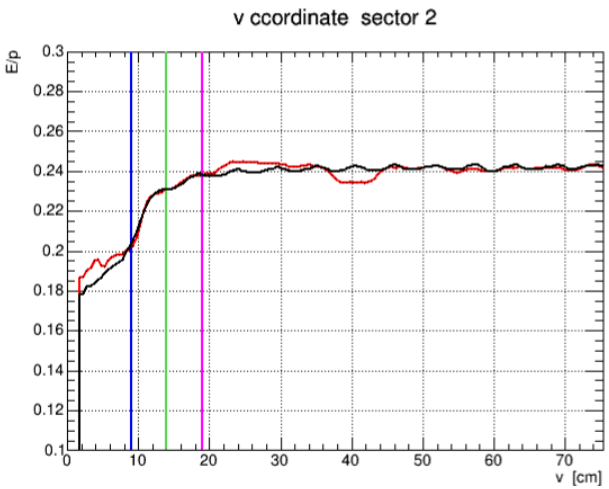
1. Cuts are defined in the local sector coordinates *lu*, *lv* and *lw* in multiples of the width of a single bar (4.5 *cm*) - "loose" is 9.0 *cm*, "medium", and "tight" are 13.5 *cm* and 18 *cm* respectively.
2. The behavior of the PCAL sampling fraction versus the local variable *lv* is shown below for electrons detected in the PCal during RGA Fa18 Inb for each sector.

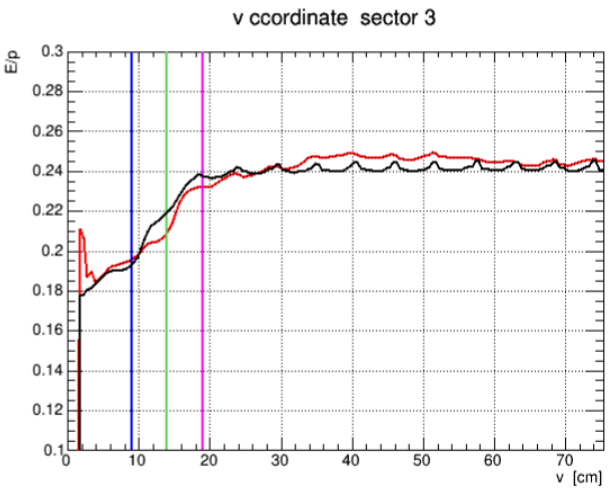


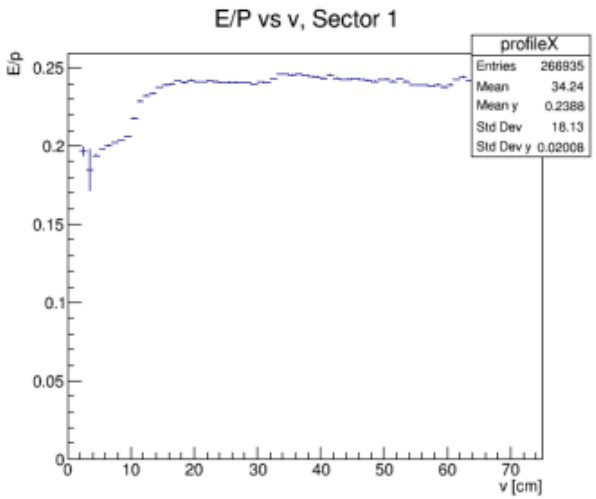
*Parameters from *RGA_Pass_2_Analysis_Overview_and_Procedures-4.pdf*.

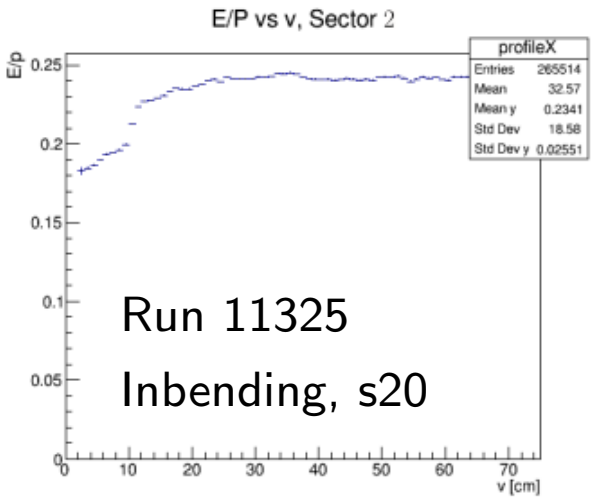
Comparison With RGB Inbending Electrons 14





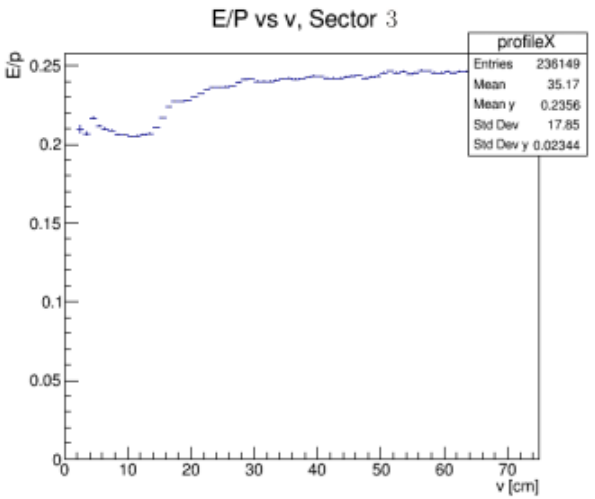




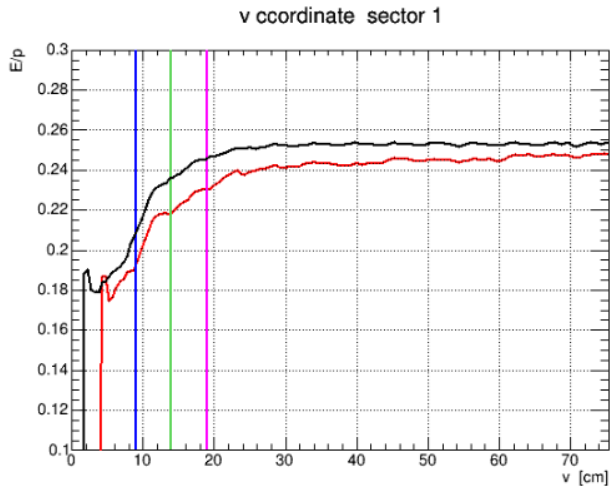


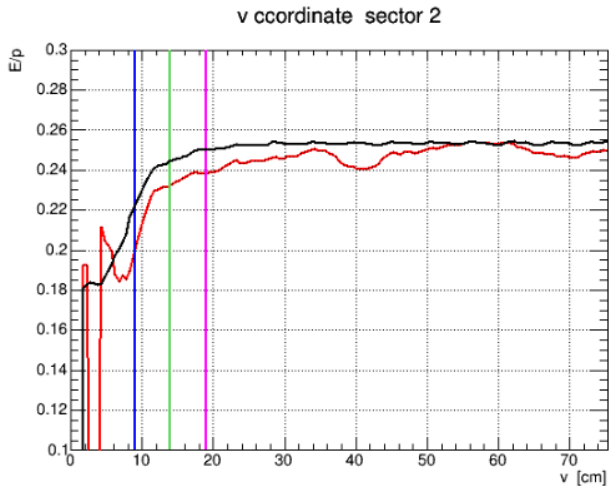
Run 11325

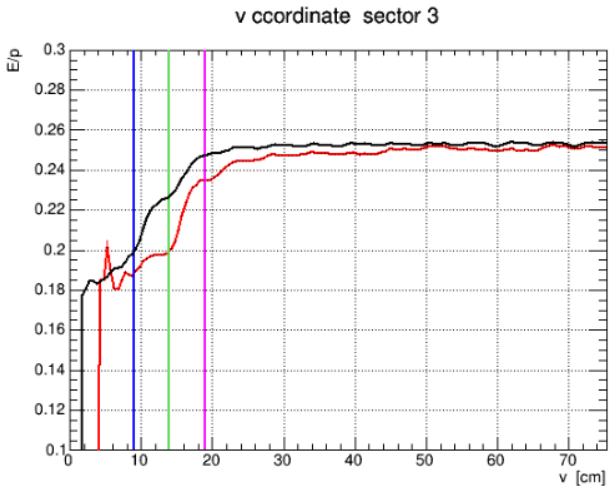
Inbending, s20

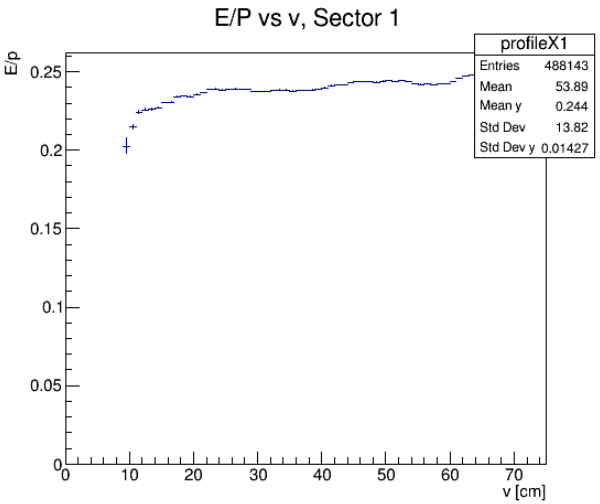


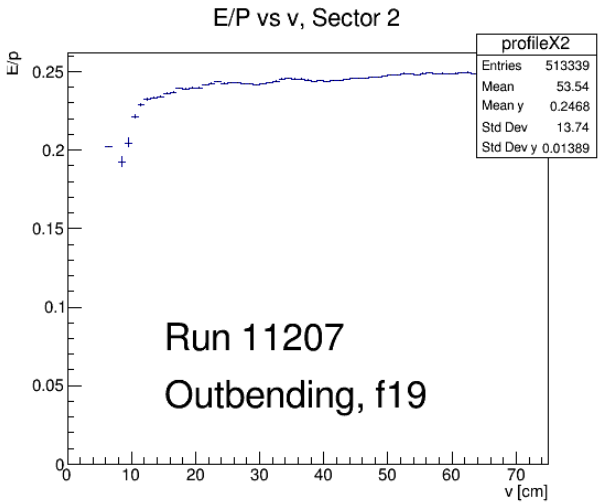
Comparison With RGB Outbending Electrons 15

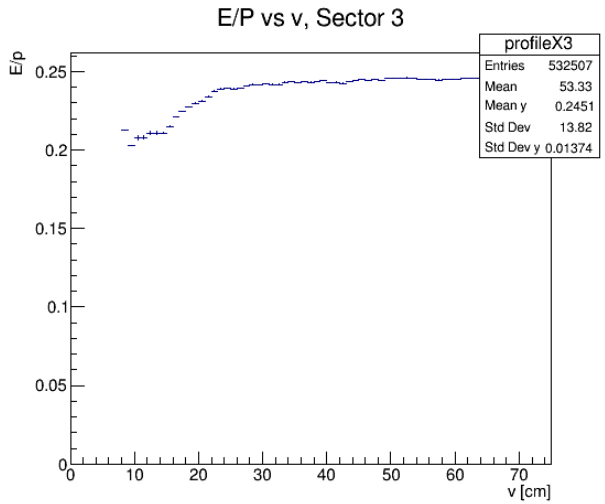




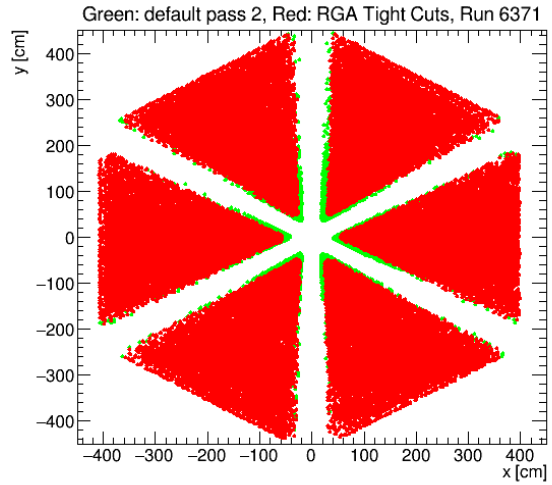


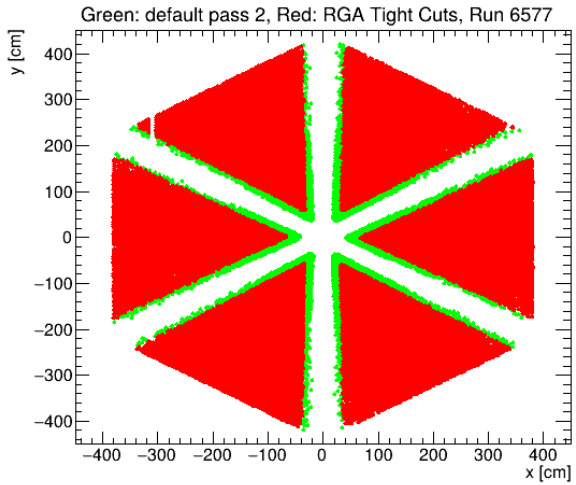


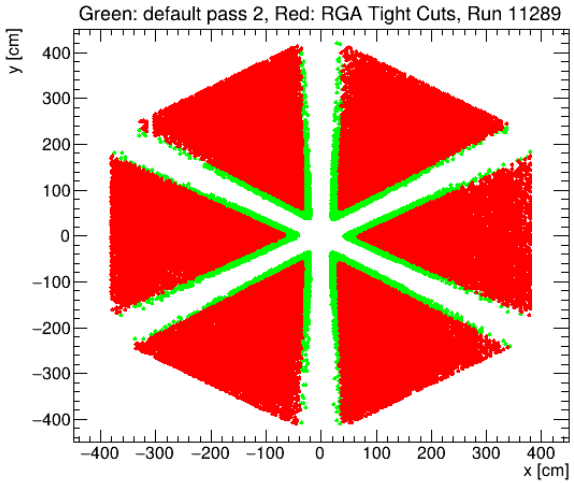


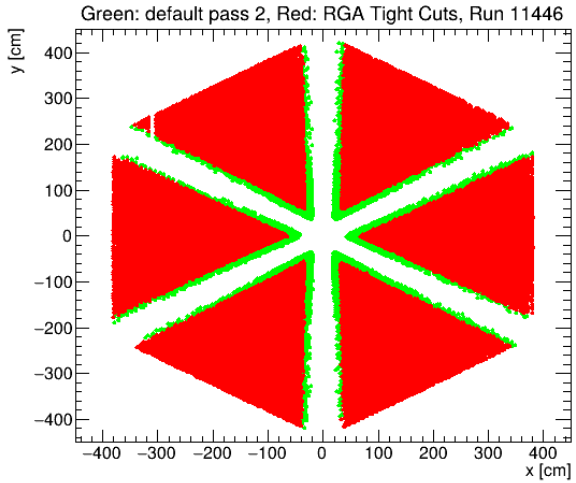


Impact of "tight" cut on electrons in PCAL* 16







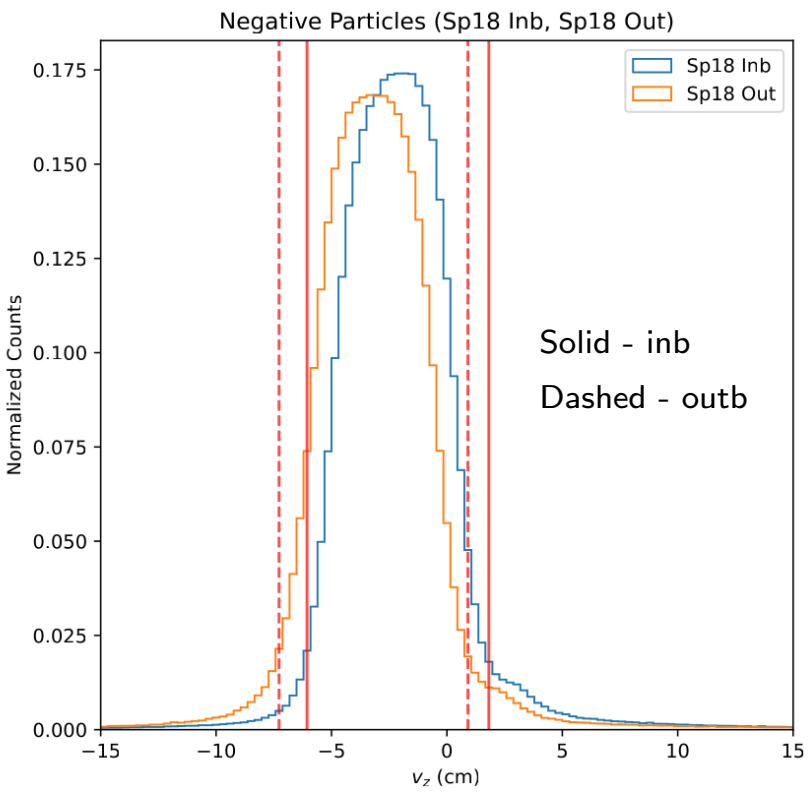


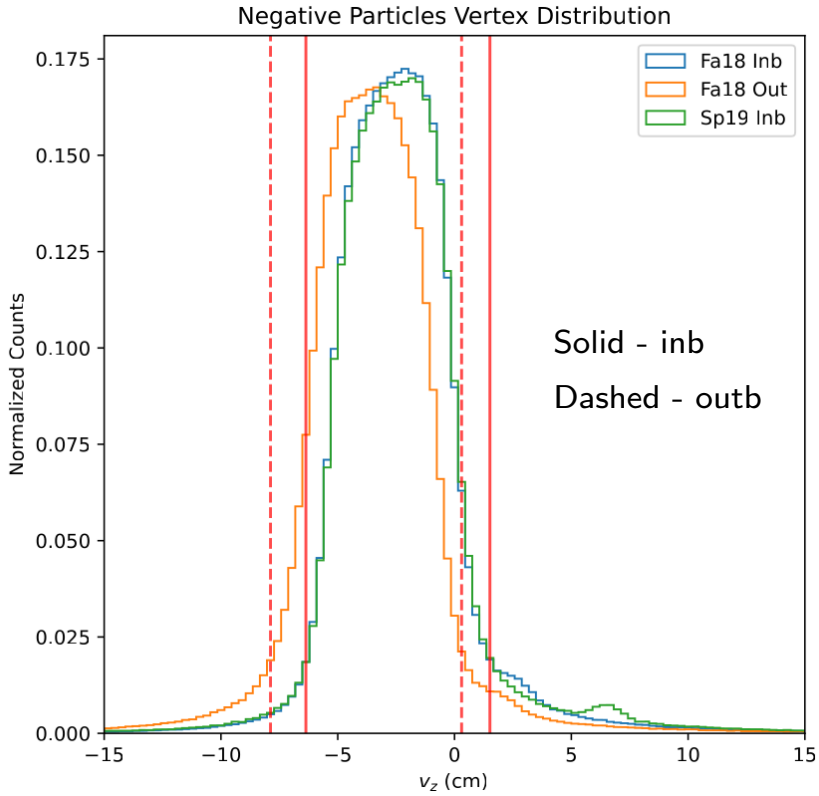
PCAL cut	$\ell v, \ell w$
tight	18.0 *cm*
medium	13.5 *cm*
loose	9.0 *cm*

Same cuts to be applied to ECinner and ECouter.

*Parameters from *RGA_Pass_2_Analysis_Overview_and_Procedures-4.pdf*.

RGA Vertex Cuts*

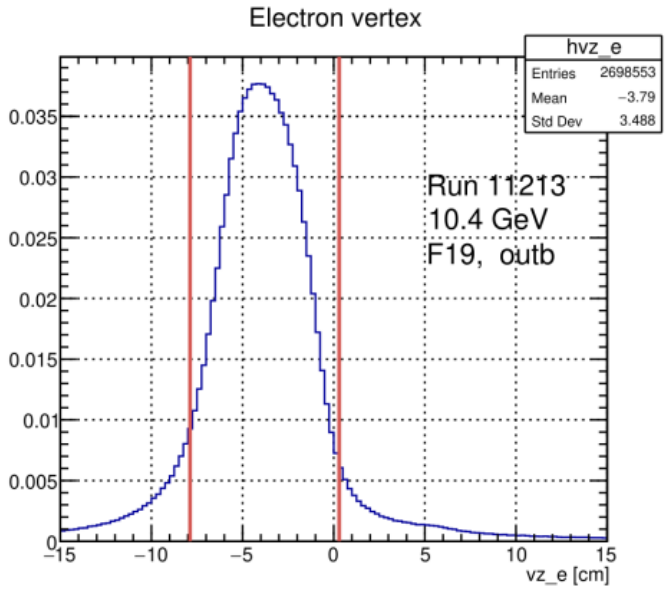




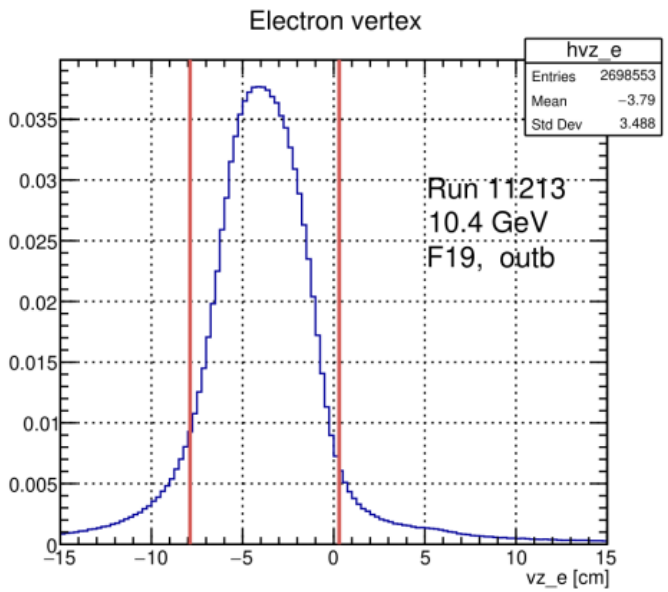
1. The vertex cuts are chosen as the point at which the normalized thresholds fall below 2% of the total to avoid the exit foils.
2. The inbending and outbending distributions do not precisely match because of imperfections in reconstruction.

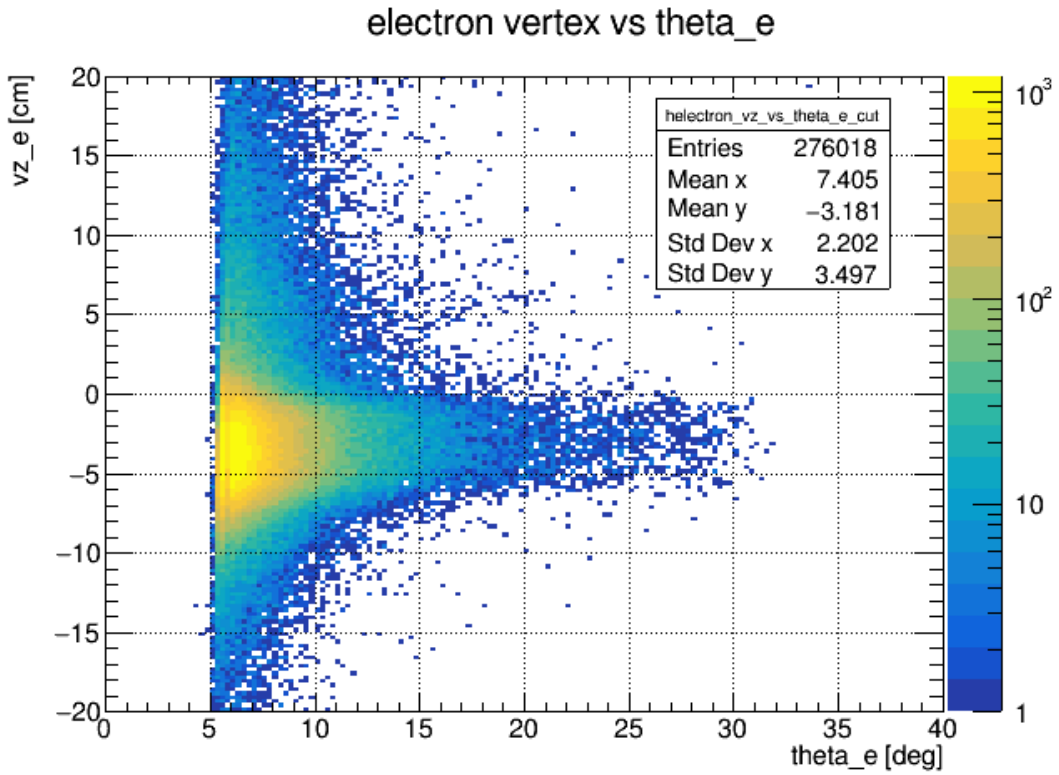
* - RGA_Pass_2_Analysis_Overview_and_Procedures.pdf, S. Alvarado *et al.*

Using RGA Vertex Cuts on Outbending RGB Electrons 18

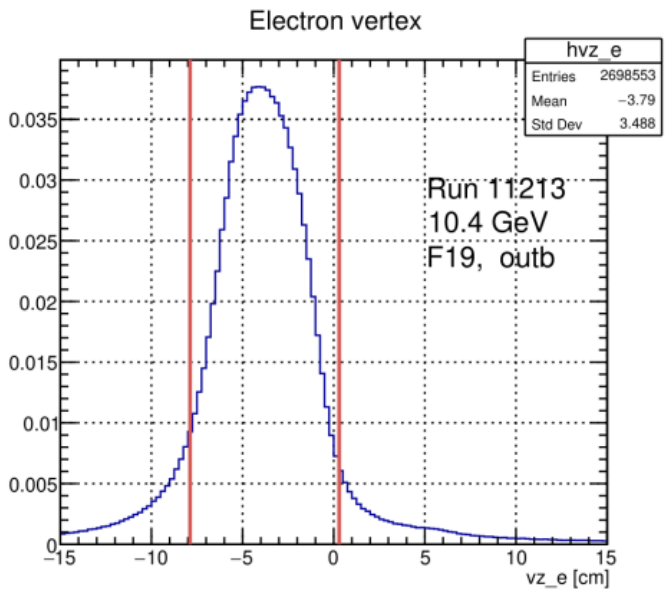


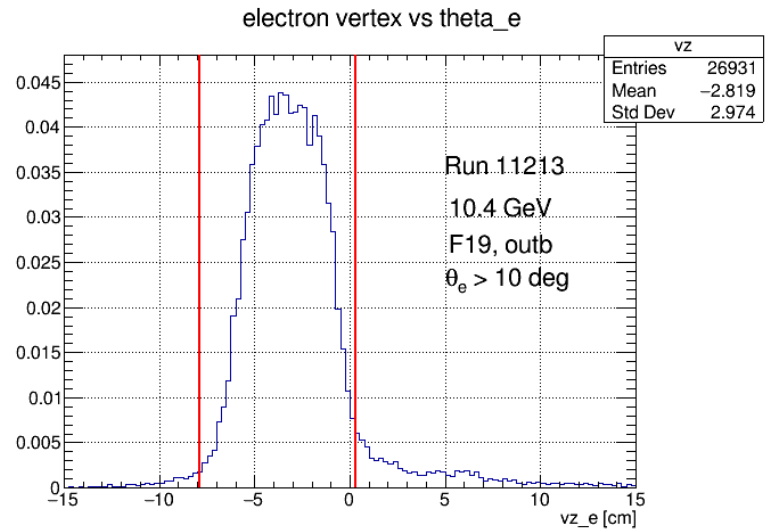
Using RGA Vertex Cuts on Outbending RGB Electrons 19

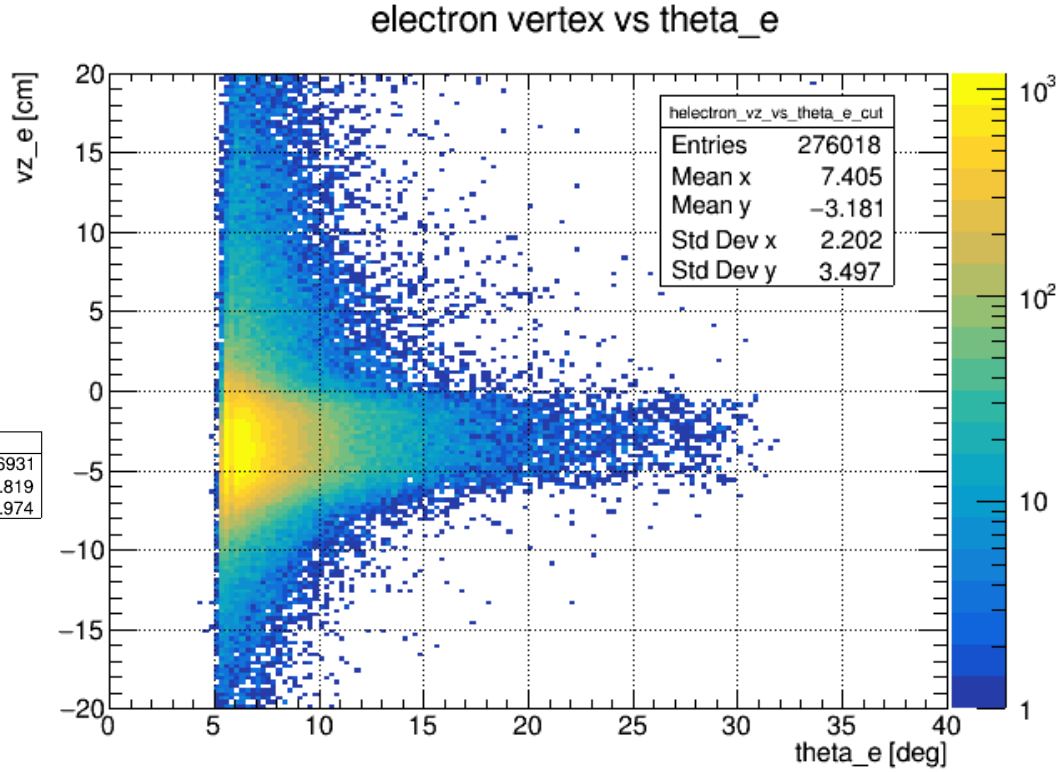




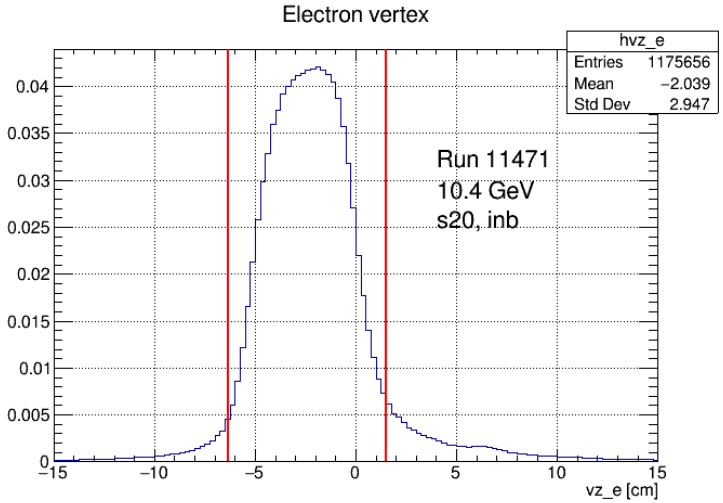
Using RGA Vertex Cuts on Outbending RGB Electrons 20



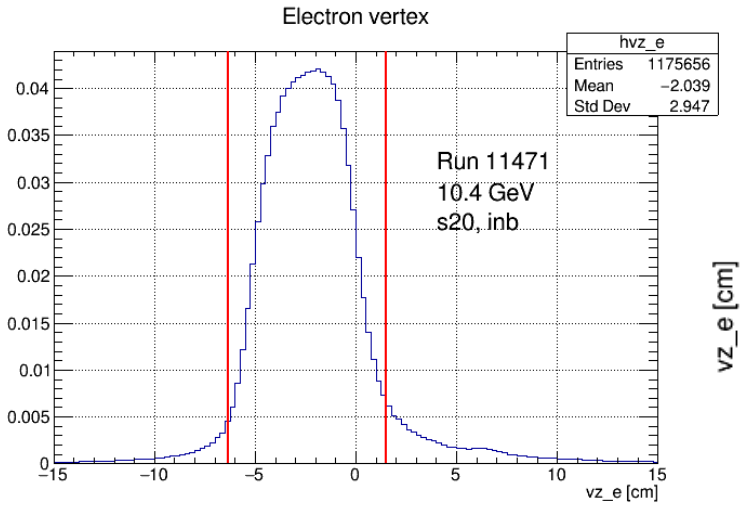


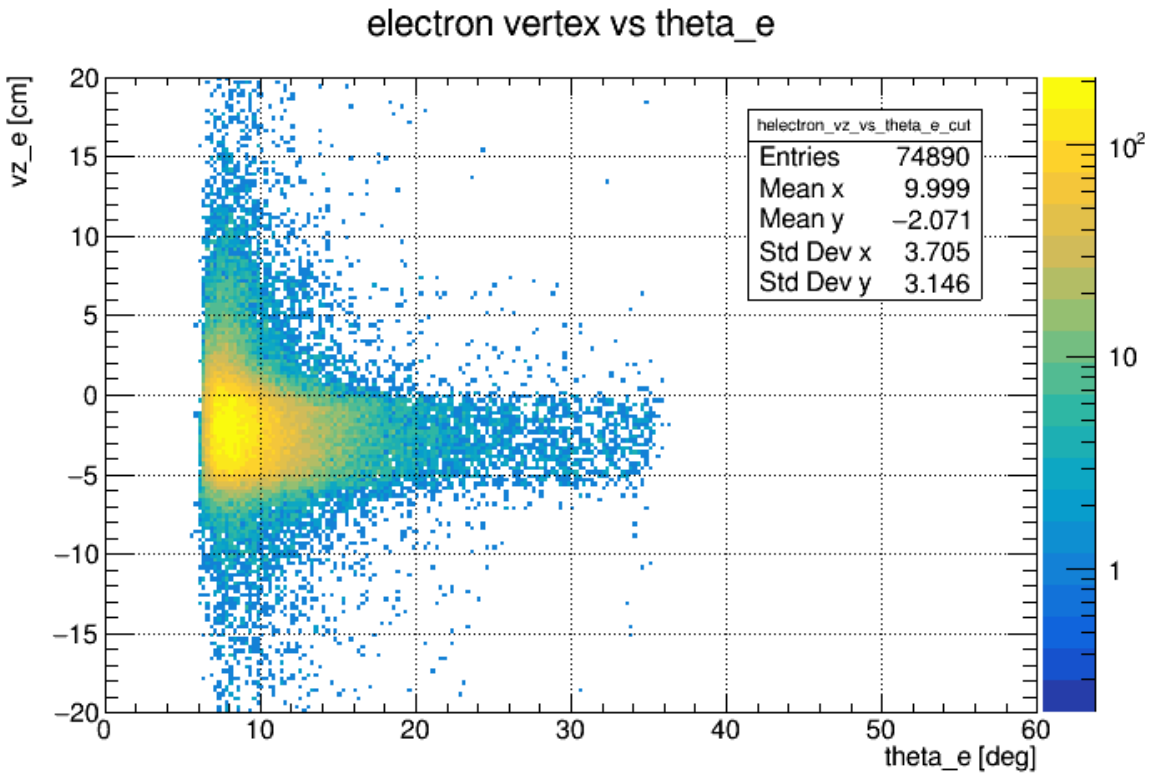


Using RGA Vertex Cuts on Inbending RGB Electrons 21

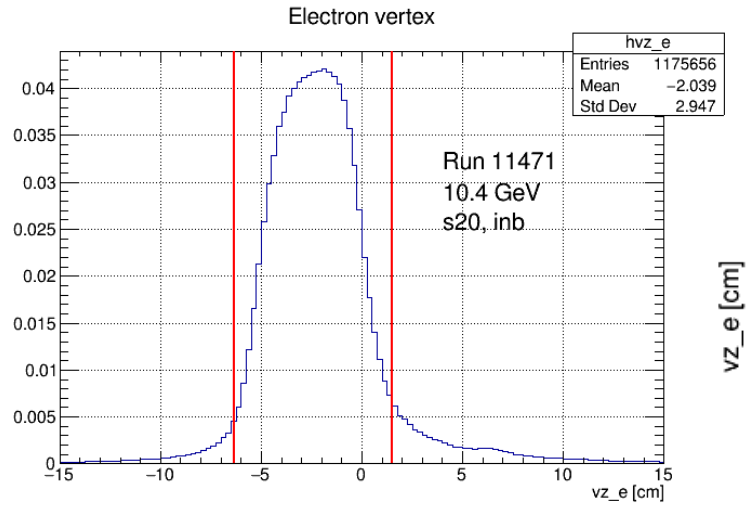


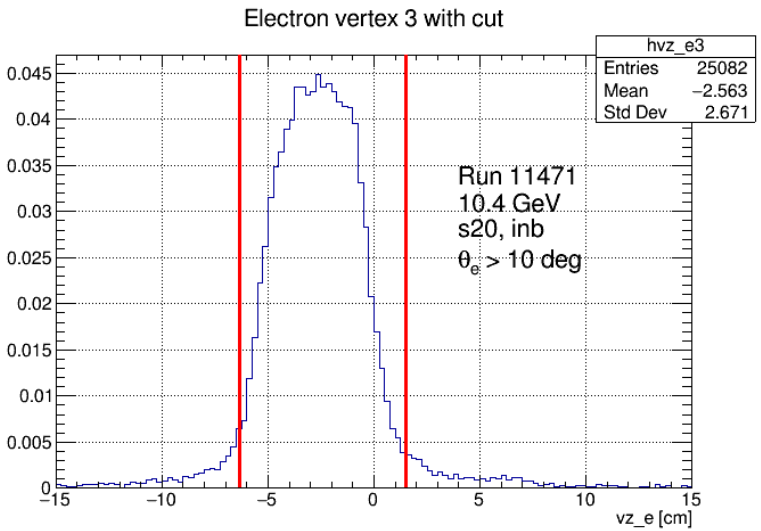
Using RGA Vertex Cuts on Inbending RGB Electrons 22

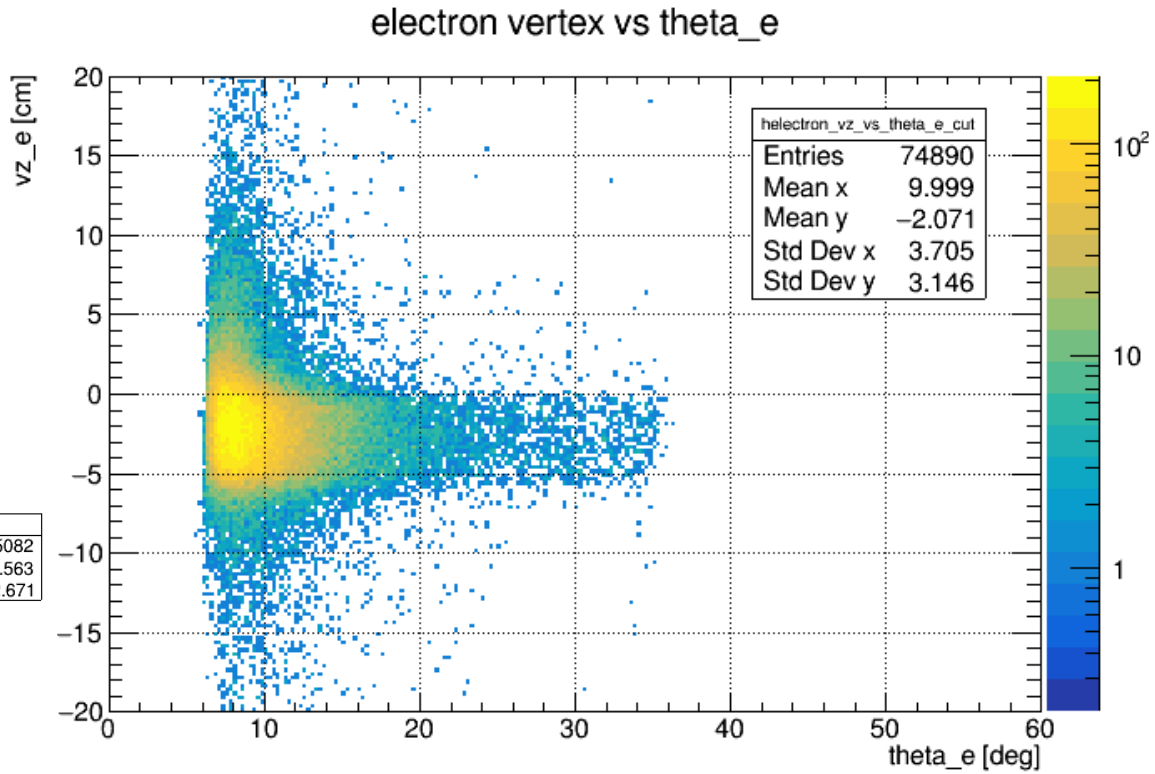




Using RGA Vertex Cuts on Inbending RGB Electrons 23







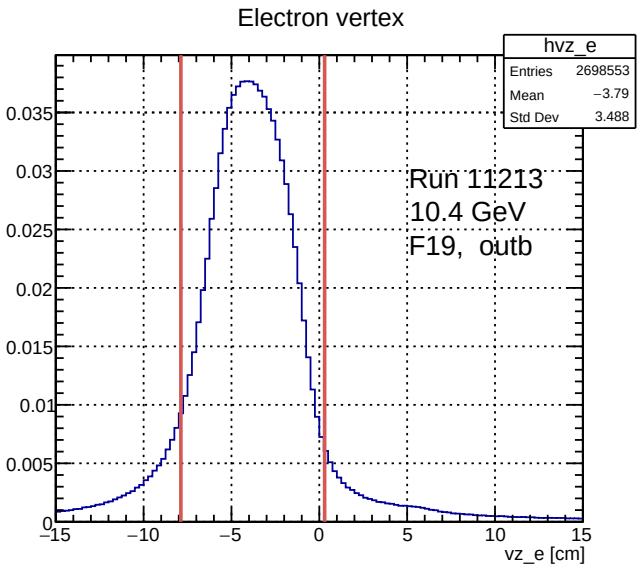
Proton vertex next.

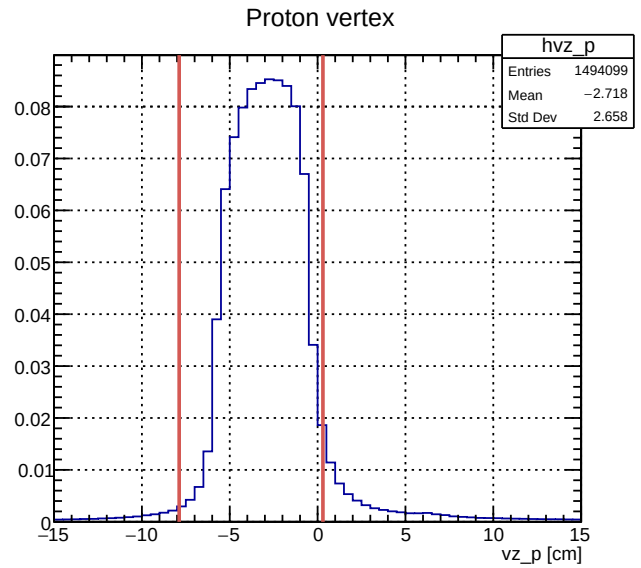
1. Started development of groovy methods to update G_M^n analysis.
2. Methods applying RGA algorithms tested for PCAL and DC fiducial cuts.
3. Tested RGA cuts to select the electron vertex. Started work on proton vertex.
4. Much work remains - see below.

EC fiducial cuts	Sampling fraction cut
Delta_vz for ep events	Calorimeter diagnol cut
chi2pid	Neutron fiducial cut
momentum corrections	electron energy loss correction
electron β correction	e, n, p momentum corrections

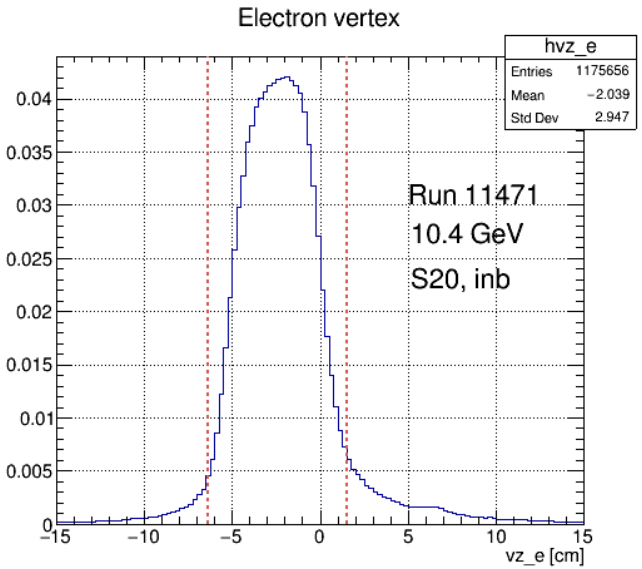
Backup-Up Slides

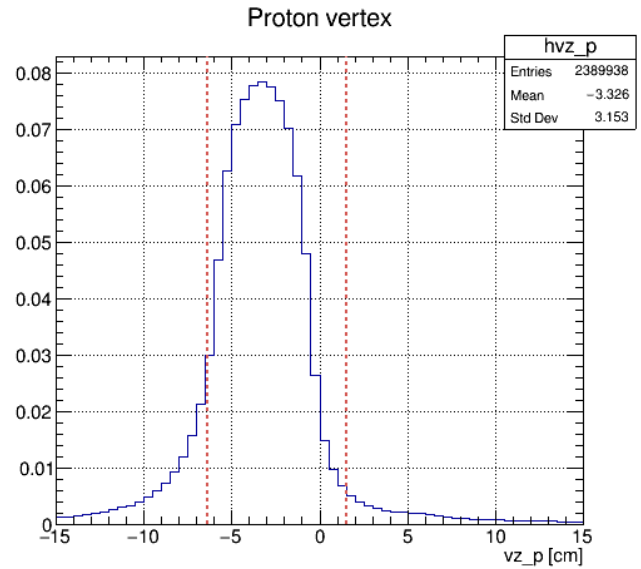
Using RGA Vertex Cuts on RGB Electrons and Protons 26





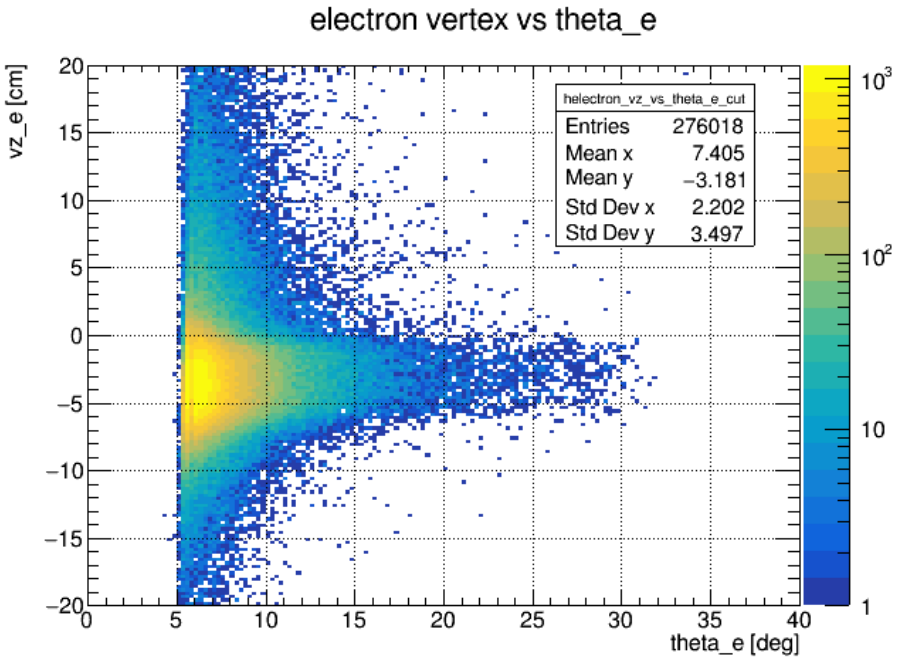
RGA F18 Out-bending cuts

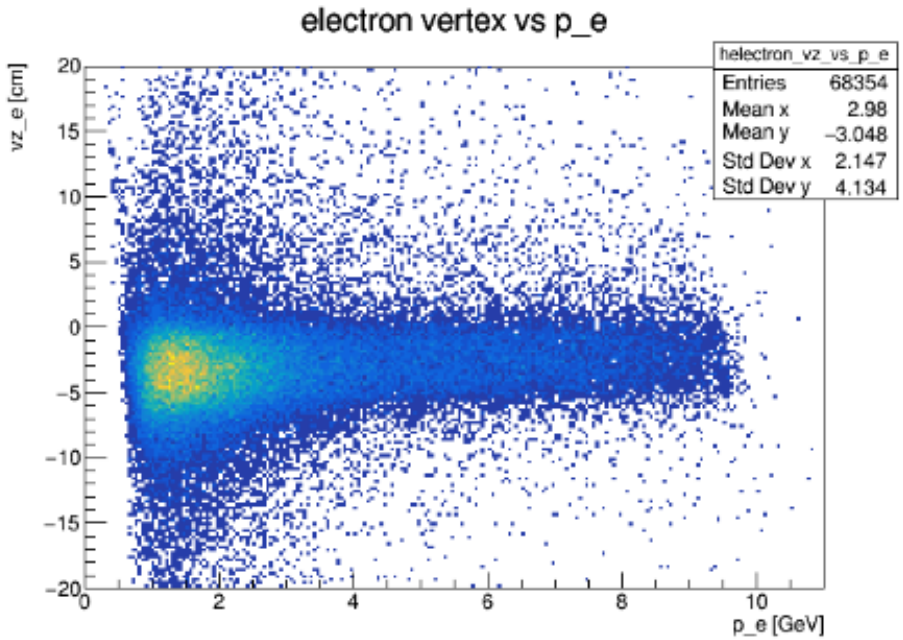




RGA F18 Inbend-ing cuts

θ_e and p_e Correlations with vz for RGB Electrons



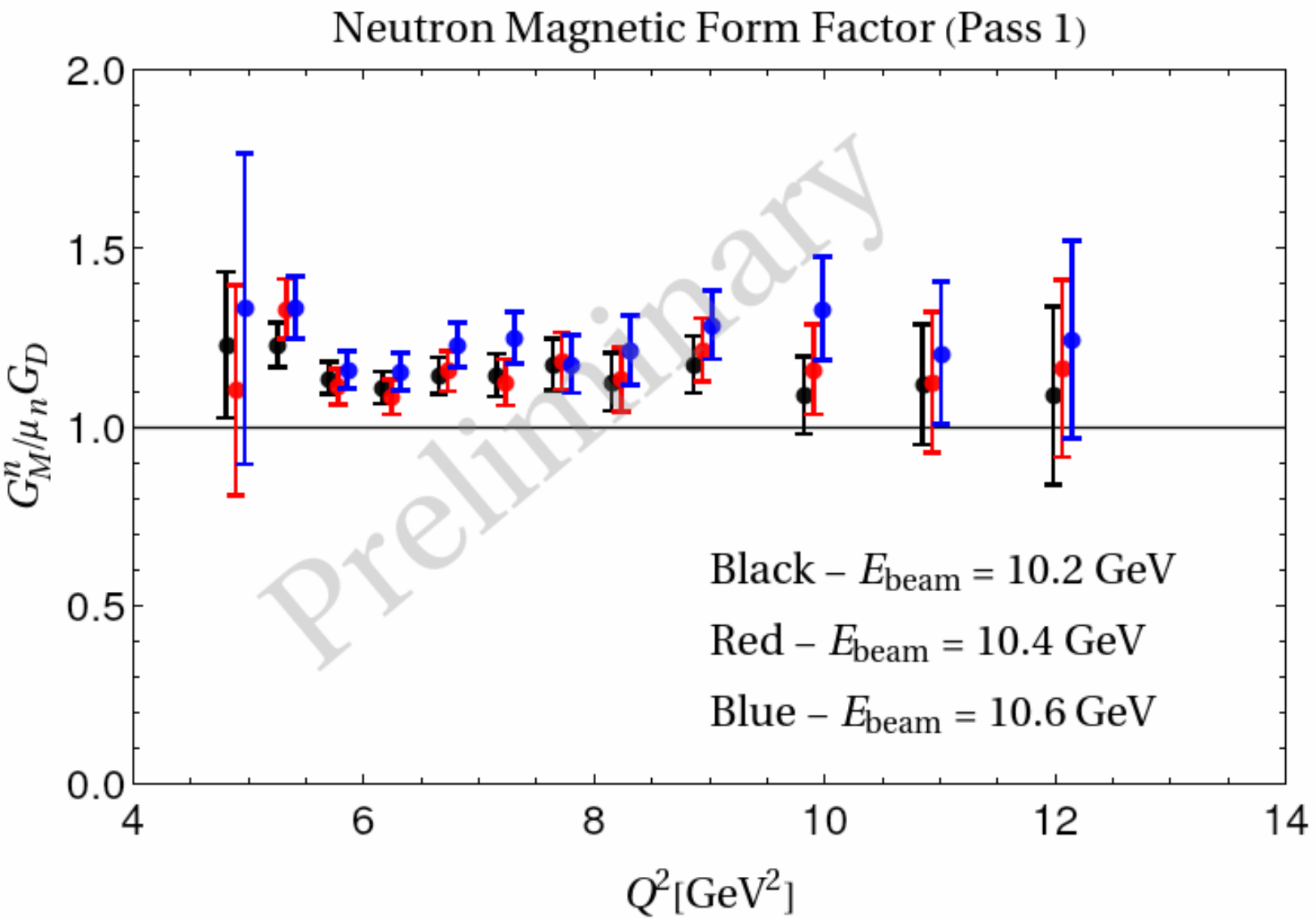


Large increase in the width of the vz_e distribution as θ_e decreases.

Initial Cuts on Lamya's Plots

electron	proton	neutron
pid = 11 v_z vertex position $N_{ph} > 2$ PCAL fiducial V, W > 14 cm cut DC fiducial cut for 3 DC regions SF vs. P_{ele} $\pm 3.5\sigma$ Diagonal cut chi2pid $\lvert\chi^2\rvert < 3$ cut Minimum PCAL $E_{dep} > 60$ MeV	Positive charge particle hit calorimeter	Neutral charge particle hit calorimeter

Pass 1 GMn


Neutron Magnetic Form Factor (Pass 1)
2.0
1.5
1.0
0.5
0.0
4
6
8
10
12
14
$G_M^n/\mu_n G_D$
Q^2[GeV^2]
Preliminary
Black – E_{beam} = 10.2 GeV
Red – E_{beam} = 10.4 GeV
Blue – E_{beam} = 10.6 GeV