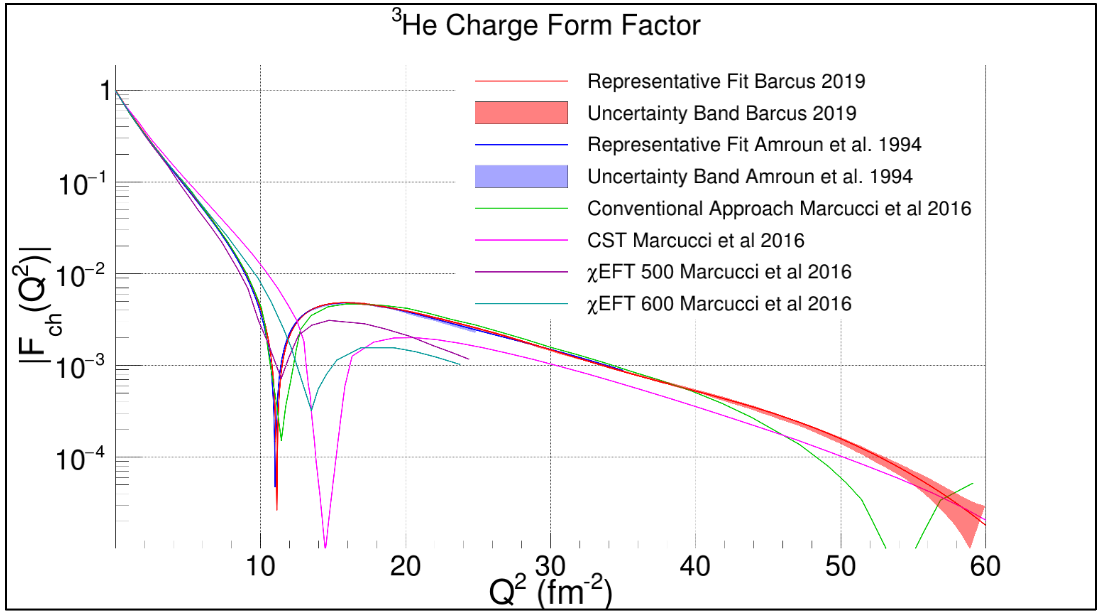
Measurement of ^{3}He Elastic Electromagnetic Form Factor Diffractive Minima Using Polarization Observables

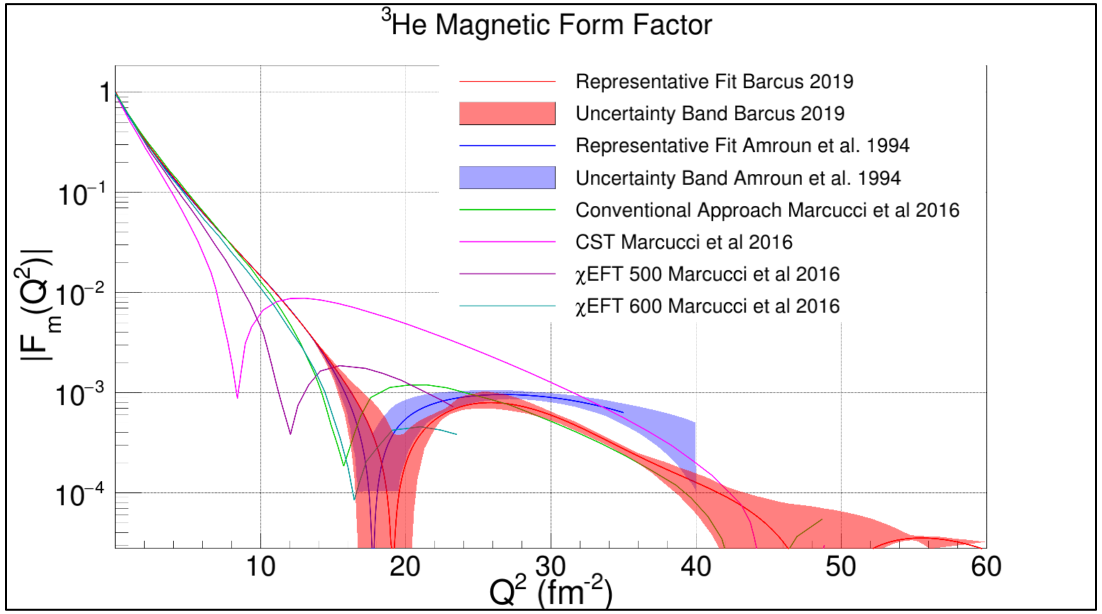
Michael Nycz

Polarized ^{3}He Collaboration Meeting

March 25, 2021

Experimental and Theoretical Comparison





- **Discrepancies in location of minima of the magnetic form factor**
- Rosenbluth separations in diffractive minima are non-trivial
- All high Q^2 ^{3}He Form Factor measurements are from unpolarized elastic scattering
- Differences in EM form factors of the proton between PO and Rosenbluth @ high Q^2

Double Polarization Measurement

Polarized electron beam and polarized target

$$A_{phys} = \frac{-2\sqrt{\tau(1+\tau)}\tan\left(\frac{\theta}{2}\right)}{G_E^2 + \frac{\tau}{\epsilon} G_M^2}\left[\sin(\theta^*)\cos(\varphi^*)\, G_E\ G_M + \sqrt{\tau\left[1+(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right]}\cos(\theta^*) G_M^2\right]$$

$$A_{meas} = \frac{N^+ - N^-}{N^+ + N^-}$$

$$A_{meas} = P_t P_l\, A_{phys}$$

Where

θ^*& φ^* - polar & azimuthal angles of polarization vector of target

P_t&P_l - Polarization of target and electron beam

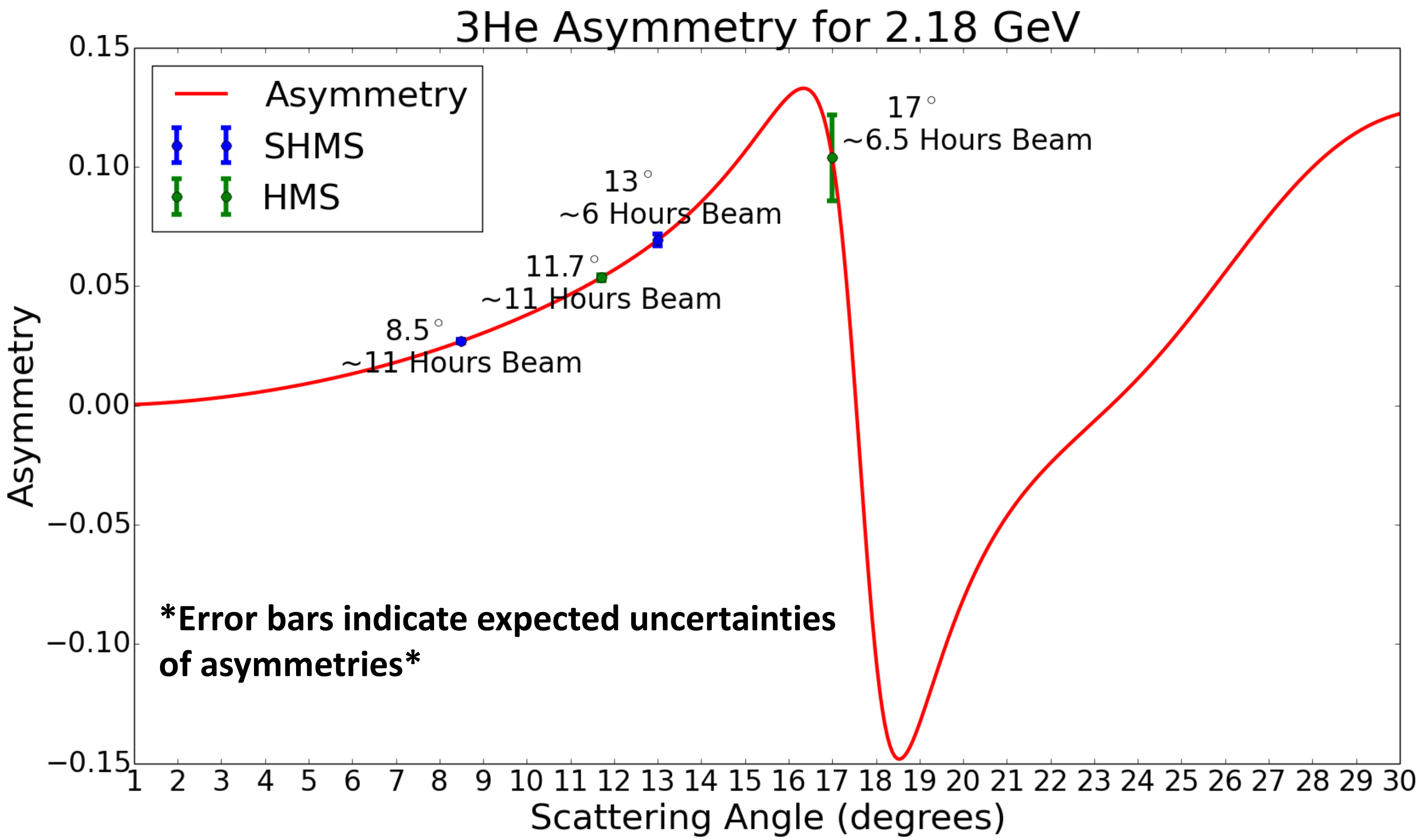
Experiment E12-06-121A

- Ran parasitically in Hall C during d_2^n
  - Configured with d_2^n planned 1st pass systematic measurements
- Target cells
  - Polarized ^3He cell
  - Reference ^3He cell
- Beam energy: 2.18 GeV
- Beam current: 30 μA
- Detect elastically scattered electrons independently in both HMS and SHMS

Kinematic Settings

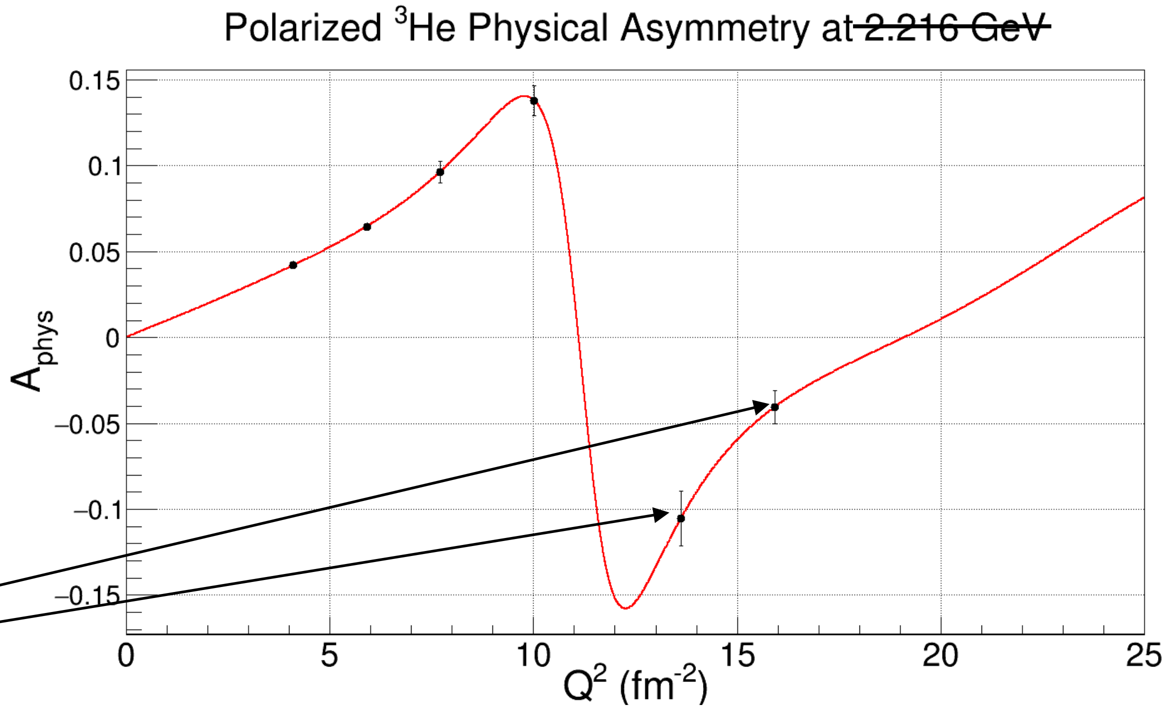
Spectrometer	θ [°]	P_0 [GeV]	Q^2 [fm^{-2}]
SHMS	8.5	2.12	2.60
SHMS	13.0	2.12	6.10
HMS	11.7	2.08	4.88
HMS	17.0	2.08	10.25

Experiment E12-06-121A



Credit: Scott Barcus

- Data Collected
  - ≈17 hours of data
- First high Q^2 ^3He elastic asymmetry points measured
- Will provided further constraints to global fit and better determination of ^3He form factors
- Proof of principle
  - Show it works



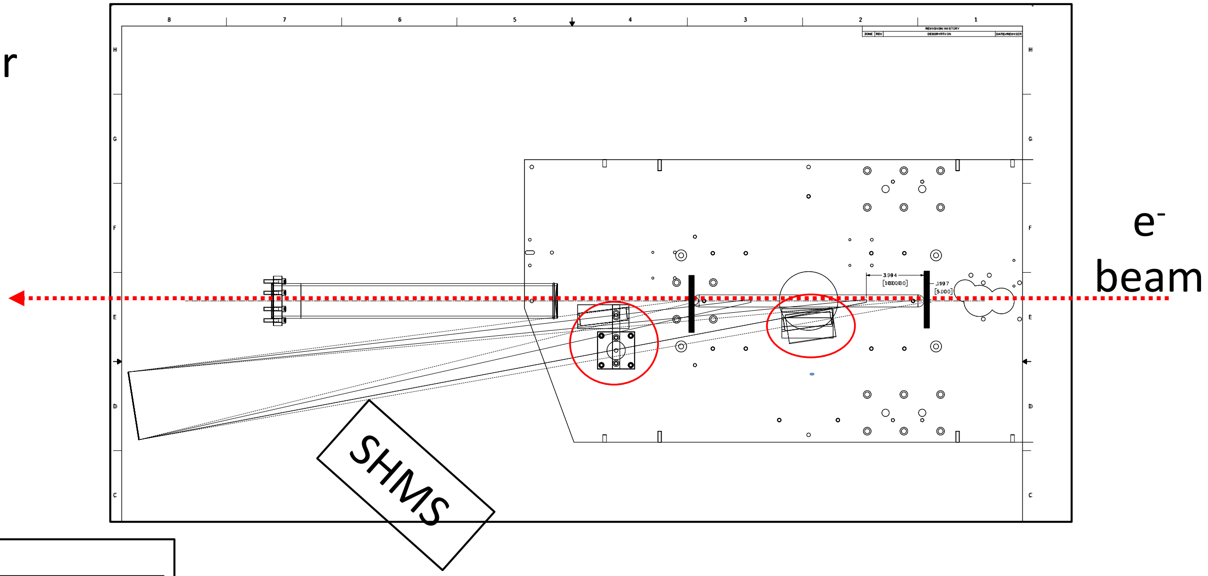
Analysis Status

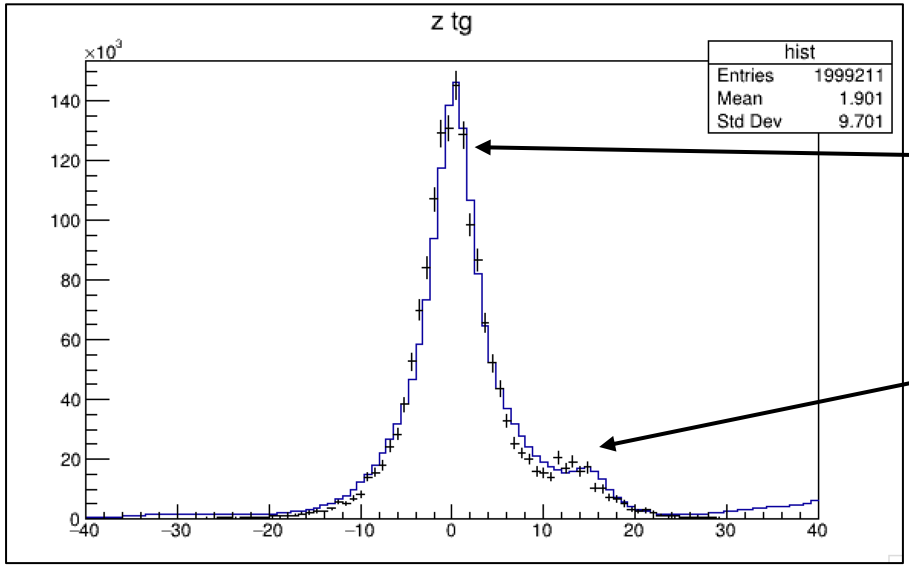
- Have focused on Monte Carlo simulation
  - Bremsstrahlung and ionization energy loss
  - Multiple scattering
  - Radiative Corrections
- First goal
  - Good agreement with Carbon foil
  - Use as benchmark before ^{3}He analysis
- mc-single arm repository
  - https://github.com/mnycz/mc-single-arm

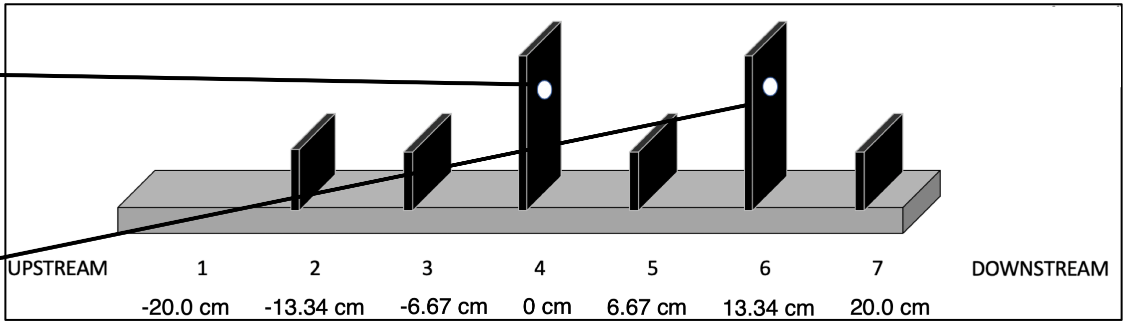
```fortran
      subroutine Bremss_Eloss(len,dens,zeff,epart,
     &                         rad_len, Bremss_Loss)


***********************************************************************
* Energy loss due to external Bremsstrahlung. This was adapted from SAMC
* version developed by Michael Paolone
***********************************************************************

      implicit none
c      include 'target.inc'
      integer  values(1:8), k
      integer  values2(1:8), l
      integer, dimension(:), allocatable :: seed
      real*8 len,dens,zeff,epart,mpart
      real*8 rad_len,Bremss_Loss
      real*8 lrad,lradp,eta
      real*8 b,bt
      real*8 rnu1,rnu2 !uniform random numbers
      real*8 U,X,H
      real*8 unif
      real*8 grnd,incl,rndm


      lrad = log(184.15 *(zeff)**(-1/3))
      lradp = log(1194*(zeff)**(-2/3))

      eta = lrad / lradp

      b = (4/3)*(1.+1./9.*(zeff+1.)/(zeff+eta)/lrad)

      bt = ((len*dens)/rad_len)*b
      U=1.0
      H=0.0
      do while(U>H)
c         write(6,*) 'Make it inside do while?'
c uniform random number [0,1]
c         write(6,*) 'in'
c         call date_and_time(values=values)
c         call random_seed(size=k)
c         allocate(seed(1:k))
c         seed(:) = values(8)
         CALL RANDOM_NUMBER(rnu1)
c         write(6,*)'first rndm',rnu1
c         DEALLOCATE(seed)
         X = (rnu1)**(1.0/bt)
****************************************
c         call date_and_time(values=values)
c         call random_seed(size=l)
c         allocate(seed(1:l))
c         seed(:) = values(8)
         CALL RANDOM_NUMBER(U)
c         write(6,*)'second rndm',U
c         DEALLOCATE(seed)
****************************************
         H = 1.0 - X + 3.0/4.0*X*X
c         write(6,*) 'in','X', X,'U',U,'H',H
      end do
```

Target Collimator (SHMS)

- Target Collimator installed in order to mask target cell windows
- Needed to be added into MC

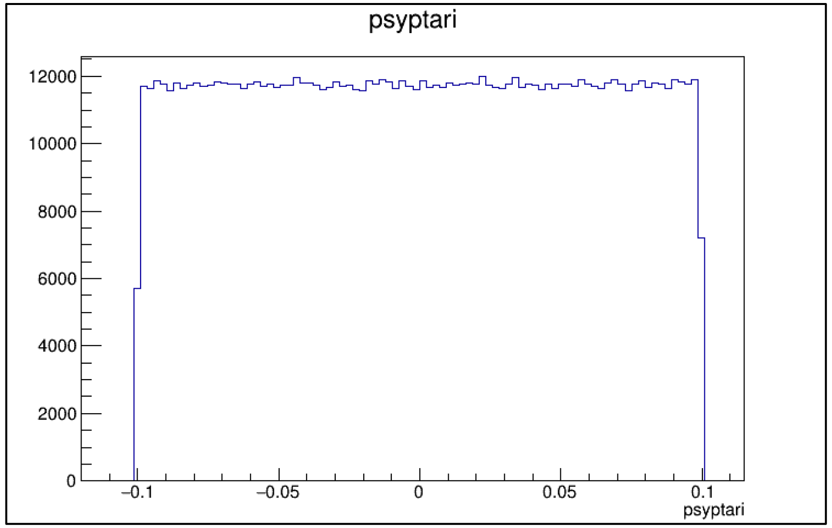


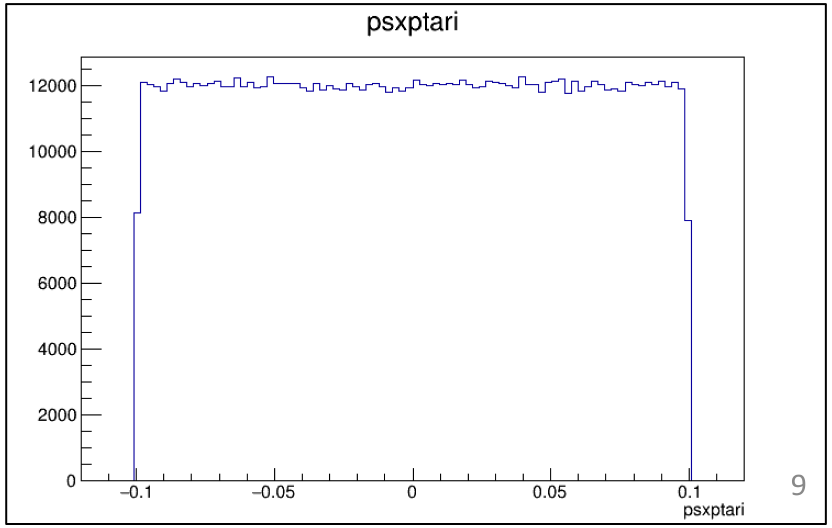




Monte Carlo and Data Comparison: ^{12}C

- Generate events over a large phase space
  - +/- 100 mr in both θ and ϕ
  - -15 > δp <25
    - Different for elastic!
- Includes Circular raster
- Wire chamber smearing
- Multiple scattering
- Energy Loss
- Simulate both Q.E. and Elastic



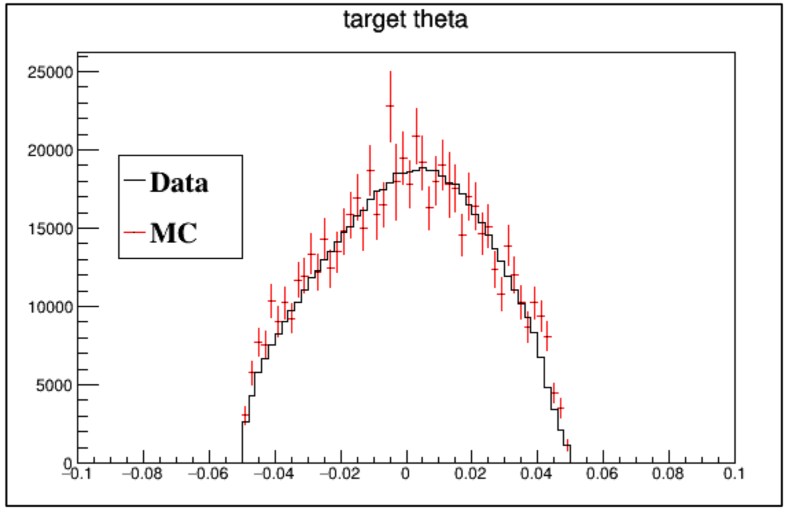


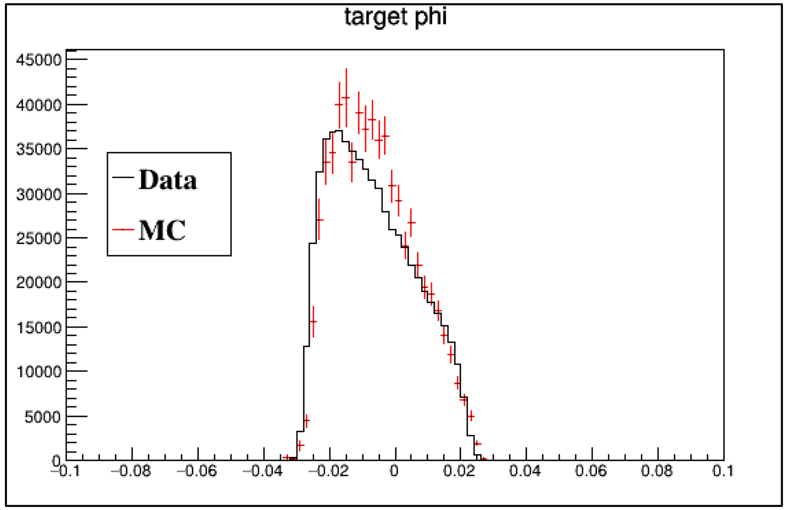
Monte Carlo and Data Comparison: Data Cuts

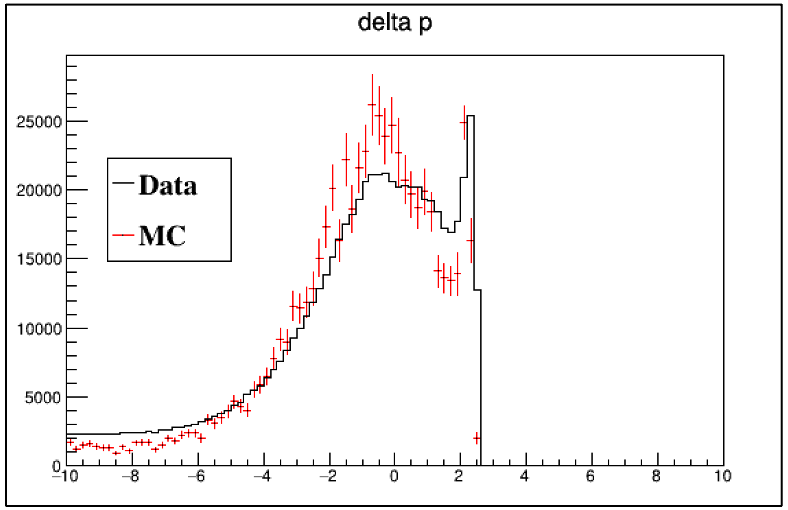
- SHMS (and HMS) carbon runs dominated by **quasi-elastic** events
- **PID**:
  - E/p>0.8 and E/p <2.0
  - Cherenkov NPE Sum >1.0
- $\boldsymbol{\delta}$**p**
  - δp > -10.0 and δp <3.0
- **Acceptance**
  - $|\phi_{tg}|$ <= 0.05 and $|\theta_{tg}|$<=0.05
- **z**
  - |z|<2
- Scale factor: $\mathcal{L}_{data} / \mathcal{L}_{MC} = \frac{(6.02e{-}10) * L_{tg} * \varrho * Q}{(1.602e{-}13) * A} / \frac{N_{gen}}{\Delta E \Delta\Omega}$

L_{tg}= target length
ϱ = target density
Q= total charge
N_{gen}=# generated events
$\Delta E \Delta\Omega$ = phase space

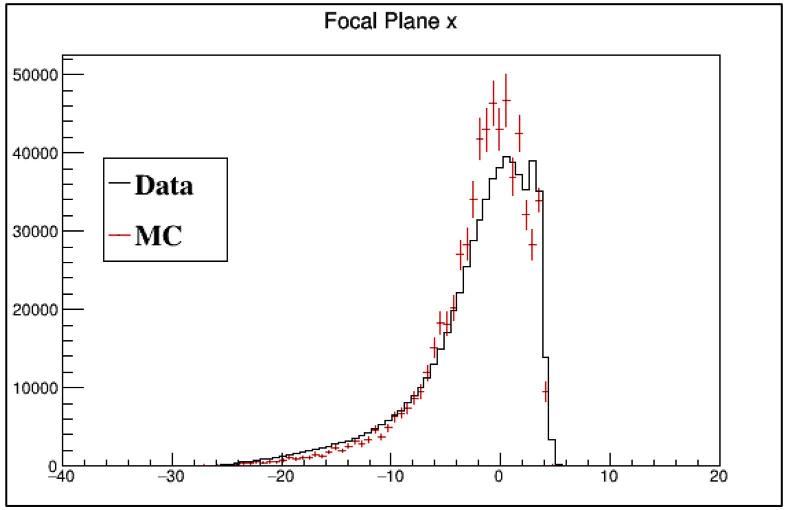
Monte Carlo to data comparison: Target

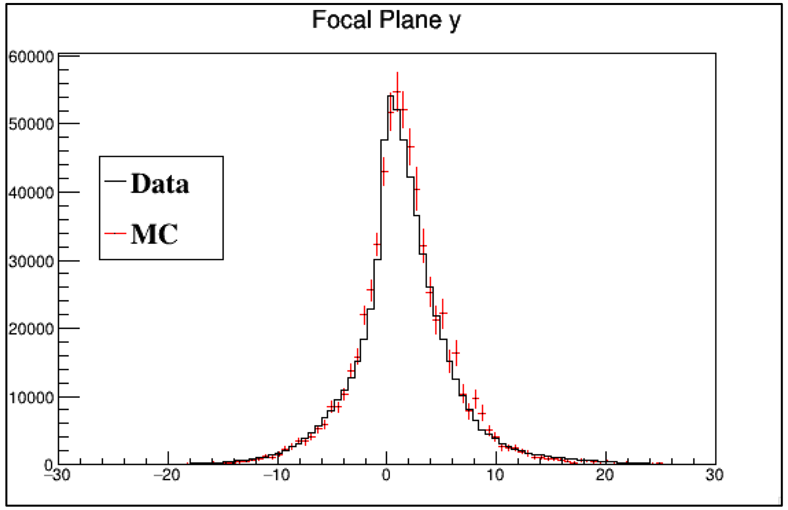


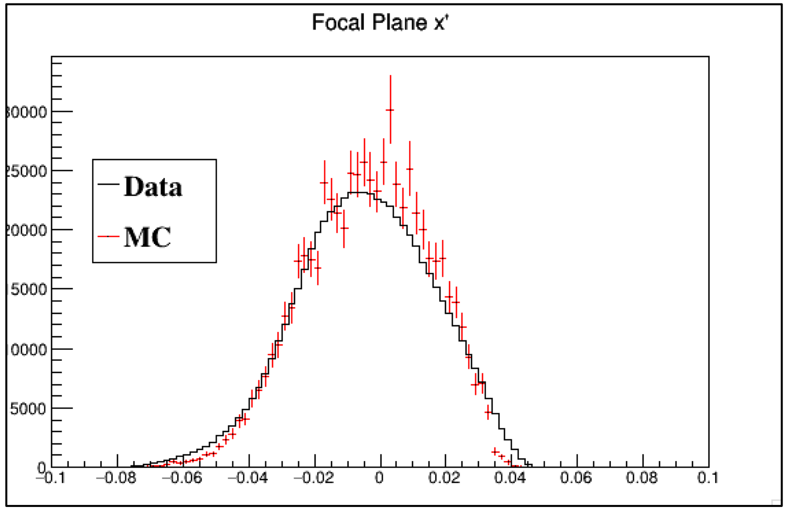


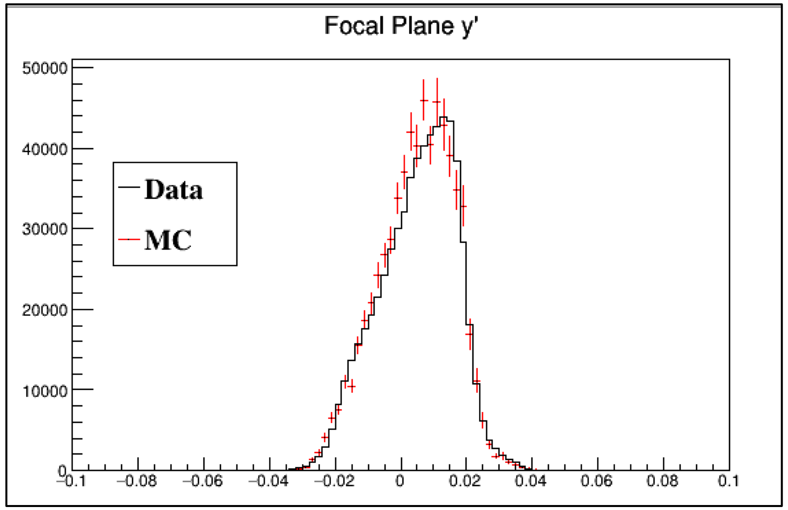


Monte Carlo to data comparison: Focal Plans









Future Plans

- Complete Carbon comparison
  - Update using radiative corrections (Thanks David Flay)
  - https://github.com/mnycz/RadiativeCorrections
- Move to polarized ^{3}He
  - Map of scintillator bars
  - Done while debugging ^{12}C
- ^{3}He results by next Collaboration meeting

1 -2 weeks

Thank you to the entire Polarized ^{3}He Collaboration

Measurement of ^{3}He Elastic Electromagnetic Form Factor Diffractive Minima Using Polarization Observables

S. K. Barcus (Spokesperson),* E. McClellan,
D. W. Higinbotham (Spokesperson), B. Sawatzky, and D. Mack
Jefferson Lab, Newport News, VA 23606

S. Li (Spokesperson)
University of New Hampshire,
Durham, NH 03824

T. Averett and M. Satnik
College of William and Mary,
Williamsburg, VA 23185

F. Hauenstein
Old Dominion University, Norfolk, VA 23529

S. Širca and M. Mihovilovič
University of Ljubljana and Jozef Stefan Institute,
1000 Ljubljana, Slovenia

T. Kolar
Jozef Stefan Institute,
1000 Ljubljana, Slovenia

X. Zheng, M. Chen, and J. Zhang
University of Virginia,
Charlottesville, VA 22904

d_2^n Collaboration

^{3}He Elastic Scattering Form Factors

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp}} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \frac{1}{1+\tau}\left[G_E^2(Q^2) + \frac{\tau}{\epsilon} G_M^2(Q^2)\right]$$

Rosenbluth Separation

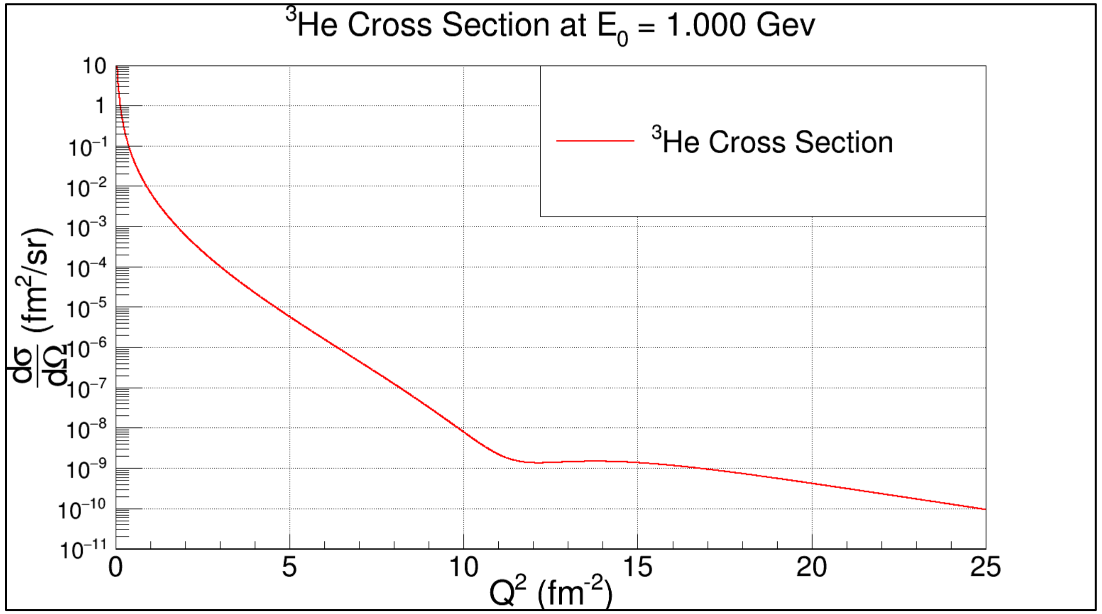
$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{red}} = \left[\epsilon G_E^2(Q^2) + \ \tau G_M^2(Q^2)\right]$$

- G_E & G_M extracted from a linear fit of the cross section with respect to ϵ
    - G_E^2 = slope
    - τG_M^2 = intercept

$$\epsilon \equiv \left(1 + 2(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right)^{-1}$$

$$\tau \equiv \frac{Q^2}{4M^2}$$

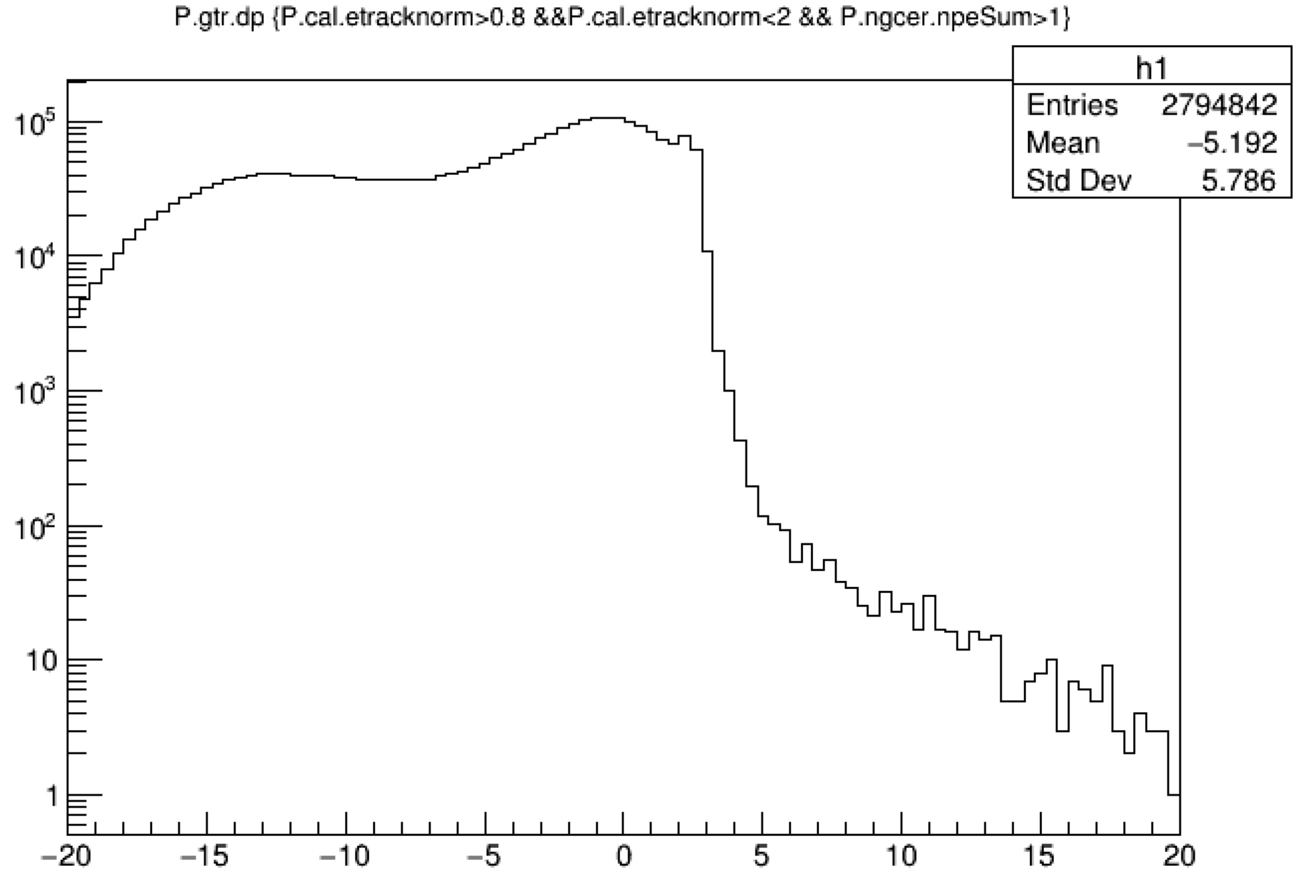
Fit to world data



- **All high Q^2 ^{3}He Form Factor measurements are from unpolarized elastic scattering**
- **Differences in EM form factors of the proton between PO and Rosenbluth @ high Q^2**

δp

With only PID cuts,
Low statistics above ~5



External Bremsstrahlung

- Energy loss due to external Bremstrahlung for materials before magnet
- $\Delta E = EU^{1/bt}$
- Where E is the electron energy, U is a uniform random number, and bt is given by
  - $bt = \frac{L\rho 4}{3}(1 + \frac{Z+1}{Z+\eta * lrad})$

```
      subroutine Bremss_Eloss(len,dens,zeff,epart,
     &                        rad_len, Bremss_Loss)


************************************************************************
* Energy loss due to external Bremsstrahlung. This was adapted from SAMC
* version developed by Michael Paolone
************************************************************************

      implicit none
c      include 'target.inc'
      integer  values(1:8), k
      integer  values2(1:8), l
      integer, dimension(:), allocatable :: seed
      real*8 len,dens,zeff,epart,mpart
      real*8 rad_len,Bremss_Loss
      real*8 lrad,lradp,eta
      real*8 b,bt
      real*8 rnu1,rnu2 !uniform random numbers
      real*8 U,X,H
      real*8 unif
      real*8 grnd,incl,rndm


      lrad = log(184.15 *(zeff)**(-1/3))
      lradp = log(1194*(zeff)**(-2/3))

      eta = lrad / lradp

      b = (4/3)*(1.+1./9.*(zeff+1.)/(zeff+eta)/lrad)

      bt = ((len*dens)/rad_len)*b
      U=1.0
      H=0.0
      do while(U>H)
c          write(6,*) 'Make it inside do while?'
c uniform random number [0,1]
c          write(6,*) 'in'
c          call date_and_time(values=values)
c          call random_seed(size=k)
c          allocate(seed(1:k))
c          seed(:) = values(8)
         CALL RANDOM_NUMBER(rnu1)
c          write(6,*)'first rndm',rnu1
c          DEALLOCATE(seed)
         X = (rnu1)**(1.0/bt)
****************************************
c          call date_and_time(values=values)
c          call random_seed(size=l)
c          allocate(seed(1:l))
c          seed(:) = values(8)
         CALL RANDOM_NUMBER(U)
c          write(6,*)'second rndm',U
c          DEALLOCATE(seed)
****************************************
         H = 1.0 - X + 3.0/4.0*X*X
c          write(6,*) 'in','X', X,'U',U,'H',H
      end do
```

JLab Hall C GEP-III PRC 96, 055203 (2017)