# Kinematics Systematics for 80 MeV Data

```
****COVARIANCE MATRIX*****
4x4 matrix is as follows

     |      0    |      1    |      2    |      3    |
---------------------------------------------------------
   0 |  5.623e-07   6.839e-07  -1.213e-07  -6.267e-08
   1 |  6.839e-07    8.34e-07  -1.488e-07  -7.014e-08
   2 | -1.213e-07  -1.488e-07   2.754e-08   8.433e-09
   3 | -6.267e-08  -7.014e-08   8.433e-09   5.617e-08

=== Optimized Parameters ===
total equations x total runs = 4x3 = 12 observations, # parameters = 4, dof = 8
initial chi2 = 35.6321 initial chi2/dof = 4.45401
chi2 = 9.36812  chi2/dof = 1.17102
dEb / Eb = -0.00164769
dEf / Ef = -0.00199839
dth_e = 0.000469832
dth_p = -0.000147982

=== Uncertainty in Parameters (Diagonal Elements) ===
sqrt[cov(0,0)] = dEb / Eb = 0.000749839
sqrt[cov(1,1)] = dEf / Ef = 0.000913231
sqrt[cov(2,2)] = dth_e [rad] = 0.000165951
sqrt[cov(3,3)] = dth_p [rad] = 0.000236996

=== Uncertainty in Parameters (Off-Diagonal Elements) ===
cov(0,1) = dEb_Eb * dEf_Ef = 6.83851e-07
cov(0,2) = dEb_Eb * dth_e = -1.21324e-07
cov(0,3) = dEb_Eb * dth_p = -6.26743e-08
cov(1,2) = dEf_Ef * dth_e = -1.48849e-07
cov(1,3) = dEf_Ef * dth_p = -7.01424e-08
cov(2,3) = dth_e * dth_p = 8.43255e-09

****CORRELATION MATRIX*****
4x4 matrix is as follows

     |      0    |      1    |      2    |      3    |
---------------------------------------------------------
   0 |          1      0.9986      -0.975     -0.3527
   1 |     0.9986           1     -0.9822     -0.3241
   2 |     -0.975     -0.9822           1      0.2144
   3 |    -0.3527     -0.3241      0.2144           1
```

**Uncertainties Used in Calculation of Systematics**

**Correlations incorporated in the systematics calculation**

# Implementation of covariance errors in analyze_differ.py

```python
# calculate total errors
sigma_the = ds_dthe*sig_the*1.e-3    #the 1e-3 is to convert relative error sig_the from mr to rad
sigma_phe = ds_dphe*sig_phe*1.e-3

sigma_thp = ds_dthp*sig_thp*1.e-3
sigma_php = ds_dphp*sig_php*1.e-3

sigma_thb = ds_dthb*sig_thb*1.e-3
sigma_phb = ds_dphb*sig_phb*1.e-3

sigma_ef = ds_def*sig_ef*ef
sigma_dE = ds_dE*sig_E*E_inc

#Covariance elements [angles are already in radians]
#Since the covariance for E_inc, Ef are in relative errors, dE_inc/E_inc, dEf/Ef
#multiply by Ef or E_inc get absolute errors
sigma_the_thp = 2.*(ds_dthe*ds_dthp)*sig_the_thp
sigma_the_Ef = 2.*(ds_dthe*ds_def)*sig_the_Ef * ef
sigma_the_Eb = 2.*(ds_dthe*ds_dE)*sig_the_Eb *E_inc
sigma_thp_Ef = 2.*(ds_dthp*ds_def)*sig_thp_Ef * ef
sigma_thp_Eb = 2.*(ds_dthp*ds_dE)*sig_thp_Eb * E_inc
sigma_Ef_Eb = 2.*(ds_def*ds_dE)*sig_Ef_Eb * ef * E_inc

sigma_tot = np.sqrt(sigma_the**2 +
                    sigma_phe**2 +
                    sigma_thp**2 +
                    sigma_php**2 +
                    sigma_thb**2 +
                    sigma_phb**2 +
                    sigma_ef**2 +
                    sigma_dE**2 +
                    #Covariance contribution
                    sigma_the_thp +
                    sigma_the_Ef  +
                    sigma_the_Eb +
                    sigma_thp_Ef +
                    sigma_thp_Eb +
                    sigma_Ef_Eb)
```

**Correlated errors implementation**

## Cross-Section Derivatives and Total Kinematic Systematics are shown for each (Pm, theta_nq) bin in the NEXT SLIDES

## Kinematic Errors Used:

$$\sigma_{\Delta E_b/E_b} = 7.49839 \times 10^{-4}$$

$$\sigma_{\Delta E_f/E_f} = 9.13231 \times 10^{-4}$$

$$\sigma_{\Delta \theta_e} = 0.165951 \text{ mr}$$

$$\sigma_{\Delta \theta_p} = 0.236996 \text{ mr}$$

## Correlated Errors:

$$\text{cov}[E_b, E_f] = 6.8385 \times 10^{-7}$$

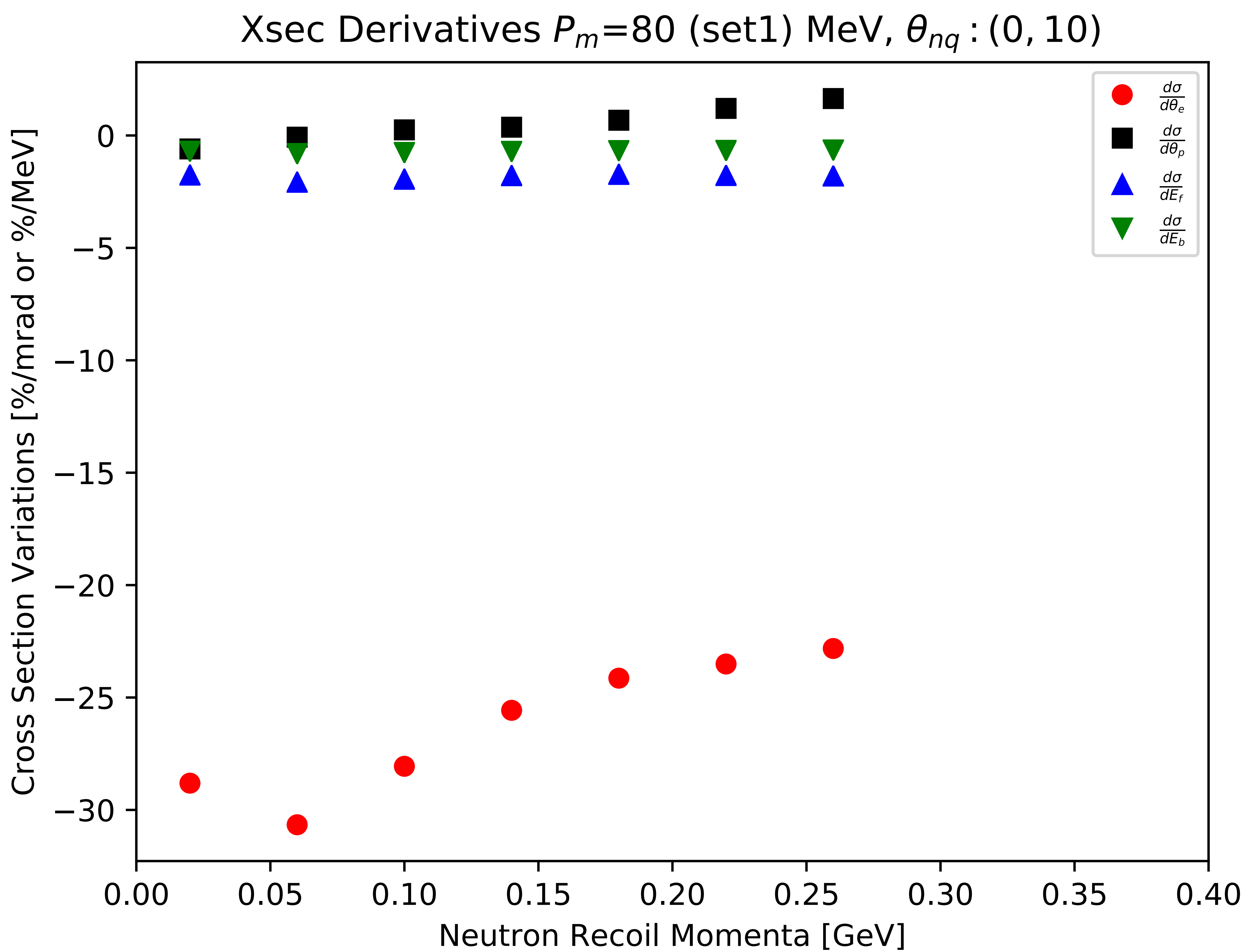
$$\text{cov}[E_b, \theta_e] = -1.2132 \times 10^{-7}$$

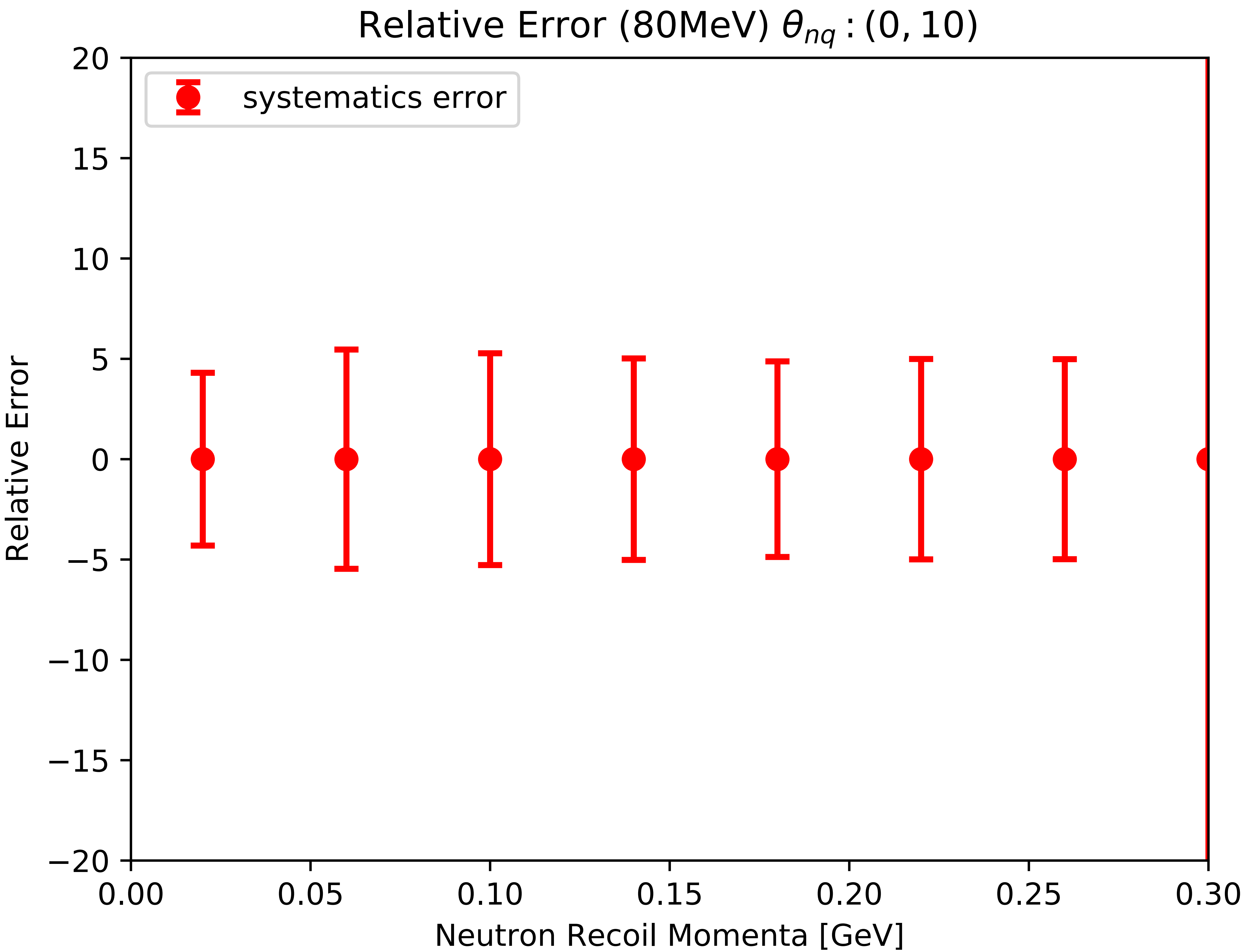
$$\text{cov}[E_b, \theta_p] = -6.26743 \times 10^{-8}$$

$$\text{cov}[E_f, \theta_e] = -1.48849 \times 10^{-7}$$

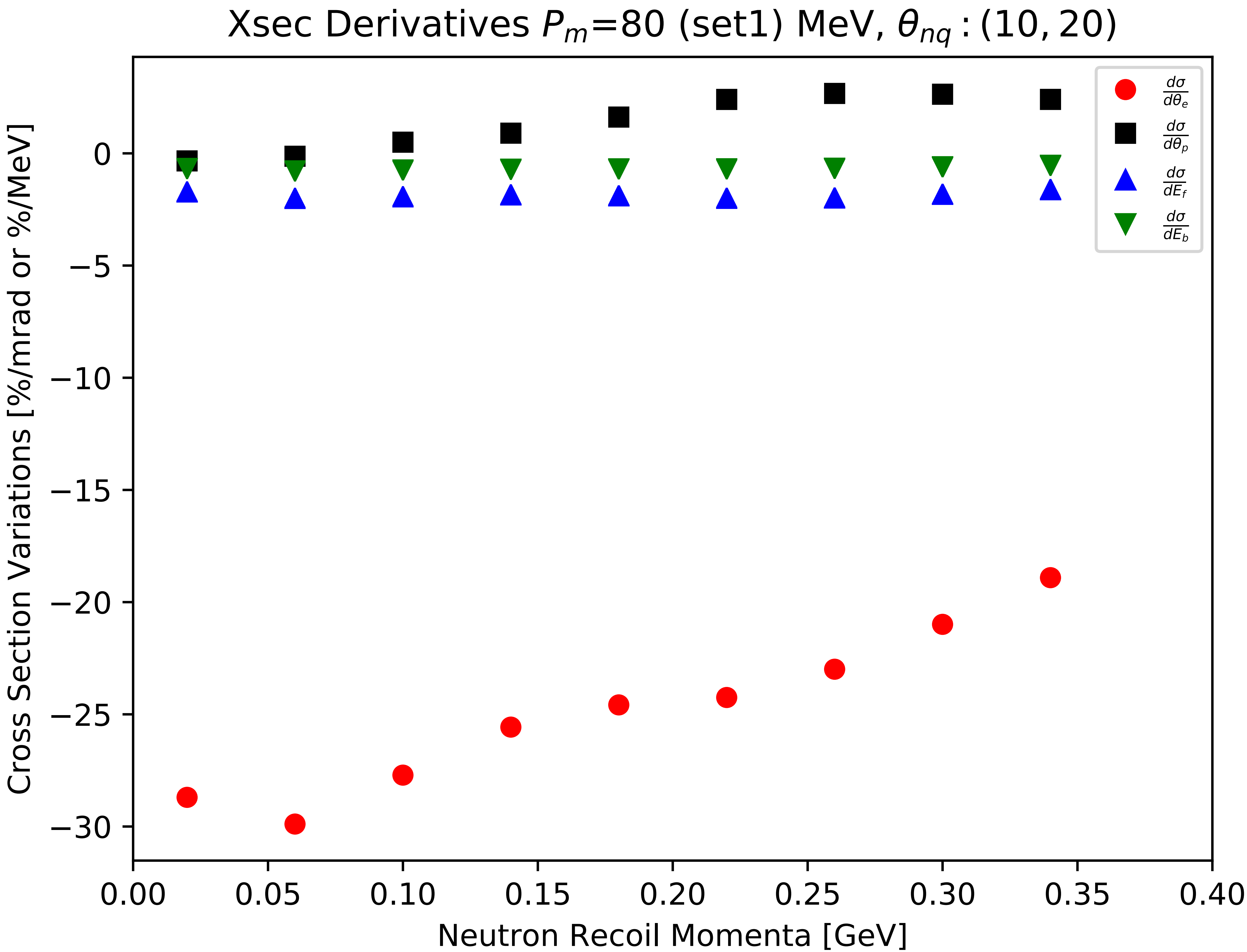
$$\text{cov}[E_f, \theta_p] = -7.01424 \times 10^{-8}$$

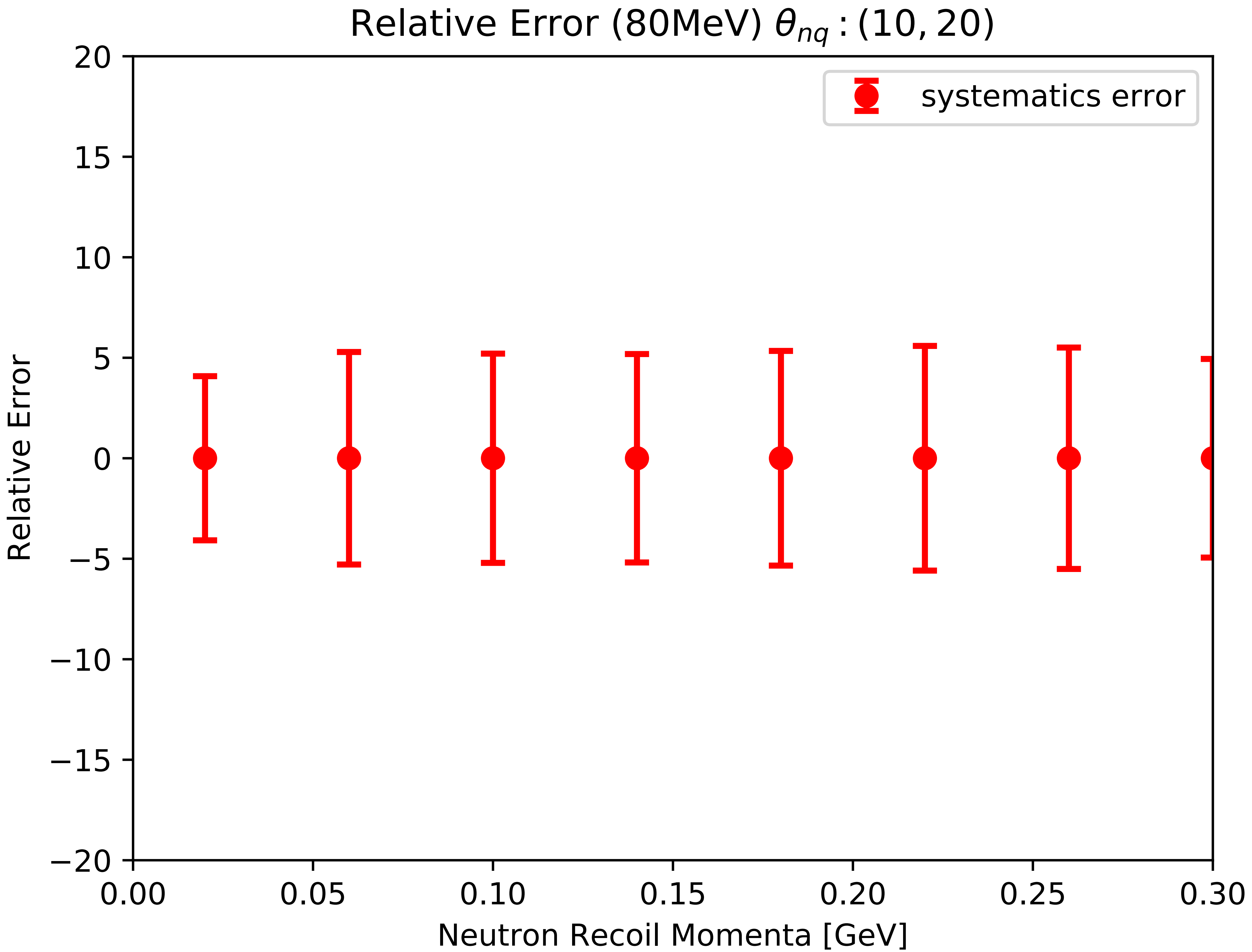
$$\text{cov}[\theta_e, \theta_p] = 8.43255 \times 10^{-9}$$


Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(0,10)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$
0
−5
−10
−15
−20
−25
−30
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40

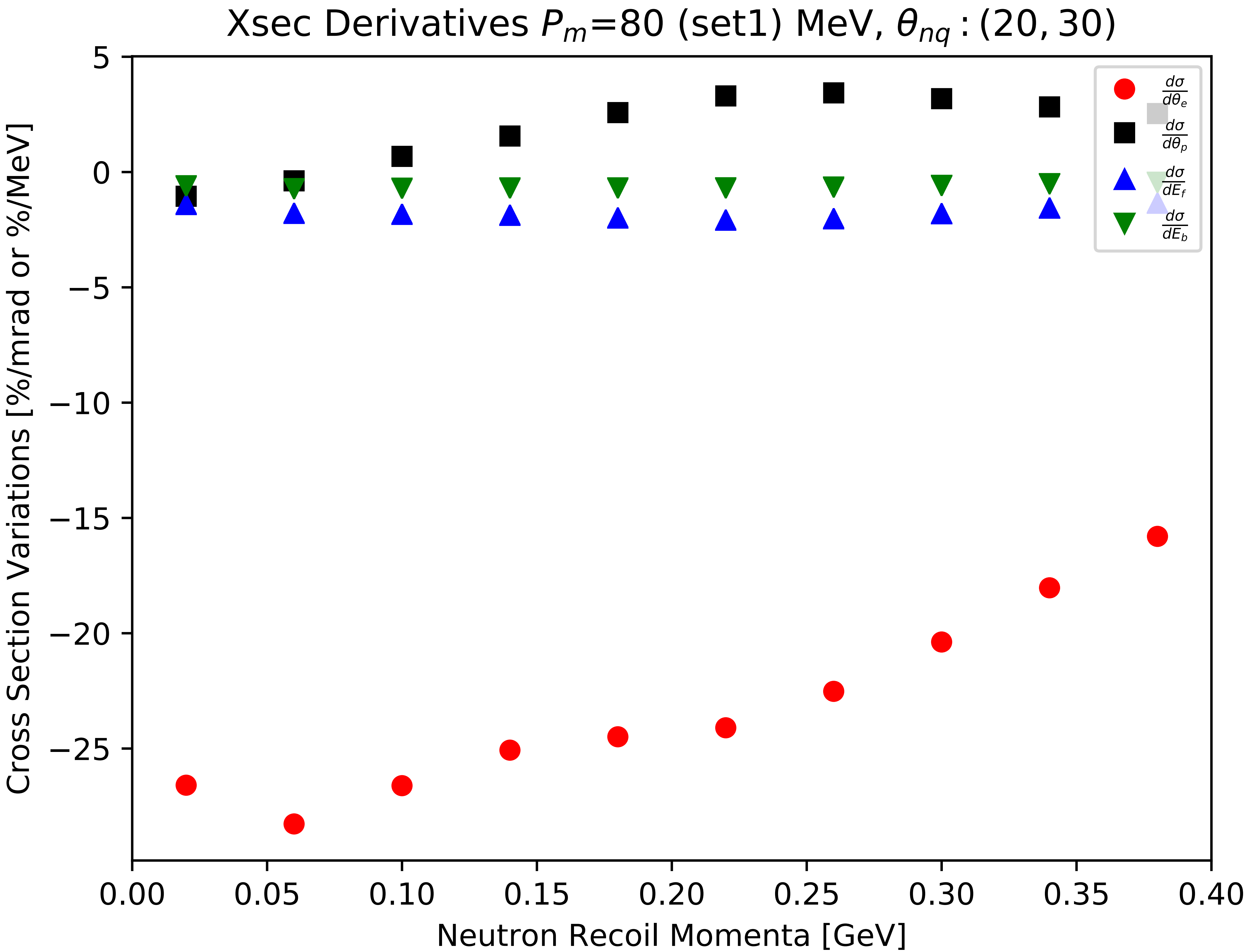


Relative Error (80MeV) $\theta_{nq}:(0,10)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30

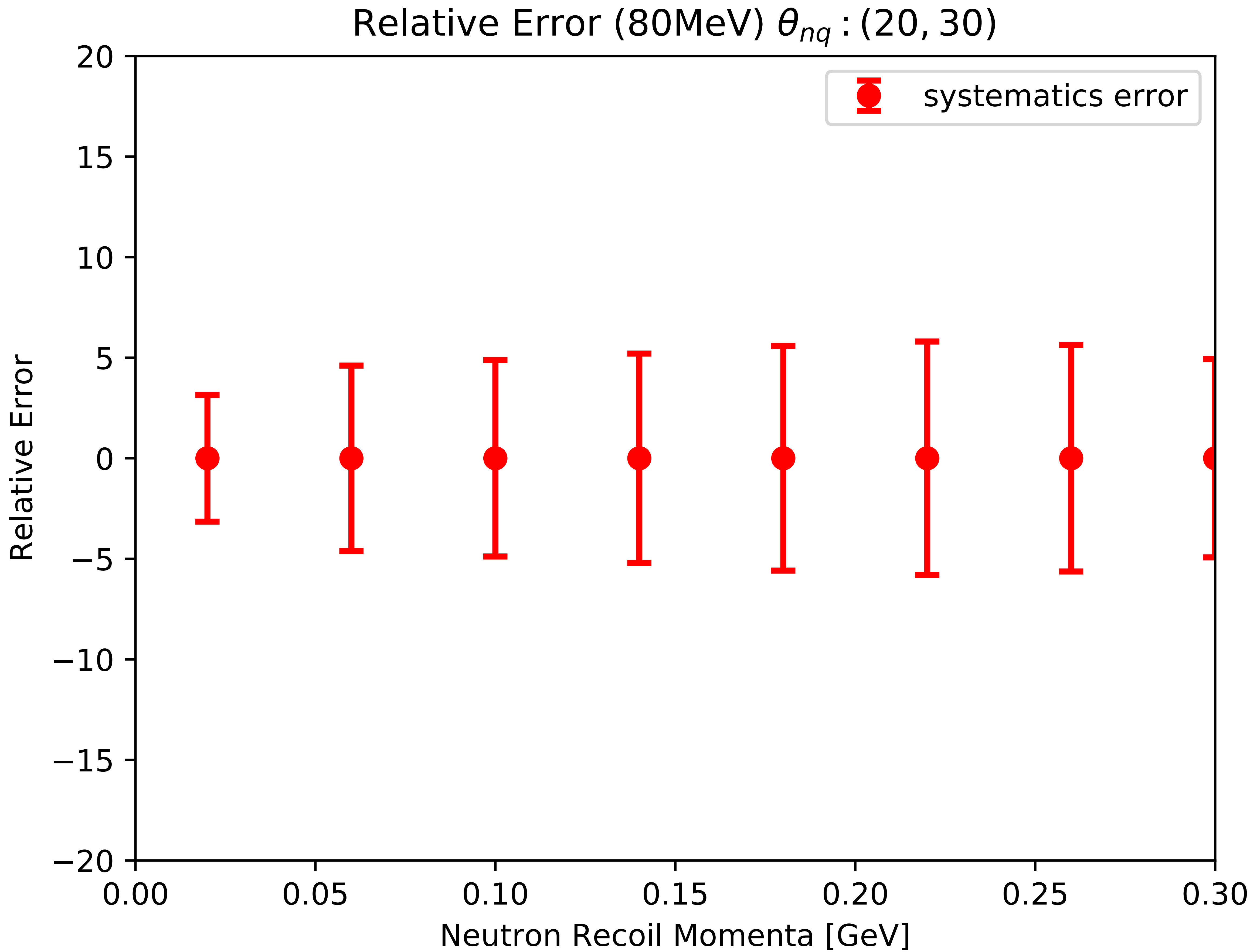

Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(10,20)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$
0
−5
−10
−15
−20
−25
−30
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40

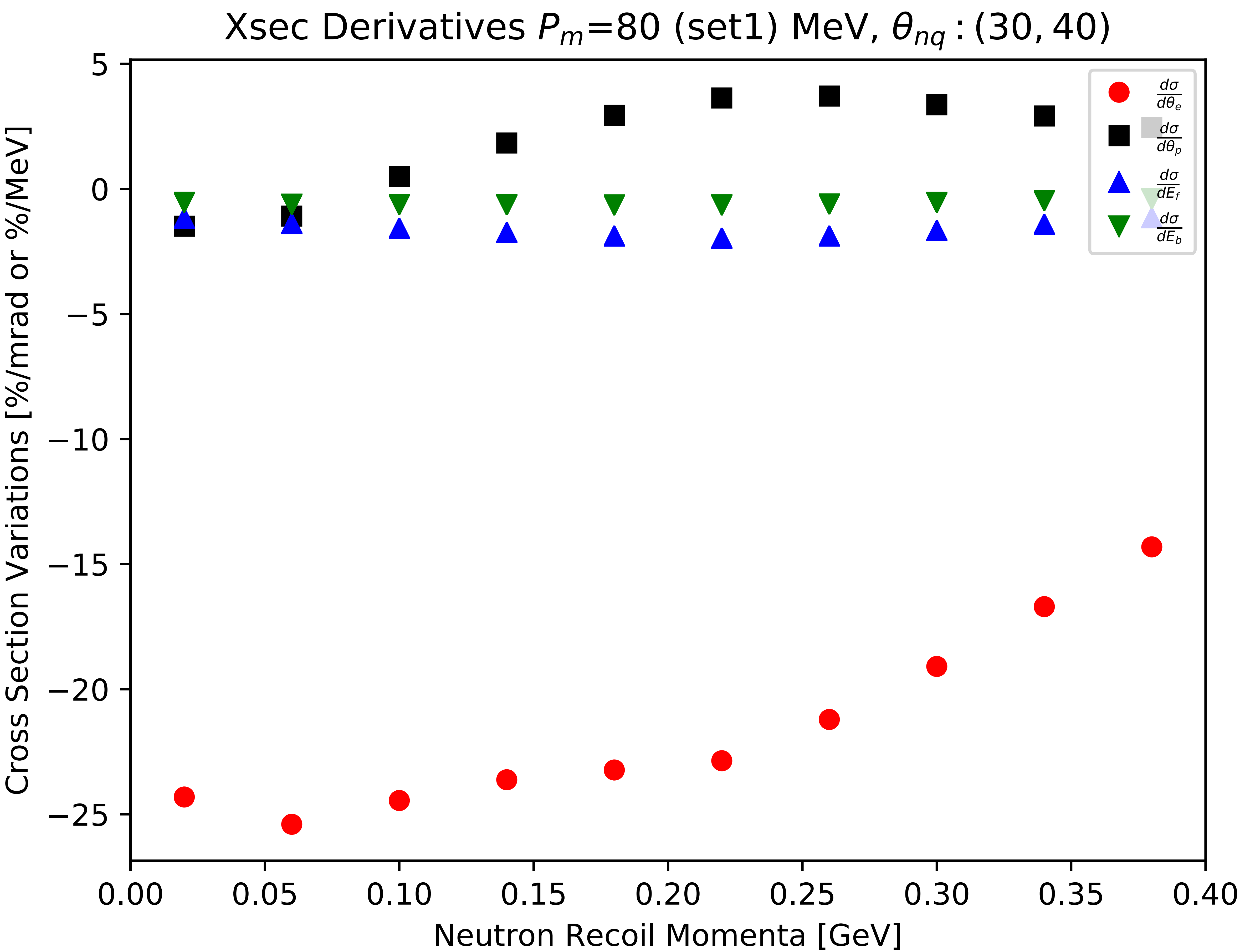


Relative Error (80MeV) $\theta_{nq}:(10,20)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30

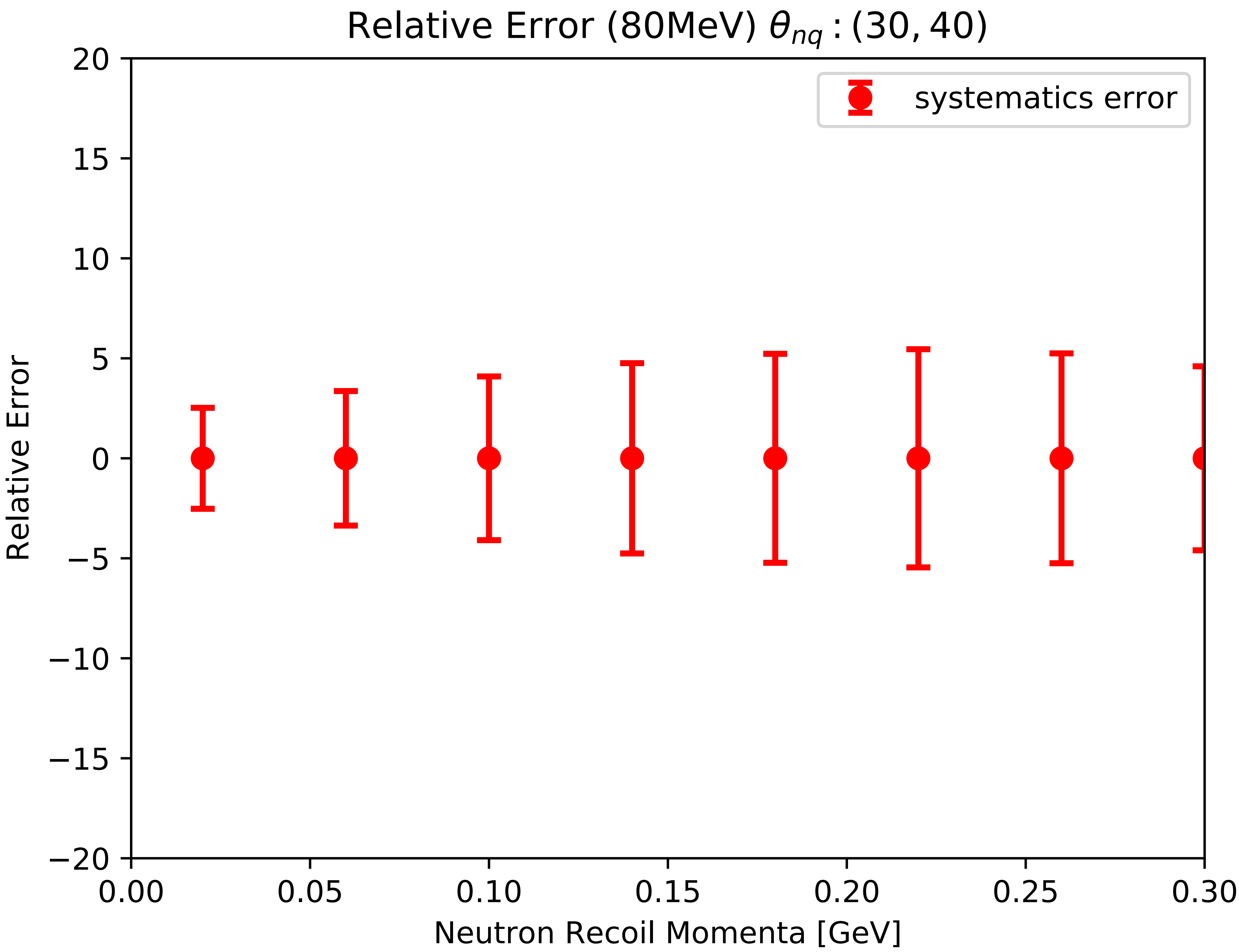


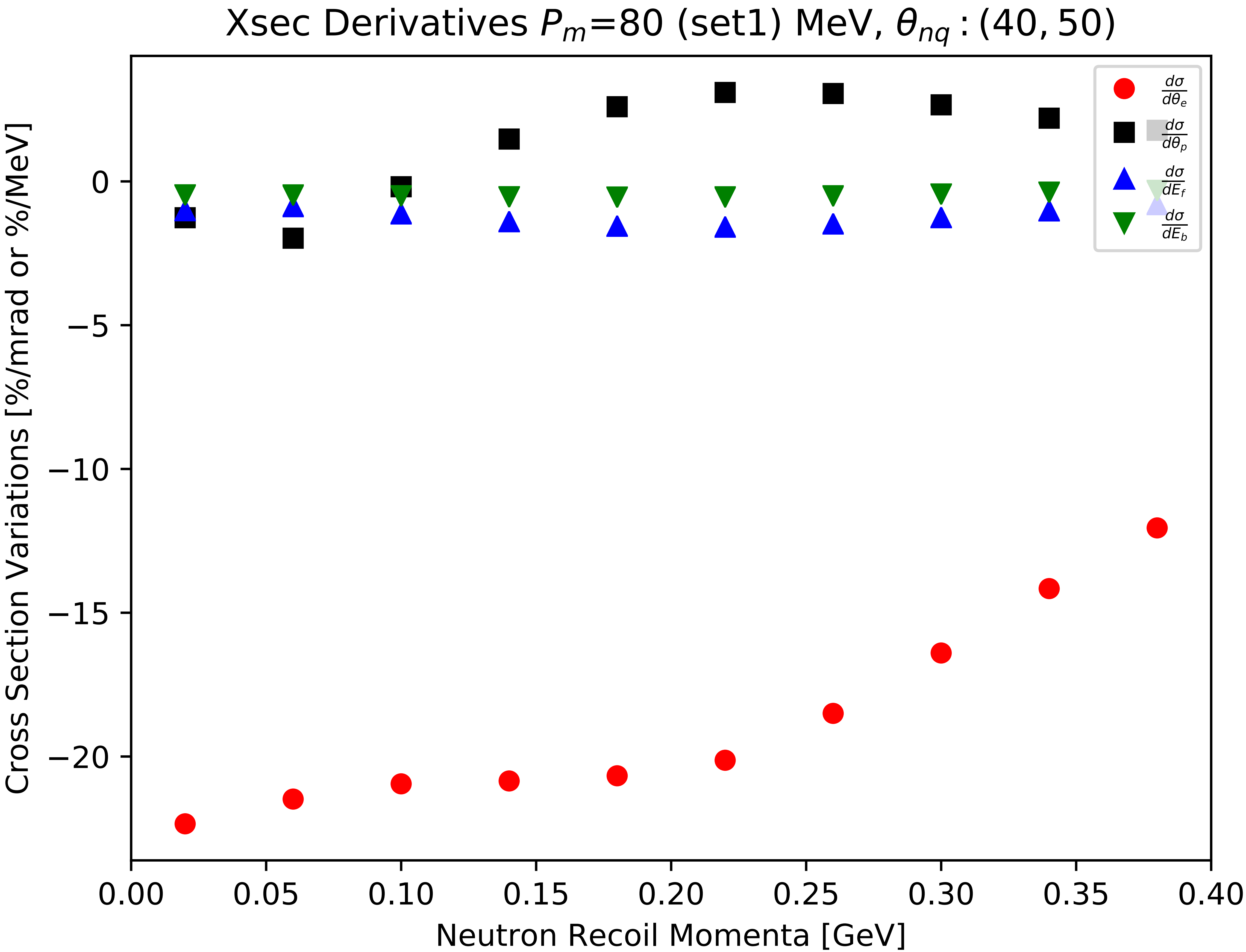
Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(20, 30)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
5
0
−5
−10
−15
−20
−25
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$


Relative Error (80MeV) $\theta_{nq}:(20,30)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30

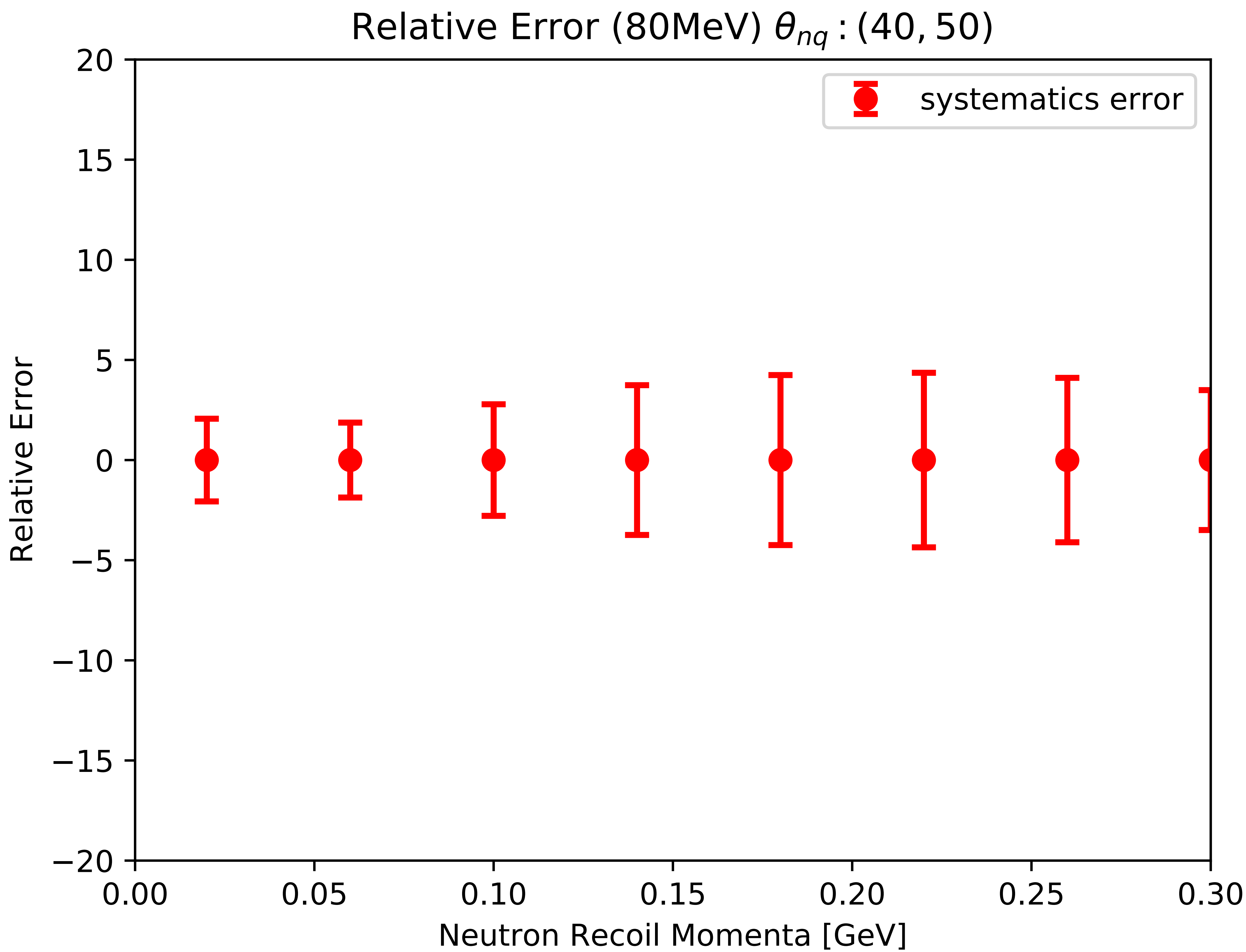


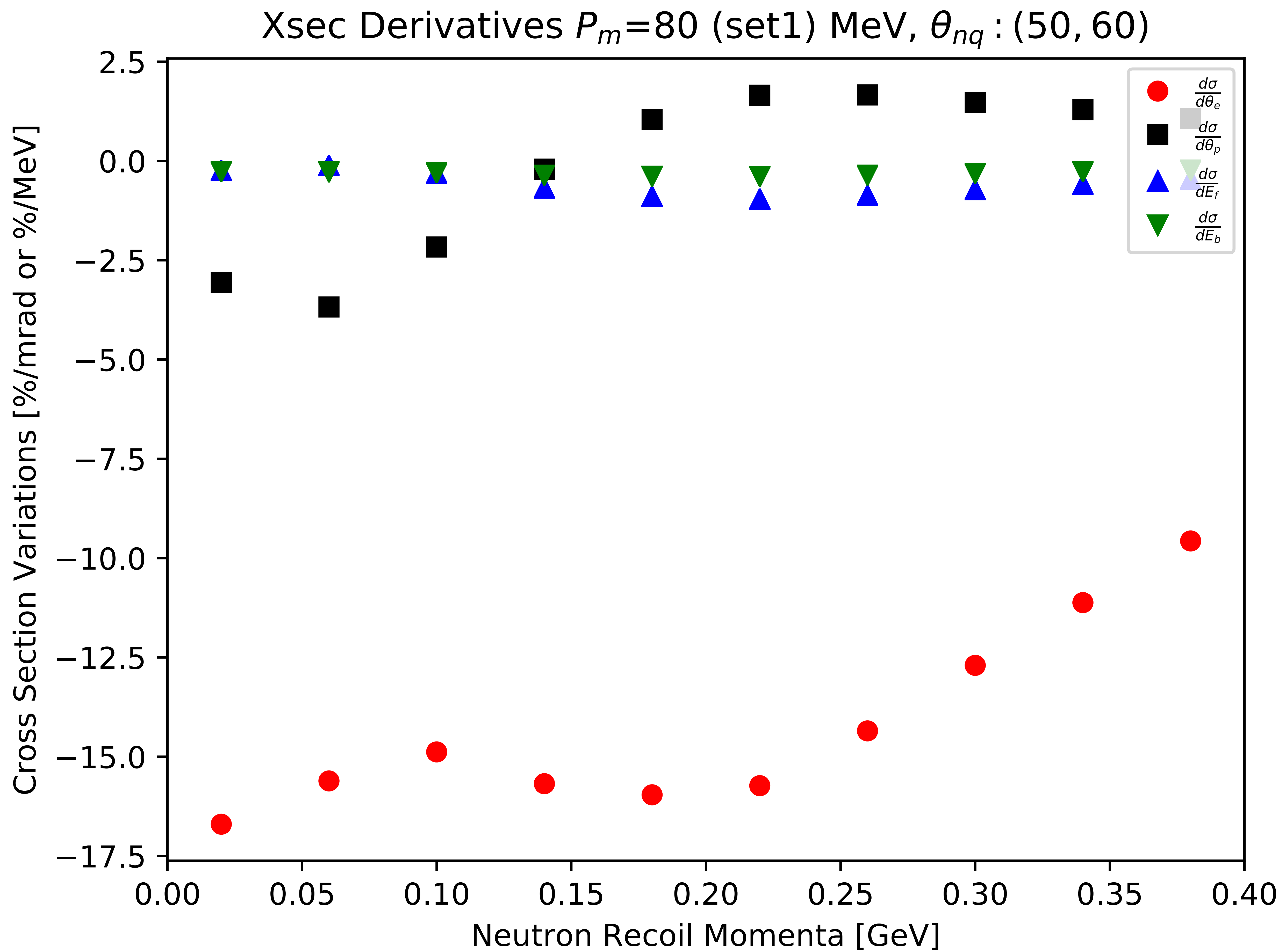
Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(30, 40)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
5
0
−5
−10
−15
−20
−25
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$


Relative Error (80MeV) $\theta_{nq}: (30, 40)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30

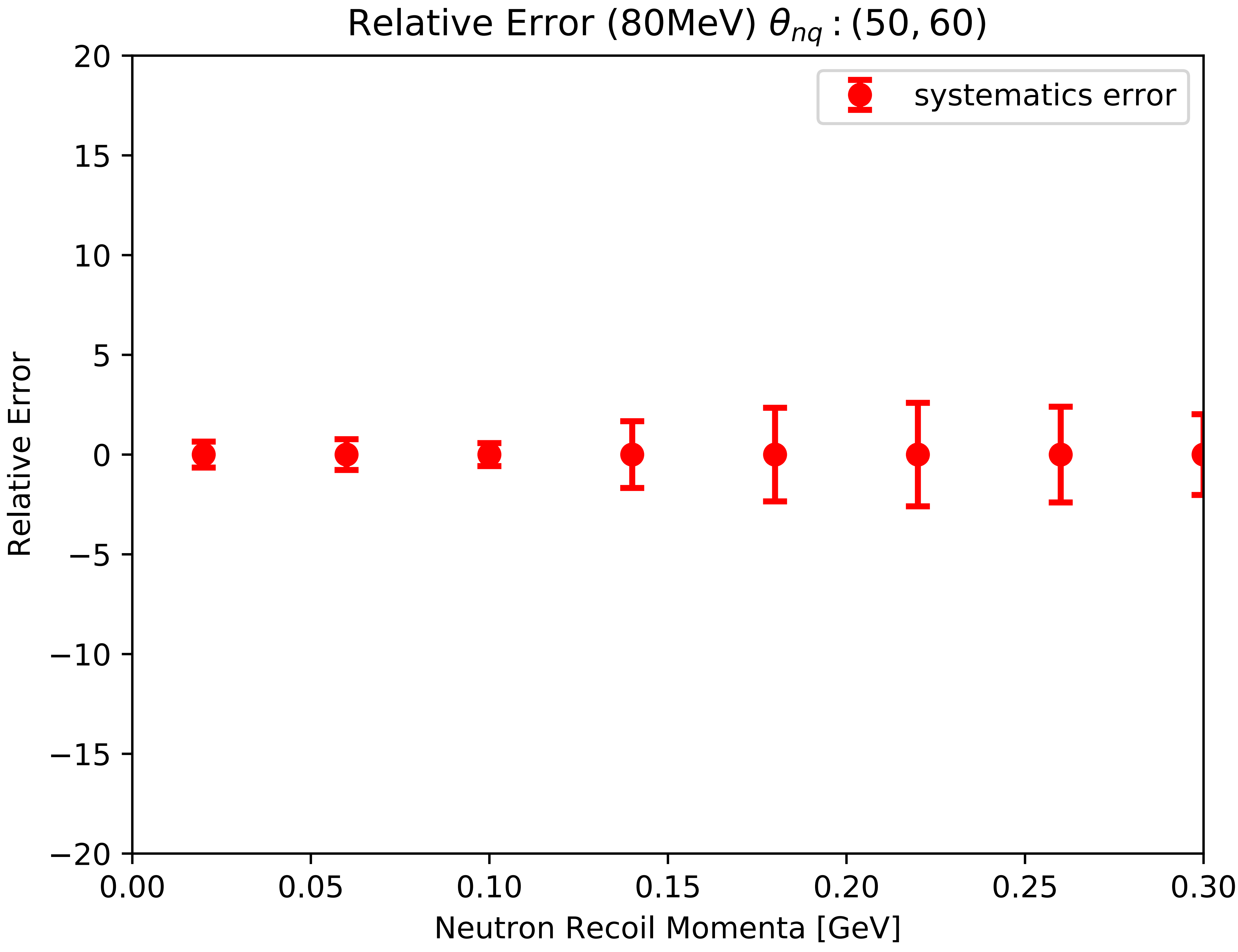


Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(40,50)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$

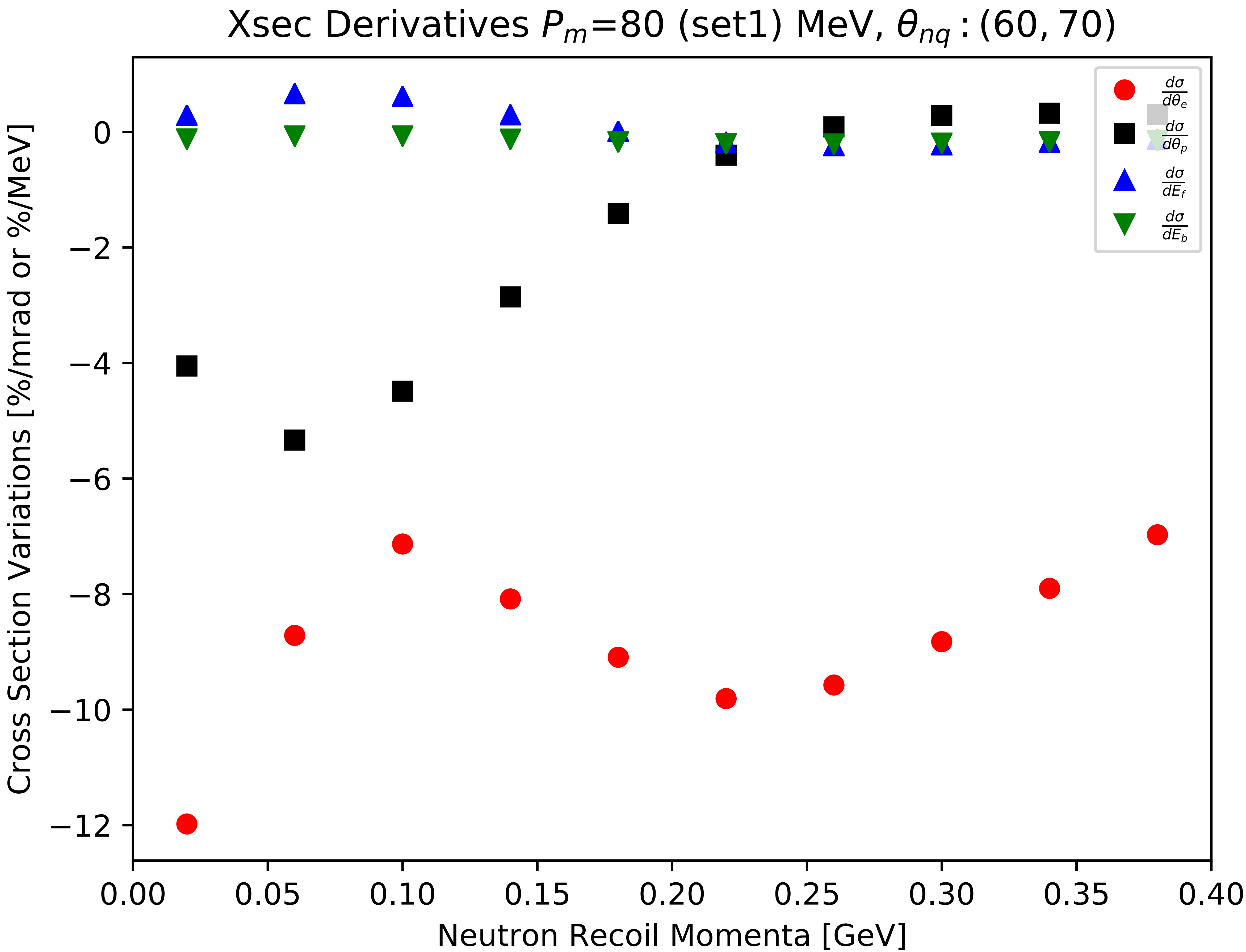

Relative Error (80MeV) $\theta_{nq}:(40,50)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30



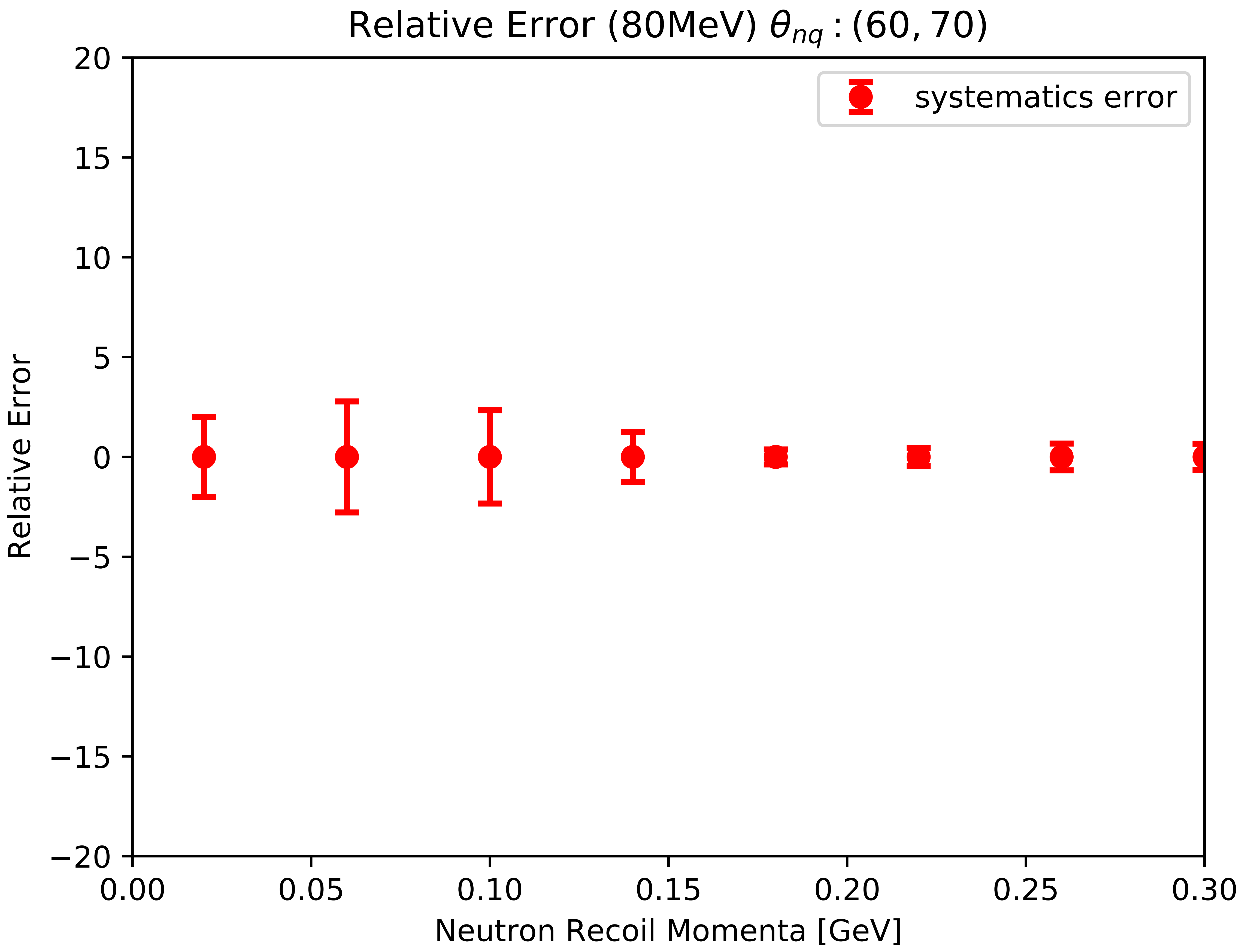
Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(50,60)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40



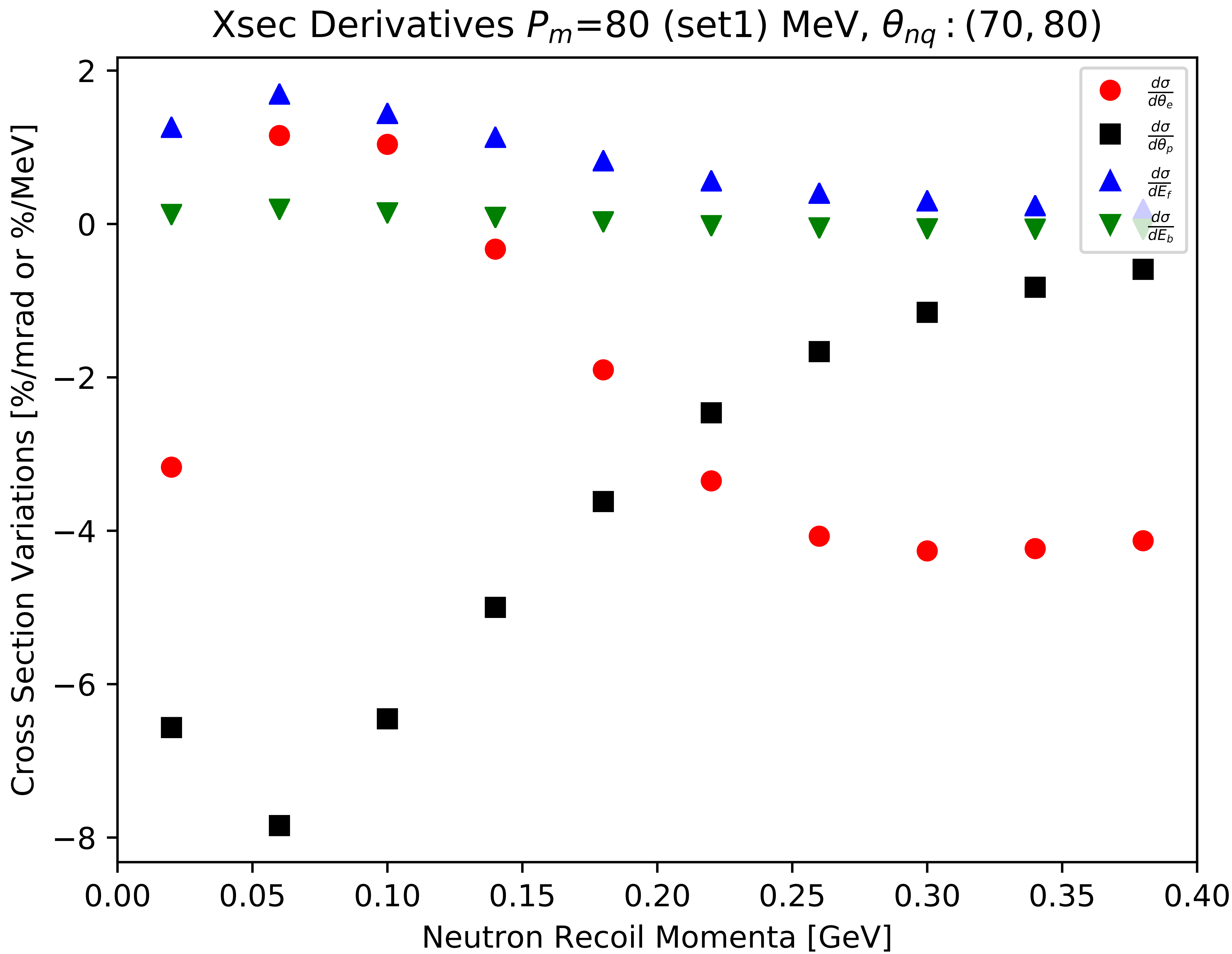
Relative Error (80MeV) $\theta_{nq}:(50,60)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30



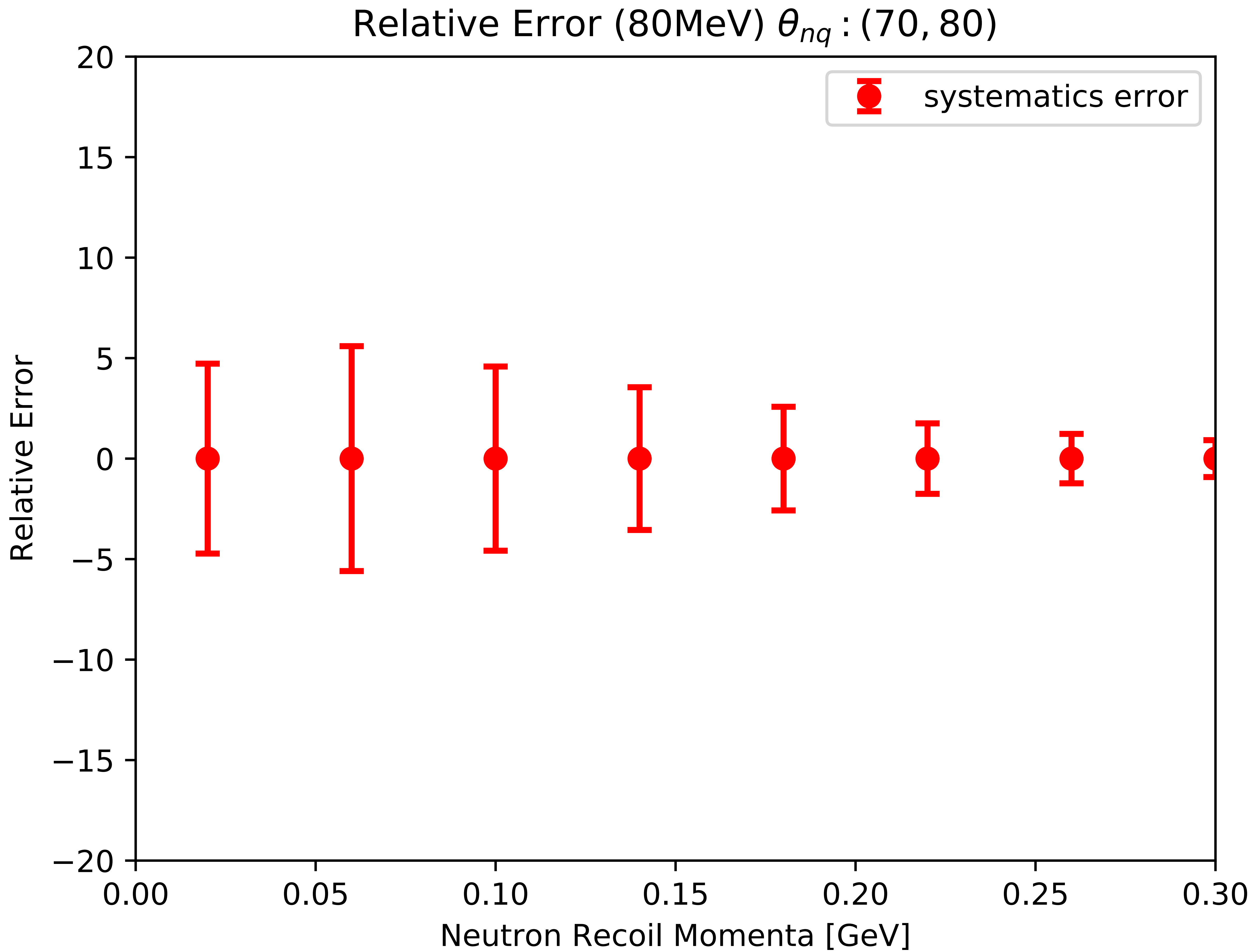
Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(60,70)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$
0
−2
−4
−6
−8
−10
−12
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40



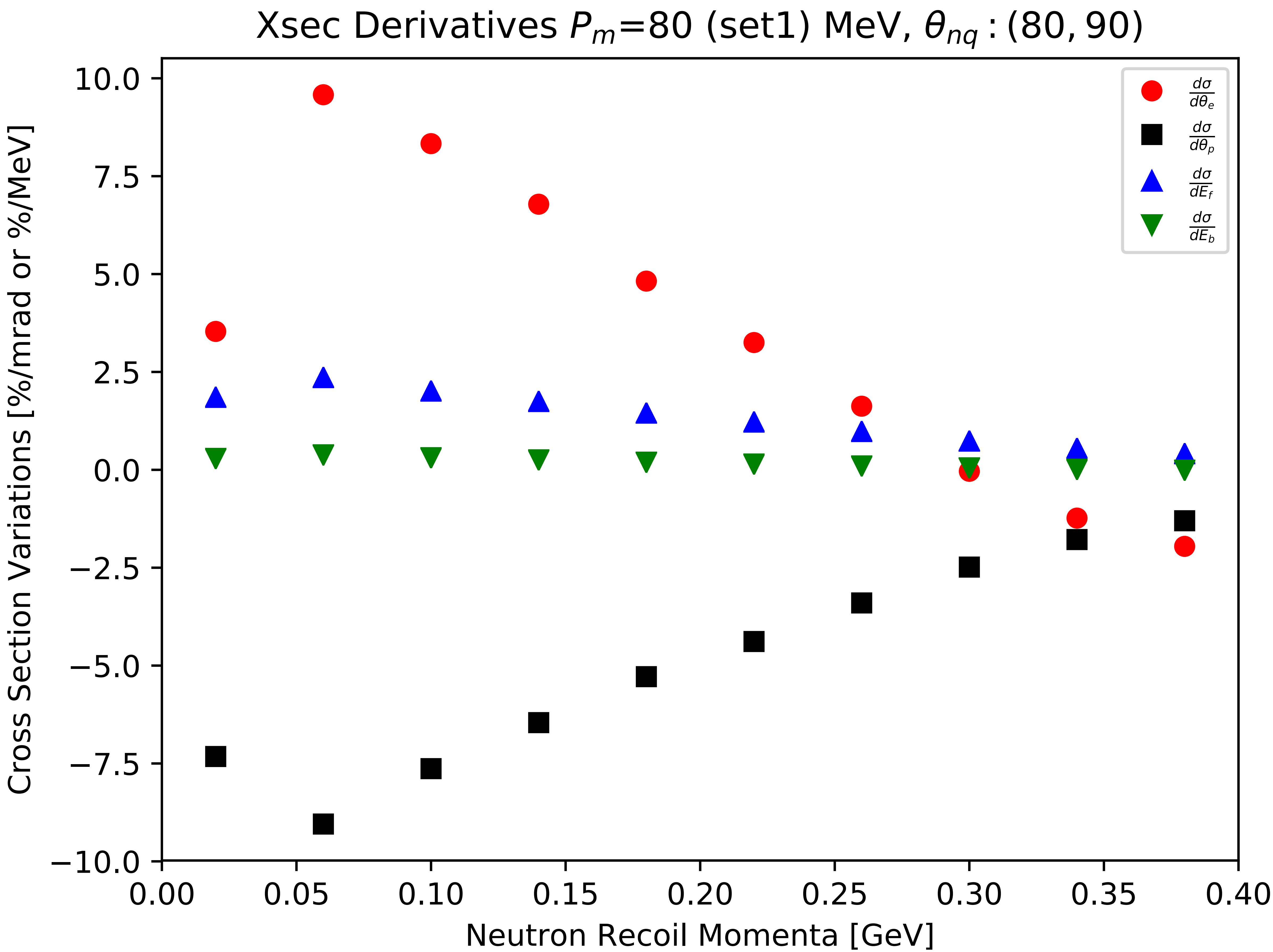
Relative Error (80MeV) $\theta_{nq}:(60,70)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30



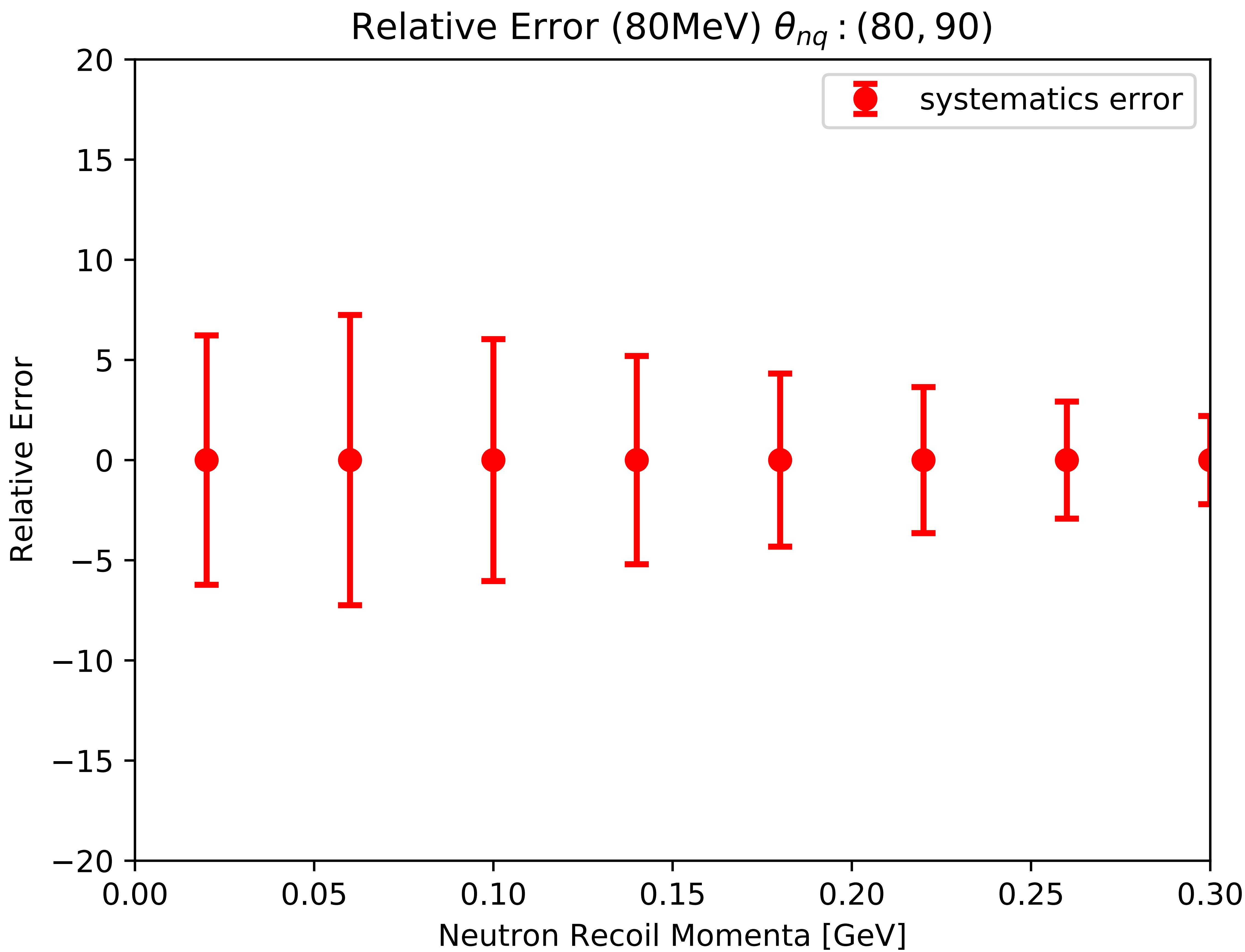
Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(70,80)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
2
0
−2
−4
−6
−8
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$



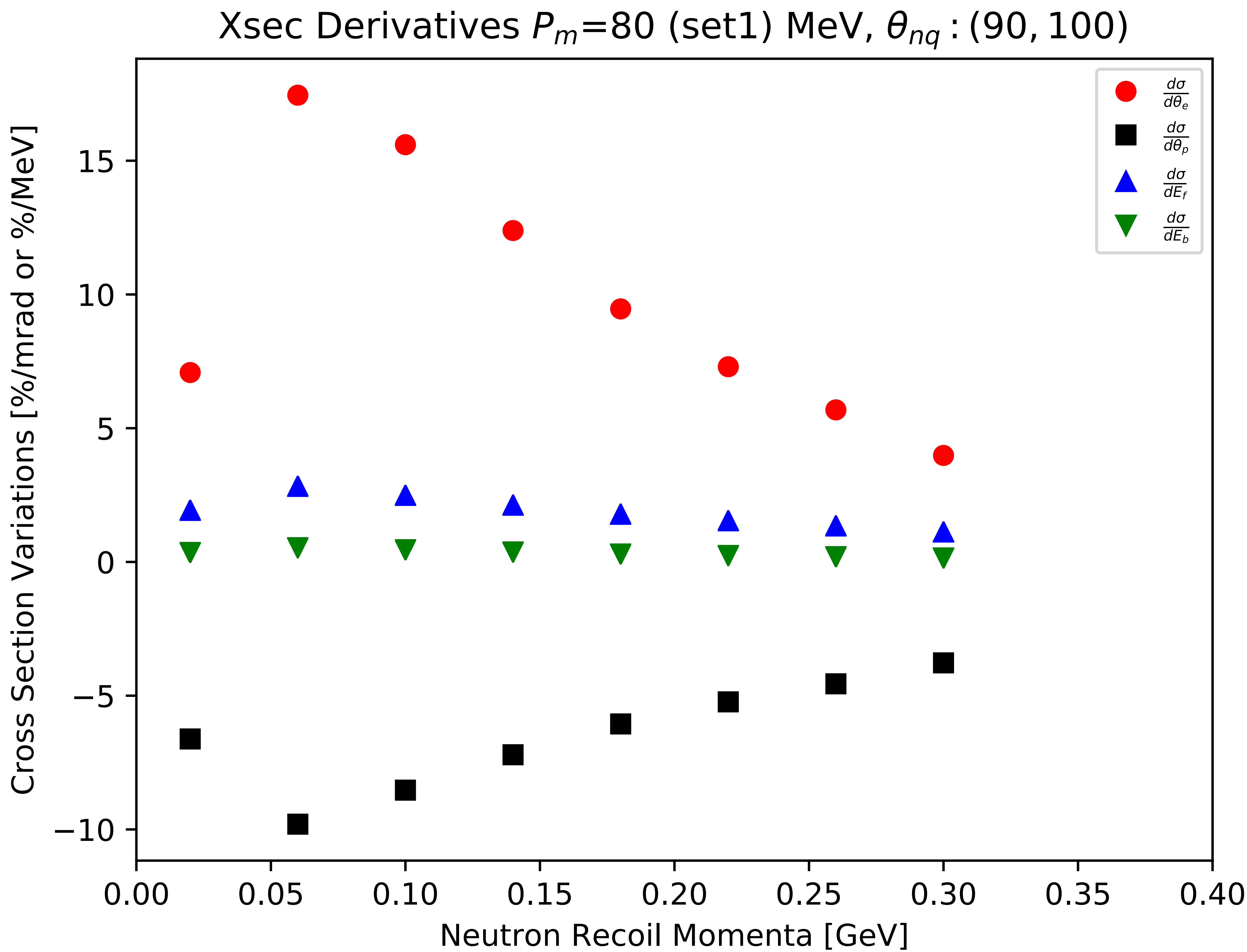
Relative Error (80MeV) $\theta_{nq}:(70,80)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30

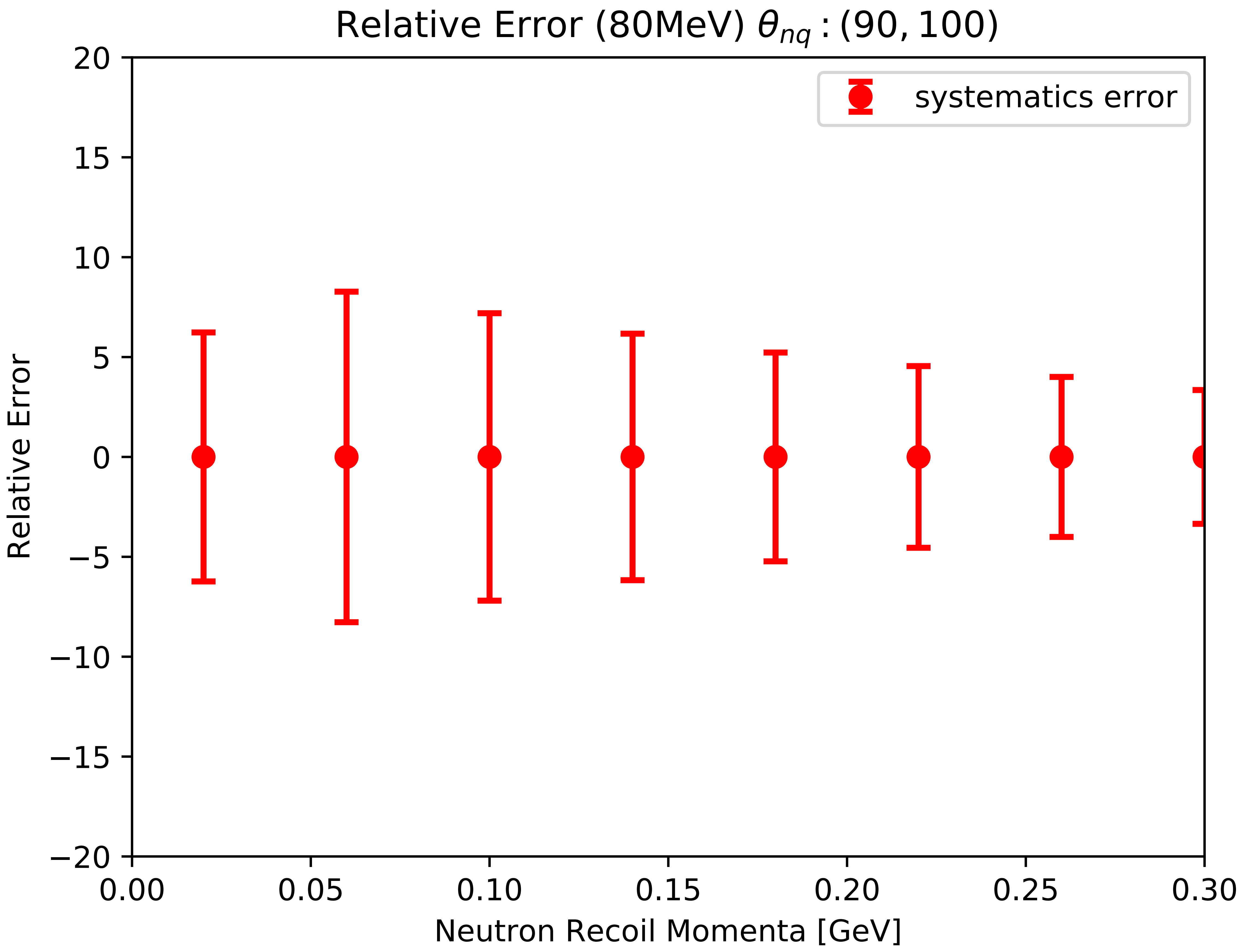


Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(80,90)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40

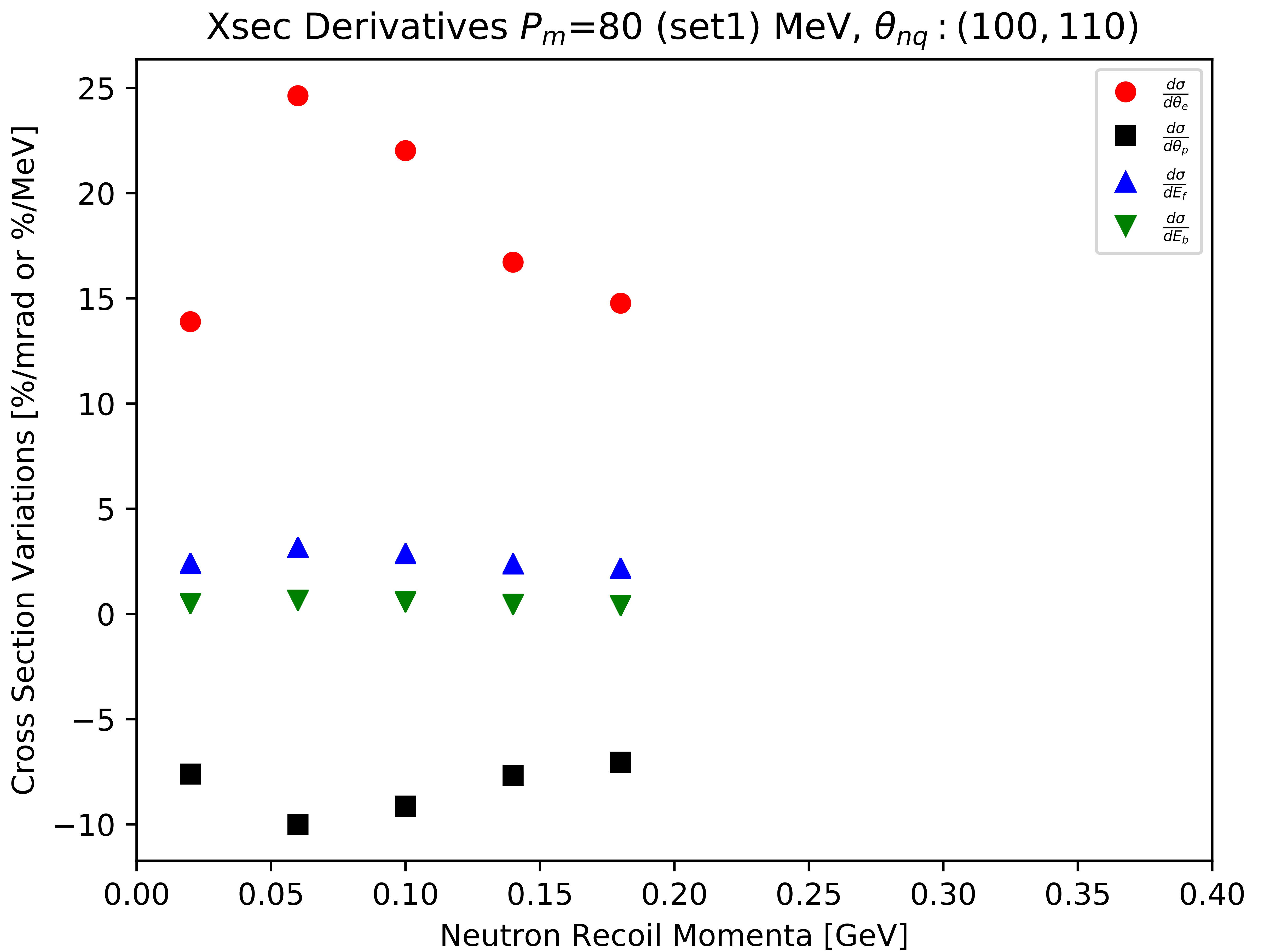


Relative Error (80MeV) $\theta_{nq}:(80,90)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30

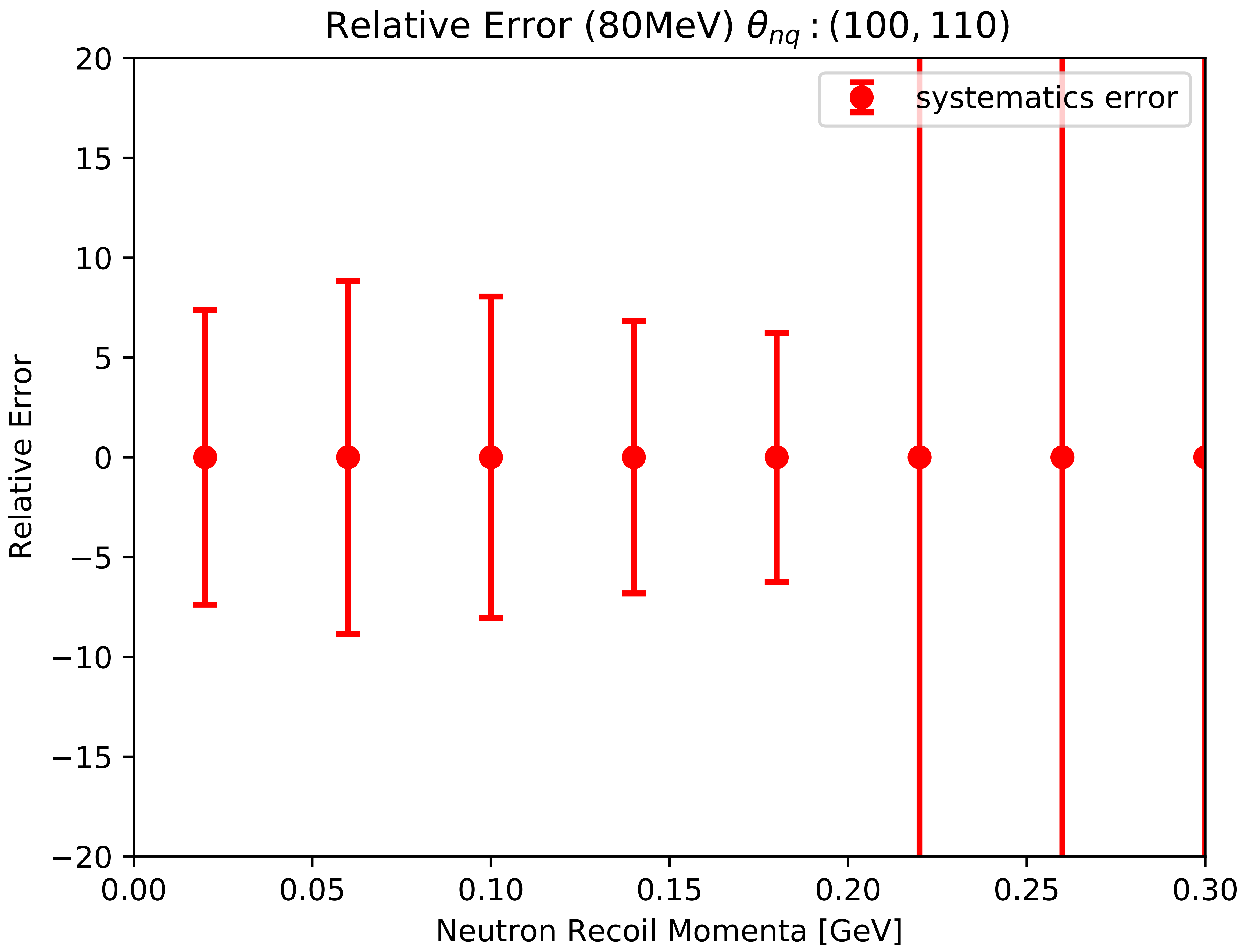

Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(90, 100)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$
15
10
5
0
−5
−10
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40



Relative Error (80MeV) $\theta_{nq}:(90,100)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30



Xsec Derivatives $P_m$=80 (set1) MeV, $\theta_{nq}:(100,110)$
Cross Section Variations [%/mrad or %/MeV]
Neutron Recoil Momenta [GeV]
$\frac{d\sigma}{d\theta_e}$
$\frac{d\sigma}{d\theta_p}$
$\frac{d\sigma}{dE_f}$
$\frac{d\sigma}{dE_b}$
25
20
15
10
5
0
−5
−10
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40



Relative Error (80MeV) $\theta_{nq}:(100,110)$
systematics error
Relative Error
Neutron Recoil Momenta [GeV]
20
15
10
5
0
−5
−10
−15
−20
0.00
0.05
0.10
0.15
0.20
0.25
0.30