JLab Hall C Experiment E12-10-002:
Cross Section Extraction from H(e,e') and D(e,e')

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OutLine :

- Drift Chamber development
- Optimization of tracking parameters
- BCM calibration
- Cross-section extraction method
- Results
  - p, d Cross-sections
  - p, d F_2 structure function
  - Duality averaging results
- Summary

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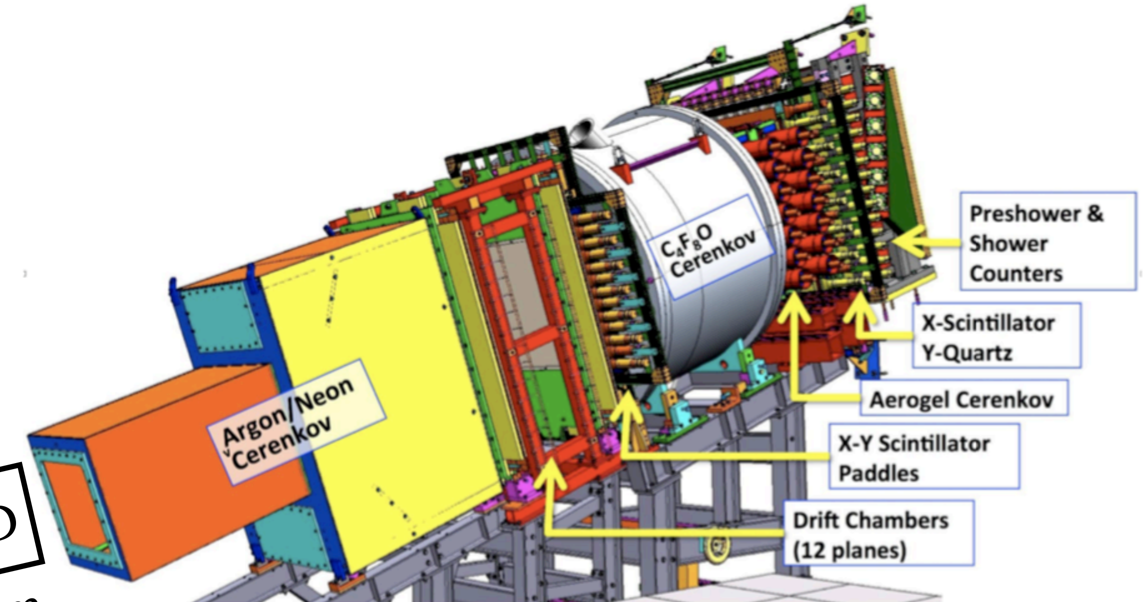
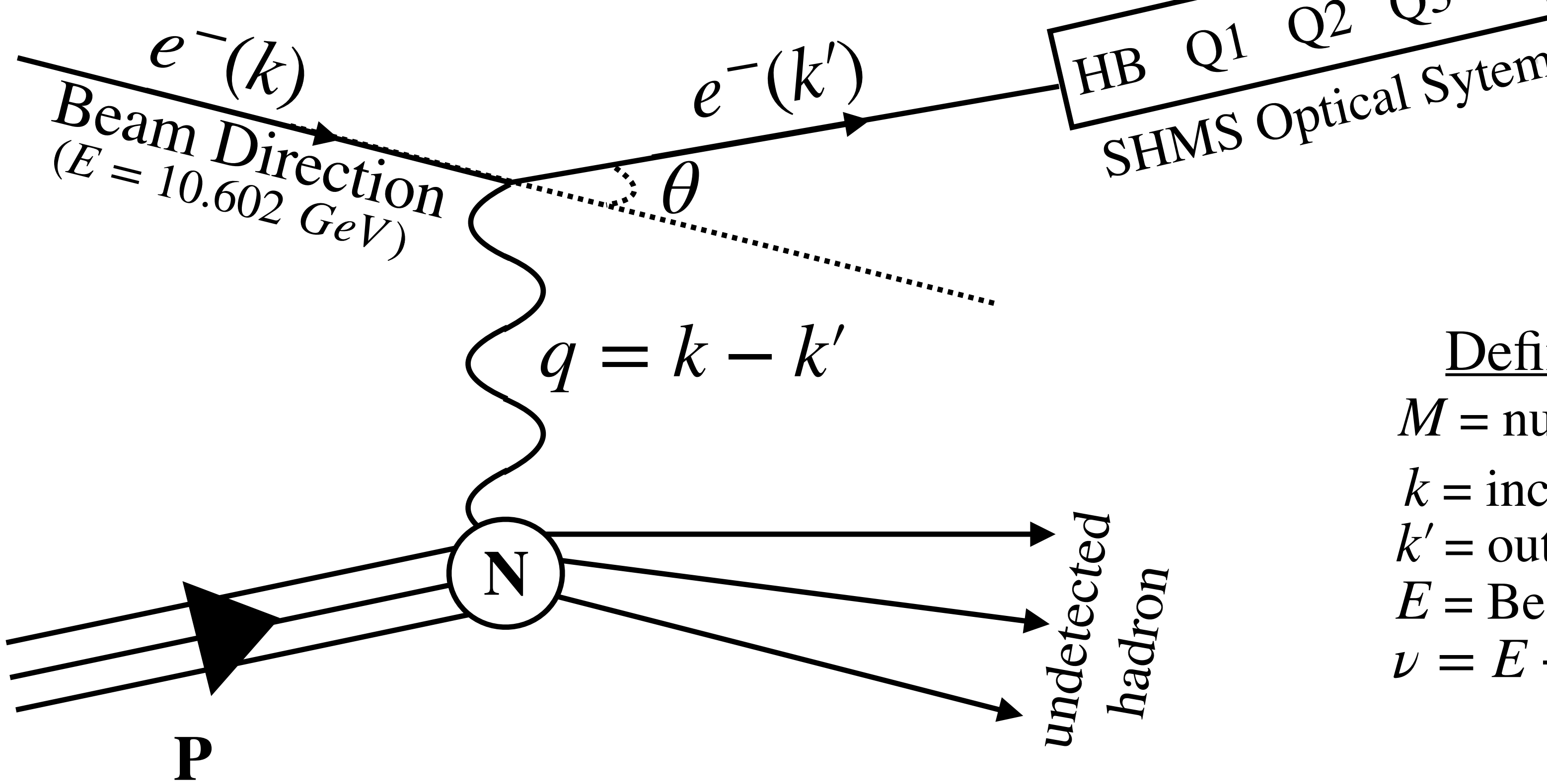
E12-10-002 : inclusive electron-nucleon scattering experiment in Hall C

- Ran in the spring 2018 in parallel with EMC
- Targets LH2, LD2, Al



<u>Basic Feynman diagram for deep inelastic electron-proton scattering</u>



<u>Definitions of several kinematic variables</u>

M = nucleon mass

k = incoming electron four momenta

k' = outgoing scattered electron four momenta

E = Beam energy, E' = recoil energy of electron

$\nu = E - E'$ = virtual photon energy

$$Q^2 = 4EE'Sin^2\frac{\theta}{2}$$

Square of 4-momentum transfer

$$X = \frac{Q^2}{2M\nu}$$

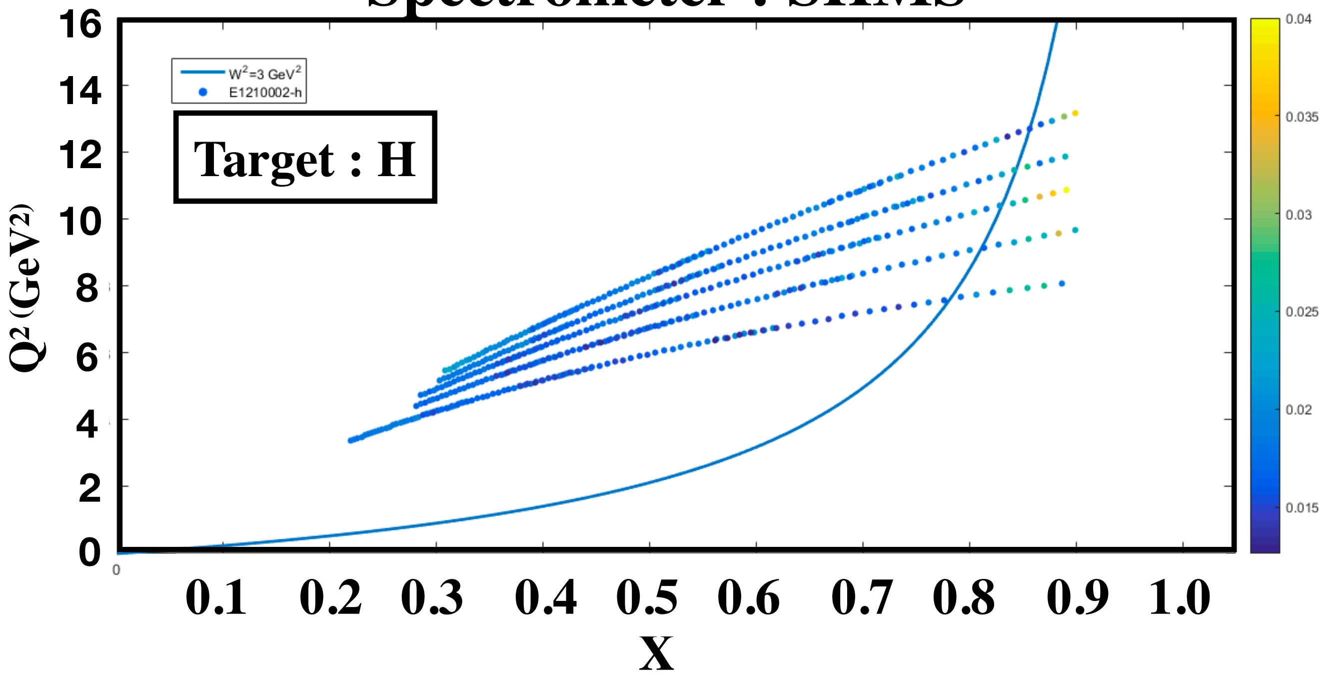
Bjorken X

$$W^2 = M^2 + 2M\nu - Q^2$$

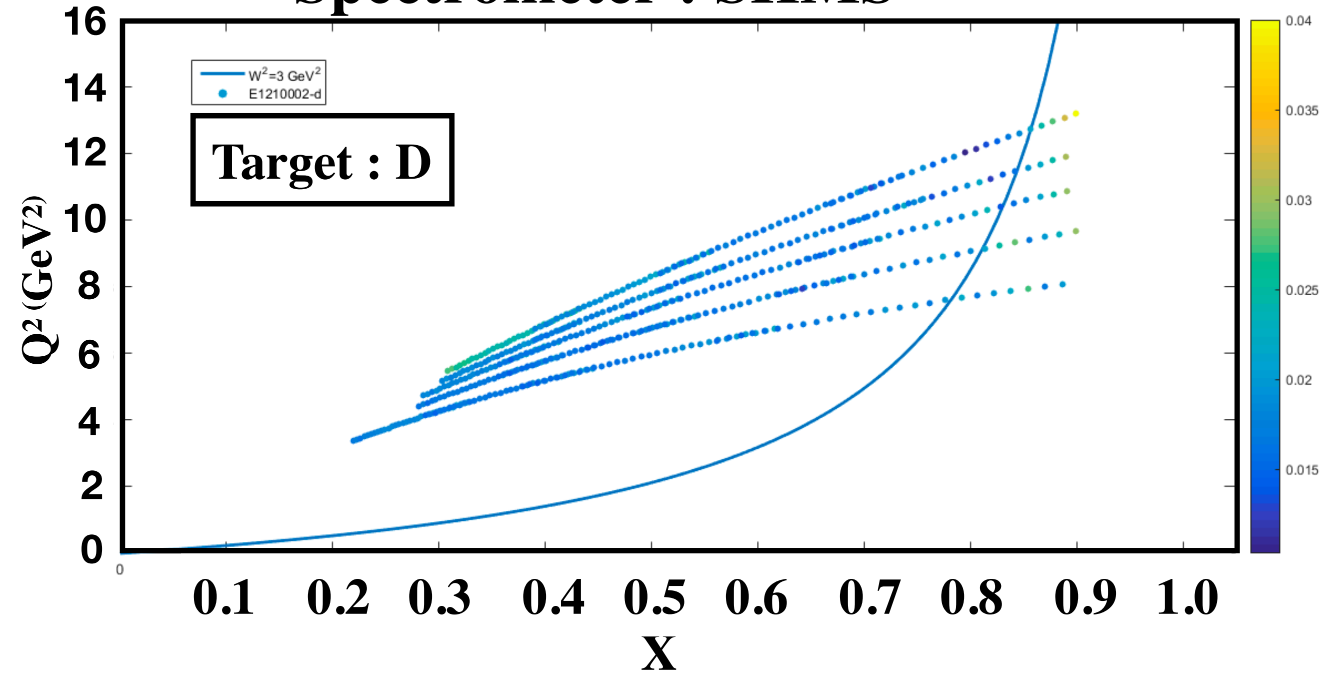
Invariant mass squared of final hadronic states

Kinematic Coverage

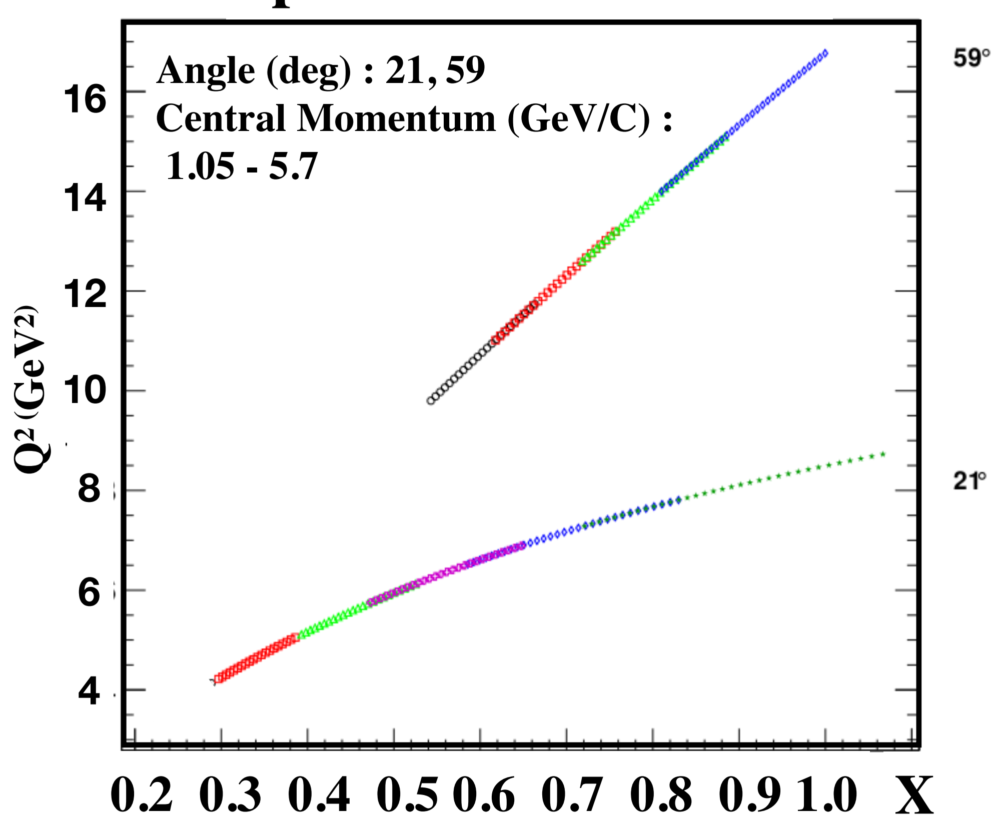
Spectrometer : SHMS



Spectrometer : SHMS

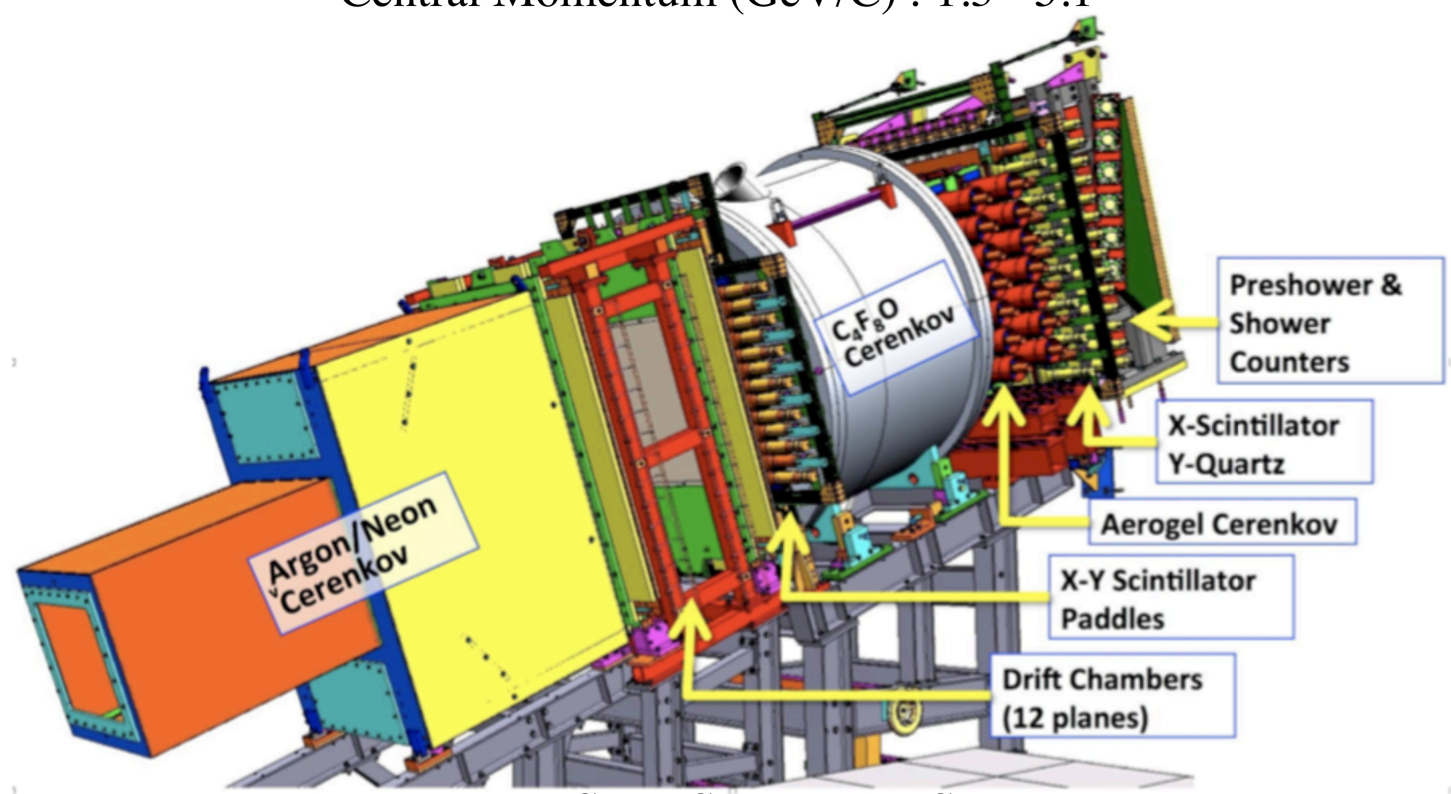


Spectrometer : HMS



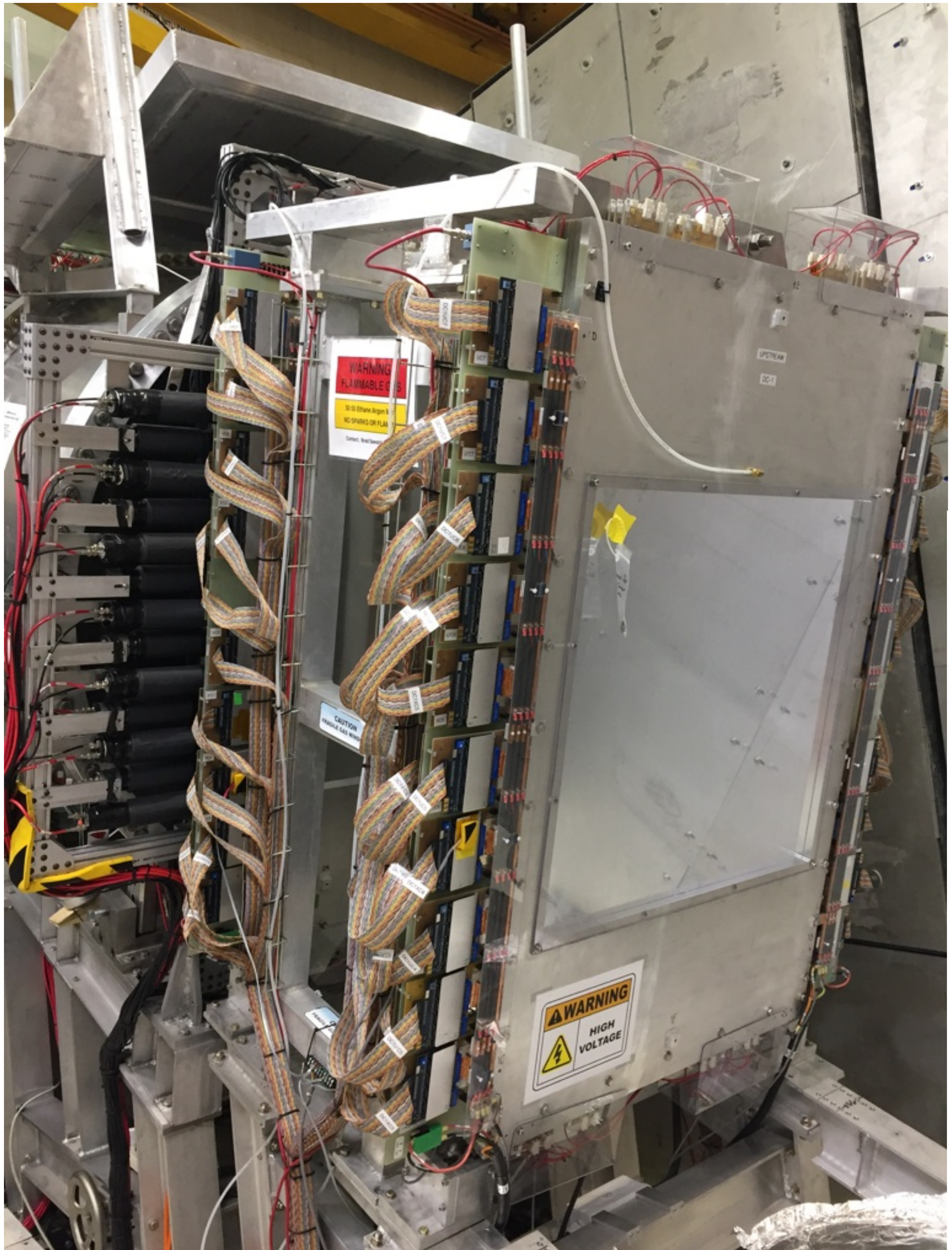
- HMS pushed the data to higher Q^2 up to 16 GeV^2
- HMS 21 deg : to cross calibrate with SHMS data

- Angle (deg) : 21, 25, 29, 33, 39
- Central Momentum (GeV/C) : 1.3 - 5.1



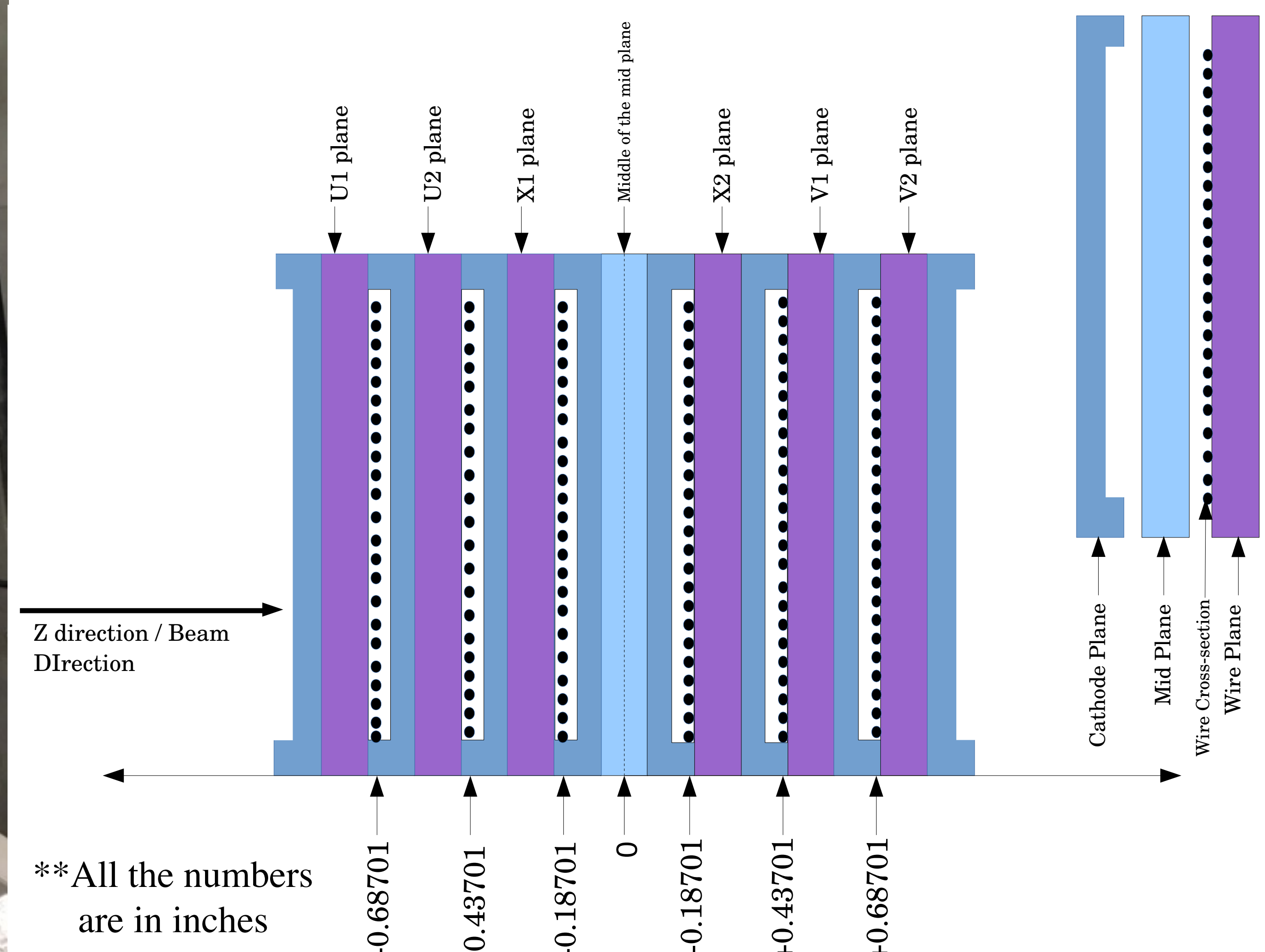
SHMS Detector System
71% data were taken by SHMS,

Drift Chamber Construction



- Total 3 Drift Chambers were made by Dr. M. Eric Christy’s group at Hampton University. 2 of them are installed in SHMS.
- Each of the drift chambers were consists 6 wire planes : 2 U, 2 X and 2 V planes
- The chamber is separated into two parts by a mid plane
- Between each of two consecutive wire planes there is a cathode plane
- The whole chamber is sandwiched between the two aluminum plates for overall structural support and dowels

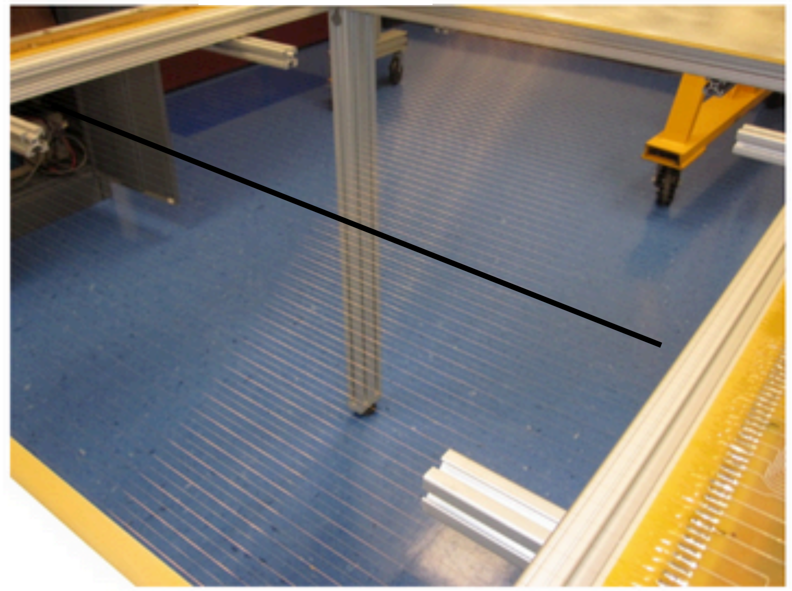
Cartoon Cross Section of a Drift Chamber



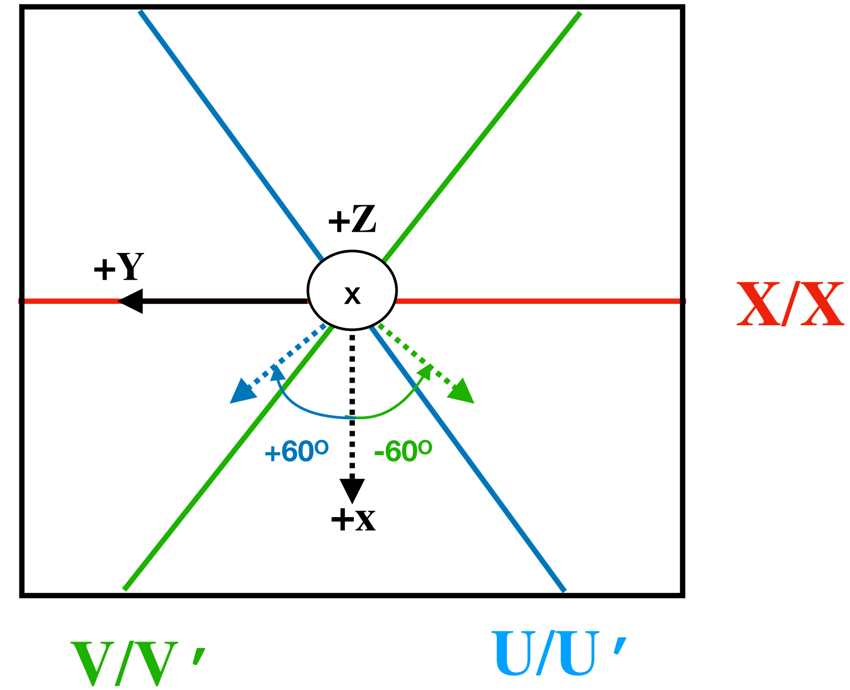
Drift Chamber Construction

U/V-Plane

X-Plane

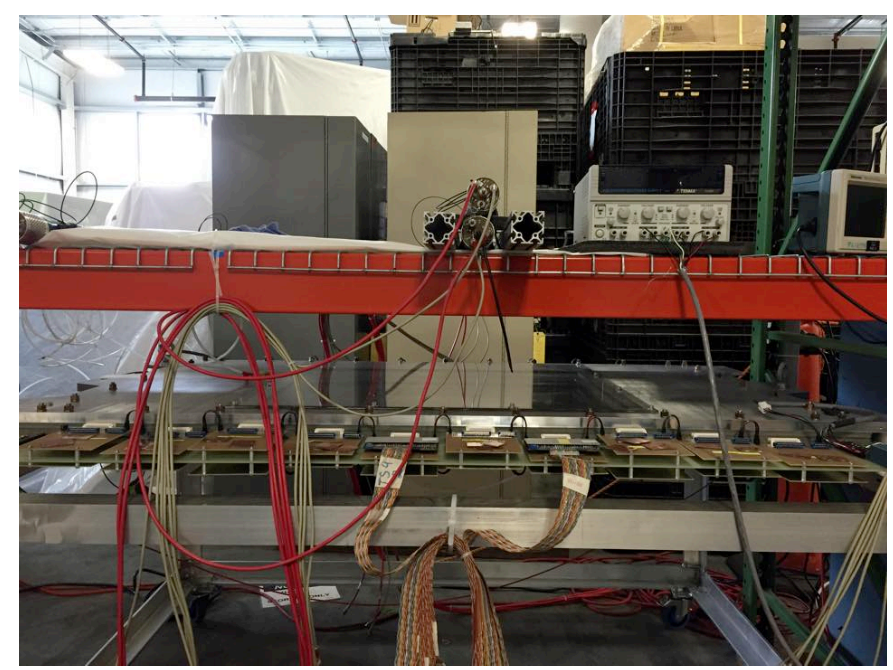


Orientation of wires



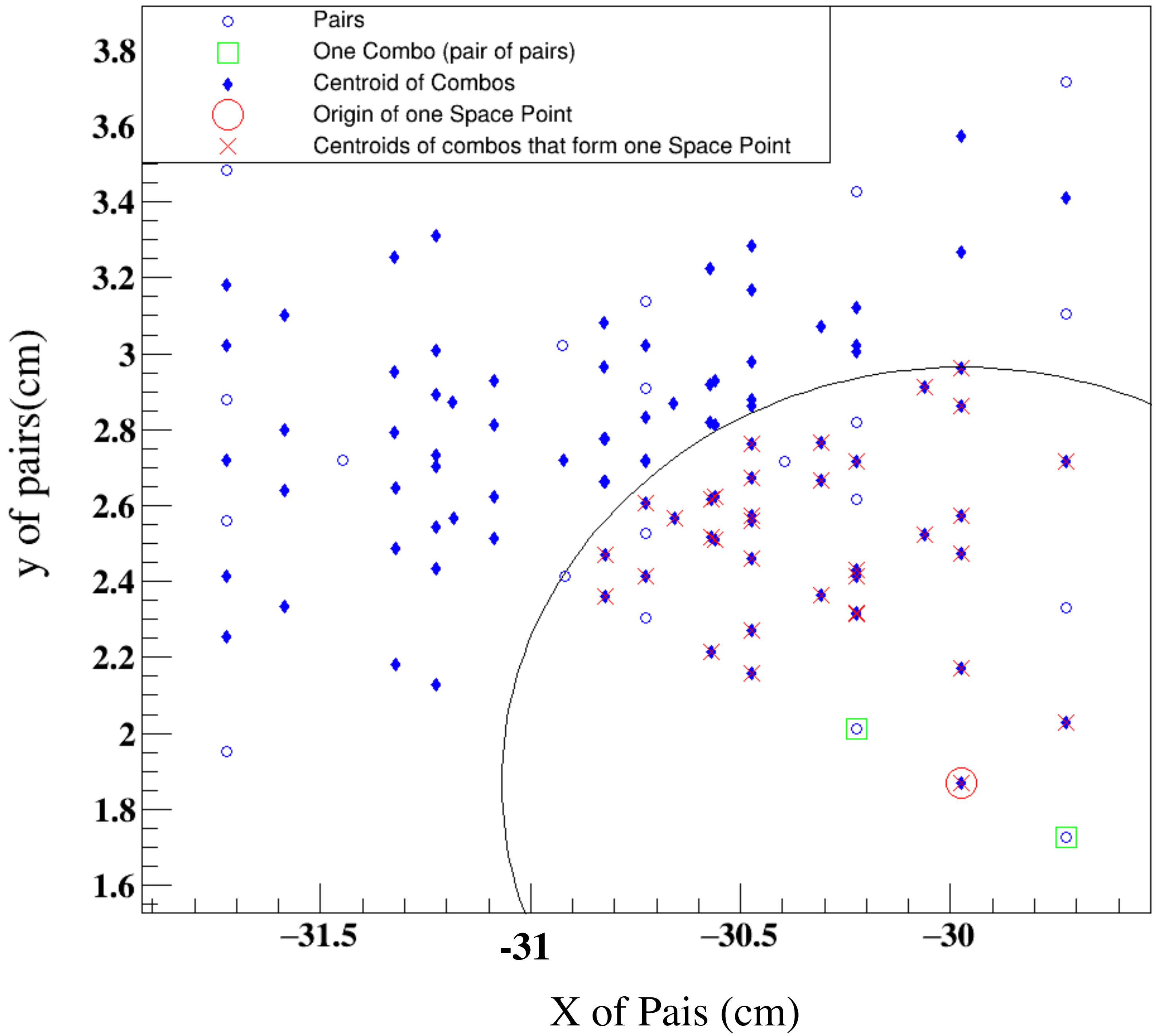
- The active area of the each chamber is 80 cm X 80 cm
- The U/U' wires are at +60° with the dispersive direction
- The V/V' wires are at -60° with the dispersive direction
- The X/X' wires are at 90° with the dispersive direction
- The prime (U',V',X') wires are shifted by 0.5 cm from the unprimed (U,V,X) wires to remove the left-right ambiguity
- Each wire plane has alternative sense wire (20 μm gold tungsten) and field wire (80 μm copper plated beryllium). The consecutive sense and field wire is separated by 0.5 cm
- The cathode planes surfaces are of 5 mil thick stretched foils of copper plated Kapton
- The cathode plane and the field wires are at ~ -1940 Volts
- The whole chamber is filled with 50:50 argon/ethane

Test stand at Jefferson Lab



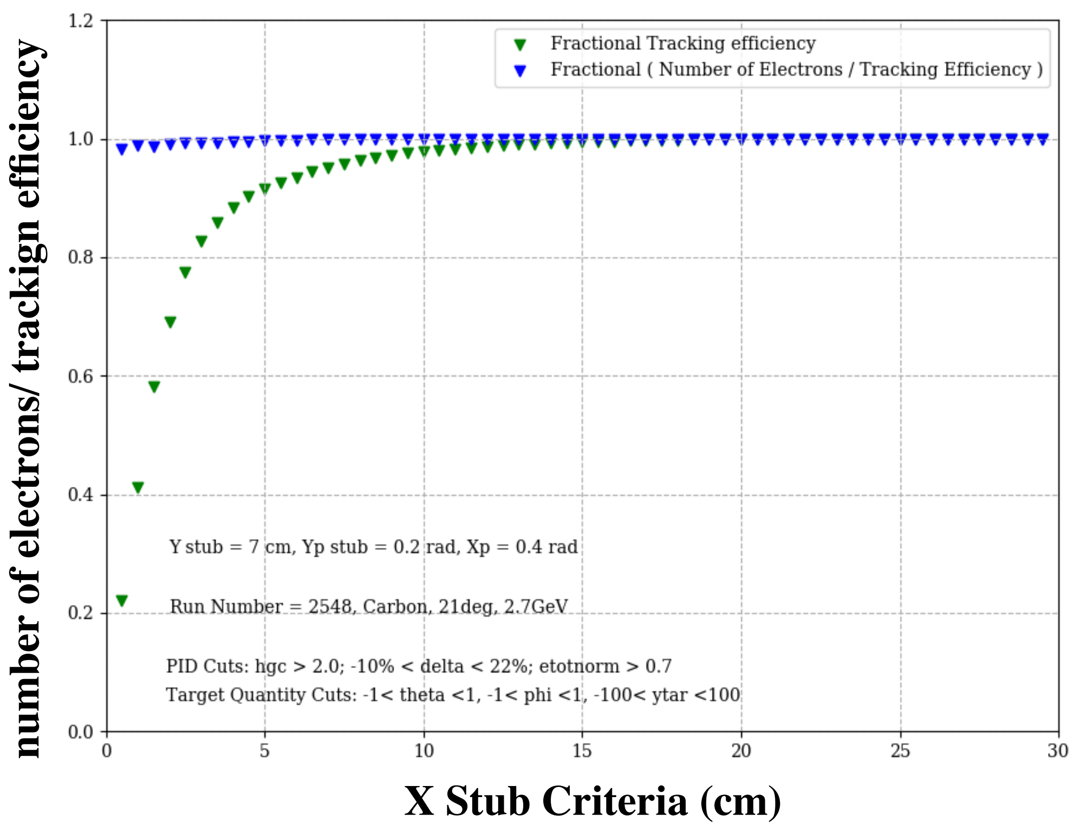
Optimization of Tracking Parameters

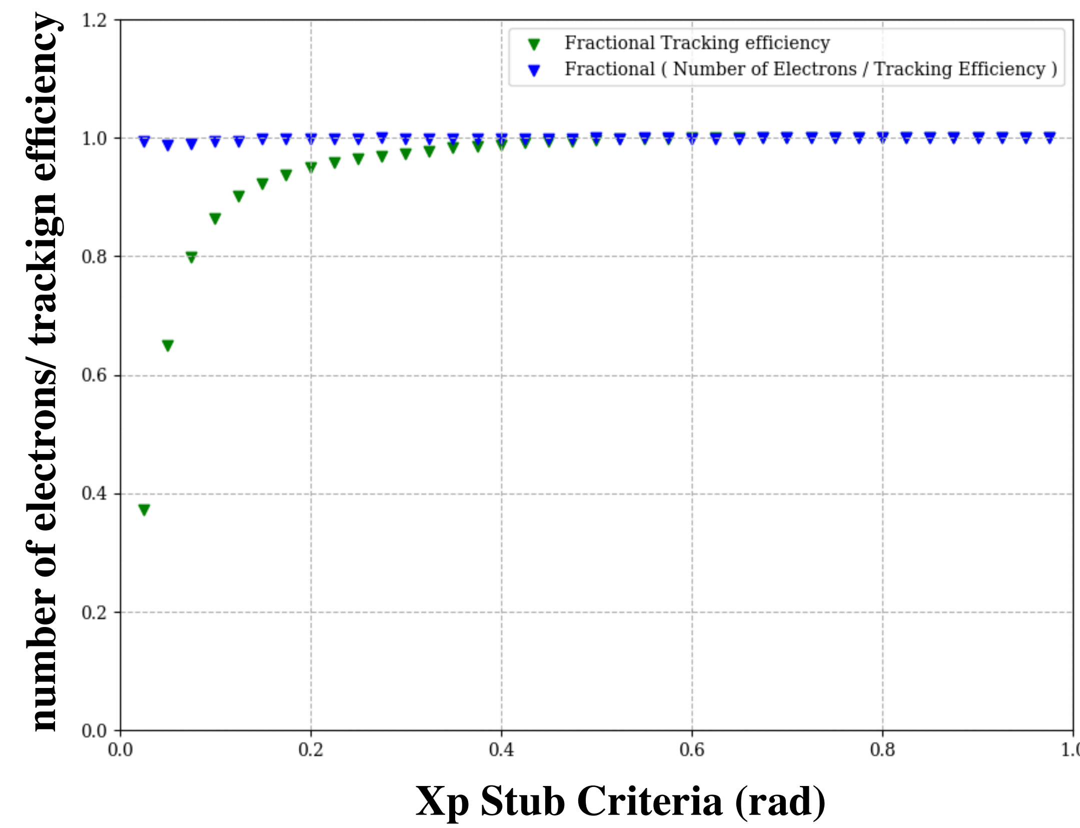
x vs y of pairs : Run Number - 2484, Event - 19th

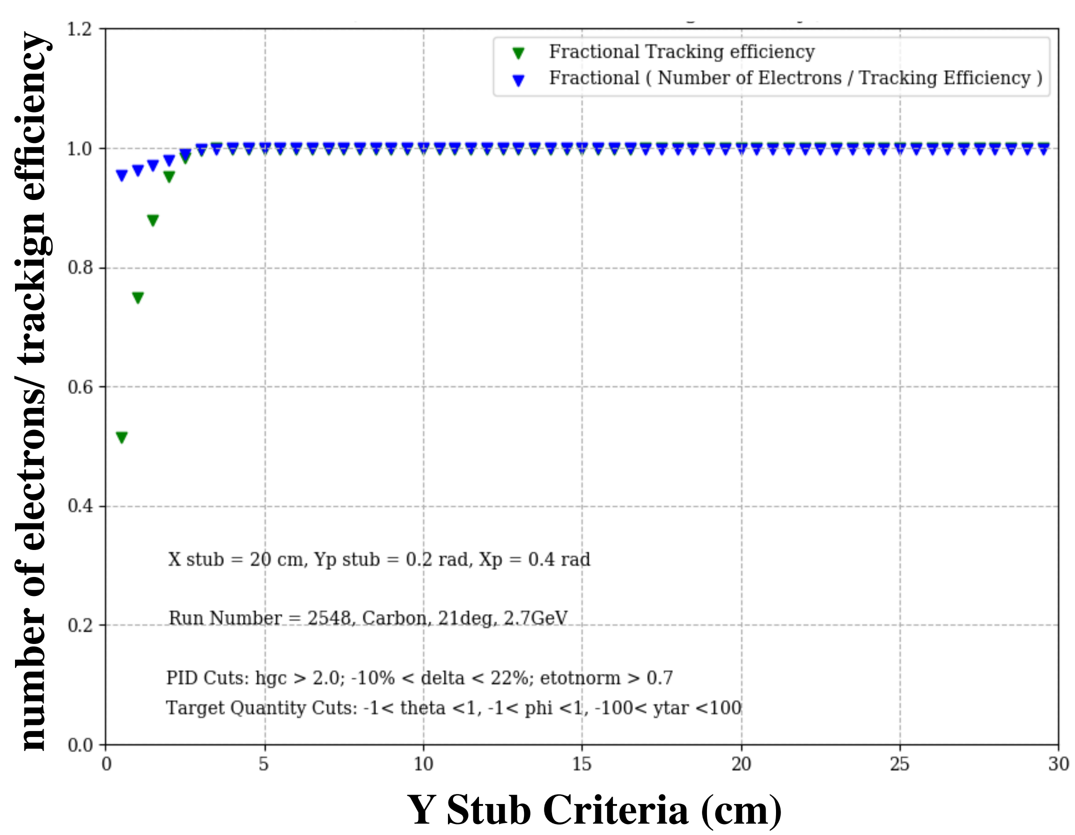


- ***Pair :*** crossing of two wires if the angle between the wires are greater than 17.5^{o} (blue circle in the picture)
- ***Combo :*** pair of two *Pairs* (The green square shows a pair of pairs which forms a *Combo*. The blue diamonds are the centroid of the *Combos*)
- A *Pair* can be shared between two Combos.
- ***Space Point :*** The tracking algorithm takes the first *Combo* centroid and together with other *Combos* which fall within the 1.2 cm (***Space point criteria***) makes a *Space Point*
- The tracking algorithm then loops over all the space points links them into a track using a χ^2 minimization fit
- Different ***stub parameters*** need to have an optimized value while inking space points into tracks so that ghost tracks can be eliminated but keeping all the real tracks

Optimization of Tracking Parameters







- To remove the ghost tracks and at the same time keeping the tracking efficiency as high as possible it is important to optimize the tracking parameters
- The tracking efficiency is very much sensitive to the stub parameters
- A particular stub parameter are varied (while keeping any other parameter constant) from a very low to very high value and plotted against tracking efficiency and (number of detected electrons/tracking efficiency)
- The value of the parameter is chosen where the tracking efficiency is flat and (number of electrons/ tracking efficiency) is just becoming flat

BCM Calibration

- BCM : Microwave Cavity Beam Current Monitor
- This is cylindrical waveguide, placed in way in beam line that beam goes along the axis of the cylinder
- Beam excites the resonant modes in the cylindrical wave guide
- The wire loop antennas pick up the signal
- Though the signal is proportional to the beam current squared, for certain modes (e.g. TM_{010}) the signal is relatively insensitive to the beam position
- To optimize this measurement the cavity size and the material can be chosen in such a way so that TM010 mode is identical to accelerator RF frequency
- There are 5 BCM s : BCM 1 , BCM 2 , BCM 4A, BCM 4B, BCM 17

Advantages

- Relatively stable offset
- High Signal / Noise Ratio

Disadvantages

- Cannot measure the absolute gain
- Gain may varies with time

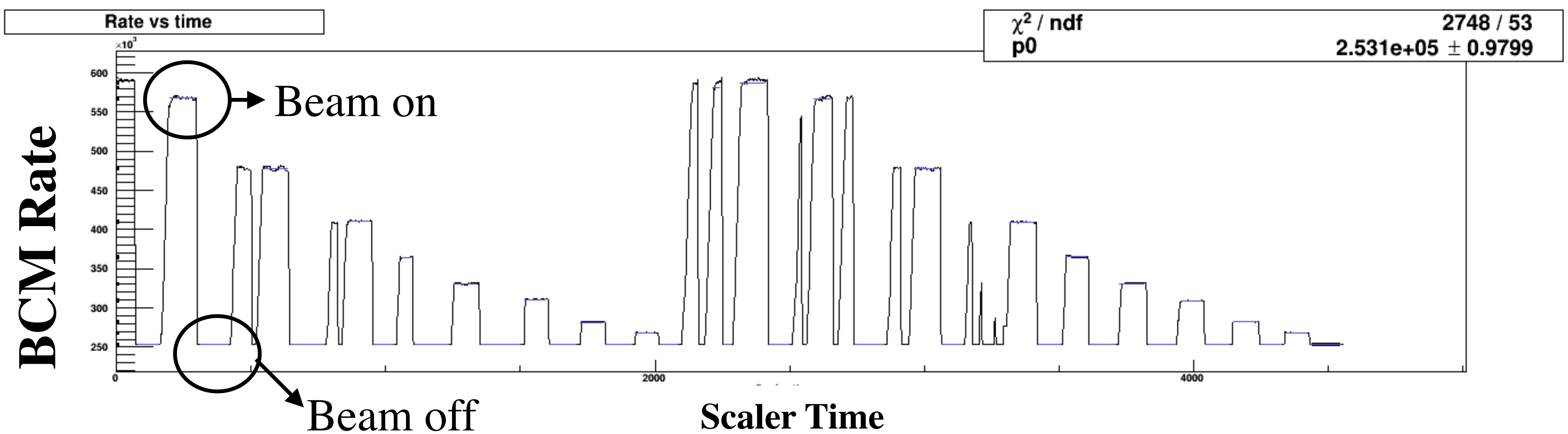
Hence we use Unser to Calibrate the BCMs

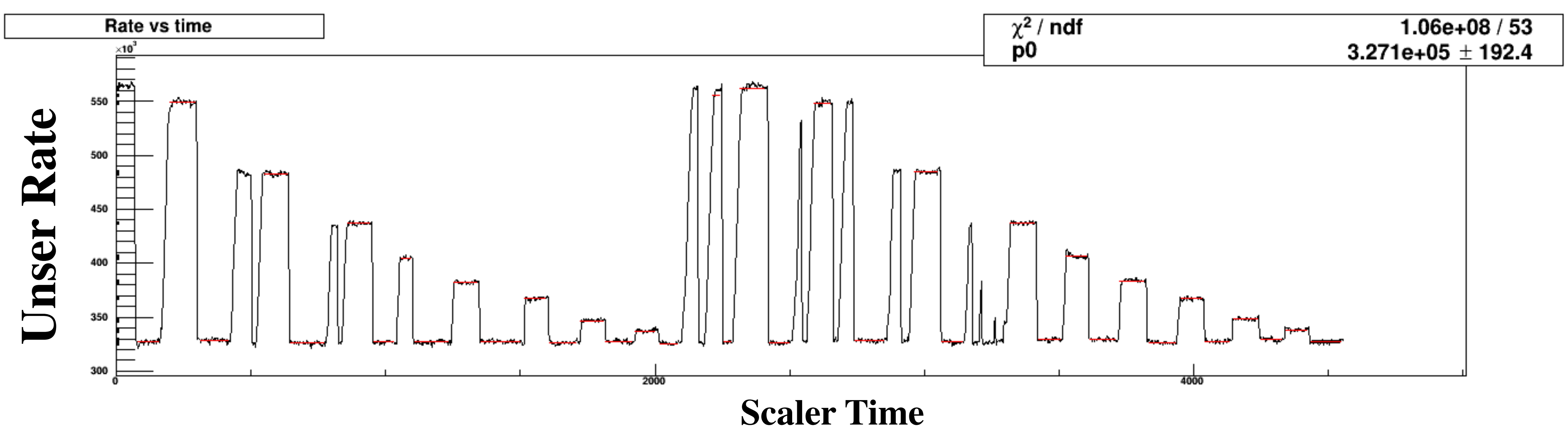
Unser

- Unser is toroidal transformer placed in a feedback loop of an operational amplifier
- Sensitive to DC currents
- Not very sensitive to environmental factors : Magnetic fields, EM interference , Mechanical vibration etc …
- Unser has *very stable and well measured gain*
- Its *zero offset can drift over relatively short period of time*, hence cannot be used alone to measure beam current

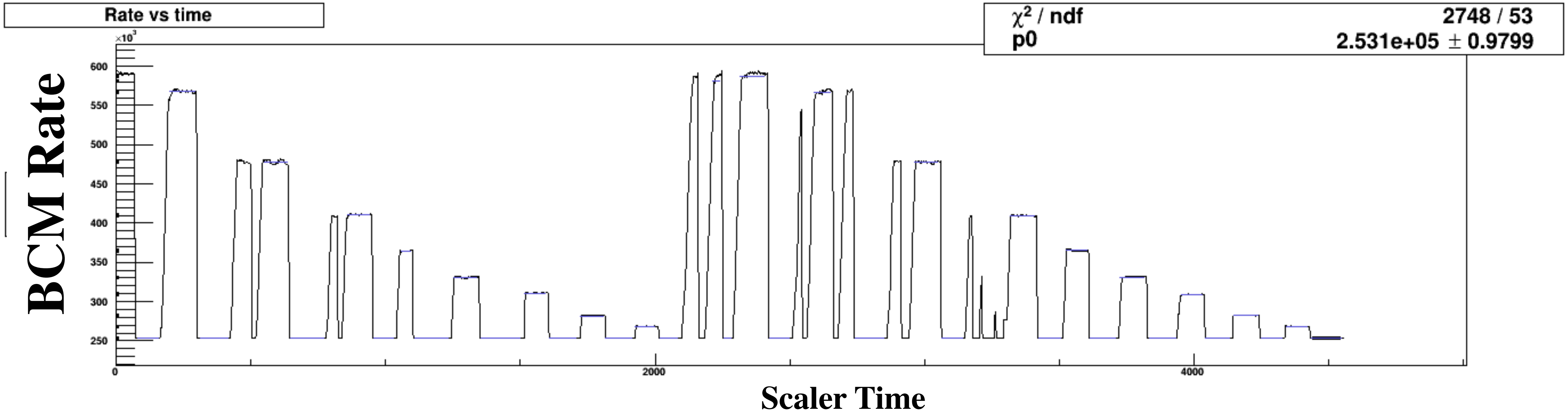
- $I = (\nu_{beam\_on} - \nu_{beam\_off})$ x $gain$; $\nu =$ frequency of the device

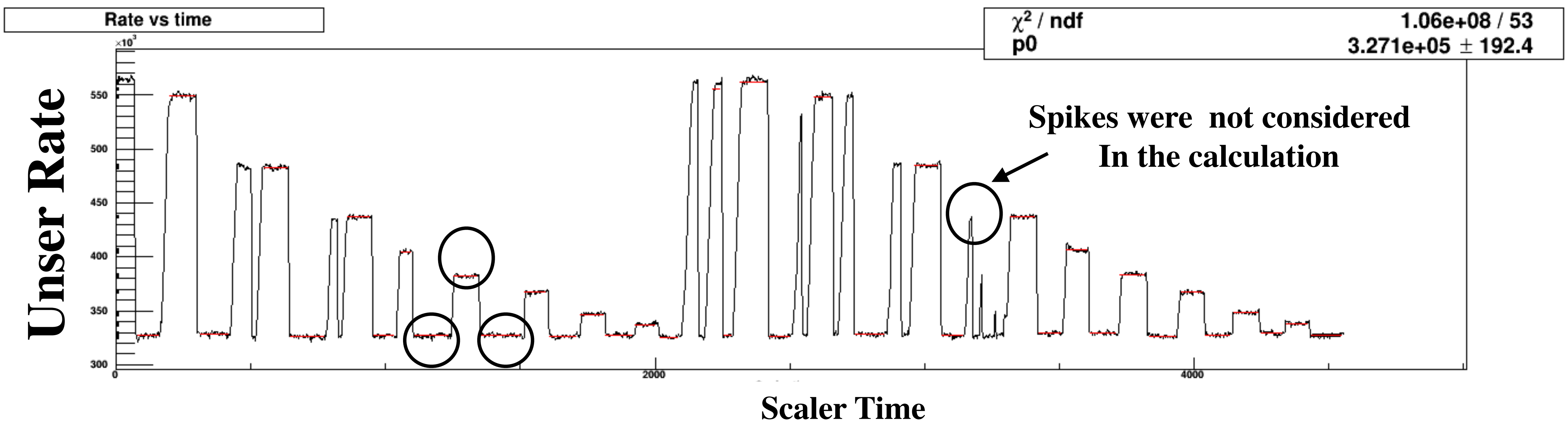
- Beam turned on and off in every 2 min period of time , beam current is incremented in certain step at every 2 min beam-on period





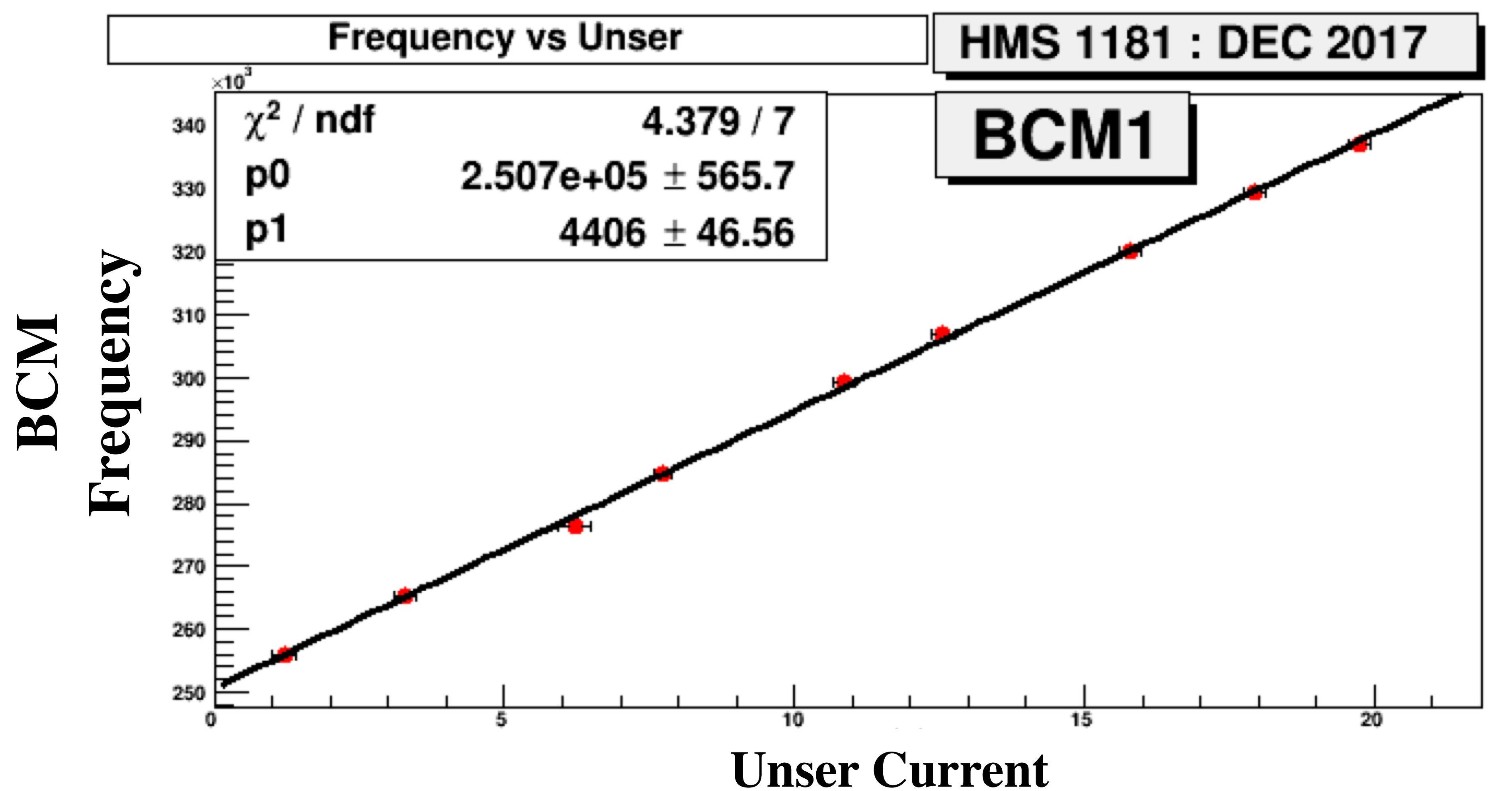
BCM Calibration





- Linear Fit (Polynomial 0) of beam-on and two beam-off positions on each side
- Average the mean values of the fit from the beam-off position
- Subtract from the mean of the beam-on position

- Unser current = Unser frequency x Unser gain
- Unser gain is calculated from the measurement done before BCM study
- Unser current vs BCM frequency is plotted and fitted with a straight line
- BCM Gain and Offset (p0 and p1) are the two fit parameters of the Linear Fit



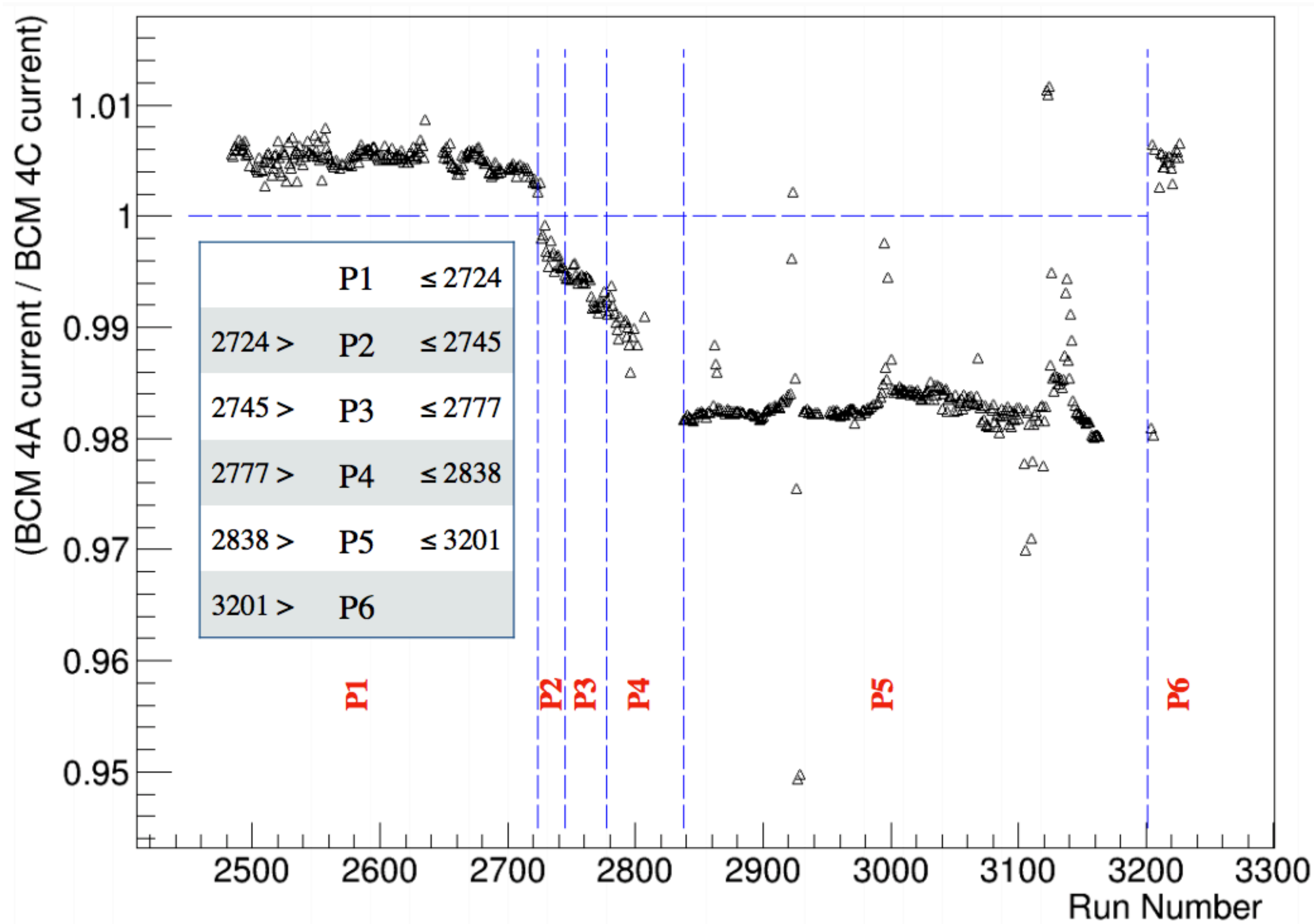
BCM Calibration Data : Time Line

December 17, 2017	**Run No : HMS 1181, HMS 1178**
January , 2018	**Run No : COIN 1892**
March 5, 2018	**Run No : SHMS 2757**
May 5, 2018	**Run No : 4322**

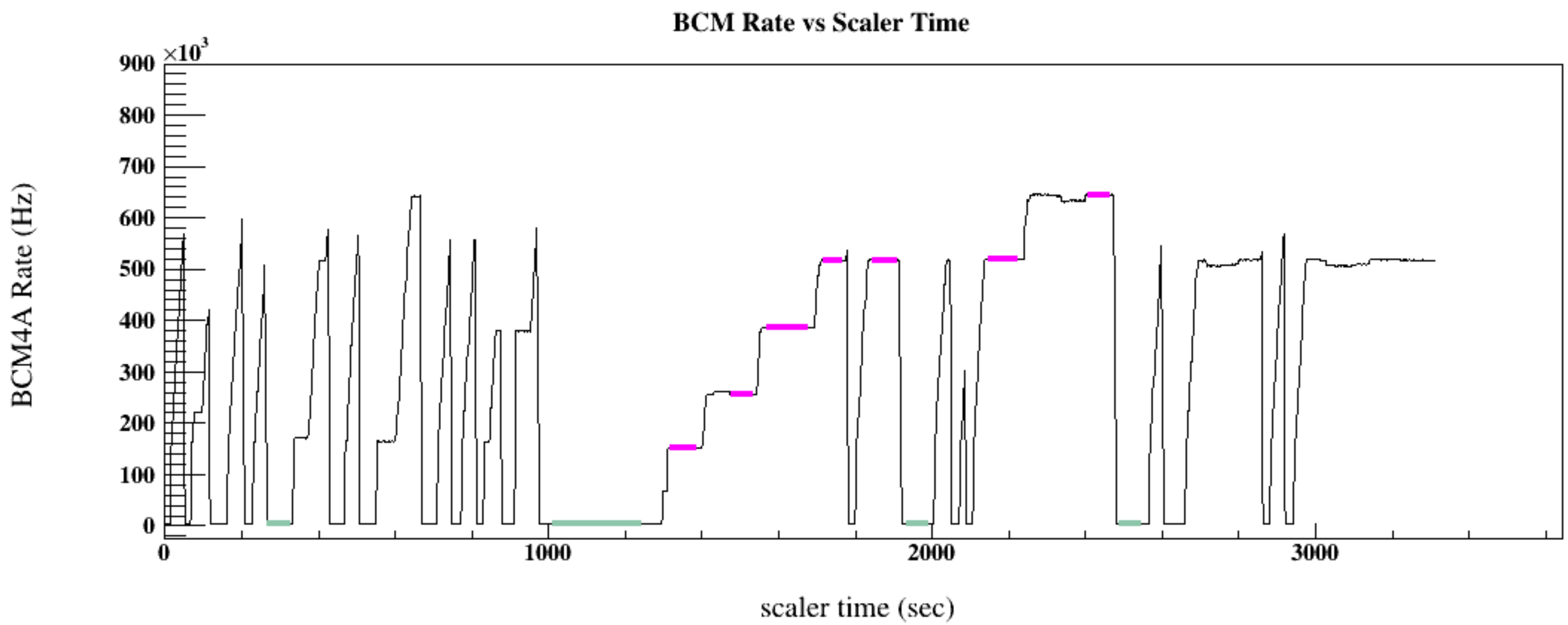
Question : How did the 5 BCMs do ?

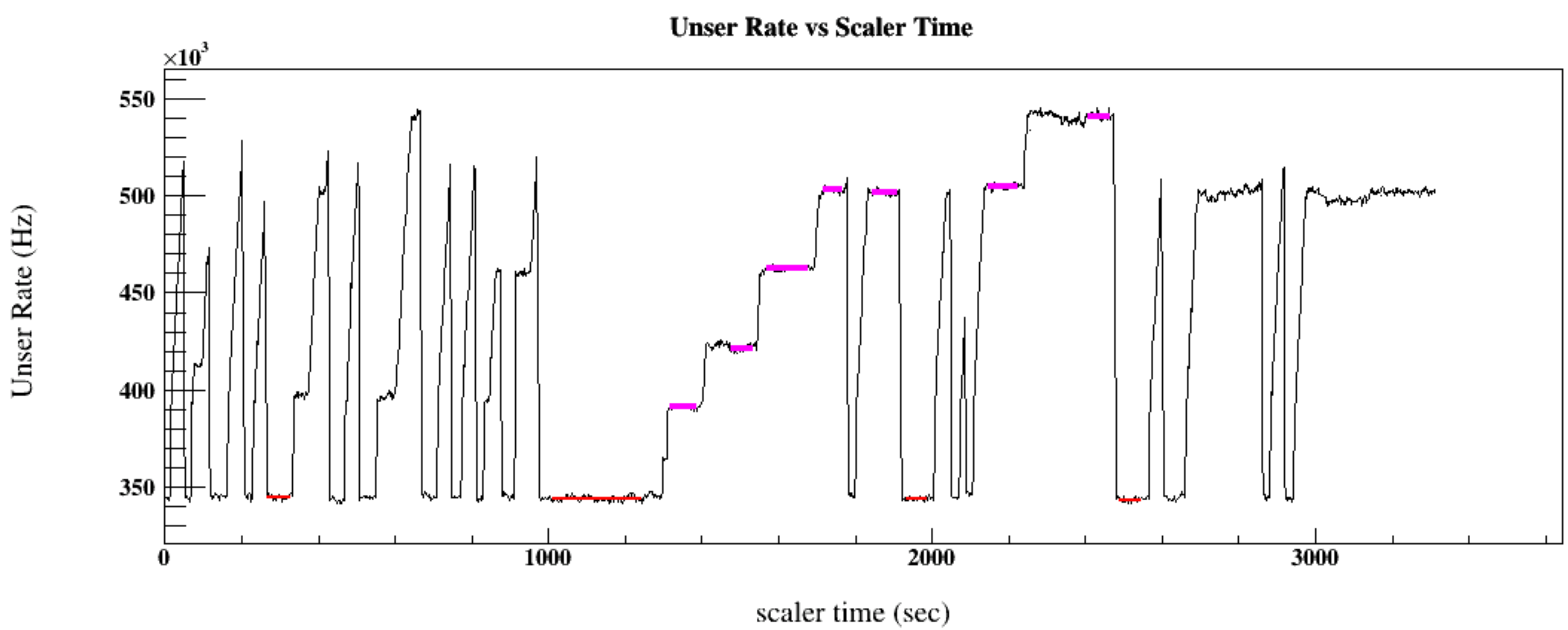
- Each BCM is calibrated for each time period separately
- Disagreement between the same BCM from different Time period
- Global Fit : Took all data from all periods for a particular BCM then calibrate

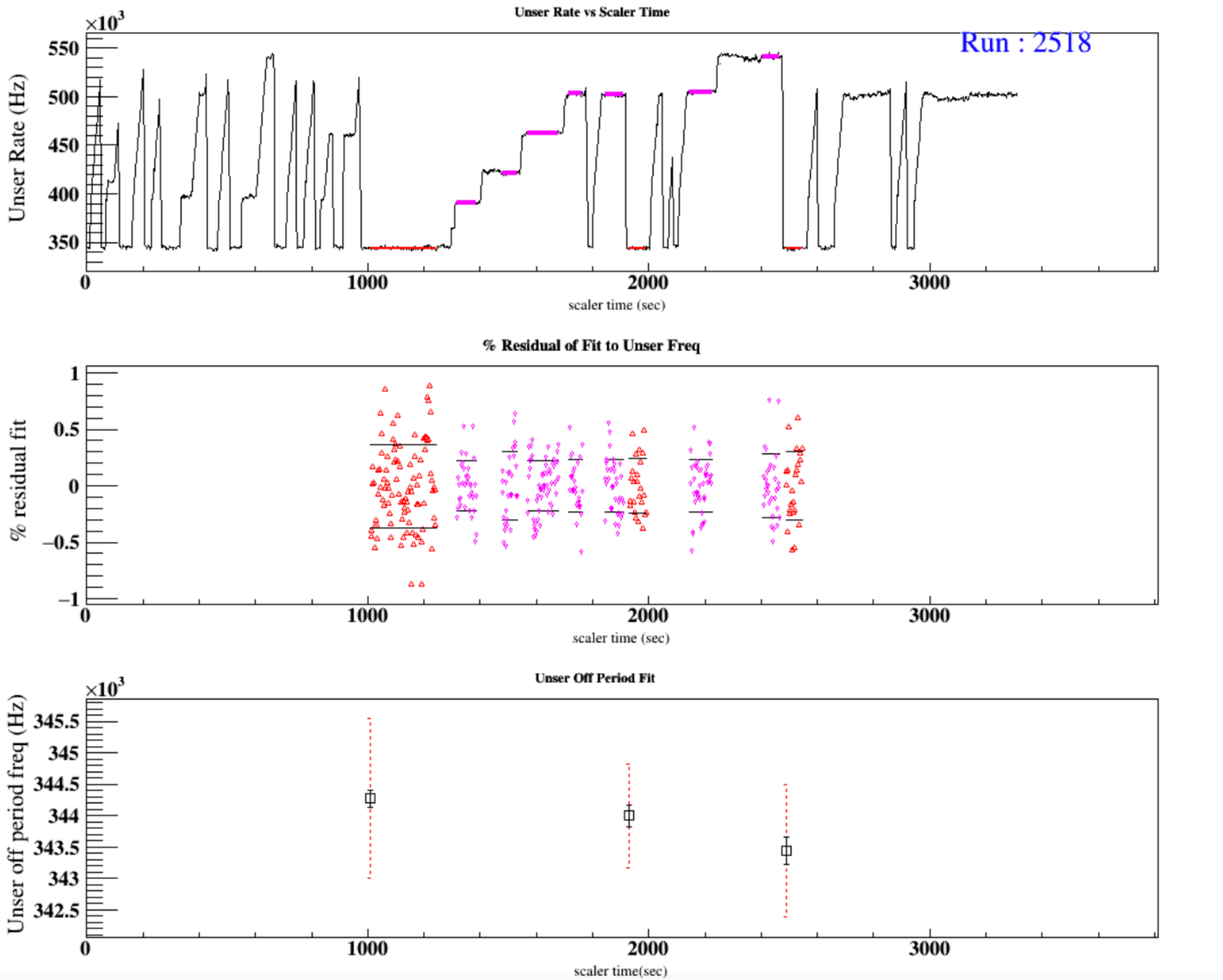
BCM Calibration



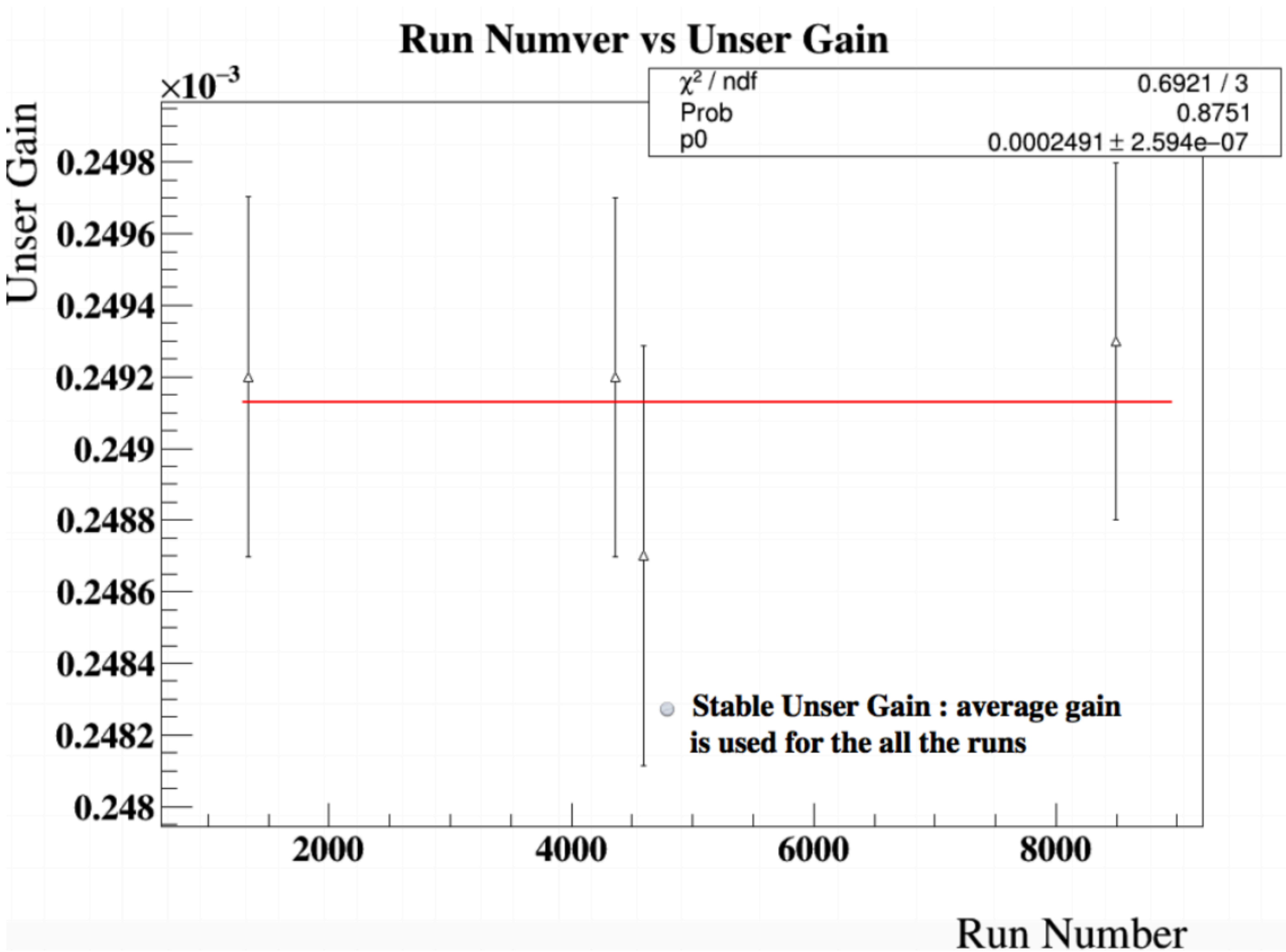
BCM Calibration

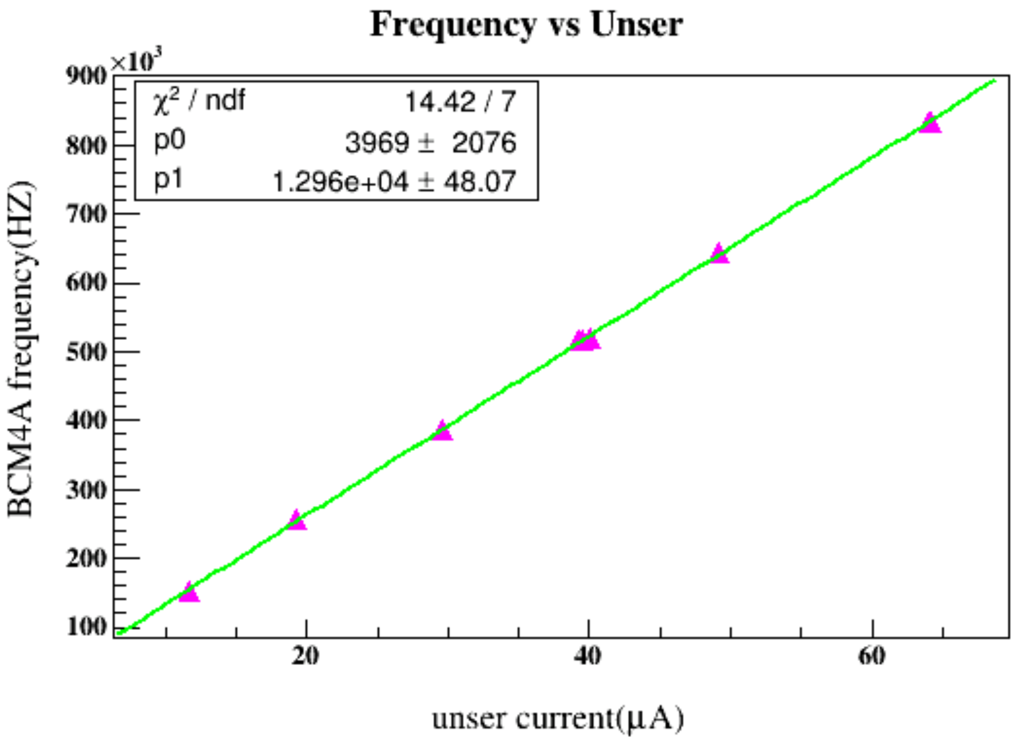


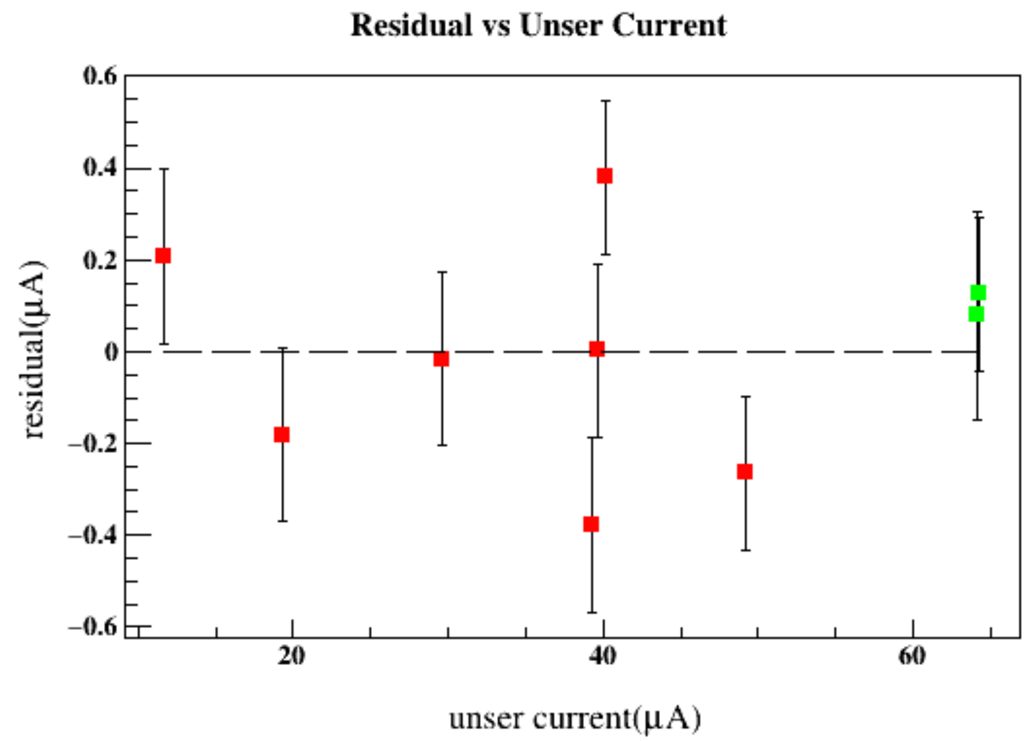


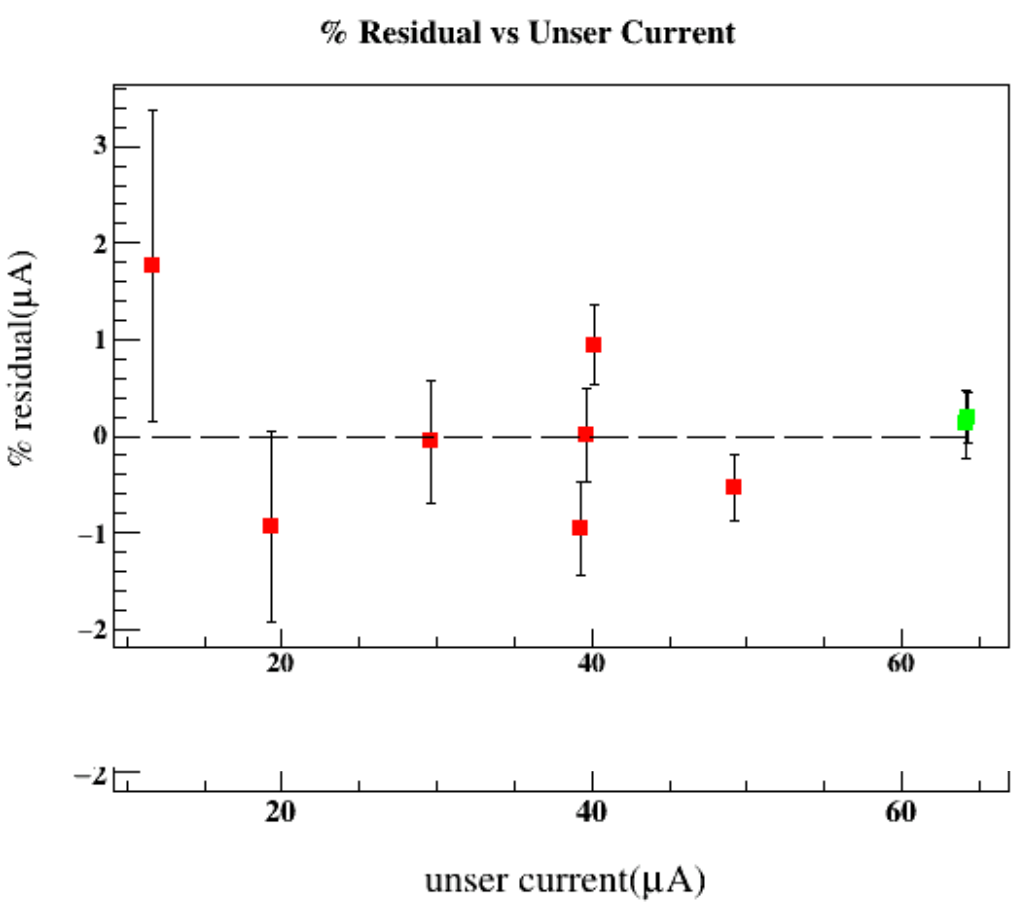

Unser Rate vs Scaler Time
Run : 2518
Unser Rate (Hz)
×10³
scaler time (sec)
% Residual of Fit to Unser Freq
% residual fit
scaler time (sec)
Unser Off Period Fit
Unser off period freq (Hz)
×10³
scaler time(sec)

Stable Unser Gain









PERIOD : P1

Run : 2518

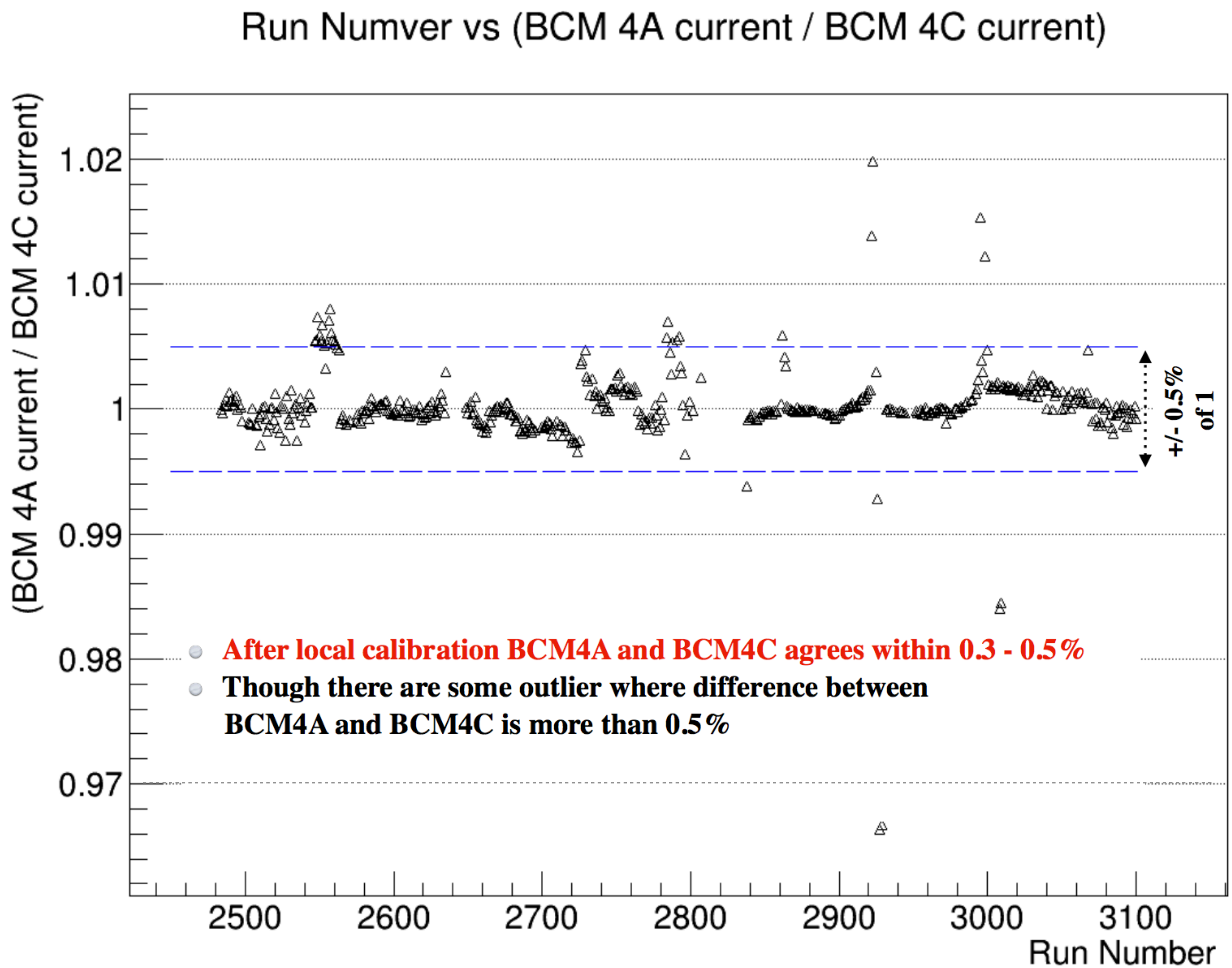
Run : 2675

List of Gains and Offsets along with corresponding errors for all periods

BCM4A	gain	Δgain	offset	Δoffset
P1	12960	48.07	3969	2076
P2	13313.4	118.198	-19725.4	6413
P3	13520	37.35	1847	1197
P4	12772.4	63.541	10551.1	3750.87
P5	13223.8	71.3652	-3377.44	3836.28
P6	13128.4	110.657	-1982.1	5738.13

BCM4C	gain	Δgain	offset	Δoffset
P1	6165.56	22.88	2205.16	987.8
P2	6380	56.56	-8286	3069
P3	6522	18.01	1088	577.5
P4	6140.17	30.55	7733	1803
P5	6439.98	58.33	-1386.78	2811
P6	6238.48	52.6	-243.23	2727

BCM Calibration

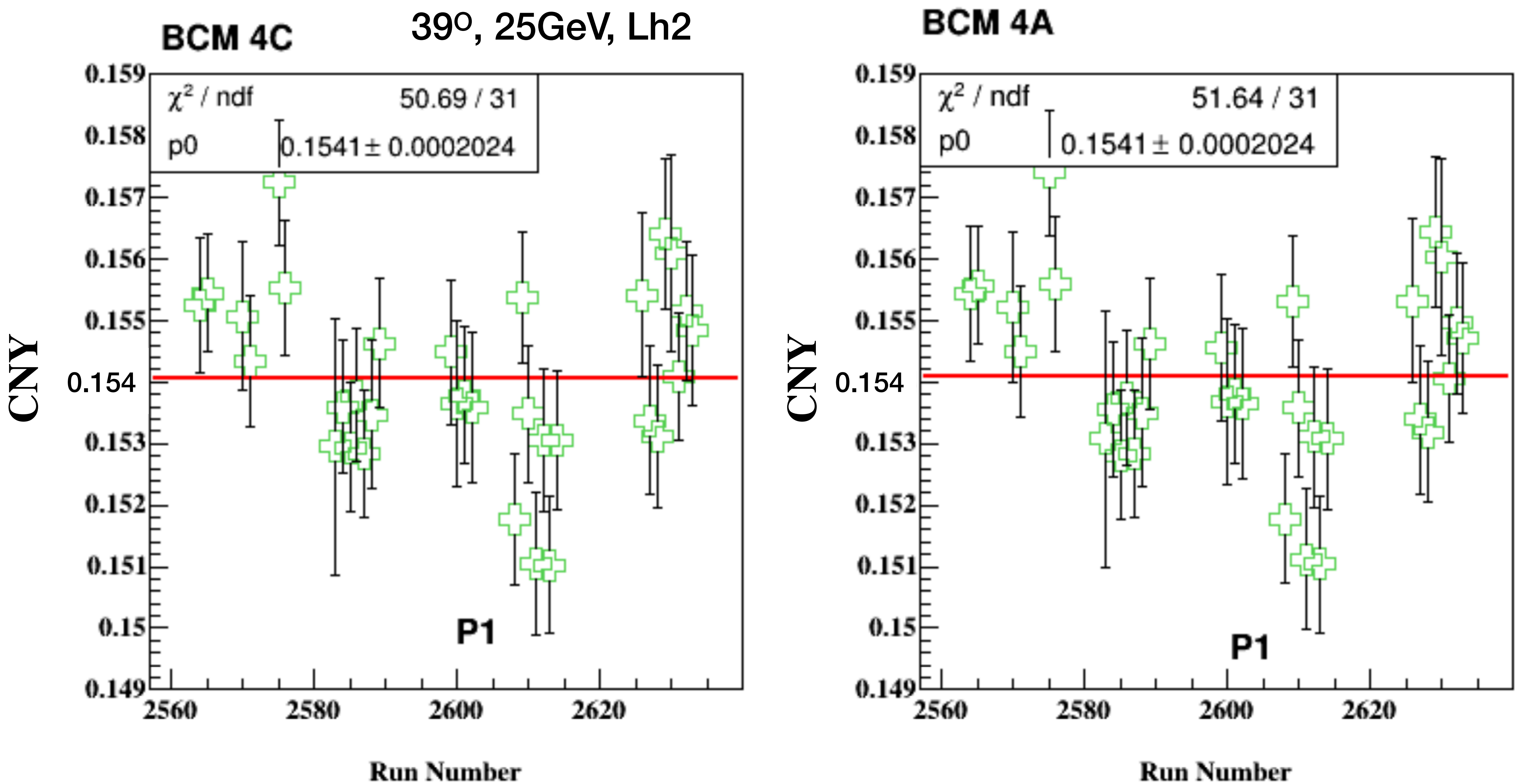


- After local calibration BCM4A and BCM4C agrees within 0.3 - 0.5%
- Though there are some outlier where difference between BCM4A and BCM4C is more than 0.5%

Still the disagreement between the BCM4A and BCM4C can't be pinned to a particular BCM!

$$\sigma \propto CNY(charge\ normalized\ yield)$$

- The CNY should be same for all the runs if the target and kinematics are exactly same
- Considering beam energy, angle, efficiencies are known with reasonable confidence
- fluctuation in CNY can be attributed to the fluctuation in charge (/ current)



Fluctuation of CNY for different runs in a single setting

All the settings does not have enough runs, hence those kinematic settings are chosen where there are enough runs for statistical purpose.

for 39^o, 2.5 GeV: χ^2/ndf: (50.69/31) : 4C < (51.64/31) : 4A => 4A fluctuates more
for 39^o, 2.0 GeV: χ^2/ndf : (43.78 /20) : 4C > (42.53/20) : 4A => 4C fluctuating more
for 33^o, 3.2 GeV: χ^2/ndf : (28.85/14) : 4C < (32.94/14) : 4A => 4A fluctuating more
for 33^o, 2.6 GeV: χ^2/ndf : (46.1 /10) : 4C > (40.92/10) : 4A => 4C fluctuating more

Indicates the fluctuation in ratio cannot be the just due to one single BCM

So the next question is how to assert the uncertainty to the charge ?

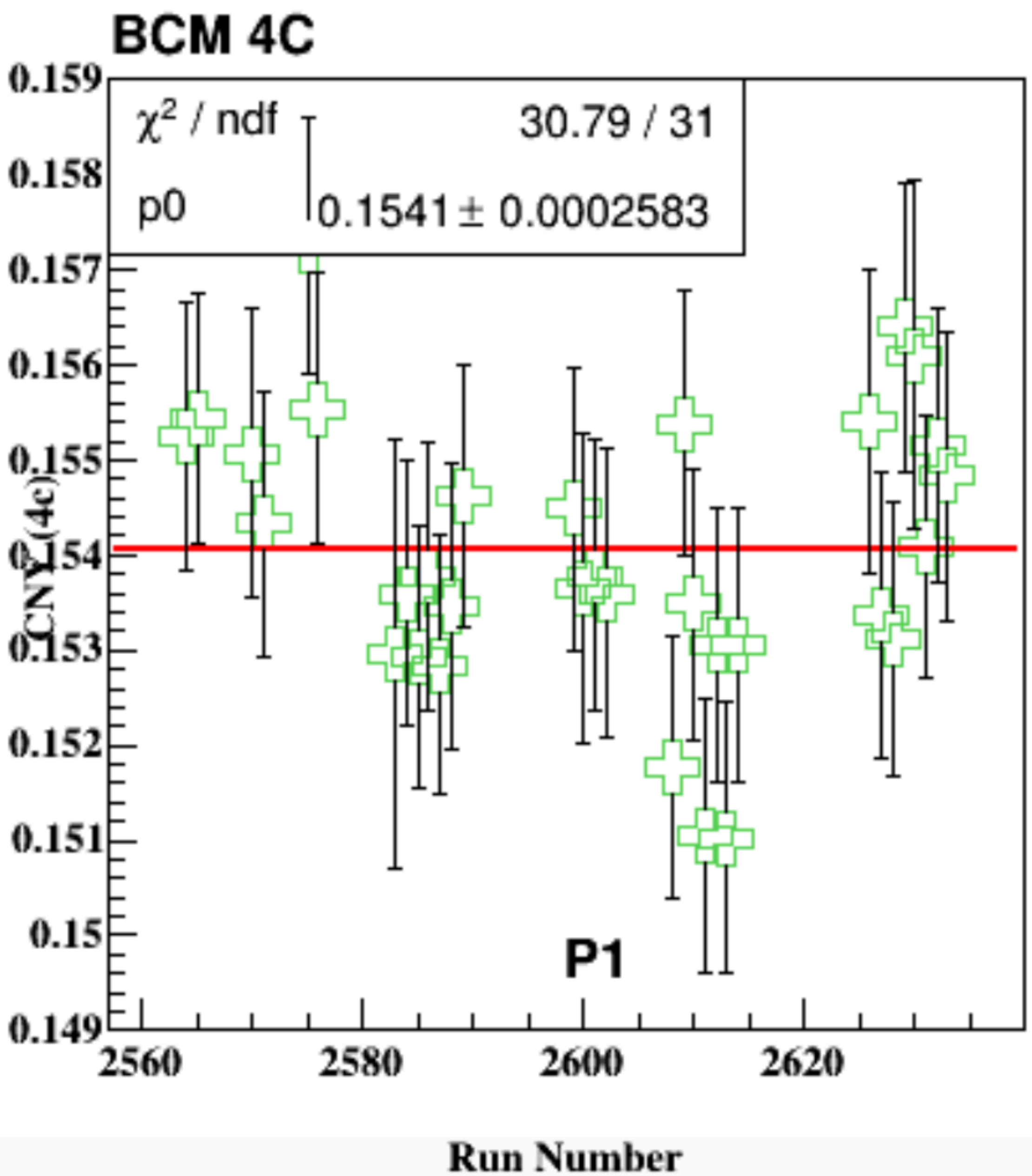
In principle CNY should be same for all the runs for a particular kinematic setting and target. In other words CNY vs Run Number should have a $\chi^2/ndf \sim 1$.

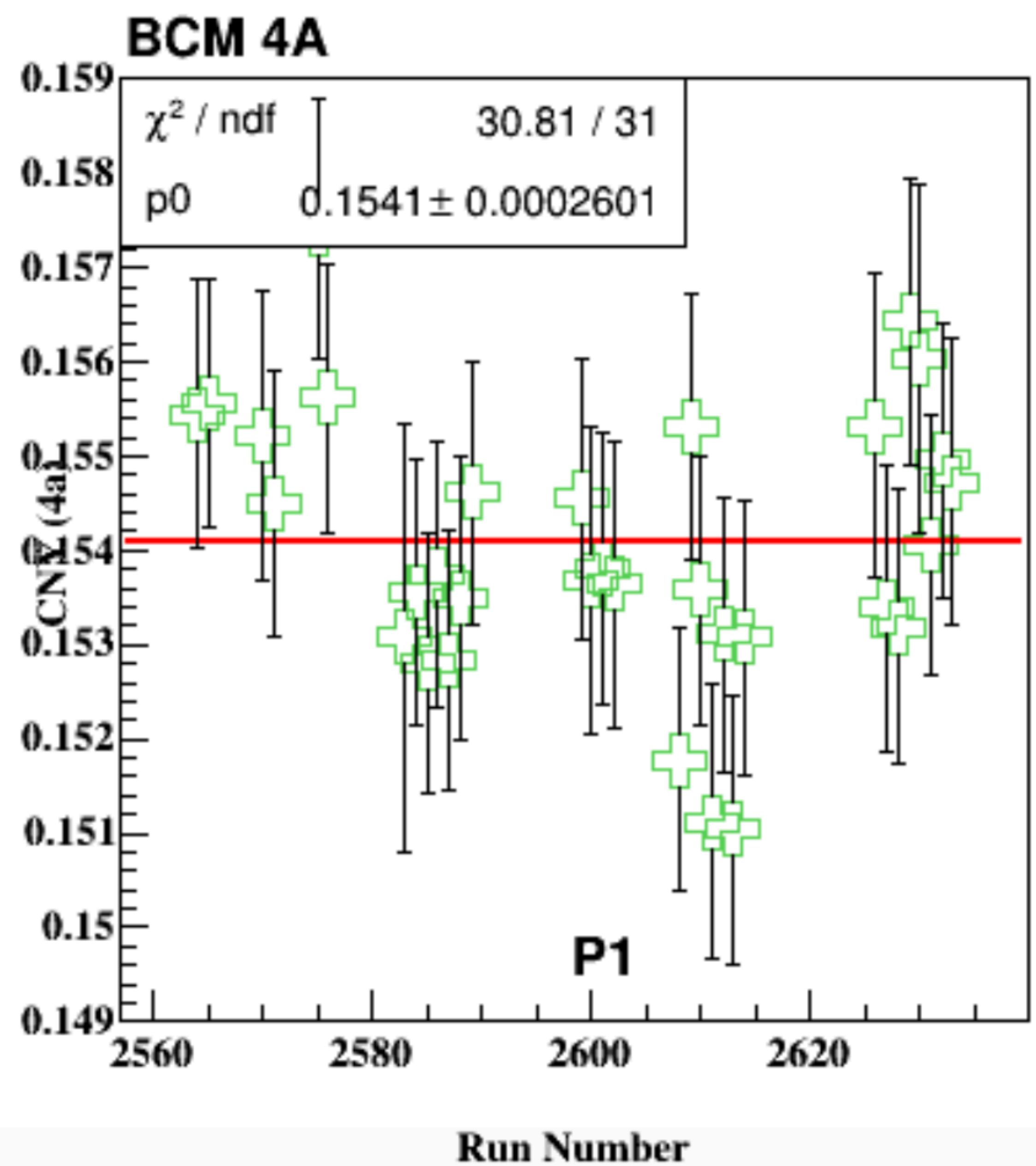
- **It is checked how much minimum error is needed to add to the charge so that CNY vs Run Number has a $\chi^2/ndf \sim 1$.**

<u>Minimum Error added to charge to get the $\chi^2/ndf \sim 1$</u>

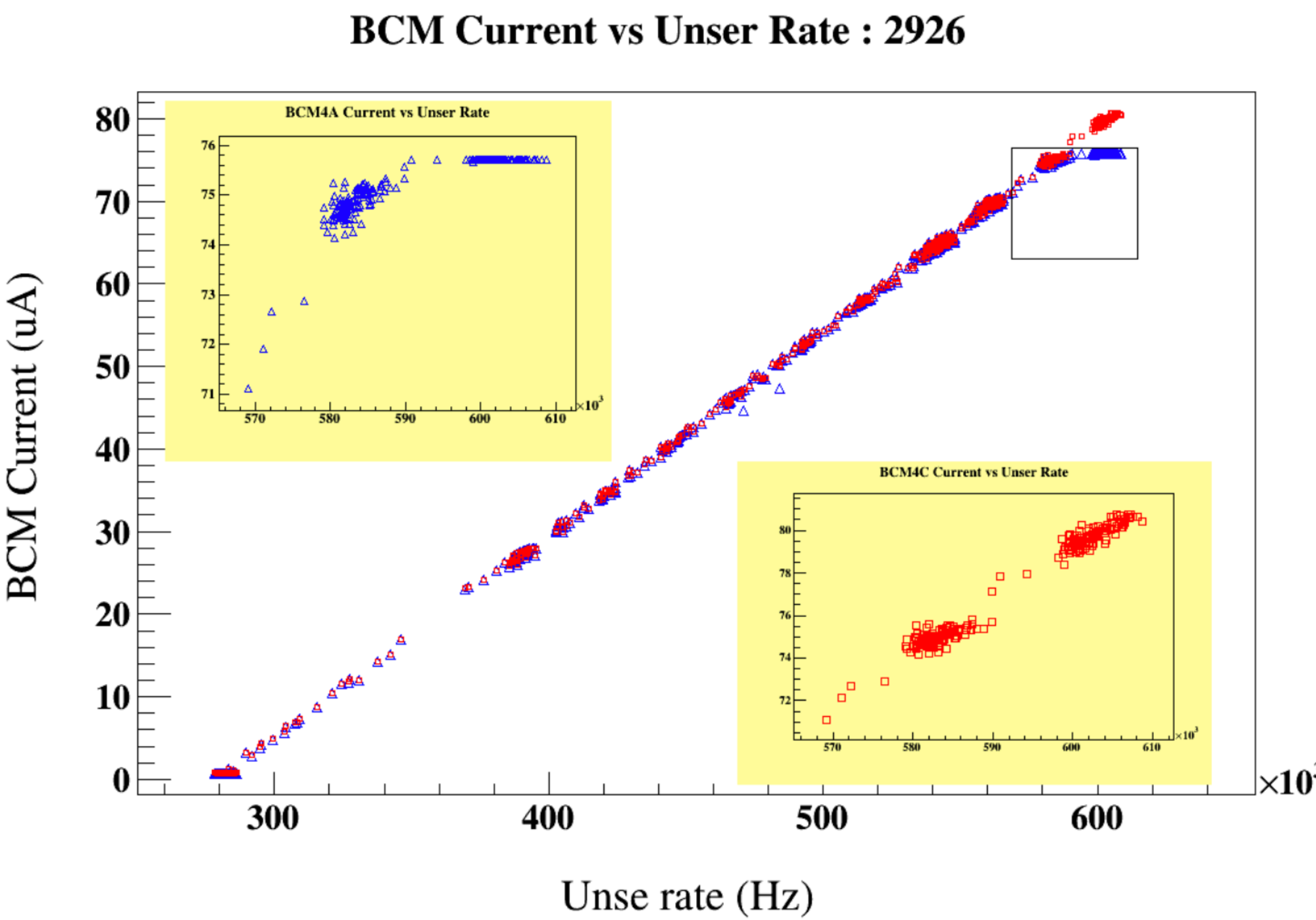
39^o 2.5 GeV : dQ_{BCM4C}= 0.59%, dQ_{BCM4C}= 0.60%
39^o 2.0 GeV : dQ_{BCM4C}= 0.43%, dQ_{BCM4C}= 0.41%
39^o 3.2 GeV : dQ_{BCM4C}= 0.58%, dQ_{BCM4C}= 0.65%
39^o 2.6 GeV: dQ_{BCM4C}= 0.47%, dQ_{BCM4C}= 0.43%

- $dQ_{BCM4C}^{average} \sim 0.5$ %





BCM 4A Saturation



- BCM4A is saturating
- These runs were not used in the calibration

Cross-Section Extraction Method

- The method used to extract the cross-section : **Monte-Carlo Ratio Method**

- For each bin in $(\Delta E', \Delta\Omega)$, number of total electrons detected by the spectrometer

$$N^{e-} = L \times (\frac{d\sigma}{d\Omega dE'}) \times (\Delta E' \Delta\Omega) \times \epsilon_{tot} \times A(E', \theta) + BG \qquad \ldots(1)$$

where, L = Integrated Luminosity = $N^{e-}_{beam} \times \dfrac{N_{target}}{Area}$

$\epsilon_{tot} =$ Total Efficiency

$A(E', \theta)$ **=** Acceptance for the bin

BG = Background

- Hence the efficiency corrected yield is defines as -

$$Y = \frac{N^{e-} - BG}{\epsilon_{tot}} = L \times \sigma \times (\Delta E' \Delta\Omega) \times A(E', \theta) \qquad \ldots(2)$$

Cross-Section Extraction Method

- Yield can be measured from the experiment (Y_{data}) and also the Monte-Carlo (Y_{MC})

$$Y_{data} = L \times \sigma^{data} \times (\Delta E' \Delta\Omega) \times A(E', \theta) \qquad \ldots (3)$$

$$Y_{MC} = L \times \sigma^{MC} \times (\Delta E' \Delta\Omega) \times A_{MC}(E', \theta) \qquad \ldots (4)$$

- Taking ratio of equation (3) and (4)

$$\frac{Y_{data}}{Y_{MC}} = \frac{L \times \sigma^{data} \times (\Delta E' \Delta\Omega) \times A(E', \theta)}{L \times \sigma^{MC} \times (\Delta E' \Delta\Omega) \times A_{MC}(E', \theta)} \qquad \ldots (5)$$

- Considering $A(E', \theta) = A_{MC}(E', \theta)$ and Monte-Carlo generated with *same luminosity* with data-

$$\boxed{\sigma^{data} = \sigma^{MC} \times \frac{Y_{data}}{Y_{MC}} \qquad \ldots (6)}$$

- **Now the question is how to get the σ^{MC}, Y_{MC} and Y_{data} ?**

$\sigma^{data} = \sigma^{MC} \times \frac{Y_{data}}{Y_{MC}}$: ***Extraction of σ^{MC} from F1F221***

- F1F221 (by M. Eric Christy) model is used to get the σ^{MC}
- F1F221 is a fit to the global data which produces F_1 and F_2
- The structure functions are related to the reduced cross-sections as follows

Total differential scattering cross-section

Transverse virtual photon cross-section

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma[\sigma_T(x, Q^2) + \epsilon\sigma_L(x, Q^2)]$$

Longitudinal virtual photon cross-section

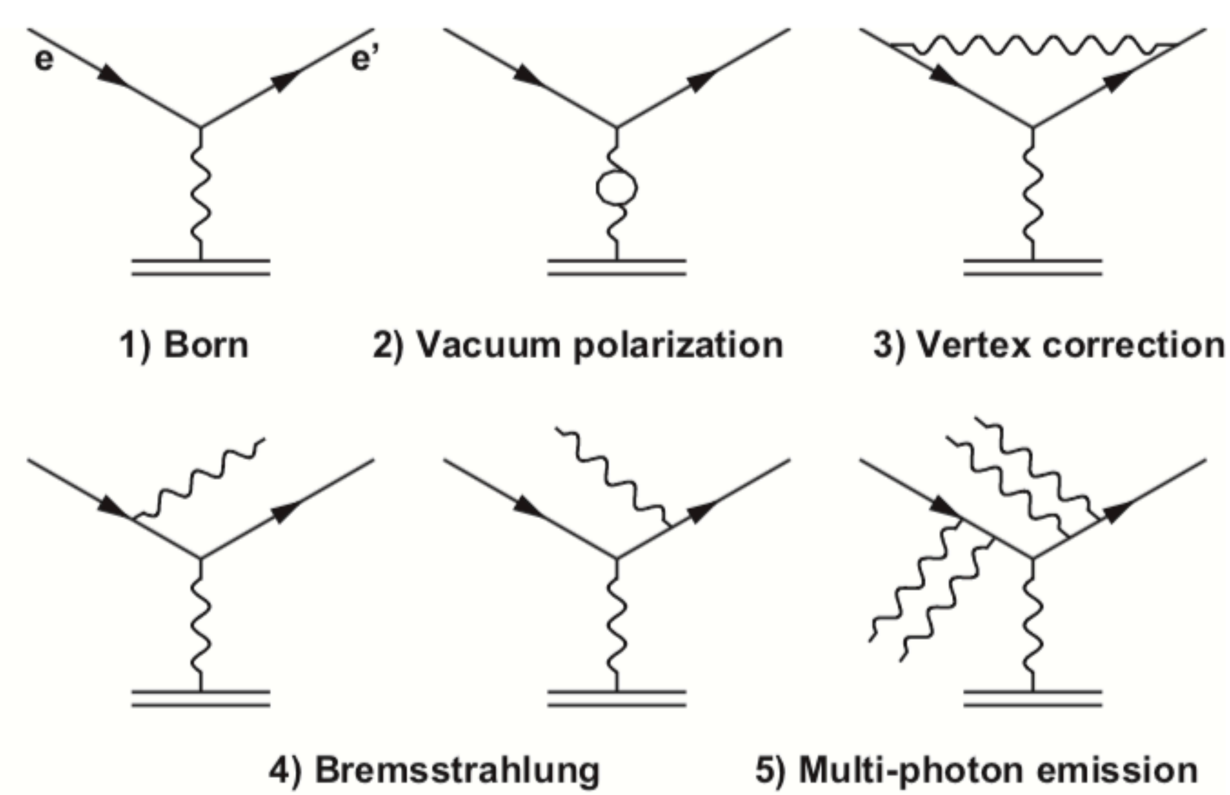
$$\Gamma = \frac{\alpha K}{2\pi Q^2}\frac{E'}{E}\frac{1}{1-\epsilon} \qquad K = \frac{2M\nu - Q^2}{2M} \qquad \epsilon = [1 + 2(1 + \frac{Q^2}{4M^2x^2}tan^2\frac{\theta}{2})]^{-1}$$

$$\sigma_T = \frac{4\pi\alpha}{KM}F_1 \qquad \sigma_L = \frac{4\pi^2\alpha}{KM\nu}[(1 + \frac{\nu^2}{Q^2})MF_2 - \nu F_1]$$

Generation of MC events & physics weighting

- For the Monte-Carlo first 1million events of scattered electrons are generated uniformly in $(E', X' \equiv \frac{dY}{dZ}, Y' \equiv \frac{dY}{dZ})$ space using the program mc-single-arm

- Monte-Carlo events generated by the mc-single-arm does not consider the effect of the several radiative processes. Born approximation is just the first order approximation in α of electron-nucleon scattering by one photon exchange. To mimic the reality we multiply the each events of MC by $\frac{\sigma^{model}_{rad}}{\sigma^{model}_{Born}}$ where, σ^{model}_{born} = model Born cross-section, σ^{model}_{Rad}= total radiative model cross-section



- For the Monte-Carlo first 1 million events of scattered electrons are generated uniformly in $(E', X' \equiv \frac{dY}{dZ}, Y' \equiv \frac{dY}{dZ})$ space using the well known program mc-single-arm

- Physics weighting is applied to the uniformly generated events

- The Monte-Carlo yield need to be calculated with the same luminosity as data. Physics weighted, (uniformly) generated Monte-Carlo events are multiplied with a factor to get the Y_{MC} :
  $Y_{MC}(E', \theta) = N^{e-} \times scale\ factor$
  scale factor is defined as the ratio of data and MC luminosity:
  $$scale\ factor = \frac{L_{data}}{L_{MC}} \times \epsilon_{tot} \times \frac{E_{LT} \times C_{LT}}{PS}$$
  where,
  $$L_{data} = target\ density \times target\ length \times Avogadro's\ number \times \frac{1}{atomic\ mass} \times \frac{beam\ charge}{elementary\ charge}$$
  $L_{MC} = \frac{generated\ events}{\Delta E'\ \Delta\Omega}$ (because we generate the events uniformly)
  $\epsilon_{tot} = \epsilon_{tracking} \times \epsilon_{cerenkov} \times \epsilon_{calorimeter}$: total efficiency
  C_{LT} : computer live time
  E_{LT} : electronic live time
  PS : prescale factor

real target length =
target length × target length
correction due to temperature
change (0.996)

Extraction of Y_{data}

Number of scattered particles form the tracks in drift chambers and pass through all the PID (cerenkov and calorimeter) cuts

Acceptance Cuts for SHMS
$-10.0 < y_{tar} < 10.0$
$-0.1 < y'_{tar} < 0.1$
$-0.1 < x'_{tar} < 0.1$
$-10.0 < \delta < 22.0$
PID Cuts for SHMS
$N_{cer} > 2.0$
$E_{calo}/E' > 0.7$
Current Cut for SHMS
$I_{BCM\ 4C} > 5.0$

Pion contamination +
Charge Symmetric background +
Cryo Cell Contribution

$$Y_{data} = \frac{N^{e-} - BG}{\epsilon_{tot} E_{LT} C_{LT}} \times PS$$

Prescale

Total efficiency :

$$\epsilon_{tot} = \epsilon_{track} \times \epsilon_{cerenkov} \times \epsilon_{calorimeter}$$

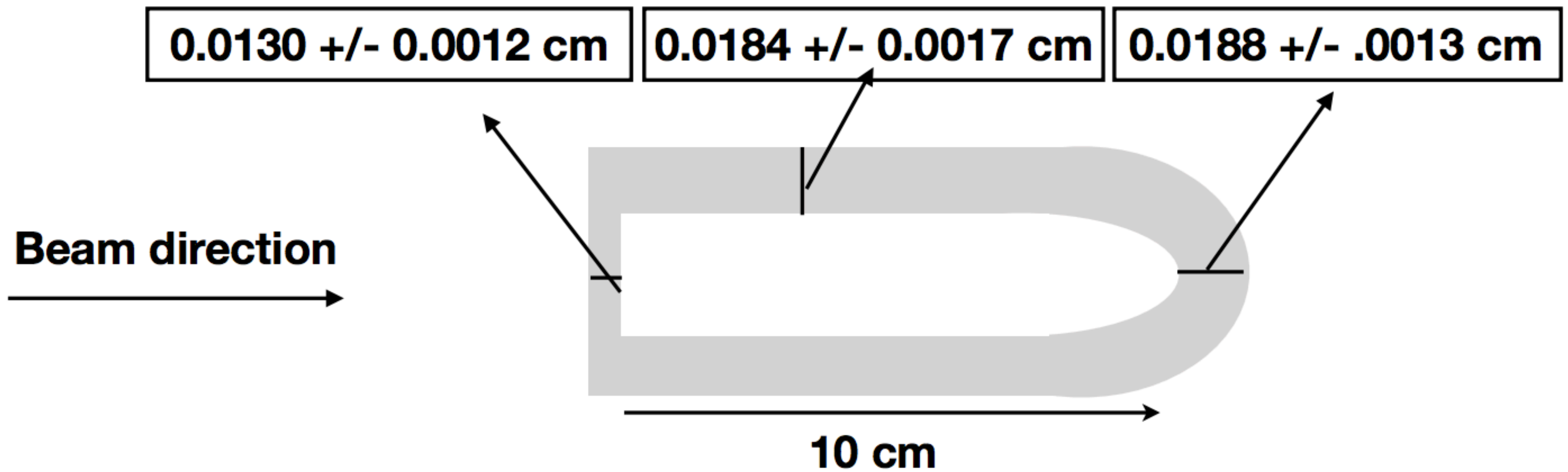
Computer live time

Electronic live time

$$\sigma^{data} = \sigma^{MC} \times \frac{Y_{data}}{Y_{MC}}$$

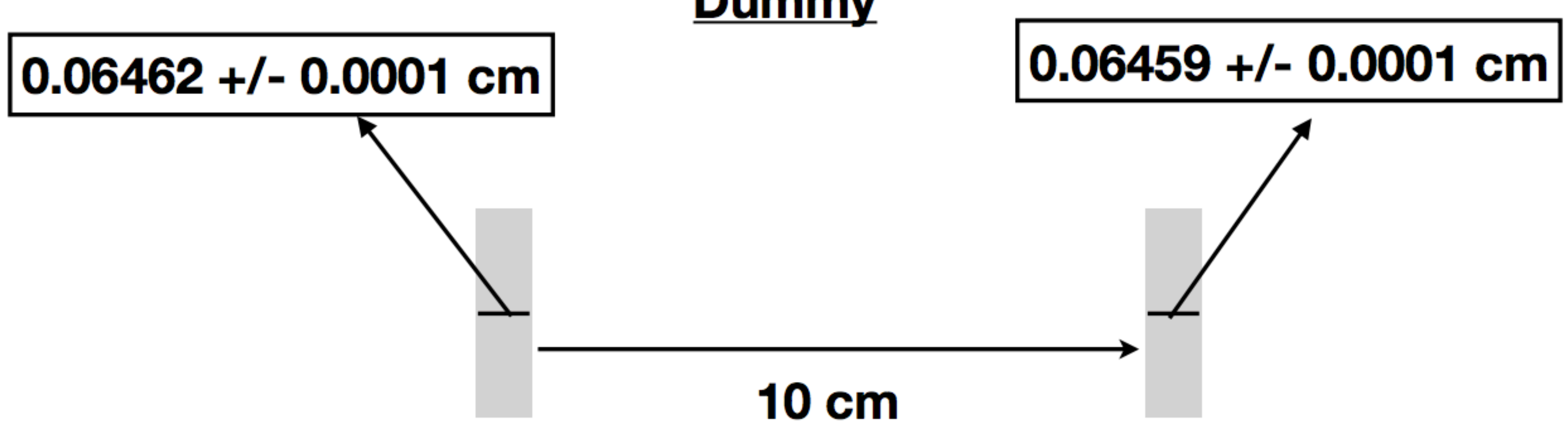
Dummy subtraction

Target cell (loop 3 : deuterium)



Exit window is ~44.61 % thicker than the entrance window

Dummy



Exit window is ~0.046 % thicker than the entrance window

Scale factor for the dummy : multiply the scale factor with dummy event by event

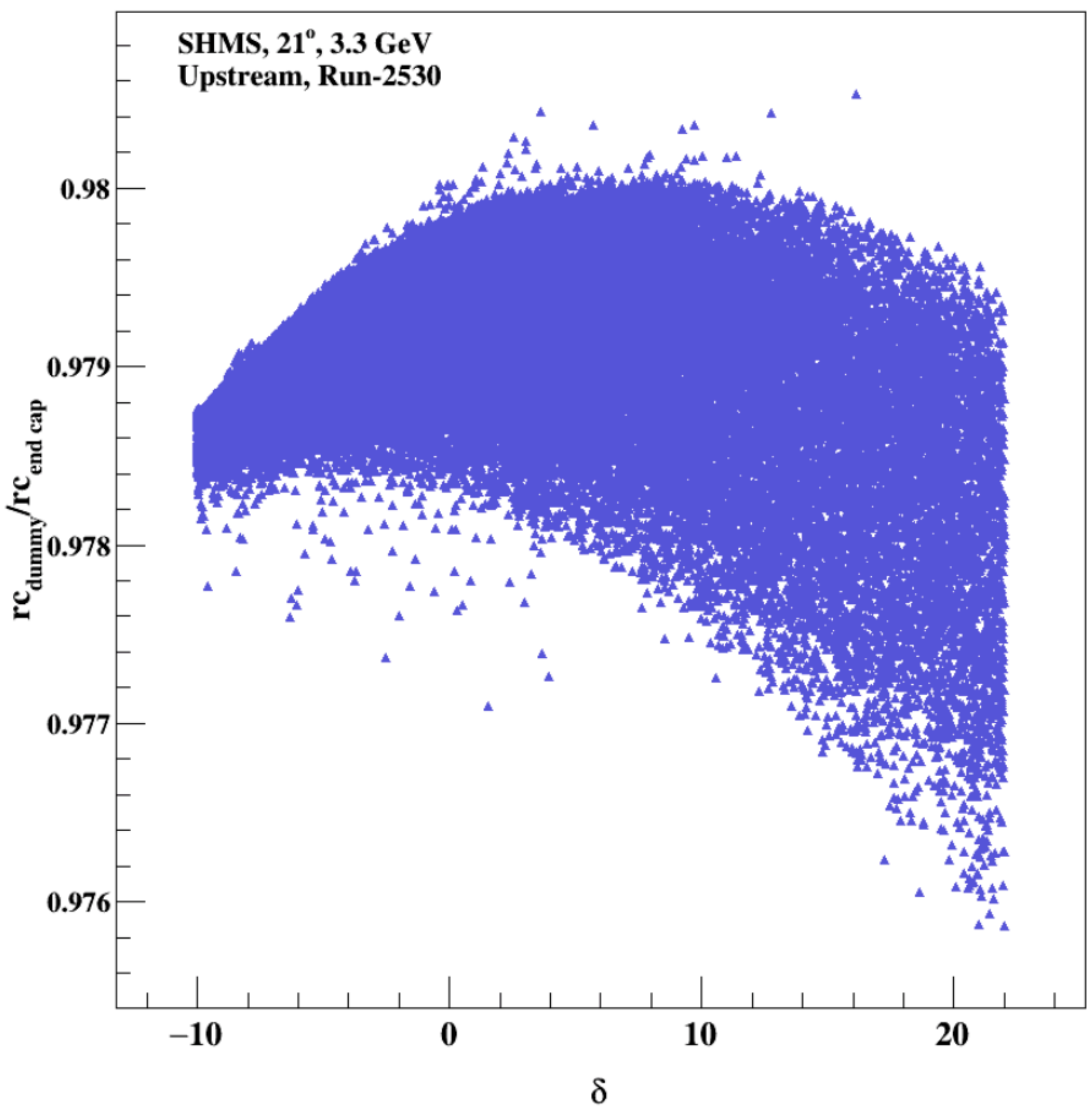
rc = radiative corrections

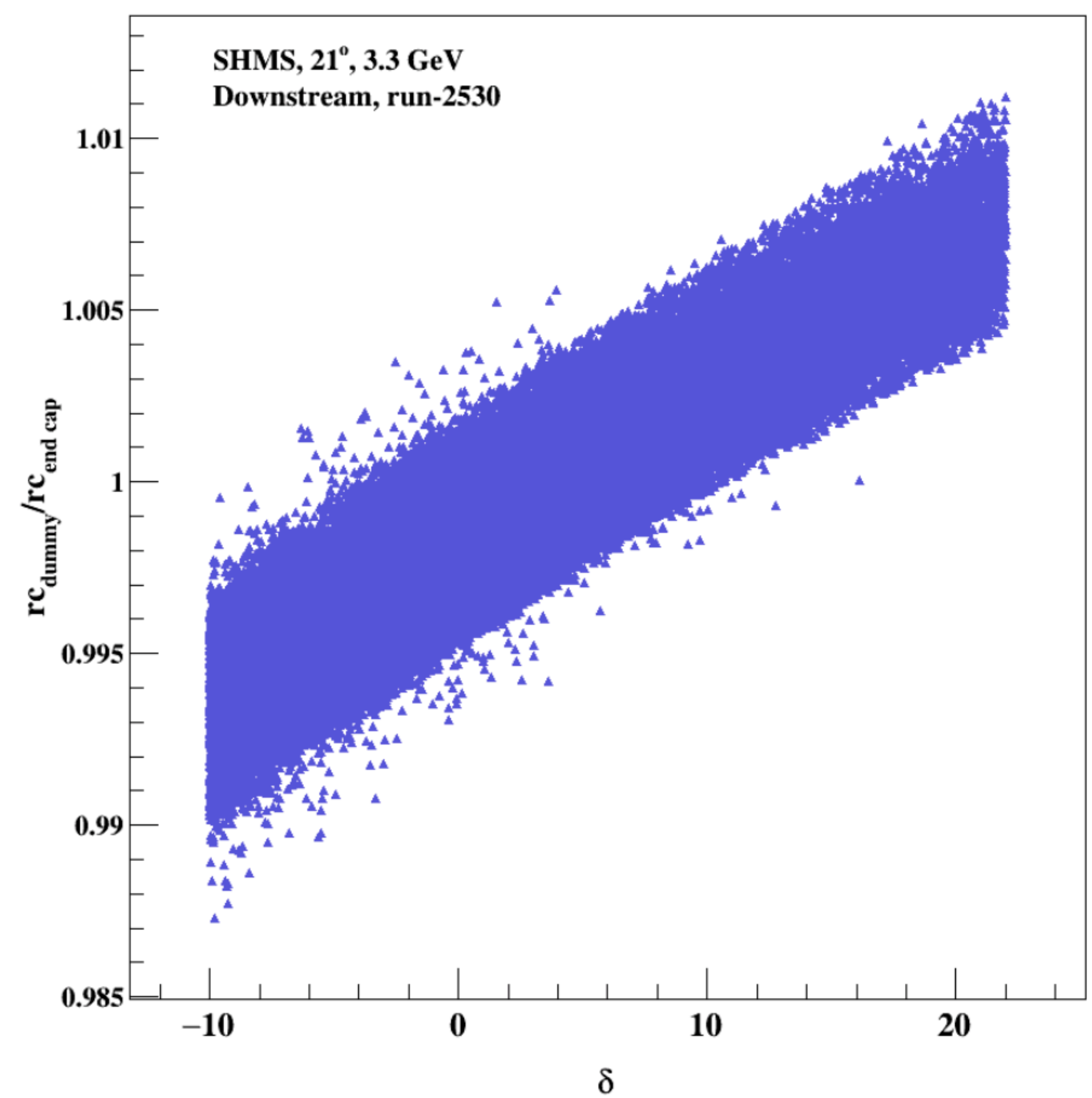
- $Yield_{cryo\ cell} = Luminosity_{cryo\ cell} \cdot \frac{\sigma_{al}}{rc_{cryo\ cell}}$
- $Yield_{dummy} = Luminosity_{dummy} \cdot \frac{\sigma_{al}}{rc_{dummy}}$
- $scale\ factor = \frac{raw\ counts_{cryo\ cell}}{raw\ counts_{dummy}}$ $[Yield = raw\ counts * \frac{ps}{eff}]$
- $scale\ factor = \frac{Yield_{cryo\ cell} * (eff/ps)_{cryo\ run}}{Yield_{dummy} * (eff/ps)_{dummy\ run}}$
- $Luminocity = \frac{Q}{e^-} \frac{N_A \rho t}{A}$
- $$\boxed{scale\ factor = \frac{(charge\,.\,eff/ps)_{cryo\ cell} \cdot t_{cryo\ wall\ width}}{(charge\,.\,eff/ps)_{dummy} \cdot t_{dummy\ wall\ width}} \cdot \frac{rc^{ext}_{dummy}}{rc^{ext}_{cryo\ cell}}}$$

As both the Cryo cell and the end caps are made up of same material , only the **<u>external radiative corrections</u>** are important - target lengths are different here !

- Dummy runs are in general have different luminosity of cryo run
- We need to find out the *raw counts of dummy for same luminosity as cryo*

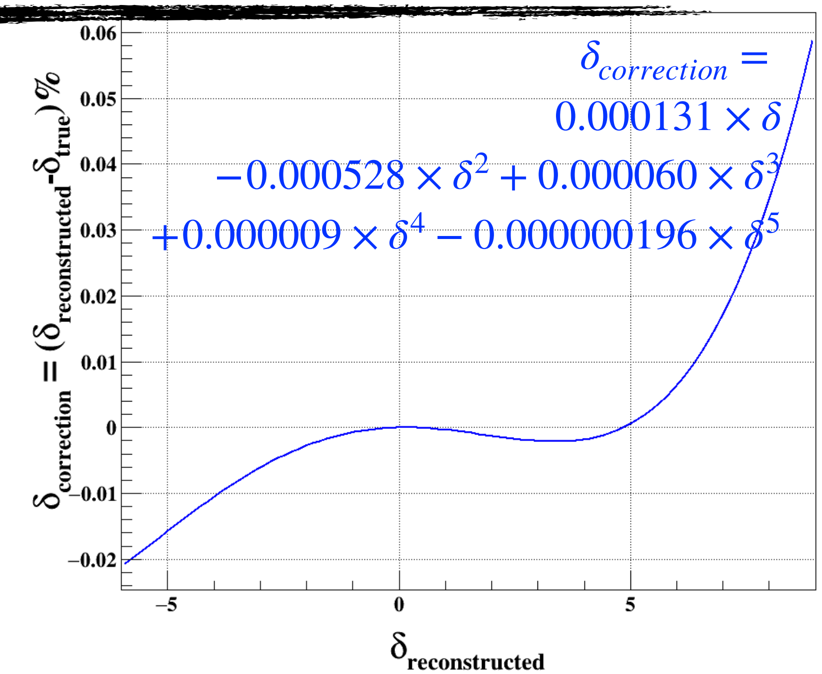
- The upstream and down stream thickness ratios are considered separately instead of a average thickness
- The ratio $rc_{dummy}/rc_{cryo\ cell}$ is maximum ~$\pm 3\ \%$ (for either upstream or downstream)
- The maximum value of CNY_{dummy}/CNY_{total} for hydrogen is ~10.33% and for deuterium for deuterium is ~5.11%
- For hydrogen the maximum effect is (3% of 10.33%) = 0.3%
- For deuterium the maximum effect is (3% of 5.11%) = 0.15%



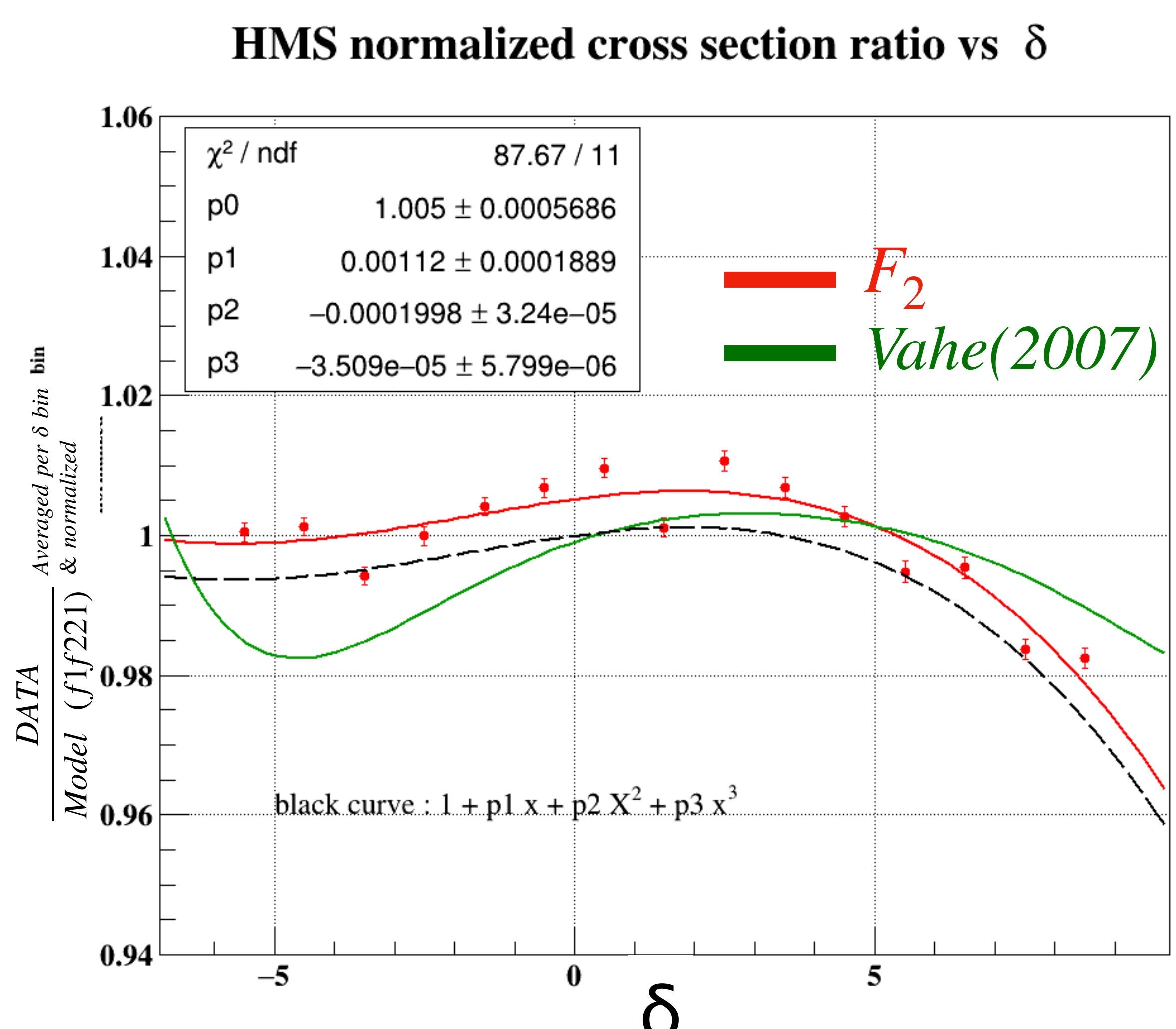


HMS δ Correction

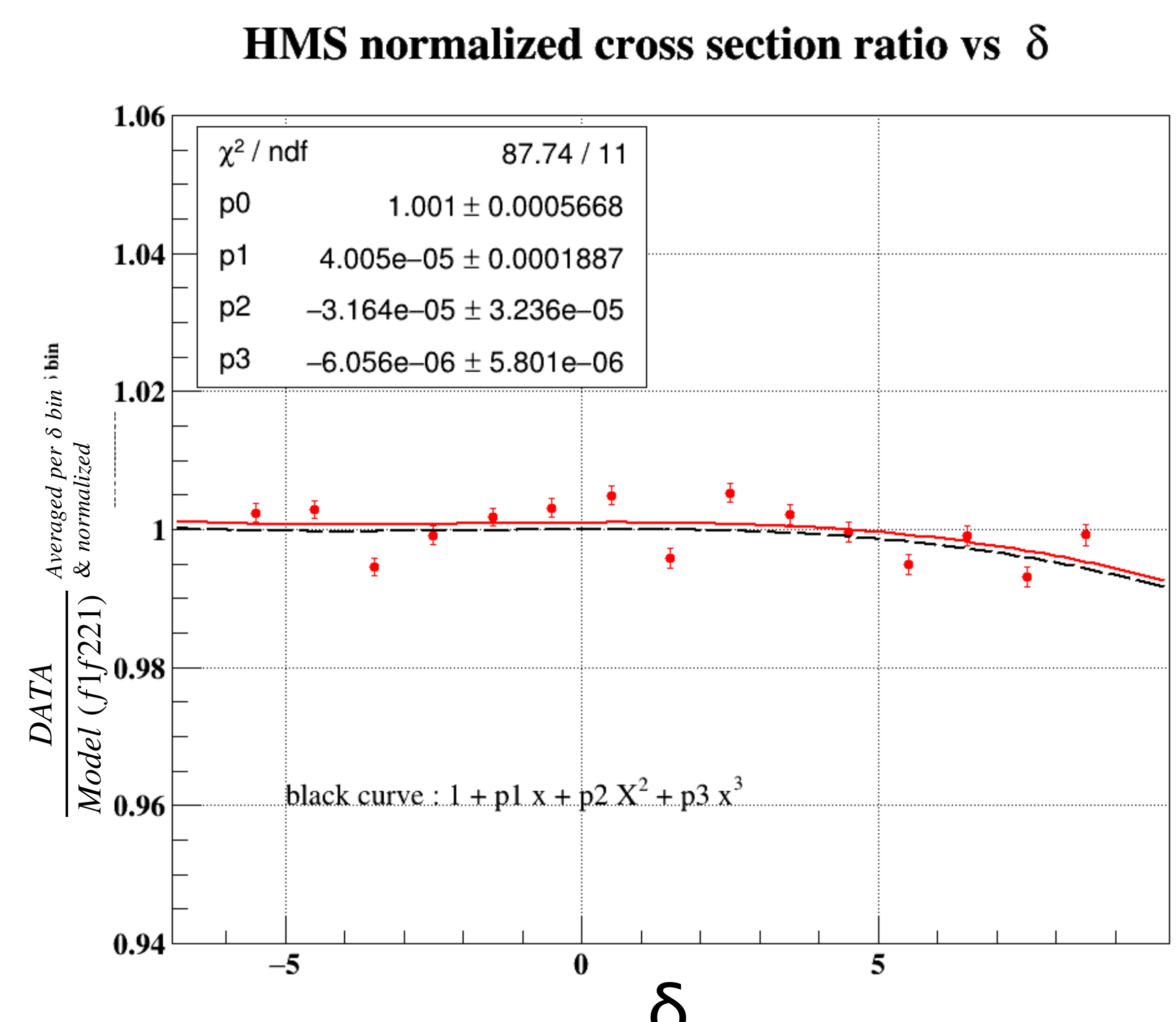
- DATA/MC vs δ plot irrespective of all kinematics and targets shows a systematic variation in data reconstructed quantities compared to MC
- This is an known issue for the HMS form 6 GeV era and can be corrected by remapping the δ bins
- Similar δ dependence has been found in SHMS data that can be fixed in a similar method
- This δ dependence is visible only for individual cross sections and cancels out for d/p ratios



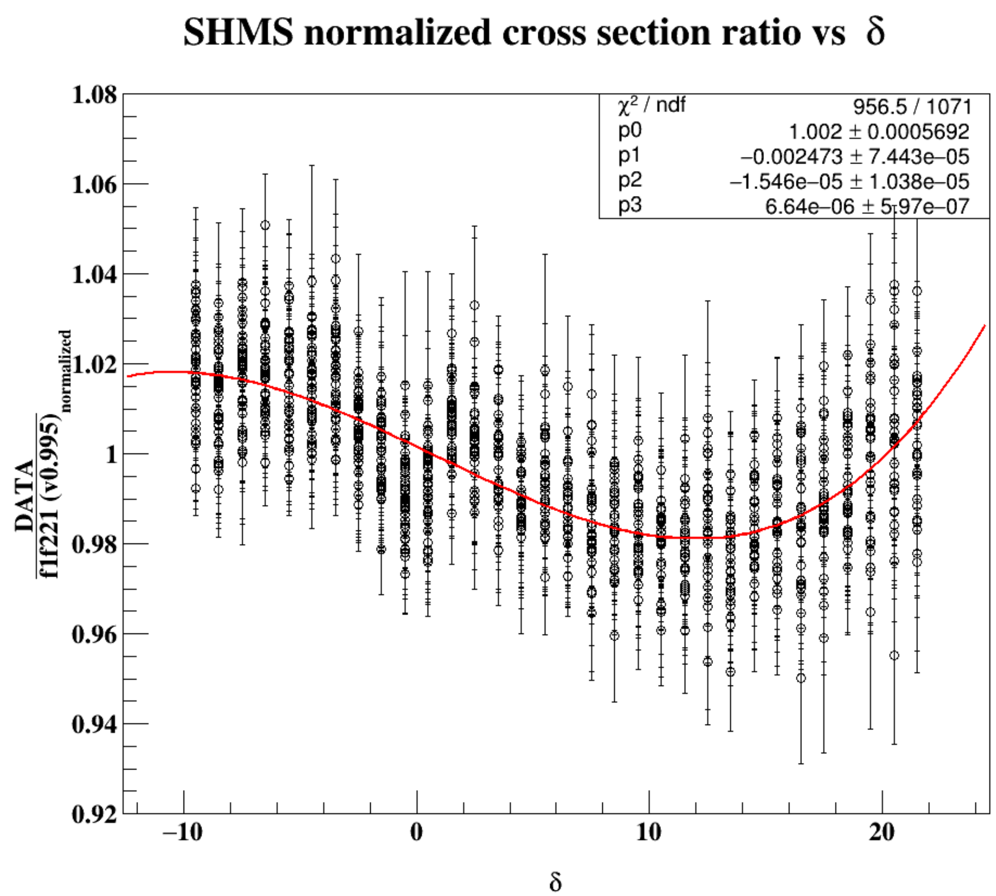
NO δ Correction

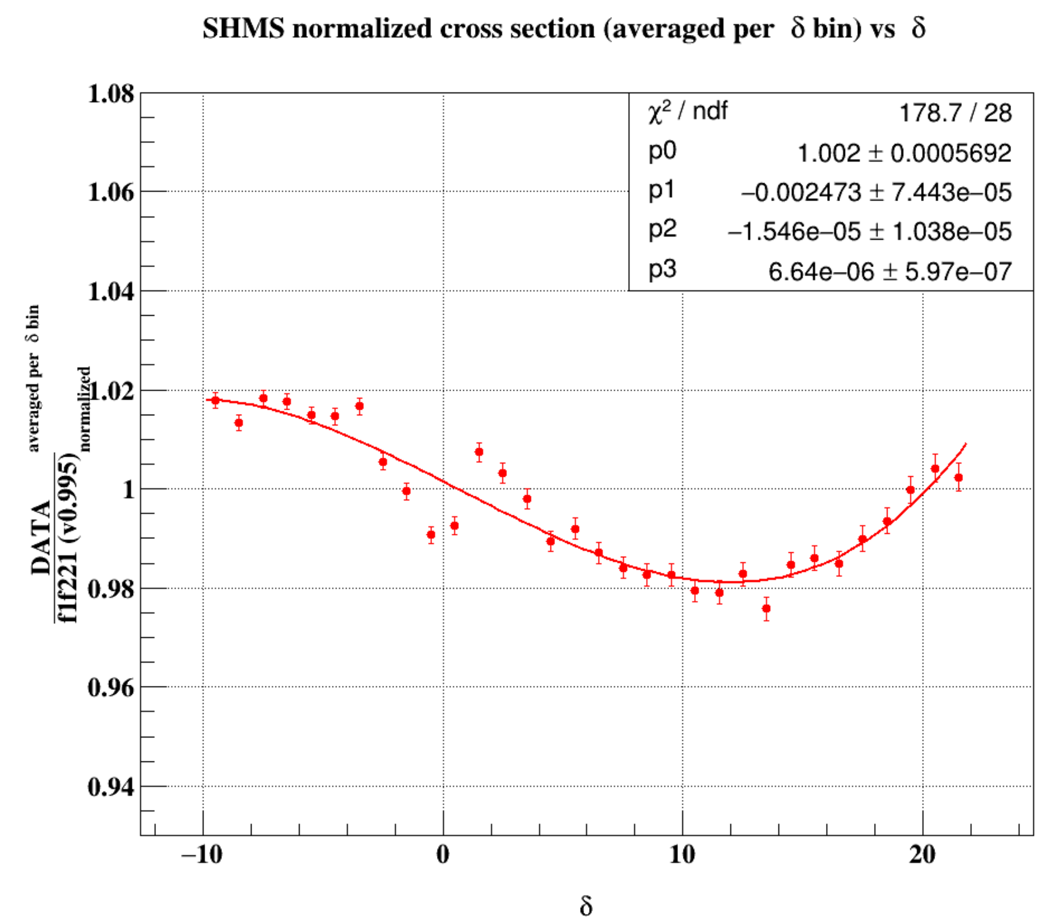


After δ Correction

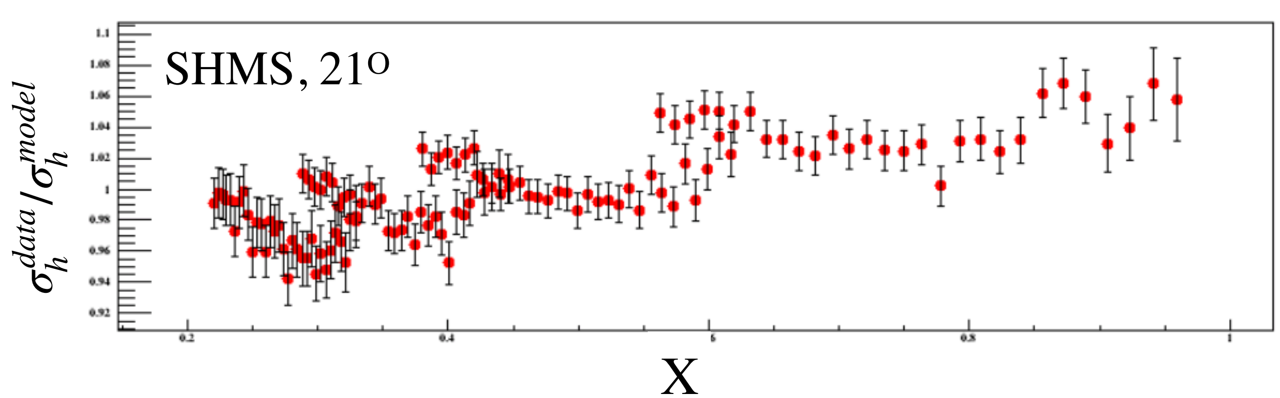


SHMS δ Correction

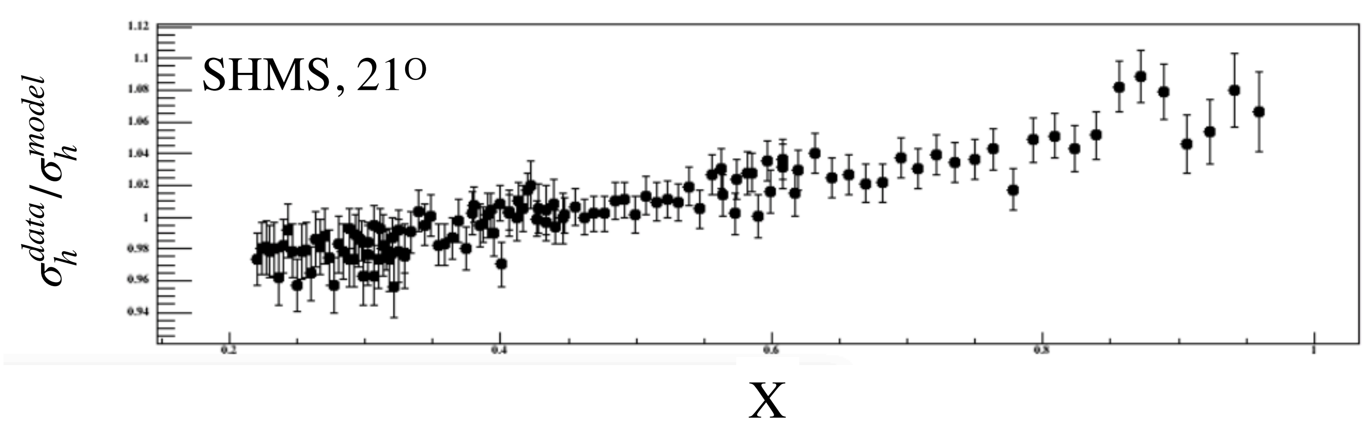


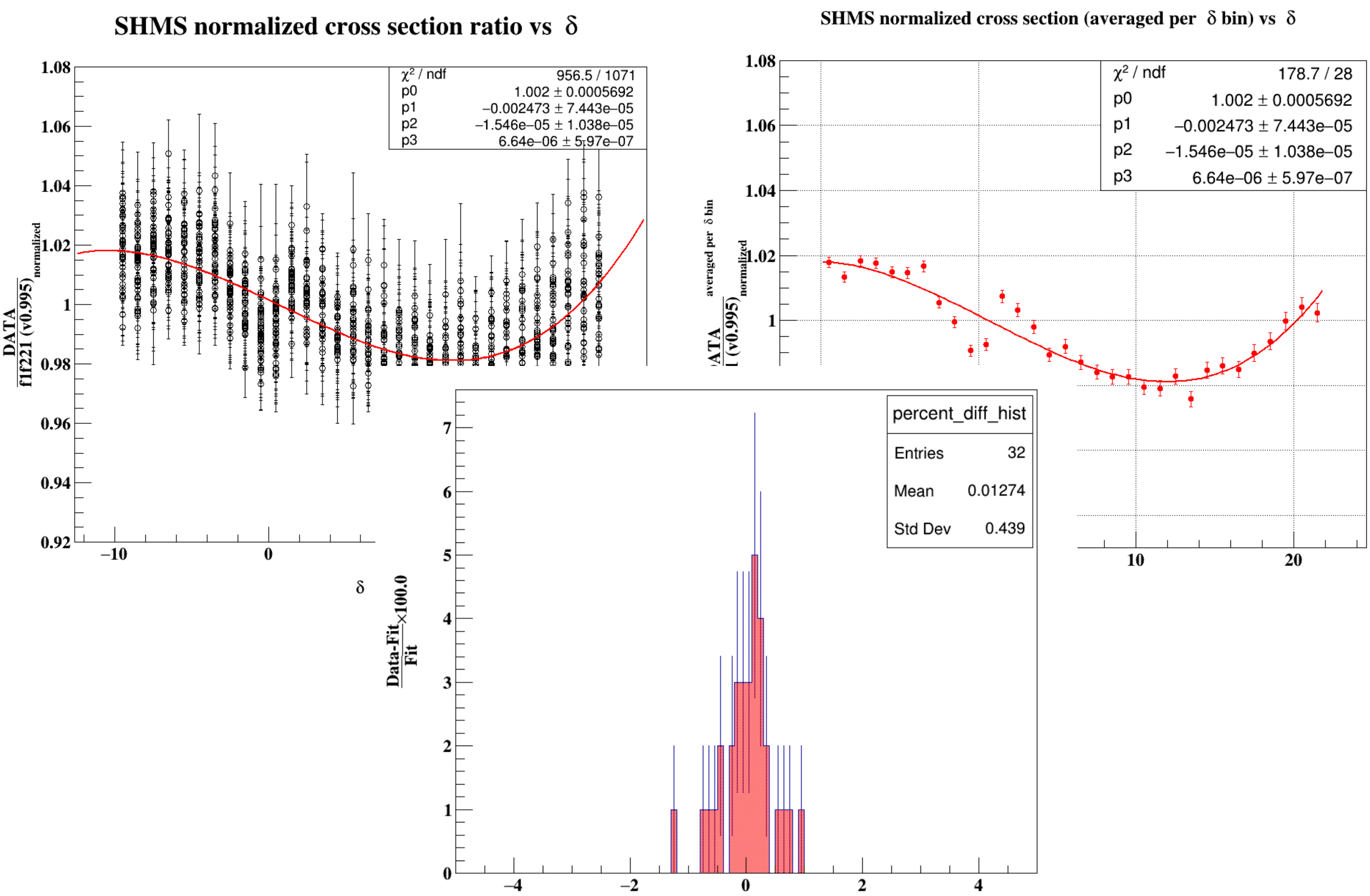


Before correction

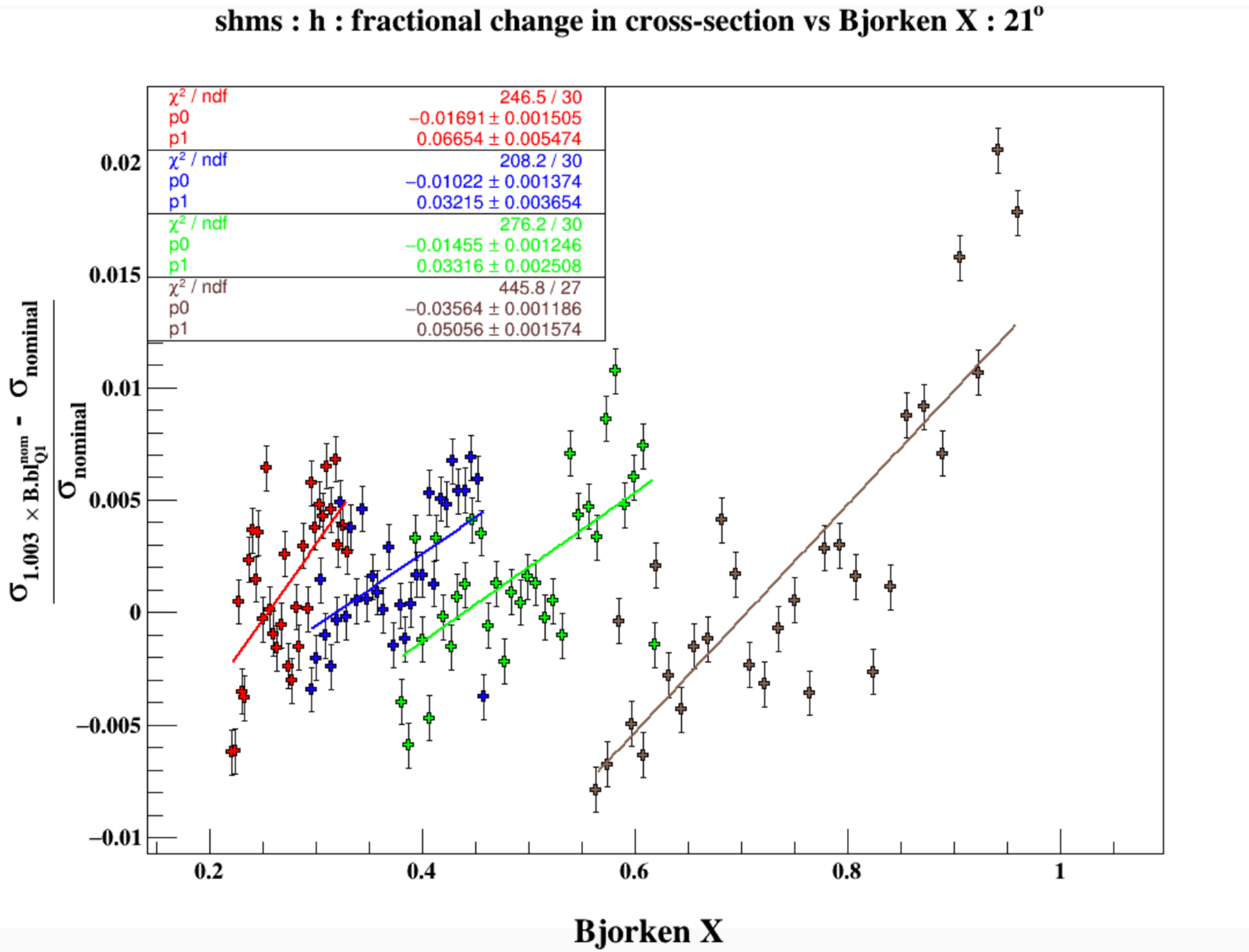


After correction



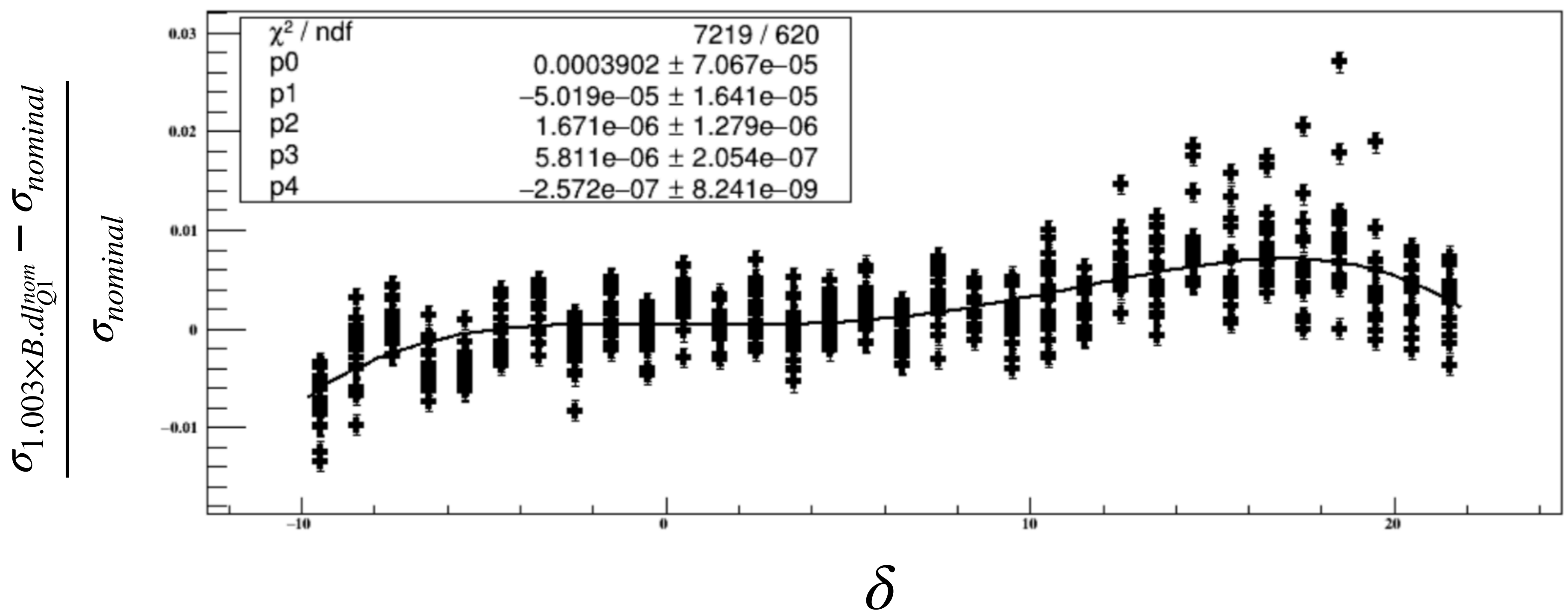

SHMS normalized cross section ratio vs δ
χ² / ndf 956.5 / 1071
p0 1.002 ± 0.0005692
p1 −0.002473 ± 7.443e−05
p2 −1.546e−05 ± 1.038e−05
p3 6.64e−06 ± 5.97e−07
DATA / f1f221 (v0.995) normalized
δ
SHMS normalized cross section (averaged per δ bin) vs δ
χ² / ndf 178.7 / 28
p0 1.002 ± 0.0005692
p1 −0.002473 ± 7.443e−05
p2 −1.546e−05 ± 1.038e−05
p3 6.64e−06 ± 5.97e−07
averaged per δ bin
percent_diff_hist
Entries 32
Mean 0.01274
Std Dev 0.439
(Data-Fit)/Fit ×100.0

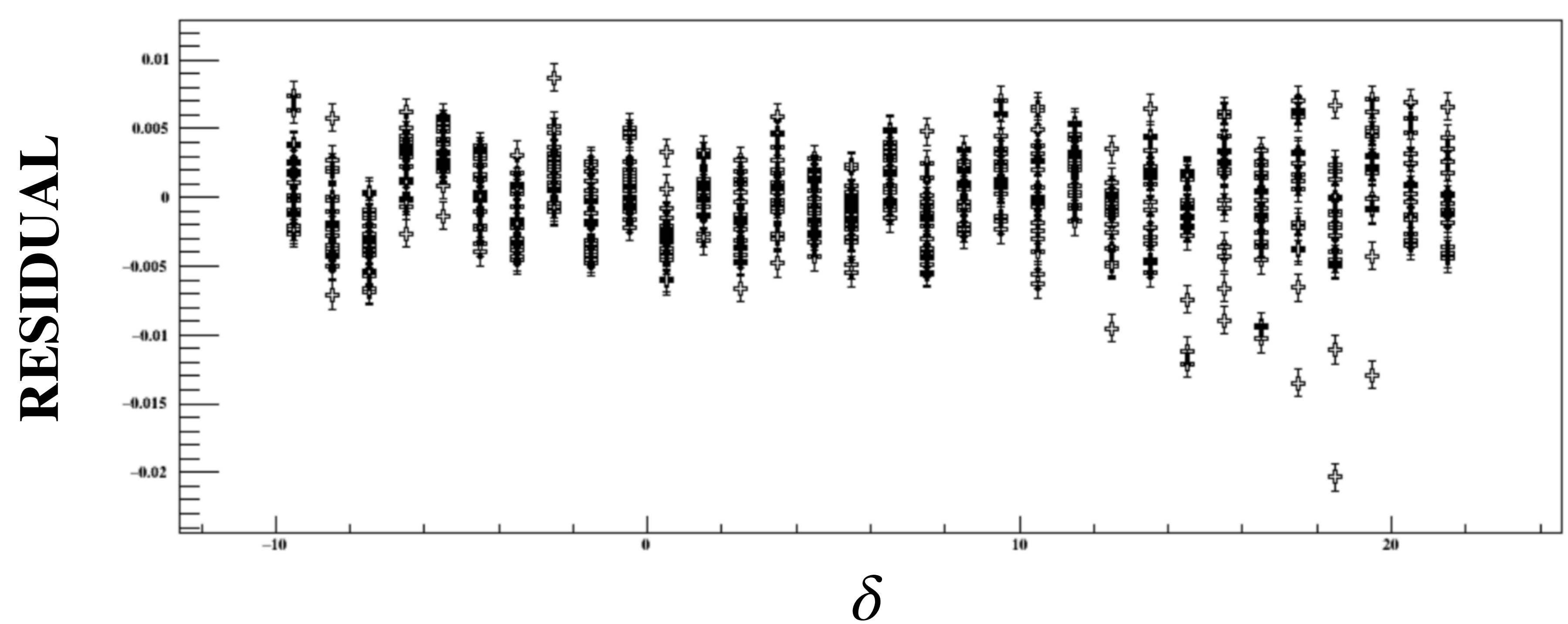
Systematics Due to Uncertainty in Forward transport Matrix



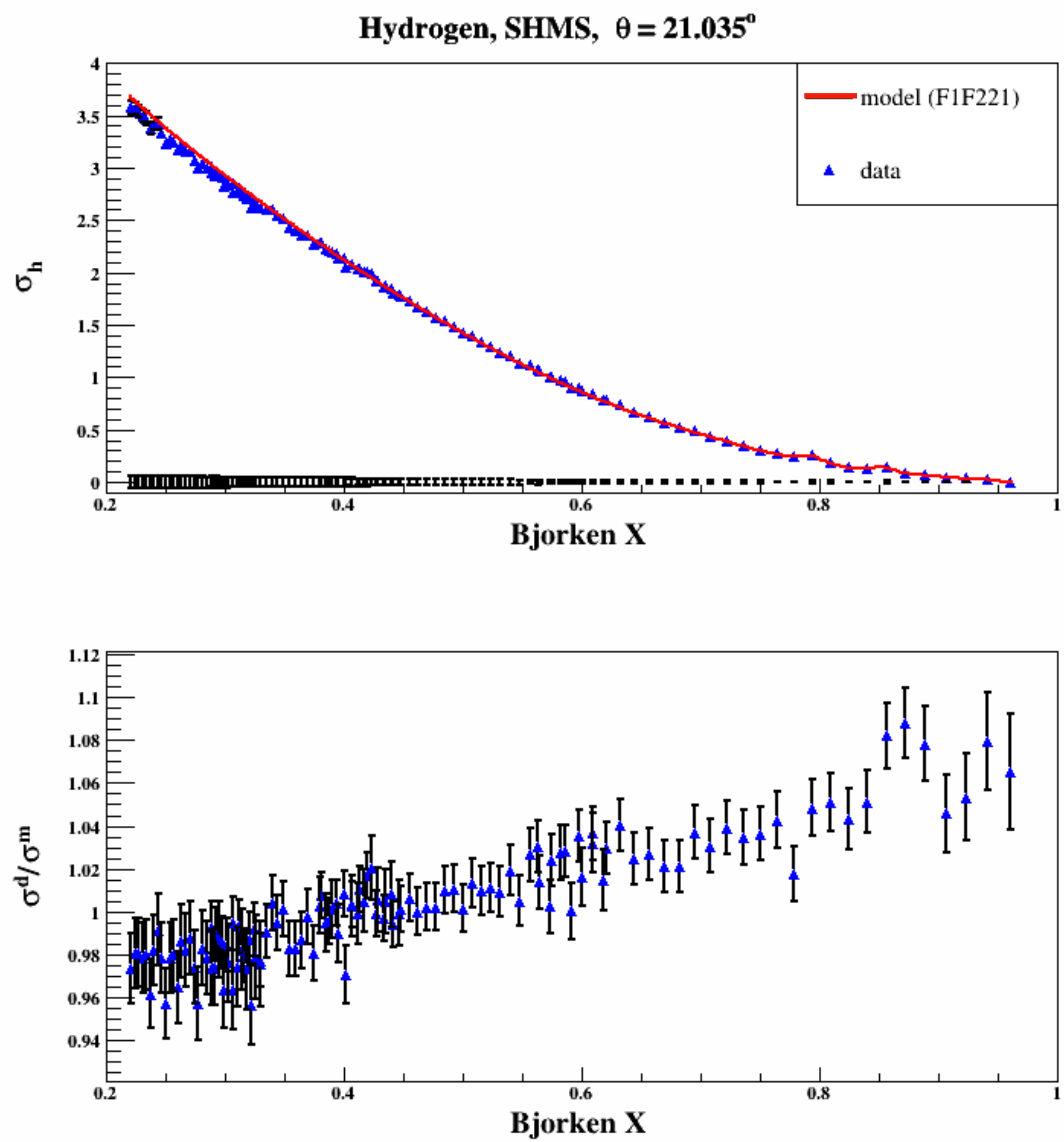
Systematics Due to Uncertainty in Forward transport Matrix

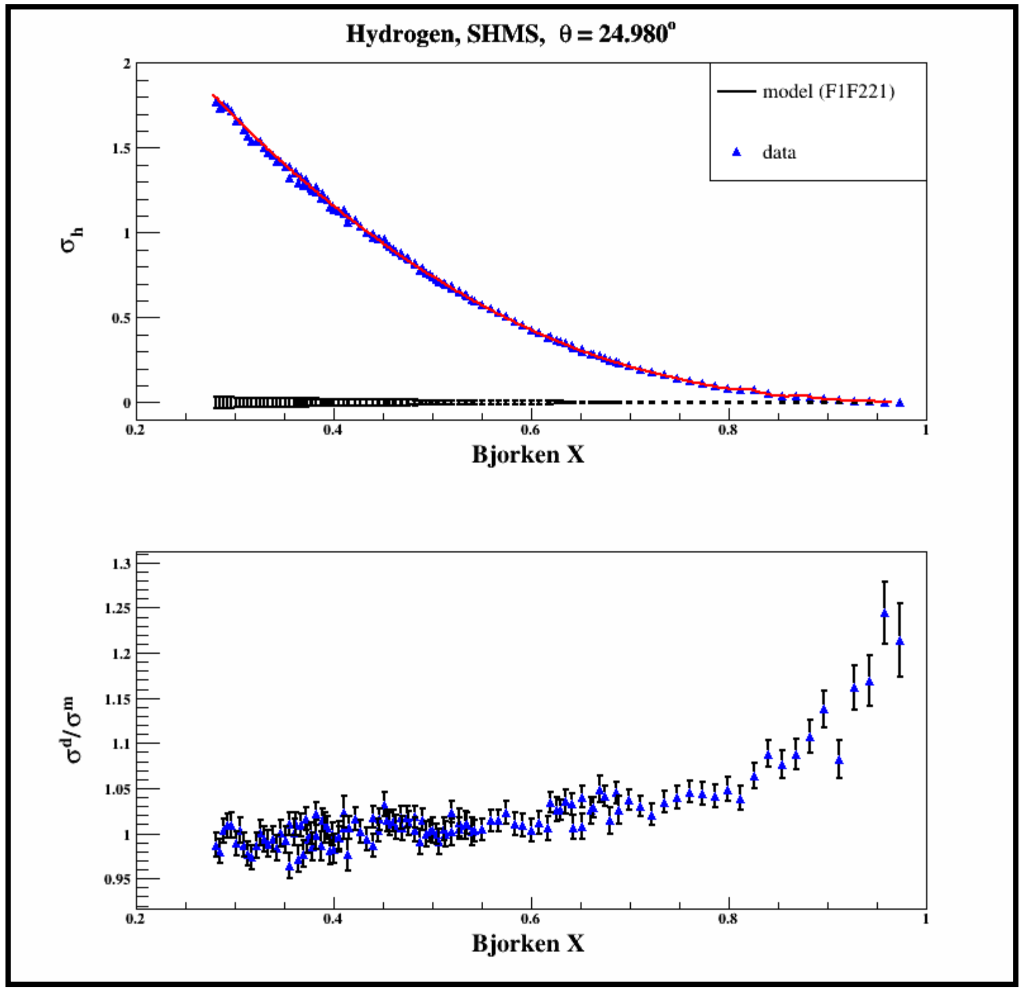
SHMS : h

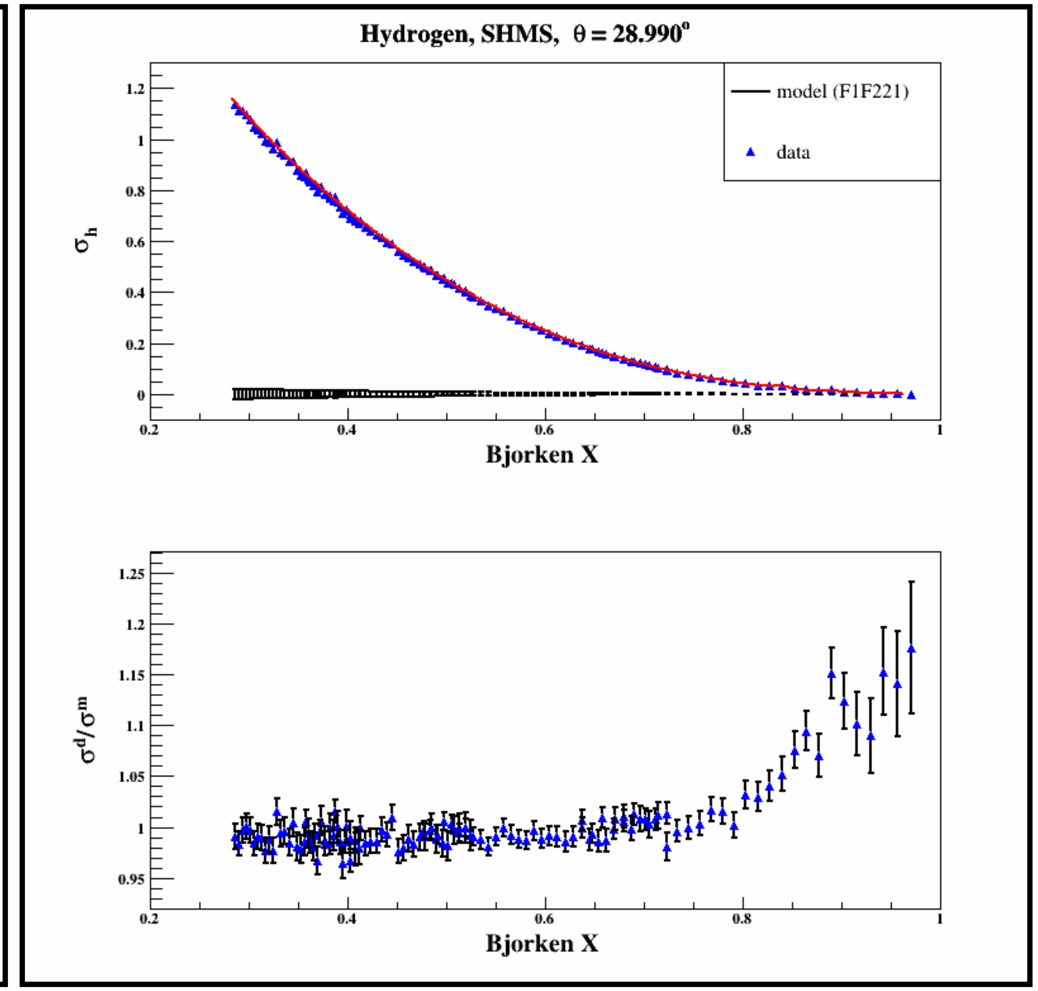


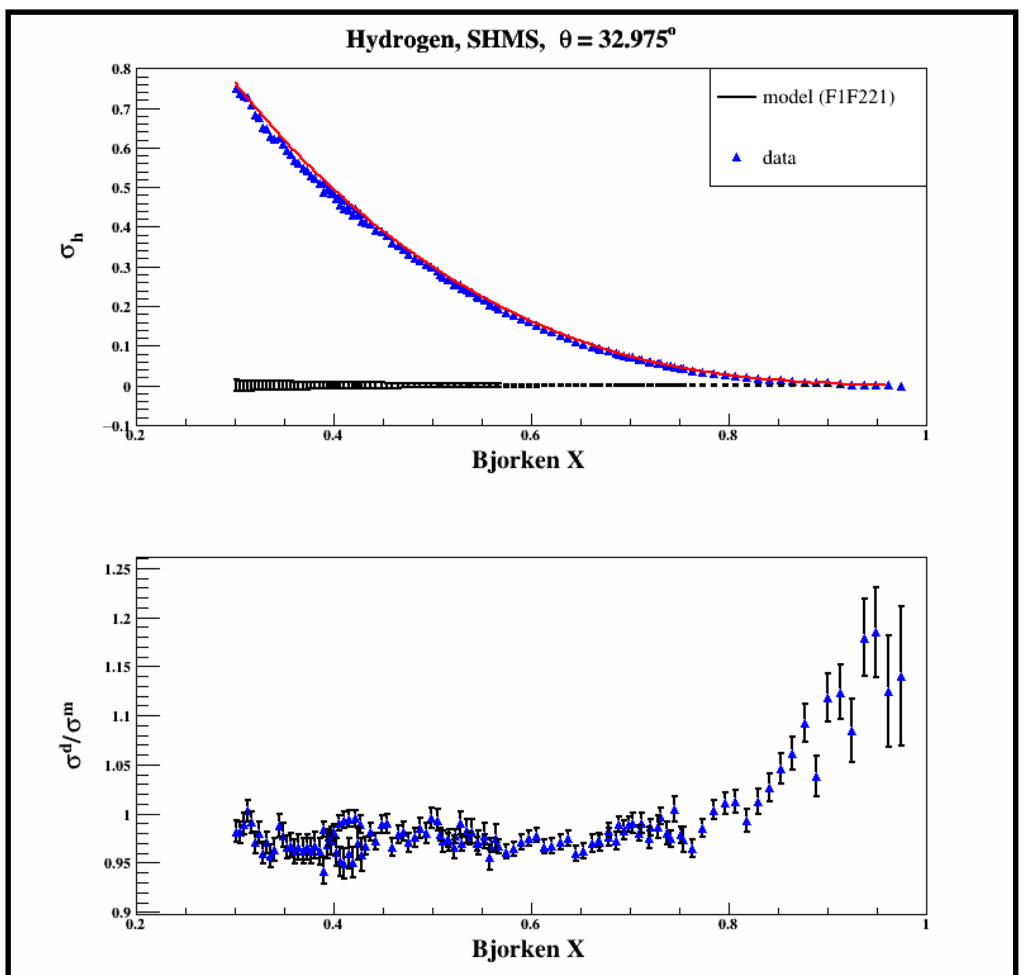


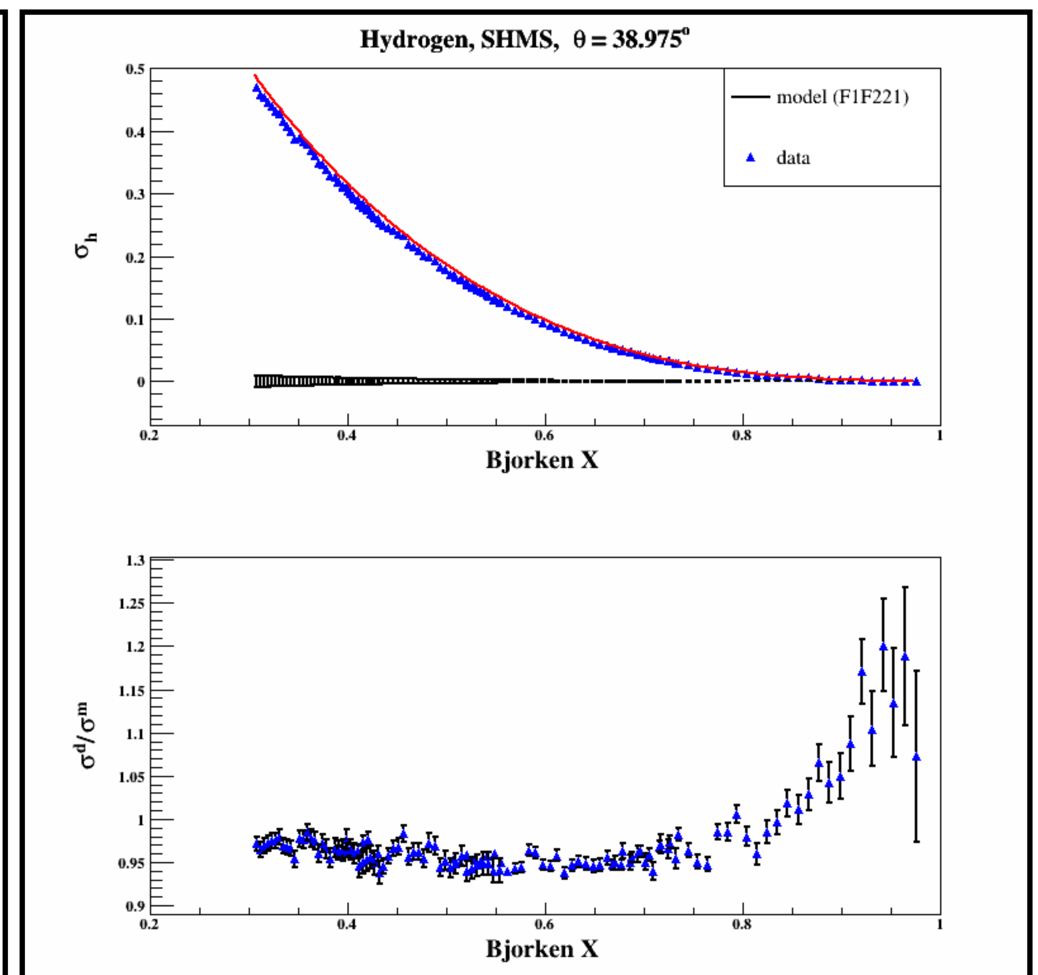
Results : Cross Sections



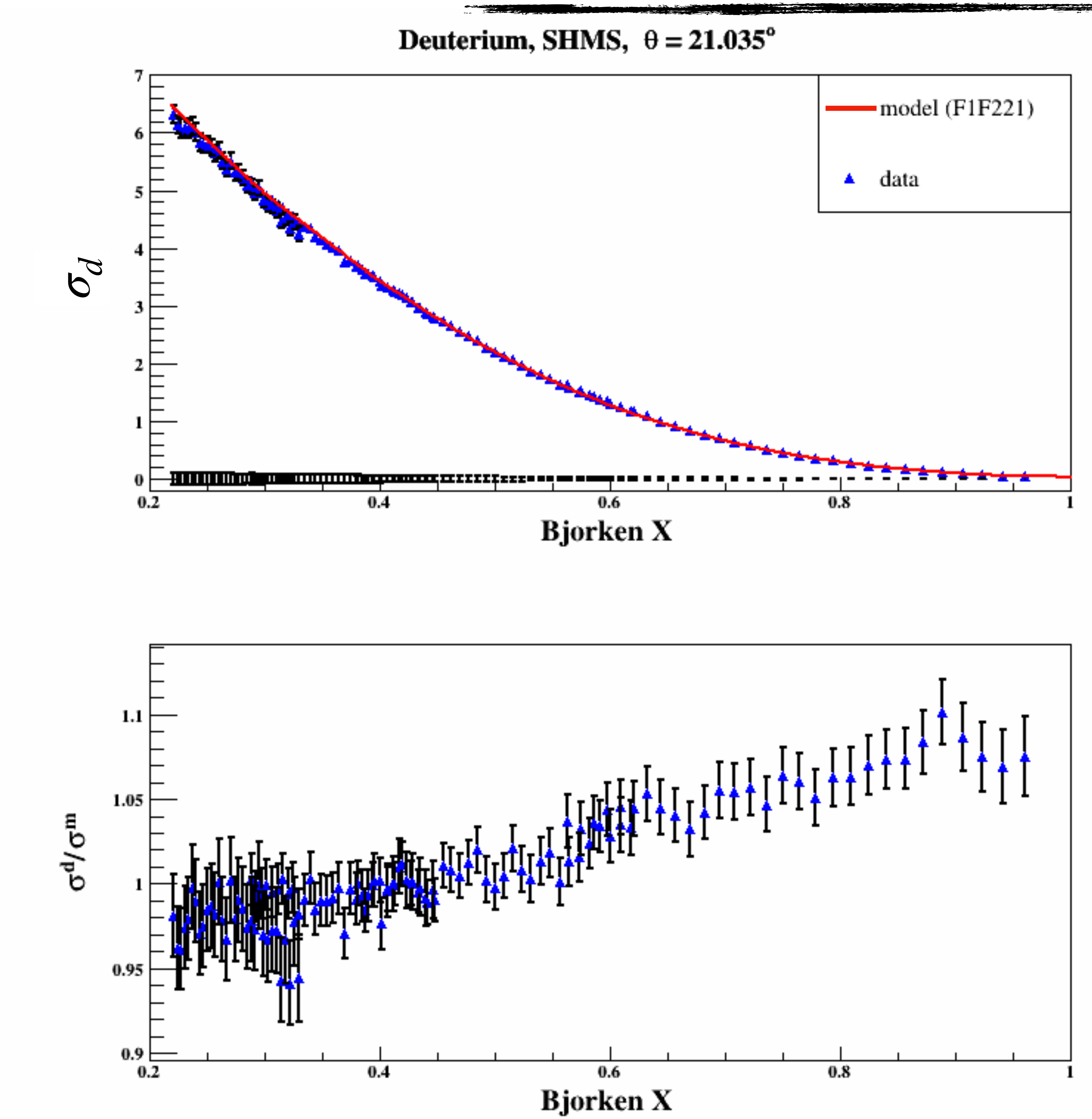

Hydrogen, SHMS, θ = 24.980°
model (F1F221)
data
σh
Bjorken X
σd/σm
Bjorken X

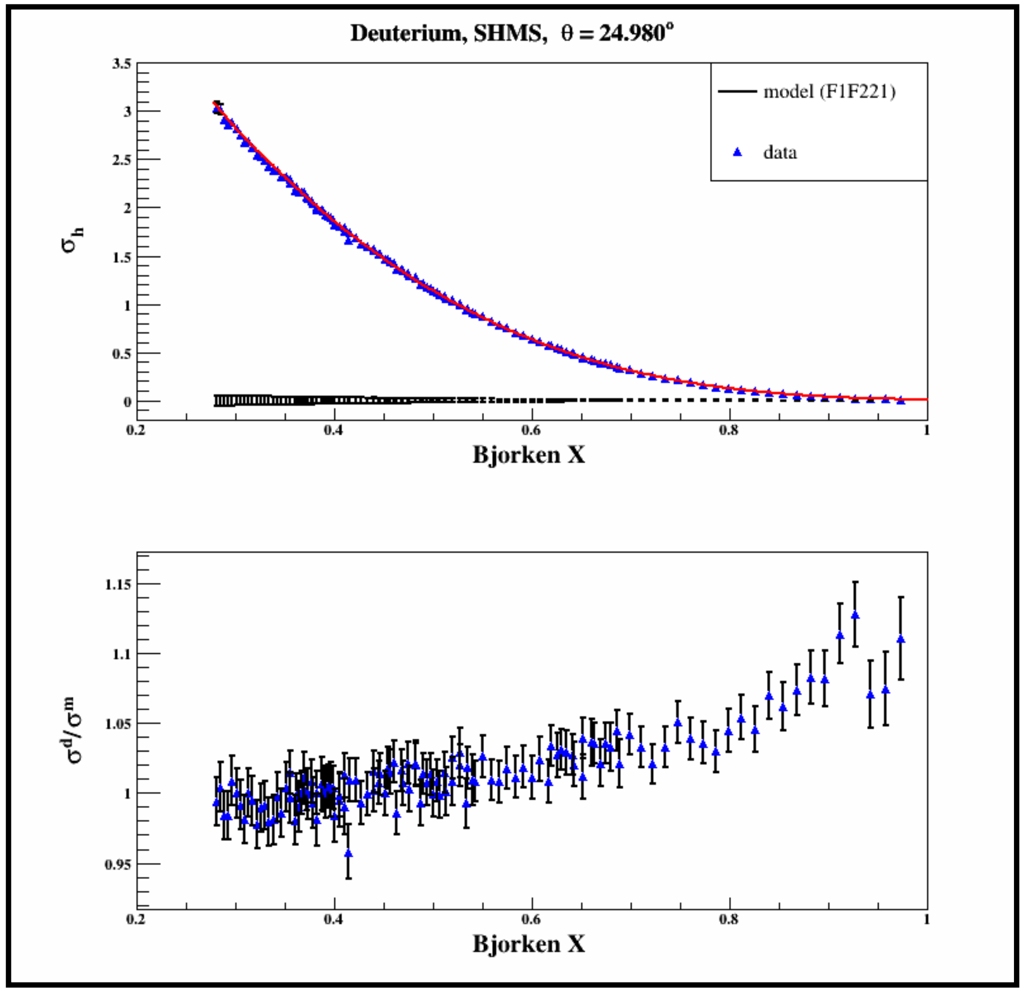

Hydrogen, SHMS, θ = 28.990°
model (F1F221)
data
σh
Bjorken X
σd/σm
Bjorken X

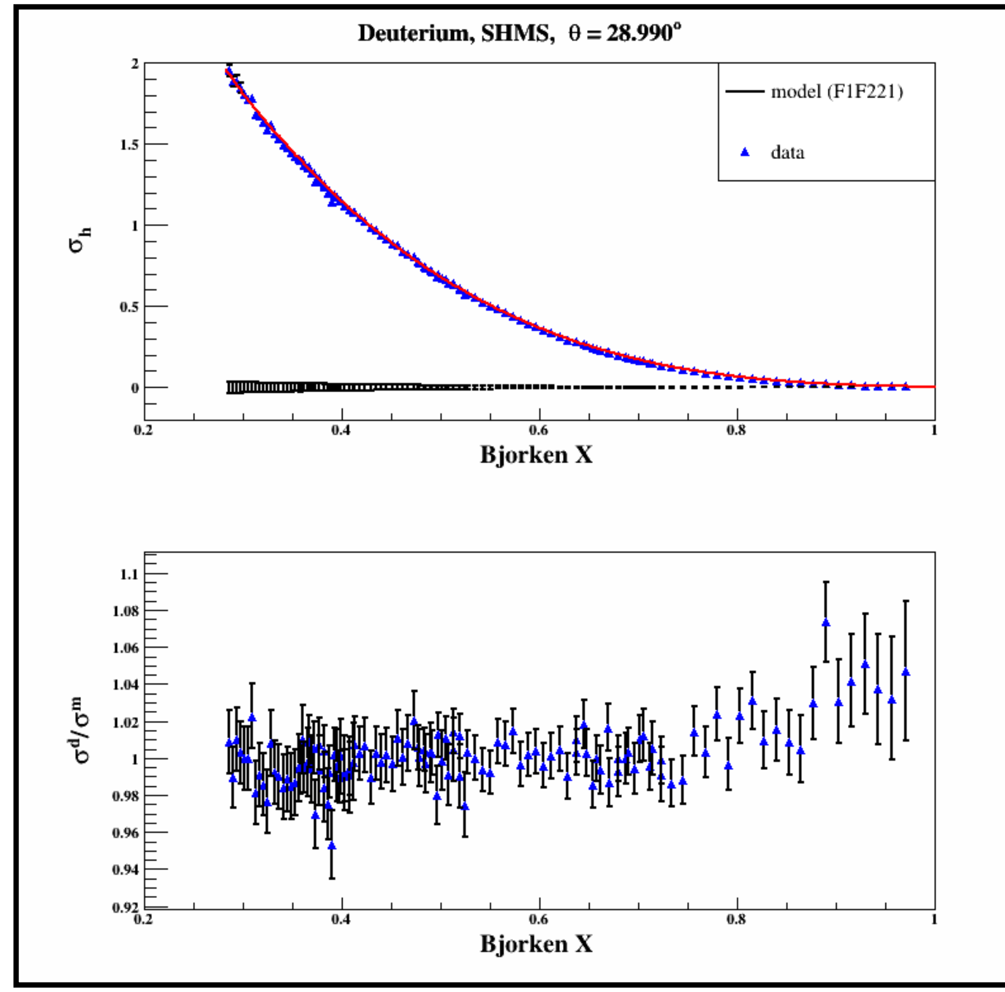

Hydrogen, SHMS, θ = 32.975°
model (F1F221)
data
σh
Bjorken X
σd/σm
Bjorken X

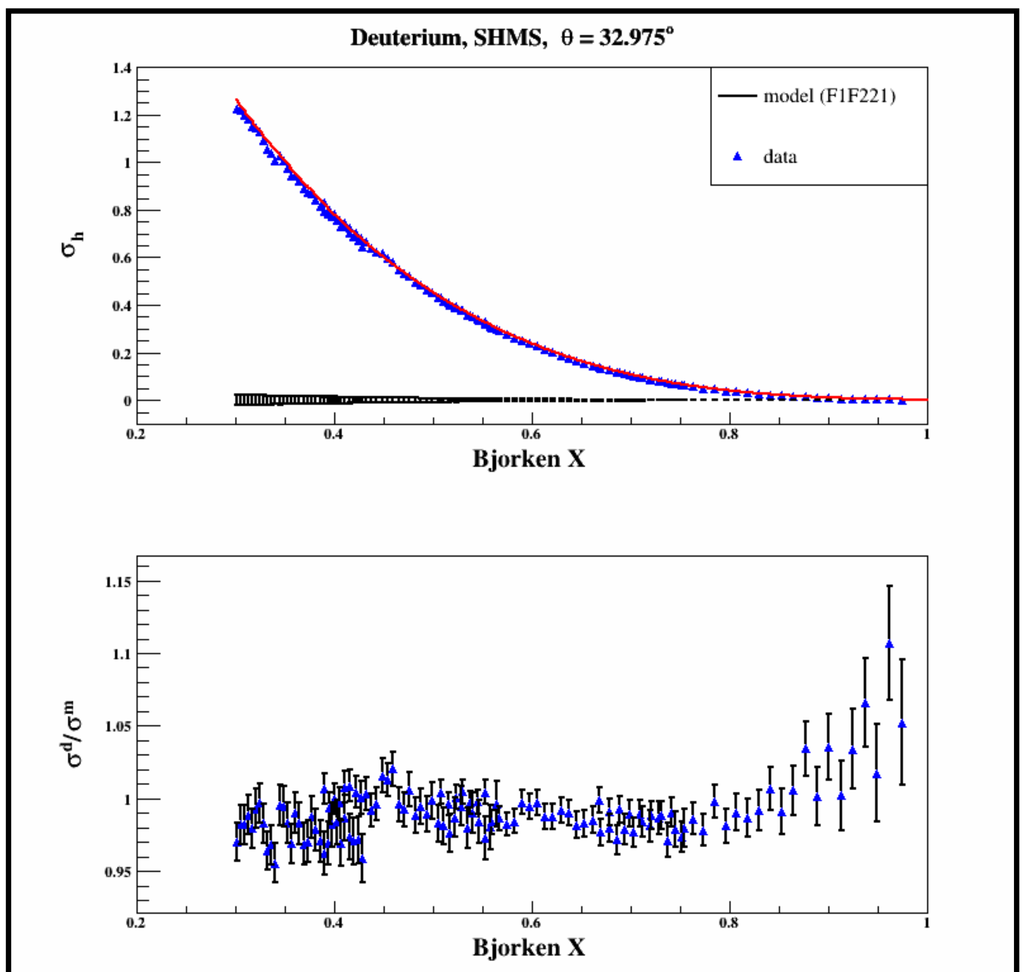

Hydrogen, SHMS, θ = 38.975°
model (F1F221)
data
σh
Bjorken X
σd/σm
Bjorken X

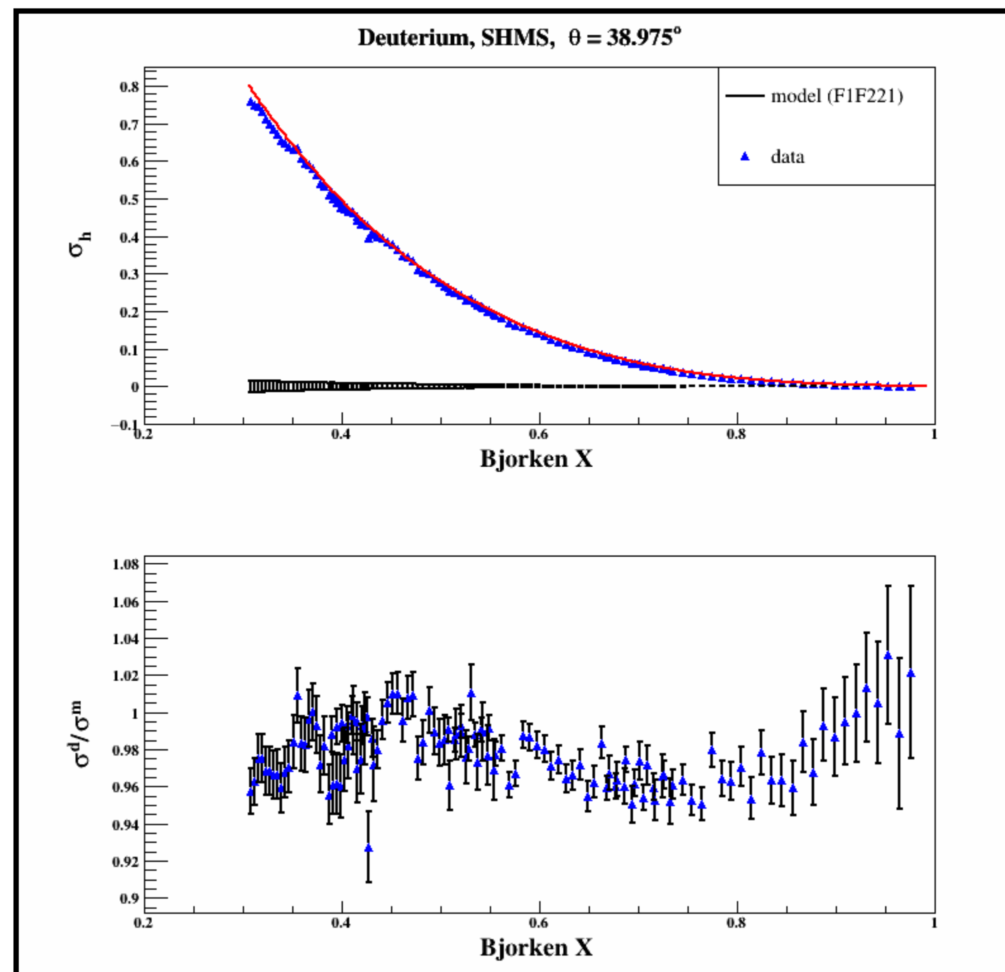
Results : Cross Sections




Deuterium, SHMS, θ = 24.980°
model (F1F221)
data
σ_h
Bjorken X
σ^d/σ^m
Bjorken X


Deuterium, SHMS, θ = 28.990°
model (F1F221)
data
σ_h
Bjorken X
σ^d/σ^m
Bjorken X

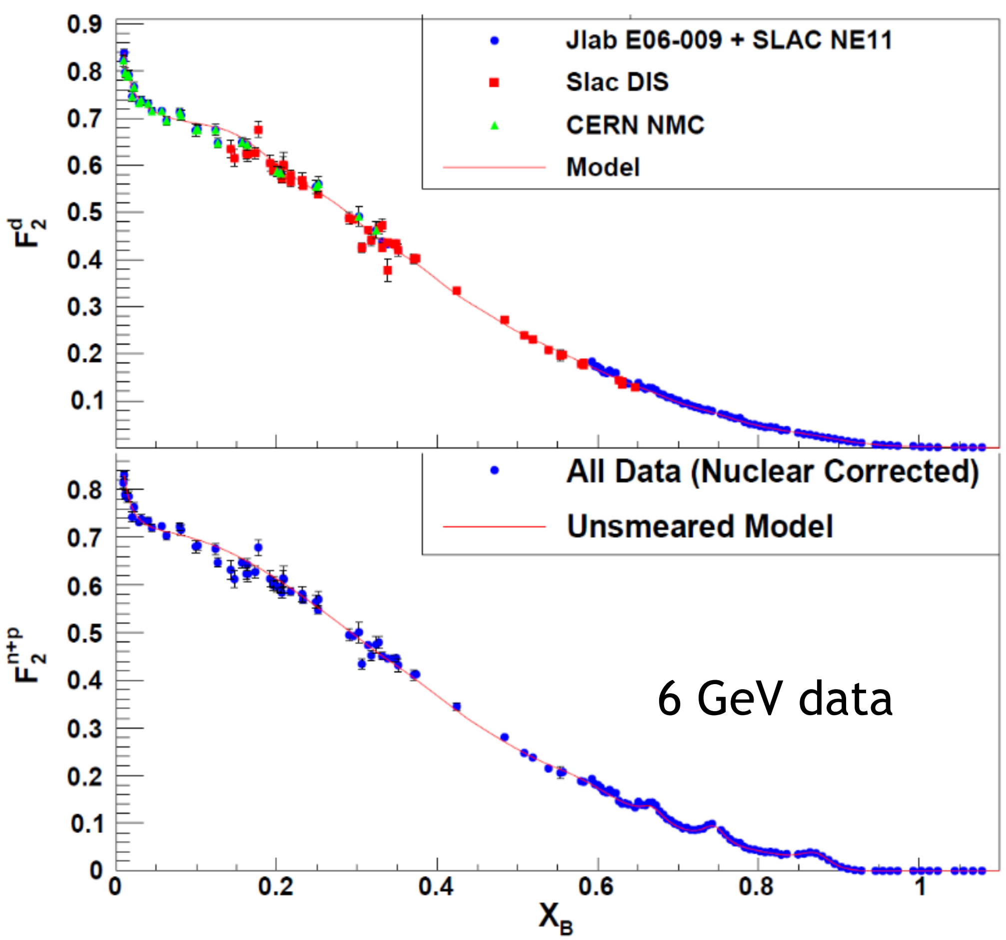

Deuterium, SHMS, θ = 32.975°
model (F1F221)
data
σ_h
Bjorken X
σ^d/σ^m
Bjorken X


Deuterium, SHMS, θ = 38.975°
model (F1F221)
data
σ_h
Bjorken X
σ^d/σ^m
Bjorken X

Extraction of Neutron Cross-section

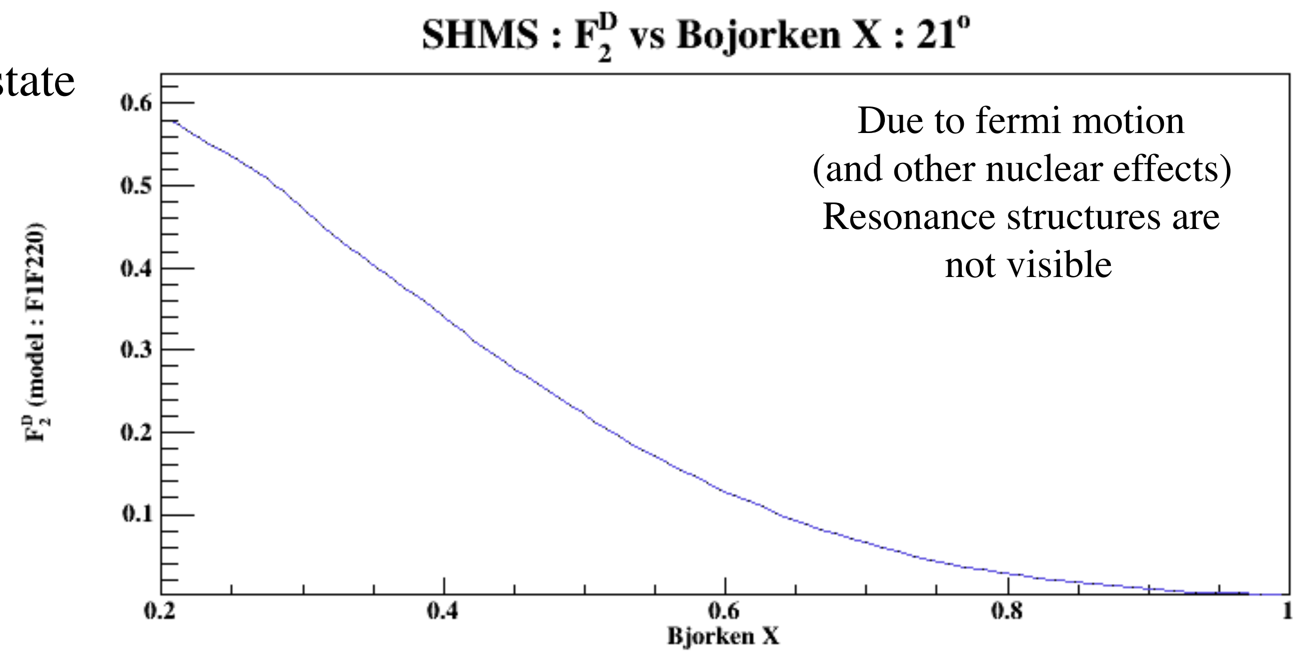
- In deuterium proton and neutron are in bound state
- Neutron cross-section can be calculated by subtracting the proton cross-section from the deuteron and nuclear effects removed
- To get the unbound p+n cross-section from the bound p+n state inside deuterium-

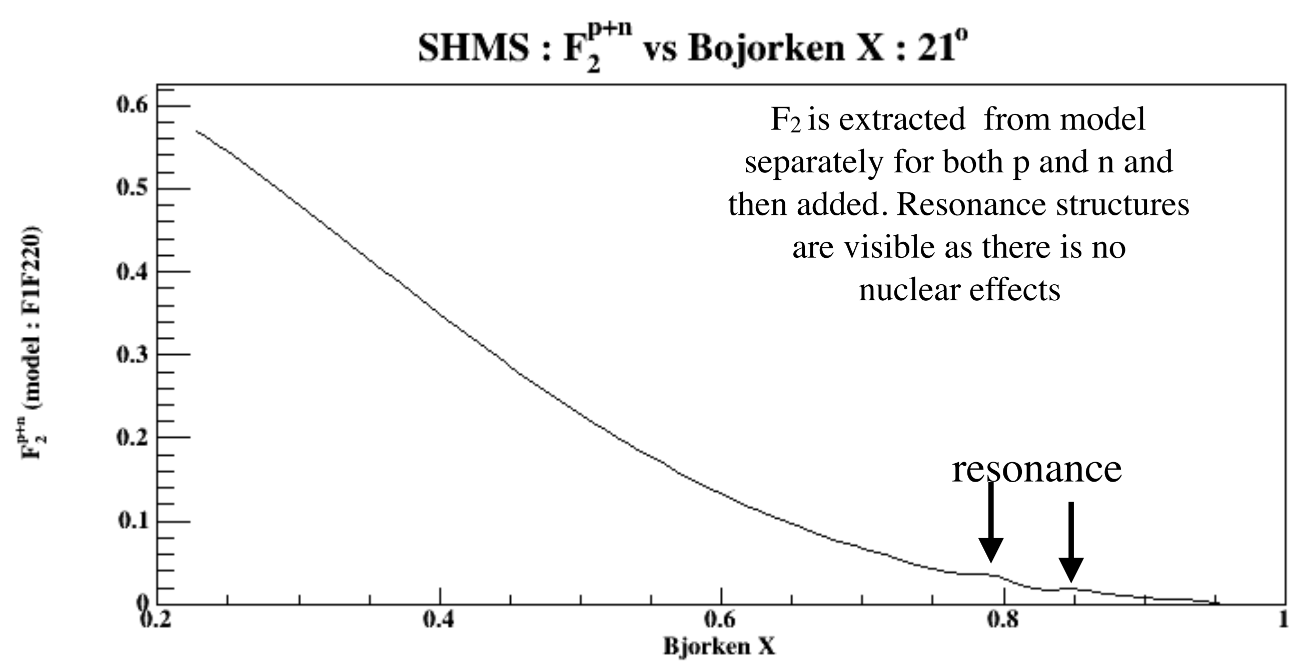
$$\sigma^{p+n} = \frac{\sigma^{p+n}_{model}}{\sigma^{d2}_{model}} \times \sigma^{d2}_{data}$$



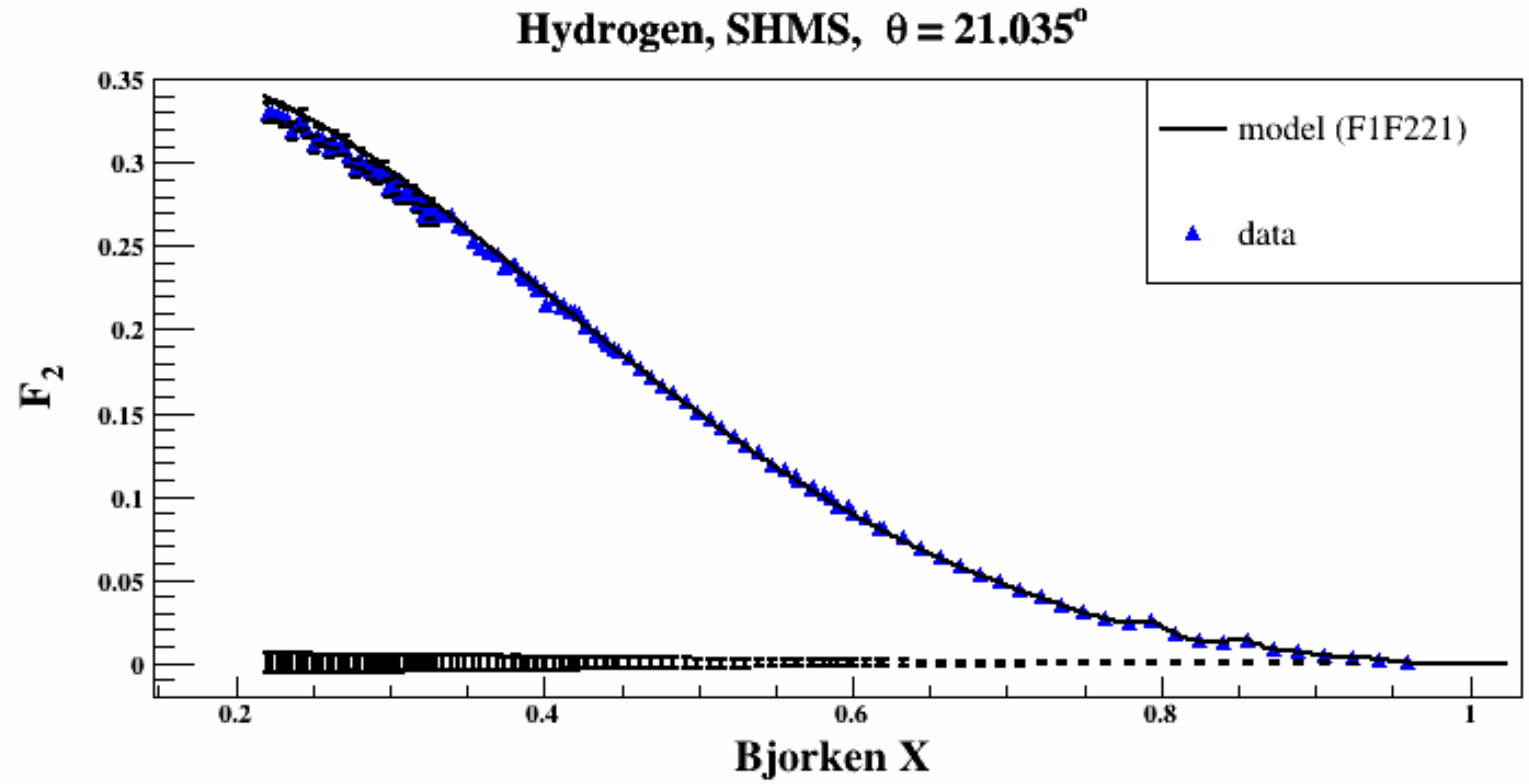
by I. Albayrak, V. Mamyan, M.E. Christy et.al.
Ref. : https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.123.022501

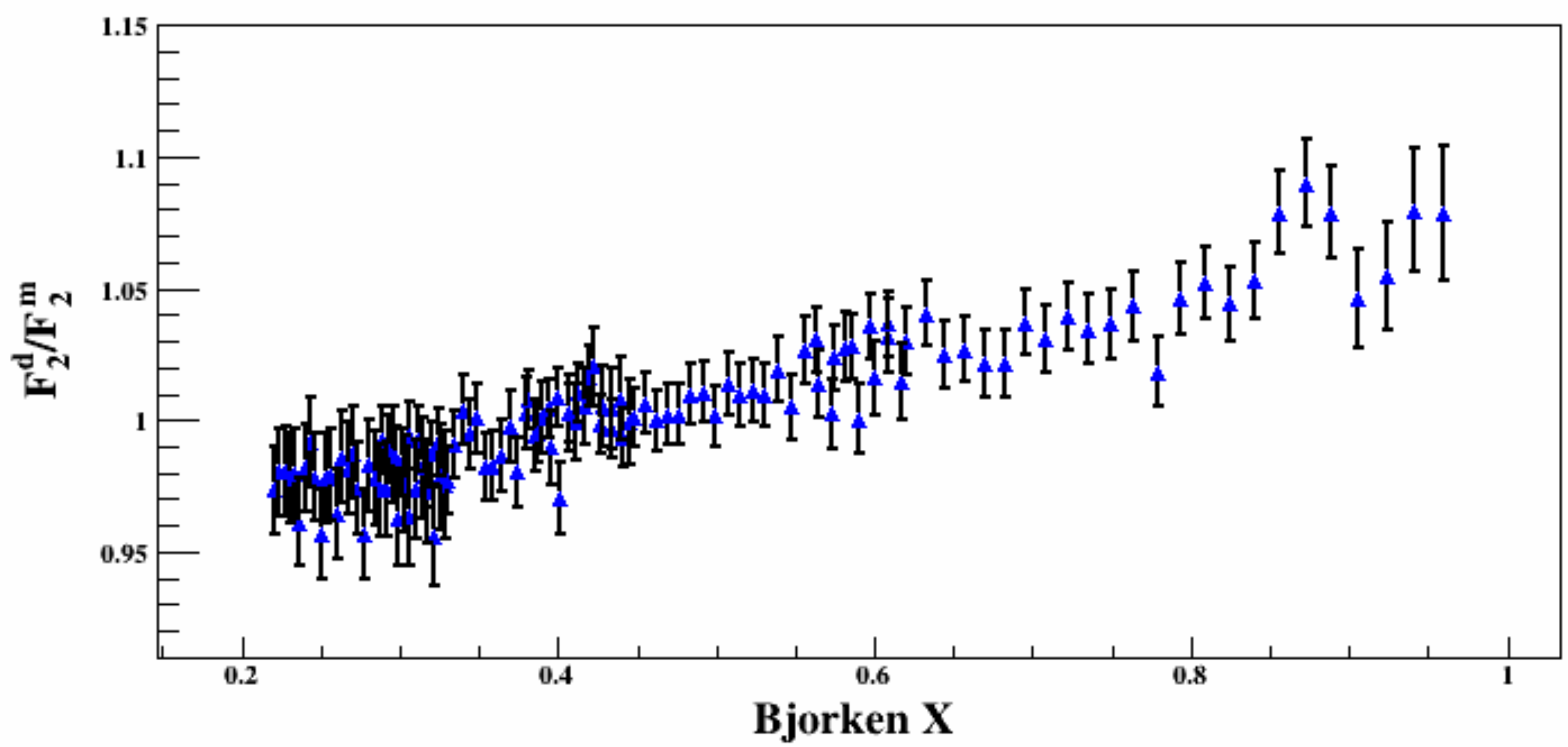
F_2 of deuteron (bound p+n) and unbound p+n

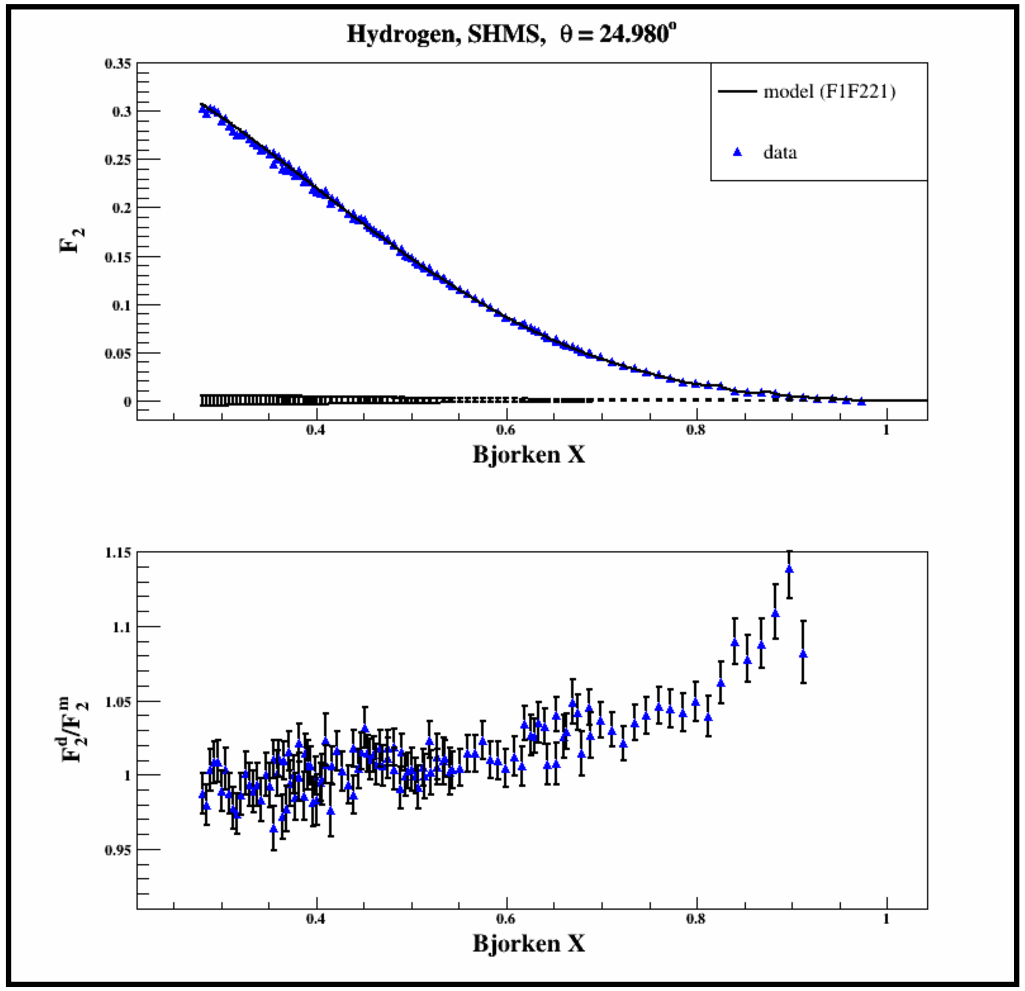


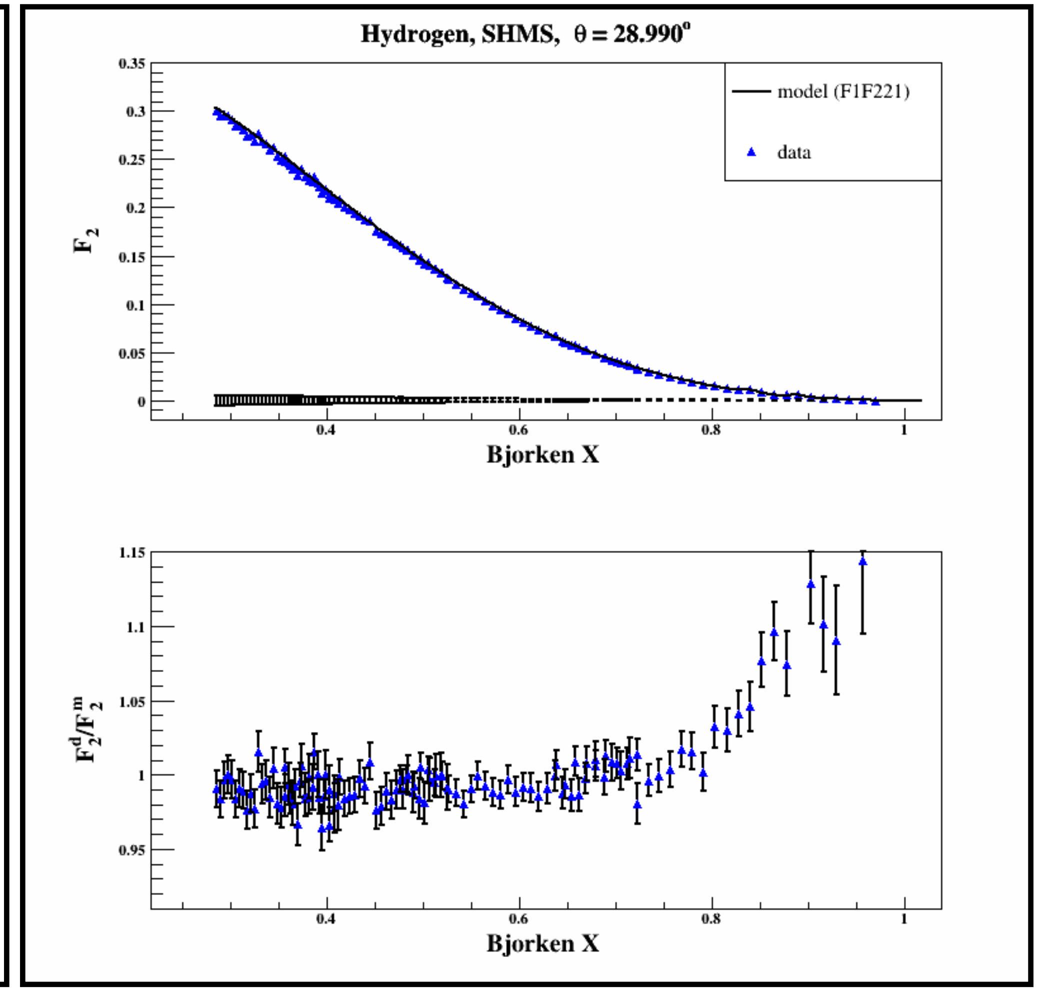


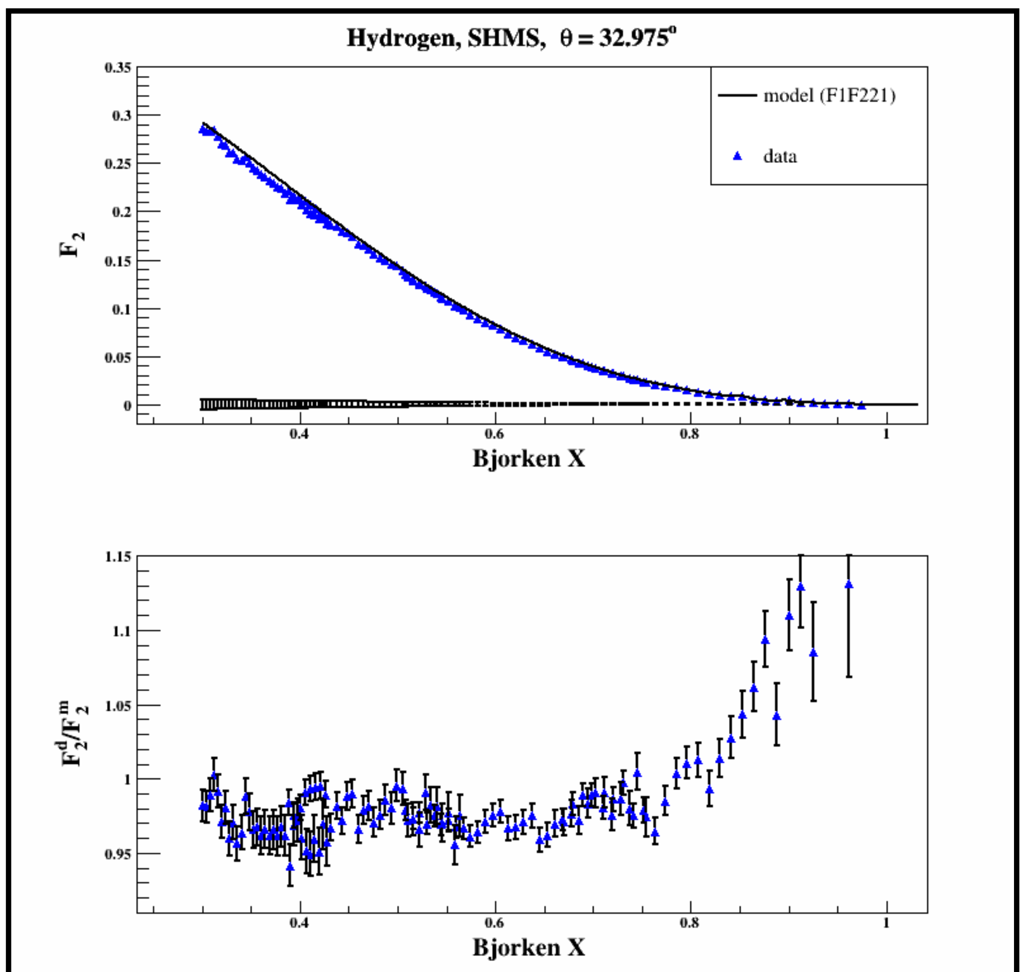
Results : F_2 structure function

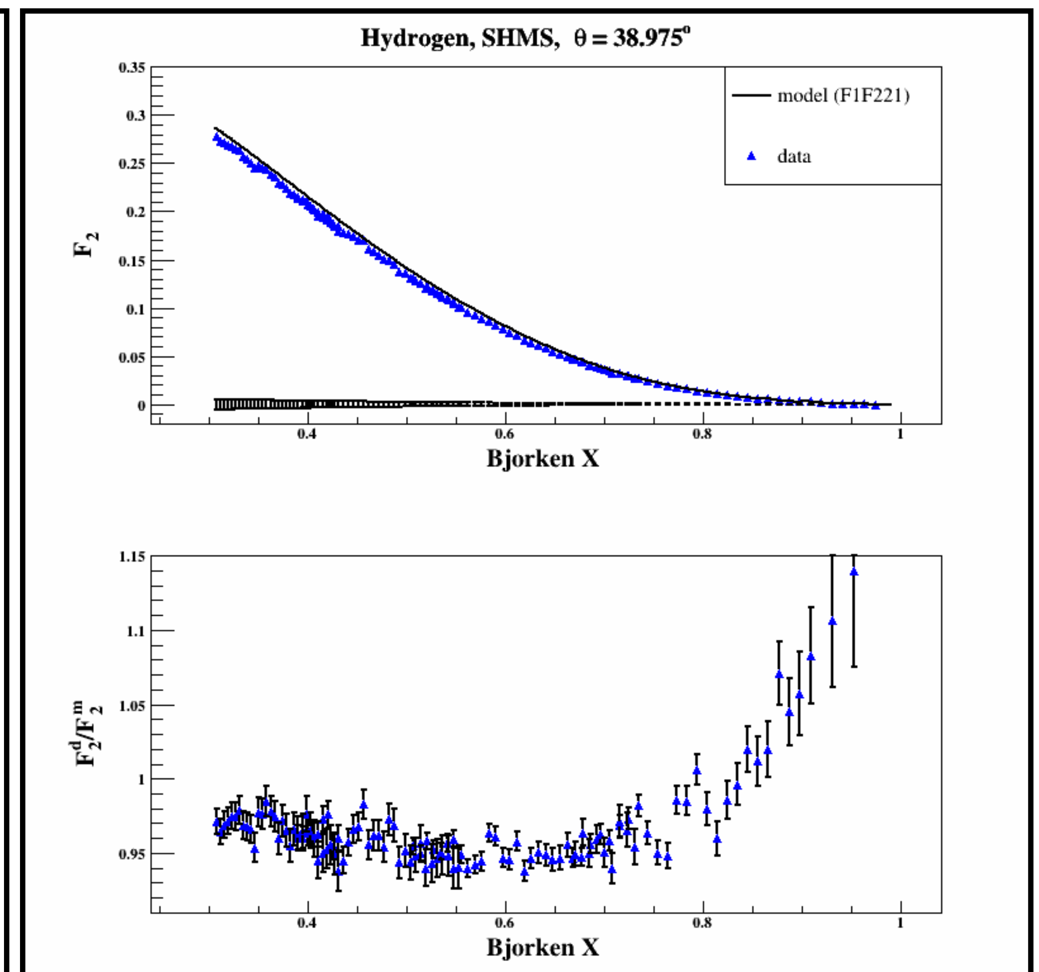




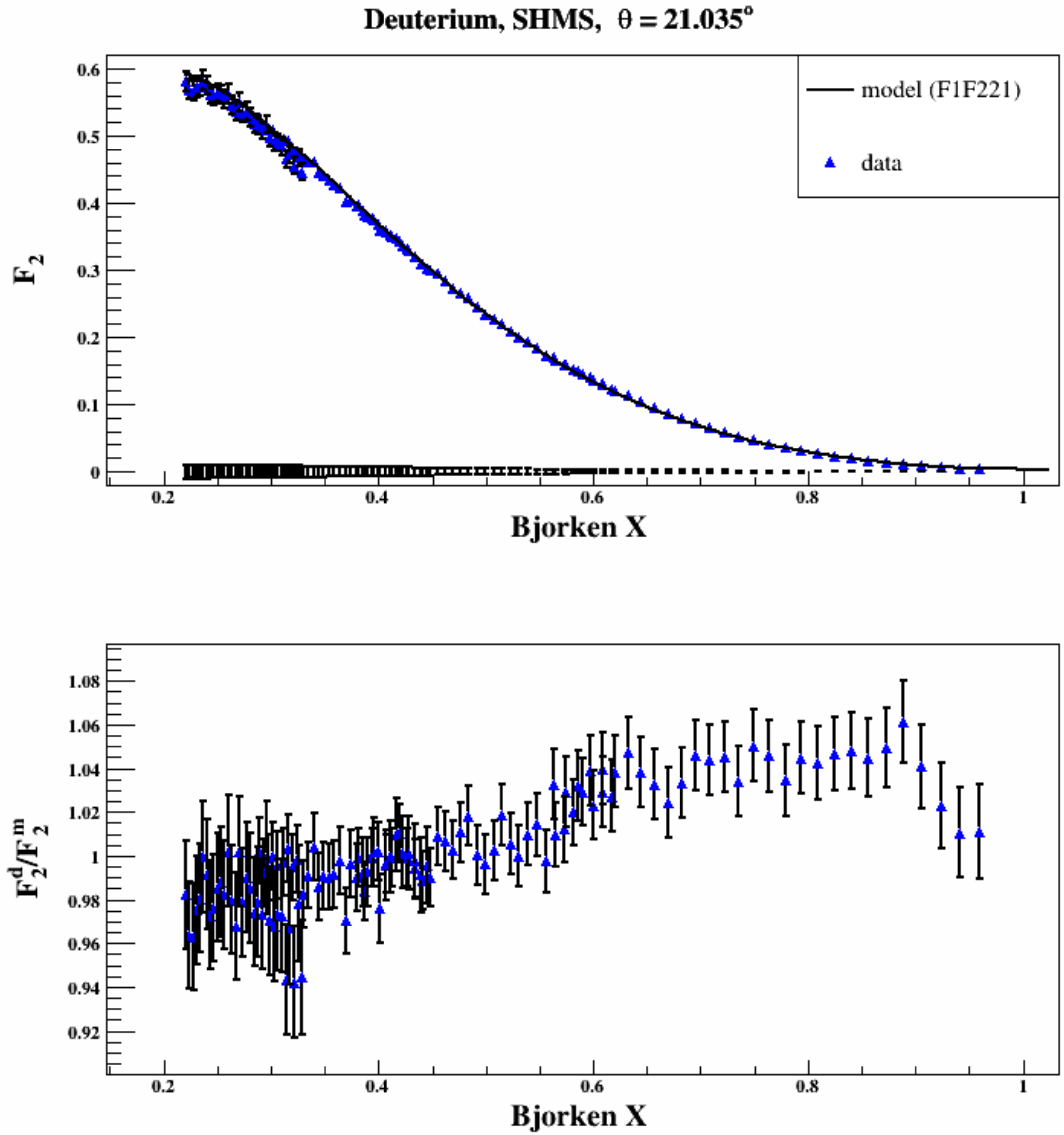

Hydrogen, SHMS, θ = 24.980°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X

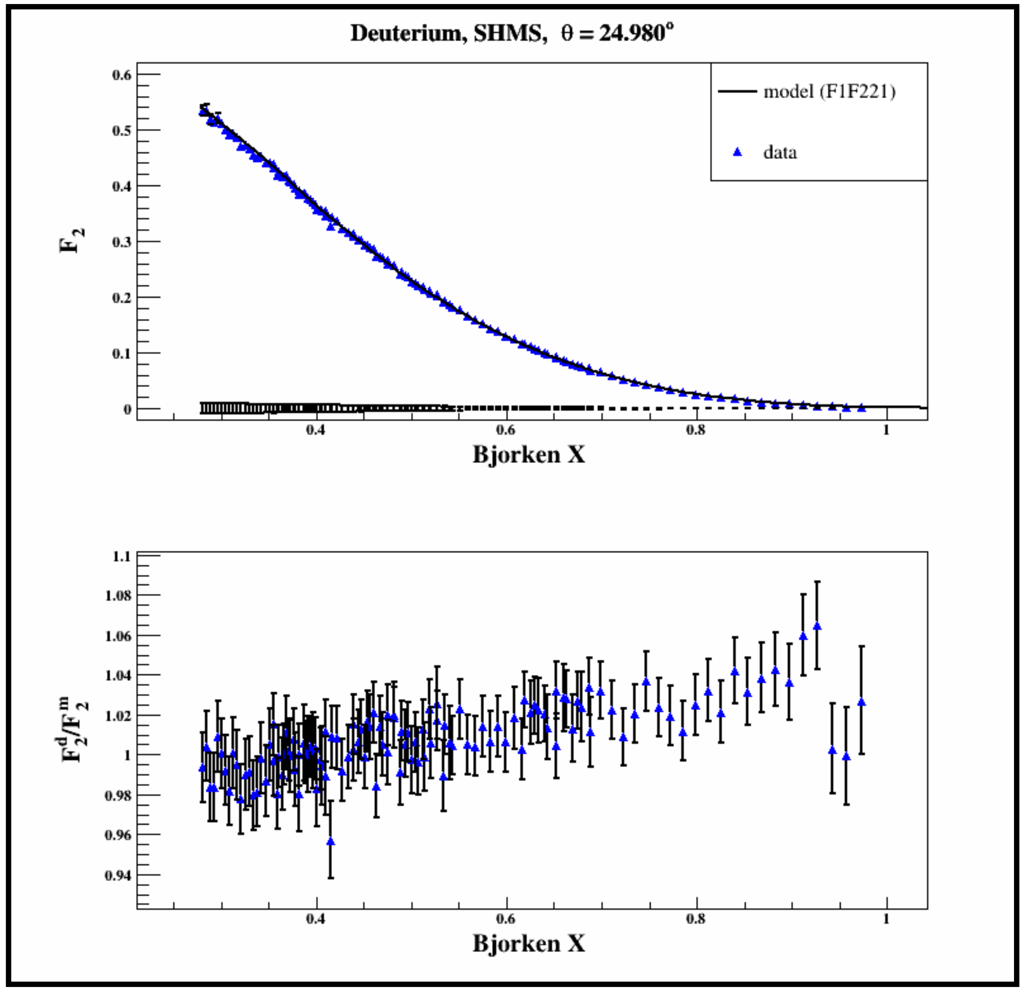

Hydrogen, SHMS, θ = 28.990°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X

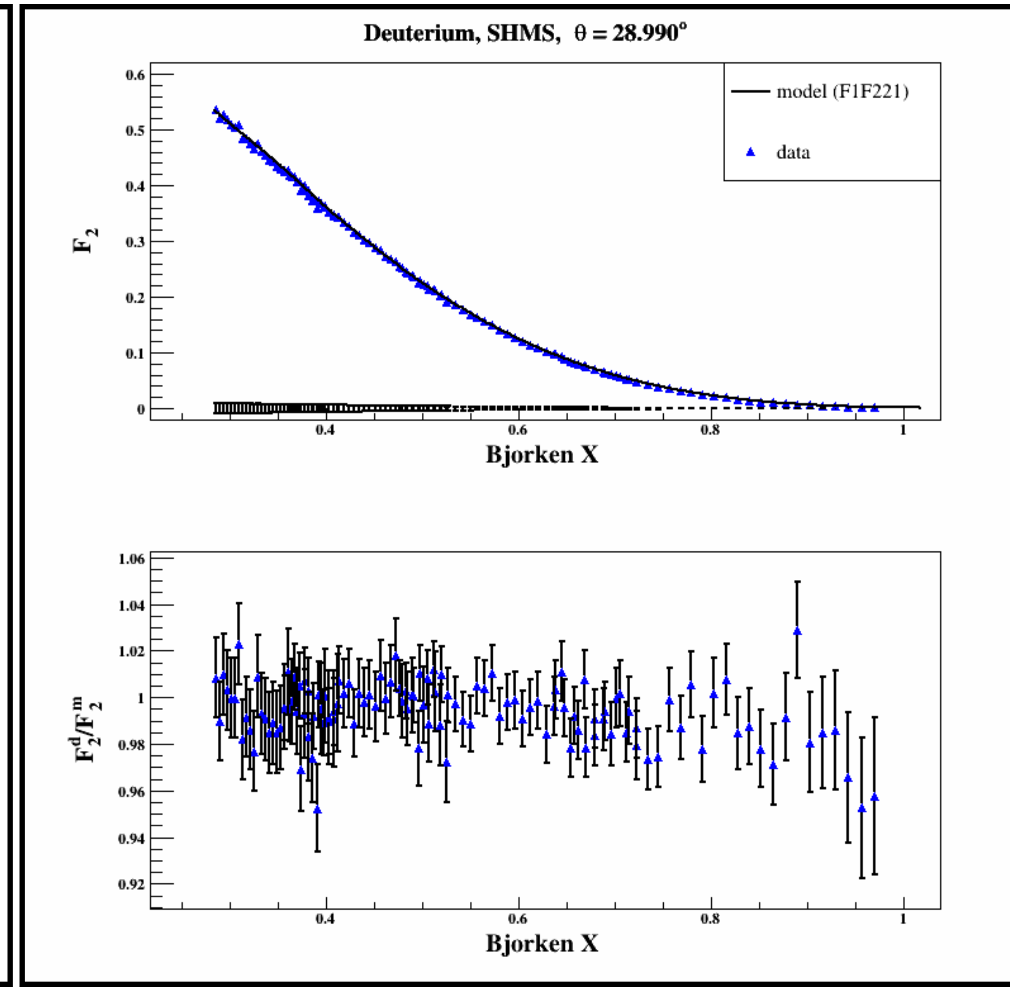

Hydrogen, SHMS, θ = 32.975°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X

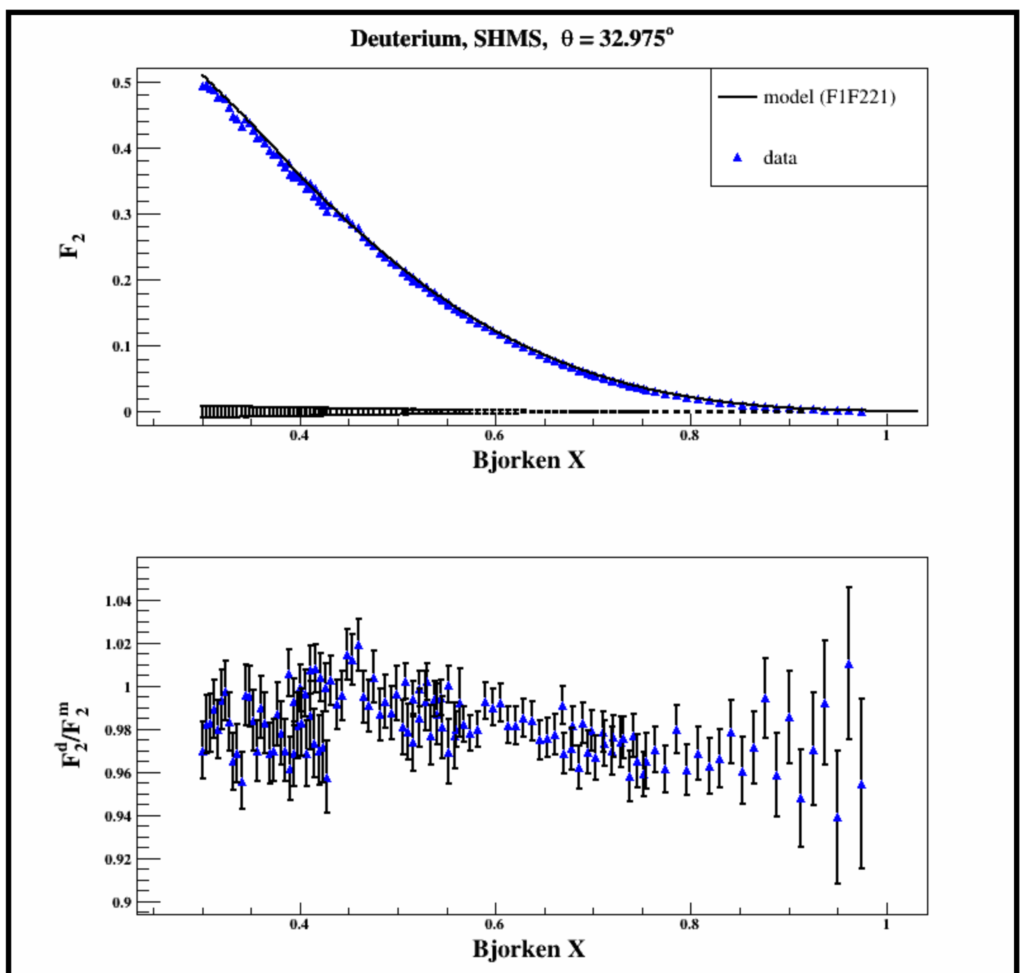

Hydrogen, SHMS, θ = 38.975°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X

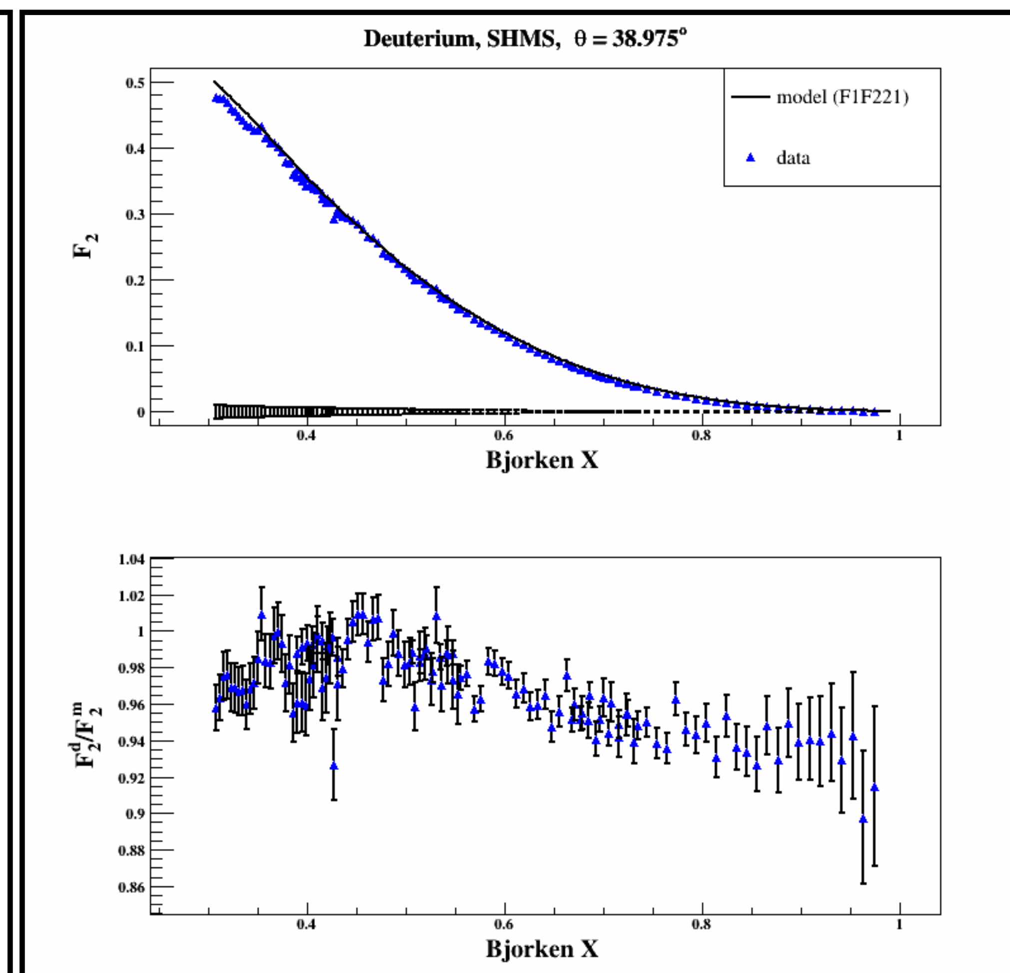
Results : F_2 structure function



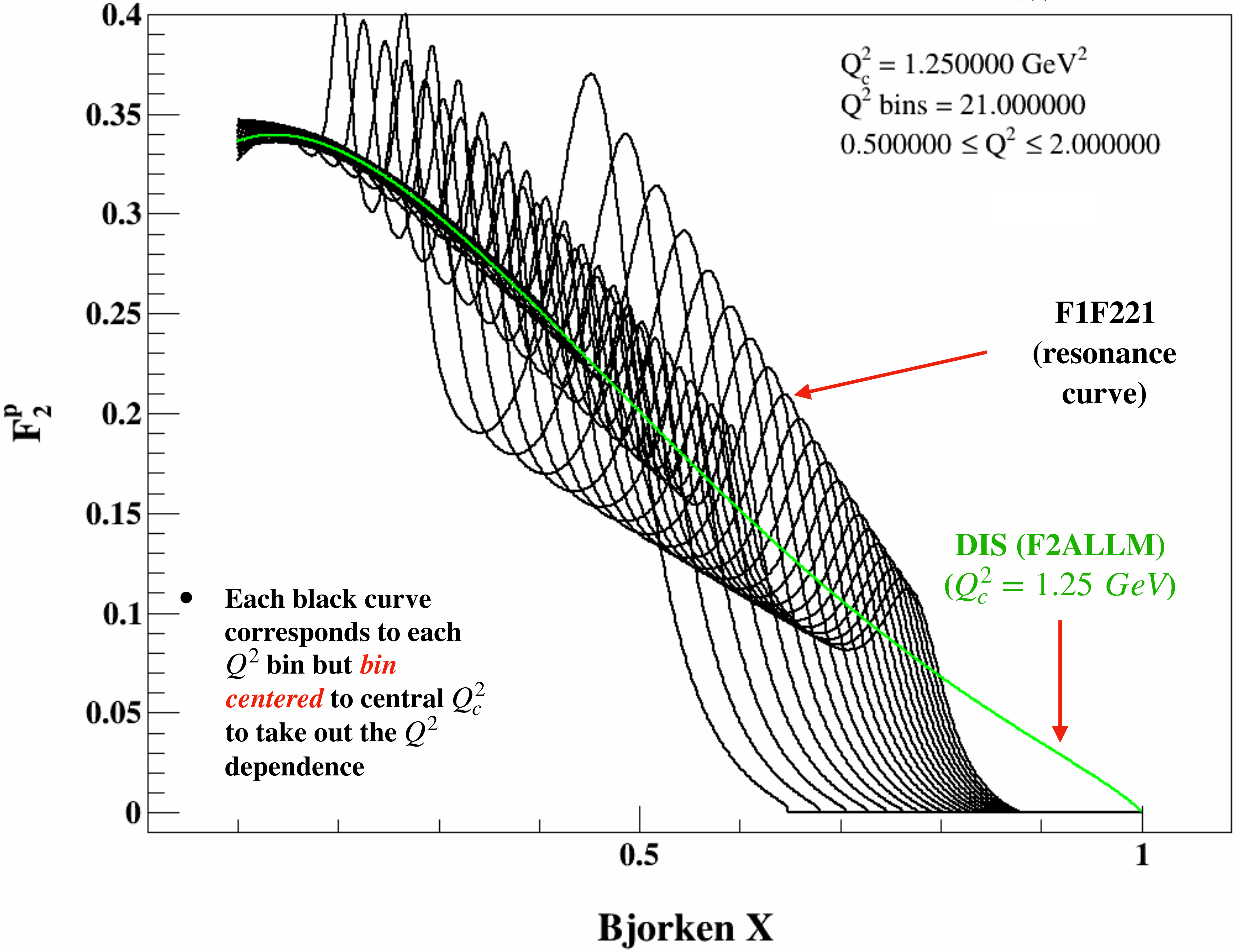

Deuterium, SHMS, θ = 24.980°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X


Deuterium, SHMS, θ = 28.990°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X


Deuterium, SHMS, θ = 32.975°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X

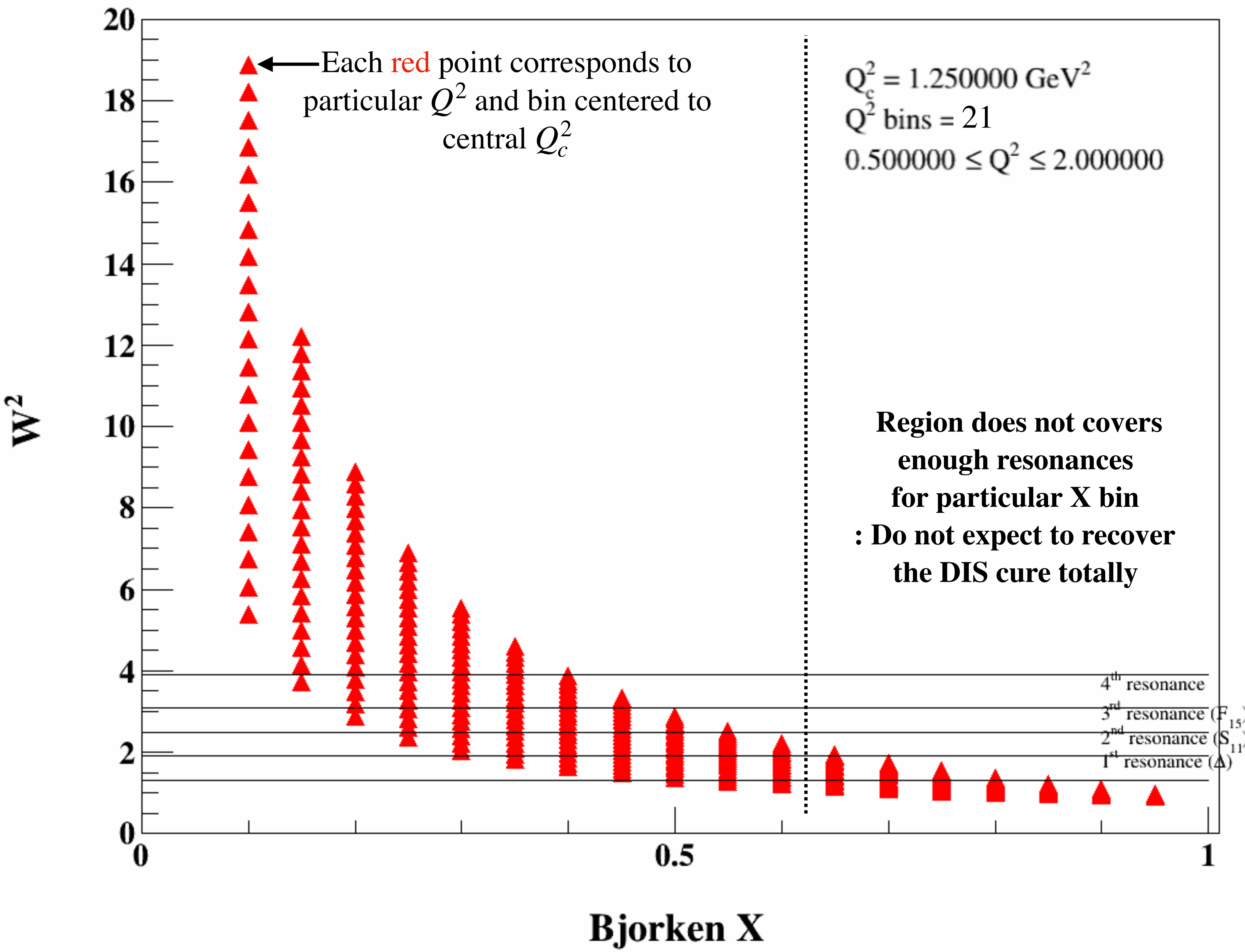

Deuterium, SHMS, θ = 38.975°
model (F1F221)
data
F_2
Bjorken X
F_2^d/F_2^m
Bjorken X

Results : Duality Averaging Procedure

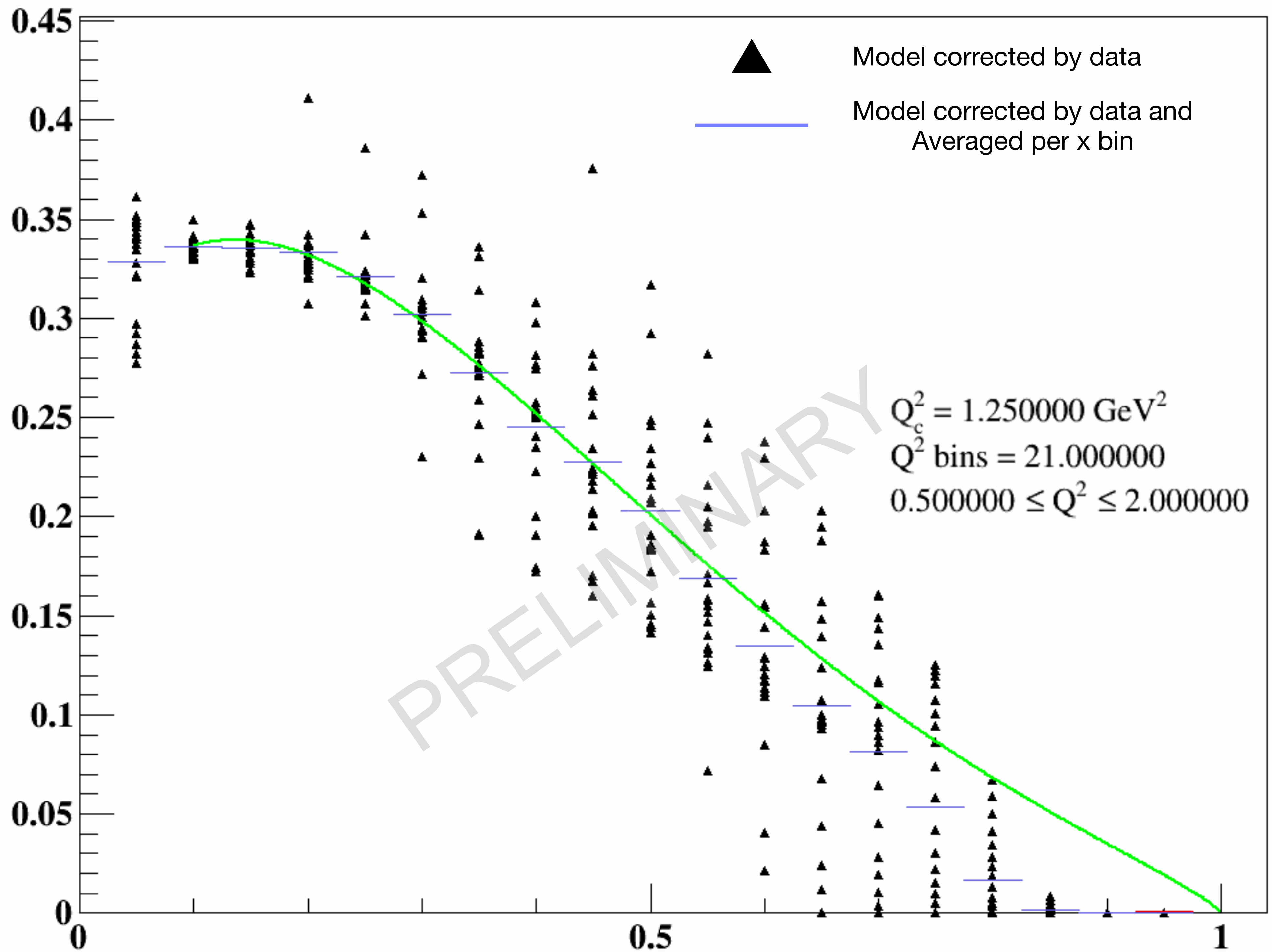


- From the pioneering work of Bloom and Gilman at SLAC we know F_2 structure function data at DIS region also describe the *average resonance* region F_2 data at same Q^2
- for a broad range of Q^2 the dips and peaks (defined by W^2) of different resonances passes through a particular X *(video)*
- Hence averaging a large enough Q^2 region should recover the scaling curve
- As the resonances are defined by W^2 it is important to check the W^2 coverage for each X bin (next slide)

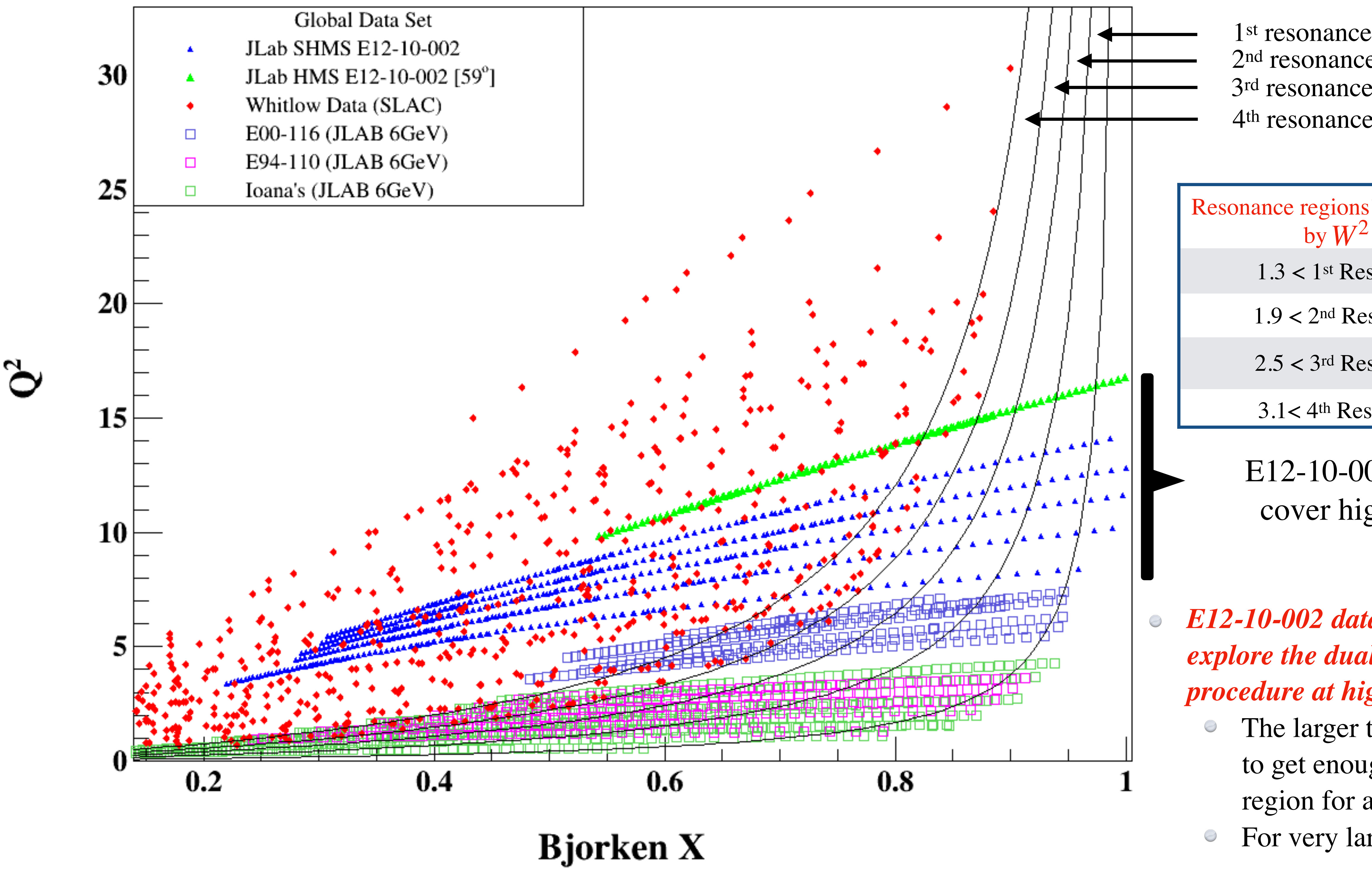
Results : Duality Averaging Procedure



Results : Duality Averaging Procedure



Results : Duality Averaging Procedure

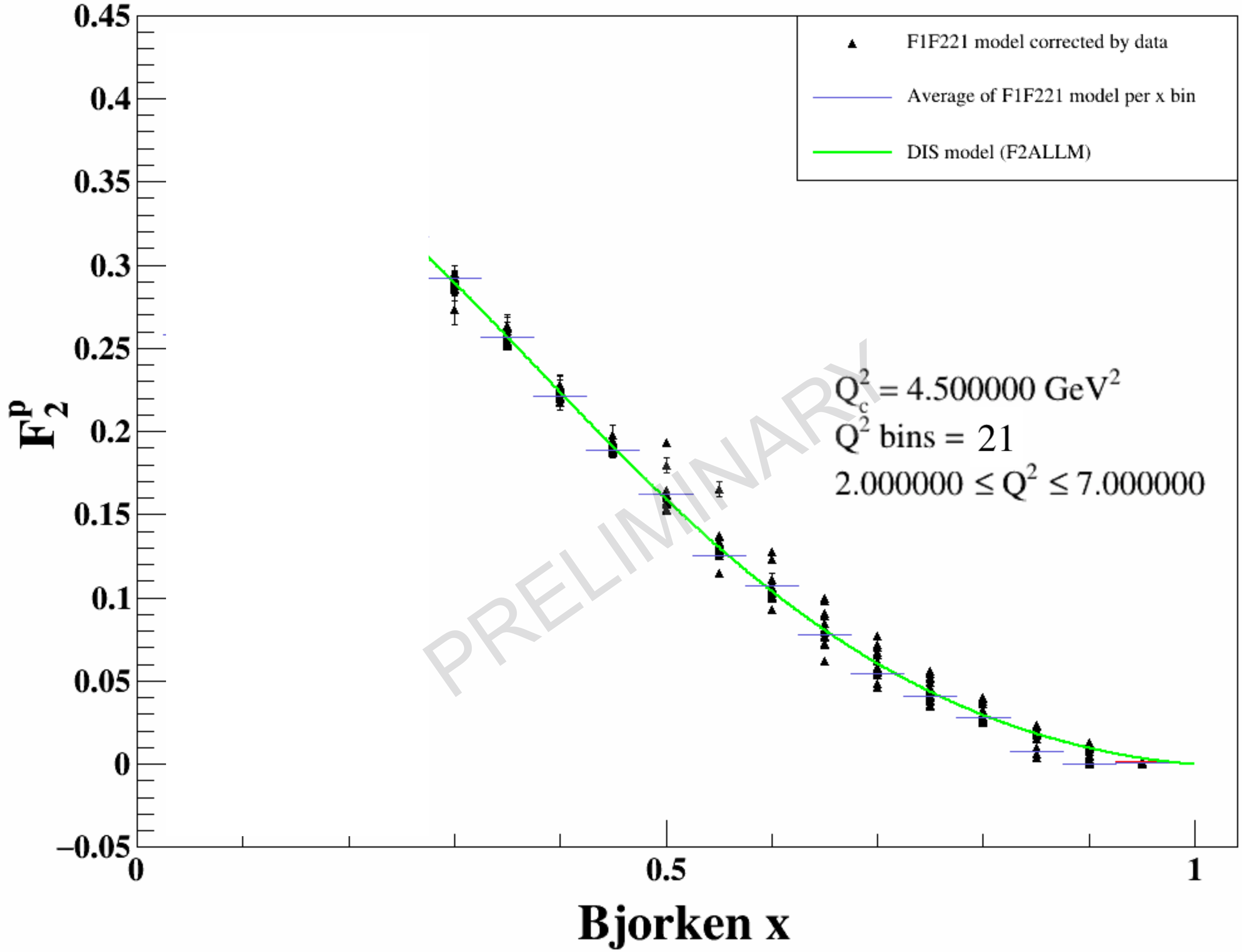


Resonance regions' boundaries defined by W^2 (GeV2)
1.3 < 1st Resonance < 1.9
1.9 < 2nd Resonance < 2.5
2.5 < 3rd Resonance < 3.1
3.1< 4th Resonance < 3.9

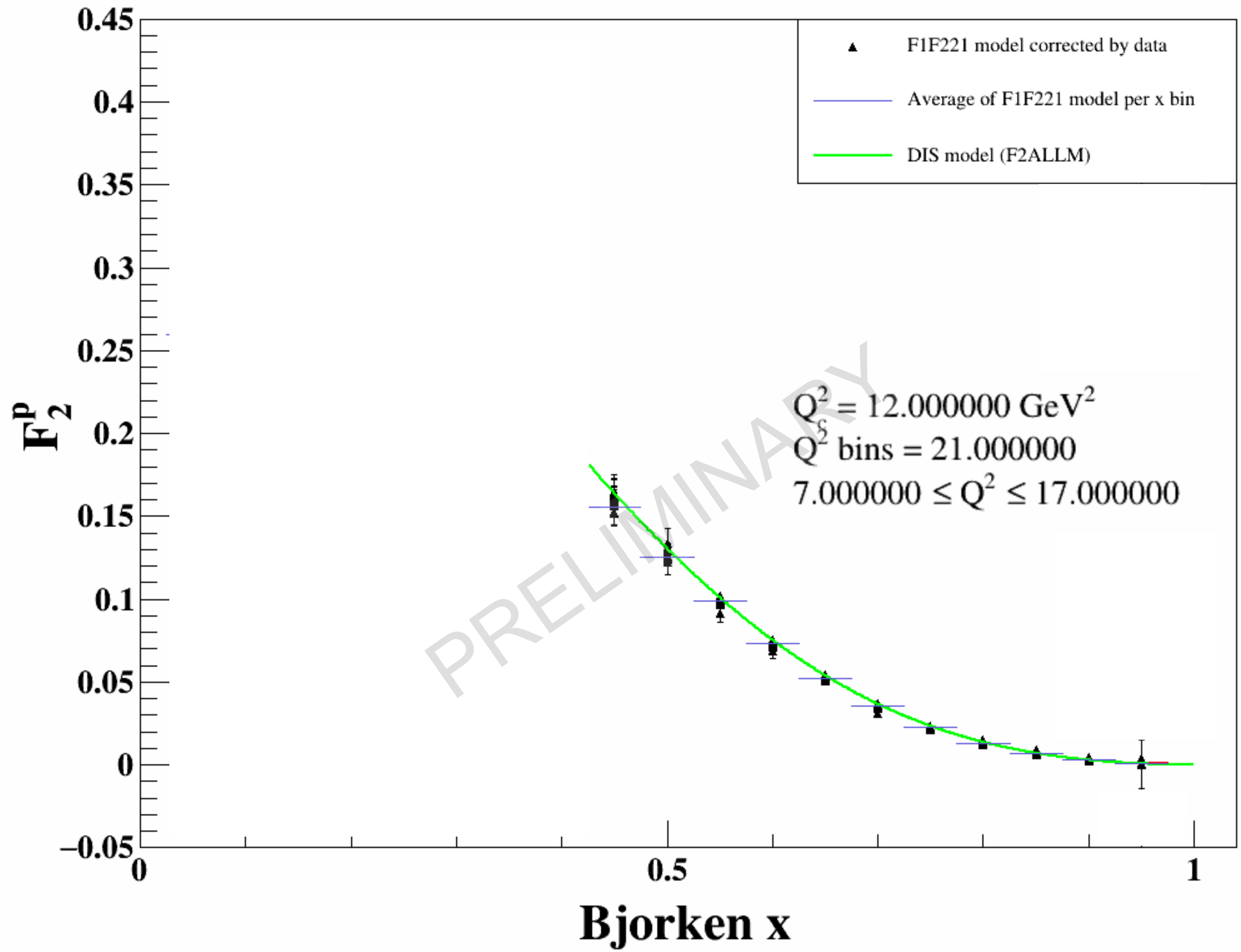
E12-10-002 data cover high Q^2

- ***E12-10-002 data enables us to explore the duality average procedure at higher Q^2 region***
  - The larger the Q^2 harder is to get enough resonance region for a fixed X bin
  - For very large Q^2 the resonance regions are almost parallel to each

Results : Duality Averaging Procedure

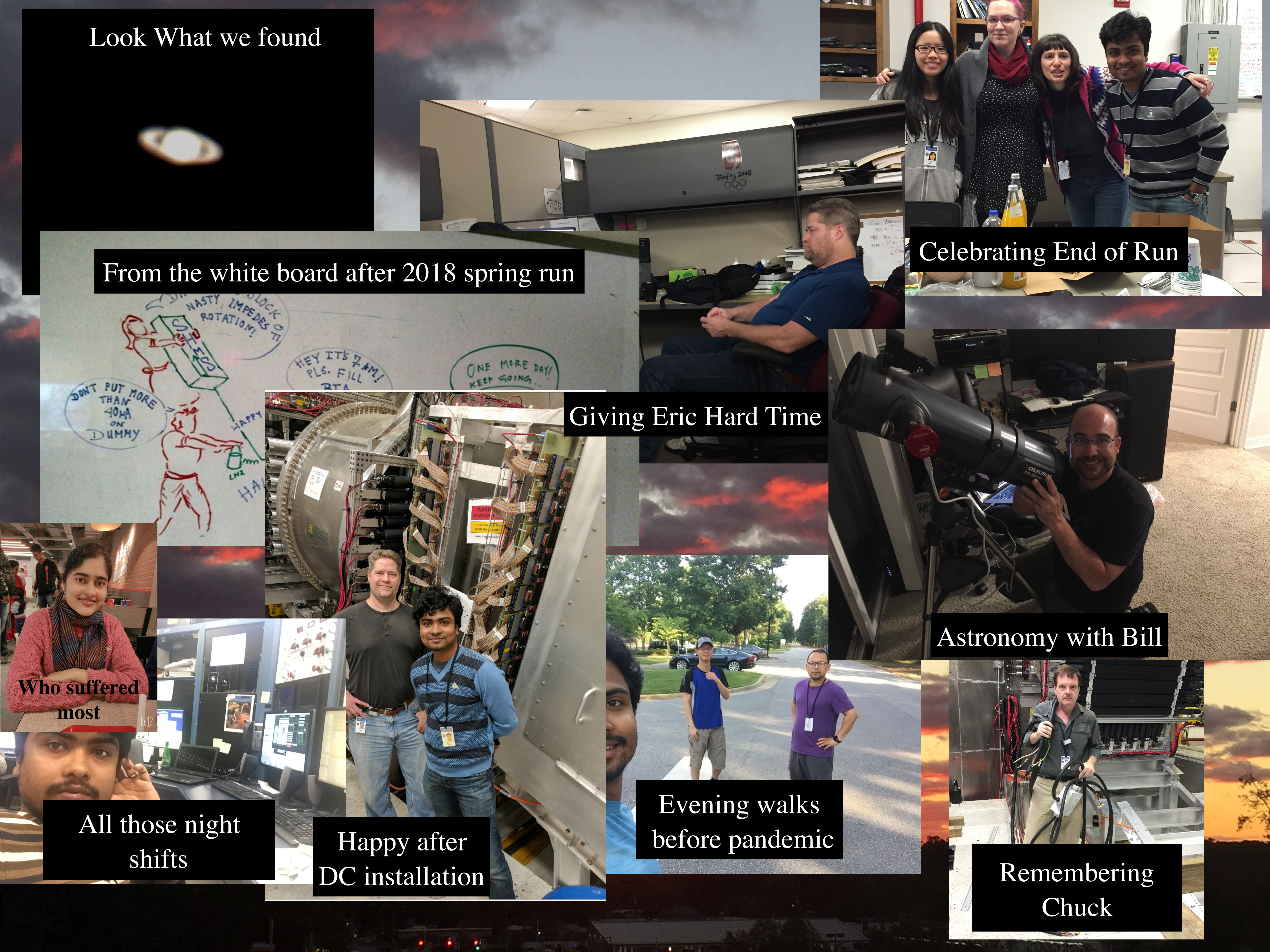


Results : Duality Averaging Procedure



Summary

- Successful Run of E12-10-002
- The Monte-Carlo ratio method is used to extract the cross-section using F1F221 model
- Proton and deuteron (and Neutron) cross-sections were extracted
- The first paper (D/H ratio) is going to publish very soon
- Duality Averaging Procedure results are going to be finalize very soon
- The results from E12-10-002 experiment will enrich physics at the Large-X region



Look What we found

From the white board after 2018 spring run

Celebrating End of Run

Giving Eric Hard Time

Astronomy with Bill

Who suffered most

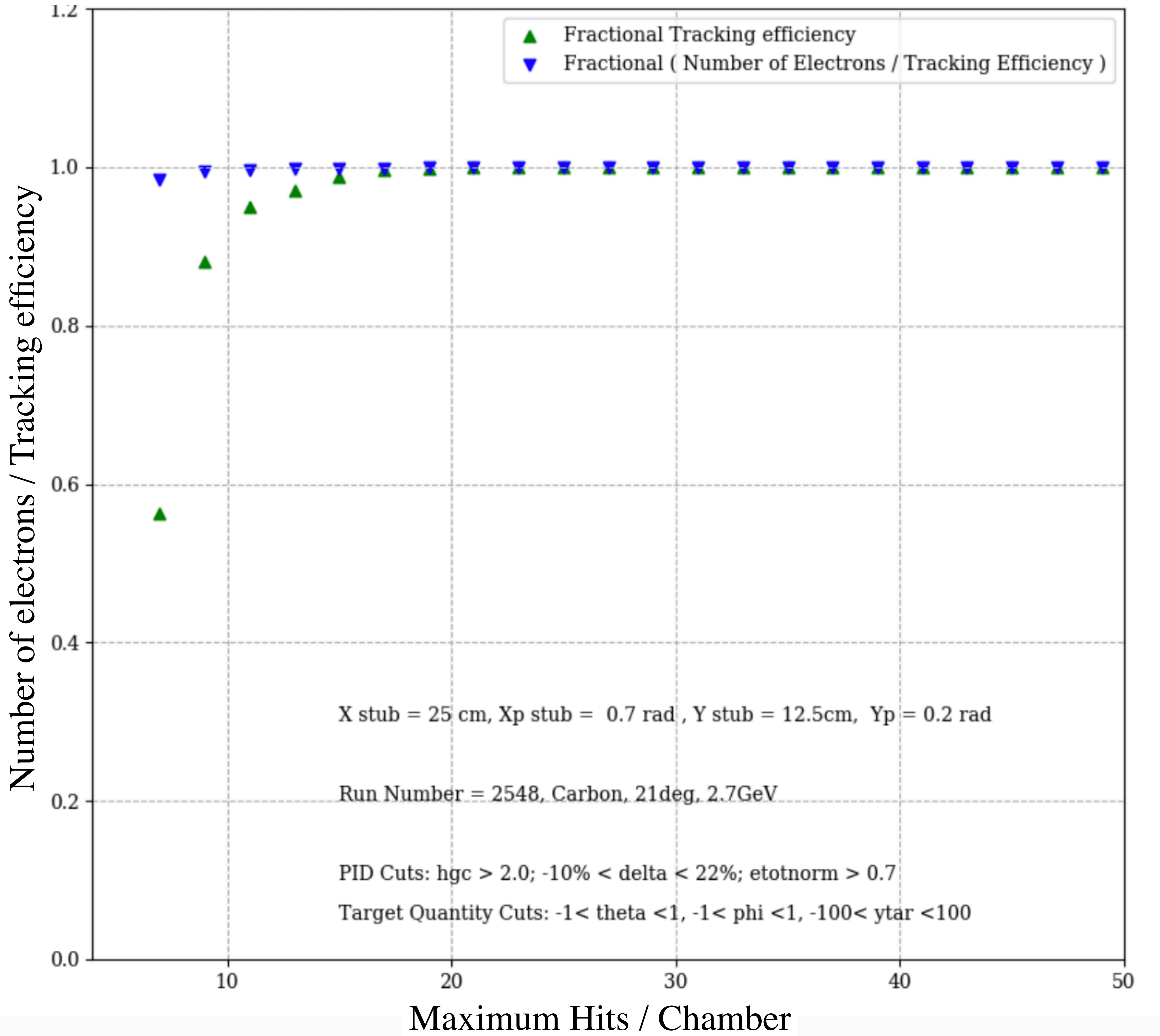
All those night shifts

Happy after DC installation

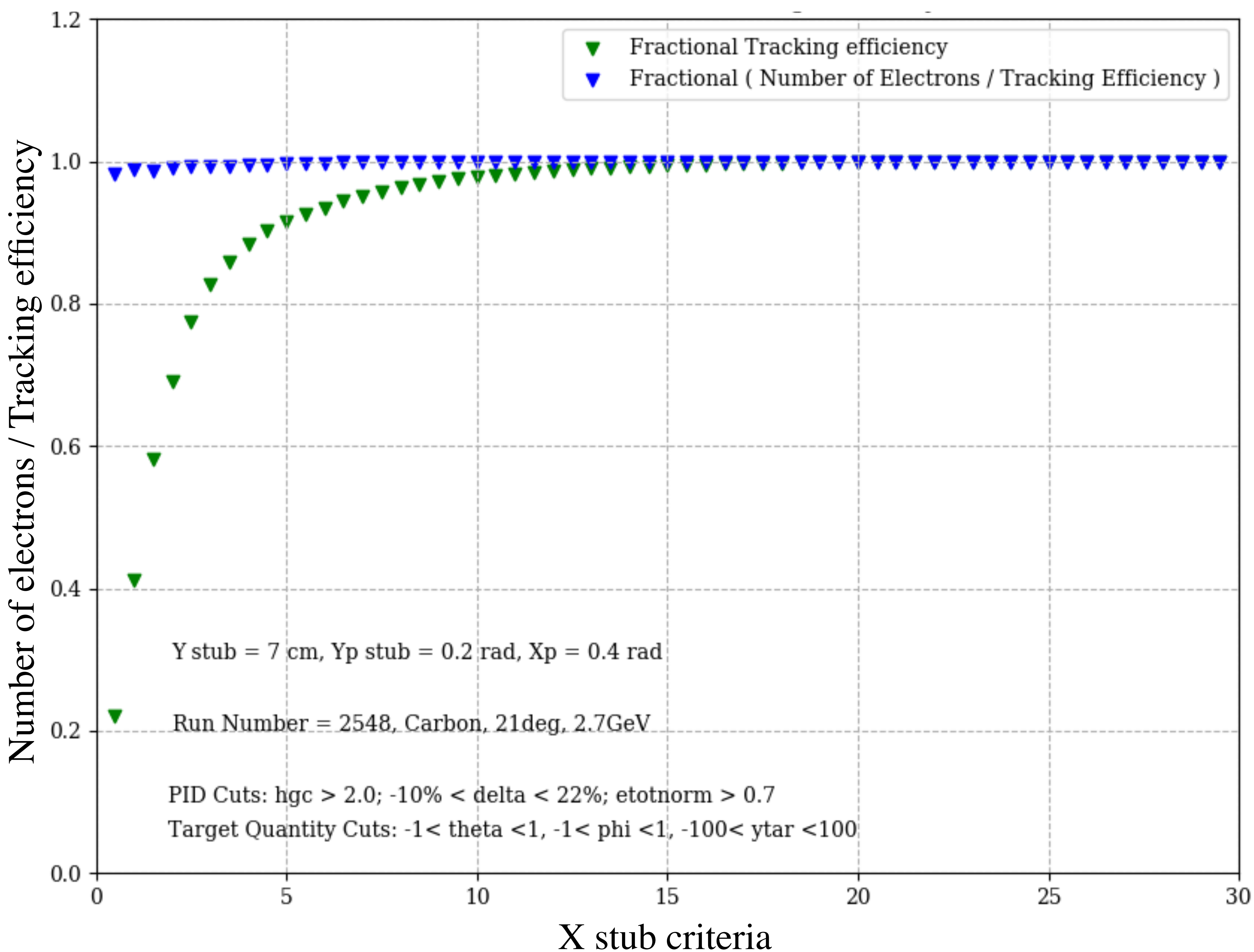
Evening walks before pandemic

Remembering Chuck

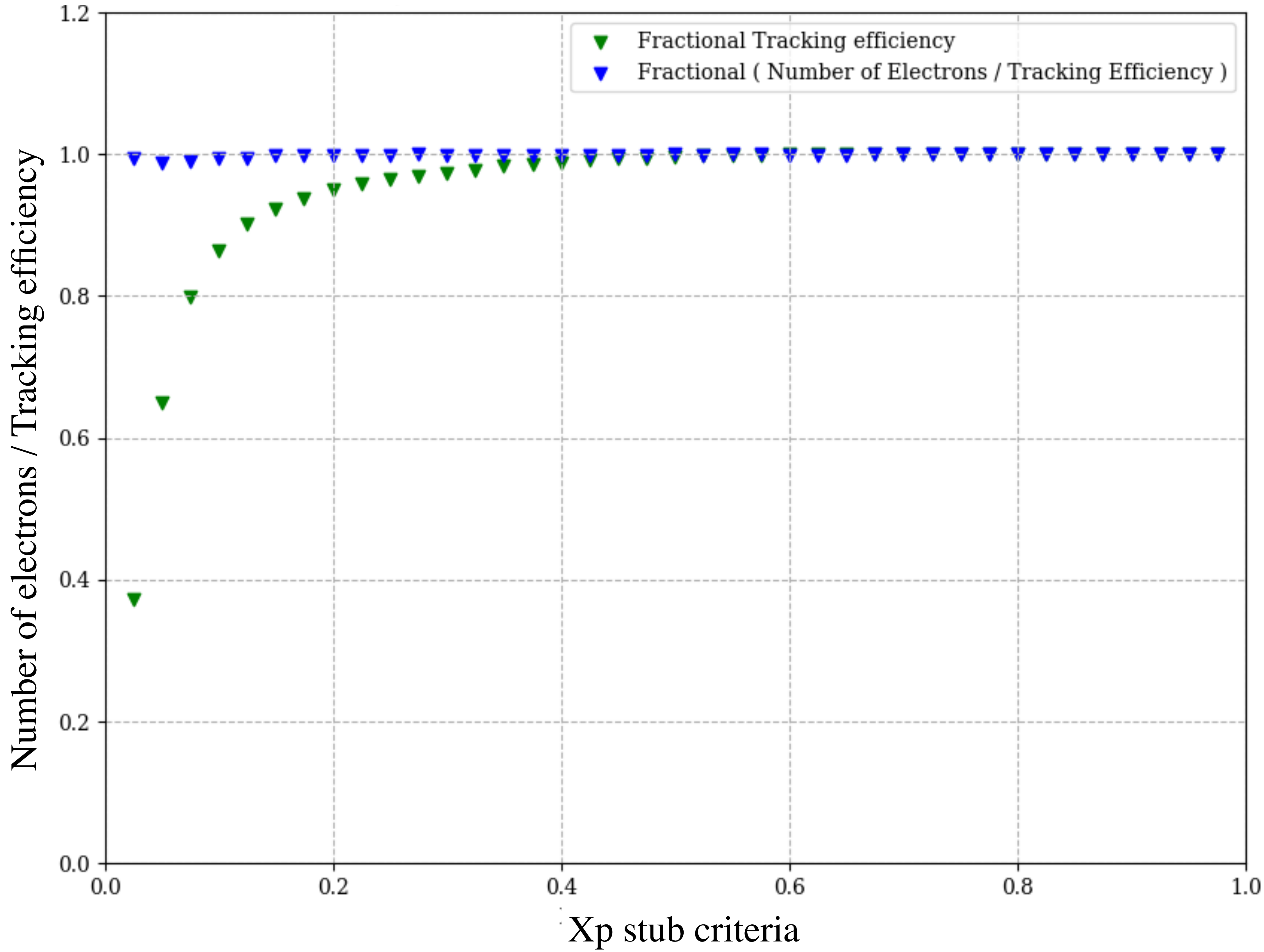
Back Up


Fractional Tracking efficiency
Fractional (Number of Electrons / Tracking Efficiency)
X stub = 25 cm, Xp stub = 0.7 rad , Y stub = 12.5cm, Yp = 0.2 rad
Run Number = 2548, Carbon, 21deg, 2.7GeV
PID Cuts: hgc > 2.0; -10% < delta < 22%; etotnorm > 0.7
Target Quantity Cuts: -1< theta <1, -1< phi <1, -100< ytar <100
Number of electrons / Tracking efficiency
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10
20
30
40
50
Maximum Hits / Chamber

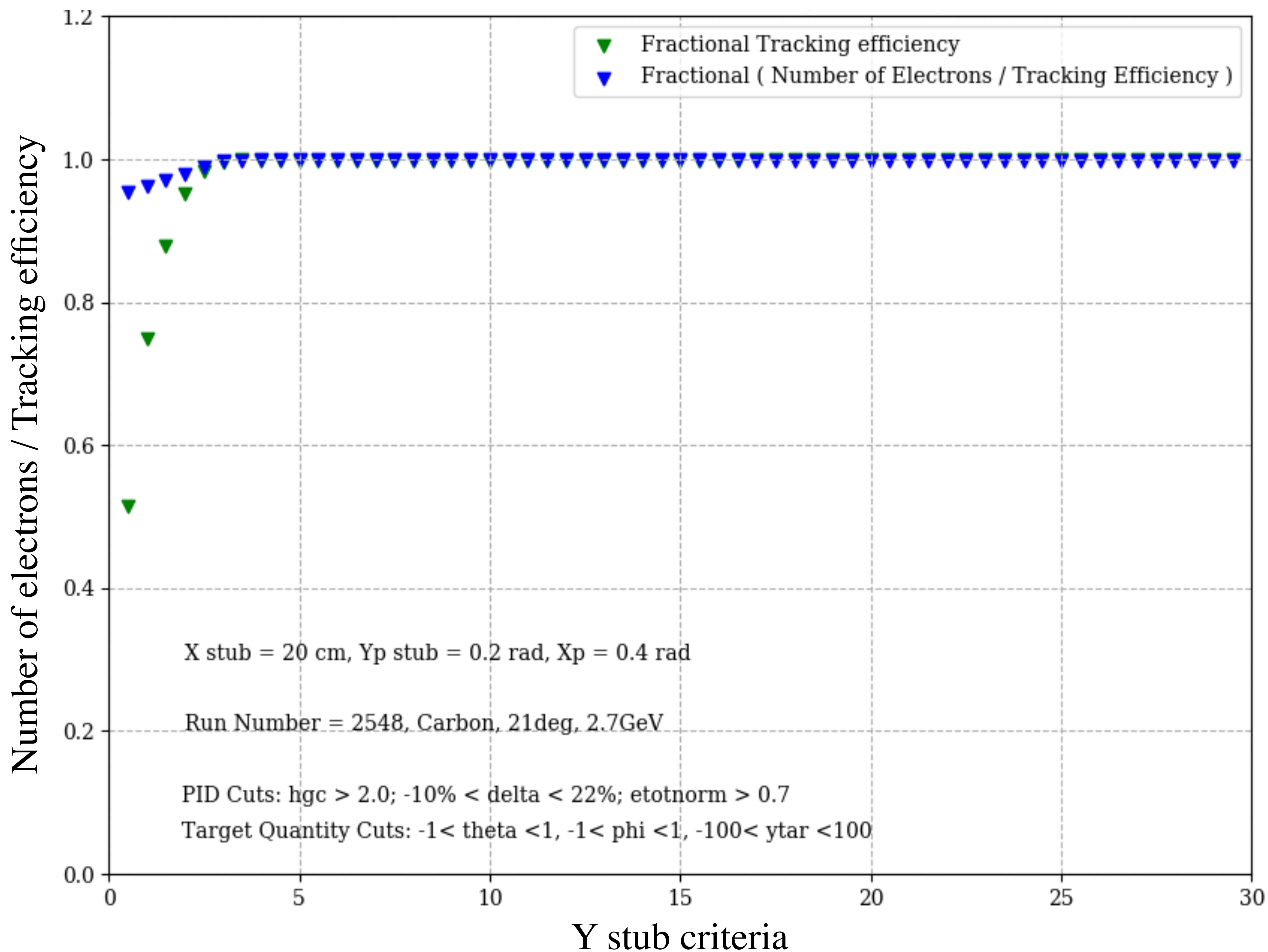
Max Number of Hits per chamber vs Tracking Efficiency & Efficiency Normalized Yield



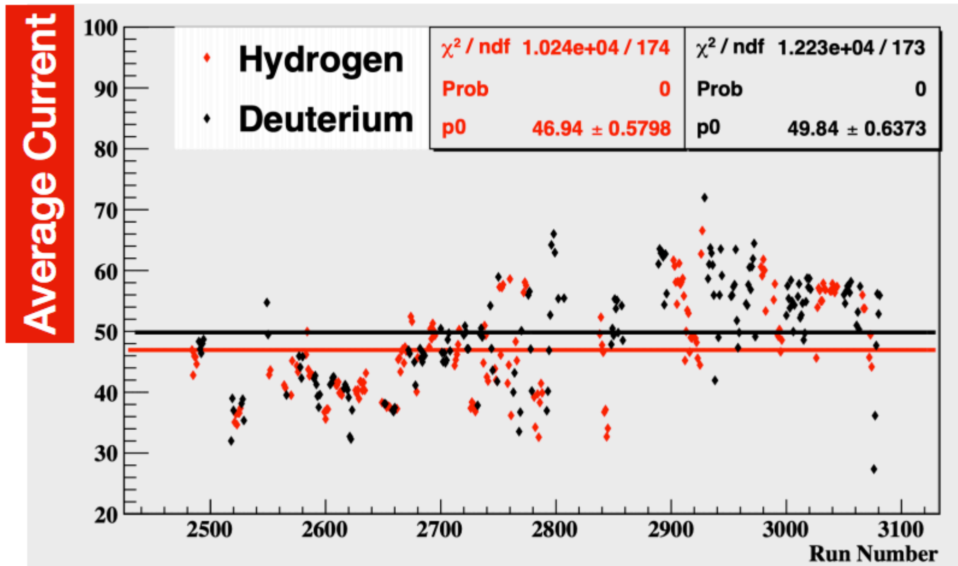
Max Number of Hits per chamber vs Tracking Efficiency & Efficiency Normalized Yield



Max Number of Hits per chamber vs Tracking Efficiency & Efficiency Normalized Yield

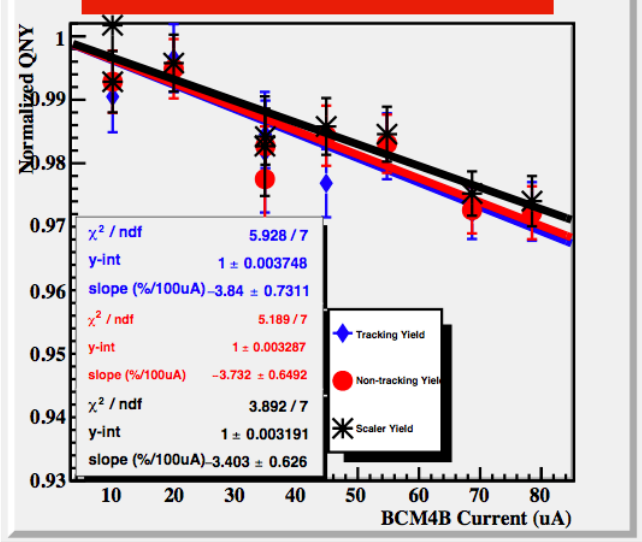


Error Analysis: Target Density

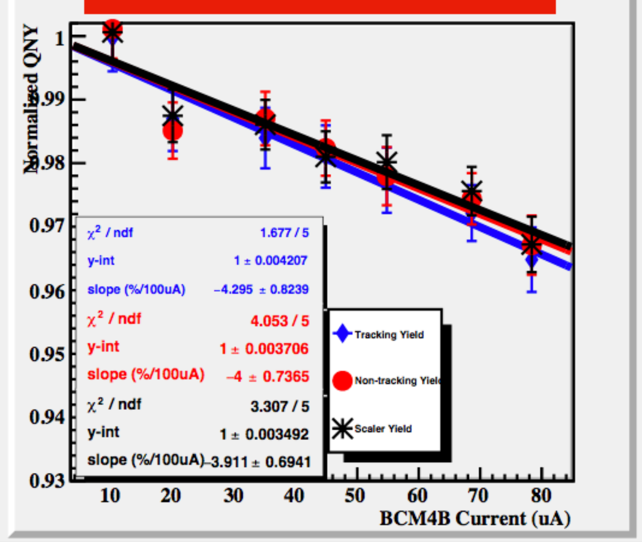


Error	Value	Uncertainty	$\frac{\delta\rho t}{\rho t}$
Temperature	19 K	$\pm 182mK$	0.27%
Pressure	25 psia	$\pm 2psia$	0.02%
Equation of State			0.1%
Length Measurement Precision	100 mm	$\pm 0.26mm$	0.26%
Length (Inner or Outer?)	100 mm	$\pm 0.26mm$	0.26%
Target Contraction	99.6%	$\pm 0.1\%$	0.1%
Beam Position	0	$\pm 3mm$	0.2%
Avg Boiling Correction LH2(LD2)			0.30% (0.36%)
Total LH2 (LD2)			0.60% (0.63%)

Hydrogen
3.84 +/- 0.73 %/100 uA

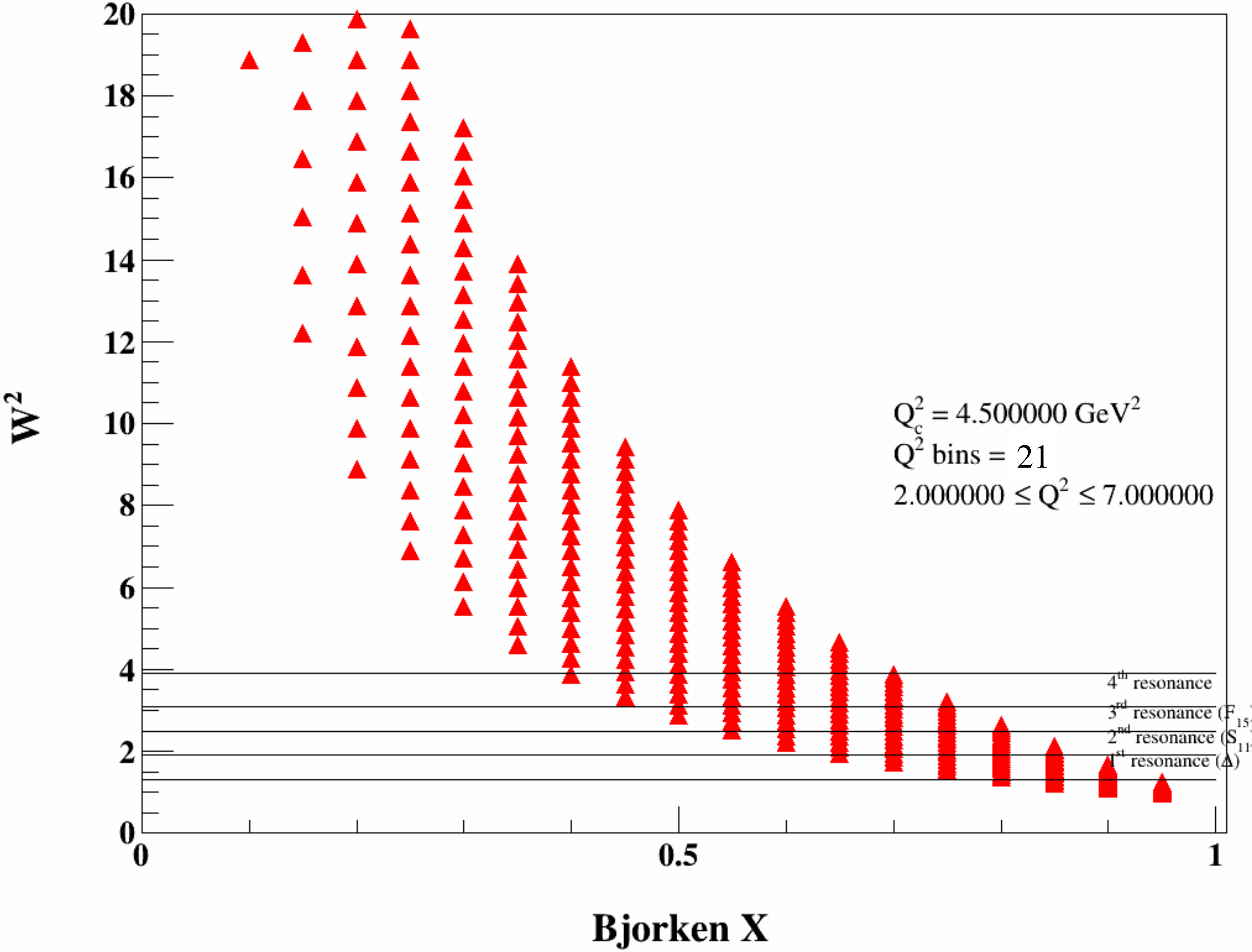


Deuterium
4.30 +/- 0.82 %/100 uA

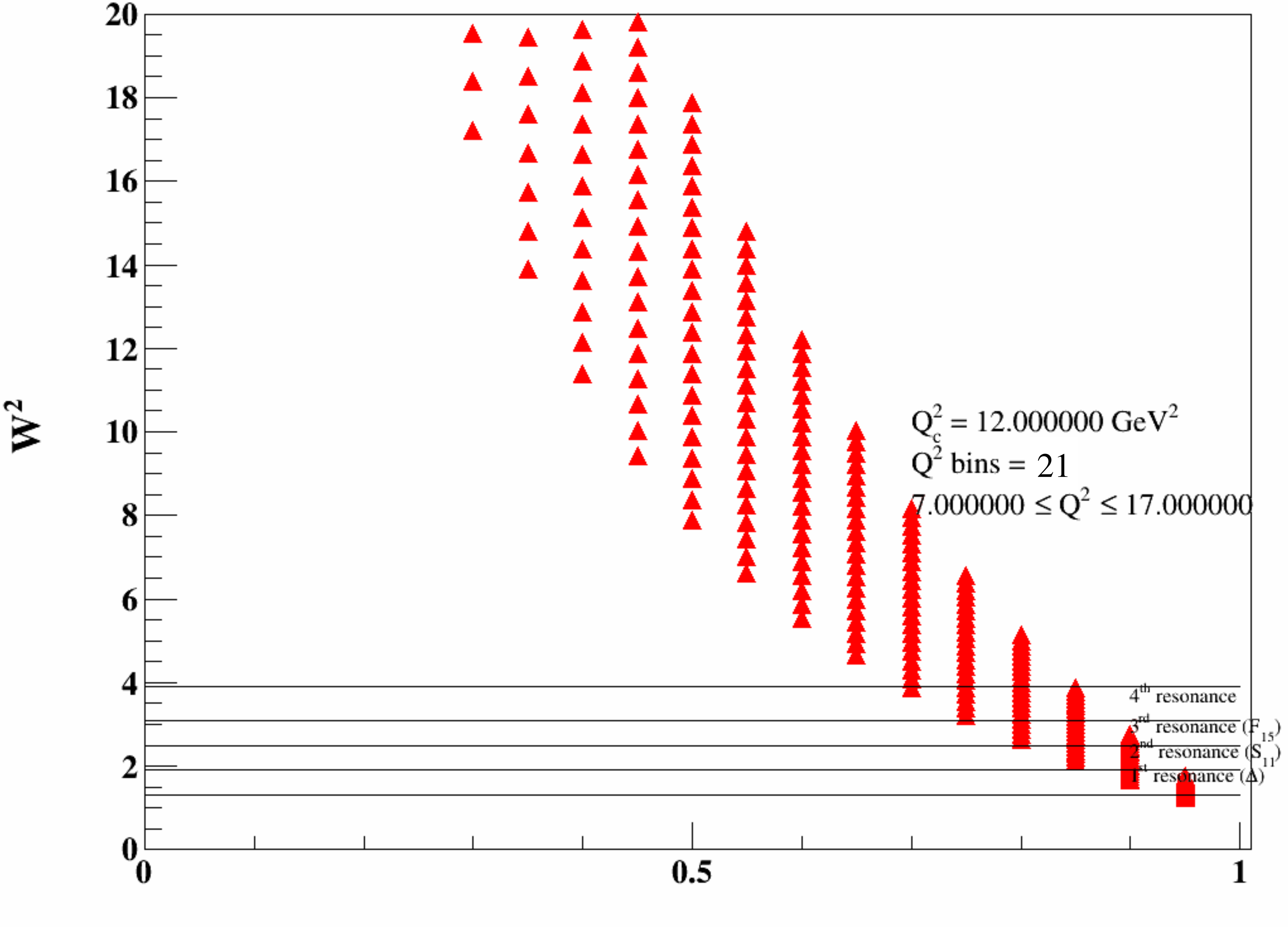


- The overall normalization uncertainty used is slightly larger than the table above; 0.75% in cross sections and 1.1% in D/H ratio.
- Global error reflects our lack of knowledge to the target boiling, temperature, density, length and beam position.
- An additional point to point uncertainity is calculated by taking the difference with the average current

From Bill

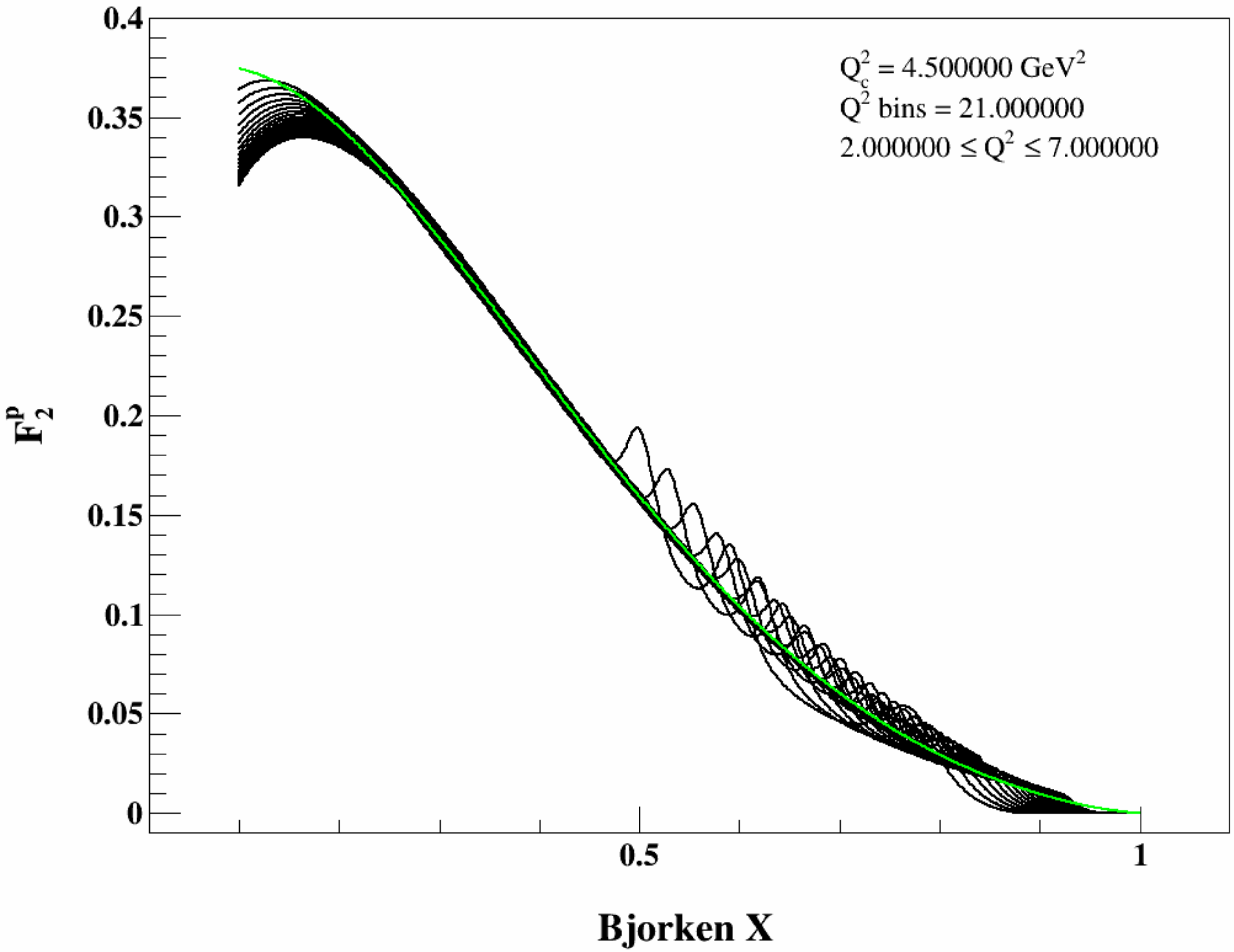


W^2
Bjorken X
Q_c^2 = 4.500000 GeV^2
Q^2 bins = 21
2.000000 ≤ Q^2 ≤ 7.000000
4th resonance
3rd resonance (F_{15})
2nd resonance (S_{11})
1st resonance (Δ)



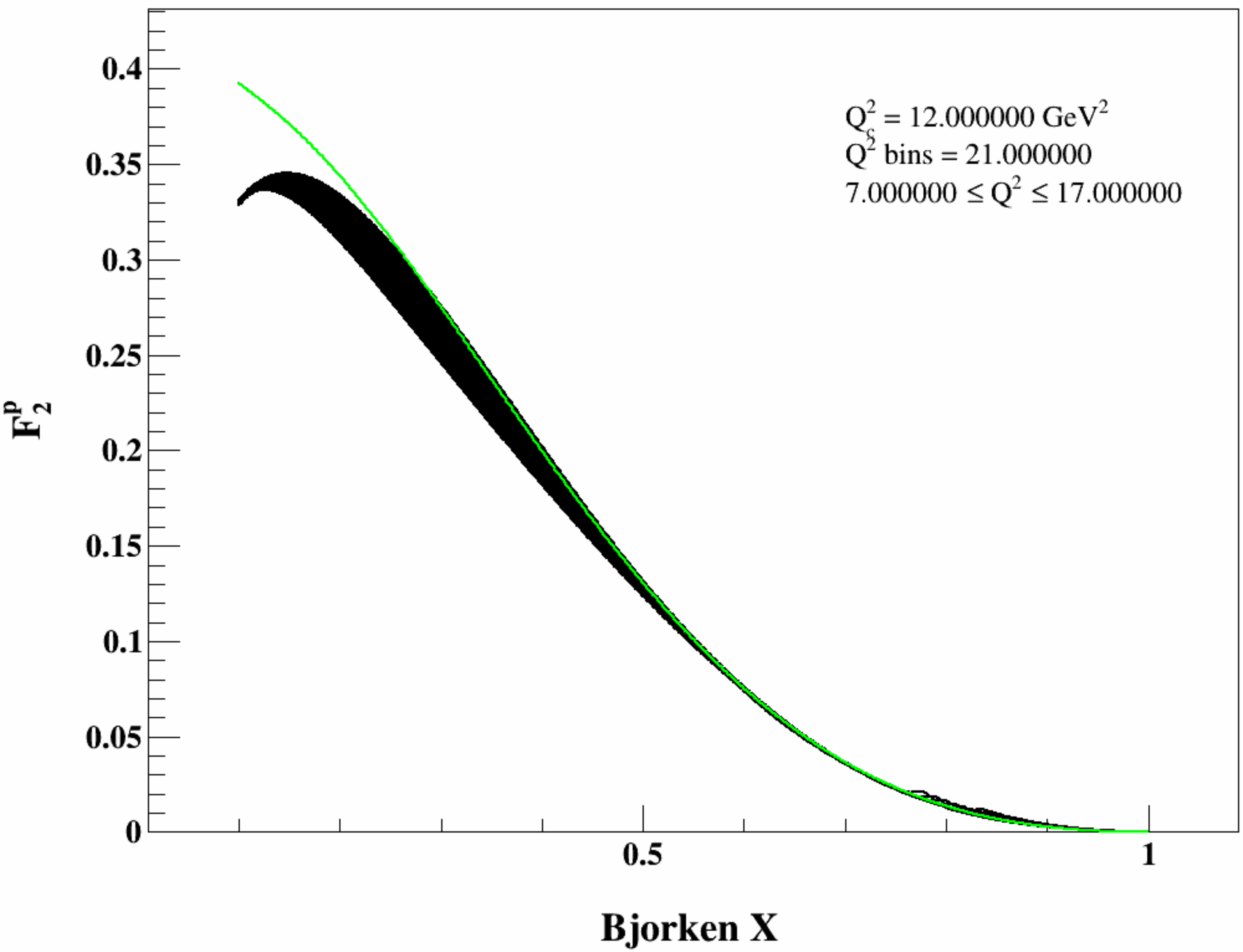
20
18
16
14
12
10
8
6
4
2
0
0
0.5
1
W^2
Bjorken X
Q^2_c = 12.000000 GeV^2
Q^2 bins = 21
7.000000 ≤ Q^2 ≤ 17.000000
4th resonance
3rd resonance (F_{15})
2nd resonance (S_{11})
1st resonance (Δ)

Duality



Q_c^2 = 4.500000 GeV^2
Q^2 bins = 21.000000
2.000000 ≤ Q^2 ≤ 7.000000
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
F_2^p
0.5
1
Bjorken X

Duality



$Q^2 = 12.000000\ GeV^2$
Q^2 bins = 21.000000
$7.000000 \le Q^2 \le 17.000000$
F_2^p
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5
1
Bjorken X

Cross-Section Extraction Method

$$\sigma^{data} = \sigma^{MC} \times \frac{Y_{data}}{Y_{MC}}$$

- F1F220 (by M. Eric Christy) model is used to get the σ^{MC}

- F1F220 is a fit to the inclusive reduced cross-sections of global data which produces F_1 and F_2

- The structure functions are related to the reduced cross-sections as follows-

$$\sigma_T = \frac{4\pi\alpha}{KM}F_1 \qquad \sigma_L = \frac{4\pi^2\alpha}{KM\nu}[(1+\frac{\nu^2}{Q^2})MF_2 - \nu F_1]$$

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma[\sigma_T(x,Q^2) + \epsilon\sigma_L(x,Q^2)]$$

- For the Monte-Carlo events of scattered electrons are generated uniformly in $(E', X' \equiv \frac{dY}{dZ}, Y' \equiv \frac{dY}{dZ})$ space using the program mc-single-arm

- Born approximation is just the first order approximation in α of electron-nucleon scattering by one photon exchange. To mimic the reality we multiply the each events of MC by $\frac{\sigma^{model}_{rad}}{\sigma^{model}_{Born}}$ where, σ^{model}_{born} = model Born cross-section, σ^{model}_{Rad}= total radiative model cross-section

- The Monte-Carlo yield need to be calculated with the same luminosity as data. Physics weighted, (uniformly) generated Monte-Carlo events are multiplied with a factor to get the Y_{MC} :

$$Y_{MC}(E',\theta) = N^{e-} \times scale\ factor$$

scale factor is defined as the ratio of data and MC luminosity:

$$scale\ factor = \frac{L_{data}}{L_{MC}} \times \epsilon_{tot} \times \frac{E_{LT} \times C_{LT}}{PS}$$, where

$$L_{data} = target\ density \times target\ length \times Avogadro's\ number \times \frac{1}{atomic\ mass} \times \frac{beam\ charge}{elementary\ charge}$$

$$L_{MC} = \frac{generated\ events}{\Delta E'\ \Delta\Omega}$$