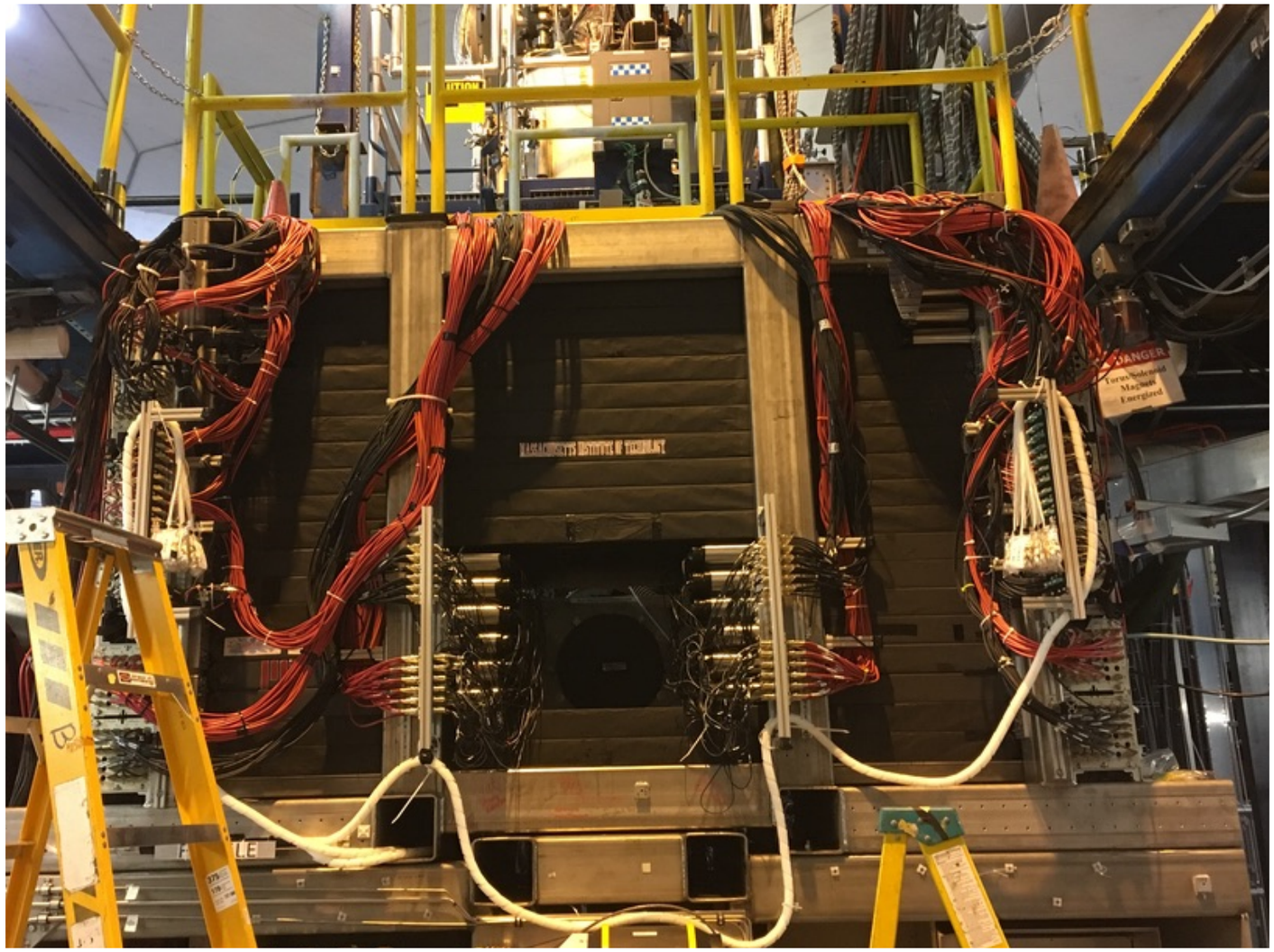
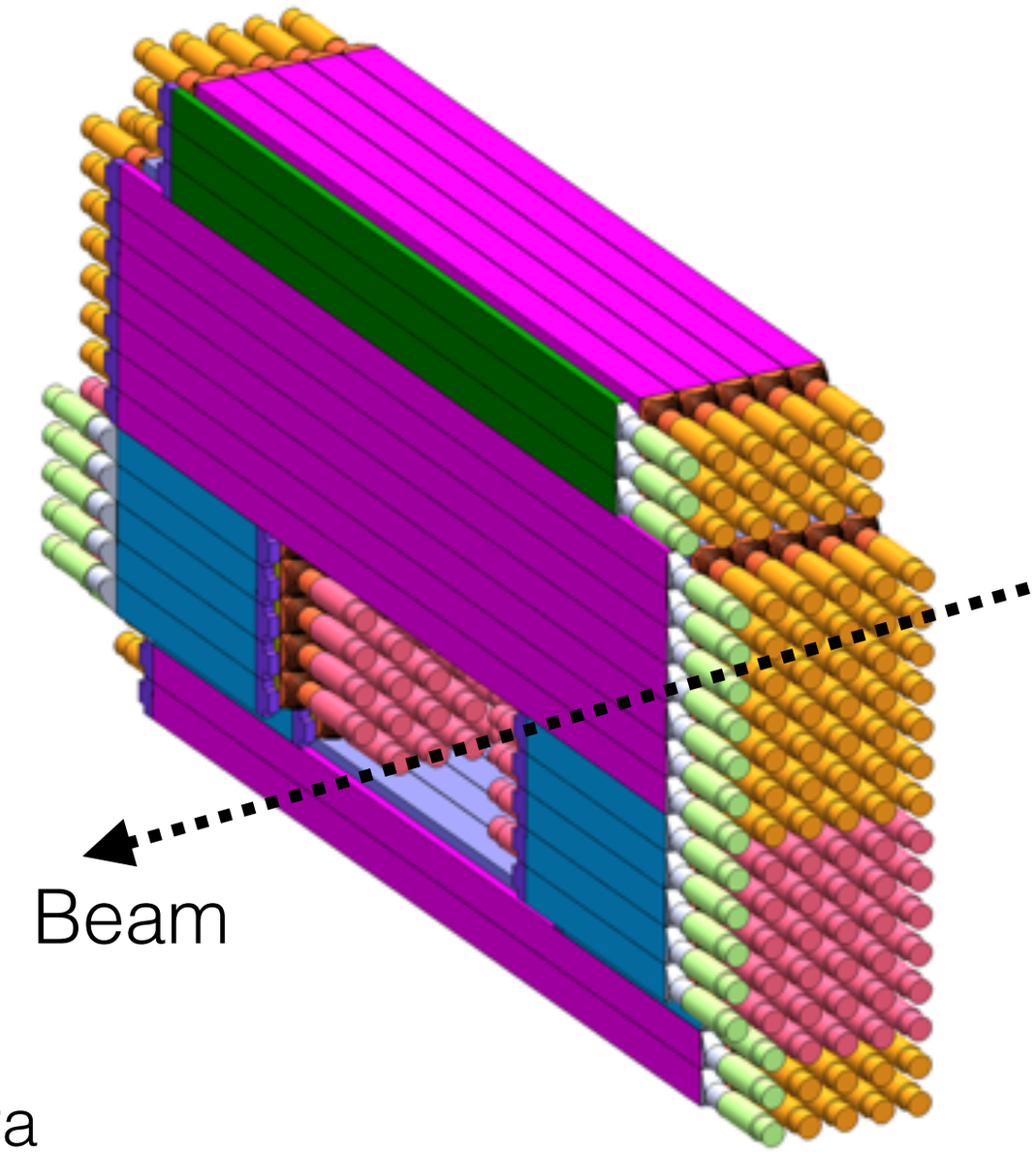
BAND hardware and calibration status
CLAS Collaboration Meeting





Efrain Segarra
Reynier Cruz Torres
Florian Hauenstein

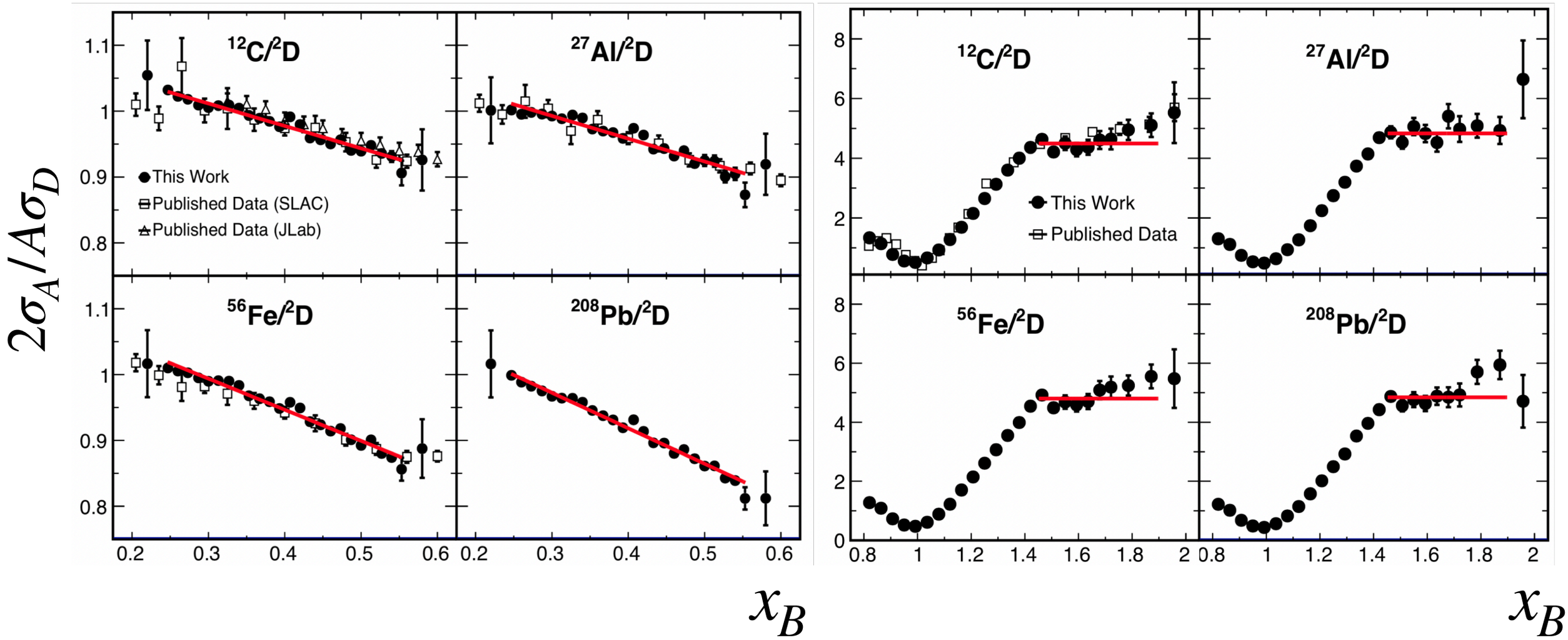
Outline

- Why the Backward-Angle Neutron Detector (BAND)
- (Re) Commissioning in Jan 2019
- Calibration Status in RGB
- Preliminary physics with BAND

EMC Effect is a *Nuclear* Effect

DIS: Quarks in bound nucleons behave differently than in free nucleons

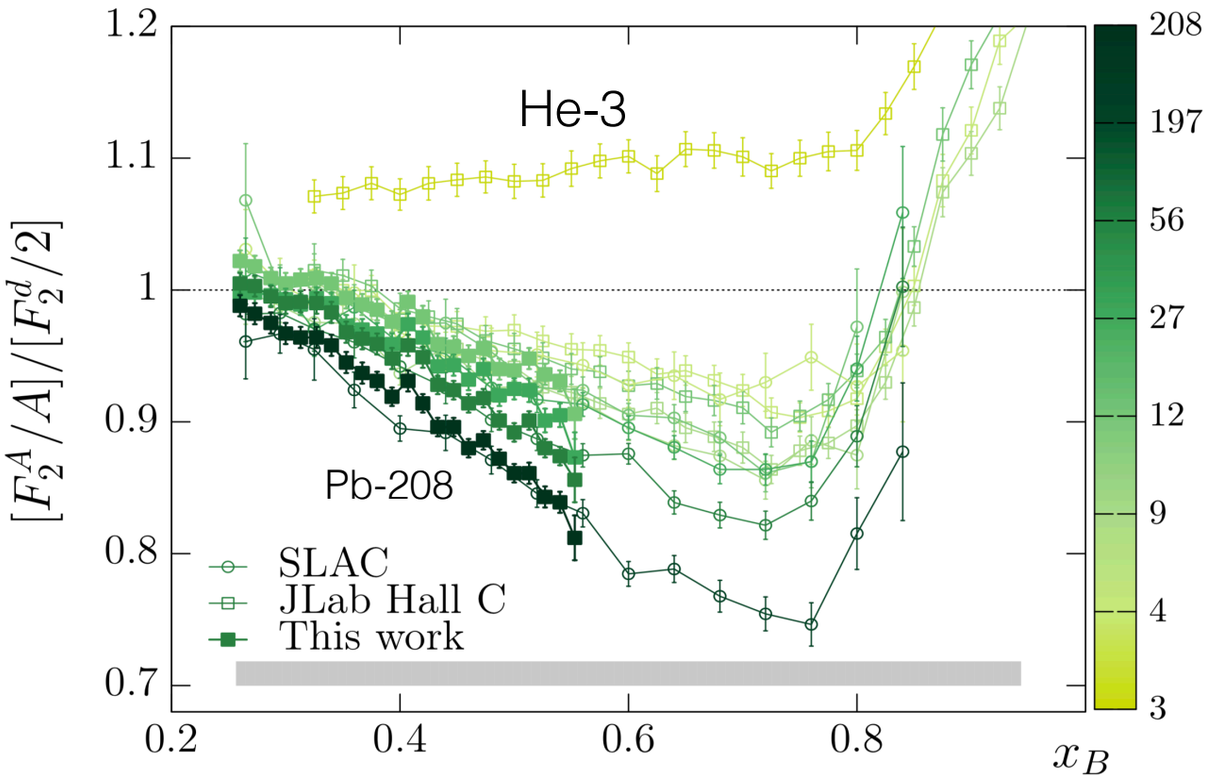
QE: Probing high momentum nucleons reveals a universal structure



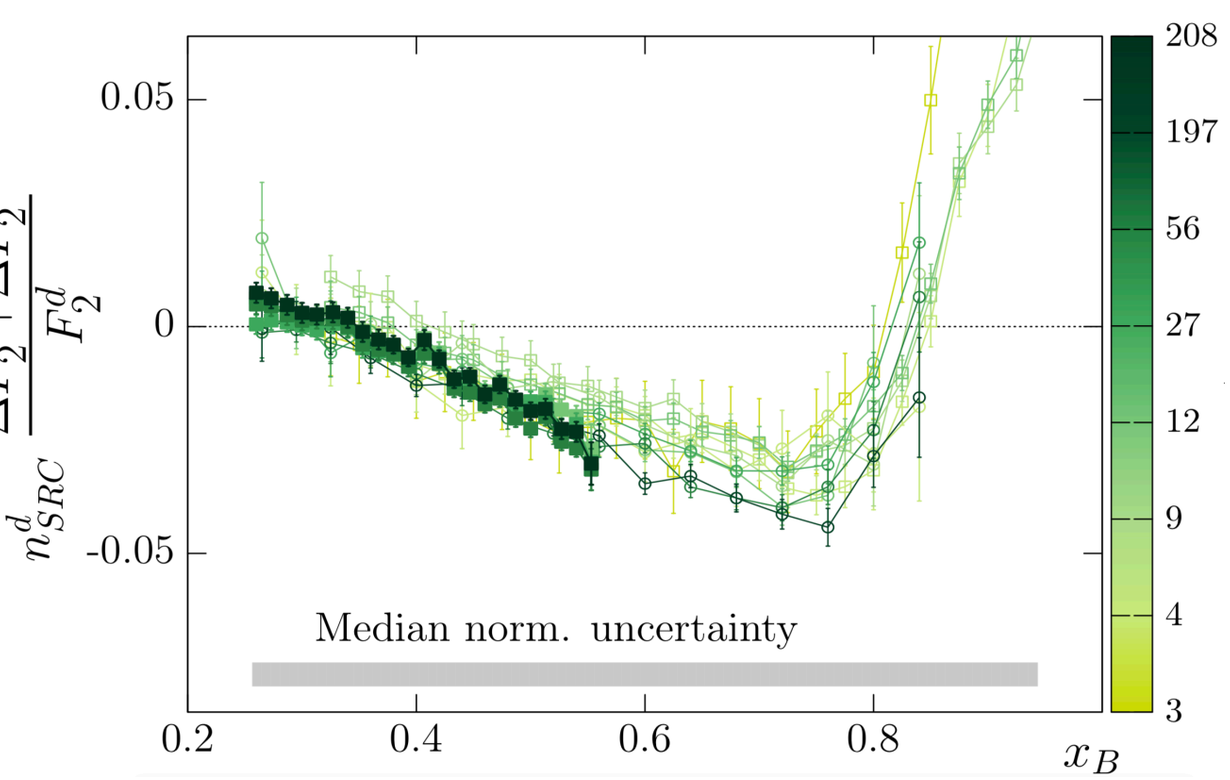
B. Schmookler, CLAS Collaboration, Nature 566 (2019) no.7744, 354-358

Is there a connection between the two?

EMC Effect



Universal Function

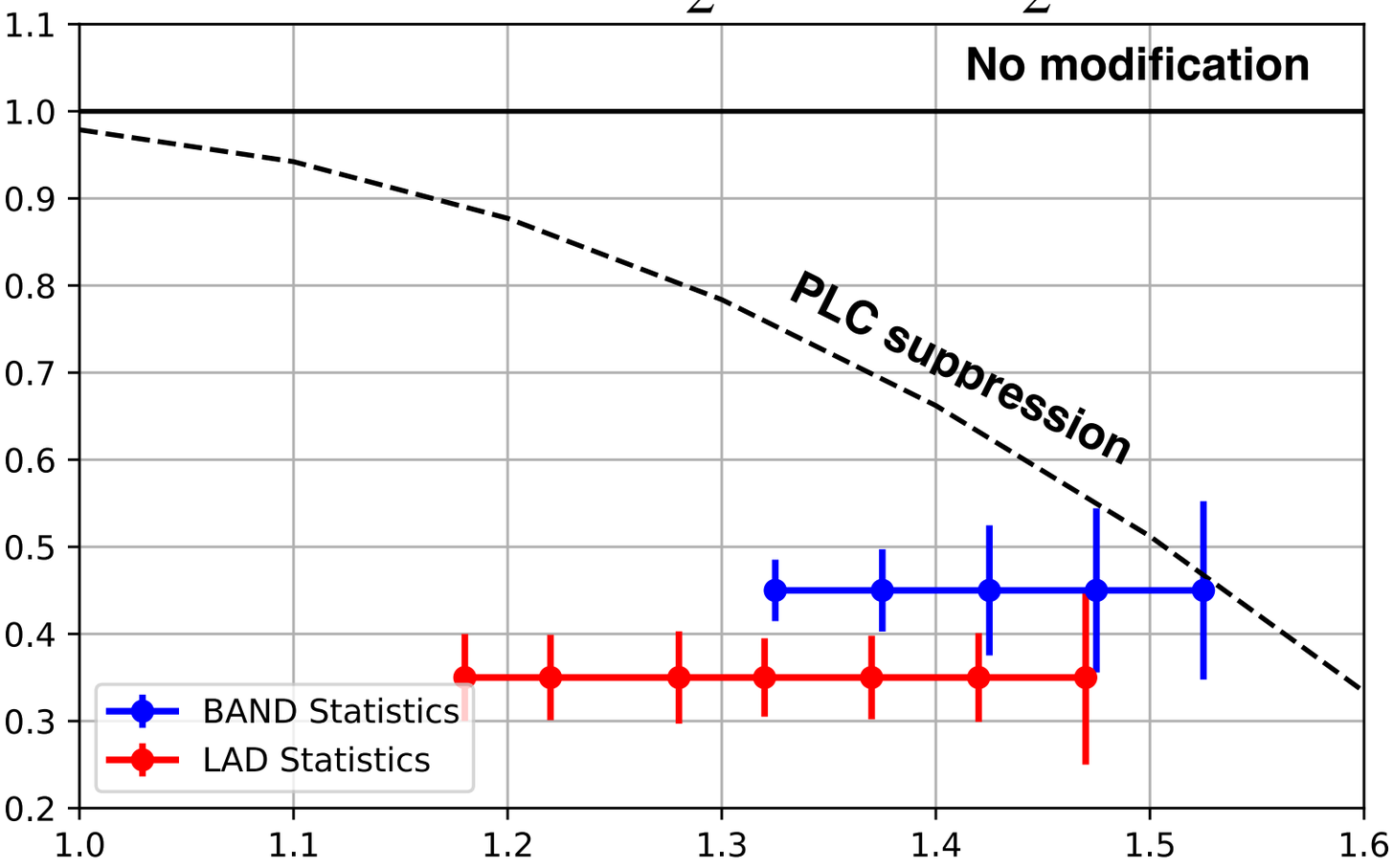


$$F_2^A = (Z - n_{SRC}^A)F_2^p \;+\; (N - n_{SRC}^A)F_2^n \;+\; n_{SRC}^A(F_2^{p*} + F_2^{n*})$$

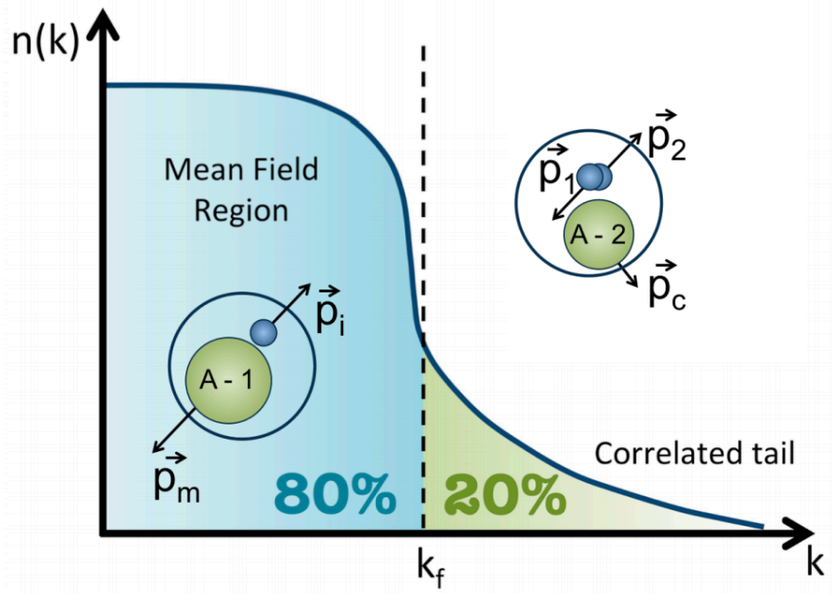
B. Schmookler, CLAS Collaboration, Nature 566 (2019) no.7744, 354-358

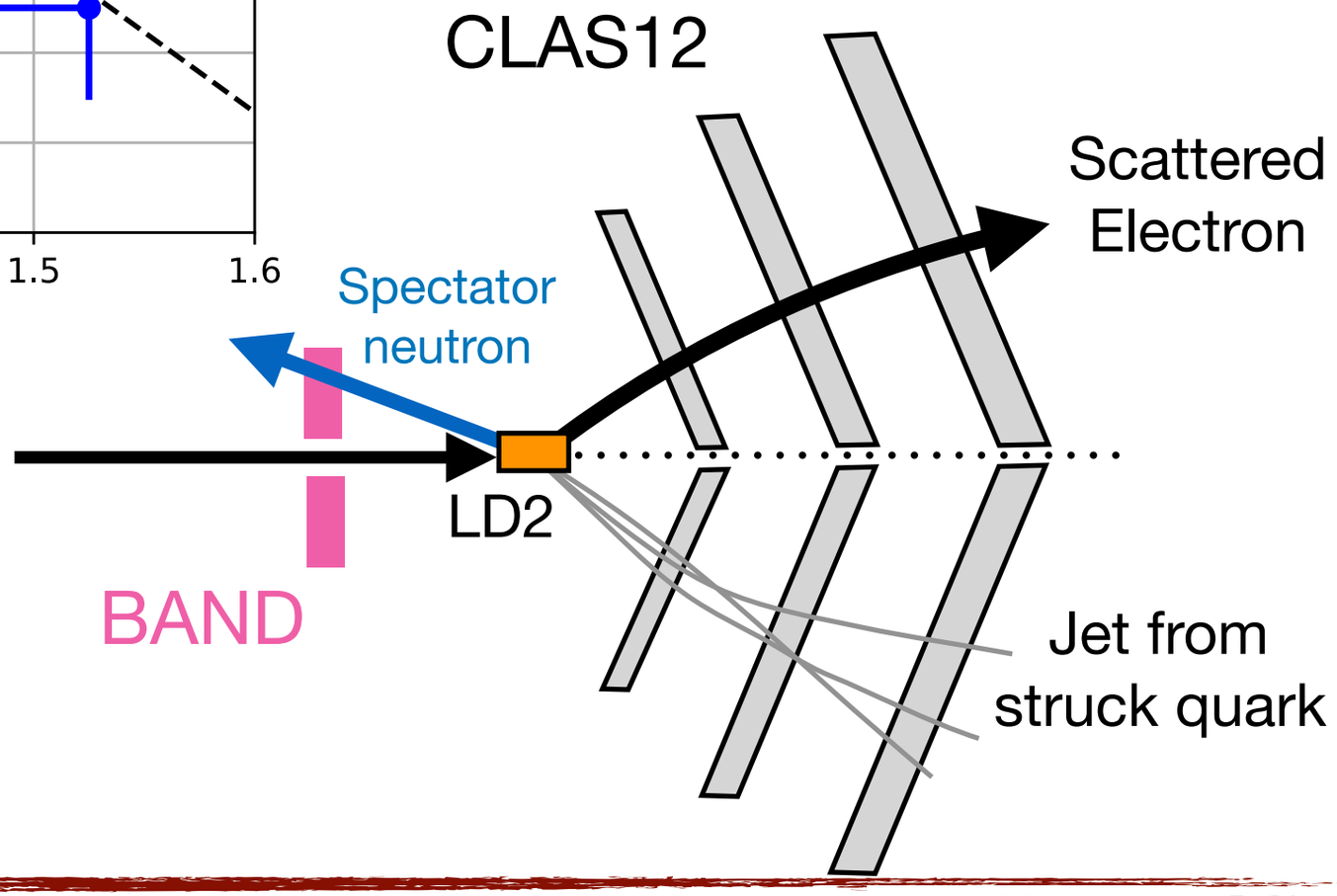
DIS Recoil Tagging d(e,e'n)X

Bound F_2/ Free F_2



$$\alpha_s = (E_S - p_S^q)/m_S$$

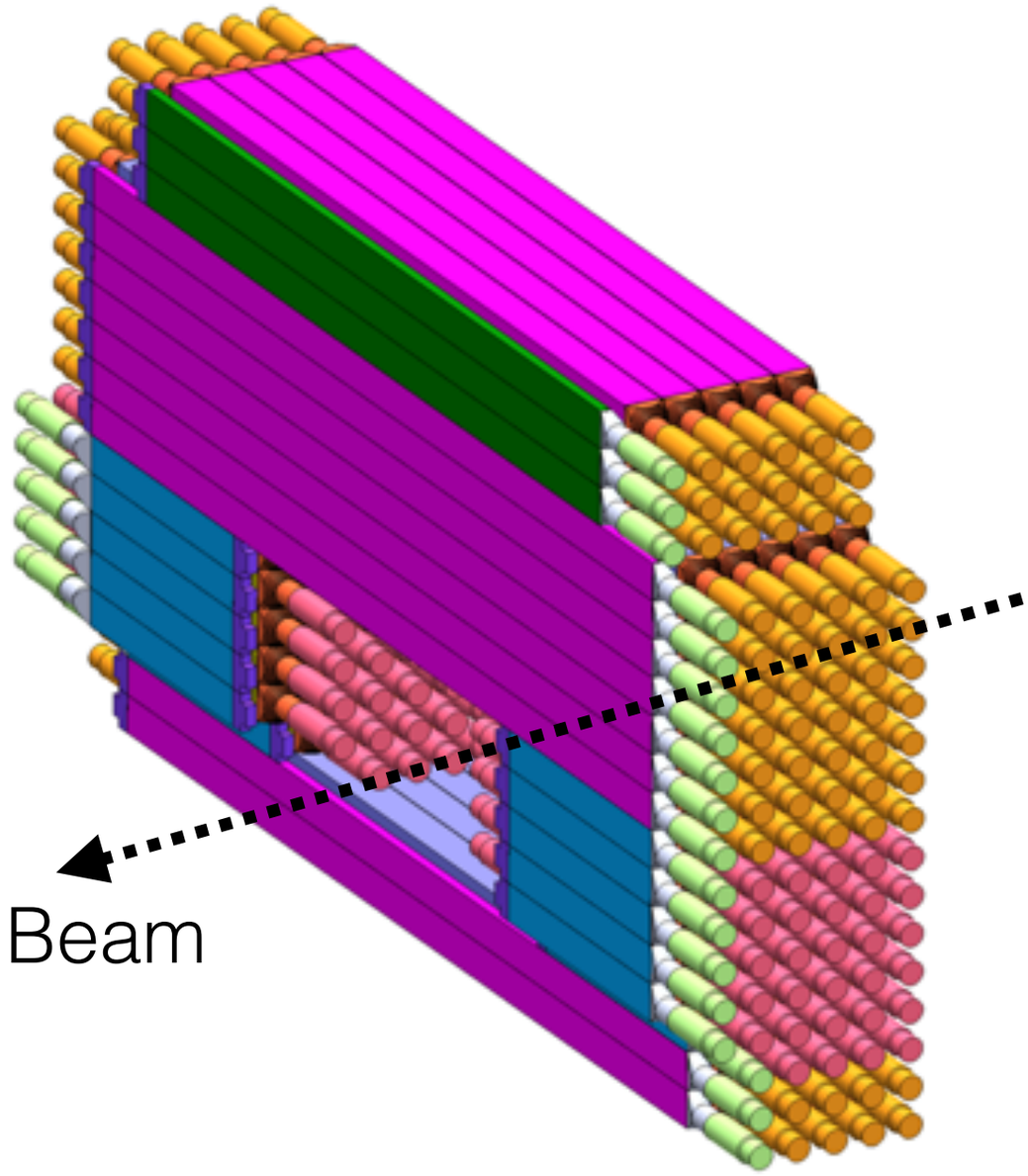




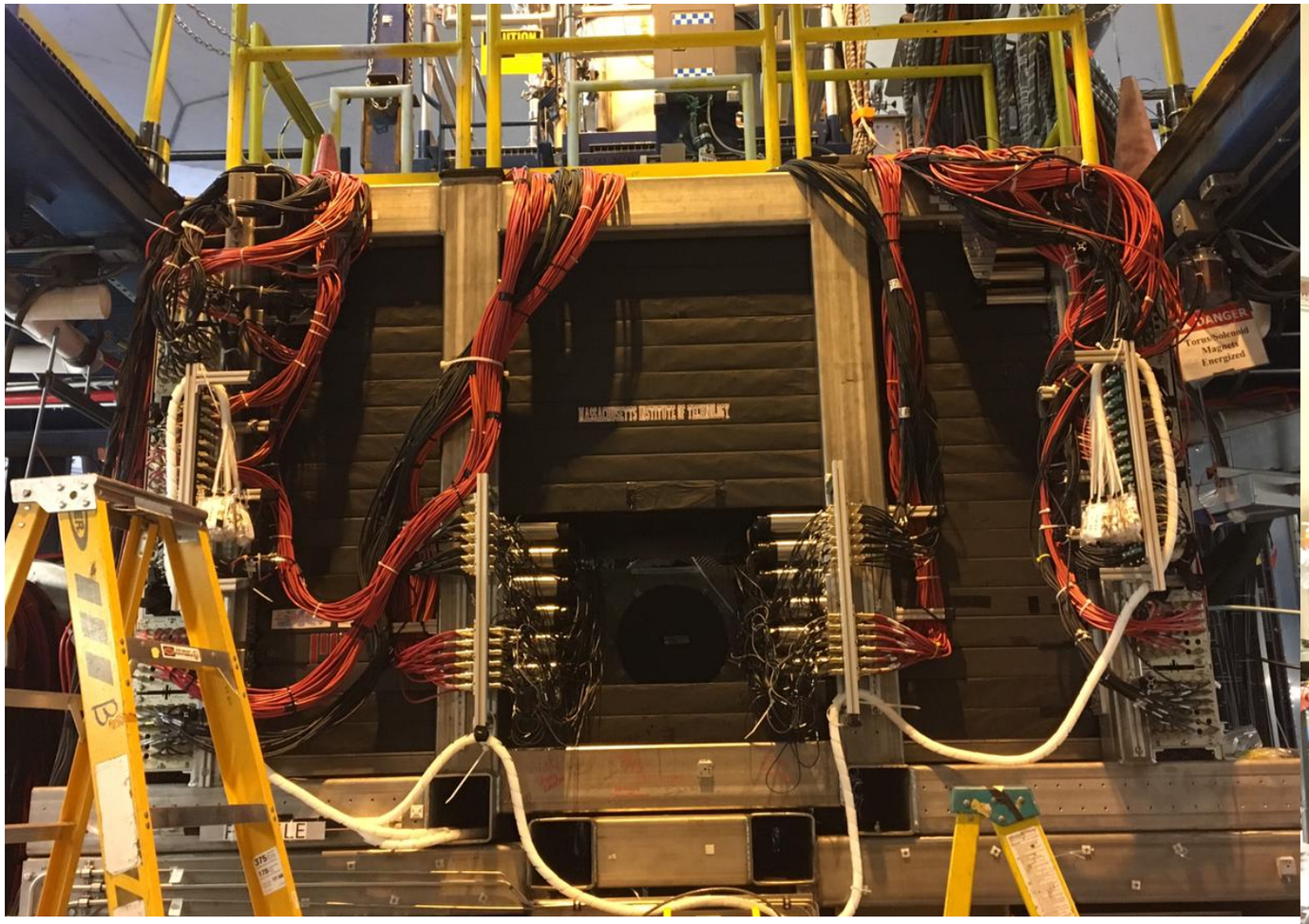
Overview of BAND

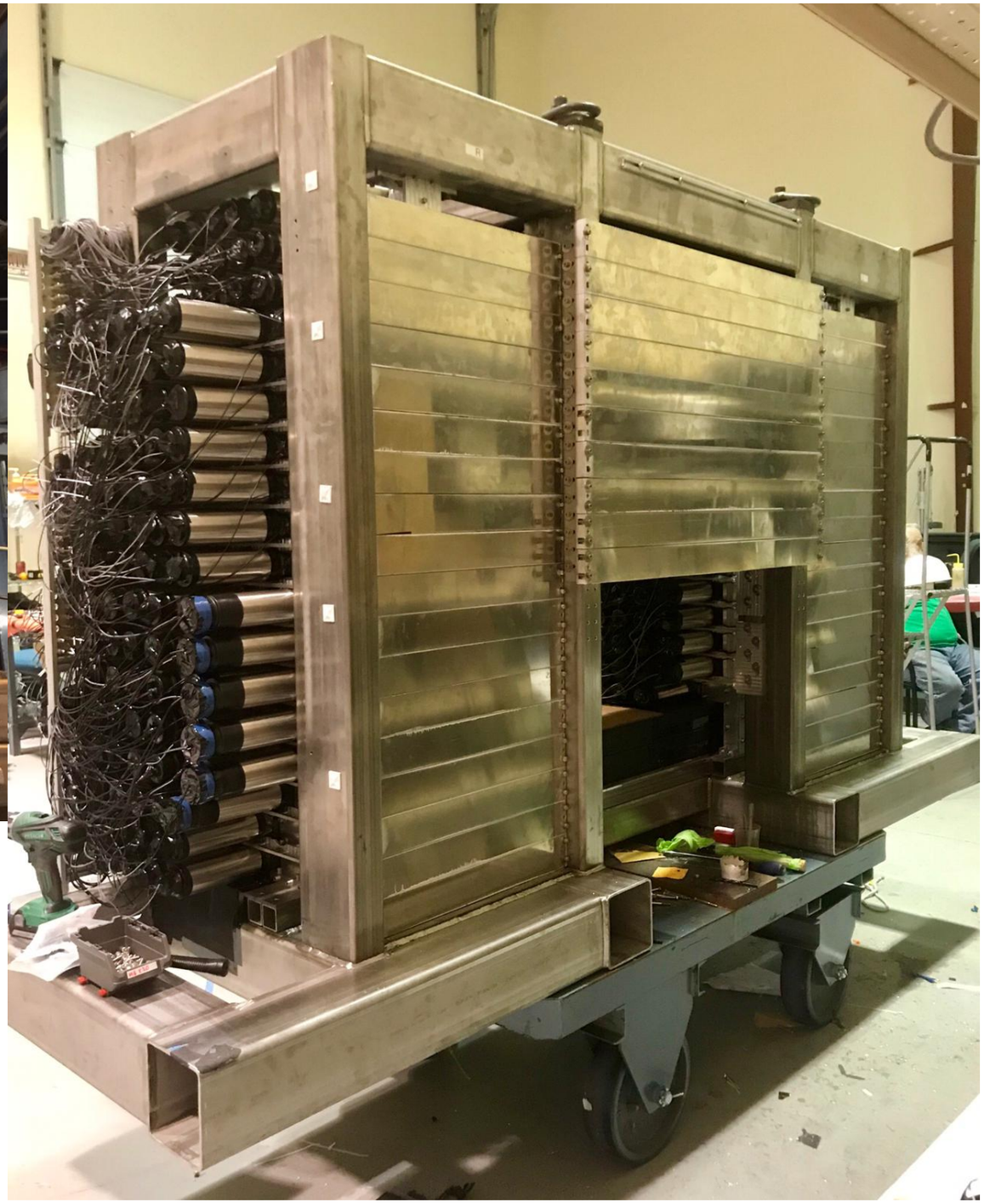
Overview of BAND

- 5 layers thick (36cm total) with veto layer (1cm thick)
- 140 bars
- Bar resolutions < 200 ps
- 3 meters upstream target cell, coverage in θ ~ 155-176°
- Design neutron efficiency ~35% and momentum resolution ~1.5% (*to be studied*)



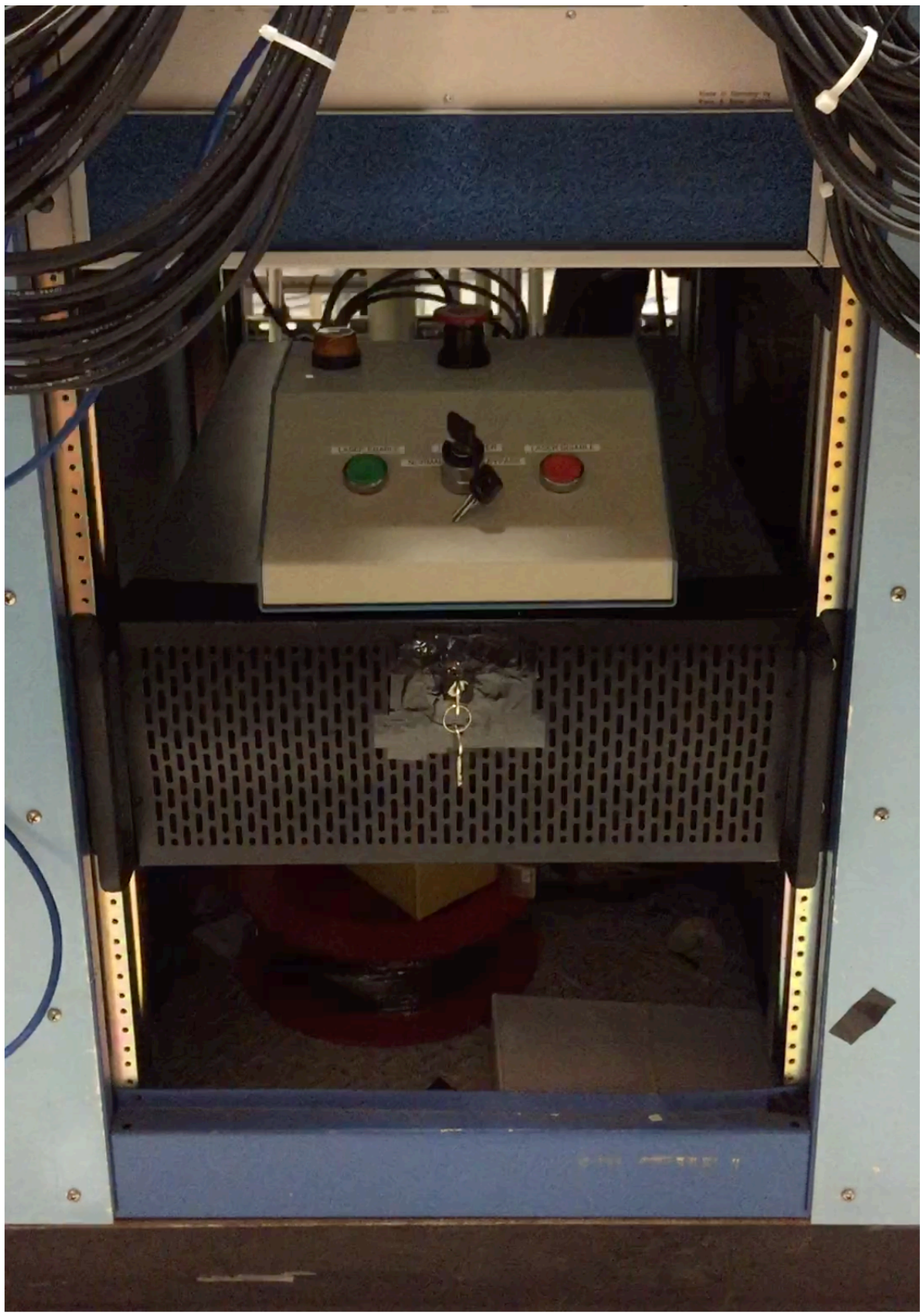
Re-commissioning of BAND



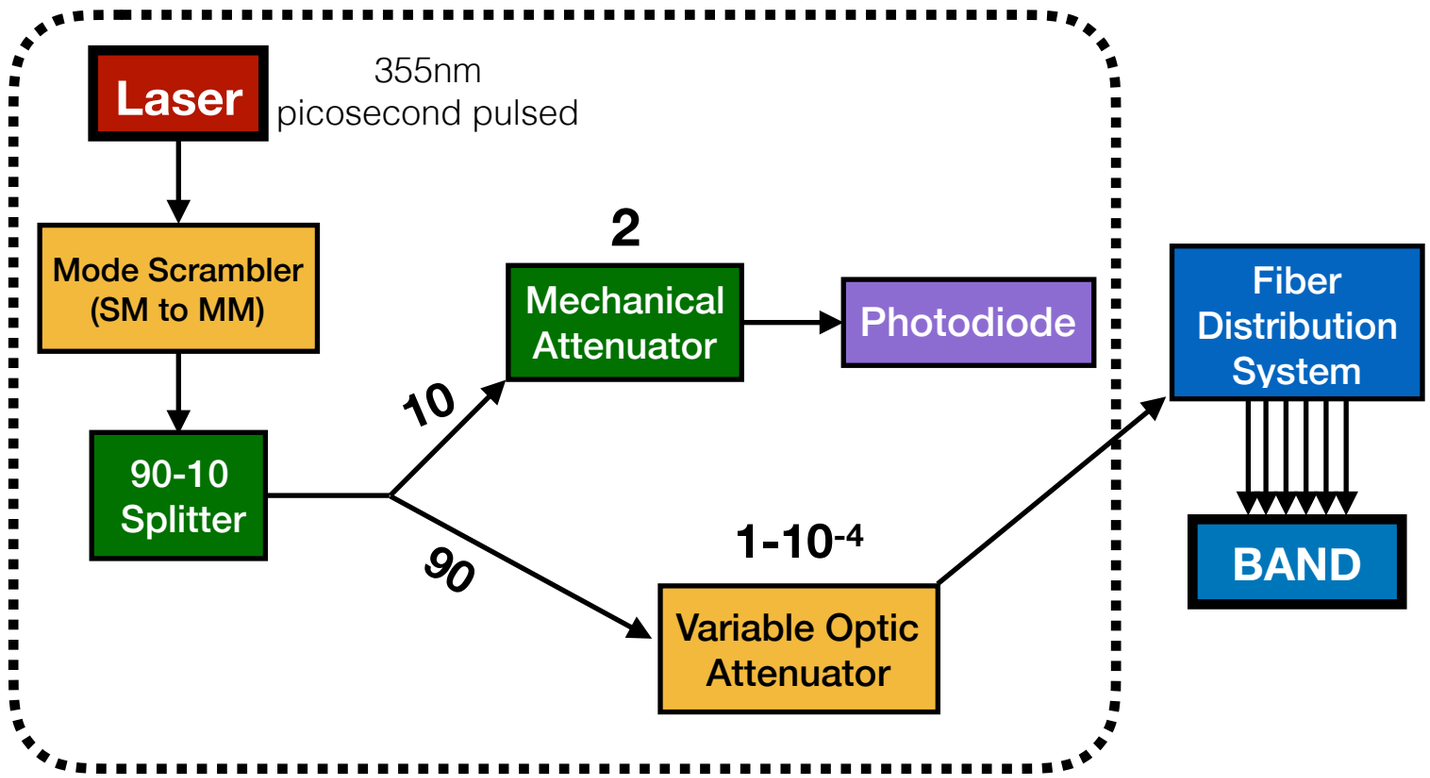


- Laser system and fiber cables
- Mechanics and electronics
- Calibration on laser, cosmics, and sources

Laser System



Used to monitor PMT stability



Base Level Calibrations

Cosmic Data

- TDC/FADC phase offset
- TDC time walk
- Bar attenuation
- Timing offsets

Source Data

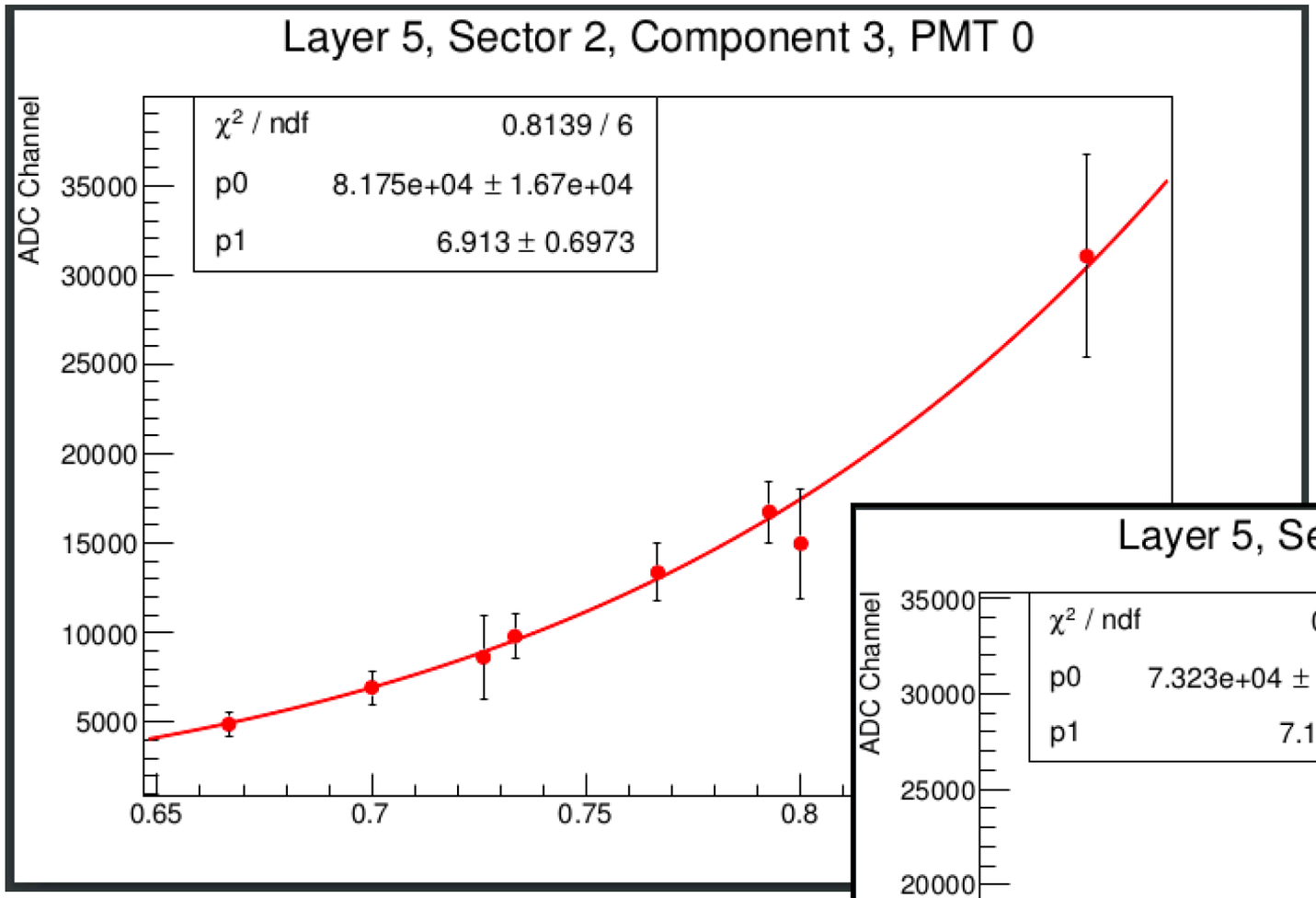
Laser Data

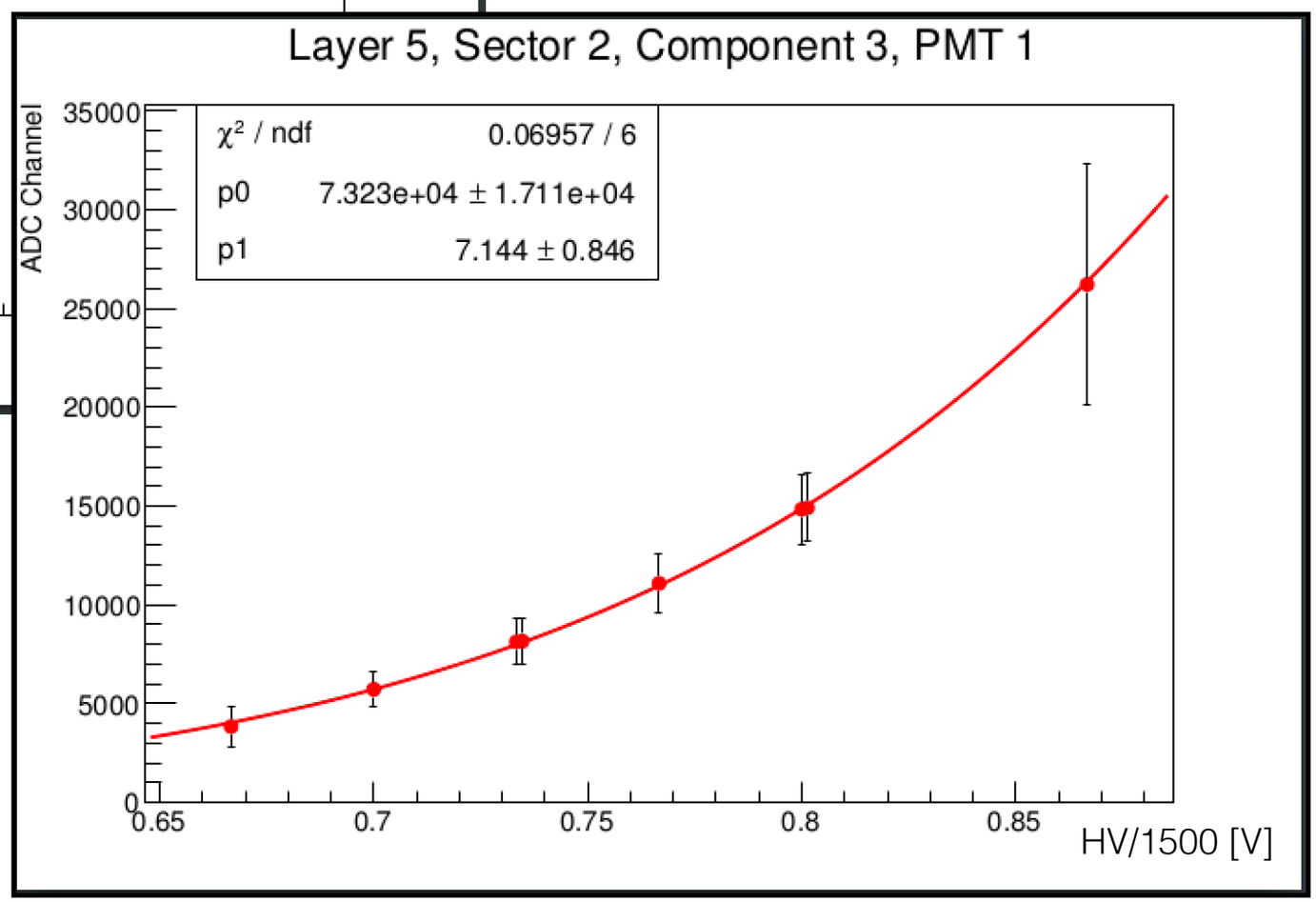
- Effective velocity

Prod Data

- Neutron efficiency
- Neutron momentum resolution

Gain Curves: Optimizing HV



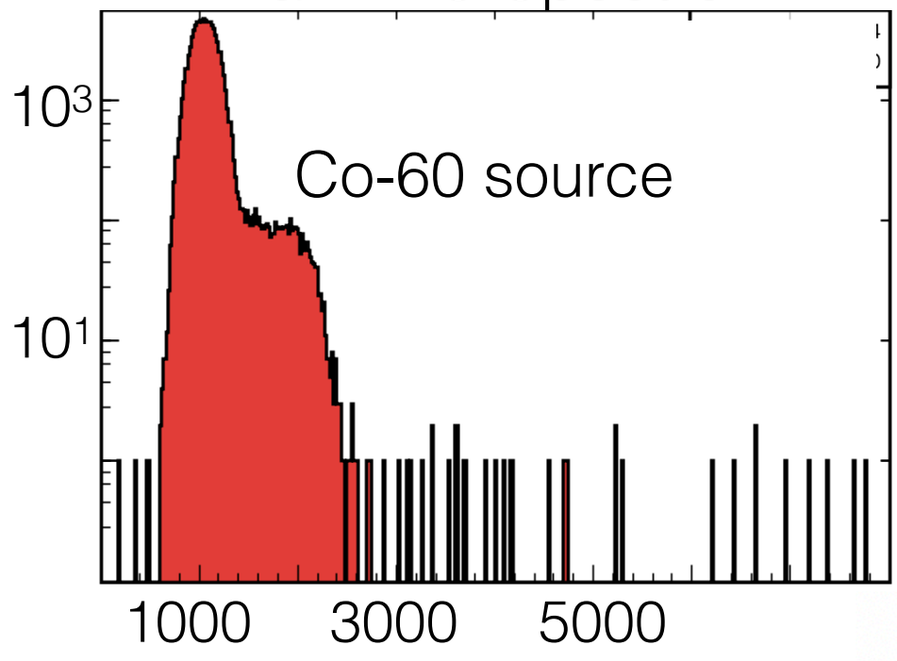


Have most ADC channels possible for neutrons while not driving PMTs into non-linearity

$$\mathrm{ADC} = p_o \left(\frac{\mathrm{HV}}{1500} \right)^{p_1}$$

Calibrating ADC to MeVee

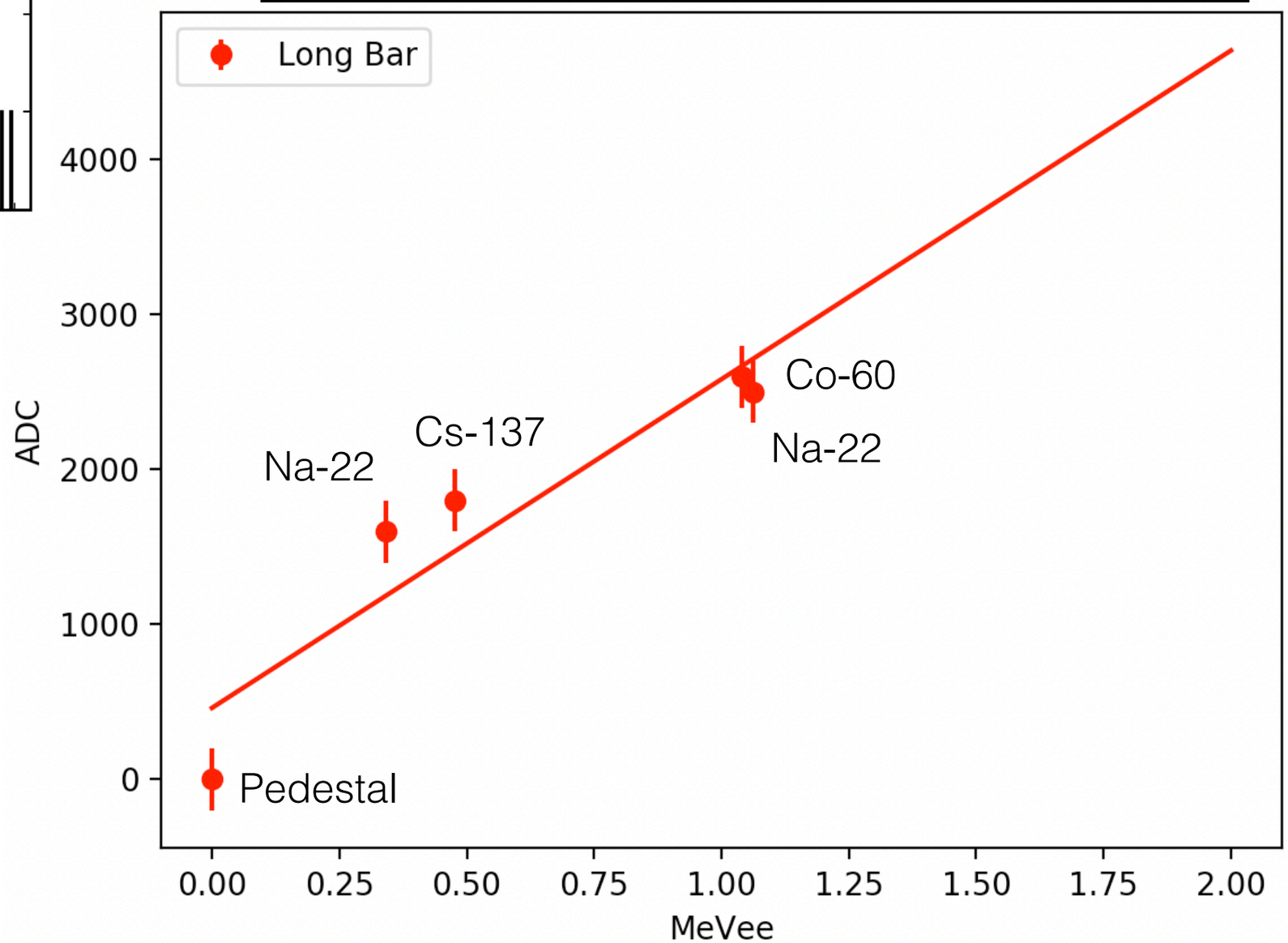
Bar ADC Spectrum



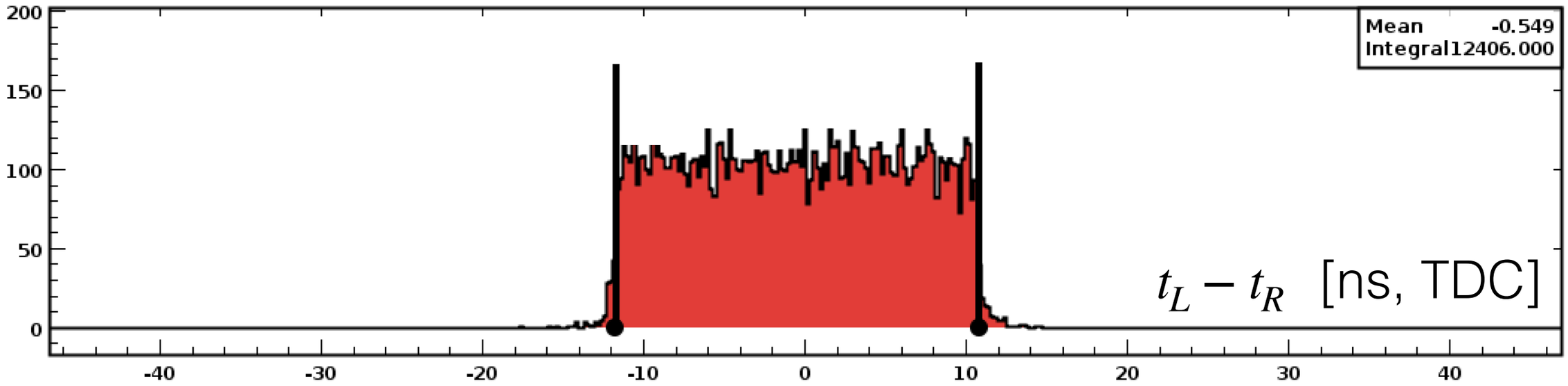
$$\sqrt{\mathrm{ADC}_L \cdot \mathrm{ADC}_R}$$

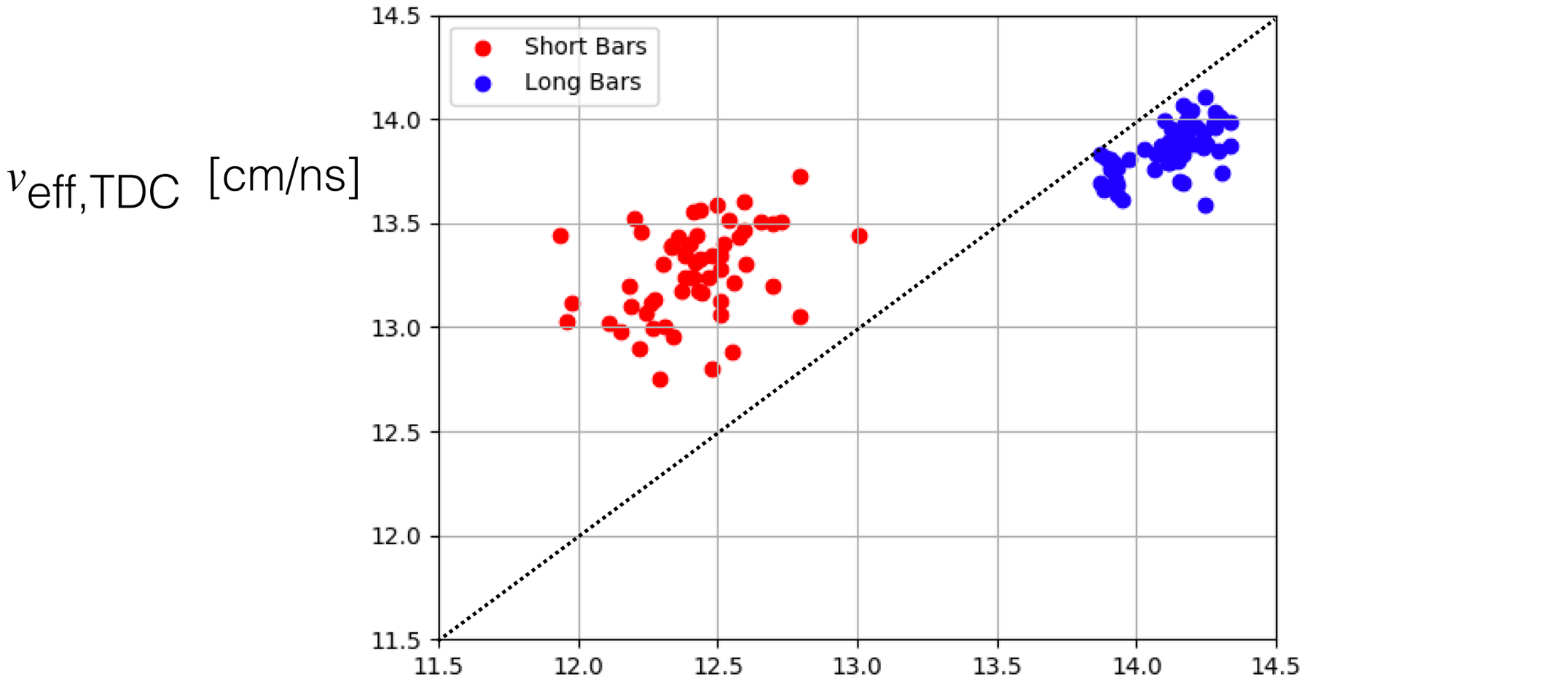
(MeVee =MeV Electron-Equivalent)

Planned software threshold of 2-3 MeVee



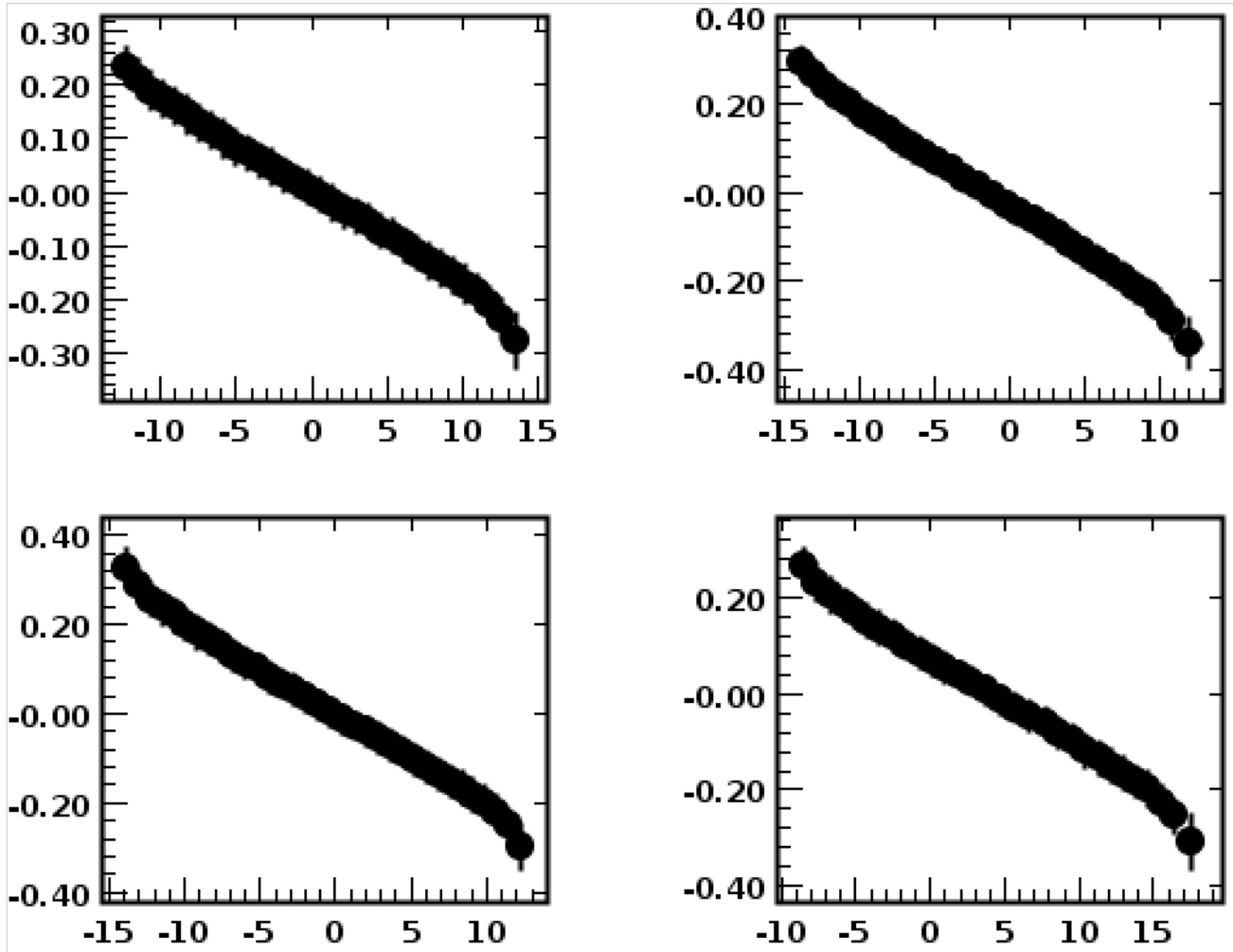
L-R Offsets and Effective Velocity





Extracting Attenuation Lengths

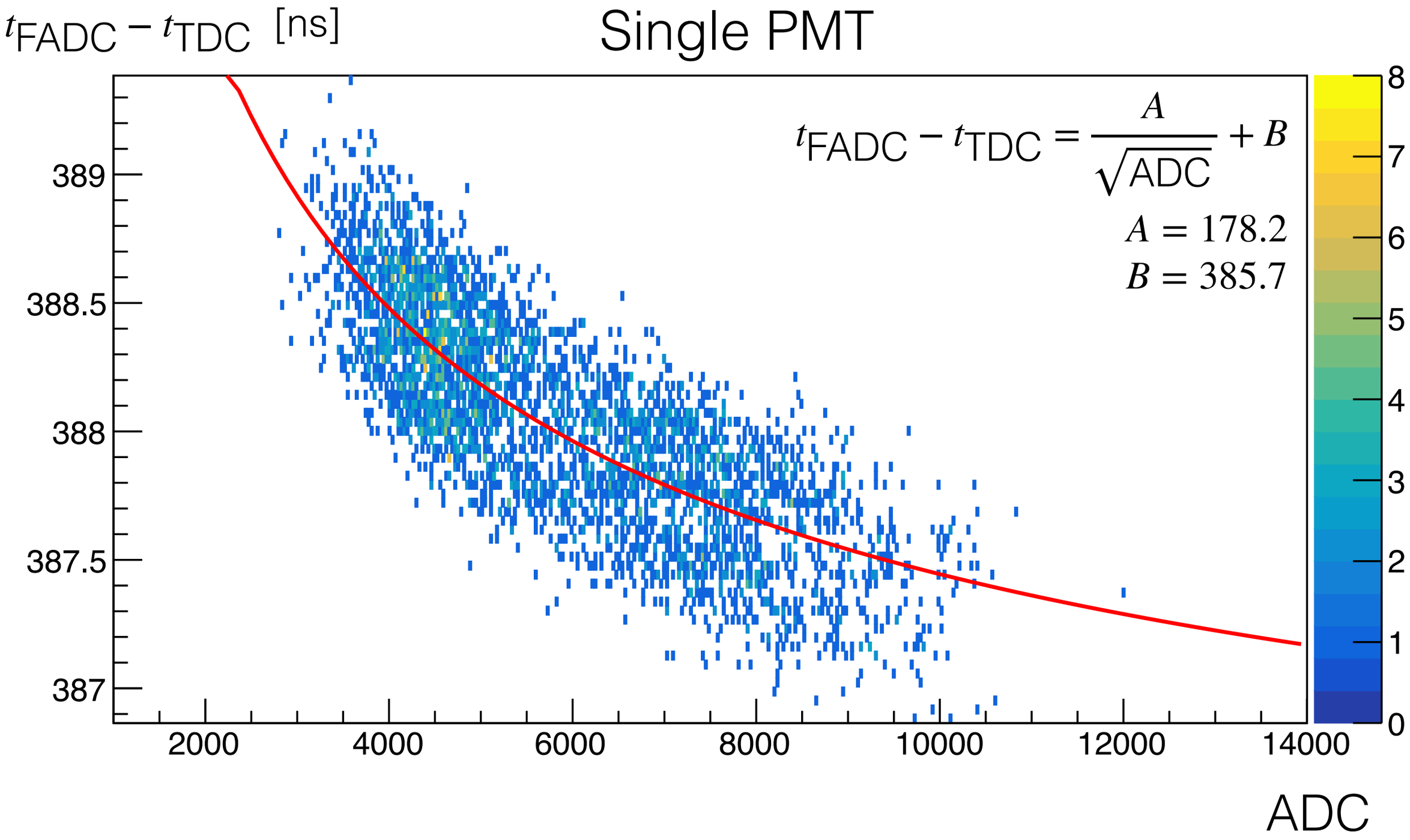
$$\ln R \equiv \ln \frac{\mathrm{ADC}_L}{\mathrm{ADC}_R}$$



$t_L - t_R$ [ns]

$$\ln R = \frac{2x}{\mu} = -v\frac{t_L - t_R}{\mu}$$

After Phase Correction with Time-Walk Fit

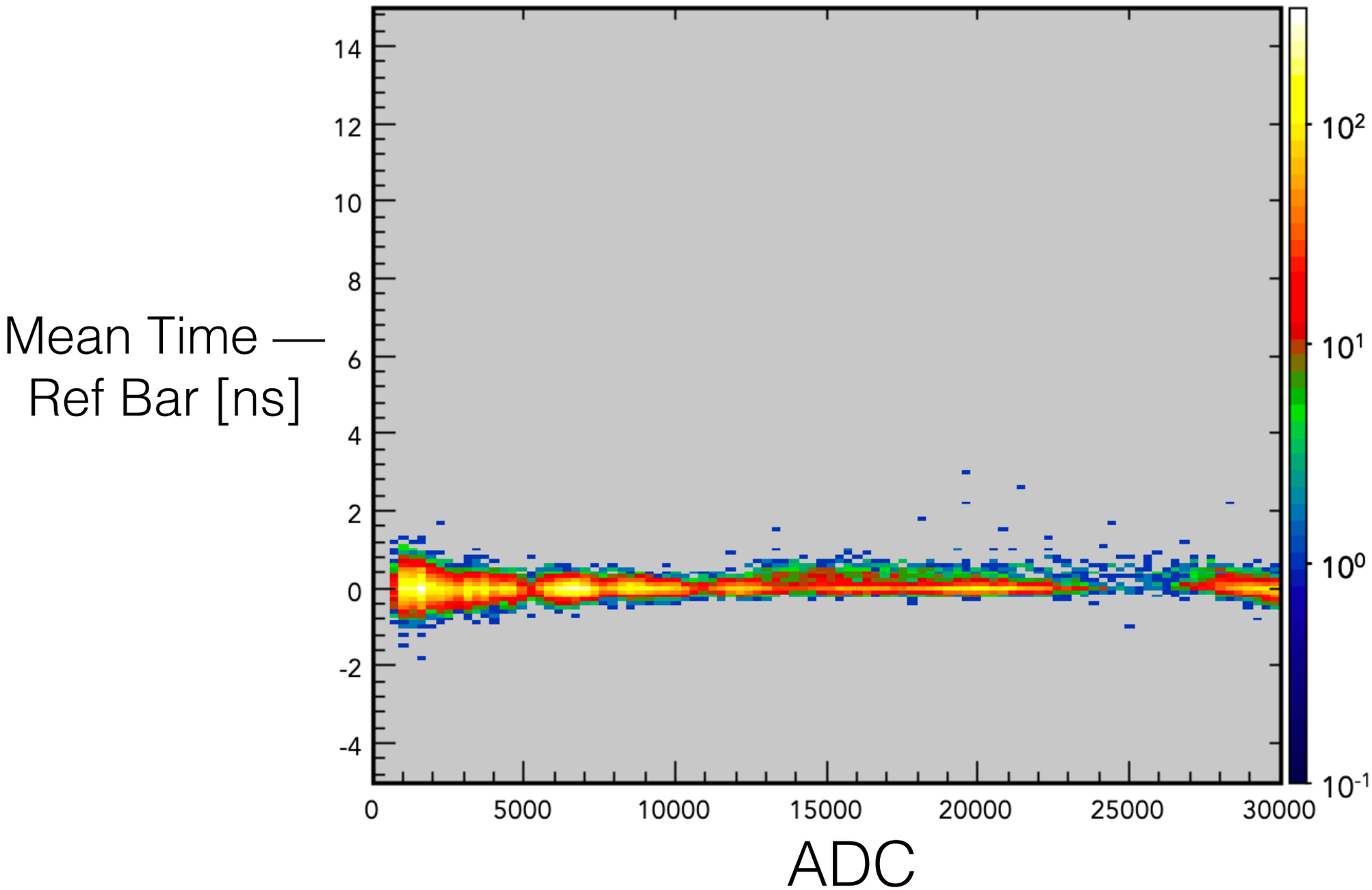


Paddle-to-paddle offsets

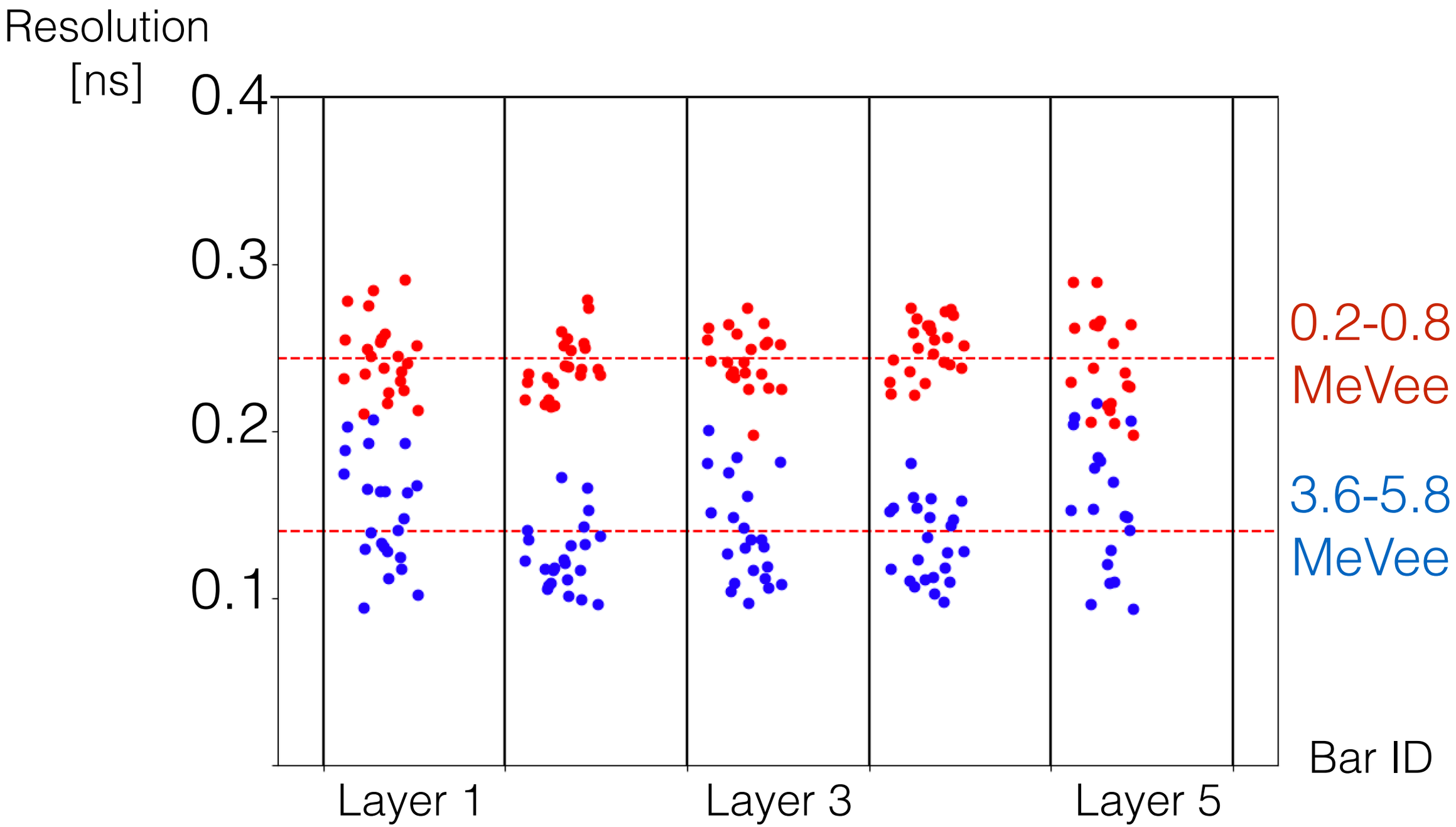
- Used stable laser timing pulse to align all PMTs in time
- Also measured time resolution

Measuring Time Resolution

Laser timing peak used as monitoring system

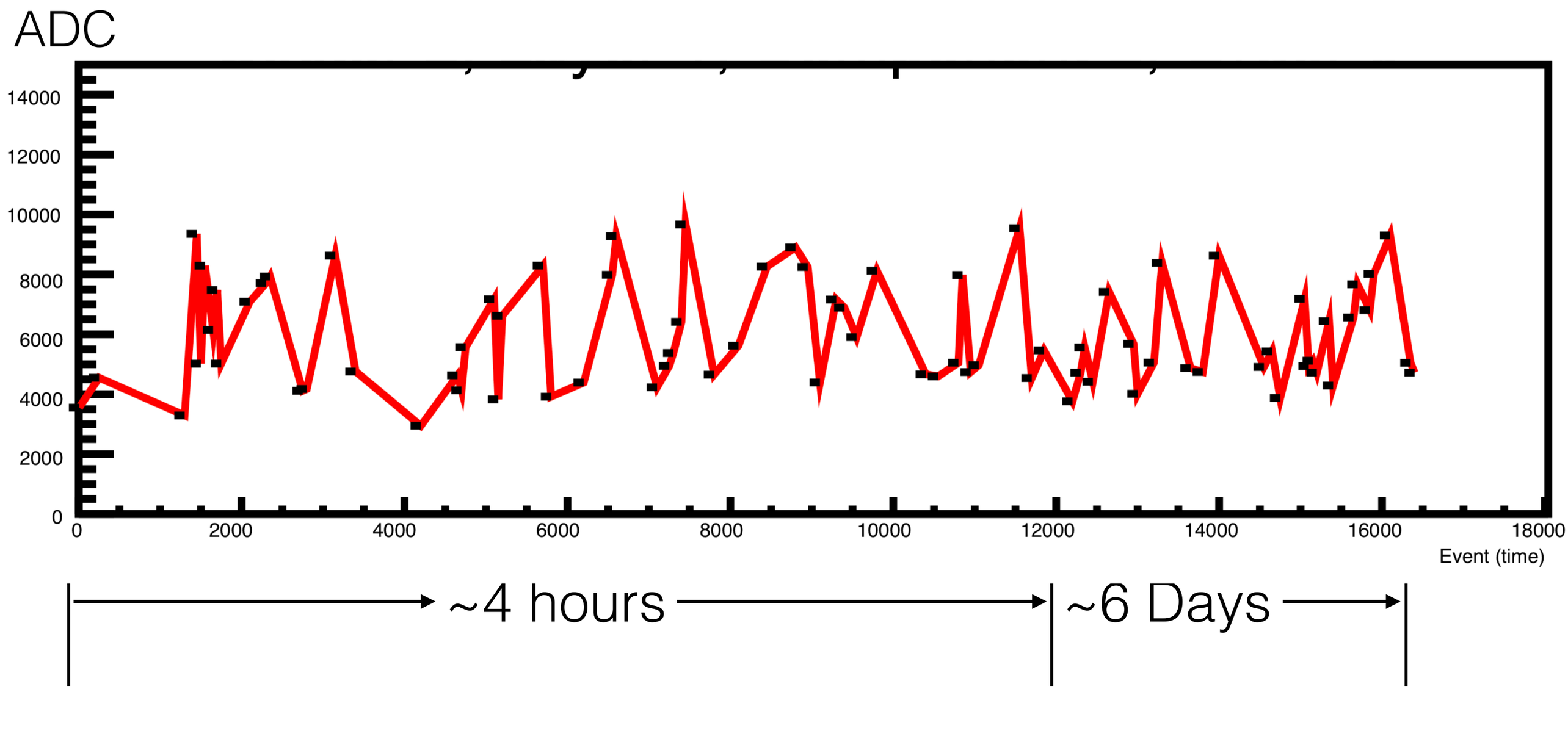


Resolutions of BAND Bars



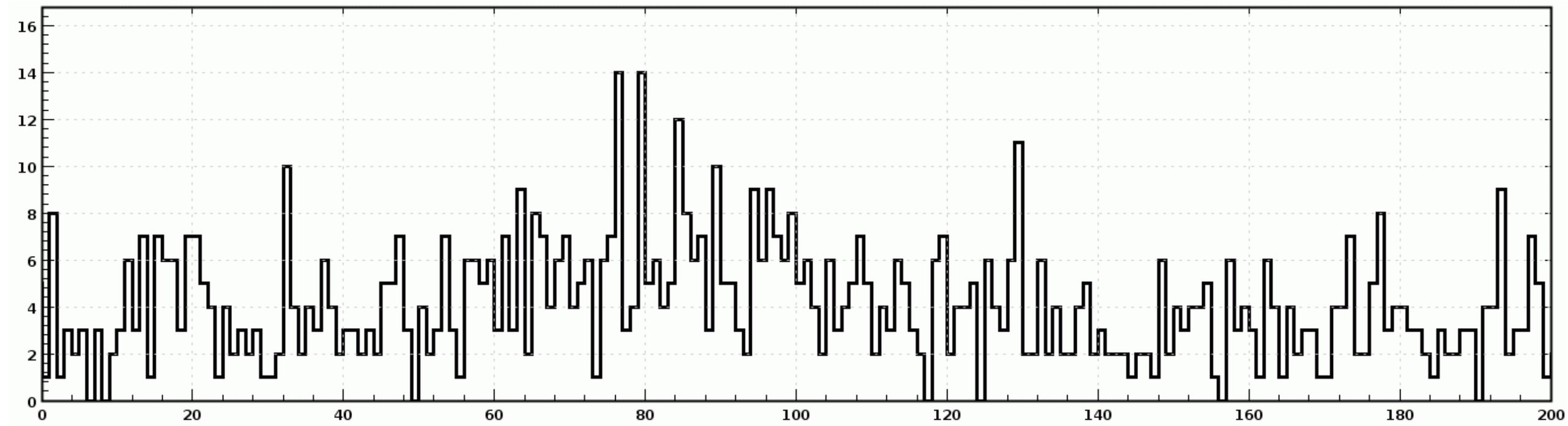
Laser System as PMT Monitoring

Single PMT ADC Response from Laser



Can we see neutrons?

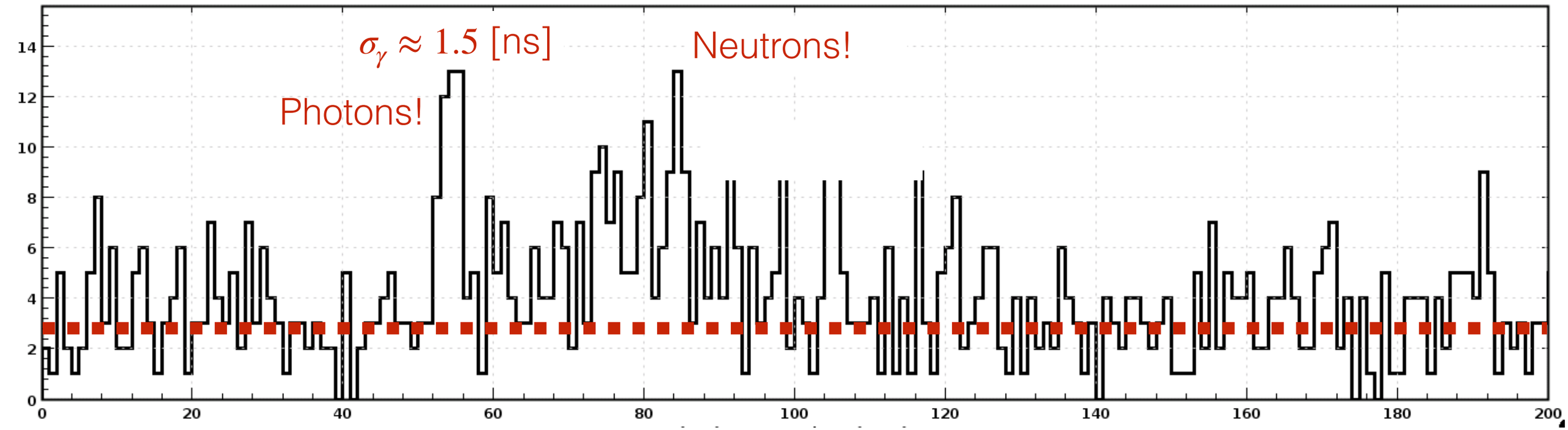
Before calibrations: All short bars in BAND, (e,e')



$$\frac{t_L + t_R}{2} - \text{STime [ns]}$$

Yes!

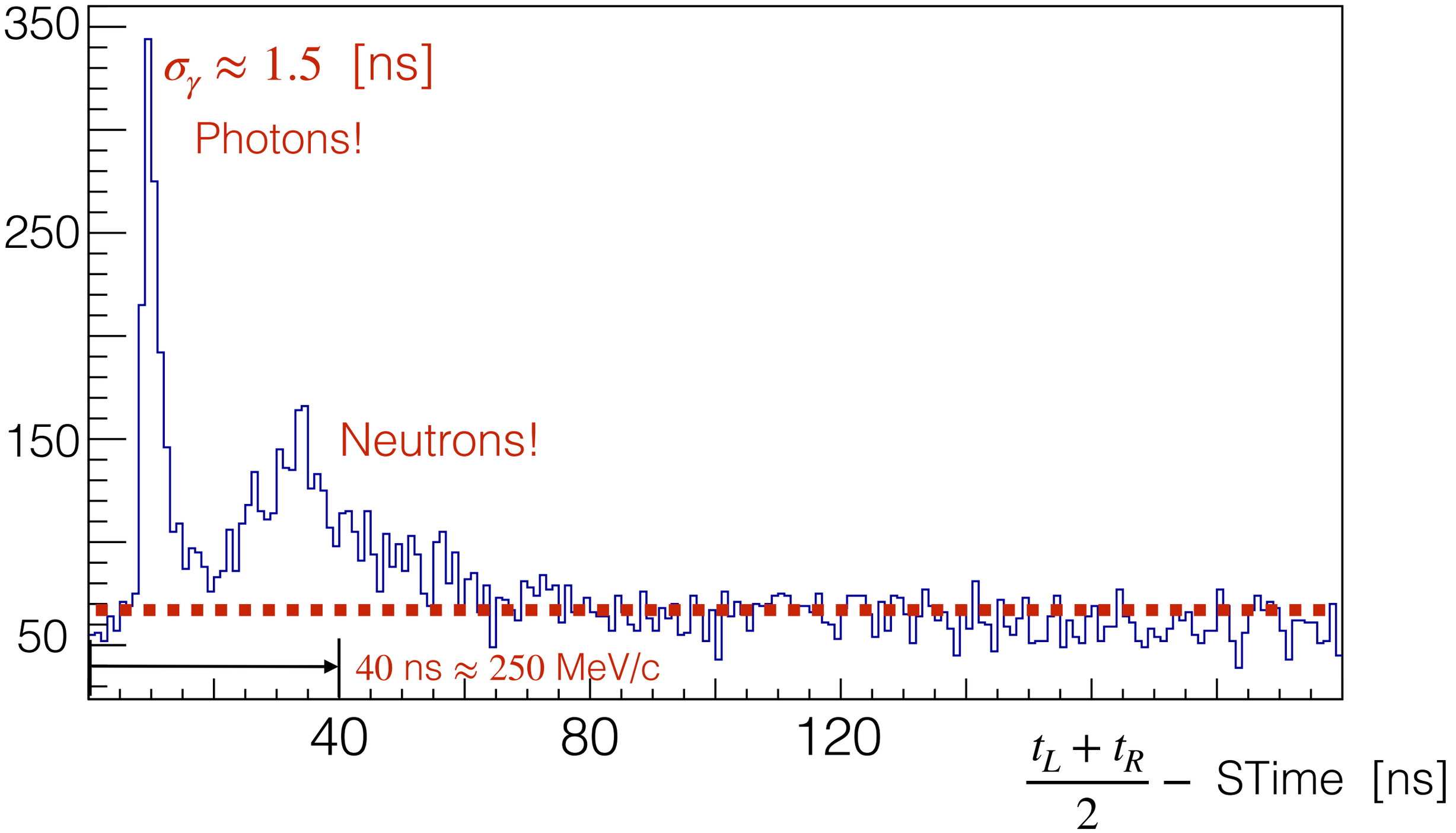
After calibrations: All short bars in BAND, (e,e')



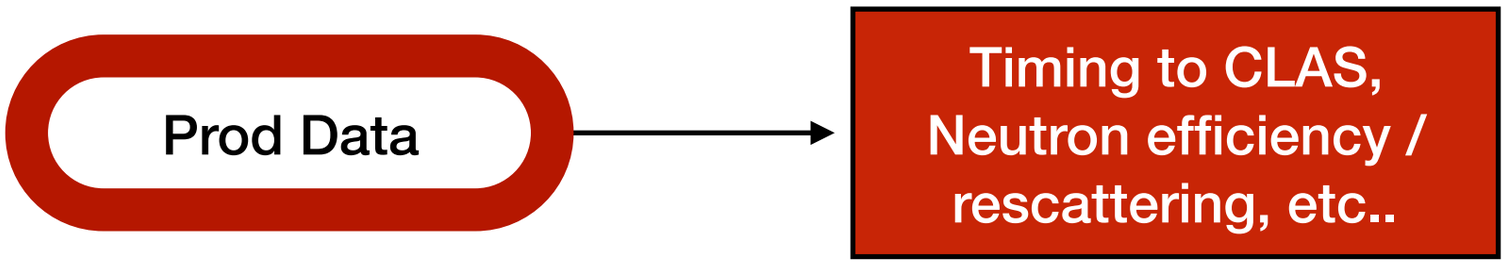
$$\frac{t_L + t_R}{2} - \text{STime [ns]}$$

Neutron Momentum Distribution

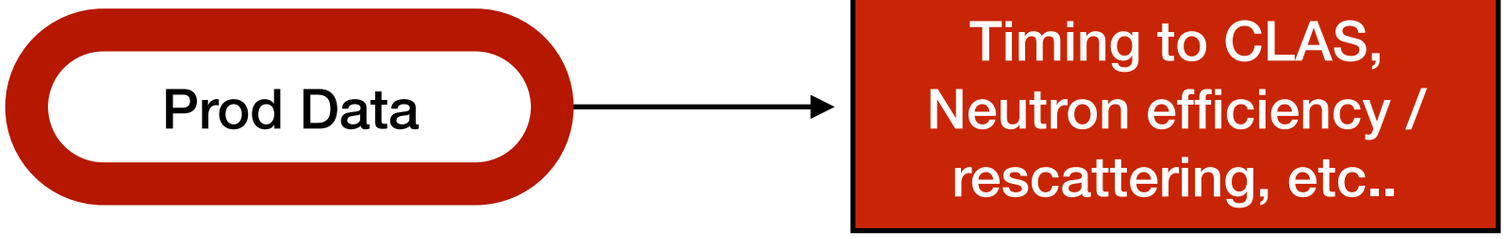
After calibrations: All long bars in BAND, (e,e')



BAND + CLAS Physics



BAND + CLAS Physics



Searching for exclusive processes

$d(e, e'p)n$ (measure n efficiency)

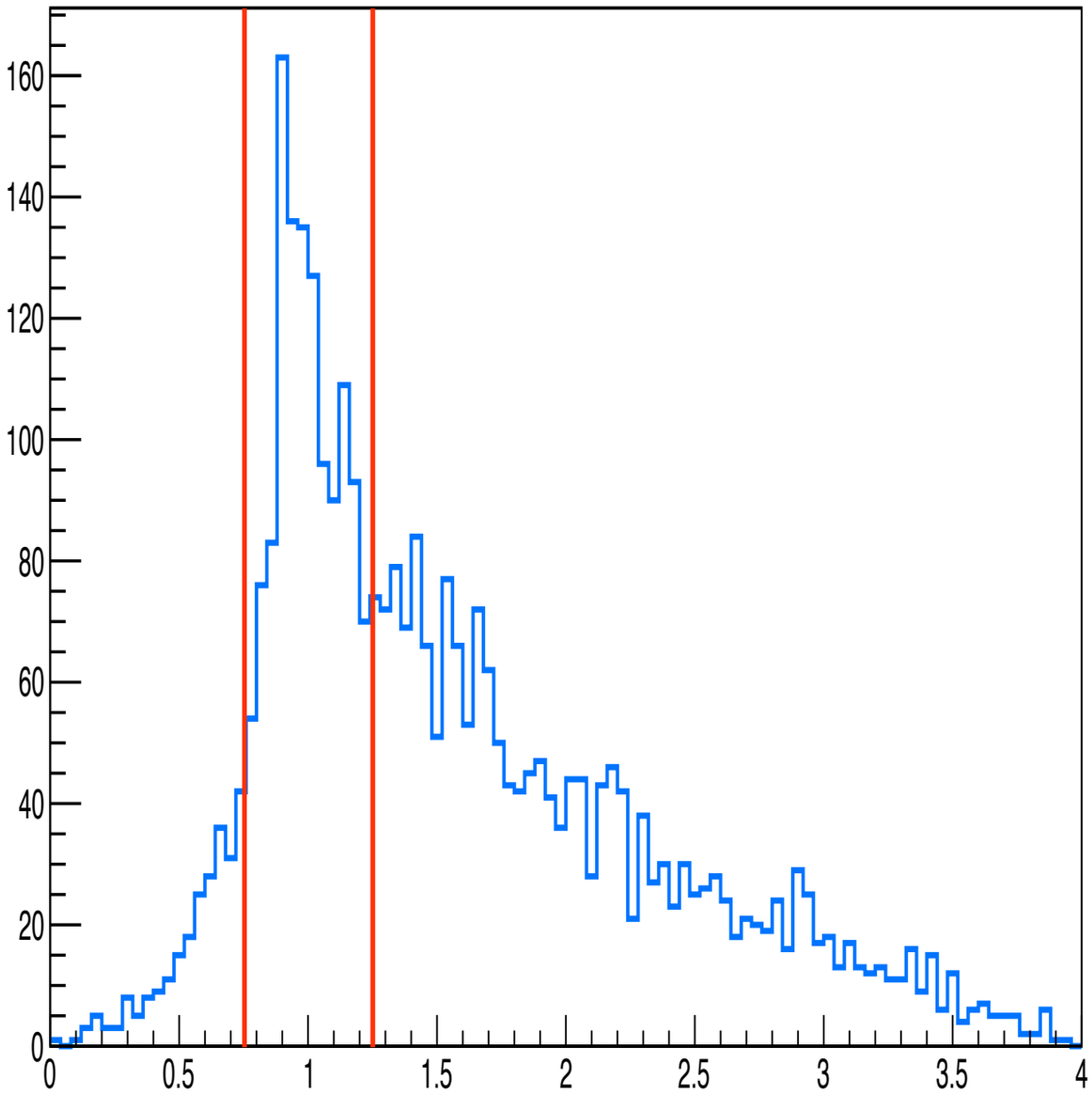
$d(e, e'p\pi^+\pi^-)n$ (measure n efficiency)

$d(e, e'pp\pi^-)$ (study resolution in CLAS)

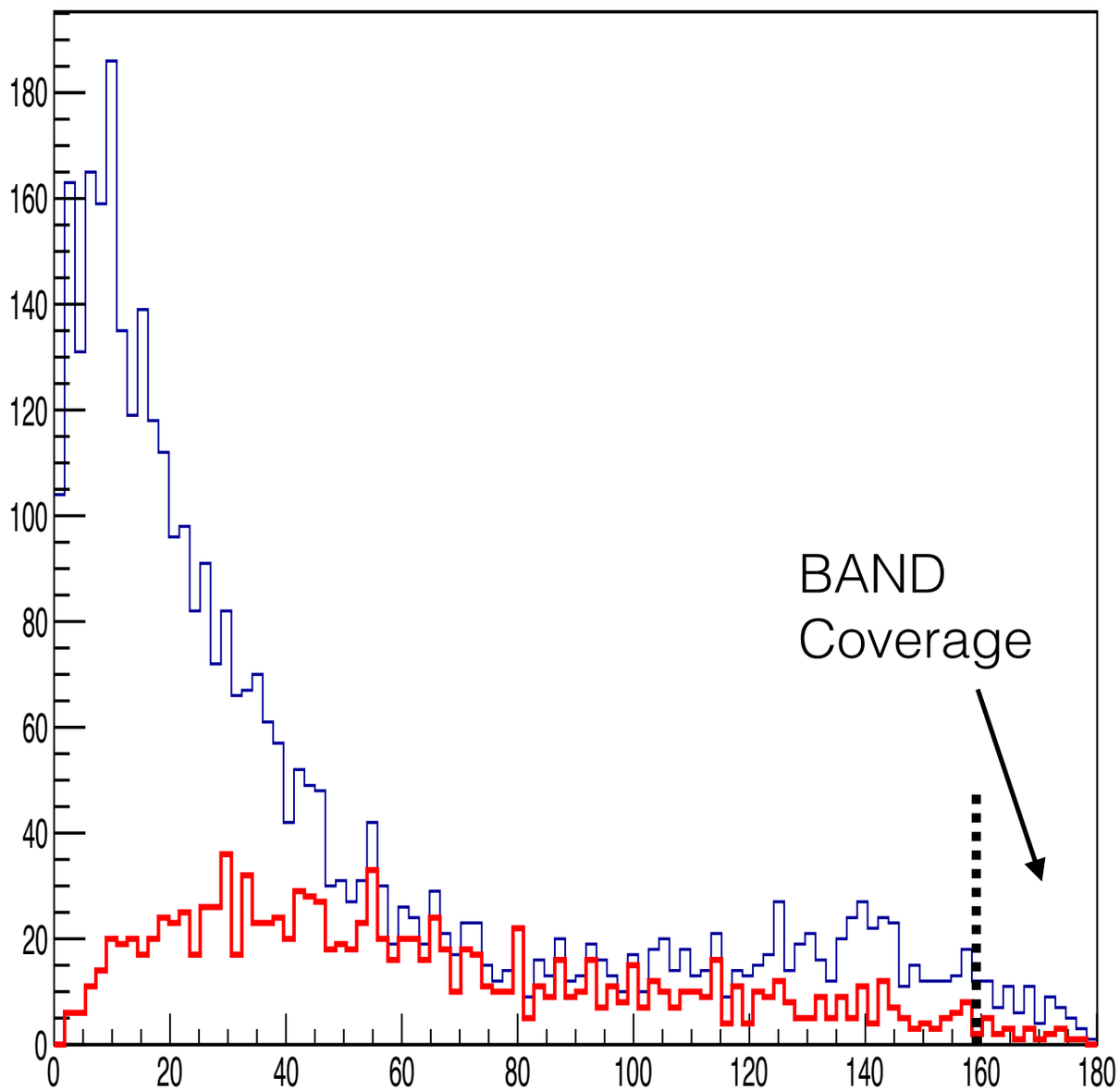
$d(e, e'p\pi^+\pi^-)n$

Run 6164, 900 splits, 3 hours of beam

m_{miss} [GeV]

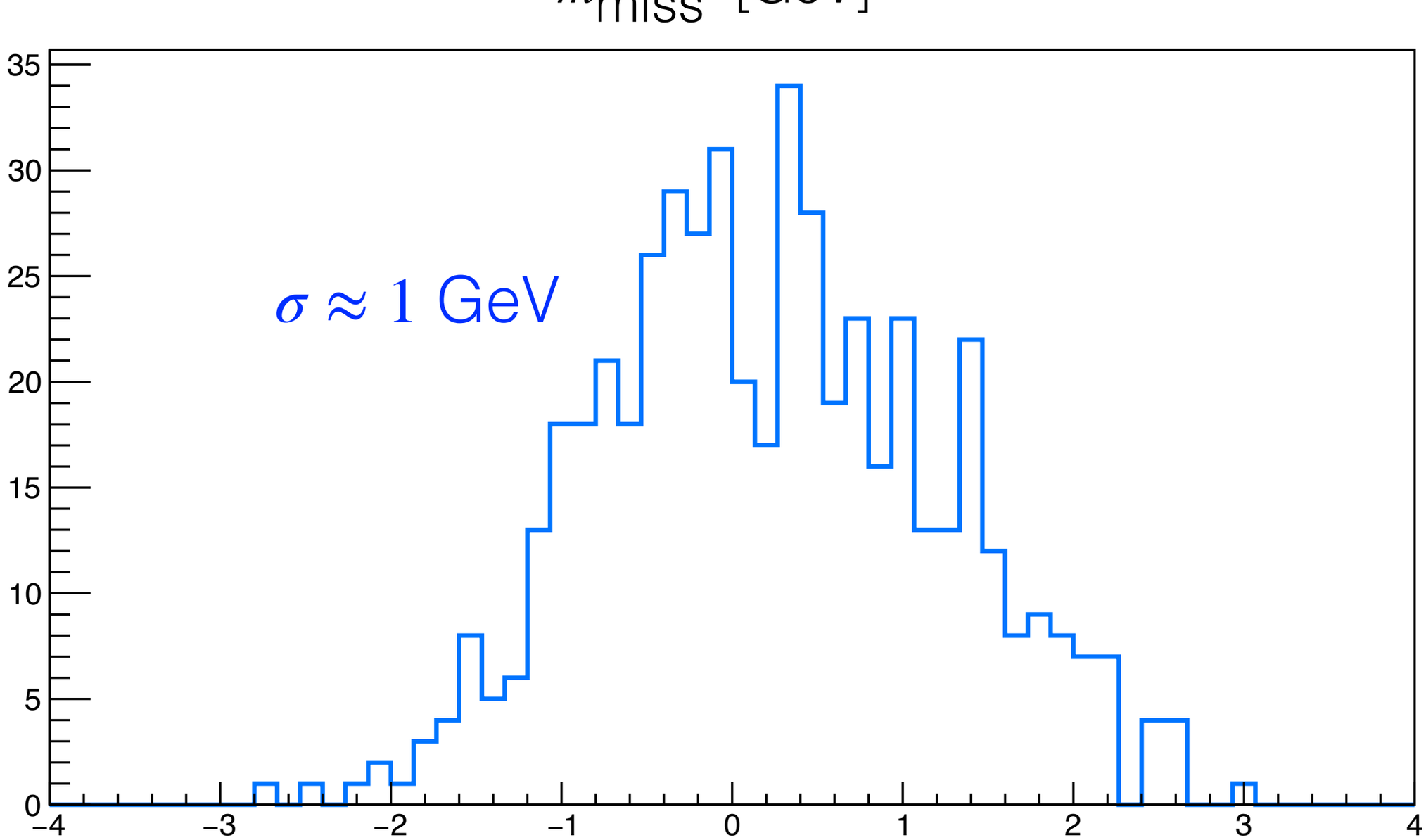


θ_{miss} [deg]



$d(e, e'pp\pi^-)$

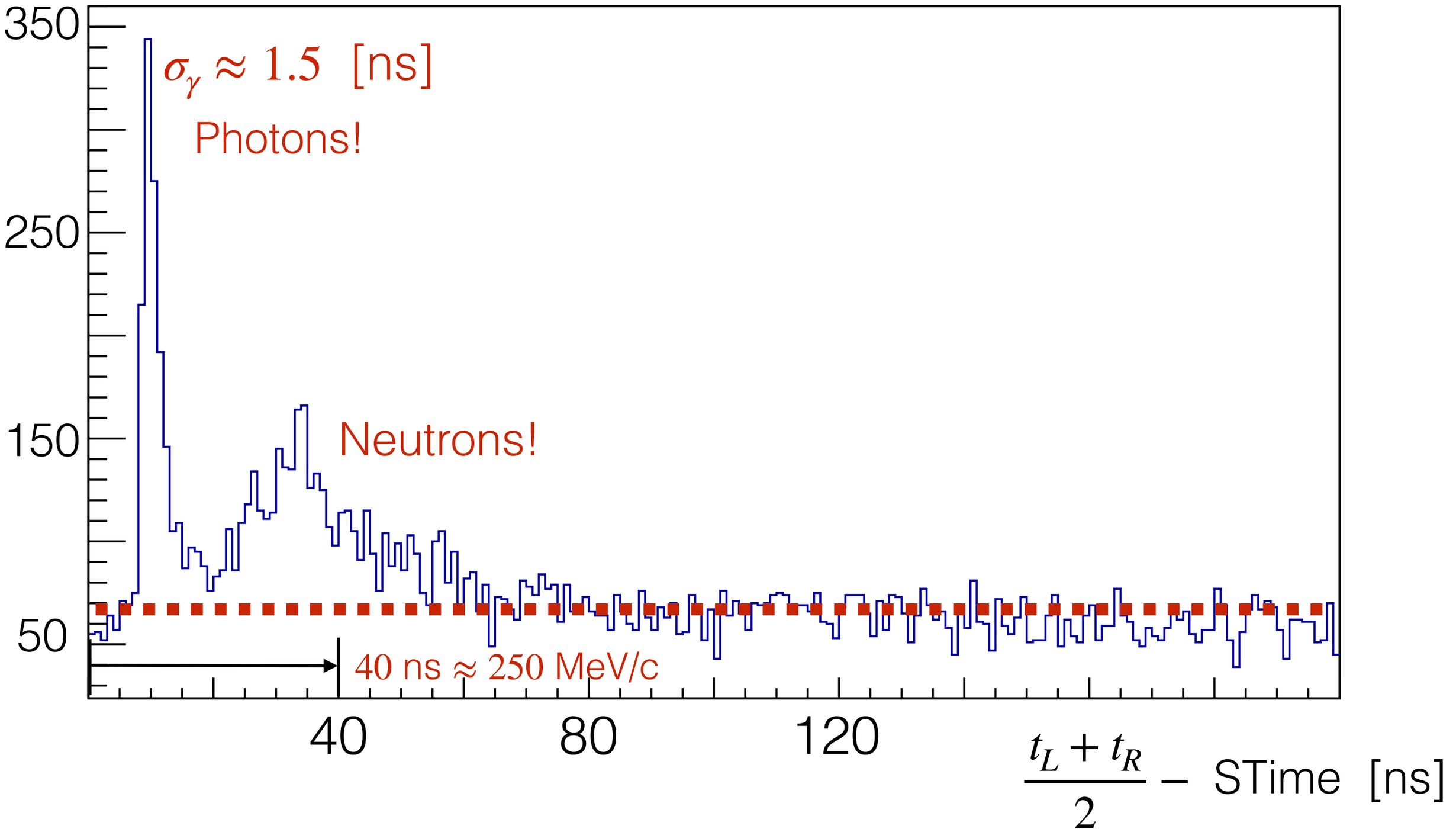
Run 6164, 900 splits, 3 hours of beam



EMC-SRC Prelim Physics

Neutron Momentum Distribution

After calibrations: All long bars in BAND, (e,e')



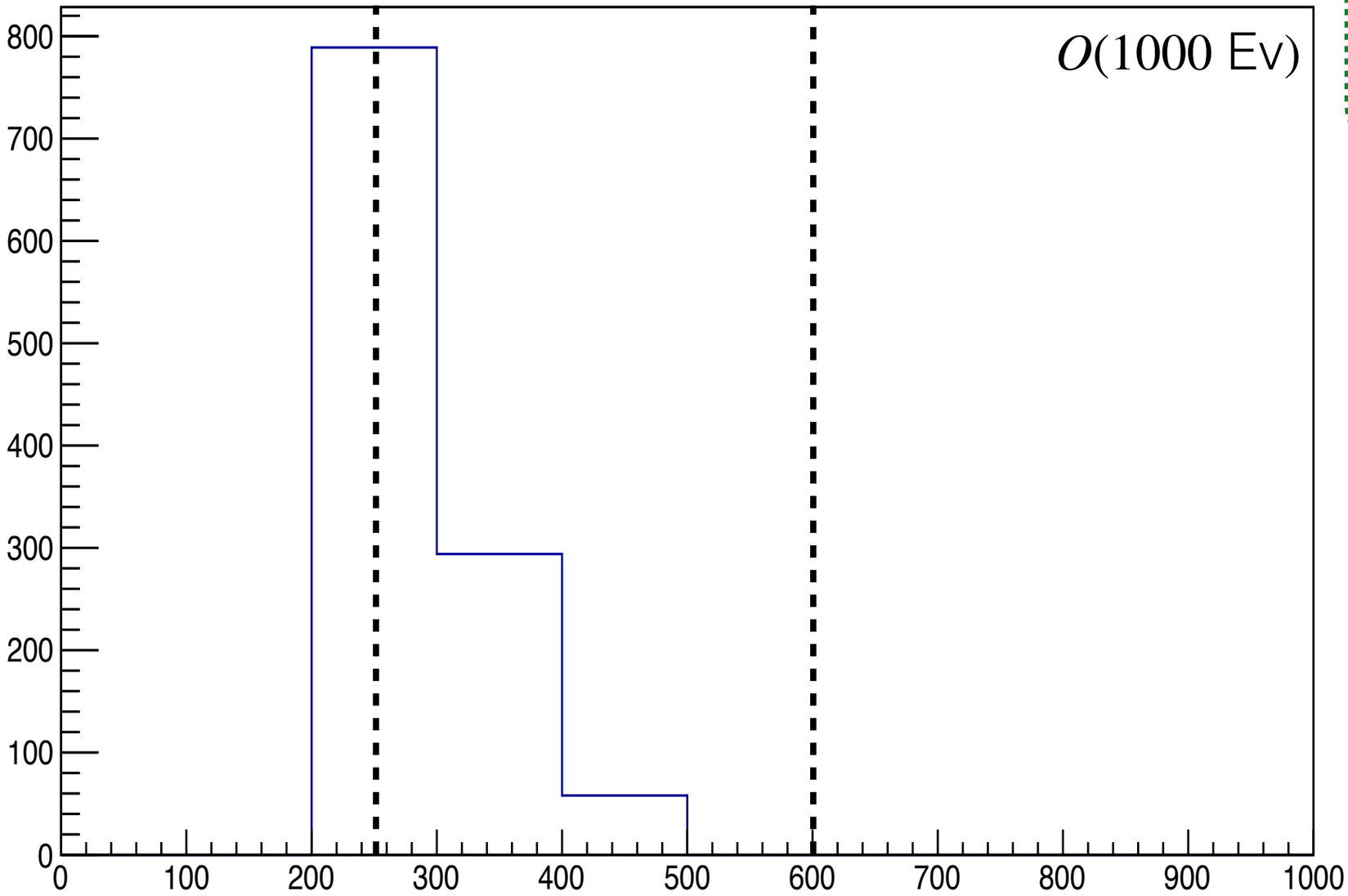
Neutron Momentum Distribution

Run 6164, 900 splits, 3 hours of beam, **(e,e'n$_{BAND}$)**

$Q^2 > 2$ GeV^2
$\cos\theta_{qn} > 110$ deg
$0.2 < x' < 0.8$
$W' > 1.8$ GeV
$p_n > 200$ MeV

Counts

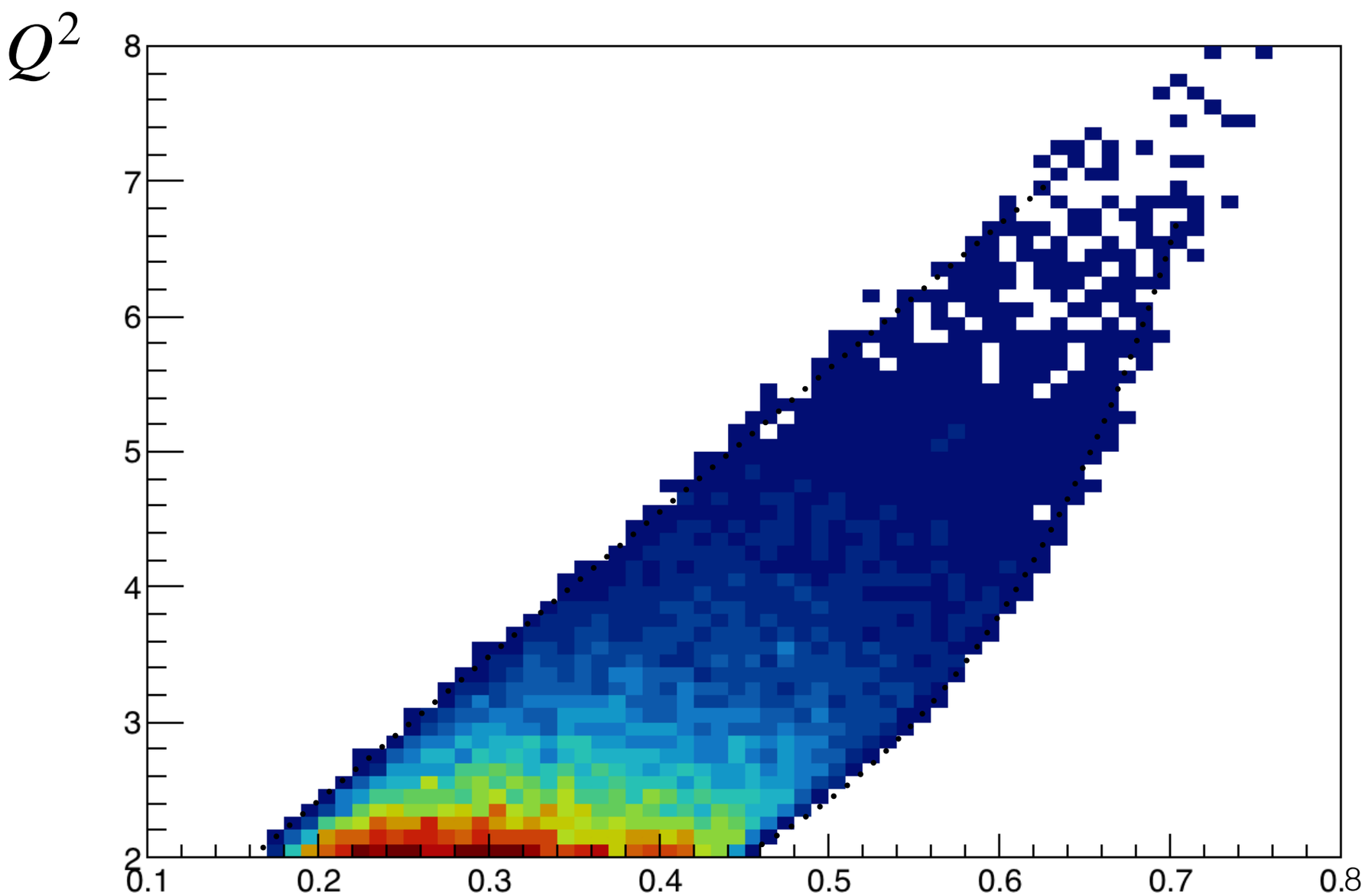
Our physics of interest



$$W'^2 = (q^\mu + p_D^\mu - p_S^\mu)^2 \qquad x' = \frac{Q^2}{2\left((m_D - E_S)\omega + \vec{p}_S \cdot \vec{q}\right)}$$

Simulated Kinematical Reach

$Q^2 > 2$ GeV^2
$\cos\theta_{qn} > 110$ deg
$W' > 1.8$ GeV
$p_n > 200$ MeV



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Kinematical Reach

Run 6164, 900 splits, 3 hours of beam, **(e,e'n$_{BAND}$)**

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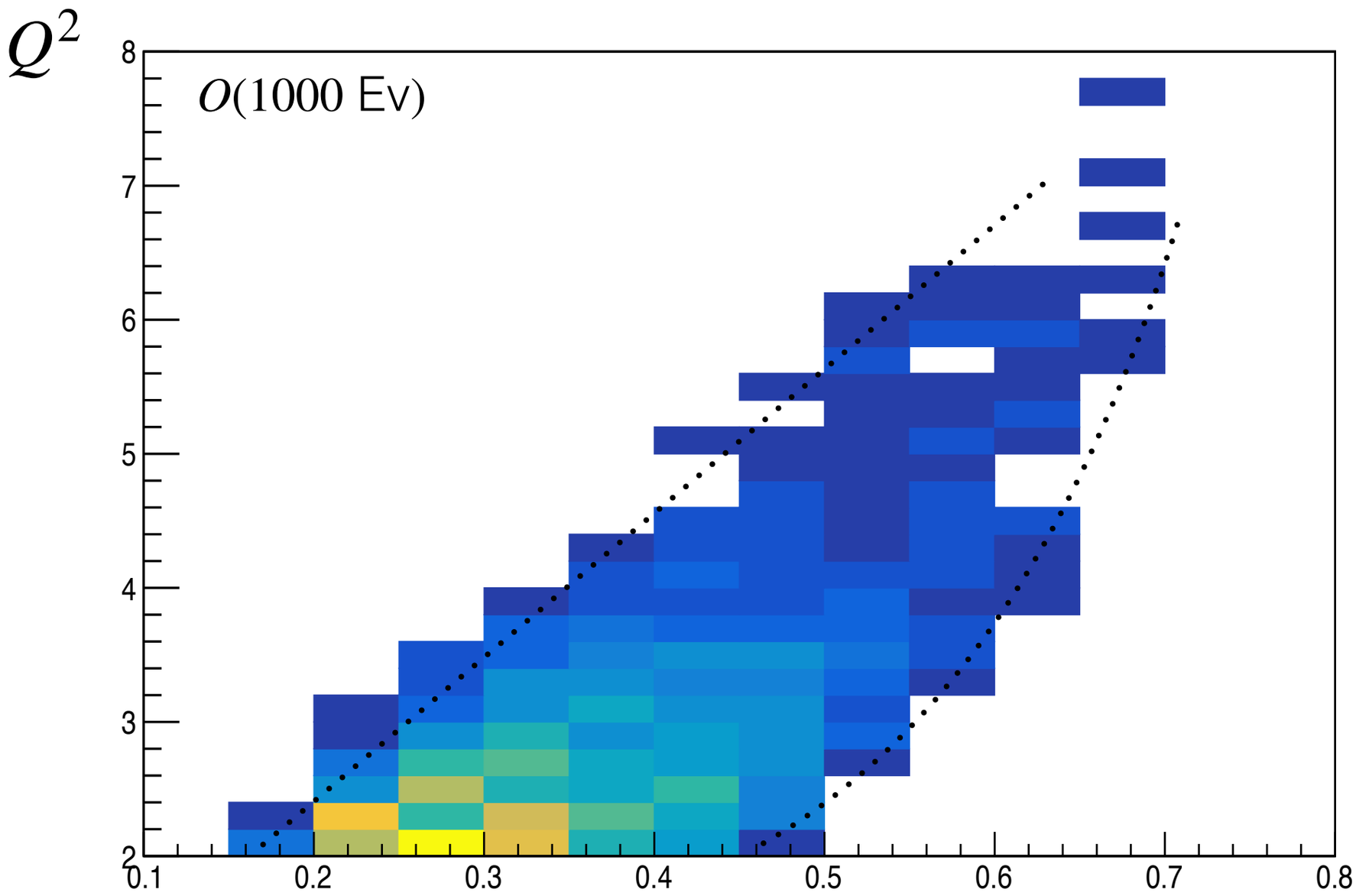

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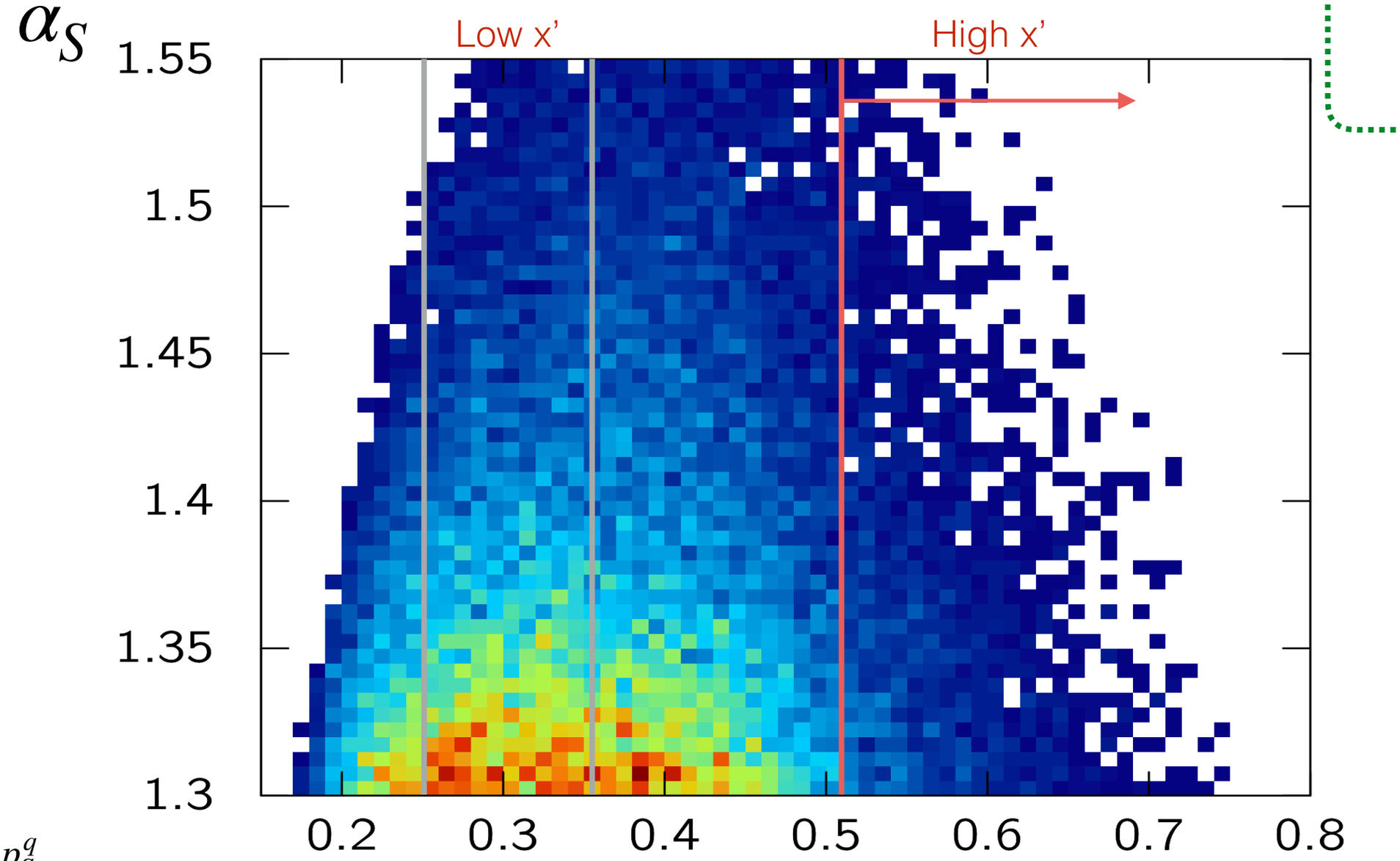

$$\alpha_s = \frac{E_S - p_S^q}{m_N}$$

$$W'^2 = (q^\mu + p_D^\mu - p_S^\mu)^2 \qquad x' = \frac{Q^2}{2\left((m_D - E_S)\omega + \vec{p}_S \cdot \vec{q}\right)}$$

Kinematical Reach

Run 6164, 900 splits, 3 hours of beam, **(e,e'n$_{BAND}$)**

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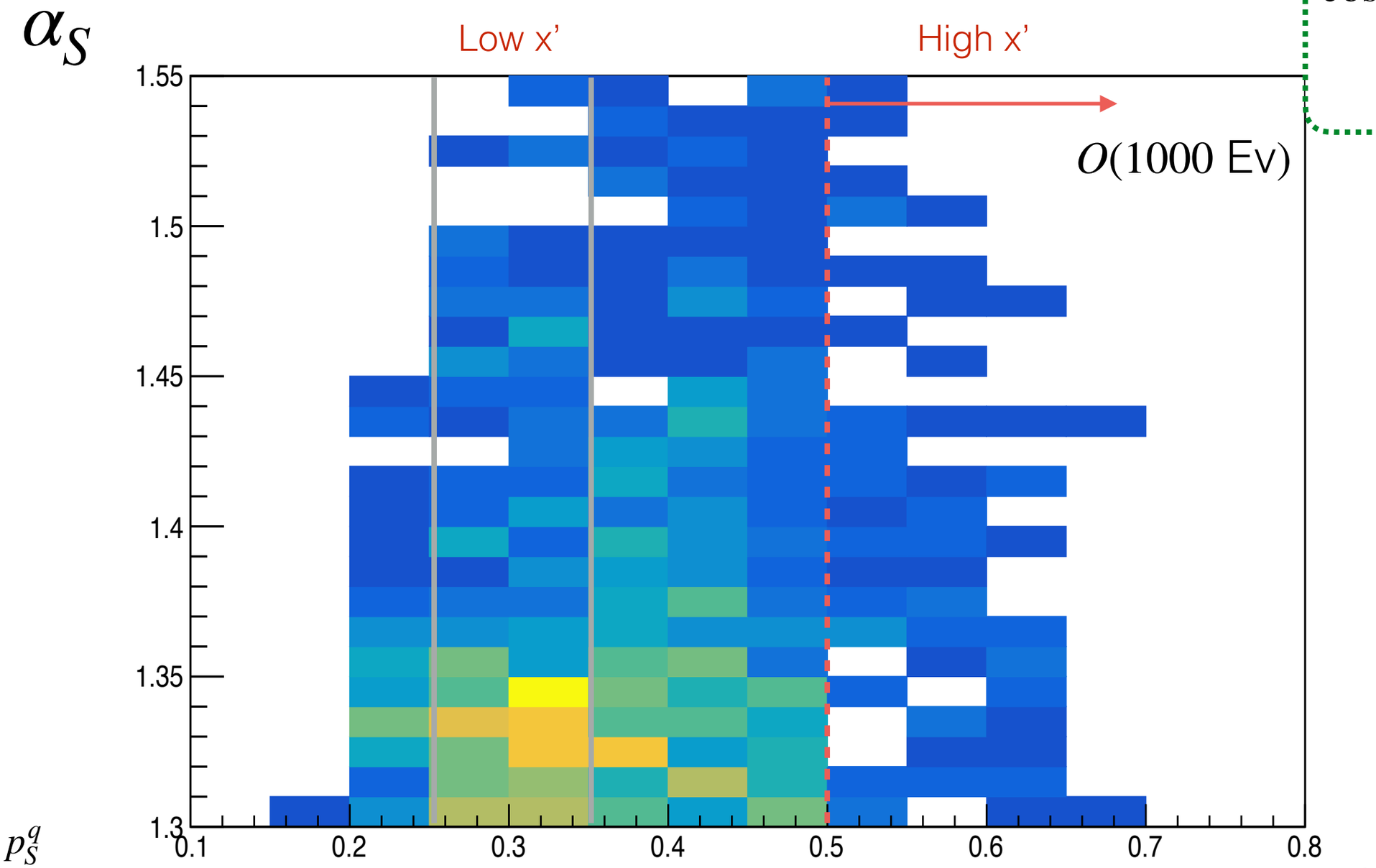

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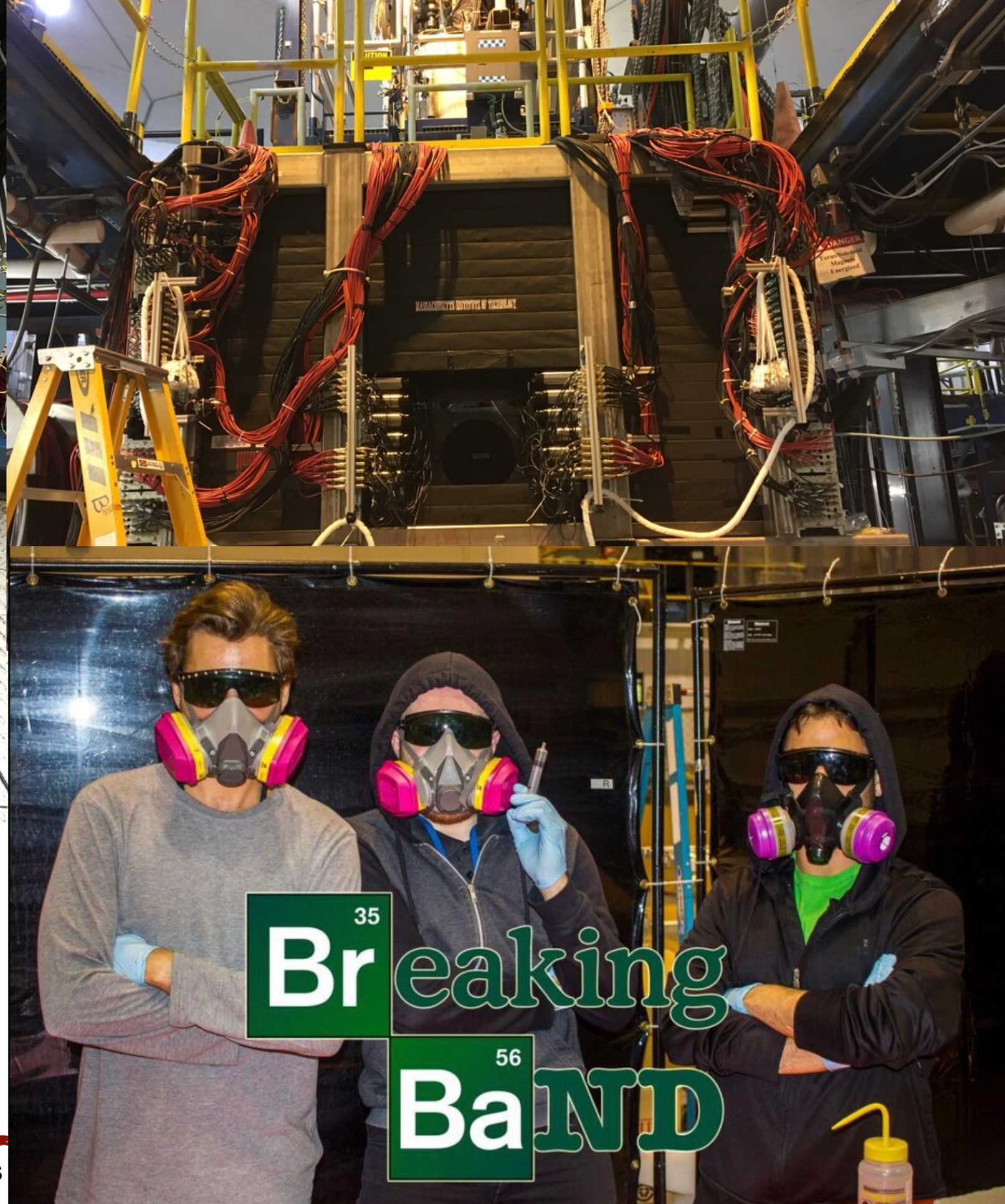
Thank you!

Efrain Segarra
Reynier Cruz Torres
Florian Hauenstein

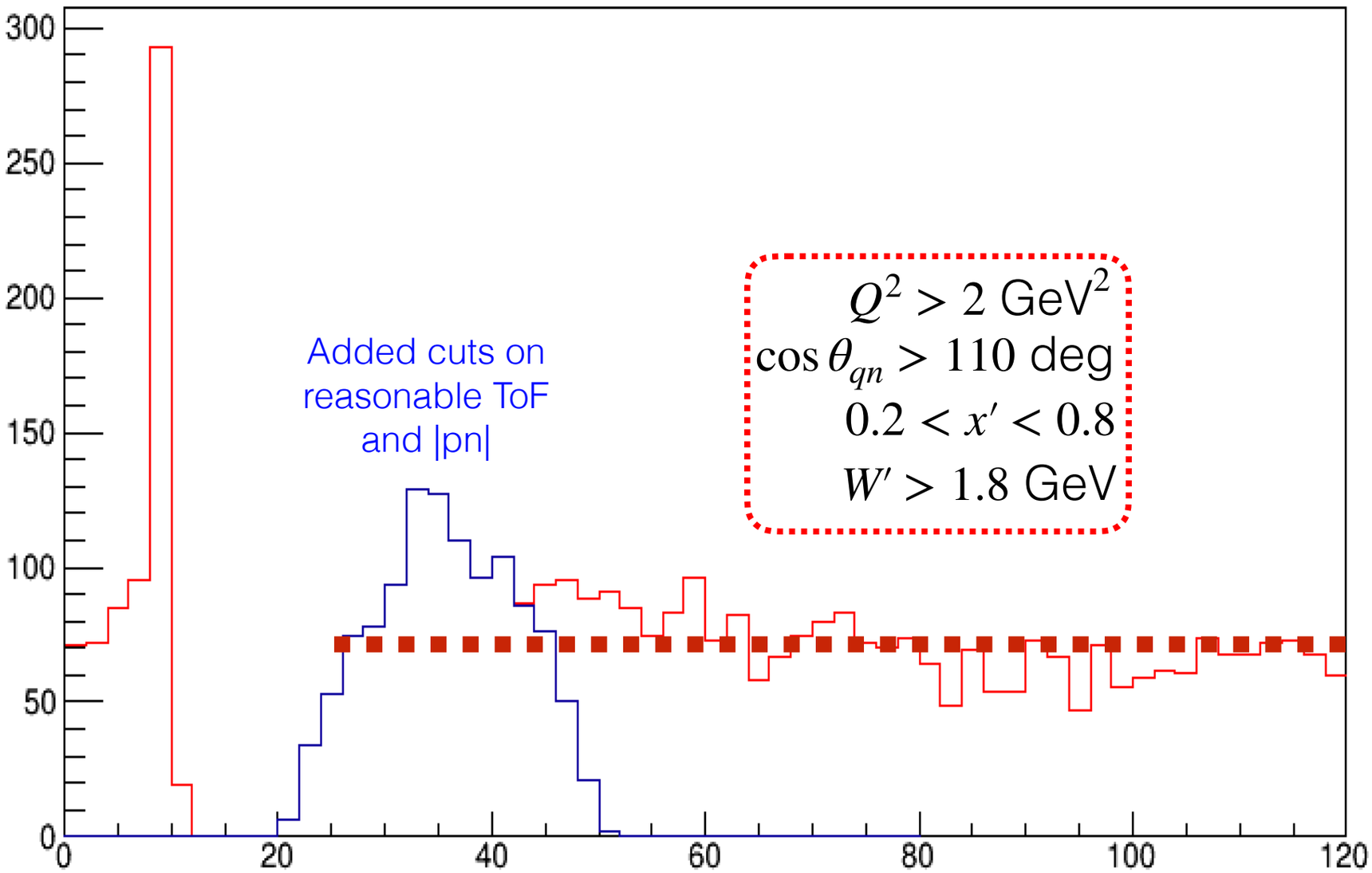


Back up slides

Lot of Events Bkgrd

Run 6164, 900 splits, 3 hours of beam, **(e,e'n$_{BAND}$)**

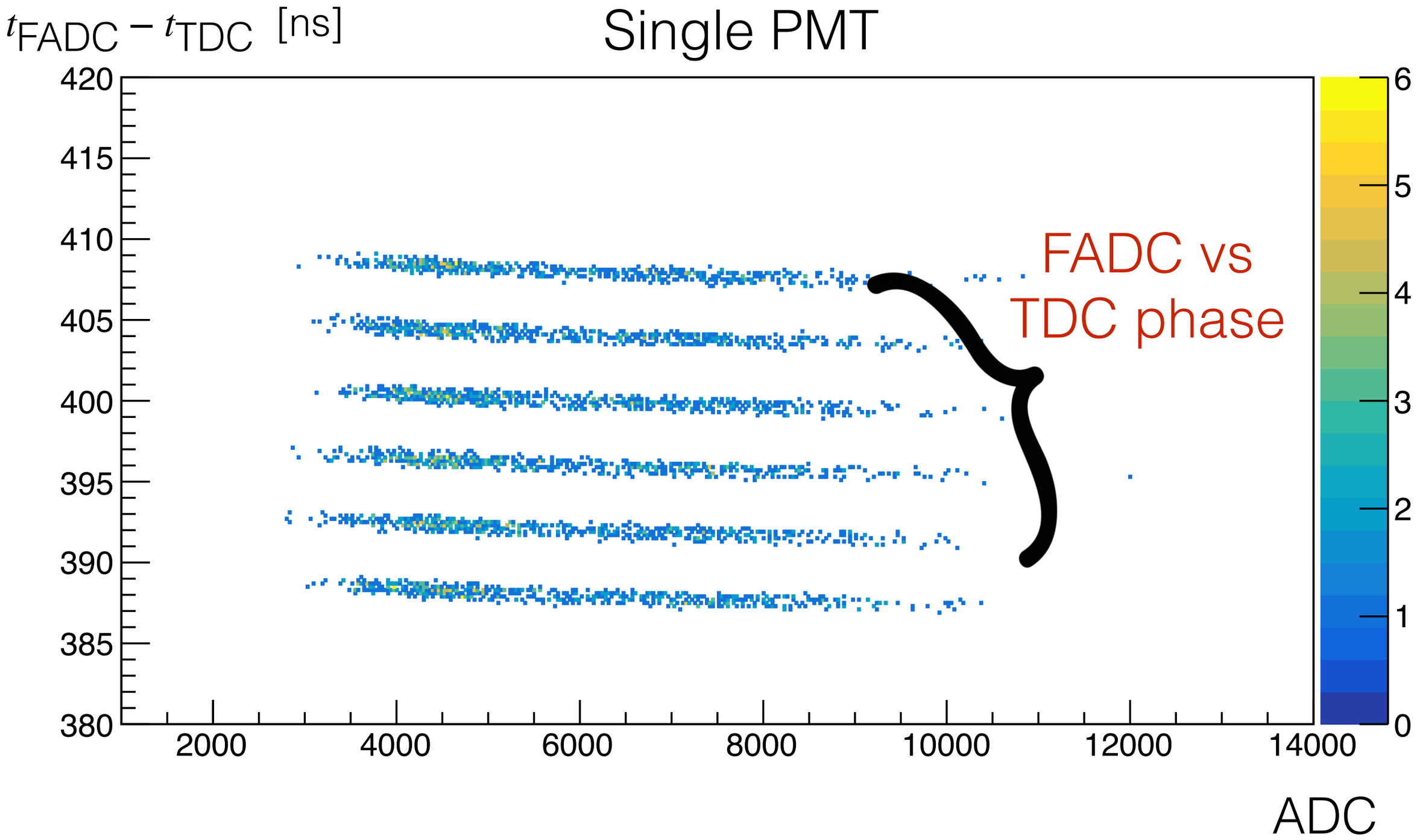
Counts



$$x' = \frac{Q^2}{2\left((m_D - E_S)\omega + \vec{p}_S \cdot \vec{q}\right)}$$

$$W'^2 = (q^\mu + p_D^\mu - p_S^\mu)^2$$

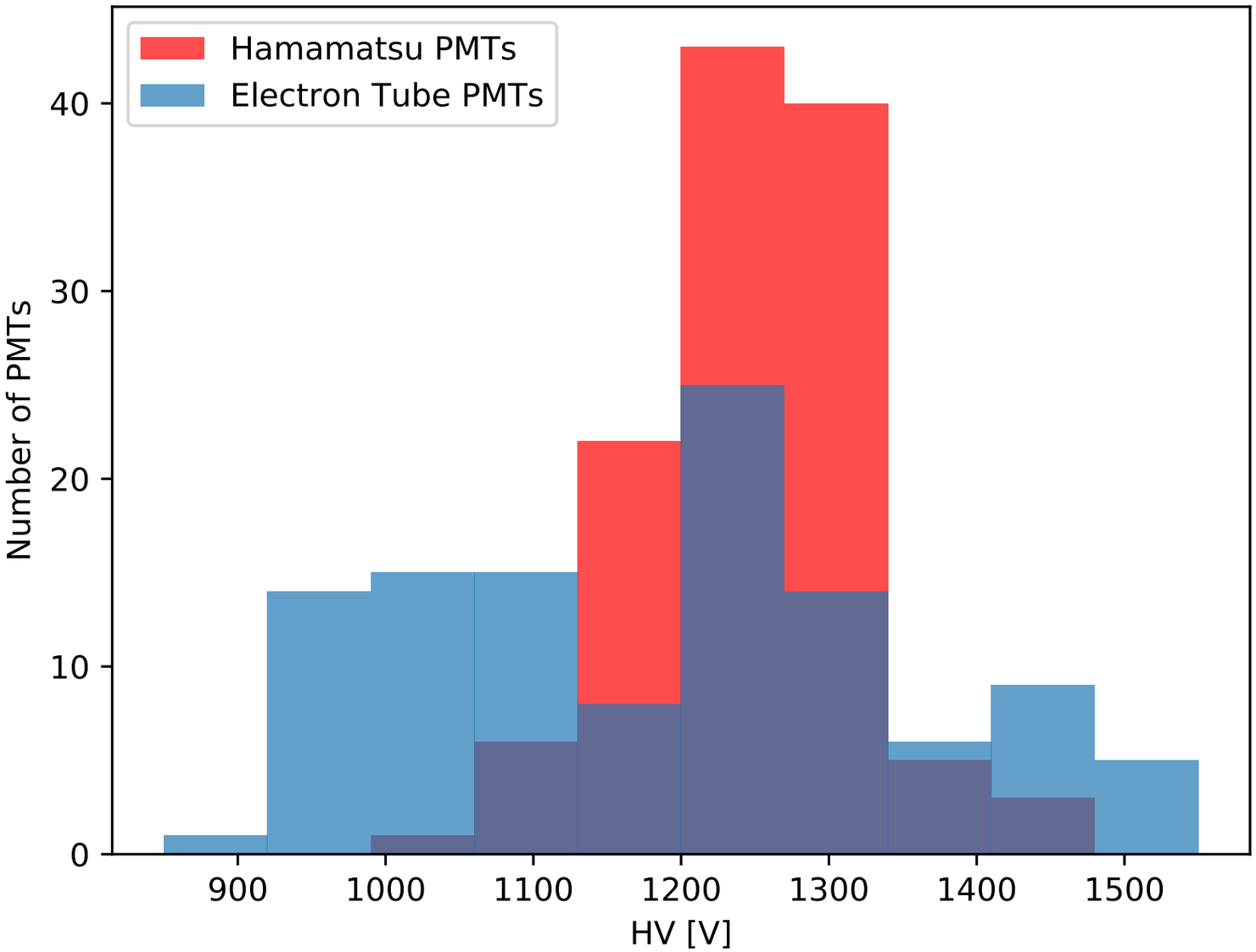
Before Phase Correction

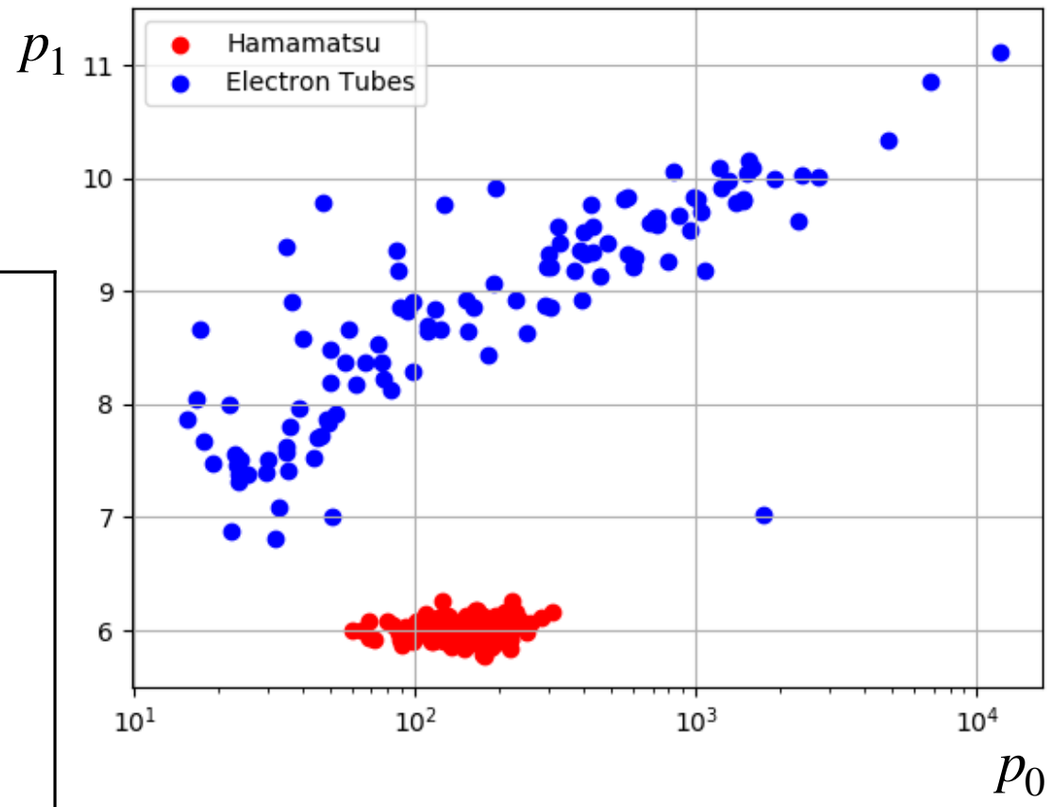


HV Settings for all PMTs

Previously seen during QC tests at MIT

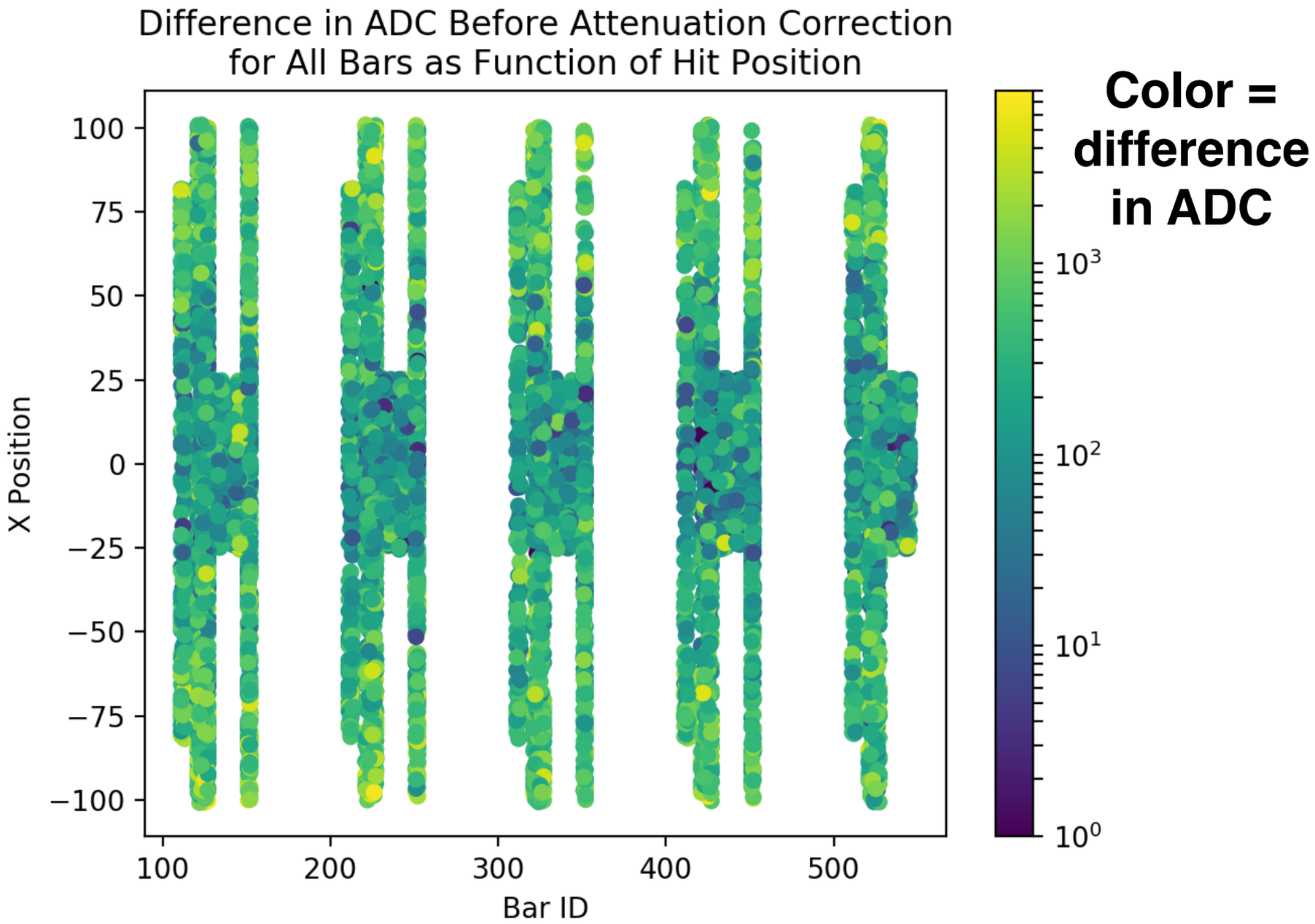
$$\mathrm{ADC} = p_o \left(\frac{\mathrm{HV}}{1500} \right)^{p_1}$$





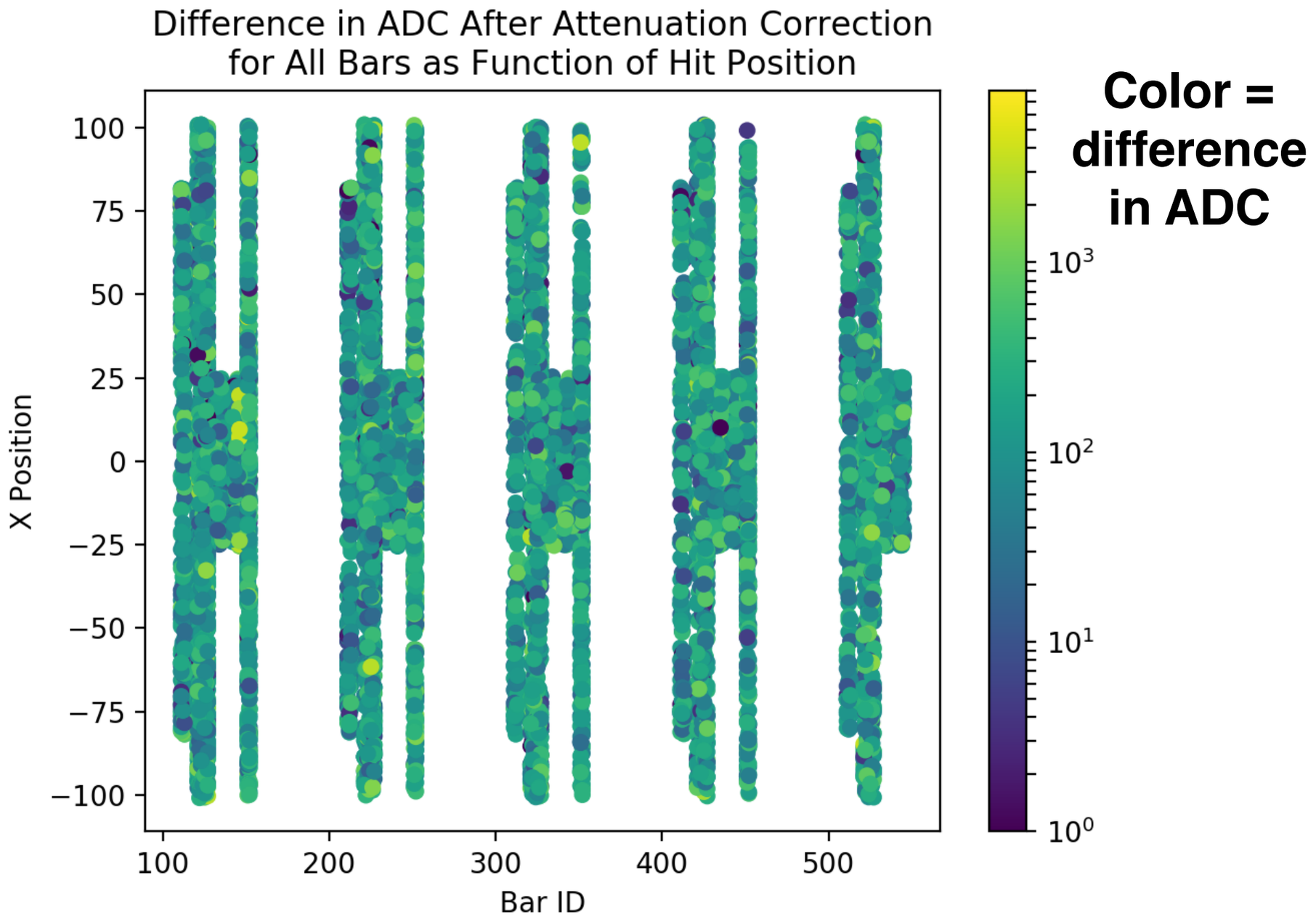
Attenuation Length Correction

PMTs measure largest difference in energy when closest to given PMT, as expected



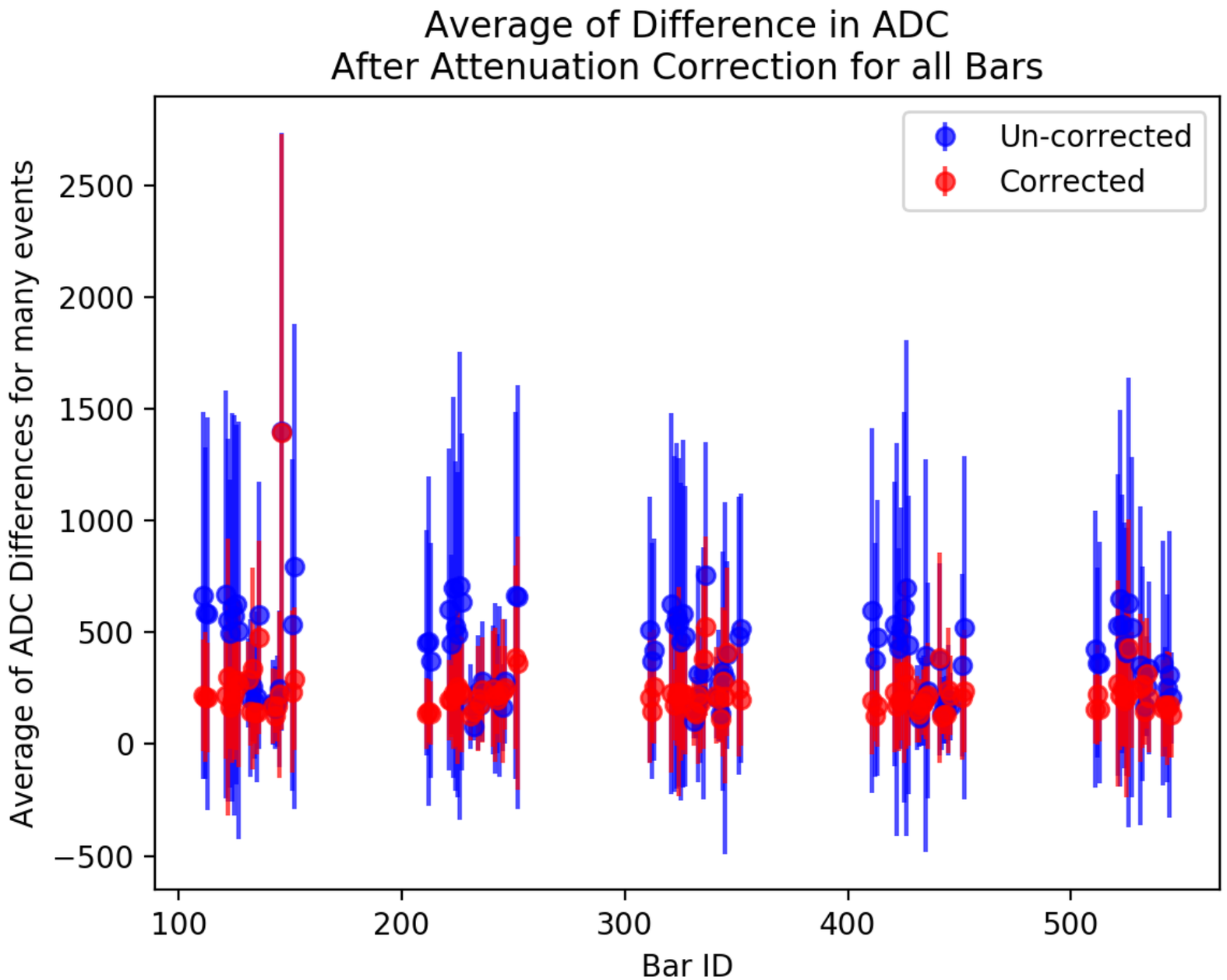
Attenuation Length Correction

More uniform, event-by-event, difference can still be large



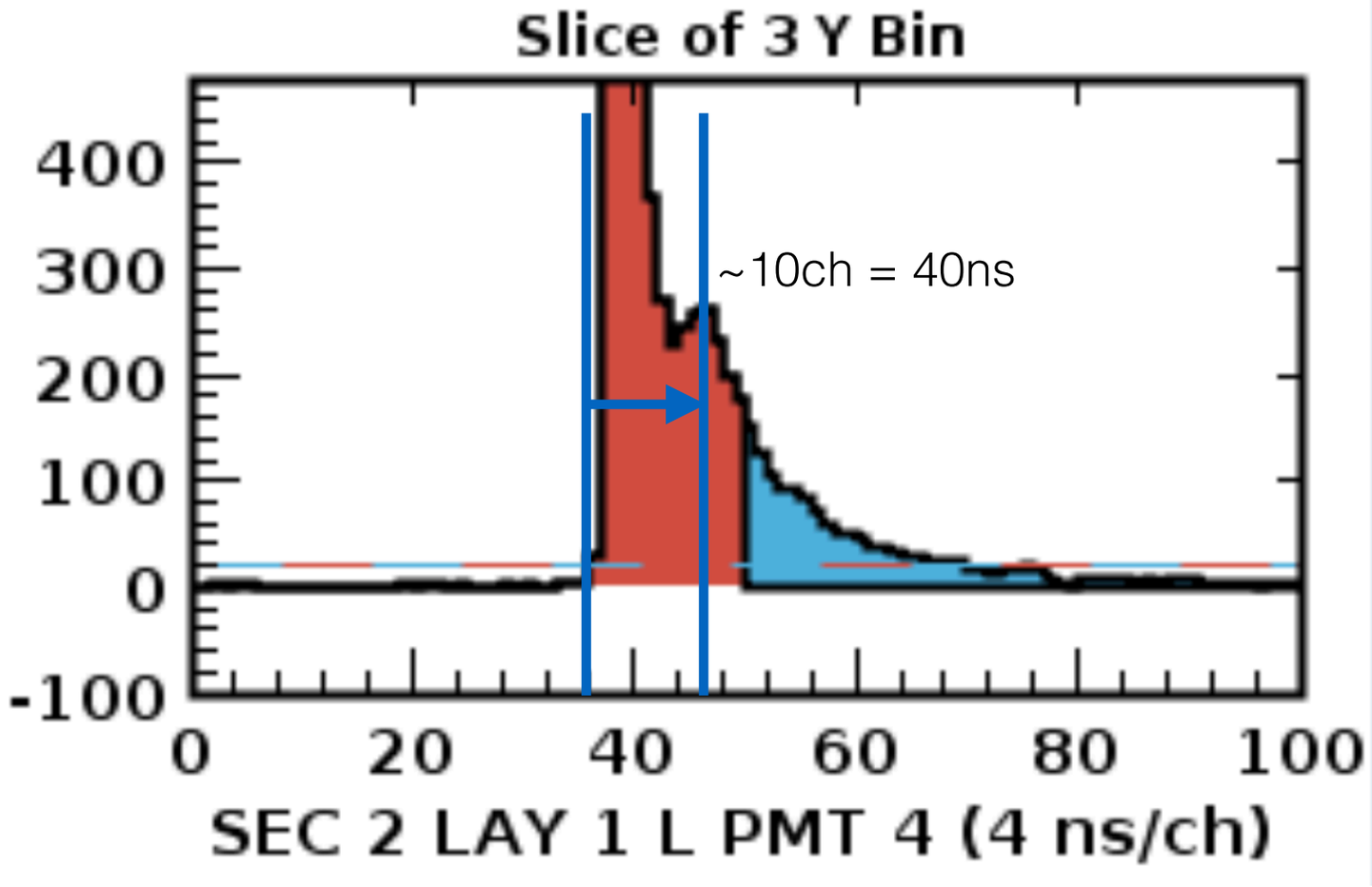
Attenuation Length Correction

Correction improved the average difference by a bit

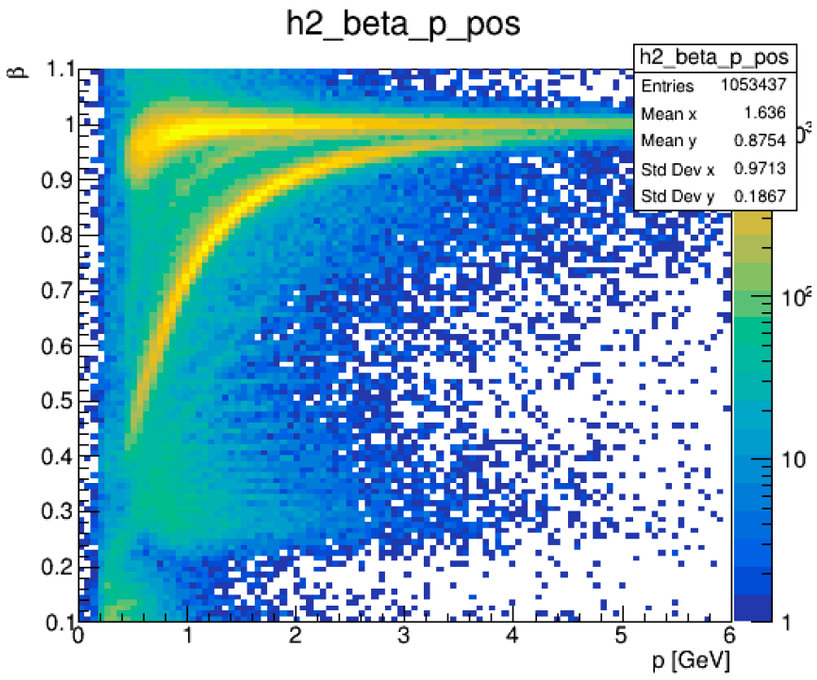


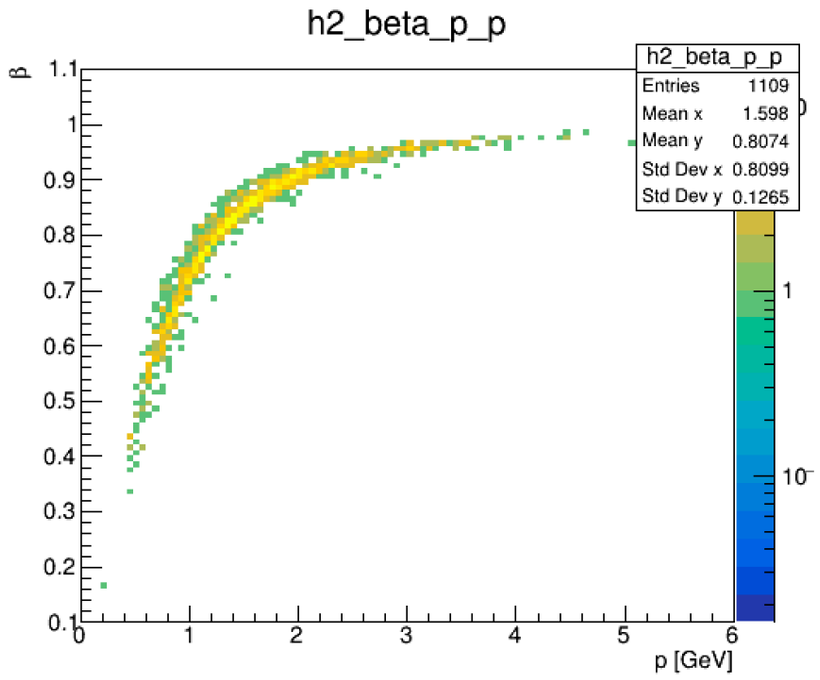
Reflections when close to LG

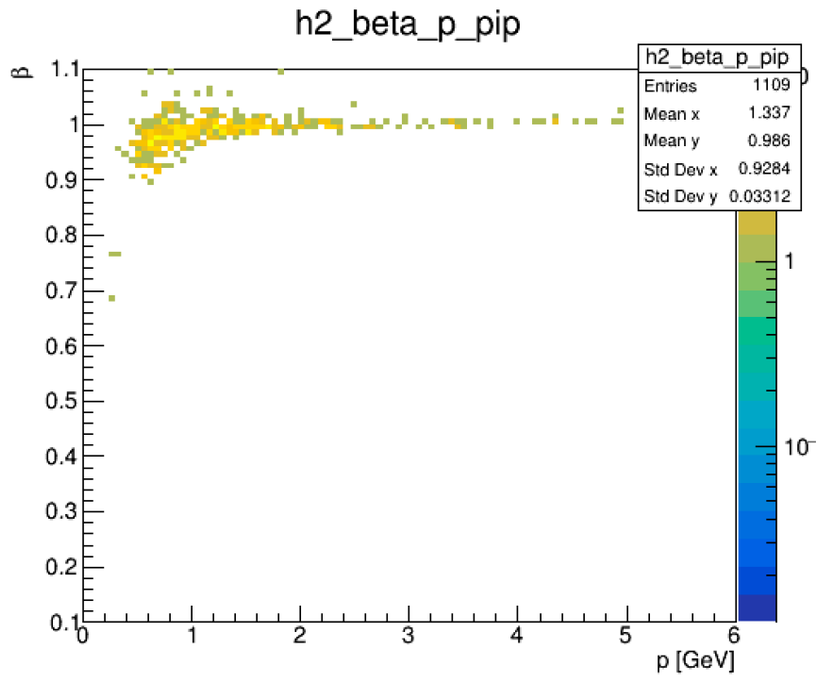
200cm long, ~14cm/ns speed of light, ~14ns for length of bar
2nd peak 40ns later —> ~3x length of bar

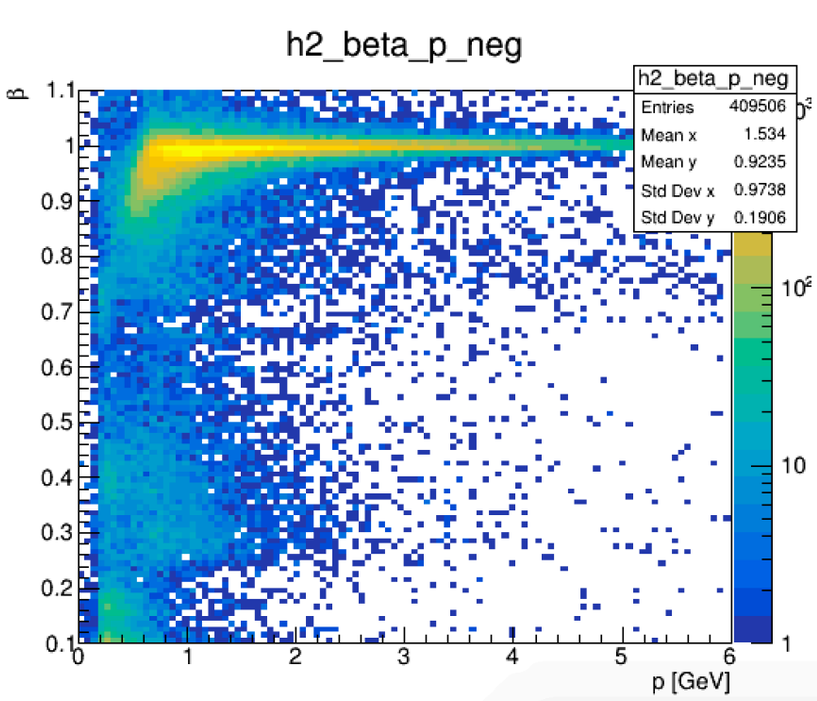


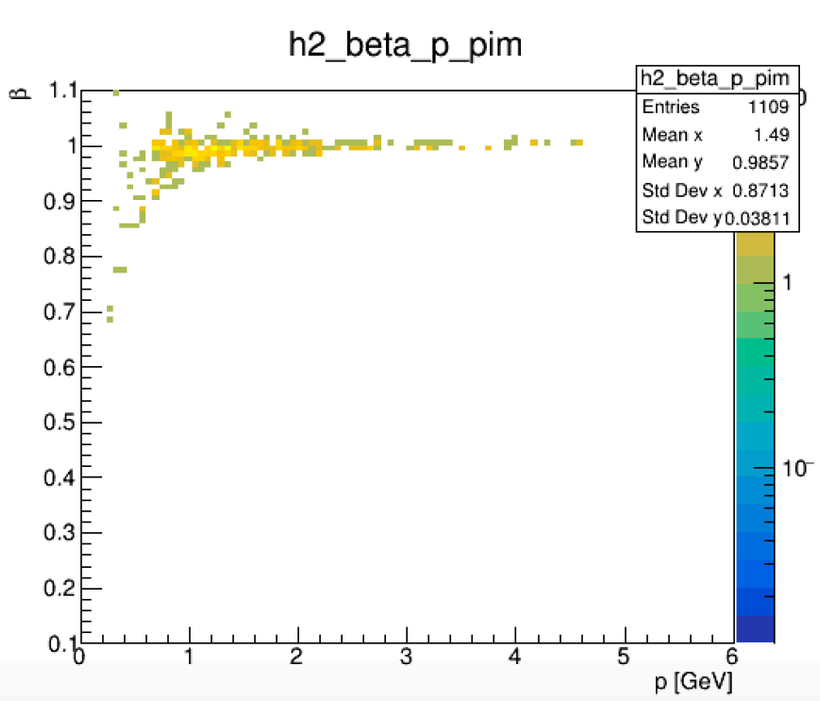
$d(e, e'p\pi^+\pi^-)n$

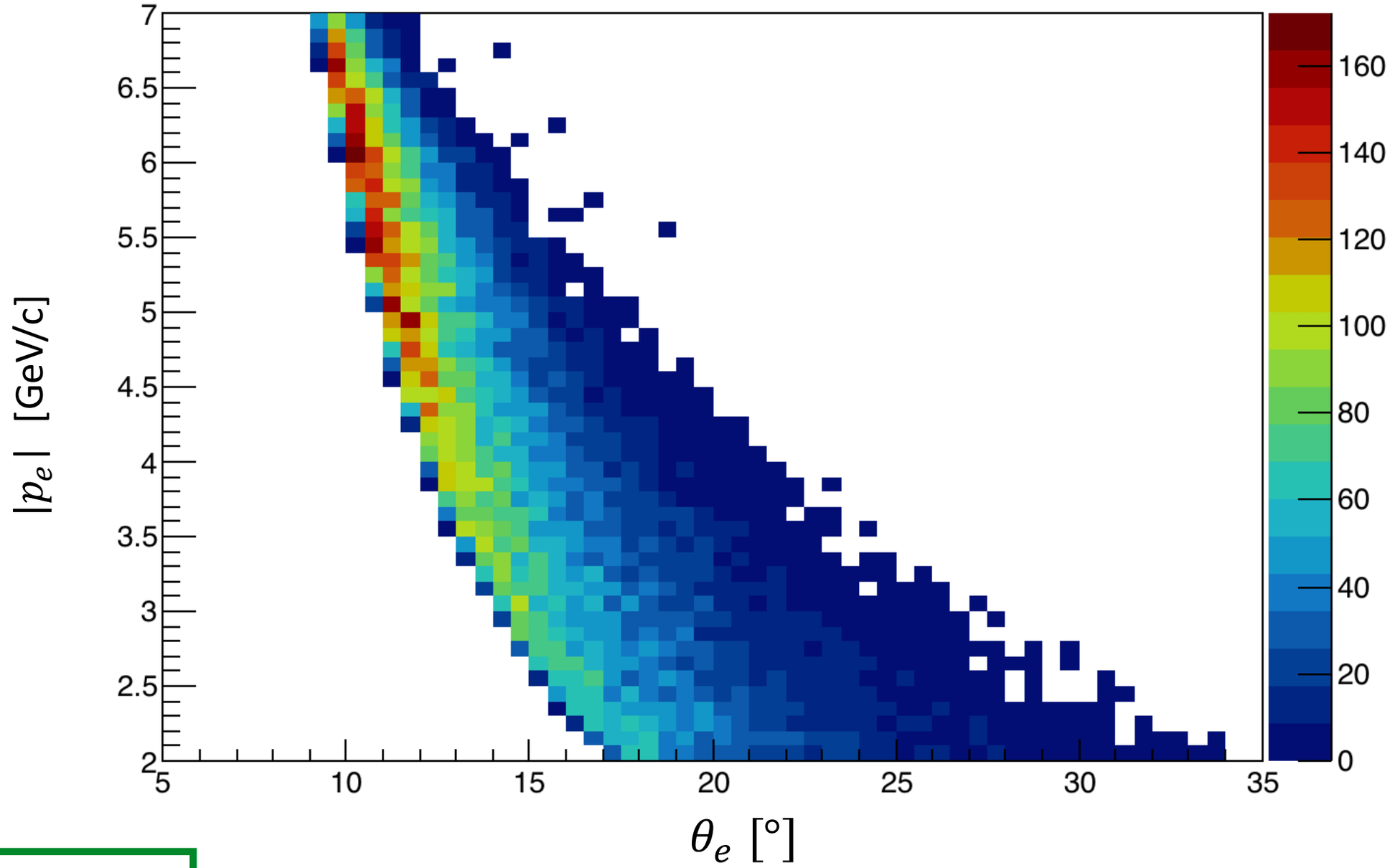

h2_beta_p_pos
h2_beta_p_pos
Entries 1053437
Mean x 1.636
Mean y 0.8754
Std Dev x 0.9713
Std Dev y 0.1867
β
p [GeV]


h2_beta_p_p
h2_beta_p_p
Entries 1109
Mean x 1.598
Mean y 0.8074
Std Dev x 0.8099
Std Dev y 0.1265
β
p [GeV]

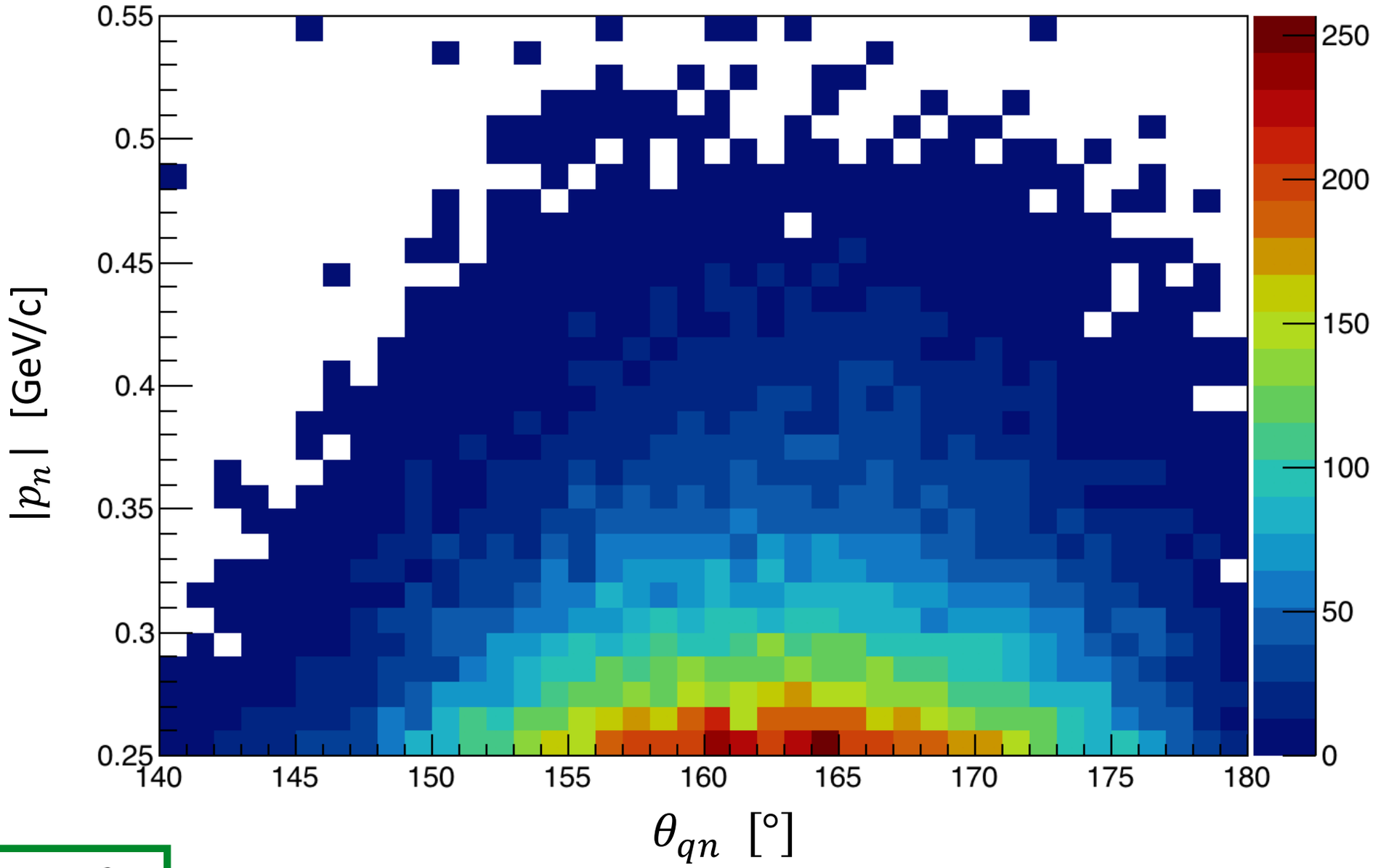

h2_beta_p_pip
h2_beta_p_pip
Entries 1109
Mean x 1.337
Mean y 0.986
Std Dev x 0.9284
Std Dev y 0.03312
β
p [GeV]


h2_beta_p_neg
h2_beta_p_neg
Entries 409506
Mean x 1.534
Mean y 0.9235
Std Dev x 0.9738
Std Dev y 0.1906
β
p [GeV]


h2_beta_p_pim
h2_beta_p_pim
Entries 1109
Mean x 1.49
Mean y 0.9857
Std Dev x 0.8713
Std Dev y 0.03811
β
p [GeV]



$Q^2 > 2$ [GeV/c]^2
$W' > 1.8$ [GeV]
$\theta_{nq} > 110°$
$|p_n| > 0.2$ [GeV/c]



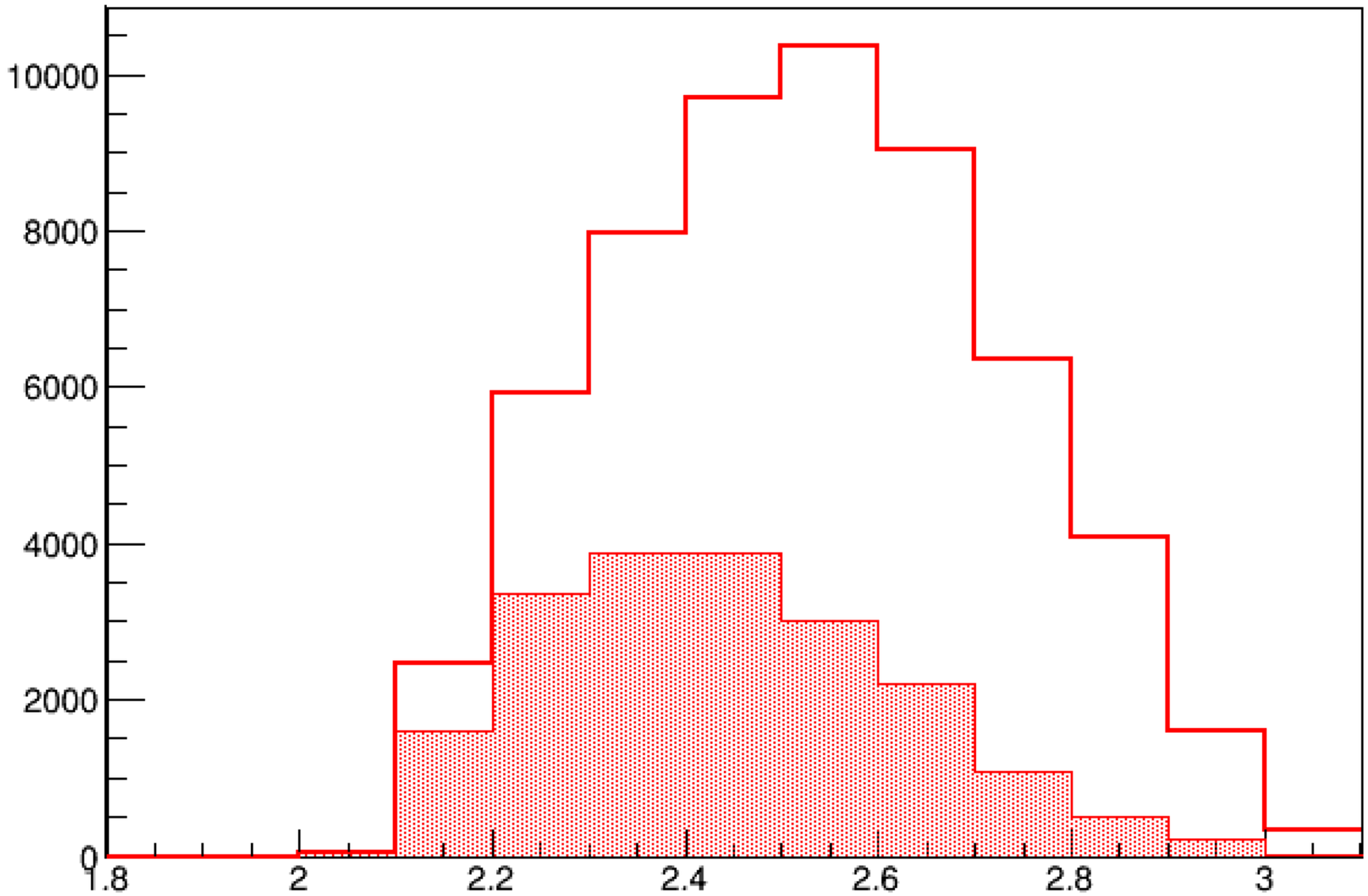
$Q^2 > 2$ [GeV/c]^2
$W' > 1.8$ [GeV]
$\theta_{nq} > 110°$
$|p_n| > 0.2$ [GeV/c]

Q^2 [GeV/c]^2

x'

$Q^2 > 2$ [GeV/c]^2
$W' > 1.8$ [GeV]
$\theta_{nq} > 110°$
$|p_n| > 0.2$ [GeV/c]

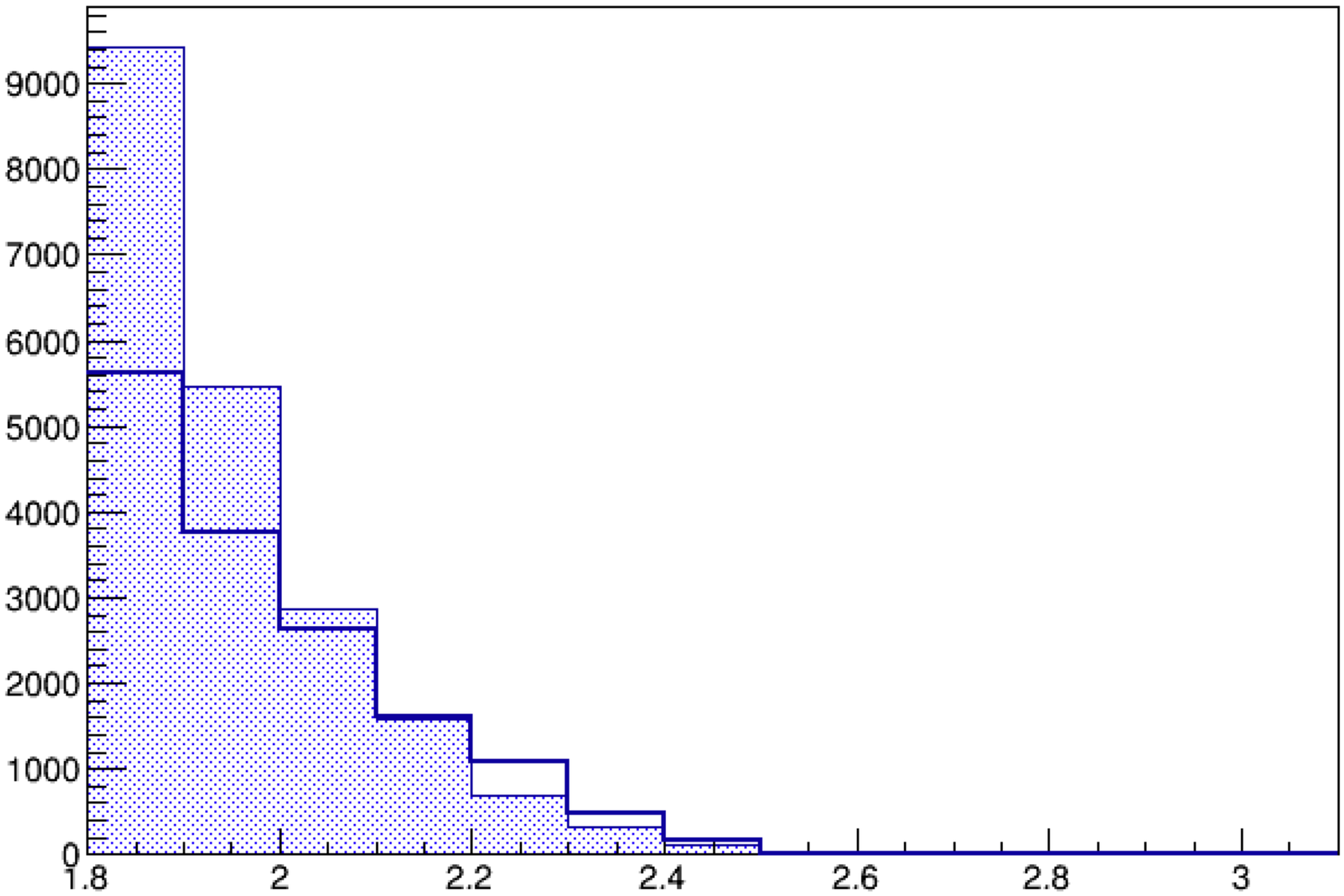
0.25 < Xp < 0.5



Shaded = background
Transparent = signal

Xp > 0.5

Counts



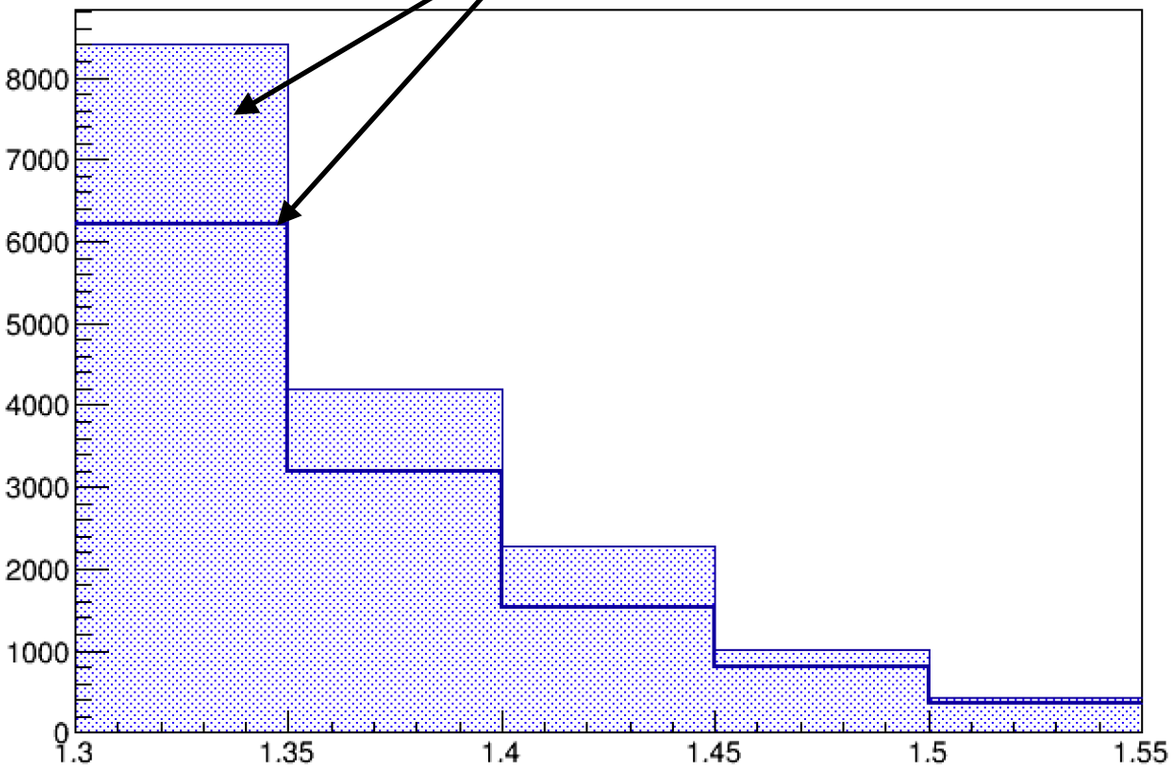
Wp

Shaded = background
Transparent = signal

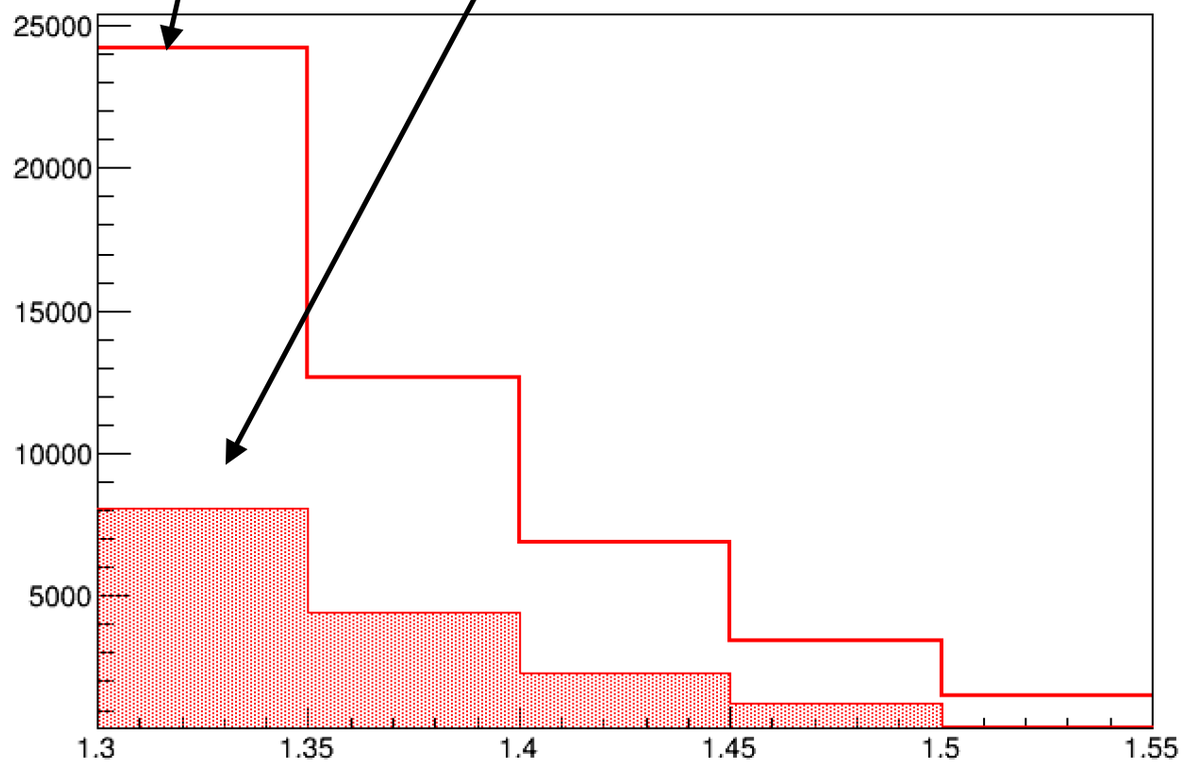
Extracting F2 Impact Plot

$$\delta(\alpha_s) = \sqrt{\frac{S_H(\alpha_s) + B_H(\alpha_s)}{S_H(\alpha_s)^2} + \frac{S_L(\alpha_s) + B_L(\alpha_s)}{S_L(\alpha_s)^2}}$$

Xp > 0.5



0.25 < Xp < 0.5



$d(e,e'p)n$

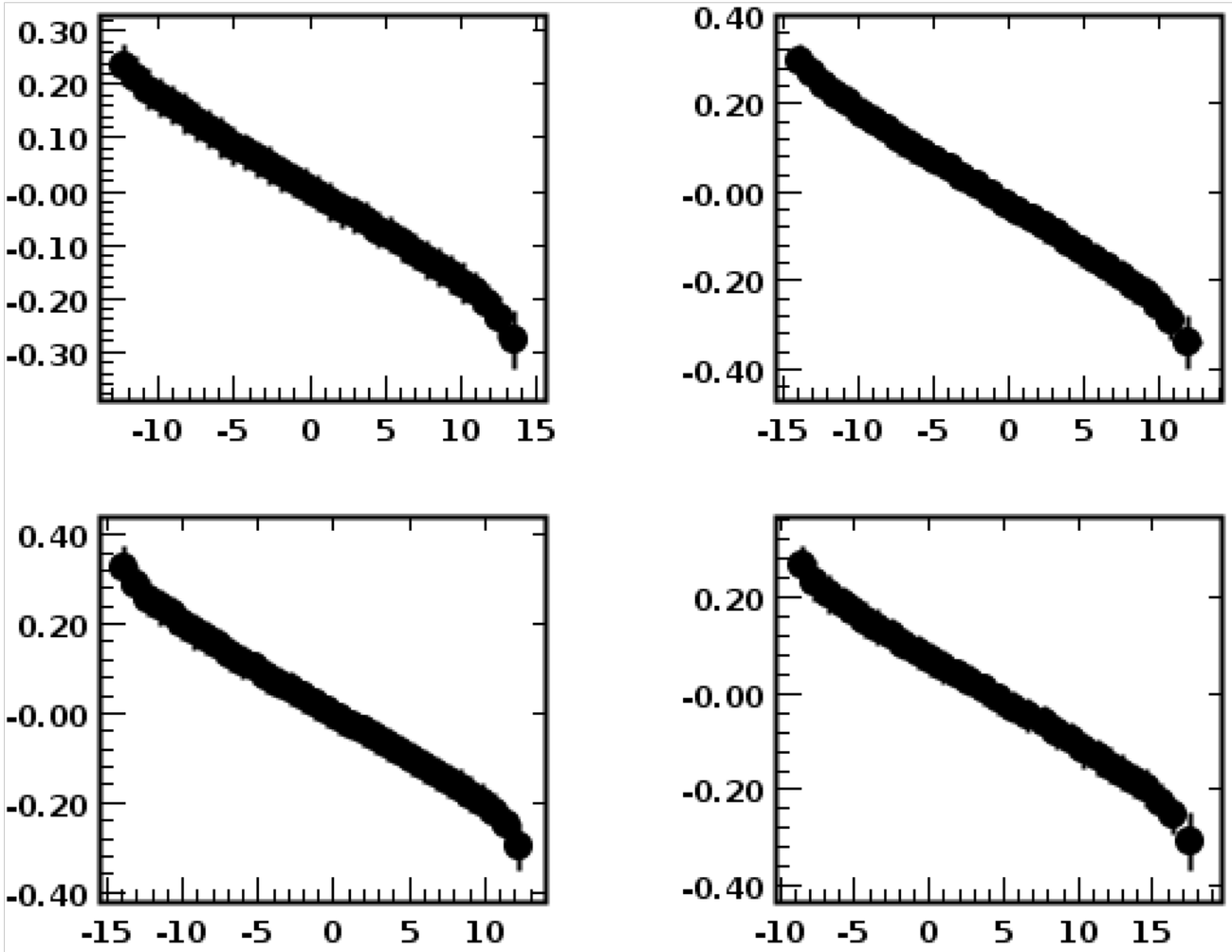
Run 6164, 300 splits, 1 hour of beam

Theta Pmiss and Mmiss peak

$d(e,e'p)n$

Extracting Attenuation Lengths

$$\ln R \equiv \ln \frac{\mathrm{ADC}_L}{\mathrm{ADC}_R}$$



$t_L - t_R$ [ns]

$$\ln R = \frac{2x}{\mu} = -v\frac{t_L - t_R}{\mu}$$

Attenuation lengths, [cm]