Discrete Readout February Testbeam Analysis First Results

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ePIC TIC Meeting

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U.S. DEPARTMENT OF **ENERGY**

Testbeam ("Discrete" part)

- Testbeam DESY Feb 17-Mar2 "Discrete readout" ("Super" version)
  - Two Scintillator trigger → **Two 16-Ch 250 MHz Caen V1725s Waveform digitizers** / core software
    Caen's provided by MIT – Milner/Hasell/Cline
  - DESY T21 TB area : 1-5 GeV electron energies
- Most data taken with 2x2 mm collimator →
  - Expect Ebeam uniformity to be better than DESY quoted RMS of ~157 MeV
  - This analysis confirms that
- Full data taken Fri/Sat ~2/21 Found that Beam energies **4,5 GeV waveforms recorded as saturated** due to baseline/pedestal setting on Caen's too high (previously set for negative pulses)
- **Slightly abbreviated second data set taken Monday 2/24 "v2ohio"**
- Data from both sets can't necessarily be mixed amongst maybe other reasons since daughter pre-amp boards (which are not individually labeled) are attached to randomly different siPM boards.
  - Possible, if preamp board does not affect calibration much
 - **THIS ANALYSIS : v2ohio SECOND data set only**

Reminder - 1 Summed siPMs Channel Per Crystal

- Same 16 3mm siPM adapter boards on Crystals As HGCROC tests

- Different "Daughter" Preamp boards swapped out

- 1 Readout Channel per crystal -> 5x5 → 25 Channels Readout by Caen digitizers

- This analysis → Full 250 MHz Sampling -- also first look at realistic EPIC sampling

➤ Each SiPM individually
➤ 400 channels
➤ 530 pF per channel

➤ SiPMs grouped by 4 in a crystal
➤ 100 channels
➤ 2120 pF per channel

➤ All 16 SiPM in a crystal read in parallel
➤ 25 channels
➤ 8480 pF per channel

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➤ 25 channels
➤ 8480 pF per channel

+ Readout with H2GCROC3b chip

+ preamp board &
CAEN V1725S 14-bit 250MS/s digitizers

Wave forms

- Second v2ohio set: ~full dynamic range 2^{14} = 16K, new baseline set at ~500, but is a rough setting and changes for each channel by +- 100's ADC U's

- ~250 pre-samples (Caen setting)

- Max 1024 samples taken (750 signal + post)

- First analysis only looked at first 512 samples.

- Signal around sample # = 230

- Other wf's appear very small % of time
  - out of time, 2x higher..

wavef:Iteration$ {ch==7}
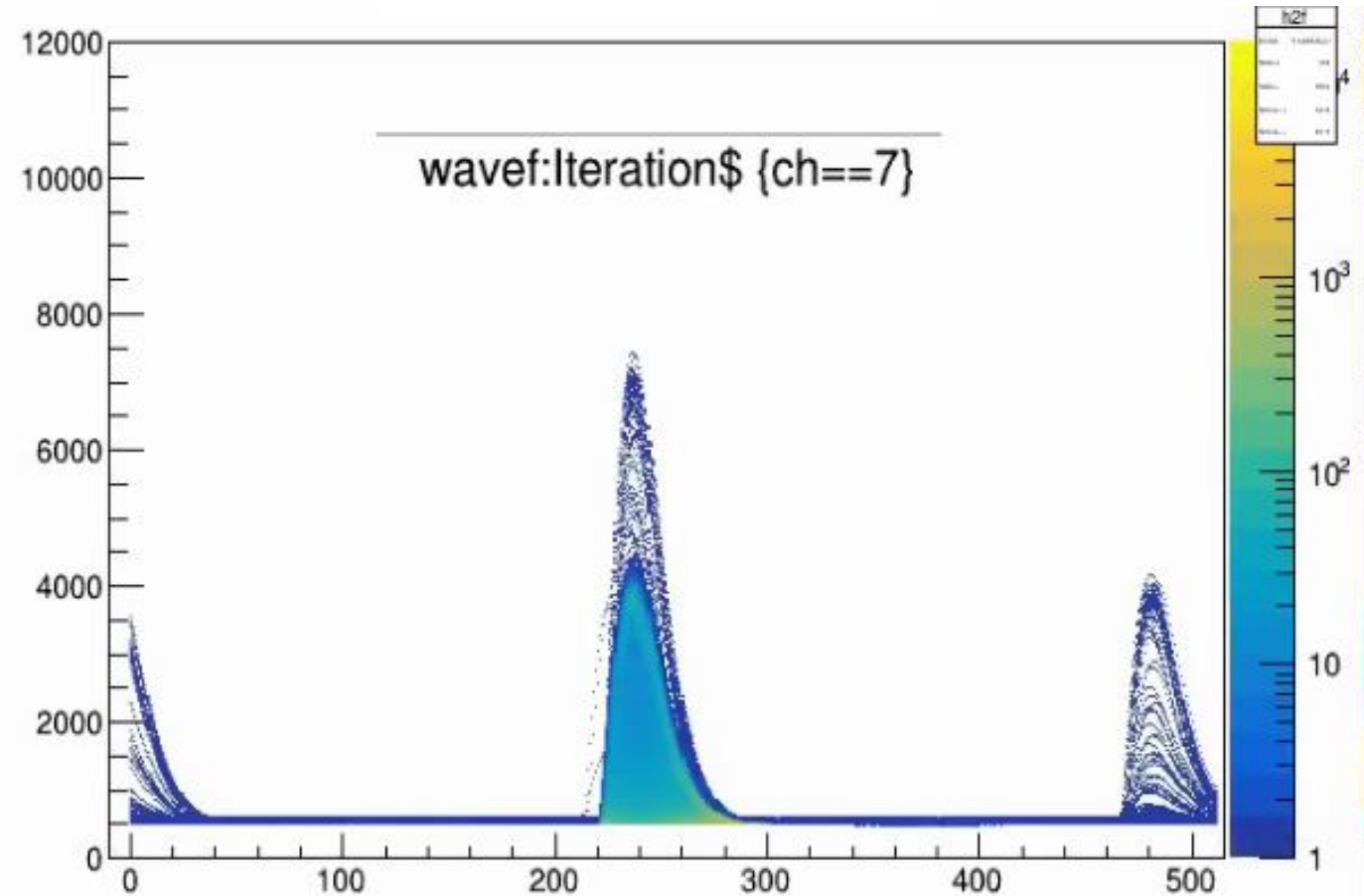
v2

All channels

- Example file from ~4 Gev center crystal "12" [13 in Orsay convention] for us this is Caen channel **7** out of 32
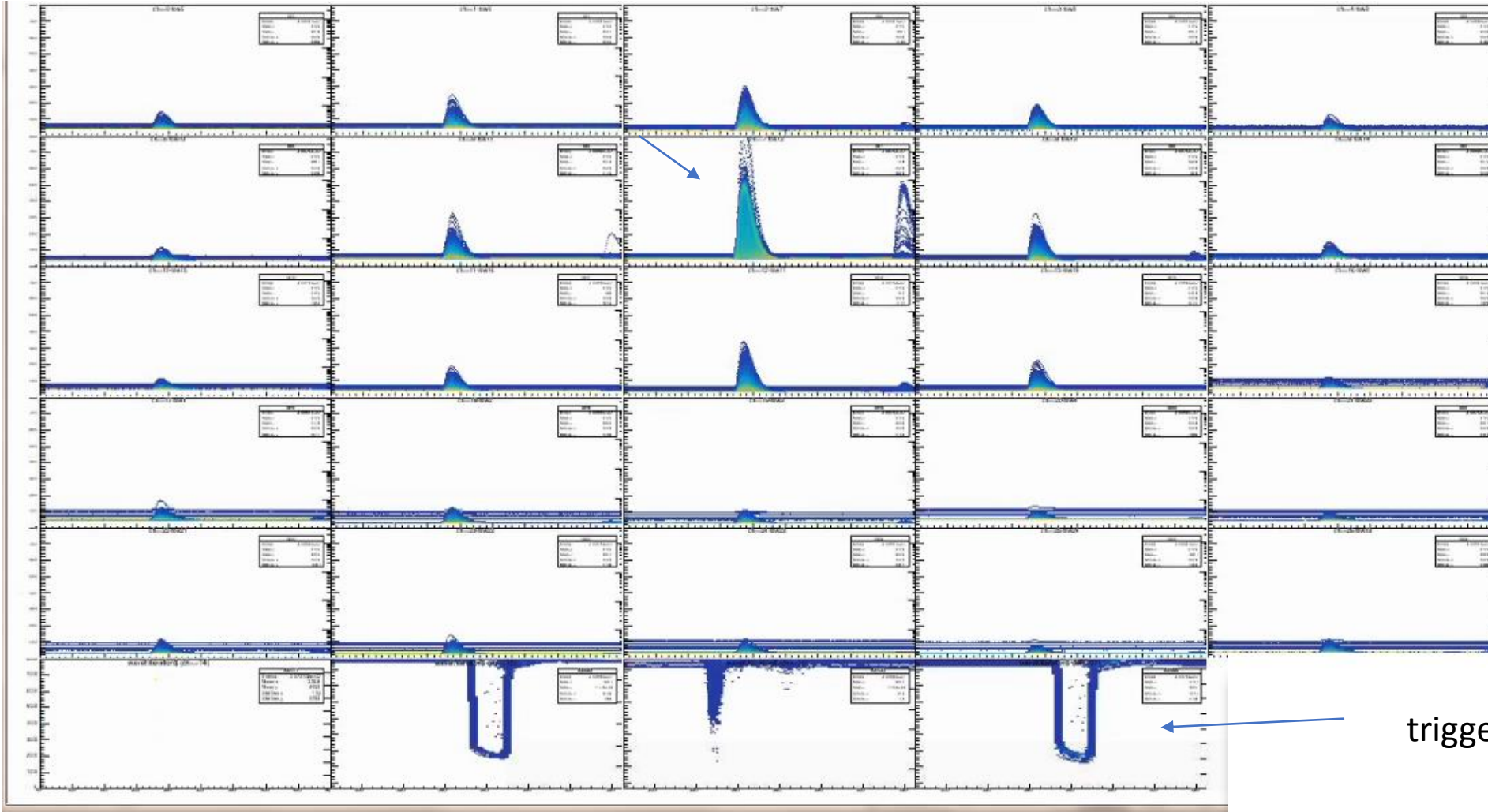
Stable in time at this zoomed out view

triggers

Layout of Daq Channels

Basic idea crystal→16-ch digi board mapping: put central core (yellow box) all on same board (b1) in case of 2-board synchronization issues

4	9	14	19	24
3	8	13	18	23
2	7	12	17	22
1	6	11	16	21
0	5	10	15	20

Note Orsay group refers to crystal locations with +1 of the above numbers on the map – (ie. lower left is 1 going up 2,…)

Originally on 2/20: those in yellow box: these 15 are on the left v1725s in increasing numerical order from top of board to bottom

crys#-bV70ch# ; crys#-bV69ch#/absCh#

5-0   0-0/16
6-1,   1-1 /17
7-2   … 4-4/20
8-3,   20 – 5/21
9-4,   21-6/22
10-5   22-7 /23
11-6   23-8 /24
12-7   24-9 /25
13-8   …
14-9   trigger logic signal:-15/31
15-10
16-11
17-12
18-13
19-14

trigger logic signal -15

the right column is crystals going into board 2 (v69) going into the boards ch # first relative to itself, then after the "/", the ch# in the software system convention which has channels going from 0-31, 0-15 b1, 16-31 b2 ie crystal 23 is is readout by ch 8 on b2 (bV69(

Starting on 2/21/25 we decided to also put copies of the analog trigger signal in both boards to allow 2-board synchronization checks.
-So we moved only crystal 19 over to board 2 (bV69) (ch10) and put both copies of analog trigger signals in ch 14
**-THIS IS CONFIG ALL DATA WAS TAKEN WITH EXCEPT TESTING THURS NIGHT**

After (2/21/2025-?)
5-0   0-0 /16
6-1,   1-1 /17
7-2   … 4-4/20
8-3,   20 – 5/21
9-4,   21-6/22
10-5   22-7 /23
11-6   23-8/24
12-7   24-9/25
13-8   19-10/26
14-9
15-10   trigger analog signal:-15/31
16-11   trigger logic signal:-15/31
17-12
18-13
trigger analog signal -14
trigger logic signal -15

Waveforms ➔ Amplitude

- **For first analysis use full 250 MHz Sampling & all ~512 Samples!**
  - Eventually, will artificially reduce sampling with this data to more realistic ePIC estimate

- Several schemes tried for amplitude extraction, not much variation with any scheme

- Current results using wf by wf pedestal subtraction and:
  - 1) Finding max sample in pulse region (220-~300)
  - 2) Integrating wf pulse region (~200,300)
  - **Both methods ~consistent – expect to need 2) integration or wf fitting in real ePIC situation**

All waveforms from one data run

wavef:Iteration$ {ch==7}
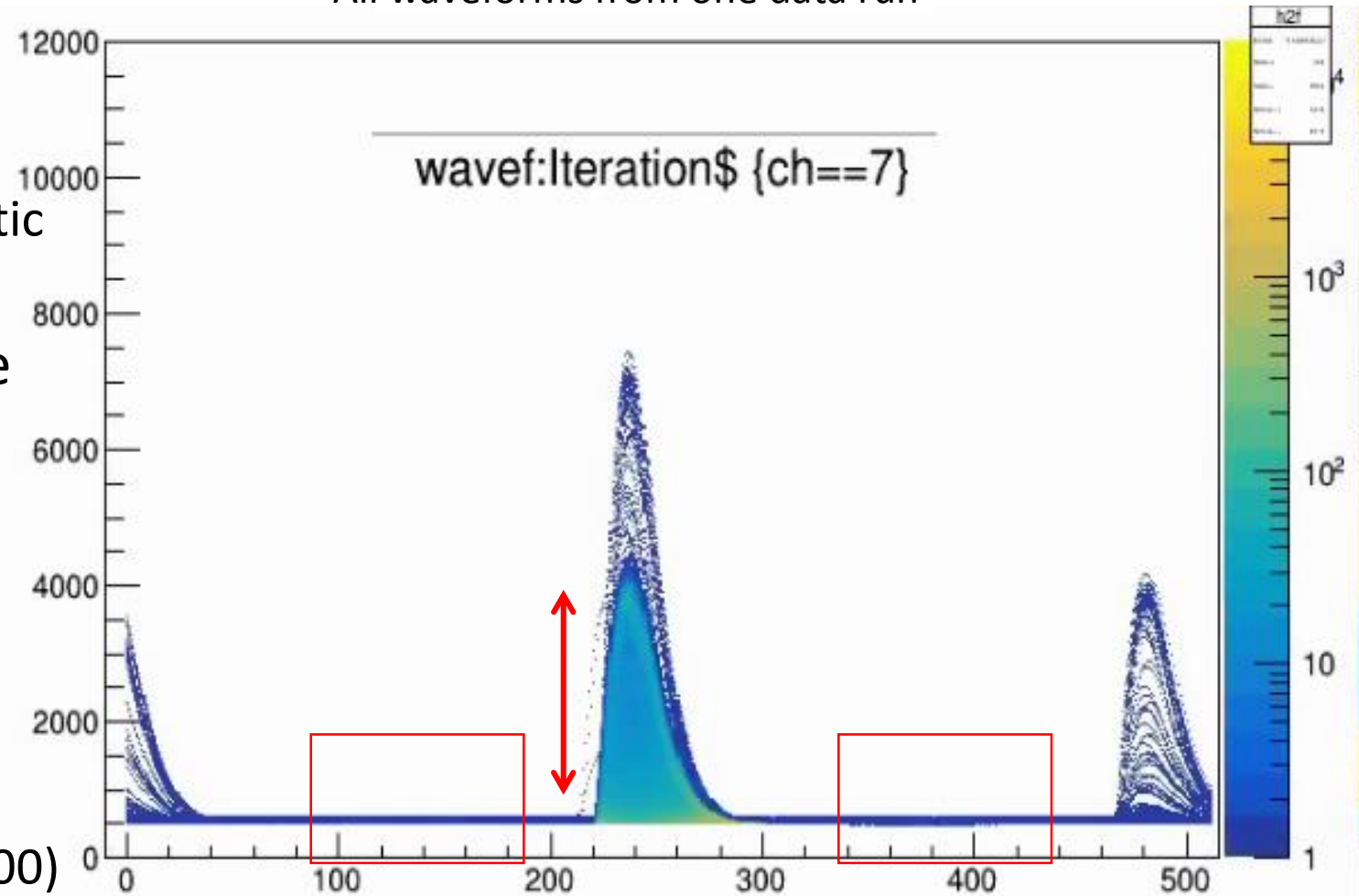
pedestal value from 80 samples before and after pulse region (160 samples total)

Amplitude Distributions from Each Channel

- Extracted distributions for:
- Center Crystal Single Channel (7-Tow 12)
- Sum of 3x3 Around/Incl Center
- Sum of Full 5x5

- Caen's send up each channel independently
- Sums required new **syncing code**

 sync'd "event"/trigger—

-- makes groups of syncd32 channels

- **Ch by Ch Flattening Calibration from Tower by Tow Beam Scans**

Ebeam = 3 GeV

hch	
Entries	221925
Mean x	13.38
Mean y	131.2
Std Dev x	8.081
Std Dev y	510.5

wf Amplitudes

Channel #
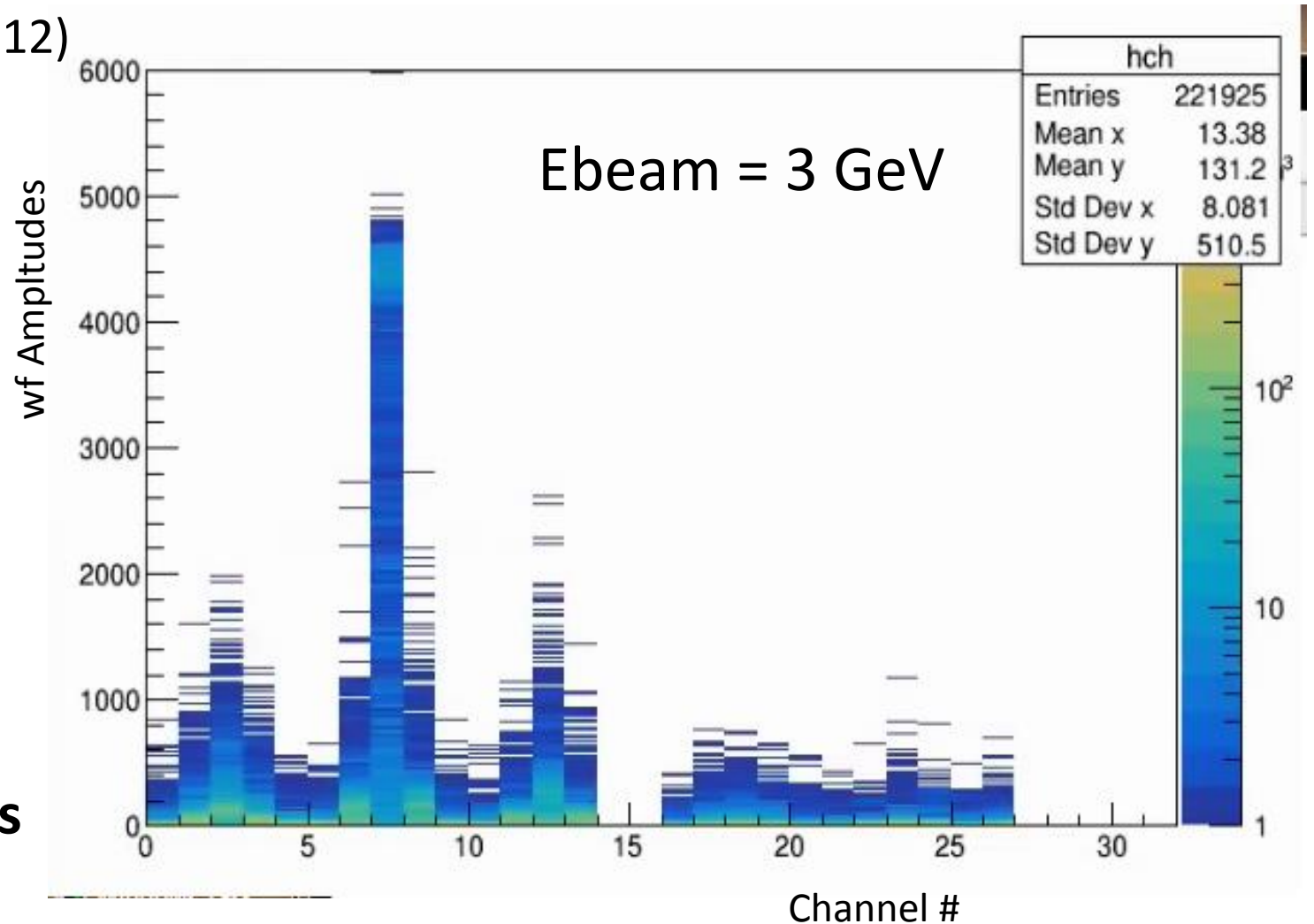
5x5 Sum Distributions -> Peak + Background

Wf max for amplitudes

Ebeam= 1 GeV

Ebeam= 2 GeV

Ebeam= 5 GeV

7200 ADCU
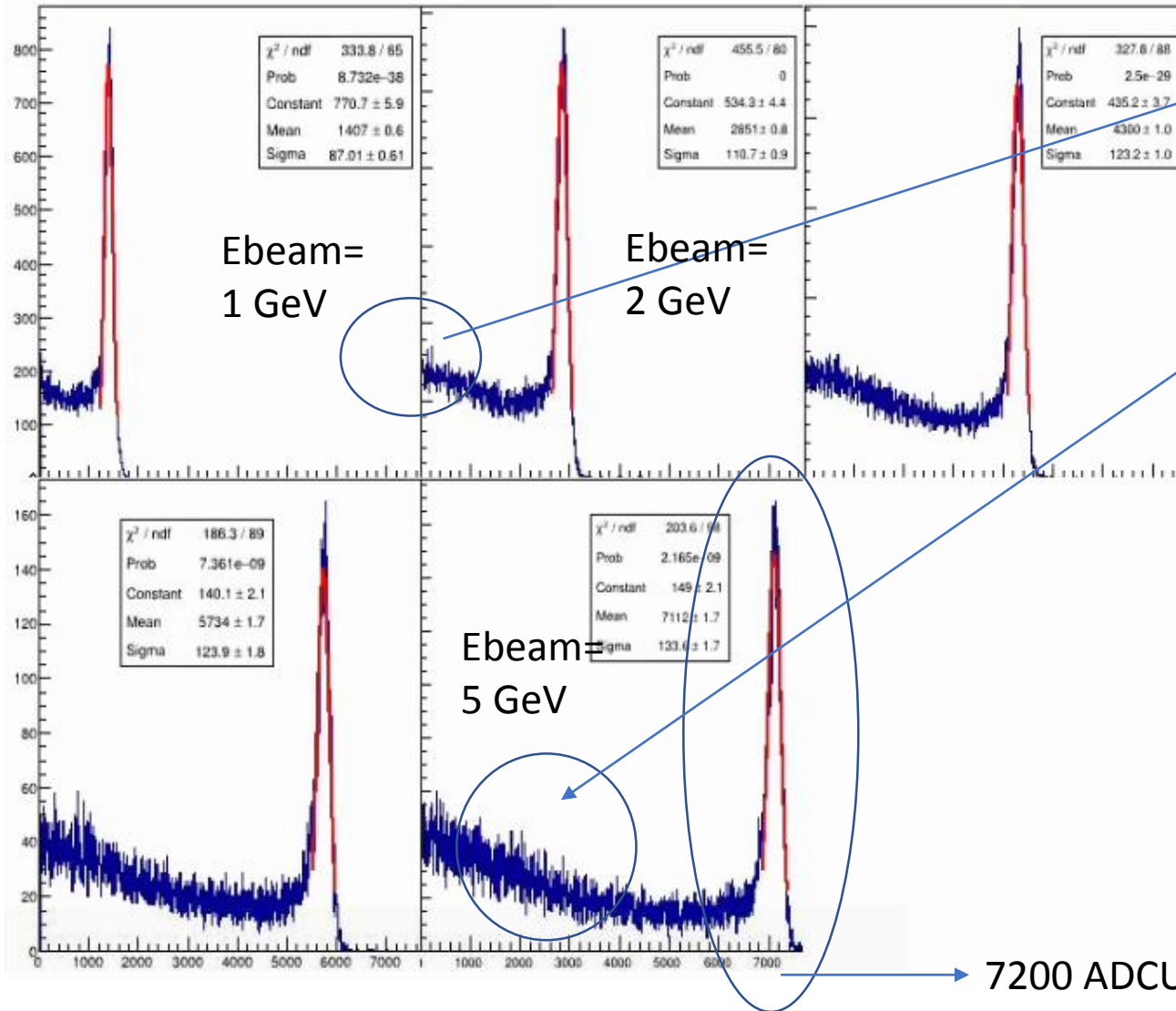
- Residual pedestal after w/ waveform by wf pedestal @ ~150 subtracted, distr is shifted
- Initial Calibration taken from peaks as shown
- **Falling Background** approaching peak: Mysterious - Studied and Subtracted
  - Not sure of source – under investigation
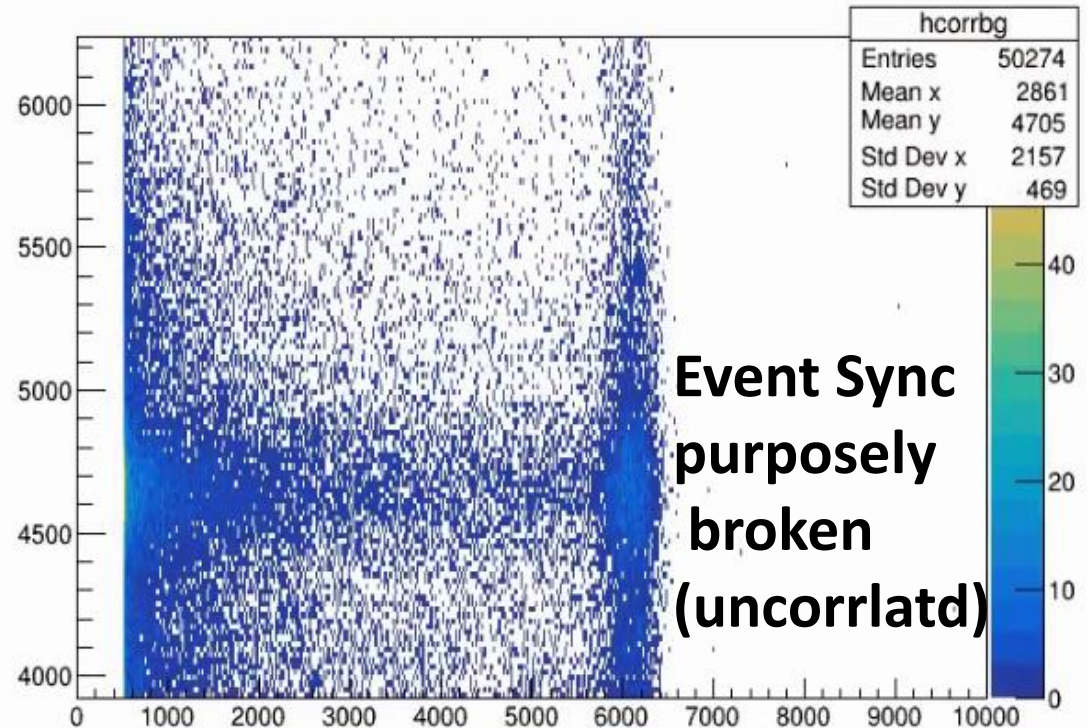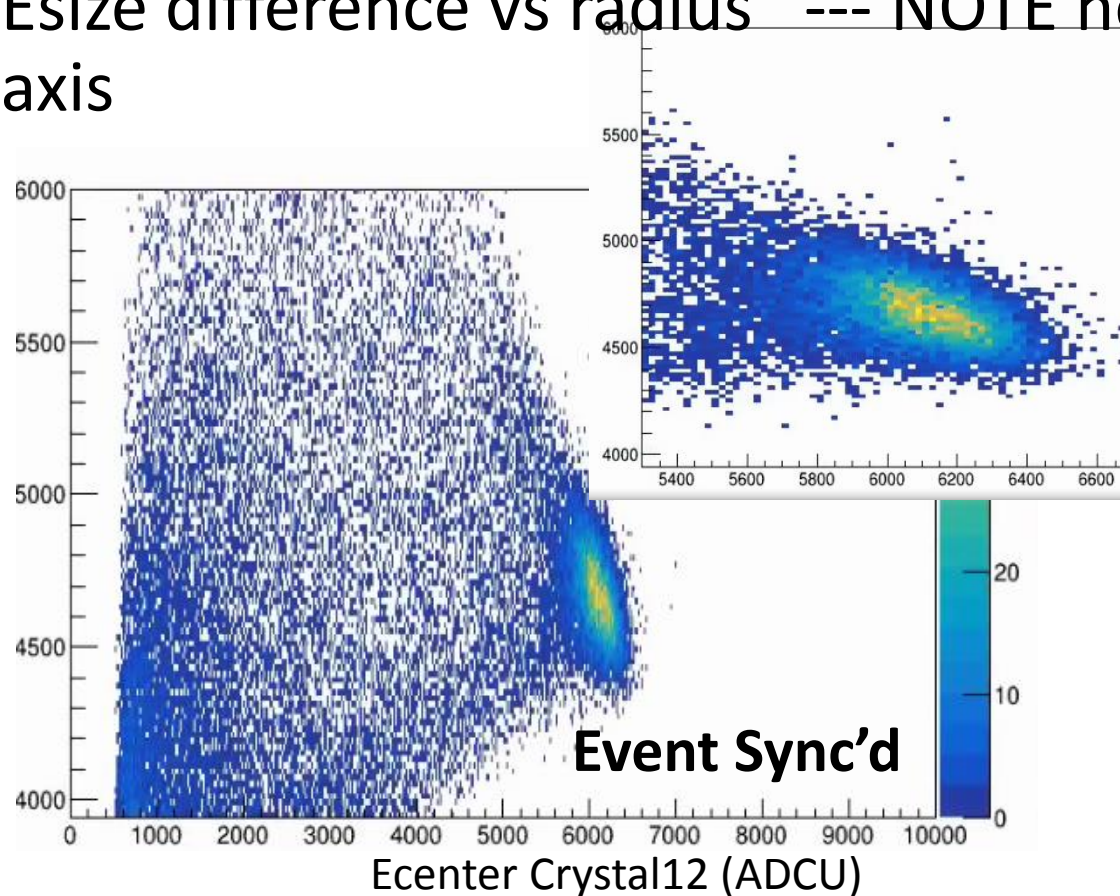 - Looks like low energy real EM showering particles, from 0 to Ebeam

736 adcu/GeV

Ebeam (GeV)
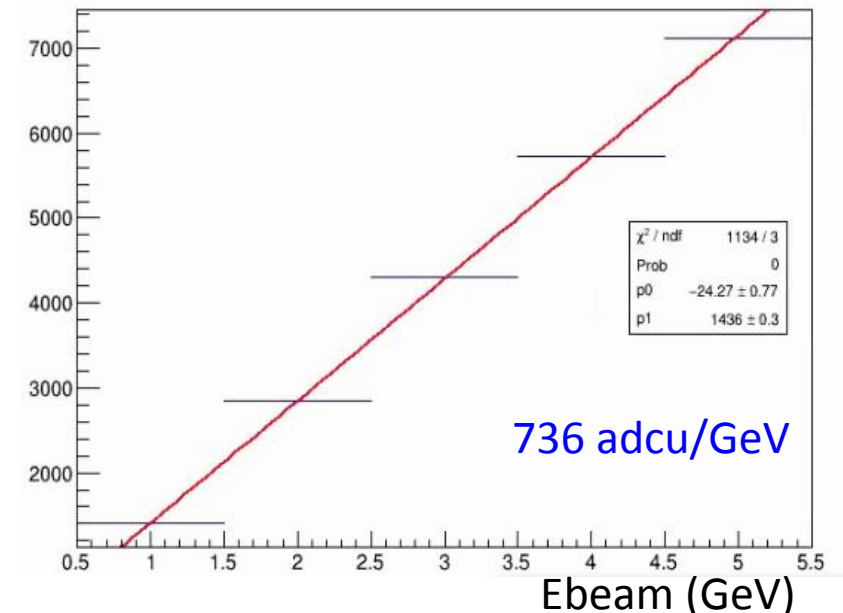
Correlations: Center Crystal E vs Rings Energy

Beam 5 GeV

- Mostly to test event syncing, looked at correlations:

- Here: **E center crystal vs bordering 8 towers Esum in next ring outside it**

- Nice peak anti-correlation as expected – mean show rough comparison of Esize difference vs radius   --- NOTE no pedestal sub here, large peds in both axis
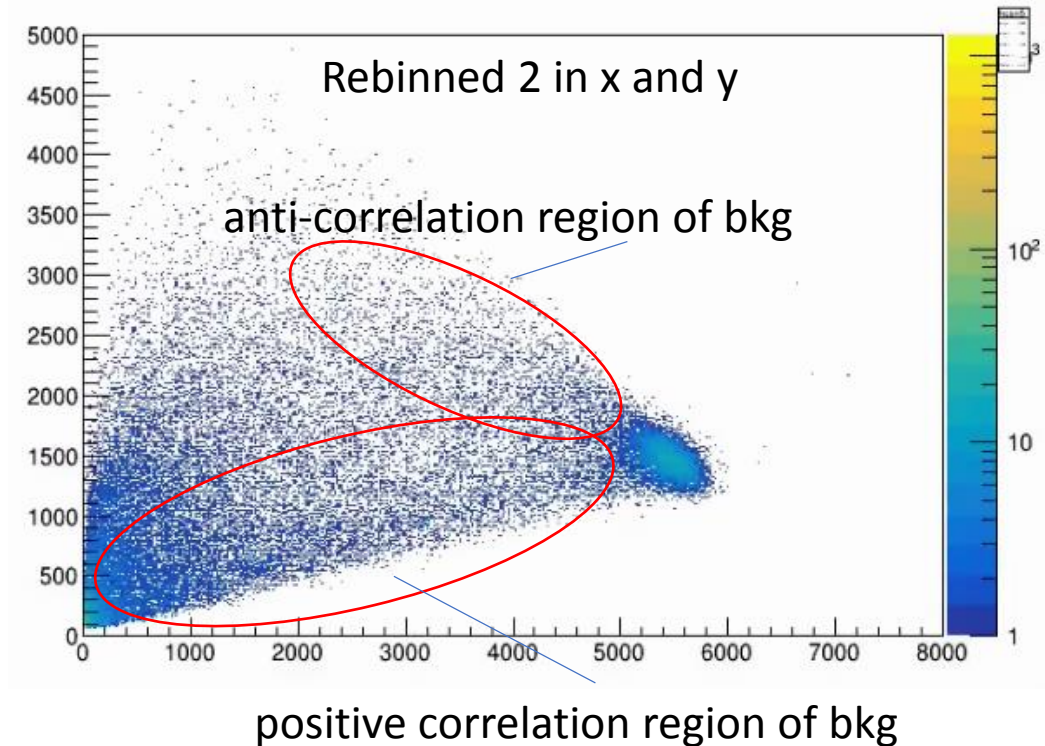

E-8 tow ring around (ADCU)

Ecenter Crystal12 (ADCU)

Event Sync'd

Event Sync purposely broken (uncorrlatd)

hcorr	
Entries	50274
Mean x	6019
Mean y	4684
Std Dev x	242.9

hcorrbg	
Entries	50274
Mean x	2861
Mean y	4705
Std Dev x	2157
Std Dev y	469

Mysterious Falling Bkg → Ecenter vs E_8$_{outer3x3}$

- Single crystal amplitude distribution is projection onto the x-axis of that correlation plot
- The correlations are in the areas of the mysterious bkg btw peak and 0 (adc = 0 is the "electronics" noise region)
- **Correlations in shower shape indicate these are real showers, real physics background**


Broad Background

Beam 5 GeV

E-8 tow ring around (ADCU)

Ecenter Crystal12 (ADCU)

true noise region

Rebinned 2 in x and y

anti-correlation region of bkg

positive correlation region of bkg
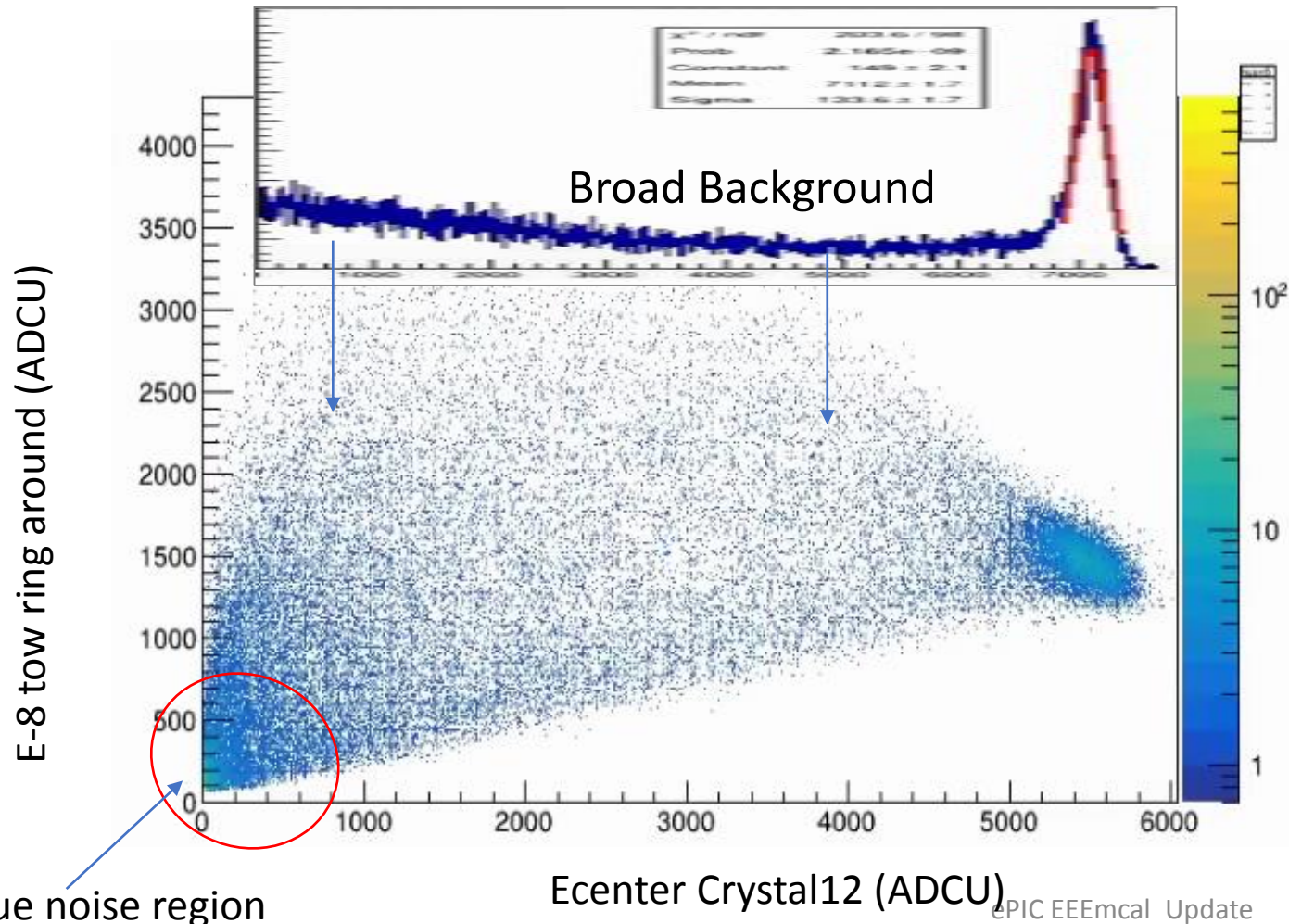
Pedestal Subtracted Ecenter vs E_8 _{outer3x3}

- **Correlation of E center crystal vs bordering 8 towers Esum in next ring outside it**

- Average Center Crystal E 5400 adcu vs 1500 in 8 tower ring just outside it
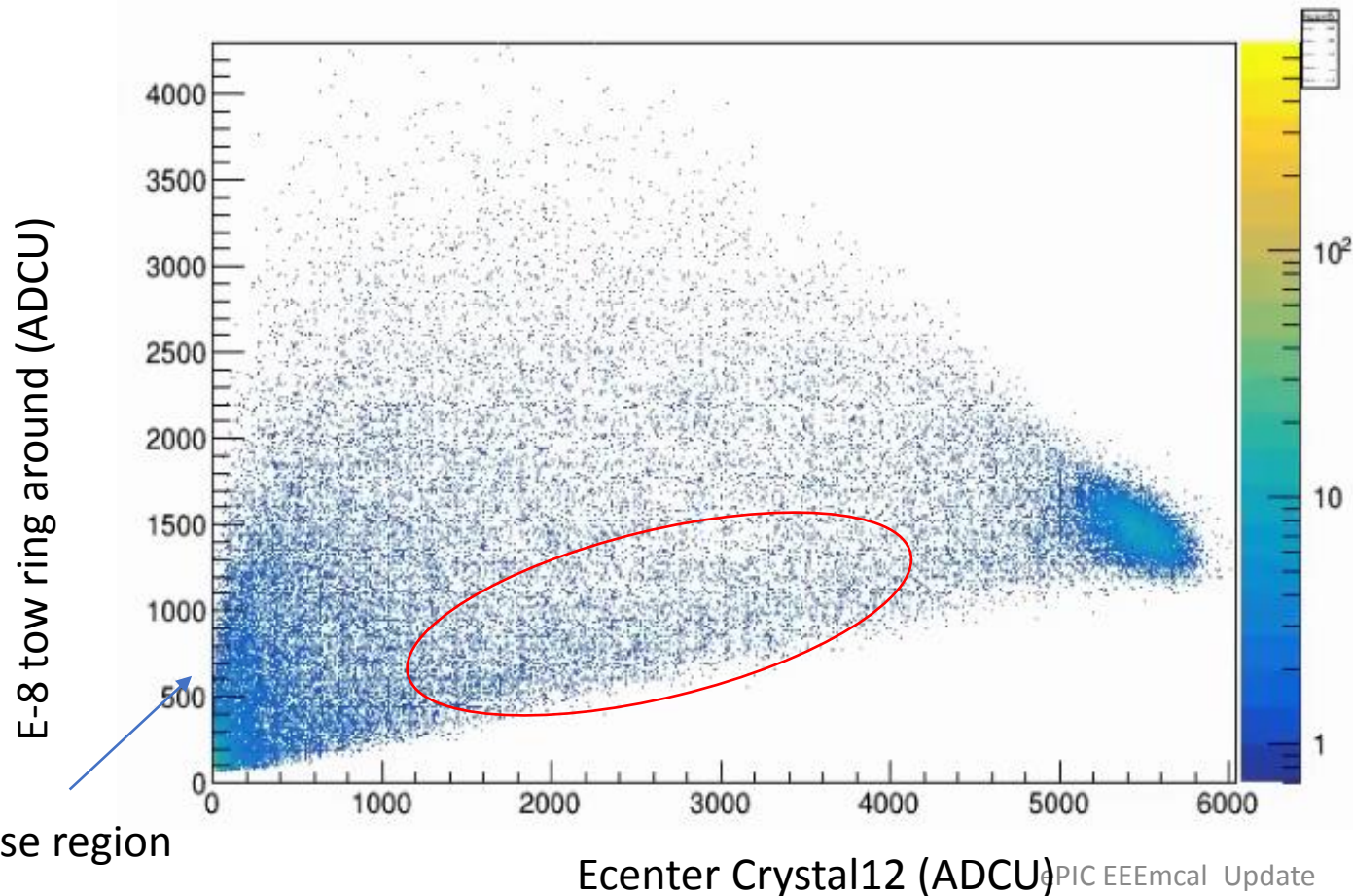
Beam 5 GeV

Correlations are present in some areas—these are a sign that this is real physics

Pedestal Subtracted Ecenter vs E_8_{outer3x3}

- Now w/ for Beam 2 GeV
- Beam 2 GeV Average Center Crystal E (in peak) 2700 adcu vs 200 in 8 tower ring just outside it (both ring and center mean vals move to lower values w/ Ebeam)
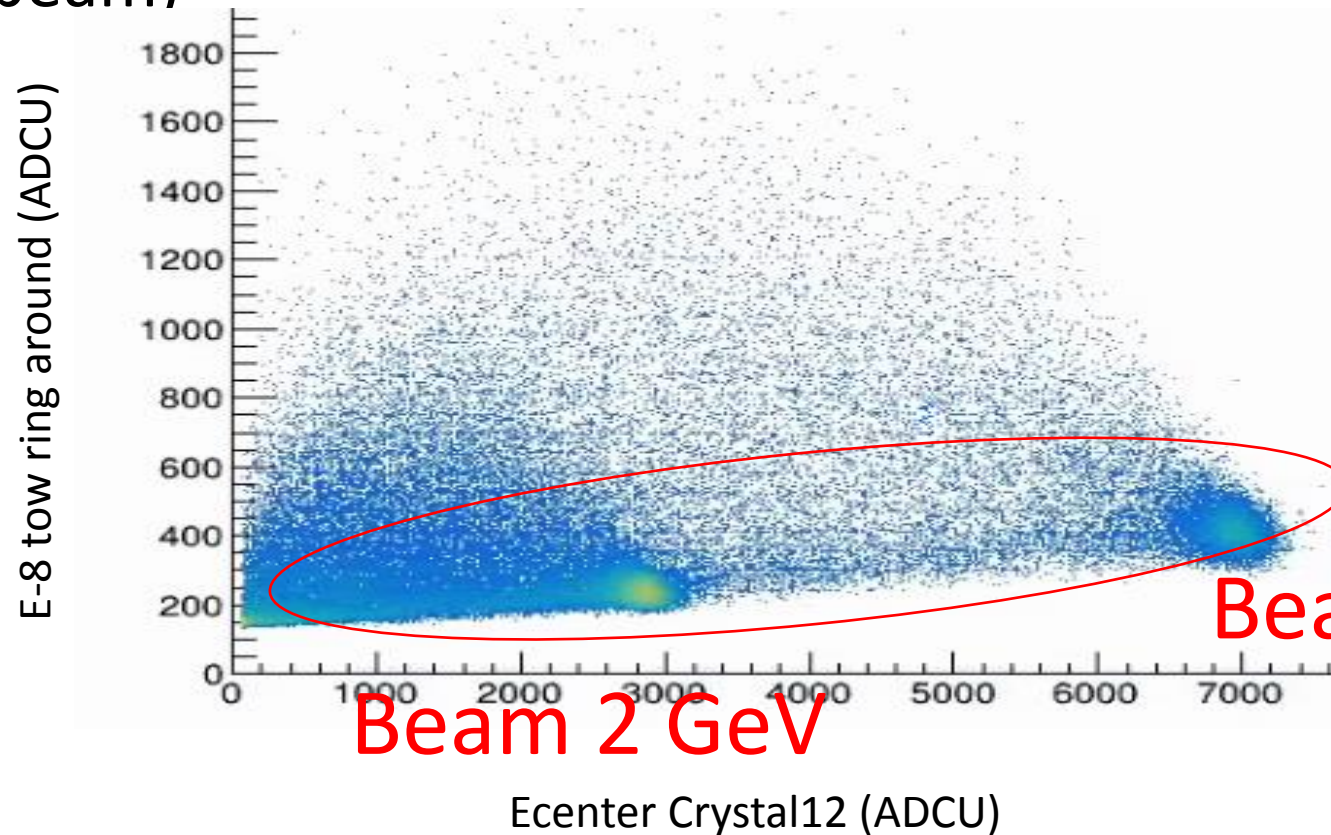
Bottom line is real particles peaked along line proportional to Eparticle

Beam 5 GeV

Beam 2 GeV

Ecenter Crystal12 (ADCU)

E-8 tow ring around (ADCU)

Energy (Anti-)Correlation 3x3 to (5x5-3x3)

- **E3x3sum vs E sum of 16tower ring boarding outside 3x3** ("r <=1 vs r= 2")

- Only about on avg ~400 ADCU of E in outer ring vs 7000 in core 3x3

- Falling Bkg also shows real shower like correlations here as well
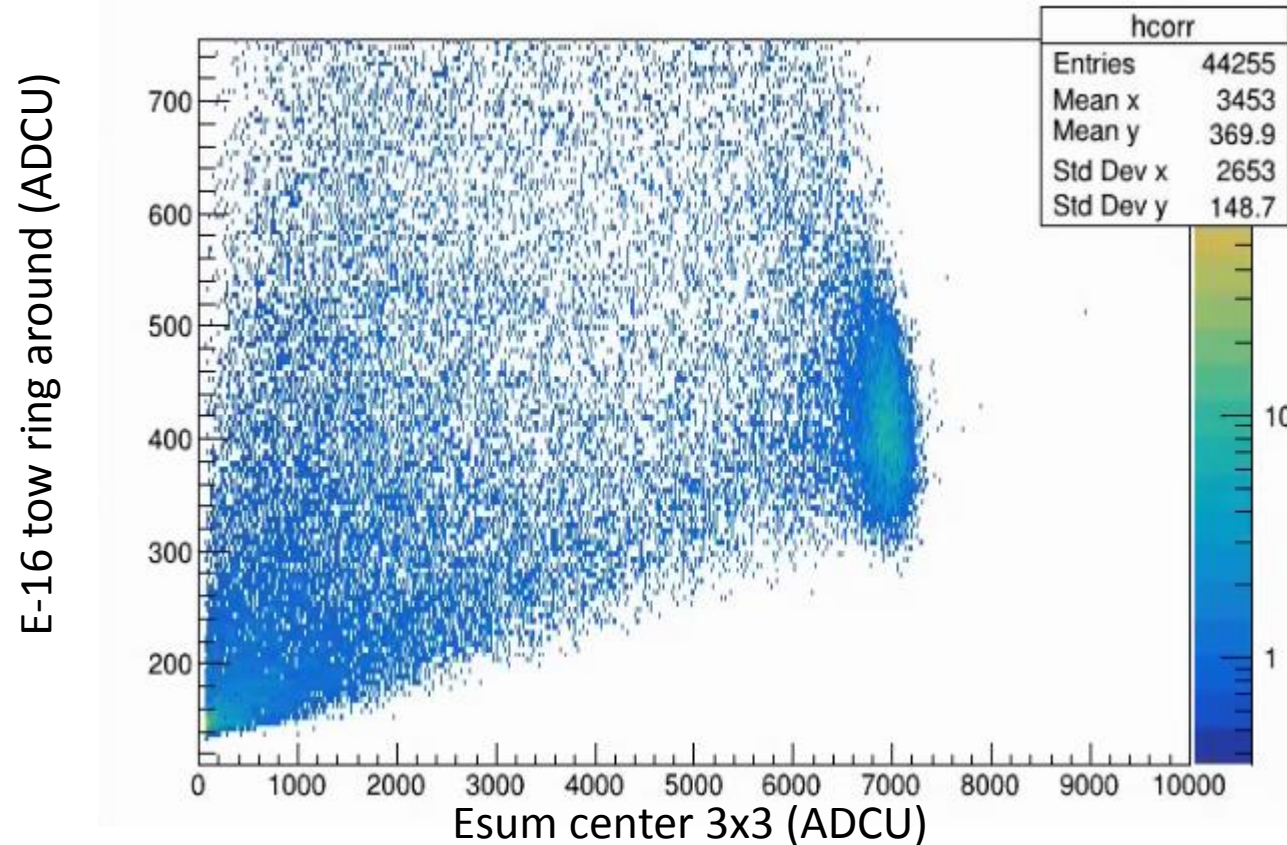
Beam 5 GeV
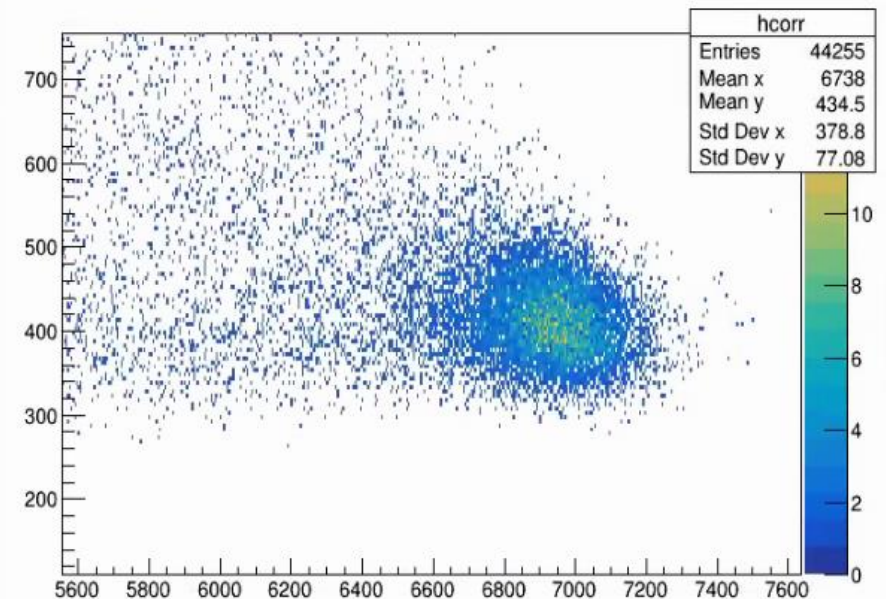
# 2nd Testbeam Data Set in March '25 - Update

- A second followup data taking session was taken at DESY in March

- PMT digi readout, MIT prototype: but ~same PWO crystals/geometry

- *different trigger scint panel – collimator set-up …*

- We hope it can shed some light on falling background
  - And compare to our resolution results.

- We have seen some first results from that analysis. It looks like there is sizable pedestal there as well, but possibly with different shape characteristics -- single channel and summed.
  - At least partially dependent on trigger scint config? March setup used thinner trigger scintillators different setup
  - **Next testbeam ~December 25 → optimize this.**

Background --> Subtraction

- **Resolution parameters from peak fits significantly affected by bkg**

- **Initial subtraction scheme applied**
  - Systematics not quantified yet
  - Can be refined
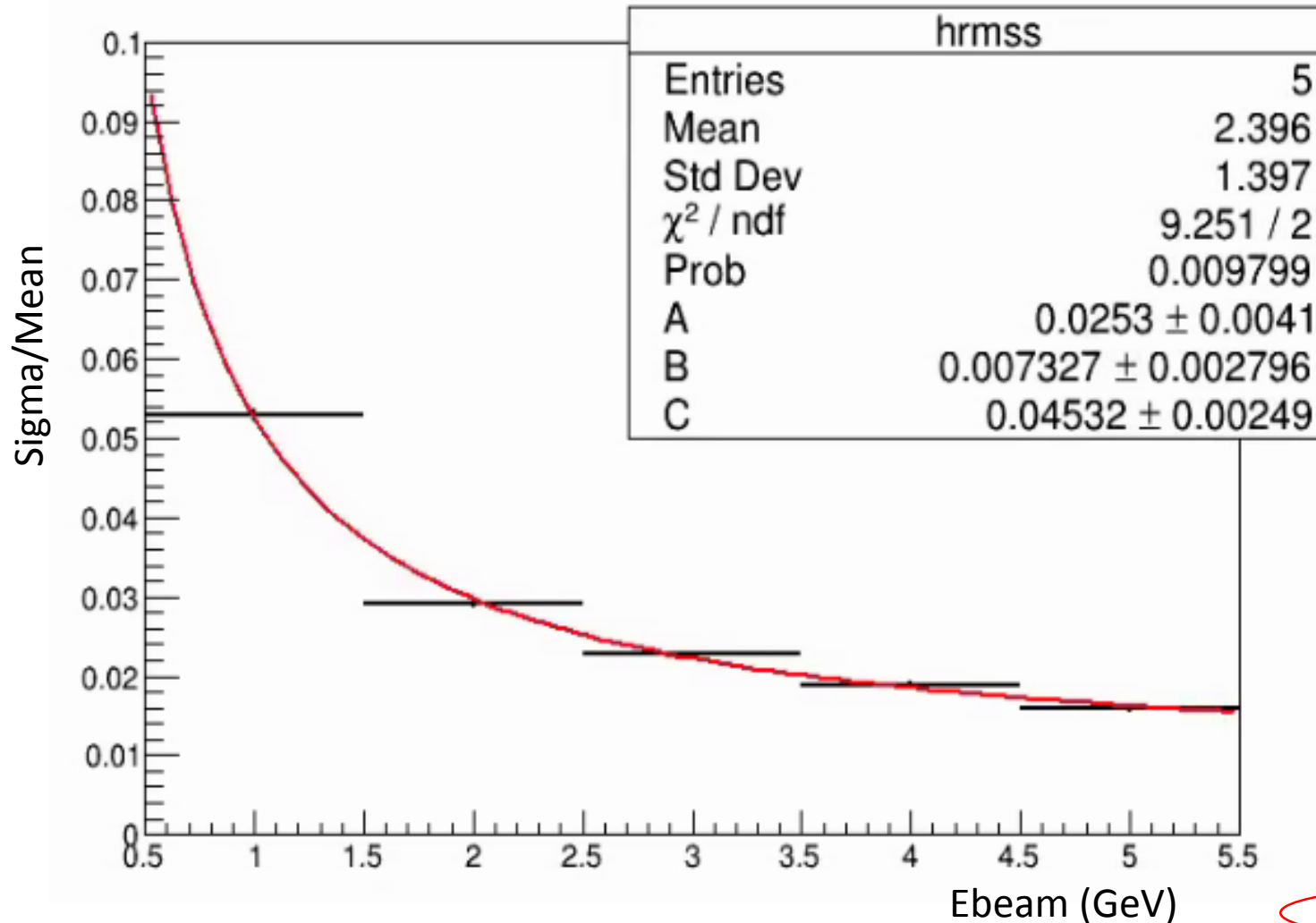 - Needs optimized for 5x5,3x3, different studies, etc.
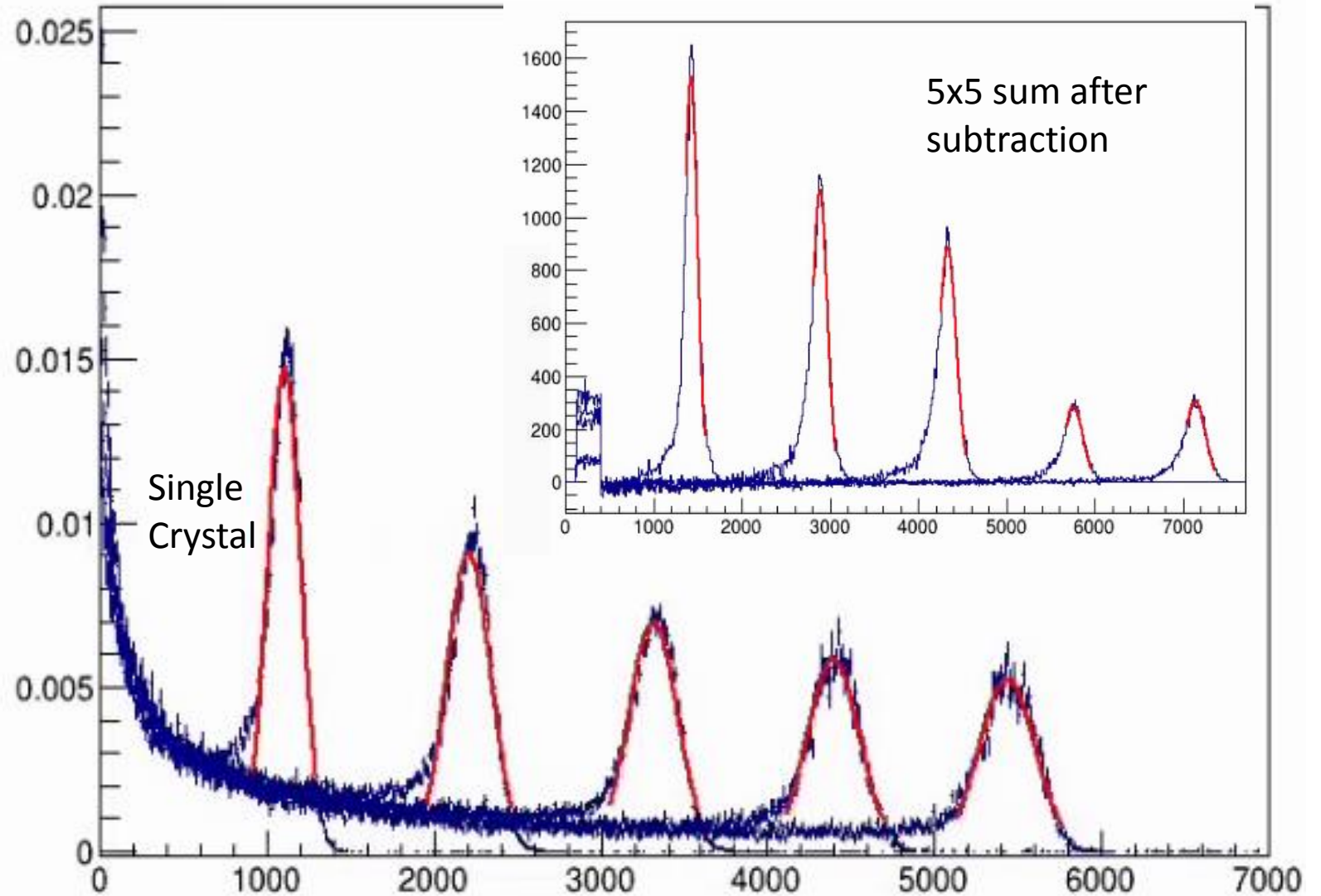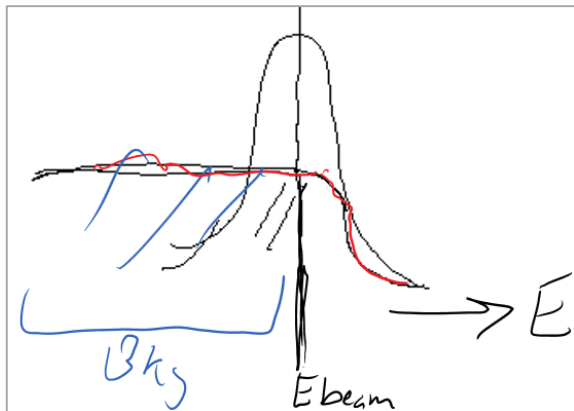
Linearity
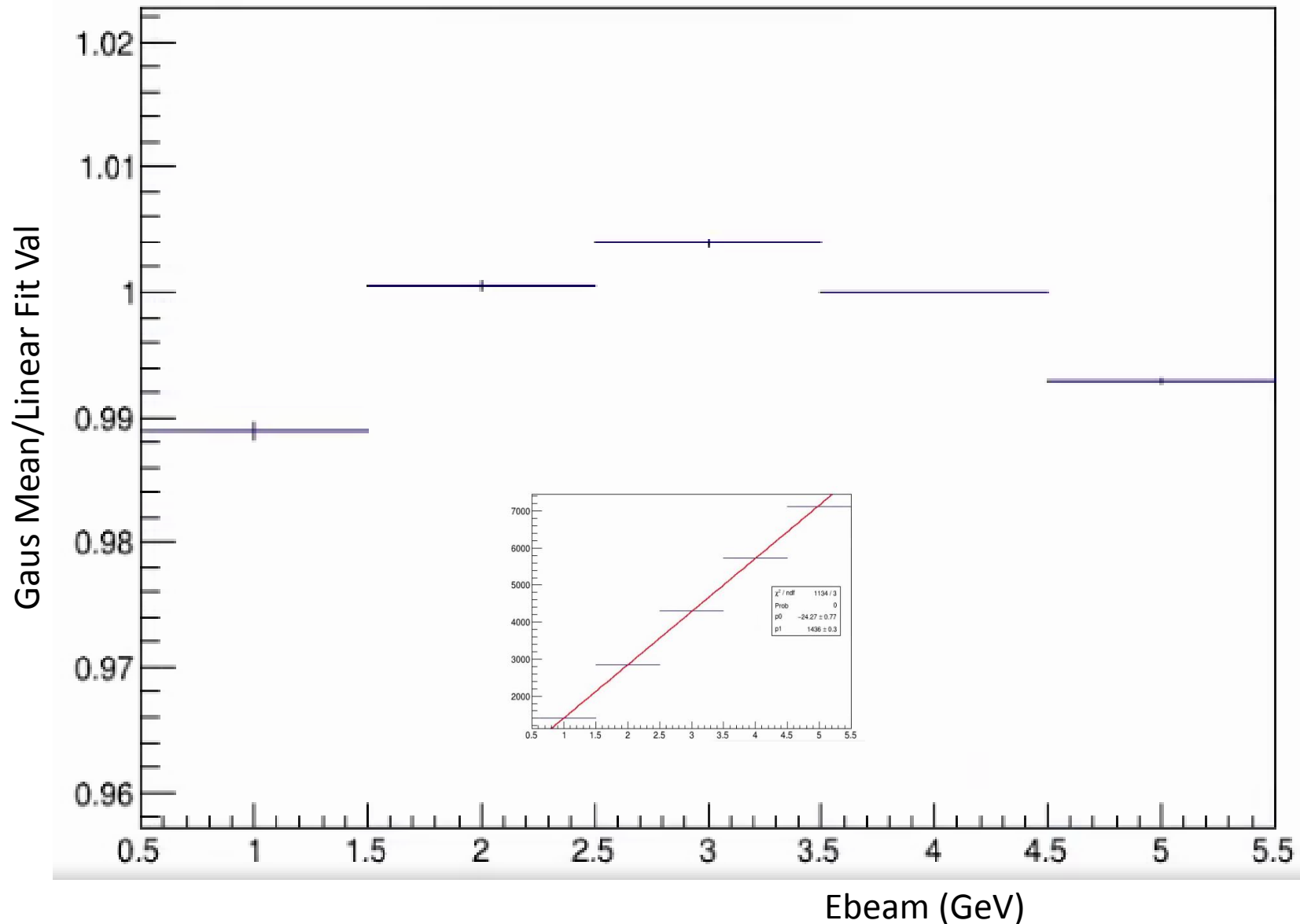
- Gaus fit means/line fit

- This result is very robust to many variations of bkg subtraction even no subtraction

Full 5x5 E resolution w/ subtraction

- Could not fit without 1/E noise term: Fit form: **A%/√E ⊕ B % ⊕ C % / E**

hrmss	
Entries	5
Mean	2.396
Std Dev	1.397
χ^2 / ndf	9.251 / 2
Prob	0.009799
A	0.0253 ± 0.0041
B	0.007327 ± 0.002796
C	0.04532 ± 0.00249

- A term 2.5%
- B term (floated) 0.7% reasonable?
  - (raising/fixing B lowers A term)

- **Noise term 4.5%/E. Large : 2nd Mystery**

- Also under investigation
- Size roughly consistent w/ pedestal channel by channel noise

but all behaviors don't hang together
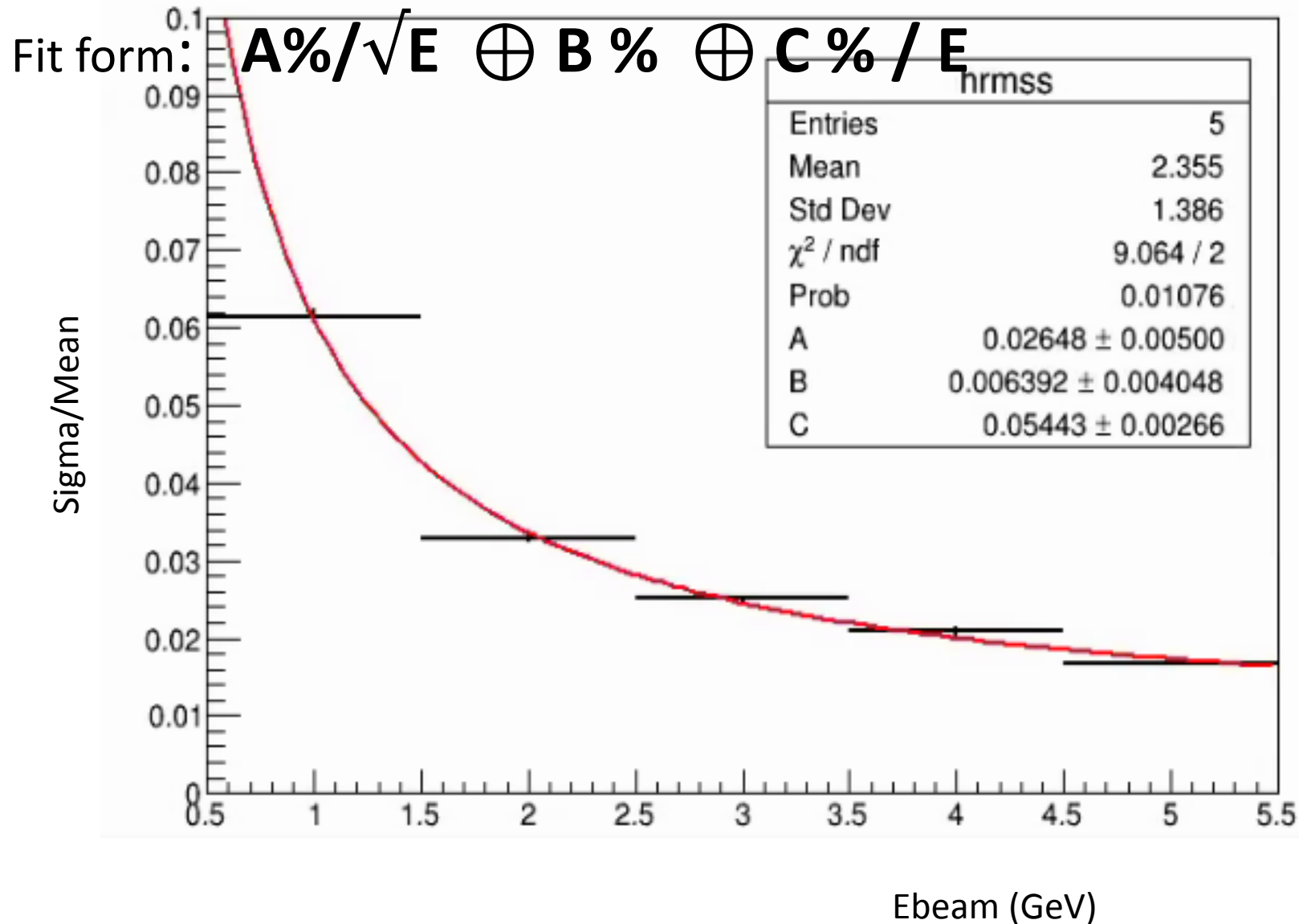
Reso 1GeV :0.0529
Reso 2GeV :0.0290
Reso 3GeV :0.0228
Reso 4GeV :0.0189
Reso 5GeV :0.0158

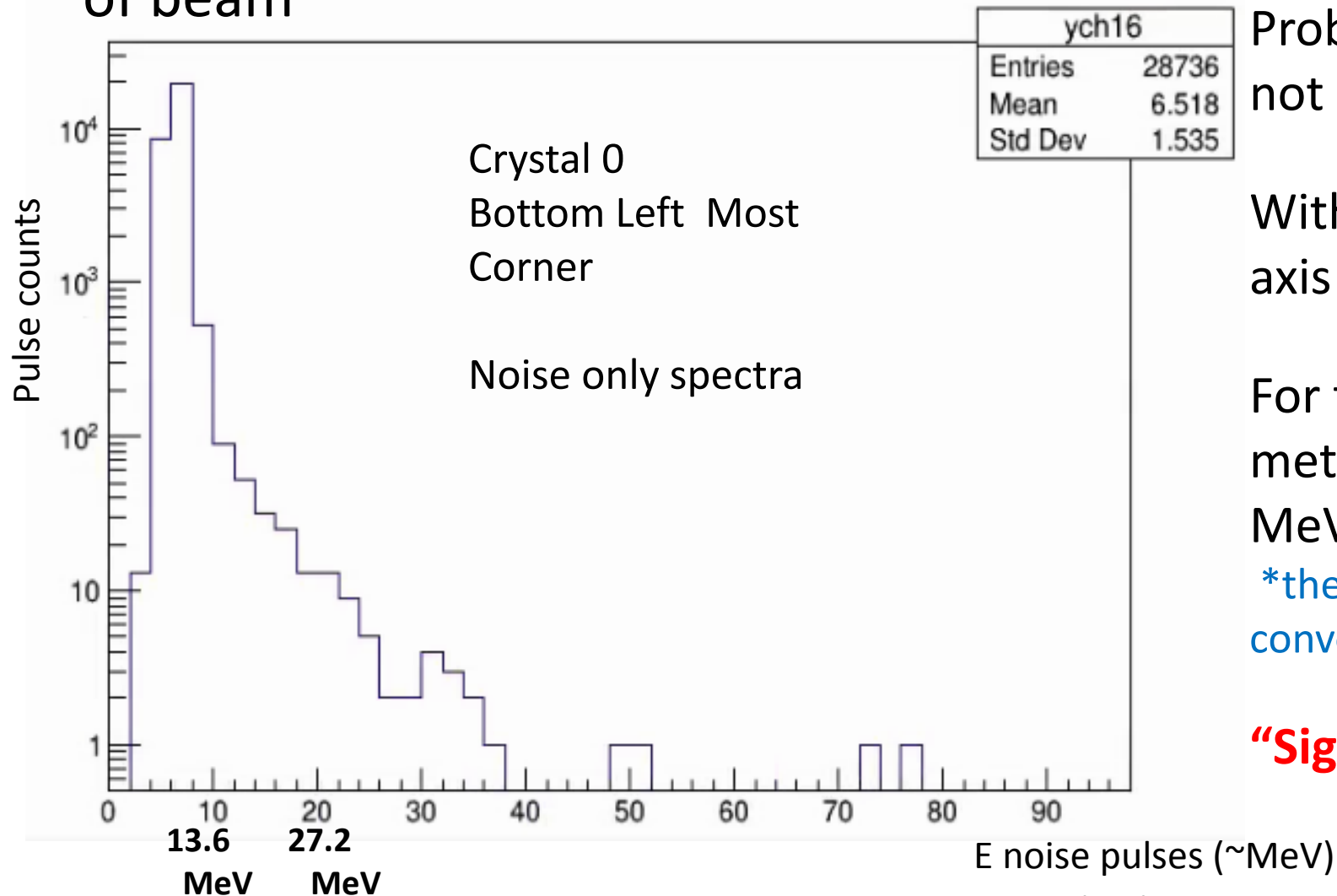significantly smaller(better) than DESY quoted beam resolution !

Ebeam (GeV)

ePIC EEEmcal Update

3x3 Resolution

Fit form: $A\%/\sqrt{E} \oplus B\% \oplus C\%/E$

hrmss	
Entries	5
Mean	2.355
Std Dev	1.386
χ^2 / ndf	9.064 / 2
Prob	0.01076
A	0.02648 ± 0.00500
B	0.006392 ± 0.004048
C	0.05443 ± 0.00266

Sigma/Mean

Ebeam (GeV)

- Resolution worsens slightly as expected
  - Compare w/ sim?

- Noise term larger

- Use this and other data to study quantify

- Source: (see later slide)
  - Power Supply instability?
  - Light leaking
  - ?????

- Looking into further noise modeling based on "pedestal" data

Small Signal Study/Noise

- Took "noise-only" run with triggers firing but prototype lowered out of beam

Crystal 0
Bottom Left Most Corner

Noise only spectra

ych16	
Entries	28736
Mean	6.518
Std Dev	1.535

Probably these preamp boards were not optimized for small noise?

With calibration we can calibrate the x-axis from ADC to MEV

For this I used waveform integration method, calibration is 7.36 "ADCU" per MeV (1 ADC = 1.36 MeV)
 *these adcu are 50 times sample adcu for convenience

"Significant" Noise up to ~13.6 MeV
-Extends to 40-50 MeV

Addressing Large Extra 1/E Noise Term

- Bias Power supply instability ?   Not confirmed yet

- Grounding issues or other general electronics (e.g. board) issues?

- For these, we are in process of exchanging components (Orsay siPM boards sent to US, making some new siPM –adapter) for testbench testing
  - 2-3 Testbench testing setups
  - Recent : Ohio U (Julie Roche, JEF, student) Full Single Channel tests, including cosmics w/ actual crystal→ Almost completely on-shell
  - Full readout chain including same Caen v1725s Modules
  - **-- borrowed from UVA/Jlab → Xiaochao Zheng UVA Group → (THANKS for patiently letting us borrow!!)**

- Light leaking → we know there was some light leaking
  - Partially investigate with data sets e.g. position dependence of noise

- Reminder: Inherent BEAM resolution also needs measured: by March 2025 Dataset measured w/ PMT's.
  - First look seems that it is indeed smaller/better than we are measuring

Small Signal Study/Noise- Chan Comparions

- "Noise-only" run with triggers firing but prototype lowered out of beam
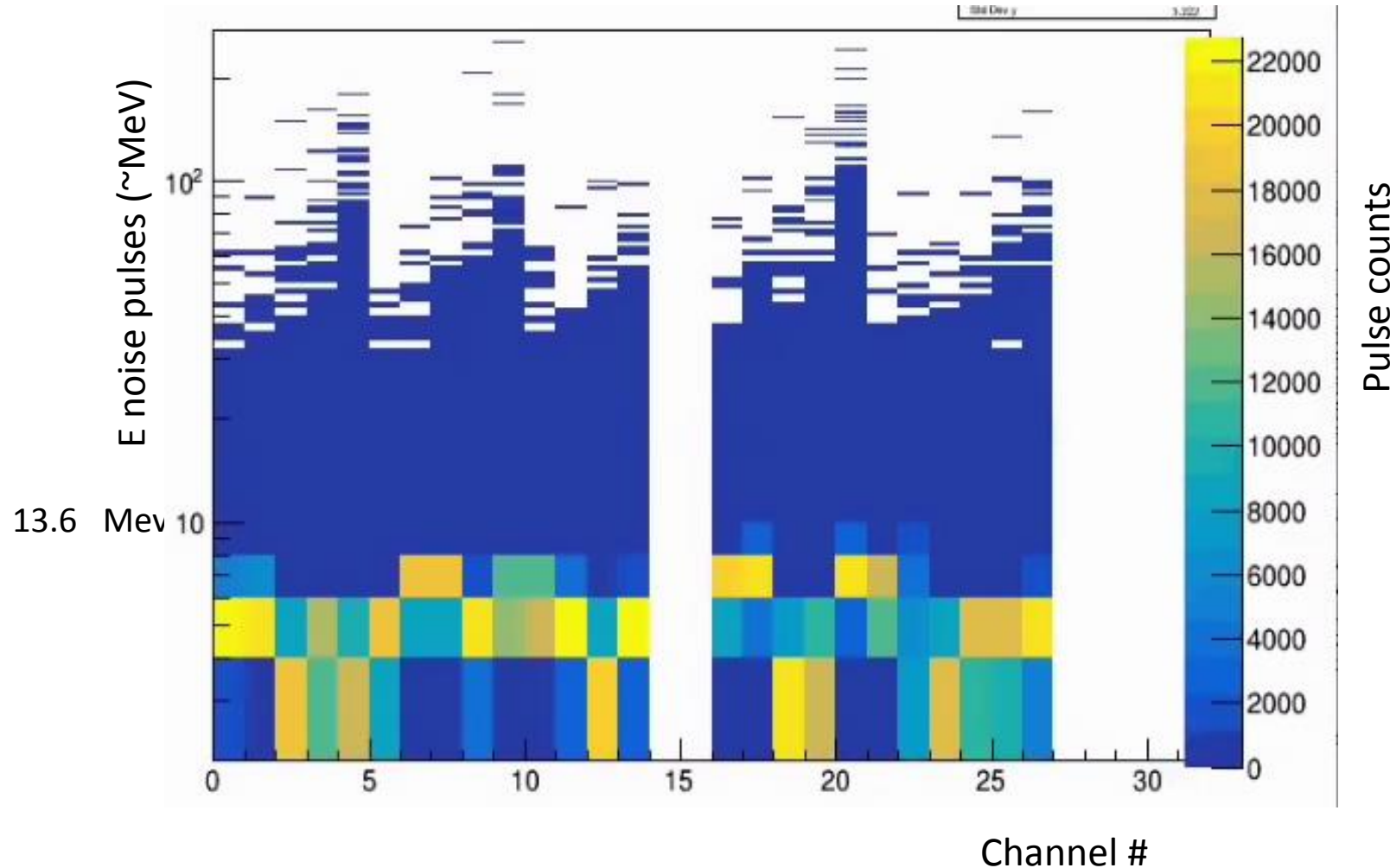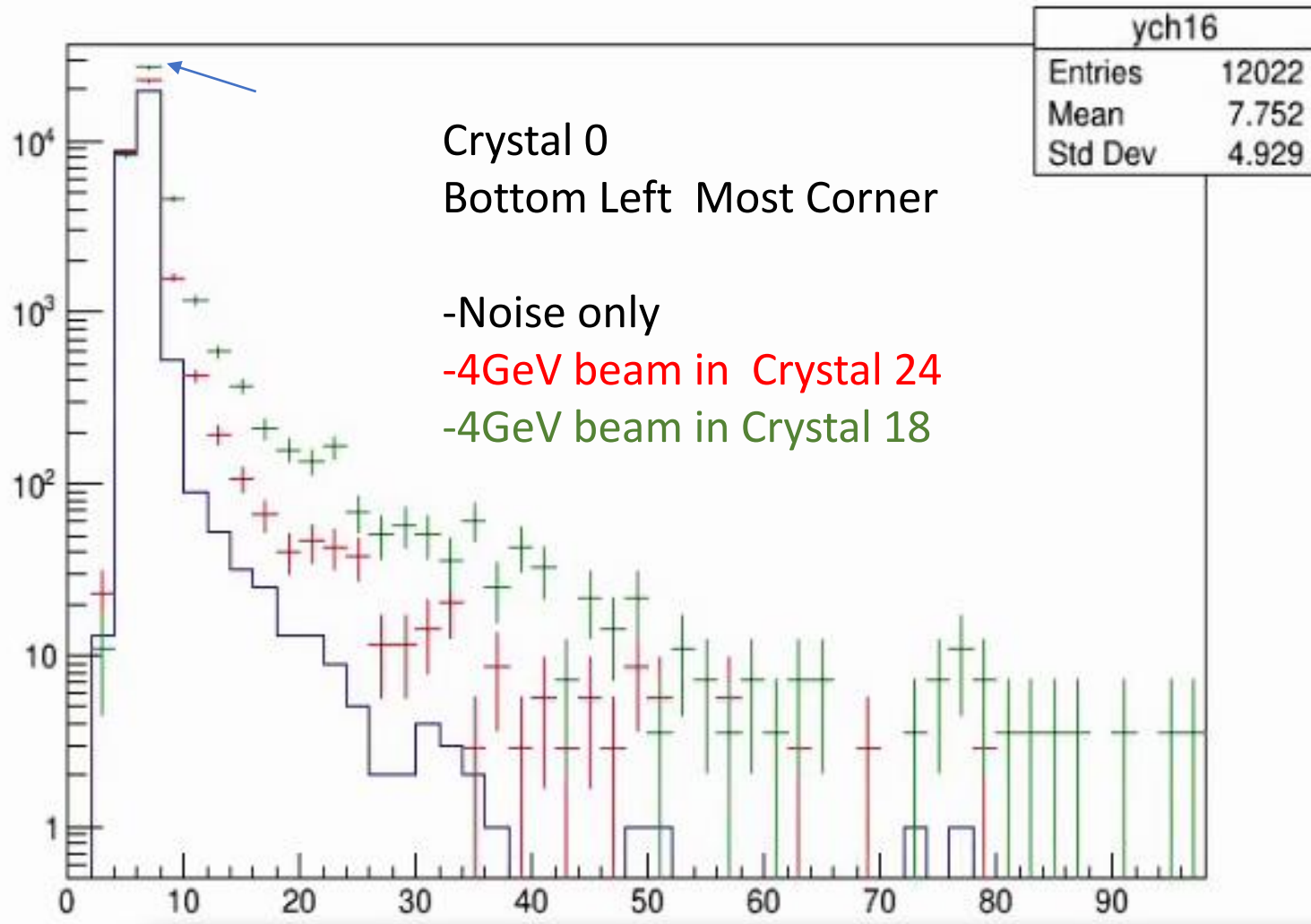

~Consistent for all channels

Some have lower e noise

Some extend as high as 100 MeV

Use this data to try to understand/quantify noise term

Small Signal Studies

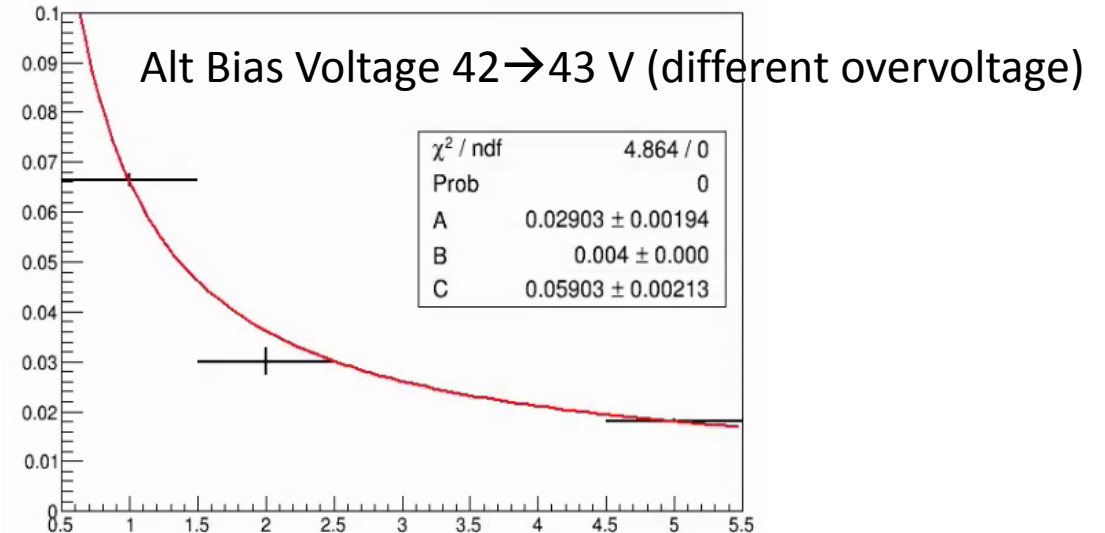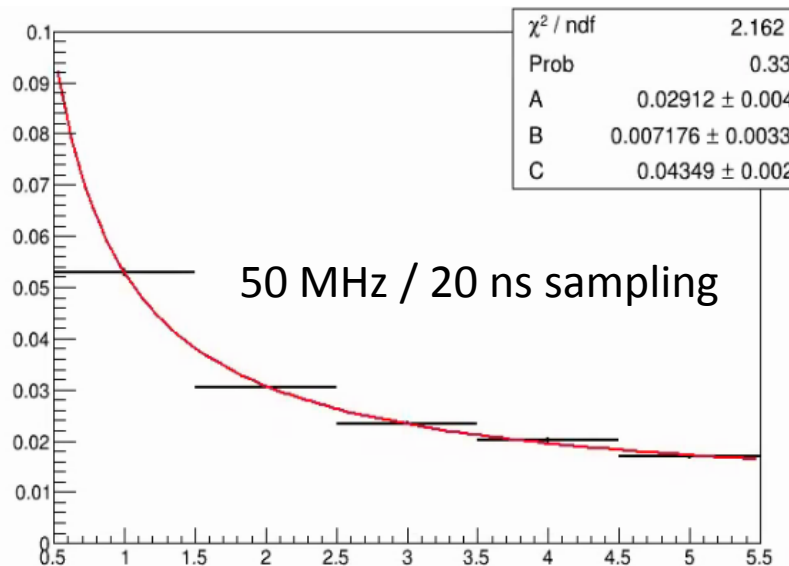Can quantify Signal/Noise at very small energy situations?

Crystal 0
Bottom Left Most Corner

-Noise only
-4GeV beam in Crystal 24
-4GeV beam in Crystal 18

- Beam pointed at Crystals 18, 24 – far away

- (still looking at Tow 0)

- Signal Excess (2:1 @ 8 Mev)

# Todos: Comparative Studies → Realistic Sampling

- Even without complete understanding of noise and backgrounds, can get an idea of some aspects of the siPM and discrete potential performance

- Most importantly, realistic ePIC sampling 250MHz/4 ns → ~40 MHz/25ns
    - First look by removing 4 out of 5 samples (keep 1/5) → 20 ns sampling
    - Small effect → Bkg subtraction needs reoptimized, but also still unrealistically large number of samples used for pedestal determination → more realistically model

- Other comparative studies possible: varying bias voltage, higher rate (5kHz) datasets, very fine position scanning sub-tower lengths.


50 MHz / 20 ns sampling

χ² / ndf	2.162 /
Prob	0.339
A	0.02912 ± 0.004
B	0.007176 ± 0.00332
C	0.04349 ± 0.002

Alt Bias Voltage 42→43 V (different overvoltage)

χ² / ndf	4.864 / 0
Prob	0
A	0.02903 ± 0.00194
B	0.004 ± 0.000
C	0.05903 ± 0.00213

Conclusions

- First analyses of "super" discrete readout for super-high frequency 250MHz fADC nearing completeness
  - But need several further studies to try to understand noise and background

- We hopefully can still learn about discrete performance regardless from some of the comparative studies.
  - Second beam test at DESY in December $\rightarrow$ should be able to understand what improvements we need to amke

- New analyzers over this summer. Wrap up studies by end of summer...
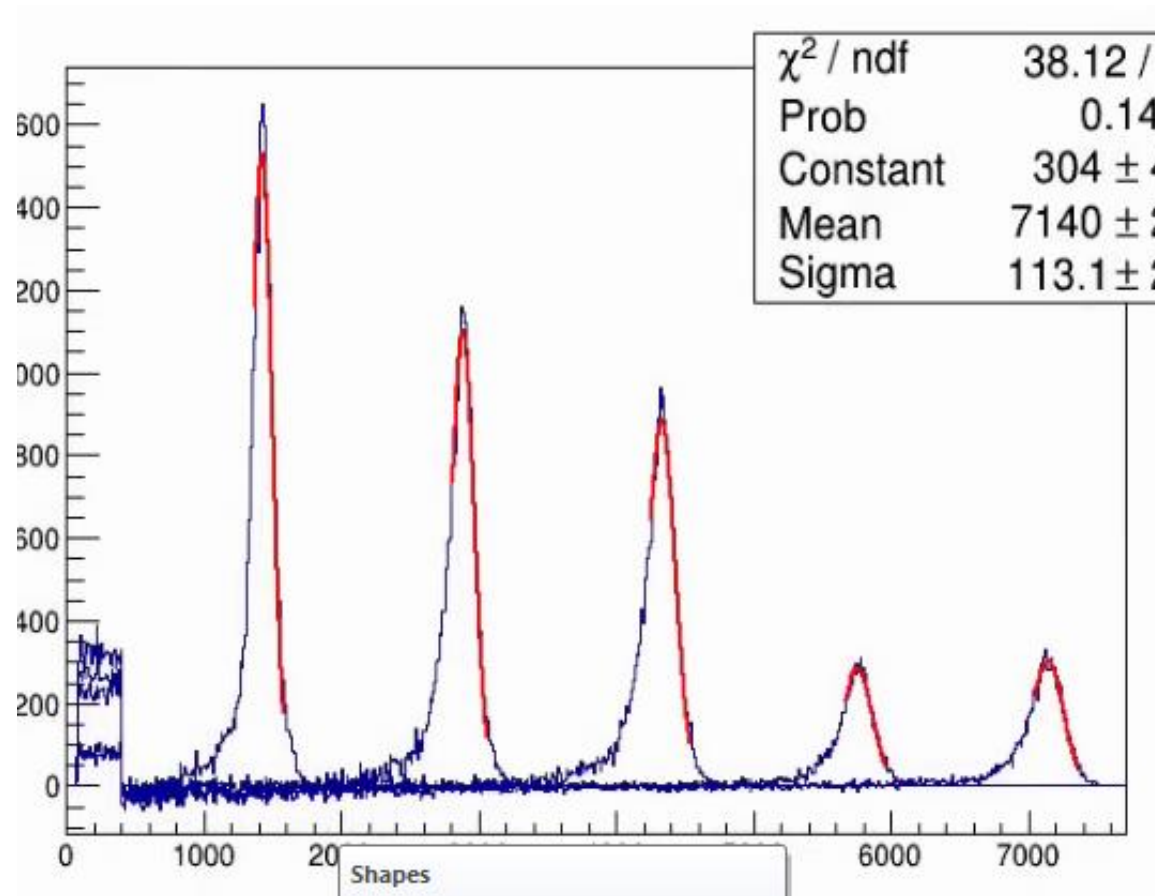
Backup slides
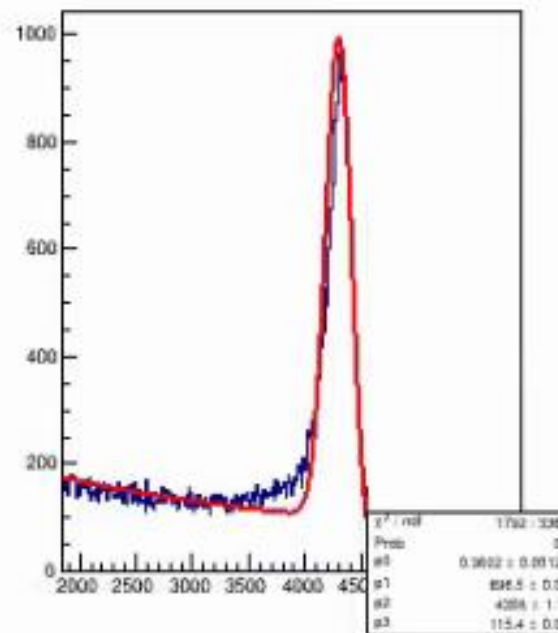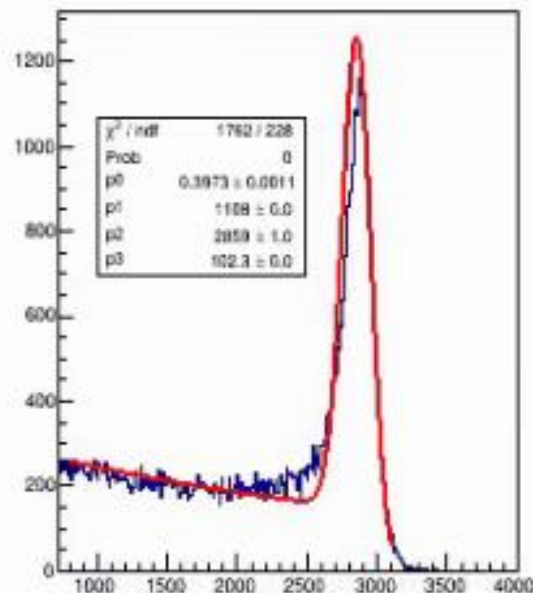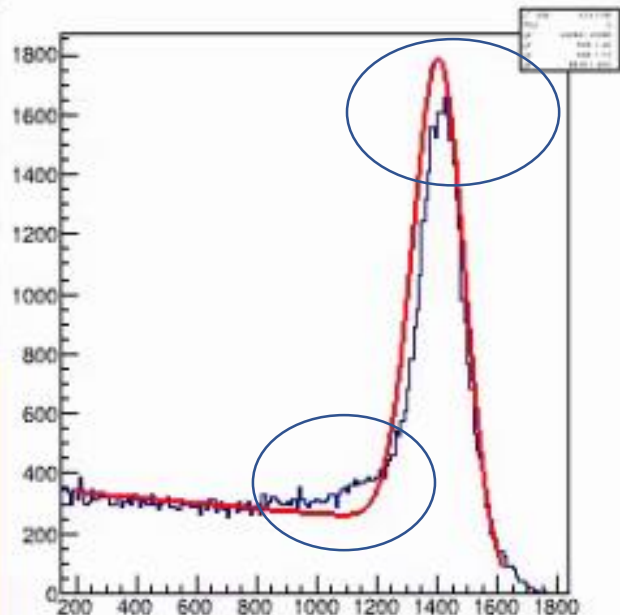
Red is Sig + Bkg

Lowside tail

Gaus peak location a little mismatched
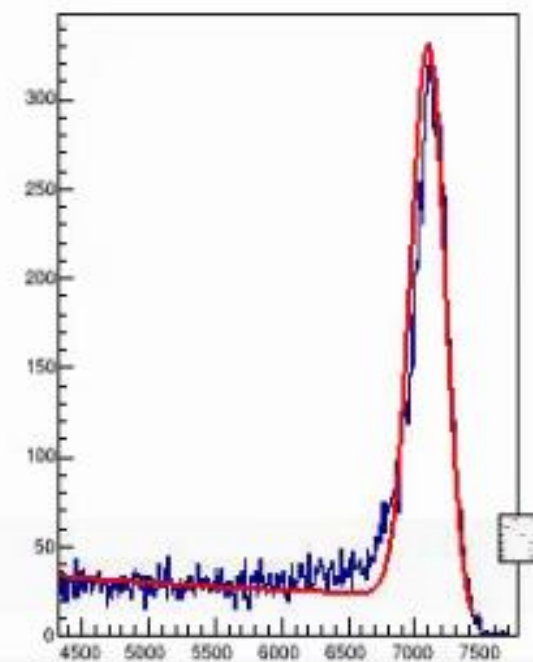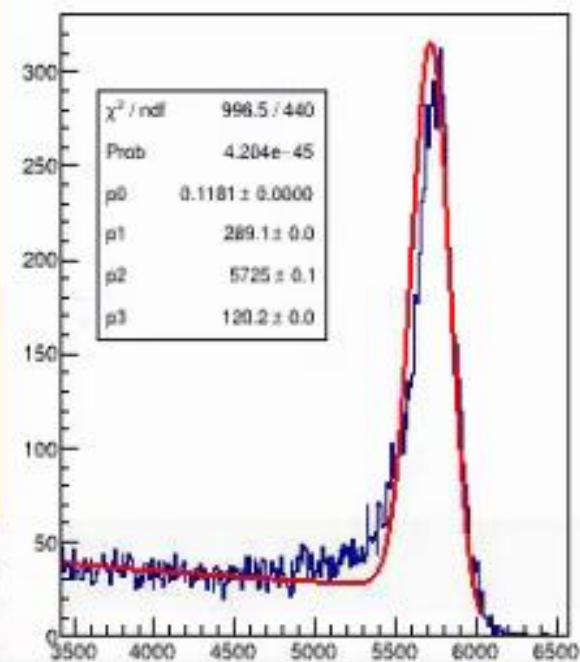
Fits are used to Subtract Bkg

- Then peaks are refit in only the core Gaussian region, [-1sigma , 2sigma] to reduce lowside tail contribution

χ^2 / ndf	38.12 /
Prob	0.14(
Constant	304 ± 4
Mean	7140 ± 2
Sigma	113.1 ± 2

Fit now matches peak area better than ever before.

Other Details

- Some other details are discussed at end of these slides, **after** the results are shown

- Such as

- Calibration
  - Beam was scanned over all towers/crystals, centered in each crystal, for calibration. (25 Runs one for each tower and one energy)
  - Mean peak location in wf amp distribution for each tower is found, calibration adjusts energies for each crystal so peak is always in same location

- Syncing
  - The Caen Sends Up Each Channel one at a time with a timestamp. All fired channels with same timestamp are from same trigger. Channels usually come in groups of 16 (one for each board) but boards but board order frequently changes. And maybe not always coming in board groupings, possible some channels never come for small amount of triggers.
  - 32 Channels from each trigger need sync'd
  - Syncing code tested in some different ways, it is almost certainly robust enough for now, might need some further improvement

Calibration

- With v2ohio Second data set more limited calibration data was taken

- 2GeV each crystal center data –some towers were missing (we went to dinner some misunderstanding, should've checked.)

- 4 GeV purposely only took central 3x3 plus a few to save time (also used 5x5 collimator for this data, increased data rate by ~8 times ~1 kHz – because it was getting very late on Monday night and I had to leave ~5am Tues morning.
    - (900 Hz "high" rate, ~no effect?)
- ~two towers(/crystals) in outer most ring, use 4 gev diagonal tower away data files for relative/flattening calibration.

- For cases of good 2 GeV and 4 GeV calib files, relative calibration agrees almost exactly.
    - If calibration is dominated by siPM's only, not preamp daughter boards (which were randomly located differently in v2ohio second data set) first set of calibration data could be used for better calibration

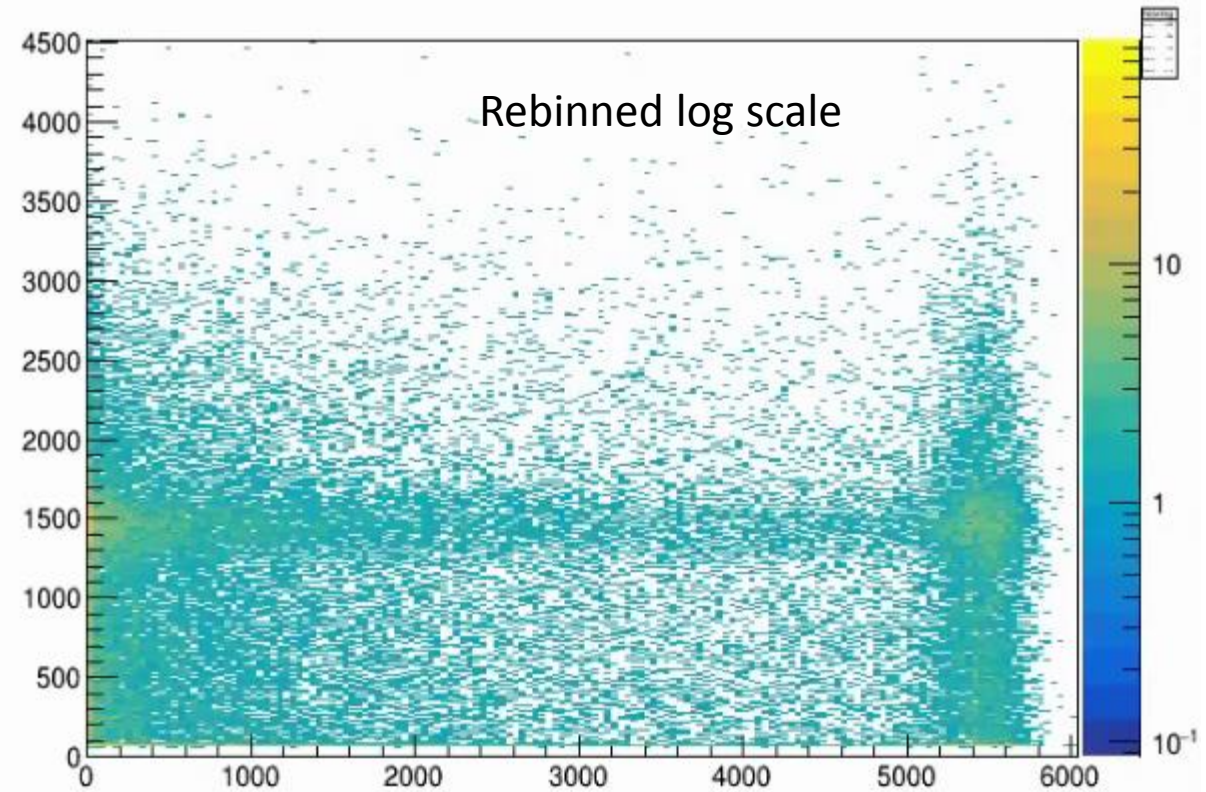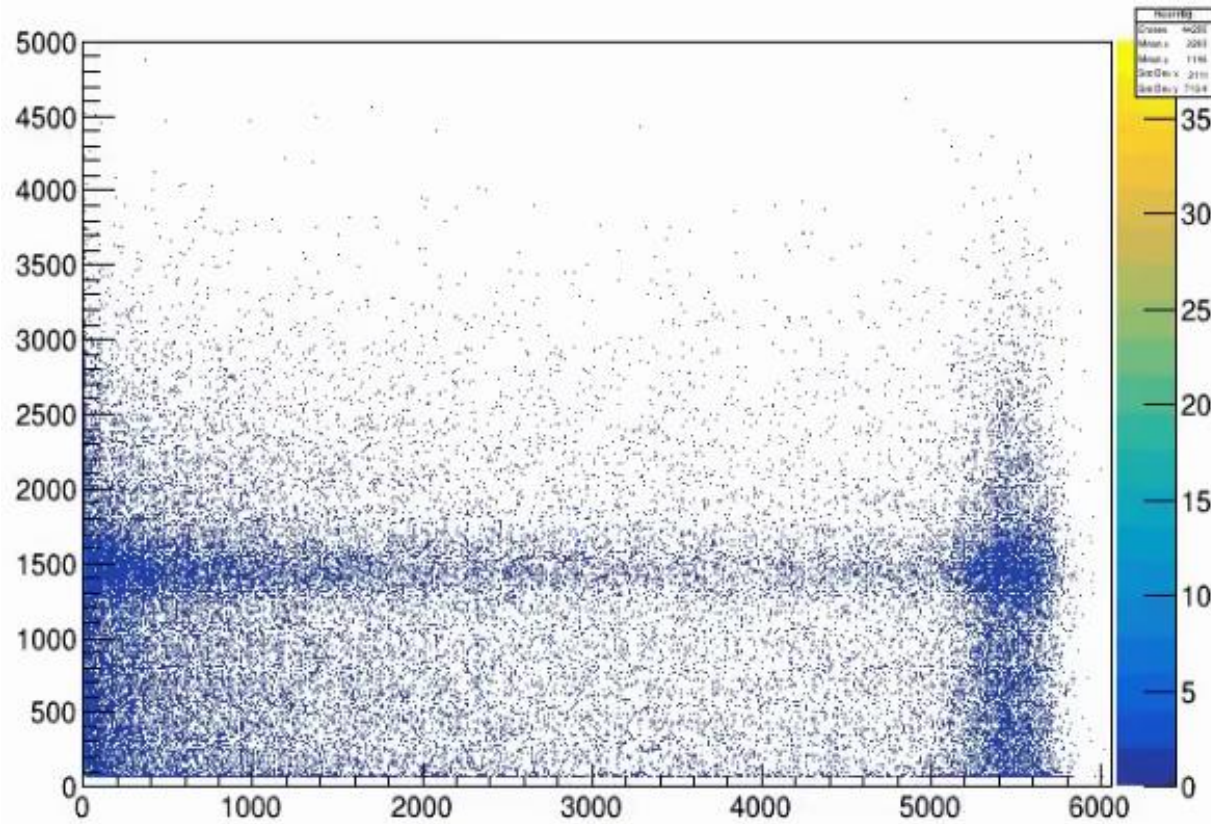# Final relative (flattening) calibration factors
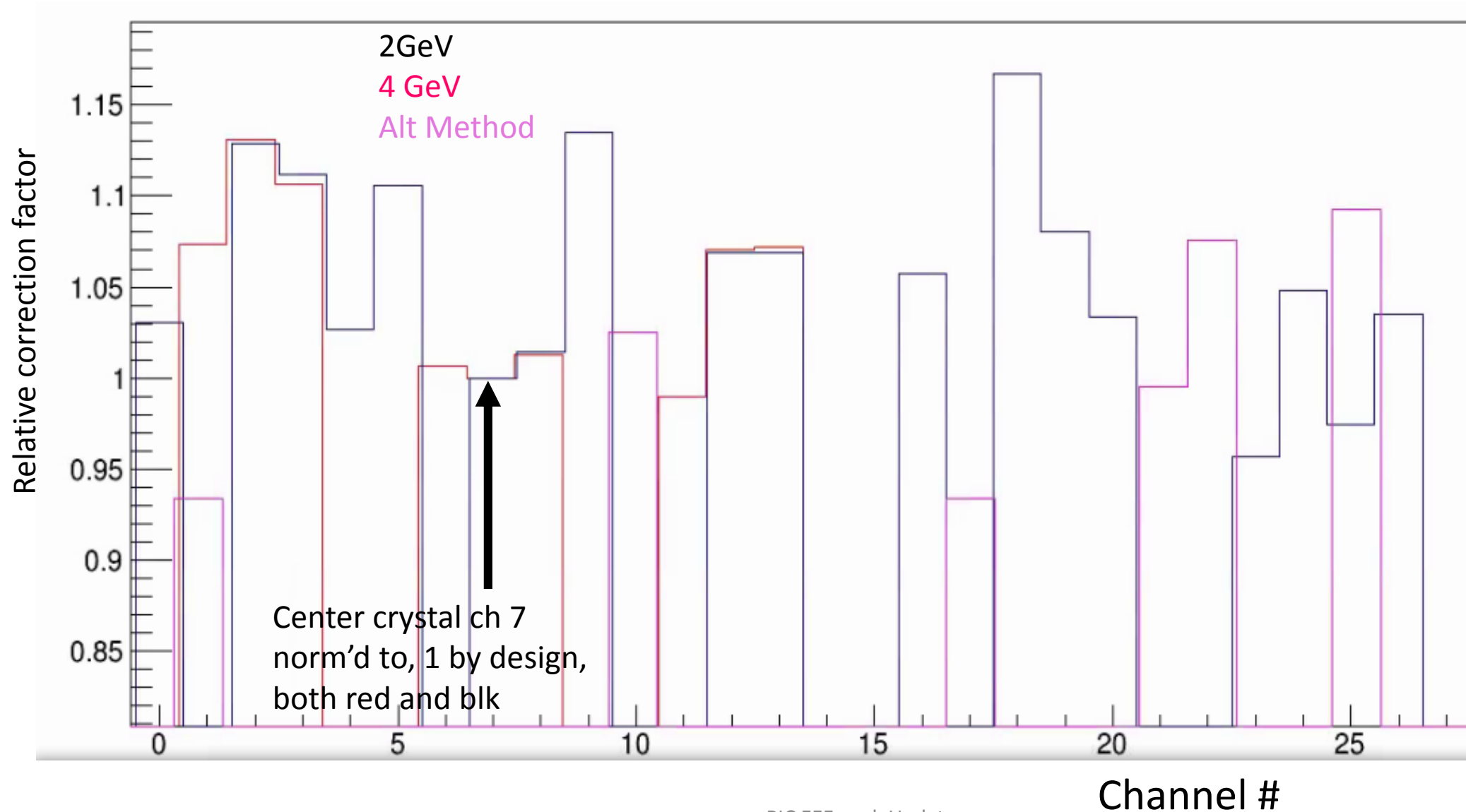
Calibration Fits

- Peak locations from fits that were used - note ch 14 & 15 are trigger channels
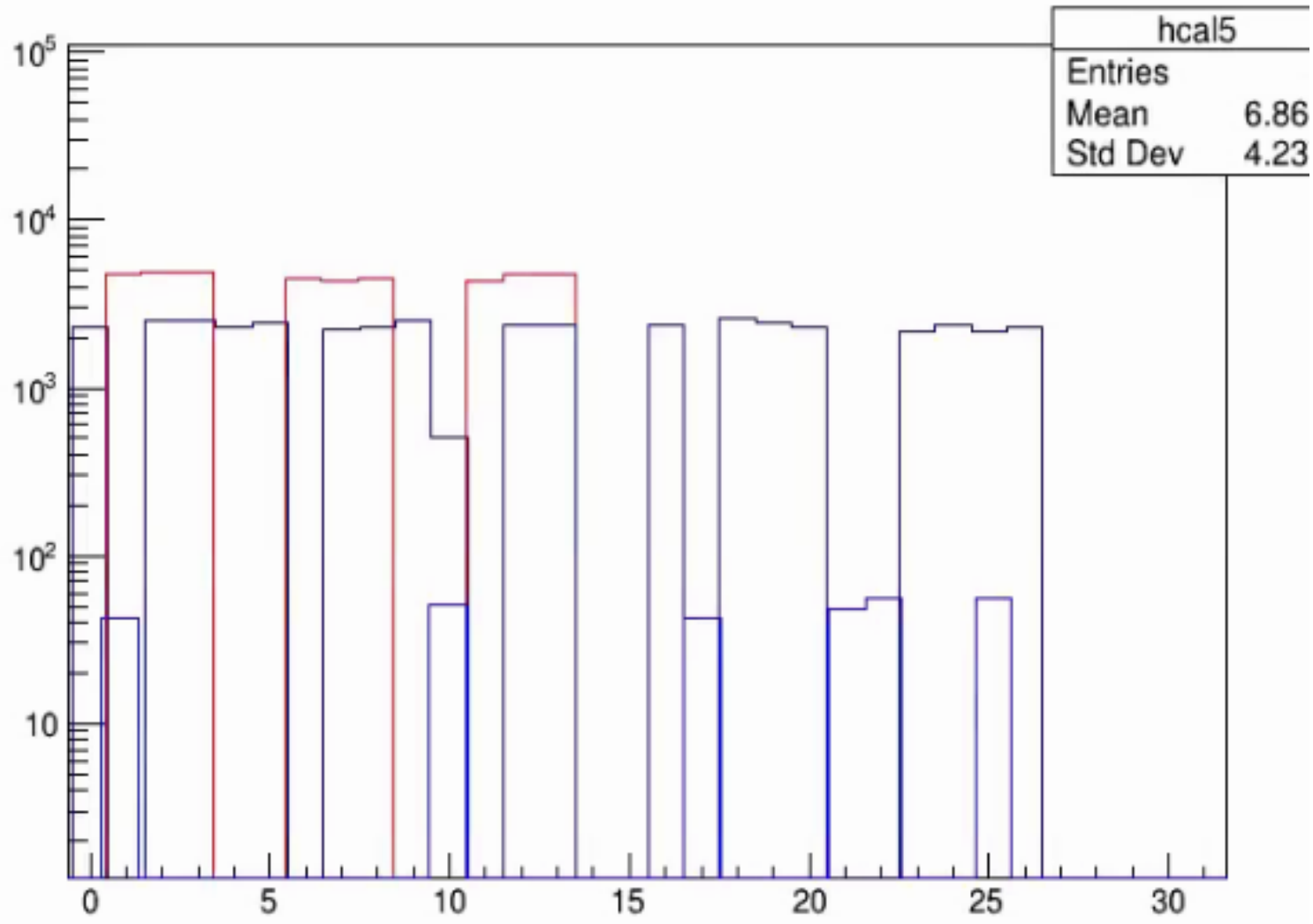
Purposely broken correlation – again pedestal

- The difference if they were uncorrelated

Rebinned log scale

Beam 5 GeV

Most likely interpretation

- The background between the peak and adc ~0 is almost certainly lower energy electrons or photons which go from 0 GeV to max of Ebeam.
  - (also explains why they always stop at Ebeam)

- The anti correlation region "peak" moves

 down right to left along the positive

correlation line because both ring and

 center AVERAGE will be positively correlated

The upper part of the triangle is just the

extension of the anticorrelation for all of the

particle energies.
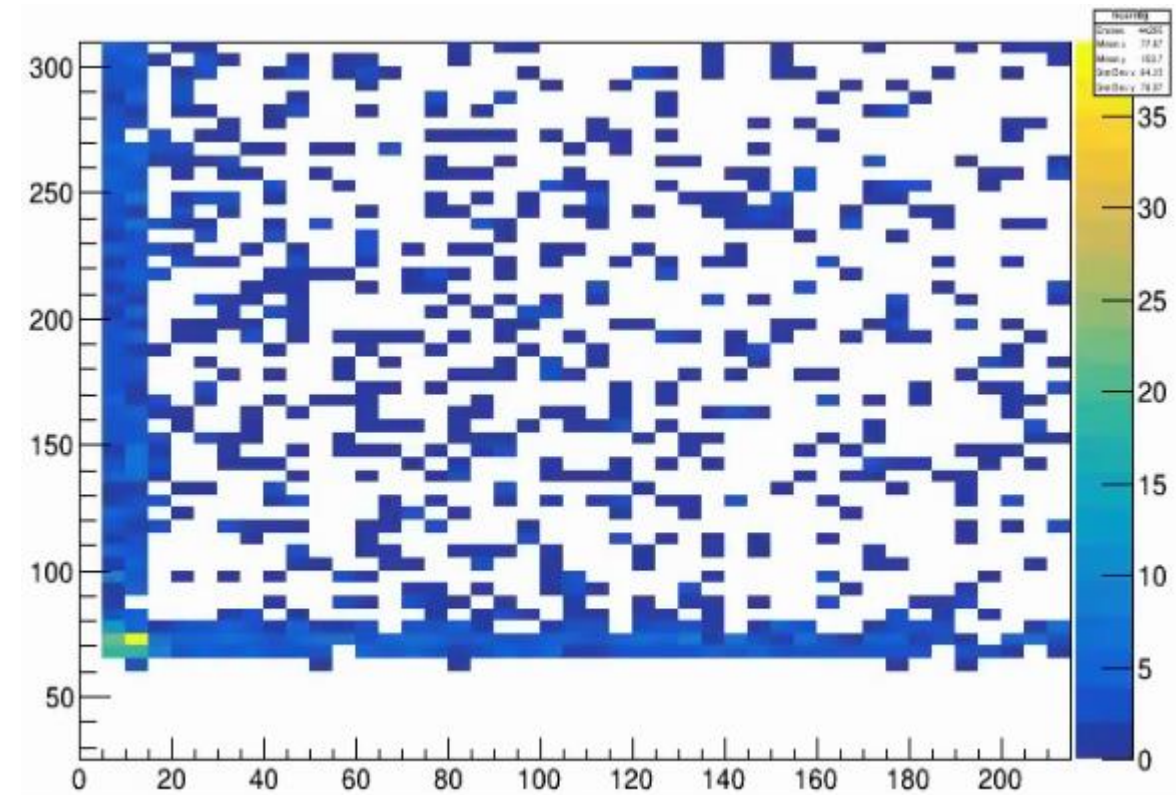
-The anti correlation espec

 means these are showers.

Rebinned 2 in x and y

anti-correlation region of bkg

positive correlation region
of bkg
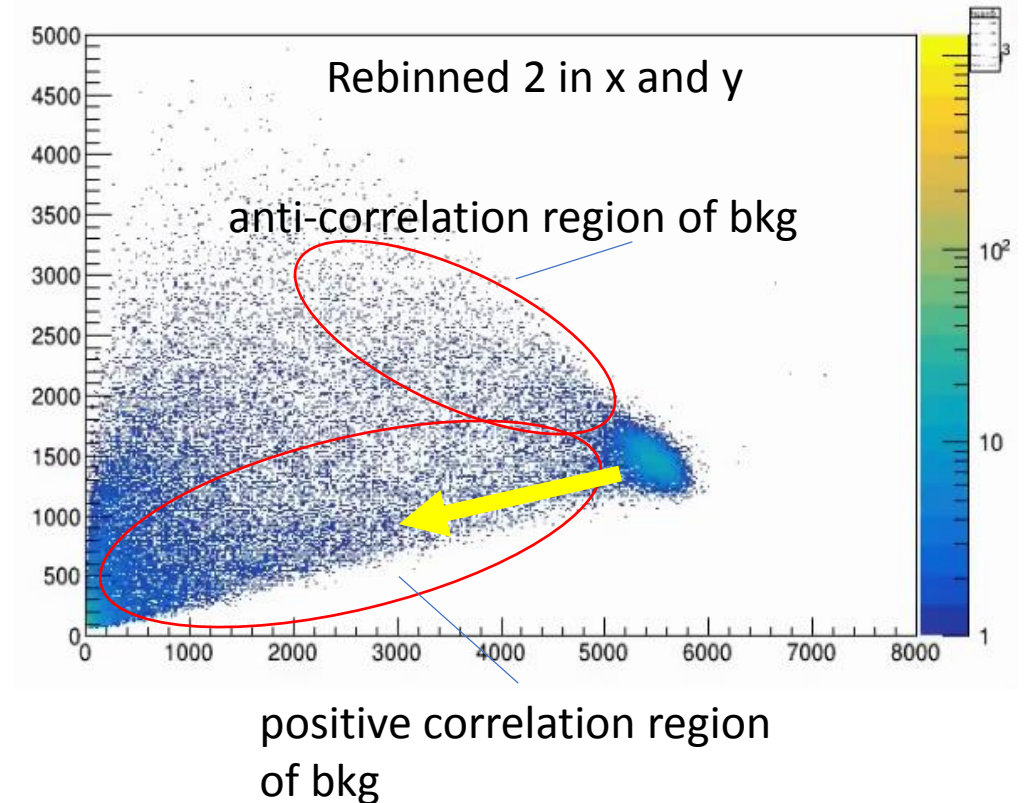
Zoomed in to NOISE REGION

- Noise region (small-small adc) is largely uncorrelated as you would think
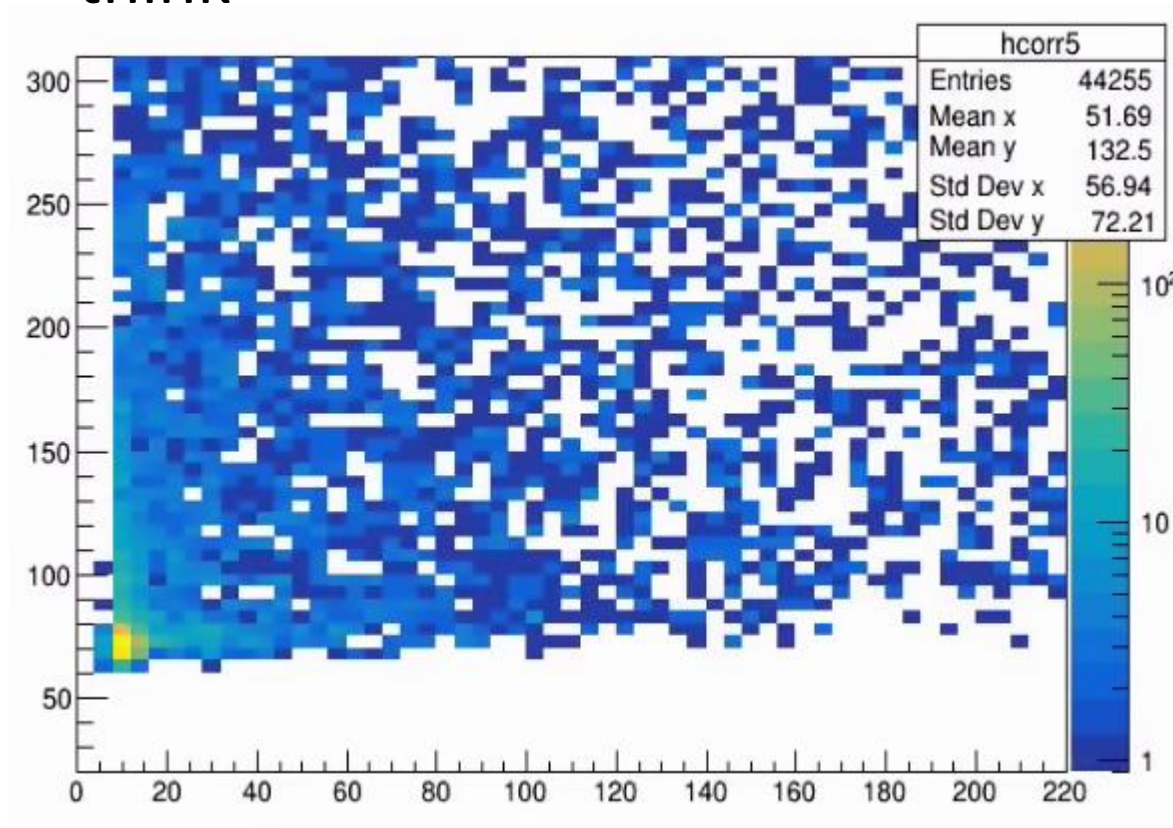
correlated (event syncd)   **sync purposely broken -- uncorrelated**