

Results from FCAL Beamtest

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Outline

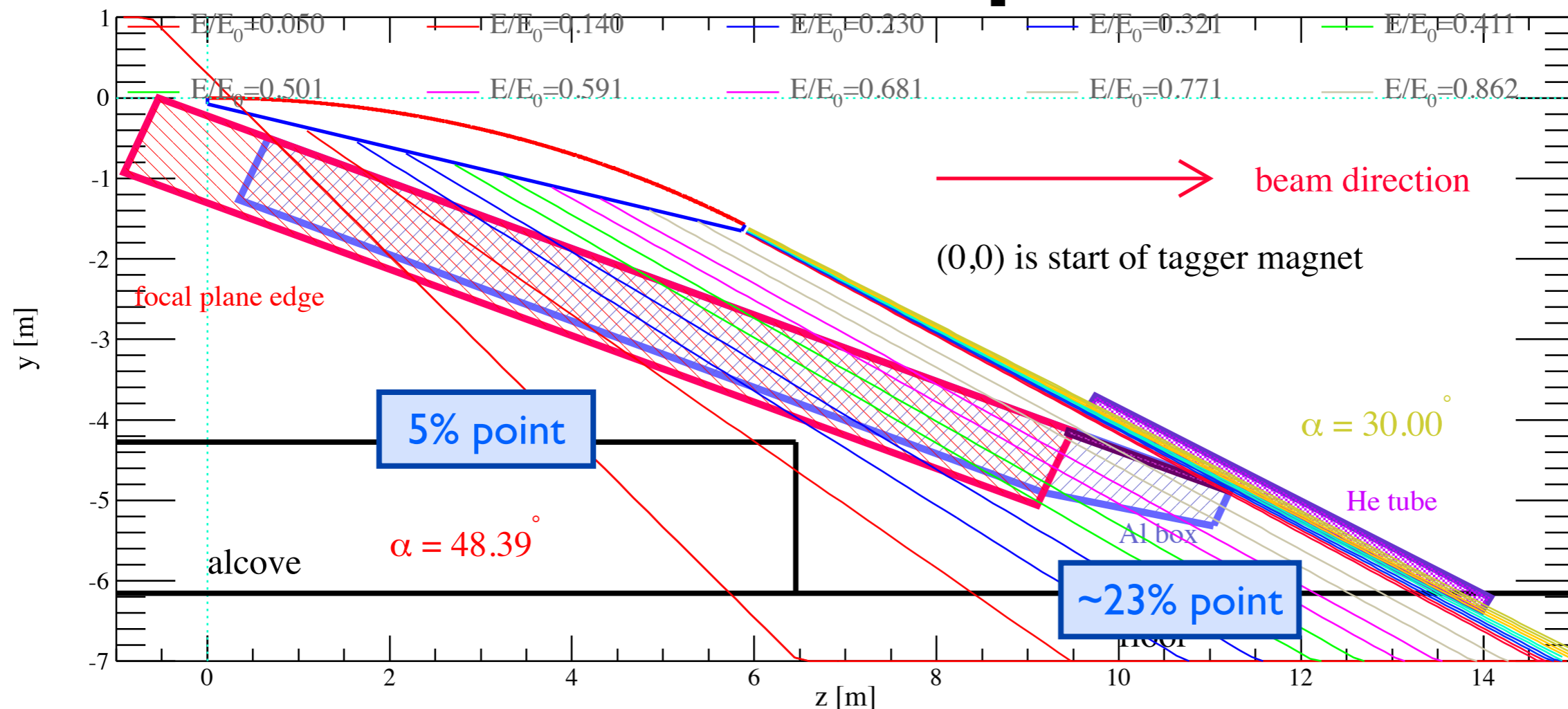
This talk summarizes the results of the FCAL beamtest that was conducted underneath the Hall B tagger during winter 2011 - spring 2012.

This talk complements the analysis note, document 2118 on the docDB.

<http://argus.phys.uregina.ca/cgi-bin/private/DocDB/ShowDocument?docid=2118>

- Details of setup
- fADC behavior
- Energy resolution studies
- Timing resolution studies

Setup



- Our detector was mostly placed at the 5% energy point of the accelerator energy.
- 4 different accelerator energies \rightarrow 4 different incoming energies
- Also took some data at the ~23% point, but are not sure of the alignment.

Incoming electron energies:

- $2.254 \text{ GeV} \times 0.05 = 112 \text{ MeV}$
- $4.446 \text{ GeV} \times 0.05 = 222 \text{ MeV}$
- $5.542 \text{ GeV} \times 0.23 = 1275 \text{ MeV}$

- $2.537 \text{ GeV} \times 0.05 = 127 \text{ MeV}$
- $5.542 \text{ GeV} \times 0.05 = 277 \text{ MeV}$

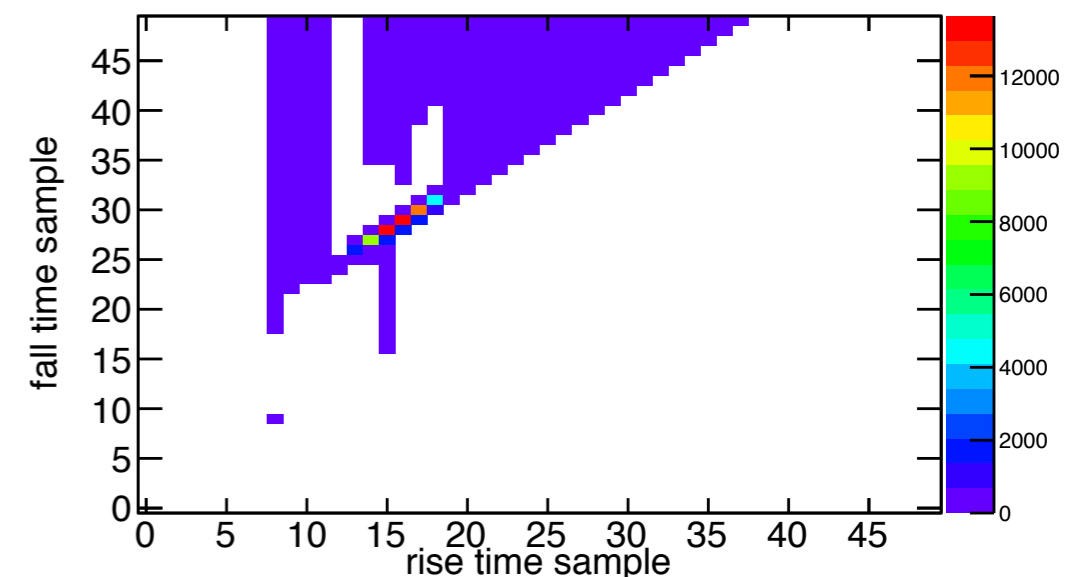
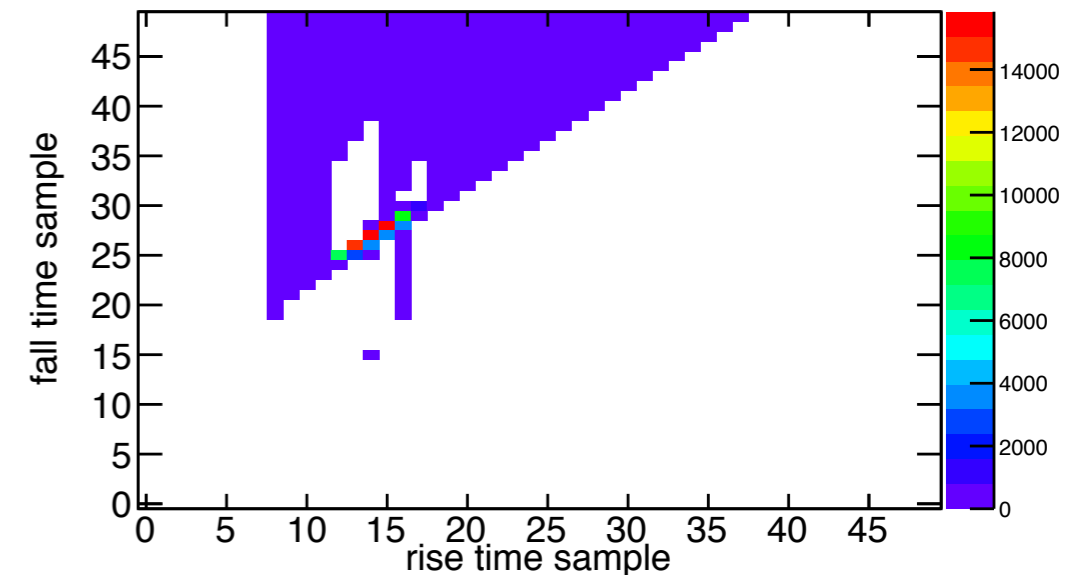
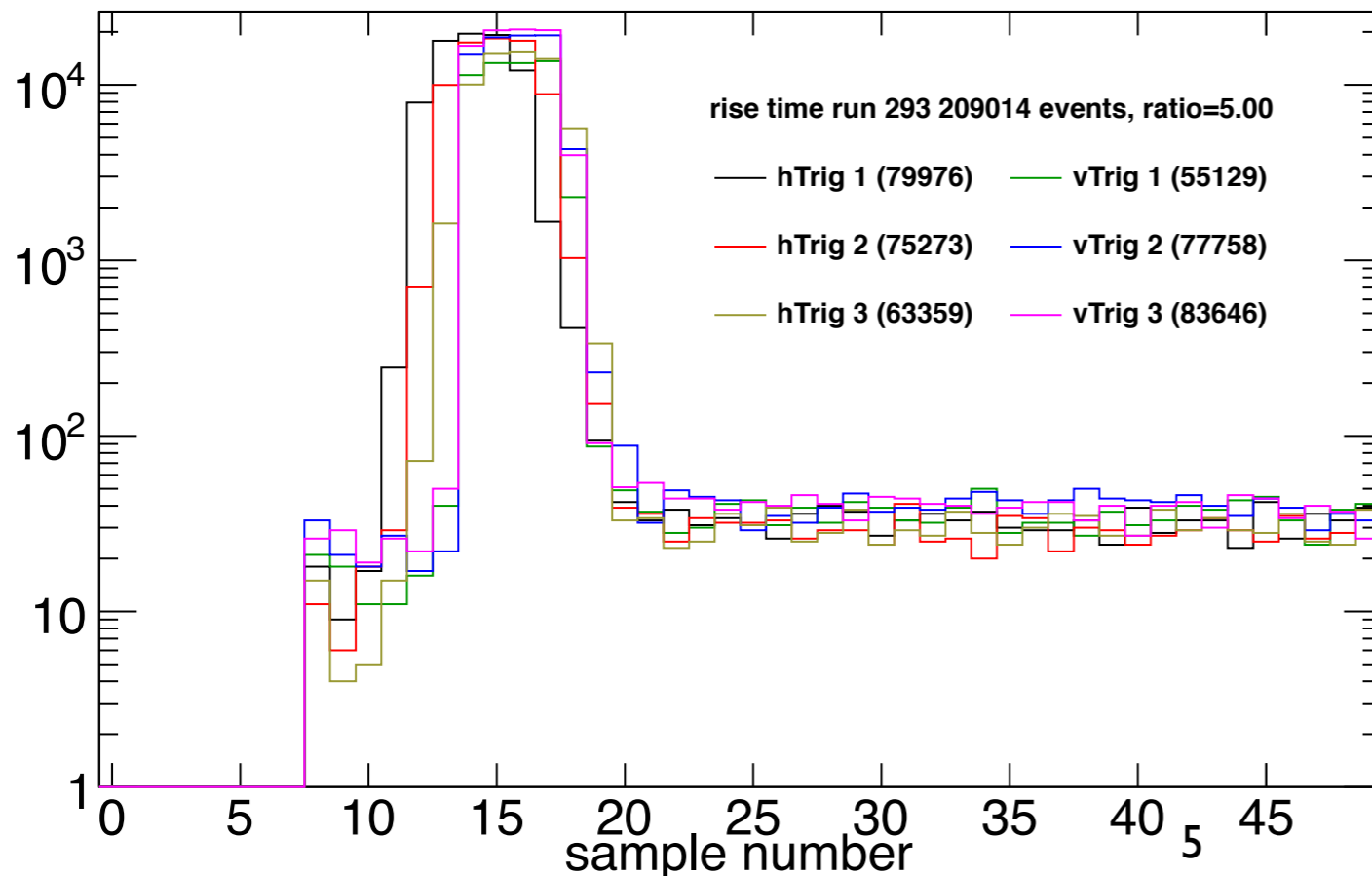
Setup of Detector

- 5x5 array of FCAL modules
- 2 arrays of 5 trigger scintillators in front
- Trigger is OR of inside 3 paddles
- Outside paddles are read out as VETO
- Thin upstream remote scintillator
- 3 fADC boards, 48 channels total



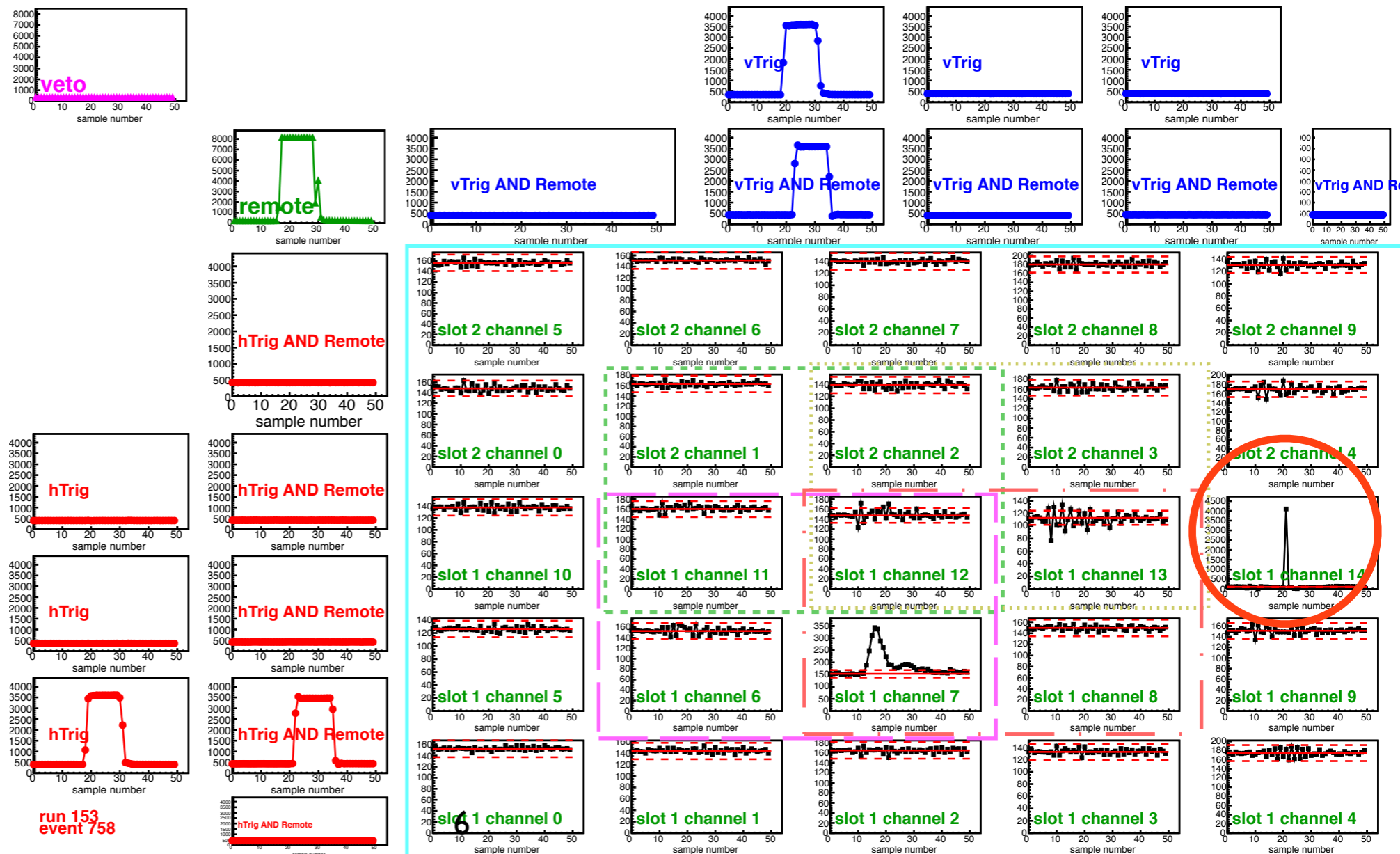
Skim of Dataset

- We want to ensure that each event is caused by one and only one incoming electron, so we make cuts on the trigger paddles
- Make sure there are no strong fluctuations in the pedestal (average of first 8 samples) for each paddle
- Cut on the rise sample (where fADC readout is x5 the pedestal) number, and also the fall sample
- No secondary pulses, only one good trigger combination.



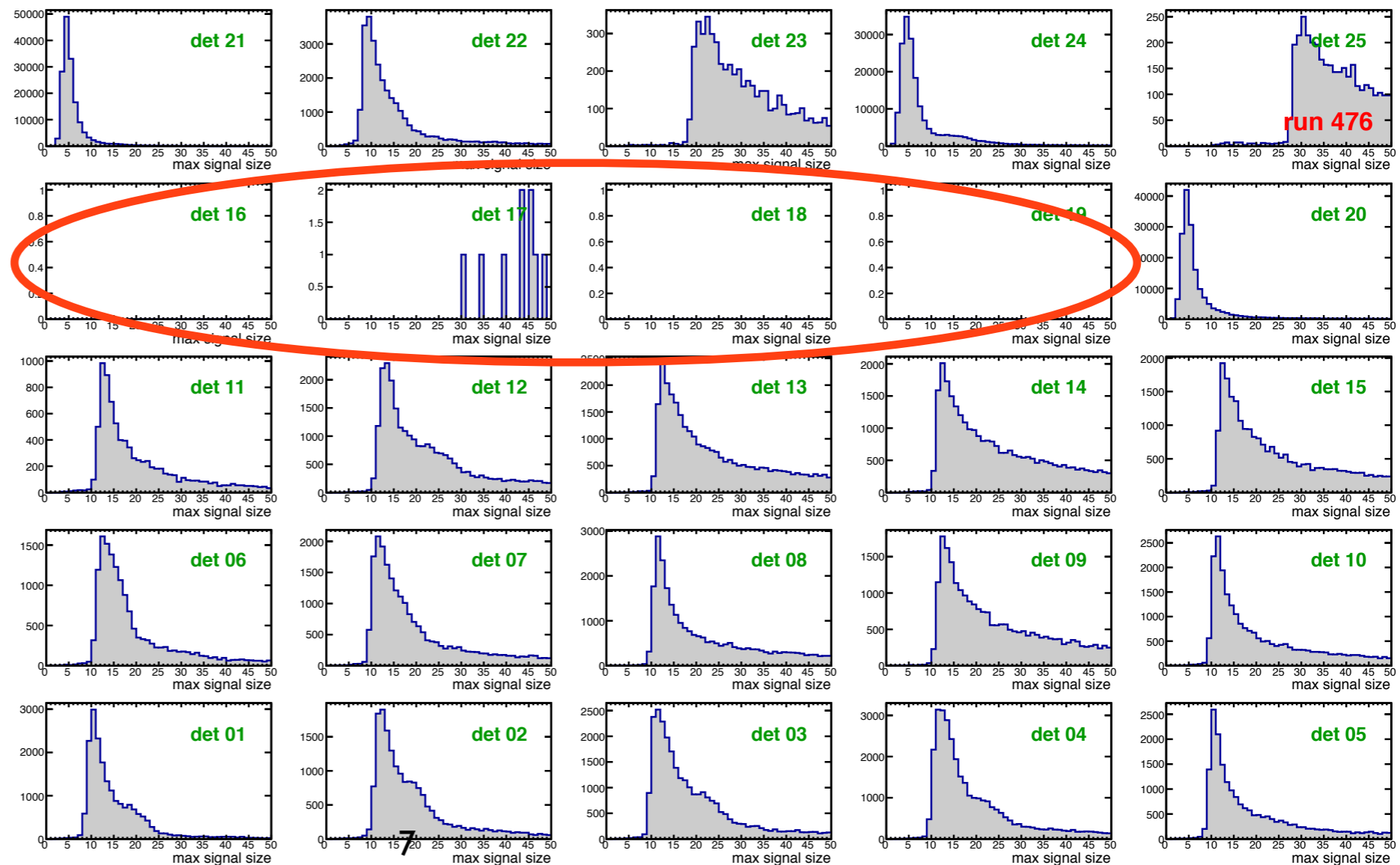
Behavior of fADCs

- Underflow of signal causes signal size of 4096 ($=2^{12}$) to be read out
- Overflow of signal causes signal size of 8191 ($=2^{13}-1$) to be read out
- Below is an event display, with the detectors in black, triggers in red and blue. An event is caused by hits in the leftmost vertical paddle and bottom horizontal paddle. The red circle shows the 4096 event.



Mistakes in Setup

- Trigger paddles were not aligned directly on top of modules, but were centered in between (actually not too bad)
- Besides the lowest energy run, all data was taken with raw+threshold mode, where the fADC channel is read out only when the maximum signal height is a certain counts above the pedestal. It was found that in all of these runs, the threshold was not set correctly for 10 modules.
- The plot shows the pedestal-subtracted maximum signal size distribution for each module for a run taken in raw+threshold mode.
- For the correctly set modules, we read out events that have a signal height 10 counts above pedestal

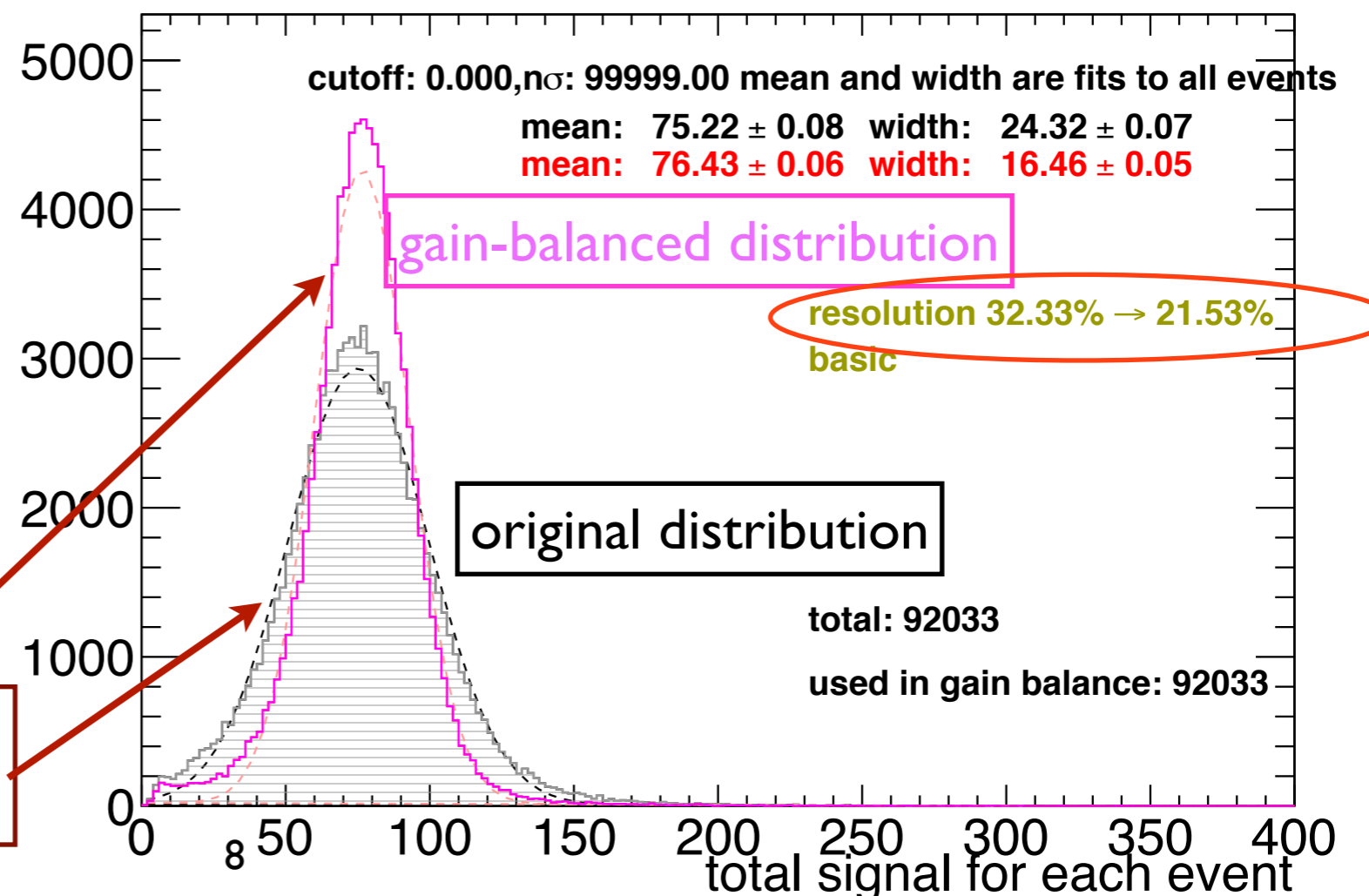


Energy Resolution Method

- Based on method used in RadPhi NIMA566, 366
- For each event,
 - Sum pedestal-subtracted signals for each module
 - Sum the signal from each module to obtain signal for that event
- For each run, minimize the width of the distribution of signal by multiplying each module i 's signal by $(1 + \epsilon_i)$
- This can be formulated as a Lagrange multiplier problem, and gives a unique solution

- The new distribution is fit with a Gaussian and linear background
- The width divided by mean is the resolution of our setup

Fit each distribution with
Gaussian + linear bg.



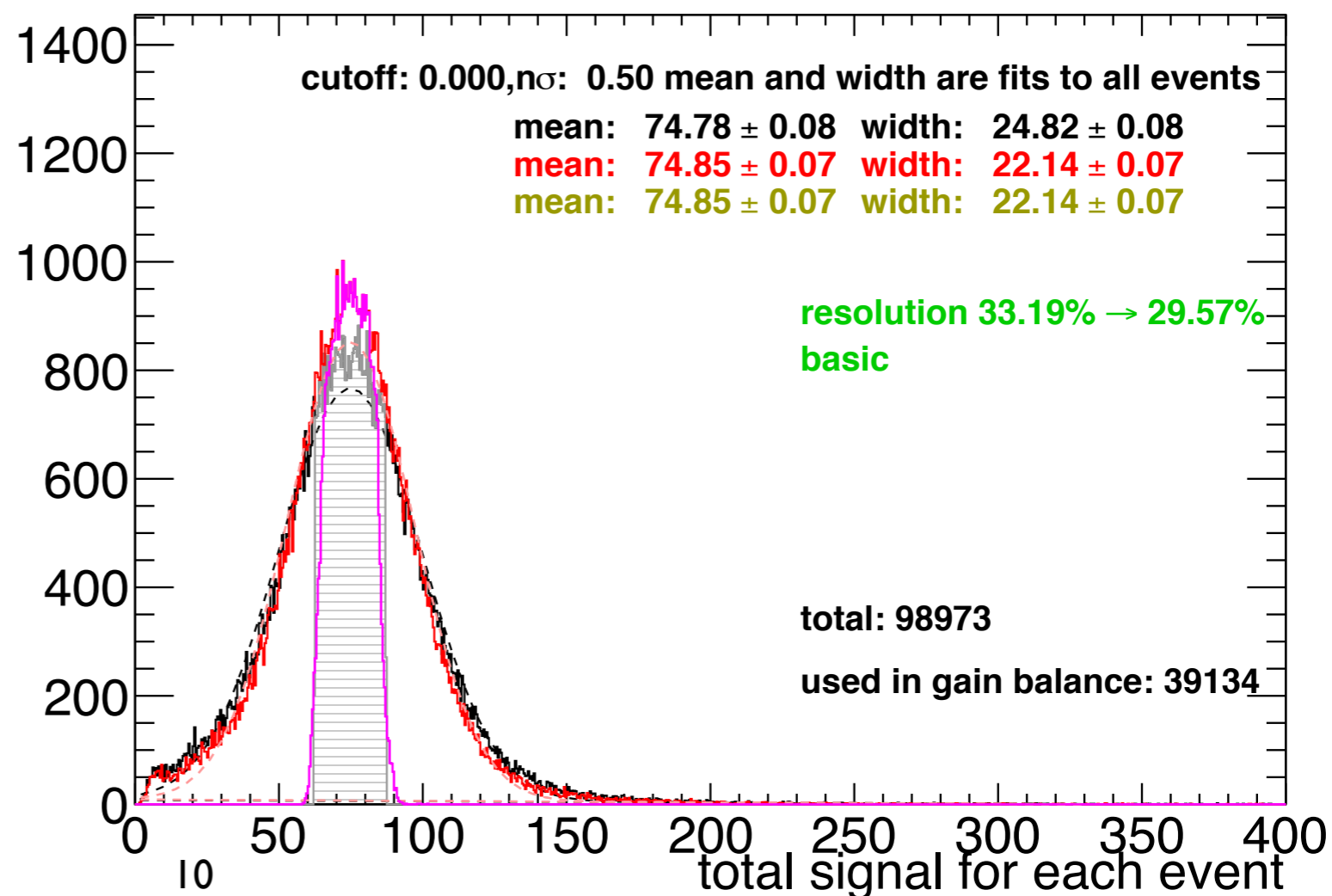
PMT HV

- The PMTs used in each module had their gains measured against HV before the beamtest started, for initial gain balancing
- The intent was that we could apply the $(1+\epsilon_i)$ corrections necessary for each module by adjusting the HV on each module
- After the beamtest concluded, it was found that the PMTs were not in the right positions, so that the initial HV values were off, as well as the adjusted HV values
- Nevertheless, since modules needing higher outputs would have had higher HV values on them, we expect some improvement, and see that in the data
- The runs that were taken with adjusted HV values do give a better resolution than ones without adjustments
- Unfortunately, we cannot know from the beamtest how well the resolution could have been with well-calibrated HV values

Variation of Cuts

- Cut on the minimum signal size from each module (=sum of ADC counts above pedestal)
- Cut on range of events to do gain balancing. Regardless of selection range to do gain balancing, all events are used to derive resolutions.
- The plot below shows when we select only $\pm 0.5\sigma$ around the initial peak. The correction factors are derived just from minimizing the width of these events, but the resolution is derived by applying the factors to all events.

- The minimum signal size worsens the resolution significantly, so we set this to 0
- The resolutions obtained by different $\pm n\sigma$ selections around the initial peak did not vary too much, as long as $n \gtrsim 3$
- See Figs 17, 18 in analysis note



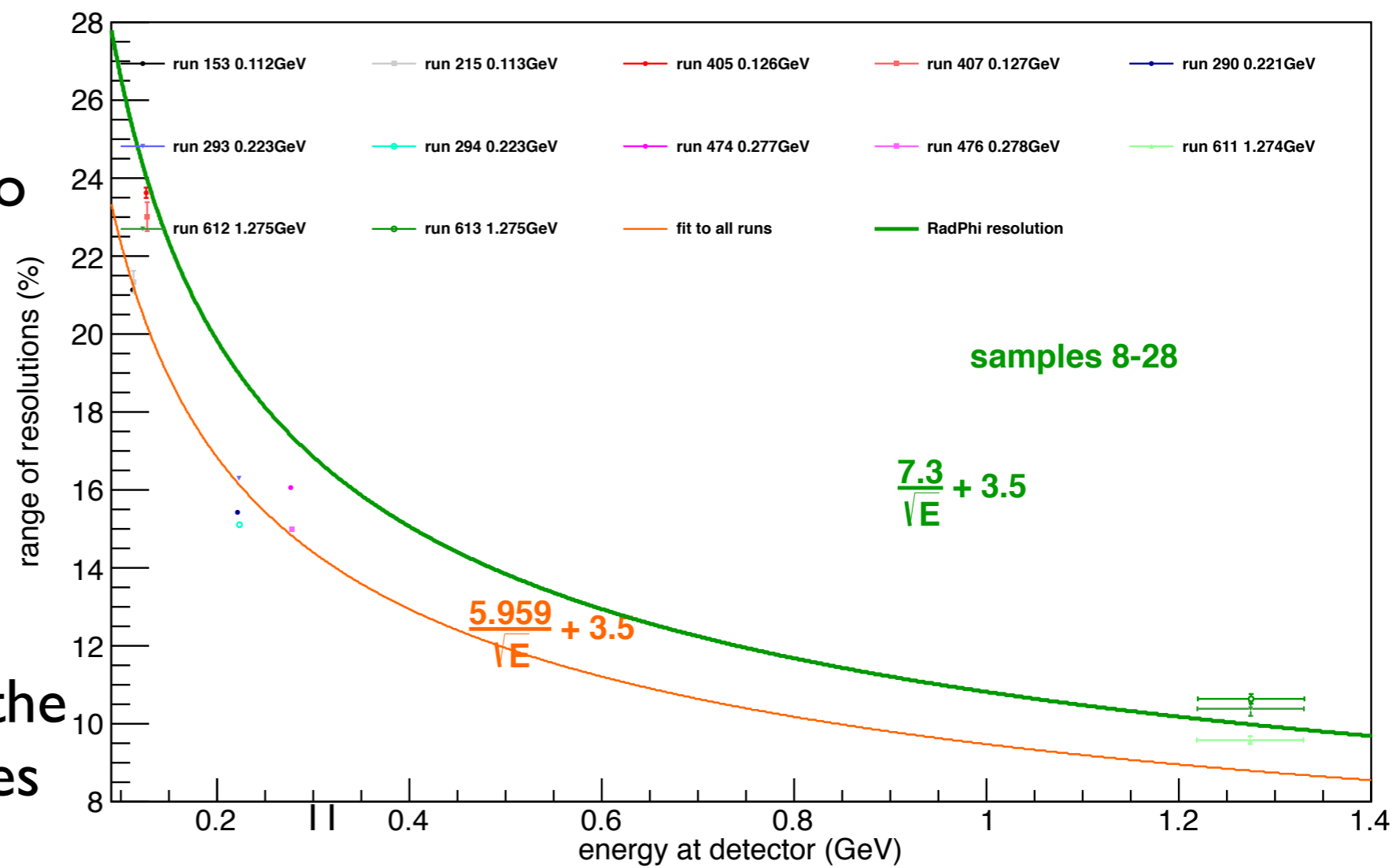
Resolution for All Energies

- Plot resolution for each run as a function of incoming electron energy
- The error on each point spans the resolution values calculated with selections of $\pm 3\sigma$ and $\pm 5\sigma$
- Data is extremely precise, but not accurate (large systematics)
- The points at 1275 MeV have a 1% uncertainty against the accelerator energy, corresponding to ± 10 cm misalignment

- A fit is done of the

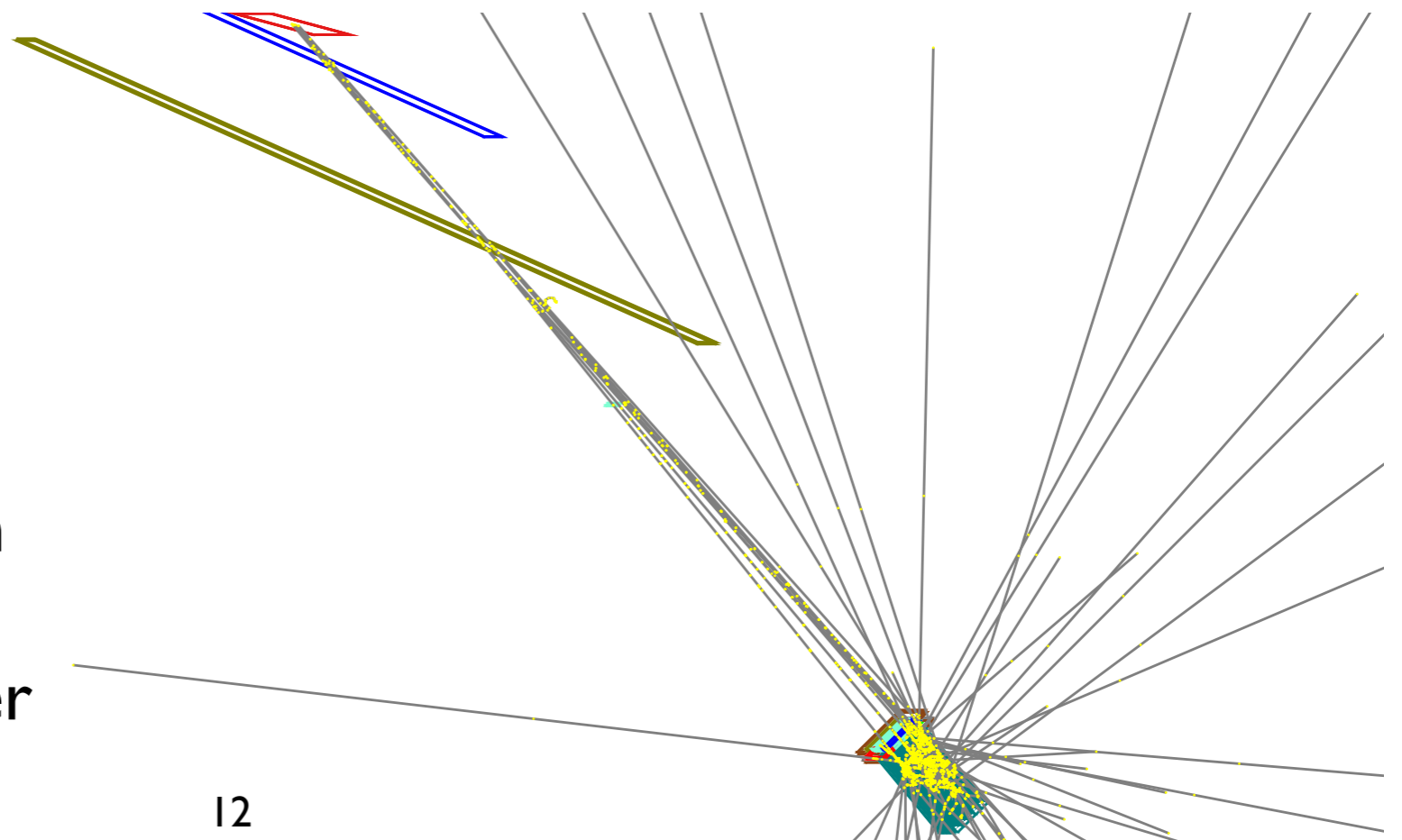
$$\text{form } \frac{\sigma_E}{E} = \frac{A}{\sqrt{E}} + 3.5$$

- The base term is fixed to that of RadPhi, as our data does not allow for precise determinations when floating this
- We do expect an improvement in the statistical term A, with the addition of optical guides



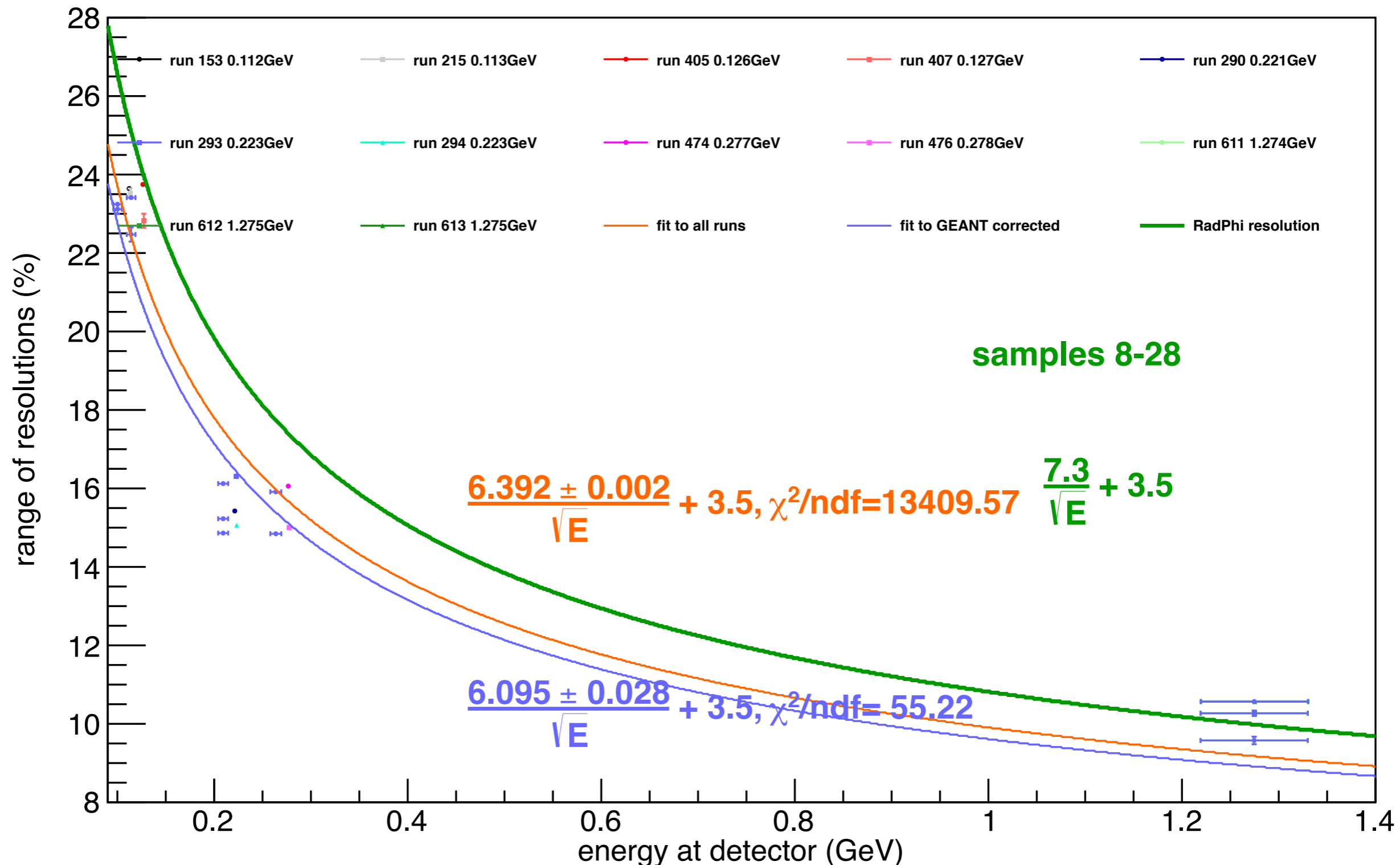
GEANT Corrections

- Due to energy loss and multiple scattering in the CLAS E-counters, T-counters etc, there is a loss and intrinsic width to the incoming electrons
- Full GEANT4 simulation of setup
- Beam is distributed with correct angles, position, and energy distribution
- For each run energy, the spread of energies entering our detector is calculated, and fit to a Gaussian
- For all runs, the mean energy is ~ 10 MeV lower than what was generated, and the width is 4.3-5.7 MeV
- We subtract off the width/mean of the incoming electron energies in quadrature from our beamtest results
- The central values of the energies are also taken down by ~ 10 MeV
- This results in a slightly better resolution for the overall fit



Final Results of Resolution

- Orange number is without GEANT correction
- Blue number is with GEANT correction

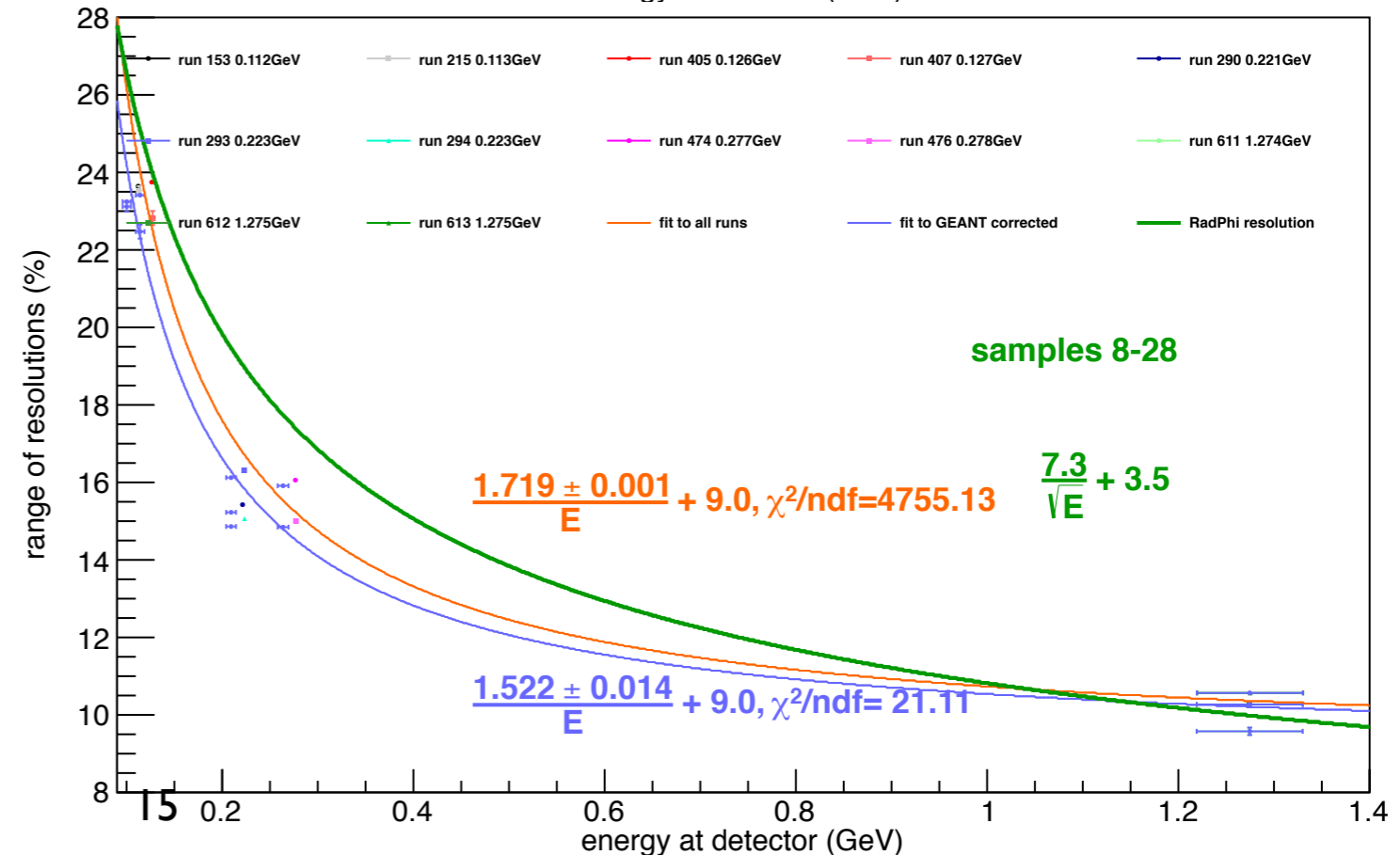
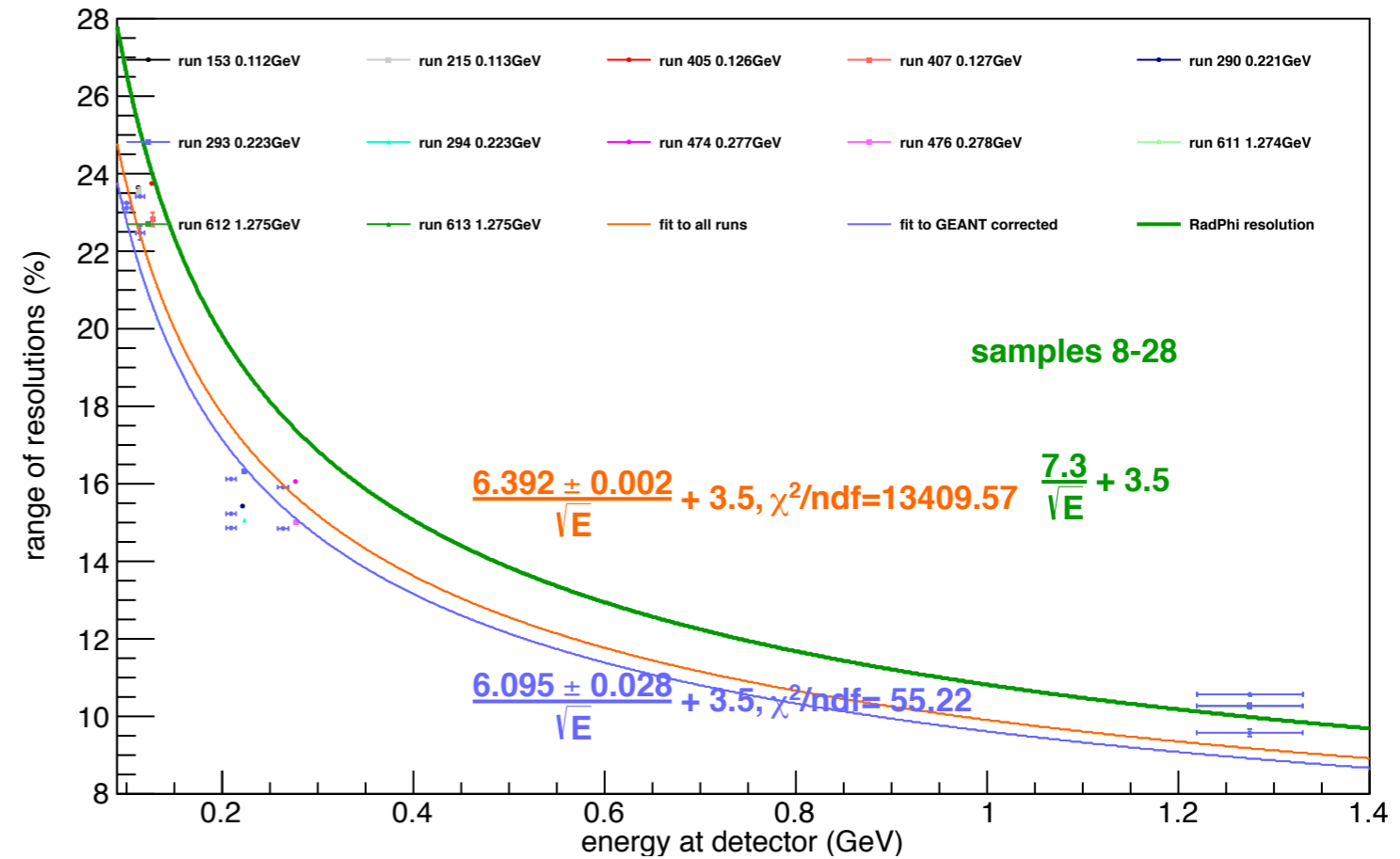


Systematics of Resolution

- Our error bars in each figure span the values obtained by $\pm 3\sigma$ and $\pm 5\sigma$ selections
- We tried an asymmetric cut around the initial distribution
- We look at the different trigger combinations, which give different resolutions (5 good combinations, 4 bad)
- We can include the highest energy runs with only a small effect on the overall fit
- We can include the GEANT results, which bump down the number a little
- The statistical error on each overall fit is tiny, but in all cases, we have a terrible χ^2/NDF . We can blow up the errors on each point so that $\chi^2/\text{NDF} \sim 1$. This does not affect the fit value itself.
- We varied the base term, which was fixed at 3.5 (value obtained by RadPhi)
- We varied the fit function from $A/\sqrt{E} + B$ to $A/E + B$

Final Results

- If we take the $A/\sqrt{E} + B$ form, with B fixed to RadPhi value, we get $A = 6.1$, with good trigger combinations giving $A = 5.4-6.2$
- We can vary the base term within the errors of RadPhi (the two terms are highly negatively correlated), and we get a change in ~ 0.4 in our final results.
- If we take the $A/E + B$ form, the final fit is something like this.

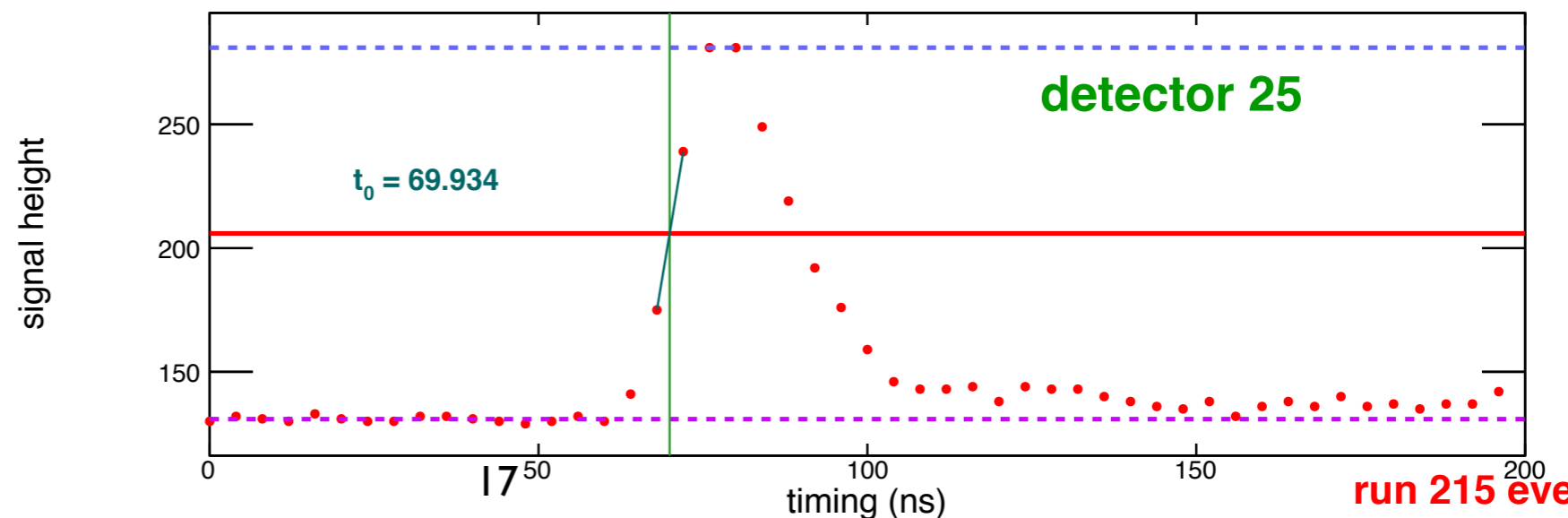
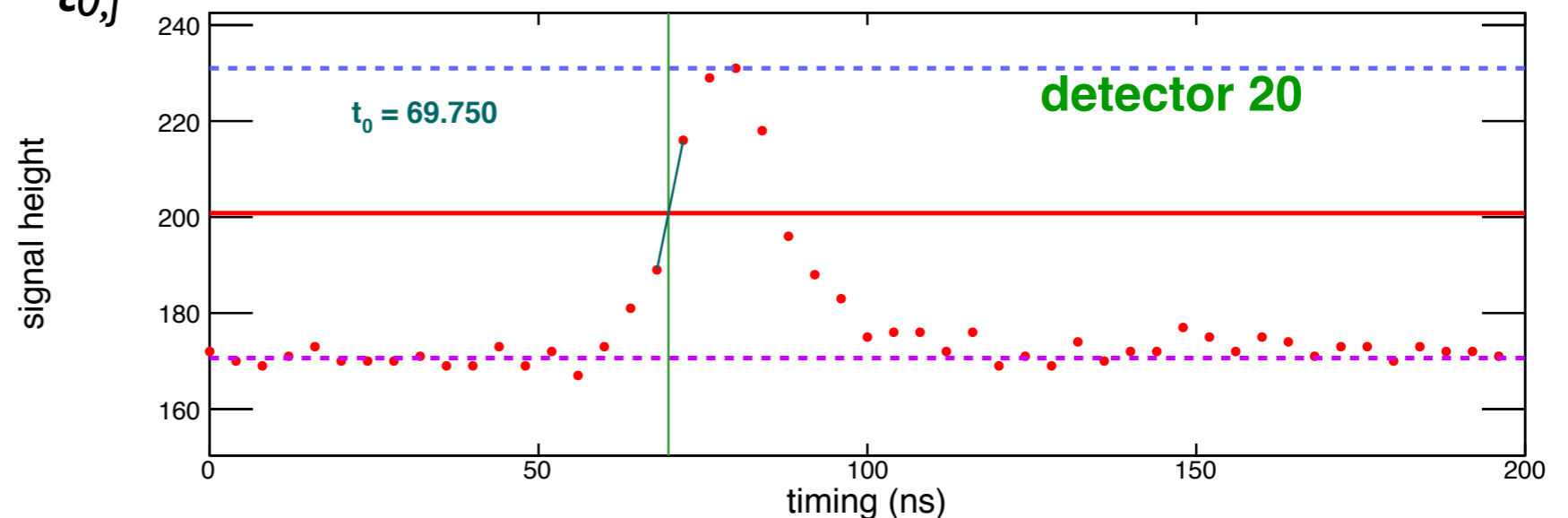


Timing Resolution

- Motivation: use of timing information allows FCAL to determine which beam bucket the photon of interest came from
- Goal is to show that the timing resolution is much better than 2 ns, the accelerator timing
- Main restriction is the fADC sampling frequency, 4 ns
- Method is the same as the one in NIMA622, 225 (2010), where the fADC timings were tested at IU with a pulsed LED

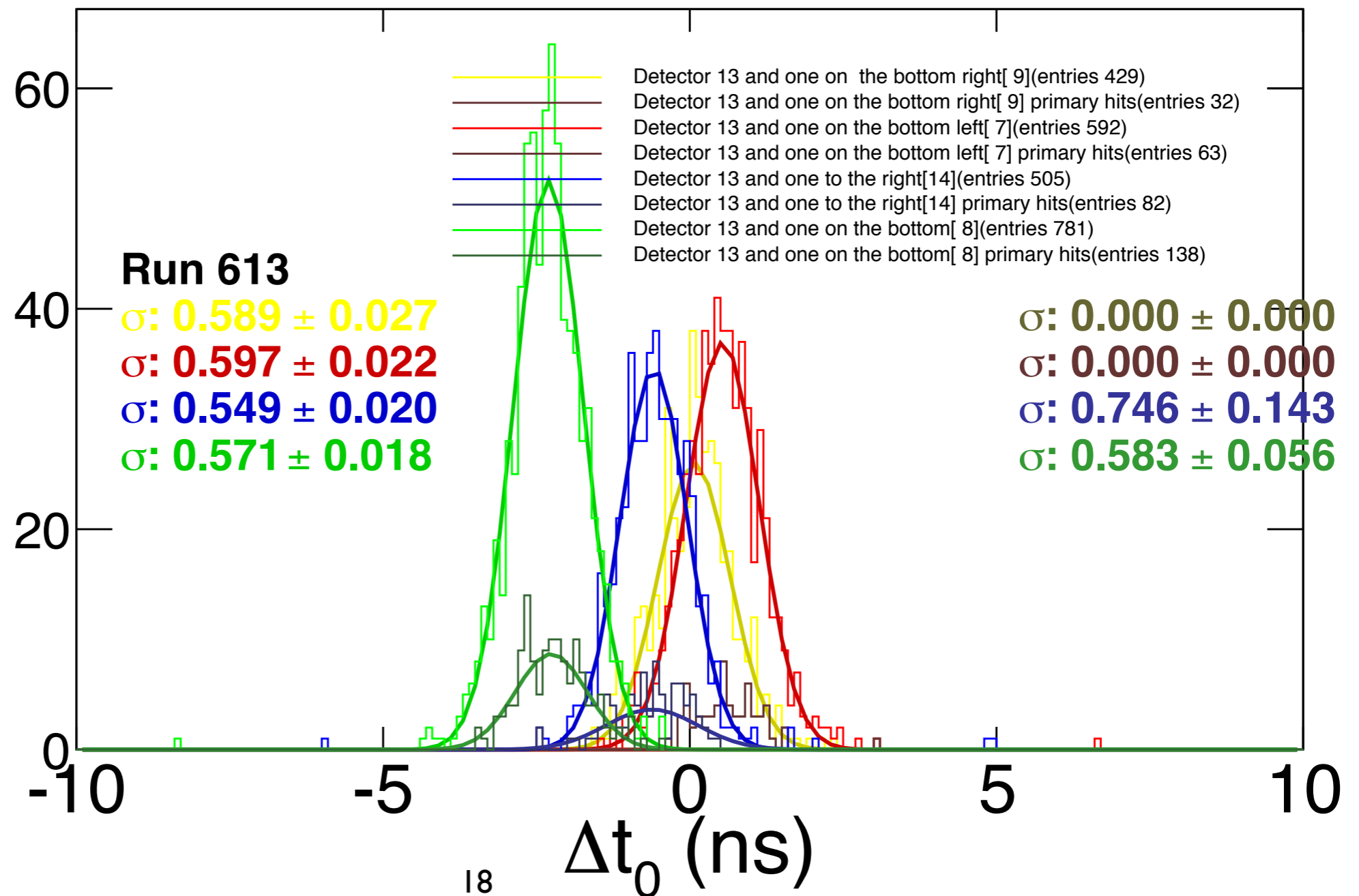
Timing Resolution Method

- Within a single module, find the largest sample S_p (above pedestal)
- Find the two samples that straddle height $S_p/2$
- Linearly interpolate between the two samples, and find where the line crosses $S_p/2$, call this timing t_{0i} for module i
- Determine this for two modules i,j within the same event, and take the difference: $\Delta t_{ij} = t_{0,i} - t_{0,j}$



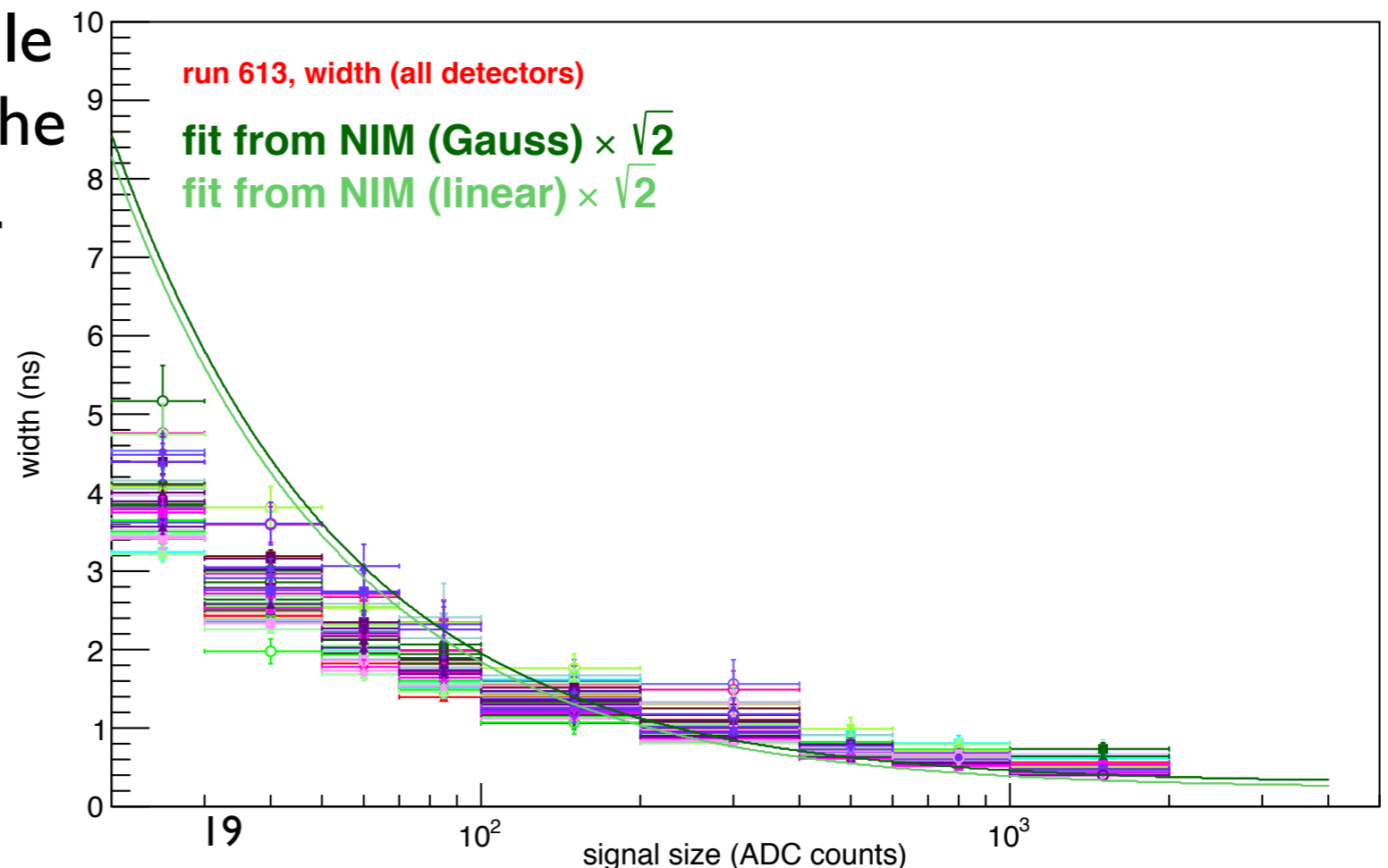
Timing Resolution

- Plot of Δt_{ij} for a given module and 4 surrounding modules
- All nearest-neighbor combinations were calculated
- Each timing difference is fitted with a Gaussian, and the mean and width are recorded, width σ_{ij} is what we want



Timing for Combinations

- Plot of Δt_{ij} for a given module and 4 surrounding modules
- All nearest-neighbor combinations were calculated
- Each timing difference is fitted with a Gaussian, and the mean and width are recorded, width σ_{ij} is what we want
- σ_{ij} varies very strongly with S_p (largest signal size above pedestal), so we have divided the data in S_p
- The plot shows σ_{ij} against S_p
- Since σ_{ij} has contributions from both modules i and j , we expect a factor of $\sqrt{2}$ compared to each module
- The green curves are from the previous paper, scaled by $\sqrt{2}$

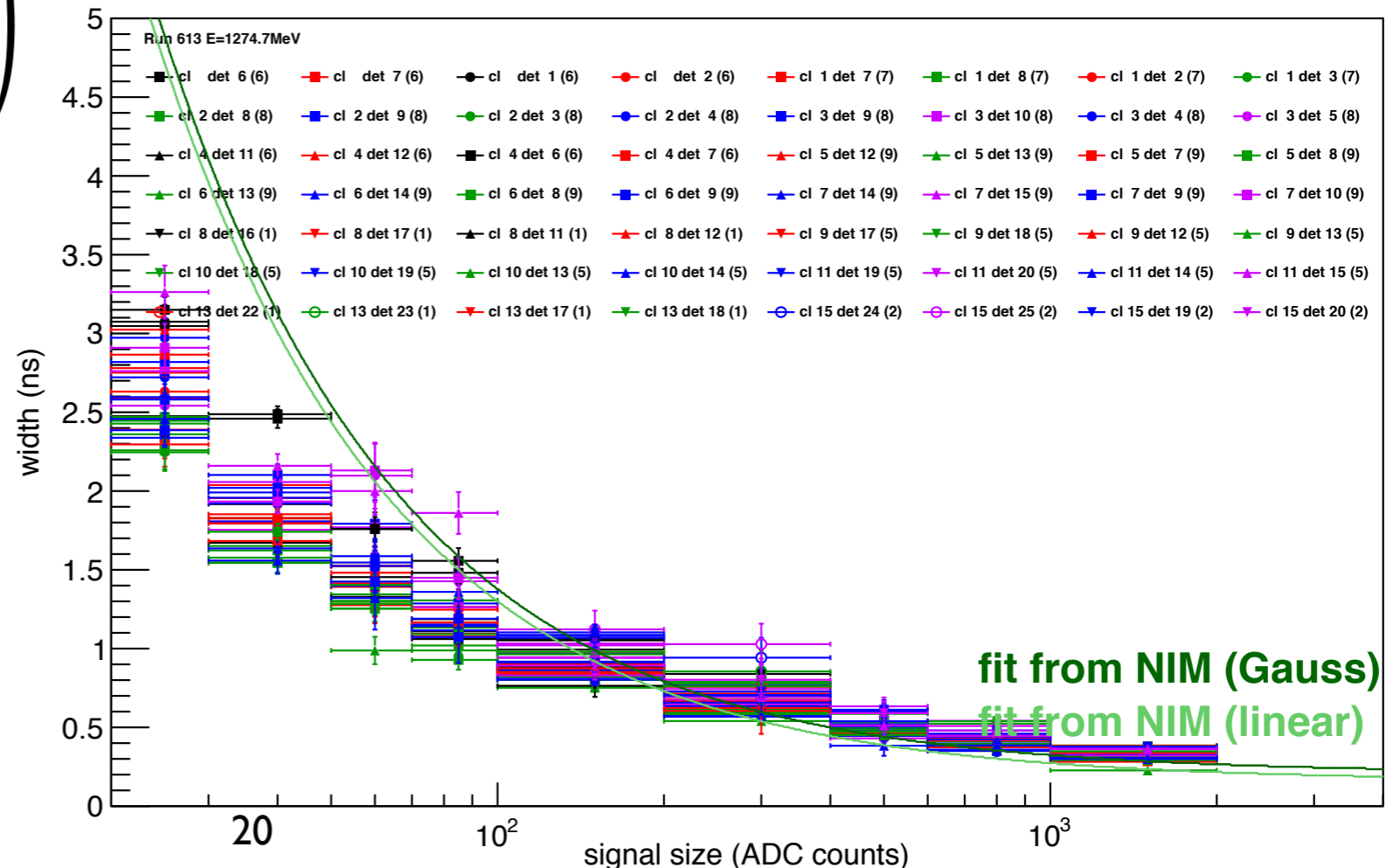


Clustering for Timing

- To get the intrinsic timing resolution for each module, we can create clusters of 2x2 arrays (16 in all)
- We require that for each S_p , we have 6 good combinations of measurements
- We assume that each σ_{ij} is a combination of each module's resolution added in quadrature
- From the 6 measurements, we can do a fit to determine each σ_i

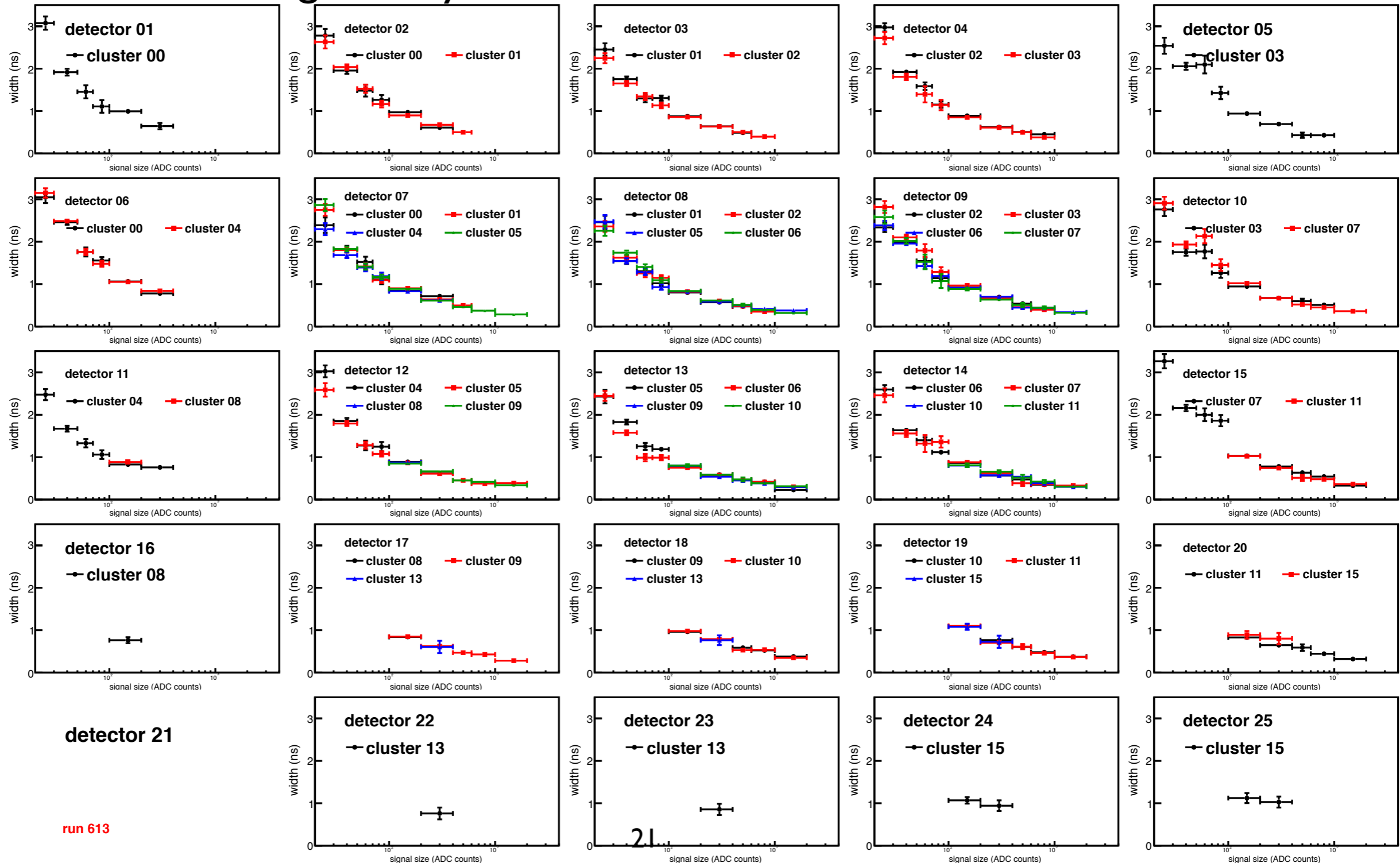
$$\chi^2 = \sum_{i,j>i} \left(\frac{\sigma_{ij} - \sqrt{\sigma_i^2 + \sigma_j^2}}{\delta\sigma_{ij}} \right)^2$$

- The resolution is similar, if not better than that obtained in a controlled environment. The previous measurement was for $300 < S_p < 1500$



Timing Resolution Results

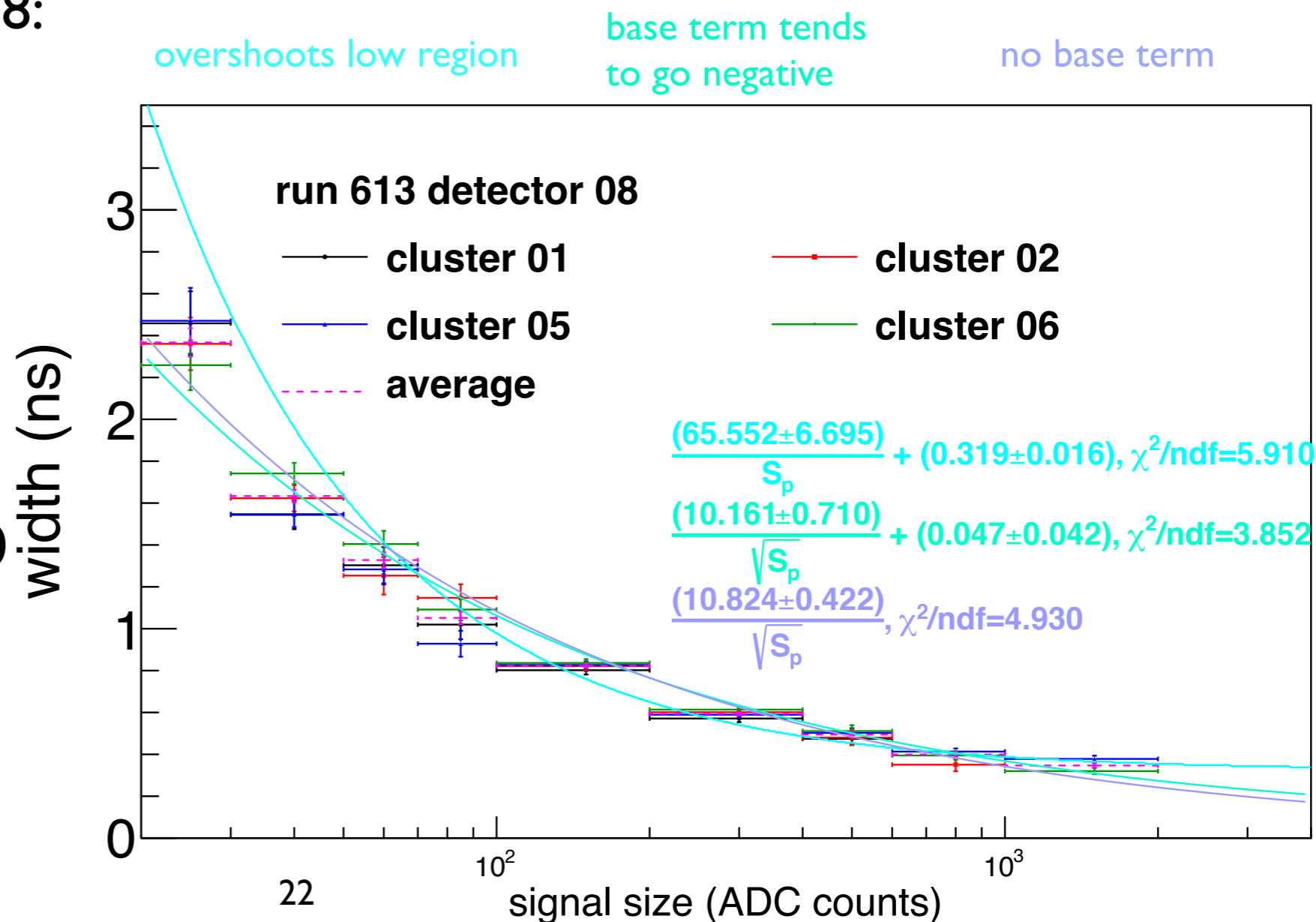
- Plot resolution for each module, which has its resolution determined up to 4 times from different clusters (different colors)
- Different clusters give very consistent results



Summary of Timing

- Each module's timing resolution can be determined using adjacent modules, and results are consistent between different combinations
- The timing resolution depends strongly on the maximum signal height
- We can combine the results for each module by taking the weighted average and standard deviation of each measurement.
- Example plot for module 8:

- Fit with $A/\sqrt{S_p} + B$, $A/\sqrt{S_p} + B$, $A/\sqrt{S_p}$ for each module
- Average, standard deviation of “good” modules gives $A = 71.2 \pm 11.1$, $B = 0.37 \pm 0.10$ for 1st function. Previous NIM paper result: $A = 114 \pm 46$, $B = 0.155 \pm 0.077$



Summary of Results

- Results are currently being worked into NIM paper
- With fixed base term, the statistical term in the energy resolution is slightly better than that of RadPhi
- Timing resolution is as good as, or even better than previous NIM results suggest

Many thanks to everybody who helped in the beamtest