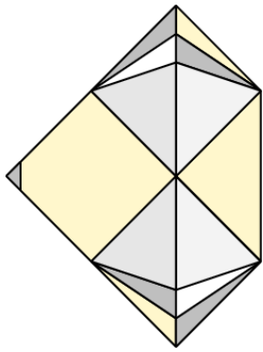
ETH zürich



Recent results of diamond radiation tolerance

Dmitry Hits
for
RD42 Collaboration

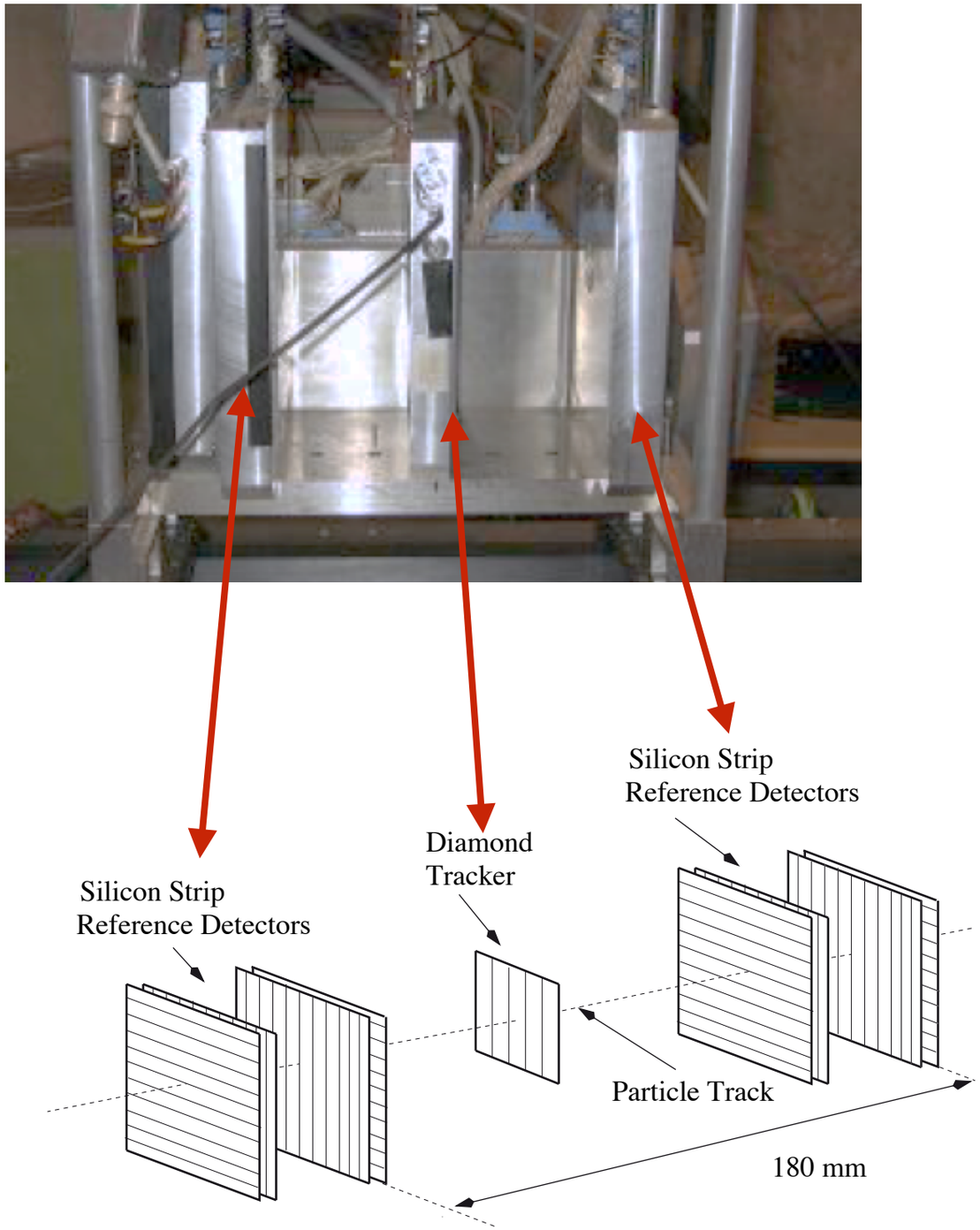
ETH Institute for
Particle Physics

Outline

- Study of radiation hardness
  - Measurement procedure
  - Analysis procedure
  - Results
  - Comparison with FLUKA Displacement Per Atom (DPA)
- Pulse height vs rate study
  - Measurement procedure
  - Analysis procedure
  - Results
- Conclusions

Beam test procedure

- CERN SPS H6A line
  - 120 GeV protons
  - 3-4k triggers per spill (10 sec)
- Strasbourg telescope
  - VA2 readout chip
  - few μm resolution
- Measure each sample at 4 different bias voltages
  - low (~500 V), high (~1000 V)
  - positive, negative polarities
- "Pump" each sample with a source before the measurement and before polarity change
  - filling the active traps

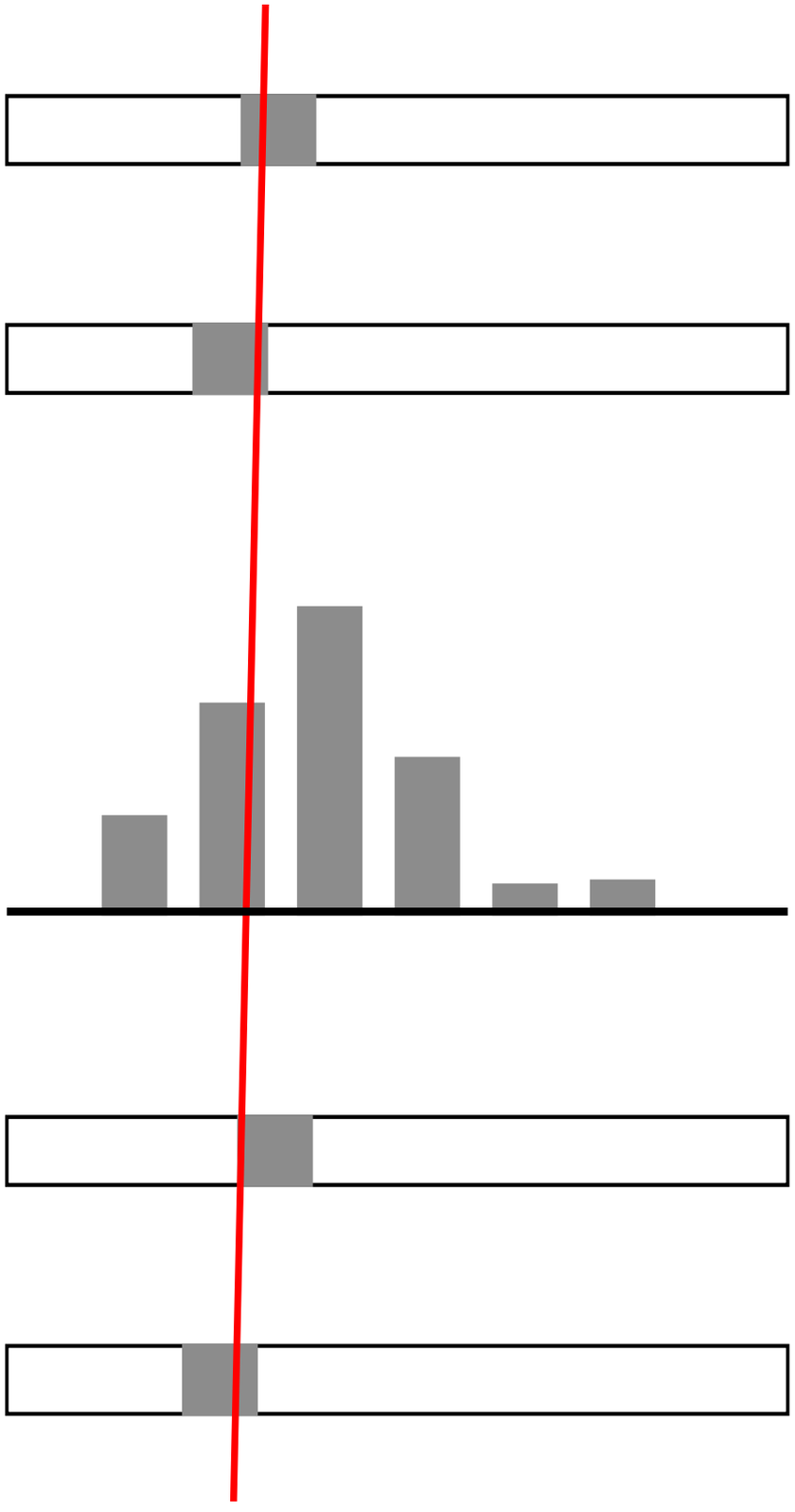


Analysis procedure

- Perform pedestal analysis and subtraction
  - Correct for the common mode
- Cluster channels above threshold(s)
  - “seed” threshold, “hit” threshold
- Select events with only one cluster in each telescope plane
- Align telescope
- Select events with only one cluster in each telescope plane and only one cluster in the diamond plane
- Align diamond plane to the telescope
- Transparent analysis
  - require only “good” tracks in the fiducial region of the telescope
  - no requirement on the diamond plane - unbiased

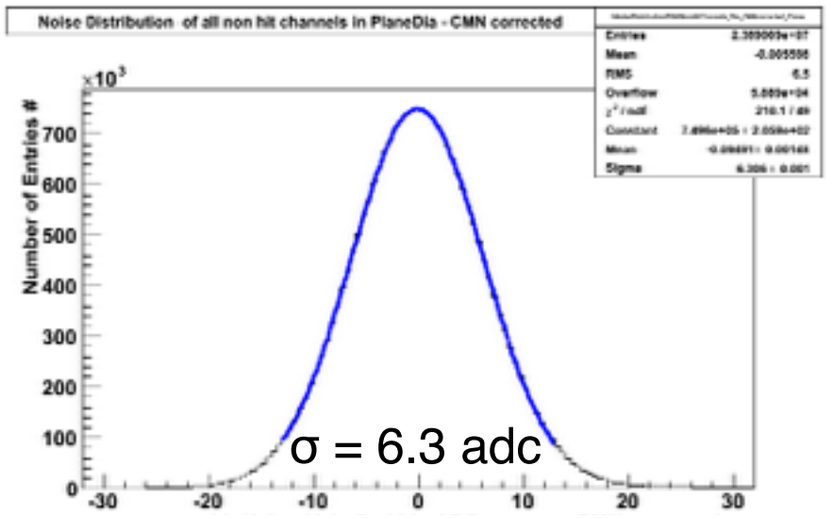
Transparent analysis

- Telescope plus DUT is aligned on a subset of tracks
  - not used in analysis
- Use telescope to predict hit position in the DUT
- In 10 strips surrounding the predicted position find two neighboring strips with the largest pulse heights
  - Measure cluster pulse height

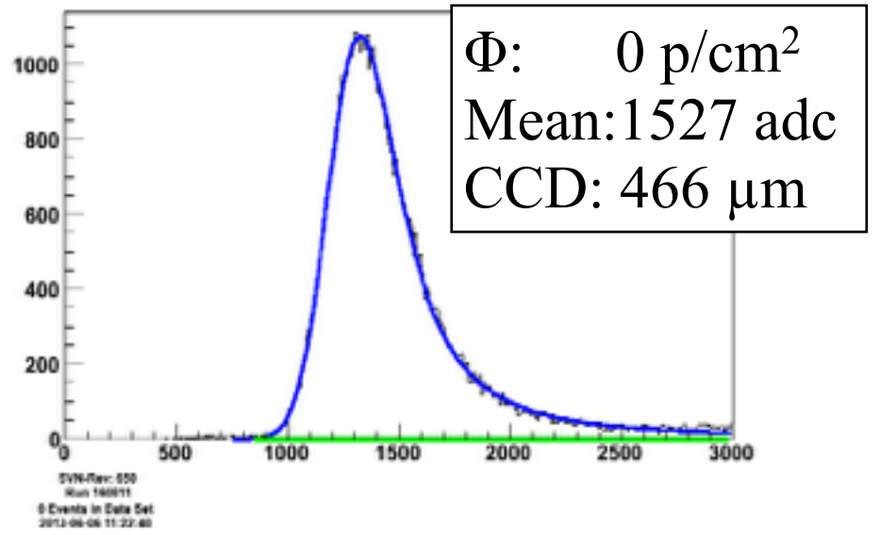


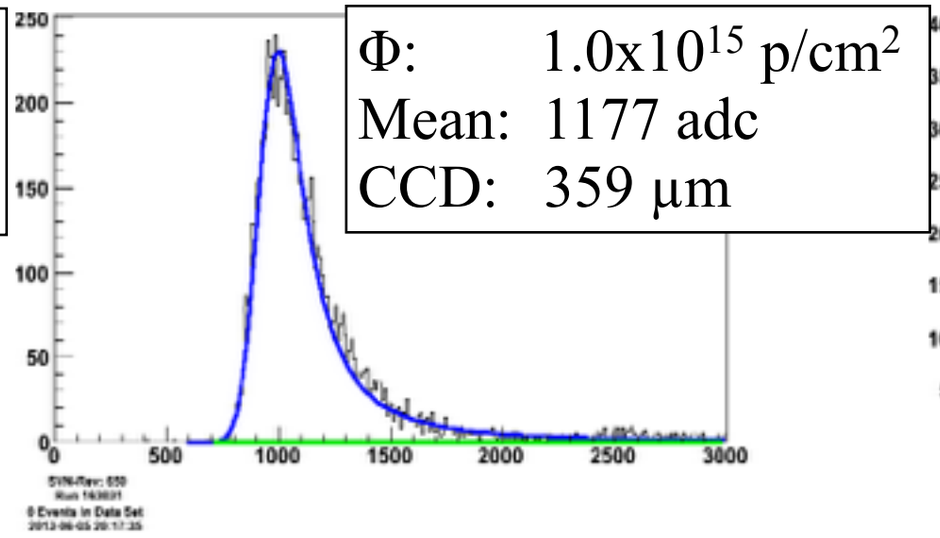
Pulse height for single crystal CVD diamond: 800 MeV proton irradiation

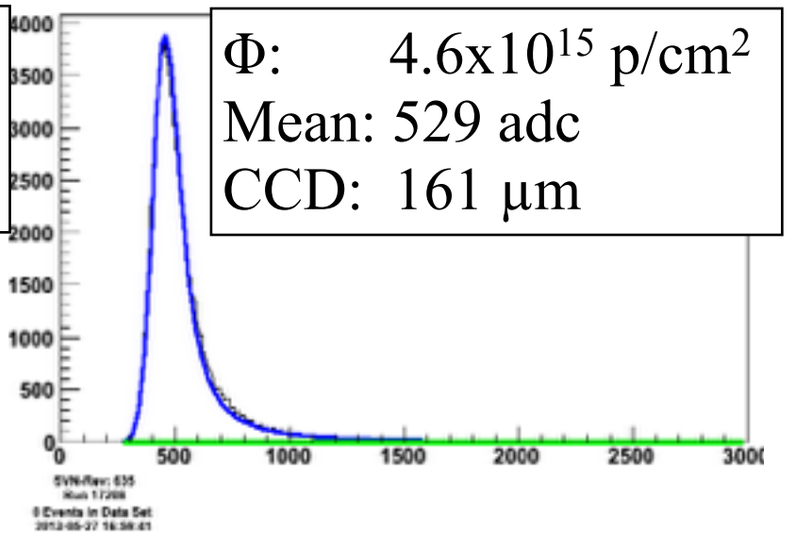
- single crystal CVD diamond sample
  - CCD is measured = to thickness for non-irradiated
- Noise is on the order 80-110 electrons
  - < 1.6% of the mean pulse height for the highest irradiation dose
- Pulse heights for 2 highest out of 10 strips closest to the predicted hit position
  - Pulse height shown for bias +1000 V (negative are similar)



Noise in non-hit channels
Common Mode corrected

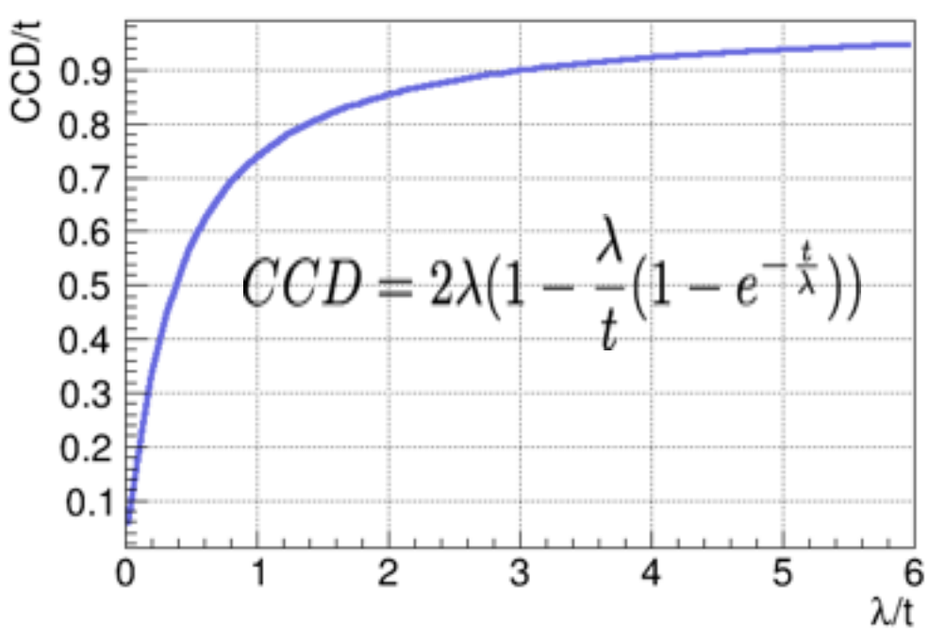






CCD vs Mean Free Path

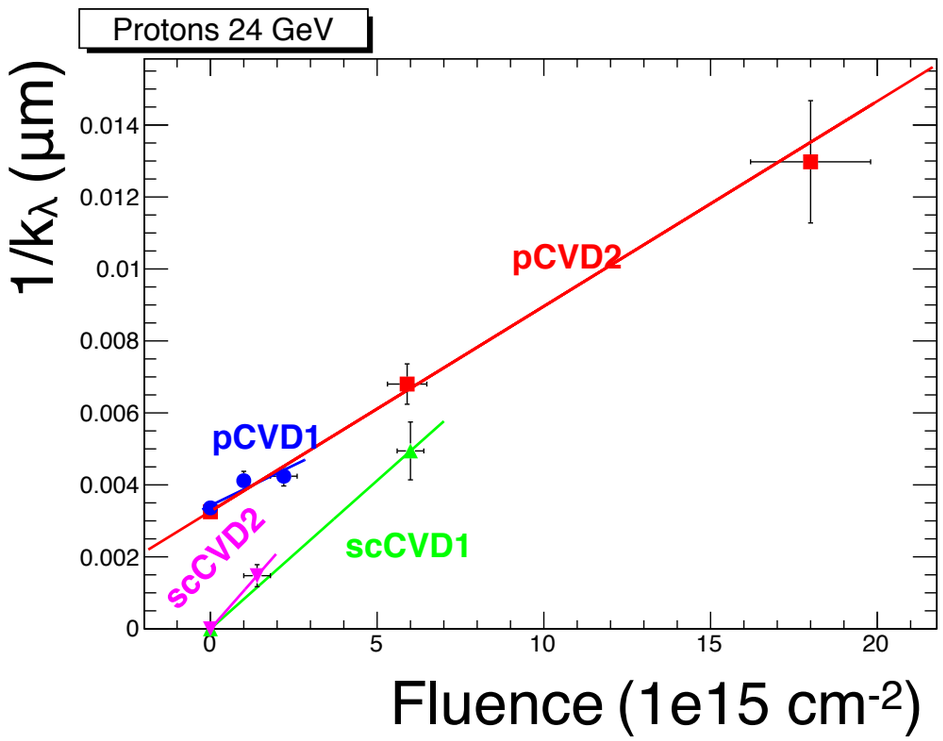
- We measure CCD
- Radiation-induced traps in fact decrease the mean free path (mfp)
- CCD~ mfp_e+mfp_h in thick detectors t >> mfp, CCD
- CCD degradation formula not applicable to scCVD since $CCD_0 = t$; $mfp_0 \rightarrow \infty$
- Relation CCD ↔ mfp for homogeneous material

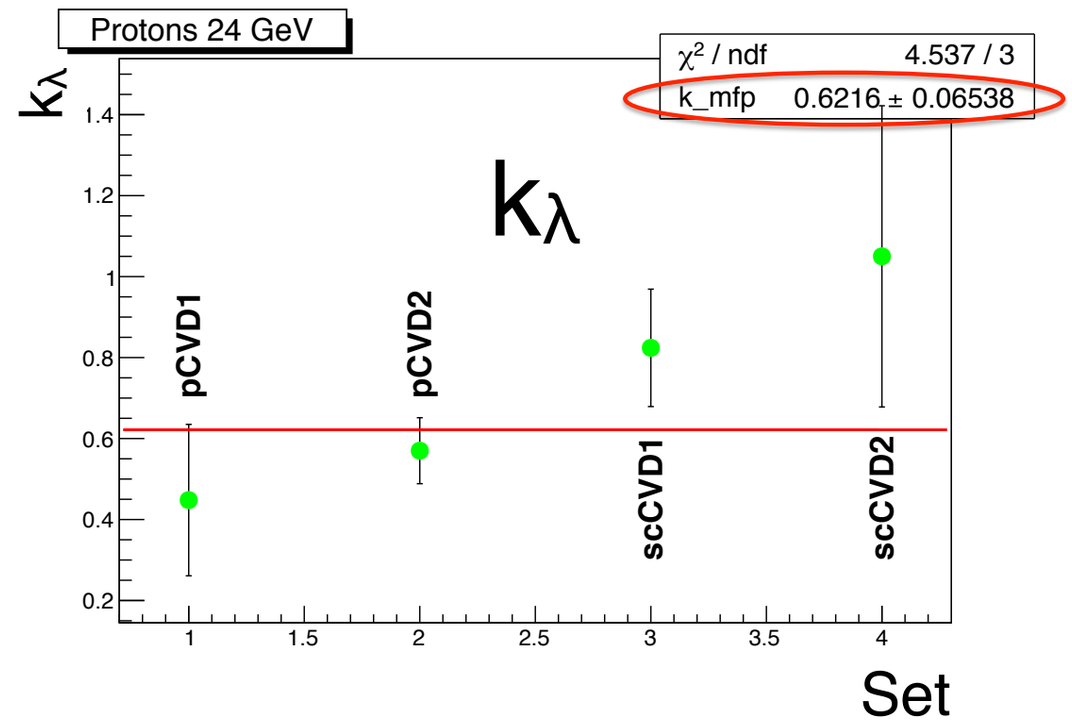


Damage curves in the subsequent slides are fitted with the following ansatz

$$\frac{1}{\lambda} = \frac{1}{\lambda_0} + k_\lambda \Phi$$

24 GeV protons: CERN PS

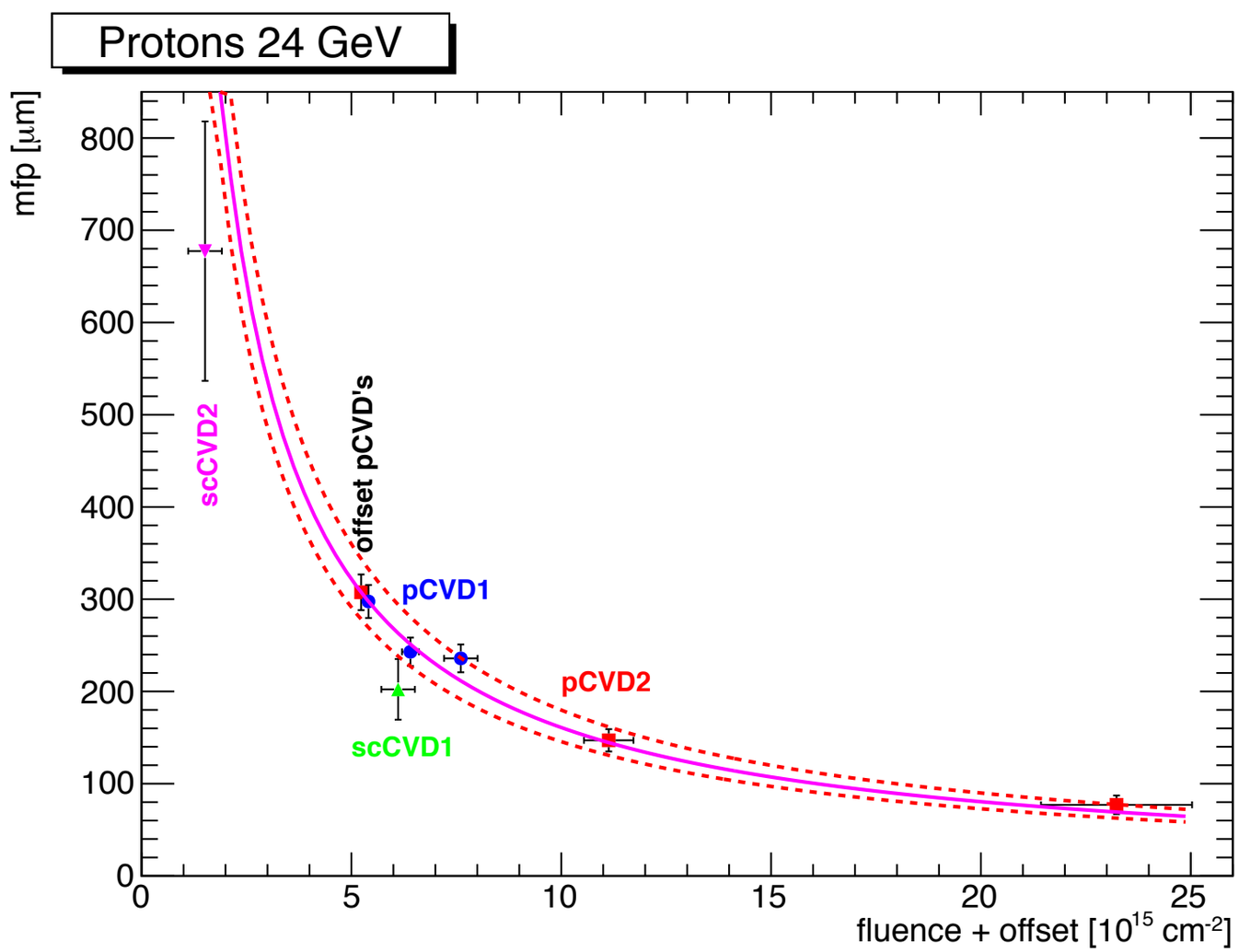




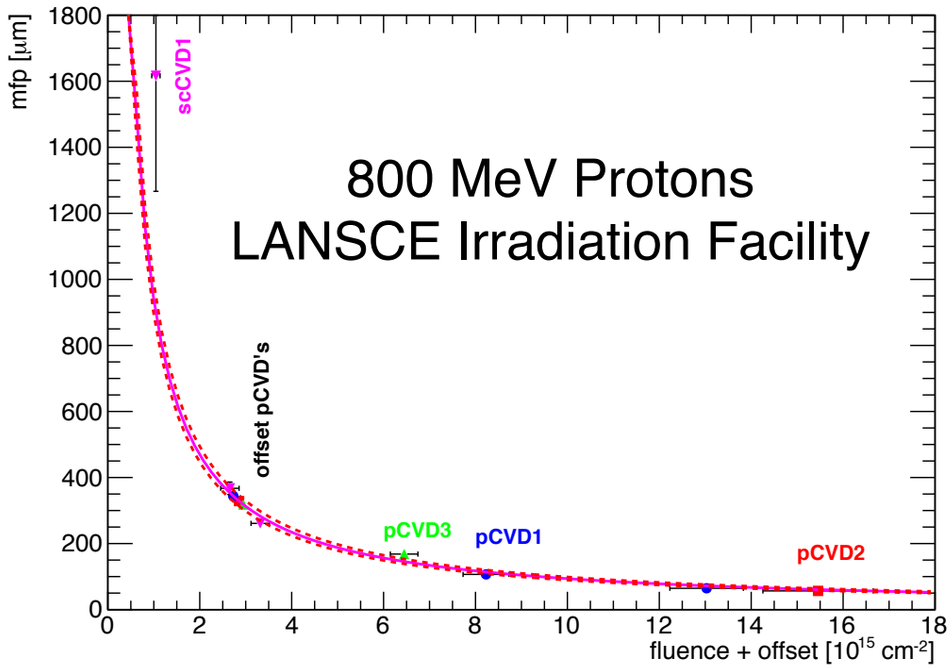
- Each irradiation set fitted separately assuming ansatz $\frac{1}{\lambda} = \frac{1}{\lambda_0} + k_\lambda \Phi$
- The damage constant is the average between various irradiation sets

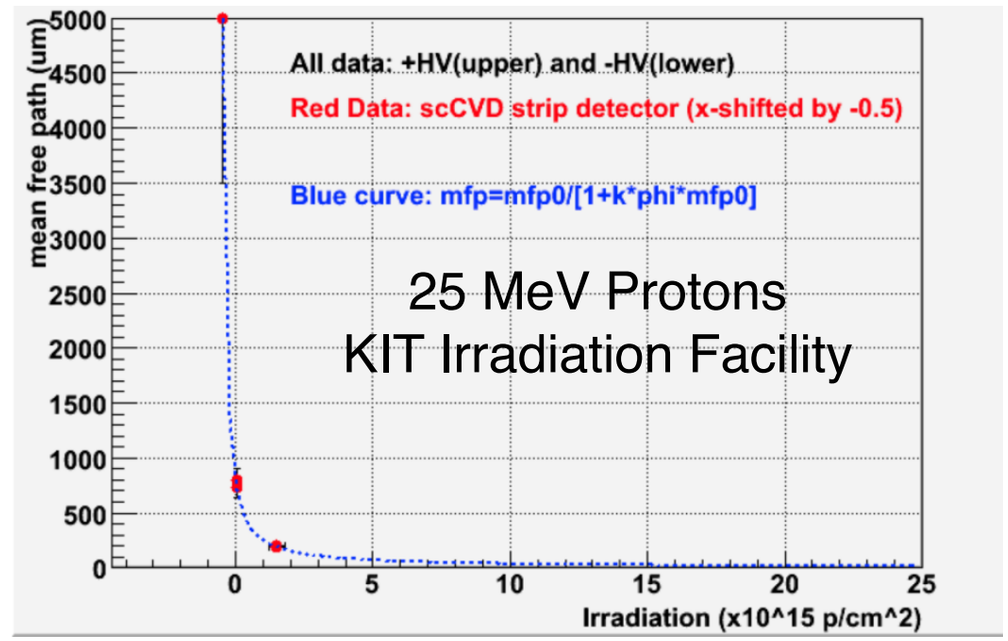
24 GeV protons: CERN PS

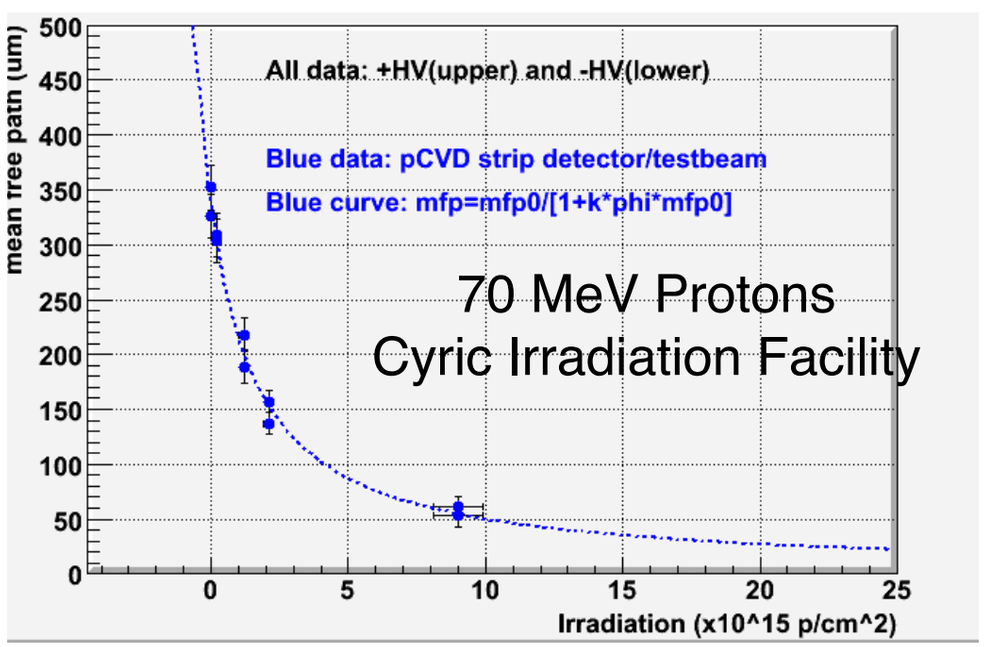
- $k_\lambda \sim 0.62 \pm 0.07 \times 10^{-18}\ \mu m^{-1} cm^{-2}$
  - pCVD offset by $\sim 5 \times 10^{15}\ cm^{-2}$
  - pCVD is considered as a "pre-damaged" scCVD
  - Both pCVD and scCVD have the same damage constant

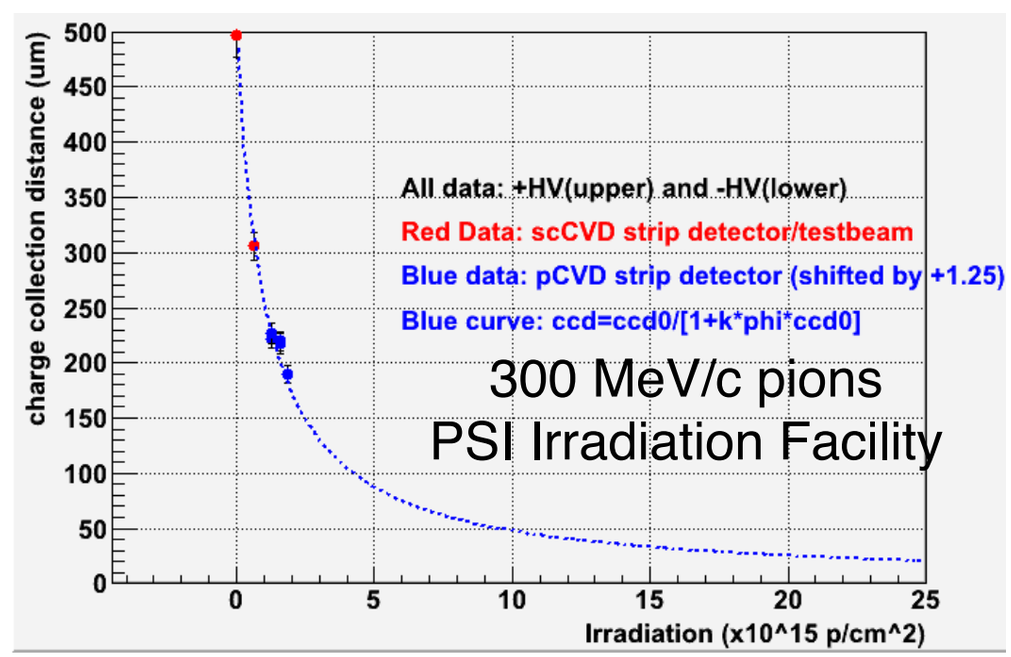


800 MeV, 70 MeV, 25 MeV protons
300 MeV/c pions









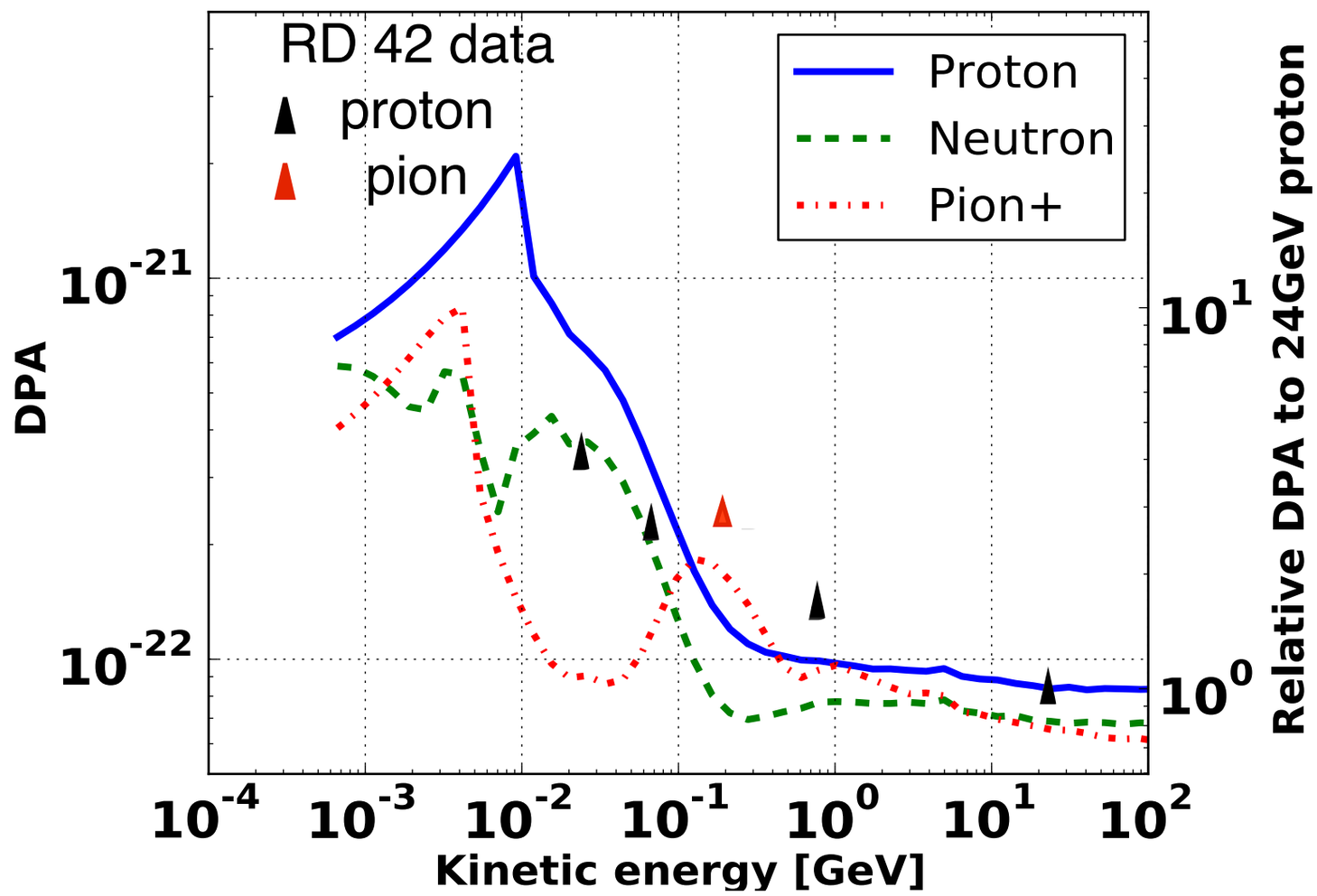
Summary of RD42 test beam results

- k_λ (24 GeV p) ~ $0.62 \pm 0.07 \times 10^{-18}$ $\mu m^{-1} cm^{-2}$
  - ~10% uncertainty on relative k_λ

particle	Energy	Relative k
p	24 GeV	1
	800 MeV	1.7
	70 MeV	2.7
	25 MeV	4.2
π	300 MeV/c	2.9

DPA comparison

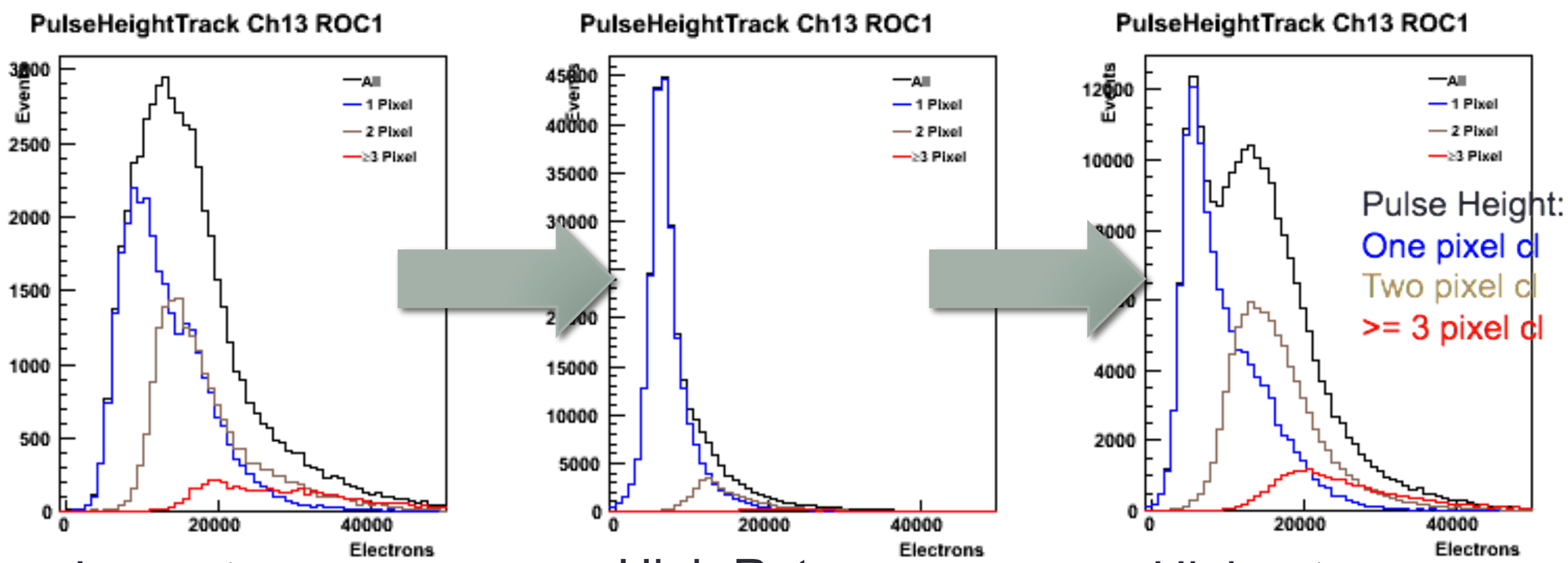
- DPA based on Displacement Energy
  - Diamond: 43.3eV
  - M. Guthoff et. al. arXiv:1308.5419
- Reasonable agreement at high energies
  - DPA scaling over predicts at low energies



Pulse heights at high rates

Indication of pulse height dependance on rate in CMS-PLT detector

- Pixel tracking detector based on scCVD diamond sensors
  - Installed on CASTOR platform for 2012 LHC run, experienced high rate of low energetic charged hadrons and neutrons (5e13 neutrons and 5e13 charged hadrons)
  - High pulse height before collisions (beam halo)
  - Pulse height drops after beam brought into collision
  - Raising the HV brings back charge collection even at full luminosity



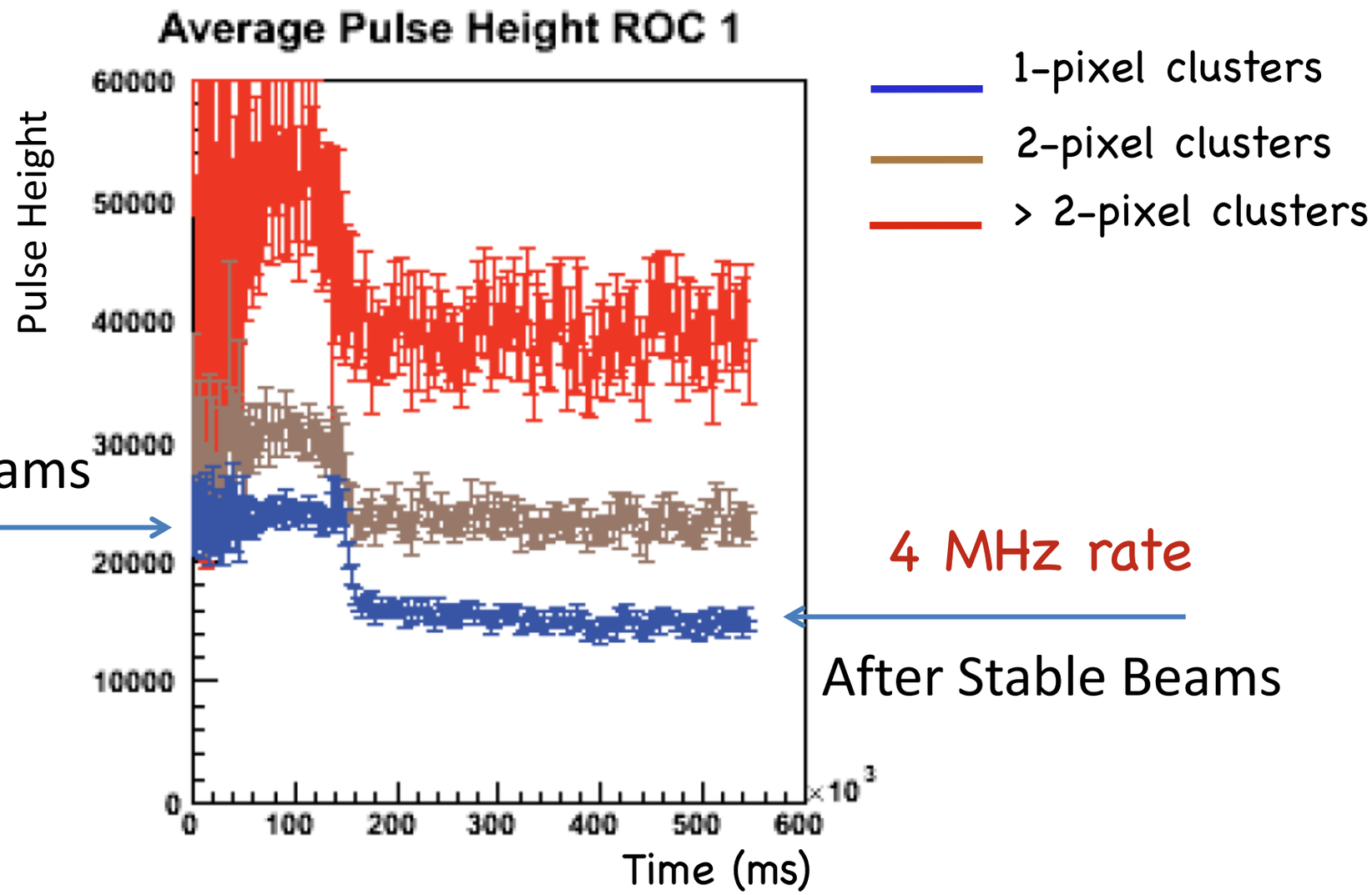
Low rate
500V

High Rate
500V

High rate
1kV

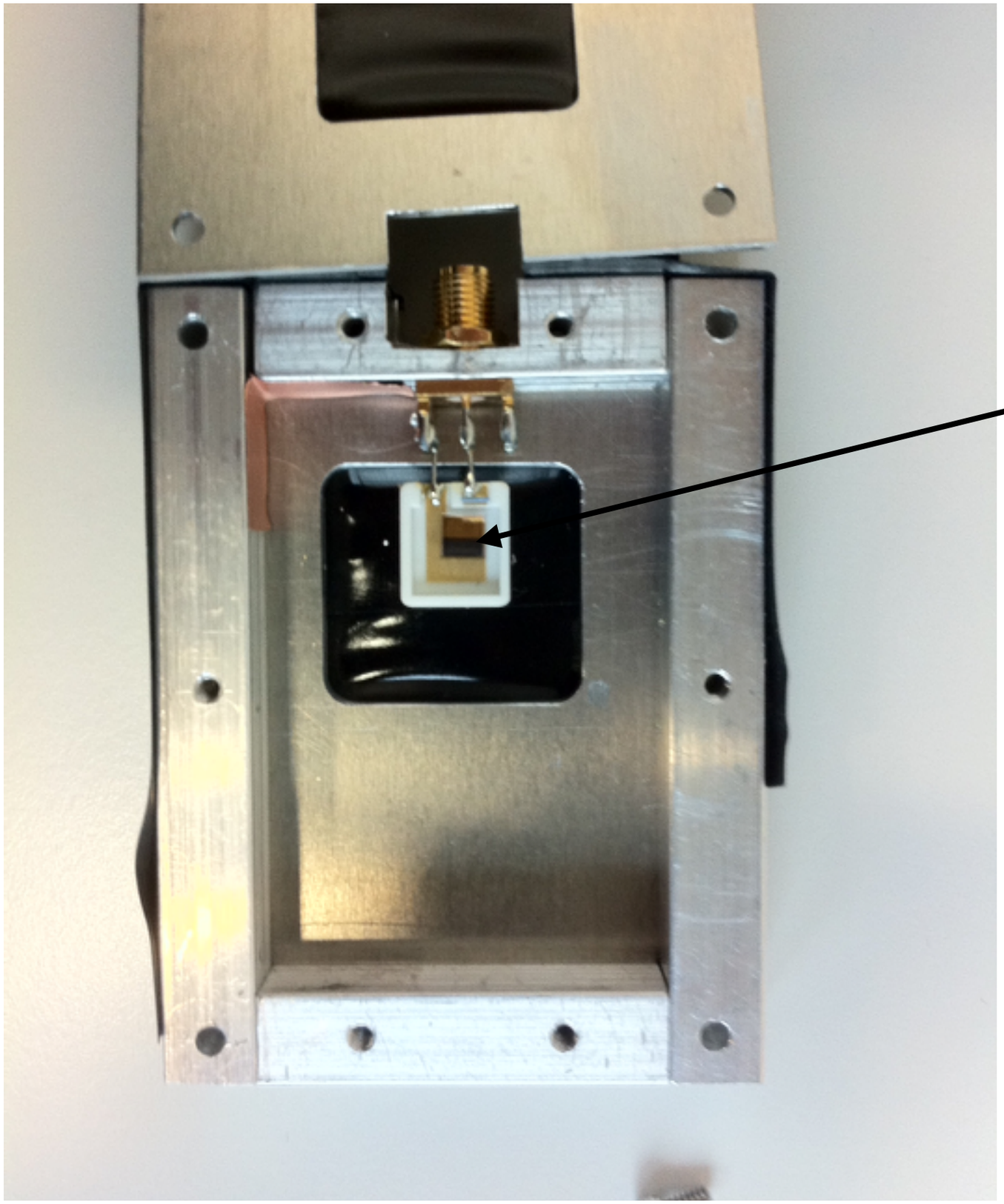
Indication of pulse height dependance on rate in PLT detector

- Shift in pulse heights with rate

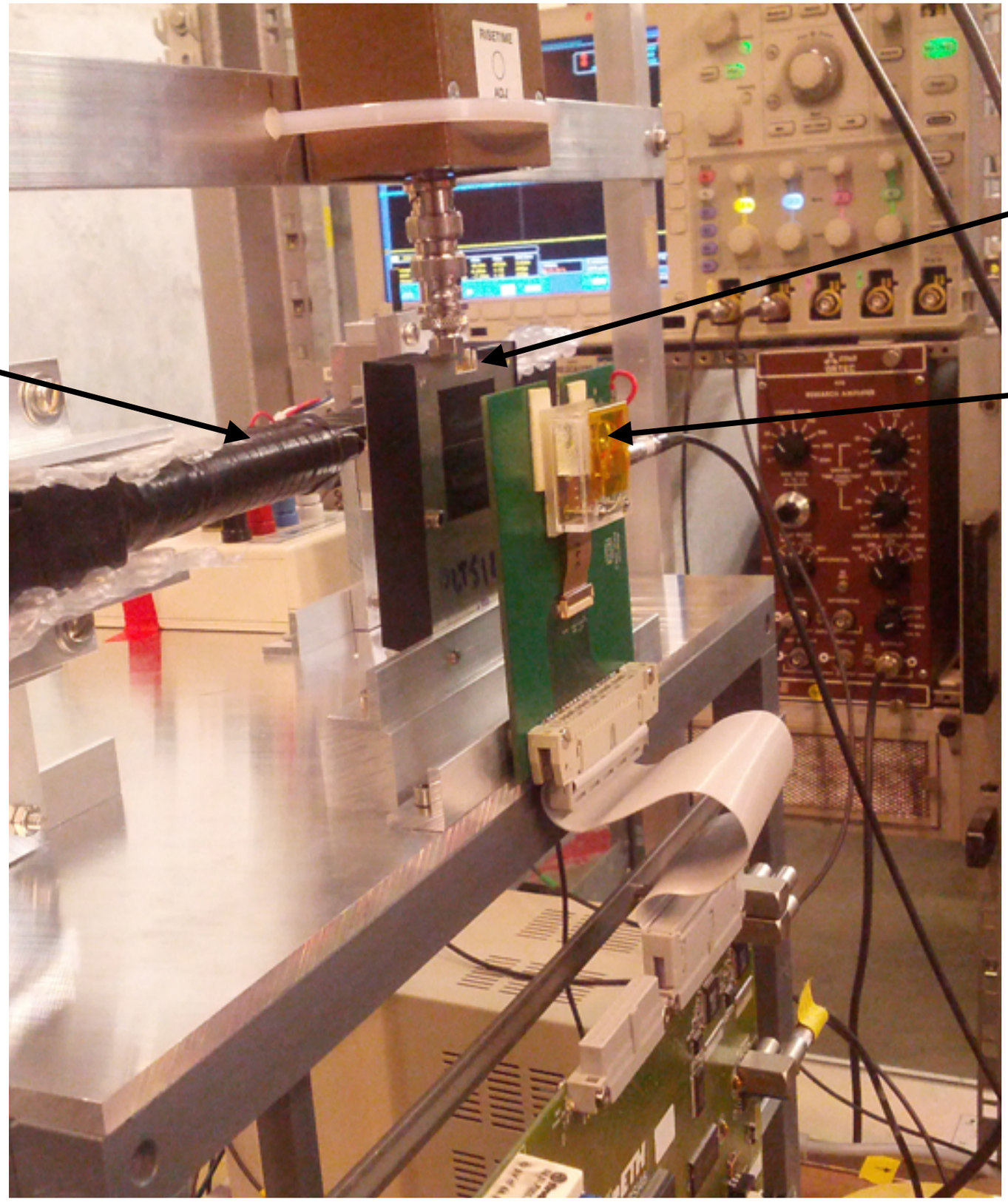


PSI Test Beam Setup

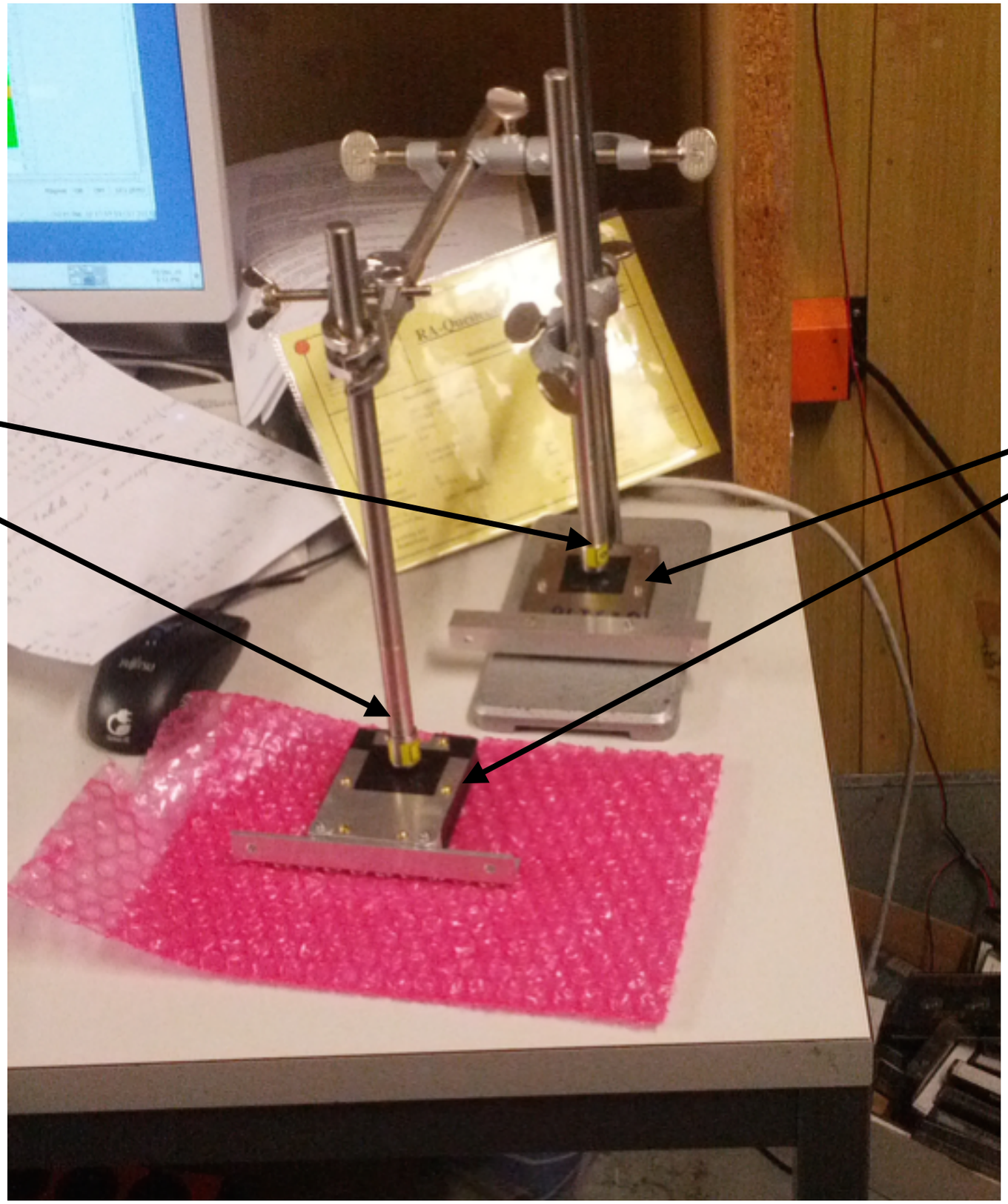
DUT box



Setup in piM1 line

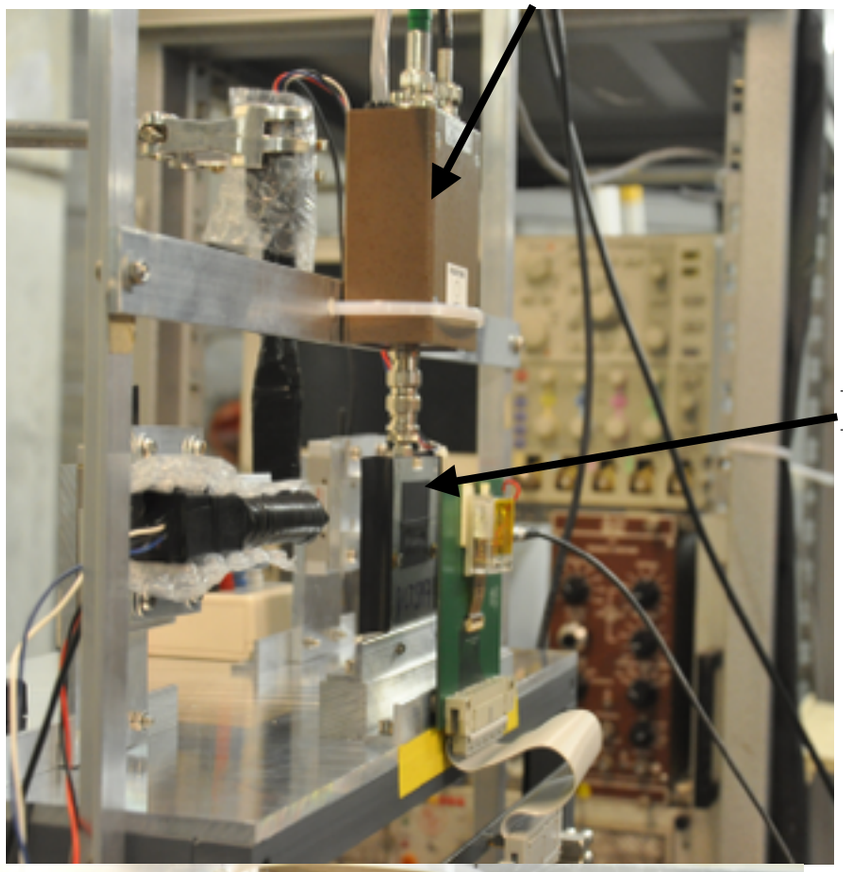


Pumping station

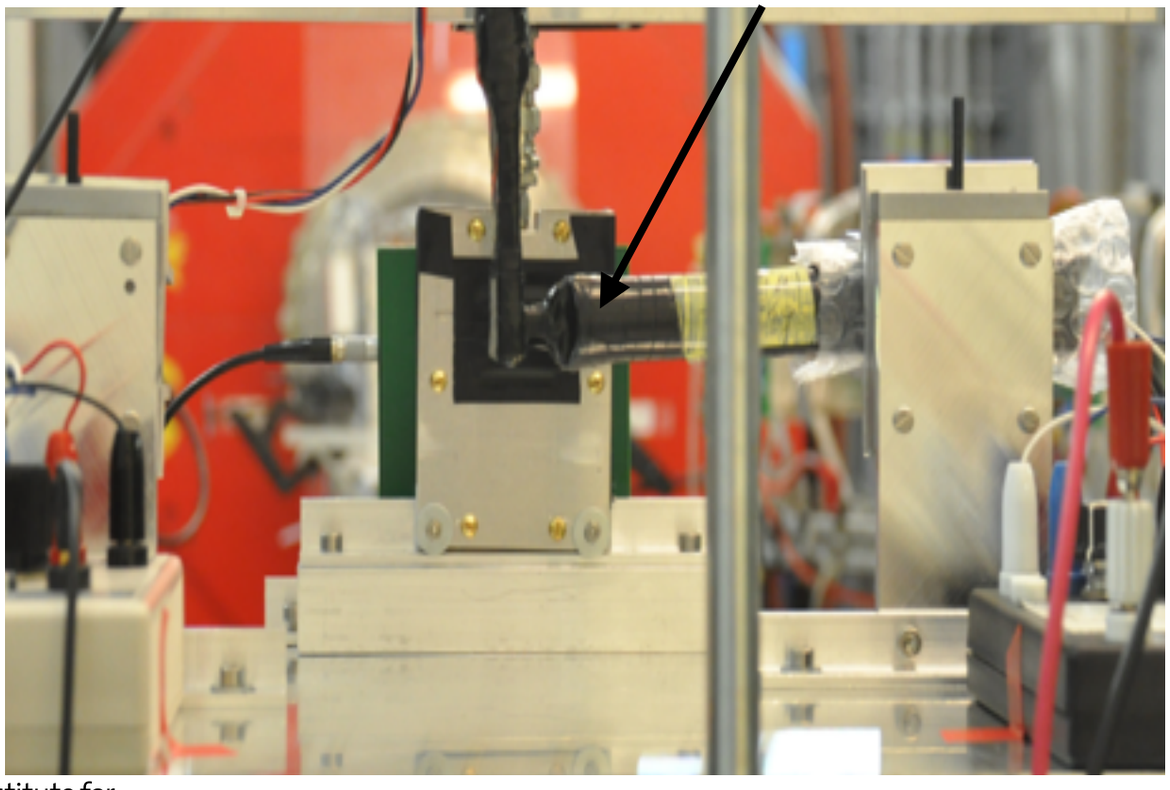


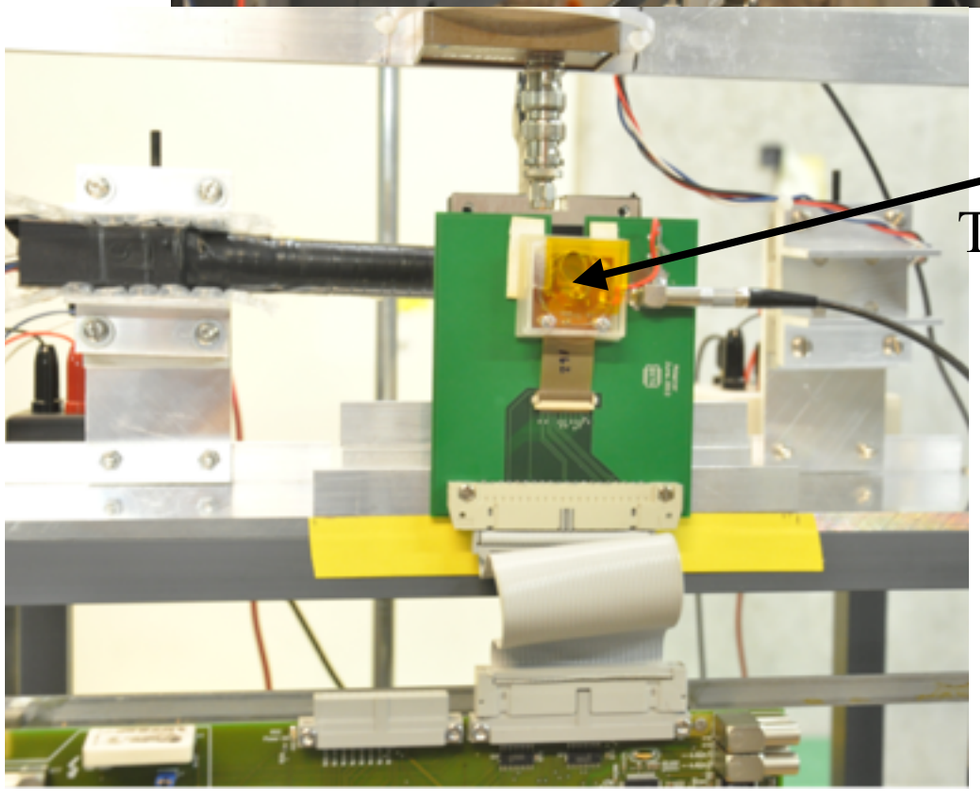
Test beam setup

- 250 MeV/c “mostly” pions
- Rate determined on the “small” 6 mm x 6 mm scintillator
- Part of the runs were taken with the “small” scintillator as a trigger
  - large background
- Last 13 runs were taken with a masked area of the pixel detector as a trigger
  - small background



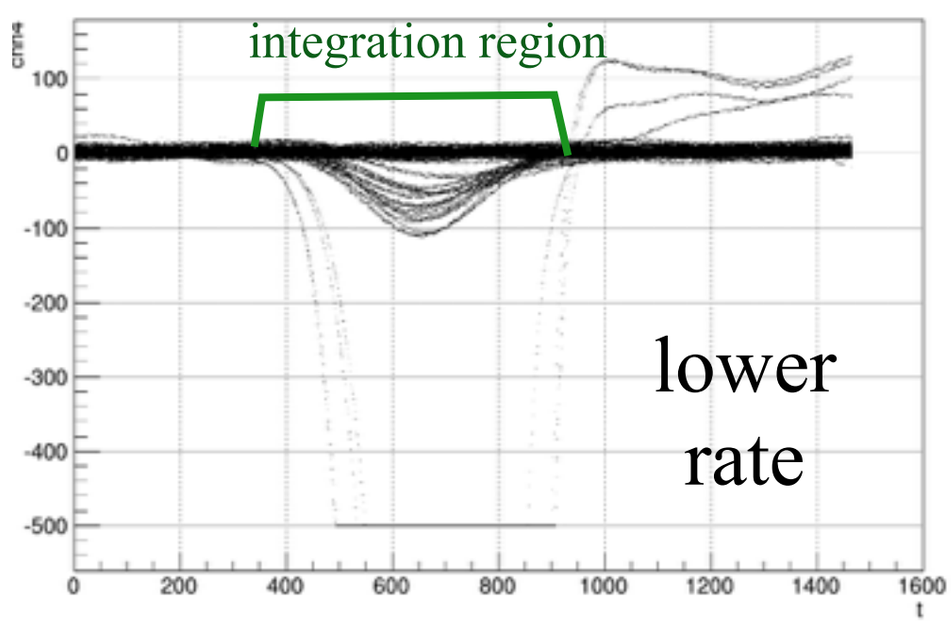
“small” scintillator

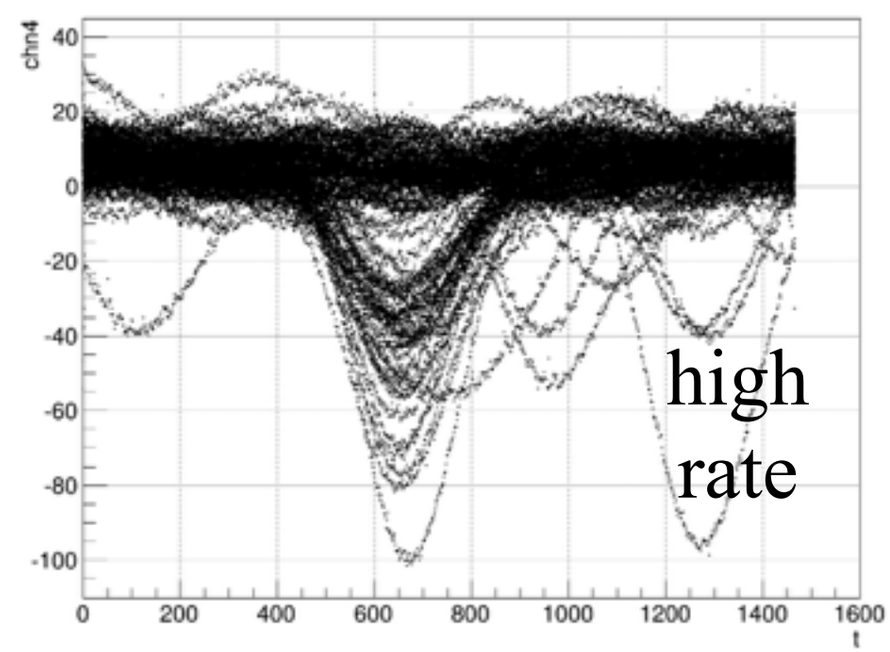




DAQ: raw signals

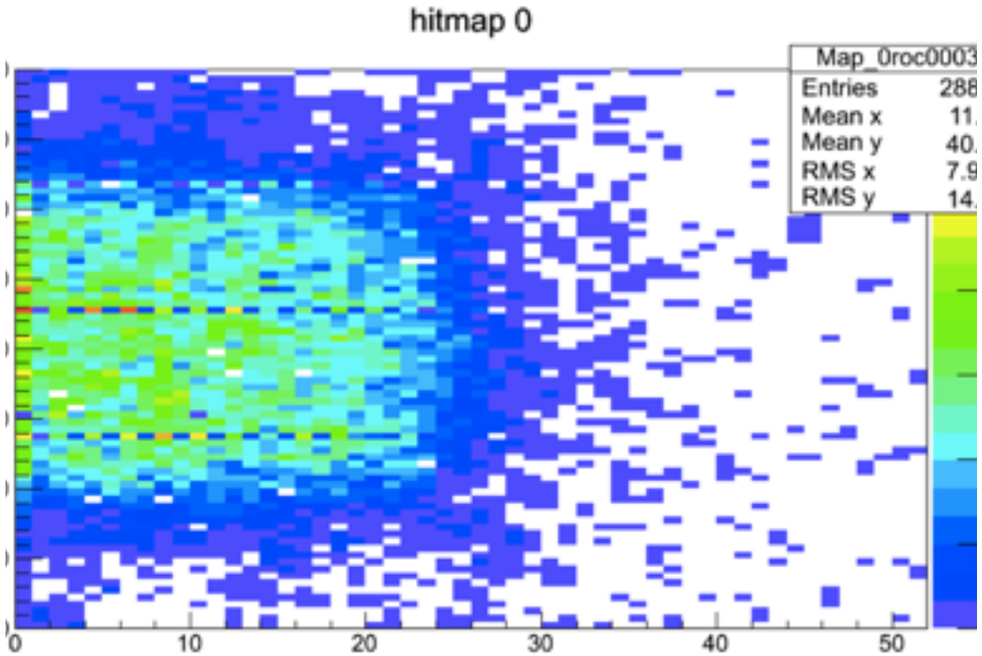
- Pulse height amplified with Ortek 142A pre-amp and Ortek 450 shaping amp
  - 300 ns shaping time
- Digitization performed with DRS4 evaluation board
  - 1024 sampling points
  - slowest sampling speed 0.7 GSPS
- Integration region from 320 ns to 920 ns

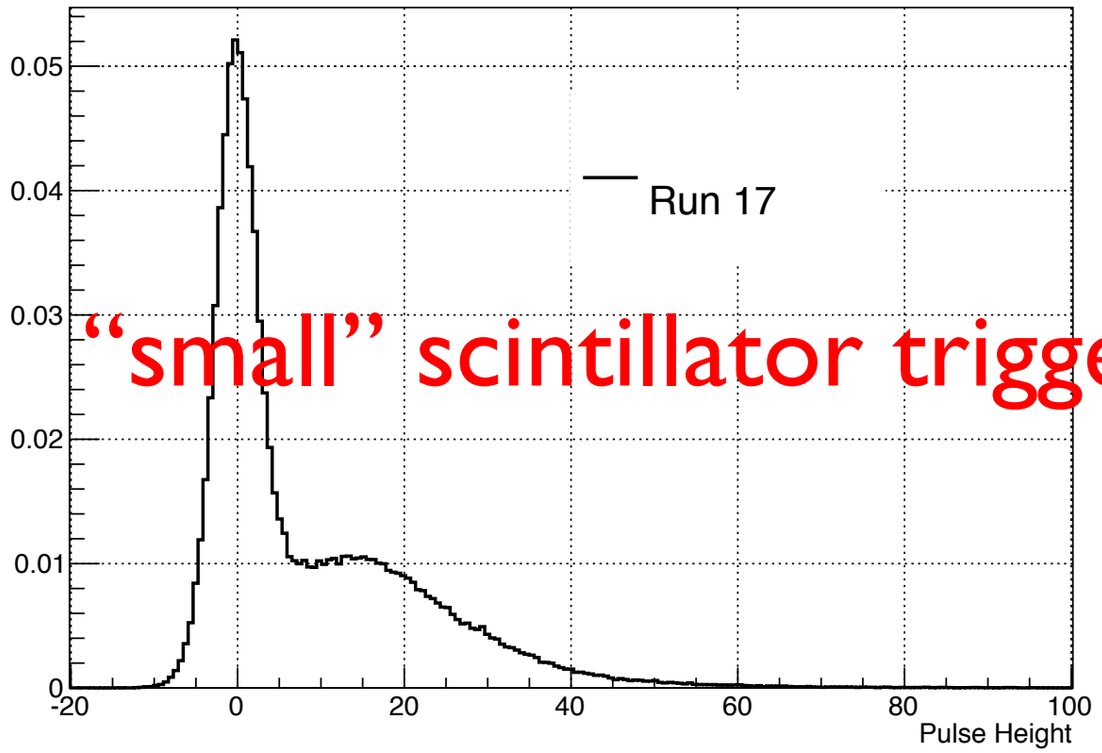




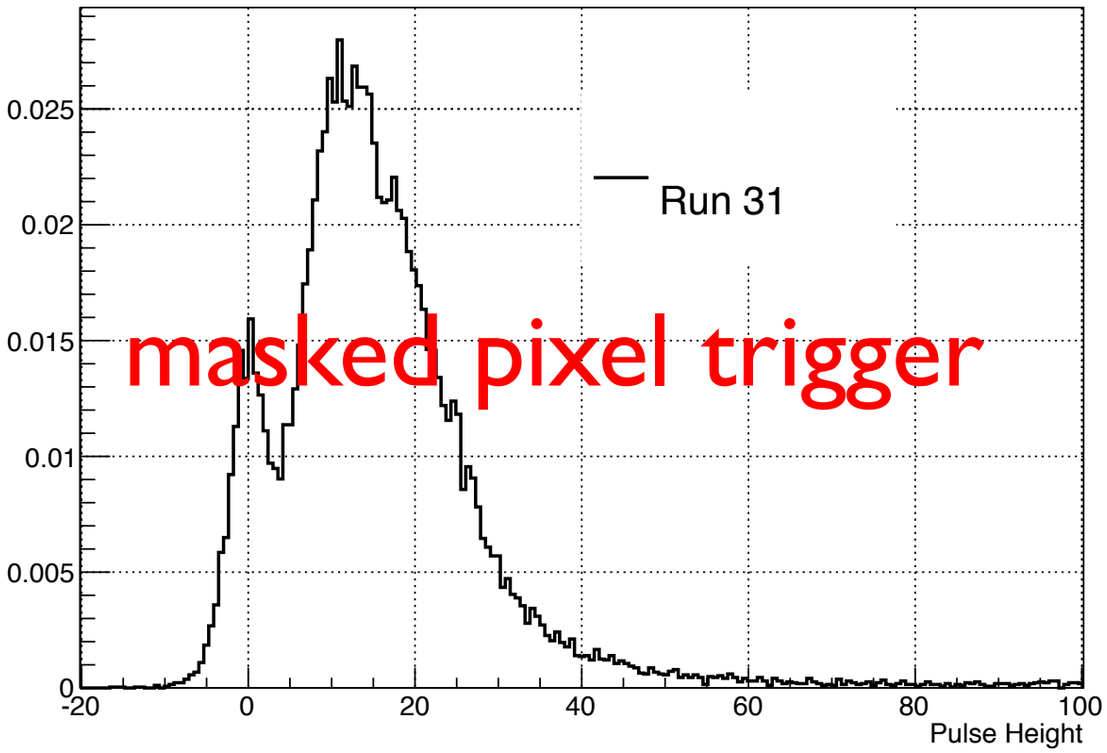
Masked pixel trigger

- Using diamond as a signal to pixel detector to find a “shadow” of the diamond
- Mask all pixels outside the diamond shadow
- Use “FastOr” of the masked pixel detector as a trigger for the diamond
- **Large improvement in signal to background ratio**





“small” scintillator trigger

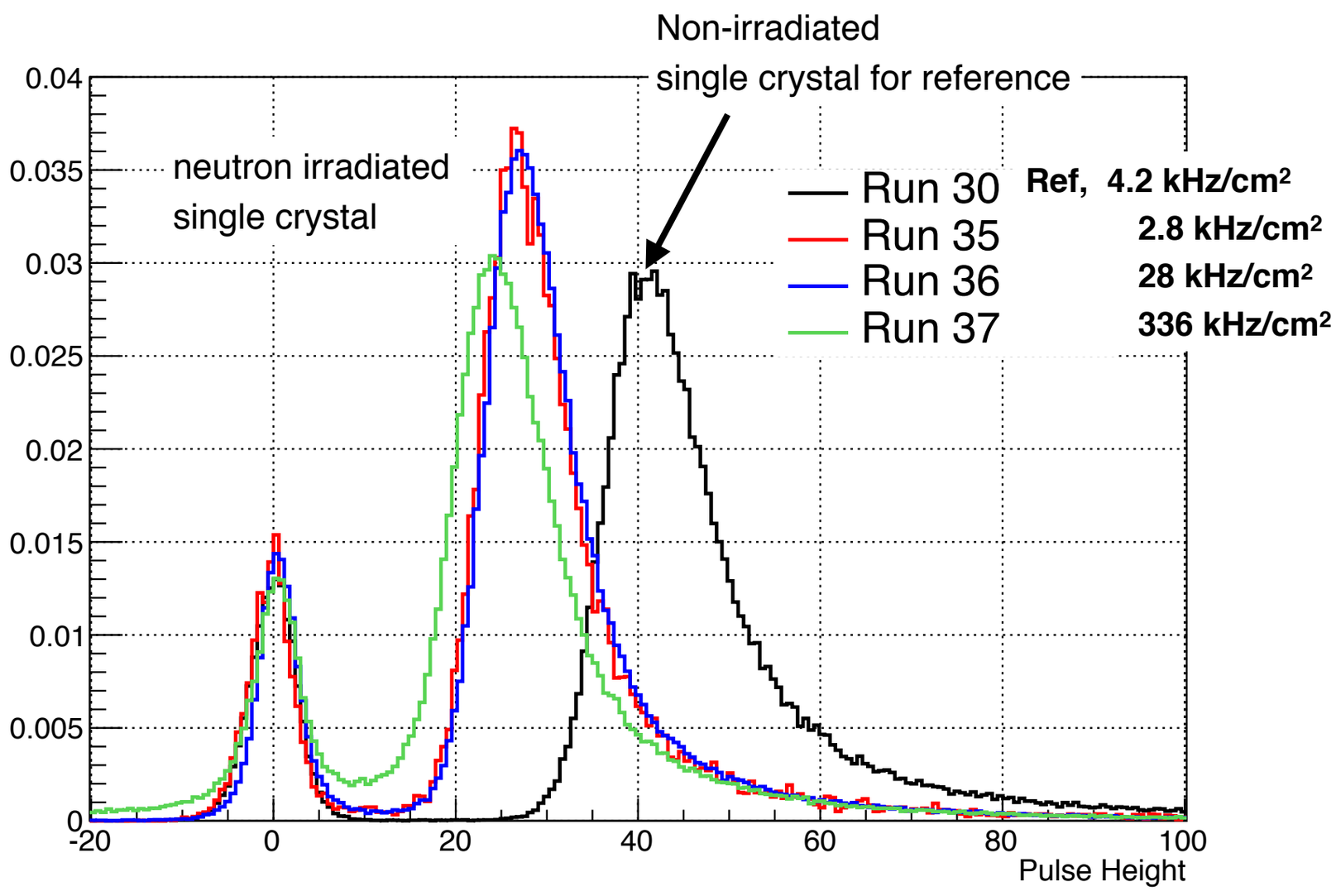


masked pixel trigger

Results

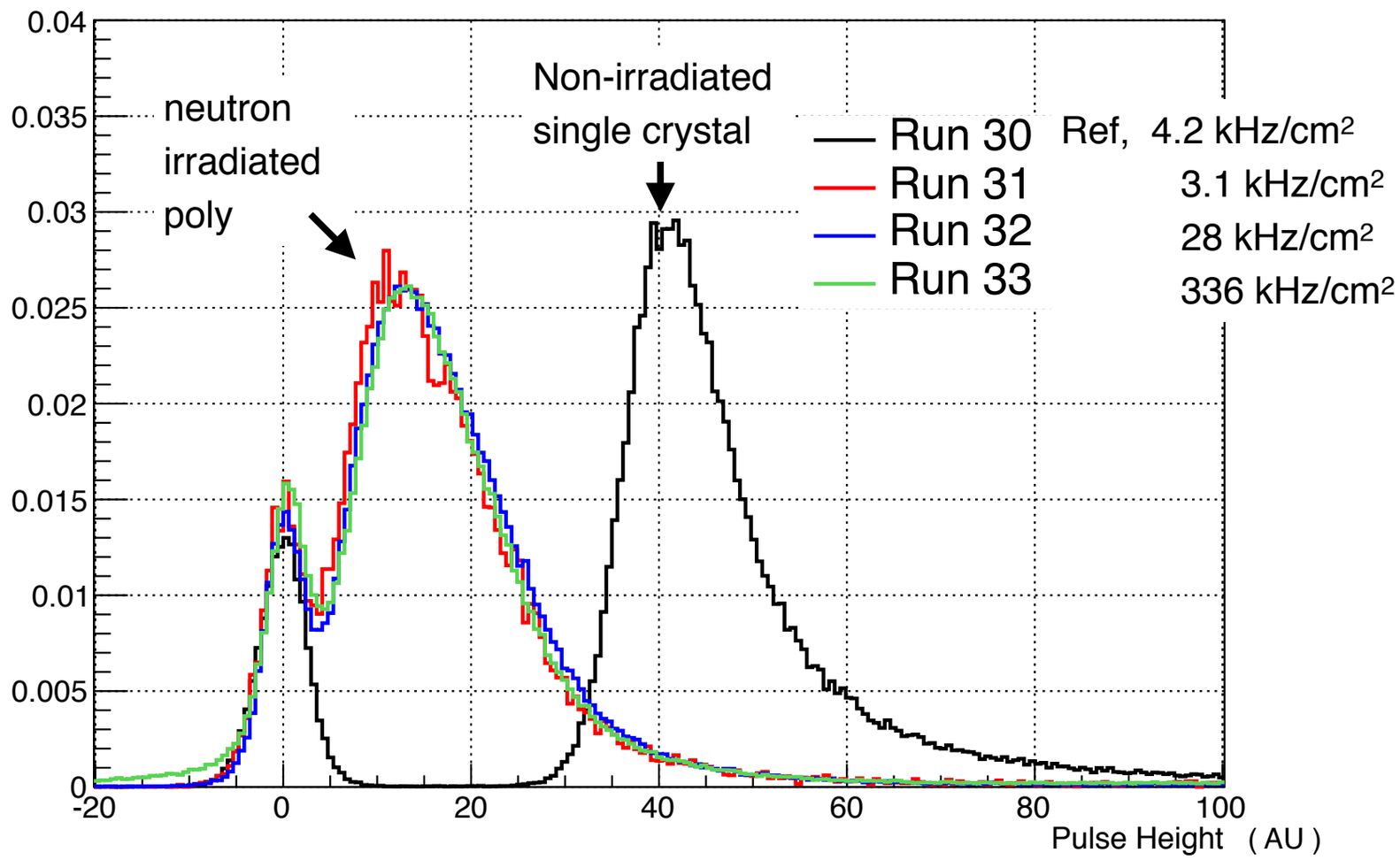
Single crystal CVD diamond n-irradiated in JSI, Ljubljana

- Irradiation dose - $5x10^{13}$ n/cm^2
- Runs at 500 V with masked pixel trigger
- Slight but obvious rate dependance



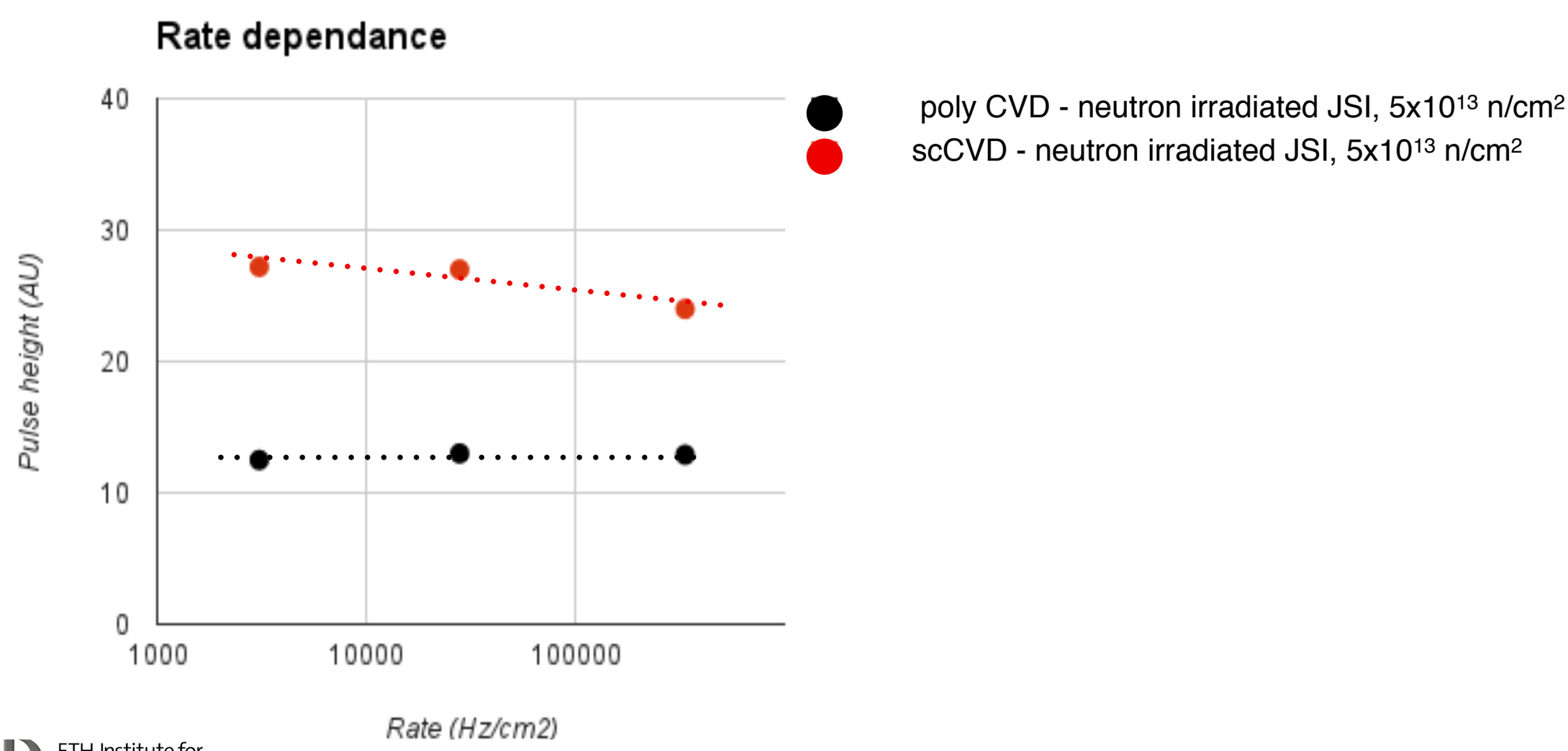
Poly-crystalline CVD diamond n-irradiated in JSI, Ljubljana

- Irradiation dose - $5x10^{13}$ n/cm^2
- Runs are at 500 V with masked pixel trigger
  - Run 30 is non irradiated single crystal for calibration
- Mean for poly - 18.9 (CCD ~ 200 um) (measured from 5 AU to 100 AU)
- Mean for SC - 47.2 (CCD ~500 um) (measured from 5 AU to 100 AU)
- **No noticeable rate dependance**



Summary of the rate dependance

- Plot most probable pulse height versus rate per cm^2
  - Irradiated single crystal diamonds show slight rate dependance
  - Irradiated poly crystalline diamond does not show rate dependance



Conclusions

- Radiation Hardness of CVD diamond is nearly quantified
  - pCVD and scCVD have the same damage constant.
- Proton results nearly complete
- Pion initial results look good
  - Both pCVD and scCVD irradiated.
- Pulse height dependance on rate of incoming particles was studied.
  - Irradiated single crystal diamond irradiated with reactor neutrons to $5x10^{13}$ n/cm^2 exhibits slight rate dependence
  - Polycrystalline CVD diamond irradiated with reactor neutrons to $5x10^{13}$ n/cm^2 does not show any noticeable rate dependance

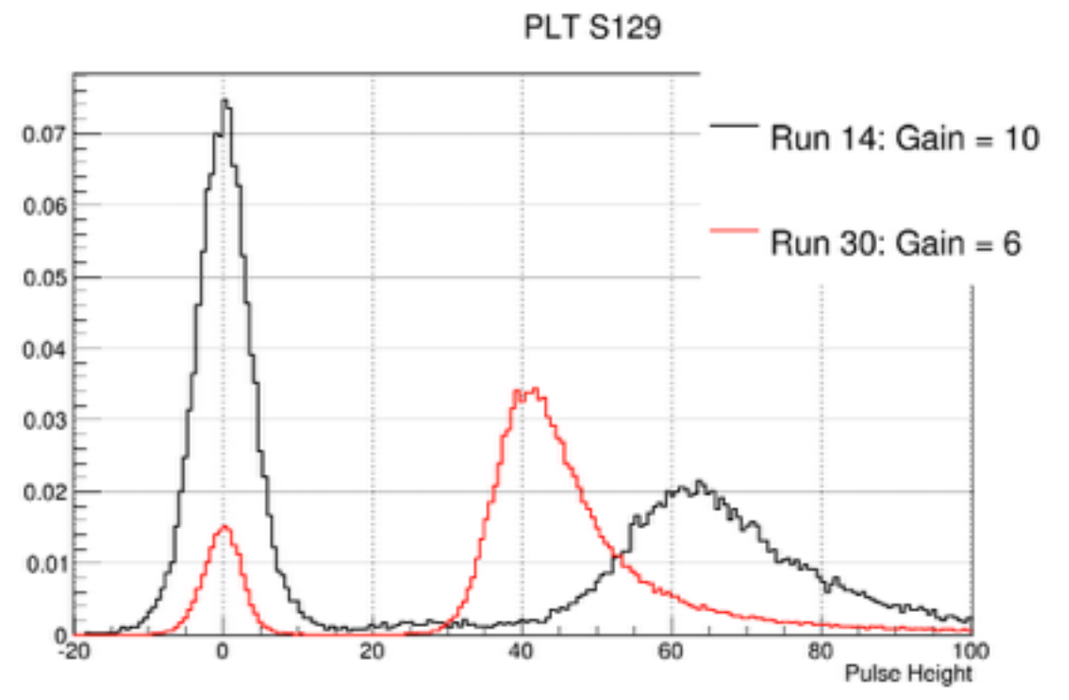
Future study of high rate dependance

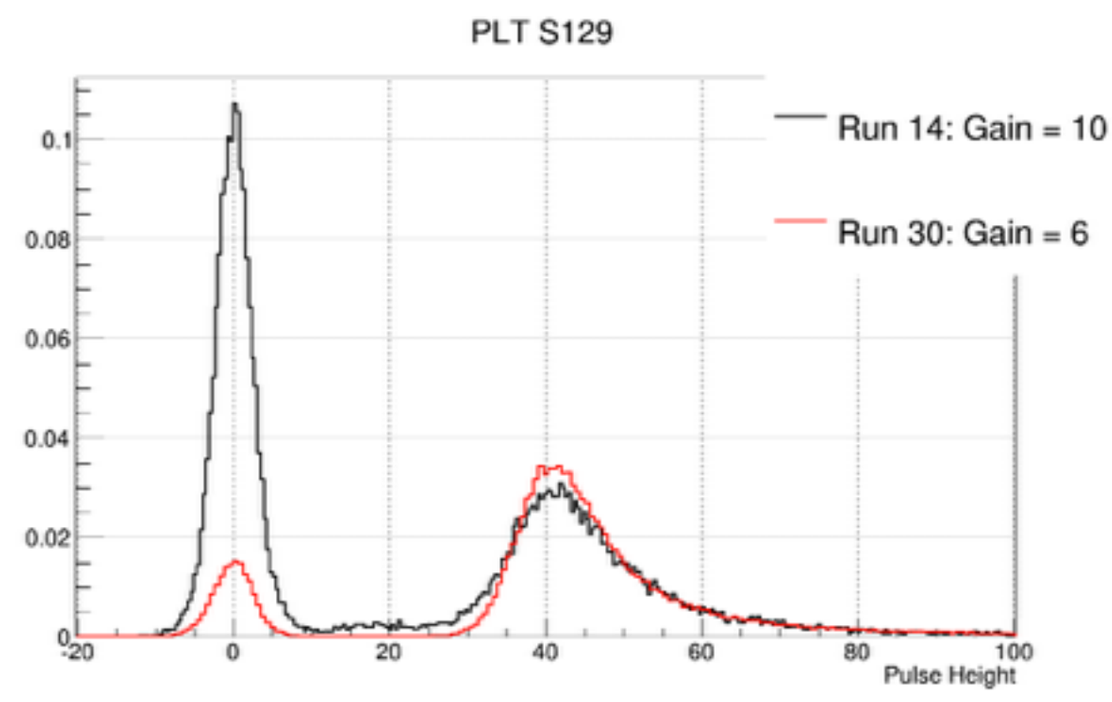
- Pixel devices
  - with analog readout for use in CMS-PLT
- Irradiated diamonds to higher dose
  - $1x10^{14}$ n/cm^2
- Proton irradiation
  - $5x10^{13}$ p/cm^2
- New polyCVD diamonds from II-VI corporation
  - higher collection distance (~ 300 um)
- Time evolution of pulse height
- Different metallization procedures

extra slides

Gain change correction

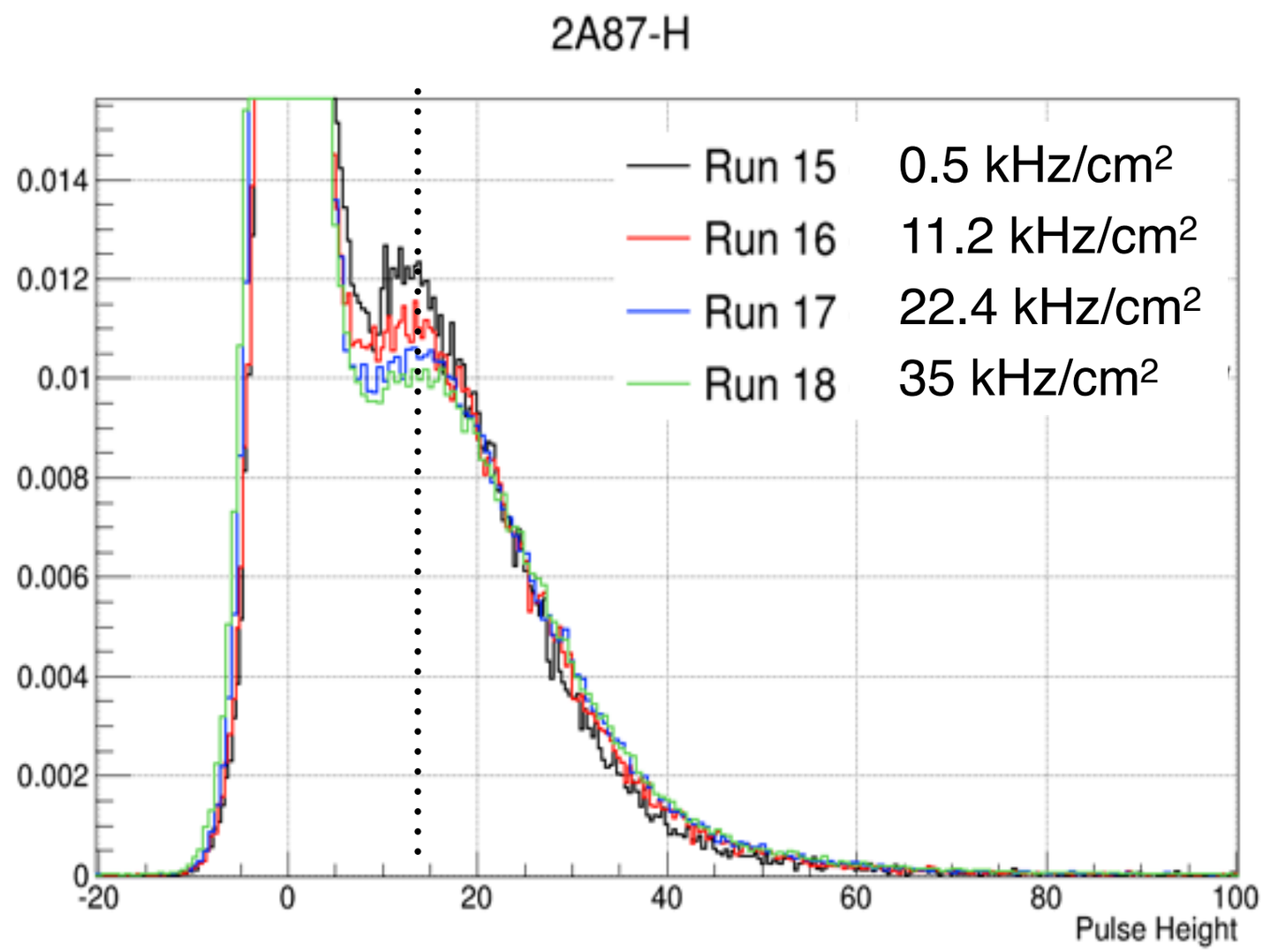
- In attempt to protect the DRS4 readout after Run 16 reduced Unipolar Output Range on Research Amp from 10V to 6V
  - gain have changed
- Use un-irradiated single crystal to determine the gain scaling factor
  - 0.658
- Run 14 was triggered on “small” scintillator
- Run 30 was triggered on masked pixel chip





2A87-H poly non-irradiated

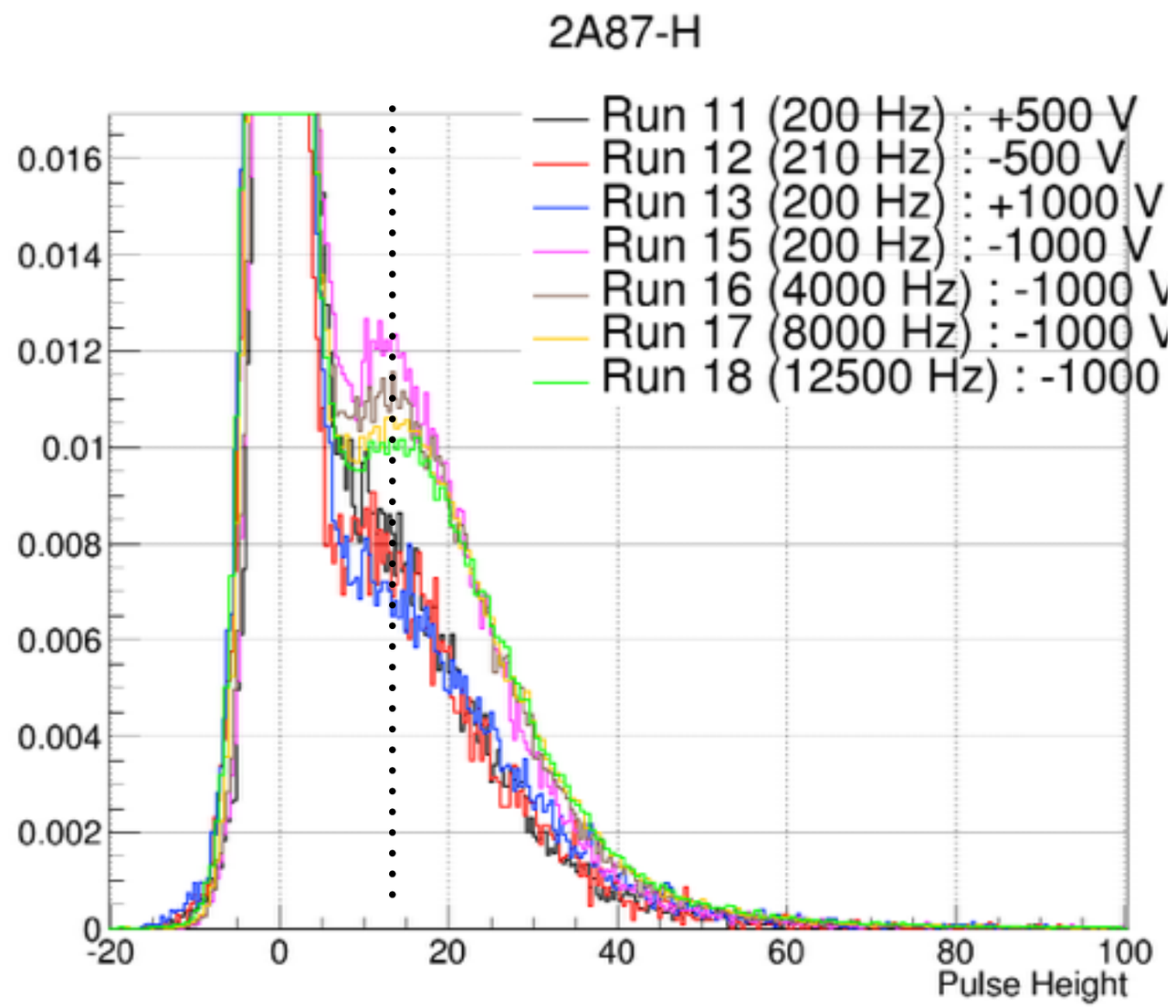
- History of 2A87-H during the test beam
  - -1000 V
  - Super Pump 30min substrate side/Super Pump 1hr growth side
  - Super Pump 20min growth side
  - Run 15, 16 only rate change
  - Changed gain from 10 to 6 after run 16
  - Run 17,18 new gain
  - Runs 11-16 are scaled down by 0.658 to match the new gain



- **No noticeable rate dependance**

2A87-H

- Did not have time to run with pixel map
- History of 2A87-H
  - Super Pump 30min substrate side/Super Pump 1hr growth side
  - Runs 11 - 13 only change voltage no pumping in between
  - Super Pump 20min growth side
  - Run 15, 16 only rate change
  - Changed gain from 10 to 6 after run 16
  - Run 17,18 new gain
  - Runs 11-16 are scaled down by 0.658 to match the new gain



Single crystal CASTOR irradiation (PLT S97)

- Irradiation dose - equal amounts of protons and neutrons - $5x10^{13}$ n/cm^2 and $5x10^{13}$ p/cm^2
- Runs at 500 V with masked pixel trigger
- Slight rate dependance