Recent results of diamond radiation tolerance

Dmitry Hits for RD42 collaboration

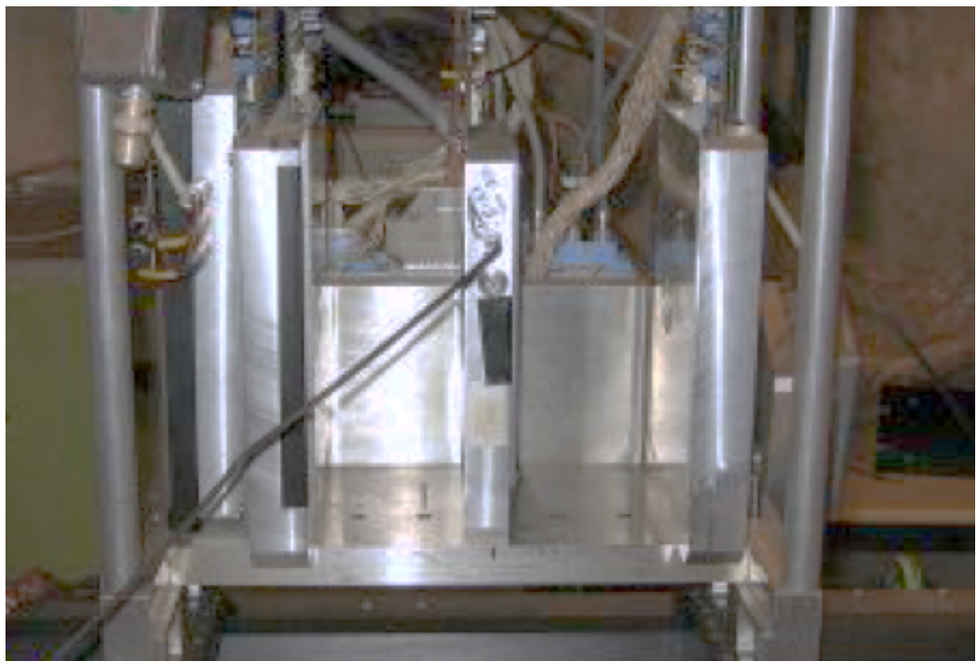
ETH Institute for
Particle Physics

Outline

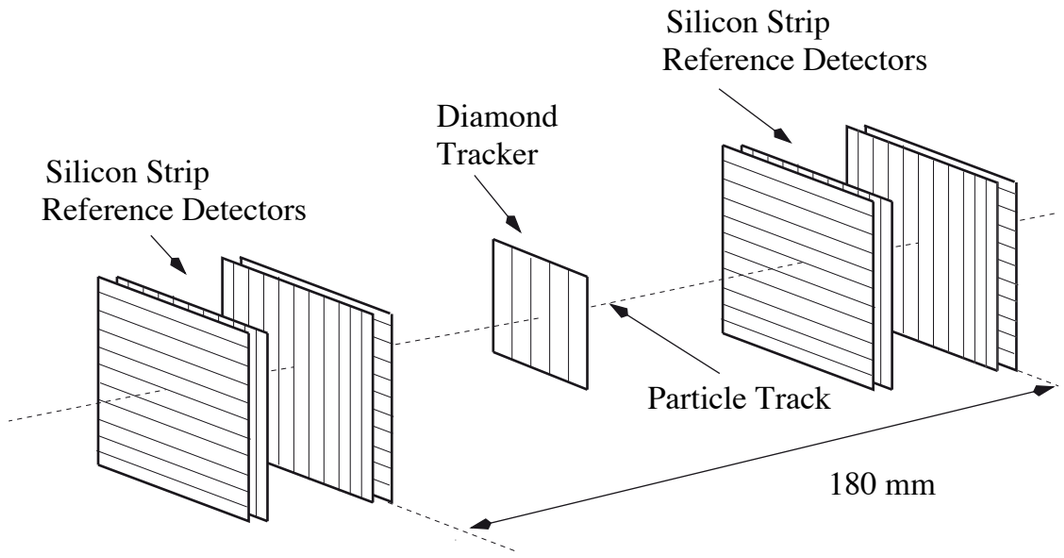
- Measurement procedure
- Analysis procedure
- Results
- Comparison with FLUKA Displacement Per Atom (DPA)

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

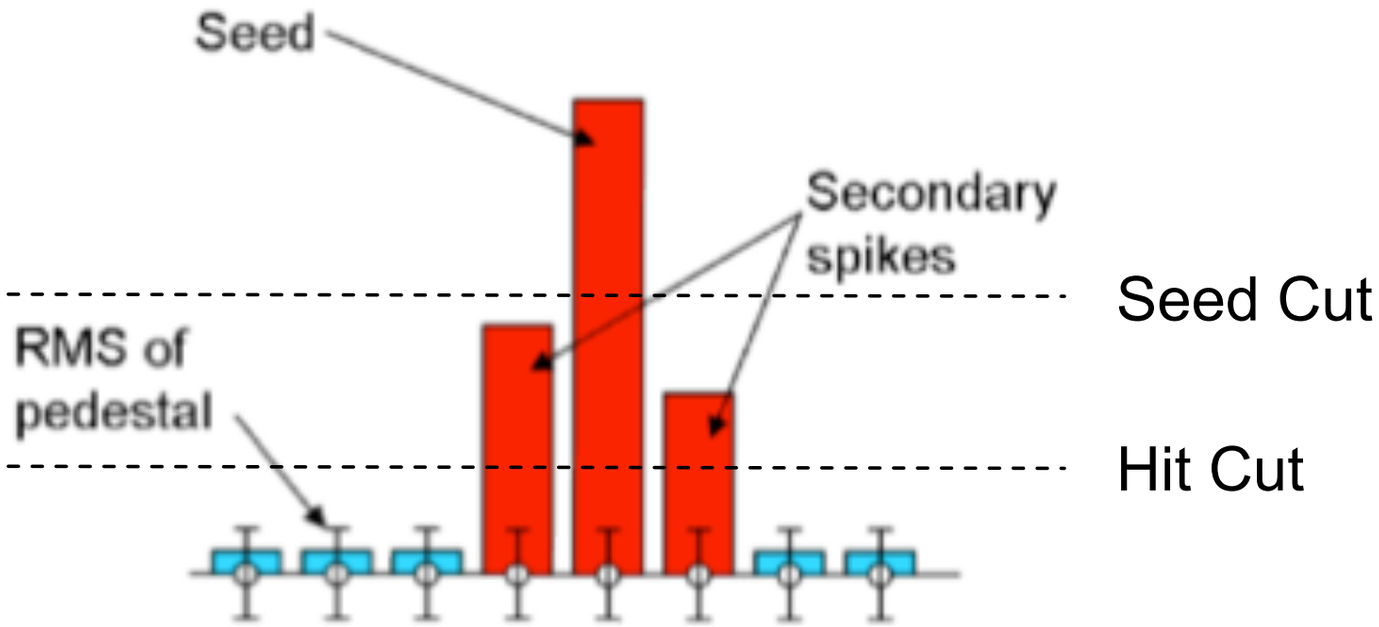


Analysis procedure

- 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

Beam test analysis: clustering

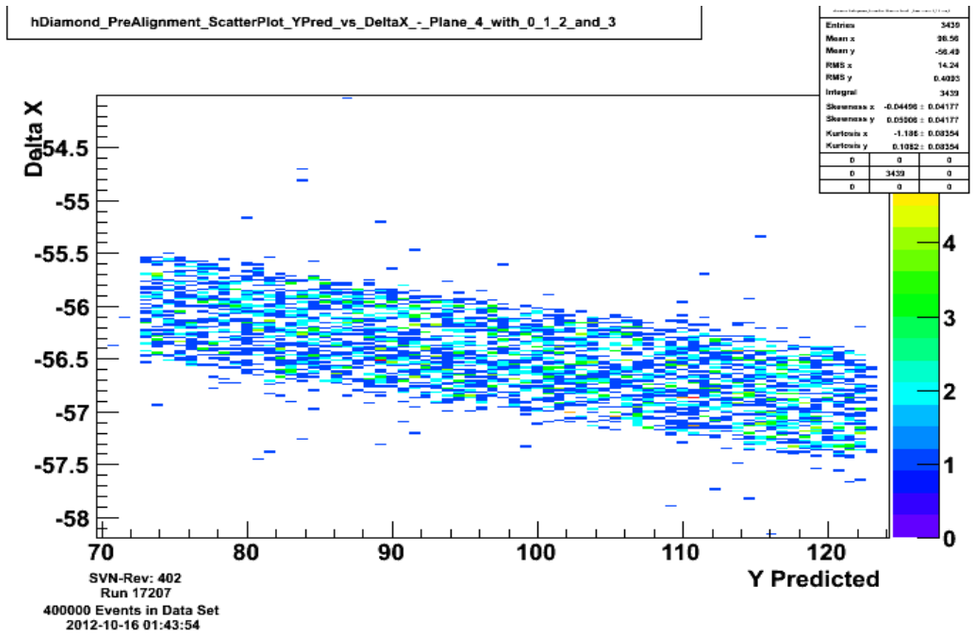
- pedestal subtraction
- clustering
  - seed cut in diamond plane is 5σ
  - hit cut 3σ

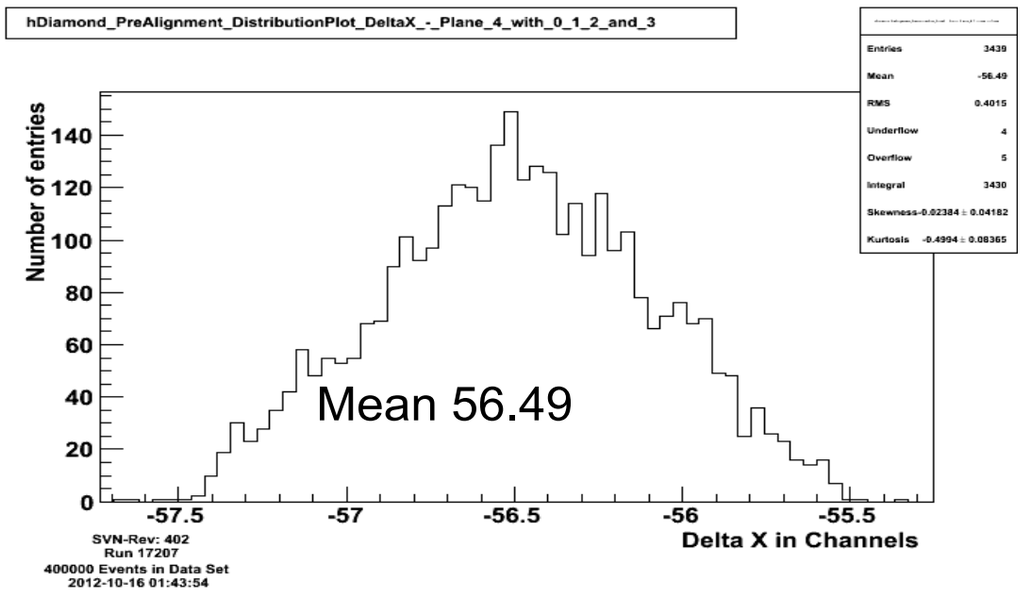


Alignment

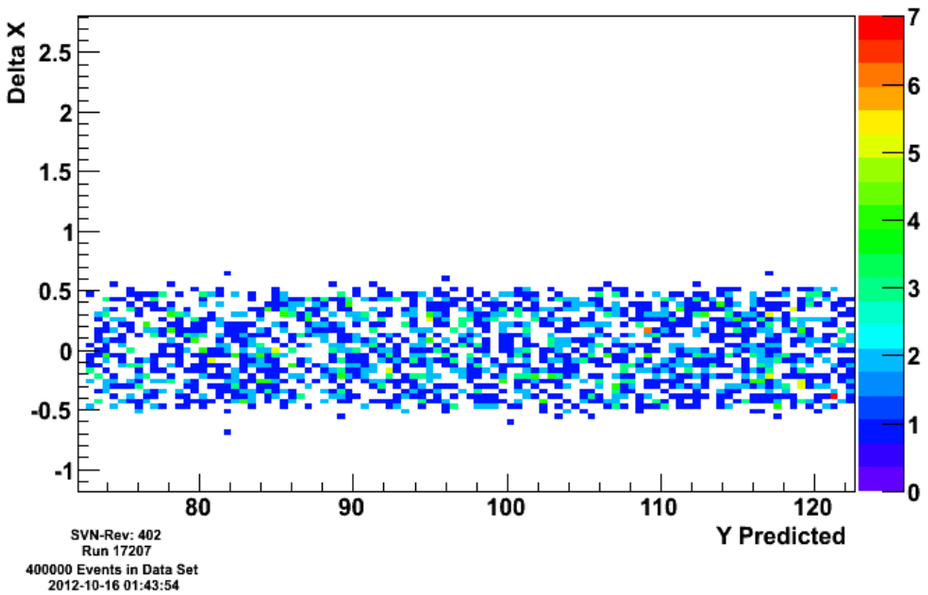
- Correct for shift and rotation in telescope and DUT planes

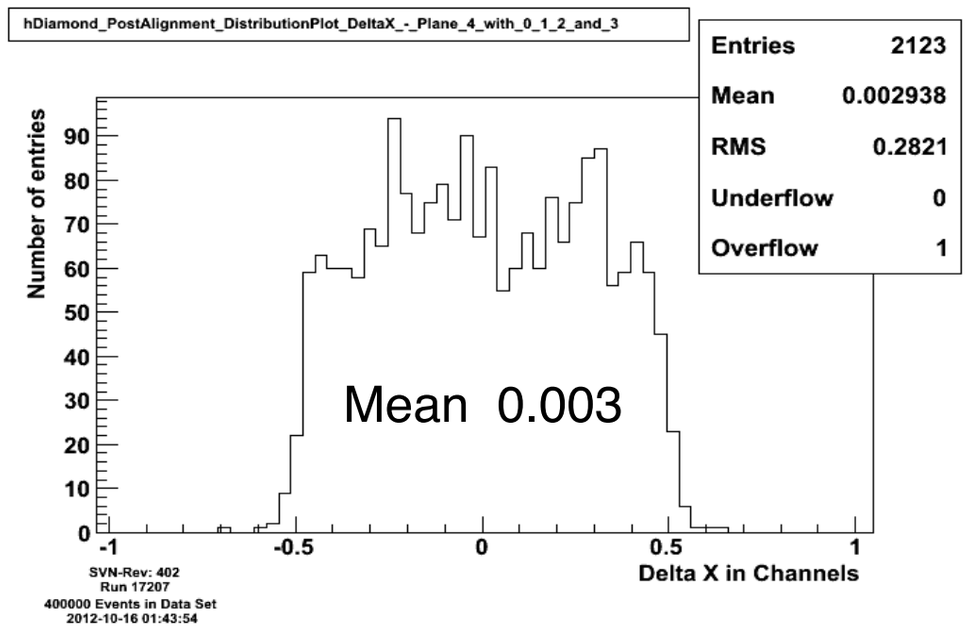
Before alignment





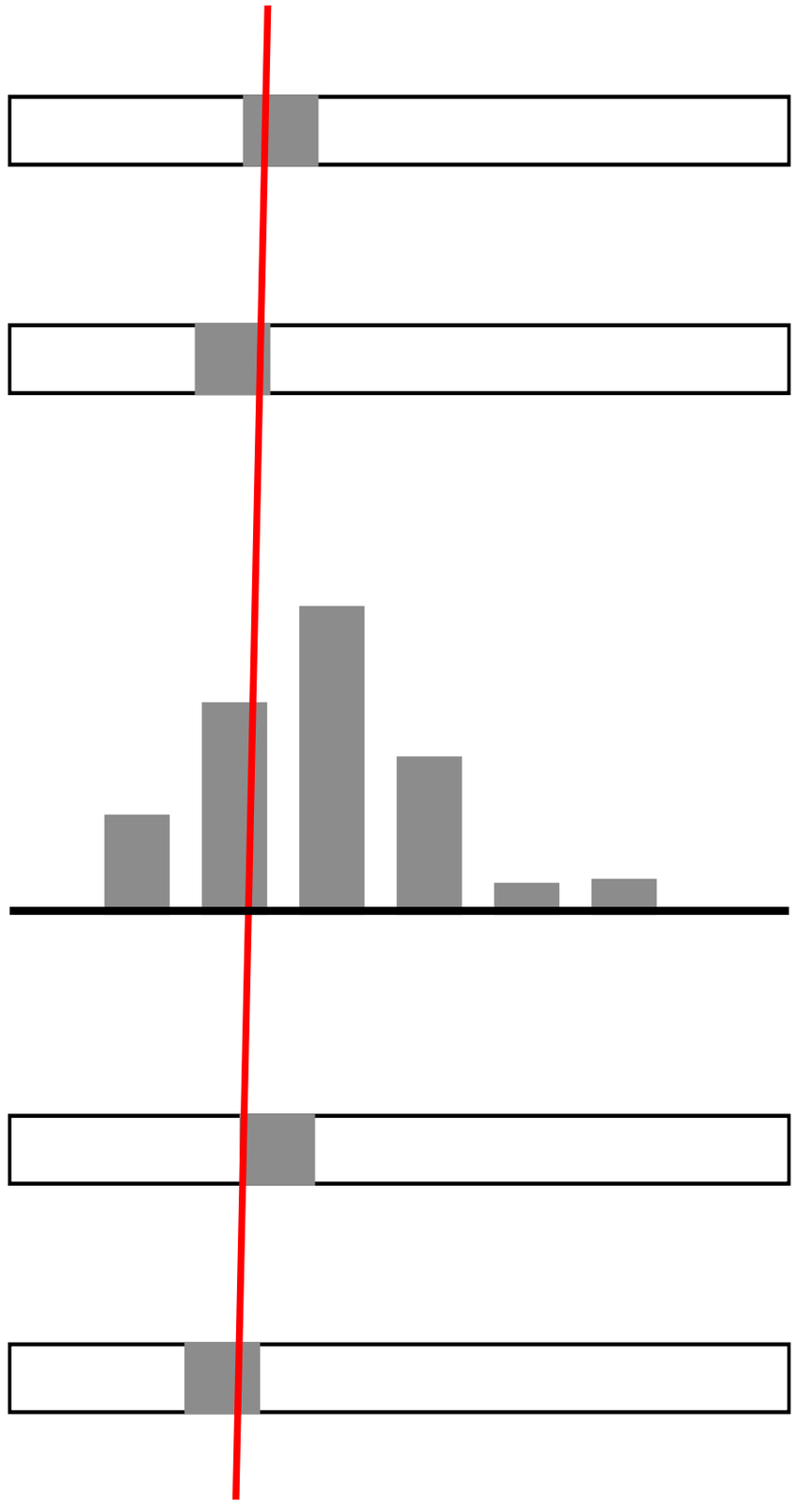
After alignment





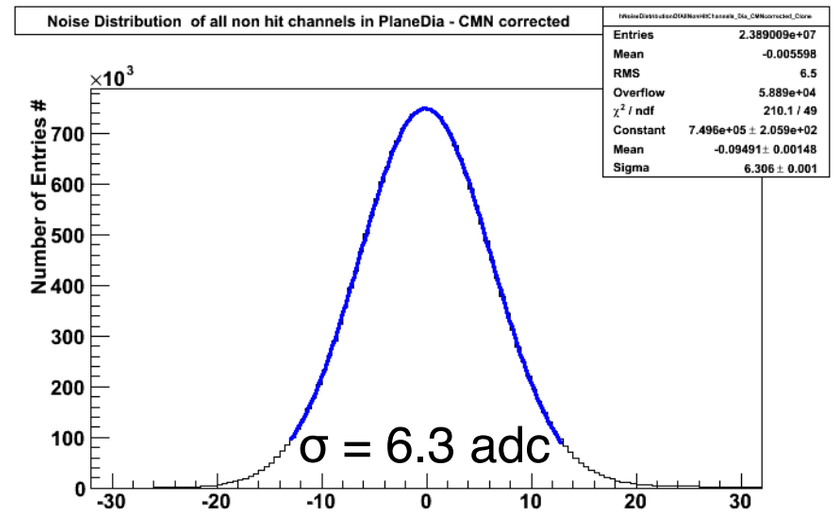
Transparent analysis

- 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
  - Measure resolution

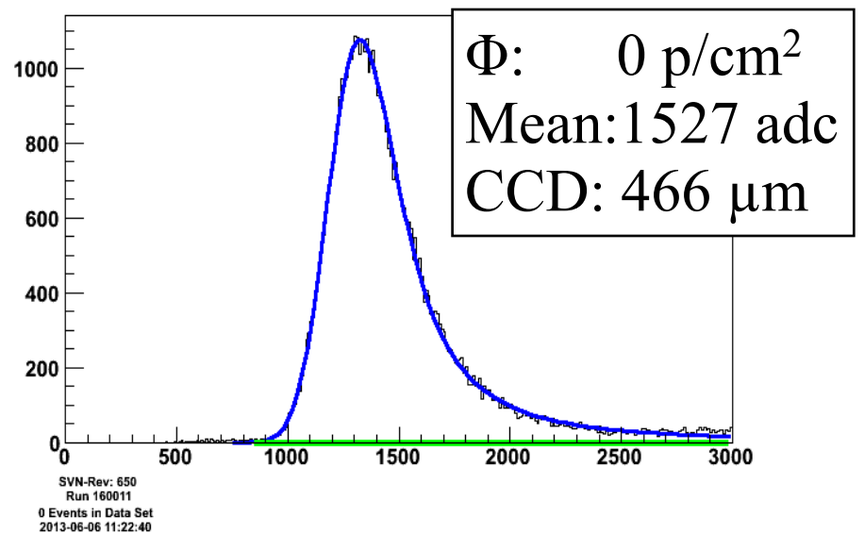


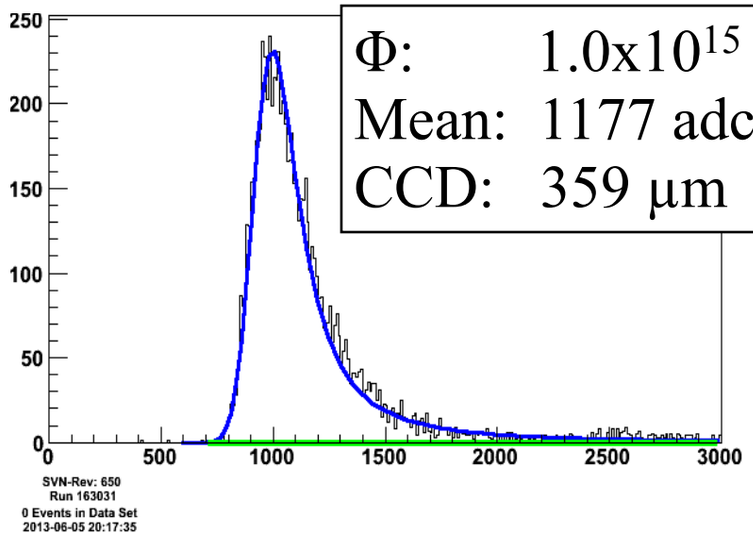
Pulse height: 800 MeV proton irradiation

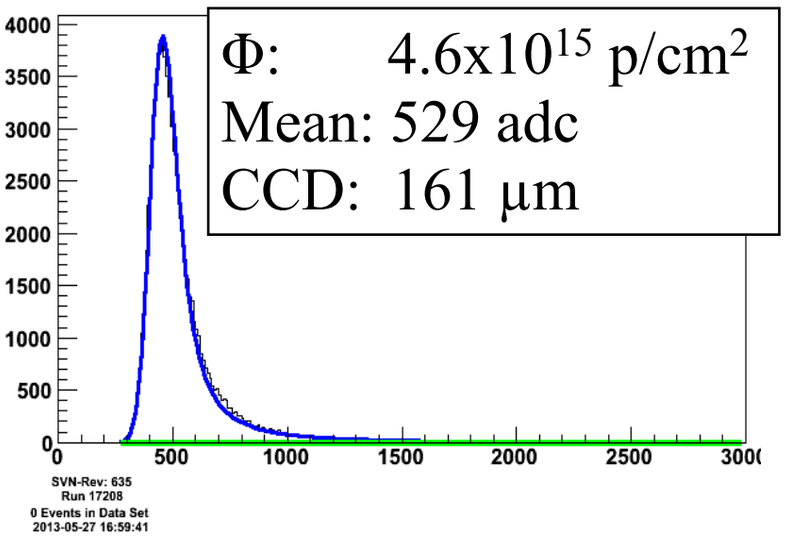
- scCVD diamond sample
  - CCD = is measured to thickness for unirradiated
- Noise is on the order 80-110 electrons
  - < 1.6% of the mean pulse height for the highest irradiation dose
- Pulse heights for 2 highest out of 10 strips closest to the predicted hit position
  - Pulse height shown for bias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



Noise in non-hit channels
Common Mode corrected

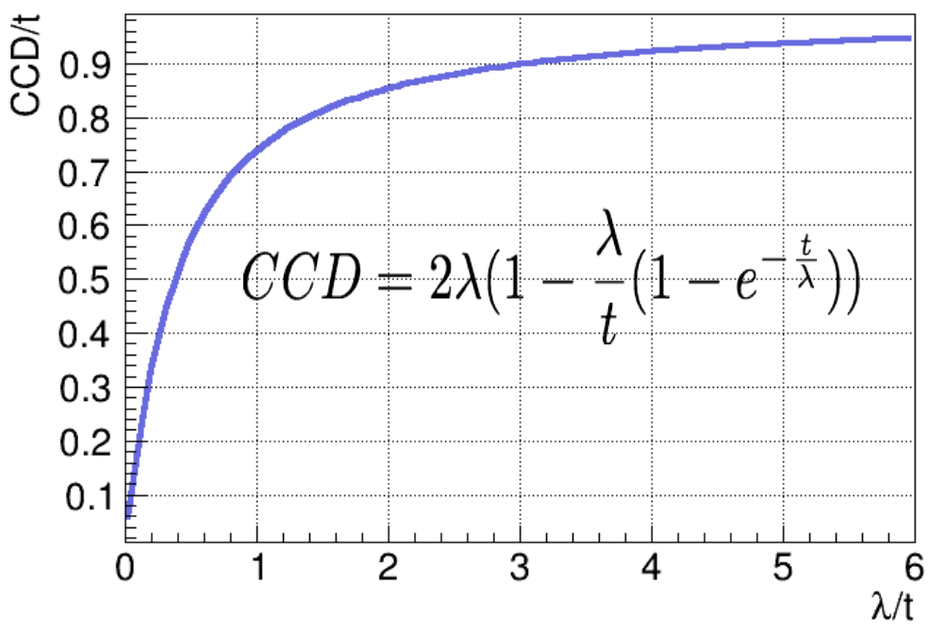






CCD vs Mean Free Path

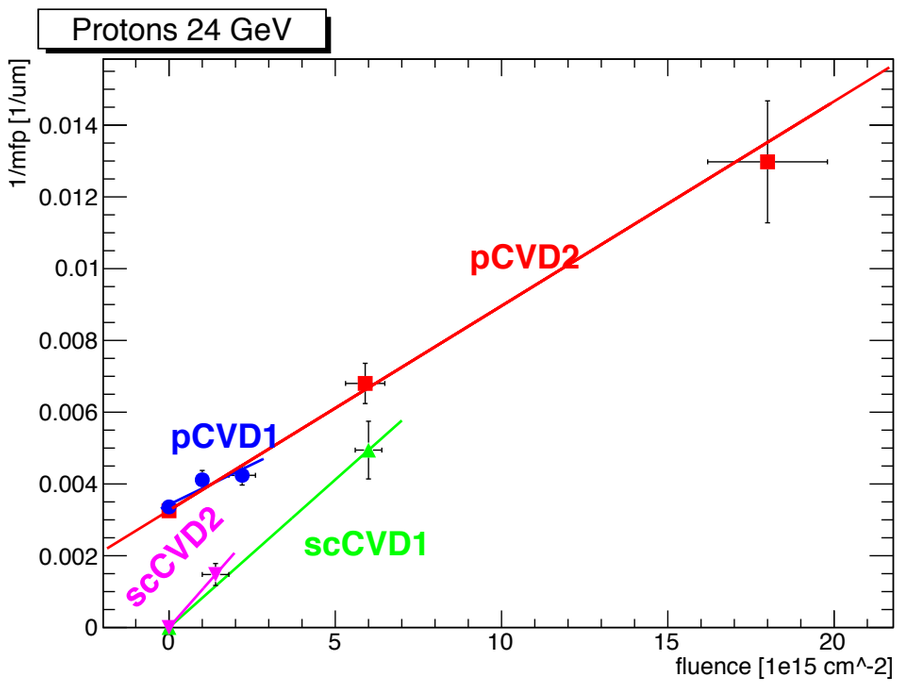
- We measure CCD
- Radiation-induced traps in fact decrease the mean free path (mfp)
- CCD~ mfp_e+mfp_h in thick detectors t >> mfp, CCD
- CCD degradation formula not applicable to scCVD since $CCD_0 = t$; $mfp_0 \rightarrow \infty$
- Relation CCD ↔ mfp for homogeneous material

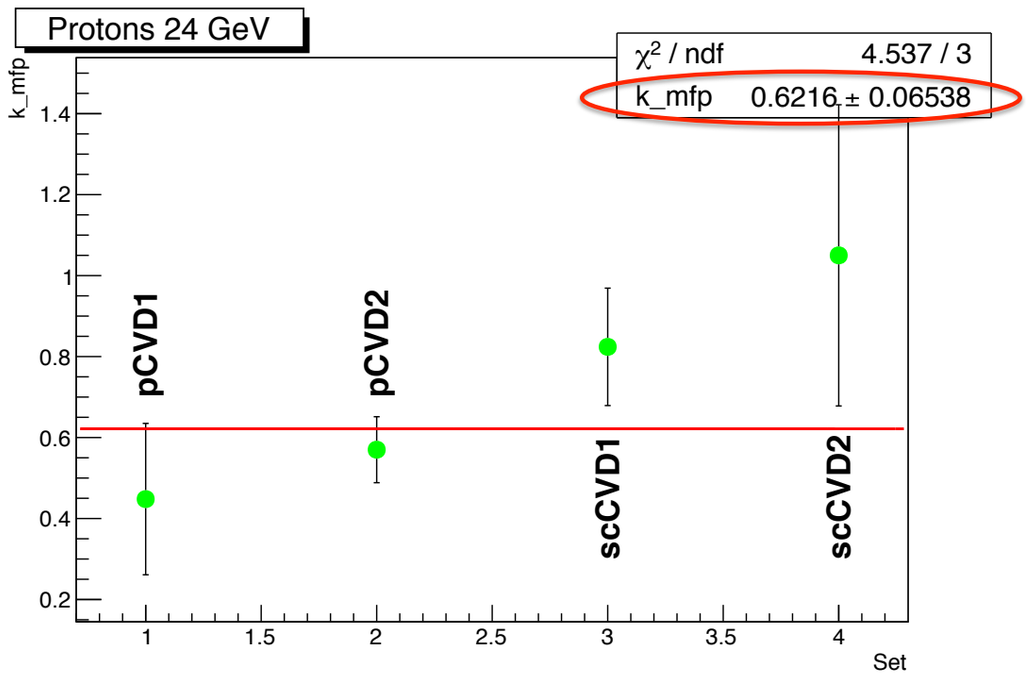


Damage curves in the subsequent slides are fitted with the following ansatz

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

24 GeV protons: CERN PS

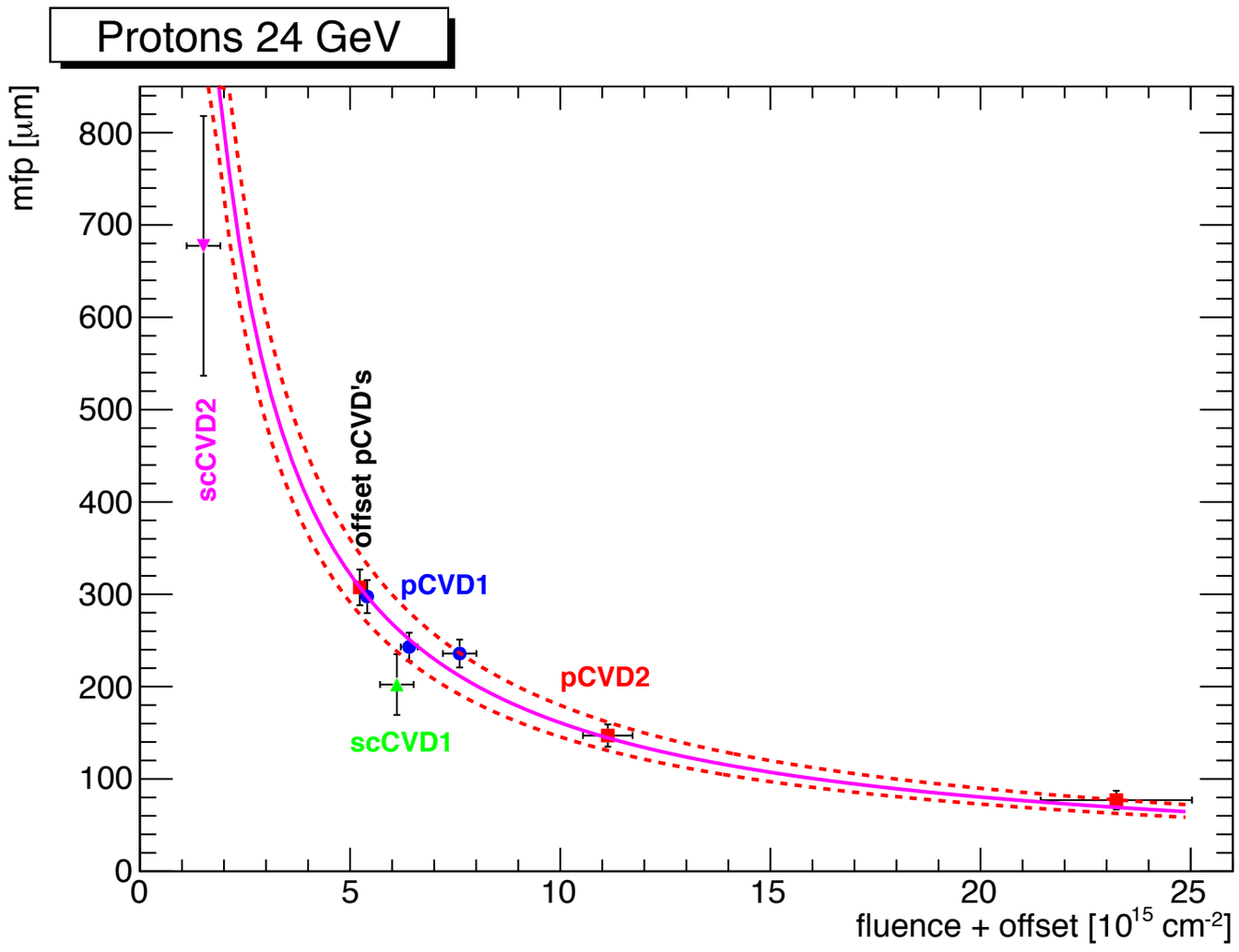




- Each irradiation set fitted separately assuming ansatz $\frac{1}{\lambda} = \frac{1}{\lambda_0} + k_\lambda \Phi$
- The damage constant is the average between various irradiation sets

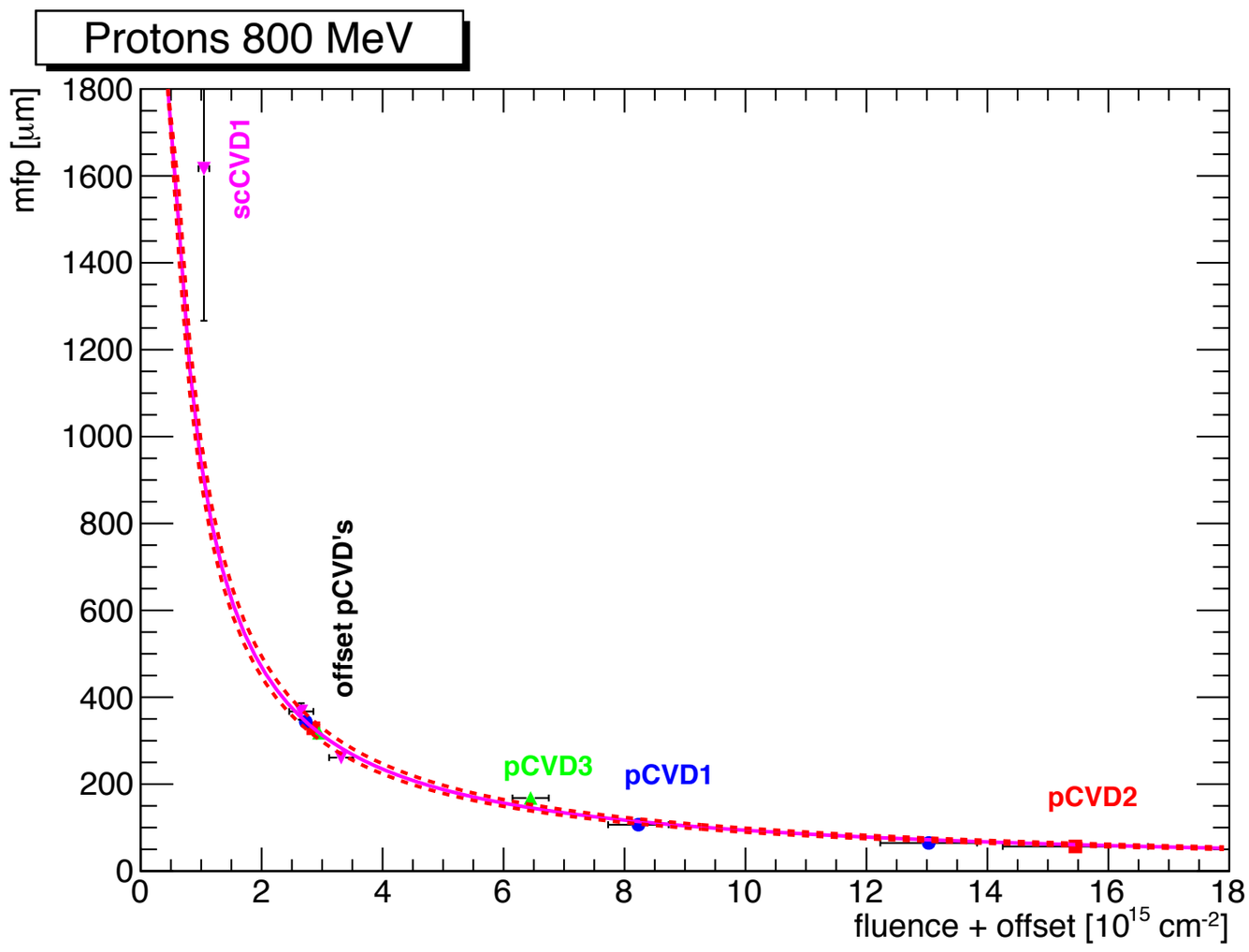
24 GeV protons: CERN PS

- k ~ 0.62±0.07x10^{-18} μm^{-1}cm^{-2}
  - pCVD offset by ~5x10^{15} cm^{-2} for plotting



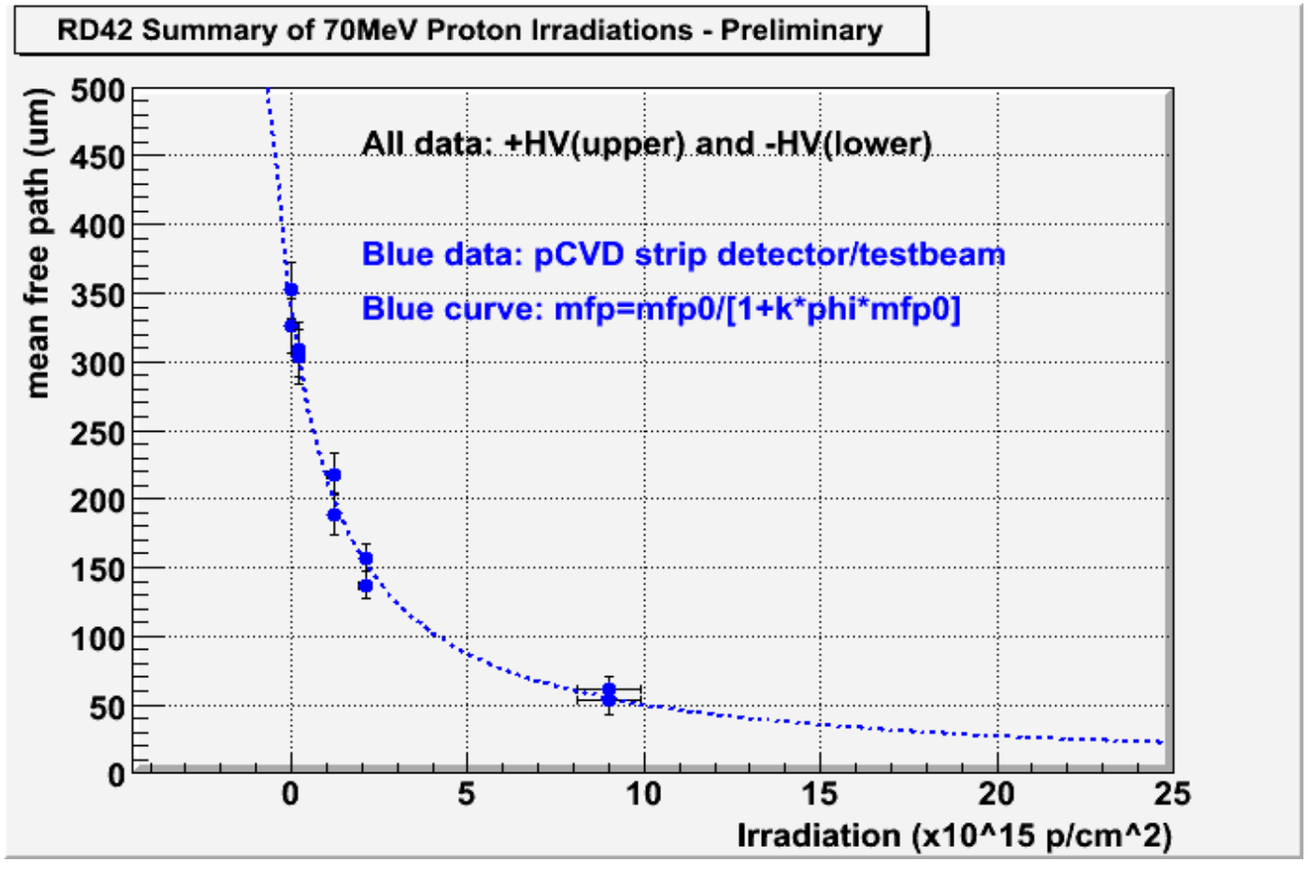
800 MeV protons

- Recent Irradiation with 800 MeV protons at LANSCE Facility in Los Alamos, US
- pCVD offset by 2.5×10^{15} cm^{-2} for plotting
- $k \sim 1.07 \pm 0.05 \times 10^{-18}$ $\mu m^{-1} cm^{-2}$
  - 1.7±0.2 times more damaging then 24 GeV protons
  - FLUKA DPA predicts ~1.3x



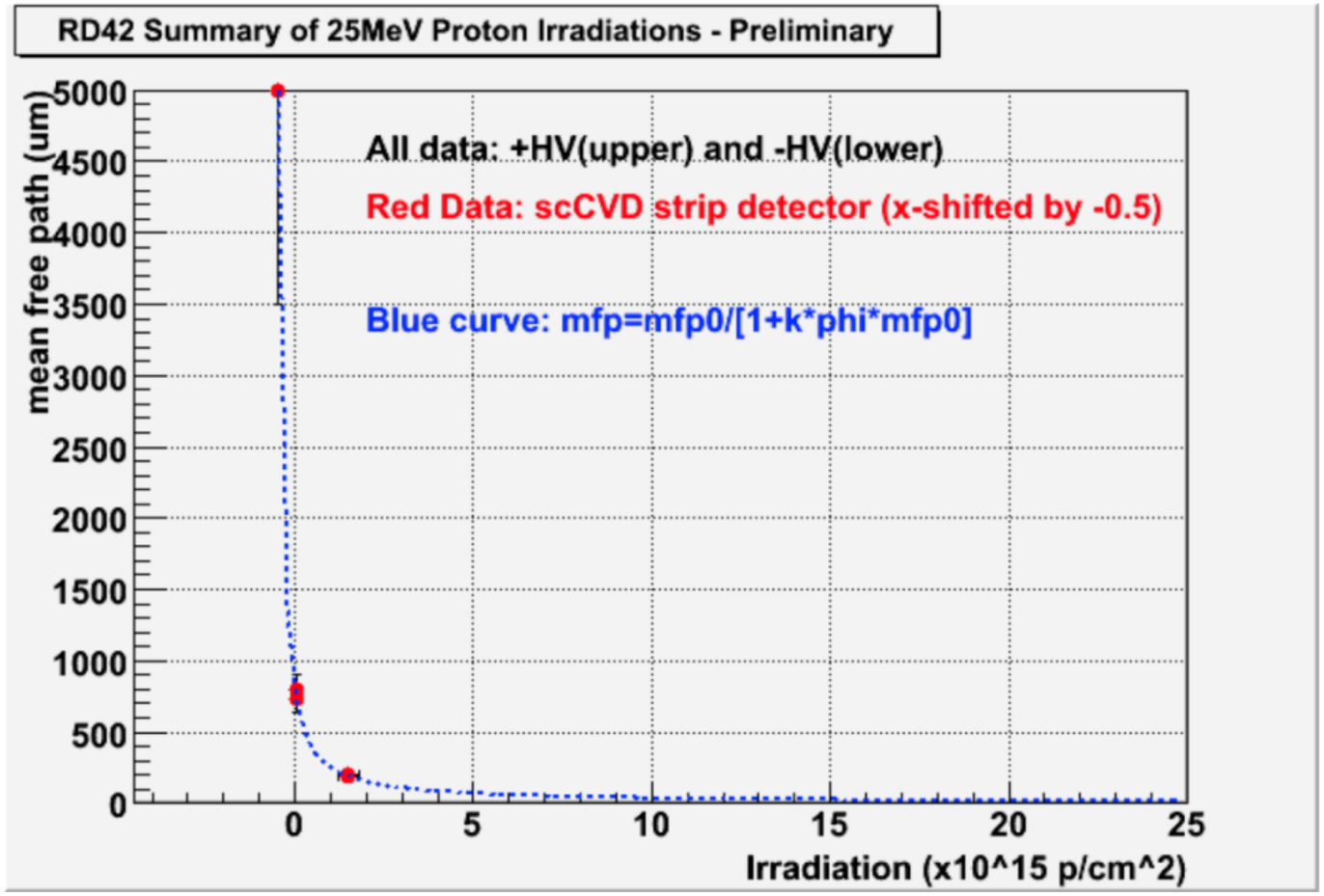
70 MeV protons

- Irradiations with 70 MeV protons at Cyric Facility in Sendai, Japan
  - $k \sim 1.7 \times 10^{-18}$ $\mu m^{-1} cm^{-2}$
  - confirmed by measurement of $k \sim (1.8 \pm 0.3)\ 10^{-18}$ $\mu m^{-1} cm^{2}$ of samples irradiated with 62 MeV protons at INFN Laboratori Nazionali del Sud (LNS) (Catania- Italy)
- ~2.7 ±0.3 times more damaging than 24 GeV PS protons
- FLUKA DPA predicts factor of 4
  - Over prediction?



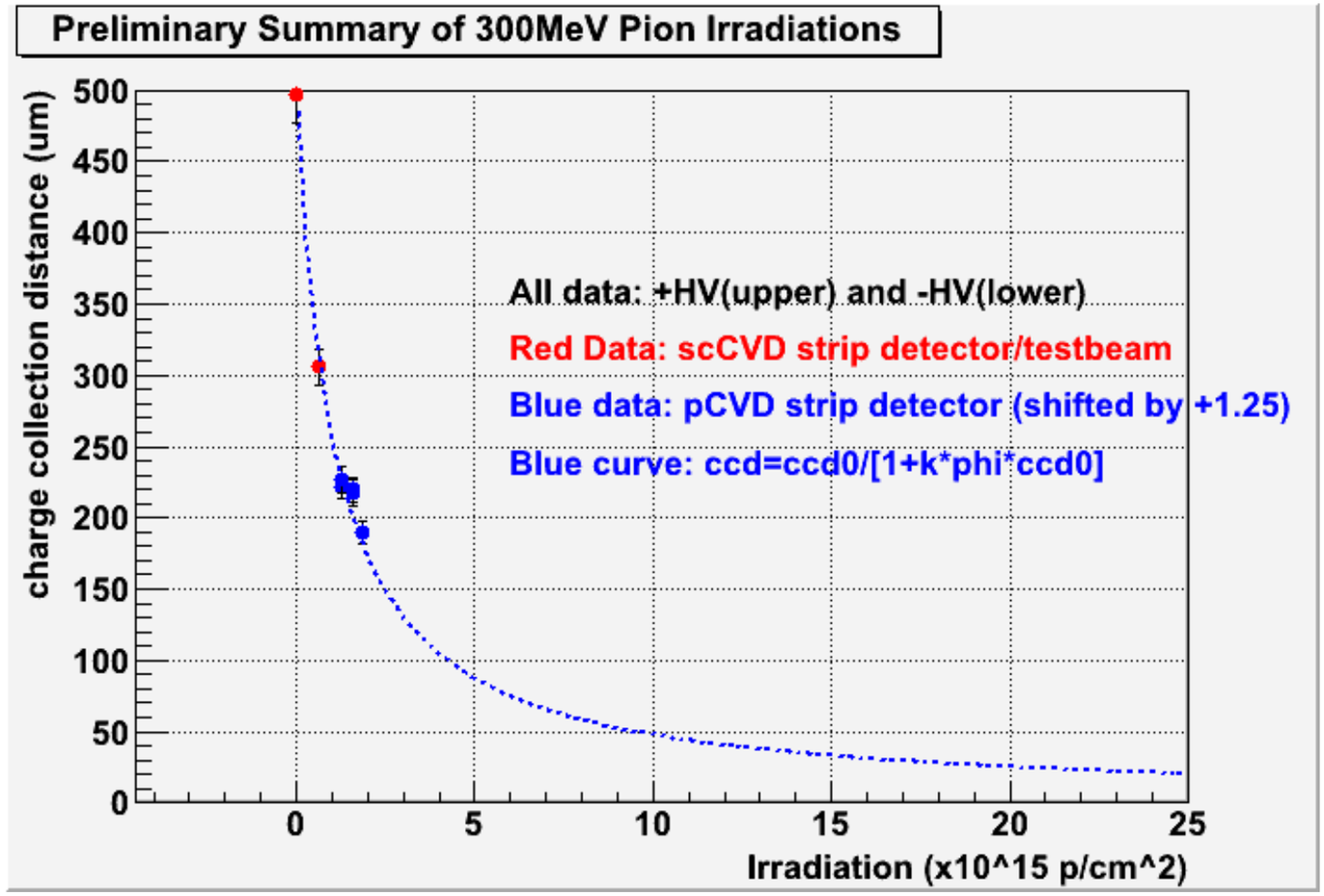
25 MeV protons

- Irradiation with 25 MeV protons at KIT Facility in Karlsruhe, Germany
- $k \sim 2.6 \times 10^{-18}\ \mu m^{-1} cm^2$
- Result: 25 MeV protons 4 ± 0.5 times more damaging than 24GeV protons
  - FLUKA DPA predicts 8x
  - Over prediction by factor of 2?



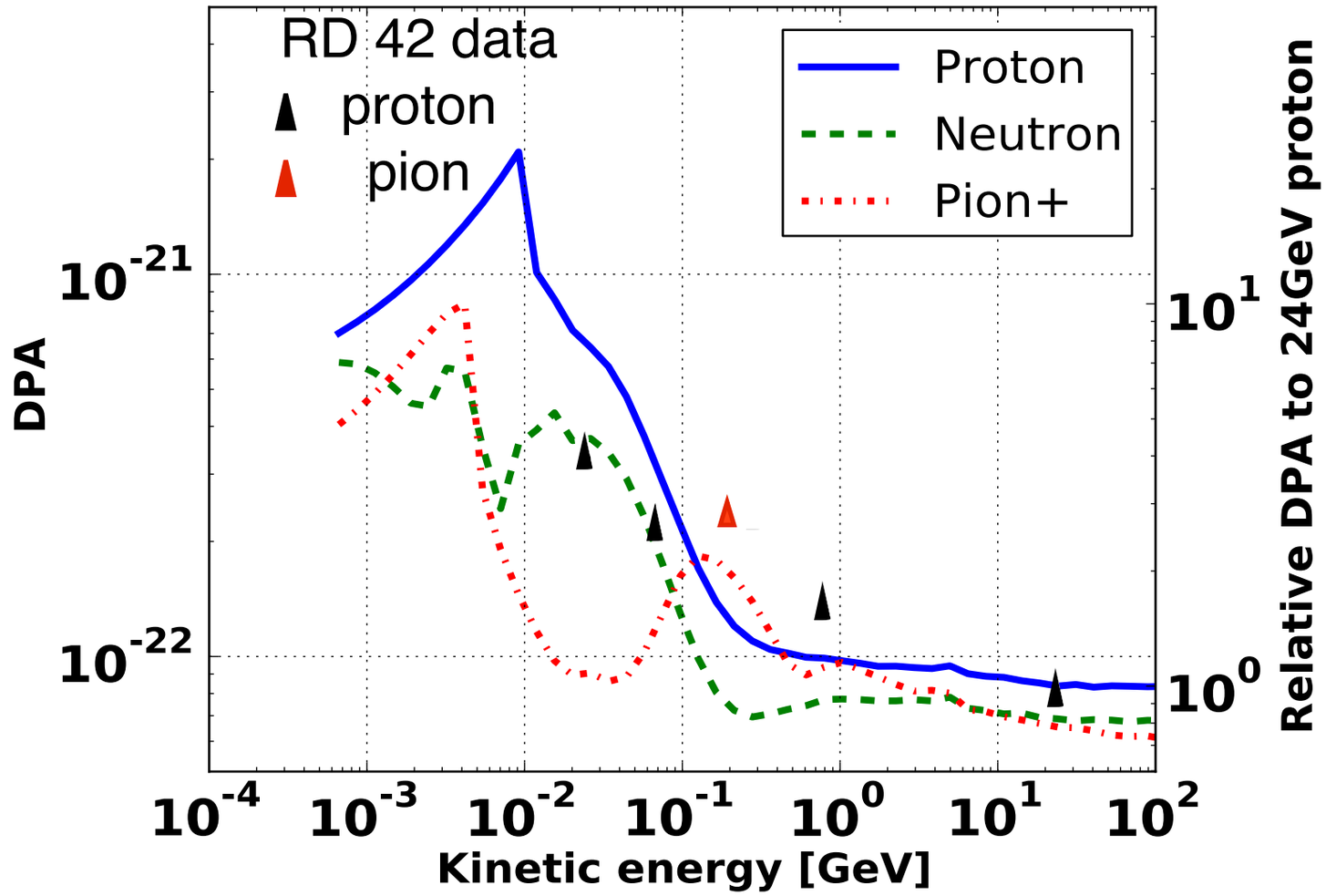
π^+ irradiation

- Performed at PSI with 300MeV/c (191.31 MeV) π up to 6.5×10^{14} π/ cm^2
- $k \sim 1.8 \times 10^{-18}$ $\mu m^{-1} cm^2$
  - 2.9 ±0.3 x more damaging than 24GeV protons
  - FLUKA DPA predicts factor of ~2.2



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



Summary of RD42 test beam results

- $k_{24\ GeV\ p} \sim 0.62 \pm 0.07 \times 10^{-18}\ \mu m^{-1} cm^{-2}$

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

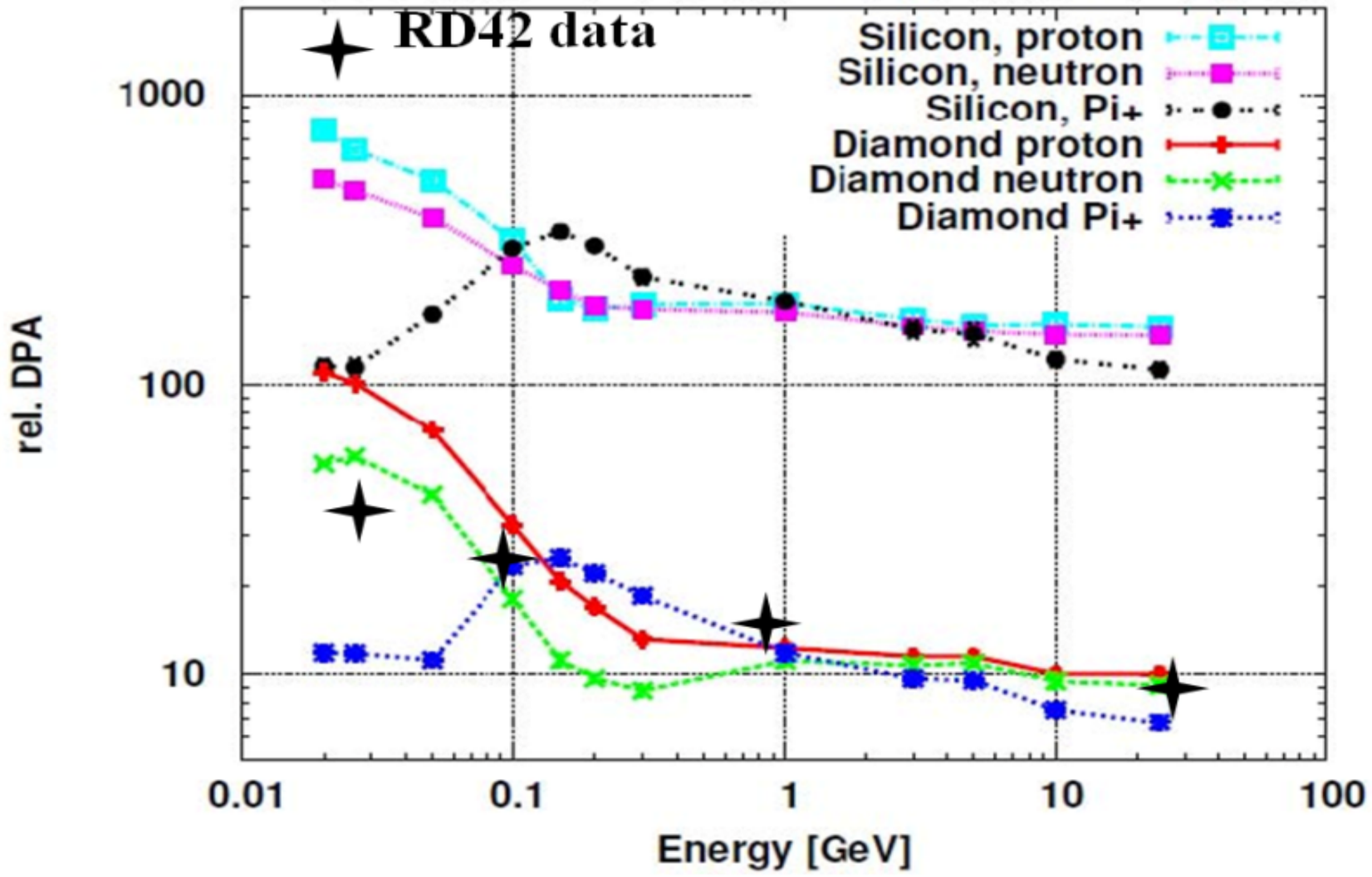
Summary

- Radiation Hardness of CVD diamond is nearly quantified
  - pCVD and scCVD have the same damage constant.
  - Dark current decreases with the dose.
  - DPA -Theory still needs a bit of work
  - ccd method not exact; mfp has assumptions; they agree
- Proton results nearly complete
- Pion initial results look good
  - Both pCVD and scCVD irradiated.
  - Dark current decreases with the dose
- Re-analyzing RD42 test beam data with a new analysis
  - new features added, bugs corrected
  - small correction to the previously analyzed data expected

Back Up Slides

DPA comparison

- DPA based on Displacement Energy (Steffen Müller Ph.D. Thesis):
  - Si:~25eV
  - Diamond:~42eV
- Reasonable agreement at high energies
  - DPA scaling over predicts at low energies



NIEL comparison

- New results from low energy irradiations
- Deviation from calculated NIEL at low energy?
  - NIEL violation? or is the theory incorrect?