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Latest Results on Radiation Tolerance of CVD Diamond Sensors

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on behalf of the RD42 Collaboration
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The 2020 RD42 Collaboration

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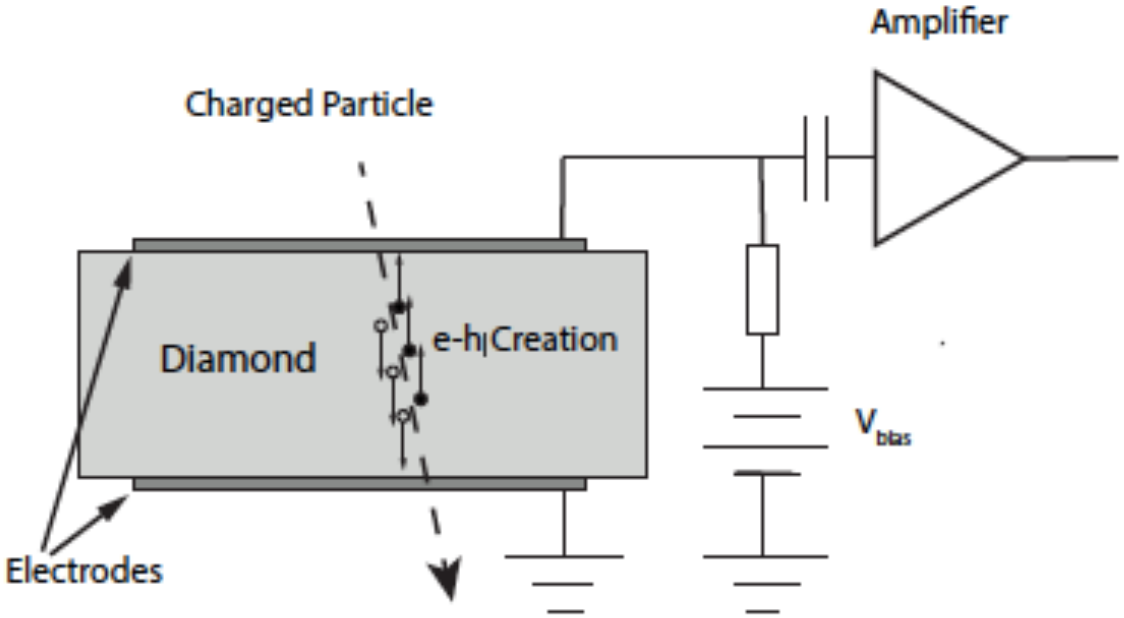
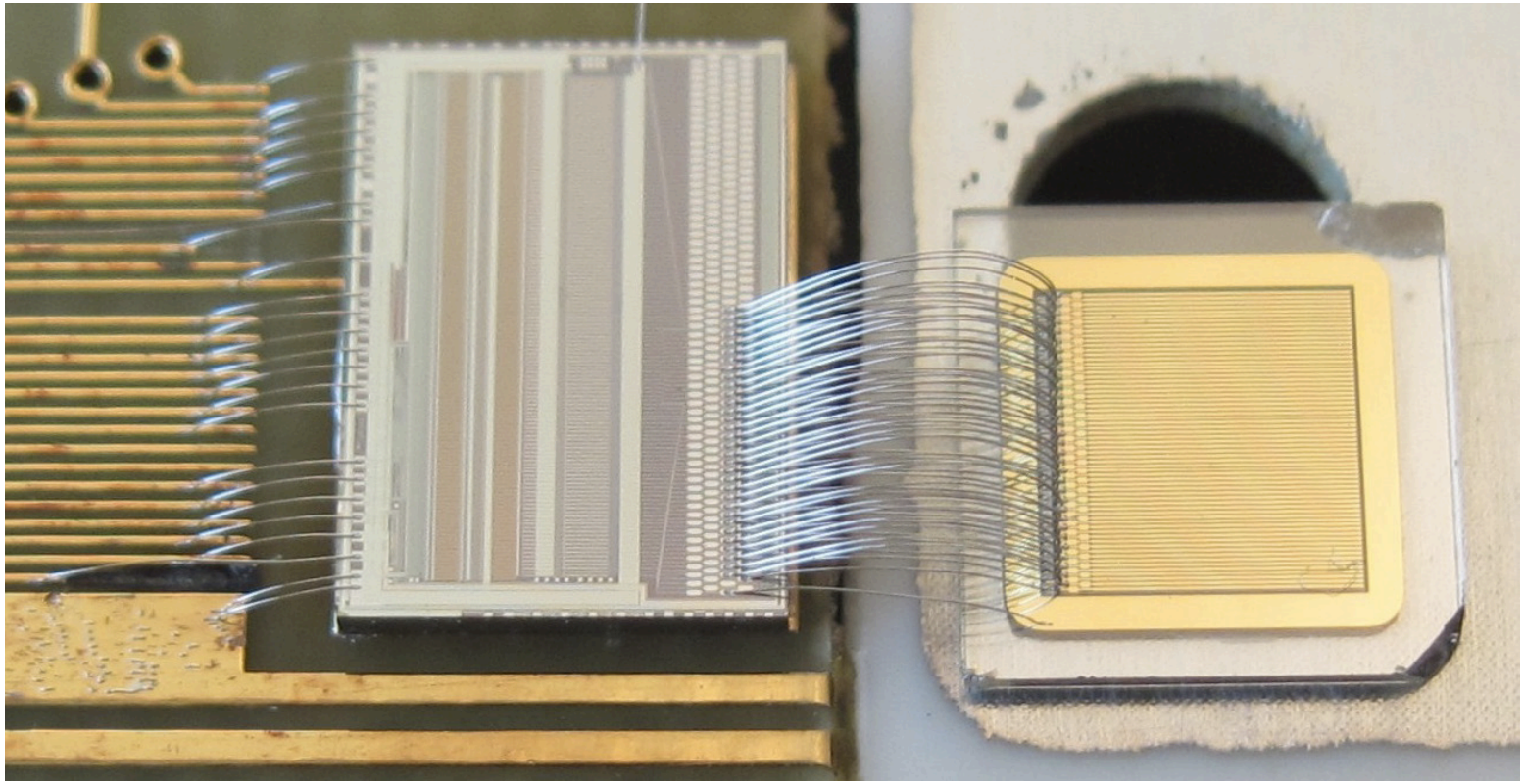
31 Institutes

Diamond as a MIP sensor



Diamond Tracker under test at SpS testbeam



128 channel VA2 readout chip

5 x 5 mm^2 scCVD diamond tracker

Pulse Height in Irradiated scCVD sensors

Sum of charge observed on 5 contiguous strips near the impact point of the testbeam track

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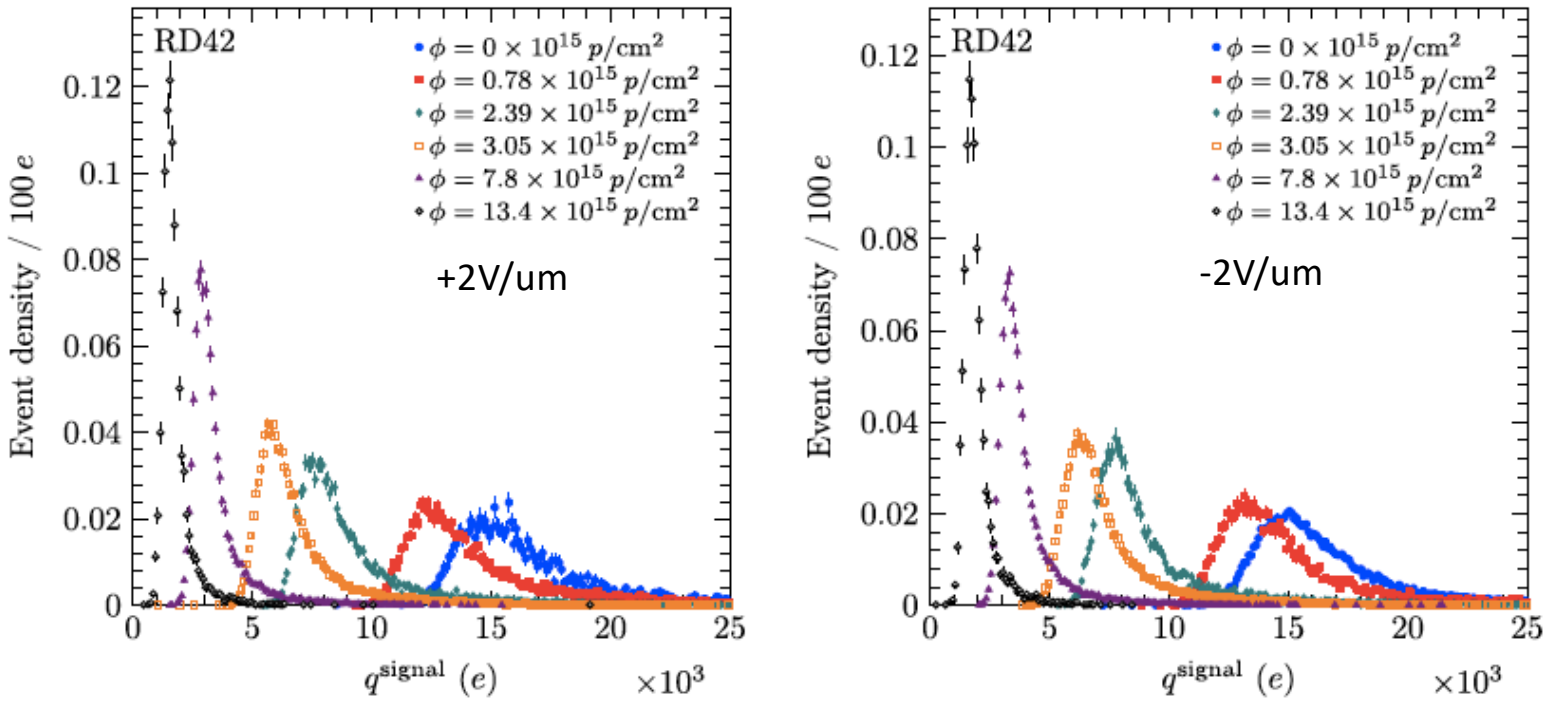
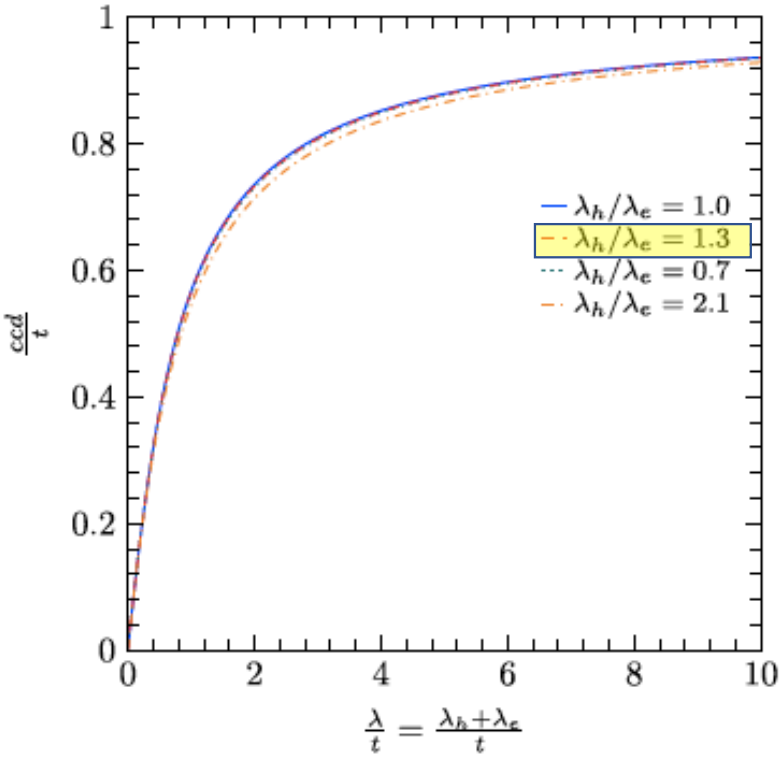
800 MeV proton irradiation



Mean Free Path in diamond vs Signal Size

- Collect all the charge only when $\lambda \rightarrow \infty$
- For low-quality material $\lambda \sim ccd$ (linear part of exp.)
- Mean free path for electrons and holes could differ
  - Carrier lifetime only 30% different in diamond
  - Consider wide range of possibilities
    - Doesn't change translation from *ccd* to λ

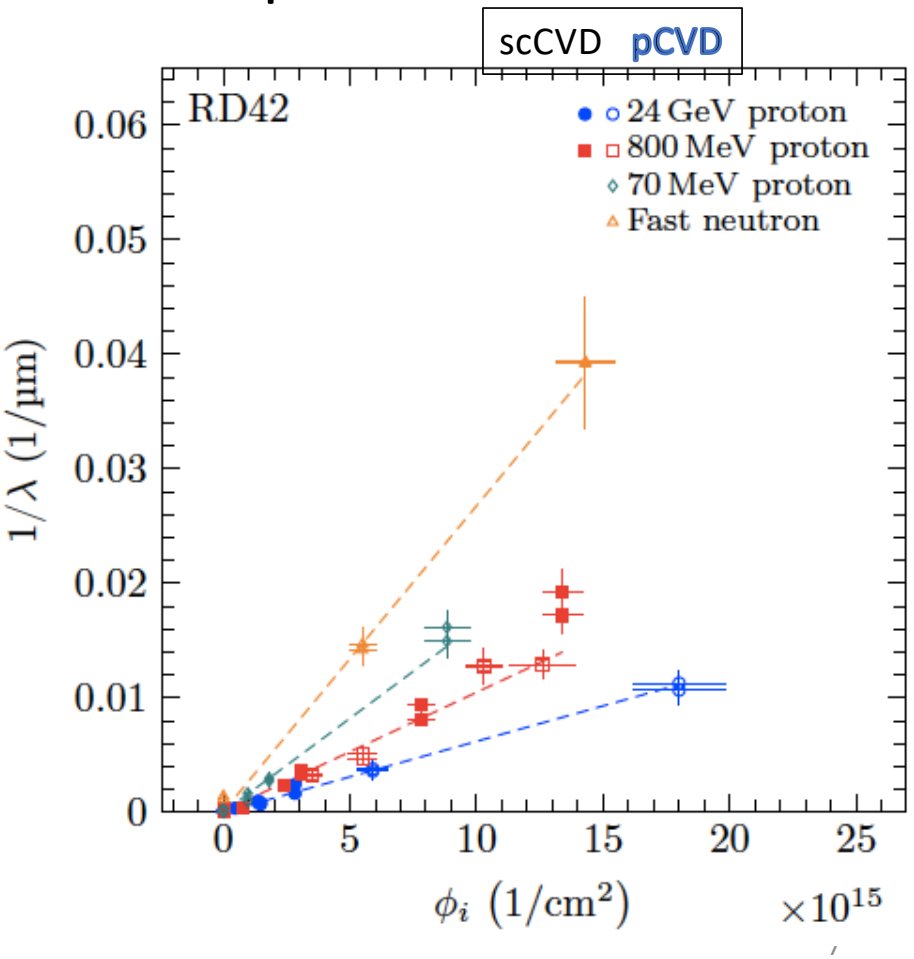
$$\frac{ccd}{t} = \sum_{i=e,h} \frac{\lambda_i}{t}\left[1 - \frac{\lambda_i}{t}\left(1 - e^{-\frac{t}{\lambda_i}}\right)\right]$$



Mean Free Path vs. Irradiation species

- Irradiation introduces traps in the material
- Lowers carrier mean free path
- Effect depends on
  - Traps in unirradiated material: λ_0
  - Proportional to fluence: ϕ
  - Irradiation species (protons, neutrons,…): k_i

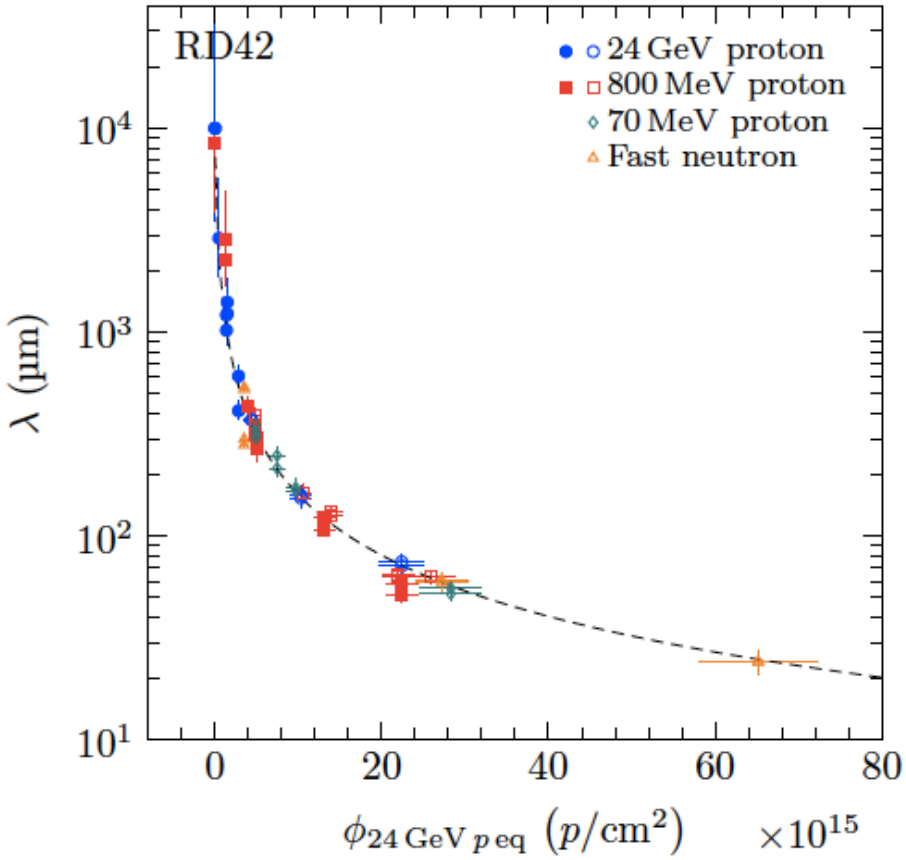
$$\frac{1}{\lambda} = \frac{1}{\lambda_0} + k_i\phi$$



Adjust each species for relative damage

- Normalise damage to 24 GeV proton fluence
- Correct for λ_0 for each sample
- Universal signal degradation curve
-

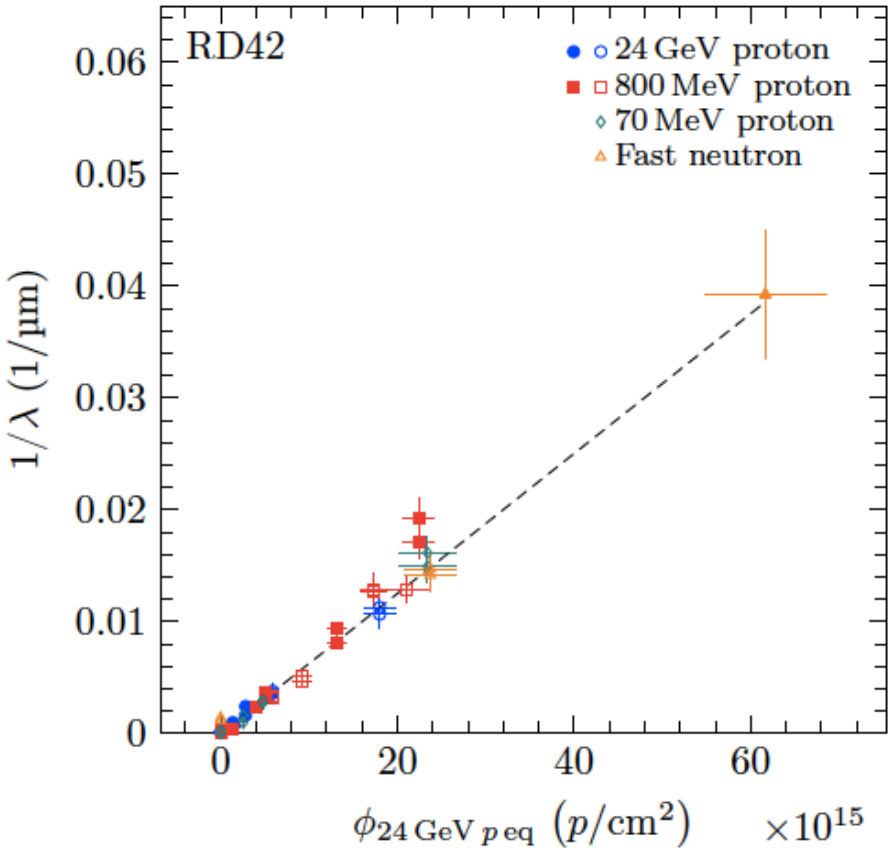
Irradiation Species	k_i
Fast neutrons	4.31 ± 0.34
70 MeV protons	2.65 ± 0.25
800 MeV protons	1.67 ± 0.09
24 GeV protons	1



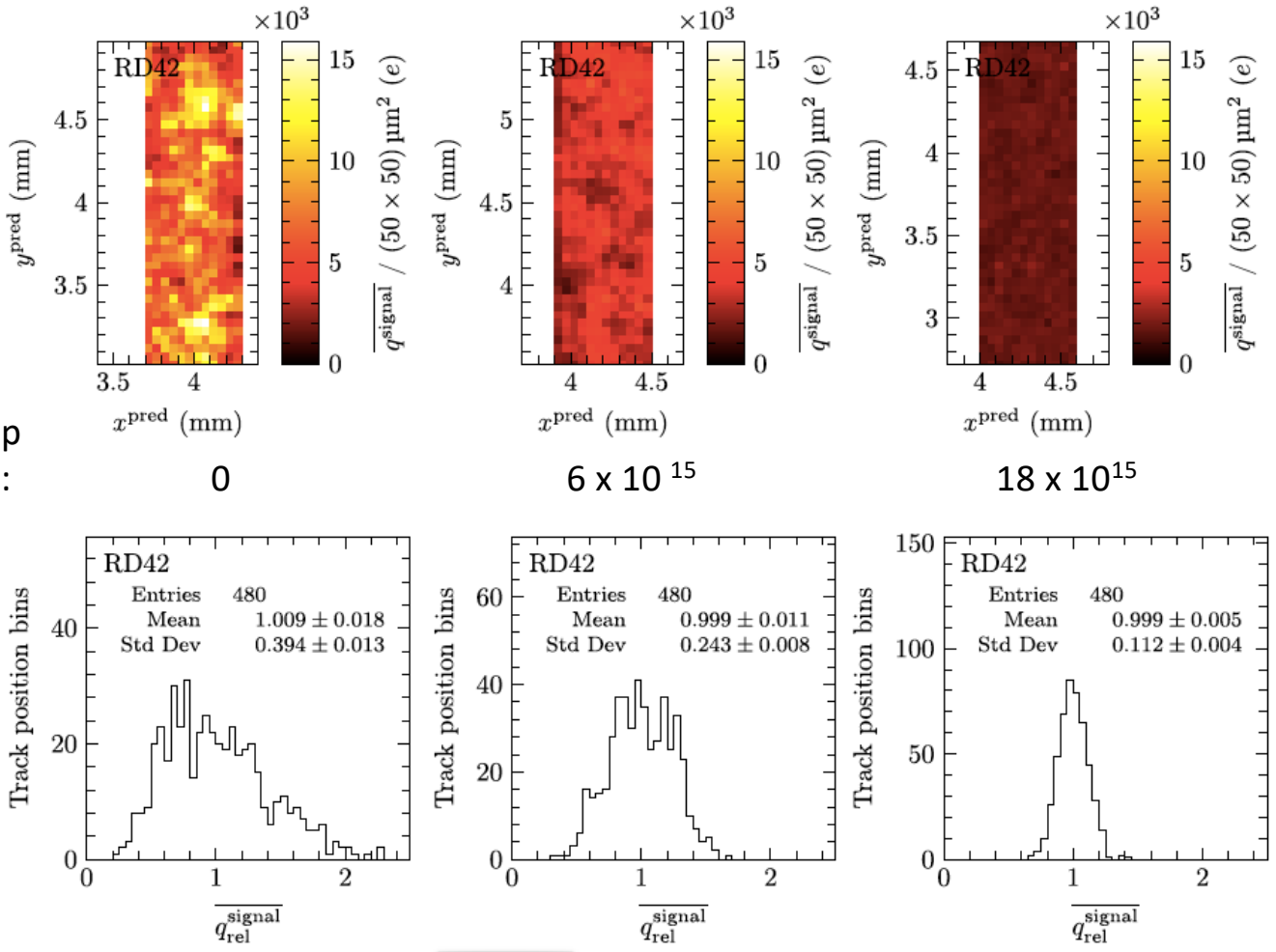
Adjust each species for relative damage

- Normalise damage to 24 GeV proton fluence
- Correct for λ_0 for each sample
-
- Alternatively, get universal curve in $1/\lambda$

Irradiation Species	k_i
Fast neutrons	4.31 ± 0.34
70 MeV protons	2.65 ± 0.25
800 MeV protons	1.67 ± 0.09
24 GeV protons	1



Signal Uniformity in Irradiated pCVD material



24 GeV p
Fluence: 0 6 x 10^{15} 18 x 10^{15}

- Re-writing λ, ϕ relation:

$$\lambda = \frac{\lambda_0}{1 + \lambda_0 k \phi}$$

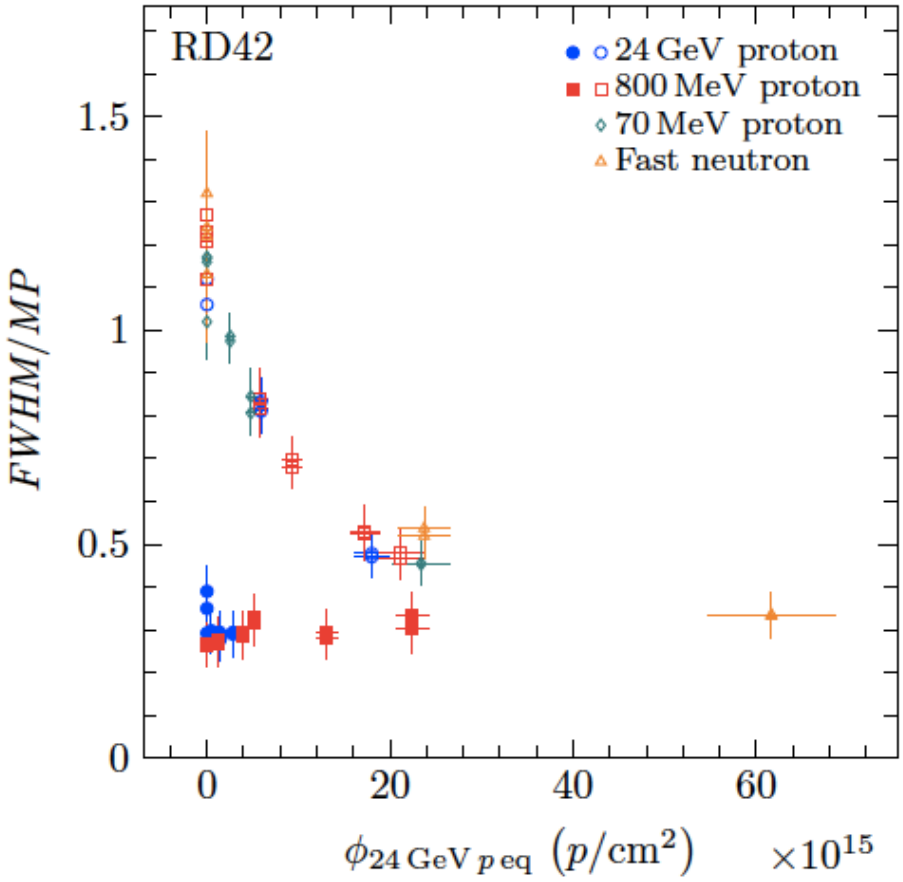
- Differentiating:

$$\frac{\mathrm{d}\lambda}{\mathrm{d}\phi} = -k\lambda^2.$$

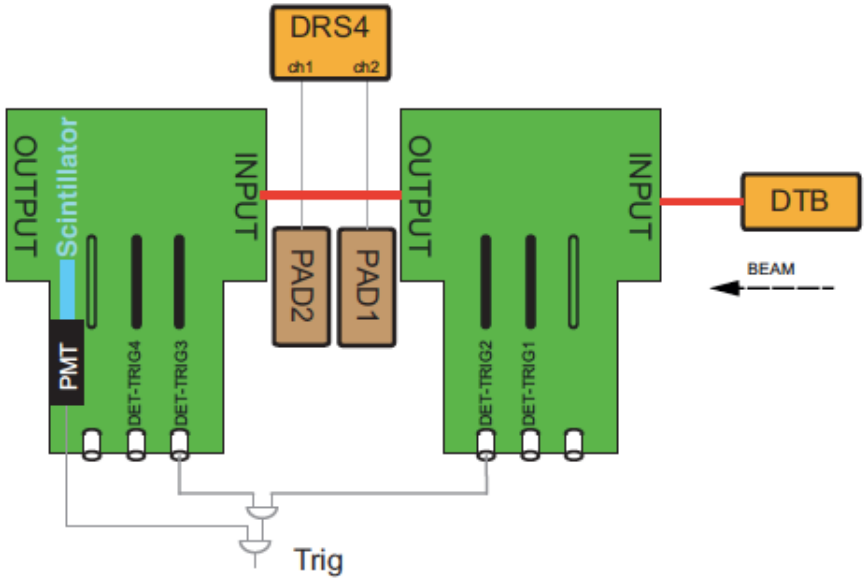
- Highest signal regions
- Suffer largest degradation
- FWHM narrows

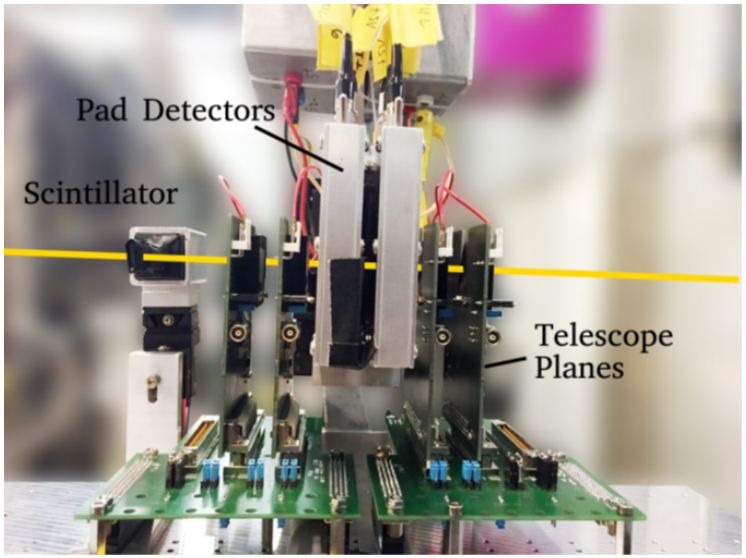
MIP Charge Resolution vs. Fluence

- Large FWHM of signal results from large spatial variation of signal
- Spatial variation damped out by irradiation
  - scCVD samples essentially unchanged
  - pCVD samples have improved energy/charge resolution



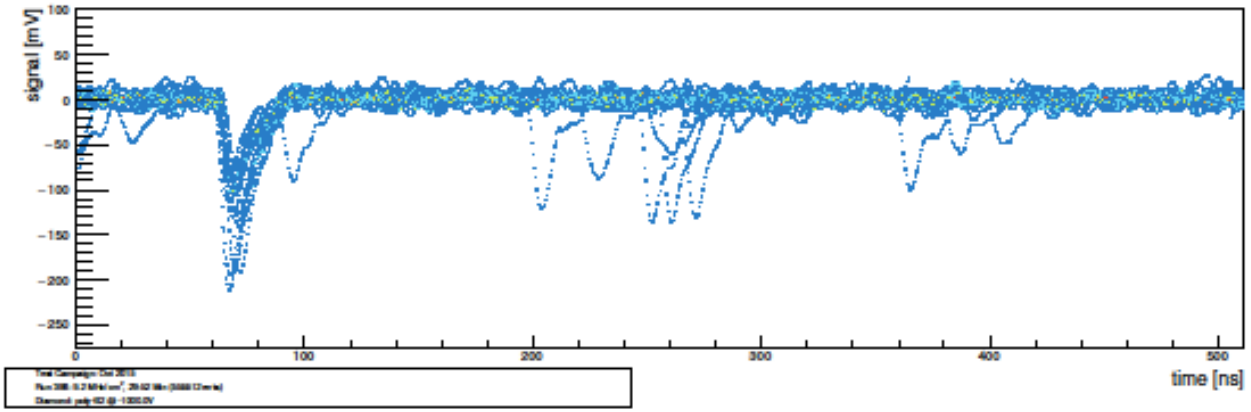
High Rate PSI Testbeam Setup



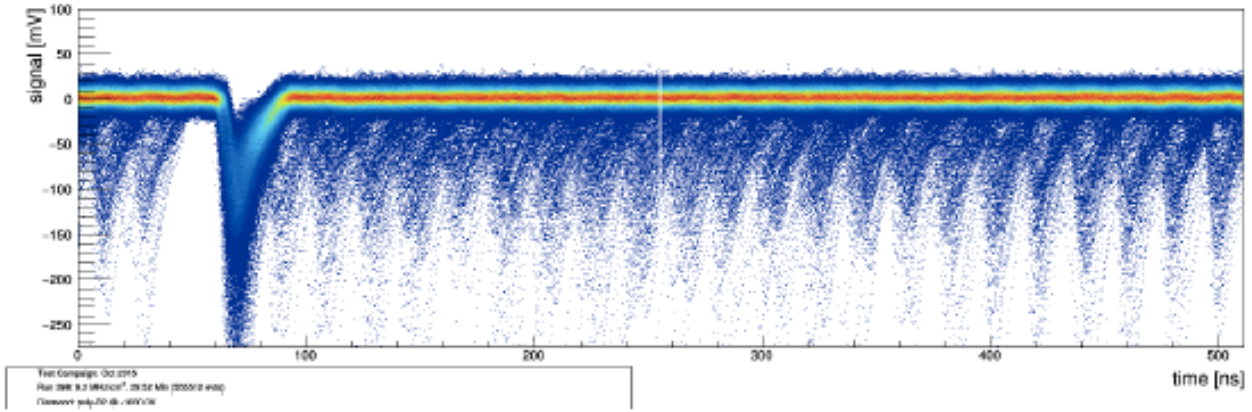


- Reference planes use CMS Pixel detectors:
  - PSI dominated by multiple scattering -- track position ~20-30 um
- Diamond pads (4-8 mm on side) readout with DRS4 flash ADC (2 GS/s)

Raw Data from 10 MHz/cm^2 Flux



20 triggers



5000 triggers

0 ns

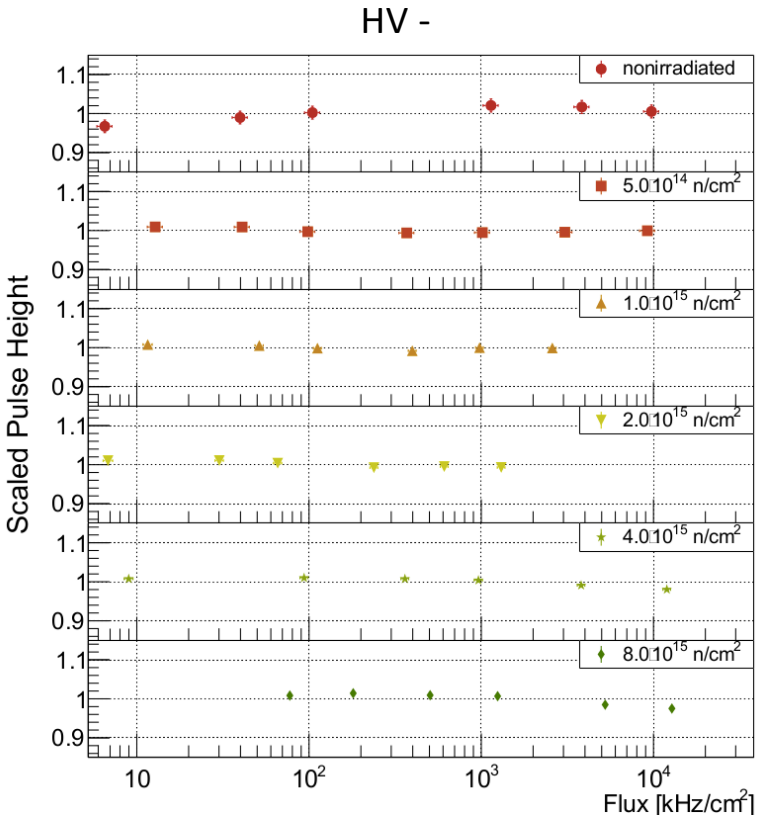
500 ns

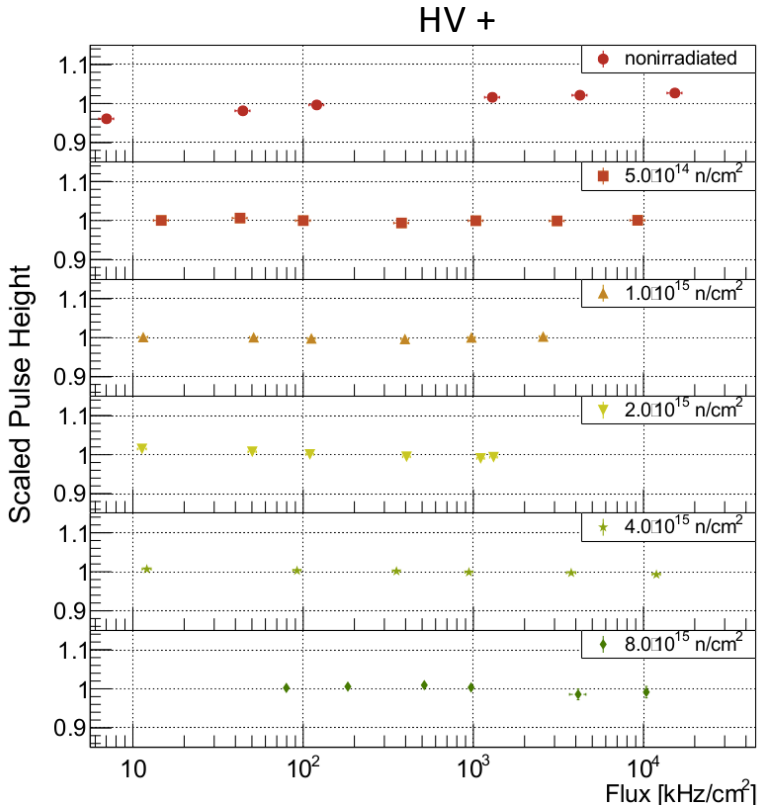
Rate independence: neutron irradiated pCVD

Fluence

0

8 x 10^{15}





Flat to better than 2% up to 10-20 MHz/cm^2. Exploring systematics of O(1%)

Summary

- Diamond sensors have a long history of applications in HEP
- Diamond sensors now give robust MIP signals even after 8 years of LHC operation
- Signals remain viable to fluences of 10^{16} /cm^2
- MIP signals stable to particle fluxes of 10-20 MHz/cm^2
- 3D devices now being studied (previous talk: Kagan)
- New beam conditions monitors being developed for HL-LHC (yesterday: Mikuz)

Backup

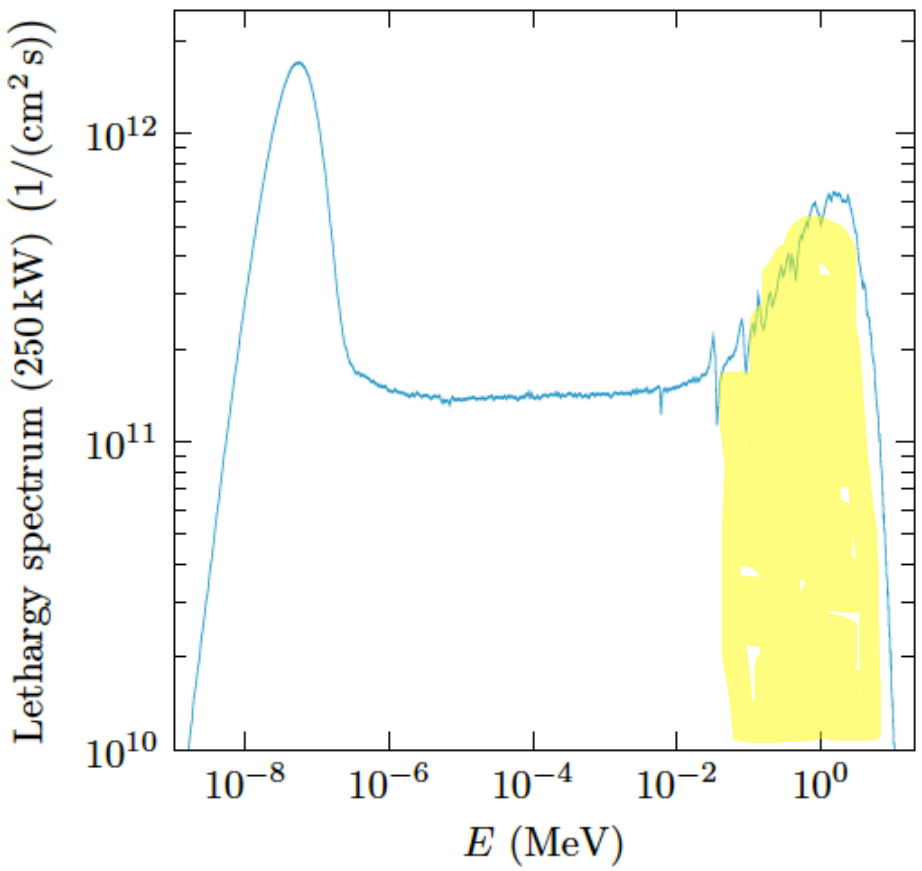


Figure 1: Lethargy neutron spectrum of channel F19 in core 189 of the TRIGA reactor, at full reactor power (250 kW) [7].