The University of Manchester

MANCHESTER 1824

14.12.2018

# Latest Results on Radiation Tolerance of Diamond Detectors & Status of 3D Diamond

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**on behalf of the RD42 Collaboration**

# RD42:
## 123 participants, 30 institutes

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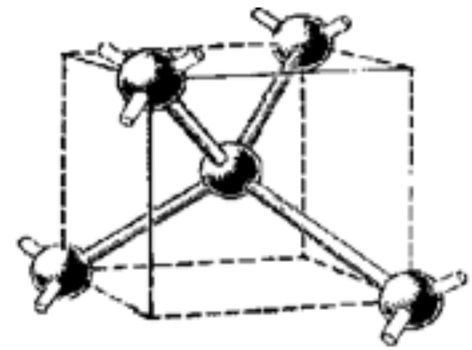
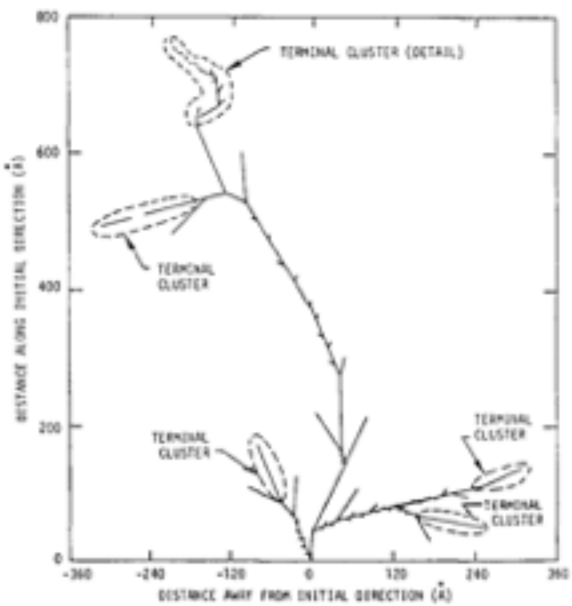
# Diamond properties

| Property | Diamond | Silicon |
|---|---|---|
| band gap [eV] | 5.47 | 1.12 |
| resistivity [Ωcm] | $>10^{11}$ | 2.3e5 |
| ionisation density MIP [eh/mm] | 36 | 89 |
| **displacement energy [eV]** | **43** | **25** |



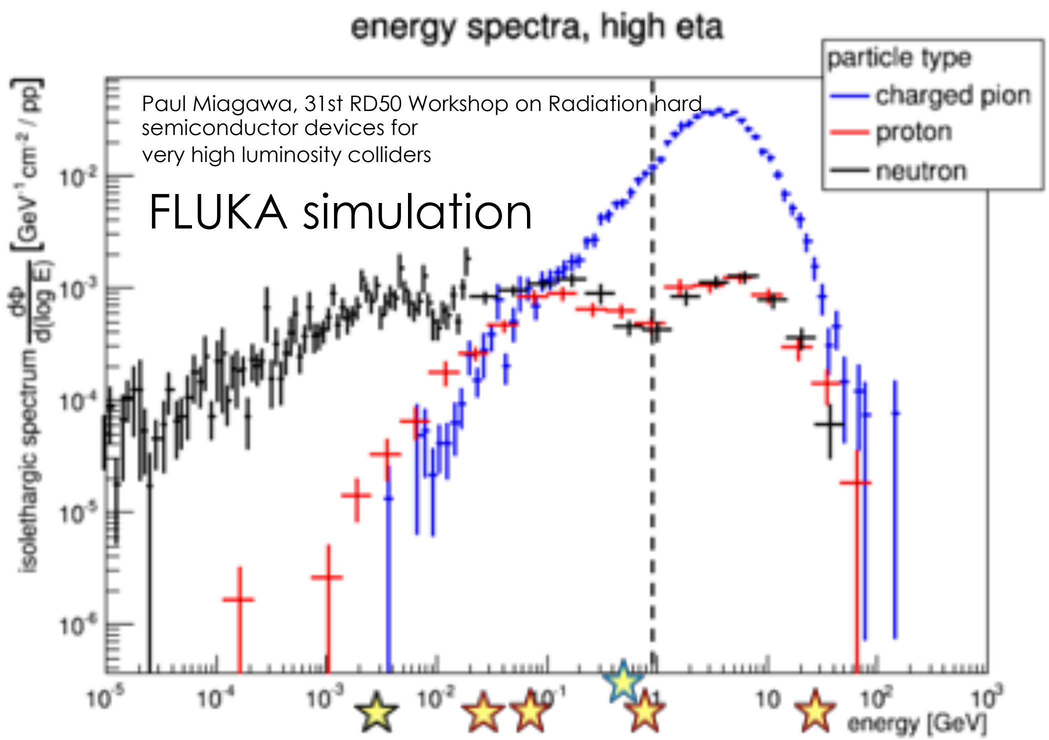



V.A.J. van Lint, R.E. Leadon and J.F. Colwell, IEEE Trans. Nucl. Sci. NS-19 (6) (1972) 181.

- Radiation produces cluster and point defects.
- Displacement energy per atom higher in Diamond compared to Silicon.
- Naive extrapolation: Diamond should be more radiation tolerant than Silicon.

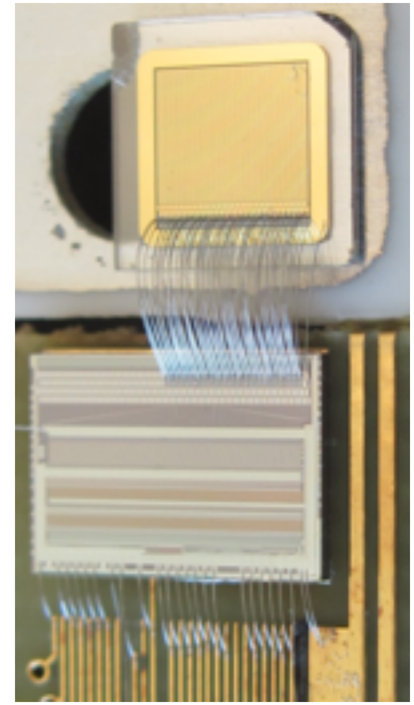
# Tests of Radiation Tolerance

- Irradiate with **proton**, **pions** and **neutrons**.
  - Energies within the expected radiation profile at HL-LHC.
  - HL-LHC fluence requirement about 2e10$^{16}$ neq.

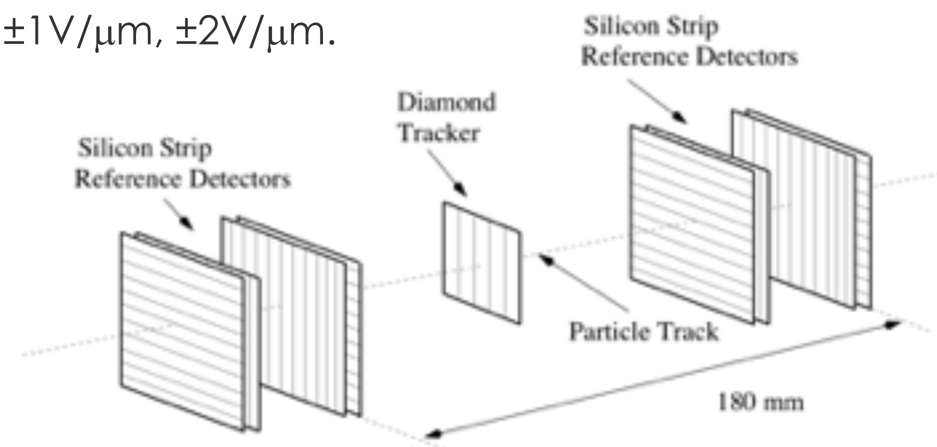



| | Proton | Pion | Neutron |
|---|---|---|---|
| **Energy** | 25MeV – 24GeV | 300 MeV | 1-10 MeV |
| **Fluence** | 1.27e16 p cm$^{-2}$ | 6e14 $\pi$ cm$^{-2}$ | 1.3e16 n cm$^{-2}$ |

# Radiation Tolerance: Characterization

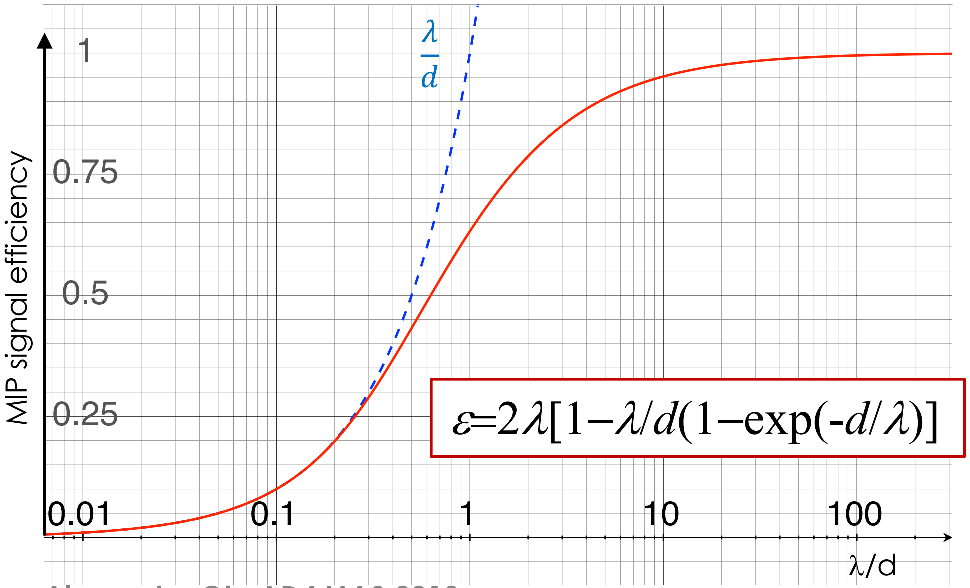


- **Irradiated sensors are metallized with strip pattern.**
  - Pitch 50um, size typically 5x5mm$^2$ or 10x10mm$^2$.
  - Strips wire bonded to multi-channel low noise charge integrating amplifier (VA2 readout, noise ~ 80e).
  - Before test sensors are exposed to $^{90}$Sr beta particles to fill charge traps.
- **Signal response tested with MIPs.**
  - **120 GeV/c protons** from CERN SPS, H6 beam line.
  - Beam telescope predicts track position to ~4μm.
  - Diamond detector electric field $E$ = ±1V/μm, ±2V/μm.
  - Require single track on active area, no threshold on strip signals.
  - Build signal of highest two strip cluster within 10 strips around the track.



# Radiation Tolerance: Characterization

- MIP signal is measured, expressed in charge collection distance defined as **$d[\mu m]=Q_m[e]$ / 36 [e/μm]**
- Traps reduce the life-time of charge carriers, or "Schubweg" (**$\lambda$**).
  - Relation between *MIP signal efficiency* $\varepsilon$ and $\lambda$:




$$\varepsilon=2\lambda[1-\lambda/d(1-\exp(-d/\lambda)]$$

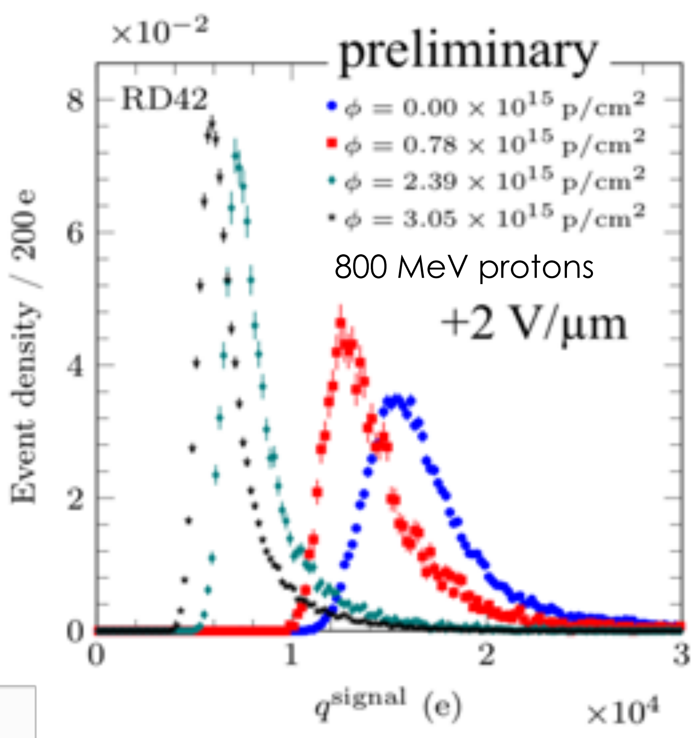
Radiation damage constant is fitted with simple model:

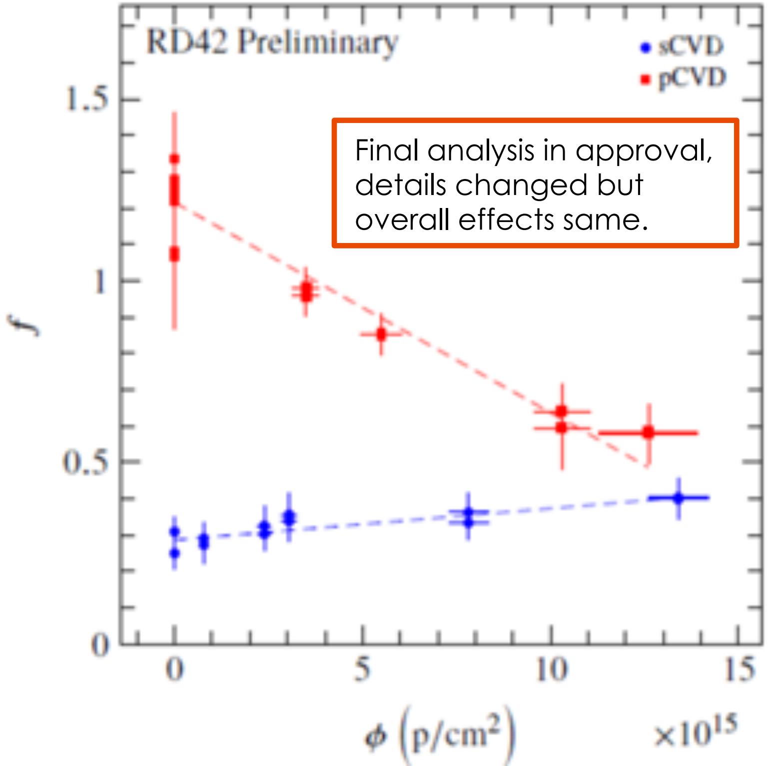
$$\frac{1}{\lambda}=\frac{1}{\lambda_0}+k_\lambda\Phi$$

damage constant ($k_\lambda$), particle flux ($\Phi$)

# Radiation Tolerance: Characterization

- Typical Landau Spectra after irradiation of pCVD.
- For pCVD see reduction of **FWHM / MP** with irradiation.
  - Expected from polycrystalline nature of material!
  - Single crystal material almost flat.



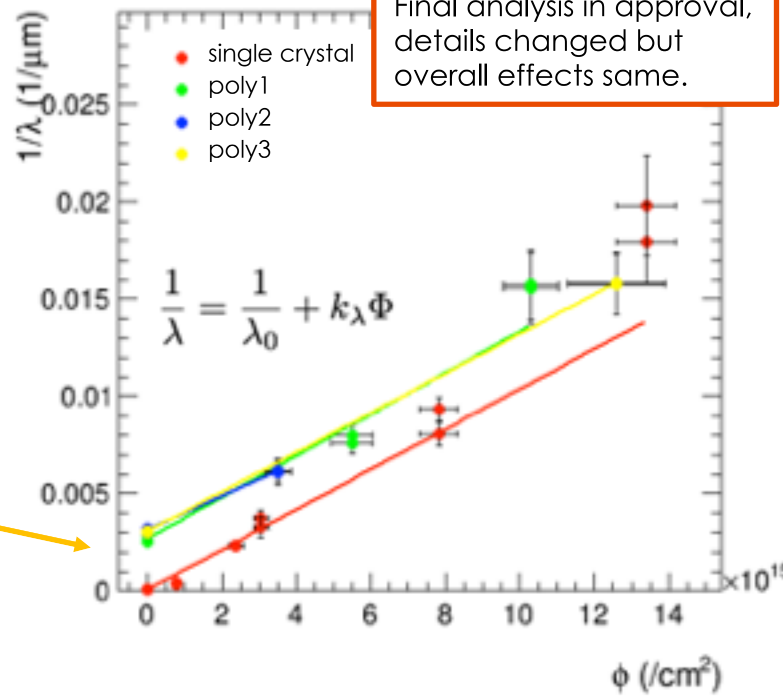



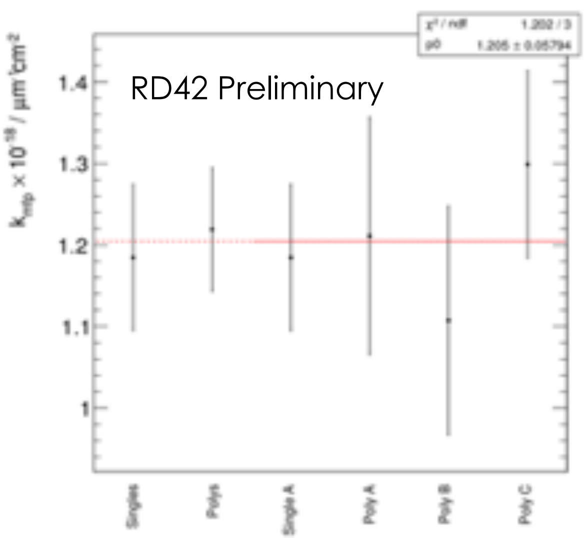

Final analysis in approval, details changed but overall effects same.

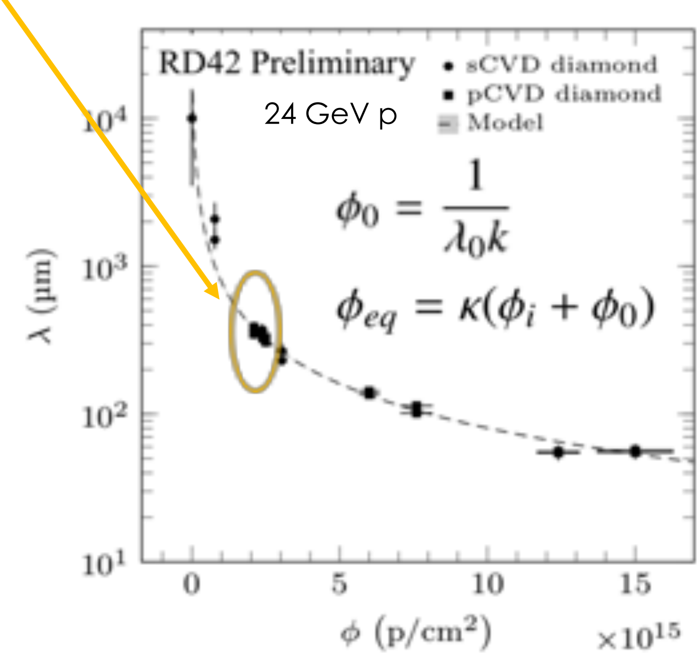
# Radiation Tolerance: Characterization

- Damage factor k is determined for each sample.
- **pCVD** diamonds are offset by $\lambda_0$ to account for initial finite carrier lifetime.
- Final damage factor averaged over all samples.

Final analysis in approval, details changed but overall effects same.



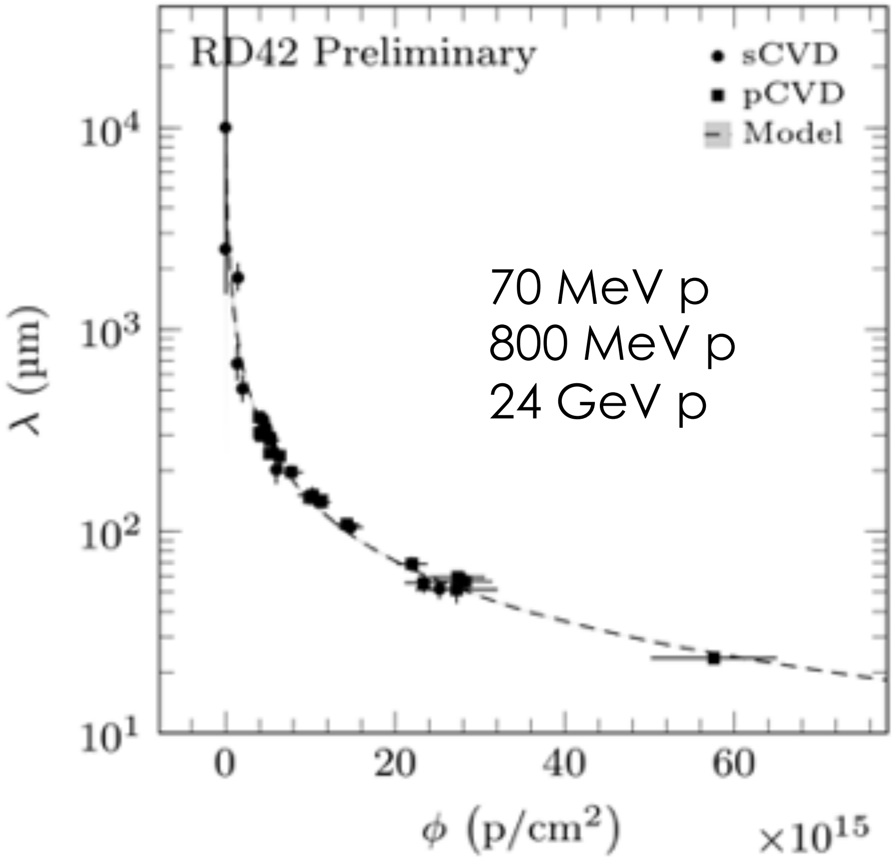



# Radiation Tolerance

Final analysis in approval, details changed but overall effects same.

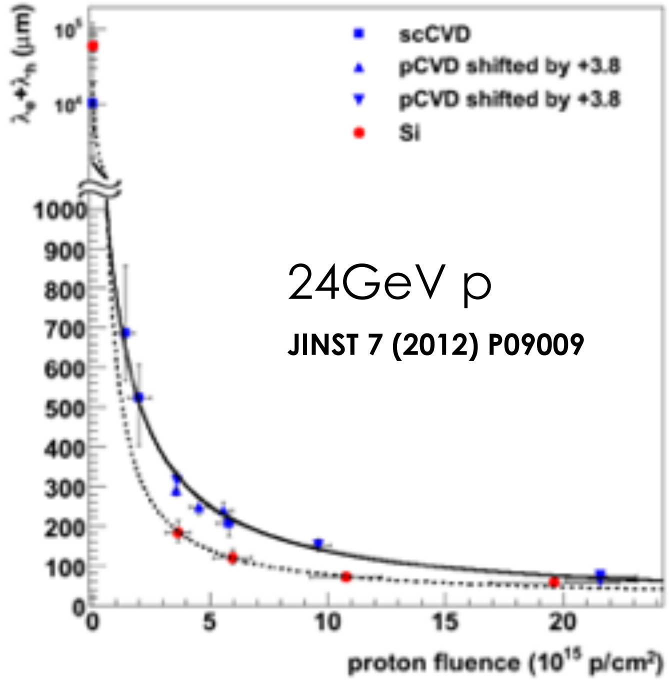
- **24 GeV protons**
  - $k_\lambda = 0.67 \pm 0.04 \times 10^{-18}\ \mathrm{cm^2 \mu m^{-1}}$
  - polycrystalline diamond sample offset by $\Phi \sim 5\times10^{15}$ to account for existing traps.
  - Poly and single crystal diamond show consistent damage constants.

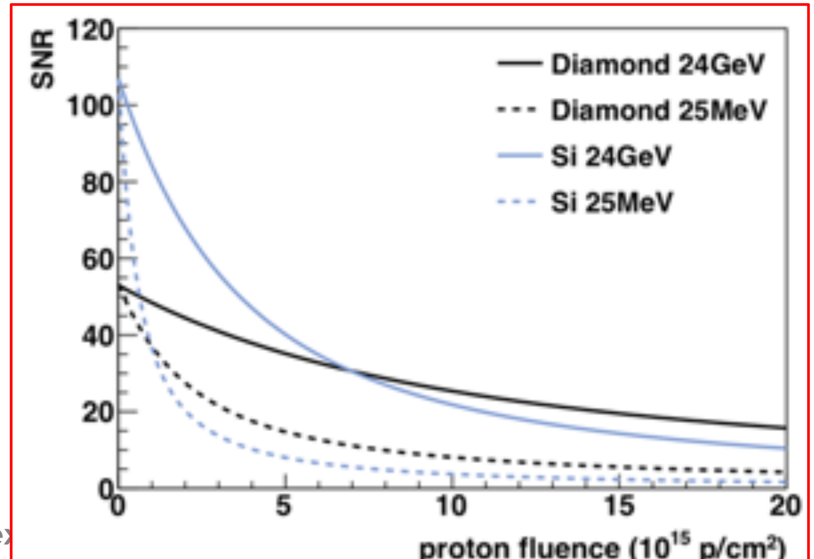


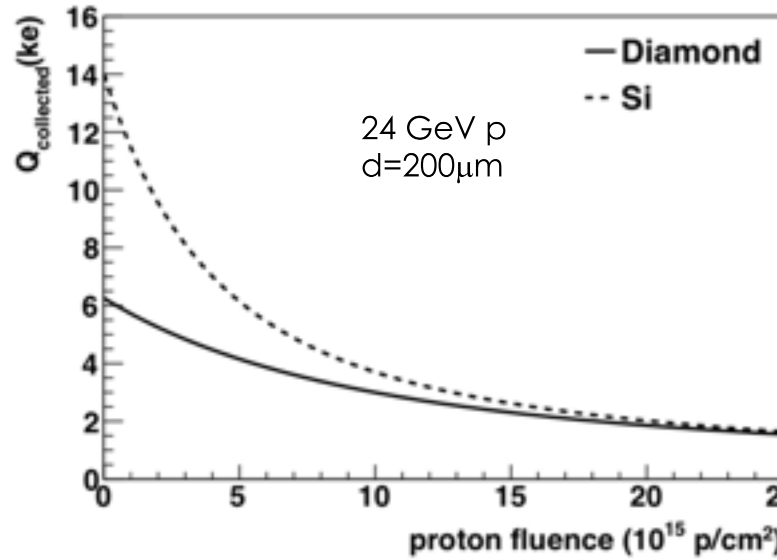

L. Baeni ETHZ Thesis
https://www.research-collection.ethz.ch/handle/20.500.11850/222412

# Radiation Tolerance: Comparison to Si

- k factors typically 2-3 times higher for Silicon.
- A comparison to Si needs to take into account:
  - leakage current
  - capacitance
- Possible figure of merit Signal to noise ratio:



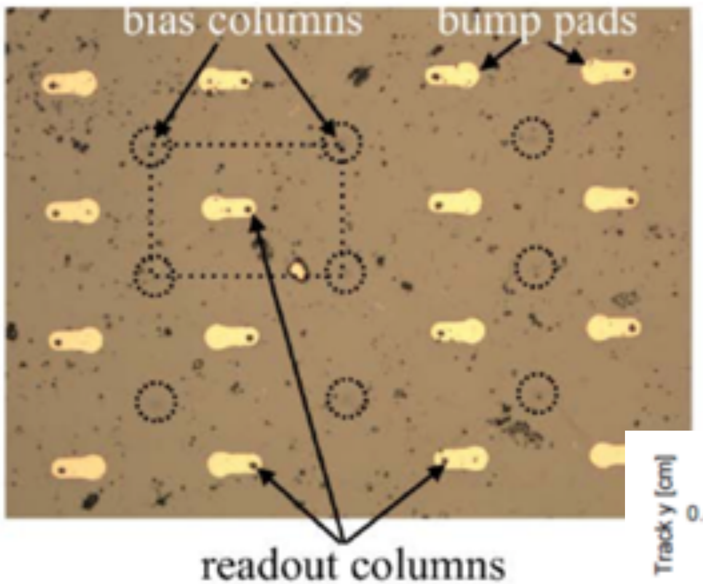



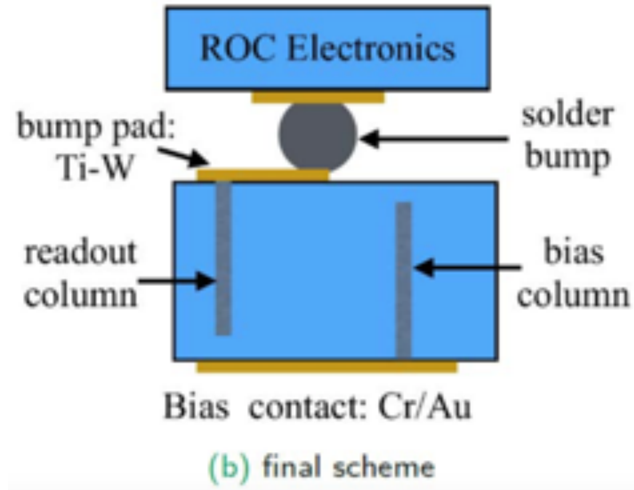
# RD42: 3D diamond pixel tests in 2017/18

- 100x150$\mu m^2$ basic cell
- 100x125$\mu m^2$ basic cell + 115x133$\mu m^2$ basic hex cell
- 50x50$\mu m^2$ basic cell, 2x3 ganging (100x150$\mu m^2$)
- 50x50$\mu m^2$ basic cell, 1x5 ganging (50x250$\mu m^2$)
- All detectors bump bonded to pixel read-out chip.
- Analysis work is in full swing, some preliminary plots in the next slides.

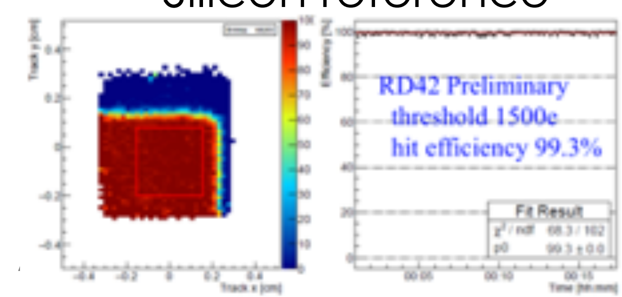
# RD42: 3D diamond pixel tests in 2017/18

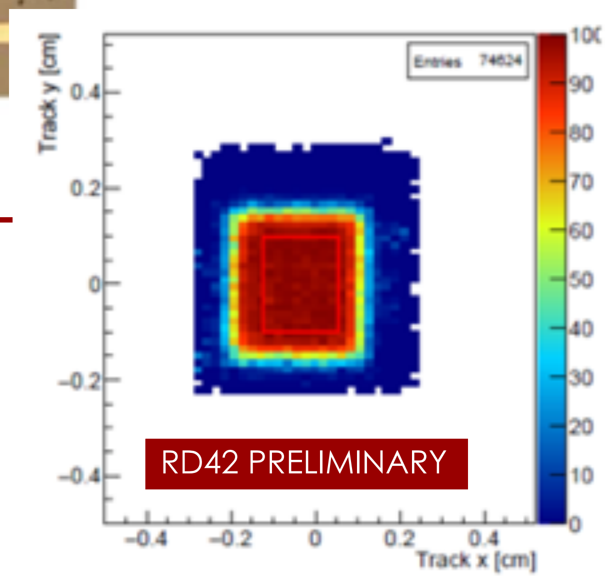
- $100 \times 150 \mu m^2$ basic cell

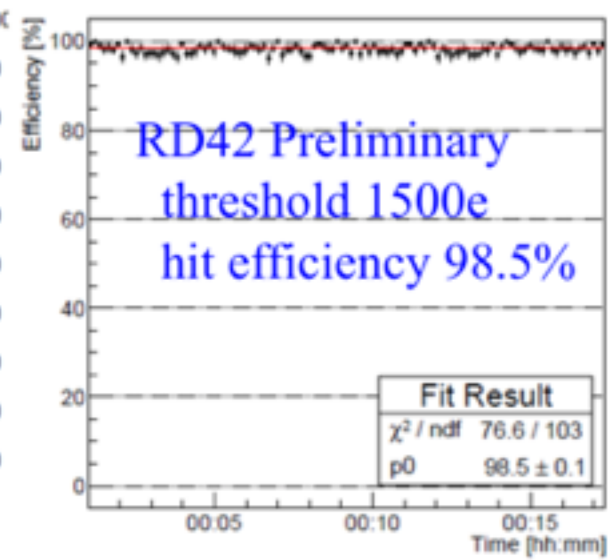



Silicon reference



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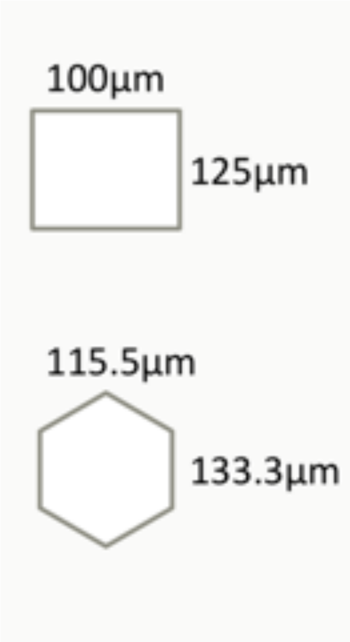
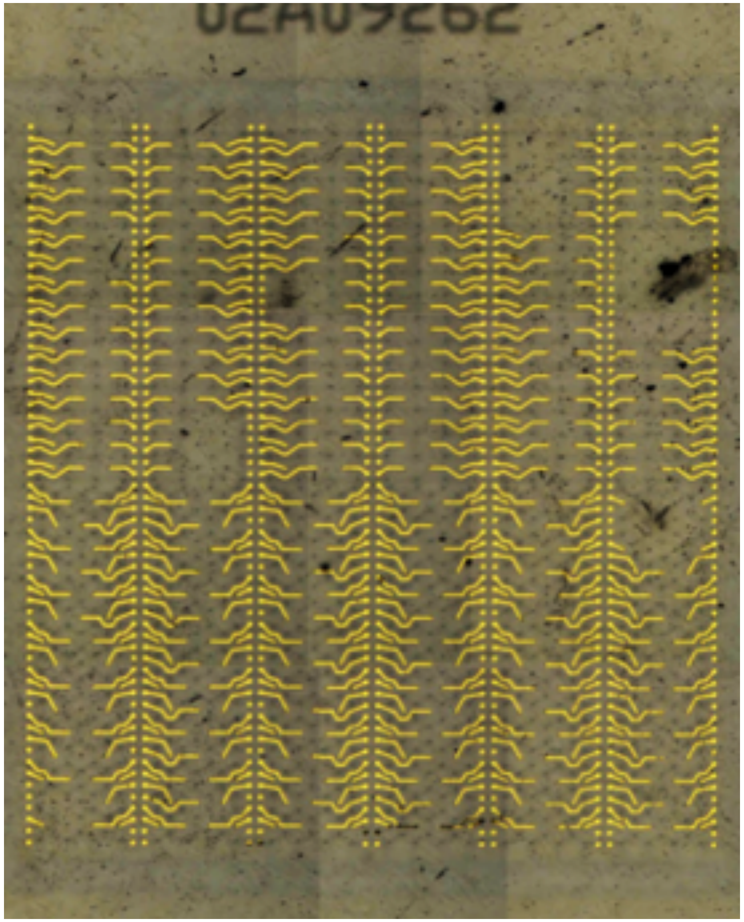
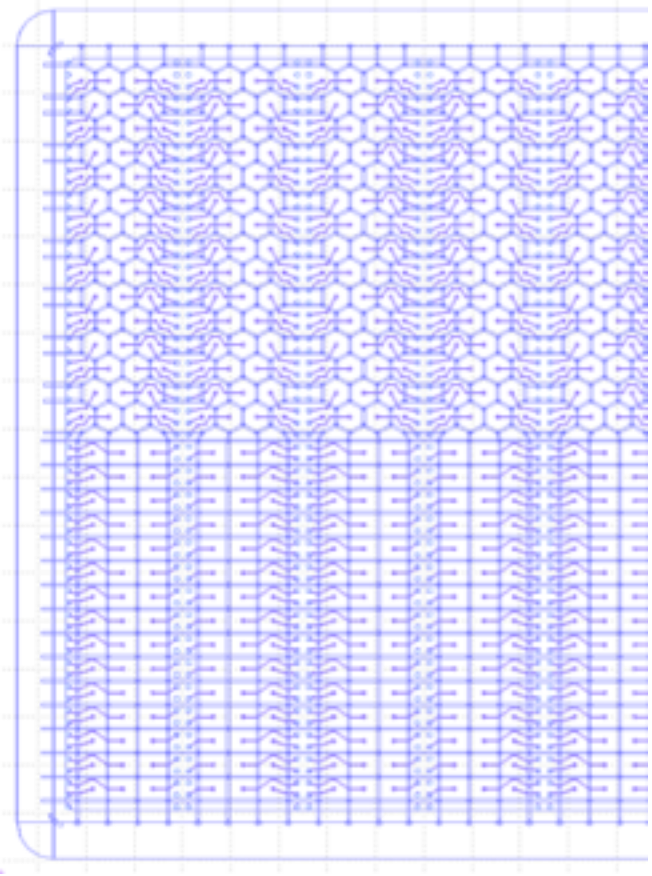
- 100x125$\mu m^2$ basic cell + 115x133$\mu m^2$ basic hex cell

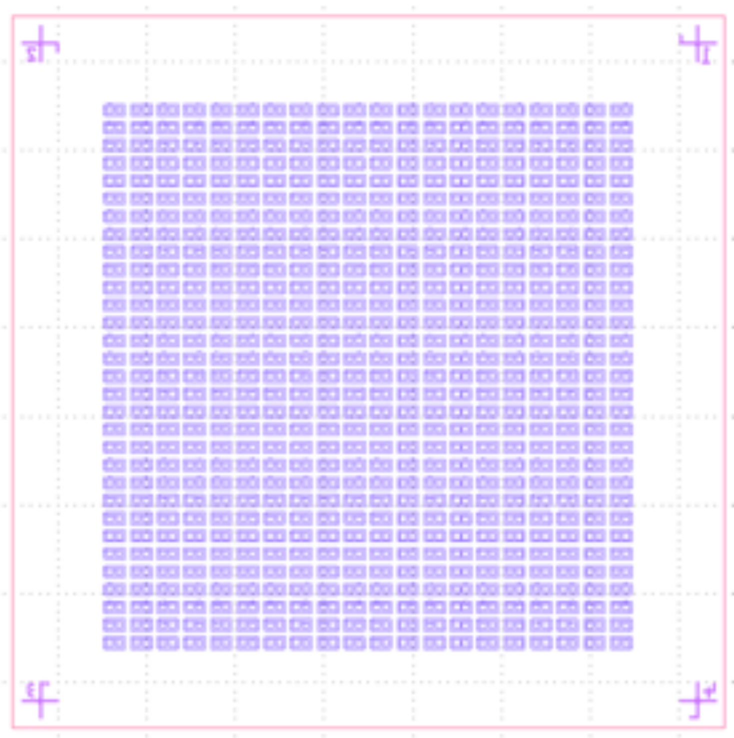


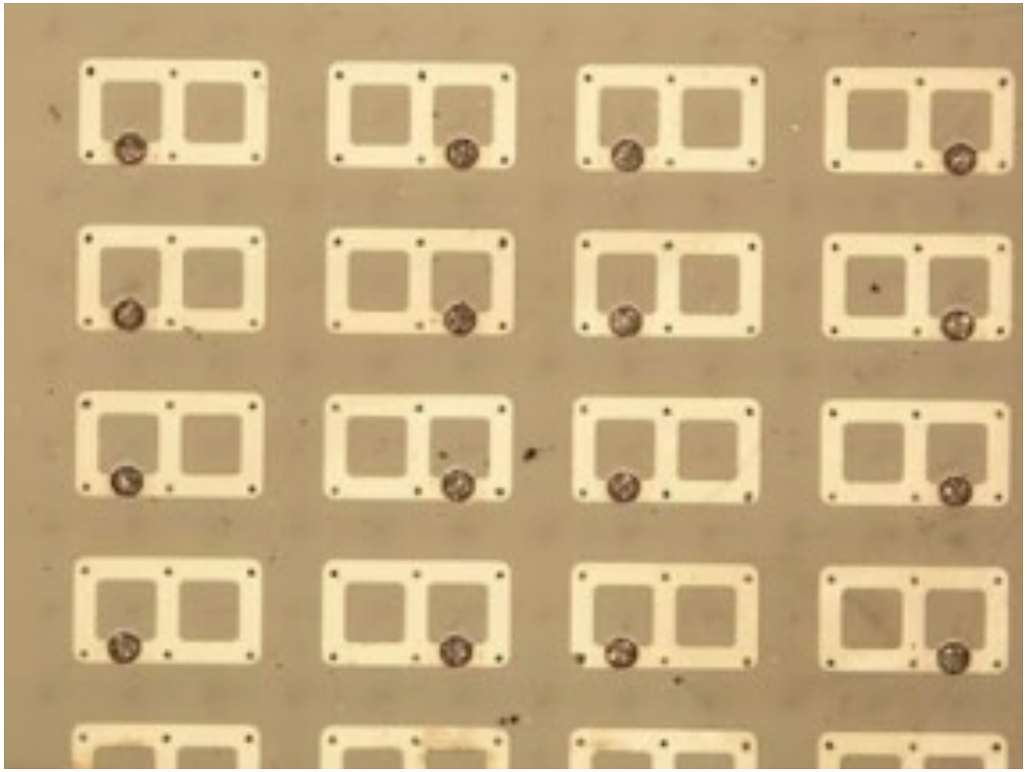





# RD42: 3D diamond pixel tests in 2017/18

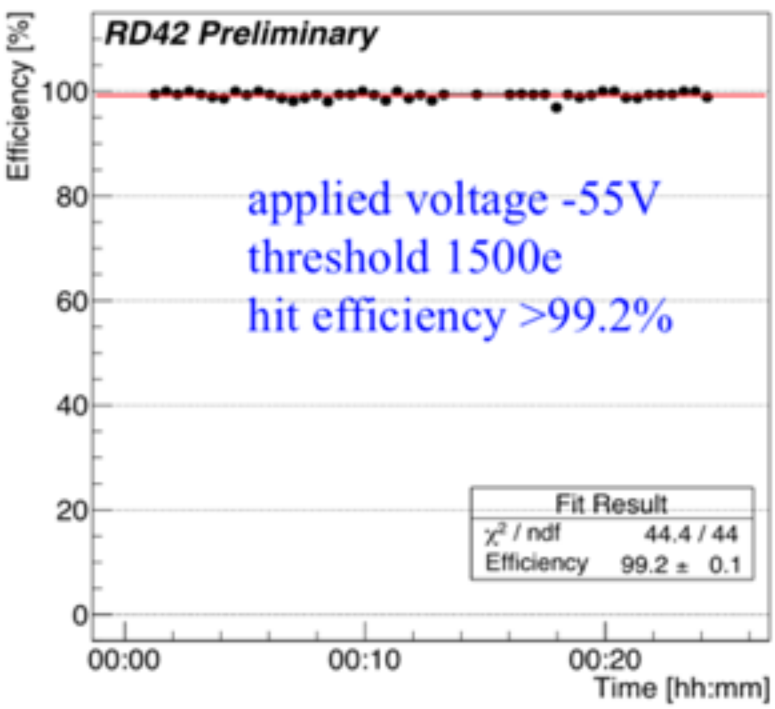
- $50 \times 50 \mu m^2$ basic cell, 2x3 ganging ($100 \times 150 \mu m^2$)

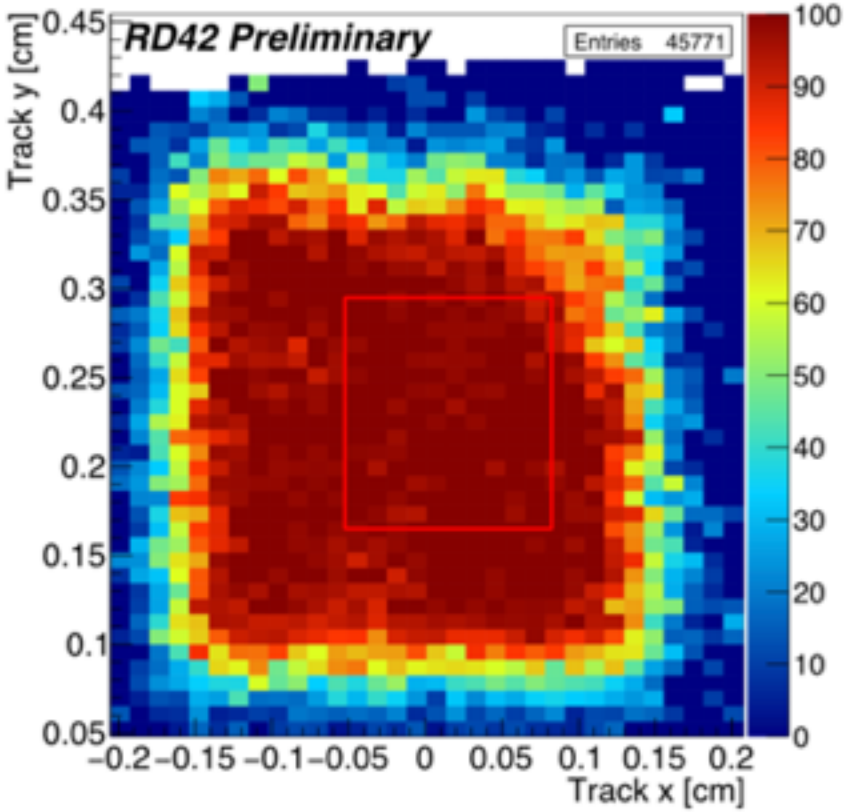




# RD42: 3D diamond pixel tests in 2017/18

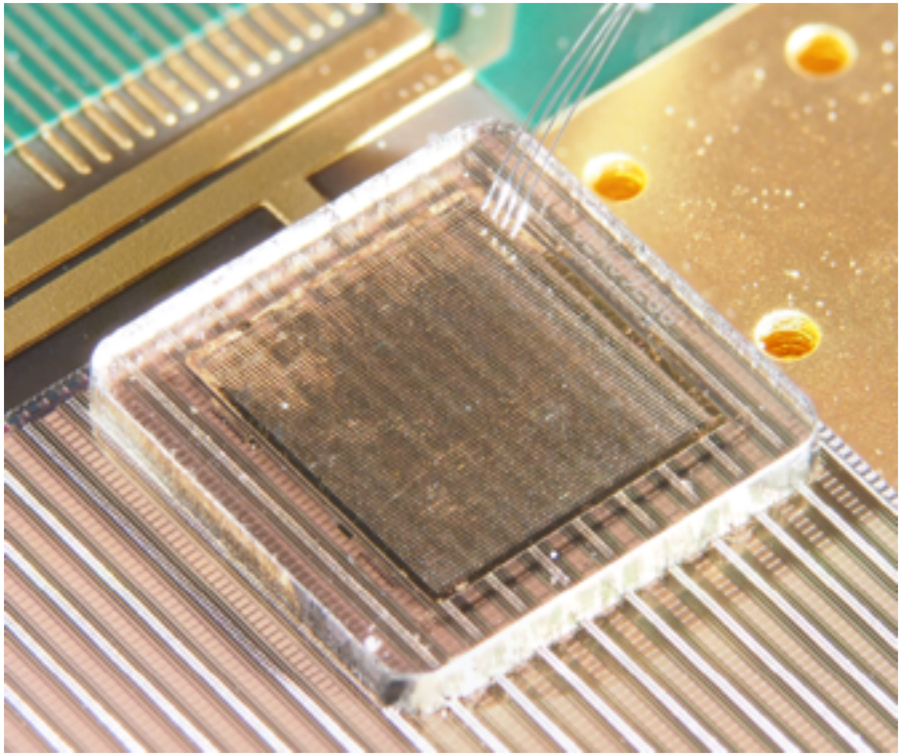
- 50x50$\mu$m$^2$ basic cell, 2x3 ganging (100x150$\mu$m$^2$)

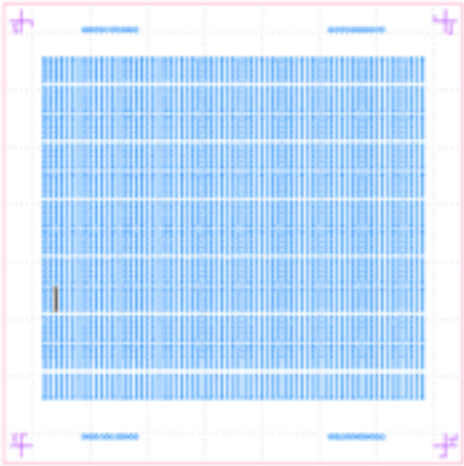


# RD42: 3D diamond pixel tests in 2017/18

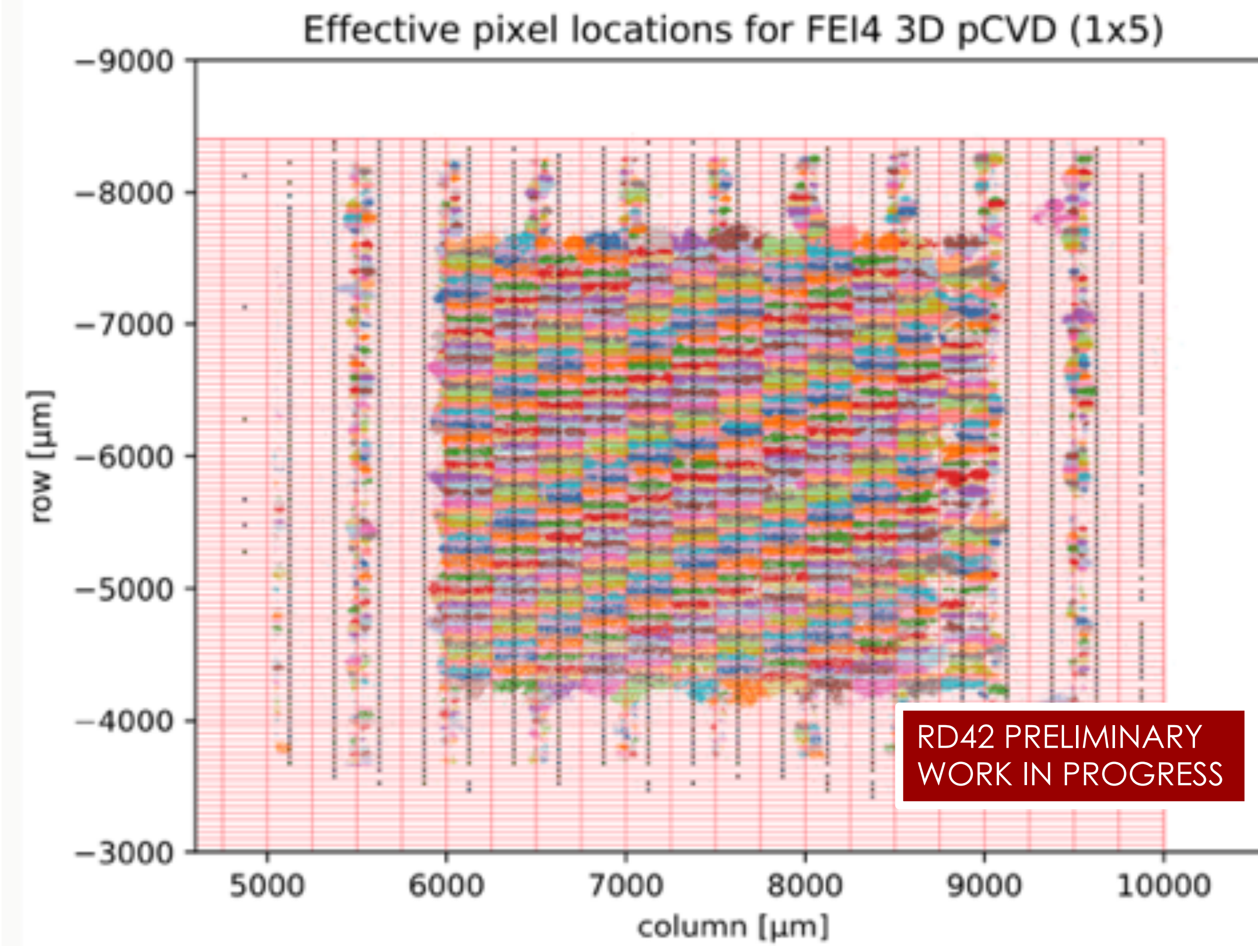
- $50 \times 50 \mu m^2$ basic cell, 1x5 ganging ($50 \times 250 \mu m^2$)





# RD42: 3D diamond pixel tests in 2017/18

- $50x50\mu m^2$ basic cell, 1x5 ganging ($50x250\mu m^2$)



# Summary & Outlook

- Radiation tolerance has been studied with protons, pions and neutrons.
  - Paper ready very soon!
- 3D detector prototype with 50x50$\mu m^2$ basic cell size tested with beams.
  - Analysis still ongoing, sneak preview shows promising results.
- For 2019:
  - Investigate irradiated 3D detectors.
  - Prototype for Beam Conditions Monitor for HL-LHC.

# Acknowledgements

The RD42 Collaboration gratefully acknowledges the staff at CERN for test beam time and their help in setting up beam conditions. We would also like to thank the beam line staff at the PSI High Intensity Proton Accelerator. The research leading to these results received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 654 168. This work was also partially supported by ETH Grant ETH-51 15-1, Swiss Government Excellence Scholarship ESKAS No 2015-0808, Royal Society Grant UF120106, STFC Grant ST/M003965/1 and U.S. Department of Energy Grant DE-SC0010061.

# BACKUP

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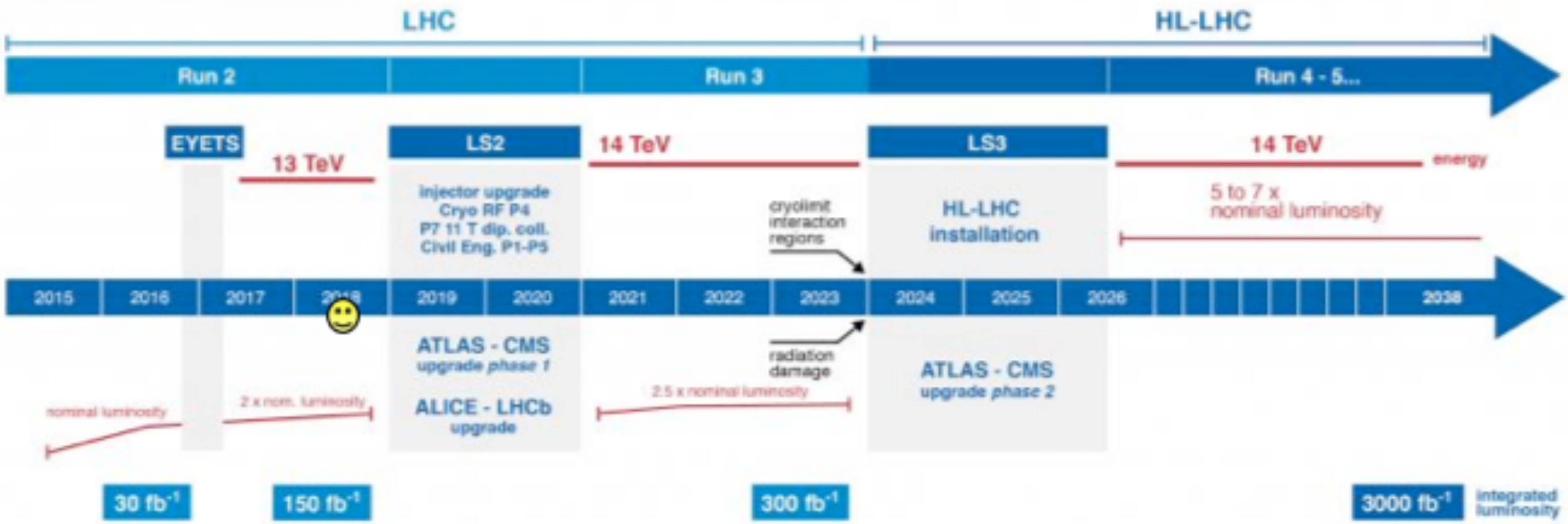
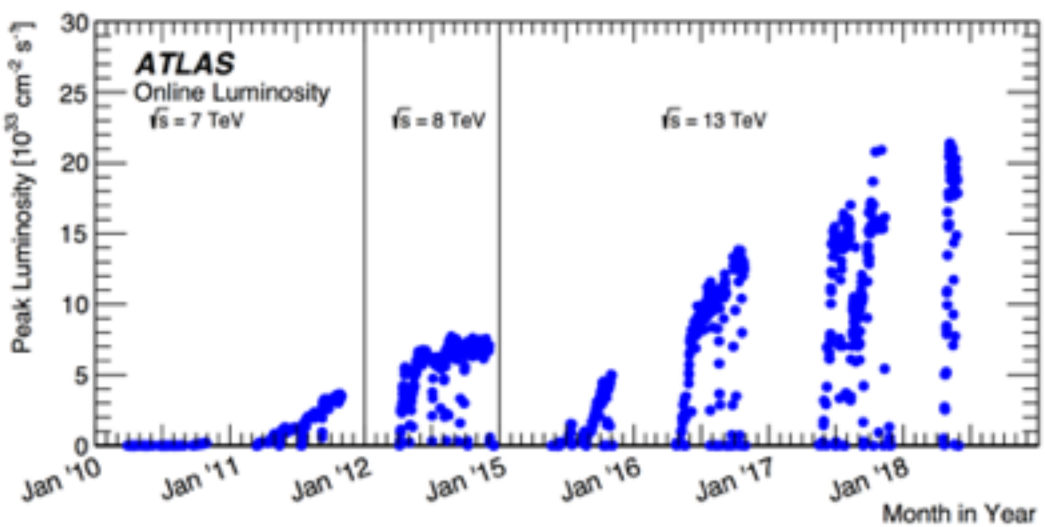
# Challenges Ahead




- Luminosity (*L*) upgrades of the LHC: instantaneous *L* by **factor ~3,** integrated *L* by **factor ~10.**
- Luminosity ~ Radiation damage.
- Need new technologies in the innermost layers to survive the radiation levels.