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28th RD50 Workshop (Torino)

Generation of shallow radiation damages at the strip surface with low energy protons

Sven Wonsak, G. Casse, P. Dervan, M. Wormald

Birmingham-Liverpool-Sheffield radiation team

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Outlook

- Geant4 simulations and Interesting pictures from the irradiations
- Collected charge after irradiation

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Aim and procedure

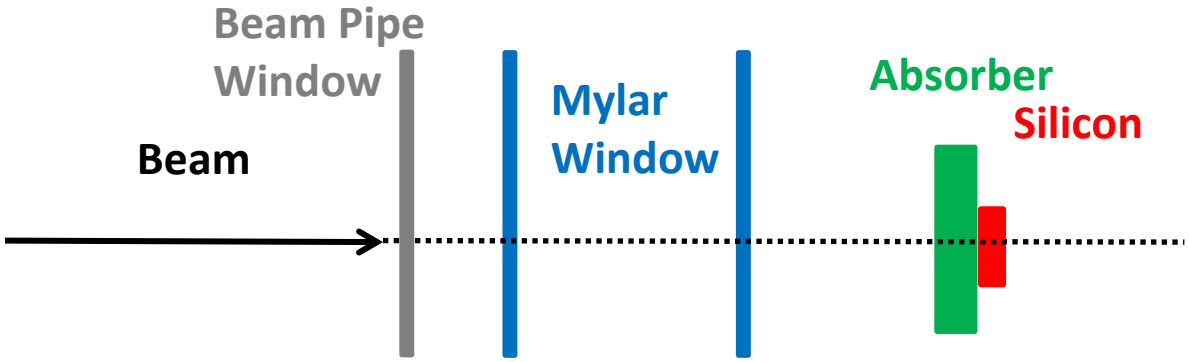
- Create a multiplication layer close to the strip surface:
  - Use a well defined proton beam at Birmingham to generate radiation damages within the first ≈20µm of the strip surface

- Geant4 simulation to find optimal parameters

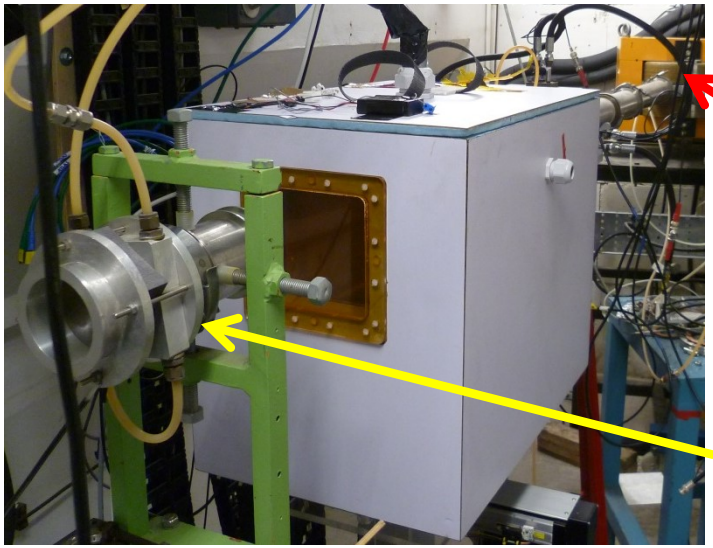
  (Based on Geant4 example B2b)
  - Beam Energy: variable would be good, but tuning takes time
    - Set to 12.0 MeV (decided during first irradiation)
  - Absorber Material
    - Perspex
    - Lead
  - Absorber Thickness

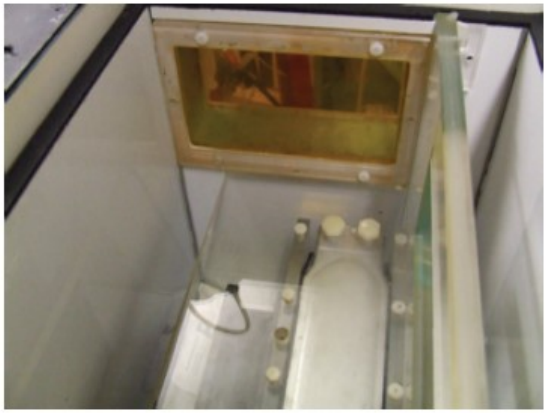
- Further irradiation of the samples at Ljubljana to $1x10^{15}n_{eq}/cm^2$ and $5x10^{15}n_{eq}/cm^2$
  - One comparison sample at each fluence (without proton irradiation)

Birmingham Beam Setup



Foil: Ni; used for dosimetry

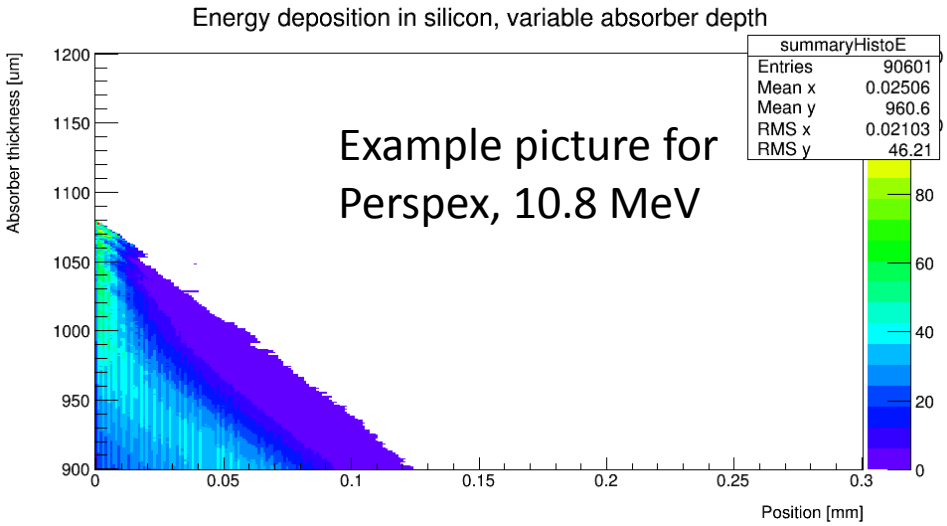




Picture: Kerry Parker, The Birmingham Irradiation Facility, IOP 2015 Manchester

More details about the Birmingham Irradiation facility in talk “The Birmingham Irradiation Facility” from Laura Gonella

Simulation example



Example picture for Perspex, 10.8 MeV

Absorber Thickness is crucial part

- Require high accuracy (challenge for workshop)

Dosimetry also not an easy task

- Test with 25µm Ni foil (standard)

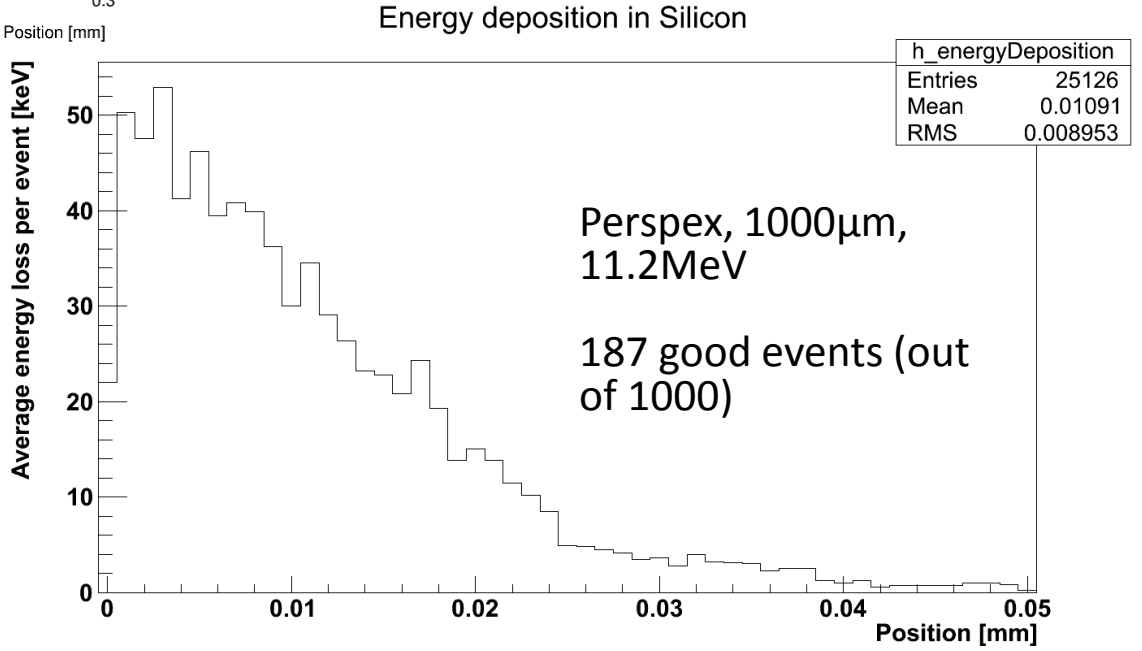
First Irradiation (December 2015) :

Perspex:

- (1000±10)µm

Lead:

- (300±10)µm

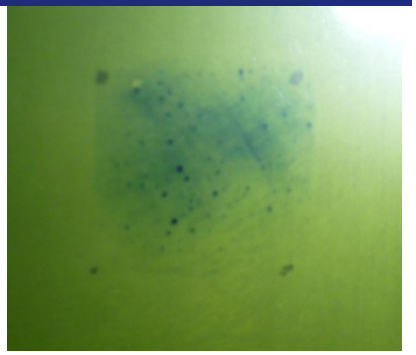


Perspex, 1000µm, 11.2MeV

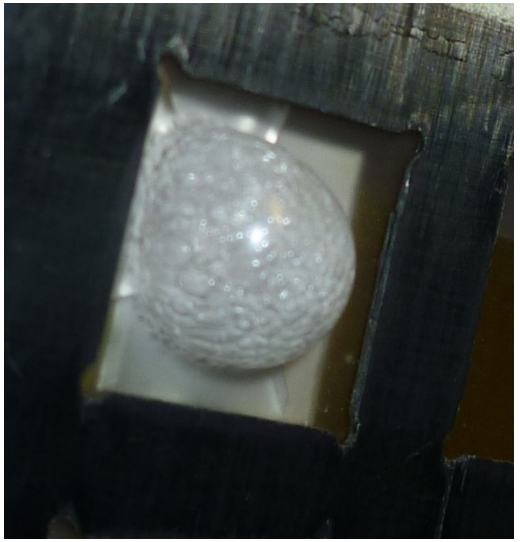
187 good events (out of 1000)

1st Irradiation at Birmingham

- 11MeV beam => no particles after absorber
  - Beam pipe window not in simulation
- 12MeV beam => see protons after absorber
  - Perspex absorber destroyed during initial measurement for dosimetry
  - No issues with lead absorber

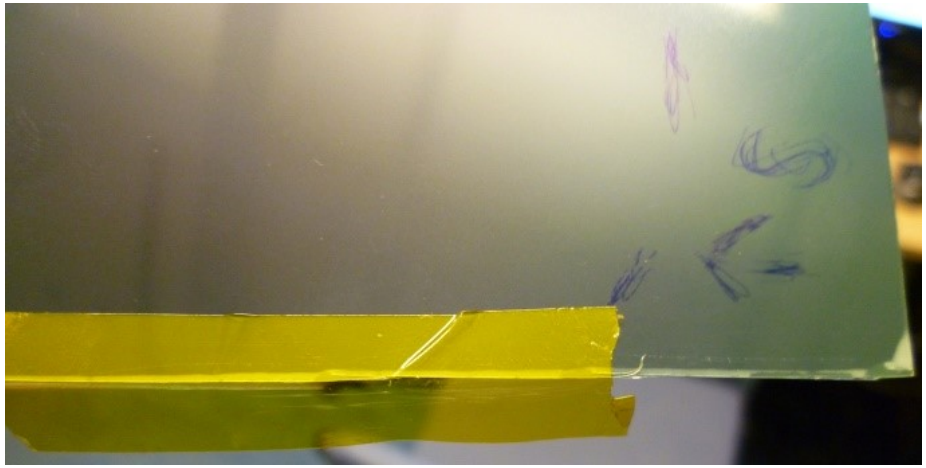


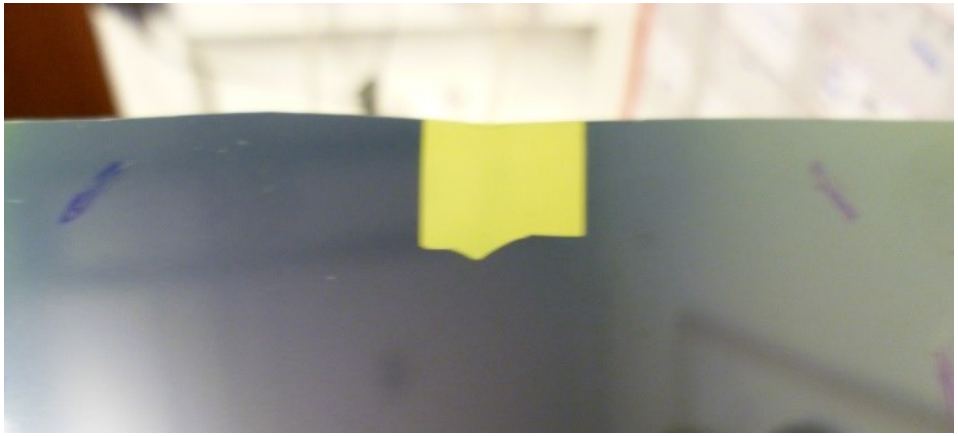
Gafchromic film
12MeV after absorber



Perspex absorber
12MeV, few minutes beam

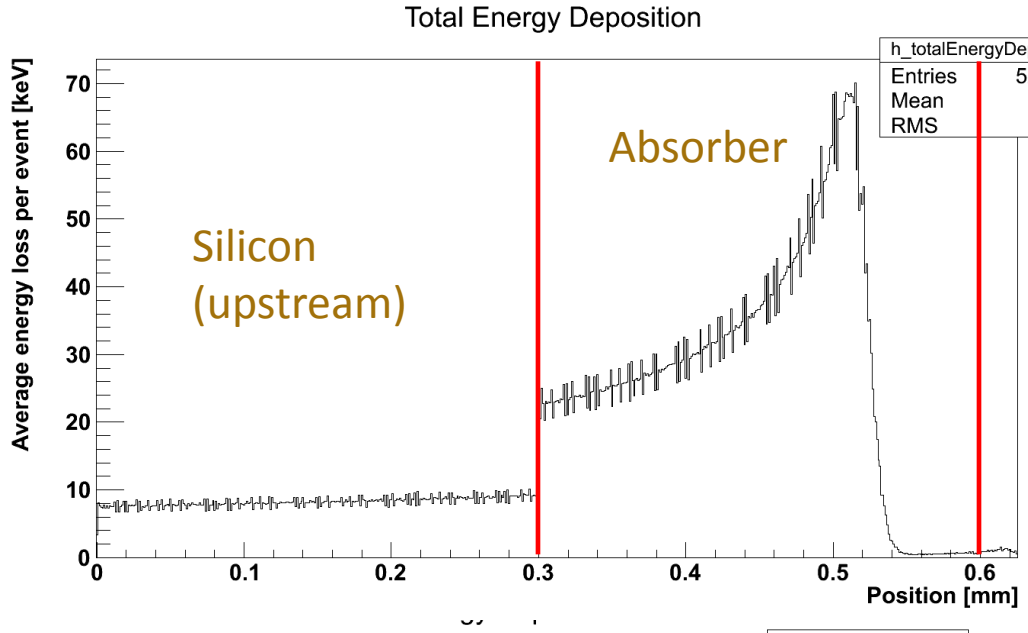
1st irradiation

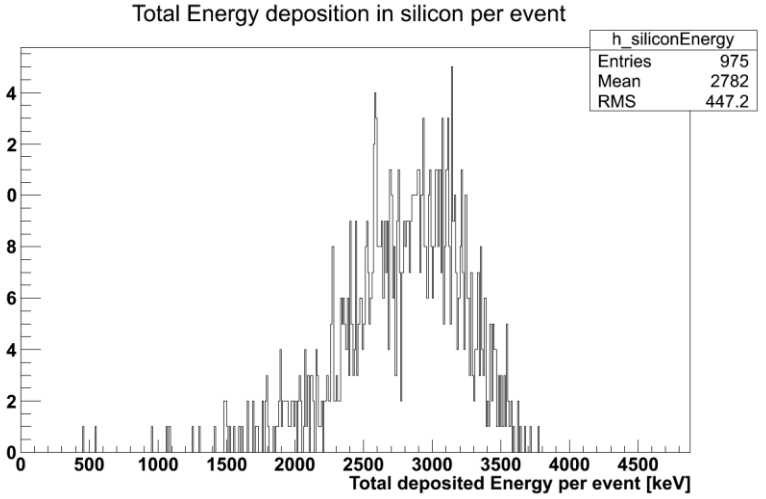




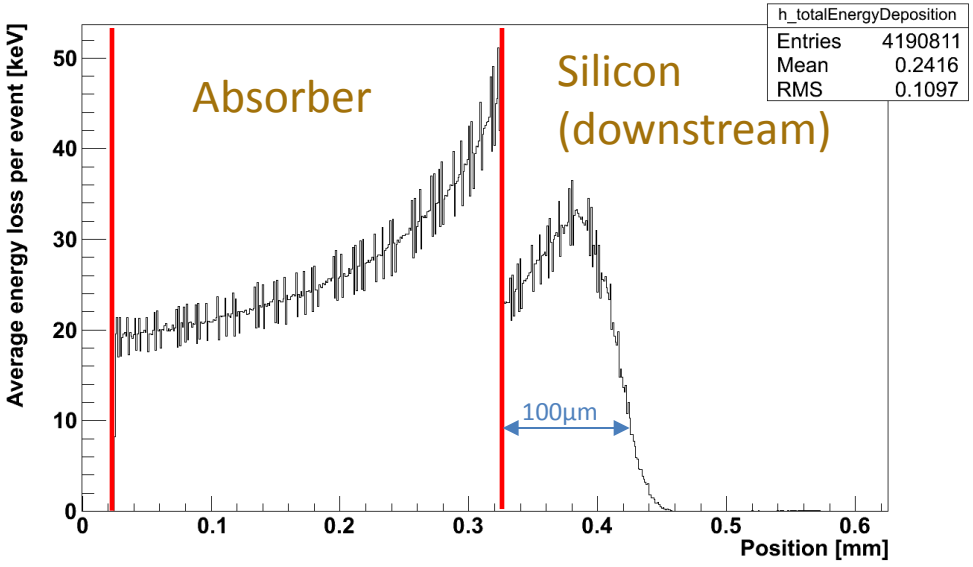
- Test with Gafchromic film at end of beam line (11MeV protons)
  - Already Kapton to fixate it enough to stop the protons (no discolouration)
- 12MeV beam energy worked, so we irradiated samples to $1x10^{15}n_{eq}/cm^2$
  - One sensor upstream of absorber,
  - Three sensors downstream

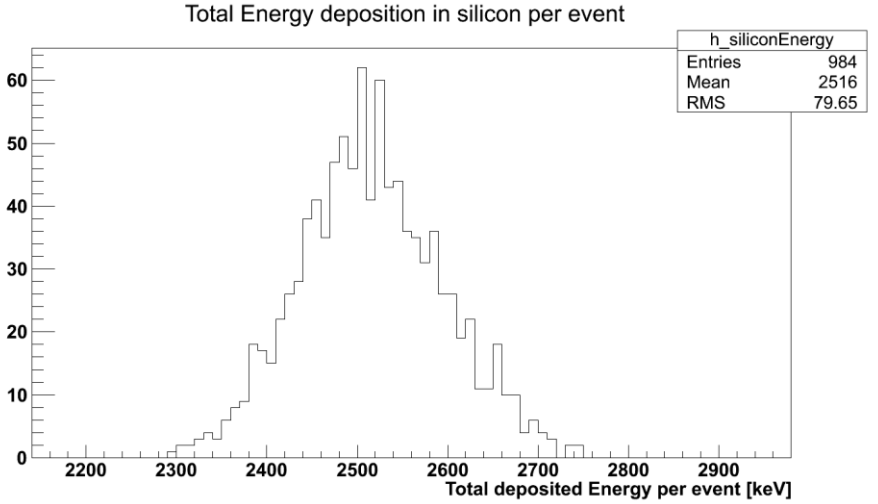
Geant4 simulation





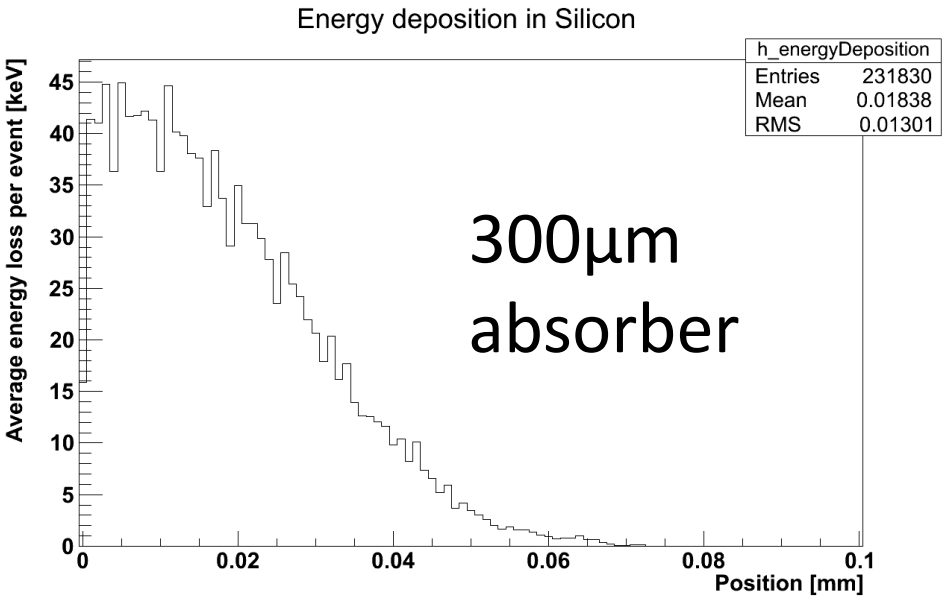
12MeV proton beam, 300µm lead absorber

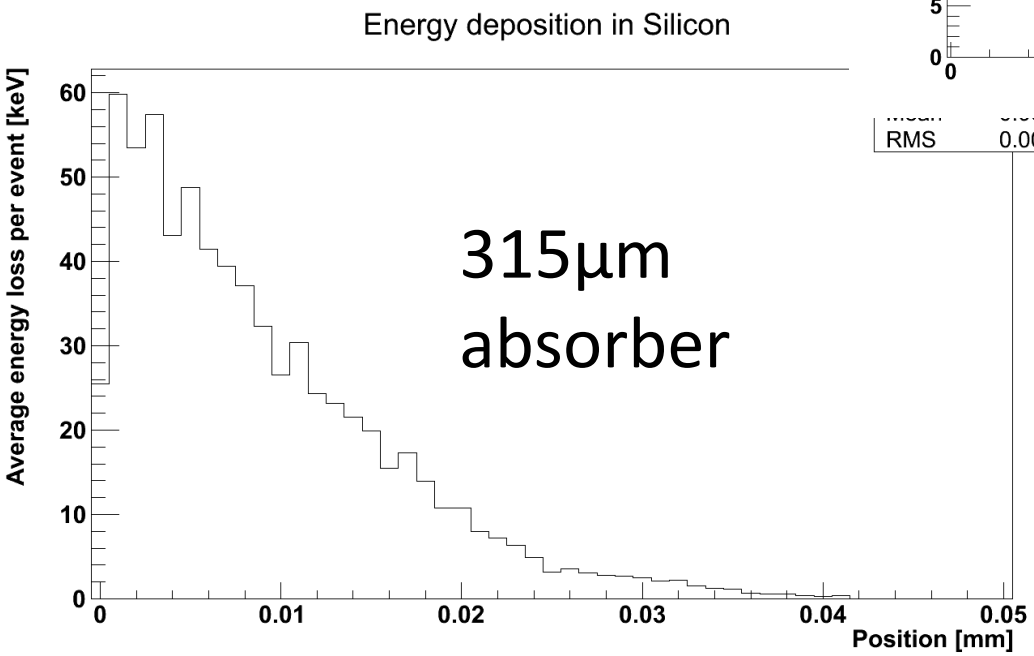


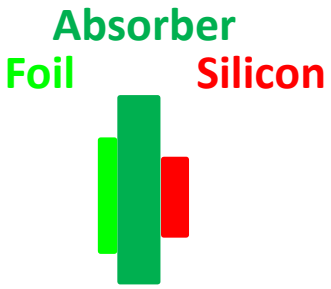


2nd irradiation simulation

- For second irradiation new absorber
  - Use foil for dosimetry



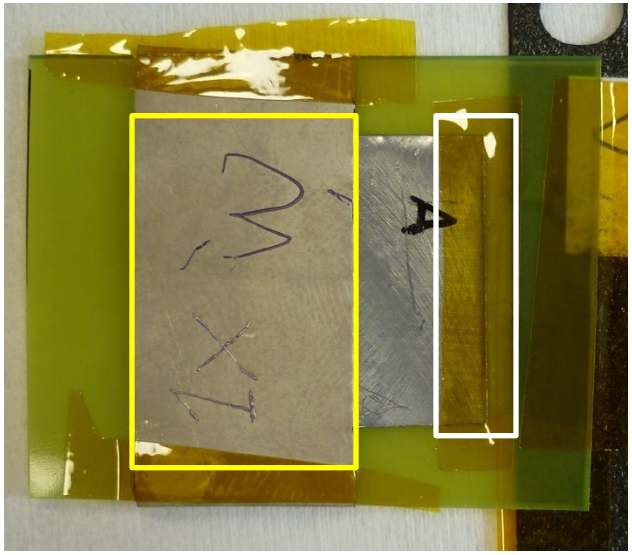


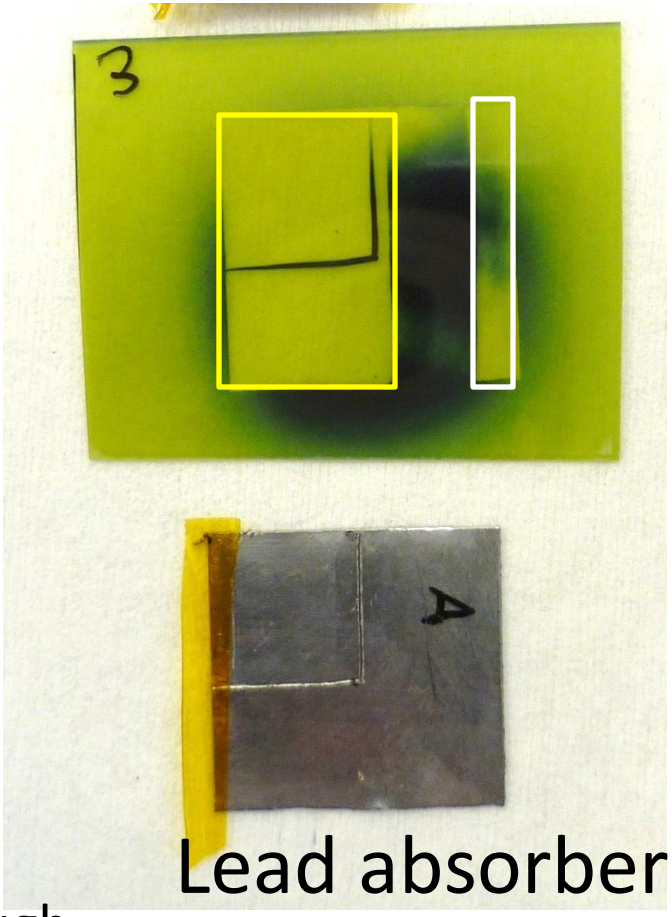


2nd irradiation

- Second irradiation in April 2016
  - 315µm thick lead absorber
- Using Gafchromic film to make sure there are protons after the absorber
  - No discolouration with or without nickel foil for new absorber
  - **Does the simulation needs more fine tuning to represent the beam line?**
- Switch back to 300µm thick absorber and irradiated two samples to $1x10^{14}$ n_{eq}/cm^2 and $3x10^{15}$ n_{eq}/cm^2

2nd irradiation





300µm lead absorber

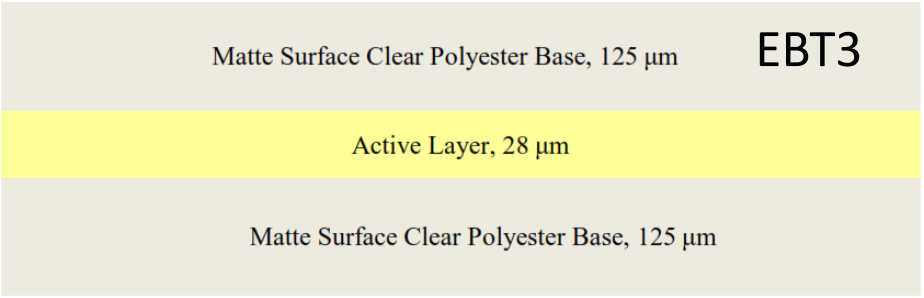
- ½ of sensor covered with Ni foil
- ¼ covered with Kapton for fixation

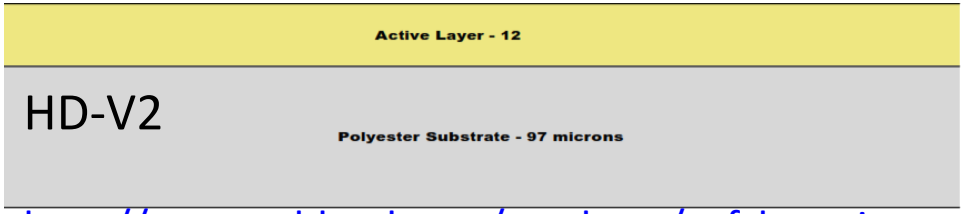
- Protons can penetrate lead, but will be stopped in foil or Kapton
  - Small cut in lead is reduces thickness enough so that protons can penetrate the additional foil

Gafchromic film

Why haven't we seen anything with the 315µm thick absorber?

- Possible explanation (investigated after irradiation):
  - Used Gafchromic film (EBT3) has 125µm thick polyester before the active material
    - All protons absorbed before reaching the active material
  - Better use HD-V2, which has no material before the absorber (only ~100µm support on backside)



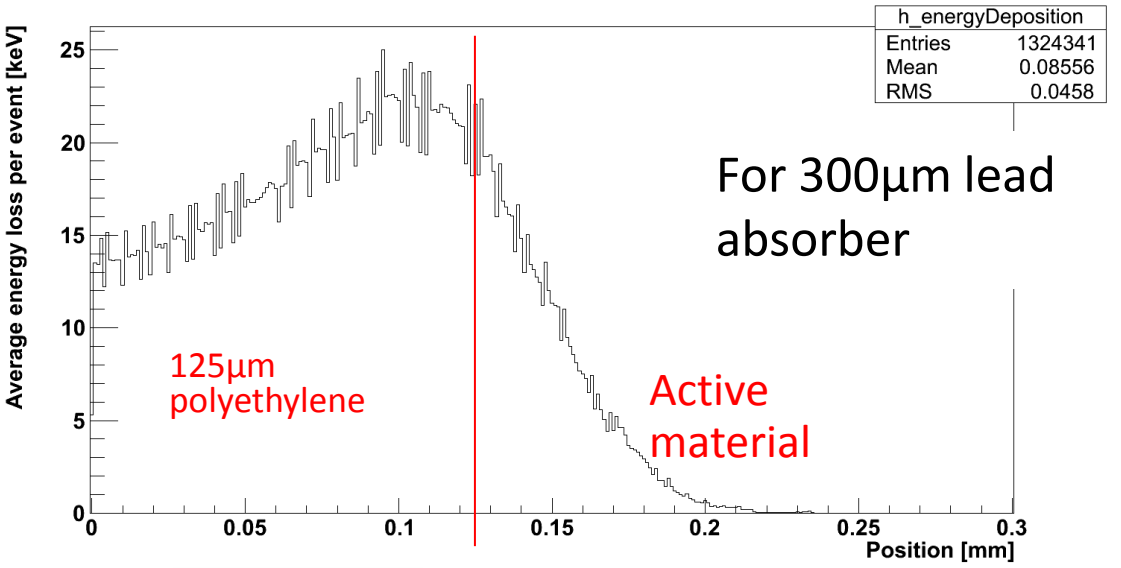


http://www.ashland.com/products/gafchromic-radiotherapy-films

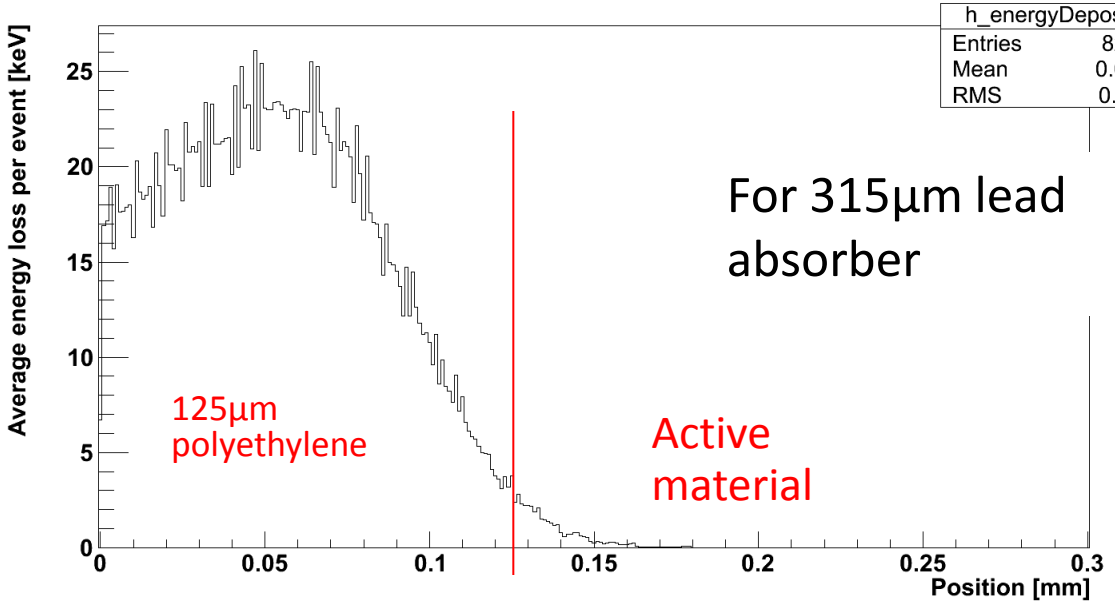
Gafchromic film

- Simulate with polyester (G4_POLYETHYLENE) instead of silicon

Absorber – Polyethylene



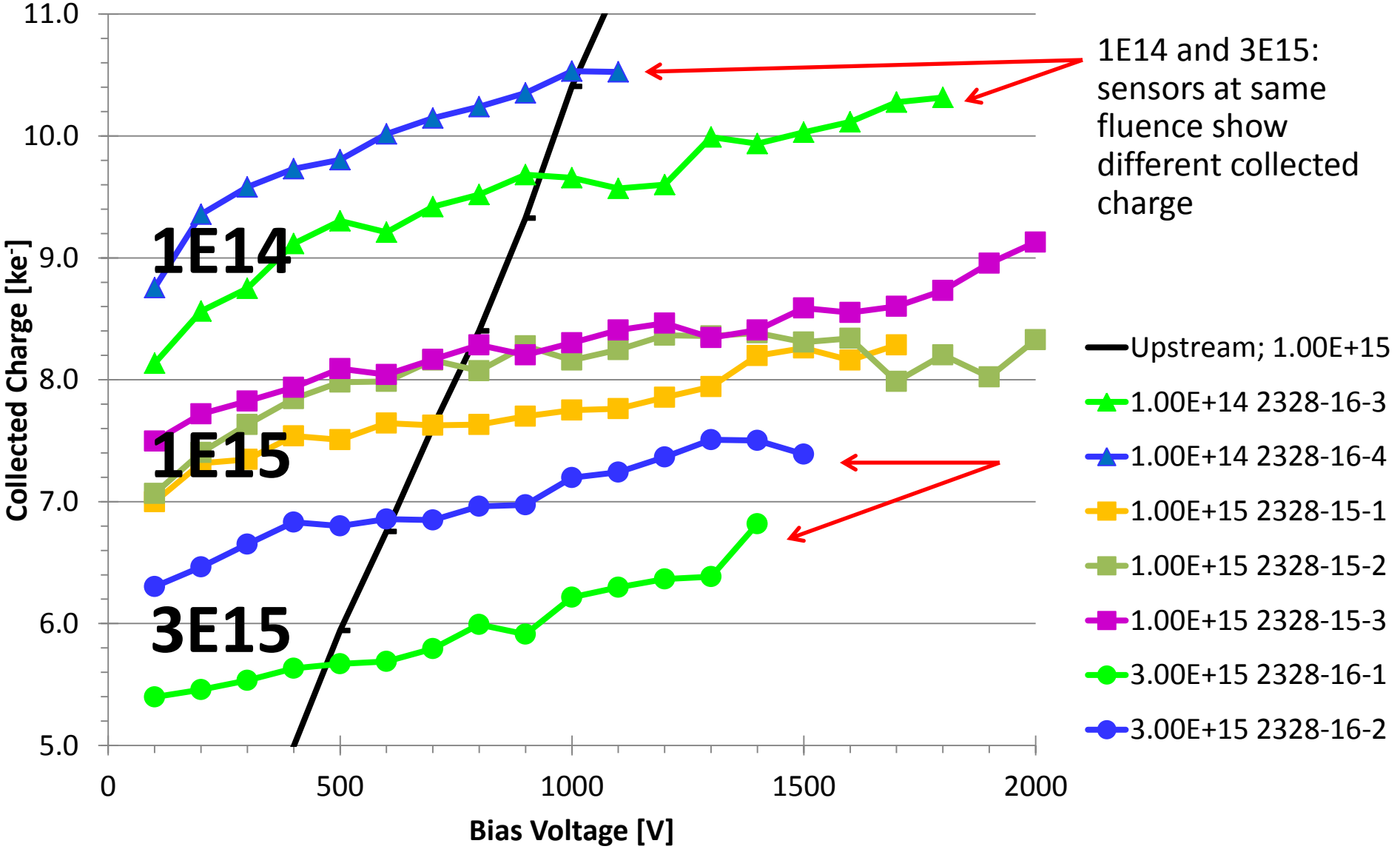
For 300µm lead absorber



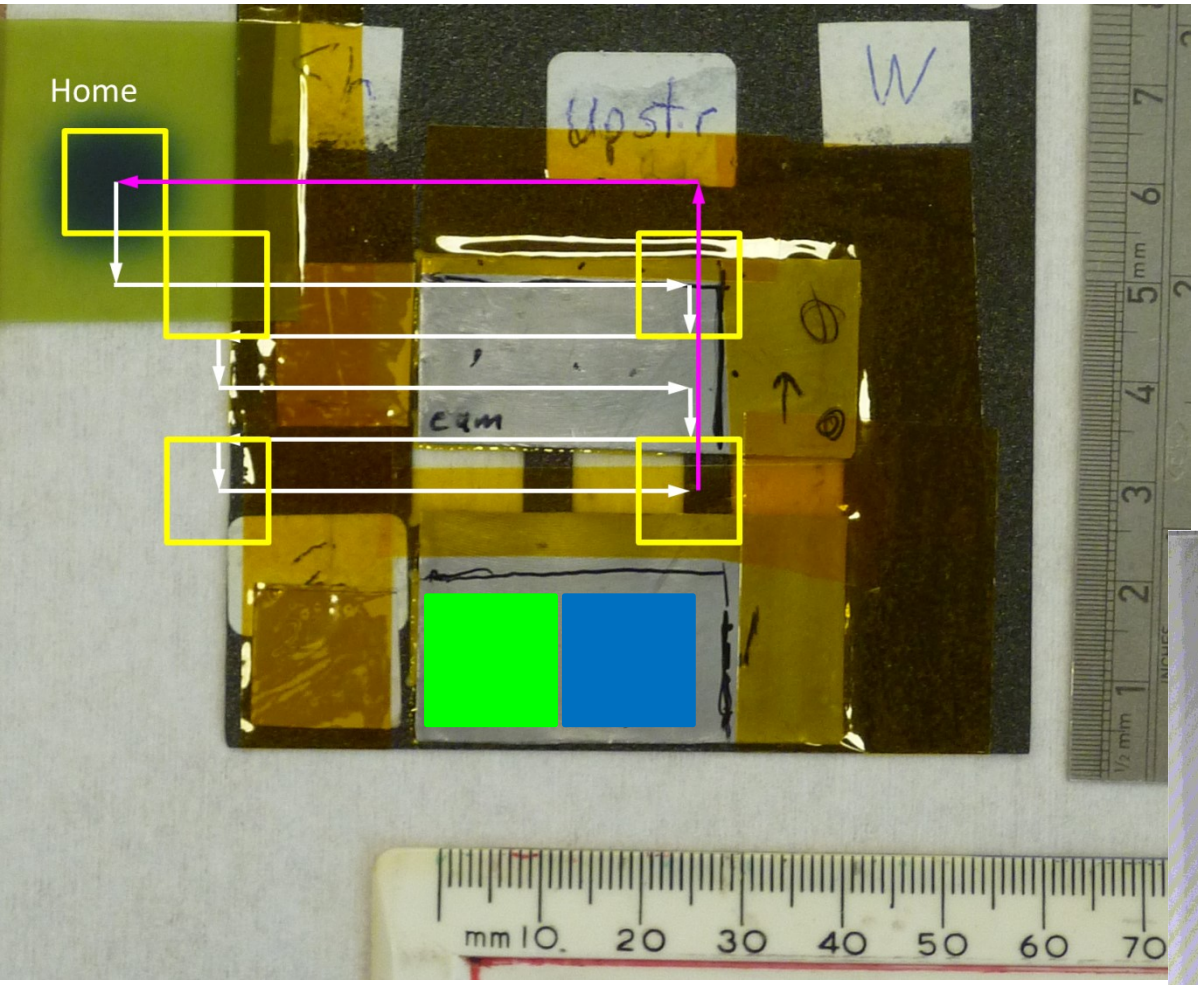
For 315µm lead absorber

- After 125µm polyethylene, reach the active material
  - Minimum response difference from 100keV into MeV range
- 300µm: enough energy left to discolour the film
- 315µm: approximately 40keV energy left in active area => not enough for discolouration

Collected charge after proton irradiation

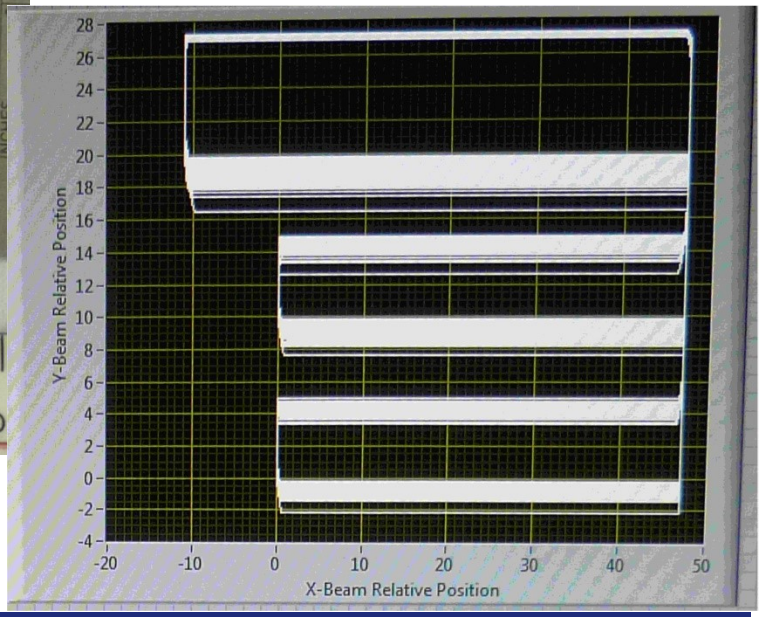


2^{nd} irradiation $3x10^{15}$ n_{eq}/cm^2 scan

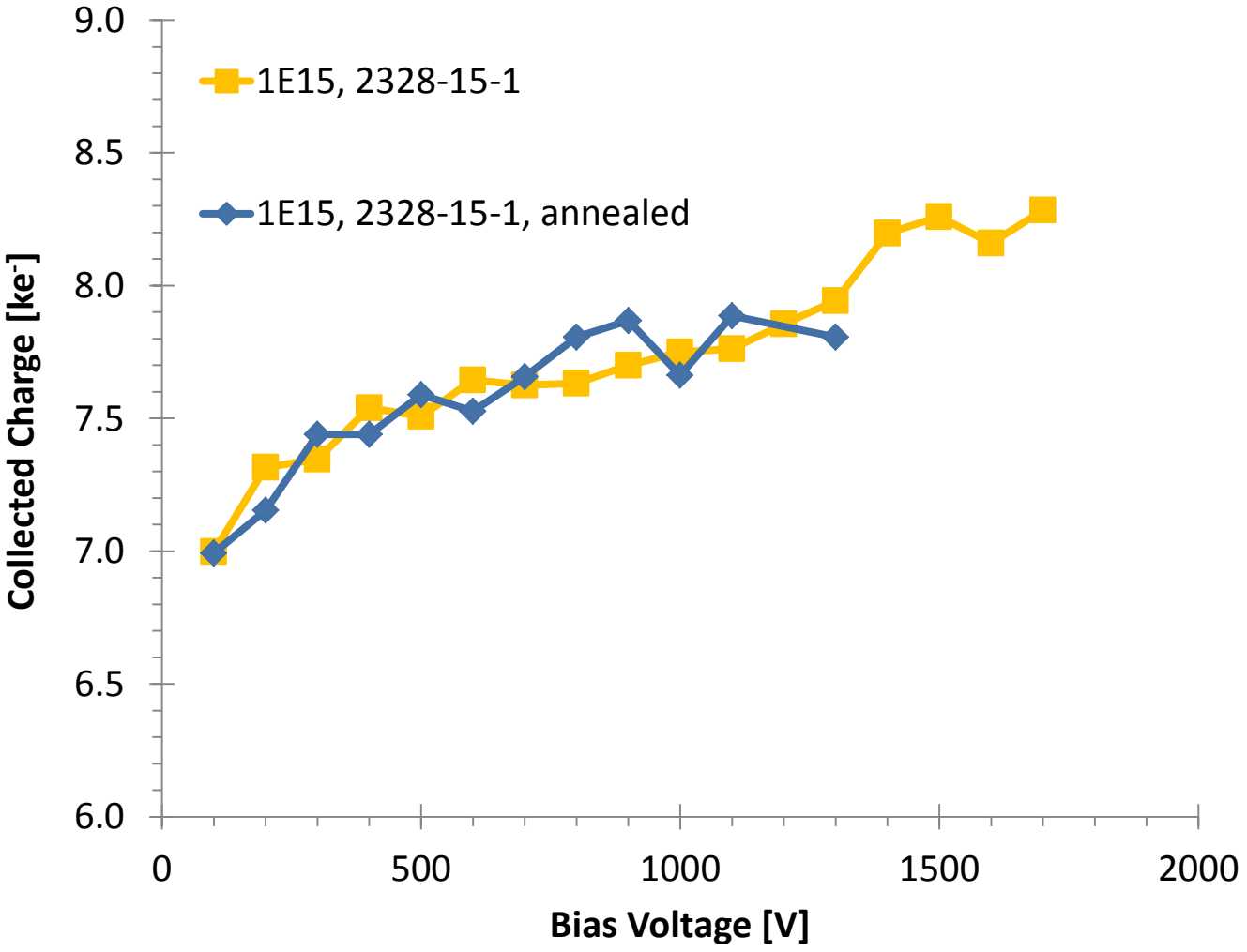


Placed sensors as close together as possible to reduce scan time

Possible explanation for issue with collected charge: sensors on right side don't get the full beam coverage during irradiation



Annealing after proton irradiation



One sensor irradiated to $1x10^{15}$ n_{eq}/cm^2 annealed: 80min at 60°C

No significant difference

Other sensors have been irradiated with neutrons at Ljubljana

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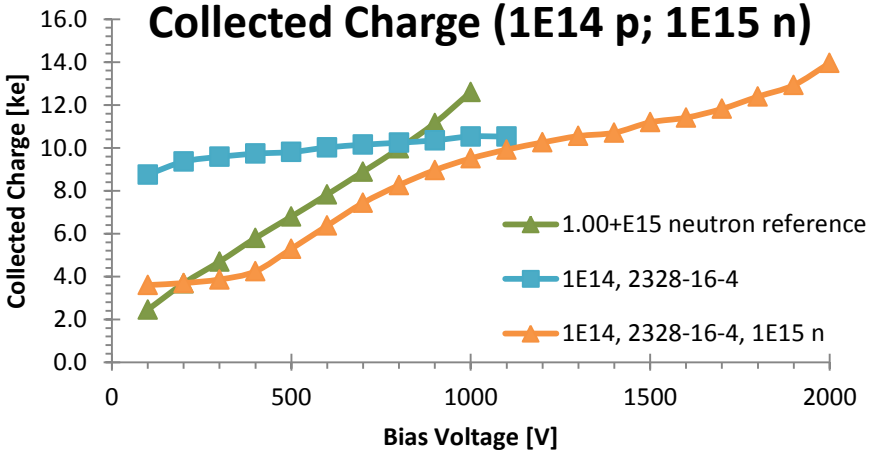
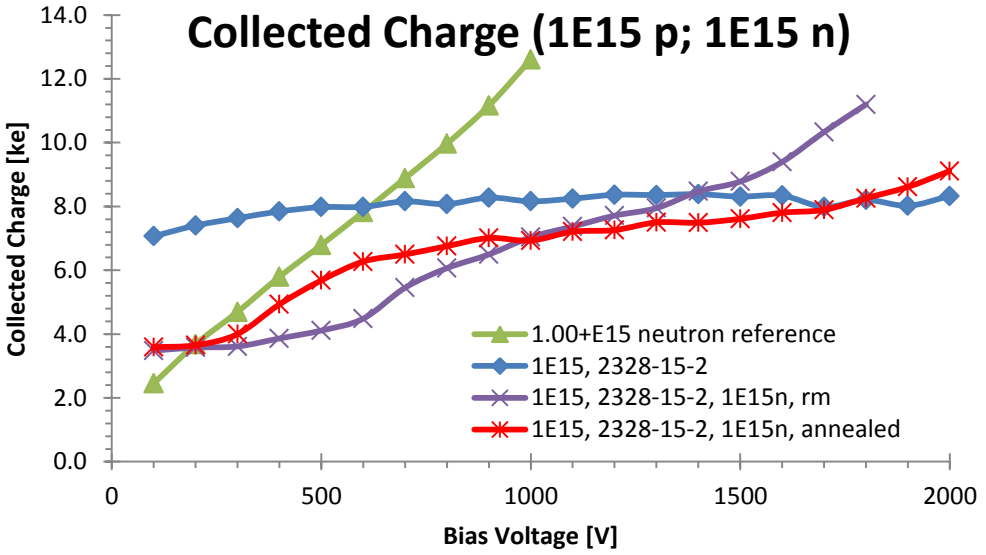
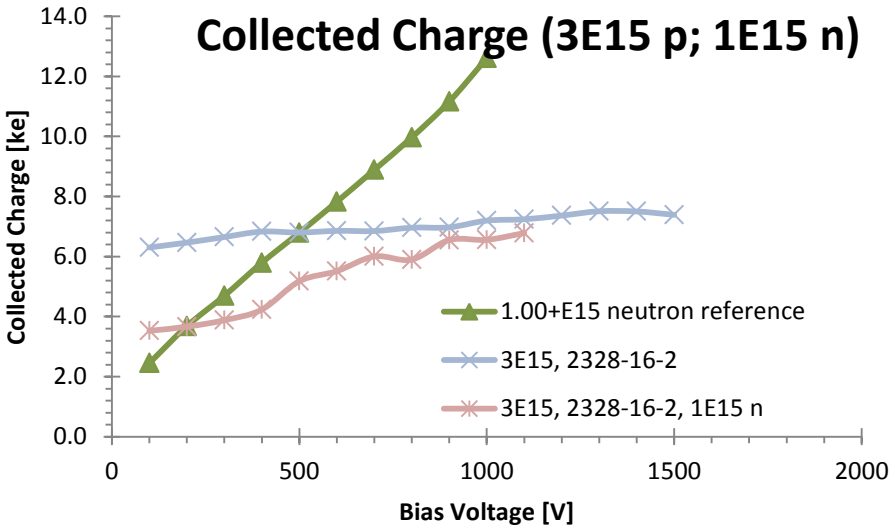
$1x10^{15}n_{eq}/cm^2$ Neutron irradiation







- Collected charge smaller than of the reference sample
- For very high voltages the charge after proton irradiation can be exceeded
- $1x10^{15}n_{eq}/cm^2$ sample annealed: expected change of curve; excess at very high voltages reduced

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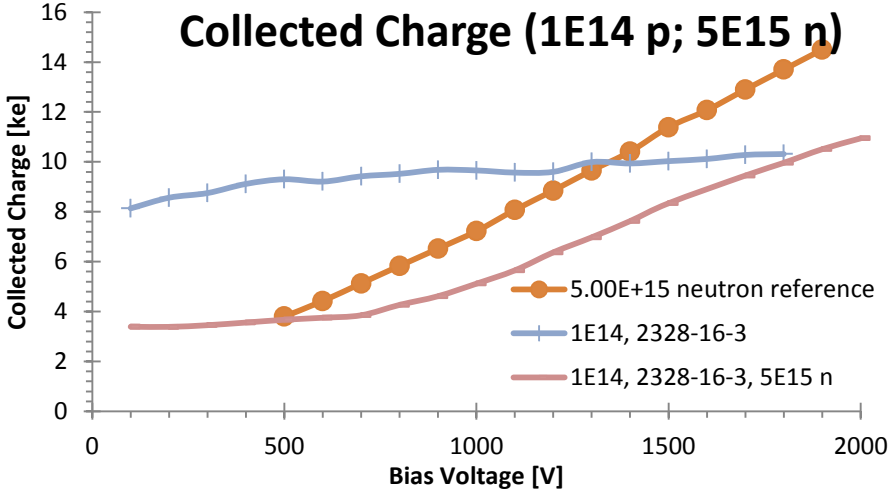
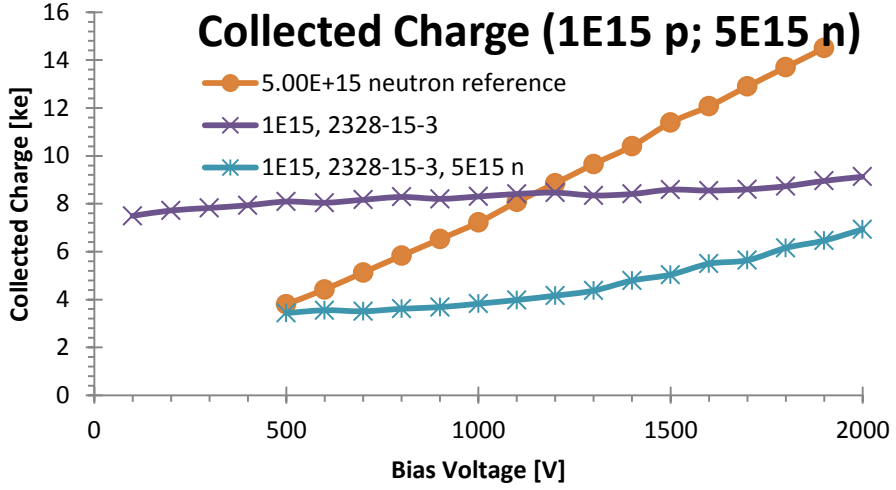
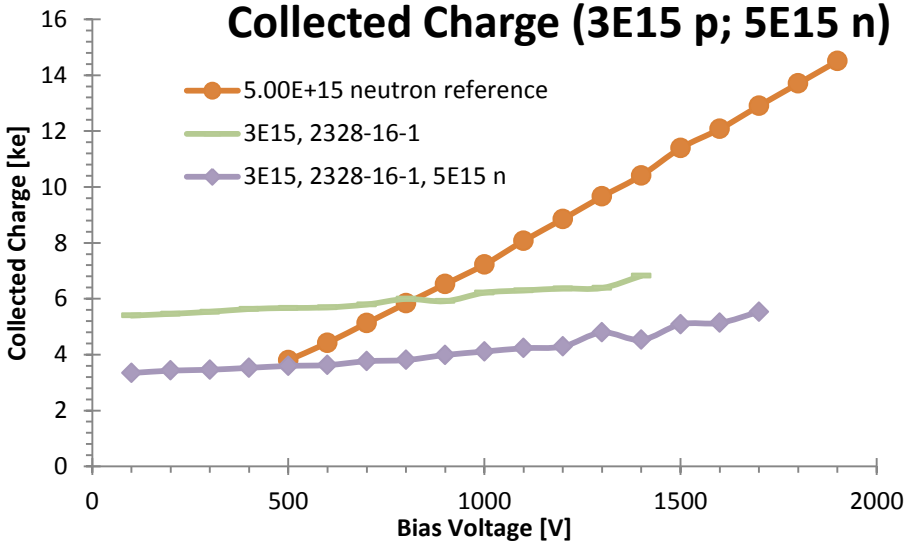
$5x10^{15}$ n_{eq}/cm^2 Neutron irradiation







- No sample exceeds the collected charge after proton irradiation

Summary

- Nickel foil in front of absorber can be used for dosimetry, but not after the absorber
- Suitable type of Gafchromic film has to be used: no polyester before active material
  - Need some more tests to make sure that the simulation represents the real irradiation

- After proton irradiation collected charge fairly flat up to 2000V for all devices

- Additional neutron irradiation to $1x10^{15}n_{eq}/cm^2$ and $5x10^{15}n_{eq}/cm^2$
  - Some samples show increased collected charge for very high voltages (>1500V)

- We learned a lot from the first irradiations and it should be possible to create a damage layer of approximately 20µm.

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Acknowledgement

- Birmingham-Liverpool-Sheffield radiation team
  - Birmingham: David Parker, Phil Allport, Laura Gonella, John Wilson, Kostas Nikolopoulos, Andy Chisholm, James Broughton, Matt Baca, Daniel Briglin
  - Sheffield: Richard French, Kerry Parker, Paul Hodgson, Hector Marin-Reyes, Paul Kemp-Russell, Simon Dixon, Vangelis Kourlitis

- Irradiation team at Ljubljana
  - Vladimir Cindro, Igor Mandić

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168.

AIDA 2020

Backup

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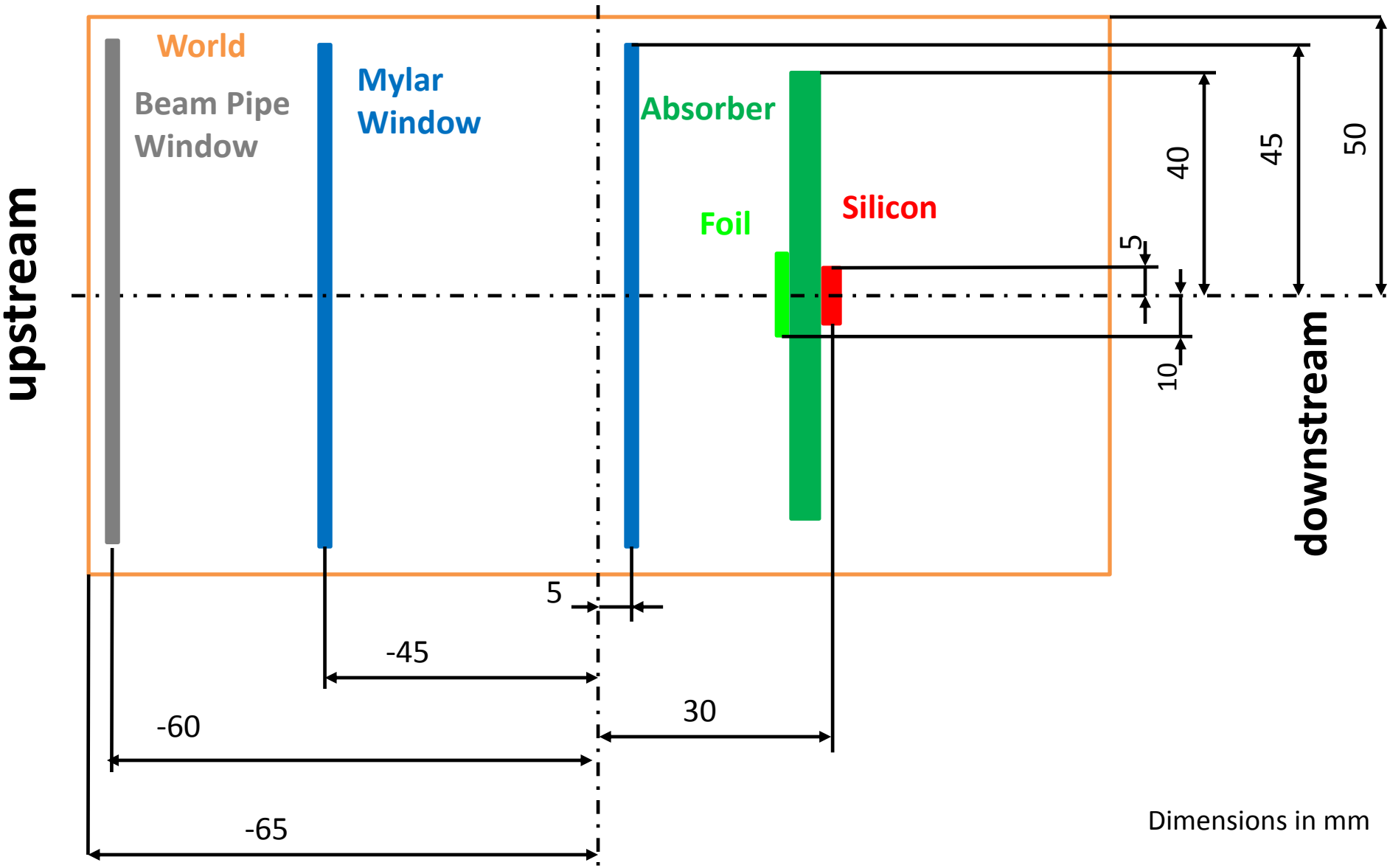
Birmingham Beam Setup



Dimensions in mm

Parameter for Geant4 simulation

- Mylar: 50µm thick (G4_Mylar)
- Silicon: 300µm thick (G4_Si)
- Absorber: variable thickness; Lead (G4_Pb)
- Foil: 25µm thick; Ni (G4_Ni)
- Beam Window: 25µm thick; Titanium (G4_Ti)
- 12MeV beam energy (Gauss profile, GeneralParticleSource, 0.1MeV sigma)

- Simulate 1000 events with a step size of 0.0001mm (in sensitive volume)

Energy loss

- It is noticeable that the total energy loss in all simulations is (10.75±0.12)MeV, which means that from the (12.0±0.1)MeV proton beam (1.25±0.16)MeV are deposited in the beam pipe window, the Mylar windows and the air in-between.

Case	Energy loss [MeV]			
	1st component	2nd component	3rd component	total
1		Lead 7.9 ± 0.3	Silicon 2.8 ± 0.4	10.75 ± 0.12
2	Nickel 0.61 ± 0.03	Lead 8.9 ± 0.5 10.00 ± 0.15	Silicon 1.3 ± 0.7	10.75 ± 0.12
3	Silicon 2.52 ± 0.08	Lead 8.23 ± 0.16	Nickel -	10.75 ± 0.12
4	Lead 7.9 ± 0.3	Nickel 2.2 ± 0.4	Silicon 1.0 ± 0.7	10.75 ± 0.12

For 300µm thick lead absorber

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Gafchromic film

- EBT3 - really too sensitive for normal use (27MeV protons) the active layer, 25 micron thick, is sandwiched between two polyester layers, each 125microns thick.
- HD-V2 - less sensitive but best for us; asymmetric construction with the active layer (12 microns approx thick) mounted on a 100 micron(approx) polyester layer.
- HD-V2 is advertised to detect particles from the 100keV range to the MeV range

- EBT3 for the low energy runs
  - protons emerging from the lead absorber have to traverse 125 microns of polyester in order to reach the active layer
- Data sheets: (http://www.ashland.com/products/gafchromic-radiotherapy-films)