Radiation hardness of plastic scintillators for the Tile Calorimeter of the ATLAS detector

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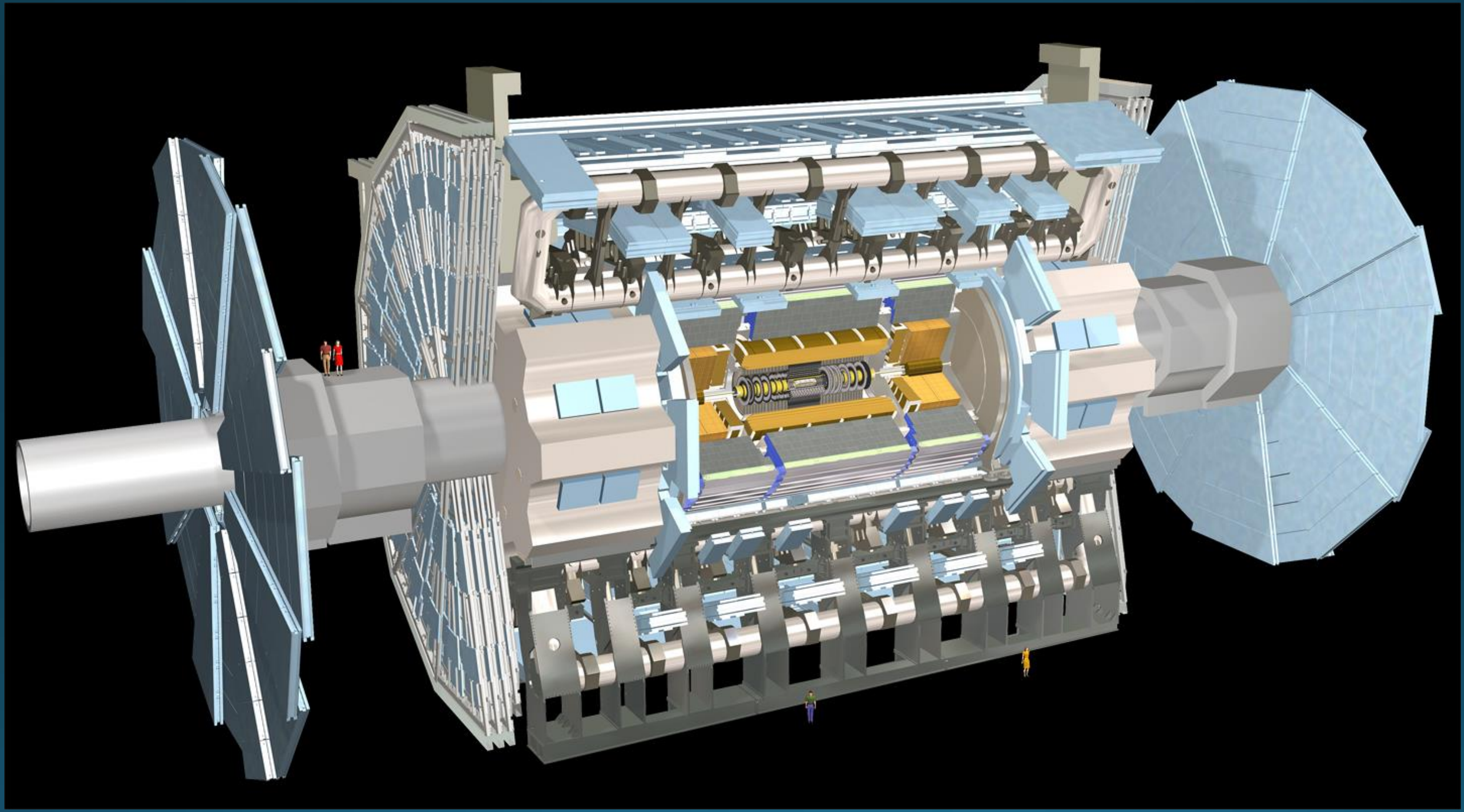
Overview

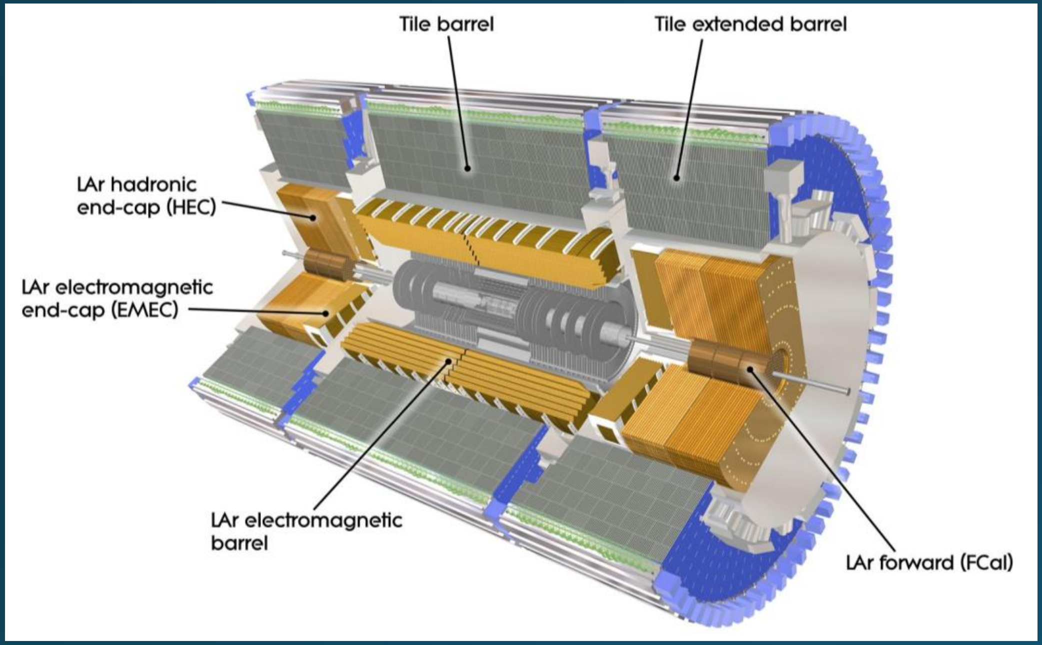
- Introduction to scintillators in the Tile Calorimeter
- The scintillation mechanism
- Simulating proton damage in plastic scintillators
- Proton irradiation at iThemba LABS, Gauteng
- Light Transmission Analysis
- Light Yield Analysis
- Analysis of structural damage using Raman spectroscopy
- Summary

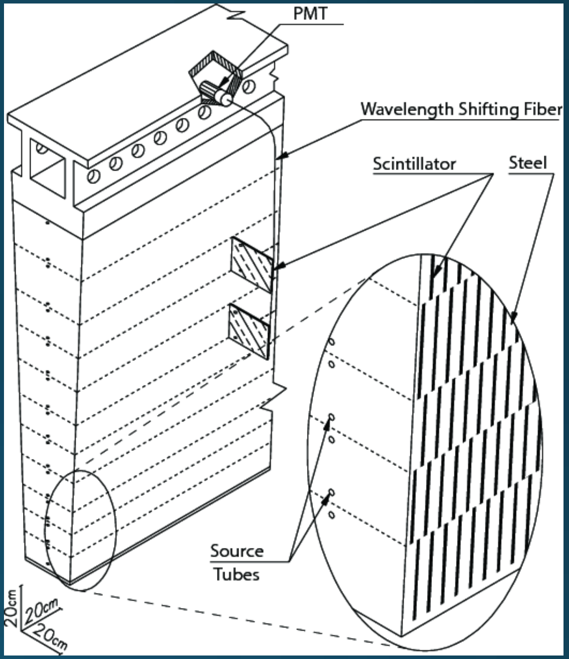
The Tile Calorimeter of ATLAS



- **The Tile Calorimeter is the hadronic calorimeter responsible for detecting hadrons, taus and jets of quarks and gluons.**

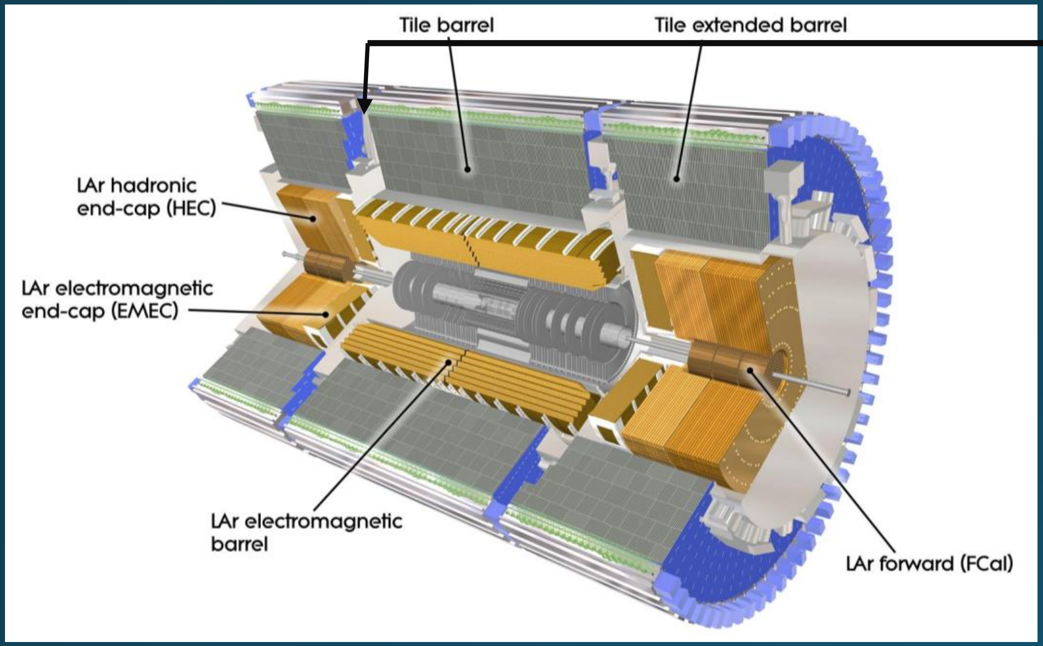
The Tile Calorimeter of ATLAS

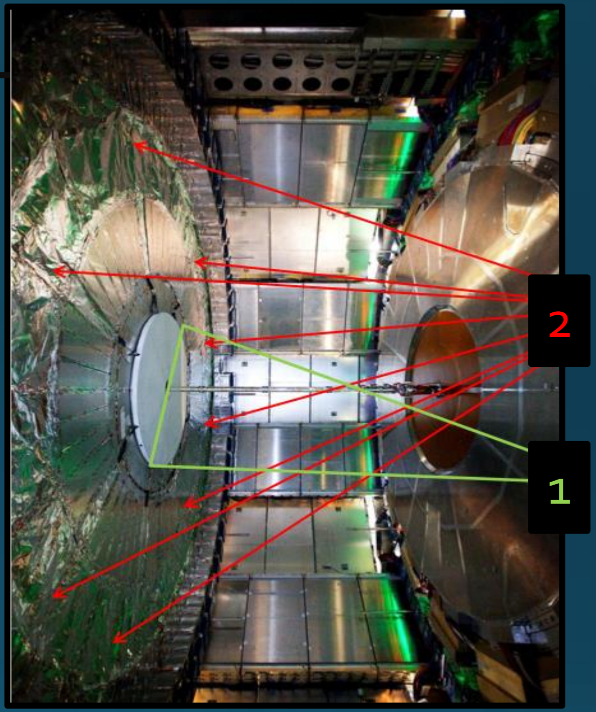




- Consists of a central barrel and two extended barrels.
- Each barrel contains 64 modules consisting of a matrix of steel and plastic scintillator plates.
- The steel plates act as an absorber medium, converting the incoming jets to a 'shower' of particles.
- The scintillator tiles absorb energy from the incoming particles and fluoresce to emit light.
- This light is passed through wavelength shifting optical fibers and detected by photomultiplier tubes.
- The signal is further processed with readout electronics in order to digitize the data for analysis thereafter.

The Tile Calorimeter of ATLAS

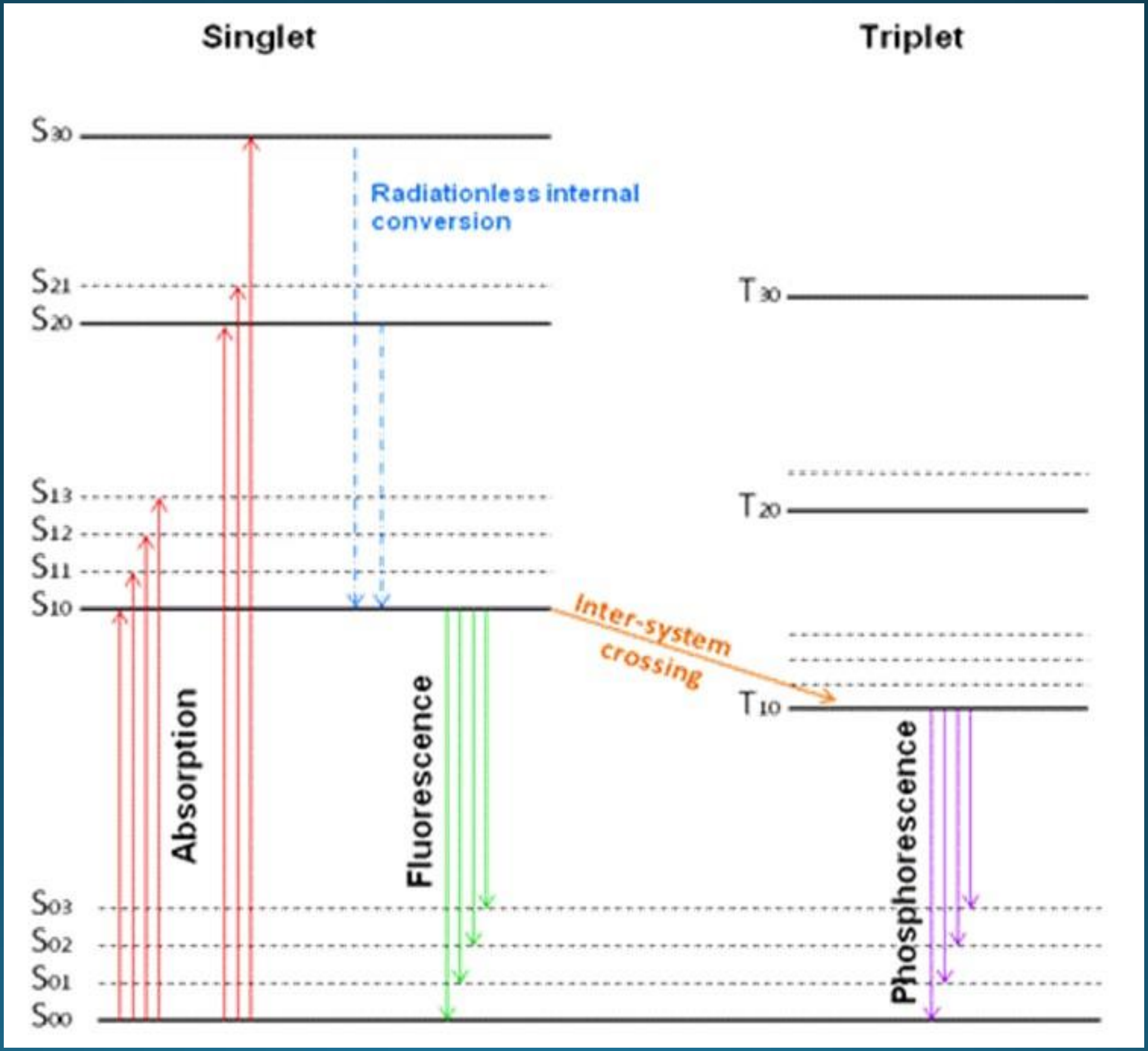




- Gap regions contain additional scintillator plates distributed radially. [1: MBTS scintillators, 2:Crack scintillators]
- During Run1, crack scintillators exposed to ~100 Gy per year. Expected to increase with Run2.
- Crack scintillators sustained a significant amount of radiation damage and will be replaced during the 2018 upgrade.
- Thus, conducting a comparative study into the radiation damage of several scintillators marketed for their radiation hardness.

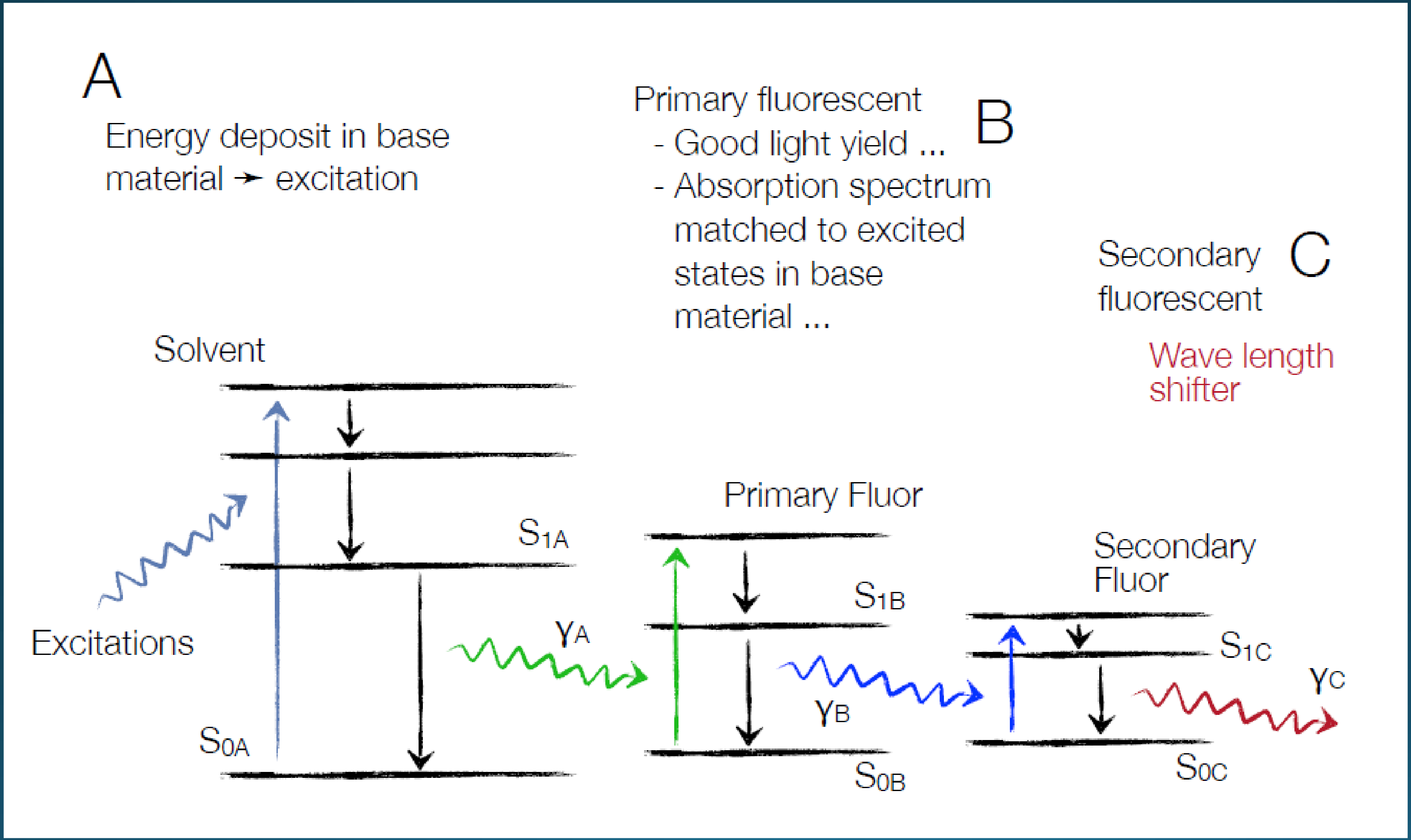
The Scintillation Mechanism

- The basic mechanism behind scintillation in organic plastic scintillators is the fluorescence process undergone by delocalized π-electrons arising within the benzene ring type structure.



Energy level diagram of an organic molecule with π-electron structure

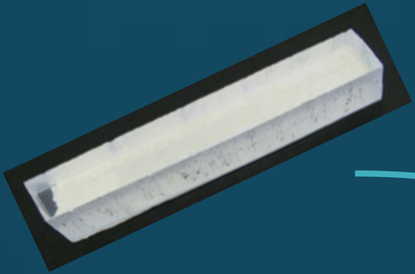
The Scintillation Mechanism

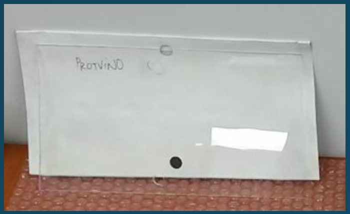


Radiative transfer of energy from polymer base to primary and secondary fluors

The Plastic scintillators studied

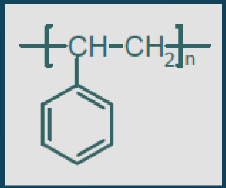
- **Scintillators produced for the Tile Calorimeter and presently used in detector:**
  - Dubna scintillator
  - Protvino scintillator



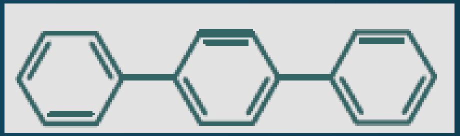


- **Commercially obtained**
  - from ELJEN Technologies :
    - EJ200
    - EJ208
    - EJ260
  - From Saint Gobain Crystals:
    - BC408

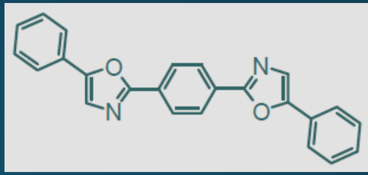
Base: Polystyrene



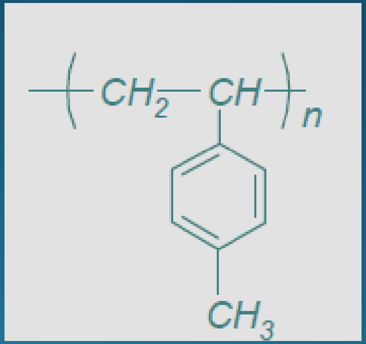
Primary fluor: PTP



Secondary fluor: POPOP

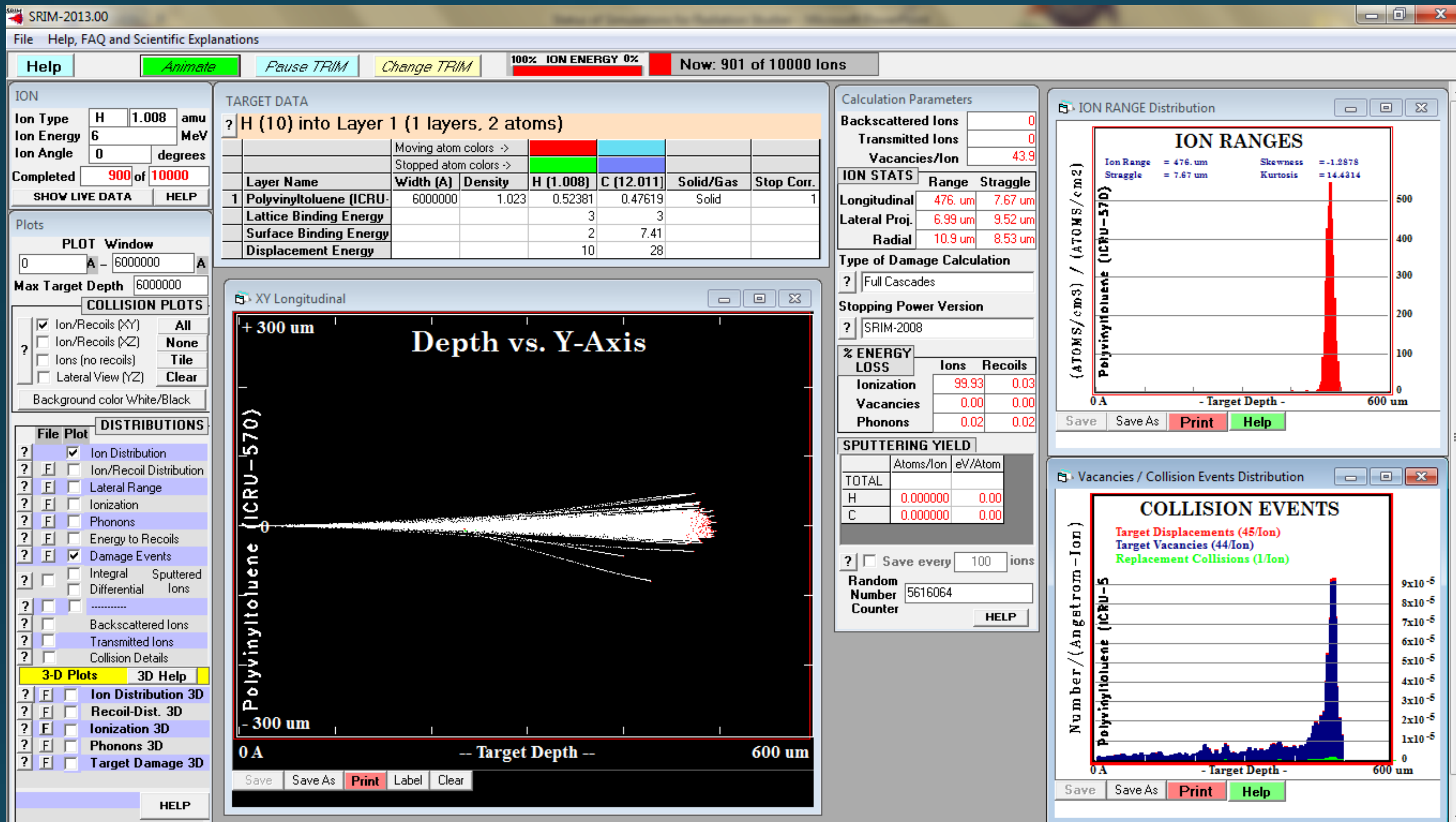


Base: Polyvinyl Toluene



3% added organic fluors

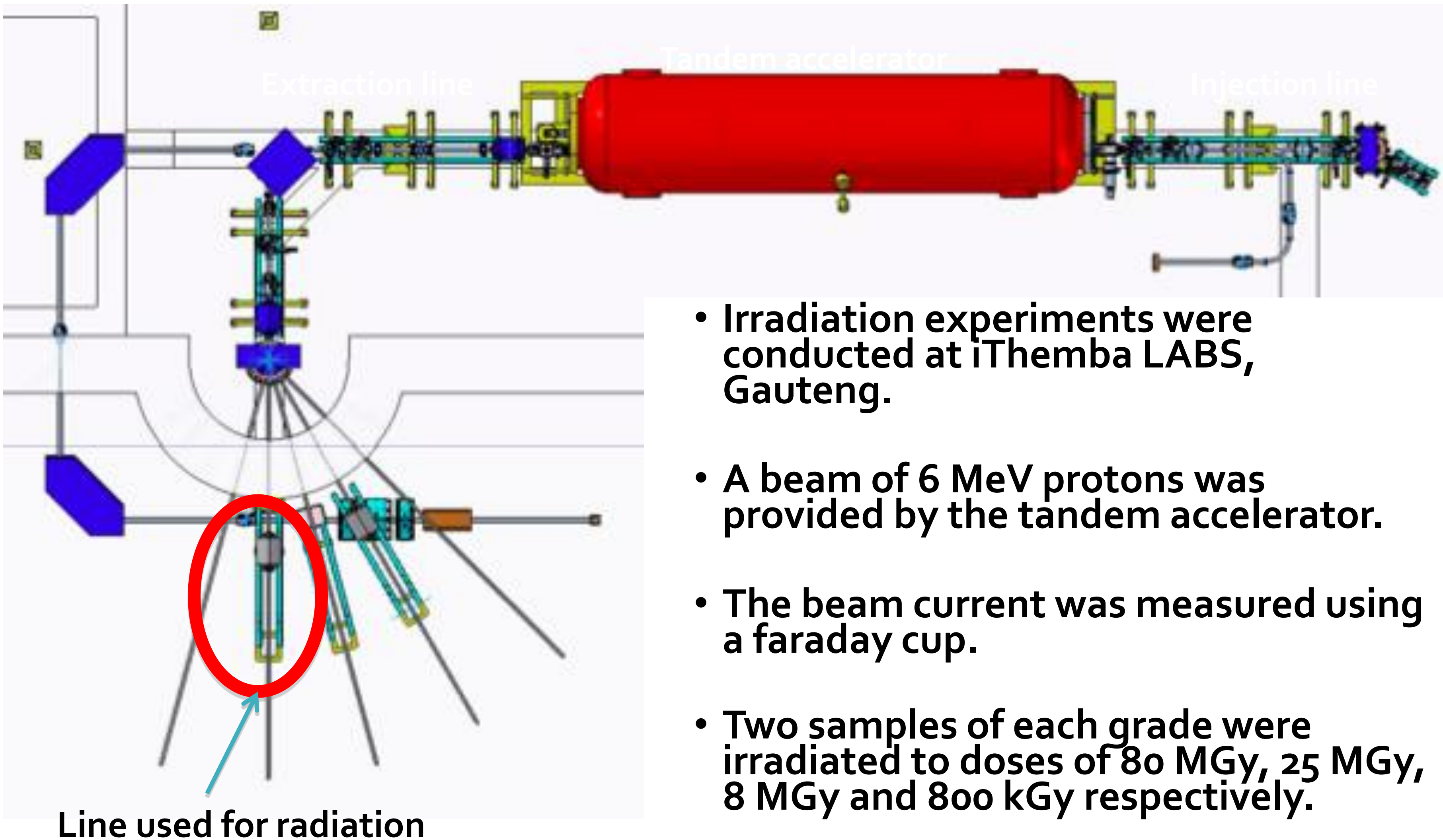
Simulating proton damage in plastic scintillators using TRIM



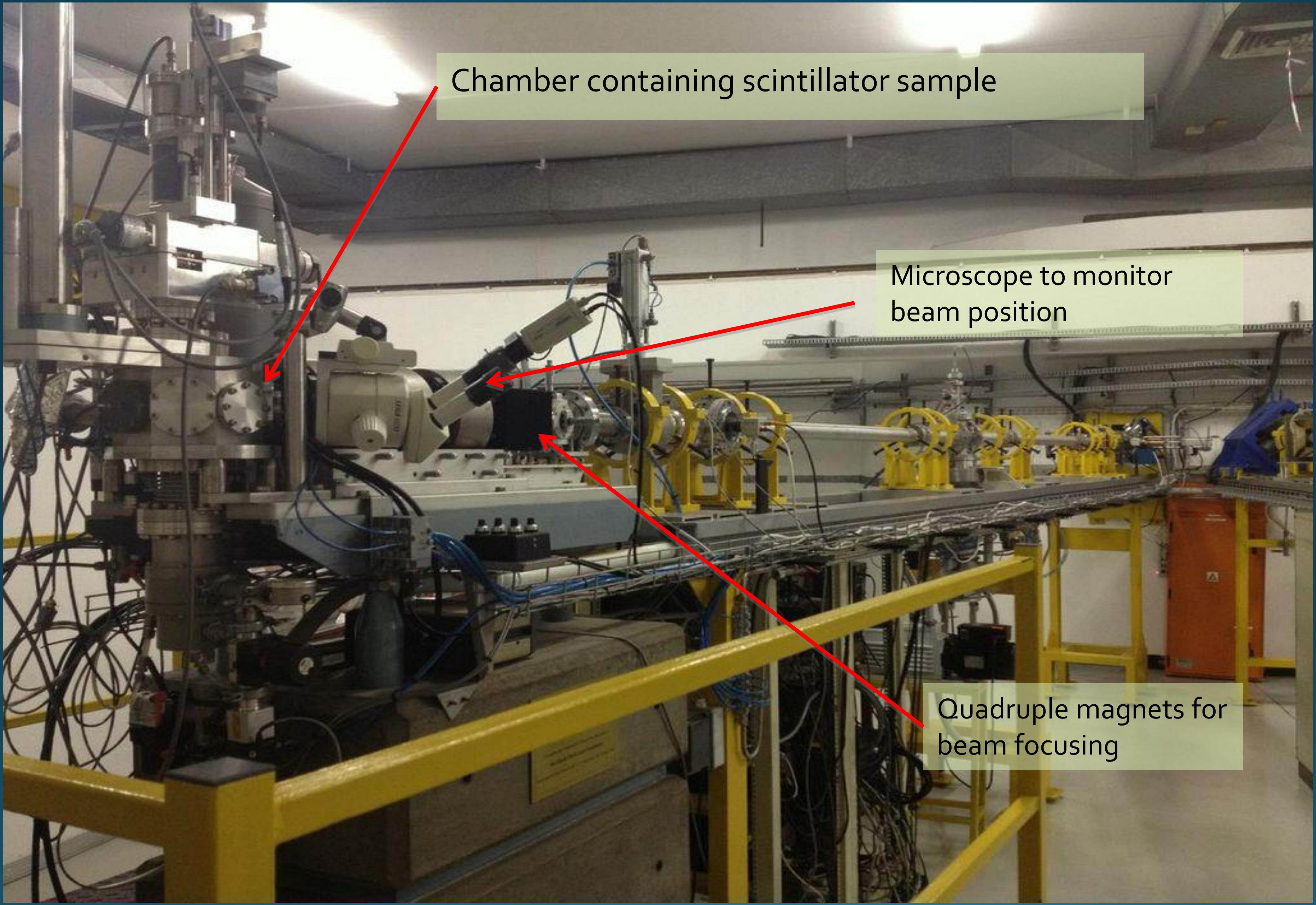
- To simulate damage, require:
  - Protons pass through samples
  - Leading energy loss through ionisation

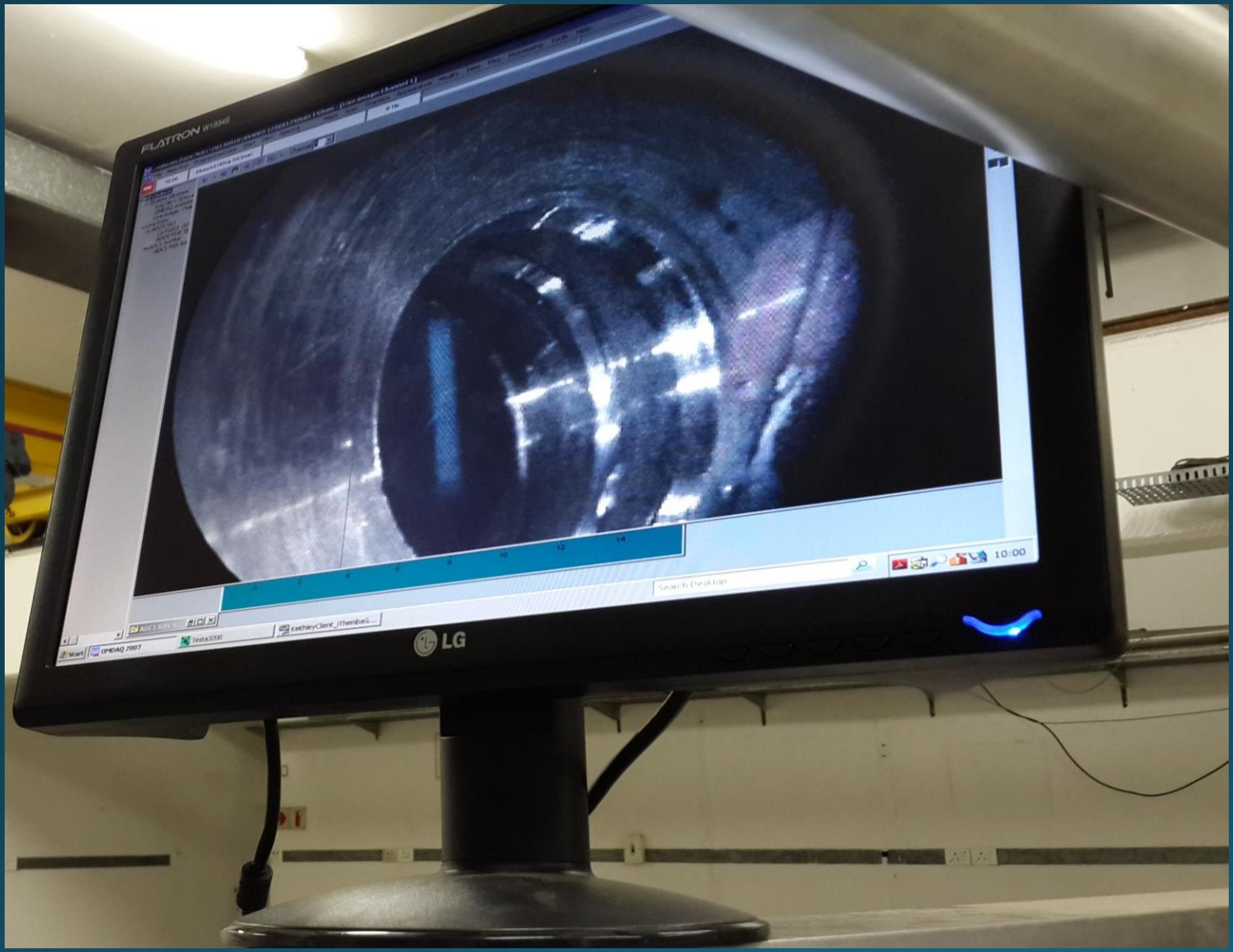
- TRIM (Transport of Ions in Matter) simulations were run to predict the stopping range of 6 MeV protons through PVT.

Proton Irradiation at iThemba LABS



- Irradiation experiments were conducted at iThemba LABS, Gauteng.
- A beam of 6 MeV protons was provided by the tandem accelerator.
- The beam current was measured using a faraday cup.
- Two samples of each grade were irradiated to doses of 80 MGy, 25 MGy, 8 MGy and 800 kGy respectively.

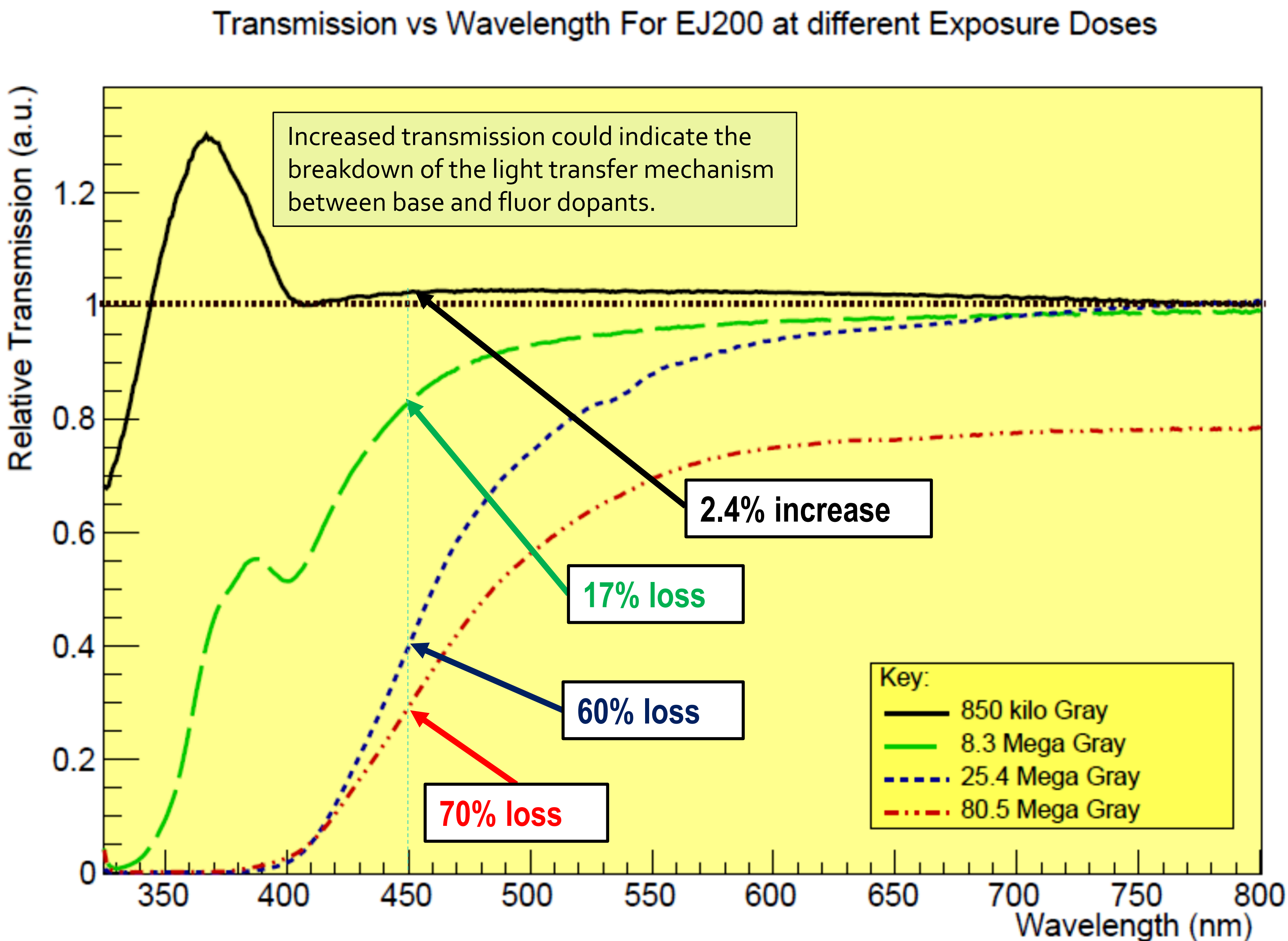

Chamber containing scintillator sample
Microscope to monitor beam position
Quadruple magnets for beam focusing



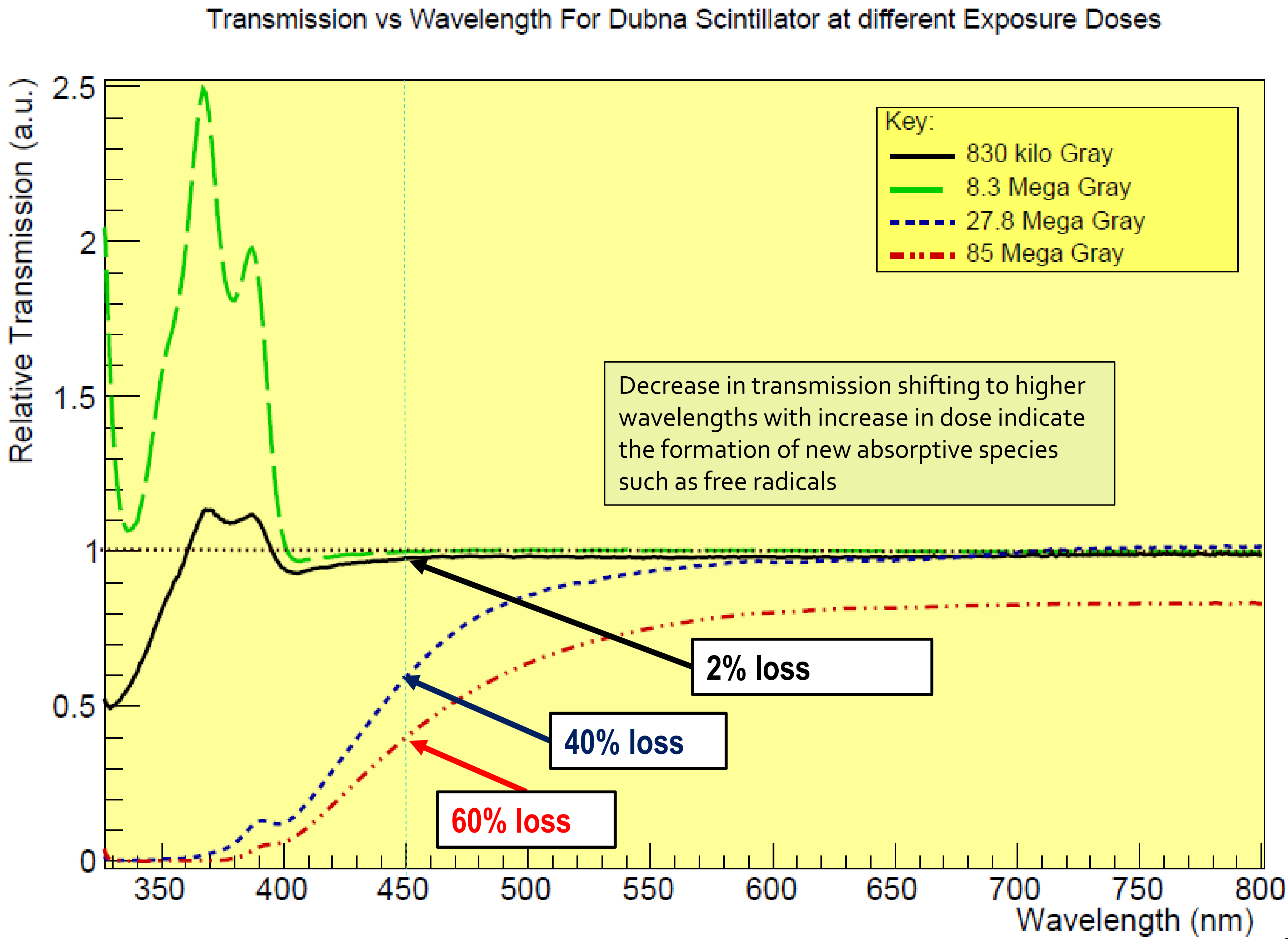
During irradiation, the proton beam is focused and then scanned in x and y across the sample to achieve an irradiation area of approximately 1.8 mm by 1.8 mm

Light Transmission Testing

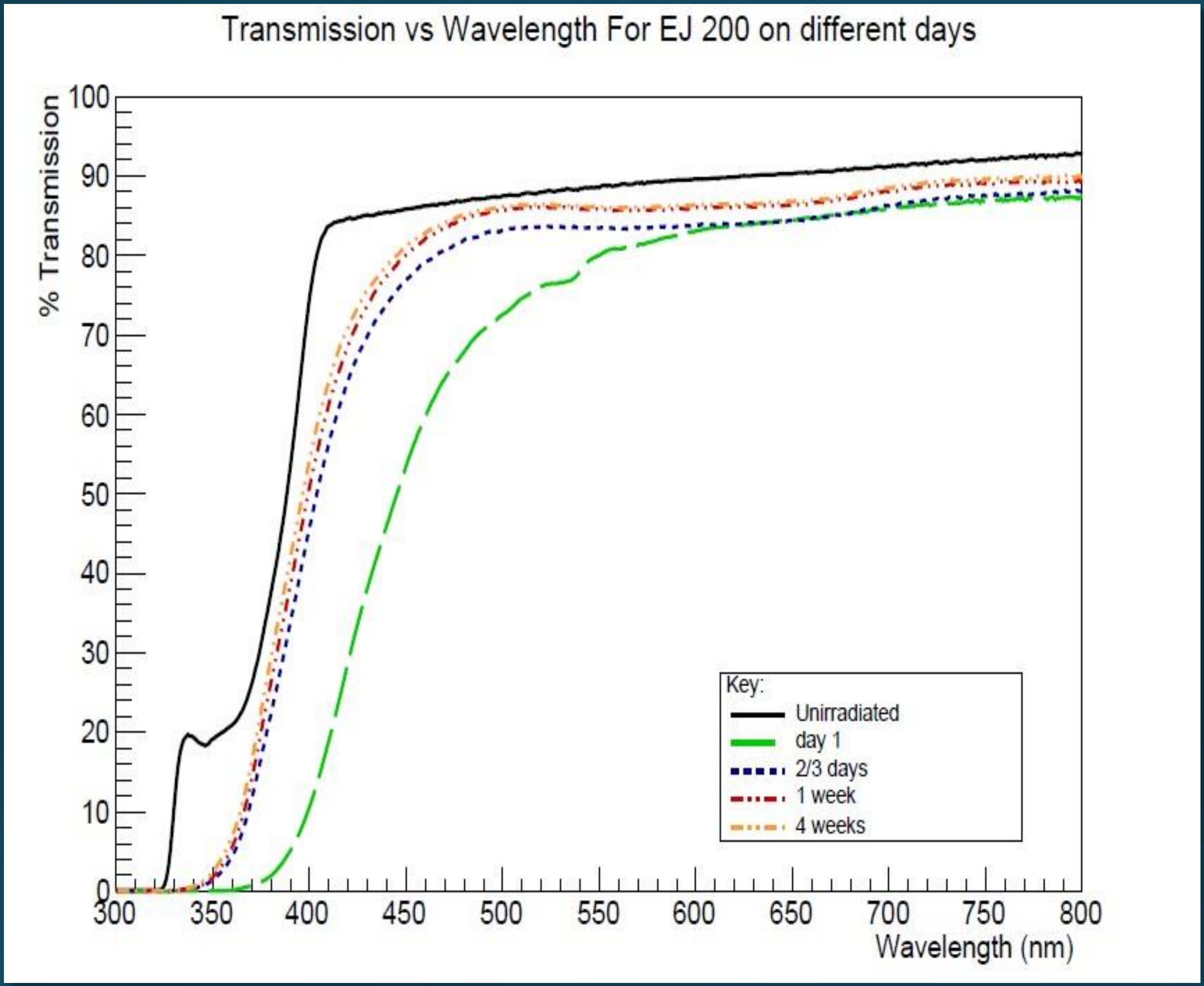
- Light transmission experiments were conducted using the Varian Cary Spectrophotometer at Wits.
- Transmission over UV and visible wavelength range (200-800 nm)
- A tungsten lamp source and diffraction grating is used in order to increment light over this range.
- Transmission of light in each irradiated scintillator sample as well as the un-irradiated samples were measured relative to transmission in air.
- The ratio of transmission in irradiated over unirradiated sample is then plotted.



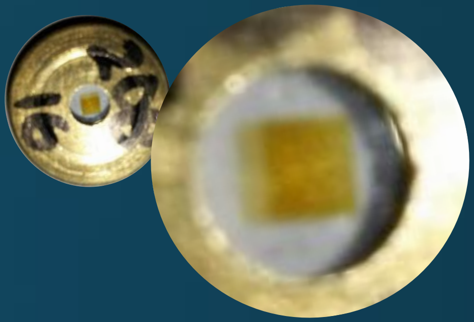
Transmission vs Wavelength For EJ200 at different Exposure Doses
Increased transmission could indicate the breakdown of the light transfer mechanism between base and fluor dopants.
2.4% increase
17% loss
60% loss
70% loss
Key:
850 kilo Gray
8.3 Mega Gray
25.4 Mega Gray
80.5 Mega Gray
Relative Transmission (a.u.)
Wavelength (nm)
0
0.2
0.4
0.6
0.8
1
1.2
350
400
450
500
550
600
650
700
750
800



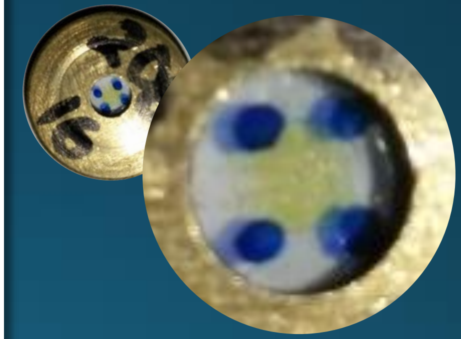
Transmission vs Wavelength For Dubna Scintillator at different Exposure Doses
Relative Transmission (a.u.)
Wavelength (nm)
Key:
830 kilo Gray
8.3 Mega Gray
27.8 Mega Gray
85 Mega Gray
Decrease in transmission shifting to higher wavelengths with increase in dose indicate the formation of new absorptive species such as free radicals
2% loss
40% loss
60% loss



Immediately after irradiation

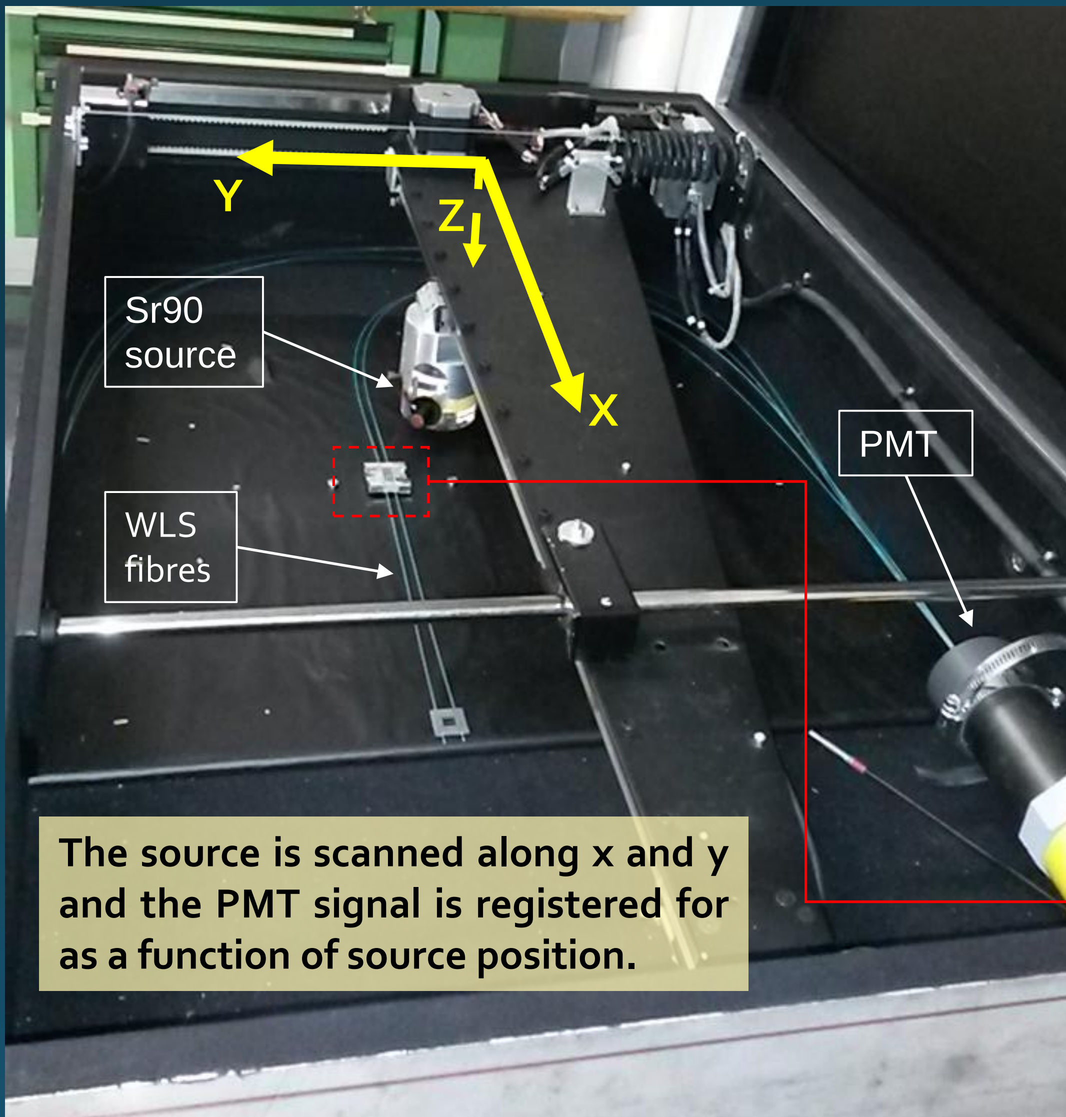


1 day after irradiation

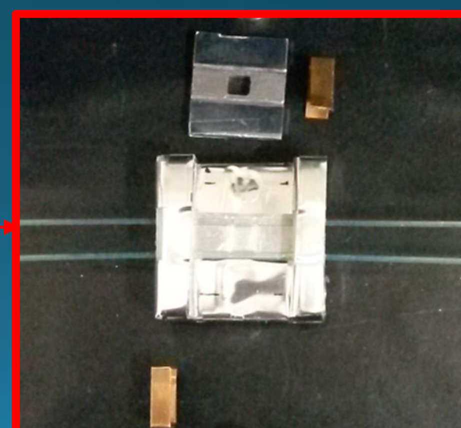


Healing of 25 MGy irradiated EJ200 scintillator sample.
Across all grades, healing occurs exponentially, with the most significant healing occurring overnight. Photobleaching is the likely cause of this healing.

Light Yield Testing

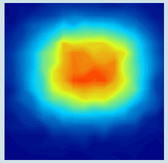
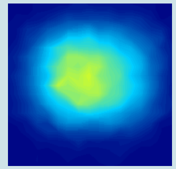
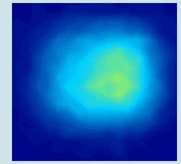
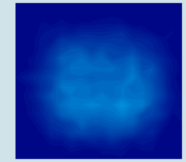
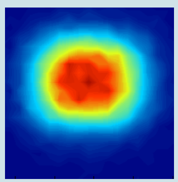
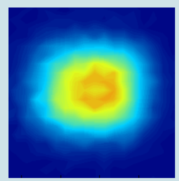
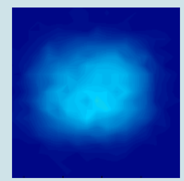
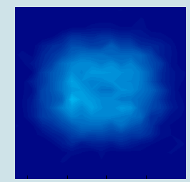
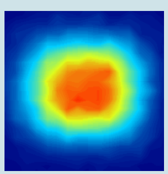
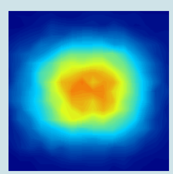
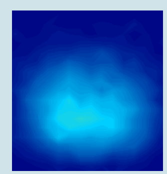
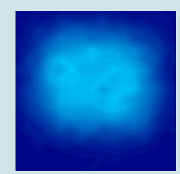


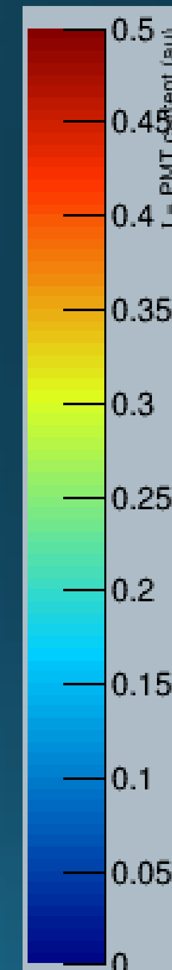
- The scintillator light response to 0.5 MeV beta electrons emitted from a Sr90 source were measured using the light box set-up at CERN.
- Two wavelength shifting fibres were coupled along opposite edges of the sample as well as to a photomultiplier.
- Electrons impinge the sample and the integrated PMT response is registered.



Sample in holder manufactured by Wits

Preliminary Light Yield Analysis

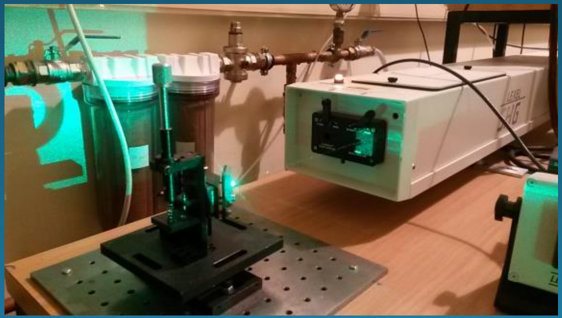
	Un-irradiated	200-370 Kilo Gray	2-3 Mega Gray	14 Mega Gray
EJ200				
Light loss relative to un-irradiated EJ200		31.03% loss	55.60% loss	73.74% loss
EJ208				
Light loss relative to un-irradiated EJ208		19.06% loss	63.82% loss	68.30% loss
Dubna				
Light loss relative to un-irradiated Dubna		10.47% loss	59.95% loss	61.98% loss



Light yield testing of final irradiated sample batch will be carried out over December

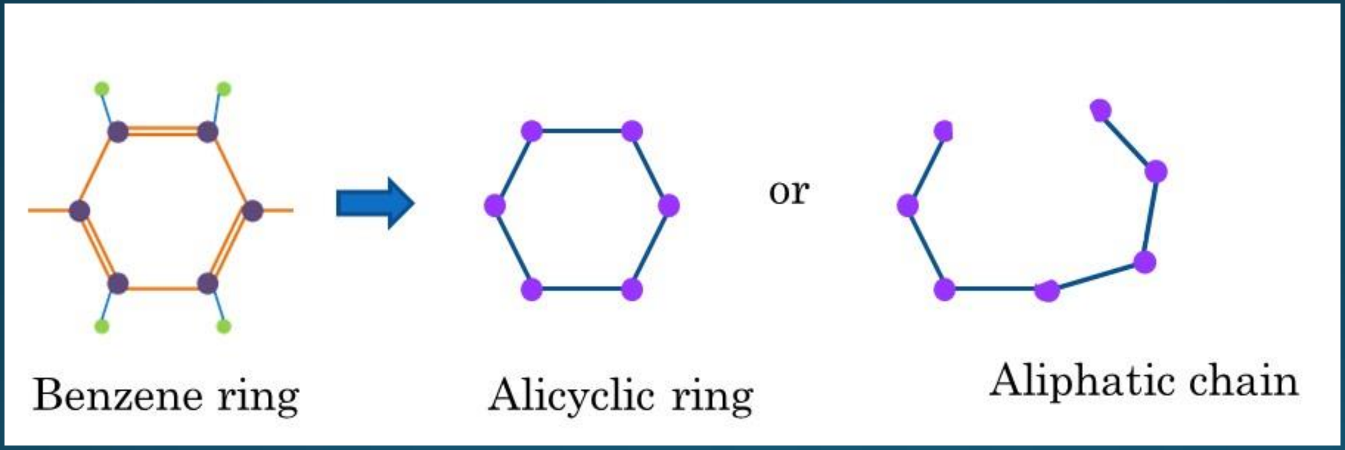
Raman Spectroscopy

- Raman spectroscopy was conducted using the LabRam HR Raman spectrograph.
- A 514.53 nm excitation laser excites vibrational modes within the sample. These then de-excite and release photons of a characteristic wavelength.
- The Raman spectrum obtained corresponds to the intensity of photons detected at various wavelengths and gives an indication of the vibrational modes and hence bonding structure present in the sample.



Implications of the Raman Results

- There is a small change in the specie content after irradiation. The scintillator heals significantly 4 weeks after irradiation
- Damage occurs to the benzene ring. As a result of the CH type bonds breaking, hydrogen lost from the benzene ring could be lost to free radicals.

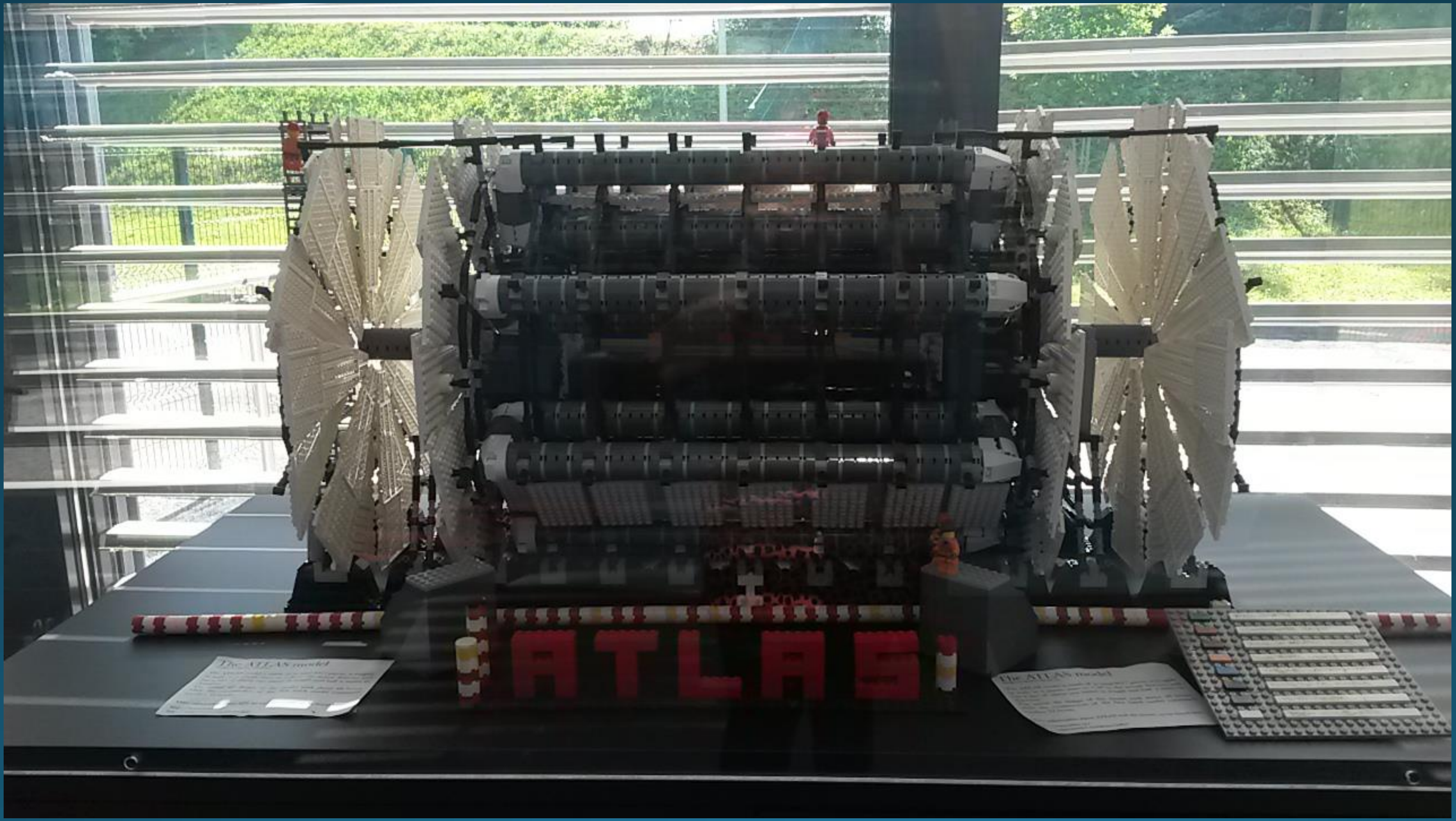


- Damage to the benzene ring directly affects the scintillation mechanism.
- EPR studies will give us a better idea of the structural damage undergone as free radicals may form when these bonds break.

Summary

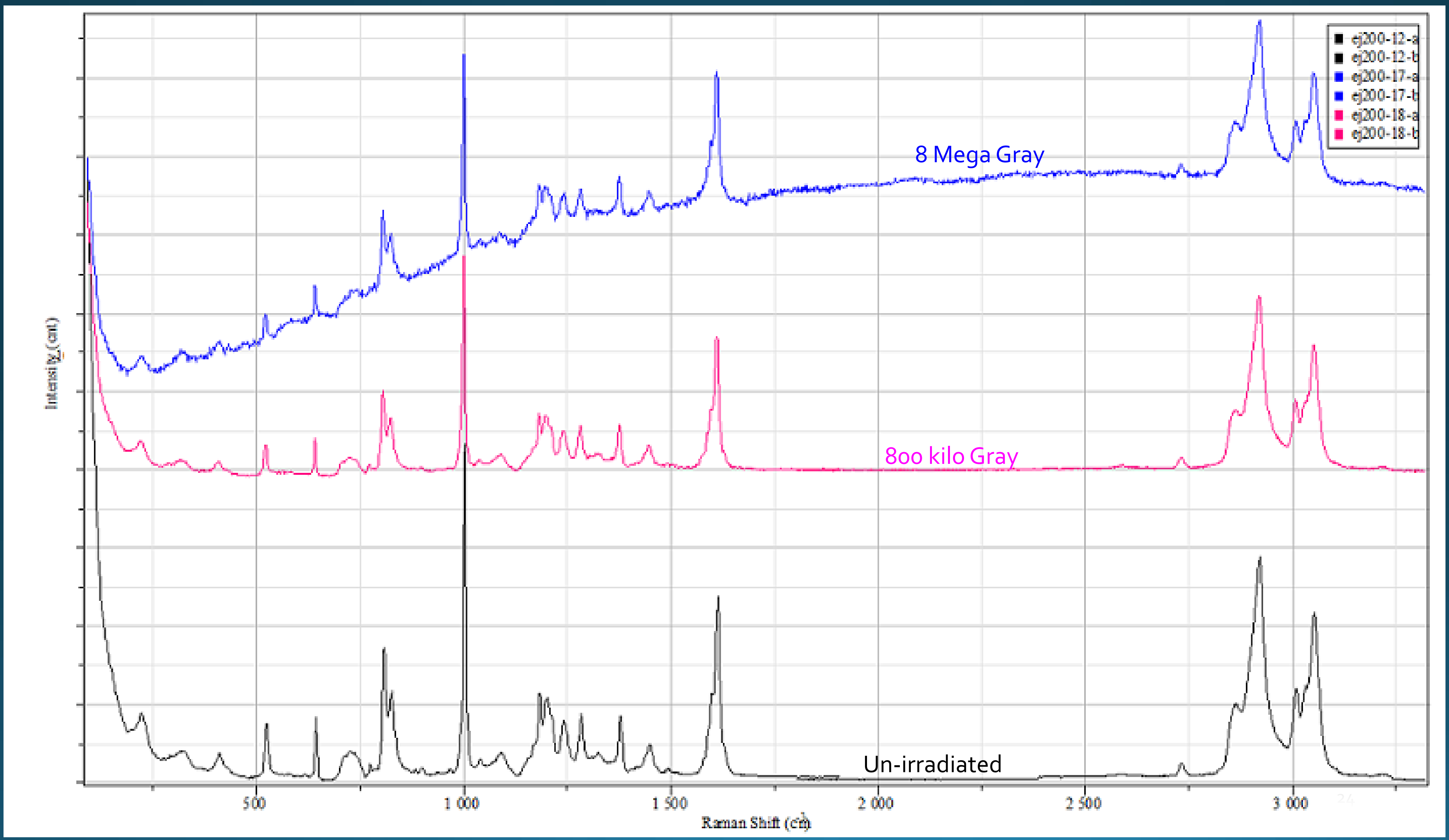
- Radiation damage in PVT and PS based scintillators subjected to proton damage is under study.
- Radiation damage at a lower dose of 800 kilo Gray causes damage to the light transfer mechanism between base and dopants. Structurally very little change is observed.
- At higher doses (8 M Gy and up), an absorptive tint forms shifting to higher wavelengths and transmission decreases with increasing dose.
- Damage to the benzene ring is noted in these higher doses. The formation of free radicals could cause the additional absorption of light.
- A significant amount of healing is observed both in the transmission spectra and in the structural recombination seen from the Raman data 4 weeks after irradiation.

Thank You for your time…

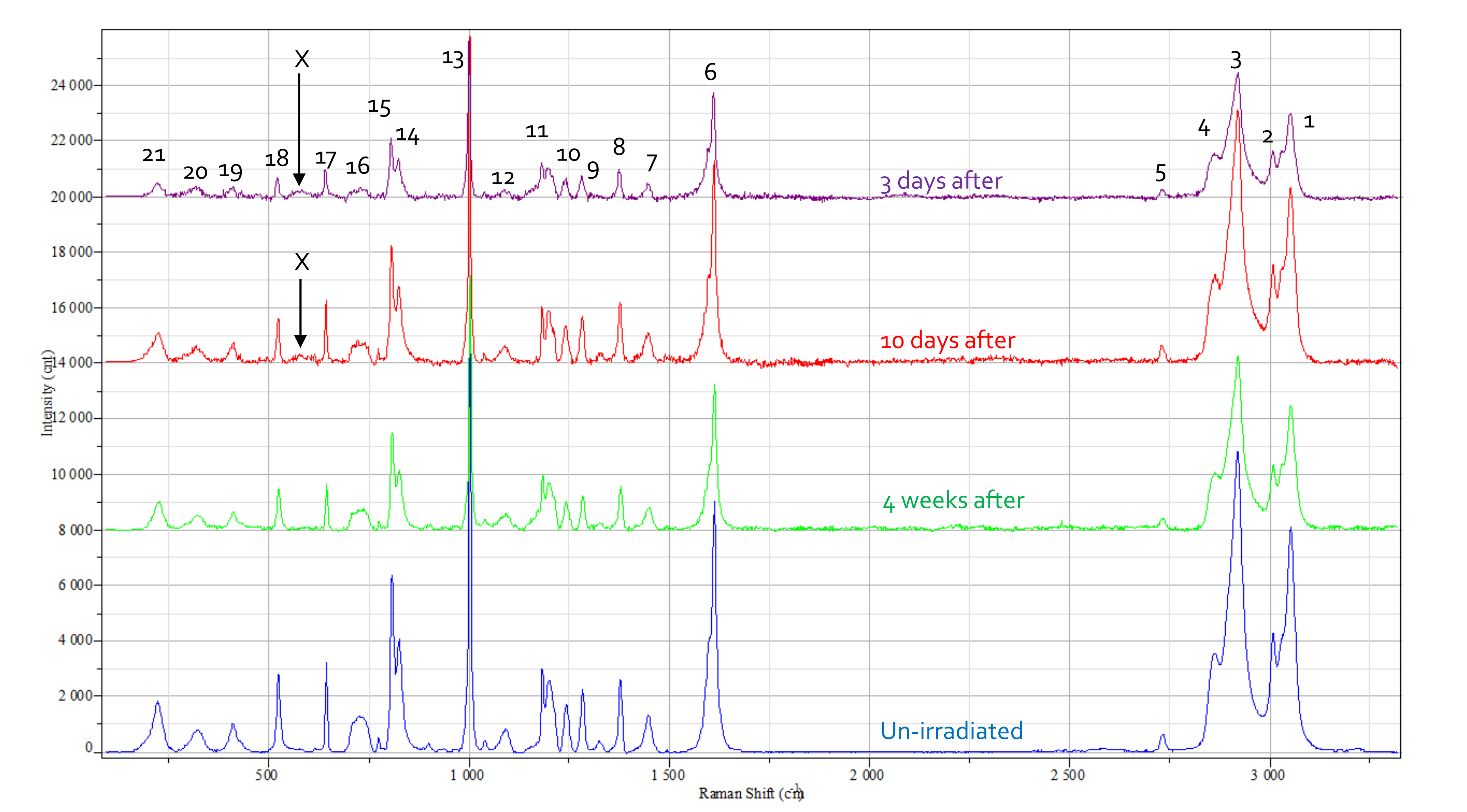


Back Up

- Results for EJ200 shown below.
- Background fluorescence increases with dose, because sample absorbs more light at 514 nm with increased dose. (Seen in transmission spectra)
- NB: The various spectra overlap but I added a constant to the 800 kGy and 8MGy spectra for visual impact



Background subtracted Raman spectra for EJ200 taken over consecutive days after irradiation to 8 Mega Gray:



δ(C-C) aliphatic	20-21	δ(CH_2) or δ(CH_3)asymmetric	7
v(C-C) alicyclic or aliphatic chain vibrations	9-12, 14-19, X	v(C=C)	6
v(C-C) aromatic ring chain vibrations	13	v(C-H)	3-4
δ(CH_3)	8	v(=(C-H))	1-2

The percentage of each peak's intensity to that of peak 13 gives an indication of the changes to the population of that functional group relative to the population of aromatic rings.