Studying the effects of radiation damage in plastic scintillators using EPR for the replacement of the MBTS plastics in the ATLAS detector

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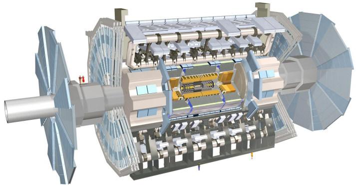
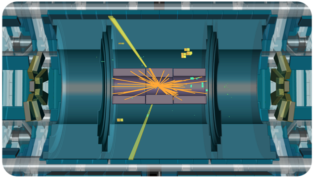
Outline

The ATLAS detector and TileCal

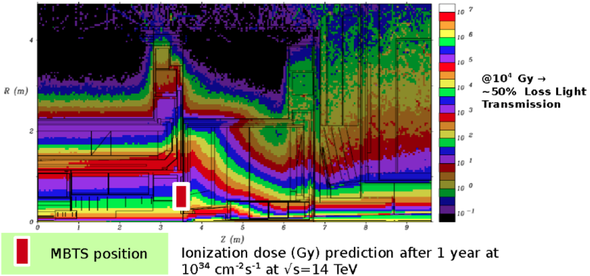




- TileCalorimeter situated in ATLAS inner detector
- Able to detect energetic particles: hadrons, quarks, jets...

- 16 Minimum Bias Trigger Scintillator polystyrene plastics located on each of the ATLAS EndCaps
- First part of Trigger System tracking trajectories of particles

Radiation Environment



Ionization dose (Gy) prediction after 1 year at 10^{34} $cm^{-2}s^{-1}$ at $\sqrt{s}$=14 TeV

doi:10.1088/1748-0221/9/10/C10020

- MBTS plastics accumulated $0.1 \sim 0.4 \times 10^4$ Gy dose
- Does not cause permanent[1] damage to 2cm thick plastics
- But plastics are susceptible to radiation and are to be replaced[2]

[1] T. Sasuga, Rad. Phys. Chem.,**37**,1 (1991).

[2] L. Torrisi, Rad. Phys. Chem., **63**, 1 (2002).

Our aims

Suitable plastic replacement

PVT based plastics

- EJ200
- EJ208
- EJ260
- Bicron

Polystyrene based plastics

- Dubna
- Protvino

Understand damage

Characterization of damage

- Electron paramagnetc resonace

Simulation of EPR spectra

- Density functional theory calculations

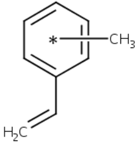
Relate to previous studies

- Light yield
- Transmission

The plastics under investigation

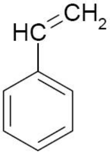
PVT plastics

- Two blue and one green emitting scintillator
- Unknown organic dopants added



Polystyrene plastics

- Three blue emitting scintillators
- Organic dopants: POPOP, pTP



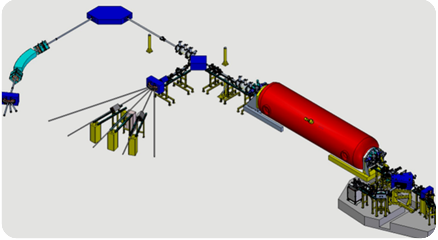
Ionization of plastics break C–H bonds[3] introducing ions and unpaired electrons into samples[4].

[3] L. Torrisi, Rad. Eff. Def. Solid, **145**, 271 (1998).

[4] H. Kashiwabara, Jap. Rad. Res., **16**, 12 (1961).

Irradiating the plastic samples

Samples were cut to width 250 μm smaller than stopping range 470 μm calculated using SRIM. Calculated $E_{\text{loss}} = 2.07$ MeV for 6 MeV protons used to calculate dose.



Absorbed dose calculated using

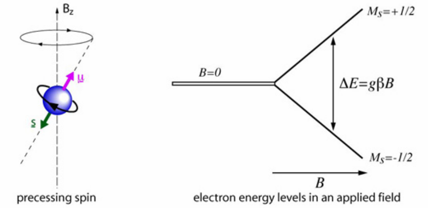
$$D_{\text{Abs}} = \frac{I \cdot t \cdot E_{\text{loss}}}{q \cdot m}$$

They irradiated using 6 MeV protons with the Van der Graff tandem accelerator to doses between 0.8 - 80 MGy.

Theory of EPR: Single unpaired electron

EPR used to study of a single, unpaired electron is by the Hamiltonian

$$\mathcal{H} = \beta \mathbf{B}^T \cdot \mathbf{g} \cdot \mathbf{S}.$$

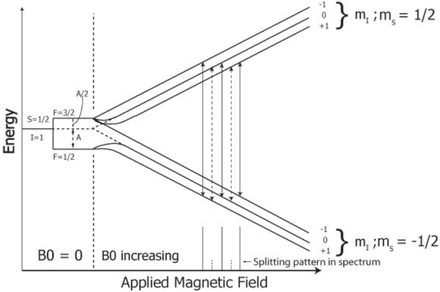


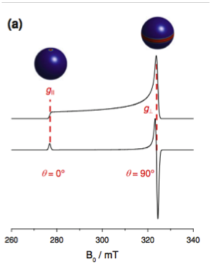
A single, unpaired electrons interaction with the external magnetic field and electromagnetic radiation (usually in microwave region)

Theory of EPR: A more complicated system

EPR used to study unpaired electrons and ions described by the Hamiltonian

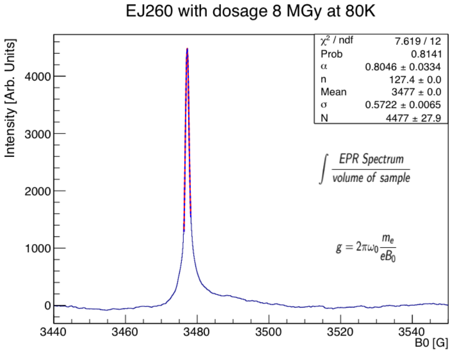
$$\mathcal{H} = \beta \mathbf{B}^T \cdot \mathbf{g} \cdot \mathbf{S} + h\,\mathbf{S}^T \cdot \mathbf{D} \cdot \mathbf{S} + h\,\mathbf{S}^T \cdot \mathbf{A} \cdot \mathbf{I}.$$





Hyperfine interactions (**A**) and anisotropy of **g**-tensor come into play.

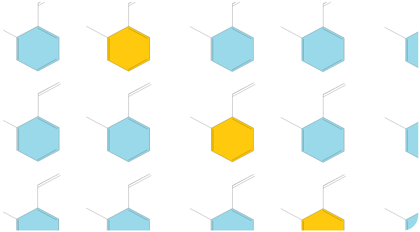
Analysis of experimental EPR

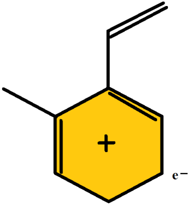


- The g-factor: gives information about spin environment
- Spin density: number of spins detected in sample

Creating “plastics”

Simulated sample crated in VASP for three isomers of PVT and one polystyrene. C-H bonds where removed, system was allowed to relax, and monomers randomly orientated.





EPR calculations were run on QUANTUM ESPRESSO based on code developed by C. Pickard (doi: 10.1103/PhysRevLett.88.086403). Tensors **g** and **A** were analysed as more bonds were removed. We looked at $\Delta\mathbf{g} = \mathbf{g} - \mathbf{g}_e$

Analysis of simulated EPR

$\Delta\mathbf{g}$-tensor components change when one, two, and three bonds are broken (first bonds in monomer)

$$\begin{pmatrix} -0.02 & 0.02 & 0.00 \\ 0.02 & 0.00 & 0.01 \\ 0.00 & 0.00 & 0.01 \end{pmatrix}$$

$\Downarrow$ one bond broken

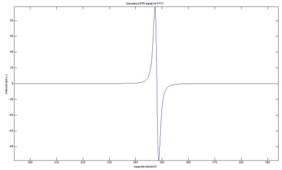
$$\begin{pmatrix} -45.11 & -1.93 & 0.94 \\ -1.99 & -42.91 & 0.83 \\ -1.72 & 0.13 & -17.64 \end{pmatrix}$$

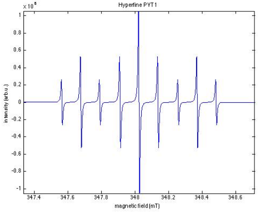
$\Downarrow$ two bonds broken

$$\begin{pmatrix} -114.55 & -72.26 & -14.91 \\ -45.79 & -421.31 & -30.94 \\ -12.32 & -40.69 & 79.46 \end{pmatrix}$$

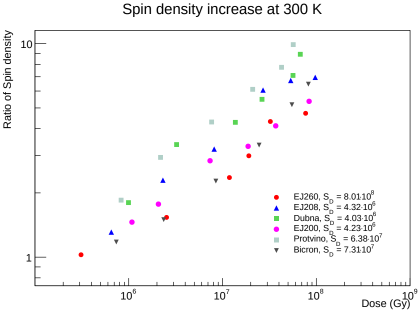
$\Downarrow$ three bonds broken

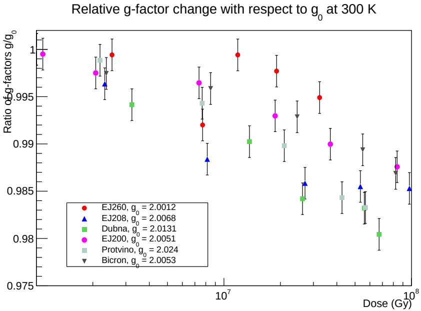
$$\begin{pmatrix} -1145.96 & -241.46 & 2.13 \\ -105.92 & -54.86 & -30.05 \\ 29.94 & -32.06 & 625.16 \end{pmatrix}$$





Experimental EPR results



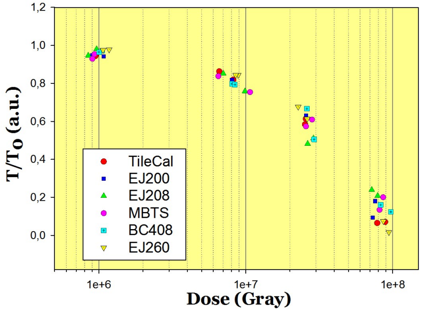


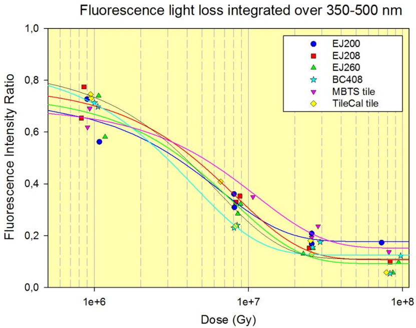
As dose increases, the g-factor decreases and spin density increases. Additional ions shield unpaired electrons from external magnetic field. Possible ions include electrons, alkly-ions[5], and hydrogen[6].

[5] J. Morton, Chem. Rev, **64**, 4 (1964).

[6] R. Barklie, Phys. Rev. B., **61**, 5 (2002).

Transmission and light yield results





The plastics transmit and yield less light with an increase in dose. Not much difference can be seen between samples[7].

[7] Studies done by H. Jivan, Wits

Conclusions

- Irradiated samples show general degradation with an increase of dose
- Broken bonds induce secondary ions that shield the detected electrons and ions resulting in a lower g-factor
- Results correspond to those with light yield and transmission