Beam Loss Monitors for Energy Measurements in Diamond Light Source

Niki Vitoratou, Pavel Karataev, Guenther Rehm

John Adams Institute at Royal Holloway, University of London
Diamond Light Source

Niki.Vitoratou.2016@live.rhul.ac.uk
niki.vitoratou@diamond.ac.uk

August 24, 2017

Overview

1. Resonant Spin Depolarisation
2. Radiation Footprint
3. Beam Loss Monitors Setup
4. Results
5. Future Studies

Resonant Spin Depolarisation (RSD)

- High precision energy measurements technique.
- Sokolov - Ternov effect: The spin of the electrons in a storage ring will develop polarization due to spin flip radiation emission.
- The spin will gradually align antiparallel with the main guide field of the bending magnets.
- Precession frequency of the electron spin depends only on the beam energy:

$$\Omega_z = \omega_0(1 + \alpha\gamma) \tag{1}$$

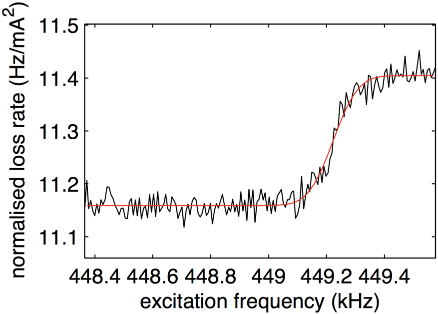
where ω_0 is the revolution frequency , α the gyromagnetic anomaly of the electron, and $\alpha\gamma$ the spin tune.

Resonant Spin Depolarisation

- The polarised beam is excited by a horizontal magnetic field produced by a vertically oriented stripline.
- The magnetic field oscillates at frequencies which match the fractional part of the spin tune.
- Excitation frequency in resonance with the spin tune $\rightarrow$ depolarization
- Touschek scattering $\rightarrow$Loss mechanism driven by large angle scattering in the electron bunch.

- Electron can exceed the longitudinal acceptance limit.

$$\frac{1}{I(t)^2}\frac{dN}{dt} \propto f_1 + f_2 P(t)^2 \quad (2)$$

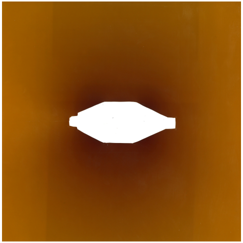


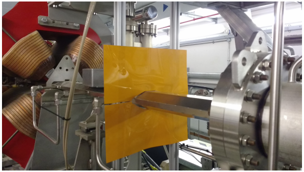
Beam Loss Monitor (BLM) parameters

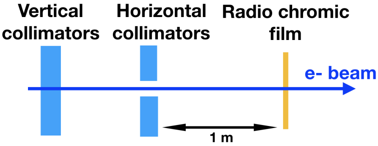
1. Location
   - downstream the collimators $\rightarrow$ small physical aperture $\rightarrow$ electromagnetic showers
2. Material of the detector
   - high number of counts $\rightarrow$ better measurement accuracy.
   - fast response for the resonance detection.
3. Design
   - capture the largest fraction of the radiation footprint

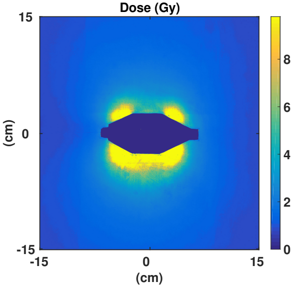
Radiochromic film

- a layer of radiation-sensitive organic microcrystal monomers on a thin polyester base with a transparent coating.
- absorbed dose→film darkening







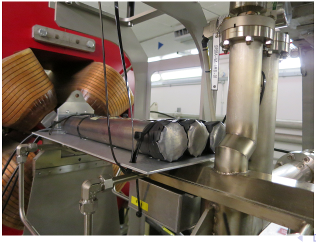


Beam Loss Monitor Setup

Beam loss detector → Light production from charged particles + Light detection

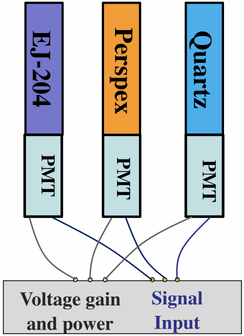
Three beam loss detectors were built and studied.

- Rod 15 cm long 3 cm diameter attached with a photomultiplier.
- Three types of material tested:
    - EJ-204 plastic scintillator
    - Perspex
    - Quartz fused glass (Cherenkov radiator)
- Detectors covered with 1.3 mm lead for low energy x-rays protection.
- Photomultipliers have adjustable voltage gain.



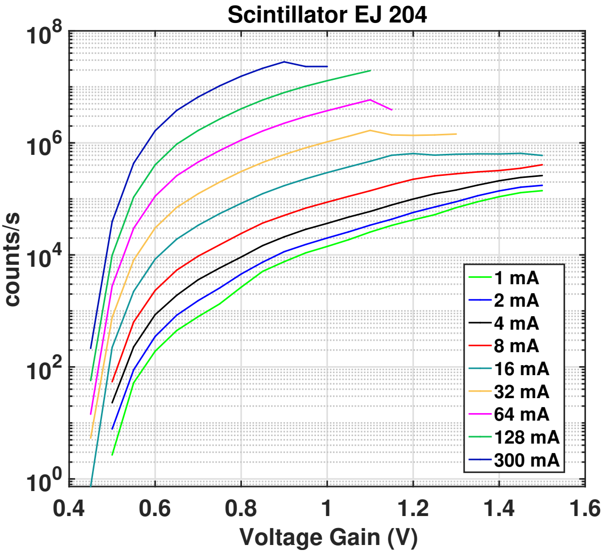
Signal Acquisition

- The detectors are connected with a commercial acquisition instrument with two hardware interfaces:
  - coaxial connectors for signal input.
  - RJ-25 pinouts for:
    - power suppling
    - gain control voltage



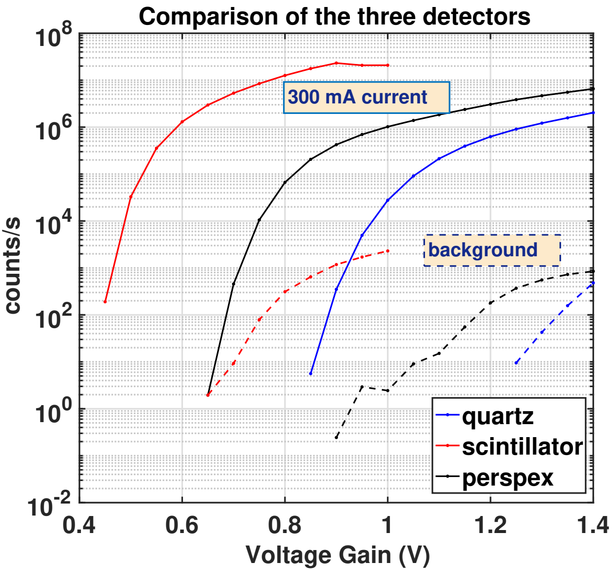
- High impendance input of 50 Ω for short individual pulses.
- The input is digitised with high speed ADC (125 MHz).
- The ADC data is continuously monitored for the negative peak value.
- Every ADC sample that exceeds the threshold value increments the counter by 1.
- Counter data rate = 10 samples/s

Scintillator EJ204 performance



- Counts/s rate was measured for various beam currents.
- Saturation was observed for high voltage gain.
- Beam current increases $\rightarrow$ the saturation starts earlier.
- Estimate the maximum voltage gain for normal user operation of 300 mA beam current.

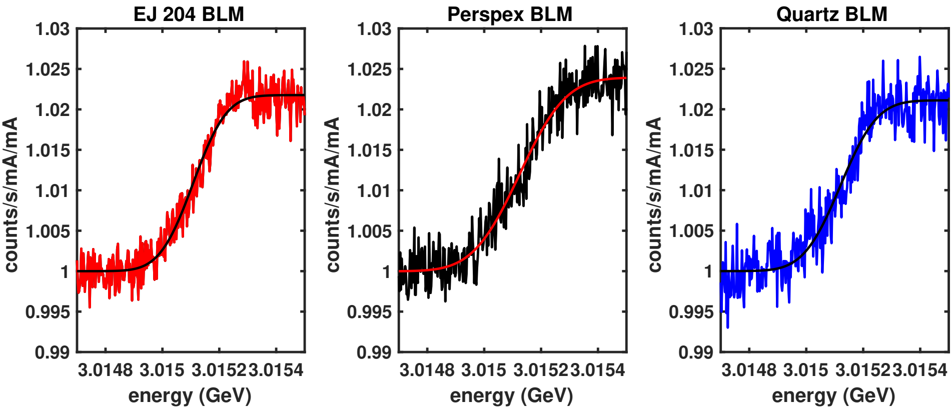
Comparison results



- Solid line for beam losses by 300 mA current.
- Dashed line for the background events, when there is no beam.
- Scintillator gives the highest count rate.

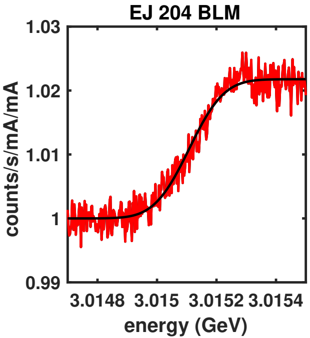
BLM performance in RSD

- Normalise the data with the beam losses before the depolarisation.



BLM performance in RSD

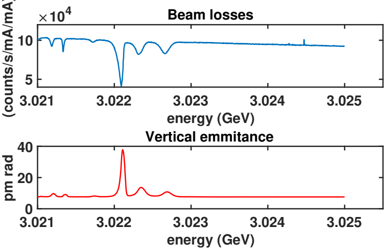
- Calculate the expected relative error: $RE = \frac{\sqrt{counts}}{counts}$.
- Calculate the rise of the losses after depolarisation.
- Measure the width of the resonance.
- Calculate the std(fit-normalized data).

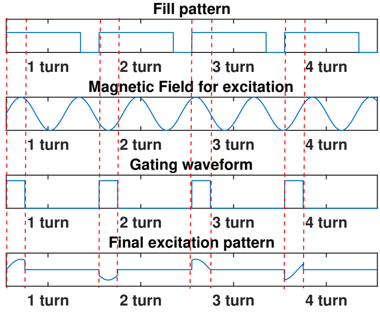


material	counts/s	RE	rise	width	std
EJ204	18 10^5	0.7 10^{-3}	2.2 %	92.4 keV	(1.8$\pm$ 0.2) 10^{-3}
Perspex	5.9 10^5	1.3 10^{-3}	2.3 %	128.6 keV	(2.3$\pm$ 0.24) 10^{-3}
Quartz	4.1 10^5	1.6 10^{-3}	2.1 %	101.9 keV	(2.4$\pm$ 0.26) 10^{-3}

AdReSD Project and Detector Design

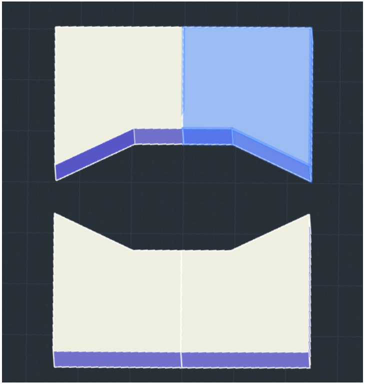
- Advanced Resonant Spin Depolarisation (AdReSD)
- Energy measurements during user time.
- Small dimension beam that does not allow to excite all the bunches during user operation.
- Excite only one part of the beam (some bunches) and depolarise.
- No wait time for the beam to polarise.
- No noticed disturbance of the beam.





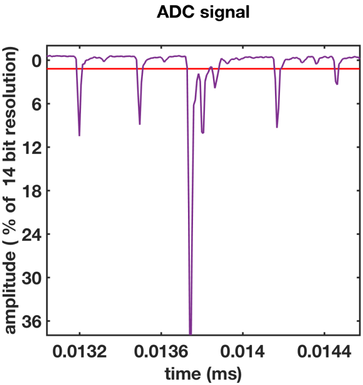
Detector Design

- Four detectors around the beam pipe.
- Lightguides to connect the detectors with the photomultipliers.
- Dimensions decided based on the radiation footprint film results.
- Capture the highest fraction of lost particles.



Acquisition improvements

- Consider different counting methods to avoid pile up.
- Test coincidence counting from Touschek particles since they lose and gain an equal amount of momentum.
- Add up the counts from the four blocks.



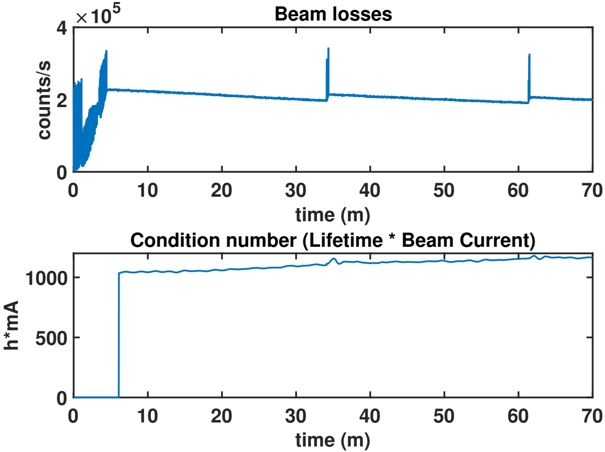
Conclusions

- Three different materials were studied, with the scintillator EJ204 to be the most efficient in terms of photon output for a given lost particle flux.
- Background studies will be continued in order to avoid counts from other events.
- The design of the detector based on the radiation footprint results will be manufactured.
- Further details of AdReSD project is going to be studied as soon as the detectors setup will be installed.

Thank you for your attention!

Polarization

$$P = P_0(1 - e^{\frac{t}{T}}) \tag{3}$$



Polarization coefficients

- $$\frac{1}{\tau} = -\frac{1}{N}\frac{dN}{dt} = \alpha[C(\varepsilon) + F(\varepsilon)P^2]N \tag{4}$$

- $$\varepsilon = (\frac{\Delta p_m}{\gamma \sigma_p}) \tag{5}$$

- $$C(\varepsilon) = \varepsilon \int_{\varepsilon}^{\infty} \frac{1}{u^2} \left\{ \left(\frac{u}{\varepsilon}\right) - \frac{1}{2} ln \left(\frac{u}{\varepsilon}\right) - 1 \right\} e^{-u} du \tag{6}$$

- $$F(\varepsilon) = -\frac{\varepsilon}{2} \int_{\varepsilon}^{\infty} \frac{1}{u^2} ln \frac{u}{\varepsilon} e^{-u} du \tag{7}$$