Investigation of a Scintillation Stopping Target for the MEG II Experiment

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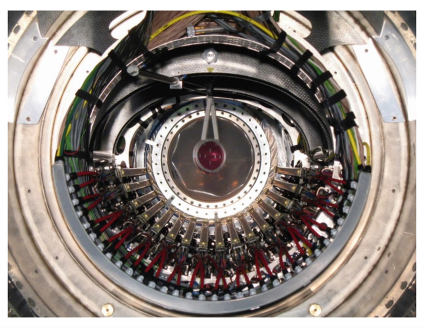
MEG II – Main Aspects of a Scintillation Target

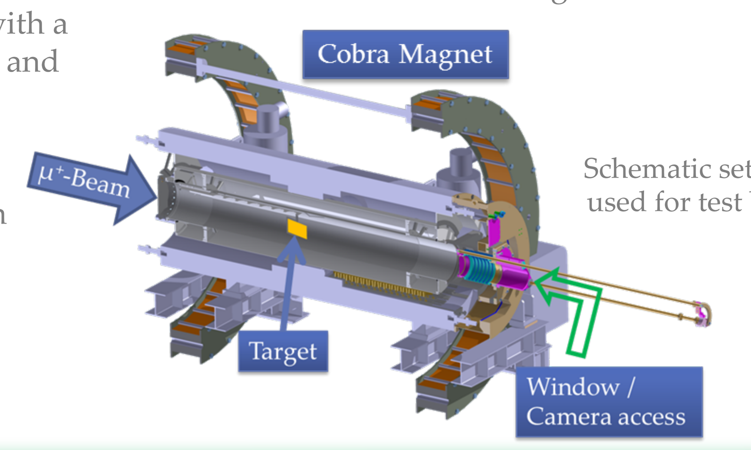
The MEG Experiment [1], which ran from 2009 - 2013, searching for the Charged Lepton Flavour Violating (CLFV) decay $\mu^+ \rightarrow e^+ + \gamma$, has set an upper limit on the branching ratio $B(\mu^+ \rightarrow e^+ + \gamma) < 4.2 \times 10^{-13}$ @ 90% confidence level. A continuous beam of 3 x 10^7 μ^+/sec (7.5 x 10^{14} μ^+ in total) was stopped in an elliptical (axes: 8 cm / 20 cm) target made of a 205 µm thick layer of polyethylene and polyester, which was mounted under a ~20° angle to the beam. The decay products were detected by a set of drift chambers in combination with scintillator bars (positrons) and a calorimeter filled with liquid Xenon (photons).



Downstream view of the MEG detector. The pink-coloured target in the middle of the detector was replaced with a thin target made of BC400B

The MEG experiment is currently being upgraded [2], aiming for an improvement in the sensitivity of one order of magnitude. A beam stopping rate of 7 x 10^7 μ^+/sec is envisaged. This is feasible since all detectors have been redesigned for enhanced resolutions. As a consequence thereof an accurate knowledge of the incoming μ^+ beam is required. This could be achieved by replacing the former target material with a 140 µm (150 µm in test beam) thin sheet BC400B scintillator mounted under a 15° angle to the beam. A CCD camera mounted approximately 1.5 m downstream in combination with a mirror system would provide Online Beam Profile Monitoring capabilities and be a great benefit.

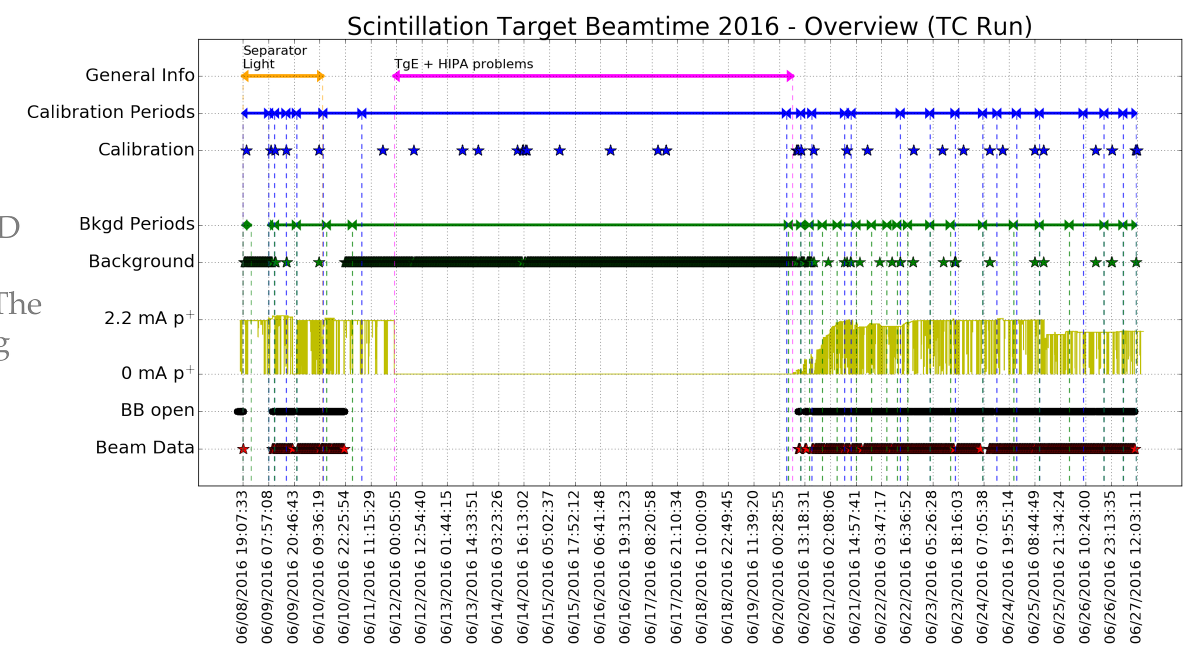
Main benefits:
- Speed up and improve beam tuning period at the beginning of each run
- Quick feedback on beam stability during run
- Easier beam trouble shooting
- Monitor target conditions (target position and surface structure)
- Provide full continuous beam parameter history



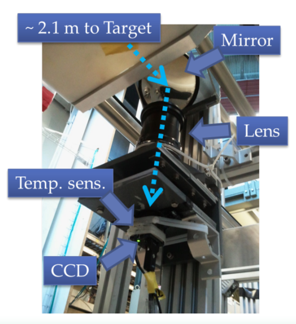
Schematic setup as used for test beam

Test Beam 2016

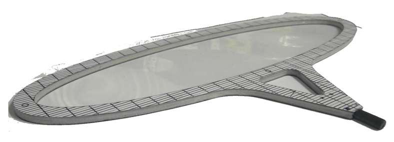
The feasibility of such a new target system was tested during the MEG Pre-Engineering Run 2016. A target was prepared from a BC400B sheet with a grid applied to the downstream face of the frame, which was needed for Perspective Correction and mm/pix calibration. The camera, a 768 x 576 pixels resolution CCD had previously been tested in a strong B-field as close to the MEG spectrometer solenoid and was mounted off-axis viewing the target from ~2.4 m via a mirror. The main data-taking period was parallel to the Test Run of the new pixelated Timing Counter (TC) for MEG, lasting from 20th June to 27th June.



Automated capturing each 10 minutes provided a continuous history of the beam period



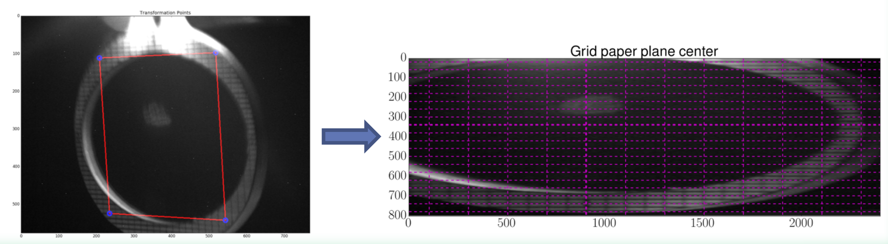
Camera (UI-2220SE-M-GL Rev.3) Setup Before attaching light-tight cover



Scintillator Stopping Target used for test beam

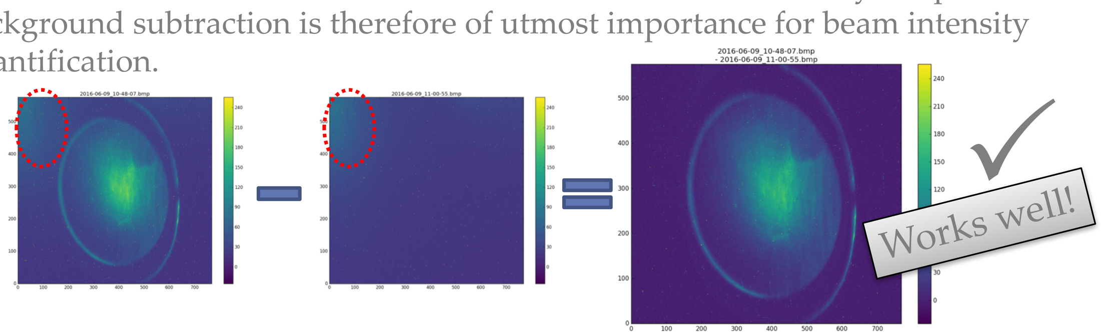
Perspective Correction

Viewing the Stopping Target under the mounting angle of 15 ° causes Perspective Distortions leading to an x dependent X- & Y-calibration. In order to get a mm / pix calibration one therefore has to apply a non-affine transformation. Using the well-defined grid points on the target frame, it is so possible to reconstruct the target shape and provide absolute coordinates in the scintillator plane.



Background Subtraction

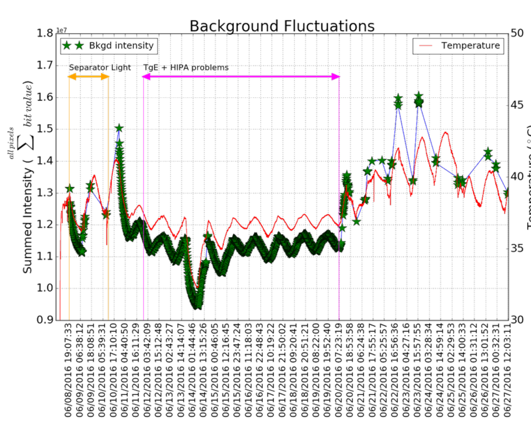
Background frames were taken with Beam Blocker closed. Histograms show that the dark current contribution amounts to ~ half of the frame intensity. Proper background subtraction is therefore of utmost importance for beam intensity quantification.



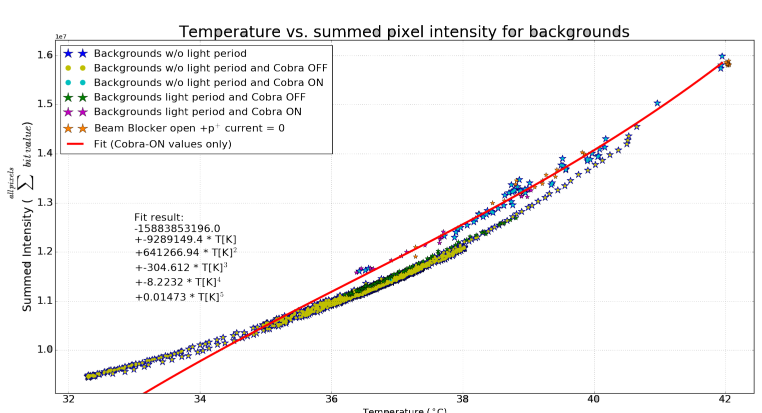
This method works well for frames adjacent in time and temperature. However intensity fluctuations / dependences need to be quantified.

Thermal Noise Correction

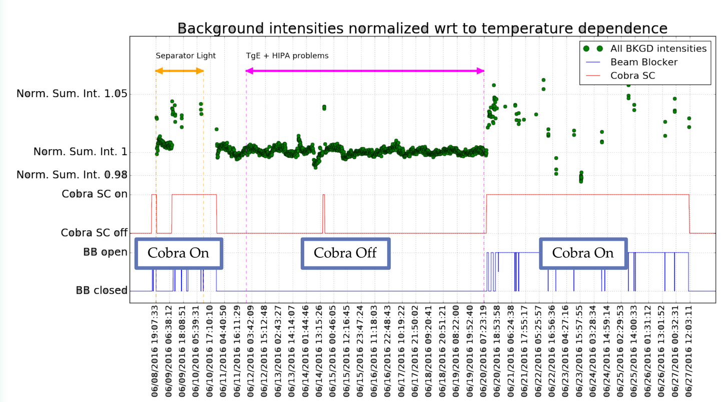
As the camera does not have an active cooling all frames suffer from dark current noise of the same order of magnitude as the signal, thereby fluctuating significant. A temperature sensor mounted on the camera housing allows for correction by use of a polynomial fit. Plotting the the summed pixel intensity against temperature, shows two visible 'bands' corresponding to the main Cobra spectrometer magnetic field ON or OFF. Fitting the 'Cobra OFF' values provides a scaling function to normalize the background (no beam signal) intensities, with a 'ripple' of ~< 1 %. Applying the polynomial fit to the background intensities with magnetic field ON reduces the 'ripple' of the normalized background intensities to ~< 2%. The derived temperature normalization is used to determine the temperature-independent light yield, which is proportional to the muon rate stopped in the target.



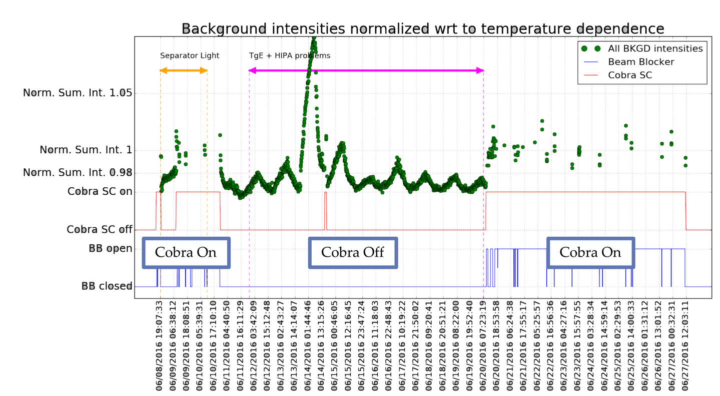
Camera housing temperature & summed pixel intensity vs. time



Fit of the temperature dependence using only points with magnetic field ON



Normalized background intensities using COBRA OFF Fit values

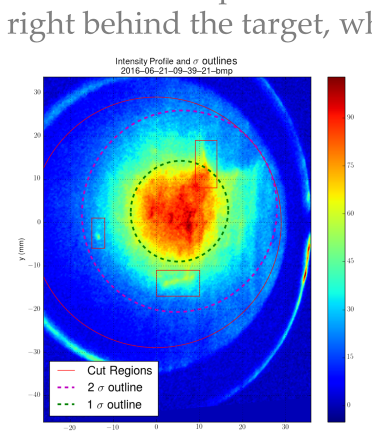


Normalized background intensities using COBRA ON Fit values. Backgrounds taken during beam period are centered and show less fluctuation

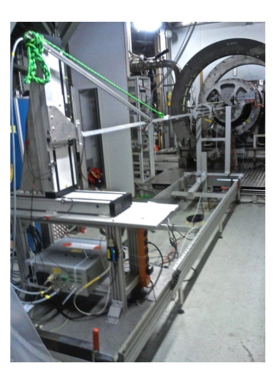
Beam Profile Comparison

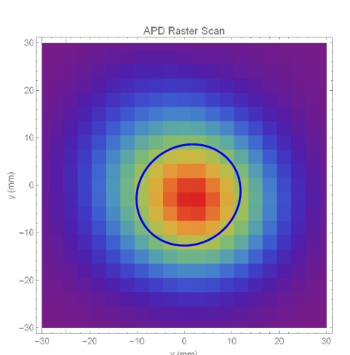
To validate the Beam Profiling properties the results of a 2D-Gauss Fit to the beam pictures (background subtracted, perspective corrected, ROI defined) are compared with an independent measurement, consisting of a 3 mm APD Raster Scan in a plane perpendicular to the incoming beam right behind the target, whereby the target (mounted under 15° angle with respect to the beam direction) extends also in beam direction. The CCD image shows bright spots, that can be identified with scratches on the scintillator surface. **The CCD profiles can be reproduced down to ~ 2% of nominal beam intensity.**

	APD Raster	Scintillator	Δ
σ_x	11.0 mm	11.3 mm	0.3 mm
σ_y	10.7 mm	11.7 mm	1.0 mm



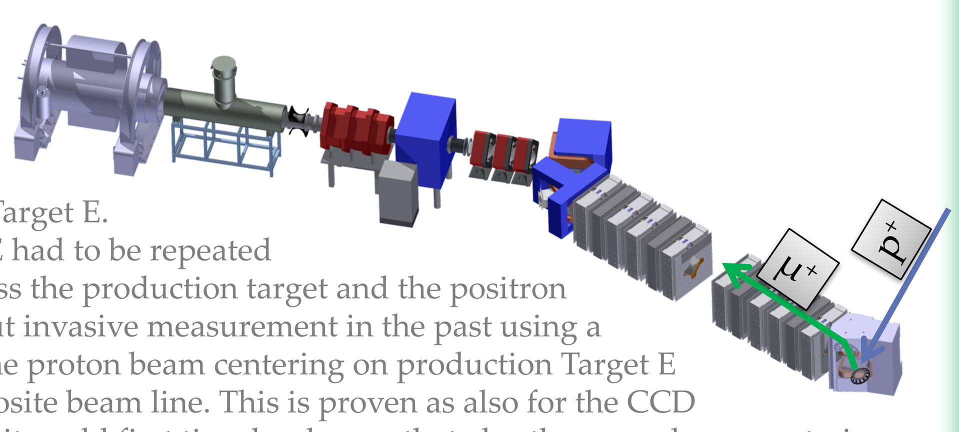
2 D Gauss Fit Results of target image



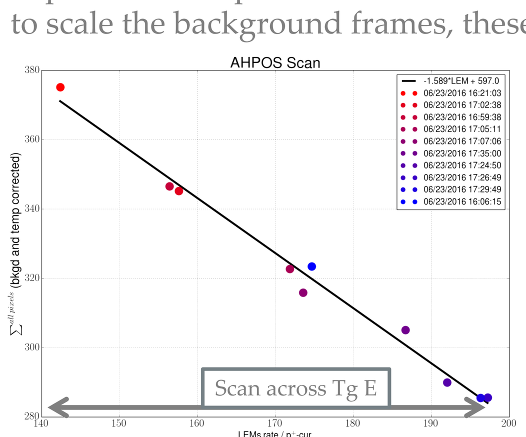


APD Scanner system used to independently measure the beam profile in the COBRA magnet

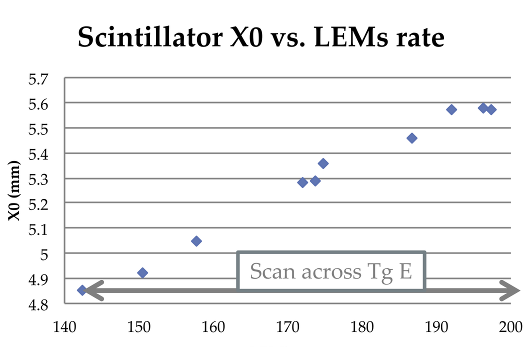
Target E centring



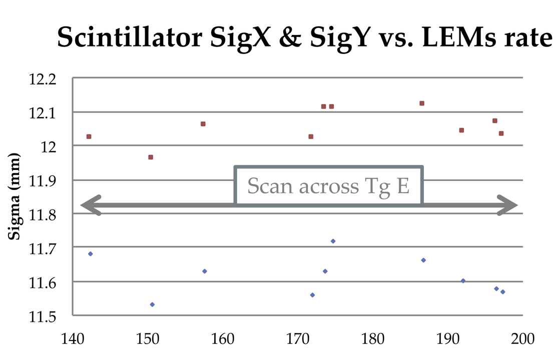
Proton beam centring on the Muon Production Target E is normally performed at the beginning of each run period. A measure of the centring of Target E is a positron beam counter in the beam line placed on the opposite side of the Target E. During our beam time the proton beam centring on Target E had to be repeated on the 23rd of June. Hence the proton beam was moved across the production target and the positron counter monitored. As already seen with an independent but invasive measurement in the past using a pill counter the muon rate fro MEG depends ~ linearly on the proton beam centering on production Target E which depends ~linearly on the positron counter of the opposite beam line. This is proven as also for the CCD monitoring of the scintillation stopping target. Furthermore it could first time be shown, that also the muon beam centering depends on the proton beam centering on Target E as well. Whereas the above described temperature normalization is used to scale the background frames, these observations can now be used to properly normalize the signal / light intensity.



Frame intensity (scaled by proton current) vs. Positron Counter rate



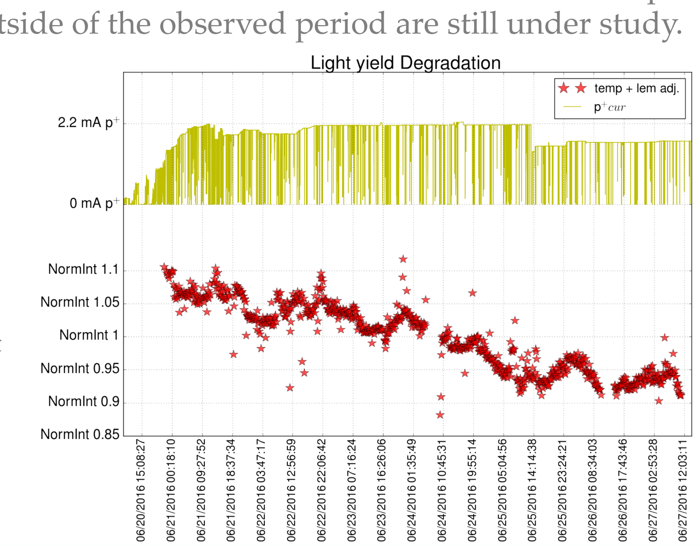
X0 from 2D Gauss Fit vs. LEMs positron Counter rate



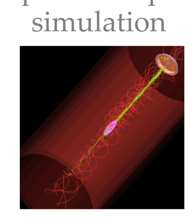
The Sigmas from 2D Gauss Fit are ~ independent of Positron Counter rate

Radiation Damage

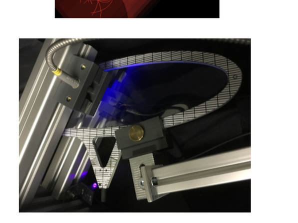
An important aspect for the further use of such a scintillation stopping target is the resistance radiation damage. As an experiment at the Intensity Frontier, MEG usually runs for several months. Therefore high doses are acquired over time and lead to the degradation of the scintillator. This was tested during the run by applying the normalization techniques described above, so deriving the intensities normalized to proton current, temperature (convolved with COBRA magnetic field) and proton beam centring. Available literature shows, that the description of radiation damage in scintillators still is an area under research and can not be fully described by models. Nevertheless comparing our measurements with simulation studies already show less radiation damage than expected [4]. A possible explanation is the short path length light has to travel in the degrading medium compared to normal situation, where scintillators are read out from the sides. Spectroscopy measurements as well as more data taken outside of the observed period are still under study.



Light yield degradation during TC Run period. On 9th until 10th June measurements were suffering from a light leak and a different proton beam setting, which requires further evaluation



Graphical output of simulation



Spectroscopy measurements were made before and after the run.

Conclusions

- Non-invasive Online Target beam profiling & monitoring for MEG II works well
- First time observation of MEG beam-spot shift due to proton beam shift on Target E
- Proved very useful for troubleshooting beam losses during the run
- Reproducible Fit for 2 % to 100% of nominal beam intensity
- Radiation damage effect observed though less than expected - further investigation required

Outlook

- Higher dose radiation damage test planned with protons at PIF facility
- Scintillator handling to be improved
- Target support mounting to be improved
- Temperature stabilized CCD camera required (B-field stability)
- Tilt-shift lens ideal (image sharpness over full field-of-view)

References

[1] Baldini, A. M.; et al. (MEG collaboration) (May 2016). "Search for the Lepton Flavour Violating Decay μ+→e+γ with the Full Dataset of the MEG Experiment". arXiv:1605.05081;

[2] A.M. Baldini et al. (MEG collaboration), MEG upgrade proposal ,arXiv:1301.7225v2;

[3] http://www.crystals.saint-gobain.com/uploadedFiles/SG-Crystals/Documents/SGC%20BC400-404-408-412-416%20Data%20Sheet(1).pdf

[4] Yu. M. Protopopov et al NIM B95 (1995) 496-500