Characterisation of Cherenkov detectors for the MOLLER experiment

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Introduction & overview

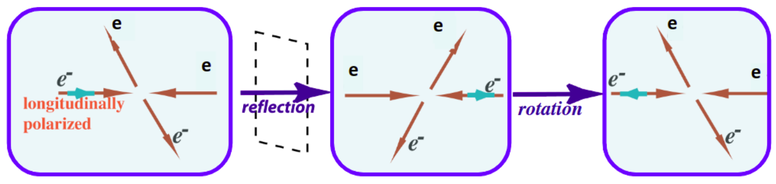
- **M**easurement **O**f a **L**epton **L**epton **E**lectroweak **R**eaction (**MOLLER**) is a future experiment at Jefferson Lab, Virginia, USA to measure the weak mixing angle with unprecedented precession.
- The weak mixing angle can be expressed in terms of the A_{PV} as;

  $A_{PV} \propto Q_W^e = 1 - 4\sin^2\theta_w$ (at tree level), θ_w is the weak mixing angle
- MOLLER projection with electron beam of 11 GeV:

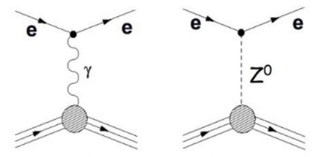
  $A_{PV} \sim 33 \times 10^{-9}$ or 33 ppb (parts per billion)

  $\delta A_{PV} \sim \pm 0.8$ ppb (2.4% precision)

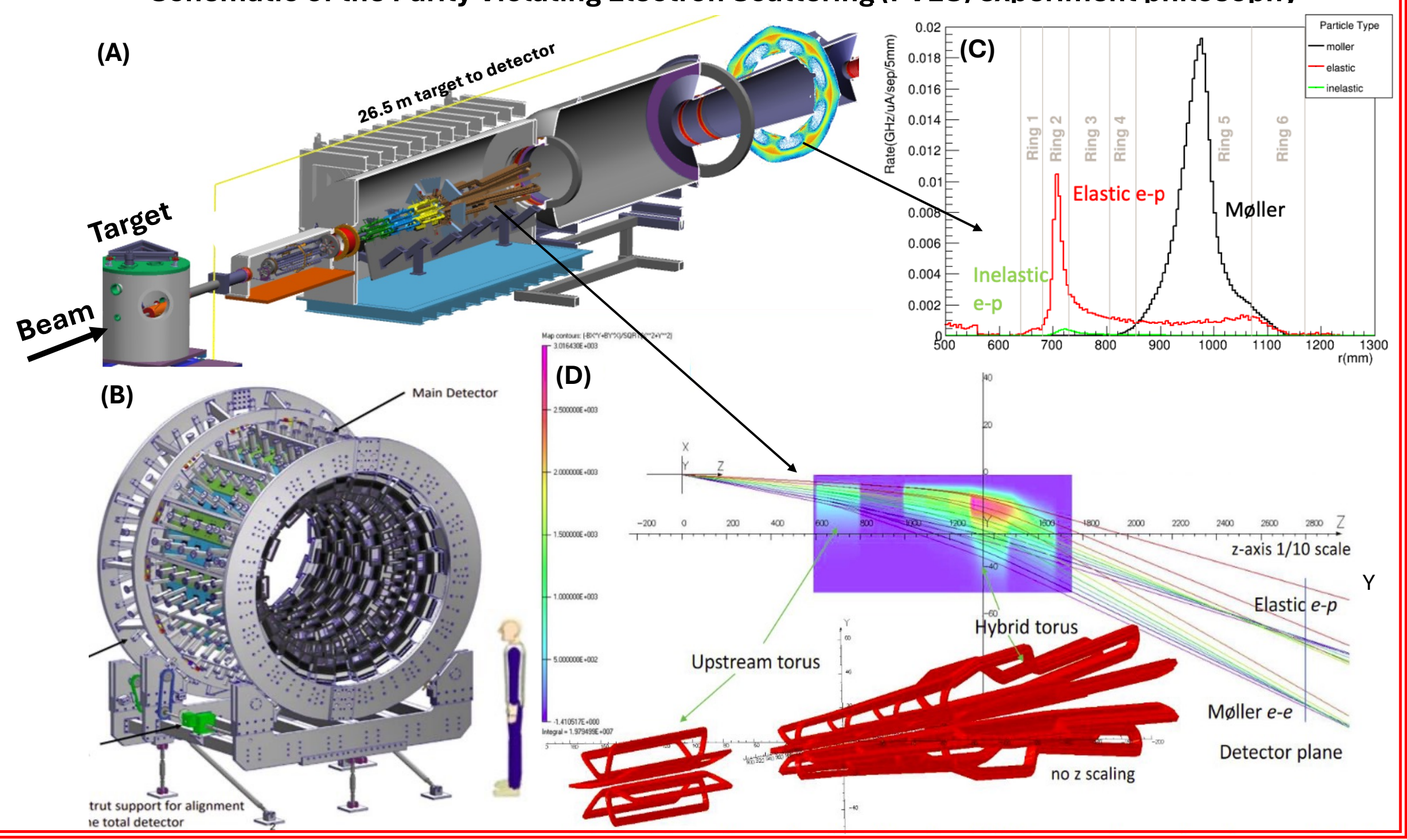
  2.4% precession on $Q_W^e \Rightarrow 0.1$ % on $\sin^2\theta_w$
- **Radiation hard thin quartz Cherenkov radiators will be used as the main detector to intercept the scattered electrons**
  - ➢ Fused silica (quartz) is chosen as the Cherenkov radiator
    - ➢ Negligible scintillation & Radiation hard
    - ➢ Highly linear and relatively large active area
  - ➢ Standard Photo Multiplier Tubes (PMT) will be used to readout the signal



$$A_{pv} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$



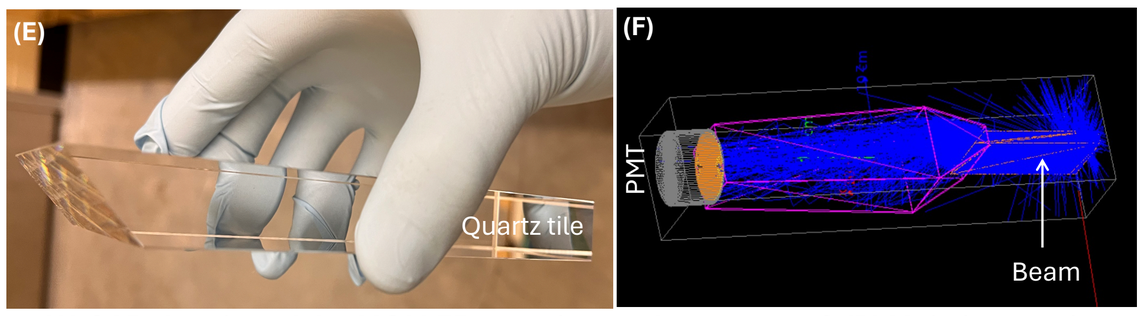
Schematic of the Parity Violating Electron Scattering (PVES) experiment philosophy



R&D of Main Integrating Detector

Design

- 224 thin detector modules & 6 radial rings
- Foreseen average electron rate is ~ 50 kHz/mm^2 but it can for the peak Møller events reach up to ~ 1 MHz/mm^2
  - ✓ 28 azimuthal channels per radial ring (84 azimuthal channels in Møller Ring 5)
- The anticipated peak dose over the experimental lifetime is 120 Mrad/5x5 mm^2 for Ring 2 and 45 Mrad/5x5 mm^2 for Ring 5



(A) CAD drawing of the MOLLER experimental apparatus & (B) Main integrating detector rings (C & D) Spectrometer principle & scattered particle profile at the main detector (E) Quartz tile (Ring 5) (F) Monte Carlo simulation of the ring

R&D stages

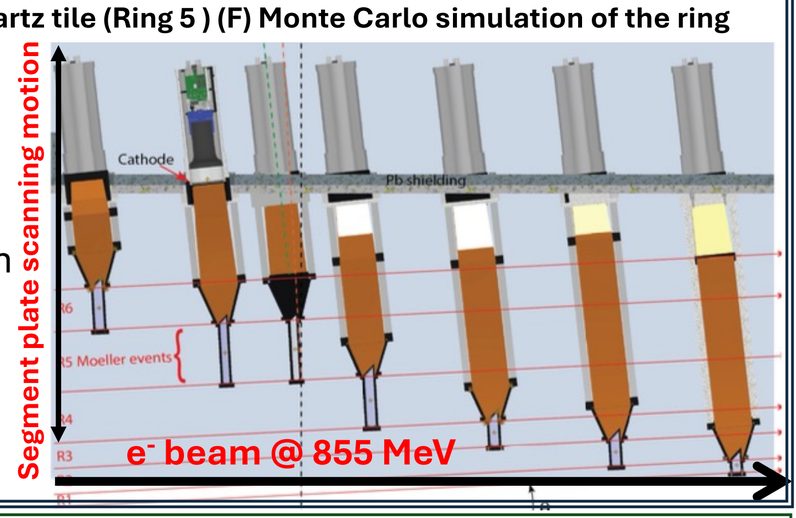
- Beam test with e$^-$ beam of 855 MeV of the Cherenkov detector prototypes at MAMI, Germany
  - Testing of different quartz tile & light-guide materials
- Irradiation test of the detector components (e.g. 3D printed parts, electronics, light tight materials etc.)
- Testing of the detector prototypes with cosmic muons to benchmark the performance with the electron beam : **Final QA test before commissioning**

Dimensions (length x breadth x height):

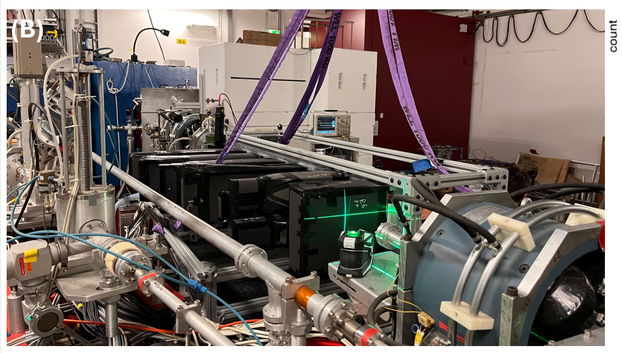
Ring1 : 169 mm x 30 mm x 20 mm

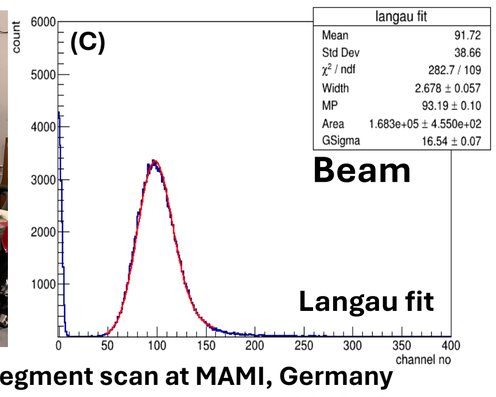
Ring5 : 80 mm x 140 mm x 17 mm

Ring6 : 260 mm x 100 mm x 20 mm

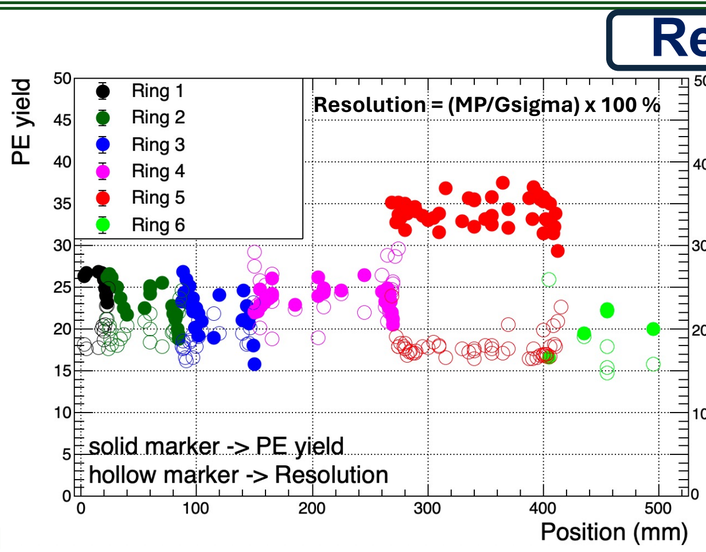


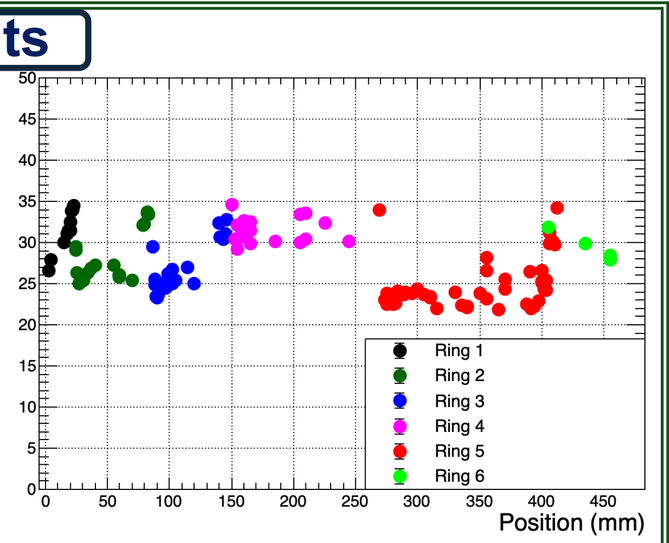
Results





(A) Ring 1, 5 & 6 detector prototypes (B) Segment scan at MAMI, Germany
(C) Typical pulse height distribution from the ring 5 prototype with 855 MeV e$^-$ beam



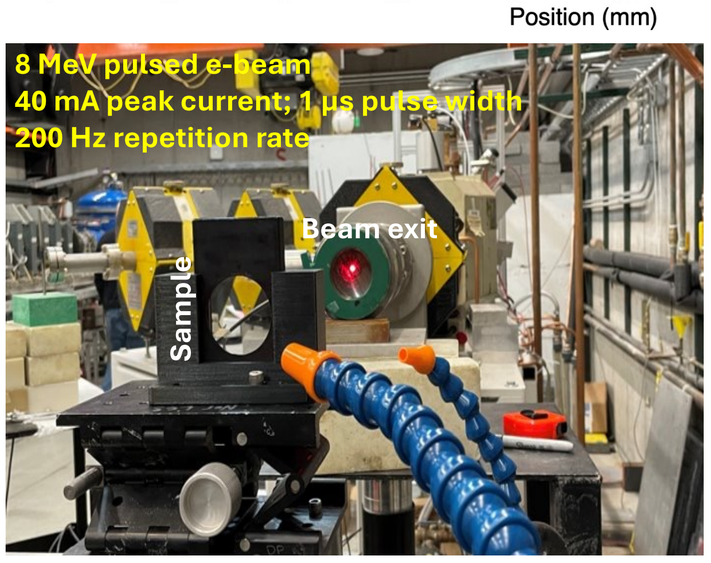


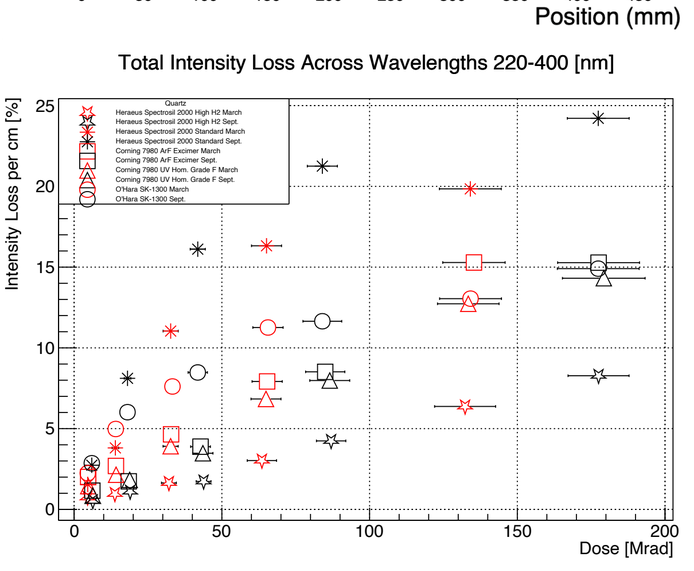
Summary & Acknowledgement

- ✓ All the prototypes behave as expected in terms of the PE yields and RMS/MEAN values at the 855 MeV e$^-$ beam test
- ✓ MC simulation agrees relatively well (~20%) with the beam data
- ✓ Radiation tests have been carried out to study the tolerances
- ✓ Design & critical detector prototyping for the main integrating detector in counting and integrating mode is complete

Design of the detector modules, read out electronics and assembly are done by the group at the University of Manitoba, Canada

Rings	PE yield (beam data)	PE yield (MC sims)	RMS/MEAN (beam data)	RMS/MEAN (MC sims)
1	26.6 + 0.1	30.2 ± 0.1	~ 30 %	30 %
2	25.0 + 0.1	26.1 ± 0.1	~ 28 %	28 %
3	22.5 + 0.8	25.5 ± 0.1	~ 28 %	28 %
4	23.6 + 0.2	24.3 ± 0.1	~ 30 %	28 %
5 BF	32.0 + 0.2	32.8 ± 0.16	~ 25 %	22 %
6	20.7 + 0.2	21.5 ± 0.1	~ 32 %	23 %





Irradiation testing at the Idaho Accelerator Center at Idaho State University campus

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References: (1) MOLLER Technical Design Report (2) The MOLLER Experiment (arXiv: 1411.4088)