Design of a luminosity monitor for the P2 experiment at MESA

HIM Helmholtz-Institut Mainz

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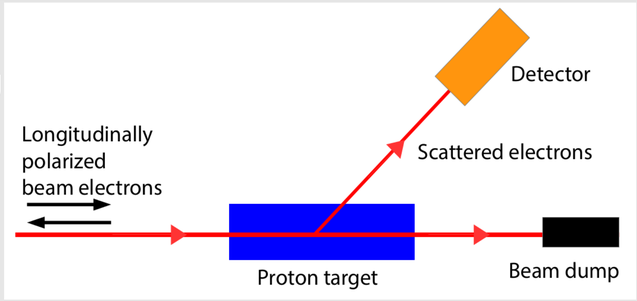
The P2 experiment

Goal of P2 experiment:

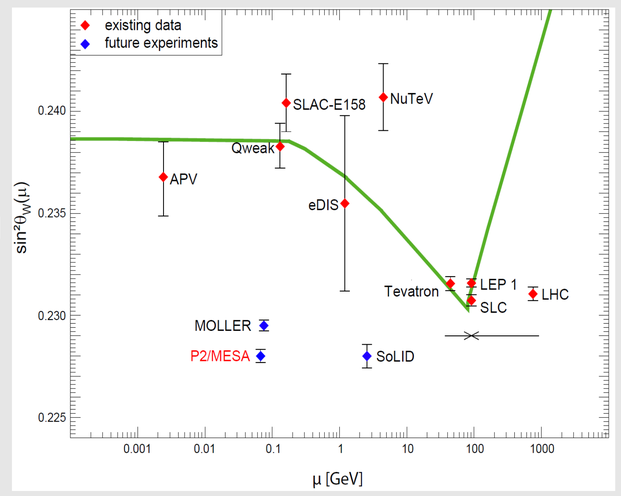
- Determination of electroweak mixing angle $\sin^2\theta_W$
- Parity violating electron-proton scattering: $A^{PV} = \frac{d\sigma_{ep}^{+} - d\sigma_{ep}^{-}}{d\sigma_{ep}^{+} + d\sigma_{ep}^{-}}$



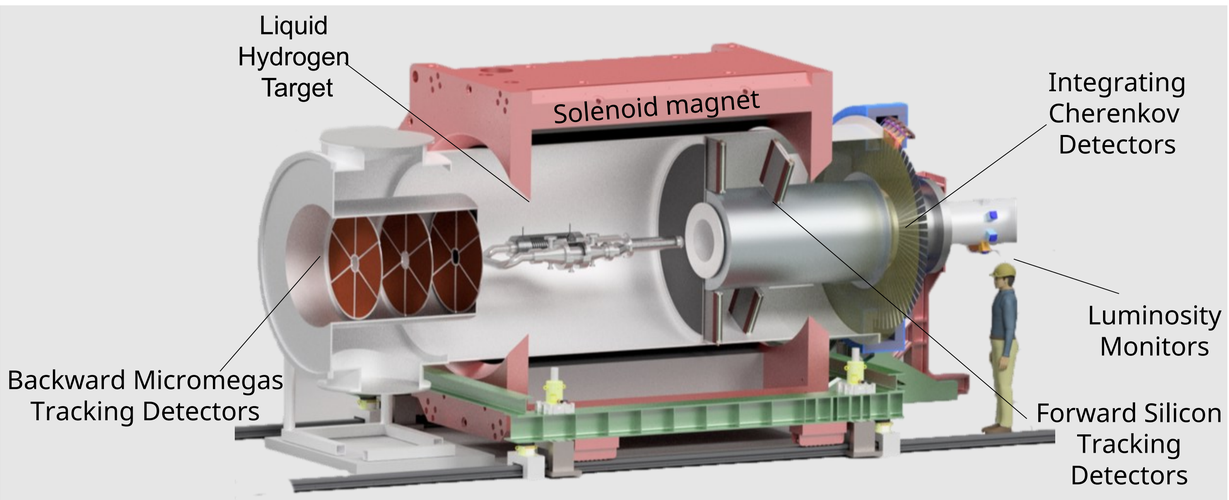
- Experimental asymmetry $A^{exp} = -39.94\ ppb$
- 72 integrating Cherenkov detectors (fused silica bars)
- Longitudinally polarized electrons 85%
- $I_{Beam} = 150$ µA, $E_{Beam} = 155$ MeV
- Provided by **M**ainz-**E**nergy-Recovering **S**uperconducting **A**ccelerator **MESA**

Physics goal of P2

- Relative error for 10000 h runtime
  - ➢ $\Delta\sin^2\theta_W / \sin^2\theta_W = 0.16\%$
- Accuracy comparable with the most accurate measurements at Z-Pole
- Sensitivity to **B**eyond **S**tandard **M**odel Physics (**BSM**) in the energy range from 70 MeV to 50 TeV

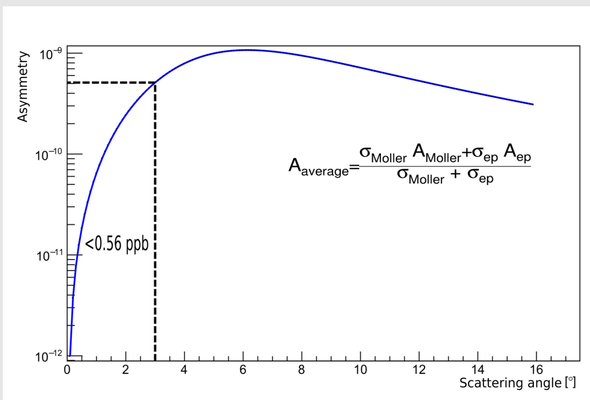


Experimental setup at MESA



Luminosity monitoring at P2

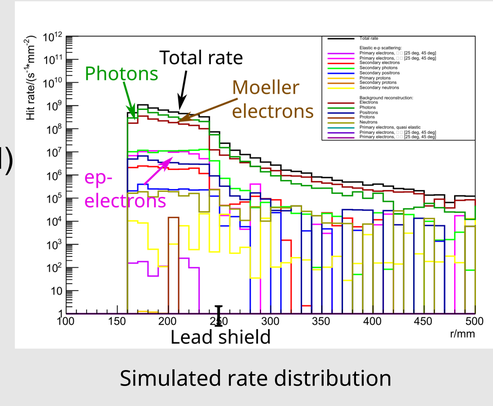
- Luminosity: $\mathcal{L} = R/\sigma$
- Luminosity in P2 experiment $= 2.38 \times 10^{39}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Monitor target density fluctuations
- Asymmetry in luminosity measurement: $A^{\mathcal{L}} = \frac{\sigma_{Moeller} A_{Moeller} + \sigma_{ep} A_{ep}}{\sigma_{Moeller} + \sigma_{ep}}$
- $A^{exp} = A^{PV} + A^{I_{Beam}} - A^{\mathcal{L}}$
- $A^{\mathcal{L}} \leq \Delta A^{PV} = 0.56\ ppb$



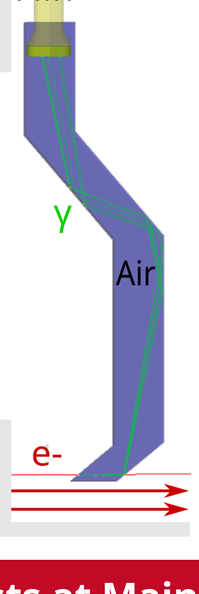
Average asymmetry of dominant scattering processes

Air cherenkov detector

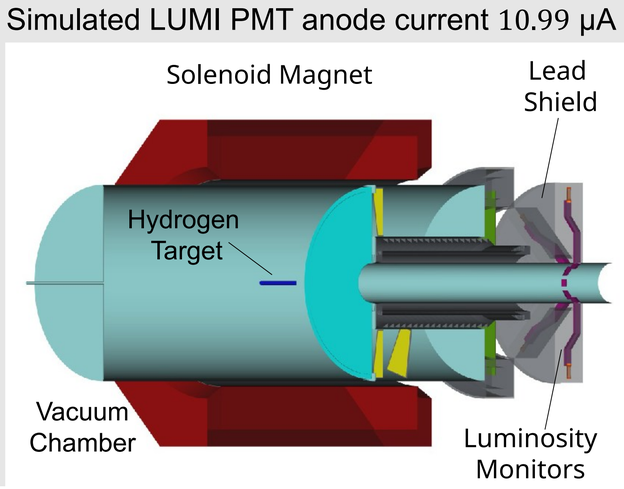
- Luminosity monitor (**LUMI**) particle rate $\mathcal{R}_{LUMI} = 1.12 \times 10^{14}\mathrm{s}^{-1}$
- Largest rate contributions: Moeller scattering and elastic ep scattering
- Idea for LUMI: analog integrating Cherenkov (Air) detector
- Cherenkov light reflected on special aluminum reflector (Alanod)
- Analog integrating detector for high rate environments
- Eight luminosity monitors for covering the whole azimuth

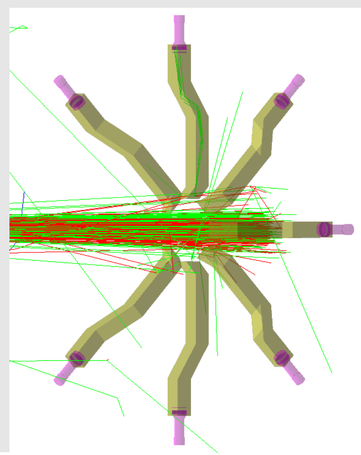


Simulated rate distribution



- Full Geant4 simulation:
  - ➢ Full P2 setup, real energy loss in target, multiple scattering, LUMI lead shield
- Simulated LUMI PMT anode current 10.99 µA



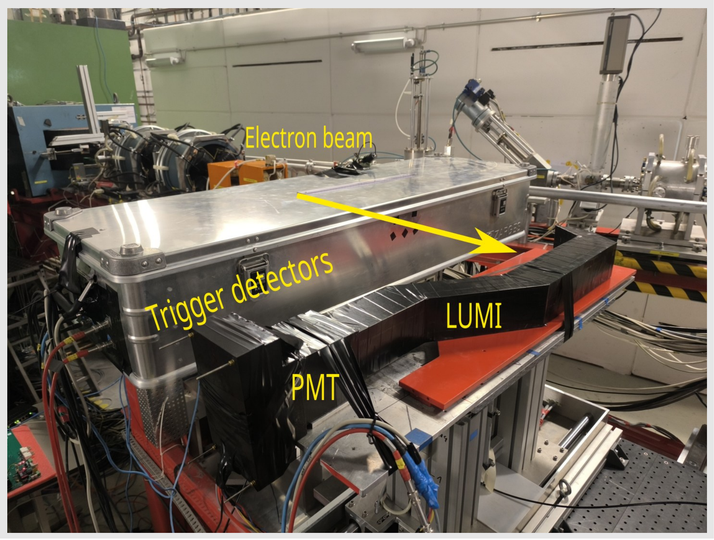


Beam tests at Mainz Microtron MAMI

- Measure **S**ingle **P**hotoelectron **S**pectrum **SPP** at Mainzer electron accelerator
- Two measurement mods:

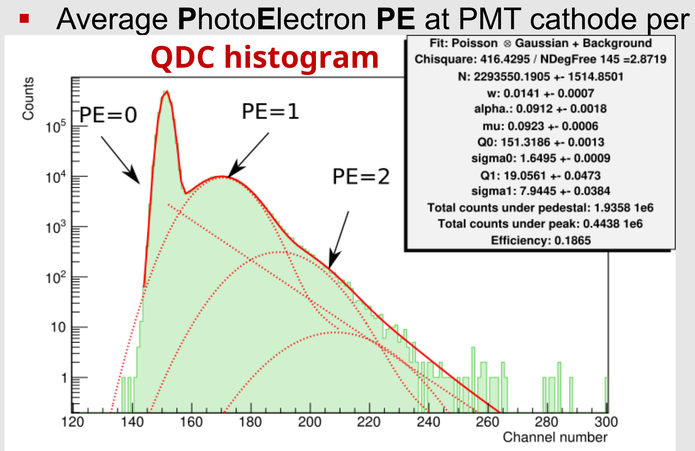
➢ Single Event mode (kHZ): Tracking detectors determine average momentum transfer of beam electrons, calibration of setup

➢ Integration mode (GHZ): Individual events not counted, PMT current integrated over one helicity window



Single Event mode

- Electron beam rate 4 kHz
- PMT current digitizing device: Charge to digital Converter **QDC**
- Average **P**hoto**E**lectron **PE** at PMT cathode per beam electron = 0.1



SPP spectrum: (Dynode structure secondary electrons)

$$S_{real} = P(n,\mu) \otimes G_n(x) \otimes B(x)$$

Photocathode **PE** — Background effects

$$P(n,\mu) = \frac{\mu^n e^{-\mu}}{n!}$$

$$G_n(x) = \frac{1}{\sigma_1\sqrt{2\pi n}}\, exp\left(-\frac{(x-nQ1)^2}{2n\sigma_1^2}\right)$$

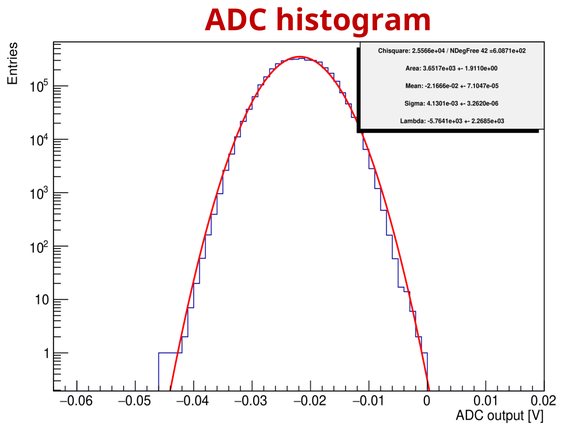
Integration mode

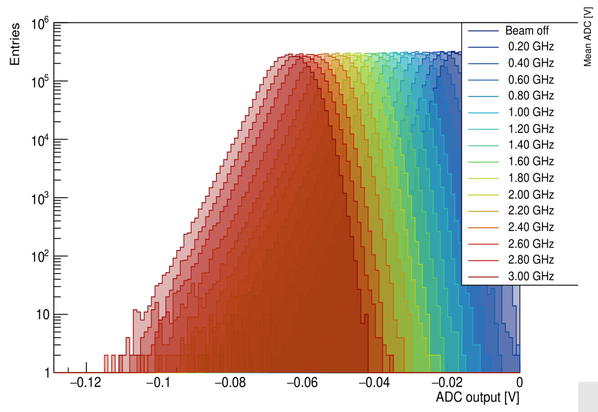
- Electron beam rate scan 0-3 GHz
- PMT current digitizing device: **A**nalogue to **D**igital **C**onverter **ADC**
- Sampling rate of 15×10^6 samples per second

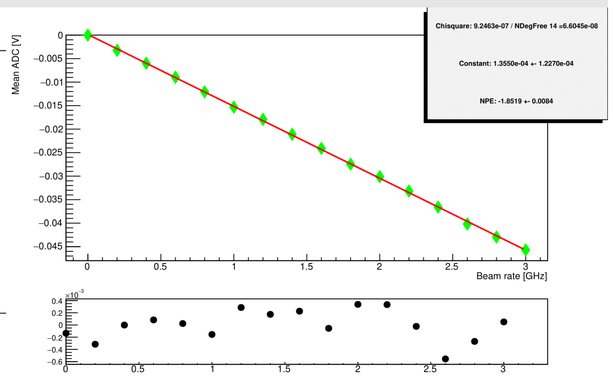
➢ $\boldsymbol{ADC_{value}(offset\ correc.) = 5.63\ \mathrm{mV}}$

➢ $\boldsymbol{ADC_{theor.}(PE, e^{-}current, gain) = 5.02\ \mathrm{mV}}$

ADC histogram







PMT output vs beam rate [GHz]