Design of a luminosity monitor for the P2 parity violating experiment at MESA

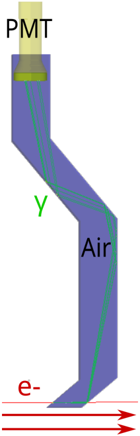
Tobias Rimke

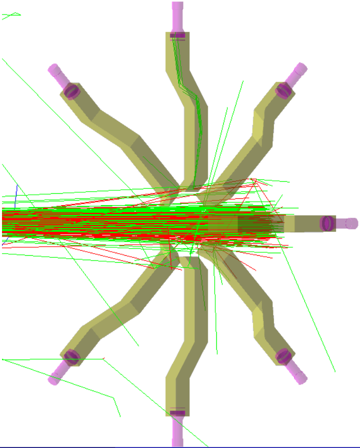
P2-Getaway

24 June 2025

Luminosity monitor prototype

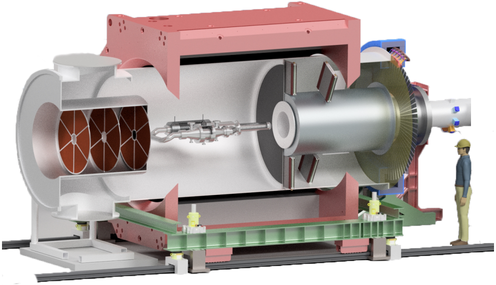
- Air (cherenkov material) stored in a funnel
- Cherenkov light is reflected on the walls, covered by special aluminium reflector from Alanod
- Detector consists of two parts: an active part within electron beam and light guide protected by lead shield
- PMT placed at the end of light guide
- Analog integrating detector for high rate environments

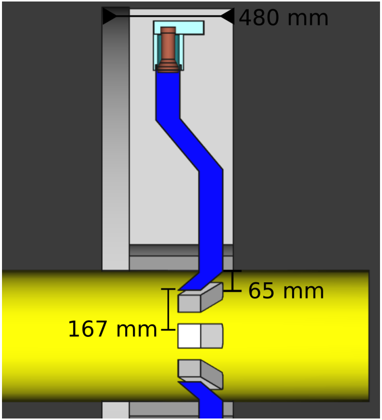




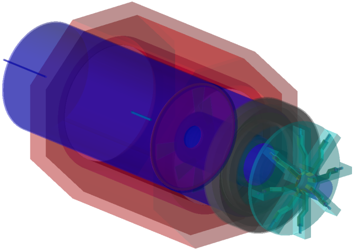
P2 setup

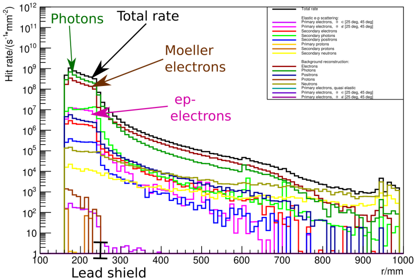
- For main detector ring consisting of 72 fused silicia bars, 8 LUMI monitors
- LUMI monitors placed downstream
- Lead shield (9.88 t) around LUMI light guide and readout electronics





Geant4 rate distribution for LUMI monitors





Simulated rate distribution of physical processes hitting luminosity monitor at $z_{position}$, r distance from beam axis, with complete P2 setup and magnetic field of solenoid

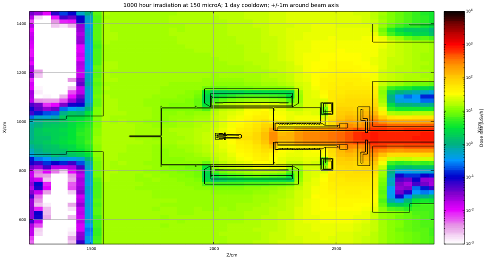
Cathode current

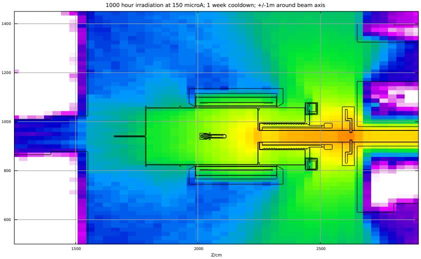
Contribution	Sickle [nA]
Elastic electron-proton scattering	
Primary electrons $\theta \notin$[25 deg, 45 deg]	20.5274
Secondary electrons	0.1095
Background reconstructions	
Electrons	63.3788
Positrons	0.6462

- Anode current(10^3 gain) per PMT 10.5902 μA
- After 5144 h or (200 C at anode) active run time LUMI-PMT output will typically reduce by a factor of 50 %

FLUKA simulation LUMI

- LUMI (10 t) shield and LUMI-detector in Fluka simulation from Jürgen Diefenbach
- Equivalent radiation dose rate after 1000 h irradiation
- Spectrum directly after turning of beam
- The dose rate is averaged over 1 meter around beam axis





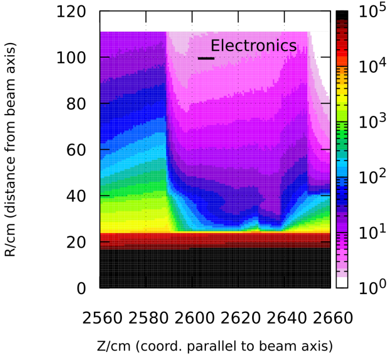
1 day cooldown

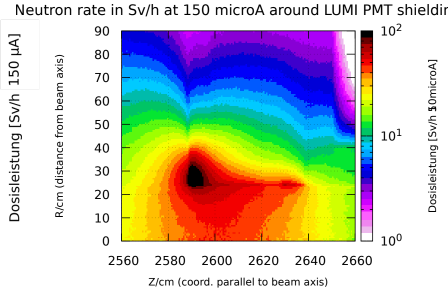
1 week cooldown

- Around beam axis ≈ 1 mSv/h
  - Not much radiation from beam dump around LUMI electronics
- "" ≈ 0.1 mSv/h

FLUKA simulation LUMI

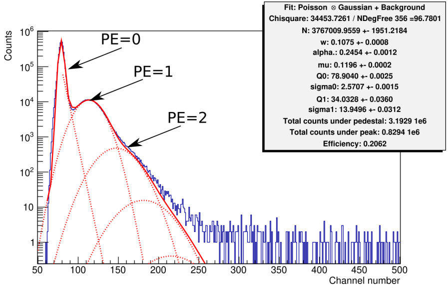
Total dose rate in Sv/h at 150 microA around LUMI PMT shielding



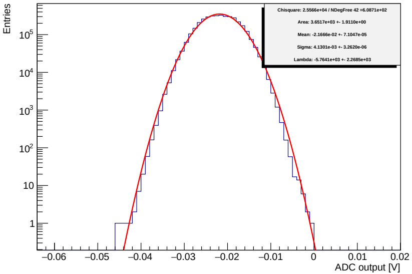


- Radiation around PMT and DIVA board $<$ 10 Sv/h
- Fluka: Absorbed energy dose on LUMI detector readout electronics: $8 \cdot (8 \cdot 9) \cdot 0.1 cm^3 = 57.6 cm^3$
- $D = 0.0233 Gy/h \rightarrow D[10^4 h] = 233.2284 Gy$
- Main detector Si ring with volume: $\pi \cdot (1332 - 1202) \cdot 0.1 cm^3 = 1033.2698 cm^3$
- $D = 0.2037 Gy/h \rightarrow D[10^4 h] = 2037.2677 Gy$

- Verficiation of single photoelectron spectra
- In both measurement mods



Operative voltage=950V, electron rate≈5 kHz



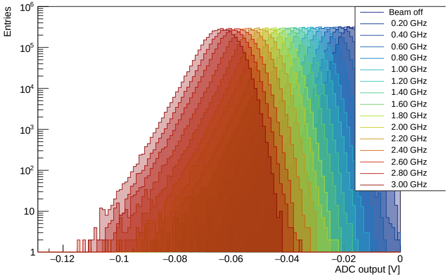
Operative voltage=500V, electron rate 3 GHz

$$Mean(offset\ correc.) = -5.631 \cdot 10^{-3} V$$

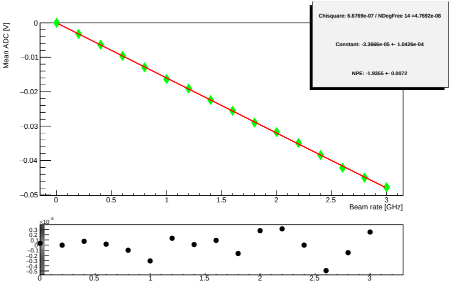
$$ADC_{value}(theo.)[NPE..] = 5.024 \cdot 10^{-3} V$$

Rate scan in integration mode

- Rate scan 0-3 GHz
- Mean ADC pedestal corrected



Rate scan at HV=900 V

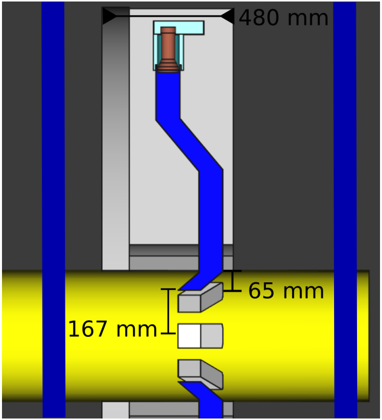


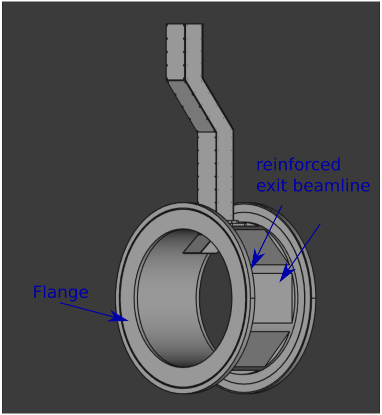
Mean ADC vs beam rate at HV=900 V

- Questions about left tail in spectra
- Originates at high operative voltages
- Moran single photon test in black box → internal electronics ("saturation") unlikely

LUMI prototype and implementation in experimental hall

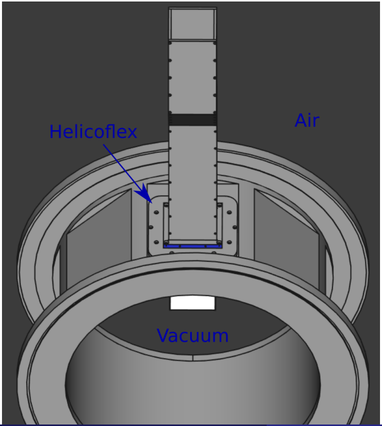
- Development of a concrete LUMI prototype
- Got an expert on this project: Paul Schöner
- 8 holes in exit beamline?? vacuum-air pressure, metal distorts
- Suggestions: small LUMI beam line section, additional reinforced beam line

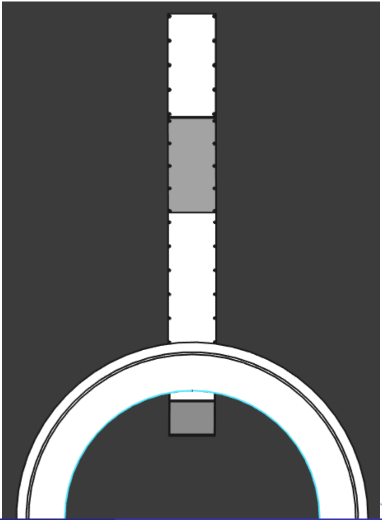




LUMI prototype and implementation in experimental hall

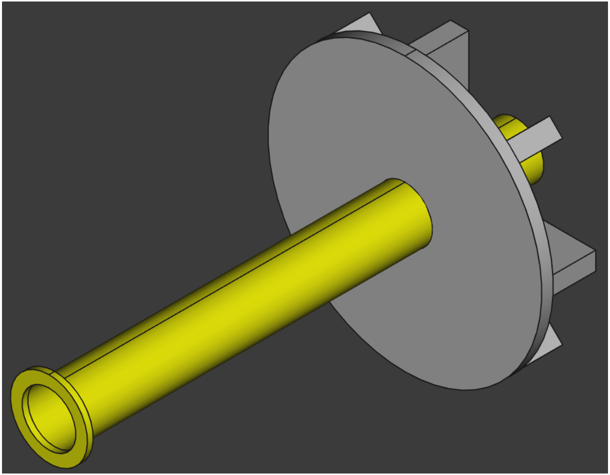
- LUMI divided in two parts: Main Cherenkov part-light guide
- Main Cherenkov part: Completely welded sits in vacuum
- Light guide: several sheets held together by screws
- Two parts divided Helicoflex flange



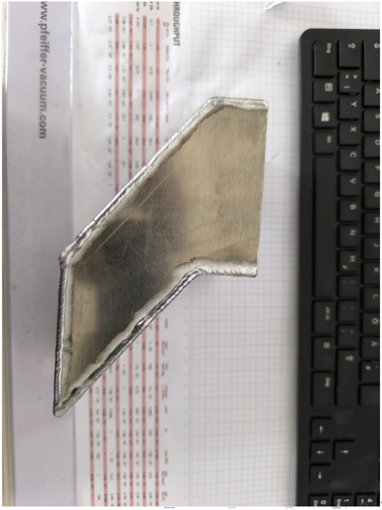


LUMI prototype and implementation in experimental hall

- Lead shield (9.88 t) exists only in simulation
- No shield design, no mounting for shield, offer from a company
- How to implement lead shield in P2 setup???????
- How to remove parts of shield to access PMTs???
- Replace mirrors time intervall??

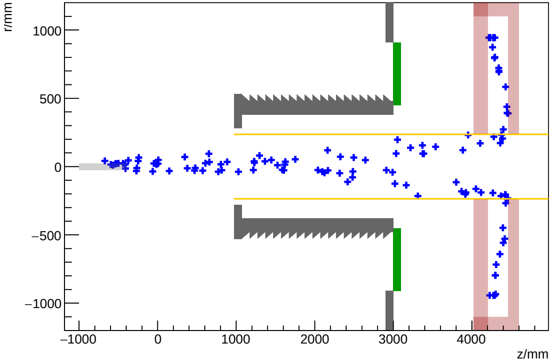


Thank you for your attention!



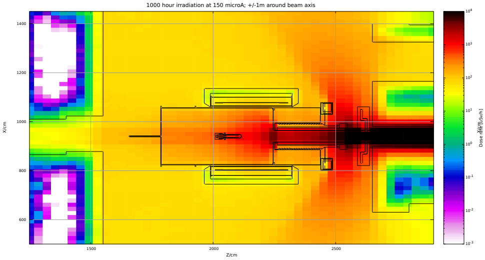
Tracking background electrons

- 950e6 beam electrons
- ≈ 40e6 Geant4 particles passes by 8 LUMI detector
- ≈ 4e6 Geant4 particles produce Cherenkov Light (energy threshold)
- 23 Geant4 particles reach 8 LUMI PMT-windows

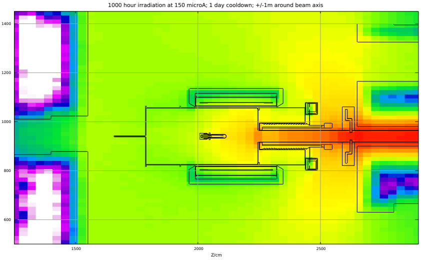


FLUKA simulation LUMI

- LUMI (10 t) shield and LUMI-detector in Fluka simulation from Jürgen Diefenbach
- Equivalent radiation dose rate after 1000 h irradiation
- Spectrum directly after turning of beam
- The dose rate is averaged over 1 meter around beam axis



Beam turned off

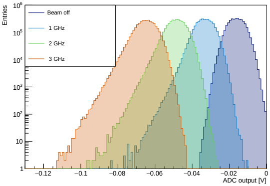


1 day cooldown

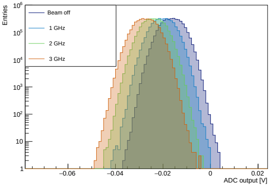
- Around beam axis ≈ 10 mSv/h
- Around beam axis ≈ 1 mSv/h
  - Not much radiation from beam dump around LUMI electronics

LUMI spectra integration mode HV scan

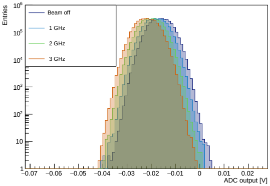
- For operative voltage > 500 V, a LUMI tail appears at higher ADC values
- Beam rate: 3 GHz, 2 GHz, 1 GHz, 0 GHz



HV=900 V



HV=600 V

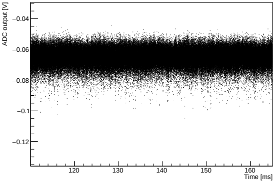


HV=500 V

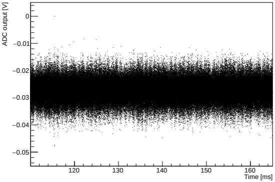
- No significant MAMI beam fluctuations
- Origin?? backscattered electrons from beam dump

LUMI spectra integration mode HV scan

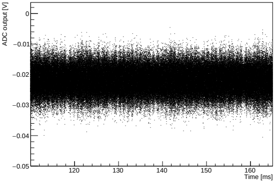
- For operative voltage > 500 V, a LUMI tail appears at higher ADC values
- Plot measured ADC value vs run time intervall [ms]



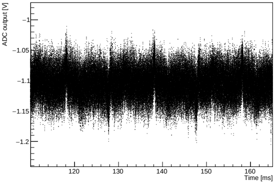
LUMI: 3GHz, HV=900 V



LUMI: HV=600 V



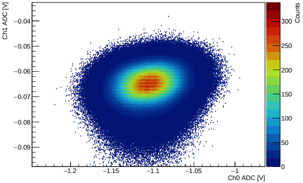
LUMI: HV=500 V



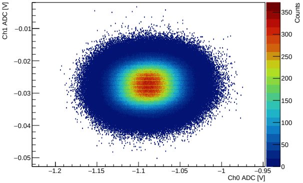
- Quartz: 3GHz, HV=490 V

LUMI spectra integration mode HV scan

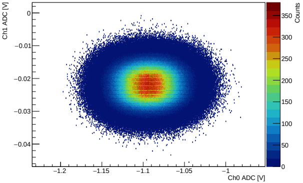
- Plot Quartz vs LUMI spectrum
- Ch0 Quartz, Ch1 LUMI



LUMI: HV=900 V



LUMI: HV=600 V



LUMI: HV=500 V

PMT ET 9305QKB

- PMT voltage divider A
- R=3.3 MΩ

8 voltage divider distribution

	k	d_1	d_2	d_7	d_8	d_9	d_{10}	a	
A	3R	R	....	R	R	R	R	R	Standard
B	3R	R	....	R	2R	3R	4R	3R	High Pulsed linearity

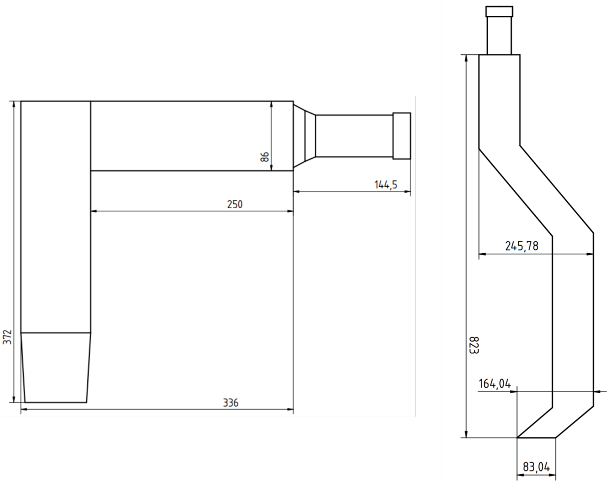
maximum ratings:				
anode current	μA			100
cathode current	nA			200
gain	x 10^6			3
sensitivity	A/lm			200
temperature	°C	-30		60
V (k-a)(1)	V			2700
V (k-d1)	V			450
V (d-d)(2)	V			300
ambient pressure (absolute)	kPa			202

- Datasheet max voltage 1700 V for norminal A/lm
- Integration mode 1-5 dynodes instead of 1-10
- For test beam in integration mode use HV=900V

Electrode	Integration mode=900 V [V]	Pulse mode=1462 V [V]
Cathode	337.5	337.38
1	112.5	112.46
2	112.5	112.46
3	112.5	112.46
4	112.5	112.46
5	112.5	112.46
6	0	112.46
7	0	112.46
8	0	112.46
9	0	112.46
10	0	112.46

LUMI prototypes

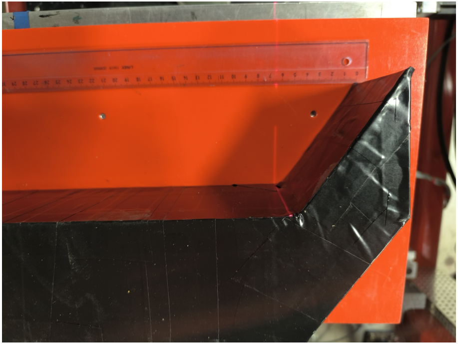
- Compare LUMI prototypes "L-Form"" and "Sickle"

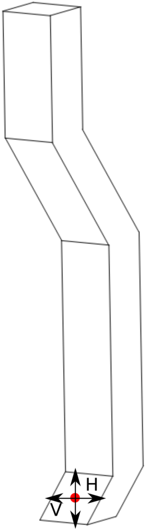


- Both detectors similar results in simulations and test beam times
- Both versions usable for P2

Position scan in integration mode

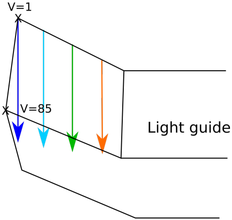
- LUMI prototype lying on moving table
- Change horizontal, vertical distance between electron beam and PMT
- Beam: 3 GHz, HV: 900 V

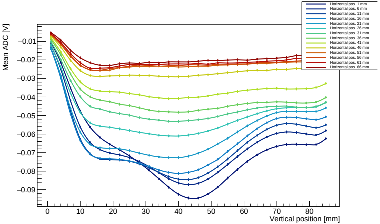


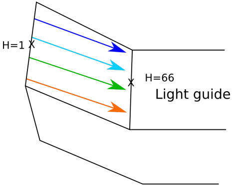


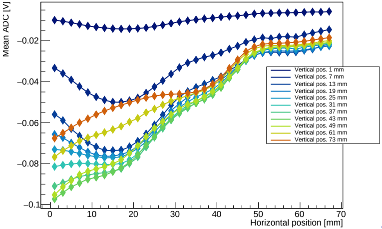
Position scan in integration mode

- LUMI prototype lying on moving table
- Change horizontal, vertical distance between electron beam and PMT
- Beam: 3 GHz, HV: 900 V
- Determine Mean ADC(x,y)



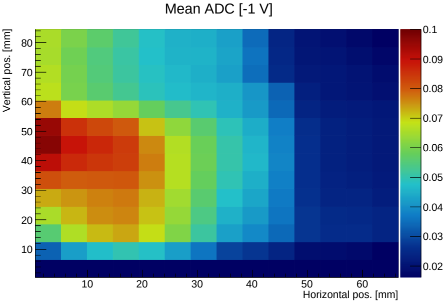


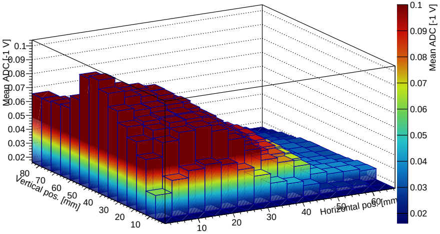


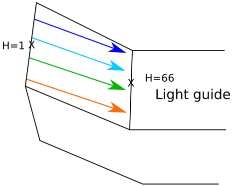


Position scan in integration mode

- Combine both measurements into single plot

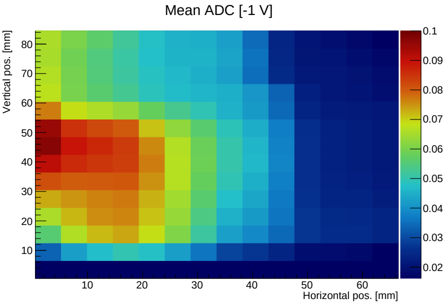




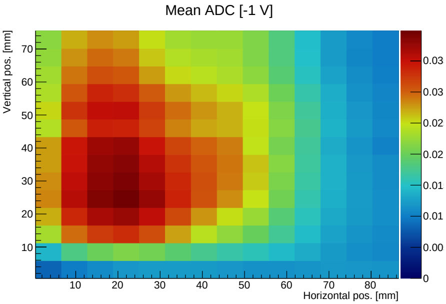


Position scan for sickle and L

- Compare position scan for both detector types
- Histogram same binning



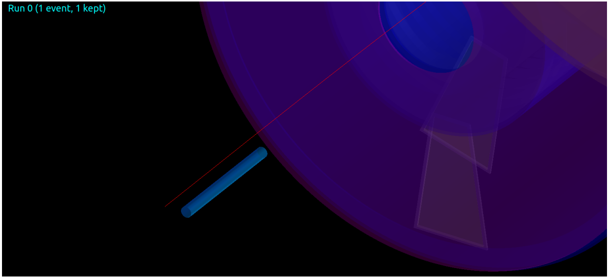
Sickle



L-Form

False asymmetries from helicity correlated beam fluctuations

- Question about influence of beam position deviation on LUMI ADC signal
- Beam position deviation $\Delta X = 1$ mm in the target
- False asymmetries results from deviations in $\Delta X = 1$ mm and $\Delta X = 0$ mm

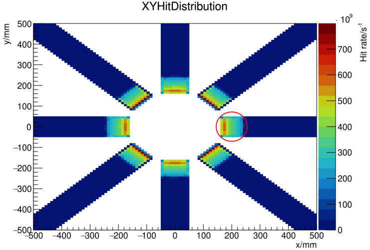


100 mm beam posiiton deviation in Geant4 as an example

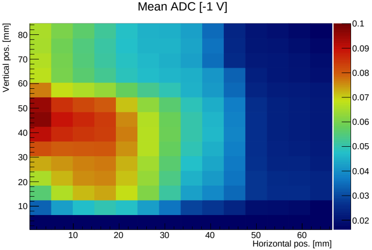
- Combine simulated rate distribution on detector and ADC position scan from beam time $\rightarrow$ resulting in ADC-signal for each LUMI
- ("less statistic dependency from production of Cherenkov photons and reflection on funnel walls")

Effects of beam position deviations

- To analyse beam position deviations $\Delta X = 1\ mm$ combine simulation and beam time results
- Initial assumption was point of entry of the beam onto the detector would have a strong influence
- Simulation = particle rate, beam time = ADC value depending on beam position
- Beam time rate $3 \cdot 10^9 1/s$, $\rightarrow$ ADC value per signal electron



X-Y hit distribution Geant4 simulation

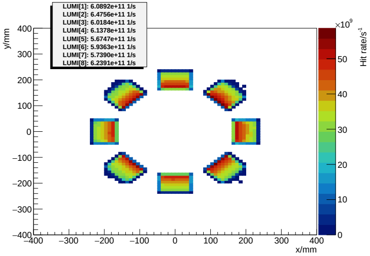


Beam time integration position scan results

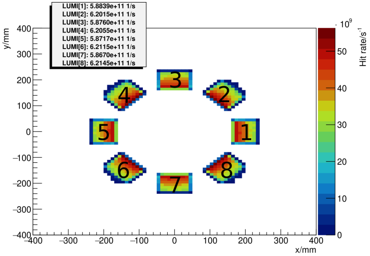
$$LUMI_{ADC}\ signal(x, y)[V] = Rate(x, y) \cdot ADC(x, y)/3 \cdot 10^9$$

False asymmetries from beam position deviations

- Compare particle rate for $\Delta X = 1$ and $\Delta X = 0$
- Only particles with energy ≤ 21 MeV, air Cherenkov threshold
- Margin of error $1/\sqrt{N}$, N number of simulated entries, statistic error



$\Delta X = 1\ mm$



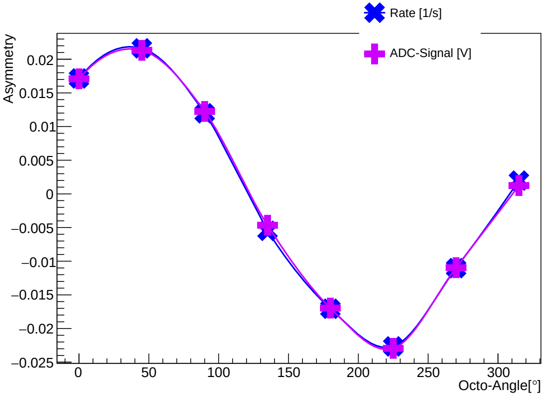
$\Delta X = 0\ mm$

$$Asym.(1) = 1.7147 \cdot 10^{-2} \pm 4.7225 \cdot 10^{-4}$$
$$Asym.(2) = 2.1622 \cdot 10^{-2} \pm 4.5881 \cdot 10^{-4}$$
$$Asym.(3) = 1.1972 \cdot 10^{-2} \pm 4.7392 \cdot 10^{-4}$$
$$Asym.(8) = 1.9753 \cdot 10^{-3} \pm 4.6286 \cdot 10^{-4}$$

$$Asym.(4) = -5.4848 \cdot 10^{-3} \pm 4.6489 \cdot 10^{-4}$$
$$Asym.(5) = -1.7062 \cdot 10^{-2} \pm 4.809 \cdot 10^{-4}$$
$$Asym.(6) = -2.2654 \cdot 10^{-2} \pm 4.6677 \cdot 10^{-4}$$
$$Asym.(7) = -1.1029 \cdot 10^{-2} \pm 4.7974 \cdot 10^{-4}$$

False asymmetries from helicity correlated beam fluctuations

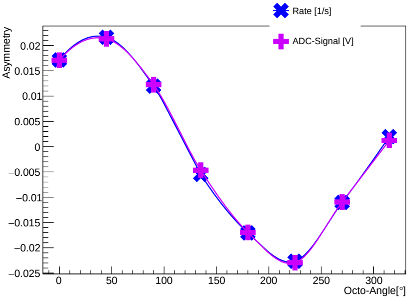
- Determine asymmetries for each LUMI detector for [1/s,1V]
- Plot asymmetries depending on polar coordinate angle ("Octo-Angle")$\Phi \in 0° ....315°$



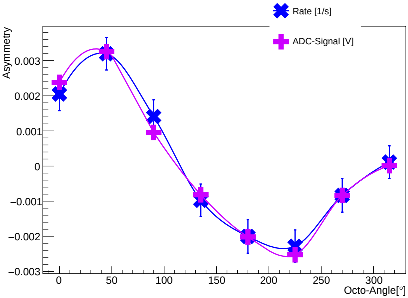
- Detector geometry (beam position dependency) no significant influence
- For rate asymmetries [1/s] for each LUMI statistical margin of error $\approx 4.5 \cdot 10^{-4}$
- Asymmetries error for each LUMI during P2 for 10^4h $\approx 1.5 \cdot 10^{-10}$

False asymmetries from helicity correlated beam fluctuations

- To test the linearity of the false asymmetries from beam deviations → simulation for $\Delta X = 0.1\text{mm}$



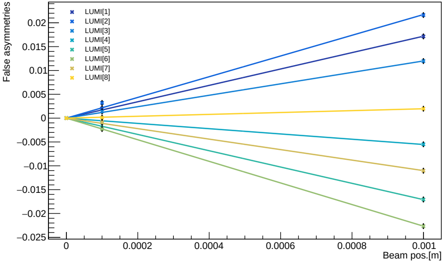
$\Delta X = 1$ mm

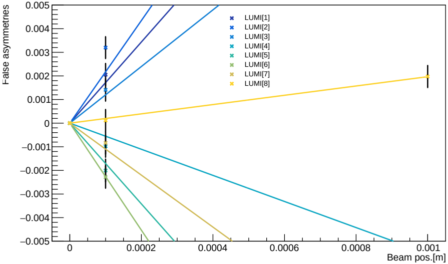


$\Delta X = 0.1$ mm

False asymmetries from helicity correlated beam fluctuations

- To test the linearity of the false asymmetries from beam deviations → simulation for $\Delta X = 0.1\text{mm}$
- Plot for each LUMI the asymmetries for $\Delta X = 1\text{mm}$ and $\Delta X = 0.1\text{mm}$
- For each LUMI linear slope fit





False asymmetries from beam position deviations

- MESA max. beam location difference at target 1 nm
- Asymmetry calculation (1 nm) estimation from fit parameters

$$Asym.(1) = 1.718 \cdot 10^{-8}$$
$$Asym.(2) = 2.1725 \cdot 10^{-8}$$
$$Asym.(3) = 1.1993 \cdot 10^{-8}$$
$$Asym.(8) = 1.9669 \cdot 10^{-9}$$

$$Asym.(4) = -5.5271 \cdot 10^{-9}$$
$$Asym.(5) = -1.7092 \cdot 10^{-8}$$
$$Asym.(6) = -2.2656 \cdot 10^{-8}$$
$$Asym.(7) = -1.1003 \cdot 10^{-8}$$