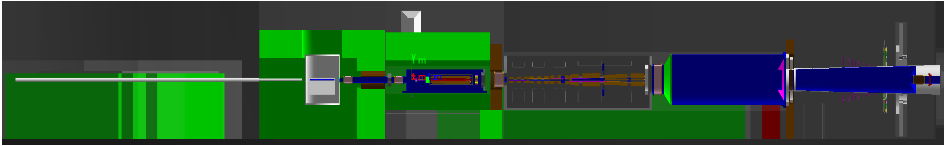
Detector rate sensitivity to Beam position, angle, energy

Zuhal Seyma Demiroglu

10 Apr, 2026

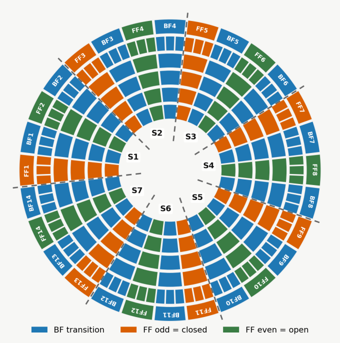
The MOLLER experiment

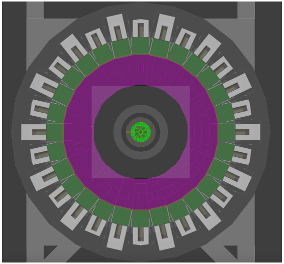


- Measure the parity-violating asymmetry A_{PV} in e^-e^- (Møller) scattering at Jefferson Lab Hall A.
- 11 GeV longitudinally polarized electron beam, $\sim$65 μA on a 1.25 m liquid hydrogen target.
- Precision: $\delta A_{PV}/A_{PV} \approx 2.4\%$ ($\sim$0.8 ppb on a $\sim$33 ppb asymmetry).

Main detector & why beam jitter matters

- **224 quartz tiles**, arranged in **6 radial rings** × **28 azimuthal segments** (Ring 5 split L/C/R).
- Azimuthal segments grouped from the 7-fold toroid geometry as **closed**, **open**, **transition**.
- Ring 5 sees the Møller peak (signal). Other rings contain ep-elastic, inelastic, and backgrounds.
- Beam jitter (position / angle / energy) at the target shifts individual tile rates and can fake an asymmetry.
- per-tile sensitivities dR/R per mm / mrad / MeV, feeding the dithering/regression corrections in the japan-MOLLER mock data generator (`thinqtz_remoll.map`).





Simulation Setup

- remoll Geant4 – develop branch, commit 2bb7397 + PR640 (coll2redesign)
- Moller + ep-elastic generators
- Scan five beam parameters independently: $pos_X, pos_Y, angle_X, angle_Y, Energy$
- Selected events with $e^{\pm}$, $\pi^{\pm}$, $k > 1\,\text{MeV}$
- Calculated

$$\text{Fractional sensitivity} = \frac{1}{R_0}\frac{dR}{dX}$$

where $X \in \{pos_X,\, pos_Y,\, angle_X,\, angle_Y,\, Energy\}$

Scan	Range	Unit
pos_X	± 1	mm
pos_Y	± 1	mm
ang_X	± 0.2	mrad
ang_Y	± 0.2	mrad
energy	± 110	MeV

- nominal $E_0 = 11\,\text{GeV}$, $\Delta E/E = \pm 10^{-2}$
- 6 rings, 28 segments, Ring 5 L/C/R
- 224 ring detector tiles

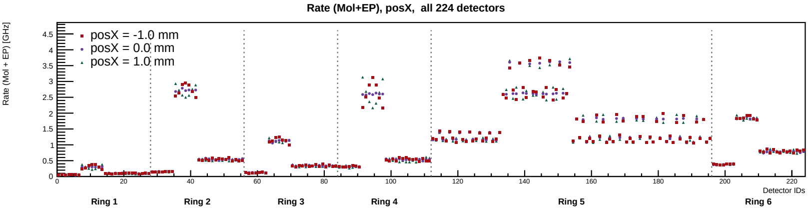
How is the fractional sensitivity calculated?

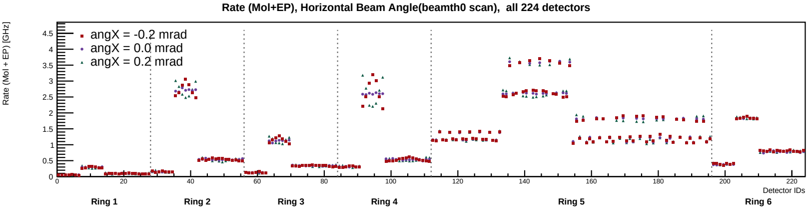
- Run 3 simulations per parameter: $X = -1, 0, +1\,\mathrm{mm}$ (or $\pm 0.2\,\mathrm{mrad}$ / $\pm 110\,\mathrm{MeV}$).
- Extract detector rate $R_d(X)$ [GHz] per tile.
- Fit a straight line through the 3 points:

$$R_d(X) = \underbrace{a_d}_{\approx R_0} + \underbrace{b_d}_{\text{slope}} \cdot X$$

- Sum Moller and EP-elastic slopes and intercepts: $b_d^{\mathrm{tot}} = b_d^{\mathrm{Mol}} + b_d^{\mathrm{EP}}$, $a_d^{\mathrm{tot}} = a_d^{\mathrm{Mol}} + a_d^{\mathrm{EP}}$.
- Fractional sensitivity per tile:

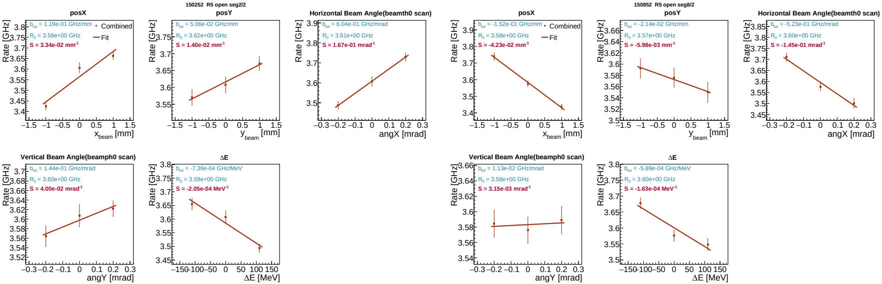
$$\frac{1}{R_0}\frac{dR}{dX} = \frac{b_d^{\mathrm{tot}}}{a_d^{\mathrm{tot}}}$$





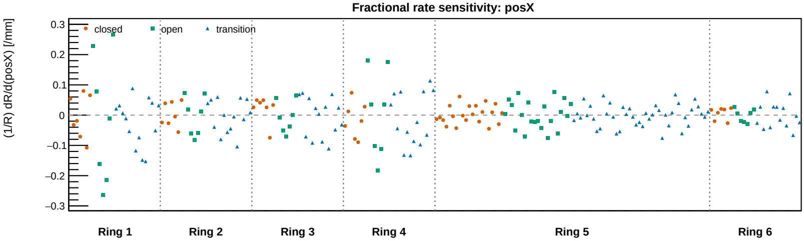
Combined (Moller+EP-elastic) rate vs tile ID for nominal, ± 1 mm (top) and ± 0.2 mrad (bottom) shifts. Tiles ordered by ring, then closed/open/transition.

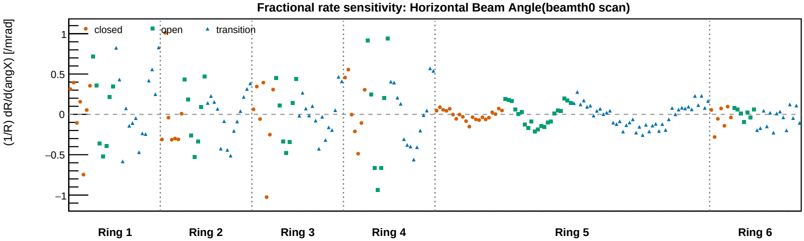
All-scan comparison for two Ring 5 open tiles



Rate vs scan value for all 5 scans, tiles 150252 (left) and 150852 (right). Good linearity; slope sign flips between opposite sectors.

Fractional sensitivity vs detector ID





$S = b_{\mathrm{tot}}/R_0$ per tile for pos_X (top) and ang_X (bottom).

Azimuthal dependence & rotated (S_r, S_t) basis

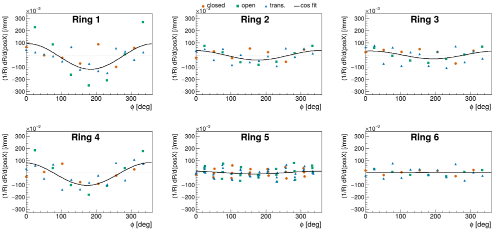
- Horizontal shift $(x) \Rightarrow$ left–right asymmetry: S_{posX} varies with ϕ as $\cos\phi$.
- Vertical shift $(y) \Rightarrow$ up–down asymmetry: $S_{posY} \propto \sin\phi$.
- Remove trivial ϕ dependence by rotating into each tile's local basis:

$$S_r = \cos\phi\, S_x + \sin\phi\, S_y$$

$$S_t = -\sin\phi\, S_x + \cos\phi\, S_y$$

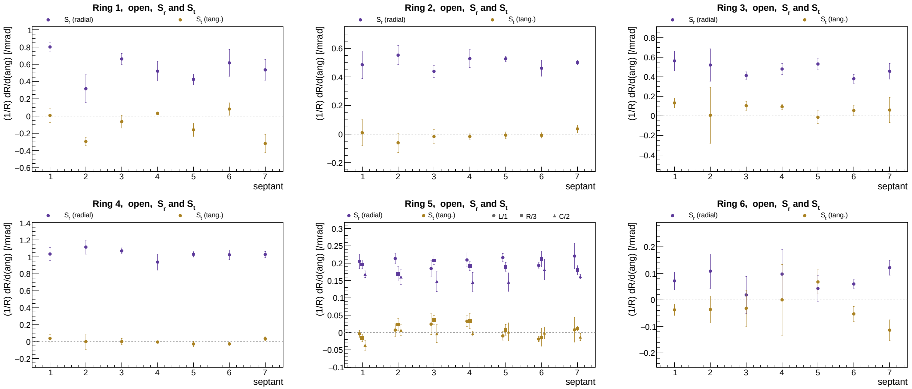
- Applied separately to position and angle scans.
- Dipole response per ring/type:

$$D_x = \frac{2}{N}\sum_k S(\phi_k)\cos\phi_k, \quad D_y = \frac{2}{N}\sum_k S(\phi_k)\sin\phi_k$$



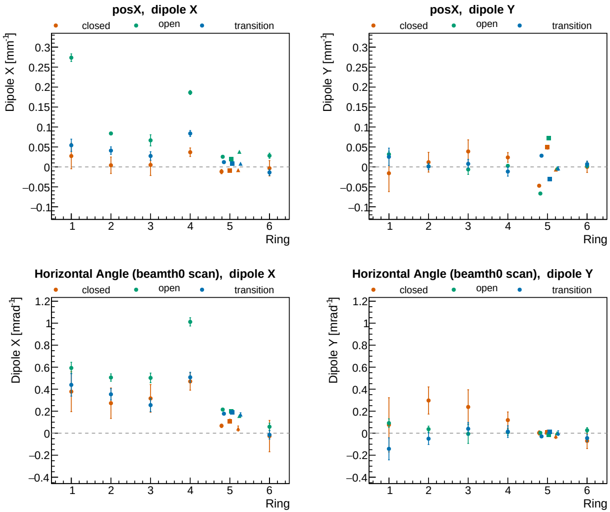
S_{posX} vs ϕ, all 6 rings, each fit to $A\cos(\phi - \phi_0) + C$.

S_r and S_t, angle sensitivity, open



S_r and S_t [$mrad^{-1}$] from angle scans, per tile, grouped by open sectors and rings.

Dipole response summary



D_x, D_y per ring for pos_X (top) and ang_X (bottom), split by sector type.

Mock data sensitivity parameters & next steps

Generated `mock_parameters_thinqtz_remoll.map` for the japan-MOLLER mock data generator, replacing placeholder sensitivities with remoll values.

- `NormRate` (Hz/μA), `VoltPerHz`, `Asym` unchanged.
- C_x, C_y: position sensitivities S_{posX}, S_{posY} in ppm/nm = mm^{-1}
- C_{xp}, C_{yp}: angle sensitivities S_{angX}, S_{angY} in ppm/nrad = mrad^{-1}
- C_e: energy sensitivity = $S_{beamE}\,[\mathrm{MeV}^{-1}] \times E_{\mathrm{beam}}\,[\mathrm{MeV}]$ ($\times$11000)

!Name	NormRate(Hz/uA)	VoltPerHz	Asym	C_x	C_y	C_xp	C_yp	C_e
TQ01_R1	110923	2.120e-07	0.0001	0.065151	−0.010319	0.302114	−0.383741	−18.454511
TQ01_R2	1144615	4.120e-08	0.0001	−0.022958	−0.134693	−0.259057	−0.332105	5.688359
TQ01_R3	756923	4.120e-08	0.0001	0.024577	−0.016492	0.021176	0.659107	−10.392786
TQ01_R4	2553846	1.140e-08	0.0001	−0.032218	−0.000421	0.459242	0.107901	−1.887232
TQ01_R5C	20307692	8.420e-10	0.0001	−0.015643	0.003089	0.050700	−0.017208	−1.328196
TQ01_R5L	17230769	2.530e-09	0.0001	−0.016734	0.036369	0.049239	−0.029879	−2.119375
TQ01_R5R	17076923	2.530e-09	0.0001	−0.008074	−0.047233	0.090440	0.001709	−0.148755
TQ01_R6	4169230	1.140e-08	0.0001	0.018375	−0.009820	0.039895	−0.042554	0.188172
TQ02_R1	375384	4.120e-08	0.0001	0.041545	0.058629	0.807687	−0.174455	3.310377
TQ02_R2	6030769	2.530e-09	0.0001	0.032854	0.073930	0.175586	0.046817	0.053490
TQ02_R3	3569230	1.140e-08	0.0001	0.063188	0.120228	−0.042144	0.546044	−10.711104
TQ02_R4	4230769	1.140e-08	0.0001	0.033616	0.093168	0.393296	0.416491	−2.759462
TQ02_R5C	18615384	8.420e-10	0.0001	−0.007894	0.044808	0.127638	0.063811	−0.129591
TQ02_R5L	15538461	2.530e-09	0.0001	−0.019304	0.006014	0.146576	0.095076	0.066807
TQ02_R5R	26307692	8.420e-10	0.0001	0.002864	0.071097	0.257897	0.054749	−0.675243
TQ02_R6	11292307	2.530e-09	0.0001	−0.025619	0.073679	−0.202410	−0.053933	−1.562488
TQ03_R1	1723076	1.140e-08	0.0001	0.225852	0.100883	0.648281	0.353843	21.373926
TQ03_R2	39076923	8.420e-10	0.0001	0.073477	0.039863	0.442524	0.211708	−0.446170
TQ03_R3	16615384	2.530e-09	0.0001	0.056354	0.038470	0.476039	0.375052	−9.647679
TQ03_R4	35384615	8.420e-10	0.0001	0.180643	0.082712	0.940339	0.491090	1.280232
TQ03_R5C	54923076	8.420e-10	0.0001	0.033010	0.013919	0.163707	0.039085	−2.281362
TQ03_R5L	40307692	8.420e-10	0.0001	0.003915	0.069600	0.188247	0.074560	−1.949280
TQ03_R5R	40307692	8.420e-10	0.0001	0.051894	−0.049028	0.180948	0.087607	−1.412514
TQ03_R6	29230769	8.420e-10	0.0001	0.028126	0.003472	0.081620	−0.003981	−2.290296

Next steps:

- Replot sensitivities vs the *accepted scattering angle* per tile (collimator-accepted, not geometric ϕ) – cleaner basis for the radial/tangential fits and more directly tied to physics corrections (A_T, etc.).

Backup

Spectrometer & Collimation – Ensuring Clean Signals

- Defines acceptance:
  - Specially designed to select forward/backward scattering in the COM frame
  - Protects magnet regions from the full beam
- The five toroidal magnet system
  - Cleanly separates Møller events from the backgrounds.