Stony Brook University

Center for Frontiers in Nuclear Science

Detector rate sensitivity to Beam position, angle, energy

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Updates

- Produce plots of tile rate sensitivities to beam energy scan with ±110 MeV shifts.
- Replotted tile rate sensitivities with each tile's azimuthal scattering angle ϕ_{acc} instead of geometric ϕ
- Fix the error bars on S_r, S_t, dipole response distributions

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 $e^{\pm}$, $\pi^{\pm}$, $k > 1$ 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 beam energy, $E_0 = 11$ GeV, scan corresponds to $\Delta E/E = \pm 10^{-2}$
- 6 rings, 28 segments,
- Ring 5 split L/C/R tiles
- 224 ring detector tiles

ϕ_{acc}: definition

- Used two remoll output branches: `hit` (every detector hit in the event) and `part` (every primary particle in the event). They are linked by a track ID.
- In order to find the primary that produced a given hit, we match `hit.trid` with `part.trid` and get `part.ph`: the lab-frame azimuthal angle of primary particle. We call this ϕ_{acc}, in contrast to ϕ_{geom}, the geometric center of the tile.
- `part.ph` is in radians in the range $(-\pi, \pi]$. For each generator (Moller, elastic), the per-tile circular mean is computed from all accepted tracks i with rate weights w_i:

$$\bar{\phi}_{gen} \;=\; \mathrm{atan2}\!\left(\sum_i w_i \sin\phi_i,\; \sum_i w_i \cos\phi_i\right), \qquad R_{gen} \;=\; \sum_i w_i .$$

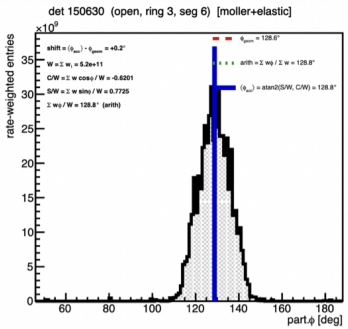
- Then, two generators are combined into a single rate-weighted circular mean per tile:

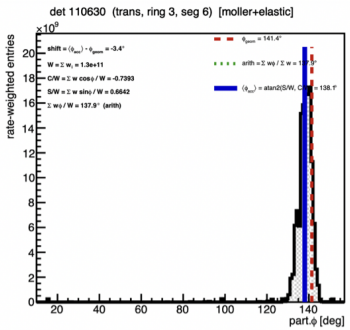
$$C \;=\; R_{\mathrm{mol}} \cos\bar{\phi}_{\mathrm{mol}} + R_{\mathrm{el}} \cos\bar{\phi}_{\mathrm{el}}, \qquad S \;=\; R_{\mathrm{mol}} \sin\bar{\phi}_{\mathrm{mol}} + R_{\mathrm{el}} \sin\bar{\phi}_{\mathrm{el}},$$

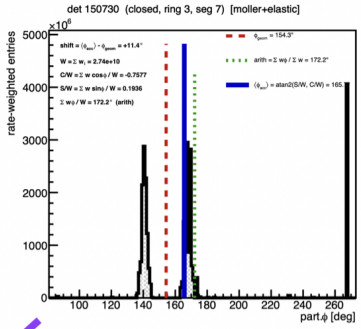
$$\langle\phi_{\mathrm{acc}}\rangle \;=\; \mathrm{atan2}(S,\, C)\,.$$

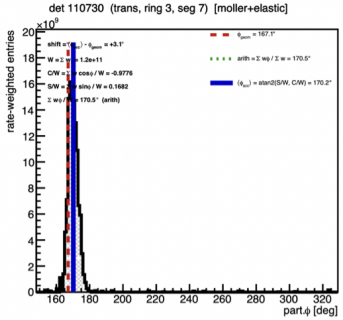
- This $\langle\phi_{\mathrm{acc}}\rangle$ is what I use as the x-axis of each tile in the S-vs-ϕ, S_r, S_t, and dipole plots, in place of ϕ_{geom}.

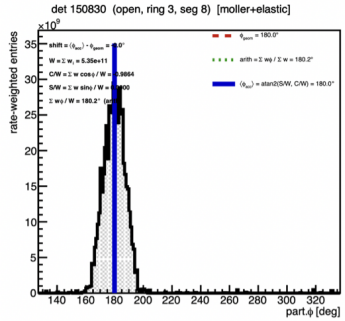
ϕ_{acc}: definition

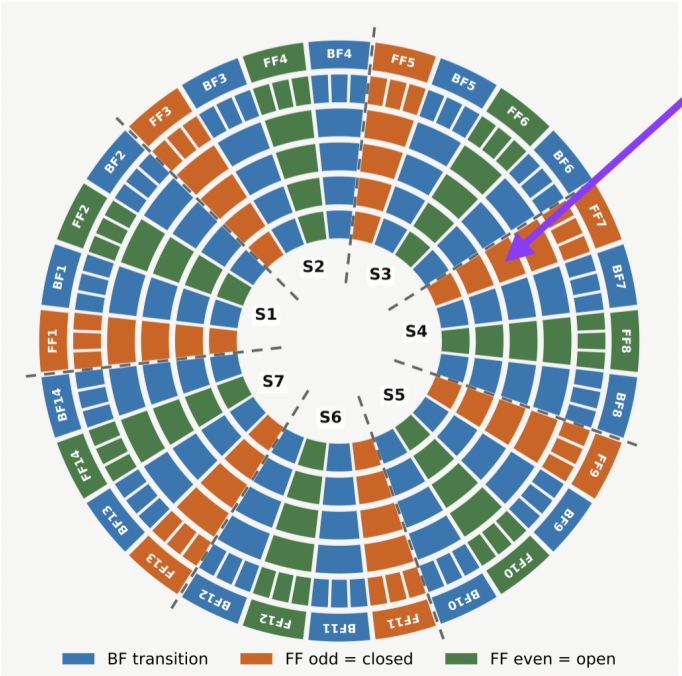




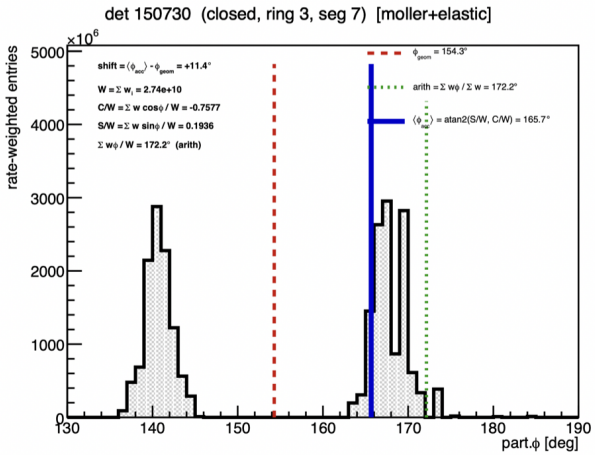


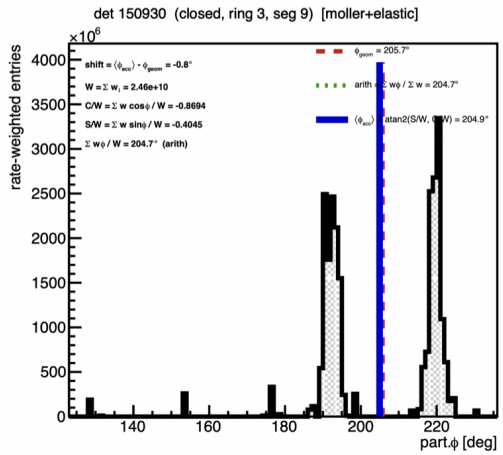




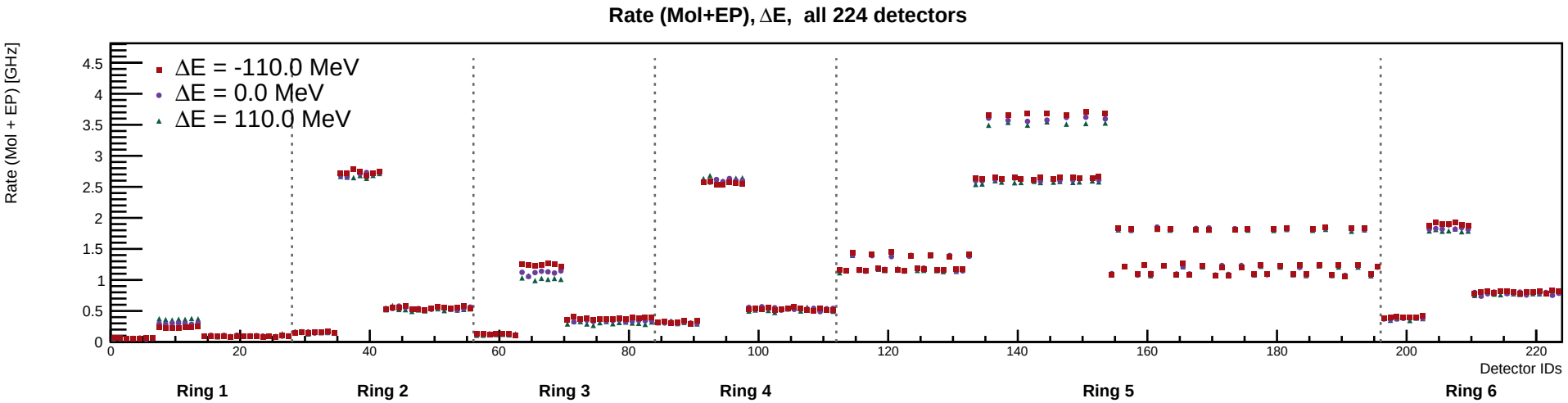


Zoomed-in



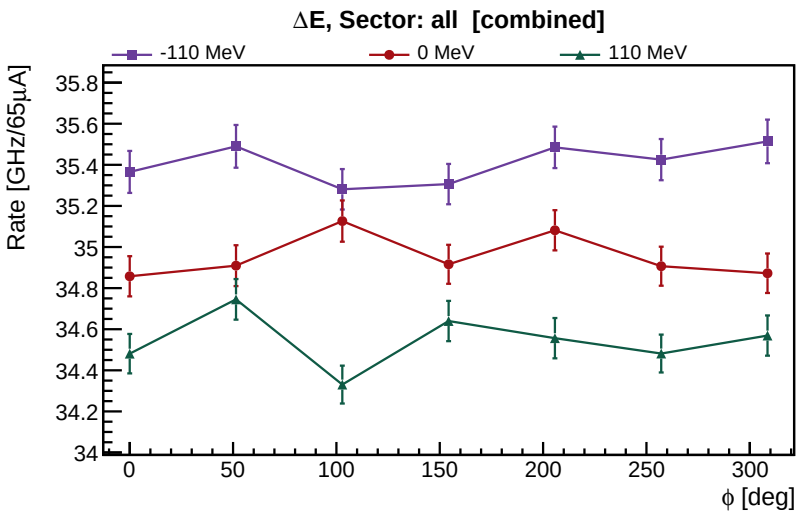


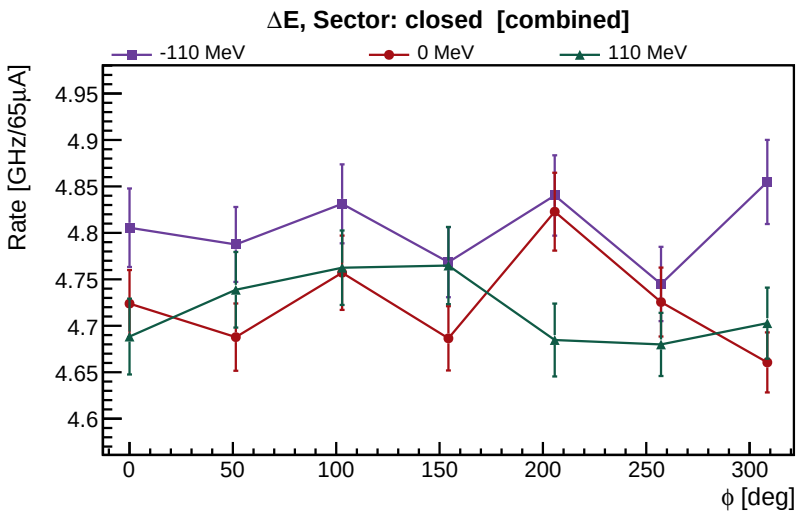
Detector rate as a function of tile ID, energy scans

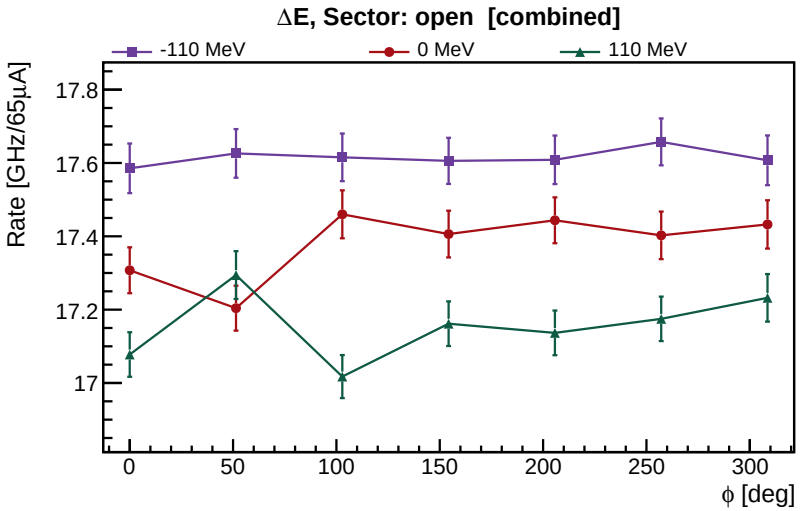


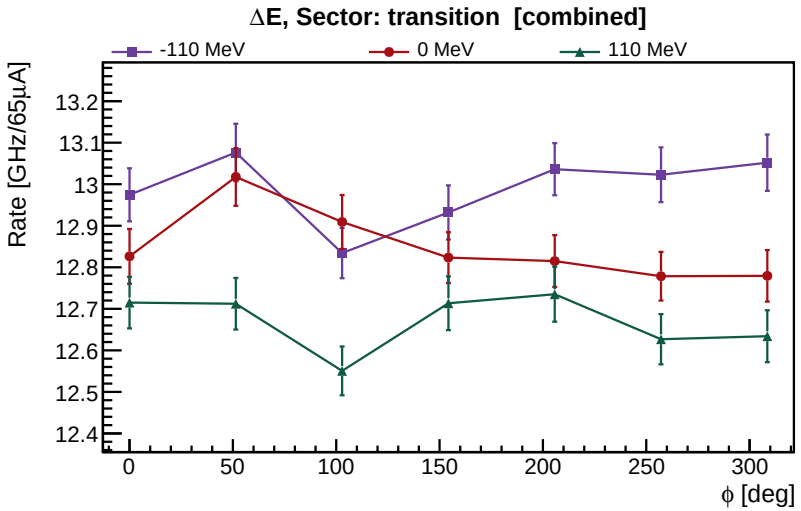
Combined rate for nominal, ±110 MeV shifts.

Septant summed detector rates, energy scan



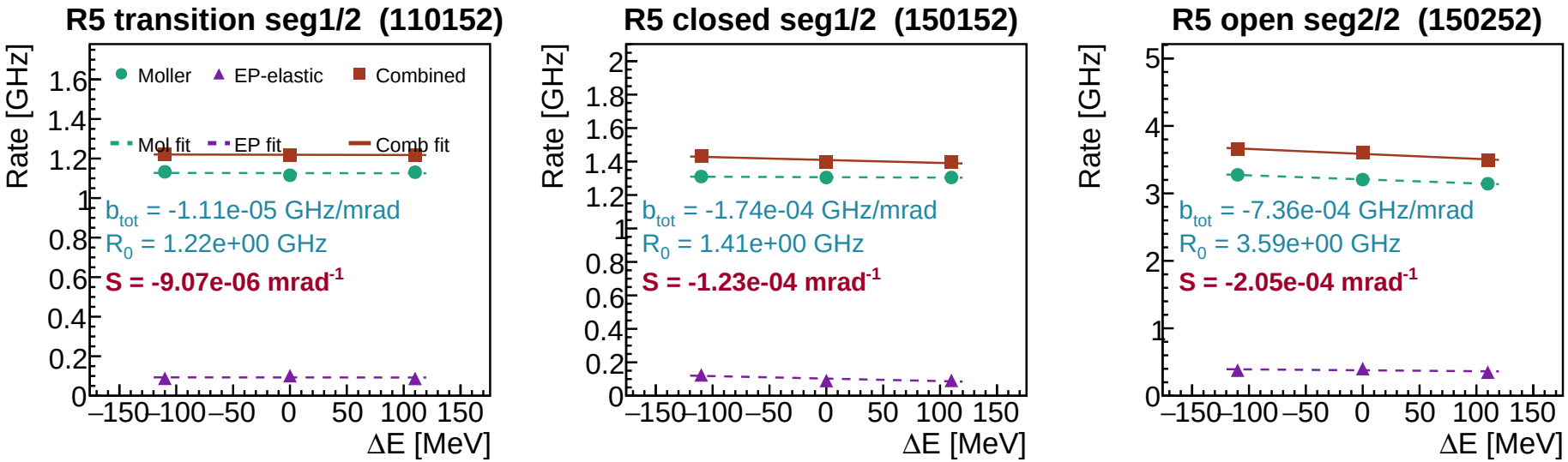






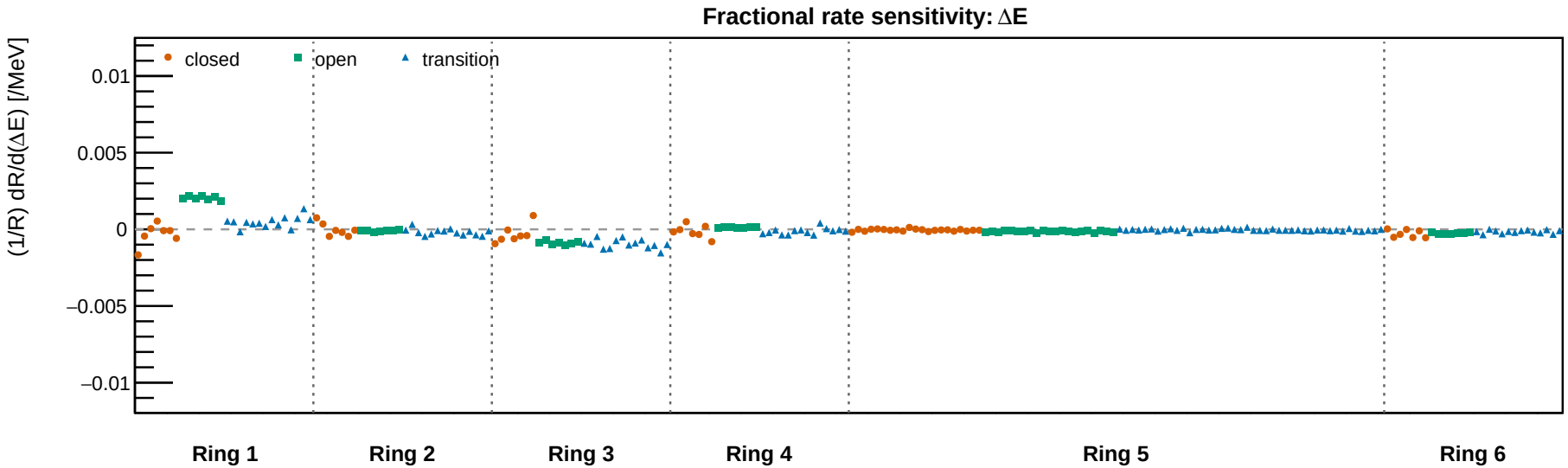
Each point is the sum of rates over all tiles in that septant, grouped by tile type (closed/open/-transition).

Detector rate as a function of beam energy scan



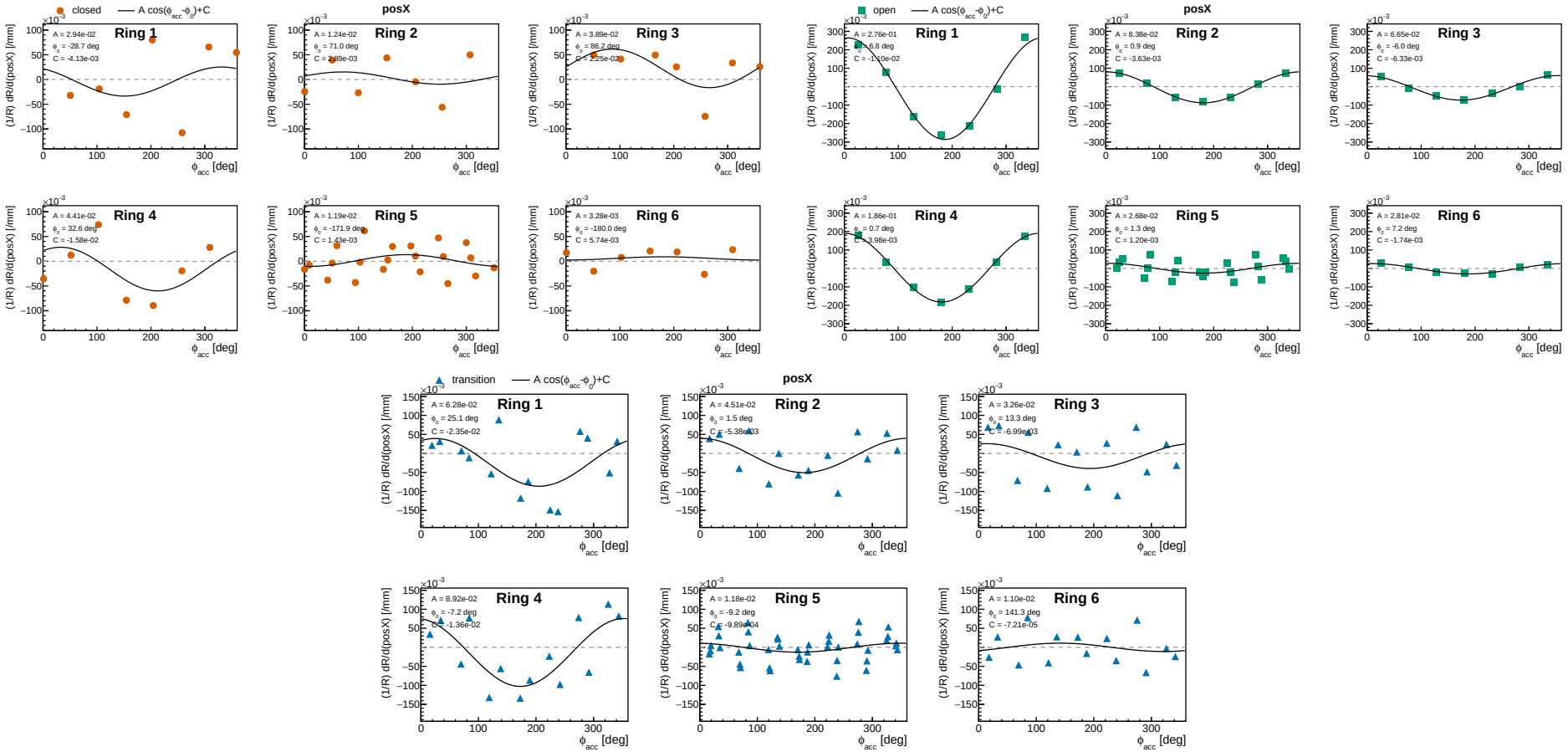
rate vs ΔE for selected tiles in transition/closed/open sector.

Fractional sensitivity as a function of detector ID, energy scans



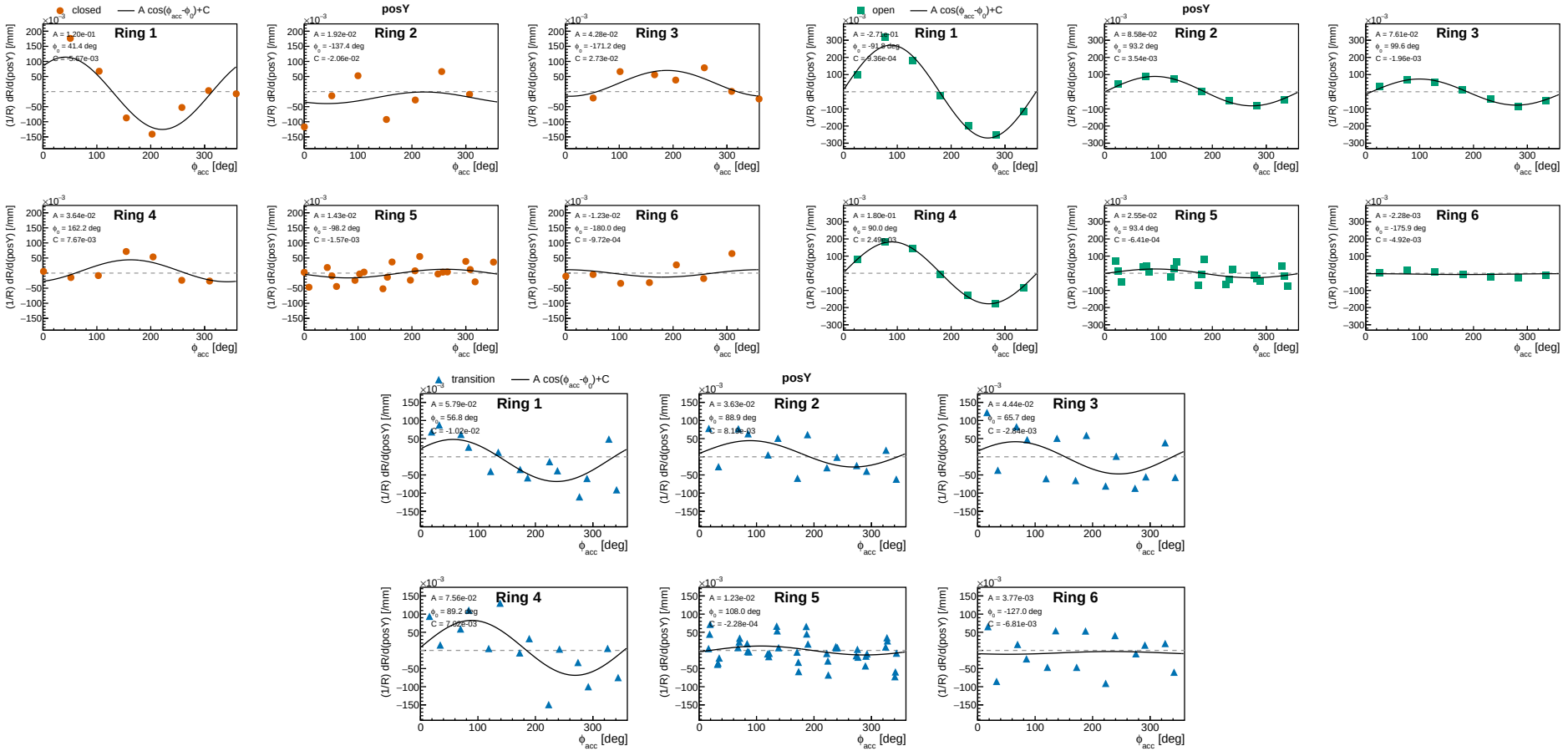
$S = b_{\mathrm{tot}}/R_0$ per tile. Tiles ordered by ring; within each ring: closed, open, transition.

Fractional sensitivity (pos_X scan) as a function of azimuthal scattering angle ϕ



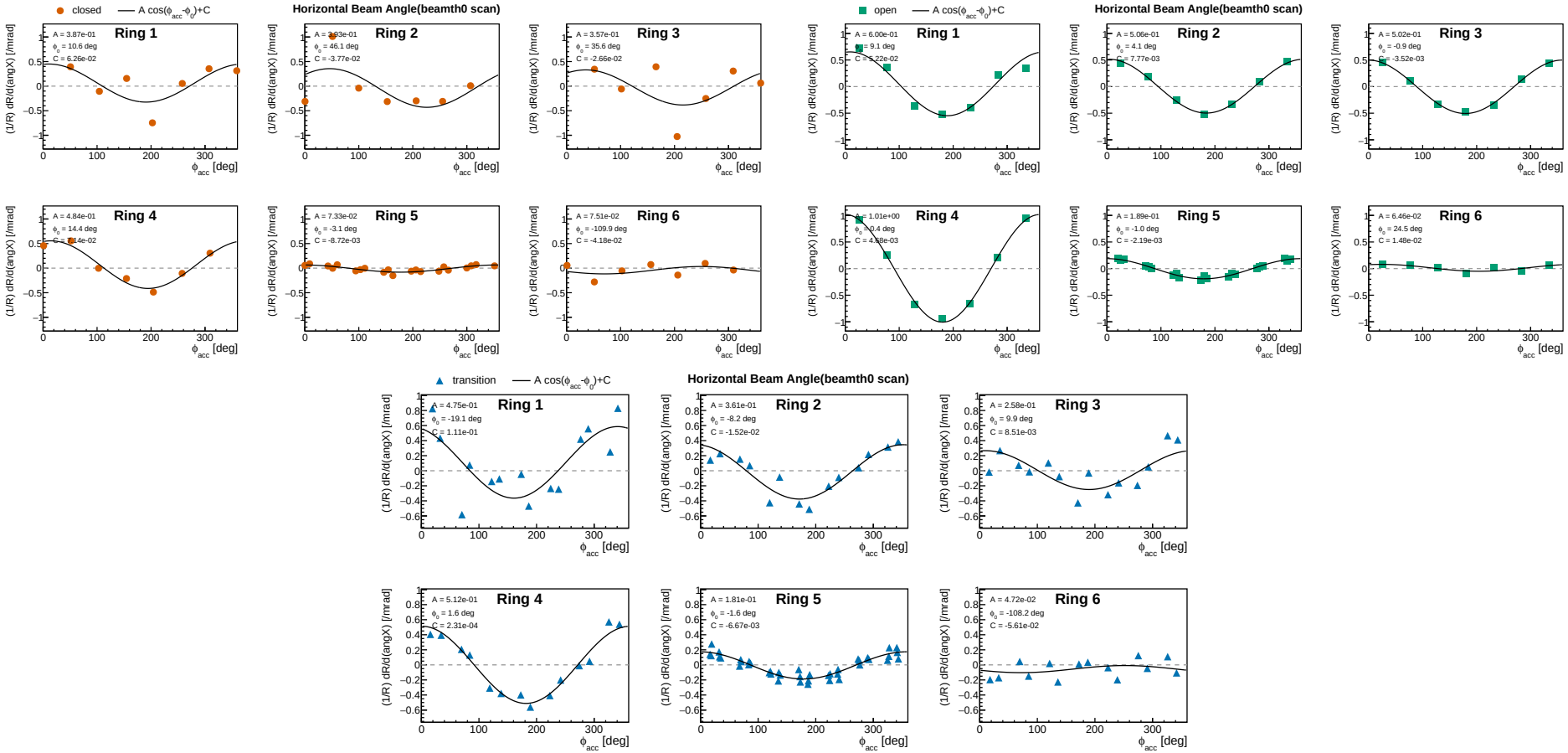
Fractional sensitivity vs azimuthal scattering angle ϕ for each ring. posX shows $cos\phi$ dependence.

Fractional sensitivity (pos_Y scan) as a function of azimuthal scattering angle ϕ



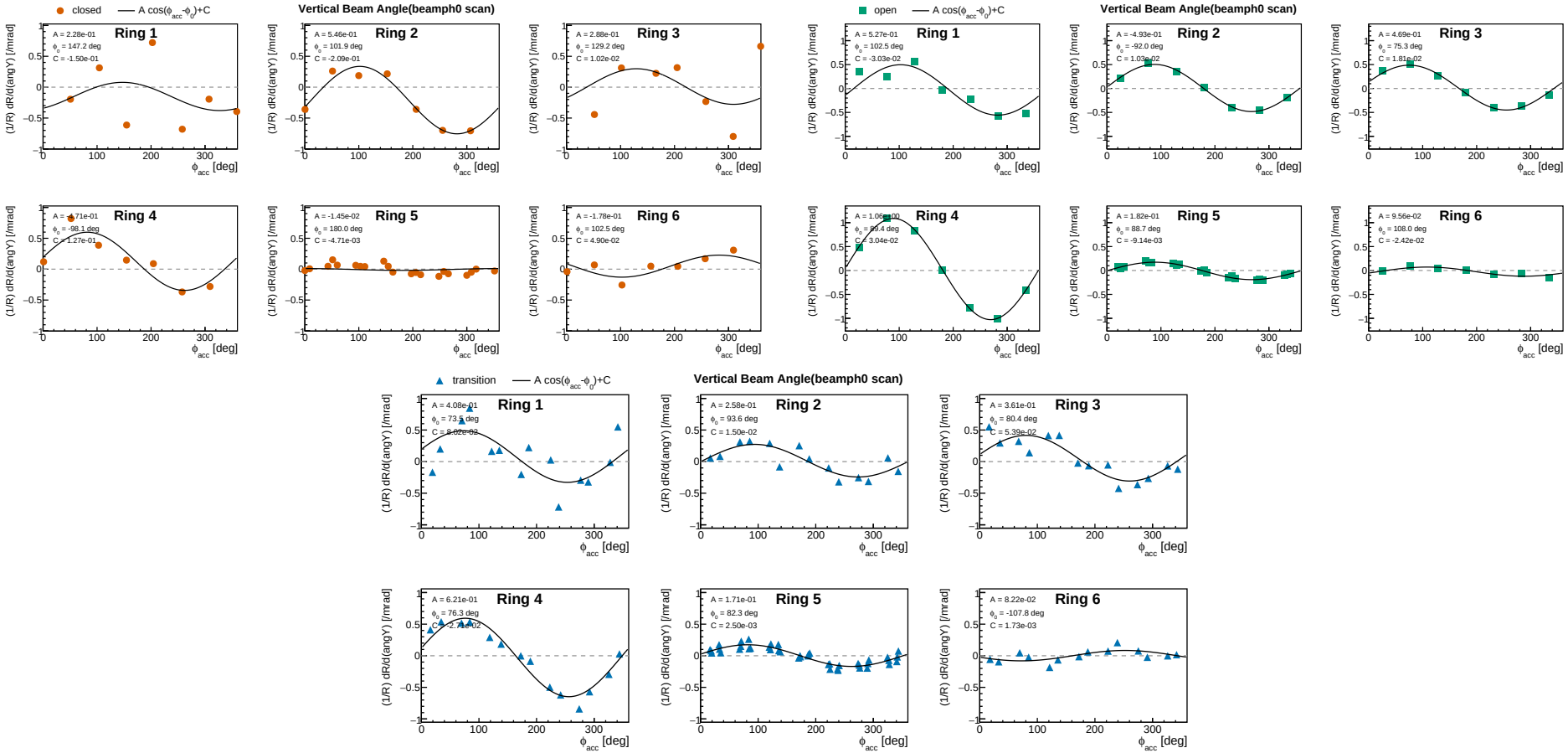
Fractional sensitivity vs azimuthal scattering angle ϕ for each ring. posY shows $sin\phi$ dependence.

Fractional sensitivity (ang_X scan) as a function of azimuthal scattering angle ϕ



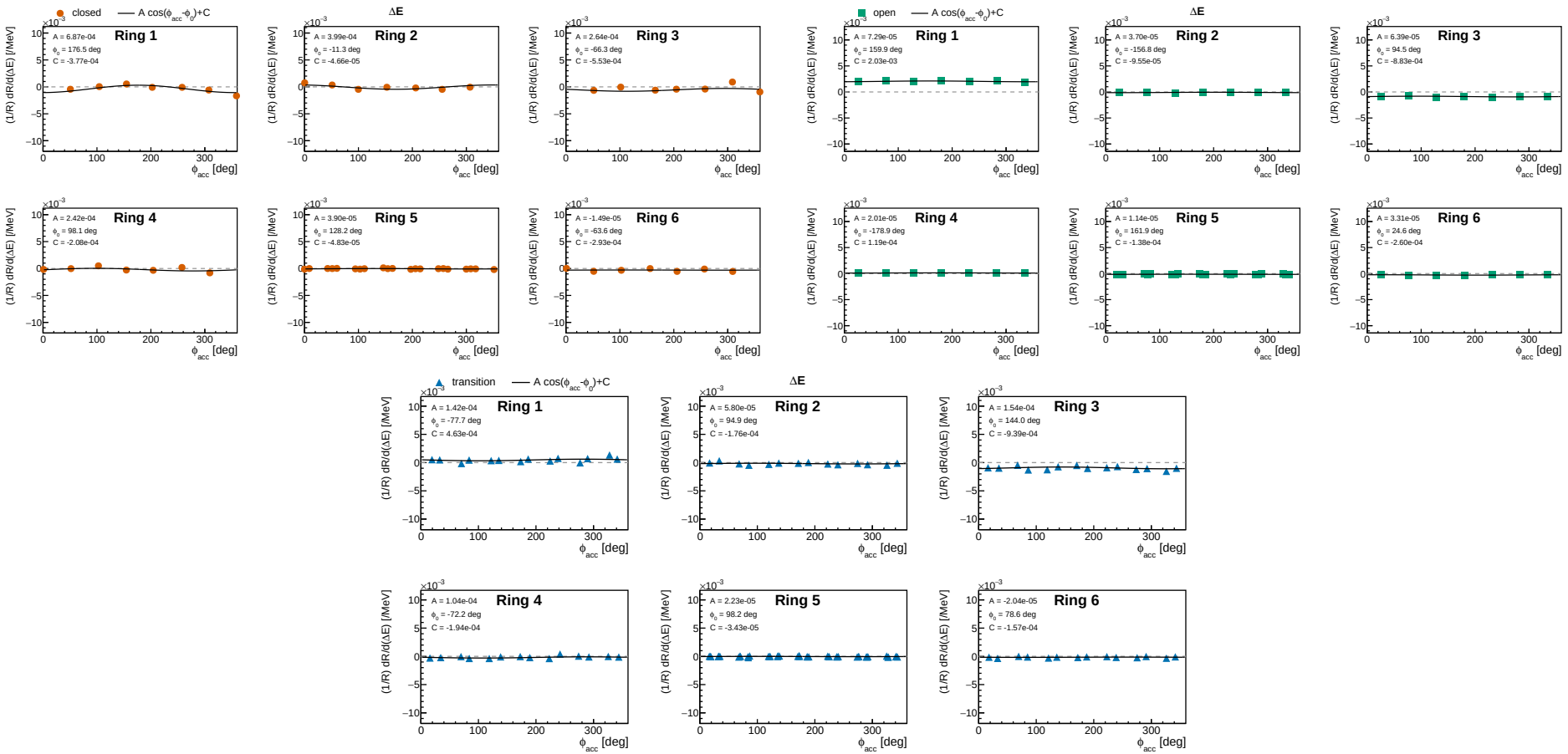
Fractional sensitivity vs azimuthal scattering angle ϕ for each ring. angX shows $cos\phi$ dependence.

Fractional sensitivity (ang_Y scan) as a function of azimuthal scattering angle ϕ



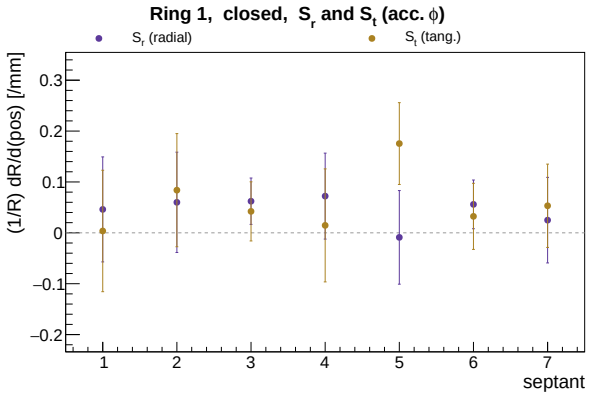
Fractional sensitivity vs azimuthal scattering angle ϕ for each ring. angY shows $sin\phi$ dependence.

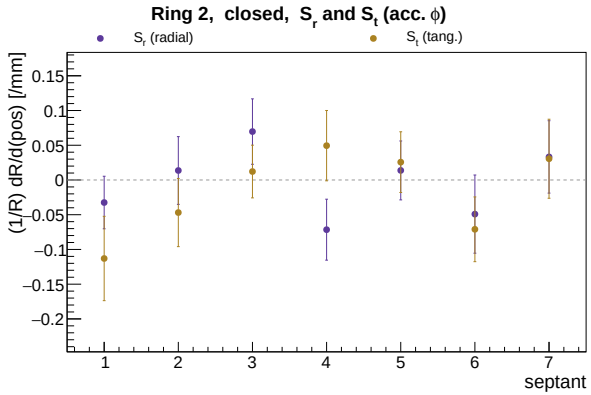
Fractional sensitivity (energy scan) as a function of azimuthal scattering angle ϕ

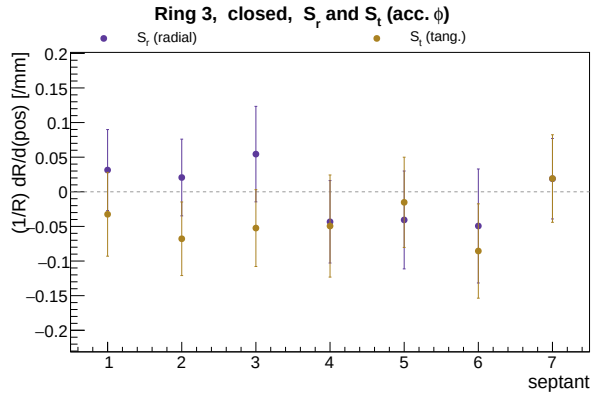


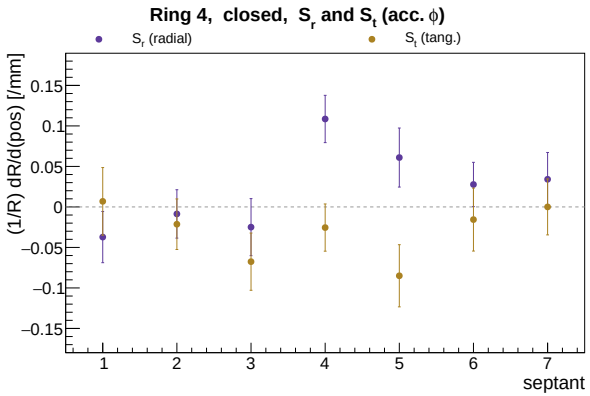
Fractional sensitivity vs azimuthal scattering angle ϕ for each ring. The curves are flat, shows that beam energy has no ϕ dependence.

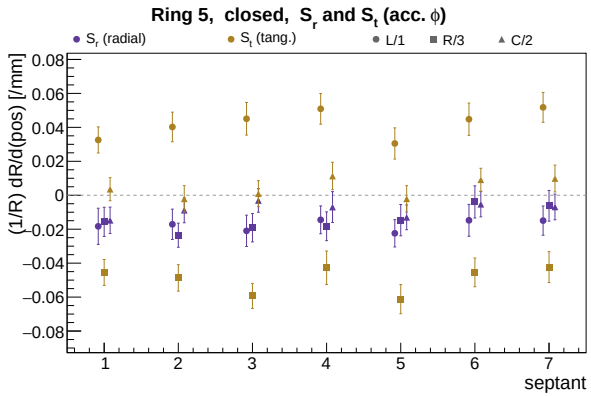
S_r and S_t, position sensitivity, closed

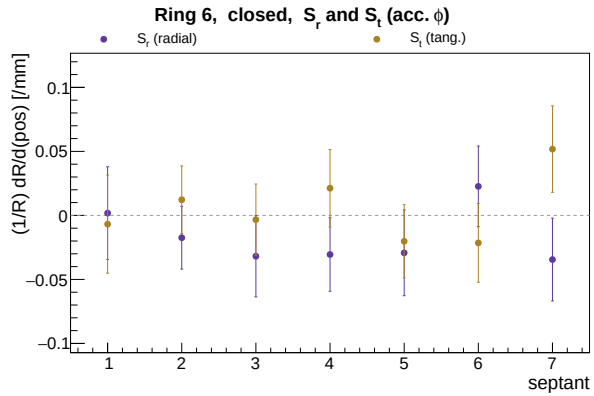






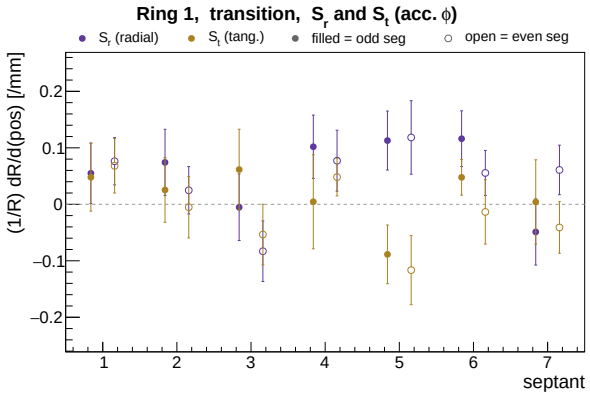


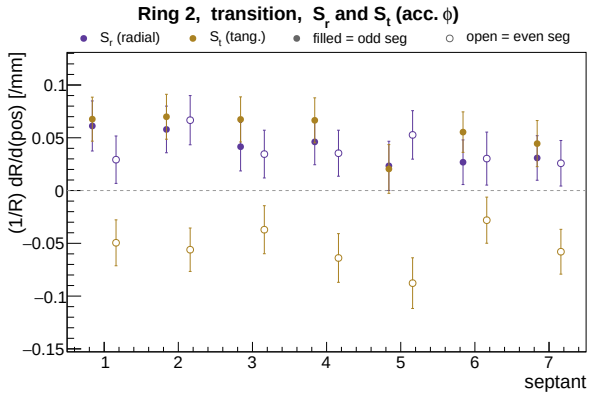


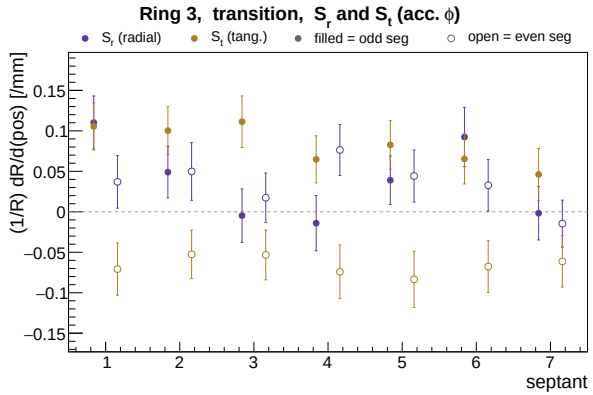


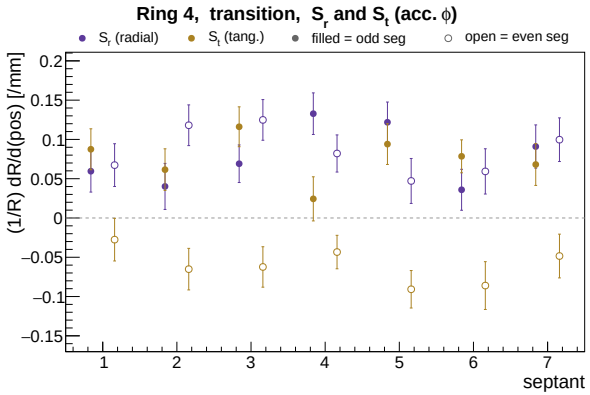
S_r and S_t $[mm^{-1}]$ from position scans, per tile, grouped by closed sectors and rings.

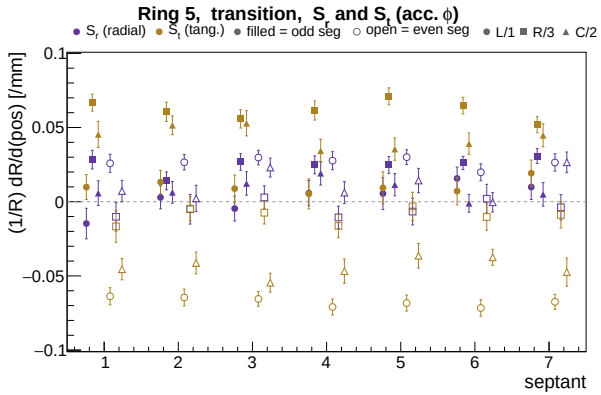
S_r and S_t, position sensitivity, transition

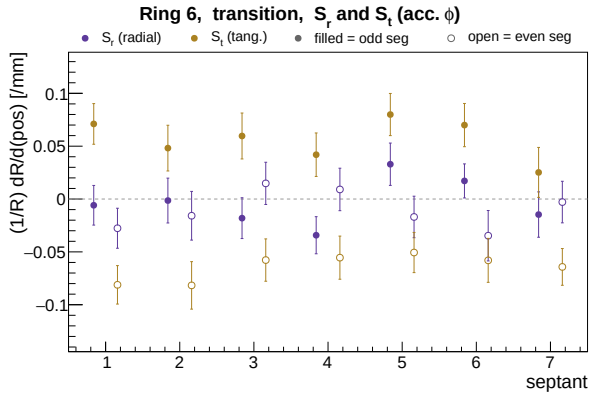






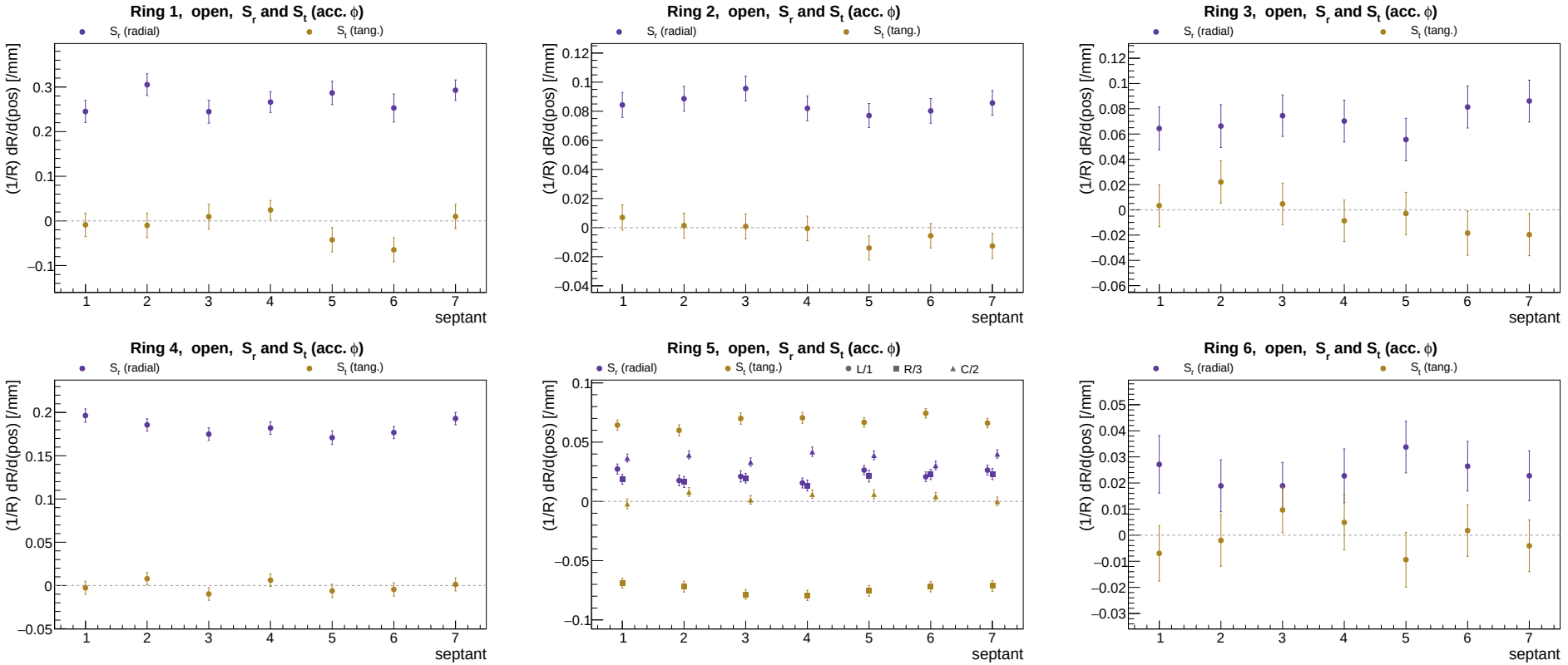






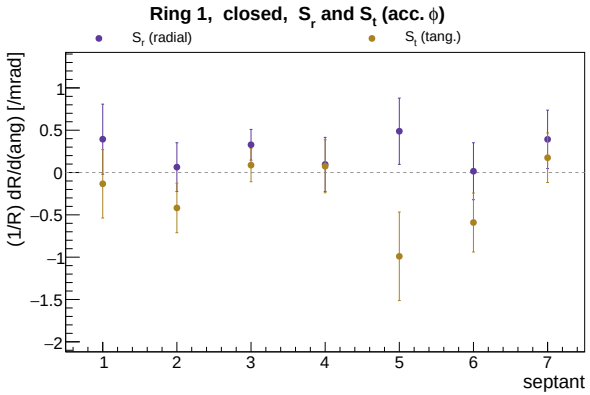
S_r and S_t $[mm^{-1}]$ from position scans, per tile, grouped by transition sectors and rings.

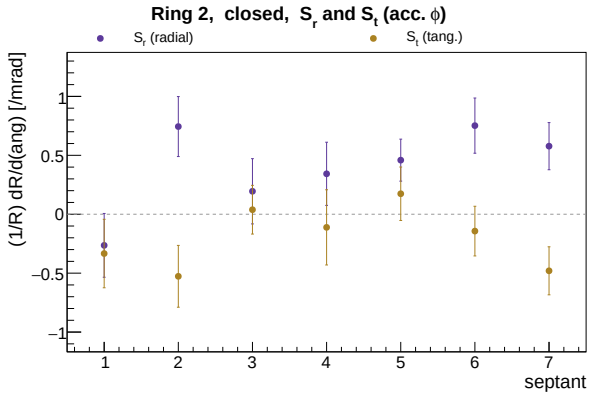
S_r and S_t, position sensitivity, open

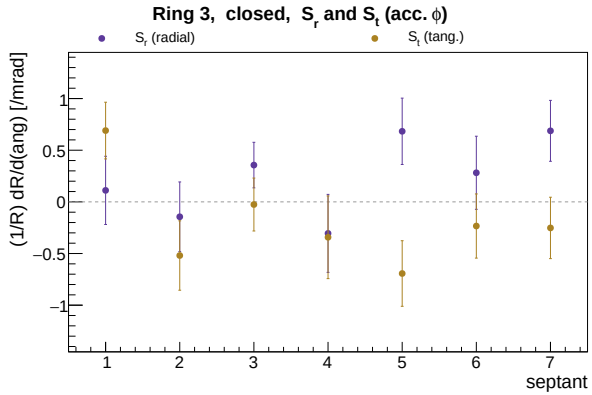


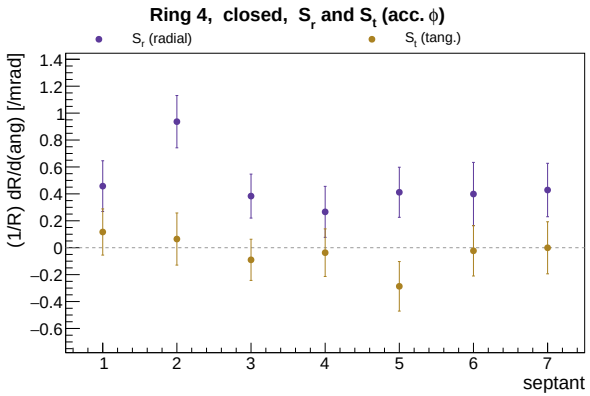
S_r and S_t $[mm^{-1}]$ from position scans, per tile, grouped by open sectors and rings.

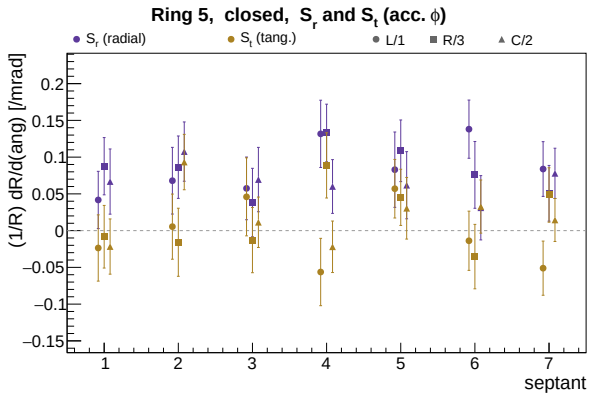
S_r and S_t, angle sensitivity, closed

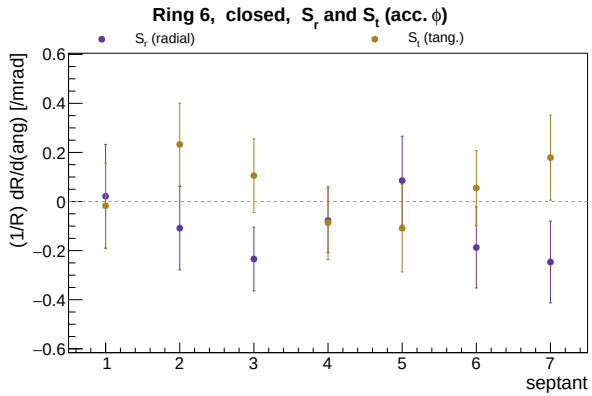






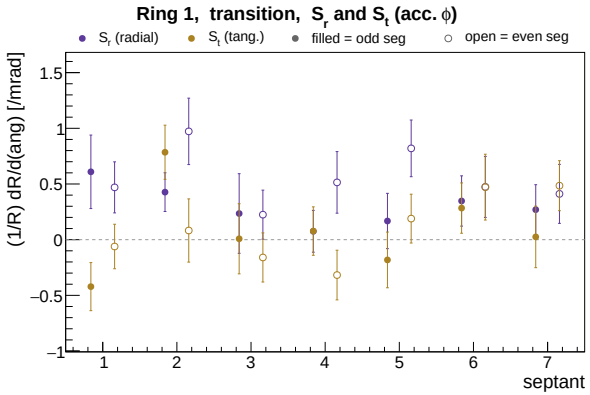


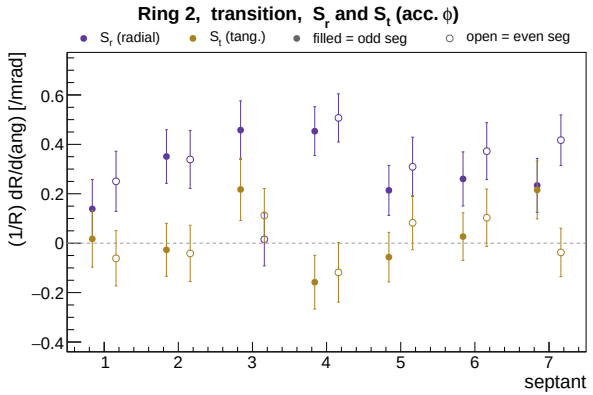


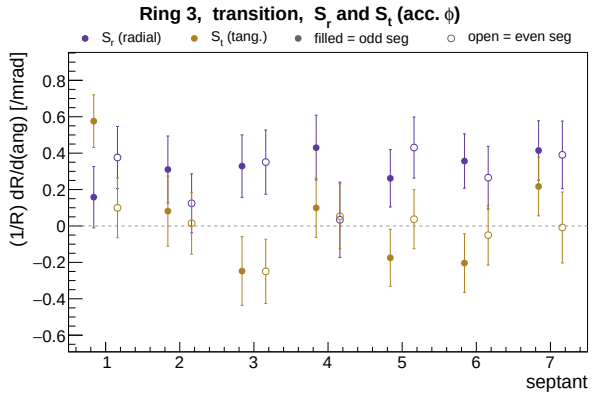


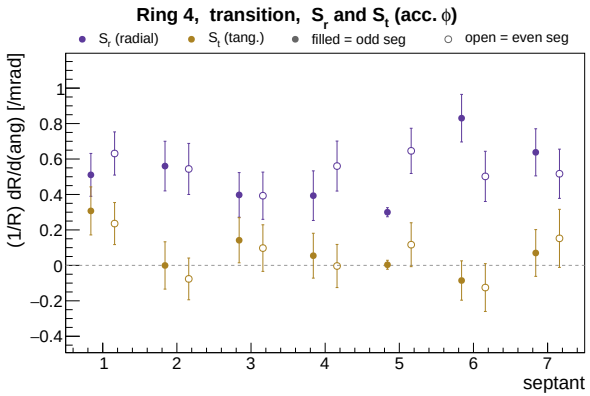
S_r and S_t $[mrad^{-1}]$ from angle scans, per tile, grouped by closed sectors and rings.

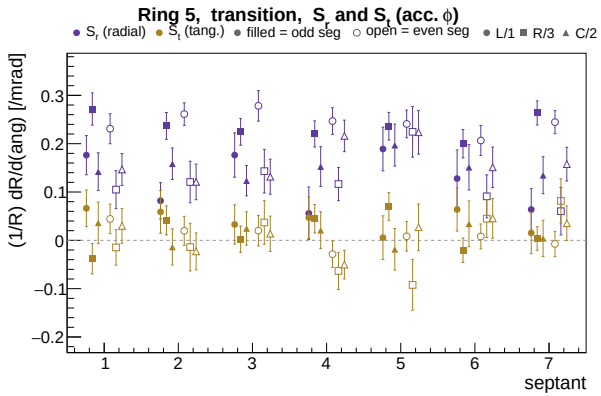
S_r and S_t, angle sensitivity, transition

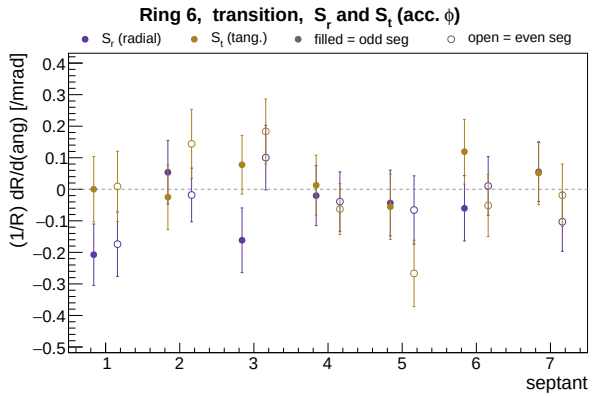






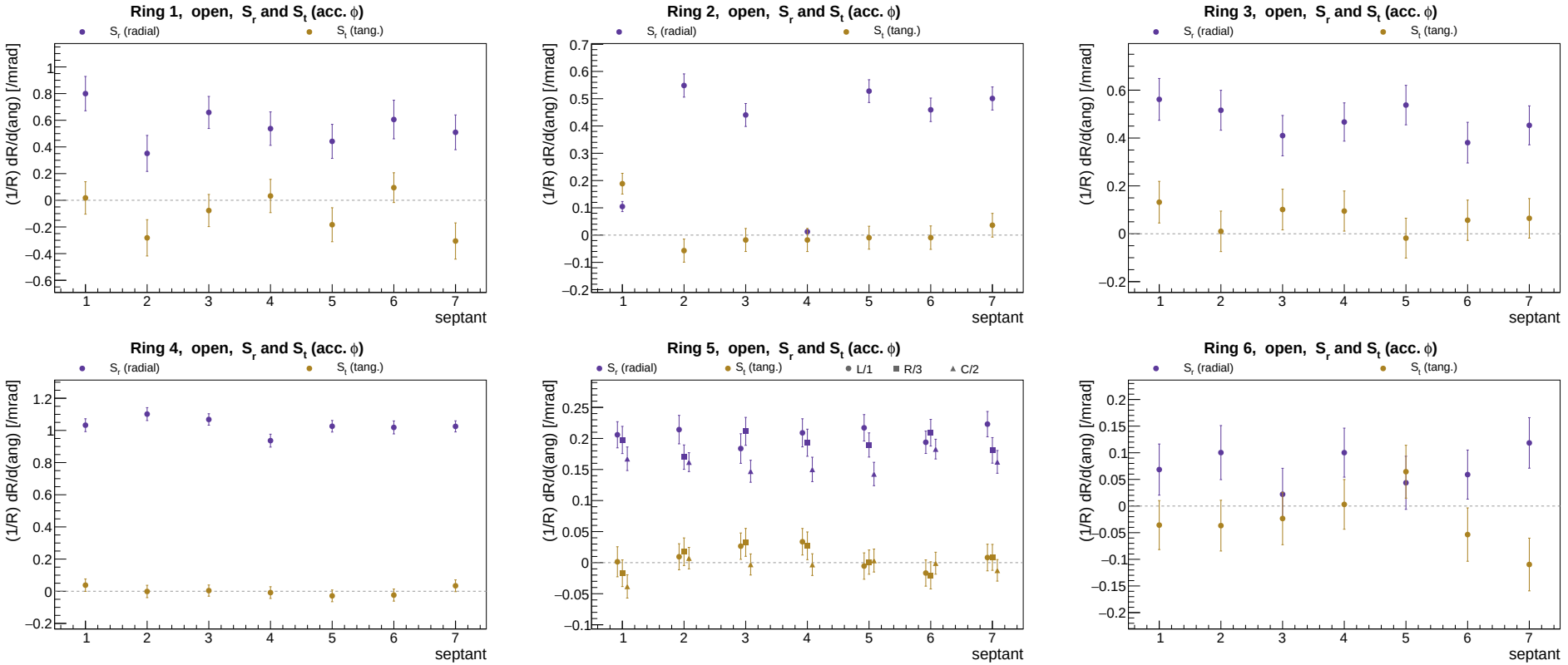






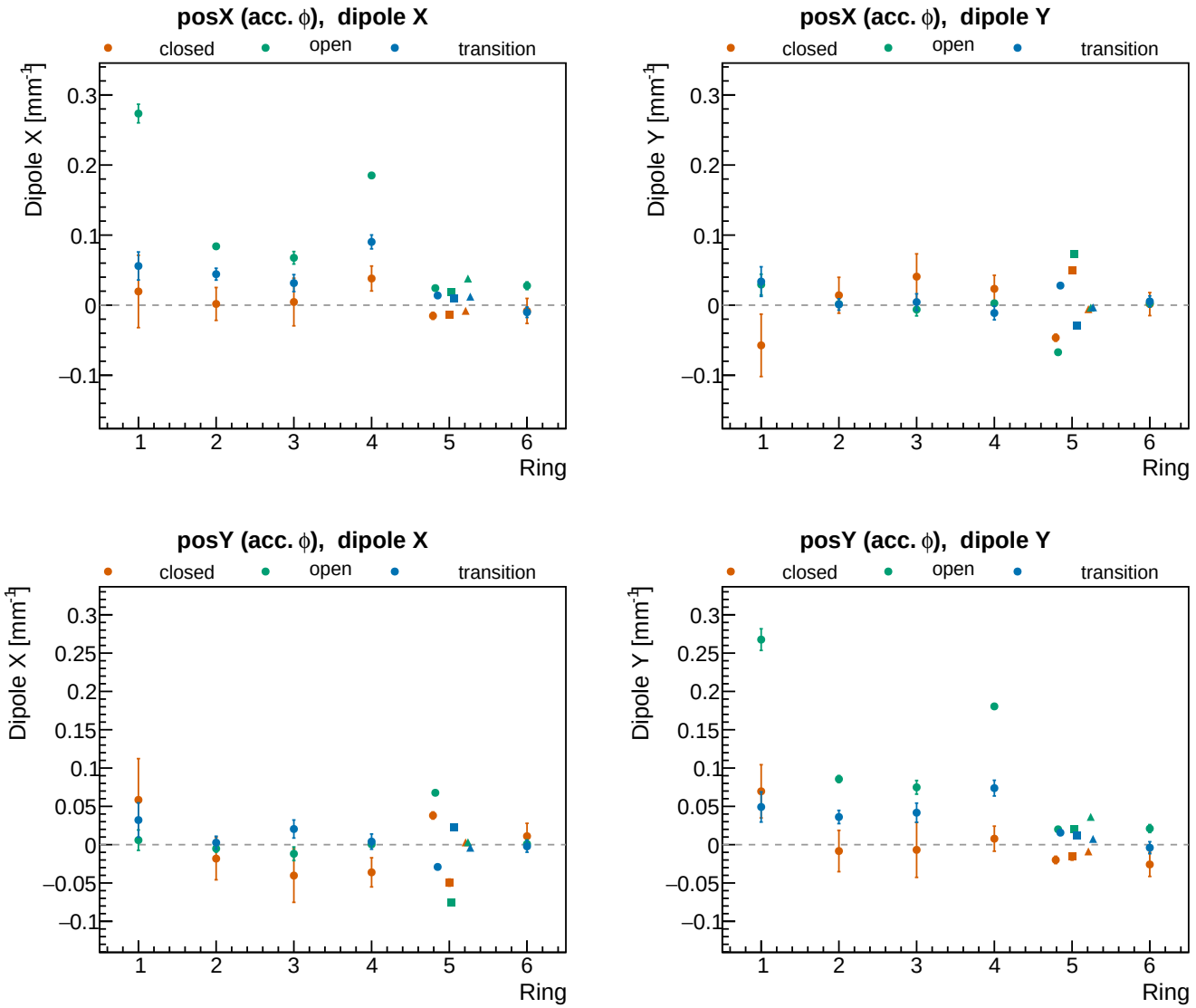
S_r and S_t $[mrad^{-1}]$ from angle scans, per tile, grouped by transition sectors and rings.

S_r and S_t, angle sensitivity, open



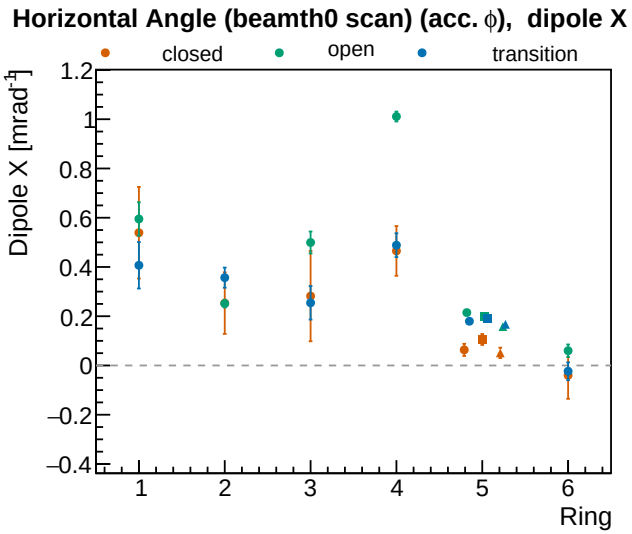
S_r and S_t [$mrad^{-1}$] from angle scans, per tile, grouped by open sectors and rings.

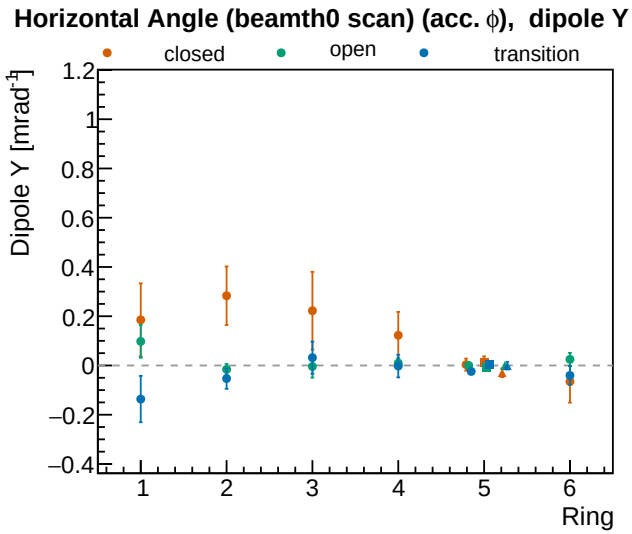
Dipole response, position scans

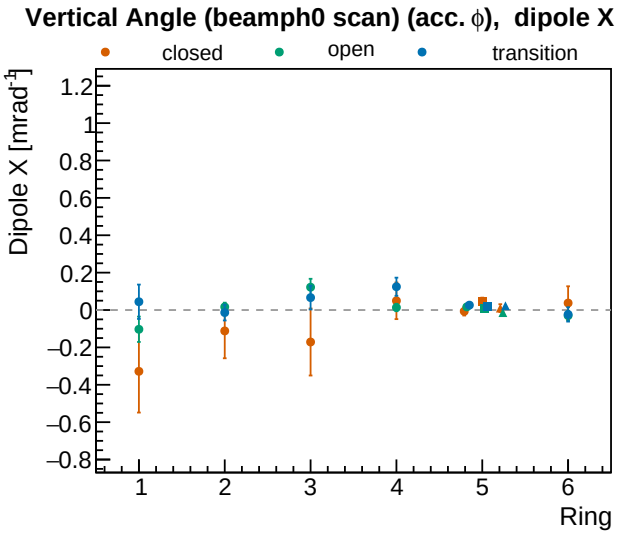


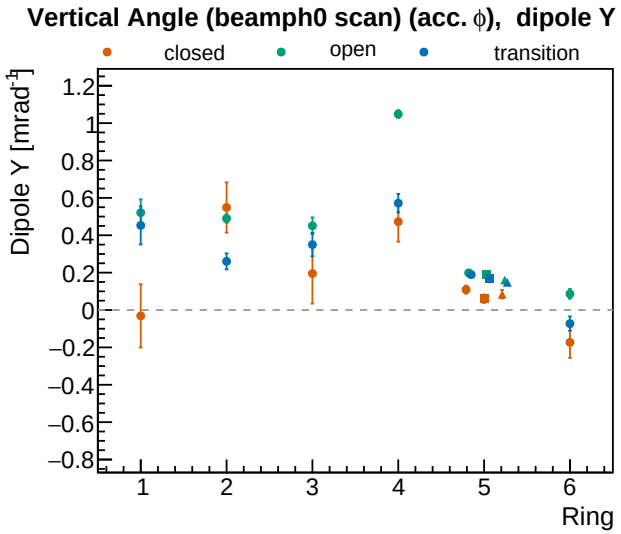
D_x and D_y from position scans, per tile, grouped by open/closed/transition sectors and rings.

Dipole response, angle scans









D_x and D_y from angle scans, per tile, grouped by open/closed/transition sectors and rings.

Mock data sensitivity parameters

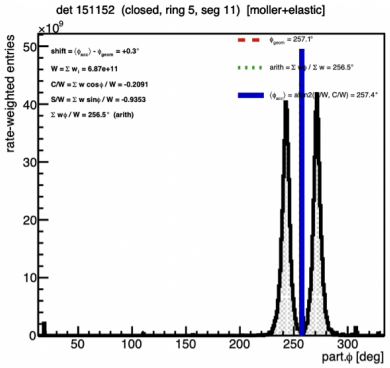
Generated mock_parameters_thinqtz_remoll.map for japan-MOLLER mock data generator, replacing placeholder sensitivities with remoll simulation values.

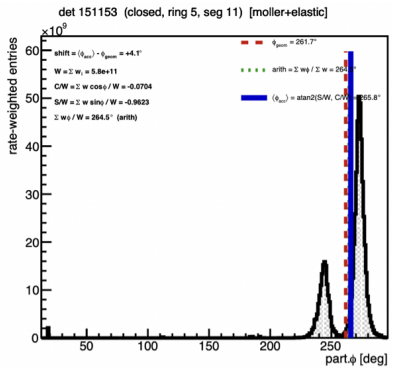
- NormRate (Hz/μA), VoltPerHz, Asym columns are unchanged.
- C_x, C_y: position sensitivities S_{posX}, S_{posY} in ppm/nm = mm^{-1}
- C_{xp}, C_{yp}: angle sensitivities S_{angX}, S_{angY} in ppm/nrad = mrad^{-1}
- C_e: energy sensitivity = $S_{beamE}[MeV^{-1}] \times E_{\mathrm{beam}}[\mathrm{MeV}]$,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

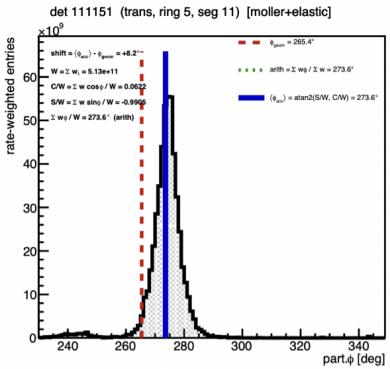
!Name	NormRate(Hz/uA)	VoltPerHz	Asym	C_x	C_y	C_xp	C_yp	C_e
TQ01_R1	110923	2.120e-07	0.0001	0.065151	-0.010319	0.302114	-0.383741	-18.454511
TQ01_R2	1144615	4.120e-08	0.0001	-0.022958	-0.134693	-0.259057	-0.332105	5.688359
TQ01_R3	756923	4.120e-08	0.0001	0.024577	-0.016492	0.021176	0.659107	-10.392786
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

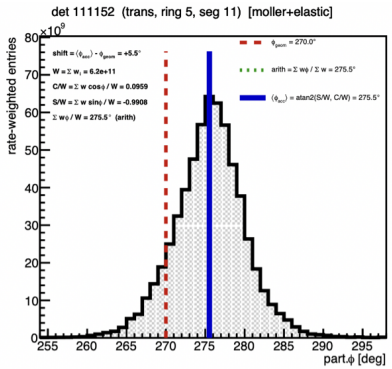
Backup

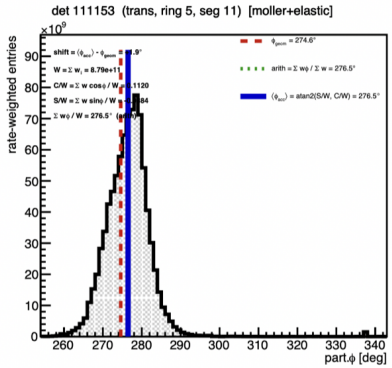
part.ph

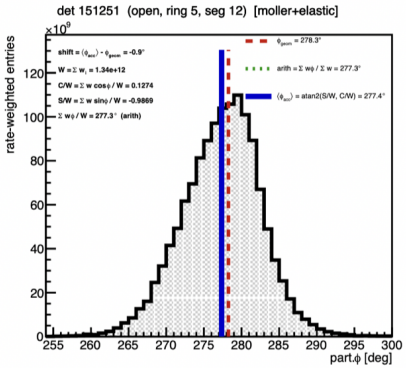

det 151152 (closed, ring 5, seg 11) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

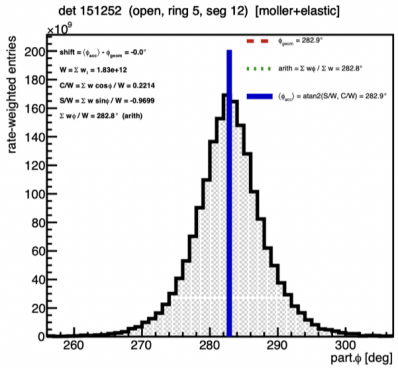

det 151153 (closed, ring 5, seg 11) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

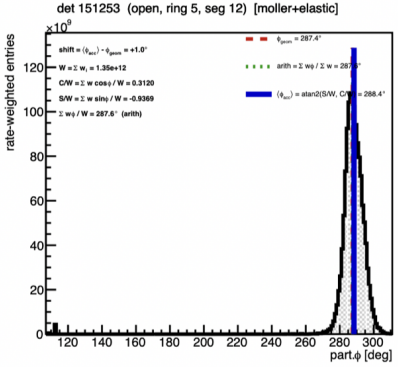

det 111151 (trans, ring 5, seg 11) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

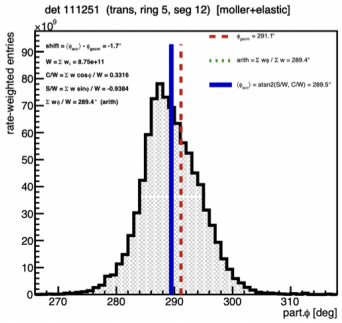

det 111152 (trans, ring 5, seg 11) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

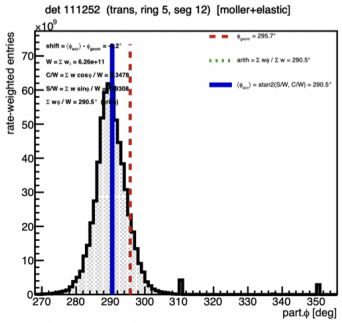

det 111153 (trans, ring 5, seg 11) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

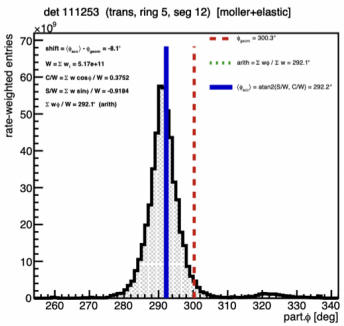

det 151251 (open, ring 5, seg 12) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

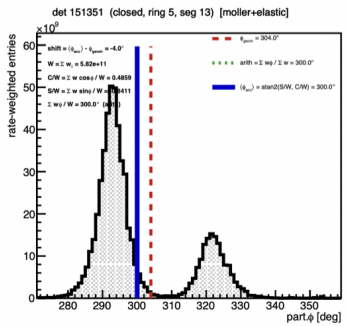

det 151252 (open, ring 5, seg 12) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

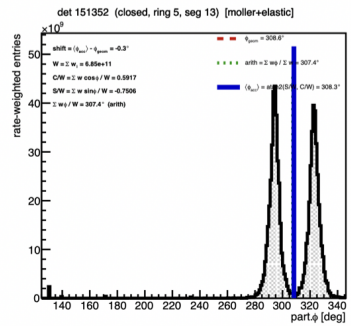

det 151253 (open, ring 5, seg 12) [moller+elastic]
rate-weighted entries
part.ϕ [deg]


det 111251 (trans, ring 5, seg 12) [moller+elastic]
rate-weighted entries
part.ϕ [deg]


det 111252 (trans, ring 5, seg 12) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

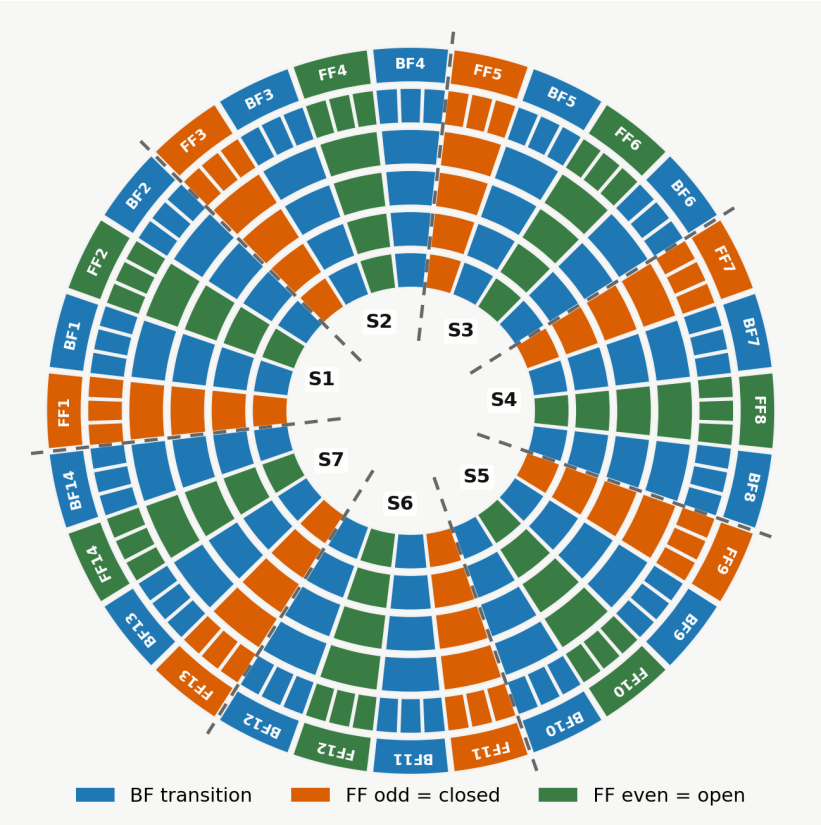

det 111253 (trans, ring 5, seg 12) [moller+elastic]
rate-weighted entries
part.ϕ [deg]


det 151351 (closed, ring 5, seg 13) [moller+elastic]
rate-weighted entries
part.ϕ [deg]


det 151352 (closed, ring 5, seg 13) [moller+elastic]
rate-weighted entries
part.ϕ [deg]

Quartz tiles

- Tiles are split into **6 rings** (Ring 1 = innermost, Ring 6 = outermost).
- Within each ring, tiles are in this fixed order:
- **Closed** FF-odd segments (1, 3, 5, 7, 9, 11, 13)
- **Open** FF-even segments (2, 4, 6, 8, 10, 12, 14)
- **Transition** BF, all segments (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14)



How is the fractional sensitivity calculated?

- Run 3 simulations: $X = -1\,\text{mm}$, 0 (nominal), $+1\,\text{mm}$ (or $\pm 0.2\,\text{mrad}$ for angles, or $\pm 110\,\text{MeV}$ for energy).
- Extract detector hit rate $R_d(X)$ [GHz] from the simulation output.
- Fit a straight line through those 3 points:

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

  $b_d = dR_d/dX$ in GHz/mm (or GHz/mrad, GHz/MeV).
- Both generators' slopes and nominal rates are summed:
  $b_d^{\text{tot}} = b_d^{\text{Mol}} + b_d^{\text{EP}}, \quad a_d^{\text{tot}} = a_d^{\text{Mol}} + a_d^{\text{EP}}$
- Divide slope by the rate at $X = 0$ (the fit intercept a_d):

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

Sensitivity depends on azimuthal angle ϕ

- a horizontal beam shift (x) will cause a left-right asymmetry in the detector response, so the sensitivity to x will vary with ϕ (max at $\phi = 0^\circ$, min at $\phi = 180^\circ$)
- a vertical beam shift (y) will cause an up-down asymmetry, so the sensitivity to y will also vary with ϕ (max at $\phi = 90^\circ$, min at $\phi = 270^\circ$)
- in order to remove the ϕ dependence, we can rotate the sensitivities into a local basis for each tile.

Rotated basis and dipole response

For each tile, we use its azimuthal angle to convert the X and Y sensitivities into that tile's own local coordinates;

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

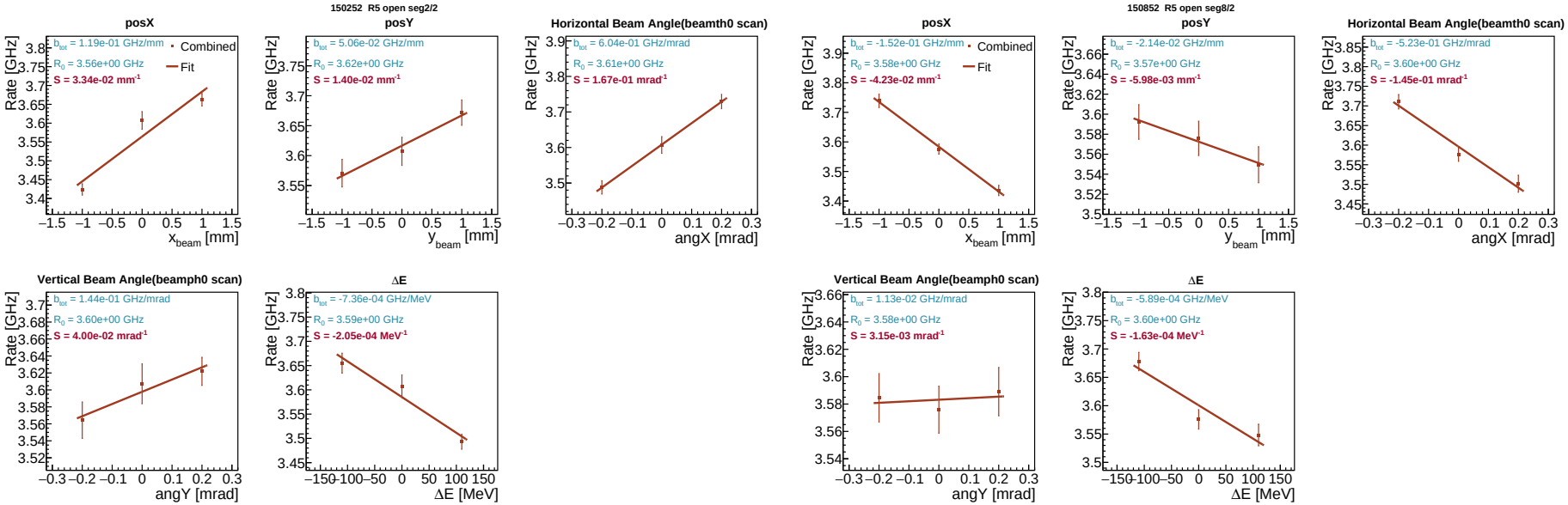
- S_r: radial sensitivity ,S_t: tangential sensitivity
- This rotation is applied separately to position (S_{posX}, S_{posY}) and angle (S_{angX}, S_{angY}) scans.
- here, azimuthal angle ϕ is geometric center of each tile.
  - FF tiles at $\phi = (n{-}1) \times 360^\circ/14$,
  - BF tiles offset by $360^\circ/28$ ($\approx 12.86^\circ$), where n is the segment number (1–14).
  - Ring 5 subtiles offset from segment center by $\pm 4.59^\circ$ (L, R).

Then, for a given ring and tile type, the dipole is computed from N tiles around azimuth;

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

- $S(\phi_k)$: fractional sensitivity of tile k for a given scan (posX, angX, etc.).
- D_x and D_y: horizontal and vertical dipole response.

All scan comparison



rate vs scan value for all 5 scans, for two selected tiles 150252 (left), 150852 (right).