Detector Tiling and Tile Asymmetry Deconvolution Analysis

MOLLER Collaboration Meeting 2023

May 05, 2023

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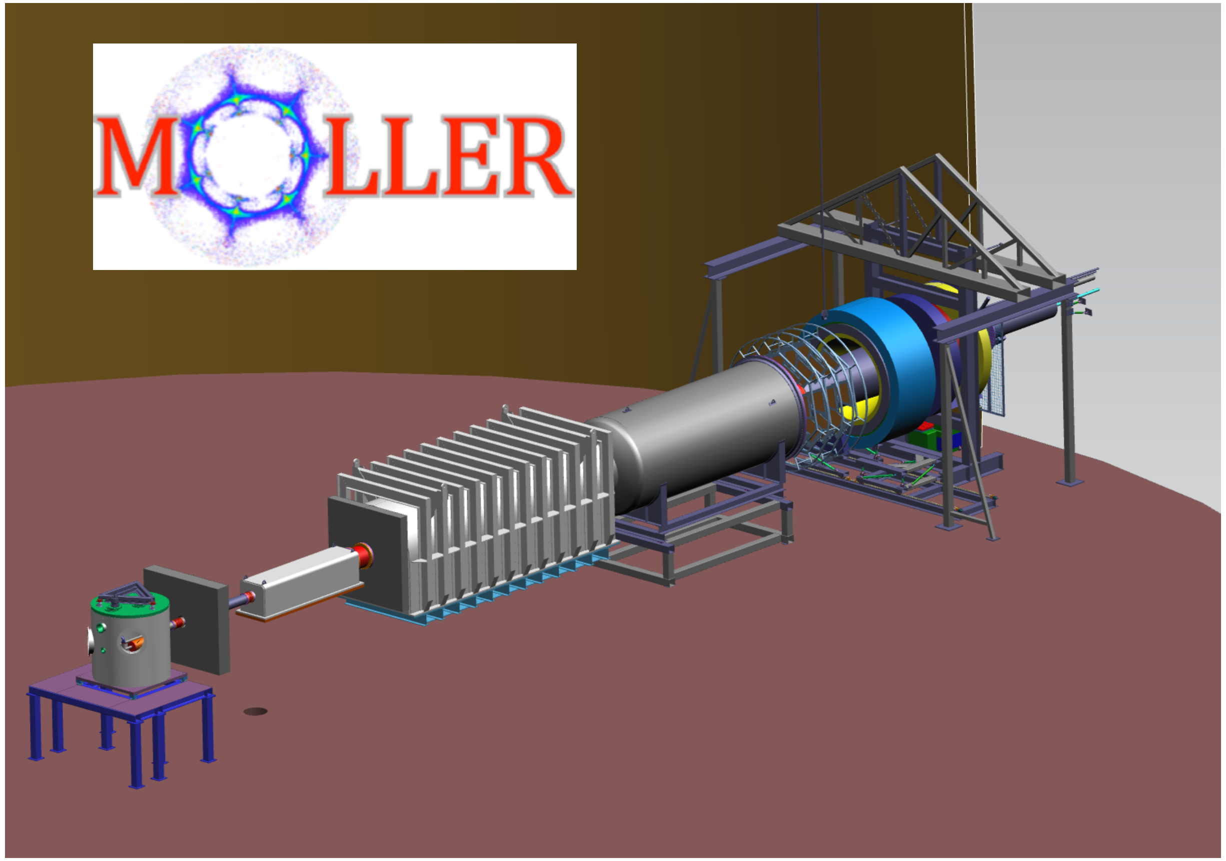
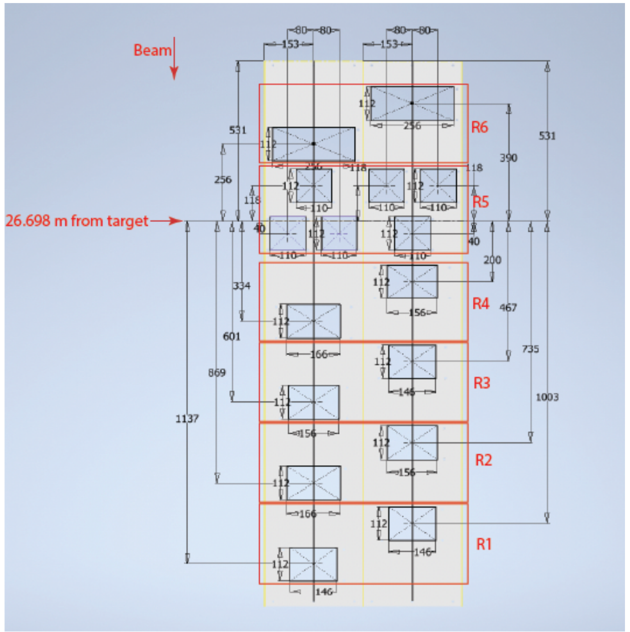
Measurement **O**f a **L**epton **L**epton **E**lectroweak **R**eaction



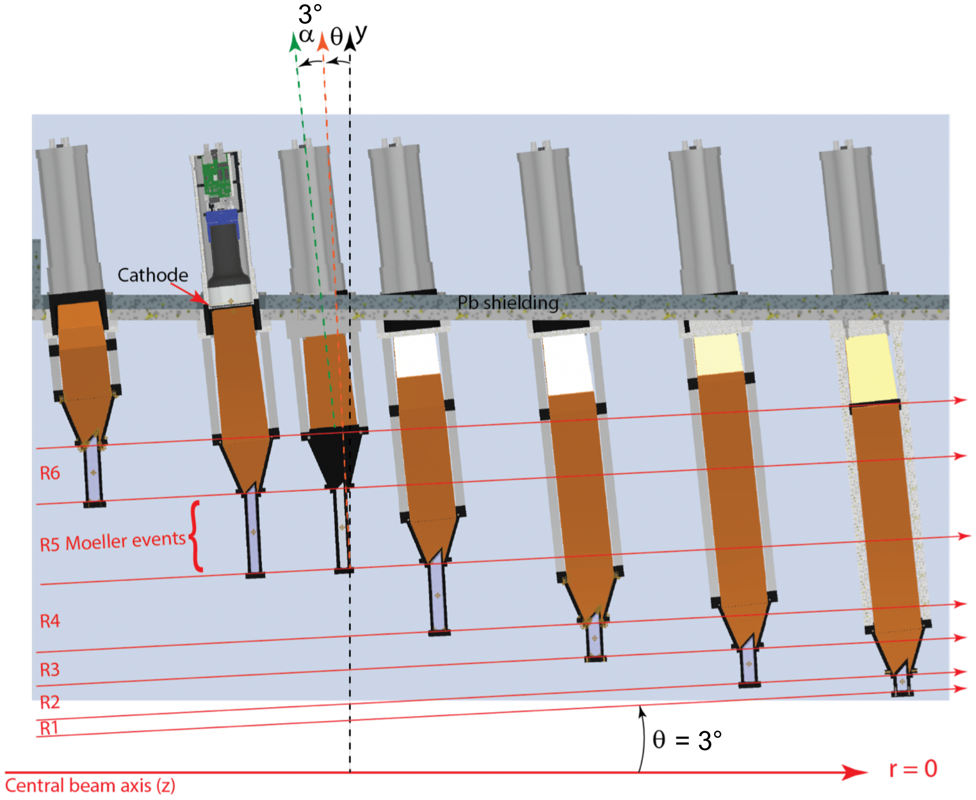
Main Detector Array

Michael Gericke

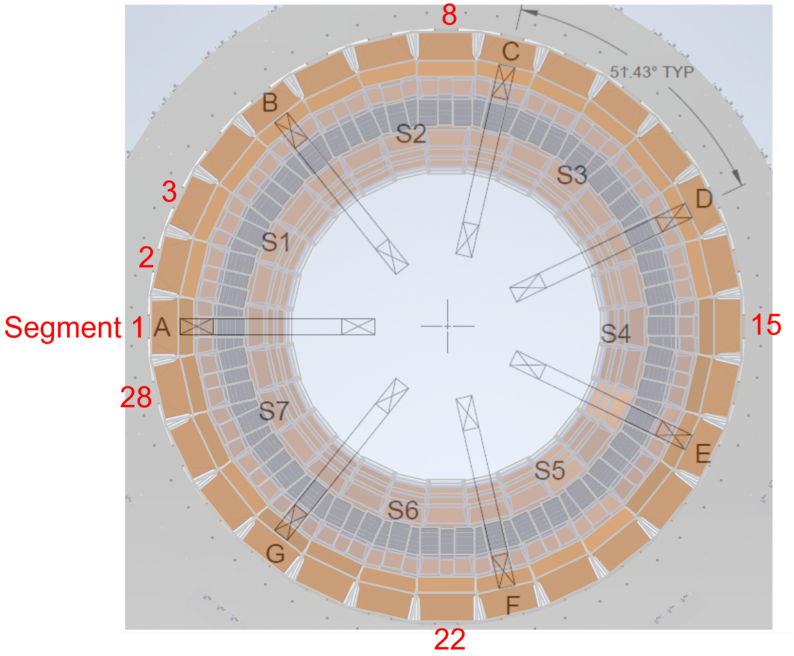
- The main detector is separated into 28 azimuthal segments and 6 radial regions.
  - There are 8 detector modules in each segment.
  - The tiles are covering the entire azimuth and radial region.



Front-flush and back-flush segment plates



Arrangement of the detector modules in the front-flush segment plate.

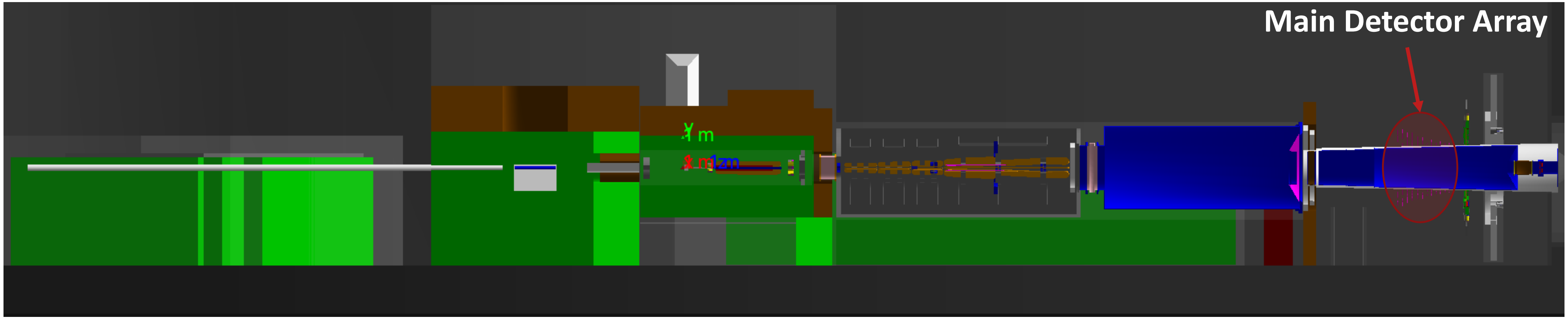


Front view (looking downstream) of the main detector array.

More detailed talks regarding the design of MD will be given at the Integrating Detector Session on May 6th.

Detector Tiling and Tiles in the GEANT4 Simulation

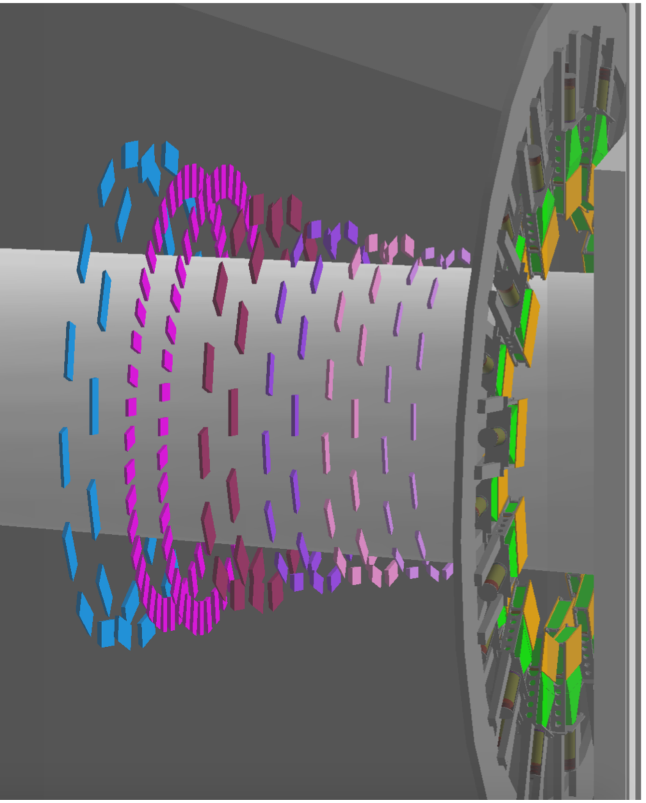
- The main aim is to improve the ability to separate the Møller signal from the e-p elastic and e-p inelastic background.
- The radial dimensions of each quartz tile are set to maximize the Møller signal and get the best precision extraction of the Møller asymmetry in Ring5.



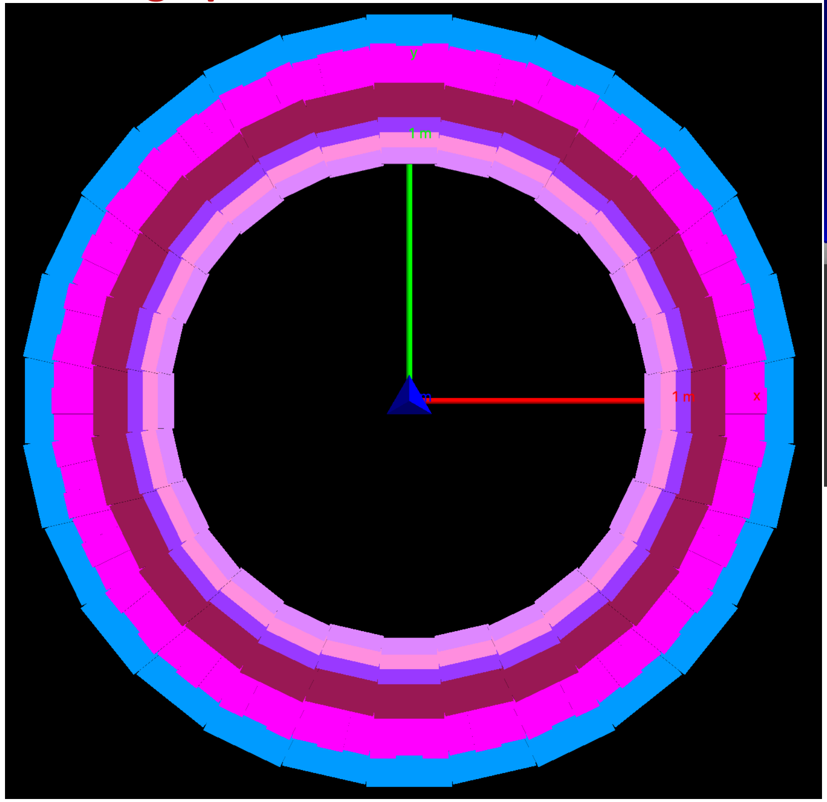
- Michael Gericke has implemented the active volume of the detector modules (224 quartz tiles) into GEANT4 simulation.

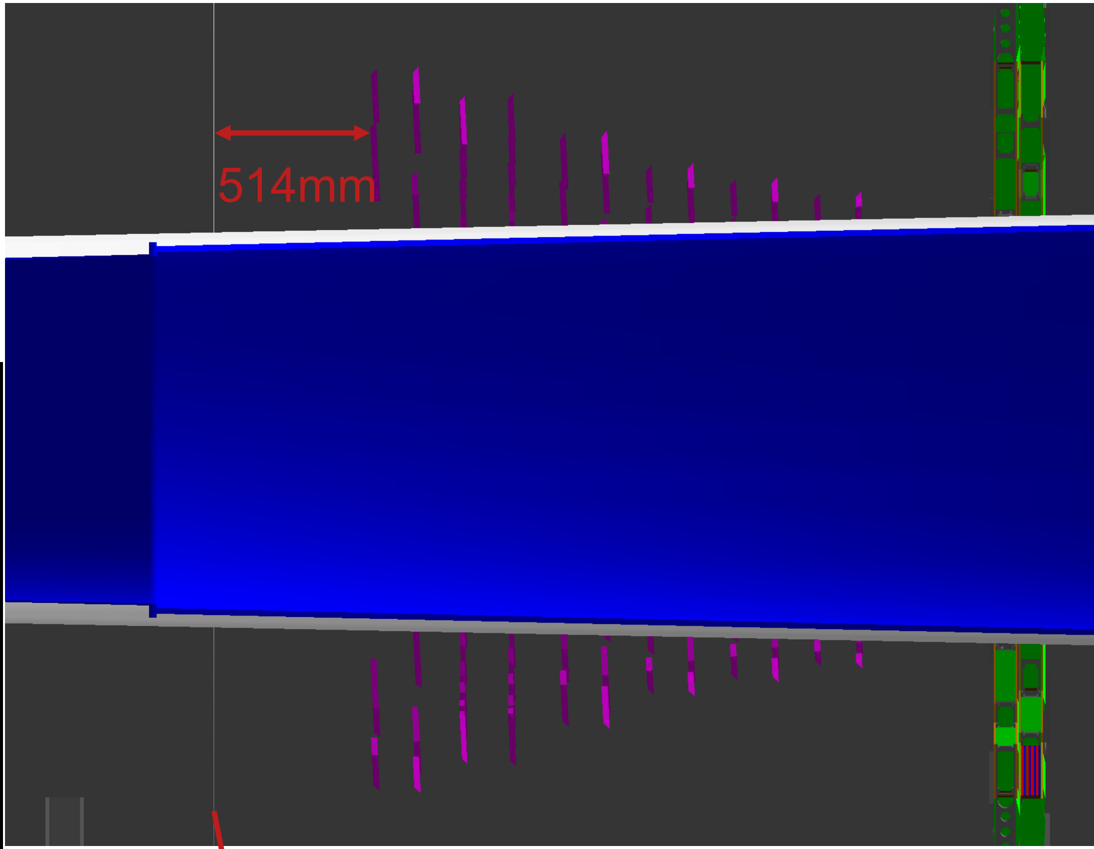
Tiles in the GEANT4 simulation

- Placing a virtual detector plane in the upstream end of the quartz tiles.
  - z-position of the virtual detector plane: 21309.65mm.



Looking upstream





Virtual detector plane, d132

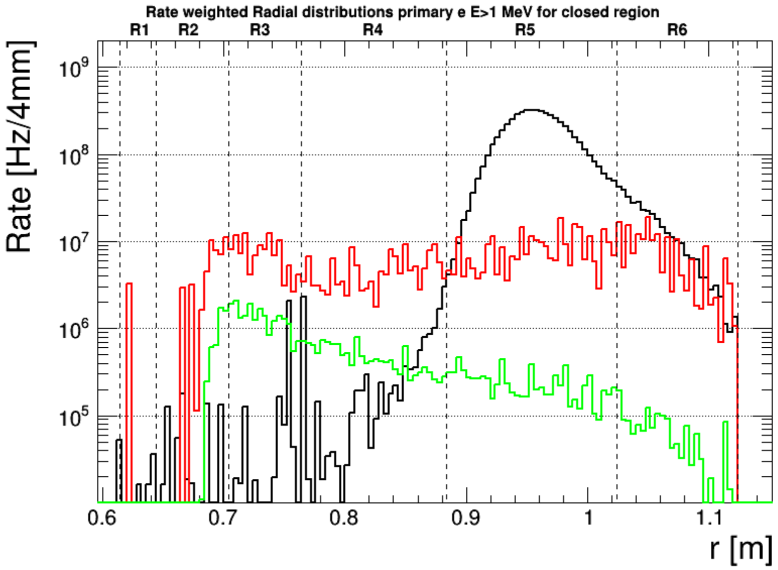
Analysis Procedure

- Run the GEANT4 simulation with the Moller, ep-Elastic, and ep-Inelastic physics generators for 3M events.
- We looked only at primary particles from the target to understand/test the quartz tile geometry (overlap regions).
  - Selected the electron hits with kinE > 1 MeV in virtual detector plane (d132) and then look if those hits will also detect in the quartz tiles.

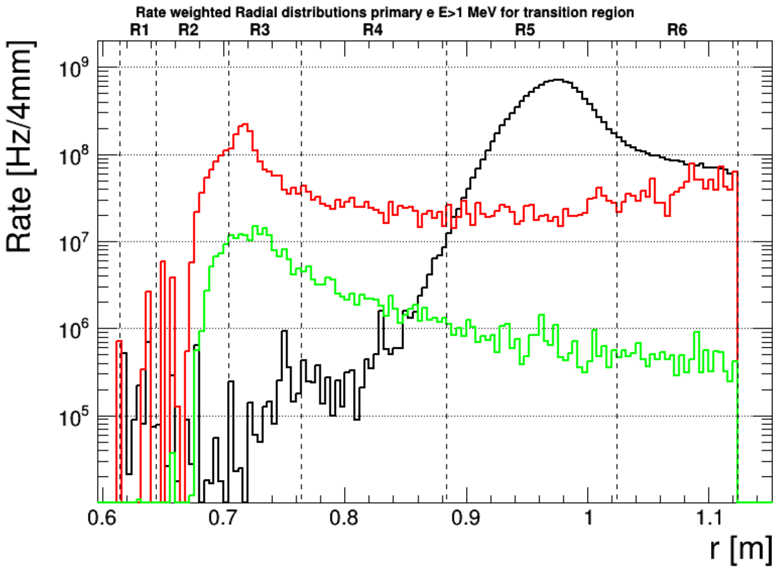
d132		**@21309.65mm**	
Ring	Rmin [mm]	Rmax [mm]	L [mm]
1	613.82	643.82	30.00
2	643.82	703.82	60.00
3	703.82	763.82	60.00
4	763.82	883.82	120.00
5	883.82	1023.82	140.00
6	1023.82	1123.82	100.00

Radial Distributions at the Detector plane #132

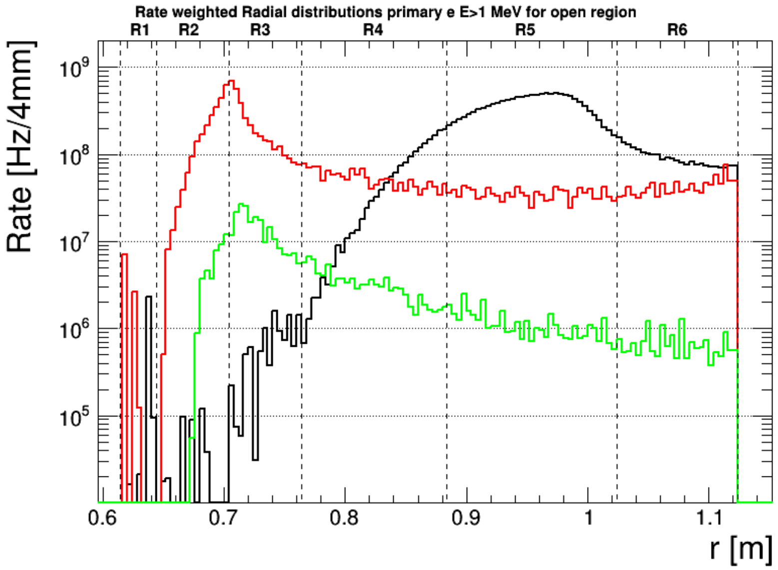
- Simulated signal and background rate as a function of radial location of detected primary electron at the virtual detector plane.



Closed sectors

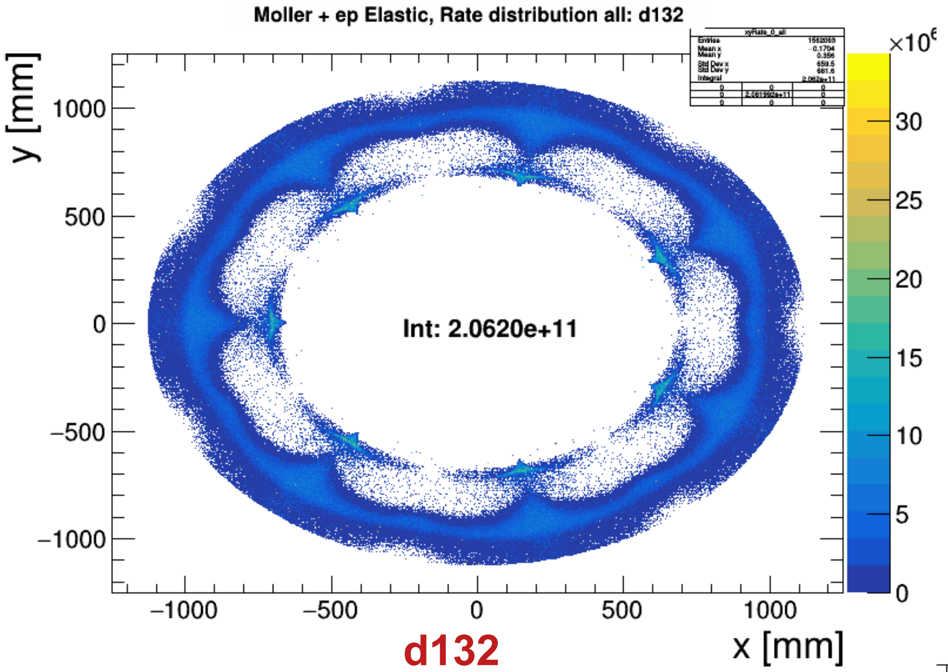


Transition sectors



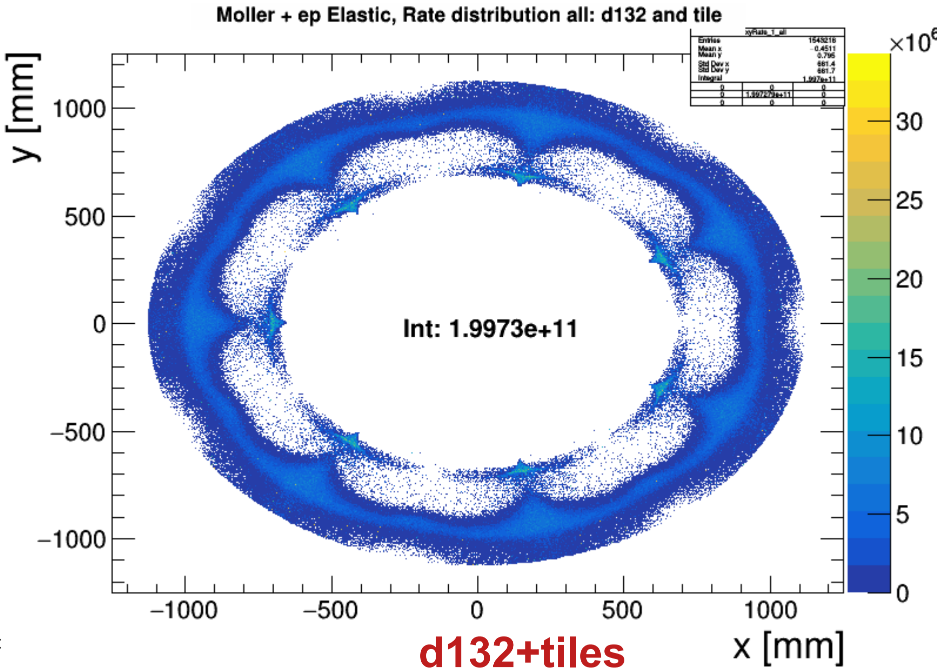
Open sectors

Hit Position Distributions (Moller + ep Elastic Gen)



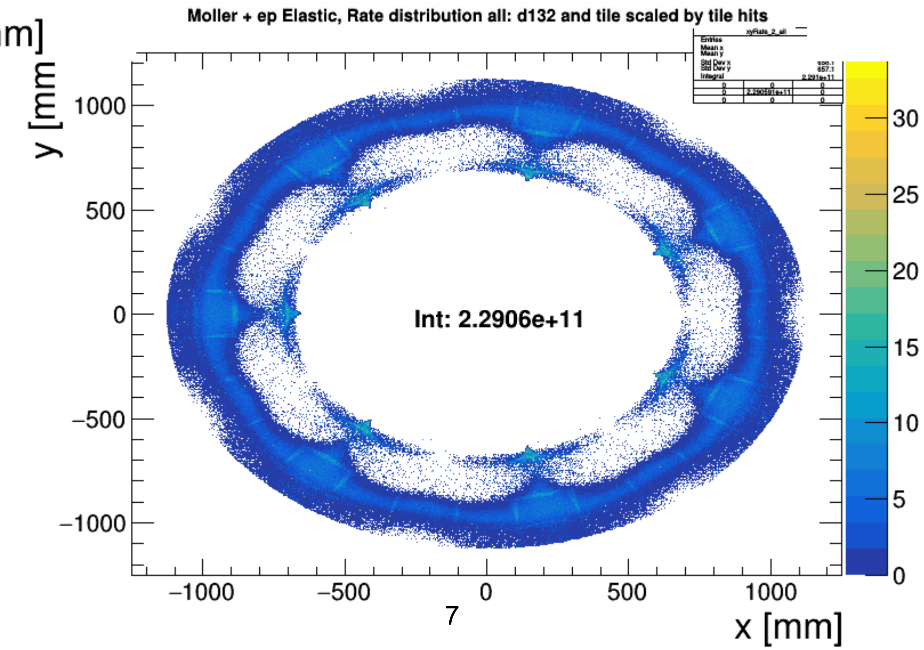
d132

2D rate-weighted the distribution of *e*-hits at d132.



d132+tiles

2D rate-weighted the distribution of *e*-hits which are also detected by quartz tiles.

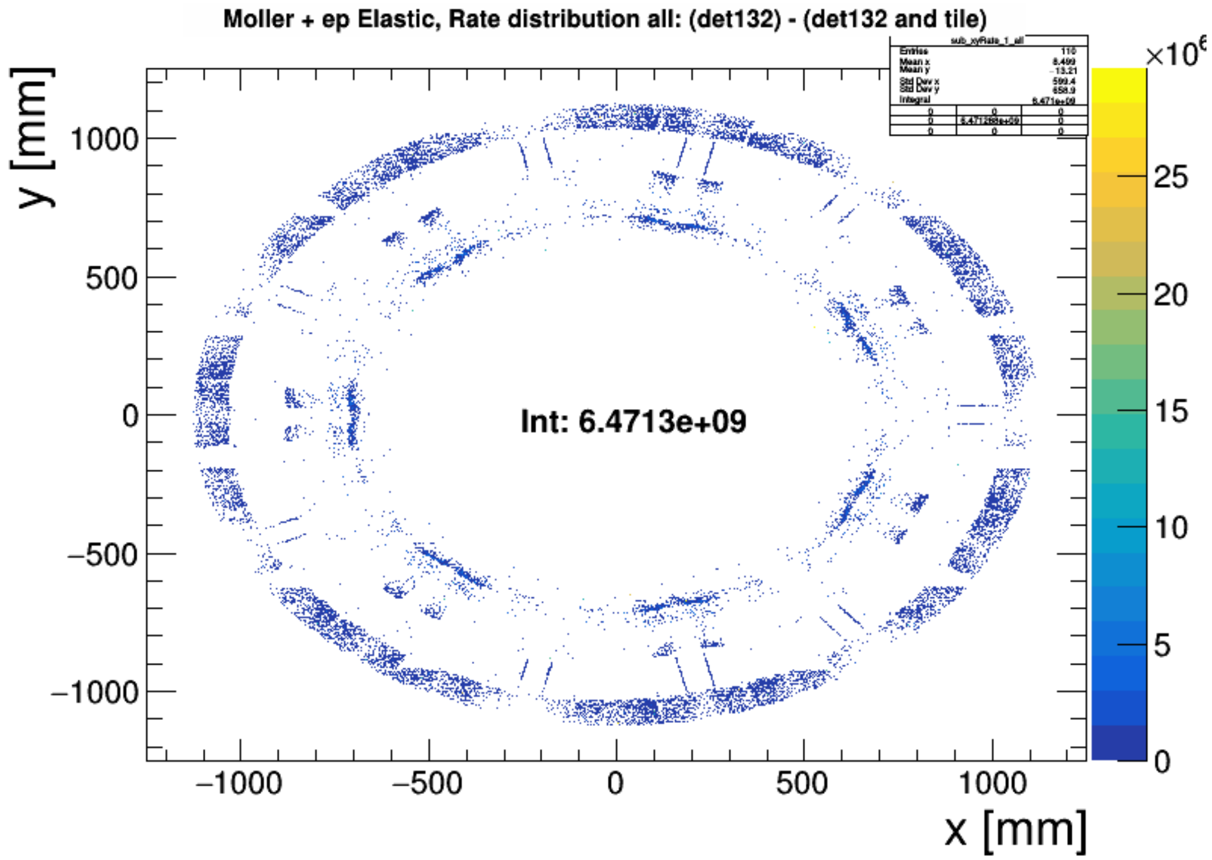


(d132+tiles)*#TileHits

2D rate*Number of tiles hits-weighted the distribution of *e*-hits which are also detected by quartz tiles.

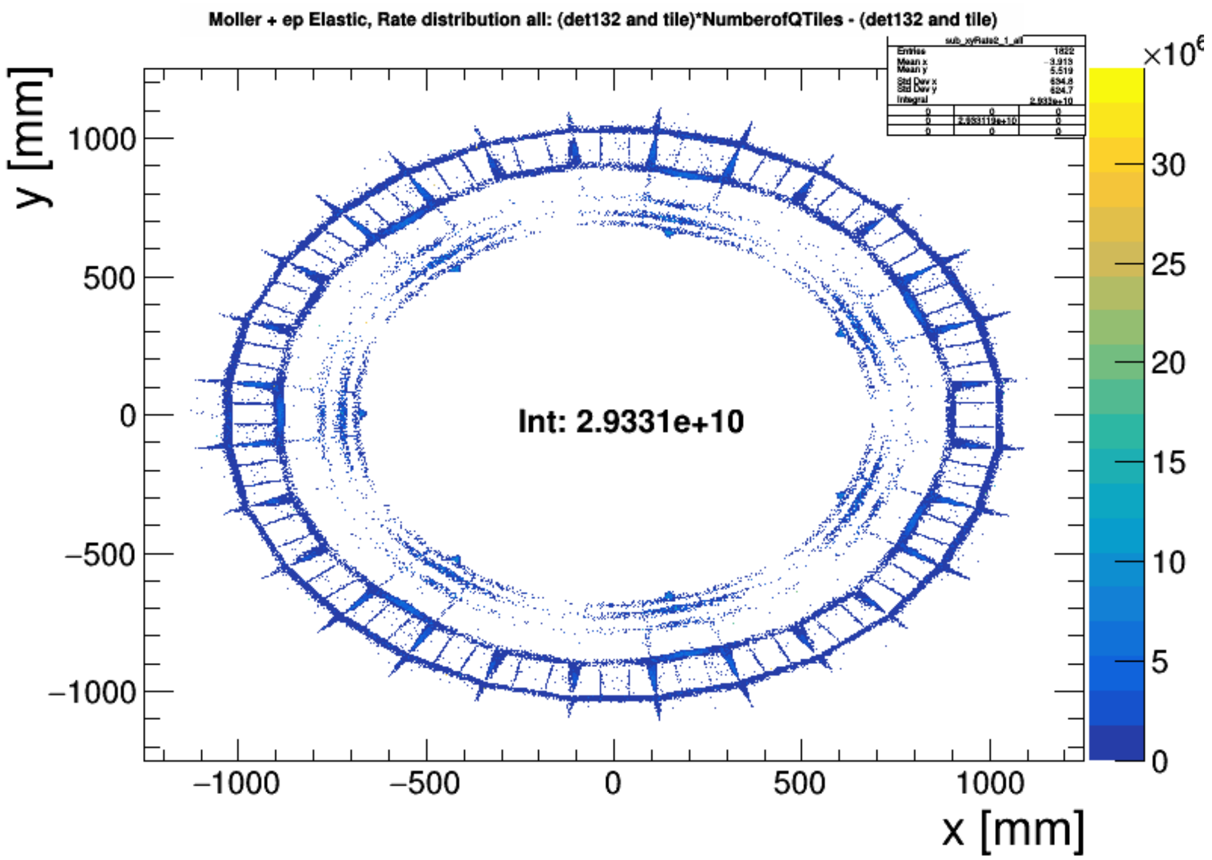
Hit Position Distributions (Moller + ep Elastic Gen)

Missed Hits



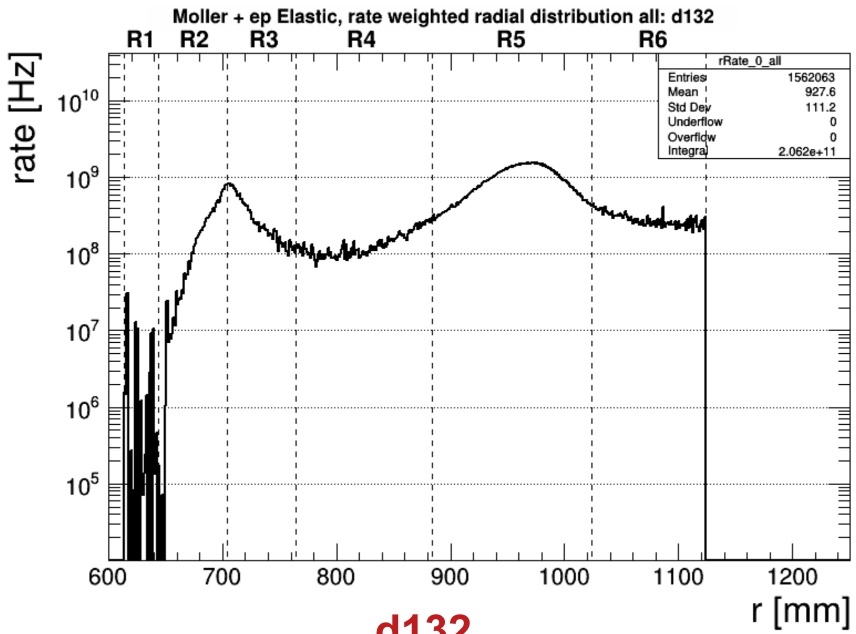
The difference in hits between **d132** and **d132+tiles**

Overlapped Hits



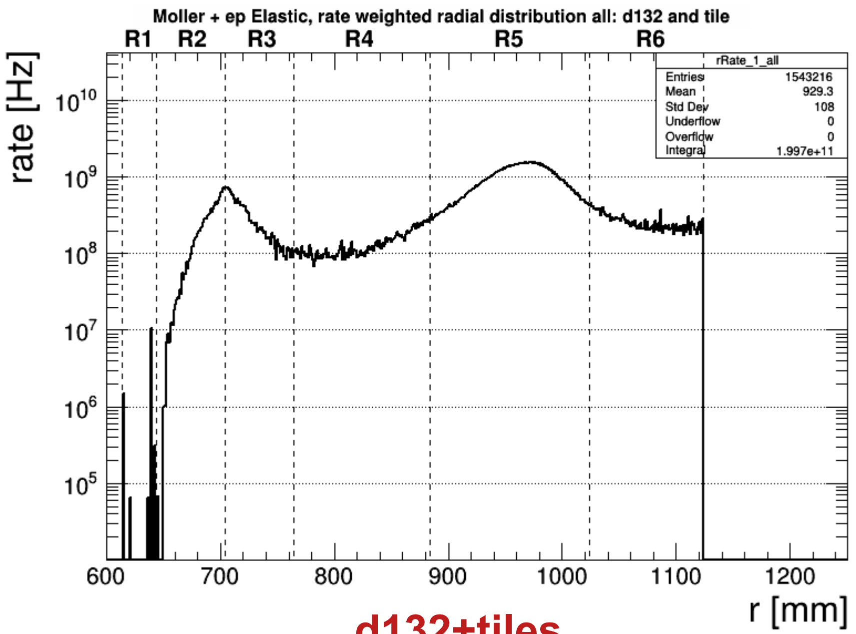
The difference in hits between **(d132+tiles)*#TileHits** and **d132+tiles**

Radial Distributions (Moller + ep Elastic Gen)



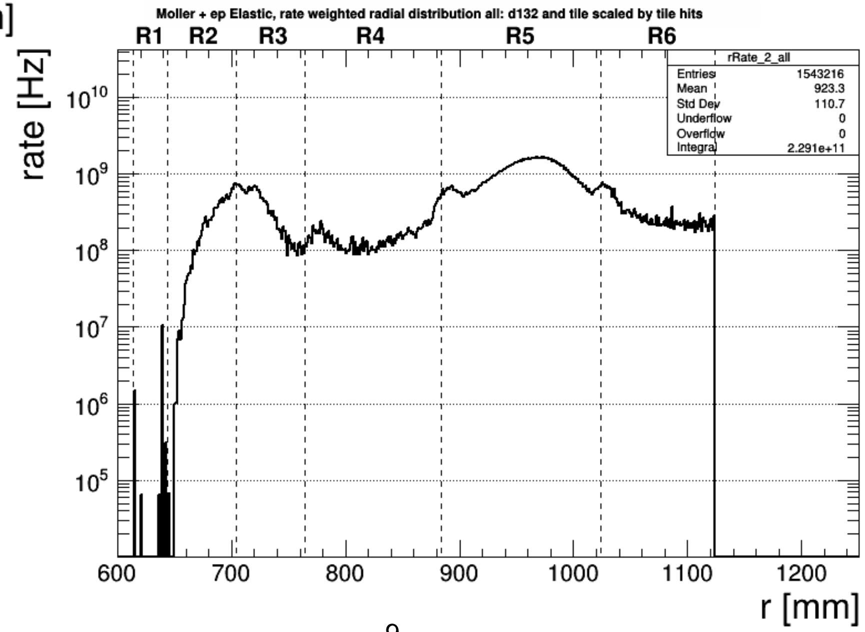
d132

2D rate-weighted the distribution of *e*-hits at d132.



d132+tiles

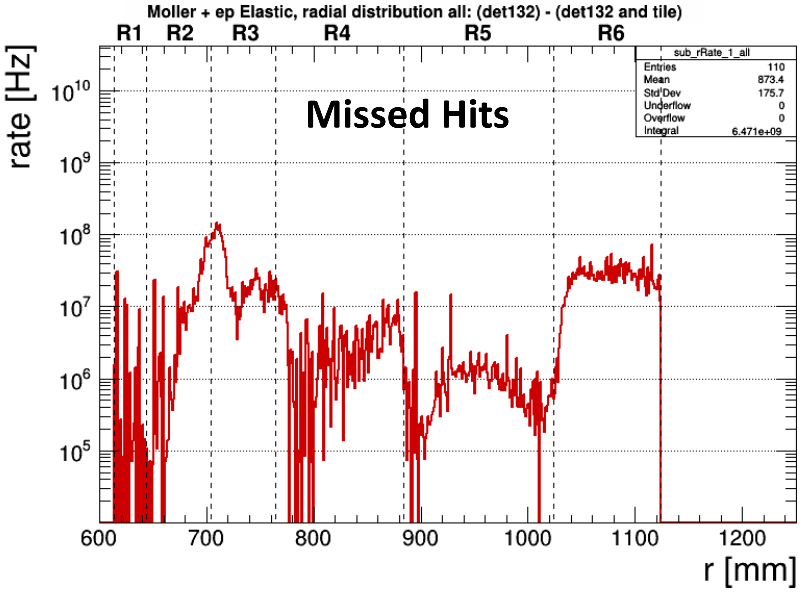
2D rate-weighted the distribution of *e*-hits which are also detected by quartz tiles.

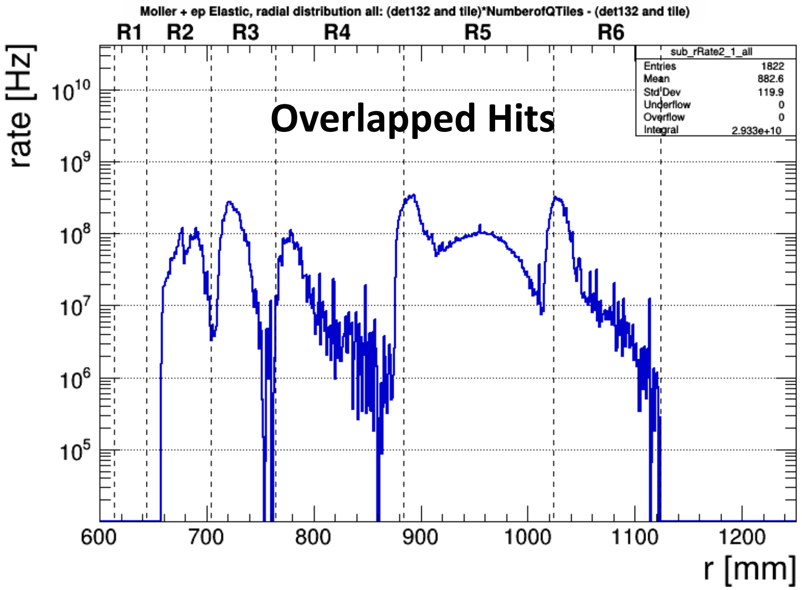


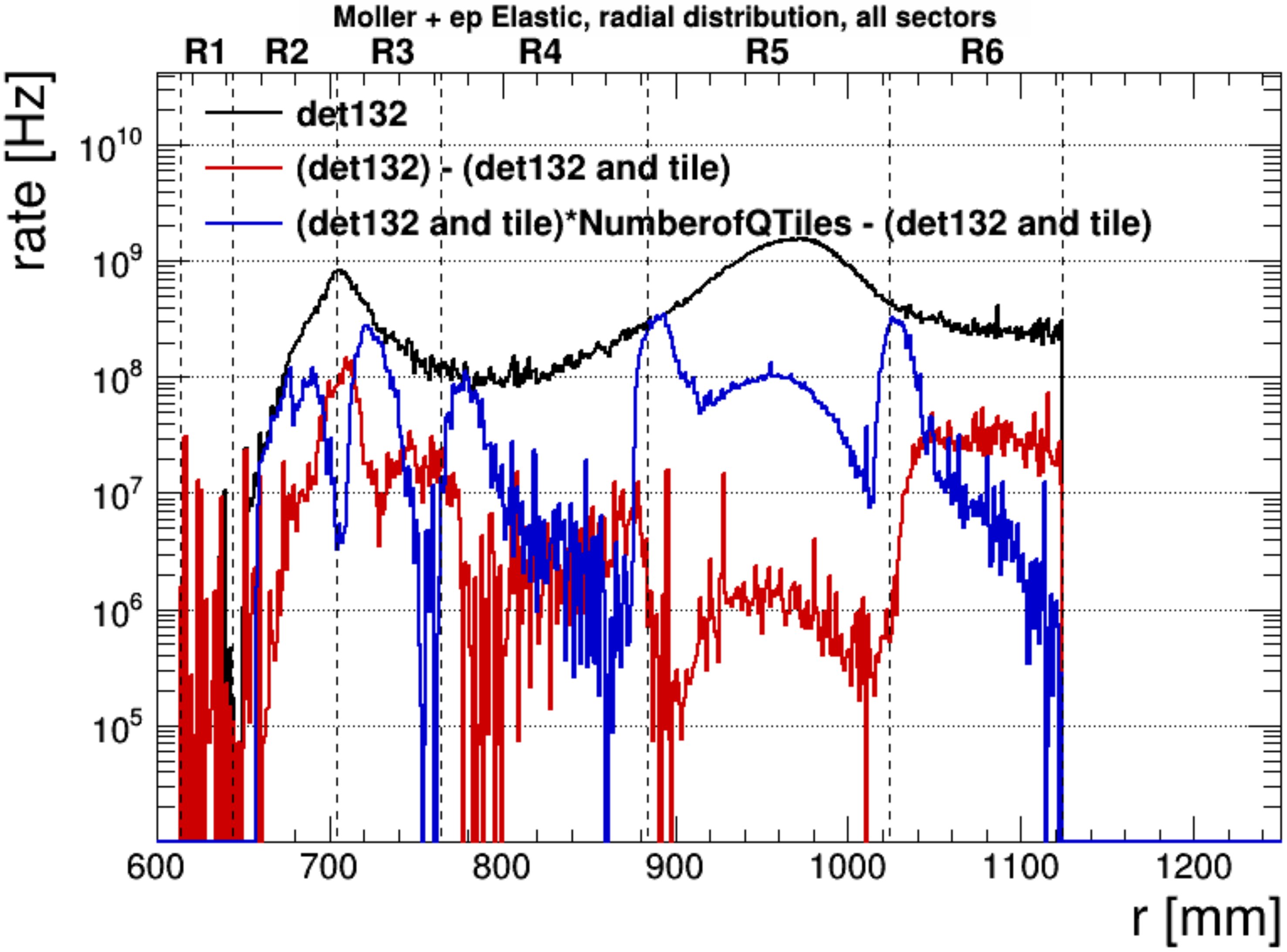
(d132+tiles)*#TileHits

2D rate*Number of tiles hits-weighted the distribution of *e*-hits which are also detected by quartz tiles.

Radial Distributions (Moller + ep Elastic Gen)







Summary Tables for the Missed/Overlapped Hits

	Integral values from rate-weighted 2d hit position distributions				
	d132	d132+tile	(d132+tile)*NumberOfTiles	Missed Hits	Overlapped Hits
Ring1	8.40E+07	1.26E+07	1.28E+07	7.13E+07	1.35E+05
Ring2	1.19E+10	1.11E+10	1.36E+10	8.96E+08	2.52E+09
Ring3	1.96E+10	1.74E+10	2.23E+10	2.24E+09	4.87E+09
Ring4	1.68E+10	1.63E+10	1.96E+10	5.14E+08	3.35E+09
Ring5	1.29E+11	1.29E+11	1.43E+11	1.50E+08	1.38E+10
Ring6	2.87E+10	2.61E+10	3.08E+10	2.60E+09	4.77E+09
allRings	2.06E+11	2.00E+11	2.29E+11	6.47E+09	2.93E+10

- Most of the missed hits that are on Ring 3 and Ring 6.

% Contribution to the total	
Missed Hits	Overlapped Hits
1%	0%
14%	9%
35%	17%
8%	11%
2%	47%
40%	16%

Tile Asymmetry Deconvolution Analysis

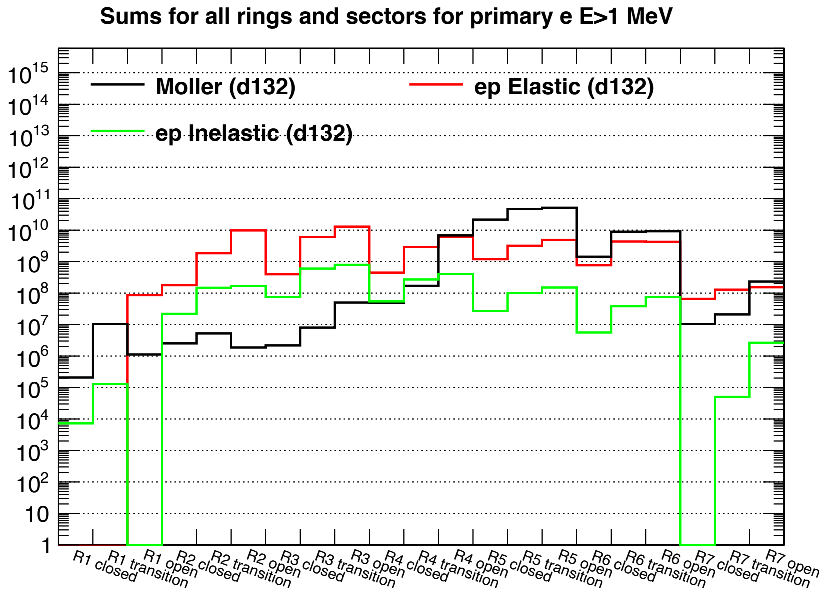
- The deconvolution analysis is used to extract the asymmetries in the signal and background processes from the data.

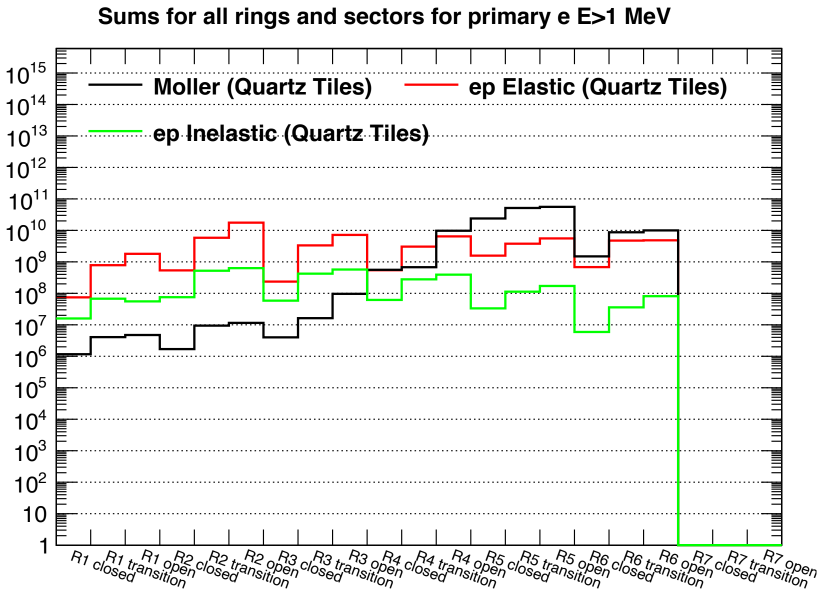
- In i_{th} (r,ϕ)bin, measured asymmetry;

$$A_m^i = f_{ee}^i\, A_{ee}^i + f_{ep-elastic}^i\, A_{ep-elastic}^i + f_{ep-inelastic}^i\, A_{ep-inelastic}^i + f_{eAl-elastic}^i\, A_{eAl-elastic}^i + f_{eAl-inelastic}^i\, A_{eAl-inelastic}^i$$

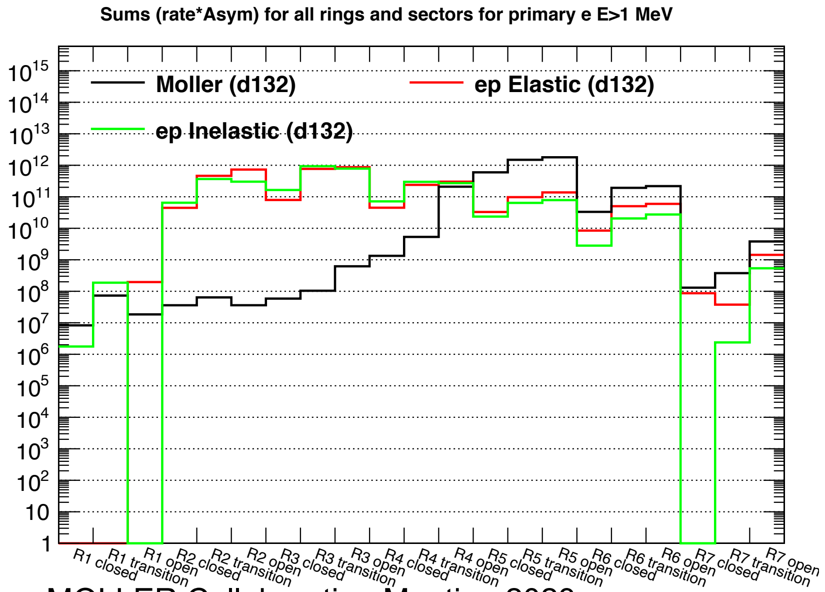
- The dilution for a given process:
  - $f_k = N_k / \sum_j N_j$, N_k: The rate of detected events from process k.
- Run the physics generators (Moller, epelastic, epinelastic, pion, elasticAl, inelasticAl, quasielasticAl) with 1M events.
- The deconvolution analysis is based on the 5 process fit.
  - Moller, ep-elastic, ep-inelastic (separated into three bins in W: $1 < W < 1.4$ GeV, $1.4 < W < 2.5$ GeV, $2.5 < W < 6$ GeV).

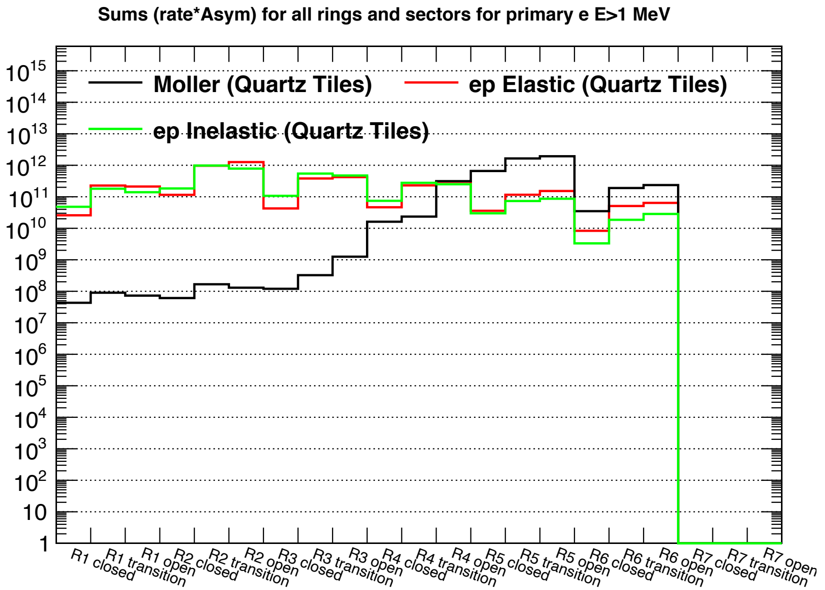
Total Rate in the Tiles





Total rate of the primary electrons in all the Rings and ϕ-sectors for Moller, ep Elastic and ep Inelastic event physics generators.

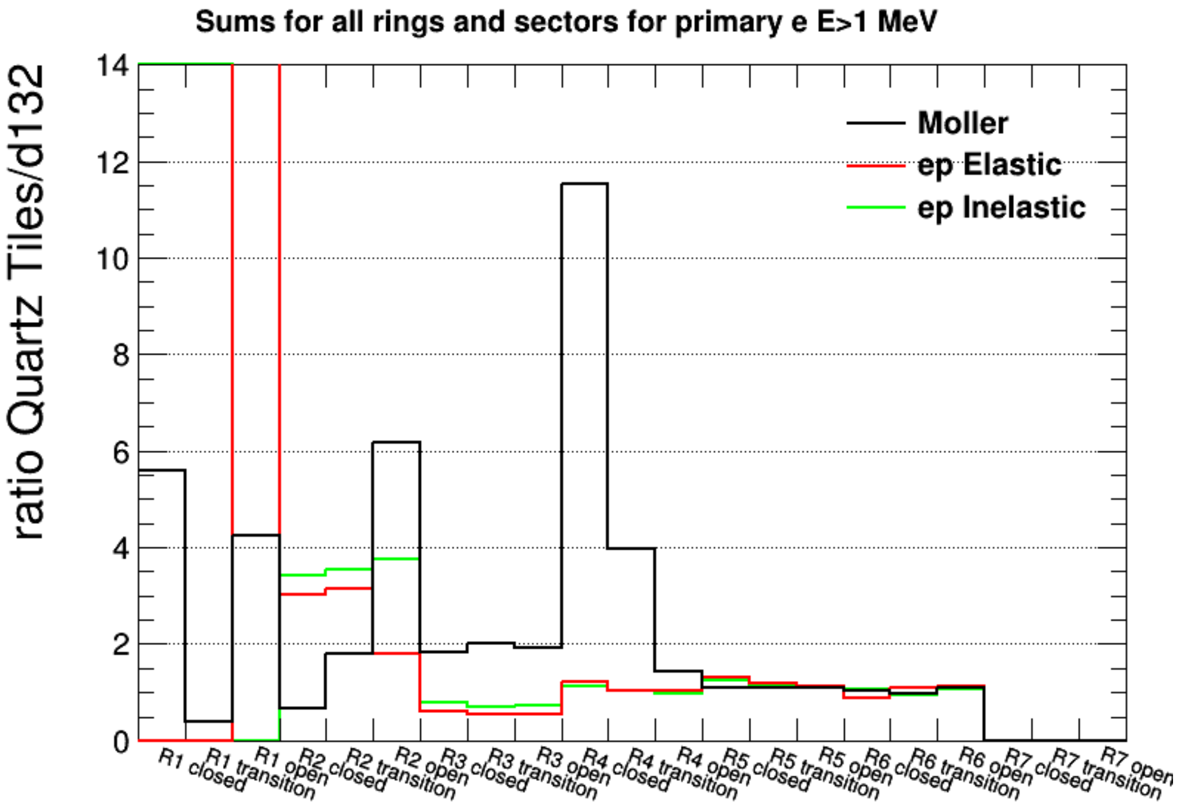




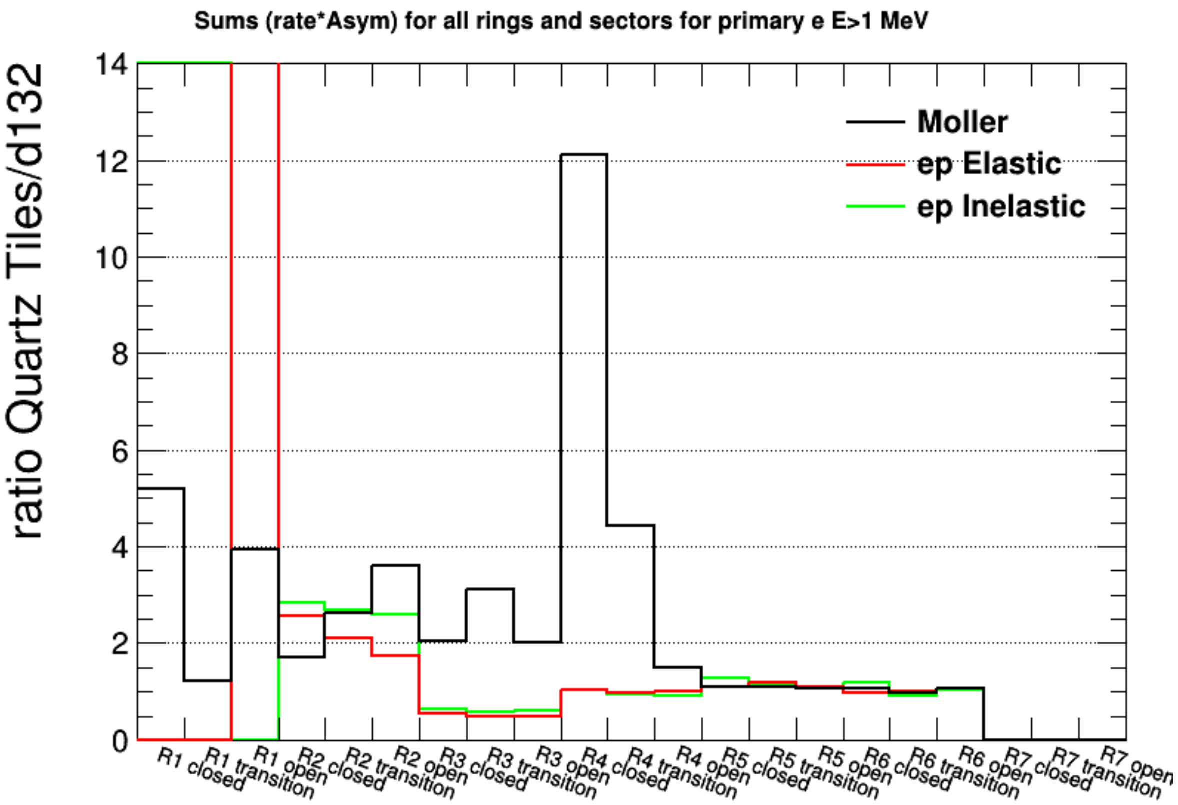
Asymmetry*rate-weighted of the primary electrons in all the Rings and ϕ-sectors for Moller, ep Elastic and ep Inelastic event physics generators.

with simulated 1M events

Ratio of Total Rate in the Tiles to det132



Total rate of the primary electrons in all the Rings and ϕ-sectors for Moller, ep Elastic and ep Inelastic event physics generators.



Asymmetry*rate-weighted of the primary electrons in all the Rings and ϕ-sectors for Moller, ep Elastic and ep Inelastic event physics generators.

Toy Dataset Simultaneous Fit Results

MØLLER

det132 @21.3m

Processes	Expected A (ppb)	σ_A (ppb)	$\frac{\sigma_A}{\lvert A \rvert}$ (%)
Møller	-34.78	0.72	2.08
ep-elastic	-27.98	1.19	4.24
ep-inelastic (W1)	-549.32	40.05	7.29
ep-inelastic (W2)	-621.88	29.81	4.79
ep-inelastic (W3)	-450.68	61.87	13.73

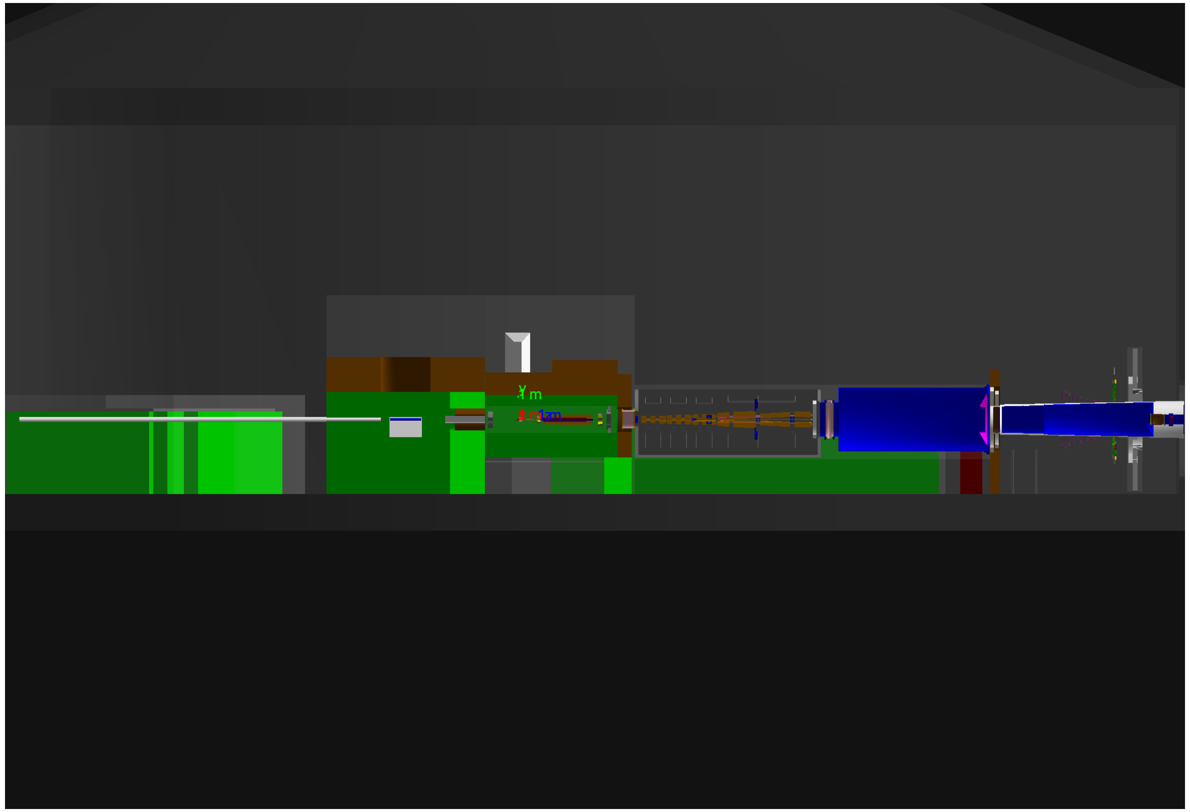
Quartz Tiles

Processes	Expected A (ppb)	σ_A (ppb)	$\frac{\sigma_A}{\lvert A \rvert}$ (%)
Møller	-34.59	0.7	2.01
ep-elastic	-27.42	1.02	3.77
ep-inelastic (W1)	-543.5	32.72	5.84
ep-inelastic (W2)	-573.47	31.43	5.48
ep-inelastic (W3)	-446.21	69.74	15.63

Results of the simultaneous fit to the 18 quartz tile asymmetries.
The asymmetries in Ring5 and their fitting errors in ppb and in % are shown.

Summary

- Implemented the quartz tile geometry into the remoll simulation.
- Performed the deconvolution study by using the quartz tiles.
  - The tile implementation results look very encouraging.
  - The trade-off between overlap and missing hits doesn't seem to produce a major impact on the deconvolution.



Backup

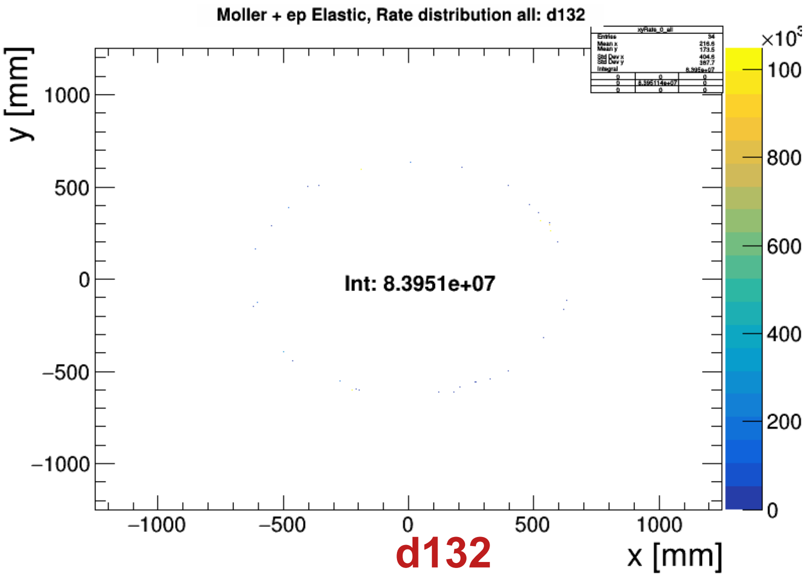
The Size of the Quartz Tiles

Quartz Tiles (FF)			
Ring	Rmin [mm]	Rmax [mm]	L [mm]
R1FF	716.72	746.72	30
R2FF	732.49	792.49	60
R3FF	778.24	838.24	60
R4FF	823.6	943.6	120
R5FF	929.43	1069.43	140
R5BF	934.17	1074.17	140
R6FF	1051.41	1151.41	100

Quartz Tiles (BF)			
Ring	Rmin [mm]	Rmax [mm]	L [mm]
R1BF	723.69	753.69	30
R2BF	739.45	799.45	60
R3BF	785.1	845.1	60
R4BF	830.48	950.48	120
R5FF	926.22	1066.22	140
R5BF	937.35	1077.35	140
R6BF	1058.37	1158.37	100

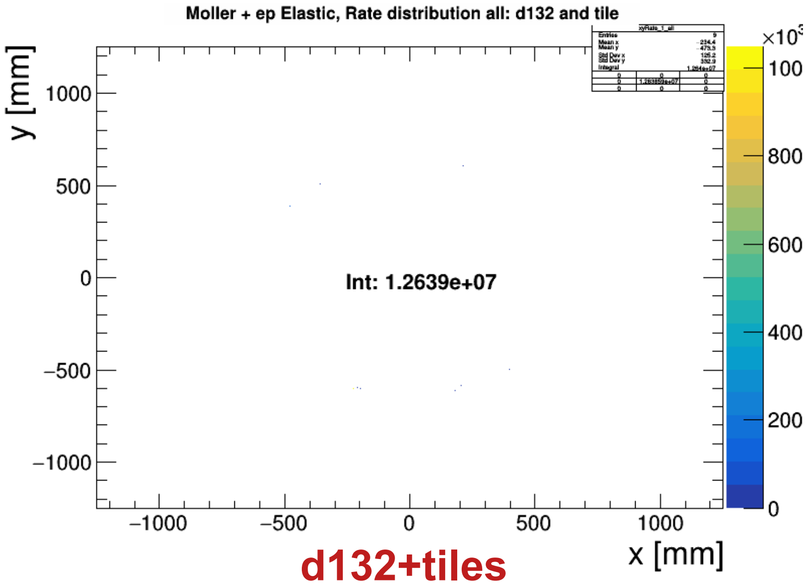
	x [mm]	y[mm]	z[mm]
Ring1	169	30	20
Ring2	179	60	20
Ring3	190	60	20
Ring4	213	120	20
Ring5	80	140	17
Ring6	260	100	20

Hit Position Distributions, Ring1



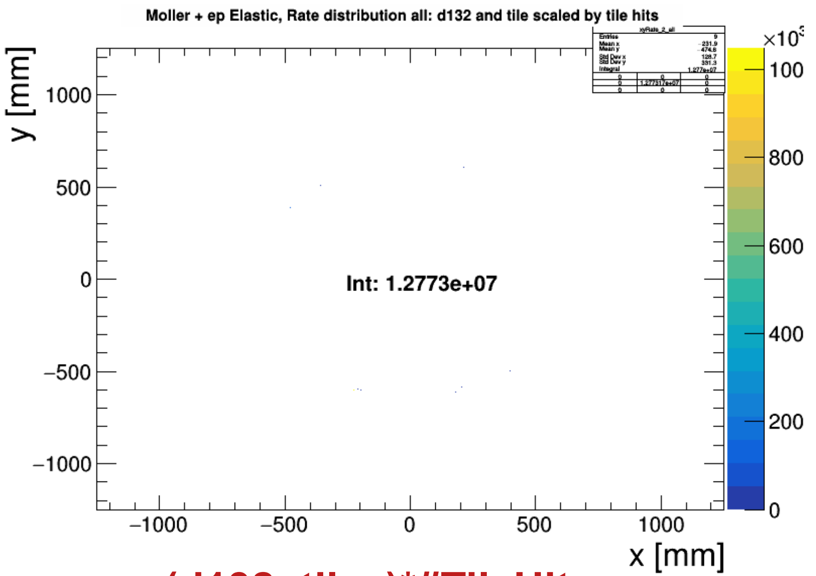
d132

2D rate-weighted the distribution of *e*-hits at d132.



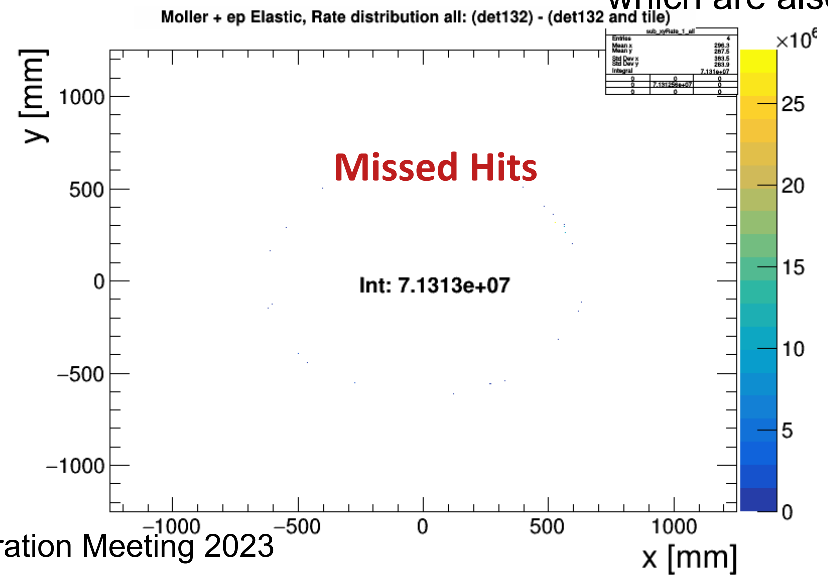
d132+tiles

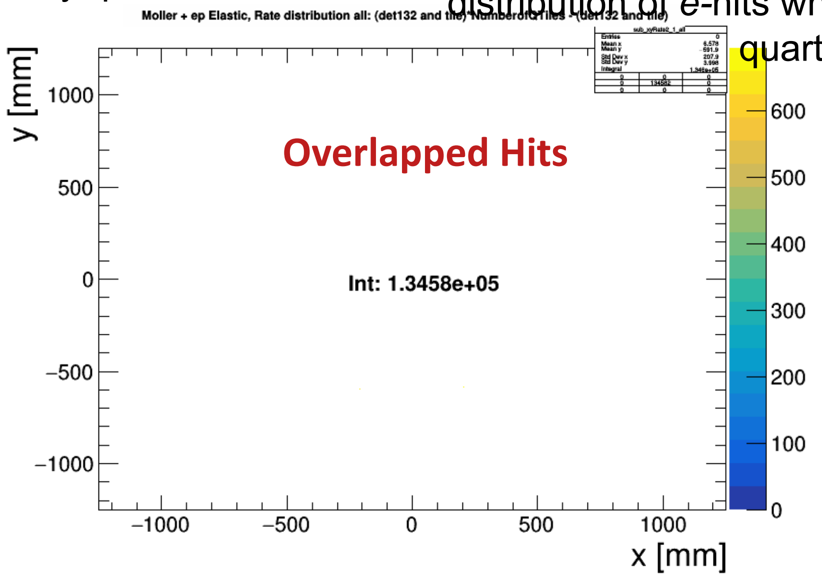
2D rate-weighted the distribution of *e*-hits which are also detected by quartz tiles.



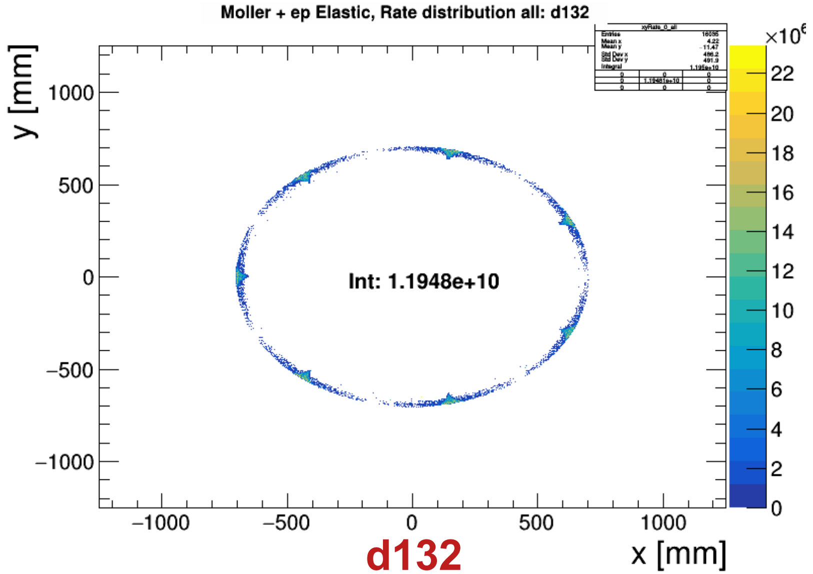
(d132+tiles)*#TileHits

2D rate*Number of tiles hits-weighted the distribution of *e*-hits which are also detected by quartz tiles.





Hit Position Distributions, Ring2



d132

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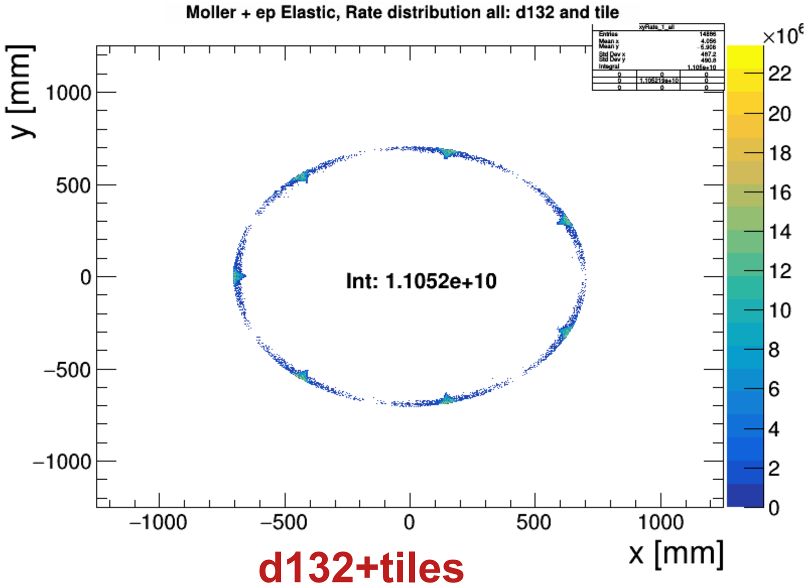
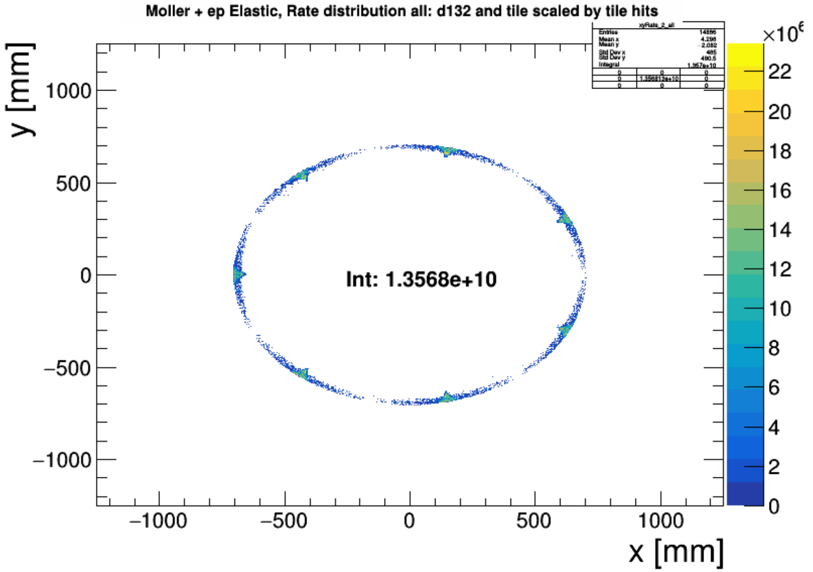


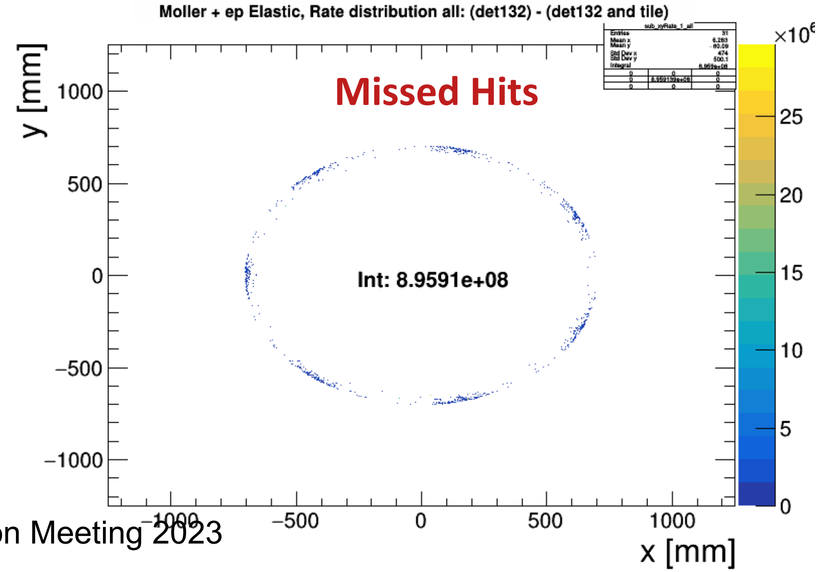
d132+tiles

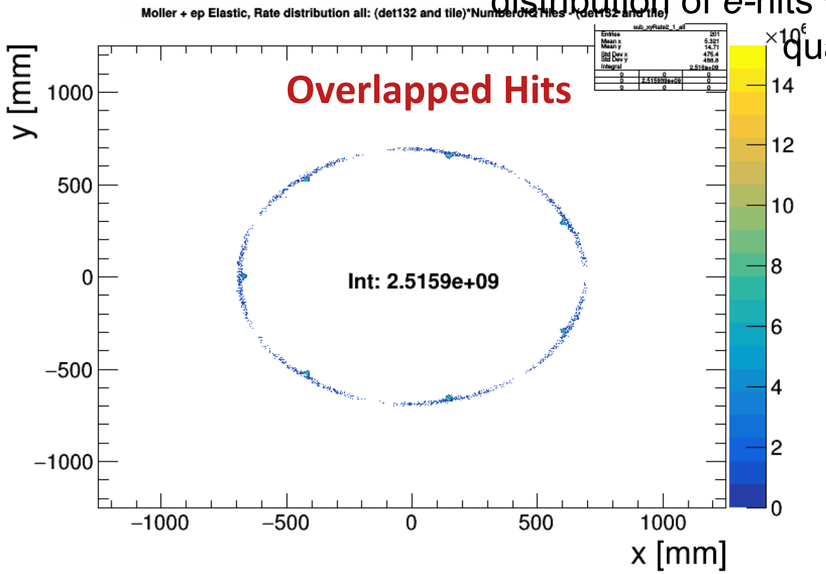
2D rate-weighted the distribution of *e*-hits which are also detected by quartz tiles.



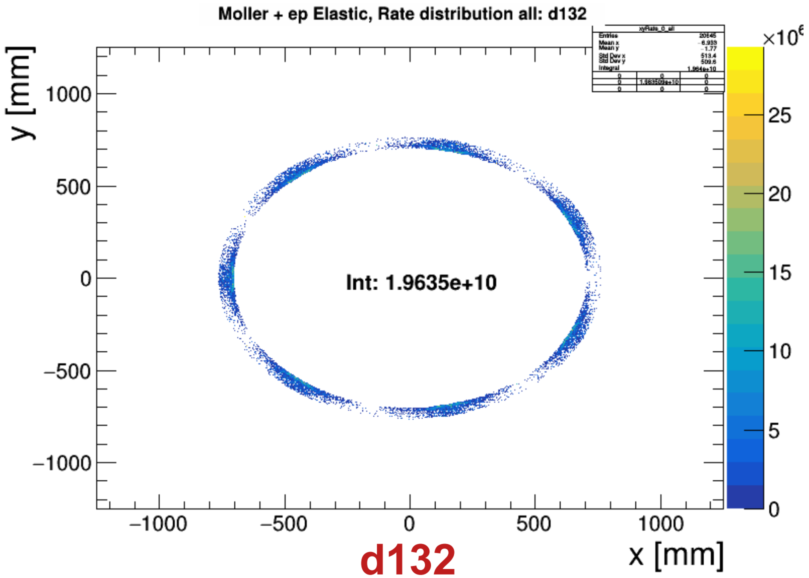
(d132+tiles)*#TileHits

2D rate*Number of tiles hits-weighted the distribution of *e*-hits which are also detected by quartz tiles.



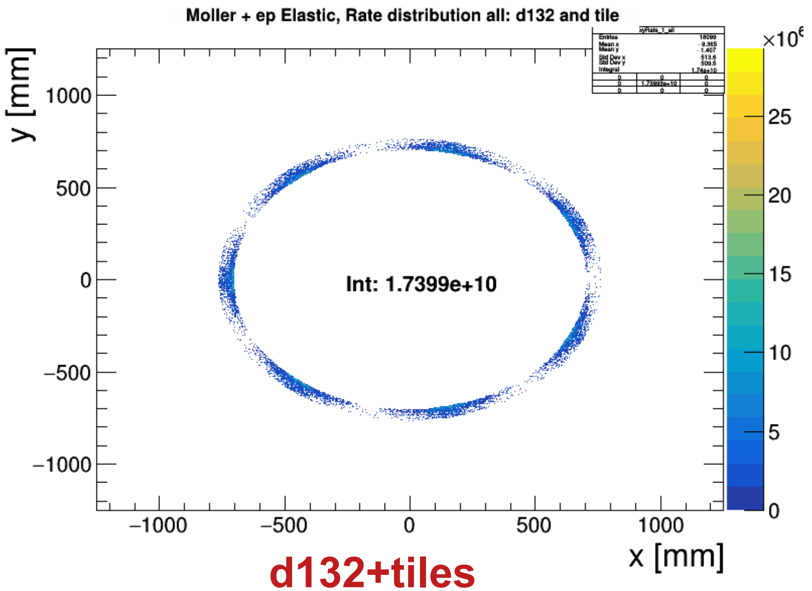


Hit Position Distributions, Ring3



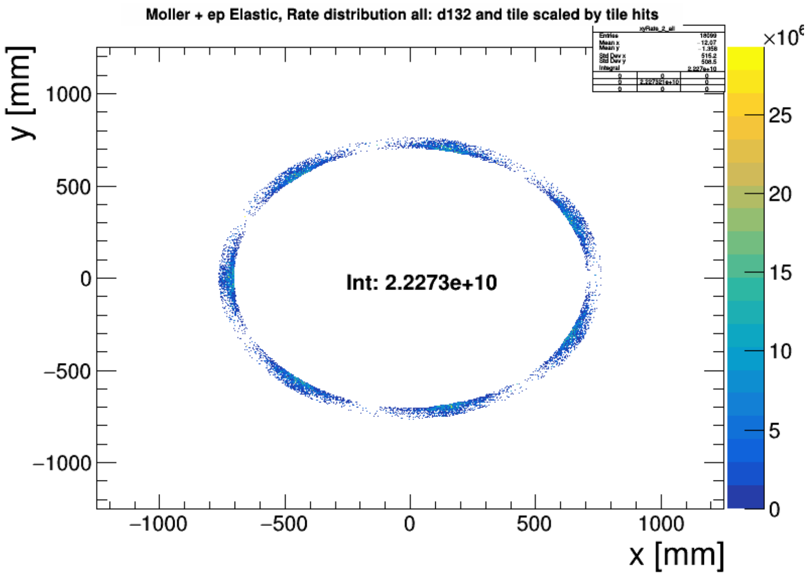
d132

2D rate-weighted the distribution of *e*-hits at d132.



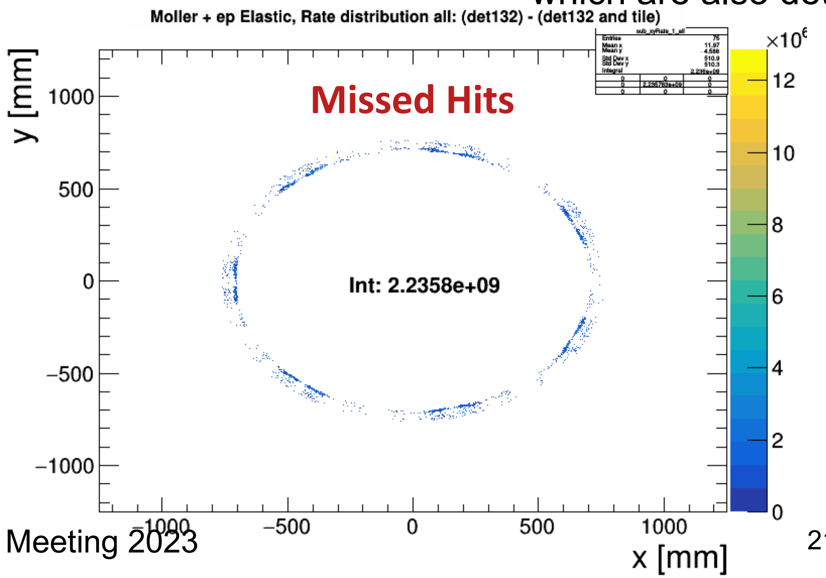
d132+tiles

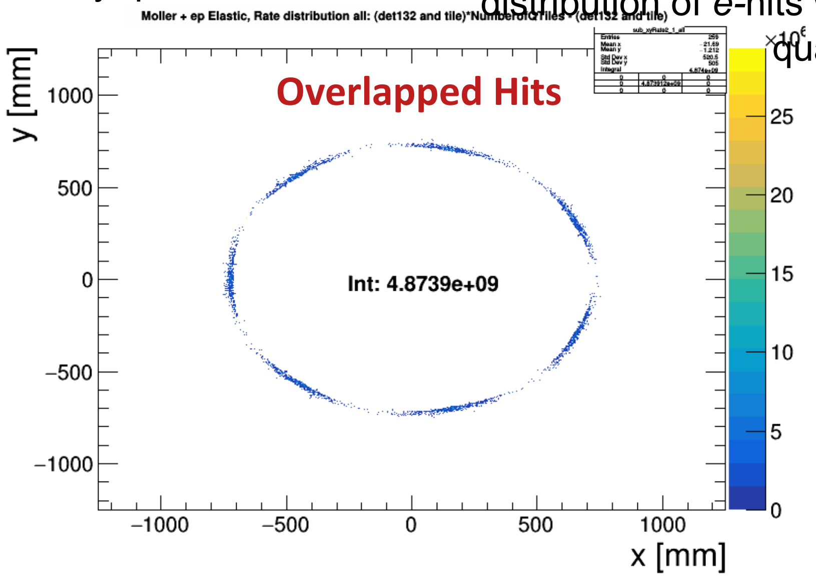
2D rate-weighted the distribution of *e*-hits which are also detected by quartz tiles.



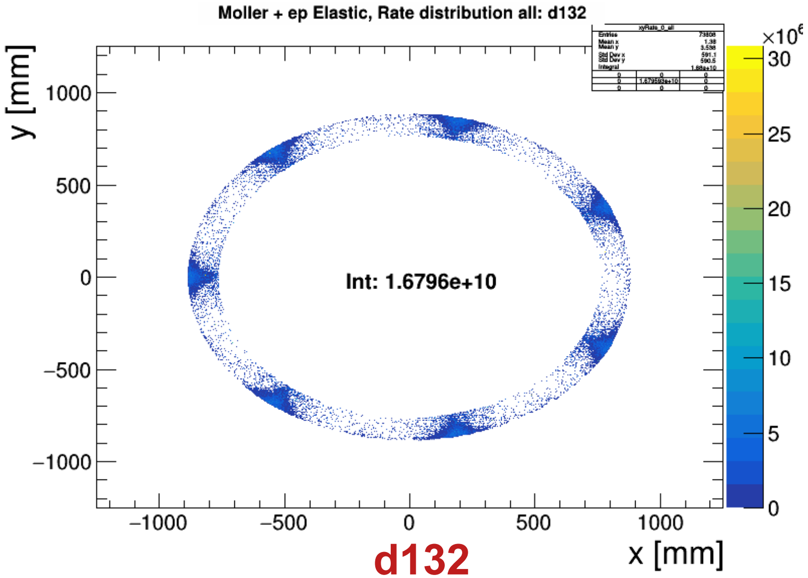
(d132+tiles)*#TileHits

2D rate*Number of tiles hits-weighted the distribution of *e*-hits which are also detected by quartz tiles.





Hit Position Distributions, Ring4



d132

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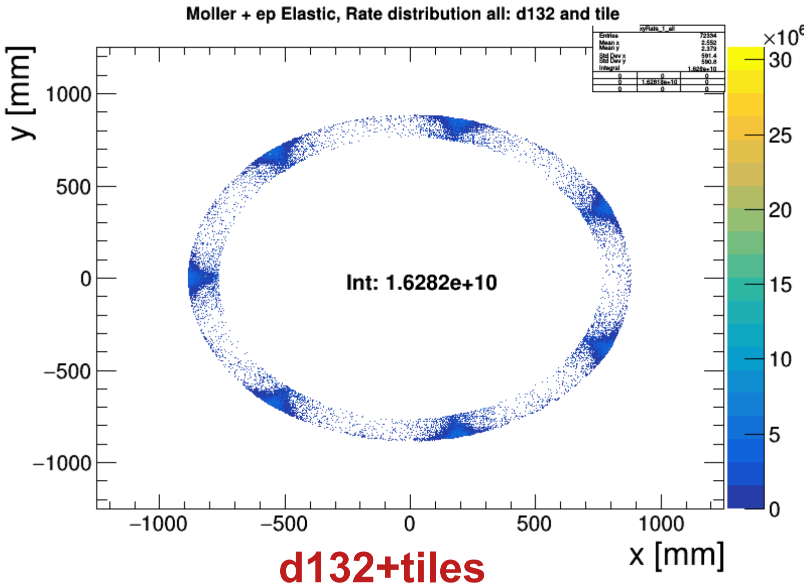

d132+tiles

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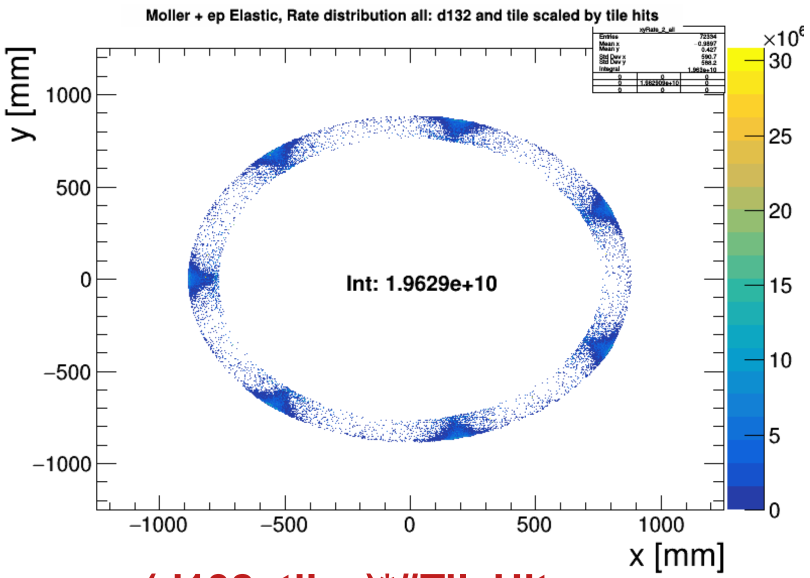

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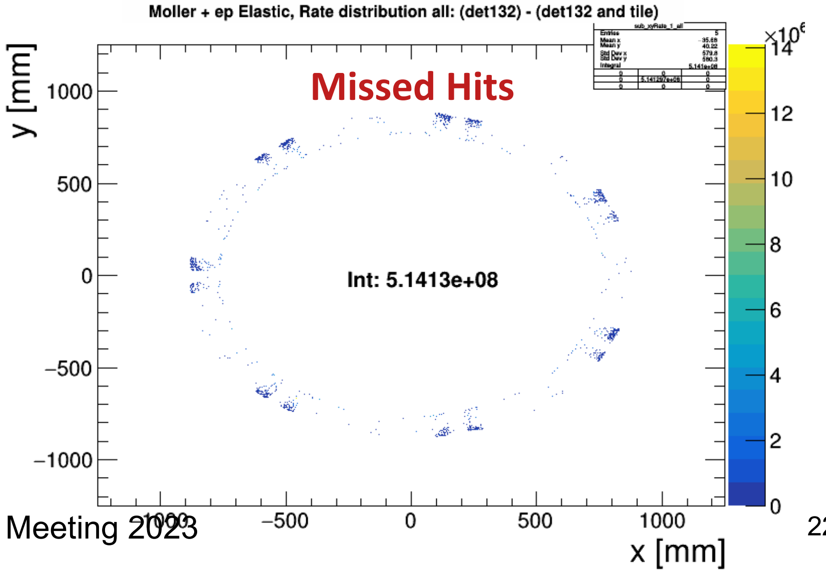
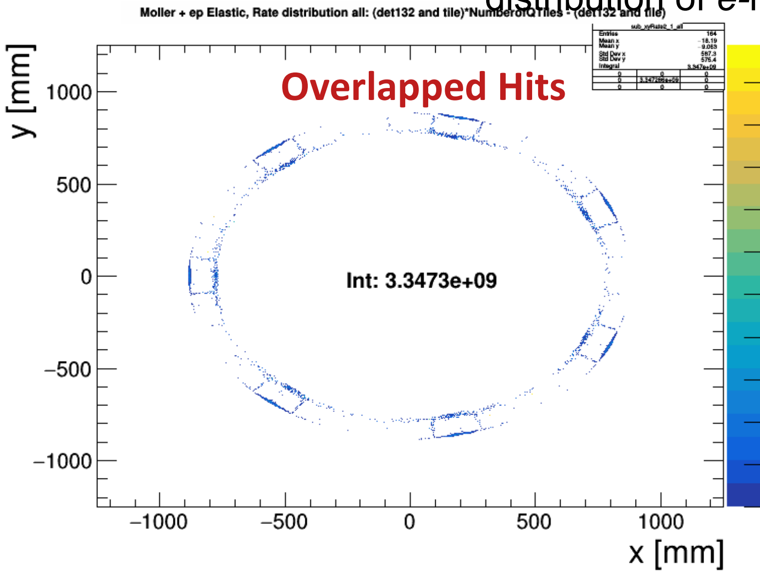
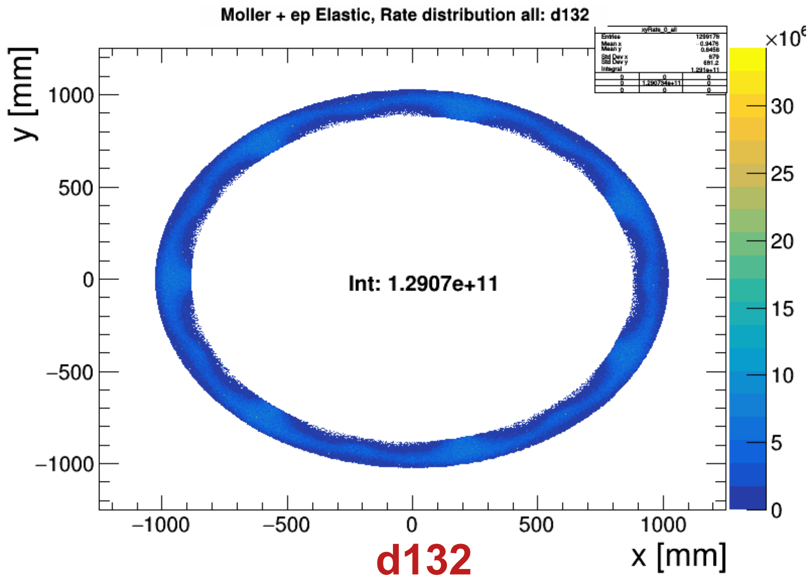


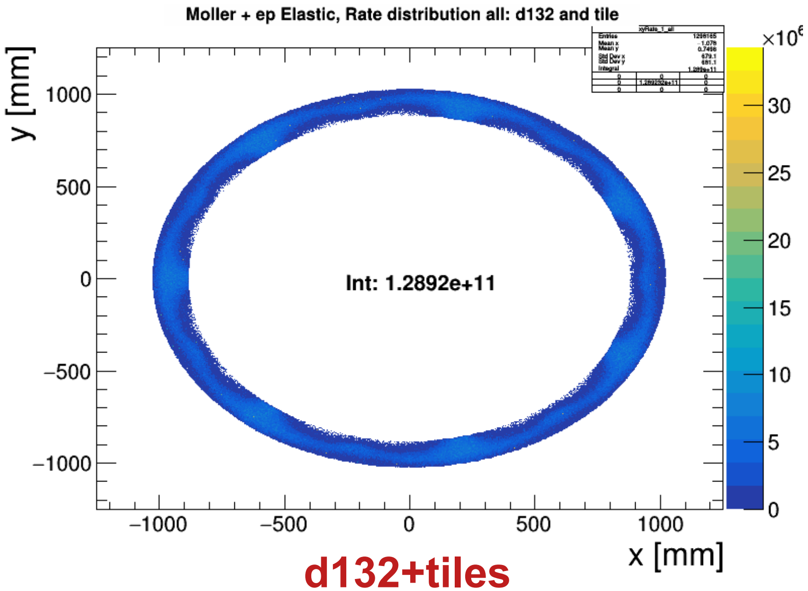


Hit Position Distributions, Ring5



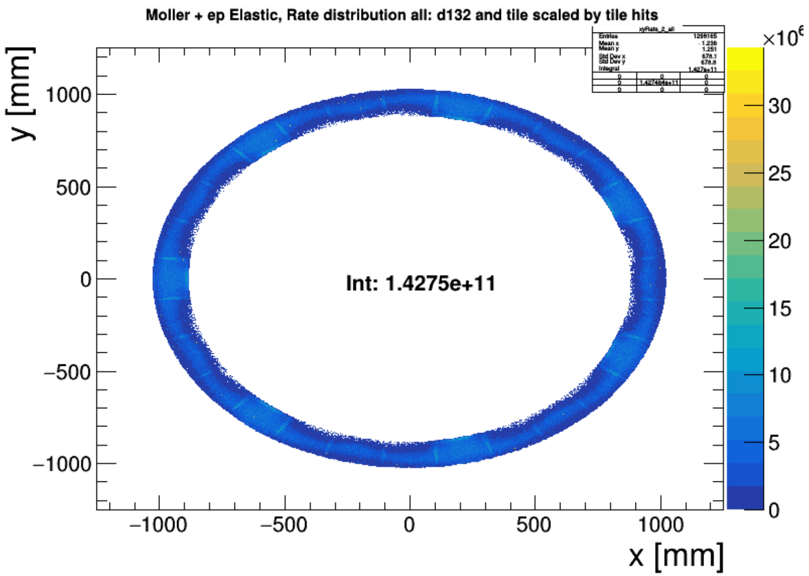
d132

2D rate-weighted the distribution of *e*-hits at d132.



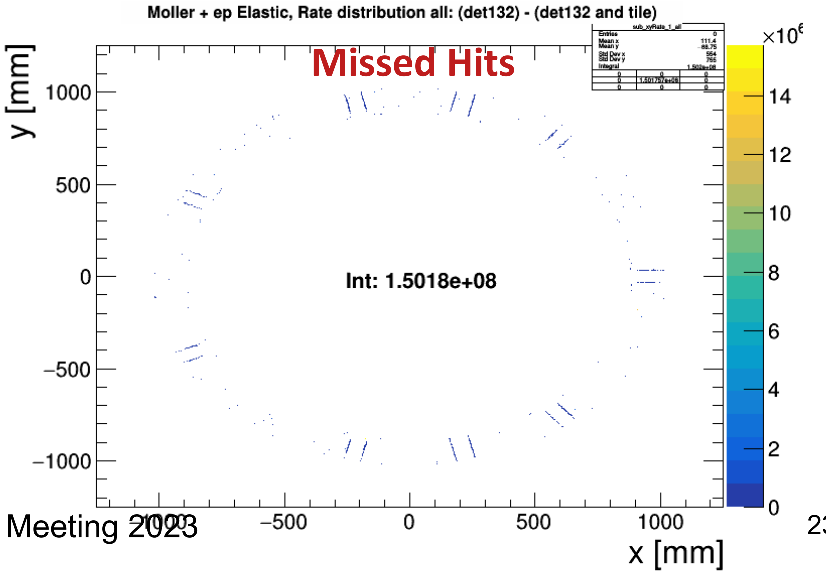
d132+tiles

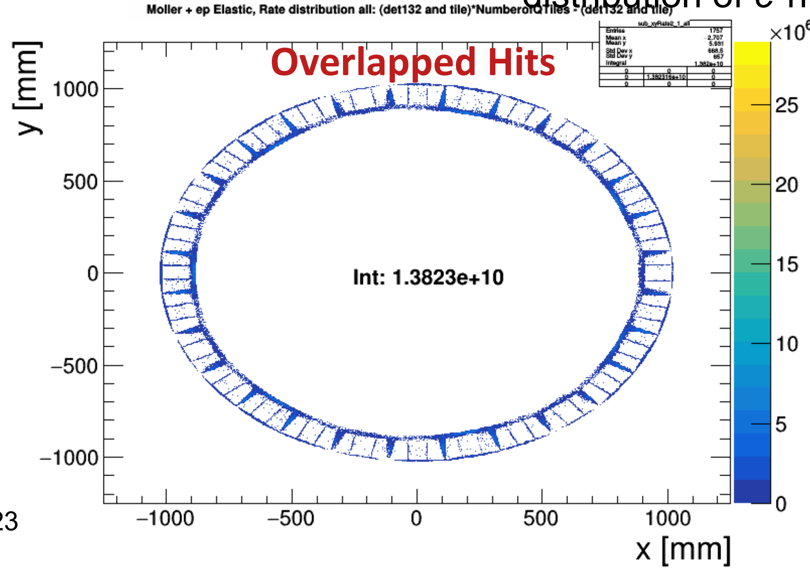
2D rate-weighted the distribution of *e*-hits which are also detected by quartz tiles.



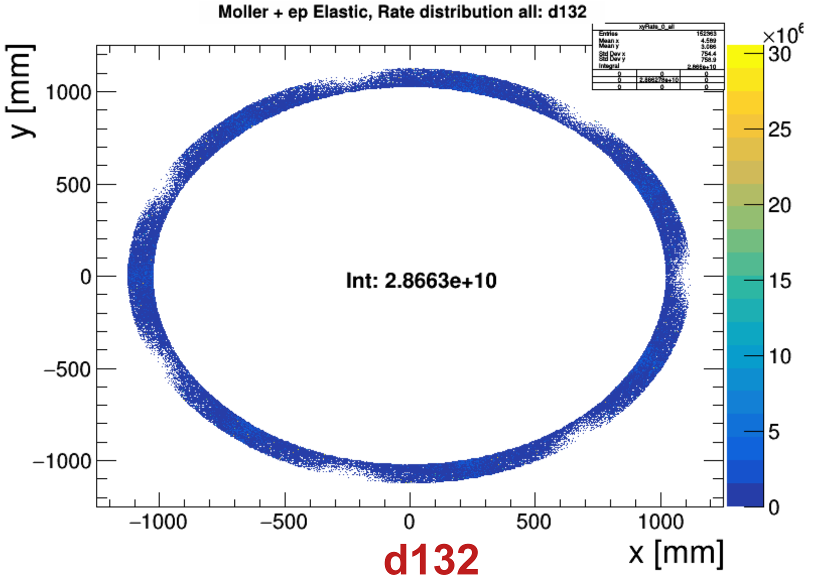
(d132+tiles)*#TileHits

2D rate*Number of tiles hits-weighted the distribution of *e*-hits which are also detected by quartz tiles.



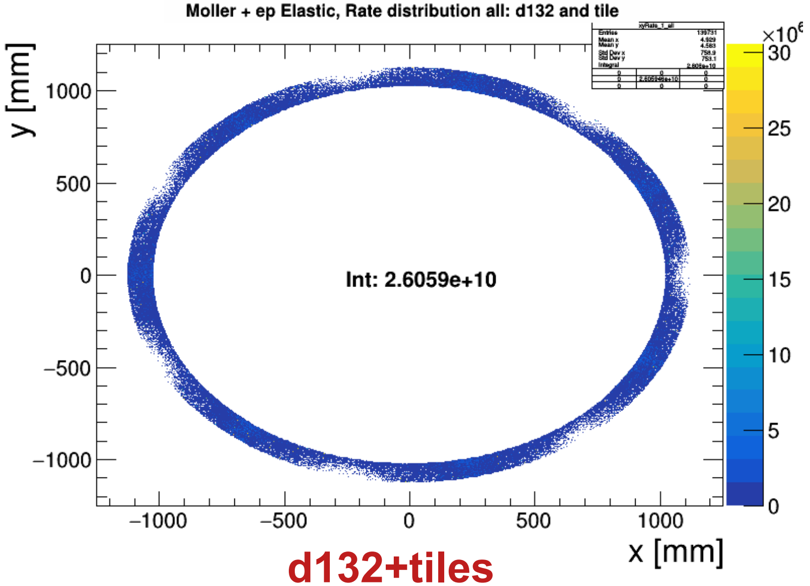


Hit Position Distributions, Ring6



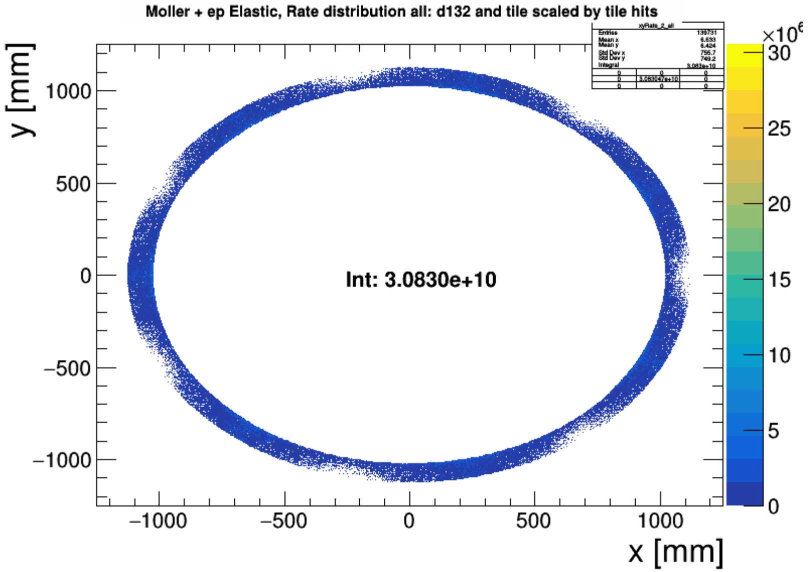
d132

2D rate-weighted the distribution of *e*-hits at d132.



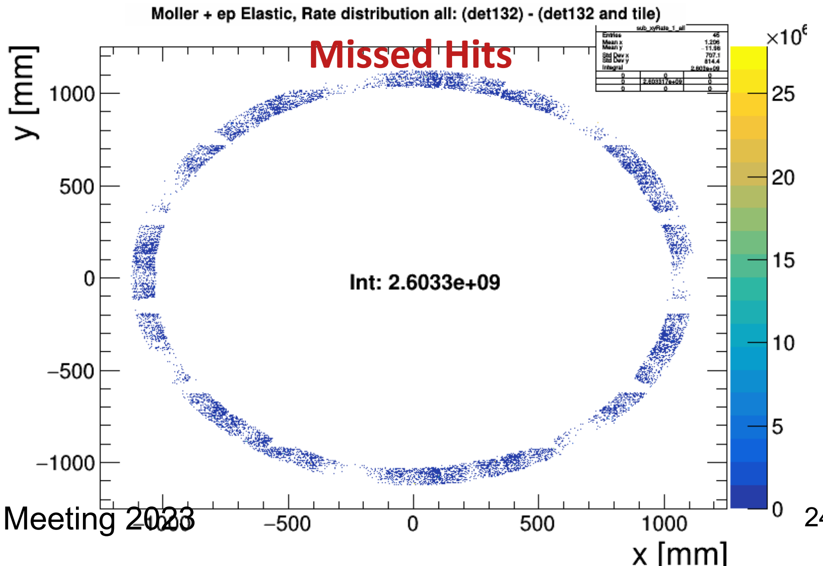
d132+tiles

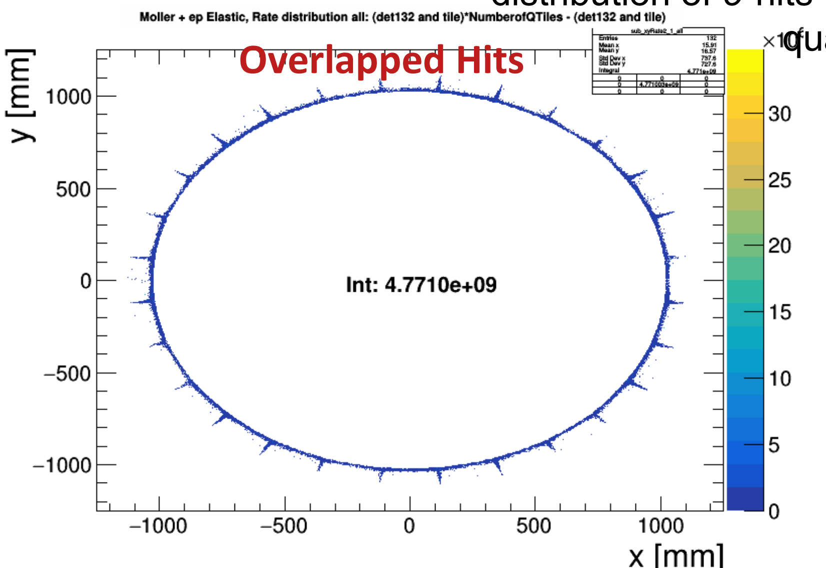
2D rate-weighted the distribution of *e*-hits which are also detected by quartz tiles.



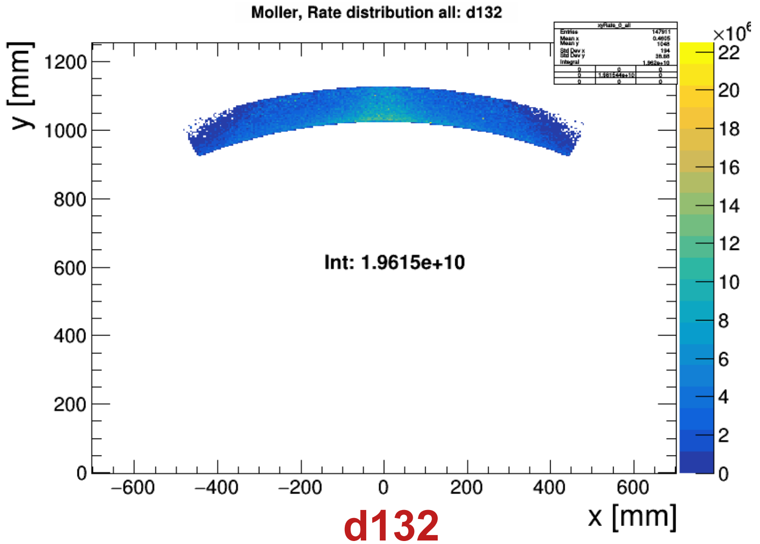
(d132+tiles)*#TileHits

2D rate*Number of tiles hits-weighted the distribution of *e*-hits which are also detected by quartz tiles.



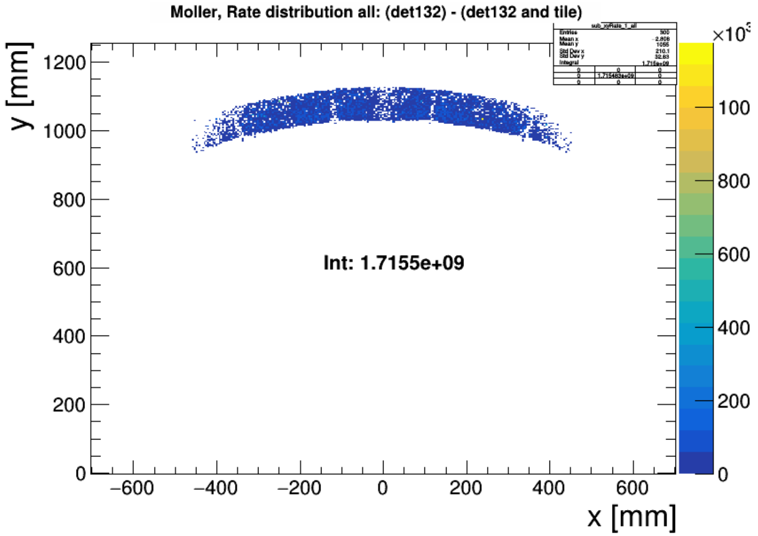


Ring6 Tiles

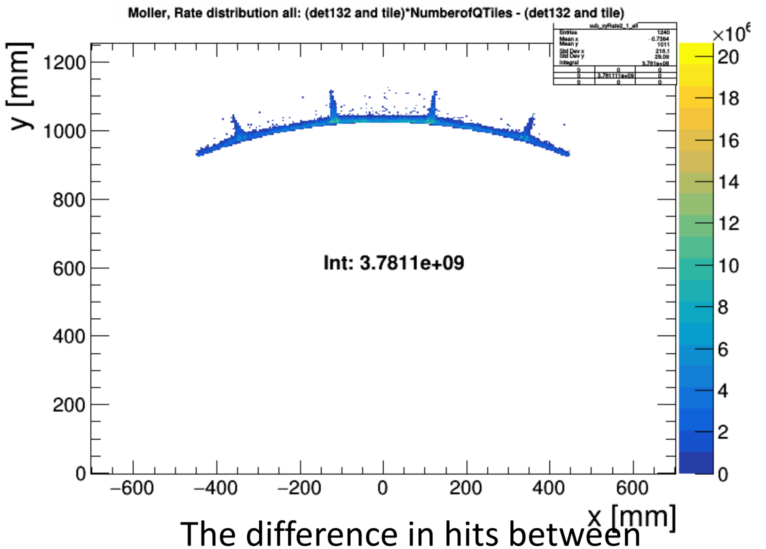


d132

2D rate-weighted the distribution of *e*-hits at Ring6 of the d132.

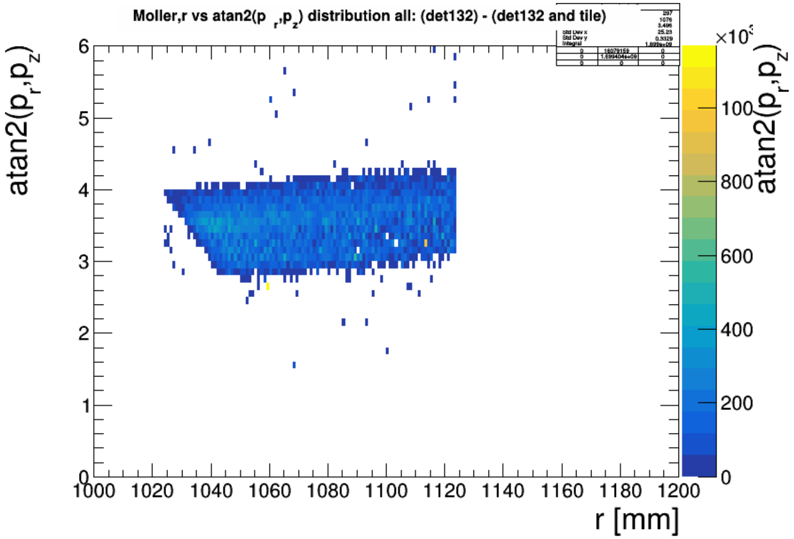


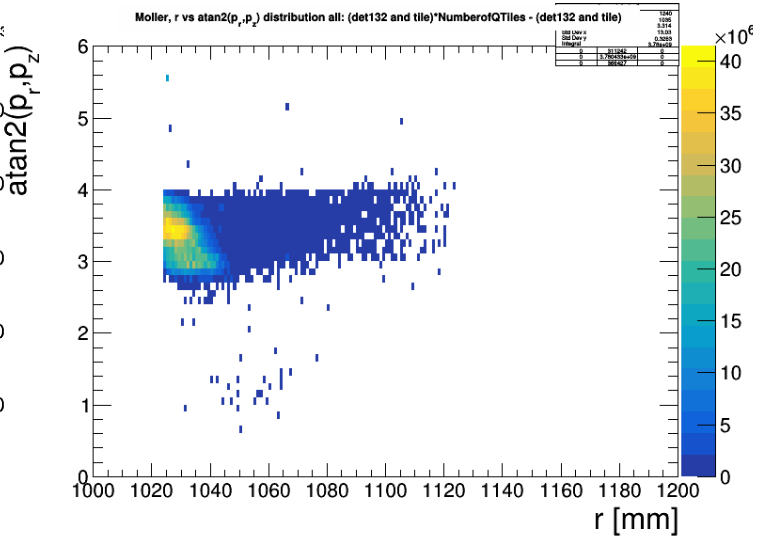
The difference in hits between **d132** and **d132+tiles**



The difference in hits between **(d132+tiles)*#TileHits** and **d132+tiles**

The distribution of the angle between p_z and p_r as a function of radius for the missed (left)and overlapped (right) hits. Here, p_z is the z-component of the particle momentum. $p_r = (x * p_x + y * p_y)/r$

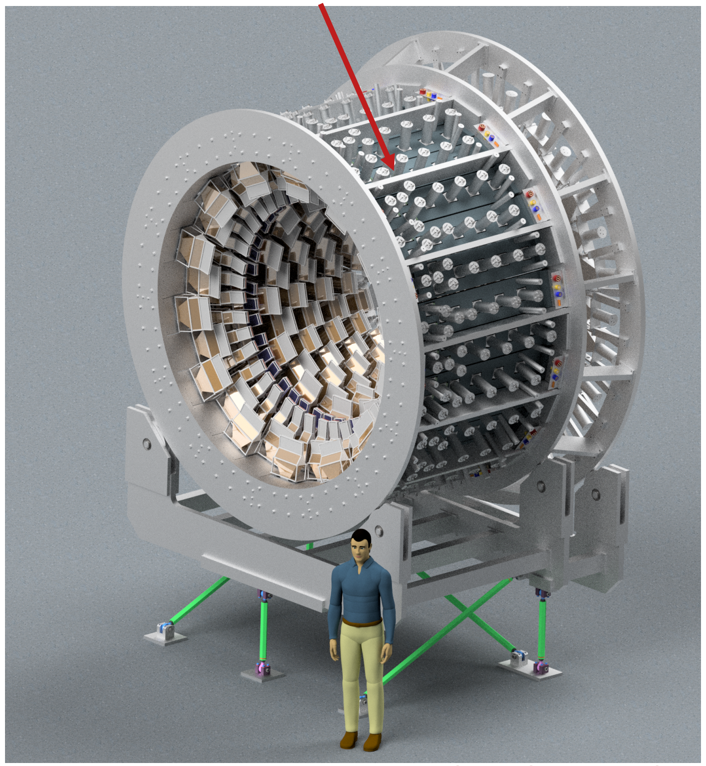


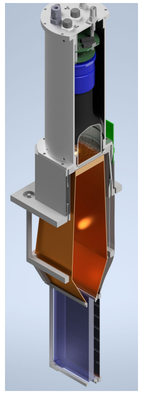


- The missed hits percentage is about 10.
- We don't have missed hits at the lower radius and at lower angle region.

Main Integrating Detector Segmentation

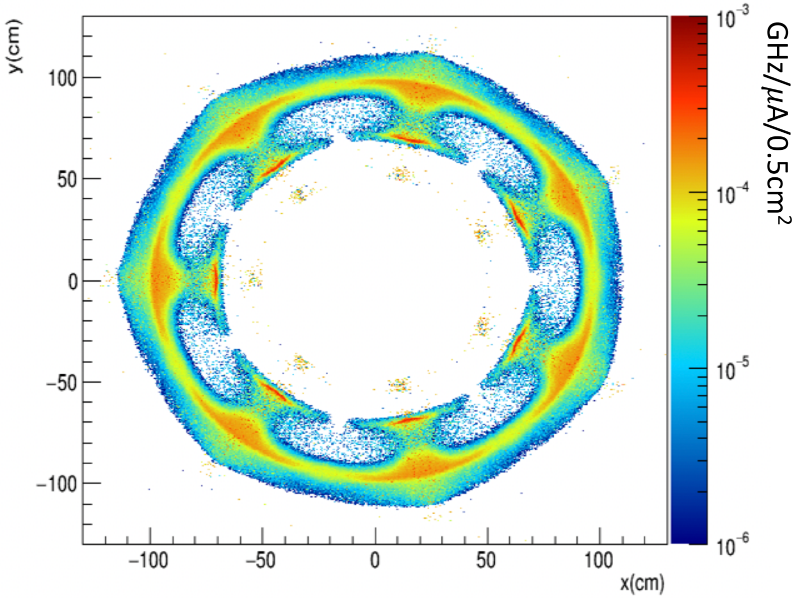
Thin Quartz (224)
6-ring Cherenkov detector



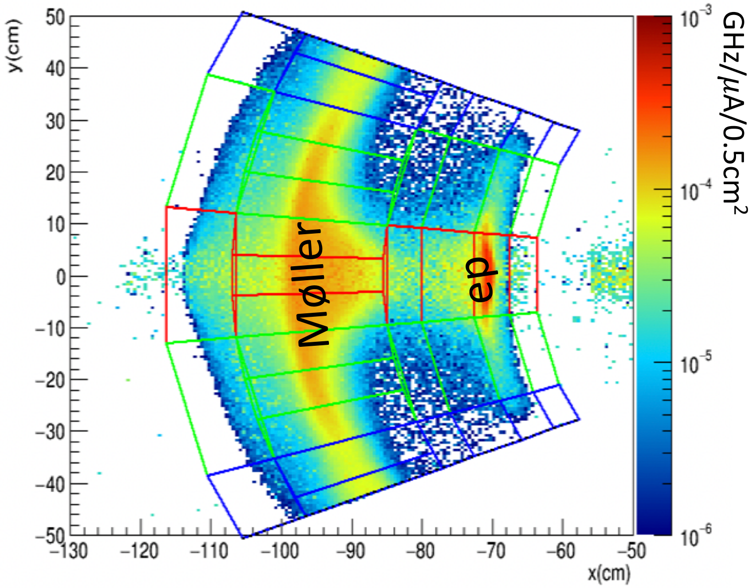


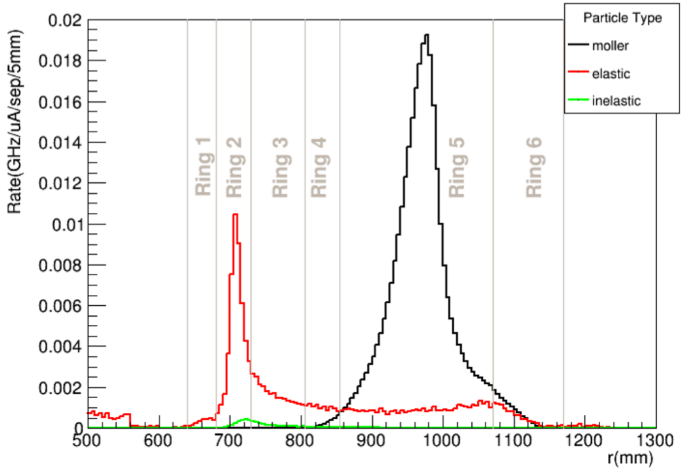
Michael Gericke

Simulated Møller and ep electron rates



Simulated Møller and ep e- rates for superimposed azimuthal and radial bins in one toroidal sector.





- **Integrating detectors** are an array of detectors based on quartz as the active element.
  - The thin detector array consist of 6 rings and 224 detectors.
    - 84 detectors in Ring 5 and 28 in each of the other rings