Massachusetts Institute of Technology

Moller Scattering Update

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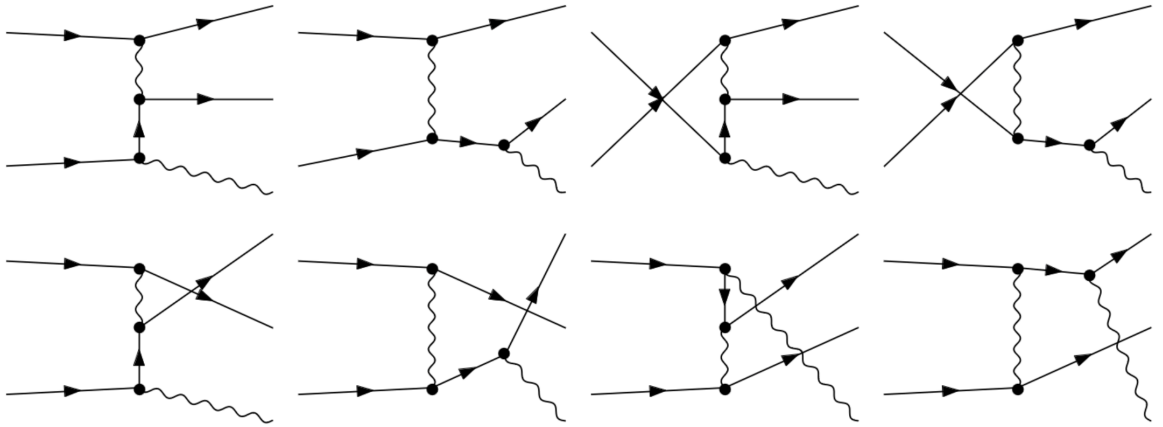
I looked, and there before me was a pale horse! Its rider was named Death, …given power over a fourth of the earth to kill by sword, famine and plague, and by the wild beasts of the earth.

Møller Scattering

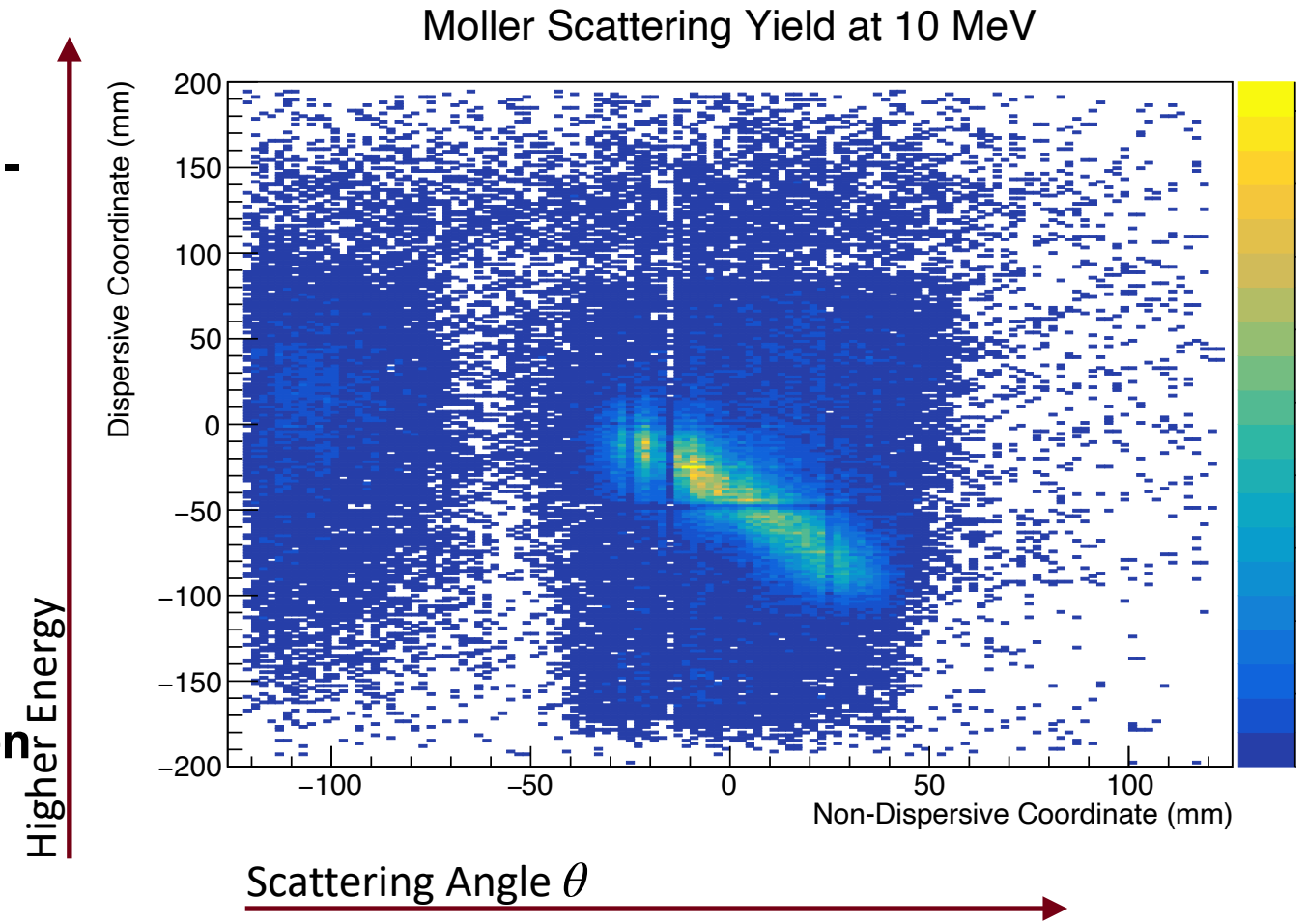
- **DarkLight performed measurement of radiative Møller scattering during commissioning beam time**
- **Data taken at 10, 15, 20, 25, and 30 MeV**
- **Have event generator on hand from C. Epstein and R. Milner**
- **Other generators exist, can test as well**
- **Testing in a regime where electron mass is not negligible**



Radiative Møller diagrams. From https://journals.aps.org/prd/abstract/10.1103/PhysRevD.94.033004

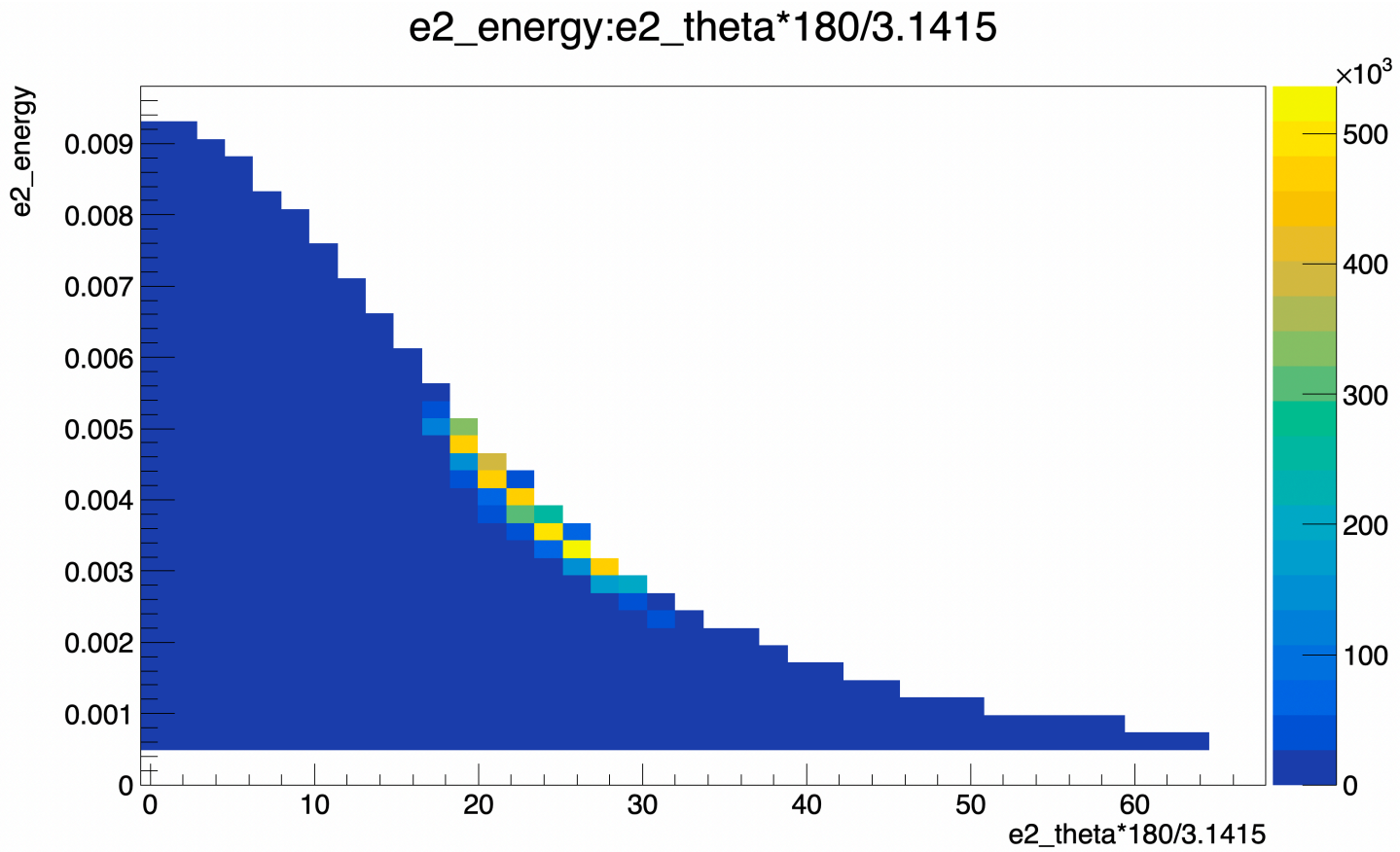
Data for 10 MeV Møller Scattering

- **Showing yield from 10 MeV Møller scattering - Right Bottom GEM**
- **Same trend for all energies, background varies depending on beam setting**
- **Would like to compare to event generator**
- **Lots of detector artifacts, dead/inefficient strips in GEMs, questions about clustering, etc.**
- **This is a combination of ALL Moller data taken at 10 MeV on the right arm**



FIRST LOOK AT SIMULATION
Nominally everything is in a “default” setting

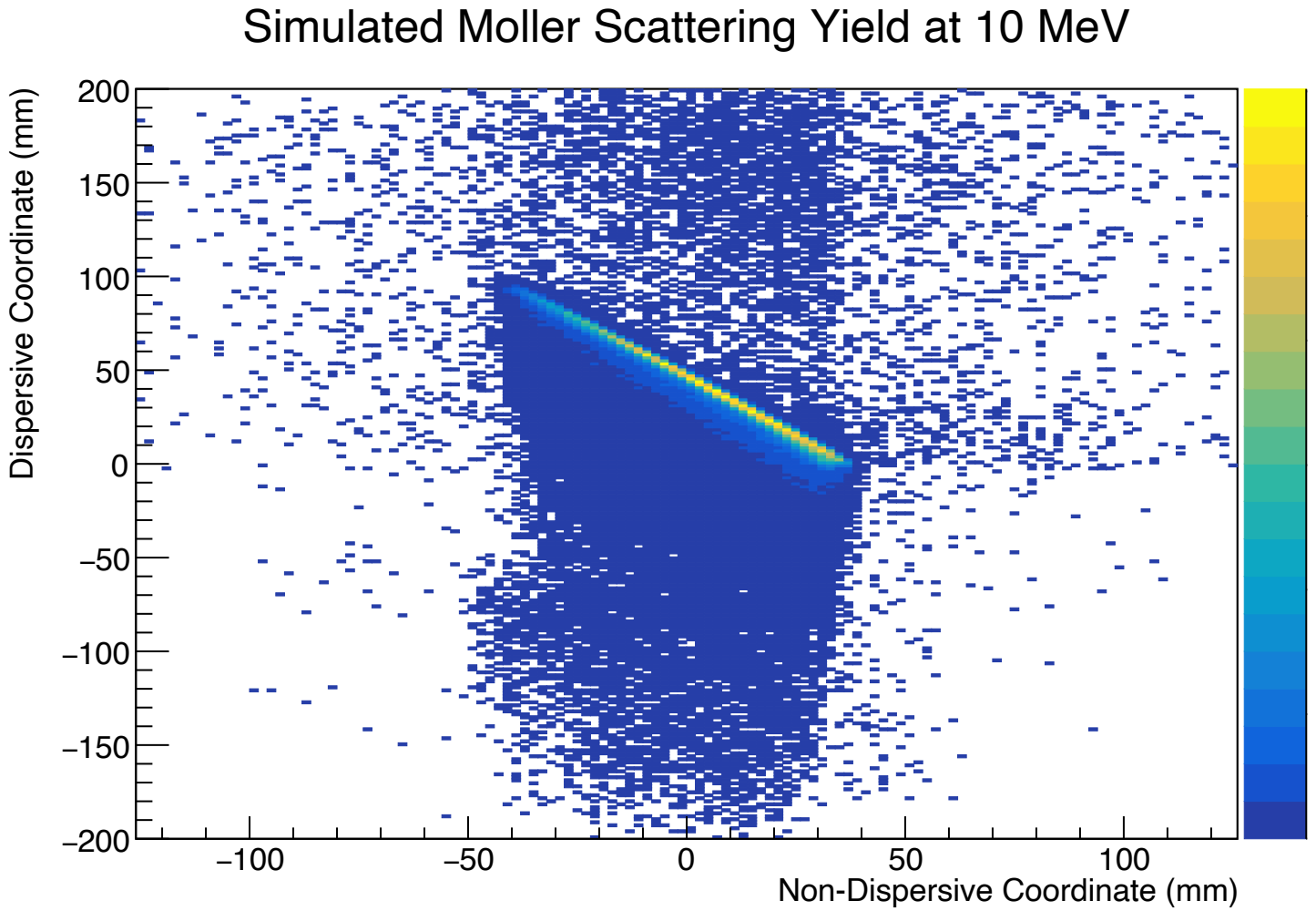
- Run generator in ~beam settings
  - 10 MeV
- Leave other settings in default configuration
  - Luminosity 1e36
  - Radiative fraction 0.75
  - dE_frac 1e-4
- Apply angular cuts in CoM frame (rads) to maximize stats going into detector
  - $1.0 < \theta < 1.5$, $-0.1 < \phi < 0.1$



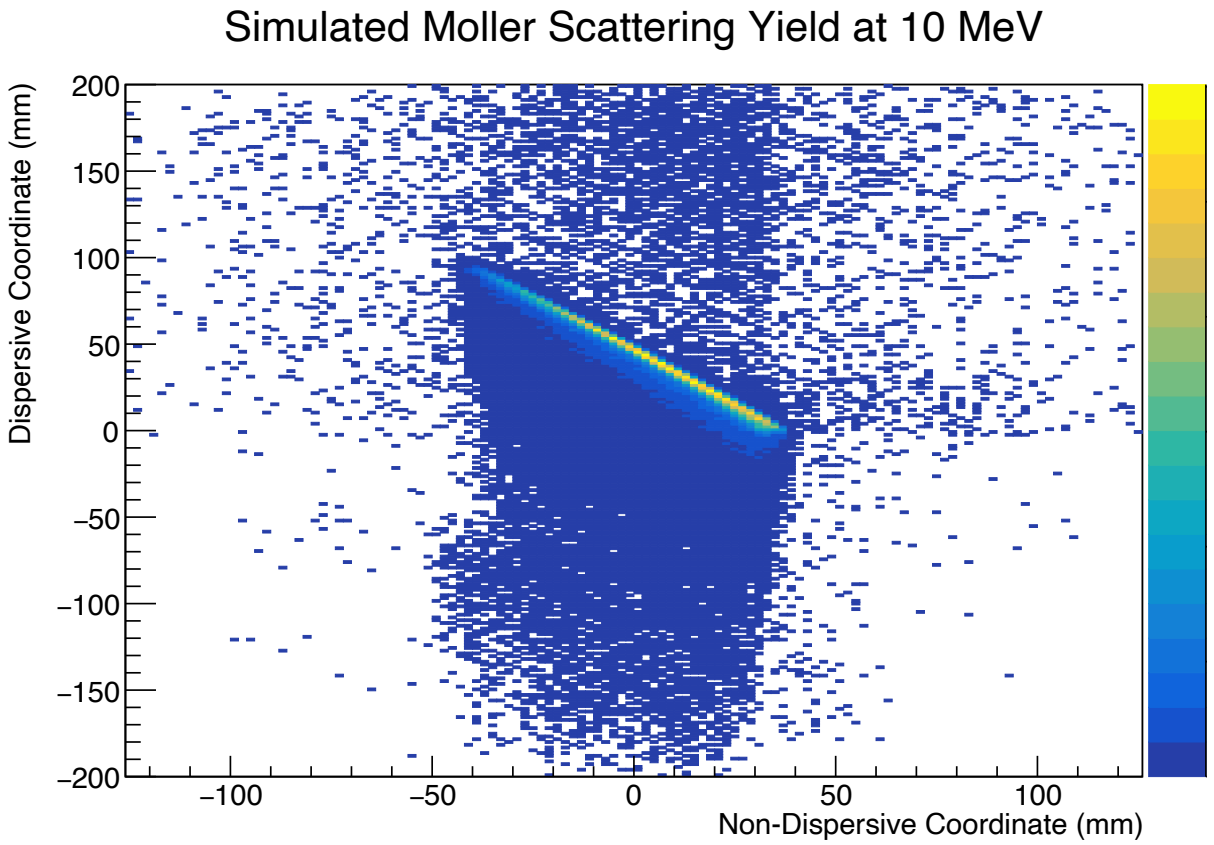
Only accept into right side spectrometer - Geant4 simulation quirk

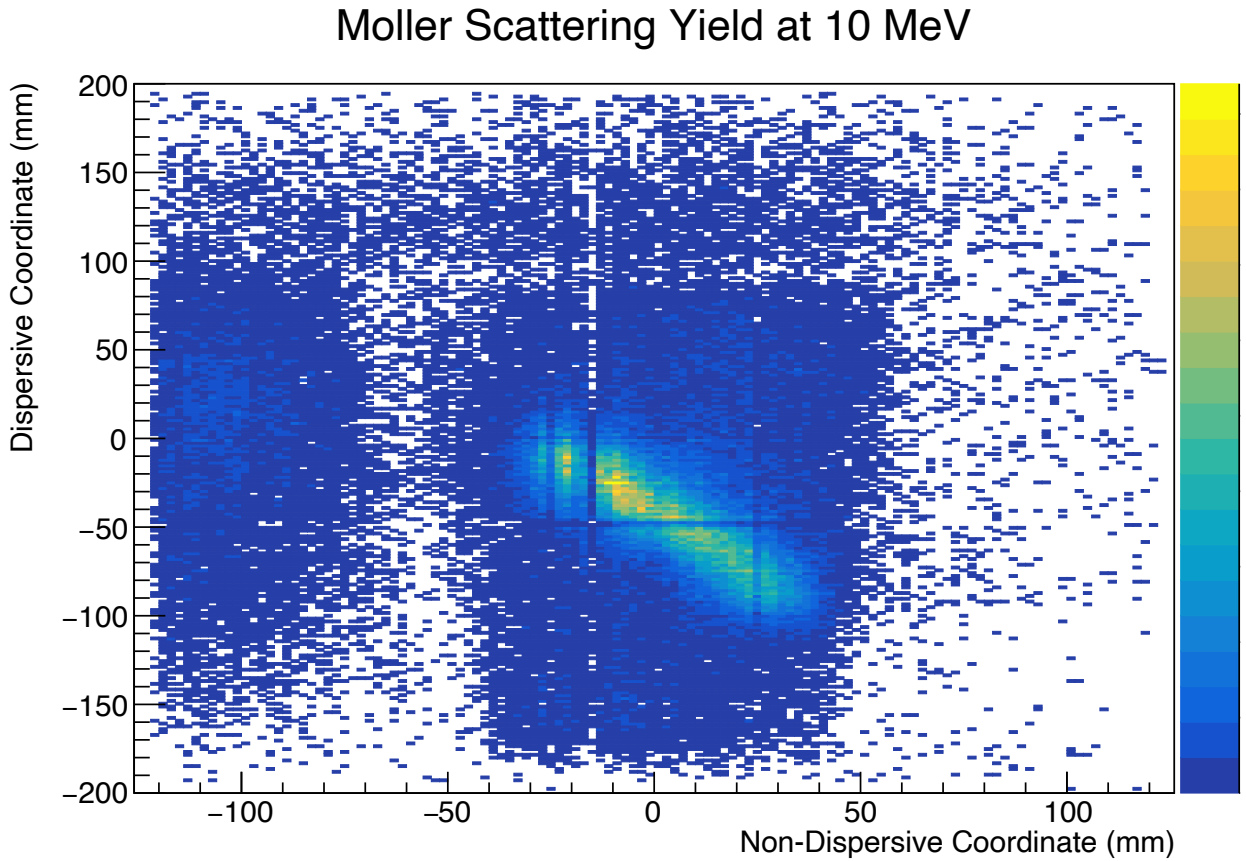
Analyze Simulation

- Put generator output through digitization, and then standard analysis
- Looking at tracks in GEMs
- Field in simulation and in data not matched
- Assumed a central magnet momentum of 4.5 MeV, likely correct within ~30 %
- Slope in sim and data in same direction!



Analyze Simulation



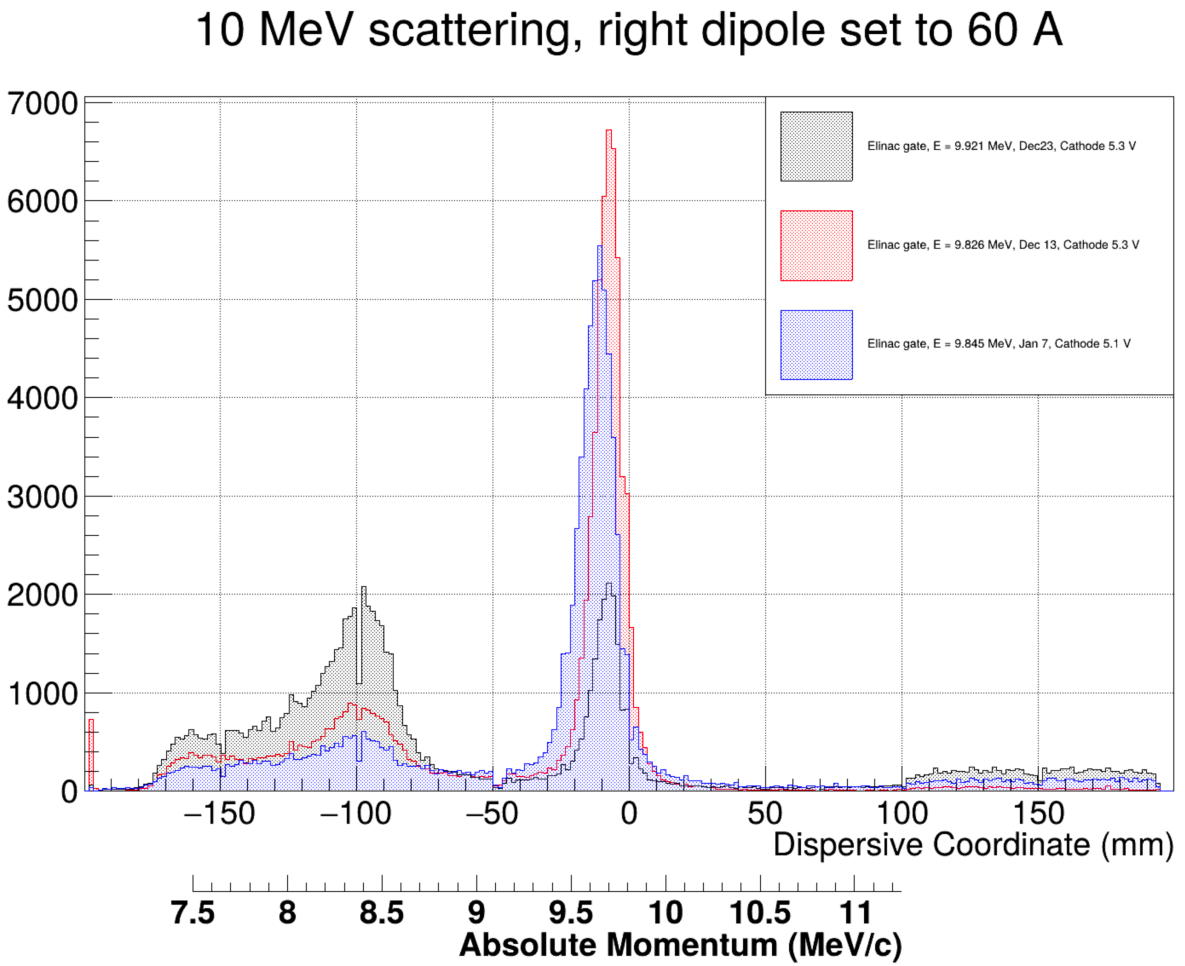


Simulation should contain same material as data. Why is it so much thinner?

Background clearly not the same in both.

We are Getting Ahead of Ourselves

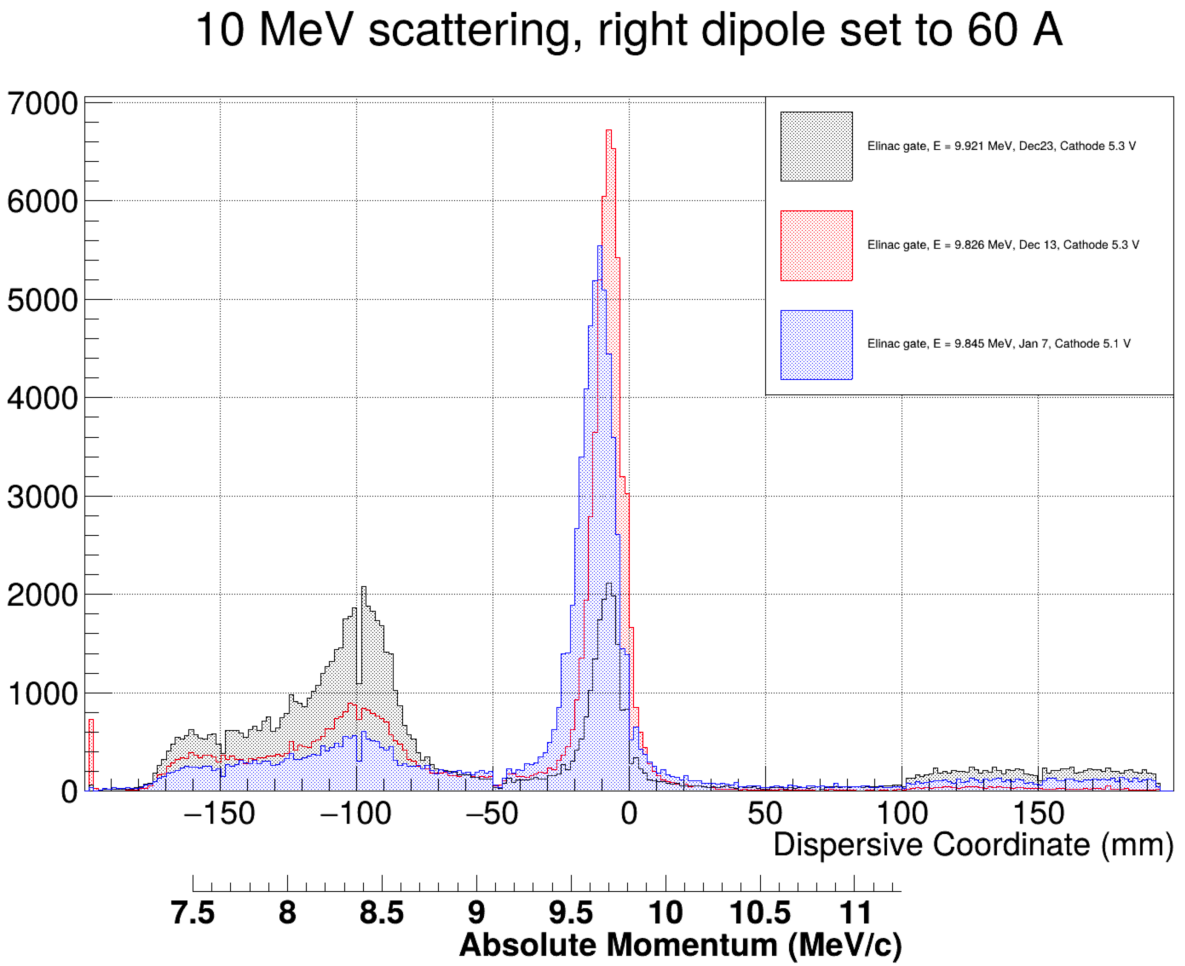
- **Before we can think about cross sections we need to understand detector performance**
  - **GEM clustering algorithm needs work**
  - **Trigger in-time hits need to be identified**
  - **Overall efficiency of detectors needs to be determined**
- **Detector alignment needs to be finalized**
- **Decision on determination of beam current**
- **Do we actually have data that can be used to identify radiative Moller events?**



Background in elastic scattering. Extends down to ~0 MeV. Can we model this well for Moller? Or at all?

We are Getting Ahead of Ourselves

- **To extract a cross-section, we need our luminosity**
- **We believe we can use the other spectrometer as a luminosity monitor**
  - **Requires clean selection of known process**
- **If we believe that we want to use elastic eC scattering, we need to select on elastic line and exclude background**



Background in elastic scattering. Extends down to ~0 MeV. Can we model this well for Moller? Or at all?

What data do we actually have?

- **GOOD DOCUMENTATION IS IMPORTANT**
- **Run list does not list Moller runs, have to do elog archaeology**
- **Will modify run DB to have all relevant info so we can select runs for Moller scattering**
  - **Workfest topic**
- **Have the good run list for now**

	Run number	Start	End	Events	RO config	Setup	Type	Comment	Left Dipole Current |	Right Dipole Current |	LG0 HV [V]	LG1
1240	2752	Nov 28, 2025, 13:59:02	Nov 28, 2025, 14:17:32	1000000	Full	e-,e-	Calibration	High stats, left arm at 15 A, right arm at 40 A to probe Moller. This is also likely all background.				
1241	2754	Nov 28, 2025, 14:22:55	Nov 28, 2025, 14:41:51	1000000	Full	e-,e-	Calibration	High stats, left arm at 10 A, right arm at 40 A to probe Moller. This may be all background.				
1243	2756	Nov 28, 2025, 15:58:38	not defined	0	Full	e-,e-	Calibration	Higher stats. Left arm at 15 A, right arm at 40 A to probe Moller. This mayyyyyyyy all be background and no beam.				
1286	2823	Dec 2, 2025, 1:29:49	Dec 2, 2025, 9:53:18	9704586	Full	e-,e-	Calibration	Long run for Moller scattering. Left dipole set to 15 A, right to 40 A. Beam died about 1.5 hours in				
1437	3035	Dec 7, 2025, 15:46:38	Dec 7, 2025, 16:13:42	1000000	Full	e-,e-	Test	Moller scattering run. Left set to 12 A, right set to 38 A. May have been a beam trip mid run.				
1438	3036	Dec 7, 2025, 16:13:57	Dec 7, 2025, 16:19:27	193249	Full	e-,e-	Test	Moller scattering run. Left set to 12 A, right set to 38 A. Beam trip right at end.				
1439	3037	Dec 7, 2025, 16:21:14	Dec 7, 2025, 16:54:58	990571	Full	e-,e-	Test	Moller scattering run. Left set to 12 A, right set to 38 A.				
1440	3038	Dec 7, 2025, 16:56:20	Dec 7, 2025, 16:59:32	100000	Full	e-,e-	Test	Moller scattering run. Left set to 15 A, right set to 43 A.				
1441	3039	Dec 7, 2025, 17:02:16	Dec 7, 2025, 17:13:11	299765	Full	e-,e-	Test	Moller scattering run. Left set to 15 A, right set to 43 A. Beam trip in middle.				
1442	3040	Dec 7, 2025, 17:13:50	Dec 7, 2025, 17:49:32	1000000	Full	e-,e-	Test	Moller scattering run. Left set to 15 A, right set to 43 A. Left GEM HV turned up to 3950 V.				
1443	3041	Dec 7, 2025, 17:57:18	Dec 7, 2025, 18:12:17	500000	Full	e-,e-	Test	Moller scattering run. Left set to 15 A, right set to 40 A. Mike changed bias voltages in trigger.				
1444	3043	Dec 7, 2025, 18:14:36	Dec 7, 2025, 18:28:56	288464	Full	e-,e-	Test	Moller scattering run. Left set to 15 A, right set to 40 A. Trigger threshold set to 160 mV. Right FE died.				
1445	3046	Dec 7, 2025, 18:31:21	Dec 7, 2025, 18:46:10	393658	Full	e-,e-	Test	Moller scattering run. Left set to 15 A, right set to 40 A. Trigger threshold set to 160 mV. Beam trip right at the end.				
1446	3047	Dec 7, 2025, 18:50:45	Dec 7, 2025, 19:05:19	500000	Full	e-,e-	Test	Moller scattering run. Left set to 15 A, right set to 40 A. Trigger threshold set to 240 mV.				
1471	3086	Dec 8, 2025, 20:53:40	Dec 8, 2025, 21:04:47	275907	Full	e-,e-	Test	24.4 MeV beam, current at ~5 uA, 2% DF. Dipole current at 40 A on the right, 15 A on the left. Looking for Moller. Beam trip.				
1472	3088	Dec 8, 2025, 21:15:07	Dec 8, 2025, 21:27:48	260246	Full	e-,e-	Test	24.4 MeV beam, current at ~5 uA, 2% DF. Dipole current at 40 A on the right, 15 A on the left. Looking for Moller.				
1473	3090	Dec 8, 2025, 21:32:18	Dec 8, 2025, 21:37:56	111708	Full	e-,e-	Test	24.4 MeV beam, current at ~5 uA, 2% DF. Dipole current at 35 A on the right, 15 A on the left. Looking for Moller.				
1474	3092	Dec 8, 2025, 21:41:46	Dec 8, 2025, 22:26:03	1000000	Full	e-,e-	Test	24.4 MeV beam, current at ~5 uA, 2% DF. Dipole current at 43 A on the right, 15 A on the left. Looking for Moller. Right FE died.				
1609	3272	Dec 16, 2025, 19:23:38	Dec 16, 2025, 19:47:35	411690	Full	e-,e-	Test	10 MeV beam, 300 Hz frequency, 33.3 us width, left arm at 70 A for elastic line, right at 28 A for Moller.				
1610	3274	Dec 16, 2025, 19:50:03	Dec 16, 2025, 20:05:25	272220	Full	e-,e-	Test	10 MeV beam, 300 Hz frequency, 33.3 us width, left arm at 70 A for elastic line, right at 28 A for Moller.				
1611	3275	Dec 16, 2025, 20:06:40	Dec 16, 2025, 20:27:07	360089	Full	e-,e-	Test	10 MeV beam, 300 Hz frequency, 33.3 us width, left arm at 70 A for elastic line, right at 28 A for Moller.				
1612	3276	Dec 16, 2025, 20:29:38	Dec 16, 2025, 20:47:49	319441	Full	e-,e-	Test	10 MeV beam, 300 Hz frequency, 33.3 us width, left arm at 70 A for elastic line, right at 28 A for Moller.				
1613	3279	Dec 16, 2025, 20:53:02	Dec 16, 2025, 20:56:05	100828	Full	e-,e-	Test	10 MeV beam, 300 Hz frequency, 33.3 us width, left arm at 70 A for elastic line, right at 28 A for Moller.				
1614	3280	Dec 16, 2025, 21:12:45	Dec 16, 2025, 21:27:08	500000	Full	e-,e-	Test	10 MeV beam, 600 Hz frequency, 16.667 us width, left arm at 13 A for Moller, right at 28 A for Moller.				
1615	3281	Dec 16, 2025, 21:27:25	Dec 16, 2025, 21:31:19	122533	Full	e-,e-	Test	10 MeV beam, 600 Hz frequency, 16.667 us width, left arm at 13 A for Moller, right at 28 A for Moller.				
1616	3283	Dec 17, 2025, 14:37:27	Dec 17, 2025, 14:42:38	172527	Full	e-,e-	Calibration	9.92 MeV beam, 600 Hz, 16.7 us width, left arm at 12.8 A and right at 28 A for Moller. RB GEM HV trip				
1617	3284	Dec 17, 2025, 14:44:05	Dec 17, 2025, 15:16:15	1030614	Full	e-,e-	Calibration	9.92 MeV beam, 600 Hz, 16.7 us width, left arm at 12.8 A and right at 28 A for Moller.				
2124	3956	Jan 15, 2026, 21:38:02	Jan 15, 2026, 22:06:12	1000000	Full	e-,e-	Production	Moller run, left trigger turned off but still reading off. Right at 28 A, left at 60 A for lumi monitor.				
2284	4159	Jan 26, 2026, 15:08:56	Jan 26, 2026, 15:27:32	1000001	Full	e-,e-	Production	Right Moller. Right arm 38 A, left arm 120 A. All GEMs at 3900 V. VME-Left died at end of run.				
2285	4160	Jan 26, 2026, 15:27:56	Jan 26, 2026, 15:44:11	472390	Full	e-,e-	Production	Right Moller. Right arm 38 A, left arm 120 A. All GEMs at 3900 V. Desync				
2286	4161	Jan 26, 2026, 15:44:18	Jan 26, 2026, 15:54:35	326302	Full	e-,e-	Production	Right Moller. Right arm 38 A, left arm 120 A. All GEMs at 3900 V. stop to change mag current				
2287	4162	Jan 26, 2026, 15:54:52	Jan 26, 2026, 15:58:13	100000	Full	e-,e-	Production	Right Moller. Right arm 36 A, left arm 120 A. All GEMs at 3900 V. Desync				
2288	4163	Jan 26, 2026, 15:59:06	Jan 26, 2026, 16:16:36	1000000	Full	e-,e-	Production	Right Moller. Right arm 36 A, left arm 120 A. All GEMs at 3900 V.				
2289	4165	Jan 26, 2026, 16:17:12	Jan 26, 2026, 16:20:39	100000	Full	e-,e-	Production	Right Moller. Right arm 34 A, left arm 120 A. All GEMs at 3900 V.				
2290	4166	Jan 26, 2026, 16:20:44	Jan 26, 2026, 16:45:02	1000000	Full	e-,e-	Production	Right Moller. Right arm 34 A, left arm 120 A. All GEMs at 3900 V.				
2291	4167	Jan 26, 2026, 16:45:09	Jan 26, 2026, 16:59:26	660604	Full	e-,e-	Production	Right Moller. Right arm 34 A, left arm 120 A. All GEMs at 3900 V. RG0 tripped.				
2292	4168	Jan 26, 2026, 17:00:58	Jan 26, 2026, 17:14:43	348842	Full	e-,e-	Production	Right Moller. Right arm 34 A, left arm 120 A. All GEMs at 3900 V. RG0 tripped.				
2293	4169	Jan 26, 2026, 17:19:59	Jan 26, 2026, 17:35:12	732928	Full	e-,e-	Production	Right Moller. Right arm 34 A, left arm 120 A. All GEMs at 3900 V. RG0 tripped				
2311	4188	Jan 27, 2026, 16:16:01	Jan 27, 2026, 16:19:57	100000	Full	e-,e-	Test	Current around 10 uA, 1.5% DF, 1.1kHz, 13.6 us width. Right at 40 A, left at 165 A. Finding place to put Moller.				
2312	4189	Jan 27, 2026, 16:24:02	Jan 27, 2026, 16:25:50	100000	Full	e-,e-	Test	Current around 10 uA, 1.5% DF, 1.1kHz, 13.6 us width. Right at 38 A, left at 165 A. Finding place to put Moller.				
2367	4252	Jan 28, 2026, 12:12:14	Jan 28, 2026, 12:44:14	1000000	Full	e-,e-	Production	Left arm 12 A, right arm 165 A, Moller.				
2368	4253	Jan 28, 2026, 12:44:20	Jan 28, 2026, 12:51:58	164940	Full	e-,e-	Production	Left arm 12 A, right arm 165 A, Moller. CB02 died at end.				
2369	4254	Jan 28, 2026, 12:52:44	Jan 28, 2026, 13:31:03	1000000	Full	e-,e-	Production	Left arm 12 A, right arm 165 A, Moller.				
2433	4332	Jan 29, 2026, 16:15:14	Jan 29, 2026, 16:47:42	1000000	Full	e-,e-	Calibration	Testing e+e- more. Right at 32, left at 12 (Moller). Coincidence plus long coincidence trigger. Same beam conditions as prev runs				

Only 35 runs have explicit mentions of “Moller” in run log, did not have Moller runtype. We took more than that.

Good Run List

What data do we actually have?

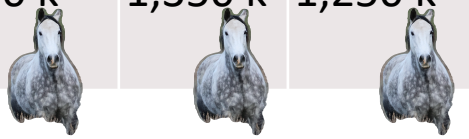
Triggers in runs labeled "Moller"	10 MeV	15 MeV	20 MeV	25 MeV	30 MeV
Left Moller	17 M	5 M	20 M	6 M	3 M
Right Moller	18 M	7 M	6 M* 	27 M 	25 M 

 = No Right Top GEM

Also trigger on elastic events on other side.
Only looking at January data, cleanest, but missing lots of 10 MeV data.
*I think I'm missing something here

What data do we actually have?

Estimated Moller Clusters	10 MeV	15 MeV	20 MeV	25 MeV	30 MeV
Left Moller	1,020 k	300 k	1,200 k	360 k	180 k
Right Moller	900 k	350 k	300 k*	1,350 k	1,250 k



= No Right Top GEM

Roughly 50,000 (60,000) Moller clusters/1 M events and 34,000 (5,000) elastic clusters/1 M events on right (left) arm.
*I think I'm missing something here

What data do we actually have?

Estimated Moller Events	10 MeV	15 MeV	20 MeV	25 MeV	30 MeV
Left Moller	300 k	90 k	350 k	105 k	50 k
Right Moller	250 k	100 k	90 k*	400 k	360 k

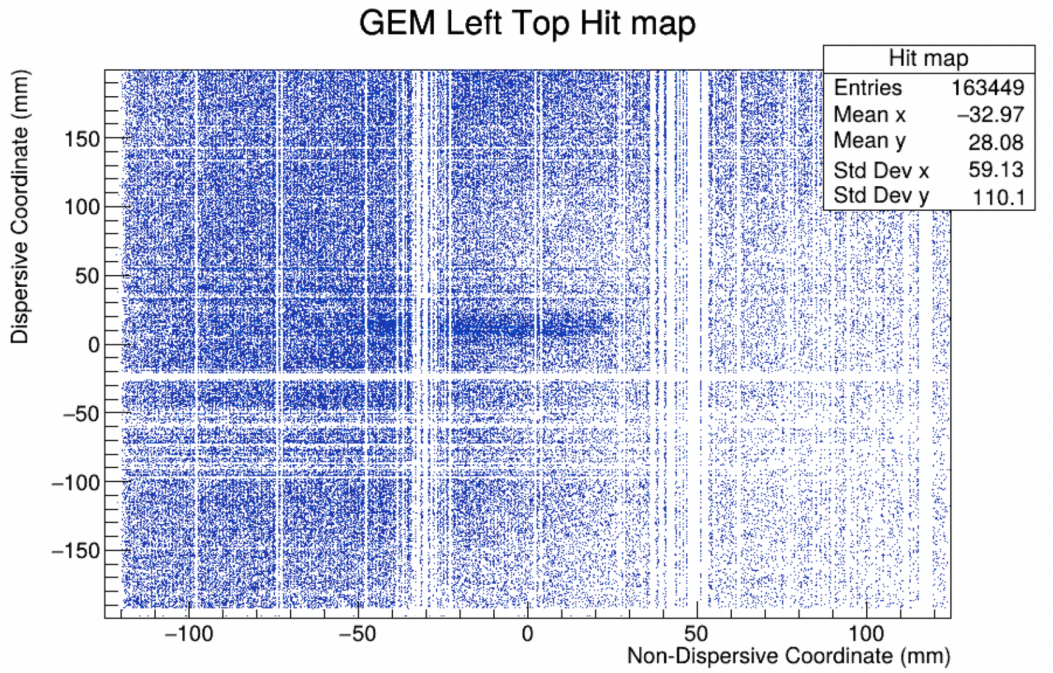


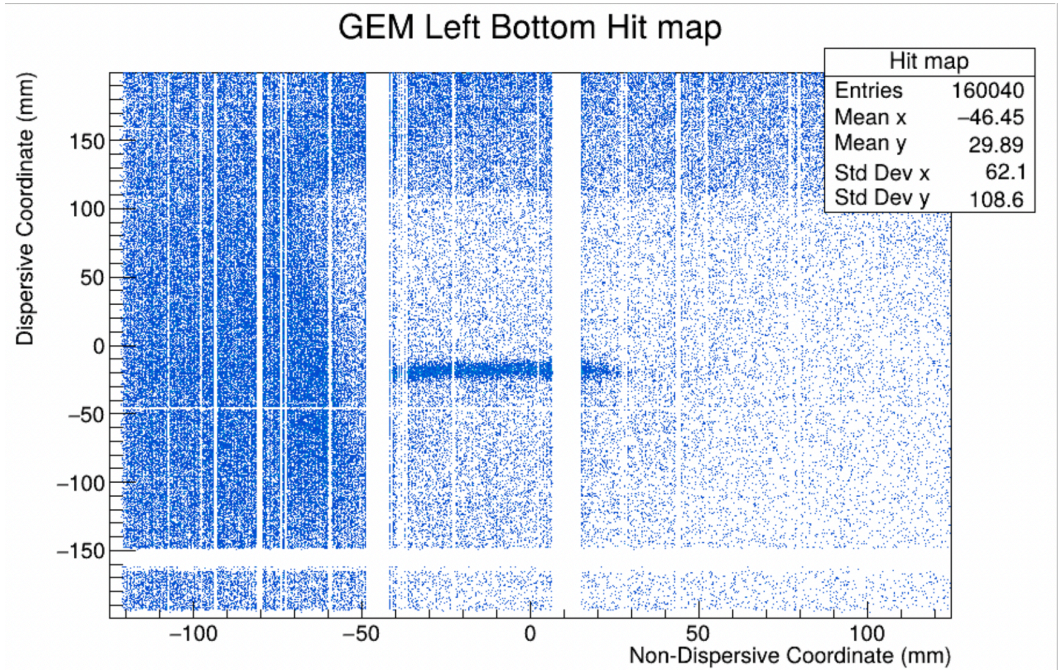
 = No Right Top GEM

Making some assumption of 30 % efficient on each GEM for tracking + some reduction due to other cuts.
*I think I'm missing something here

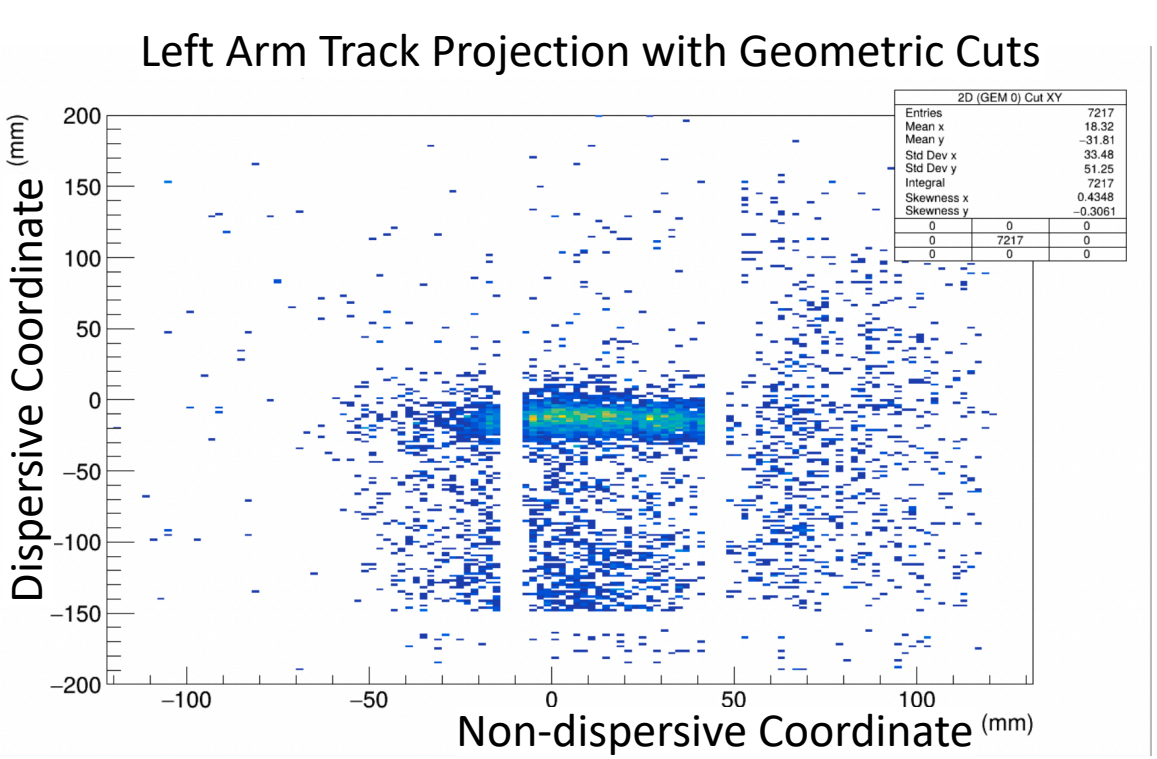
NOISE

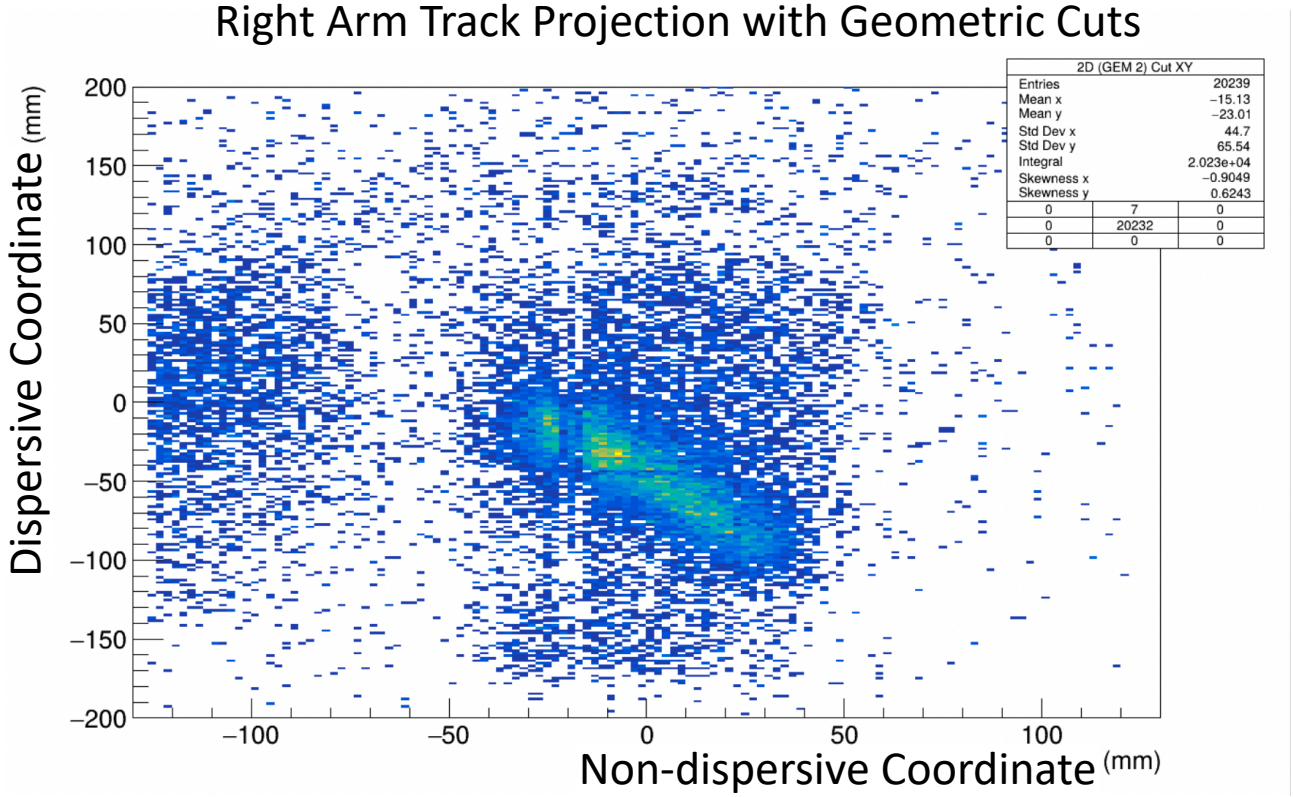
- When measuring Moller scattering on right, left arm might be luminosity monitor.
  - Look at tracks that point toward scintillator bar with hit over the course of a run
- Concerned about noise levels in GEM left top
- Obviously dead regions are a problem too
  - Need to be matched in simulation





Moller and Elastic Scattering, Run 3815, 10 MeV





Looking forward

- Low level detector performance is current holdup
- Need to have robust clustering algorithm, and well-timed trigger hits
    - Need to implement dead/inefficient GEM regions into simulation to match data
- In principle higher-level analysis is not “complicated”
- Have simulation files for all Moller energies on my laptop
    - Can move to a central location