Lost Muon Study on Muon G-2

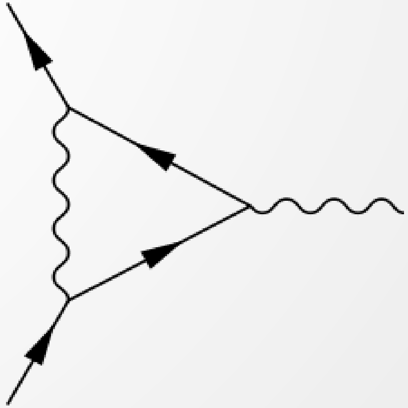
Ludovico Mark Capparelli
Fermilab Summer Internship
24th September, 2014
Supervisor: Dr. Adam Lyon

An overview of Muon G-2 (E989)

- Magnetic moment of any elementary particle is related to its intrinsic spin by the “g-factor”

$$\vec{\mu} = \mathbf{g}\frac{e}{2m_{\mu}c}\vec{S}$$

- Spin ½ point particles are predicted by the Dirac equation to have g=2
- But quantum loop corrections produce an anomaly.
- g is slightly different from 2



An overview of Muon G-2 (E989)

- In this experiment, a polarized beam of positive muons will orbit inside a magnetic ring with a „magic“ momentum of 3.09 GeV

$$\frac{d\vec{p}}{dt} = e\vec{v} \times \vec{B} \quad \Rightarrow \quad \omega_c = \frac{eB}{\gamma mc}$$

$$(\vec{v} \cdot \vec{B} = 0)$$

- Magnetic and electric fields cause the precession of the spin of the muon

$$\frac{d\vec{S}}{dt} = \vec{\mu} \times \vec{B} \quad \Rightarrow \quad \omega_s = \frac{geB}{2mc} + (1-\gamma)\frac{eB}{\gamma mc}$$

Larmor precession

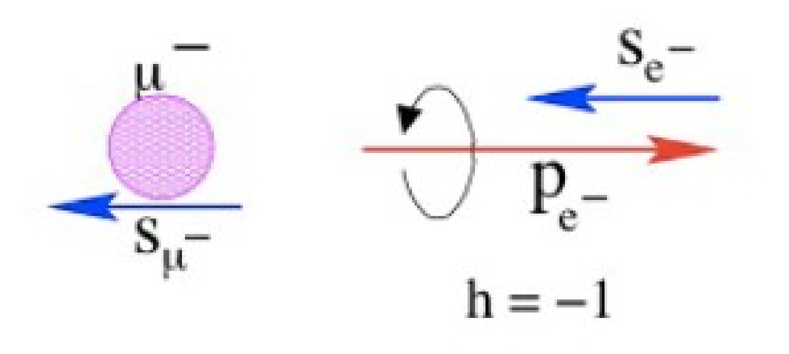
Thomas precession

An overview of Muon G-2 (E989)

- We measure the frequency

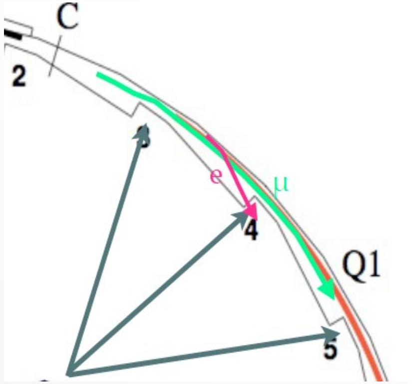
$$\omega_a \equiv \omega_s - \omega_c = a_\mu \frac{eB}{mc}$$

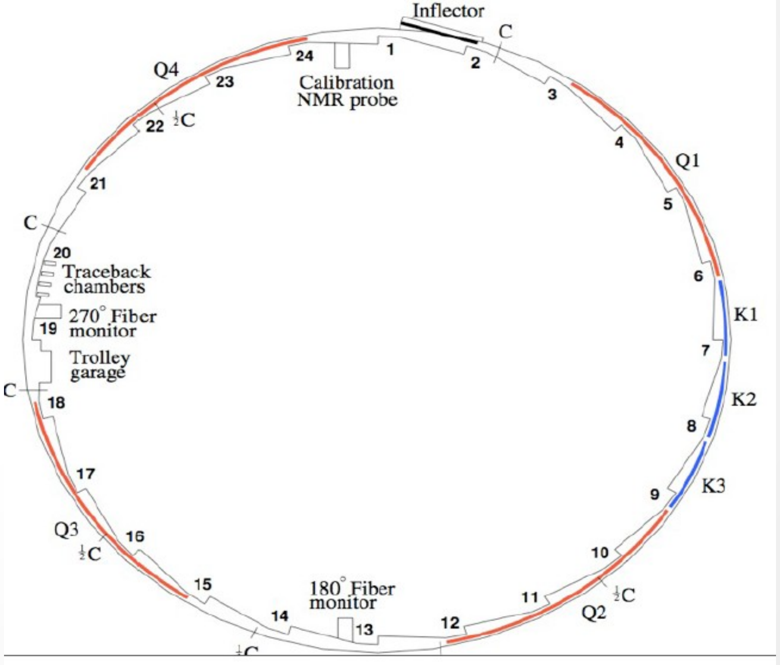
- Parity violations in the weak muon decay μ->ν+e cause the positron to be emitted preferentially in the direction opposite to the muon's spin



An overview of Muon G-2 (E989)

- Positrons will not remain on the stable orbit. They will fall on to a smaller radius and hit one of 24 calorimeters.
- Energy deposited in each calorimeter due to positrons is therefore correlated to muon spin





Systematic Errors

- Precision measurement plagued by systematic error
- ω_a affected by
  - Calorimeter gain
  - Pileup
  - CBO
  - Lost Muons ←- The bulk of my studies

Losing Muons...

- If Muons are lost from the beam, the average polarization could change.
- Muons could exit „magic“ orbit and hit calorimeters producing false signals
- My focus was to study these events
- Previous experiment studied these events from the data. We wish to understand them via MC Simulation

Lost Muons - A few objectives

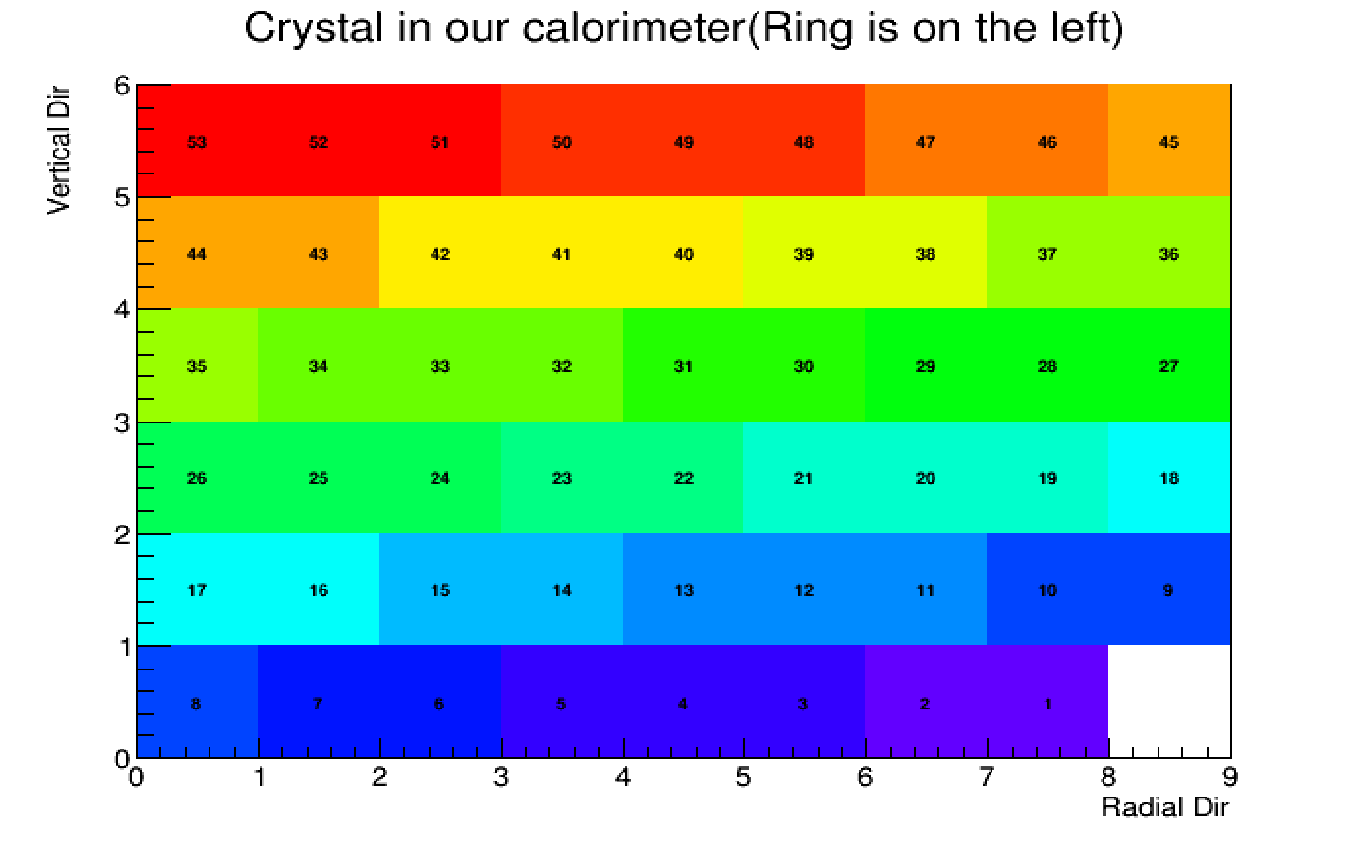
- Questions to answer:
  - What are the characteristics of events with lost muons?
  - How can we find these events in our data?
  - How do the muons exit the magic orbit?

Lost Muons - Topology

- The first working hypothesis is that a muon exiting the „magic“ orbit can hit more than one calorimeter. In fact, it is a MIP.
- On the other hand a positron will likely deposit all its energy.
- The rectangular calorimeters are divided into crystals.
- If a muon hits more than one calorimeter we expect correlations between which crystals where hit.
- Such correlations could allow us to infer when a hit is due to a muon

Lost Muons - Topology

The crystals is our calorimeter



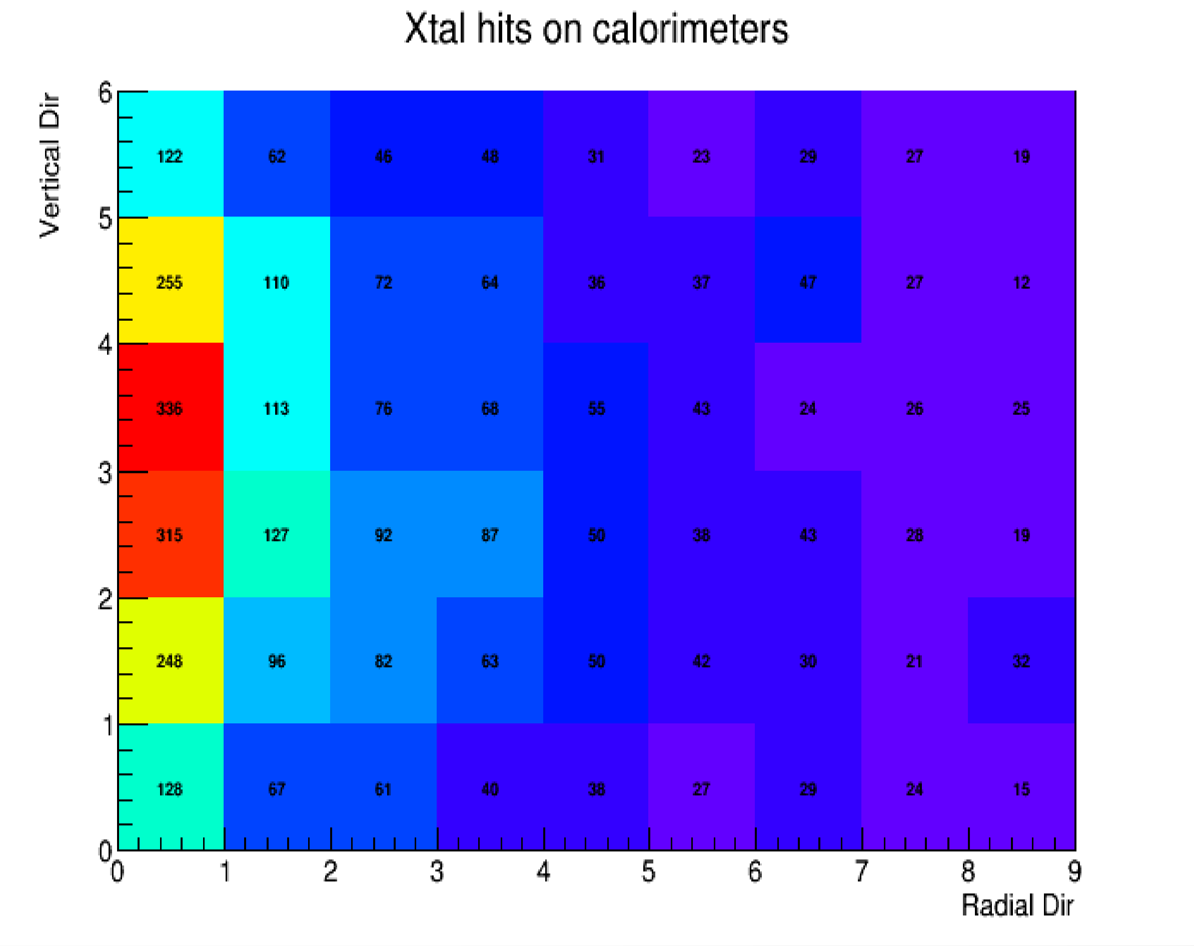
53	52	51	50	49	48	47	46	45
44	43	42	41	40	39	38	37	36
35	34	33	32	31	30	29	28	27
26	25	24	23	22	21	20	19	18
17	16	15	14	13	12	11	10	9
8	7	6	5	4	3	2	1	

Lost Muons - Topology

- At first we are not interested on how exactly muons are lost from the beam.
- Most probable cause is muons whose momentum or initial position deviates enough from „magic“ orbit so that it will hit passive ring material and lose energy.
- To make the losses „democratic“ we fill our simulated ring with Xenon. Muons will lose energy via this interaction.

Lost Muons - Topology

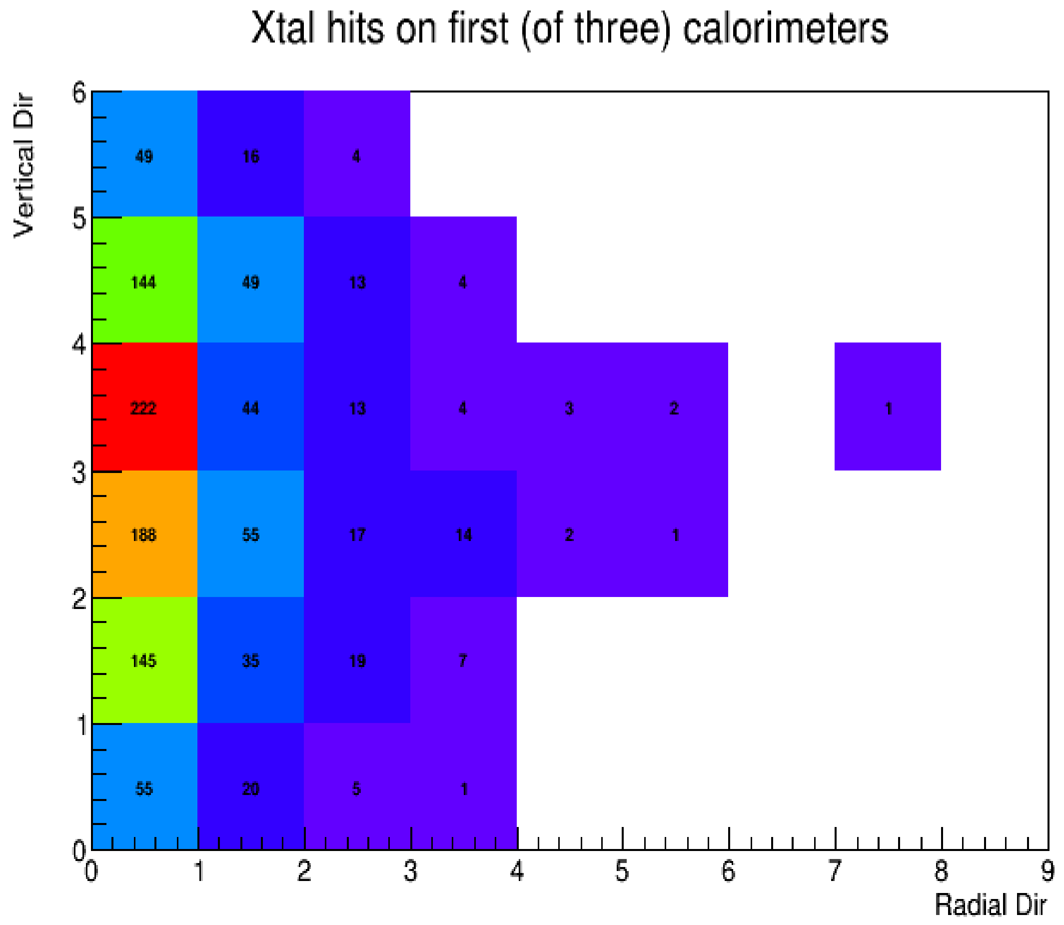
- This way we can find a generic distribution of muon hits on the crystals(Xtals) in a calo
- Most hits are ringside, as expected



122	62	46	48	31	23	29	27	19
255	110	72	64	36	37	47	27	12
336	113	76	68	55	43	24	26	25
315	127	92	87	50	38	43	28	19
248	96	82	63	50	42	30	21	32
128	67	61	40	38	27	29	24	15

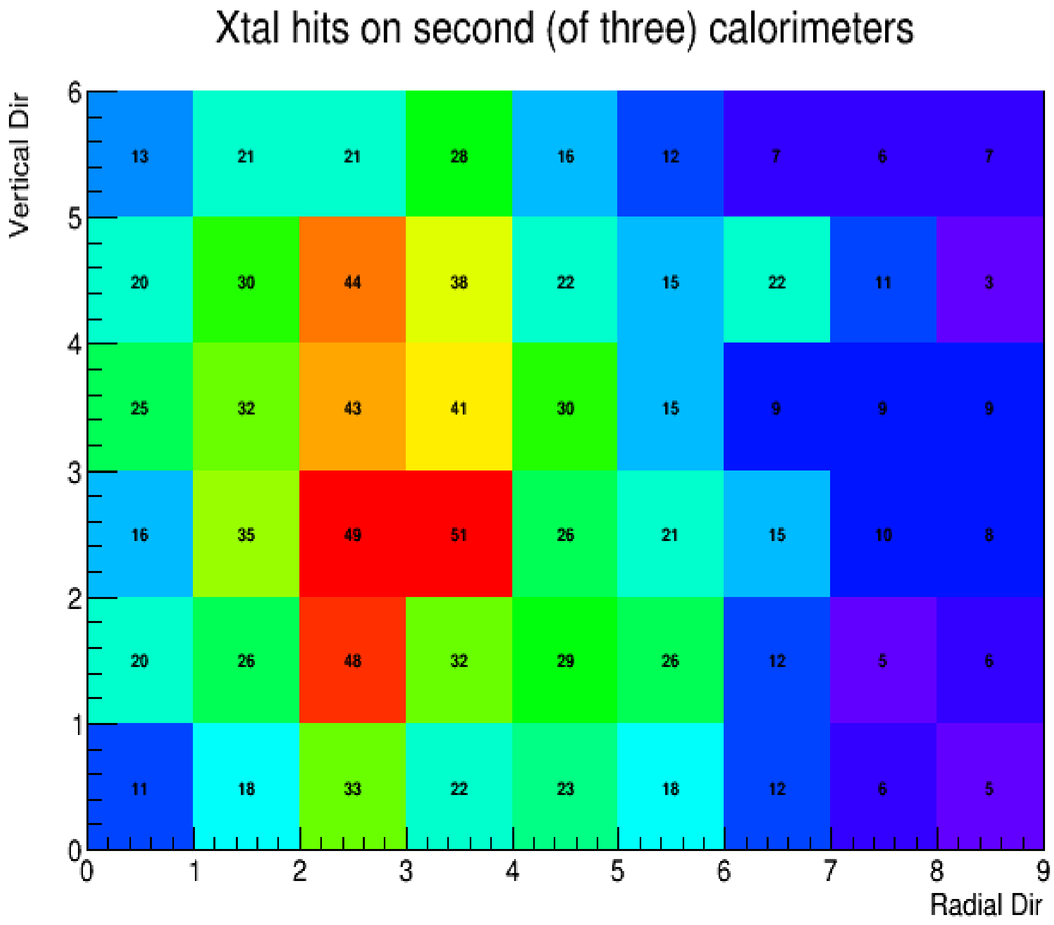
Lost Muons - Topology

- Most lost muons will hit three Calorimeters.
- We analyze the distribution of the first of the three calorimeter hits.
- The first hit in the sequence is „usually“ ring-side



Lost Muons - Topology

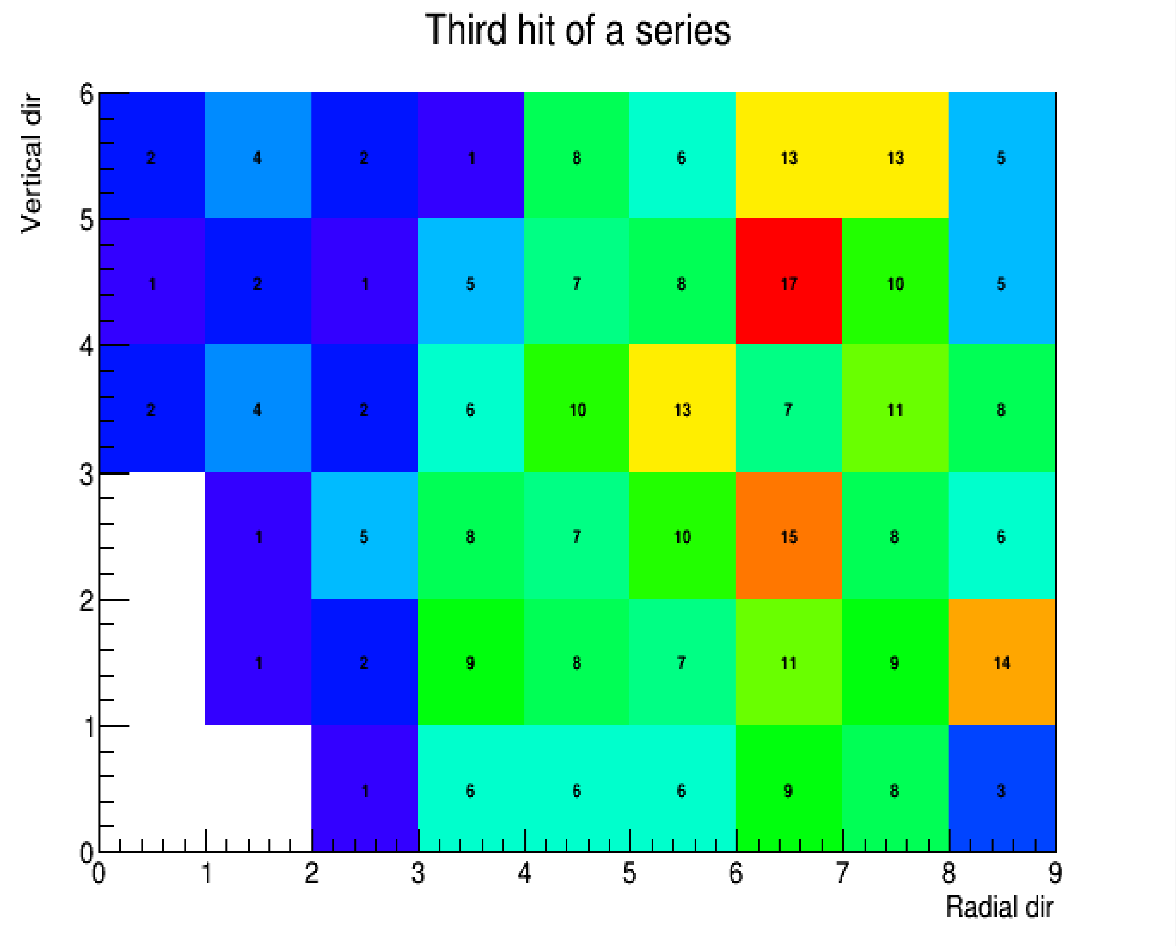
- The hits on the second calorimeter are in the center(as we move to the right we move to a lower orbit)
- This is expected: a muon loses energy by interacting with the first calo



13	21	21	28	16	12	7	6	7
20	30	44	38	22	15	22	11	3
25	32	43	41	30	15	9	9	9
16	35	49	51	26	21	15	10	8
20	26	48	32	29	26	12	5	6
11	18	33	22	23	18	12	6	5

Lost Muons - Topology

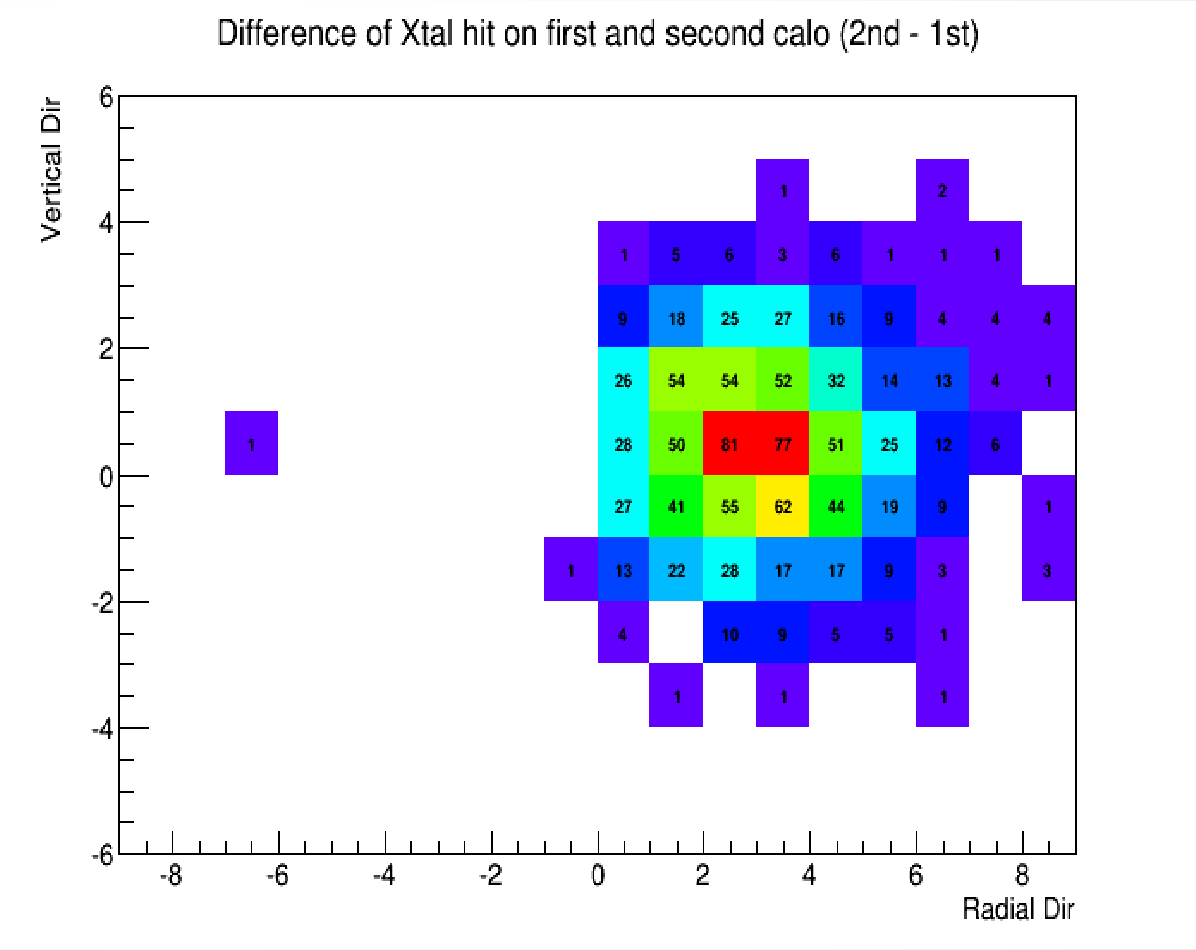
- The third hits are more on the innerside.
- This graph would probably need more simulation time to generate more statistics...


Third hit of a series

2	4	2	1	8	6	13	13	5
1	2	1	5	7	8	17	10	5
2	4	2	6	10	13	7	11	8
	1	5	8	7	10	15	8	6
	1	2	9	8	7	11	9	14
		1	6	6	6	9	8	3

Lost Muons - Topology

- We also analyze the difference between the xtal hit in two consecutive calos.
- As shown, after hitting a calo, muons move to a lower radius but stay, on average, at the same height (vertical axis)

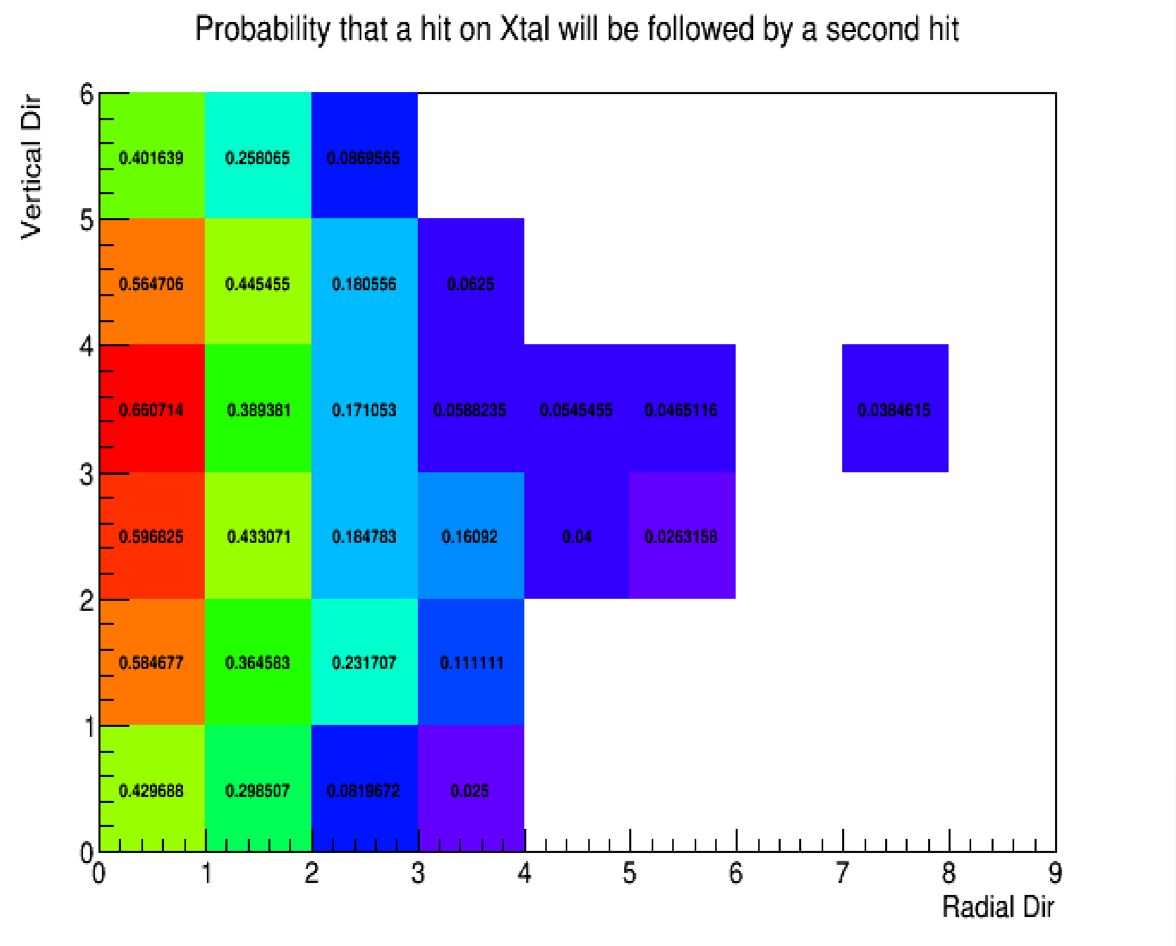


Lost Muons - Topology

- The important thing to study is the conditional probabilities that if a crystal is hit, it is part of a sequence of calorimeter hits by a muon.
- These probabilities would depend on the dynamics of the muon and the interaction with the calos.
- In a complex real event, these probabilities can allow us to determine if there are hits due to lost muons

Lost Muons - Topology

- This graph shows the probability that, given an xtal hit, it is the first of a sequence of three hit calos

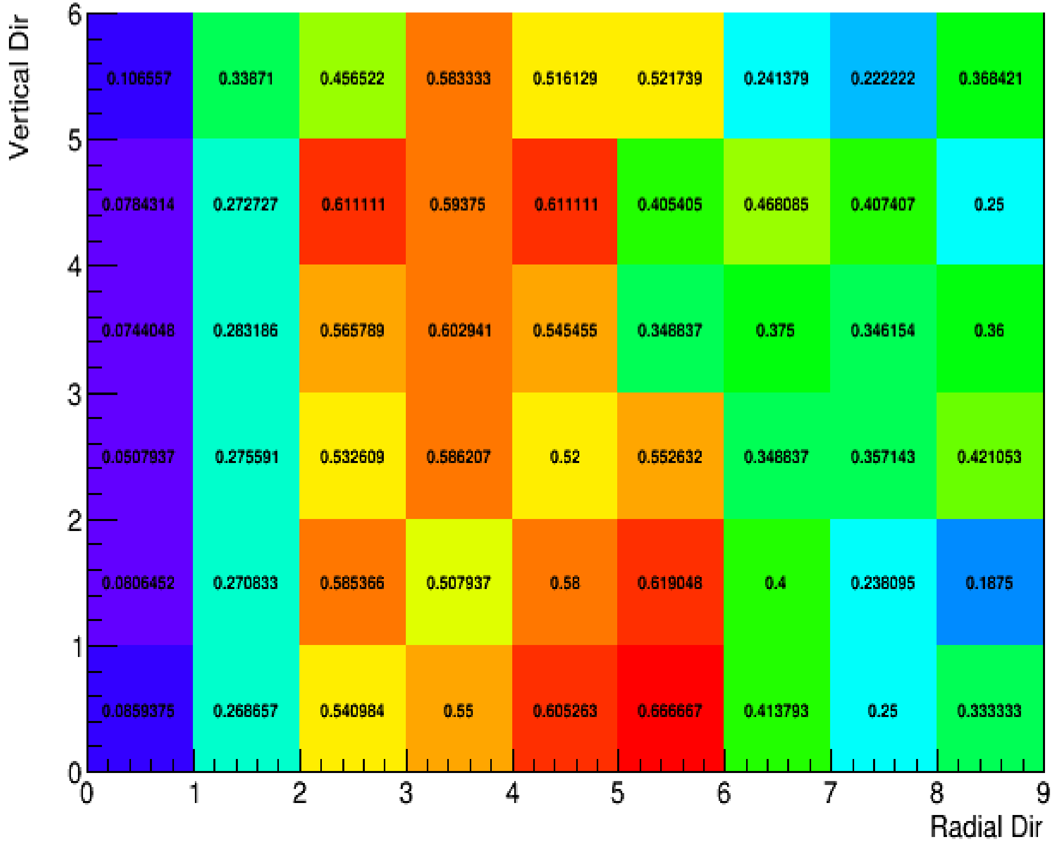


24.09.14

Lost Muons - Topology

- The second hit of a series again, happens most likely in the center of the calo...

Probability that a hit on Xtal is the second of a series(of 3)

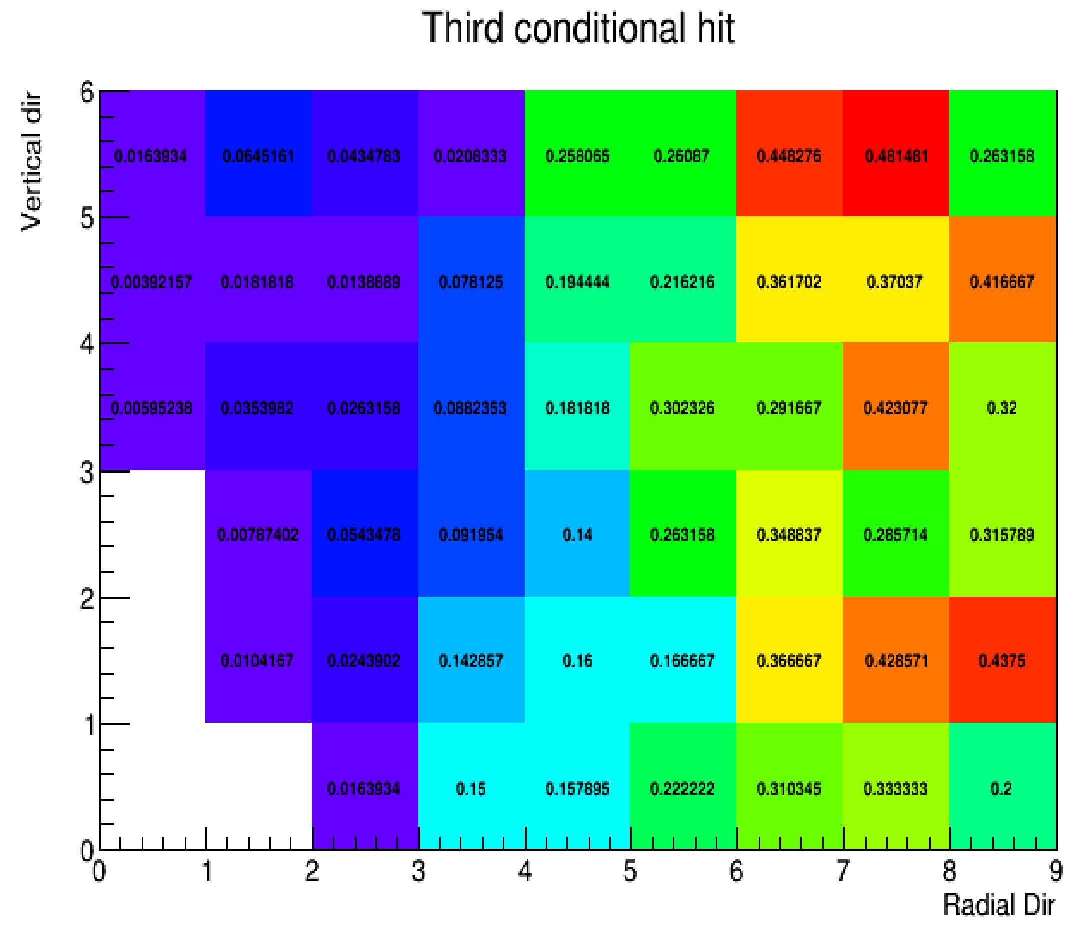


0.106557	0.33871	0.456522	0.583333	0.516129	0.521739	0.241379	0.222222	0.368421
0.0784314	0.272727	0.611111	0.59375	0.611111	0.405405	0.468085	0.407407	0.25
0.0744048	0.283186	0.565789	0.602941	0.545455	0.348837	0.375	0.346154	0.36
0.0507937	0.275591	0.532609	0.586207	0.52	0.552632	0.348837	0.357143	0.421053
0.0806452	0.270833	0.585366	0.507937	0.58	0.619048	0.4	0.238095	0.1875
0.0859375	0.268657	0.540984	0.55	0.605263	0.666667	0.413793	0.25	0.333333

24.09.14

Lost Muons - Topology

- And the third is likely to come on the innermost side.

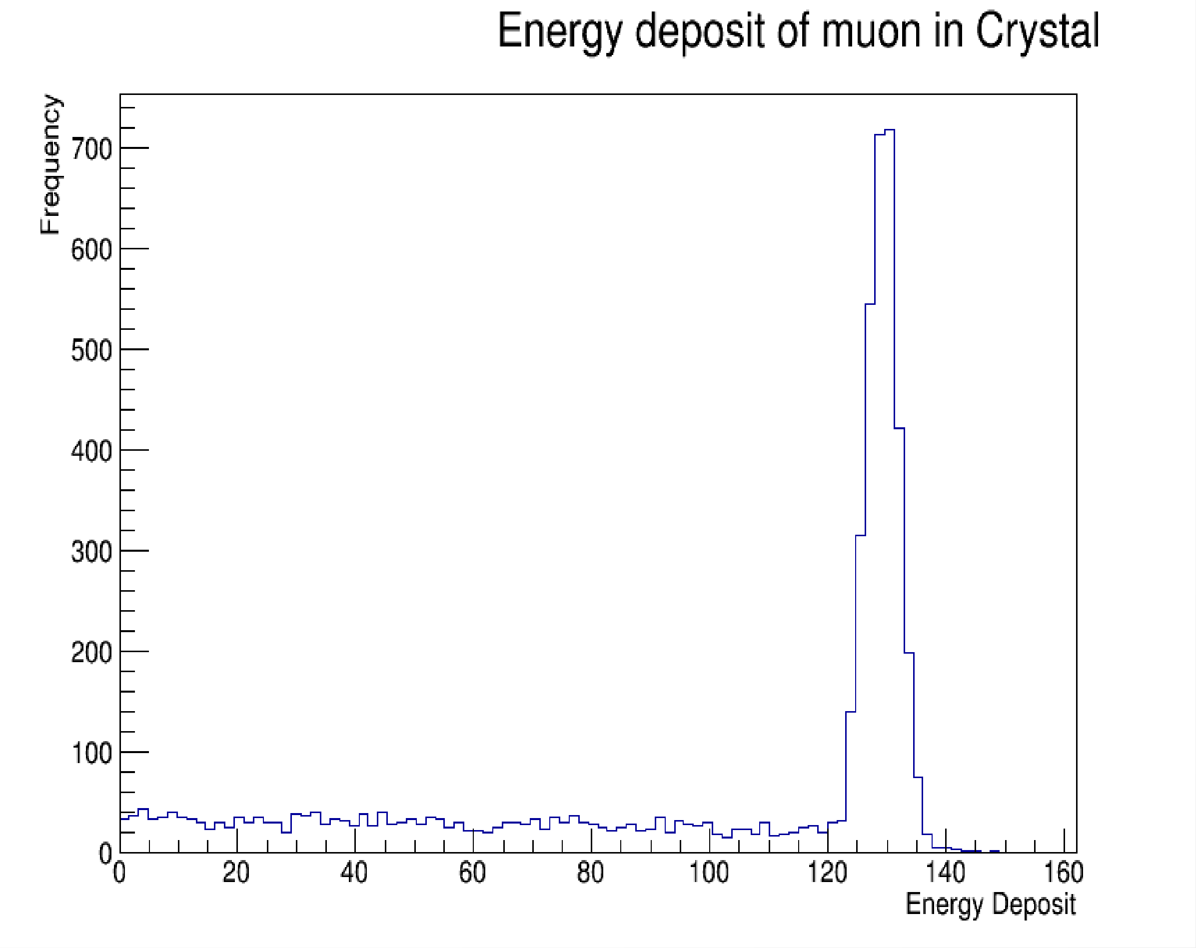


Third conditional hit

0.0163934	0.0645161	0.0434783	0.0208333	0.258065	0.26087	0.448276	0.481481	0.263158
0.00392157	0.0181818	0.0138889	0.078125	0.194444	0.216216	0.361702	0.37037	0.416667
0.00595238	0.0353982	0.0263158	0.0882353	0.181818	0.302326	0.291667	0.423077	0.32
	0.00787402	0.0543478	0.091954	0.14	0.263158	0.348837	0.285714	0.315789
	0.0104167	0.0243902	0.142857	0.16	0.166667	0.366667	0.428571	0.4375
		0.0163934	0.15	0.157895	0.222222	0.310345	0.333333	0.2

Lost Muons – Energy Loss

- Being a MIP, muons will likely lose less energy in a xtal than the electron. We found the distribution of energy loss of a muon in a crystal.
- The energy loss is centered around 130 MeV



Lost Muons – Conclusions

- I Performed preliminary studies toward lost muon systematic uncertainty evaluation.
- I Determined lost muons topology using simulated events
- My work represent a first attempt in building the logic to discriminate lost muons vs real electron signal