H2020-MSCA-RISE-2015 – Grant Agreement N° 690835

Lost Muons correction

(E989 g-2 Experiment)

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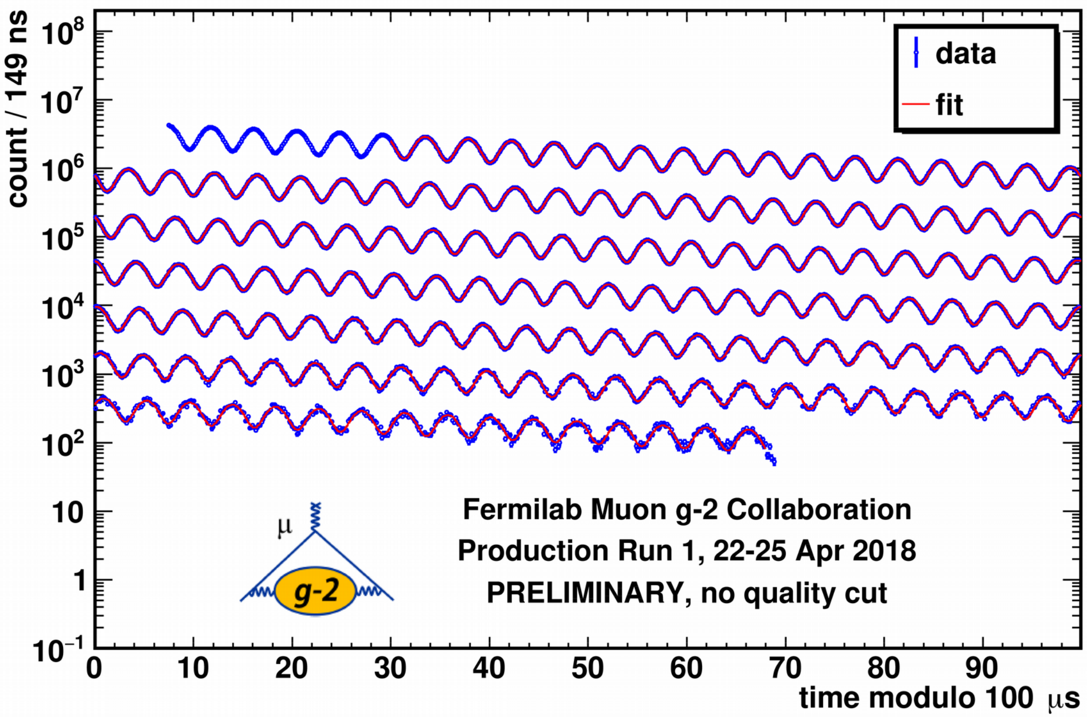
Lost Muons correction

Collecting Higher energy positrons, emitted preferentially in direction of muon spin we obtain a distribution over time

5-parameter fit function: $N(t) = \left(\frac{N0}{\tau}\right) * e^{-t/\tau} * [1 - A\cos(\omega_a t + \phi)]$

Number of high energy positrons as a function of time



Systematics!

Need to correct for

- **pileup,**
- **coherent betatron oscillations,**
- **Pitch effect,**
- **Lost Muons**

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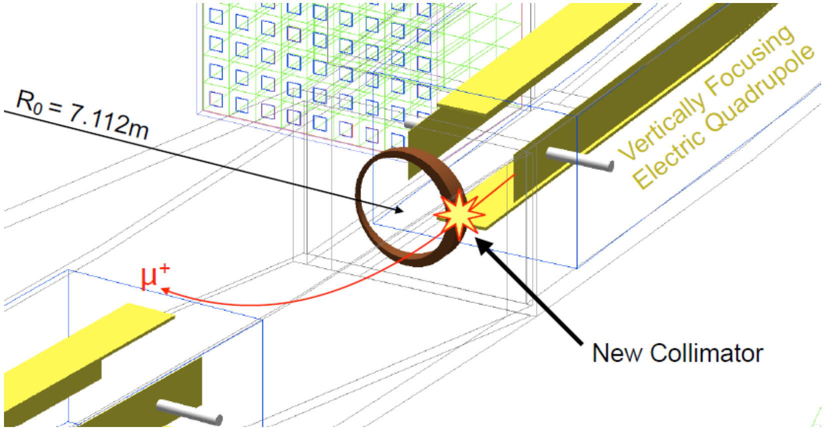
Systematic Errors: Lost Muons from Storage Ring

Category	E821 [ppb]	E989 Improvement Plans	Goal [ppb]
Gain changes	120	Better laser calibration	
		low-energy threshold	20
Pileup	80	Low-energy samples recorded	
		calorimeter segmentation	40
Lost muons	90	Better collimation in ring	20
CBO	70	Higher n value (frequency)	
		Better match of beamline to ring	< 30
E and pitch	50	Improved tracker	
		Precise storage ring simulations	30
Total	180	Quadrature sum	70

New Collimators to remove muons outside the 9 cm diameter storage region



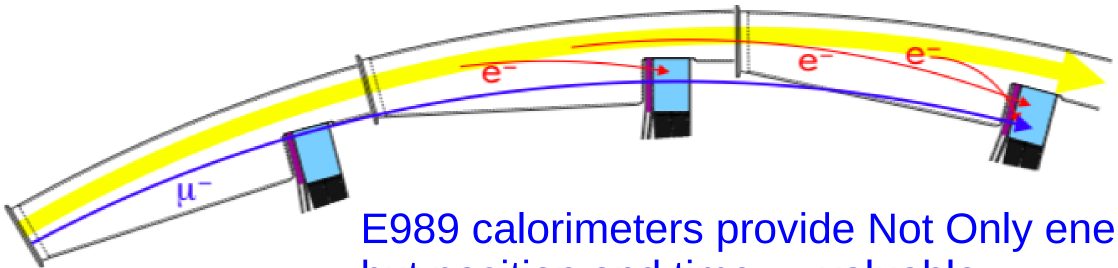
Muons that get kicked out by the collimators and punch through calorimeters (MIPs) during measurement

Need to determine: how many muons are lost, aim to keep the relative number of lost muons below 10^{-4} per τ

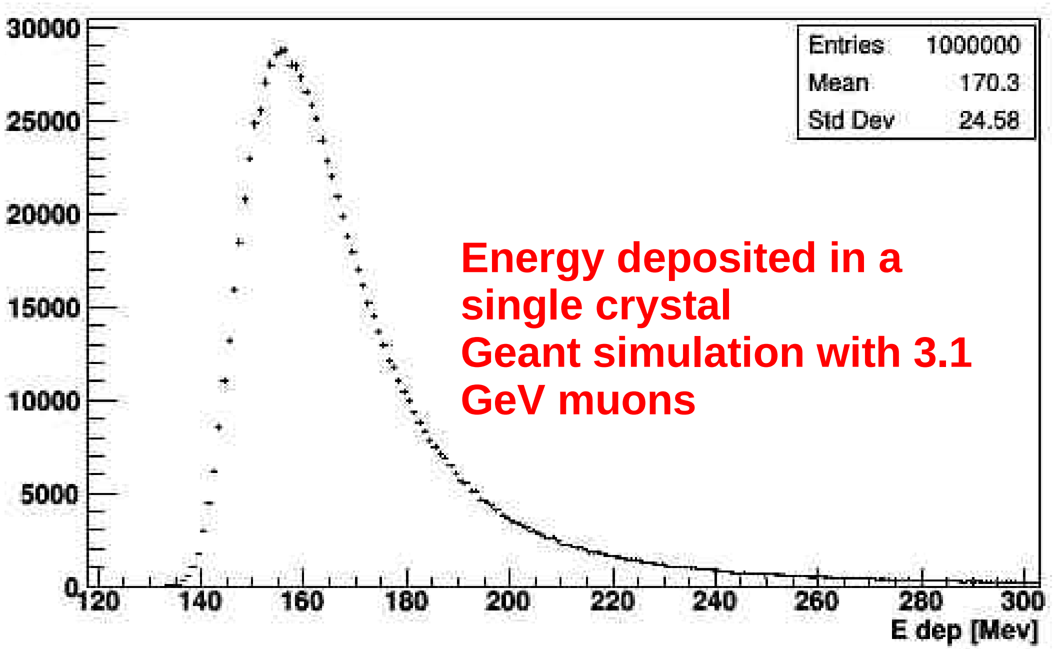
How Do We Detect Lost Muons?

- Muons can pass through many calorimeters without stopping
- Look for coincidences in two (three) consecutive calorimeters

A muon typically takes 6.25±0.5 ns (time-of-flight) to travel from one calorimeter to the next calorimeter depositing MIP-like energies in a single crystal in each calorimeter



E989 calorimeters provide Not Only energy but position and time → valuable information for MIP (Minimum Ionizing Particles) signal detection
(54 crystals x calo)



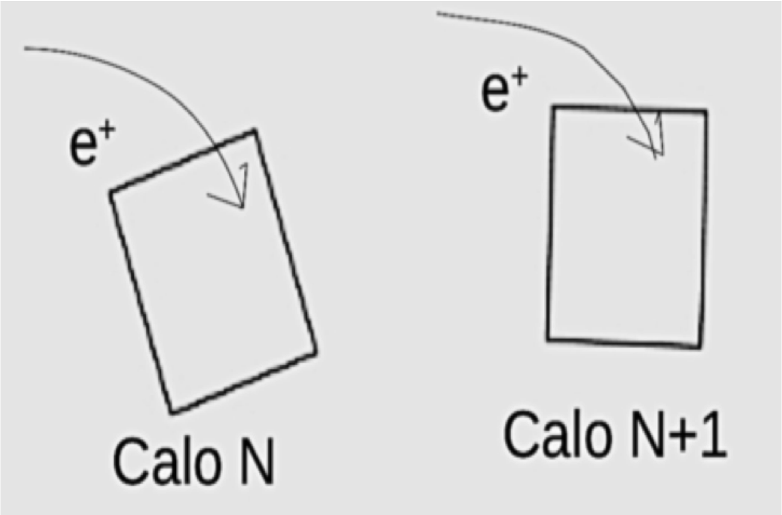
Energy deposit of a MIP in a crystal should be ~ 170MeV
With a Landau like distribution

[1.54MeV/gm cm^2 * 7.77 gm cm^{-3} (density of material) *14 cm (crystal length) = 166 MeV]

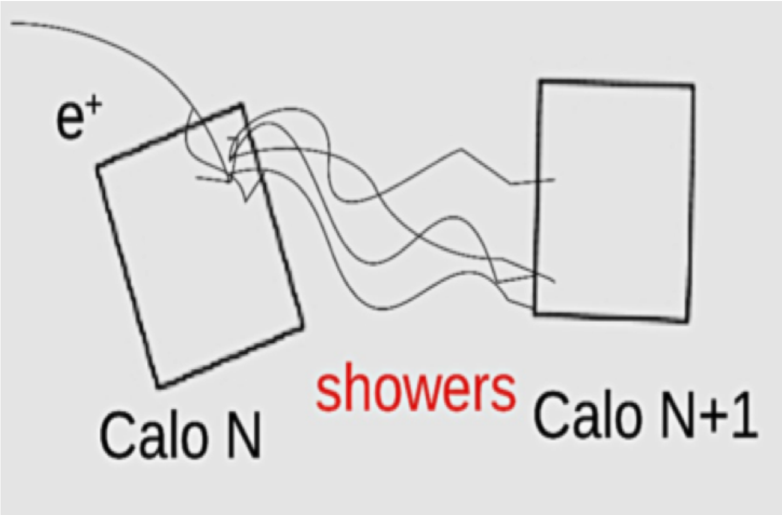
Source of backgrounds

Low energy decay positrons produces a MIP-like signature

Uncorrelated 2 e+ background: appears in coincidence-time-window & out-of-time windows



Correlated 1 e+ background: Appears only in coincidence-time-window in consecutive calorimeters



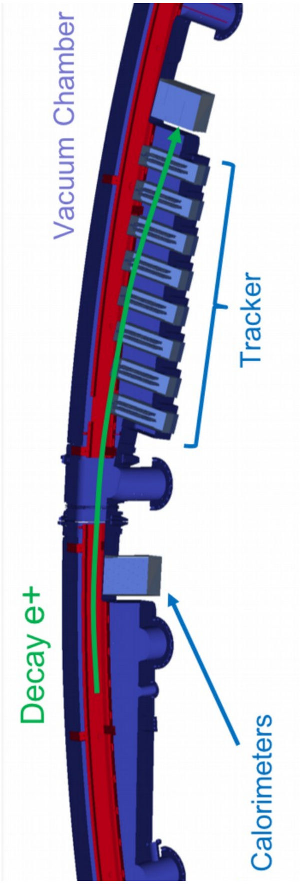
Previus studies (Sudeshna doc-db 9530) demostrates Optimize signal vs. background detection in triple coincidence, it is enough to use only ΔE and ΔT cuts

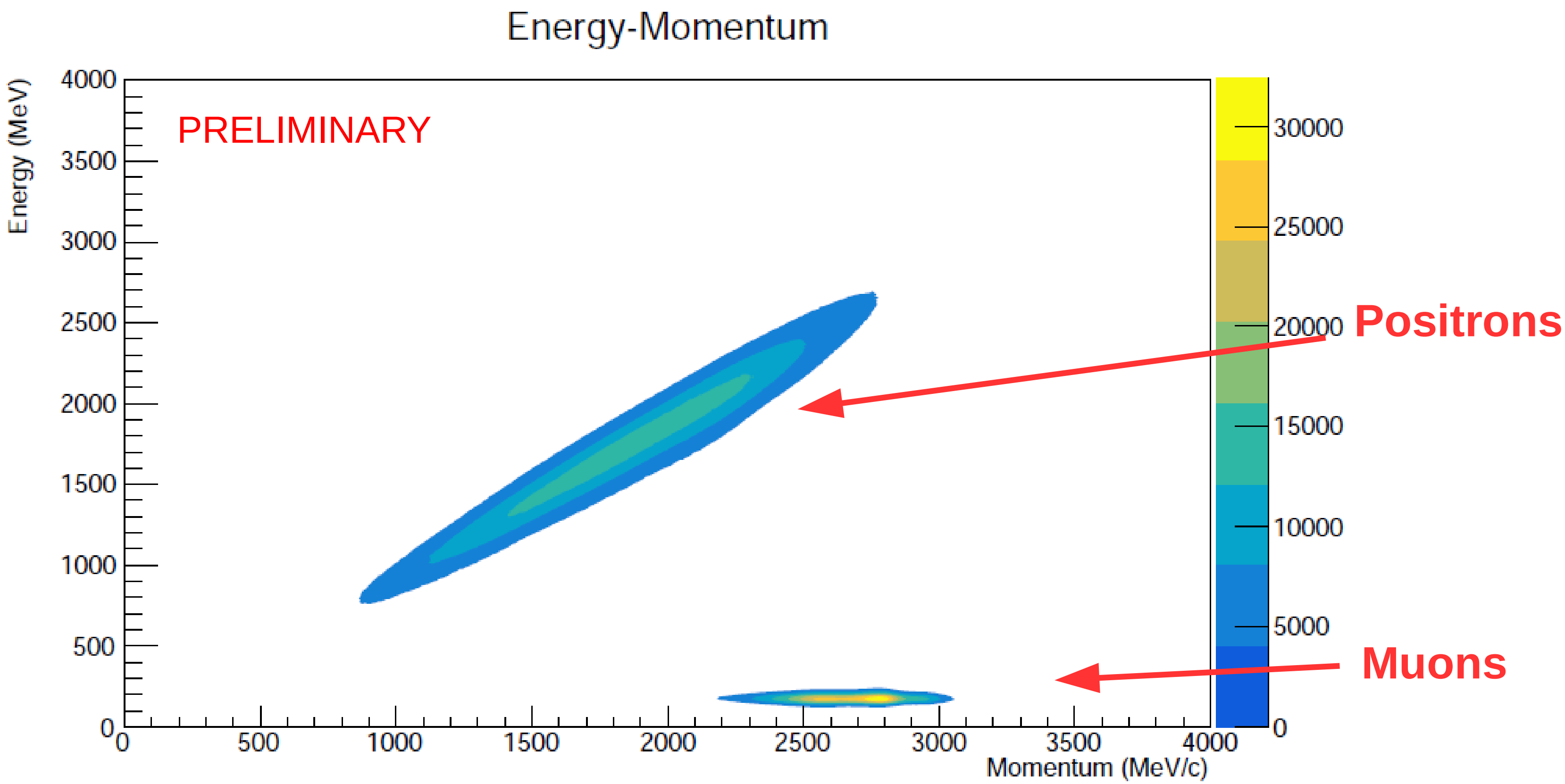
Double coincidences have dominating irreducible (correlated) backgrounds come from shower leakage from the back-side of the calorimeter. Need to use additional cuts

Tracker Identification

Tracker station combined together with the calorimeter, allows to identify a particle by its energy and its momentum

The identification can be applied only to calorimeters matched with tracker stations (data from calorimeters number 13 and number 19 presented)





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Preliminary results
ω_a Europa analysis group

Lost muons analysis:
M. Sorbara, A. Gioiosa, A. Driutti, S. Di Falco

Data used and cuts applied

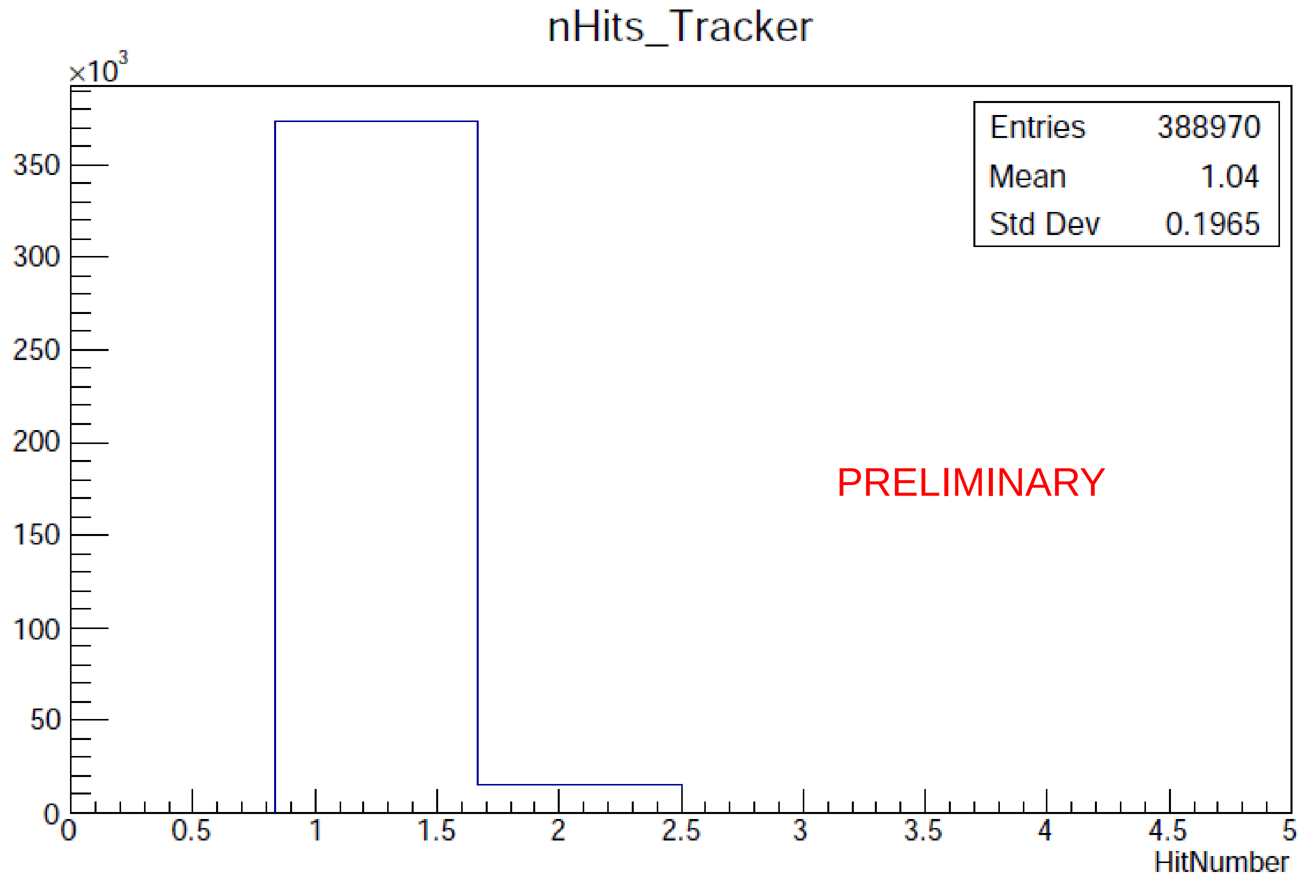
- **60 hours dataset with DQC**
  - Date: April 22-25, 2018
  - homogeneous Quad and Kicker settings

- **Double Coincidence**
  - MIP like energy on each calorimeter: 100 MeV < E < 500 MeV
  - Time difference between two consecutive calorimeters: $5\text{ ns} < \Delta T_{21}(T_2 - T_1) < 7.5\text{ ns}$
  - Cluster Size in Calo1 (Crystal hits in a cluster) = 1
  - $\Delta E_{21} = E_2 - E_1 \leq 40\text{ MeV}$

- **Triple Coincidence**
  - MIP like energy on each calorimeter: 100 MeV < E < 500 MeV
  - Time difference between each pair of consecutive calorimeters: $5\text{ ns} < \Delta T_{21}(T_2 - T_1) < 7.5\text{ ns}$ and $5\text{ ns} < \Delta T_{32}(T_3 - T_2) < 7.5\text{ ns}$
  - Cluster Size in Calo1 (Crystal hits in a cluster) = 1
  - $\Delta E_{21} = E_2 - E_1 \leq 40\text{ MeV}$ and $\Delta E_{32} = E_3 - E_2 \leq 40\text{ MeV}$

Data used and cuts applied

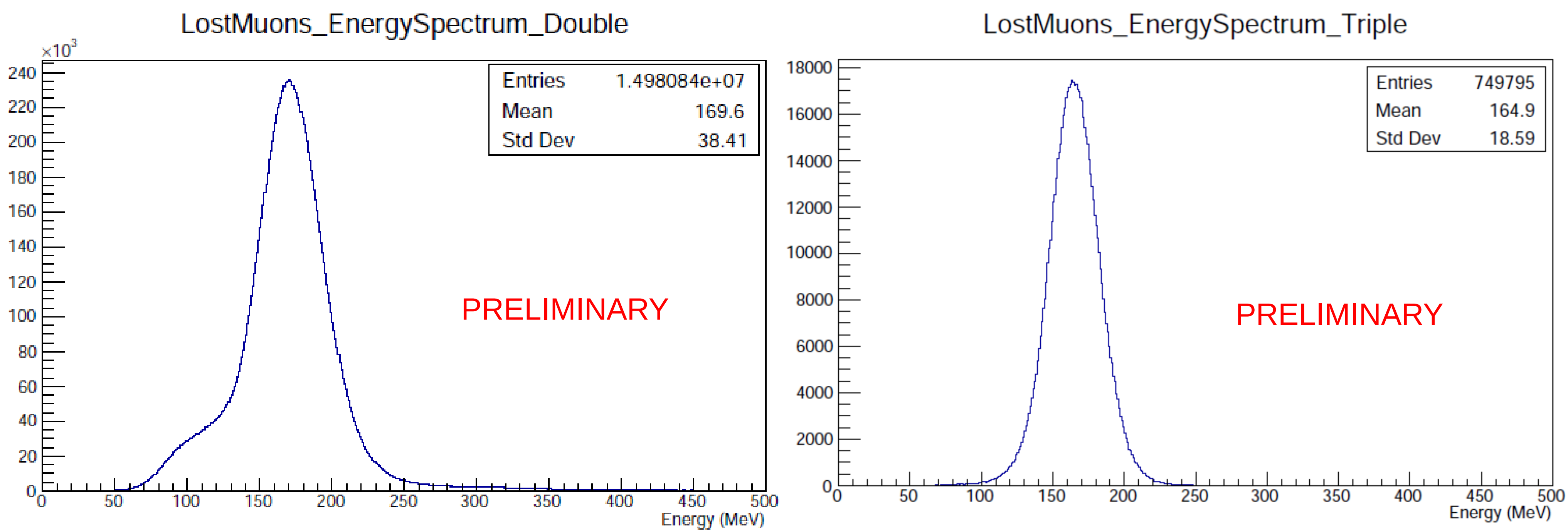
Number of crystals fired by a muon identified by the tracker. The number of events with hits greater than 1 is negligible (~ 4%) compared to the total number of muon events



We use only data with 1 crystal hit in a cluster

Energy spectrum measured by calorimeters

the energy spectra for double and triple coincidences Both spectrum has a peak in the right energy region around 170 MeV as expected from the simulation



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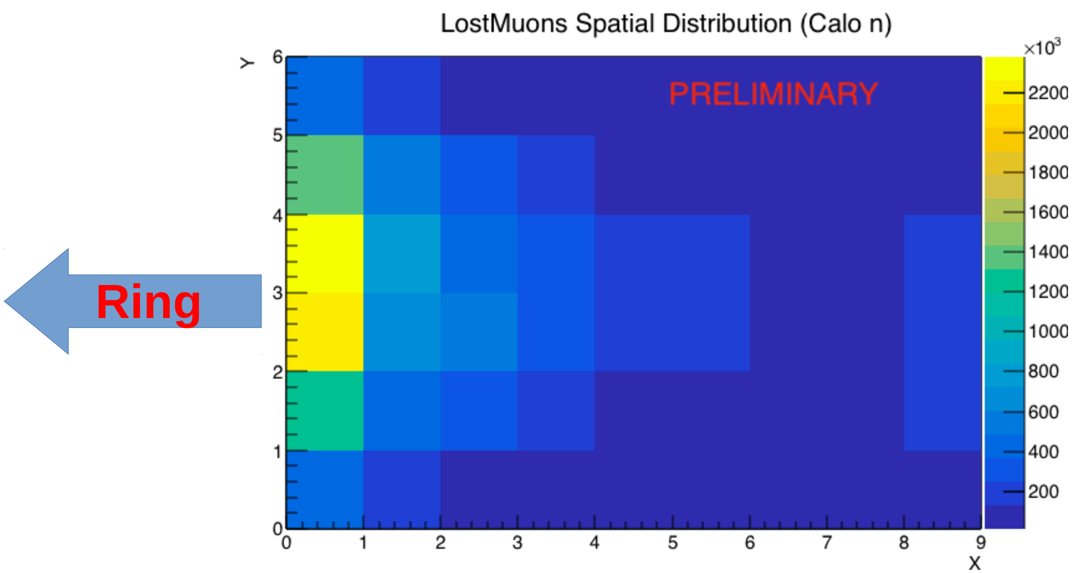
Spatial distribution

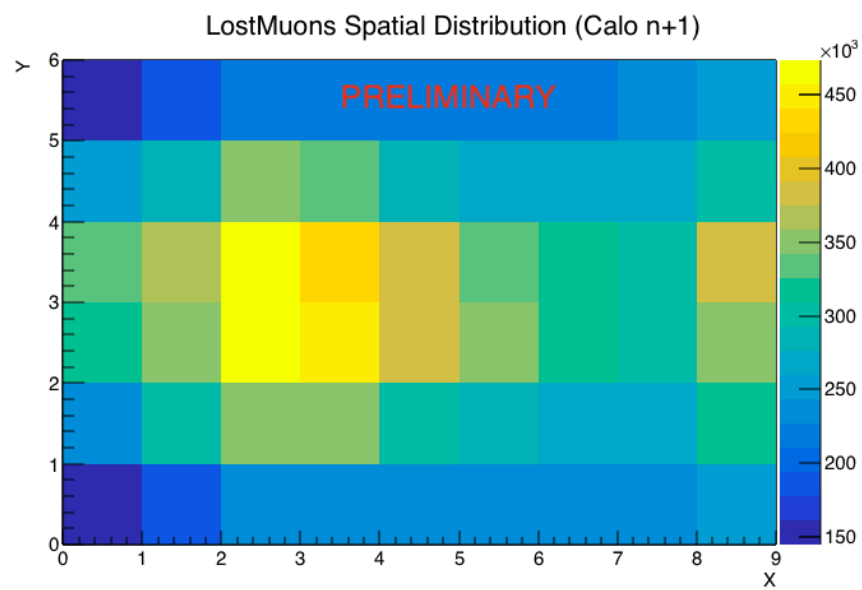
The segmented structure of the calorimeters allow to measure the position of a particle into the calorimeter itself

Lost muons mostly hit the calorimeter on the region near the ring

And curl inside due to the residual magnetic field in the calorimeters' region

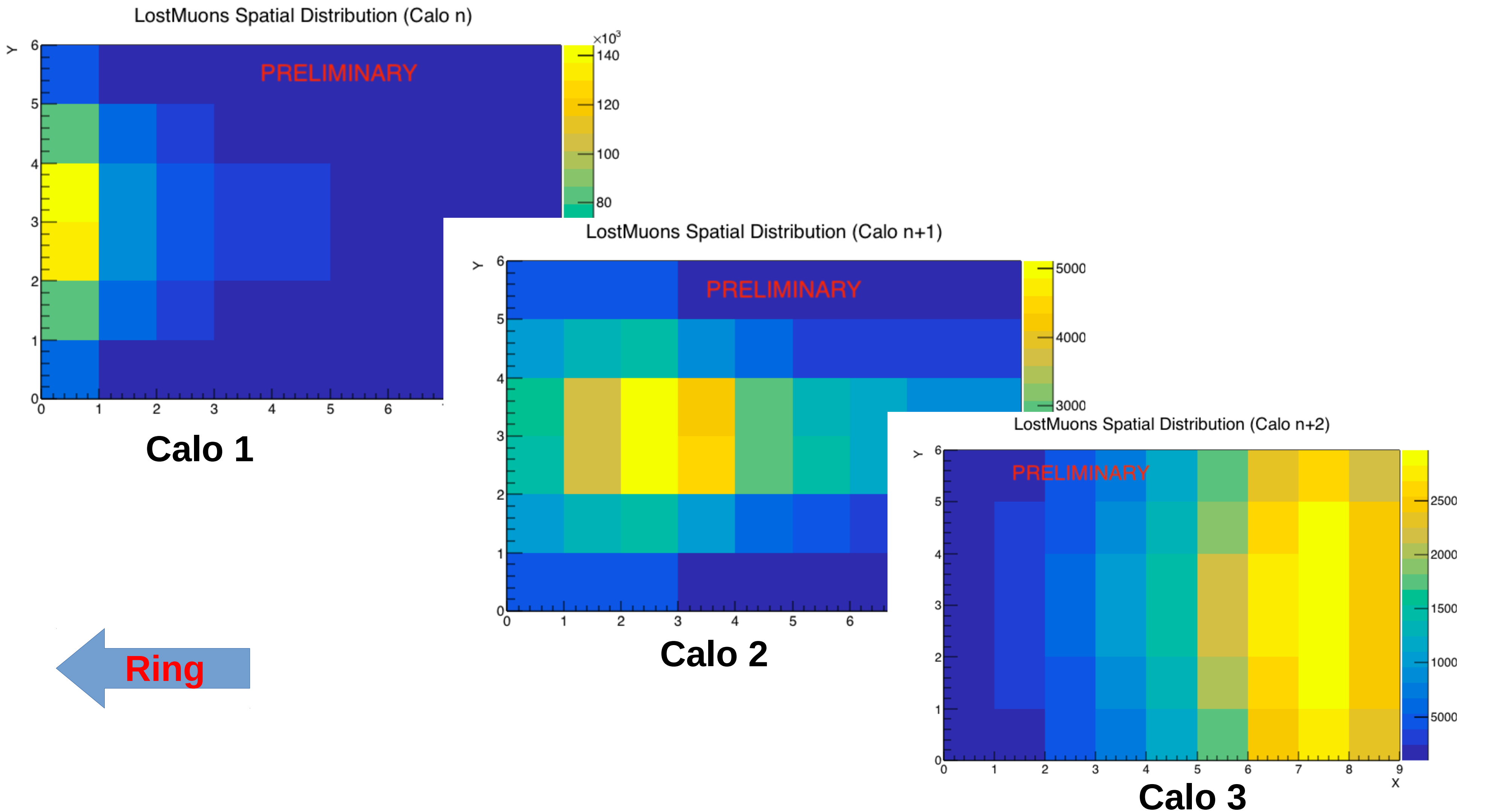
Double coincidence





Spatial distribution

Triple coincidence



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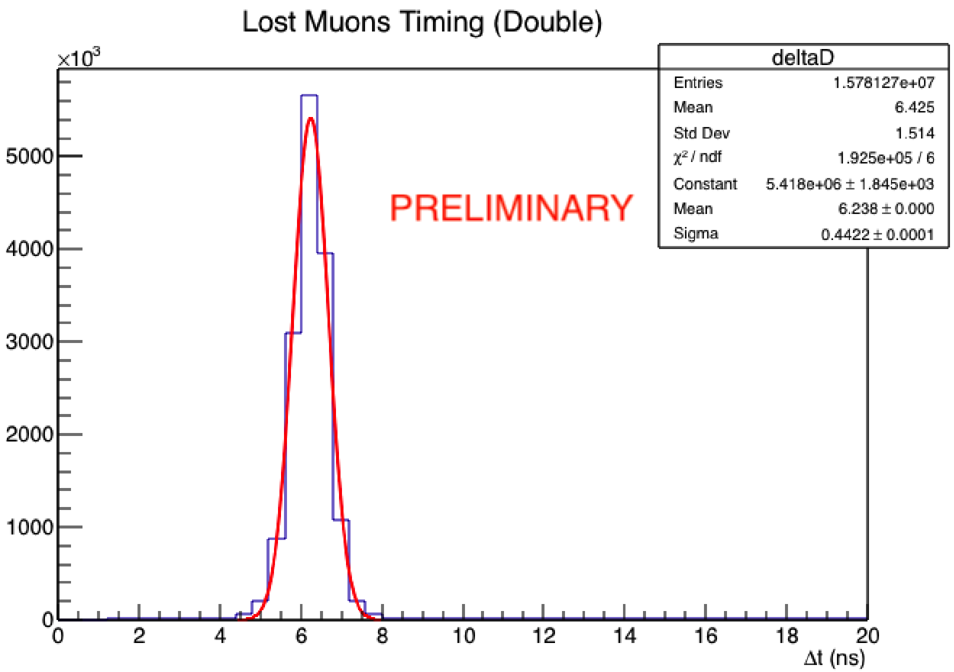
Timing

A muon with γ = 29.3 has a speed v = 0.99942c

Takes about 6.2 ns to cover the distance between two calorimeters

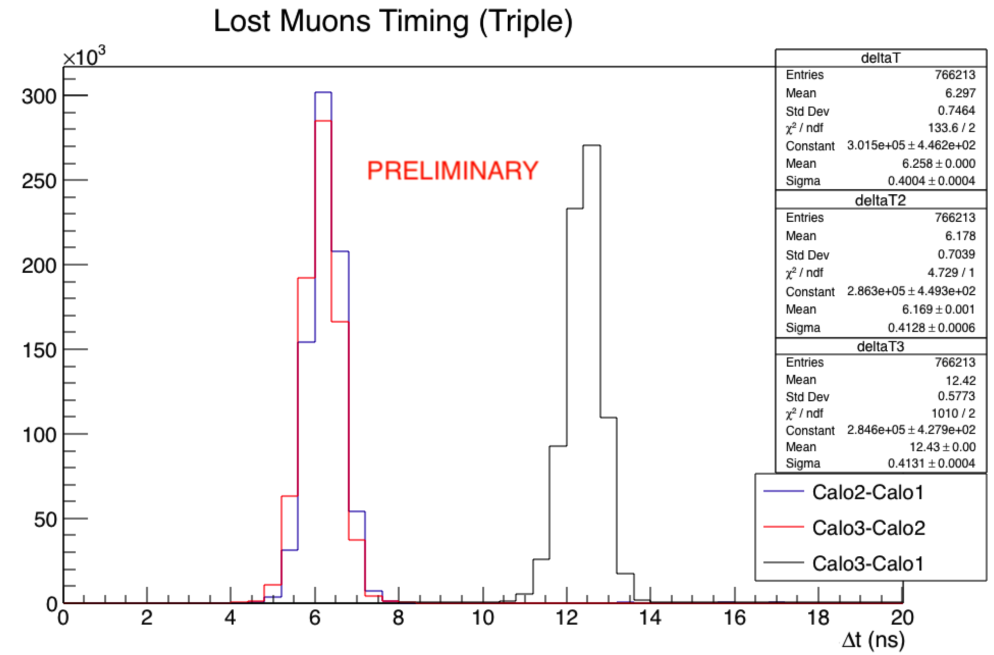
Time difference $\Delta t_{21} = t_2 - t_1$ between two consecutive calorimeters in the **double** coincidences

Peak at 6.24 ns as expected



Time difference in **triple** coincidences

Peaks in two regions: 6.2 ns and 2 · 6.2 ns = 12.4 ns as expected



Construction of the loss function

- Rate of losses is not constant in time
- Muons at the edge of the phase space are favorably lost at early times → Deviation from pure exponential muon decay
- Average spin of the lost muons can differ from that of the fully stored muons, if they are created at different points in production beam line
- Difference in average spin phase can cause a shift in measured ω_a
- **We need to incorporate muon losses into the fit function:**

Modified fit function:

$$N(t) = \frac{N_0}{\tau} e^{-t\tau} \Lambda(t) \left[1 - A\cos(\omega_a t + \varphi)\right]$$

$$\frac{dN_\mu}{dt} = -\left(\frac{N_\mu}{\tau} + cL(t)\right)$$

Construction of $\Lambda(t)$

$$\Lambda(t) = 1 - Ce^{-t_0/\tau} \int_{t_0}^{t} L(x) e^{x/\tau} dx$$

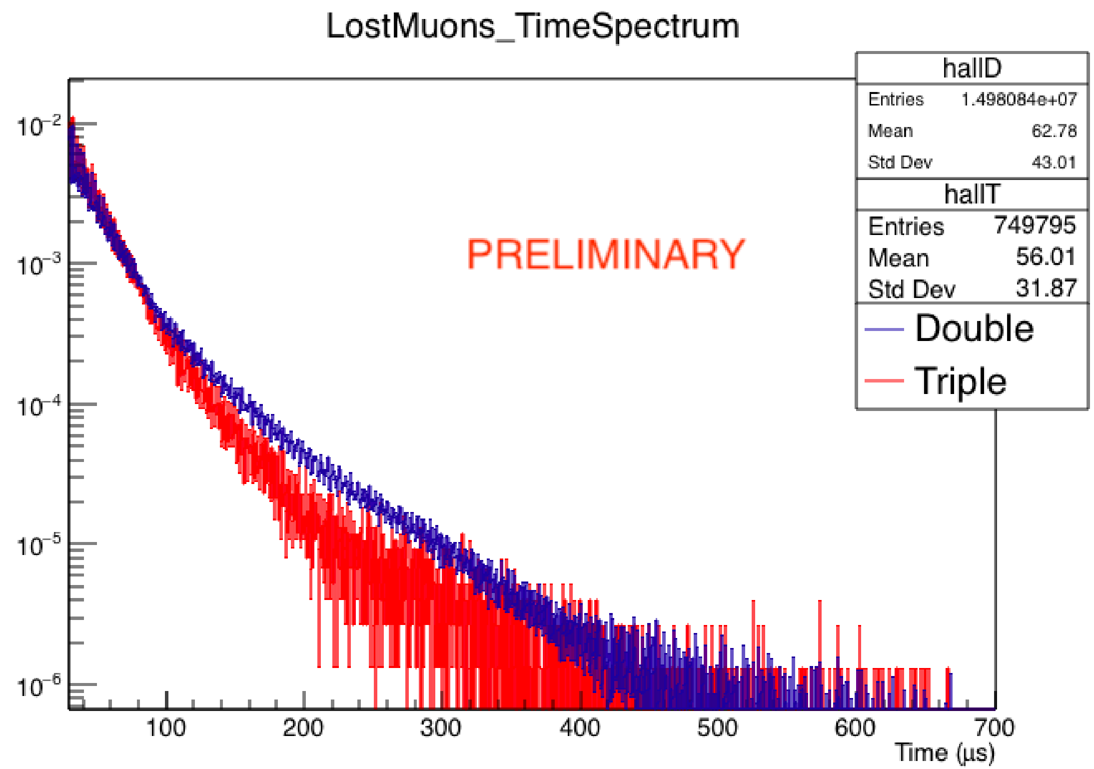
Lost Muons Function from Double and Ttriple Coincidences

Lost muons time spectrum for the double and triple coincidences (L2(t) and L3(t) functions)

Muons at the edge of the phase space are favorably lost at early times

Two different slopes can be identified in the curves

Higher fluctuations after 300 μs are due to the low statistics of triple coincidence in that region of time



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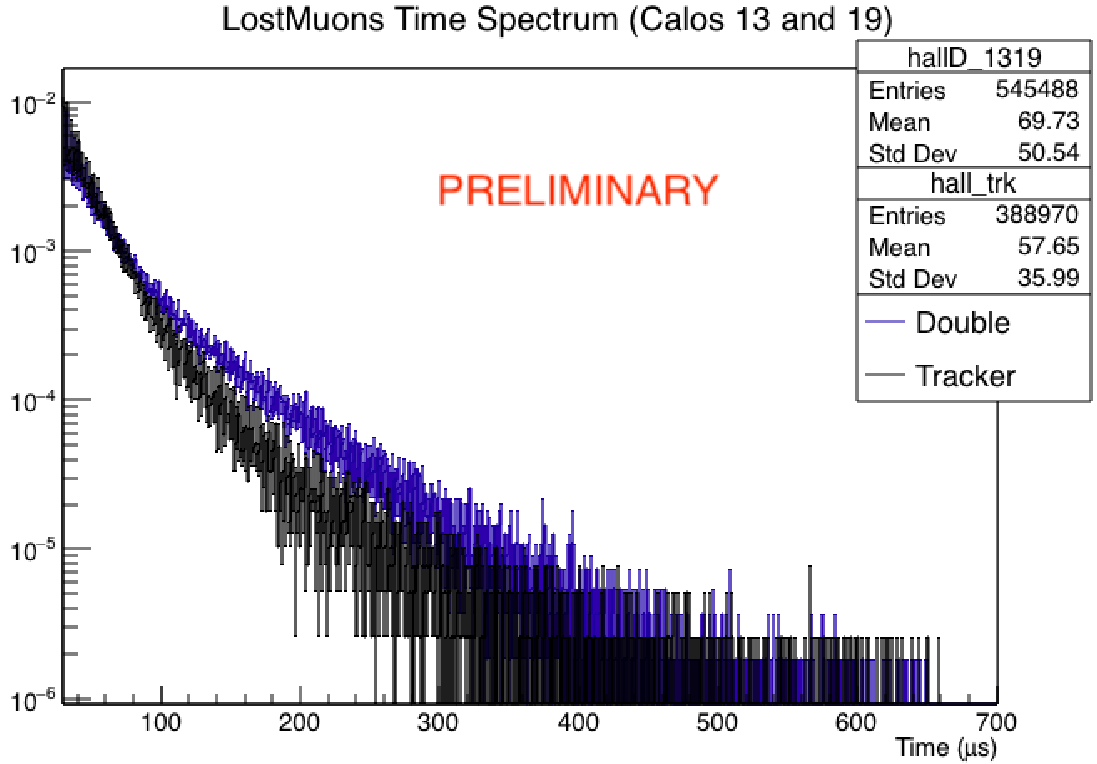
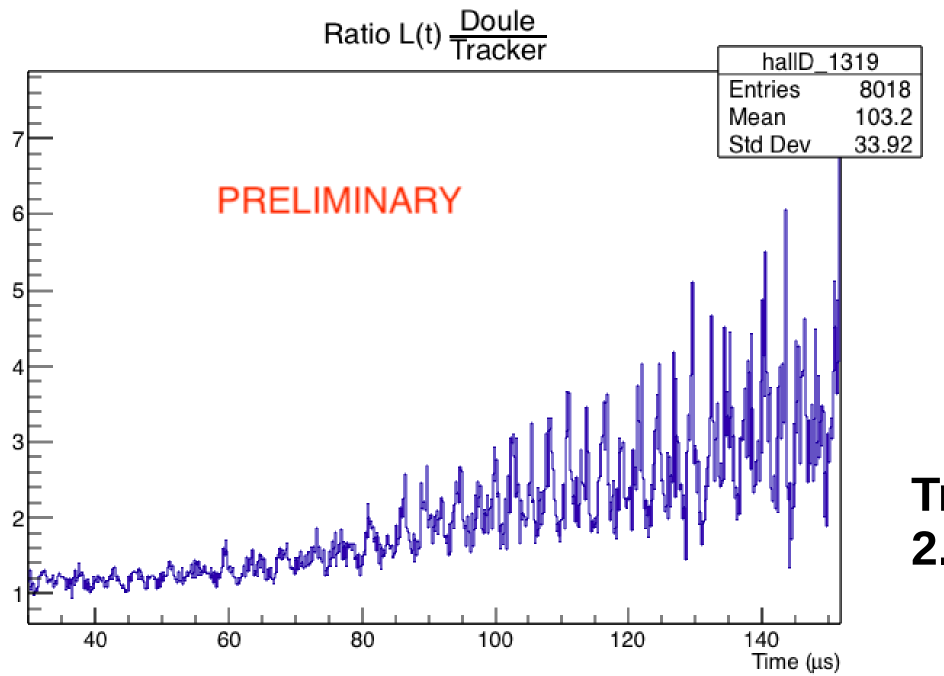
Lost Muons Function and Tracker matching

Comparison between the L2(t) function and the $L_{tk}(t)$ distribution of lost muons detected by trackers



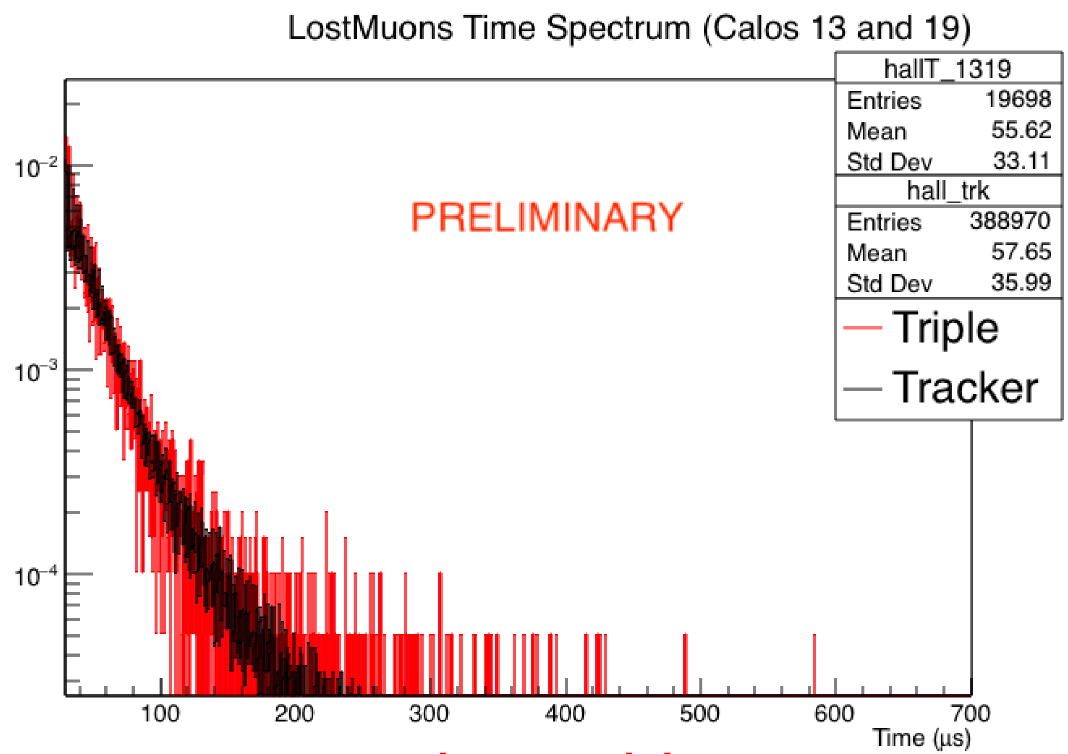


background still present

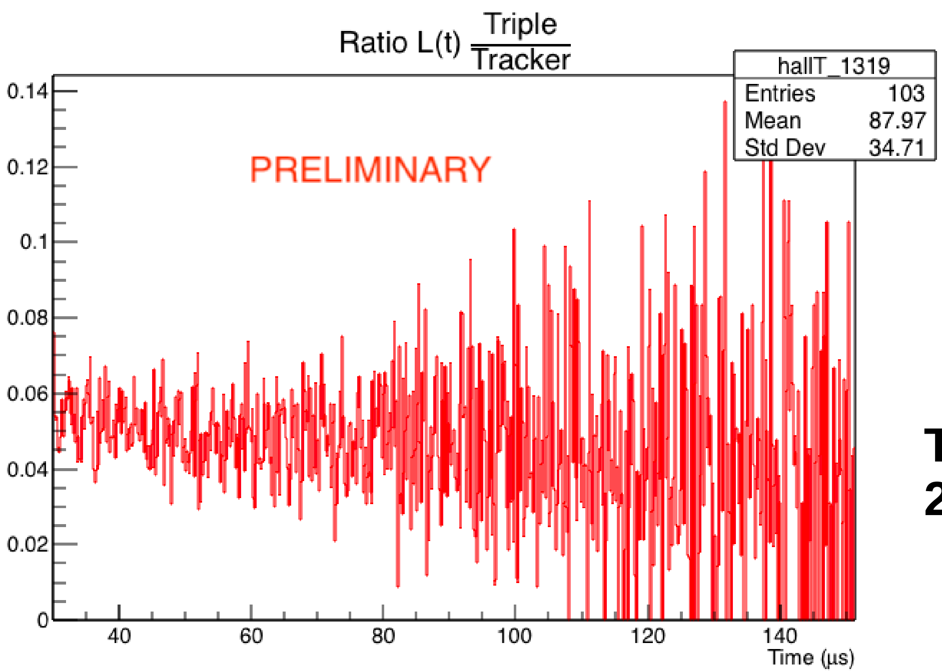
Tracker cuts
$2.3 < p_{TRACKER} < 3.0$ GeV + $130 < E_{CALO} < 220$MeV

Lost Muons Function and Tracker matching

Comparison between the L3(t) function and the $L_{tk}(t)$ distribution of lost muons detected by trackers



Good matching

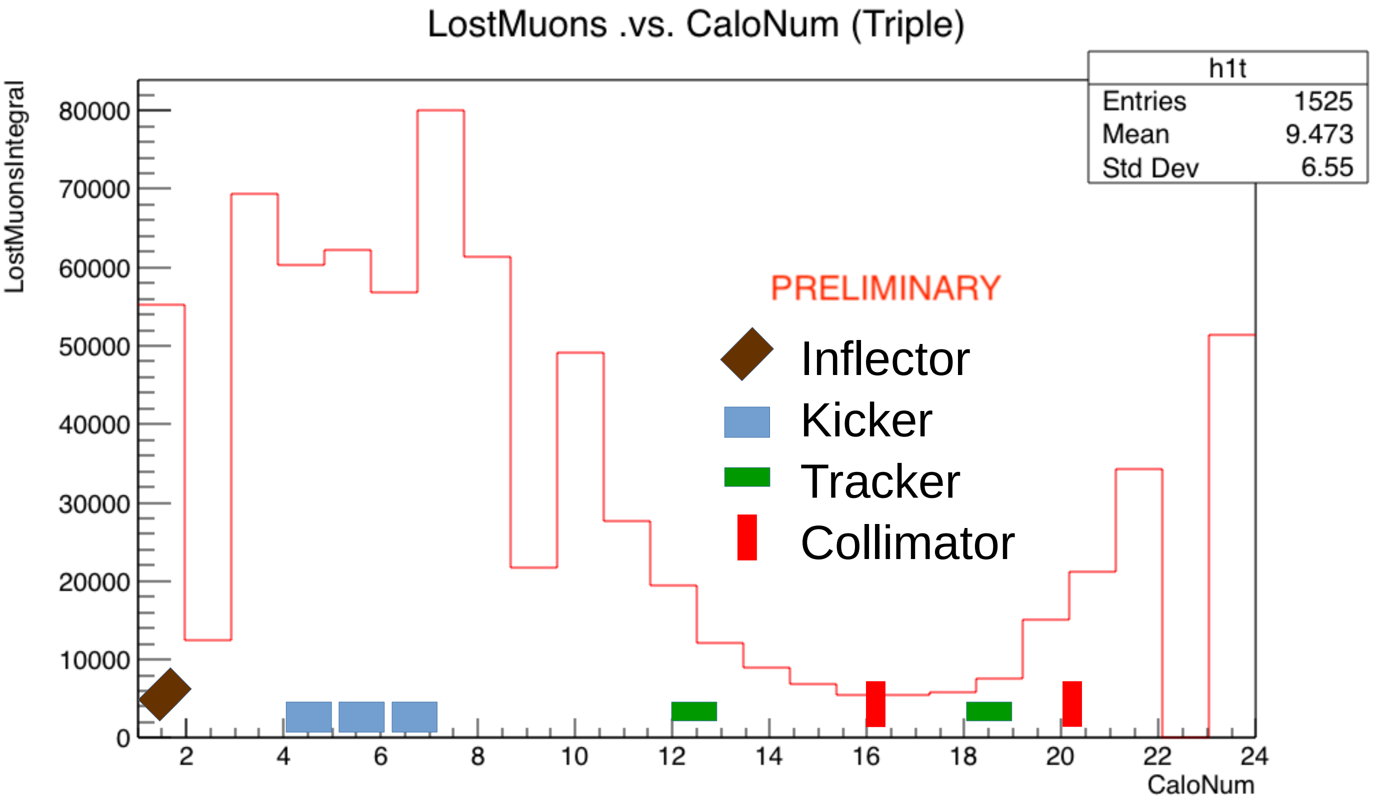


Tracker cuts

2.3 < $p_{TRACKER}$ < 3.0 GeV + 130 < E_{CALO} < 220MeV

Lost Muons around the Ring

The number of lost muons along the ring varies because of the different materials the beam goes through into the vacuum chamber



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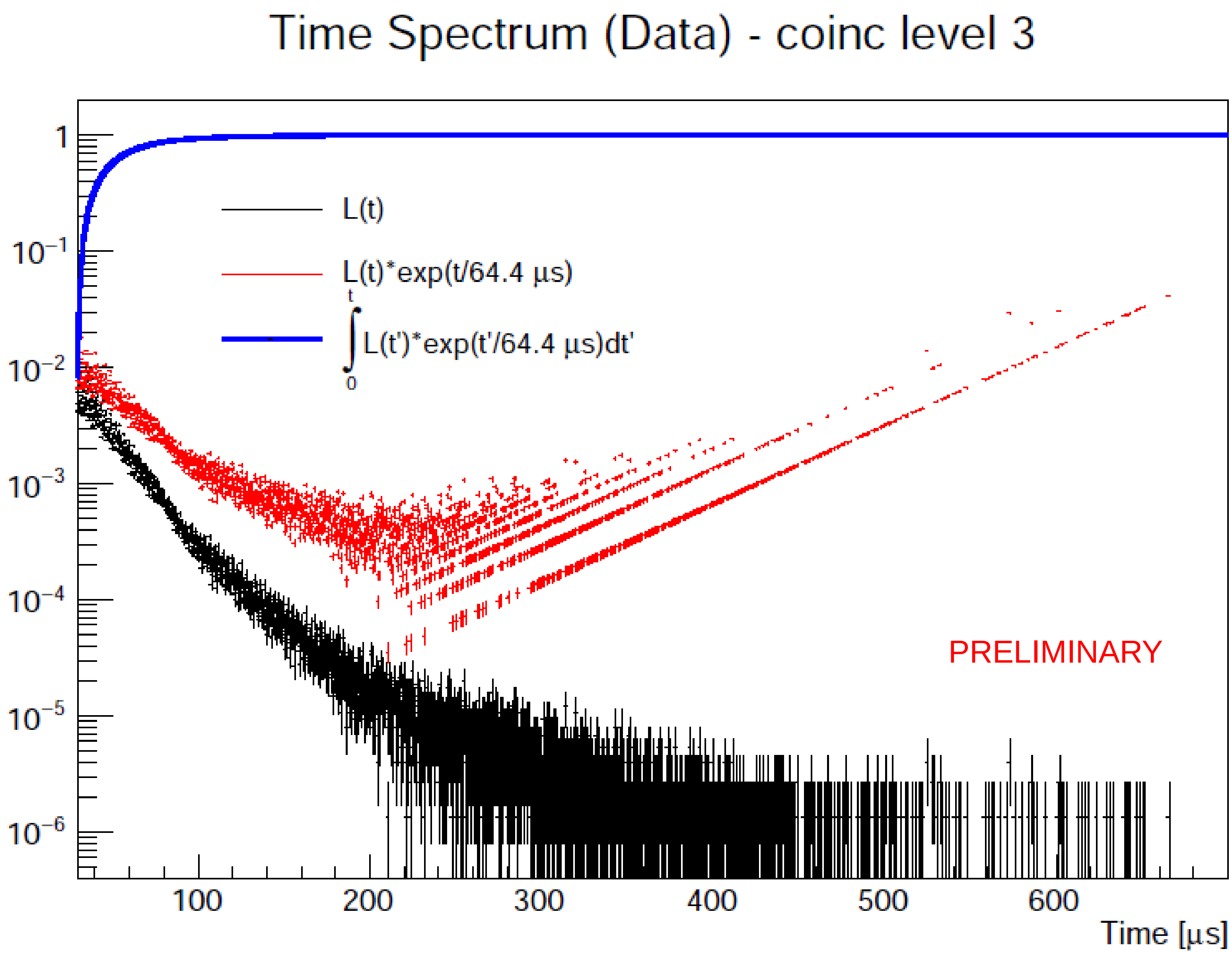
Construction of the loss function



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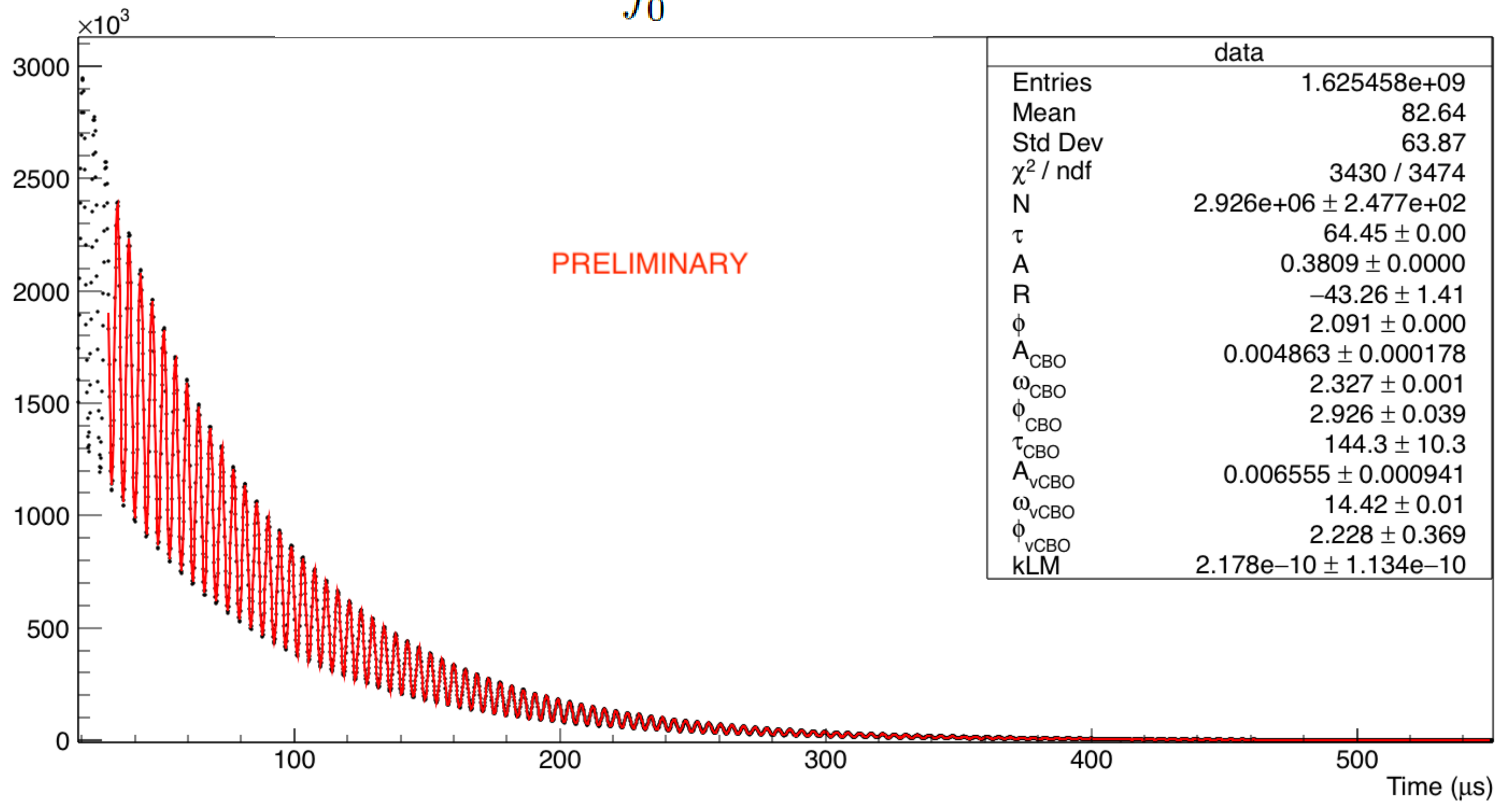
Wiggle function
11-Parameters Fit

Time spectrum of positrons with energy E e + > 1.7 GeV from the 60h dataset

The 11-Parameter fit includes the CBO, pile up *(ref. to GM2-doc-14535-v2)*

And Lost Muons correction $\Lambda(t) = 1 - K_{LM}\int_0^t L(t')e^{\frac{t'}{\tau}}dt'$



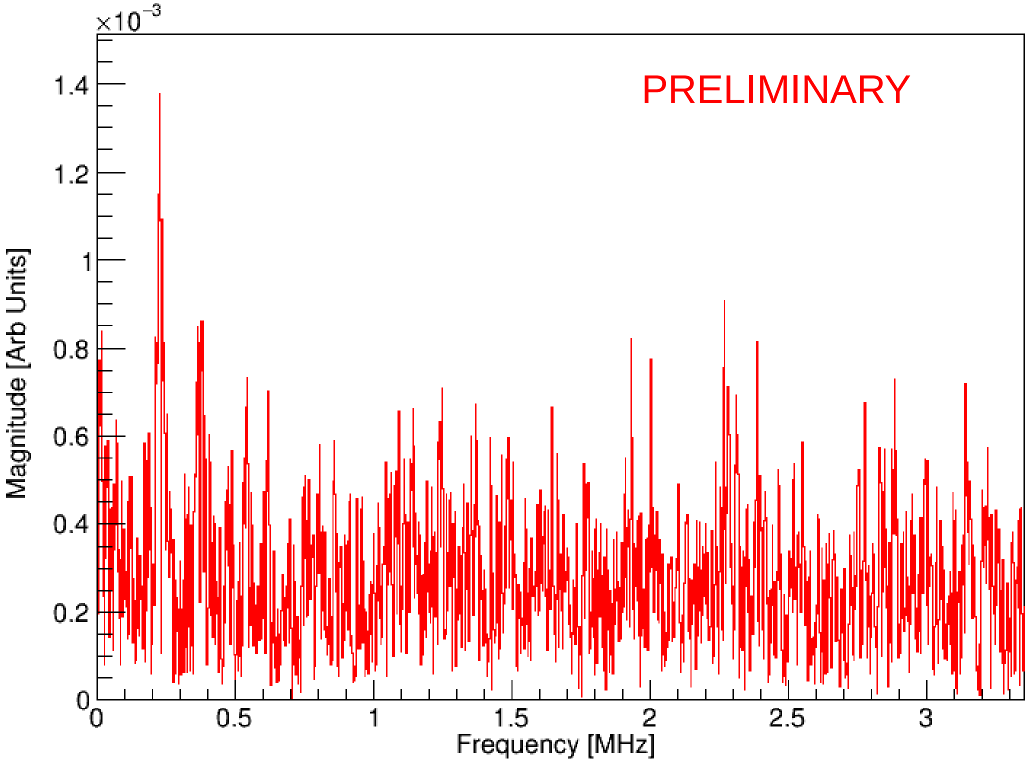
Blinded Fit
There is not an explicit ω_a value

Wiggle function
11-Parameters Fit

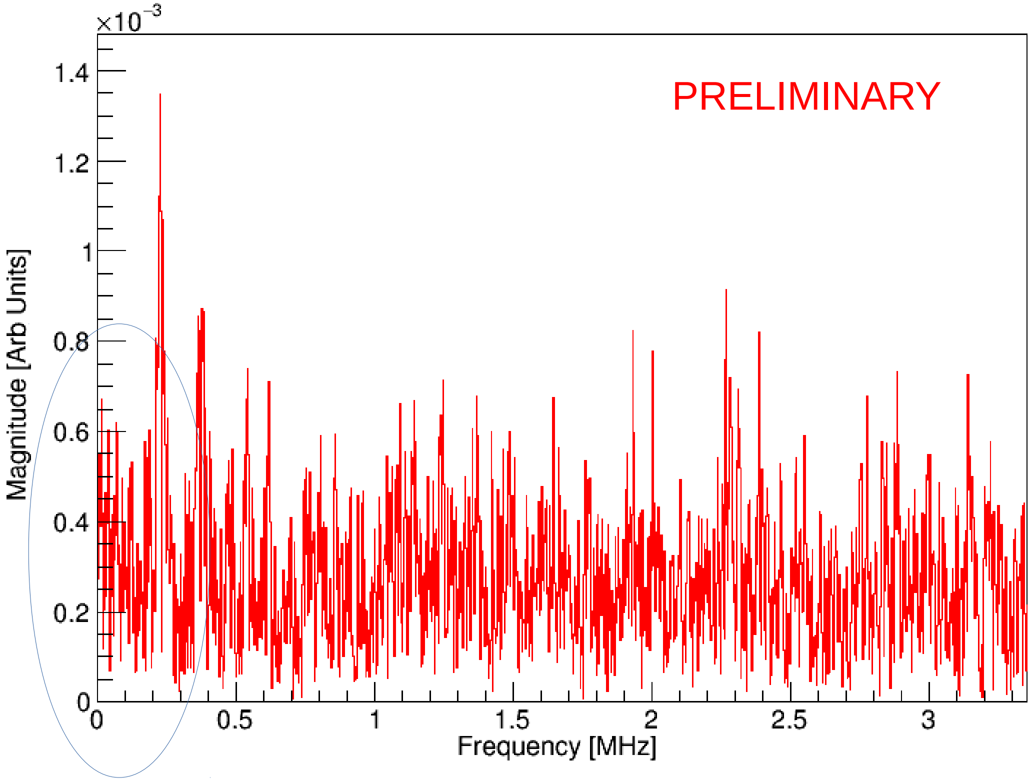
FFT of Residuals

(ref. to GM2-doc-14535-v2)

WITH PILEUP CORRECTION no LM term



WITH PILEUP CORRECTION + LM term



Summary

- Analyzed 60 hours dataset to extract the muon loss function using double and triple coincidences: These algorithms take advantage of highly segmented calorimeters to separate the muon signal from the much larger decay positron backgrounds

- An encouraging preliminary fit of the ω_a function shows a χ^2 improvement using the $L_3(t)$ funcion triple coincidences together with the other corrections

- We are working to assign a systematic error to this procedure

- Needs to start looking at MC simulation to better characterize lost muons