Mu2e Calorimeter triggers

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MUSE workshop
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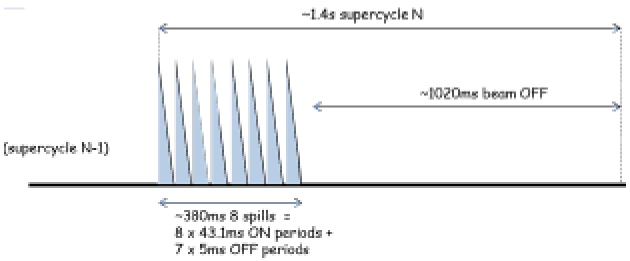
General requirements for Mu2e triggers

AVERAGE PROCESSING TIME



ON SPILL: 8 spills of 43.1 ms each 1.4s

1 event=1.7μs → 25Keventi/spill → ~145Keventi/s

OFF SPILL: 1 event/1.8μs → 55Keventi/s

200Keventi/s /40 nodi/20 thread= 250 eventi/s

→ Tempo medio per processare un evento: **4 ms**

AVERAGE PHISYCS BANDWIDTHS

Tracker:	18 GB/s	**Total DAQ bandwidth: ~31 GB/s**
Calorimeter:	8 GB/s	Storage limit: 7 PB/y ~**0.7 GB/s**
CRV:	4 GB/s	
Monitors	~1 GB/s	Required trigger rej. Factor > 45

CALORIMETER TRIGGERS

Physics triggers (beam ON)

- Calorimeter only
- Dual tracker-calorimeter
- *special run conditions (low B or I, commissioning)*

Expected to have efficiency >90% on events of physics interest

Calibration triggers (beam OFF)

- Cosmic muons
- Radioactive source
- Laser pulses
- FEE pulses
- unbiased (random)

Outline

Only some of the possible calorimeter triggers will be treated here:

CE Calorimeter standalone:

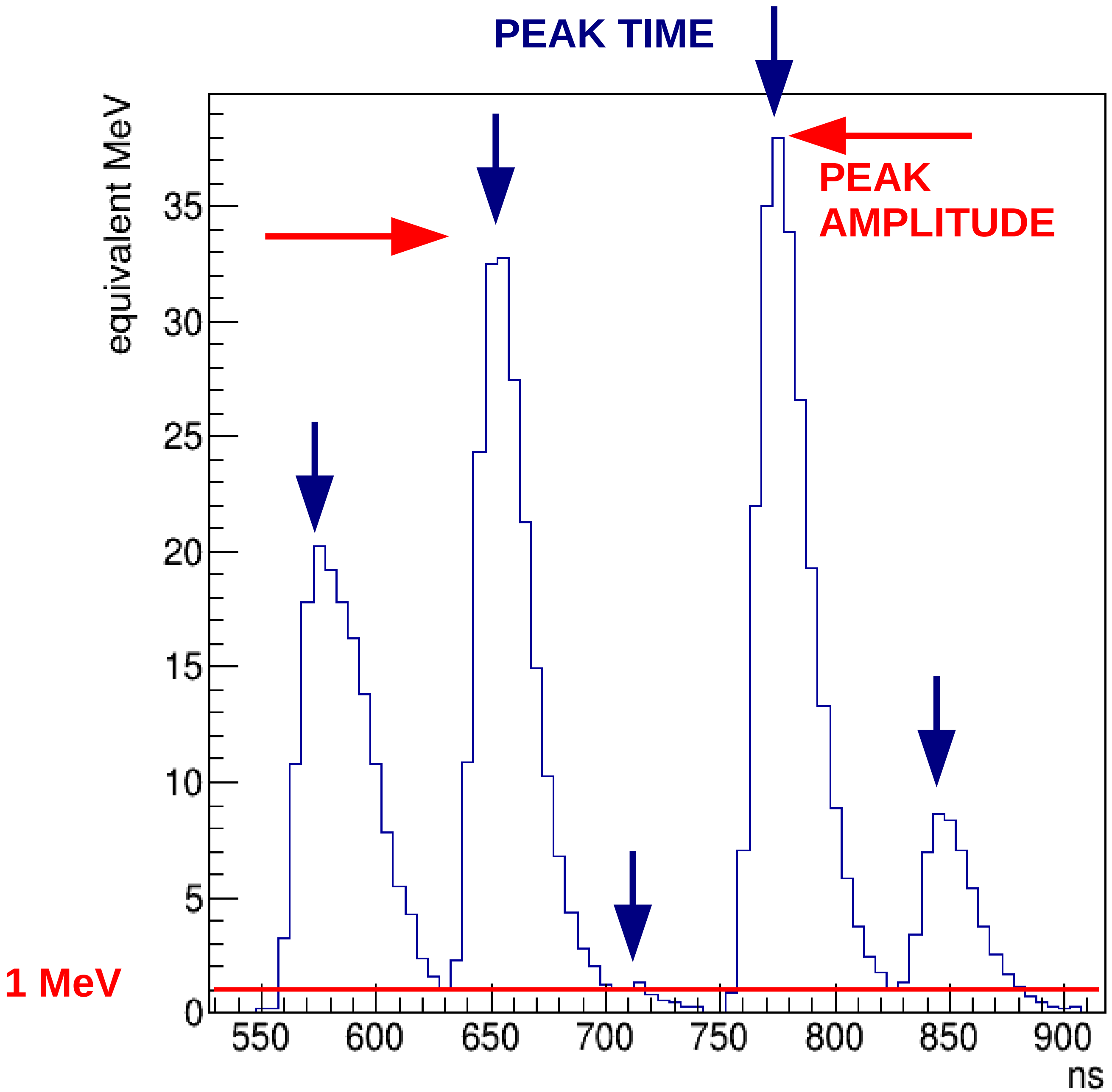
- Boosted Decision Tree (BDT) using time, position, energy and highest neighbour energies of energy peaks (doc-db 12272)

CE Calorimeter+Straw Hits:

-uses calorimeter BDT to find calorimeter seeds, larger BDT involving straw hits matching time, position and phase increment of calorimeter seed (doc-db 15369)

Calorimeter trigger efficiency on photons

DIGITIZER WAVEFORM PROCESSING



Find the peaks:
i-th bin such that
$E_i \geq E_{i-1}$ & $E_i \geq E_{i-2}$ &
$E_i > E_{i+1}$ & $E_i > E_{i+2}$

Time consuming step: can be performed in Digitizer FPGAs

A TRIGGER DATAPRODUCT containing peak information has been created

Conversion Electron (CE) training sample

Track preselection (from doc-db 8219 (app.B)):

- $-80\ \text{mm} < d_0 < 105\ \text{mm}$
- $450\ \text{mm} < d_0+2/\omega < 680\ \text{mm}$
- $500\ \text{ns} < t_0 < 1695\ \text{ns}$
- $45^o < \theta < 60^o$
- MVA > 0.4

Track cluster matching preselection (from doc-db7298v5):

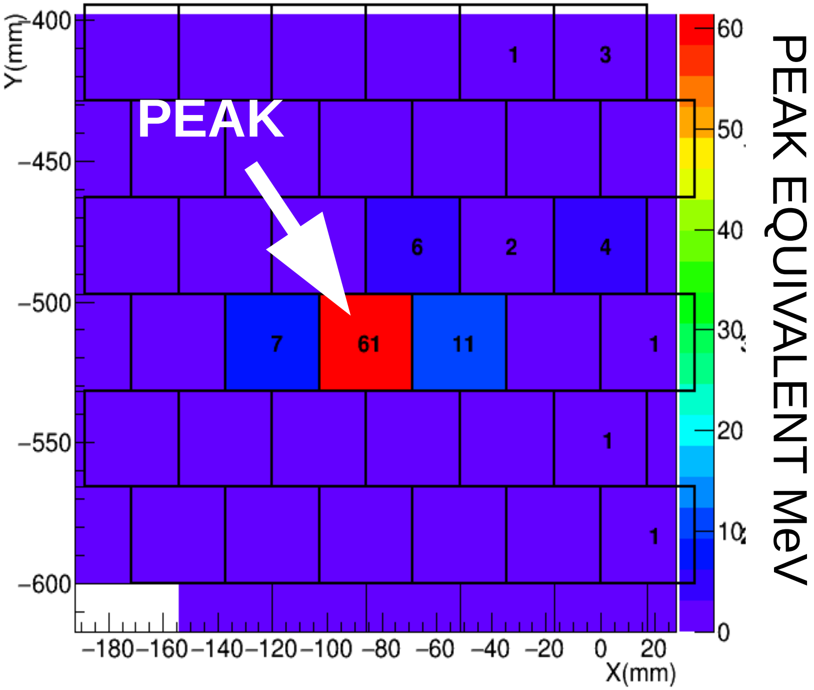
- $100 < p_{track} < 110$ MeV/c
- $E_{cluster} > 10$ MeV
- $\chi^2 < 100$
- $-5\ \text{ns} < T_{track} - T_{cluster} < 8\ \text{ns}$

PID preselection (see 7109v1):

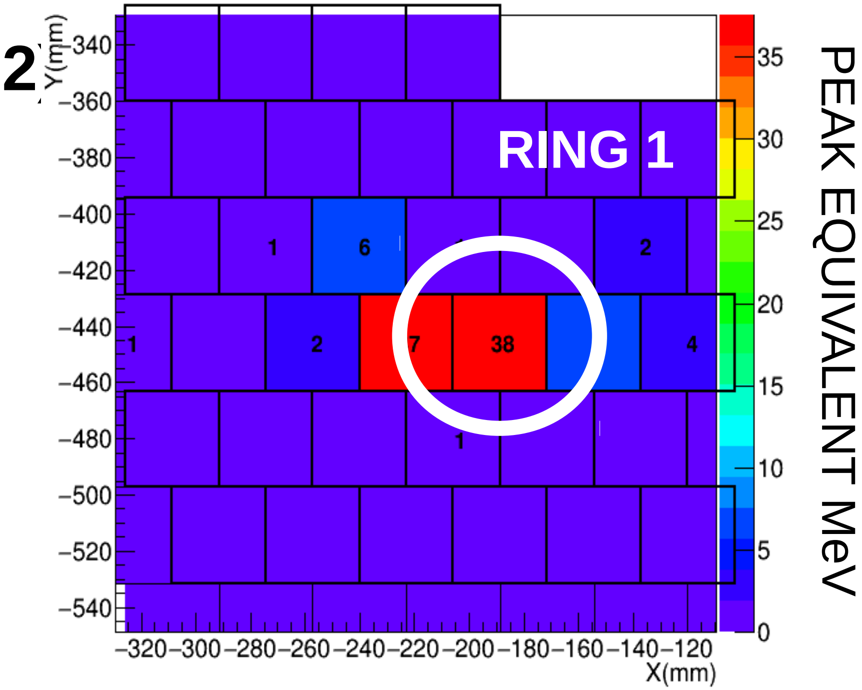
- $E_{cluster} > 50$ MeV

VARIABLES TO CHARACTERIZE CE SHOWERS

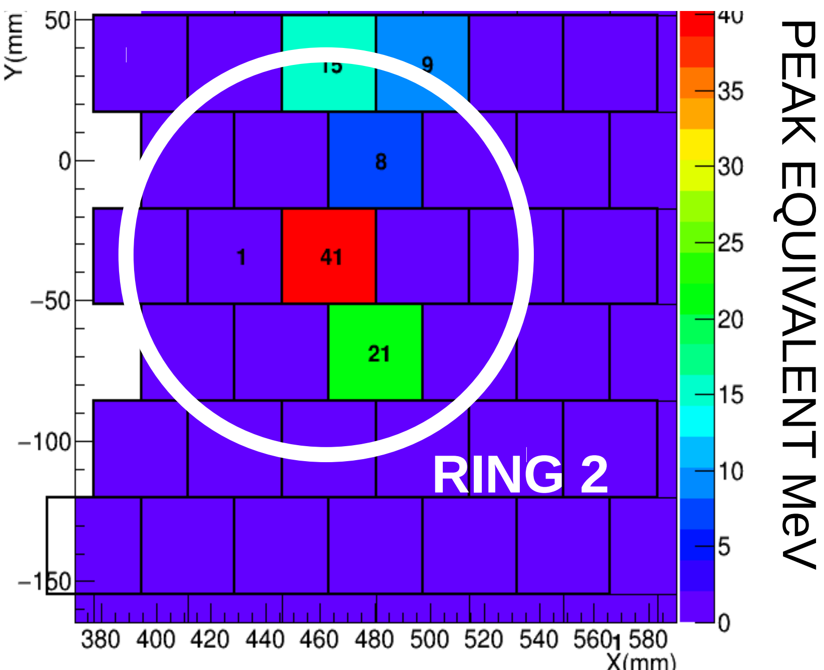
1)



2)



3)



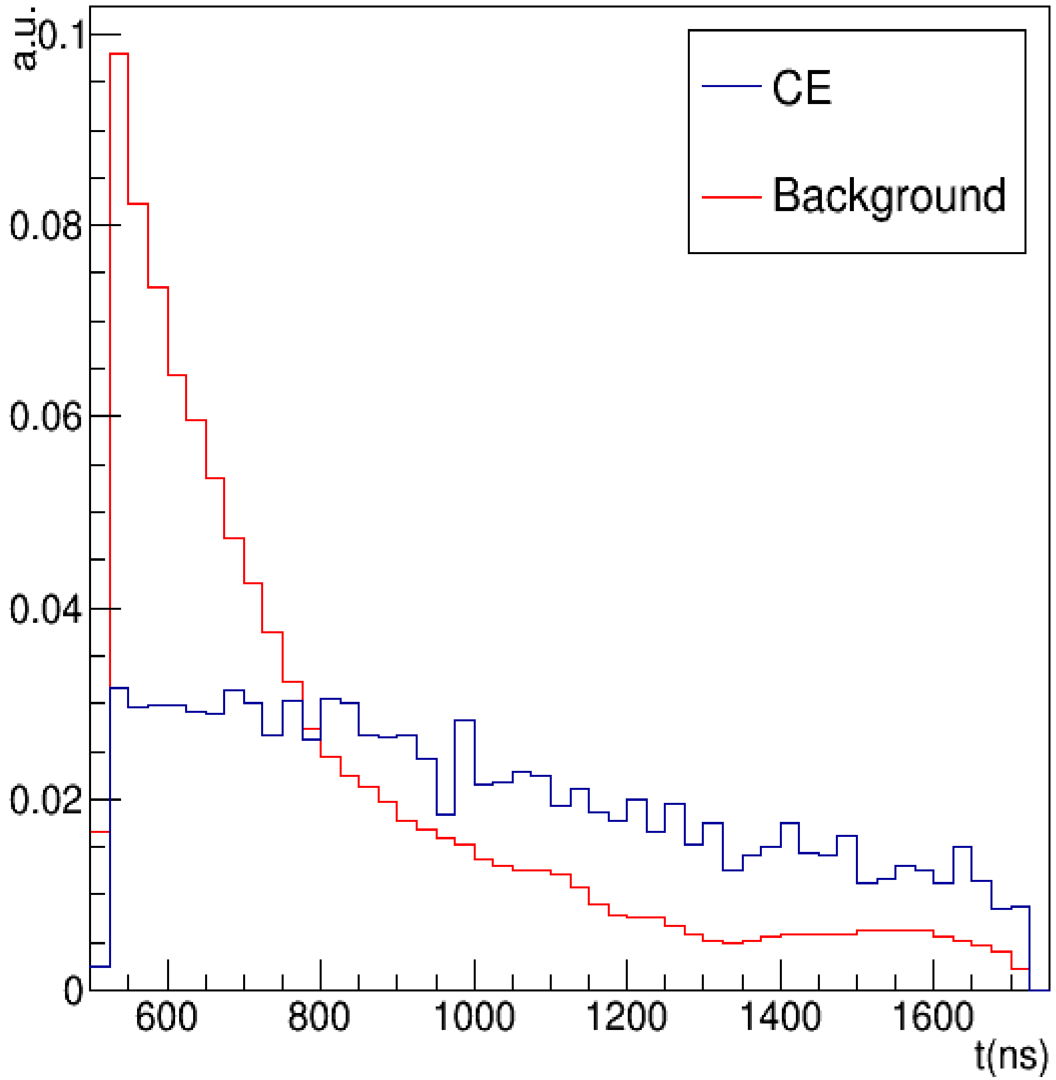
1) PEAK ENERGY:

energy of the most energetic crystal (“SHOWER PEAK”)
Must be higher than 20 MeV

2-3) RING 1: highest and 2nd highest amplitude adiacent to the shower peak

4) RING 2: highest amplitude adiacent to crystal adiacent to the shower peak

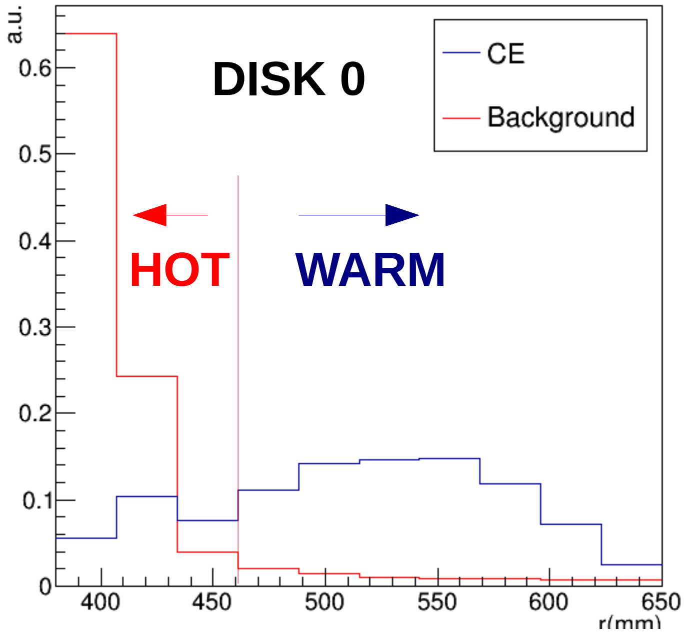
VARIABLES TO SUPPRESS BACKGROUND: PEAK TIME

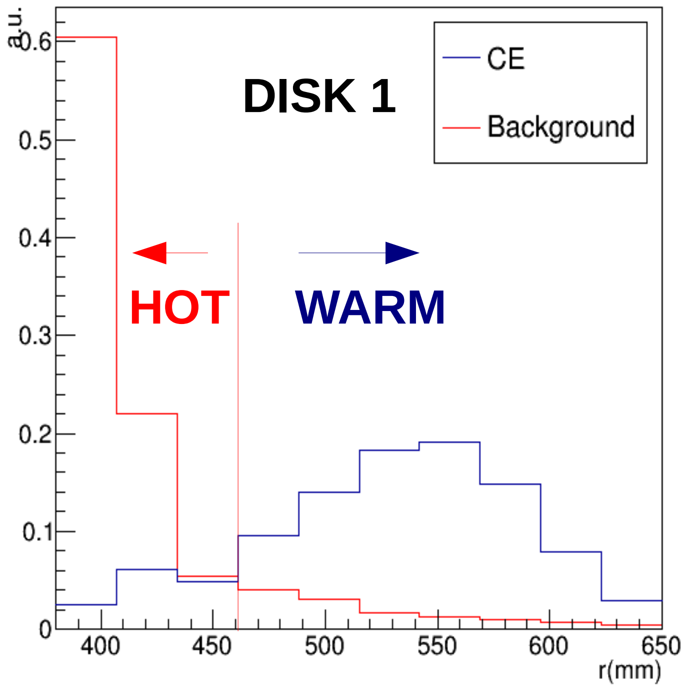


5) SHOWER PEAK TIME: waveform peak time of the shower peak

Prompt background has a different time distribution

VARIABLES TO SUPPRESS BACKGROUND: PEAK RADIUS

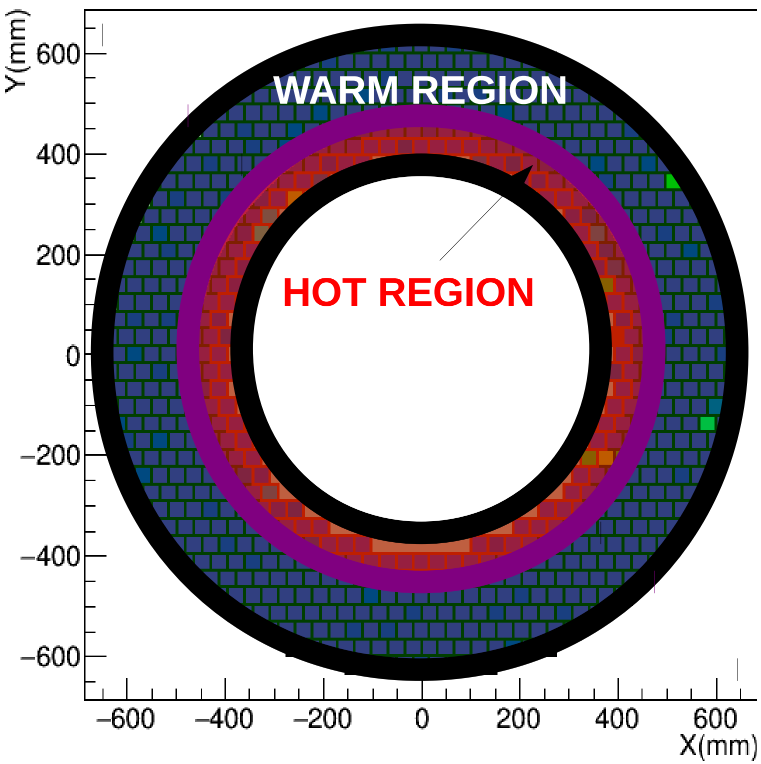




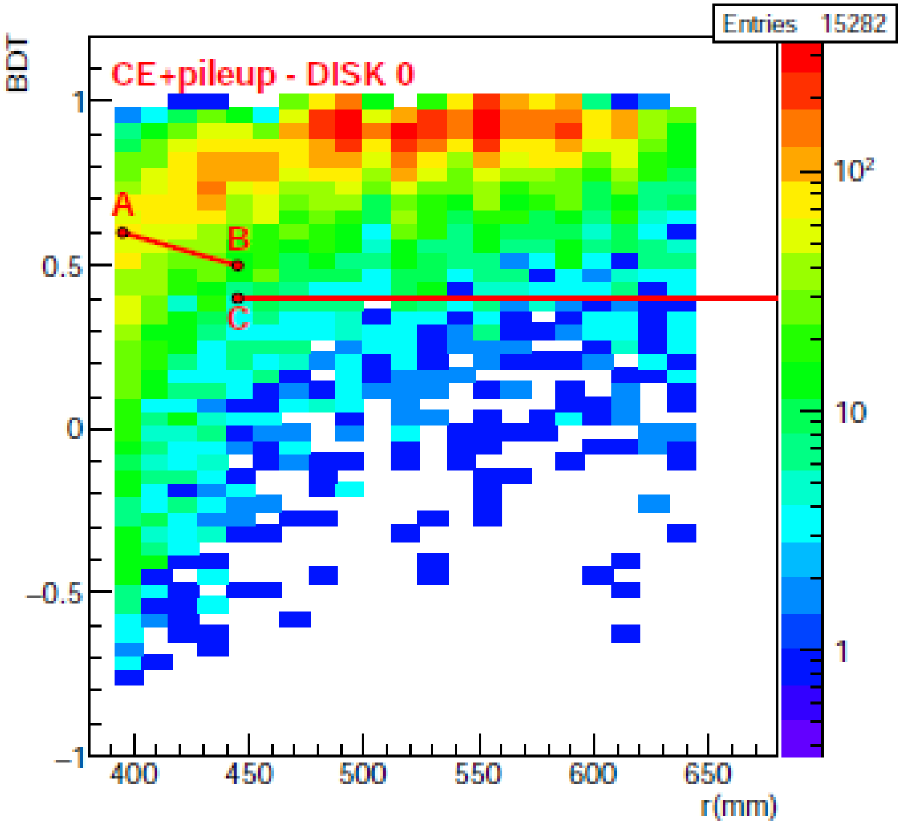
6) SHOWER PEAK RADIUS:
radial position of the shower peak

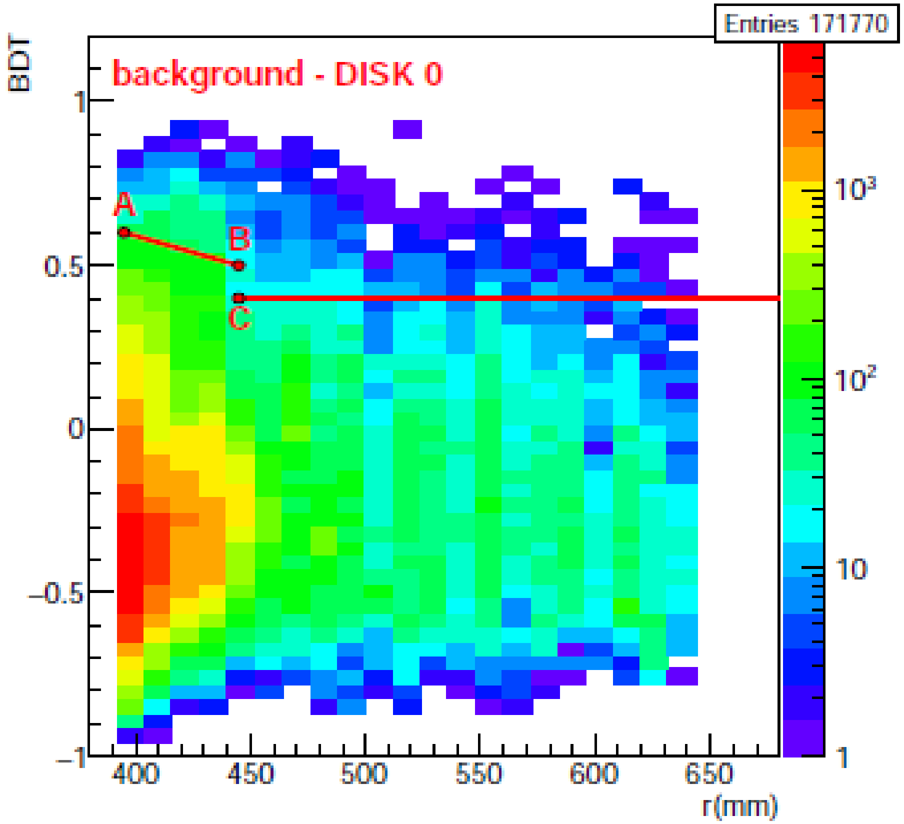
Background is concentrated at low radius:
r < 460 mm (HOT region) r > 460 mm (WARM)

The radial distribution is different for the two disks: in total 4 different training regions



BDT CLASIFFIER





A Boosted Decision Tree classifier is obtained from the peak variables for CE and background.
A cut on BDT value as function of the peak radial position defines the trigger threshold.

ECAL STANDALONE: processing time

Xeon(R)CPUE5-2680v4@2.40GHz grid machine

~400000 events from CE+background
dig.mu2e.CeEndpoint-mix.MDC2018d.art dataset

TimeTracker printout (ms)	Avg
CaloTrigger	**0.4**
FilterEcalMVATrigger	**0.1**

~37000 events from background
dig.mu2e.NoPrimary-mix-det.MDC2018d.art dataset

TimeTracker printout (ms)	Avg
CaloTrigger	**0.4 [was 0.5]**
FilterEcalMVATrigger	**0.02 [was 0.06]**

Very low cpu time/event: 20 μs!

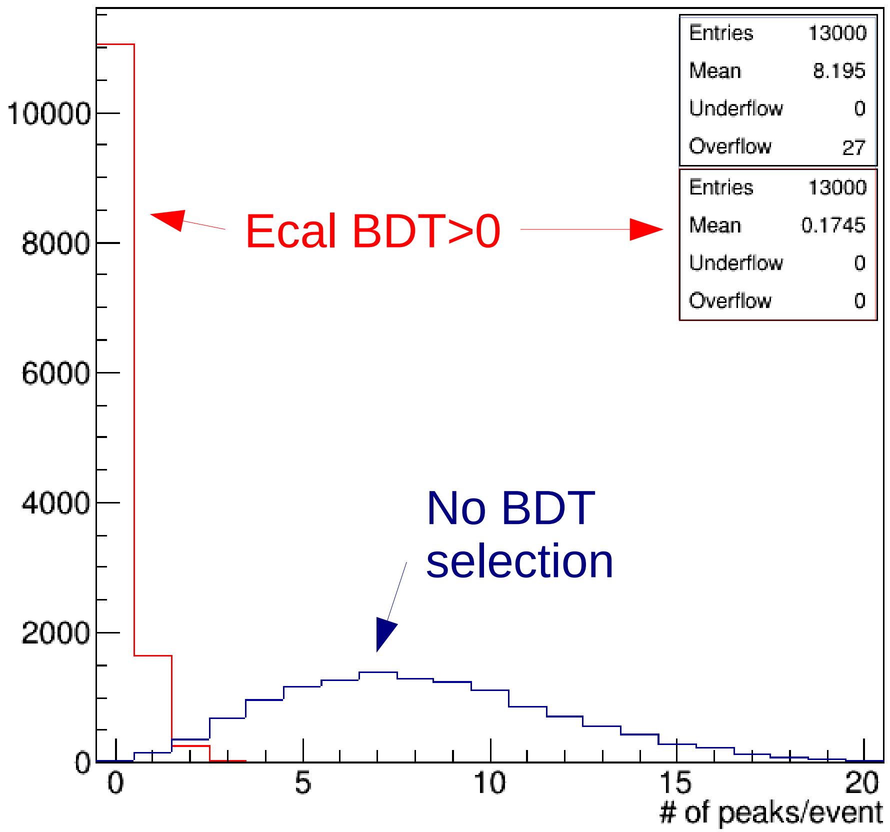
ECAL STANDALONE: efficiency & rejection

	Efficiency on Conversion electrons (CE) (t>700 ns)			BKG rejection (t>500 ns)
NORMALIZATION	CE hits* on ECAL virtual detectors (no requests on track)	Good quality tracks + CE virtual hit	Good quality tracks matching cluster with E>50 MeV + CE virtual hit	
Max rej	74.4% (±0.3)	81% (±0.1)	91.0% (±0.1)	430 (±30)

*hit associated to an electron with p>90 MeV/c

CE MIXED TRACKER-CALORIMETER*

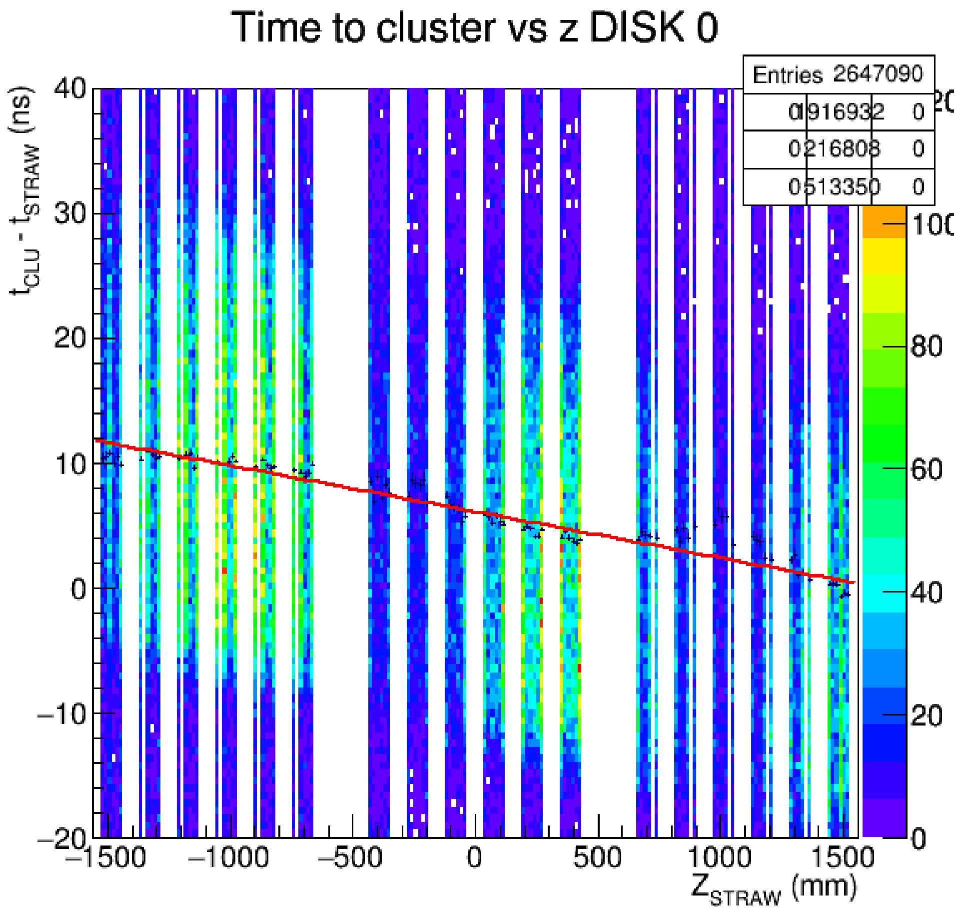
1) Loose cut on ECAL trigger BDT to reduce the average number of calorimeter seeds from 8 to 0.2



*This very fast trigger mainly based on calorimeter that uses only the tracker straw hits information. Another trigger using the calorimeter seeds to simplify the track pattern recognition produces an higher rejection in a still acceptable time. A standalone tracker trigger with high efficiency runs in a time close to the requested limit.

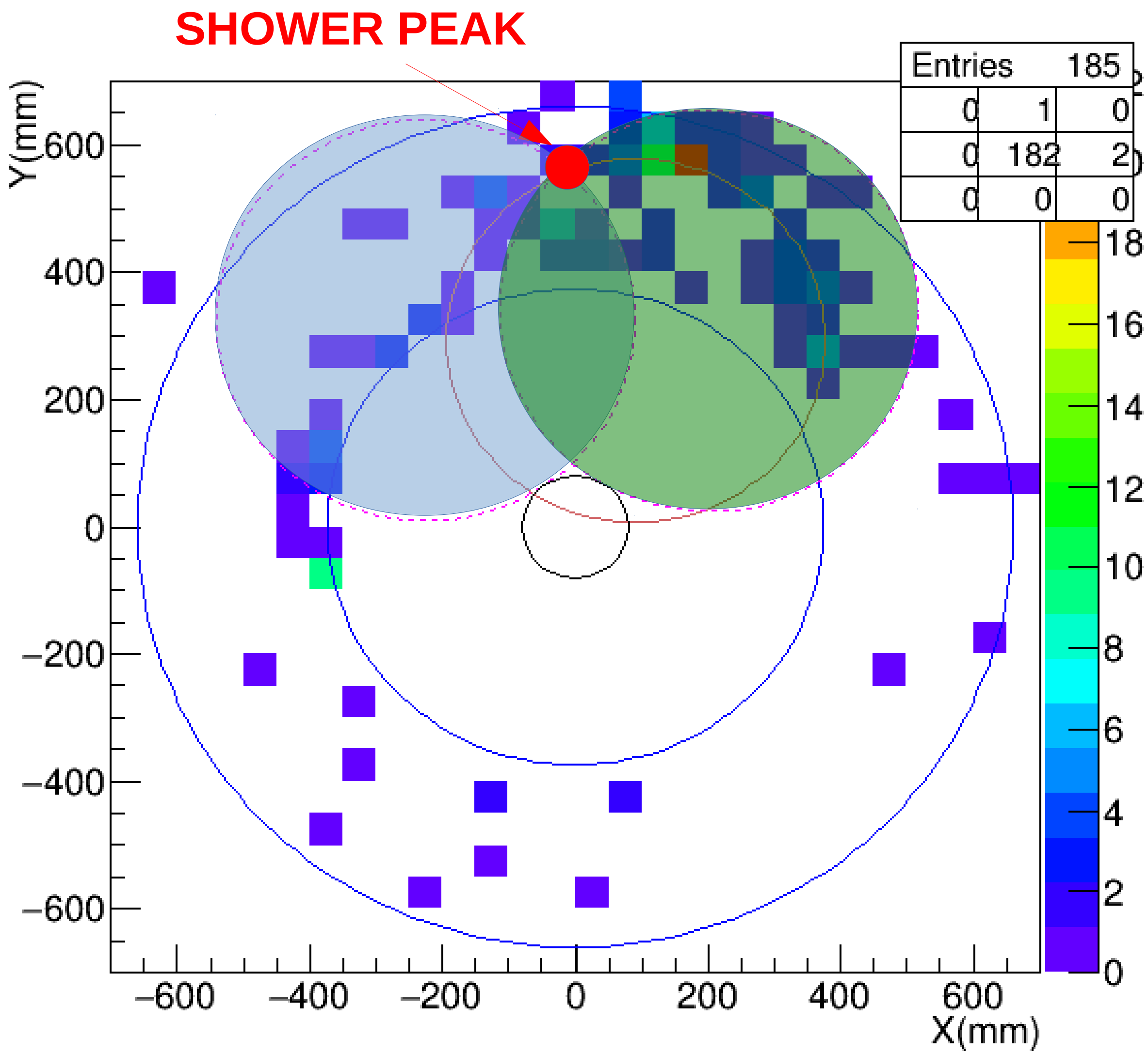
CE MIXED TRACKER-CALORIMETER

2) Select straws **matching in time** **with the calorimeter seed using an average β_L correction**



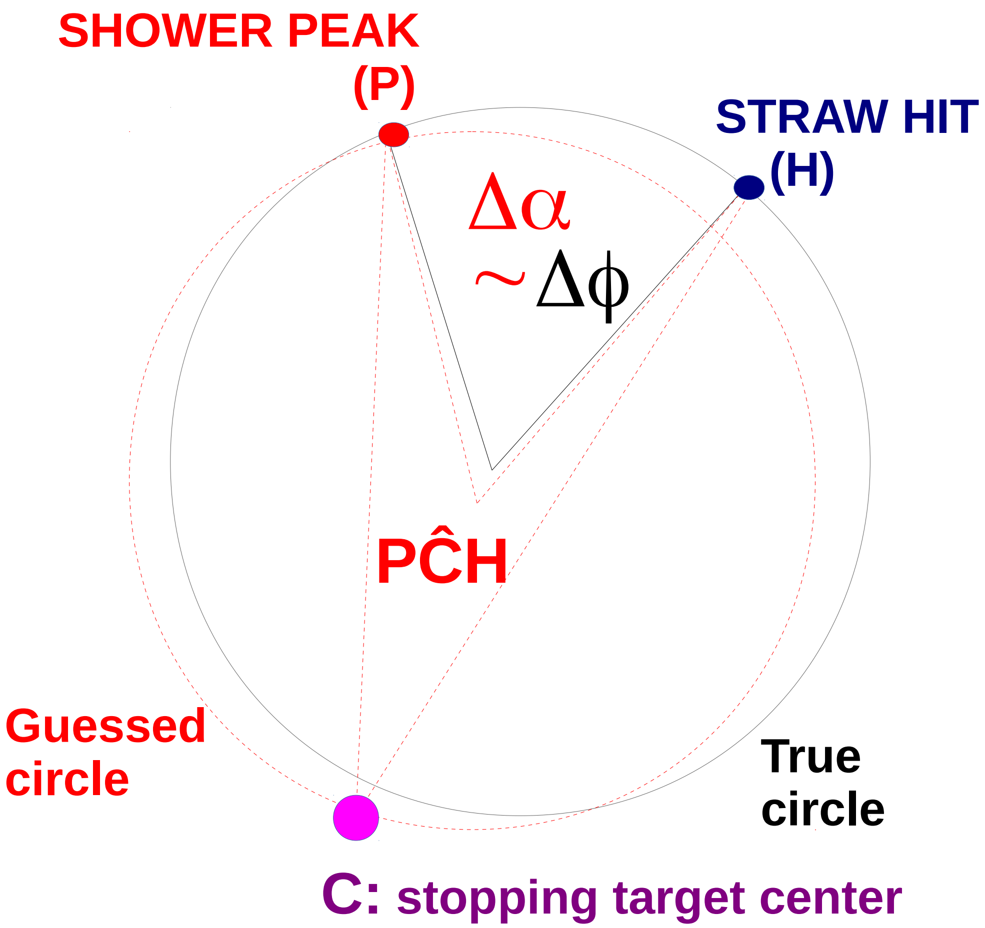
CE MIXED TRACKER-CALORIMETER

3) Select straws compatible with circles with 225< R < 315 mm originating in the stopping target and passing through the calorimeter seed, aka shower peak (dashed regions)



CE MIXED TRACKER-CALORIMETER

4) Estimate the phase difference between the straw hit and the CE assuming the circle is crossing the stopping target center

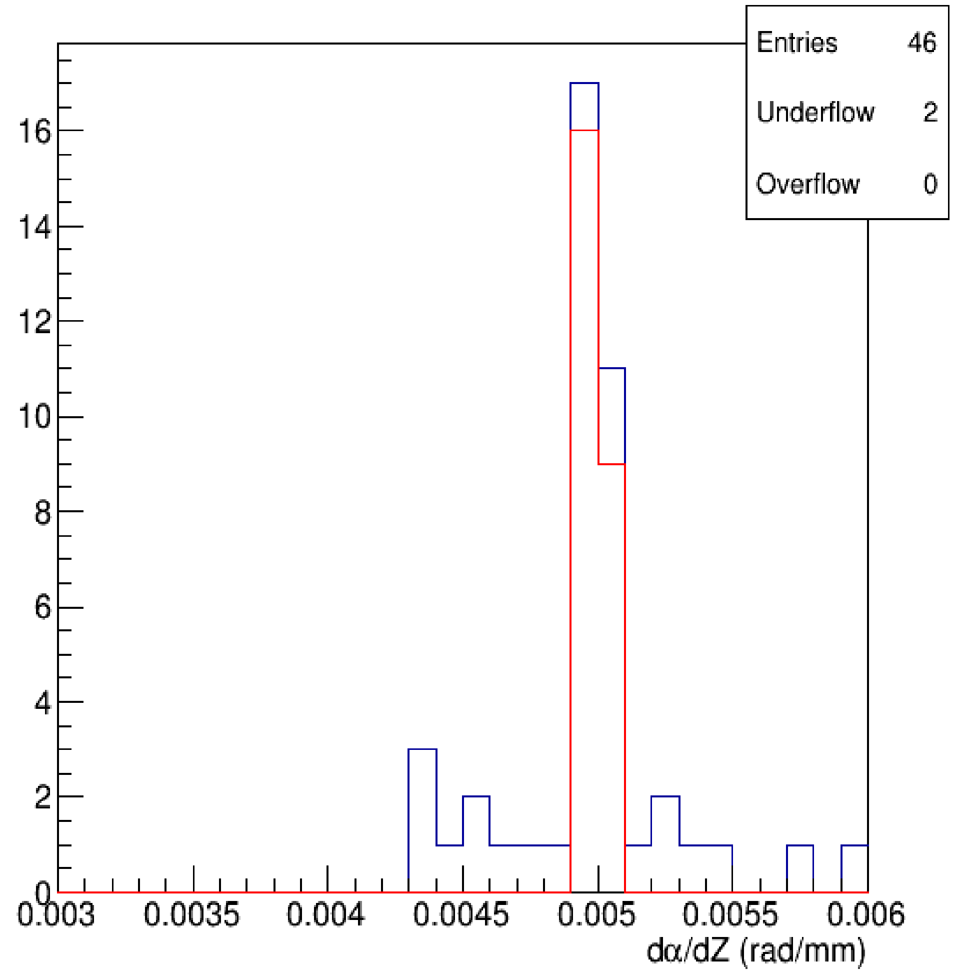


CE MIXED TRACKER-CALORIMETER

5) Estimate the phase increment from the most probable value for dα/dz
Find the circle radius as

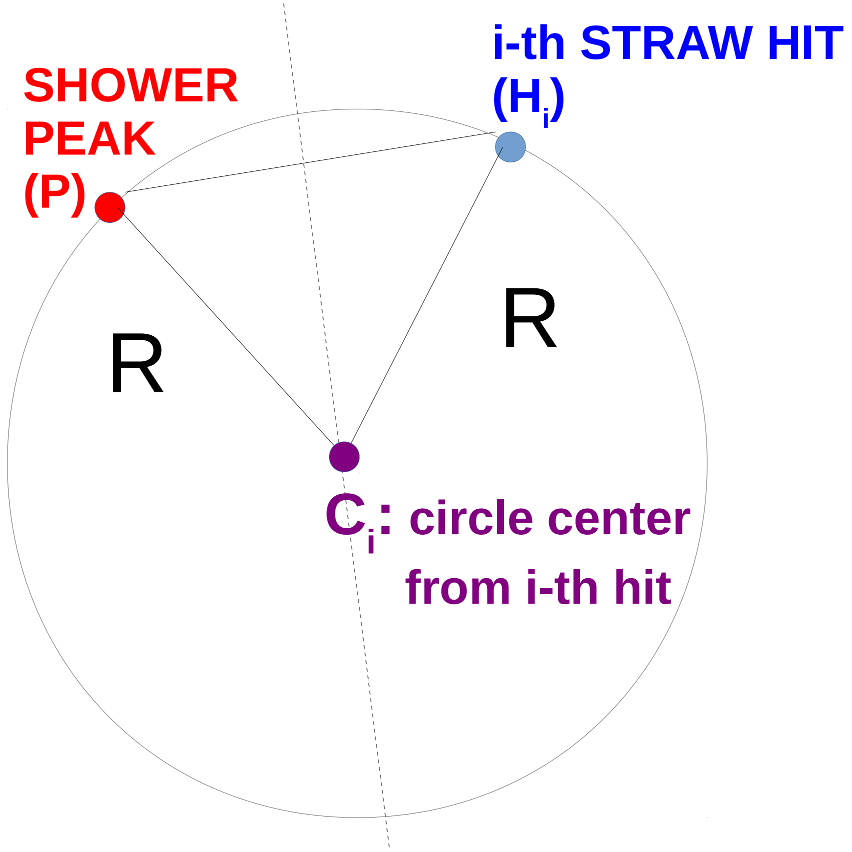
$$R = \sqrt{\left(\frac{p}{0.3}\right)^2 - \left(\frac{1}{\frac{d\alpha}{dz}}\right)^2}$$

where p~103.3 MeV/c



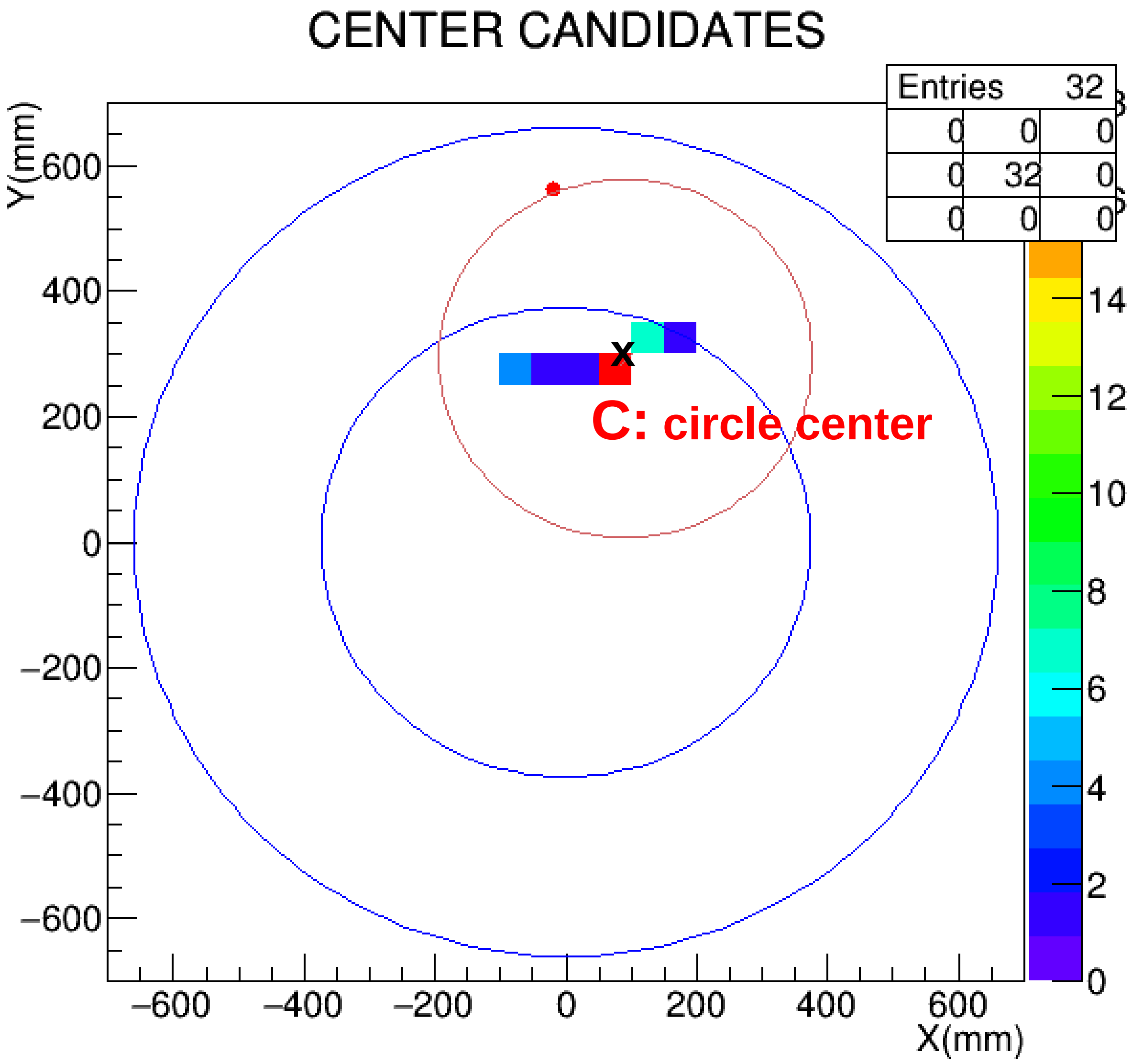
CE MIXED TRACKER-CALORIMETER

6) For each straw hit find a circle center candidate imposing the circle radius R



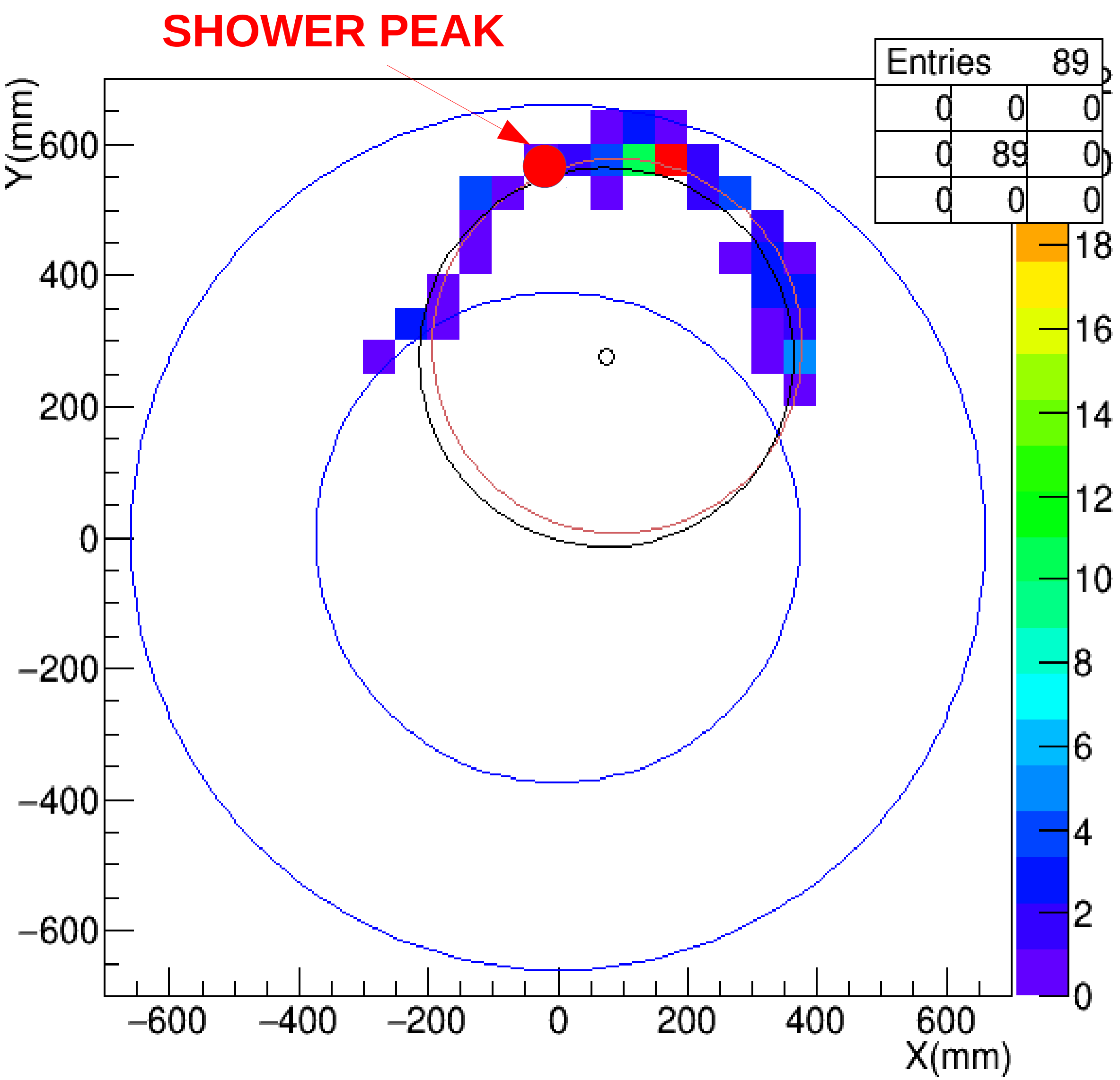
CE MIXED TRACKER-CALORIMETER

7) Select the most probable circle center in a grid of 5x5 cm²
This fixes the circle in the transverse plane



CE MIXED TRACKER-CALORIMETER

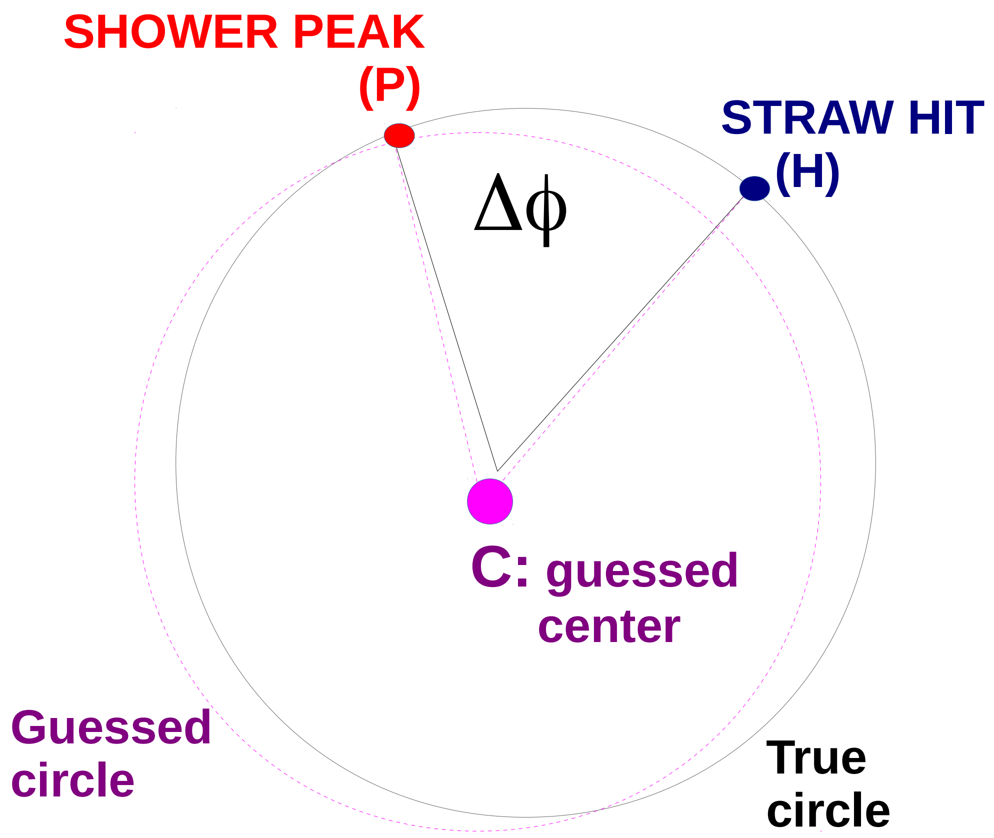
8) Select the **hits on the circle** **(distance<50 mm)**



CE MIXED TRACKER-CALORIMETER

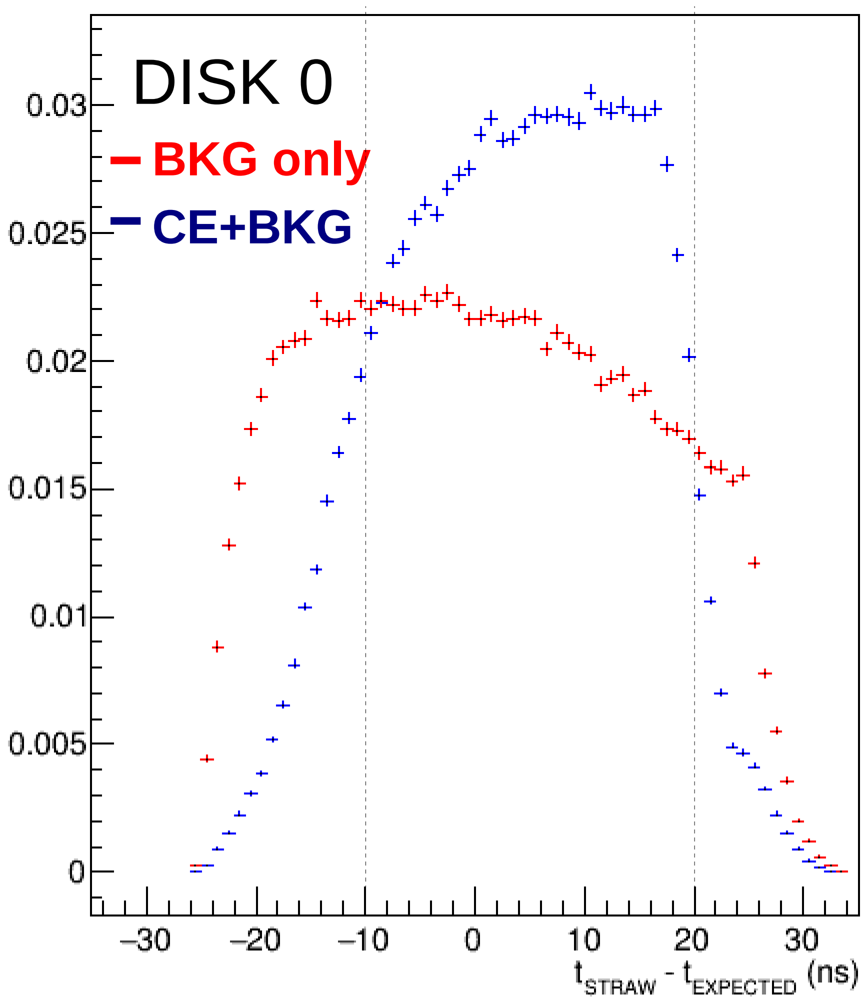
9) Riestimate the phase increment (dϕ/dz) for each straw hit and calculate the longitudinal speed from its most probable value:

$$\beta_L = \frac{p_L}{p} = \frac{0.3}{p \frac{d\phi}{dz}|_{BEST}}$$



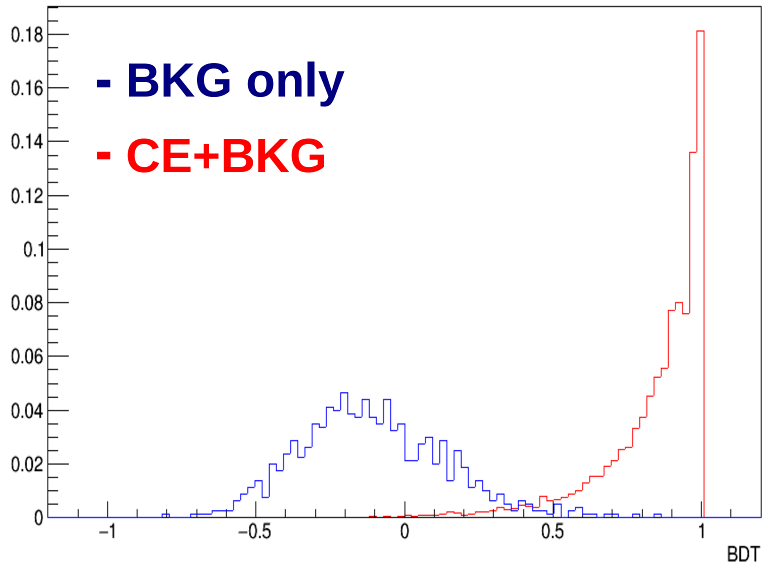
CE MIXED TRACKER-CALORIMETER

10) Make a tighter time matching selection using the time corrected for the longitudinal speed



CE MIXED TRACKER-CALORIMETER

12) Calculate a MIXED BDT using calorimeter shower and selected straw hits information



Calorimeter

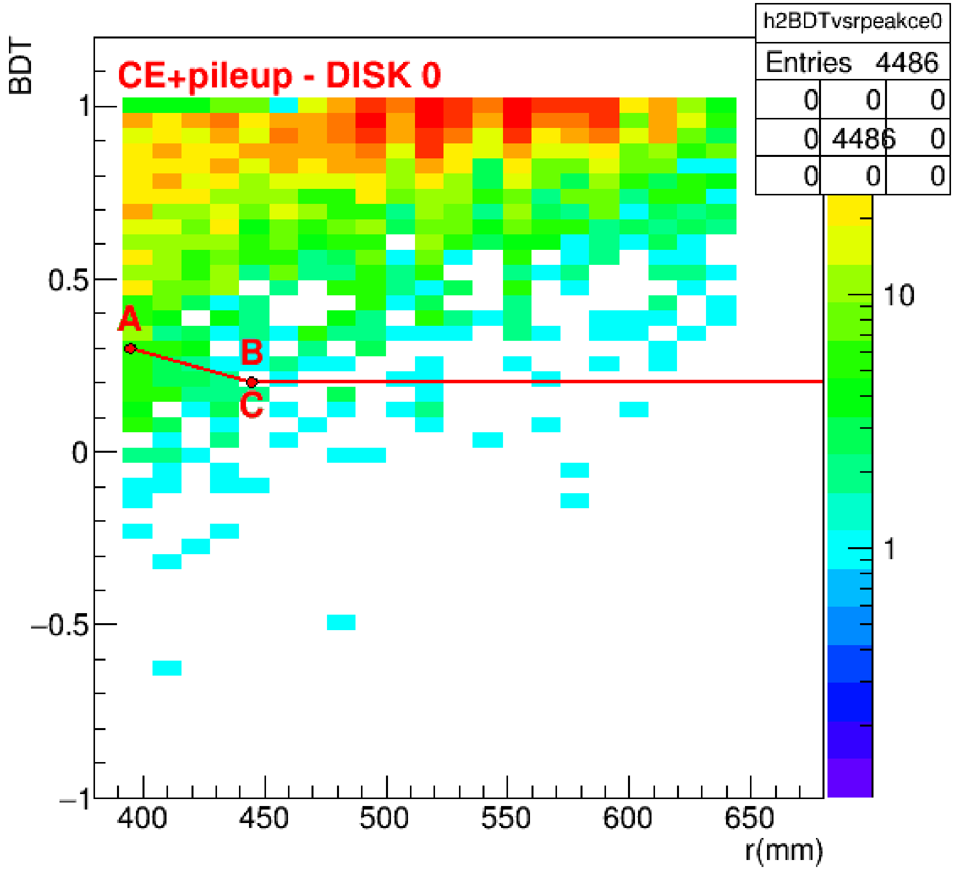
1)Shower peak radius
2)Shower peak time
3)Shower peak energy
4)First ring highest energy
5)First ring 2nd highest energy
6)Second ring highest energy

Selected Tracker Hits

1)Hits matching ϕ (central region)
2)Hits matching ϕ (side regions)
3)Average z
4)Longitudinal spread
5)Average r
6)Radial spread
7)Azimuthal spread

CE MIXED TRACKER-CALORIMETER

13) Perform an optimized cut on MIXED BDT value as function of the calorimeter seed radial position



ECAL-TRACKER MIXED: processing time

Xeon(R)CPUE5-2680v4@2.40GHz grid machine

~400000 events from CE+background
dig.mu2e.CeEndpoint-mix.MDC2018d.art dataset

TimeTracker printout (ms)	Avg
CaloTrigger	**0.44**
FilterEcalMixedTrigger	**0.25**

~37000 events from background
dig.mu2e.NoPrimary-mix-det.MDC2018d.art dataset

TimeTracker printout (ms)	Avg
CaloTrigger	**0.33**
FilterEcalMixedTrigger	**0.03**

Very good cpu time/event of ECAL: 30 μs!

ECAL-TRACKER MIXED: efficiency & rejection

	Efficiency on Conversion electrons (CE) (t>700 ns)			
NORMALIZATION	CE hits* on ECAL virtual detectors (no requests on track)	Good quality tracks + CE virtual hit	Good quality tracks matching cluster with E>50 MeV + CE virtual hit	BKG rejection (t>500 ns)
Max rej	74.3% (±0.1)	84.1% (±0.1)	95% (±0.1)	1250 (±150)

*hit associated to an electron with p>90 MeV/c

SUMMARY

Calorimeter can provide a stand alone trigger very fast, with an efficiency >90% on conversion electrons that can be used for the analysis and a background rejection factor of >400. The processing time is 20 μs+ 400μs mostly needed to process the calorimeter digitizer waveform. This time can be significantly reduced if the waveform analysis is performed in the calorimeter digitizer itself.

The described mixed calorimeter-tracker trigger is able to obtain an efficiency >95% on conversion electrons with a rejection factor >1000. The additional time required is 30 μs.

Muse members are deeply involved in the development of Mu2e trigger system: other calorimeter triggers are under study to provide calibration samples and significant efficiency on other interesting physics processes such as radiative muon and pion captures, and μ^- conversion to e^+.