Mu2e Calorimeter Trigger Studies

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Riunione referees GR I

Roma, 6 Settembre 2017

Mu2e TRIGGER REQUIREMENTS

Mu2e triggers must satisfy the requirements listed in the "Mu2e Trigger and DAQ Requirements" document (Mu2e doc-db 1150):

1) Efficiency > 90% on Mu2e physics dataset

2) Background rejection > 100

3) Processing time < 3.6 ms/event

This study is focused on a standalone calorimeter trigger for conversion electrons (CE)

CE PRESLECTION

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

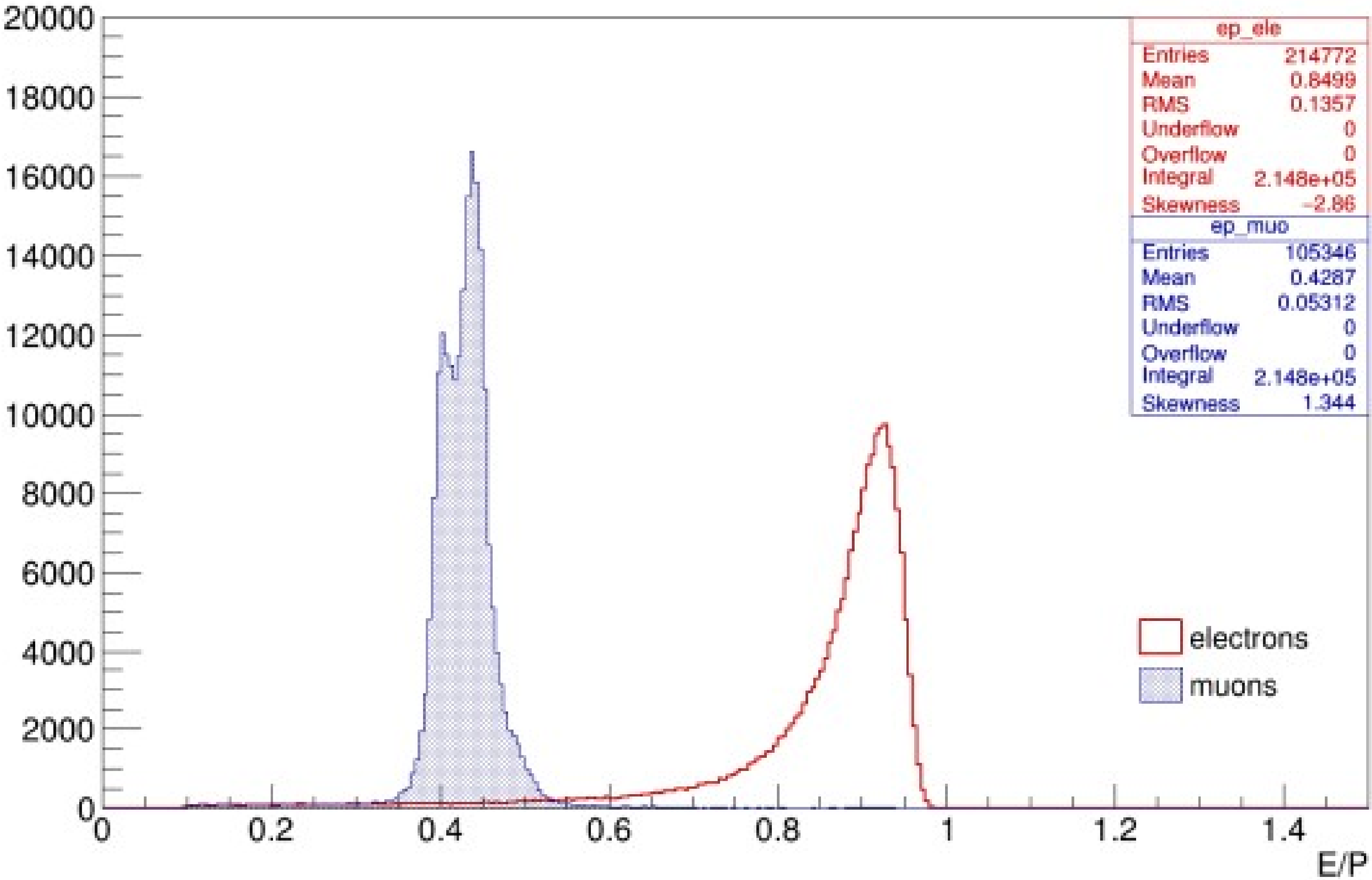
- -80 mm < d_0 < 105 mm
- 450 mm < $d_0 + 2/\omega$ < 680 mm
- 500 ns < t_0 < 1695 ns
- $45^o < \theta < 60^o$
- MVA > 0.4

Track cluster matching preselection (doc-db7298):

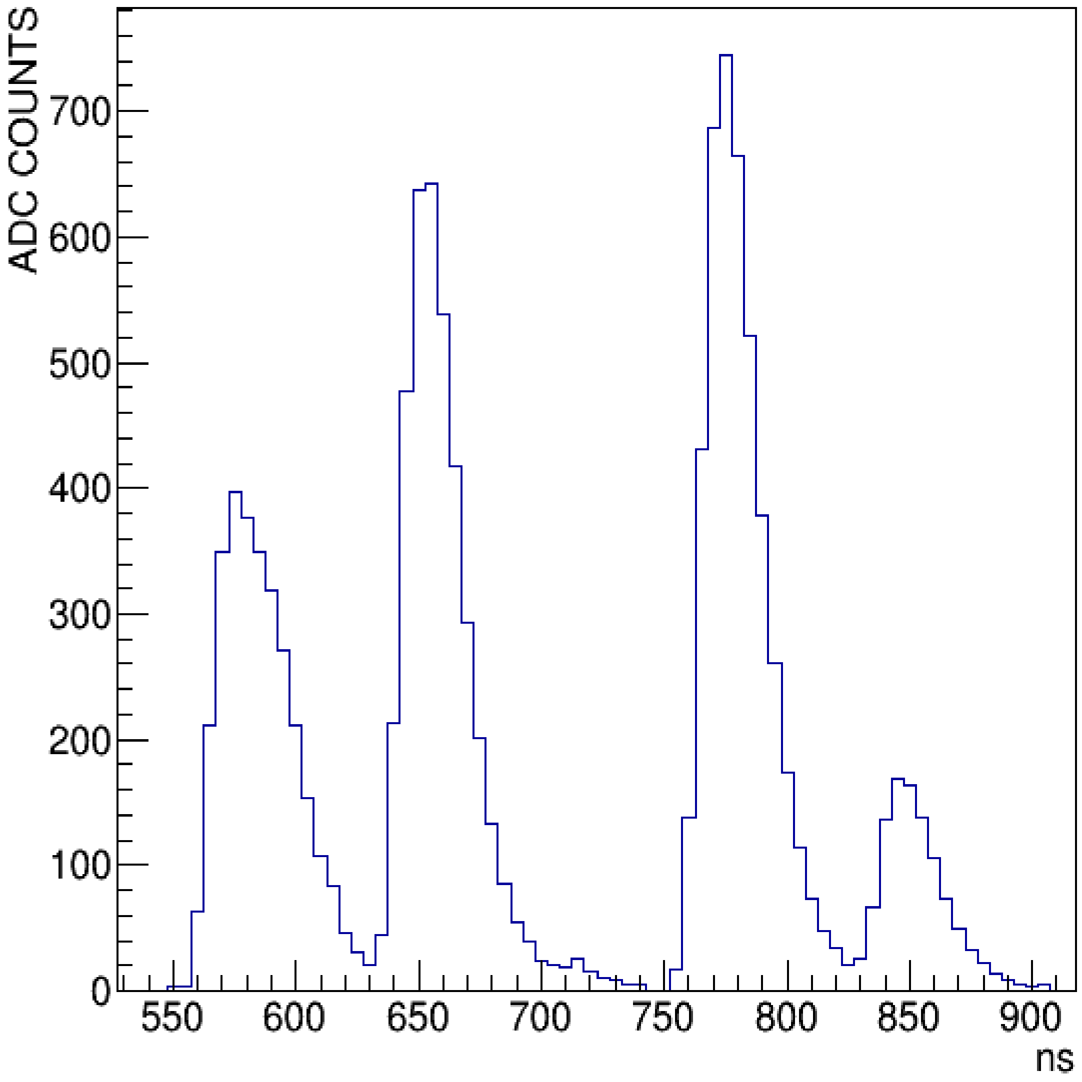
- 100 < p_{track} < 110 MeV/c
- $E_{cluster}$ >10 MeV
- χ^2<100
- -5 ns < $T_{track} - T_{cluster}$ < 8 ns

PID preselection (doc-db7109): $E_{cluster}$ >50 MeV

PID PRESELECTION (doc-db 7109)

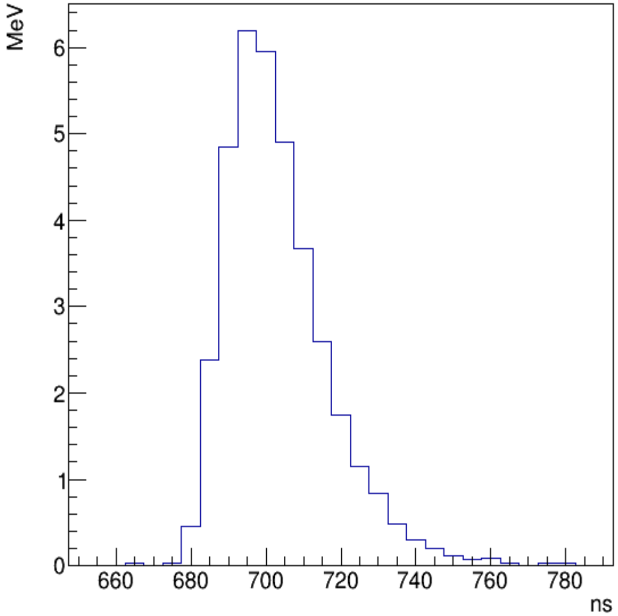


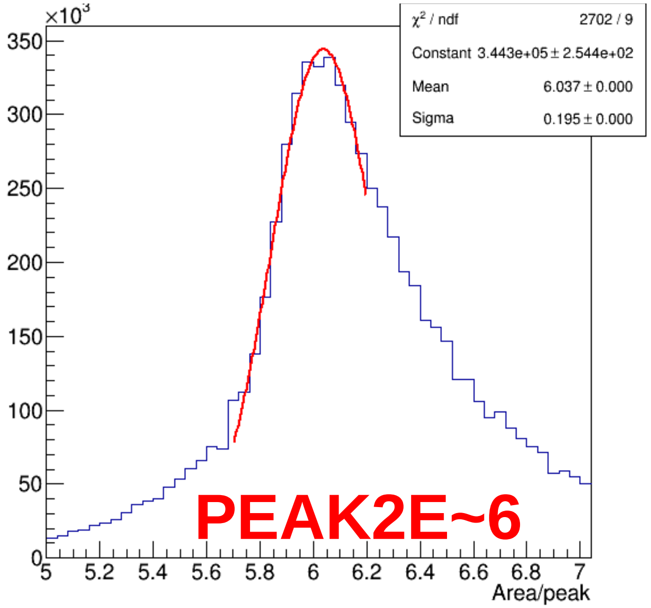
CALORIMETER TRIGGER INPUT DATA: 'raw' digitized waveform



Simulation of a bit stream coming from the calorimeter digitizer after zero suppression is applied

ENERGY EQUALIZATION and PEAK CONVERSION





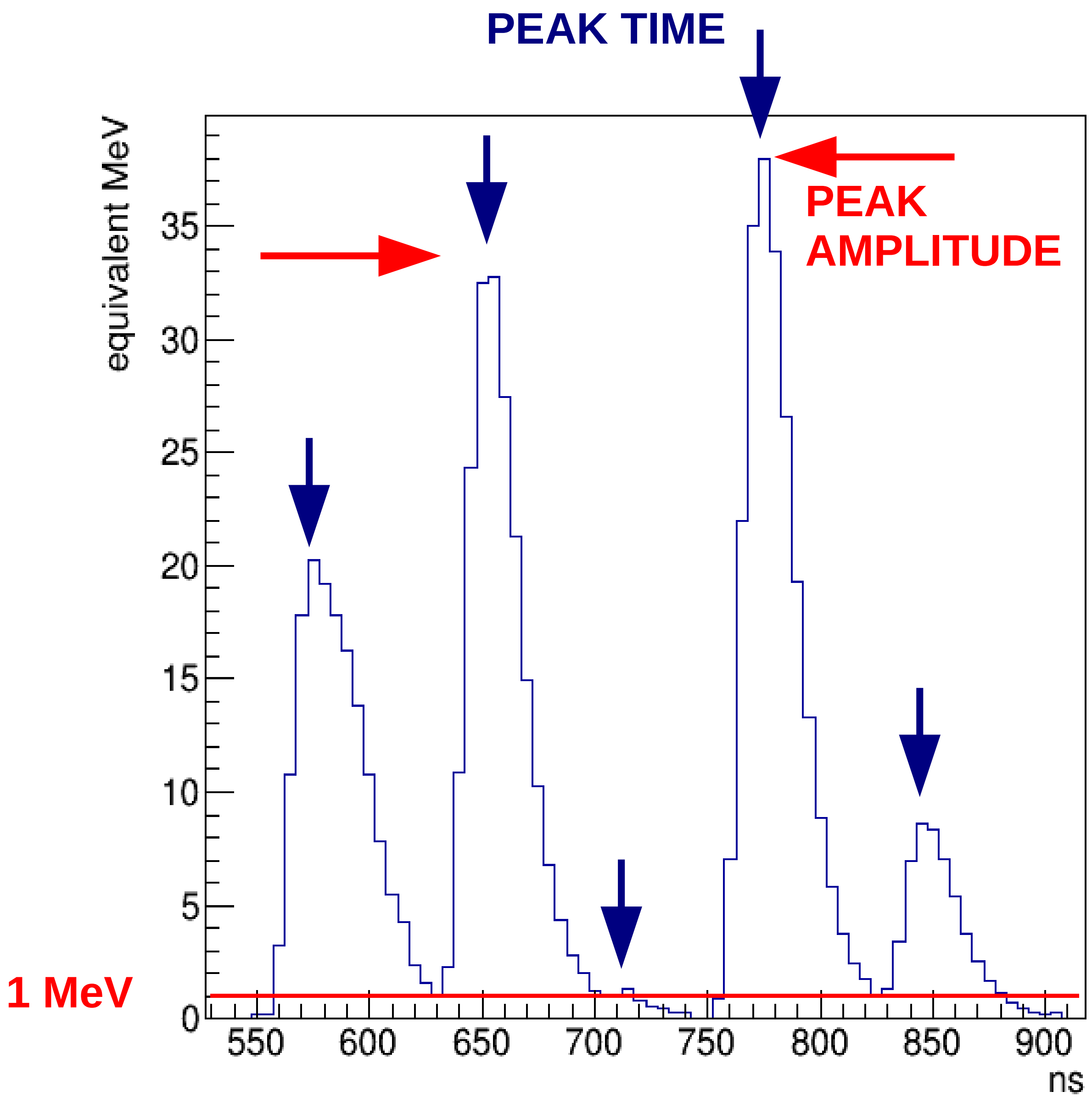
EQUALIZATION:

MEV= ADCCOUNT*ADC2MEV
(ADC2MEV=0.0076
from cluster energy calibration
Depends on sensor calibration)

PEAK CONVERSION:

PEAK AMPLITUDE -> INTEGRATED ENERGY
MEVeq= MEV*PEAK2E
(depends on waveform shape)
-> Shape independent algorithm

DIGITIZED WAVEFORM PROCESSING



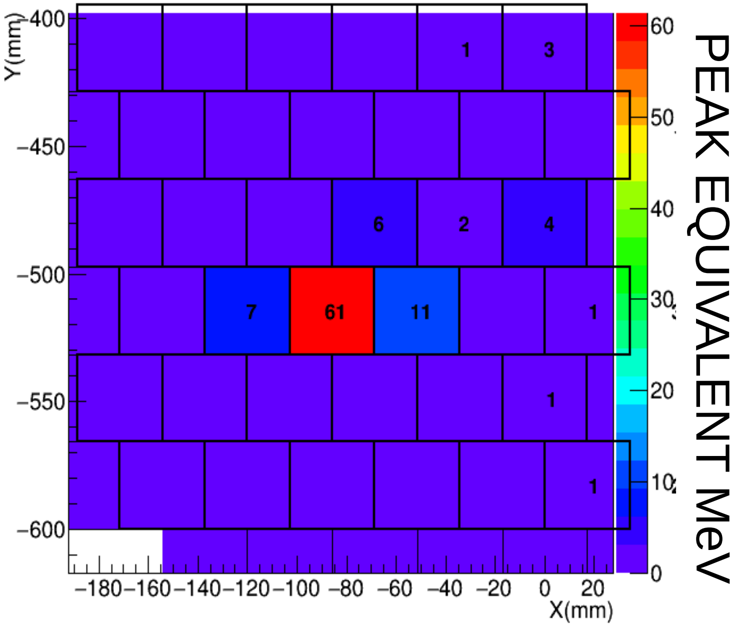
Find the peaks:
i-th bin such that
$A_i > A_{i-1}, A_{i-2}, A_{i+1}, A_{i+2}$
$A_i > 1$ MeVeq

Store in a multimap structure the list of peak equivalent energies, times and sensor Ids

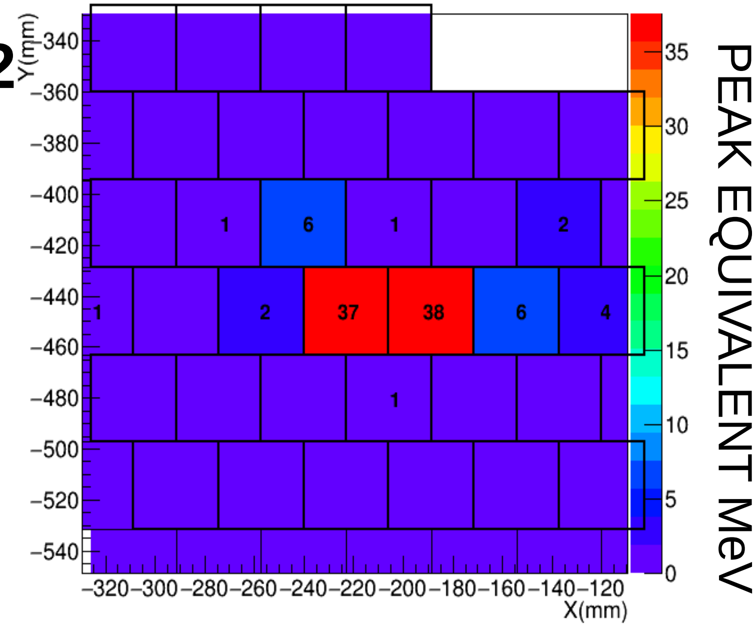
Time consuming step: can be performed in FPGAs (?)

CE SHOWER EXAMPLES

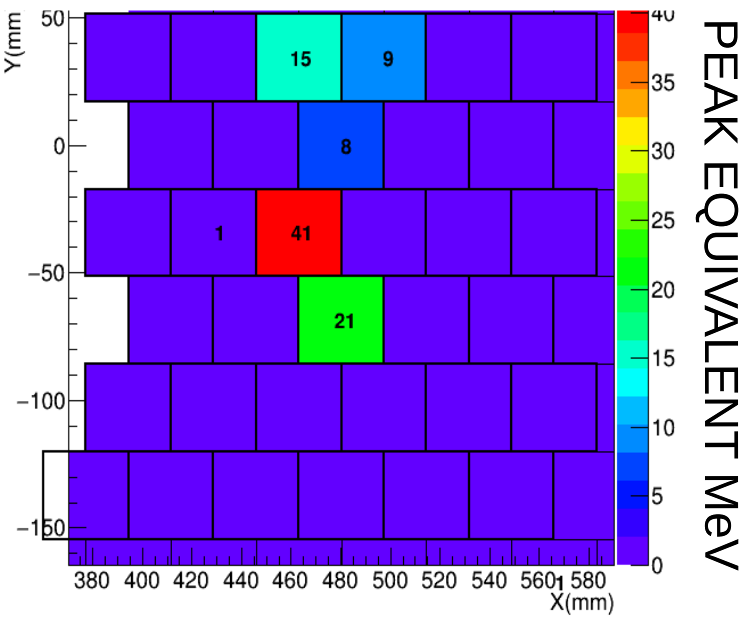
1)



2



3)



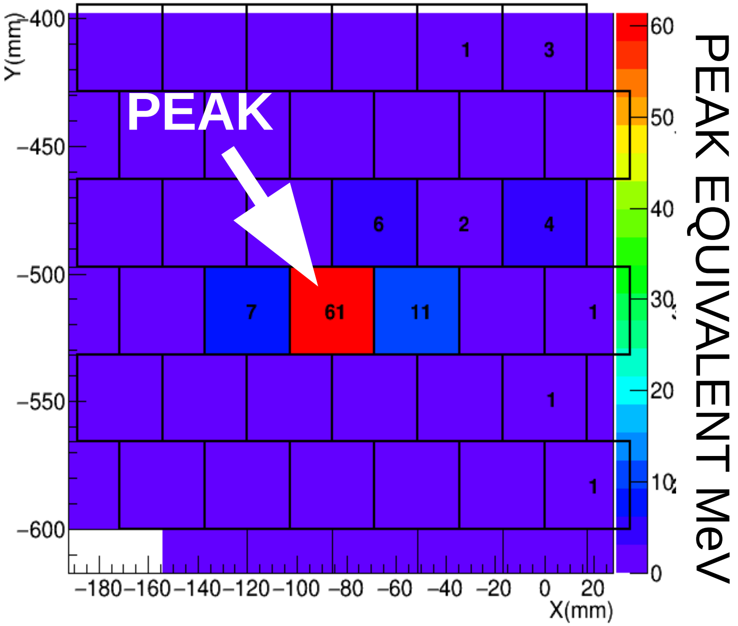
<u>1) “peaked”:</u> most of energy in 1 crystal

2) “large”: most of energy shared between
some adiacent crystals

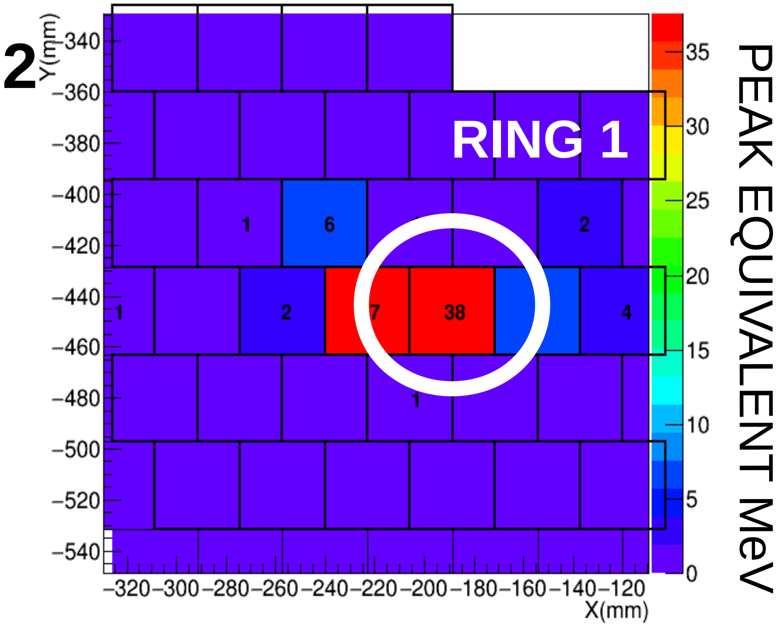
3) “long”: significant energy deposit 2 crystals far from the highest energy deposit

VARIABLES TO CHARACTERIZE CE SHOWERS

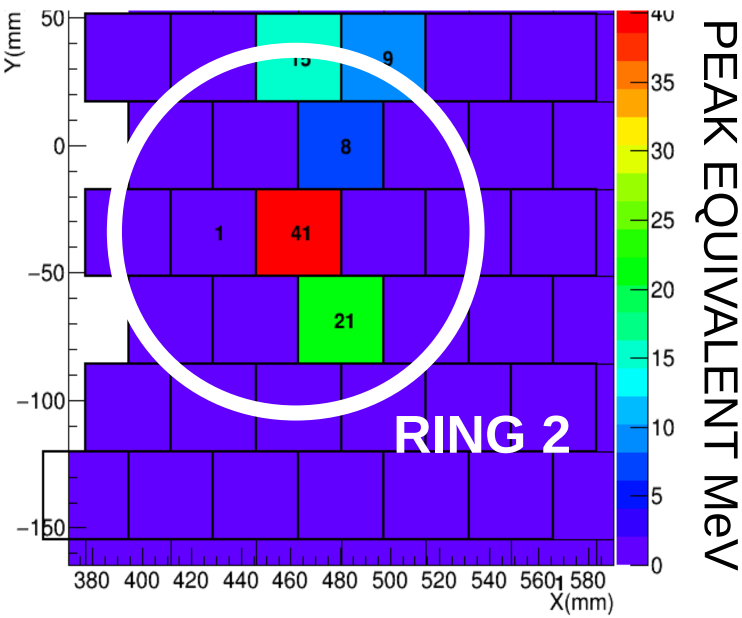
1)



2)



3)

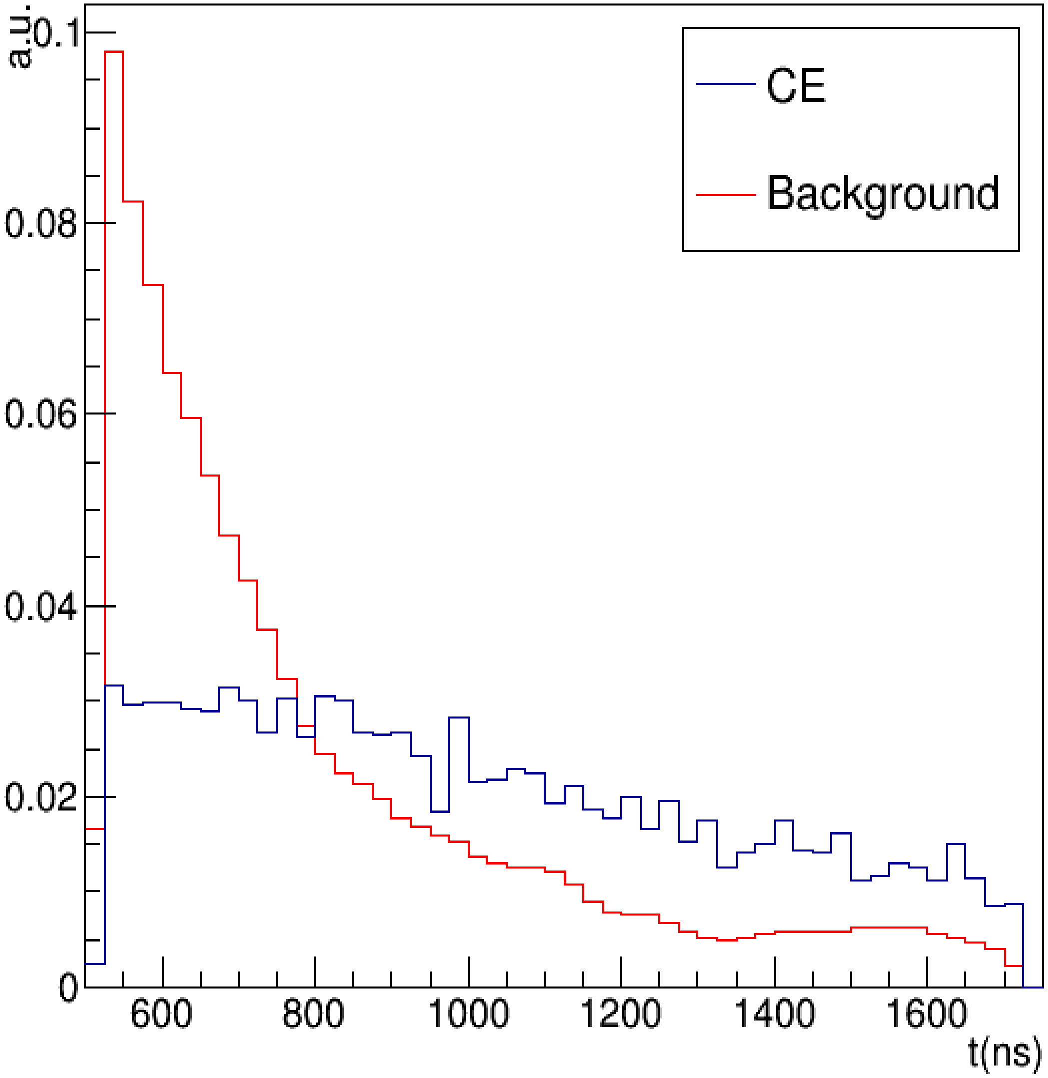


1) PEAK ENERGY:
energy of the most energetic crystal ("SHOWER PEAK")
Must be higher than 20 MeV

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

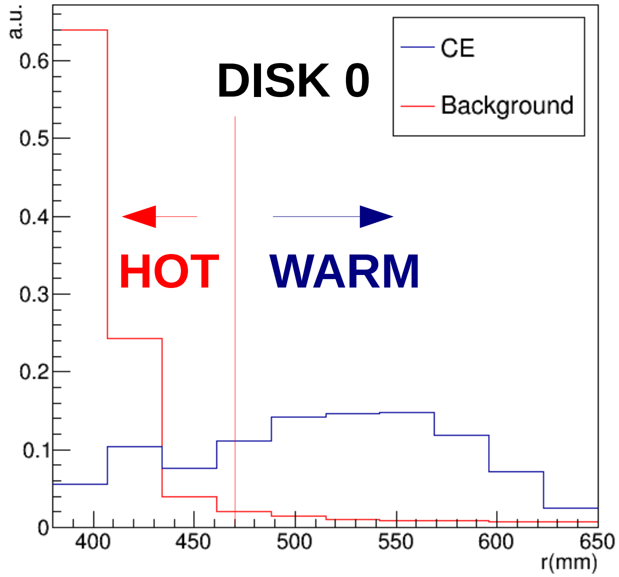
VARIABLES TO SUPPRESS BACKGROUND: PEAK TIME

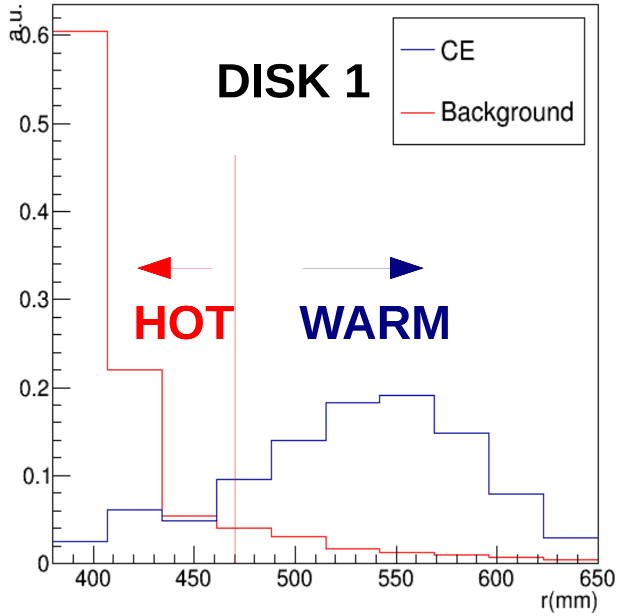


5) SHOWER PEAK TIME:
waveform peak time of the shower peak

Prompt background has a different time distribution

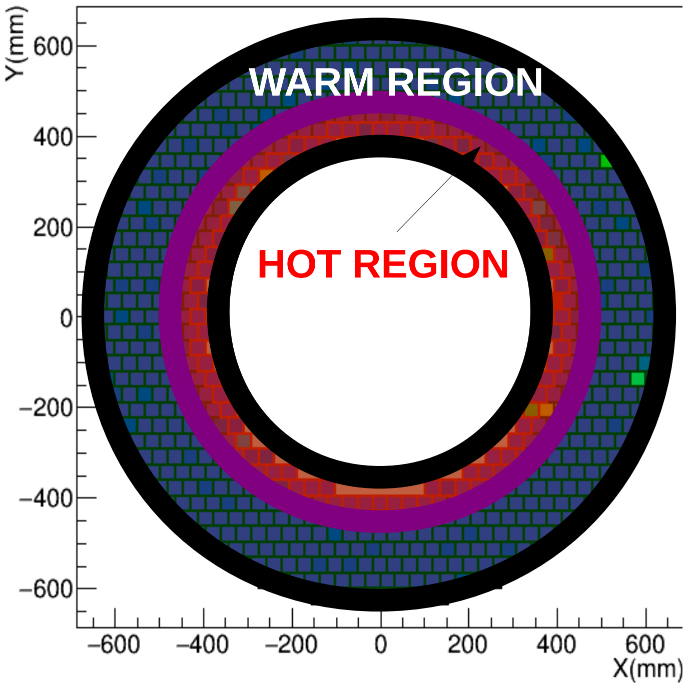
VARIABLES TO SUPPRESS BACKGROUND: PEAK RADIUS



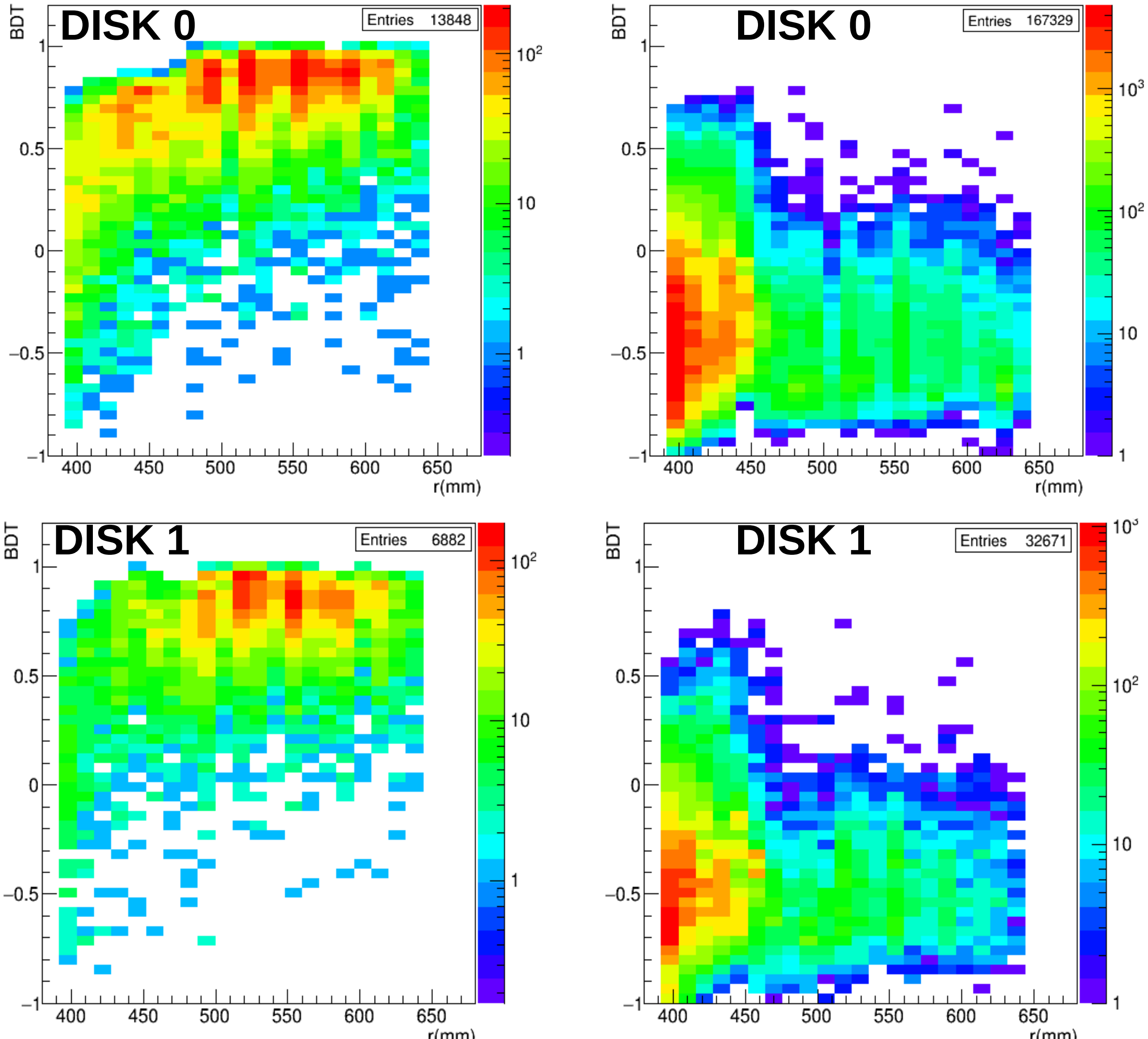


6) SHOWER PEAK RADIUS:
radial position of the shower peak

Background is concentrated at low radius:
r < 460 mm (HOT region) r > 460 mm (WARM)
Radial distribution is also different for the two disks -> 4 different training regions



BEST BDT IN THE EVENT vs SHOWER PEAK RADIUS



CE+PILEUP

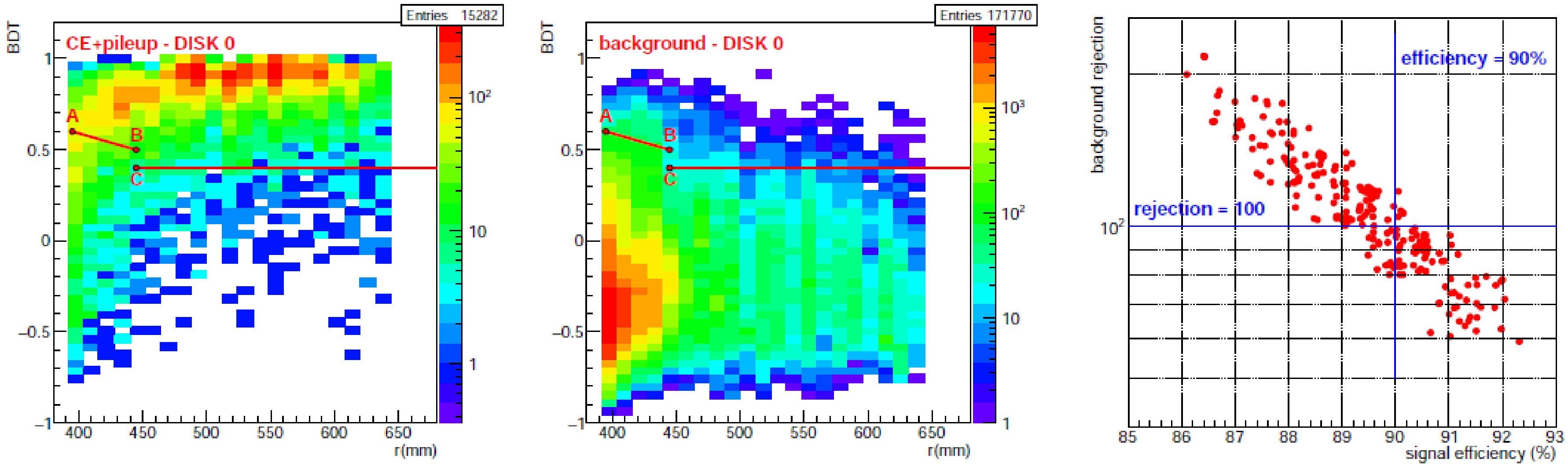
BACKGROUND

Log scale!

Most of the events have the best peak in DISK 0

Considering the 4 training categories a radius dependent cut appears to be more performant

BDT CUT as FUNCTION OF PEAK RADIUS

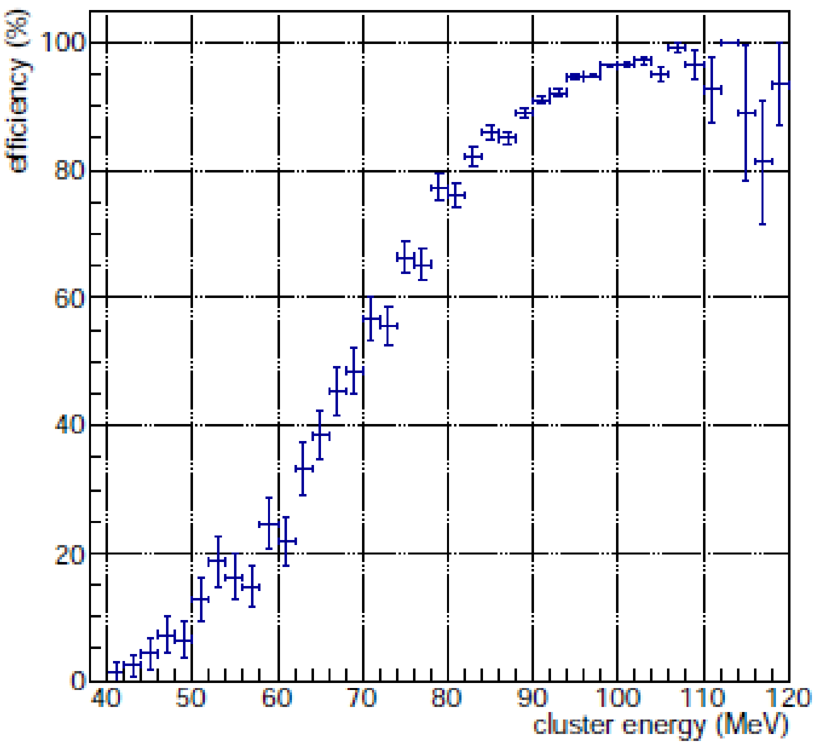


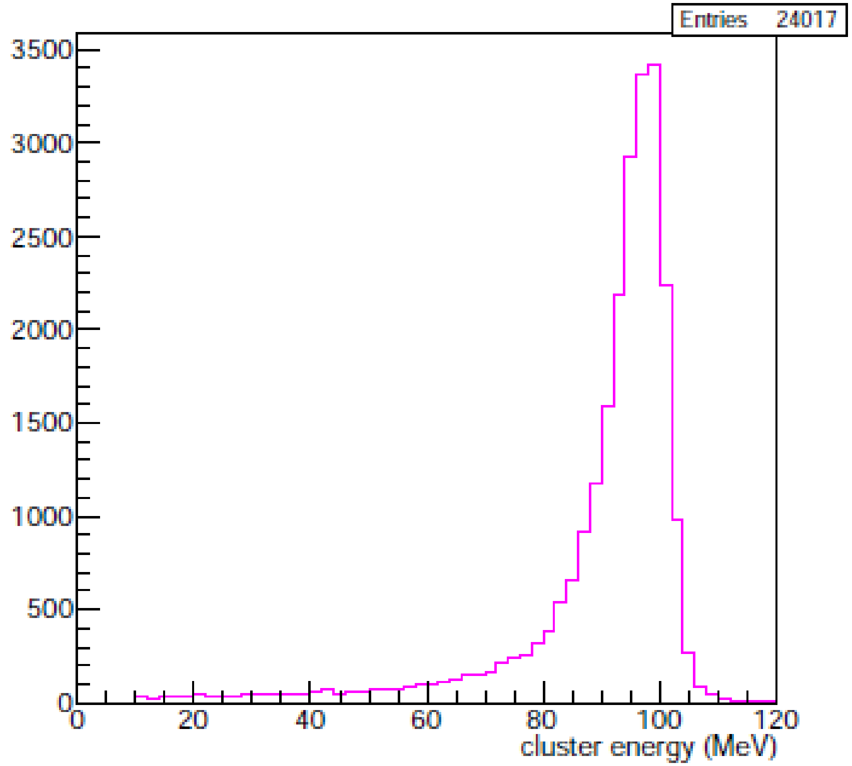
The points A, B and C are used to parametrize the cut function
The parameter space is scanned to find the optimal cut profile

More profiles have an efficiency ~90% with a rejection ~100 (one of them used in the following)

It's possible to increase the rejection to 200 by reducing the efficiency to 86%

TRIGGER EFFICIENCY vs CLUSTER ENERGY

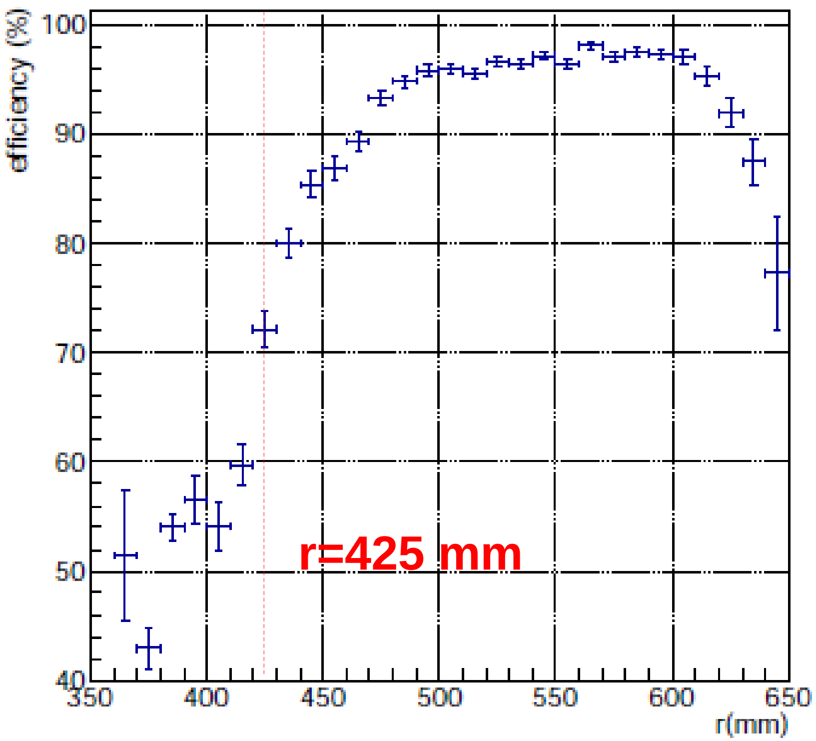


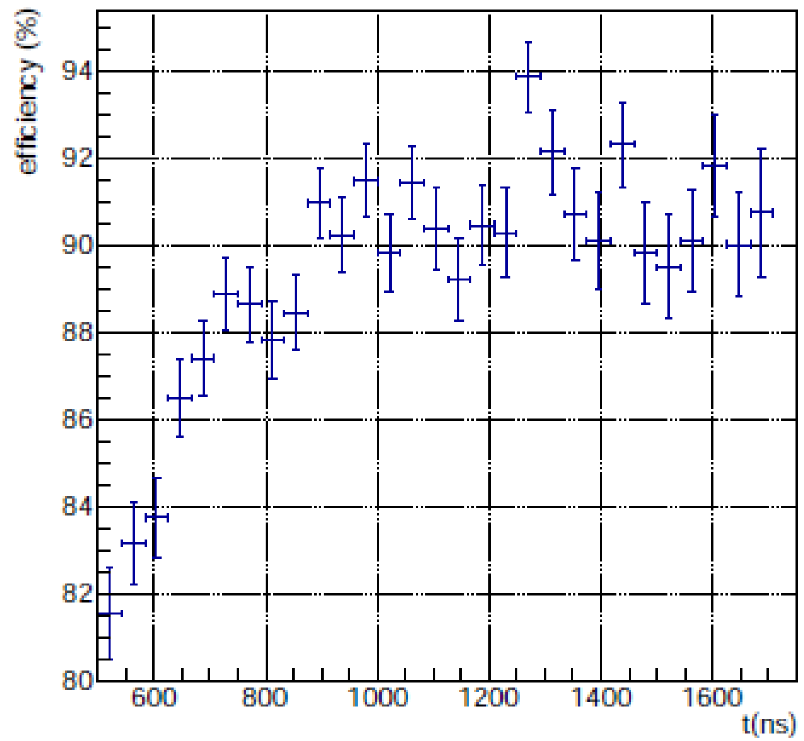


Trigger efficiency on preselected events

Cluster energy spectrum of preselected events ($E_{cluster}$ >50 MeV cut released)

TRIGGER EFFICIENCY vs ECAL IMPACT POINT





The region r<425 mm corresponds to the inner edge of the ECAL disks

Efficiency is still >80% below 700 ns

CE TRIGGER EFFICIENCY ANS REJECTION

Preselection	Preselection Efficiency (%)	Trigger Efficiency (%)	Global Efficiency (%)
Good track	13,4 ± 0,1%	**83,2 ± 0,3%**	11,2 ± 0,1%
+ Good Track-cluster matching	11,9 ± 0,1%	**87,3 ± 0,3%**	10,4 ± 0,1%
+E>50 MeV	11,4 ± 0,2%	**90,5 ± 0,3%**	10,3 ± 0,1%

Rejection = 101 ± 3

AVERAGE PROCESSING TIME PER EVENT

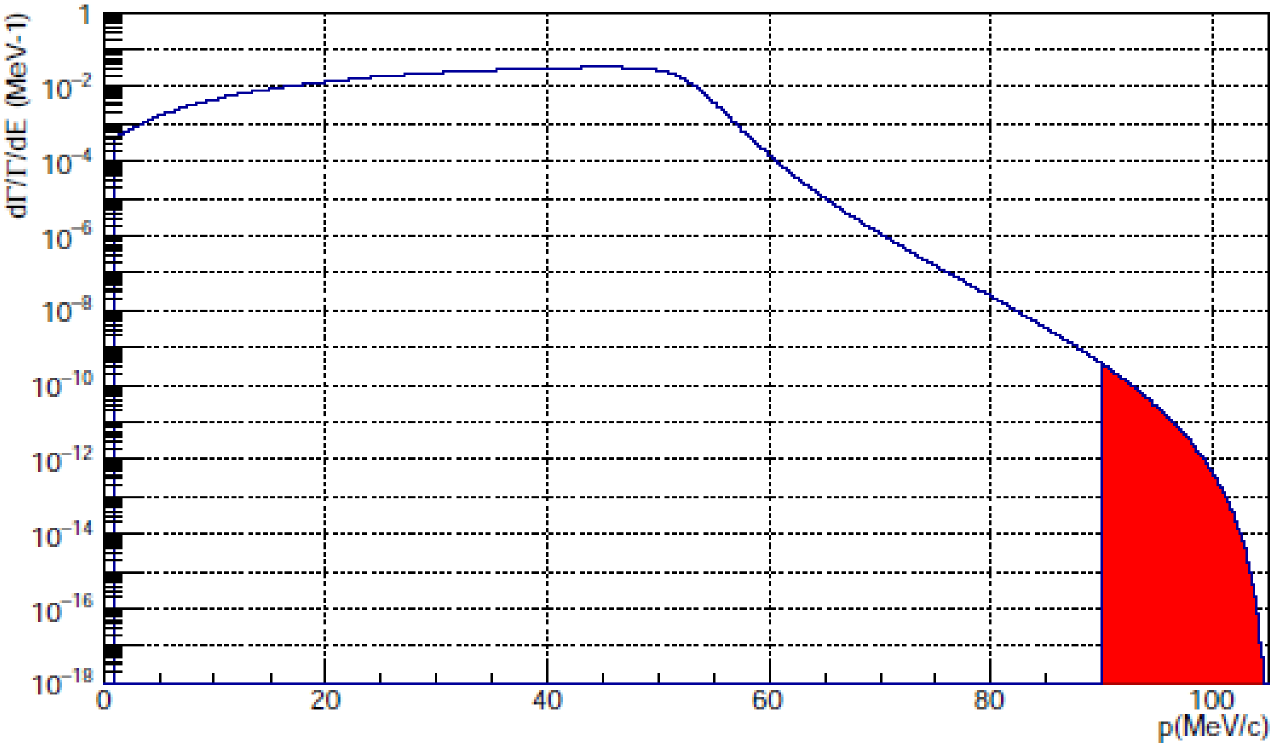
CPU model	CUP frequency (GHz)	number of grid jobs	average time per event (ms)
Opteron^{TM} Processor 6128	2.0	21	1.6
Opteron^{TM} Processor 6128HE	2.0	4	1.7
Opteron^{TM} Processor 6134	2.3	5	1.7
Opteron^{TM} Processor 6376	2.3	17	1.4
Xeon® CPUE5-2670v3	2.3	11	1.1
Xeon® CPUE5-2680v4	2.4	42	0.9

CPU TIME BREAKDOWN*

algorithm step	total CPU time (ms)	exclusive CPU time (ms)
Waveform peak search	0.53	0.53
MVA input variables	0.71	0.18
BDT calculation	0.92	0.21

***On a 2.4 GHz Xeon CPUE5-2680v4 machine**

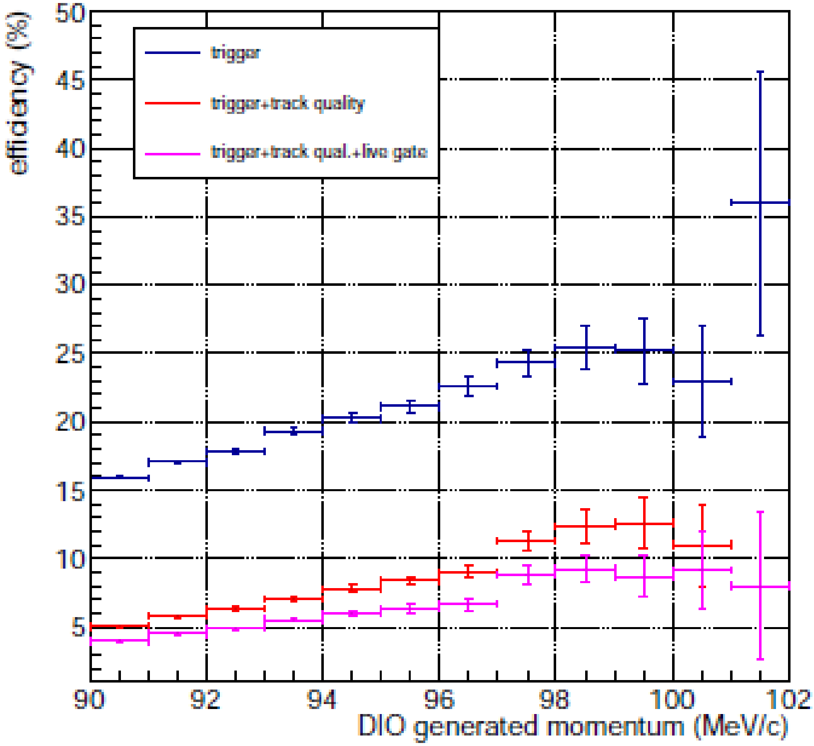
TRIGGER PERFORMANCE ON DIO EVENTS

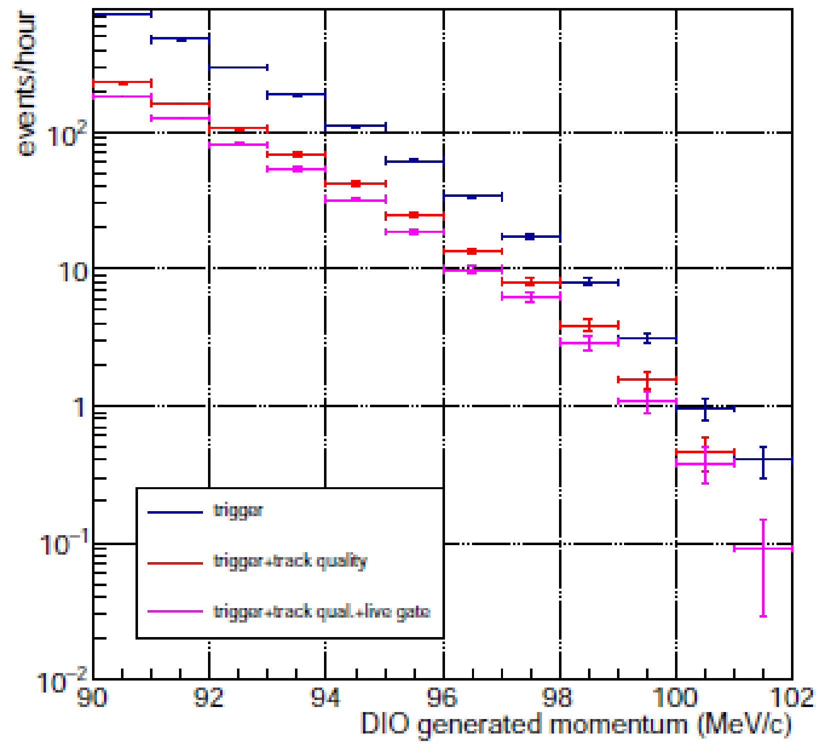


DIO events generated according to the Czarnecki-Szafron spectrum starting from **90 MeV/c**

Same preselections as for CE applied

DIO EFFICIENCY AND RATE

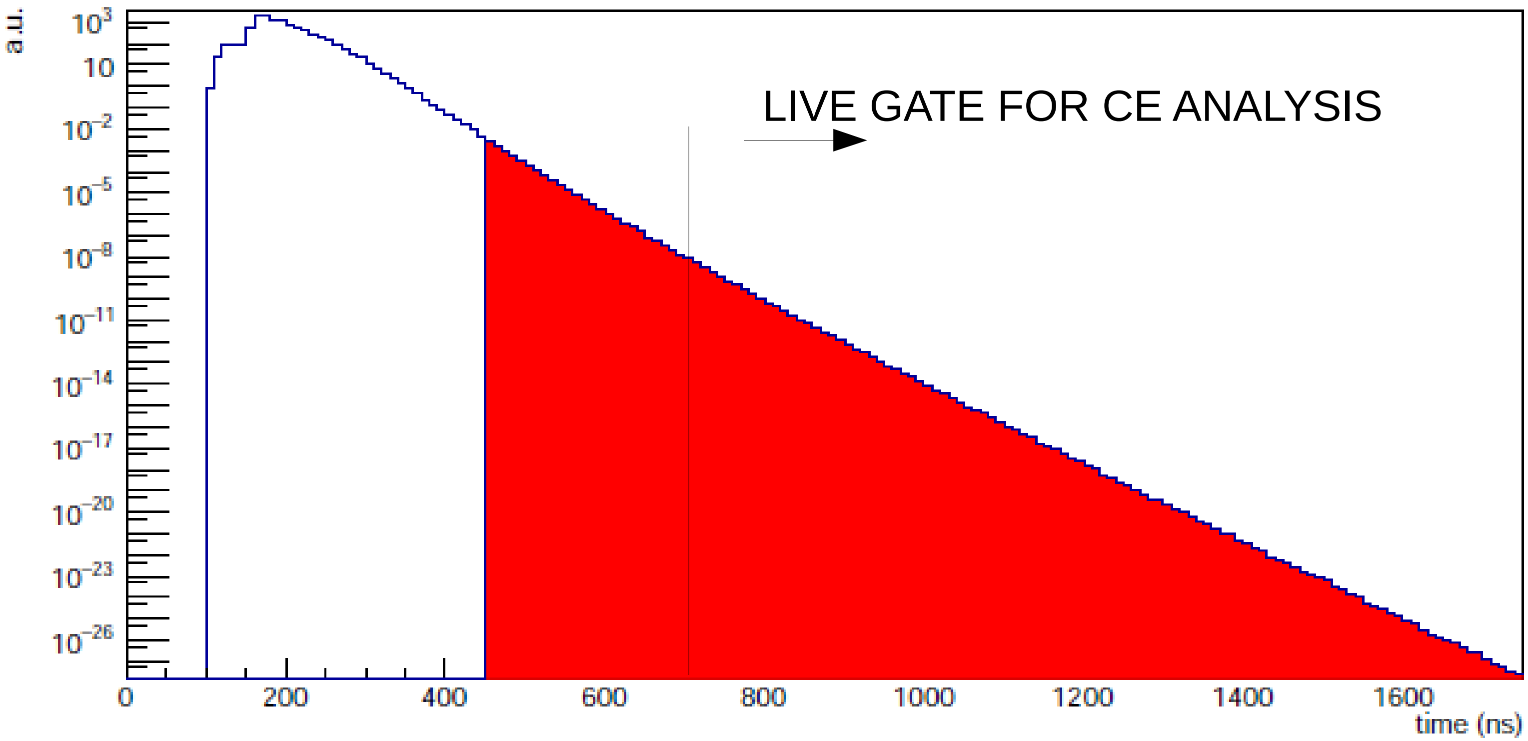




Efficiency versus momentum for different preselections
Normalized to generated events

1900 events/h with p>90 MeV/c
650 good quality tracks/hour
500 in the live gate (t>700 ns)
(30% beam duty factor applied)

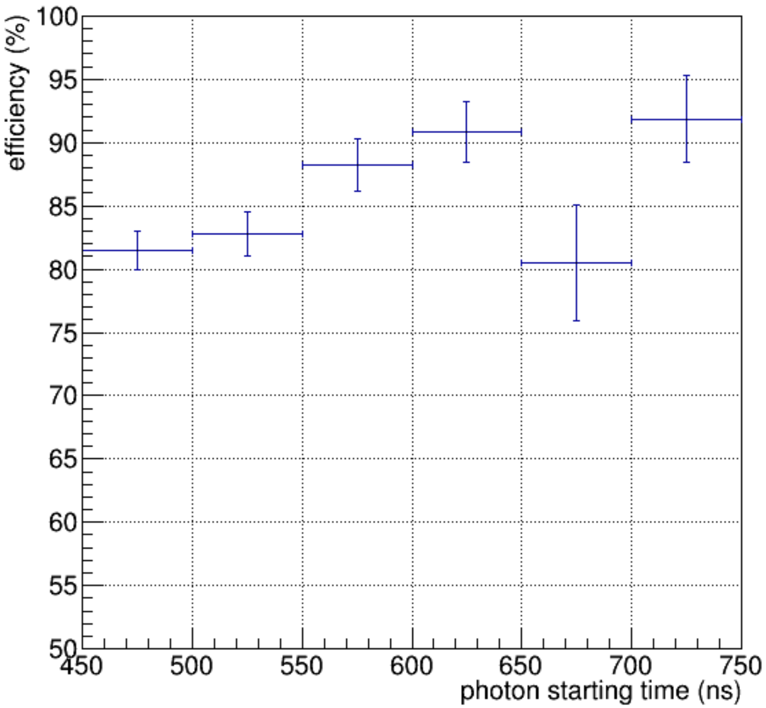
TRIGGER PERFORMANCE ON RPC EVENTS

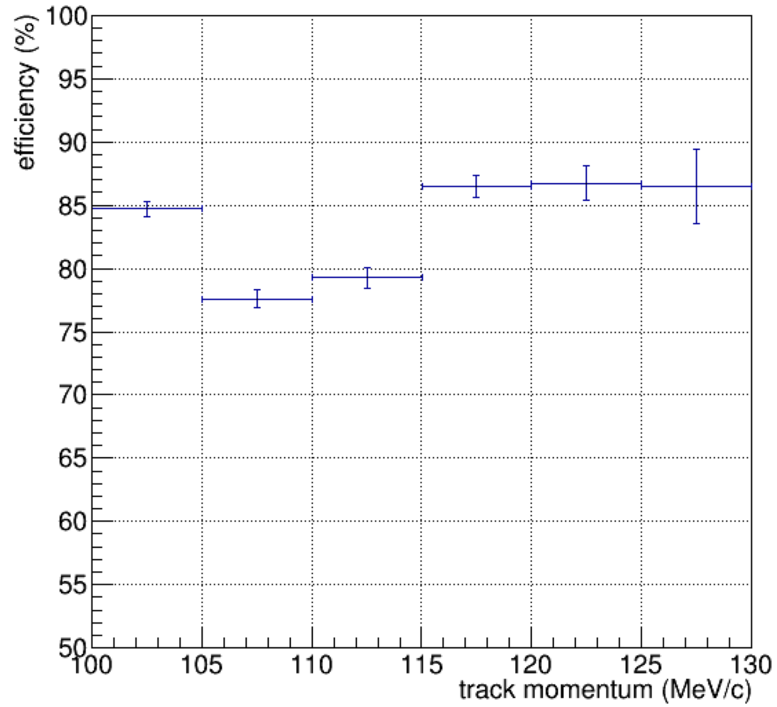


RPC generated using Stage 1 of RPC background analysis (doc-db 8923) but considering only photon times t>450 ns

Only internal conversions studied (same background contribution expected from external conversions)

PION INTERNAL CONVERSIONS EFFICIENCY AND RATE





Efficiency vs radiated photon time (CE preselection + momentum window applied)

Most of events at 500<t<550 ns

Efficiency vs track momentum (CE preselection applied) -> efficiency ~80%

CALORIMETER TRIGGER CONCLUSIONS

The feasibility of a calorimeter trigger for CE events satisfying the trigger requirements is demonstrated

The same trigger also provides a good efficiency on DIO events (needed to cross check the tracker trigger efficiency and the track reconstruction efficiency) and RPC events (needed to evaluate their contribution to CE background)

Improvements in the processing time can come by the use of FPGAs for the waveform peak finding

Improvements in calo-seeded track search trigger (G.Pezzullo)

- We already demonstrated that "CalPatRec" can be used at the trigger level: R_{bkg} ~ 200 with ϵ ~ 95%
- The main problem that affects all the track triggers in Mu2e is the timing performance of the δ-ray removal algorithm:
  ~20 ms/event (3.6 ms/event is the whole time budget!)
- Recent studies showed that using the calorimeter hits pre-selection **reduces this time by a factor > 30**, with no cost for "CalPatRec" trigger efficiency
- Calo hits pre-selection reduces also other straw-hit related reconstruction steps, like the "stereo-hit" processing
- Indeed, **Calo driven helix search** is ~3.5 times faster than the one that uses only the tracker information
- **CalPatRec is so far the best track-trigger candidate**

Upgrade of the Mu2e tracking framework (G.Pezzullo)

- **The ultimate goal is a migration to a 6 parameters Track fit:**
  - time is explicitly used in the Kalman fit
  - Track-t_0 is a parameter and t=parametric variable
- We also improved the software architecture to include the calorimeter cluster info in the Kalman fit
- Work is still ongoing – preliminary results already show 10% relative improvement in the track-reconstruction efficiency