$3x1x1\ m^3$ light data analysis

Spanish WA105 Meeting – 12/01/2018
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on behalf of CIEMAT, IFAE and LAPP groups

Outline

1. 3x1x1 m3 prototype
   → trigger typologies
   → data taking configurations

2. PMT calibration

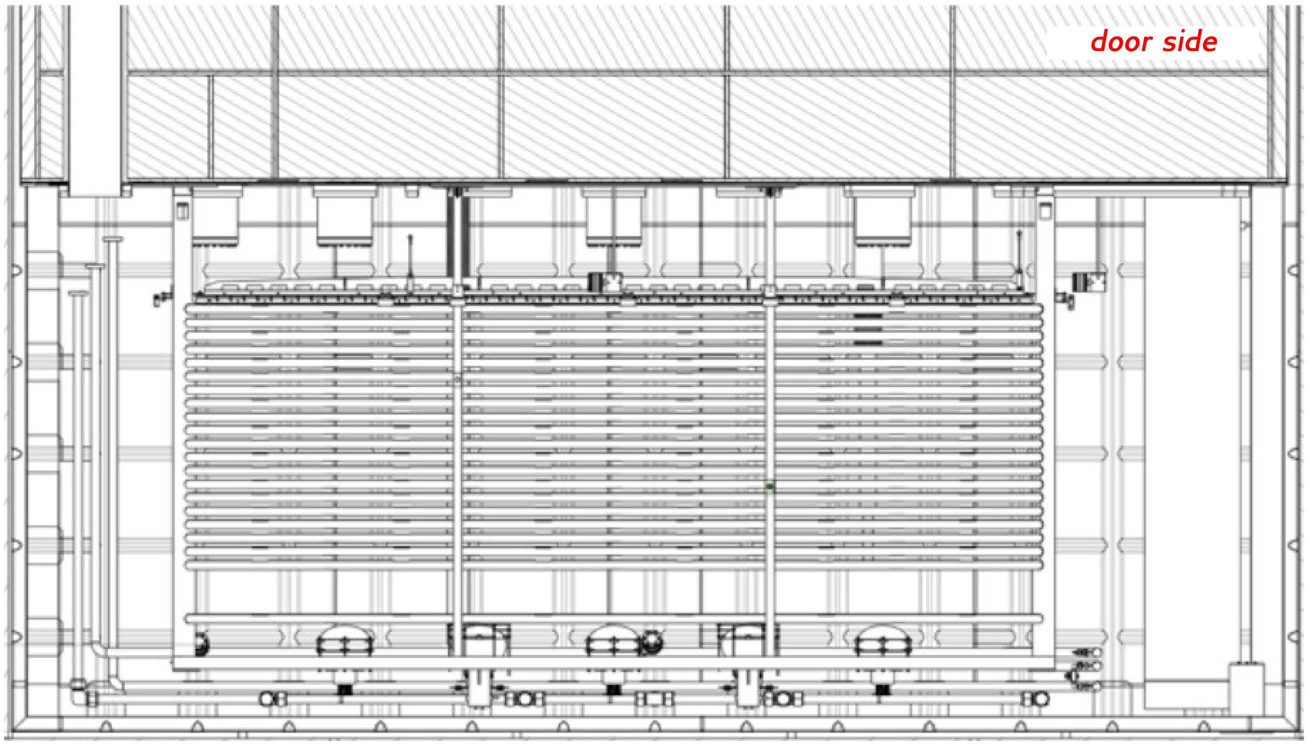
3. Scintillation light of the S1 signal
   → comparison with the MC

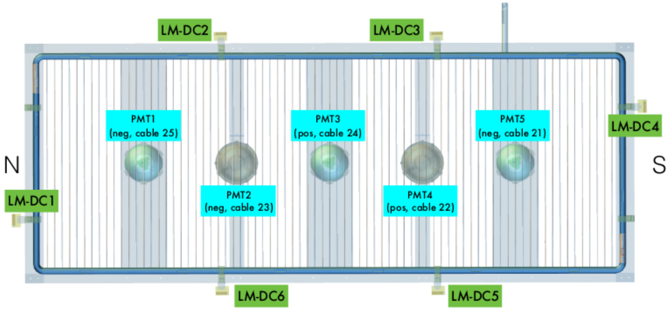
4. Charge-Light, combined analysis

5. Conclusions

Description of light system

- 5 PMTs (8 inches Hamamatsu R592-02 Mod) positioned under the cathode
  → different TPB coating (direct or through a plate)
  → different HV power supply configuration (positive/negative polarization)



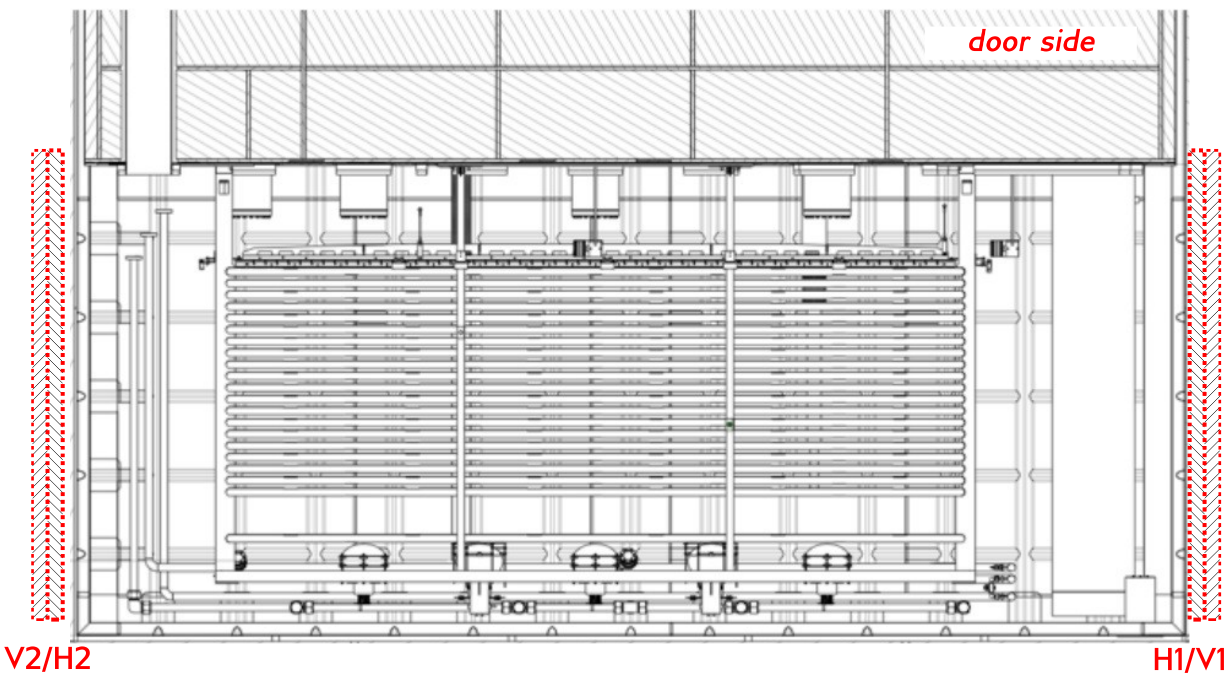


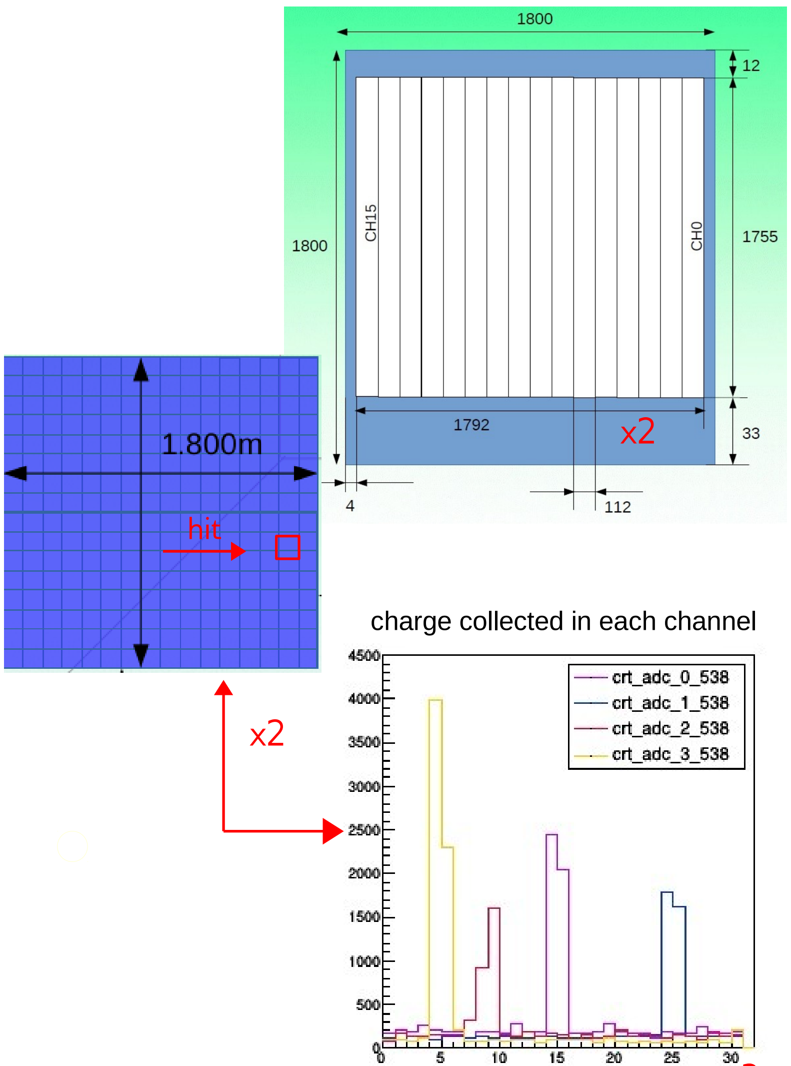
Name	PMT1	PMT2	PMT3	PMT4	PMT5
PMT #	FA0093	FA0092	FA0090	FA0094	FA0091
ADC channel	0	1	2	3	4
Pos/Neg	— (2 wires)	— (2 wires)	+ (1 wires)	+ (1 wires)	— (2 wires)
HV cable #	25	23	24	22	21
Signal cable #	3	2	none	none	16
TPB	direct coating	plate	direct coating	plate	direct coating
Base	KEK	KEK	CIEMAT	CIEMAT	KEK

CRT trigger

Cosmic Rays Taggers (CRT) → 4 modules of scintillators made by 16 strips per module (1.8m x 1.8m)
- each strip is read by 2 optical fibers connected to 2 SiPMs

→ 2 panels per side with horizontal (H1, H2) and vertical (V1, V2) strips
- matrix (256 hits) per side

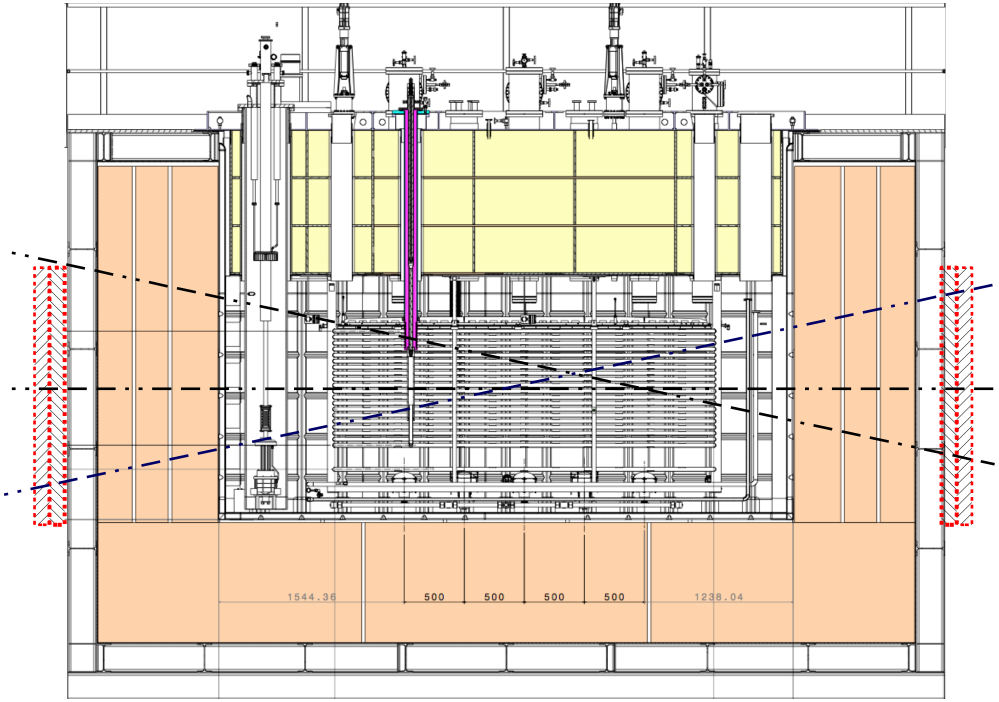


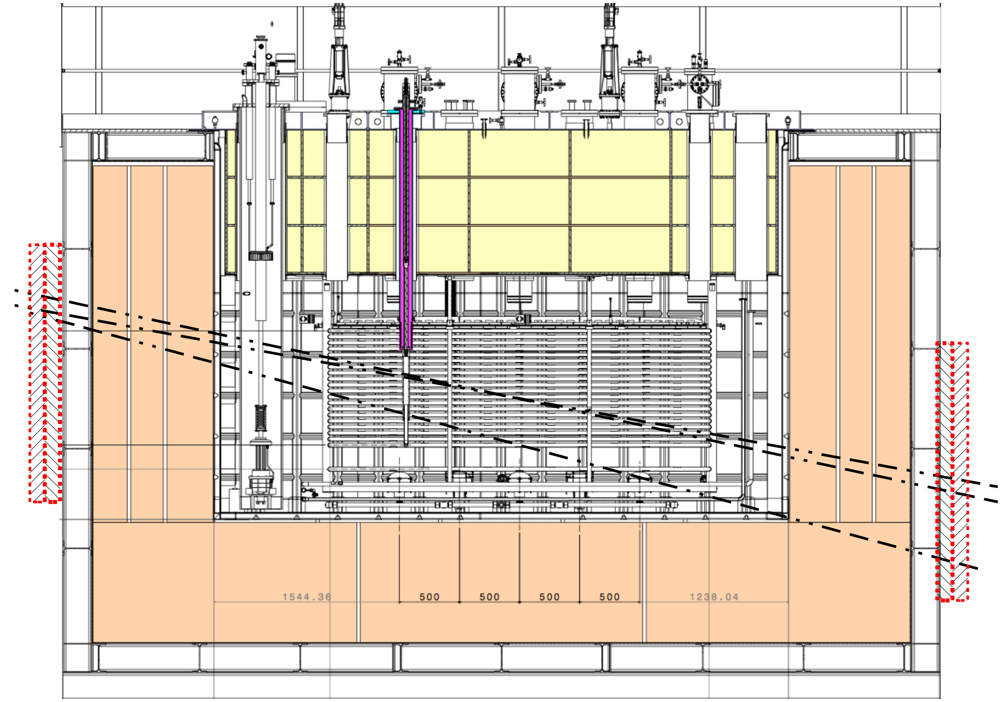


CRT trigger

2 CRT geometries available: - CRT panels aligned with the center of field cage (CRT parallel)

- CRT panels dis-aligned (CRT shifted): V1/H1, -90 cm
H2/V2, +15 cm



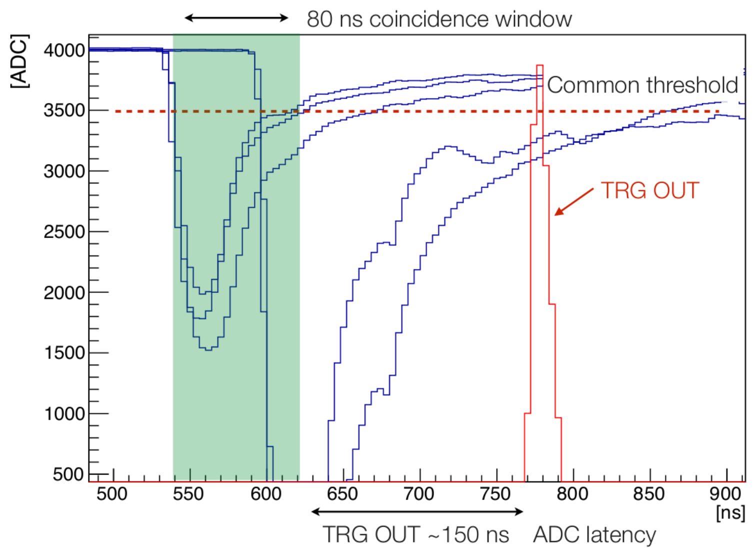


PMT trigger

- 5-fold coincidence on a given threshold (1,81 mV) corresponding to a ~3 Hz, maximum frequency to trigger the charge

- signal from positive bases arrives with 60 ns of delay

  → coincidence on 5 PMTs in a time window of 80 ns

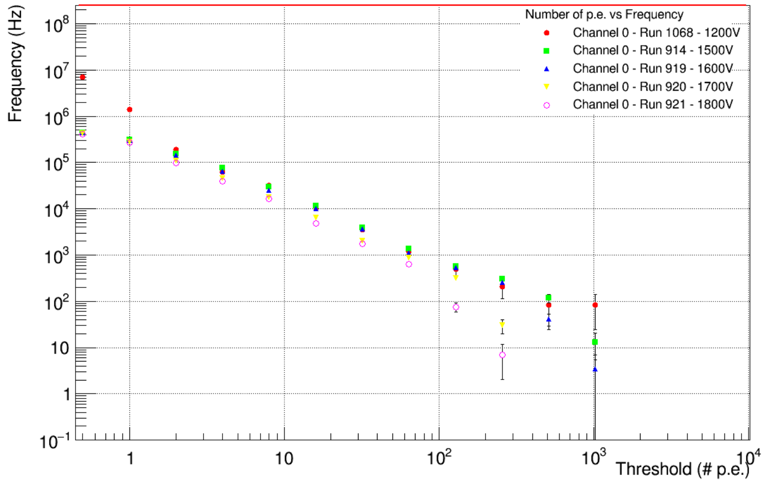


Random trigger

- PMT acquisition randomly activated (usually frequency 100 Hz) during 4 μs

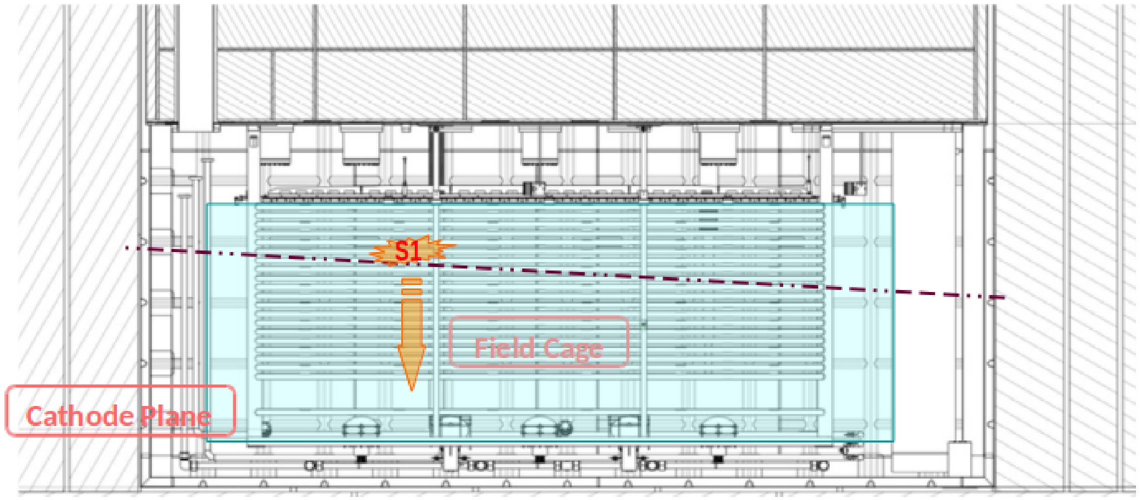
- used to study PMT calibration (see next slide) and the rate of the events as a function of their charge

  → 0,3 MHz ~1 PE
  (DAQ sensitivity limited at 250 MHz ~ 1000 PEs)

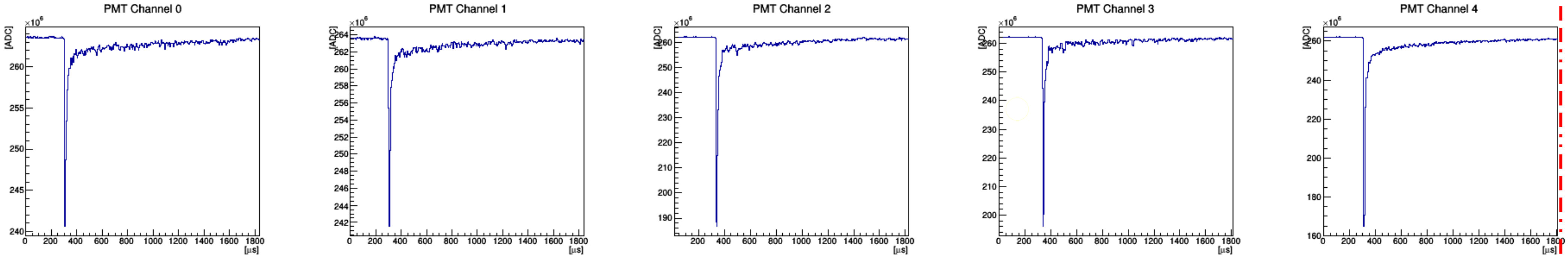


Data taking configuration

- Detector started taking data with cosmic rays working without amplifcation in GAr phase
  → detection of S1 signal produced by tracks crossing the LAr phase

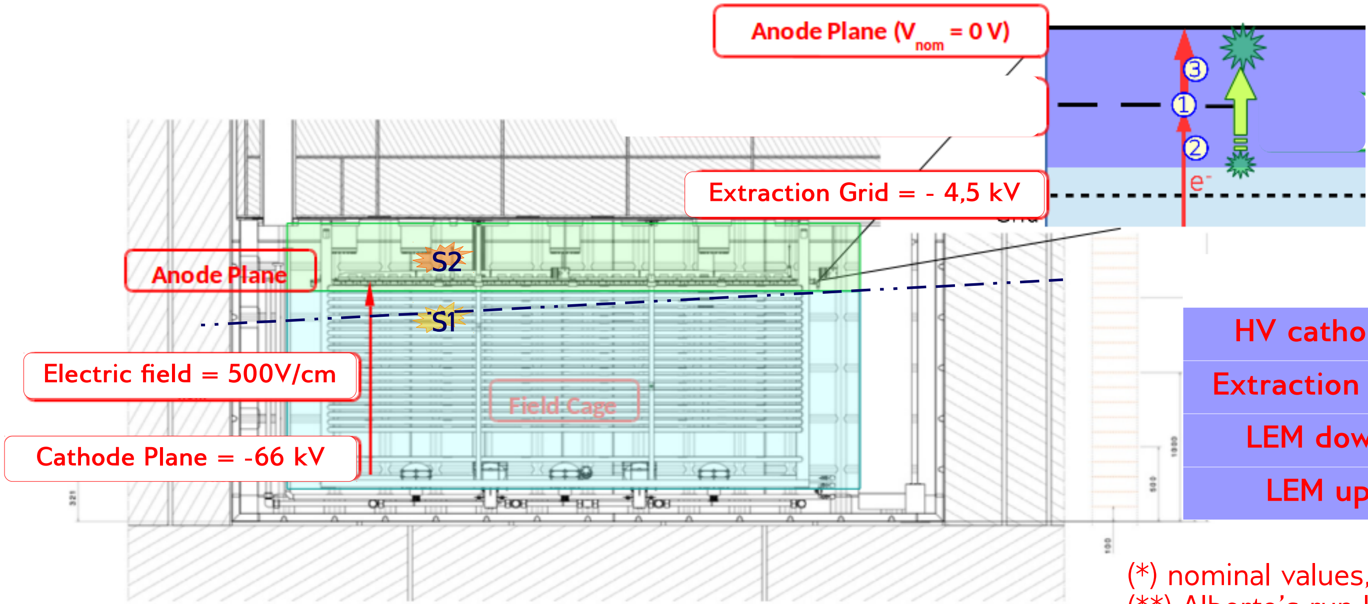


Data taken with the three trigger configurations and with both CRT geometries



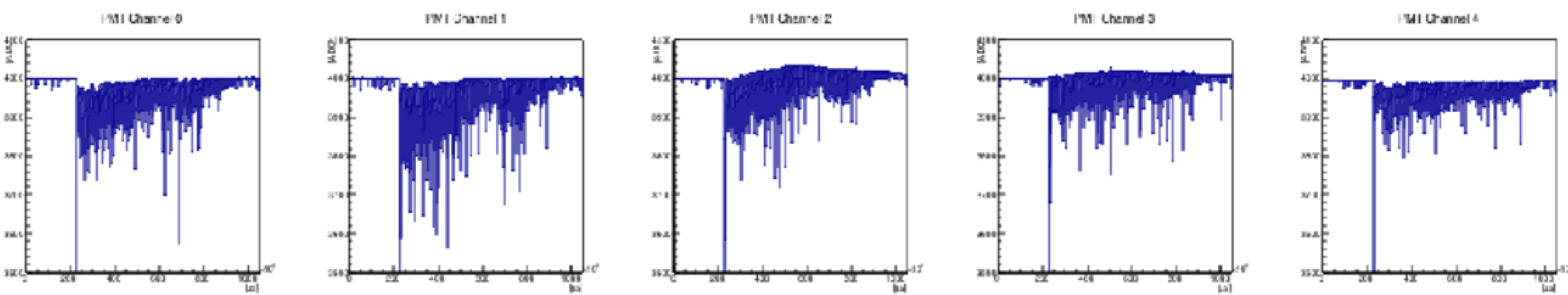
Data taking configuration

- Detector started working with DP configuration when extraction field and LEMs have been switched on
  → charge extraction and amplification available
  → detection of S1 and S2 signals produced by tracks crossing the LAr phase and charge amplified in GAr phase



	max reached (**)	nominal (*)
HV cathode	-66 kV	-66 kV
Extraction grid	-5,5 kV	-4,5 kV
LEM down	-2 kV	
LEM up	-3,5 kV	

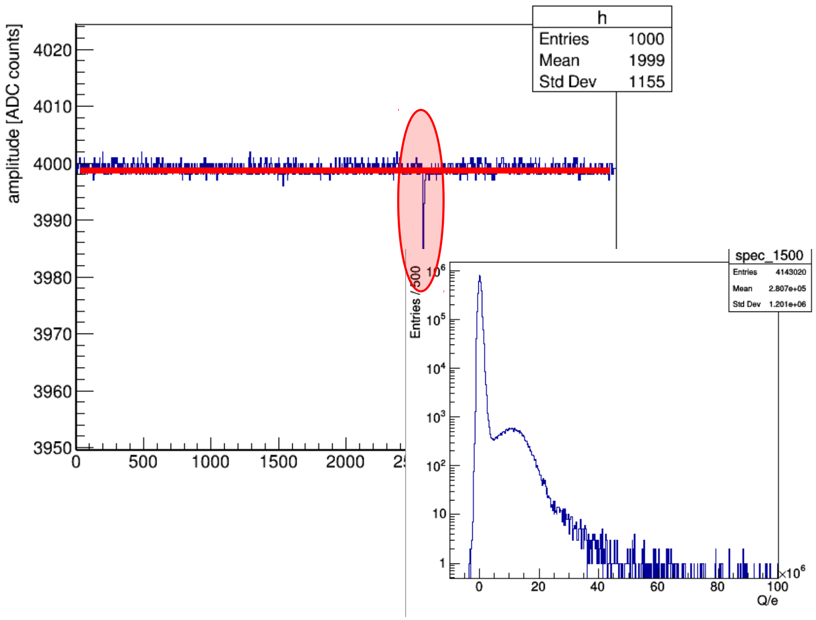
(*) nominal values, Laura's talk in the Review of Sept 25th
(**) Alberto's run list document

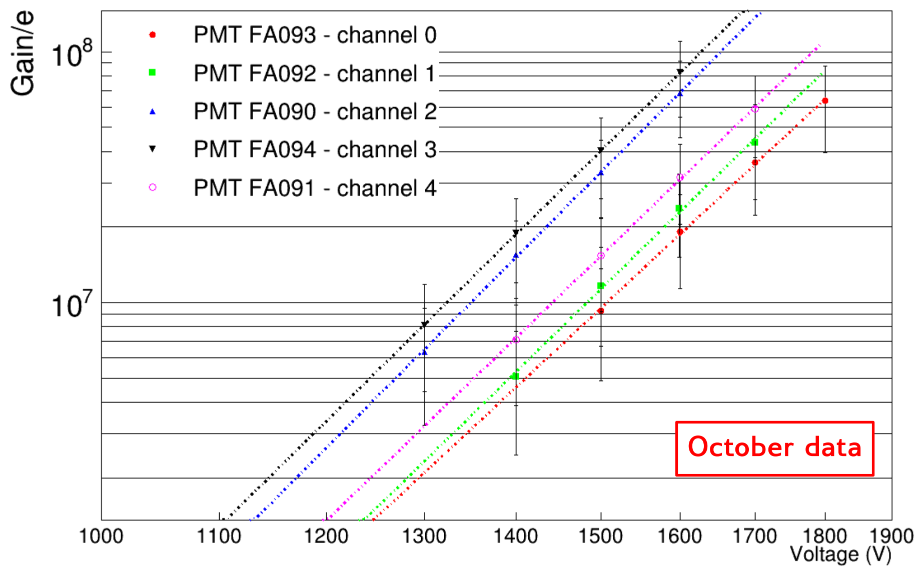


PMTs calibration from 3x1x1 data

- PMTs gain has been lowered during 3x1x1 data taking, two dedicated calibration campaigns have been performed
  → SPE spectrum obtained from random trigger

- the lowering of the gain does not allow to operate the PMTs in their best conditions
  → the gain at low voltage is obtained from the function $G=A*V^B$, which is determined using measurements at higher voltages



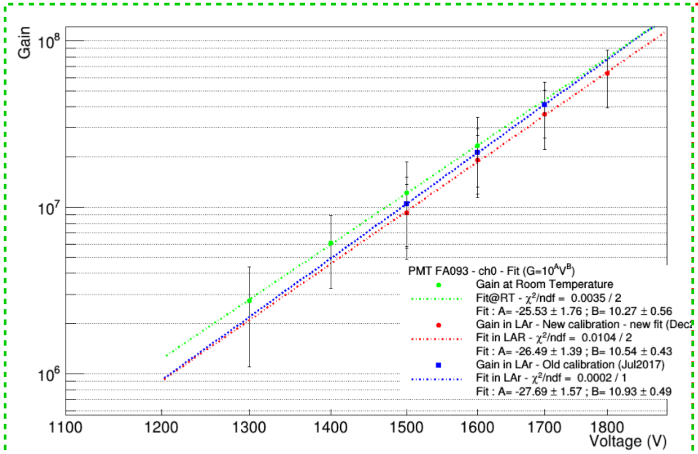


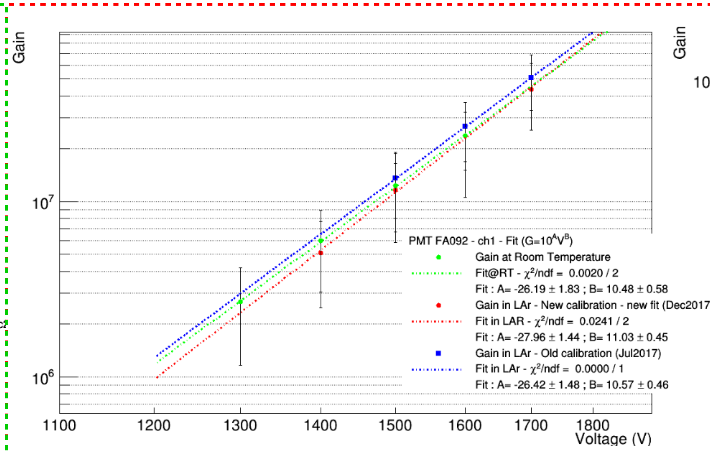
Gain @1200V	July calib	October calib	$\Delta G/G_{Oct}$
PMT1	$(10,6 \pm 0,4)*10^6$	$(9,7 \pm 0,4)*10^6$	- 9%
PMT2	$(14,2 \pm 0,5)*10^6$	$(11,8 \pm 0,2)*10^6$	- 20%
PMT3	$(36,6 \pm 0,3)*10^6$	$(32,1 \pm 0,2)*10^6$	- 14%
PMT4	$(49,6 \pm 0,4)*10^6$	$(39,6 \pm 0,4)*10^6$	- 25%
PMT5	$(17,2 \pm 0,4)*10^6$	$(15,1 \pm 0,3)*10^6$	- 14%

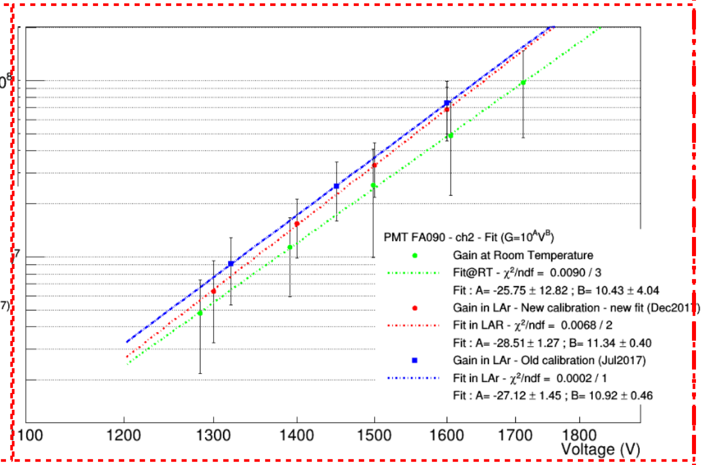
gain decreasing between two calibrations

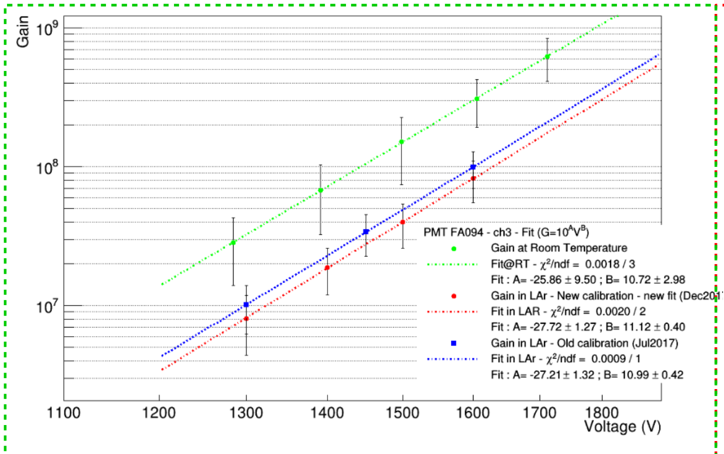
PMTs calibration from 3x1x1 data

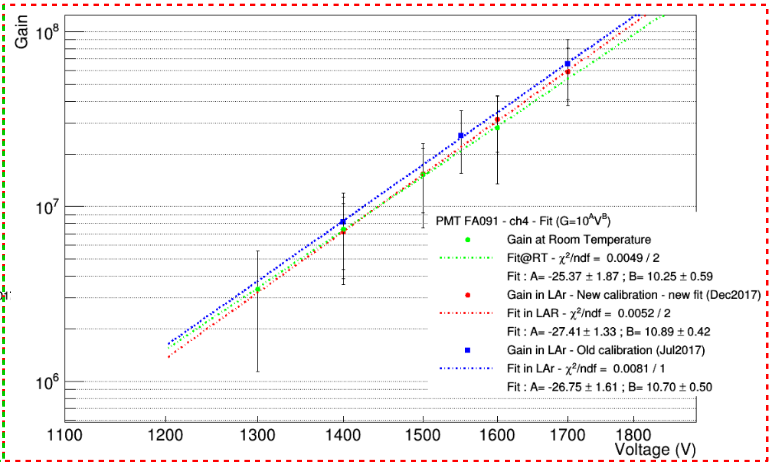
- Comparison with calibration done at RT, not all the PMTs have lower gain at CT than at RT











→ PMT 2, 3 and 5 higher/equal gain at CT than at RT (this result is not understood)

S1 scintillation light analysis

Goal: events characterization producing S1 signal for the comparison with the MC

Runs analyzed: - S1 only, no drift, extraction and amplification fields
- CRT in shifted geometry

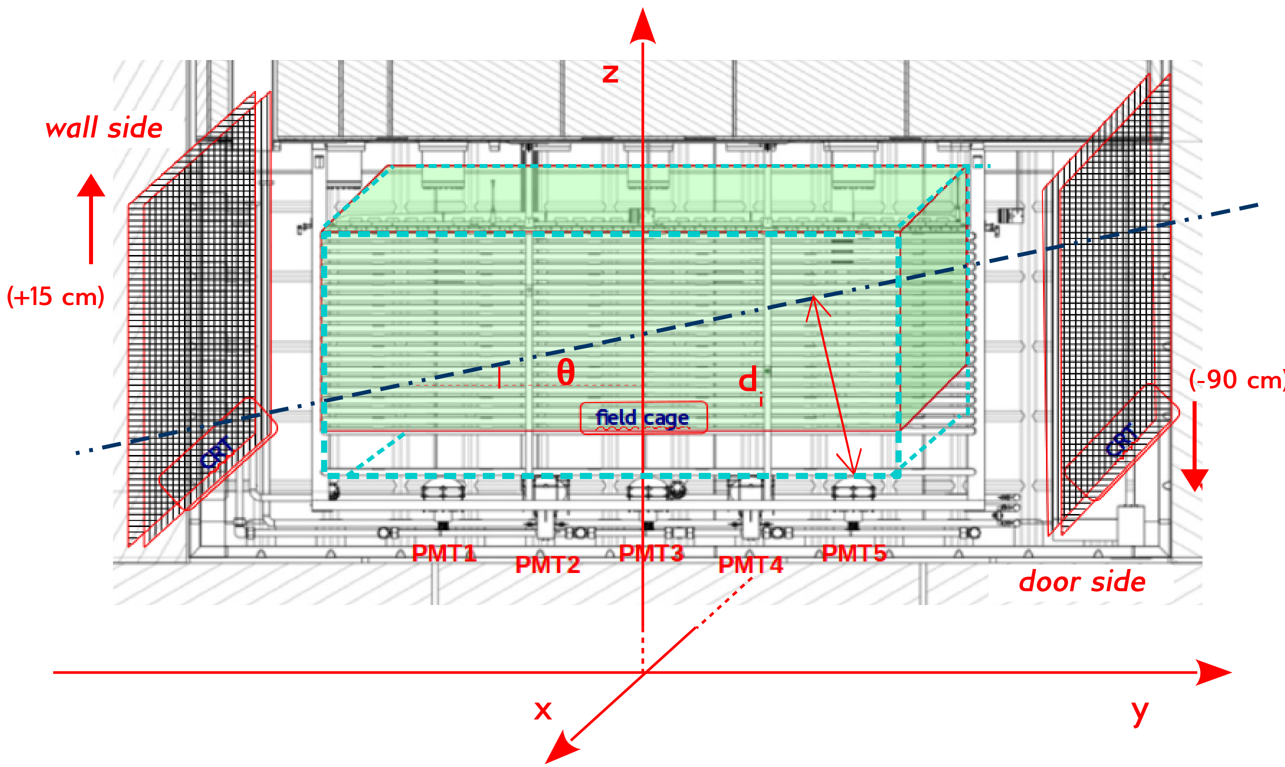
- n. 1324, starting with ~18000 entries (July)
- n. 1333, starting with ~51000 entries (July)
- n. 1608-1614, starting with ~ 5400 entries (August)

PMTs conditions: voltage applied, gain and charge corresponding to 1PE

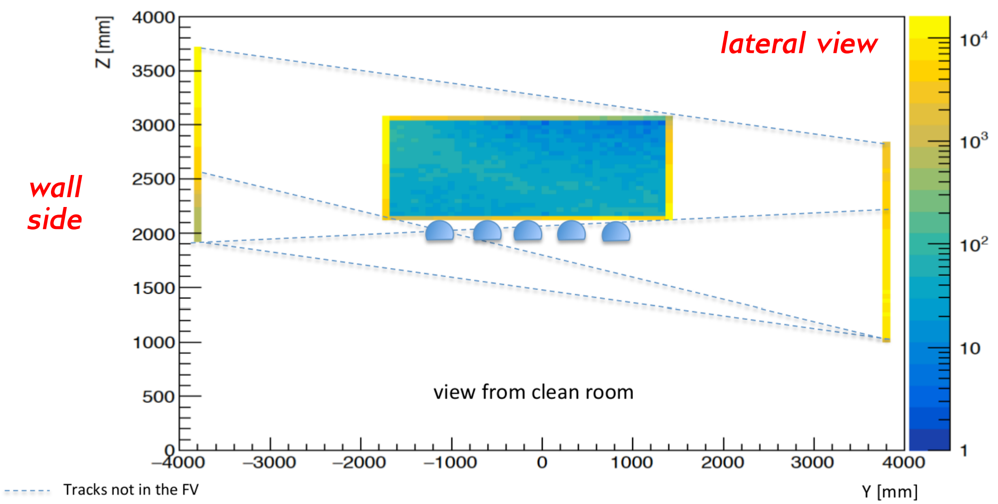
	PMT1	PMT2	PMT3	PMT4	PMT5
Voltage	1200	1200	1150	1150	1200
Gain	$(0{,}92 \pm 0{,}13)*10^6$	$(1{,}01 \pm 0{,}12)*10^6$	$(1{,}58 \pm 0{,}16)*10^6$	$(2{,}07 \pm 0{,}20)*10^6$	$(1{,}33 \pm 0{,}15)*10^6$
Q(1PE) [pC]	0,14	0,15	0,24	0,31	0,20

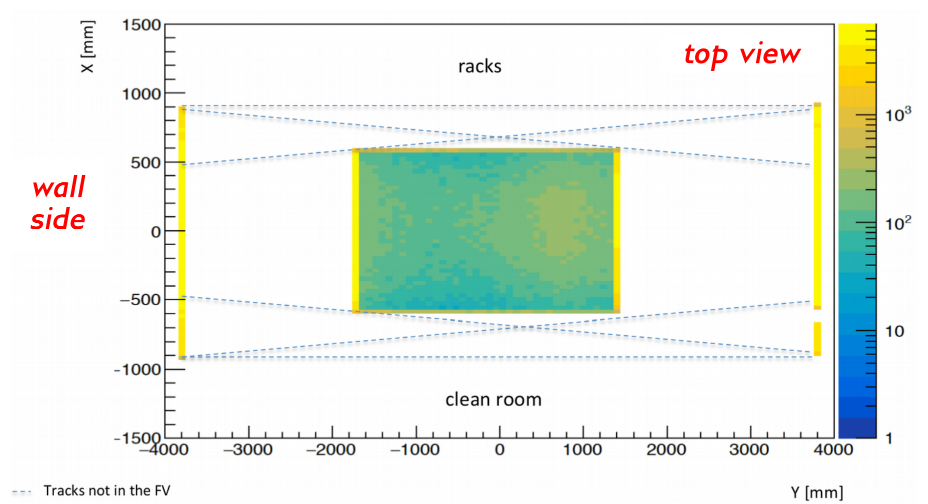
Variables describing μ-events in CRT track reconstruction

The variables we took into account in the analysis are:



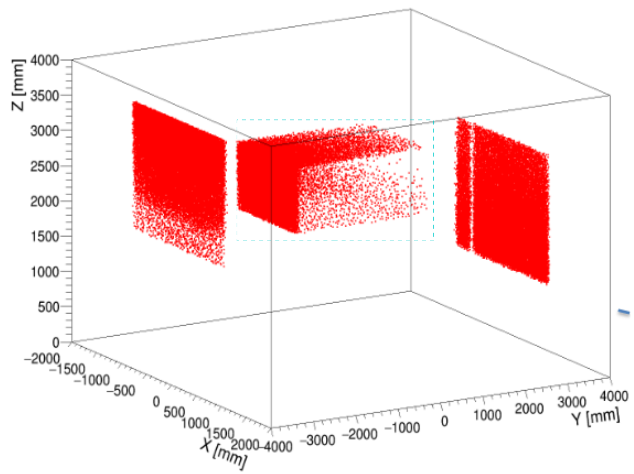
- Time of Flight (ToF) = time difference between the CRT trigger on the *door* side panels and the *wall* side ones
- |tan θ|, being θ the angle formed in the YZ plane
- z_{in}, x_{in} and z_{out}, x_{out}, respectively the z and x coordinates in the *door* and *wall* sides
- fiducial volume (FV), volume inside ---- lines
- track length, the length of the track inside the fiducial volume
- d_i, the minimum approach distance of the tracks from the center of the surface of each PMT



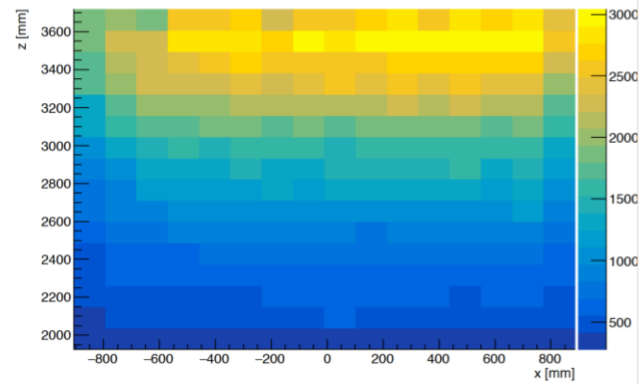


CRT maps

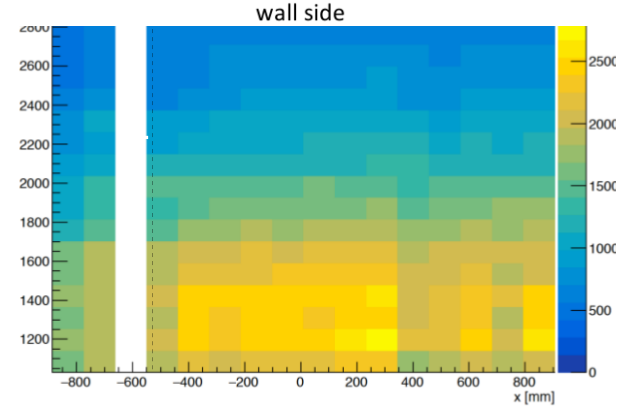
- CRT maps are consistent with top-bottom trajectory of most of the muons crossing the FV
- most of the μ-like events have ToF>0 due to CRT geometry



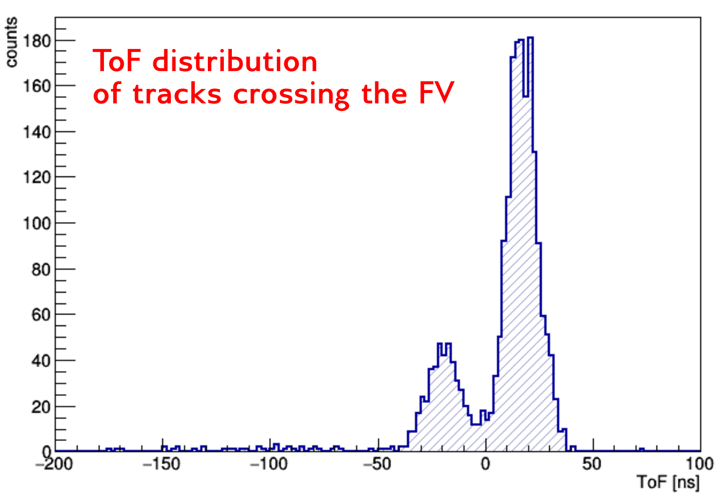
Entry points in the FV -----



wall side



door side



- ToF distribution in agreement with CRT position:
  → mainly tracks crossing the FV from top to bottom
  → contamination of fake coincidence (bundle muons) and fake tracks (CRT strips noise)

Muon events selection

To obtain the best μ-events selection, we applied the following quality cuts :

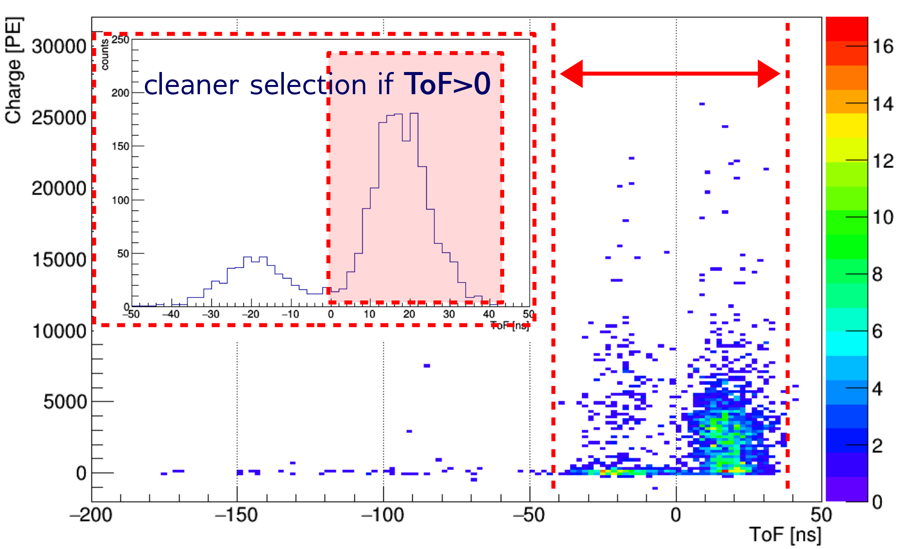
1. CRT-DAQ match
CRT-DAQ Match is true → the CRT event info is available through the Socket connection and it is matched with the PMT waveforms

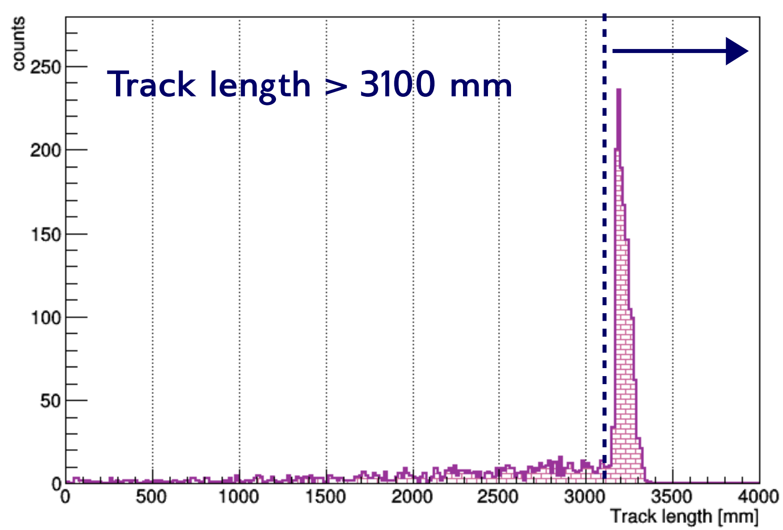
2. CRT-Reco
CRT-Reco is true → there is one hit per CRT plane, the track can be reconstructed unambiguously

3. PMTs saturation
PMT waveform does not saturate→ all the waveforms must be within the ADC dynamic range ([0, 4096] ADC or [0, 2]V)

4. FV flag
Excluding all reconstructed tracks passing outside the fiducial volume

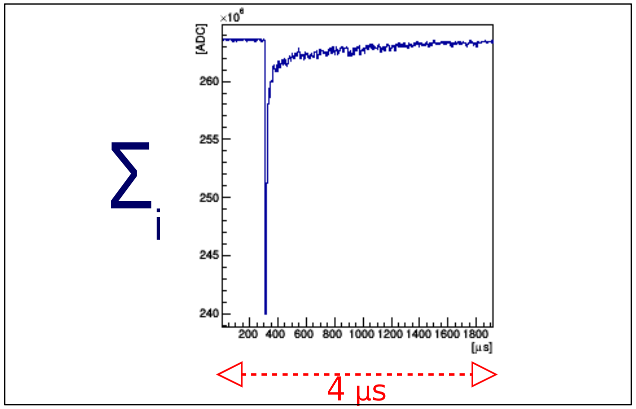
5. Cleanest sample
Top-bottom diagonal reconstructed tracks crossing completely the FV

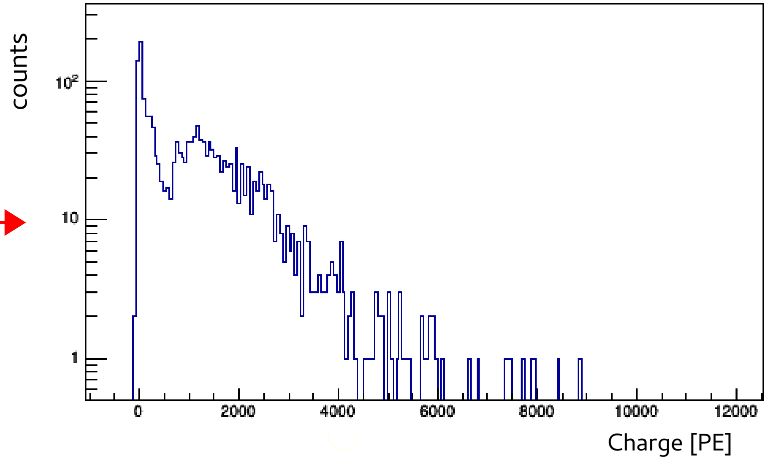




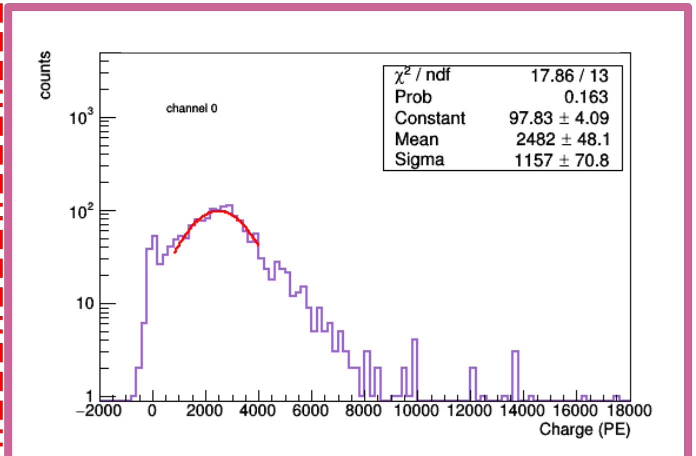
Observable

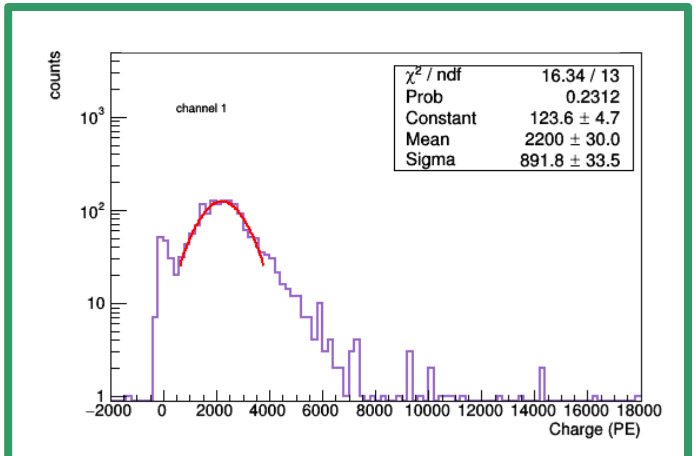
Charge spectrum (in photo-electrons – PE) of μ-events is the observable we looked at in the data analysis to compare with MC simulation.

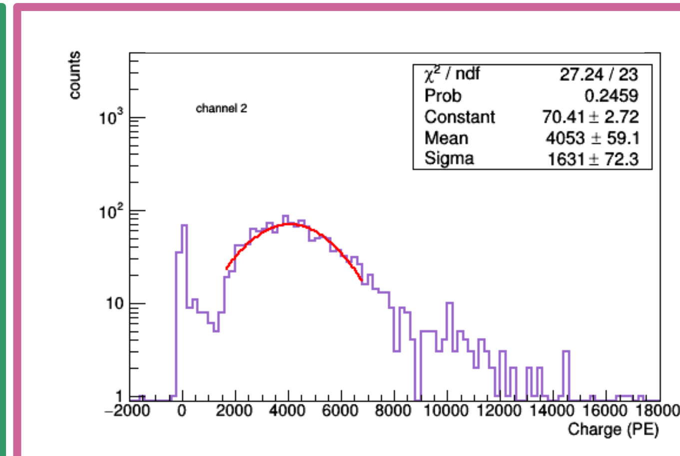


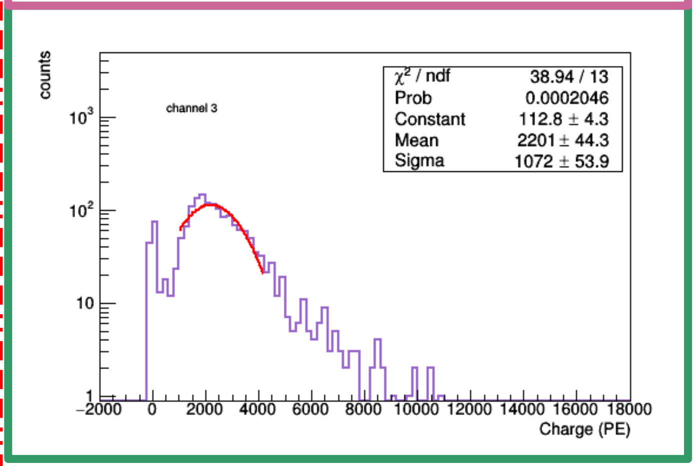


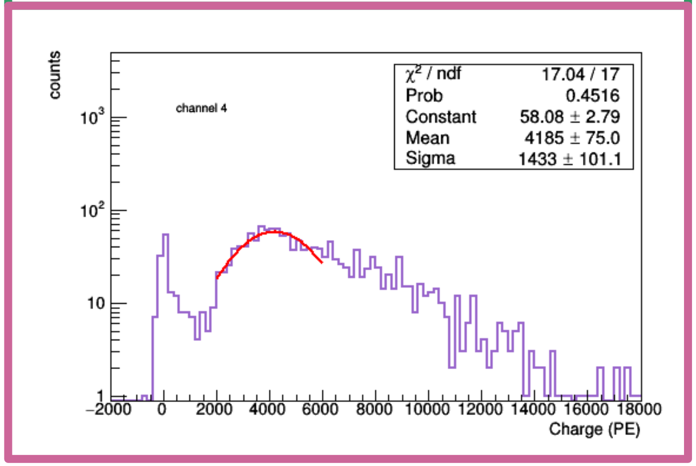
Diagonal μ-events crossing completely the FV











gaussian fit of peak position [PE]
(preliminary)

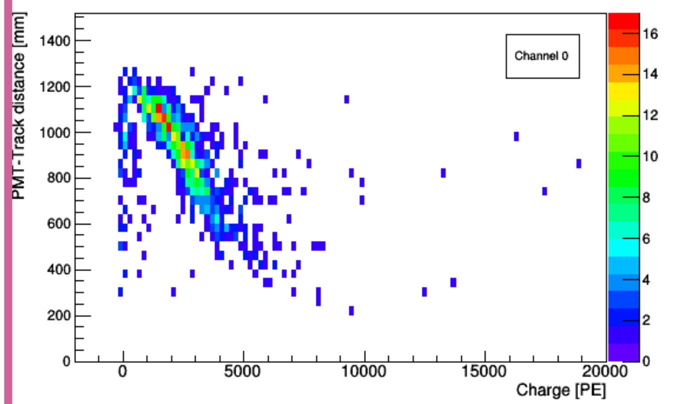
Ch0	Ch1	Ch2	Ch3	Ch4
2482 ± 48	2200 ± 30	4059 ± 59	2201 ± 44	4185 ± 75

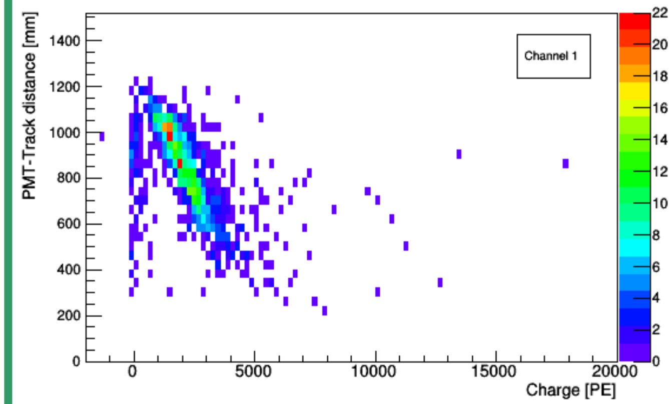
- Two charge contributions:
  - → events with ~ 0 charge (fake reconstructed tracks, due to CRT strips noise + bundle muons)
  - → real μ-events, mainly diagonal tracks crossing completely the FV

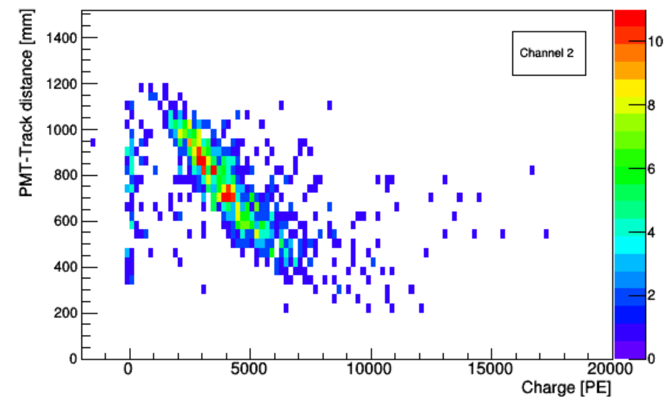
- peak position in Ch1 and Ch3 is similar and lower than the others (both PMTs use the TPB plate)

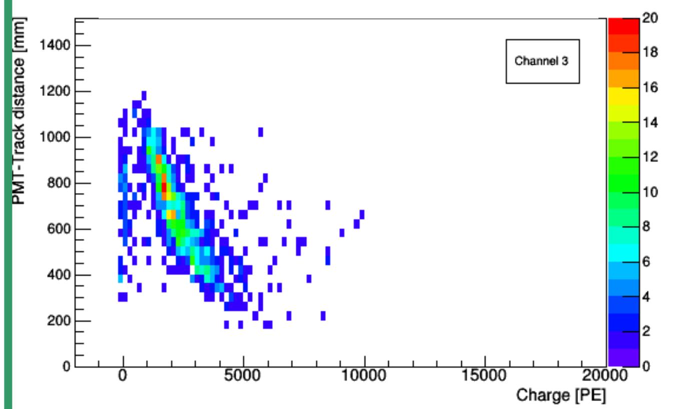
- peak position in Ch0, Ch2 and Ch4 is different and in agreement with CRT shifted geometry (Ch0, PMT farthest from crossing tracks)

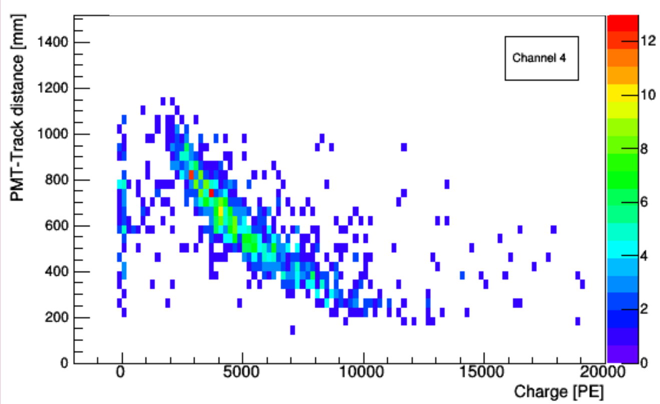
Low charge events







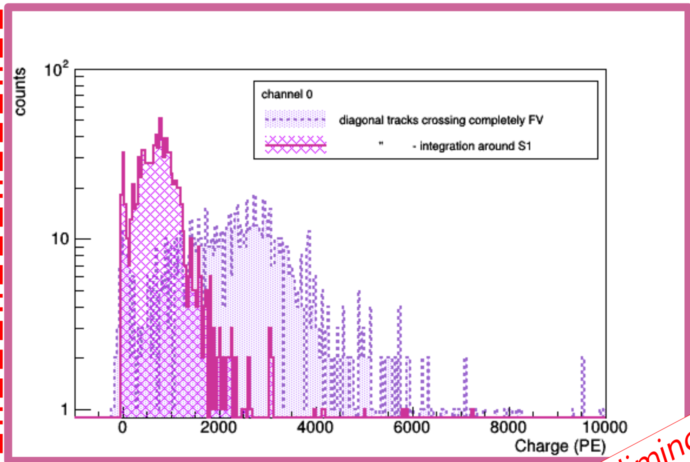


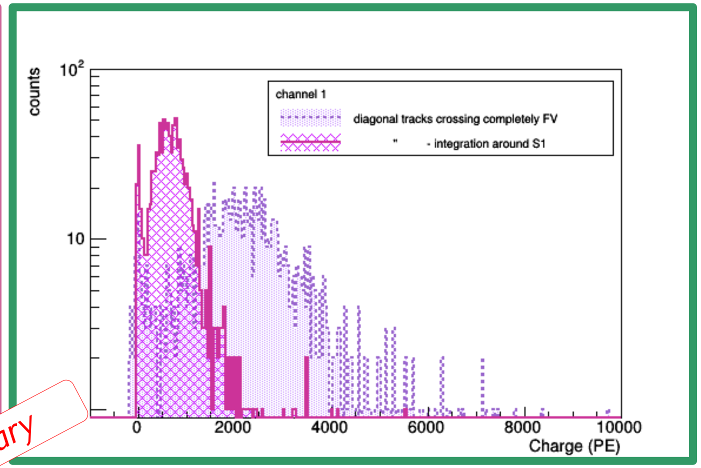


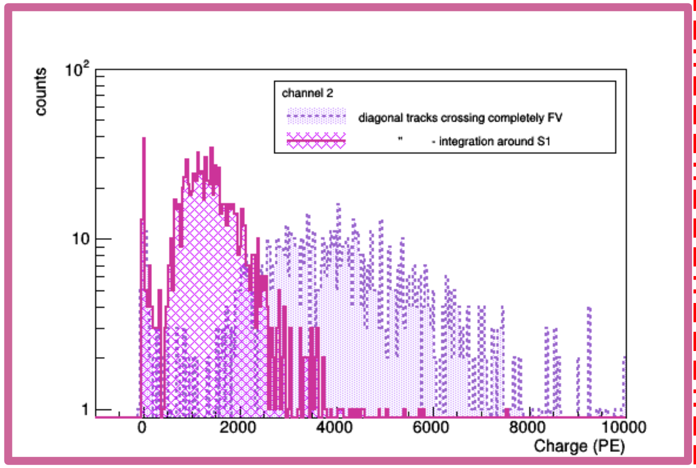
Two topologies of events:
- μ-events whose charge decrease as a function of the track-PMT distance

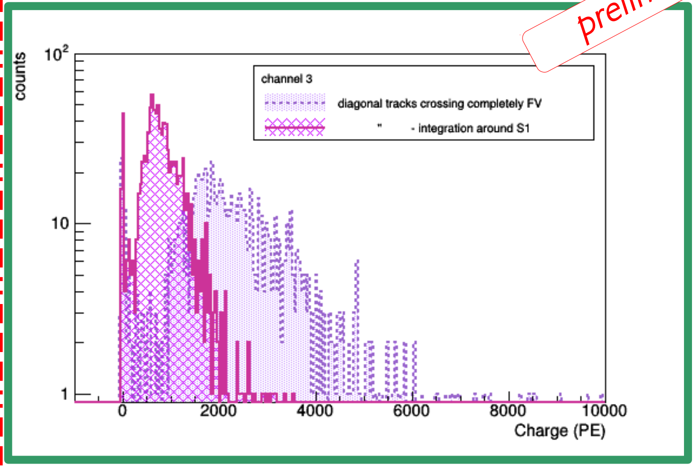
- events with 0 charge does not show any correlation with the distance to the PMTs
  → not caused by S1 signal attenuation

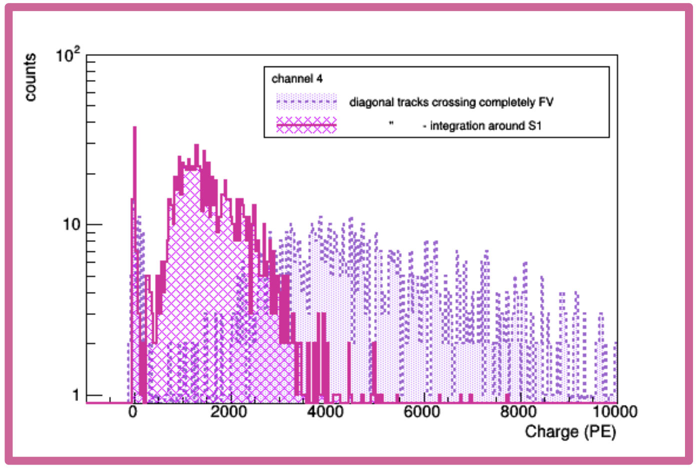
Integration around S1

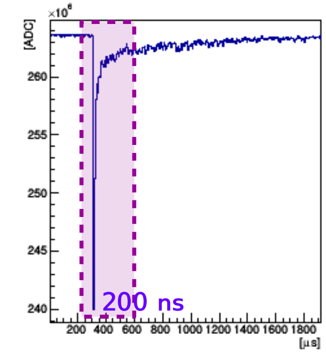










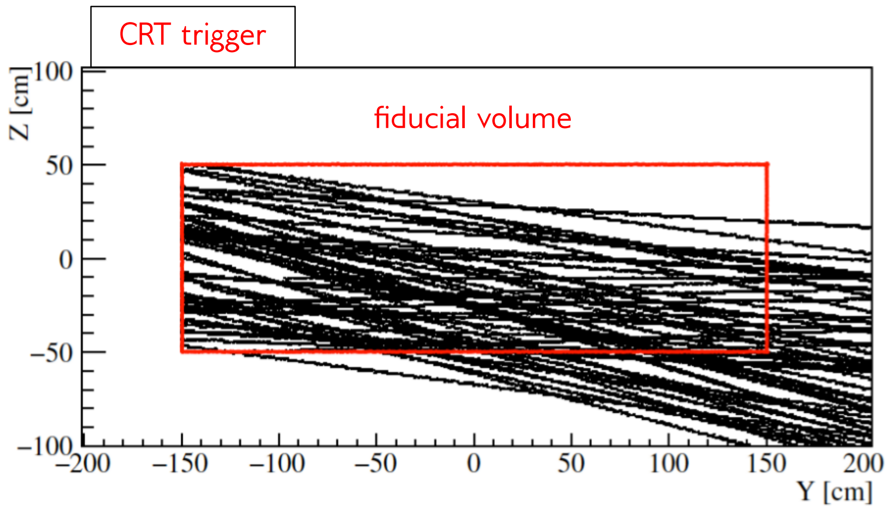


- Integration around S1 excludes events with negative charge (noisy waveforms)
  → peak at 0 is still present
  → next step: add a cut on the S1 signal amplitude (study on going)

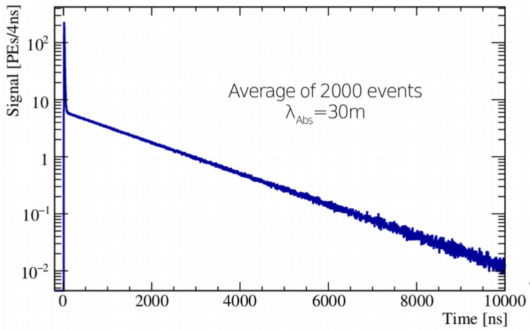
- peak position shifted on the left, since only the fast S1 component has been integrated

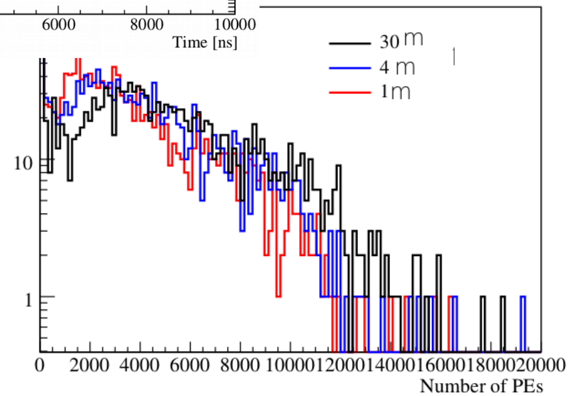
Comparison data/MC

- Implementation of the CRT trigger system
  → muons generated between two CRT planes mimic shifted geometry with energy in [2,4] GeV



- n. of PE collected obtained from light propagation simulated using pre-calculated light maps present in QScan

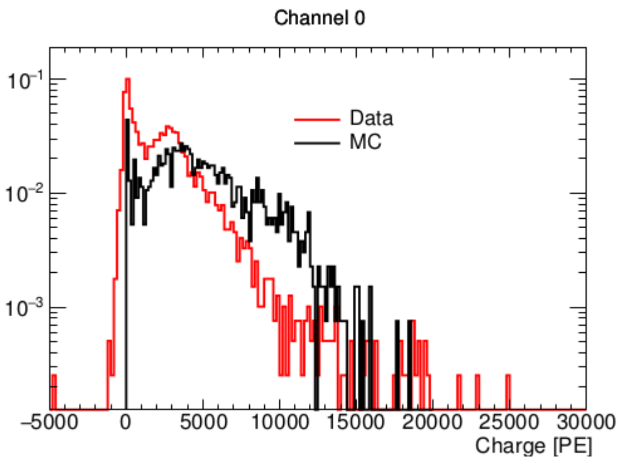


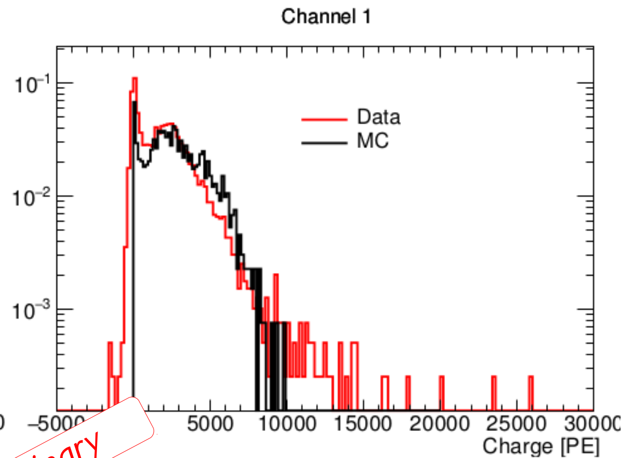


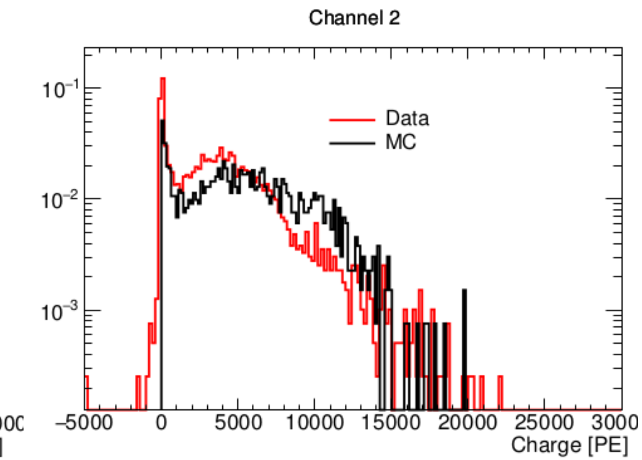
included in the simulation	not included in the simulation
TPB coating	PMT response
loss due to isotropic re-emission (50%)	integration of single waveforms (average waveform in 1ms time window)
absorption and Rayleight scattering	tuned absorption length (λ_{abs} = 30m)
PMT quantum efficiency = 20%	

Comparison data/MC

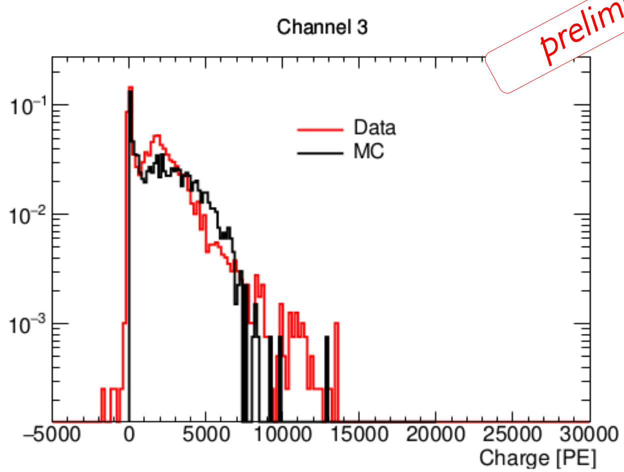
- Preliminary comparison between data and MC considering all tracks crossing the FV (cut on the track length not included in this comparison)

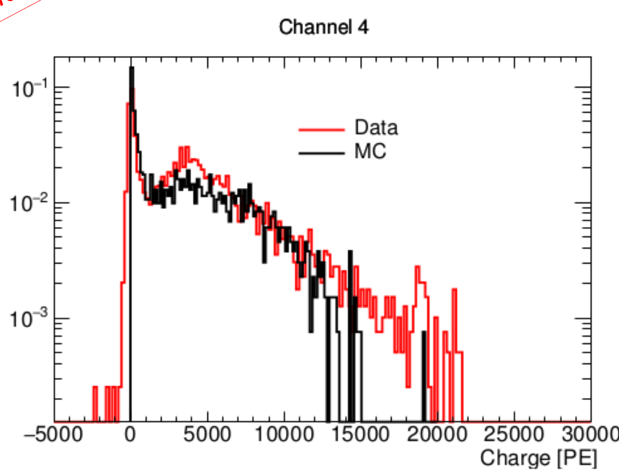






preliminary



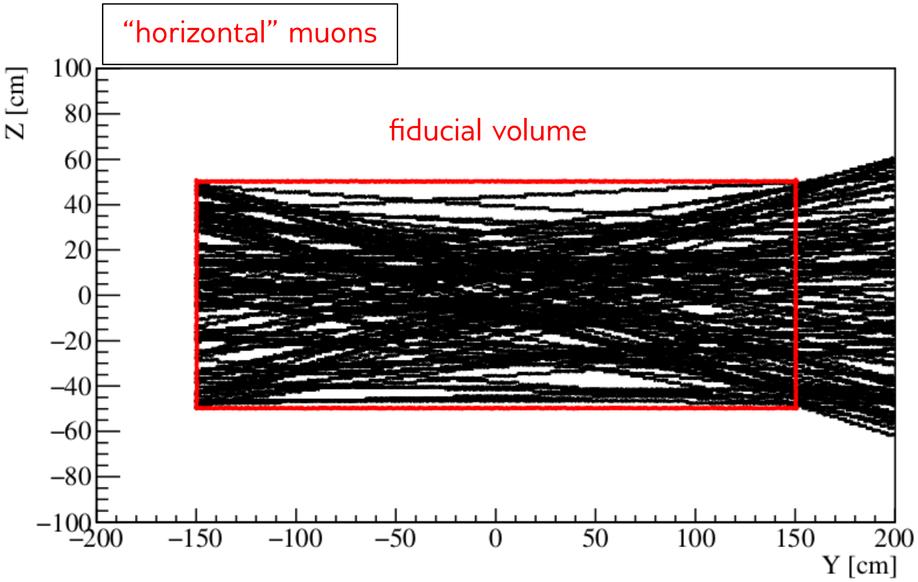


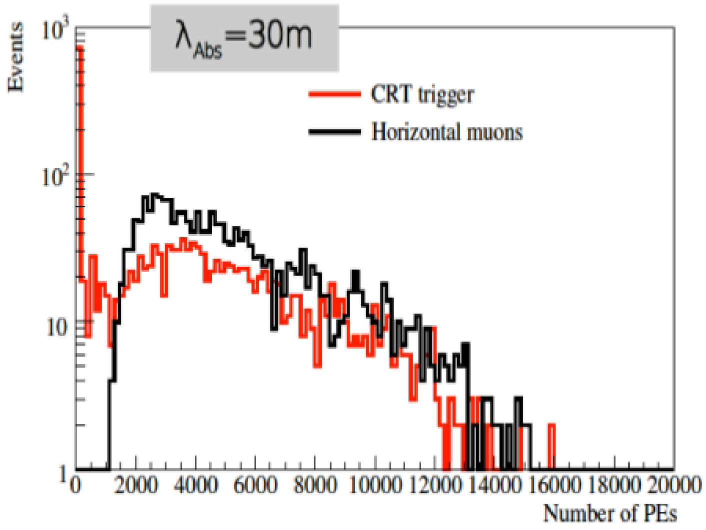
	Ch0	Ch1	Ch2	Ch3	Ch4
data	2482 ± 48	2200 ± 30	4059 ± 59	2201 ± 44	3812 ± 95
MC	3869 ± 357	2341 ± 165	4813 ± 357	2163 ± 261	3654 ± 281

- Ch1 and Ch3 see lower charge, in agreement with data (TPB plate)
- collected charge by Ch4 w.r.t. Ch0, Ch2 is different in data and MC (it could be due to that λ_{abs} MC > λ_{abs} data)

Comparison data/MC

- Implementation of the CRT trigger system
  → muons generated with energy in [2,4] GeV mimic CRT parallel geometry





- "Horizontal" muons selection in runs with CRT shifted not conclusive due to low statistics
  → to do: analyze data taken with CRT in parallel geometry

First conclusions

- μ-events triggered by CRT panels in shifted geometry without drift/extraction/amplification fields have been studied

  → S1 signal from muons crossing the fiducial volume is detected by the PMTs

- The charge corresponding to S1 is measured to be ~2200-4200 PE depending on the PMT

- A small fraction of μ-like events triggered by the CRTs remain undetected (Q<200 PE)

On going studies

- reject fake tracks and/or fake coincidence applying a threshold on the S1 signal amplitude

  → equivalent to a posteriori cut on the charge spectrum

Next steps

- implement in the MC same cuts as in data (FV, etc..)

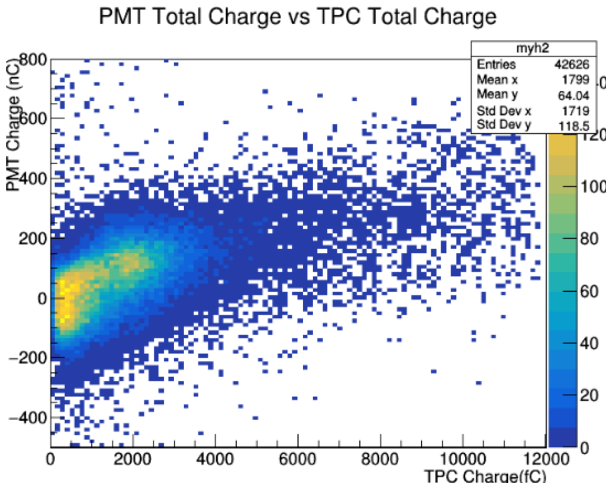
- improvement of the MC simulation to include PMT response, background and noise

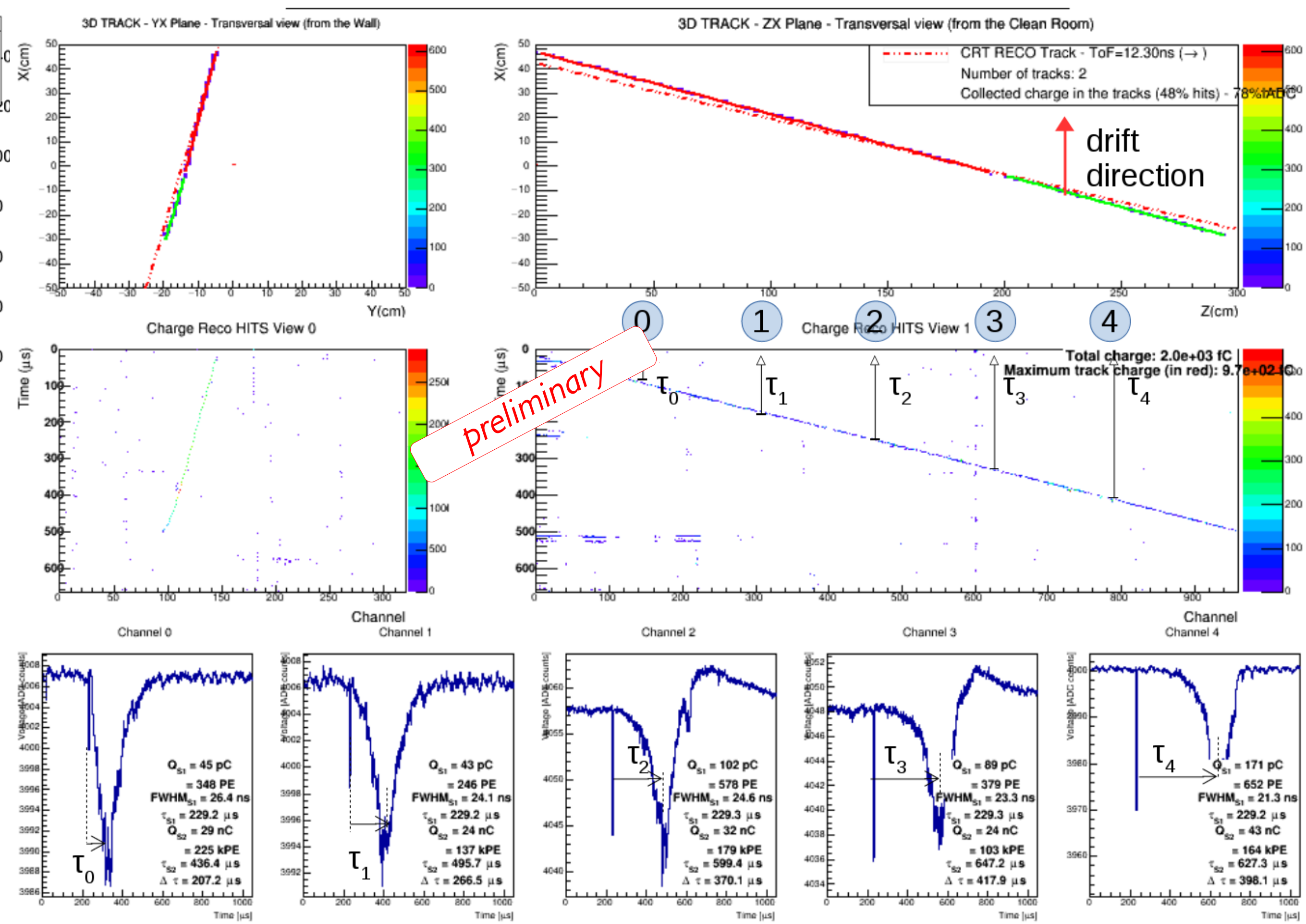
- tuning of the MC parameters (e.g. absorption length) to improve data simulation and to extrapolate 3x1x1 results to the 6x6x6

- study runs taken with CRTs in parallel position to compare them with MC

- add S2 studies and run with PMT trigger

Charge-Light correlation





- positive correlation between the quantity of light and the collected charge

- tracks reconstructed with LArSoft

→ track reconstruction in good agreement with drift time as a function of the charge position

Conclusions

- 3x1x1 light data has been collected in different detector configuration and using three trigger typologies:
  → S1 signal only, S1 and S2 signals
  → CRT trigger (parallel and shifted geometries), PMT trigger, random trigger

- PMT calibration has been performed and compared with RT calibration done before PMT installation
  → some PMT have lower gain at RT than at CT (not understood)
  → different gain values in two calibration done

- 3x1x1 light data with only S1 signal has been studied with CRT trigger in shifted geometry
  → good reconstruction of tracks crossing the FV has been obtained
  → charge spectrum of reconstructed tracks crossing completely the FV has been studied
    - identified two topologies of events: ° μ-like events whose charge collected decrease as a function of track-PMT distance
      ° very low charge events caused by fake tracks or fake coincidence
    - improvement in events selection considering integration around S1 signal and excluding events with short S1 amplitude is on going
  - a preliminary comparison with MC has been done
    – improvement on the MC simulation is expected
  - study of data taken with CRT in parallel geometry is on going
  → a preliminary study of data with both S1 and S2 signal has been done
    - preliminary correlation of light with charge data has been done
    - a deeper study of charge-light combination is expected

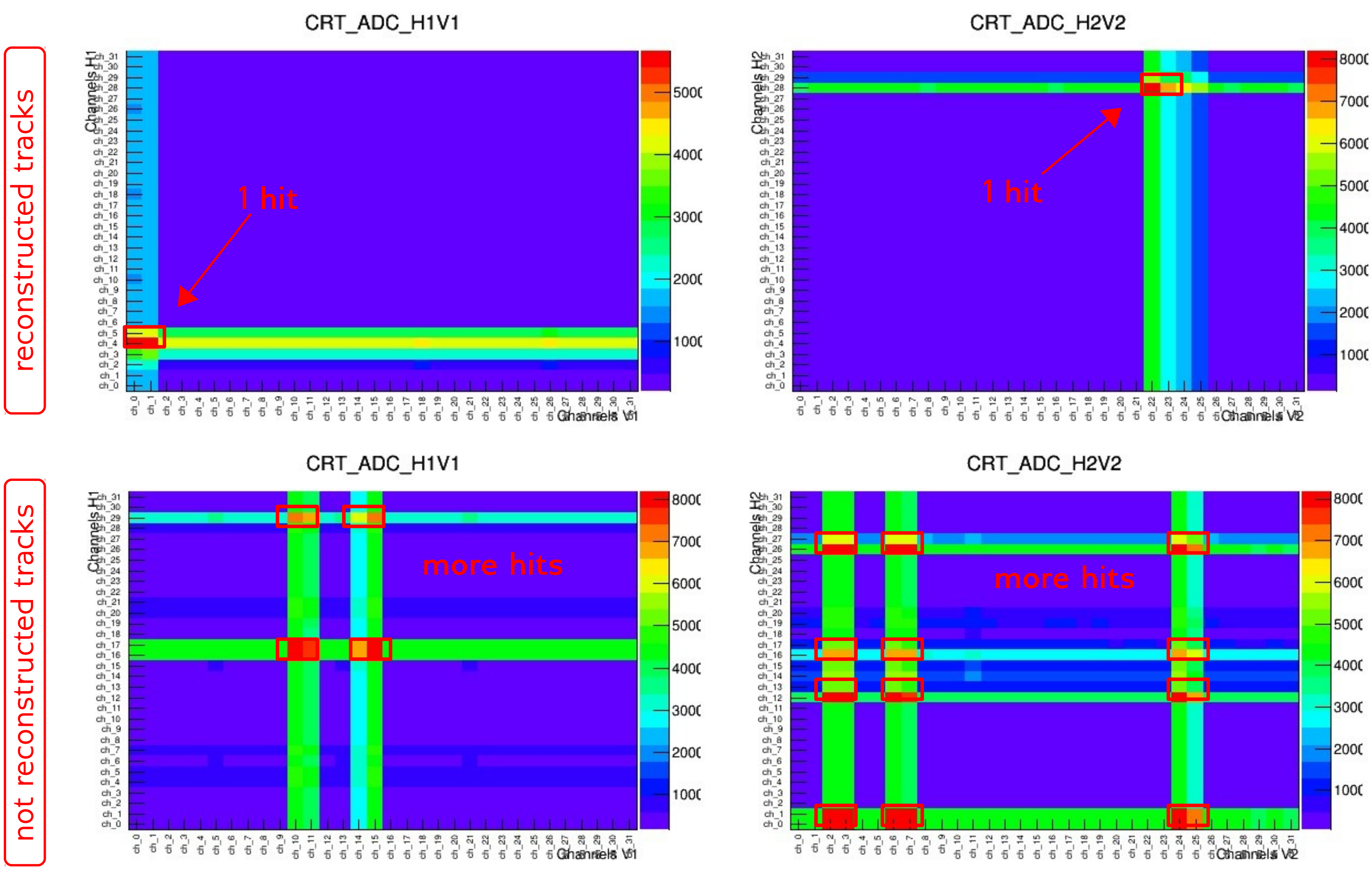
..thanks a lot for your attention!

Bkp

CRT reconstruction

“Reconstructed” track

Event which corresponds to a track crossing the CRT panels and creates only one hit (*) per pair-panels is a reconstructed track



(*) ADC value must be over 500 ADC counts (Pedestal) and under 4080 ADC counts (not saturated)

CRT trigger

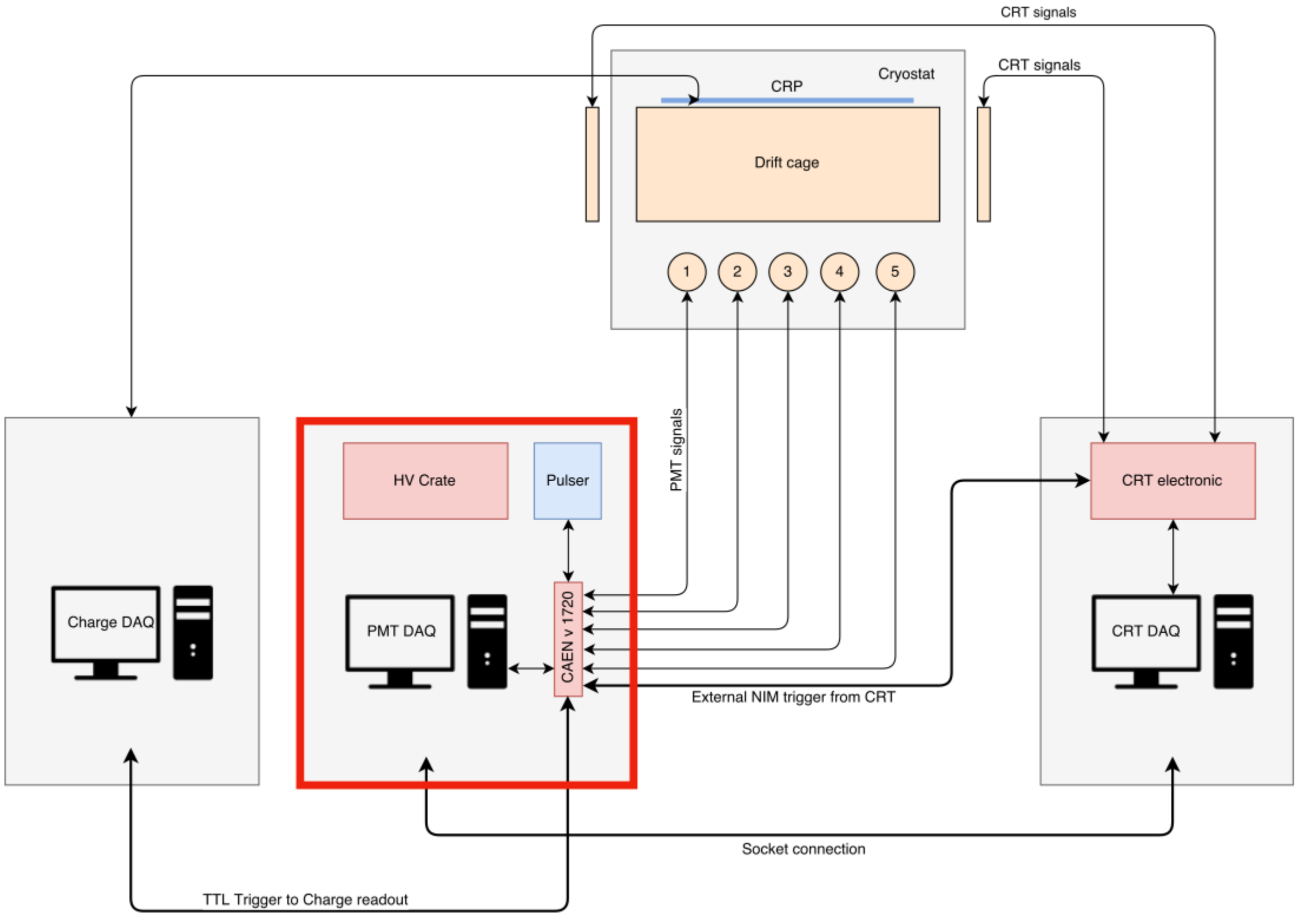
CRT trigger is created upon 4-fold coincidence among the 4 CRT panels (at least one hit per panel).

CRT-DAQ publishes the event information on a ZMQ server.

PMTs are read-out upon receiving the external trigger from the CRTs.

PMT-DAQ query the ZMQ server to retrieve the event which generated the trigger.

Matching is done using the TimeStamp of PMT and CRT DAQs. It has a resolution of the ms. CRT and PMT DAQs are not synchronized.



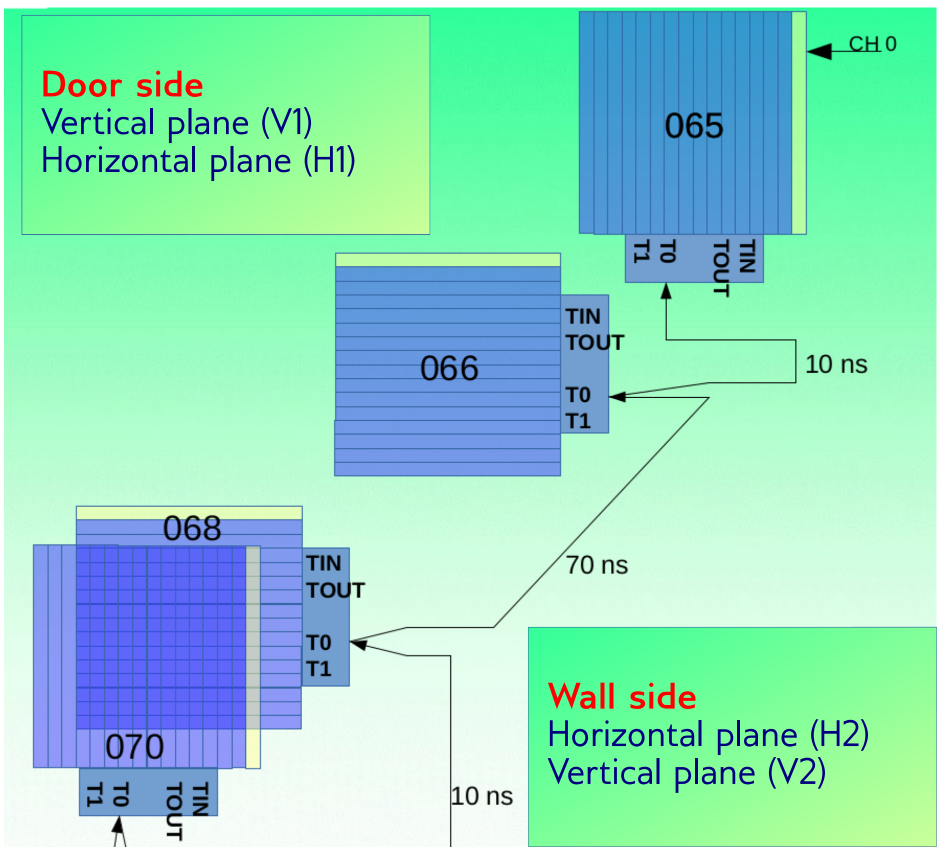
CRT trigger

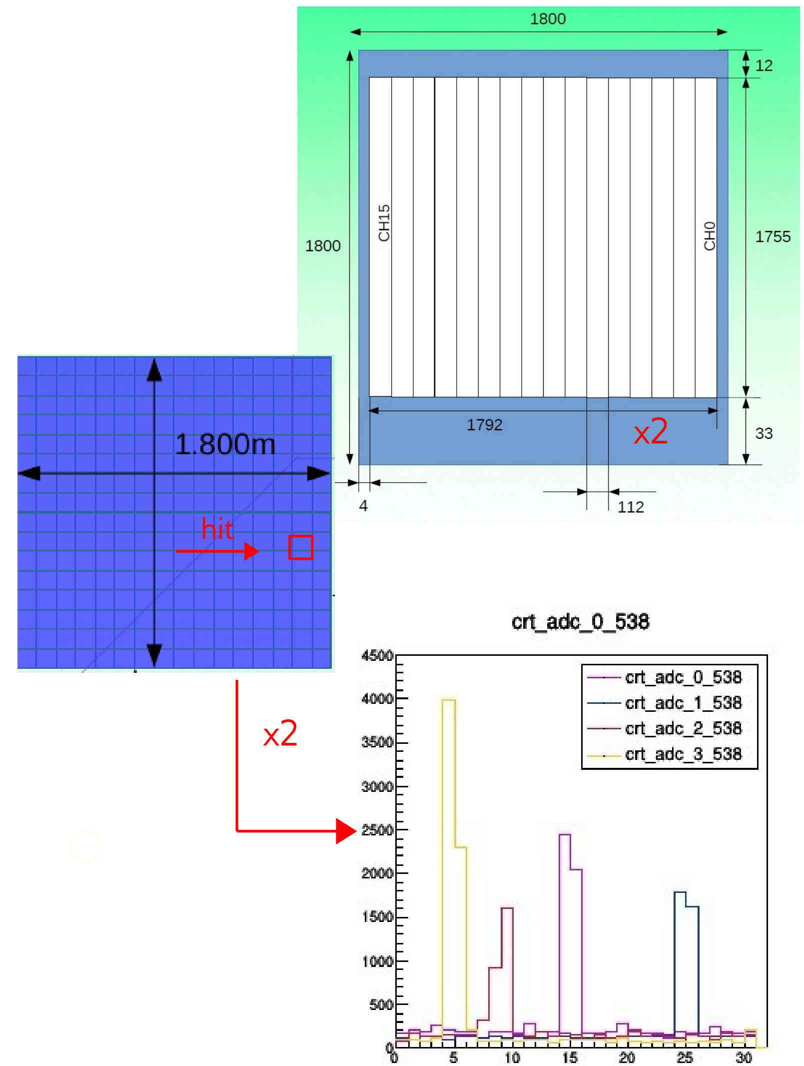
Cosmic Rays Taggers (CRT) → 4 modules of scintillators made by 16 strips per module (1.8m x 1.8m)

- each strip is read by 2 optical fibers connected to 2 SiPMs

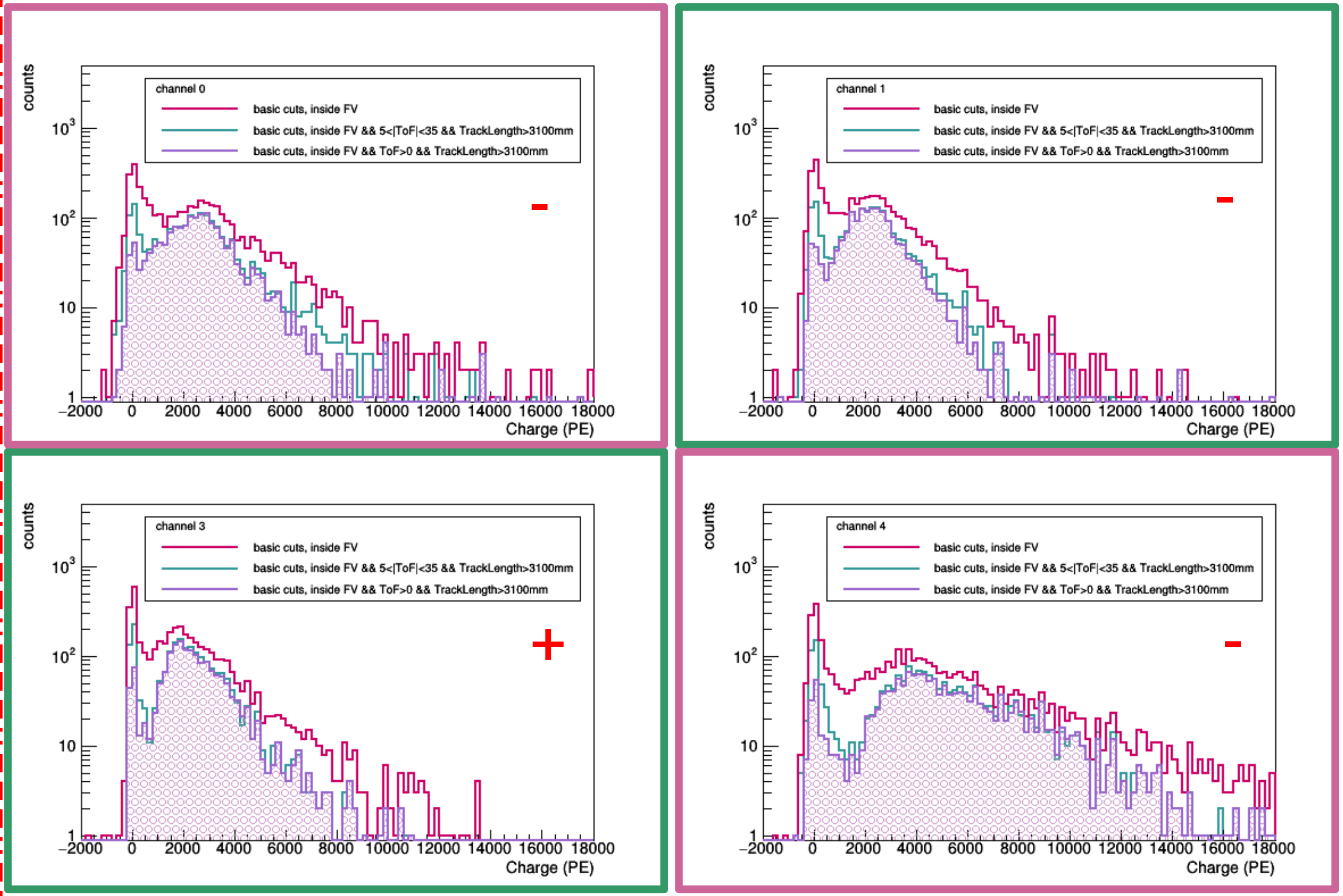
→ 2 panels per side with horizontal and vertical strips

- matrix (256 hits) per side





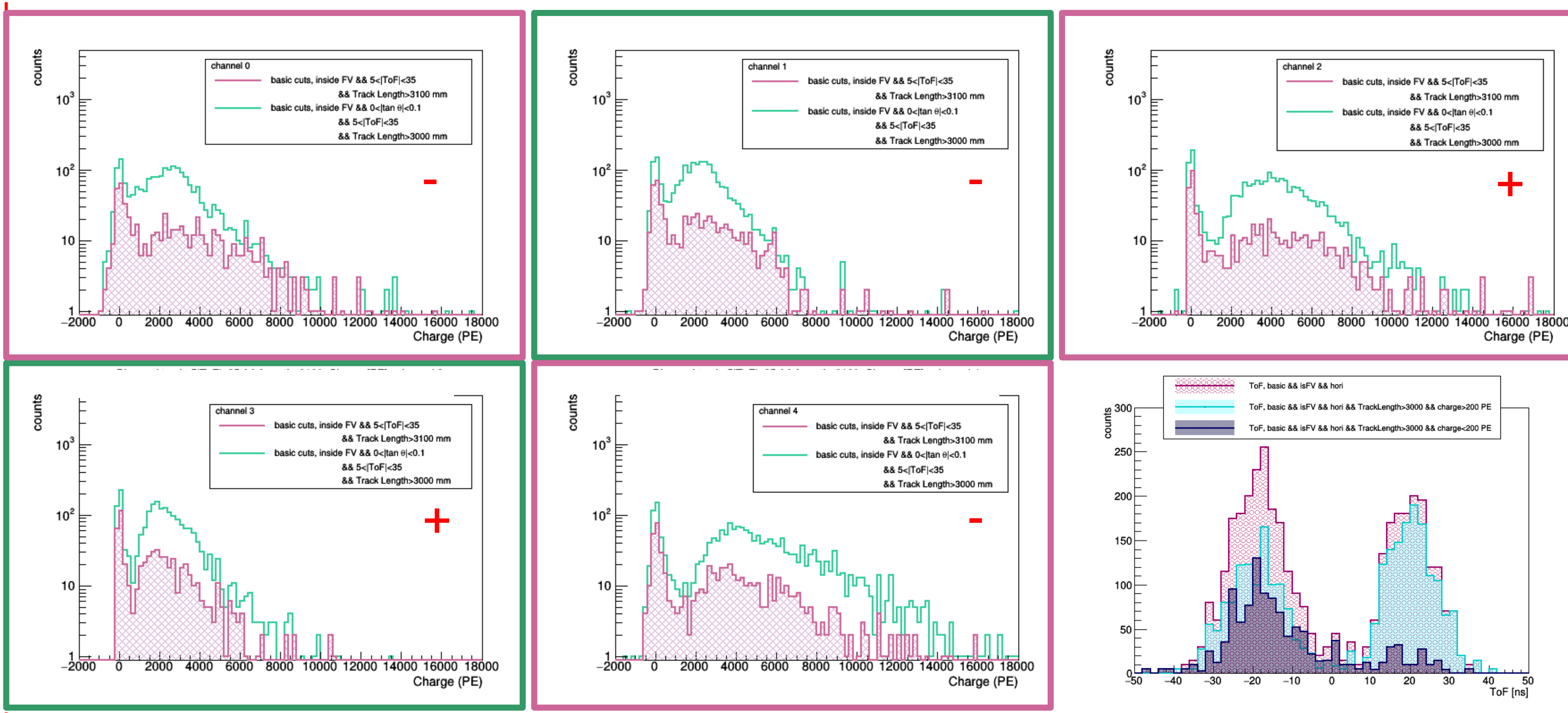
Charge spectrum [PE]



- μ-events selection is improved requiring track length > 3100 mm inside the FV

- inside the FV, there are two charge contributions:
  - → "shoulder", events with ~ 0 charge (noise, recognized as "fake reconstructed tracks" + real low charge events – *still under study*), most of them has ToF<0
  - → "bump", mainly diagonal tracks corresponding to μ-events crossing completely the FV

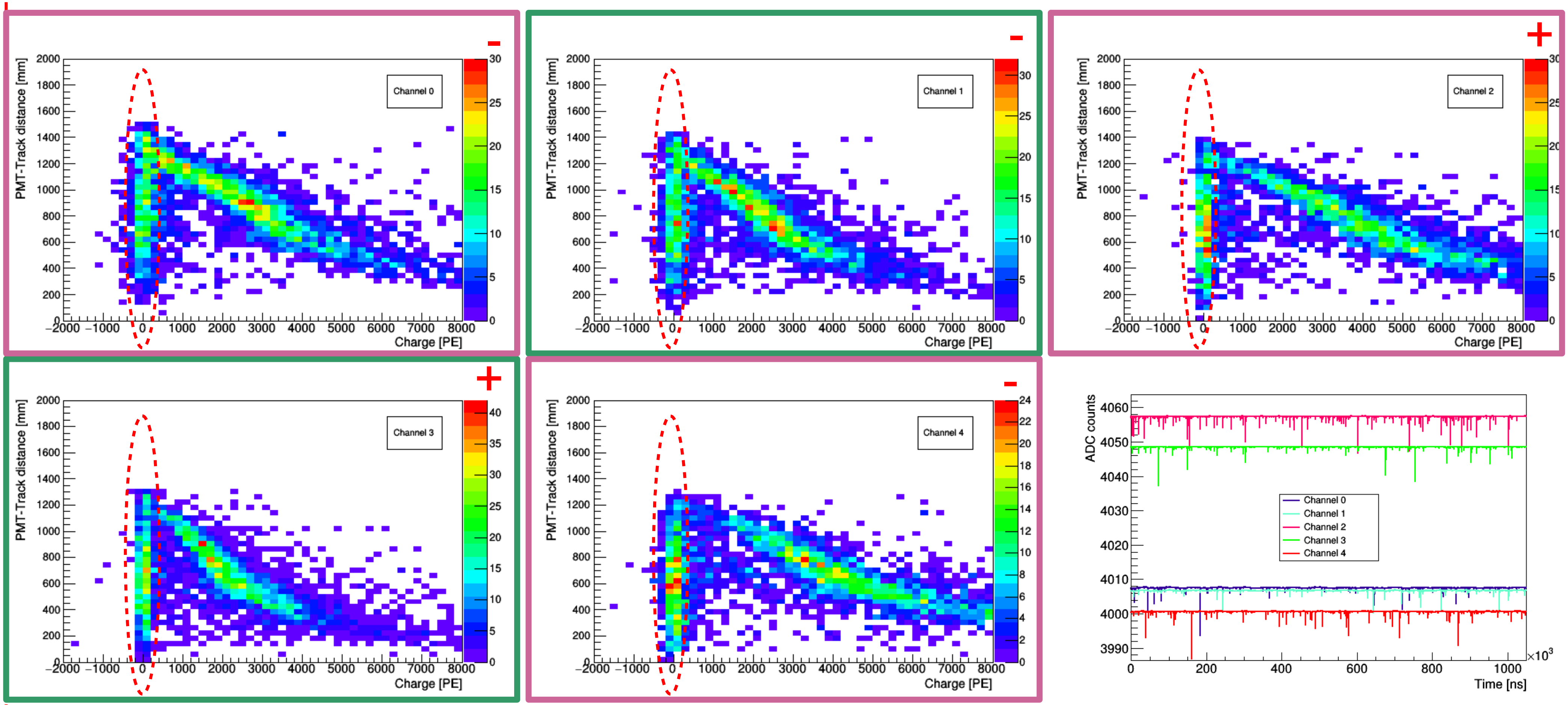
Horizontal μ-events in the “bump” region



- horizontal tracks inside the FV has been selected considering a maximum track inclination ~6°
  → charge spectrum shape and “bump” peak position almost unchanged
  → low statistics in CRT shifted geometry

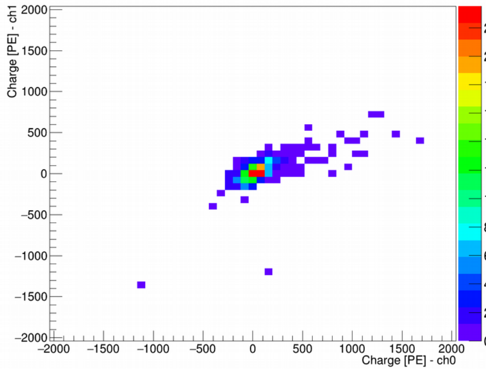
- most of the events with low charge have negative ToF

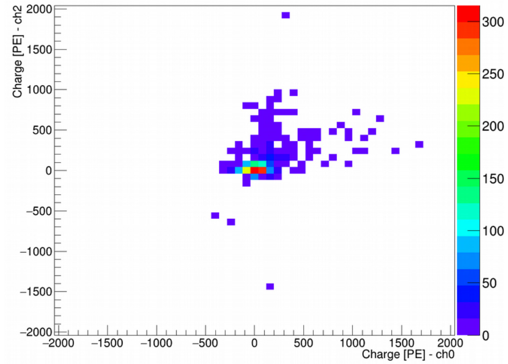
Low charge events

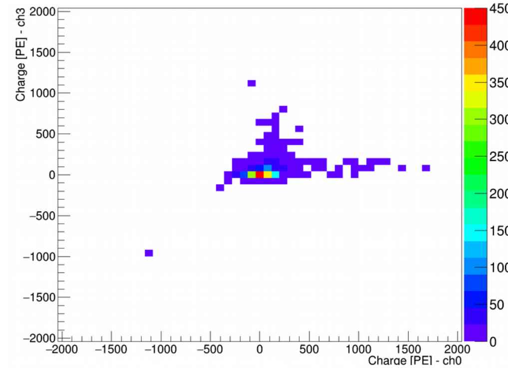


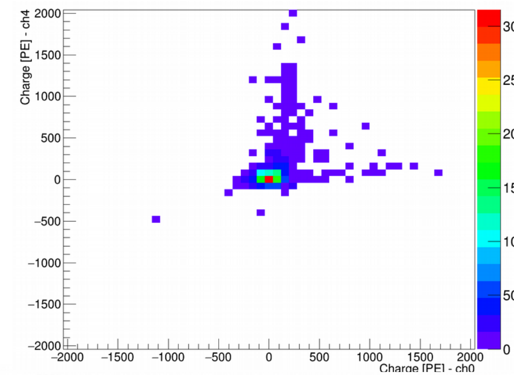
- no correlation with the distance to the PMTs → not caused by S1 signal attenuation

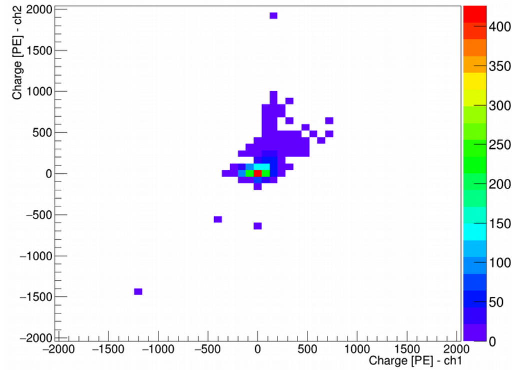
Low charge events

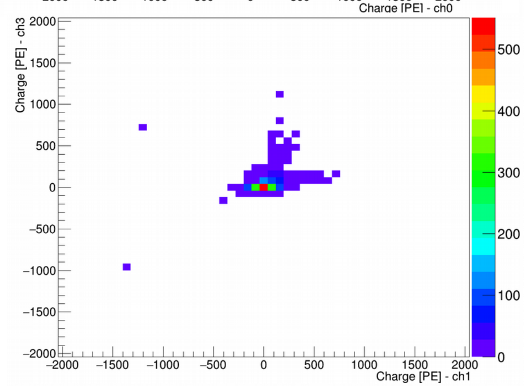


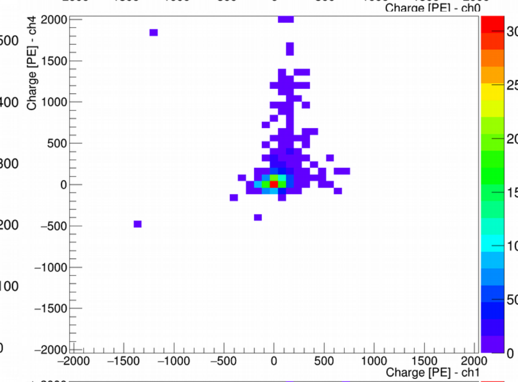


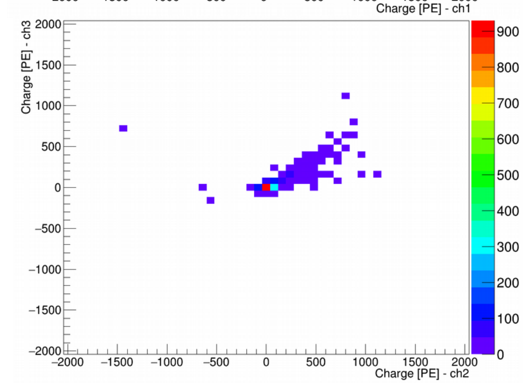


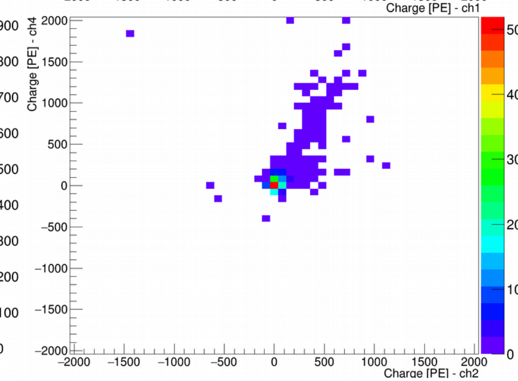


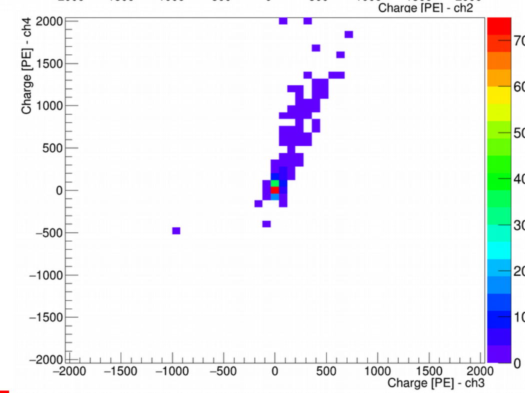












- Charge correlation among PMTs for events with Q_i<200 PEs

  → most of the times, all the PMTs see low charge

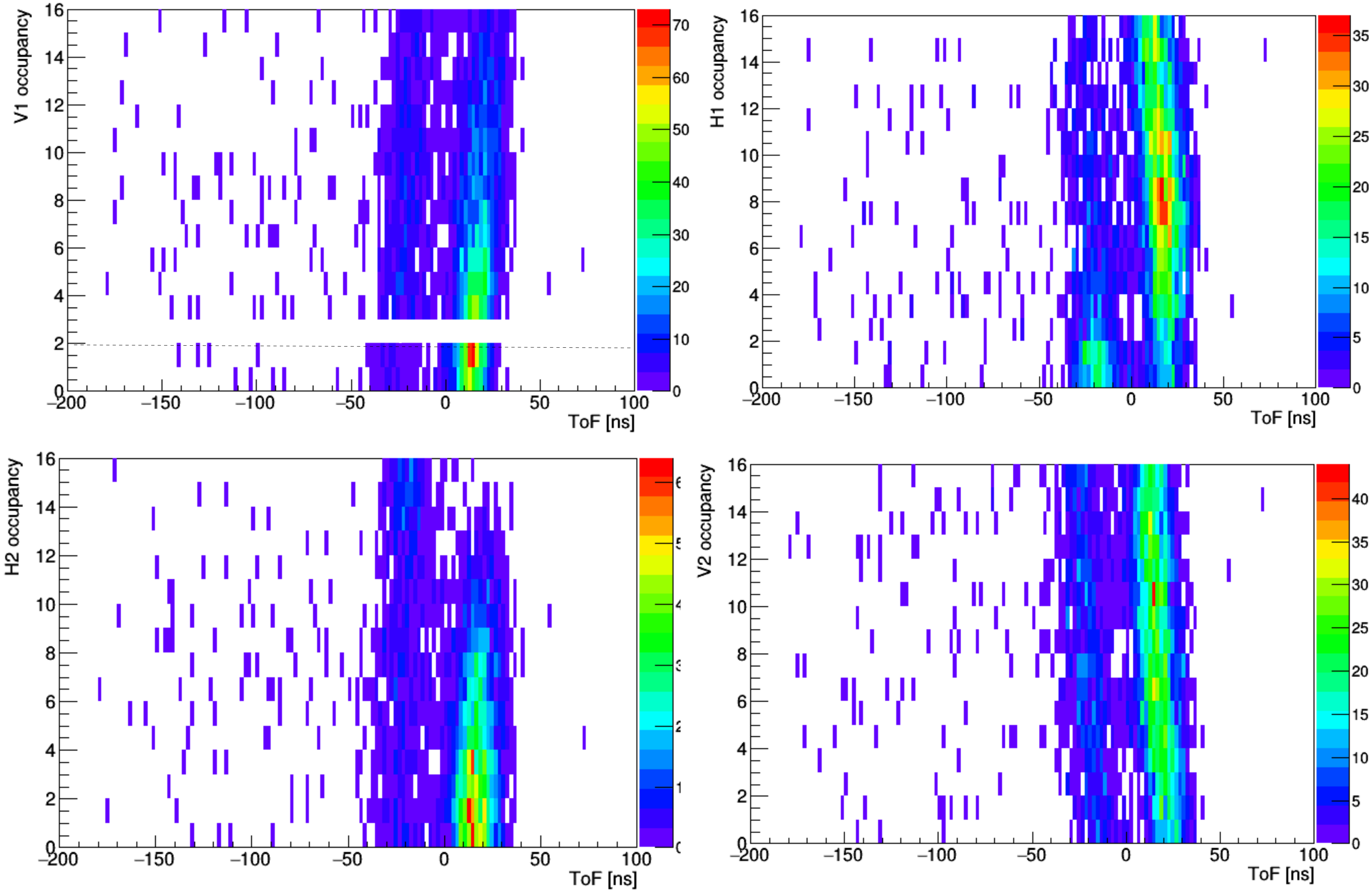
Note: the requirement on charge is verified when at least one of the PMTs satisfies this condition

Low charge events

ToF -vs- occupancy distribution per CRT panel

door side
(-90 cm)

wall side
(+15 cm)



- H1 occupancy have two excess, one if ToF>0 && one if ToF<0

→ due to the CRT shifted geometry, ToF>0 excess ↔ diagonal tracks

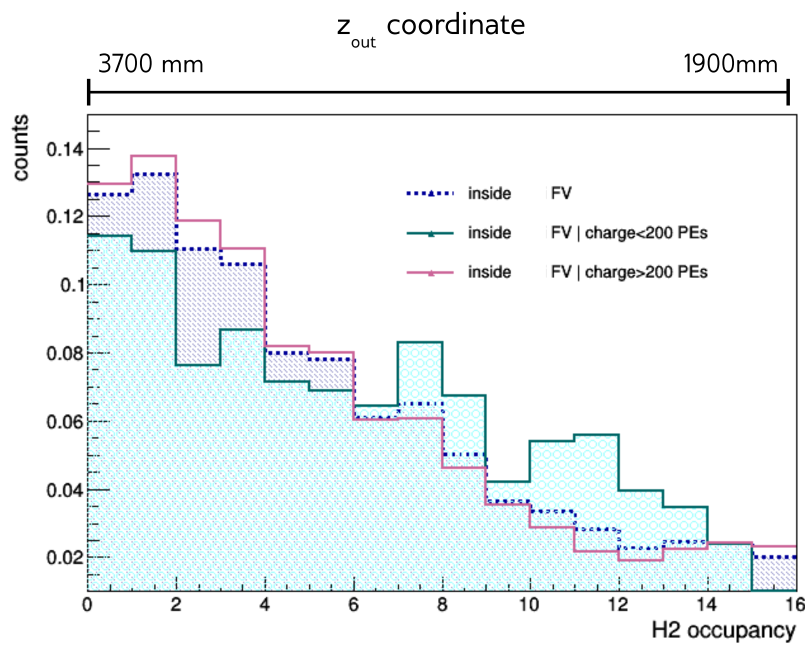
vs

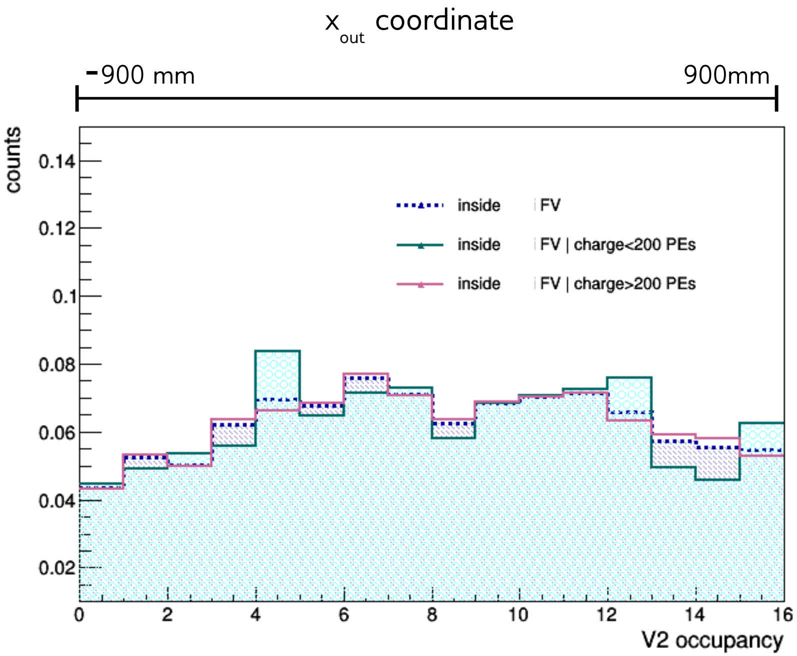
ToF>0 excess ↔ horizontal tracks

Low charge events

Occupancy = n. of events hitting each CRT strip (per panel), drawn normalized to the n. of entries

wall side
(+15 cm)



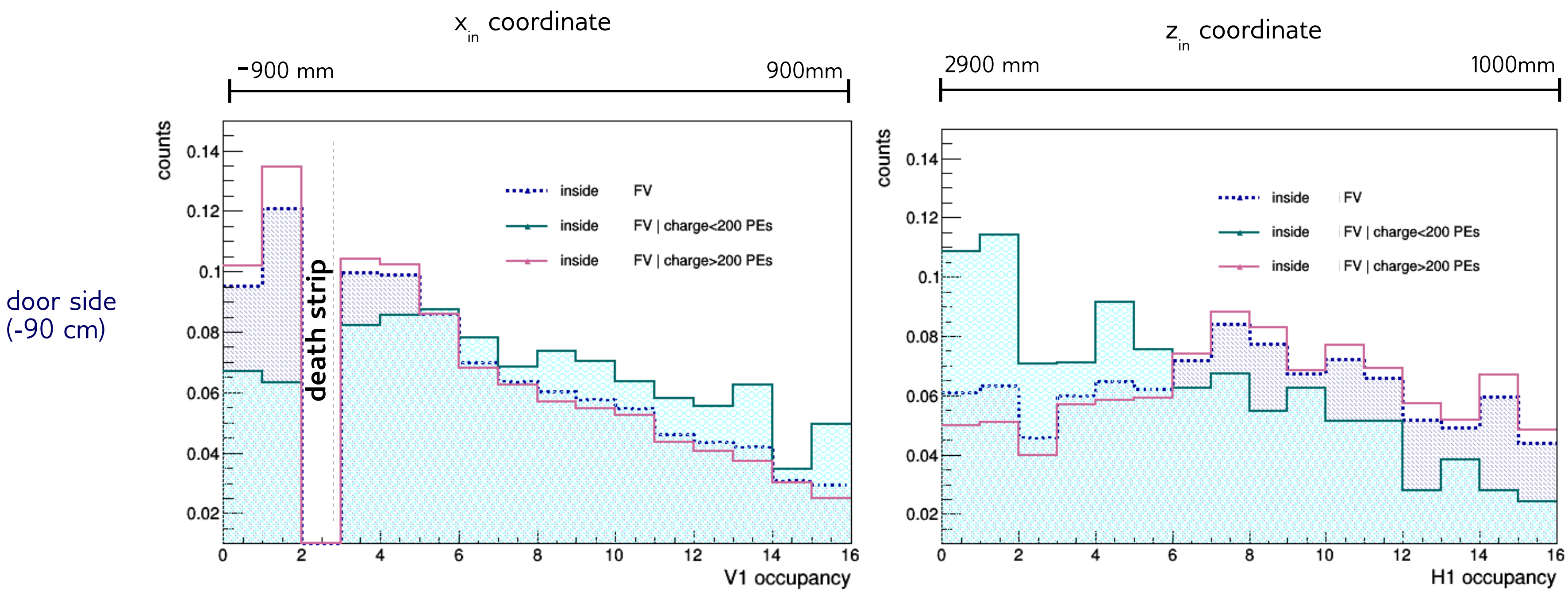


Particles entering from "wall" side will correspond to ToF>0

- occupancy distribution in agreement with top-bottom diagonal tracks crossing the FV
- no differences between high and low charge events

Low charge events

Occupancy = n. of events hitting each CRT strip (per panel), drawn normalized to the n. of entries



Particles entering from “door” side will correspond to ToF<0

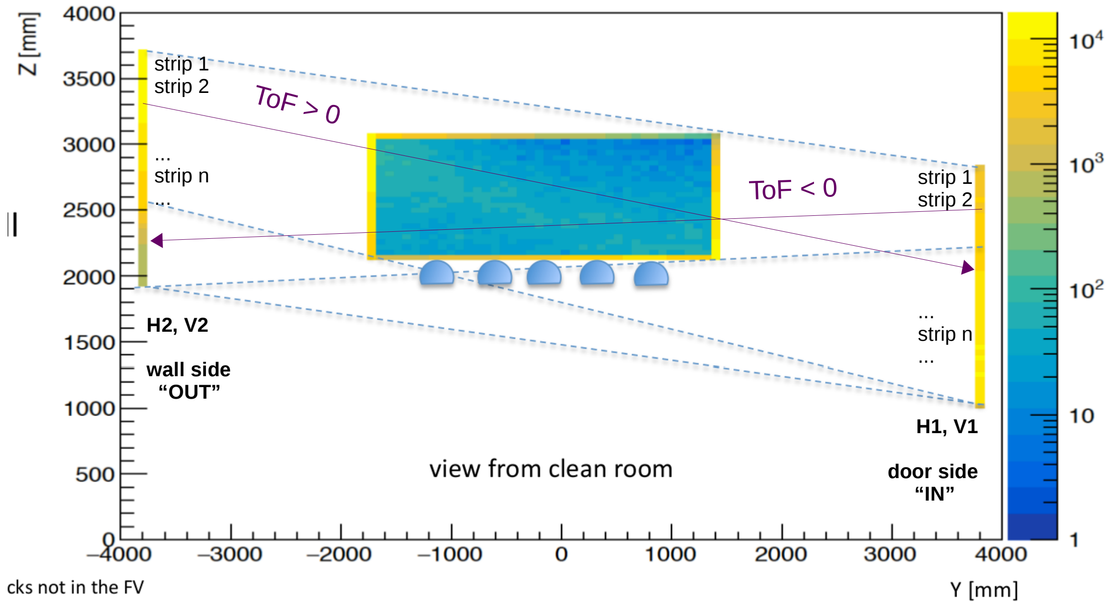
- for events with charge lower than 200 PEs there is an asymmetry in z, more events hitting top part of CRT (about double of the entries w.r.t. other strips)

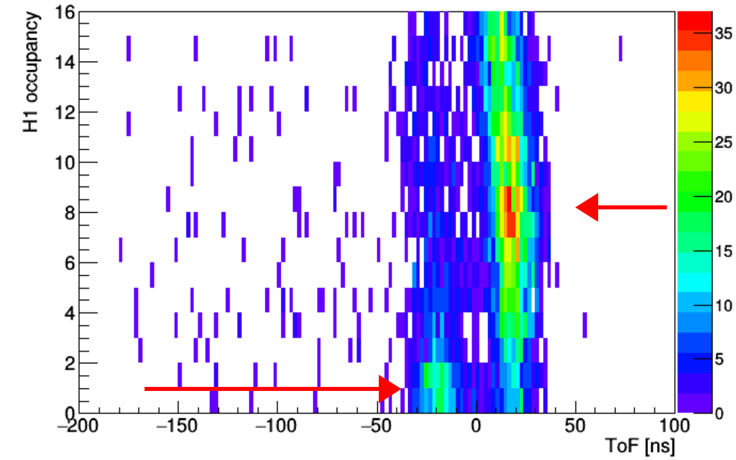
  → asymmetry inverted for events with higher charge

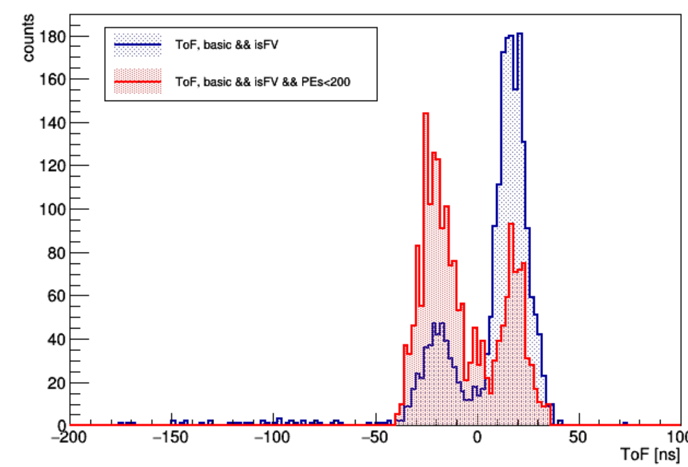
- asymmetry in x coordinate, more events with negative x coordinate

  → this asymmetry becomes less evident in events with low charge

Low charge events







OPTION 1: - Strip 1 and 2 are noisy strips

→ fake reconstructed tracks

OPTION 2: - Due to the CRT geometry, ToF<0 events should hit strips 1, 2 in H1 panel

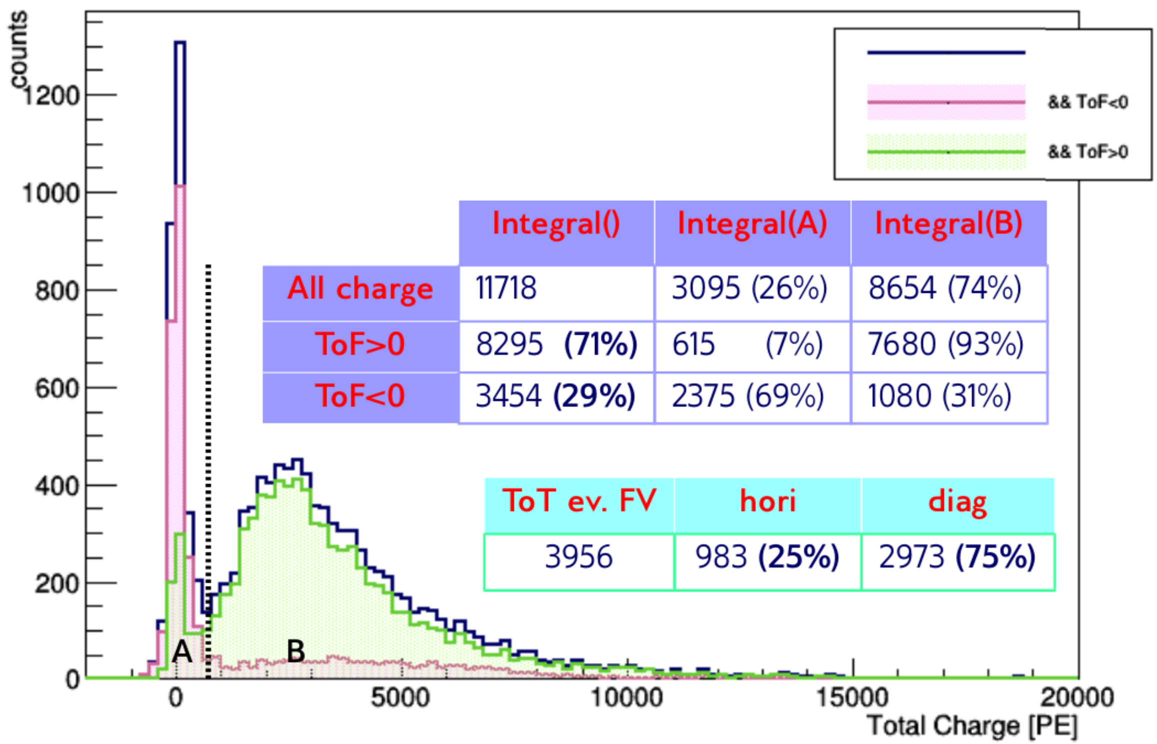
→ result compatible with real physics events ...why low energy events?

Study data taken with parallel CRT geometry could help the understanding of these features

Fraction of events with low charge

Total charge of all PMTs, distributions obtained if ToF<0 or ToF>0

→ ~7%, events with low charge for diagonal tracks completely crossing the FV

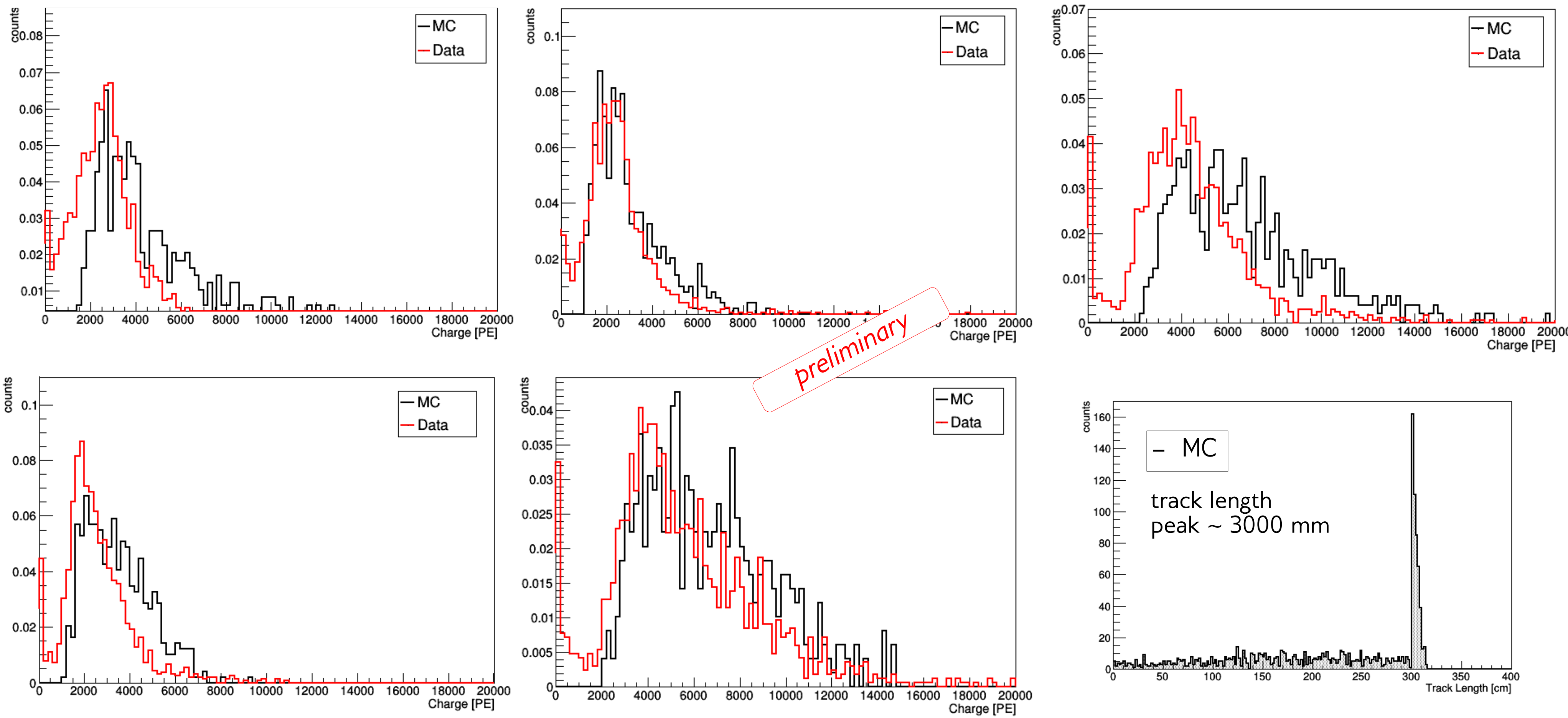


	Integral()	Integral(A)	Integral(B)
All charge	11718	3095 (26%)	8654 (74%)
ToF>0	8295 **(71%)**	615 (7%)	7680 (93%)
ToF<0	3454 **(29%)**	2375 (69%)	1080 (31%)

ToT ev. FV	hori	diag
3956	983 **(25%)**	2973 **(75%)**

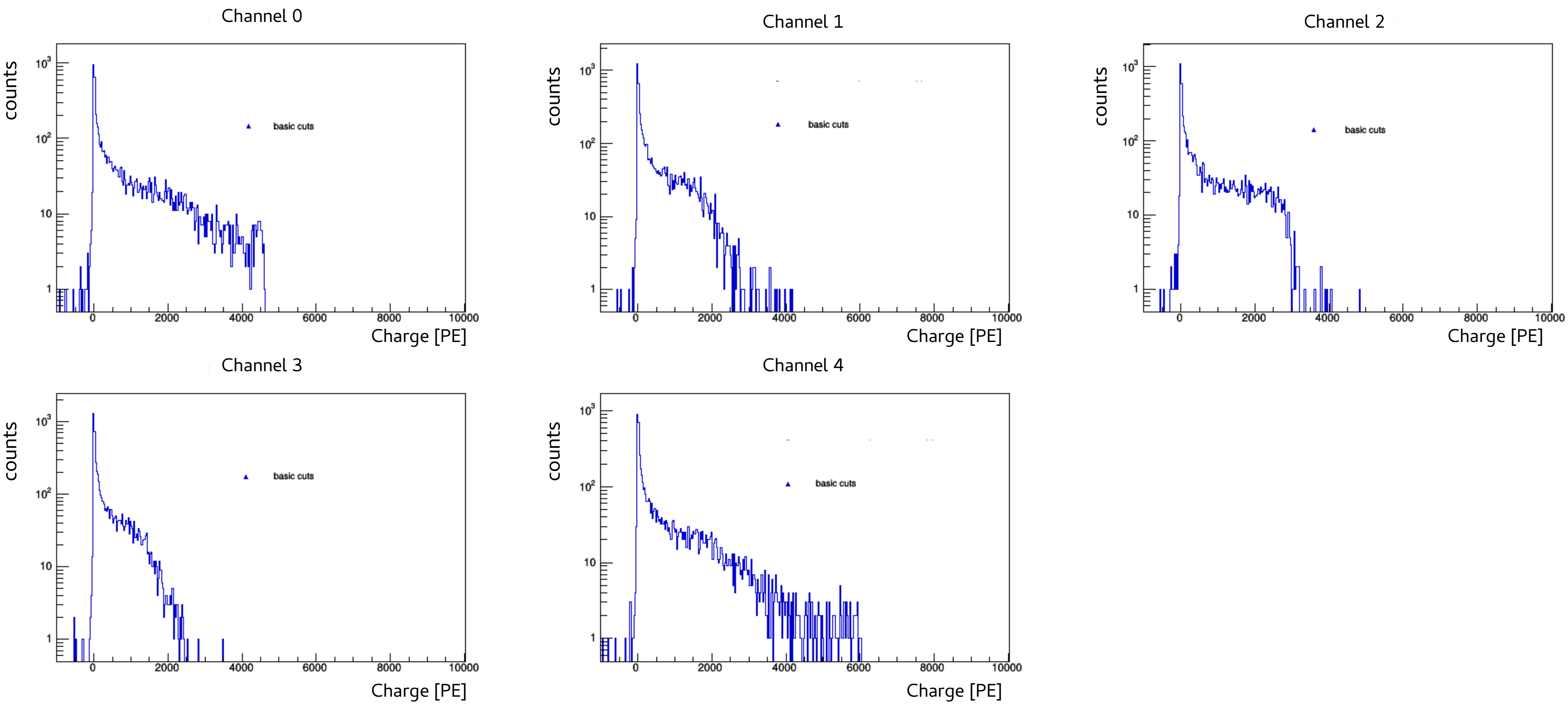
Comparison data/MC

- Preliminary comparison between data and MC considering tracks completely crossing the FV



- in MC events with low charge are only due to the short tracks not fully in the FV

Charge spectrum (PE units) – run n. 837, all channels



Independently from the channel, the physical “bump” is covered by “background-like” exponential contribution.