S1 and S2 Analysis with DPD reprocessed files and MC

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Interesting runs [more runs added!]

Charge runs	***Light runs***	***Trigger***	***Drift field***	***Extraction Field in liquid***	***Amplification Field***	***Induction Field***
986-987 988-989	1670	CRT	0.49	2.14	25	1
990-991 993-994	1671	CRT	0.48	2.14	25.5	1
996	1682	PMT	0.48	2.14	26	1
997-998 999	1683	PMT	0.48	2.15	26.5	1
1003	1685	PMT	0.49	2.1	27	1
1007-1008 1009-1011	1687	PMT	0.48	2	27	1.25
1012-1013 1014-1016 1035-1036 1037-1038	1688 1689 1690	PMT	0.48	1.95	27.5	1.25
840 842	1406 1407 1408	PMT	0.49	1.85*	28*	1.5*

** : only for central LEMs*

Interesting runs - statistics

Charge runs	*N trigger*	*N muons-like*	*Drift field*	*Extraction Field in liquid*	*Amplification Field*	*Induction Field*
986-987 988-989	11390	1761	0.49	2.14	25	1
990-991 993-994	35636	5428	0.48	2.14	25.5	1
996	19020	1988	0.48	2.14	26	1
997-998 999	49365	5152	0.48	2.15	26.5	1
1003	36850	3714	0.49	2.1	27	1
1007-1008 1009-1011	44329	4595	0.48	2	27	1.25
1012-1013 1014-1016 1035-1036 1037-1038	86843	8122	0.48	1.95	27.5	1.25
840 842	52643	12025	0.49	1.85*	28*	1.5*
840-842 central muons	-	1530	0.49	1.85*	28*	1.5*

** : only for central LEMs*

Previously on light meeting

At the S1 analysis level :

- Understand the shift in PMT 2&3 for some runs
- Improve off-time track selection
- Do not use TProfile

At the S2 analysis level :

- Check S2 charge with drift field with MC
- Check S2 drift velocity analysis with MC
- Test the S2 increase with LEM field analysis with MC

On the off-time track selection

Up to now I only considered late off-time ‘entering’ at the anode and ‘exiting’ at the cathode
I added :
- Tracks can also enter from the side of the detector - they still have to ‘exit’ at the cathode, otherwise we cannot get their delayed time
- Earlier tracks are considered, for the light point of view only tracks arriving 228 μs before the trigger can be considered.

-> The number of off-times track selected increased by ~30%

On the MC generation

- Generated in QScan
- Using the 'old' light map
- Light produced outside of the charge active volume taken into account:
  - near the field cage
  - in between the cathode and the ground grid

- Some previously found bugs were corrected : 311 geometry, PMT response, recombination
- Some known bugs still here and can't be yet corrected
  - light maps interpolation at the level of the volume between cathode & ground grid: only 1 voxel along the z-axis was simulated

- Same light reconstruction algorithm used as in the data

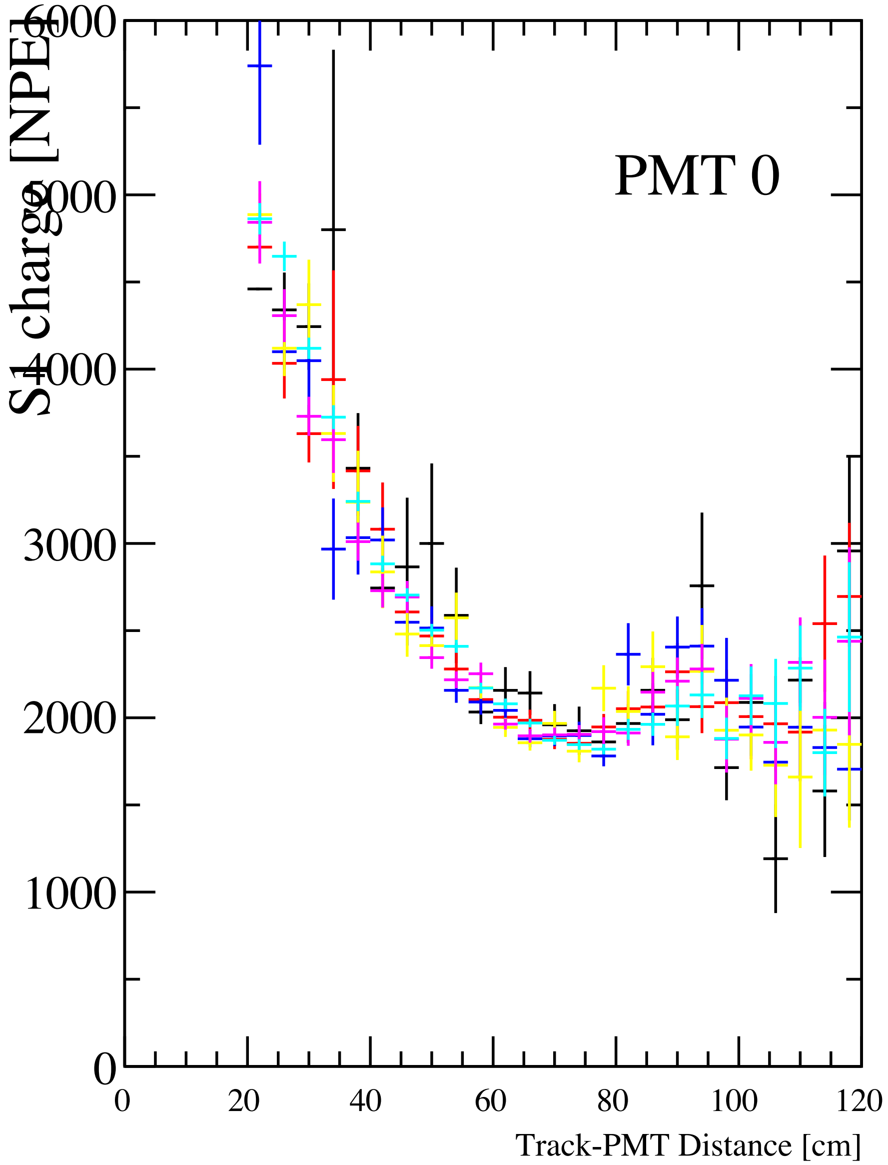
- Otherwise stated, the default parameters in the following slides are :
  - Muon momentum at 4 GeV/c ; uniform drift field of 500 V/cm ; no impurities
  - Muon generated randomly from the anode to the cathode
  - Rayleigh at 55 cm
  - Absorption length at 30 m
  - G_{el} = 160 photon/extracted e^-

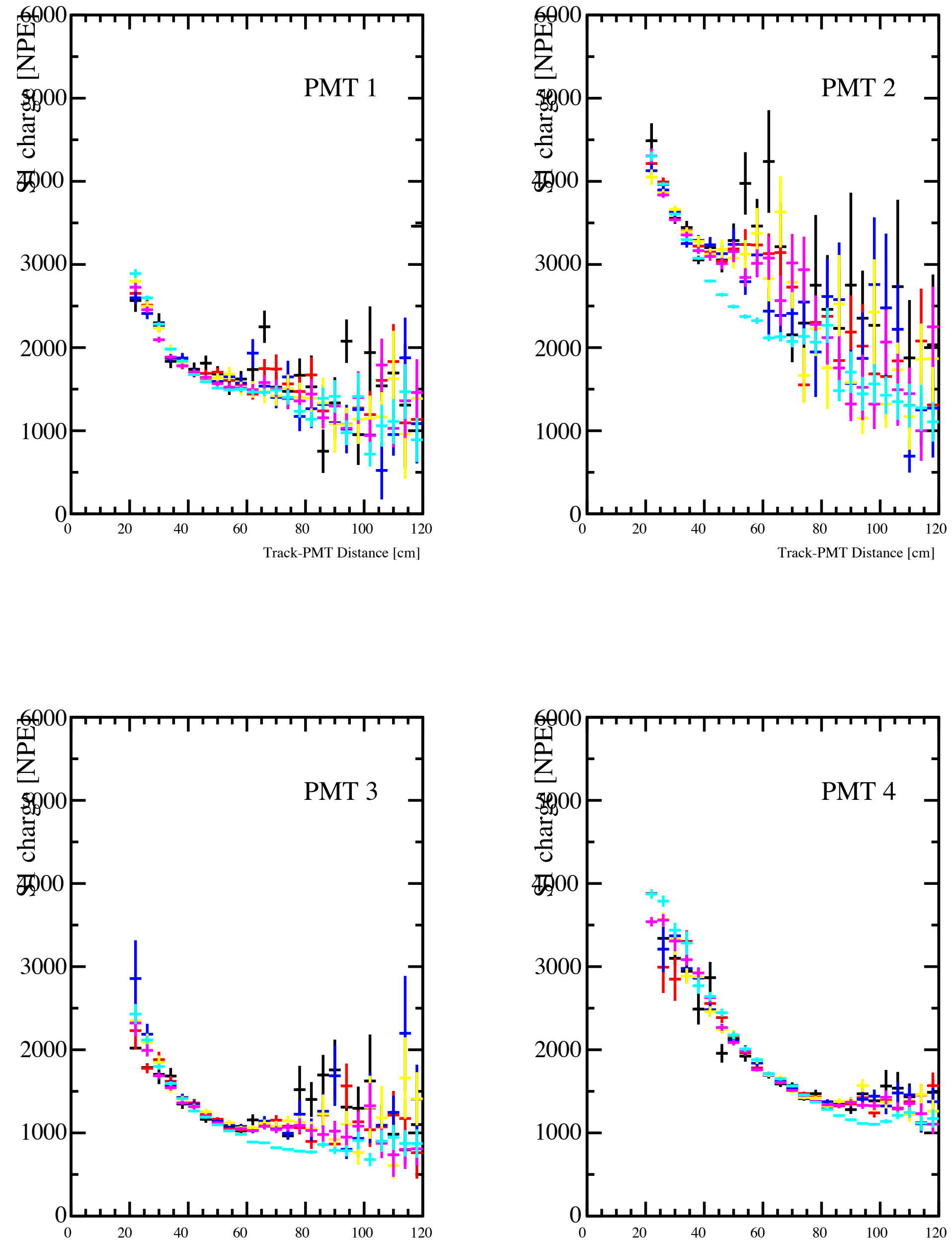
On the S1 analysis [data; PMT trigger]

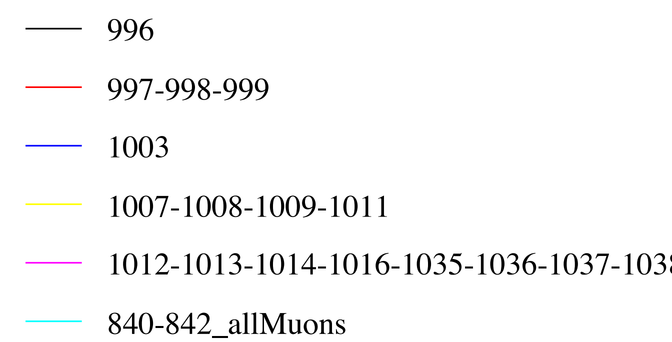
At last meeting : some shift seen for PMT 2&3 for two runs

↳ As expected, it was a mistake at the code level when computing the PMT gain

-> All PMT runs agrees within each other (TProfile is used here)



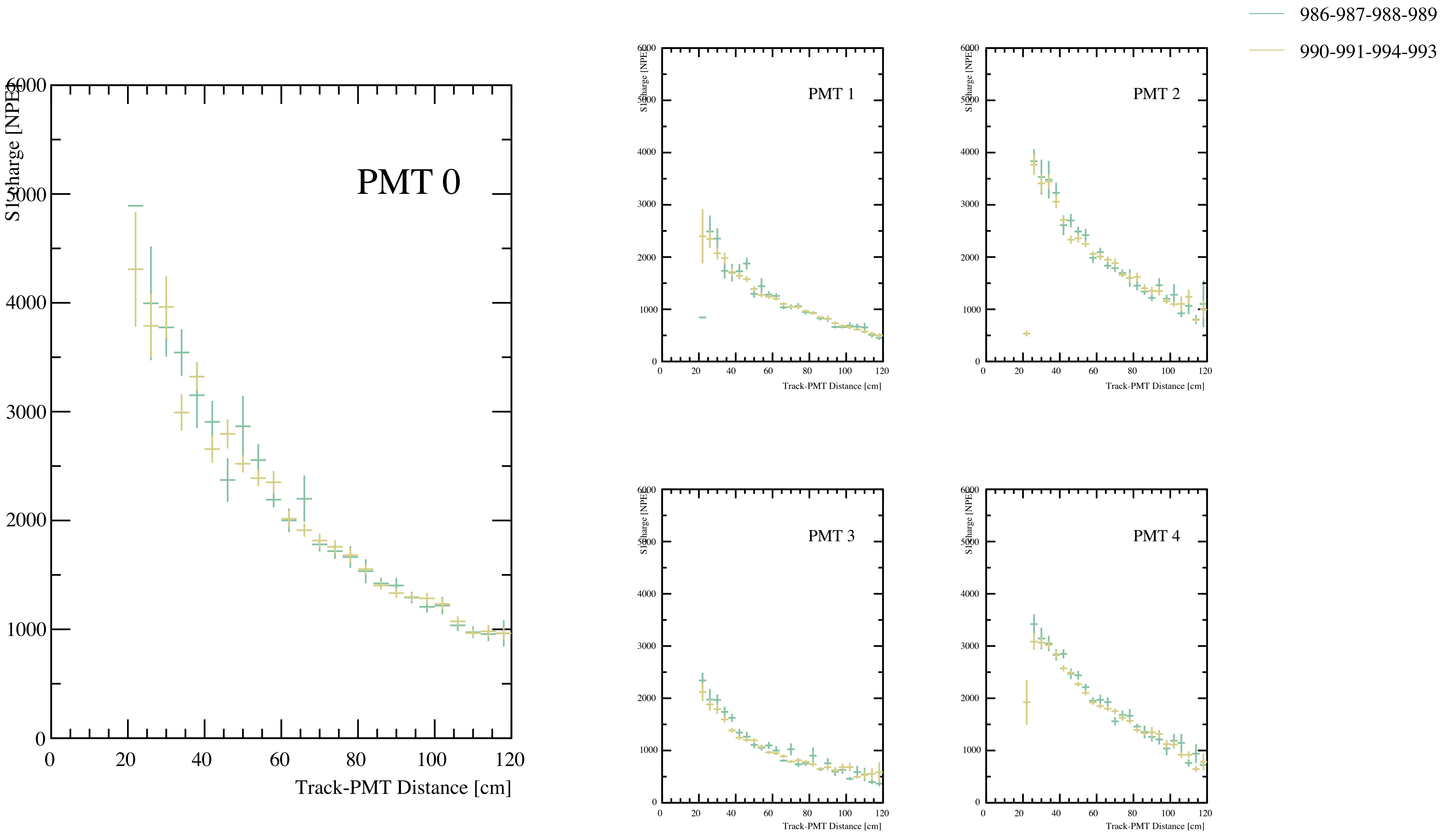




Selection of
trigger + off-time tracks
At d ≳ 80 cm, statistics gets low (only offtimes tracks)

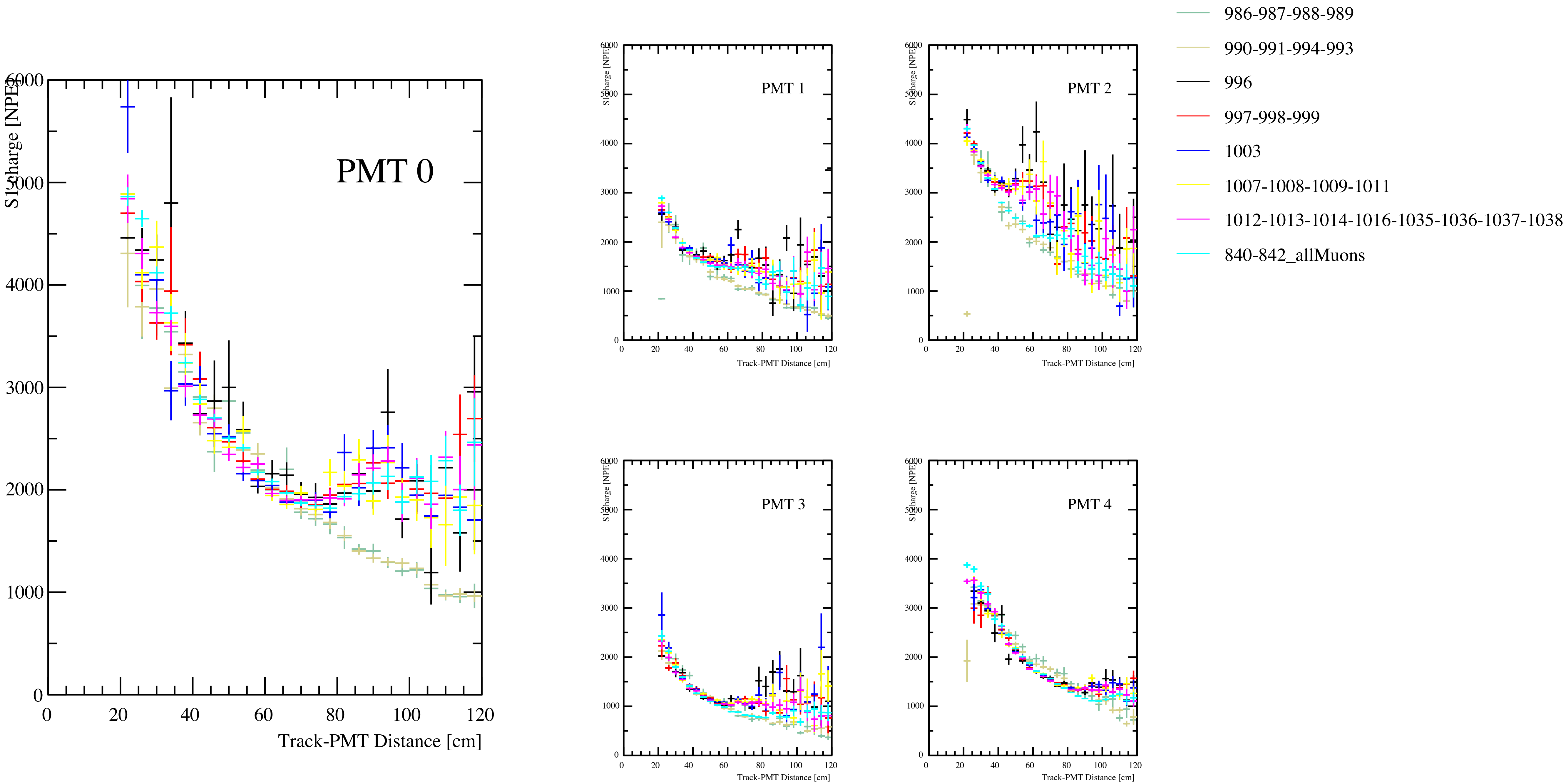
On the S1 analysis [data; CRT trigger]

-> All CRT runs agrees within each other (TProfile is used here)

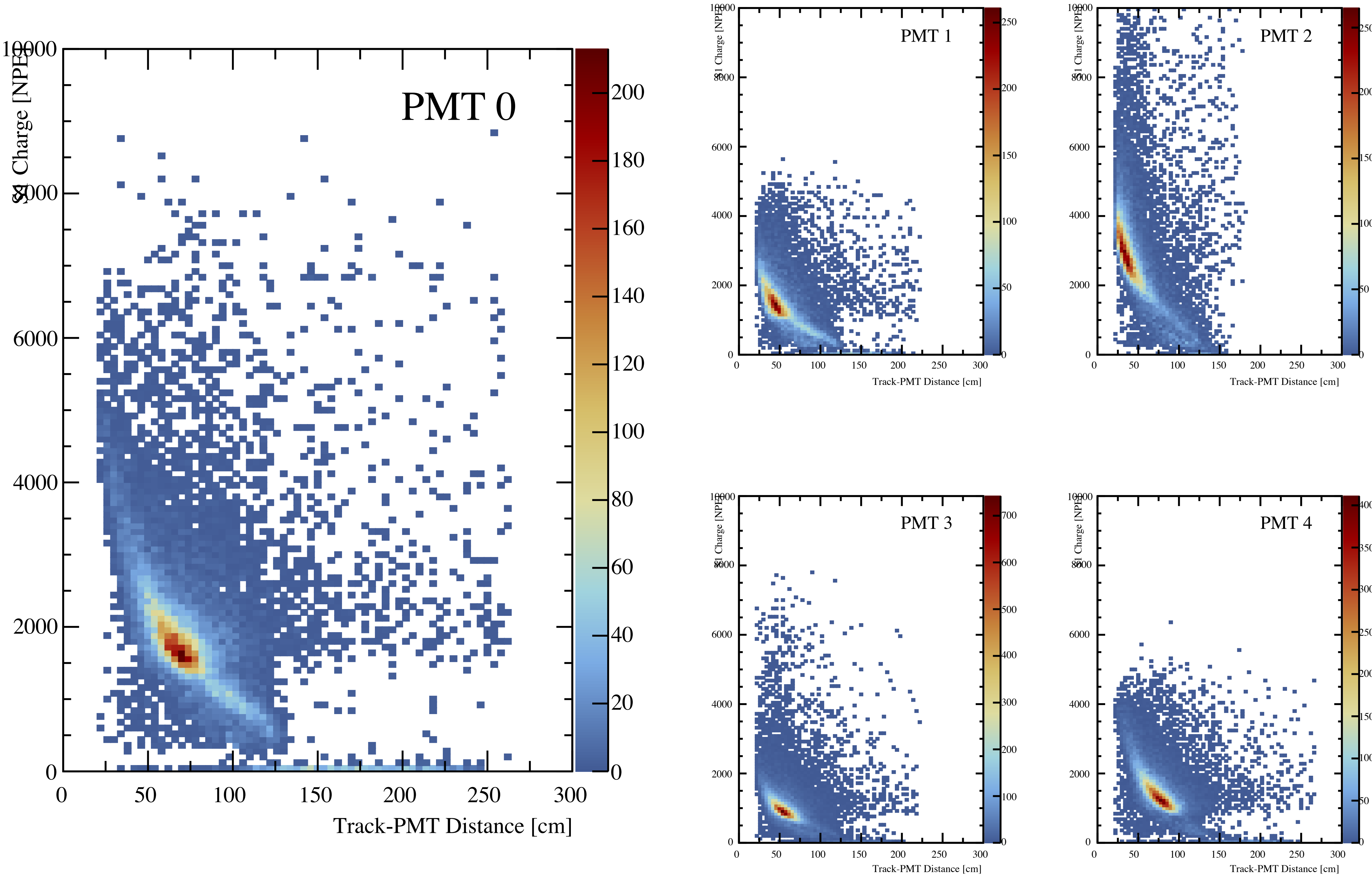


On the S1 analysis [data; CRT and PMT trigger]

-> All runs agrees within each other (TProfile is used here)

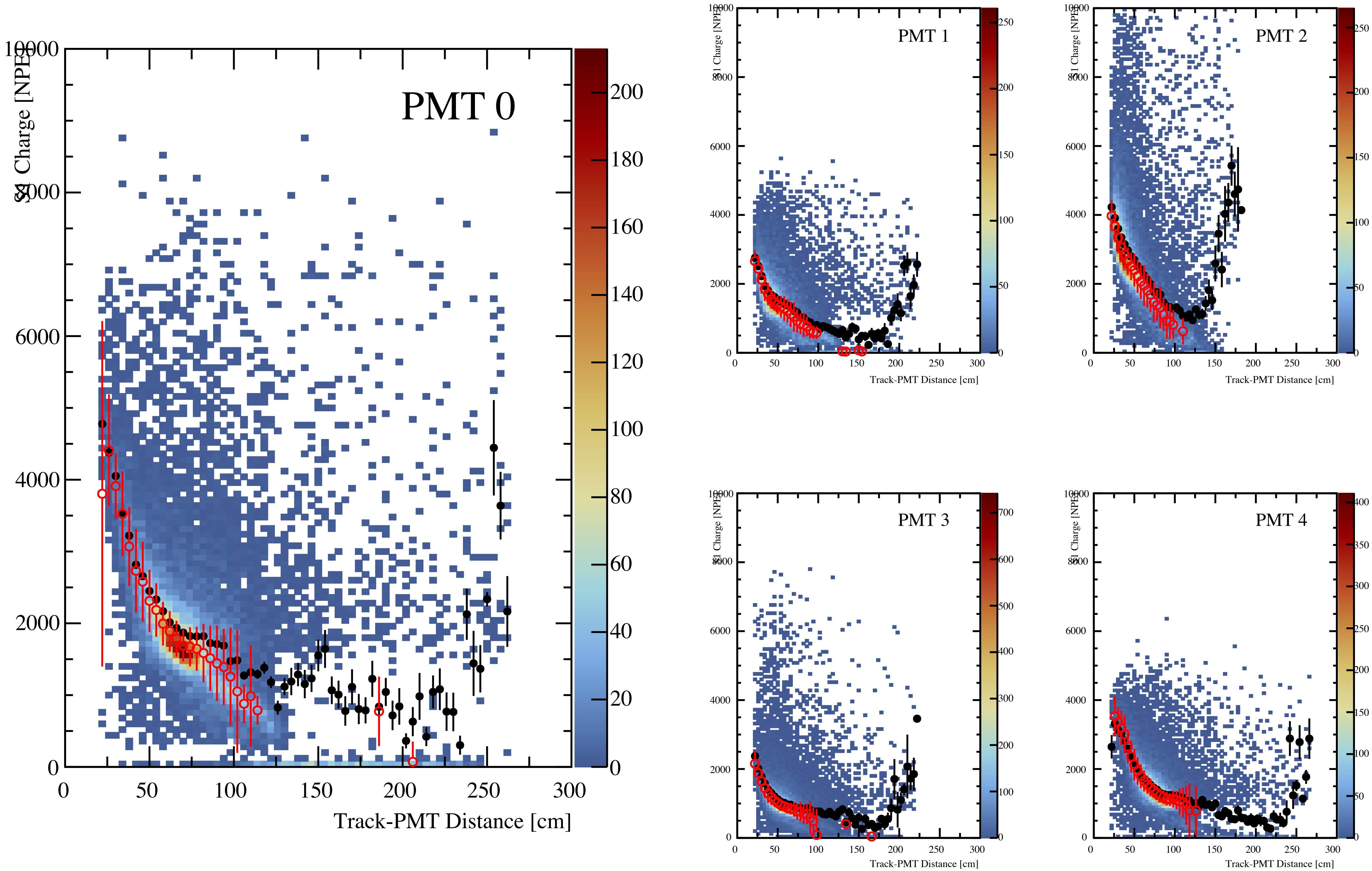


On the S1 analysis - summing all runs



On the S1 analysis - summing all runs

- • : TProfile by ROOT
- • : Gaussian fit

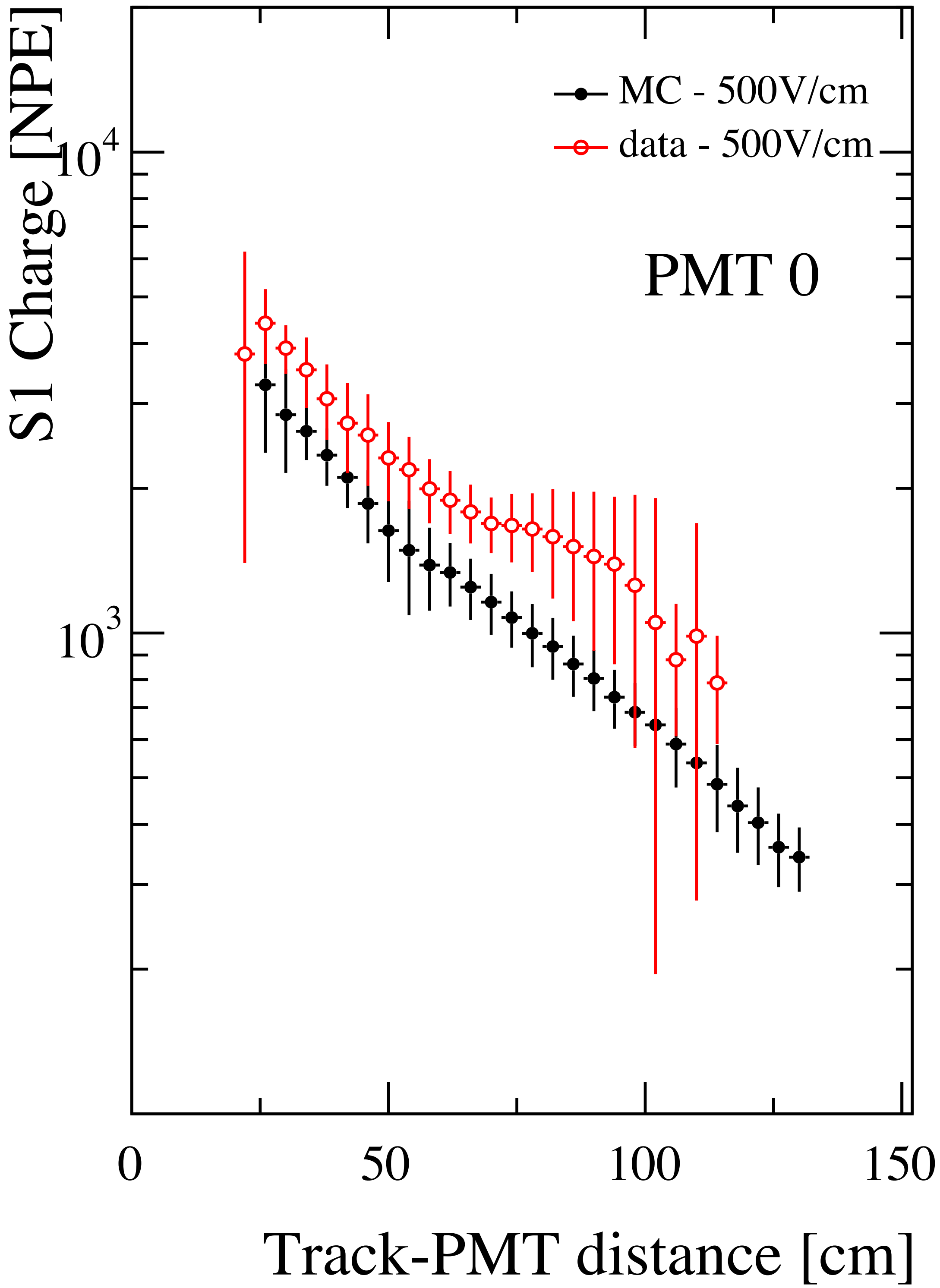


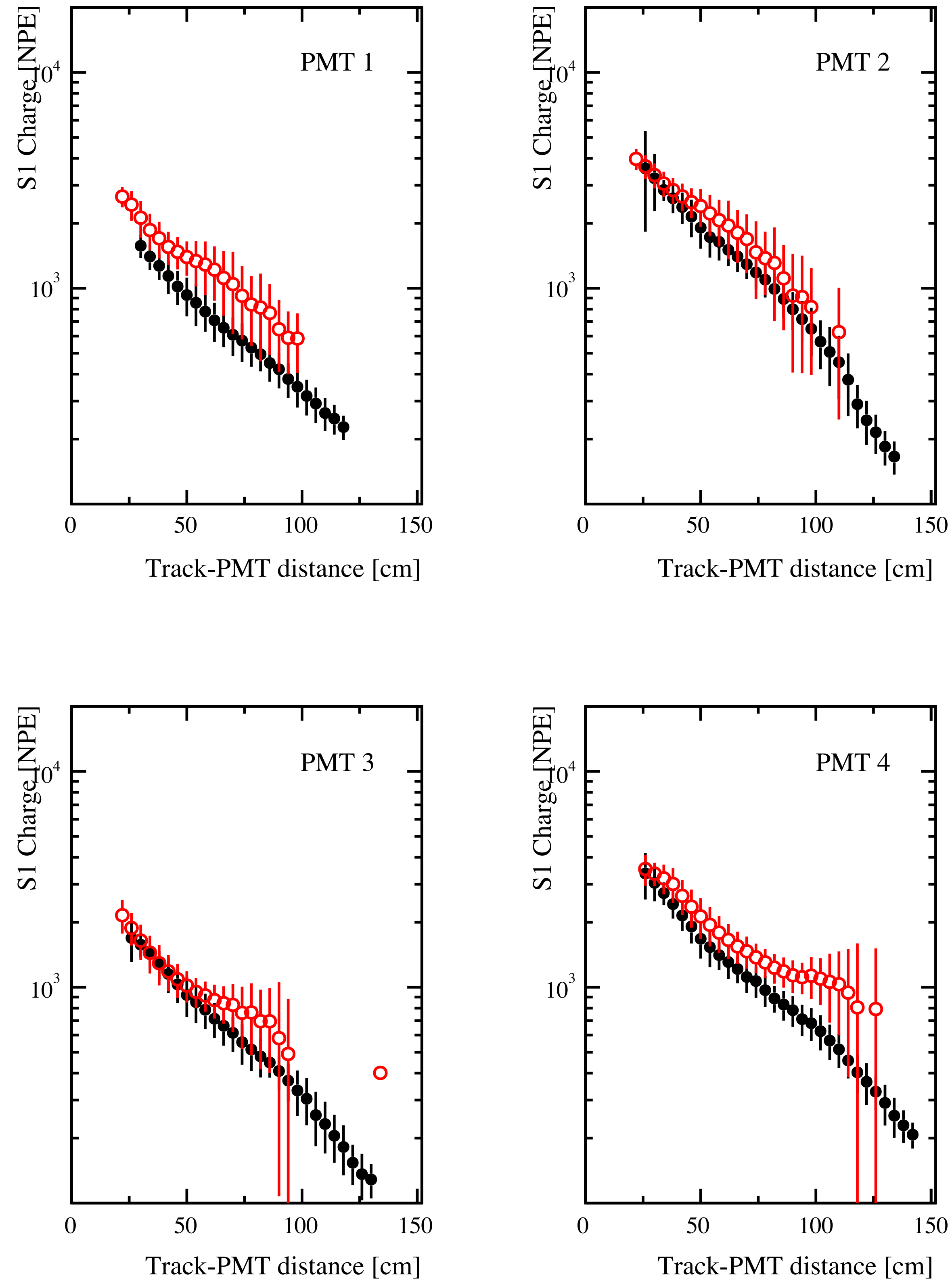
S1 analysis with MC [only at λ_{ray} = 55 cm]

Both using gaussian fit

- : MC
- : Data

This is a comparison at E_{drift} = 500 V/cm !





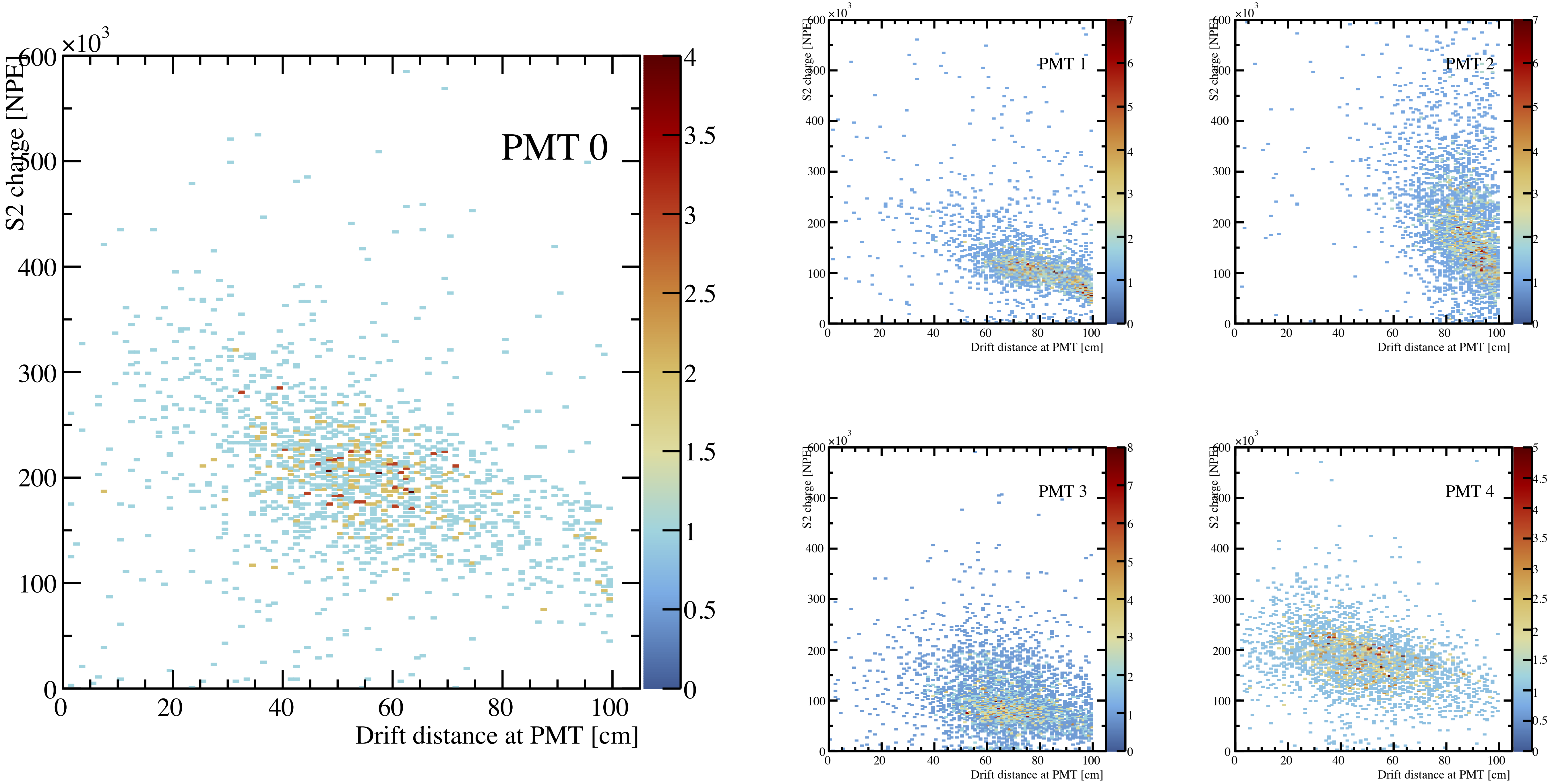
S1 results : comments & conclusions

- At 500 V/cm, compatible results on S1 charge vs track-pmt distance for CRT and PMT runs
  -> Add all runs together
  -> Off-time tracks adds extra points at low S1 charge (cut by the trigger) and large track-PMT distance

- Not super conclusive comparisons with the MC
  -> This is not a surprise !
  -> MC uses icarus parametrization for the amount of light generated through the recombination factor - we already suspect that this is wrong from Chiara results
  -> In the MC, no intermediate component is generated, the S1 charge is here computed by a 1 μs range as in data
  -> We know that we have an interpolation problem in between voxels underneath and above the cathode

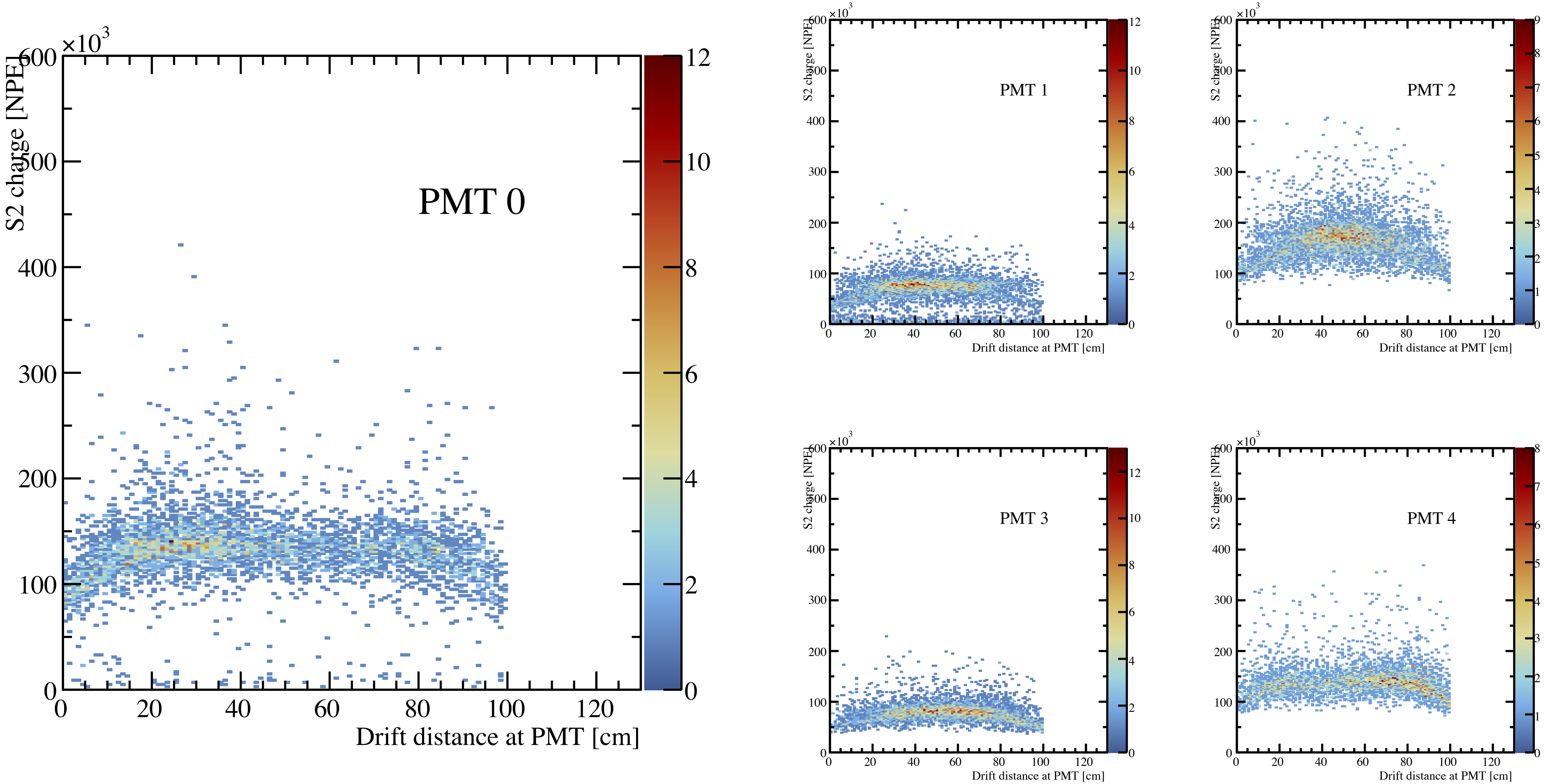
- Let's wait for Chiara's final results at 0V/cm to do the recombination measurement !
- Let's wait for the final MC to do the Rayleigh measurement !

S2 charge vs drift distance - data



runs 1012 .. 1038 at E_{LEM} = 27.5 kV/cm E_{ind} = 1.25 kV/cm for all LEMs

S2 charge vs drift distance - MC

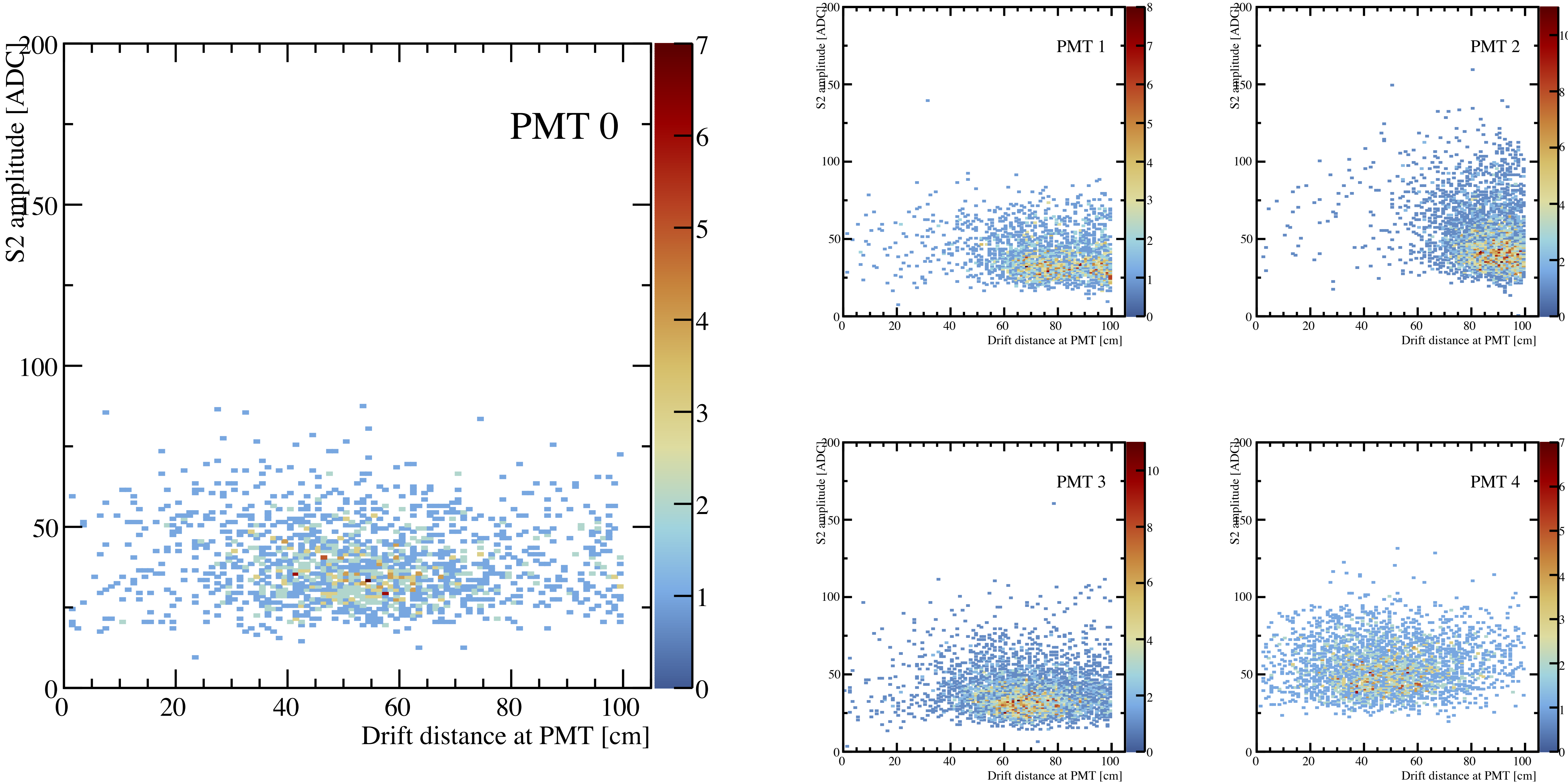


All muons have the same energy (4 GeV) - no impurities - no SCE - G_{el} = 160

Can see the banana effect

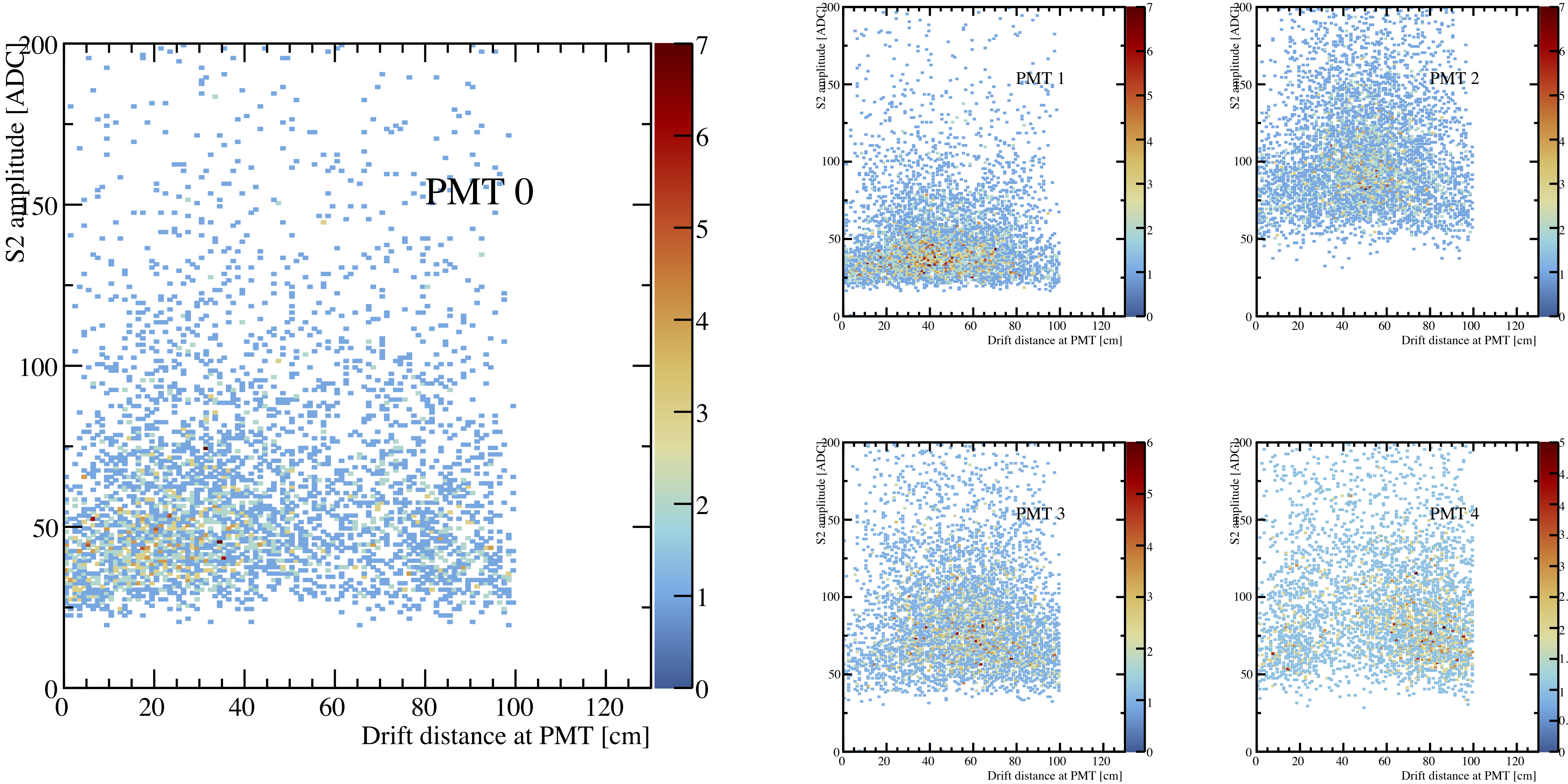
Confirms the hypothesis of S2 being 'too' visible

S2 amplitude vs drift distance - data

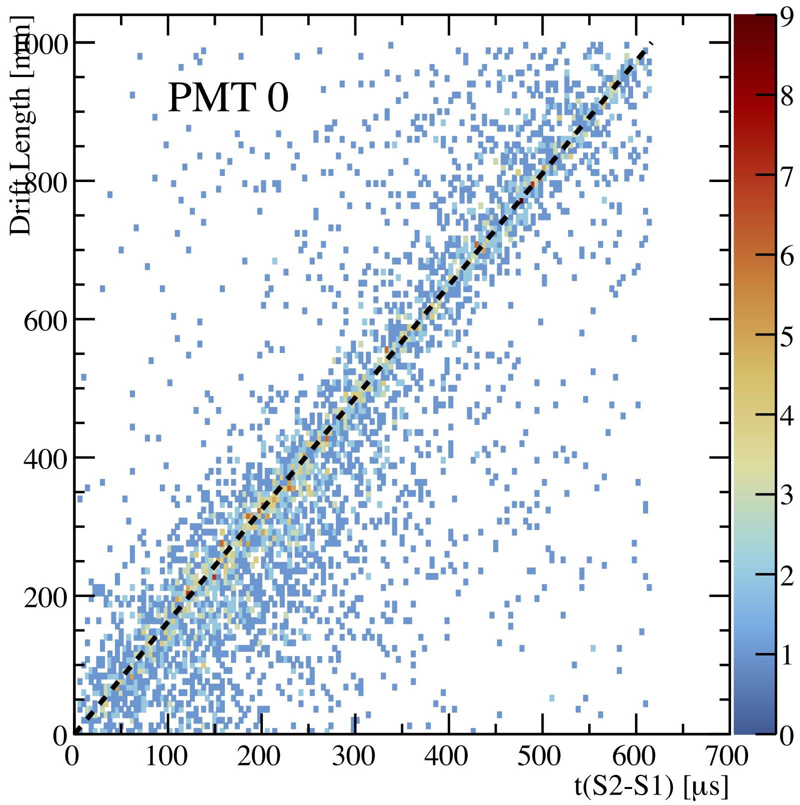


runs 1012 .. 1038 at E_{LEM} = 27.5 kV/cm E_{ind} = 1.25 kV/cm for all LEMs

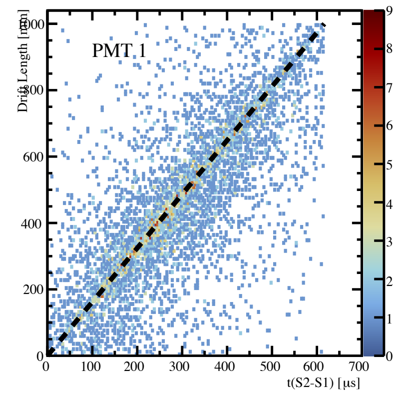
S2 amplitude vs drift distance - MC

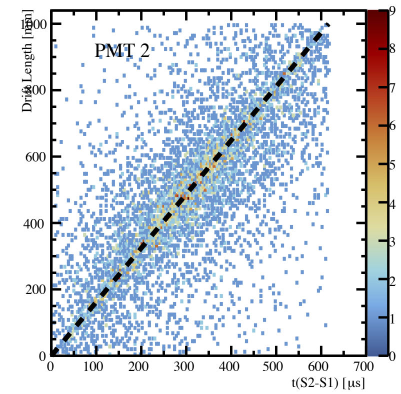


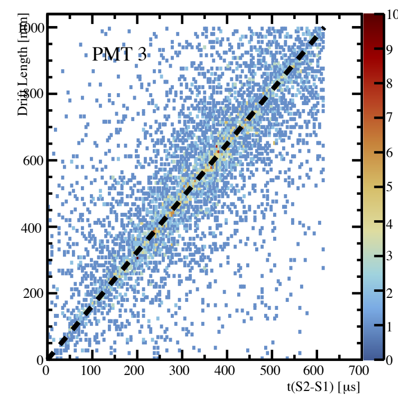
Drift Velocity measurement - MC

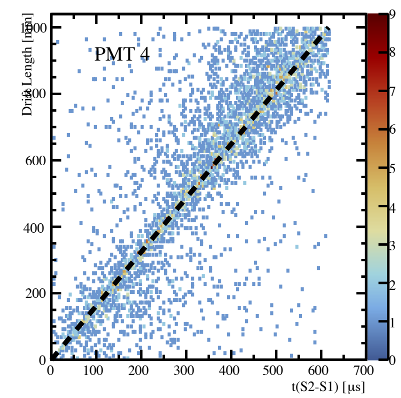


- - - : guide line







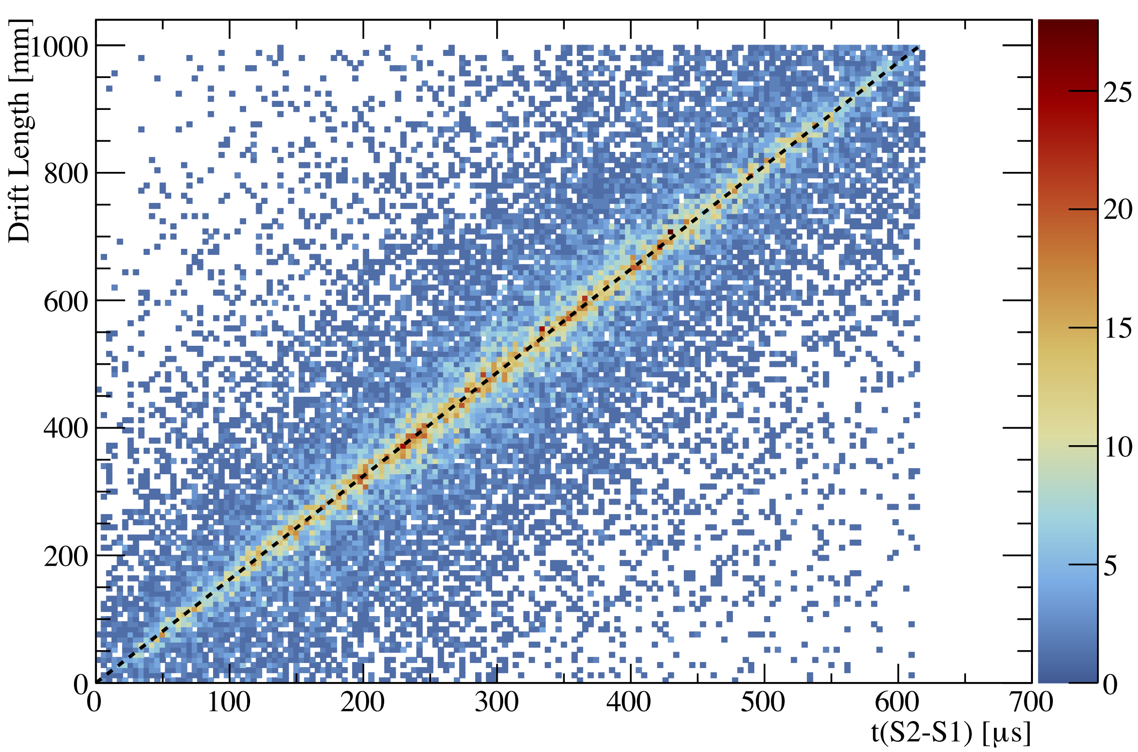


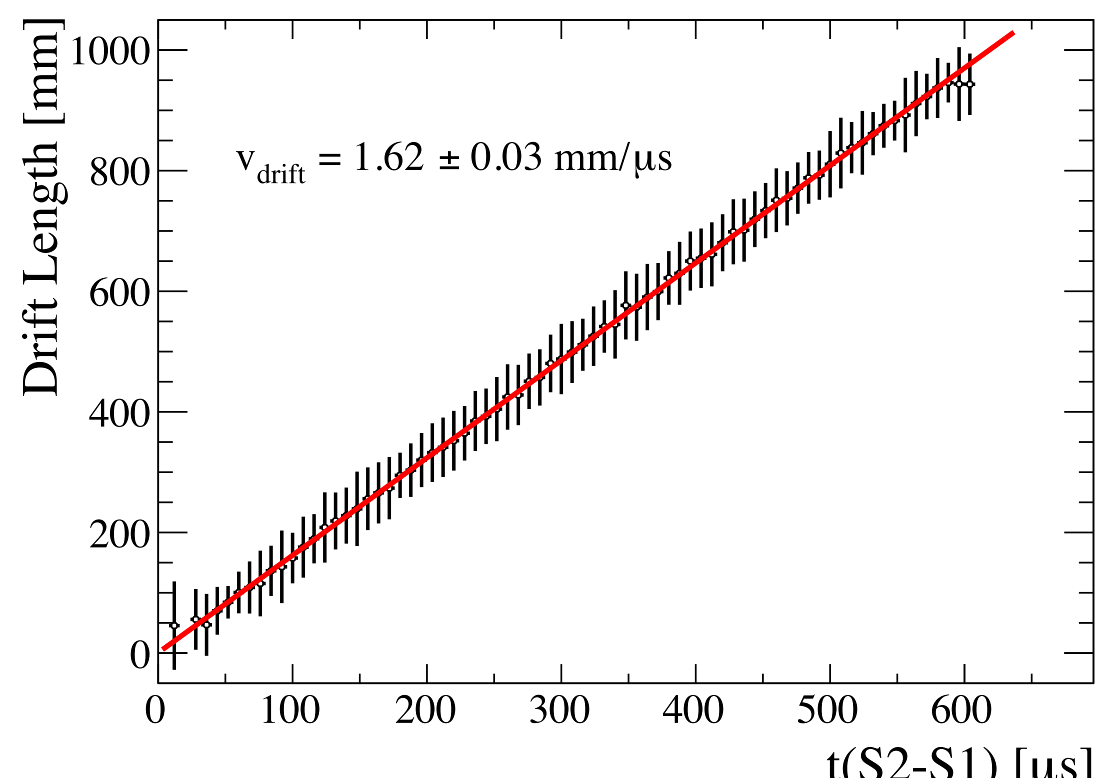
G_{el} = 160 ; no space charge effect

The drift length is computed with the ***MC true*** track information

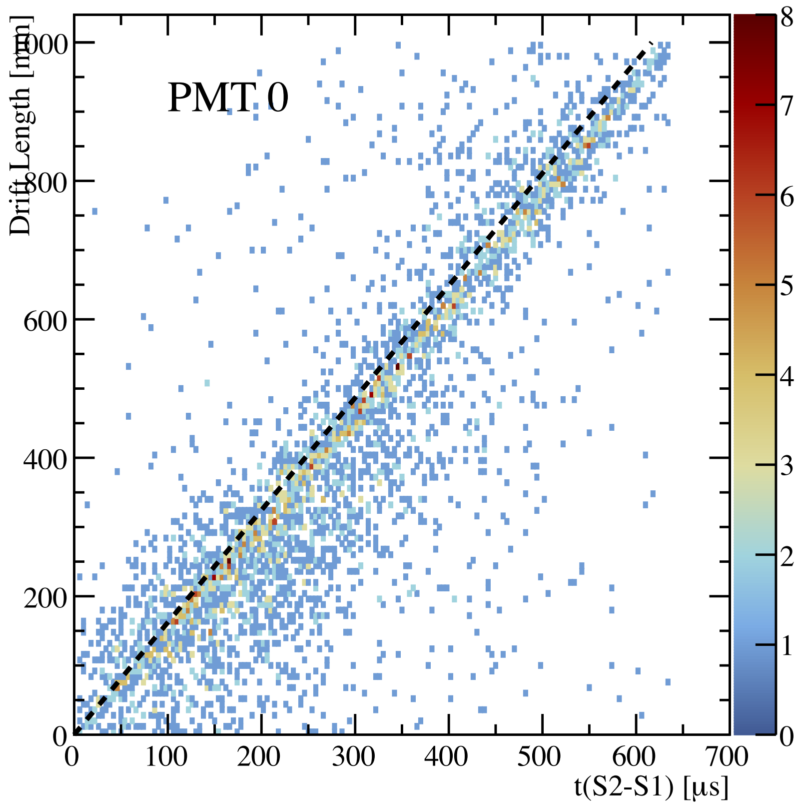
-> comparable with the CRT case in data

- QScan input :
  v_{drift} = 1.622 mm/μs
- Gaussian fit for each point
- Δt = 8μs

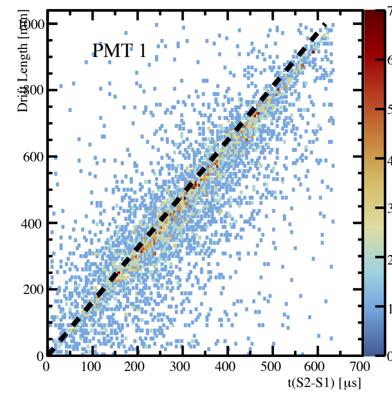


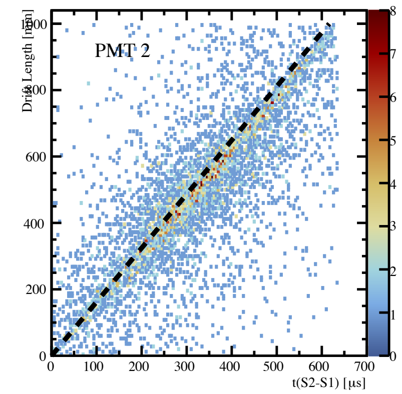


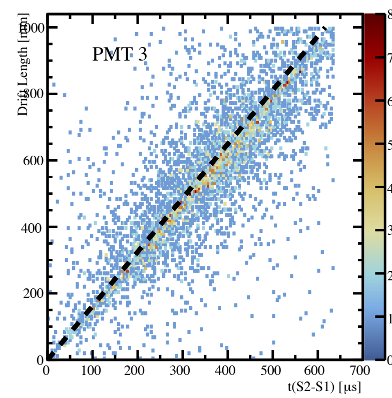
Drift Velocity measurement - MC

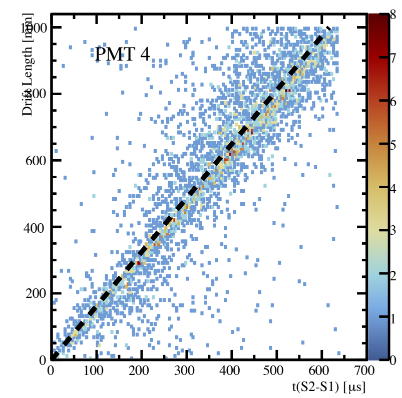


- - - : guide line





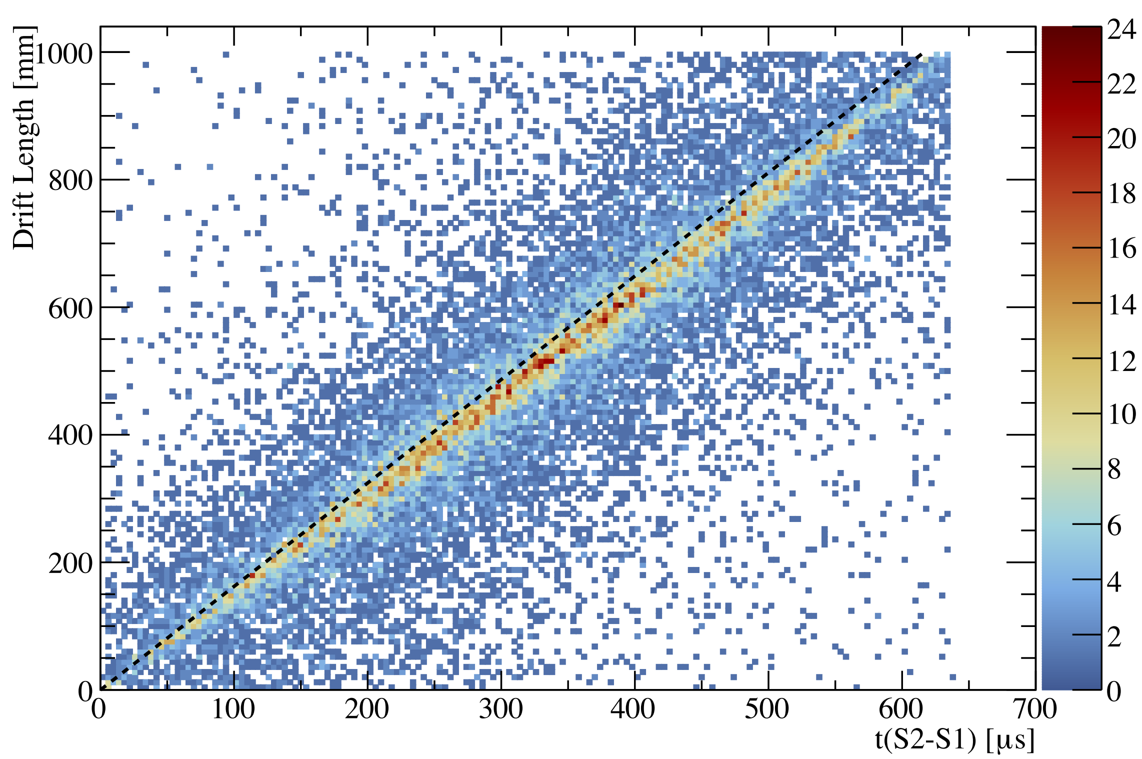


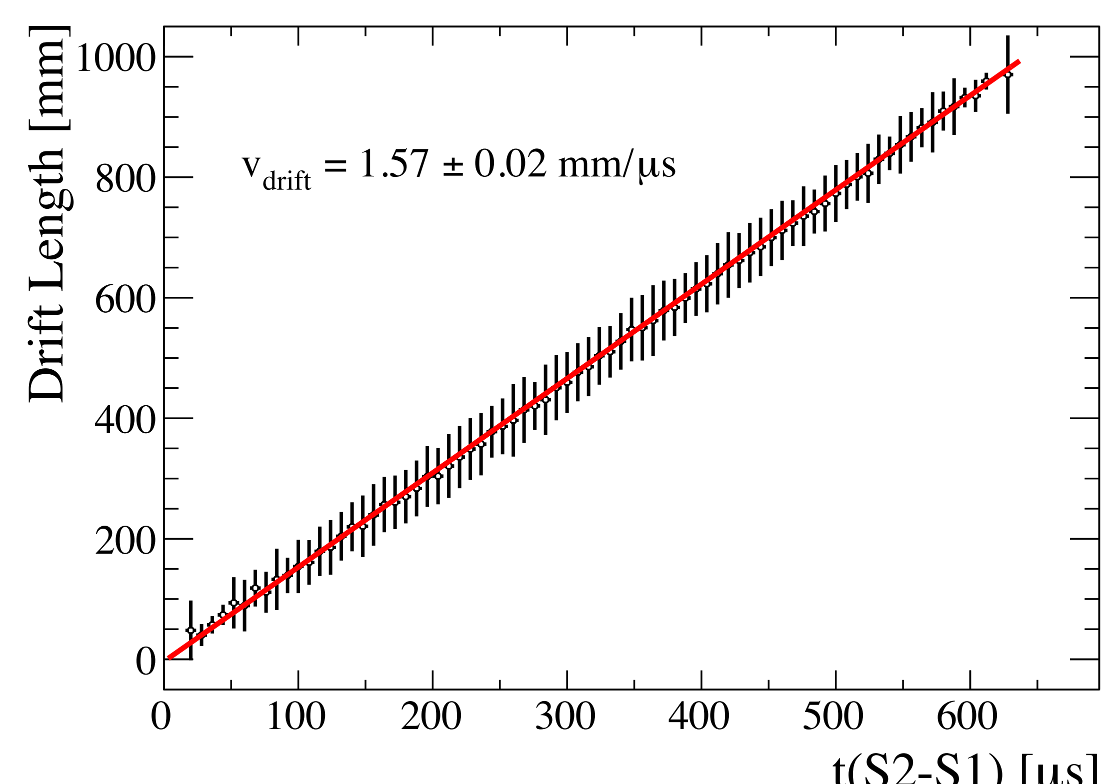


G_{el} = 160 ;
space charge effect with 50% IBF

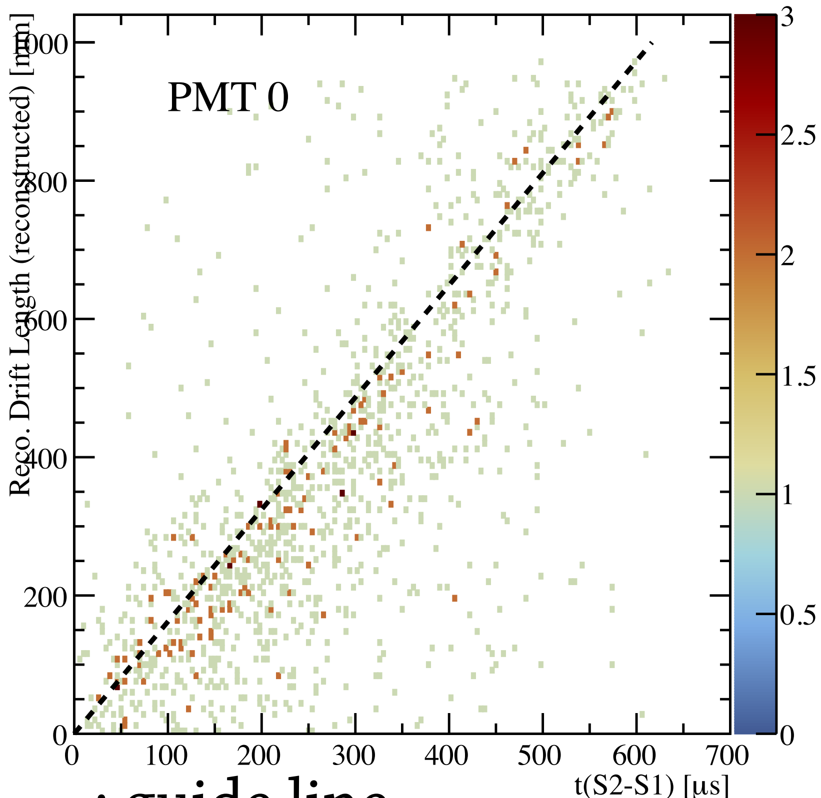
The drift length is computed with the ***MC true*** track information
-> comparable with the CRT case in data

- QScan input :
  v_{drift} **= 1.622 mm/µs**
- Gaussian fit for each point
- Δt = 8µs

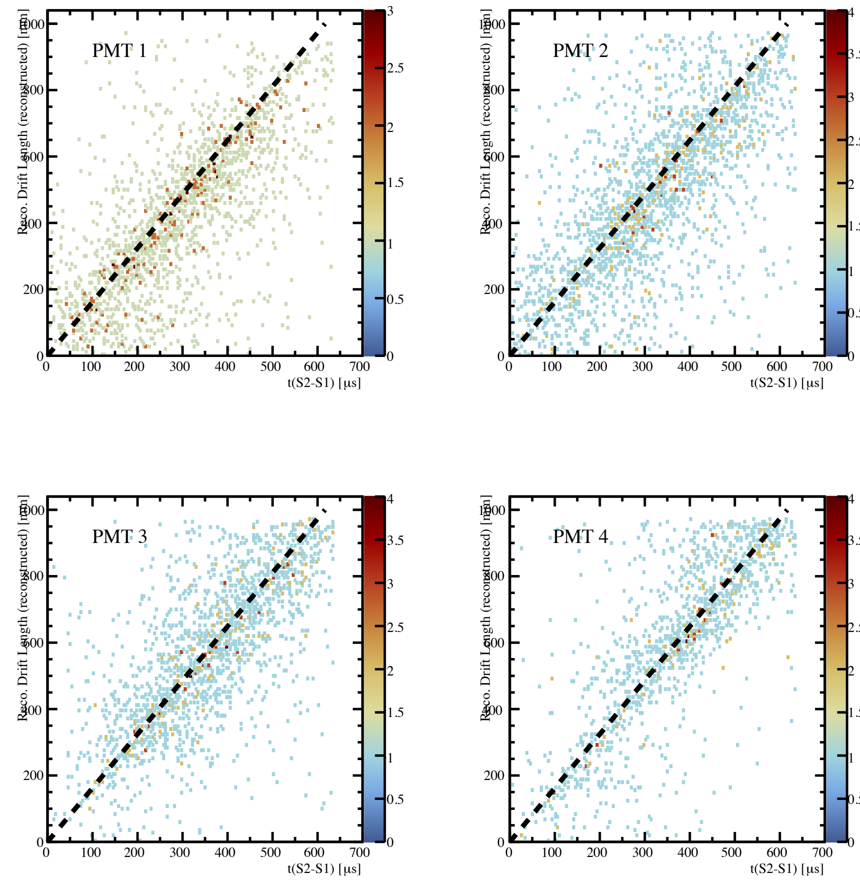




Drift Velocity measurement - MC



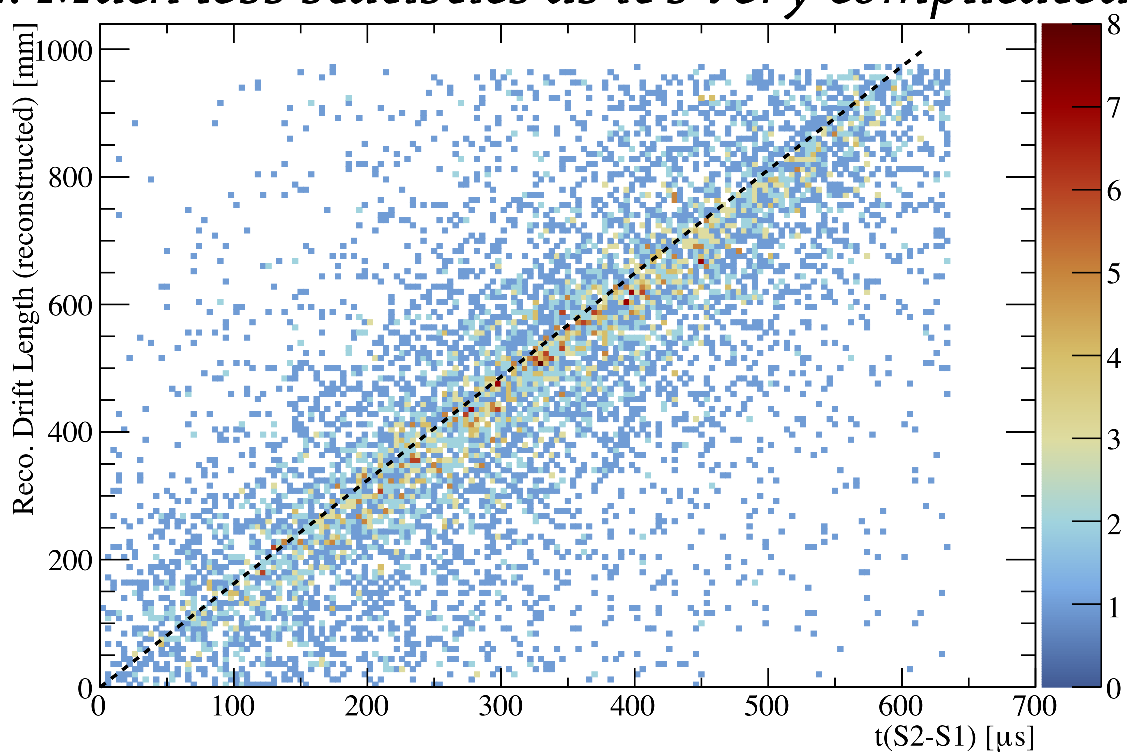
- - - : guide line

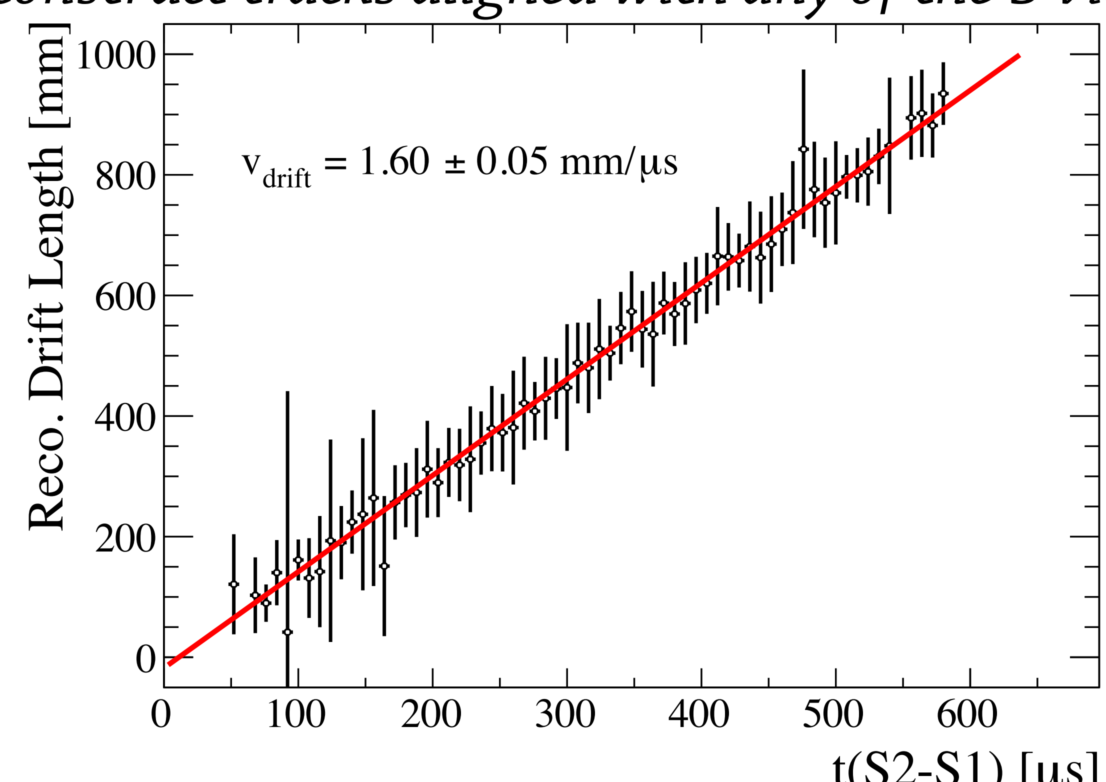


G_{el} = 160 ;
space charge effect with 50% IBF

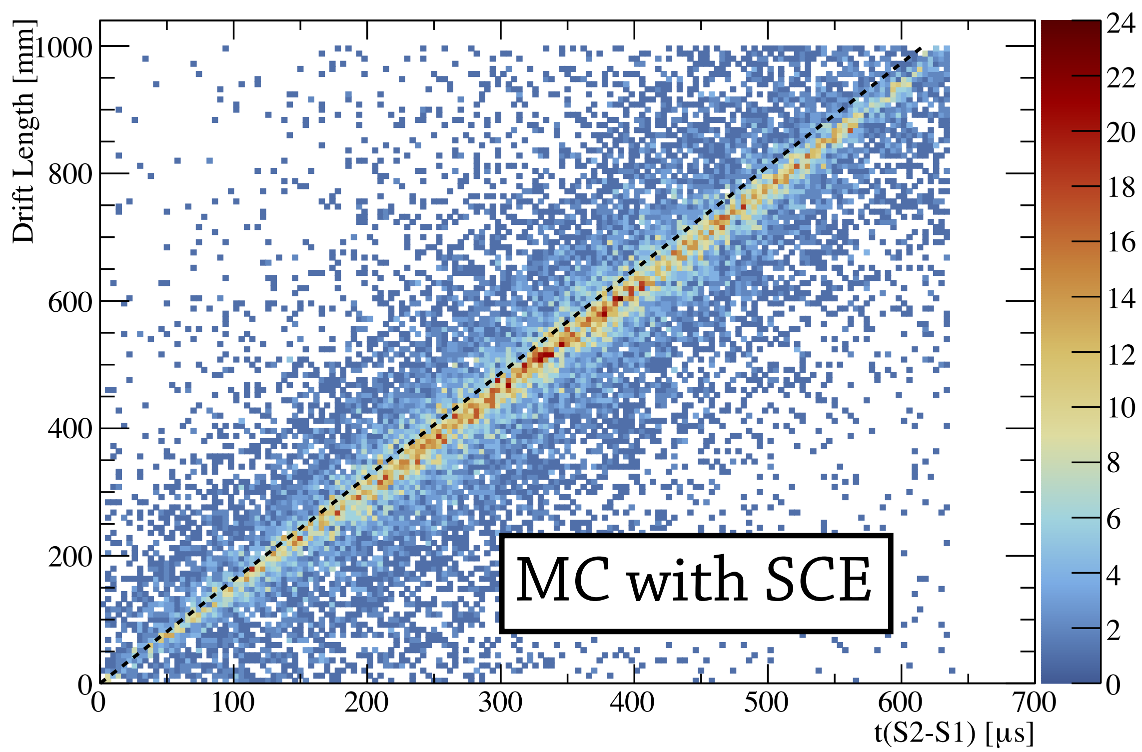
The drift length is computed with the track ***reconstructed*** information
-> comparable with the PMT case in data

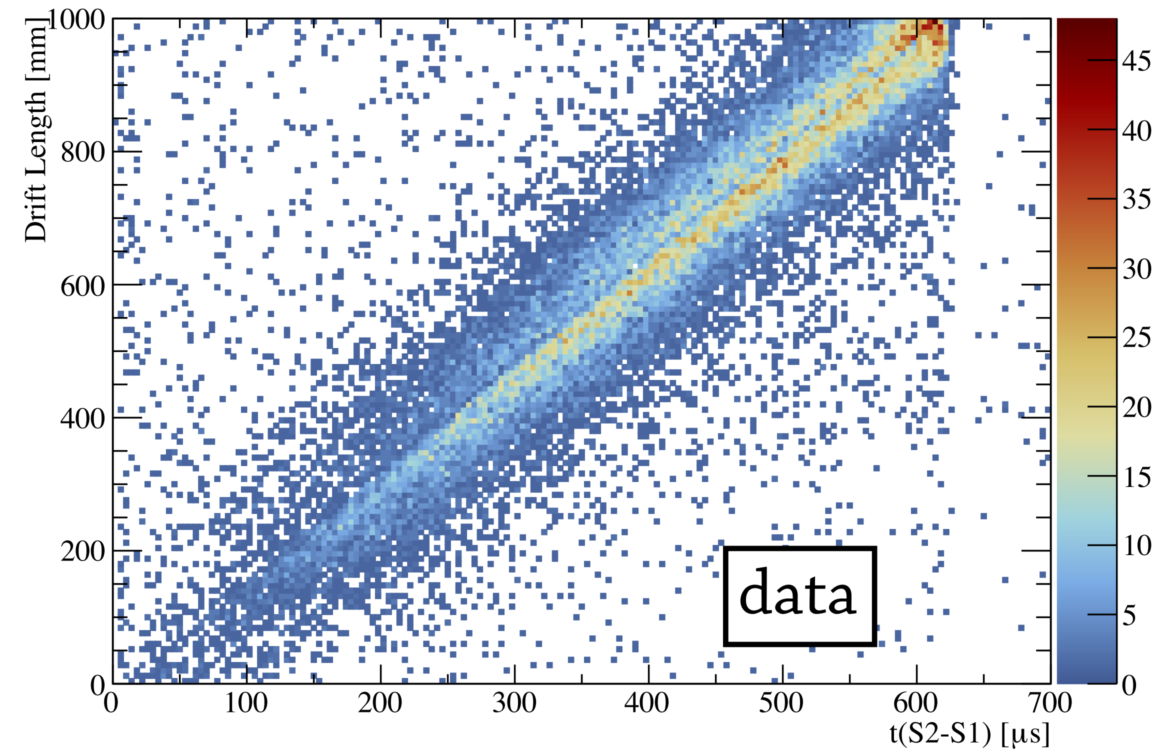
NB : 1. I used my charge reconstruction code, which is different from the one used in the DPDs
2. Much less statistics as it's very complicated to reconstruct tracks aligned with any of the 3 views



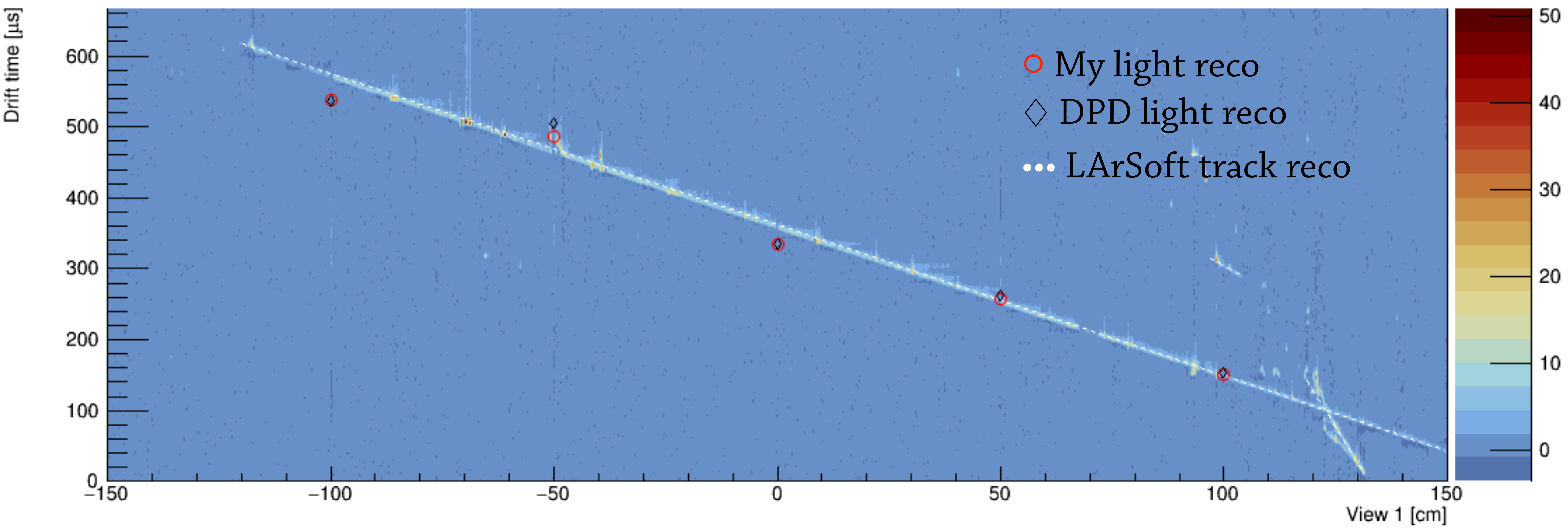


Drift Velocity measurement - data/MC

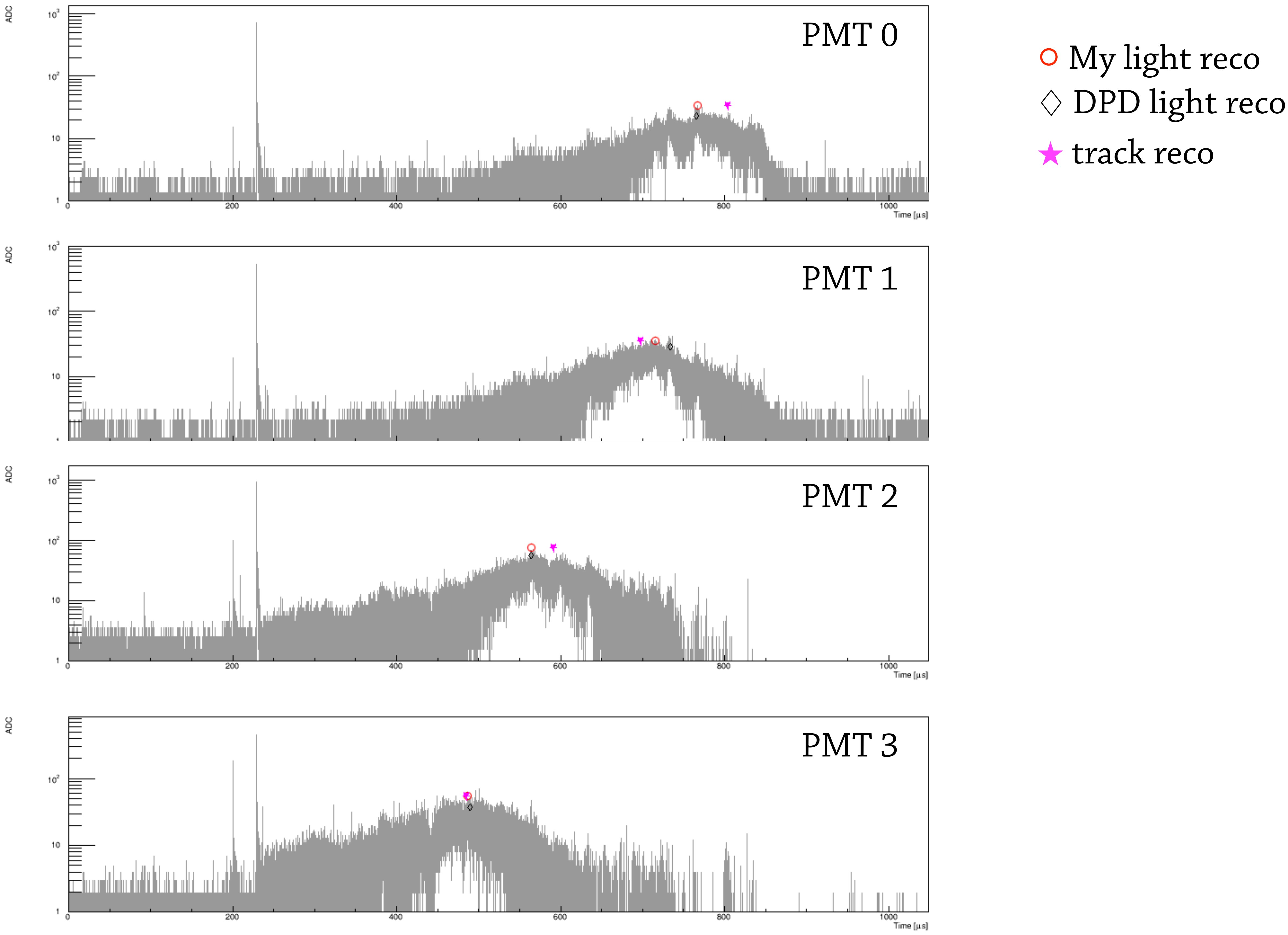




Drift Velocity measurement - event example



Drift Velocity measurement - event example



Drift Velocity measurement - data - remarks

The method used so far [track drift length vs t(S2-S1)] suffers from a few issues :

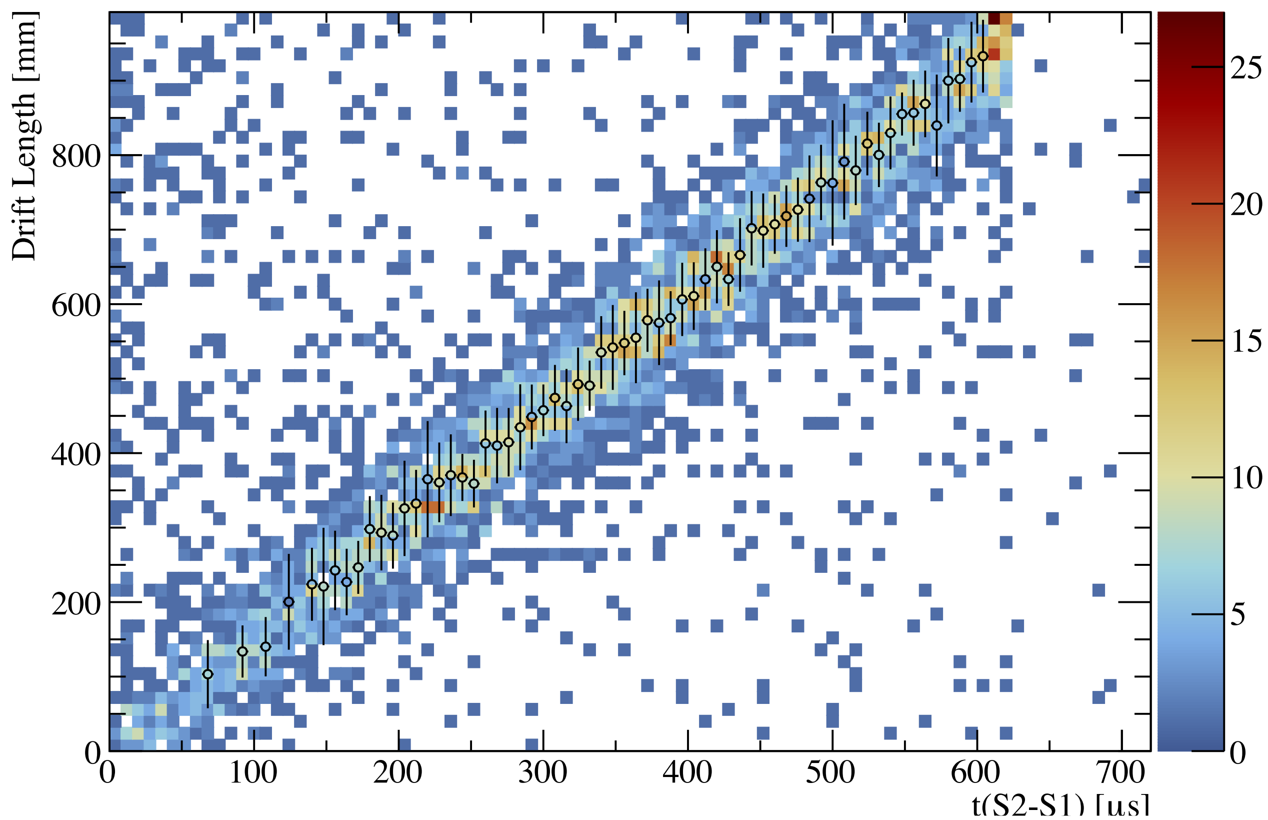
1. For CRT trigger runs
   -> We know the drift length at PMT from the CRT vertices reconstructions given with a ± 5.5 cm uncertainty
   One should estime the error we make with this method.

2. For PMT trigger runs
   The drift length at PMT is given by the charge 3D reconstruction. But the position of the track inside the detector is computed assuming a certain e^- drift velocity : the only information one has is the amount of charge collected at a given time. In LArSoft, at 500 V/cm ***v_{drift} = 1.6205 mm/μs***
   This method is then not correct. For PMT trigger, it is just a cross check that the S2 algorithm works OK

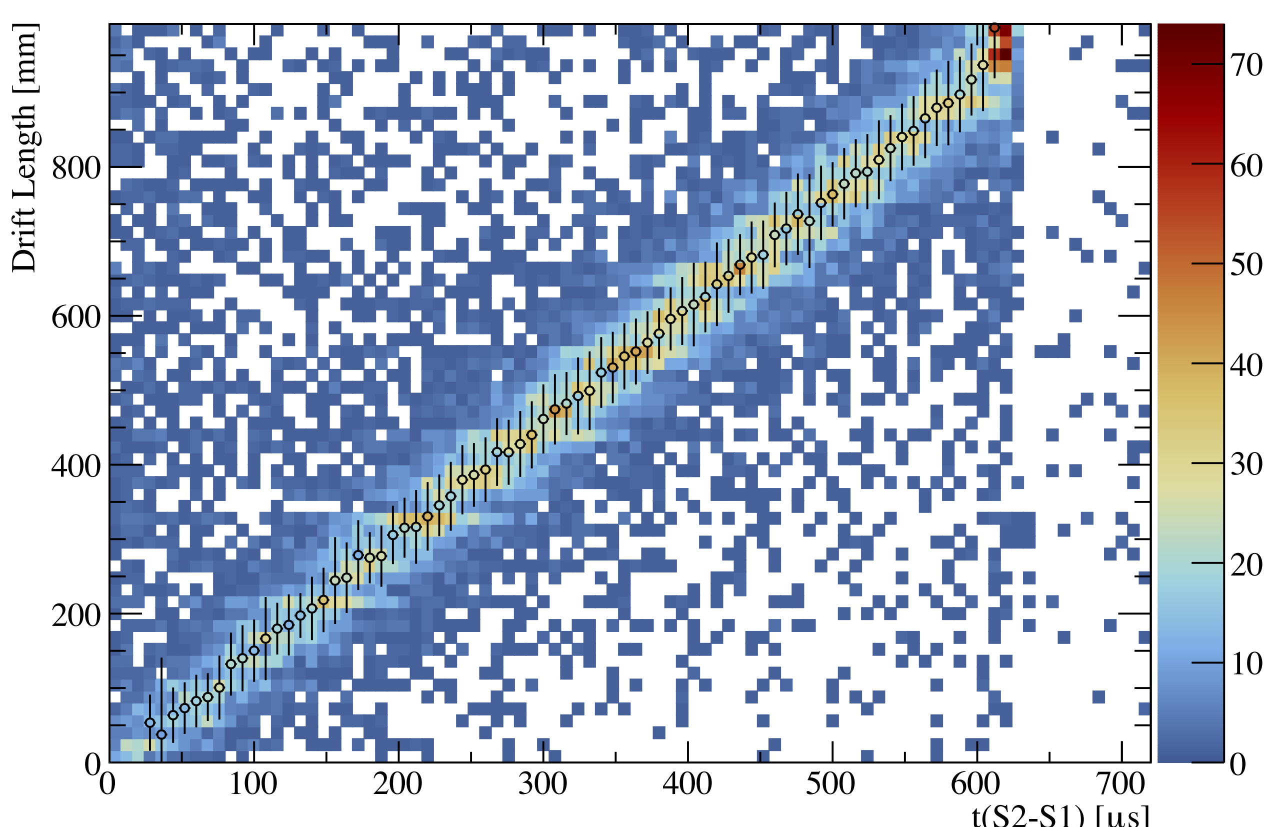
I propose an alternative analysis, where no assumptions on the track position is needed : looking only at the S2 end time
-> Should have a large peak corresponding to L_{drift} = 1000 mm with a continuum for tracks escaping on the side / off-time tracks

Drift Velocity measurement - data - 2D method

run(s) 986-987-988-989

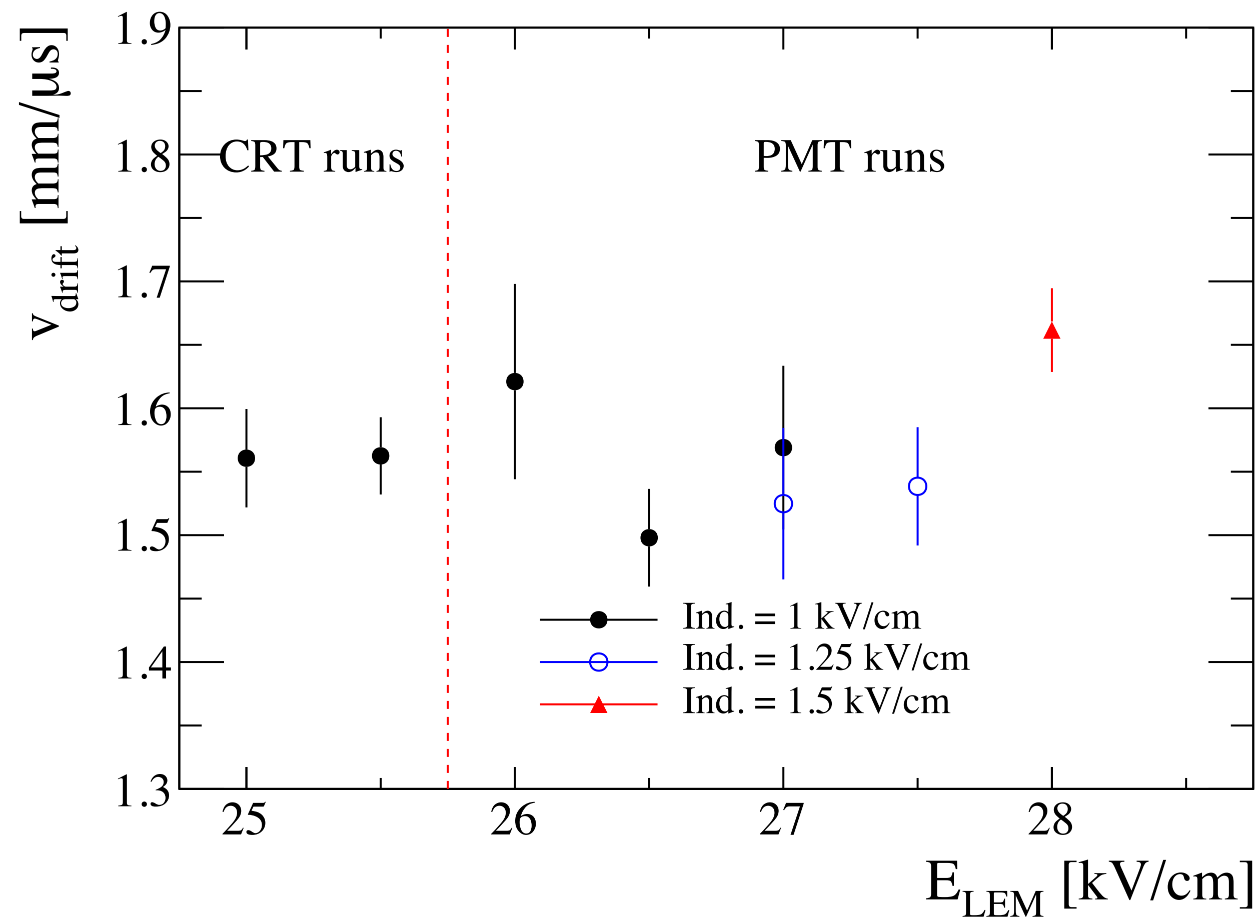


run(s) 990-991-994-993



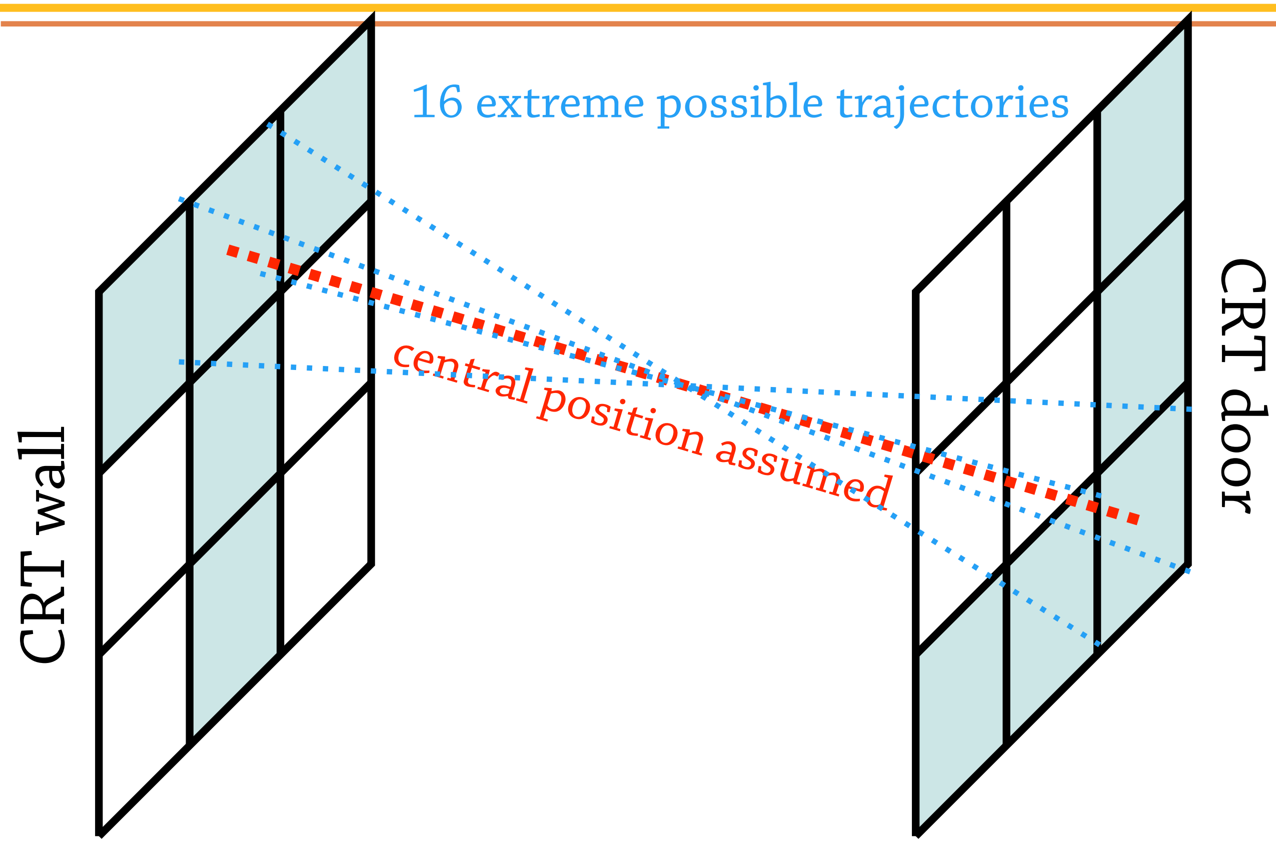
For CRT runs :

$\mathbf{v_{drift} = 1.56 \pm 0.04}$ **mm/µs**



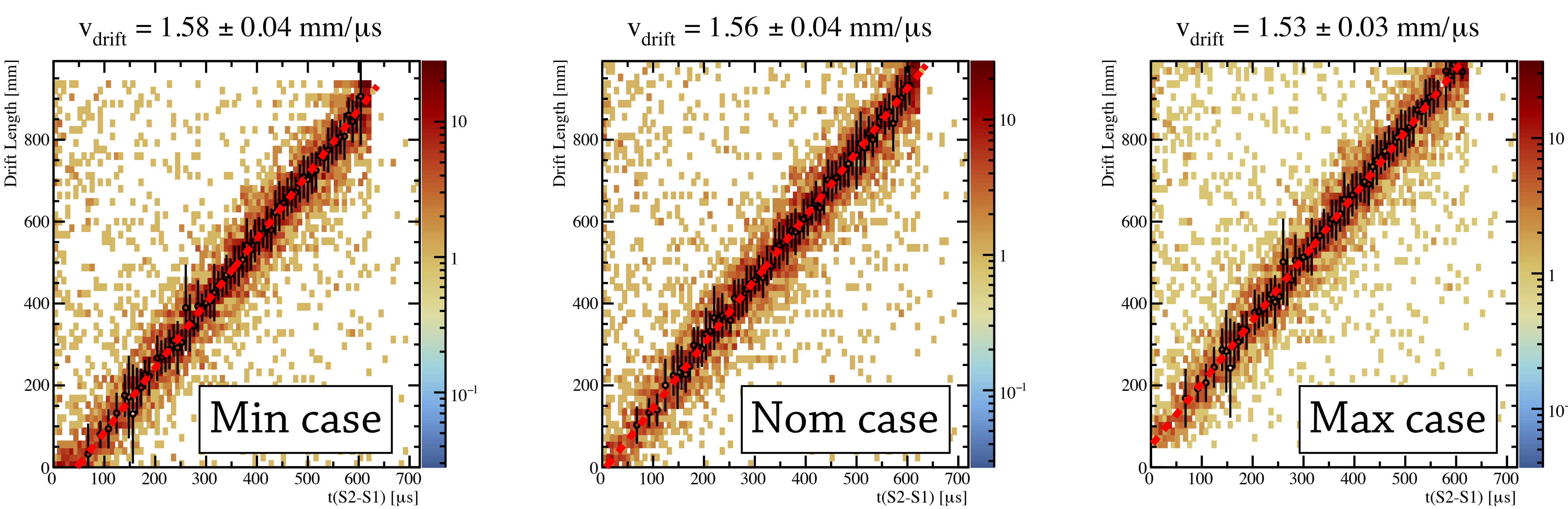
NB : Here assuming central position in CRT panels (more next slide)

Drift Velocity measurement - data - 2D method



-> We don't exactly where the track crossed each panels, we made the central assumptions in all of our analysis so far

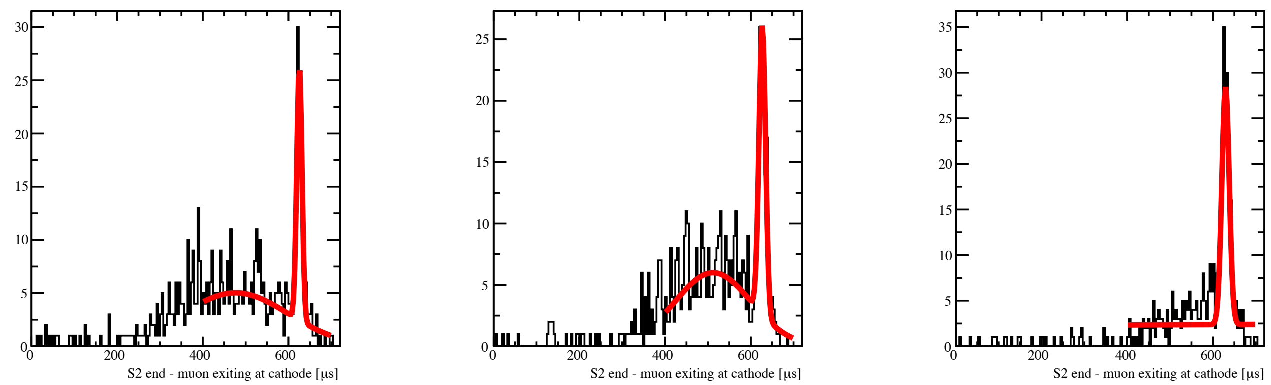
For the drift velocity analysis (in CRT runs), out of the 16 extreme possible trajectories, I computed the shortest and longest possible drift length for each track and each PMT

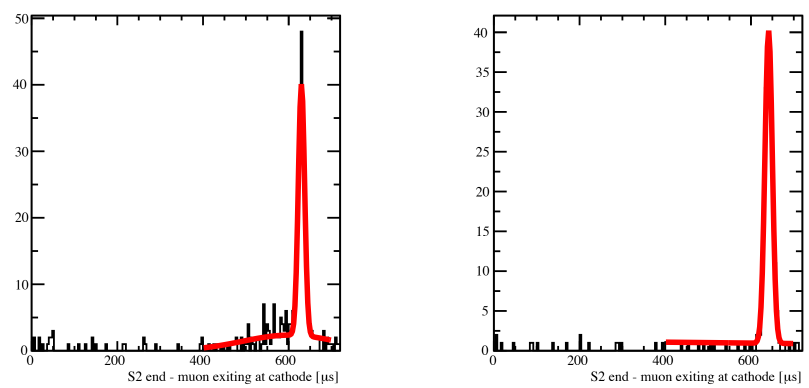


similar results for the other CRT run

- To be added as a systematic ?
- Must do the same for all CRT analysis where the track position is used

Drift Velocity measurement - data - S2 end

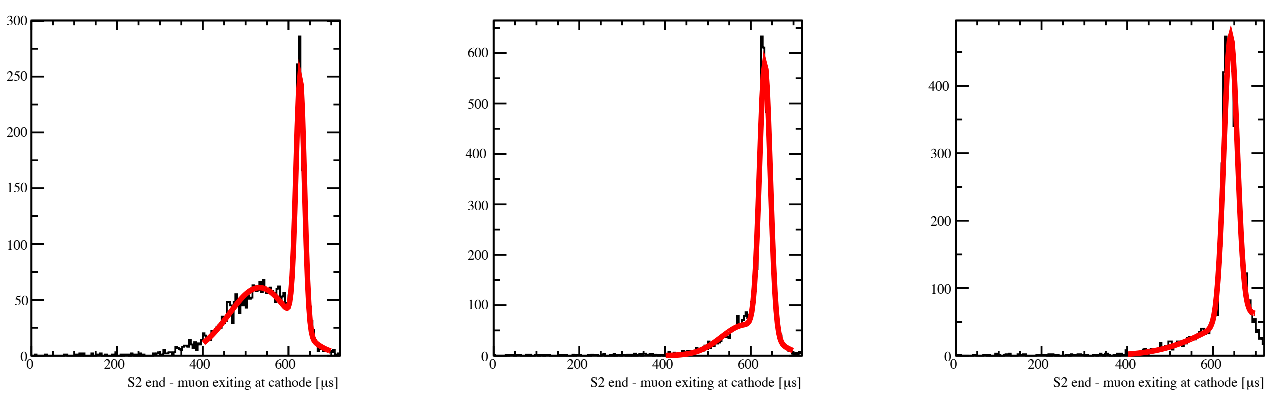


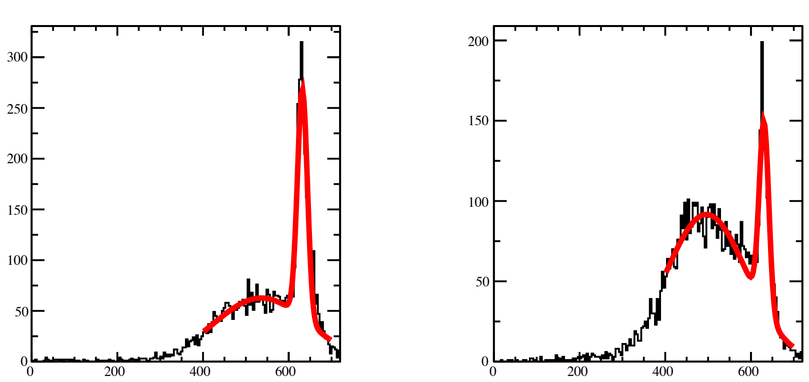


run(s) 986-987-988-989

amplification = 25.0 kV/cm

induction = 1.0 kV/cm





run(s) 840-842_allMuons

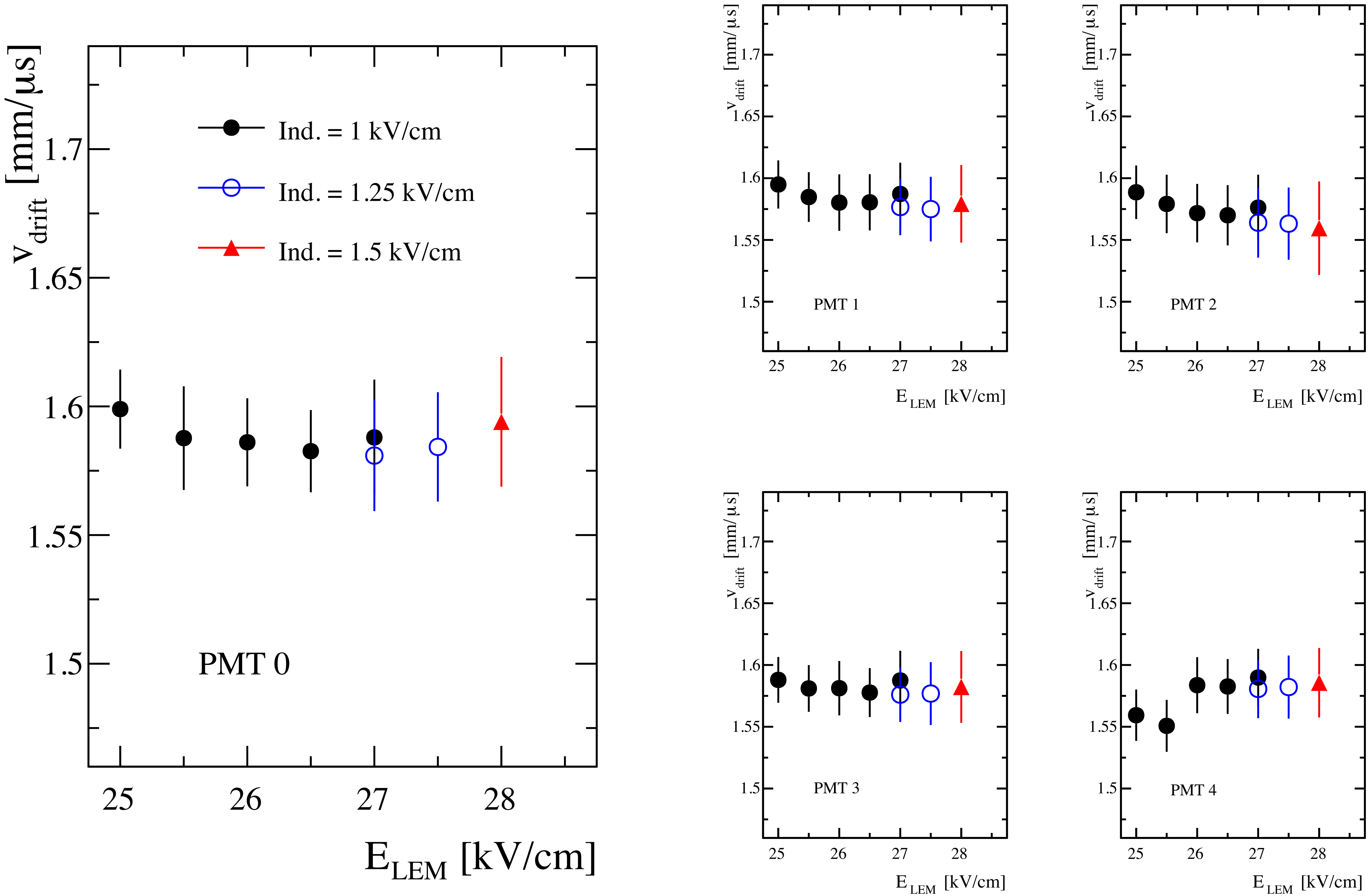
amplification = 28.0 kV/cm

induction = 1.5 kV/cm

End S2 end distributions are fitted with a sum of 2 gaussians:
- one for the continuum
- one for the L_{drift} = 1m peak

NB : Here I ask specifically for the muon to escape at the level of the cathode.
One can remove this requirement and be completely track reconstruction free

Drift Velocity measurement - data - S2 end



Drift Velocity measurement : remarks

On the uncertainties :

- Is it really 1m drift ? We do have 1000 mm from the end of the cathode largest ring to the anode
  - Does the field line do really start at the bottom of the cathode ring ? (cathode ring diameter is 34mm)
  - We have actually not a very precise idea of where was the anode wrt to the LAr level

  -> we extracted electron so LAr is above the extraction grid -> anode 13mm above LAr

  -> we amplified electron so LAr is underneath the LEM -> anode 3mm above LAr
  - None of the 8 LM gave a consistent value, and the position of the LM were not measured precisely

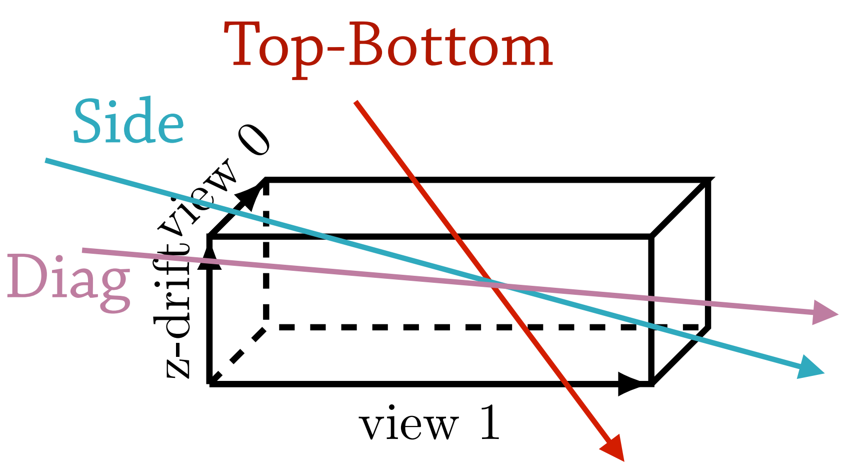
-> A conservative error should be 44 mm over 1000mm (4.4%)

  - The field cage was tilted: corner near PMT5 was lower by ~1.1 cm than on the other side

  Do we take it into account as well ?

S2 increase with field - MC analysis

Electroluminescence gain explored in the MC from 100 to 180.
For each case, 2k muons randomly generated from the anode to the cathode ("top-bottom")
At G_{el} = 120, 160 extra 2k muons randomly generated from up wall to low door ("side")
and 2k muons from wall to door ("diag")



Only the angular distributions change

S2 maximum peak distributions are fitted with a landau

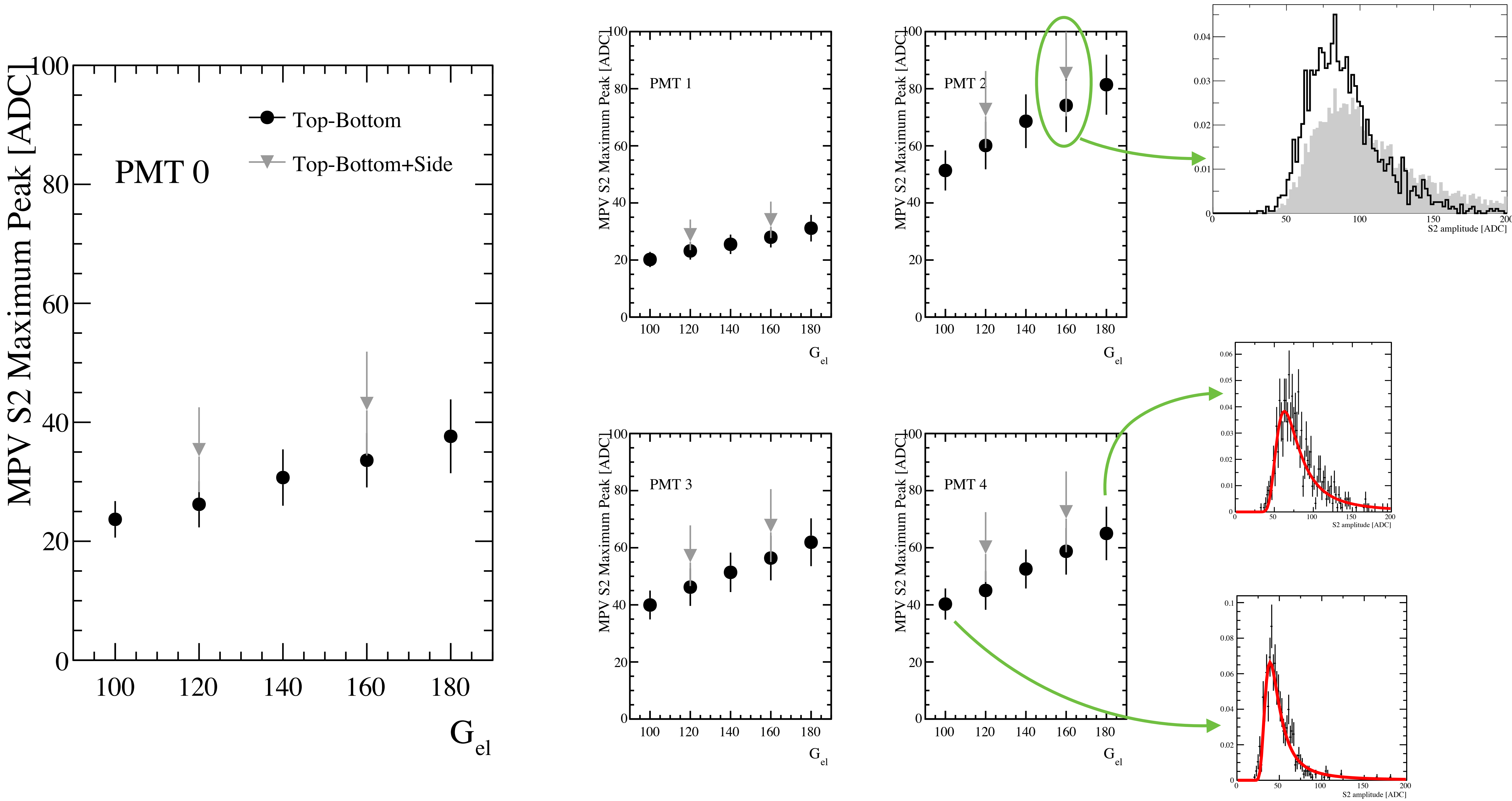
↳ the maximum S2 corresponds to the point along the track above the PMT - it should follow a landau-like distribution as for the dE/dx

S2 charge distributions are fitted with a gaussian

↳ the charge distribution is the (visibility-weighted) sum of all dE/dx, if our muons are at m.i.p. then it should be a gaussian

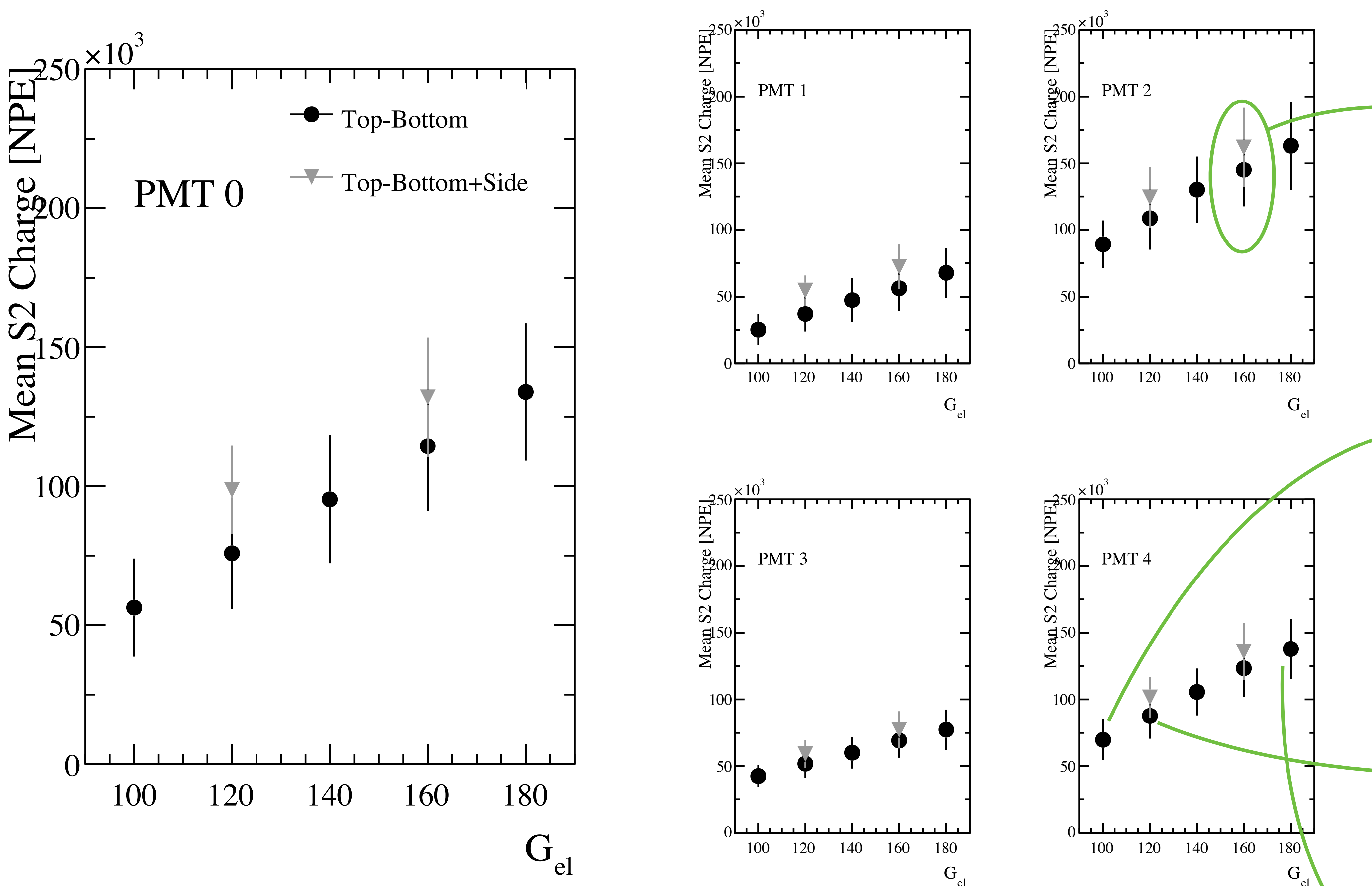
NB : same fit for data

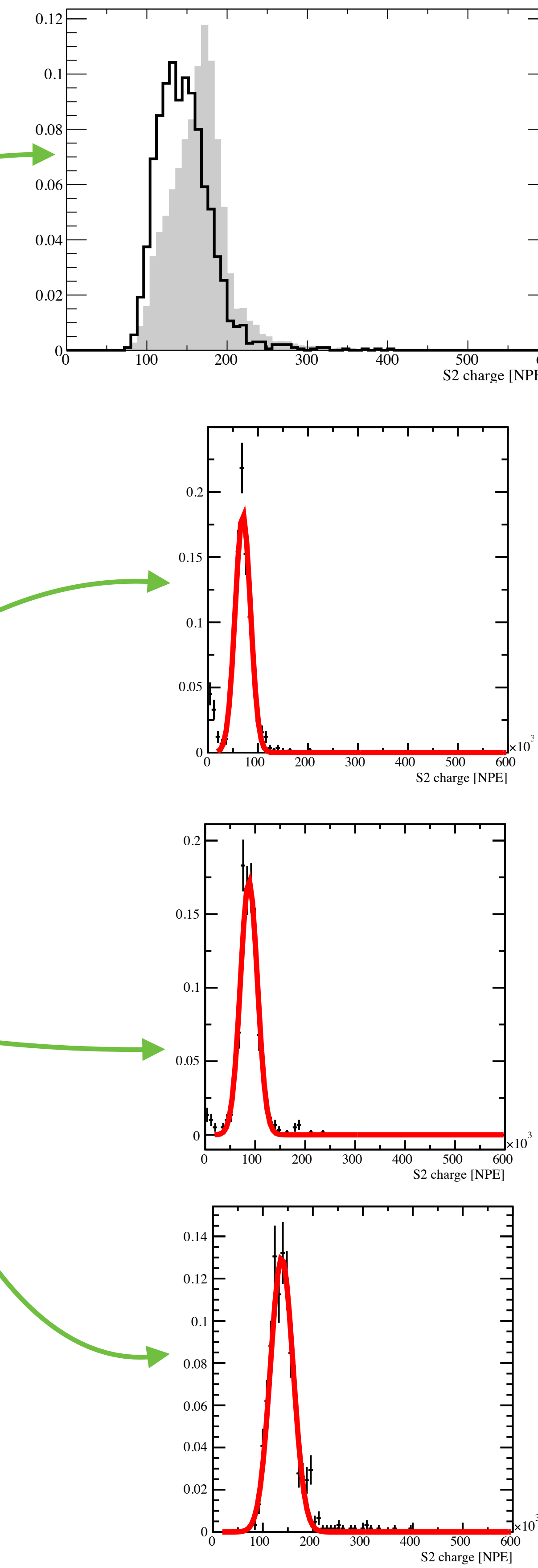
S2 increase - MC : S2 max. amplitude



- no problems with the landau fit for the S2 amplitude
- One can see that the track topologies changes the level of S2 collected by the PMT

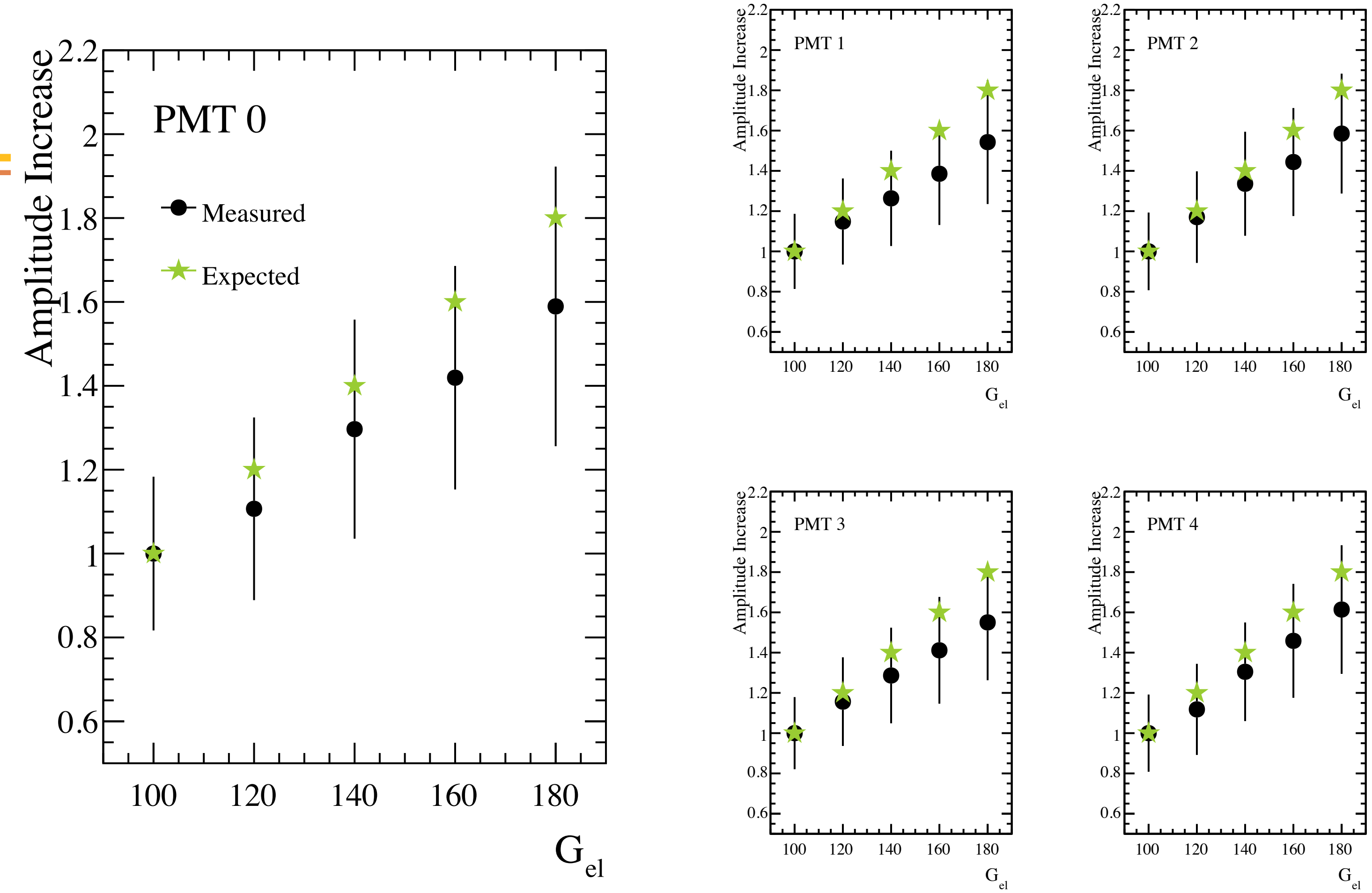
S2 increase - MC : S2 charge

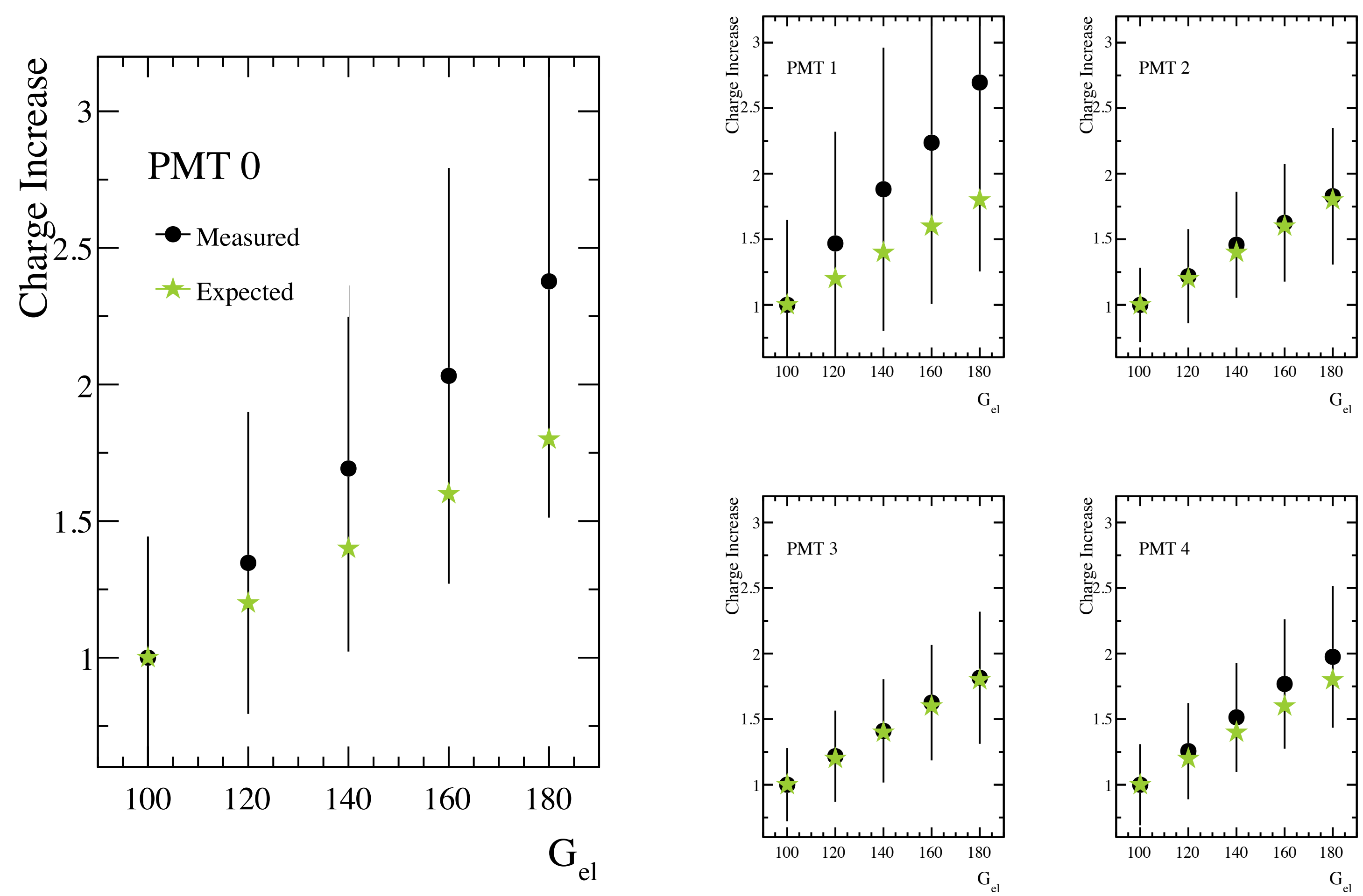




Again, one can the dependance of the track topologies

S2 increase with G_{el}





Looking at how much S2 increase wrt to the lowest G_{el} value is a bit dangerous as for the point at $G_{el} = 100$, the fits have harder time to converge (especially for the charge fit)

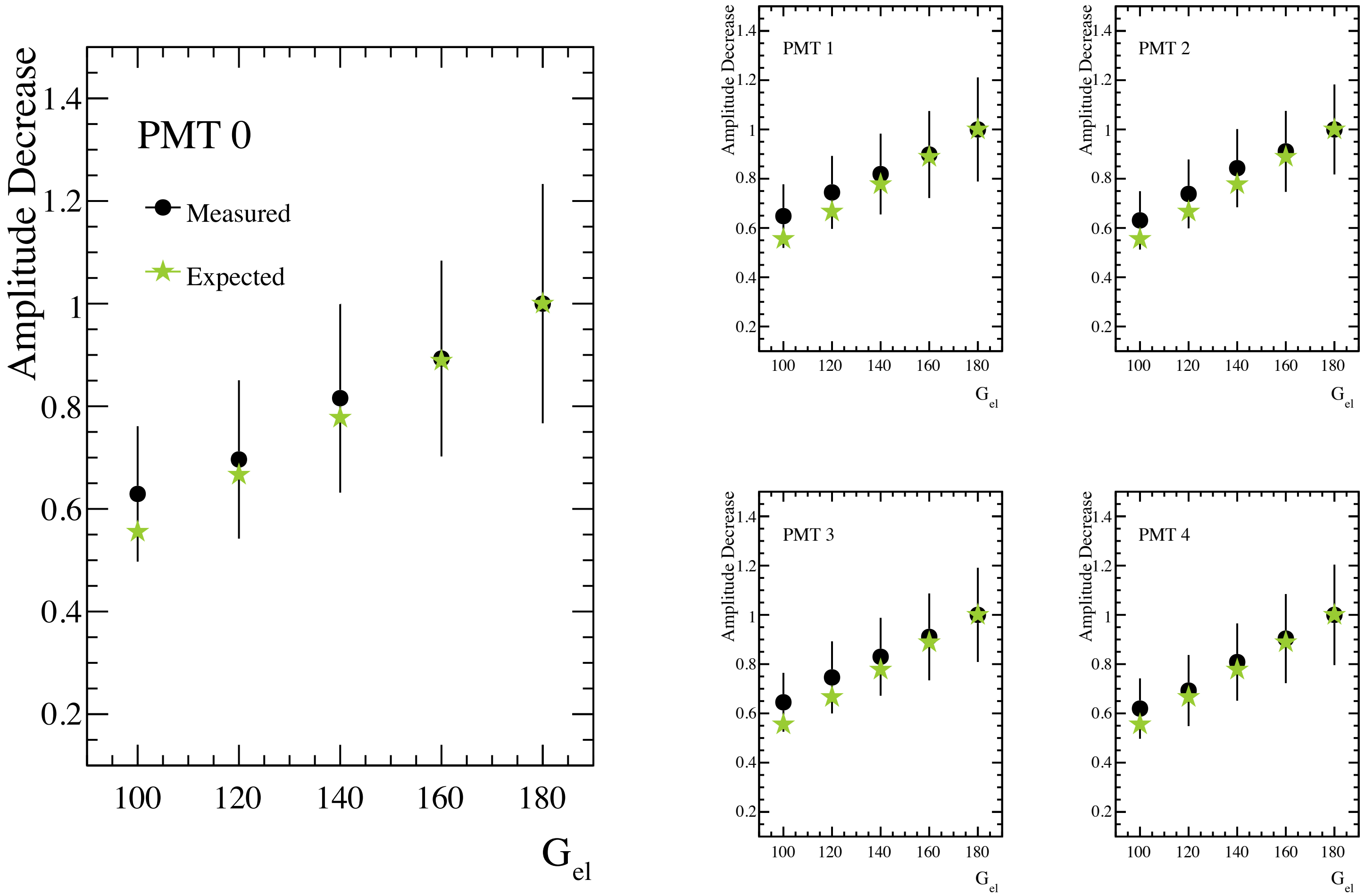
(NB : only looking at top-bottom samples)

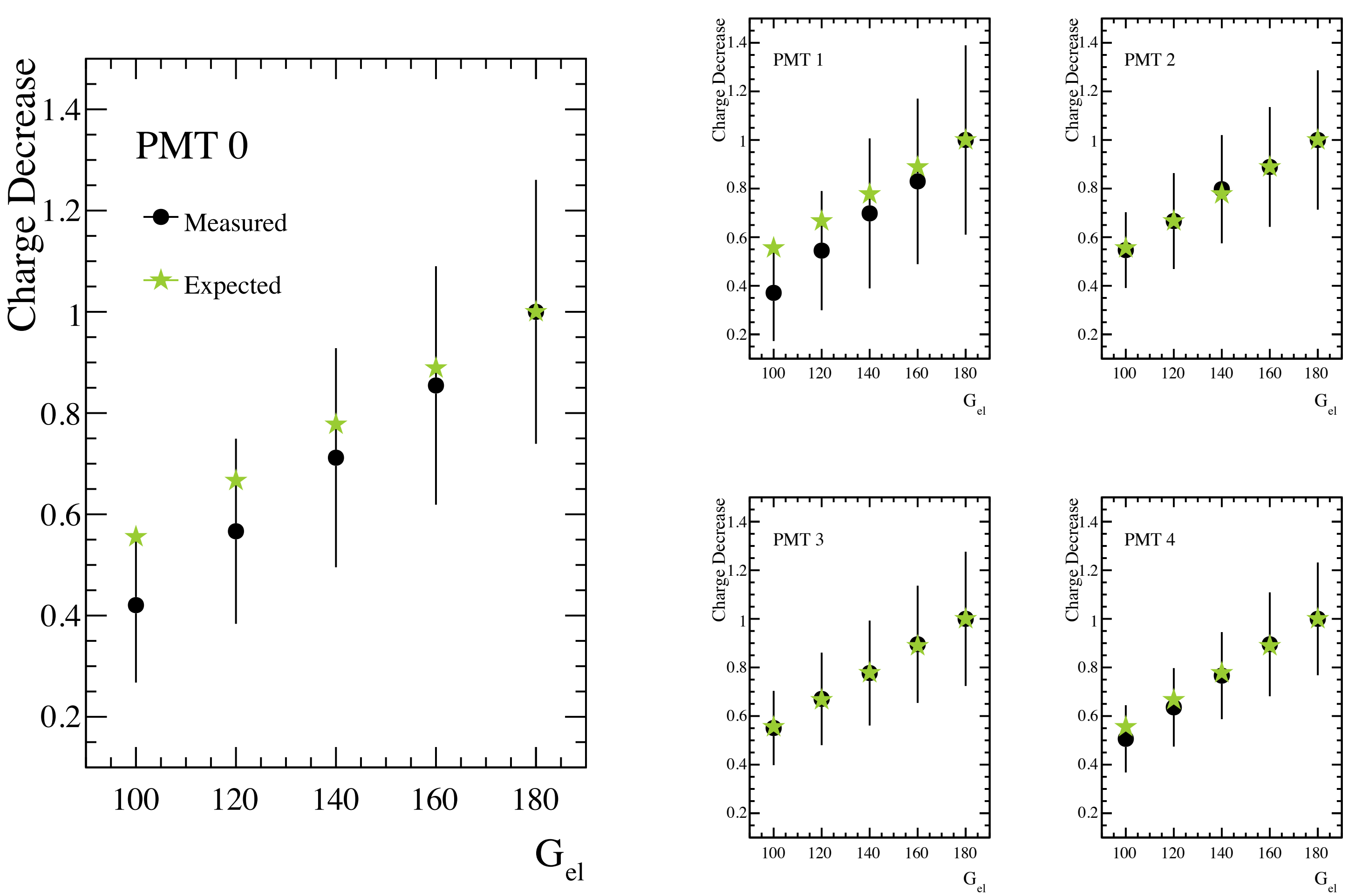
S2 decrease with G_{el}

Looking at how much S2 decrease wrt to the highest G_{el} value is a bit safer as the fits gets easier fro G_{el} = 180

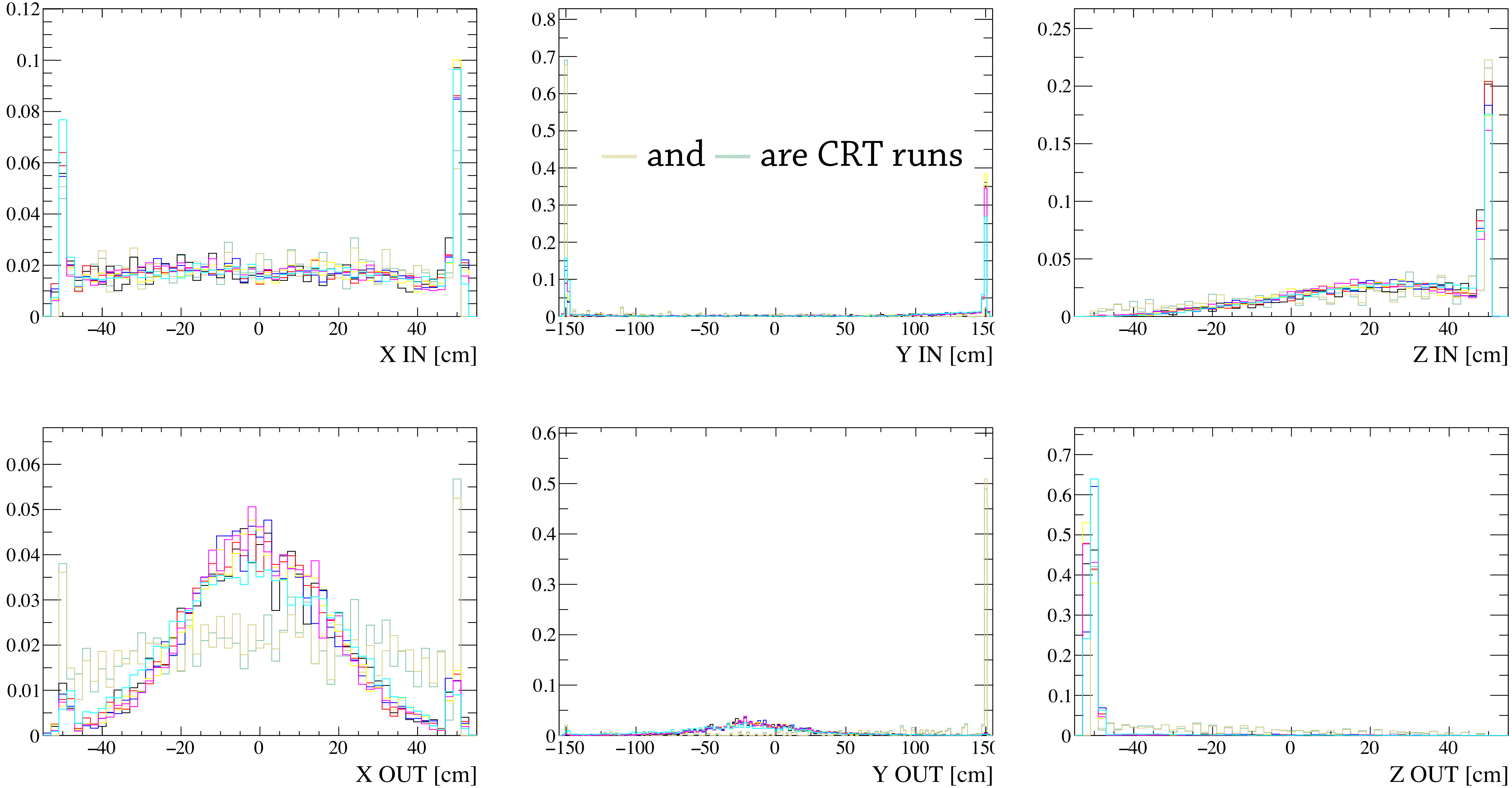
(but still all points relies on that fit)

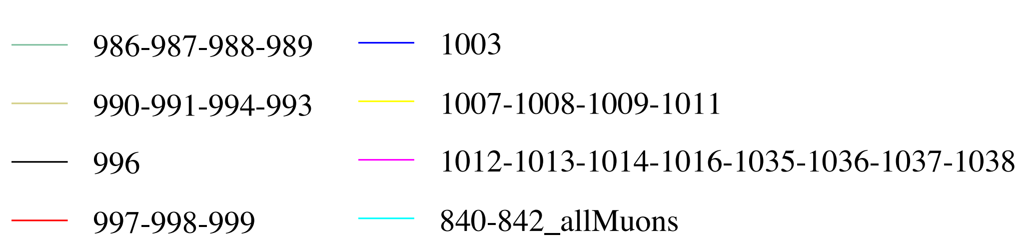
(NB : only looking at top-bottom samples)



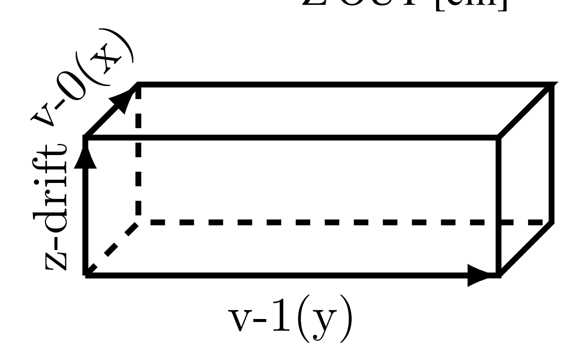


S2 dependance with E_{LEM} - Track topologies

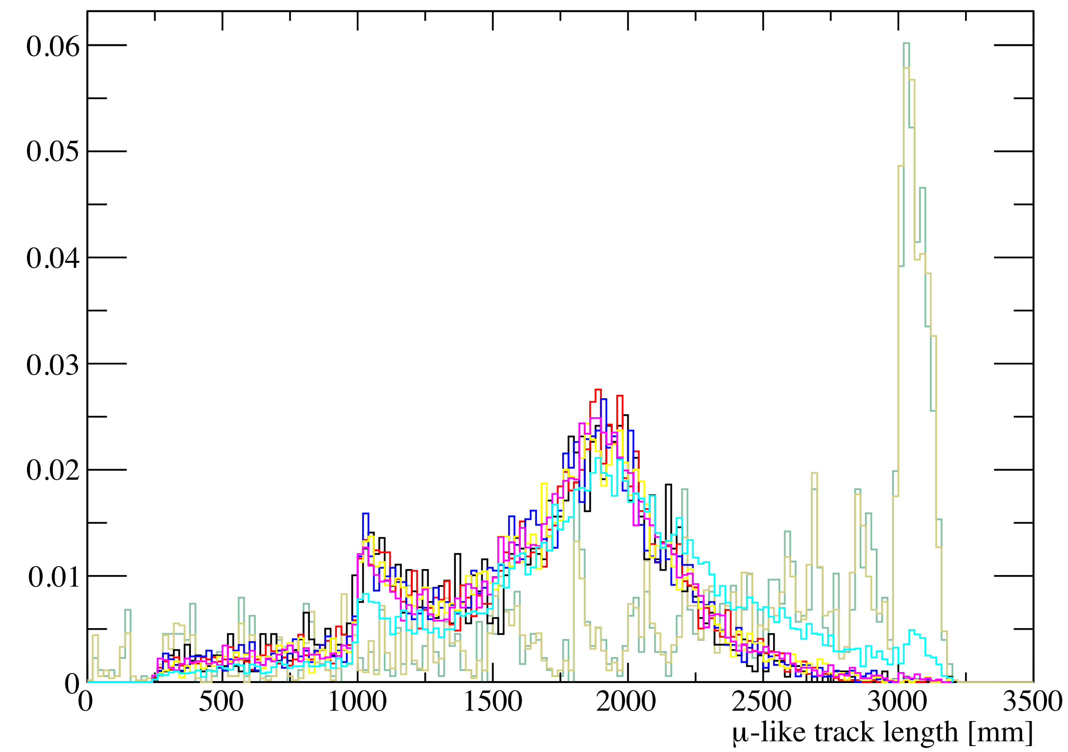


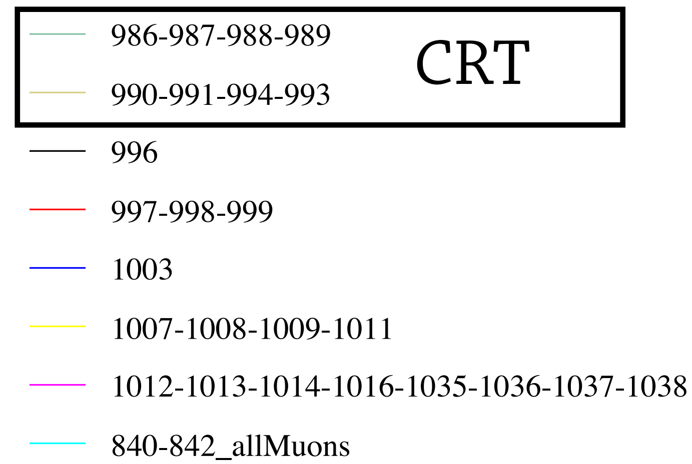


PMT runs have similar topologies
CRT runs have different topologies



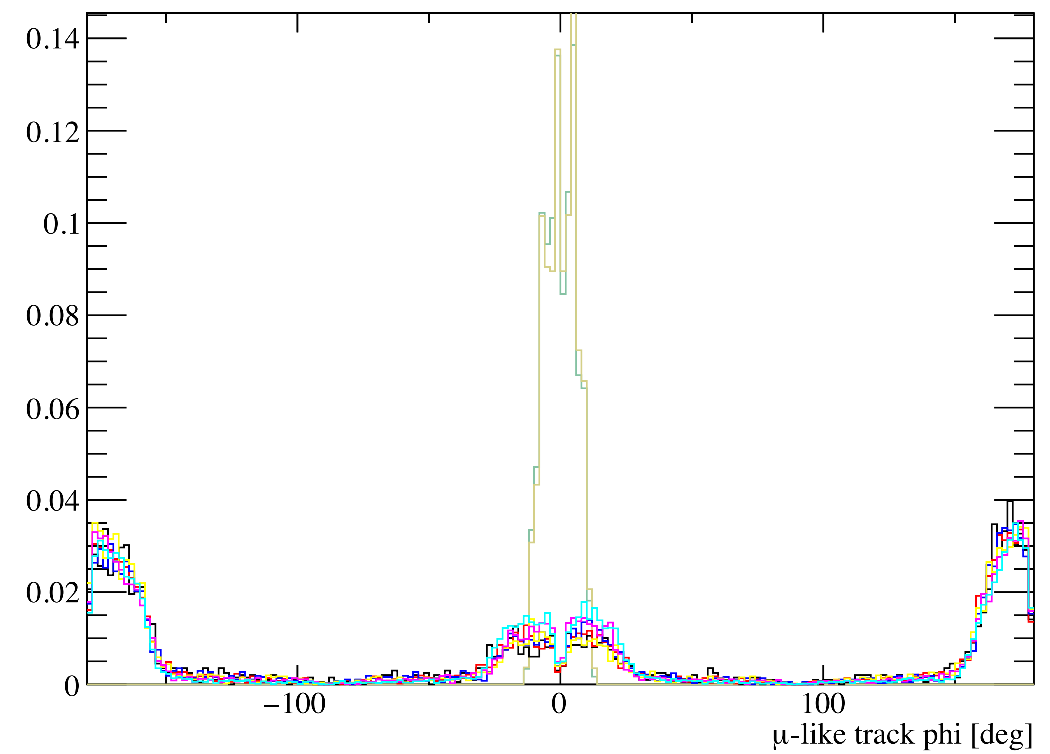
S2 dependance with E_{LEM} - Track topologies

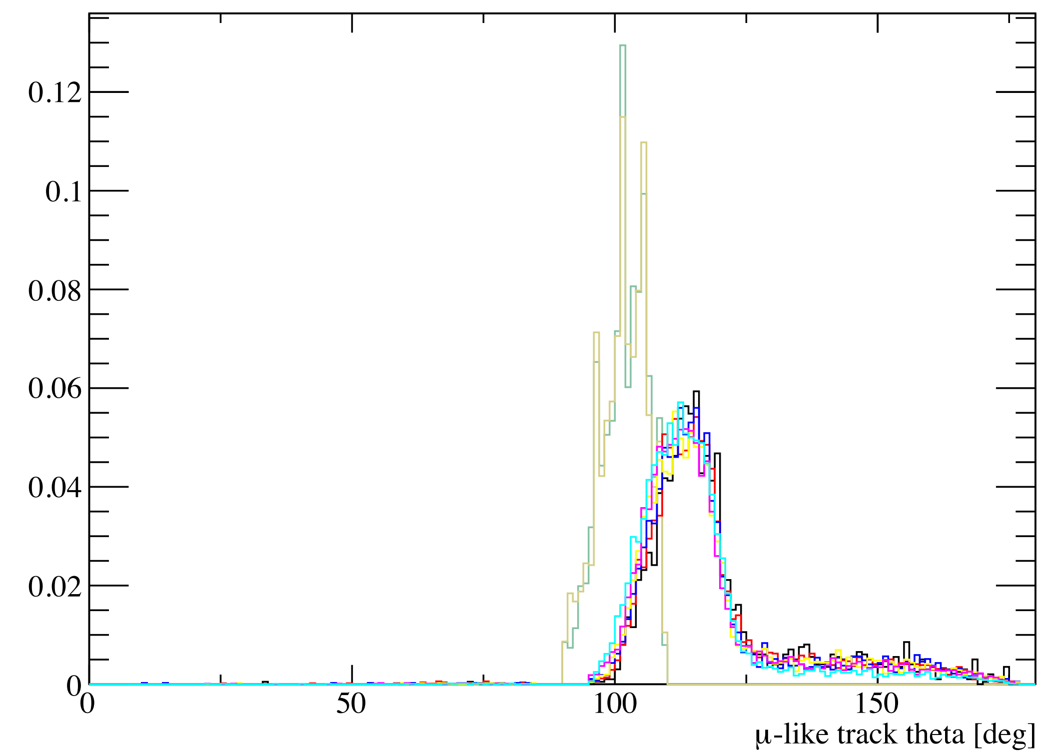




CRT and PMT runs have different topologies
PMT runs have similar topologies

— and — are CRT runs



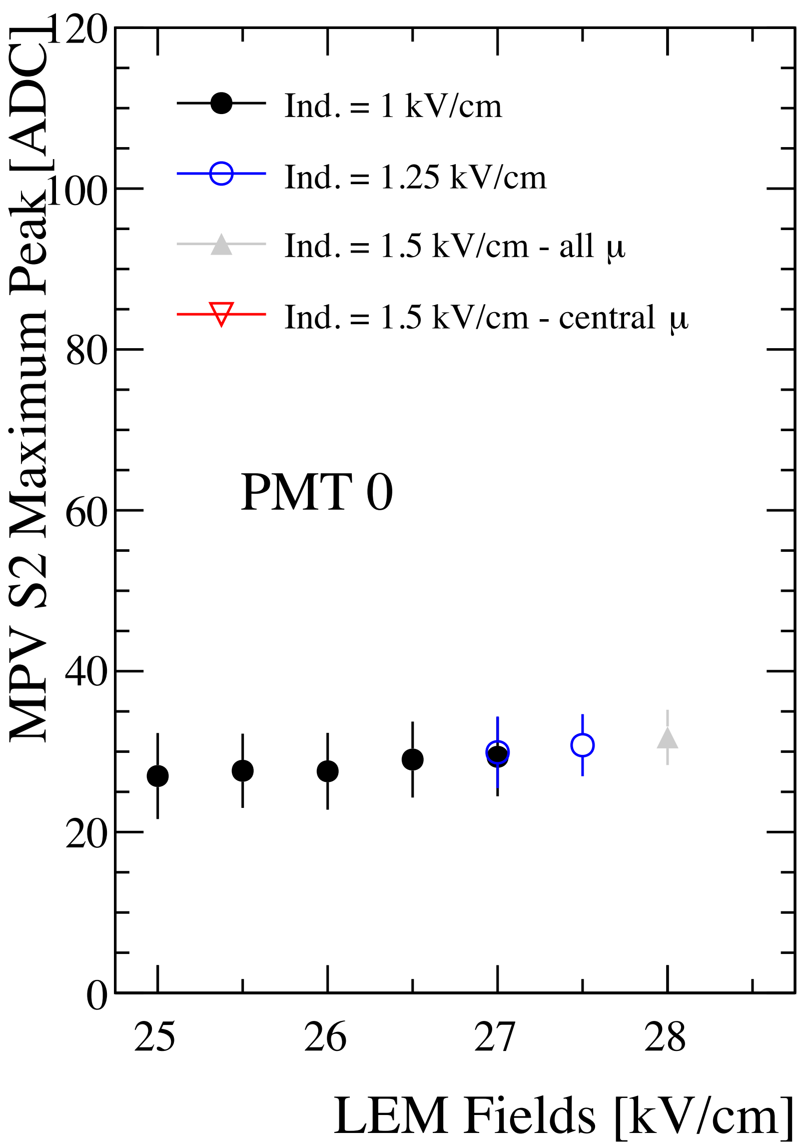


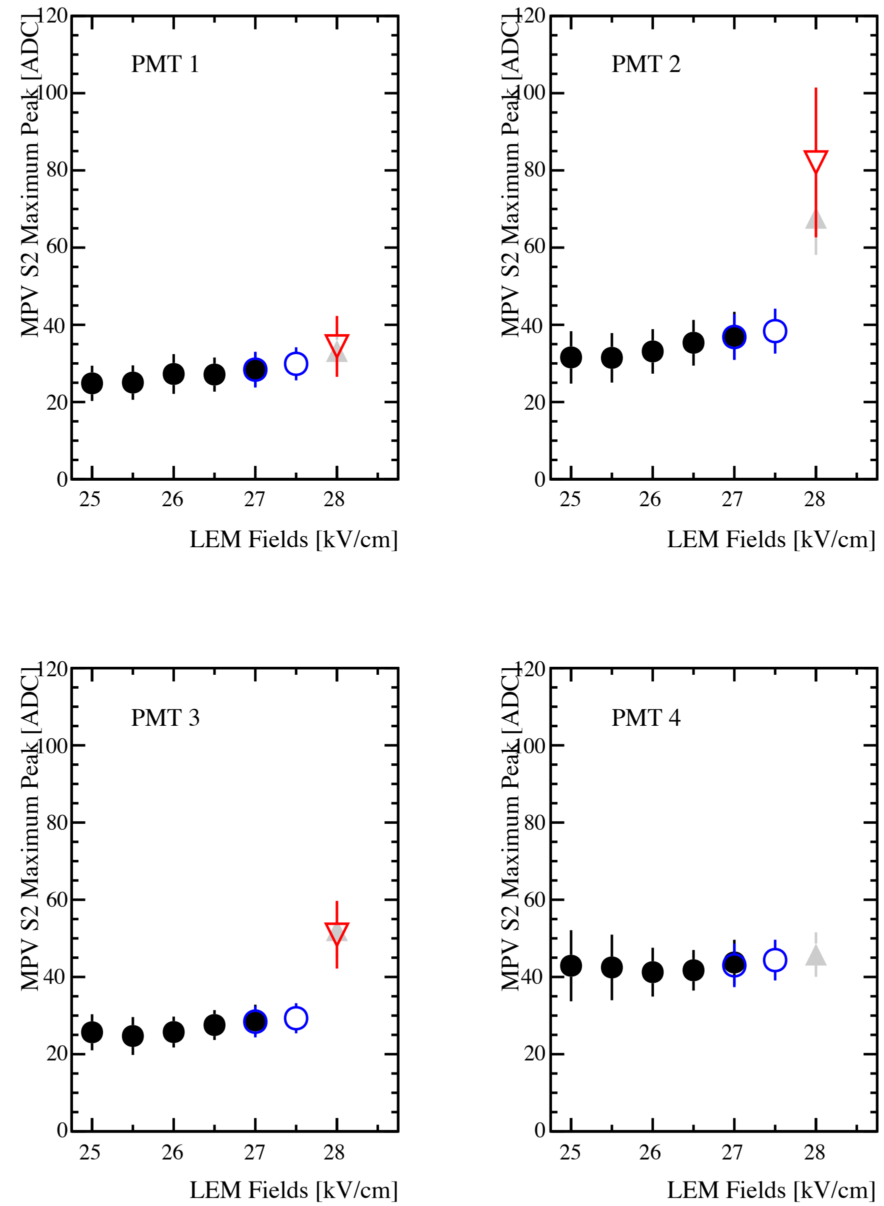
S2 dependance with E_{LEM}

We have seen that the amount of S2 charge collects depends on the track topology
-> in PMT runs, selected tracks have similar length, θ, φ, in and out vertices
-> statistics is quite large : at least 2k muons/configuration

From MC, the method seems to work, although ons may still think of a summary plot
-> maybe relative increase/decrease wrt to neighbor point ?

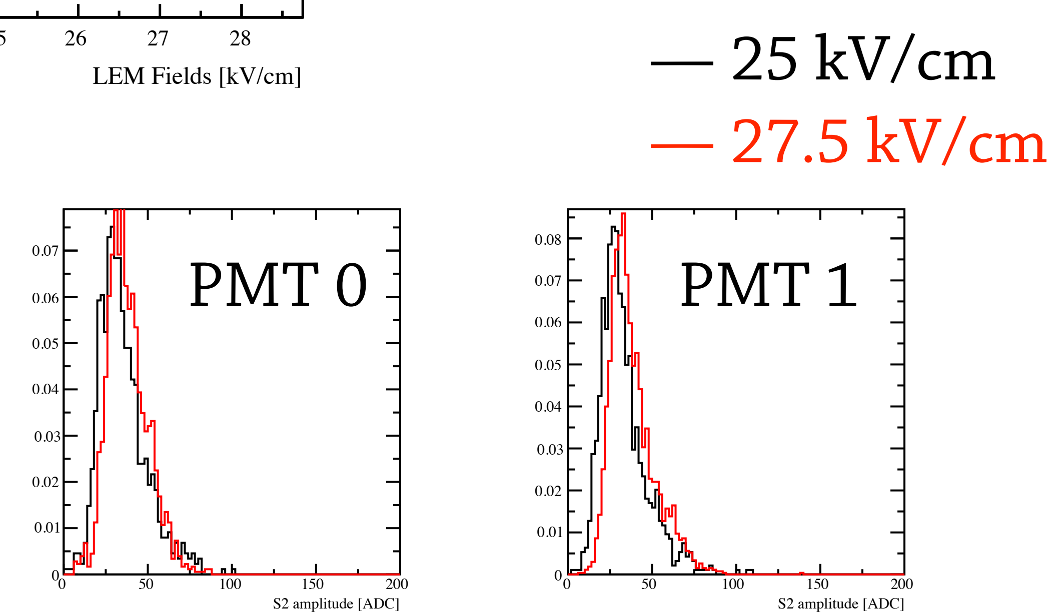
S2 dependance with E_{LEM} - S2 max. amplitude



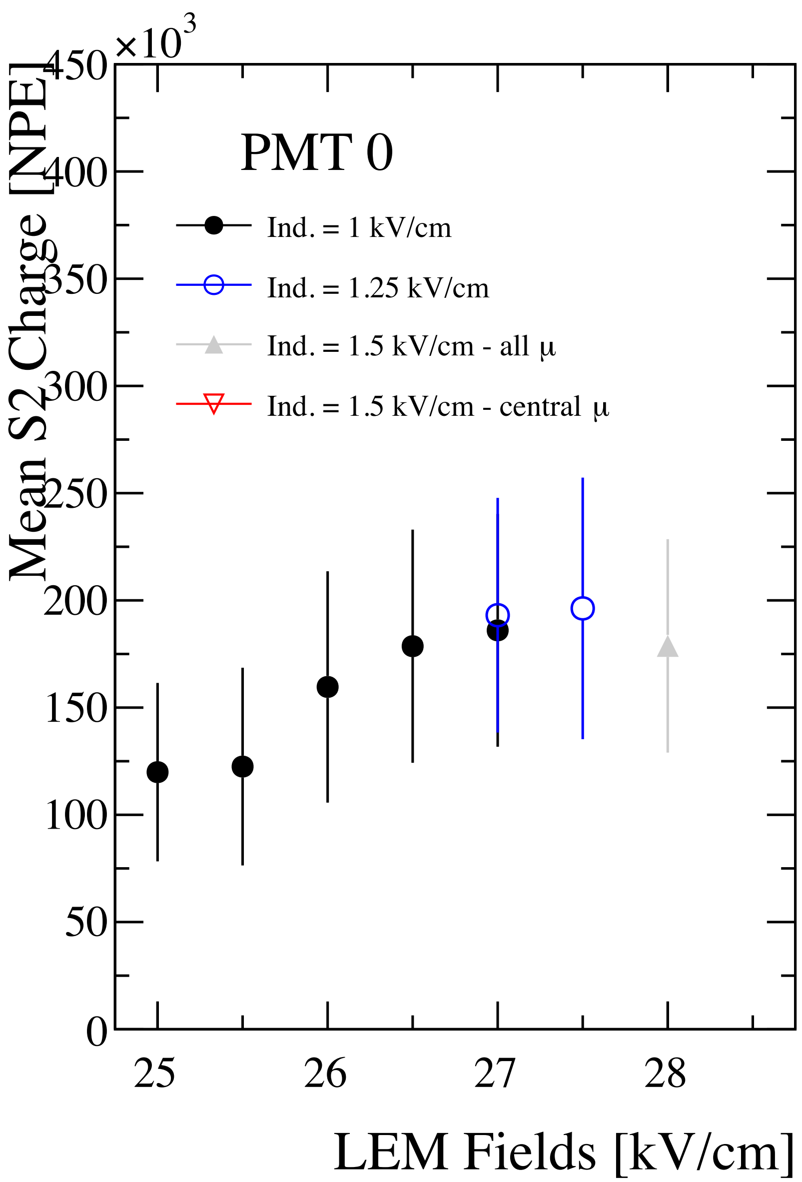


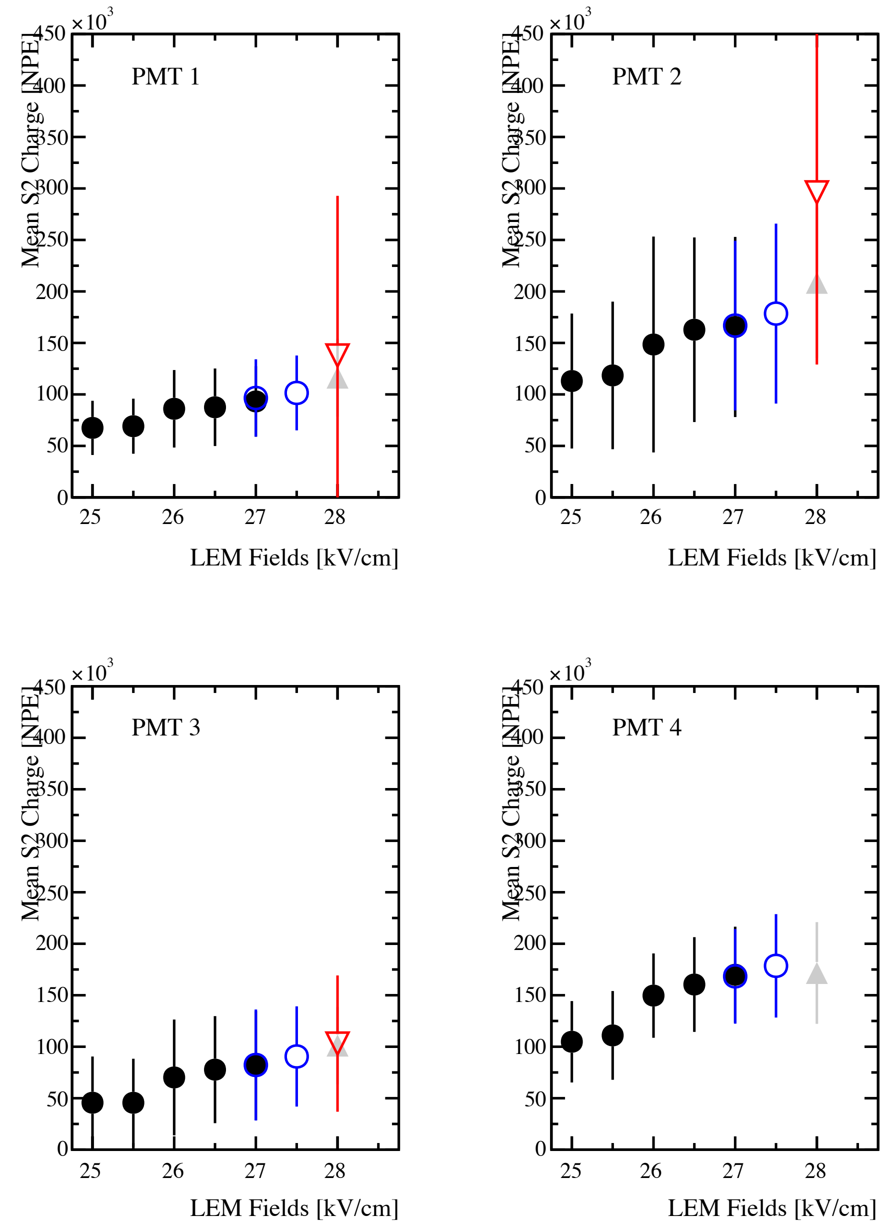
Almost no variation of the S2 max amplitude with E_{LEM}

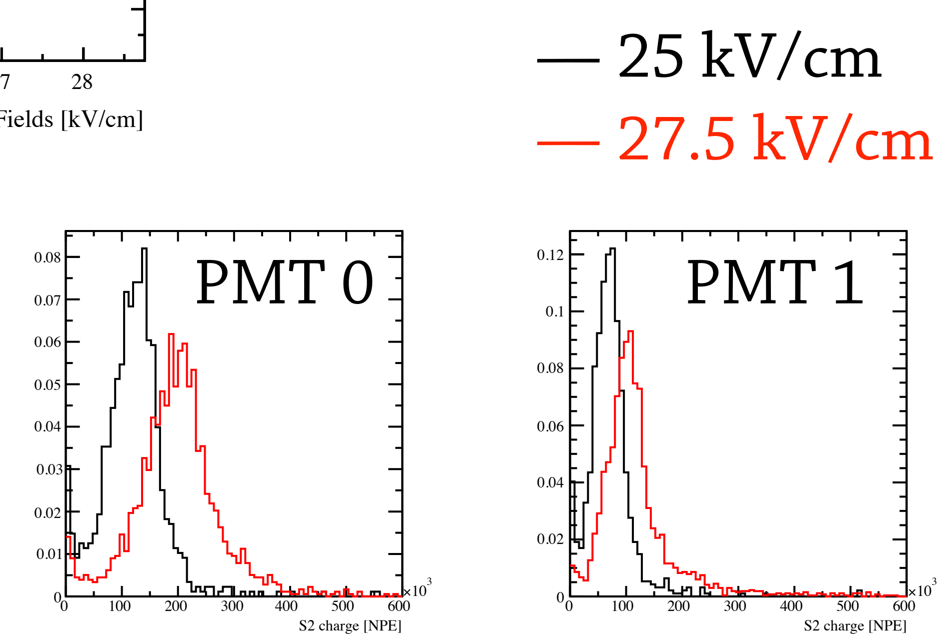
Not a fit problem, the distributions are very similar →



S2 dependance with E_{LEM} - S2 charge







- Some S2 charge increase is visible
- One can see the difference between CRT and PMT runs
- No effect of the induction field

S2 increase with E_{LEM}

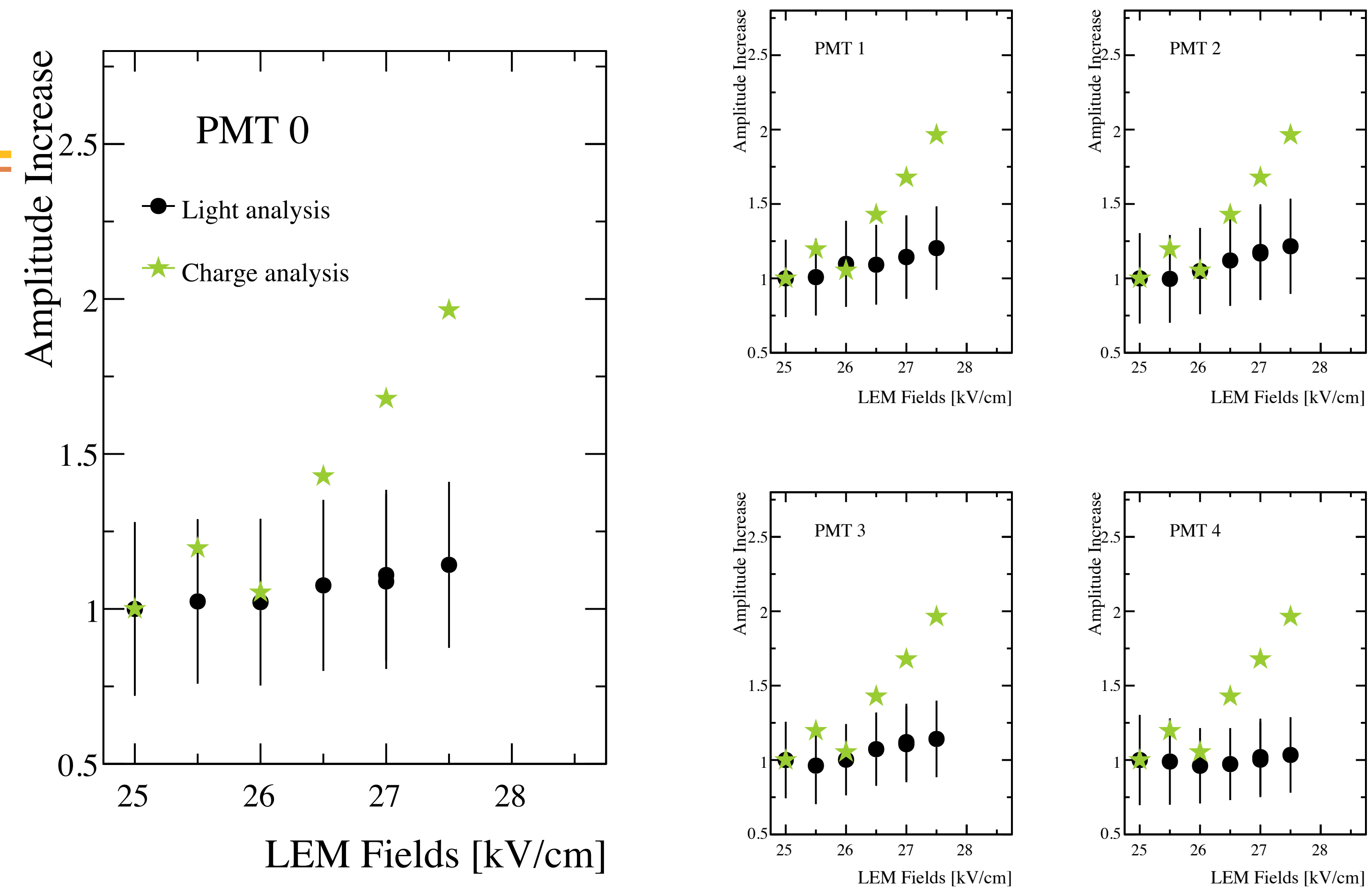
Charge analysis points are extracted from the Philippe Cotte PhD (not yet available & in french)

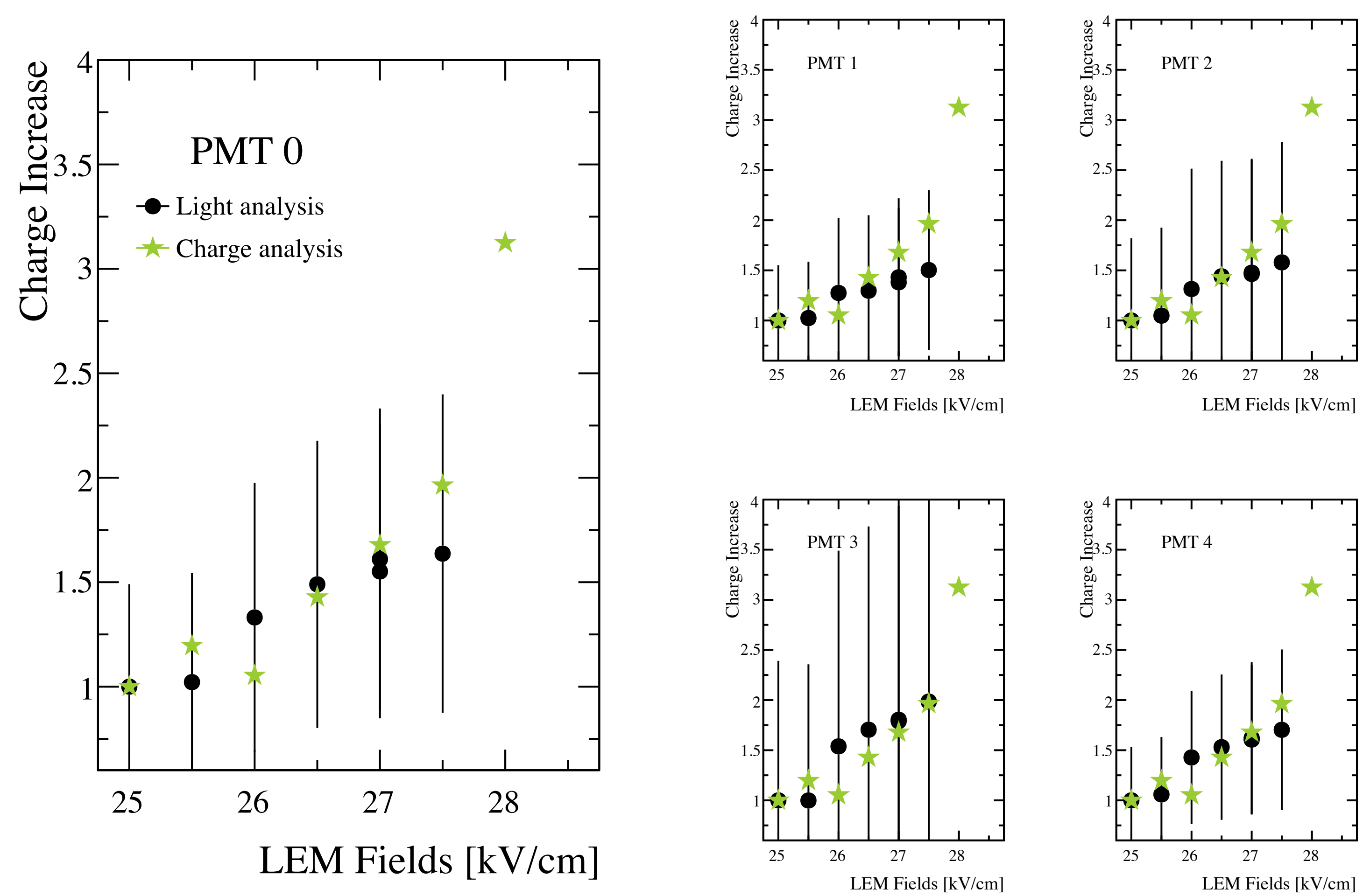
Again, looking at the S2 increase is not very safe/correct :
25 kV/cm point is a CRT run
low S2 level -> tougher fit

In general :

<u>using S2 amplitude</u> : very different results wrt to charge analysis

<u>using S2 charge</u> : comparable within large error bars





S2 decrease with E_{LEM}

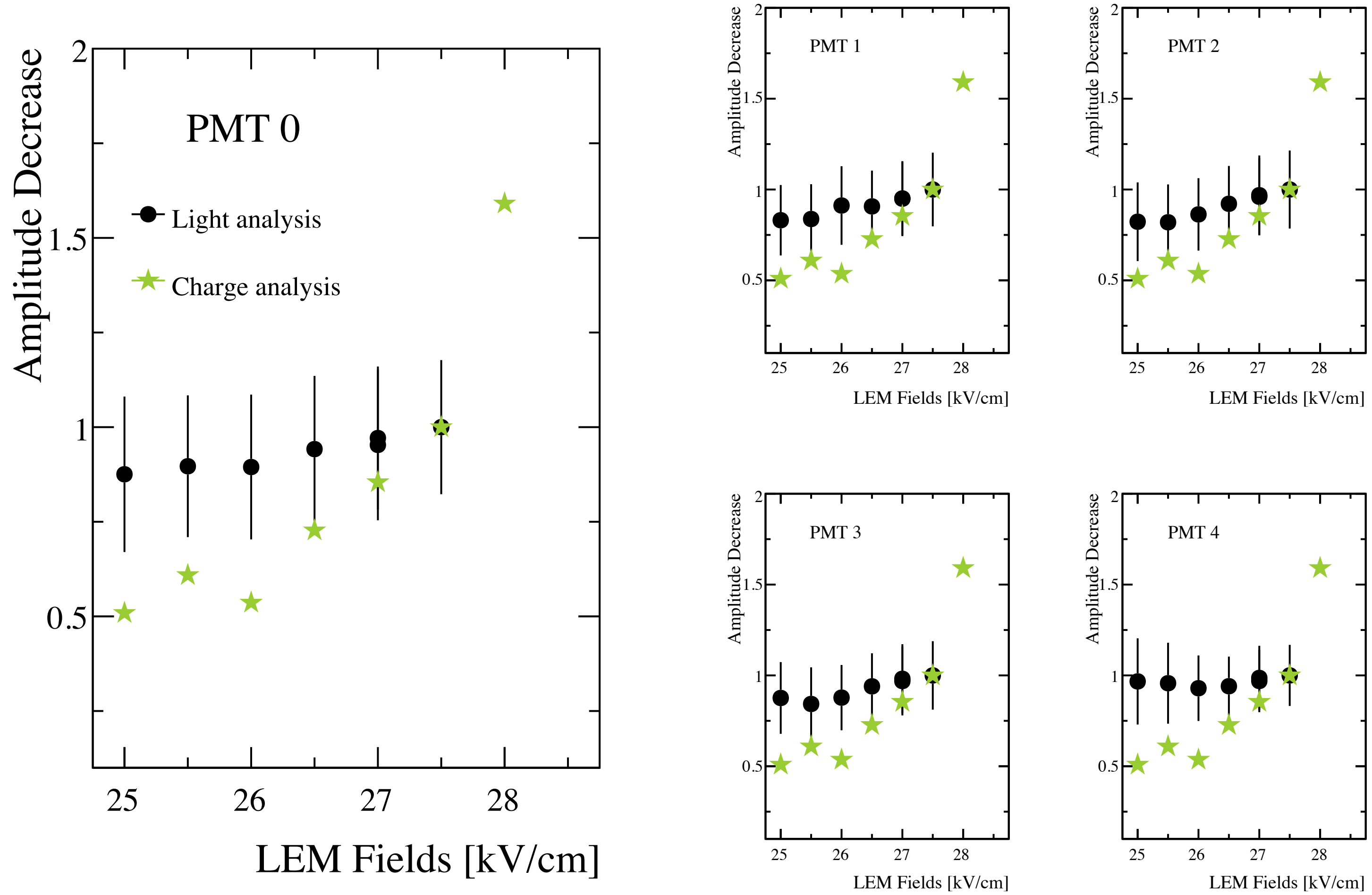
Charge analysis points are extracted from the Philippe Cotte PhD (not yet available & in french)

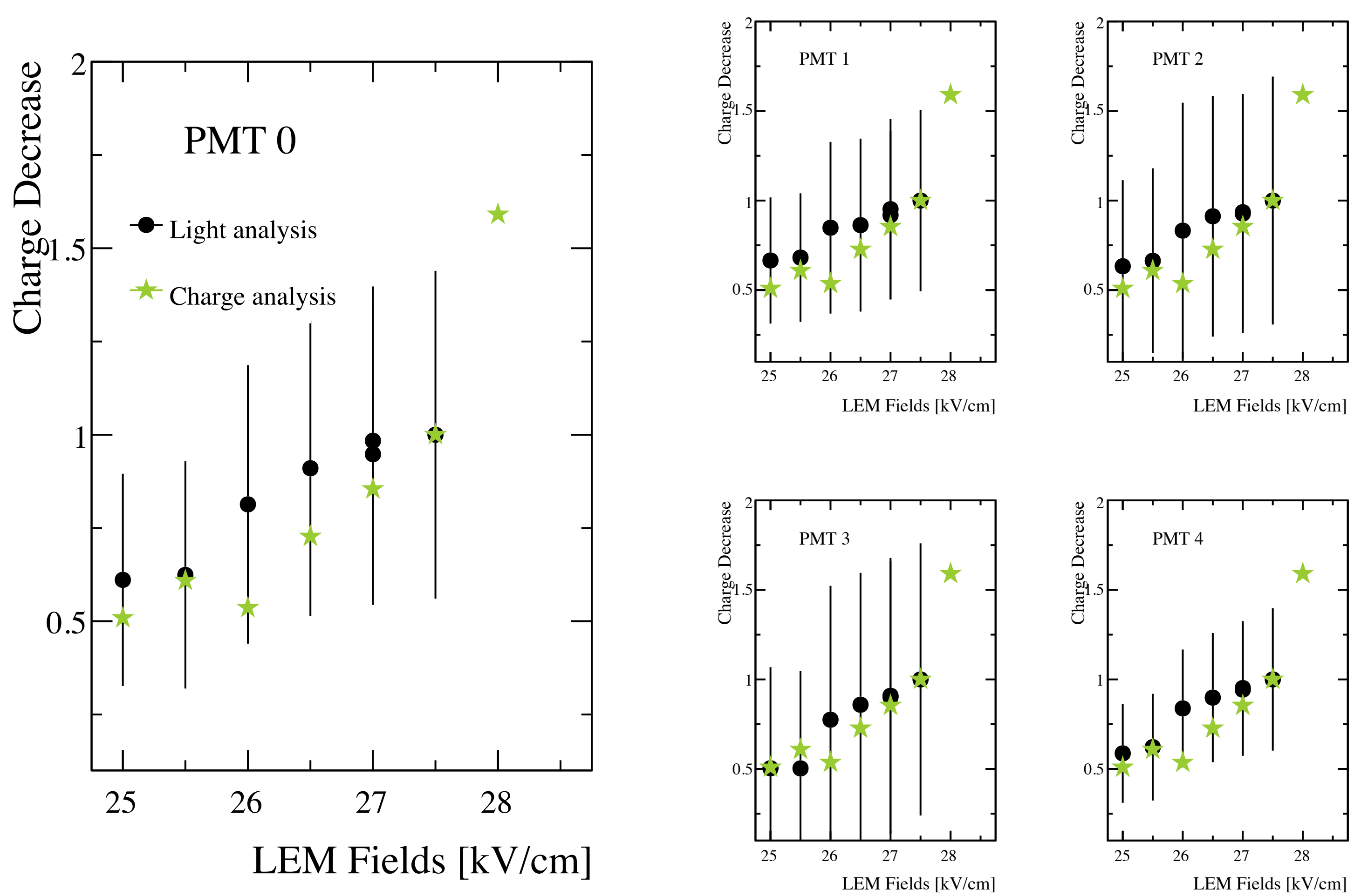
-S2 decrease done wrt to 27.5 kV/cm point as the run at 28 kV/cm is special

In general :

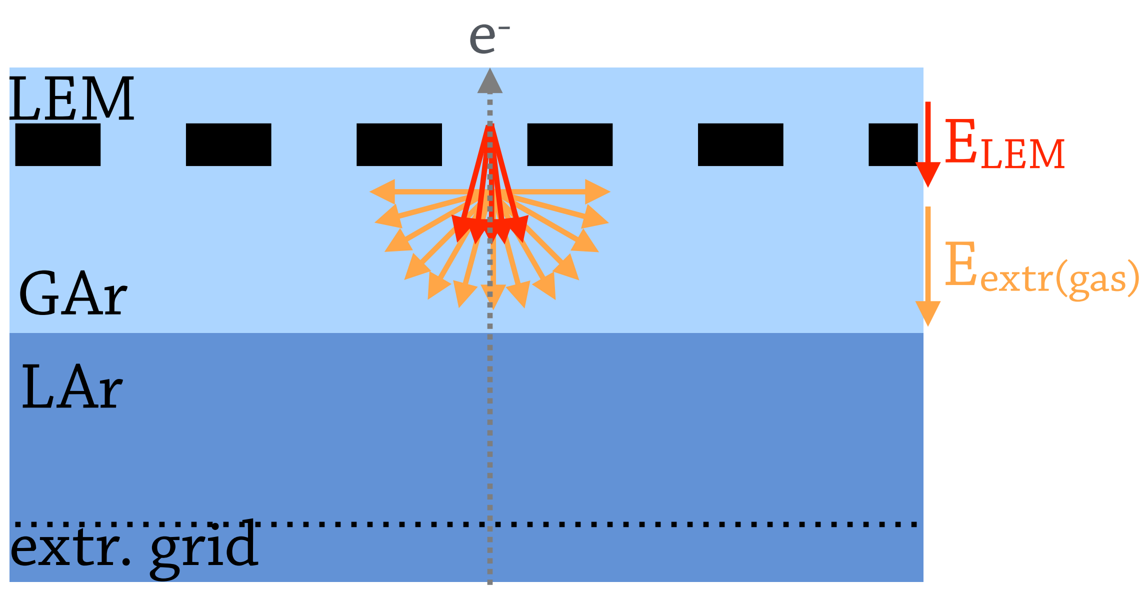
<u>using S2 amplitude</u> : very different results wrt to charge analysis

<u>using S2 charge</u> : comparable within large error bars





S2 level with field - My interpretation 1/2



We have two regions where S2 can be emitted:

1. The extraction layer
   - from the LAr level to the bottom of the LEM
   - S2 emitted in 2π (LEM absorbs the upper emission)
2. The amplification layer
   - inside LEM holes
   - S2 is very boosted along the drift axis (cf thorsten analysis)

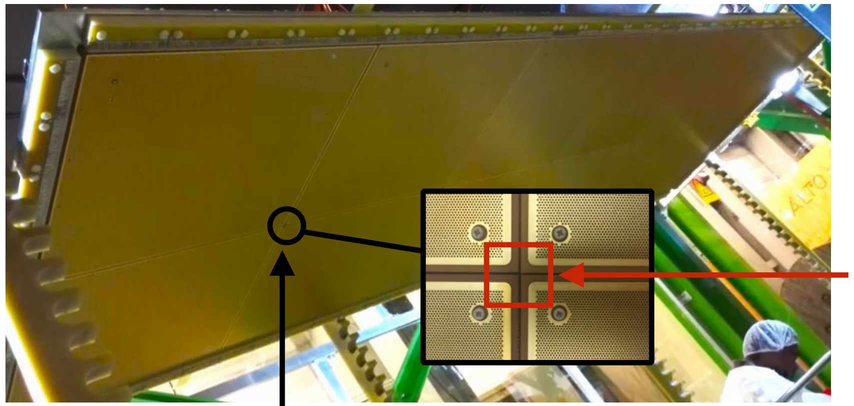
$$S_2 = \underbrace{G_{el}[\text{extr.}] \times w_0[\text{extr.}]}_{\text{small}\times\text{large}} + \underbrace{G_{el}[\text{LEM}] \times w_0[\text{LEM}]}_{\text{large}\times\text{small}}$$

From the runs we have looked at:
- The extraction field in gas is always very similar (~3.2 kV/cm)
- The amplification field is quite low
  Charge analysis claims a LEM gain of around 2-3 at most

-> In those runs, we mostly see the extraction S2 and a tiny fraction of amplification S2
-> For those runs, the charge analysis is sensitive to the amplification field (~same extraction & induction)

S2 level with field - My interpretation 2/2

In the 3×1×1, the PMTs are inconveniently located underneath LEM junctions



This is an inactive area !

e.g. PMT 0 (or 4) is just under these 4 LEM corners

When we look at the S2 max amplitude, we can barely see the amplification S2 as the LEMs are inactive there :

-> Explains why the S2 amplitude seems to be almost independent of E_{LEM}

-> S2 amplitude is mainly S2 extraction and the extraction field is almost constant

-> This feature is not implemented in MC (it is for the charge, not for the light)

When we look at the S2 charge (i.e. integrate over the whole S2 spectrum) we pick up some amplification S2 thanks to the Rayleigh and the opening angle of the S2 emission

-> S2 charge is sensitive to E_{LEM}, although not as much as we simulate in the MC