Few notes on KL tuning

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I. KL tuning using December 2011 data

1. **Description of geometry:** It is clear that correct geometry for these data is unknown, there are some guesses about what was the distance between TOF0, TOF1, TOF2. The exact distance between TOF2 and KL is not at great importance. The numbers I got from Durga (who got them from Yordan) and which he claims he used for TOF calibration are:

   L01 = 7693.4 mm
   L12 = 2500.0 mm

   It seems that L01 is taken from some survey, while the round number L12 suggests it is taken by eye.

   Now the first problem arises with TOF calibration itself. From time-of-flight electron peak in data one can calculate how much is L01. The expectation is to get back the distance used for calibration, but I get ~10 cm longer. And this new number comes out from all three data runs 3253, 3426, 3407.
   At this point I can't do anything but to accept one of the two numbers and to put it in the simulation. I decided to take the calculated one. So I put L01=7.8 m and crossed fingers to get the electron peak at the same position as in data, but no... the peak was again shifted. The end of this story is the that I had to fix the distance at about 7.74 m (the middle of claimed and calculated numbers) in order to center the electron peaks in MC and data. (Fig.1)
   The situation with L21 is even worse so I will skip it in the rest of this notes.

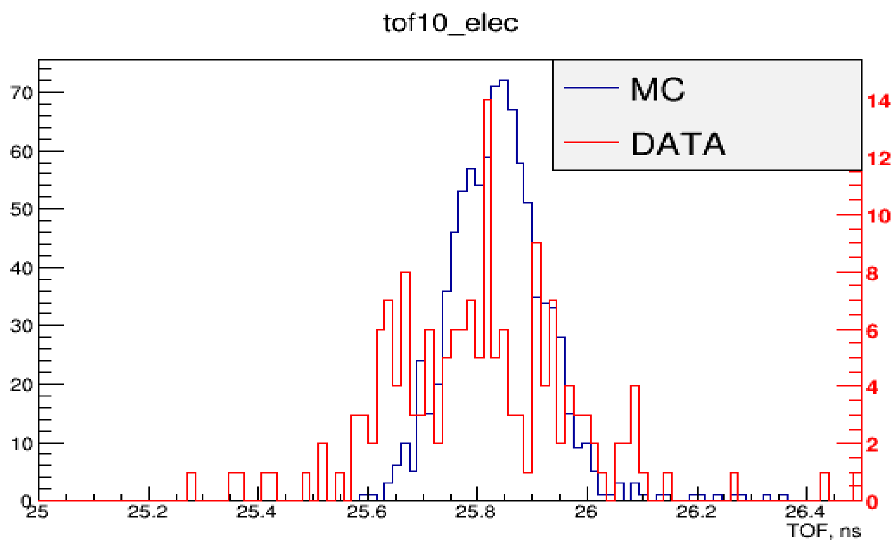

Fig. 1. Electron peak from data and MC. It is important the position of the peak, but not its spread.

2. **Description of TOF distributions for muons**. Once the distance L01 is already known we can use it and to calculate momenta of muons (255 MeV/c) from data set using TOF10 for muons. The first check here is to simulate muons with calculated momenta. On top of calculated momentum one should take into account the momentum loss in TOF0 station. An estimation at about 15 MeV/c is made. Unfortunately I had to double this loss (to 30 MeV/c) in order to reproduce muon peak position. (Fig.2). It looks like that this difference comes again from calibration - 15 MeV/c additional momentum corresponds to about 10 cm difference. The sigma of the particle energy might be also taken from TOF distribution. Just taking the sigma of muon TOF peak and transfer it to momentum sigma (15 MeV/c). After this calculations are made the simulation is performed. The result shows that muon TOF peaks in MC and data coincide.

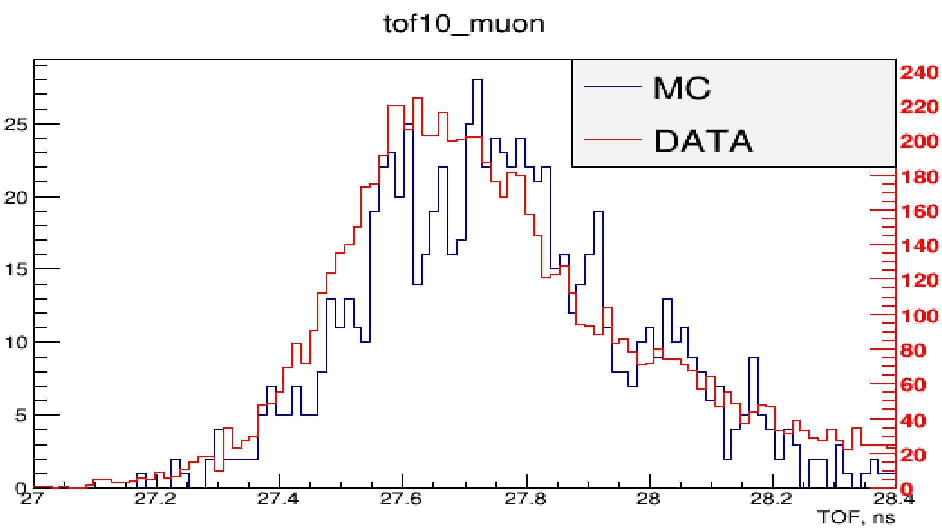

Fig. 2. TOF10 for muons for data and MC. The muon momentum is the sum of calculated one (255 MeV/c) + 30 MeV/c to compensate the energy loss. The sigma is 15 MeV/c.

3. **Center and width of KL ADC distribution.** Once we have correct momentum and sigma of momentum of incoming particle we can use it in order to center the adc peaks in KL data an MC through tuning the conversion factor(s). There are four places where this can be done.
- Smearing of produced photons in scintillator fibers. They obtain Poisson statistic so such is applied. In principal one can replace it with Gaussian because the number of photons created is large enough for such an approximation and then can play with the gaussian sigma, but I think it is hard to be defended.
- photoelectrons created on pmt photochatode also have poisson statistics. Here we can't replace it with gauss because the number of photoelectrons is small enough so such an approximation is illegal.
- pmt gain also obtain statistical properties. But this time it is not neither poisson nor gauss. Nevertheless it turns out (ref.: *ipnpr.jpl.nasa.gov/progress_report/42-68/68H.PDF*) that for simplicity one can use gaussian distribution with mean = pmt gain and sigma = half of the gain. KL pmt's have gain ~2x10^6, so their sigma is simply 10^6. I introduced this level of uncertainty in the code as well.

- conversion from photoelectrons to adc, - a simple number.
Then with first three numbers in hand I decided to tune adc conversion factor using muons from run 3253. In Fig.3 is shown the result for KL adc smearing for muons in run 3253 and MC.

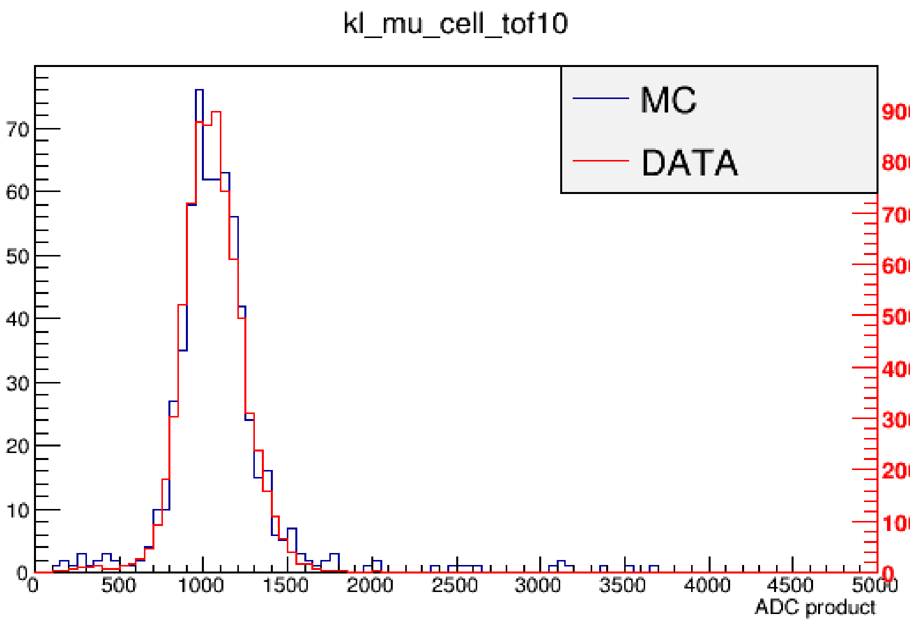

Fig. 3. Comparison of KL adc spectrum for muons from run 3253 with muons from MC. The simulated muon momentum and sigma are taken from data TOF distribution. Here MEANmc=1060, MEANdata=1058, SIGMAmc= 167 =SIGMAdata.

So there was no need to change the conversion factor. Amazing...-:)... But wait, lets see how digitization with these numbers works for G4Beamline MC sets (prepared by John) and real data (runs 3407, 3253, 3426).
In Fig.4 is shown KL distribution for muons in run 3407. What is visible is that:

i) data are shifted to right, which means more dEdx. This can be explained by tof distribution in Fig.5, where data are shifted to the right too, which means less energetic particles, therefore more dEdx.

ii) sigma is larger for data, but this is because the momentum spread of data is larger (again Fig.5).

In Fig. 6 and Fig.7 are shown KL distributions for muons and pions in run 3253. In both species data distributions are wider. But this can be explained again by broader momentum (Fig.8).

The situation for run 3426 is similar.

My conclusion is that current smearing describes correctly the width and center of the muon and pion peaks. It is introduced in the code now. In any case for a while I left the possibility to change adc conversion factor, gain and sigma of the gain by datacards.

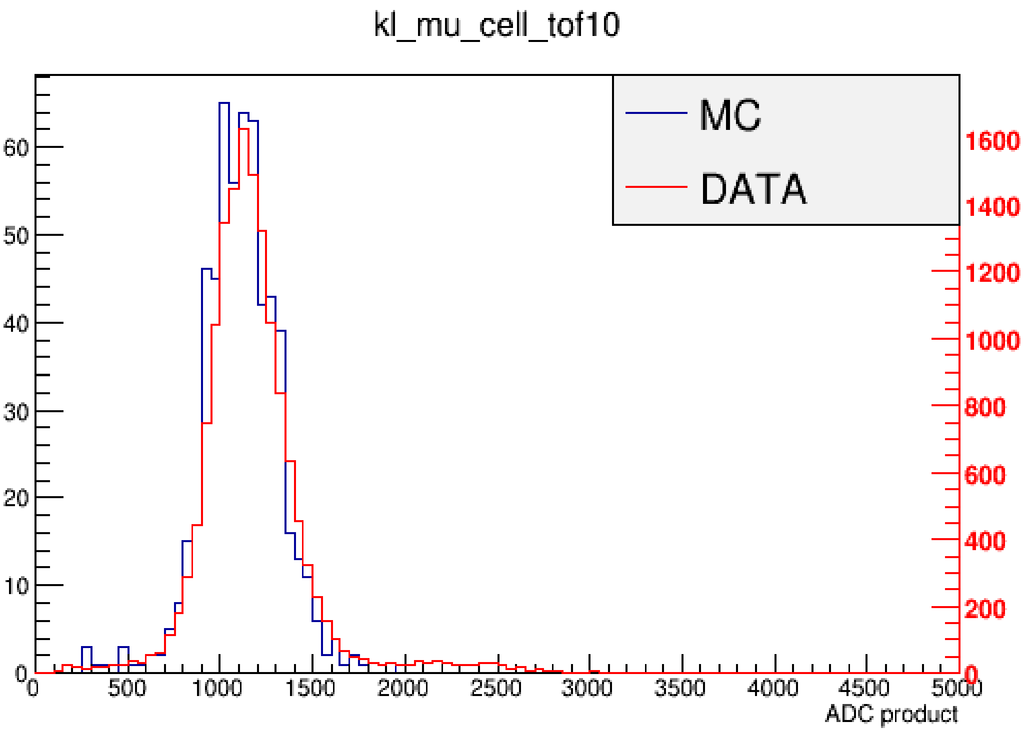

Fig. 4. KL adc spectrum for muons run 3407. Here MEANmc=1120, MEANdata=1145, SIGMAmc= 177, SIGMAdata=187.

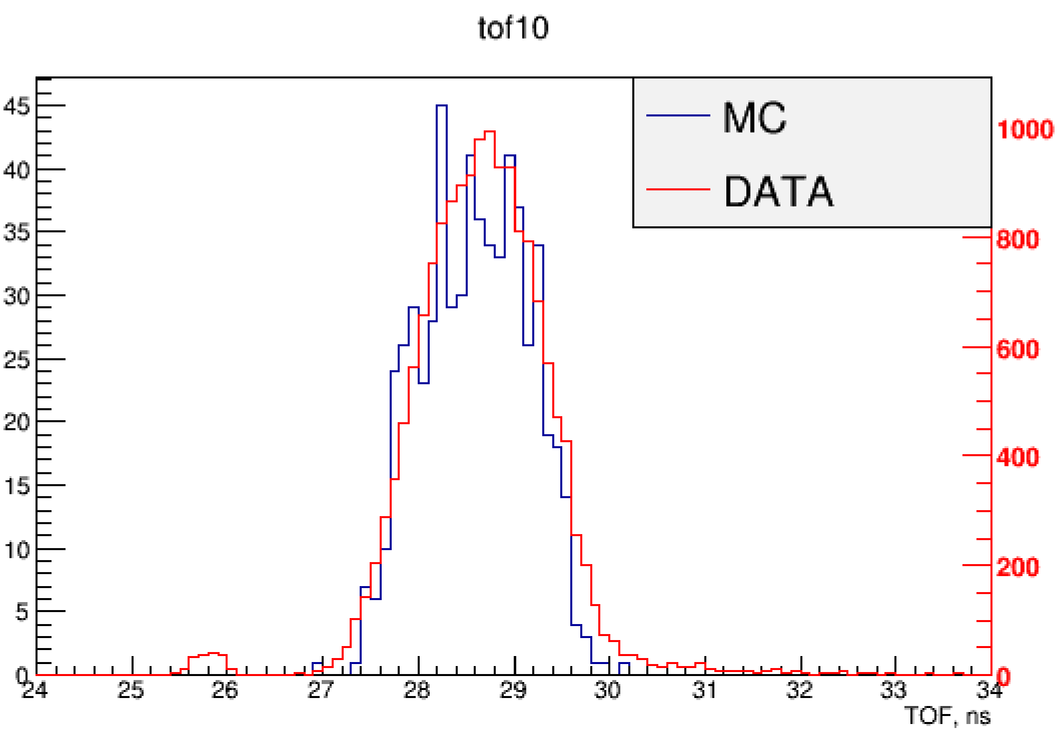

Fig. 5. TOF for muons in run 3407. Here MEANmc=28.59, MEANdata=28.67, SIGMAmc= 0.54, SIGMAdata=0.59.

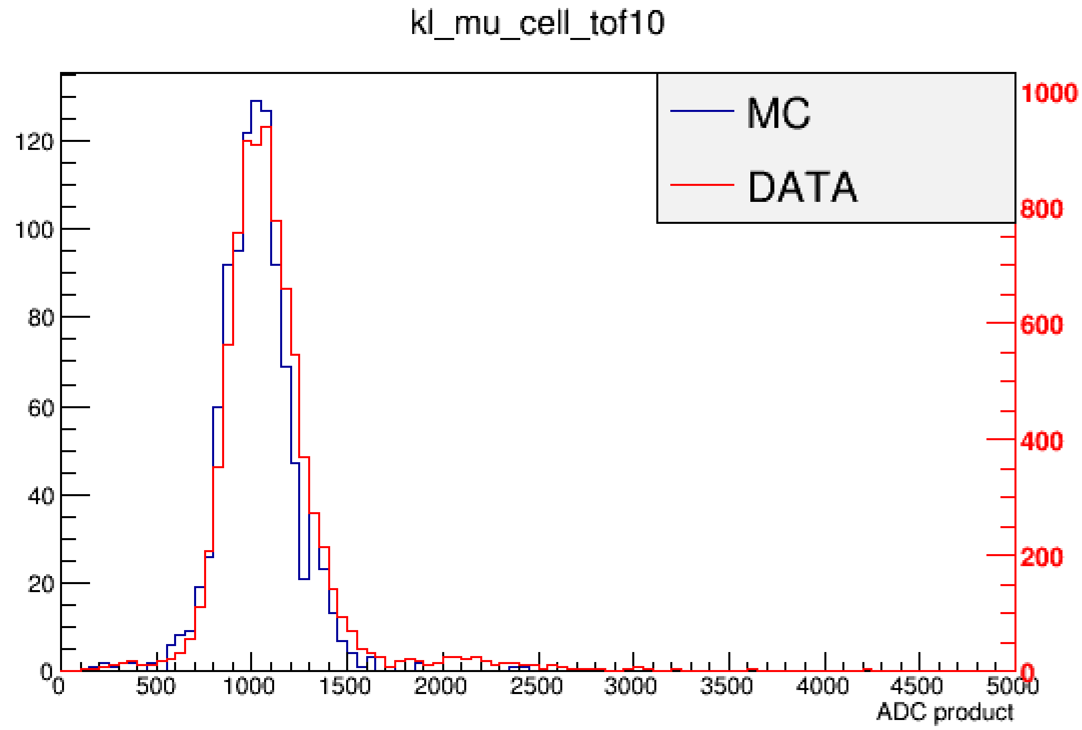

Fig. 6. KL adc spectrum for muons run 3253. Here MEANmc=1016, MEANdata=1058, SIGMAmc= 151, SIGMAdata=169.

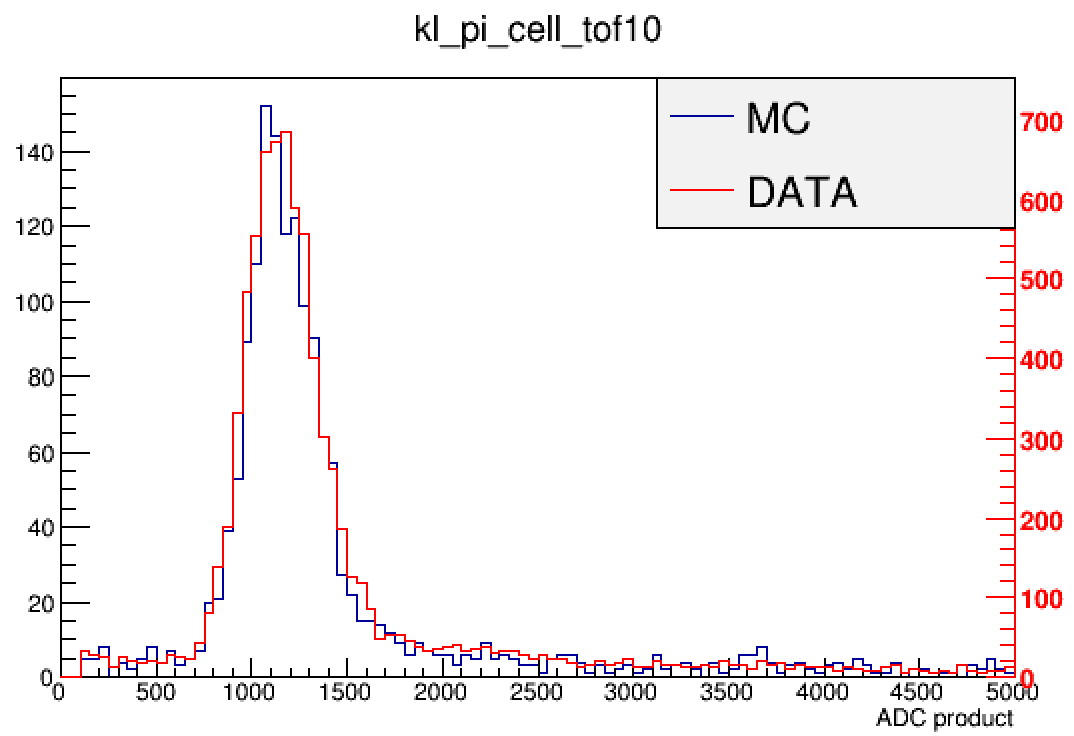

Fig. 7. KL adc spectrum for pions run 3253. Here MEANmc=1157, MEANdata=1159, SIGMAmc= 182, SIGMAdata=192.

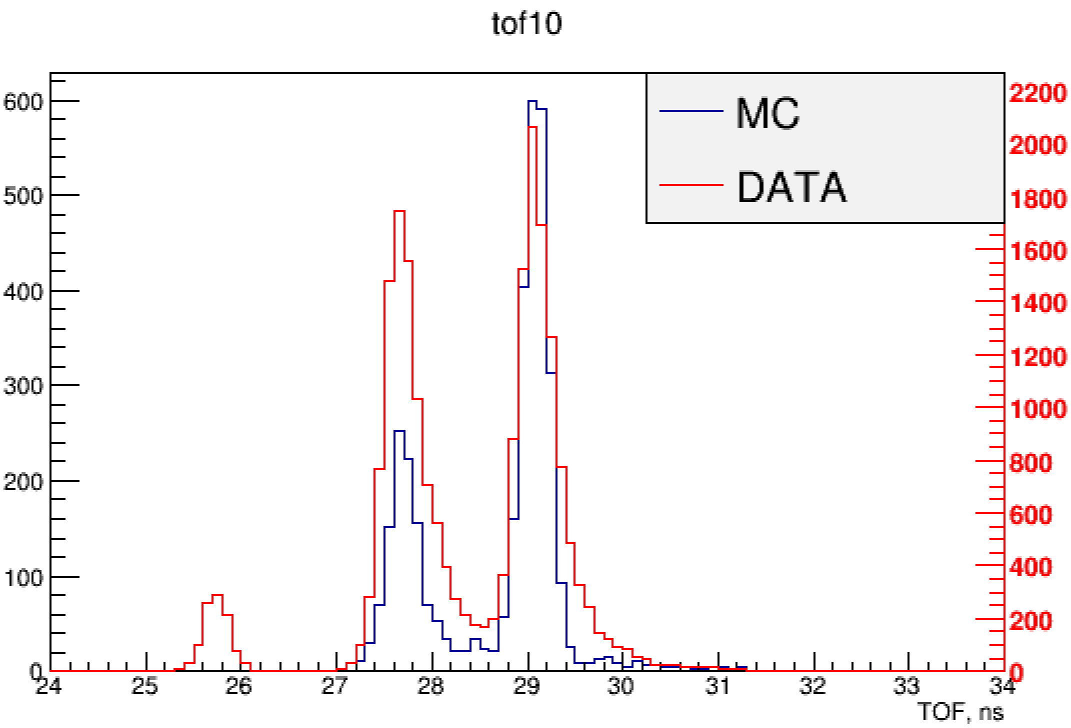

Fig. 8. TOF for muons and pions in run 3253. Here both muon and pion peak are well centered, but data peaks are broader than MC.

5. **The peak at small adc's:** Now in the code the same cut which is used for zero suppression in data is used for MC. No need to add a new one.
   I should remind something. This peak can arise also in cases when adc_product is plotted directly as it comes from the reconstruction. This product is attached to a single KL cell. In one particle event we can have 0, 1, 2, 3... illuminated cells (see later multiplicity). If one needs to have full energy deposited in KL for a given particle event, a loop over KL cell hits must be done. In the other case if the particle hits 2 cells it energy will be distributed between these cells, therefore two signals with smaller adc content each.

II. KL energy resolution to electrons:

With above setup I simulated a double thick KL bombarded by electrons with 54, 79 and 100 MeV with sigma 1%. These are the settings from BTF test in Frascati. The results are shown in Fig. 9. and Table 1. I would say that they match pretty well.

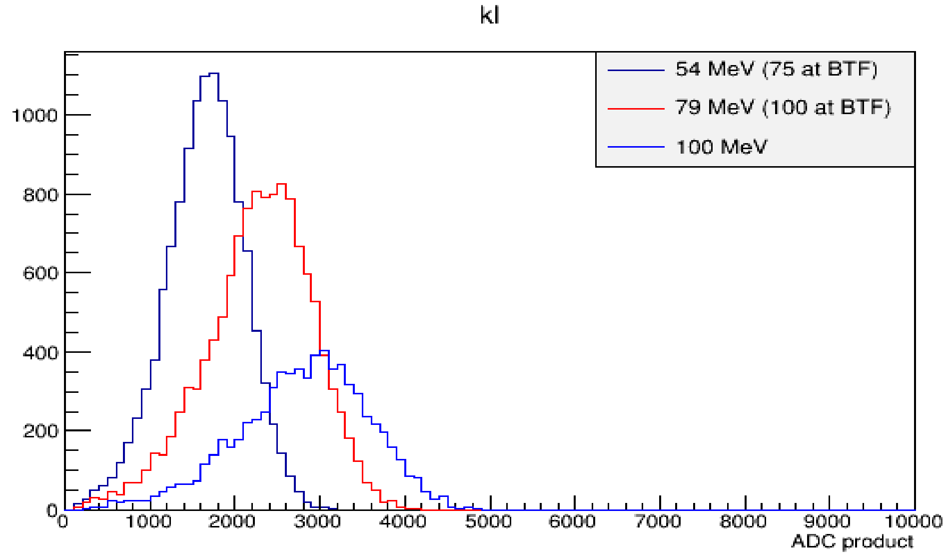

Fig. 9. Simulation of double thick KL as it was in BTF beam.

Simulation energy, MeV	BTF energy, MeV	Simulation resolution σ/E, %	BTF resolution σ/E, %	Simulation resolution at 1 GeV, %	BTF resolution at 1 GeV, %
54	75 (21 MeV loss in TOF)	27.3	28	6.3	6.5
79	100 (21 MeV loss in TOF)	25.2	25	7.1	7.0
100	100 (no TOF)	25.1	23	8.0	7.2

T*able 1. KL energy resolution to electrons. The setup is taken from BTF.*

III. **KL double peak and multiplicity**. The presence of the second peak is strongly related with cell multiplicity. The multiplicity for muons in run 3253 is shown in Fig.10. The majority of events is only with one cell hit, but there are also many events with 2 hits. In Fig. 11 are shown KL adc distribution in cases with 1 and 2 cell hits. When there is only one cell hit the second peak disappears. In principle one particle can illuminate two adjacent cells (probably 3 not). But when we have two illuminated cells which are not adjacent it simply means that there is a second particle, but we don't know which one is "our". Of course the opposite isn't true, if you have two hits in adjacent cells, it doesn't mean that they are hit by only one particle (Fig.12).

It looks like that for the pion case in the same 3253 run the second peak is not so strongly expressed (Fig.13).

Now the question for the contamination study is whether if we reject all the events with more than 1 cell hits, we will bias our sample.

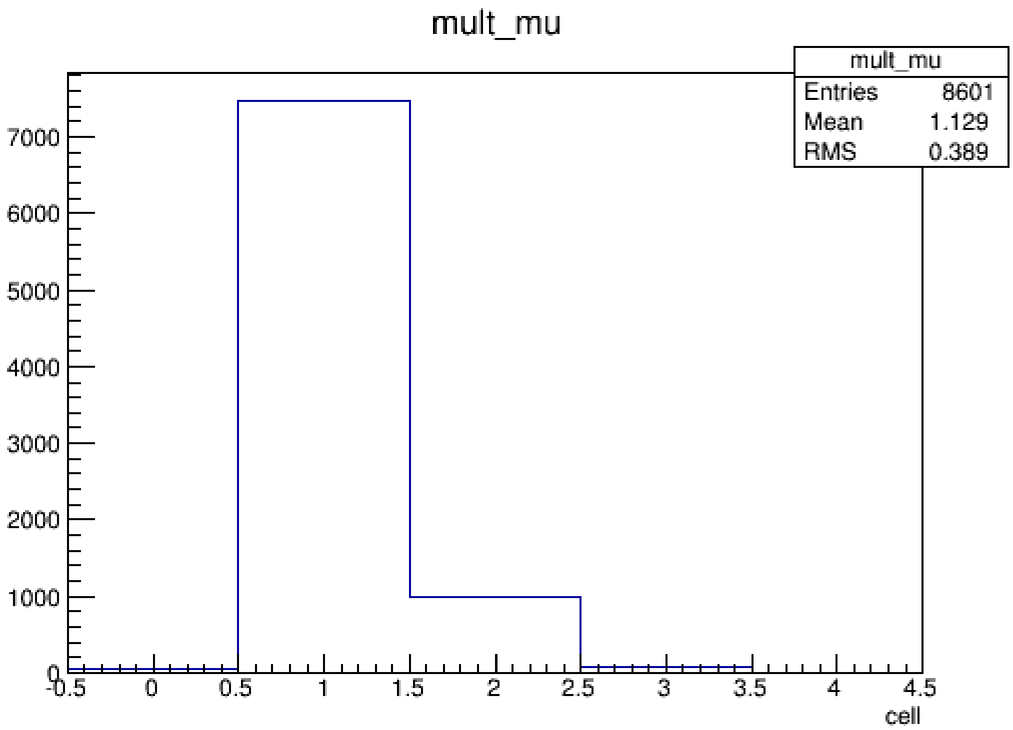

Fig. 10. Multiplicity for muons in data run 3253. Very few events where TOF10 is reconstructed, but no hit in KL. The main fraction is with 1 KL hit. Not negligible with 2 cell hits, few with 3 and no one with 4 or more hits.

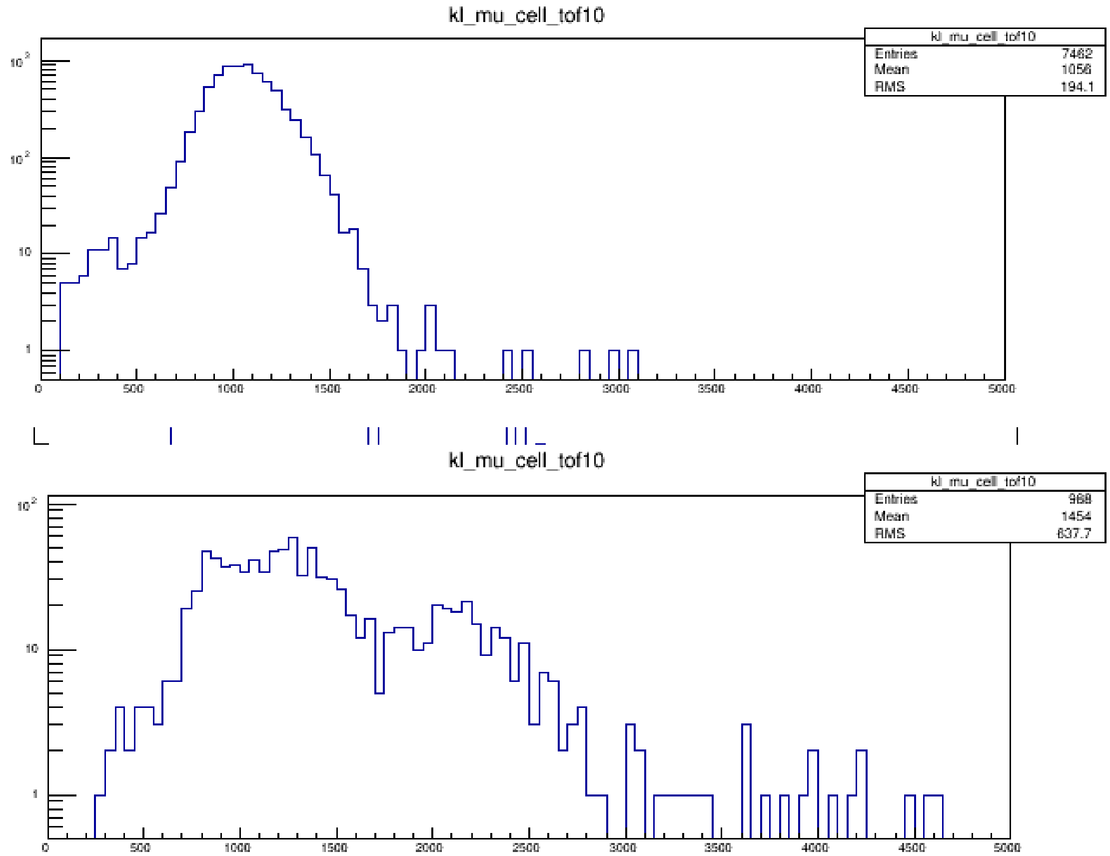

Fig. 11. KL adc distribution for muons in run 3253. Top: only 1 cell hit; bottom only 2 cell hits.

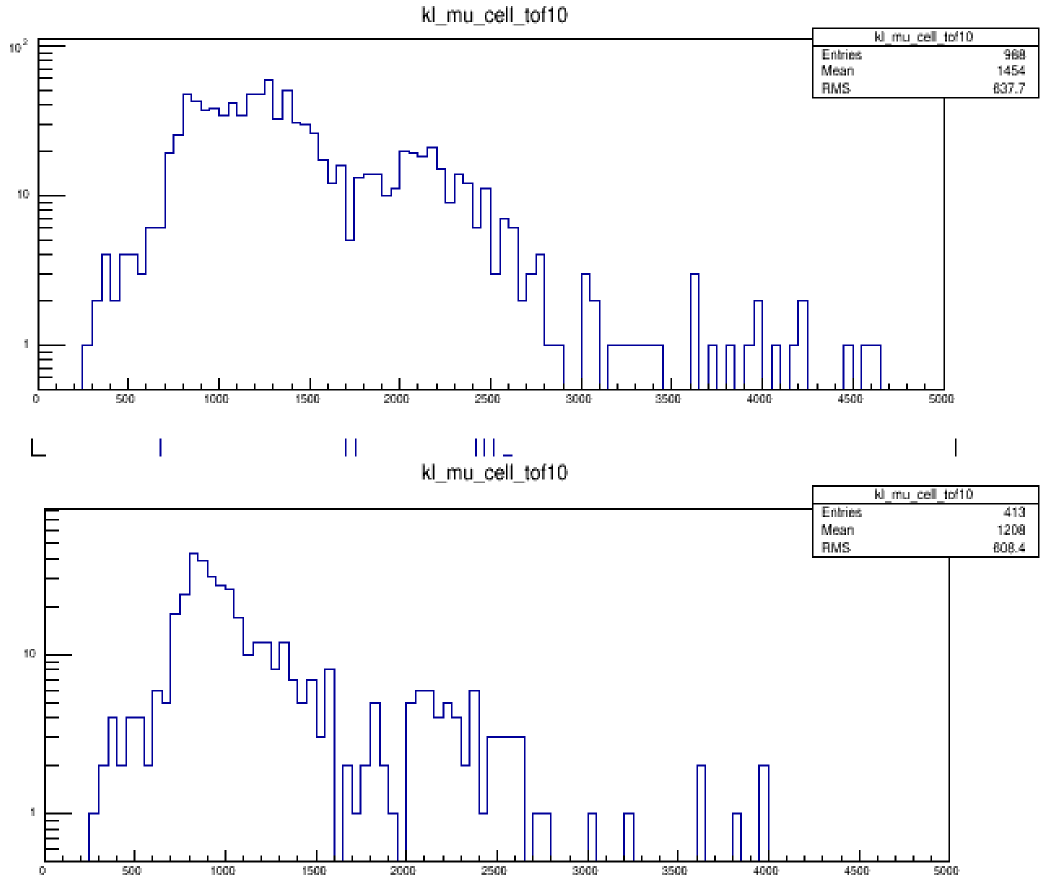

Fig. 12. KL adc distribution for muons in run 3253 when KL has exactly 2 cell hits. Top: all events with 2 hits; bottom: 2 hits in adjacent cells, the second peak is still present.

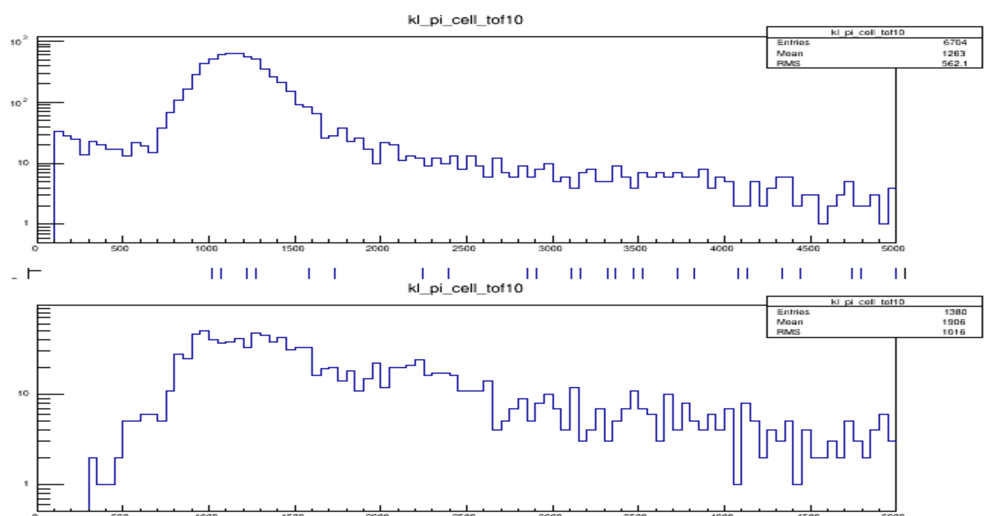

Fig. 13. KL adc distribution for pions in run 3253. Top: only 1 cell hit; bottom only 2 cell hits.

IV. **Tail distributions**. In Fig. 14 MC and data for muons in run 3253 are shown. In this case is not applied any cut on multiplicity, see Fig. 15. While the general shape (except the small shift and width) of the main peak is reproduced, the second peak is not visible in MC. Fig. 15 shows multiplicity in both cases. It is clear that we can't reproduce well multiplicity. This probably means that we can't reproduce some real process, for example secondary particles. And I guess here is the place for playing with geant cuts.
The situations with pions looks a bit better (Fig. 16) because the second peak is not well present. The pion multiplicity in pion case is not simulated well too.

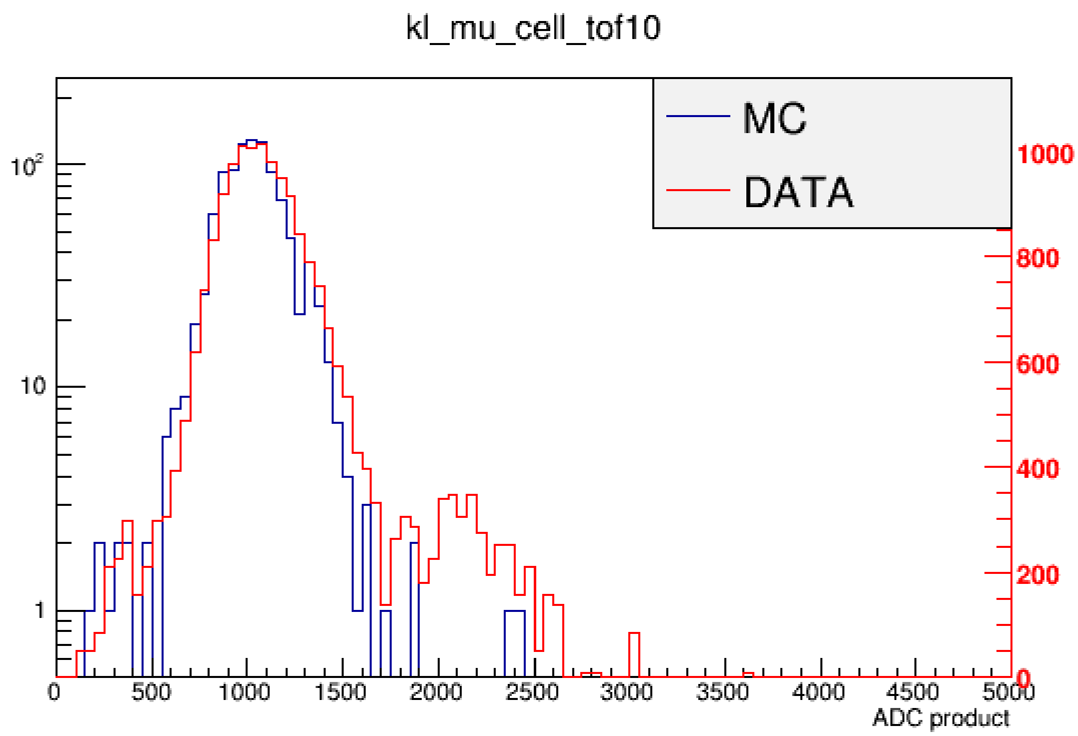

Fig. 14. KL ADC spectrum for muons in run 3253 for MC and data.

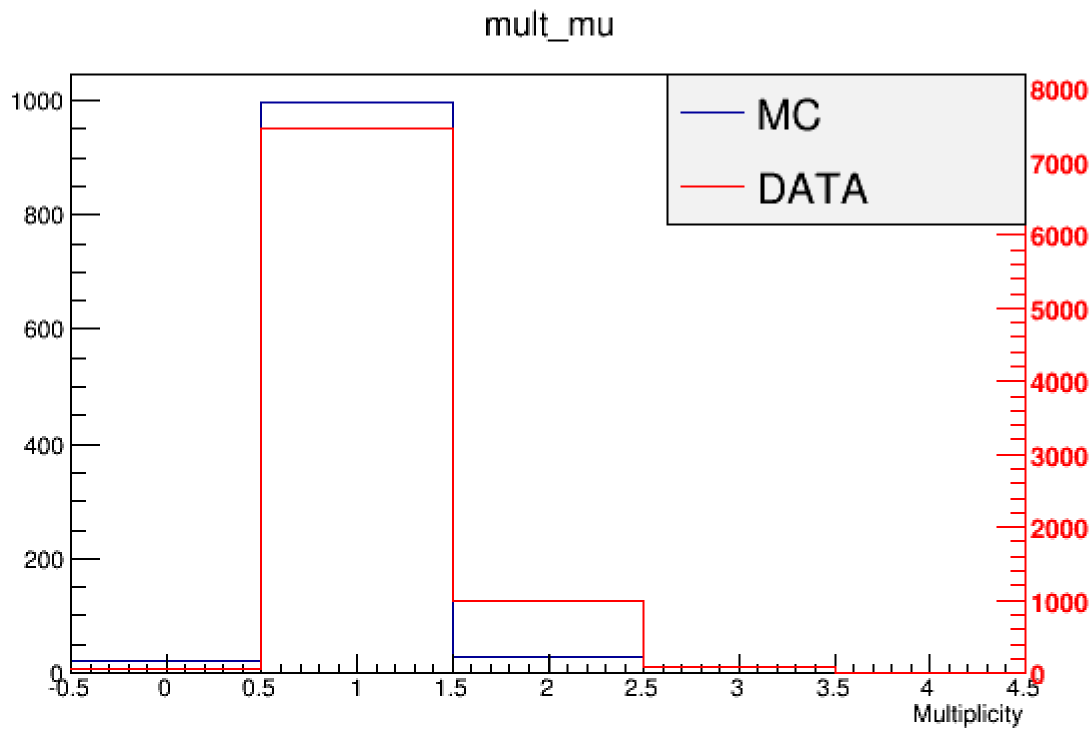

Fig. 15. Multiplicity in MC and data for muons in run 3253.

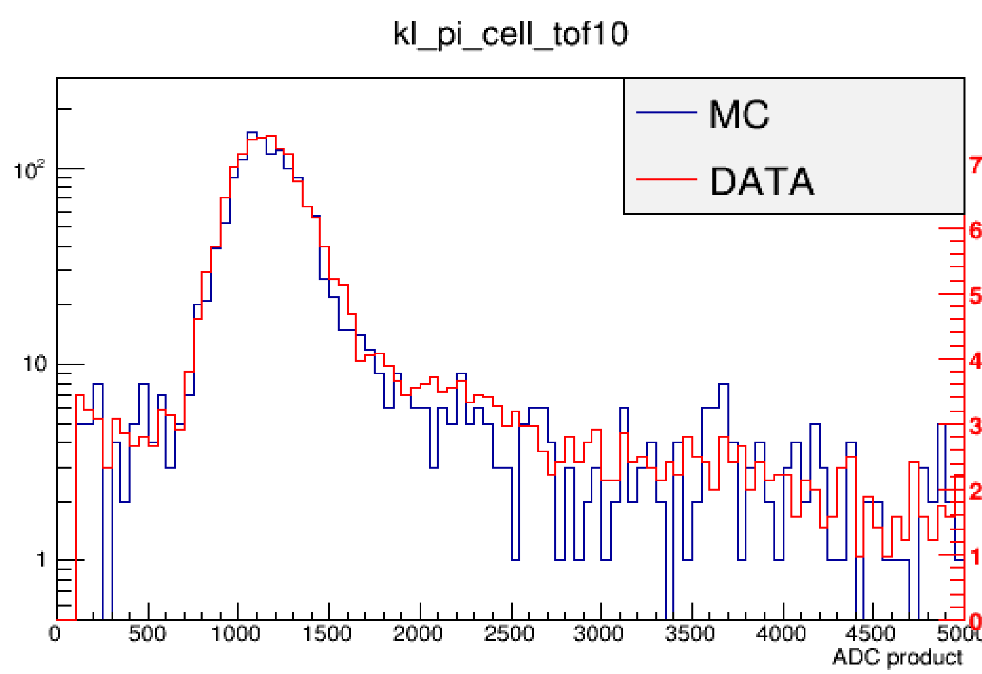

Fig. 16. KL ADC spectrum for pions in run 3253 for MC and data.

V. Conclusions.

1. The geometry is not correct. A geometry which is between claimed and reconstructed one is choosen.
2. This will lead to redefinition of points 1,2,3 (in terms of TOF).
3. TOF2 is not used for this analysis because of geometry. (In principle TOF2 info can be used on lower level, for example space point, in order to apply additional cut to solve multiplicity issue.)
4. With MAUS are simulated beams with muons which are tuned to TOF distributions in data.
5. These beams are used to tune center and sigma of KL MC main peak. There are three places for smearing: photons by poisson, photoelectrons on cathode by poisson, pmt gain by gauss.
6. This tuning is used for digitization and reconstruction of beams generated by John. There is slight shift in center and sigma between MC and data. But they are present also on TOF level.
7. The problem with the peak at small adc is solved.
8. Electron beams in BTF are simulated. MC describe well data and resolution.
9. The double peak in data is strongly related to cell multiplicity. It disappears if only one hit in KL is asked, but question is whether this is correct to do.
10. We can't simulate the second peak. Probably some process is missing in the simulation.

Now what?

1. To be decided which geometry.
2. To simulate the double peak.
3. Can g4beamline beams, which simulate 3253, 3407, 3426, be improved? I have no idea.
4. To test what contamination we are getting with MC now.
5. John, good luck ;-).

PS. The new code is in lp:~mbogomilov/maus/devel4. I guess it will go into the next release. My advice is to rerun data too with this code, because I introduced few changes also there.