Single-electron challenge
Review of developments (since Nov. 2018)

P. Lautridou – NEWS Coll. Meeting 12/06/2019

Developed tools

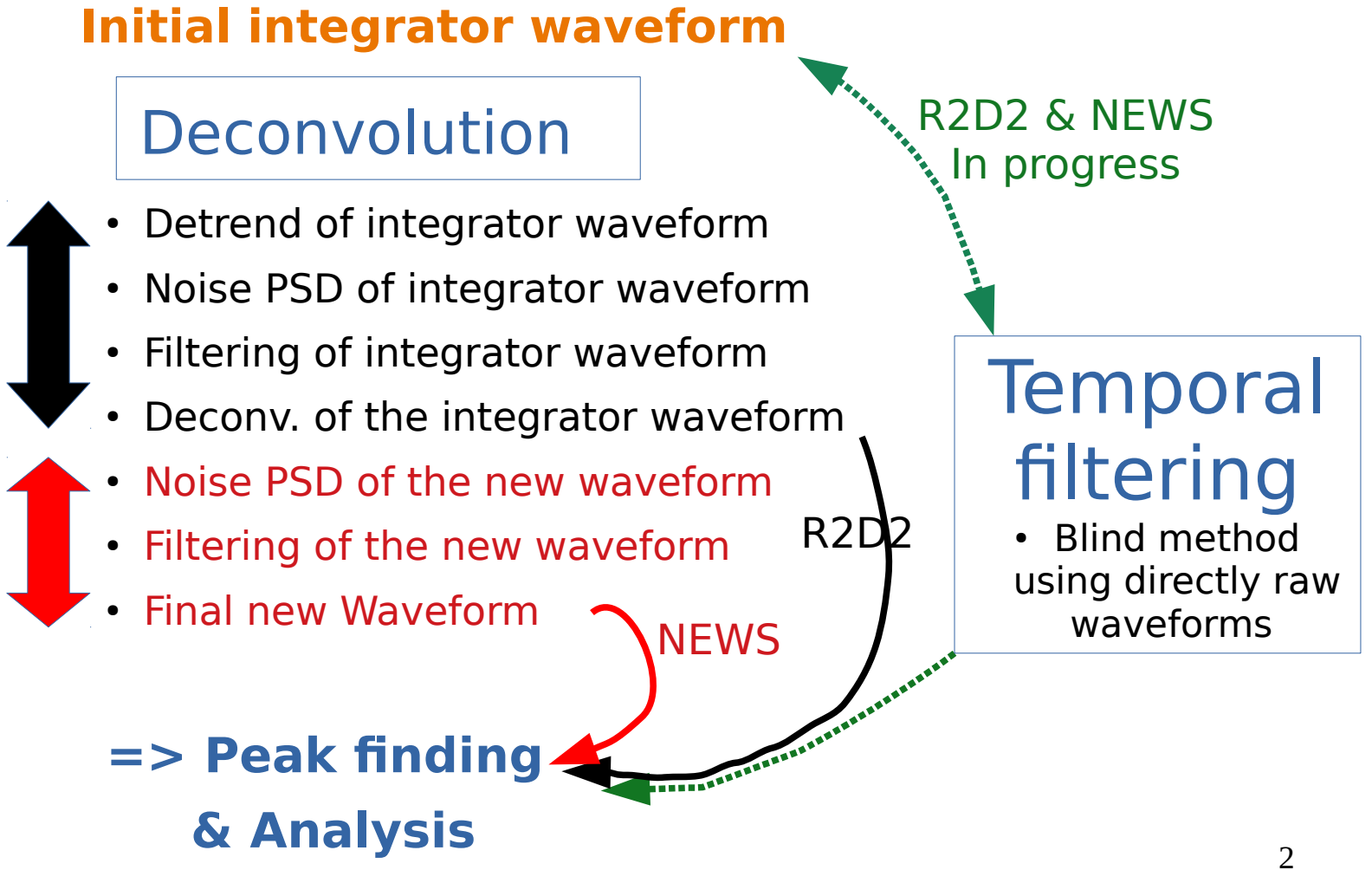
- Deconvolution method (in frequency) => operational (use off-line)
- Temporal filters (time series) => operational (use on/off-line) (Smoothers, Differentiators)

For trigger and/or physical parameter extraction (amplitude, charge, time, ...)

- Mix of the previous tools => in test

But all methods require a minimal knowledge of the noise...

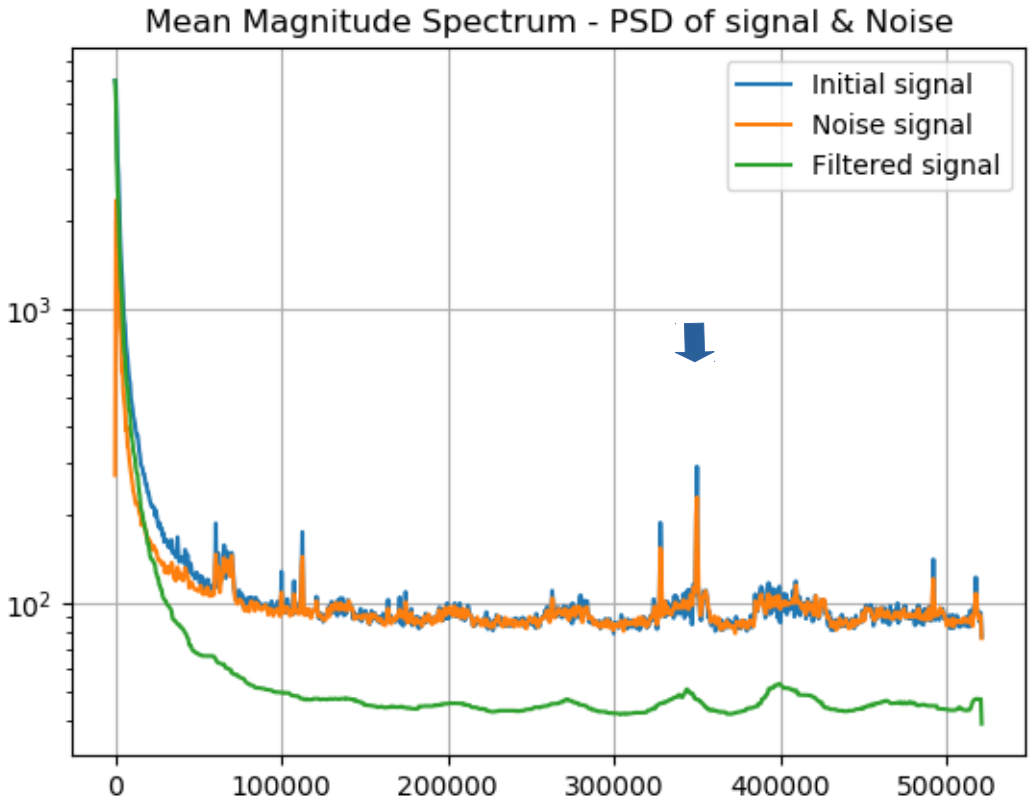
Methods


Initial integrator waveform
Deconvolution
R2D2 & NEWS
In progress
1-filtering stage (big signals)
• Detrend of integrator waveform
• Noise PSD of integrator waveform
• Filtering of integrator waveform
• Deconv. of the integrator waveform
2-filtering stage (small signals)
• Noise PSD of the new waveform
• Filtering of the new waveform
• Final new Waveform
R2D2
Temporal filtering
• Blind method using directly raw waveforms
NEWS
=> Peak finding & Analysis

Results with deconvolution

Noise attenuation of the raw signal

@ stage 1

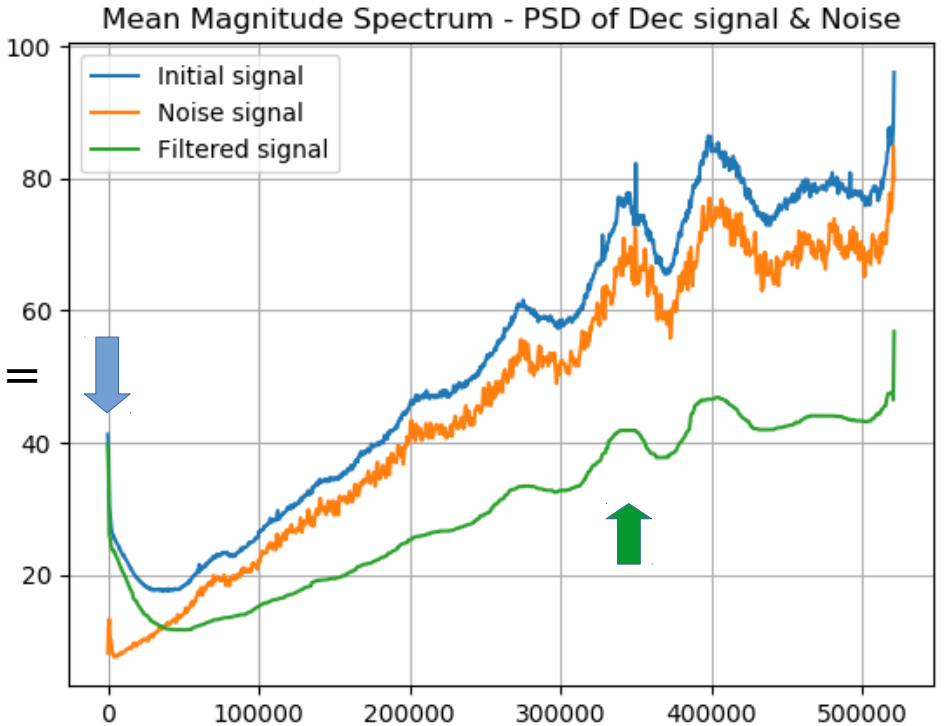


Initial integrator signal (after detrend)

Noise PSD of integrator signal

Signal after filtering stage 1 => Noise / 2 in amplitude

Noise attenuation of the deconvolved signal @ stage 2



Deconv. signal after filtering stage 1
Noise PSD of deconv. signal

Deconv. signal after filtering stage 2 => > 200 kHz: Noise / 2 in amplitude

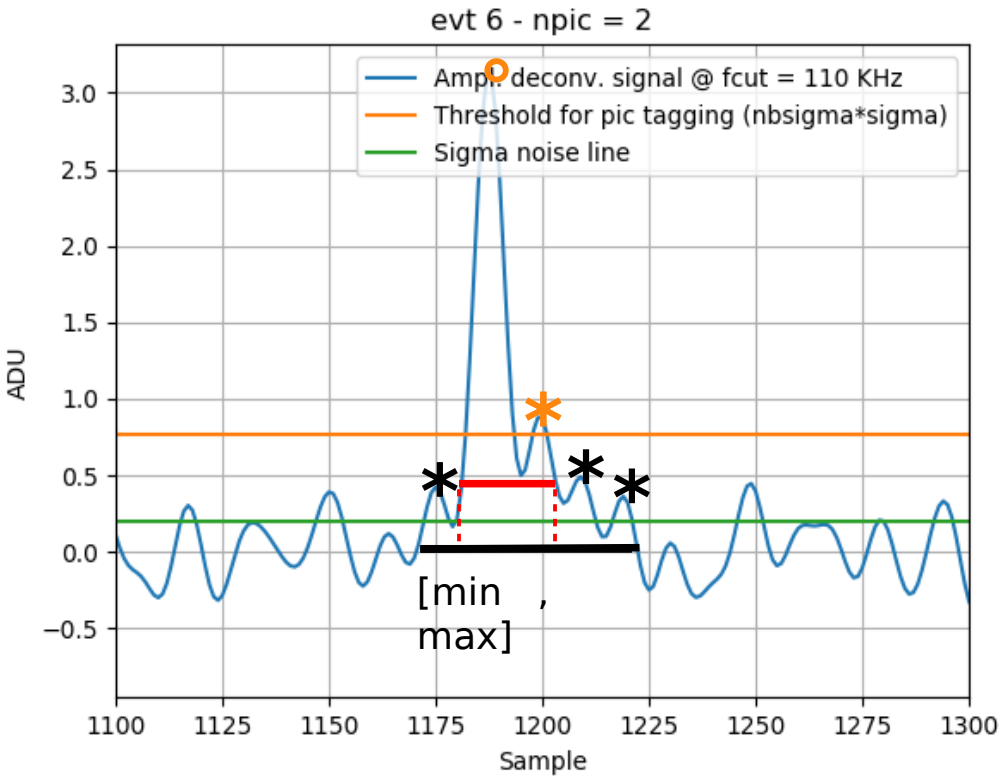
- After 2-stage => at best Noise / 10
- But HF inflation imposes an additional cut in frequency (< 150 kHz)

Analysis Meeting 05/03/2019
(with deconv. signals)

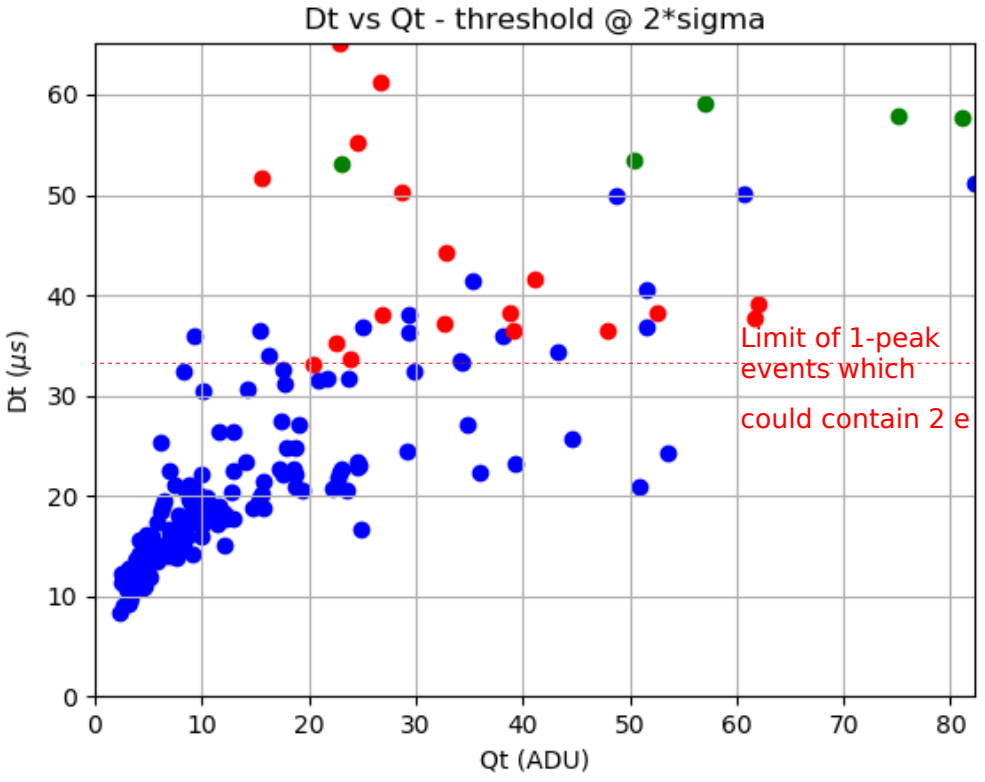
Method

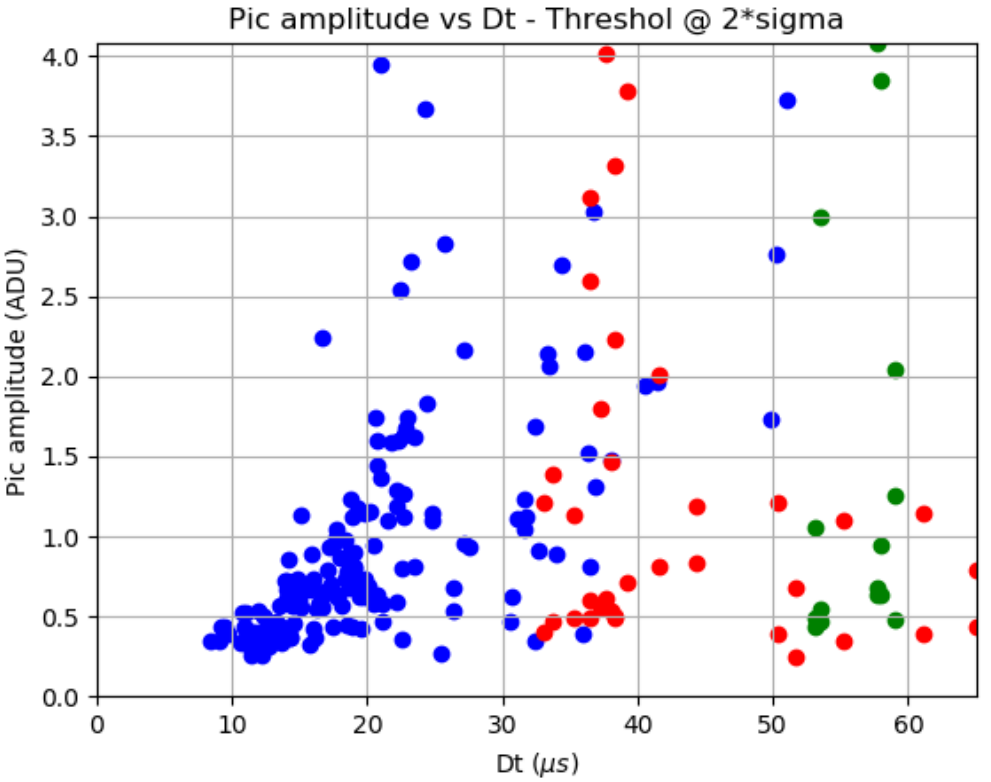
- Find sigma of noise in [0:1000]: —
- Determine max(s) with trigger algo: °
- Determine zero crossing interval [min, max]: —
- Find all pics in [min, max]: *
- Determine threshold to select pics => sigma * f([min, max]): —
- Find relevant pics: *
- Compute global observables of event @ 2*sigma : Qt, Dt —

+ peak features (time position, amplitude, FWHM)



Simu events - fcut = 55 Khz





1-pic events
2-pics events
3-pics events

Here more pics (210) than events (182) !

Analysis Meeting 02/04/2019
(with deconv. signals)

Improvements

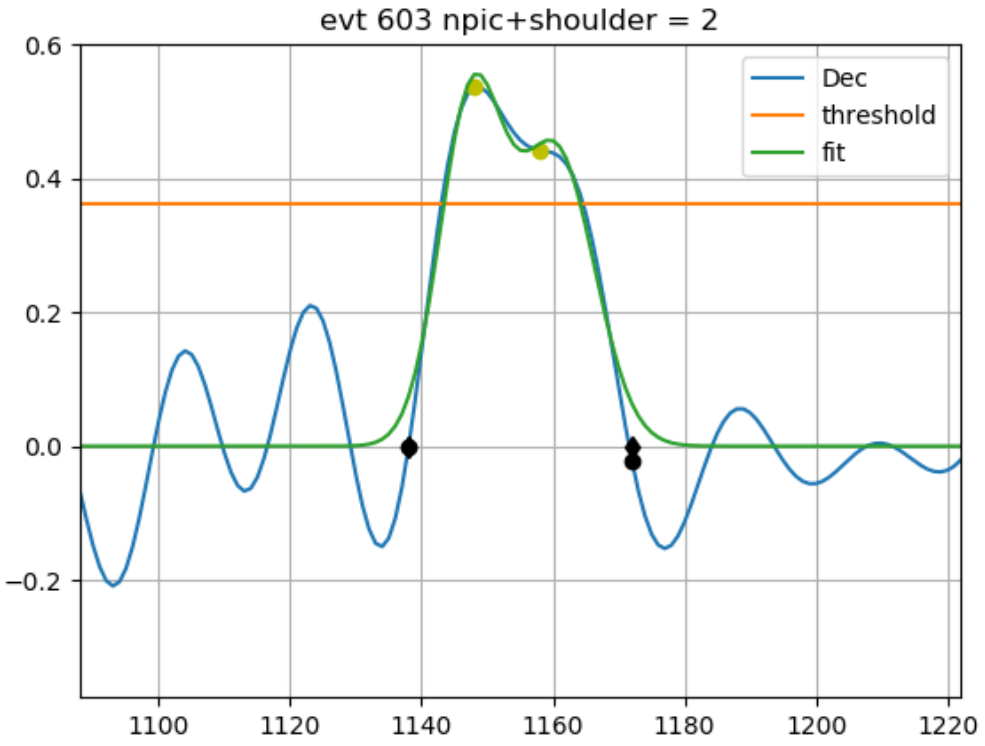
- Implementation of a Gaussian-fit of the peaks

=> init. Param. = ampl., positions, sigmas=5

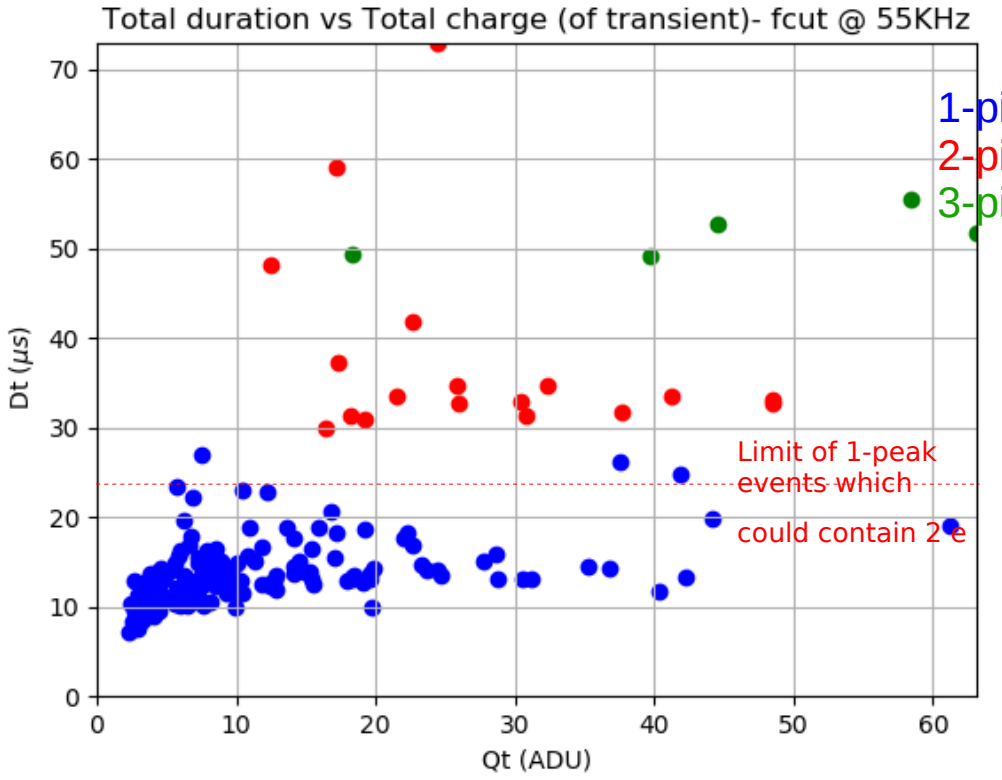
- Implementation of a treatment of shoulders for 1-peak events => but few events concerned (<<10)

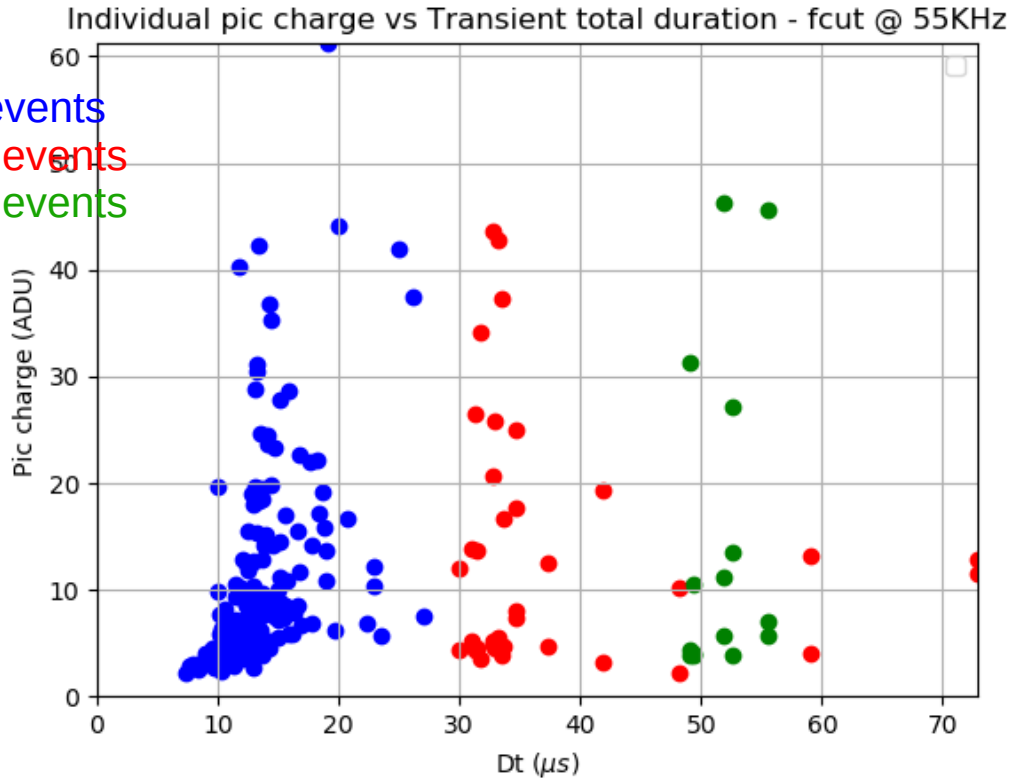
- All observables calculated from fit outputs @ FWHM

=> Qt = ∑Qpeak, Dpeak = FWHM of peak, Dt = right – left time limits of peaks



Simu events - fcut = 55 Khz + no shoulder treatment



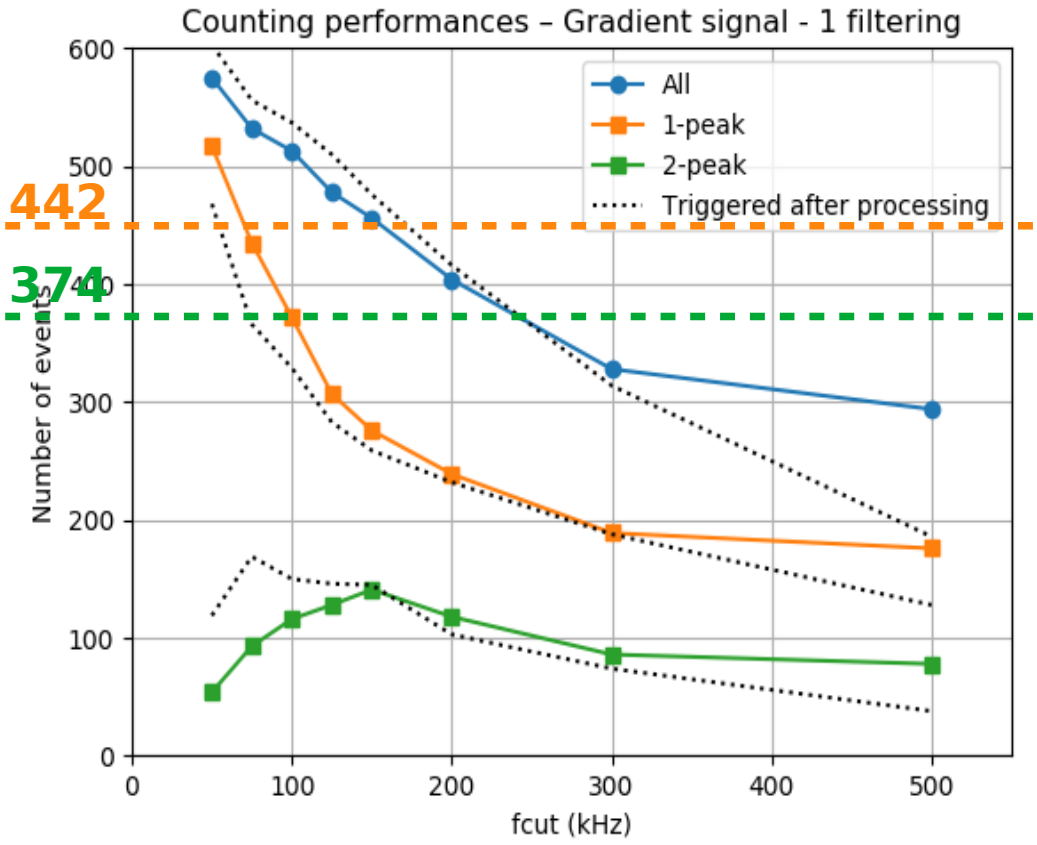


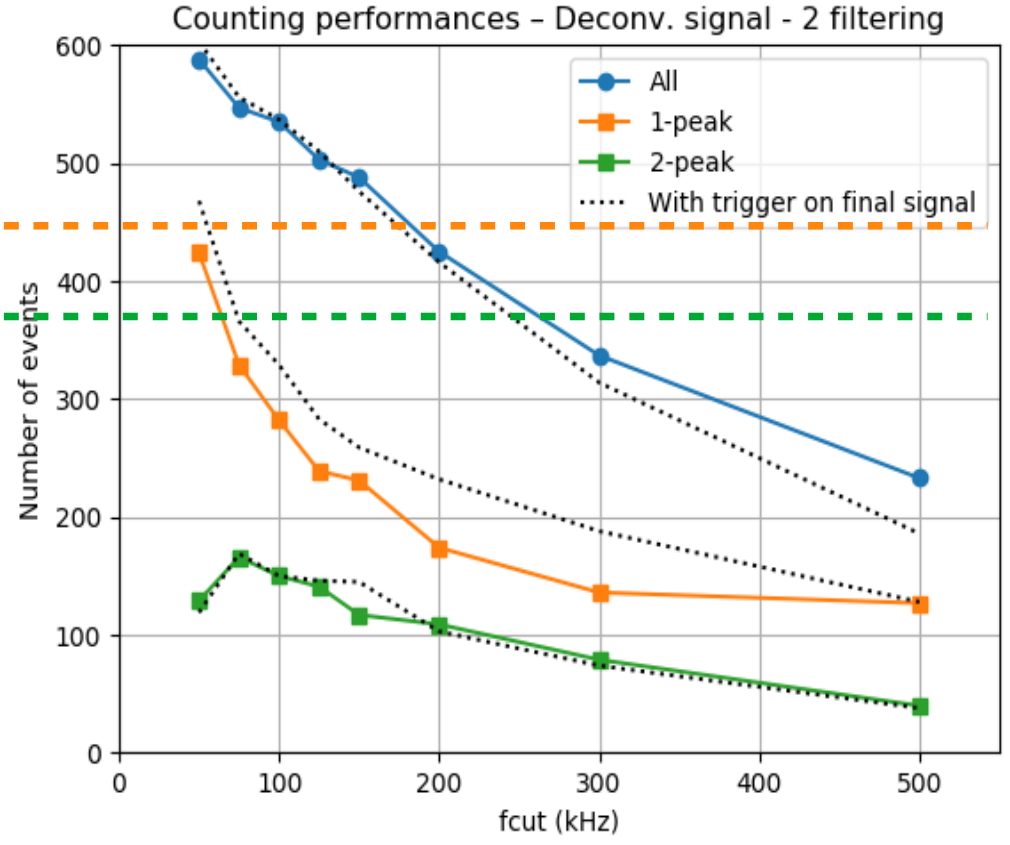
Gaussian adjustments enhanced the discrimination but also affect the accuracy of the estimates ...

Analysis Meeting 18/04/2019 - Counting performances

Total events in file (doubleelectron_dat, 1000 waveforms) = 796, 1-peak event = 442 , 2-peak events = 374

- **First step: trigger on raw data using SMA (or EMA) + Comb filter => Trigged events = 621 (78% of efficiency)**
- **After analysis => 1-peak events = 420 - 520 max (~ 100%) , 2-peak events = 160 max (efficiency max 40%)**





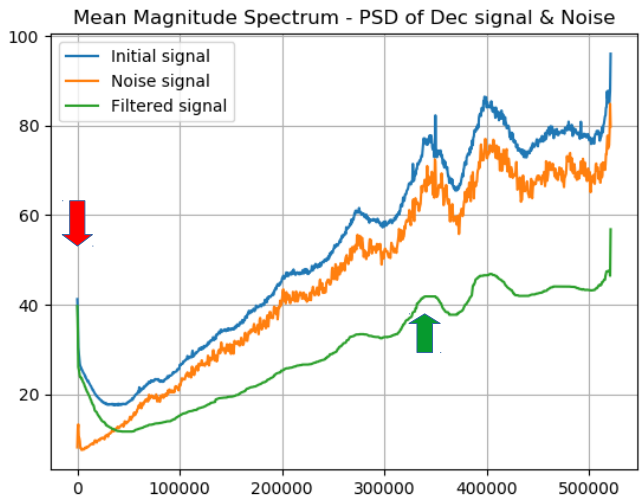
Results with temporal filtering

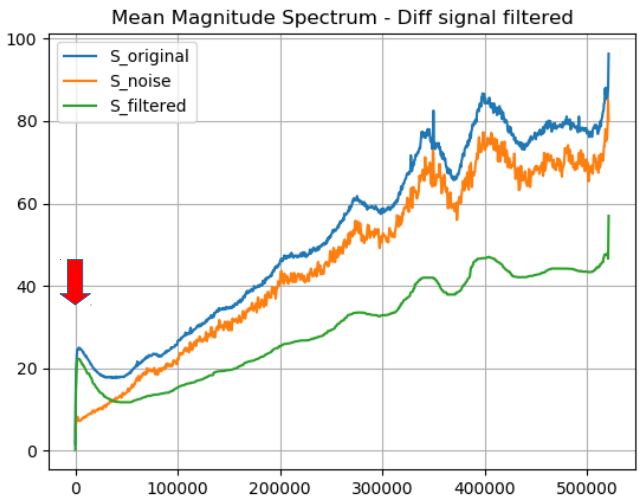
Must have adapted characteristics against the noise pattern **=> Several filters tested**

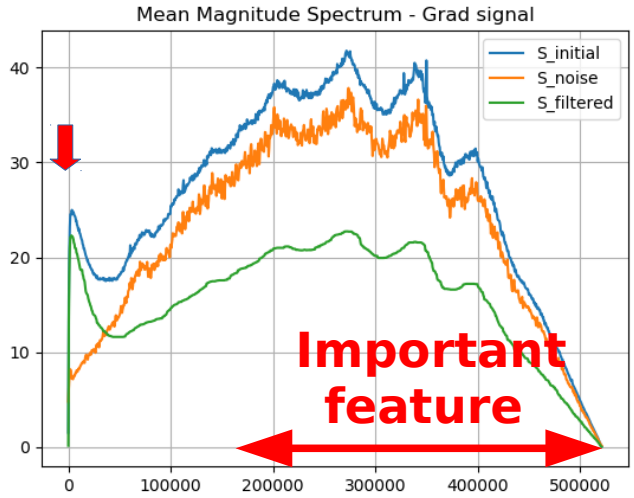
1) Differentiators

- First difference: $y_i = x_{i+1} - x_i$
- Central difference (or gradient): $y_i = (x_{i+1} - x_{i-1})/2$

and others: SL2, RLD, ...







=> Frequency responses are close to (see better for f = 0) than those of deconvolution

2) Moving smoothers

2 mains parameters: lmoy, lcomb

- **SMA:**
  - SMA-C section: $u_i = x_{i-lmoy/2} + .. + x_{i+lmoy/2}$ => Comb structure in f => fnull=k*fs/lmoy , k= 1, 2 ...lmoy/2 , fs=fe/2
  - COMB section: $y_i = u_i - u_{i-lcomb}$ => Comb structure in f => fnull=k*fs/lcomb , k= **0**, 1, 2 ...lmoy/2 **=> acts as DC blocker**
  - => **Except central everage, strictly equal to CIC (recursive implementation of SMA)**

- **CIC-C:**
  - CIC section: $u_i = x_i - x_{i-lmoy} + u_{i-1}$ => Comb structure in f
  - COMB section: $y_i = u_i - u_{i-lcomb}$ => Comb structure in f

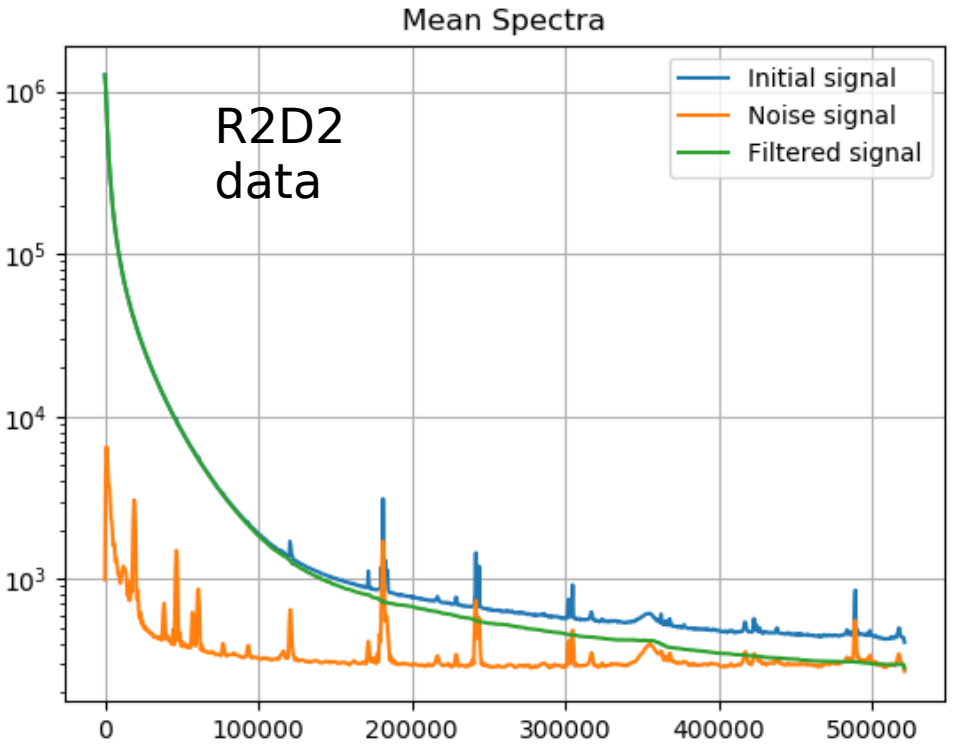
- **EMA-C** (a = 2/(1+lmoy))
  - EMA section: $u_i = a*x_i + (1 - a)*u_{i-1}$ => **No comb structure in f** (smooth spectrum)
  - COMB section: $y_i = u_i - u_{i-lcomb}$ => Comb structure in f

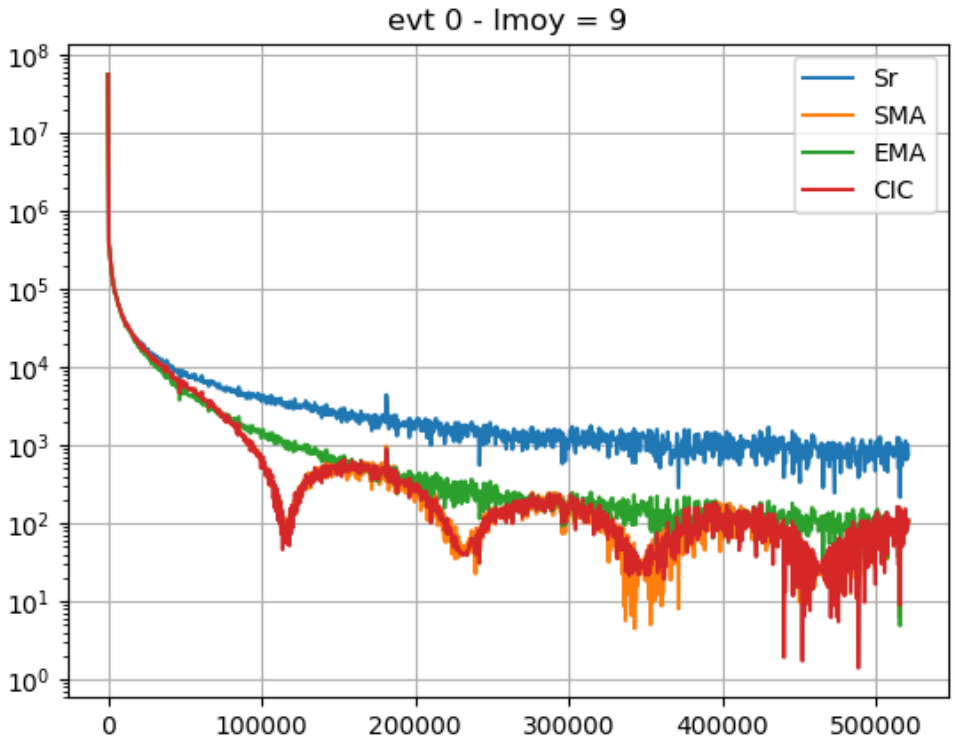
- **COMB section of order 1 (lcomb = 1) = first derivative of the signal (only fnull=0 => frequency spectrum grows smoothly - see previous slide)**
- **Filter time delay is about lmoy/2 and lcomb/2**

Adapt lmoy & lcomb to noise pattern

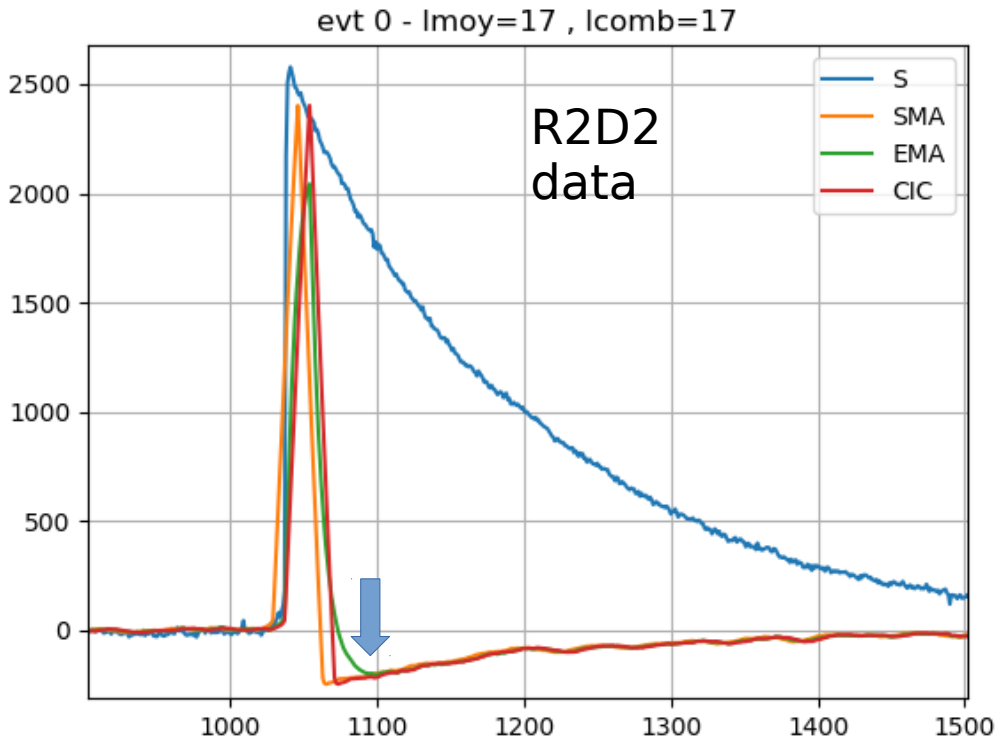
=> Mitigation of the RFI features of the signals determines the choice of lcomb

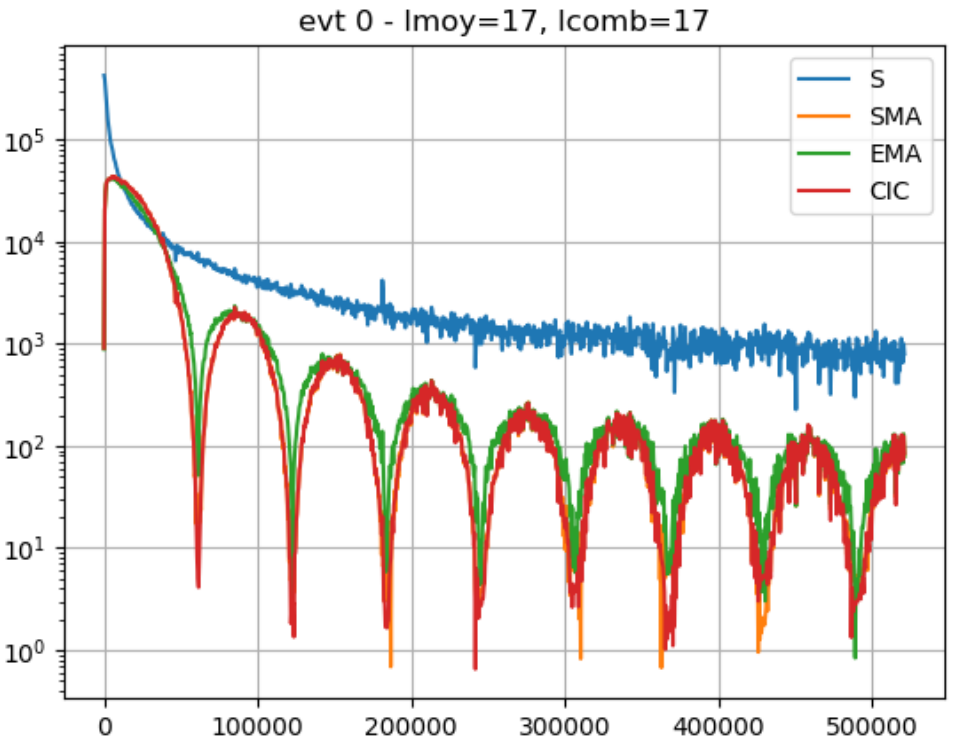
=> improvement of S/N





Results with lmoy = 17 & with lcomb = 17





+ Another differentiating filter has been identified to complement these filters (analysis of the shape of the transient)

Analysis Meeting 28/05/2019 - Counting performances

(with doubleelectron_data, 1000 waveforms)

Nb of trigger vs filter type in [1100-1200]

- Trigger on Dec. signal = 602
- SMA-CD(17,17) = 596
- EMA(17;17) = 597
- CIC(17,17) = 588

Signal/Noise performances

Raw integrator signal 6.62

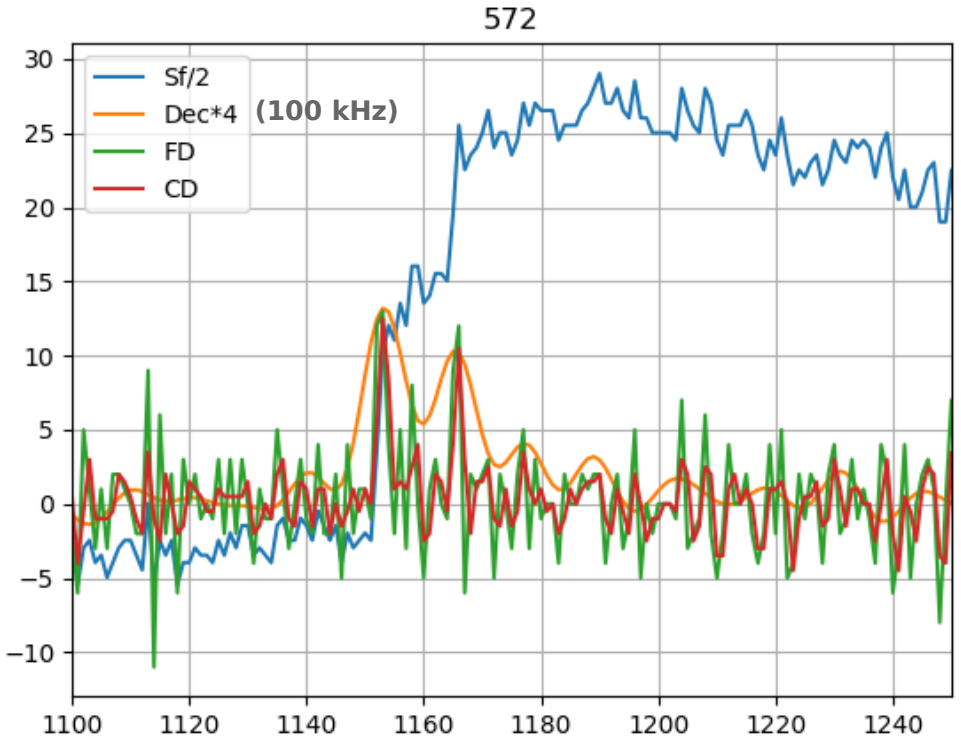
SMA-CD(17,17)	12.57	**Adapted for trigger**
EMA(17,17)	**12.51**	
CIC(17,17)	12.43	
SMA(20,50)	< 11	
Dec.(150 kHz)	**13.46**	**Adapted for all but touchy**
(the best we can hope for)		
PHOSSD15	**7.78**	**Adapted for multi-peaks**
CD	4.02	
RLD	3.81	
SL2-7	4.61	

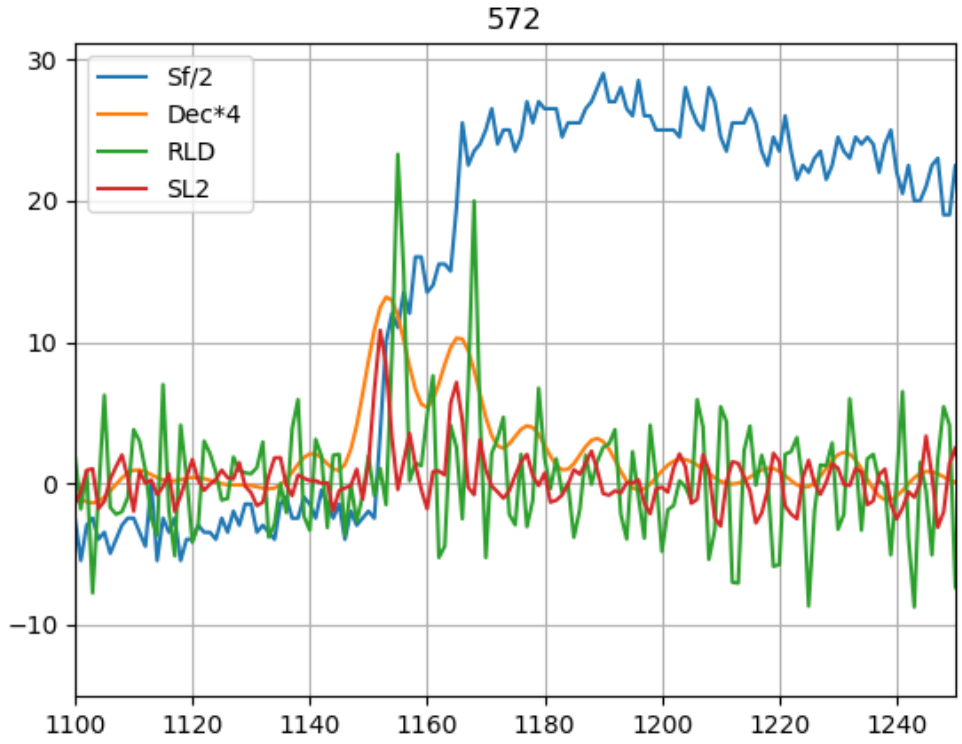
Data treatment - noise : issues

Final tool choice (Deconv, Temporal filters ? ...)

- Depends on Shapes, S/N, speed
- Trigger, Multi-peak counting capabilities
- Use of amplitude or of integral observable for energy estimation?
- Same analysis for low energy events and high energy events ? (can we connect the 2D plots or the energy estimators using different tools)

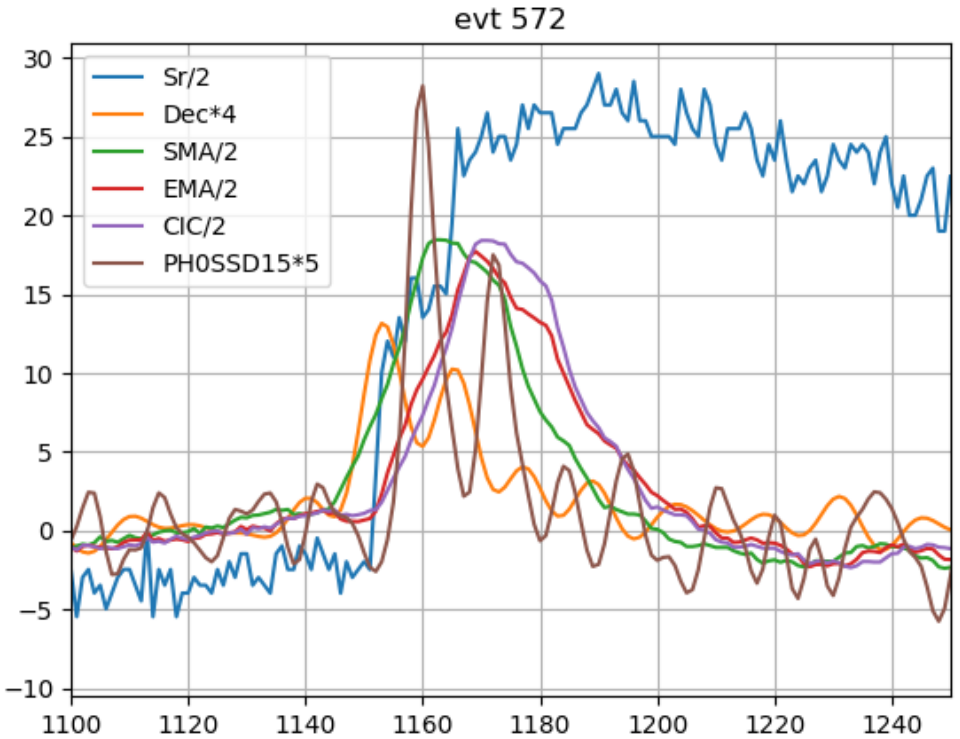
Comparisons of Deconv. & Temporal filterings
1)Shape





NEWS – doubleelectron data

Comparisons of Deconv. & Temporal filterings
1) Shape

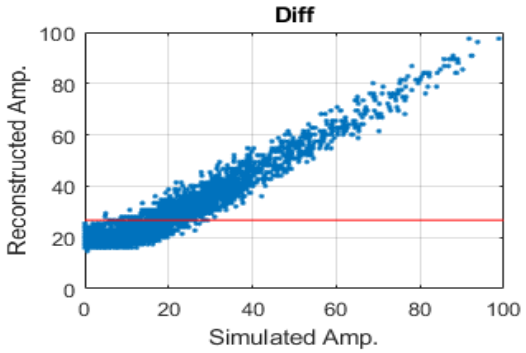


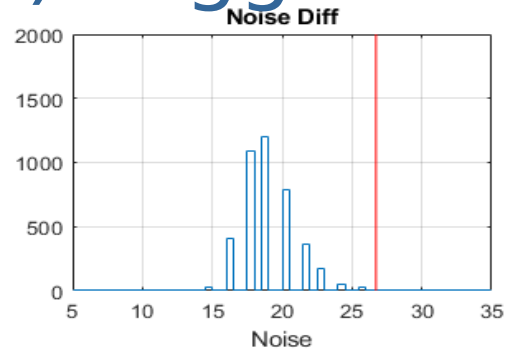
=> Final tool choice depends on several features of the final signal …

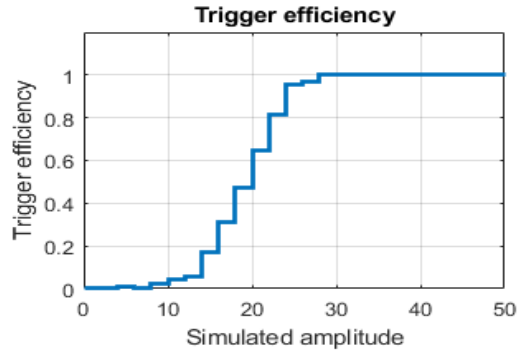
Analysis of Guillaume 23/05/2019

2) Trigger

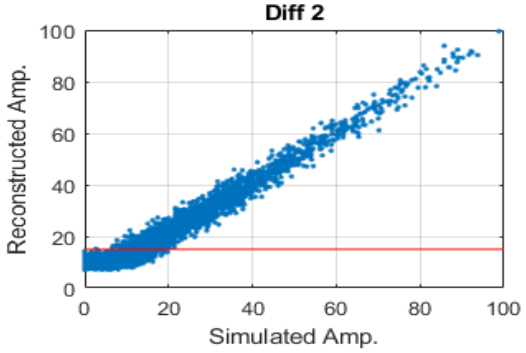
SMA(20)+
diff1(i) = y(i) - y(i-1)

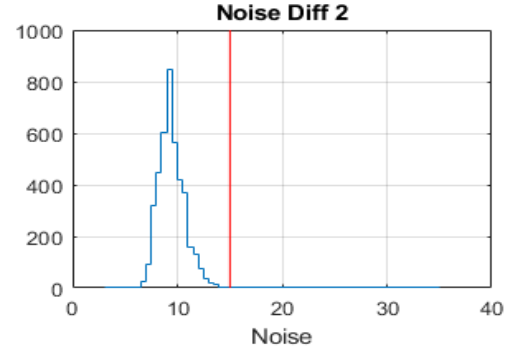


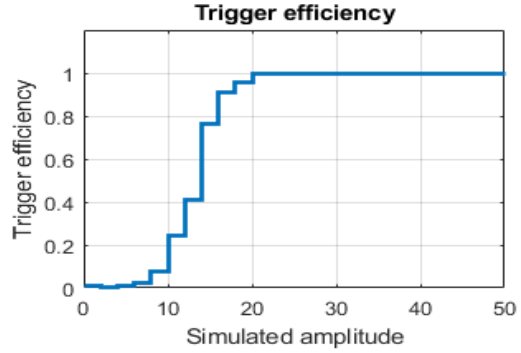




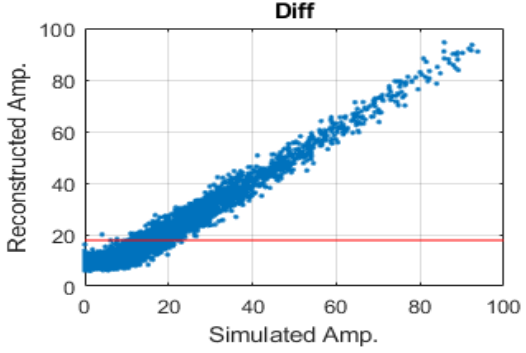
diff1(i) = y(i) - y(i-10)

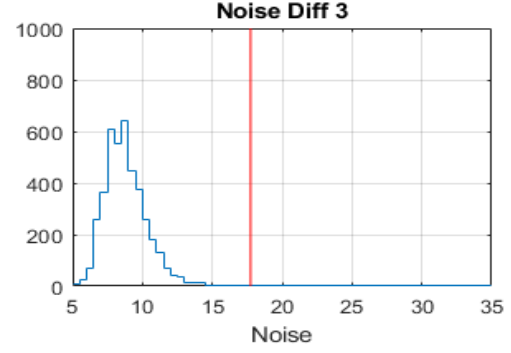


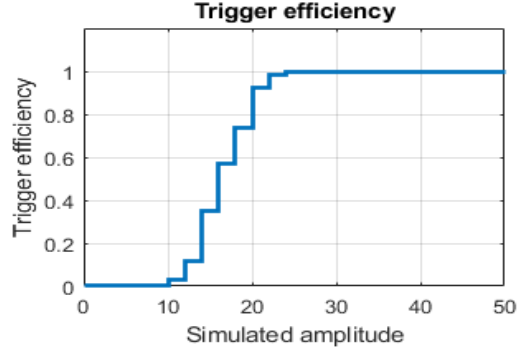




diff1(i) = y(i) - y(i-50)







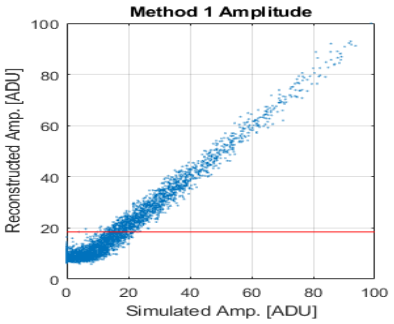
Trigger

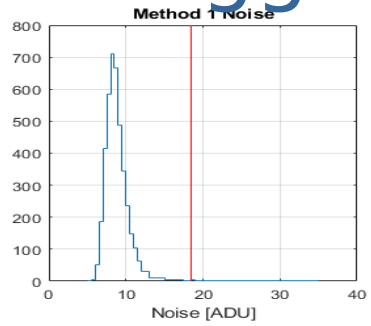
Analysis of Guillaume 04/06/2019

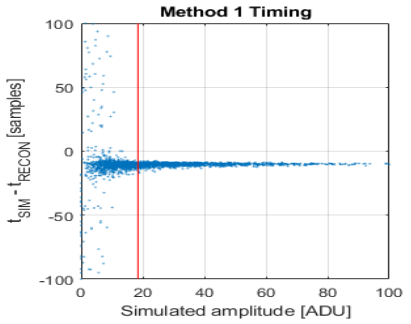
SMA-C(17,17)

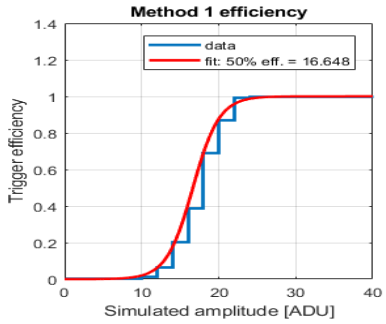
CIC-C(17,17)

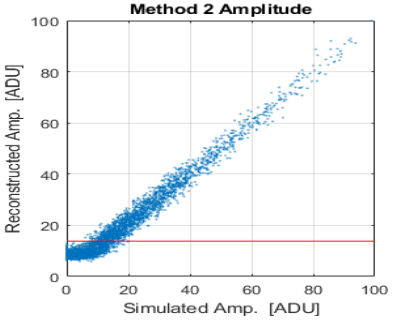
EMA-C(17,17)

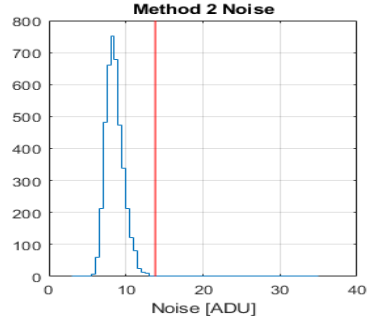


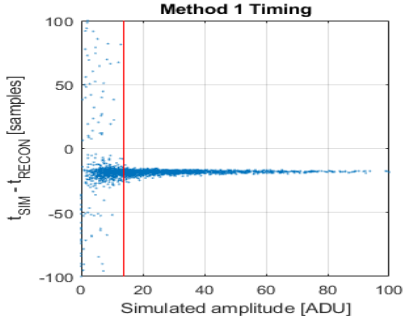


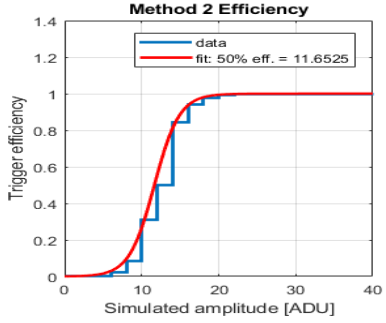


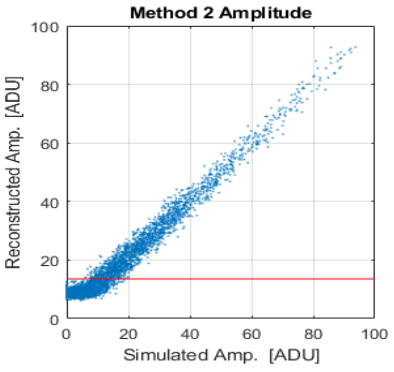


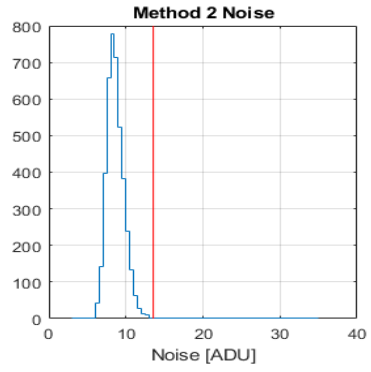


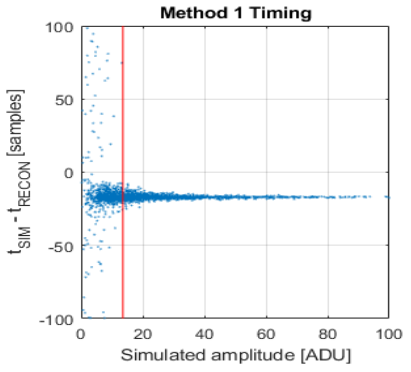


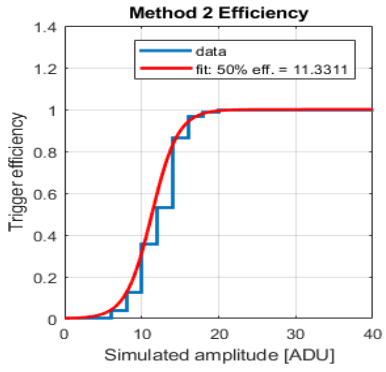




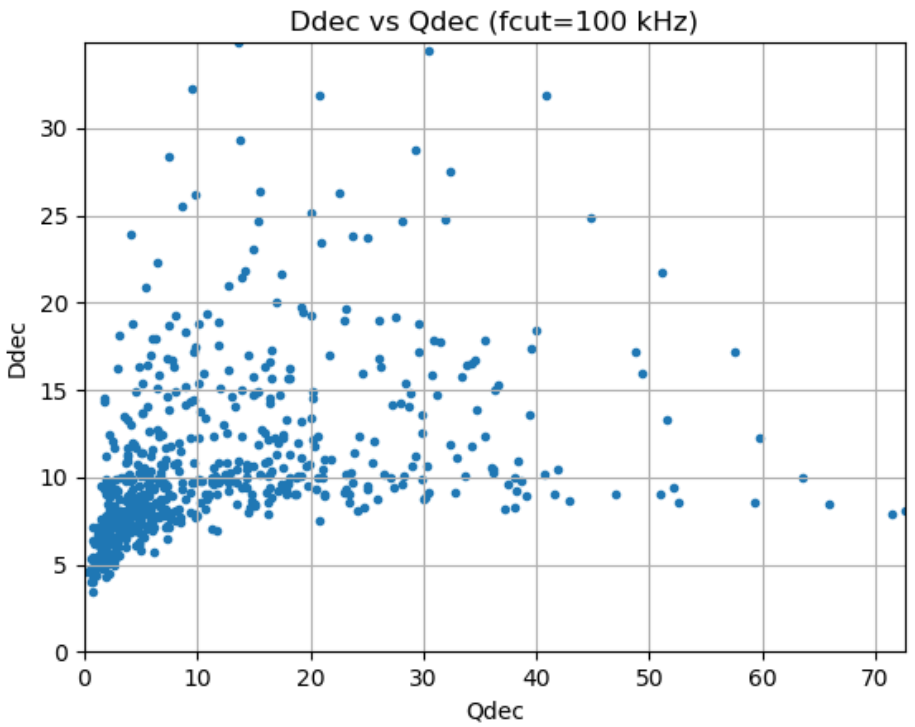


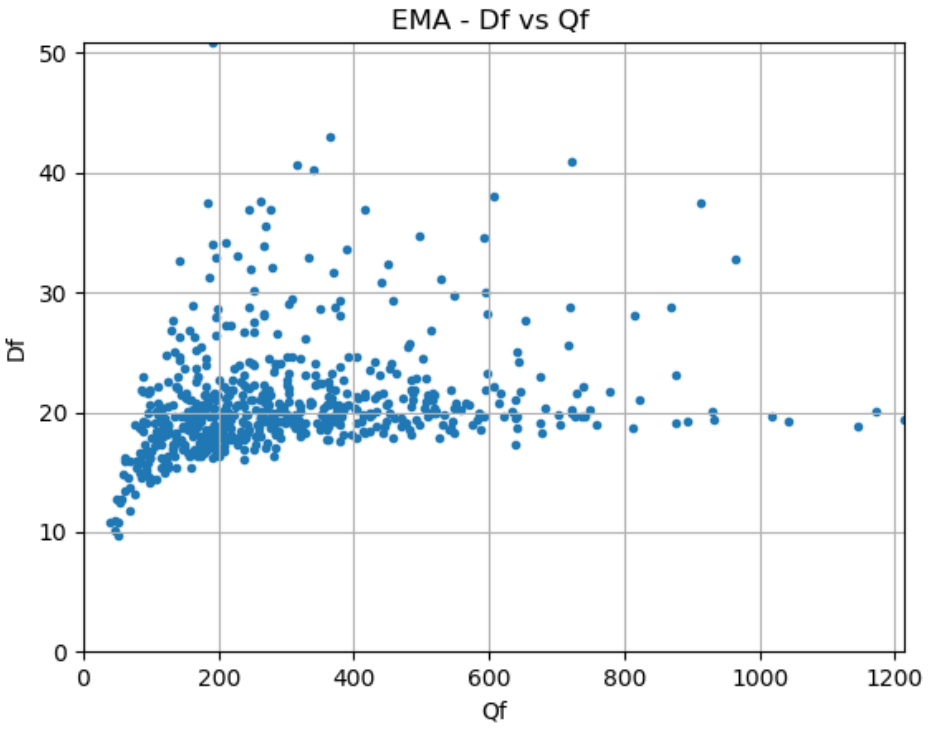






For small signals (like single-electrons) can we use EMA-C for physical parameter extraction ?

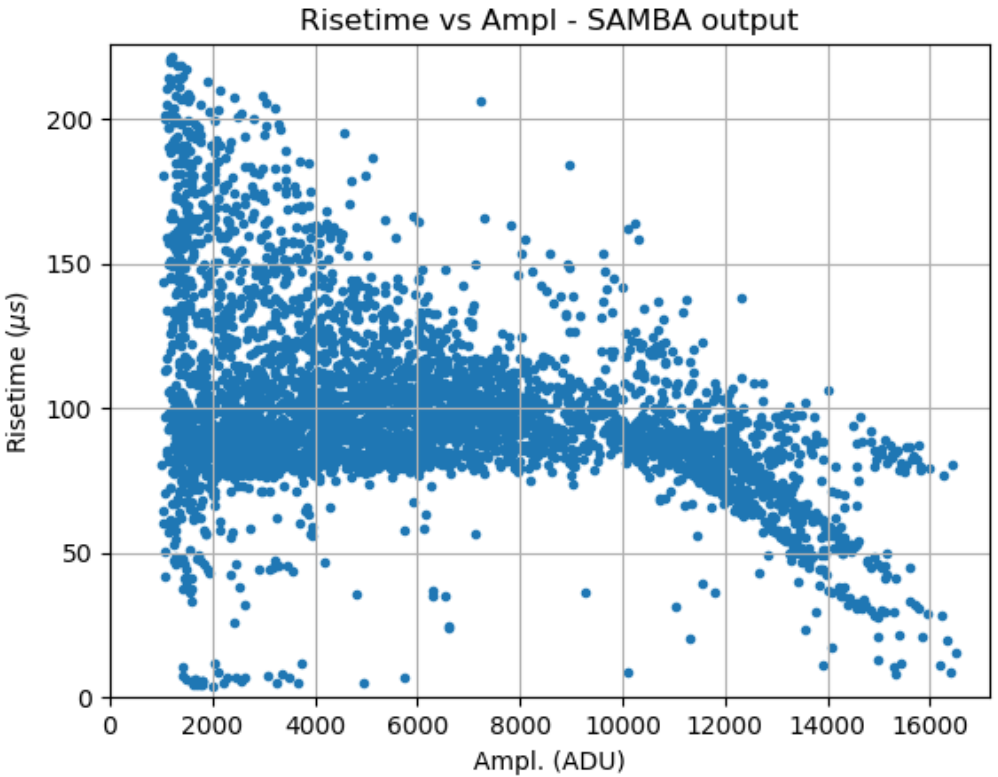


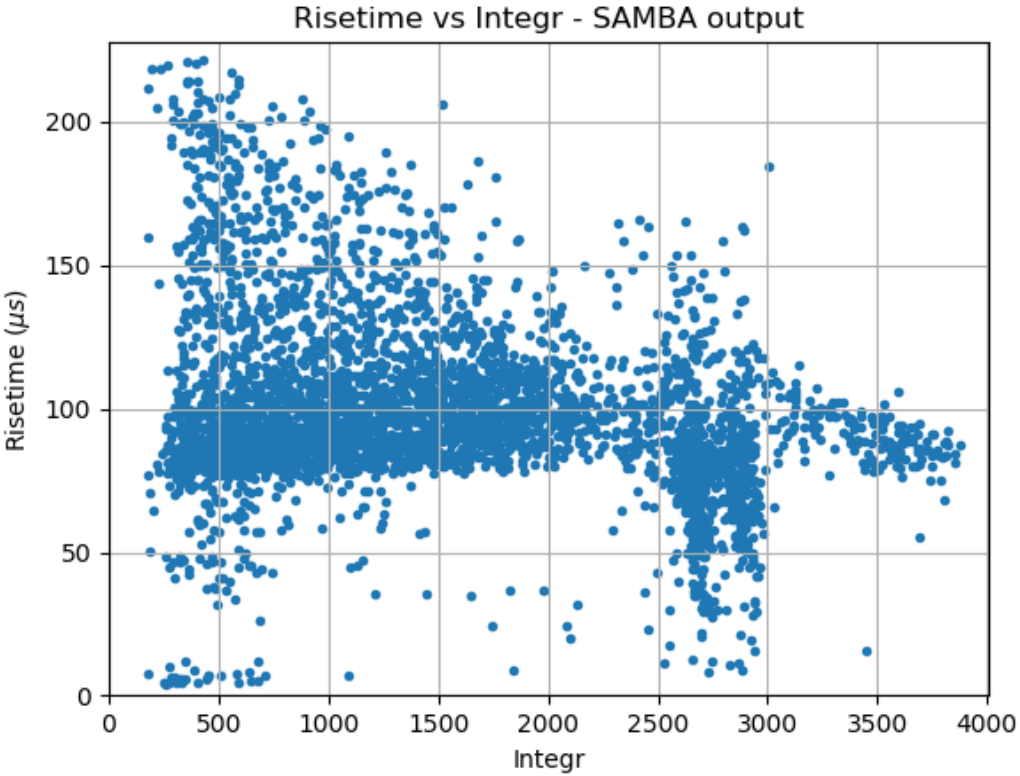


Use amplitude, integral ? => Analysis in progress

2D Identification diagrams & Energy estimations

R2D2 data - Thorite rods – Rn220 source



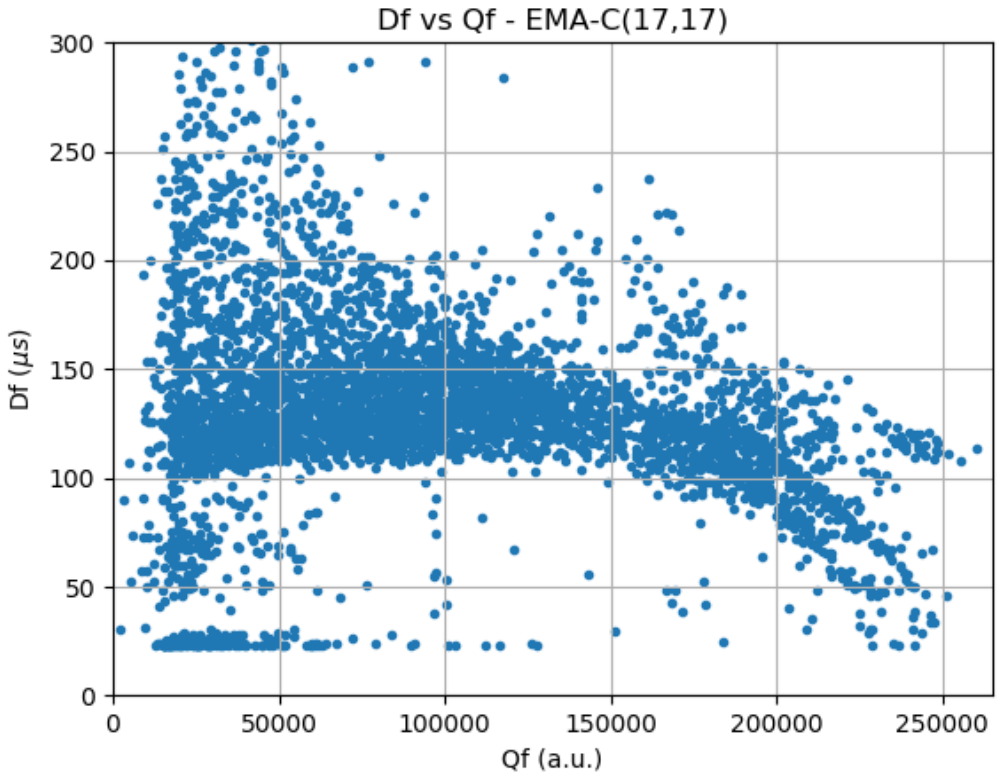


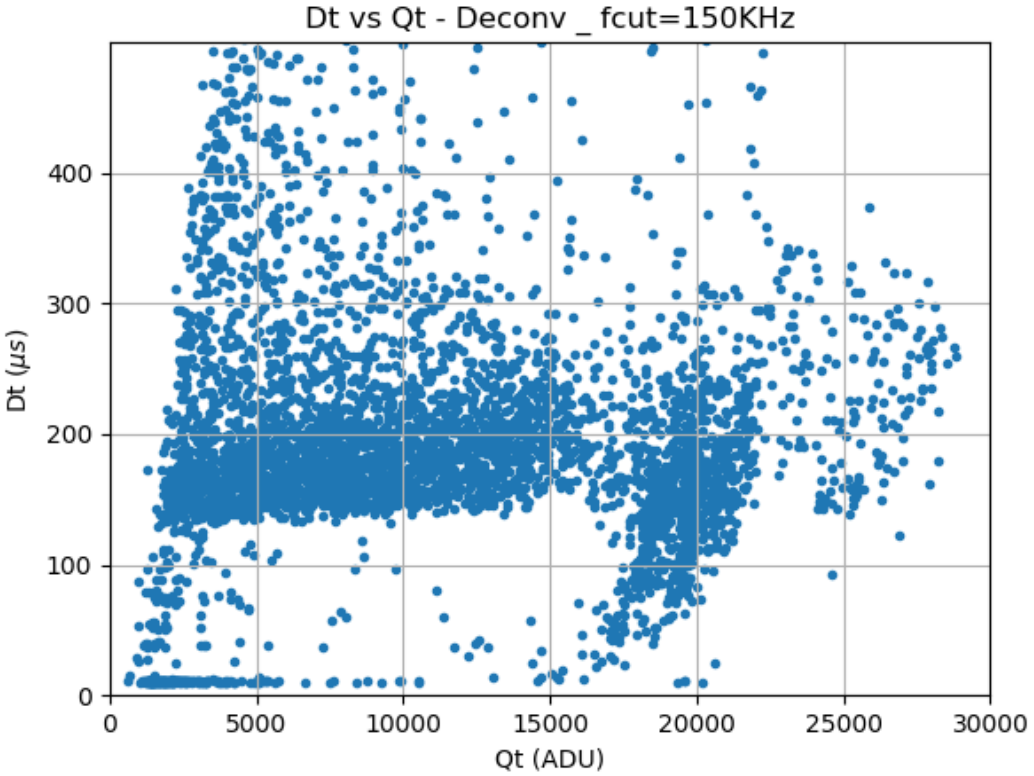
Bi212(6070) Rn220(6288) Po216(6778) Po212(8784)

Identification vs Filters

Thorite rods – Rn220 source

Bi212(6070) Rn220(6288) Po216(6778) Po212(8784)



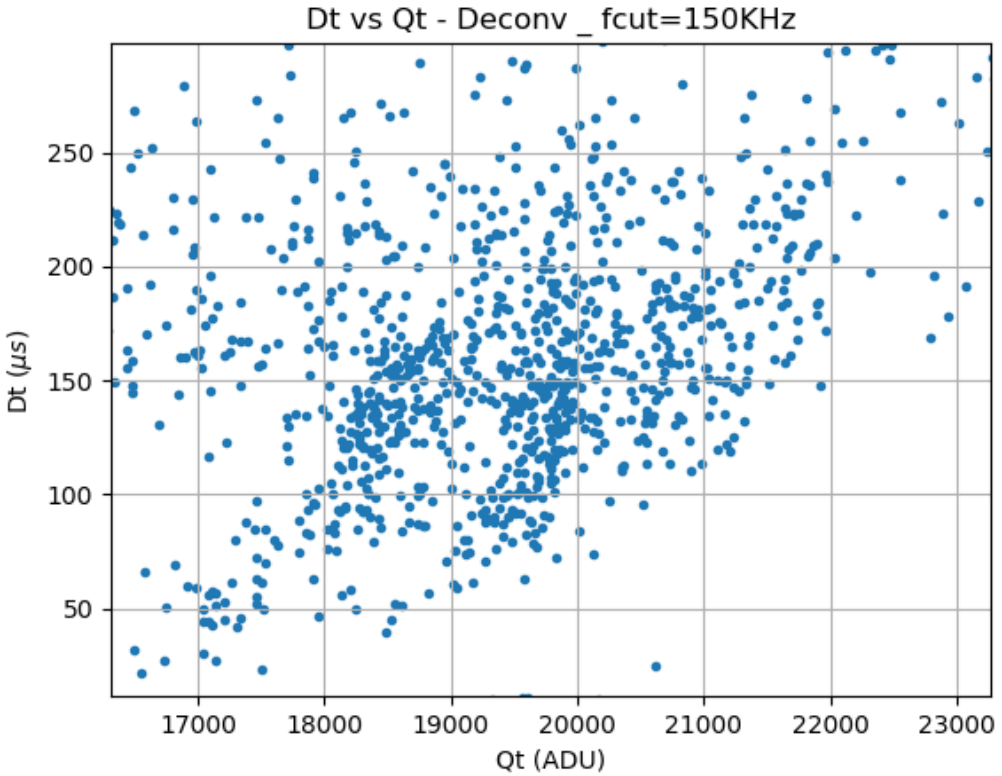


Integral of EMA-C signal

Identification vs Filters

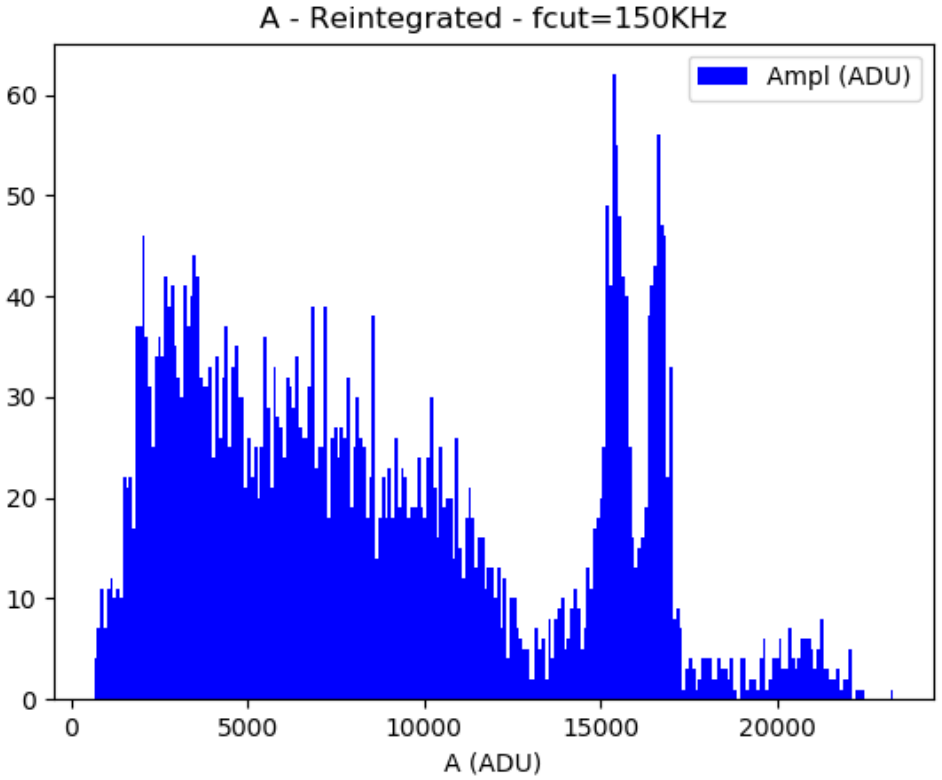
Thorite rods – Rn220 source

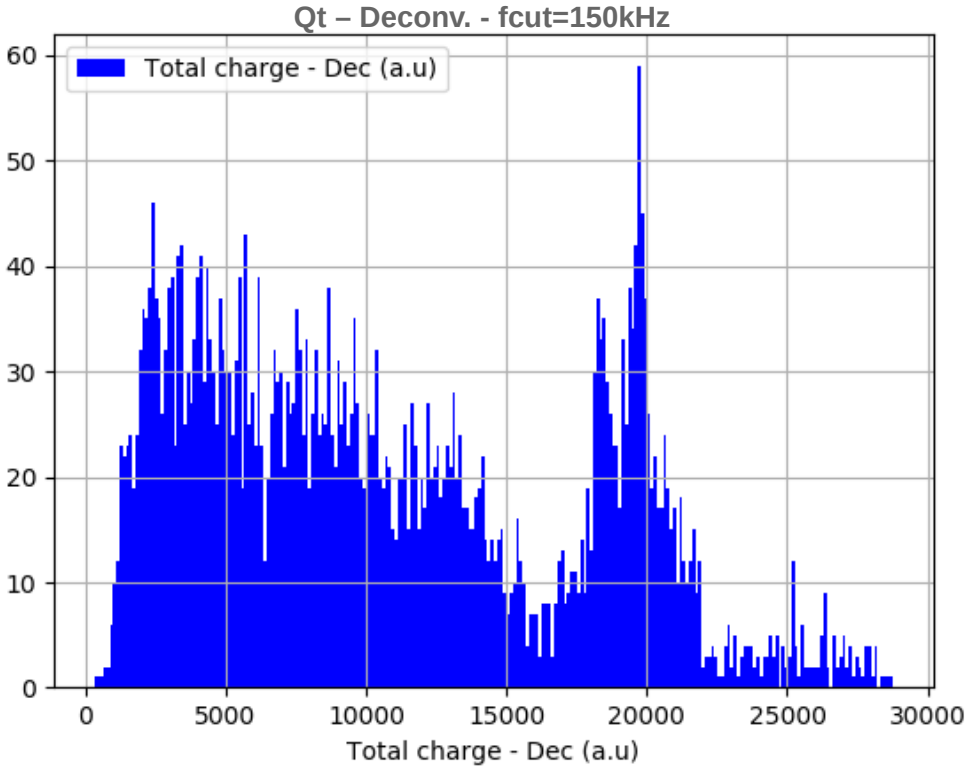
Bi212(6070) Rn220(6288) Po216(6778) Po212(8784)



Identification vs Filters

Thorite rods – Rn220 source





Bi212(6070) Rn220(6288) Po216(6778) Po212(8784)

Conclusion

- Tools are ready
- Time filtering is faster for triggering => EMA-C has the best properties
- For physical parameters extraction => Deconv. Signal (possible reintegration) but possibly

  other methods (in progress)

- Deconv. signal vs re-integrated signal paradigm

  => Advantage to non-re-integrated signal due

  to time limited signal ?