Update on the status of the ^{205}Tl(n,γ) cross section measurement

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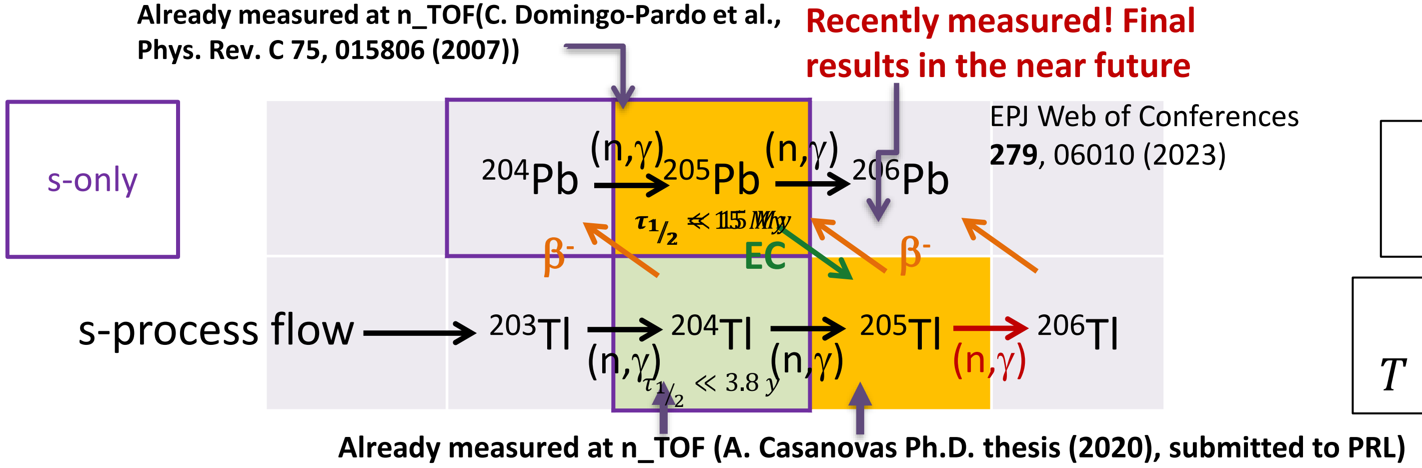
Outline of the presentation

- Reminder of the motivations for the measurement
- Report of the signal analysis work (still ongoing)
- Calibrations with simulations

The ^{205}Pb-^{205}Tl decay system

- ^{205}Tl is the most abundant (71%) stable (at earth) thallium isotope (Z=81)



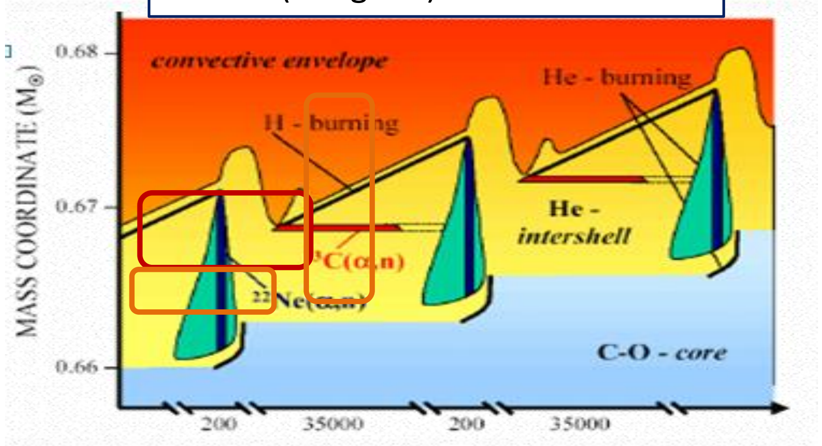
After s-process

C-13 pocket s-process
$T \sim 10^8\ K\ (kT \sim 8\ keV)$

TP s-process
$T \geq 3 \cdot 10^8\ K\ (kT \sim 25\ keV)$

- The **^{205}Pb/^{204}Pb ratio** could be used as a "chronometer" of the s-process[1,2,3]
  - Time elapsed since the last injection of main s-process products into the pre-solar nebula
  - Stellar effects on ^{205}Pb: at s-process sites temperature, EC decay is so strongly enhanced that its **survival is compromised**
  - Activation of the **bound state β decay** of ^{205}Tl

AGB (red giant) time evolution



1. K. Yokoi et al., ***The production and survival of Pb-205 in stars, and the ^{205}Pb/^{205}Tl s-process chronometry***, Astronomy and Astrophysics 145, 339-346 (1985)
2. R.G.A. Baker et al. , ***The thallium isotope composition of carbonaceous chondrites — New evidence for live ^{205}Pb in the early solar system***, Earth and Plan. Sc. Lett (2010)
3. Mowlavi, N., Goriely, S., Arnould, M., ***The survival of ^{205}Pb in intermediate-mass AGB stars***, Astron. Astrophys. 330, 206–214 (1998)

Main ideas

- ^{205}Tl is the most abundant (71%) stable (at earth) thallium isotope (Z=81)

Already measured at n_TOF(C. Domingo-Pardo et al., Phys. Rev. C 75, 015806 (2007))

The **^{205}Pb/^{204}Pb ratio** has the potential to be used as a "chronometer" of the s-process

The ^{205}Tl(n,γ) capture reaction, by affecting the abundance of ^{205}Tl, could play a relevant role in the final abundance (and survival) of ^{205}Pb

A precise knowledge of this cross section is also important to complete the analysis of the ^{204}Tl branching point

- Stellar effects ... temperature, EC decay is so strongly enhanced that its surviva...
- Activation of t...
- The ^{205}Pb/^{204}P... "chronometer" of the s-process
  - Time elapsed since the last injection of main s-process products into the pre-solar nebula

1. K. Yokoi et al., *The production and survival of Pb-205 in stars, and the ^{205}Pb/^{205}Tl s-process chronometry*, Astronomy and Astrophysics 145, 339-346 (1985)
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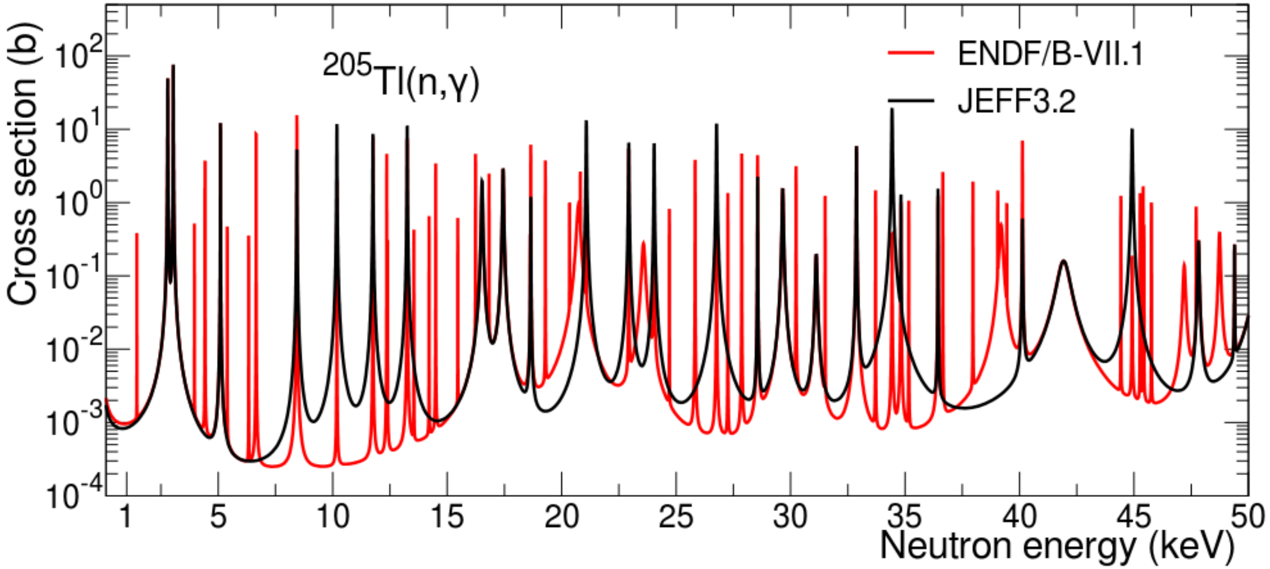
Status of the data for ^{205}Tl(n,γ) : cross section

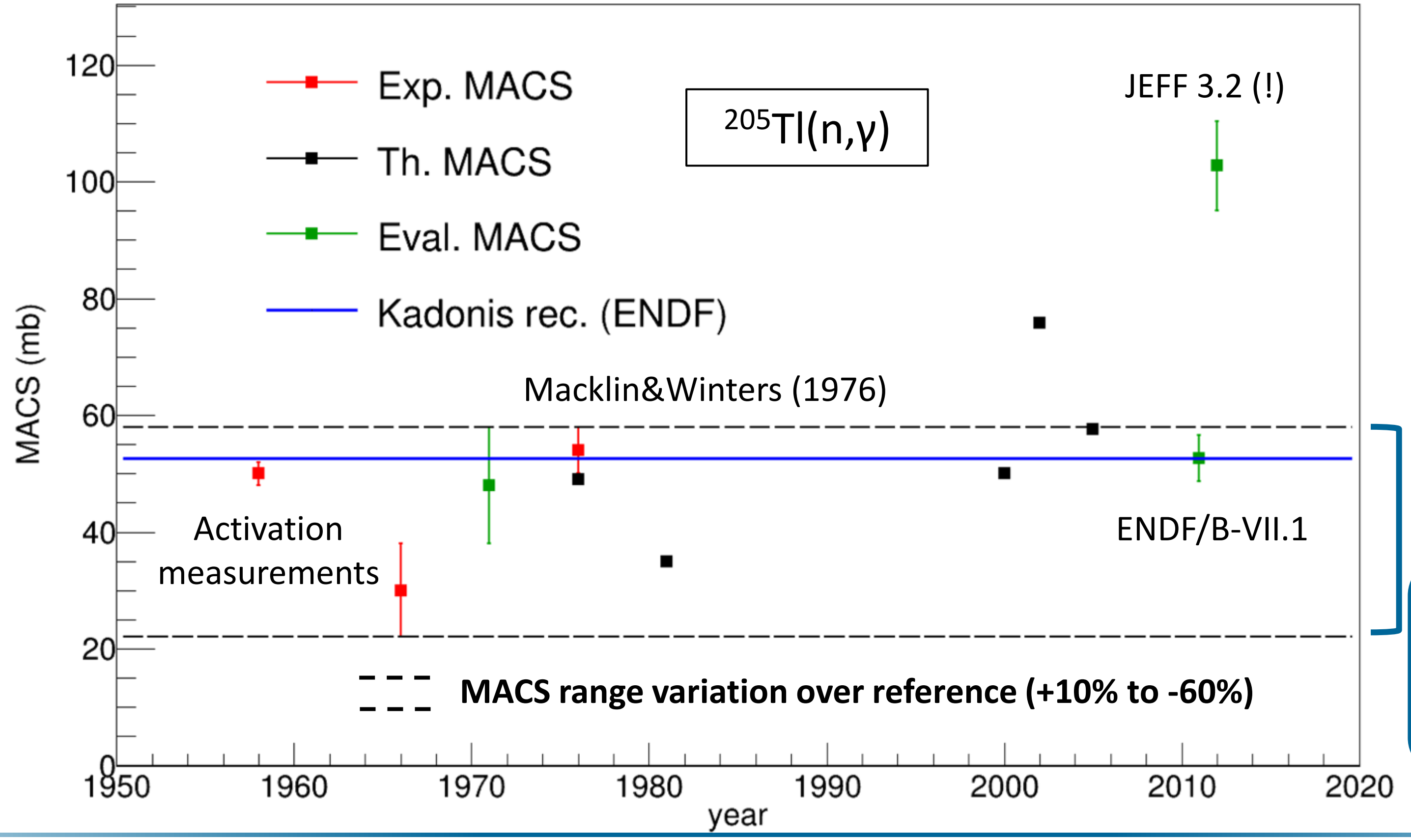
- Only one previous measurement: R. L. Macklin and R. R. Winters, *Stellar neutron capture in the thallium isotopes*, Astrophys. J. **208**, 812 (1976)
  - Experimental capture cross section or resonance parameters never published
  - Related EXFOR data: only resonance kernels, no uncertainties, up to 102 keV
  - Explicit correction factor for systematic error at ORNL: not known (0.95 for ^{203}Tl)

- Most recent evaluations show **important discrepancies**:



Status of the data for ^{205}Tl(n,γ): MACS

- MACS at 30 keV comparison:
  - Kadonis reference value: 52.6 ± 3.9 mb (ENDF evaluation)
  - Examination of ENDF data suggests it is based on 1976 ORNL measurement
  - No direct uncertainty assessment in the whole energy range (8 keV to 50 keV)



+10%
-60%

Estimation of the uncertainty in the accuracy of the MACS

Main points

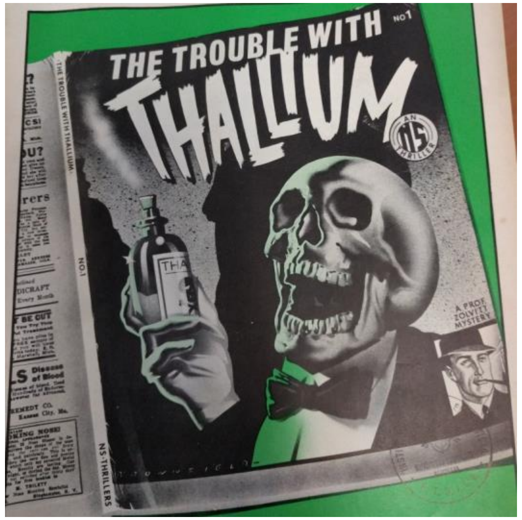
- From the current status of the data a **+10% to -40%** uncertainty in the value of the ^{205}Tl(n,γ) is assumed

- This leads to an approx. **40%** global uncertainty in the **^{205}Pb/^{204}Pb ratio** only due to this reaction

- Goal: increase precision and accuracy of ^{205}Tl(n,γ) to reduce the uncertainty in the ^{205}Pb/^{204}Pb ratio

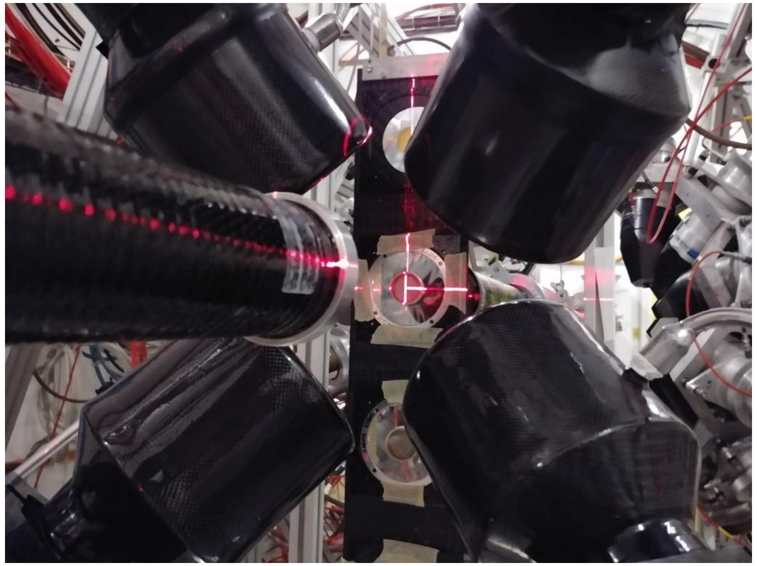
^{205}Tl(n,γ) measurement: sample issue

- Acquired "pure" sample was heavily contaminated with bromine
- A new, on-the-go sample of **natural thallium** was produced in a few days thanks to our PSI colleagues (E. Maugeri's team)
  - 3.7 g of natural thallium, of which 2.6 g is ^{205}Tl
  - Same diameter, similar thickness
- **This sample luckily had no bromine**
  (or an undetectable amount)



- **As nat. Tl, sample contains also 29% of ^{203}Tl**
- Resonance spacing of Tl isotopes resonances is high
  →"easier" to separate them
- ^{203}Tl was measured in 2015, resonance information up to 25 keV
- Higher energy results could be used to complete ^{203}Tl(n,γ) analysis of 2015 measurement (to be carefully studied)

- Meas. Setup: standard C_6D_6 Legnaro detectors, "old" PMT



Measurement summary

TOTAL	**2.508E+18**
Assigned	**2.60E+18**
Sum on good targets:	**1.853E+18**
Sum backgrounds:	**4.315E+17**
Sum useful data:	**2.284E+18**
Sum Tl-nat 99%:	**1.613E+18**
Sum Tl-nat 99% filters:	1.09E+17
Sum dummy:	2.322E+17
Sum dummy filters:	6.743E+16
Total dummy:	**2.996E+17**
Sum Gold:	**1,314E+17**
Sum Pb-nat:	4.753E+16
Sum Pb-nat filters:	4.403E+16
Total Pb-nat	9.156E+16
Sum empty:	4.036E+16
Sum Br cont. thick:	1.822E+17
Sum Br cont. thin:	4.165E+16
Sum contaminated:	**2.238E+17**

$2{\cdot}10^{18}$ protons approved
$1.7{\cdot}10^{18}$ allocated

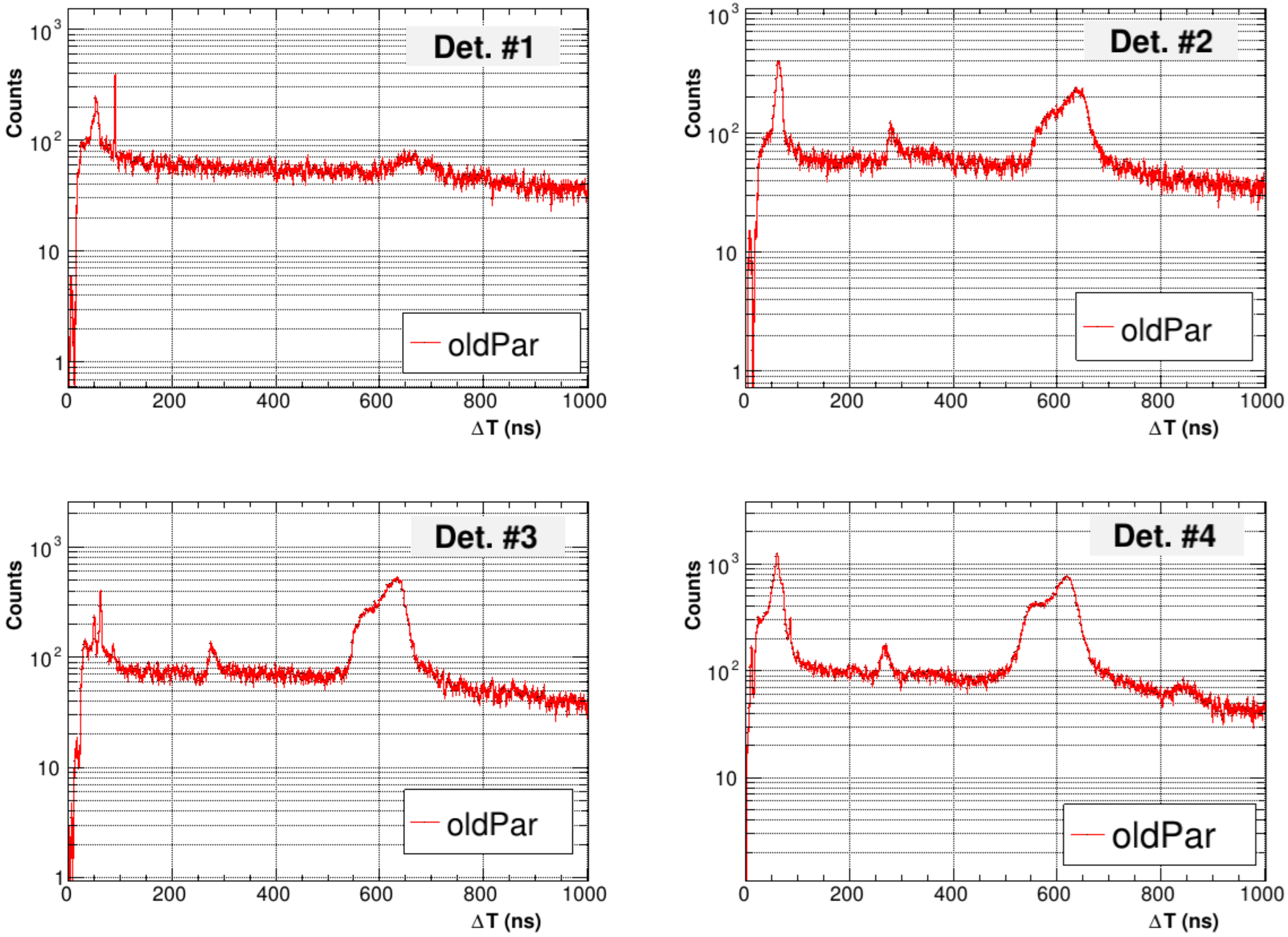
First steps: signal analysis

- EAR1 Legnaro C_6D_6 detectors equipped with old PMT **have always suffered from strong "rebound" signals**, appearing around ~600 ns after the primary signal and with much les amplitude (for example, see multiple talks by V. Babiano on ^{80}Se(n,g), or more recently by F. García on ^{176}Yb(n,g), etc.)
  - Issue much worse in some detectors tan others

- Since Legnaro became the standard C6D6 setup, **this issue has been circumvented by using high E. dep. thresholds** (250 - 300 keV)
- "Official" PSA routine parameters not changed in years: parabolic fit to the amplitude, no PSF, no fit of the baseline

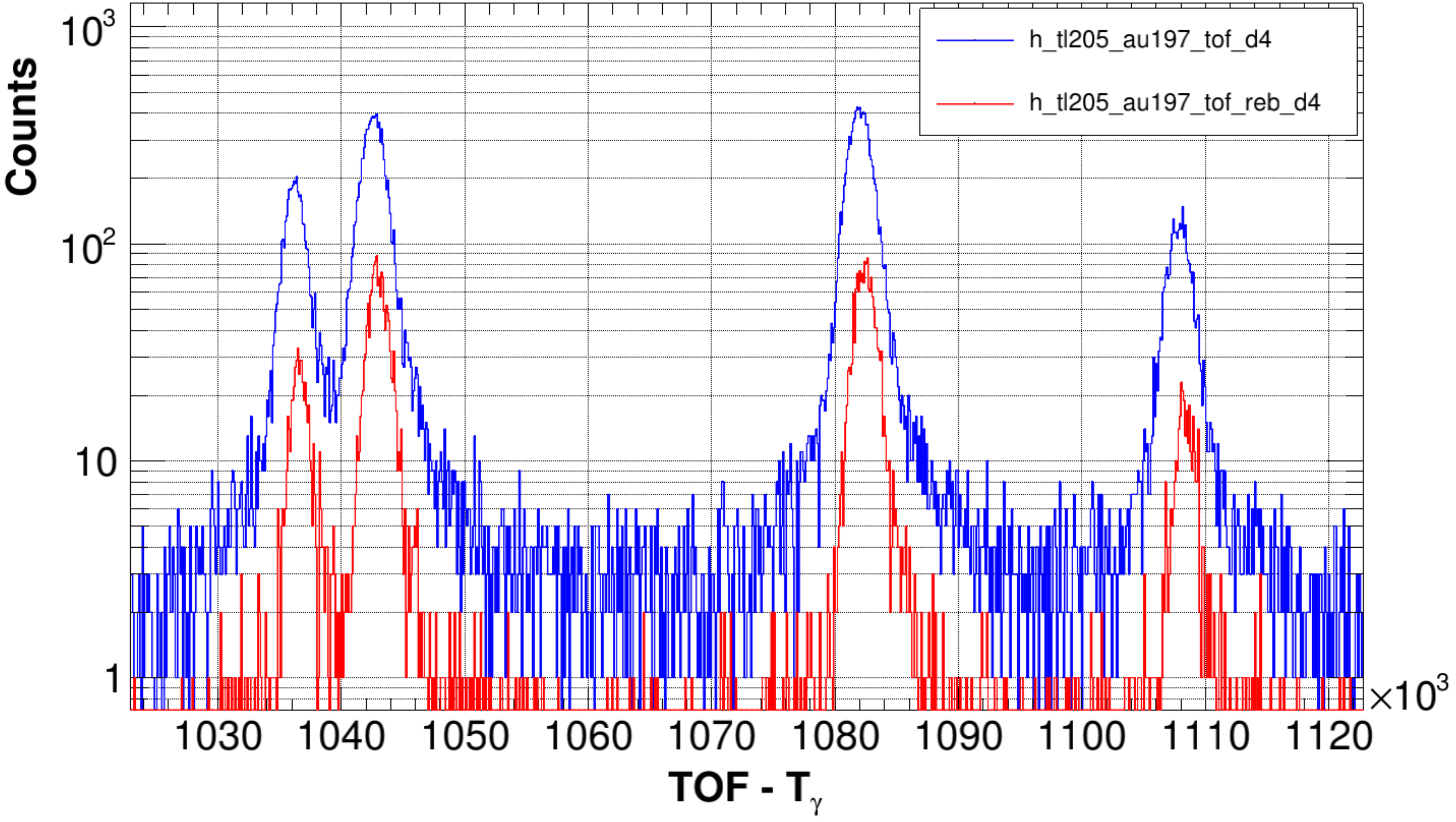
- As a first step in the analysis, we have been working in new sets parameters:
  - Same old parameters, but with PSF and adaptative baseline ("oldParPSF")
  - PSF + baseline + new more agressive parameters to try to eliminate 600 ns rebounds during PSA ("newPar" parameters)

ΔT between consecutive signals (E.dep. th = 120 keV)

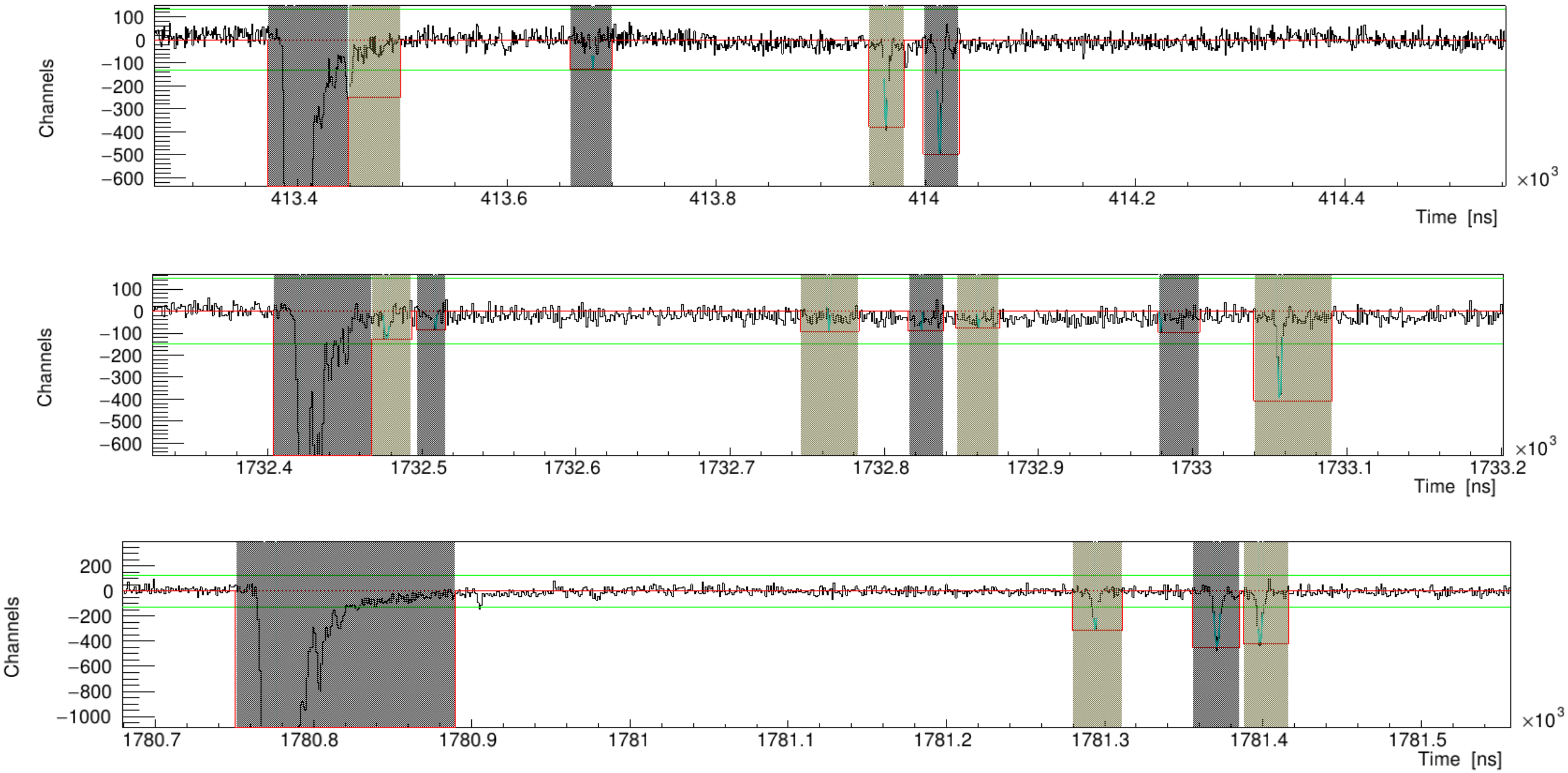


Rebounds in data (E. dep. = 120 keV)

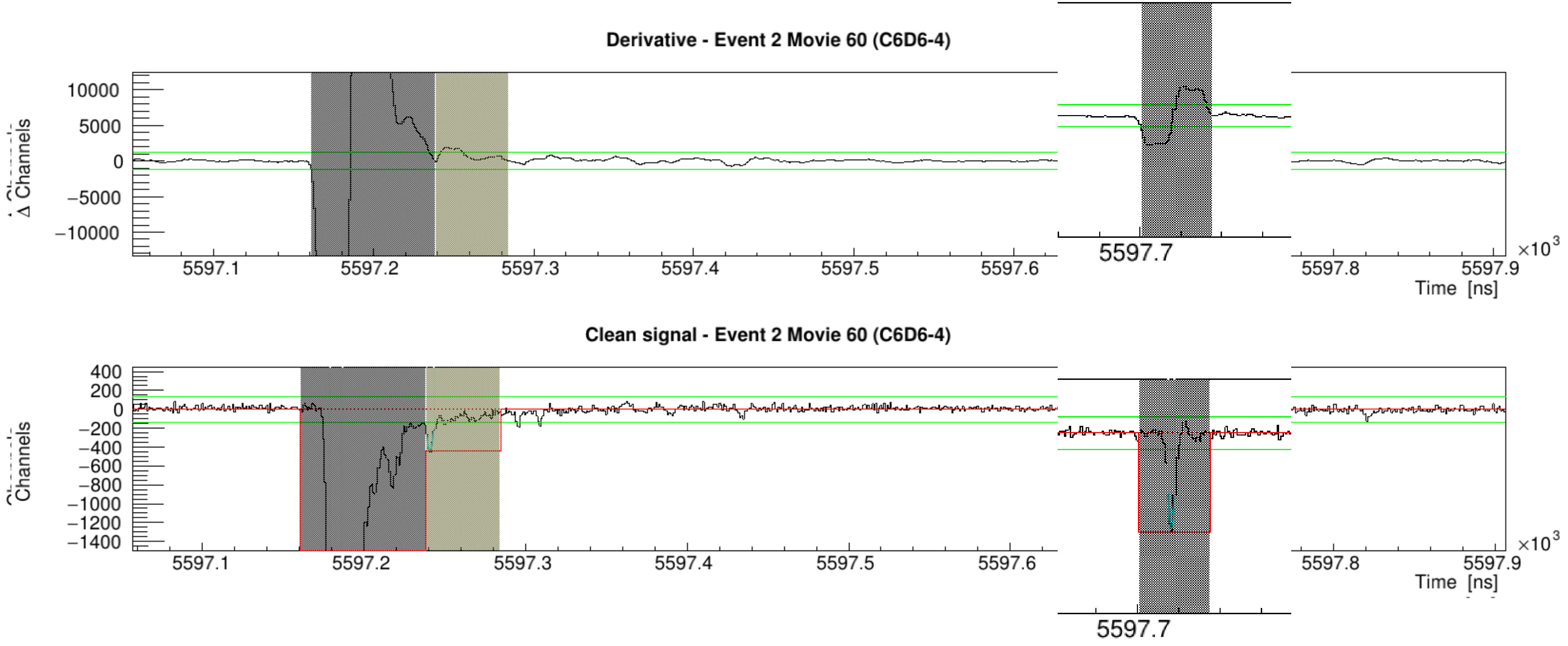
- Rebound is artificial contribution to resonance integrals
- Can lead even to false double structures



Old PSA parameters and rebounds



Old PSA parameters and rebounds



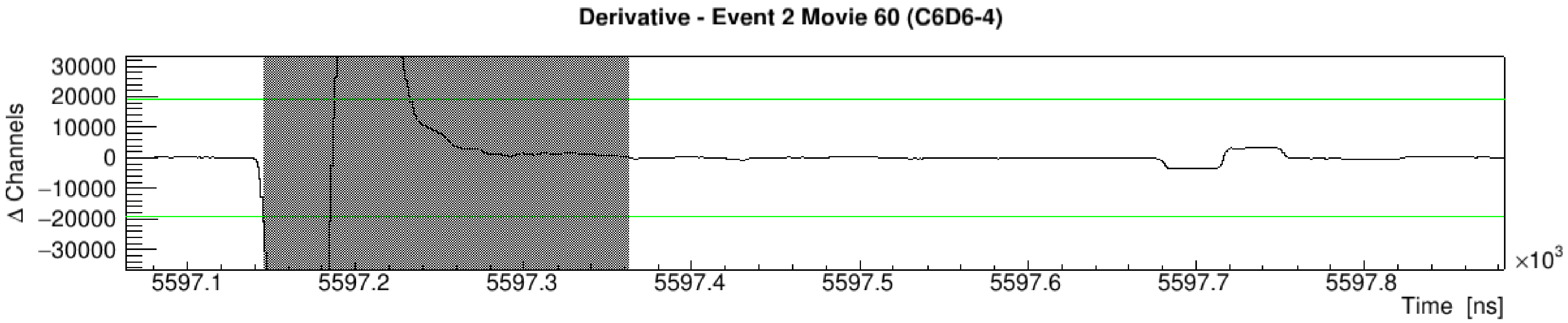
Old vs new parameters

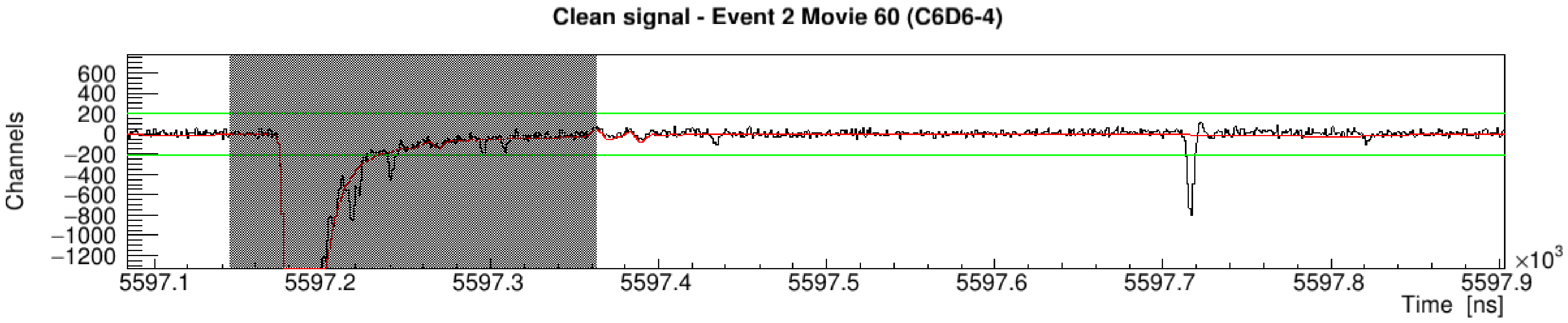
```
C6D6          1          PSA    15     0      0      0      0     12e3/1E9   1
         9000            2            300          0
C6D6          2          PSA    15     0      0      0      0     12e3/1E9   1
        9000            2            300          0
C6D6          3          PSA    20     0      0      0      0     12e3/1E9   1
        9000            2            300          0
C6D6          4          PSA    15     0      0      0      0     12e3/1E9   1
 -:---  UserInput_2018_EAR1_Tl205_official.h   Top (4,0)     (C/l Abbrev)
0          500            4000                    0
####
C6D6        1            PSA     15      0      0       0       0      100e6      1
      9000          2              300      3   cs137_det1.dat y88_high_det1.dat vhigh_det1.dat
C6D6        2            PSA     15      0      0       0       0      100e6      1
    9000          2              300                                        igh_det2.dat
C6D6        3            PSA     15                                          00e6      1
  9000          2              300      3                                    gh_det3.dat
C6D6        4            PSA     30                                          0e6       1
9000           2              300          3                                 h_det4.dat

 -:---  UserInput_2018_EAR1_Tl205_vOld_wPSA
SILI          4       PSA    500     0      0      0      0     1e9/1e9    0      500.
0          500            4000                    0
C6D6          1       PSA    30/25     0      0      0      0     100e6      1
        9000          10           300     2   y88_high_det1.dat vhigh_au197_det1.dat
C6D6          2       PSA    30/28     0      0      0      0     100e6      1
        9000          10           300     2   y88_high_det2.dat vhigh_au197_det2.dat
C6D6          3       PSA    35/35     0      0      0      0     100e6      1
        9000          10           300     3   cs137_det3.dat y88_high_det3.dat vhigh_au197_
C6D6          4       PSA    35/25     0      0      0      0     100e6      1
      9000            10           300     2   y88_high_det4.dat vhigh_au197_det4.dat

 -:---  UserInput_2018_EAR1_Tl205_v01_local.h   83% (82,0)     (C/l Abbrev)
```

- Derivative step
- Threshold in derivative

New PSA parameters (first version)

- New parameters: increase in step size and derivative threshold
- **Goal: eliminate rebounds while keeping signals of similar amplitude**





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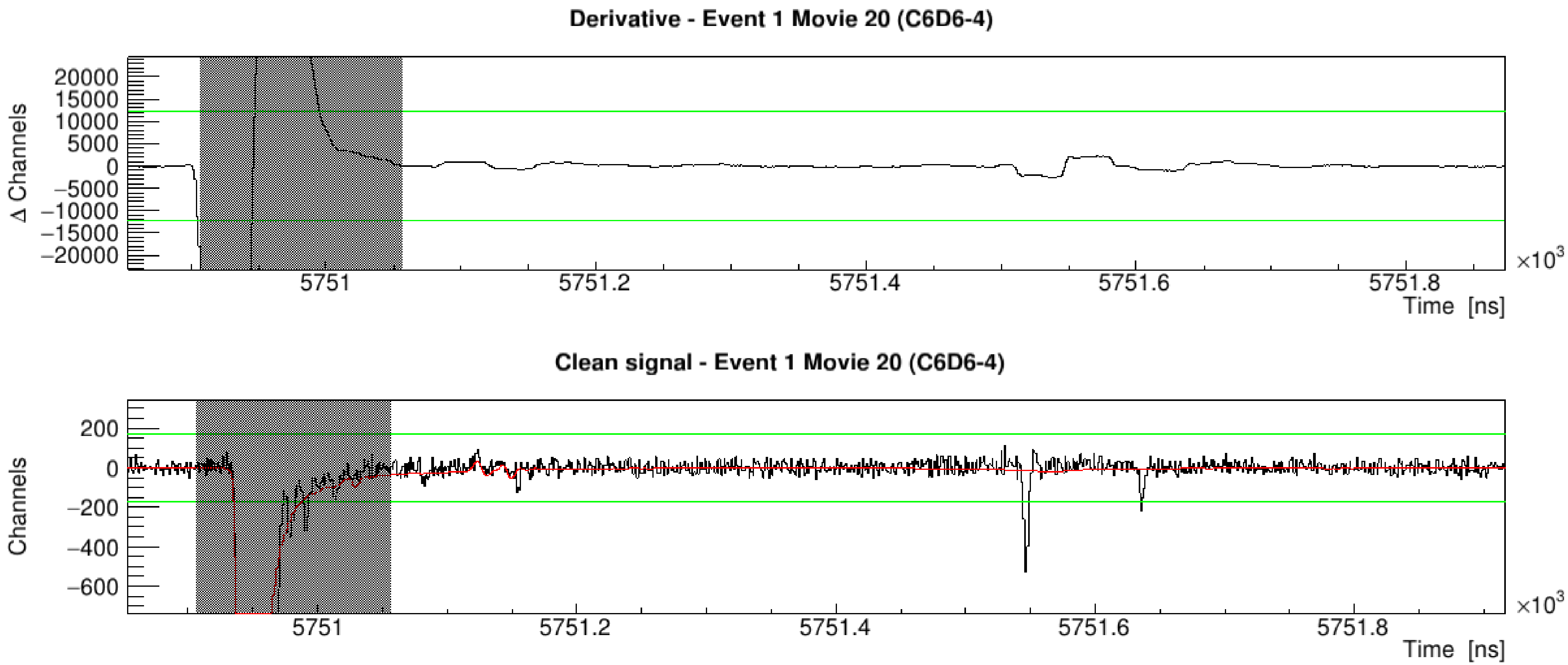

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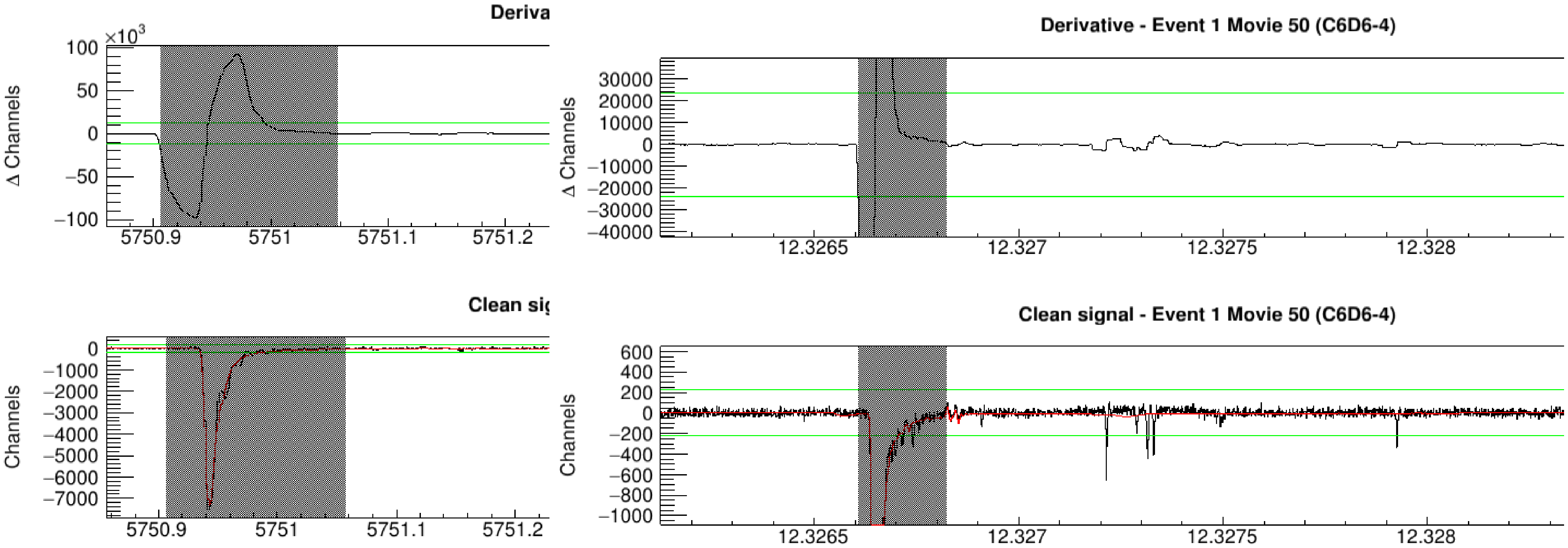

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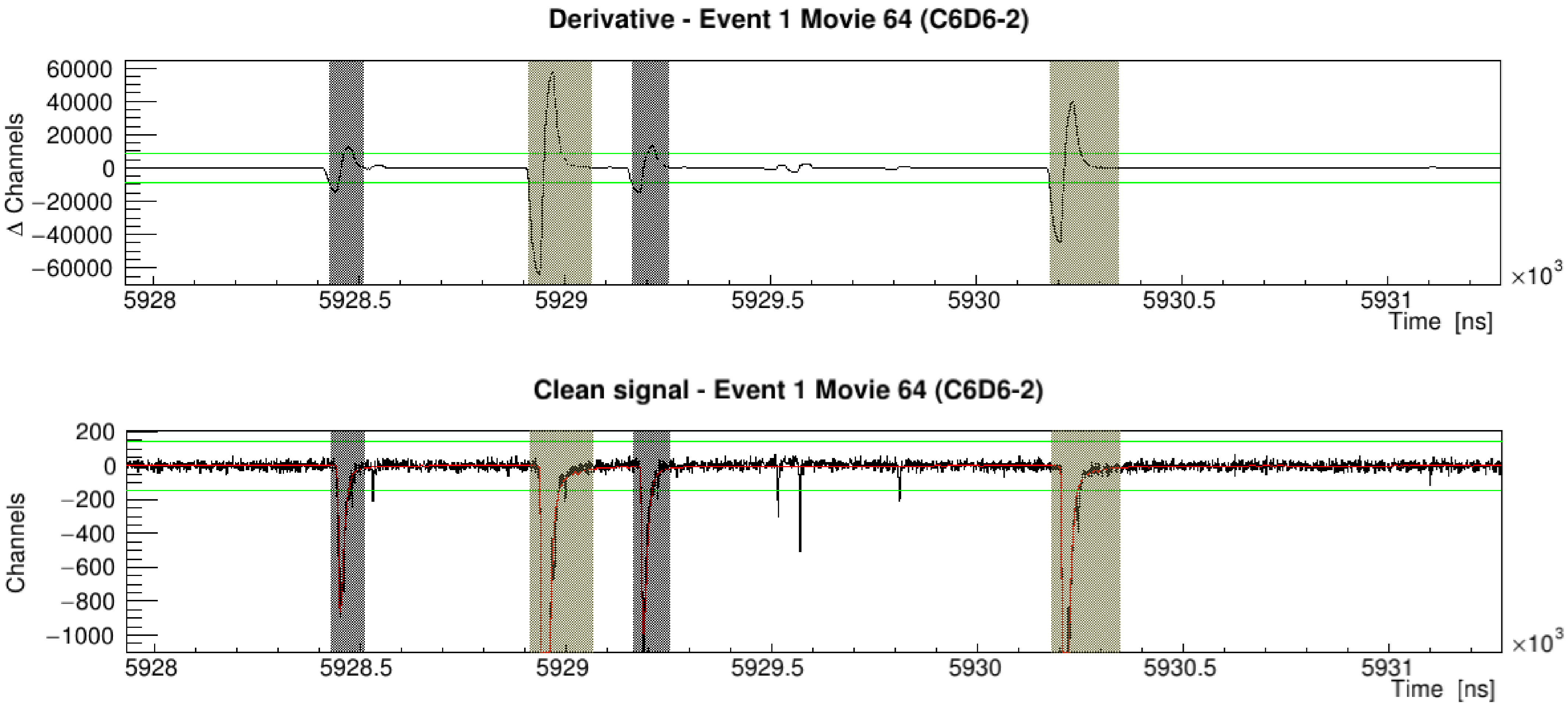

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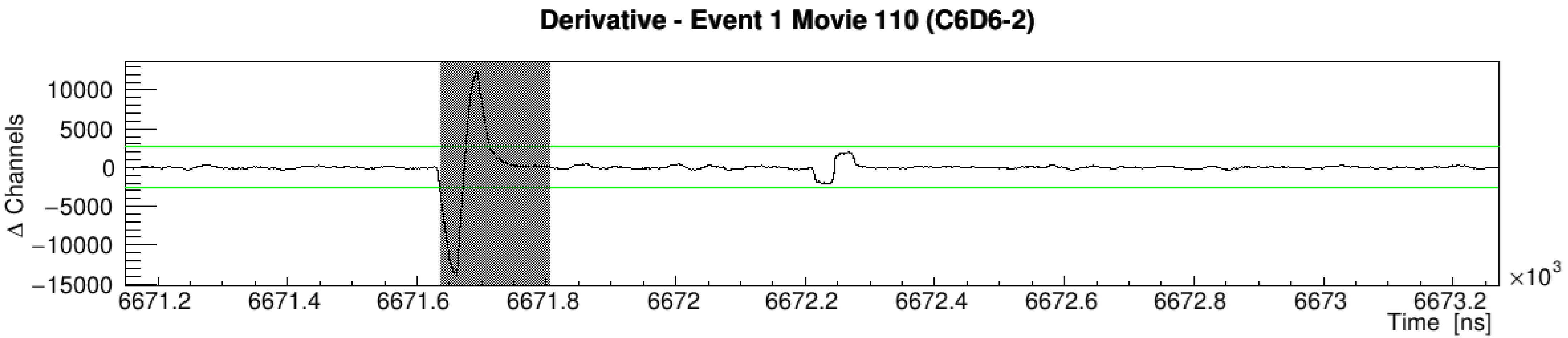

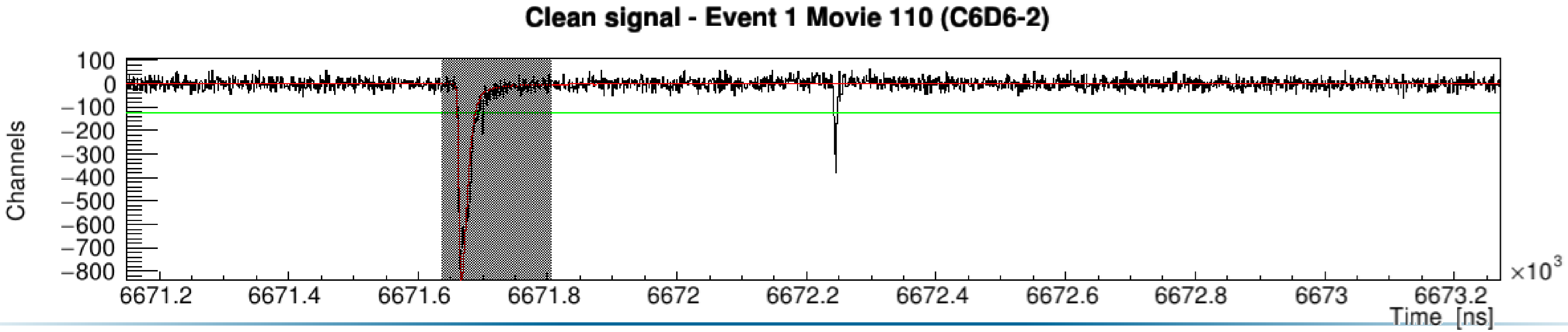

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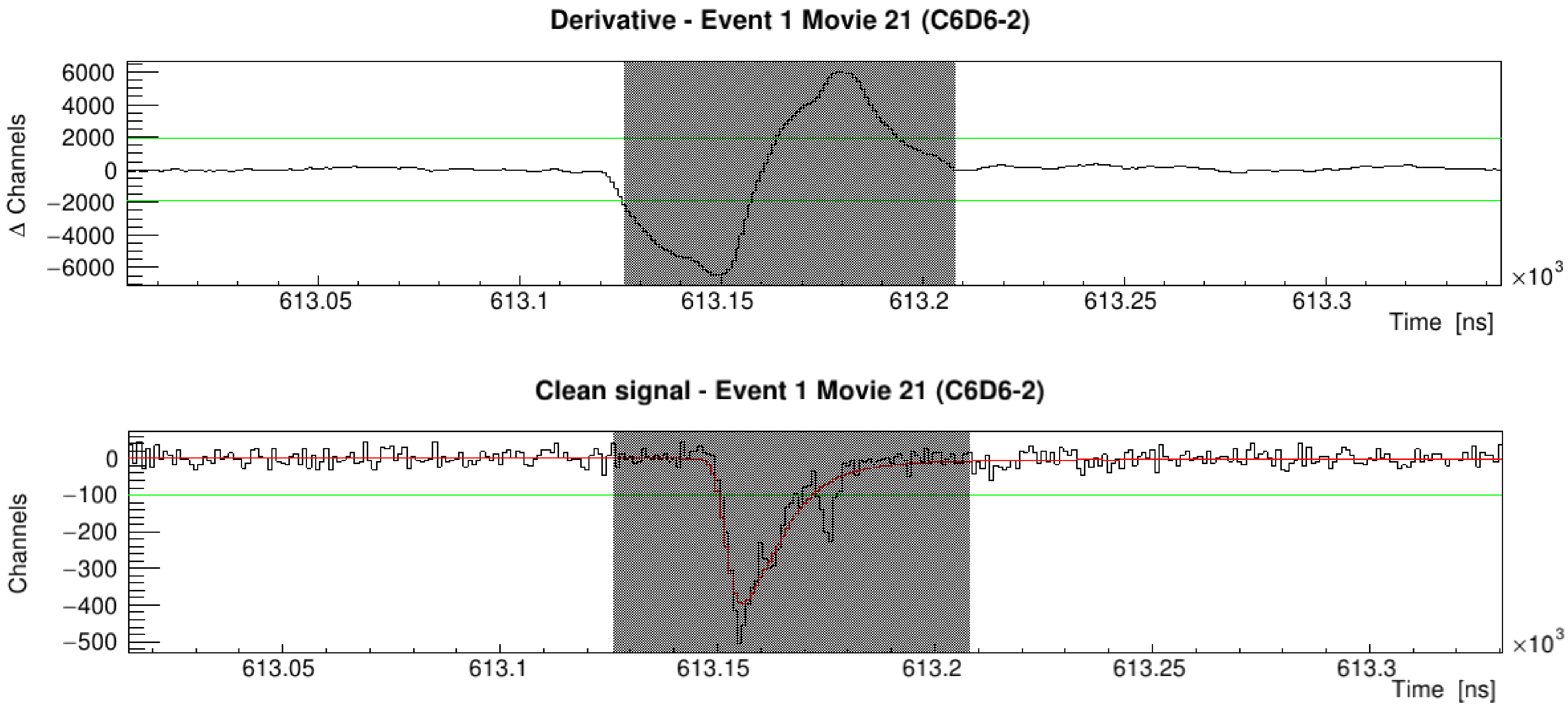
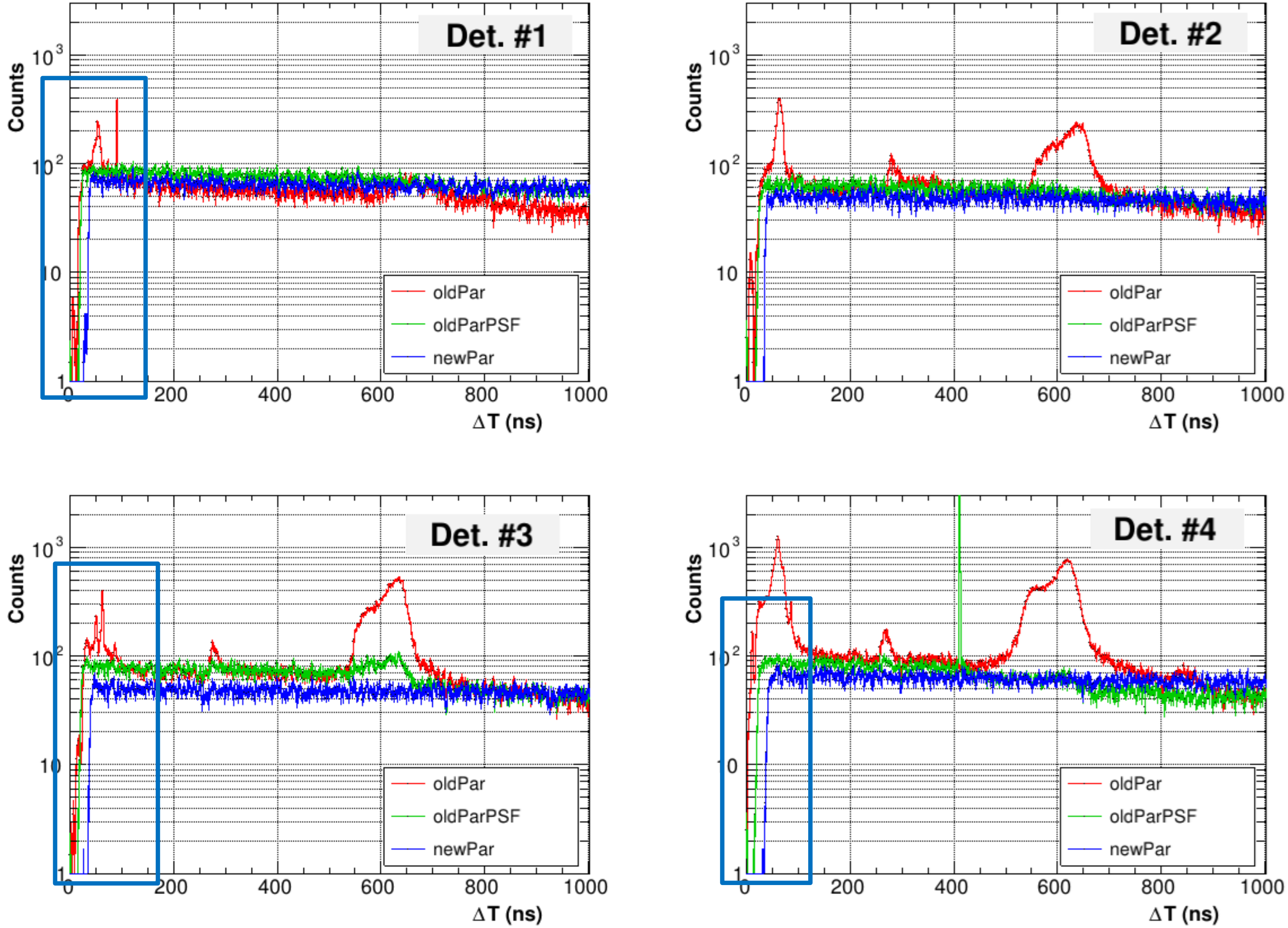
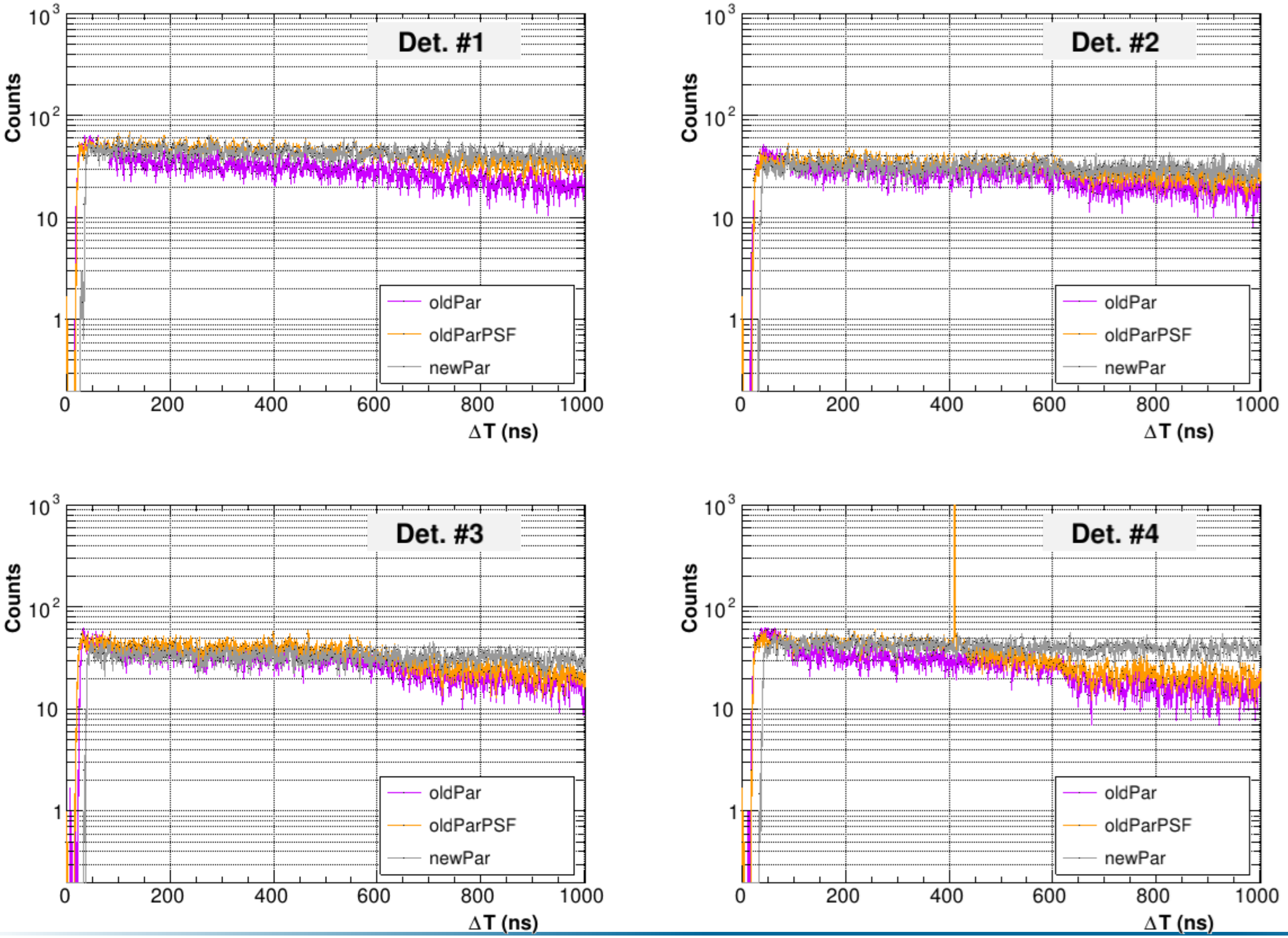


ΔT between consecutive signals: th=120 keV



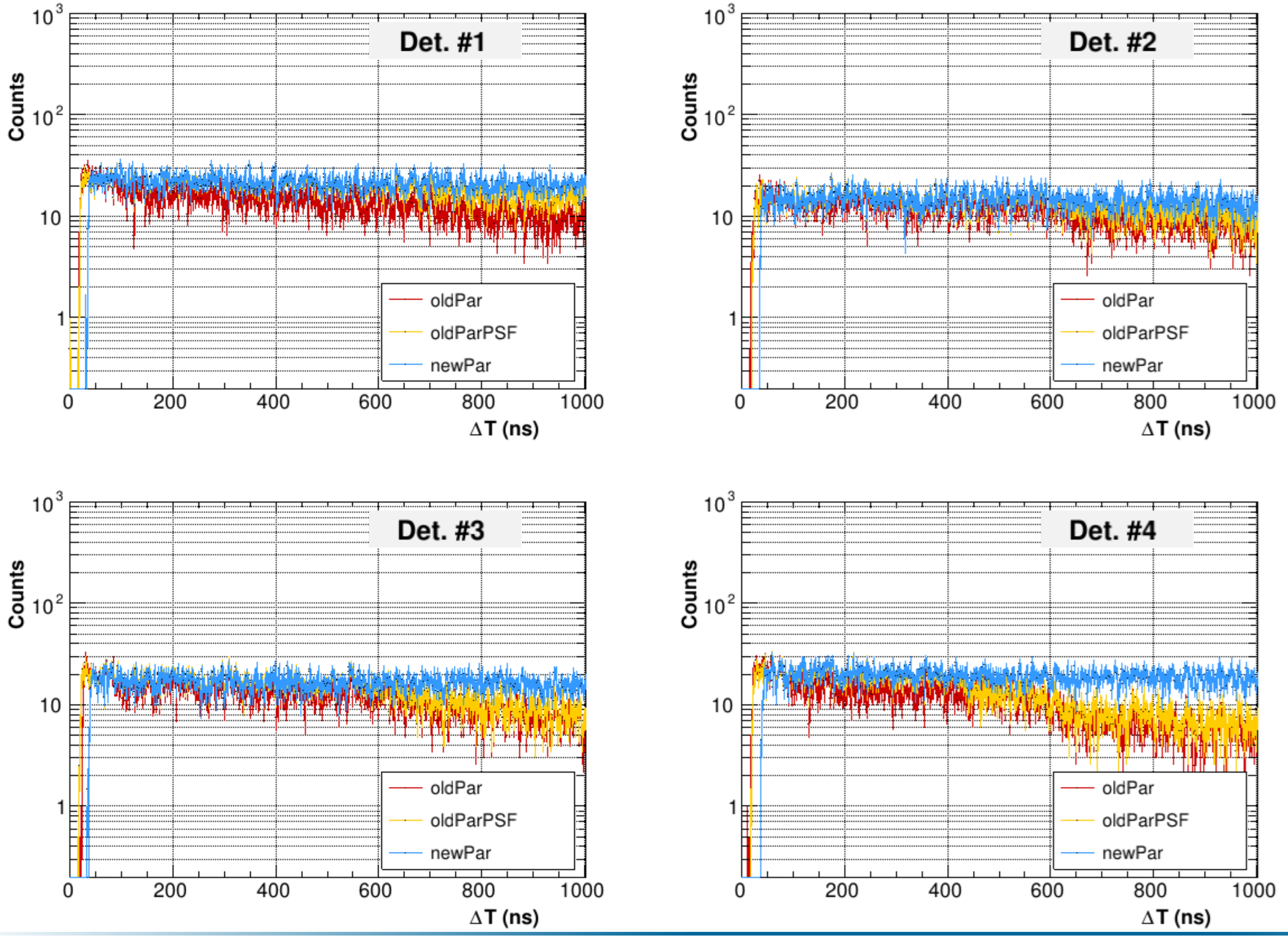
- Flat distribution also for low threshold
- Increase in step size increases “dead time” (i.e. time under which two signals can’t be distinguished) from ~30 to ~40 ns → 25% additional pile up correction
- Due to wider stepsize, not reliable for TOF ≲ 25-30 us (~200 keV)

ΔT between consecutive signals: th=250 keV



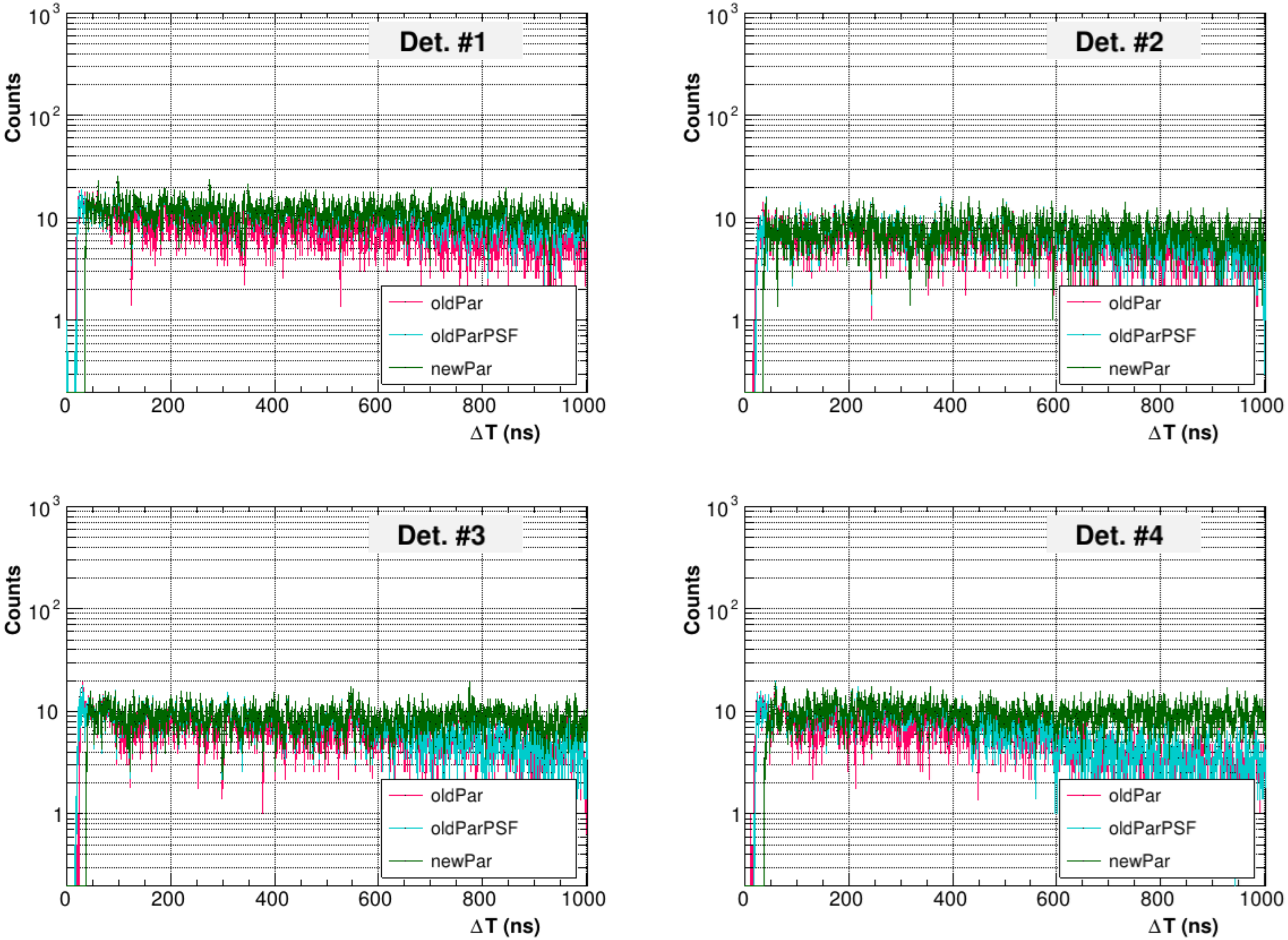
- Flat distribution also for low threshold
- Increase in step size increases “dead time” (i.e. time under which two signals can’t be distinguished) from ~30 to ~40 ns → 25% additional pile up correction
- Due to wider stepsize, not reliable for TOF ≲ 25-30 us (~200 keV)

ΔT between consecutive signals: th=600 keV



- Flat distribution also for low threshold
- Increase in step size increases "dead time" (i.e. time under which two signals can't be distinguished) from ~30 to ~40 ns → 25% additional pile up correction
- Due to wider stepsize, not reliable for TOF ≲ 25-30 us (~200 keV)

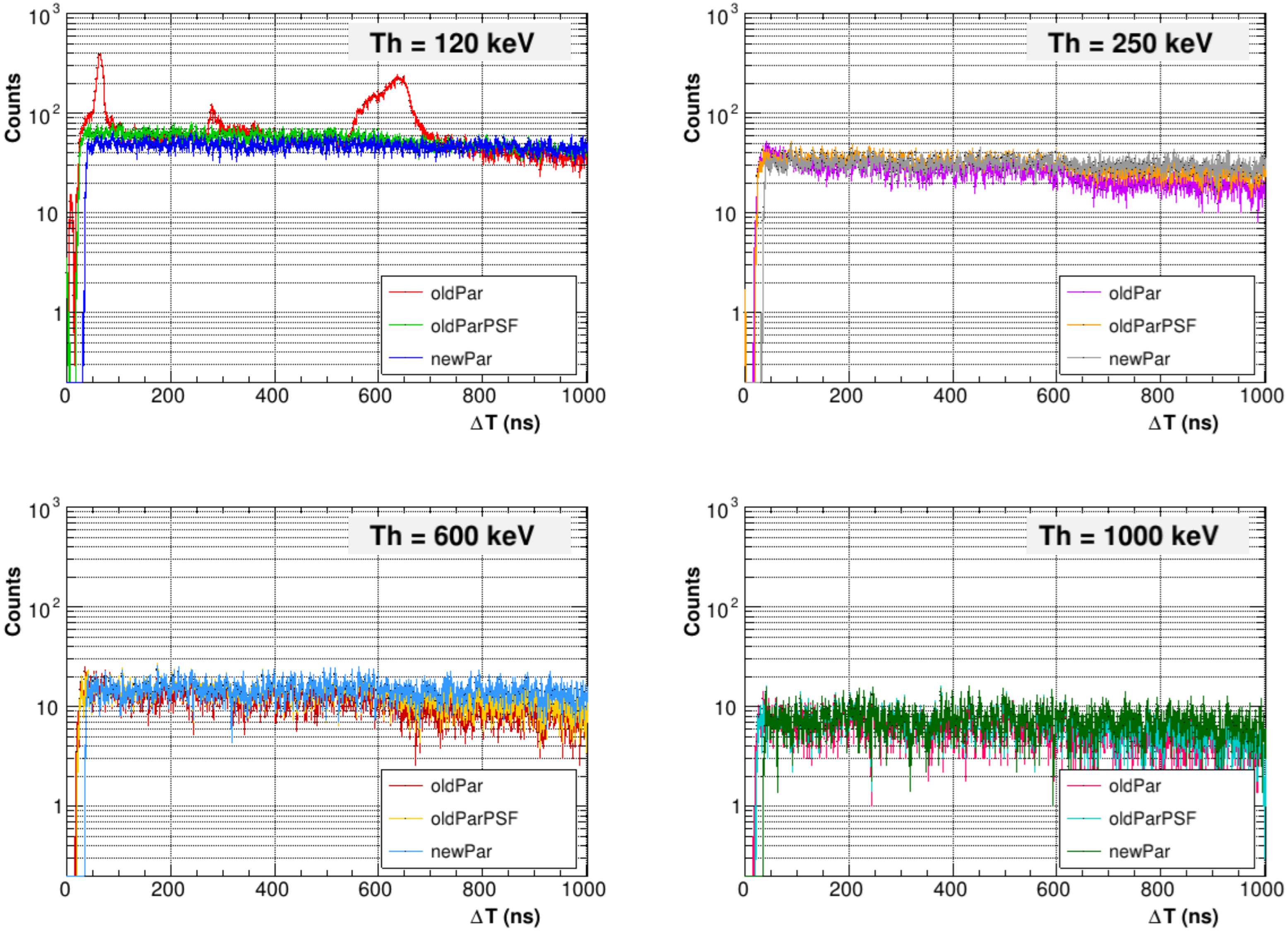
ΔT between consecutive signals: th=1000 keV



- Flat distribution also for low threshold
- Increase in step size increases "dead time" (i.e. time under which two signals can't be distinguished) from ~30 to ~40 ns → 25% additional pile up correction
- Due to wider stepsize, not reliable for TOF ≲ 25-30 us (~200 keV)

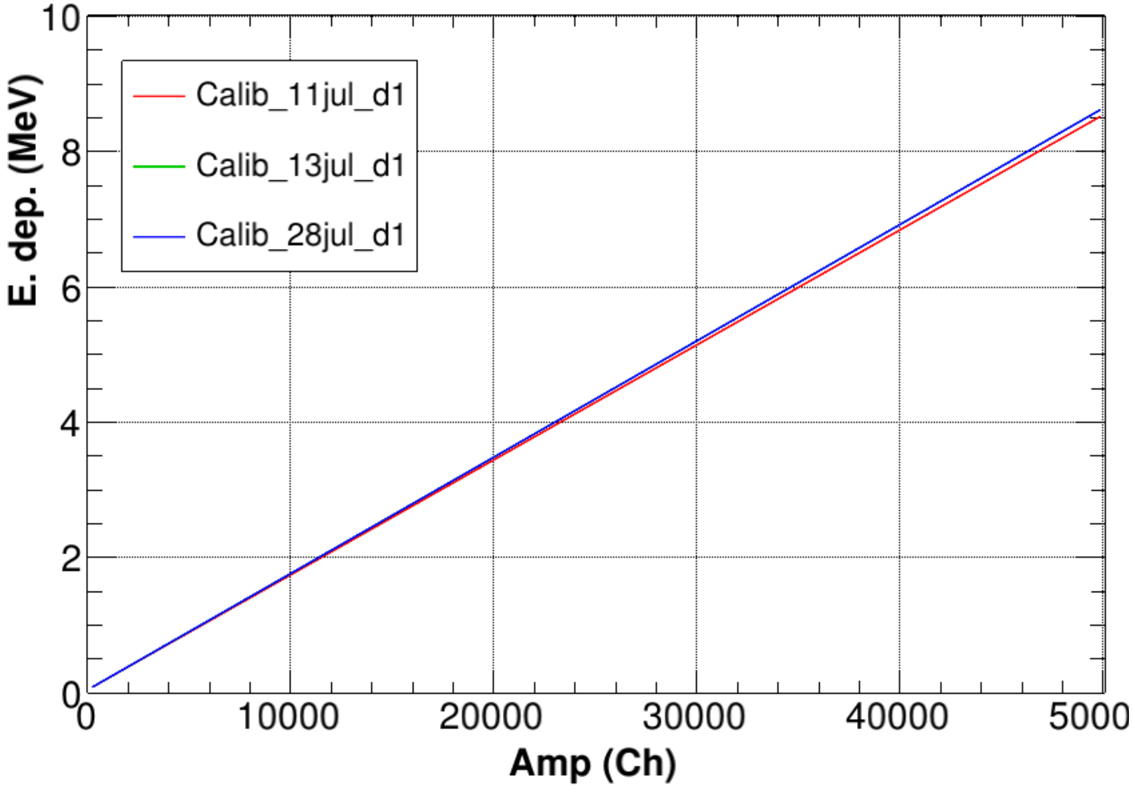
ΔT between consecutive signals: same detector

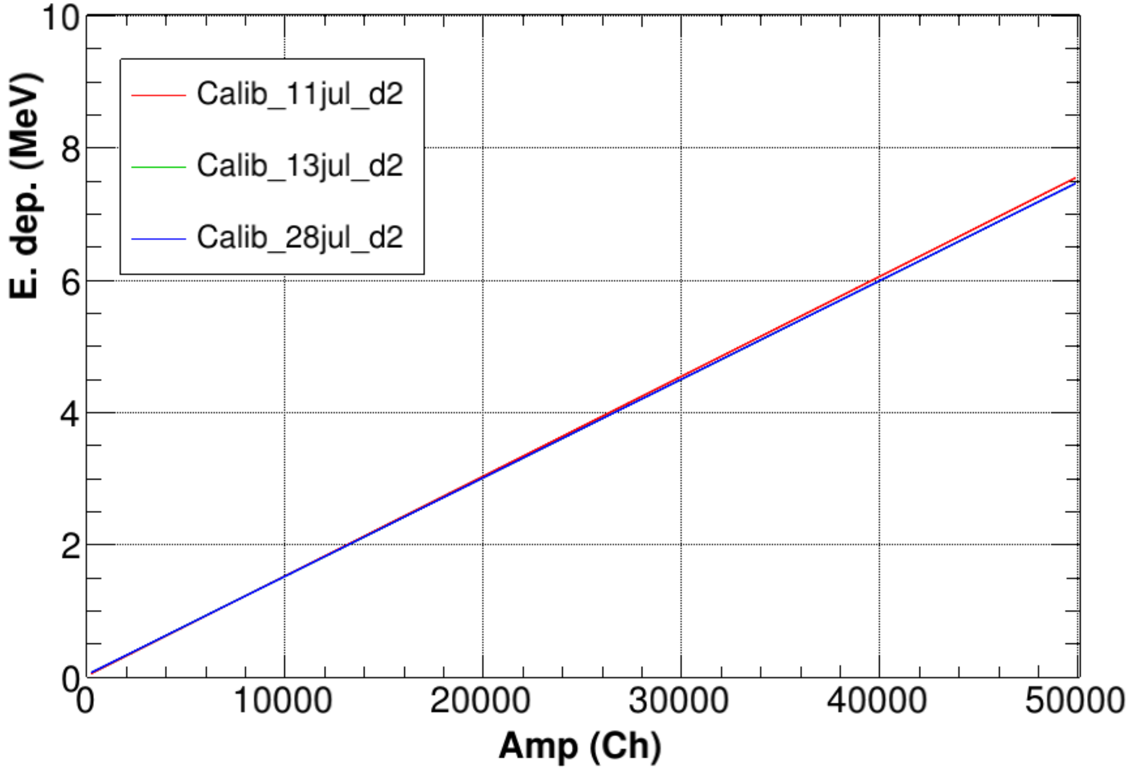
- L6D6-2-C



Calibrations with simulations

- Linear or double linear calibrations provide a satisfactory agreement with sources for all detectors
- Overall very good gain stability (±1-2%) along the measurement





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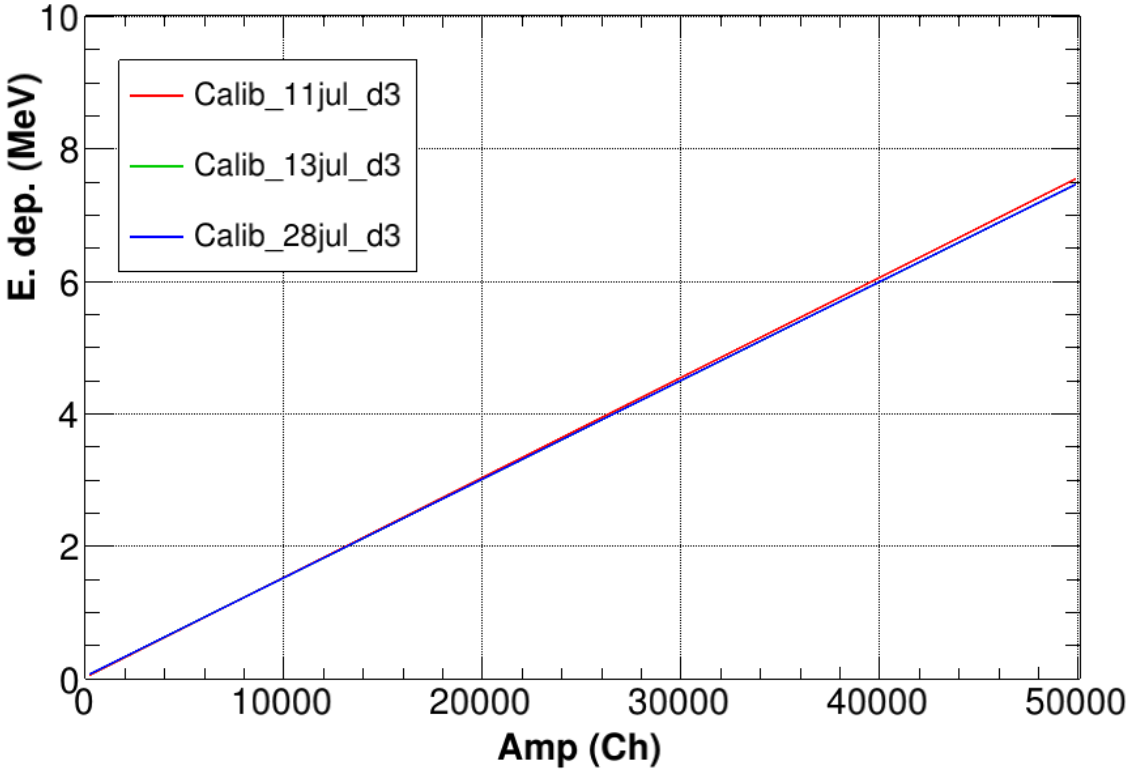

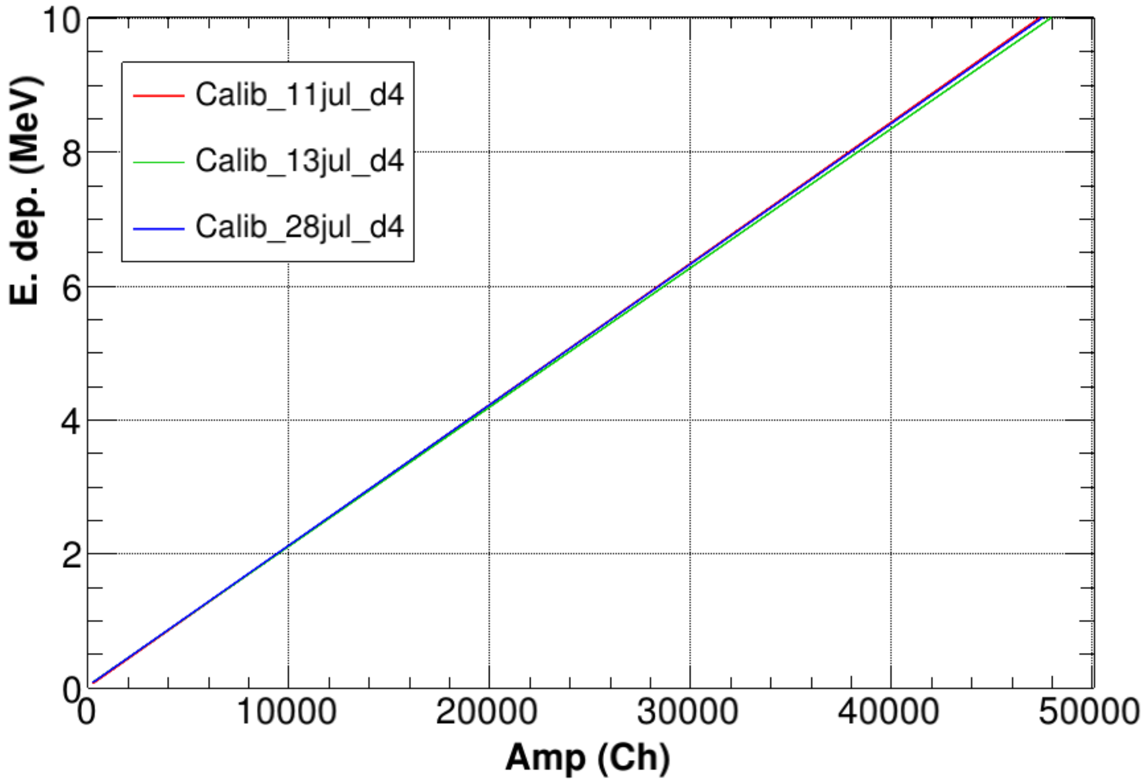

Calibrations with simulations

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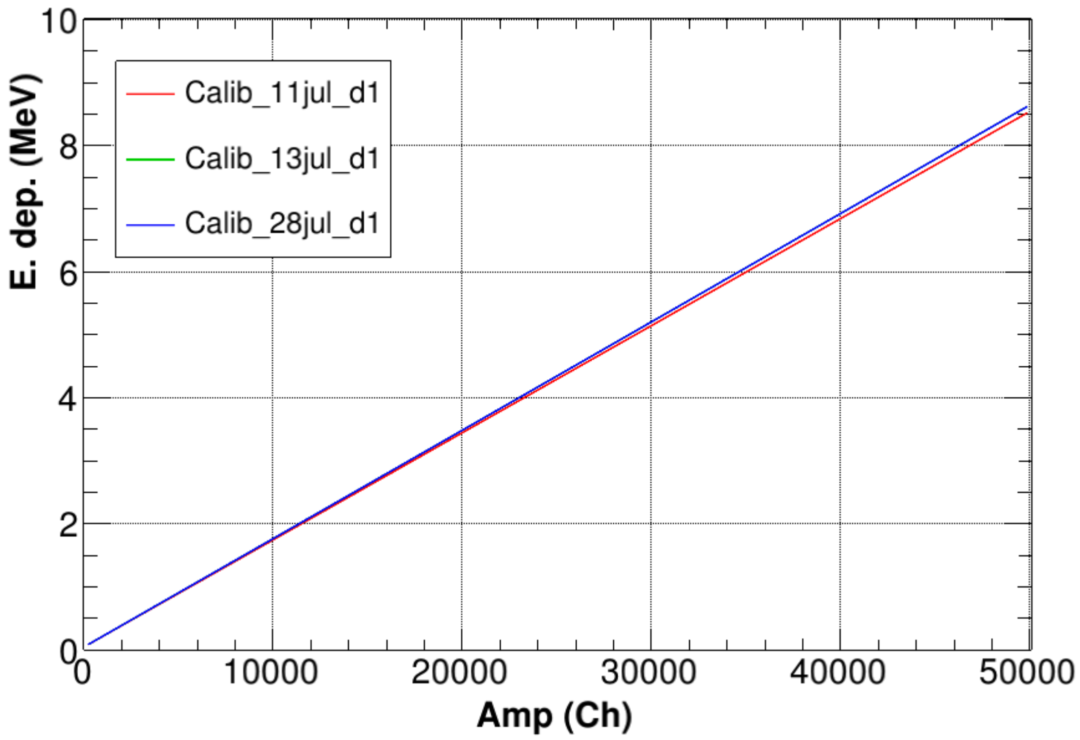
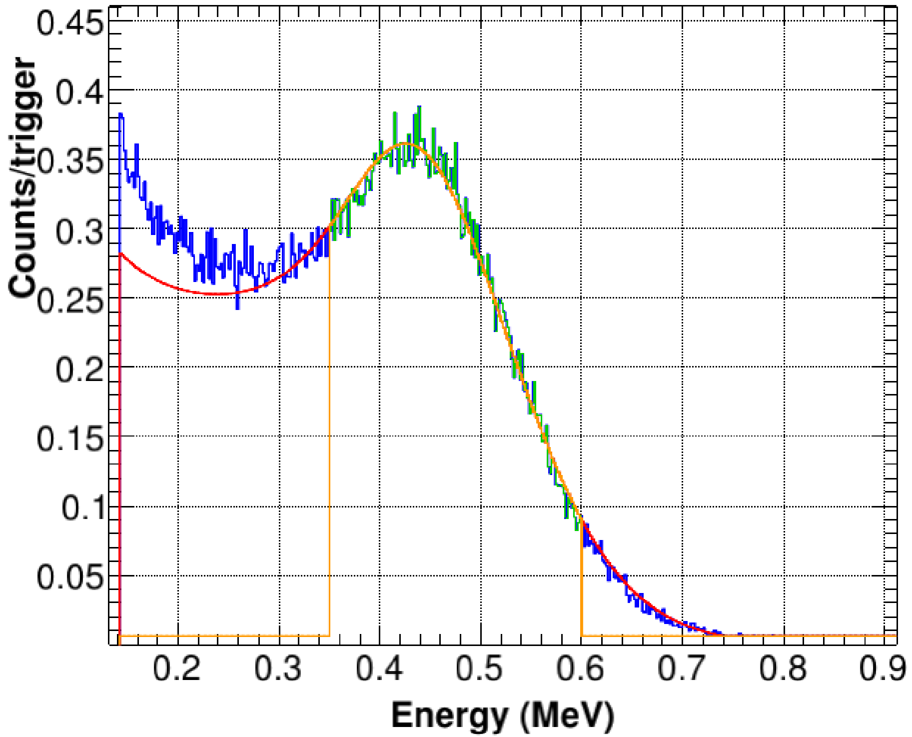
- Overall very good gain stability (±1-2%) along the measurement
- **Example L6D6 1-G: Good agreement with a single linear calib for Cs-137 (0.662 MeV)**





Calibrations with simulations

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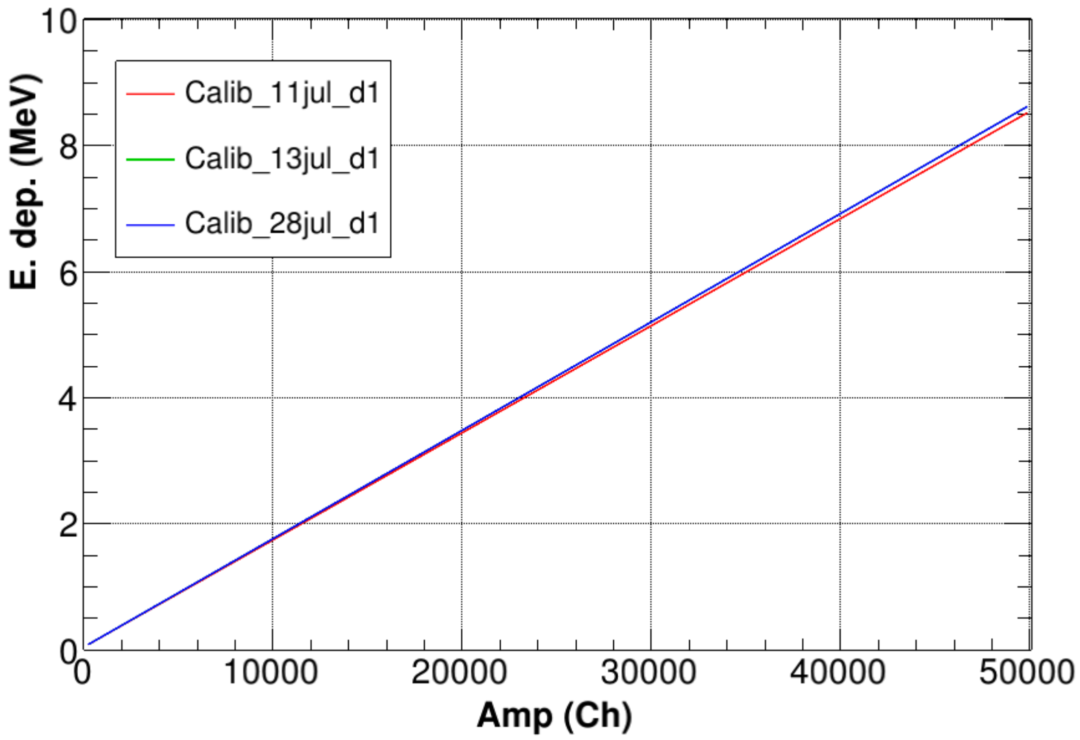
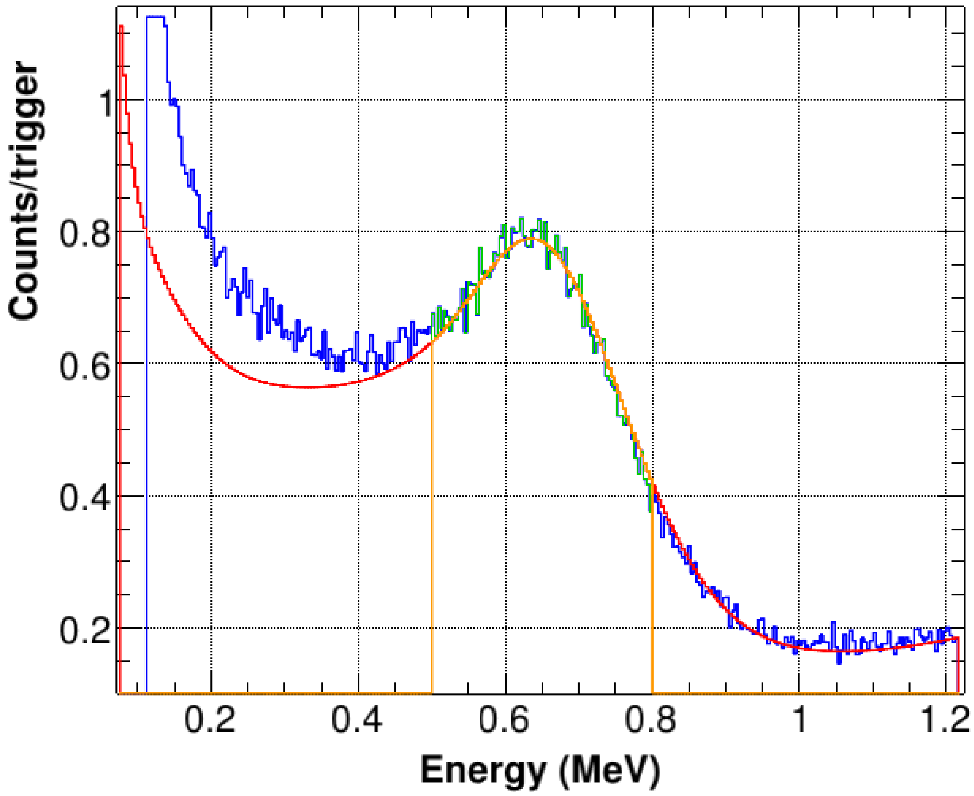
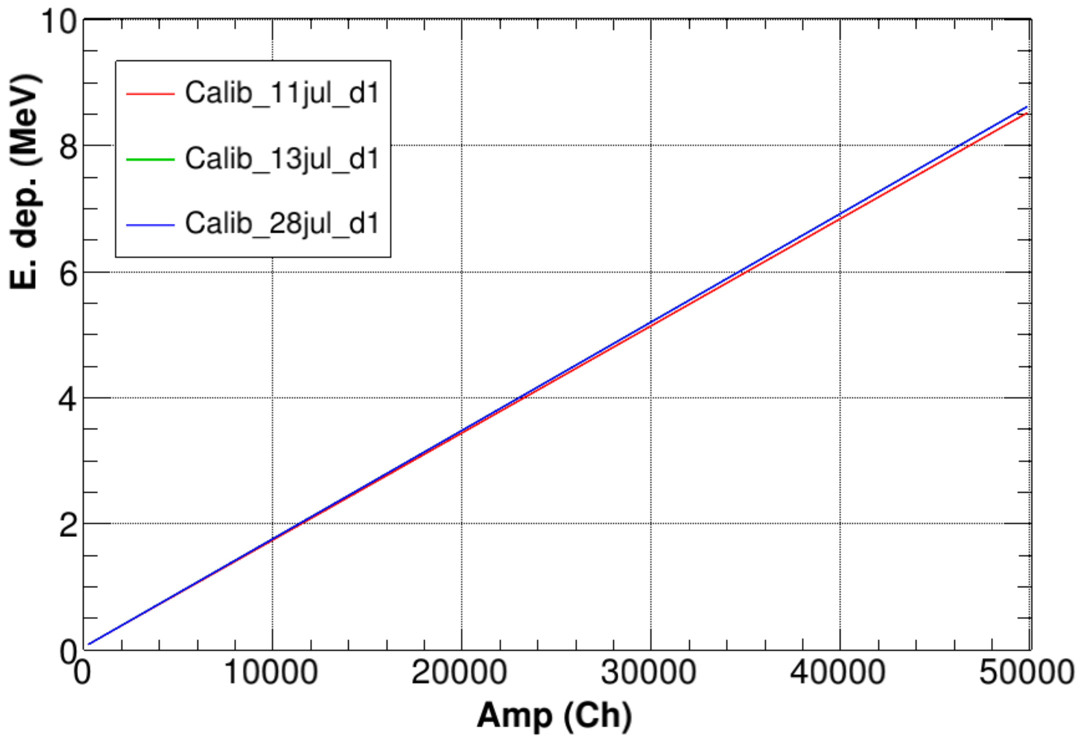
- Overall very good gain stability (±1-2%) along the measurement
- **Example L6D6 1-G: Good agreement with a single linear calib for Y-88 (0.898 MeV)**

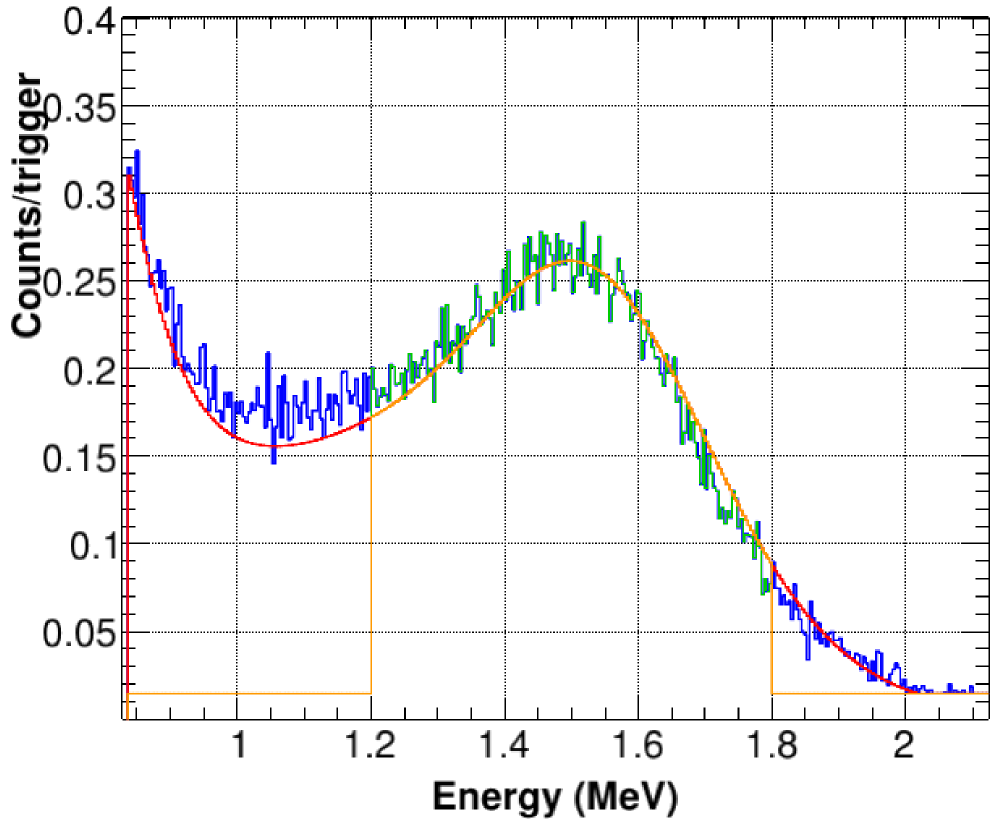




Calibrations with simulations

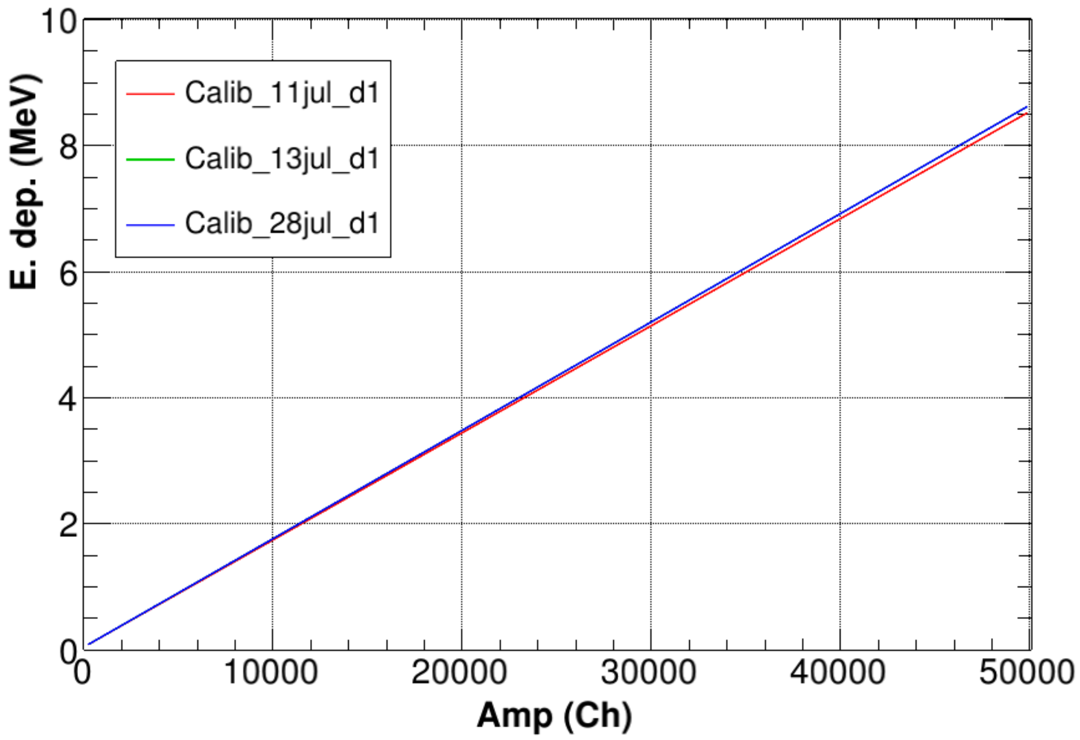
- Linear or double linear calibrations provide a satisfactory agreement with sources for all detectors
- Overall very good gain stability (±1-2%) along the measurement
- **Example L6D6 1-G: Good agreement with a single linear calib for Y-88 (1.8 MeV)**

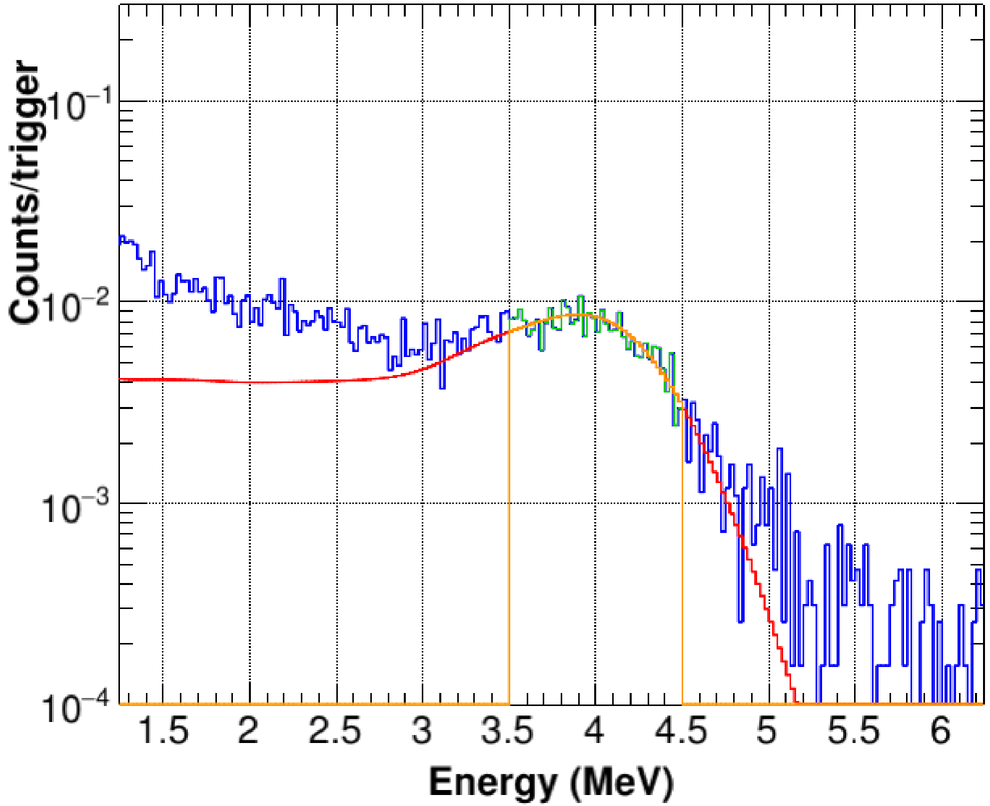




Calibrations with simulations

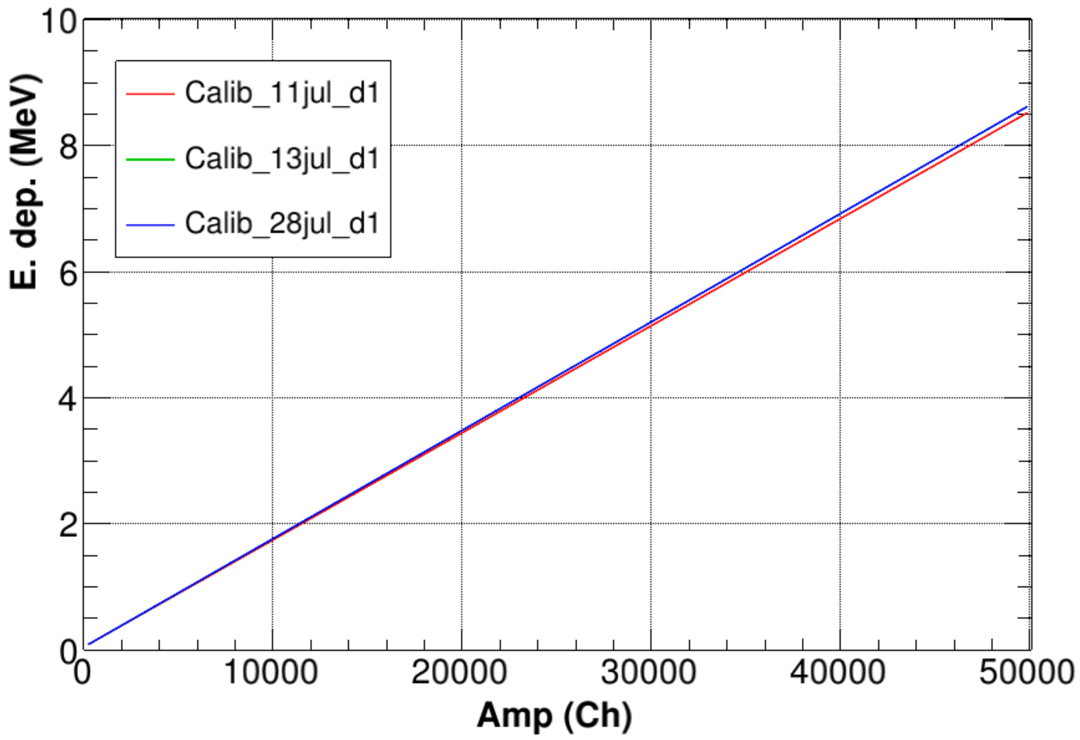
- Linear or double linear calibrations provide a satisfactory agreement with sources for all detectors
- Overall very good gain stability (±1-2%) along the measurement
- **Example L6D6 1-G: Good agreement with a single linear calib for AmBe (4.43 MeV)**

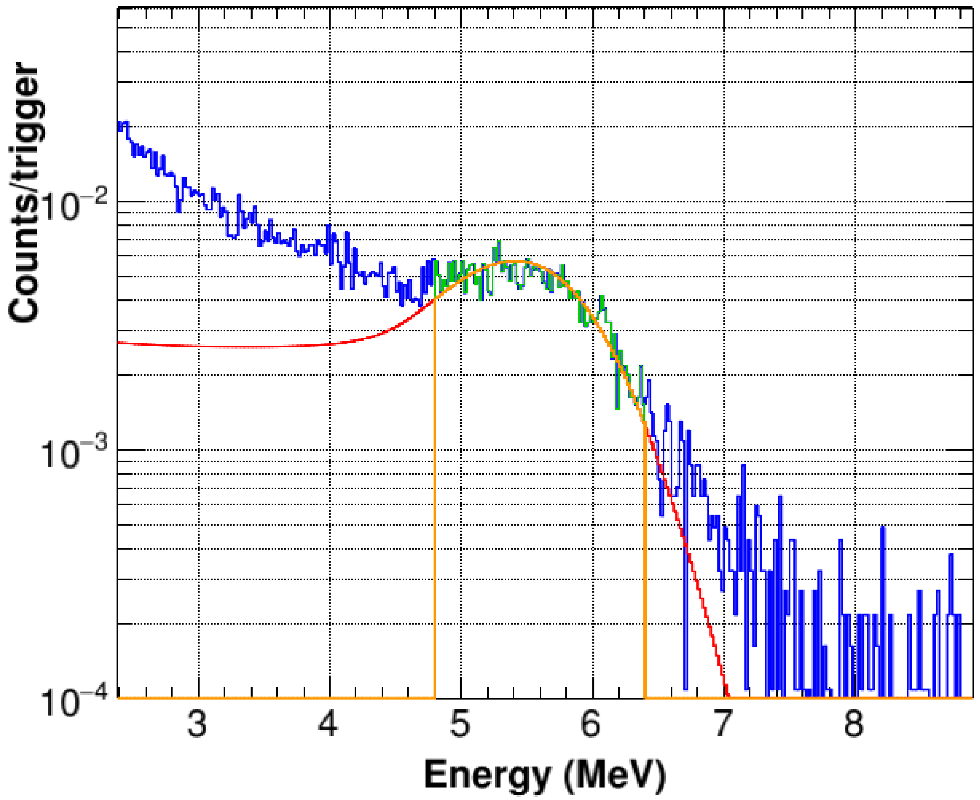




Calibrations with simulations

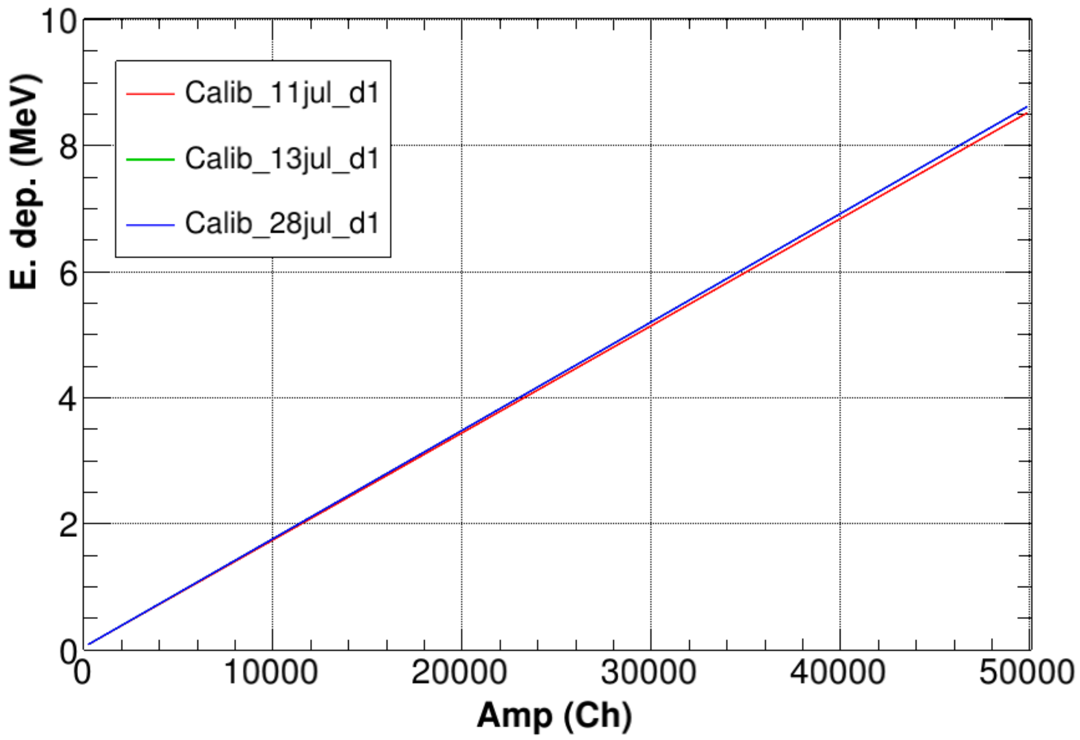
- Linear or double linear calibrations provide a satisfactory agreement with sources for all detectors
- Overall very good gain stability (±1-2%) along the measurement
- **Example L6D6 1-G: Good agreement with a single linear calib for CmC source (6.12 MeV)**

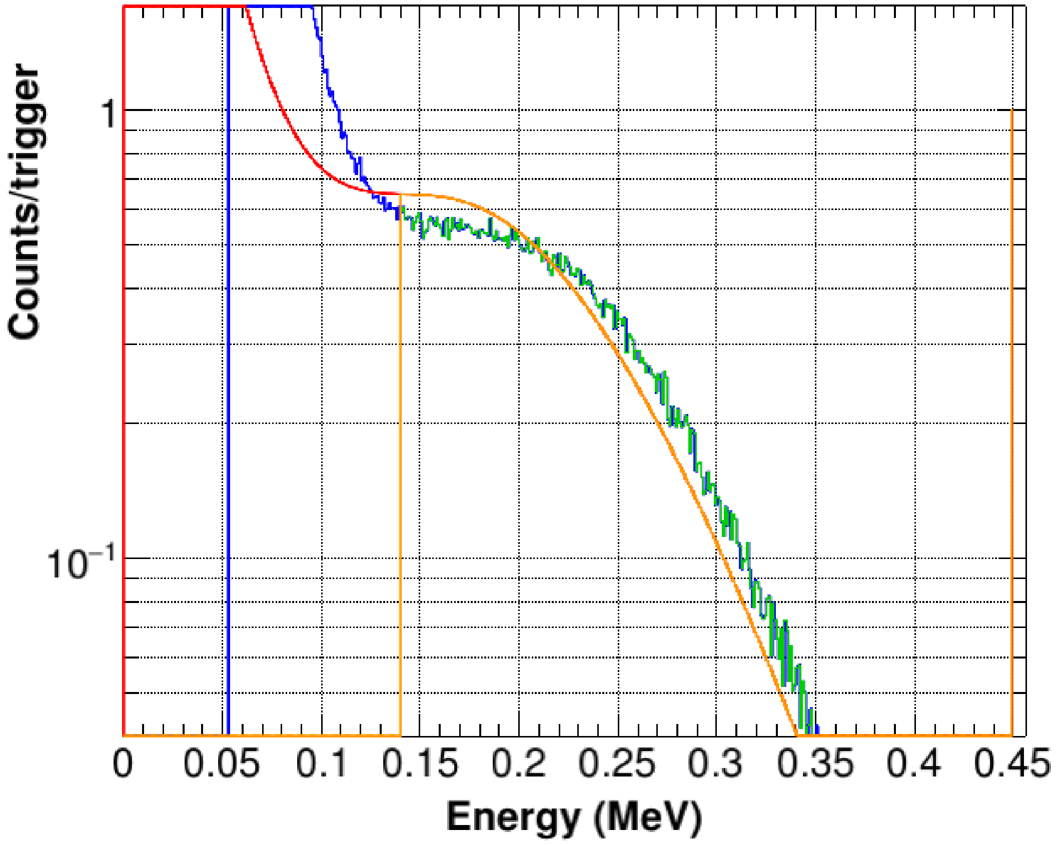




Calibrations with simulations

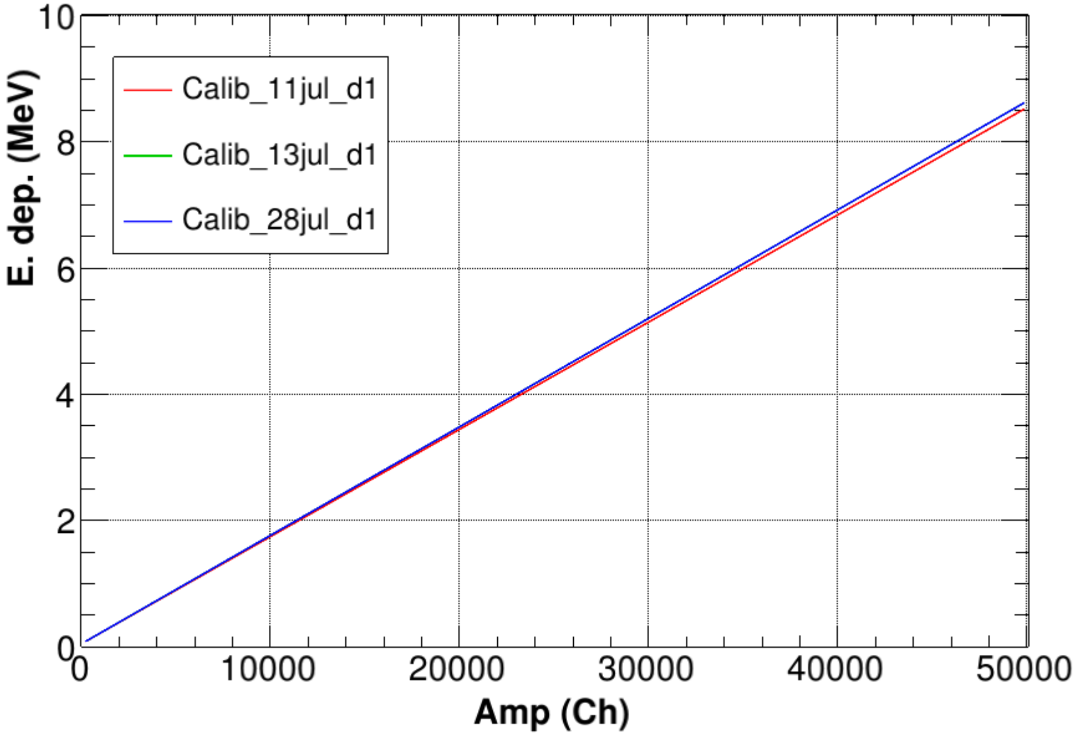
- Linear or double linear calibrations provide a satisfactory agreement with sources for all detectors
- Overall very good gain stability (±1-2%) along the measurement
- **But… agreement with Ba-133 source bad → second double linear needed for low energy**

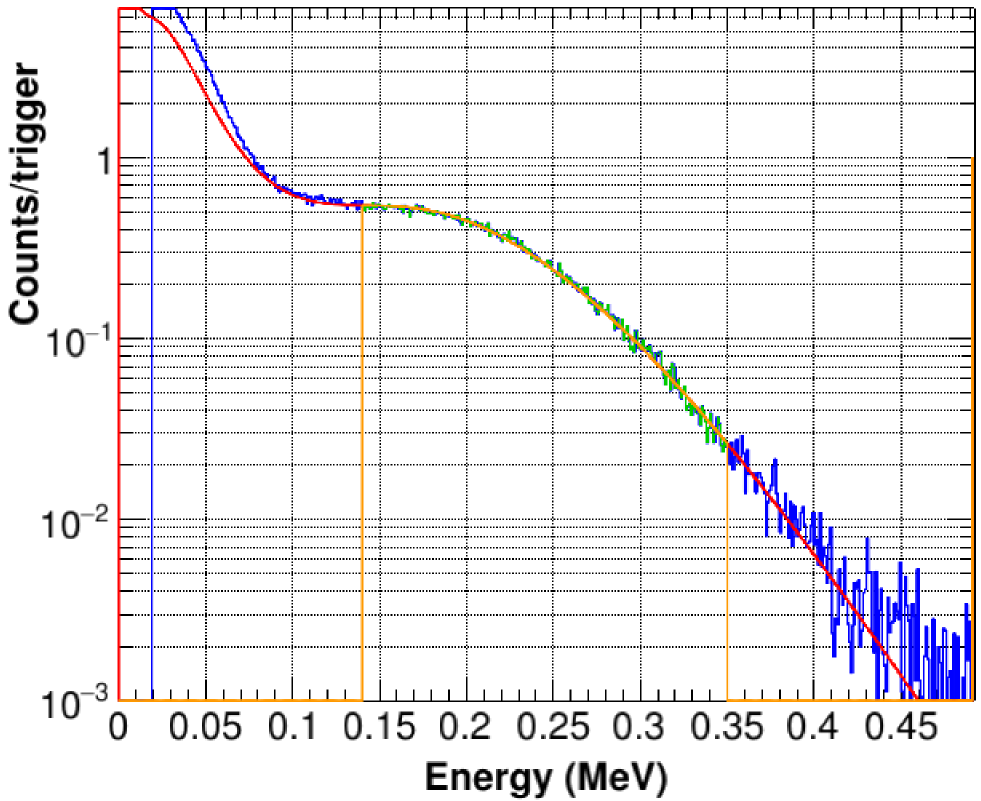




Calibrations with simulations

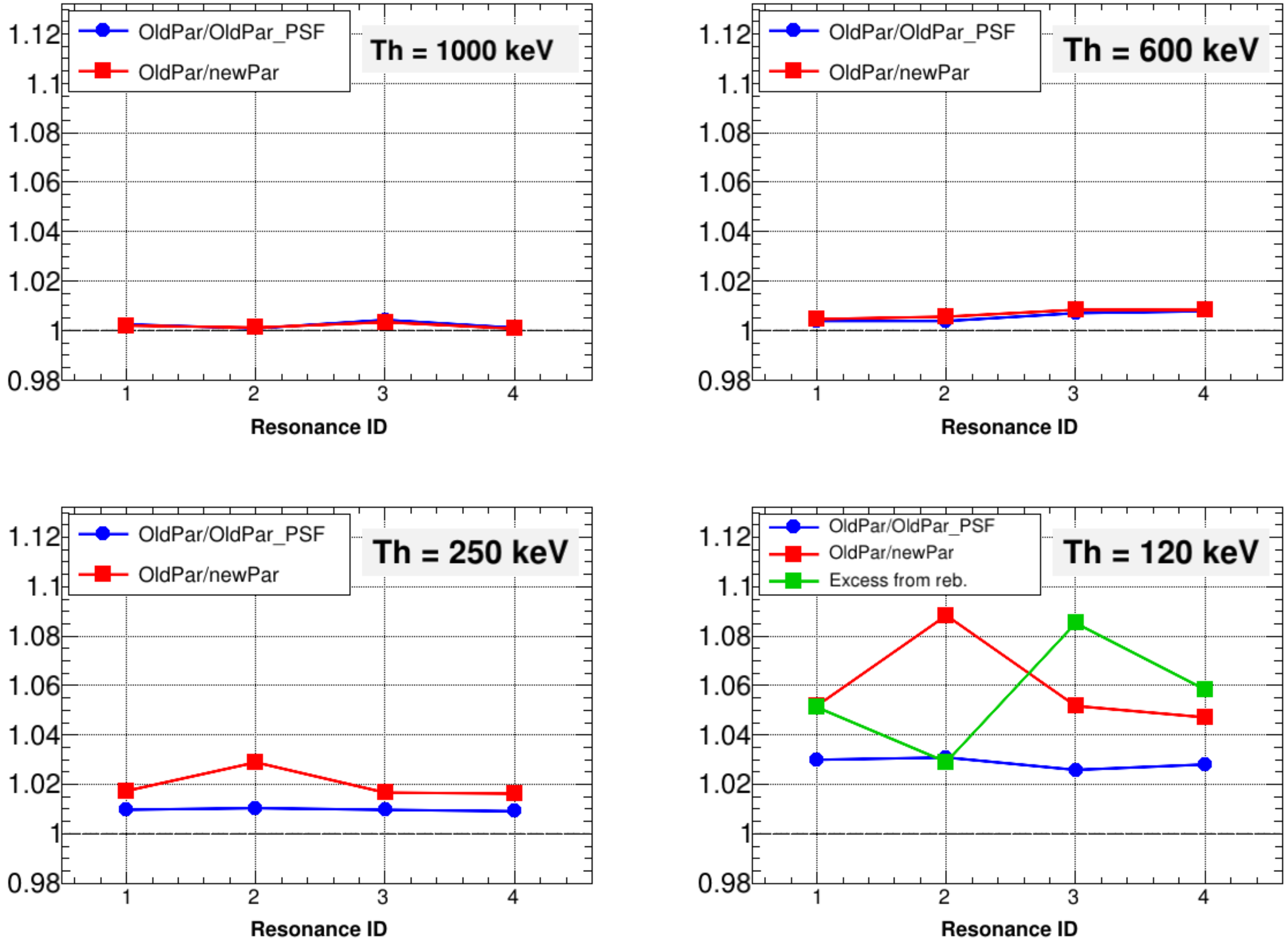
- Linear or double linear calibrations provide a satisfactory agreement with sources for all detectors
- Overall very good gain stability (±1-2%) along the measurement
- **Second linear at low E. dep. (<400 keV) for det. 1 and 3 → Ba-133 source calibration very important (few gamma rays below 300 keV)**





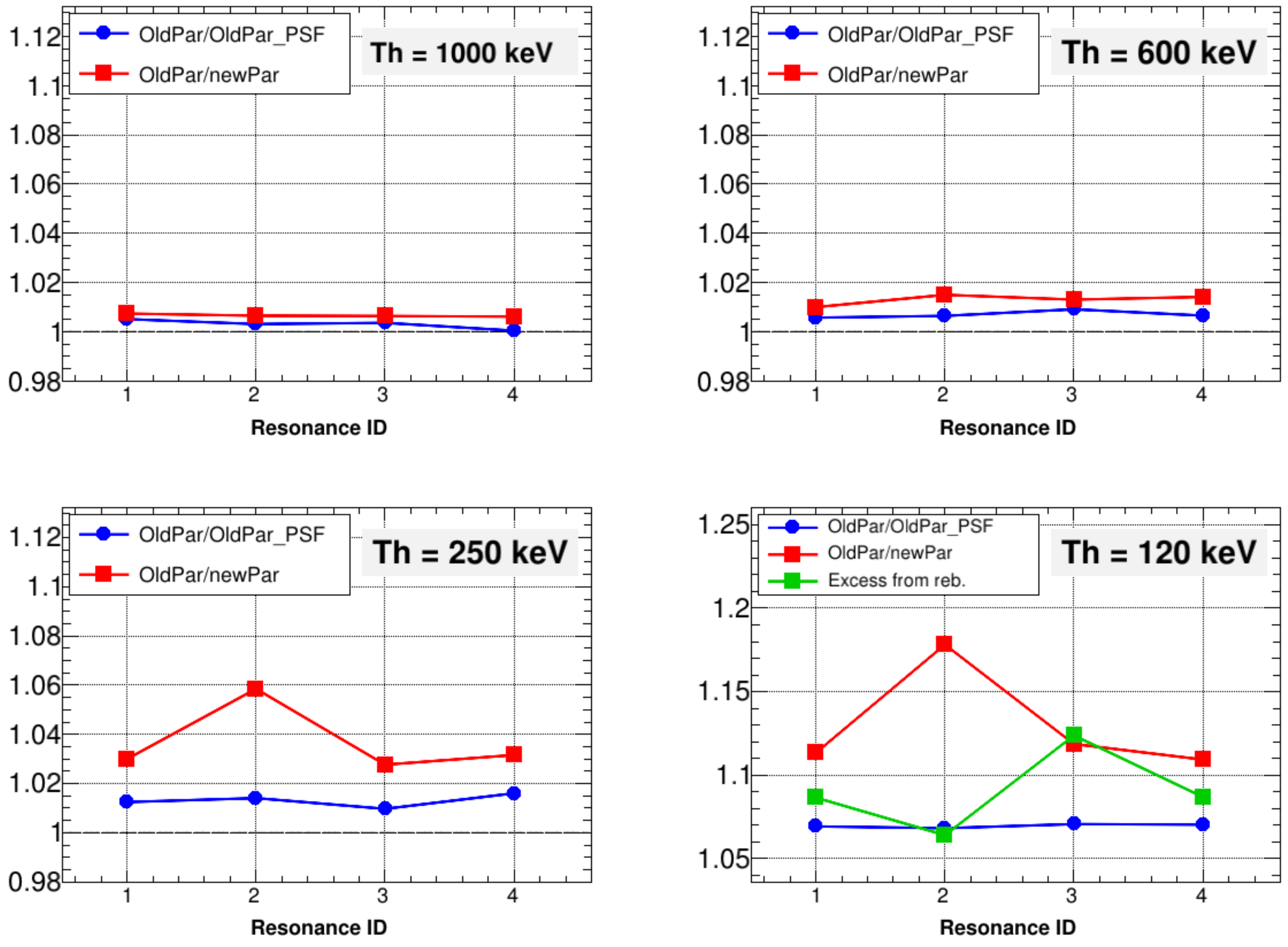
Ratios between resonance integrals

- Ratios obtained for four Au resonances (4.9 eV, 60 eV, 79 eV, 110 eV) for each threshold and detector
- L6D6-1-G



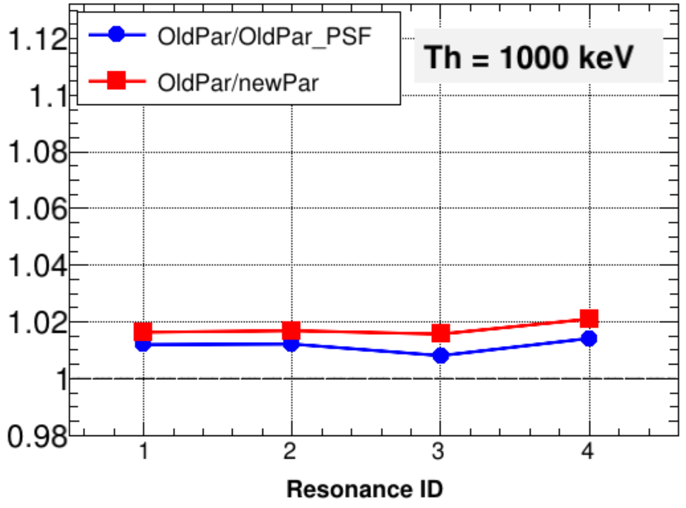
Ratios between resonance integrals

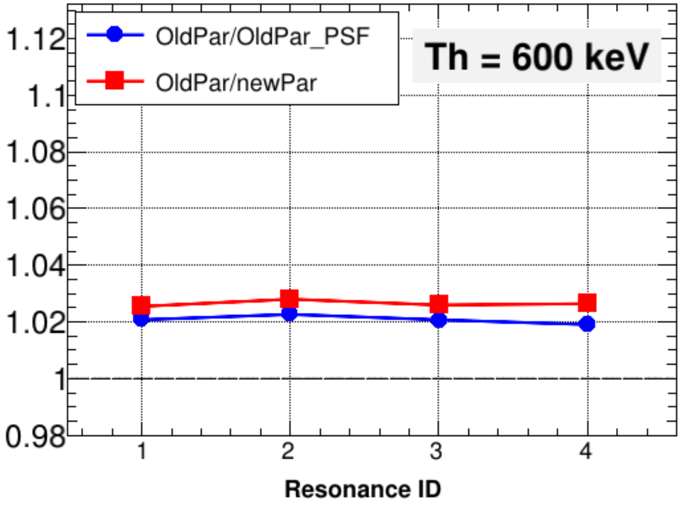
- Ratios obtained for four Au resonances (4.9 eV, 60 eV, 79 eV, 110 eV) for each threshold and detector
- L6D6-3-D

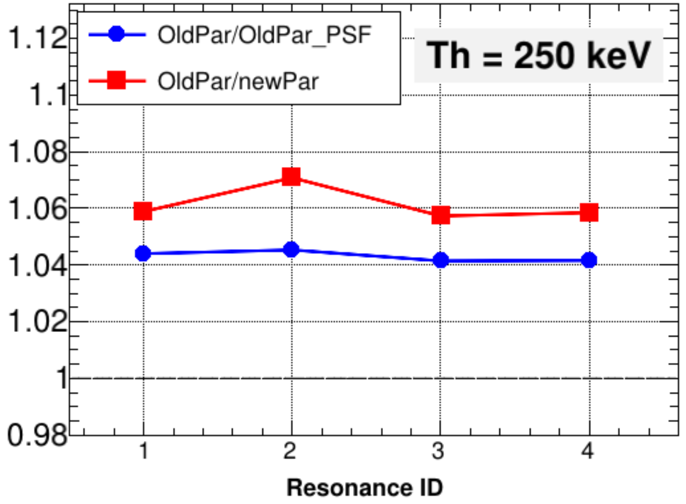


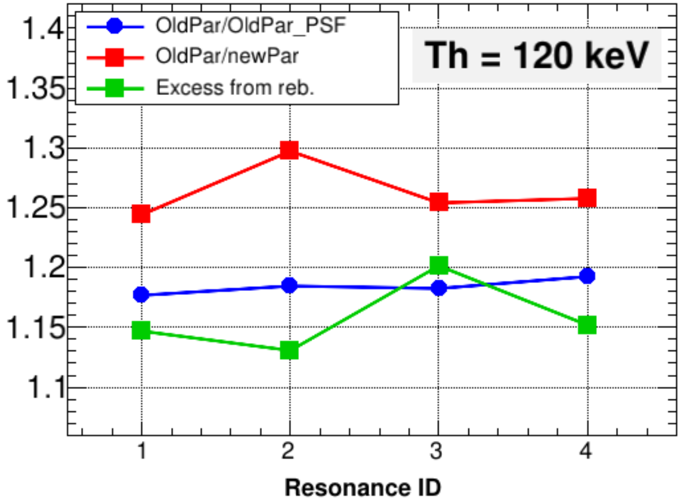
Ratios between resonance integrals

- Ratios obtained for four Au resonances (4.9 eV, 60 eV, 79 eV, 110 eV) for each threshold and detector
- L6D6-4-D









Summary and outlook

- A fine tuning of the PSA values should allow for a “clean” elimination of the rebounds, while **allowing to keep the threshold in deposited energy as low as possible**
- **Work still in progress**
  - **Check comparison signal Area-amplitude ratio, C6D6 low amplitude signal high dispersion in shape**
- **I warmly encourage everyone working on C6D6 data analysis to play with the PSA and provide new (and possible) better parameters**

- Detector calibrations with simulations confirm very stable and linear behaviour of the four detector
- Next meeting: analysis should be in advanced stage