Xe doping analysis update

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Analysis flow

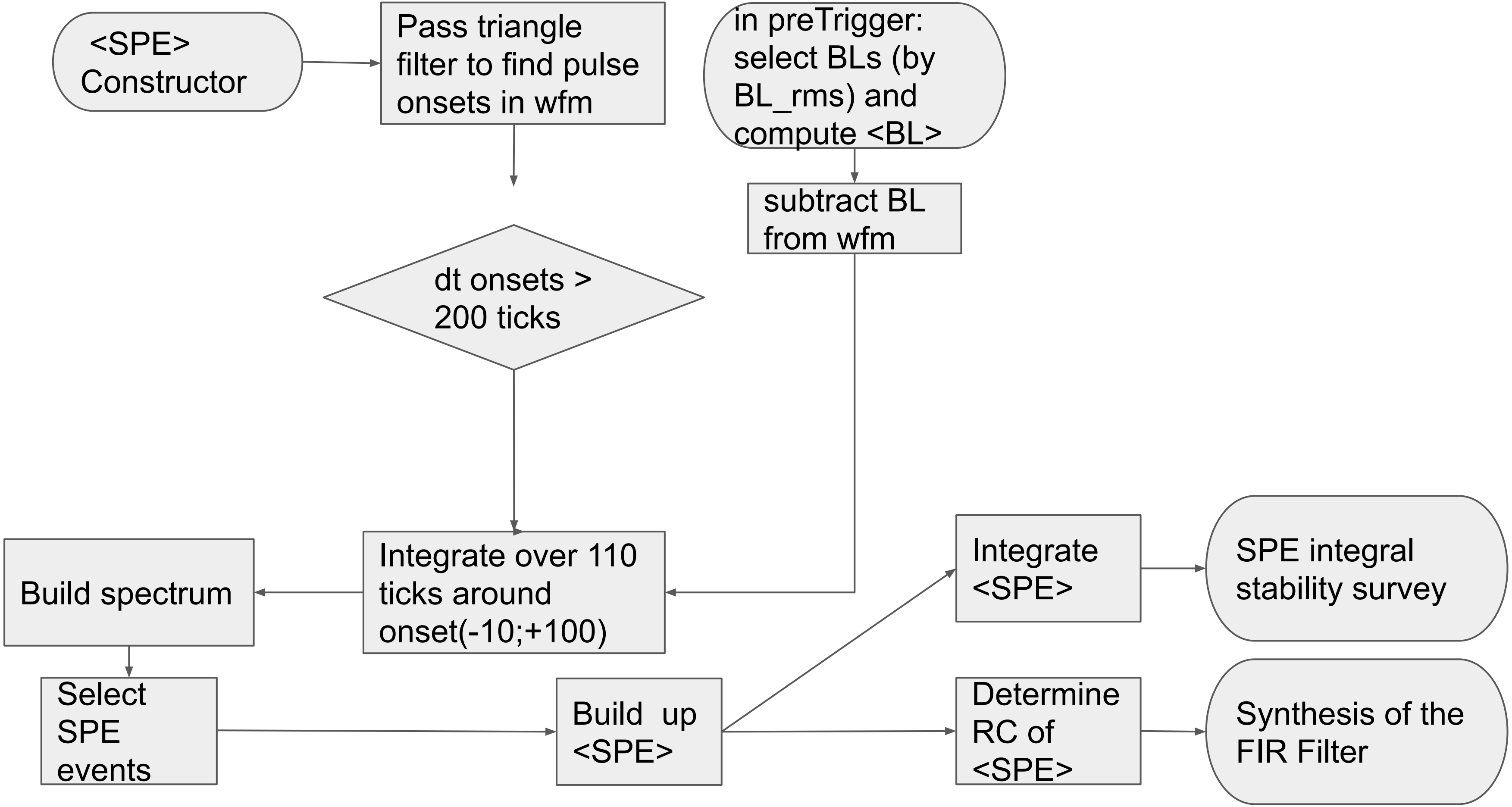
- Build <SPE> wfms
    1. scan wfms with a triangle filter
    2. record onsets
    3. require dt between pulse onsets >200 ticks.
    4. Integrate pulse within (-10+100) ticks around onset and build spectrum
    5. Select events in first peak of the spectrum
    6. synchronize, subtract BL and build <SPE>
    7. Integrate the <SPE> and plot for the time survey

- NEW: Update of SPE Stability survey including the latest data (up to 2nd May)
- NEW: Evaluate τ_{RC} for each Ch and verify its stability

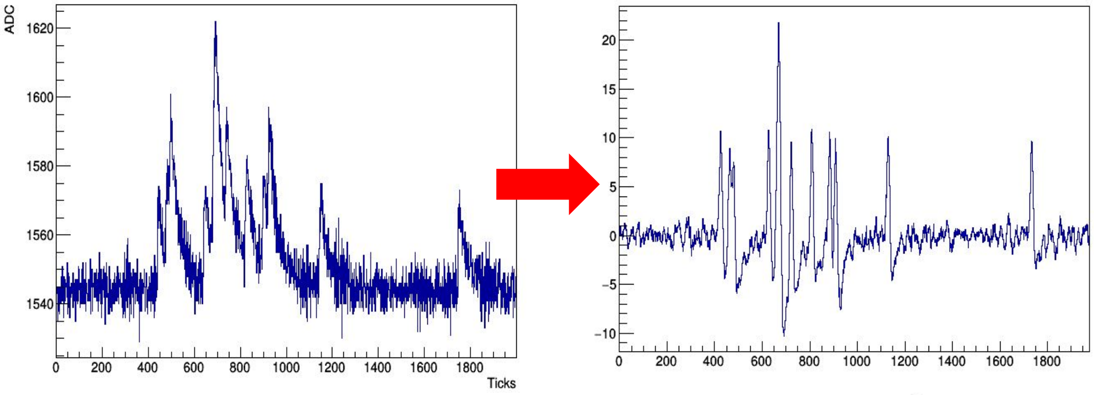
- NEW: 6 FIR filter (99 ns integration (too much), 33 ns shaping) tailored to deconvolute the individual Ch RC decay have been synthesized : **PH{filtered pulse} ~ SPE area**

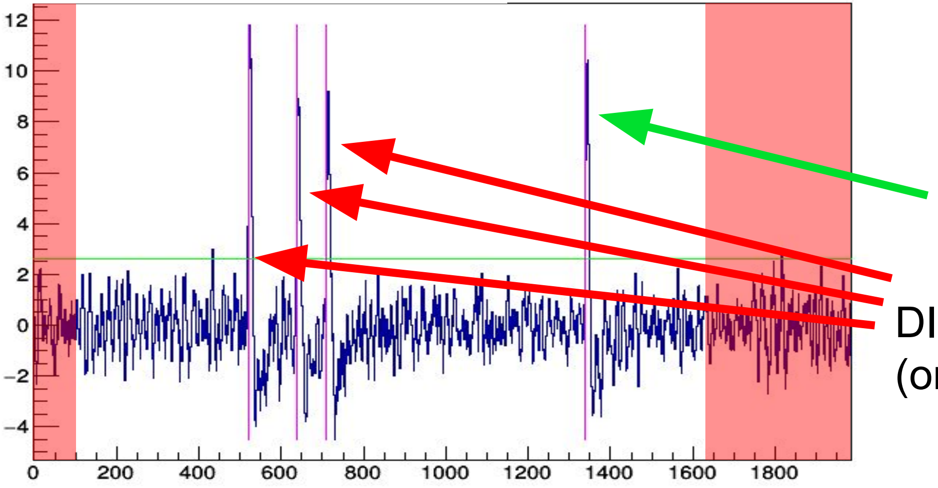
- <WFM> is built on a run by run basis from unfiltered wfms
- <WFM> is deconvoluted by FIR filter (for each Ch)
- **Verified linear Calibration of PH{filtered pulse} vs. Pulse Integral**
- **The calibrated wfms units are # of detected photons**

1. SPE analysis flow chart



Look for SPE: find peak onsets



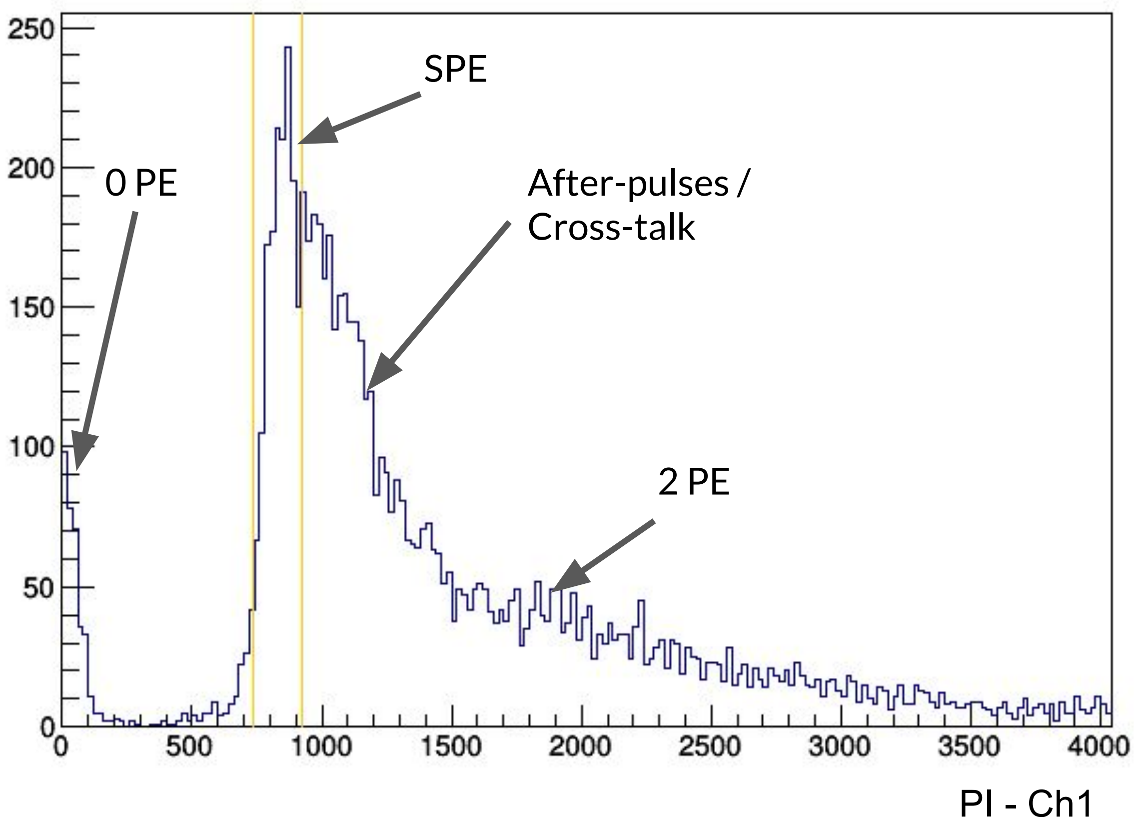


ACCEPTED

DISCARDED
(onsets too close)

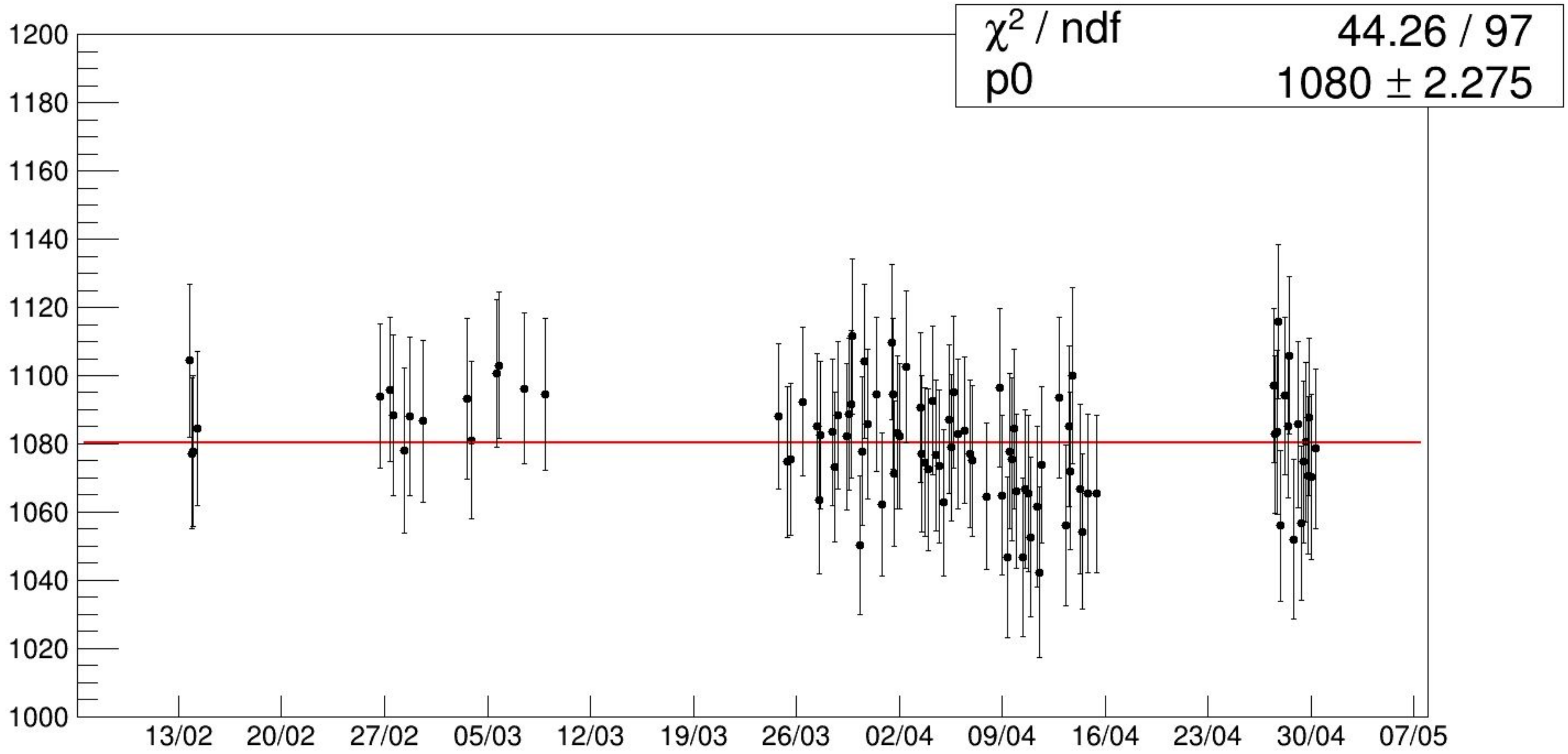
- a differentiating filter (zero-area 16-ticks wide triangle filter) is applied to the waveform
- signal onsets are found by putting a threshold on the differentiated wf
- signals are discarded/accepted based on the position of their onset relative to other onsets and wfm beginning/end

Look for SPE: pulse integral distribution

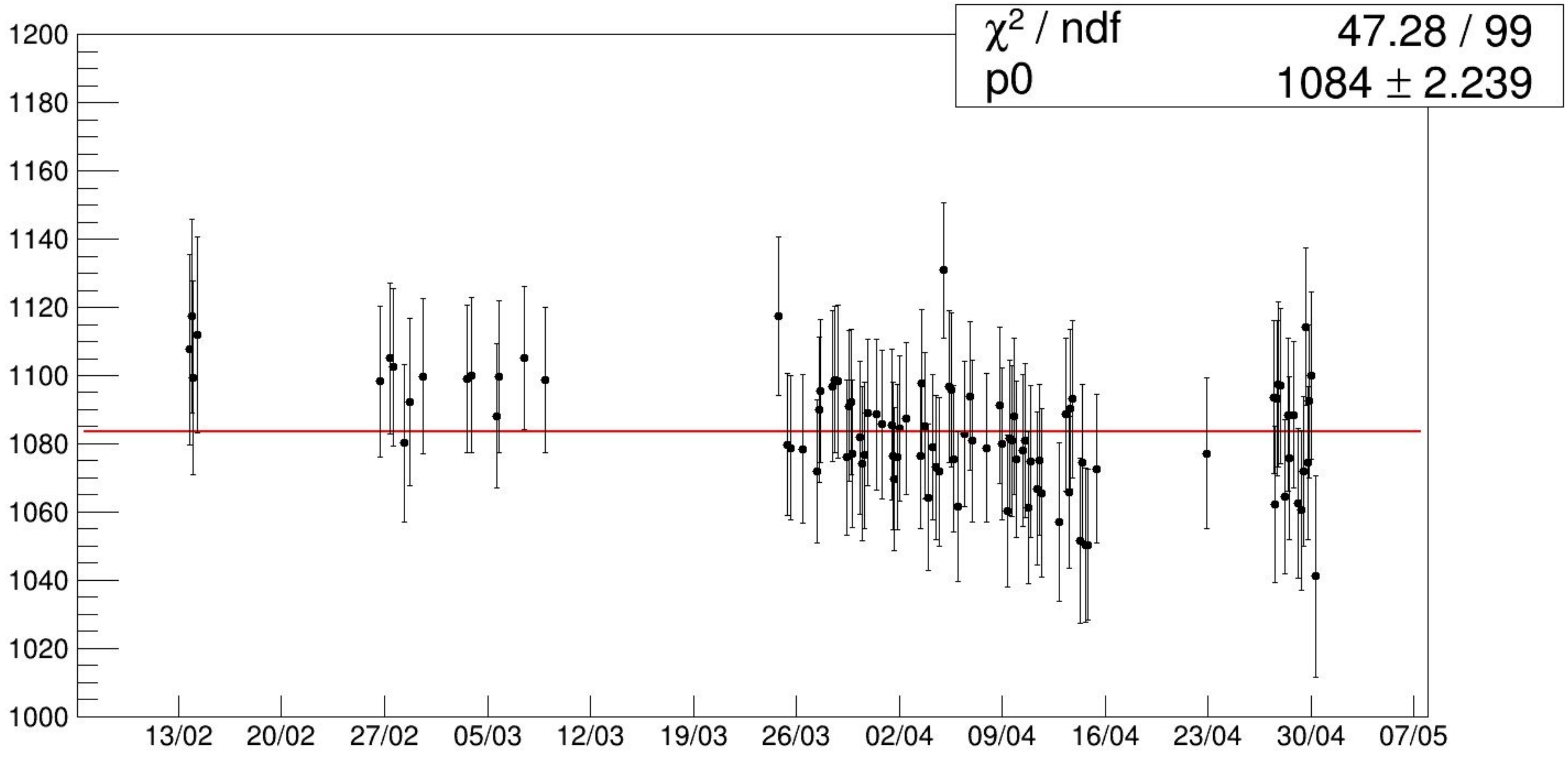


- For all accepted events, integrate the pulse over 110 ticks
- In the pulse integral distribution, select a suitable cut for the SPE peak
- average the pulses in this population to obtain the <SPE>

Ch1 <SPE> integral vs time



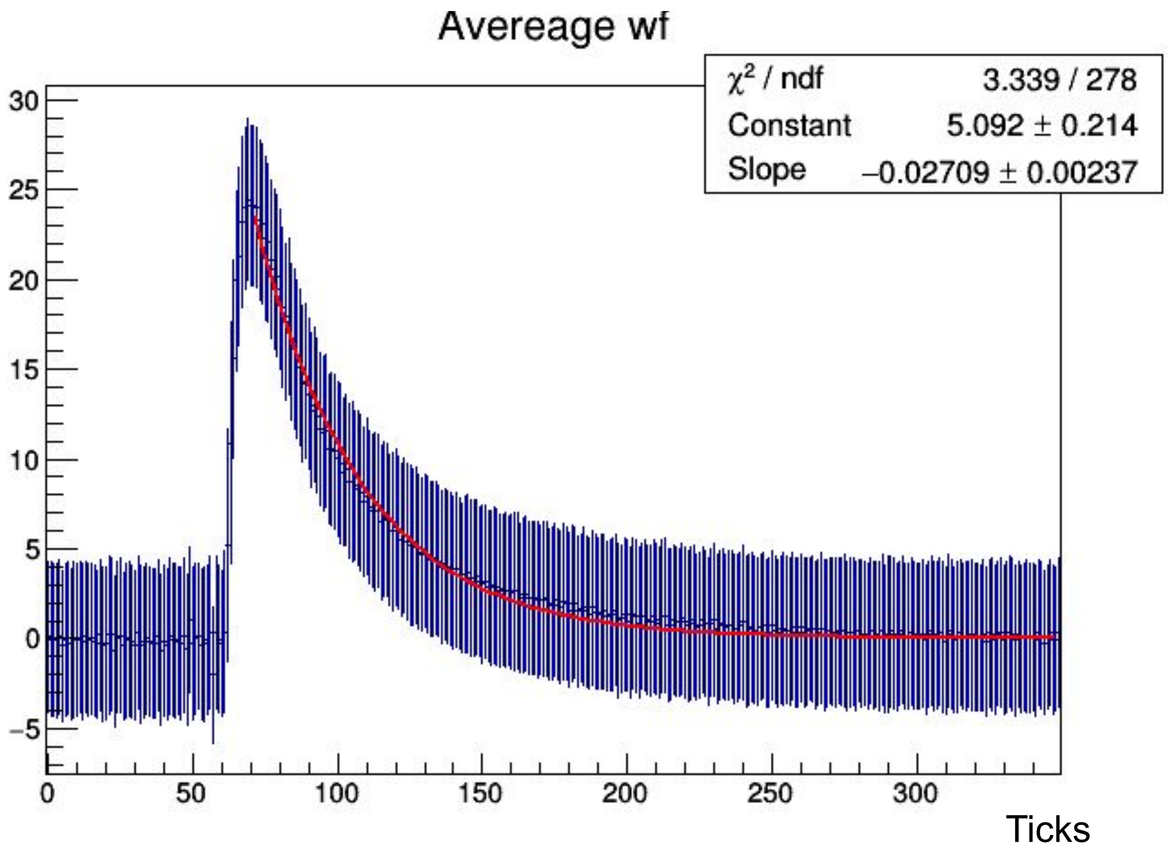
Ch3 <SPE> integral vs time



<SPE> Pulse integral stability - comments

- The individual <SPE> pulse integral is determined for each run, with an error of ~2%
- While there are some fluctuations in some channels, for all channels it remains stable within the error bars (fit well by a constant fit)

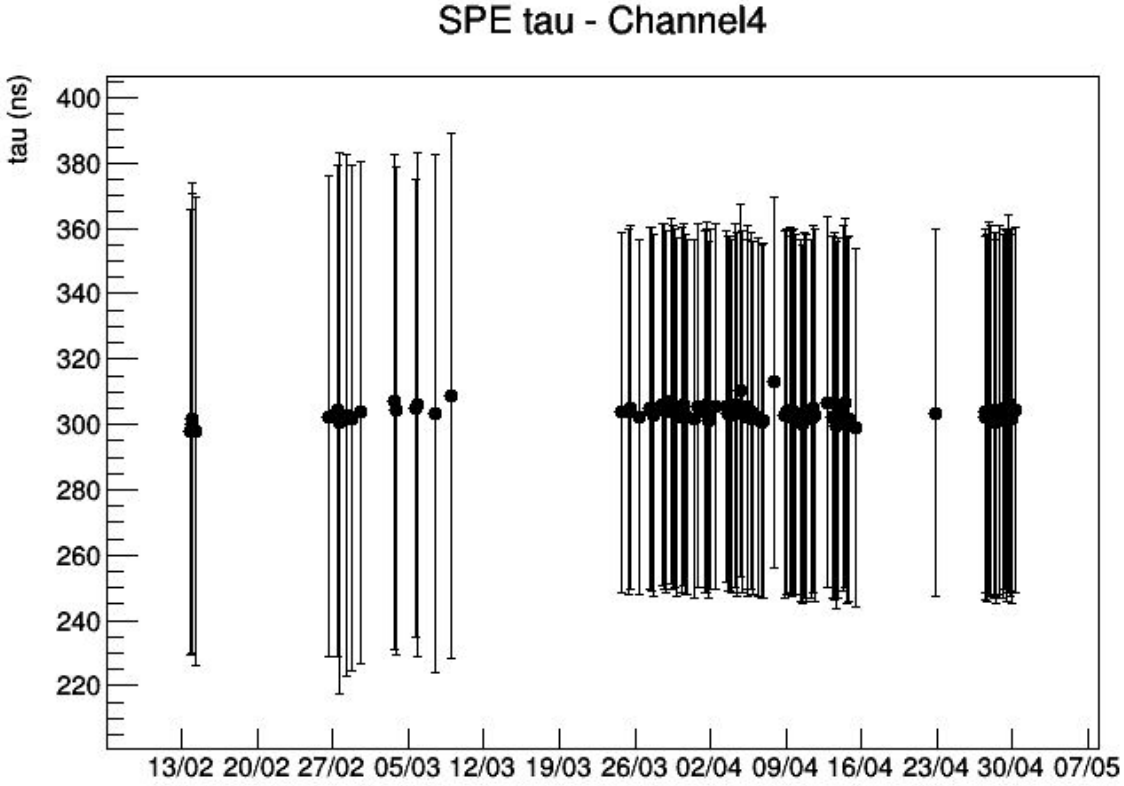
Fitting the RC decay in the <SPE>



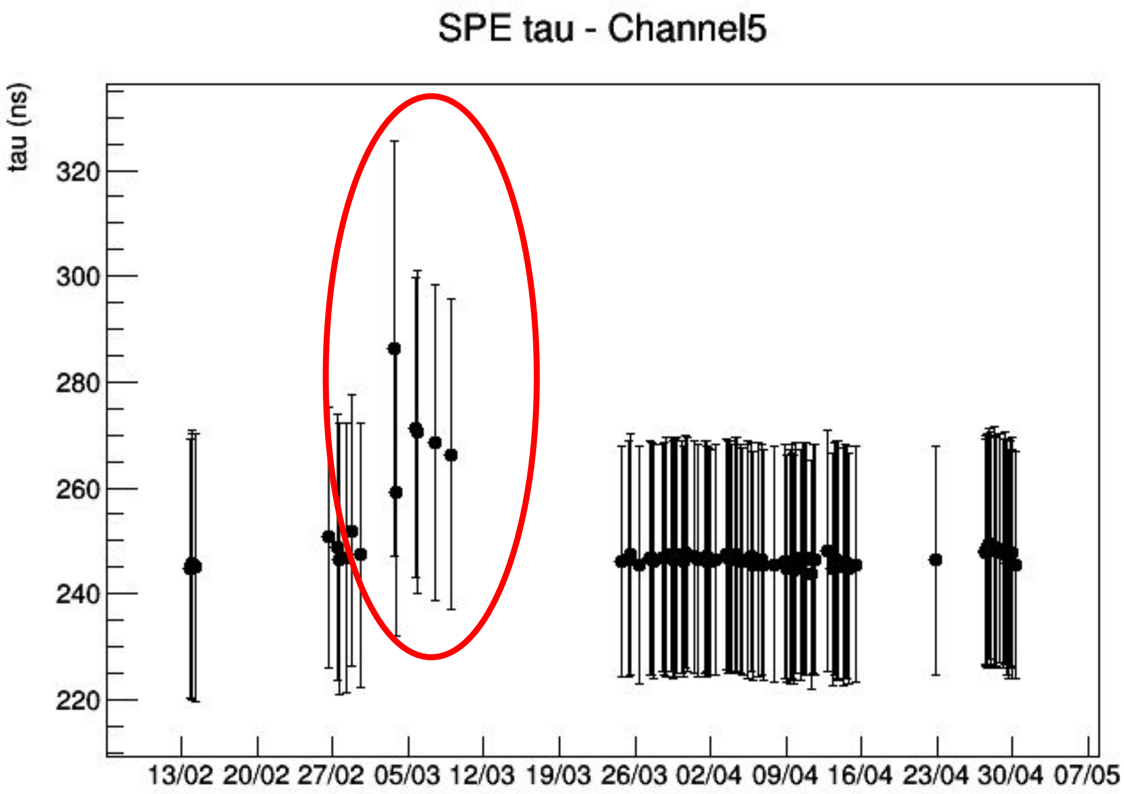
- The decay is well fit by single expo decay (τ)
- run used: Dope3_ext_08
- stability of SPE shape and decay time verified in D1-D4

Ch	Filter τ (ns)
1	330
2	412
3	330
4	300
5	244
7	314

RC decay in the <SPE> - stability survey

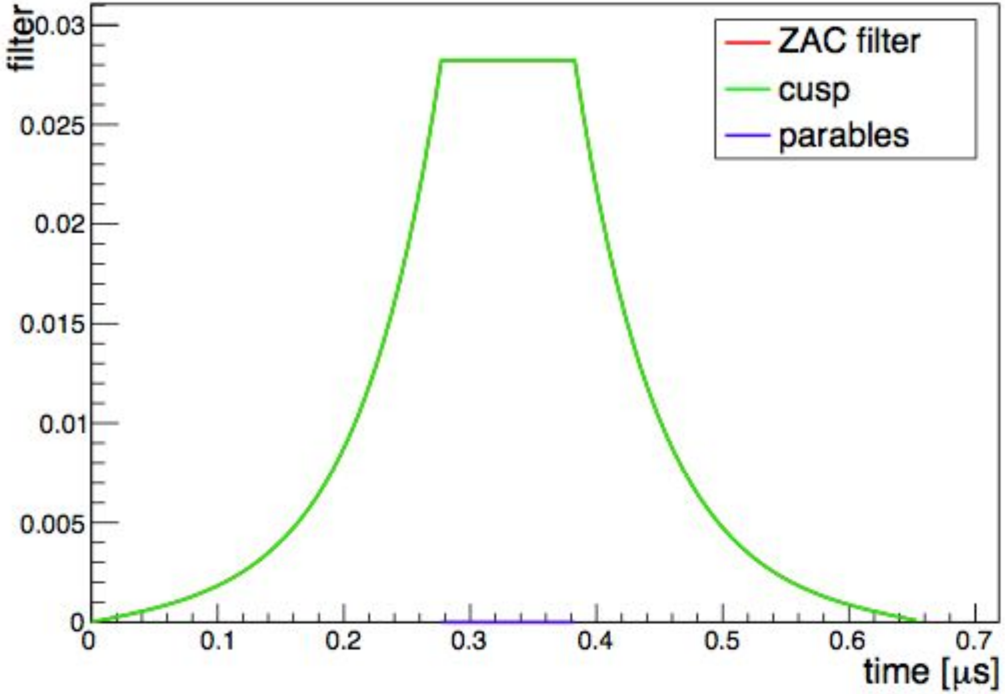


RC decay in the <SPE> - stability survey



- Most channels are stable within ~10 ns
- only in channel 5 a few runs show a significantly different $\tau \rightarrow$ needs further analysis

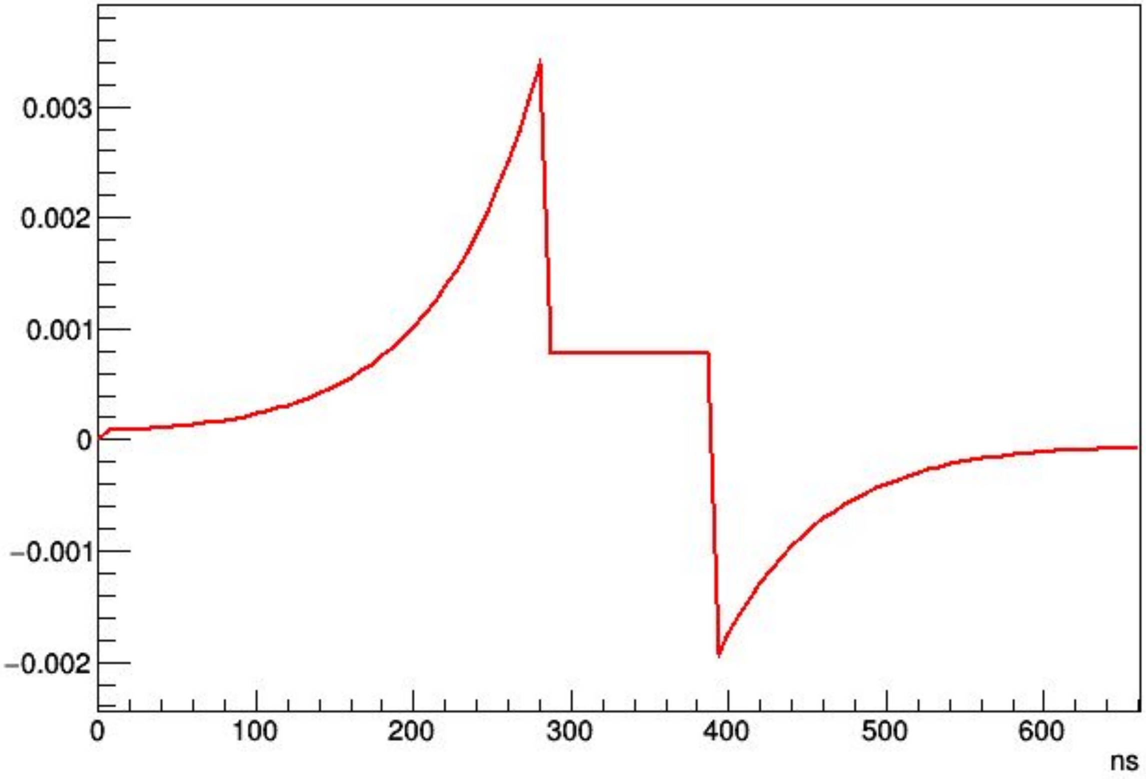
A FIR filter to integrate & denoise the signals



weighting function: truncated cusp

- 660 ns (100 ticks) length
- 33 ns shaping factor
- 99 ns flat top (too long, will redo analysis with shorter ft)

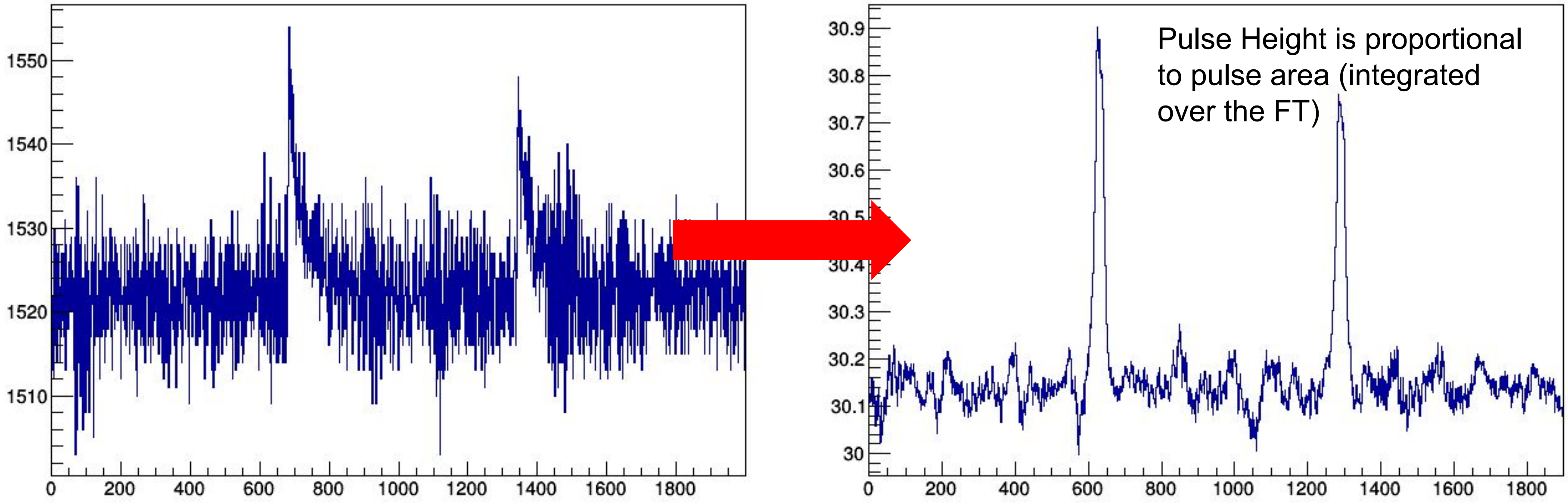
Add the RC decay to FIR filter to deconvolve signals



- The cusp is then convolved with the SiPMs RC exponential decay (τ).
- τ is evaluated on each Channel by fitting the average raw SPE waveforms

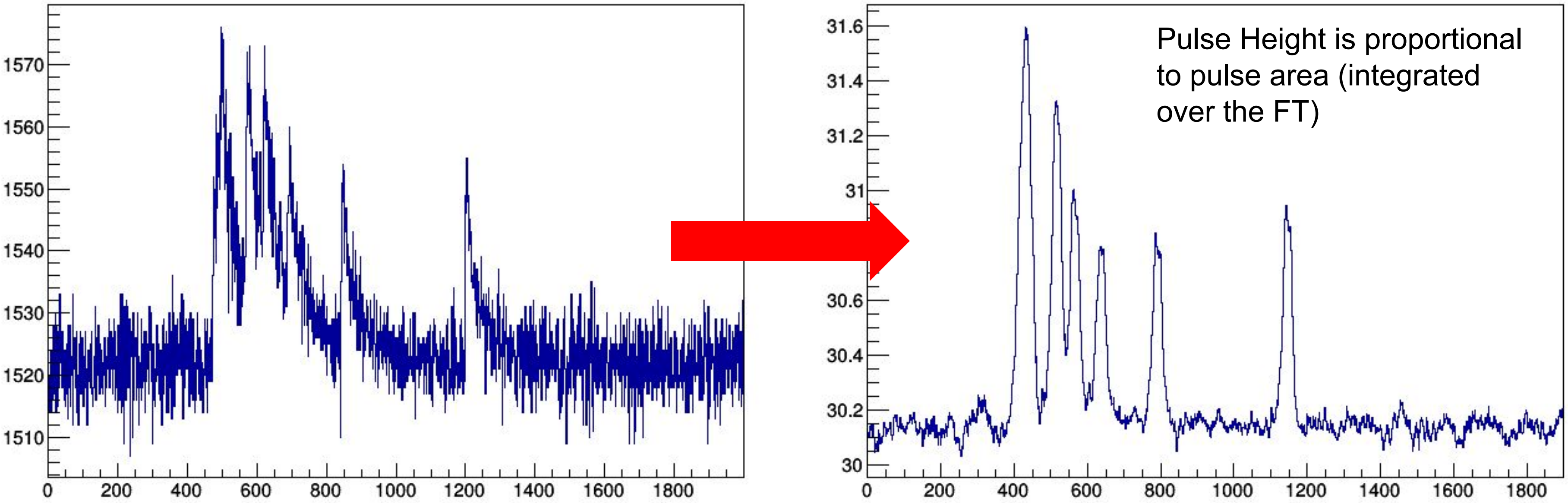
Apply the tailored FIR filter: example - 2 SPEs

Run Dope3_ext_08 - Ch1

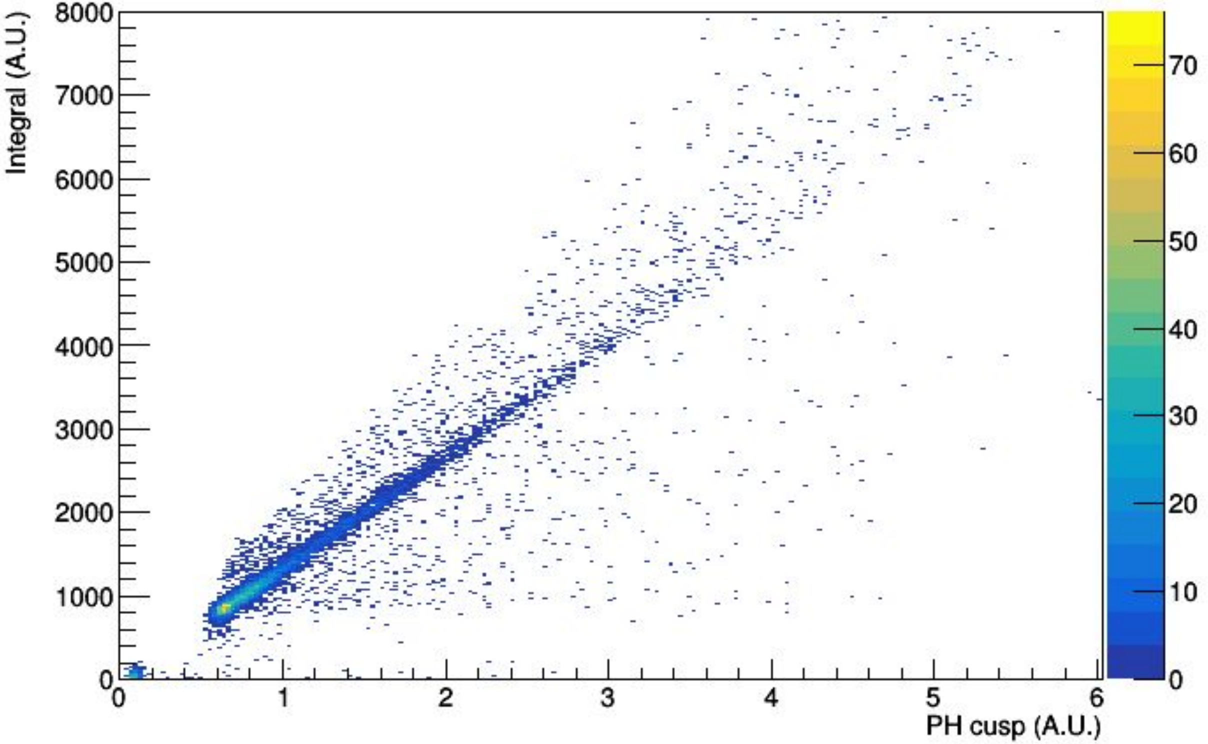


Apply the tailored FIR filter: example - multi PE event

Run Dope3_ext_08 - Ch1



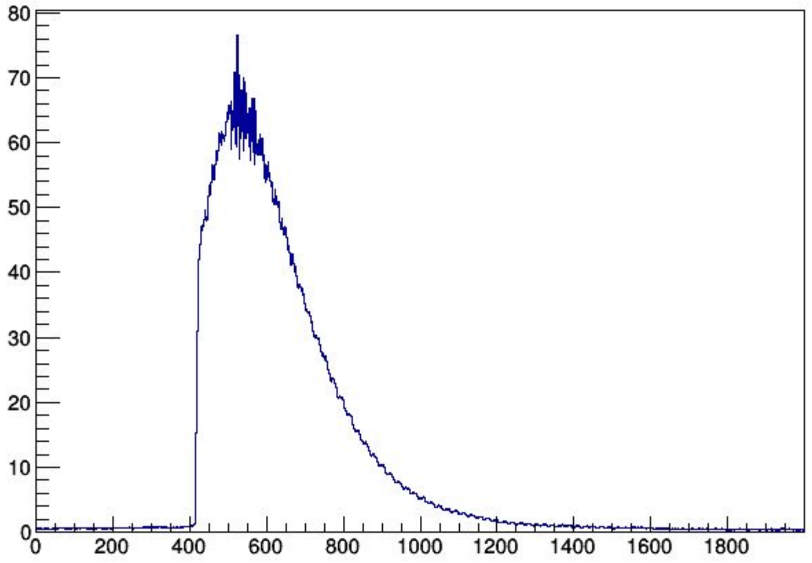
Check the correlation of PI{raw} vs PH{Filtered}



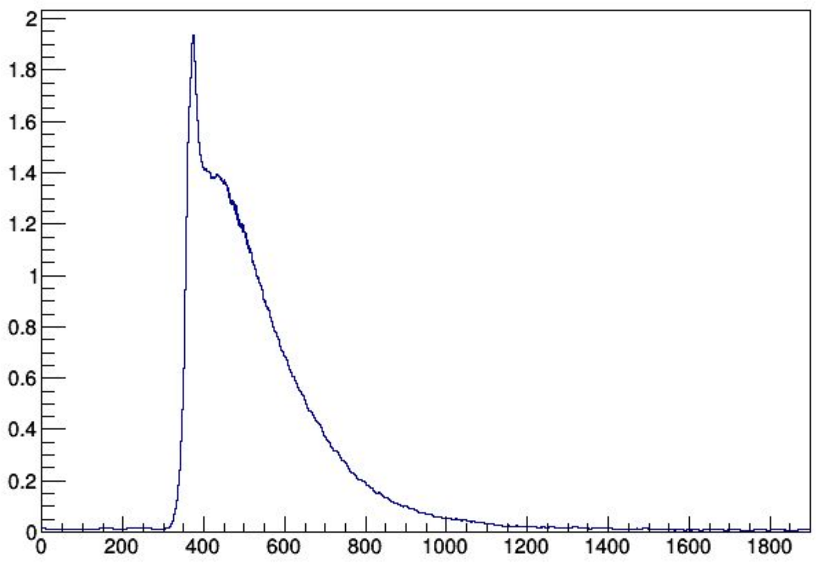
- scan raw wfm selecting events with dt(onsets)>200 ticks (to reject pile-up),
- the smoothed waveform of selected pulses is integrated over a 110 ticks range (onset-10+100)
- the cusp-filtered pulse height is computed by finding its local maximum within 60 ticks from the onset
- plot PH{Filtered} vs PI{raw}
- as expected, there is a good correlation

Apply the FIR to averaged wfs

Average raw waveform

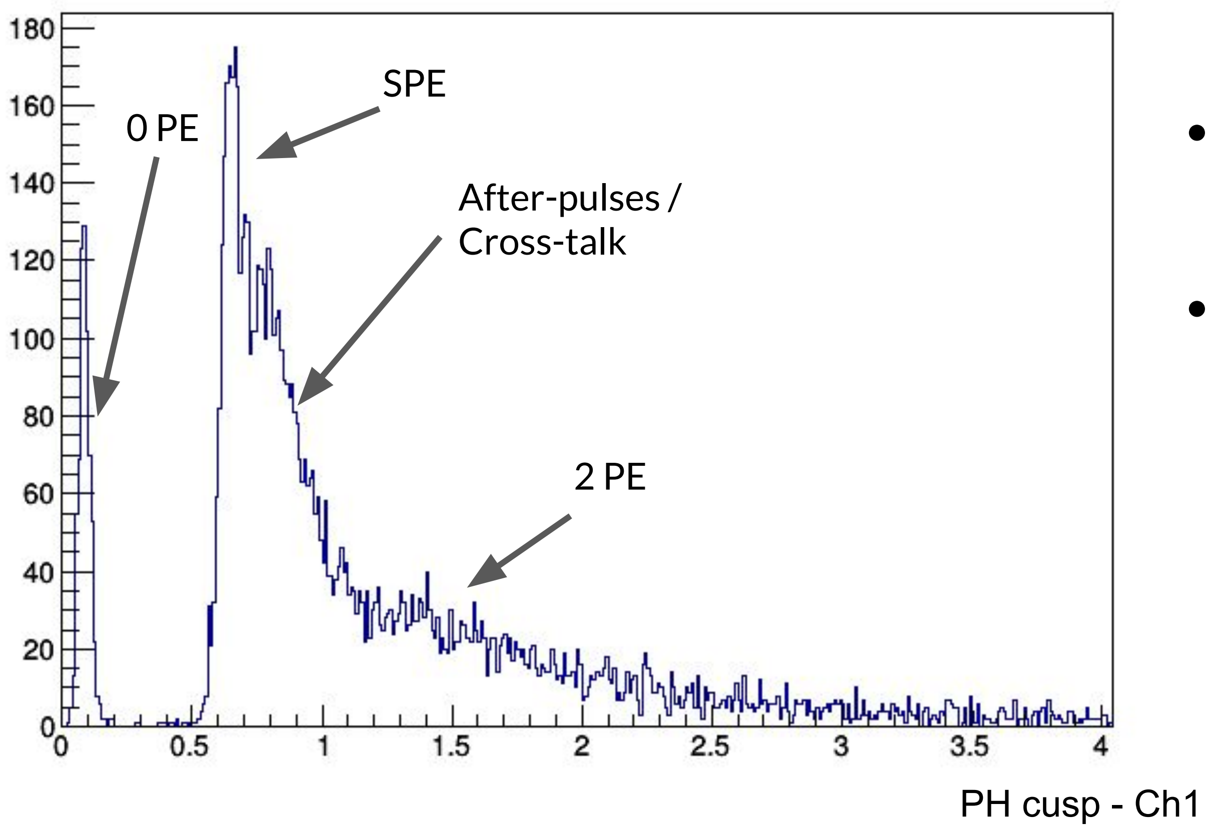


Average filtered waveform



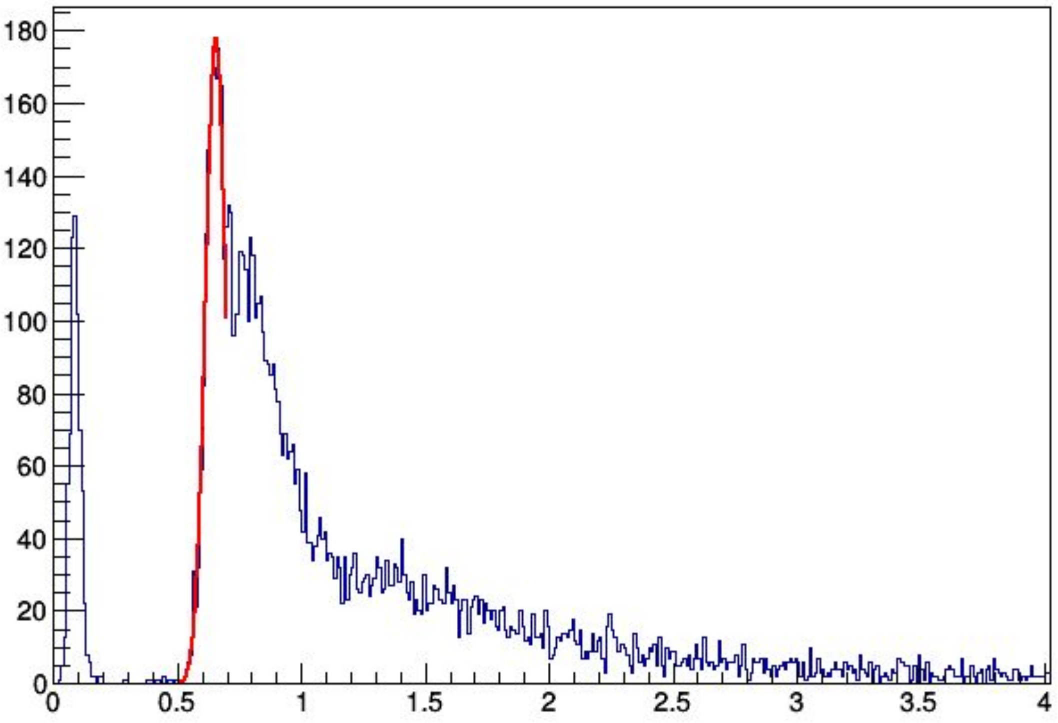
- The average raw wfm is made by only discarding events with NO pulses (signal avg < baseline + 3σ)
- The filter is then once applied directly to the averaged wf
- The baseline is subtracted

Filtered pulse height distribution



- In all channels, structures for SPE and DPE peak are visible → a calibration can be established!
- the PH is computed as a local maximum in the wf, thus the 0 PE peak is slightly shifted to the right (~2-3 sigma from the baseline)

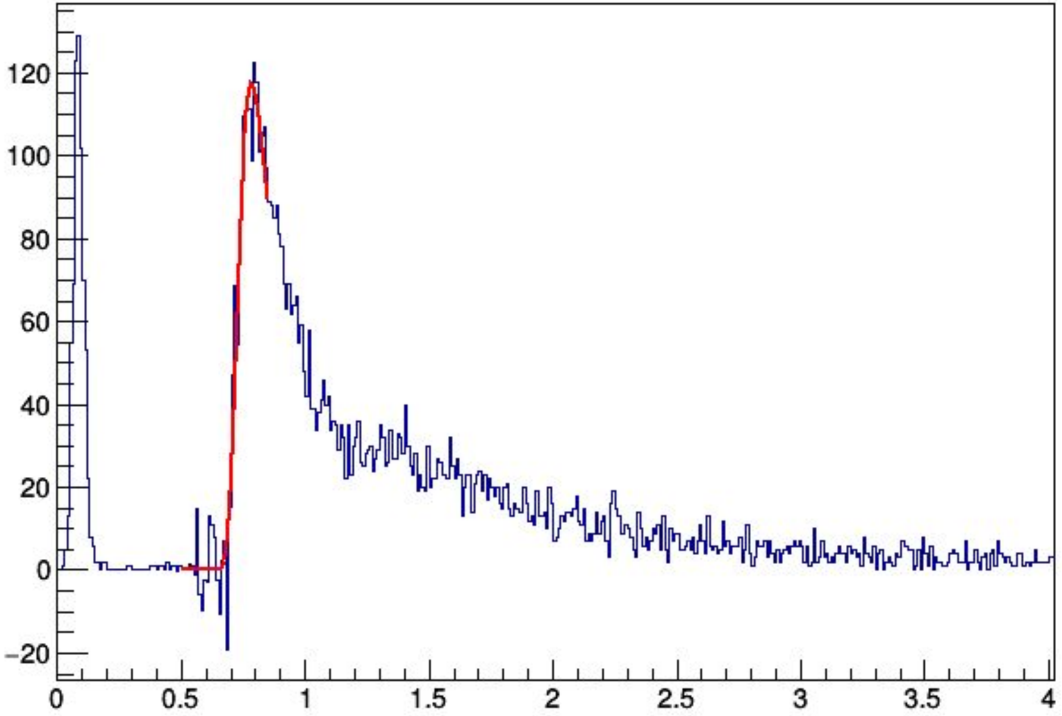
Calibration of PH{FIR-Filtered wfm}: gaussian fit of SPE



PH cusp - Ch1

- fit the left side of the SPE peak with a gaussian
- take the mean of this gaussian as the SPE peak position

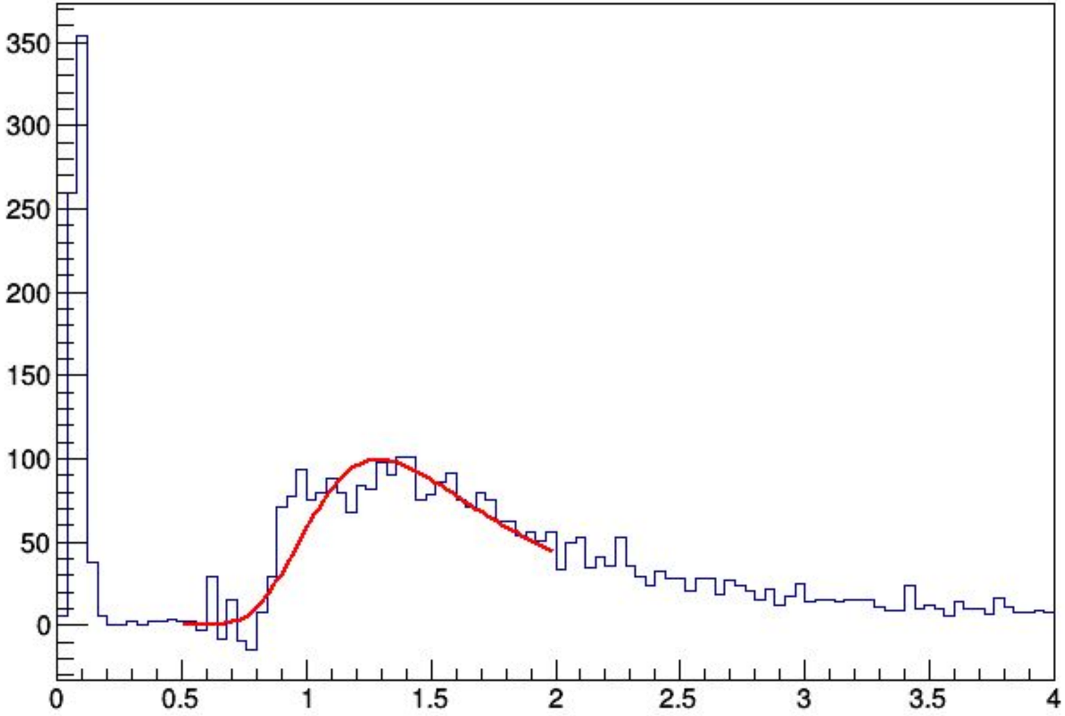
Calibration of PH{FIR-Filtered wfm}: Landau fit of after-pulse/cross-talk structure



PH cusp - Ch1

- Subtract the SPE gaussian from the spectrum
- fit the left side of the after-pulse/cross-talk peak with a landau distribution

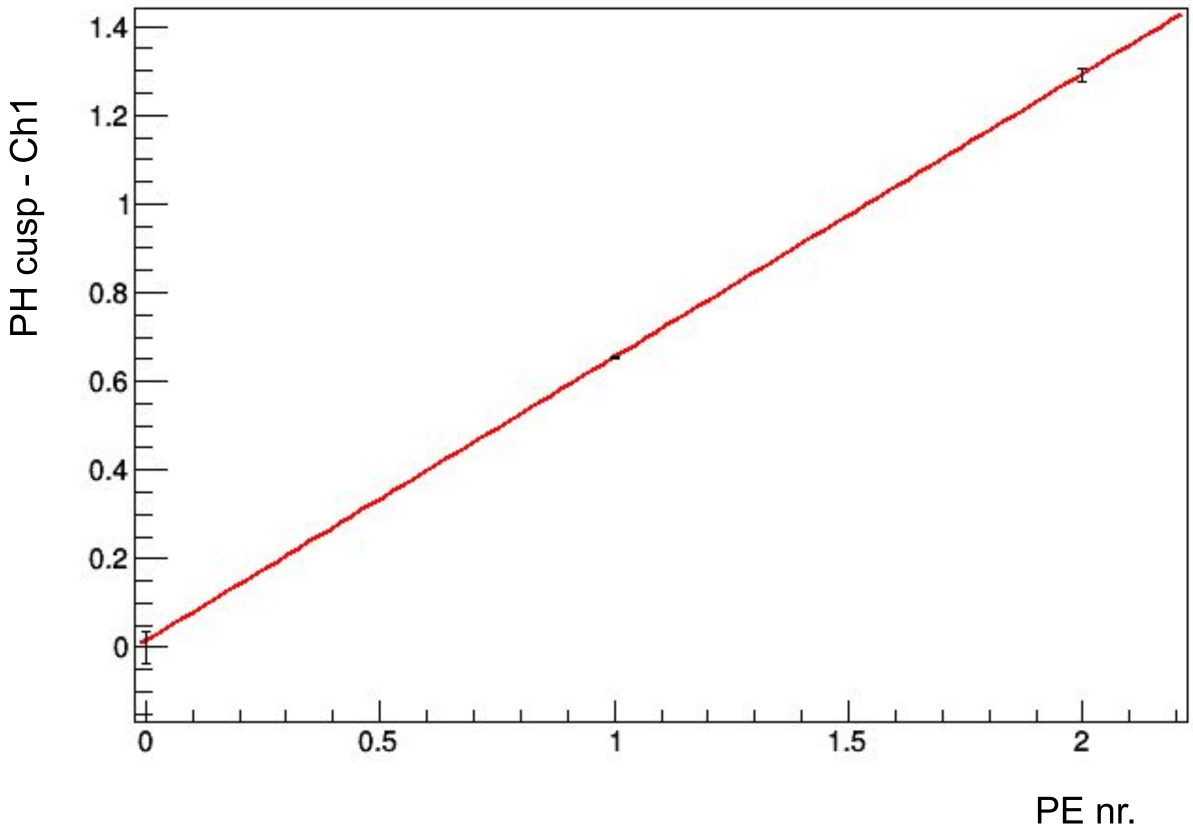
Calibration of PH{FIR-Filtered wfm}: Landau fit of DPE



PH cusp - Ch1

- Subtract the after-pulse/cross-talk landau from the spectrum
- widen the binning
- fit the DPE peak with a landau distribution
- take the landau most probable value as the DPE peak position

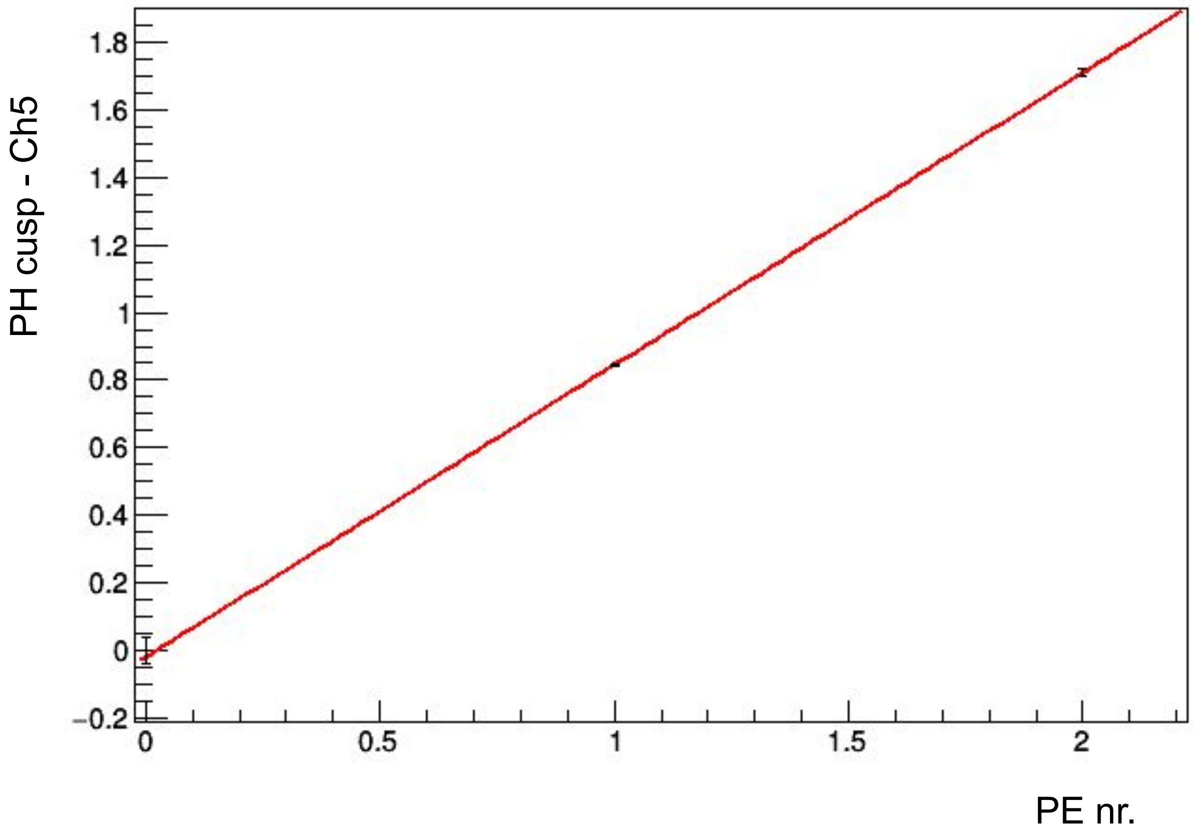
Calibration of PH{FIR-Filtered wfm} - CH1: results



- the 0 PE point is set to 0, with error = sigma of the baseline distribution
- the fit is good, p0 is compatible with 0 within 1 σ
- the same calibration has been performed for all channels, for run Dope3_ext_08

p0(+/-)	0.015(0.015)
p1(+/-)	0.64(0.01)
χ^2/ndf	0.25 / 1

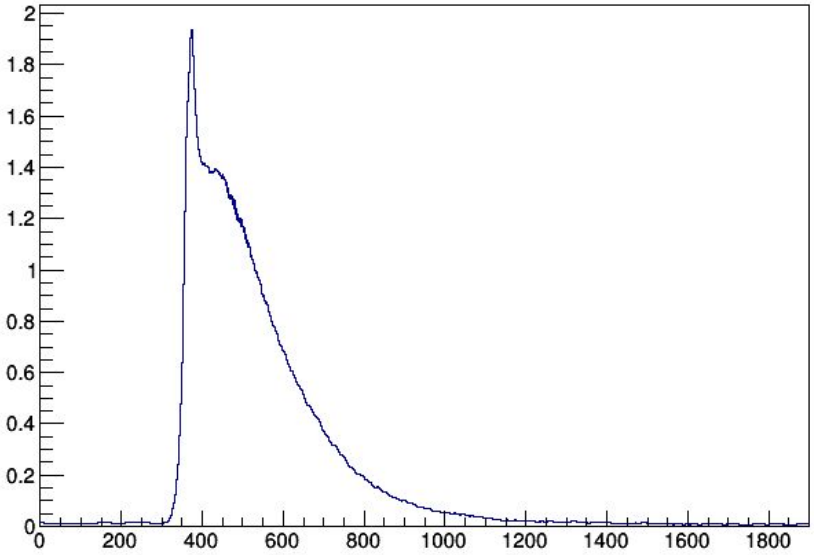
Calibration of PH{FIR-Filtered wfm} - CH5: results



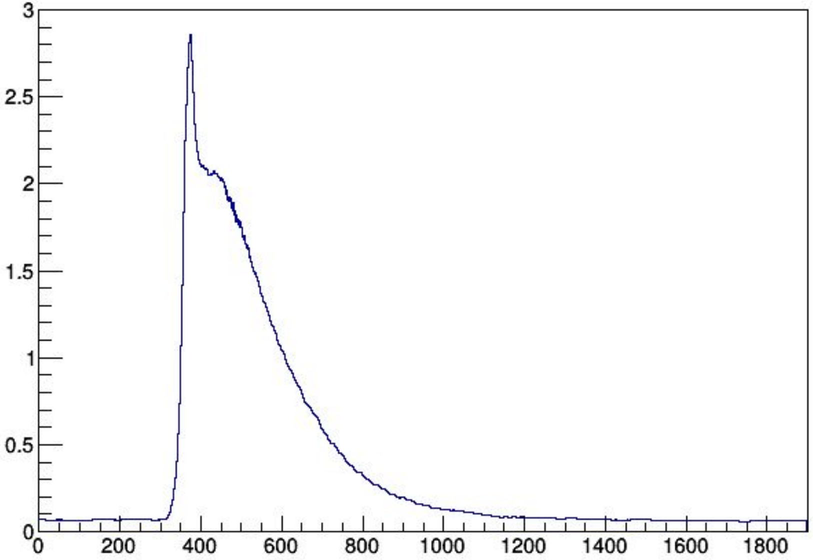
p0(+/-)	-0.021(0.012)
p1(+/-)	0.87(0.01)
χ^2/ndf	0.37 / 1

Apply the calibration to averaged waveforms

Filtered average waveform



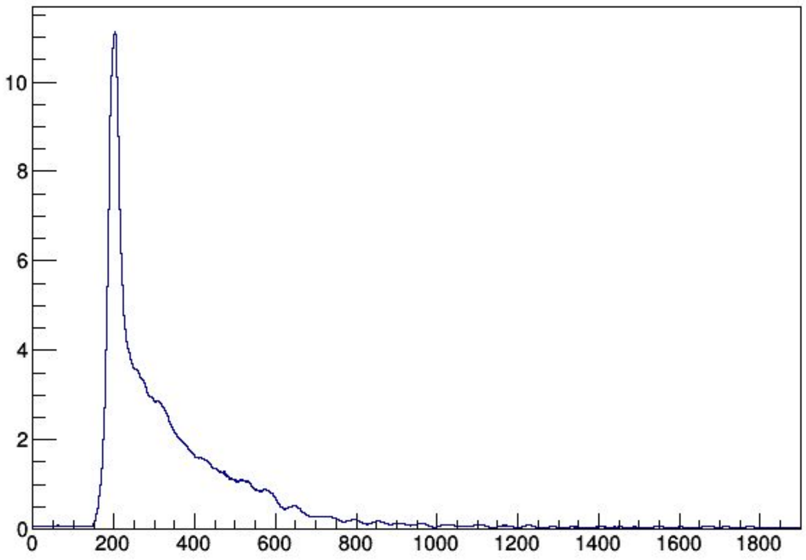
Calibrated filtered average waveform



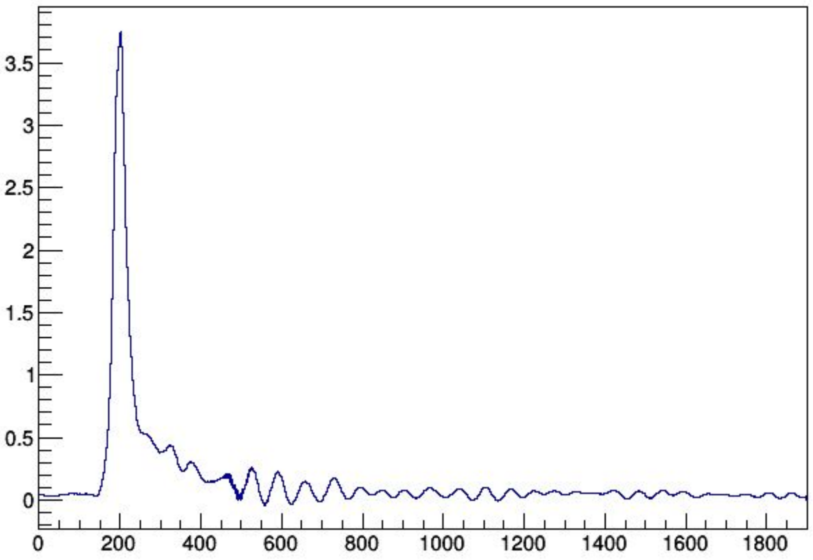
- The y-axis of the wfm is simply re-scaled according to the calibration found
- So far for a given channel the calibration is the same for all the runs. SPE stability survey allows for this (1st order): at 2-nd order it might need to be adapted on a run-by-run basis

Calibrated deconvolved wf - pre doping

Ch1 - no quartz

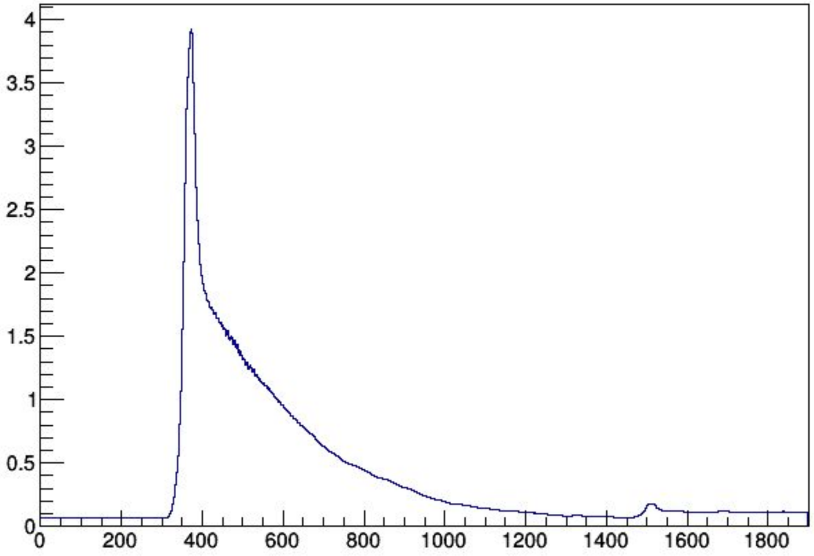


Ch5 - quartz

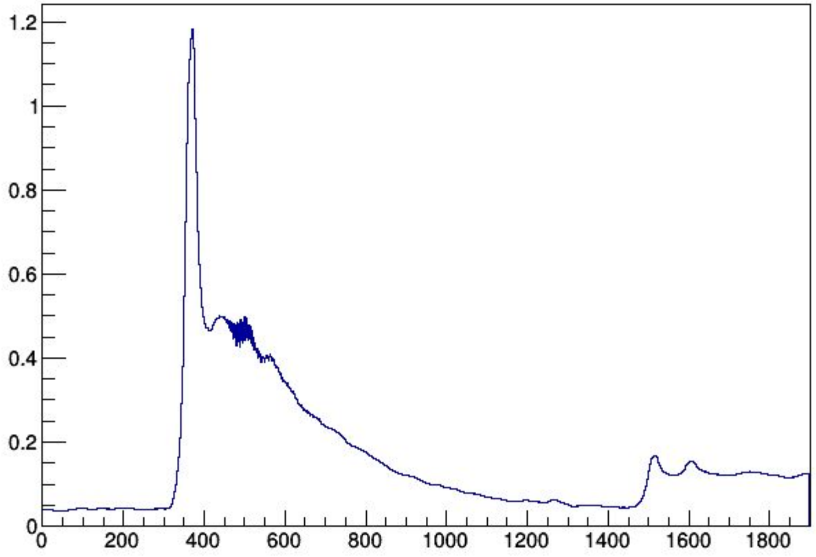


Calibrated deconvolved wf - start of 2nd doping

Ch1 - no quartz

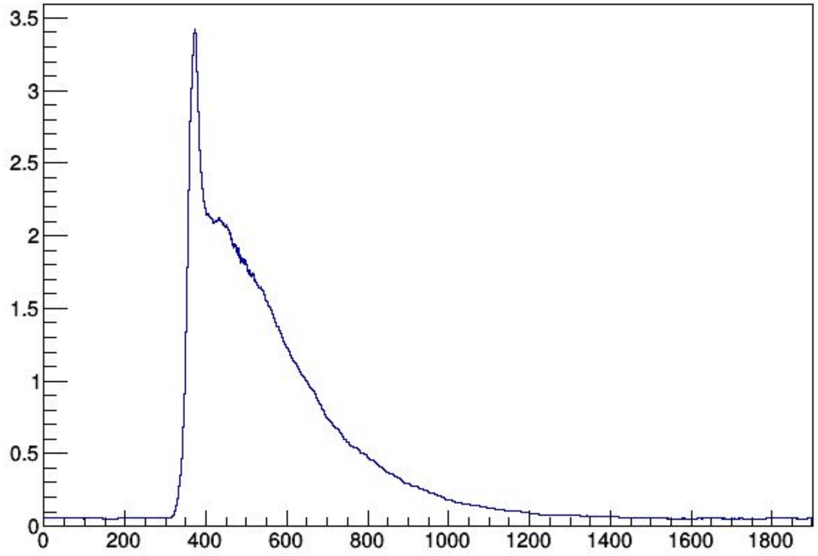


Ch5 - quartz

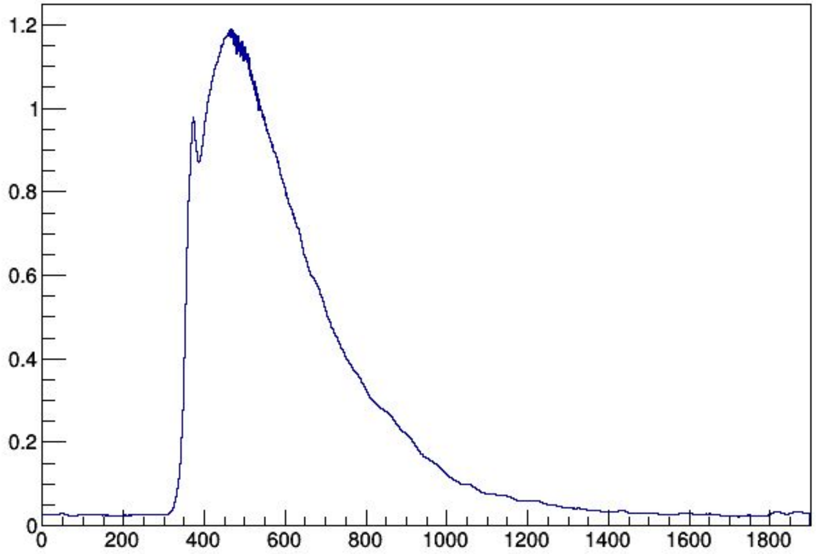


Calibrated deconvolved wf - start of 3rd doping

Ch1 - no quartz

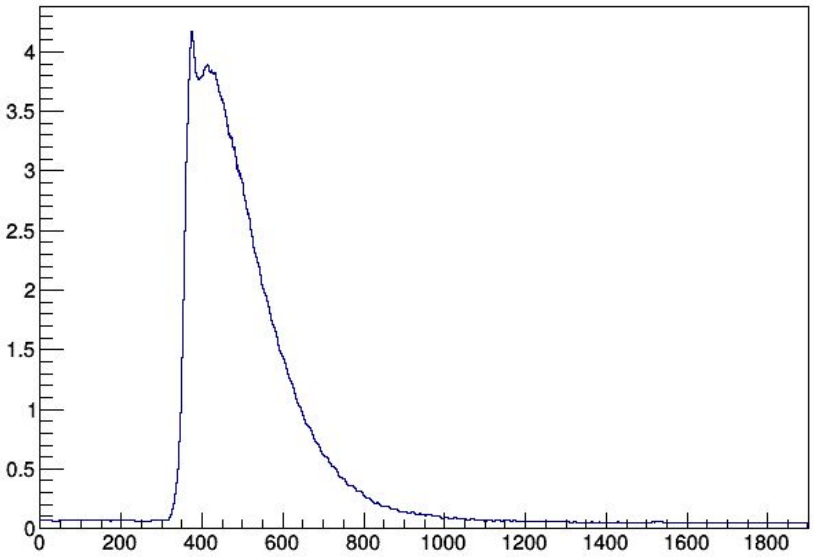


Ch5 - quartz

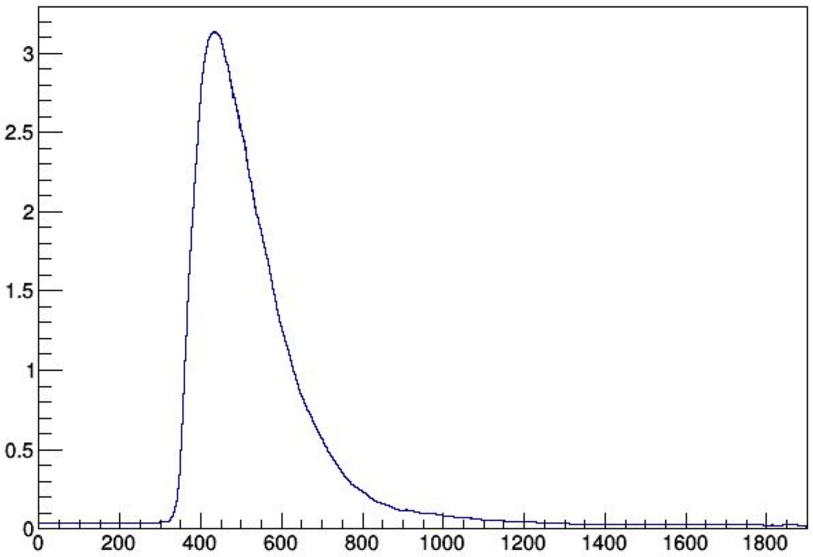


Calibrated deconvolved wf - start of 4th doping

Ch1 - no quartz

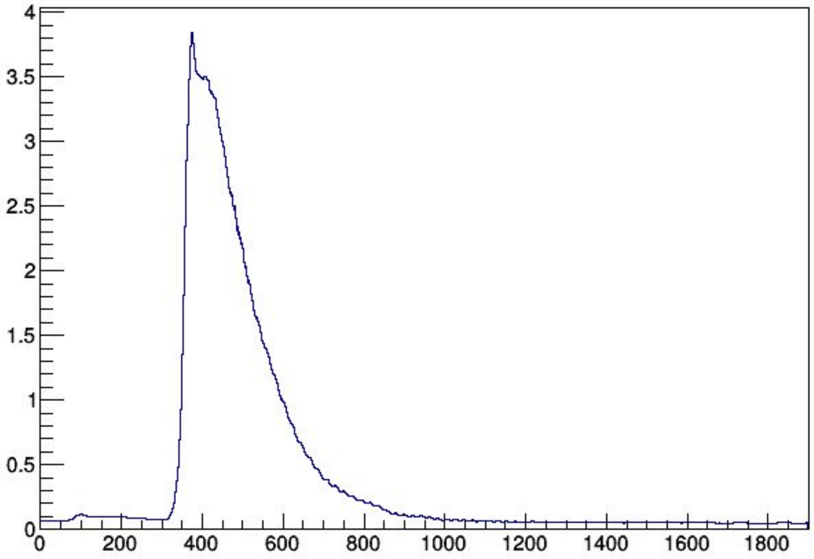


Ch5 - quartz

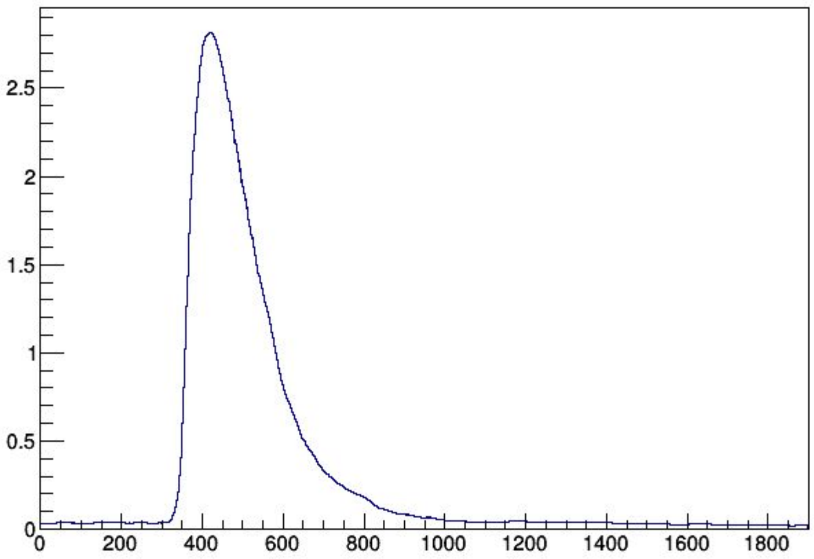


Calibrated deconvolved wf - latest run

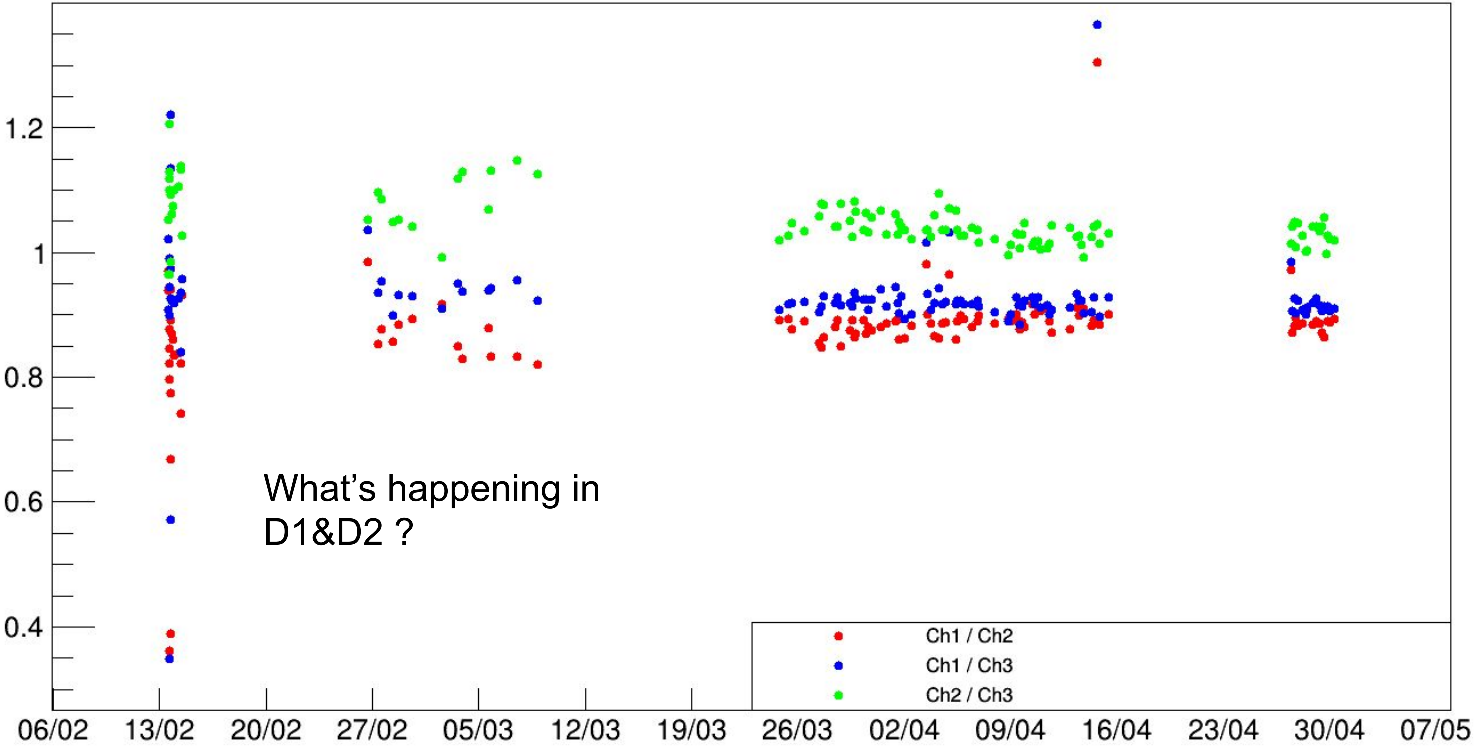
Ch1 - no quartz



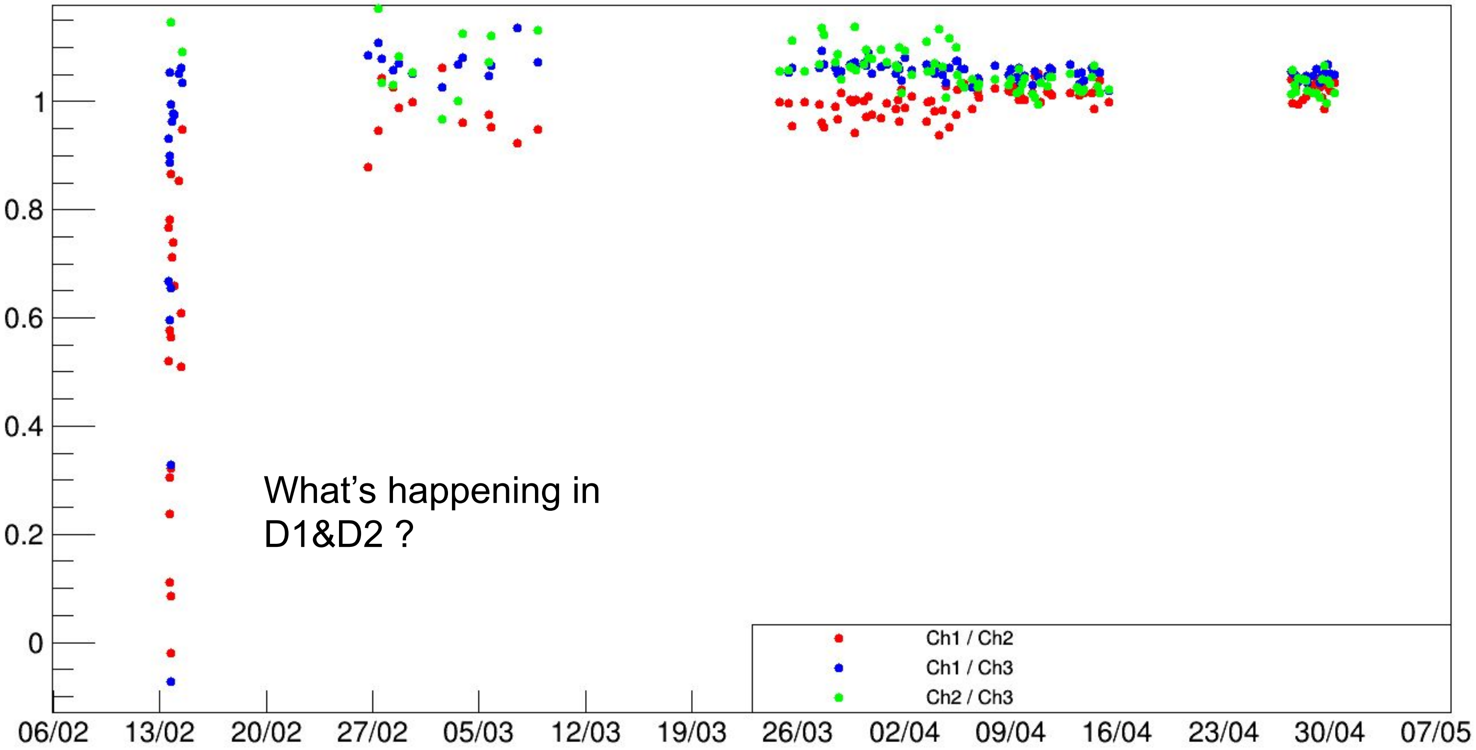
Ch5 - quartz



Survey of the detected light ratio among Chs no quartz XArapuca

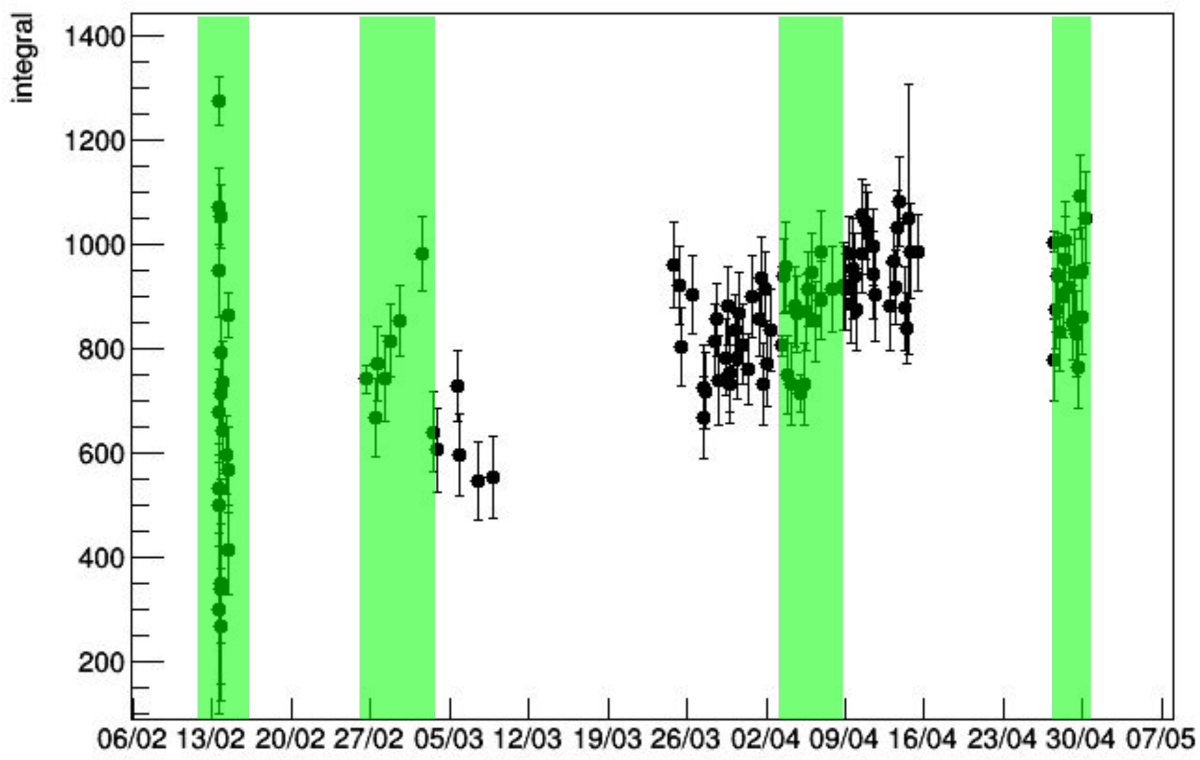


Survey of the detected light ratio among Chs - quartz XArapuca



What's happening in D1&D2 ?

Survey of the avg deconvolved integral - no quartz XArapuca



Def.:

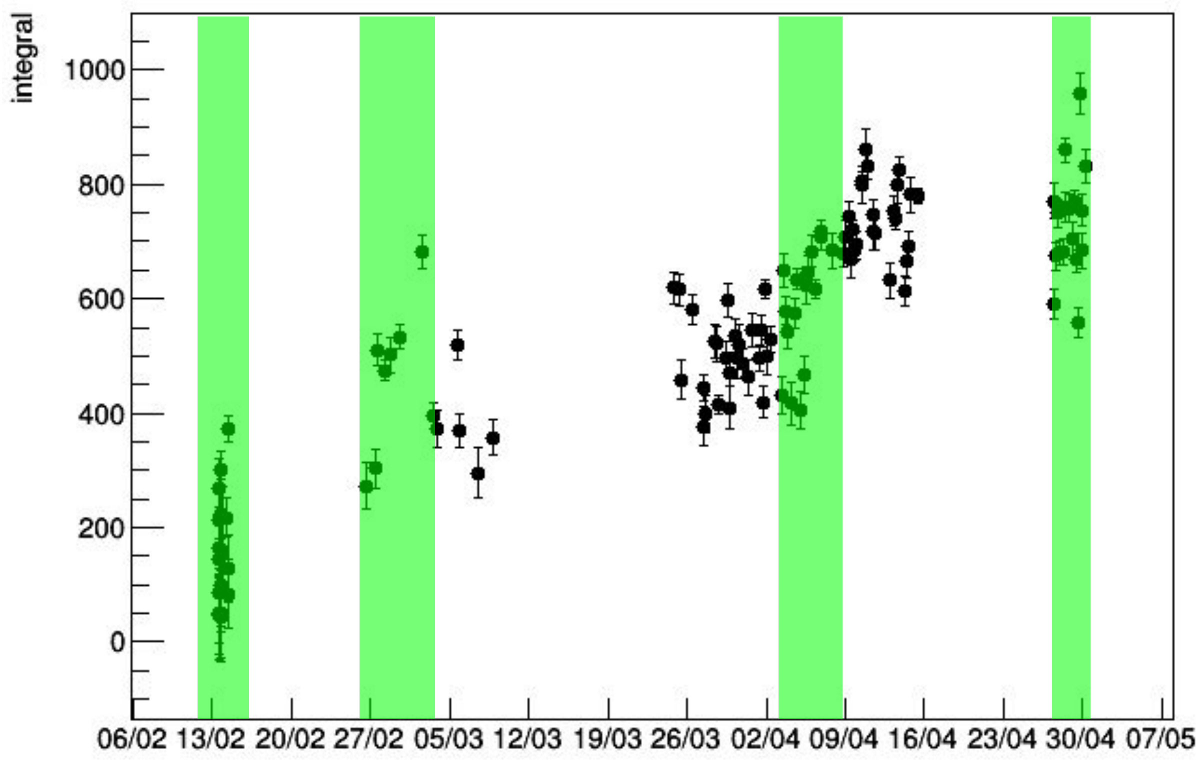
$<\text{Integral}>_{NQ} = \sum_{i=1,2,3} \text{Integral}_i / 3$

Def.:

$\sigma <\text{Integral}>_{NQ} = \text{STDdev}(\text{Integral}_i)$

NOTE: due to the width of the flat top, the integral does not correspond to the actual number of photons, but should be proportional to it

Survey of the avg deconvolved integral - quartz XArapuca



Def.:

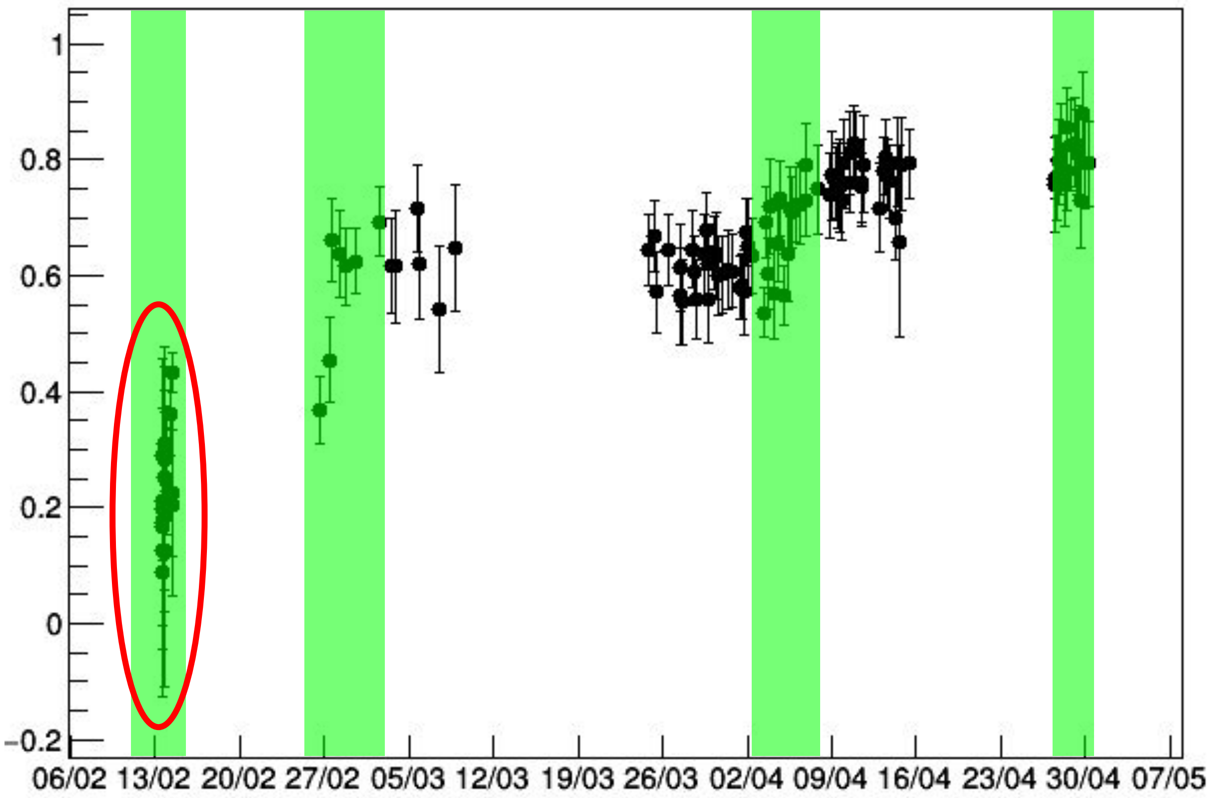
$\langle Integral \rangle_Q = \Sigma_{i=4,5,7} Integral_i / 3$

Def.:

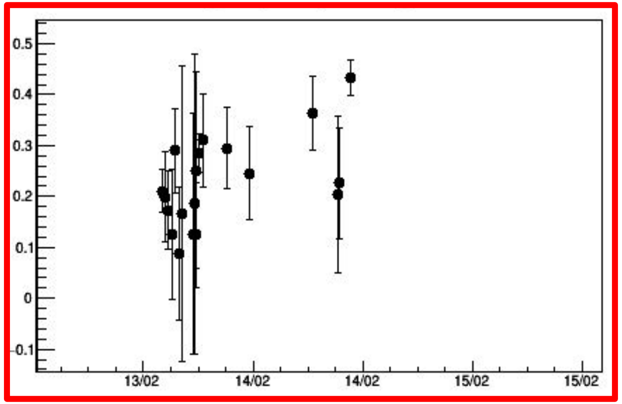
$\sigma \langle Integral \rangle_Q = STDdev(Integral_i)$

NOTE: due to the width of the flat top, the integral does not correspond to the actual number of photons, but should be proportional to it

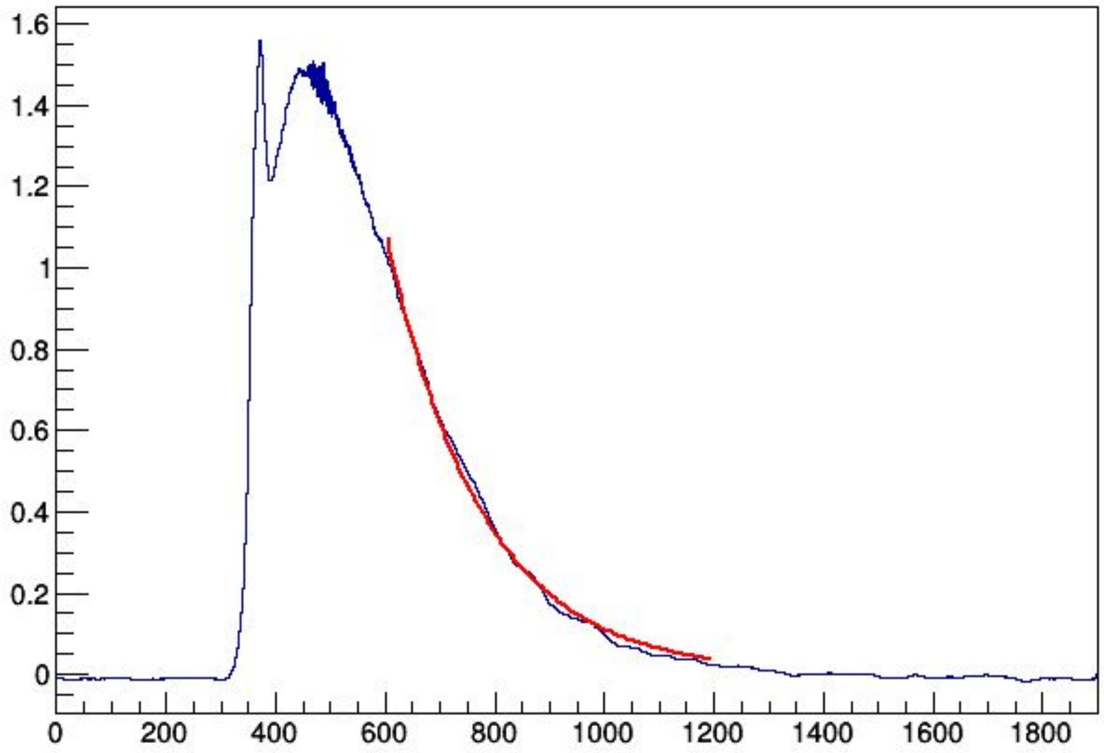
Survey of the avg deconvolved Q/NQ integral ratio



Zoom on D1

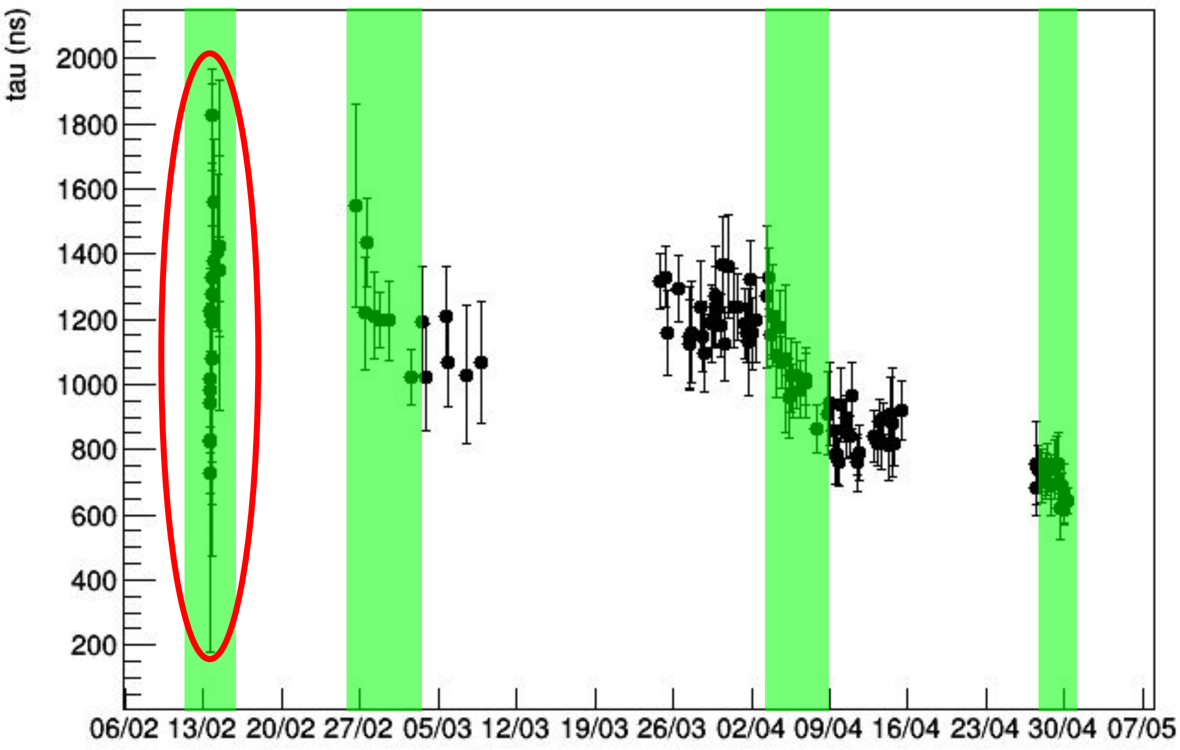


Fitting the slow component in deconvolved average wfms



- the deconvolved averaged waveforms are fitted with a single exponential
- fit limits are (350,1200) for Doping1 runs, (600,1200) for Doping 2 onward

Survey of the avg slow component - no quartz XArapuca



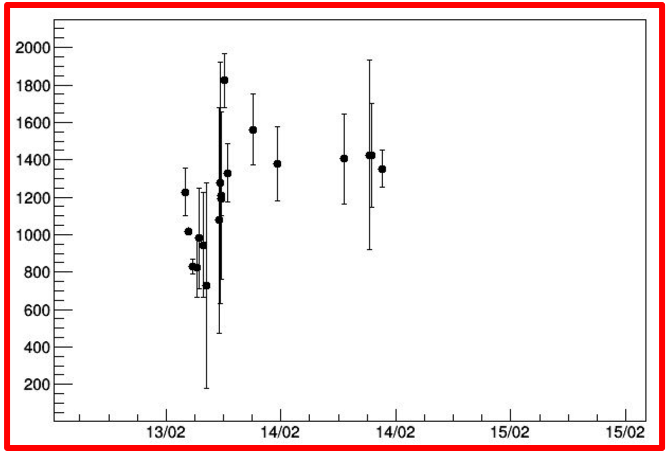
Def.:

$< \tau >_{NQ} = \Sigma_{i=1,2,3}\, \tau_i / 3$

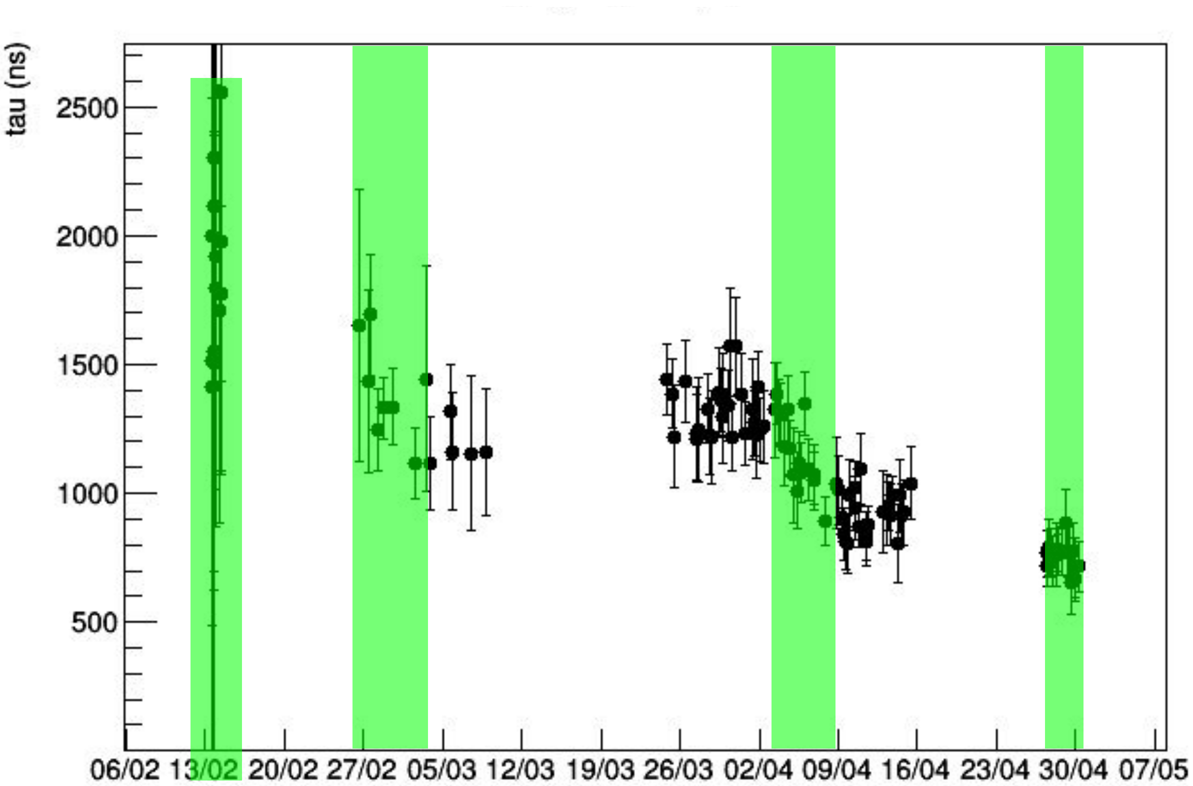
Def.:

$\sigma < \tau >_{NQ} = \text{STDdev}(\tau_i)$

Zoom on D1



Survey of the avg slow component -quartz XArapuca



Def.:

$< \tau >_Q = \sum_{i=1,2,3} \tau_i / 3$

Def.:

$\sigma <\tau>_Q = \text{STDdev}(\tau_i)$

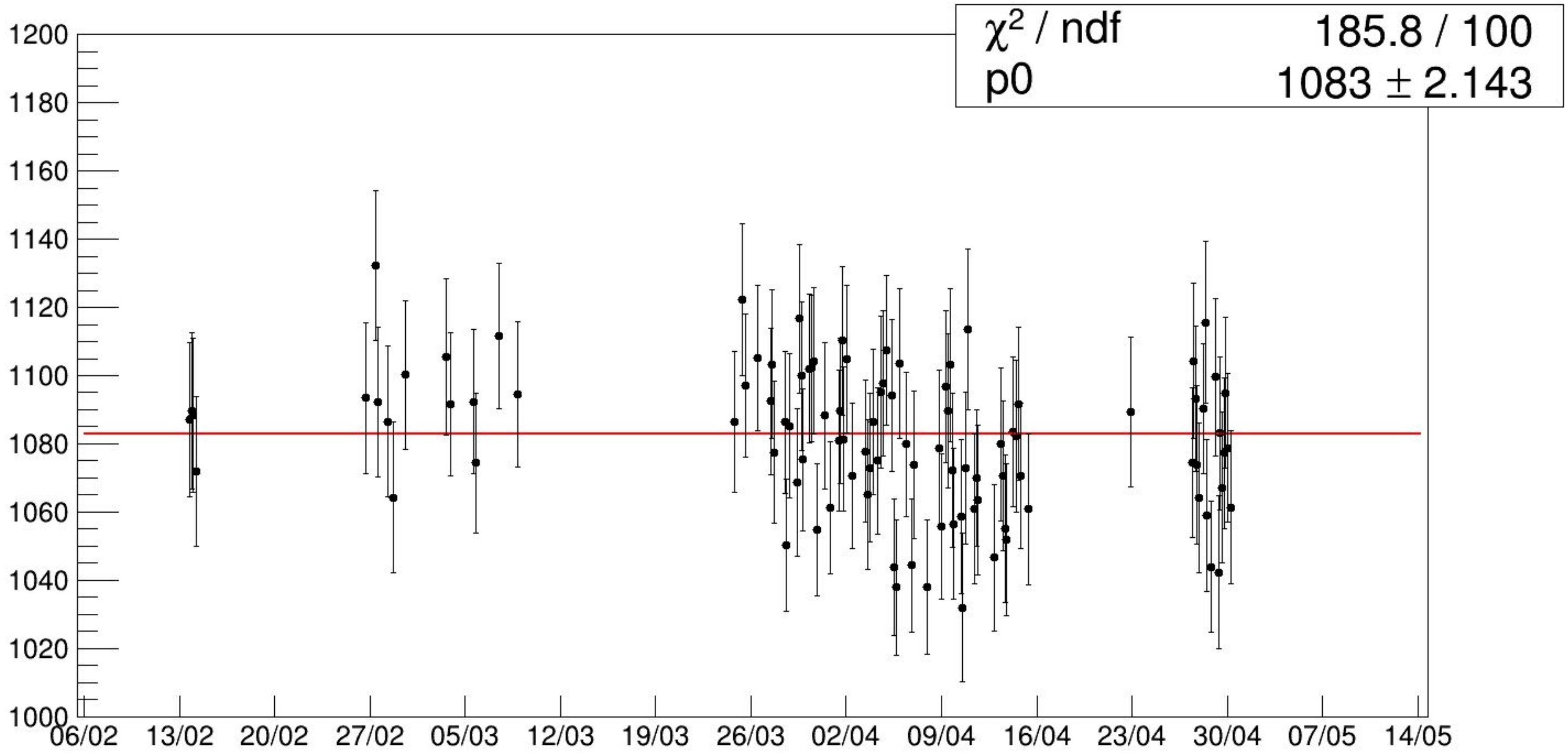
Conclusions

- Updated <SPE> time survey with newer runs and τ_{RC} stability
- For all channels, from a first order analysis <SPE> is stable in both integral and shape
- Calibrated and analyzed deconvolved average waveforms with the FIR method
- plotting the quartz / no quartz integral ratio evolution over time shows the expected increase
- plotting the $\boldsymbol{\tau}_{slow}$ evolution over time shows an initial increase followed by a subsequent decrease with each doping

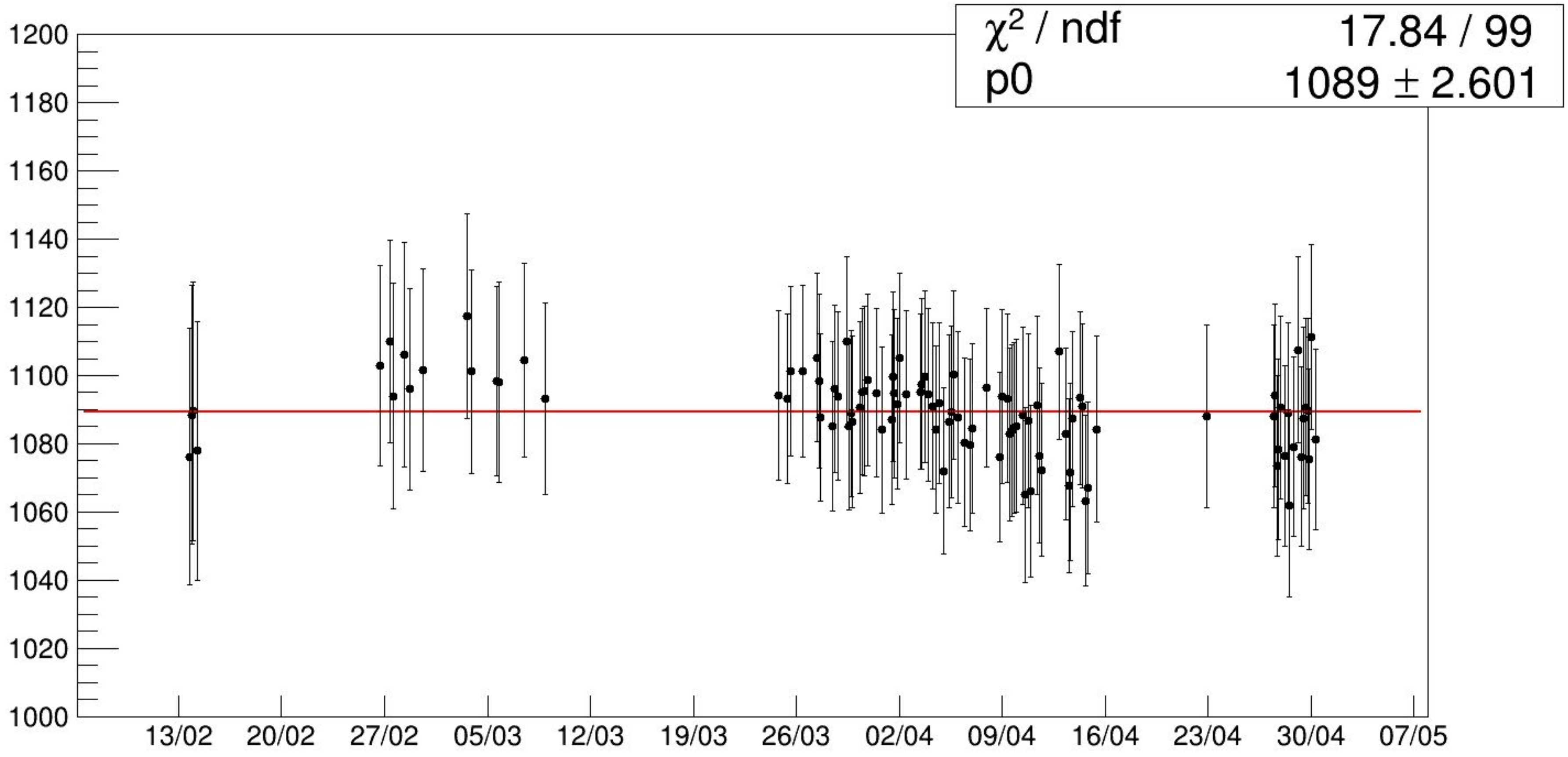
To do:

- update the <SPE> stability survey with missing runs
- understand the issue with Ch5 $\boldsymbol{\tau}_{RC}$ in some runs
- if necessary, run by run corrections and calibration for the FIR filter
- absolute calibration of the filtered waveform in number of photons

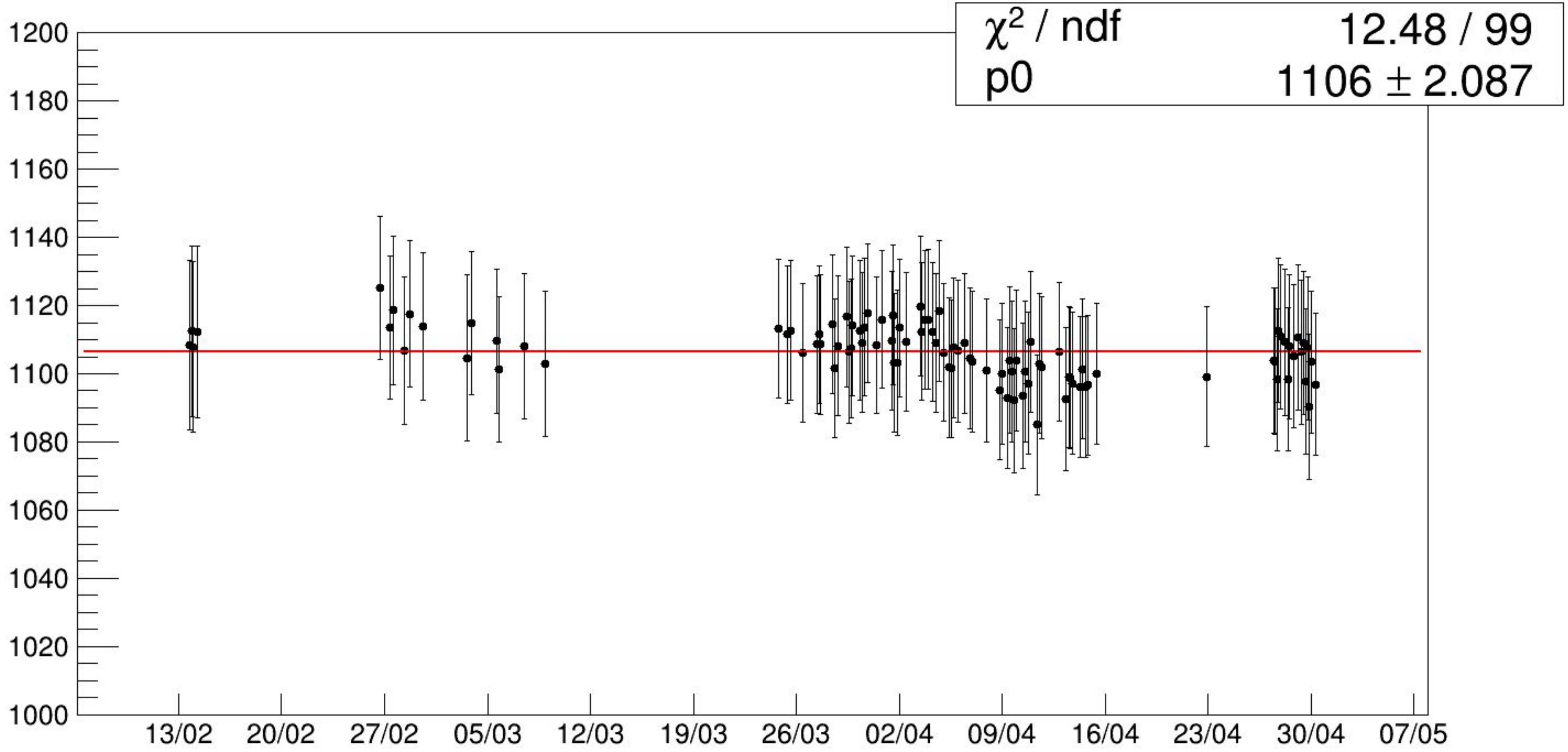
Ch2 <SPE> integral vs time



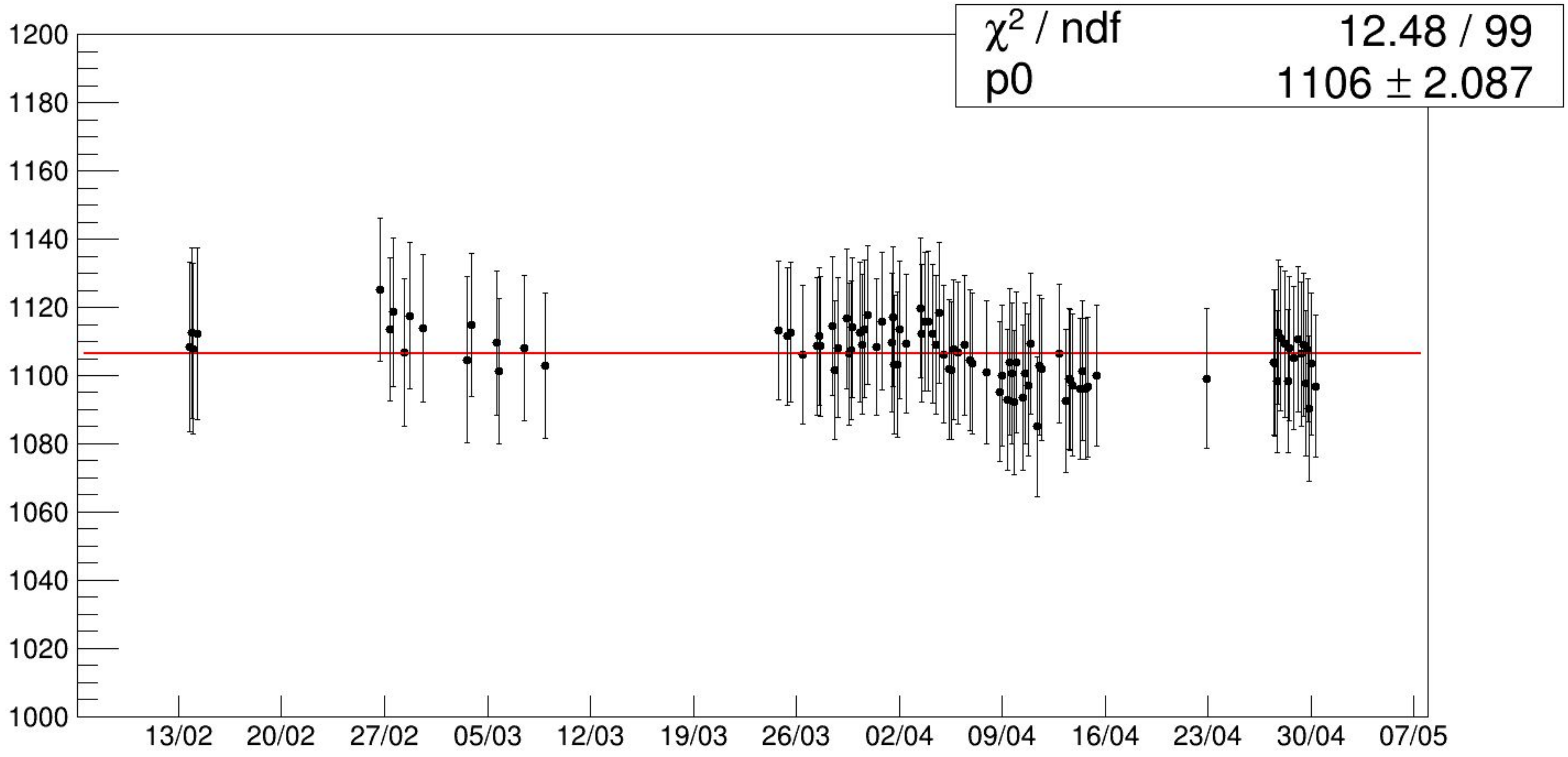
Ch4 <SPE> integral vs time



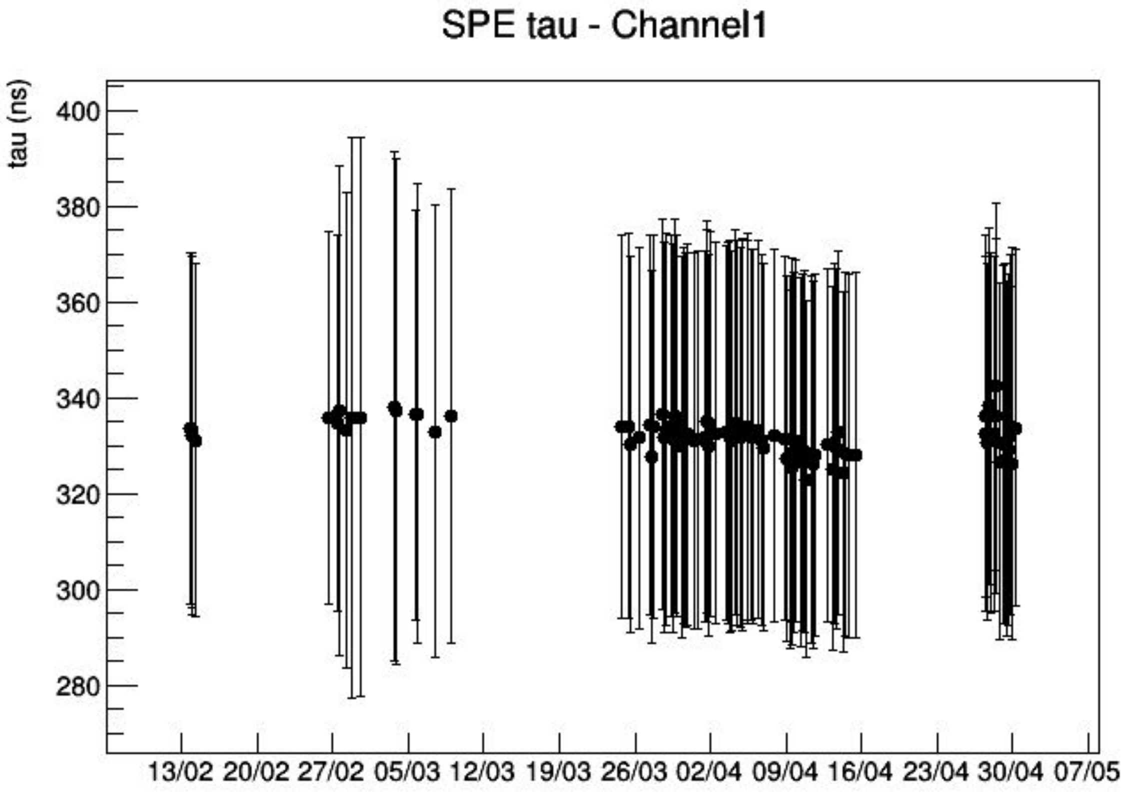
Ch5 <SPE> integral vs time



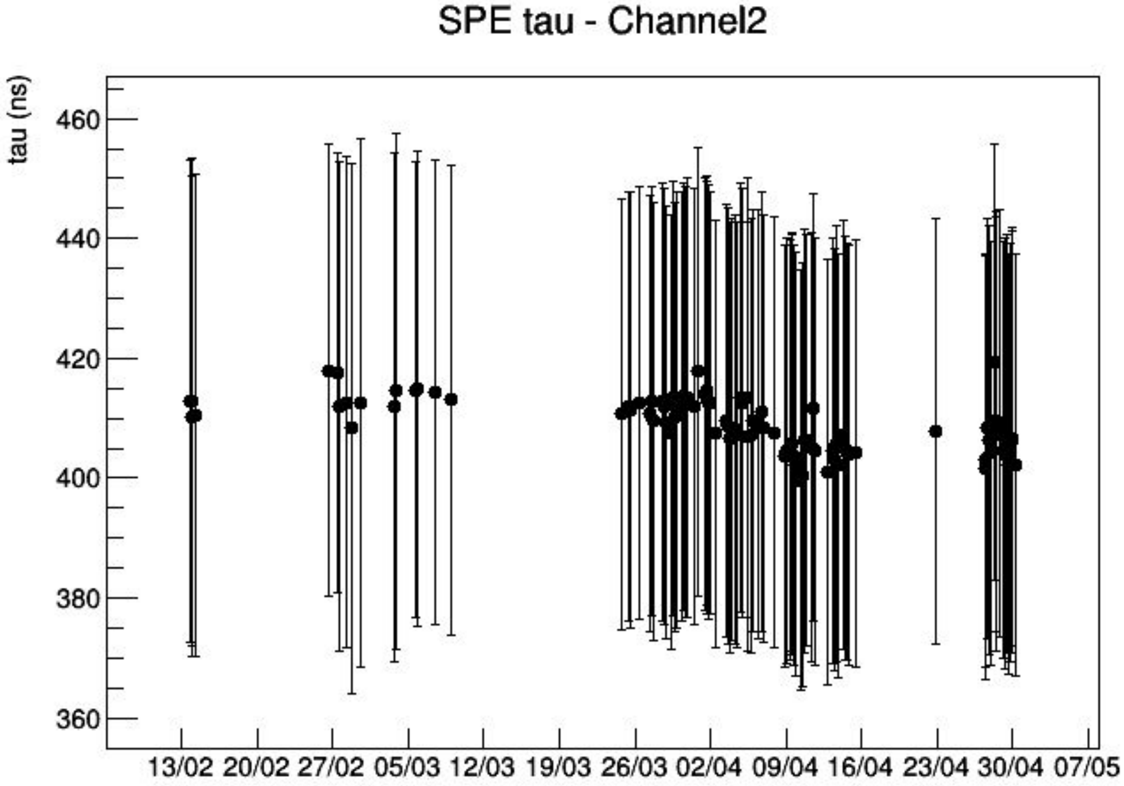
Ch7 <SPE> integral vs time



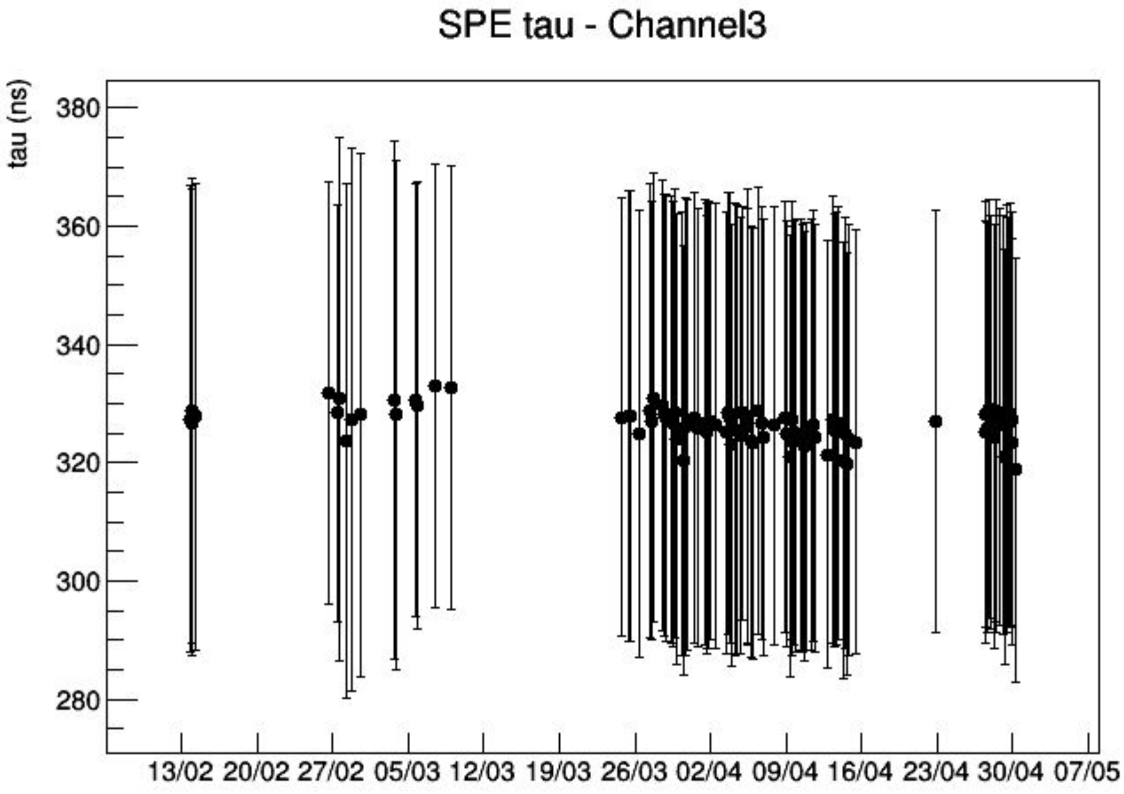
RC decay in the <SPE> - stability survey



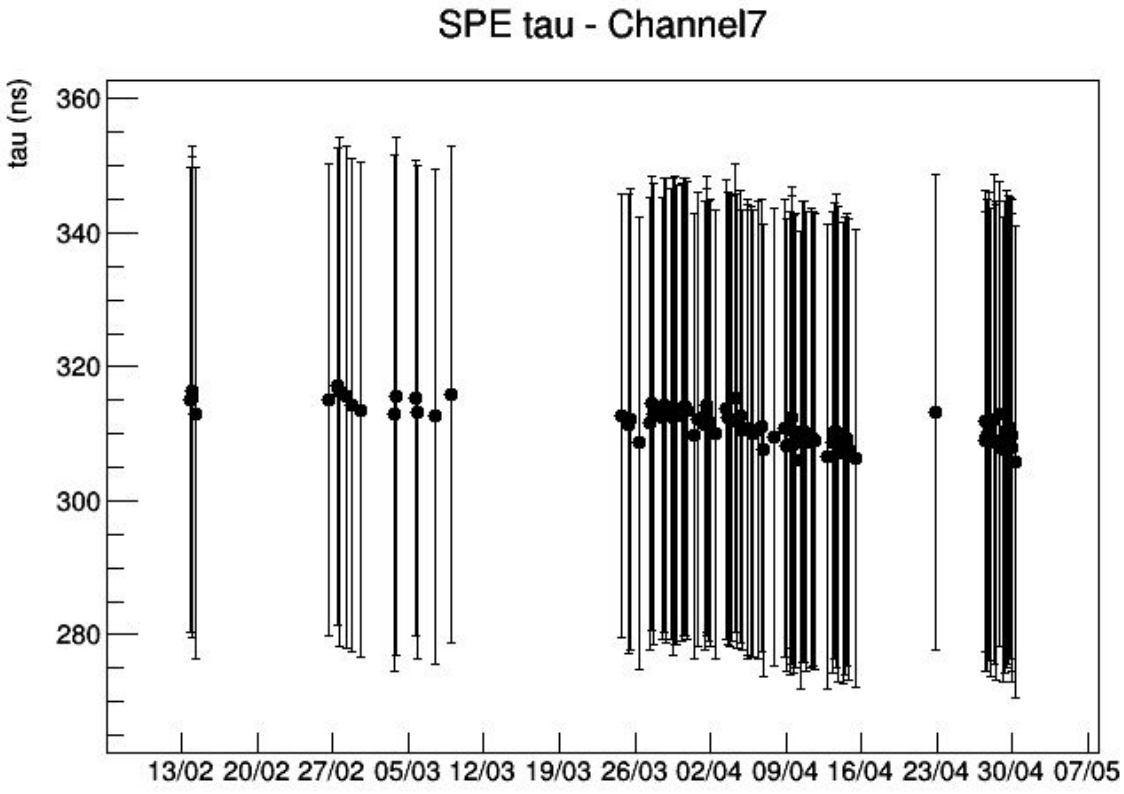
RC decay in the <SPE> - stability survey



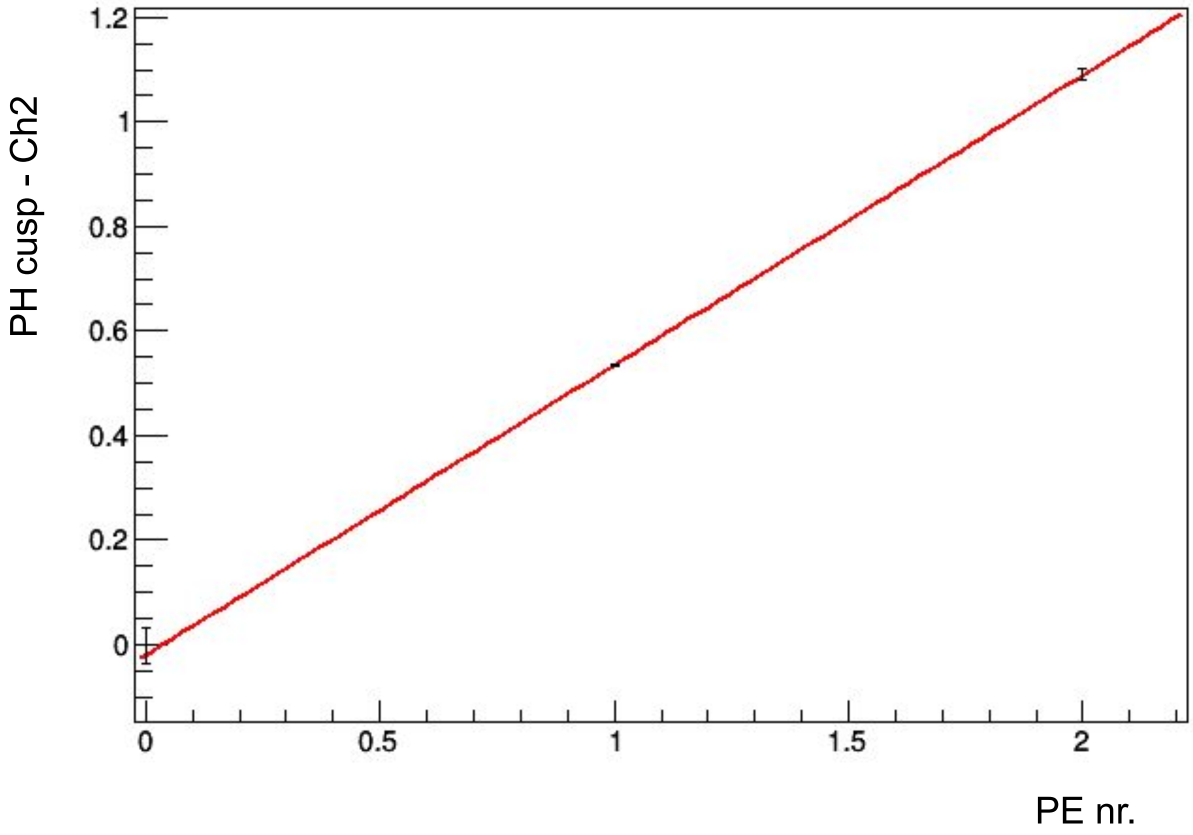
RC decay in the <SPE> - stability survey



RC decay in the <SPE> - stability survey

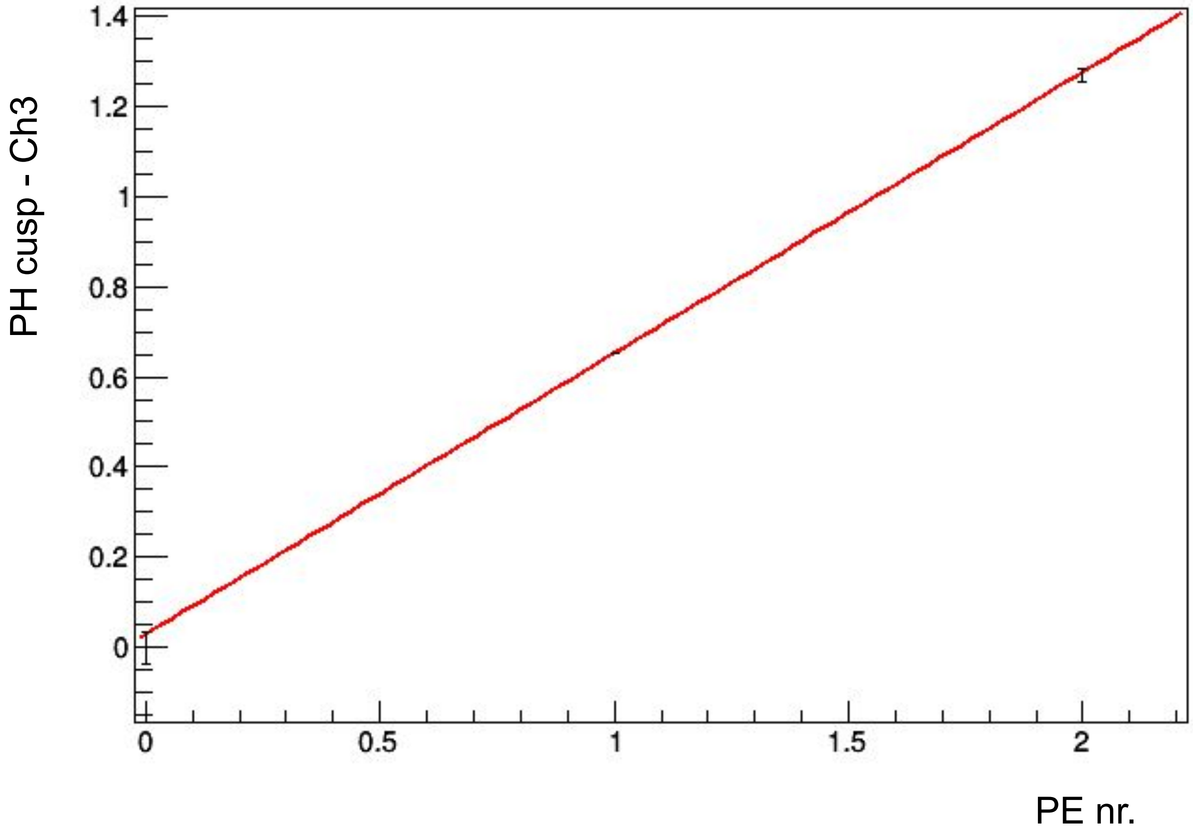


Calibration of PH{FIR-Filtered wfm} - CH2: results



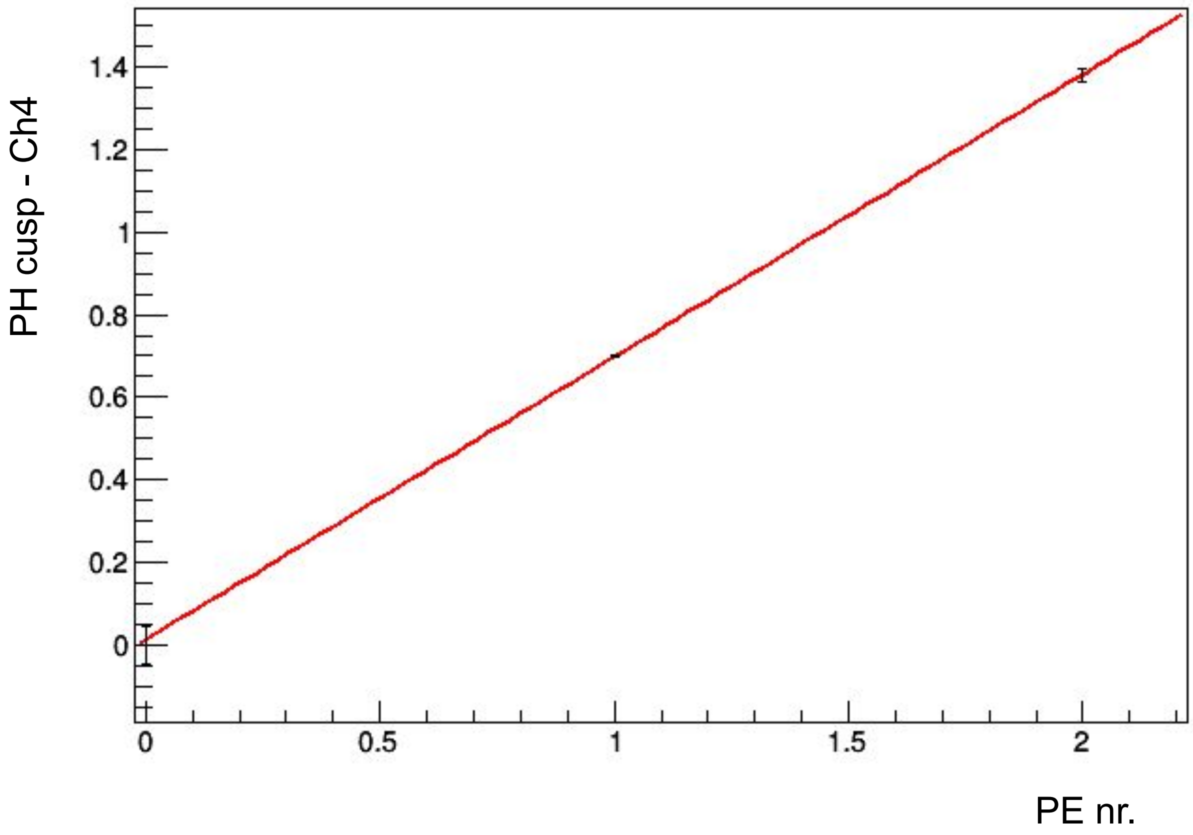
p0(+/-)	-0.020(0.011)
p1(+/-)	0.55(0.01)
χ^2/ndf	0.38 / 1

Calibration of PH{FIR-Filtered wfm} - CH3: results



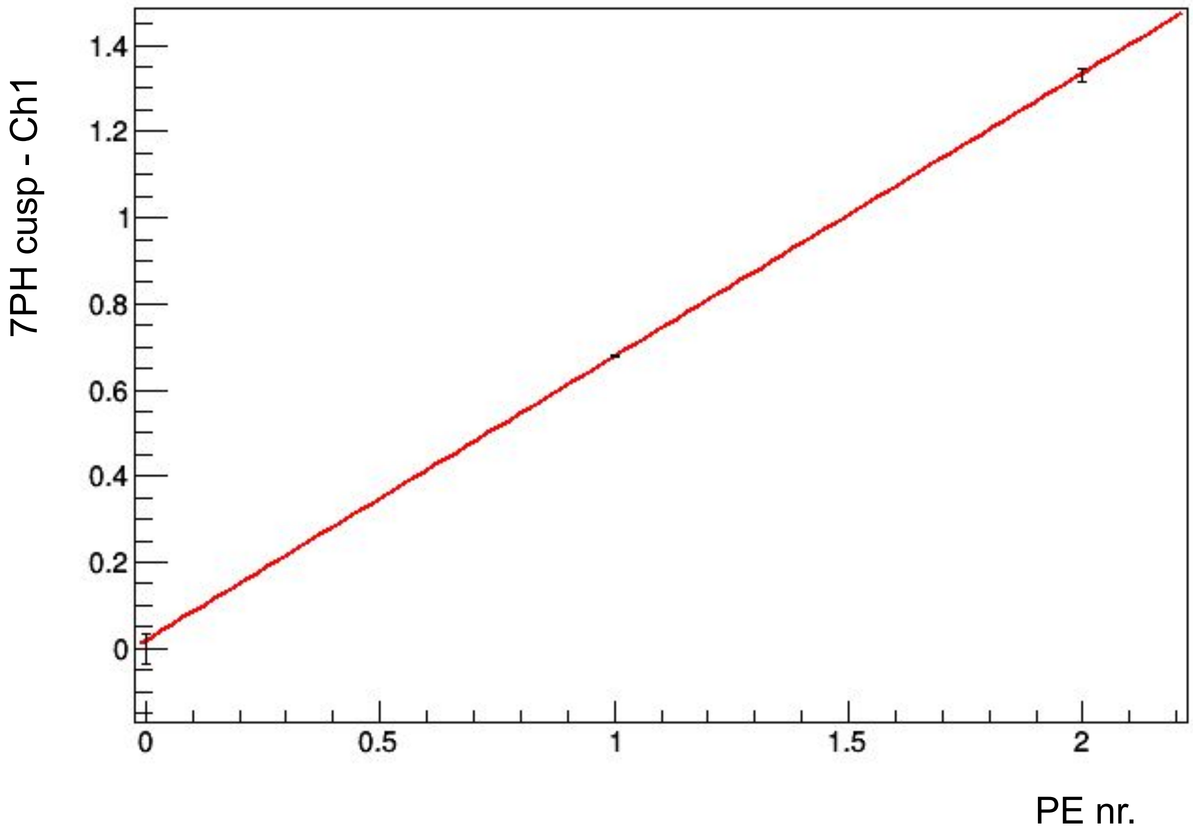
p0(+/-)	0.029(0.015)
p1(+/-)	0.62(0.01)
χ^2/ndf	0.89 / 1

Calibration of PH{FIR-Filtered wfm} - CH4: results



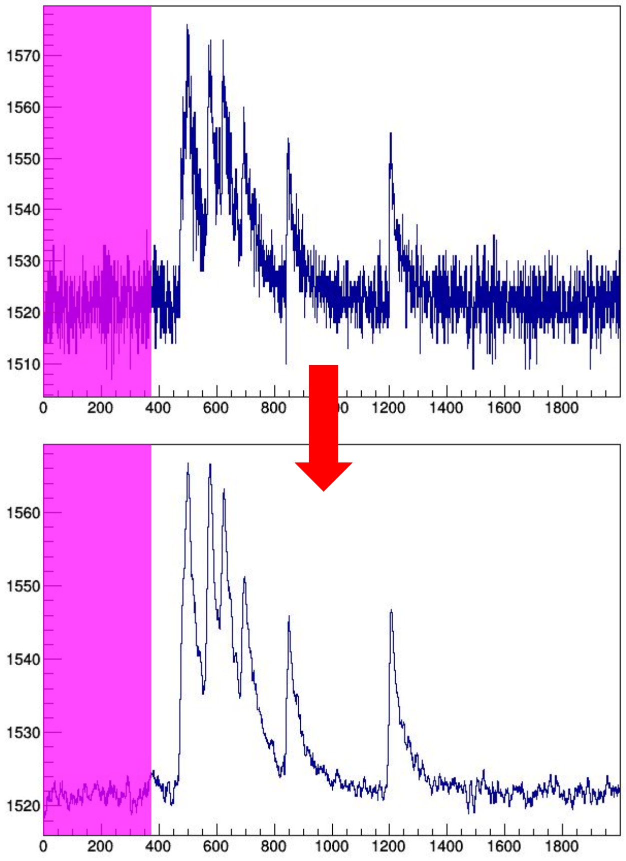
p0(+/-)	0.012(0.017)
p1(+/-)	0.69(0.02)
χ^2/ndf	0.10 / 1

Calibration of PH{FIR-Filtered wfm} - CH7: results

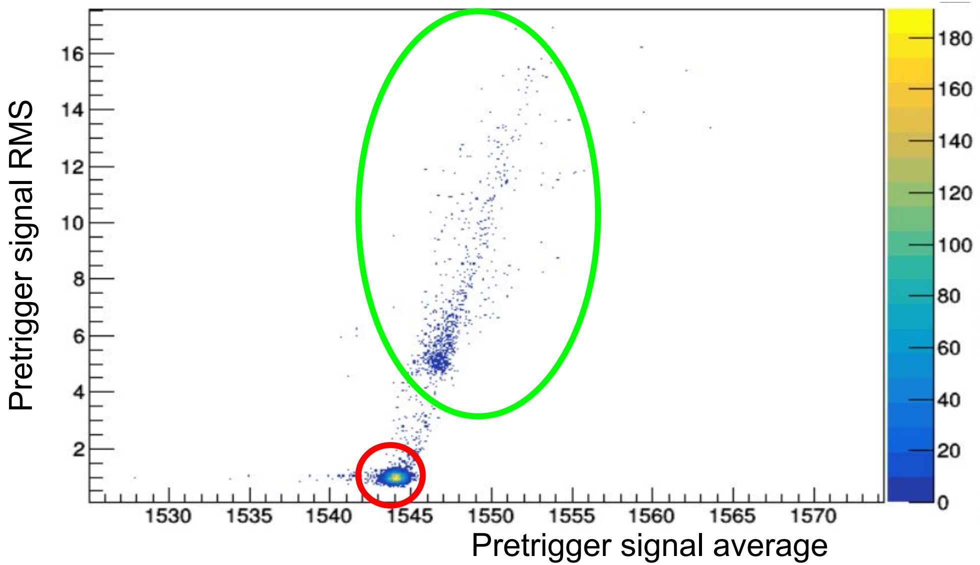


p0(+/-)	0.019(0.014)
p1(+/-)	0.66(0.01)
χ^2/ndf	0.40 / 1

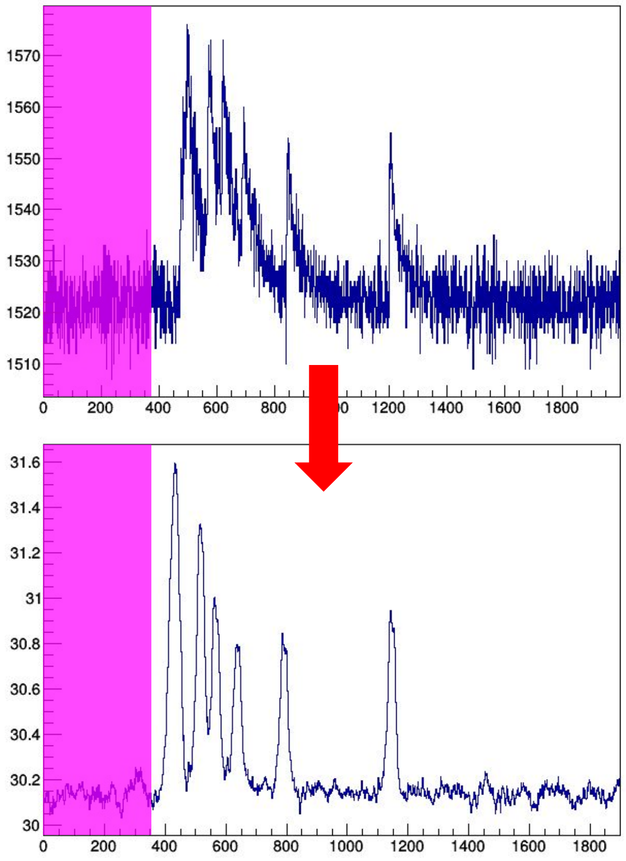
Study of the signal baseline



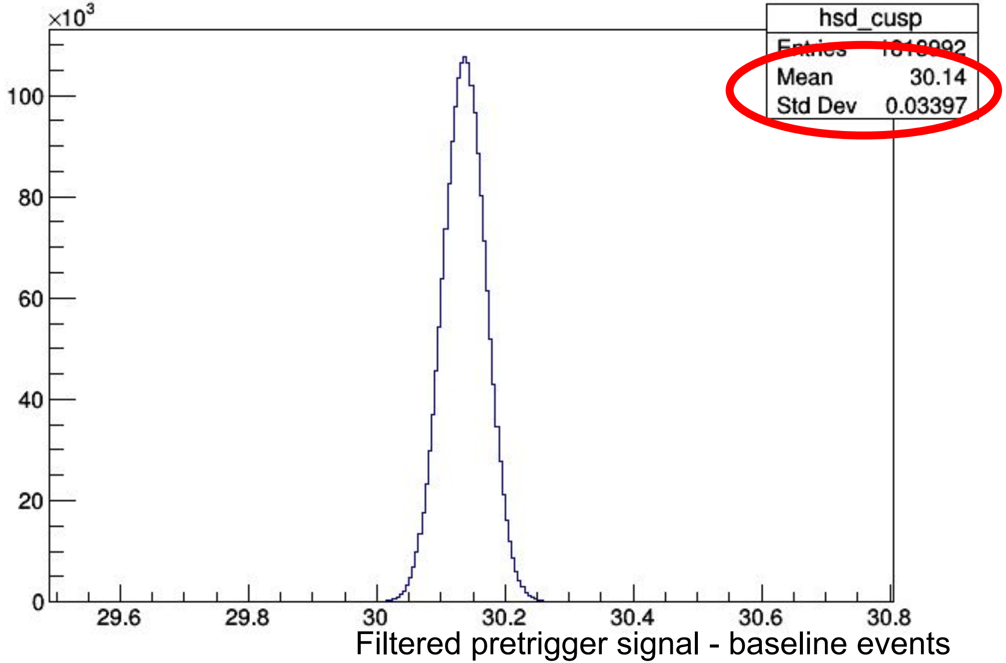
- Only pretrigger (first 400 ticks) is considered
- smoothed (13 ticks-wide moving average) signal distribution is computed, along with its mean and RMS
- mean and RMS are used to classify events as **"baseline"** or **"signal"**



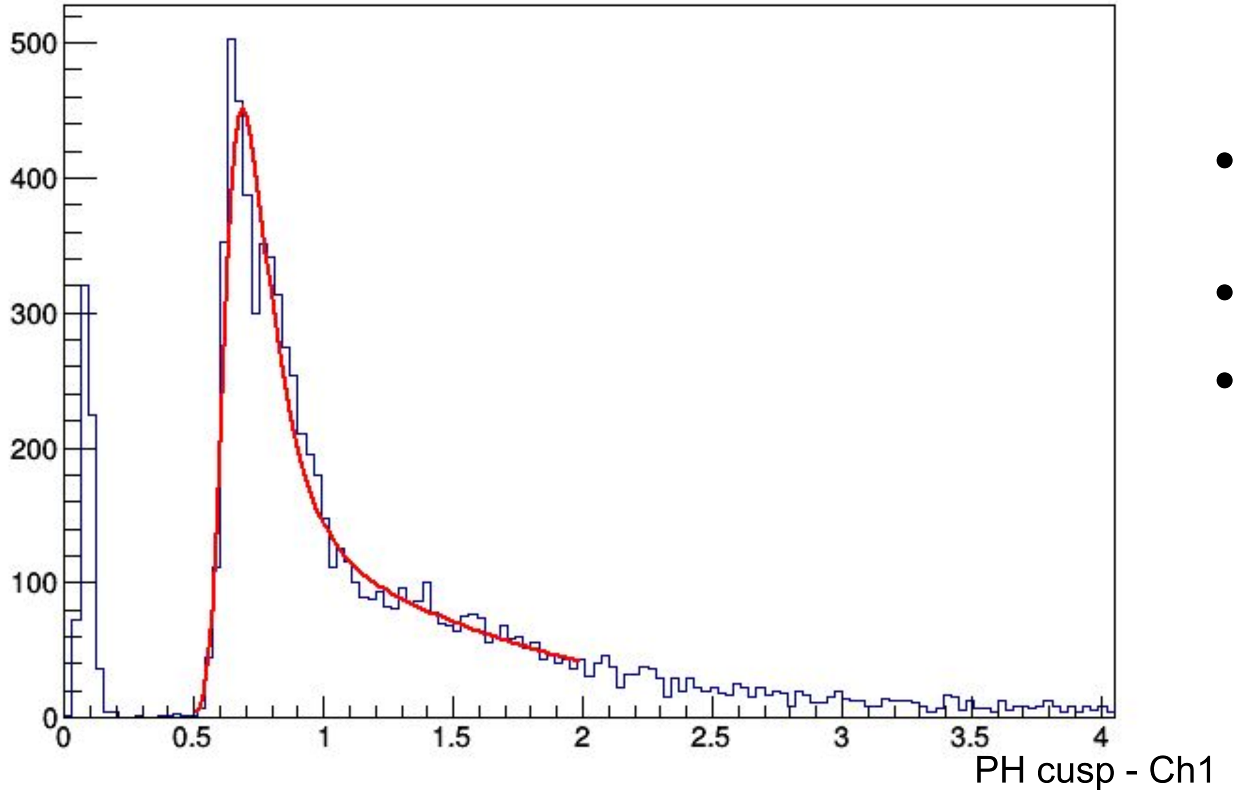
Study of the signal baseline



- The FIR is applied to **“baseline”** events
- filtered signal distribution is computed from these events
- Filtered baseline average and RMS are obtained from this distribution

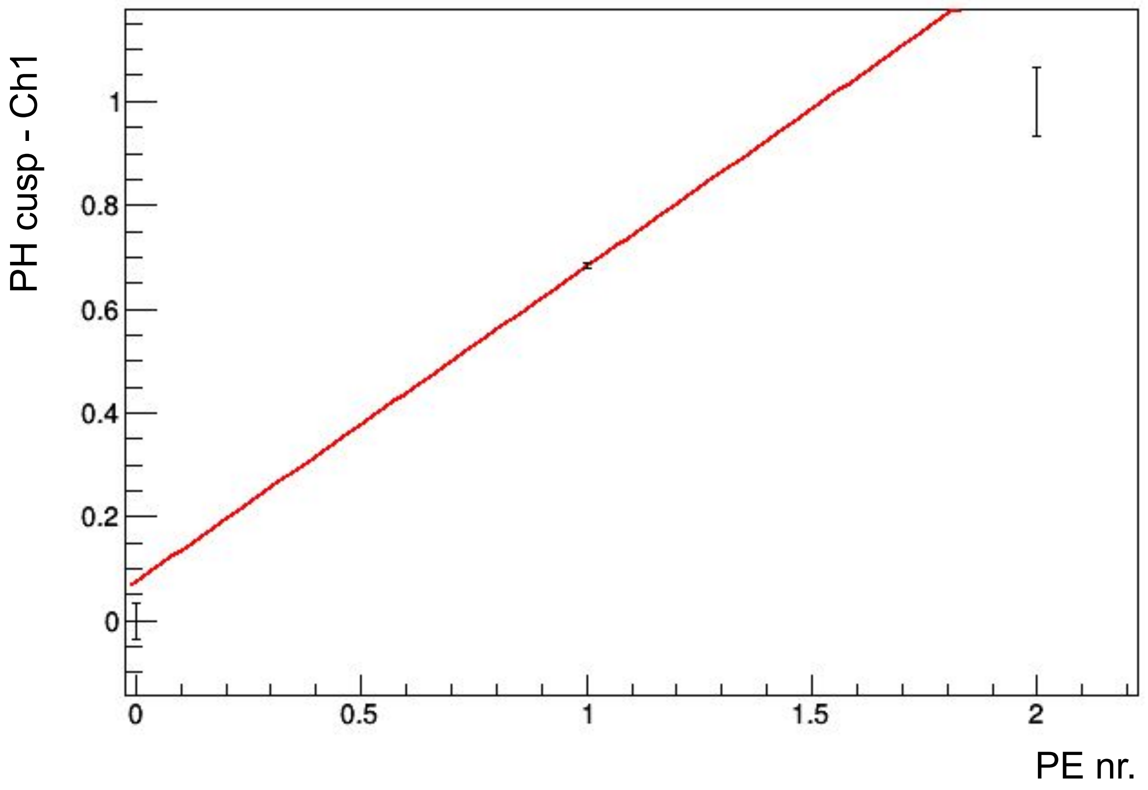


1st calibration attempt: simple landau fit



- Widen the binning, so that the SPE and after-pulse/cross-talk peaks can be fitted as one
- fit the SPE and DPE peaks with a sum of 2 landau functions
- take the most probable value of each landau as the peak position

1st calibration attempt: results



- the 0 PE point is set to 0, with error = sigma of the baseline distribution
- the calibration is clearly not working
- Hypothesis: when conflating it with the after-pulse/cross-talk peak, the SPE peak position is overestimated by a much greater capacity than the DPE peak