Toy Model For Hyperfine Measurement

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Scheme of the Simulation

Scheme of the Monte Carlo Toy for generating the events

Loop from 0 to Ntrials
Inner Loop: from 0 to Repetition

- Definition of LineShape and onset.

- Discretization of the Lineshape (FreqStep)

add a delay (± FreqStep/2)
onset = onset + delay

- Generate Counts for each frequence

- Annihilation on the Walls
- Annihilation Residual Gas
- Cosmic Background

Generate radius for each type of event.

Fill and Save the DataSet.

In this simulation, the data are created and analyzed using *RDataFrame* framework.

A brief introduction about the Monte Carlo

We have developed a Monte Carlo Toy that produces two `.root` dataset files. The variables are columns of values that are shown in the figure below:

Row	runNumber	random.ra	delay.del	frequence	type.type	radius.ra
0	0	0.4849736	2.4987087	-25	2	2.8792768
1	1	0.2899349	-1.685450	15	0	2.0739069
2	1	0.0197818	-1.685450	15	0	1.8959179
3	1	0.2412478	-1.685450	15	0	2.8919173
4	1	0.3846191	-1.685450	15	0	3.3842529
5	1	0.4549068	-1.685450	15	0	1.9130180
6	1	0.3739825	-1.685450	15	0	1.6047382

Figure: Structure of the dataset.

- *runNumber*: identifies which run the event belong to (from 0 to $Repetition - 1$)
- *random*: values uniform distributed from 0 to 1, can be used to randomize the selection or for sub-sampling in the data
- *shift*: store the onset shift
- *frequence*: the frequency of the event
- *type*: type of the event: 0 annihilation on the walls, 1 residual gas annihilation, 2 cosmic event
- *radius*: radius of the annihilation vertex.

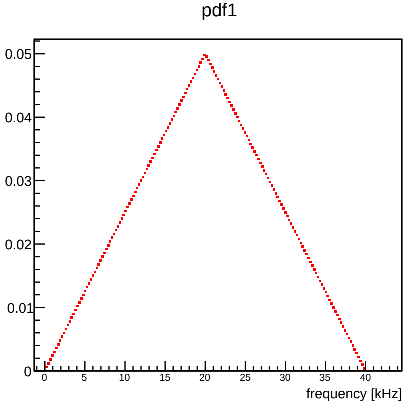
A brief introduction about the Monte Carlo

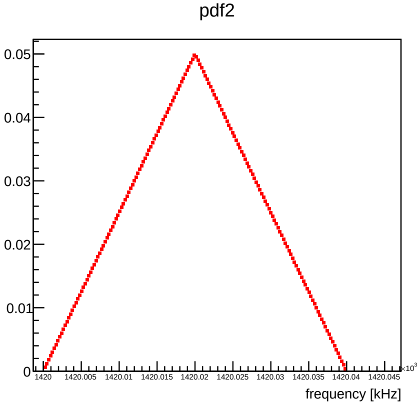
The Annihilation on the walls are generated as function of the frequency, using the two line-shapes of the transitions (c $\rightarrow$ b) and (d $\rightarrow$ a). The Annihilation on the residual gas and the cosmic background are generated uniformly on the frequency spectrum. The most important parameter of the simulation are listed here:

- N_{stack}: number of stack for each run.
- *NHbar* : number of $\overline{H}$ per single stack.
- *Repetition*: number or time a run is repeated.
- $percentage_{wall}$: percentage of annihilation on walls ($percentage_{res\ gas} = 1 - percentage_{wall}$)
- *TimeStep*: time interval single frequency step.
- *SweepStep*: length of the frequency scan.
- *FrequencyStep*: step in frequency during the scan.
- *CosmicRate*: expected cosmic rate (in s^{-1})

Triangular Line-shape Pdfs

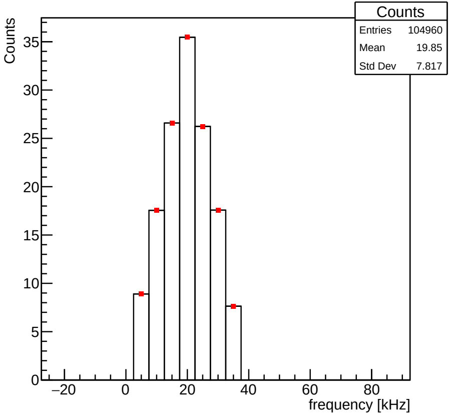
For this first use of the toy, we have chosen simple line-shapes, triangular with a symmetric rise and fall.

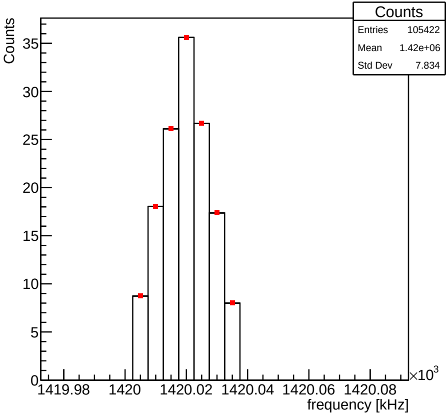




Triangular Line-shapes Simulation

We sample at the given frequency step of 5 kHz the Pdfs, to simulate the experimental line-shapes. We applied the onset finding algorithm to this distribution.



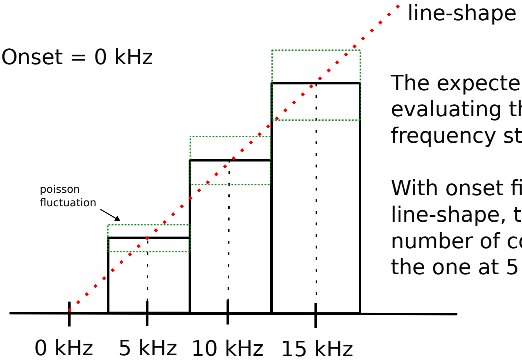


The onset is fixed ad $f = 0\,\text{kHz}$. In this sample the cosmic background is set to zero.

A simple Onset finding Algorithm

The first algorithm that is tested is quite simple: **the onset is identified by the first bin with a content over a given threshold** ($> N\mu_{cosmic}$) [1]

Before showing the plot with the simulated data, it is useful to remind how this algorithm deals with the frequency step:



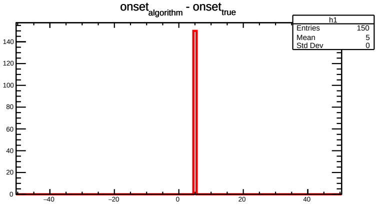
The expected bin content is given evaluating the lineShape at each frequency step (+ 5 kHz, +10kHz ...).

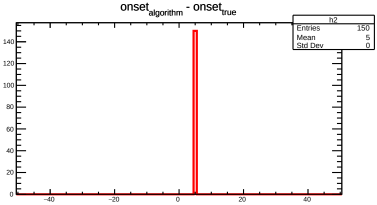
With onset fixed at 0, and a linear line-shape, the first bin with an expected number of counts different from 0 will be the one at 5 kHz (bias).

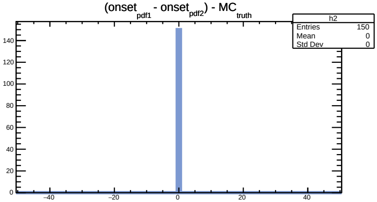
[1] Where the μ_{cosmic} is computed from the Poisson distribution of the cosmic counts expected per bin.

Consistency Check 1

We have tested the algorithm with a dataset without cosmic background and shift fixed to zero. The algorithm identifies the onset at frequency 5 kHz.

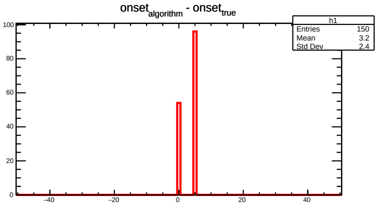


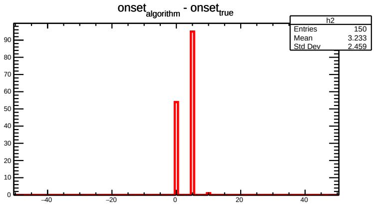


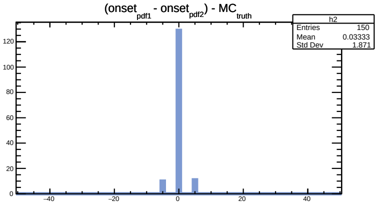


Consistency Check 2

We have tested the algorithm with a dataset without cosmic background. The shift is uniform distributed in $-2.5\,\text{kHz}$ and $2.5\,\text{kHz}$.

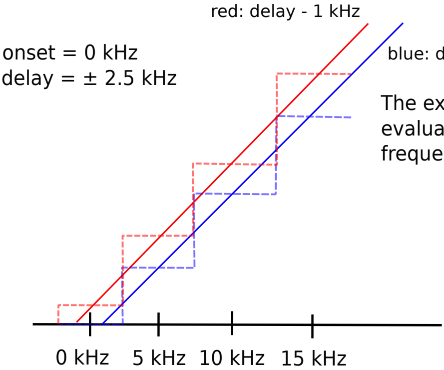






With the shift, two bins ($\textit{frequency} = 0\,\text{kHz}$ and $\textit{frequency} = 5\,\text{kHz}$) are populated.

Consistency Check 2



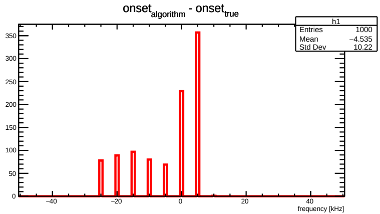
The expected bin content is given evaluating the lineShape at each frequency step (+ 5 kHz, +10kHz ...).

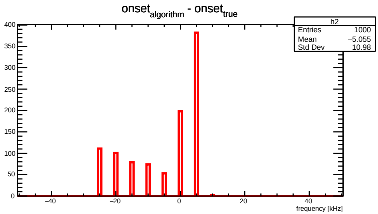
The frequency step are fixed, and the lineshape is shifted accordingly to the extracted value of the shift. In few words:

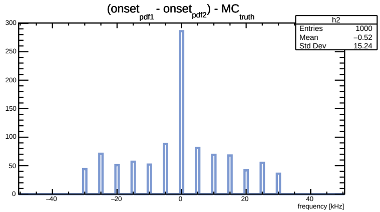
- step 1): fix the frequency steps (the frequency effectively used in the experiment)
- step 2): define the new value of the onset adding a uniform distributed shift
- step 3): shift the lineshape accordingly to the new value of the onset, discretize the lineshape and proceed with the generation of the data.

algorithm test: threshold $> 3\mu_{cosmic}$

In this case, we have applied the algorithm to simulated data with cosmic background (using a rate of $0.051\,\frac{event}{s}$, from passcut1). Each bin has an expected cosmic background of $dwelltime \cdot rate = 0.408$. The shift is uniform distributed in -2.5 kHz and 2.5 kHz.

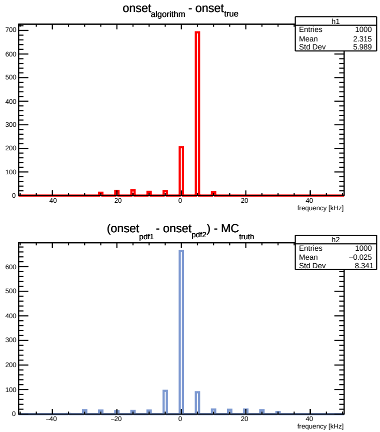






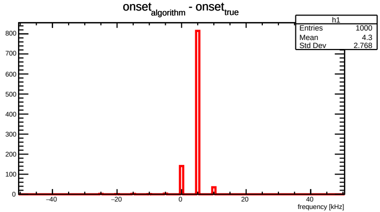
algorithm test: threshold $> 5\mu_{cosmic}$

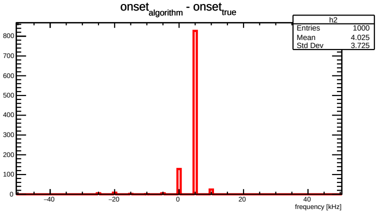
In this case, we have applied the algorithm to simulated data with cosmic background (using a rate of $0.051 \frac{event}{s}$, from passcut1). Each bin has an expected cosmic content of $dwelltime \cdot rate = 0.408$. The shift is uniform distributed in -2.5 kHz and 2.5 kHz.

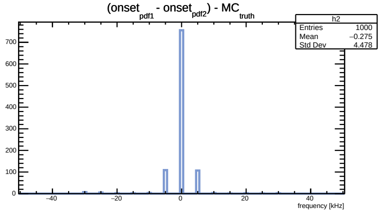


algorithm test: threshold $> 8\mu_{cosmic}$

In this case, we have applied the algorithm to simulated data with cosmic background (using a rate of $0.051\,\frac{event}{s}$, from passcut1). Each bin has an expected cosmic content of $dwelltime \cdot rate = 0.408$. The shift is uniform distributed in -2.5 kHz and 2.5 kHz.







Improvements of the week (30/11 - 07/12)

- Implemented the onset-finding algorithm of 2017 ($first > 0, second > 1$)
- Simulation with a lineShape following the `run 69373` (lineShape with high statistics).
- Implementation and test of different onset finding algorithms.

Fit to the data of run 69373

The lineShape is fitted using a Cruijff function, which takes into account the asymmetry of the left-right tails, $(model = N \cdot exp(\frac{-(x-x_0)^2}{2\sigma_{0,1}+k_{0,1}(x-x_0)^2}))$

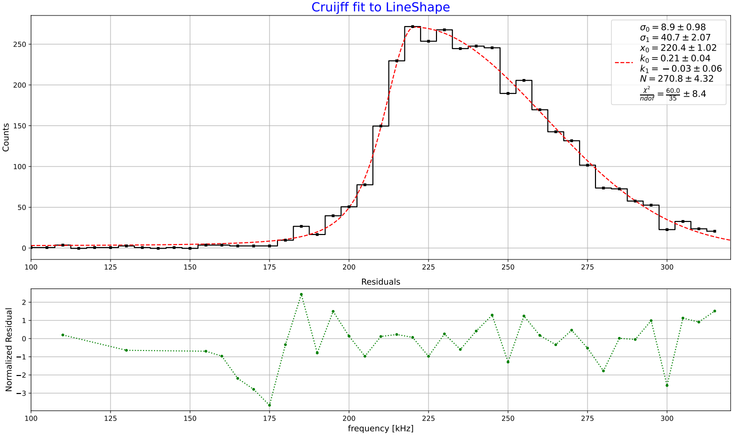
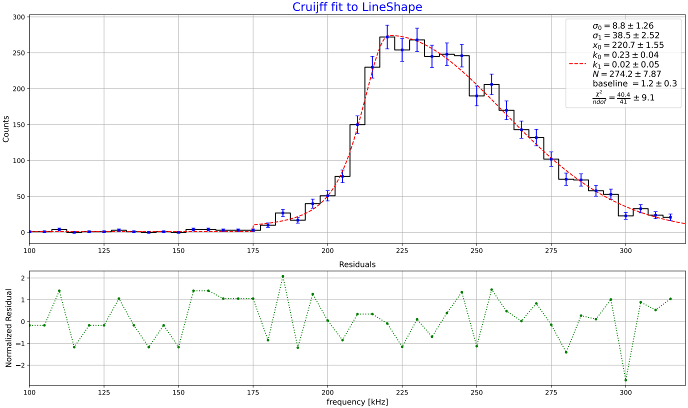


Figure: On top plot, the black line represents data and the red line the fit with the Cruijff function.

The Cruijff function is used in the simulation to generate the data. **The Cruijff is truncated at $f_0 = 175\,\text{kHz}$.** In this way the onset of the lineshape is unambiguously determined. The new model is:

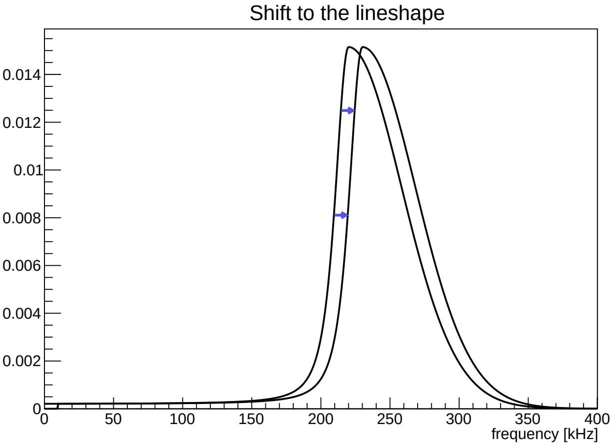
$$model = \begin{cases} baseline & f \leqslant 175\,\text{kHz} \\ N \cdot exp(\frac{-(x-x_0)^2}{2\sigma_0 + k_0(x-x_0)^2}) & 175\,\text{kHz} < f \leqslant x_0 \\ N \cdot exp(\frac{-(x-x_0)^2}{2\sigma_1 + k_1(x-x_0)^2}) & f > x_0 \end{cases} \tag{1}$$



Is the baseline compatible with the Cosmic Background?

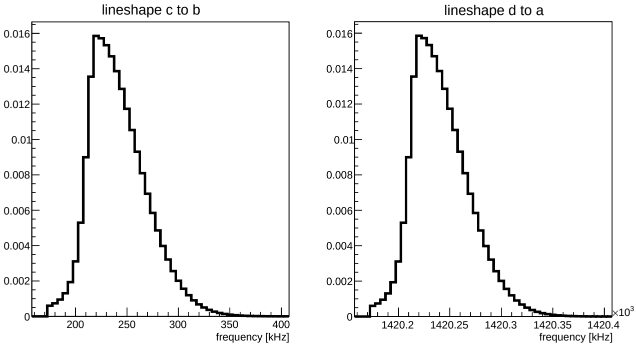
shift of the lineshape

To generate the data, the lineshape is shifted with a uniform distributed random value.



Discretization of the lineshape

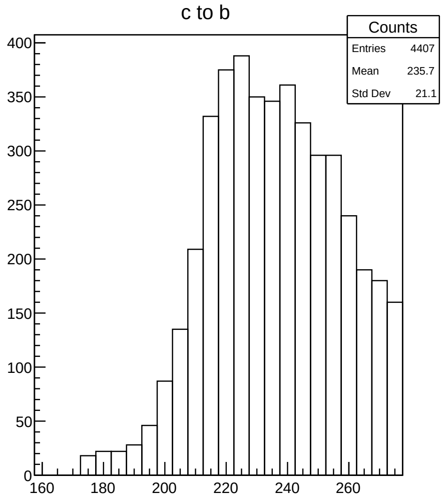
Here we plot the discretized lineshape, obtained sampling the Cruijff function with the optimal parameters by the fit of the previous slide. The lineshape is discretized into a series of 50 points, with a increment step of 5 kHz.

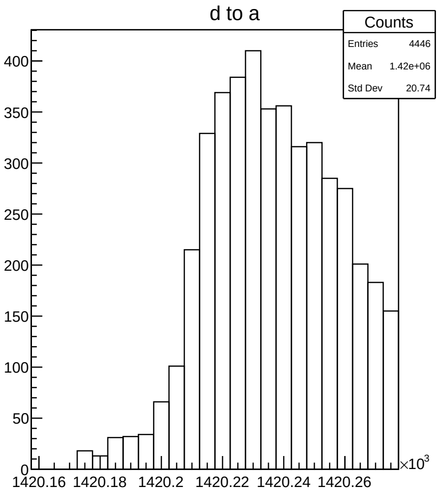


The discretized lineshapes here represents the model which the simulation programs uses to generate the data.

Generate Counts for each frequency

For illustration purposes, in this plot we show the simulated distribution (24 steps) for a single run with an artificially high number of antihydrogen (5000 in the following plot), without adding the cosmic background:





Parameters of the Simulation

We have studies the case of the series of run 4b. The parameters of the simulation are:

- $N_{stack} = 20$.
- $N_{\overline{H}\ per\ stack} = 14$.
- $SweepSteps = 24$.
- $Repetition = 5$ (not yet used in the following).
- $TimeStep = 8\,\mathrm{s}$
- $FrequencyStep = 5\,\mathrm{kHz}$.
- $\mu_{cosmic} = 0.051\,\mathrm{s}^{-1}$
- $onset_{1,true} = 175\,\mathrm{kHz}$; $onset_{2,true} = 1\,420\,175\,\mathrm{kHz}$
- $shift = \pm 2.5\,\mathrm{kHz}$.

The percentage of events of annihilation to residual gas is set to zero. The amount of anti-hydrogen is divided equally for the two transition c-b and d-a.

The first algorithm that we test is the one applied to the data taking of 2017. The onset is exstimated taking the frequence which fulfills the criteria

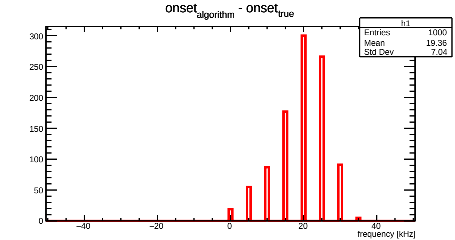
$$f_i : bin(i) > 0; bin(i+1) > 1 \tag{2}$$

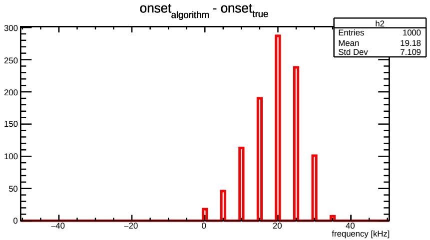
a second version of the same algorithm is implemented, analyzing the frequencies in decreasing order (reversed algorithm):

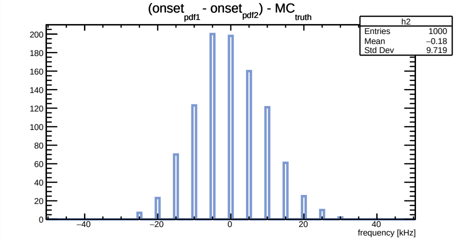
$$f_i : bin(i) < 3; bin(i-1) < 2$$

test 2017 algorithm

The algorithm is tested for $N_{trial} = 1000$.The amount of events per transition is expected to be poissonian distributed with mean $\simeq 130$. In this first scenario the cosmic events are removed from the data.

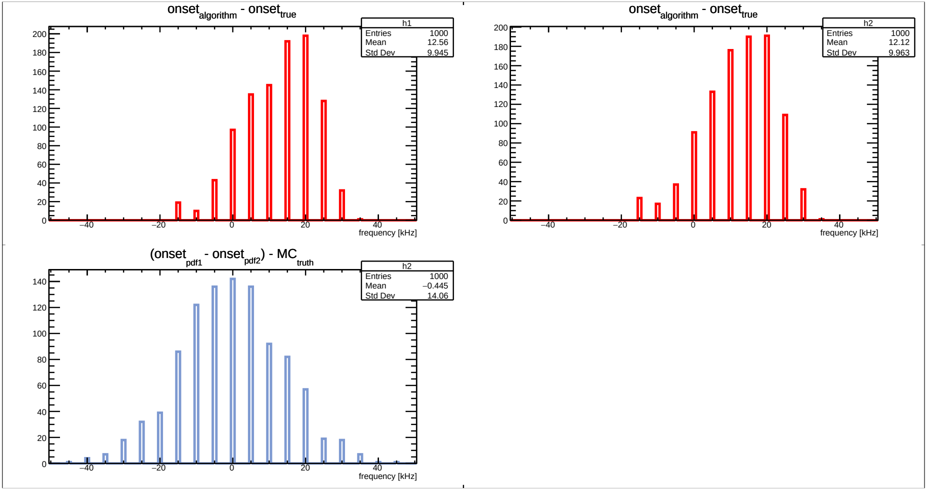






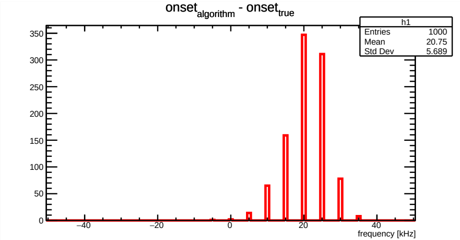
test 2017 algorithm

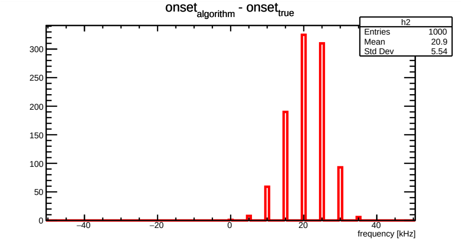
The algorithm is tested for $N_{trial} = 1000$. The amount of events per transition is expected to be poissonian distributed with mean $\simeq 130$. The cosmic background is fixed to 0.41 events per frequence.

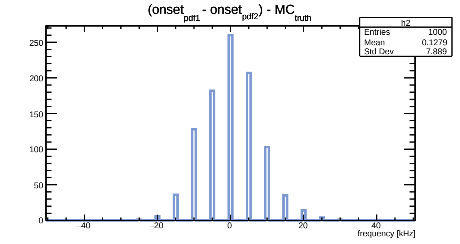


test 2017 algorithm (reversed)

The algorithm is tested for $N_{trial} = 1000$. The amount of events per transition is expected to be poissonian distributed with mean $\simeq 130$. In this scenario the cosmic background is removed.

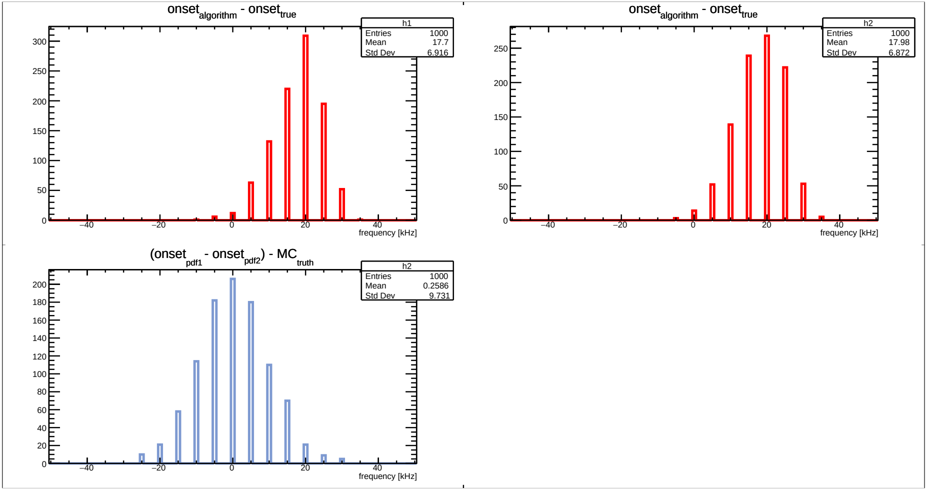






test 2017 algorithm (reversed)

The algorithm is tested for $N_{trial} = 1000$. The amount of events per transition is expected to be poissonian distributed with mean $\simeq 130$. The cosmic background is fixed to 0.41 events per frequence.



Other stategies

We have tested other 2 different algorithms, that can be useful to identify the onset. The first algorithm indetifies the onset ad the first frequency with counts over threshold:

$$f_i : bin_i > Threshold \tag{3}$$

The second algorithms is a constant fraction discriminator. It works similarly to the previous algorithm, except for the fact that the threshold is computed each time as:

$$threshold = p \cdot max\{bin_i\} \tag{4}$$

where p is a parameter of the algorithm, in the range (0,1).
In the end we have tested another algorithm (*sumNeighbors*), defined is this way:

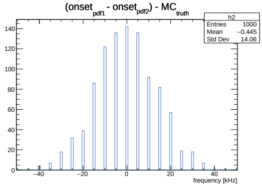
$$f_i : bin_i + bin_{i+1} + bin_{i+2} > 3 \cdot \mu_{cosmic} + \sqrt{3}N \cdot \sqrt{\mu_{cosmic}} \tag{5}$$

Where N is a parameter of the algorithm. This algorithm is directly derived from the t-student test.

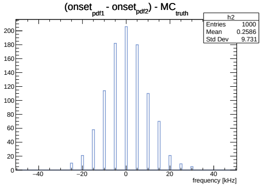
Results

algorithms	μ [kHz]	σ [kHz]	μ [kHz]	σ [kHz]
	without cosmic background		with cosmic background	
2017 ($> 0; > 1$)	-0.18	9.7	-0.445	14.1
2017 reversed ($< 2; < 1$)	$+0.13$	7.89	$+0.25$	9.73
threshold (> 1)	$+0.025$	11.5	$+0.005$	16.72
threshold (> 2)	-0.06	9.56	$+0.67$	14.1
threshold (> 3)	-0.1	7.48	-0.07	9.96
const. fraction ($p = 10\%$)	-0.02	11.56	$+0.19$	16.66
const. fraction ($p = 20\%$)	-0.215	9.05	$+0.55$	13.06
const. fraction ($p = 30\%$)	$+0.08$	7.43	$+0.05$	8.84
sumNeighbors ($N = 1$)	$+0.01$	9.47	$+0.055$	13.03
sumNeighbors ($N = 2$)	-0.425	8.83	$+0.005$	12.69
sumNeighbors ($N = 3$)	-0.47	7.85	$+0.115$	11.66

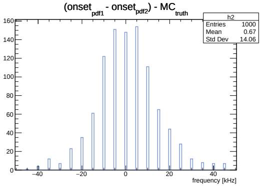
Table: Result of the simulation for $N_{trials} = 1000$. In the first two column the cosmic background is removed from the data. The last two columns contains the result of the simulation adding the cosmic background. The μ and σ are the quantities computed from the distribution of $(onset_2 - onset_1) - MC_{truth}$.



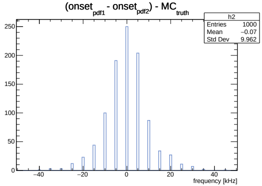
(a) *algorithm 2017*



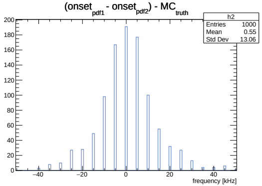
(b) *algorithm 2017 reversed*



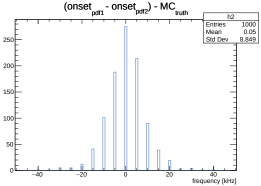
(c) *threshold* (> 2)



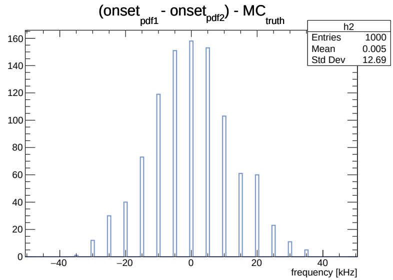
(d) *threshold* (> 3)



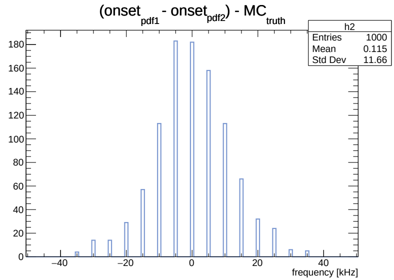
(e) *const fraction* ($> 20\%$)



(f) *const fraction* ($> 30\%$)



(g) *sumNeighbors* $(N > 2)$



(h) *sumNeighbors* $(N > 3)$

Next steps

- Add to the simulation the magnetic field drift
- Systematic studies of the relative shape asymmetry for the two transitions and its effect on the onset determination.