'Is there anybody in there?'

Federico Virzi on behalf of LNGS group

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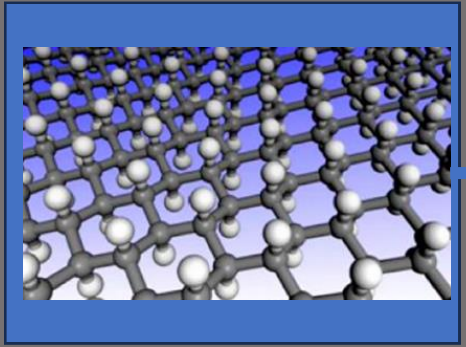
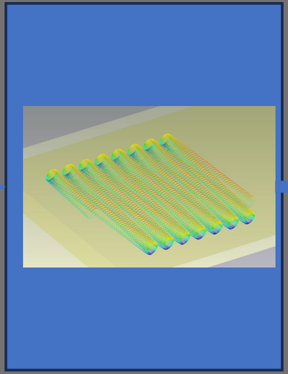
Introduction: PTOLEMY RF region

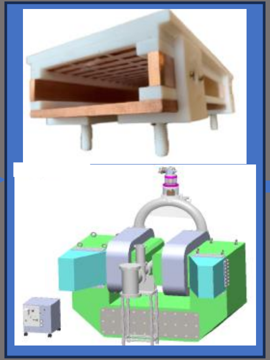
Tritium target



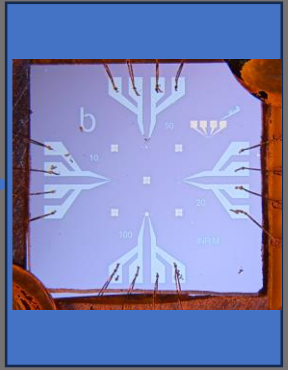
RF region

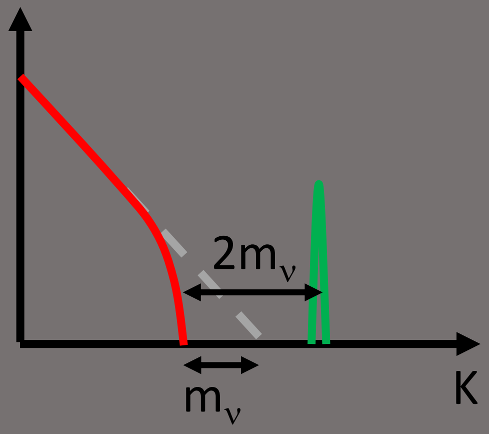


Filter



TES



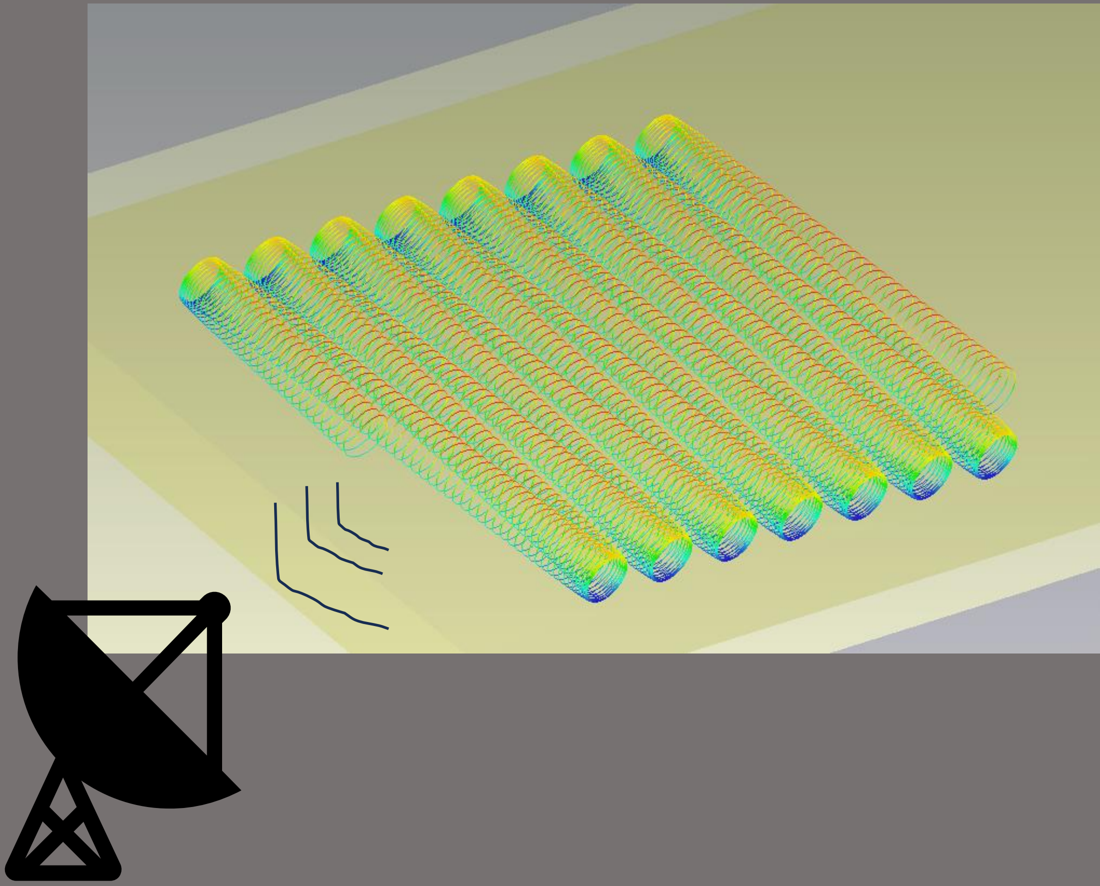


Filter trigger
K and Θ, fast and rough measurement

Energy Drain
+filter

σ_K=50 meV

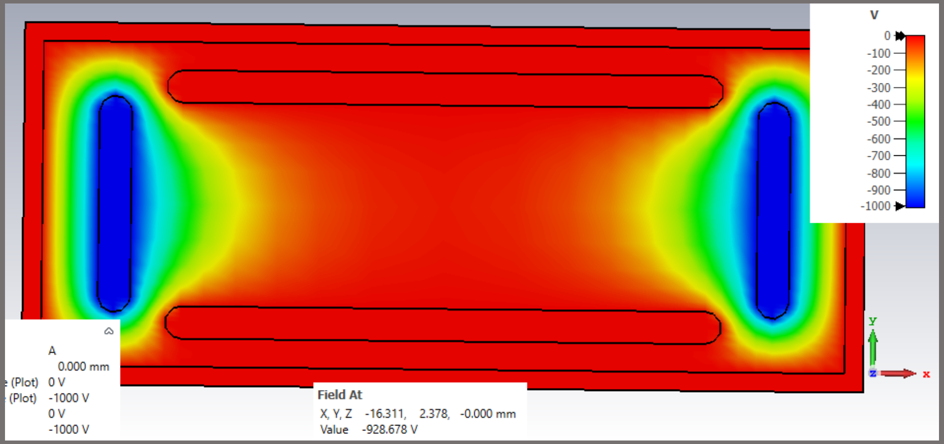
Electron Trap goals

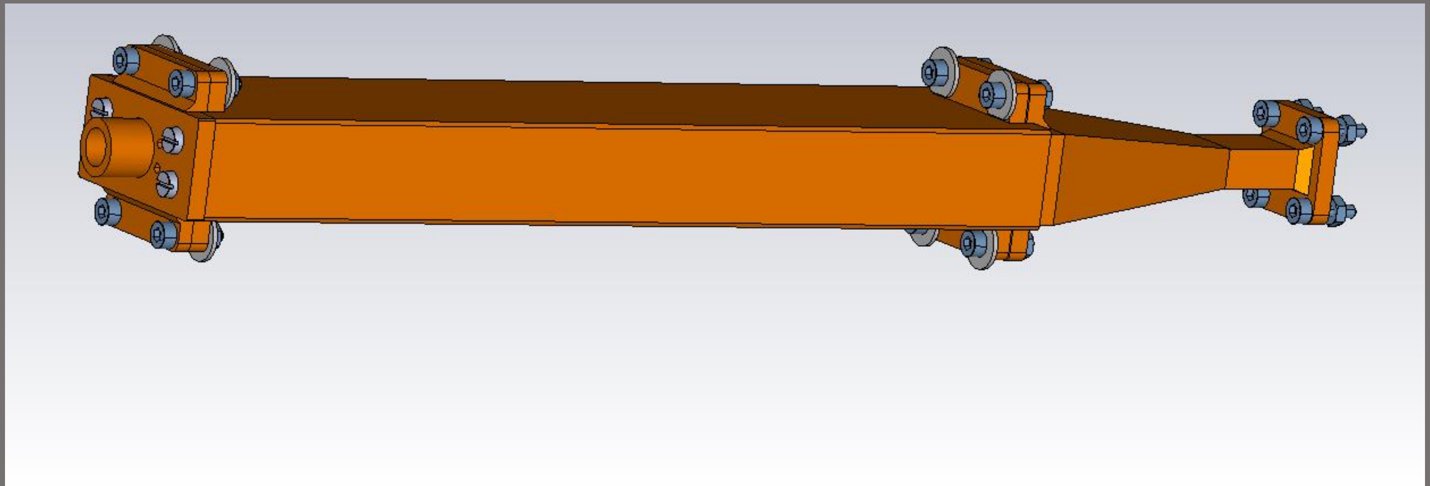


- Study RF pattern of electrons in bouncing motion
- Reconstruction of K, K_L by f_c and T_b
- σ_E and T_{obs} = O(drift time) ?
- What could be a good range of pitch angle in PTOLEMY RF Region?

Electron Trap concept

- We need to design a test setup ->electron trap
- Rectangular waveguide (for RF collection) with inside electrodes (ptolemy-like electron motion)



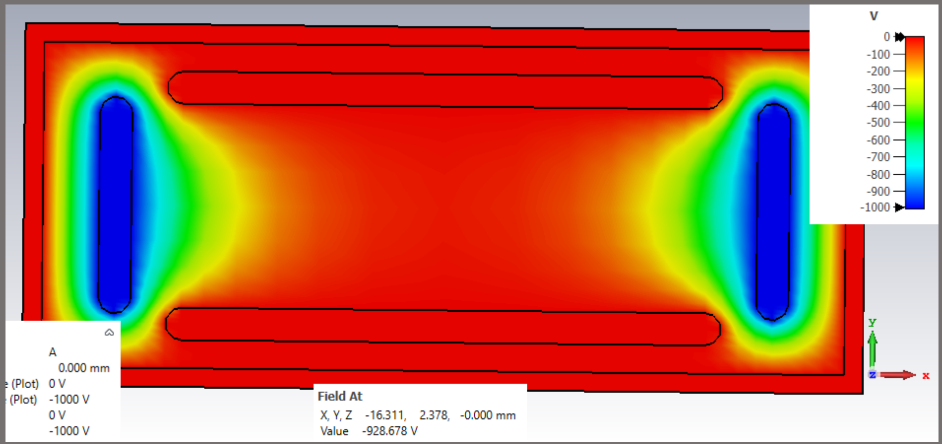


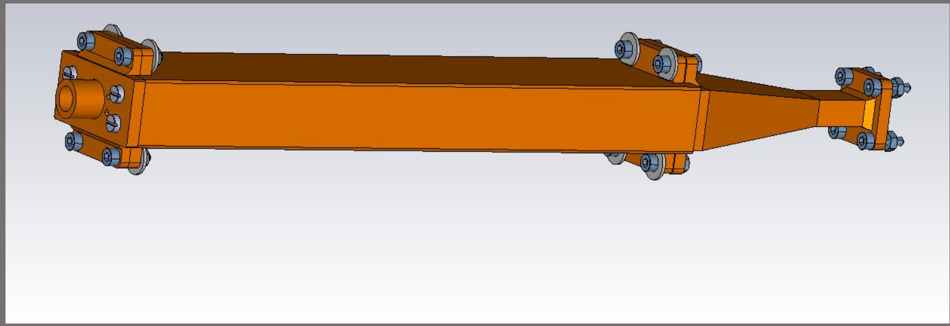
Electron trap: state of art

1. Electron trap design — Naples meeting
2. Electron trap simulation
3. Identify K, K_L reconstruction method from f_c, T_b
4. Design of Test Setup

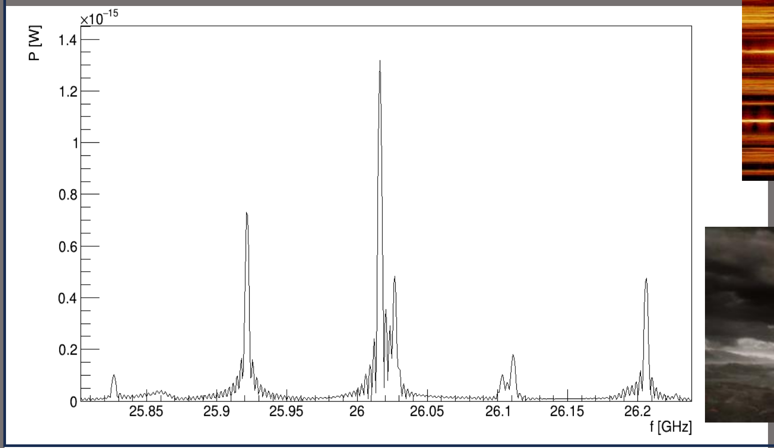
LNGS meeting (items 2–4)

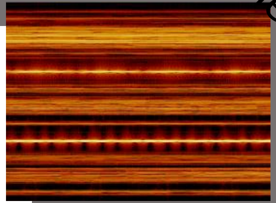
5. Assembly of electron trap test setup — Pollica meeting



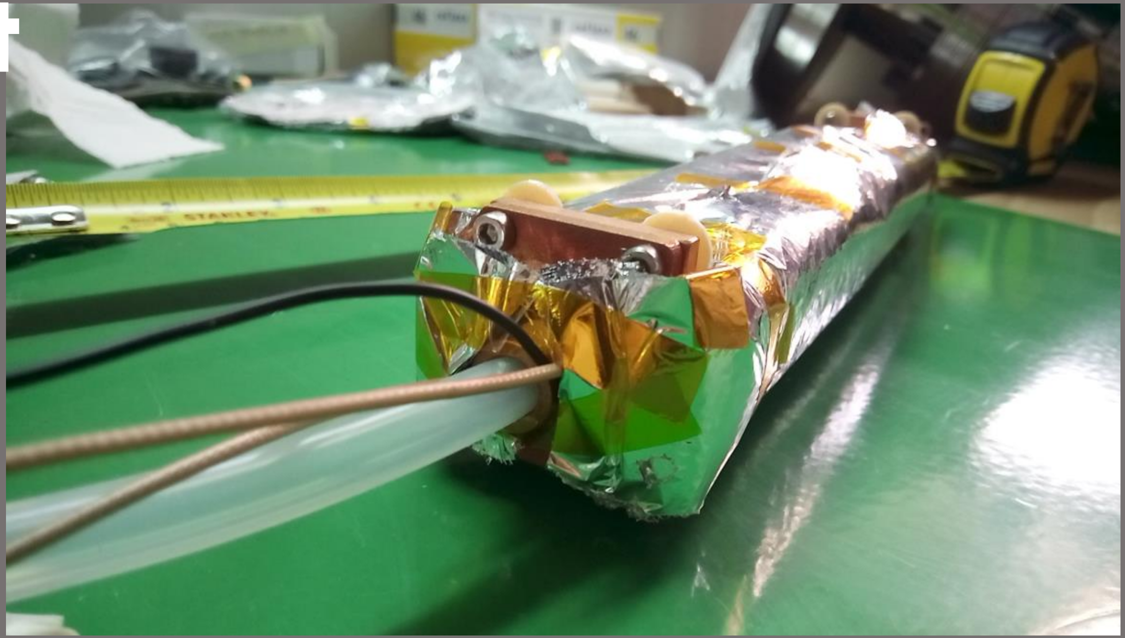


LNGS meeting





Electron trap: state of art

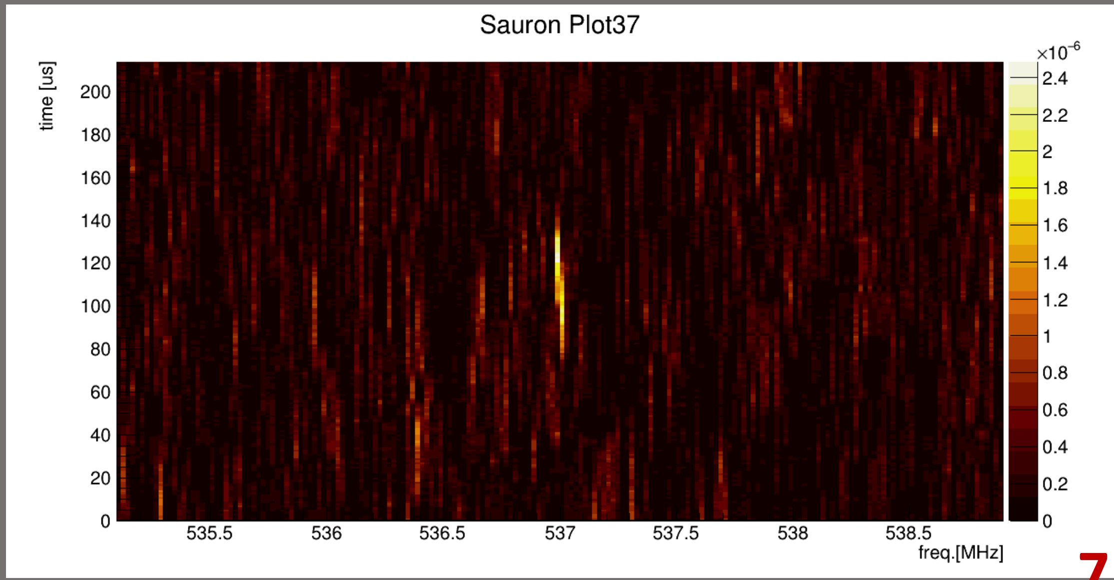


1. Electron trap design — Naples meeting
2. Electron trap simulation
3. Identify K, K_L reconstruction method from f_c, T_b
4. Design of Test Setup

(Items 2–4: LNGS meeting)

5. Assembly of electron trap test setup — Pollica meeting
6. Data taking: phase 1
7. Data taking: phase 2

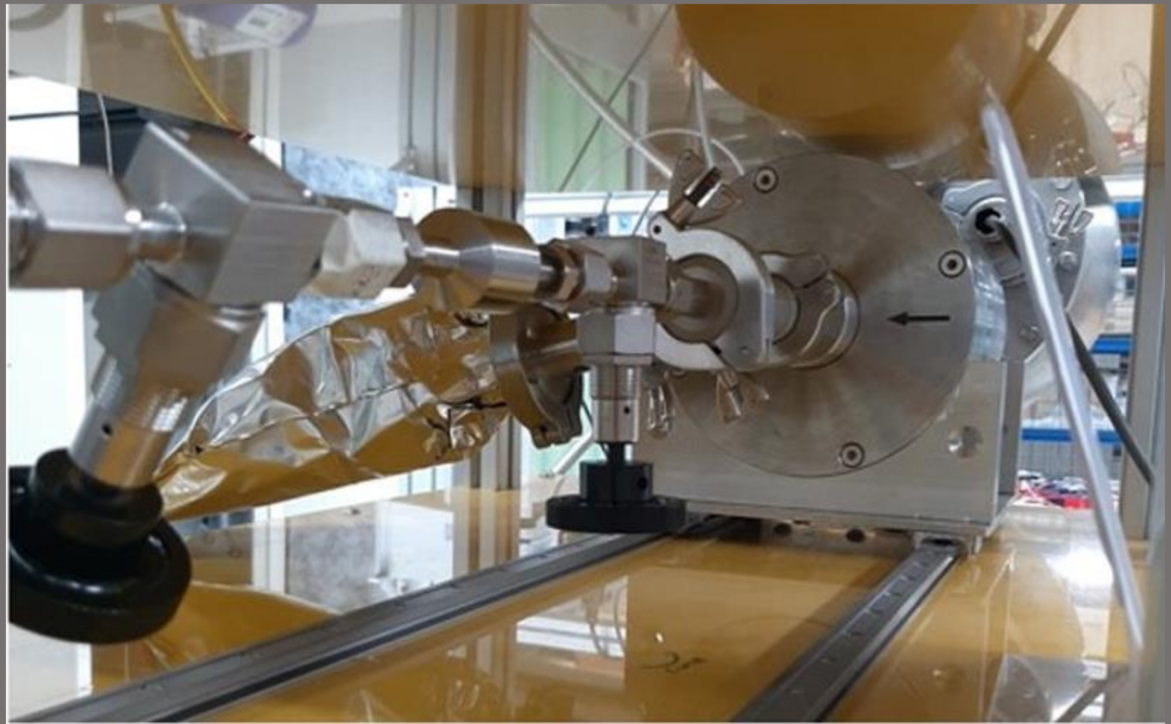
(Items 6–7: Genova meeting)



The Krypton source

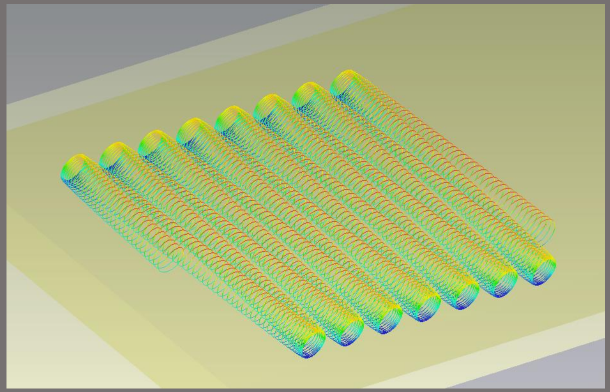
τ_{Kr}=158.1min
Main lines:

L=30.4keV
M=31.9keV



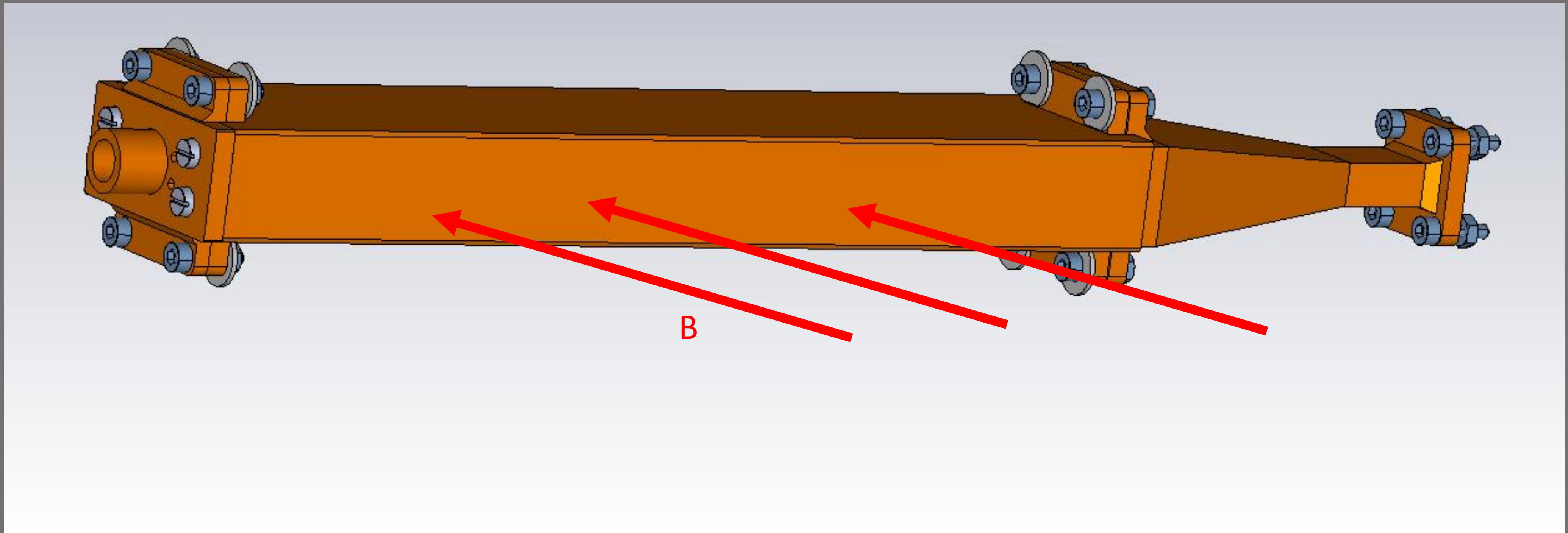
Line	K [eV]	BR [%]
K	17824.2(5)	24.8(5)
L1	30226.8(9)	1.56(2)
L2	30419.5(5)	24.3(3)
L3	30472.2(5)	37.8(5)
M1	31858.7(6)	0.249(4)
M2	31929.3(5)	4.02(6)
M3	31936.9(5)	6.24(9)
M4	32056.4(5)	0.0628(9)
M5	32057.6(5)	0.0884(12)
N1	32123.9(5)	0.0255(4)
N2	32136.7(5)	0.300(4)
N3	32137.4(5)	0.457(6)

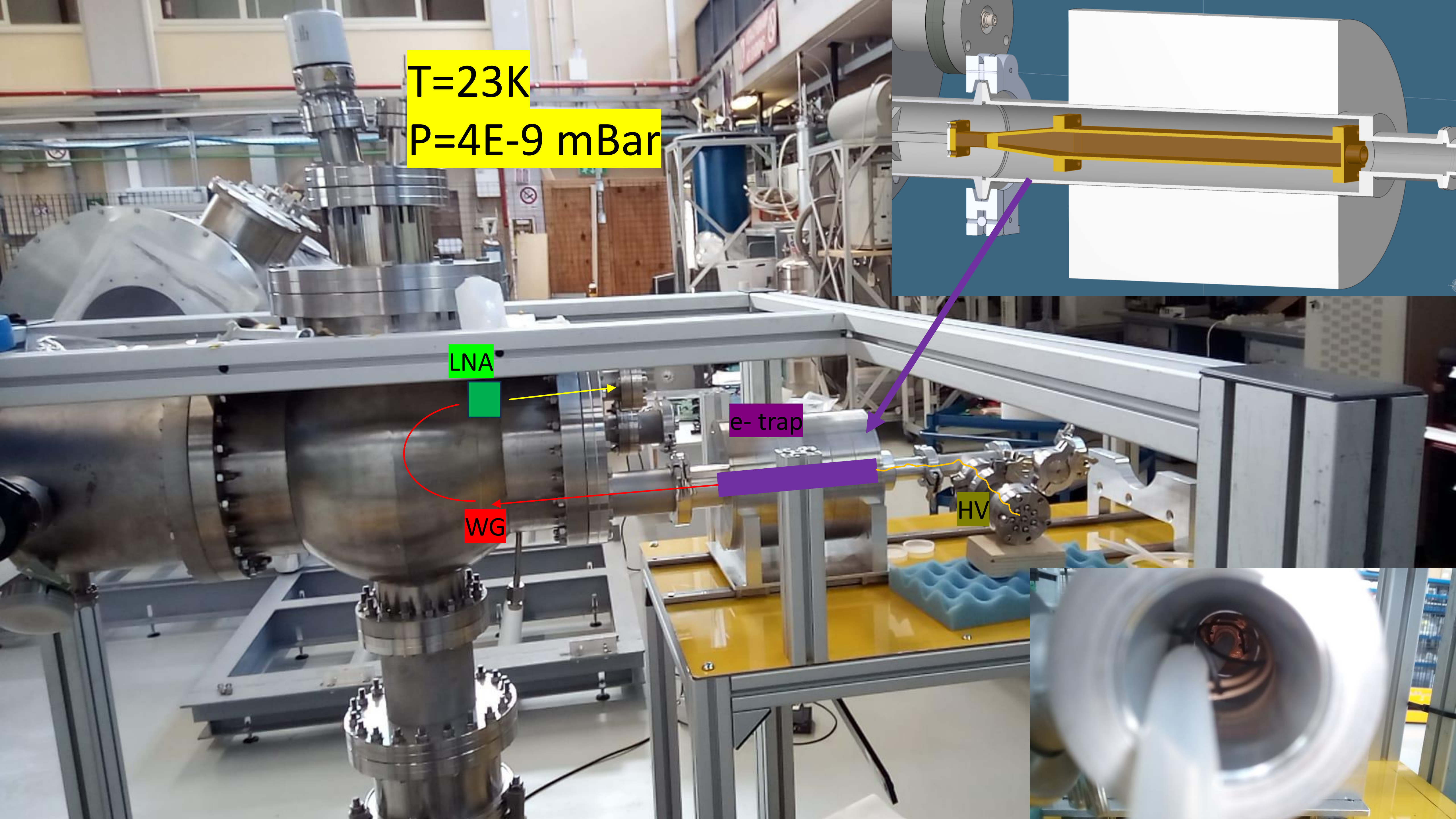
Electron Trap: 3D Geometry



- Rectangular WG (37x15) mm with inside bouncing electrodes
- Left: Kr source inlet
- Right: RF readout

- Inside:
  electron in cyclotron motion+ bouncing motion+ Z drift

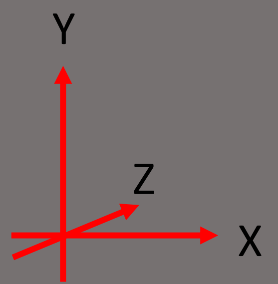


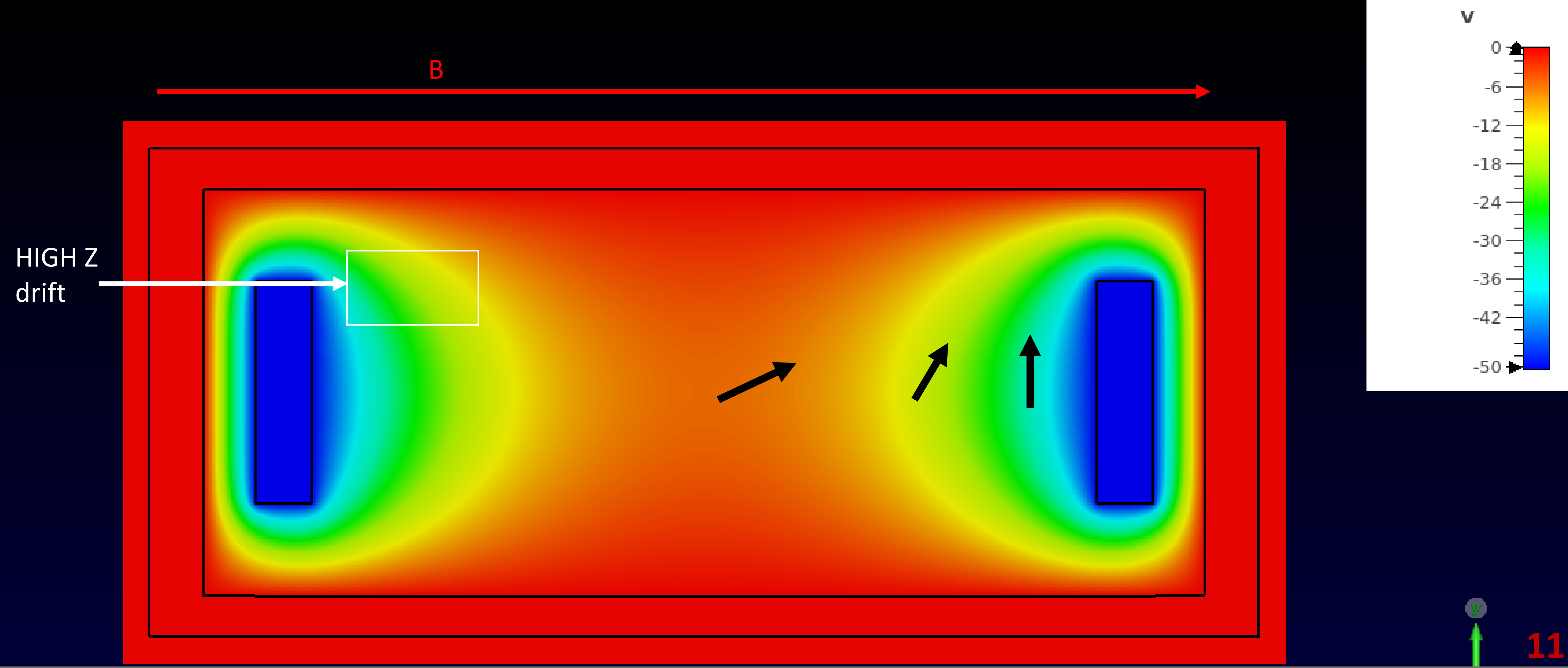

T=23K
P=4E-9 mBar
LNA
e- trap
HV
WG

Electron motion in electron Trap

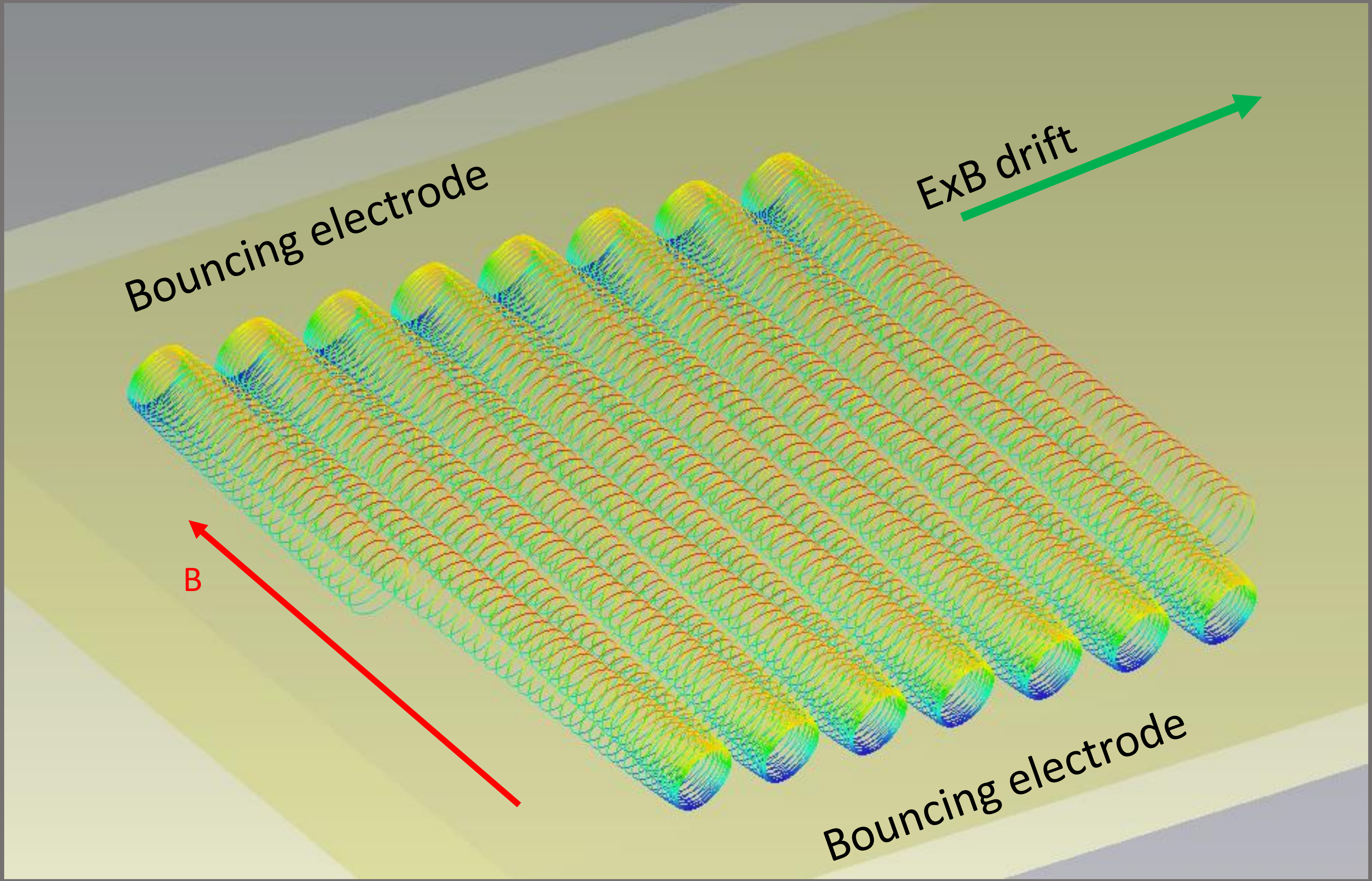
- $V_z = E_y/B$
- Potential well
- $V_z = V_z(y)$
- Pitch angle acceptance

NO Y drift





Motion: cyclotron + bouncing + Z drift (snake-like GCS trajectory)



Electron RF emission

$$f_c = \frac{1}{2\pi}\frac{|q|B}{m}\frac{1}{K/m+1}$$

During the motion: cyclotron emission in potential well

↓

K variation

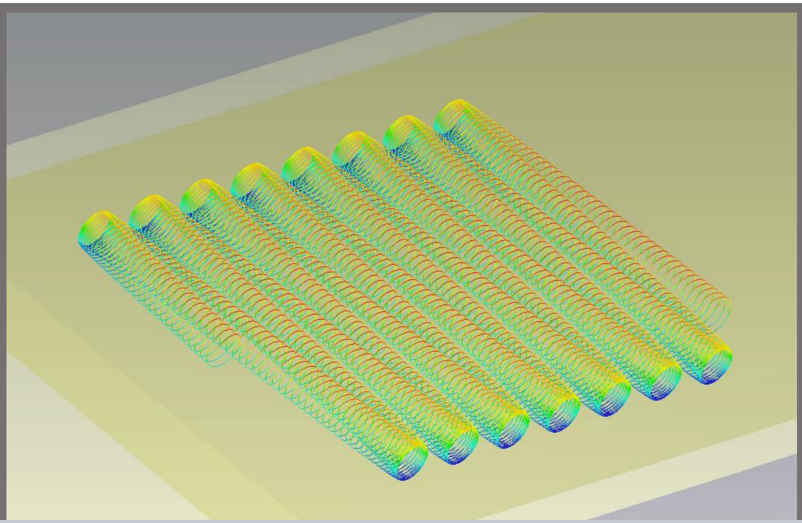
↓

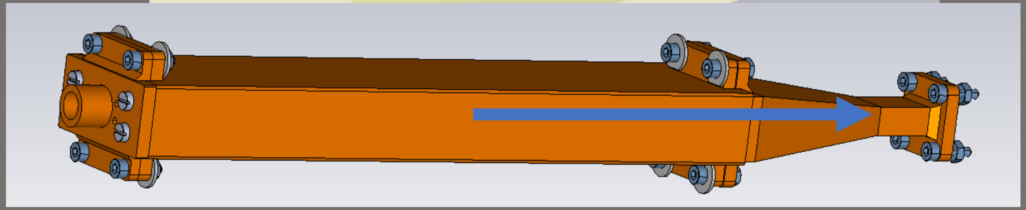
Frequency variation

↓

Measure <K> → Non trivial frequency pattern

$$P = \frac{1}{4\pi\epsilon_0}\frac{2q^2\omega_0^2}{3c}\frac{p_\perp^2/E^2}{1-p^2/E^2}$$

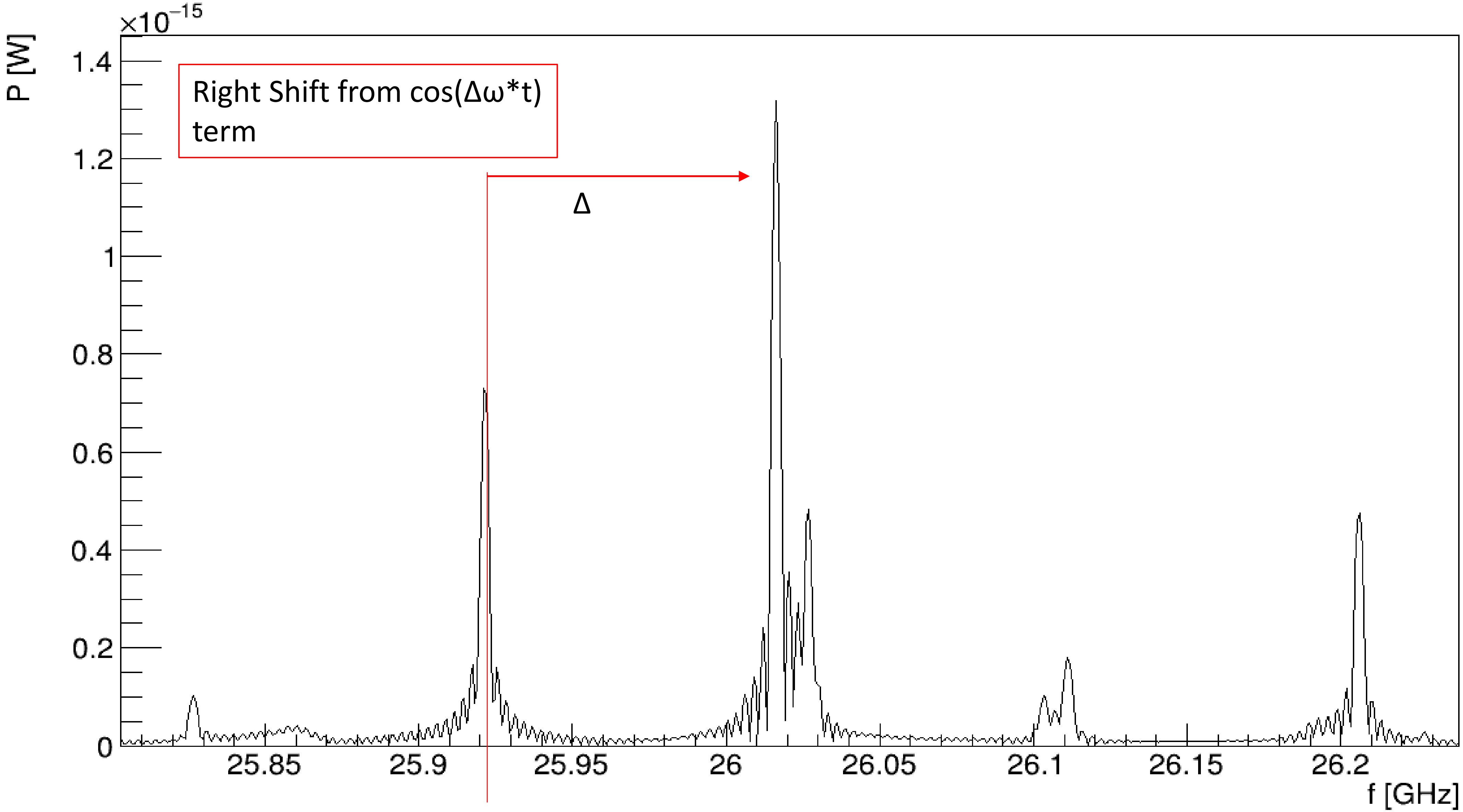




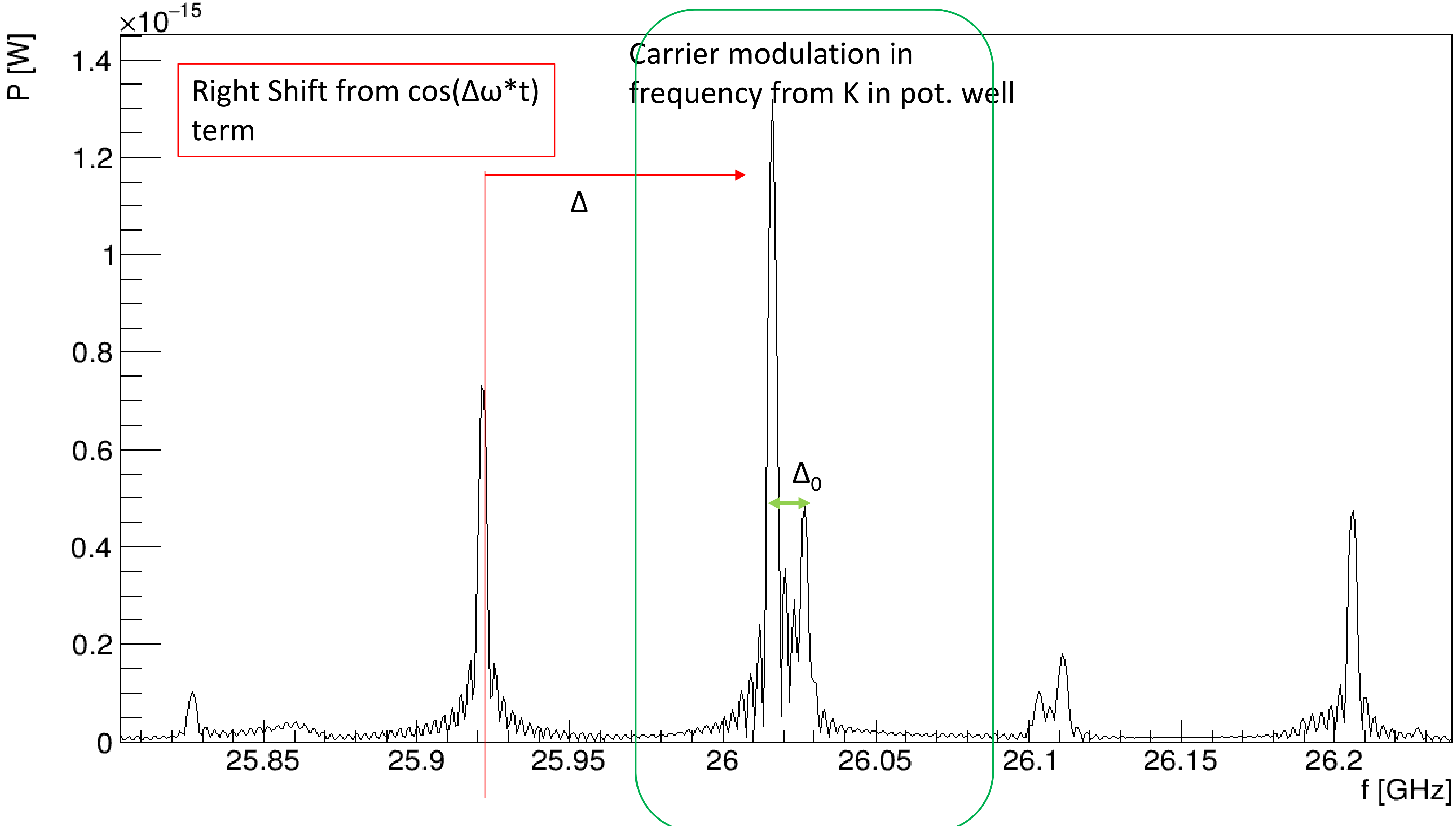
f=26GHz

P=2fW

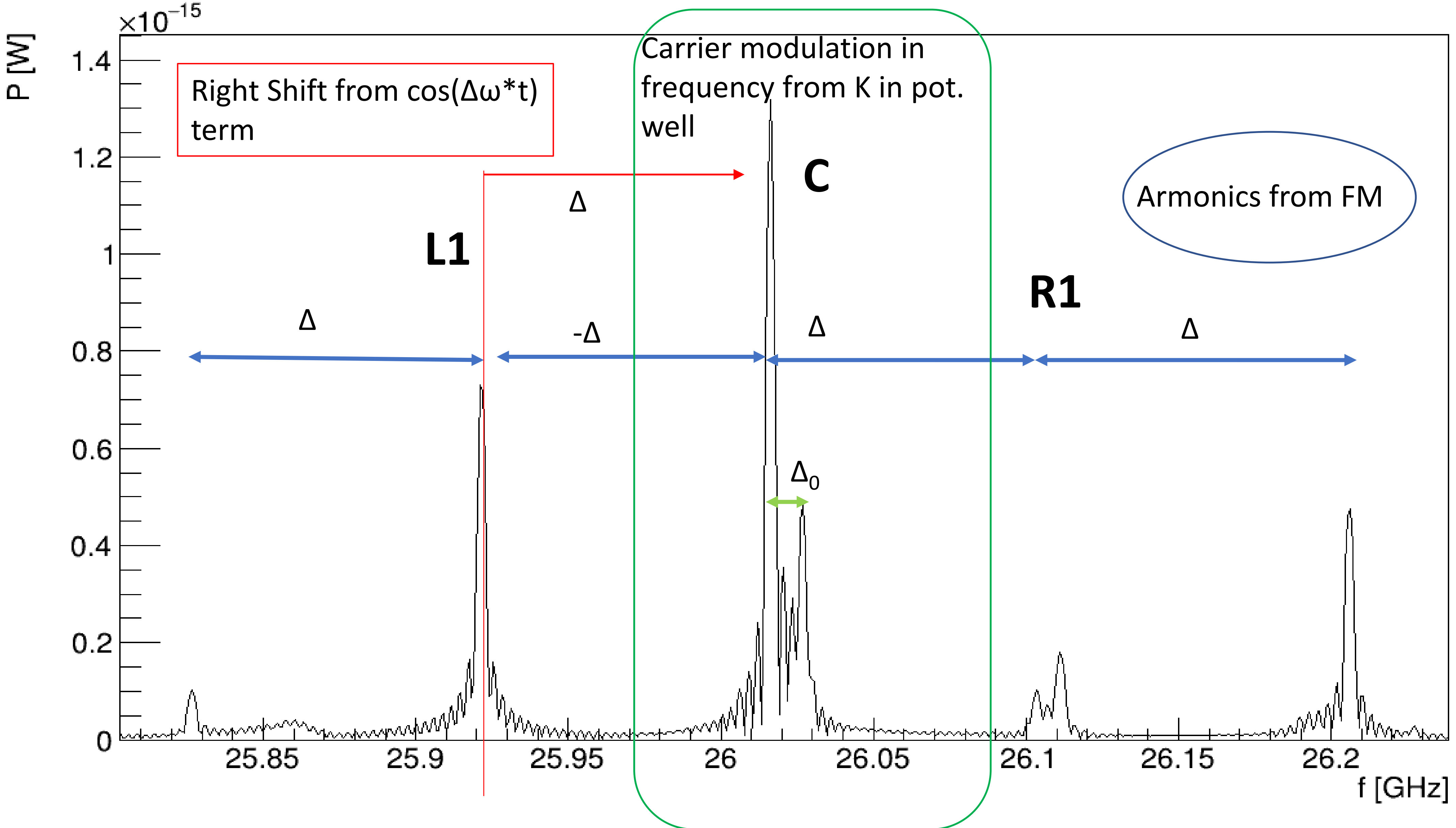
Simulation of single electron emission



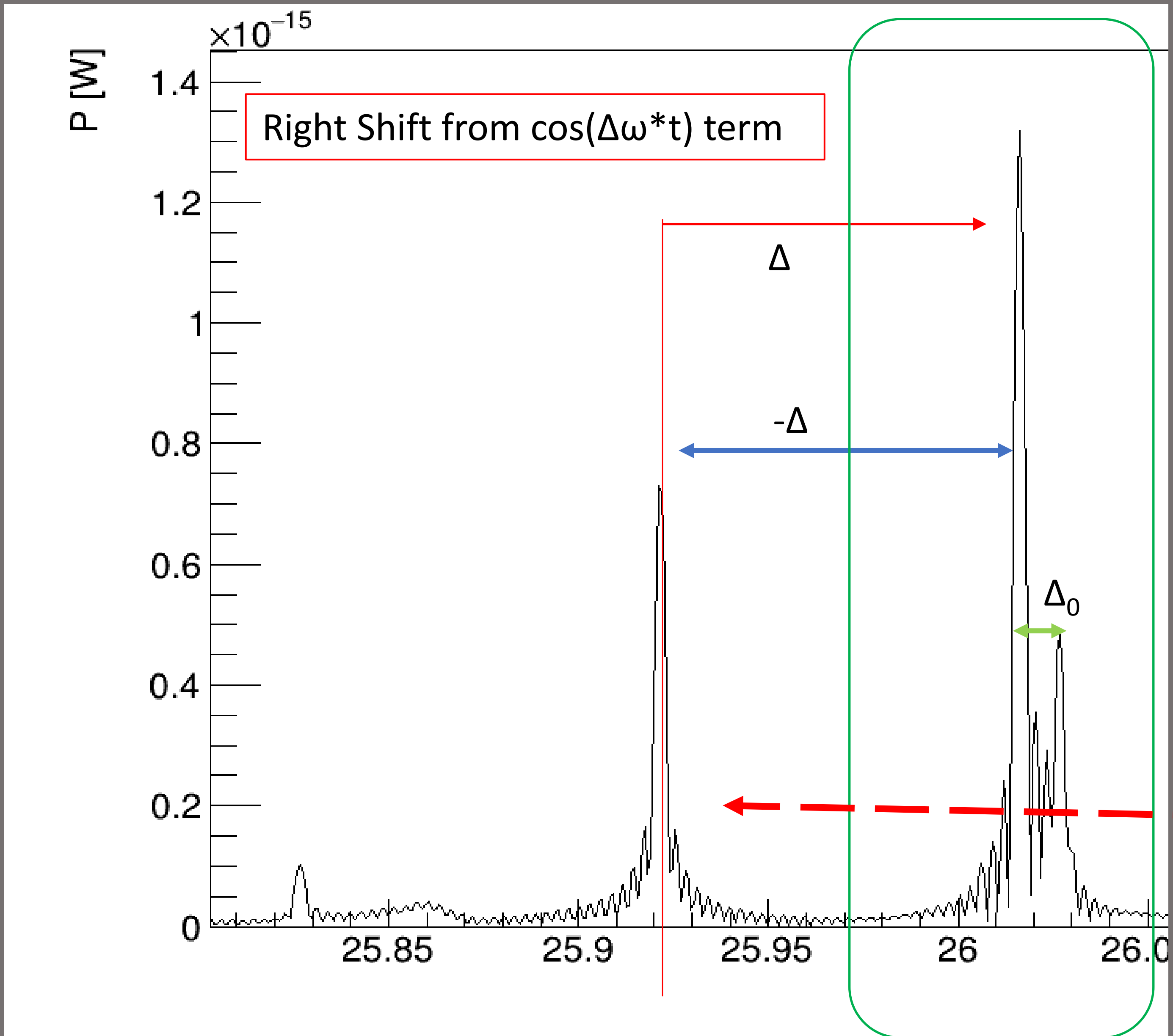
Simulation of single electron emission

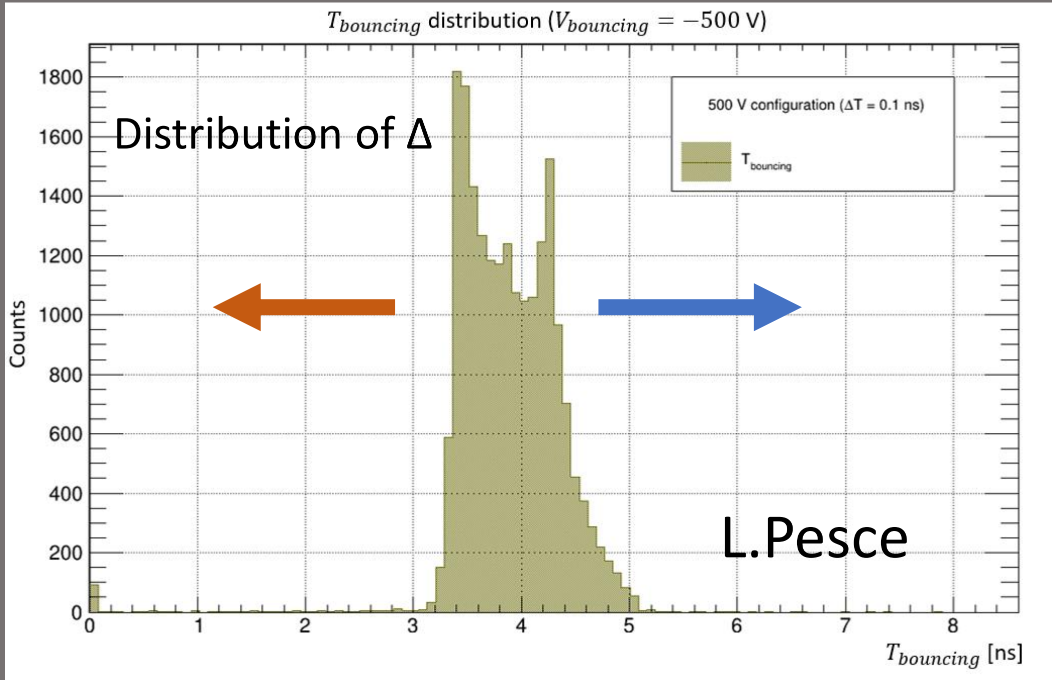


Simulation of single electron emission



Montecarlo pattern RF



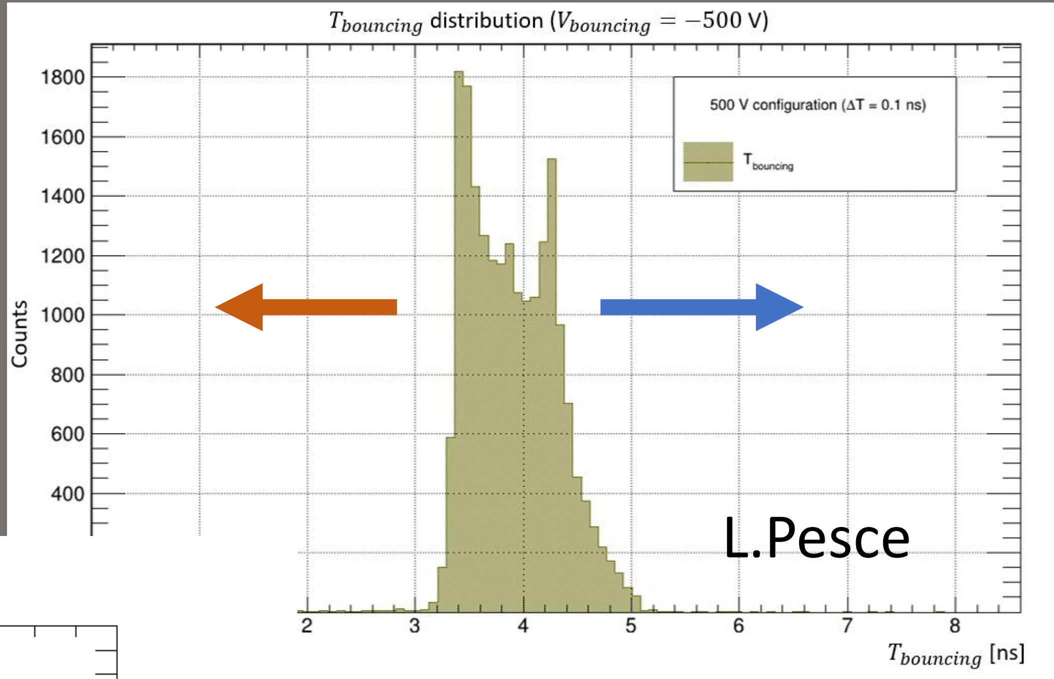


Narrow (in real life: potential well effect)

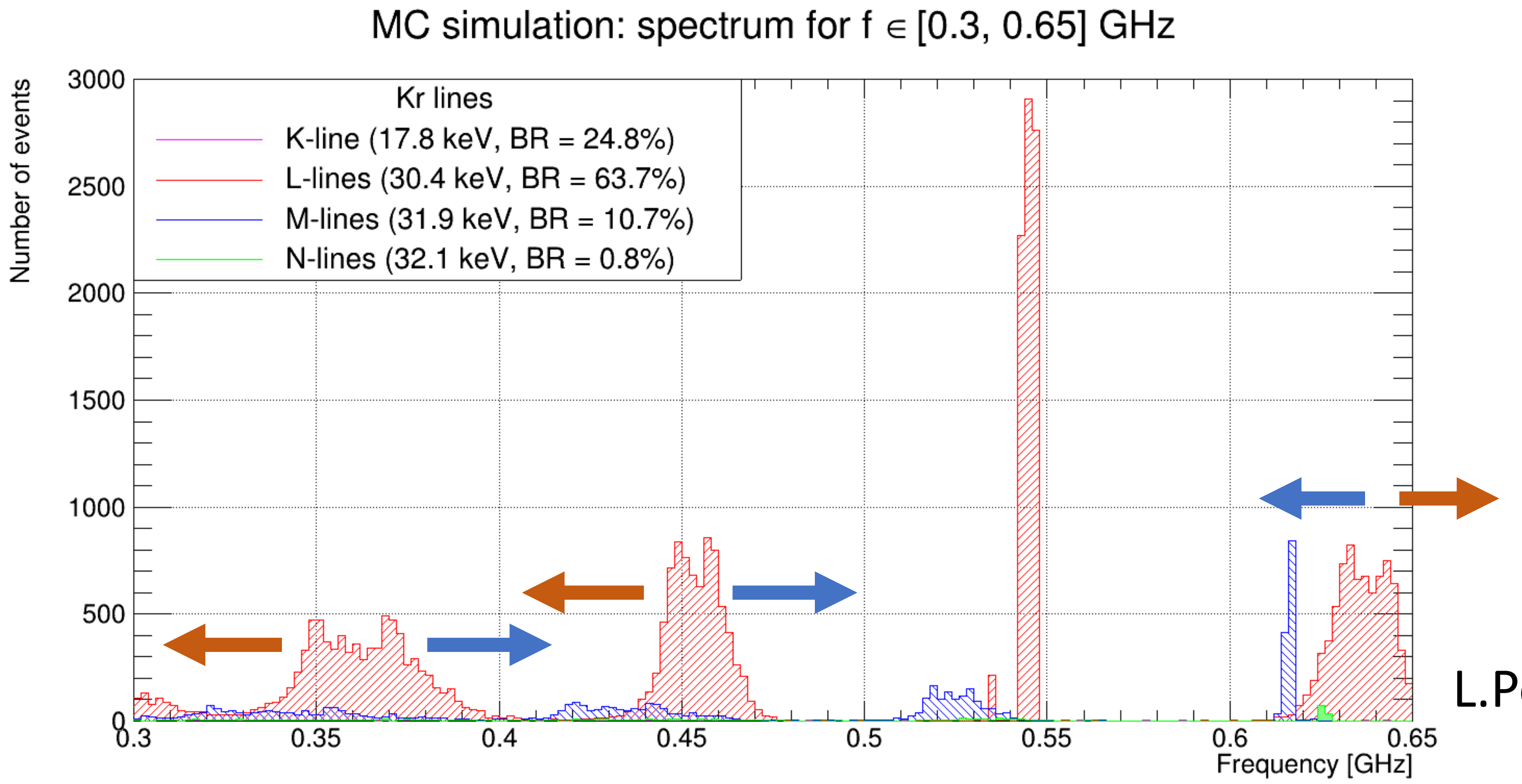
+Δ-Δ=0

Montecarlo: Expected Pattern RF

What is the extected RF pattern for all Kr lines for N electrons?

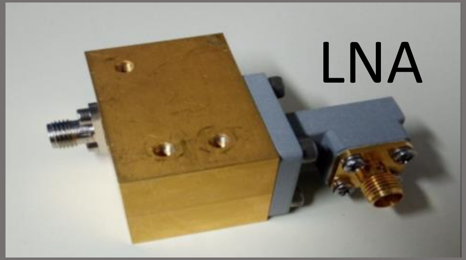


L.Pesce

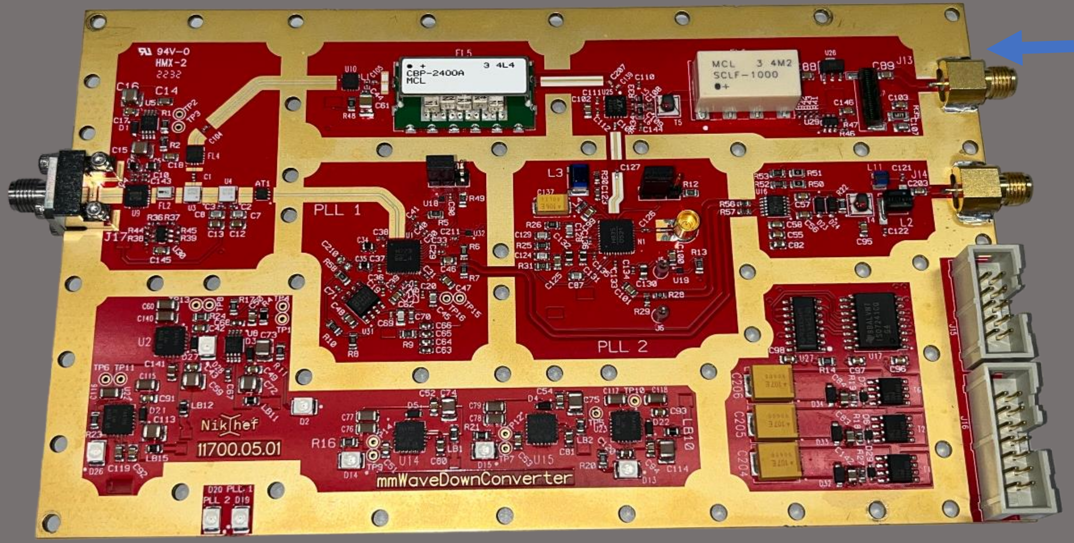


L.Pesce

Electron Trap: readout electronics



RTO64 used for trigger task



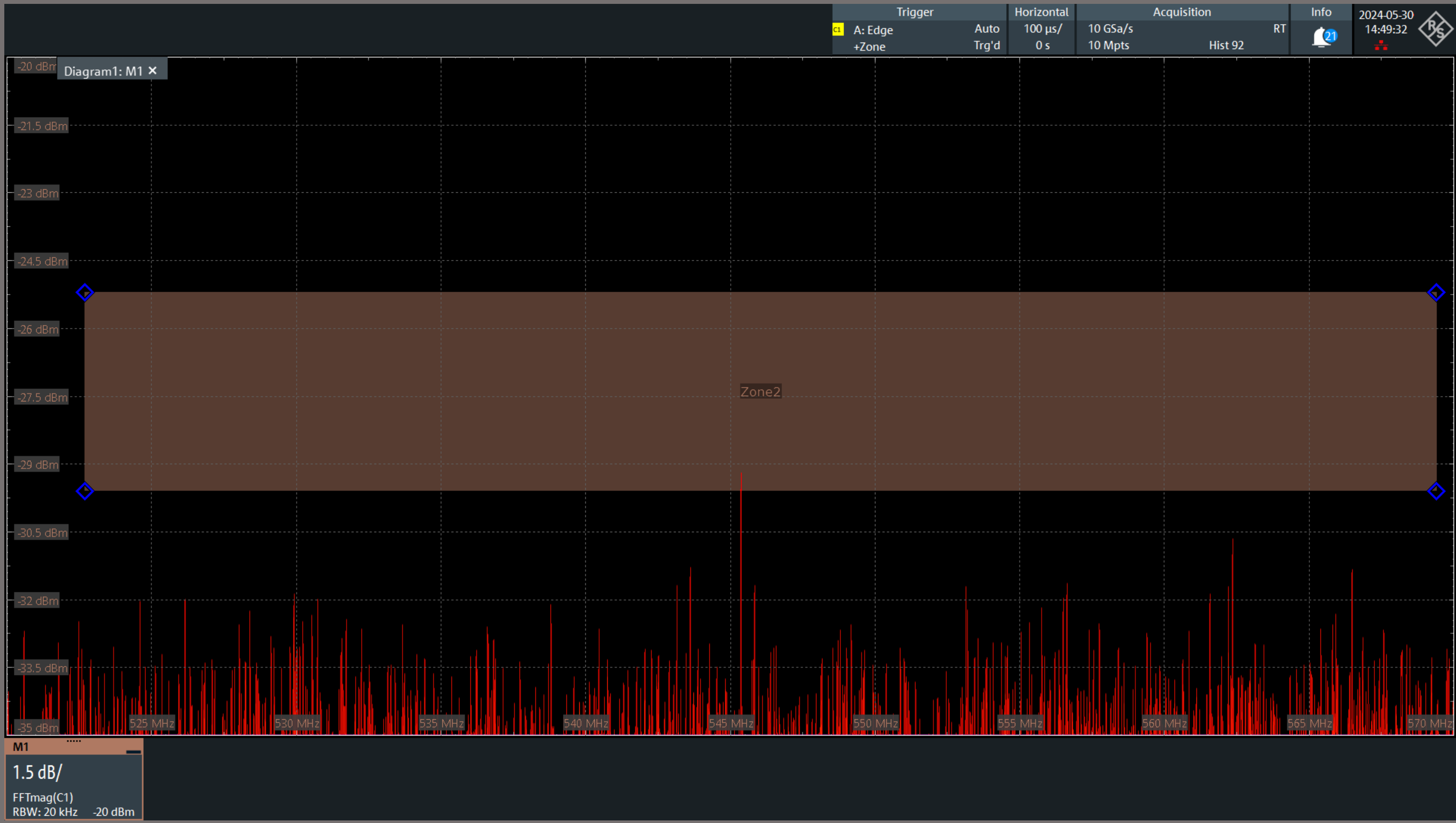
Dedicated downconverter developed @ NIKHEF

DAQ with FPGA trigger under development @ NIKHEF

f(IF)=f(downc.)-f(RF)+0.45GHz

Trigger: how it works

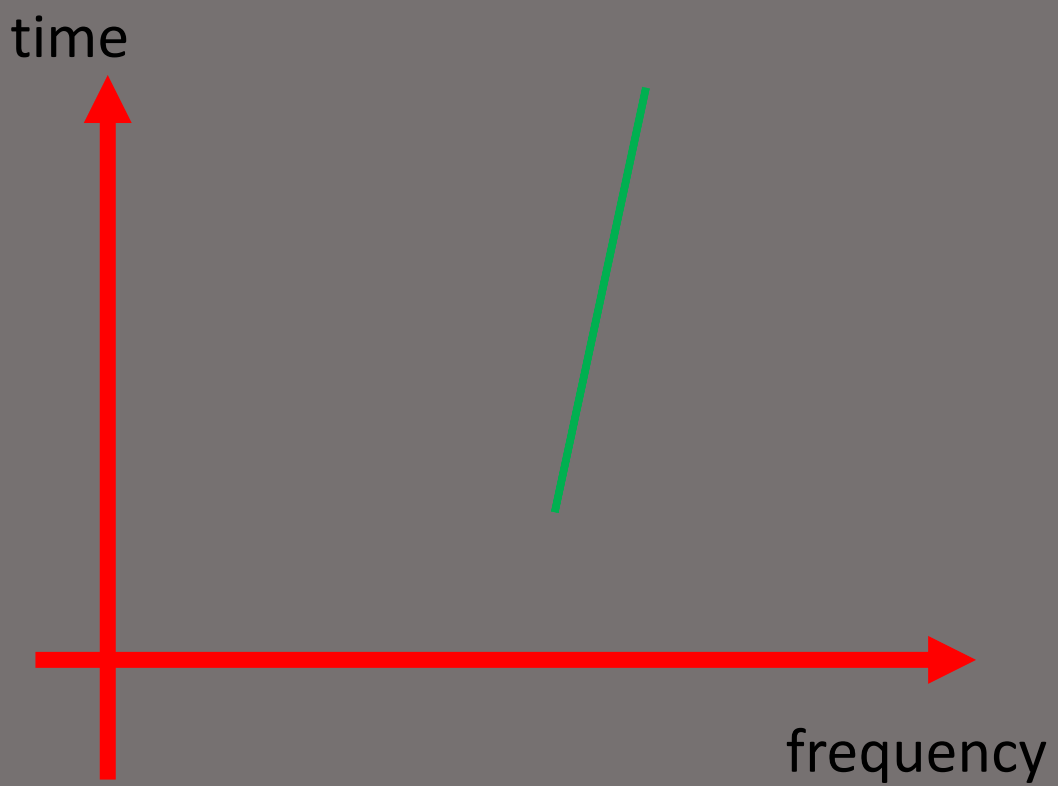
1. Take the avg noise
2. Draw the trigger area
3. Shift up in power by the desired SNR
4. If FFT(signal) =inside trigger area->save time series



Data analysis

How to show electron tracks: The Sauron Plot

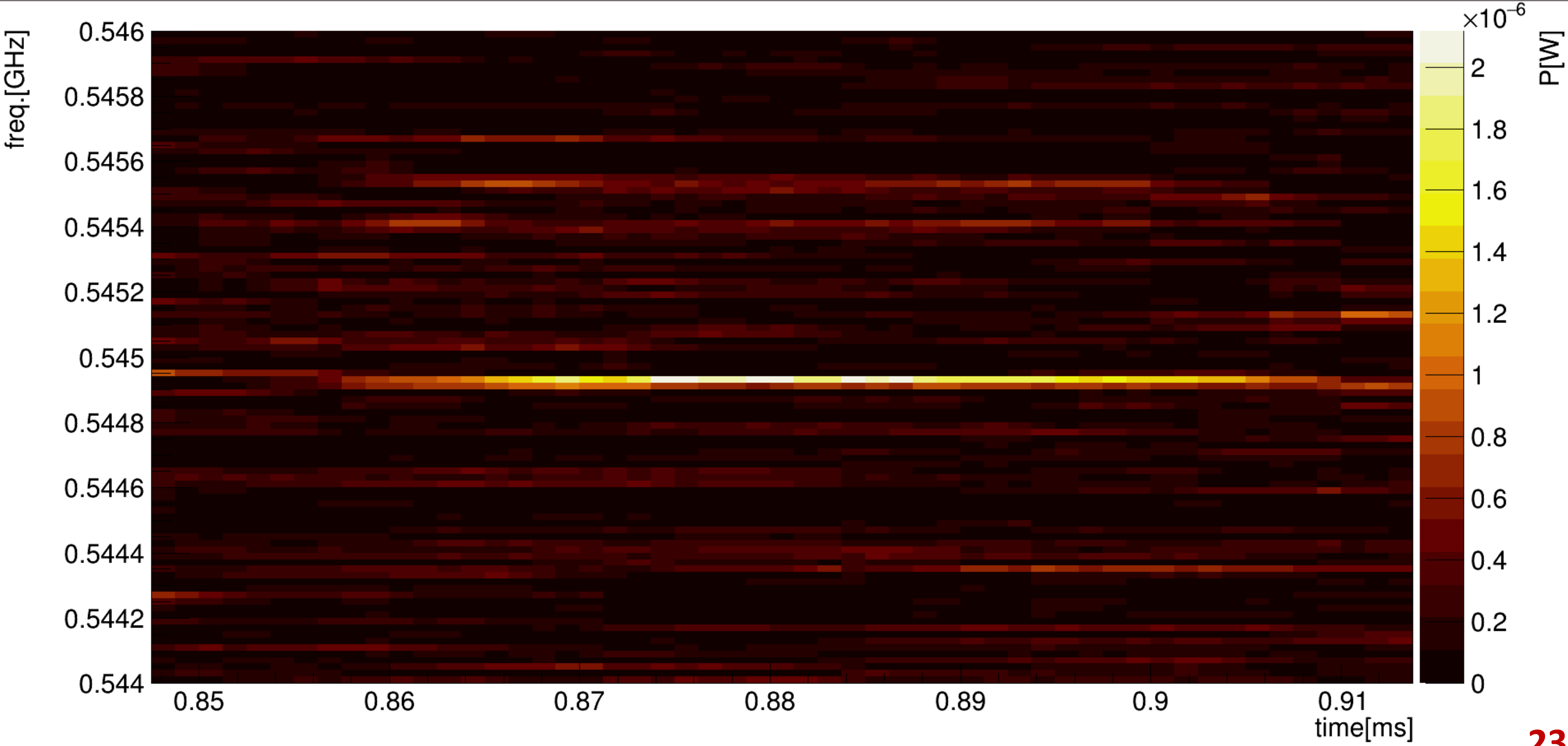
- Spectrogram: method to plot a FFTs over time



Sometimes the axis are inverted

Sauron plot: Bkg

Thermal noise (short time window) with 50 µs FFT->50 µs track



Sauron plot: electron signal (project 8)

- Project8 designed for long tracks

  ↓

  You expect to see variation of frequency over time

- Electron trap: designed for short track (fast trigger goal)

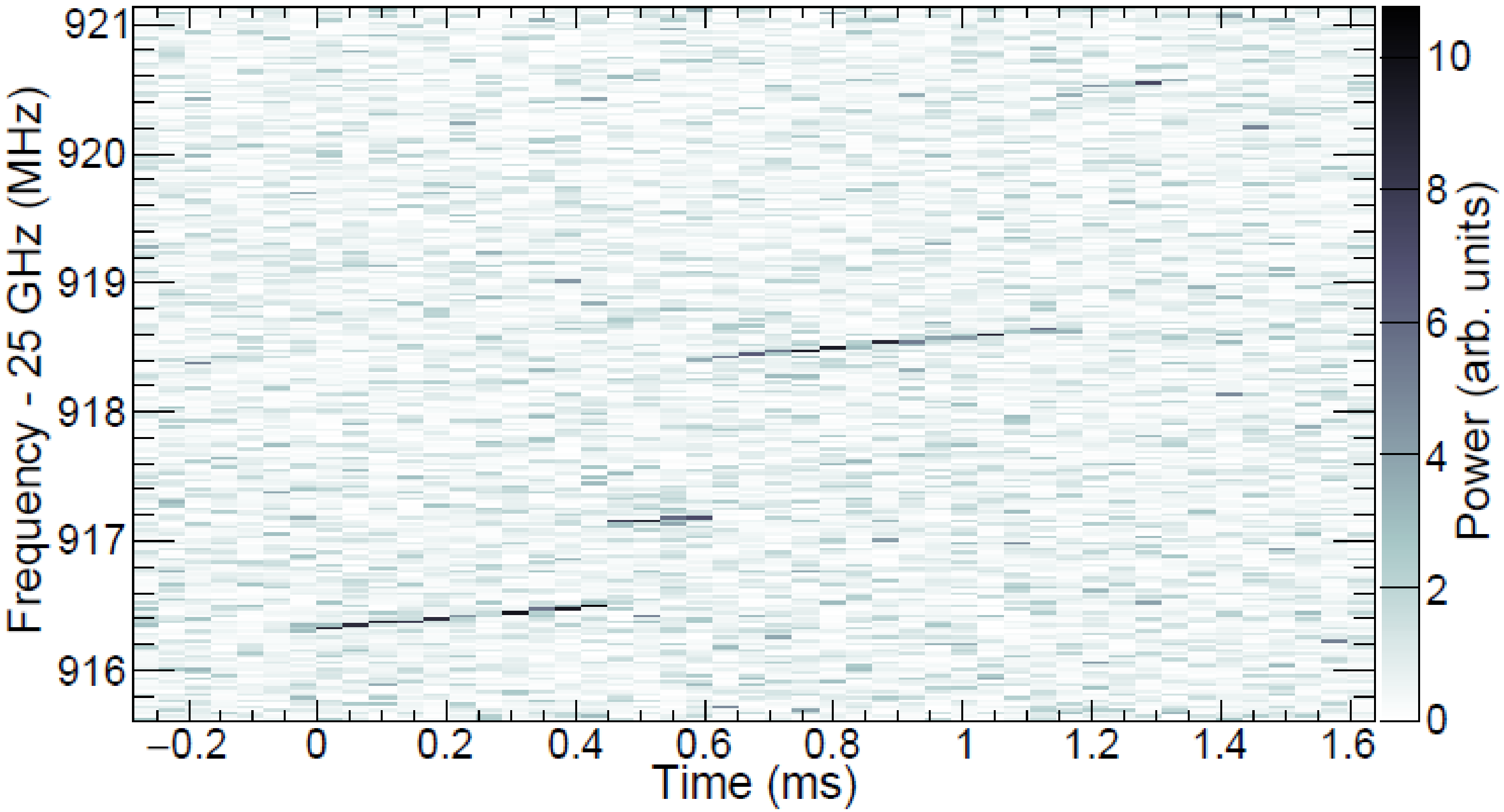
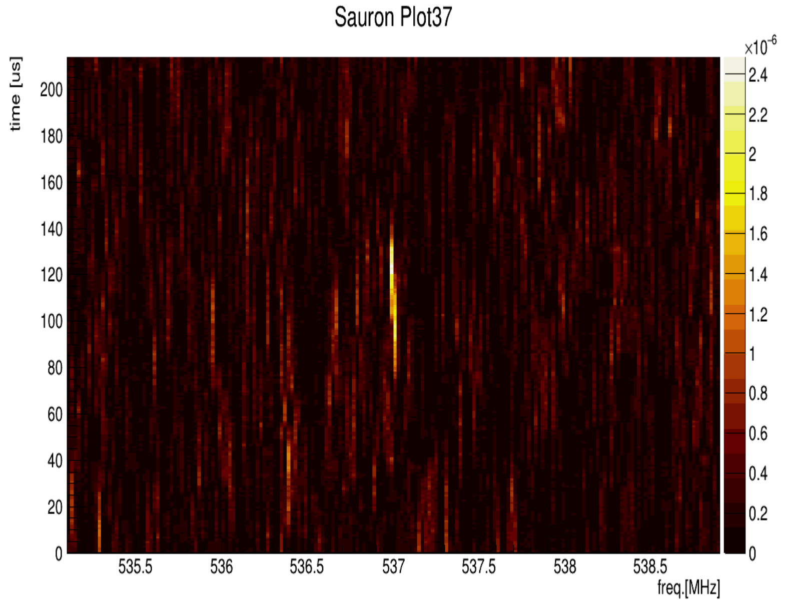


FIG. 2. Spectrogram of the first CRES event detected from a tritium beta decay electron. Raw time-series data are Fourier-transformed in time bins of 40.96 µs, yielding 24.41 kHz frequency bins.

Sauron plot: electron signal

- Electron trap: designed for short track (fast trigger goal)
- Electron in potential well
- Do you expect to see df/dt?



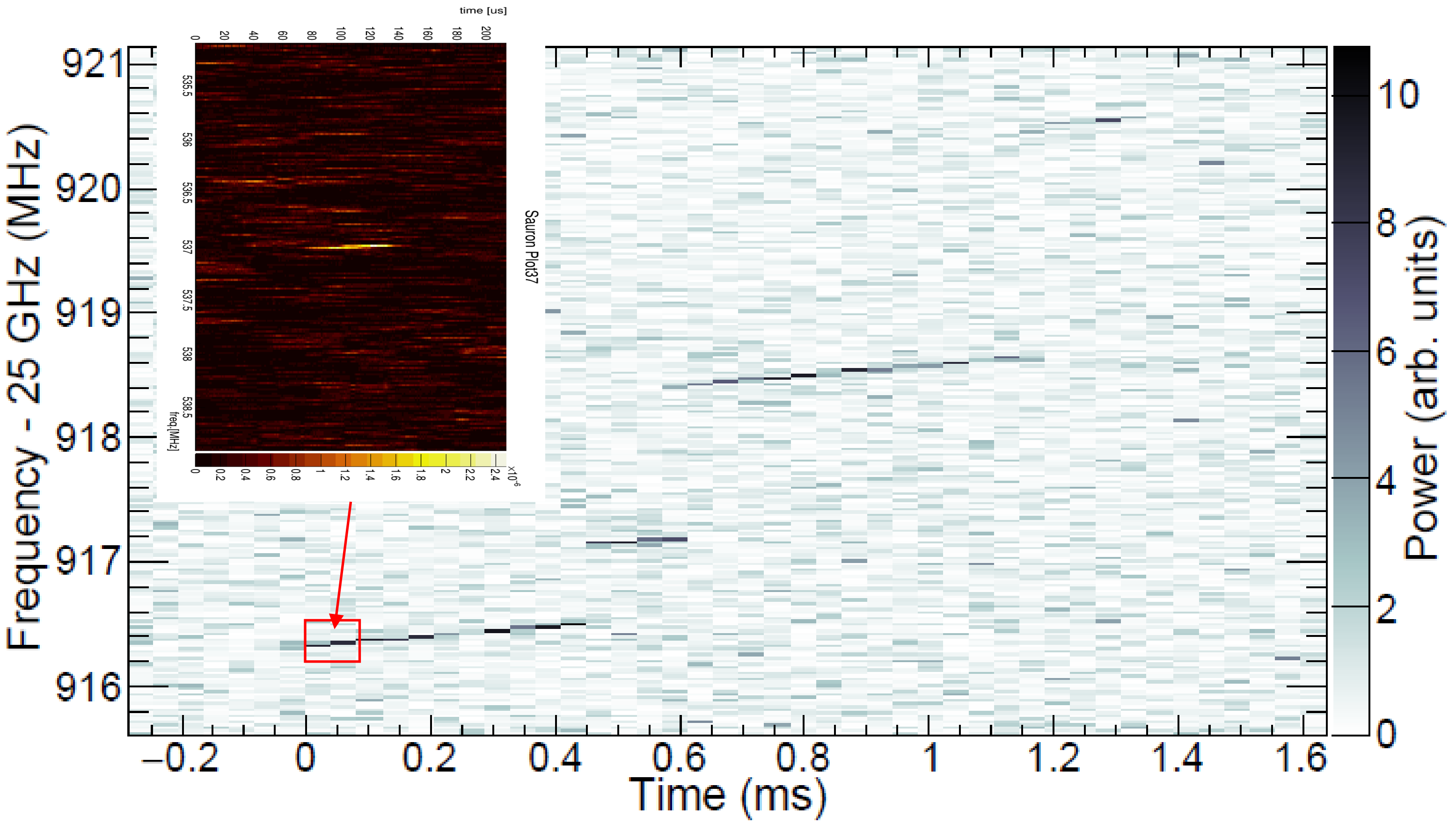
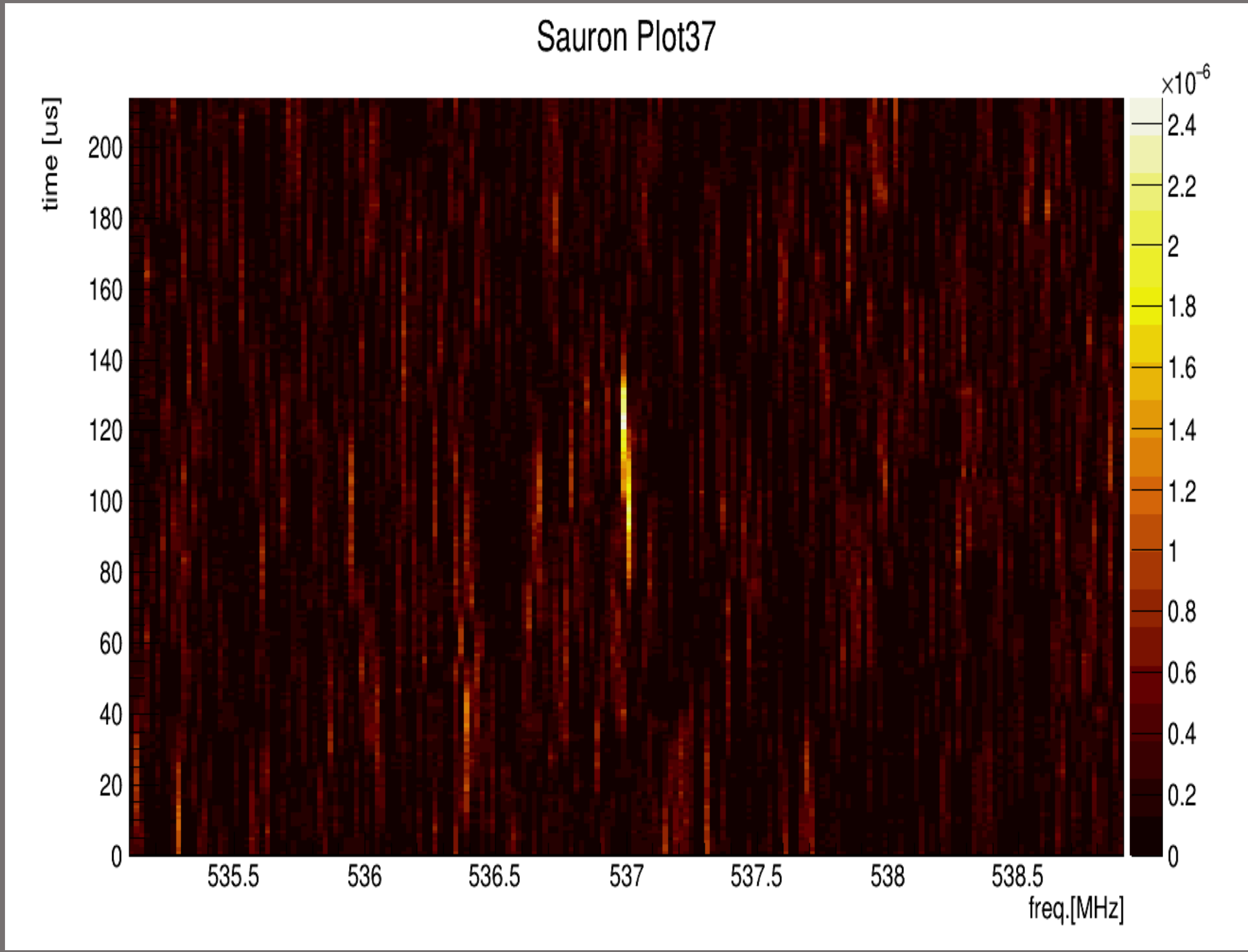


FIG. 2. Spectrogram of the first CRES event detected from a tritium beta decay electron. Raw time-series data are Fourier-transformed in time bins of 40.96 µs, yielding 24.41 kHz frequency bins.

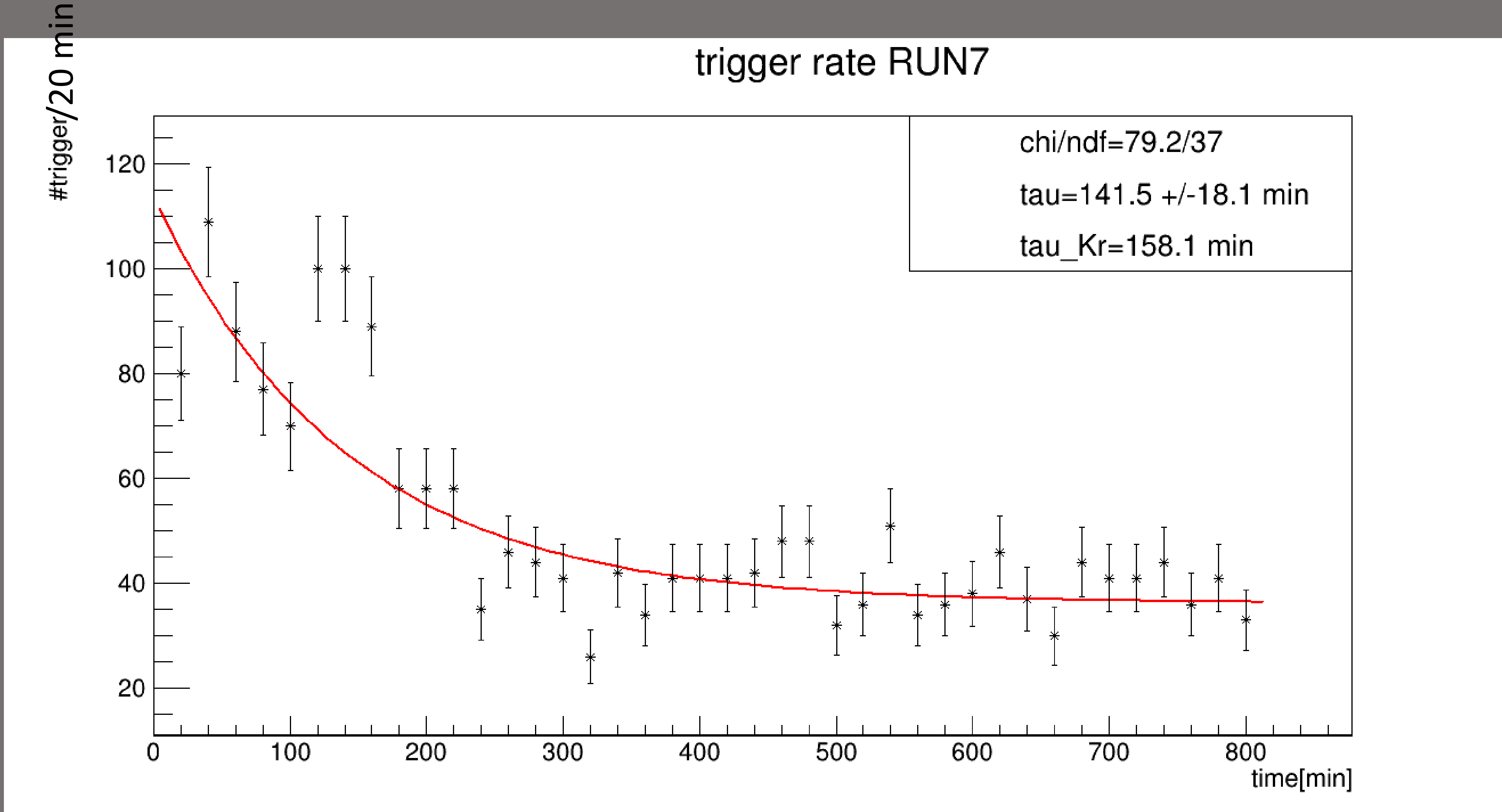
Results of electron trap phase 1

- A lot of short tracks:
  Is something like that an electron or BKG event?
- Trigger rate: Kr evidence
- RF pattern(statistical basis)

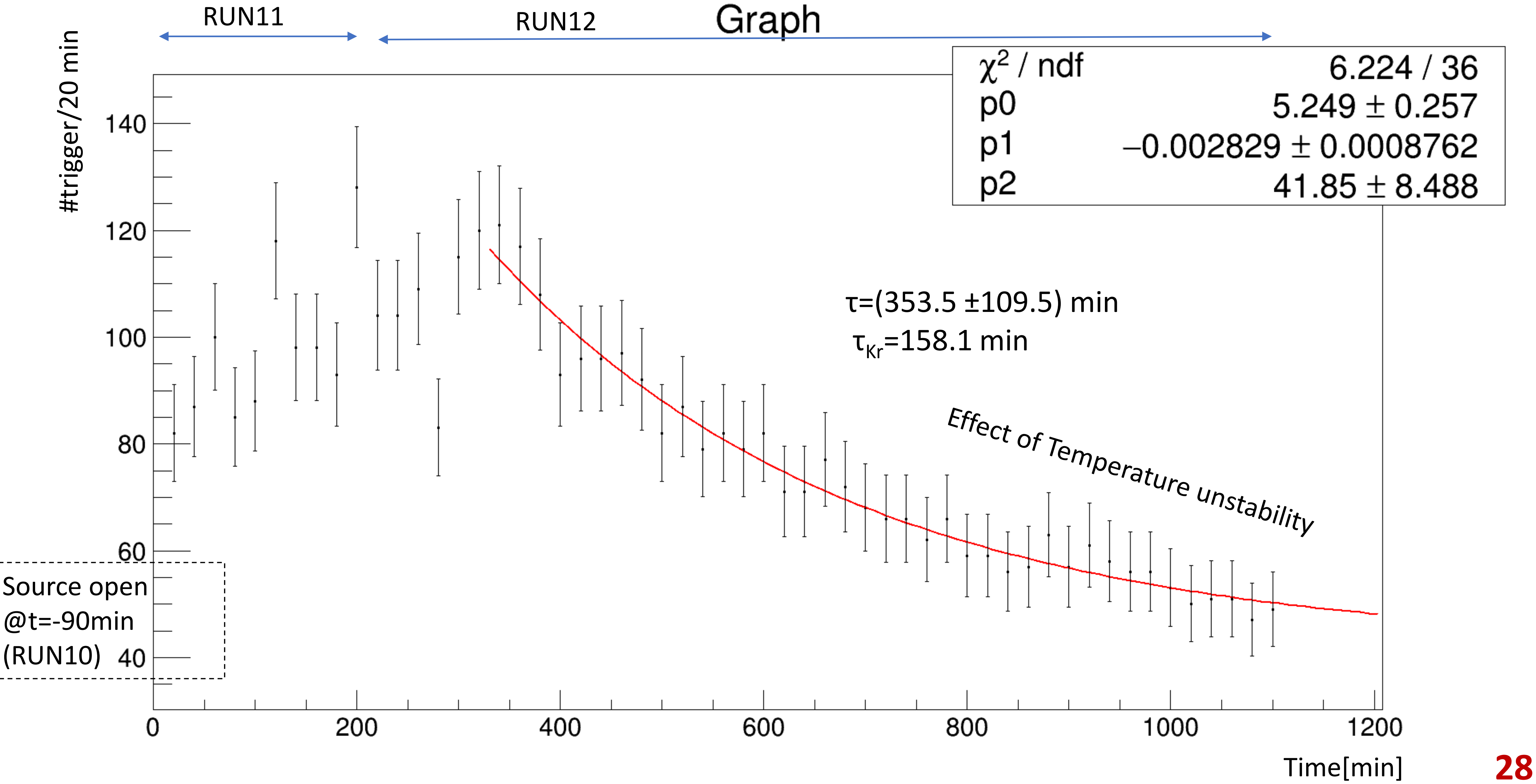


Electron Trap: Krypton lifetime

- Trigger on expected frequency
- Source was open by several hrs
- Time=0 source closed

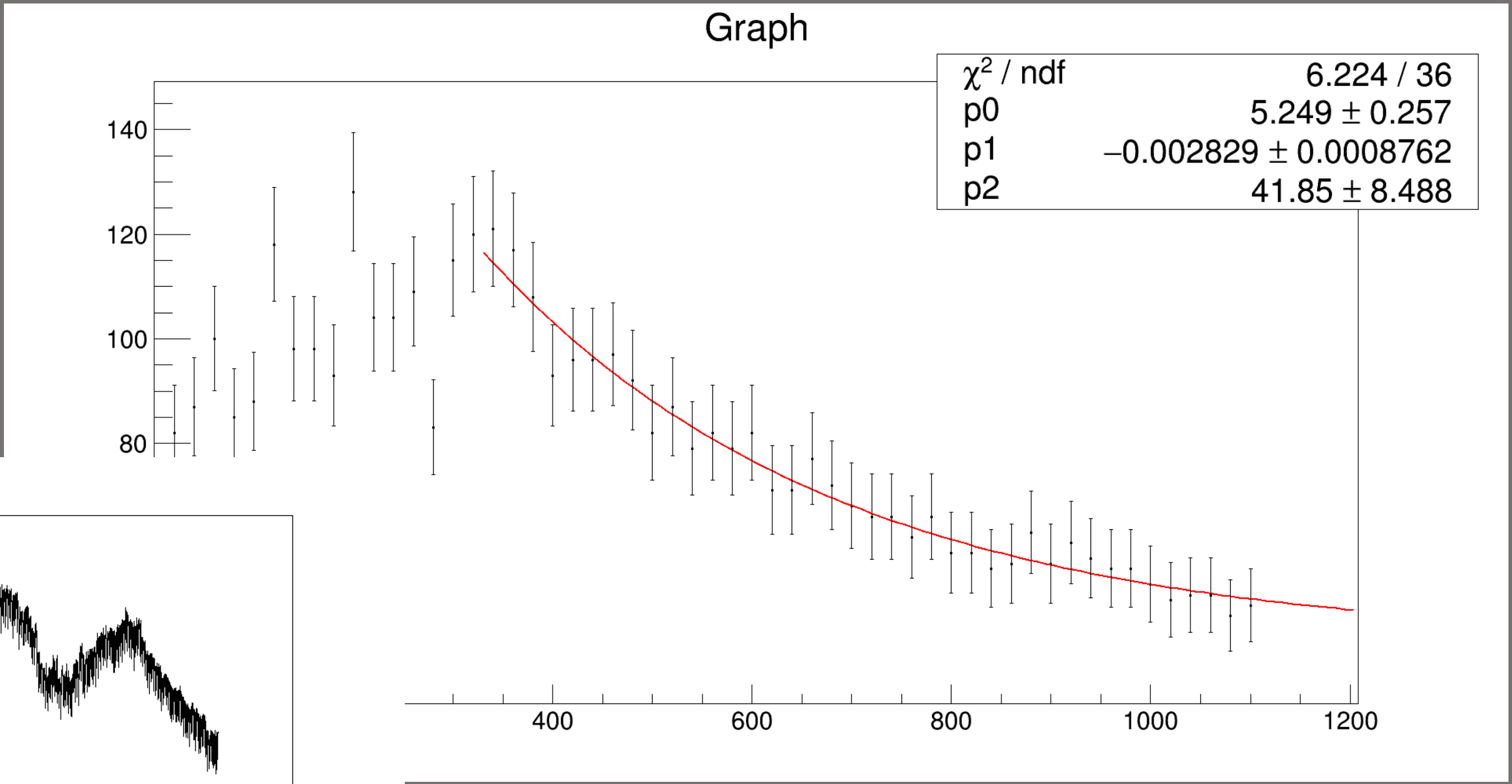


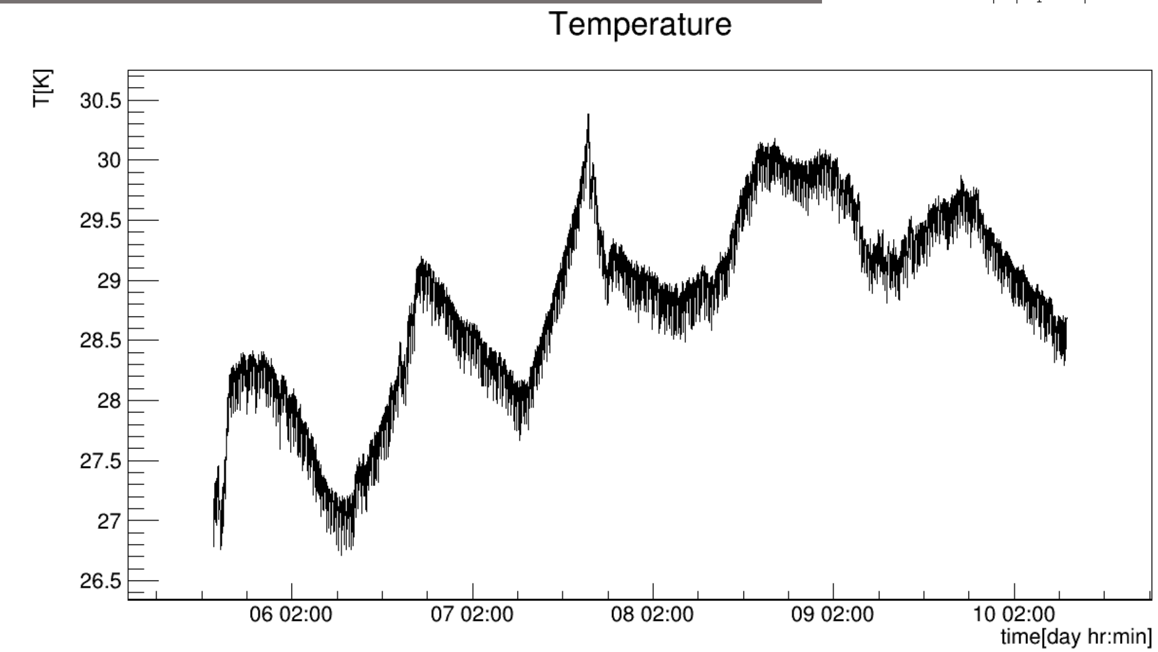
Trigger rate: 'rise-decrease' plot



What can emulate this rise-decrease trigger rate?

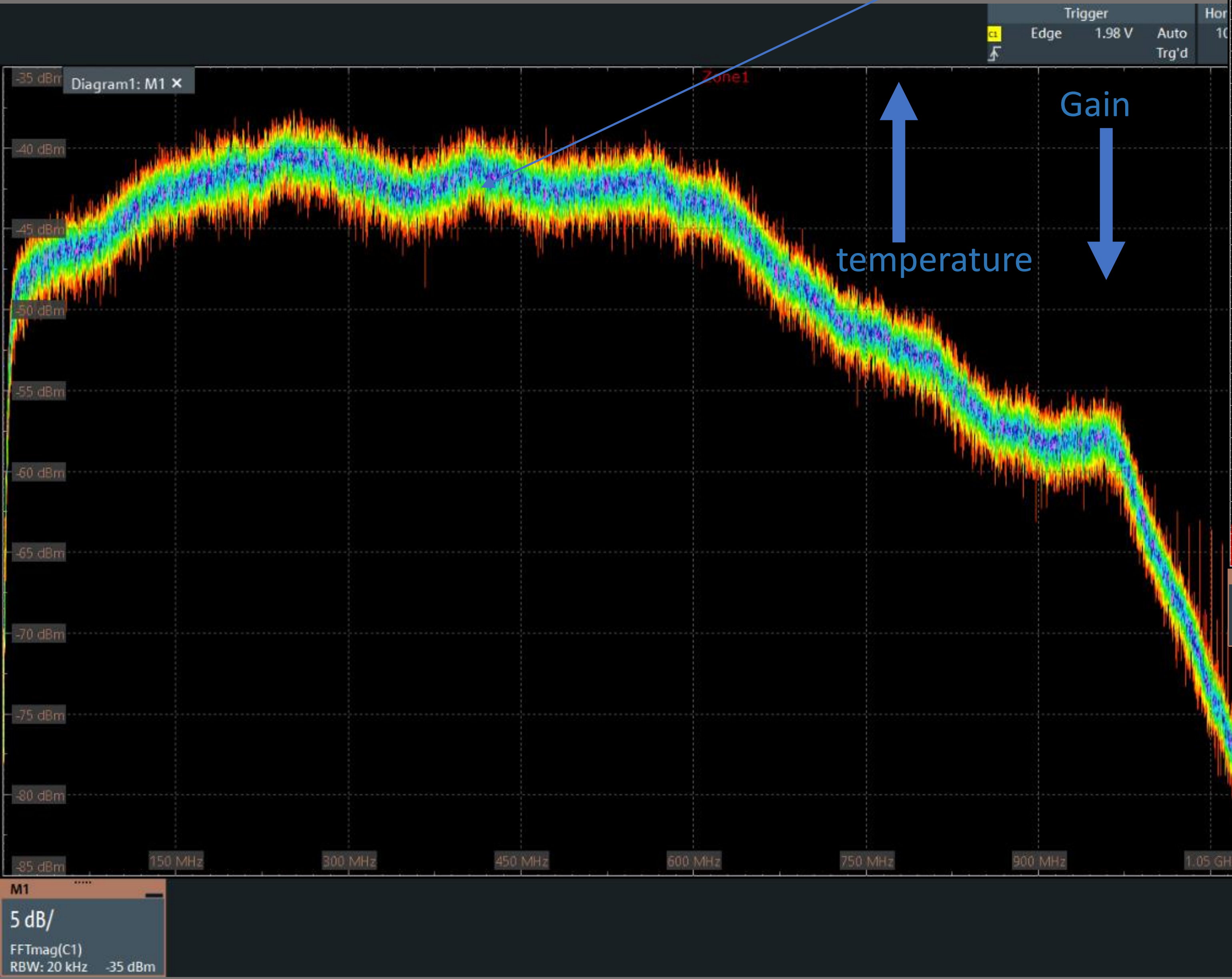
- LNA gain depends by temperature
- Cyrcadian variation of temperature

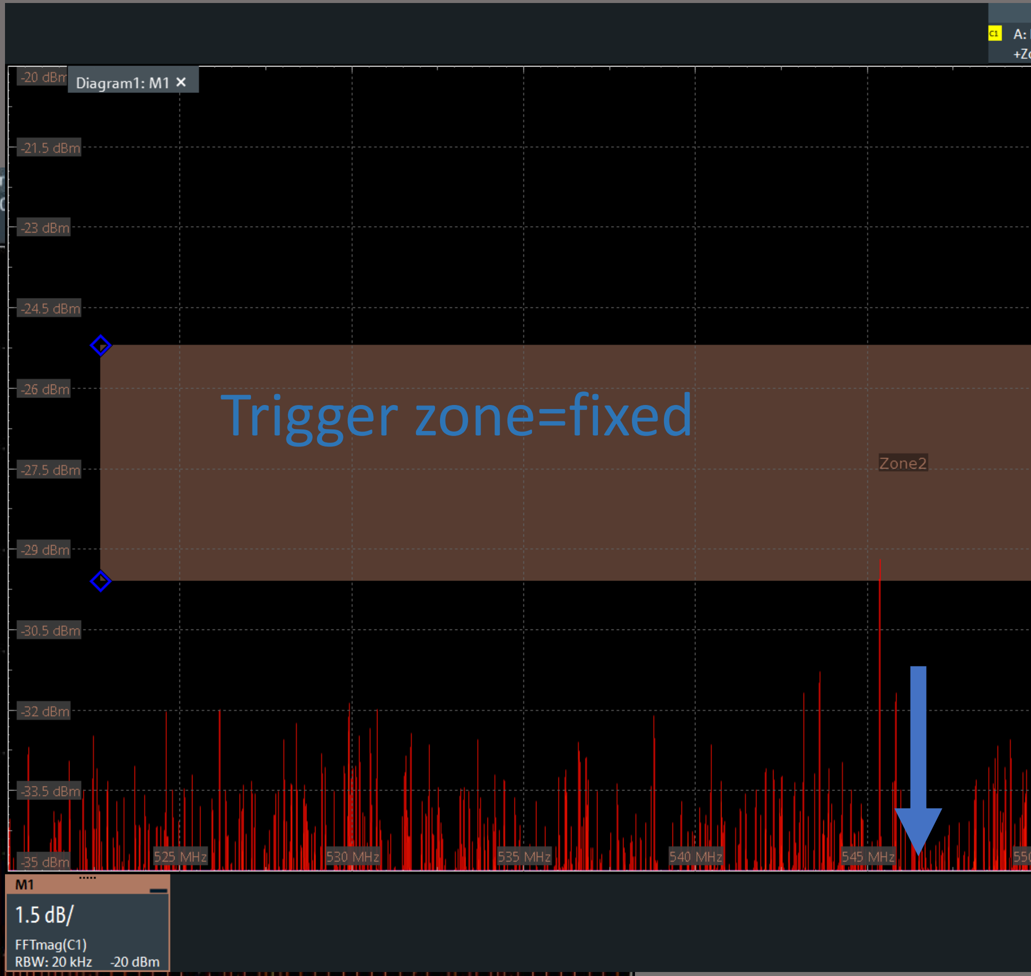




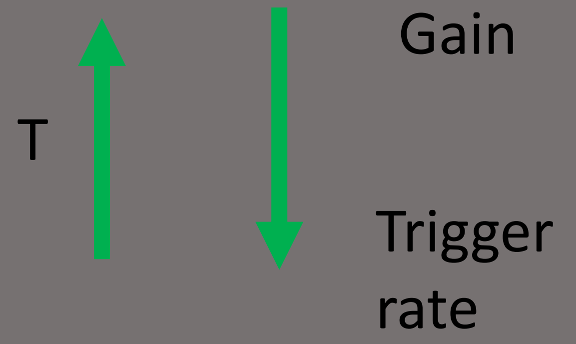
Noise trigger

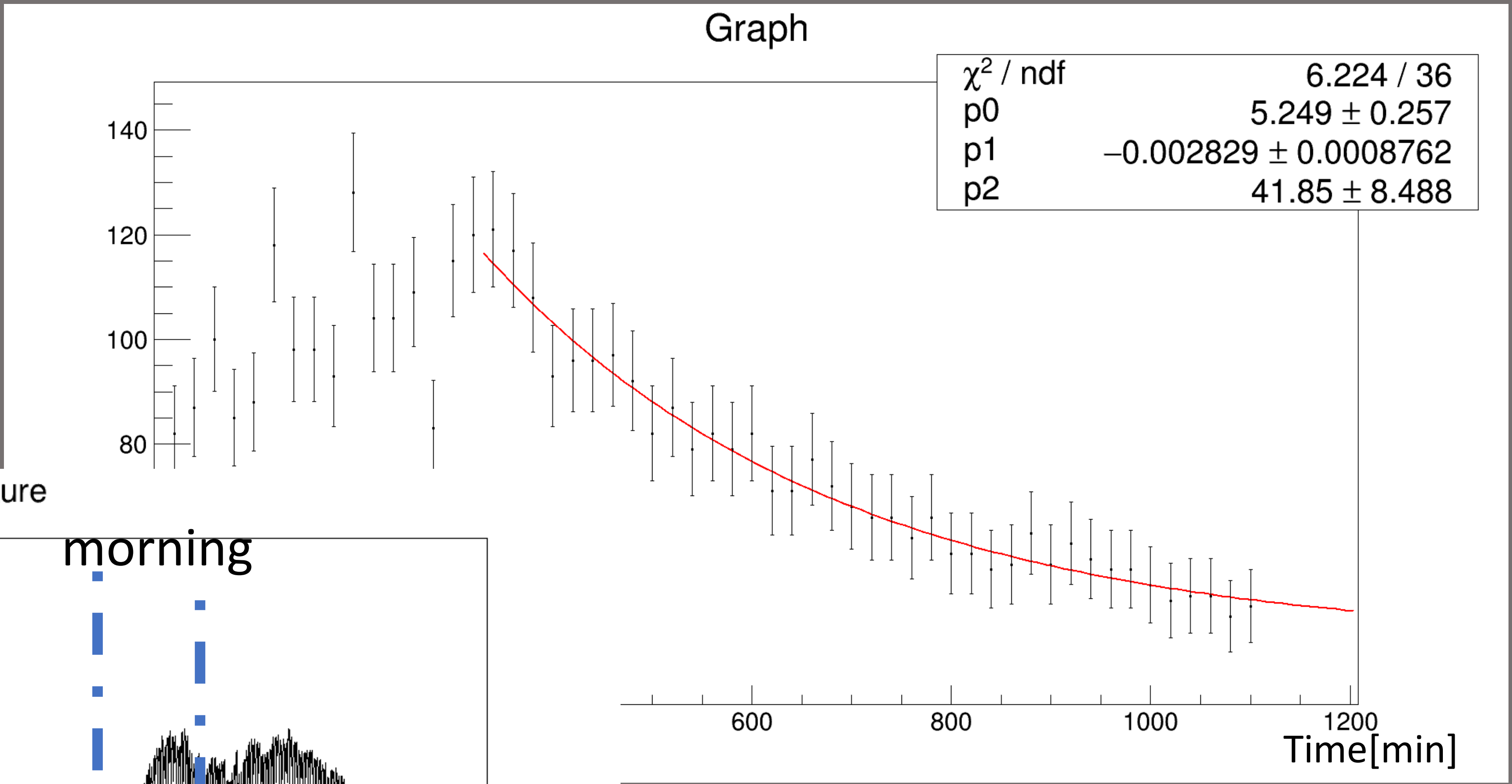
$$\langle N\rangle=10LOG_{10}(KT\Delta f/1mW)+G$$

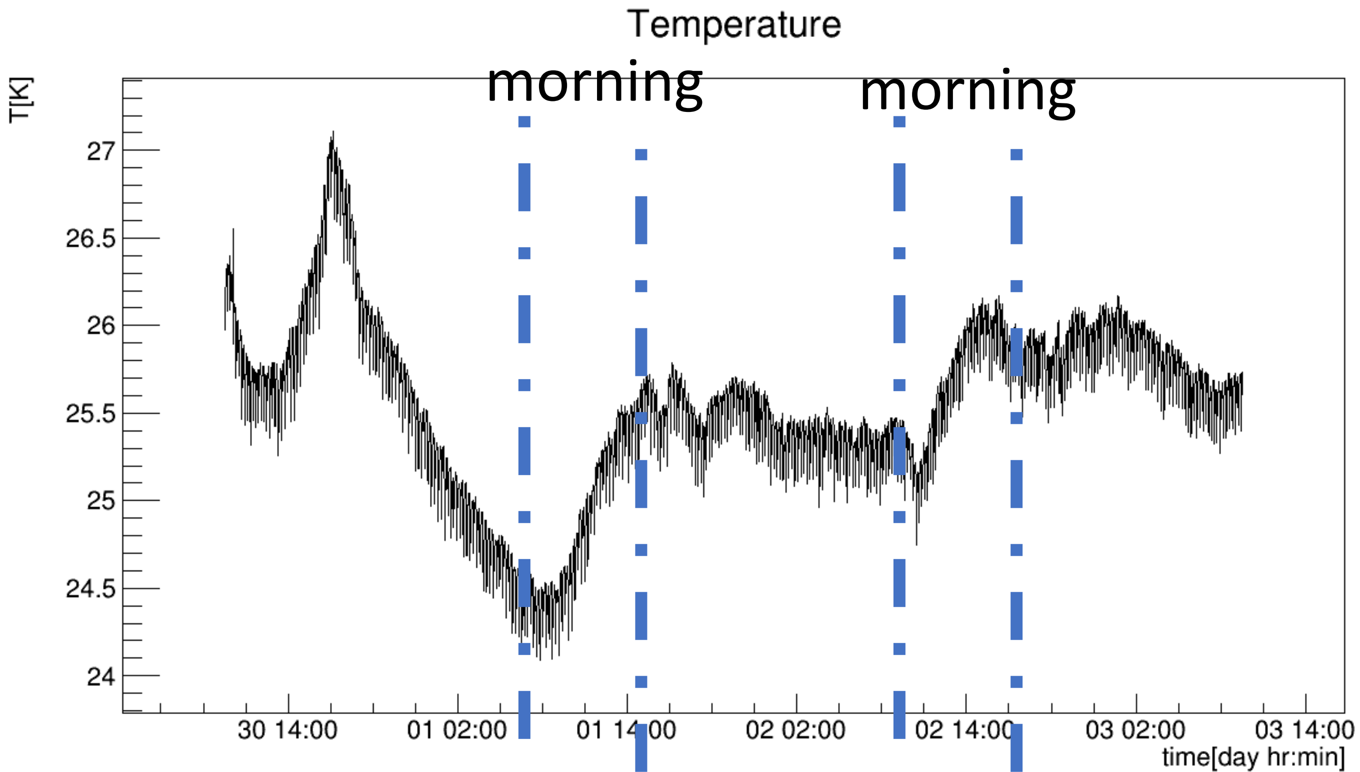




What can emulate this 'rise-decrease' trigger rate?





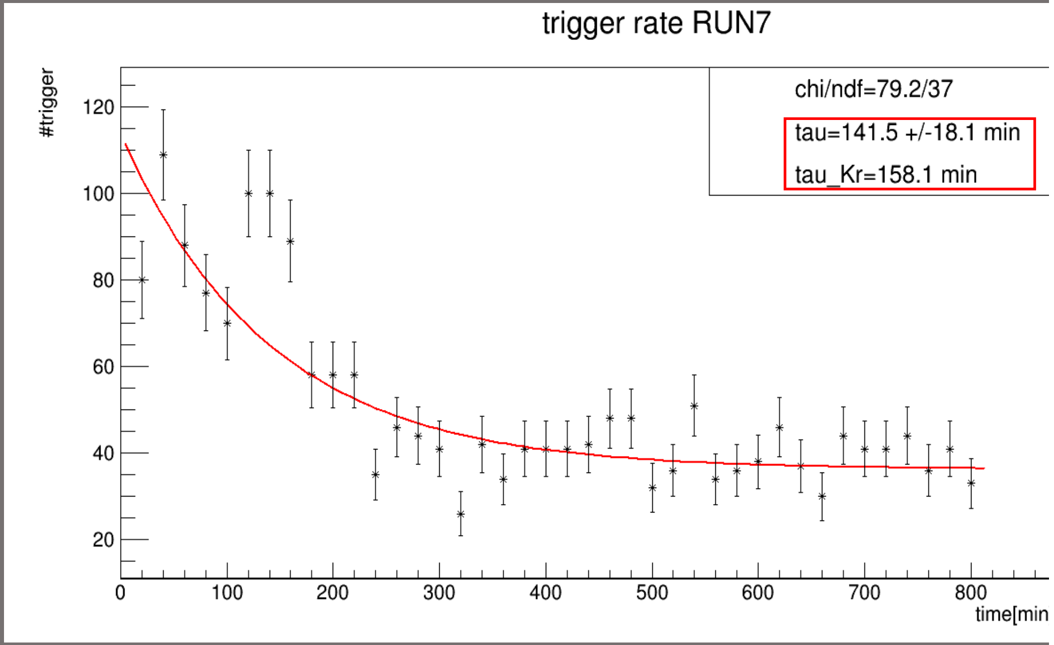


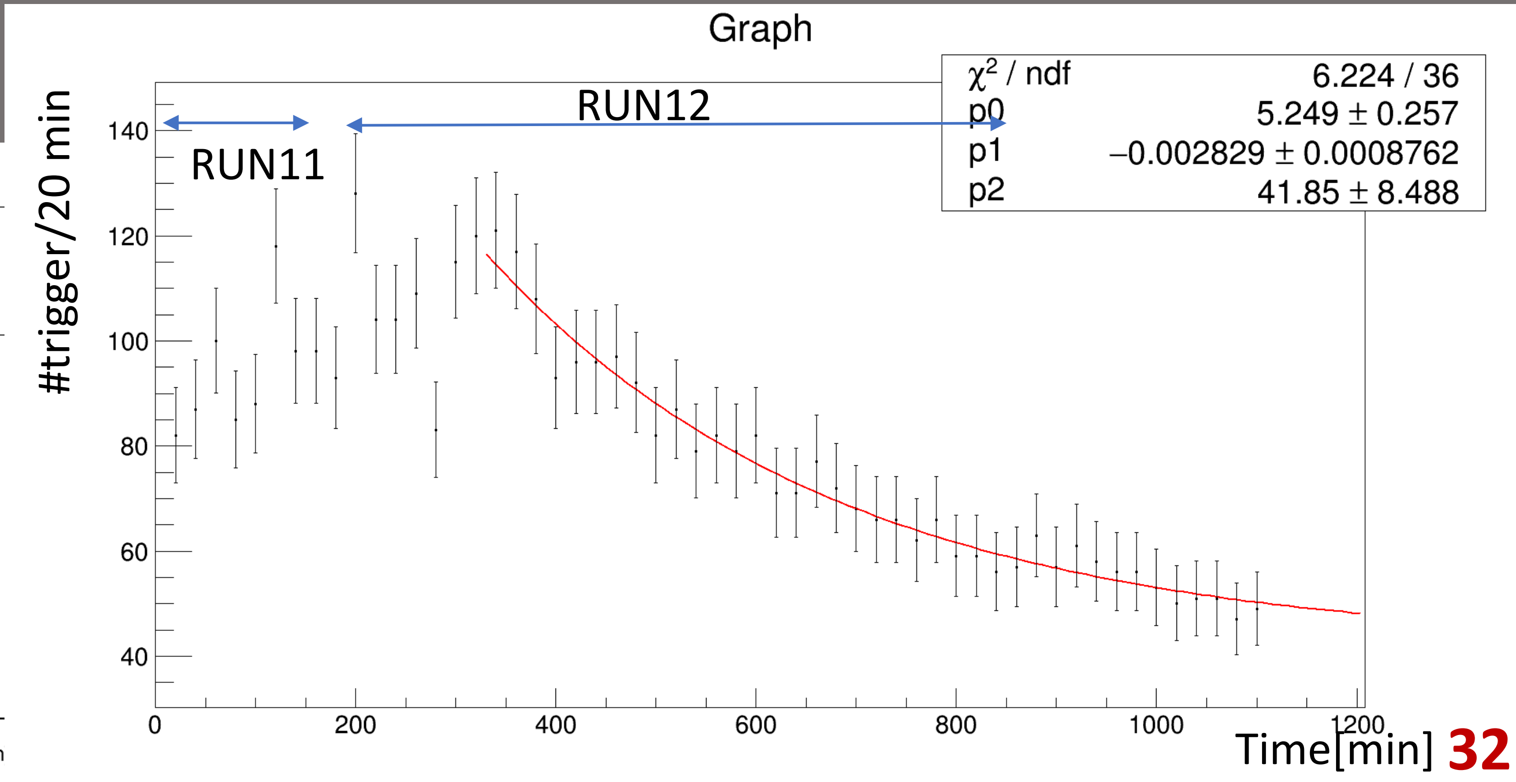
(example of temperature behaviour, not related to the trigger rate measurement)

What can emulate this ‘rise-decrease’ trigger rate?

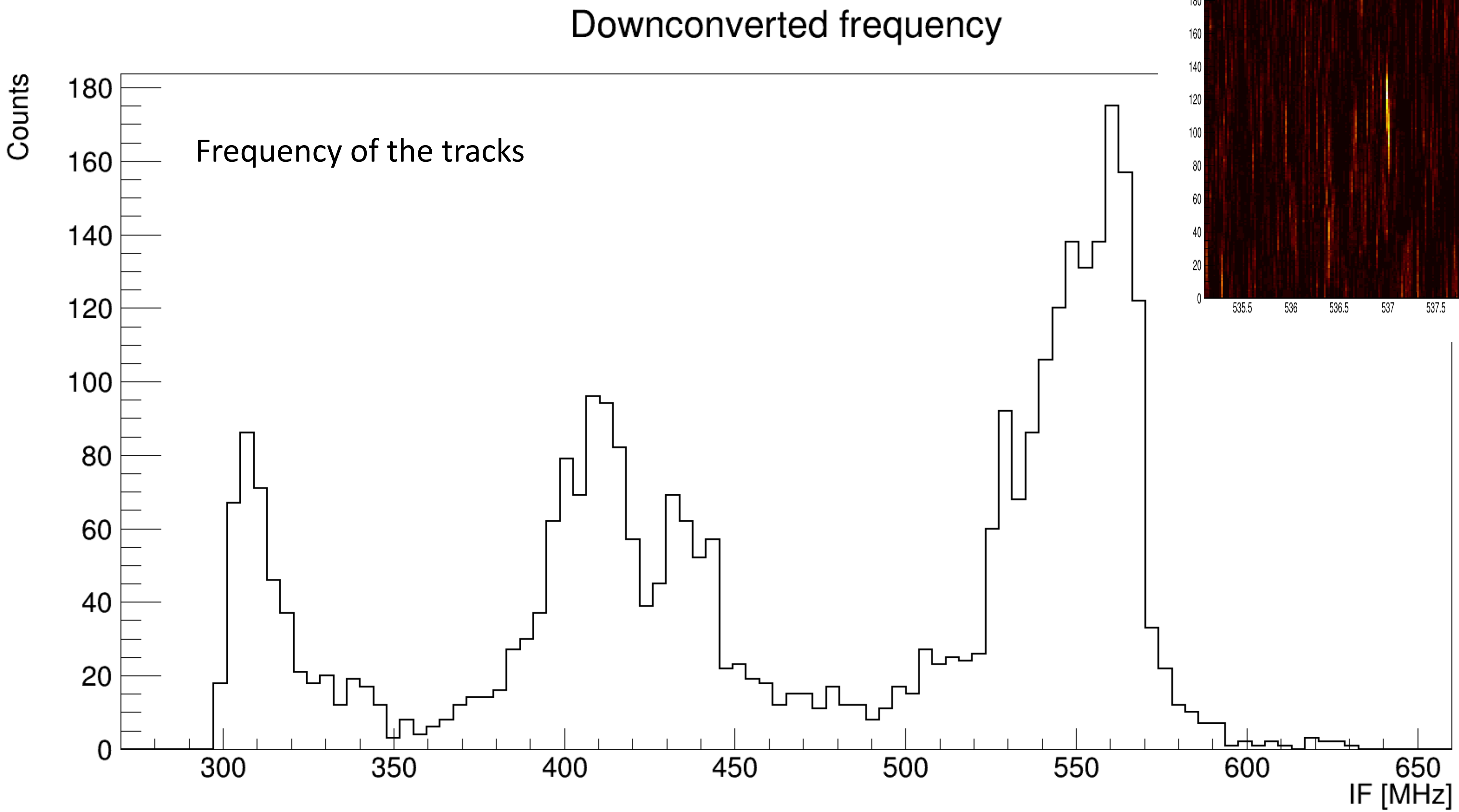
- This is a strong evidence that we where triggering something related to Krypton source(beginning of summer)

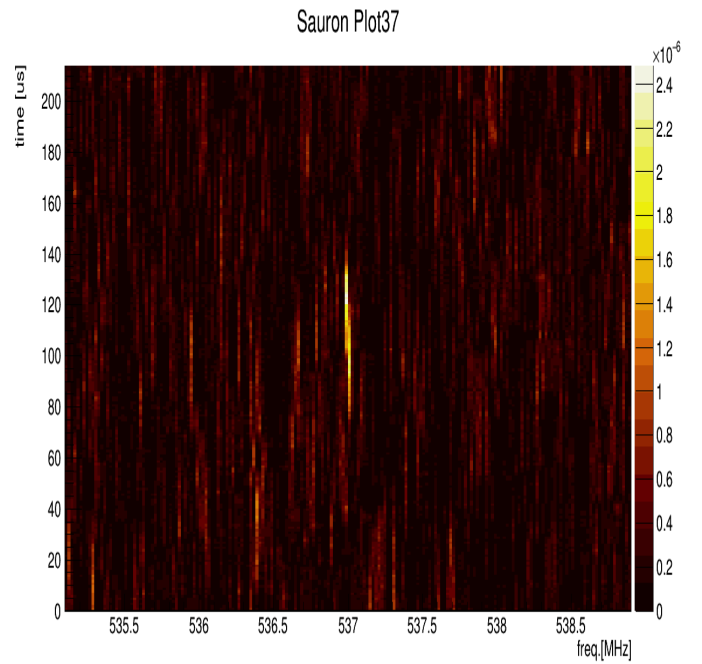
- After those measurements the trigger becomes broken
- Trigger repaired few weeks ago





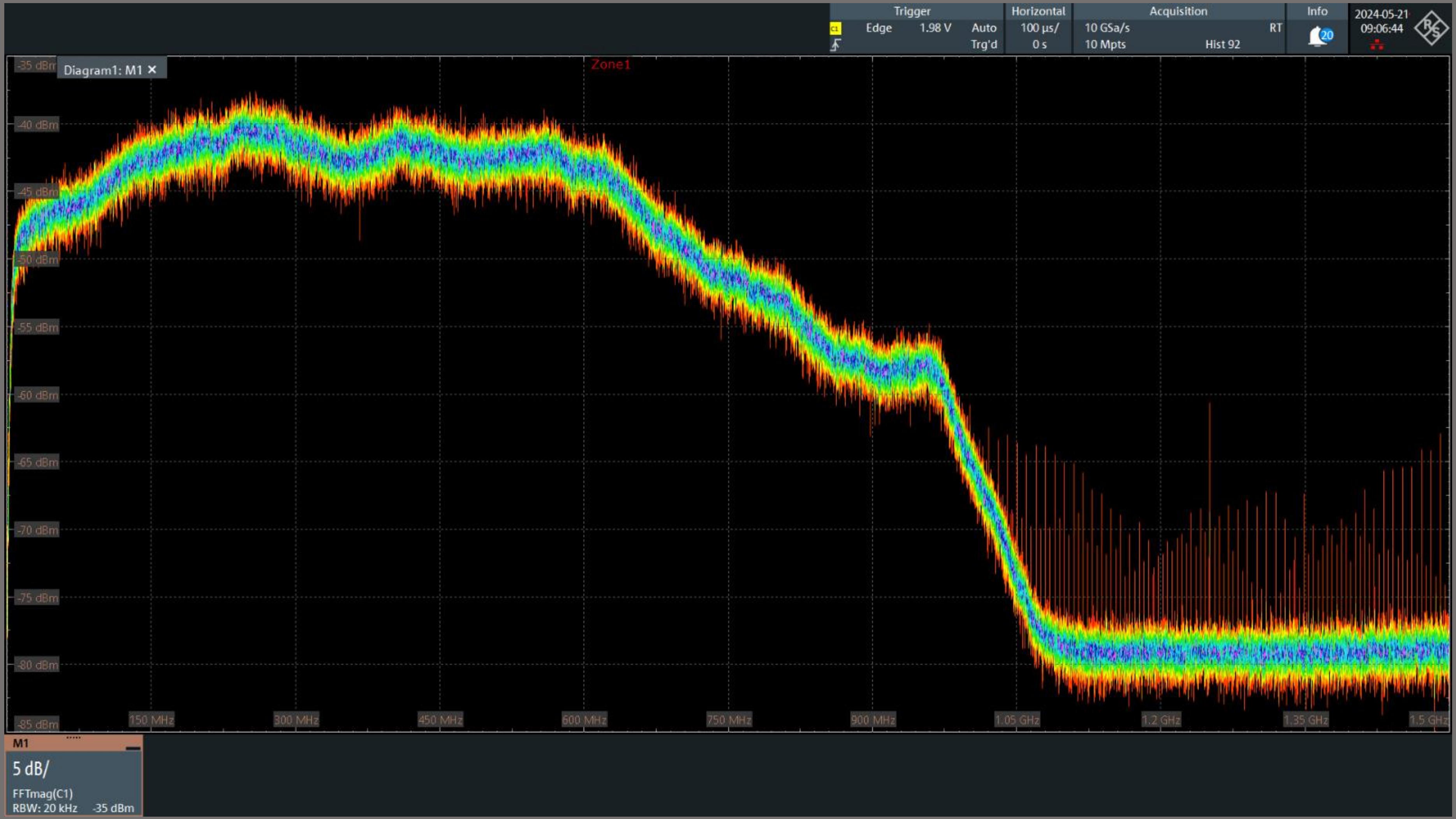
Measured Pattern RF





What can emulate this results?

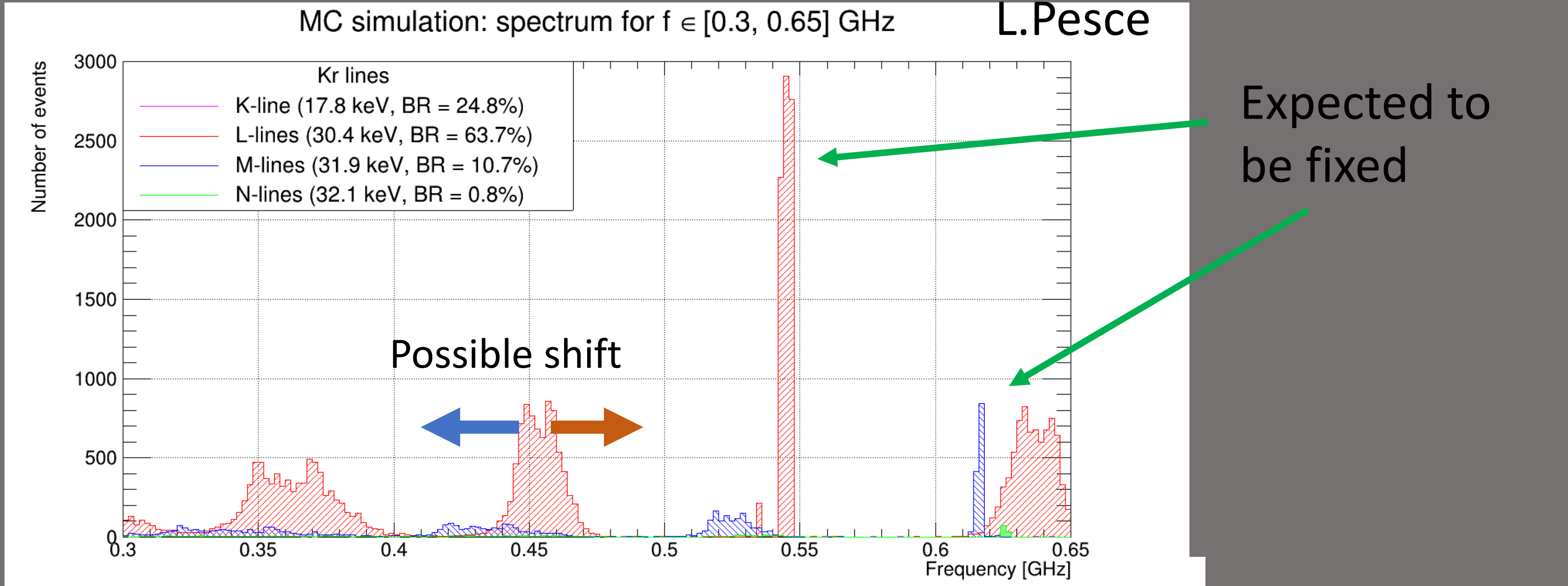
- The Gain of the electronics is not flat(histogram obtained by flat cut)

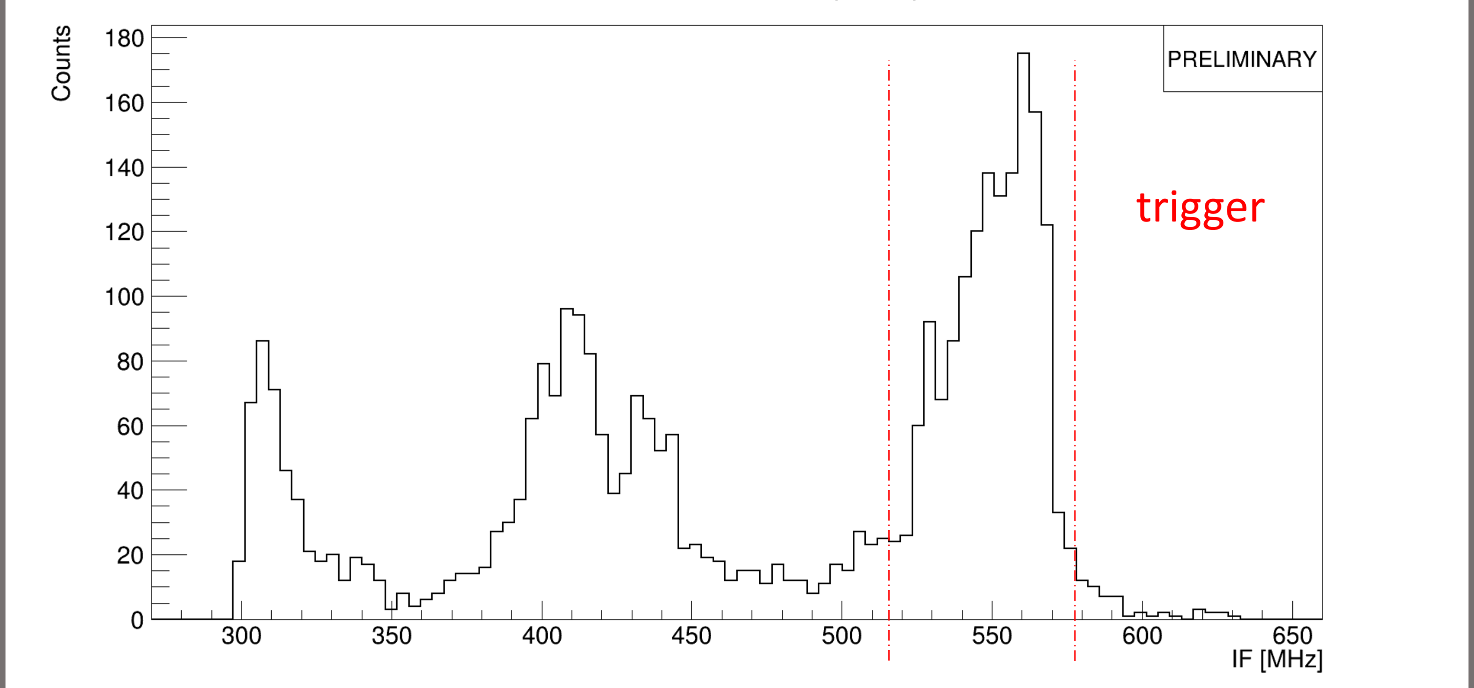


…but there is a good evidence of good signals at backup slide 65…

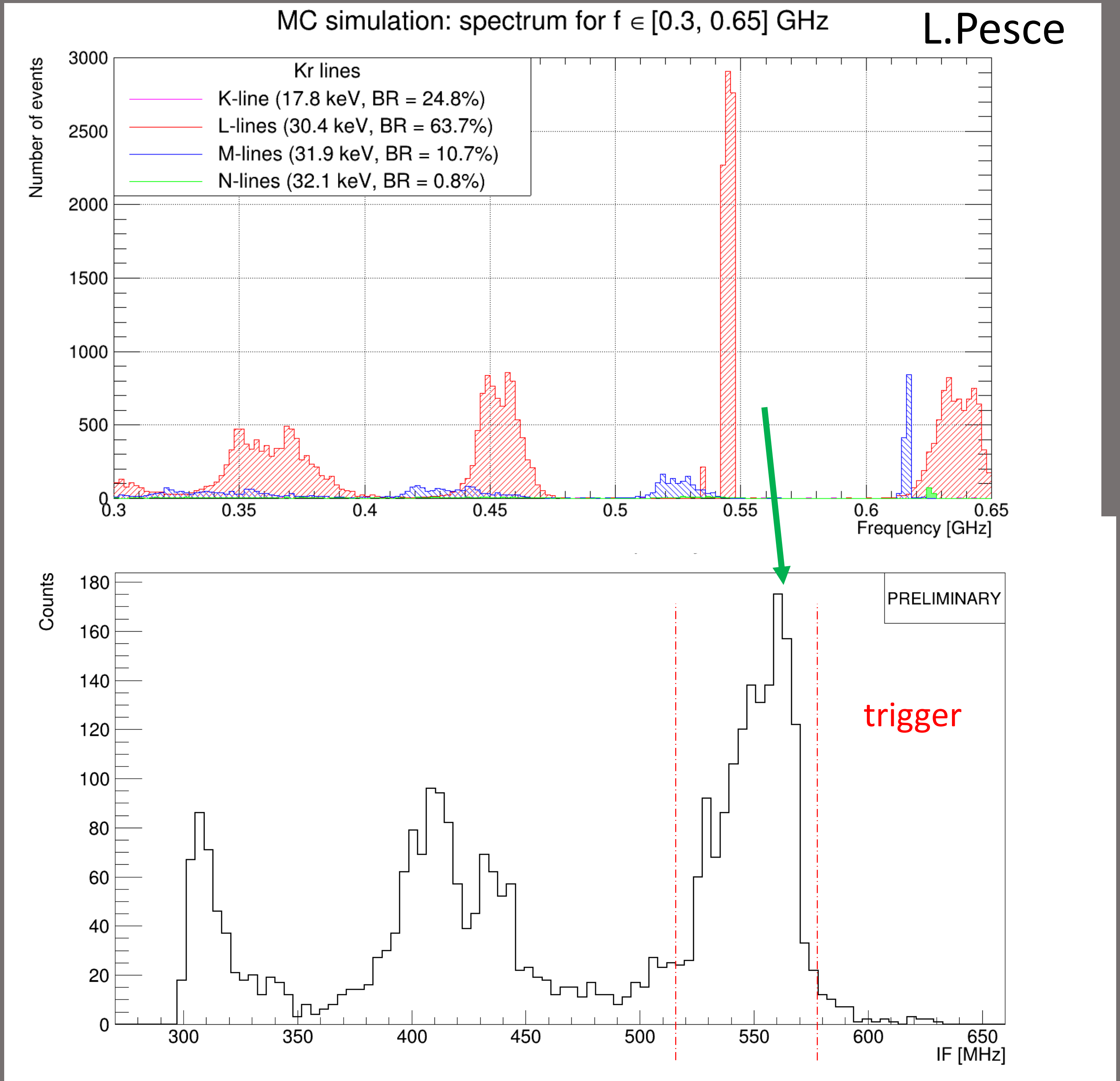
Montecarlo vs data

L.Pesce



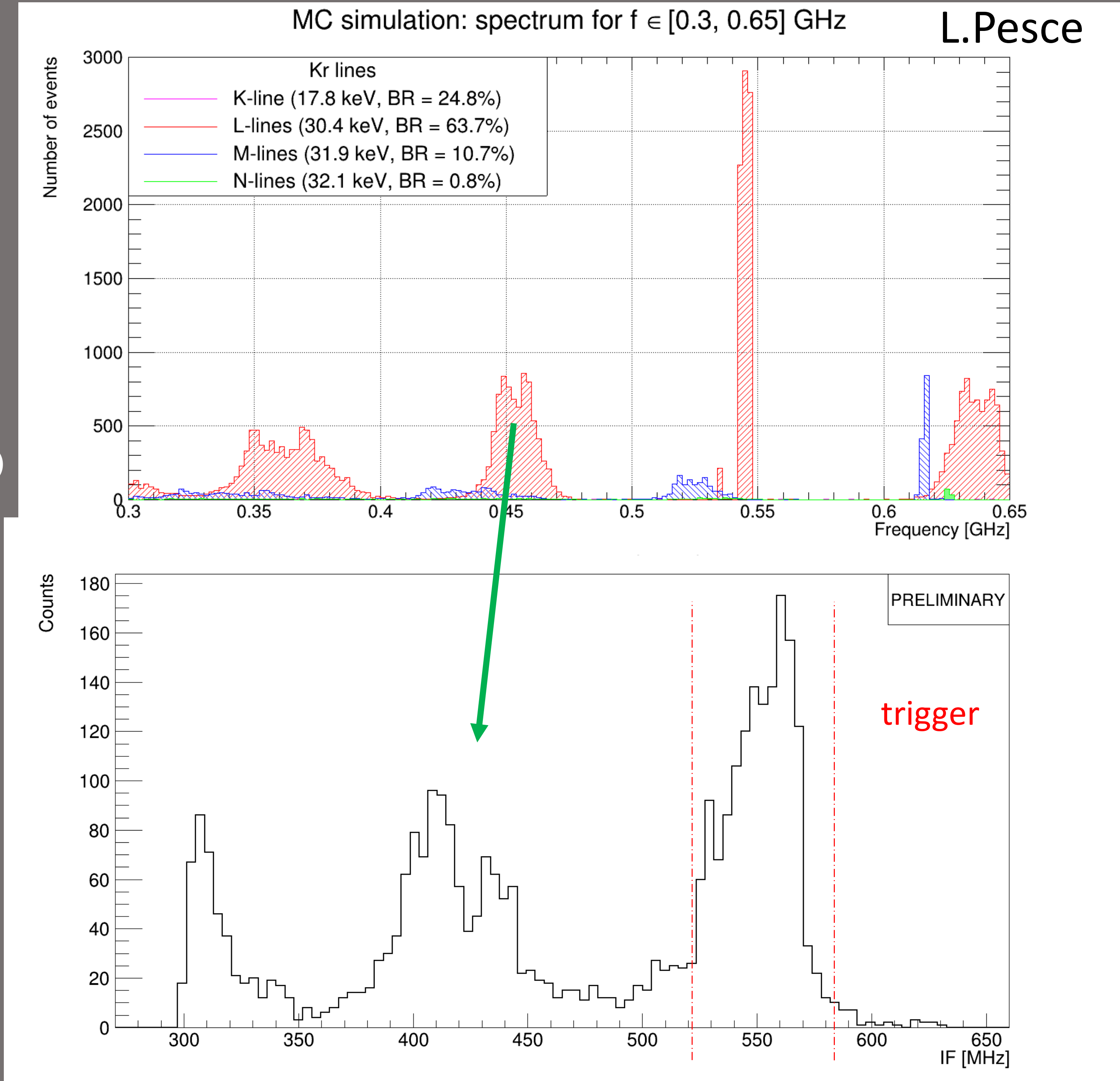


Montecarlo vs data



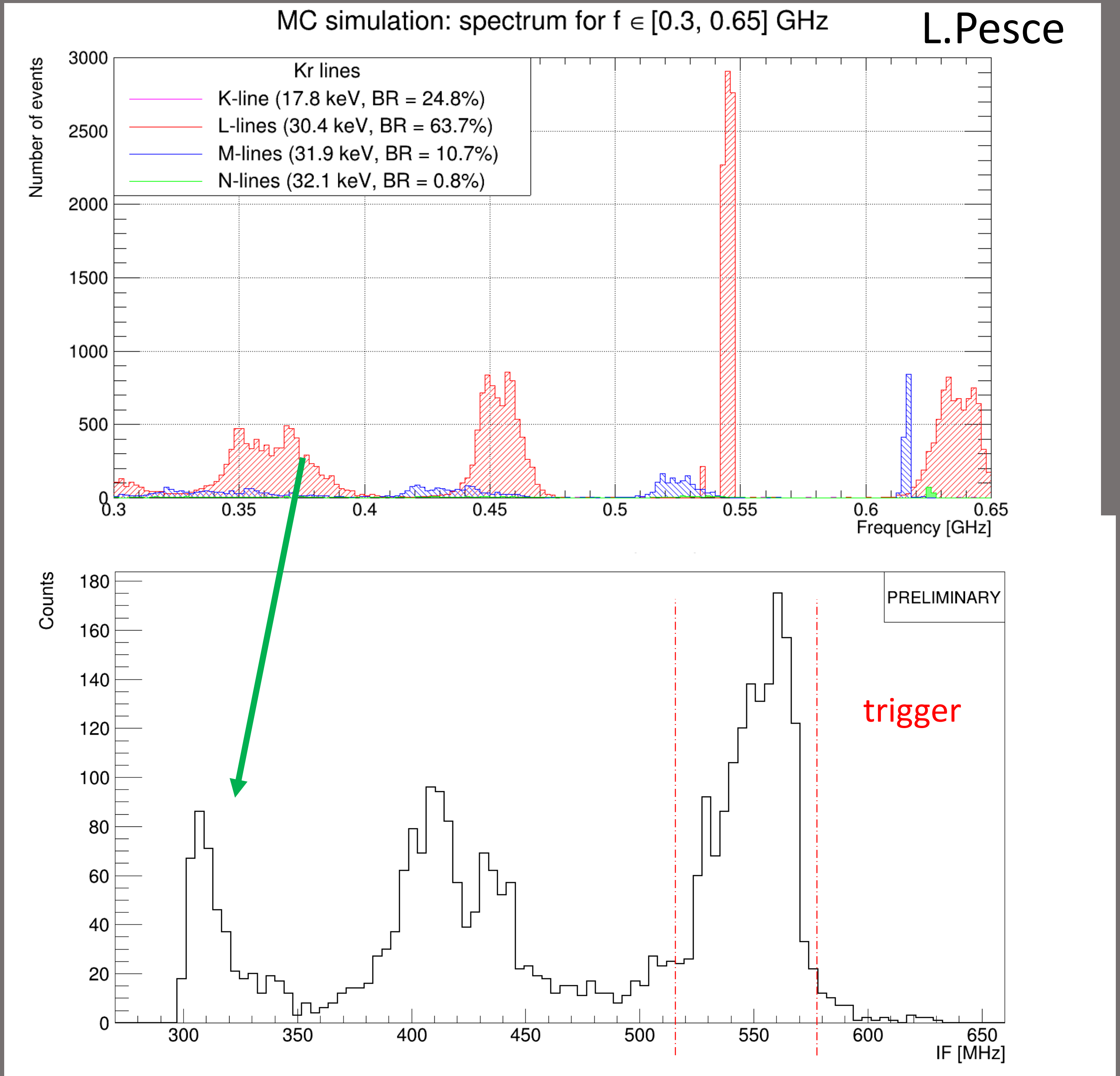
Narrow sideband (L1) in trigger zone

Montecarlo vs data



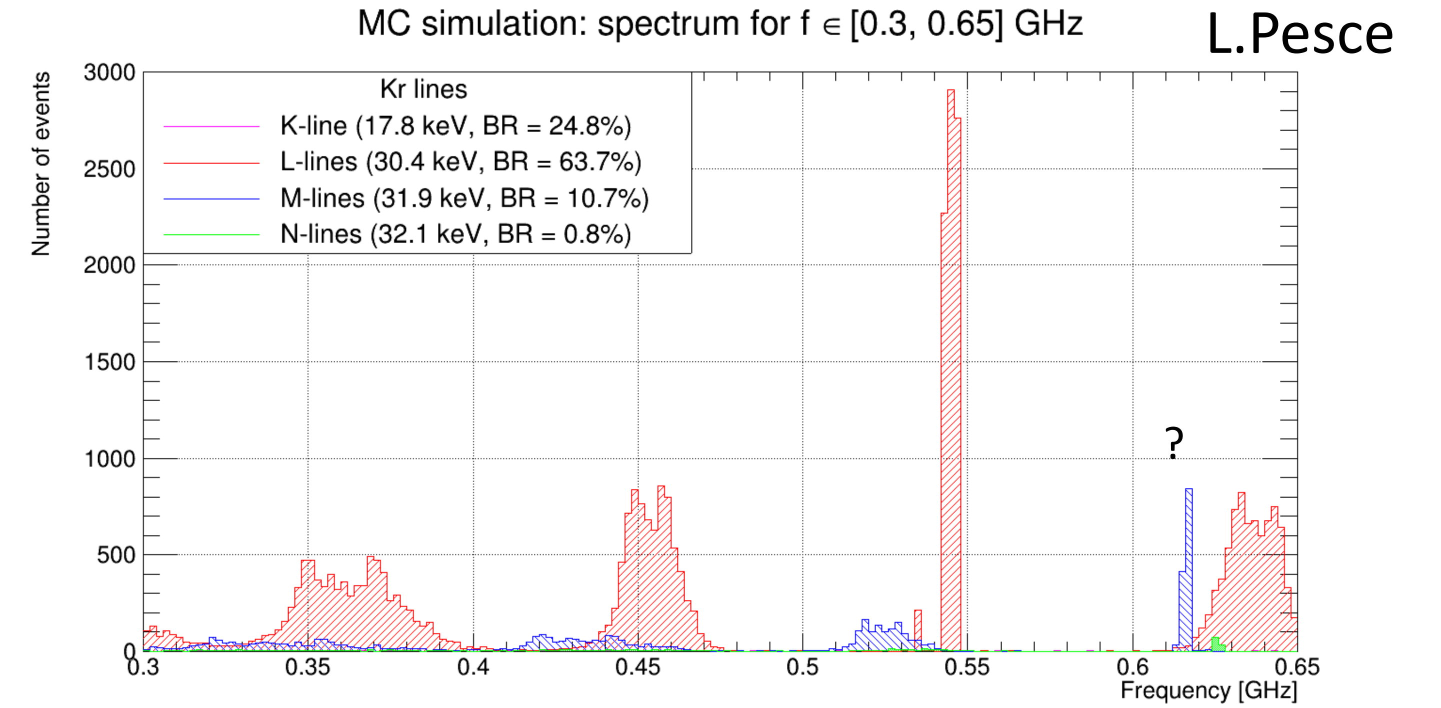
Double peak structure (carrier)

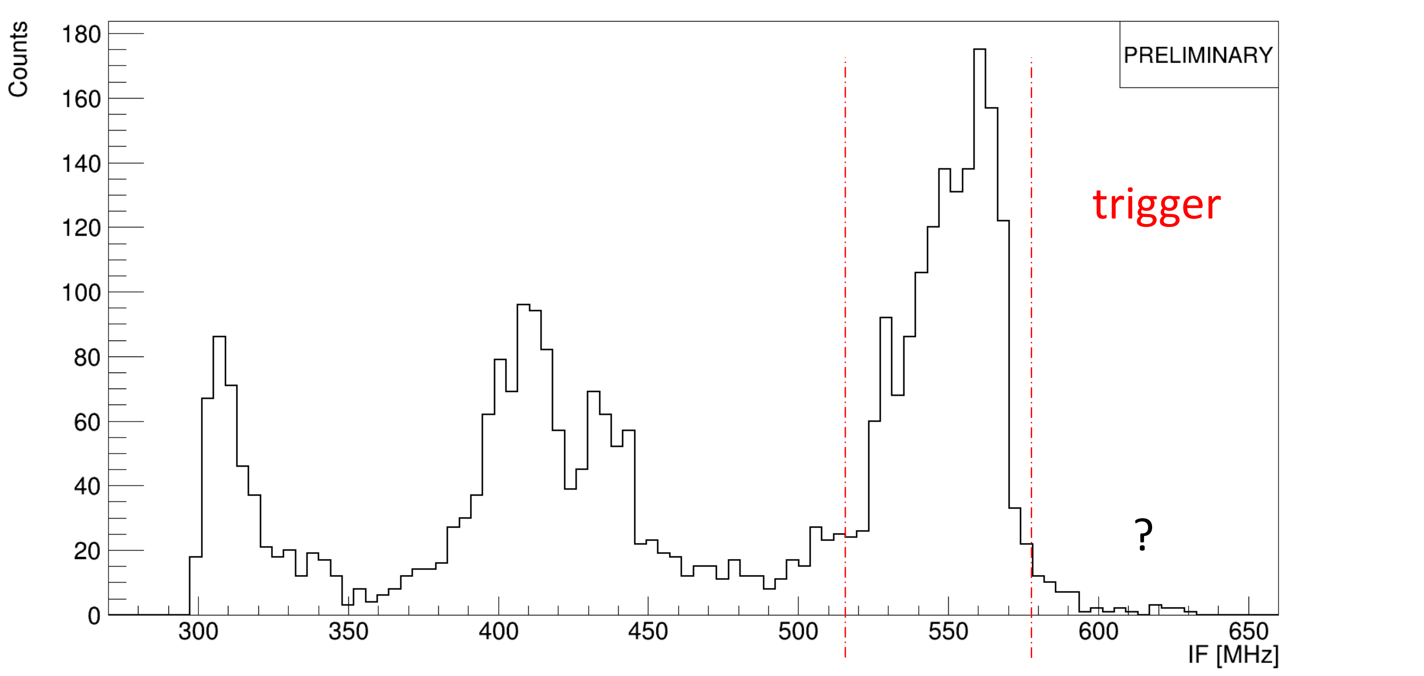
Montecarlo vs data



Rise of right sideband

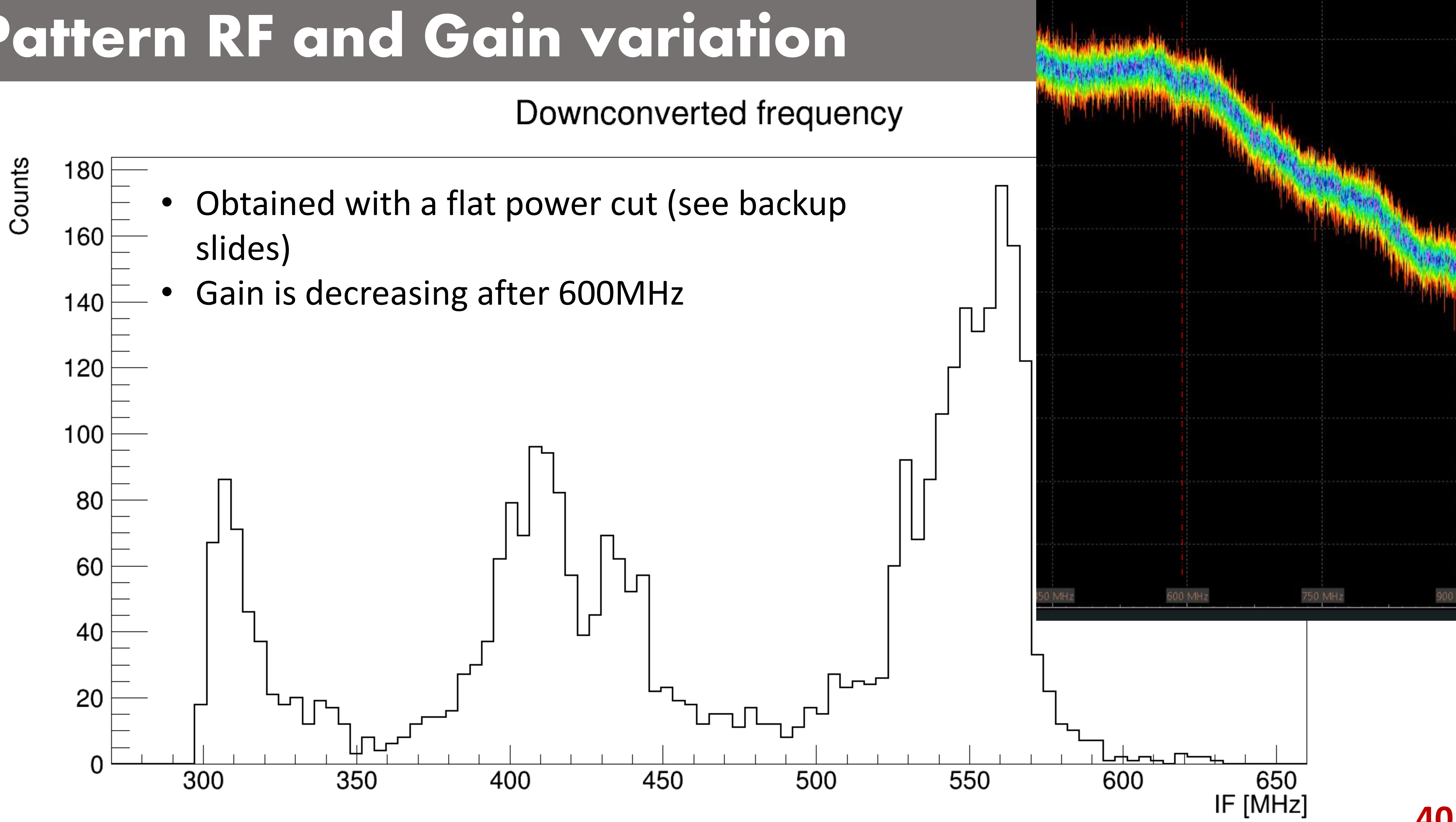
Narrow blue sideband?



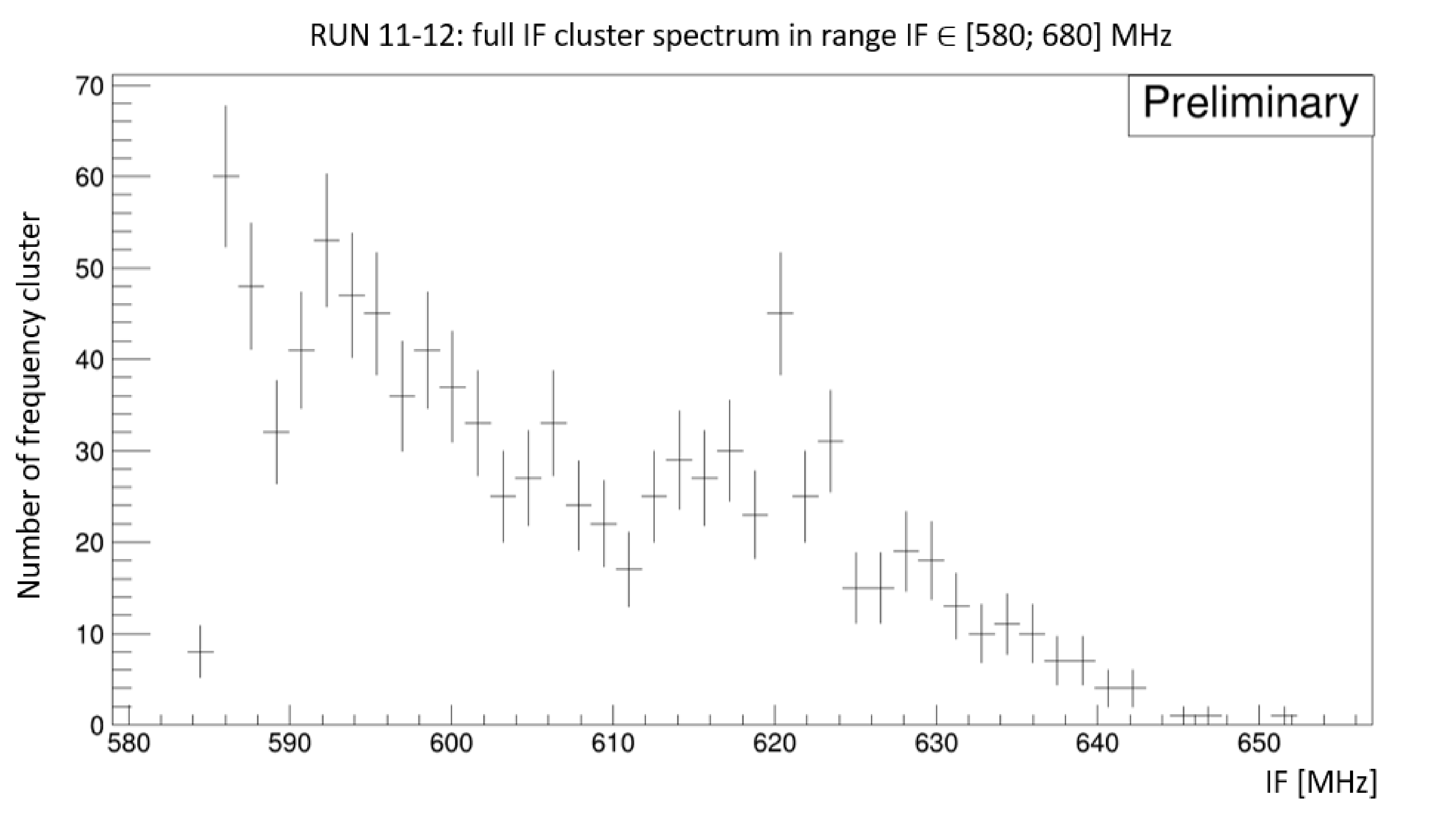


Pattern RF and Gain variation

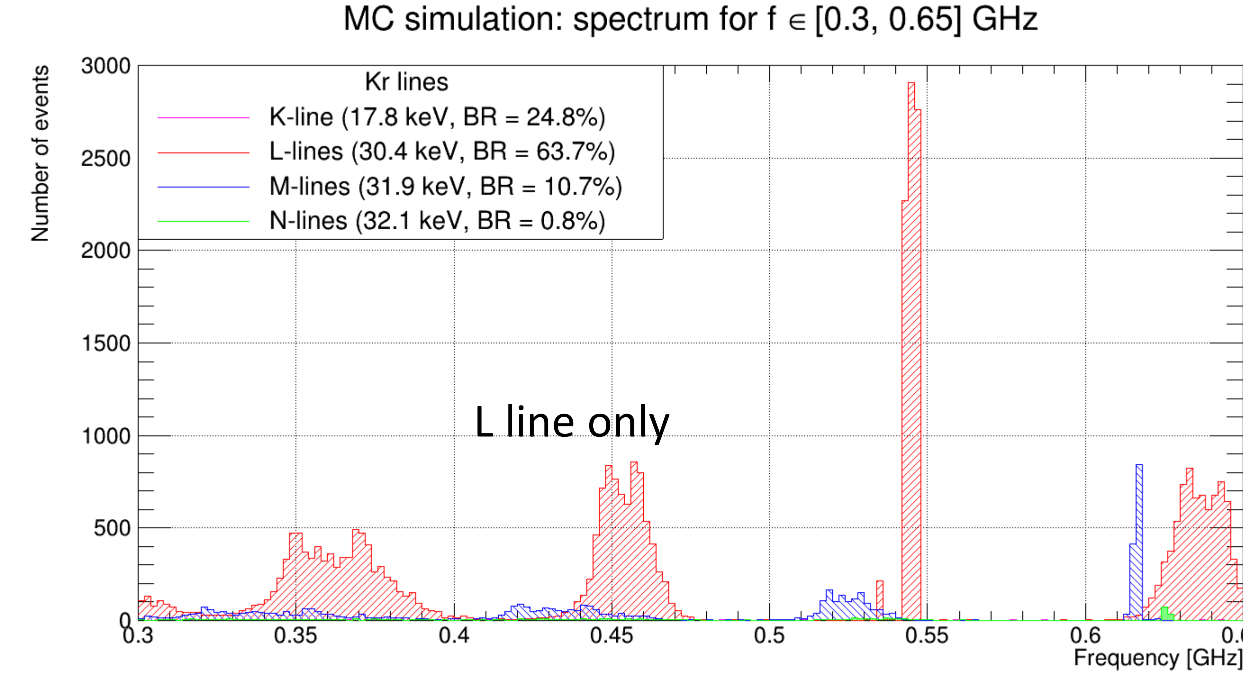
- Obtained with a flat power cut (see backup slides)
- Gain is decreasing after 600MHz

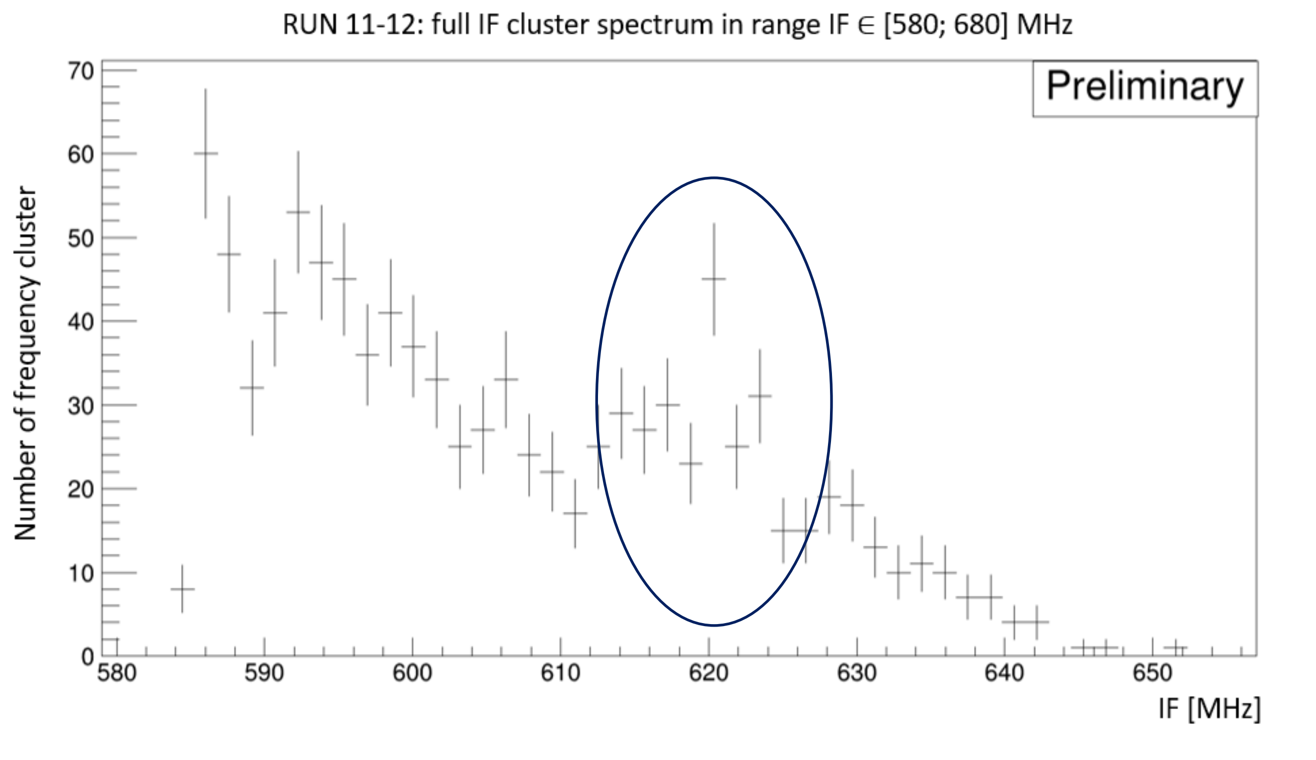


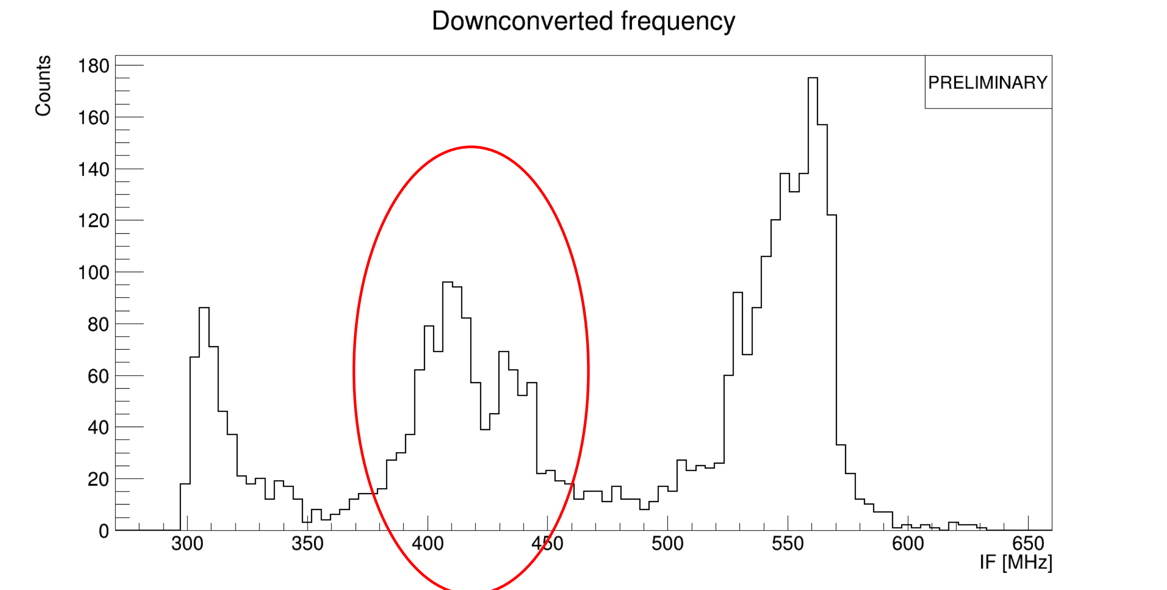
Candidate distribution of left sideband of M lines



Branching fraction ratio





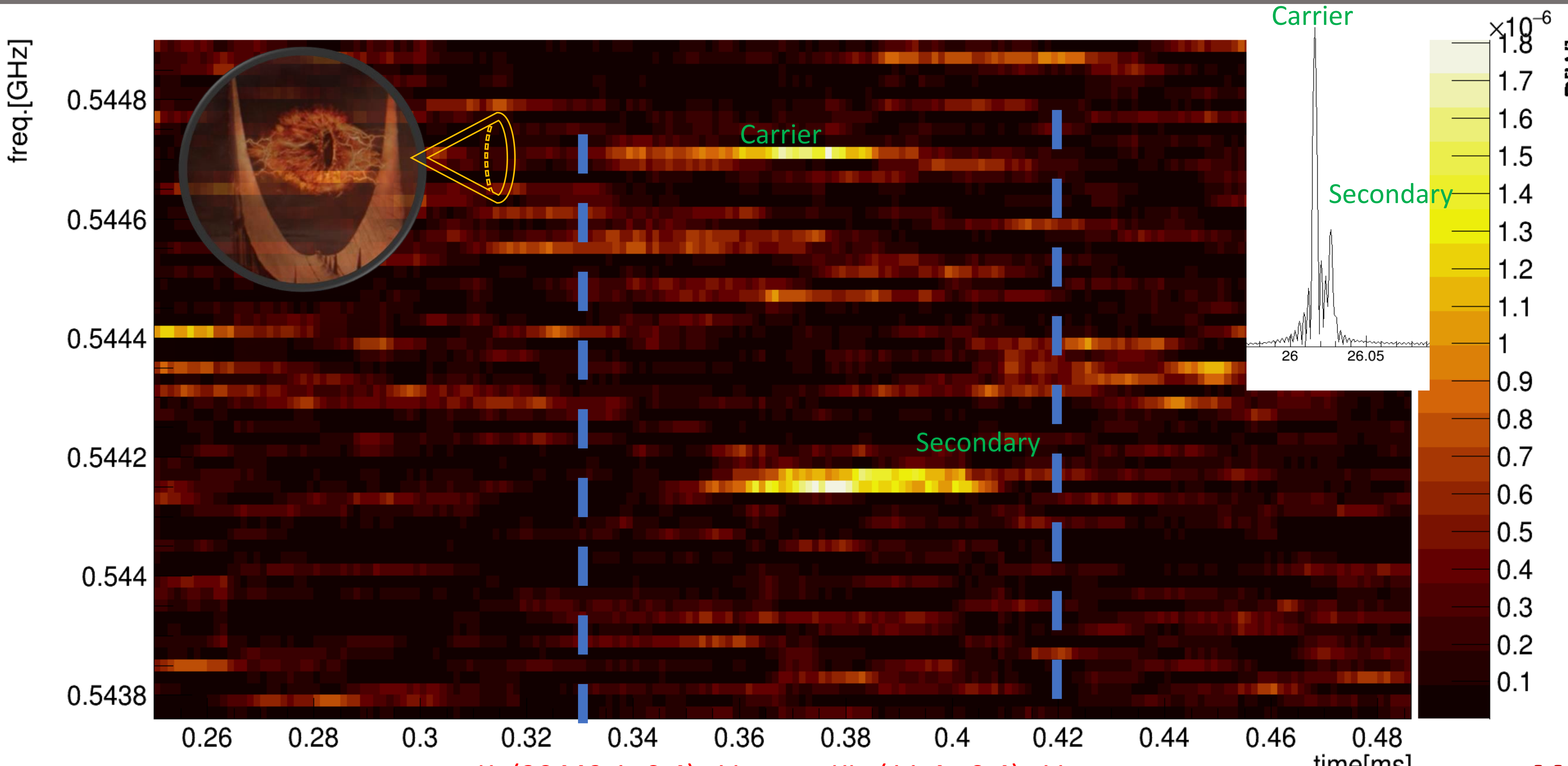


R_{teor}=BR(L)/BR(M)=5.95

$R_{measured}$=6.36+-1.04

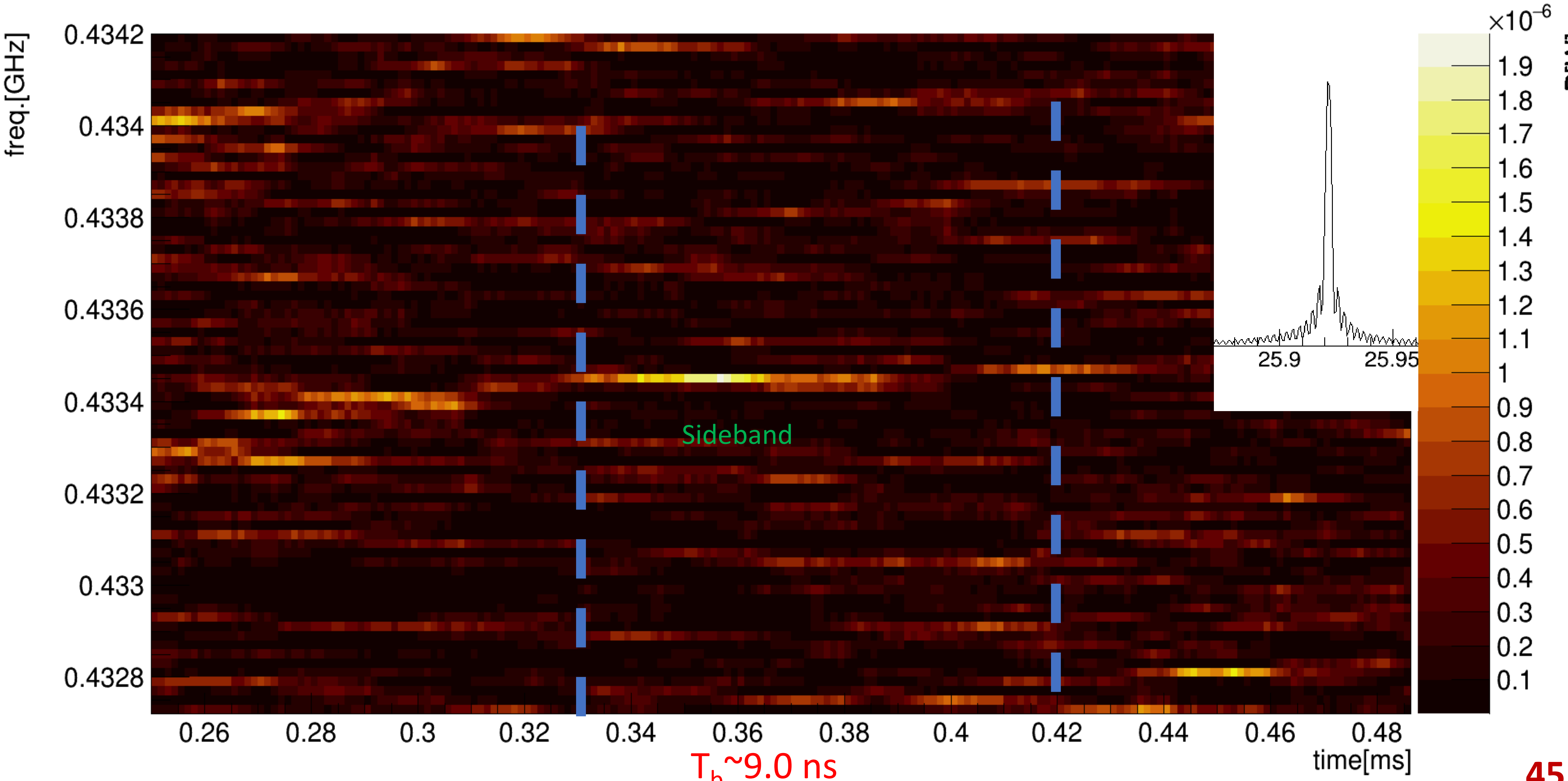
An example of a (nice) Sauron Plot

Carrier and secondary candidates



K=(30449,1±0.4) eV KL=(11.4 ±0.4) eV

Sideband candidate



T_b~9.0 ns

Electron trap phase 1: do we have measured electrons?

- Kripton lifetime mesurement
- Pattern RF
- Short tracks (and so no df/dt due to radiation emission) why?
- Hard background rejection

Electron trap: systematics

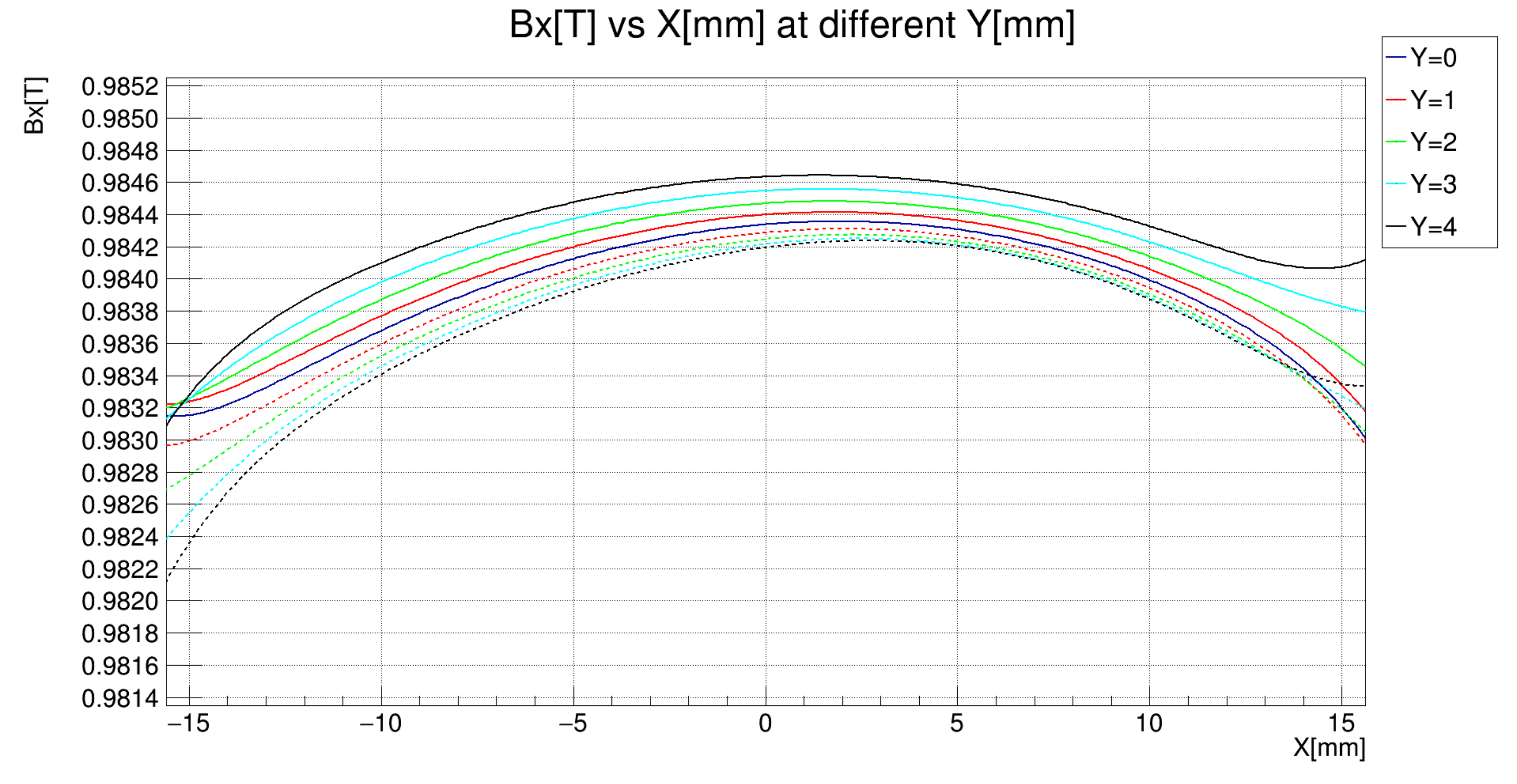
…Yes, the talk is almost concluded

Understanding the systematics of electron trap setup

- Effective Magnetic field
- Relative angle trap-magnet
- Bended electrodes
- Variation of gain during the day

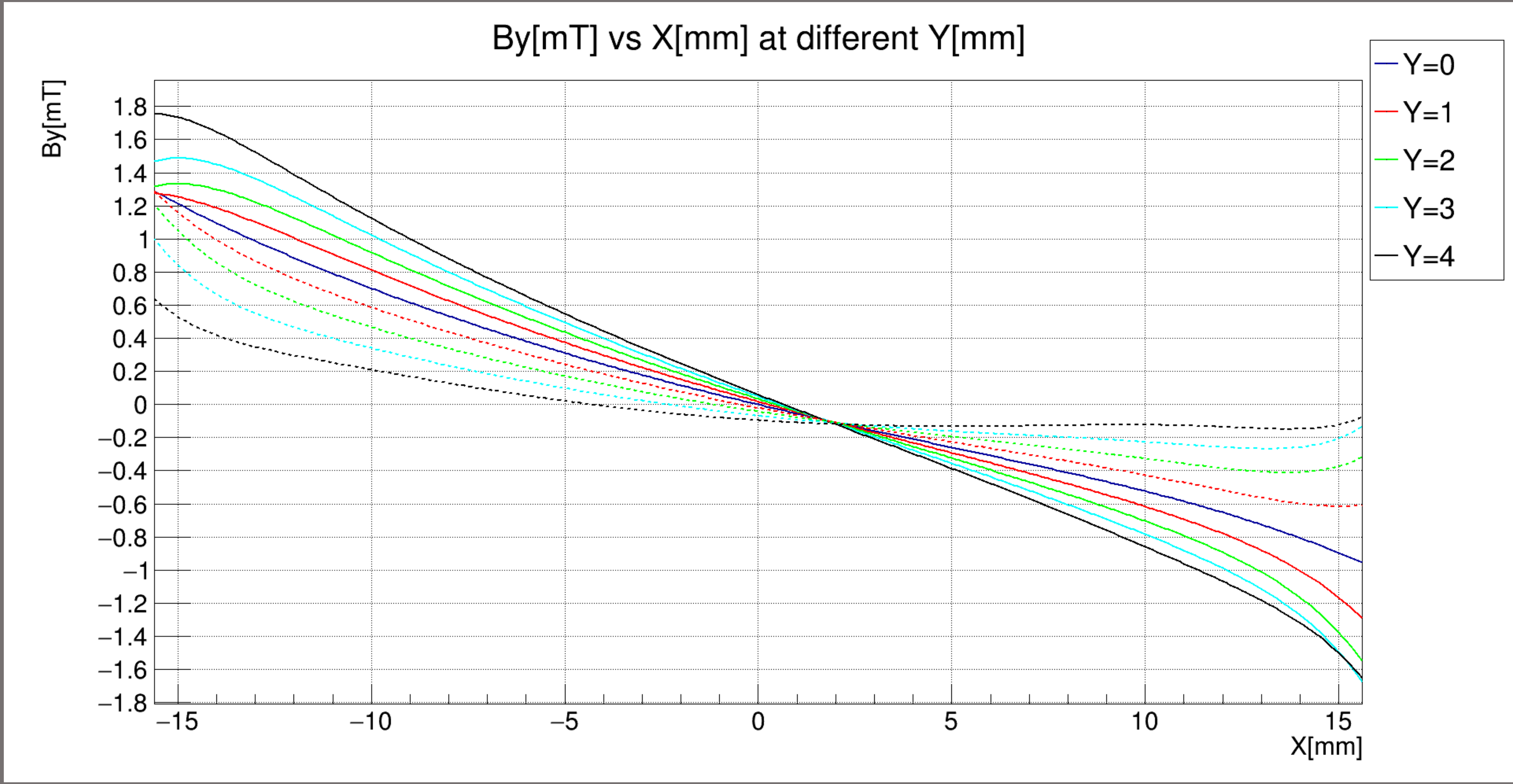
Field map: Bx

- Need to implement the true field map on CST



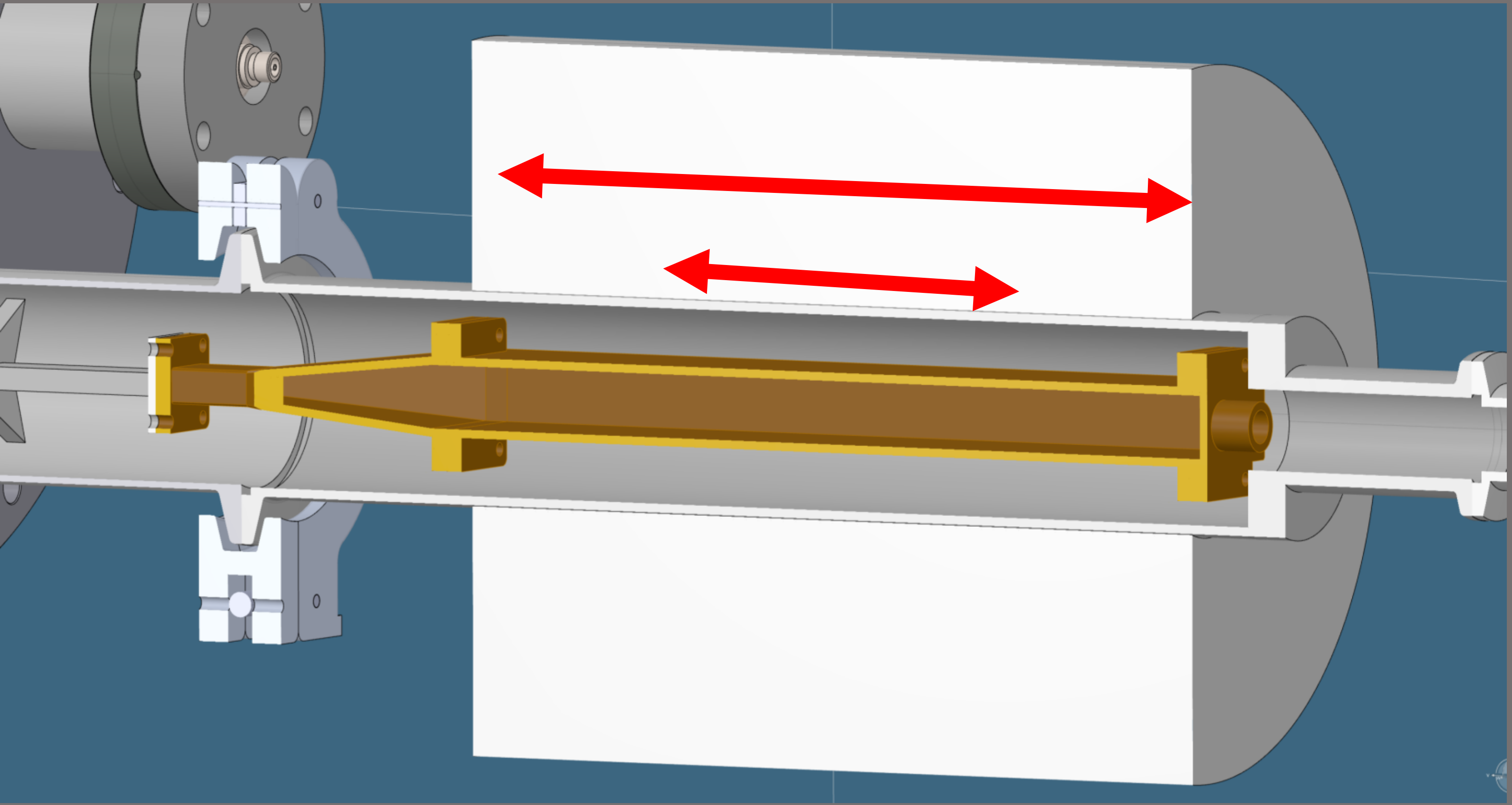
Field map: By

- Need to implement the true field map on CST



Magnetic field effective volume

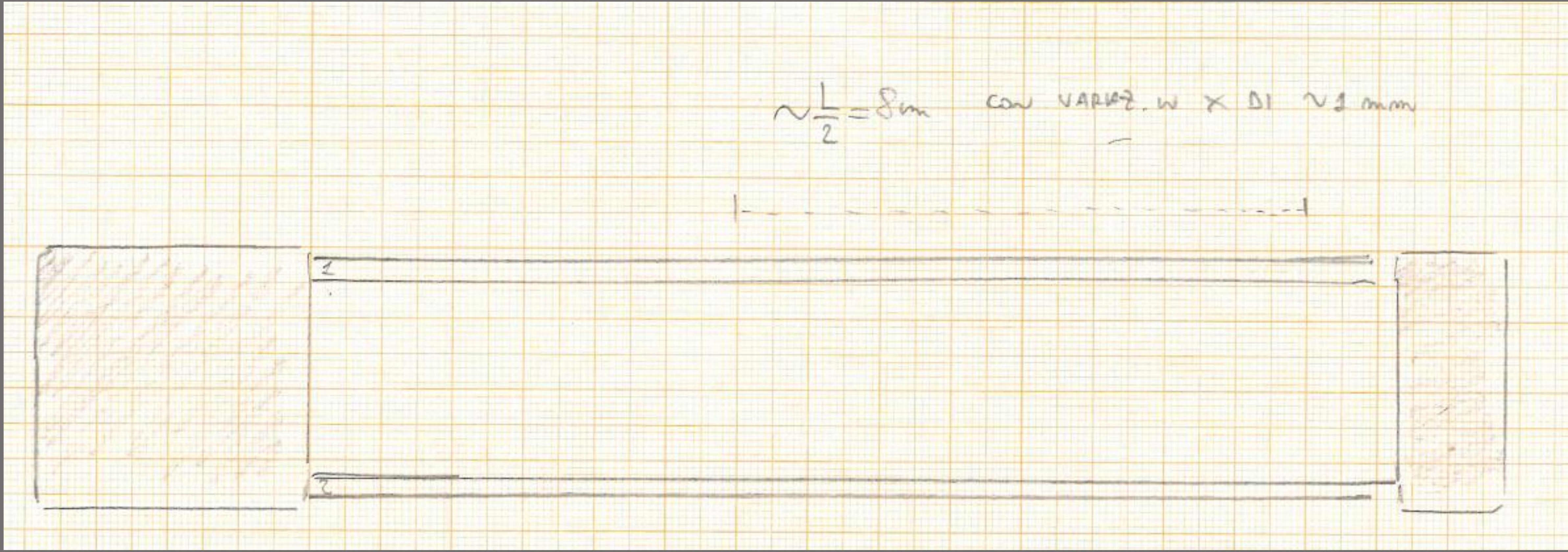
- We have seen (with an home-made probe) that the effective volume of magnetic field is half of the expected
- Centering of the trap is crucial



We are buying a 3000 E probe for magnetic field measurement for field map task

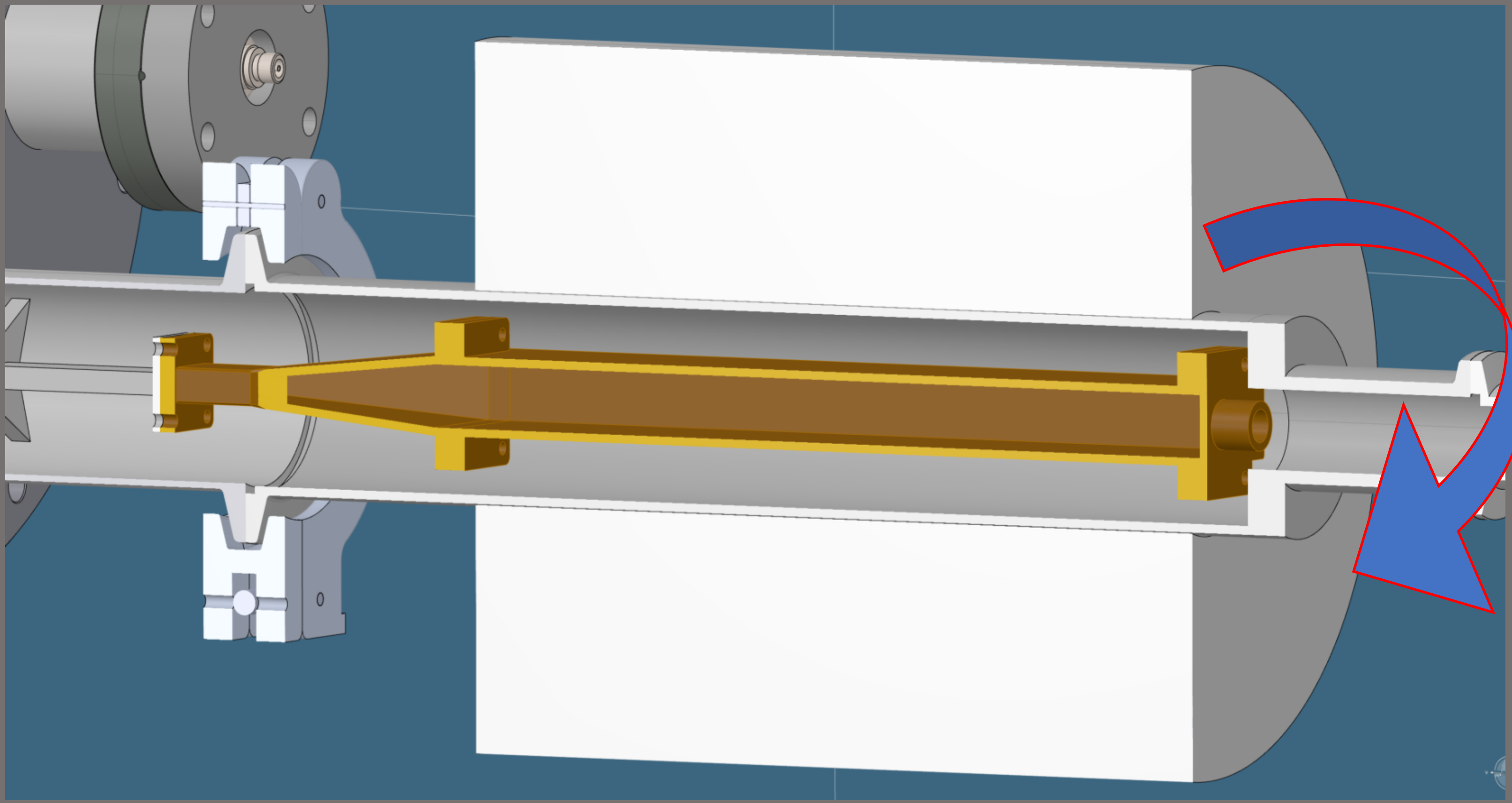
Bended electrodes

- Electrodes of phase 1 were lightly bended
- Possible effect on electron drift?



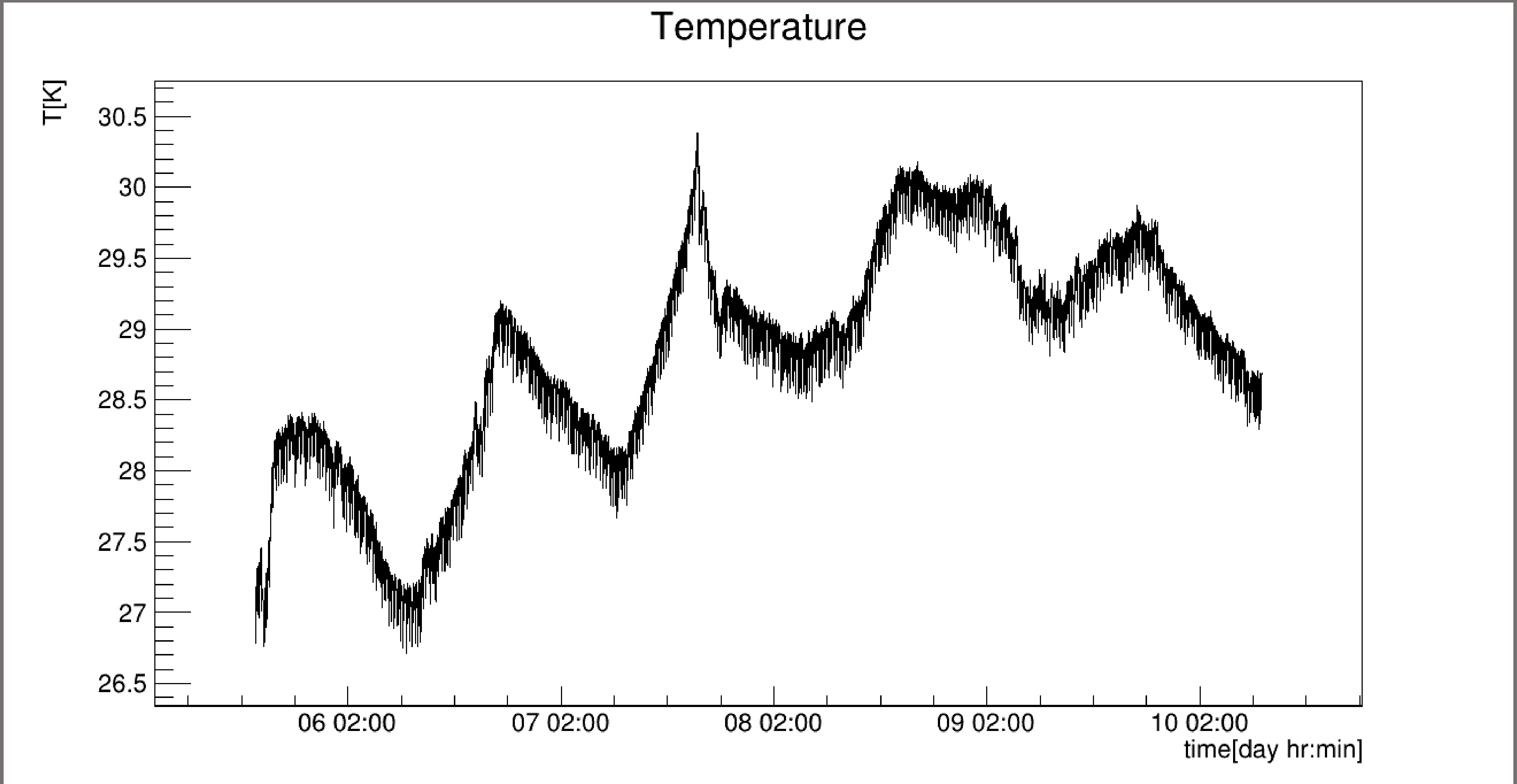
Relative angle between trap and magnet

- Possible sisyematics for pitch angle, bouncing period and Vz?



Temperature improvements

- Better insulation between phase 1 and 2 (best temperature T=23K)
- Still have cyrcadian modulation->PID



Electron trap: outlook

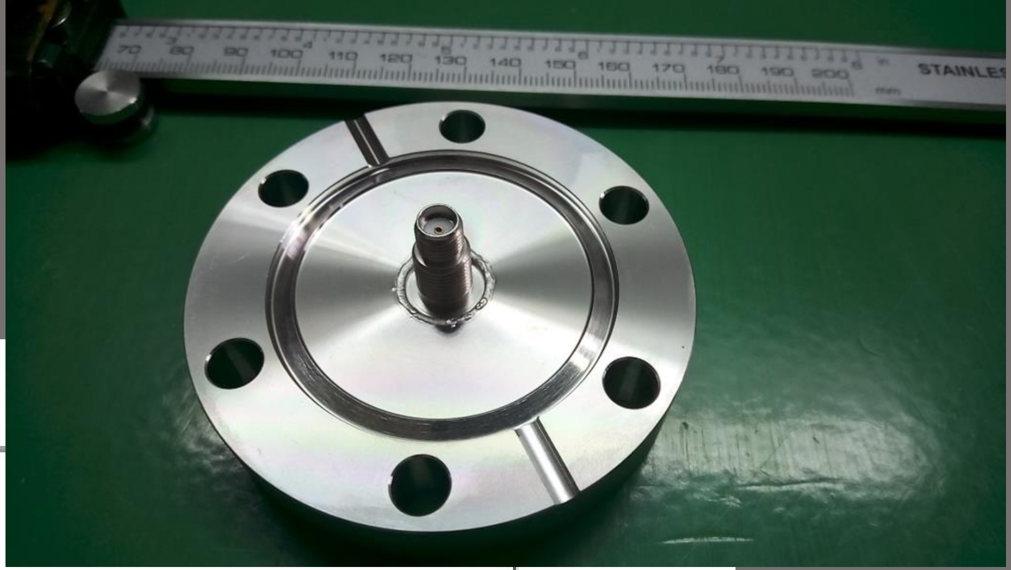
Ok, now the talk is really almost concluded

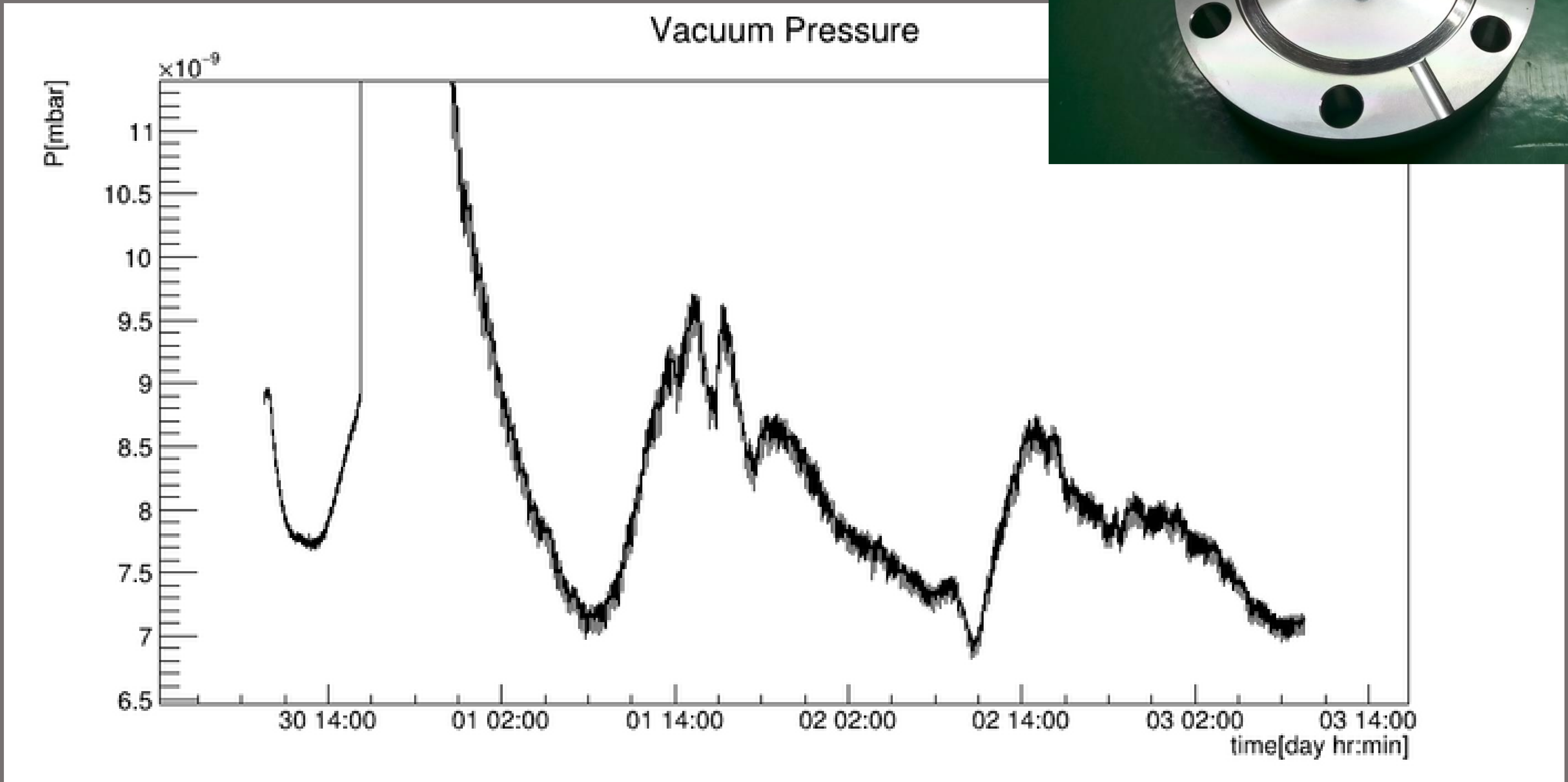
Electron Trap phase 2

- Goal: obtain material for a convincent Paper
- Longer tracks?
- Higher SNR?

New RF flange

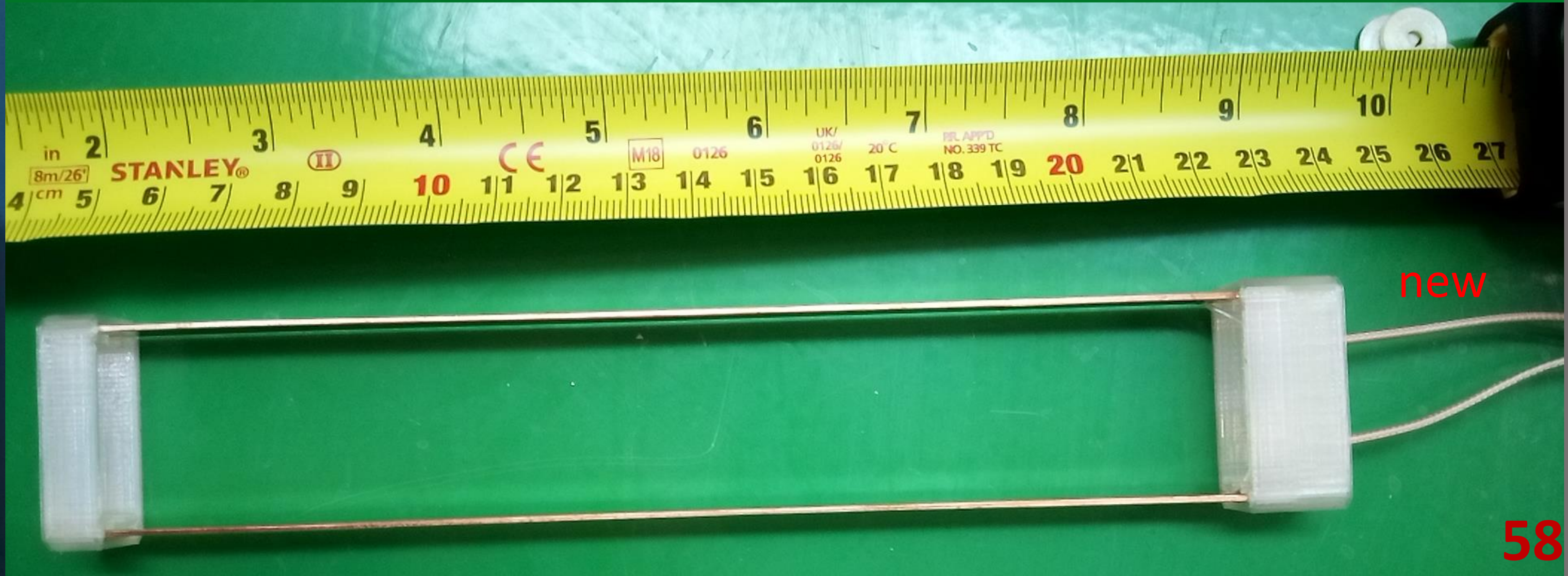
- Better vacuum pressure thanks to new RF flange(x2)





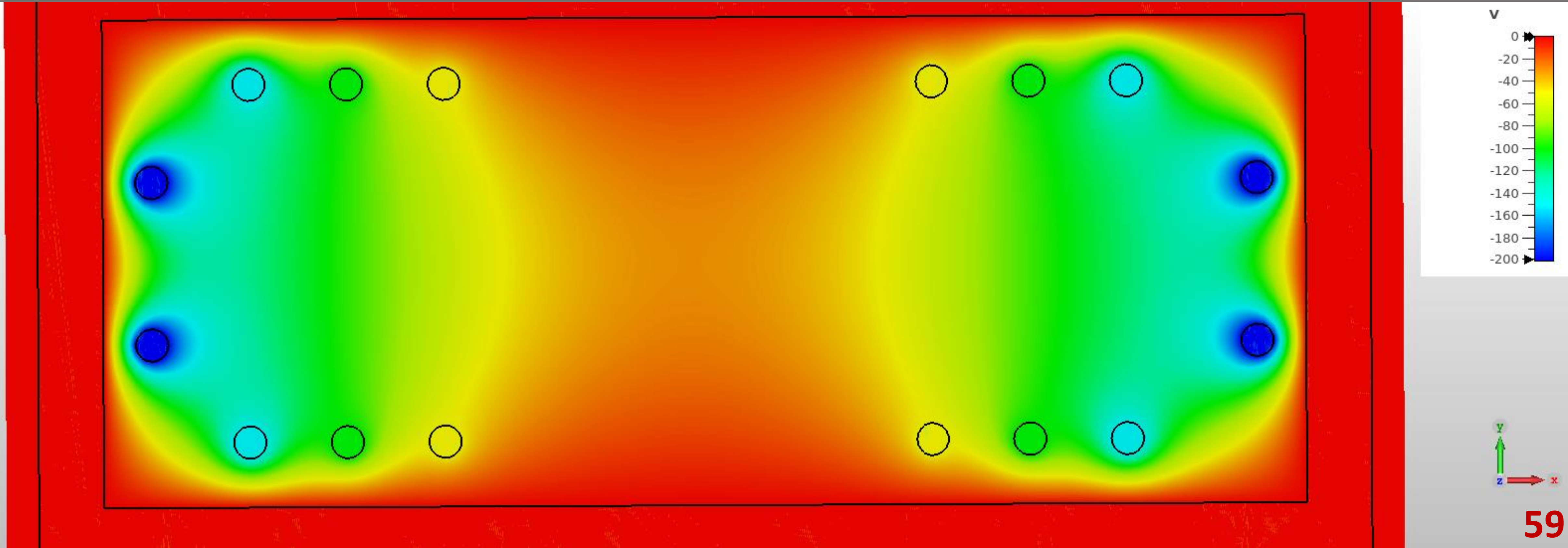
New electrodes support and thin electrodes

- Half of conductor volume
- ¼ of dielectric volume
- Less power loss (5.5dB instead of 8.3dB)->Better rejection



Electron trap phase3 (march?)

- Wire electrodes (much less Vz->longer tracks)
- High activity source



Conclusions

PHASE 4 :
Injection with e-gun

5/6/24 3/7/24

PHASE 1*:
Setup commissioning and preliminary data taking

PHASE 2:

- Good electron track identification
- first Paper
- K,KL reconstruction on event by event basis

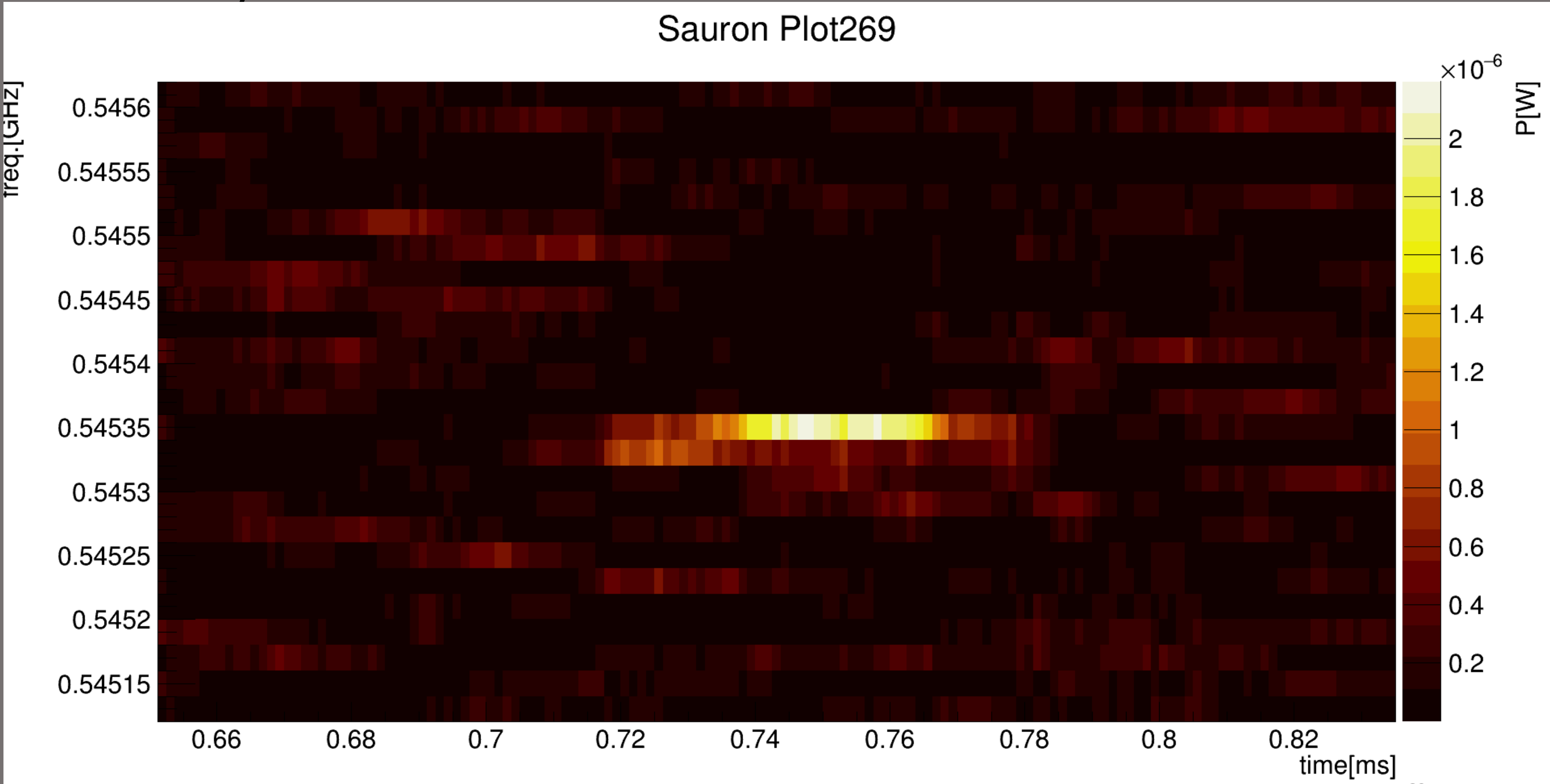
PHASE 3:

- σ_E, T_{obs}, K,KL reconstruction based on event by event basis, with large statistics
- second Paper with 'official numbers'

Need more activity, new source?

Backup slides

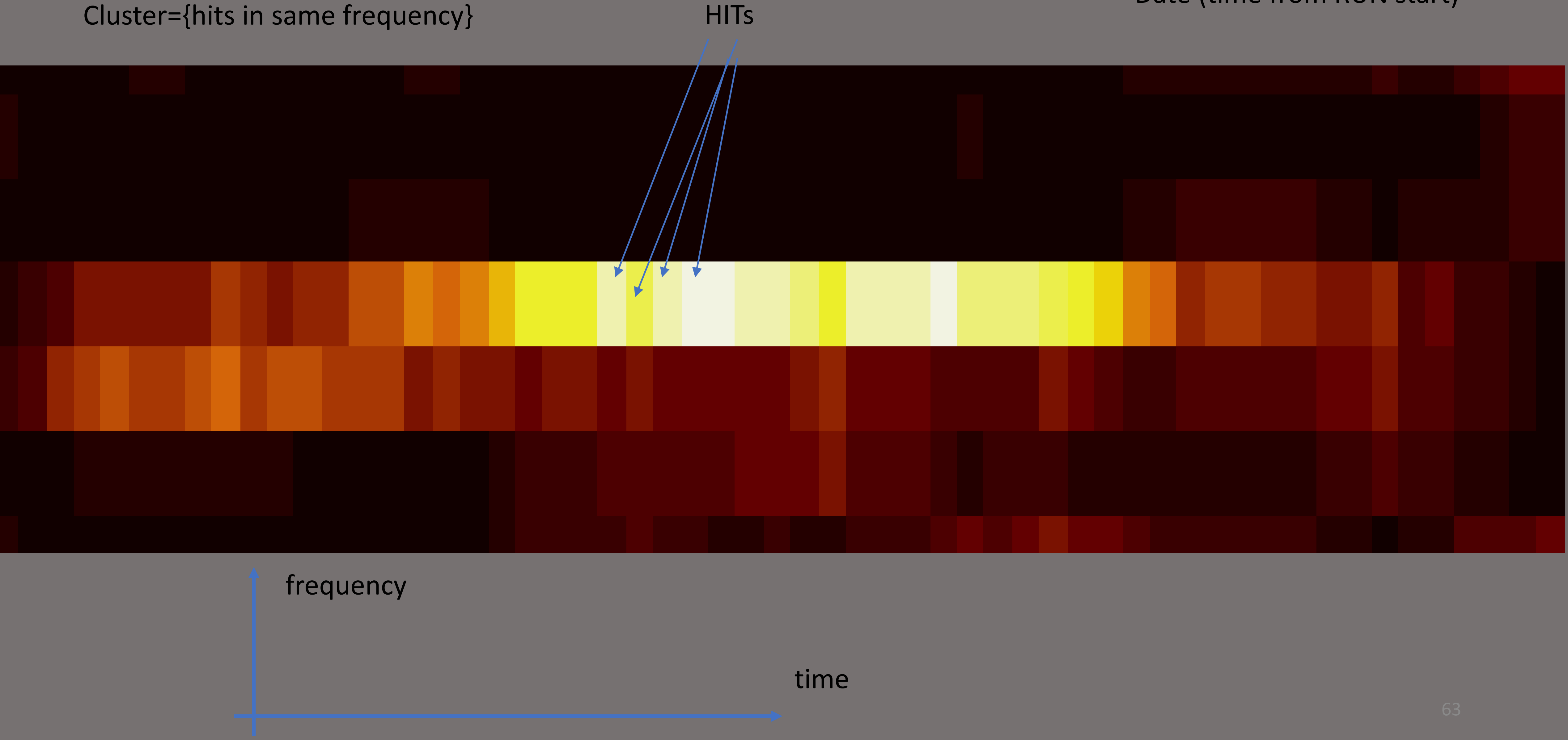
Data analysis



Data analysis

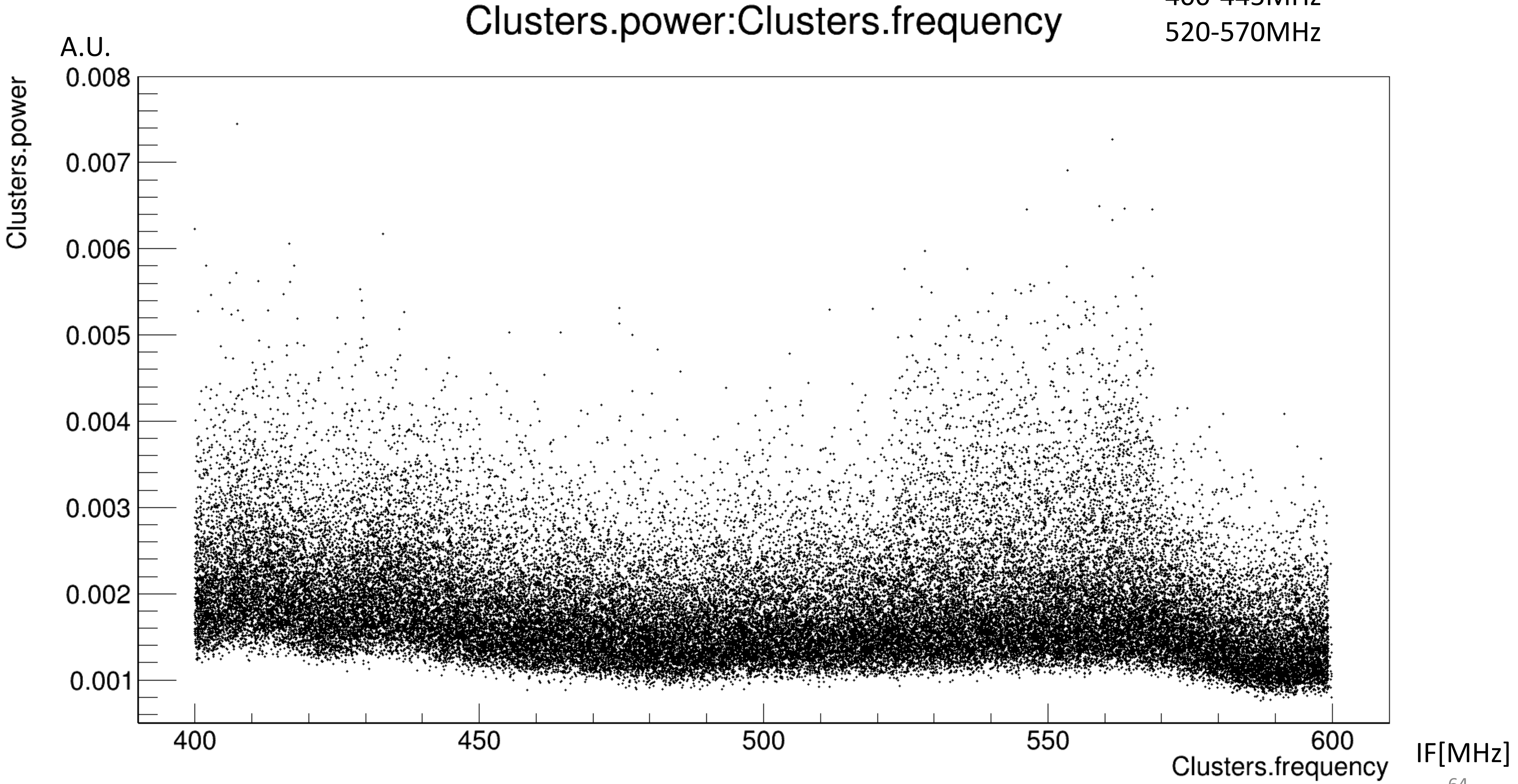
HIT → Frequency
Power
Time
Date (time from RUN start)

Cluster={hits in same frequency}



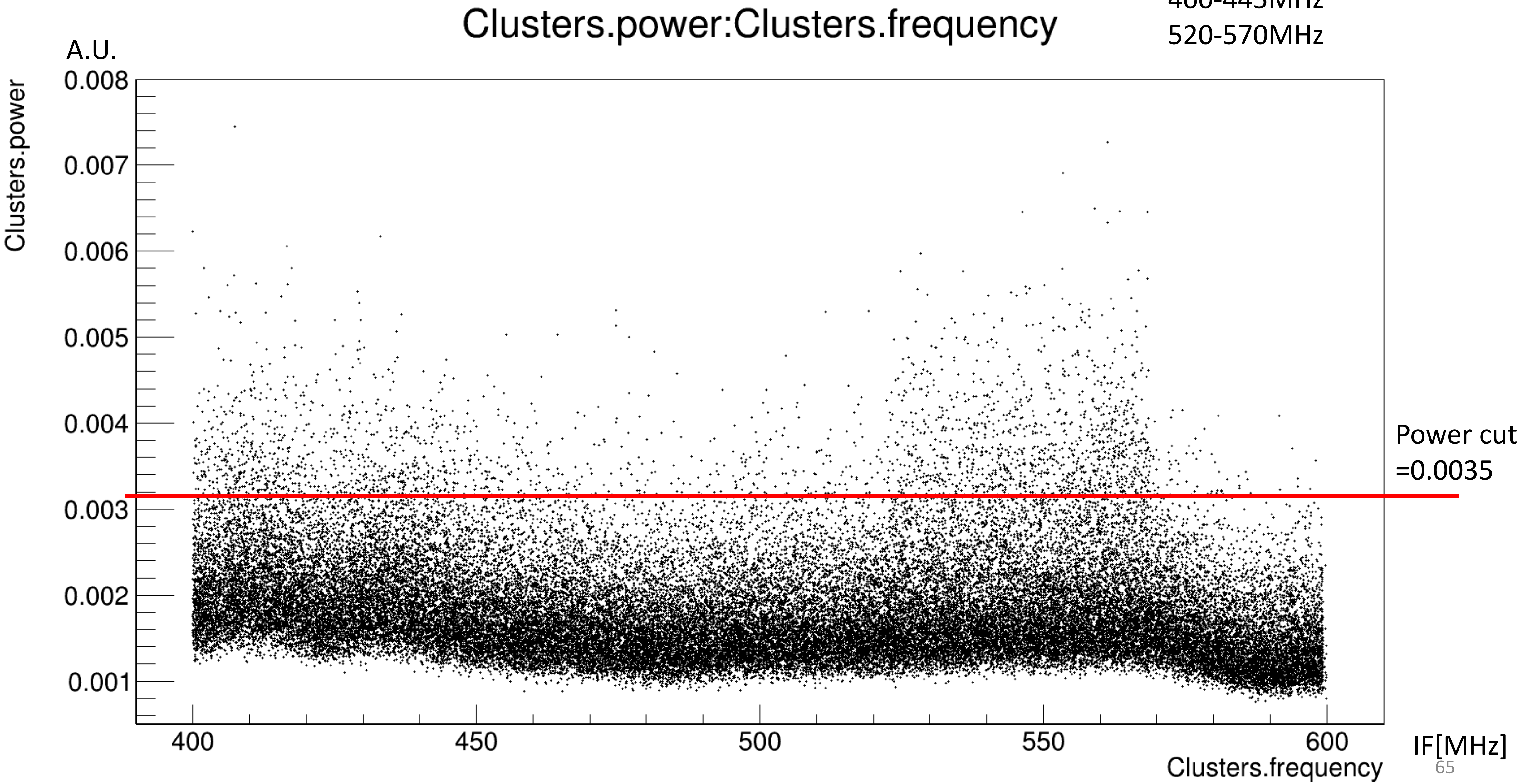
Cluster integrated power vs frequency

clusters with most power at
400-445MHz
520-570MHz



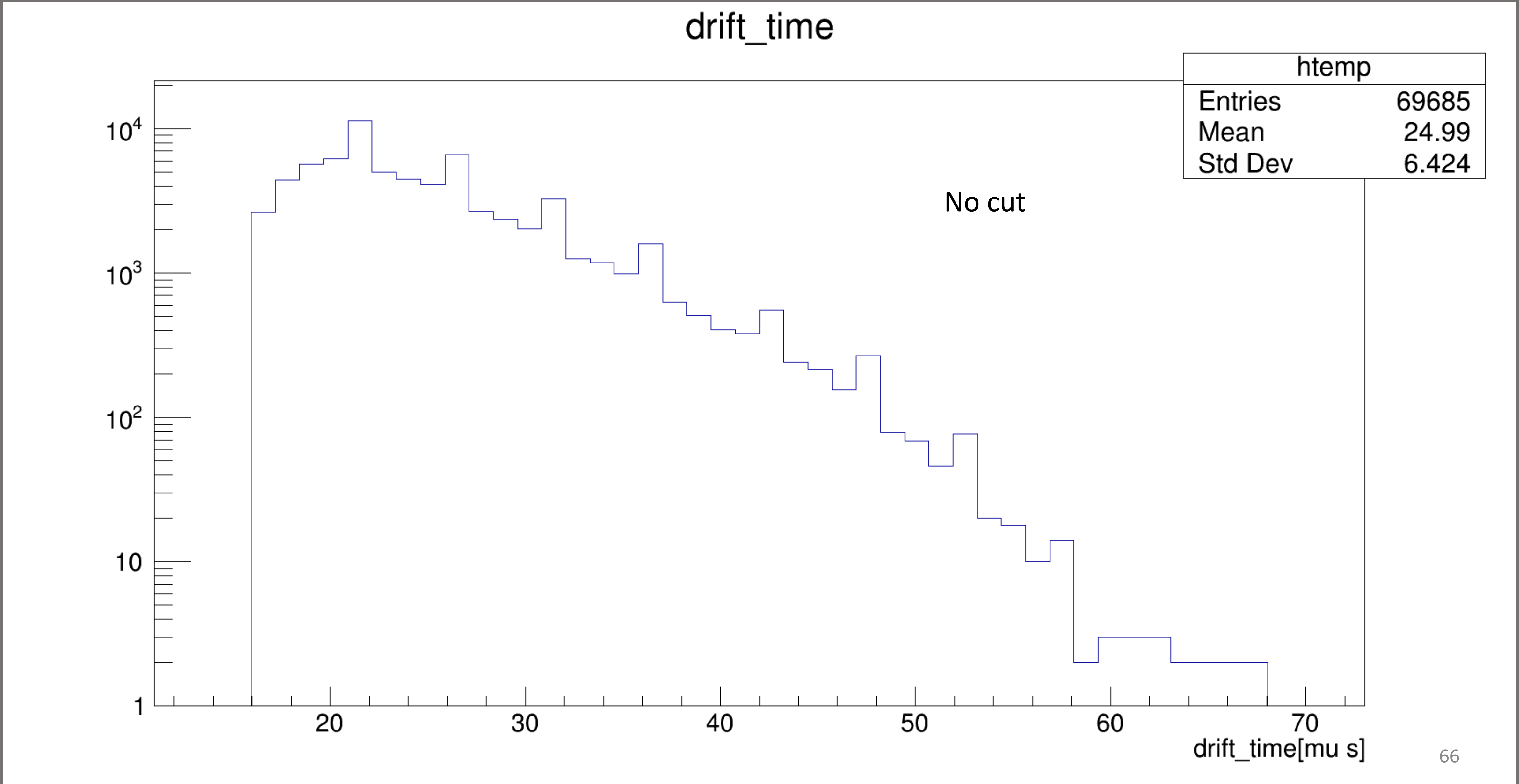
Cluster integrated power vs frequency

clusters with most power at
400-445MHz
520-570MHz

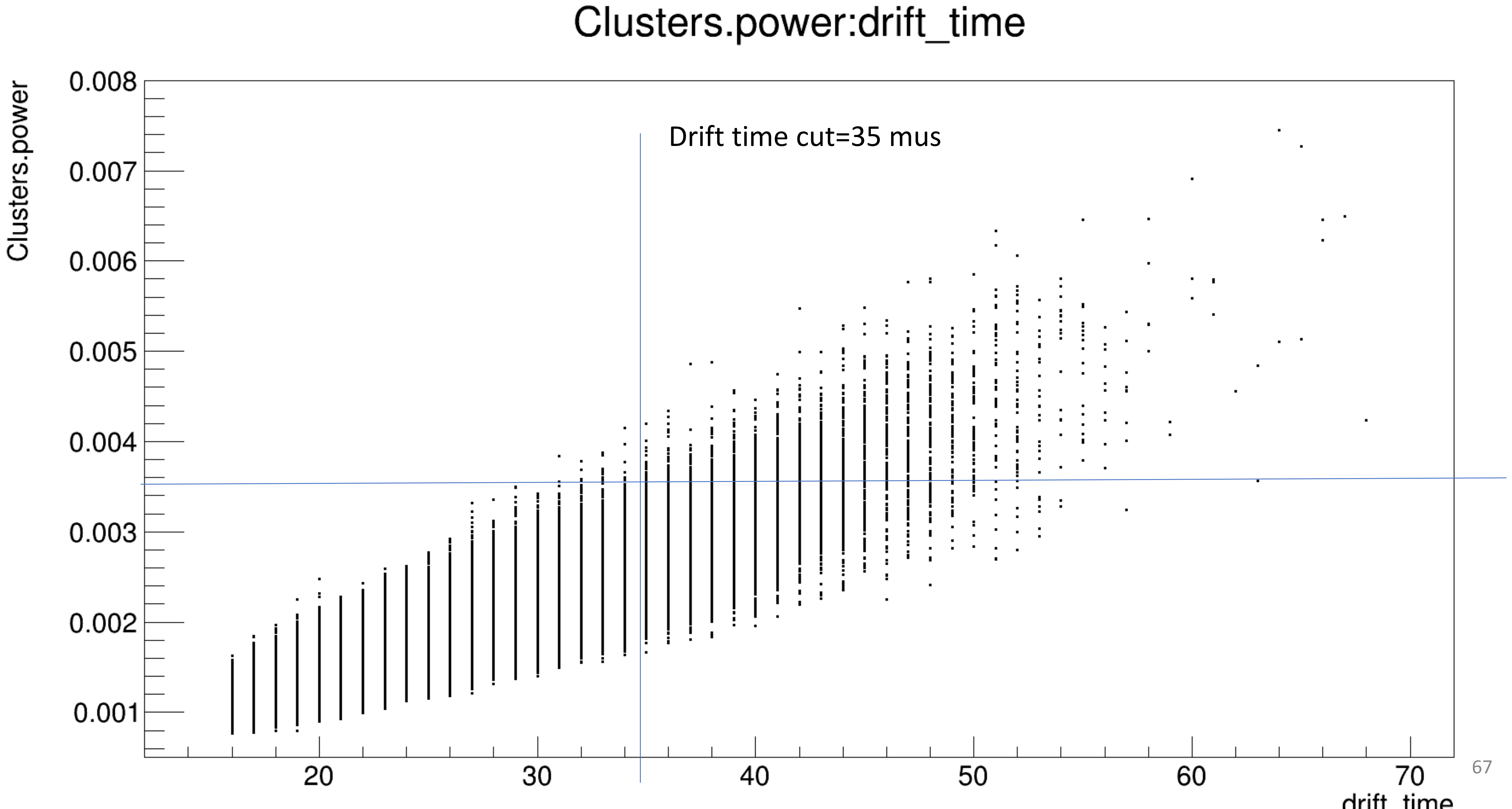


Clusters drift time

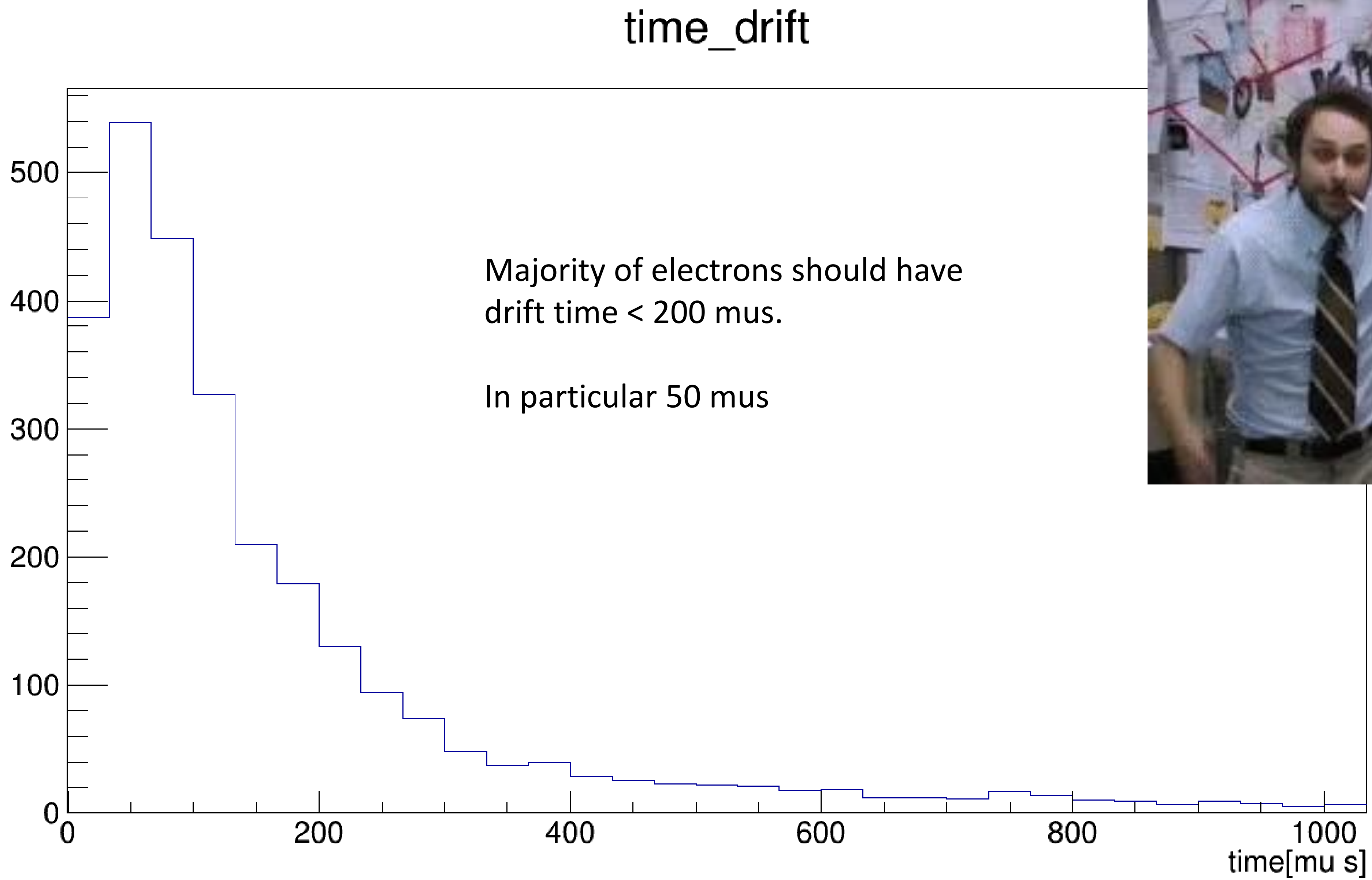
Electron trap is 20cm long
We are searching for long tracks → Electrons are very fast in bouncing geometry!!!



Cluster power v drift time

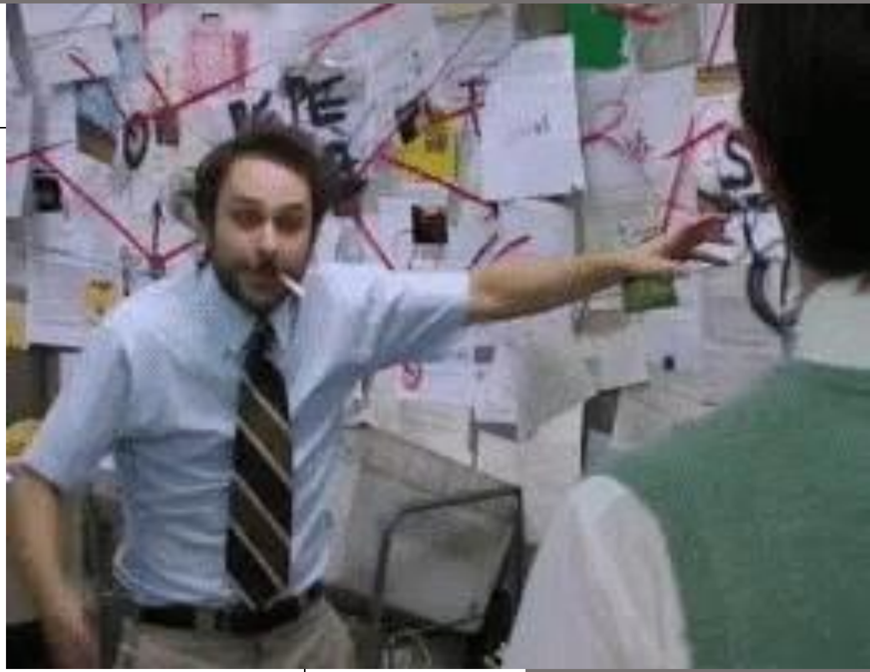


Expected electron drift time: montecarlo

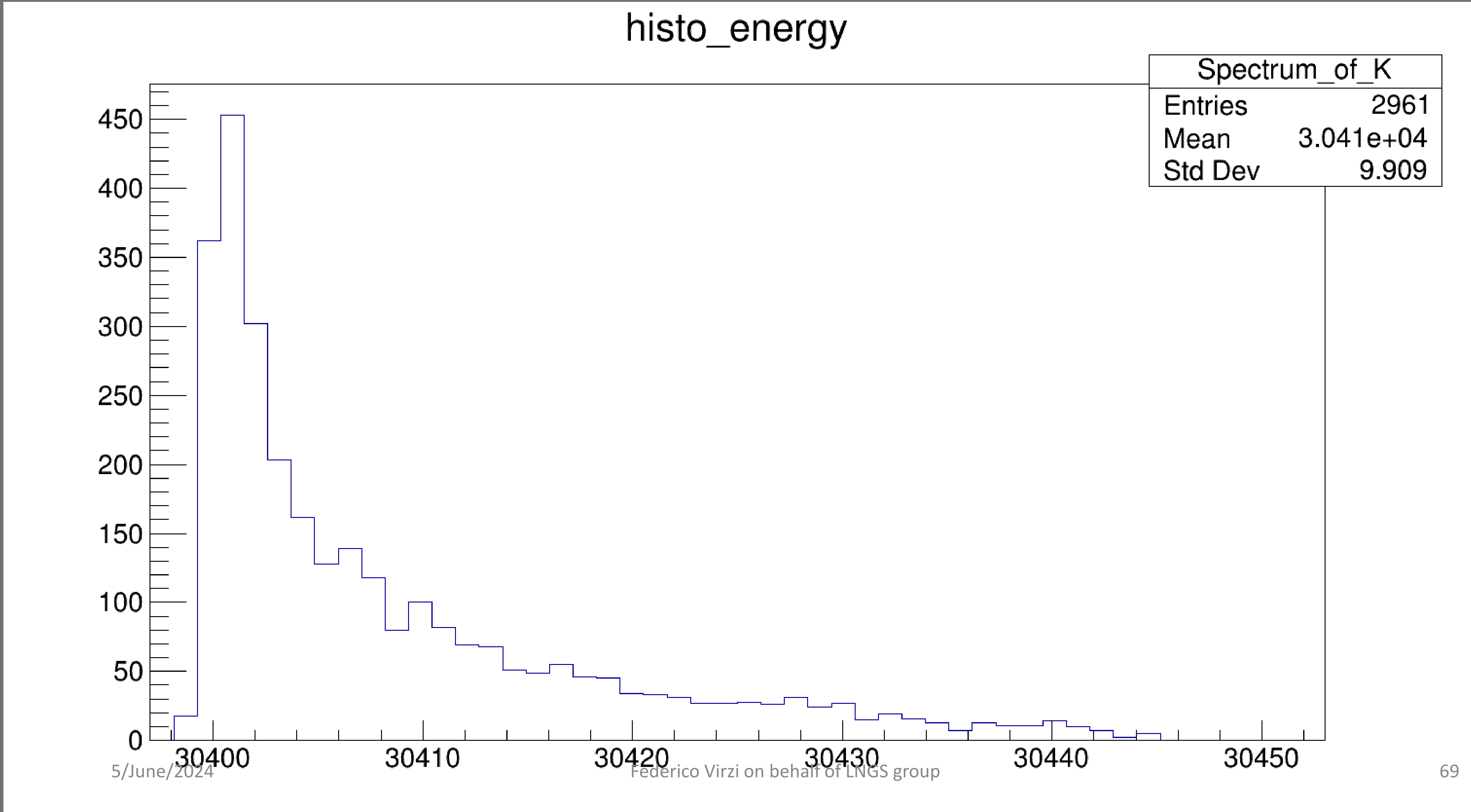


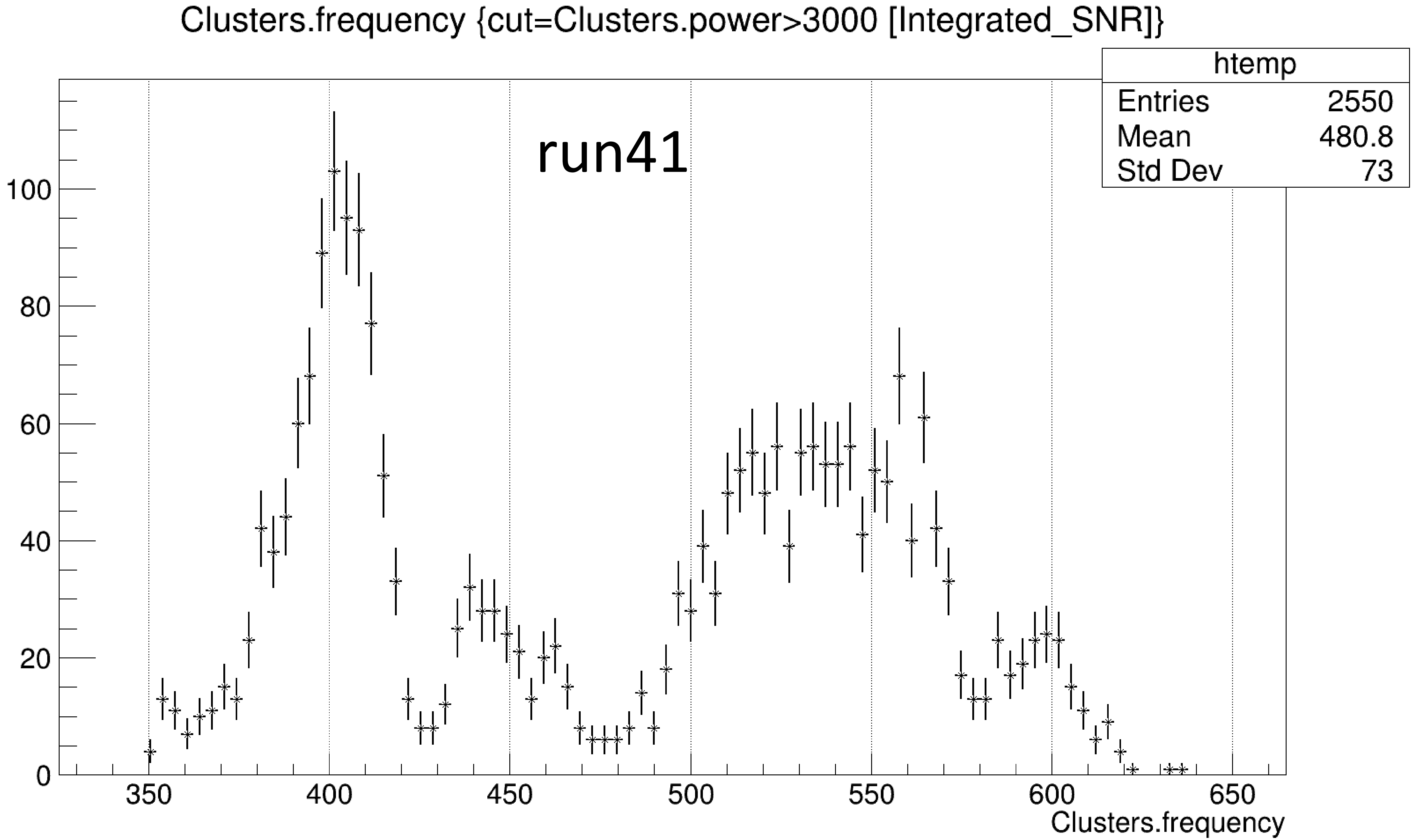
Majority of electrons should have drift time < 200 mus.

In particular 50 mus



Montecarlo: potential well effect





Clusters.frequency {cut=Clusters.power>3000 [Integrated_SNR]}
htemp
Entries 2550
Mean 480.8
Std Dev 73
run41
100
80
60
40
20
0
350
400
450
500
550
600
650
Clusters.frequency

3) Data analysis

We have the RF analysis1.1 package for raw Data analysis:
from raw data to cluster tree

→

ElectronTrapAnalysis.C root macro for cluster analysis with(or without) time coincidence

→

Graphics part:
Mini_SauronPlot.C root macro for sauron plot of selected clusters

Debugging

3) Data analysis: RFAnalysis from 1.1 to 1.2

V 1.1

- Cluster and hit power in arbitrary units (what power are we cutting?)
- Cluster power dependent by avg noise (light)

3/7/24

V 1.2

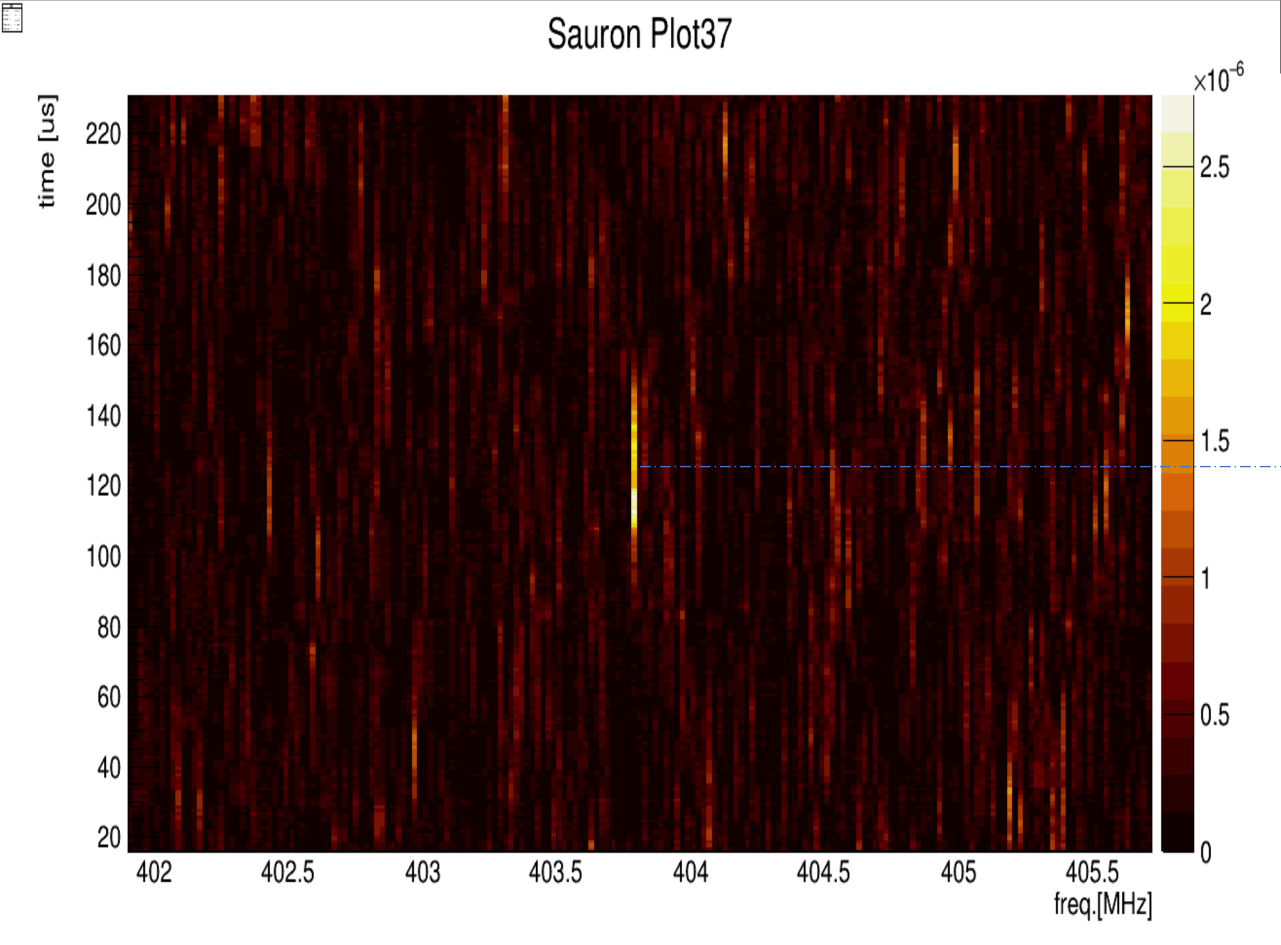
Debugging

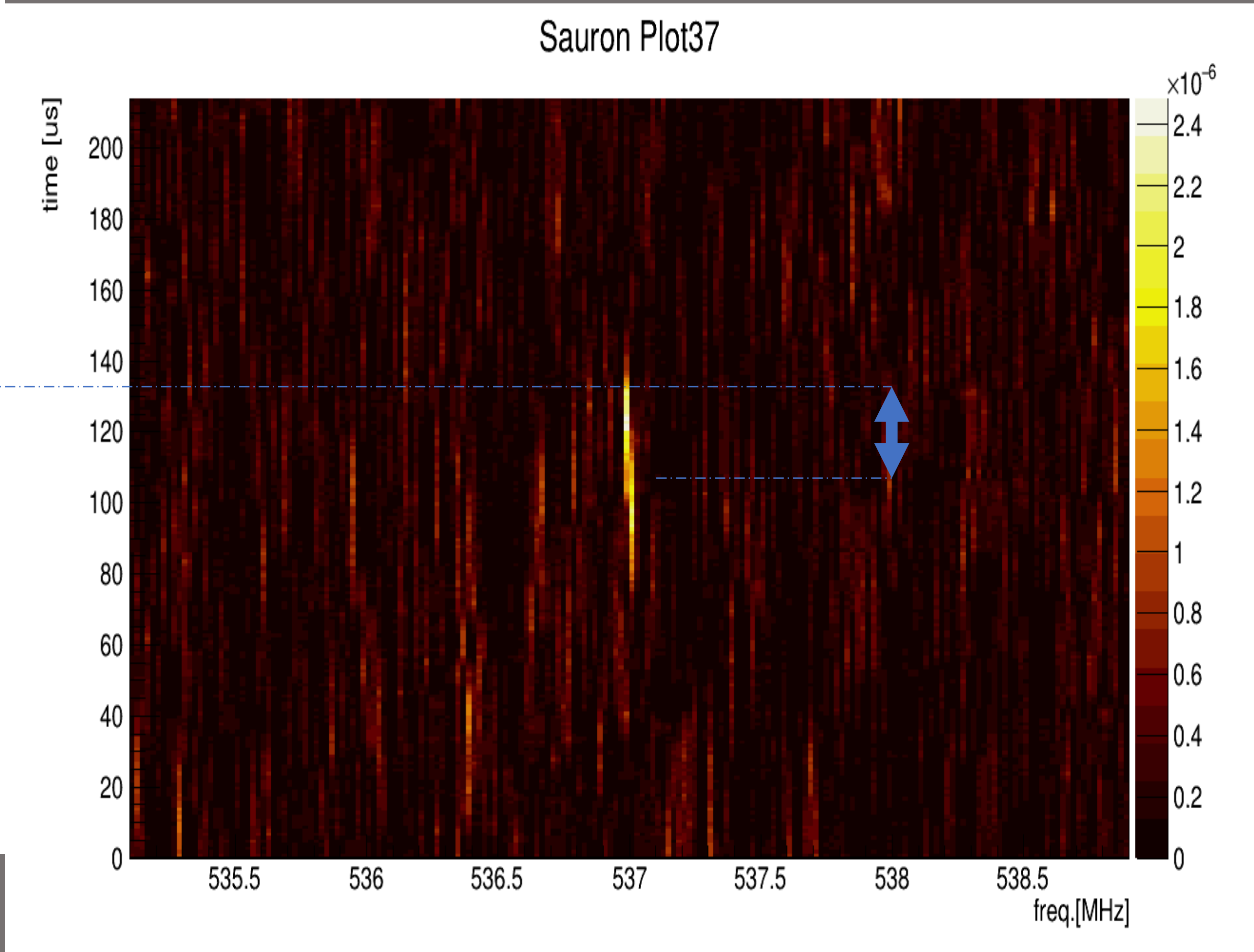
- hit power in SNR units with respect to avg noise (avg on 5MHz and on time of the spectrogram)
- Track finder

Better power cuts

3) Data analysis: ElectronTrapAnalysis.C

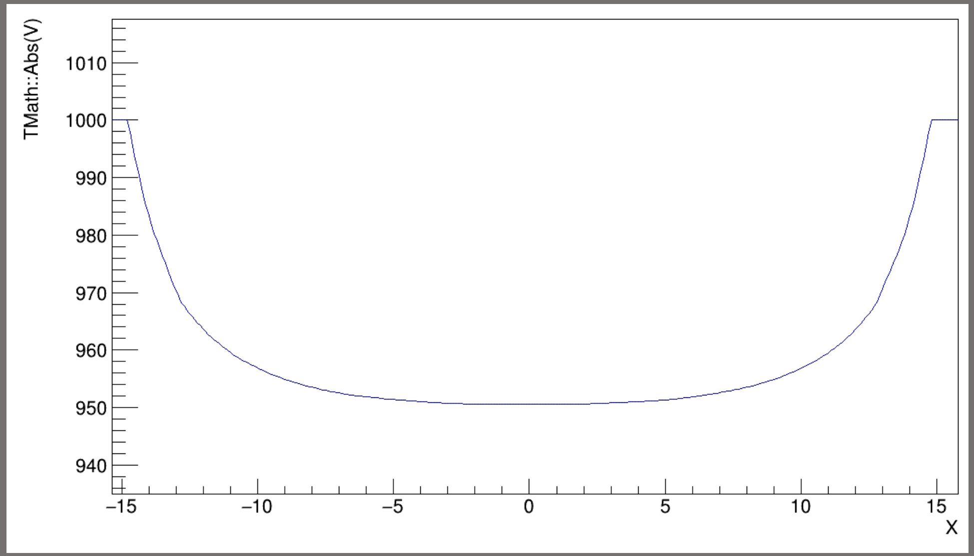
We are studyng the time shift that is acceptable between carrier and sidebands signals

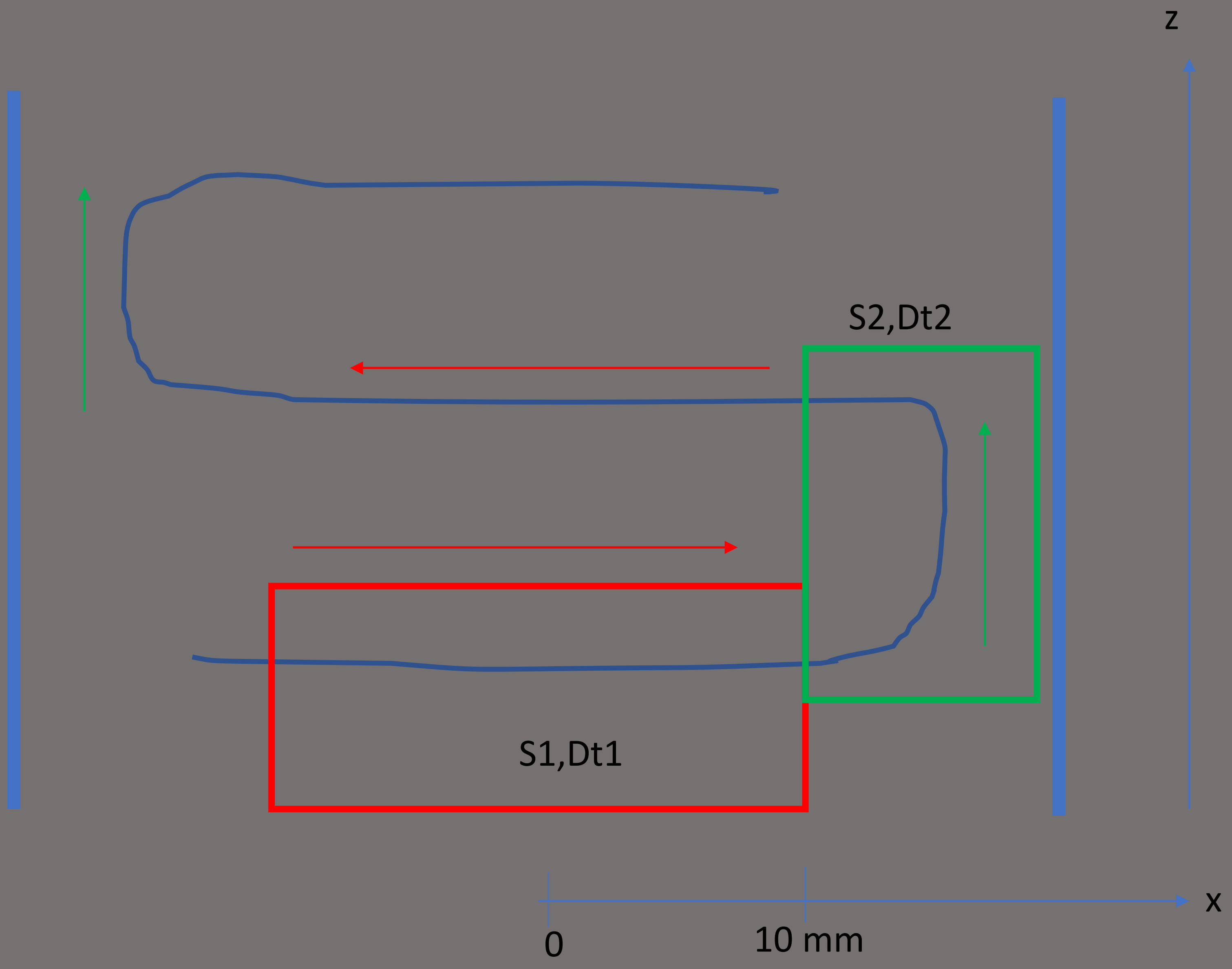




5)Electron motion

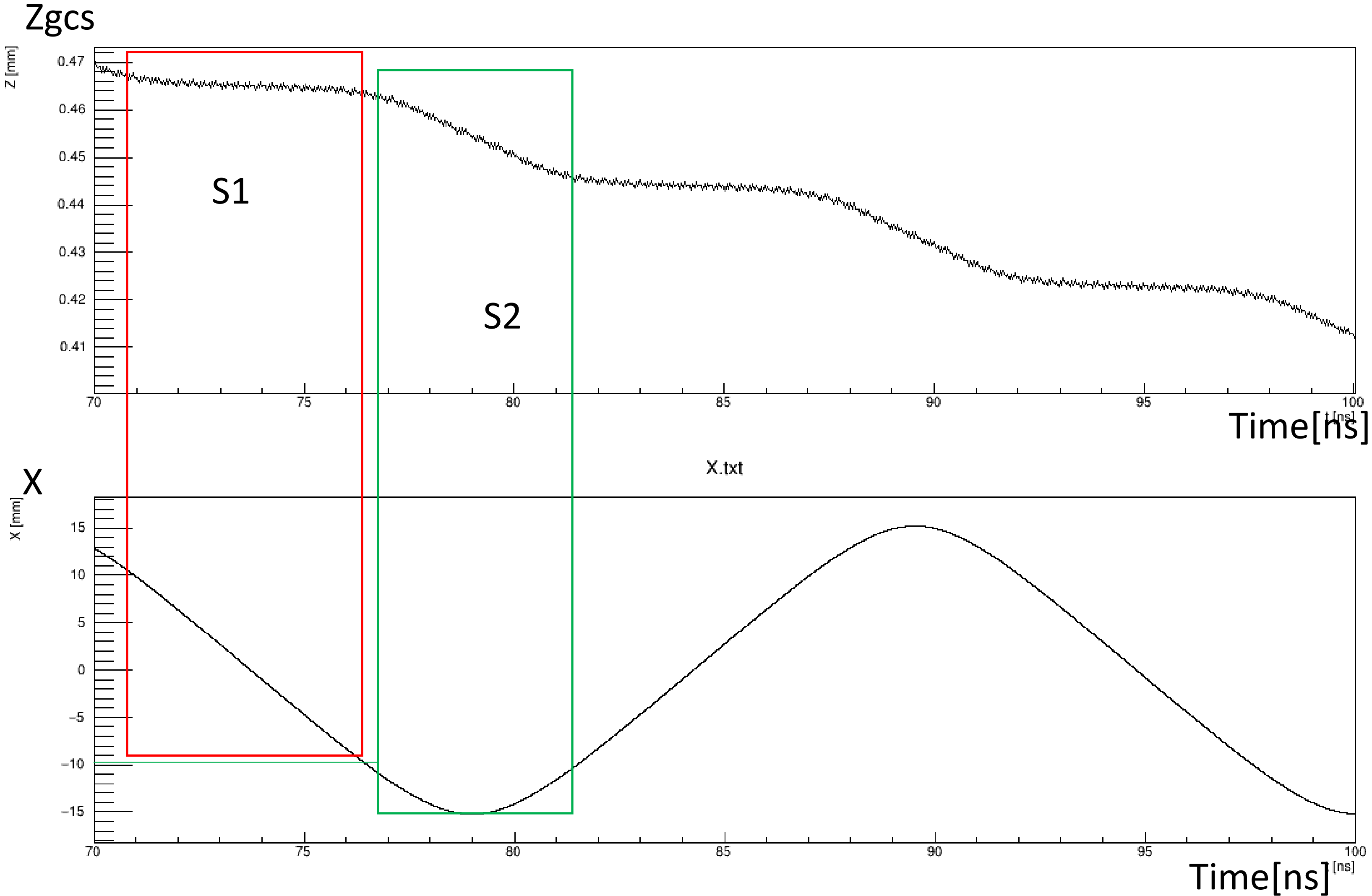
- S1: no Zdrift, bottom of potential well
- S2: Zdrift, top of potential well



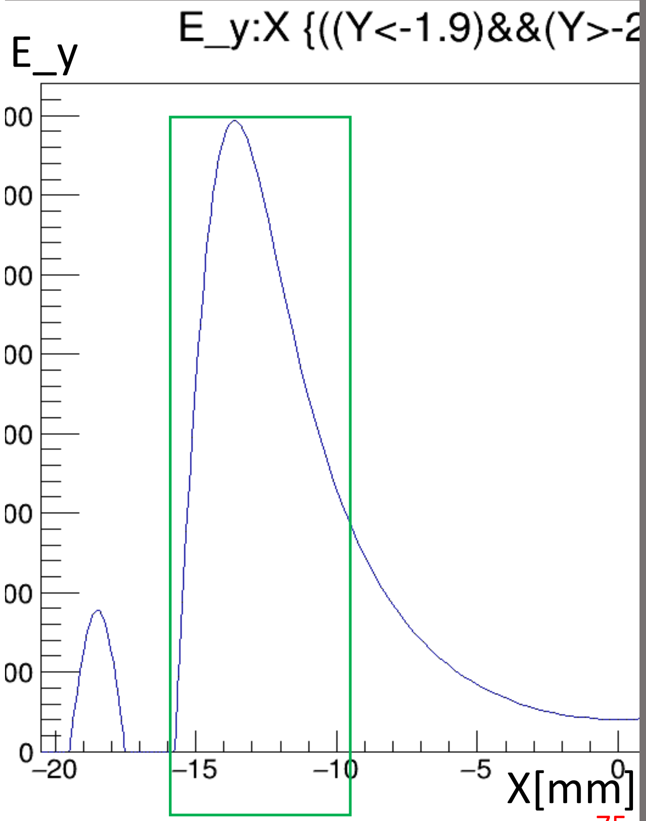


5)Electron motion

- Drift only during S2 (10<|x|<15, close to bouncing electrodes)
- Vz=3*10^-4cm/ns

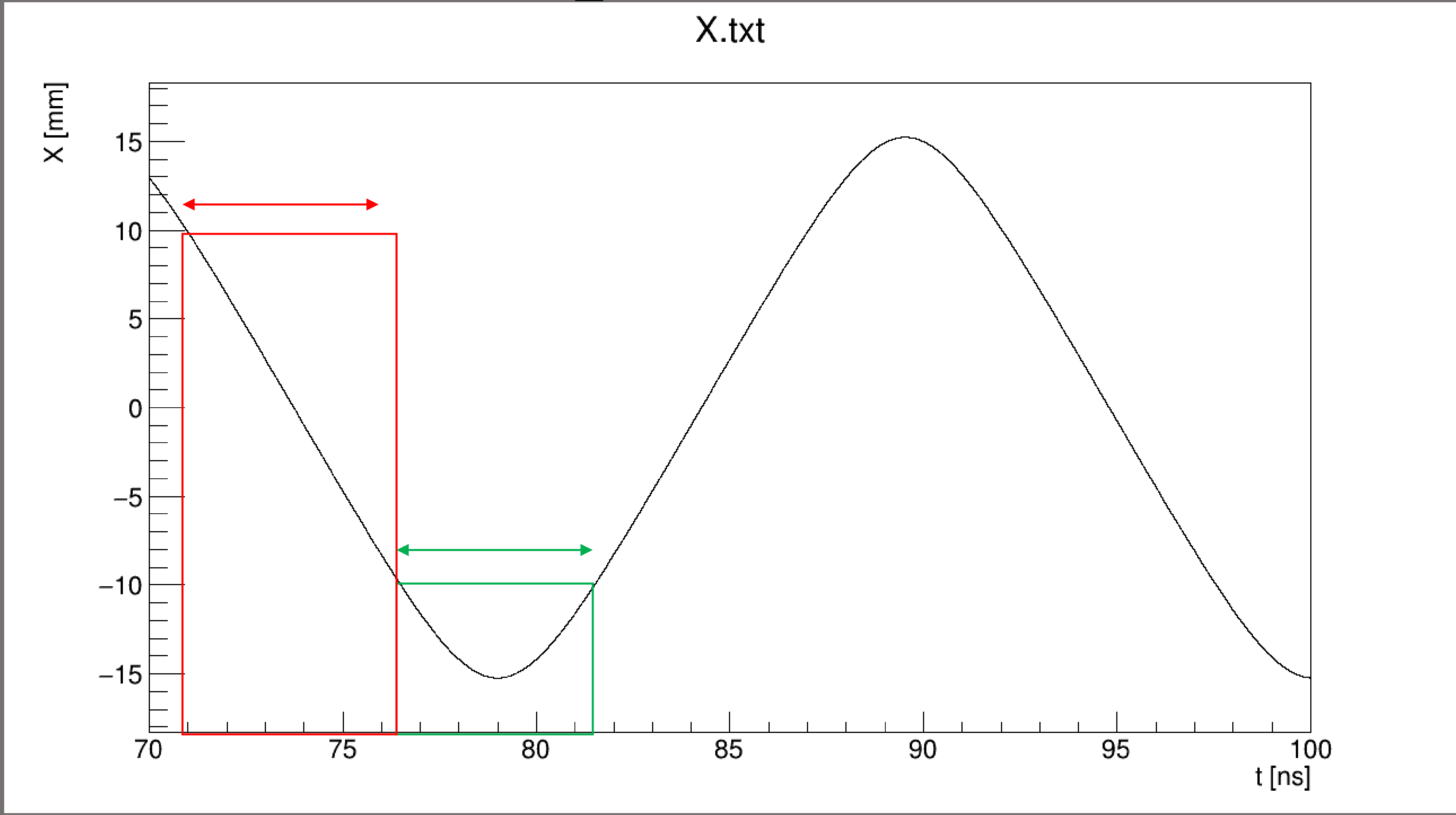


Vz=E_y/B



5)Electron motion: bouncing period

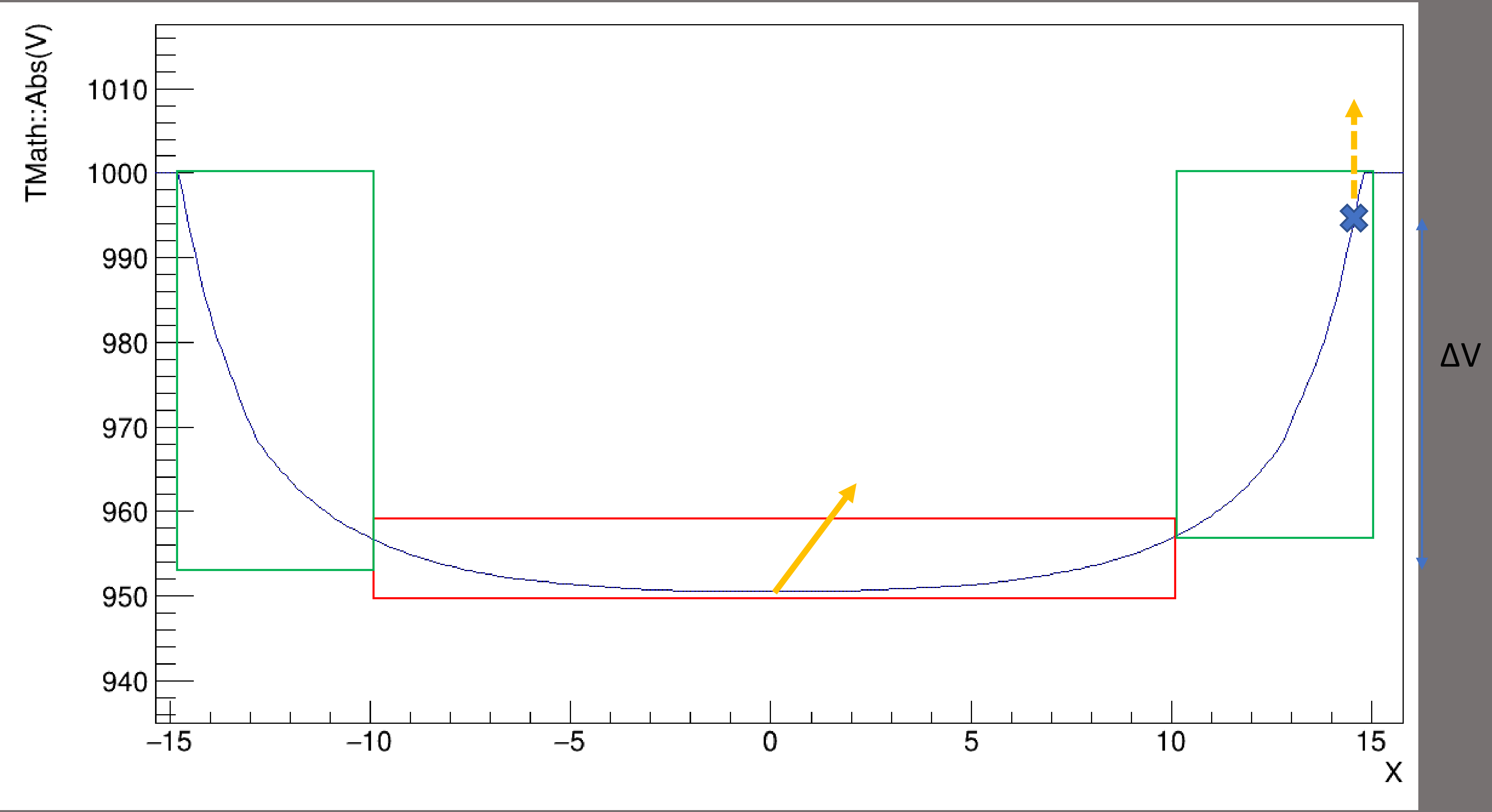
- t1≈76.5-71=5.5ns
- t2≈81.5-76.5=5ns → T_b=10.534ns



5)Electron energy

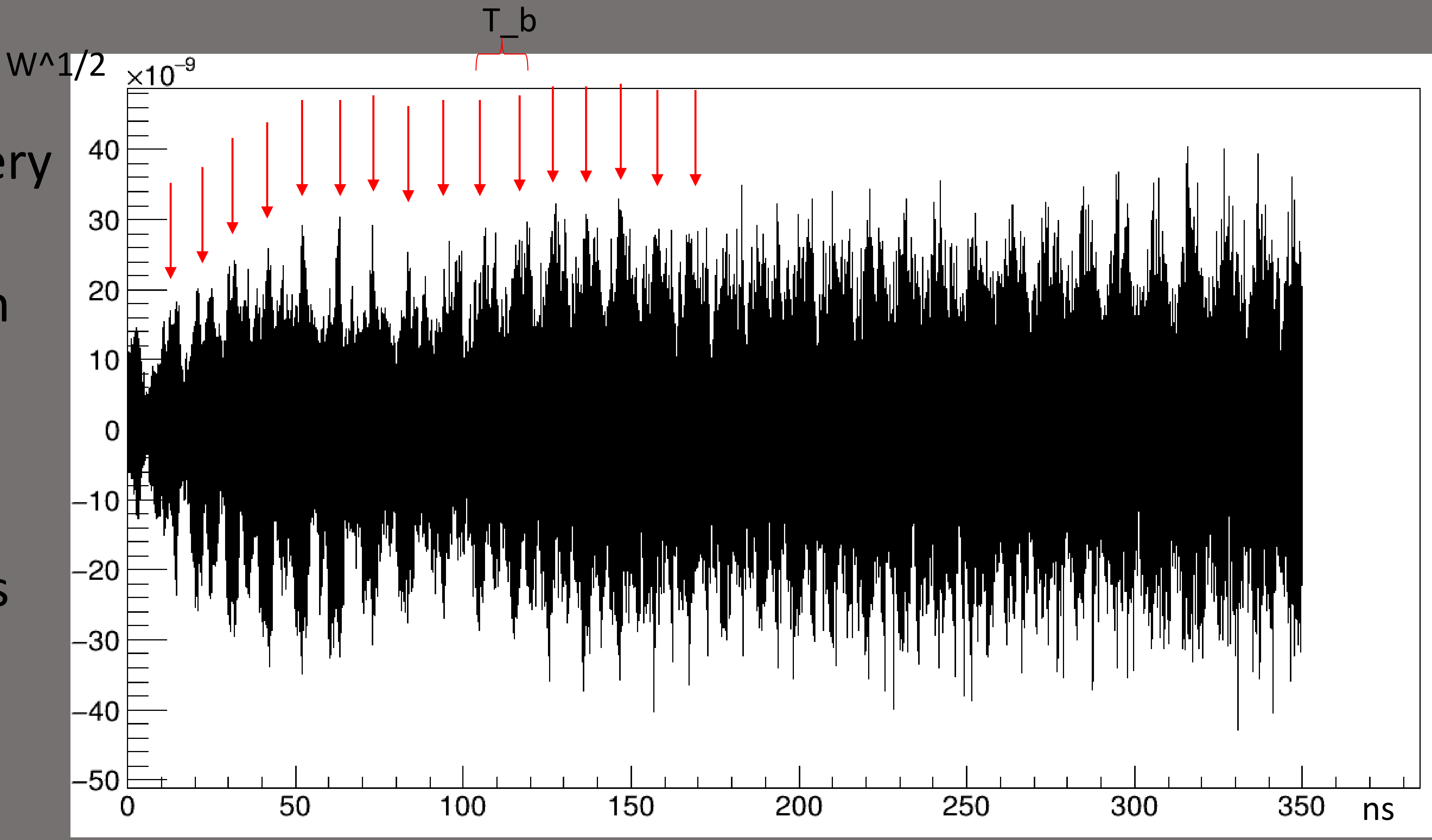
- If electron start at X=0

K(S1)=K_perp+K_l=K'
K(S2)=K_perp=K'-ΔV



5)Port signals

- Periodicity of S1 every T_b
- FM modulation with signal of frequency 1/T_b=Δ1
- High order armonics at +-n/T_b=+-nΔ1 from carrier



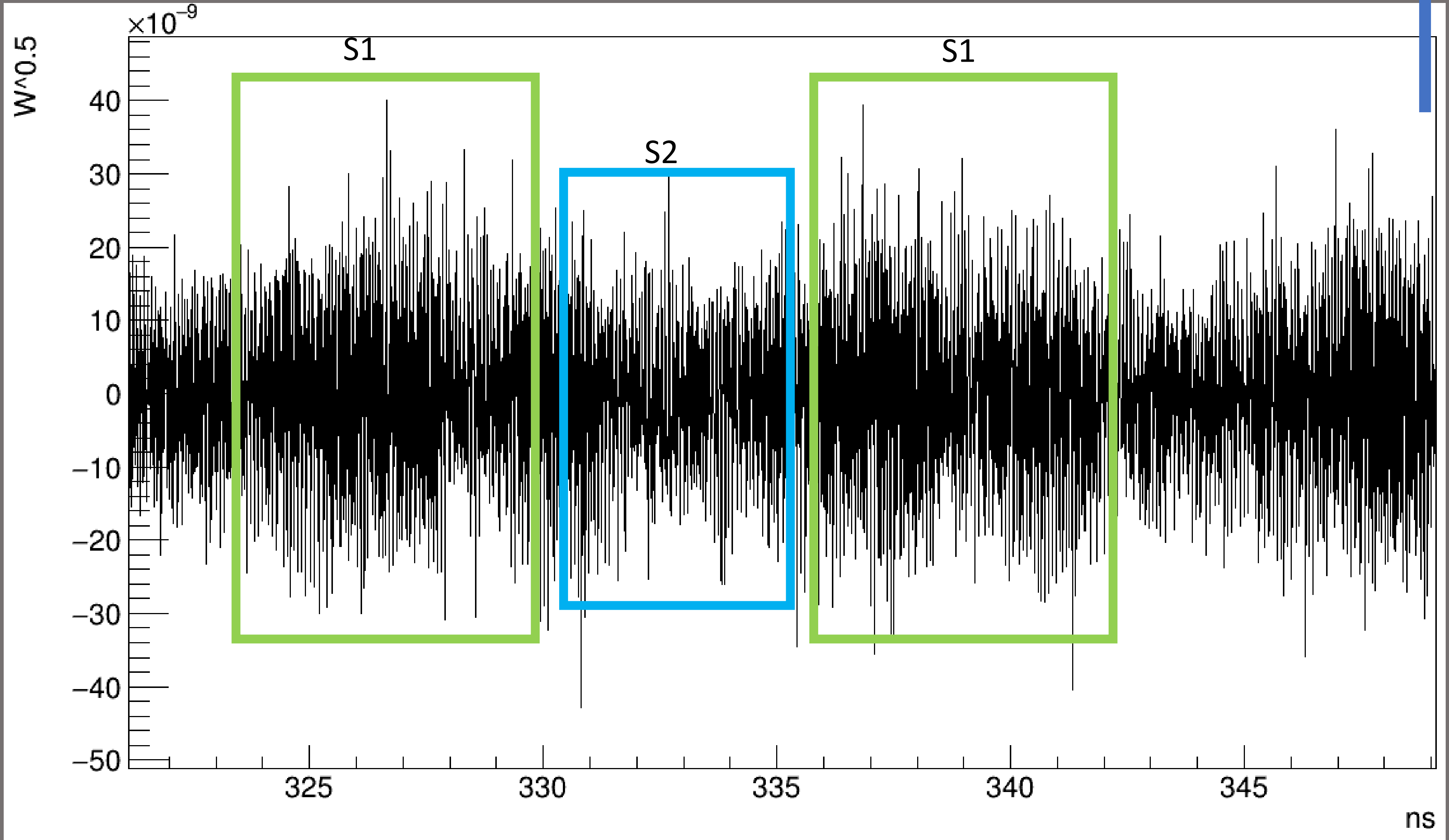
5)Carrier Frequency right shift

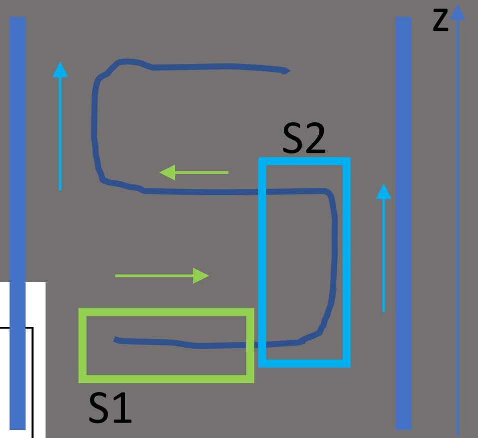
- Period(S1)=period(S2)=T_b

- It is like S1*cos(Δω*t)->right shift of about Δω=1/T_b= Δ= Δ1

Those are the first ns of the simulation
The right shift it is at stationary regime

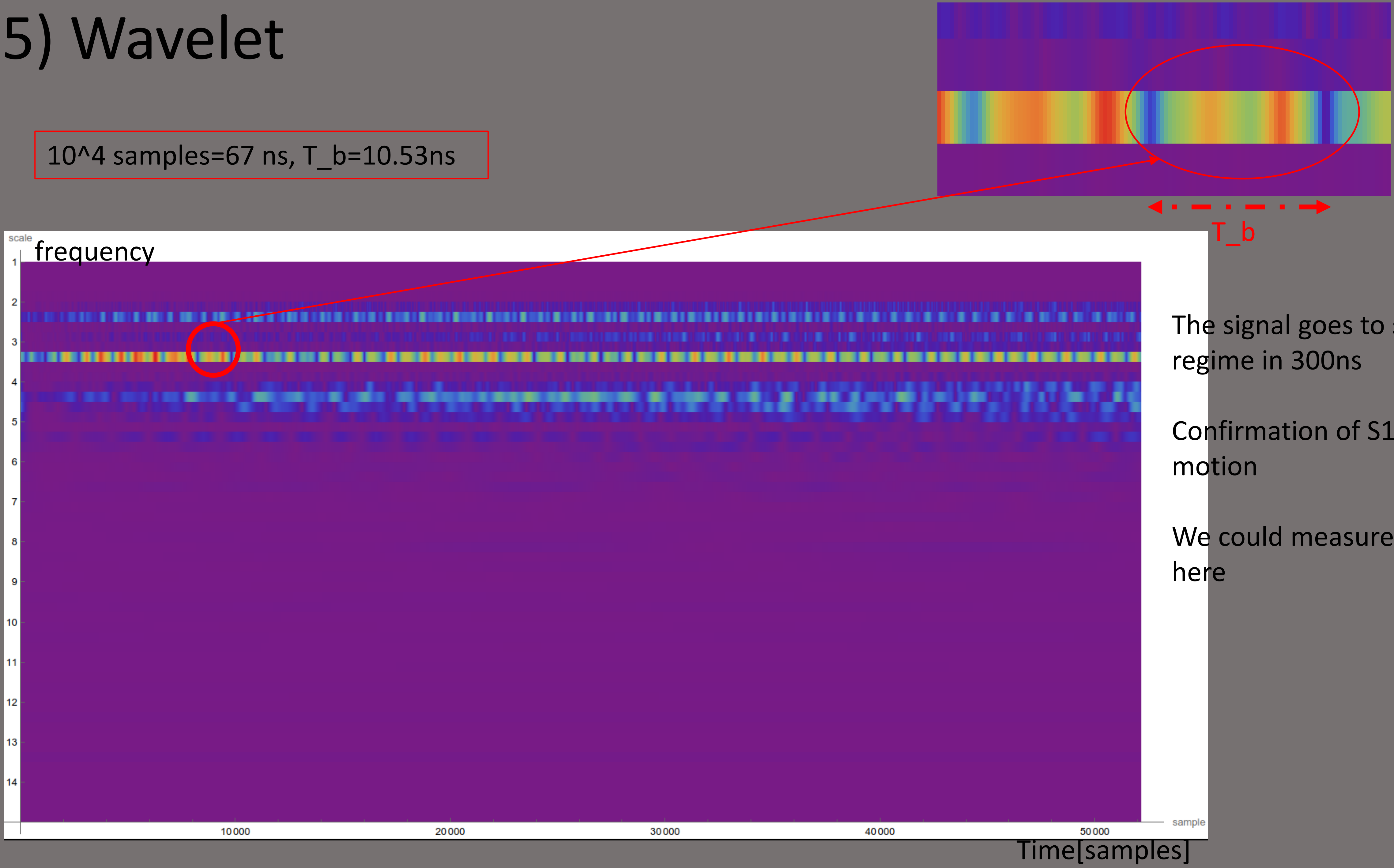
5) Frequency Right shift at stationary regime





5) Wavelet

10^4 samples=67 ns, T_b=10.53ns



The signal goes to stationary regime in 300ns

Confirmation of S1-S2 motion

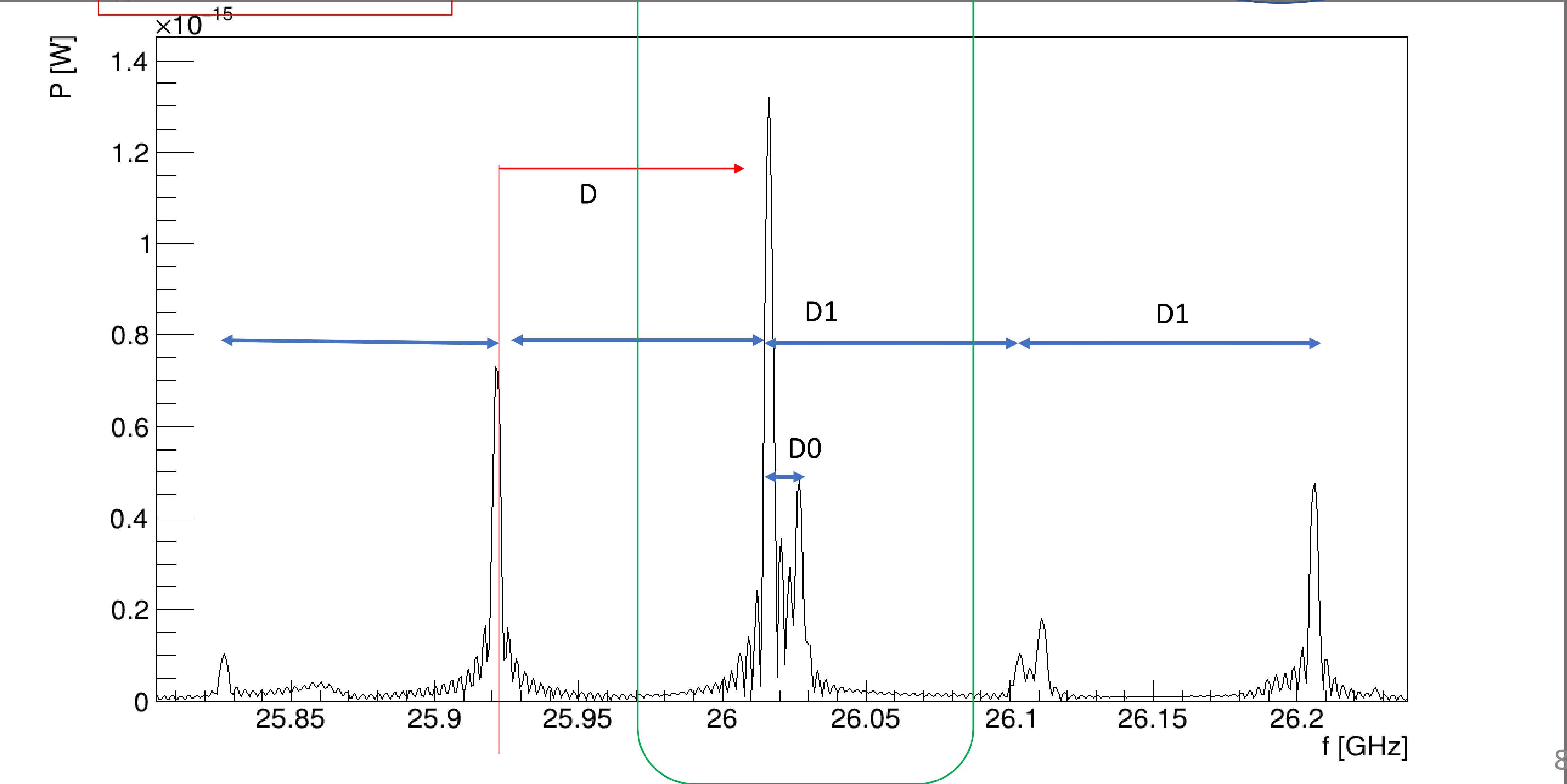
We could measure T_b also here

5)CST simulation

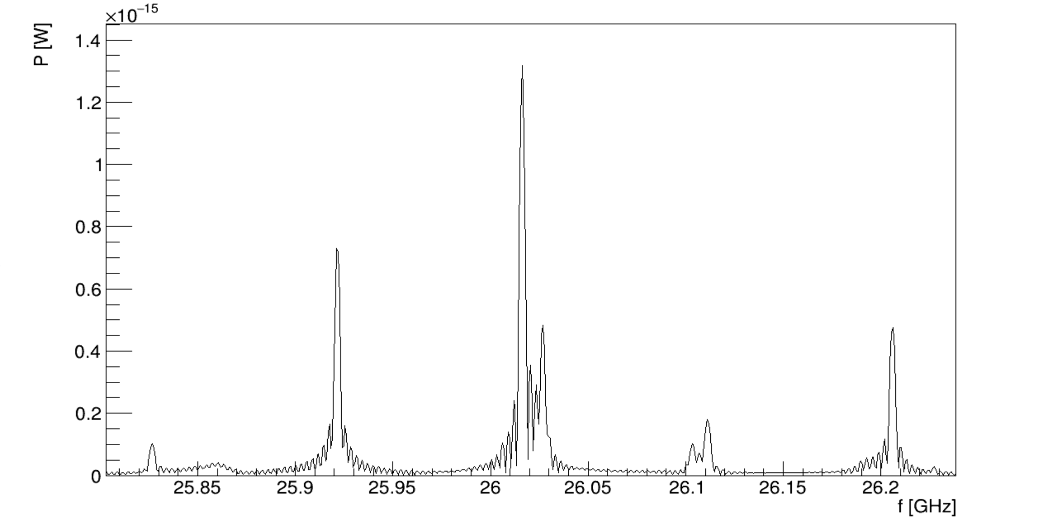
Right Shift from cos(Δω*t) term

Carrier modulation in frequency from K in pot. well

Armonics from FM



6) Experimental procedure

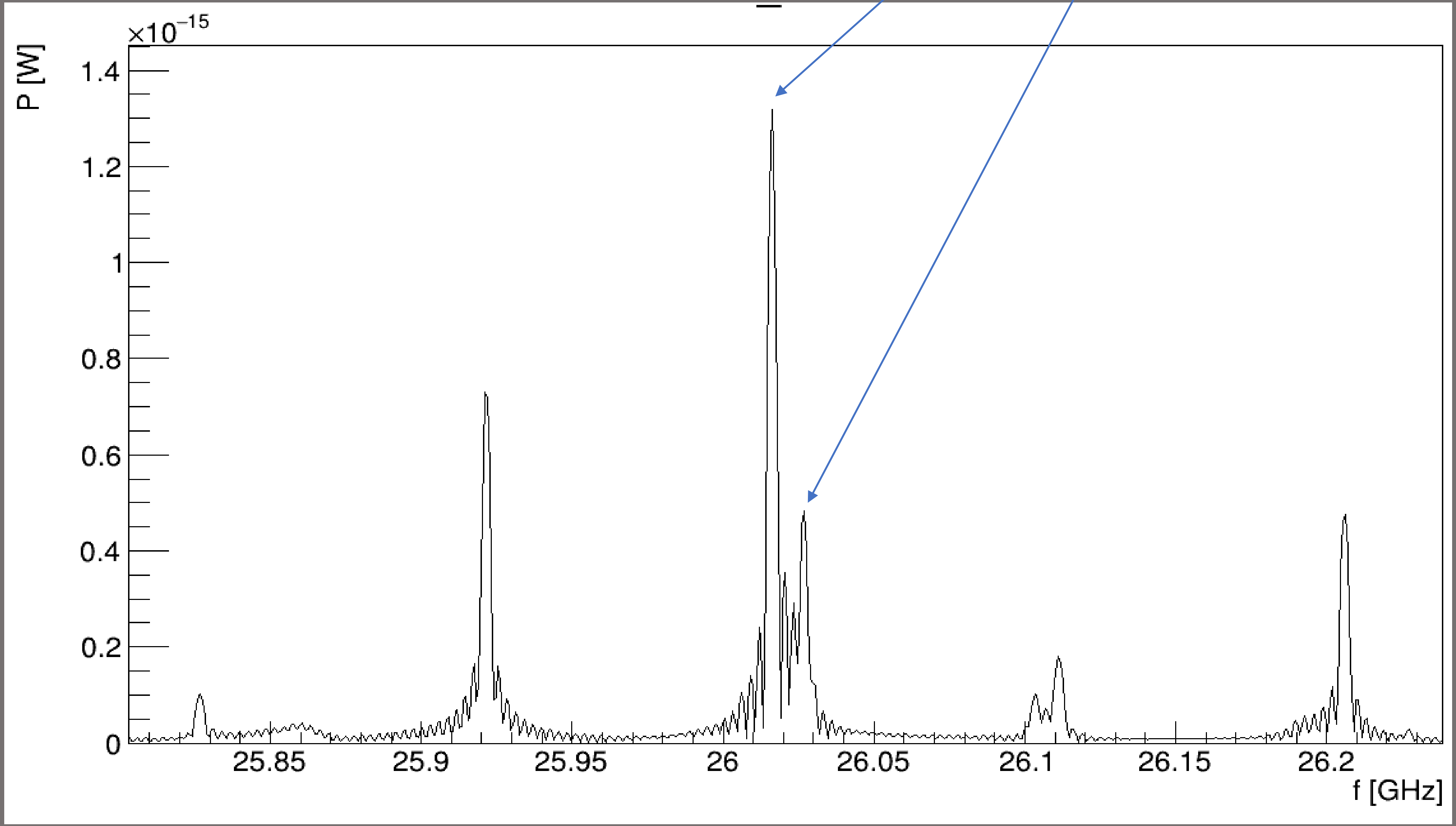


- Let’s think that these are experimental data->measure K,KL
- We expect: T_b=10.53ns , K=32151.6eV, KL=43.2eV

1. Measure Δ1=1/T_b by FM modulation
2. Shift carrier frequency to the left by Δ1
3. Measure S1->K
4. Measure KL by T_b and K

6) Experimental procedure

- F(S1)=26,0165 (7) GHz
- F(S2)=26,0260 (7) GHz



6)Experimental procedure: measure T_b

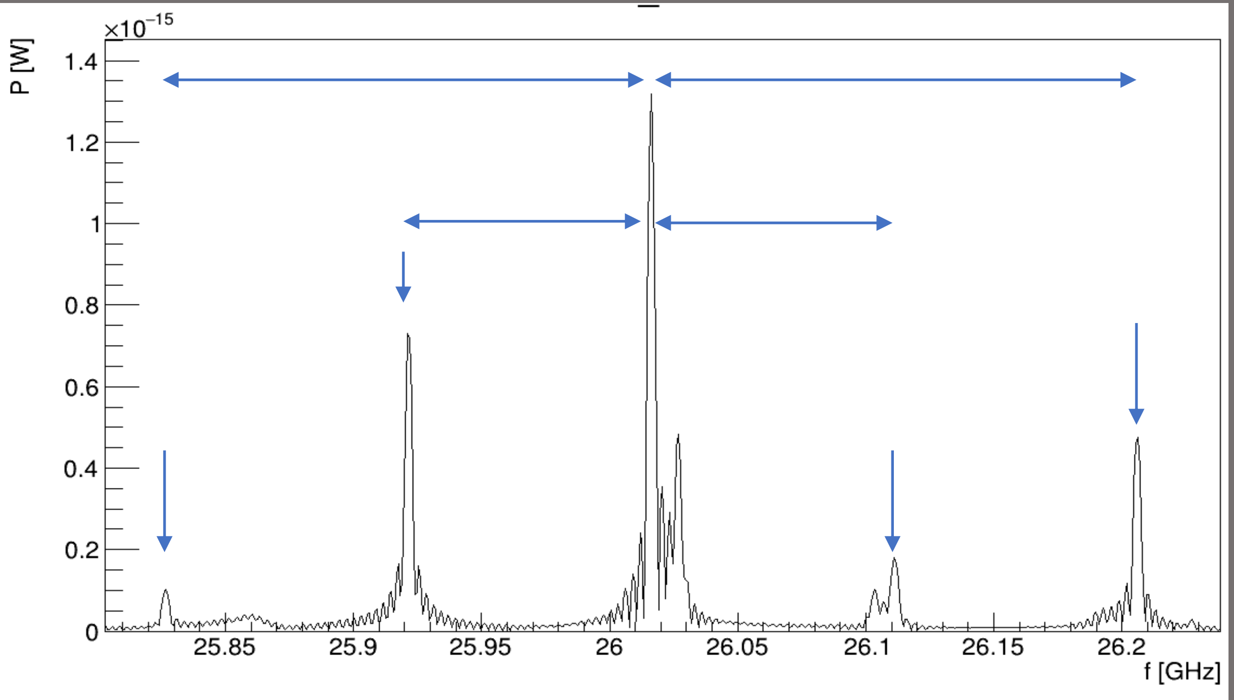
F(S1)-F(nΔ,L/R)= Δ

- F(1D,L)=25,9215 (7) GHz — 0,095
- F(2D,R)=26,2060 (7) GHz — 0,09475
- F(1D,R)=26,1110 (7) GHz — 0,0945
- F(2D,L)=25,8270 (7) GHz — 0,09475

<Δ>=0,09475 GHz

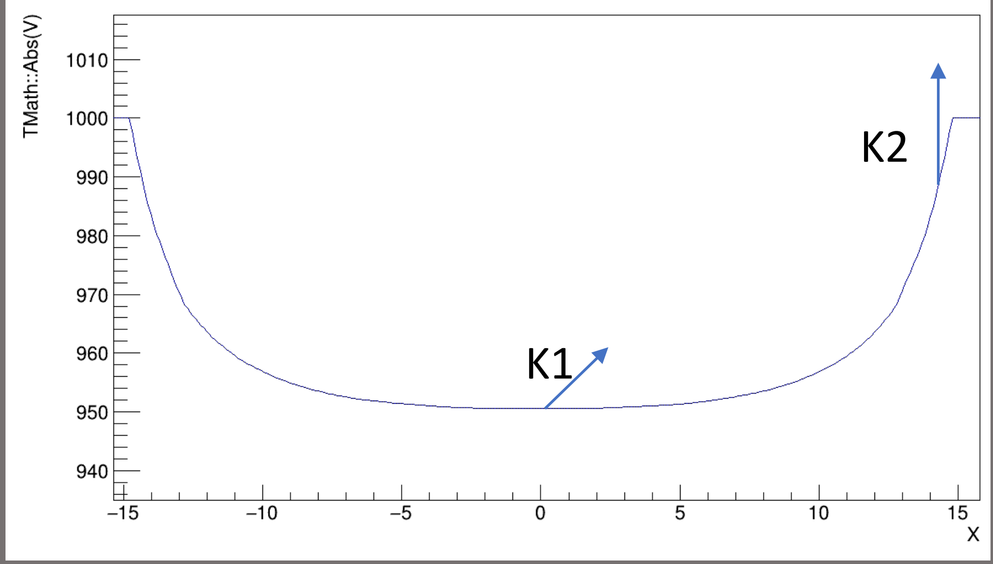
T_b=1/<Δ>=10,554 ns

T_b(expected)=10,534 ns



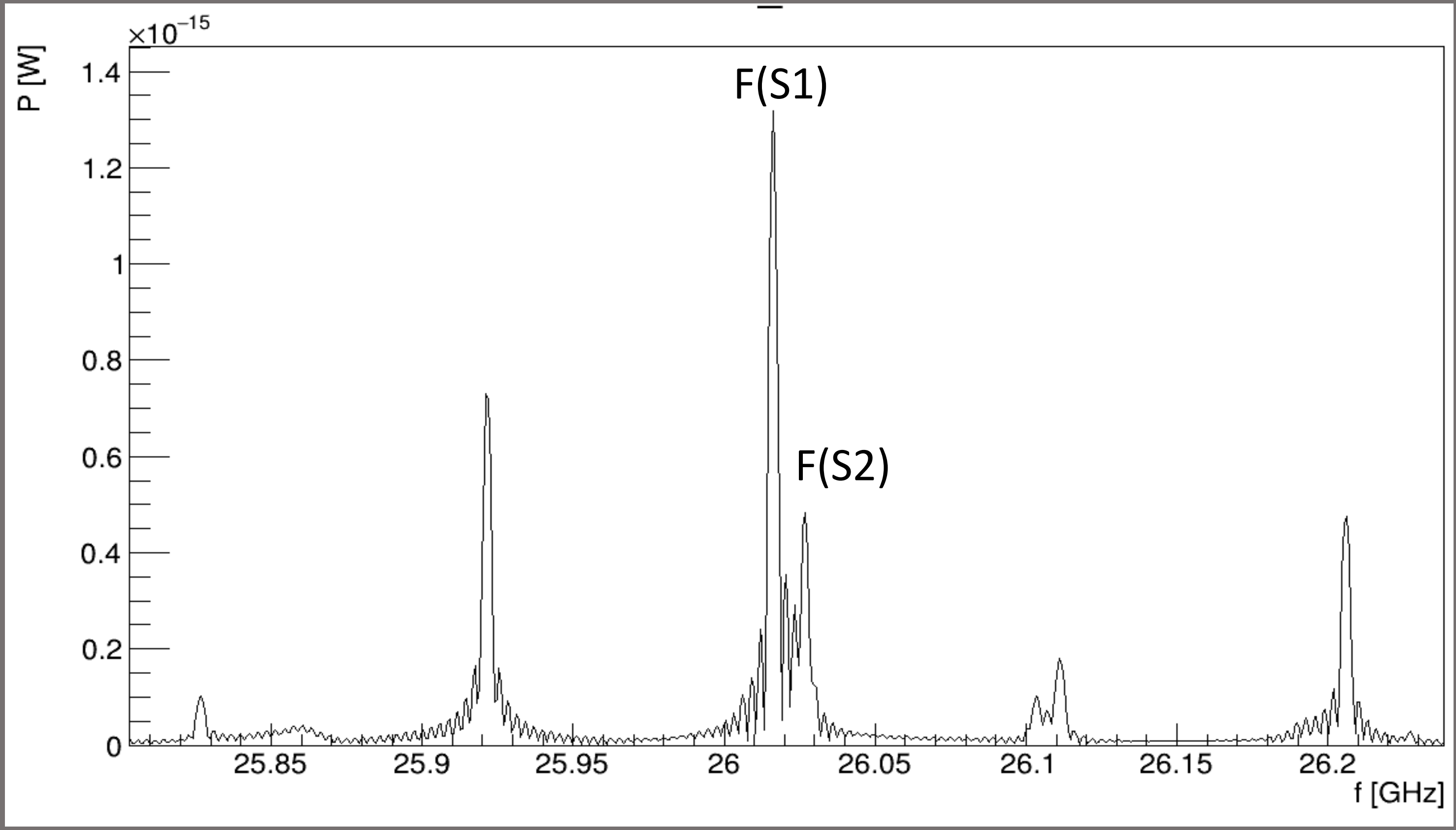
In real life some of them will be hidden below thermal noise

6)Measure of K



$$f_c = \frac{1}{2\pi}\frac{|q|B}{m}\frac{1}{K/m+1}$$

- F(S1)- <Δ>=25,9218 (7) GHz->K=32193.7eV=K1
- K(expected)=32151,6eV



One could also estimate KL by F(S2)- <Δ> but it is not accurate

F(S2)- <Δ> =25,9312 GHz->K=31994,7eV=K2

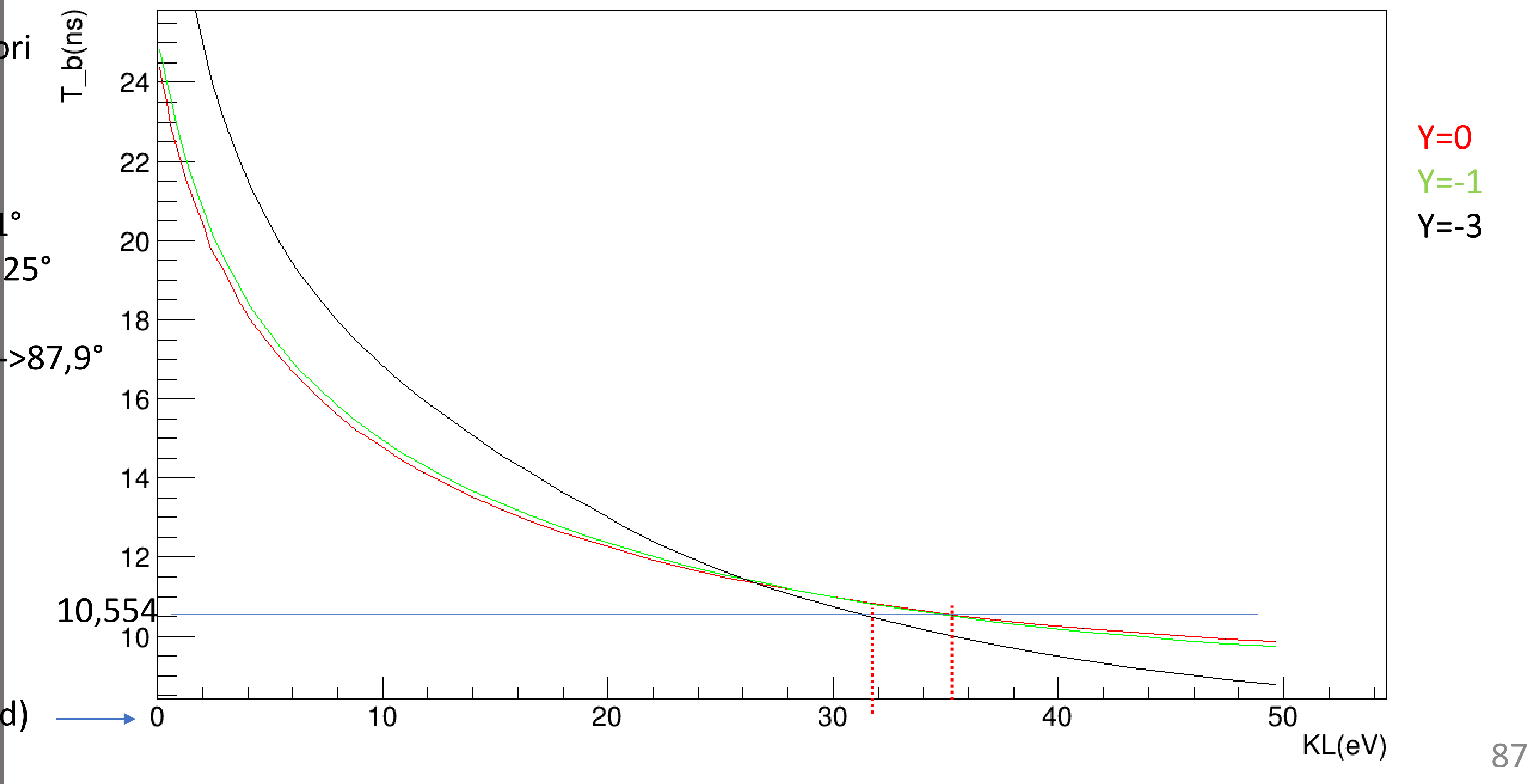
K1-K2=KL=199eV->ϴ=85.5°

6)Measurement of KL

Obtained from tracker simulations

- KL=Kcos^2(theta)
- Plot T_b(cos^2(theta))

- We don't know Y a priori
- T_b=10.554ns
- KL(Y=0)=35,39eV->88,1°
- KL(Y=-3)=30,02eV->88,25°
- KL(expected)=43.17eV->87,9°



Cos^2(theta) * K (measured)