Detection of 27 GHz single electron cyclotron radiation in the PTOLEMY detector

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About me

- I have joined PTOLEMY collaboration in 2021
- Master thesis on the detection of high frequency RF signal in the PTOLEMY filter
- I will be PhD student of Univaq at the LNGS on the PTOLEMY project for the next three years

PTOLEMY EM filter Goal

Antenna region:

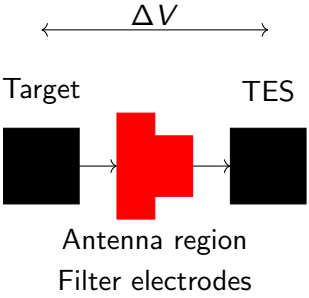
- Estimate K with $\Delta K = 10eV$

Filter electrodes:

- Filter e^- from target with $\Delta K = 10eV$ around Tritium Q_β
- Decrease K to $O(10eV)$ for energy measurement

$$\downarrow$$

- **We need this online ($\sim 10\mu s$)**



Antenna region

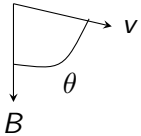
Fields:

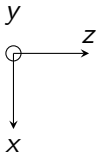
- $\overrightarrow{E} = (0, E, 0)$
- $\overrightarrow{B} = (B, 0, 0)$

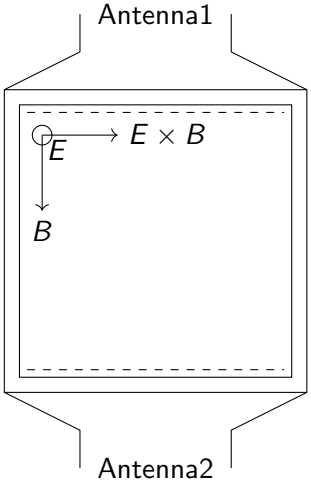
Electron in cyclotron motion:

- Cyclotron along X
- Bouncing motion along X
- Drift along Z
- No Y component

During the motion: RF emission







Antenna region

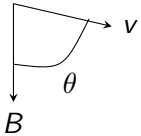
Measure $(P, f) \rightarrow (K_\perp, K)$

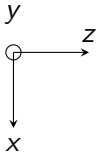
- $P \propto \frac{K_\perp/E^2}{1-K/E^2}$
- $f_c = \frac{1}{2\pi}\frac{qB}{m}\frac{1}{K/m+1}$

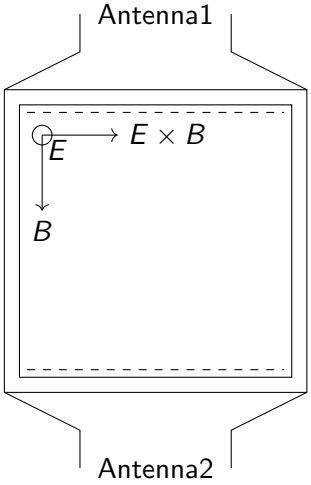
For electron at $Q_\beta = 18.6keV$:

- $P = 1.2fW = 7.3eV/ms$
- $f_c = 27.0GHz$

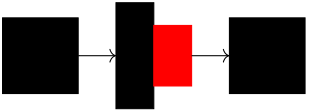
With a $\Delta K \sim 10eV \rightarrow$
$\Delta f = 100kHz \rightarrow \Delta t = 10\mu s$
The detection requires a proper electronic chain







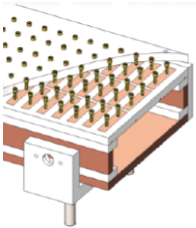
EM Filter



- Measuring K,$K_\perp$ in less than $10\mu s$
- This information goes to the filter electrodes system

If the electron is selected to be:

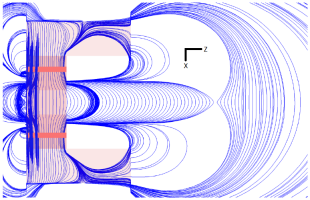
- BKG electron $\rightarrow$ filter sides
- Endpoint electron $\rightarrow$ TES

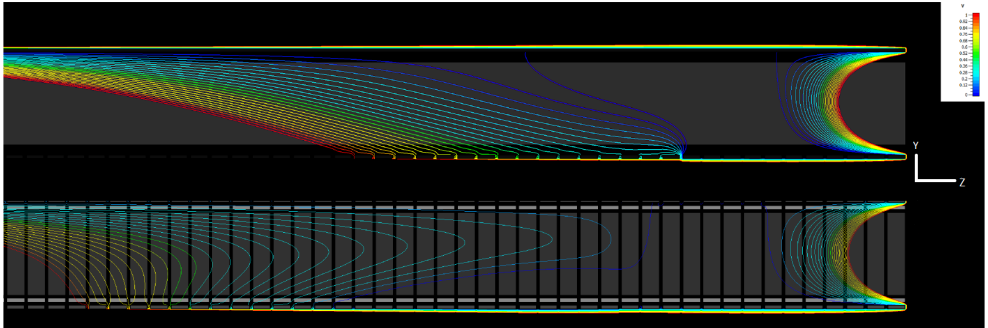


EM Filter: fields

- Exponential decreasing B field
- E field by equipotential hills
- Electron lose Kinetic energy

Filtering is done by varying E

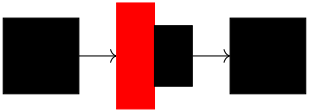




RF readout chain requirements

RF electronics goal:

- RF Detection of $f_c = 27GHz$ and $P = 1fW = -120dBm$
- Detection in $\Delta t = 10\mu s \rightarrow RBW = 100kHz$



$$P[W] = 10^{(P[dBm]-30)/10}$$

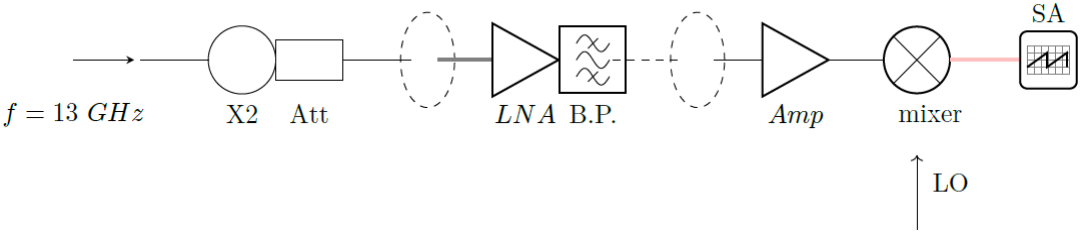
$$P[dBm] = 10Log_{10}(\frac{P[W]}{1mW})$$

- Decrease the frequency (down-conversion)
- Amplify the signal with **low noise**

RF readout chain

- Calibration stage
- Amplification stage
- Frequency mixer

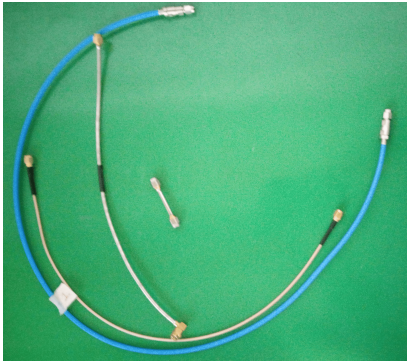
Spectrum Analyzer: up to 26GHz



Cables

Cables:

- High frequency cables
- SMA connectors
- Cryogenic cable is O(50cm)

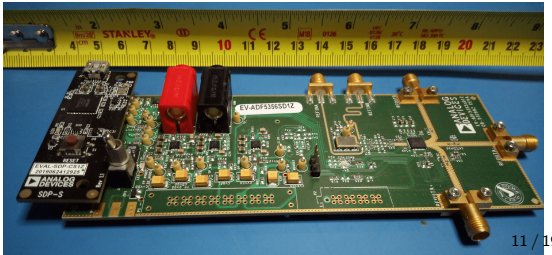


Calibration stage

- Frequency sinthesizer ADF5356S1DZ
- Passive frequency doubler
- Passive attenuators

↓

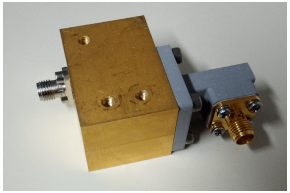
$$P = -120dBm$$
$$f = 26GHz$$

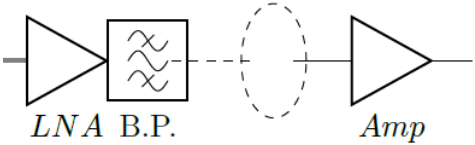


Amplification stage

- Friis law: $F_{tot} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$
- F_1 lowest possible $\rightarrow$ Cryogenic Low Noise Amplifier (LNA)
- LNA LNF-LNC16-28WB) $G = 29dB, NF = 0.086dB$
- Amp ALN2225-38-4025) $G = 39dB, NF = 2.5dB$

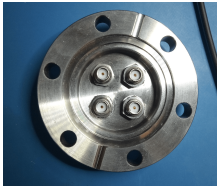
Cryogenic LNA

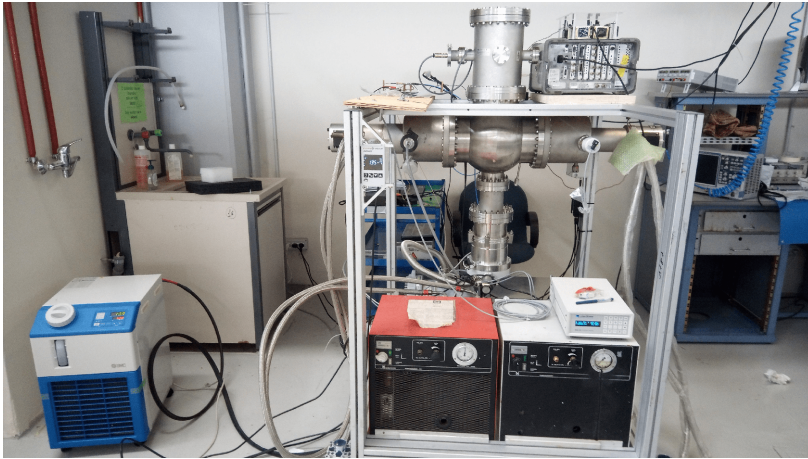




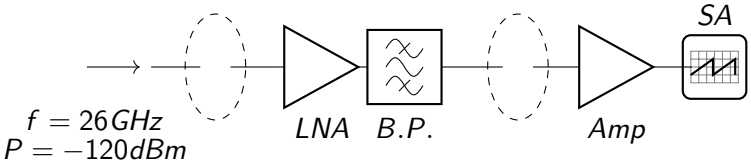
Cryogenic system

- Two GM cold heads
- LNA mounted on copper support
- $T_{LNA} \simeq 25K$
- I/O with RF flange

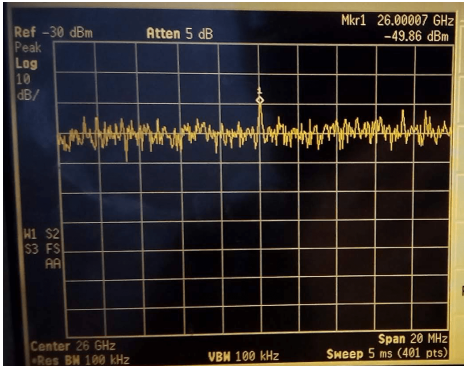




Amplification

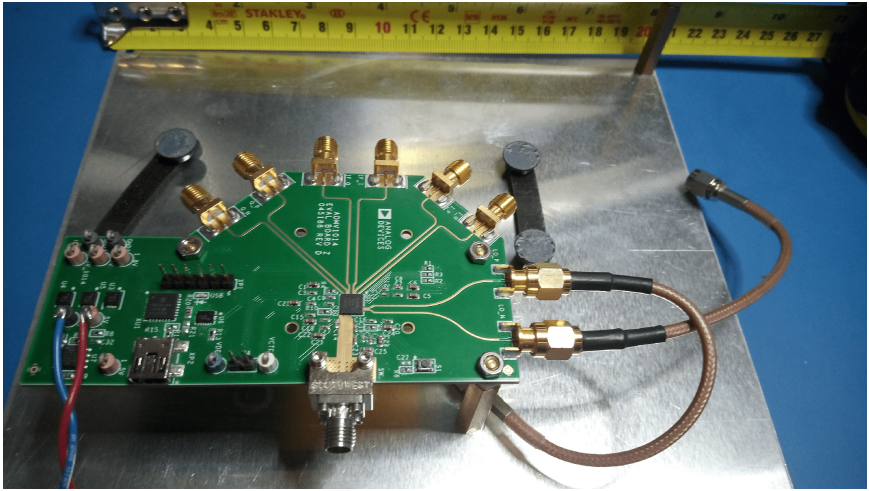


- $G_{tot}(25K) = 60.5dB$
- RF reflections on I/O ports

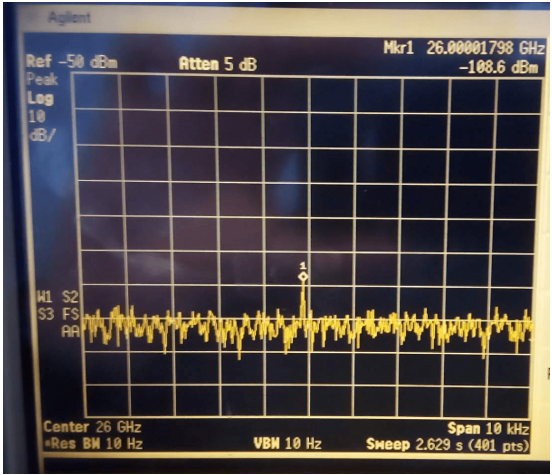


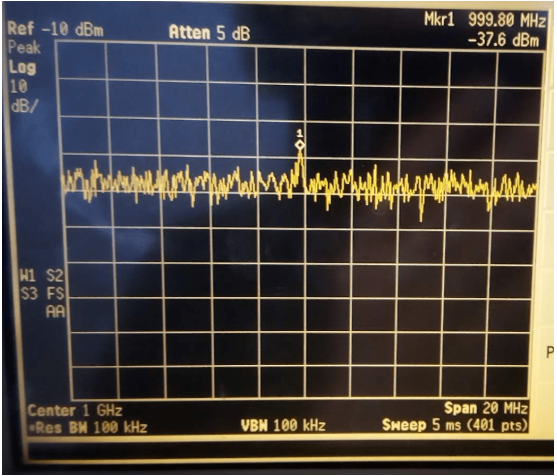
Frequency Down-conversion

- $f_{IF} = f_{RF} - f_{LO}$, ADMV1014, $G_{mixer}(f_{IF} = 1GHz) = 17.5dB$



Results


Agilent
Ref -50 dBm
Atten 5 dB
Mkr1 26.00001798 GHz
-108.6 dBm
Peak
Log
10
dB/
W1 S2
S3 FS
AA
Center 26 GHz
Span 10 kHz
Res BW 10 Hz
VBW 10 Hz
Sweep 2.629 s (401 pts)


Ref -10 dBm
Atten 5 dB
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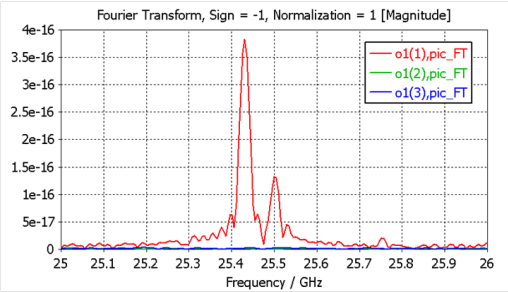
Peak
Log
10
dB/
W1 S2
S3 FS
AA
Center 1 GHz
Span 20 MHz
Res BW 100 kHz
VBW 100 kHz
Sweep 5 ms (401 pts)

Outlook

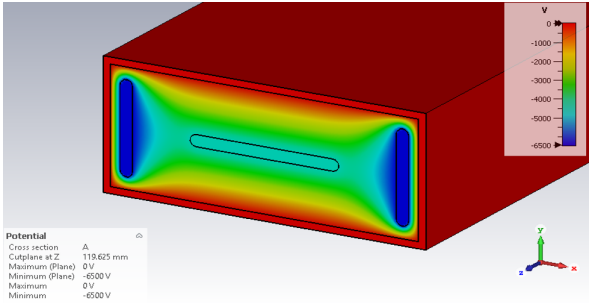
- Smaller RF cables $\rightarrow$ less RF reflections
- Scattering parameters characterization
- Test with physical electrons (electron-trap)

Electron trap

- Signal from physical electron
- Study and test of RF detection with Doppler effect



Ribbon Potential



Conclusions

- EM Filter for BKG rejection and K decrease
- Rough and brief K measure in antenna region with RF measurement
- High frequency and low power detection