AMY: Air Microwave Yield

Investigating the molecular bremsstrahlung radiation in GHz range from air-shower plasma

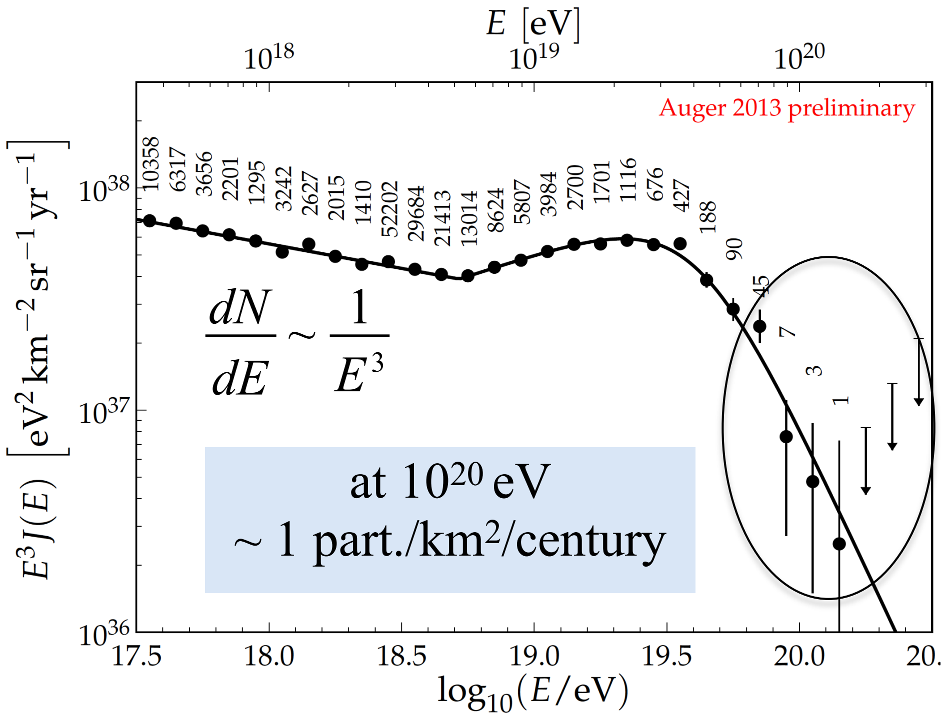
Claudio Di Giulio*

INFN ROMA Tor Vergata

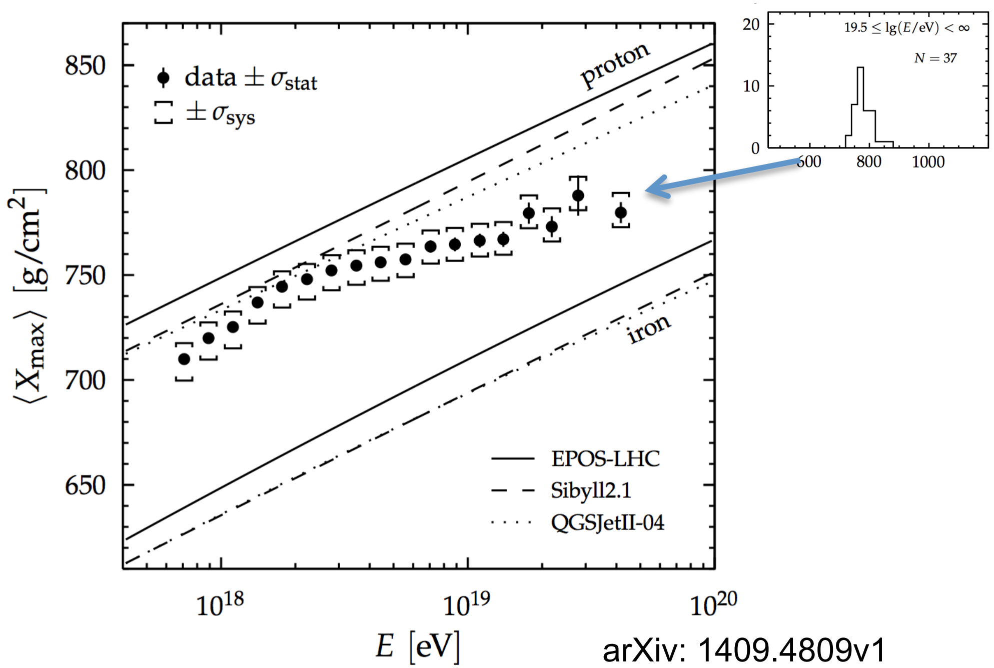
*** for the AMY Collaboration**

INFN
Istituto Nazionale di Fisica Nucleare

The UHECR FLUX: very low!!



A. Schulz et al 33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013



arXiv: 1409.4809v1

Data from 3000 km² Auger detector from January 2004 to 31 December 2012.

Aims of the radio detection

- Enhance the capabilities of the next generation observatory in determining the UHECR mass composition.
- Study the requirements for a very large aperture detection system in the next generation of air shower arrays.

Molecular Bremsstrahlung Radiation (MBR)

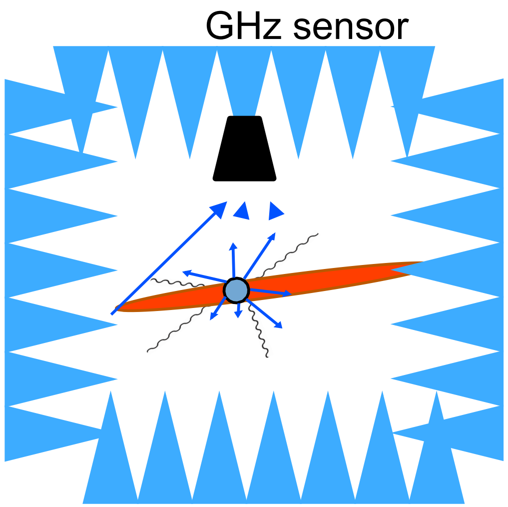
Observations of microwave continuum emission from air shower plasma **(SLAC)**

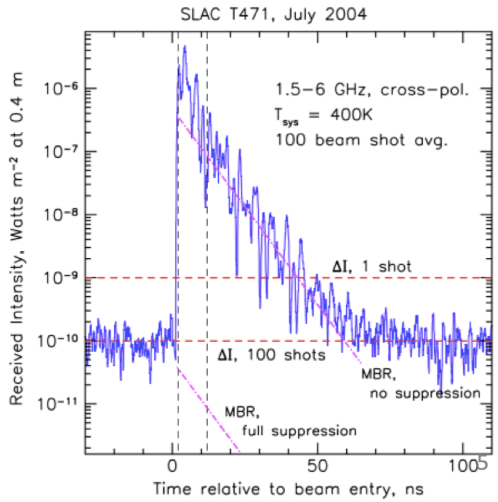
P.W. Gorham et al.
Ph. Rev. D 78, 032007 (2008)

- Free electrons interact with air molecules
→ **MBR** emission in **GHZ** regime

- ***Unpolarized and isotropic emission***

- Scaling with no. of secondary charged particles





Energy deposit → **plasma $T_e \sim 10^5$ K** →

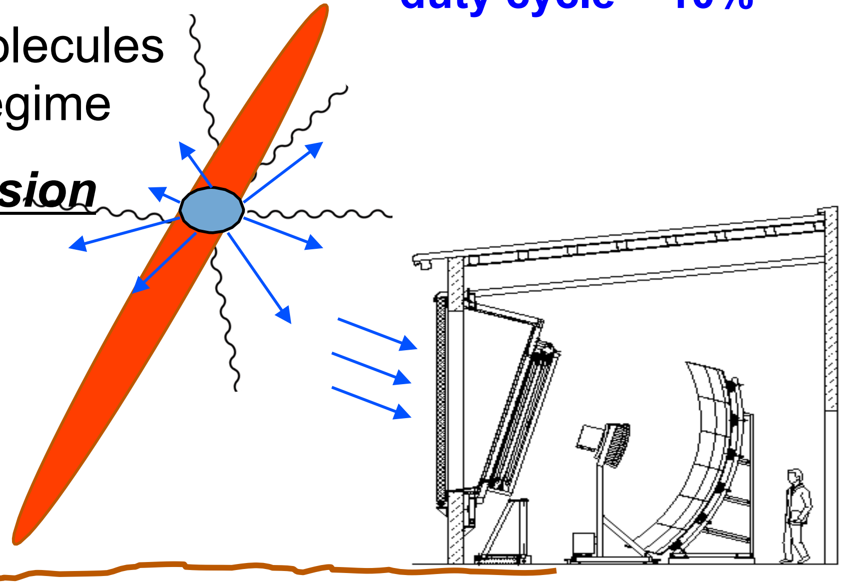
Secondary electrons produce bremsstrahlung radiation in the field of the neutral molecules

The fluorescence telescope technique

- EAS charged particles → Ionization → plasma

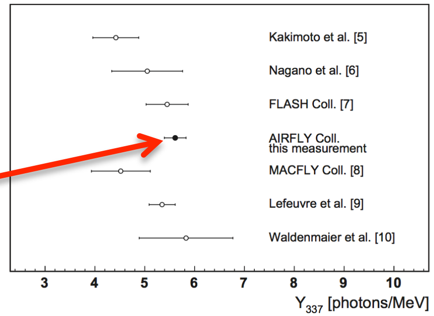
Fluorescence telescope duty cycle ~ 10%

- Free electrons interact with air molecules → **Fluorescence** emission in **UV** regime
- ***Unpolarized* and *isotropic* emission**
- Scaling with no. of secondary charged particles
- measure the longitudinal profile ->mass composition



Energy deposit → **plasma $T_e \sim 10^5$ K** → **Secondary electrons excite N_2**
- **fluorescence radiation**

M. Ave et al. / Astroparticle Physics 42 (2013) 90–102



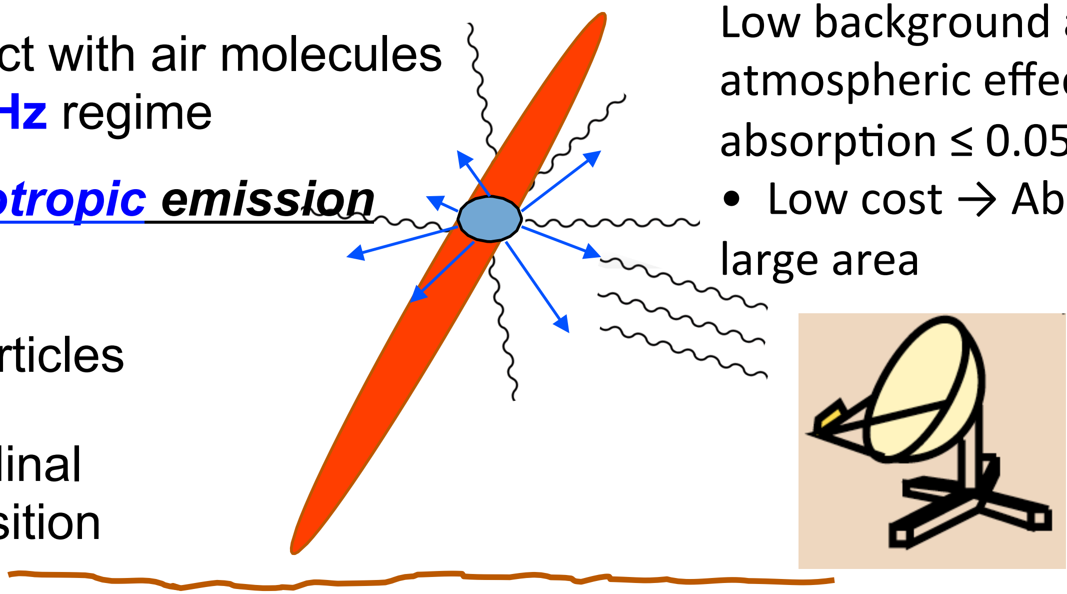
The GHz telescope technique

- EAS charged particles → Ionization → plasma
- Free electrons interact with air molecules → **MBR** emission in **GHz** regime
- ***Unpolarized* and *isotropic* emission**
- Scaling with no. of secondary charged particles
- measure the longitudinal profile ->mass composition

GHz telescope duty cycle ~ 100%

Low background and limited atmospheric effects: microwave absorption ≤ 0.05 dB/km

- Low cost → Ability to cover large area



Energy deposit → **plasma $T_e \sim 10^5$ K** → **Secondary electrons produce <u>bremsstrahlung radiation in the field of the neutral molecules</u>**

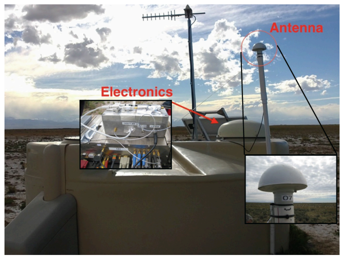
GHz research activies in CR community:

AMBER

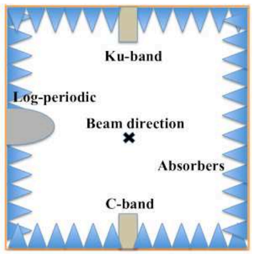
MIDAS

1. M. Monasor et al., arXiv:1010.5224v2
2. R. Smida et al., arXiv:1108.0588v2
3. M. Monasor et al., arXiv:1108.6321
4. J. Alvarez-Muñiz *et al.*, *Phys. Rev. D*86, (2012) 051104 (R)
5. E.Conti et al., arXiv:1408.5886
6. I. Al Samarai et al., arXiv:1409.5051

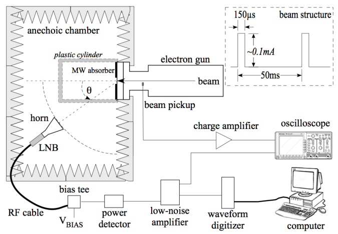
CROME



EASIER



MAYBE

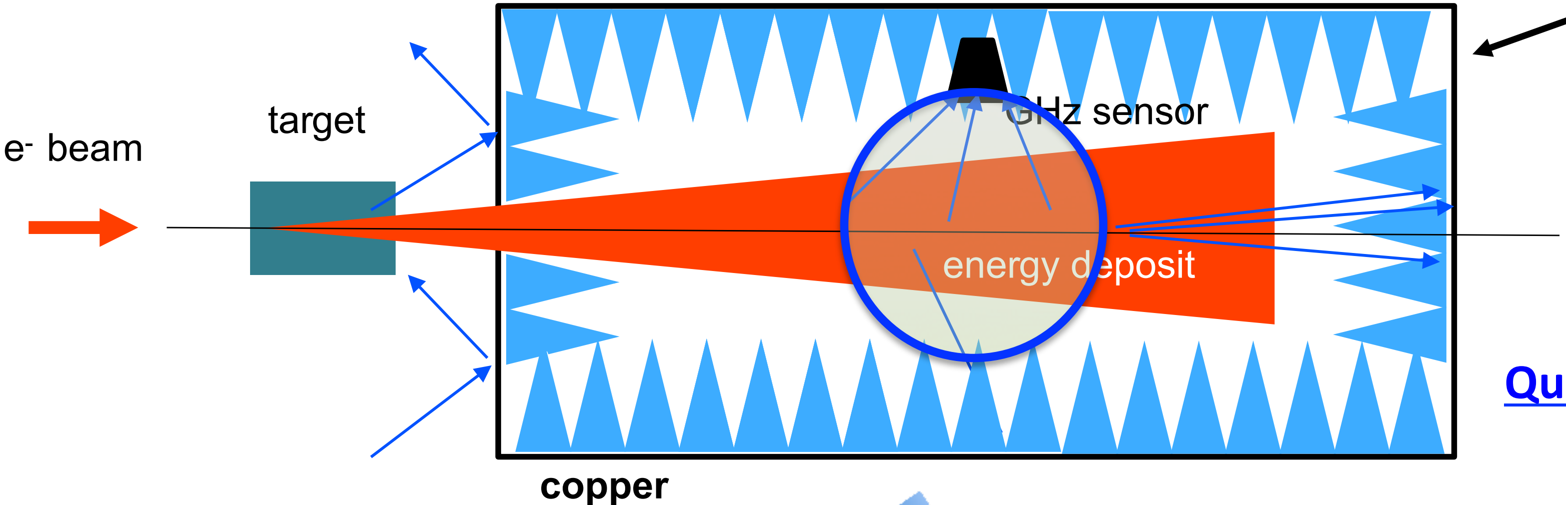


Conti et al.

AMY EXPERIMENT

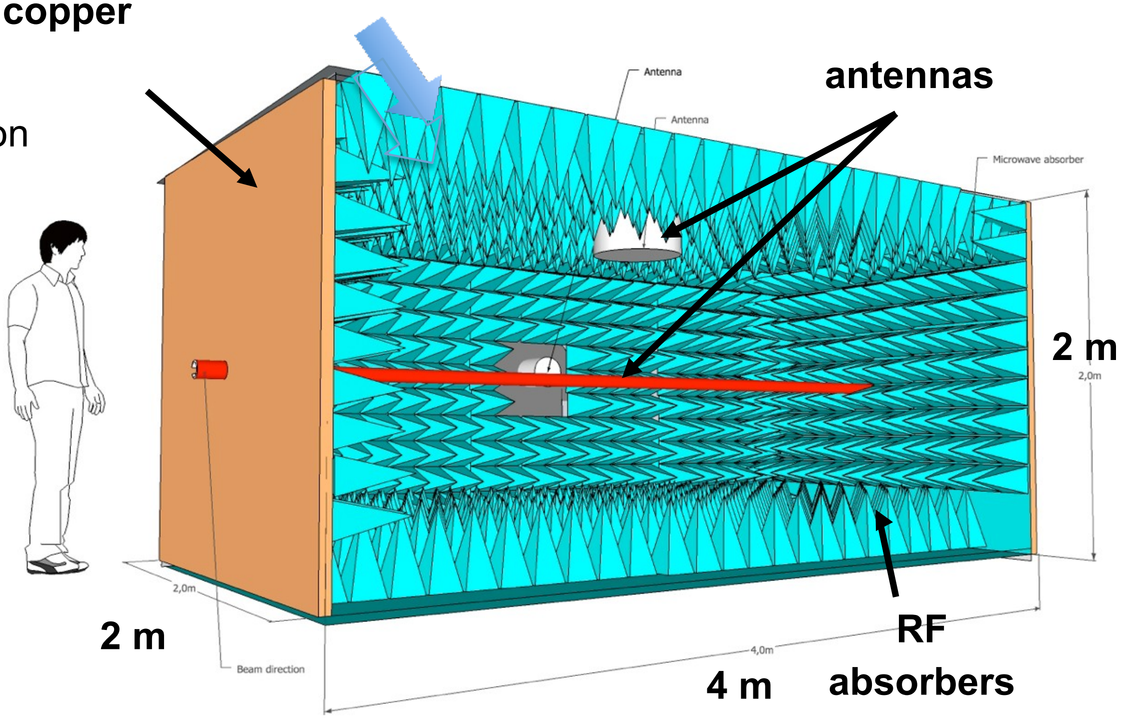
16 m³

vs 1 m³ @ SLAC



Quiet Zone

- MBR ~ energy deposit
- shield from outside radiation
- avoid reflections within the chamber

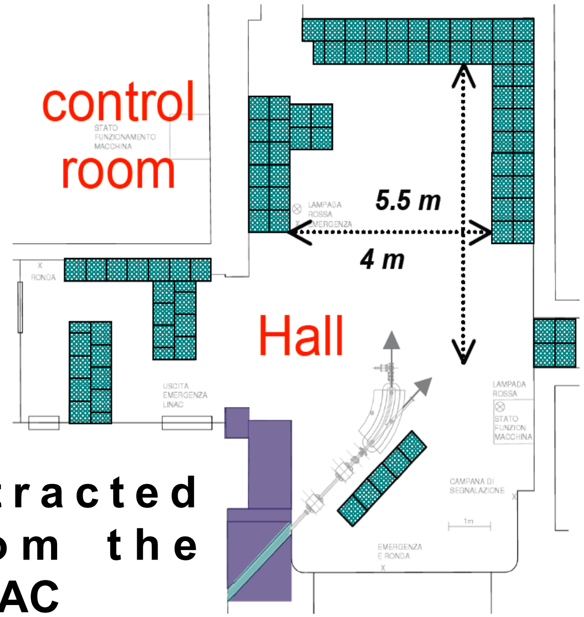


Beam Test Facility (BTF) AT DAΦNE

INFN Frascati National Laboratories

beam	e^-
energy range	510 MeV
repetition rate	few Hz
pulse duration	1.5 3 and 10 ns
max particle/bunch	10^{10}

extracted from the LINAC

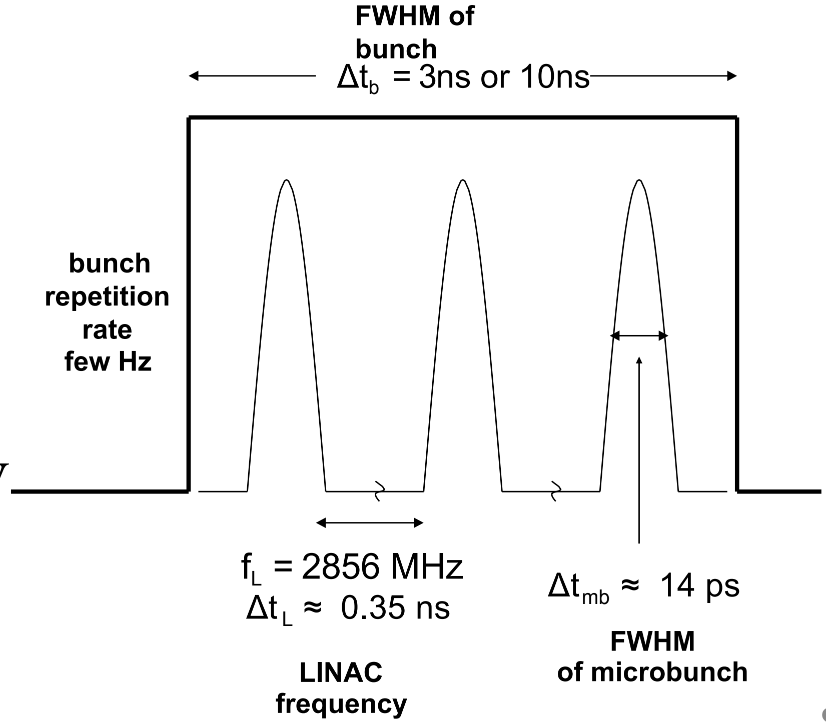


factor 10 higher intensity:

$$\text{BTF} \quad 10^{10}\,\frac{e^-}{\text{bunch}}\cdot 510\ \text{MeV} \approx 5\cdot 10^{18}\text{eV}$$

$$\text{SLAC} \quad 2\cdot 10^{7}\,\frac{e^-}{\text{bunch}}\cdot 28\ \text{GeV} \approx 3\cdot 10^{17}\text{eV}$$

Observations of microwave continuum emission from air shower plasma Physical Review D **78**, 032007 (2008)



AMY COLLABORATION

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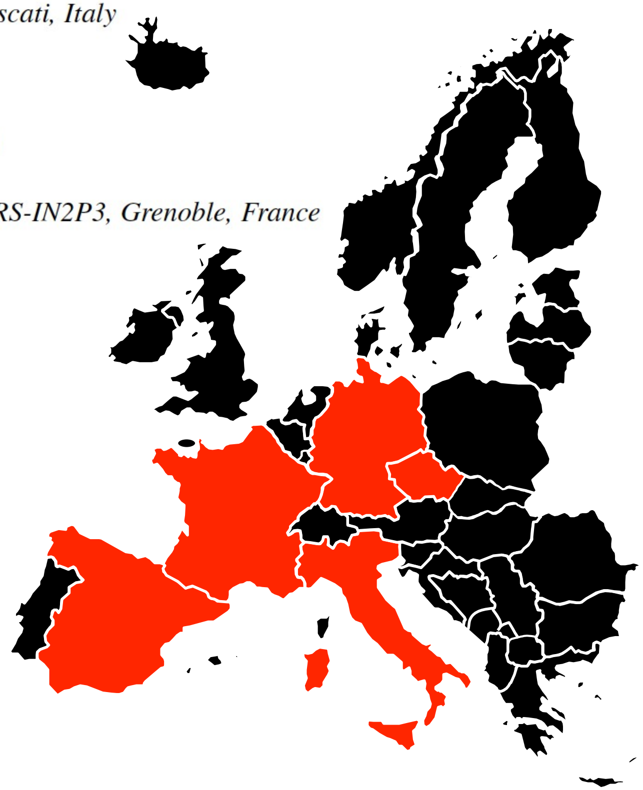
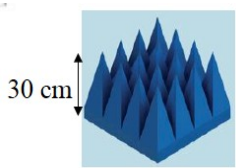
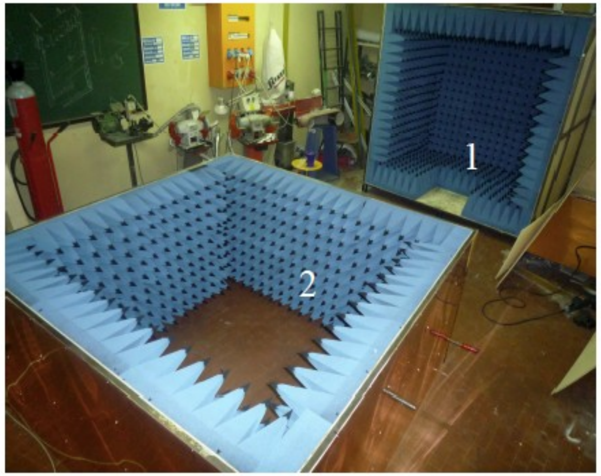


PORTABLE ANECHOIC FARADAY CHAMBER

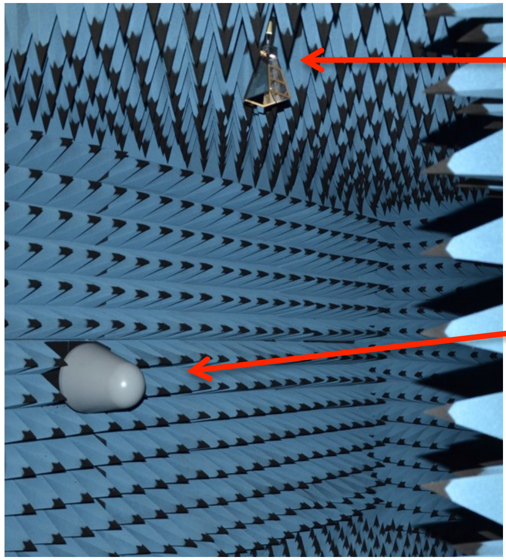
Three modules
(Thanks to Roma Tor Vergata University)

SATIMO
AEP 12
attenuation
1GHz: 30 dB
> 6 GHz: 50 dB



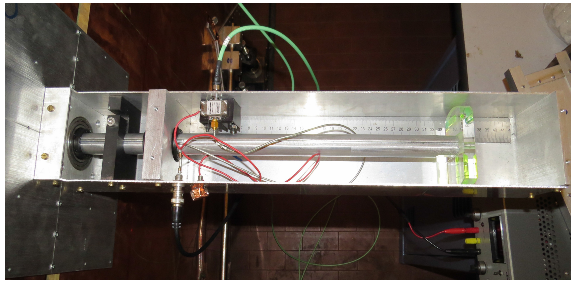


ANTENNA CHARACTERIZATION

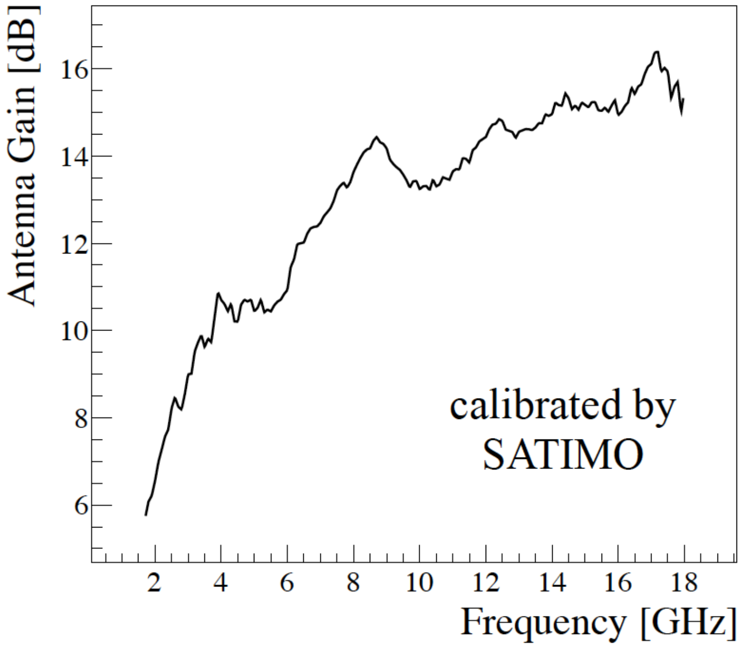


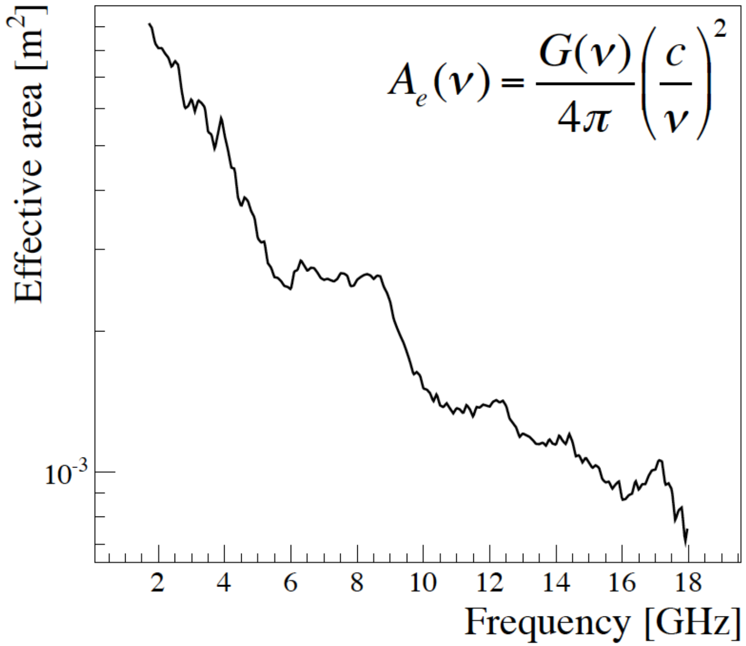
Horn RF Spin DRH20
1.7 - 20 GHz Gain: from 6 to 16 dBi

Log Periodic Rohde&Schwarz HL050
0.25 - 26.5 GHz
Gain: ~ 8.5 dBi



- support external to chamber
- rotation of polarization plane





SETUP AT THE TEST BEAM

1m cable
SMA MM

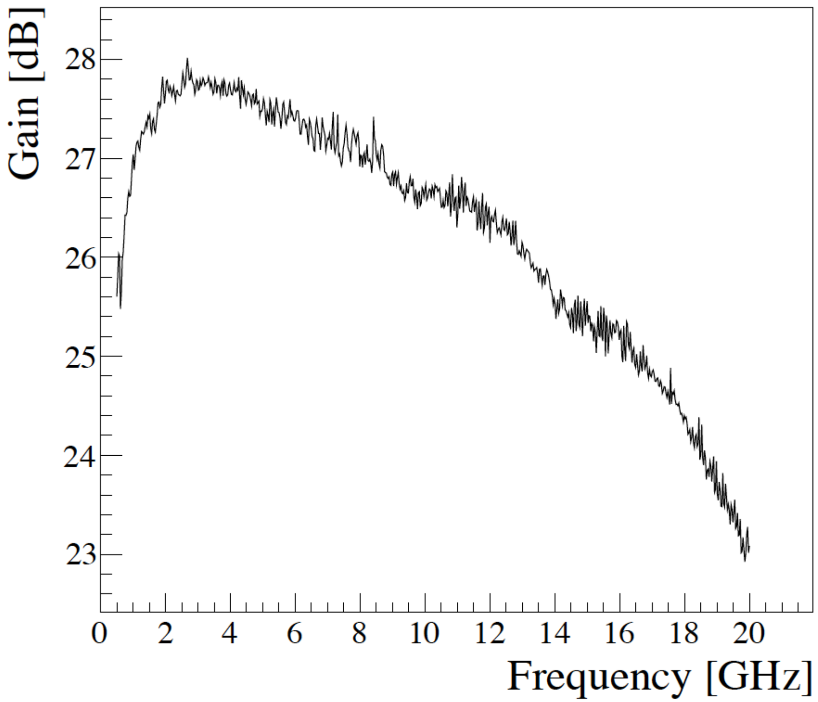
amplifier
SMA FF

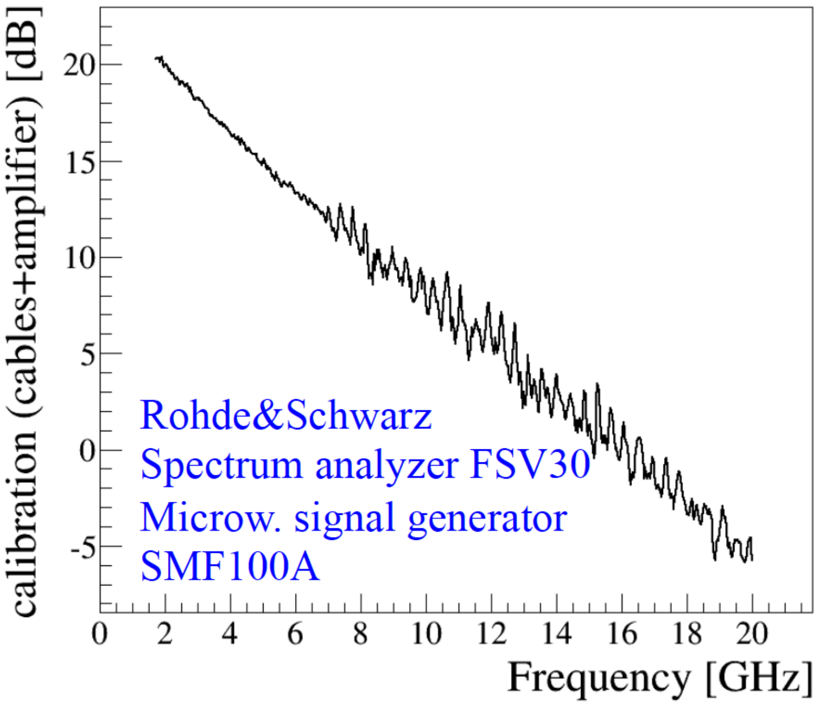
18 m cable
SMA MM

Oscilloscope
(control room)

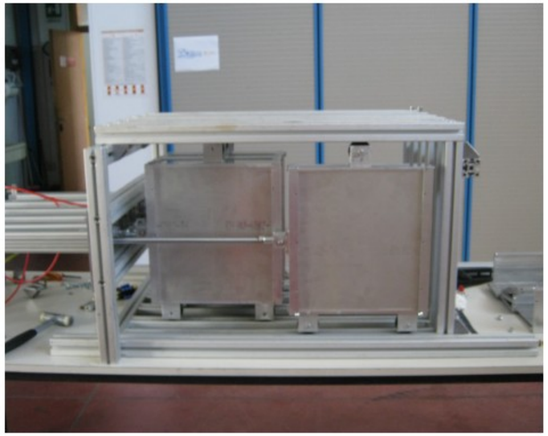
Mini-Circuits
ZVA-213-S+
Gain: ~ 26 dB

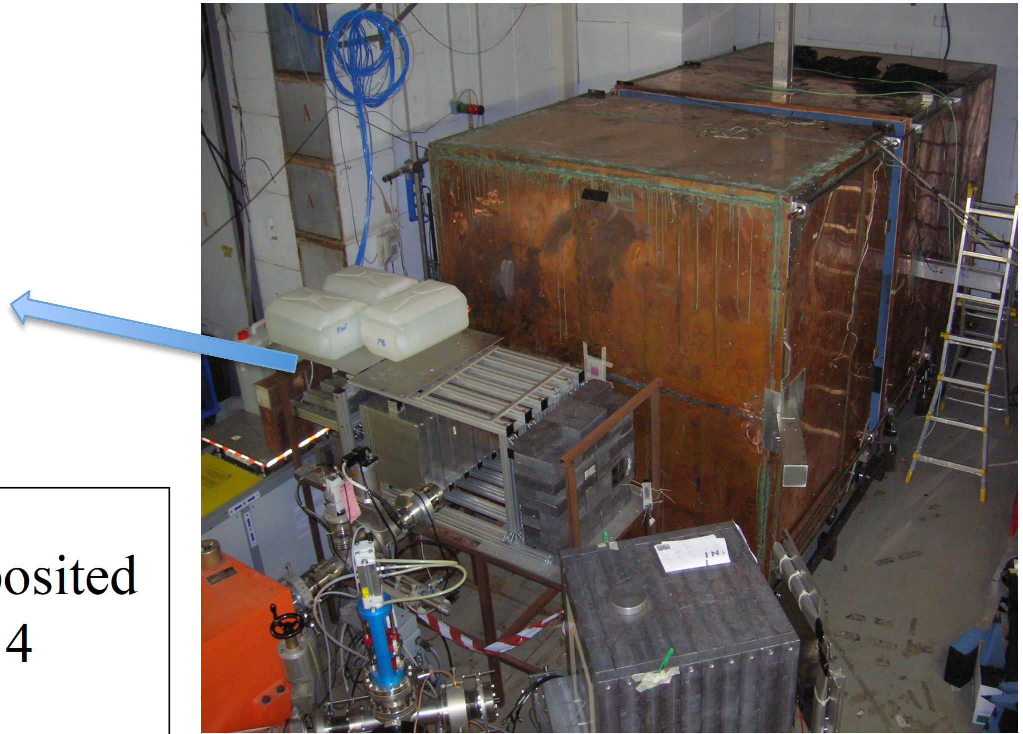
Lecroy SDA 830Zi-A
<u>**20 GHz real time bandwidth**</u>
4 ch. , 40 GS/s

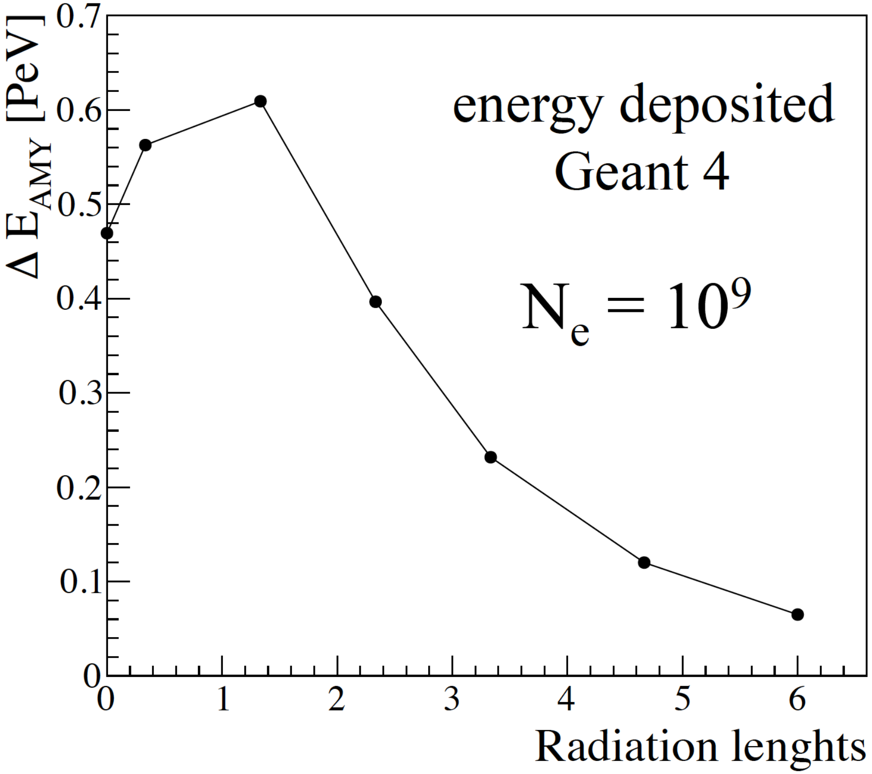




SETUP AT THE TEST BEAM







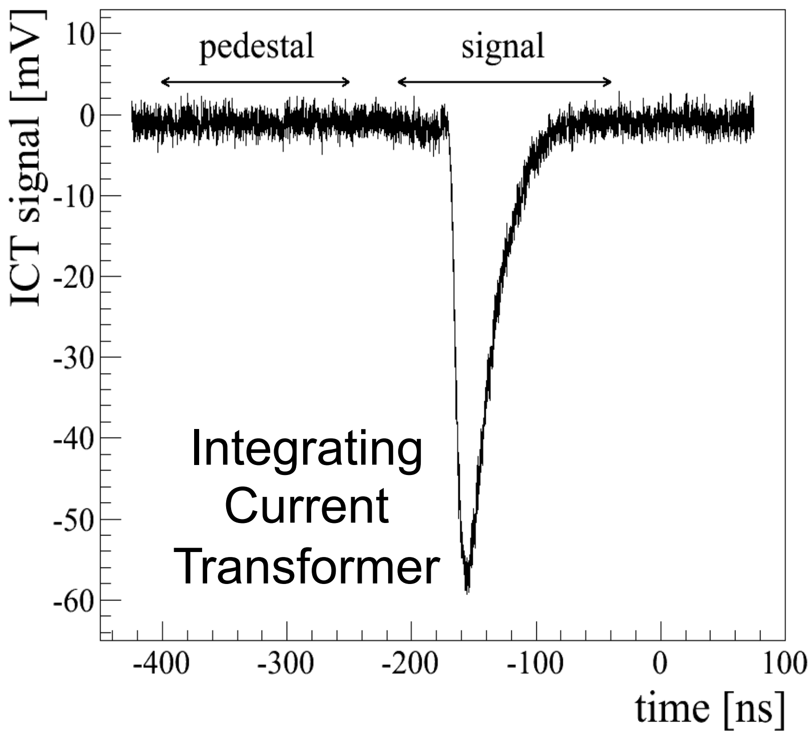
Al_2O_3 $X_0 \approx 7.5$ cm

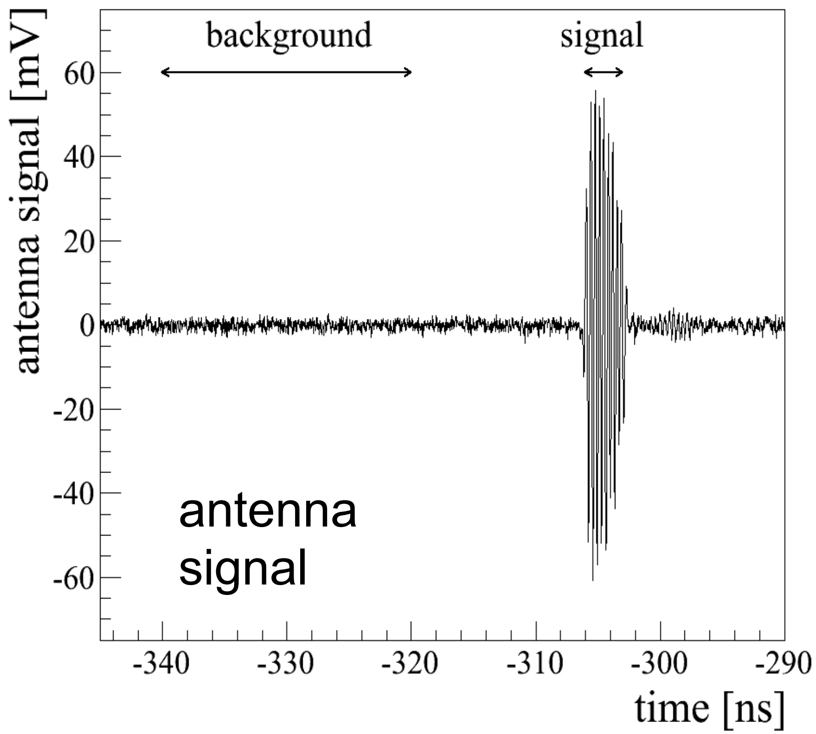
6 modules remotely controlled with compressed air system

SIGNAL DEFINITION

For each bunch

- trigger from LINAC
- acquire beam and antenna signals with the oscilloscope
 (Δt = 25 ps)



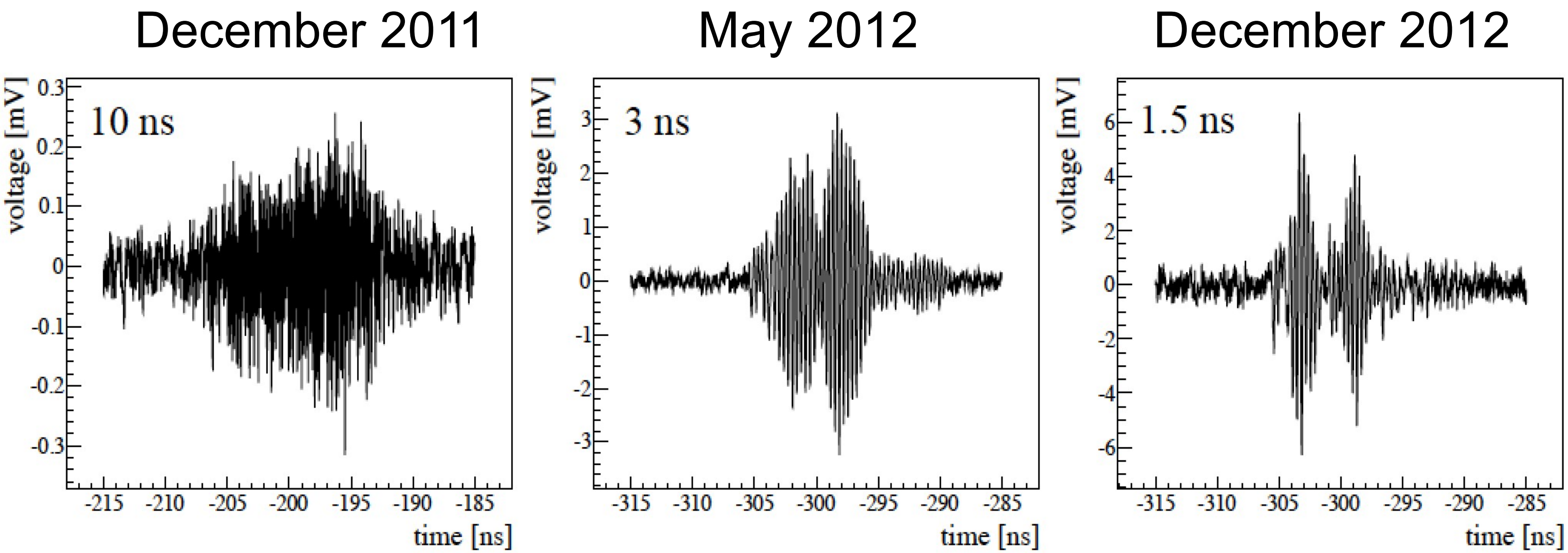


$$N_e \propto \int dt\, V(t)$$

$$\text{Power} = \frac{(V_{RMS}^{sgn})^2 - (V_{RMS}^{bkg})^2}{R}$$

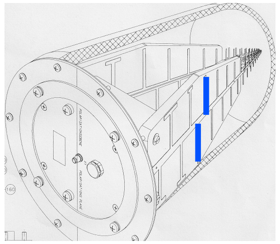
BUNCH LENGTH

three test beams:

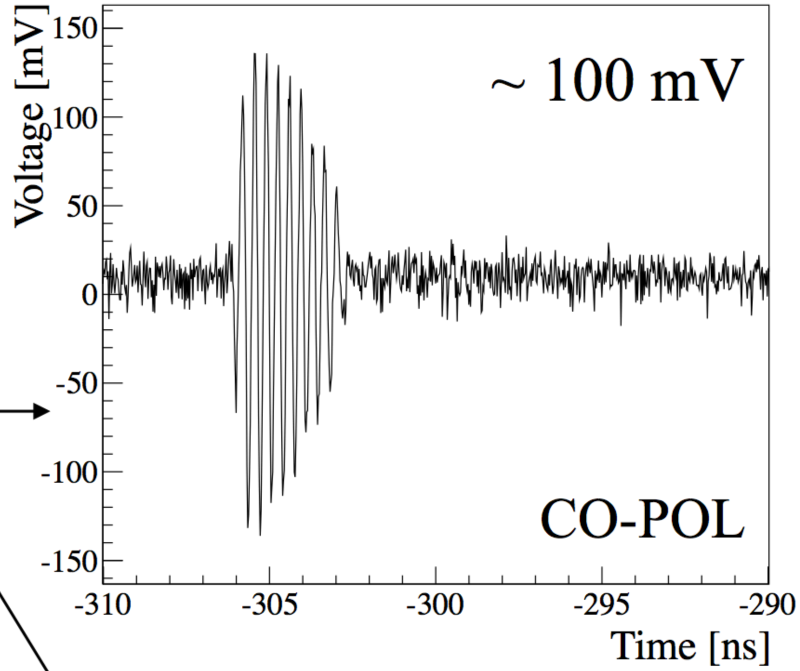


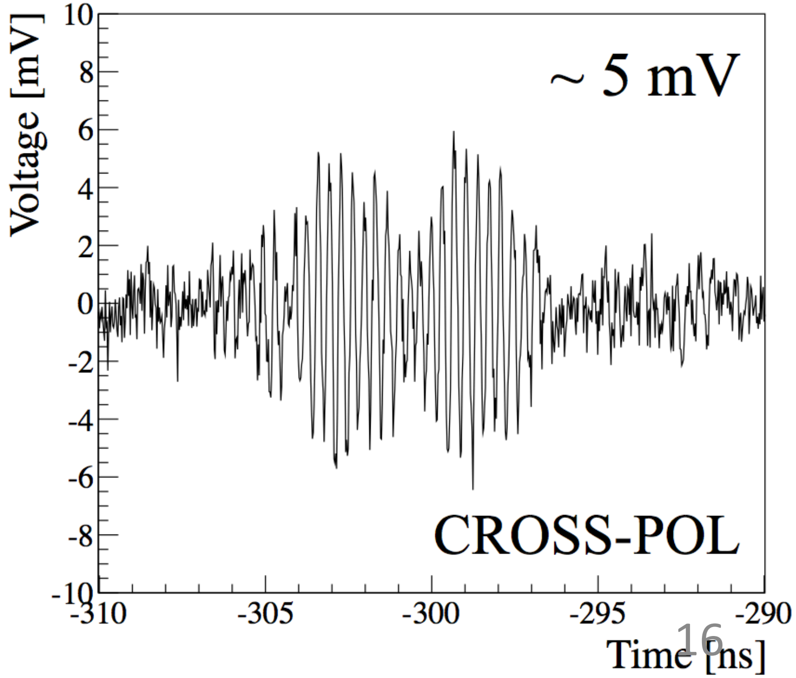
short bunch length reveals a particular signal time structure

CROSS/CO POLARIZATION

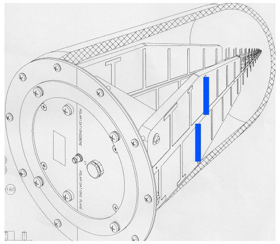


Cherenkov background reduced with dipoles perpendicular to beam axis

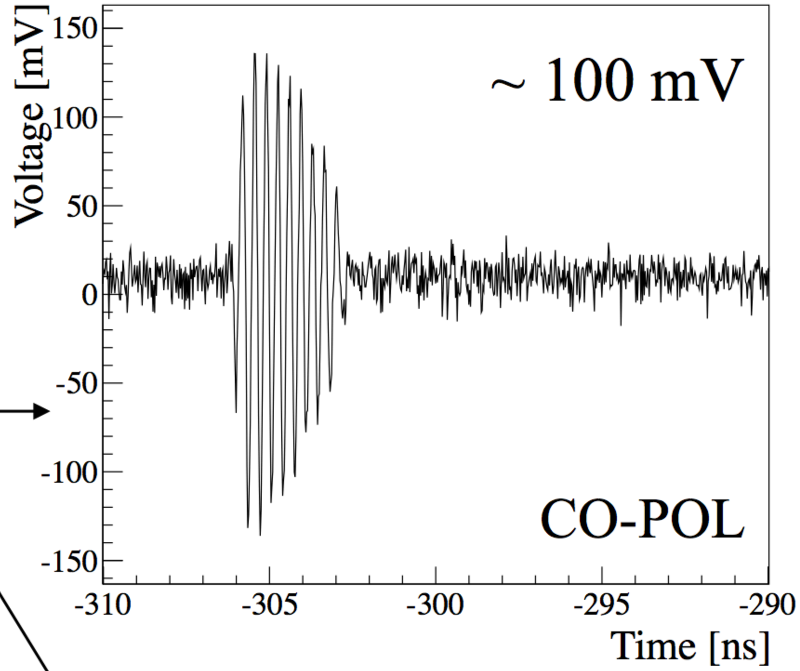




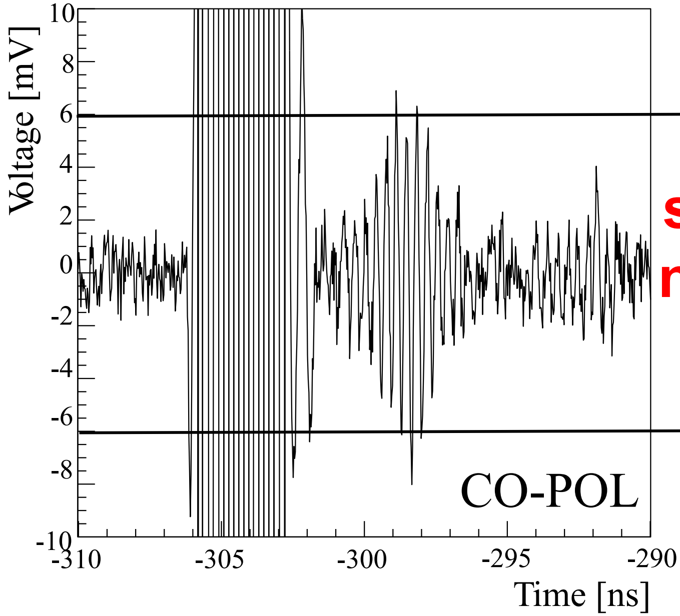
CROSS/CO POLARIZATION



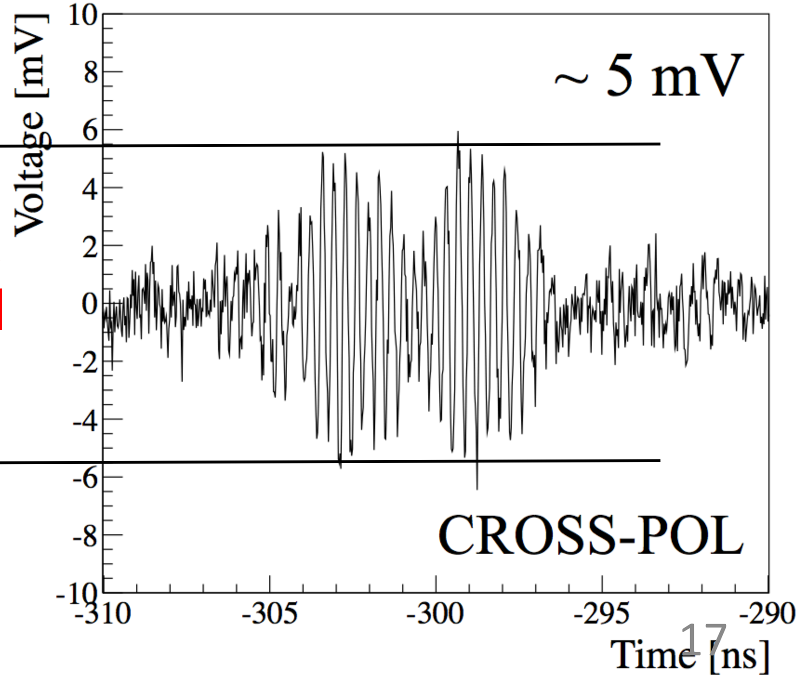
Cherenkov background reduced with dipoles perpendicular to beam axis



saturated



second peak nonpolarized (MBR?)

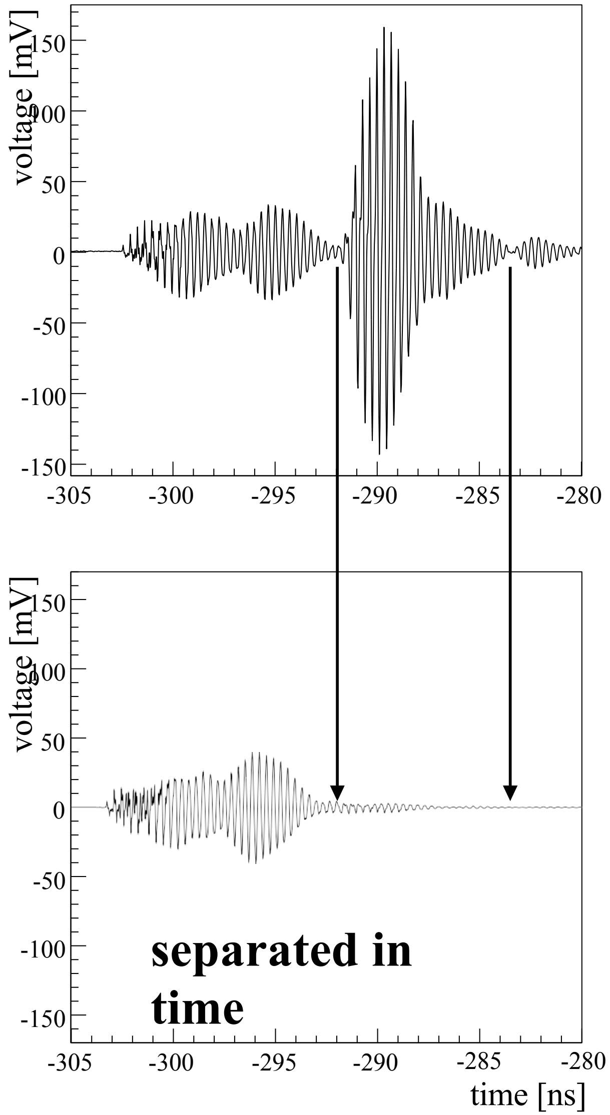


INTERPRETATION ?

Second peak seems not generated by reflections

- **in the chamber**
- **cables**
- **amplifier**
- **….**

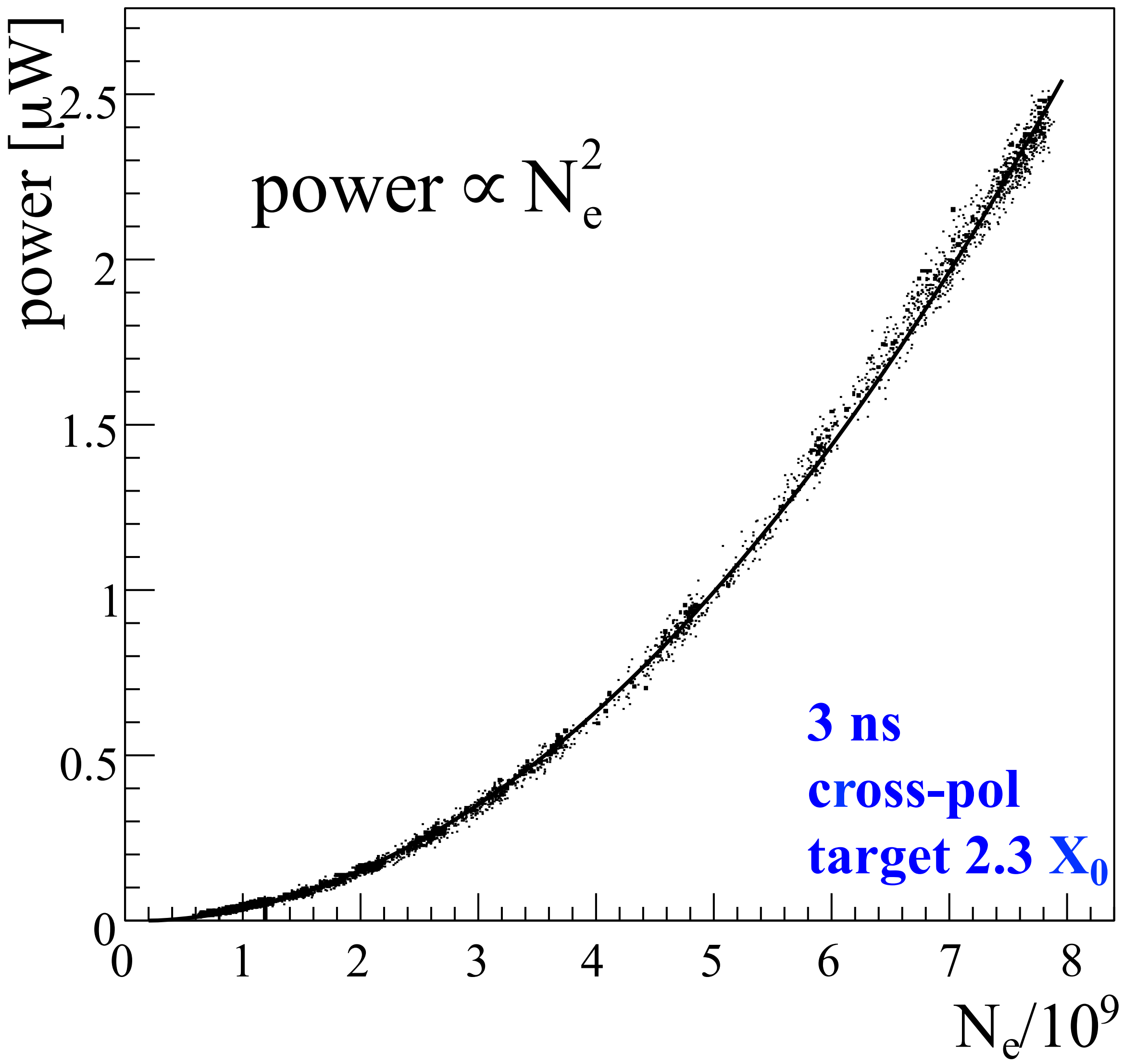
very difficult …



big reflections *only* with a metal plate centred at the end of the chamber

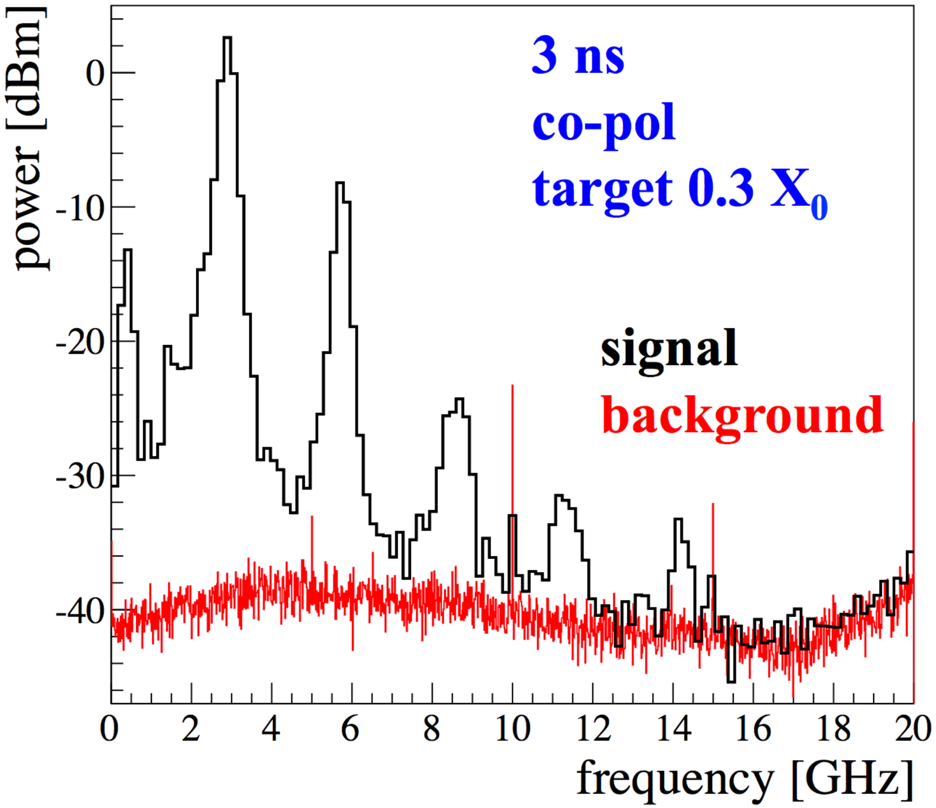
without reflector

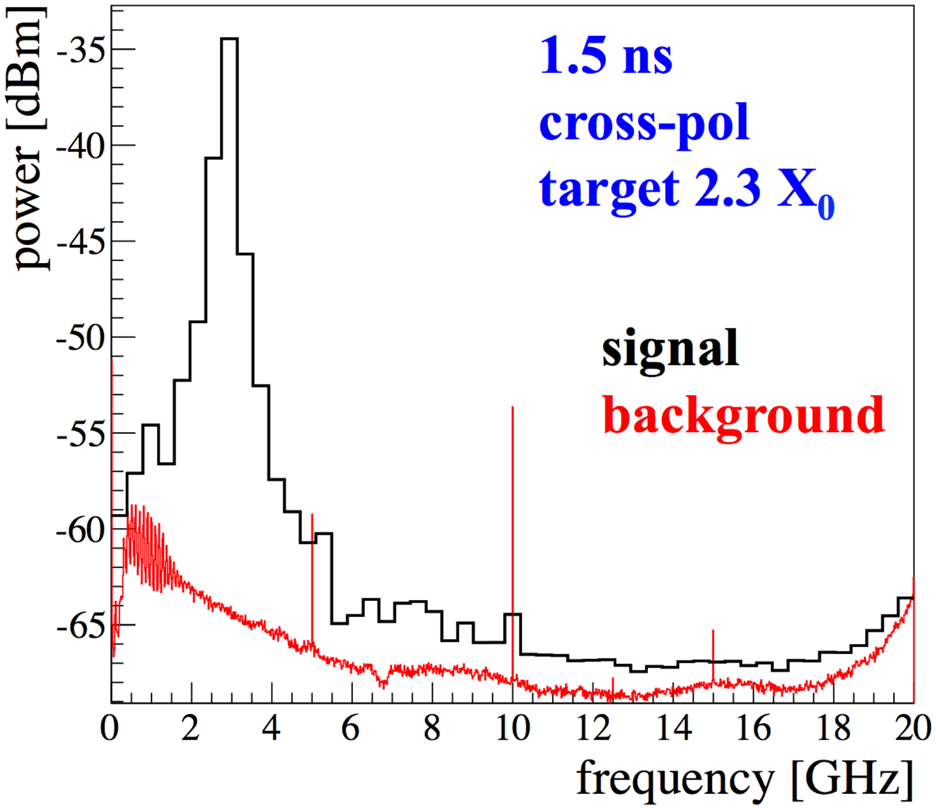
POWER vs BEAM INTENSITY



FREQUENCY SPECTRUM

FFT of oscilloscope traces (average over many triggers)

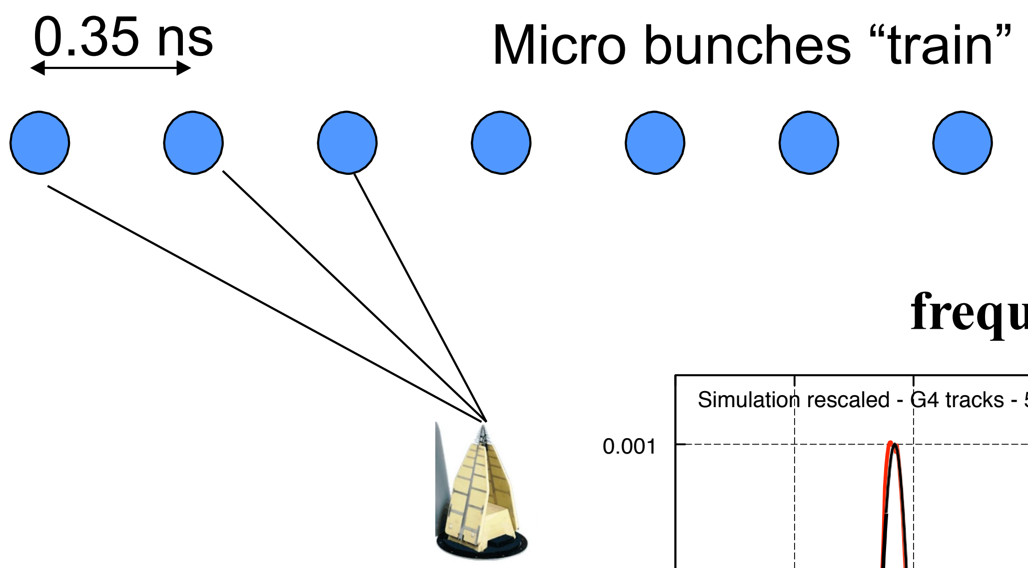




main line at f_{LINAC} = 2.85 GHz

for small thickness of the target (higher signals) harmonics at multiples of f_{LINAC}

FREQUENCY SPECTRUM

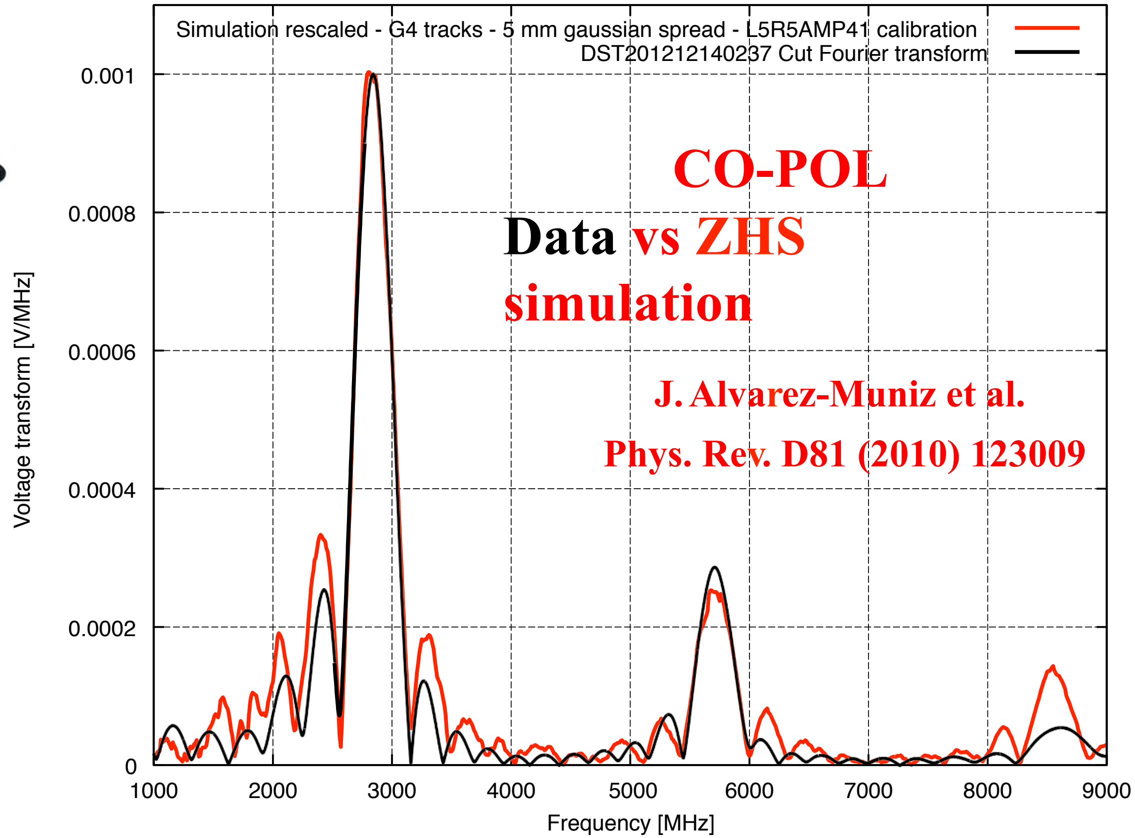


simulation of Cherenkov radiation

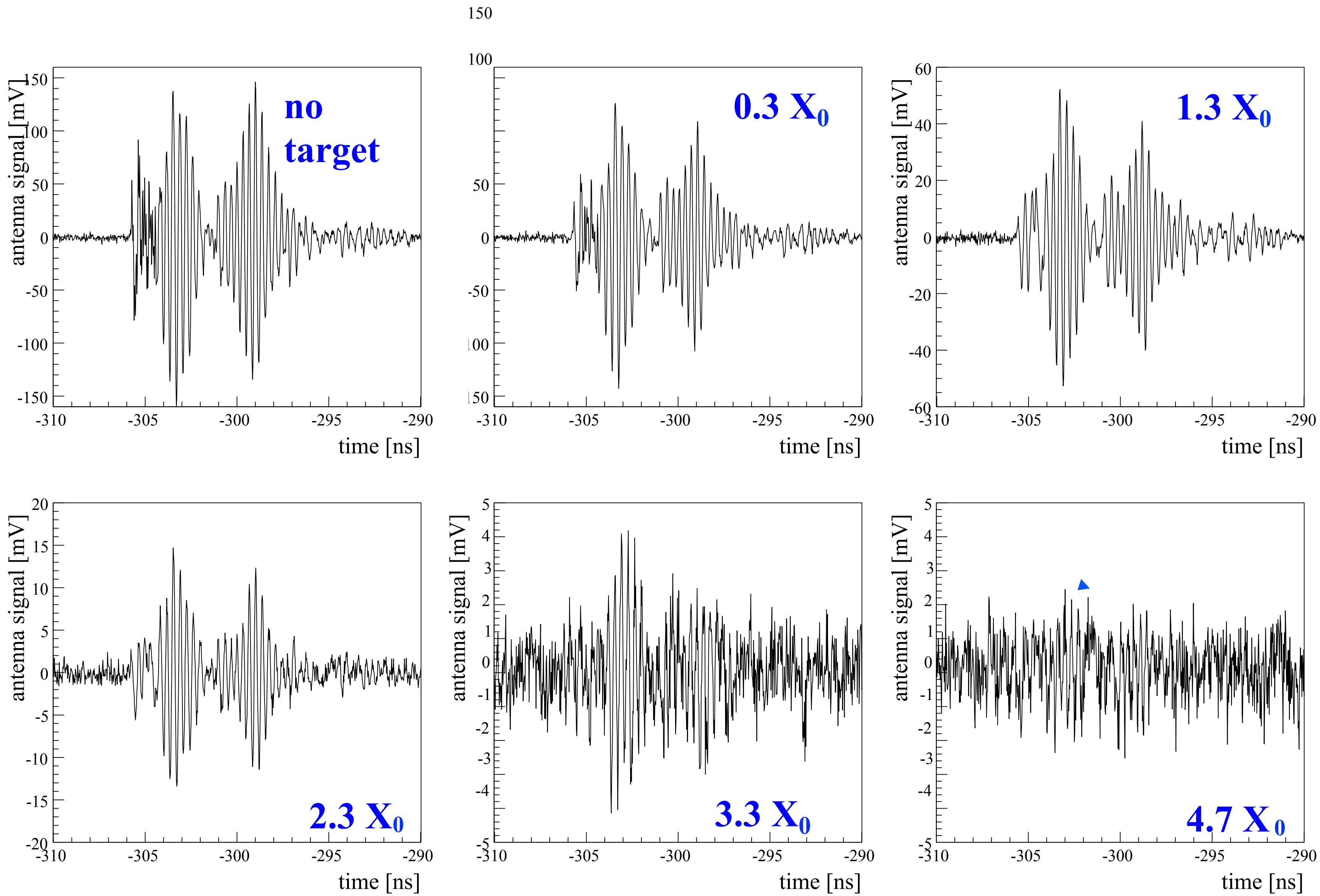
↓

interference peaks at the LINAC harmonics

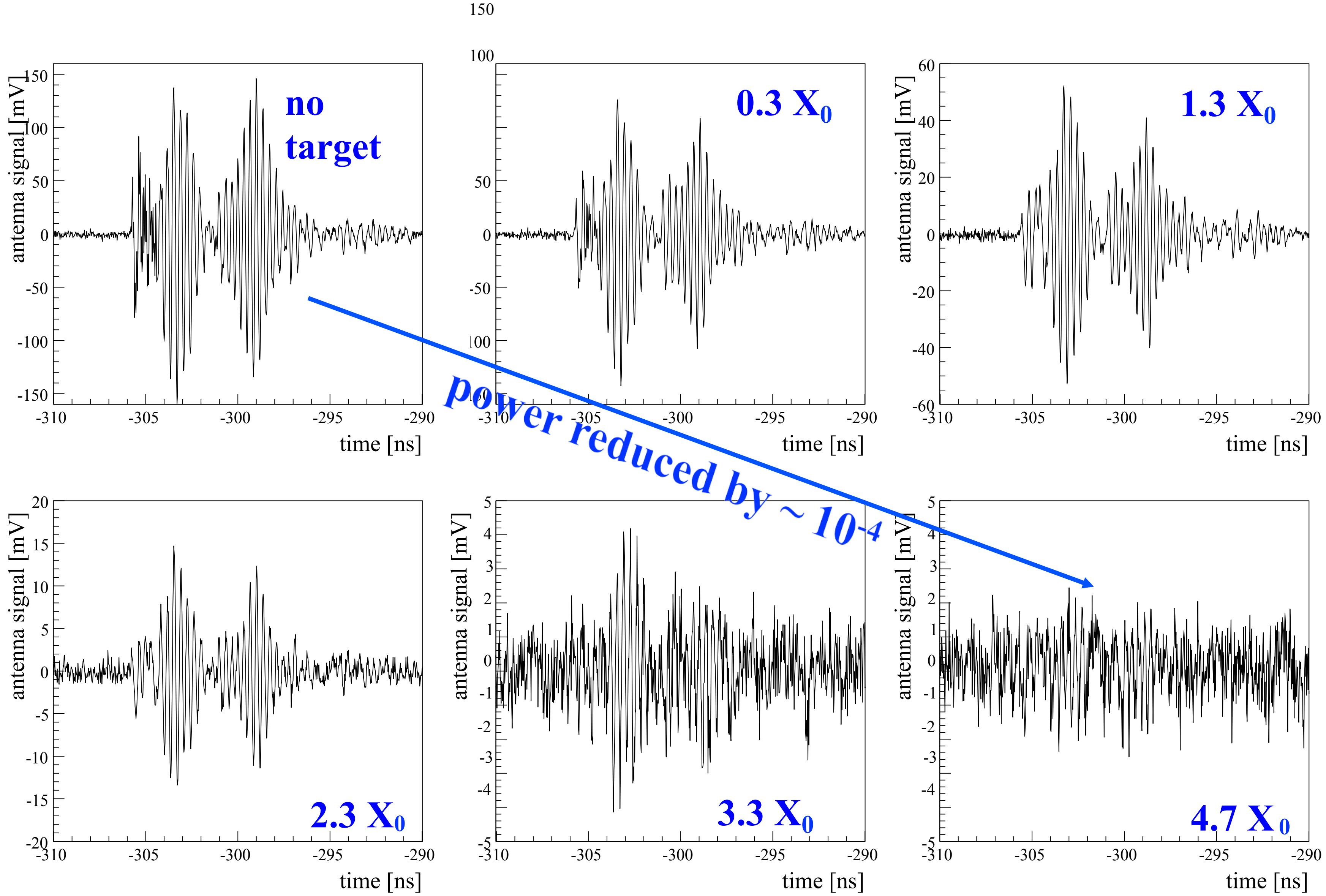
frequency spectrum



SIGNAL vs TARGET TICKNESS



SIGNAL vs TARGET TICKNESS

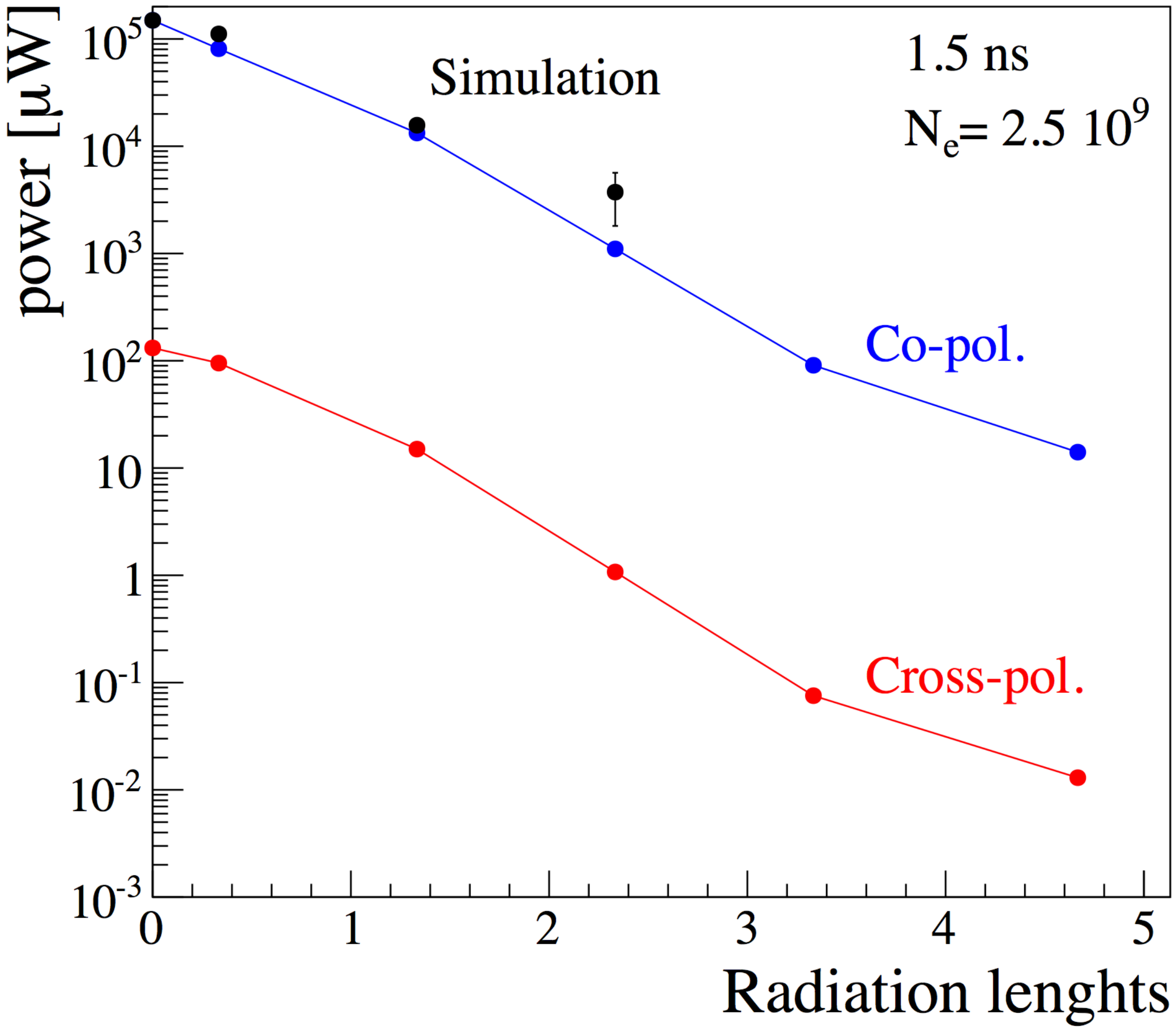


SIGNAL vs TARGET TICKNESS

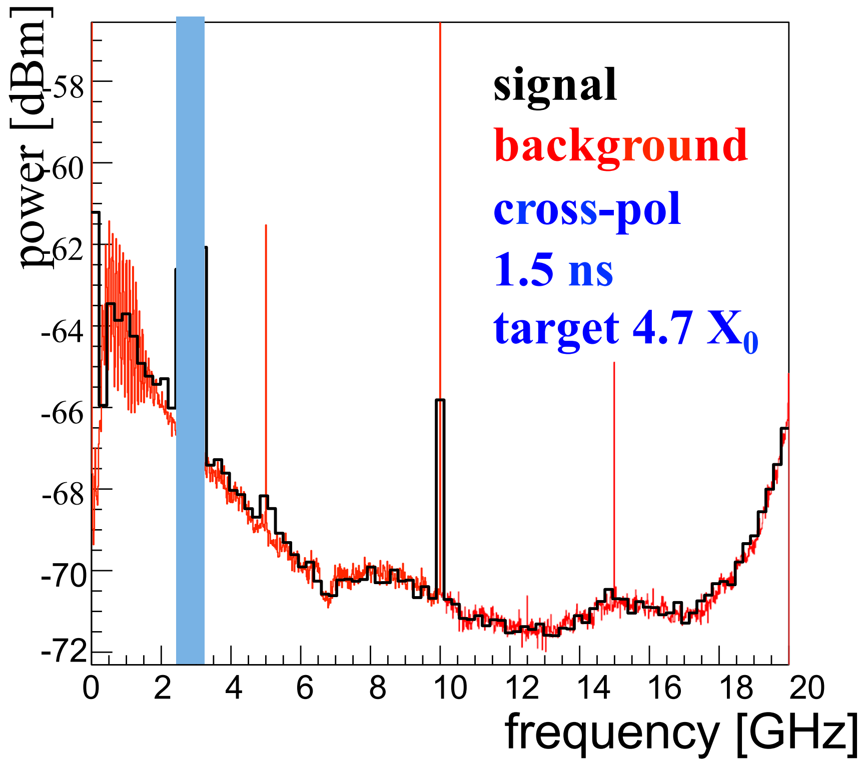
Cross-pol very similar to Co-pol

coherence partially destroyed by the target

confirmed by Cherenkov simulation (preliminary)



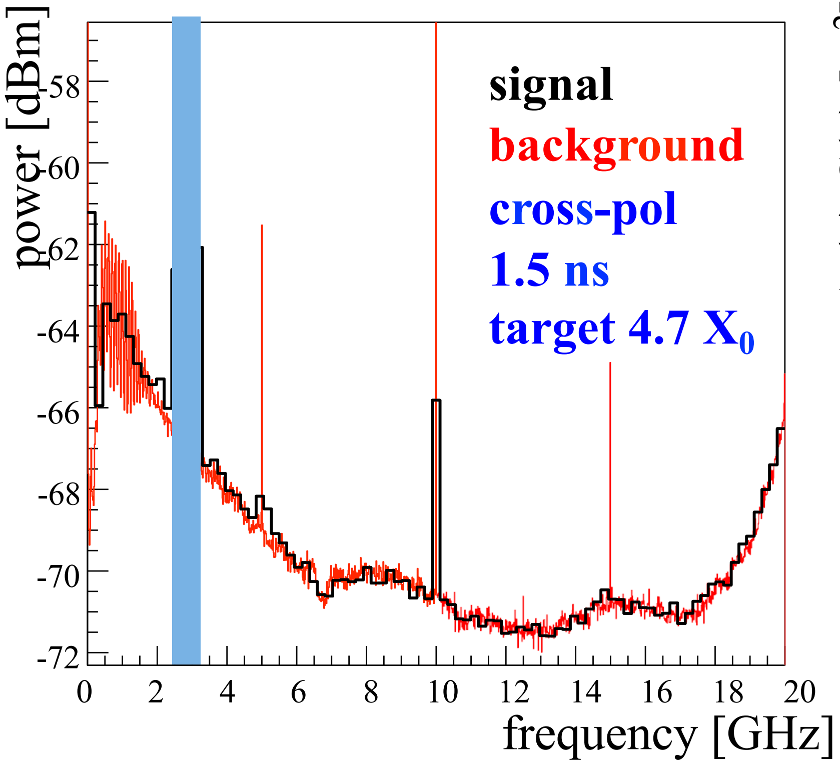
CROSS-POL SIGNAL WITH 4.7 X_0

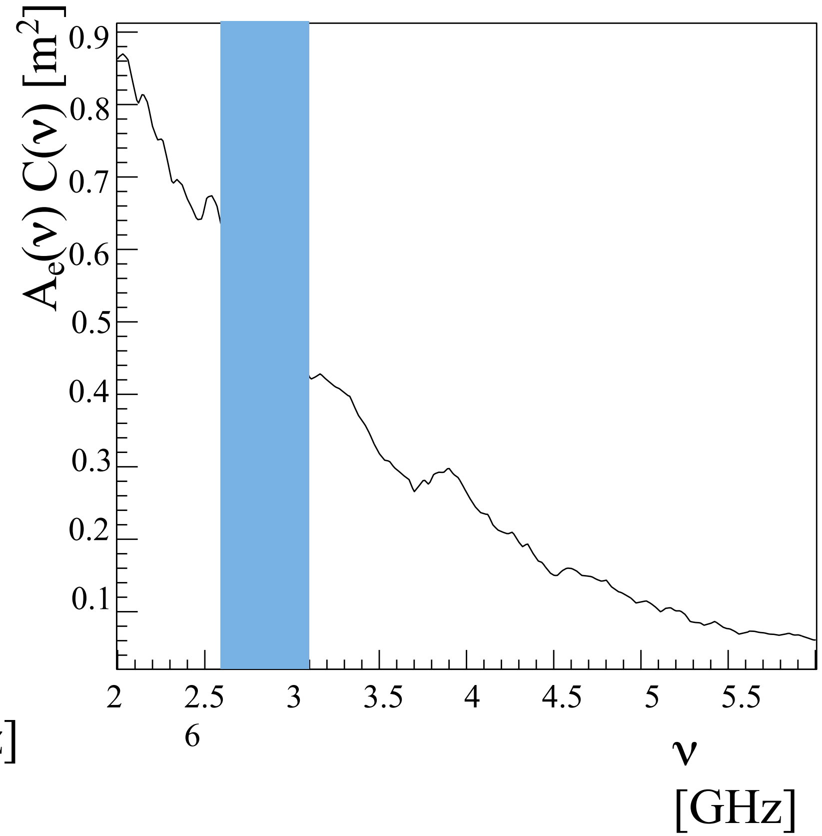


strong coherence induced by the LINAC even with maximum target thickness

- **If MBR, in atmospheric showers the yield should be lower**
- **Density flux ($W/m^2/Hz$) ?**

CROSS-POL SIGNAL WITH 4.7 X_0





$$P(\nu_1,\nu_2) = \int_{\nu_1}^{\nu_2} d\nu \; I(\nu)\; A_e(\nu)\; C(\nu)$$

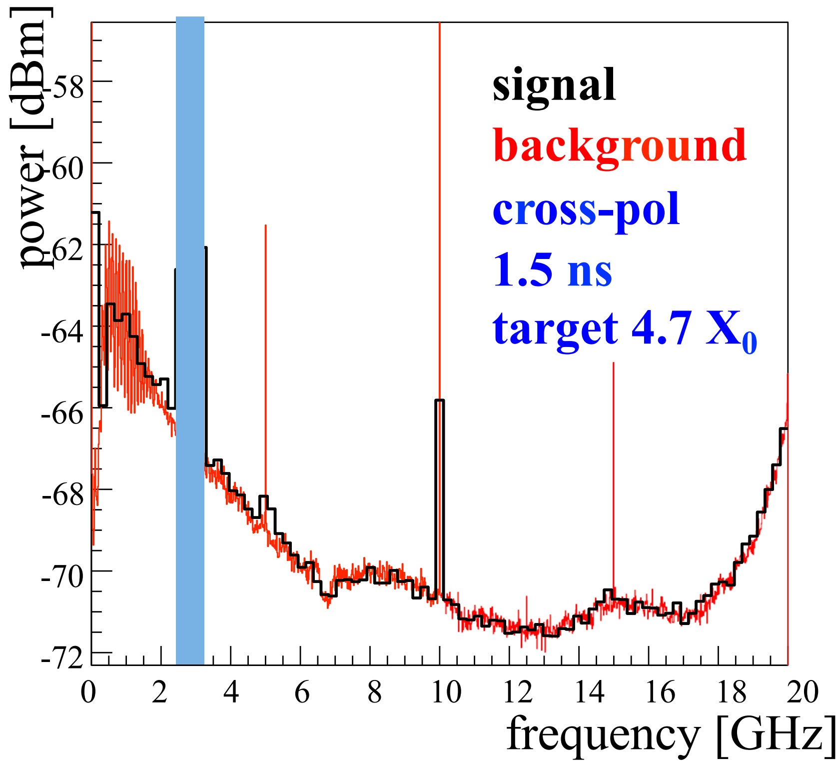
density flux — antenna effective area — calibration cables +amplifier

$$I_{meas} \approx \frac{P_{meas}}{\Delta\nu \;\; A_e(\nu_L)\; C(\nu_l)}$$

$$\nu_L = 2.86 \; GHz$$

$$\Delta\nu \sim 0.5 \text{ GHz}$$

CROSS-POL SIGNAL WITH 4.7 X_0



PRELMINARY

$$P_{meas} \approx 10 \text{ nW}$$

$$I_{meas} \sim 5 \cdot 10^{-17} \frac{\text{W}}{\text{m}^2\text{Hz}}$$

$I_{meas} < 4\ 10^{-16}$ W/m²/ Hz

Physical Review D **78**, 032007 (2008)

$$P(\nu_1,\nu_2) = \int_{\nu_1}^{\nu_2} d\nu\ I(\nu)\ A_e(\nu)\ C(\nu)$$

density flux

antenna effective area

calibration cables +amplifier

$$I_{meas} \approx \frac{P_{meas}}{\Delta\nu\ A_e(\nu_L)\ C(\nu_l)}$$

$$\nu_L = 2.86\ GHz$$

$$\Delta\nu \sim 0.5 \text{ GHz}$$

OUTLOOK

- **AMY: three successful tests at the BTF**

- **not clear interpretation of the cross-pol signal Cherenkov, MBR, ..?**

- **strong coherence induced by the LINAC→if MBR, in atmospheric showers the yield should be lower**

- **density flux (at 4.7 X_0) ~ 5 x 10^{-17} W/m^2/Hz**

- **other test beam in Dec 2014: increase the sensitivity between LINAC peaks (hardware in narrower bands → 60 db amplifiers)**

END