The Air Microwave Yield (AMY) experiment to measure the GHz emission fom air shower plasma

- Gabriella Cataldi (for the AMY collaboration)
  - The collaboration
  - The physics case
  - The AMY experiment
  - Simulation
  - Test Beams @BTF
  - Second Test Beam @ BTF
  - Conclusions

The Collaboration and the experiment aim

AMY CSN-V financed for 2 years 2011-2012

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- Siegen: M. Settimo
- Karlsruhe: R. Engel, M. Riegel, R. Smida, F. Werner

The aim is to make a precise measurement of the MBR power and frequency spectrum repeating a test similar to a previous measurement

The physics case

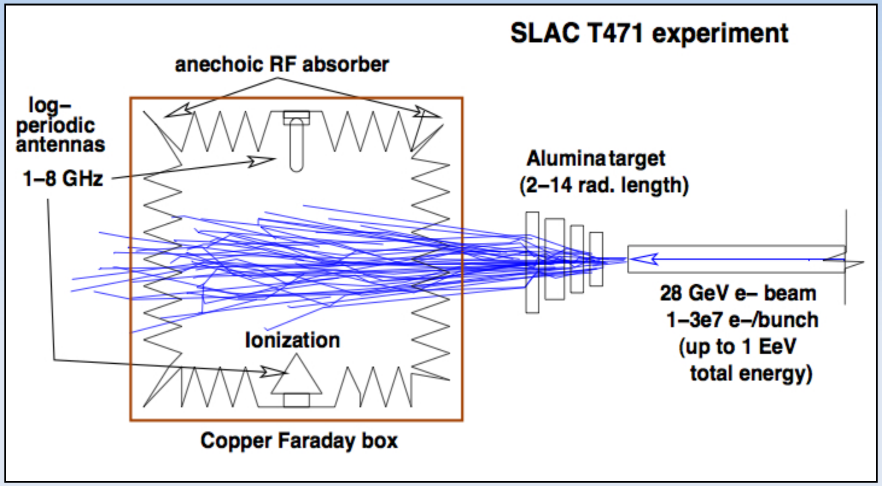
- Recently (in 2008), the observation of a microwave continuum emission from air shower plasmas has raised the interest in a possible new detection technique for ultra-high energy cosmic rays
- The plasma is created after the release of the energy shower in the atmosphere and it is made by electrons with temperature of about 10^5 K
- The plasma cooling process holds over a time scale of a few nanoseconds and it comes mainly via the medium excitation.
- A Microwave Bremsstrahlung Radiation (MBR) is emitted by secondary electrons accelerating in collisions with neutral molecules of the atmosphere.
- The radiation is expected to be isotropic and un-polarized.

The AMY project aims to measure the MBR absolute yield and its frequency spectrum between 1 and 20 GHz at the Beam Test Facility (BTF) of Frascati INFN National Laboratory. The final purpose is to characterize a process to be used in a next generation detectors of ultra-high energy cosmic rays (10^{20} eV).

SLAC Experiment

P.W. GORHAM ET AL., PHYS. REV. D 78, 032007 (2008)

Experimental apparatus



- e-beam on Alumina target
- 2 log- periodic antennas

Intensity vs time shows an exponential decay (15-30 ns)

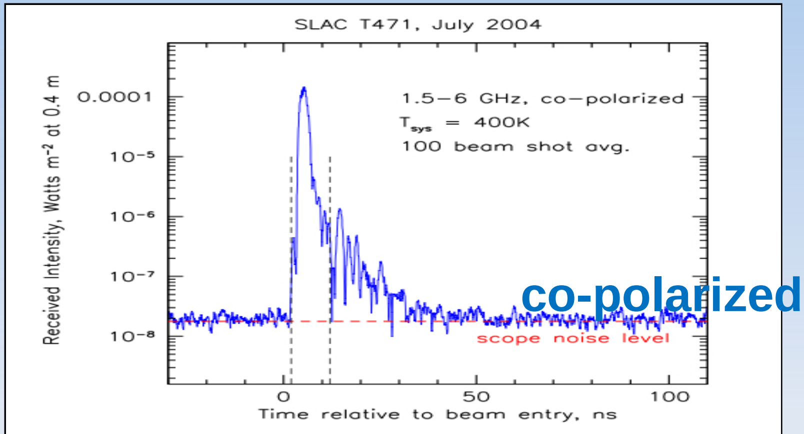


FIG. 6: Average microwave emission amplitude from 100 beam shots taken near shower-maximum in the 2004 SLAC T471 experiment, using a broadband antenna that was polarized along the electron beam axis, and was thus sensitive to partially coherent radiation directly from the relativistic electron shower as it transited the Faraday

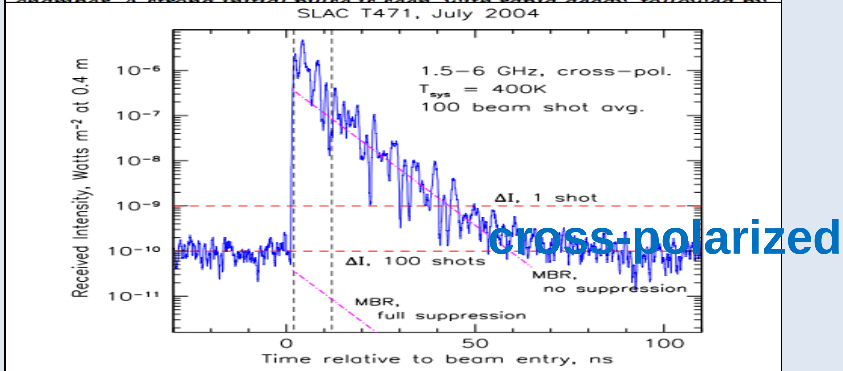
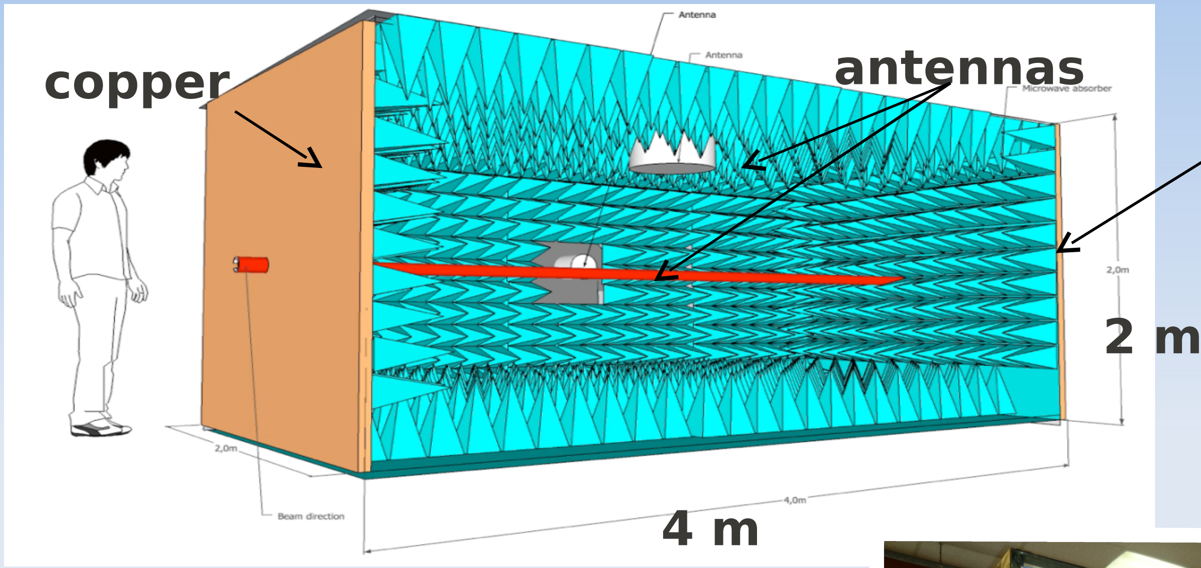
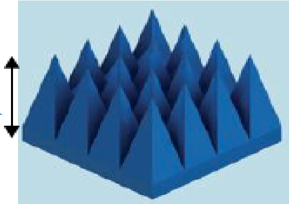


FIG. 7: A plot similar to the previous figure, but now using a cross-polarized antenna which was insensitive to radiation polarized with the electron beam. The dynamic range of the system was now improved so that the noise level is determined by thermal noise, and the detected microwave emission extends out to 60 ns or more, with an exponential decay time constant of about 7 ns. The upper and lower dashed red horizontal lines indicate the minimum detectable intensity, as given by equation 8 for the single-shot case, and the 100-shot average. The diagonal dot-dash lines are the two extreme-case estimates for MBR emission: the upper case for no net collisional suppression and the lower case for maximal collisional suppression of the emission, both for the case where the electron thermalization time constant is the source of the 7 ns exponential decay observed.

AMY Experimental apparatus: The anechoic Faraday chamber

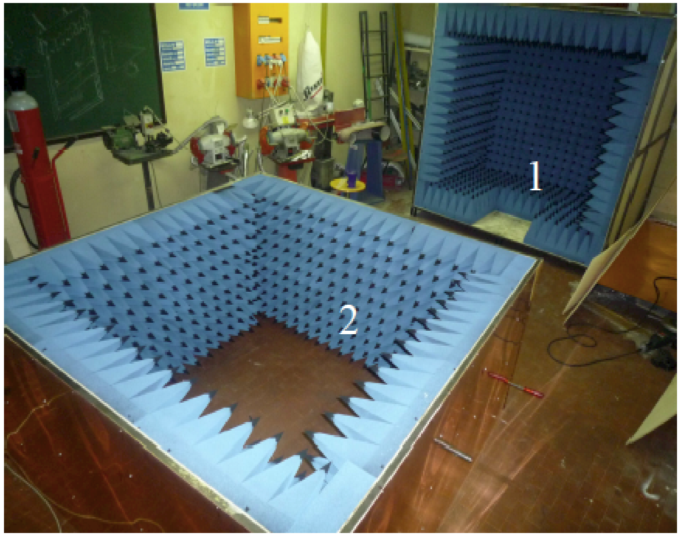




RF ABSORBERS
SATIMO AEP 12
Attenuation:
- 1GHz : 30 dB
- <6GHz: 50 db

Three modules:
- 1-3 length 1,5 m
- 2 length 1 m

Measured shielding for outside radiation above 4 GHz better than 85 dB, it reduces down to 40 dB at 1 GHz.

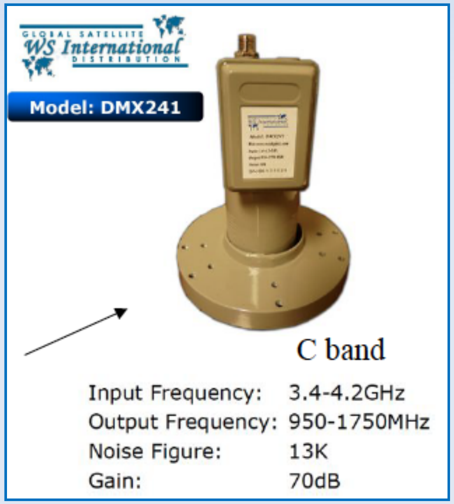


AMY Experimental apparatus: Instrumentation

(2) HORN DRH20 RFSPIN
•Range: 1.7-20 GHz
• Gain: 6-16 dBi

(2) Log Periodic Rohde&Schwarz HL050
•Range: 0.25-26.5 GHz
•Gain: ~8.5 dBi

Amplifier Mini-Circuit ZVA-183-S+
•800MHz-21GHz
•Gain 26dB



- Oscilloscope LECROY SDA 830Zi-A: 4 ch, 20 GHz real time bandwidth, 40 GS/s
- Spectrum analyzer ROHDE&SCHWARZ SFSV30: 9-30 kHz, 40 MHz bandwidth
- Microwave signal generator ROHDE&SCHWARZ SMF100A: 100 KHz to 22 GHz.

GRAZIE a Dr.Notaro (LeCroy) e ad **Alessandro Corvaglia**

The key point of the measurement

- Above ≈ 20 MeV the electrons in air emit cherenkov radiation

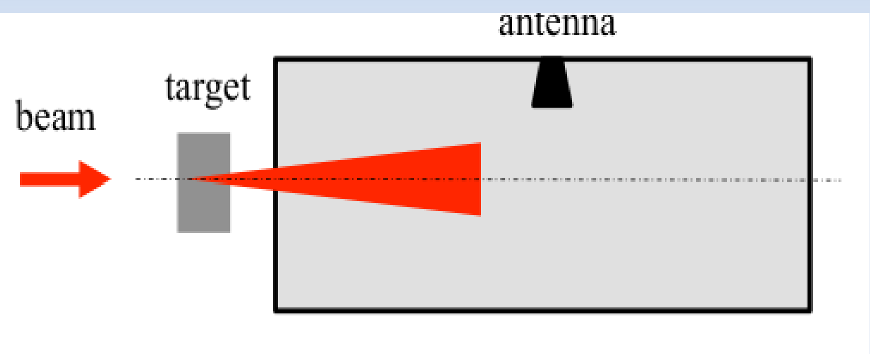
BTF – 510 MeV (SLAC – 28 GeV)

very strong electric field from the beam at the GHz frequencies (bkg)

- MBR should be produced by secondary electrons

maximize the energy deposit

by producing an air shower



- the cherenkov radiation is polarized in the plane defined by the poynting vector and the electron velocity

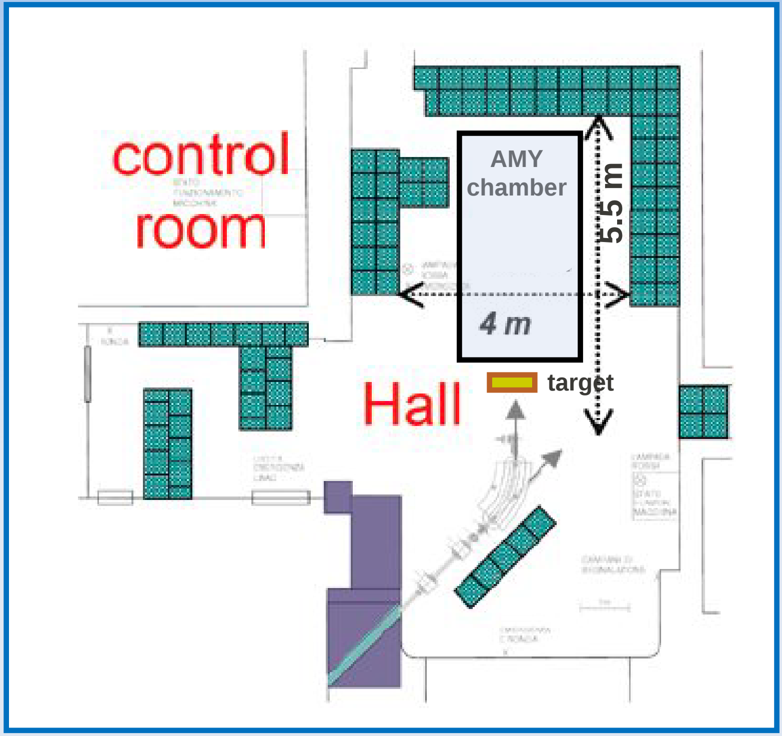
Antenna polarization

orthogonal to this plane (cross-pol.) minimize cherenkov

parallel to this plane (co-pol) maximize cherenkov

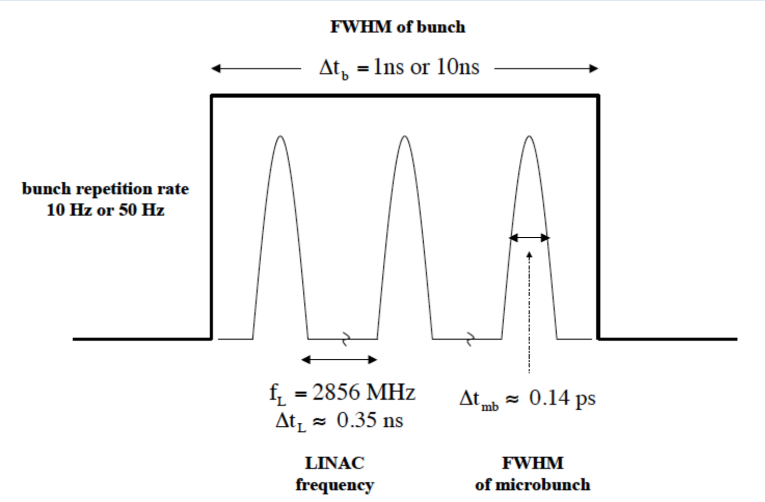
as suggested in the P.Gorham et al. paper

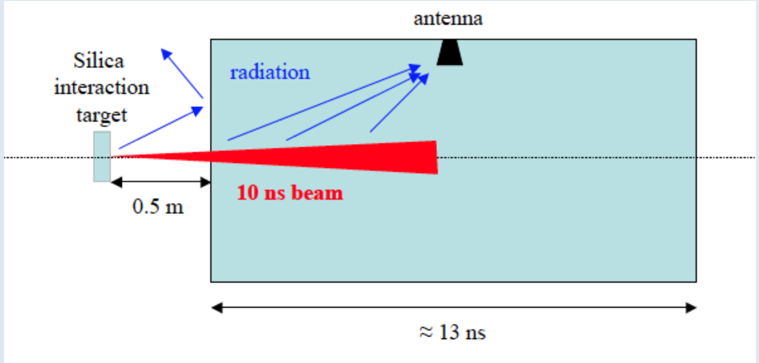
First test beam nov21-dec04 2011 at BTF of INFN LNF



e-beam delivered @ BTF

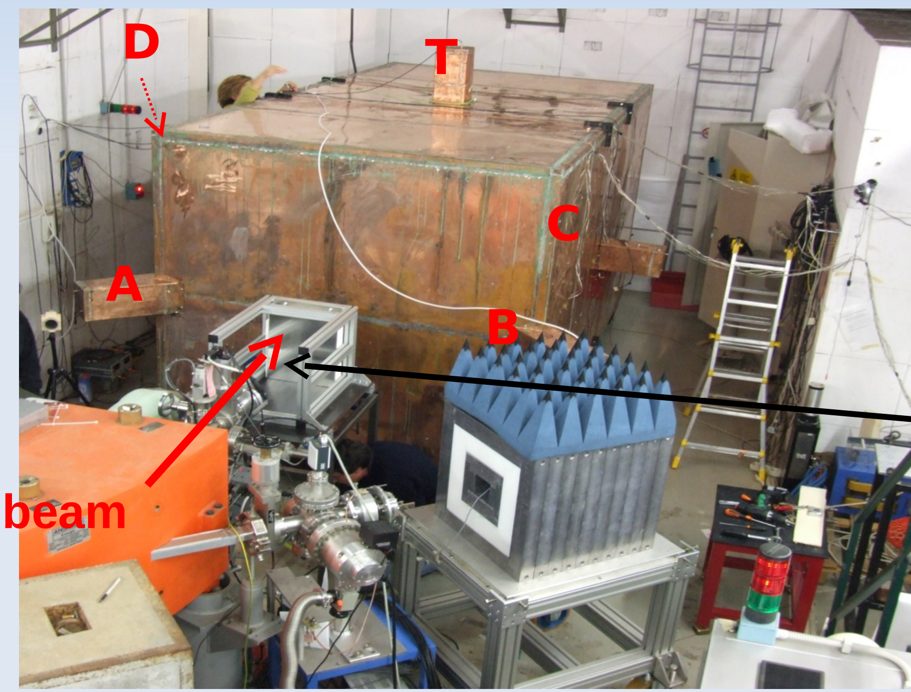
- energy range: 25-750 Mev (510 MeV)
- max. rep. rate : 50 Hz (1 or 2 Hz)
- pulse duration: 1-10 ns (i.e. 30 microbunch)
- particles/bunch: up to 10^{10} ($\sim 10^{9}$)

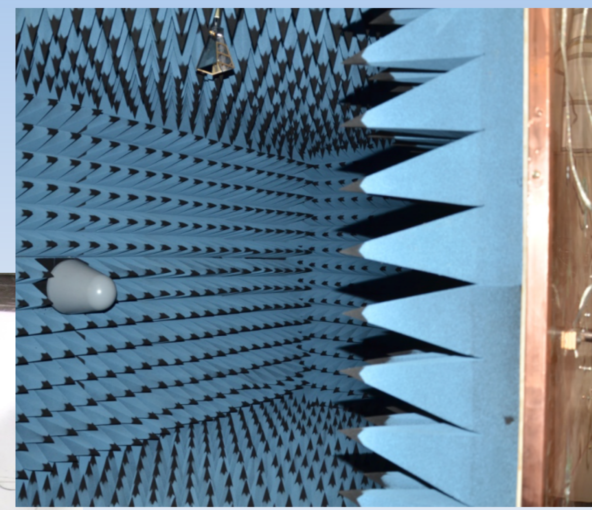


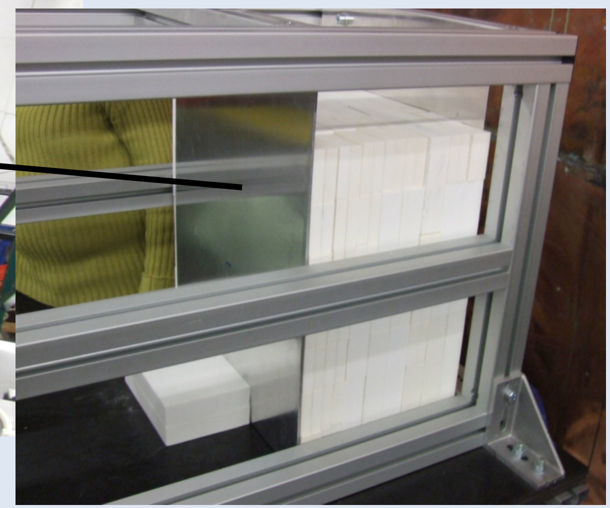


THE BTF AREA @ INFN FRASCATI LAB
ANECHOIC CHAMBER AND TARGET VIEW

5 antennas positions:
- 2 at the corners (A, B)
- 2 on the sides (C, D)
- 1 on the top (T)







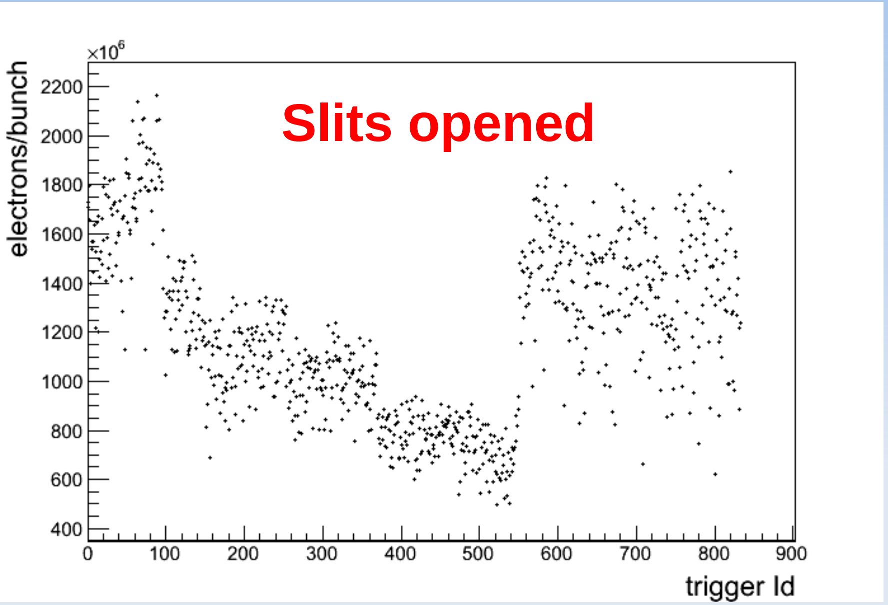
20 cm of alumina target (shower maximum in air at 10 cm)

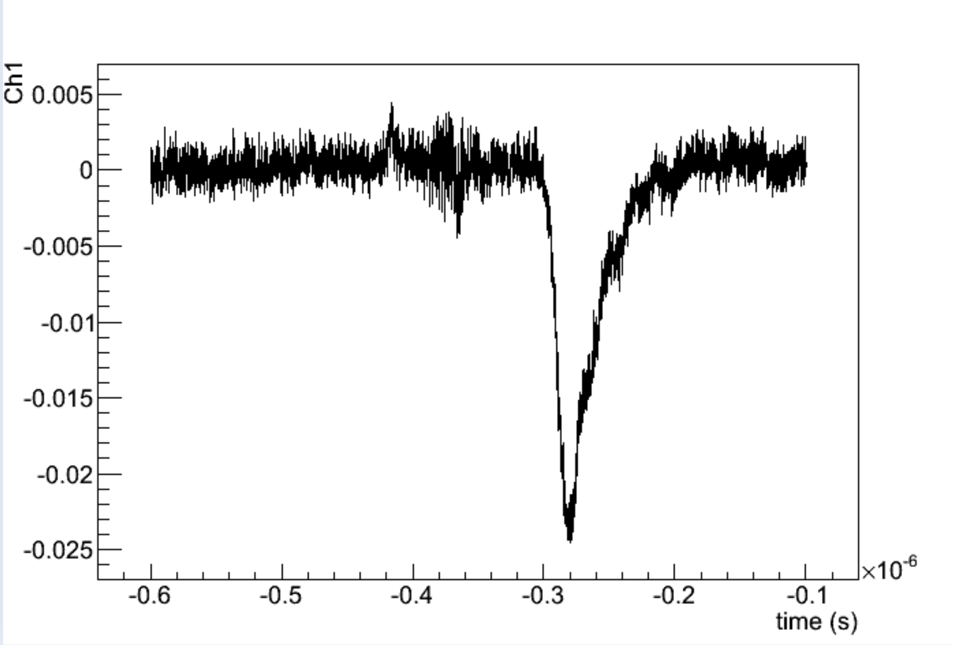
notice:
- only two days of runs with the target
≈ 13000 triggers
problems with the radiation safety rules of LNF
- runs in parallel to the normal DAFNE

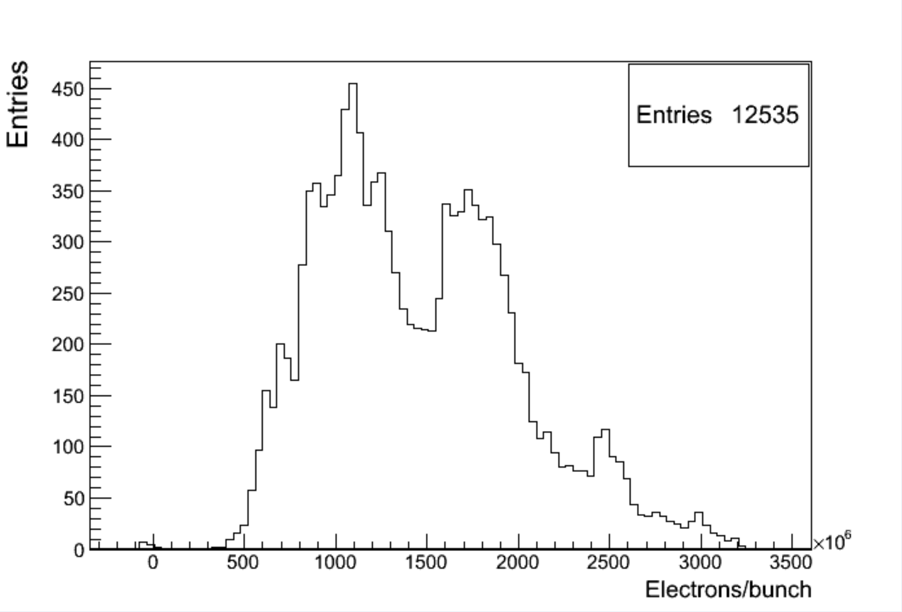
BEAM SIGNAL

Beam signal given by an integrating current transformer pulse integral μ N_e

- Trigger from RF (few ps jitter)
- possibility to change the beam intensity acting remotely
- charge calculation



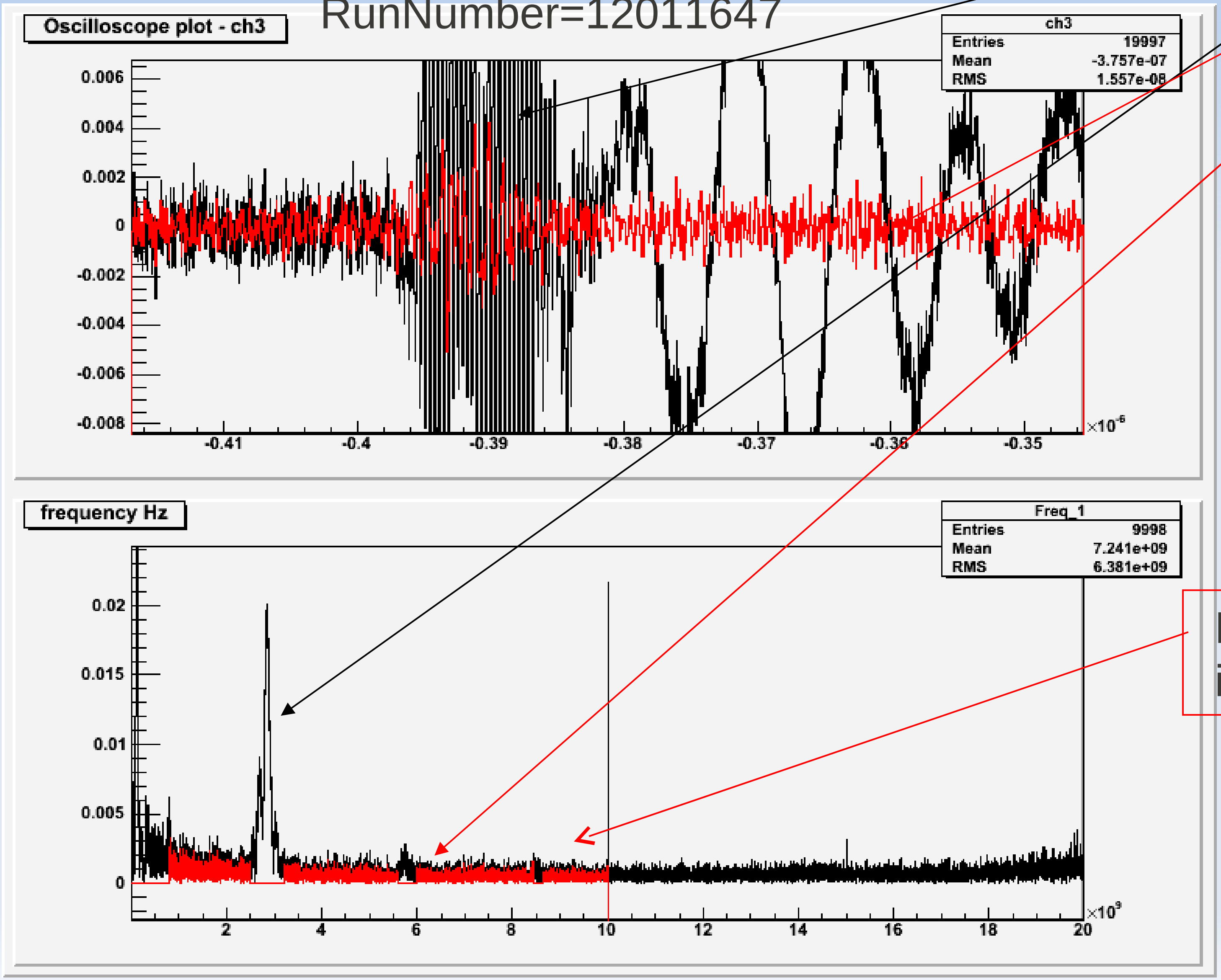




Typical analysis steps

Analysis steps: Signal from Scope
FFT
filter out peaks invFFT
FFT

RunNumber=12011647

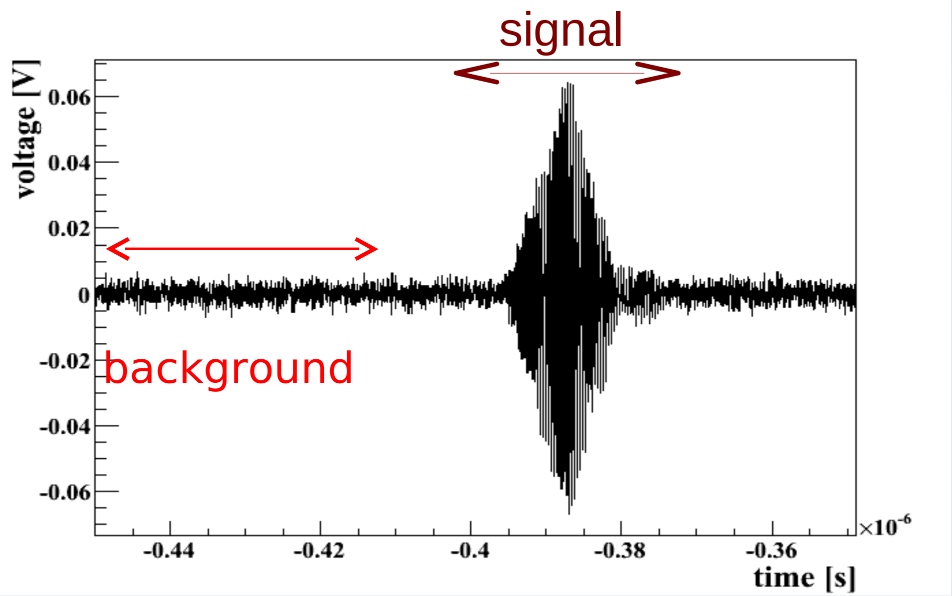


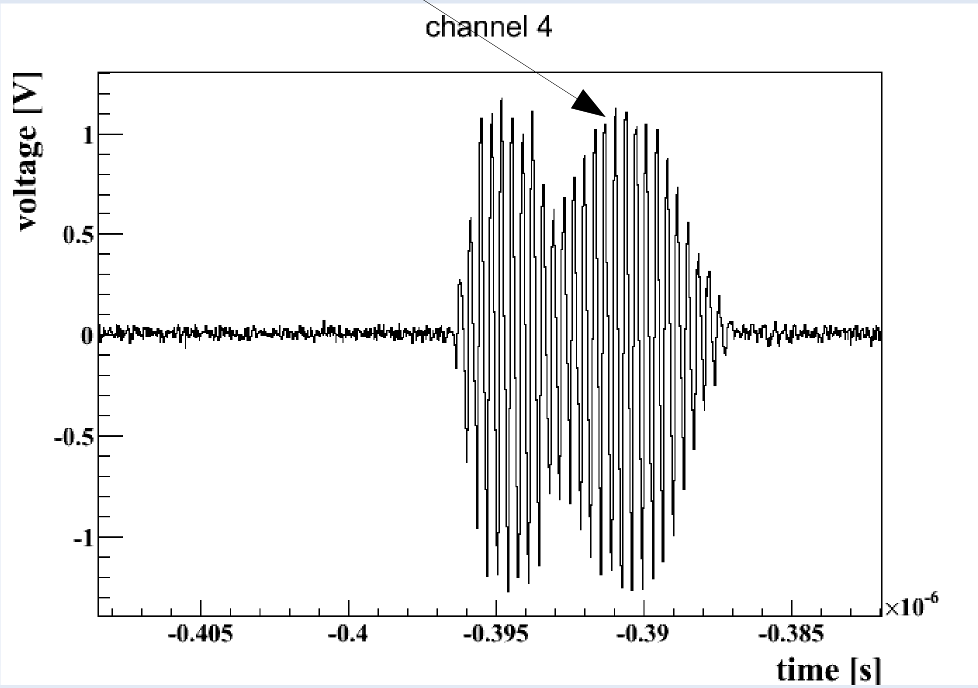
LogPeriodic lateral to the beam copolarized

Note the difference in range of the frequency

ANTENNA SIGNAL
HORN

Range starting from 1.7 GHz
Signal much more clean
Anechoic chamber shield up to 1 GHz around 40 dB
But pattern sometimes very puzzling





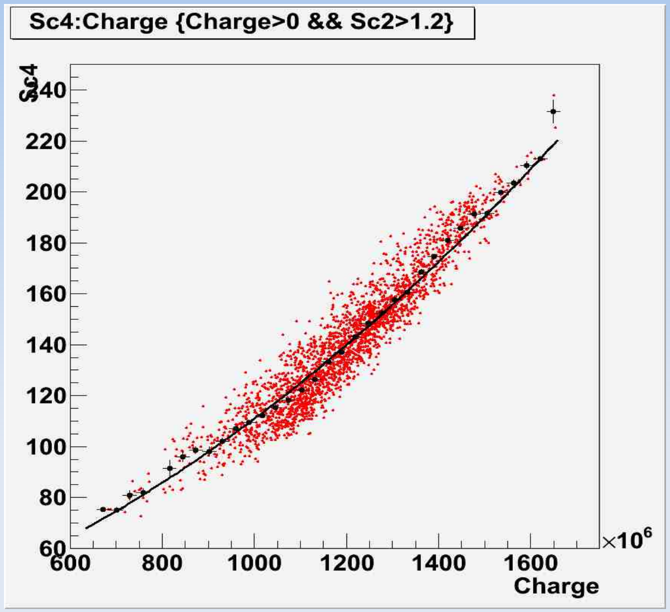
Power Calculation :

Power * 50 Ω = $(Vrms_{sgn})^2 - (Vrms_{bkg})^2$

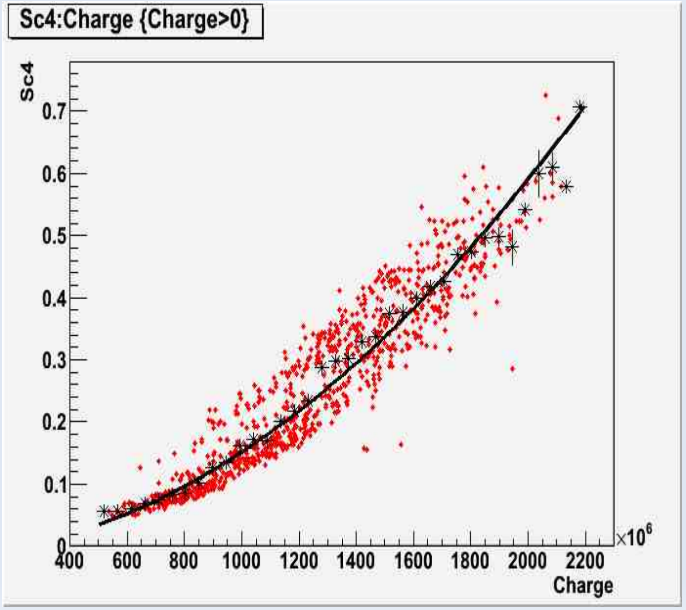
SIGNAL POWER QUADRATIC SCALING

- Power signal shows a quadratic dependence from the beam intensity .
- This trend does not depend on the orientation of the antenna polarization plane.

- Linac peaks included



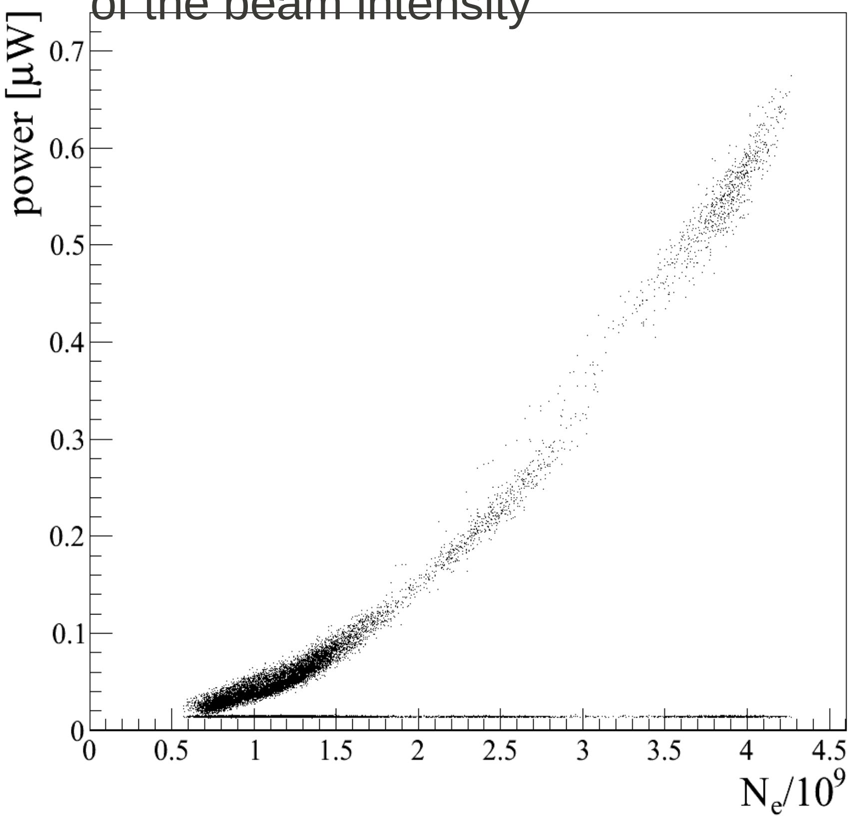
signal Vs Charge for 2600 events in horn Co-polarized looking at the beam
The fit is with a 2nd order Polinomial.



signal Vs Charge for 900 events in horn Cross-polarized looking at the beam
The fit is with a 2nd order Polinomial

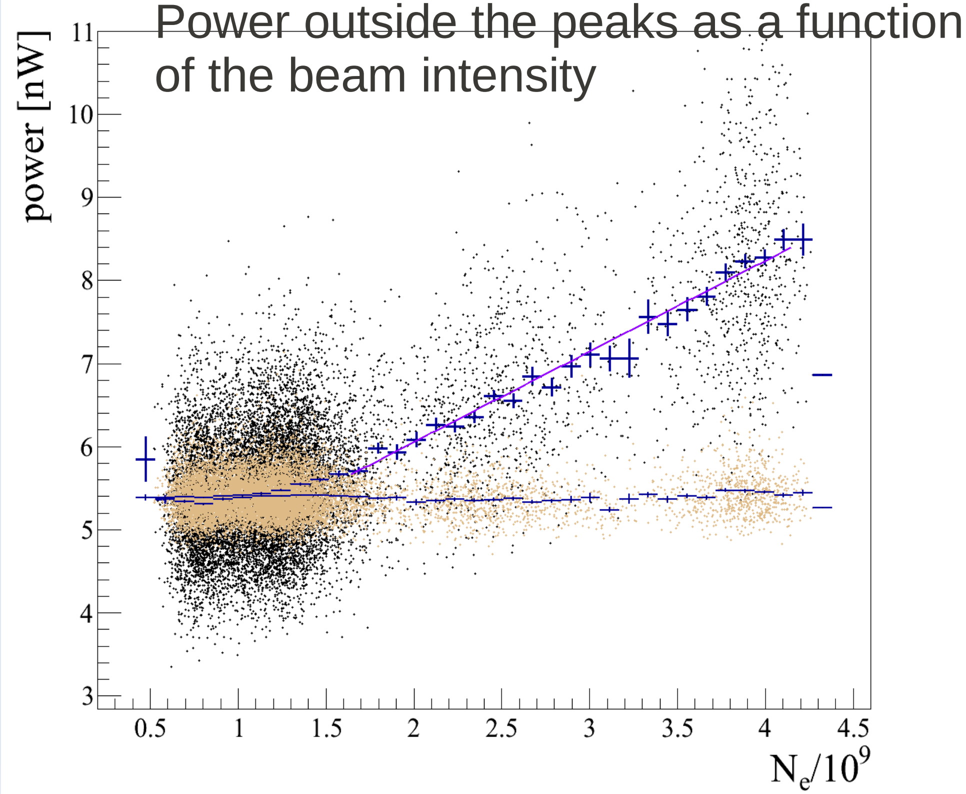
SIGNAL POWER QUADRATIC SCALING ?

Power in the full bandwidth as a function of the beam intensity



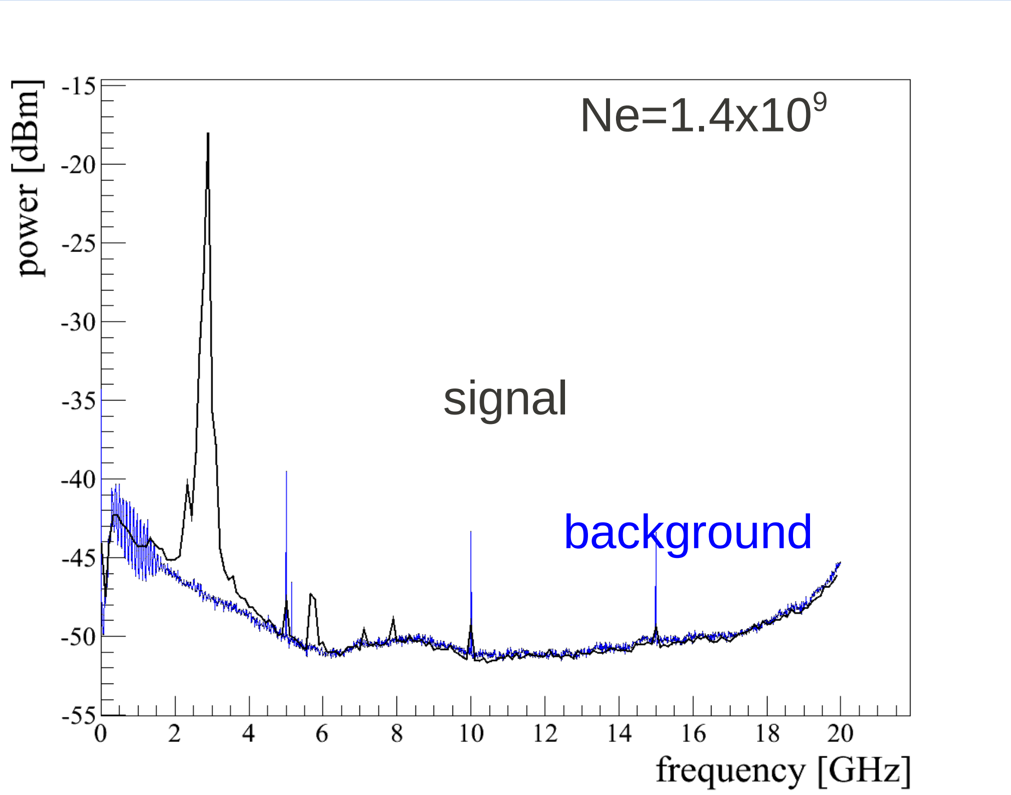
13000 triggers with interaction target

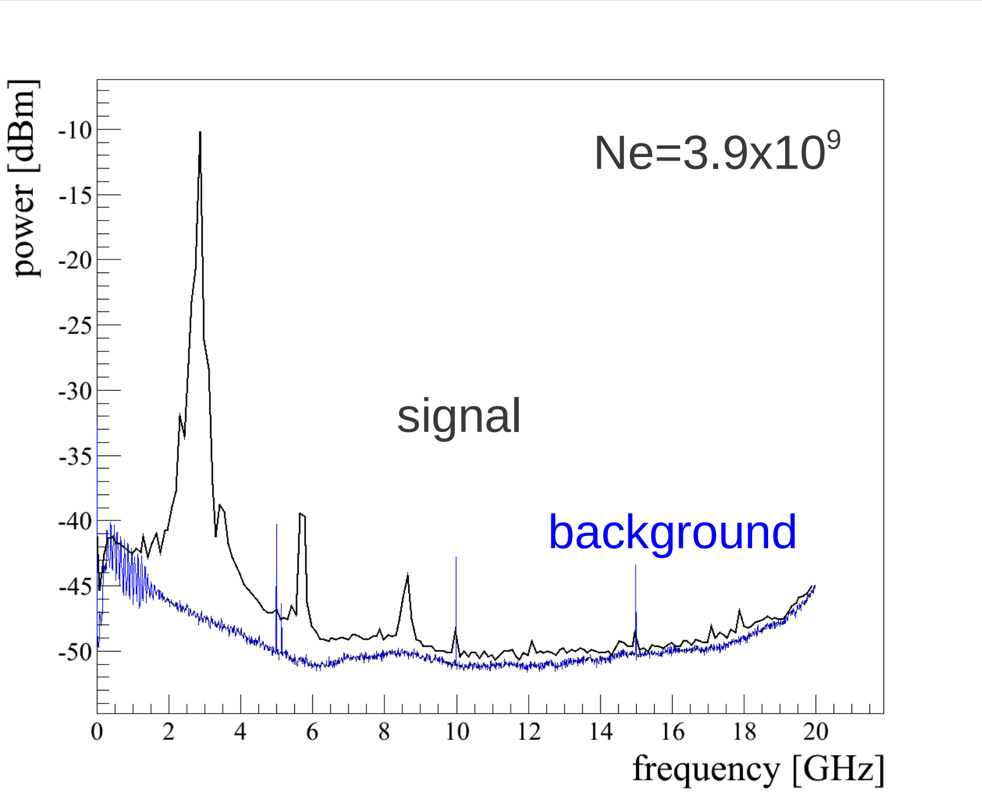
Power outside the peaks as a function of the beam intensity



the quadratic scaling observed over the full bandwidth is dominated by the LINAC peaks

Average signal Vs Frequency
(frequency spectrum of the FFT scope traces)





The radiation outside the LINAC peaks becomes observable when the current is higher

Second test Beam

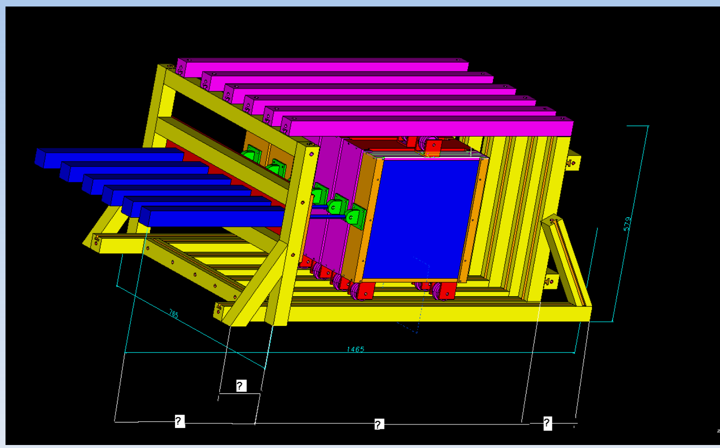
May 14 - 27 (2012)

THE MAIN LIMITATIONS TO OVERCOME HAVE BEEN CLEAR ONLY AFTER THE FIRST TEST BEAM.

- Remote control of the interaction target **(LECCE)**
- Improve the overall geometrical precision of the camera (antenna positioning and orientation of the polarization plane) **(ROMA2)**
- Increase the beam current by a factor 10 – radiation protection service
- 3 ns bunches

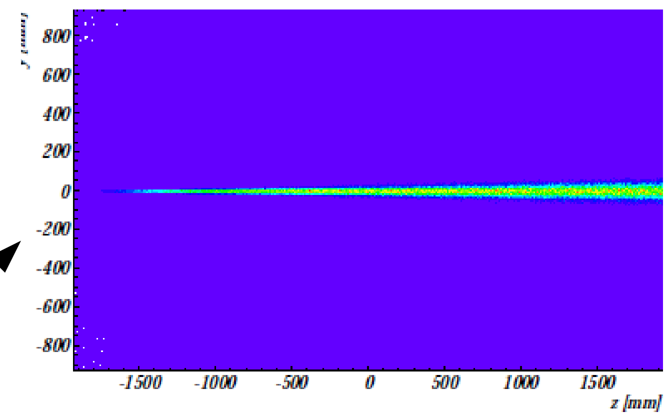
THANKS TO Pino FIORE (Mechanical service)

Remote control of the interaction target (technically designed and built in Lecce (Pino Fiore), cooperation with Dr. Martina Bohacova (stay at Lecce in 2012-INFN-FAI)

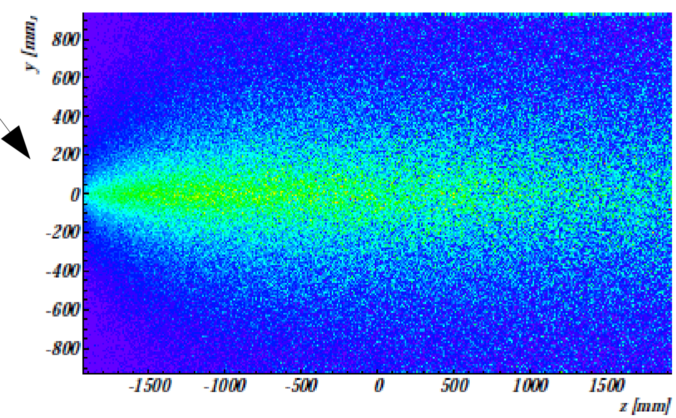


GEANT4 simulation of the Energy Deposit distribution inside the chamber.

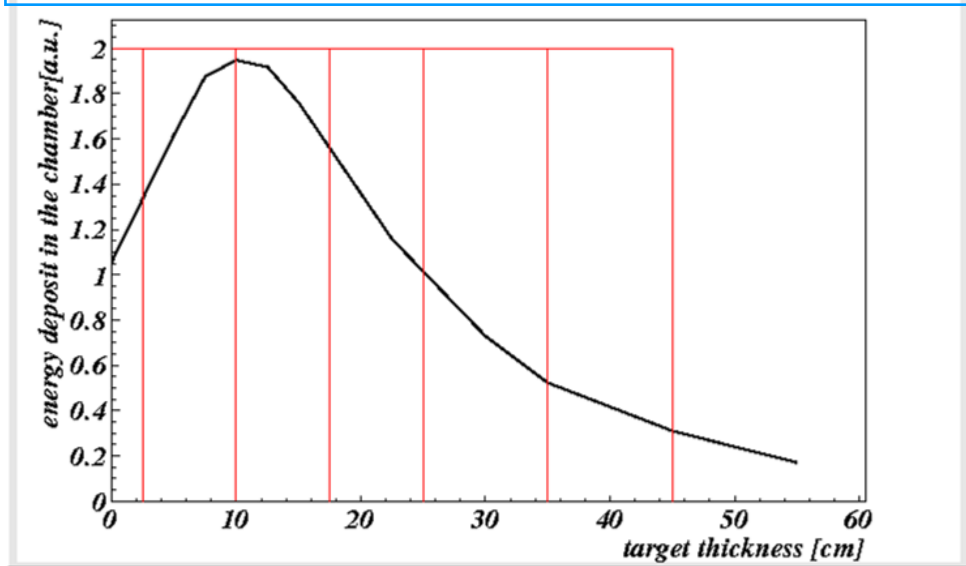
Without interaction target and



5 modules inserted



The shower is fully developed already after passing 10 cm allumina

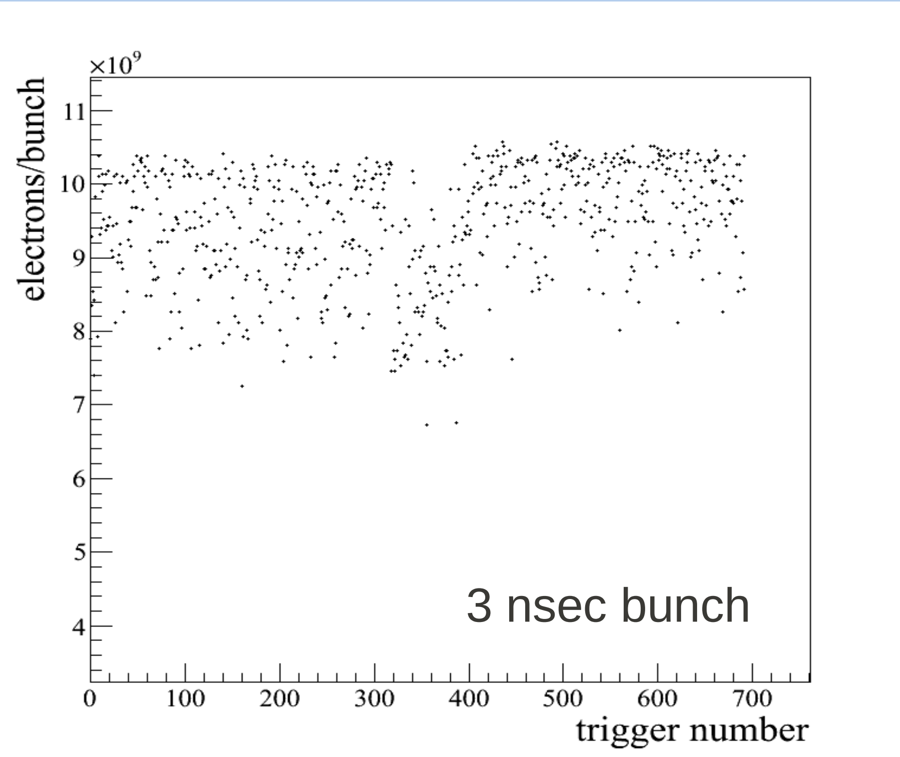


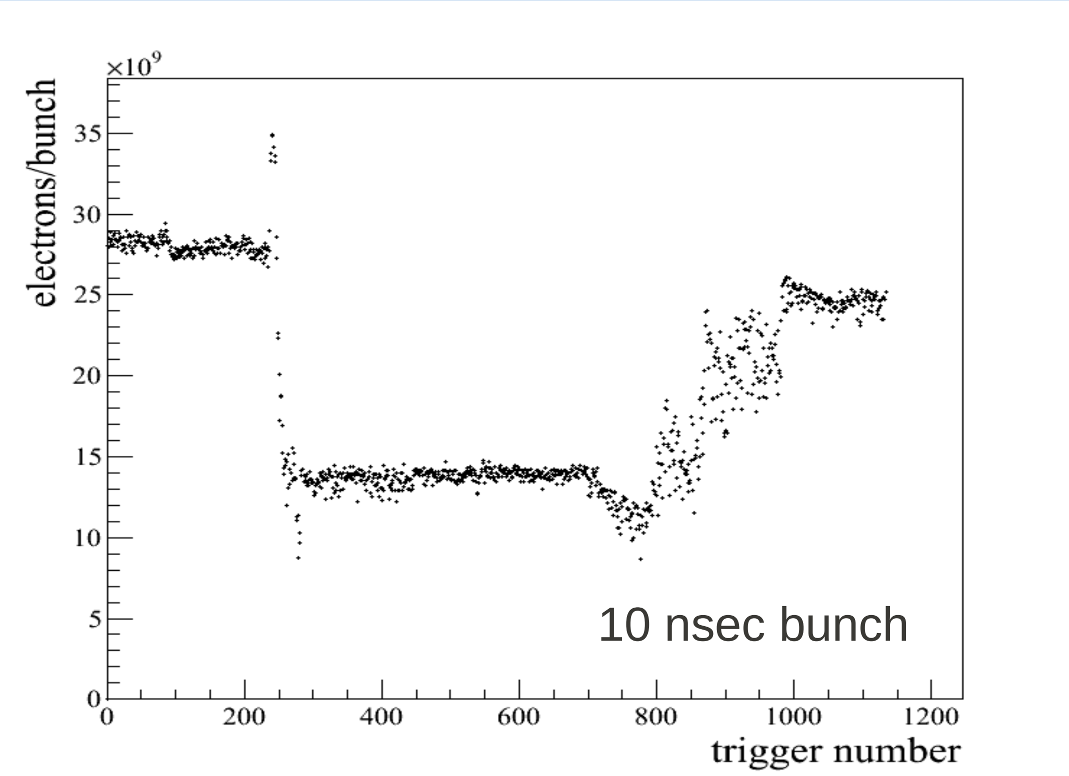
6 Modules: 2.5 cm (x35cmx35cm)
7.5 cm
7.5 cm
10.0 cm
10.0 cm

Interaction target in the BTF area
During mounting

- 6 radiation lengths selectable
- compressed air system

5 days of dedicated runs + Higher intensity + 3ns bunch



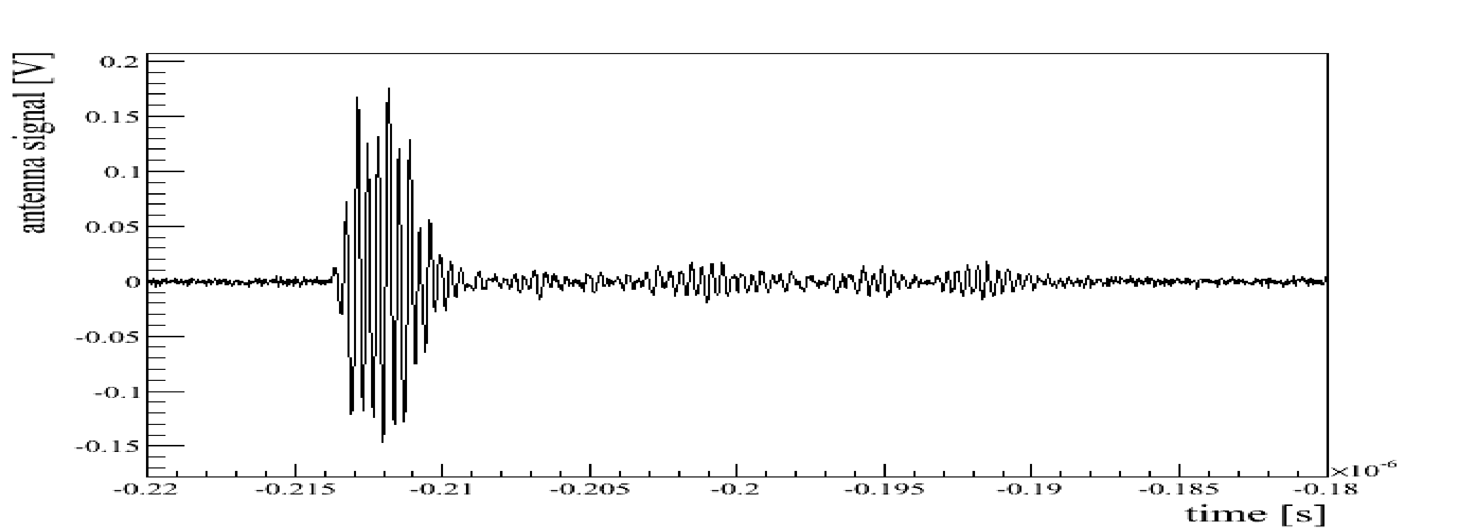


The beam intensity was stably between 10^9 and 5 10^9 electrons/bunch (notice: radiation safety problems at the previous test when running with the target)

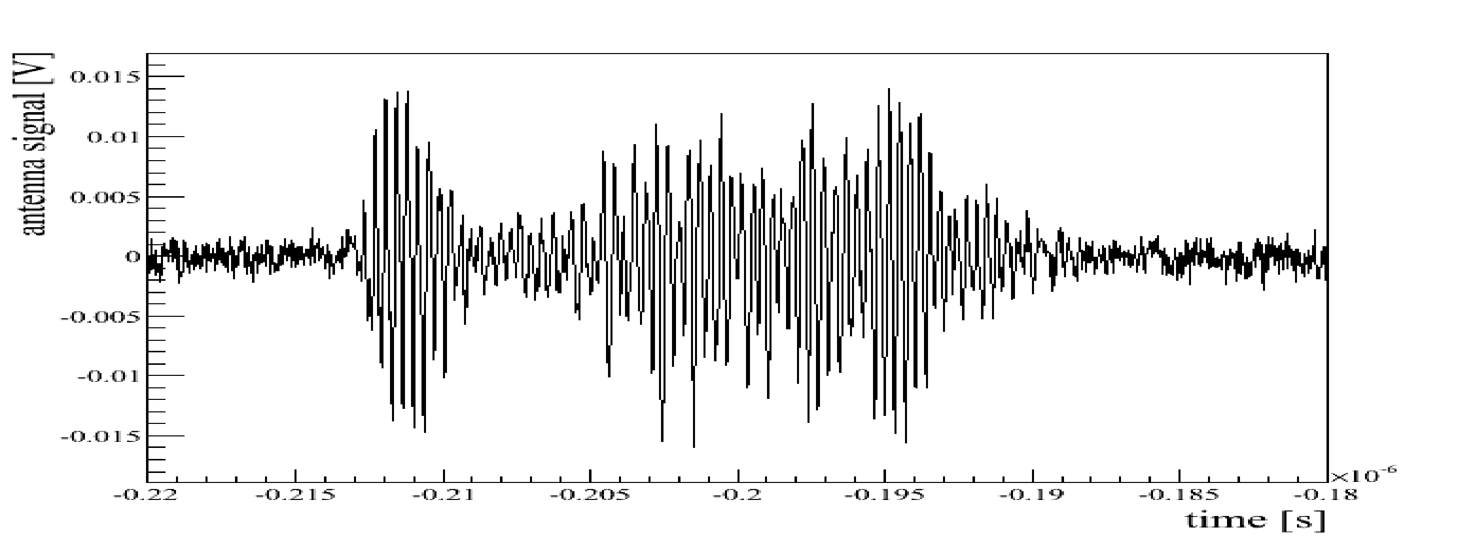
Few runs a factor 10 higher current

Presence of Reflections inside the chamber ?

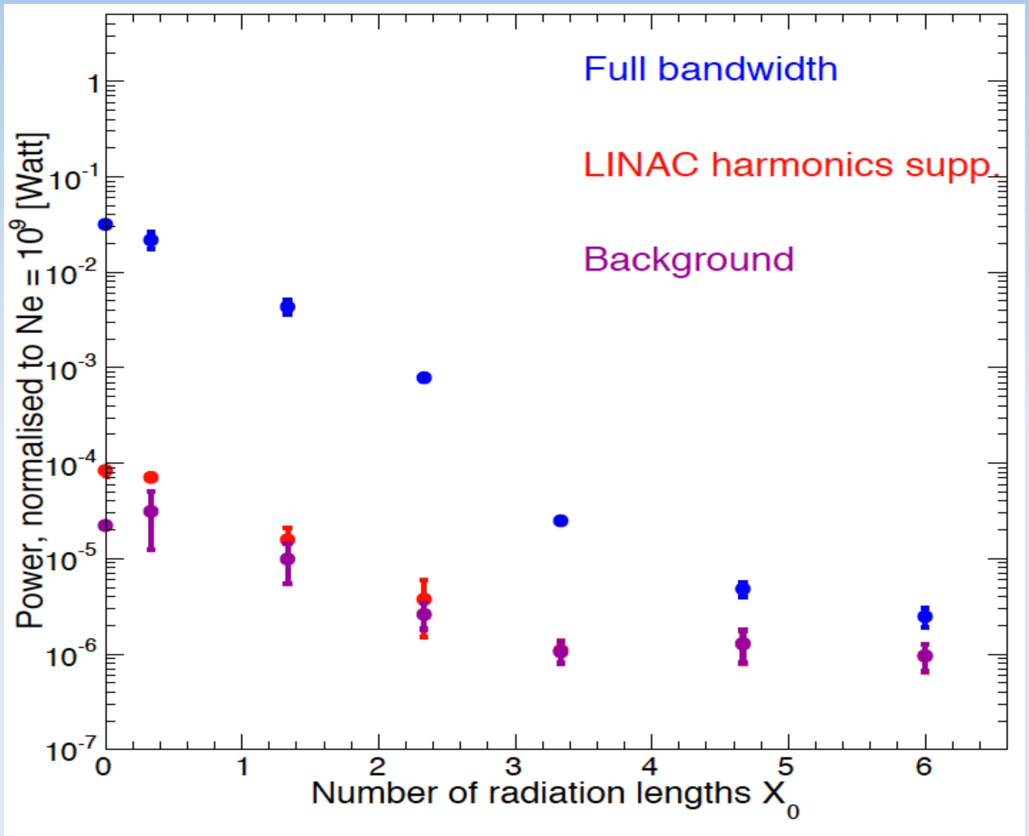
Horn
co-polarized

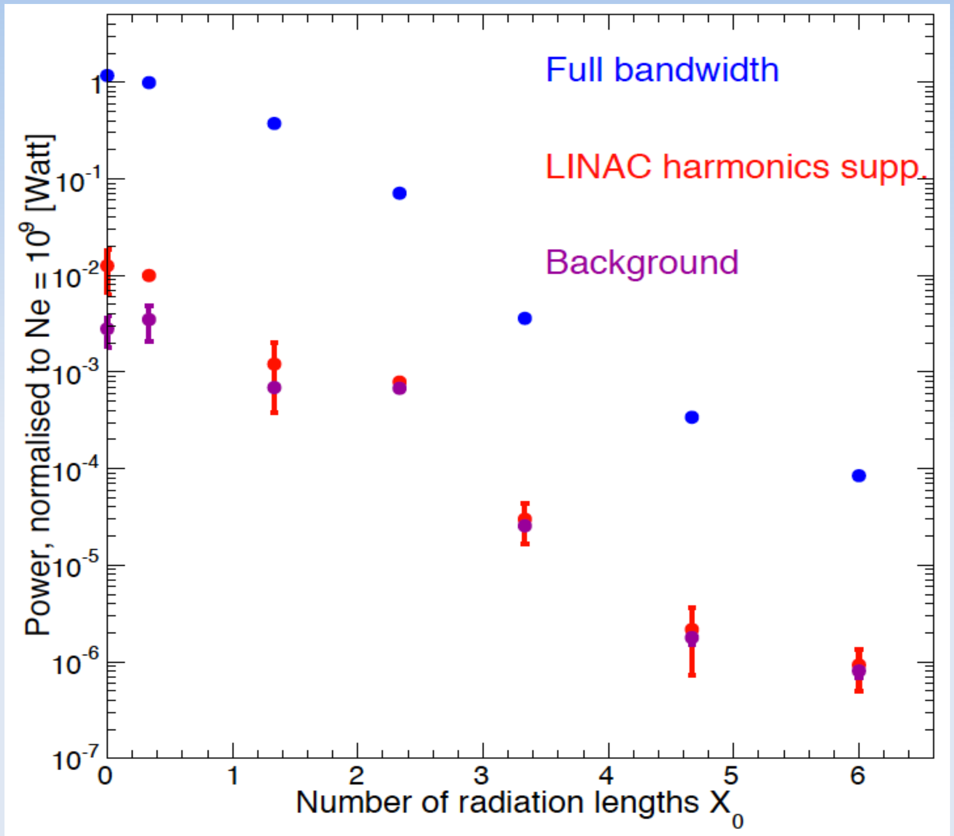


Horn
cross-polarized

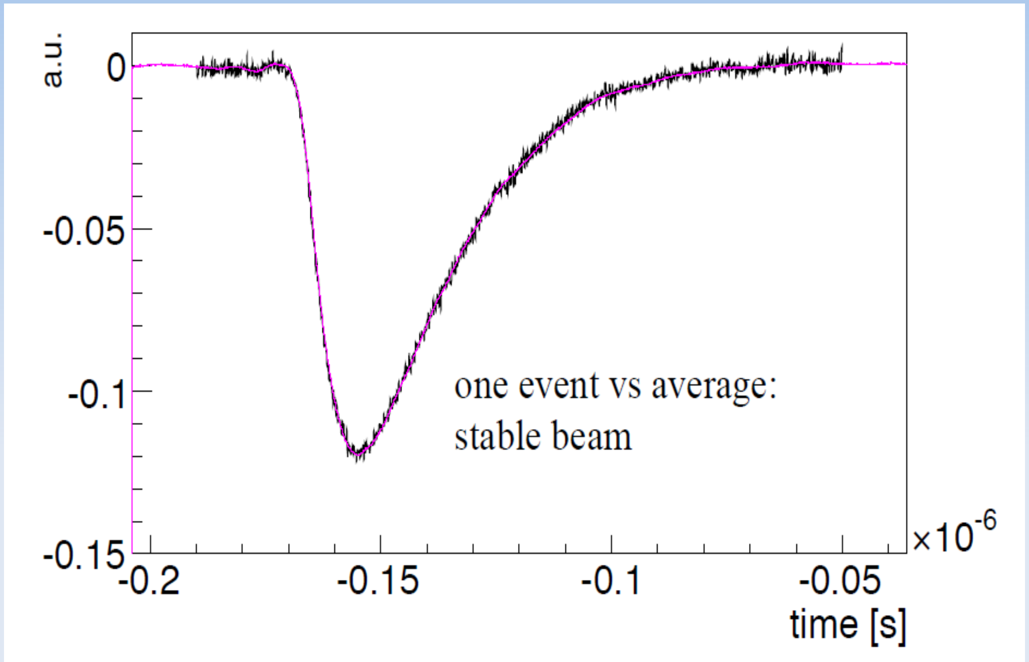


Signal Vs Target Tickness





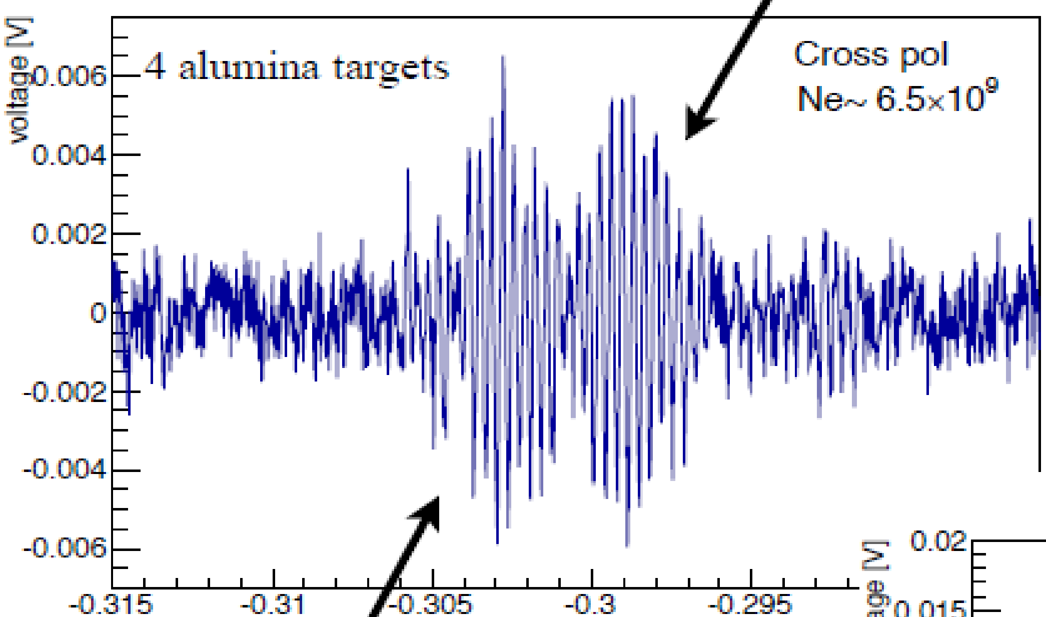
Third Test Beam (December 2012)



Some hardware improvement
of the LINAC
No dedicated BEAM
10 nsec, 3 nsec and few 1.5 nsec runs
Particles/bunch up to 10^{10}
Data acquired with horn in
several positions in Co-Cross
Various target

Third Test Beam (December 2012) -analyzing the 2nd peak

2nd peak?

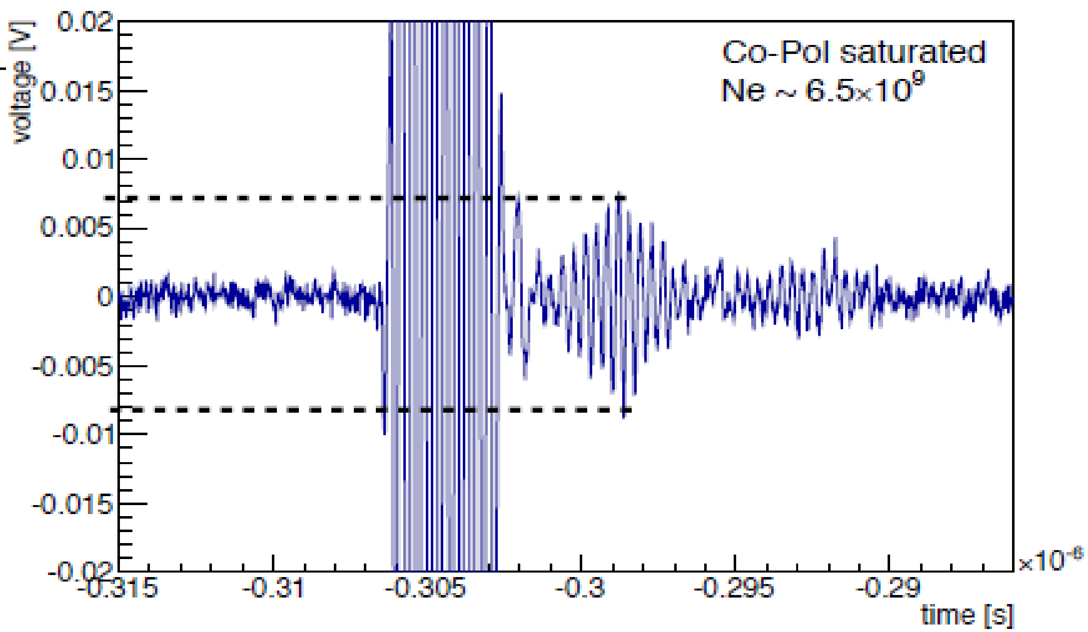


prompt signal from beam

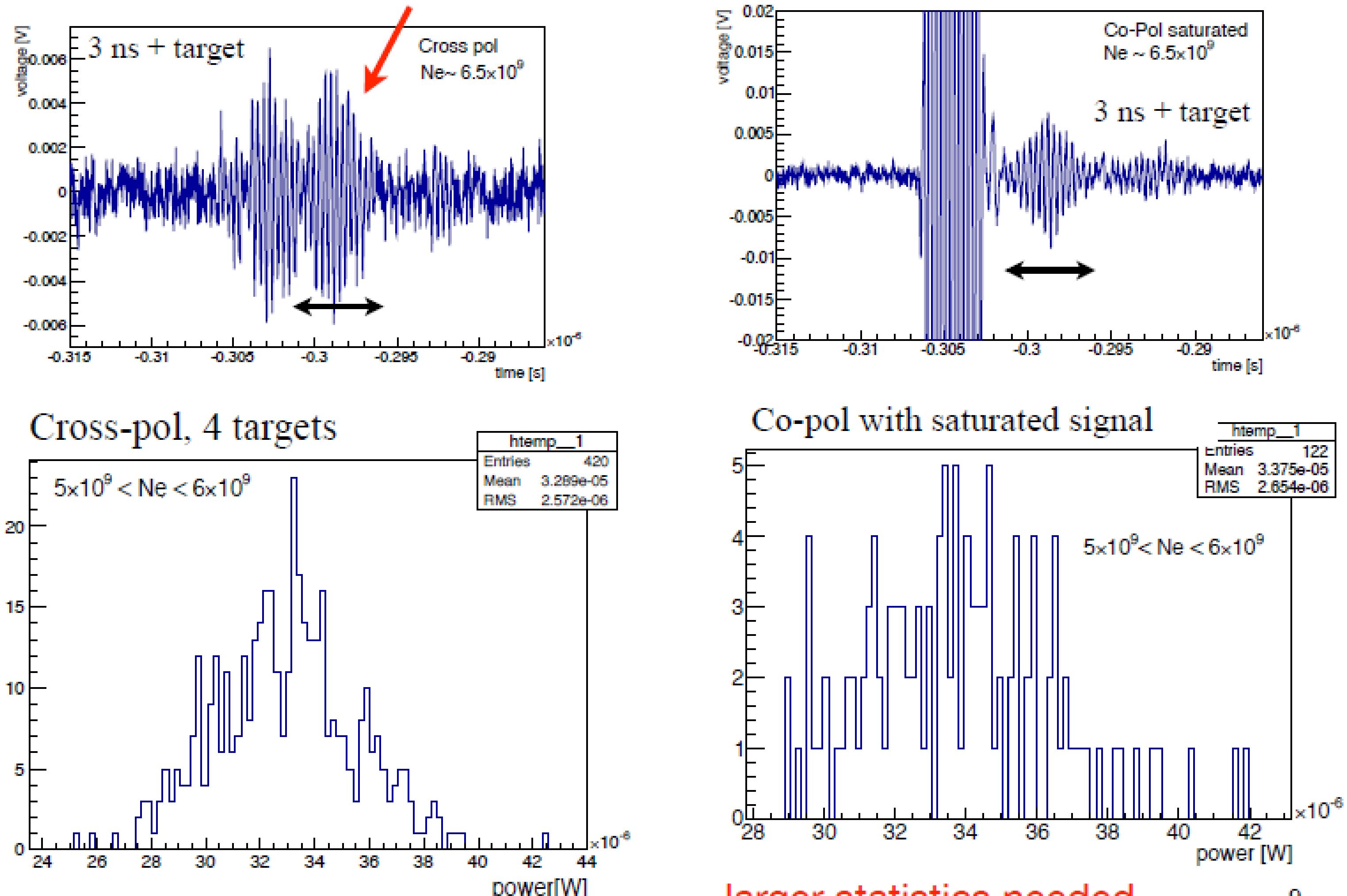
3 ns beam, with alumina target

a second peak clearly visible in cross polarized antennas after ~ 5 ns

a similar peak also visible in the co-polarized antennas: **similar intensity**



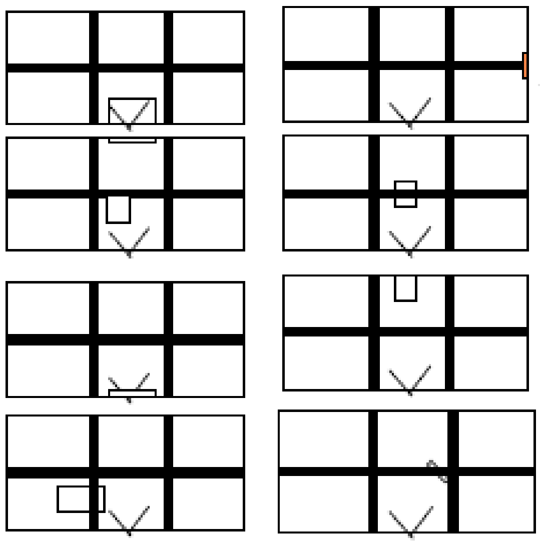
Third Test Beam (December 2012) -Intensity of the 2nd peak



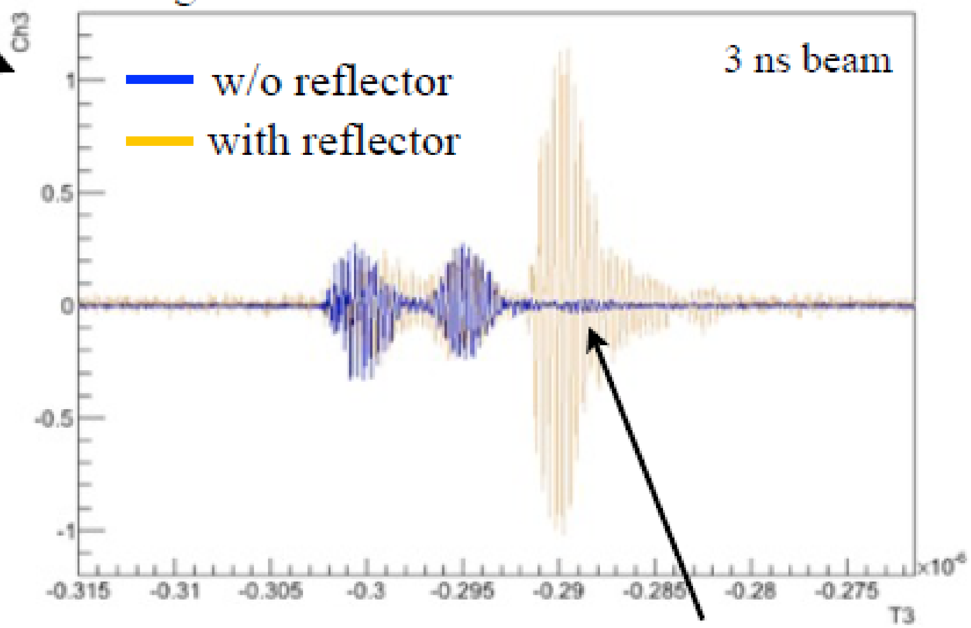
larger statistics needed

Third Test Beam (December 2012) -Possible sources of reflections.

Several sources of reflections tested inside the chamber and due to cabling, electronics and antenna supports



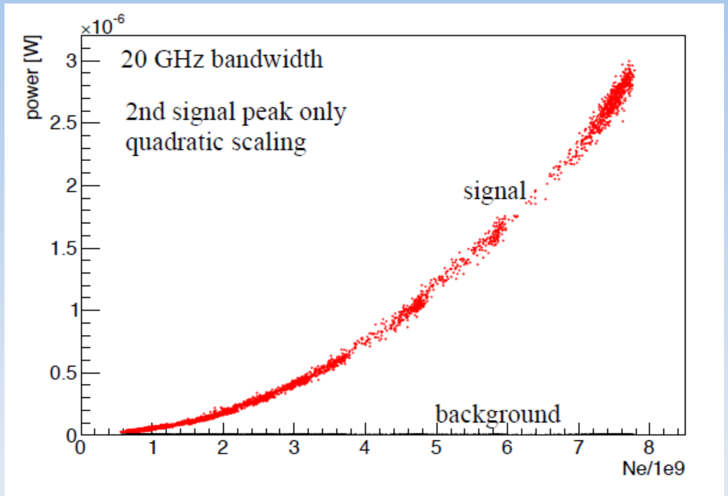
copper reflector at the end of the chamber along the beam line



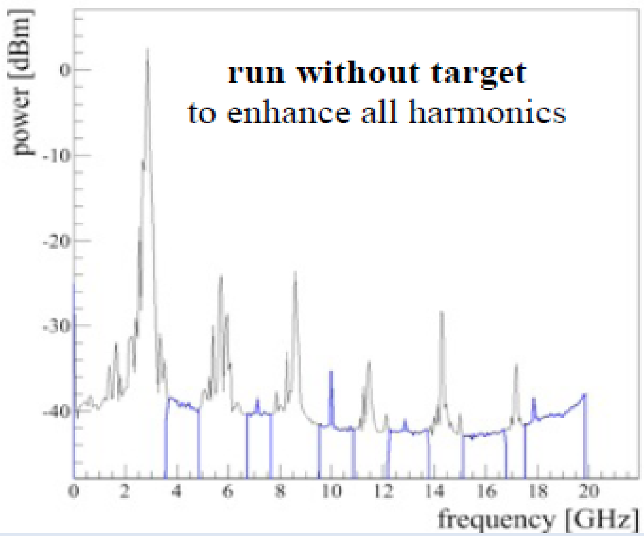
The 2nd peak intensity seams to do not depend on the metal reflector position.

This peak intensity enhanced with a metal reflector is a the chamber beam exit.

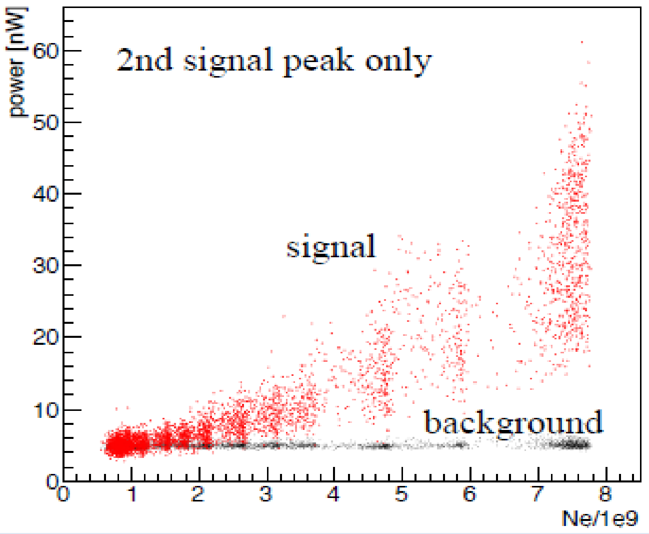
Third Test Beam (December 2012) -Signal in the full bandwidth and out of the peaks.



Selection of power to exclude the LINAC peaks



Power outside the LINAC peaks as a function of the beam intensity



CONCLUSIONS

- The experiment has ended in 2012- a further test *(1.5 nsec maybe in 2014)*
- Analysis work ongoing.
- Papers up to now:
  - *The Air Microwave Yield (AMY) experiment to measure the GHz emission from air shower plasmas.-* **EPJ Web of Conferences 53, 08011 (2013)**
  - *Air Microwave Yield (AMY): An experiment for measuring the GHz emission from air shower plasma-* **Il nuovo Cimento C-2013- Issue 1 (pagg 134-138)**
  - *The AMY experiment to measure GHz radiation for Ultra-High Energy Cosmic Ray detection-* **J. of Phys.: Conf. Ser. 409 (2013) 012082-012085**
  - *AMY (Air Microwave Yield) Laboratory Measurement of the GHz Emission from Air Showers –* **ICRC 2013**

- Three test beam performed: November – December 2011/May 2011/December 2012
- With the second/third very good run conditions (radiations, 3ns, $>10^{10}$, …) even if no dedicated beam.
- We should have detected the MBR if it has the intensity reported by P.Gorham et al. Do we have detected it? Difficult to say, analysis and simulation are underway
- We have to understand what is the configuration maximizing the sensitivity to MBR (= minimizing Cherenkov)

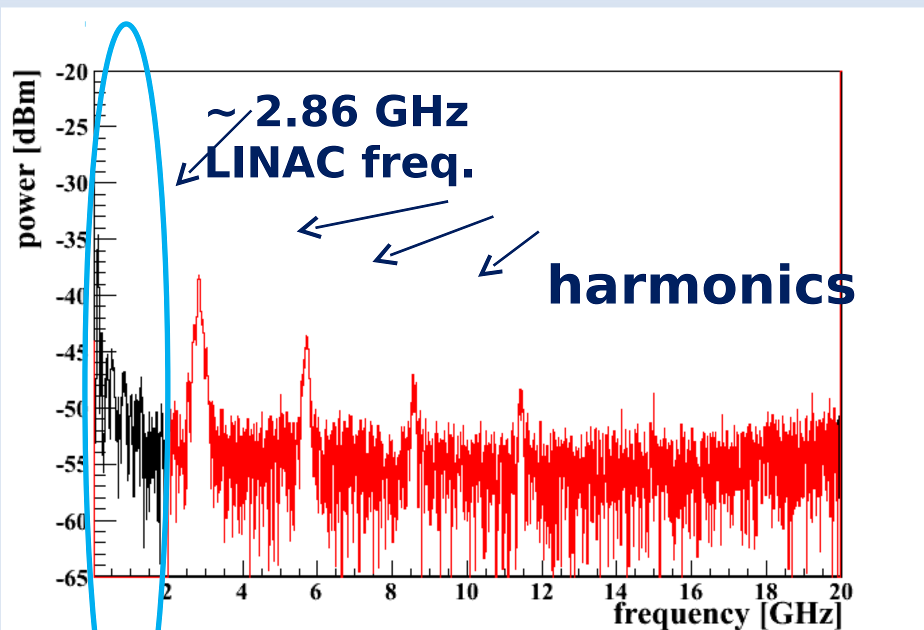
A double peak structure evident in the signals more evident with bunches at 3 ns and 1.5 nsec not understood yet:
- Second peak unpolarized
- Several sources of reflections checked.

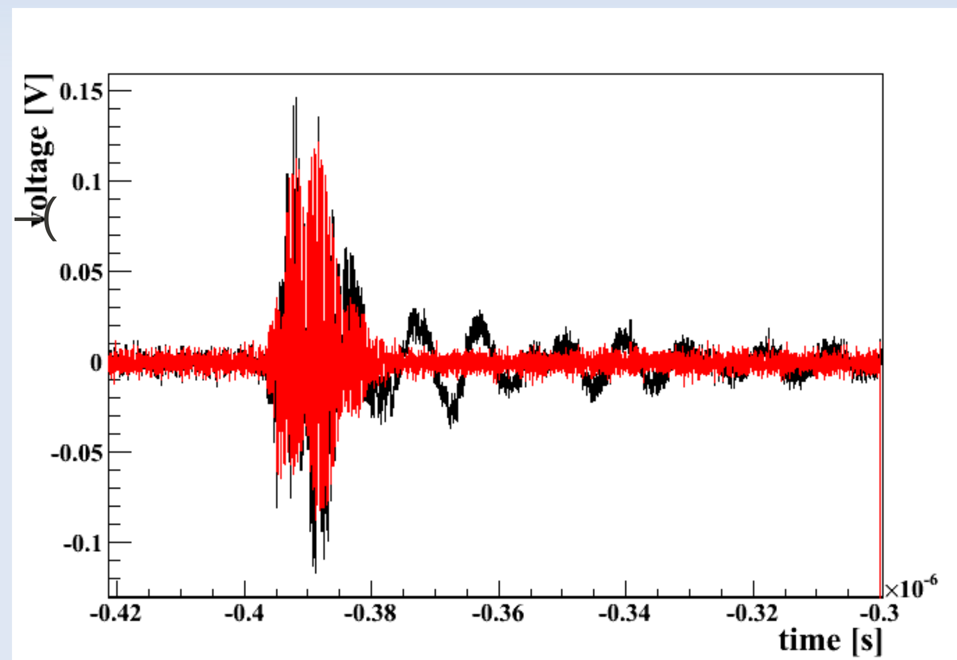
BACKUP

SPECTRUM ANALYSIS
FFT

FFT of the row signal
FFT of the filtered signal

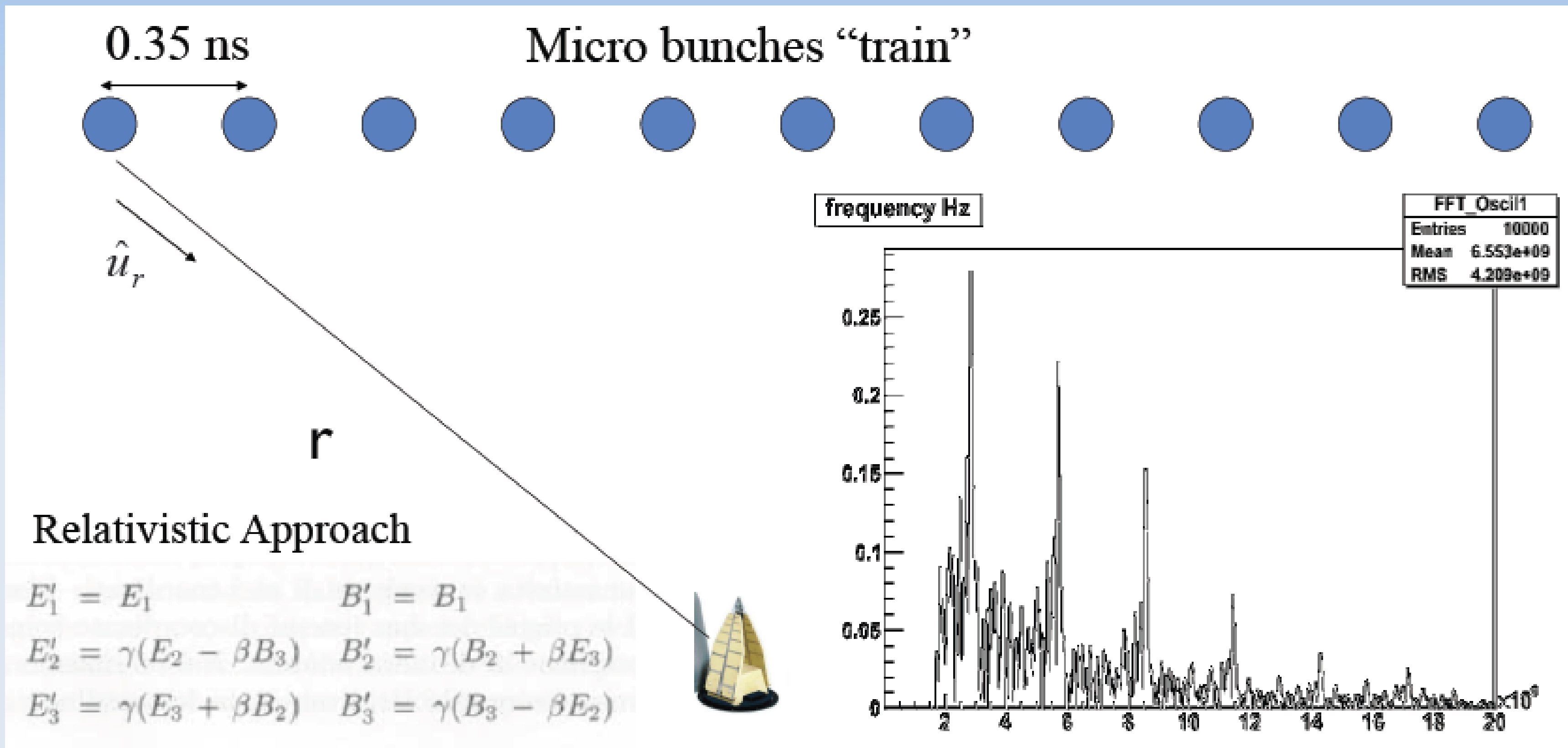
row signal
filtered signal





low frequency background
(in log periodic antenna)

SIMULATION



- E and B calculated each 6.6×10^{-13} s in the lab ref. syst.
- The charge are propagated along the beam assuming constant speed and using time step of $6.c\times10^{-13}$ s
- The propagation time of the signal from the bunch to the antenna is take into account

Simulation of the electric and magnetic filed produced by the beam near the antenna

- **Understanding the radiation emitted by the beam**
- **Background for MBR**
- **Benchmark to understand the detector**

OSCILLOSCOPE SIGNALS

- Run Id: 201112040620
  Event Id: 43160
- about 300 runs
- most of the time e^{+}-beam
- events/run ≈ 1000
- event trigger with signal from pickup coil