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SOUTH POLE
ASKARYAN RADIO ARRAY

TELESCOPE ARRAY PROJECT

Results of the ARAcalTA experiment:
measurement of the coherent radio emission from an electron excess in ice.

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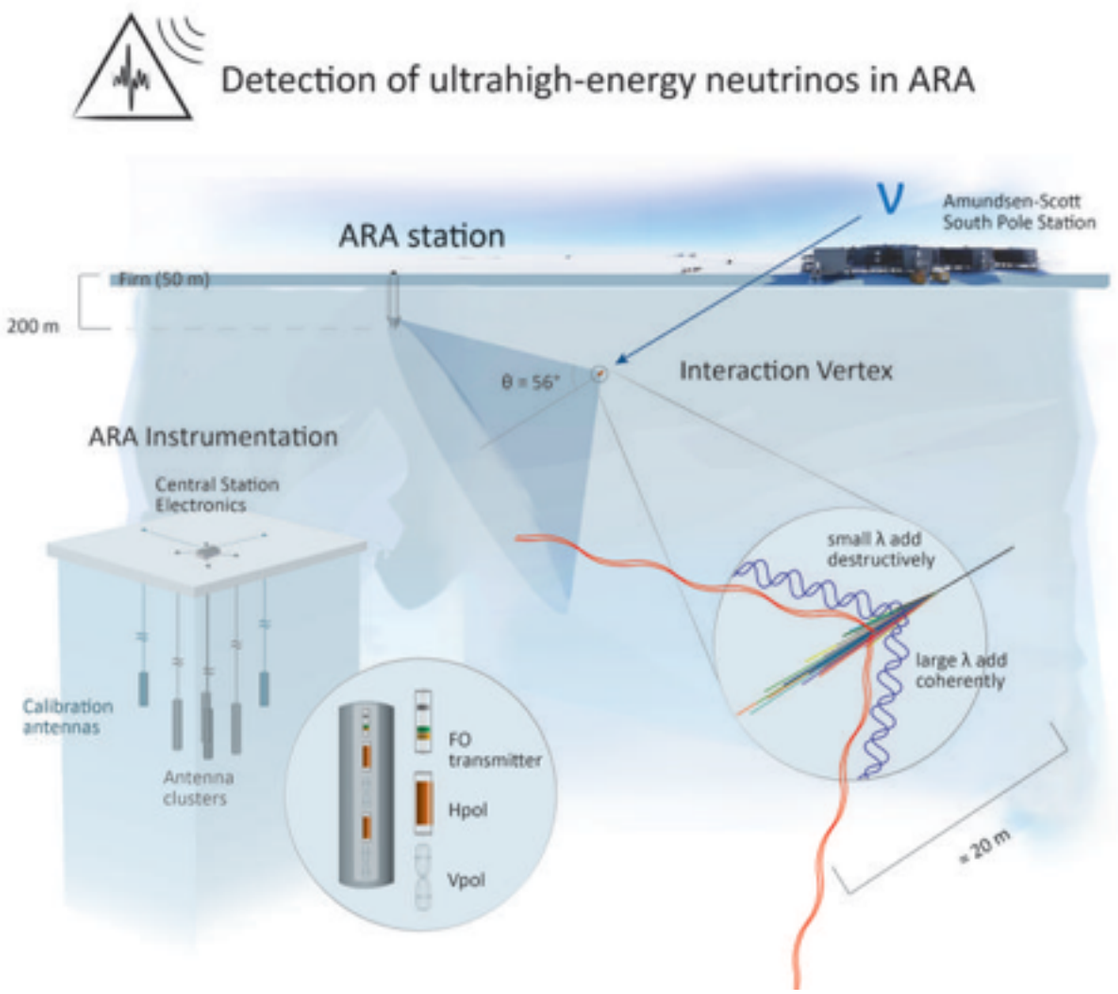
Chiba University

Introduction

ARA



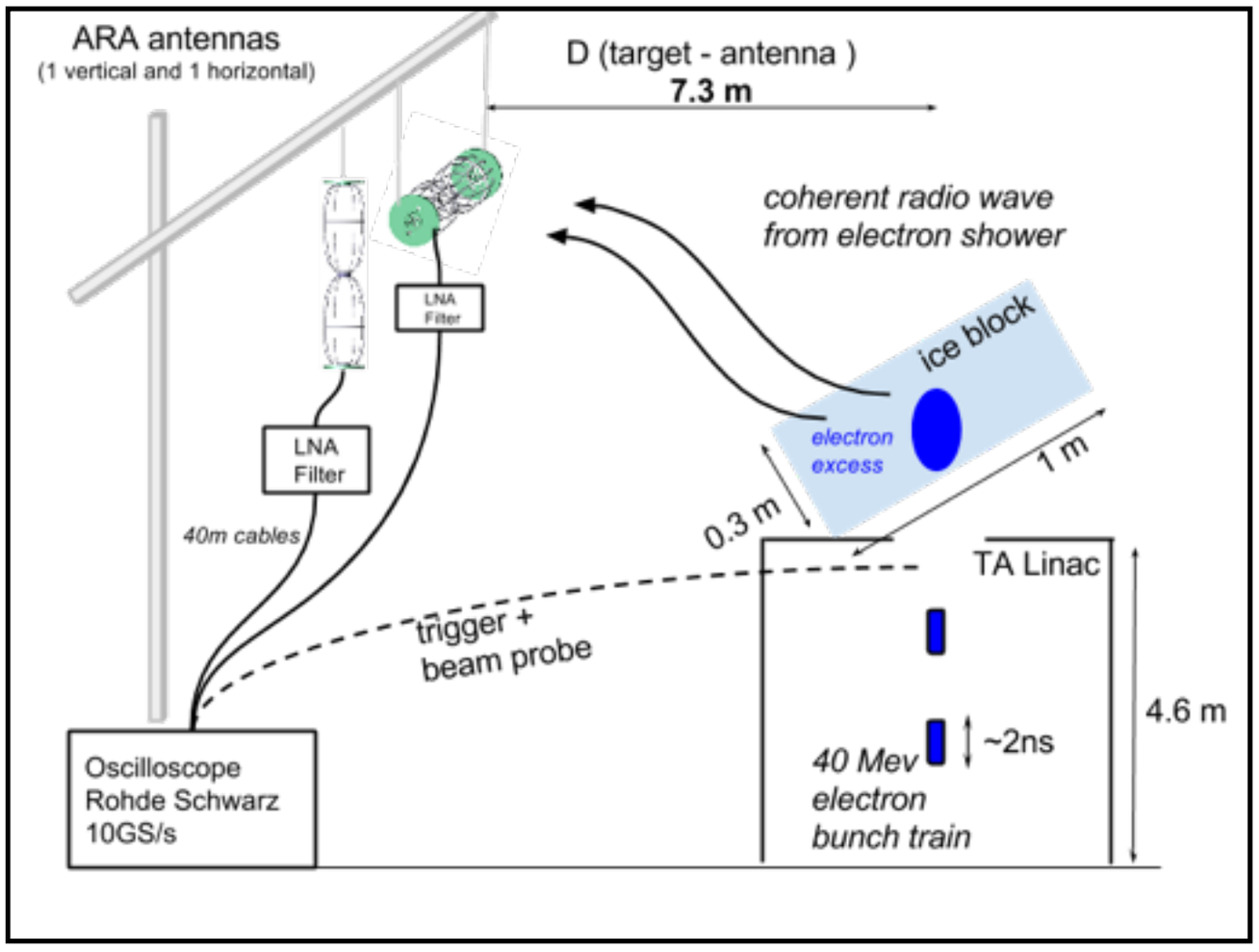
- High Energy Neutrino (E> 100PeV) radio detector
- Collects the radio emission from charge excess in ice
- Never observed insitu

Askaryan radiation experiments in lab

Several beam experiment were carried out since 2000.

- 2000 Salzberg *et al.* First observation in silica sand (Phys. Rev. Lett. 86, 2802)
- 2005 Gorham et al. Observation in rock salt (Phys. Rev. D 72, 023002)
- 2007 Gorham et al. Observation in ice (Phys. Rev. Lett. 99, 171101)
- 2015 Belov et al. Observation with B field (arXiv:1507.07296 [astro-ph.IM])

ARAcalTA



Setup

Source: 40MeV Telescope Array Electron light source
+ block of ice (1m x 0.3m x 0.3m)
Detector: ARA antenna (Vpol)
+ Low noise ampli. + filter + fast sampling osci

Data taking

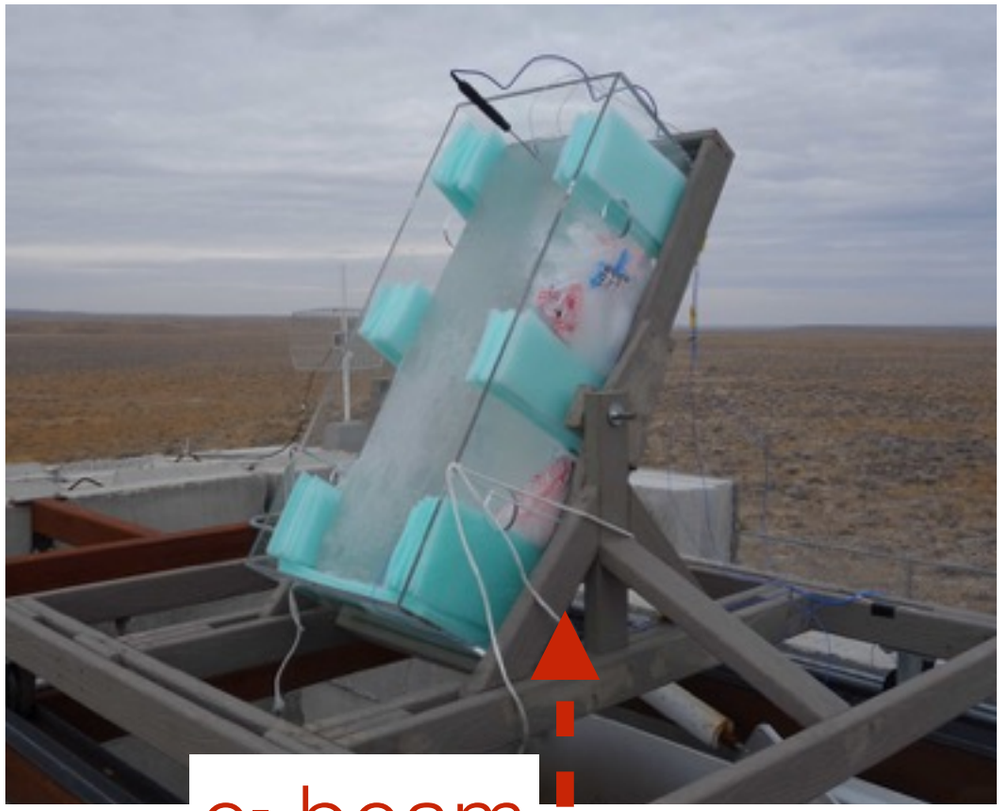
15 days in Delta Utah (TA site)
~7 days of beam in January 2015
Different runs:

- with ice target
- without target
- only plastic box

Goals

- Confirm the intensity of Askaryan radiation
- Check our signal simulation method
- Check our detector response

ARAcalTA



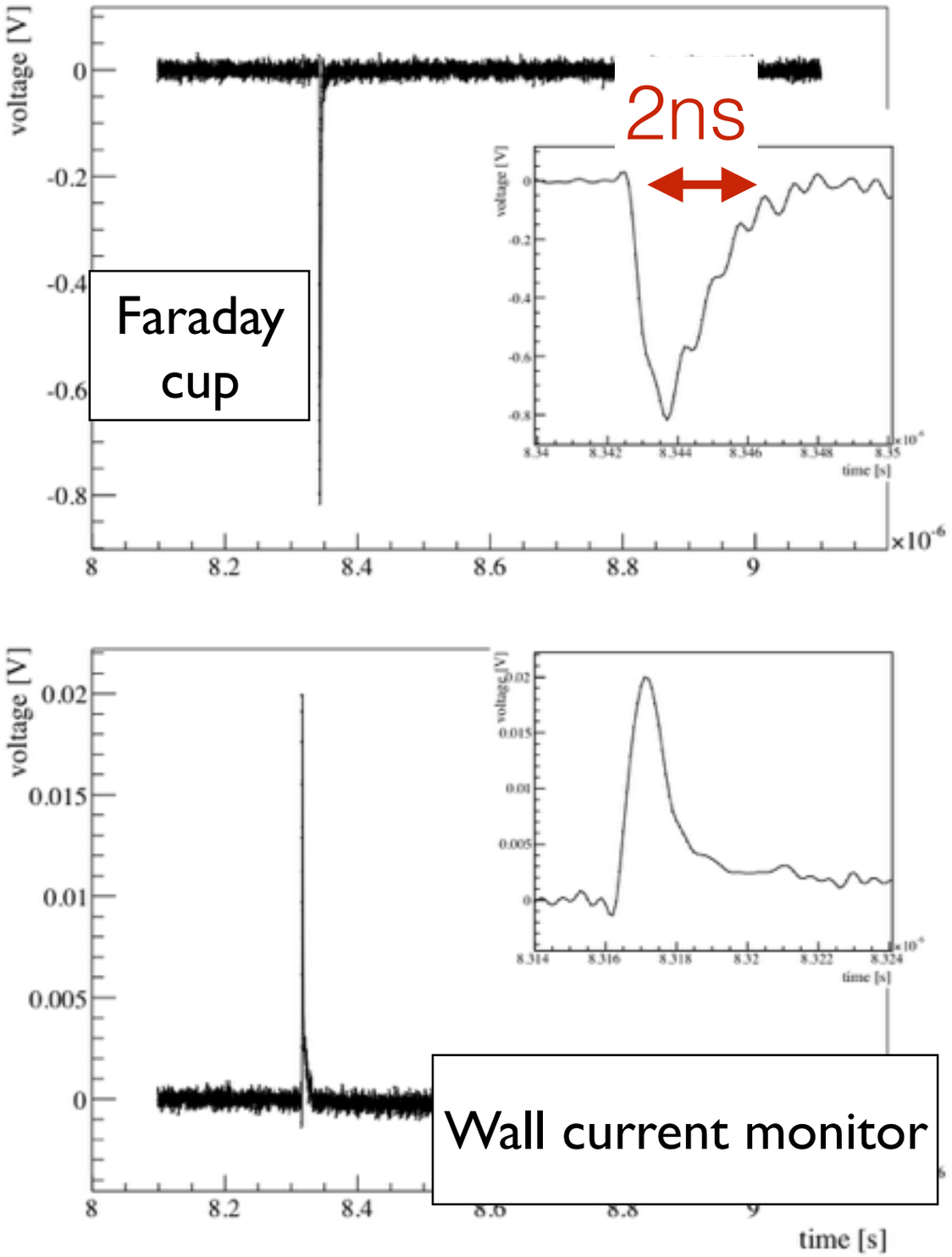
Target

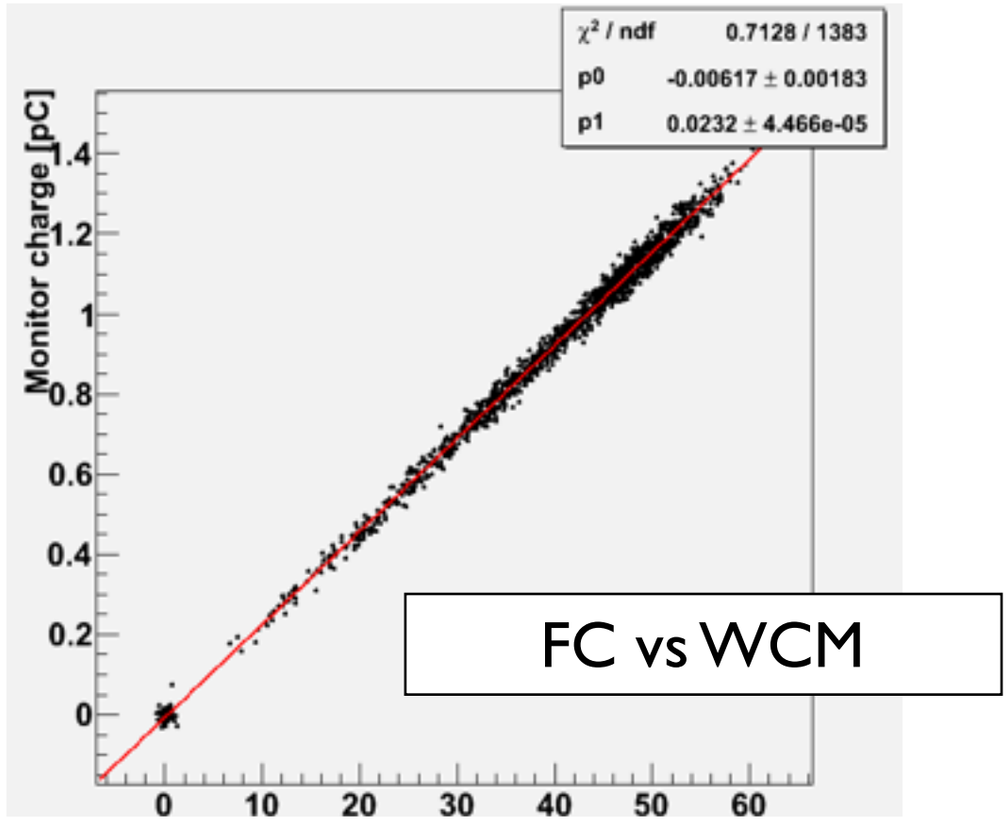
- ice target (kept a low temp.)
- plastic structure
- target angle adjustable
- target removable

Detector

- 2 polarization antenna on a pole
- pole height adjustable up to 7m above the beam exit
- Filter (230-430MHz) and LNA at the exit of the antenna
- ~40m cable to DAQ

Beam configuration





Beam width: ~2-3 ns width

Beam charge: 25-60 pC (~2 - 4 x10^8 e^-)

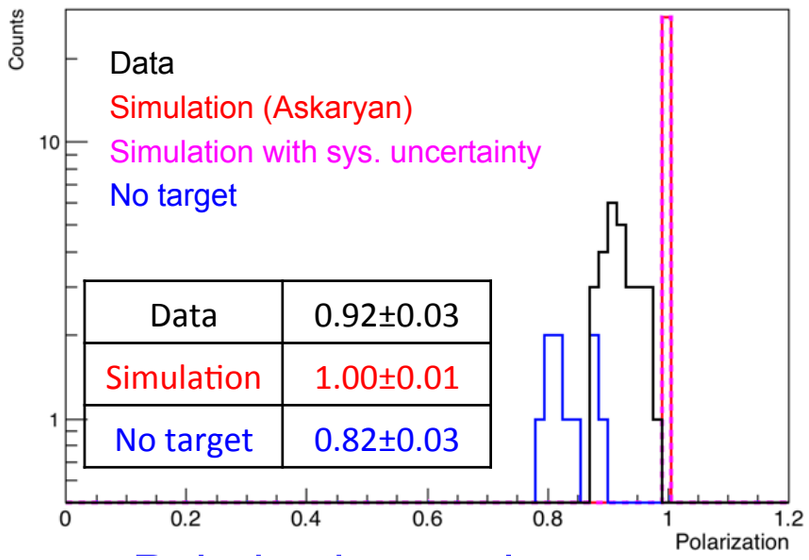
2 monitors:

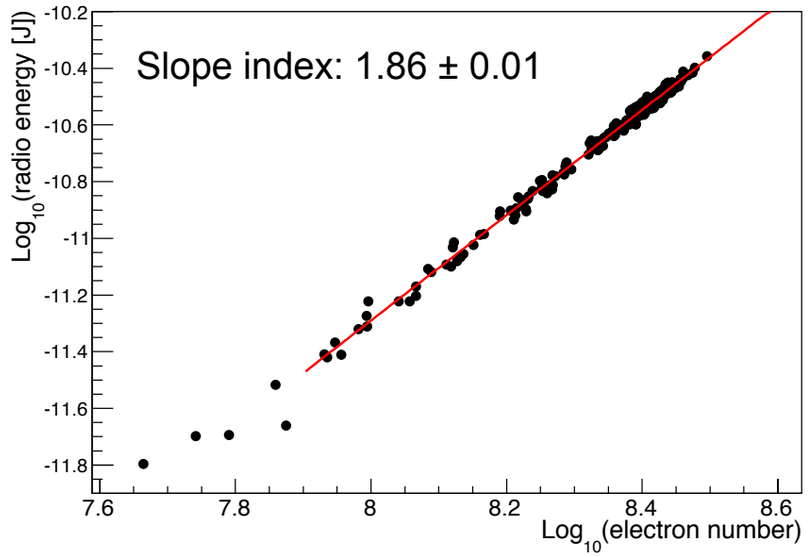
Faraday cup: stop the beam (calorimetric meas.)

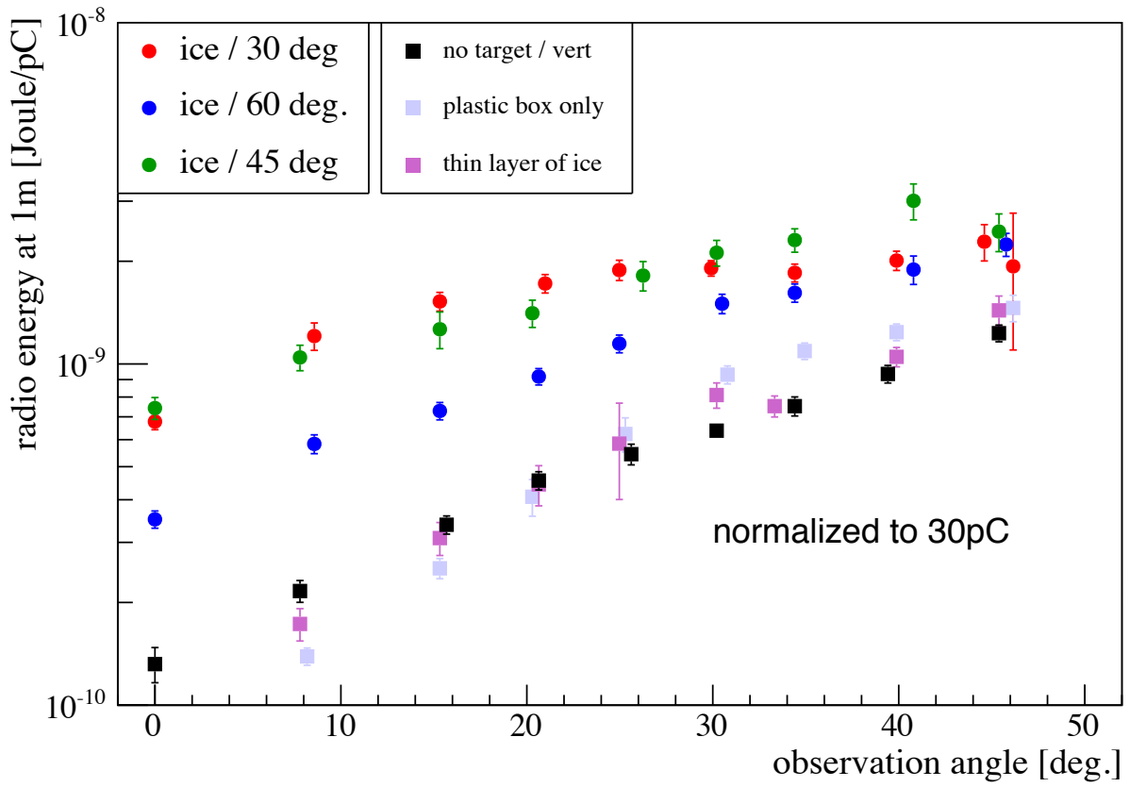
Wall current monitor: let the beam go through

→ can calibrate WCM with FC on dedicated runs

Results: Polarization/Coherence /Intensity

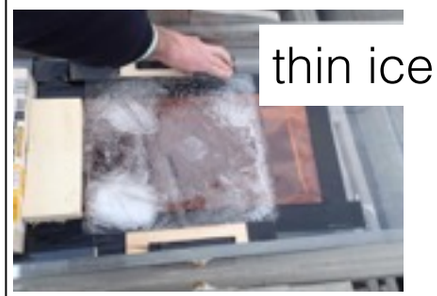






(observation angle: angle from ice to antenna)

ice



thin ice

plastic box

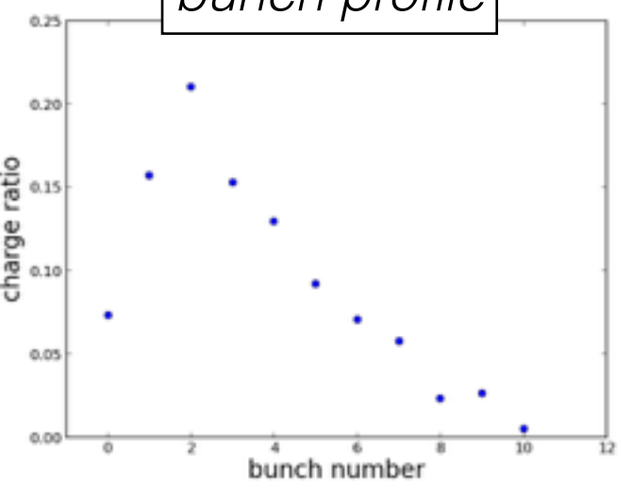
- Very polarized signal in all cases (ice target and no target) (expected for a field from the beam or electron shower)
- Charge dependence of the radio signal: almost fully coherent
- Signal with ice target at least 2 times larger than without
- No specific background from plastic box

Simulations

Simulations chain

1. Particle simulation: Geant4 based, realistic beam profile and lateral spread

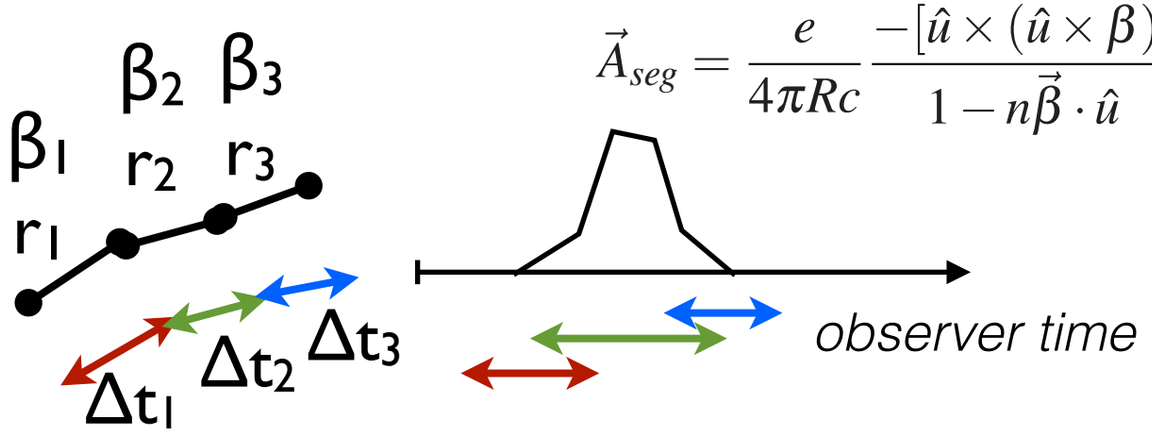
bunch profile



Input
- bunch time profile
- lateral spread
- total charge

- most of particle contained in ice thickness

2. Radio simulation: ZHS based computes the potential vector for electron tracks



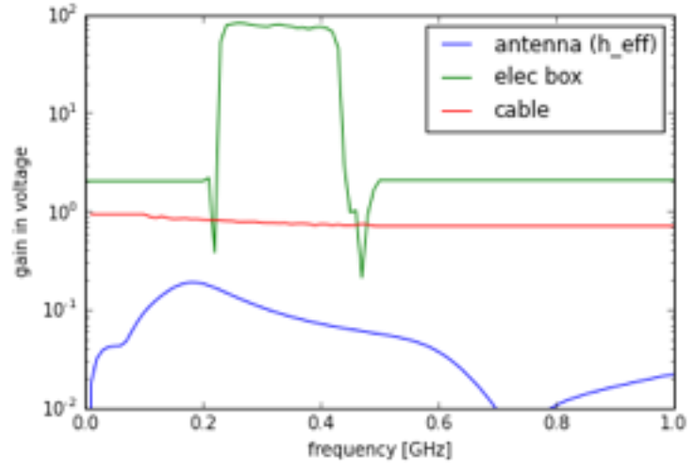
$$\vec{A}_{seg} = \frac{e}{4\pi Rc} \frac{-[\hat{u} \times (\hat{u} \times \vec{\beta})]}{1 - n\vec{\beta} \cdot \hat{u}}$$

→ E field by time derivation

3. Detector simulation:

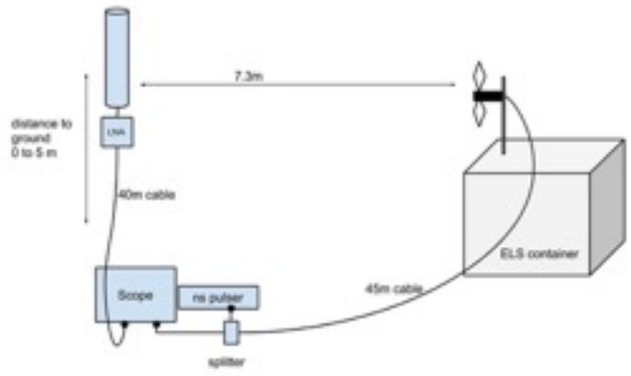
antenna: Time domain simulation

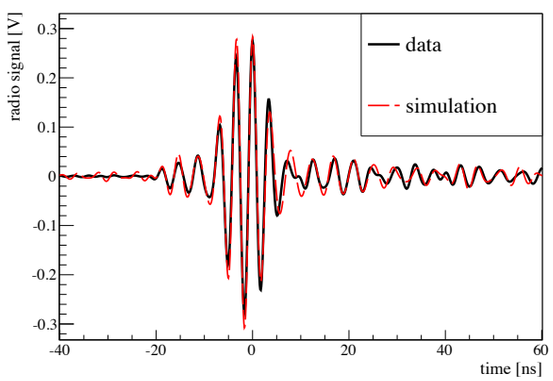
electronics: frequency spectrum measurement



validation: emit a pulse with an antenna and measure it with our detector

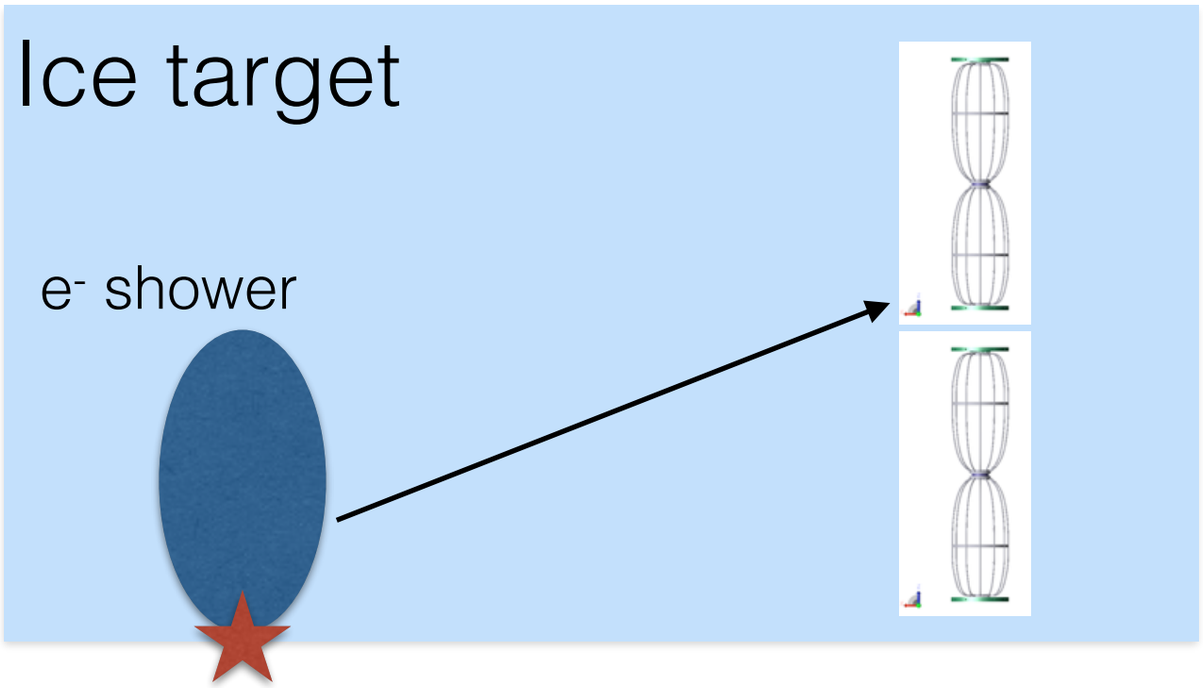
→ ΔP/P < 15%

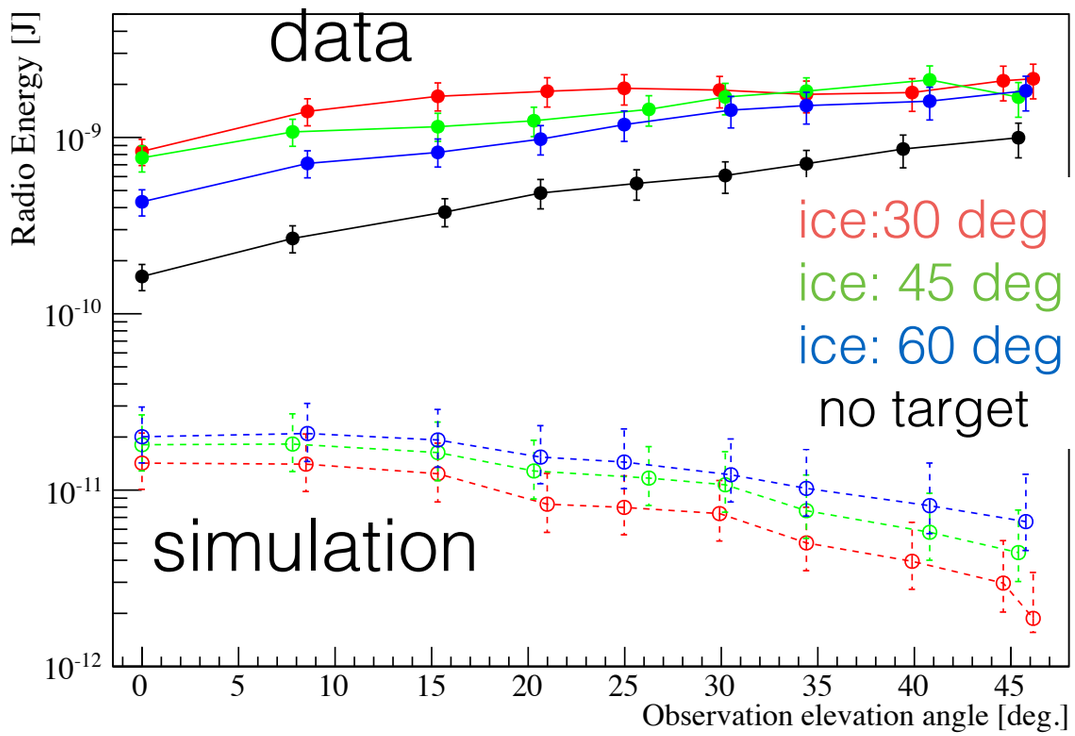




Simulation with target

Ice target: simulate a big block of ice





Simulation configuration:

- Simplified: only ice environment (neglect air contribution and Transition radiation)
- Refraction accounted afterwards

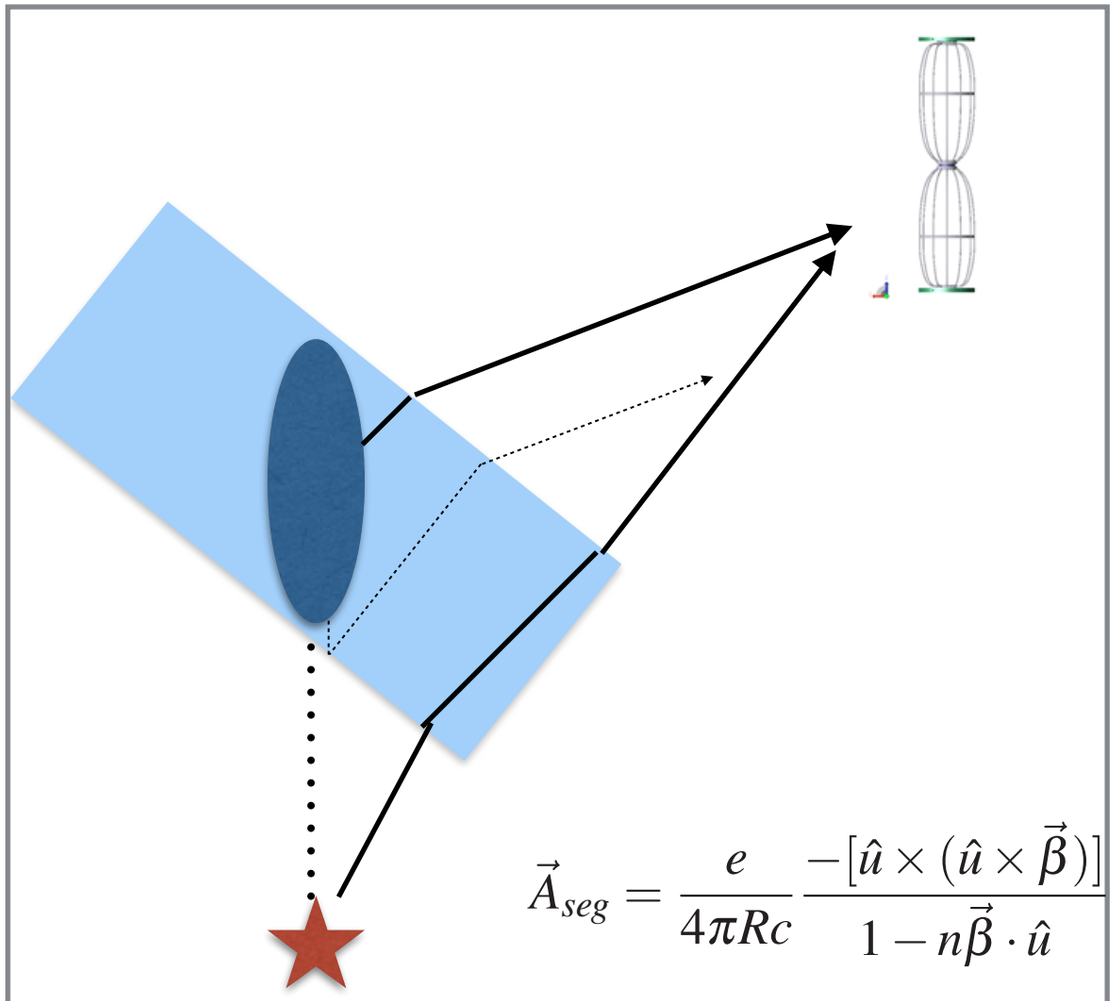
Comparison with data

- large discrepancy in absolute value
- different angular dependence

→ Other emission process dominate

On going improvement

Large discrepancy data/simulation → make our simulation more detailed:



$$\vec{A}_{seg} = \frac{e}{4\pi Rc} \frac{-[\hat{u} \times (\hat{u} \times \vec{\beta})]}{1 - n\vec{\beta} \cdot \hat{u}}$$

source of E field =
change of potential vector

- from beam appearance point
- change of index
- shower development

Simulation of field source:

Implement the real geometry
Account for air contribution through ice and for reflected ray

→ Other process included (esp. transition radiation)

→ should increase the absolute scale

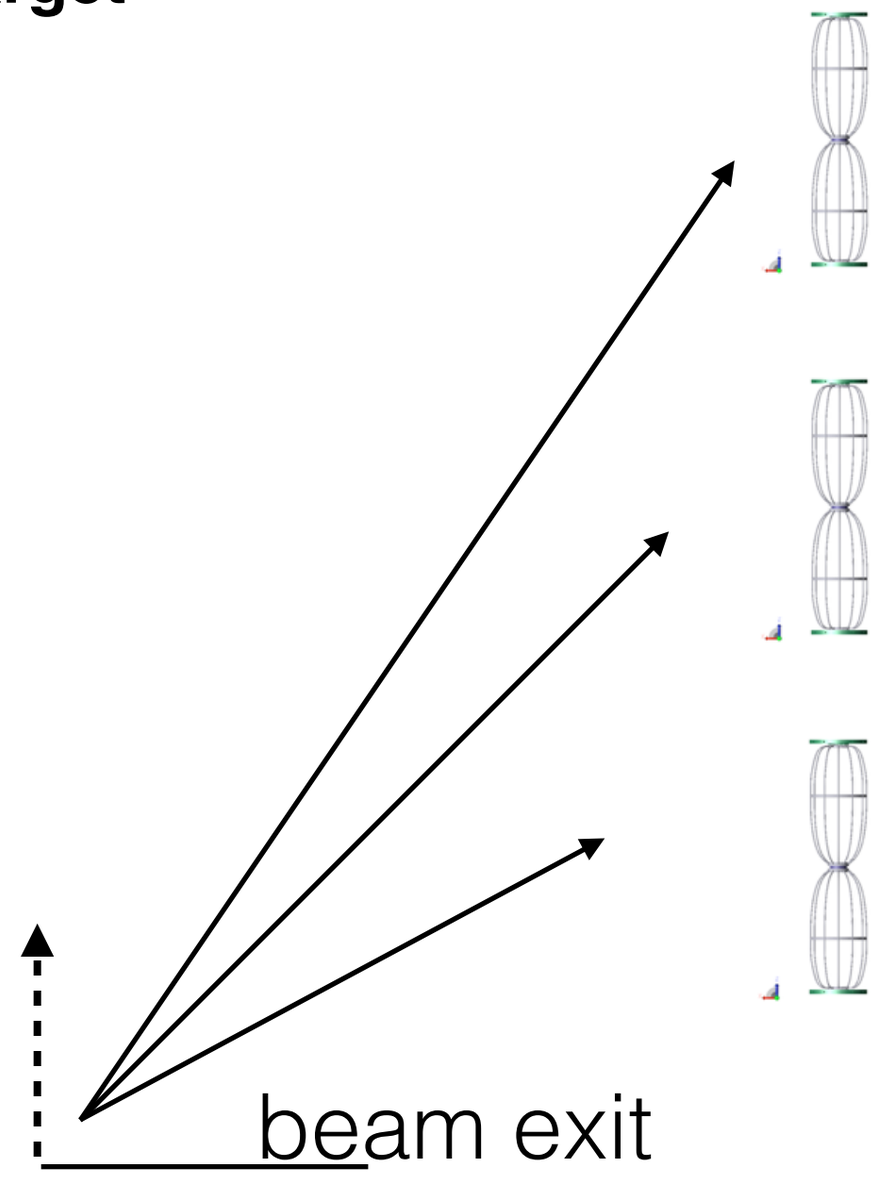
Other effects studied:

- diffraction from ice (size of ice block comparable to λ)
- Index of refraction of the ice

→ can modify the angular dependence

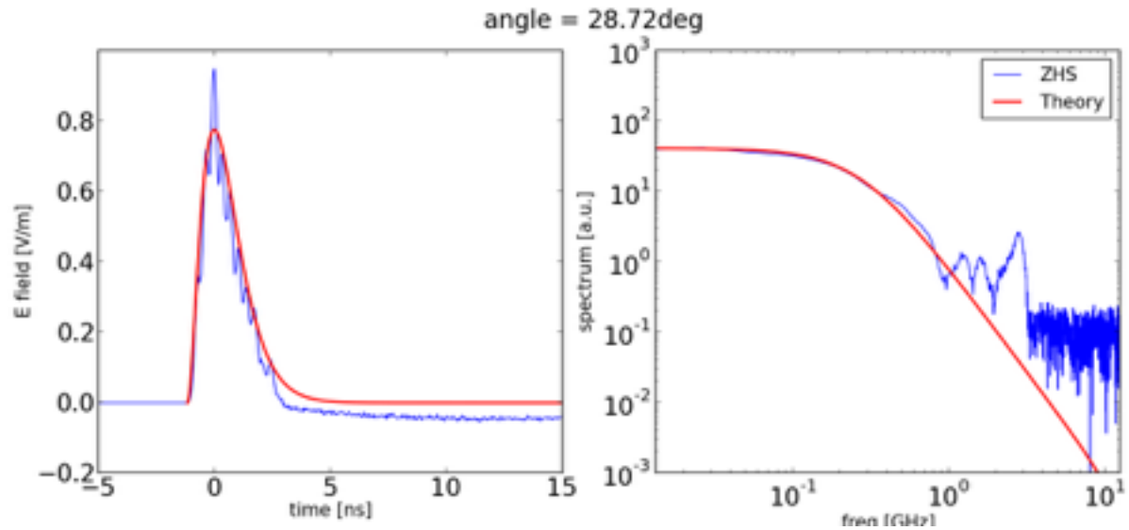
Simulation with no target

No target



Change of potential vector from beam appearance point

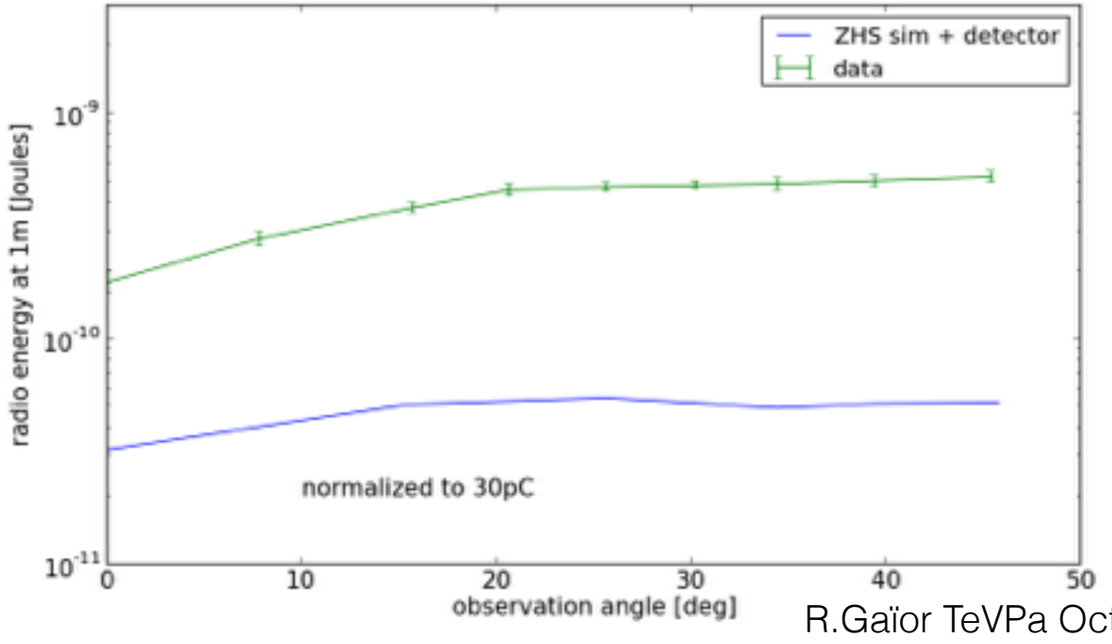
Comparison with theory



$$E(\omega) = \frac{e}{4\pi\varepsilon_0 c^2 R} \frac{\vec{v}_\perp}{1 - \frac{\hat{k}\cdot\vec{v}}{c}} \sum_i \exp(i\omega t_i - \vec{k}\cdot\vec{r})$$
$$\vec{v}_\perp = \hat{k} \times (\hat{k} \times \vec{v})$$

done by Pavel Motloch (at U. of Chicago)

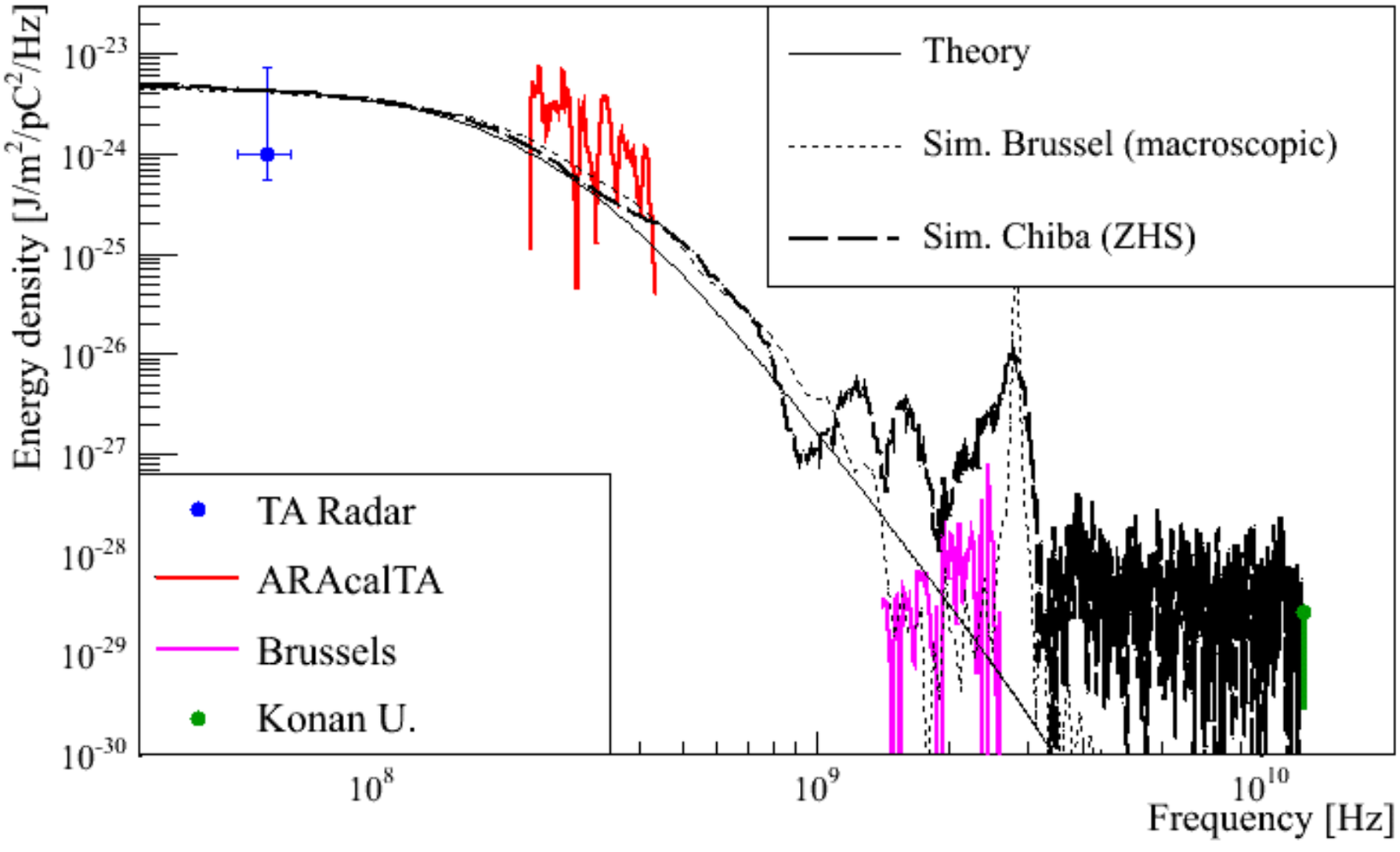
Comparison with data



No target run: Comparison with other experiments

TA LINAC used for several radio experiment

- TA Radar: Radar for UHECR detection (~50MHz)
- Brussels IceCube group: Radar on plasma in ice for ν detection (~2-3GHz)
- Konan University: Molecular Bremsstrahlung (12GHz)



Conclusions

Observation of coherent radiation from electron at UHF

- Set of data for different configuration:
  - no target - ice block - background check
- Highly polarized an coherent radio signal observed
  -> emission from electron beam and shower
- Signal observed with ice larger than no target measurement

Comparison with simulation

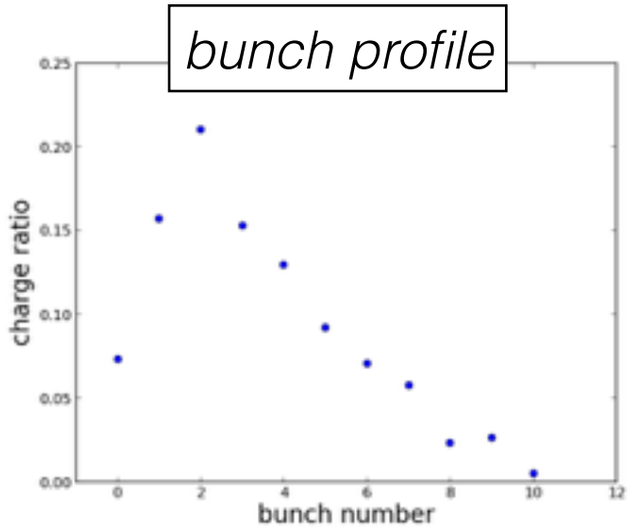
- Askaryan component seems lower than dominant background
- No target run has already a shift in absolute scale:
  - detector simulation checked
  - comparison with theory checked

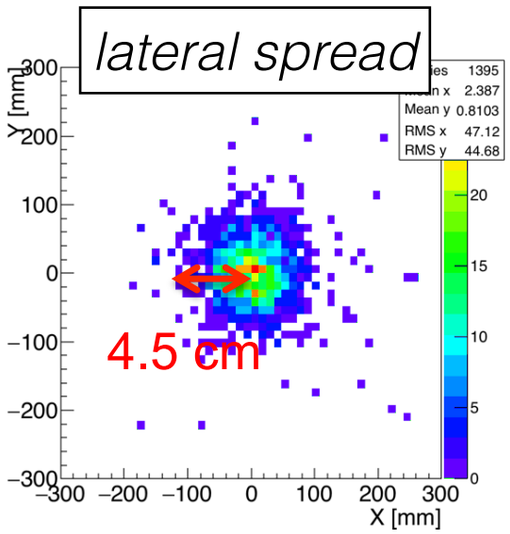
Complementary studies

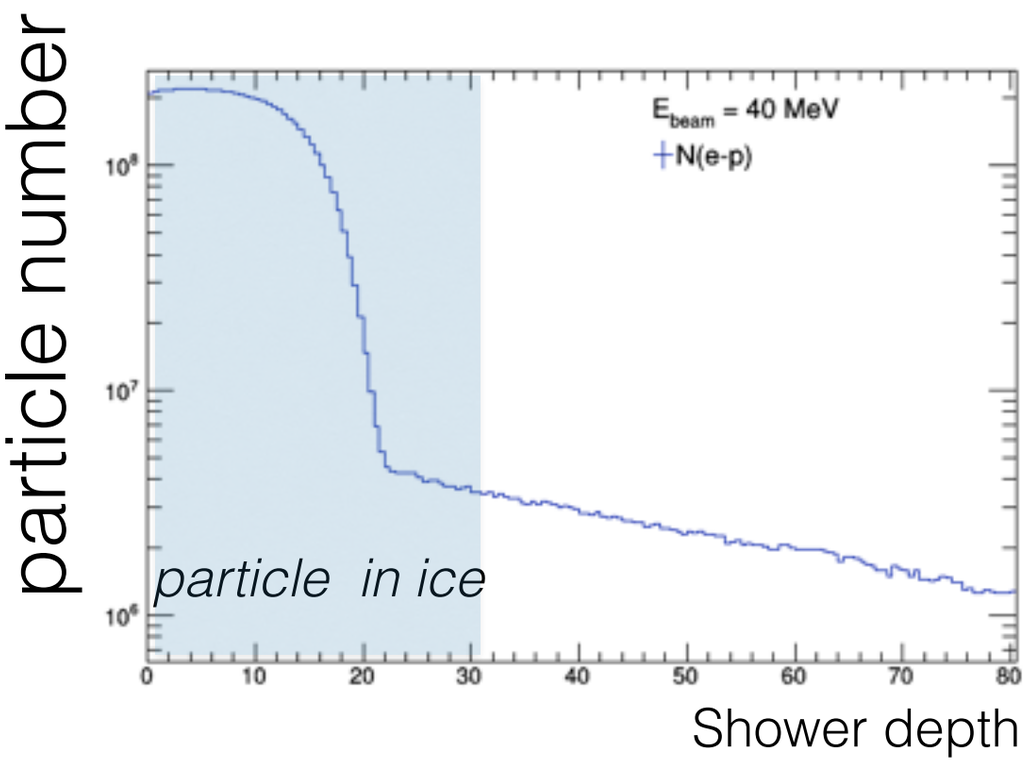
- No target runs compared with other radio experiment
  → important for their background understanding
- Ice target run: possibly data of transition radiation at UHF
  → radiation studied for the detection of neutrino shower
  (http://arxiv.org/pdf/1509.01584v1.pdf)

Radio signal simulations

Particle simulation: Geant4 based, realistic beam profile and lateral spread

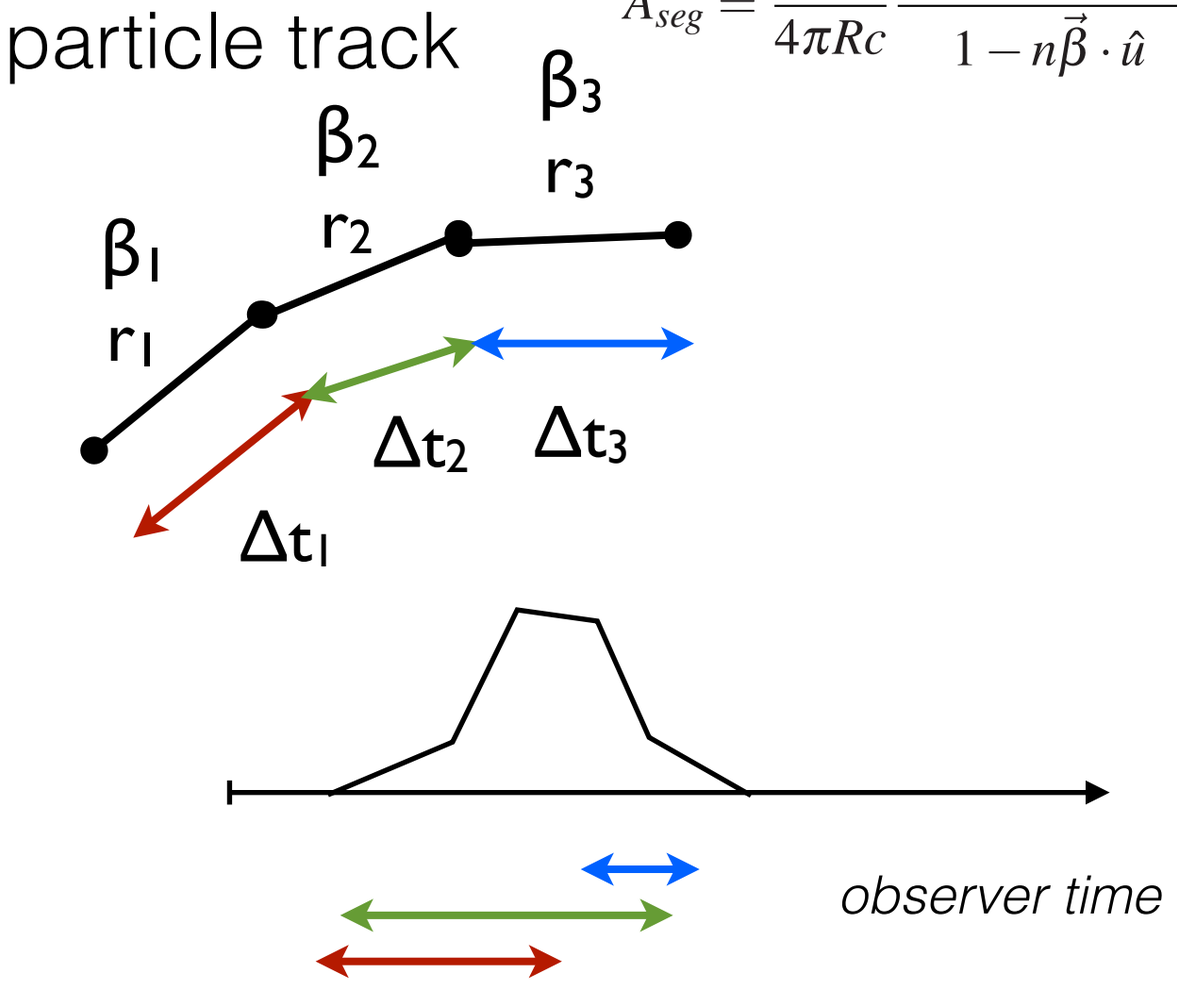






Radio simulation: ZHS based computes the potential vector for electron tracks

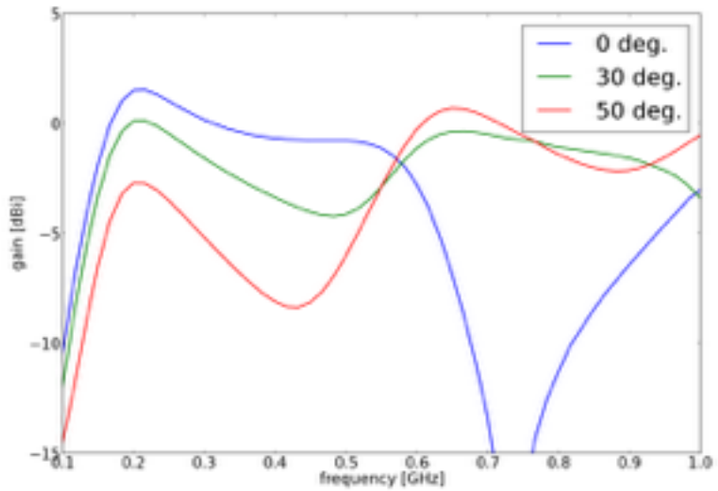
$$\vec{A}_{seg} = \frac{e}{4\pi Rc} \frac{-[\hat{u} \times (\hat{u} \times \vec{\beta})]}{1 - n\vec{\beta} \cdot \hat{u}}$$



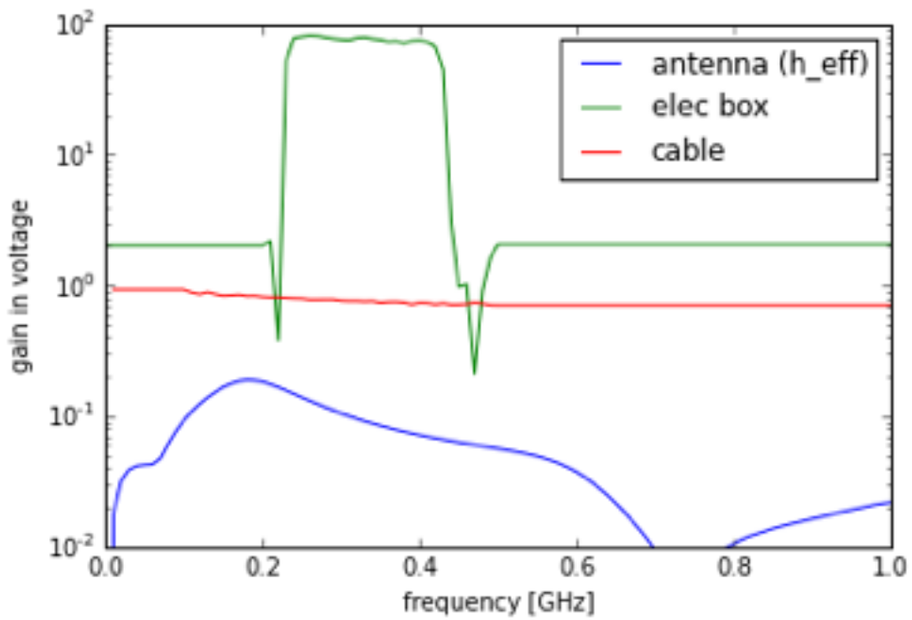
→ E field by time derivation

Detector simulations

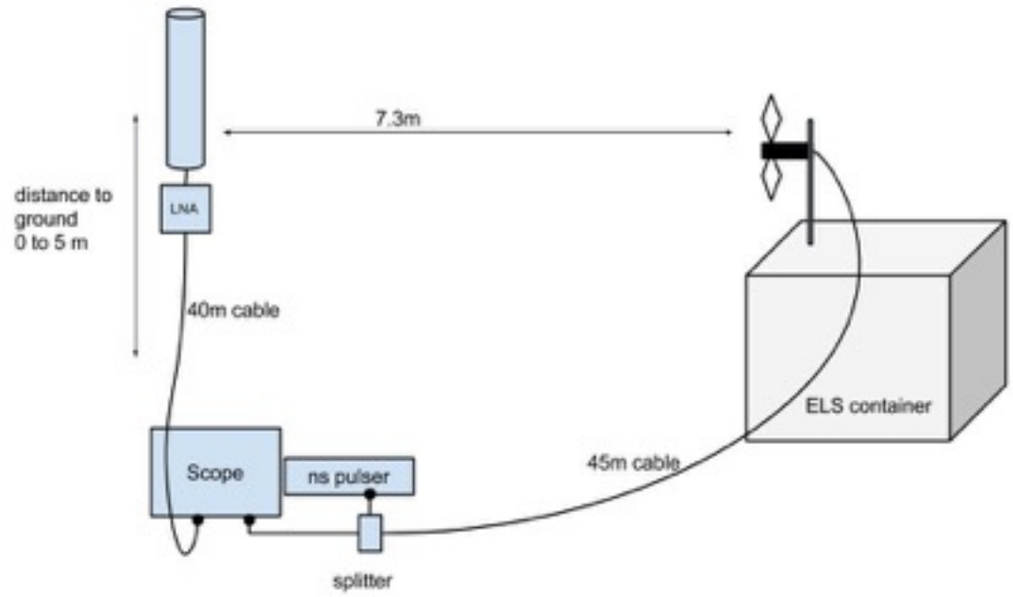
Antenna: Time domain simulation with XFDTD software (method in http://www.farr-research.com/biblio.html (note 555))

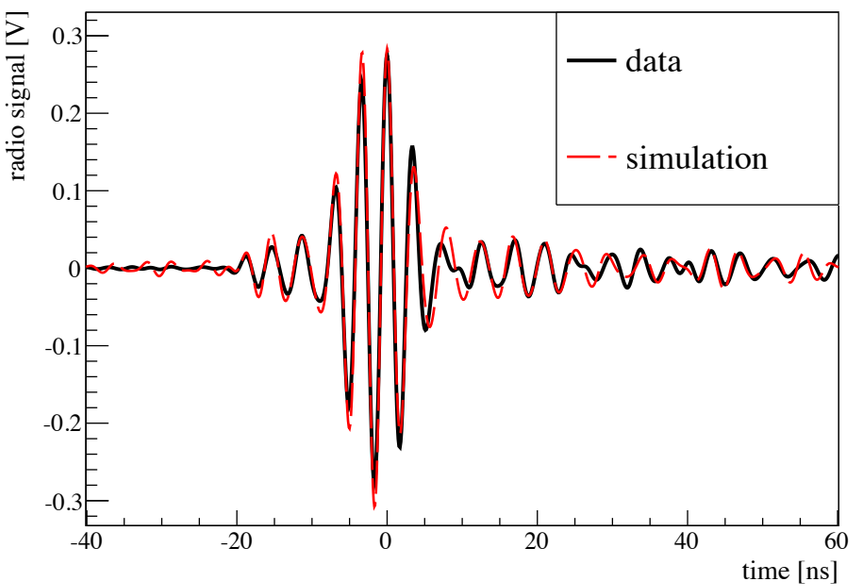


Electronics: Based on measured gain/phase

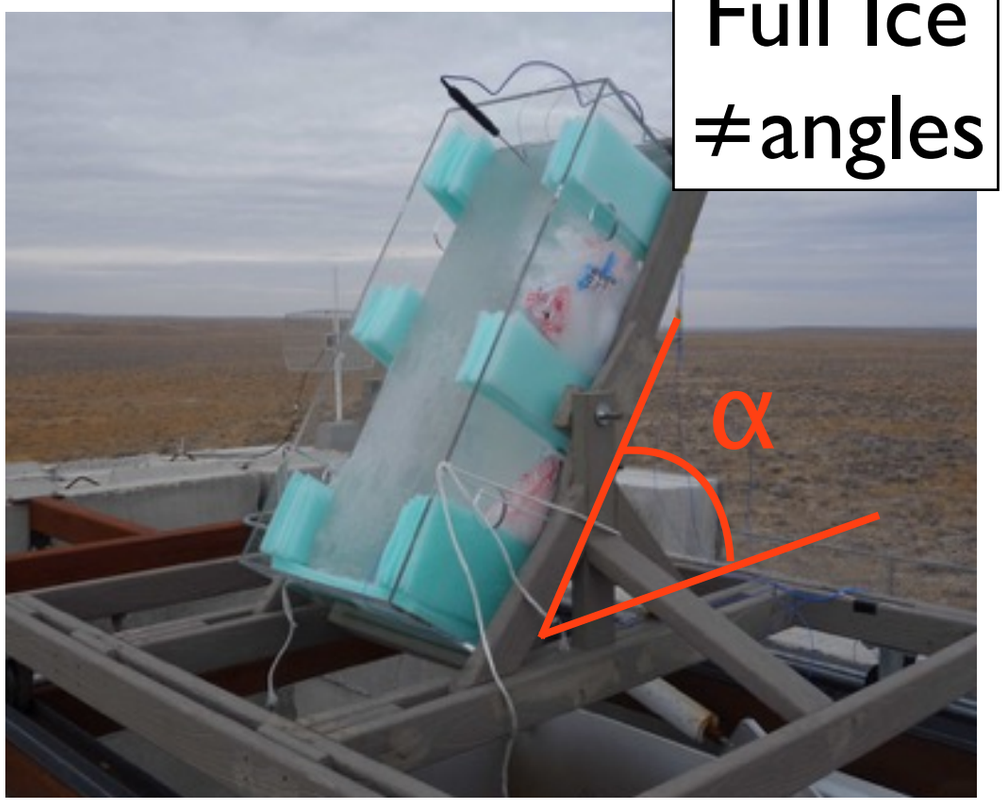


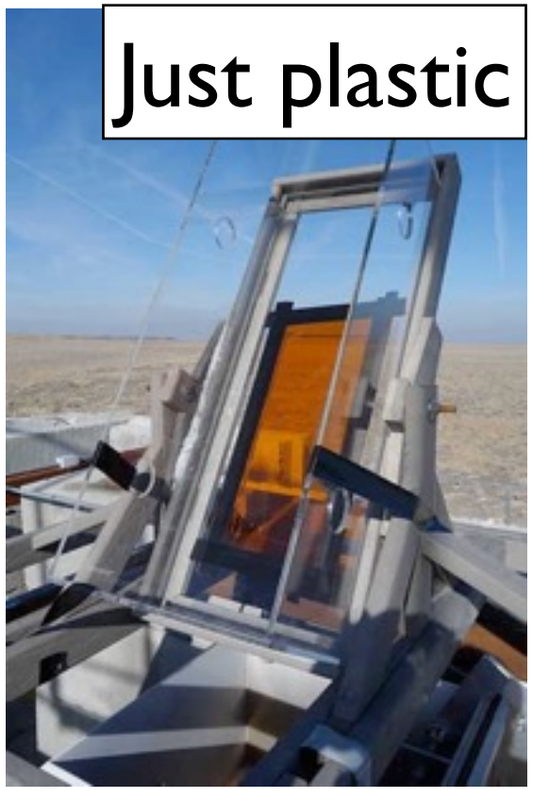
Detector simulation validation

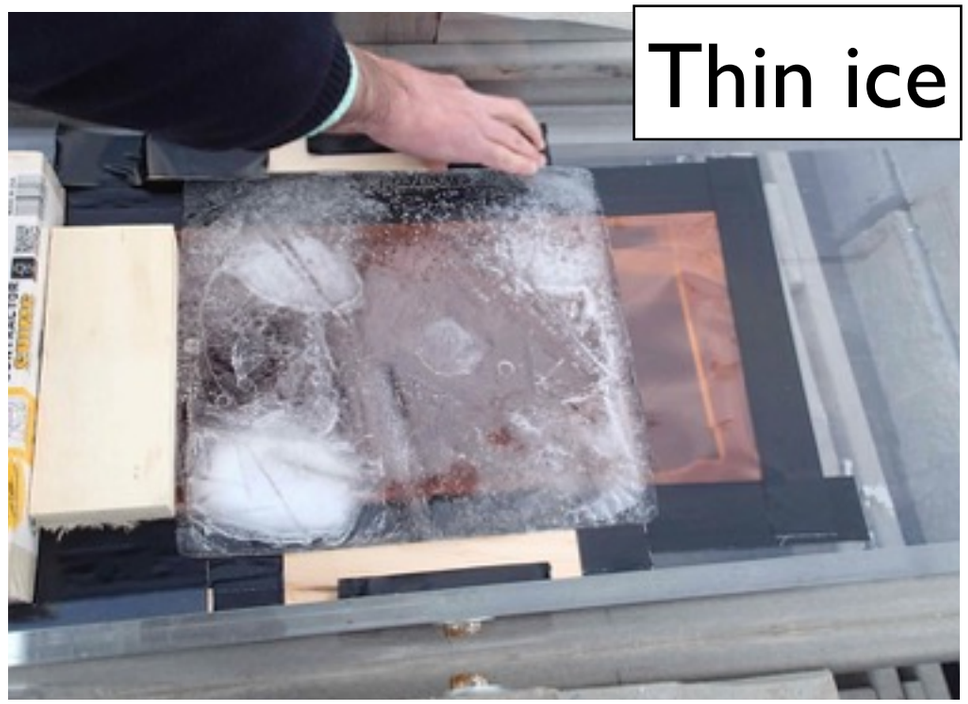




ARAcalTA: main runs



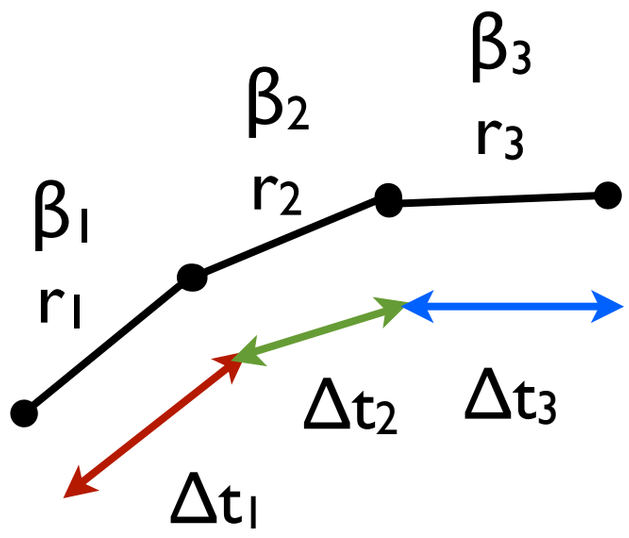




- **physics:** nominal configuration i.e. block of ice (ice angle 30, 45, 60 deg.)
- **background:** replace target by nothing, just plastic case, thin layer of ice...

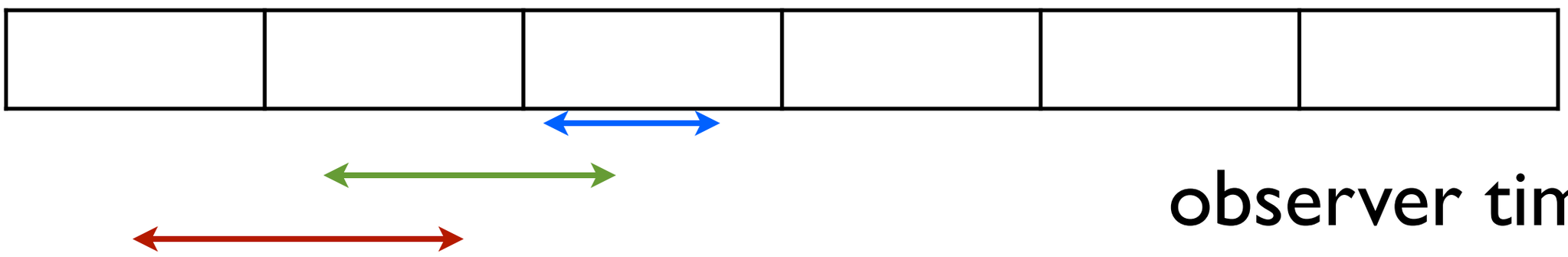
- ***calibration:*** *use bicone antenna and scan height, beam monitoring*
- ***interference test:*** *vertical and horizontal antenna*

ZHS

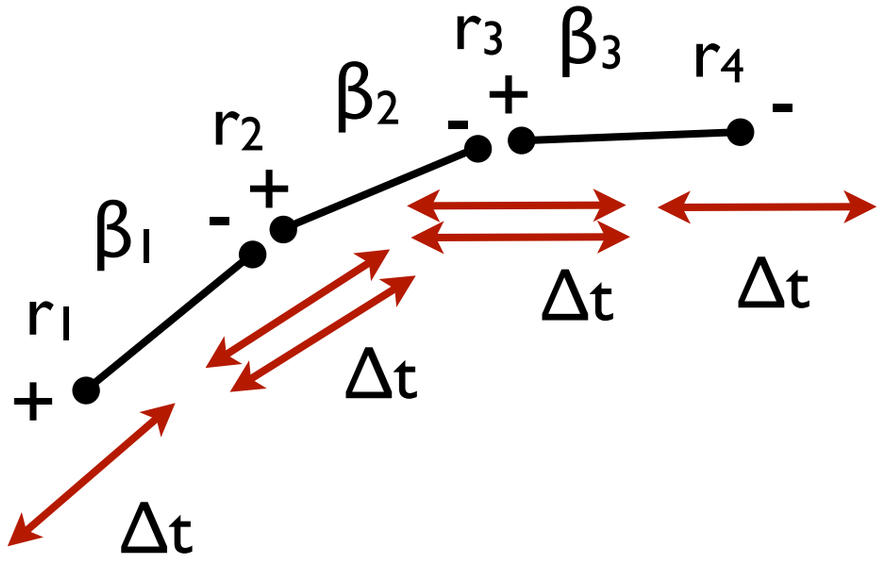


$$\vec{A}_{seg} = \frac{e}{4\pi Rc} \frac{-[\hat{u} \times (\hat{u} \times \vec{\beta})]}{1 - n\vec{\beta} \cdot \hat{u}}$$

For each **segment** vector potential is computed

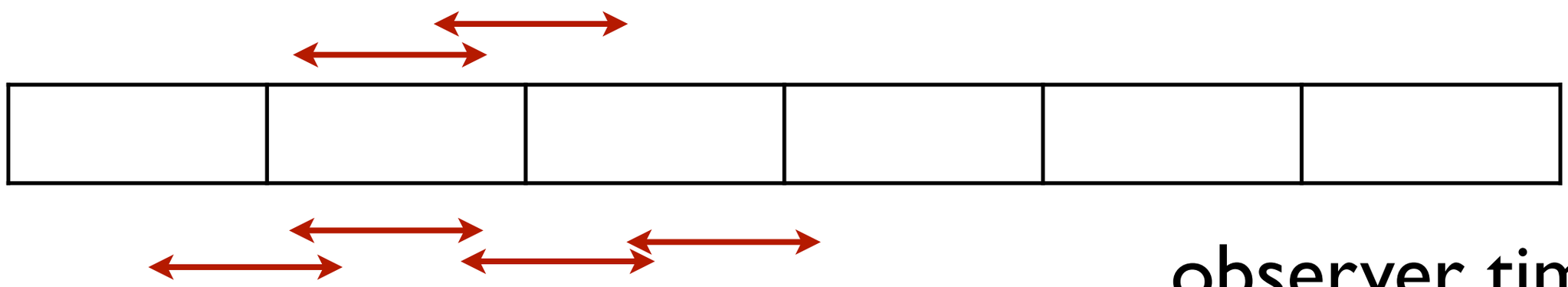


End point method



$$\vec{E}_{\pm}(\vec{x},t) = \pm\frac{1}{\Delta t}\frac{q}{c}\left(\frac{\hat{r}\times[\hat{r}\times\vec{\beta}^{*}]}{(1-n\vec{\beta}^{*}\cdot\hat{r})R}\right)$$

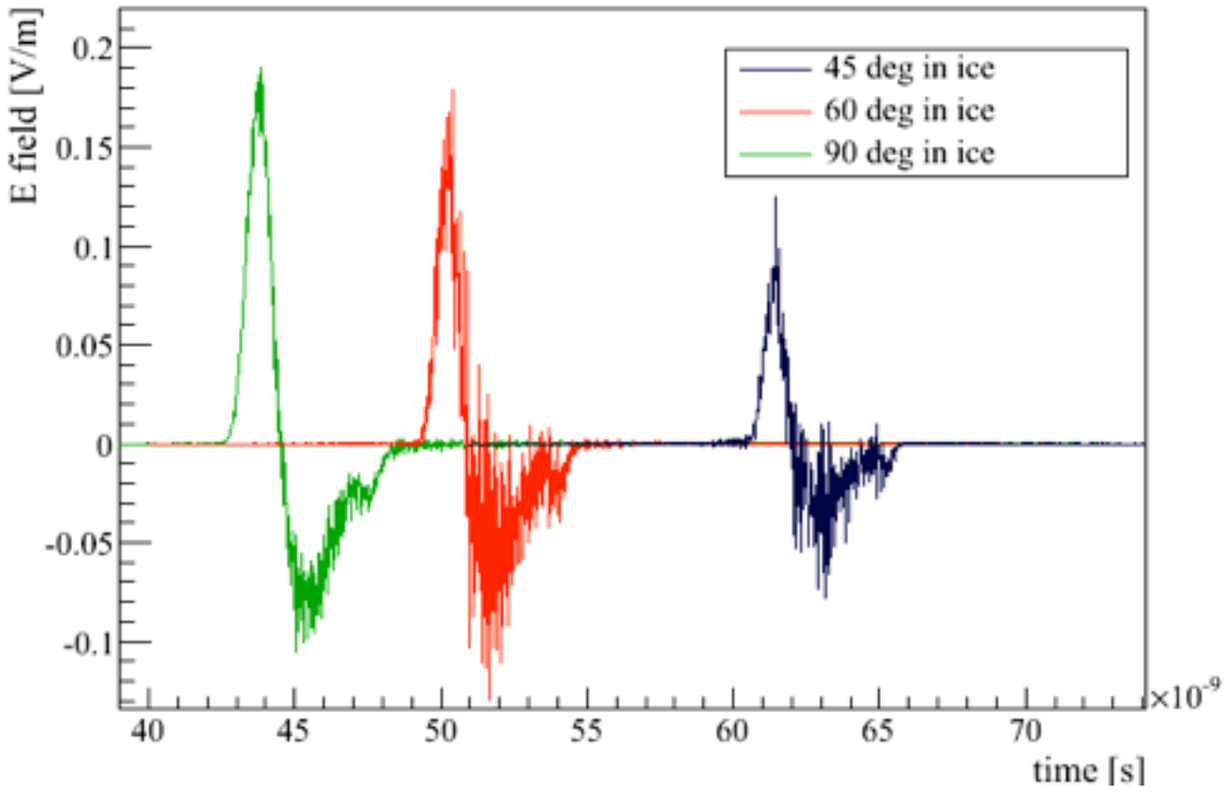
For each **point**
+/- E field
is computed



source time
= obs time

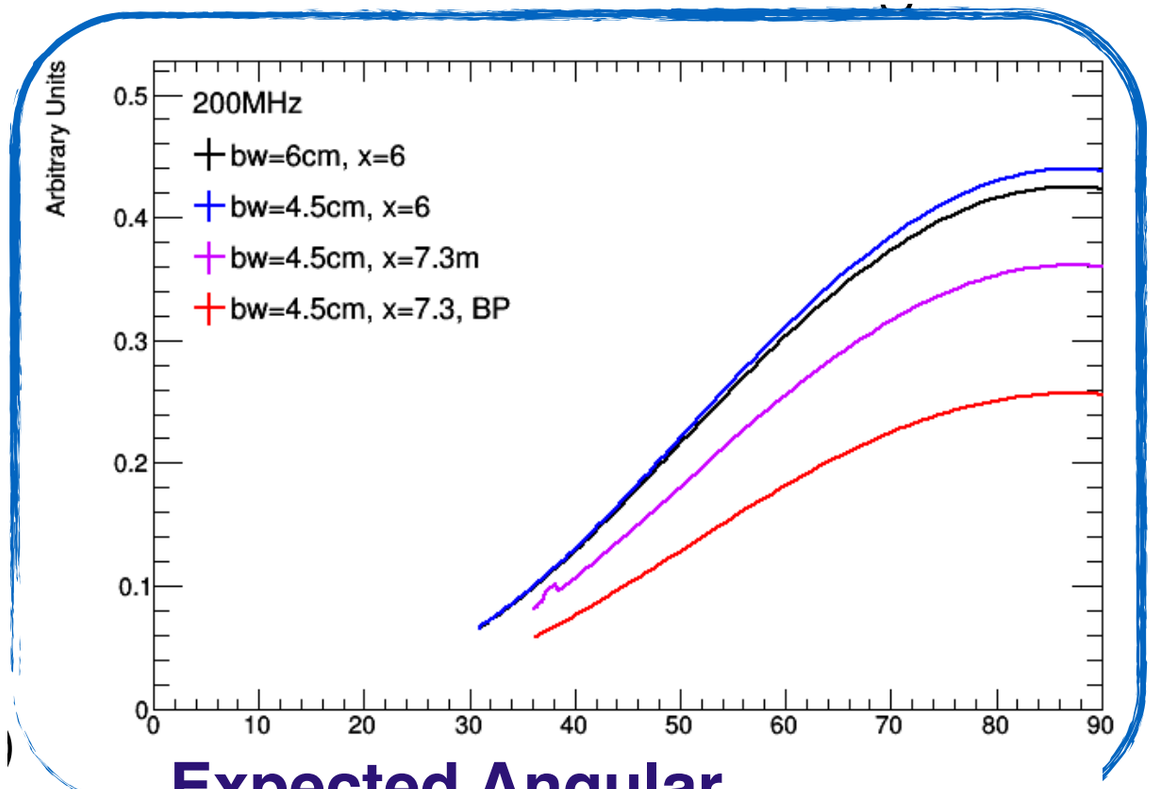
observer time

Simulation



Expected bipolar pulse

- the inner structure due to subbunches are wash out by the beam spread)
- Absolute timing (w.r.t. to emission time)
- Similar signal to what is expected in ARA



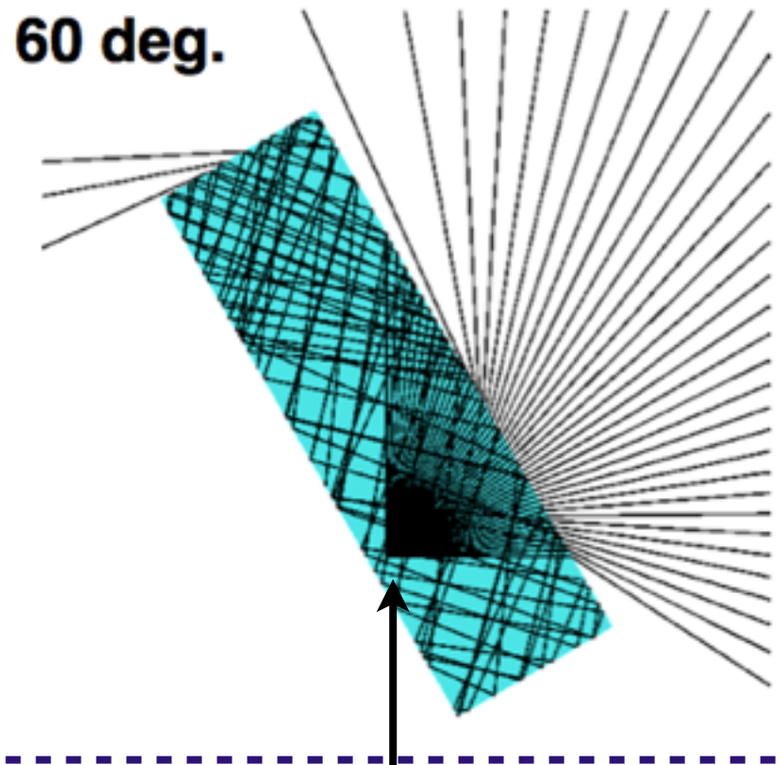
Expected Angular distribution (for different beam conditions)

- Dependance of the signal with beam spread
- realistic beam profile reduce the total expected field

Source and Target

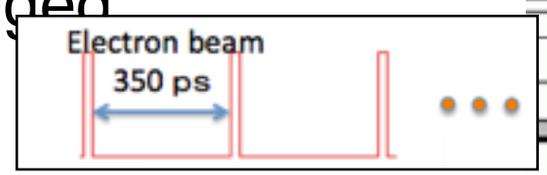
Target: Ice block

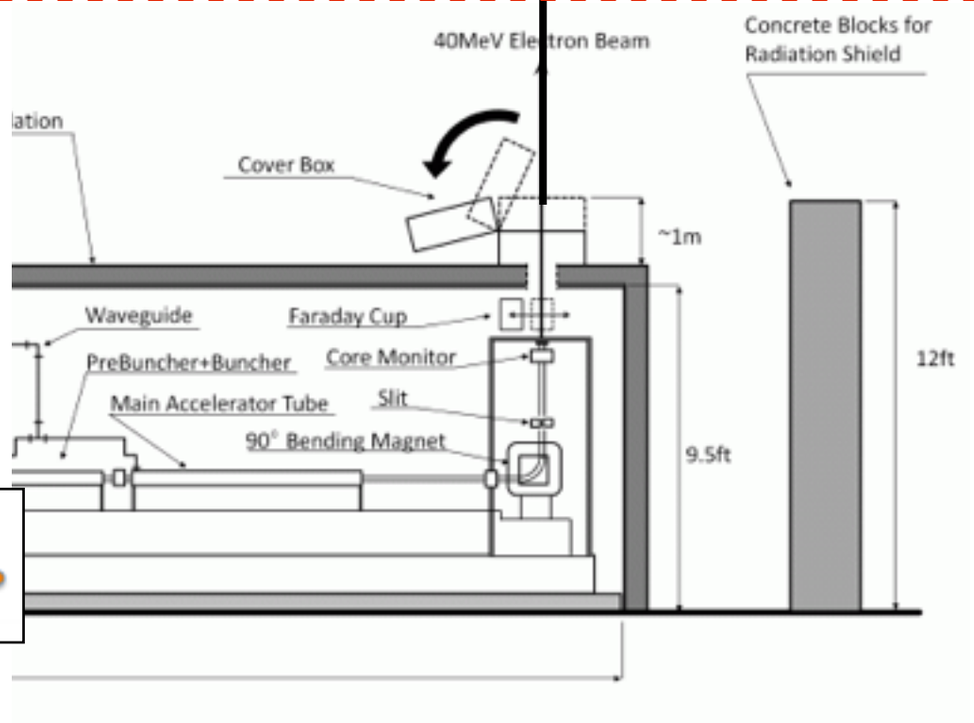
- 100cm x 30cm x 30 cm
- Installed in a plastic box 1m above the beam exit
- can be inclined to choose the exit angle of radio wave
- Due to refraction, angle of target will give the accessible emission angle in ice



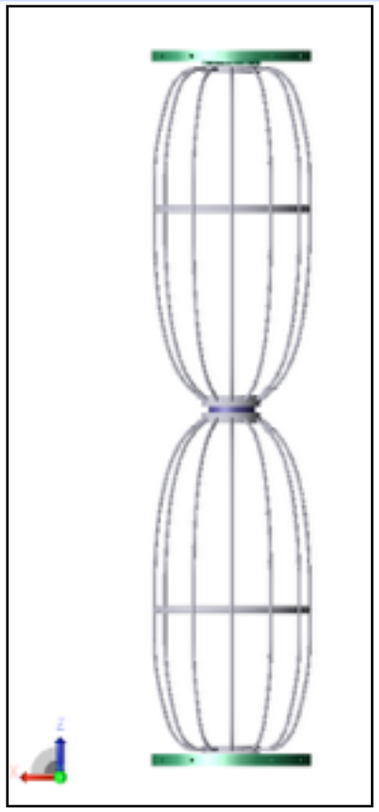
Source: TA LINAC

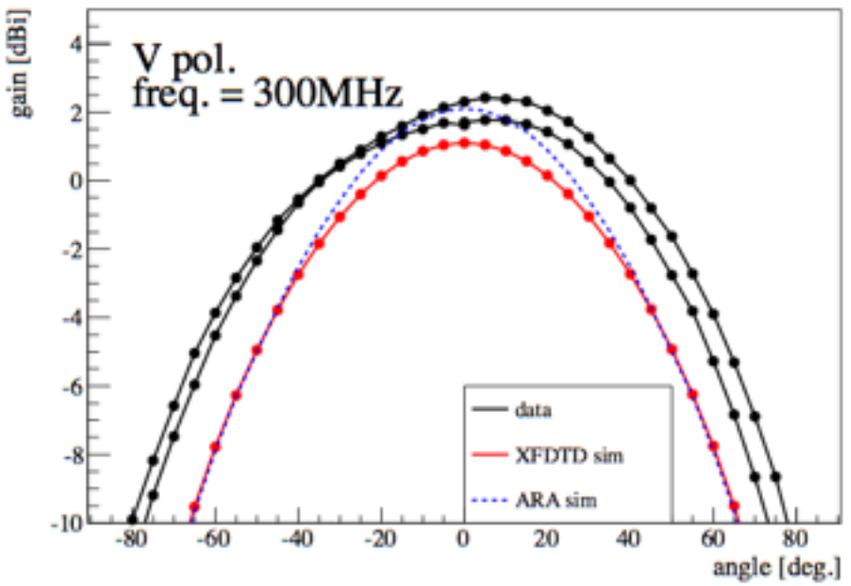
- source of 40 MeV electron
- maximum of 10^9 particles/s
- bunch of few ns long divided in sub bunches
(every 350 ps)
- bunch length can be changed

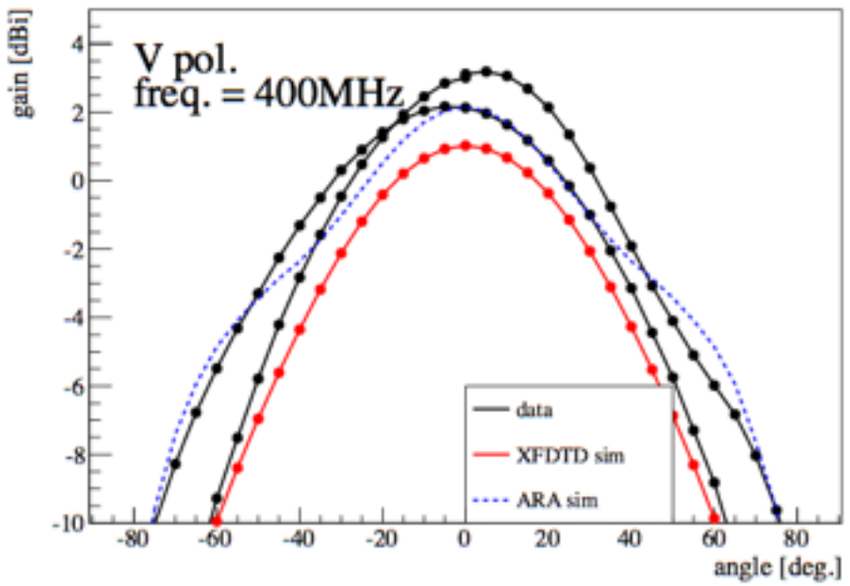


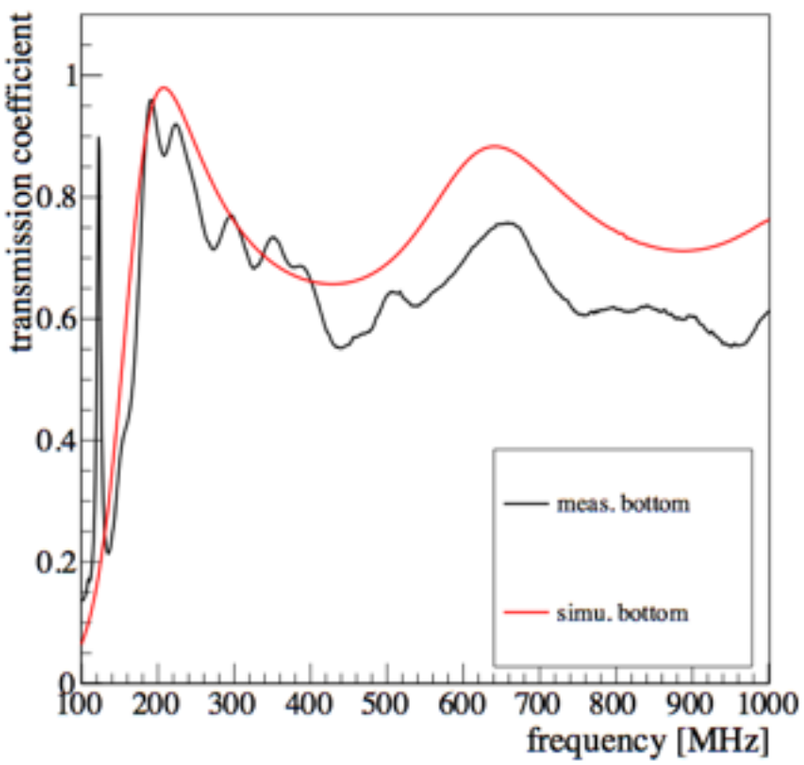


Prior Detector calibration









Antenna simulation

- Pattern simulation + VSWR
- Time domain solver XFDTD
- Work on time domain response simulation (account for the antenna phase response)

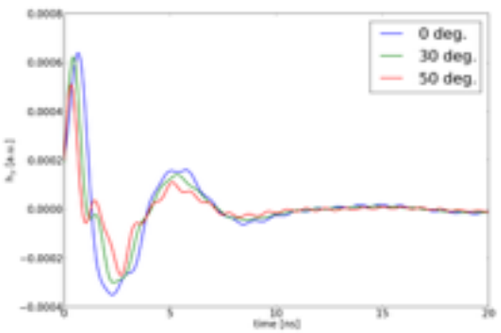
Antenna calibration

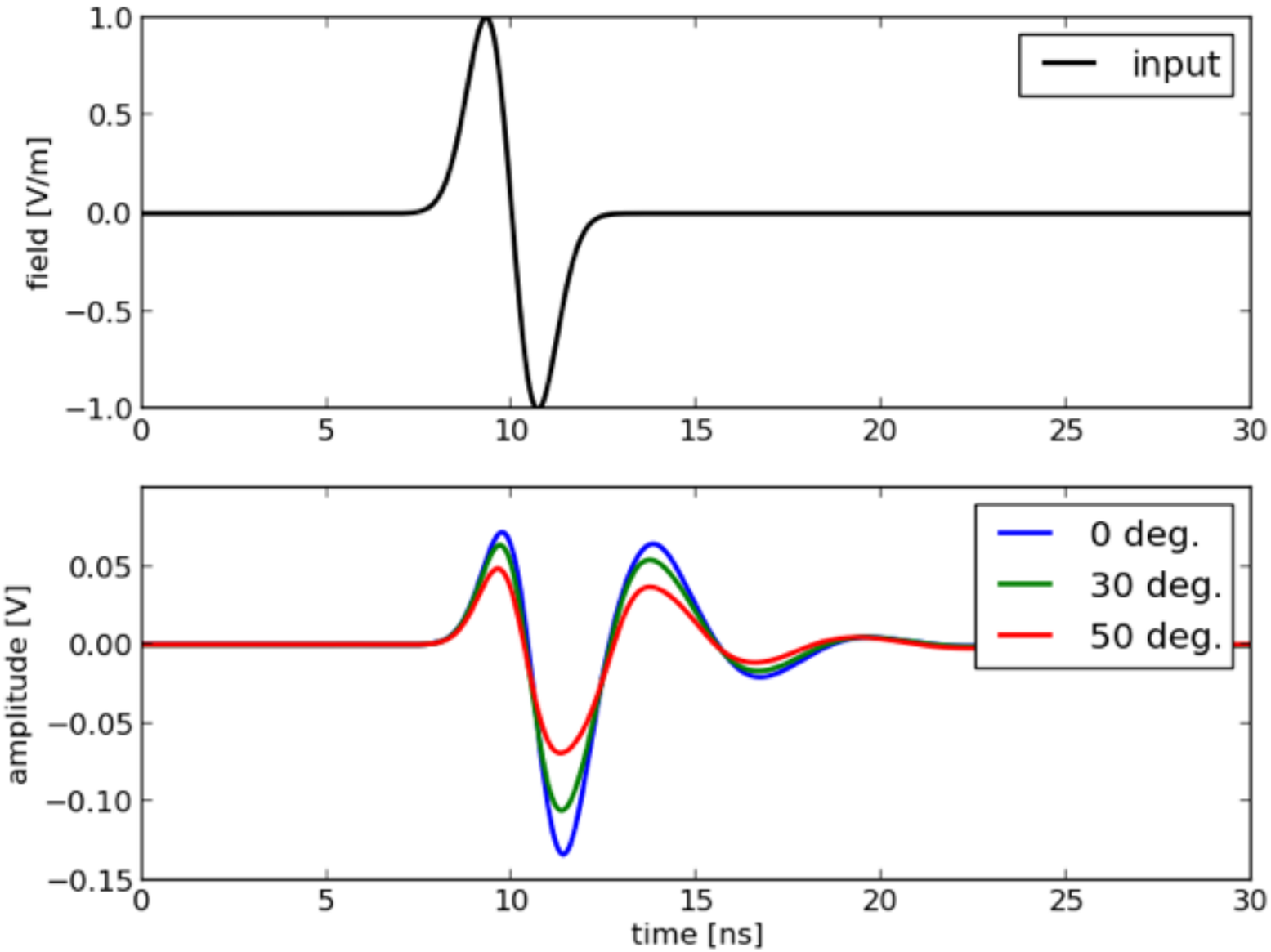
- pattern measurement in Anechoic chamber

Simulation

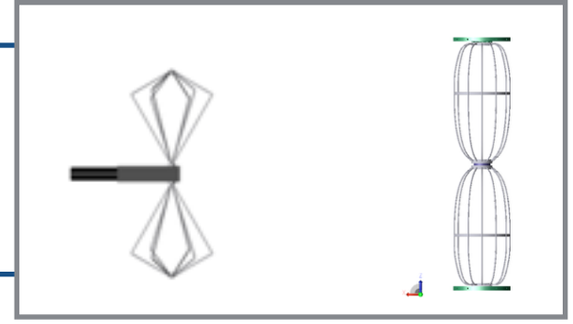
response to simulated pulse

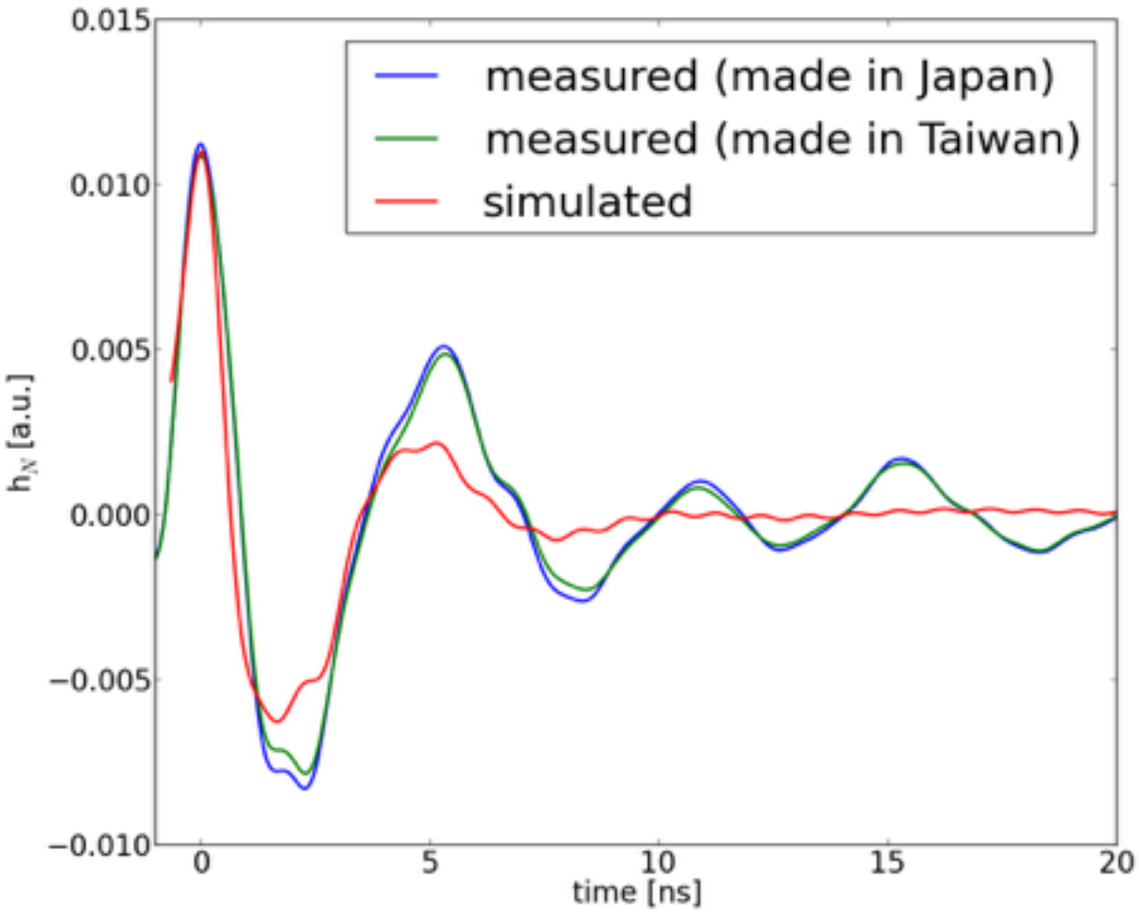
Antenna response convolution

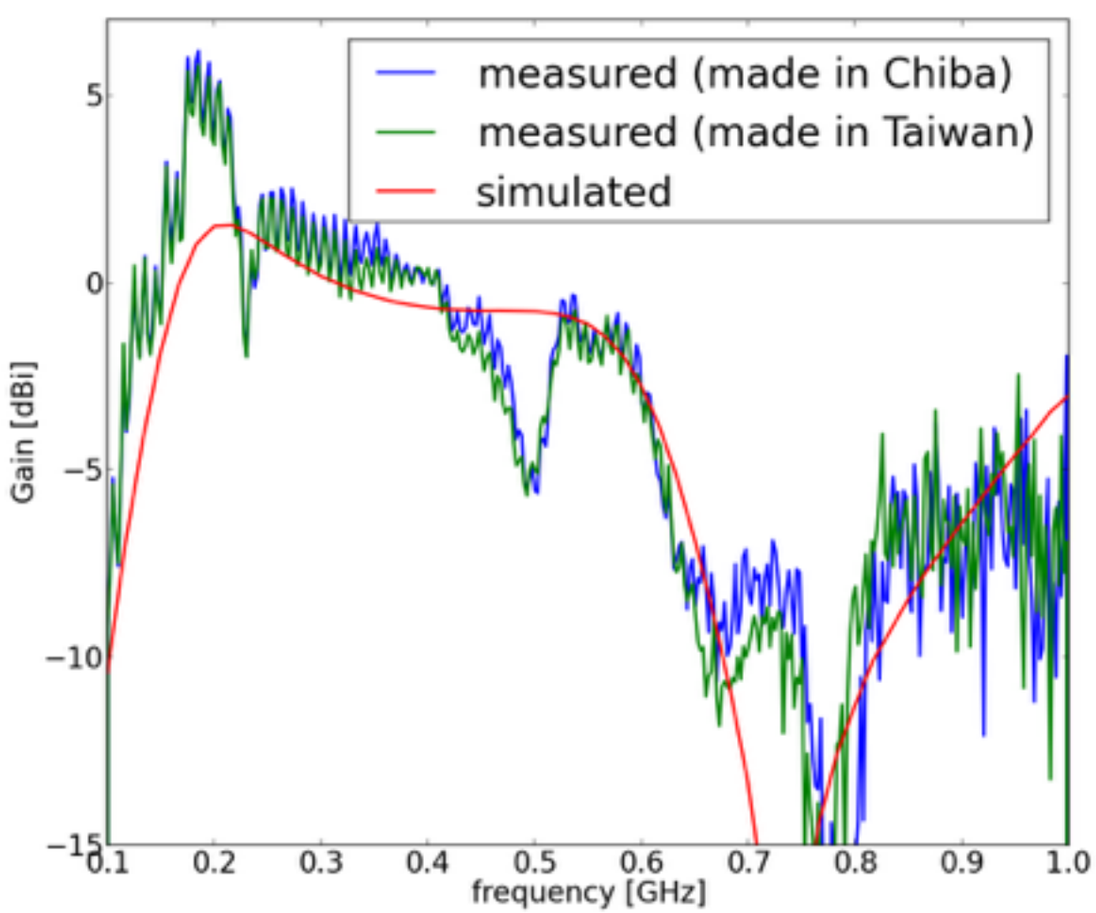


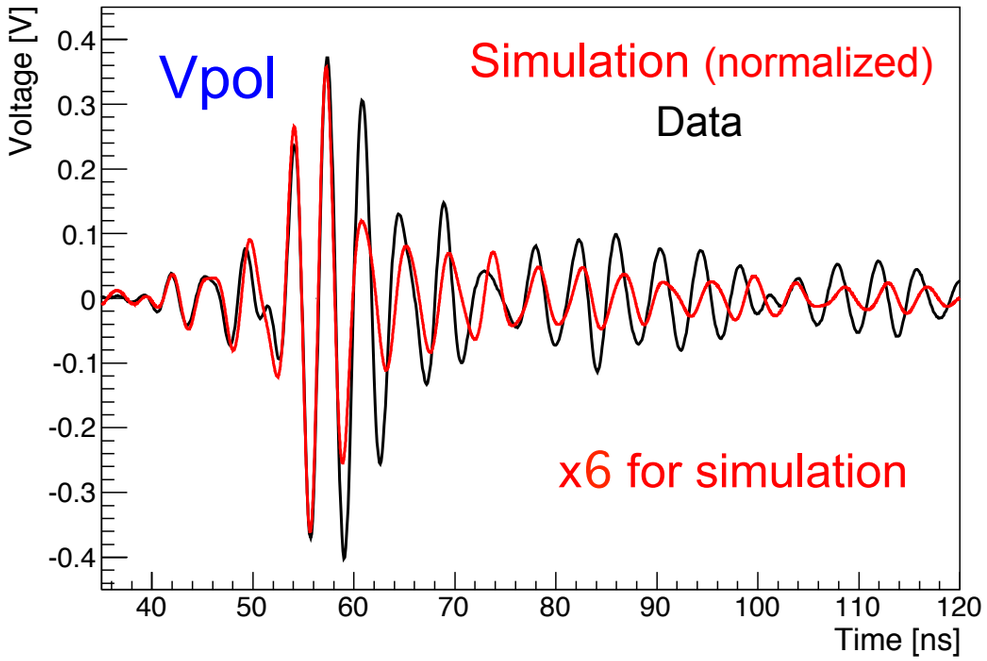


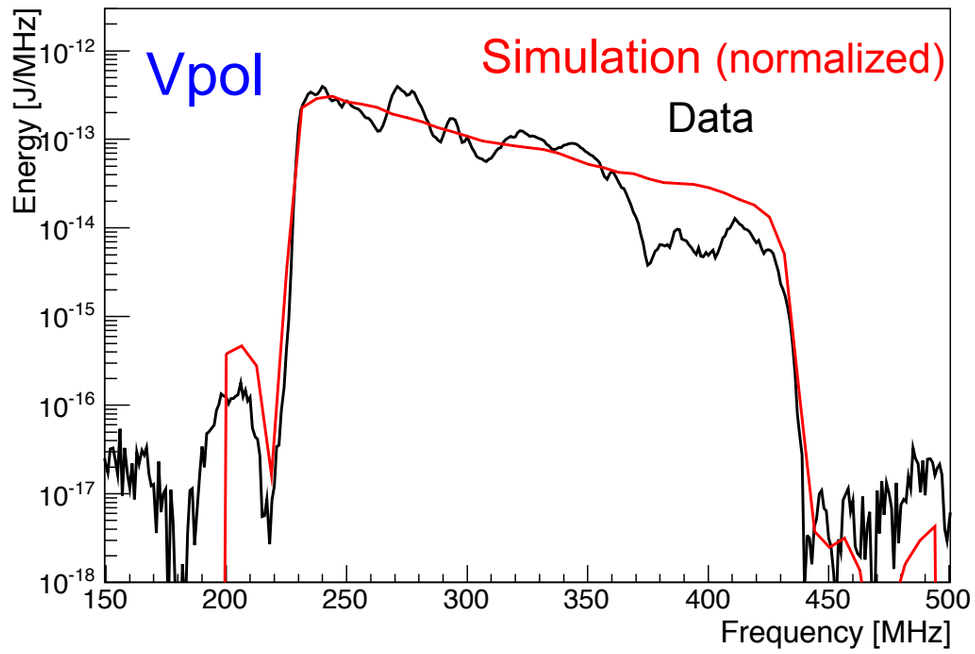
Results: ARA antenna








Vpol
Simulation (normalized)
Data
x6 for simulation
Voltage [V]
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
40
50
60
70
80
90
100
110
120
Time [ns]


Vpol
Simulation (normalized)
Data
Energy [J/MHz]
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
150
200
250
300
350
400
450
500
Frequency [MHz]