On the radar detection of neutrino induced particle cascades in ice

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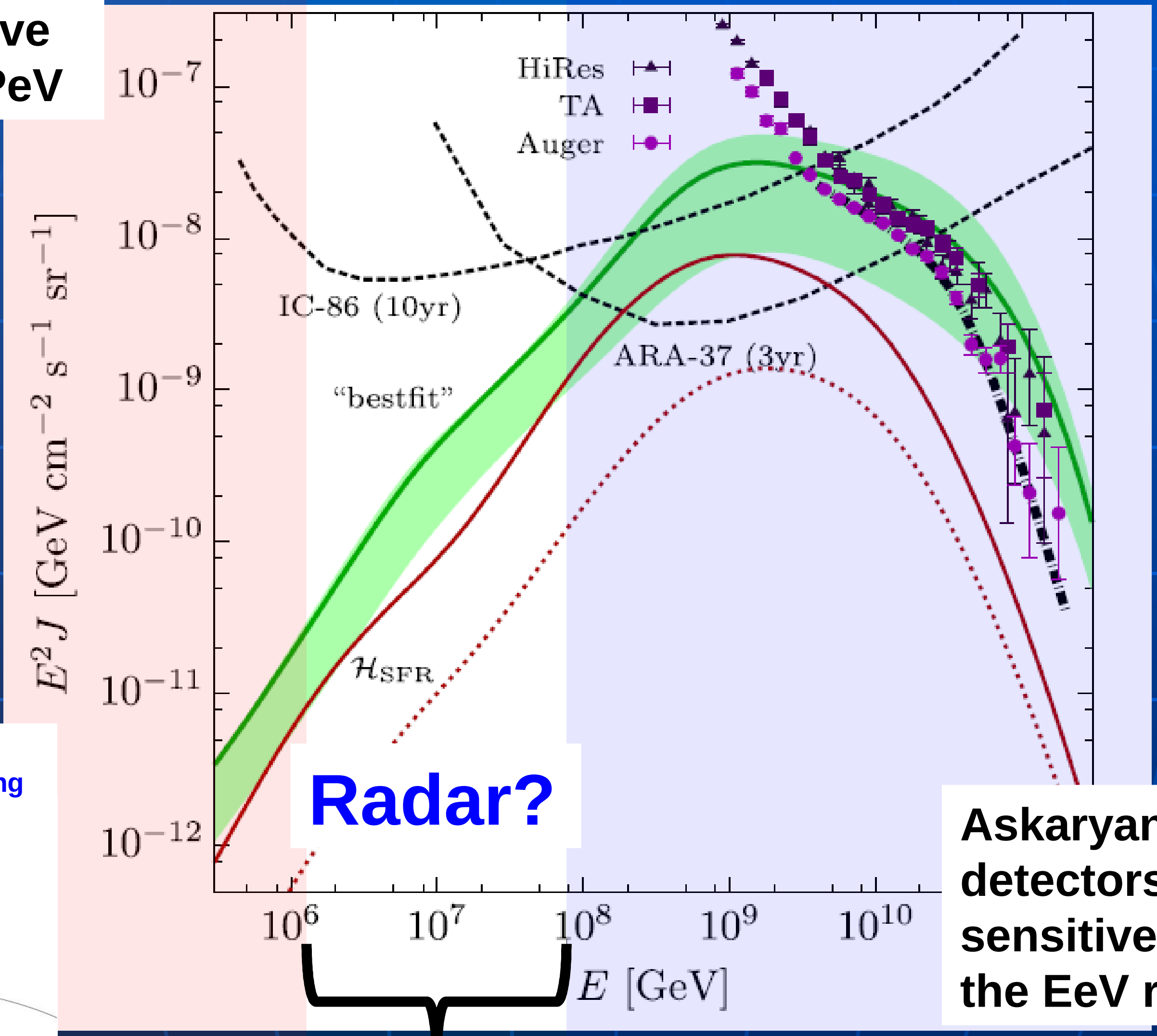
Motivation

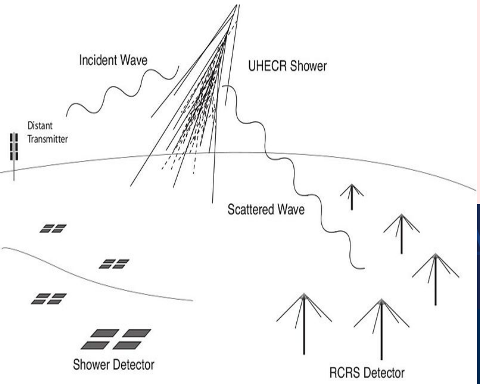
IceCube sensitive below several PeV



Askaryan Radio detectors become sensitive close to the EeV region

Sensitivity Gap in PeV – EeV region

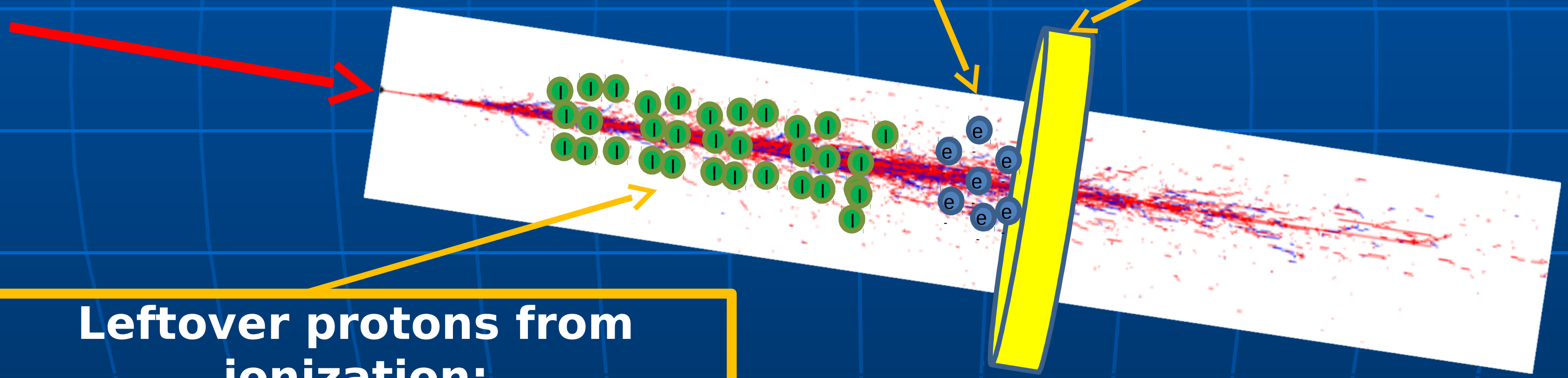
M. Abou Bakr Othman et al, Proceedings 32nd ICRC, Beijing 2011



Radar scattering of a neutrino induced plasma

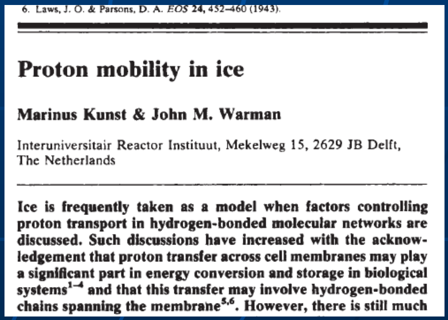
Leftover electrons from ionization:
Extension: O(30 cm)
Lifetime: O(1-20 ns)

Shower front electrons:
Extension: R_L = O(10 cm)
Lifetime: O(100ns)
Moving!



Leftover protons from ionization:
Wide extension: O(5m)
Lifetime: O(10-1000 ns)

Ionization numbers come from Physical Chemistry research!


6. Laws, J. O. & Parsons, D. A. *EOS* **24**, 452–460 (1943).

Proton mobility in ice

Marinus Kunst & John M. Warman

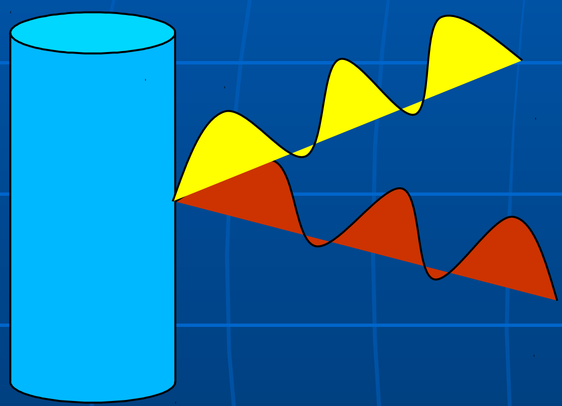
Interuniversitair Reactor Instituut, Mekelweg 15, 2629 JB Delft, The Netherlands

Ice is frequently taken as a model when factors controlling proton transport in hydrogen-bonded molecular networks are discussed. Such discussions have increased with the acknowledgement that proton transfer across cell membranes may play a significant part in energy conversion and storage in biological systems[1–4] and that this transfer may involve hydrogen-bonded chains spanning the membrane[5,6]. However, there is still much

Figure from arXiv:1210.5140v2

RADAR scattering

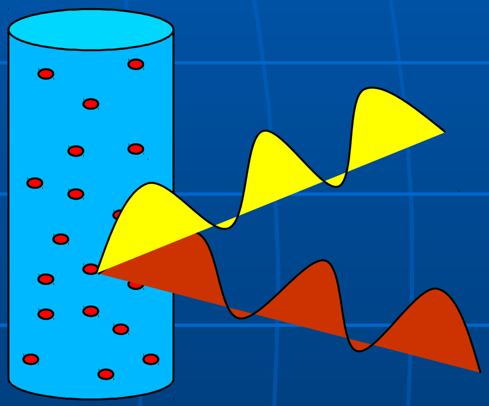
- Over-dense scattering:



Radar frequency < Plasma Frequency

Reflection from the surface of the plasma tube

- Under-dense scattering:



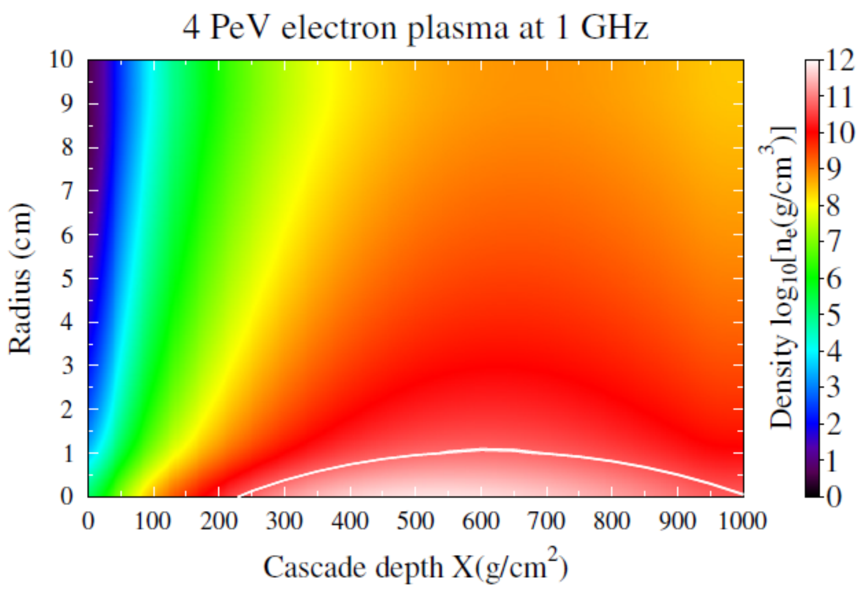
Radar frequency > Plasma Frequency

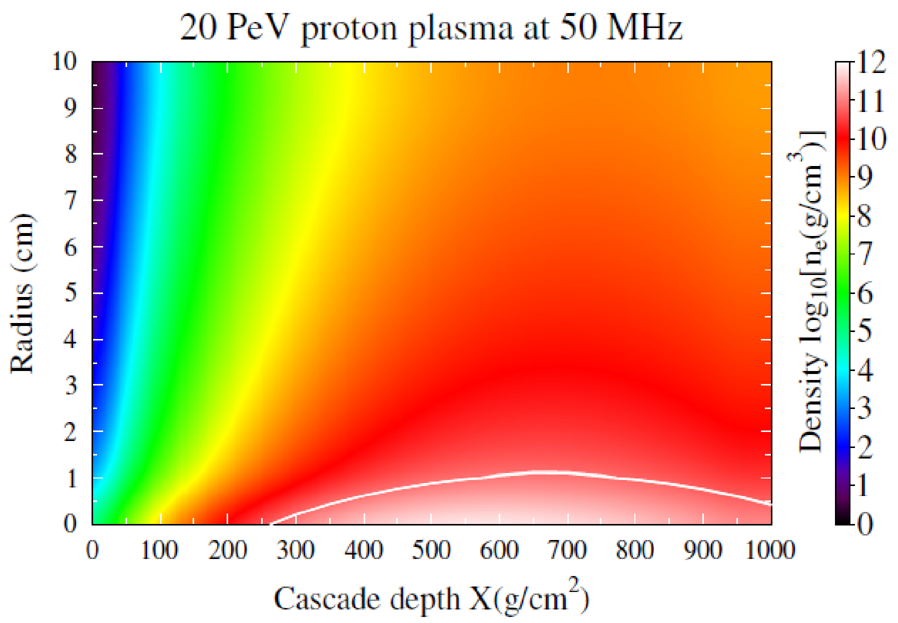
Scattering off of the individual charges in the plasma

Over-dense scattering

$$\upsilon_{Plasma} > \upsilon_{Radar} > \begin{cases} 1/\tau_{Plasma} & c_{med}\tau_e < l_c \\ c_{med}/l_c & c_{med}\tau_e > l_c \end{cases}$$

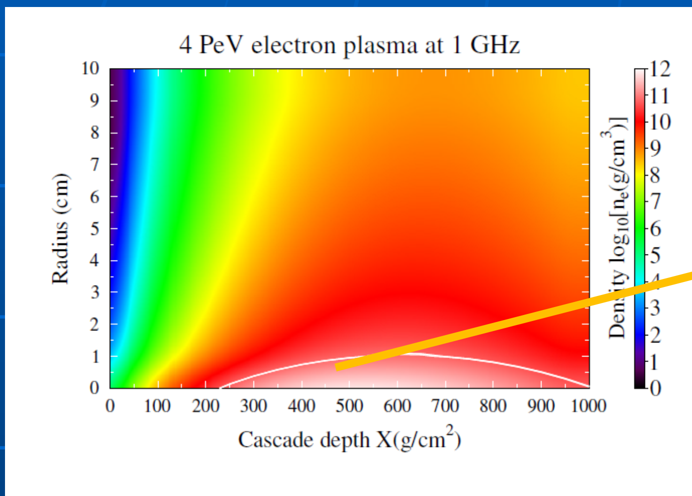
$$\upsilon_{Plasma} \propto \sqrt{n_{Plasma}} \propto \sqrt{E_{primary}}$$

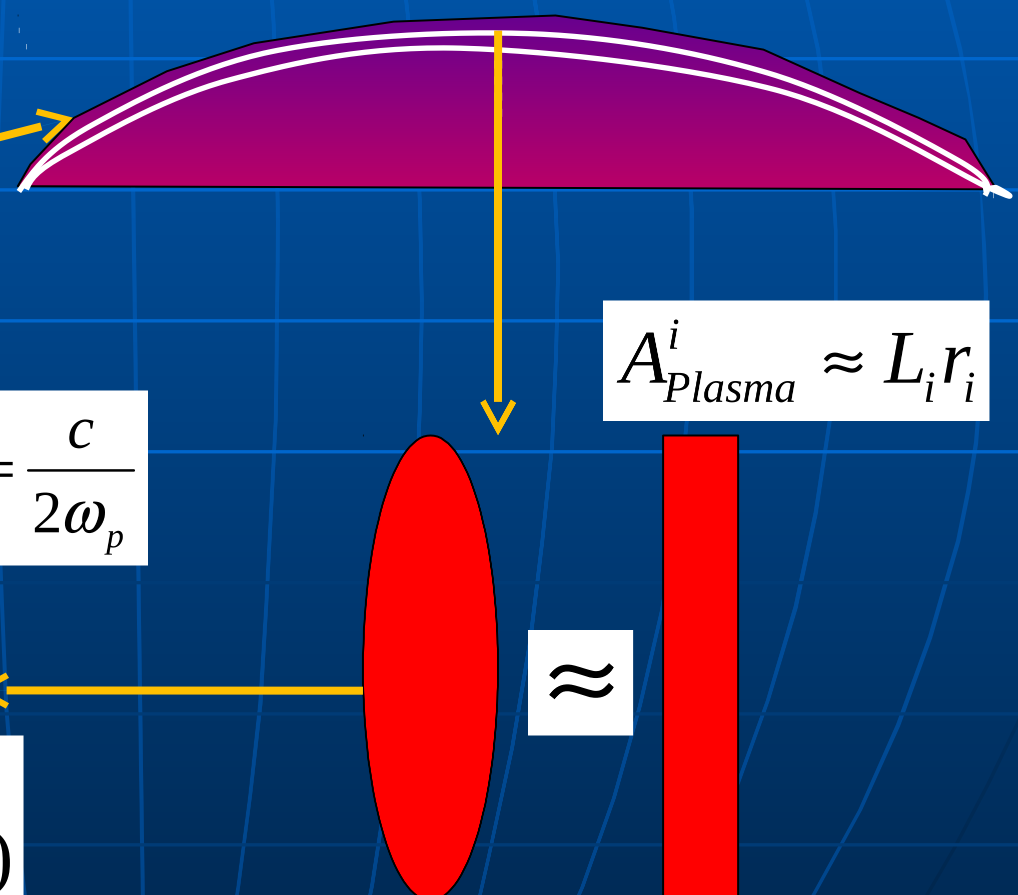




Skin Effects

Model: Consider over-dense cylinders of equal density





$$A^{i}_{Plasma} \approx L_i r_i$$

$$\approx$$

Calculate skin depth for a collision less plasma:

$$\delta = \frac{c}{2\omega_p}$$

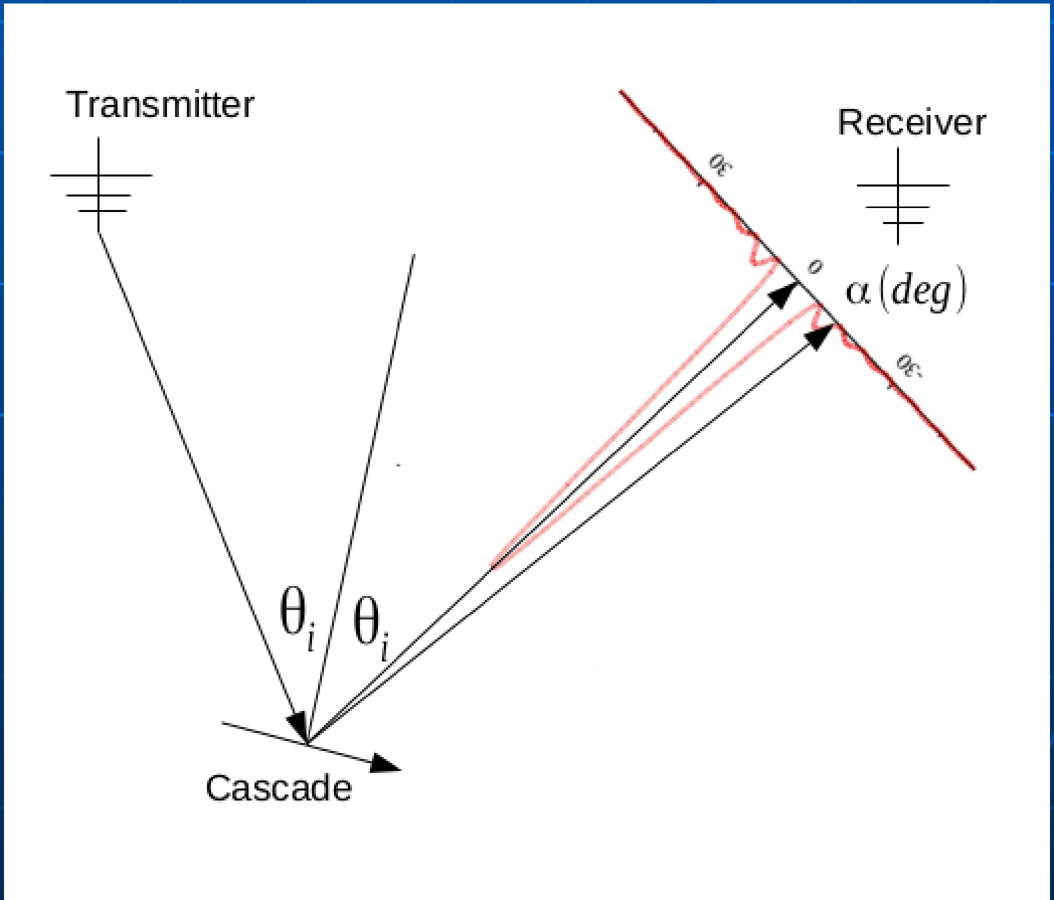
Within 1 skin depth the amount of power absorbed and re-scattered equals:

$$f^{i+1}_{skin} = (1 - f^{i}_{skin})(1 - e^{-\frac{x}{\delta_i}})$$

The over-dense radar cross-section

This approach:

1. Include skin-effects directly into the radar cross-section.
2. Consider projected area and polarization angles for in/out-going wave

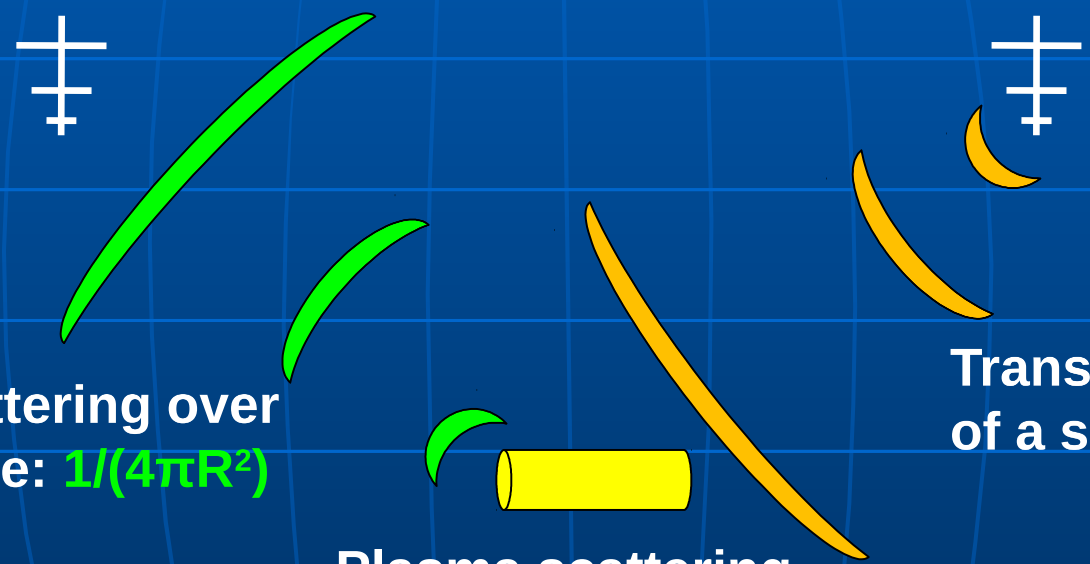


RADAR return power estimation

Bi-static RADAR configuration

Effective area of receiver: A_{eff}

Transmitted power: P_t



Re-scattering over a sphere: $1/(4\pi R^2)$

Transmission over ¼ of a sphere: $1/(\pi R^2)$

Plasma scattering surface: σ_{eff}

Attenuation by the medium

$$P_r = P_t \eta \frac{\sigma_{eff}}{\pi R^2} \frac{A_{eff}}{4\pi R^2} e^{-4R/L_\alpha}$$

Effective Area

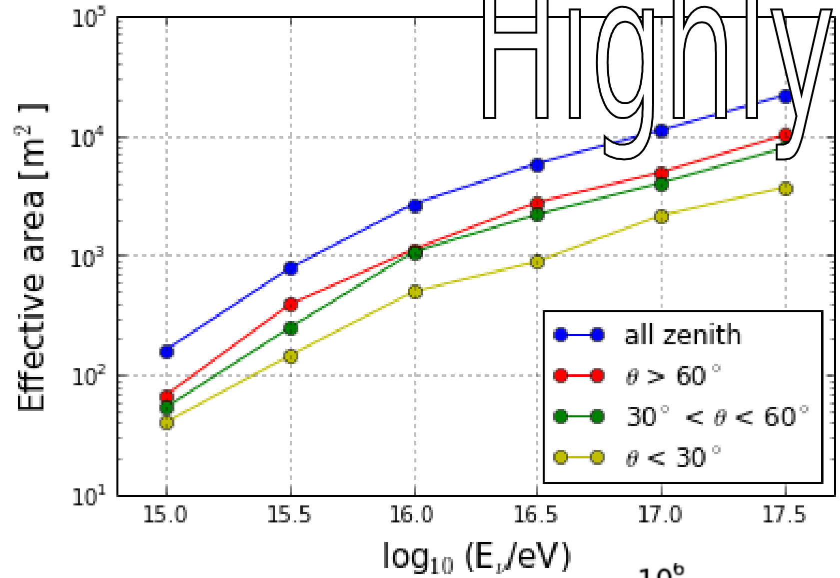
Proton plasma
Tx = 50 MHz, 1 KW

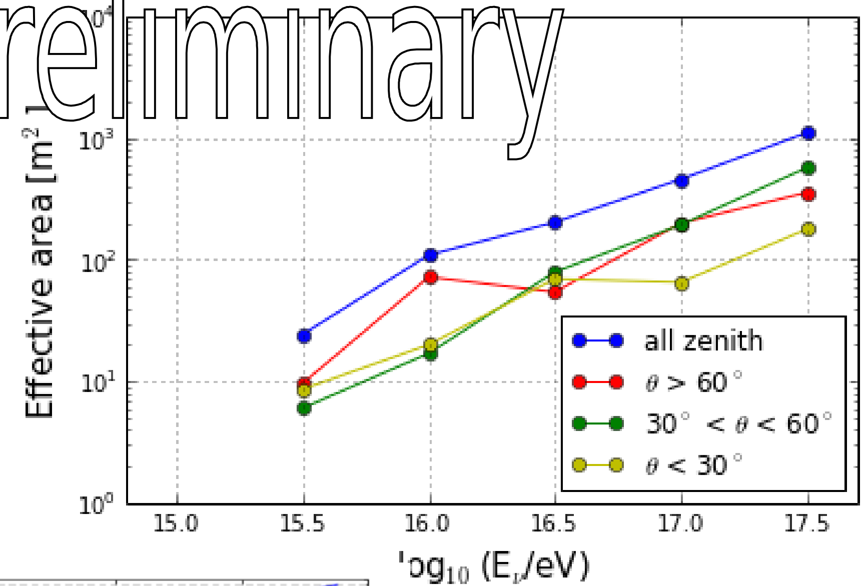
τ = 1000 ns
Trigger: $N_{ant} > 1$

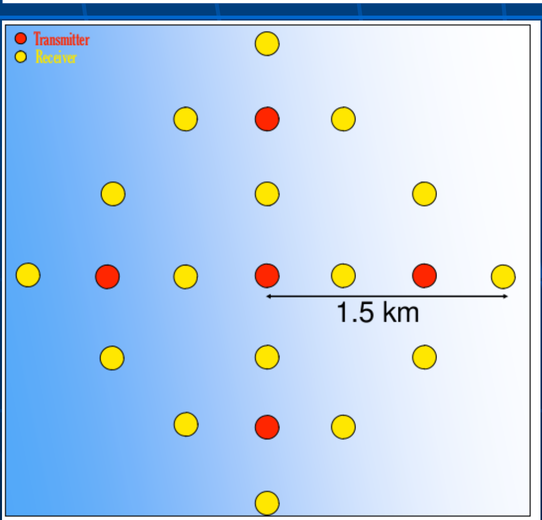
Electron plasma
Tx = 1 GHz 1 KW

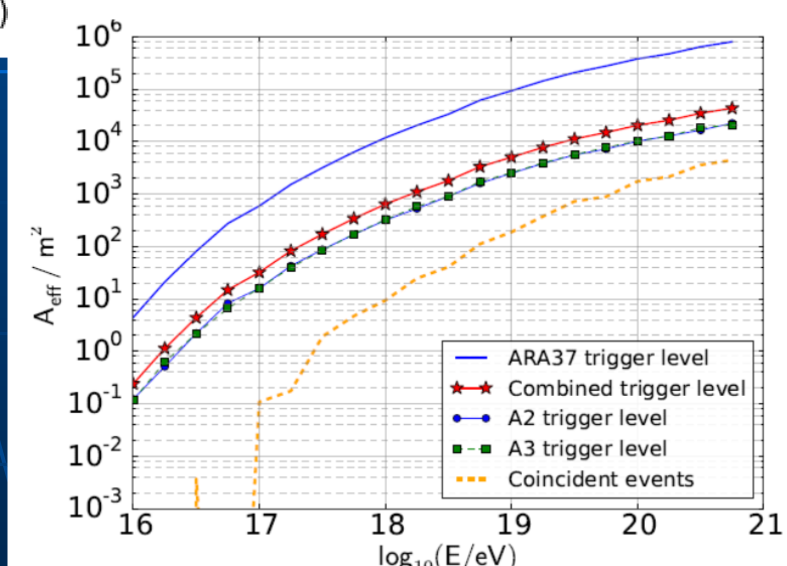
τ = 20 ns
Trigger: $N_{ant} > 1$

Highly preliminary









Signal Trigger at 10σ above thermal noise measured at ARA site.

Open questions: The Plasma

- How large is the over-dense plasma?

- What is the influence of skin-effects?

- What is the lifetime of the plasma?

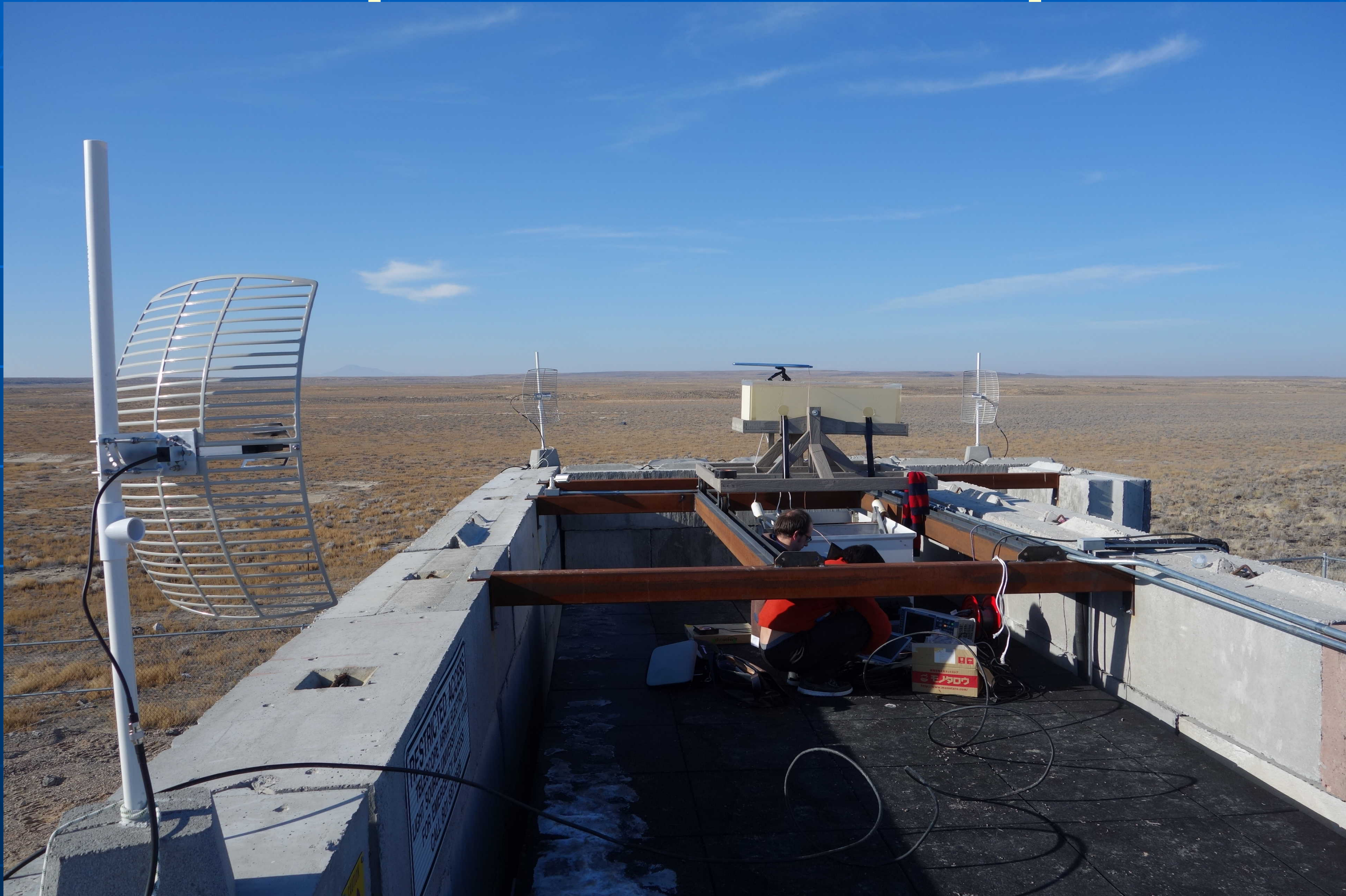
- Is the plasma collision frequency low enough?

→ **Experimental verification needed!**

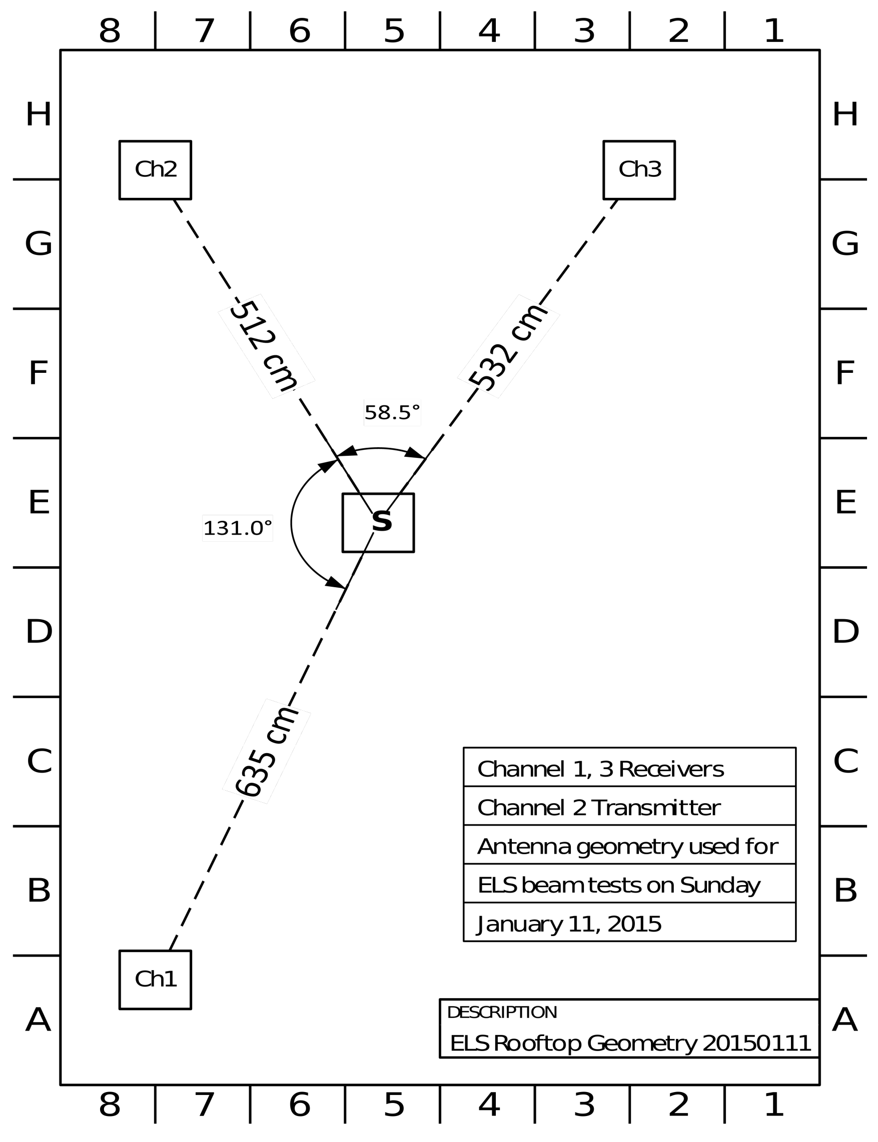
Radar scattering experiment at TA-ELS

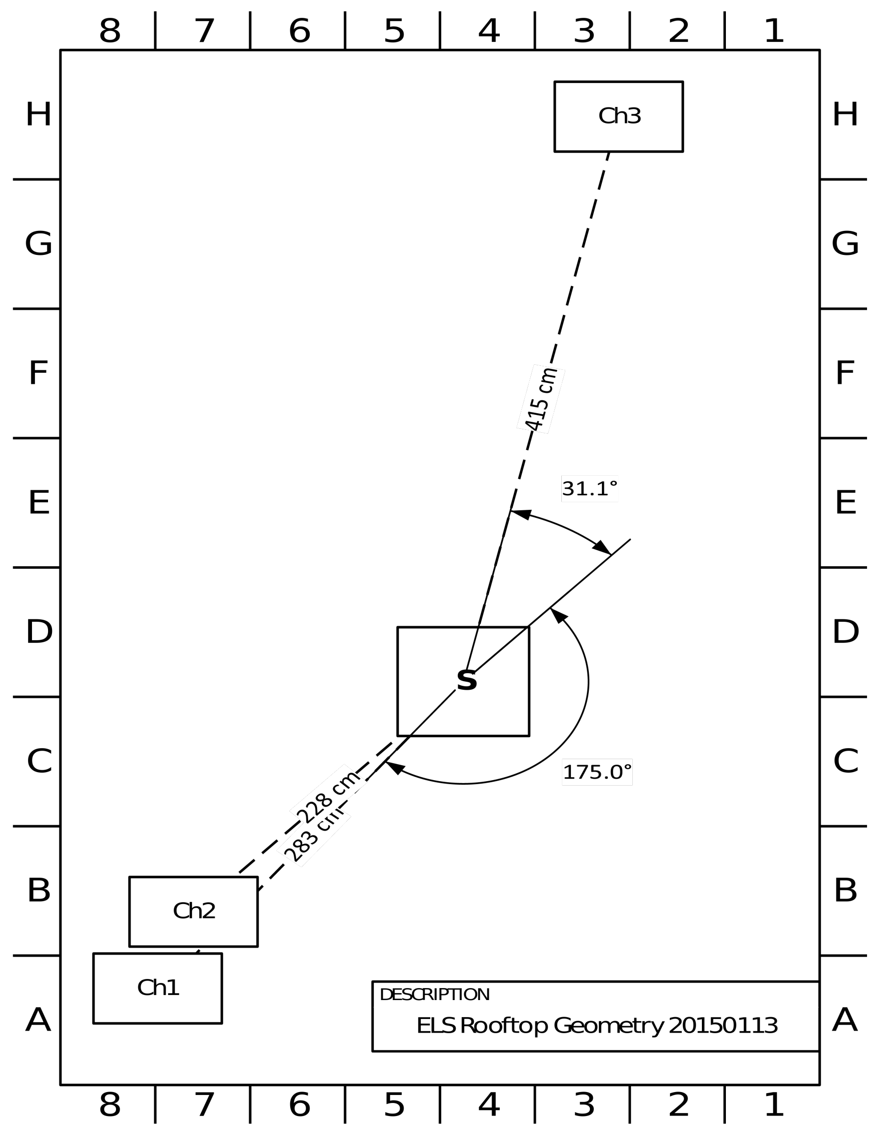
Many thanks to the Chiba group and the Telescope Array Collaboration !

Experimental setup



Experimental setup

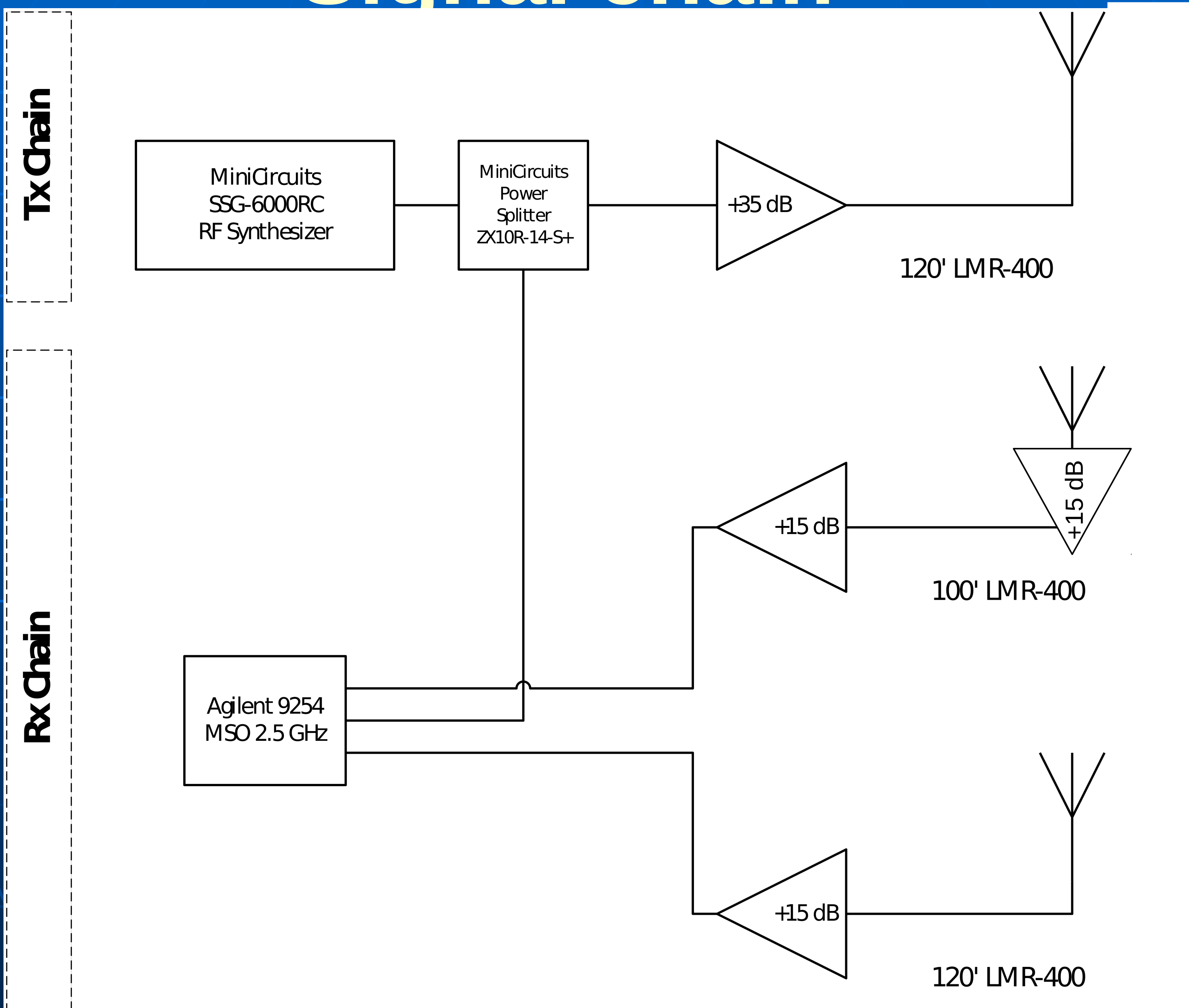




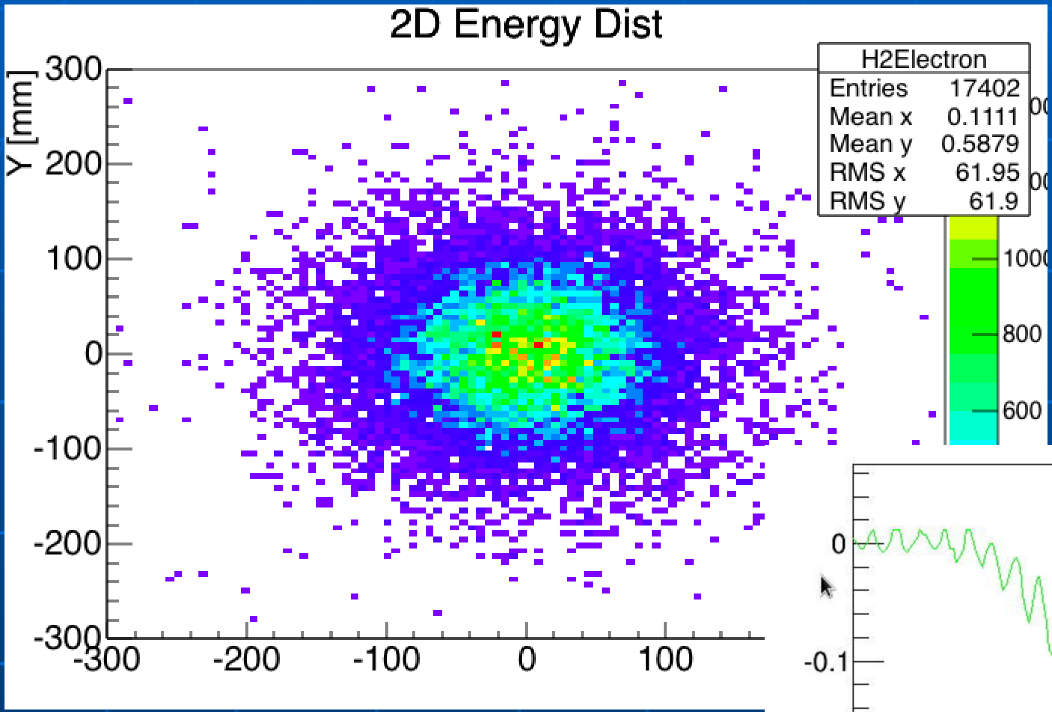
Early Configuration

Later Configuration

Signal chain

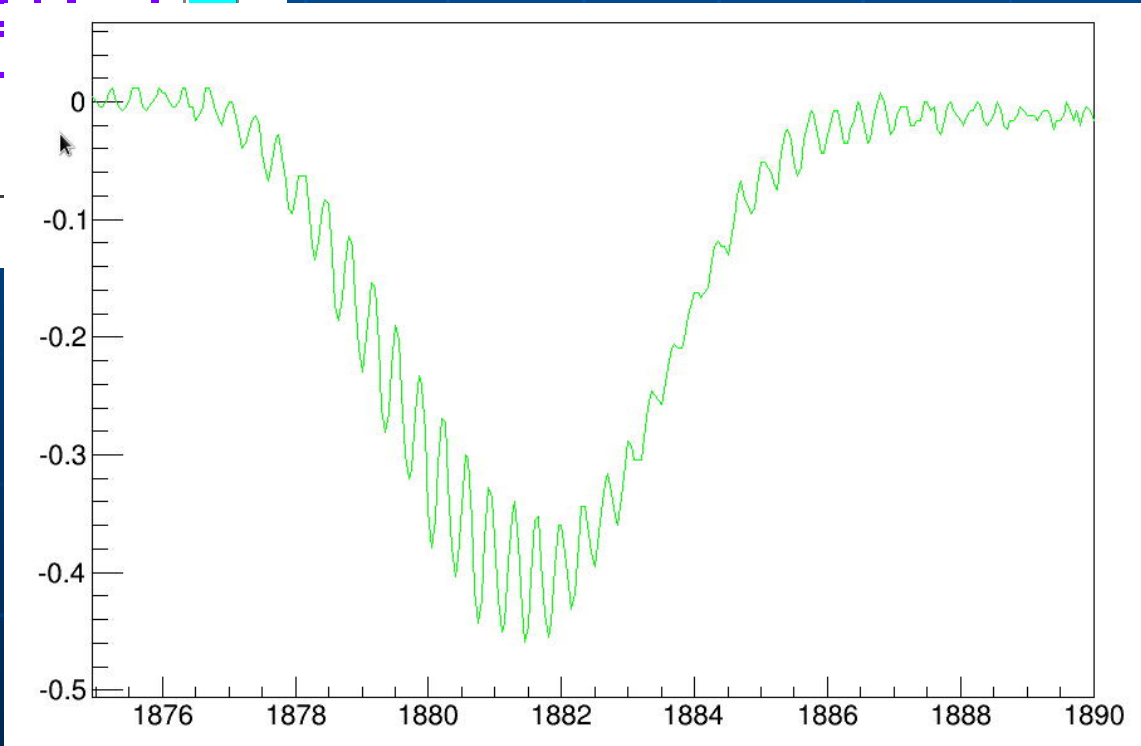


Radar scattering
Beam characteristics

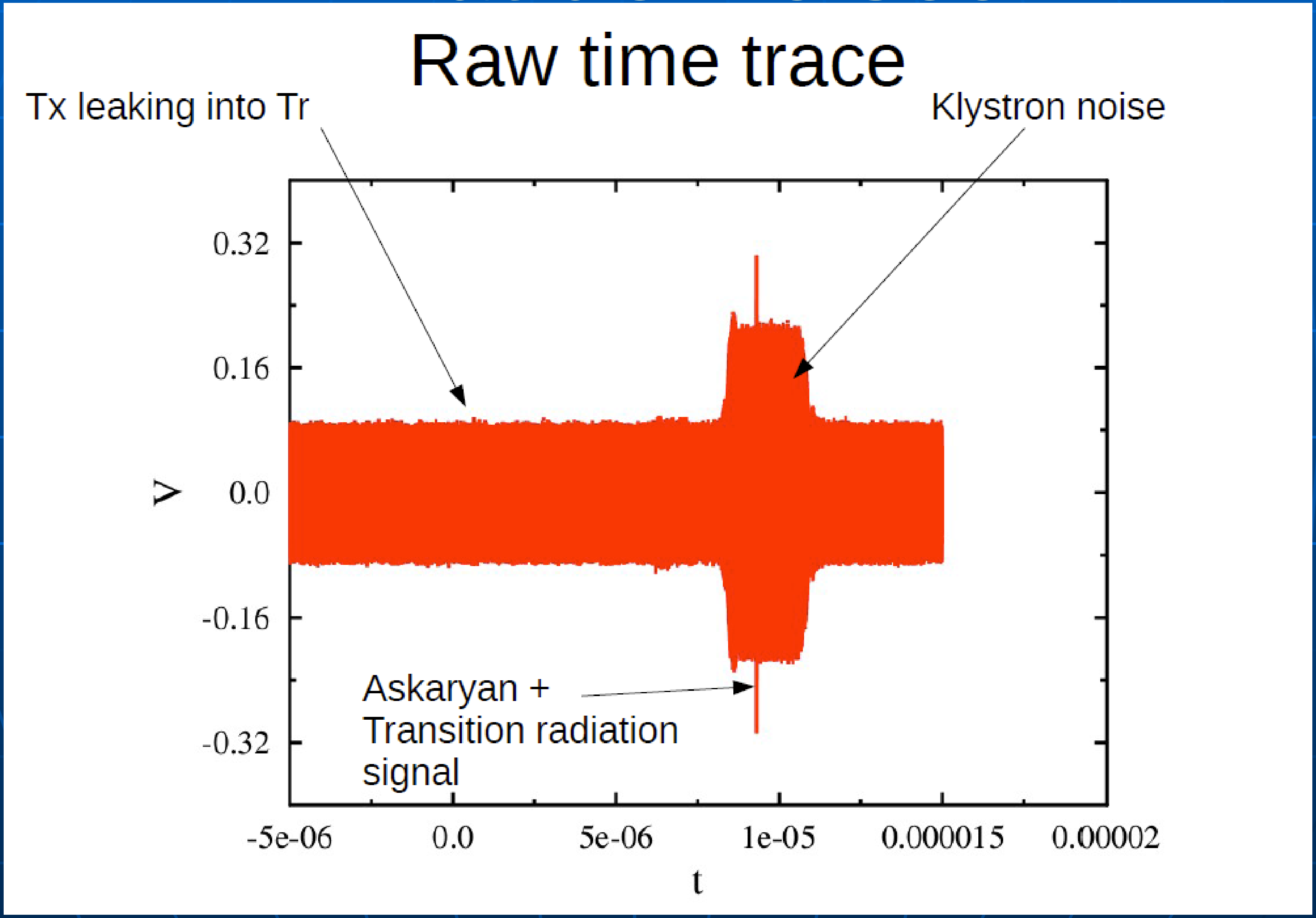


~10^9 (40 MeV) electrons

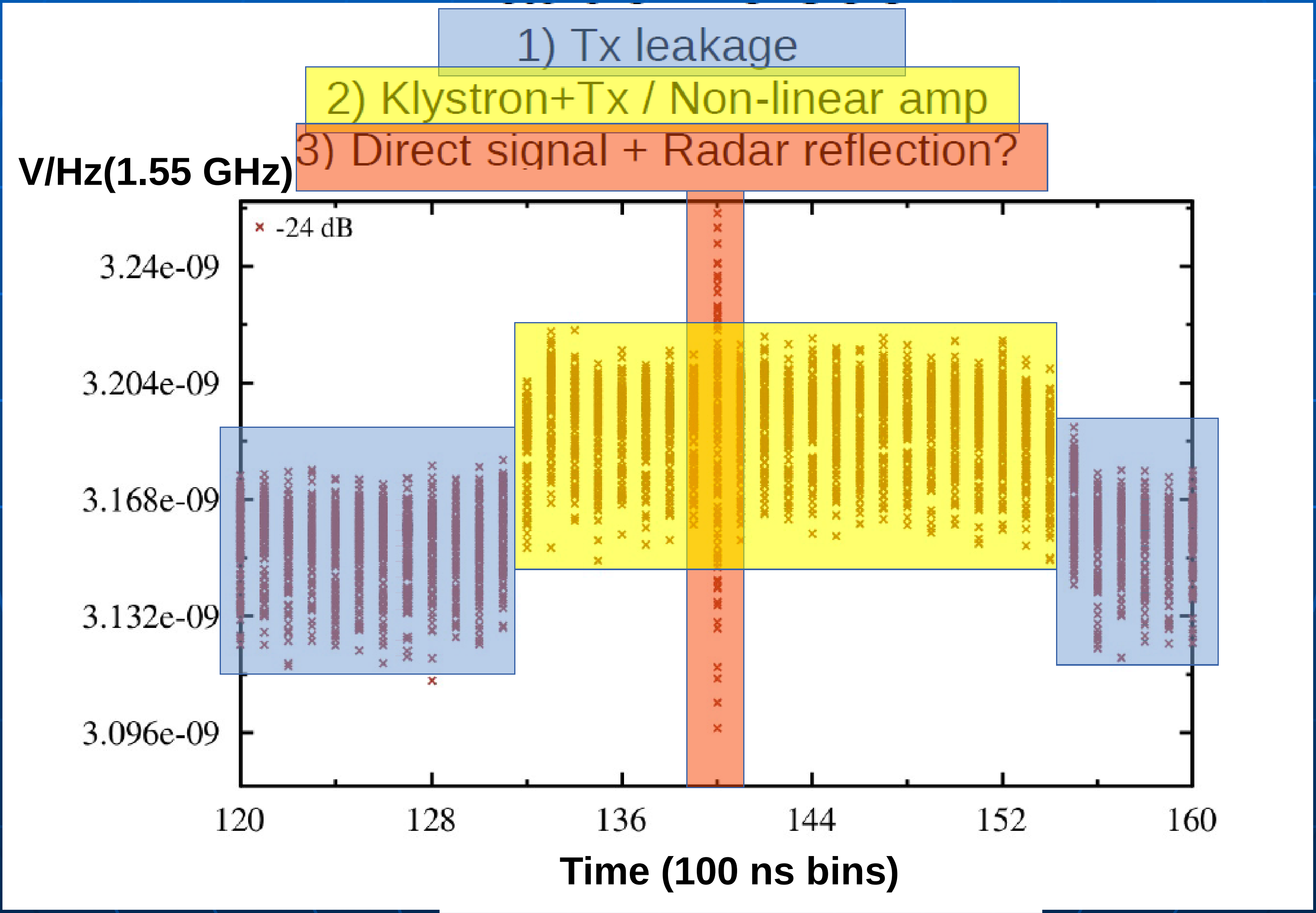
~ 40 PeV



Radar scattering
What do we see?



Radar scattering
What do we see?



Radar scattering
Interference and instrumental effects

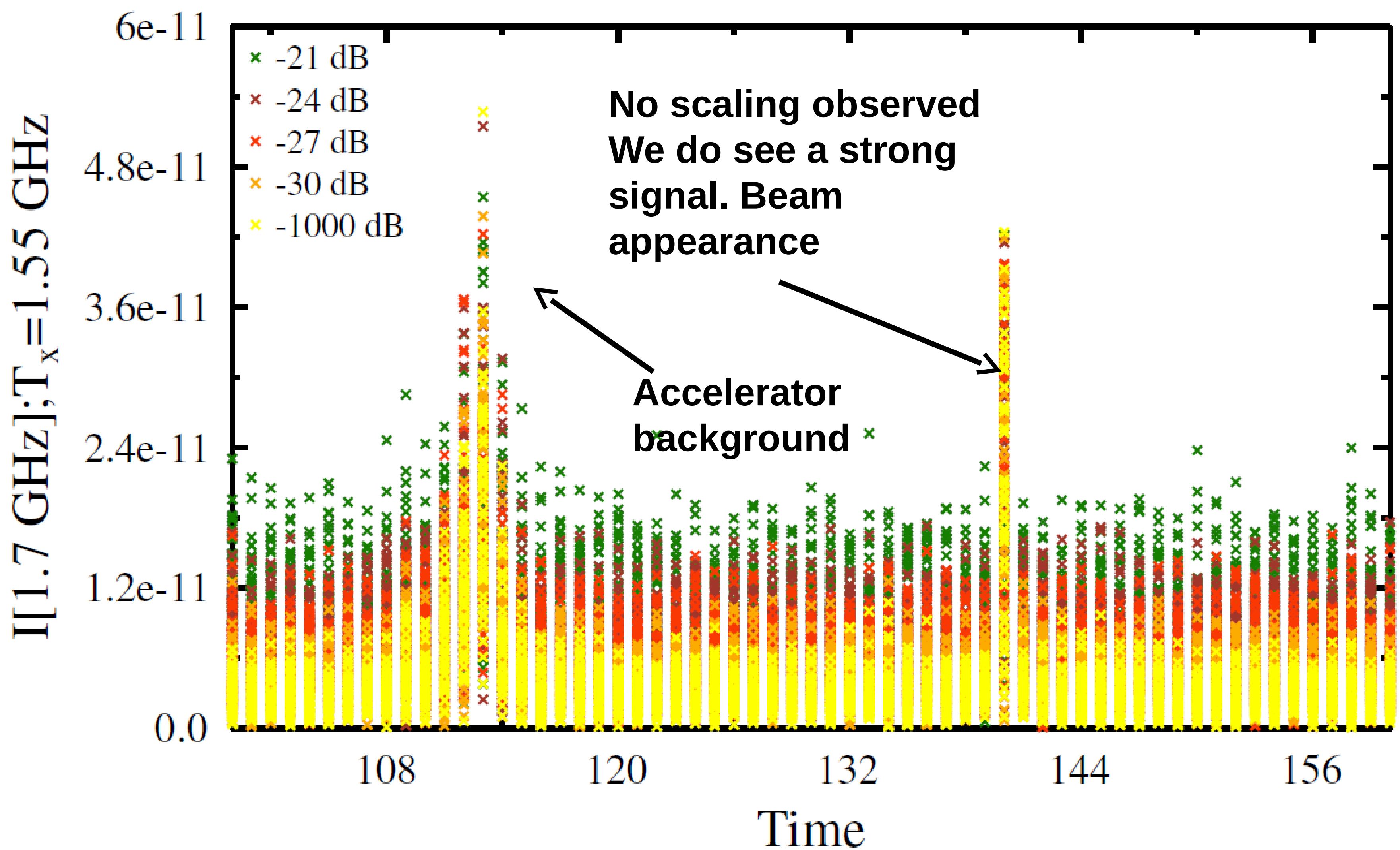
- Accelerator noise interferes with our transmit signal

- Non-linear amplifier response

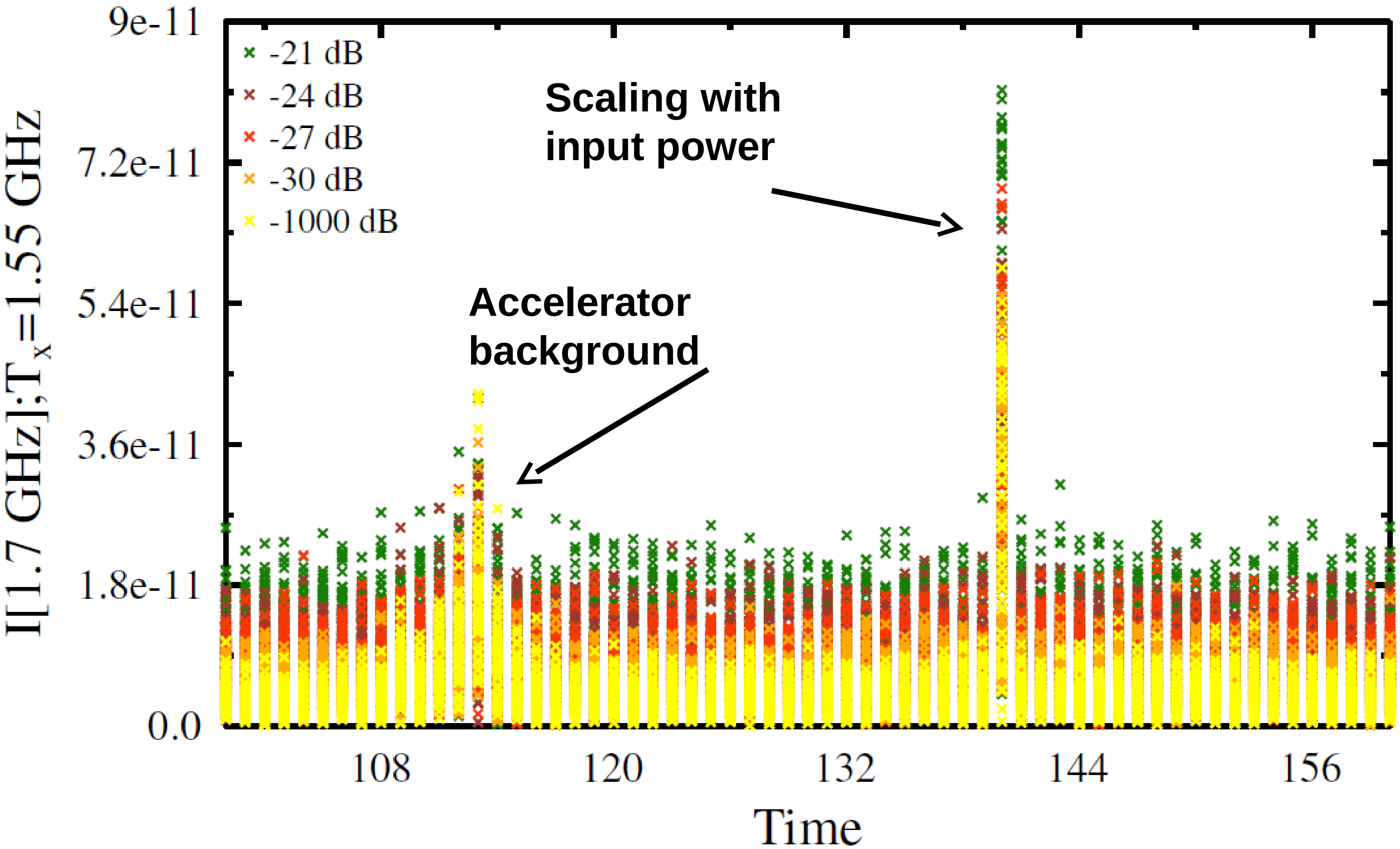
- Signal can be mimicked by these effects!

- What if we look at a different frequency than our transmit frequency?

Radar scattering Air



Radar scattering Ice



Conclusions

- Modeling the RADAR scattering of high-energy neutrino induced cascades gives an energy threshold of several PeV.

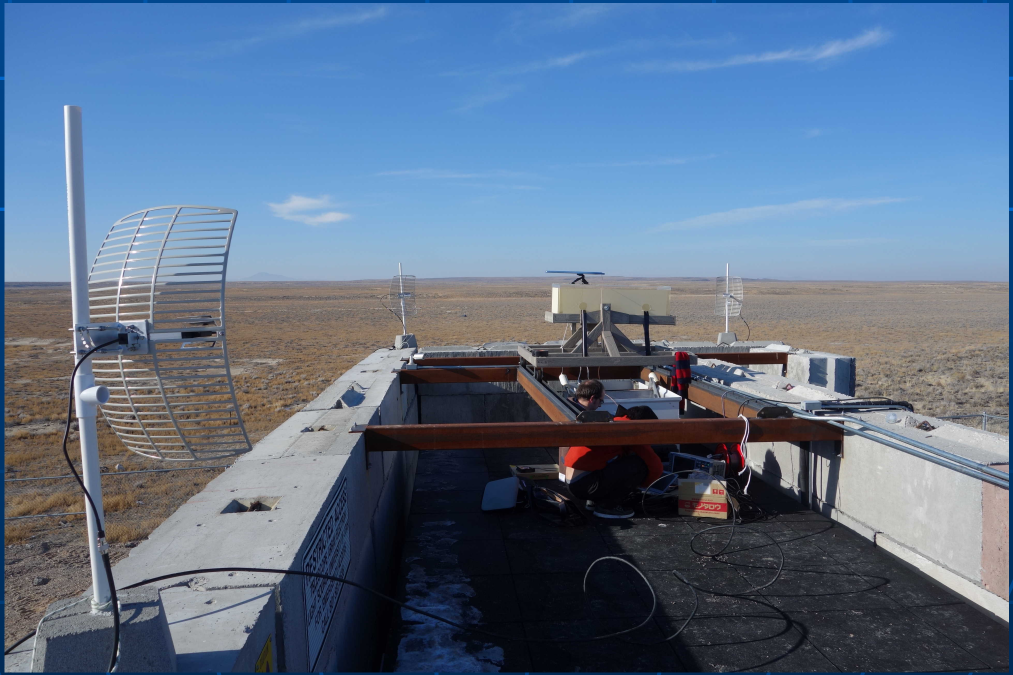
- Preliminary effective area looks very Promising.

- We performed a measurement to determine the feasibility of this method. Obtained data hints toward a scattered signal, analysis is ongoing.

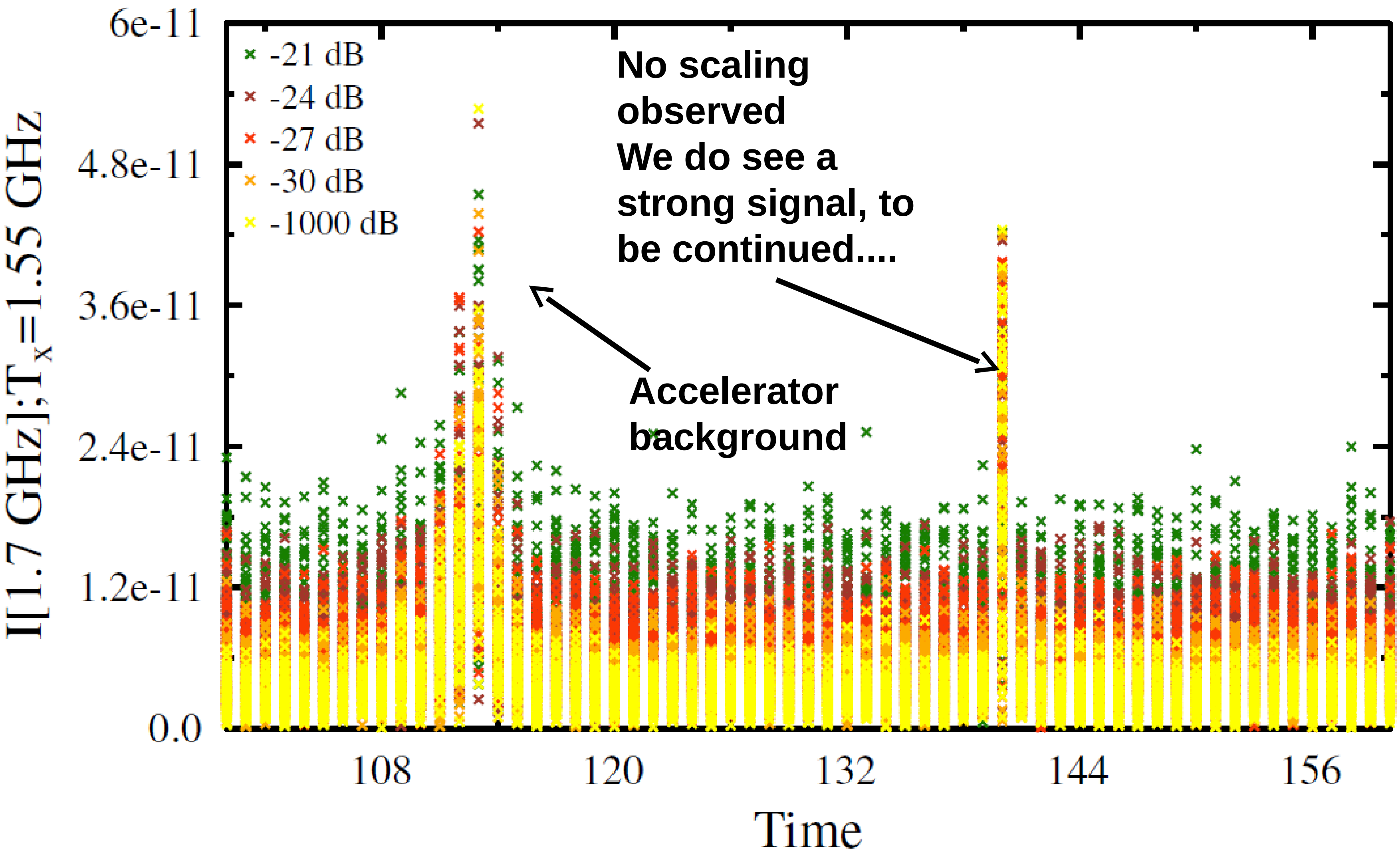
Outlook

- New experiment(s) planned in the near future. ELS background well understood. Search for scattered signal continues.

- More detailed modeling of the Radar scattered signal is under development.

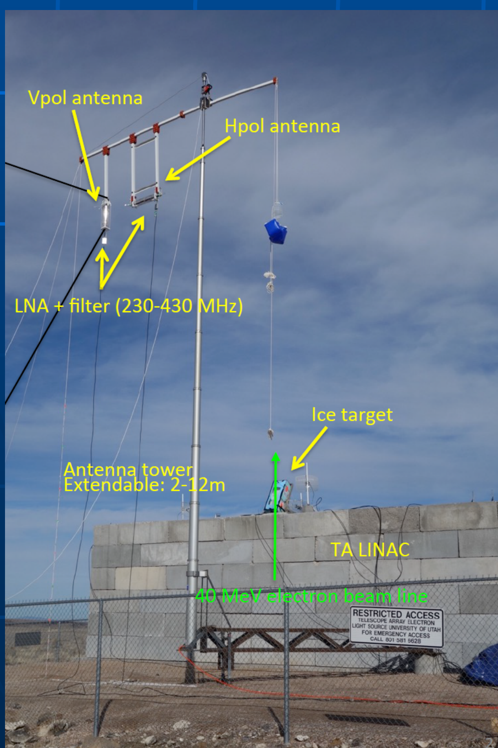


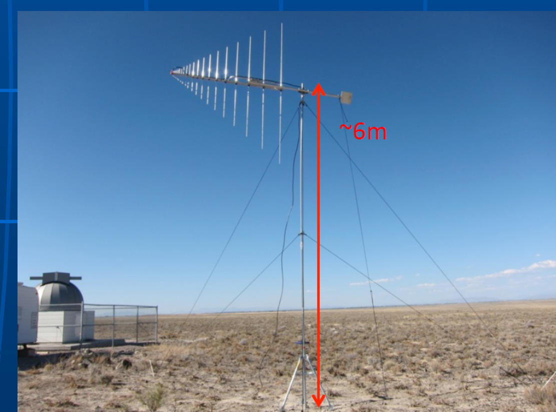
To be continued....



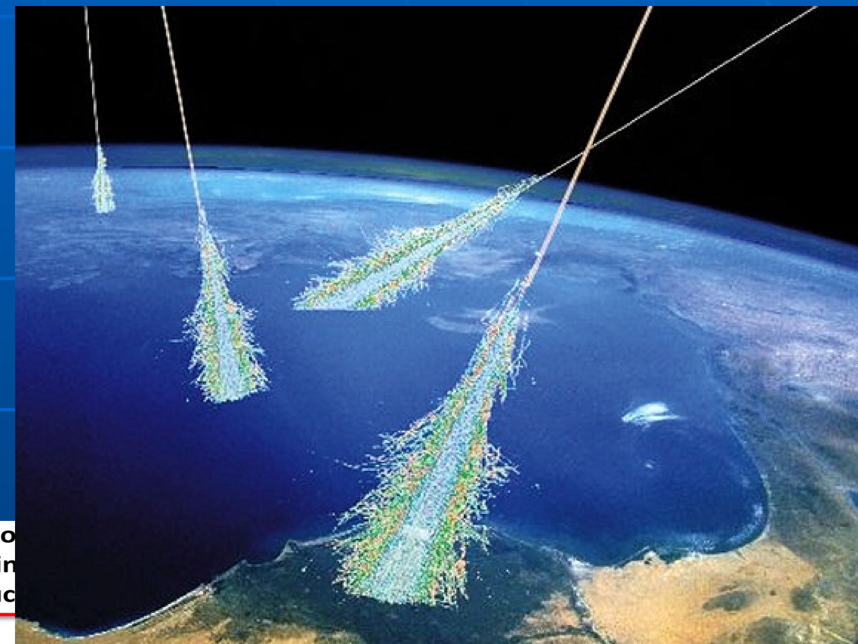
Beam "sudden appearance" signal
Major background signal in radio beam test experiments

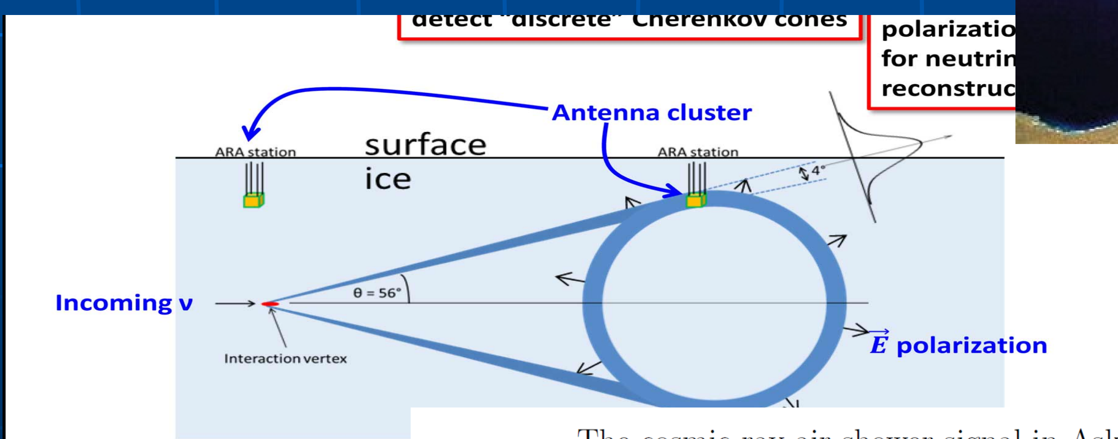
Tokonatsu Yamamoto, Izumi S. Ohota (Konan U)
Krijn de Vries (Vrije Universiteit Brussel)
Kael Hanson, Thomas Meures (UW-Madison), Aongus O' Murchadha (ULB)
Daisuke Ikeda, Masaki Fukushima, Hiroyuki Sagawa, (ICRR)
Romain Gaior, Keiichi Mase, Shigeru Yoshida, Aya Ishihara, Matthew Relich, Takao Kuwabara, Shunsuke Ueyama (U of Chiba)
Gordon Thomson, John N. Matthews (U of Utah)
Shouich Ogio (OCU), Shin Bakkyun (Hanyang U), Tatsunobu Shibata (KEK)





Modeling the sudden appearance signal
Application in nature





The cosmic-ray air-shower signal in Askaryan radio detectors

Krijn D. de Vries[a], Stijn Buitink[a], Nick van Eijndhoven[a], Thomas Meures[b], Aongus Ó Murchadha[b], Olaf Scholten[a,c]

[a] *Vrije Universiteit Brussel, Dienst ELEM, B-1050 Brussels, Belgium*
[b] *Université Libre de Bruxelles, Department of Physics, B-1050 Brussels, Belgium*
[c] *University Groningen, KVI Center for Advanced Radiation Technology,Groningen, The Netherlands*

Accepted for publication in Astroparticle Physics

The cosmic ray air shower signal in Askaryan radio detectors

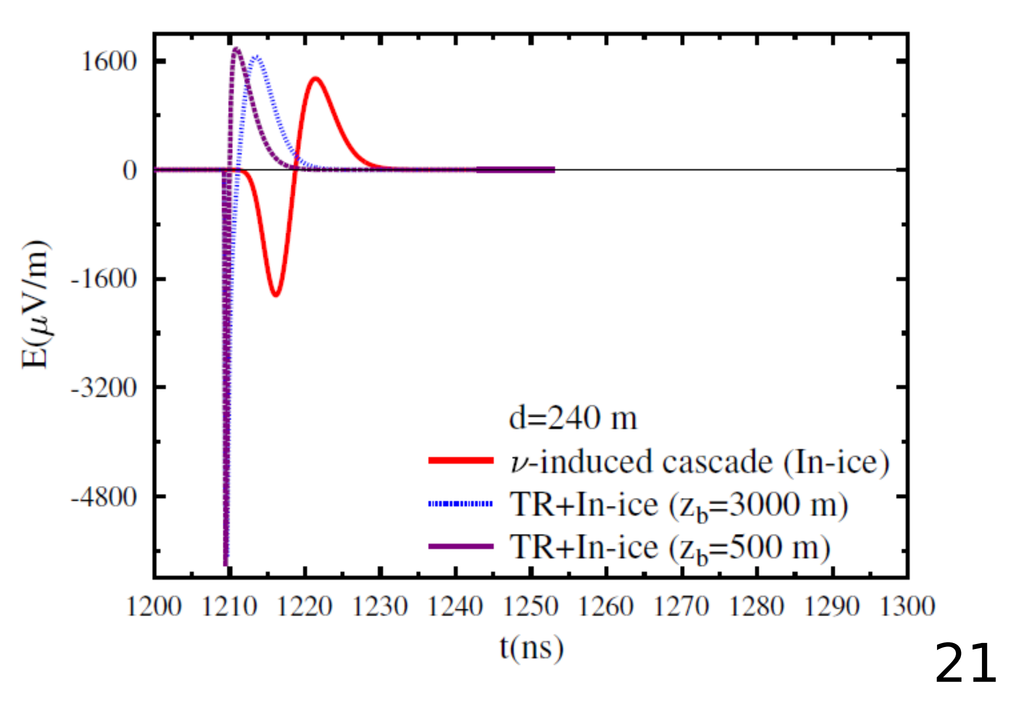
$$E^i_{tr}(t,\vec{x}) = \frac{\partial t_r}{\partial x^i}\frac{\partial}{\partial t_r}A^0$$

$$= \frac{e\delta(c(t_r - t_b))}{4\pi\epsilon_0 c}\lim_{\epsilon\to 0}\left(\frac{x^i}{|\mathcal{D}|^2_{t_r+\epsilon}} - \frac{x^i}{|\mathcal{D}|^2_{t_r-\epsilon}}\right)$$

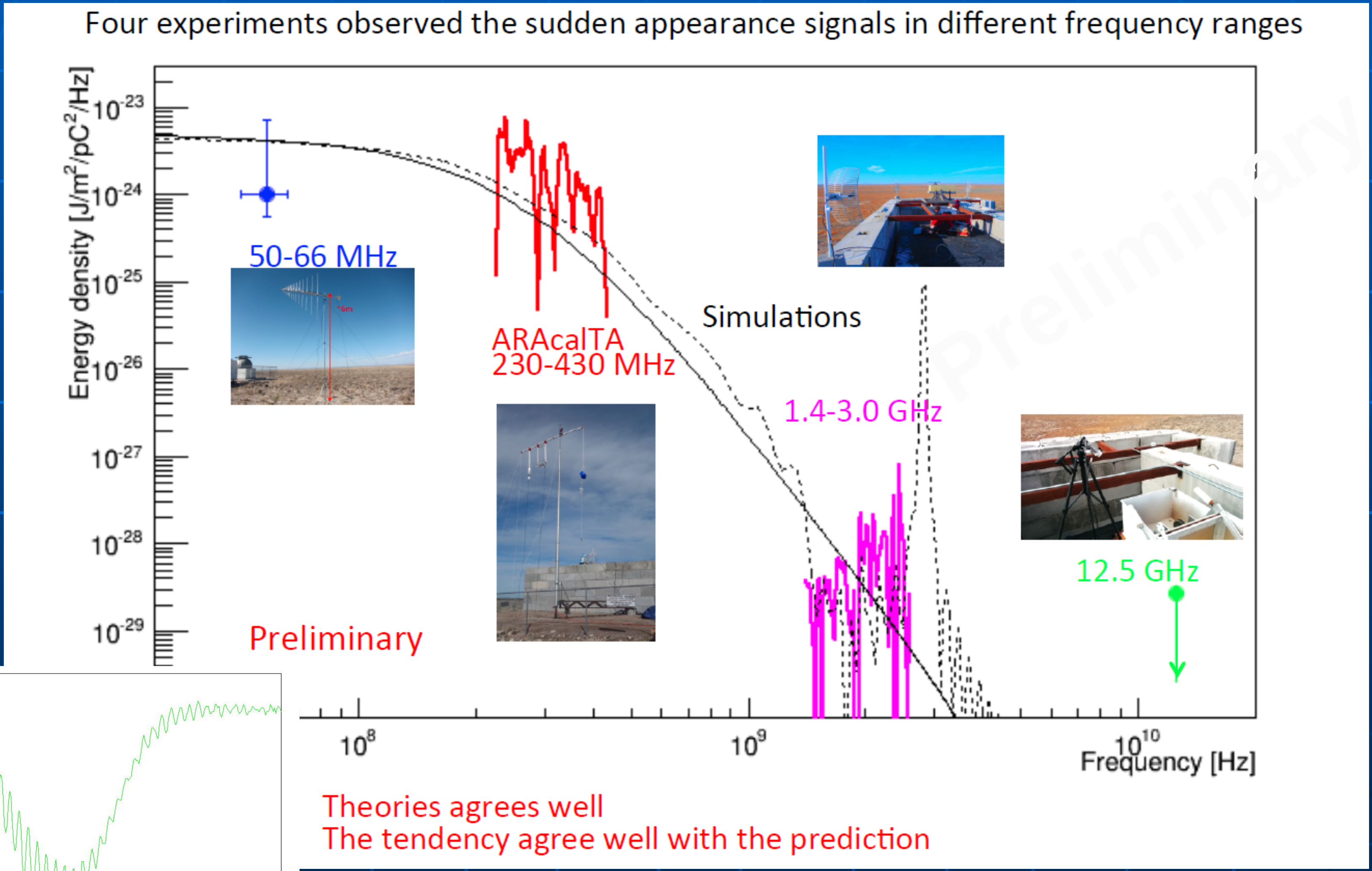
Sudden appearance signal very similar to transition radiation!!

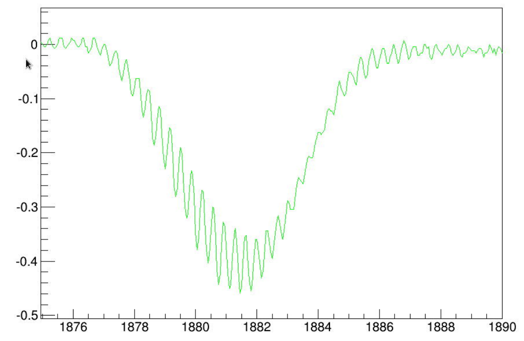
Cosmic-ray air shower signal very similar to neutrino induced signal.

1) **Possible background for Askaryan radio detectors**
2) **In combination with surface detectors, the signal becomes a very interesting calibration signal.**
3) **Observed signal would show on-site feasibility of the detection method!!**



Sudden appearance energy density spectrum





Conclusions (2)

- Different experiments have measured a strong “Sudden appearance” signal.

- Simulations show that this signal is strongly linked to transition radiation.

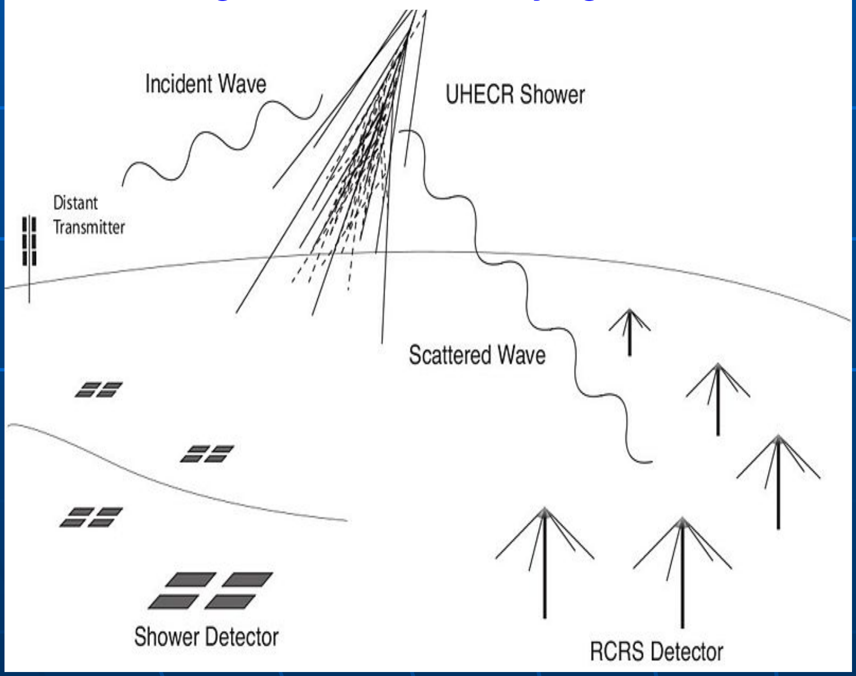
- Process similar to Cosmic Ray air shower signal in Askaryan radio detectors.

- Signal has been modeled, first data analysis performed. Data and simulations qualitatively agree.

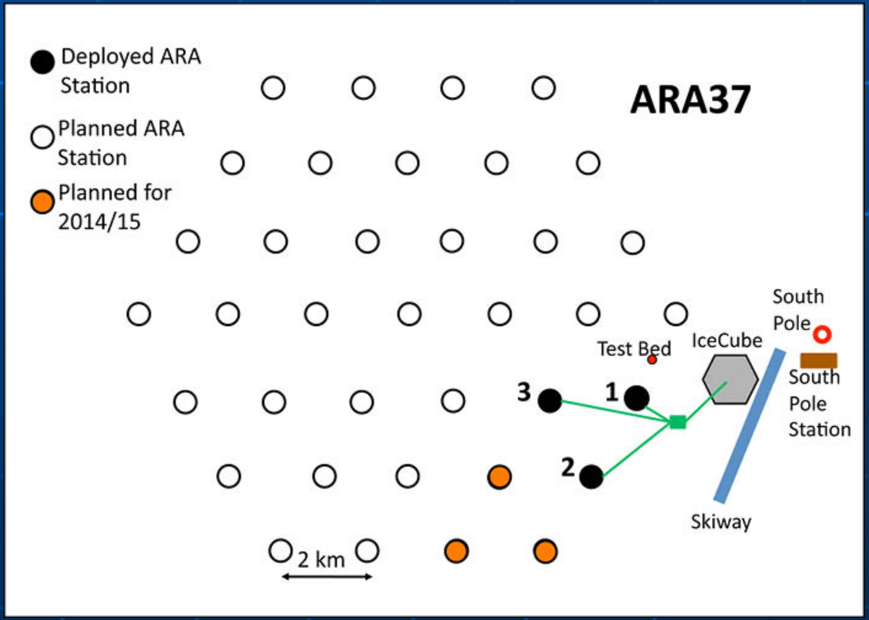
New detection method

If a RADAR signal can be bounced off of a neutrino induced cascade in ice, we have control over the signal strength!

M. Abou Bakr Othman et al,
Proceedings 32nd ICRC, Beijing 2011



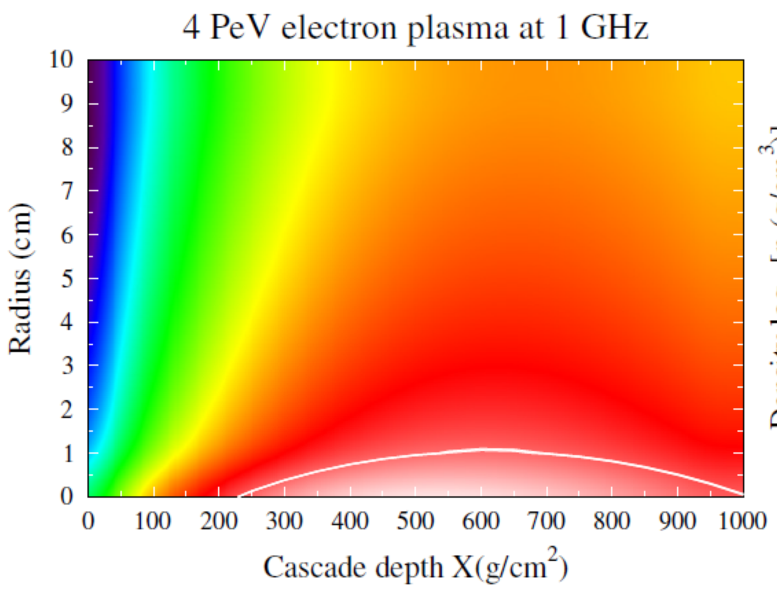
Infrastructure already available!

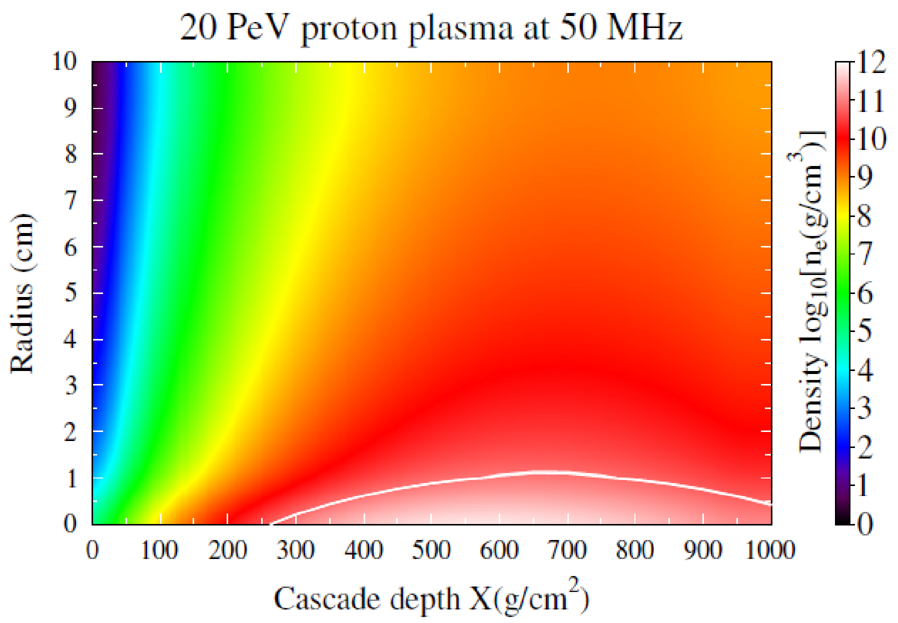


Over-dense scattering

$$\upsilon_{Plasma} > \upsilon_{Radar} > \begin{cases} 1/\tau_{Plasma} & c_{med}\tau_e < l_c \\ c_{med}/l_c & c_{med}\tau_e > l_c \end{cases}$$

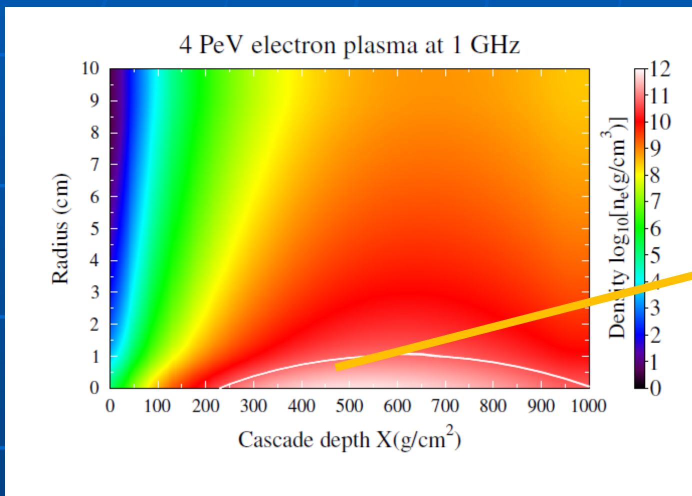
$$\upsilon_{Plasma} \propto \sqrt{n_{Plasma}} \propto \sqrt{E_{primary}}$$

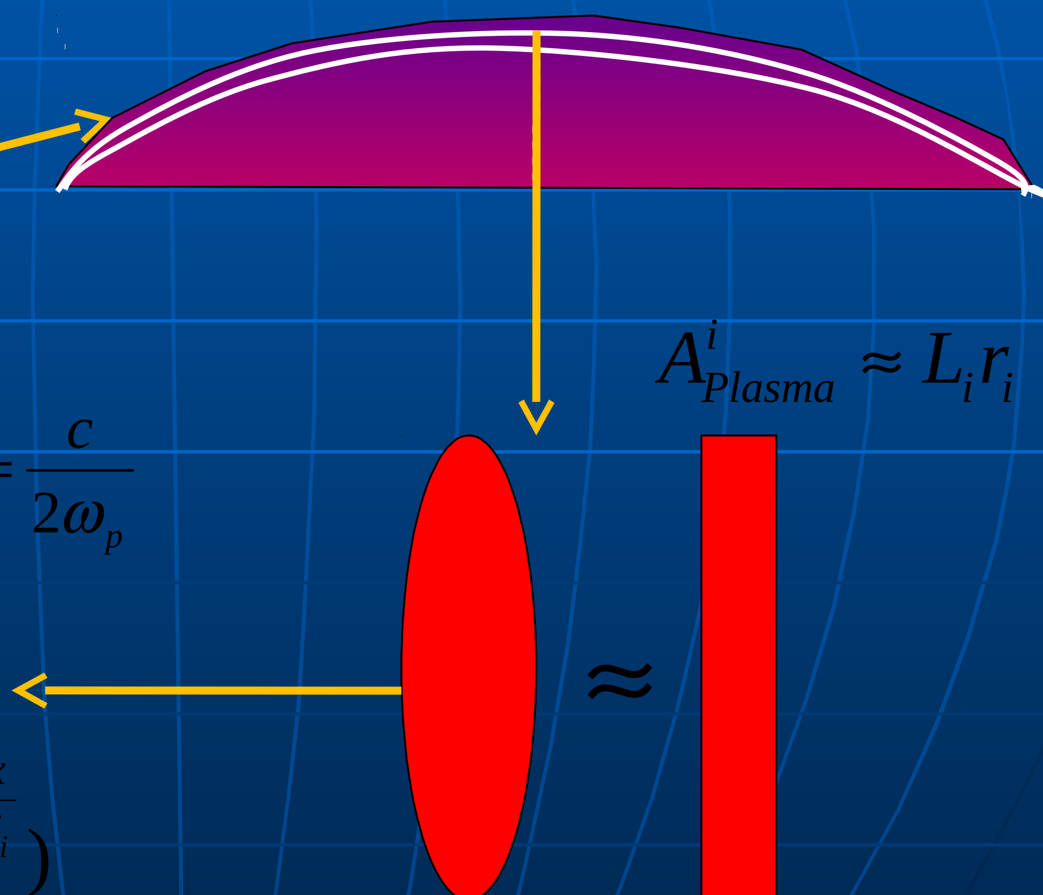




Skin Effects

Model: Consider over-dense cylinders of equal density





$$A^i_{Plasma} \approx L_i r_i$$

Calculate skin depth for a collision less plasma: $\delta = \dfrac{c}{2\omega_p}$

Within 1 skin depth the amount of power absorbed and re-scattered equals:

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