# Coherent transition radiation at radio frequencies from the electron beam sudden appearance


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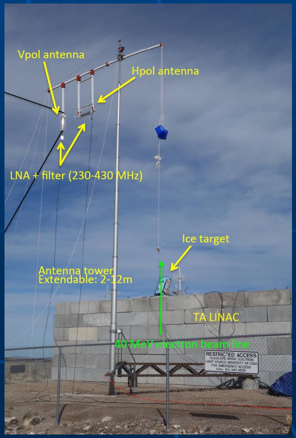
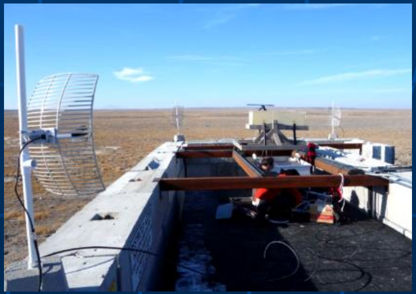
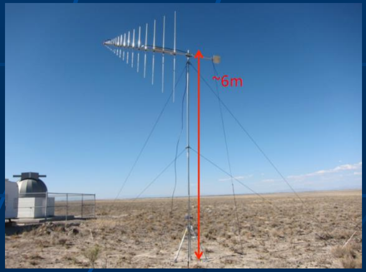
**Tatsunobu Shibata (KEK)**
**Gordon Thomson, John N. Matthews (U of Utah)**
**Pavel Motloch (U of Chicago)**

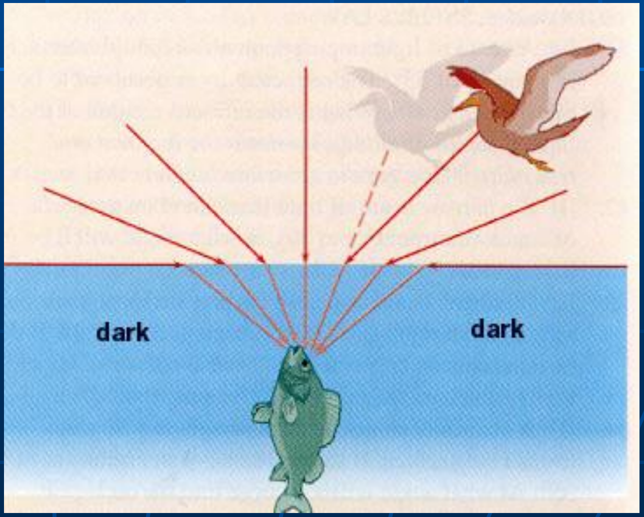





# Modeling the Beam sudden appearance: Coherent Transition Radiation

$$
\begin{aligned}
\vec{E}_{tr}(t,\vec{x}) &= \lim_{\epsilon\to 0}\int \mathrm{d}h\,\mathrm{d}^2r\left[\frac{e\,dN_e(t_r)\,w(\vec{r},h)}{4\pi\epsilon_0 c}\right.\\
&\times \left.\left(\frac{1}{|\mathcal{D}|^2_{t_r-\epsilon}}-\frac{1}{|\mathcal{D}|^2_{t_r+\epsilon}}\right)\right]\\
&\times \delta(h-c(t_r-t_b))\,\hat{p}
\end{aligned}
$$

**D: Apparent relativistic (four) distance --> Undefined at a boundary. Coherent TR can be described as the superposition of emission just above and below the boundary.**




**Particle Cascade**

# Modeling the Beam sudden appearance: Coherent Transition Radiation

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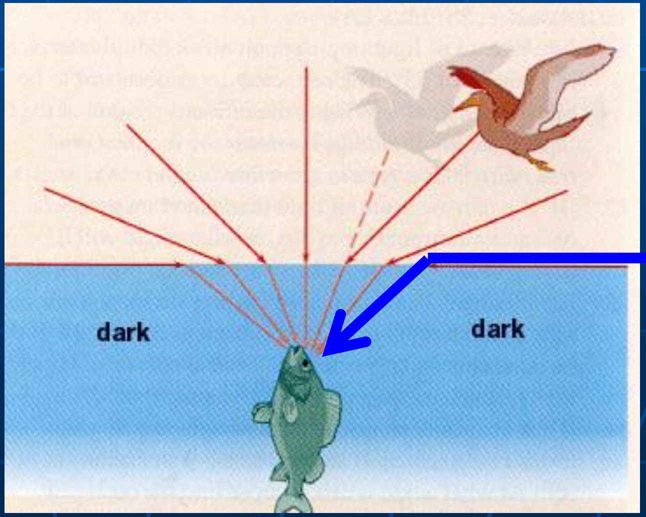


**Particle Cascade**

# Modeling the Beam sudden appearance: Coherent Transition Radiation

$$\begin{aligned}\vec{E}_{tr}(t,\vec{x}) &= \lim_{\epsilon\to 0}\int \mathrm{d}h\,\mathrm{d}^2r \left[\frac{e\,dN_e(t_r)\,w(\vec{r},h)}{4\pi\epsilon_0 c}\right.\\ &\times \left.\left(\frac{1}{|\mathcal{D}|^2_{t_r-\epsilon}} - \frac{1}{|\mathcal{D}|^2_{t_r+\epsilon}}\right)\right]\\ &\times \delta(h - c(t_r - t_b))\,\hat{r}\end{aligned}$$

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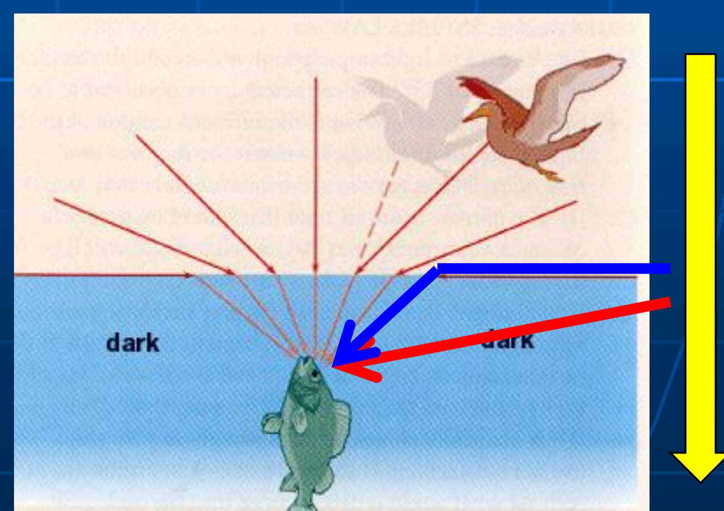



Particle Cascade

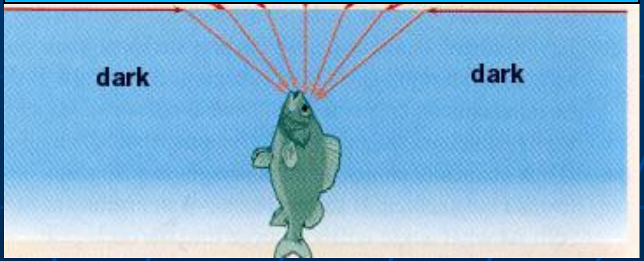
# Modeling the Beam sudden appearance: Coherent Transition Radiation

$$\begin{aligned}\vec{E}_{tr}(t,\vec{x}) \quad = \quad & \lim_{\epsilon\to 0}\int \mathrm{d}h\, \mathrm{d}^2 r \left[\frac{e\, d\, N_e(t_r)\, w(\vec{r},h)}{4\pi\epsilon_0 c}\right. \\ \times \quad & \left.\left(\frac{1}{|\mathcal{D}|^2_{t_r-\epsilon}} - \frac{1}{|\mathcal{D}|^2_{t_r+\epsilon}}\right)\right] \\ \times \quad & \delta(h - c(t_r - t_b))\, \hat{p}\end{aligned}$$

**0**

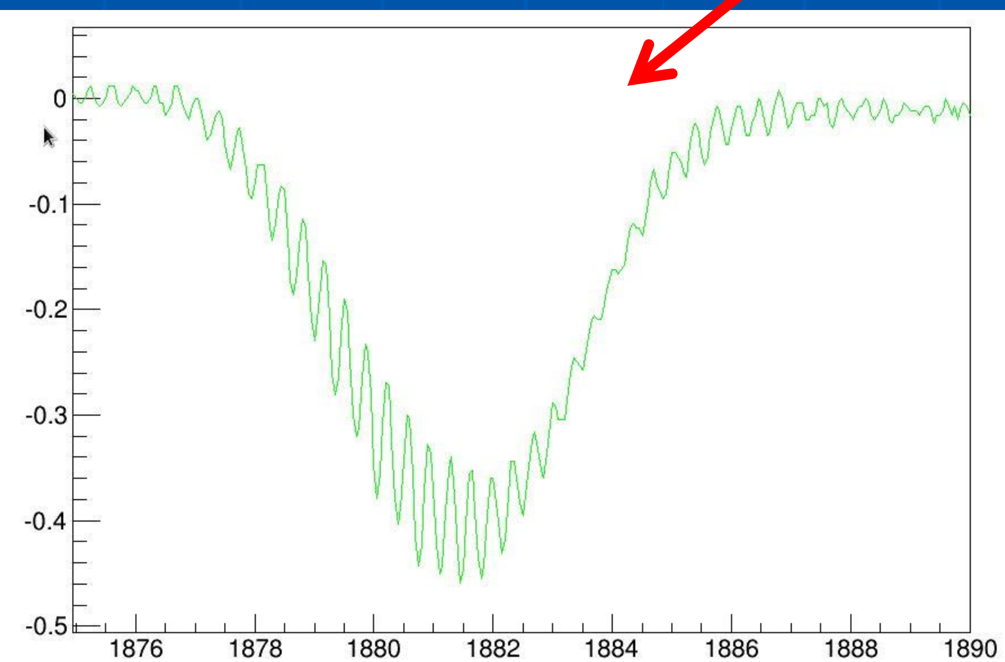
**D: Apparent relativistic (four) distance --> Undefined at a boundary. Coherent TR can be described as the superposition of emission just above and below the boundary.**

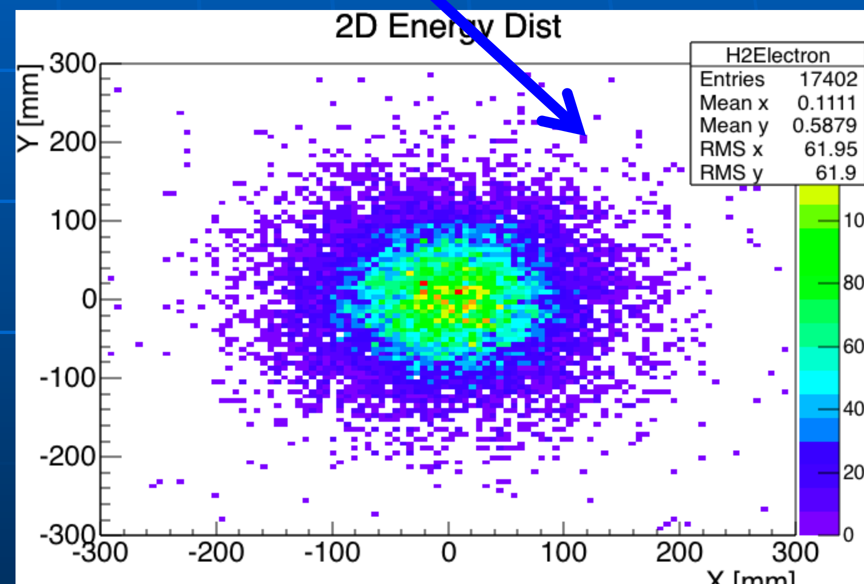
**Emission absorbed / shifted outside the coherent frequency band**



# What do we expect to observe?
# The Beam characteristics

$$\vec{E}_{sa}(t,\vec{x}) = \lim_{\epsilon\to 0}\int \mathrm{d}^2 r \, \frac{e\, d N_e(t_r)\, w(\vec{r},h)}{4\pi\epsilon_0 c\, |D|^2_{t_r+\epsilon}}\,\hat{p}\,\Big|_{h=c(t_r-t_b)}$$



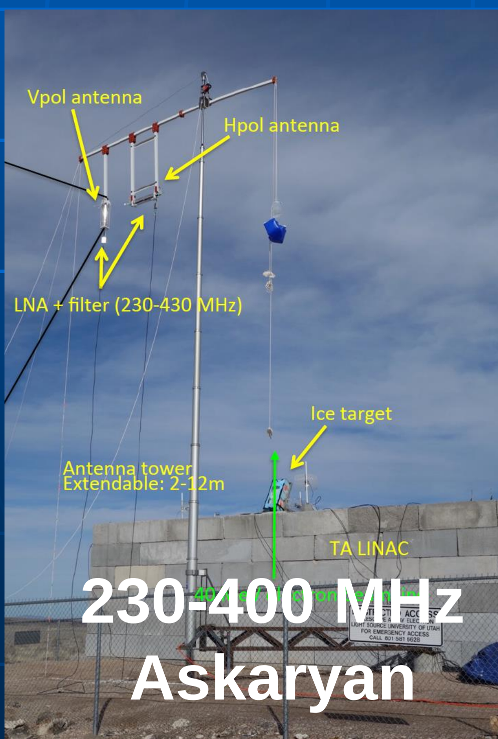




**~$10^9$ (40 MeV) electrons**

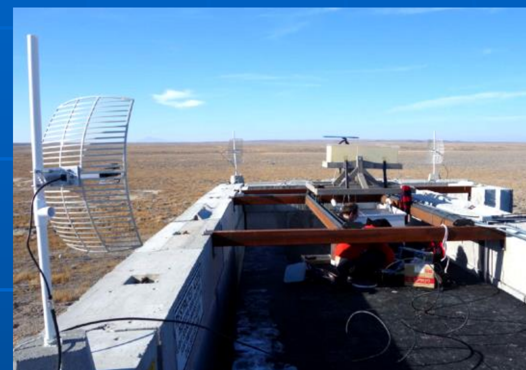
**~ 40 PeV**

# Experimental setup

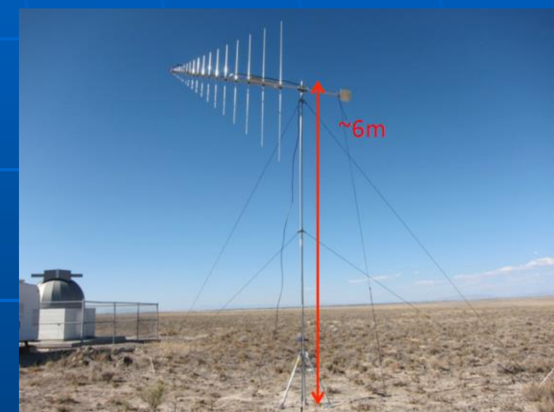
# Experimental Setups




**230-400 MHz**
**Askaryan**



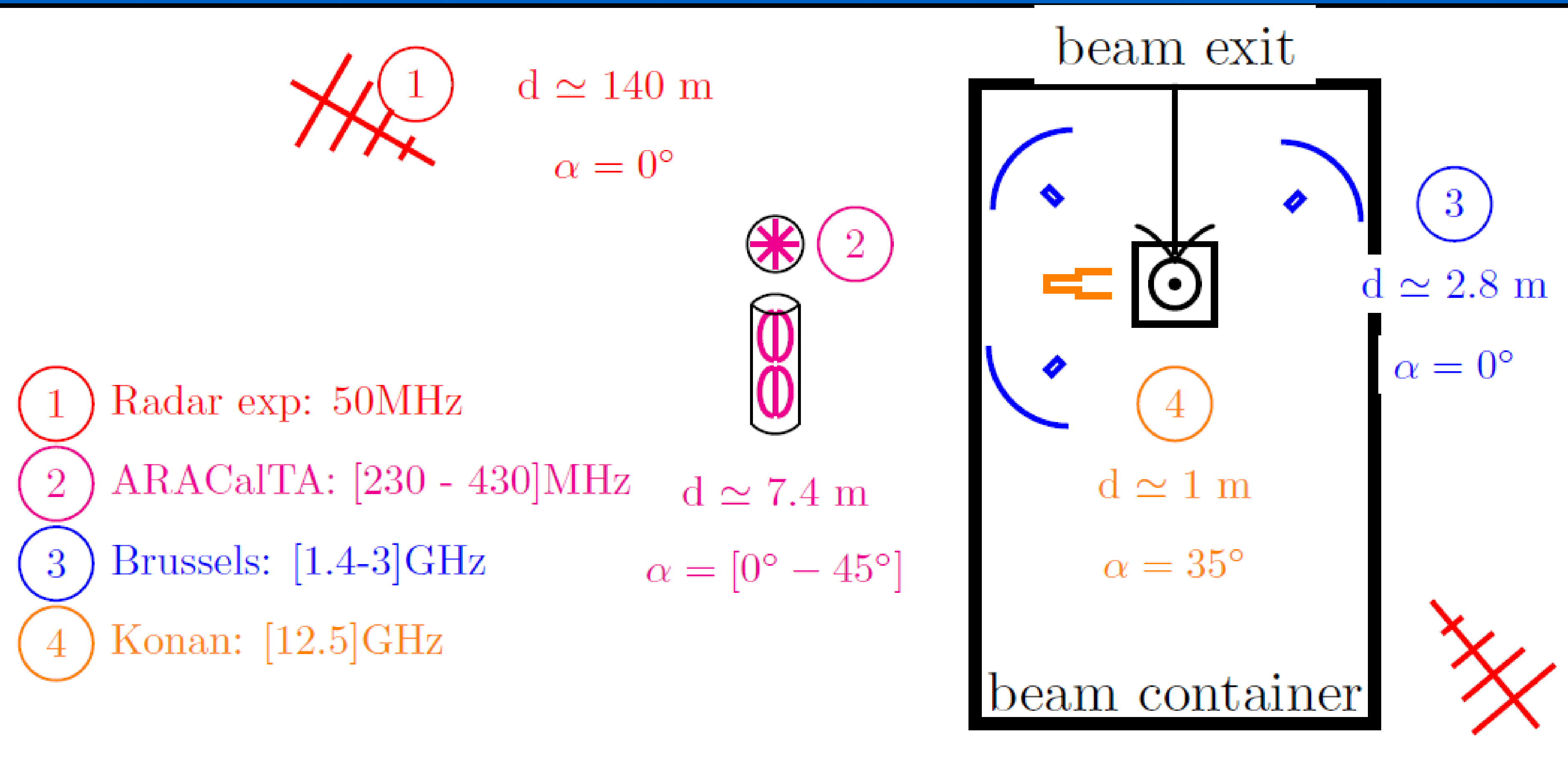
**1.4-3 GHz**
**In-ice Radar**




**50-66 MHz**
**In-air Radar**

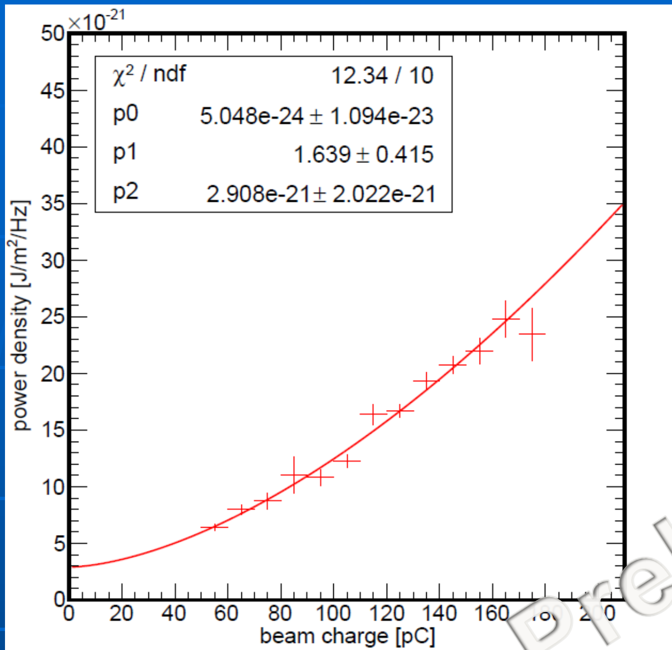
**12.5 GHz**
**Molecular Bremsstrahlung**

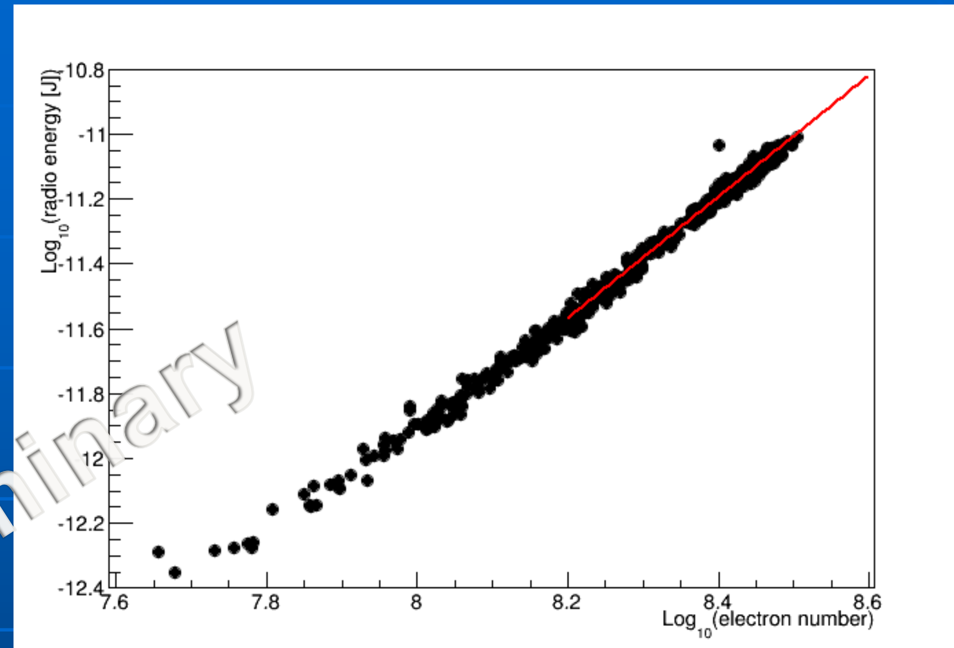
# Experimental setup




Credits: Romain Gaior

# Results and Coherence






**50 MHz**
**Power Density:**

**P=1.002 +- 0.014 (stat) +5.17 –0.56 (sys) [10^-24 J/m^2/Hz/pC^2]**

**Charge dependence P~(Q^S):**

**S = 1.639 +- 0.415**

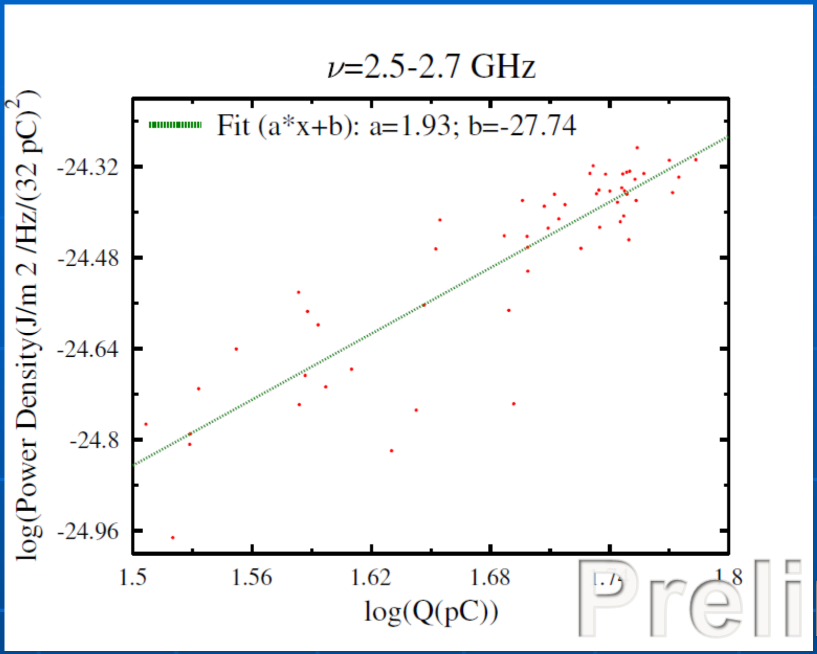
**230-430 MHz**
**Power Density:**

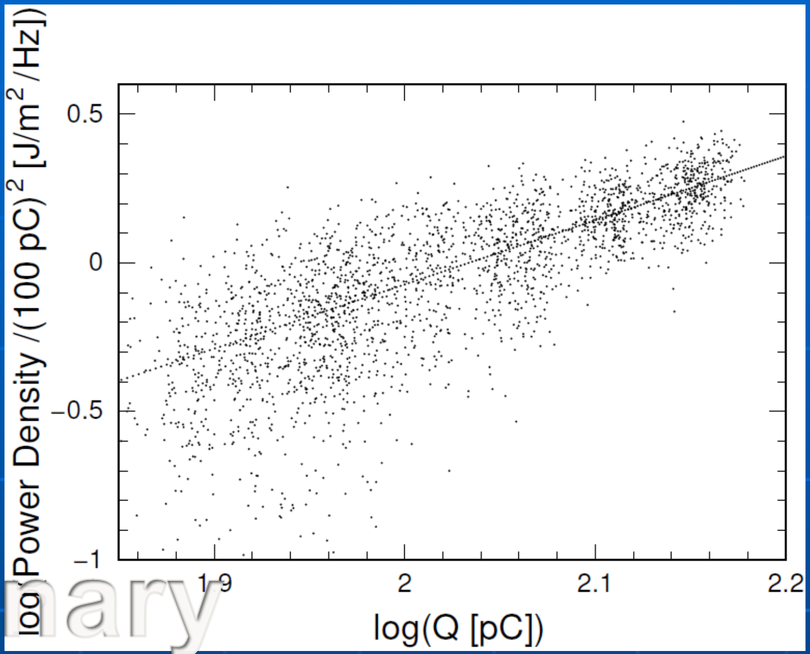
**P=O(10^-24 – 10^-25) ; Freq dependent, see next slide**

**Charge dependence P~(Q^S):**

**S= 1.87 +- 0.01**

# Results and Coherence




Preliminary

**1.4-3 GHz**
**Power Density:**

**P=O(10^-27); Freq Dep.**
**See next slide**

**Charge dependence P~(Q^S):**

**S=1.93 +- O(0.1)**

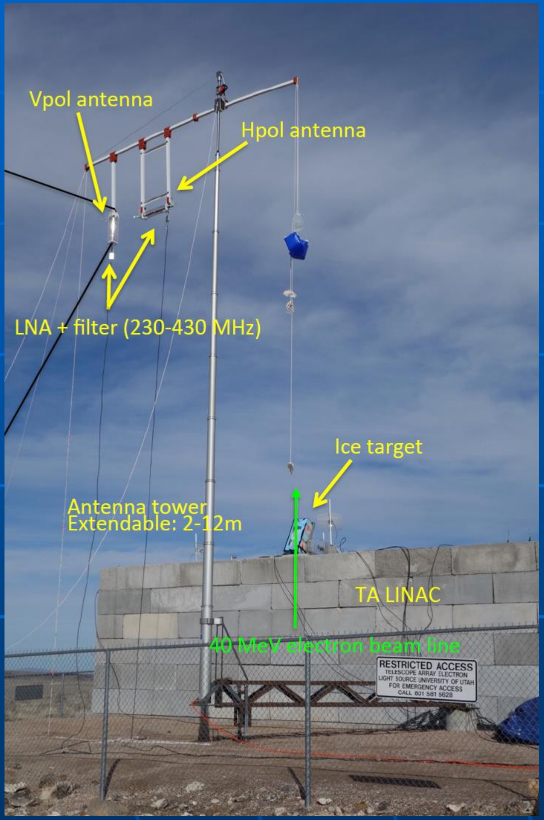
**12.5 GHz**
**Power Density:**

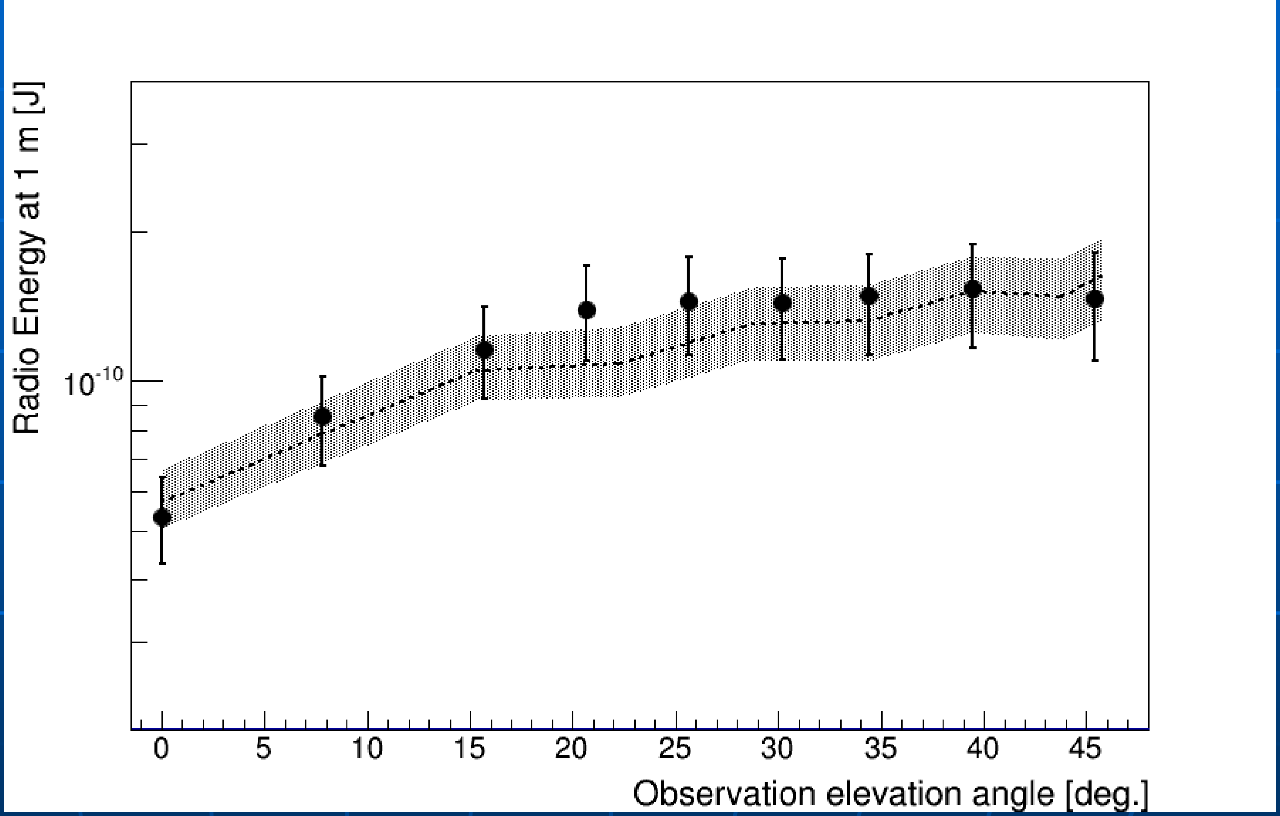
**P=8.46 +- 0.13(stat) +- 4.27 (sys)**
**[10^-29 J/m^2/Hz/pC^2]**

**Charge dependence P~(Q^S)**

**S= 2.16 +- 0.056**

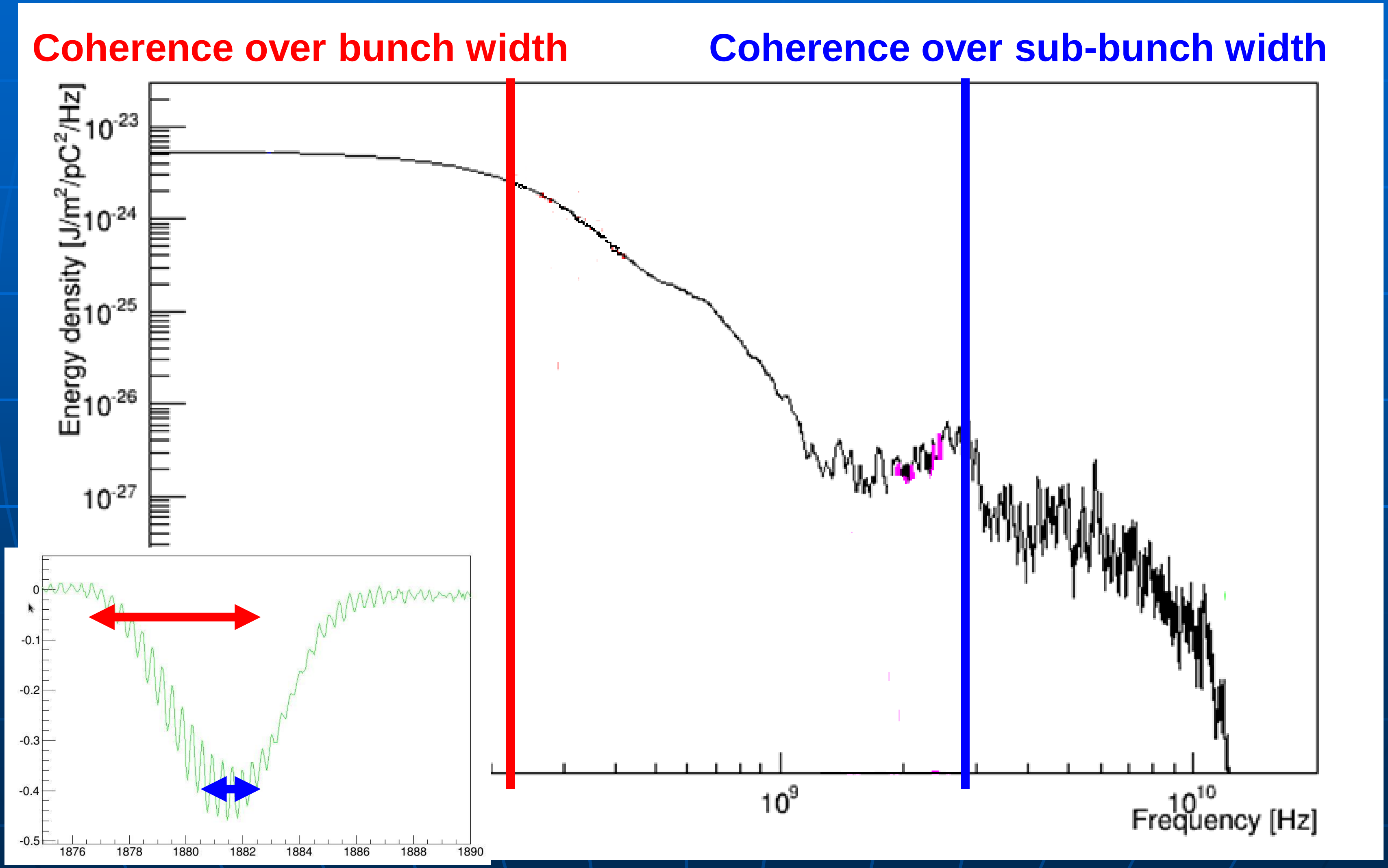
# Results: Angular distribution (230-430 MHz)



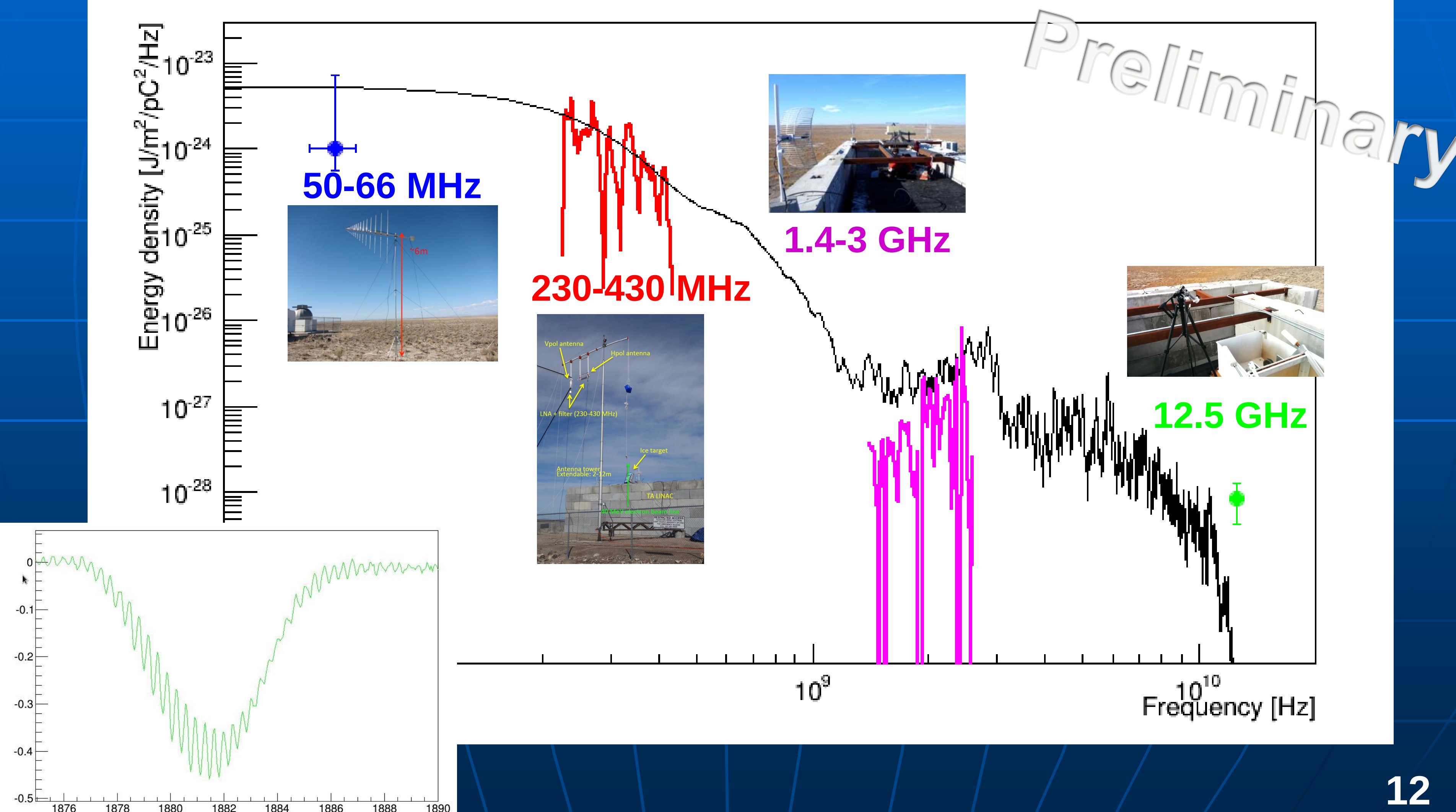

**Simulation (grey band) agrees very well to data (black dots)**

# Simulation Results: The sudden appearance energy density spectrum



# (Qualitative) Results:
# The sudden appearance energy density spectrum

**Four experiments observed the sudden appearance signal in different frequency ranges**



# Application in nature:

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

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[c] *University Groningen, KVI Center for Advanced Radiation Technology,Groningen, The Netherlands*

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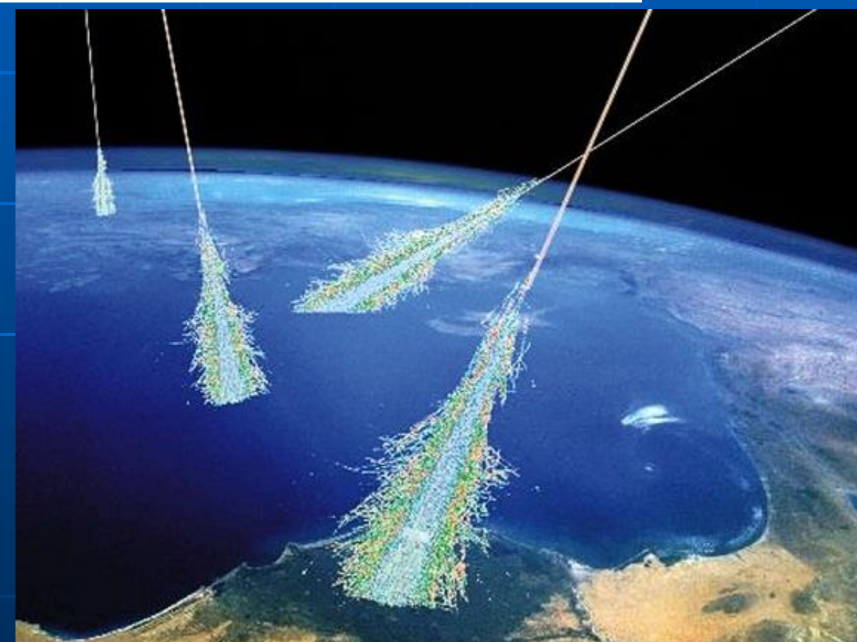
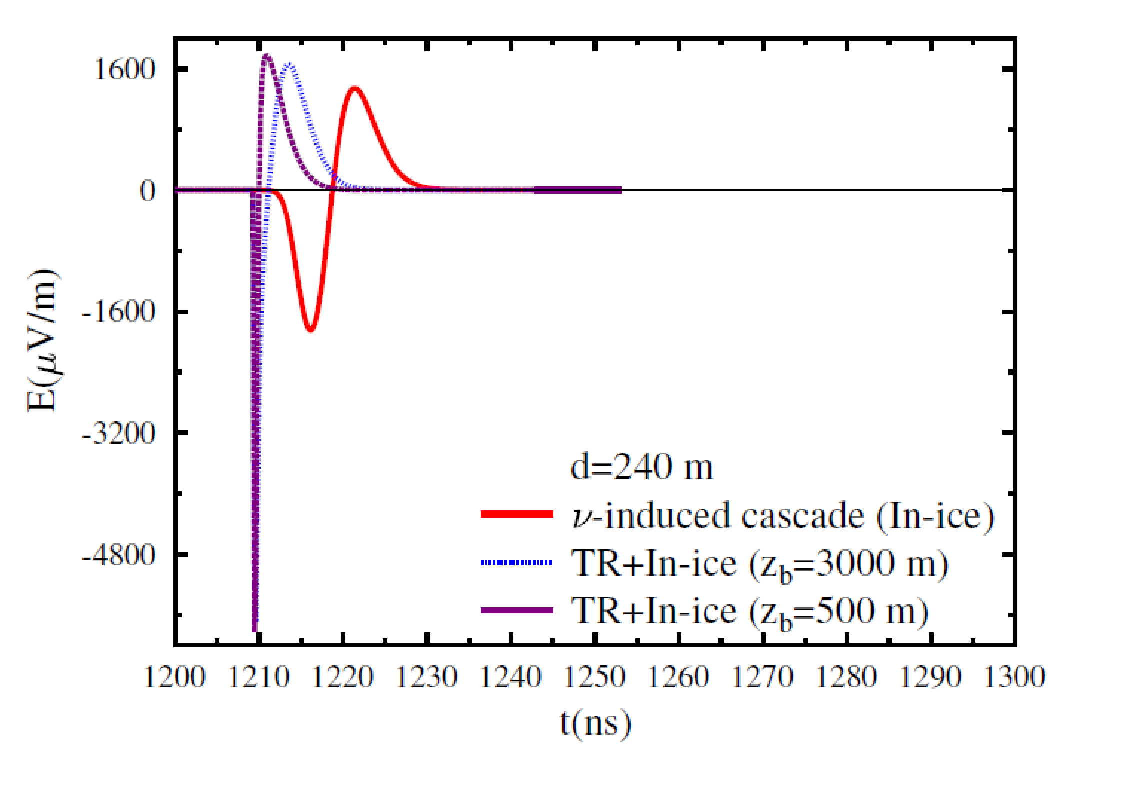
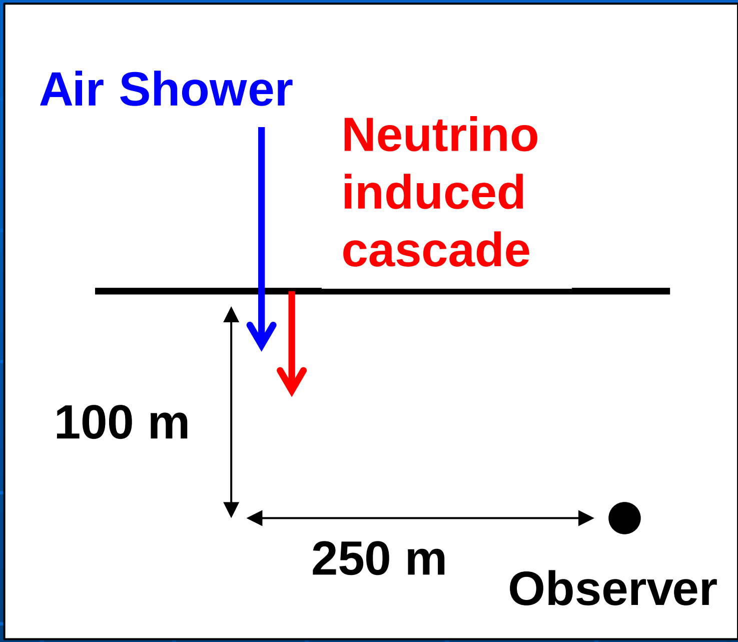
**arXiv:1503.02808**

# The air shower signal vs the neutrino induced cascade

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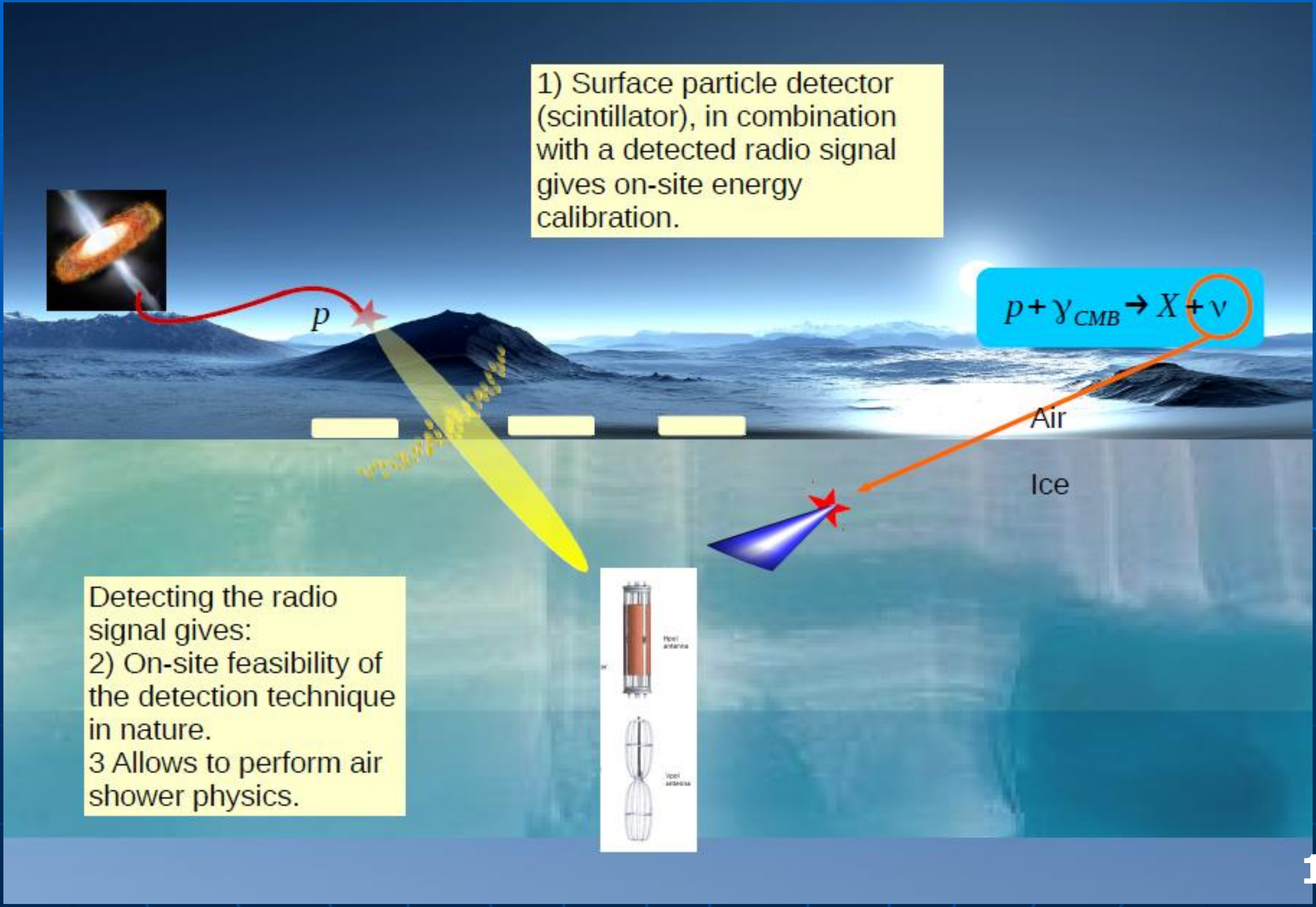
# How can we use the CR air shower signal in Askaryan radio detectors?



# Summary

- We report on the measurement of Coherent transition radiation at radio frequencies from the electron beam sudden appearance

- The signal is observed over a wide range of frequencies from 50 MHz – 12.5 GHz.

- All measurements show a high-level of coherence.

- The power density spectrum directly reflects the electron beam profile, and matches the simulations both qualitatively and quantitatively (still preliminary). The signal is well understood.

- The in-nature application is found in high-energy particle cascades traversing different media.

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