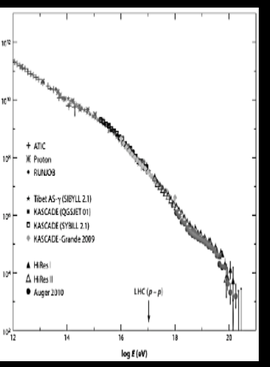


Paris Feb.9 2015

Grand Workshop

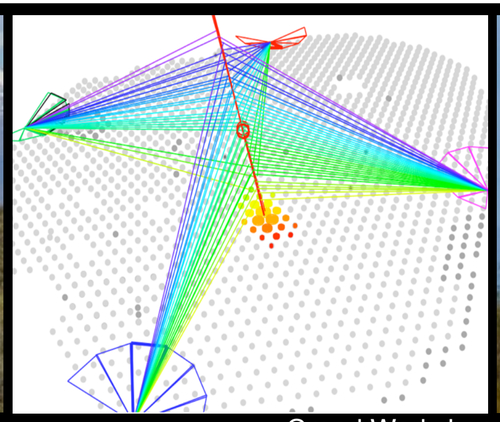
SELFAS

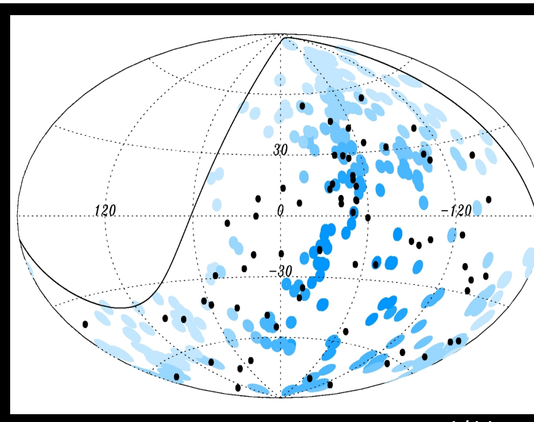
***S**imulation of **EL**ectric **F**ield emitted by **A**ir **S**hower*

Focus on horizontal air showers

Vincent Marin

Subatech Nantes France





SELFAS Concept

➡ Dedicated to radio emission in the MHz range

➡ Autonomous code which doesn't launch any full shower simulation (CORSIKA, AIRES)

➡ Based on air shower universality

➡ Using relevant universal distributions :

- -GIL Longitudinal profile or CONEX
- -Energy distribution
- -Vertical and horizontal momentum direction
- -lateral distribution
- -Delay time (shower front thickness)

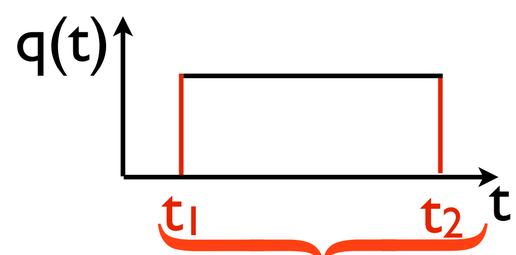
➡ Generate only e^+ and e^- of the shower front (3D)

➡ Track each e^+/e^- along their trajectory to compute and sum up all individual field contribution at any observation point

Formalism, field

Individual charge with a finite life time

t_1 = start point time t_2 = end point time



Charge density $\rho(\boldsymbol{x}',t') = q[\theta(t'-t_1)-\theta(t'-t_2)]\delta^3(\boldsymbol{x}'-\boldsymbol{x}_0(t'))$

Current density $\boldsymbol{J}(\boldsymbol{x}',t') = \rho(\boldsymbol{x}',t')\boldsymbol{v}(t')$

With Maxwell equations : (Lorentz gauge)

$$\boldsymbol{E}(\boldsymbol{x},t) = \frac{1}{4\pi\epsilon_0}\int d^3x'dt'\frac{1}{R}\left[-\boldsymbol{\nabla}'\rho-\frac{1}{c^2}\frac{\partial \boldsymbol{J}}{\partial t'}\right]_{\text{ret}}\delta\left\{t'-\left(t-\frac{|\boldsymbol{x}-\boldsymbol{x}'|}{c}\right)\right\}$$

Performing time and spatial integrations :

$$\boldsymbol{E}(\boldsymbol{x},t)=\frac{1}{4\pi\varepsilon_0}\left\{\left[\frac{\boldsymbol{n}q(t_{\text{ret}})}{R^2(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}}+\frac{1}{c}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{n}q(t_{\text{ret}})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}}-\frac{1}{c^2}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{v}q(t_{\text{ret}})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}}\right\}$$

Shower generation

At shower scale : summing up all contributions

$$\boldsymbol{E}_{tot}(\boldsymbol{x},t) = \frac{1}{4\pi\epsilon_0}\left\{ \sum_{i=1}\left[\frac{\boldsymbol{n}_i q_i(t_{ret})}{R_i^2(1-\boldsymbol{\beta}_i.\boldsymbol{n}_i)}\right]_{\text{ret}} + \frac{1}{c}\frac{\partial}{\partial t}\sum_{i=1}\left[\frac{\boldsymbol{n}_i q_i(t_{ret})}{R_i(1-\boldsymbol{\beta}_i.\boldsymbol{n}_i)}\right]_{\text{ret}} - \frac{1}{c^2}\frac{\partial}{\partial t}\sum_{i=1}\left[\frac{\boldsymbol{v}_i q_i(t_{ret})}{R_i(1-\boldsymbol{\beta}_i.\boldsymbol{n}_i)}\right]_{\text{ret}} \right\}$$

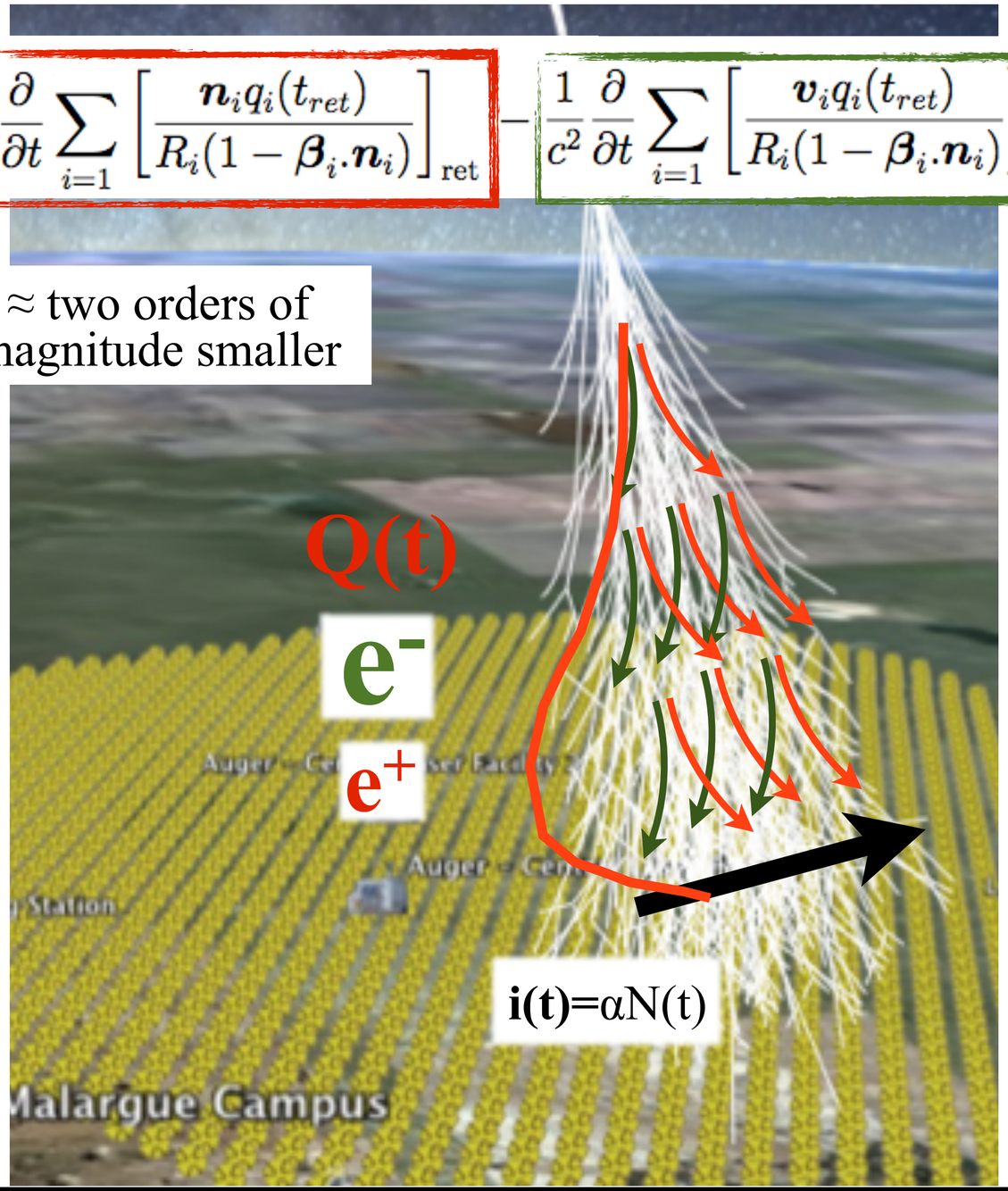
global Coulombian	Summation of all individual static contributions.

≈ two orders of magnitude smaller

Charge excess variation	Due to the e^- in excess $Q(t)= \alpha N(t)$

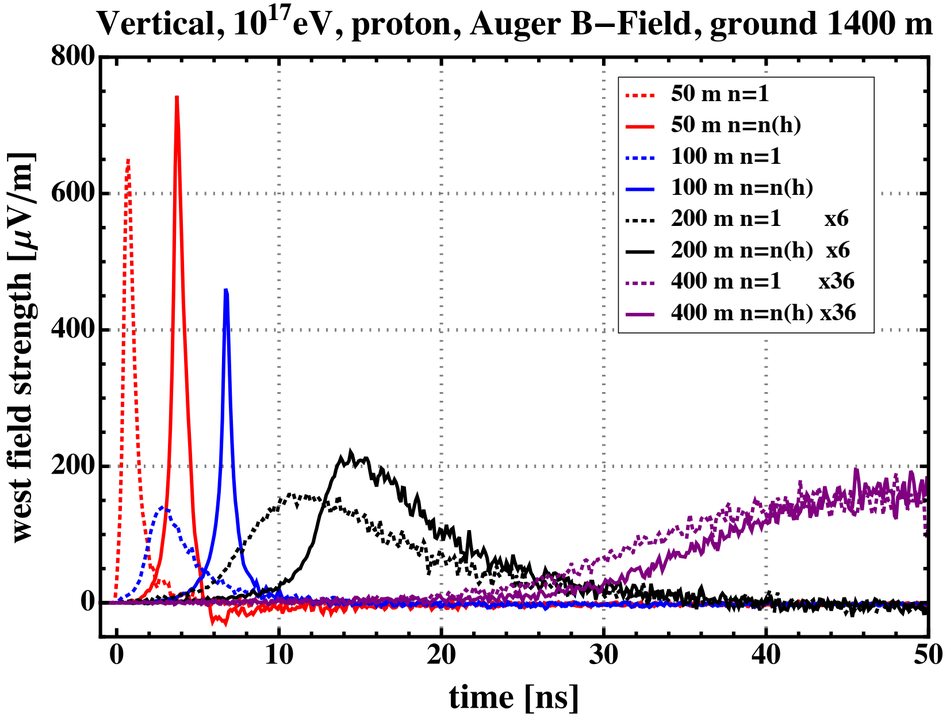
Transverse current variation	Systematic opposite drift of e^- and e^+ in the earth magnetic field.

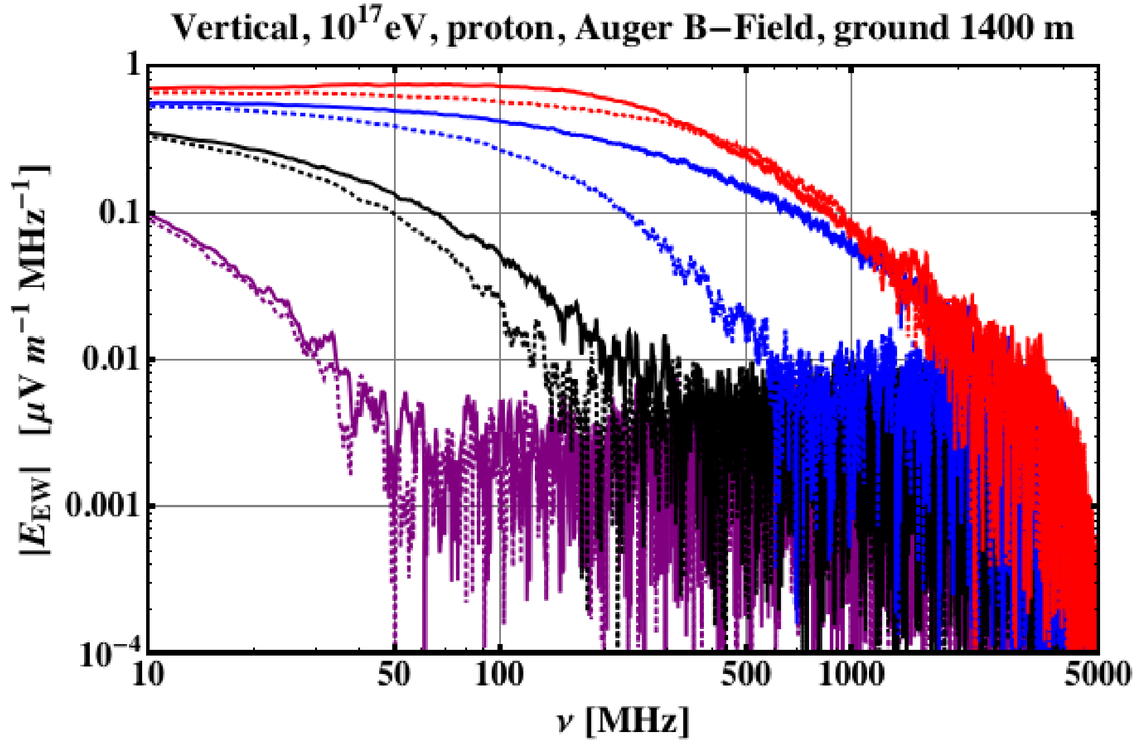
Dominant, except for showers parallel to the geomag. field

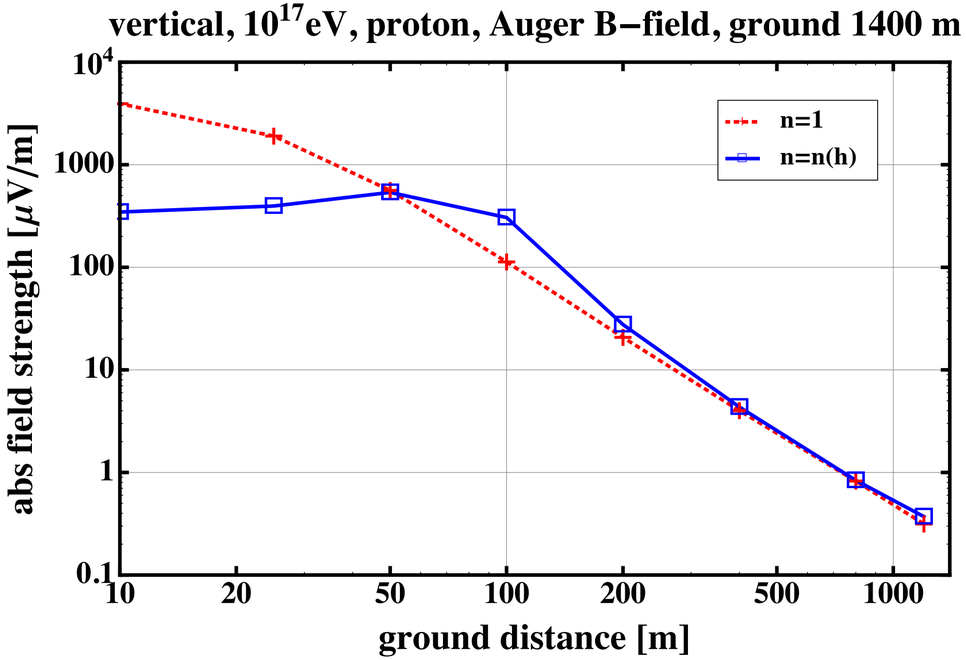


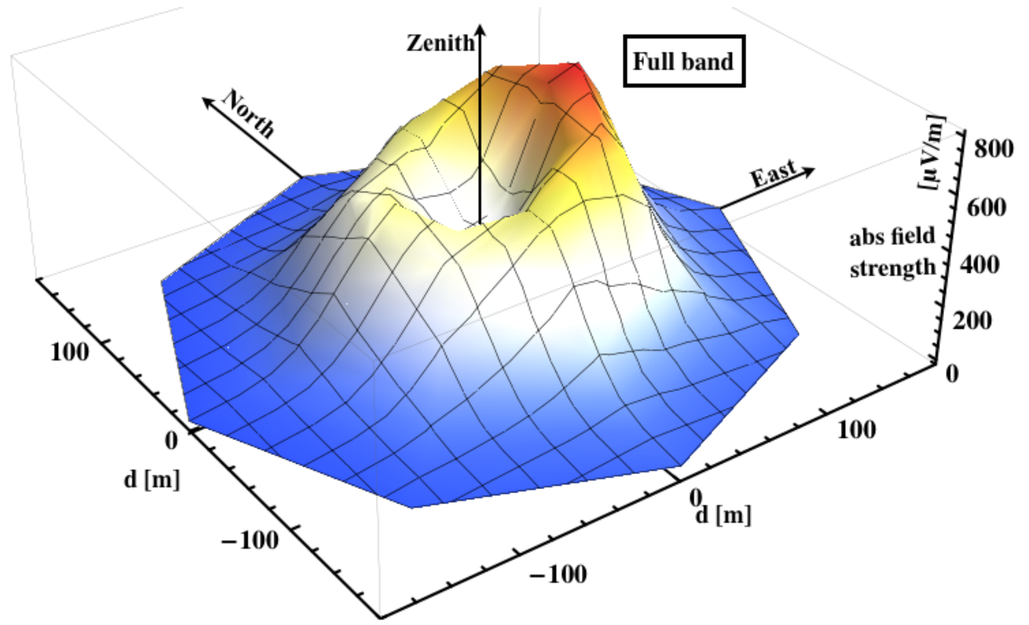
Some results…Vertical case

- *Concept*
- *Formalism*
- *Shower generation*
- *Some results…*
- *Horizontal showers*
- *Conclusion*









Some results…

Focus on horizontal air showers

Preamble…

Adapt SELFAS to the situation…..

…. to prepare this workshop….

No Neutrino → Use of proton induced showers

Atmosphere density — **important for shower development & radio propagation** → *constant* ρ(3000m)

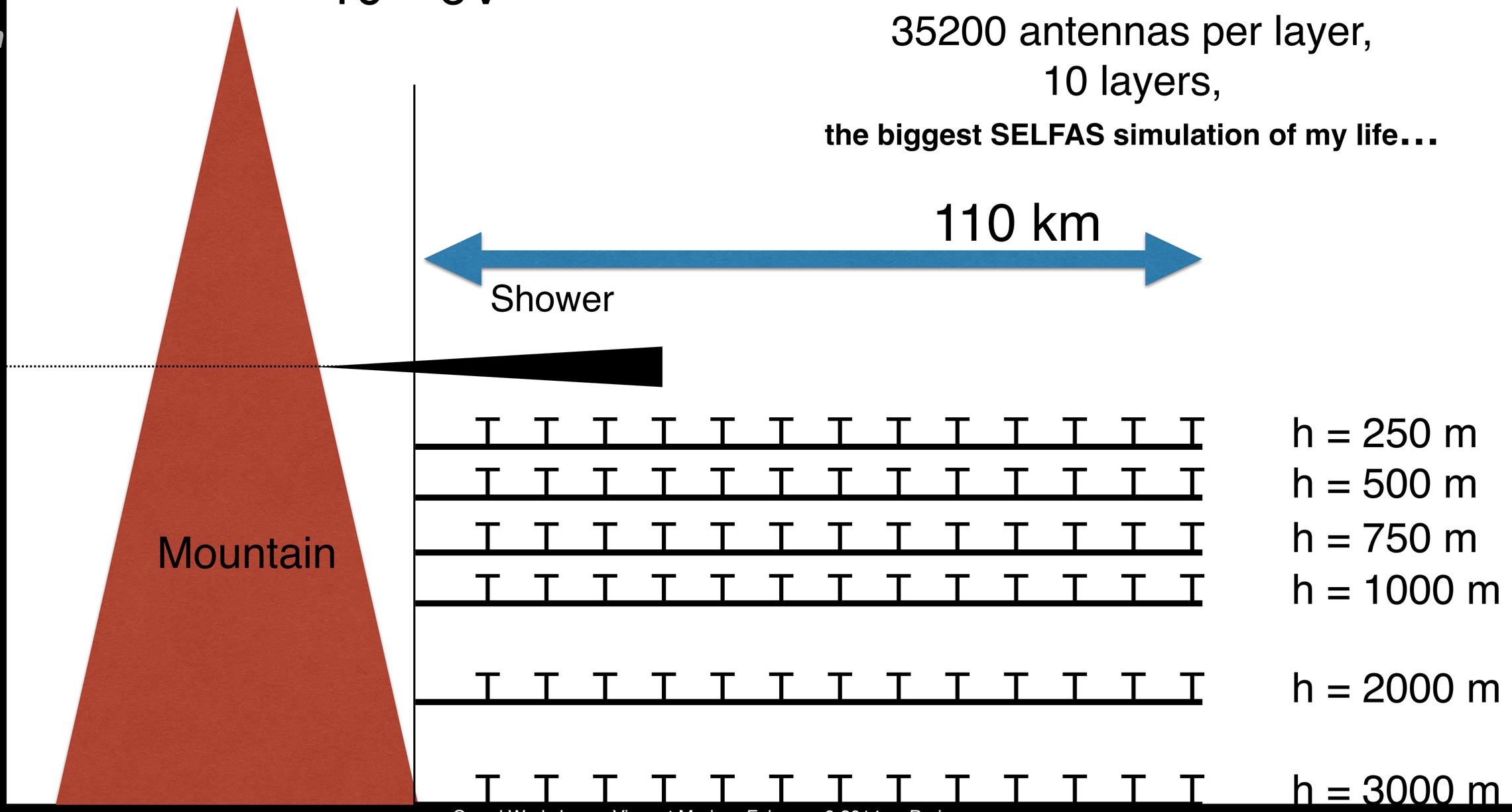
Ground effects for horizontal showers … ??

Antenna response with ground effects is needed

The set-up…

- *Concept*
- *Formalism*
- *Shower generation*
- *Some results…*
- ***Horizontal showers***
- *Conclusion*

Proton induced shower
10^{17} eV

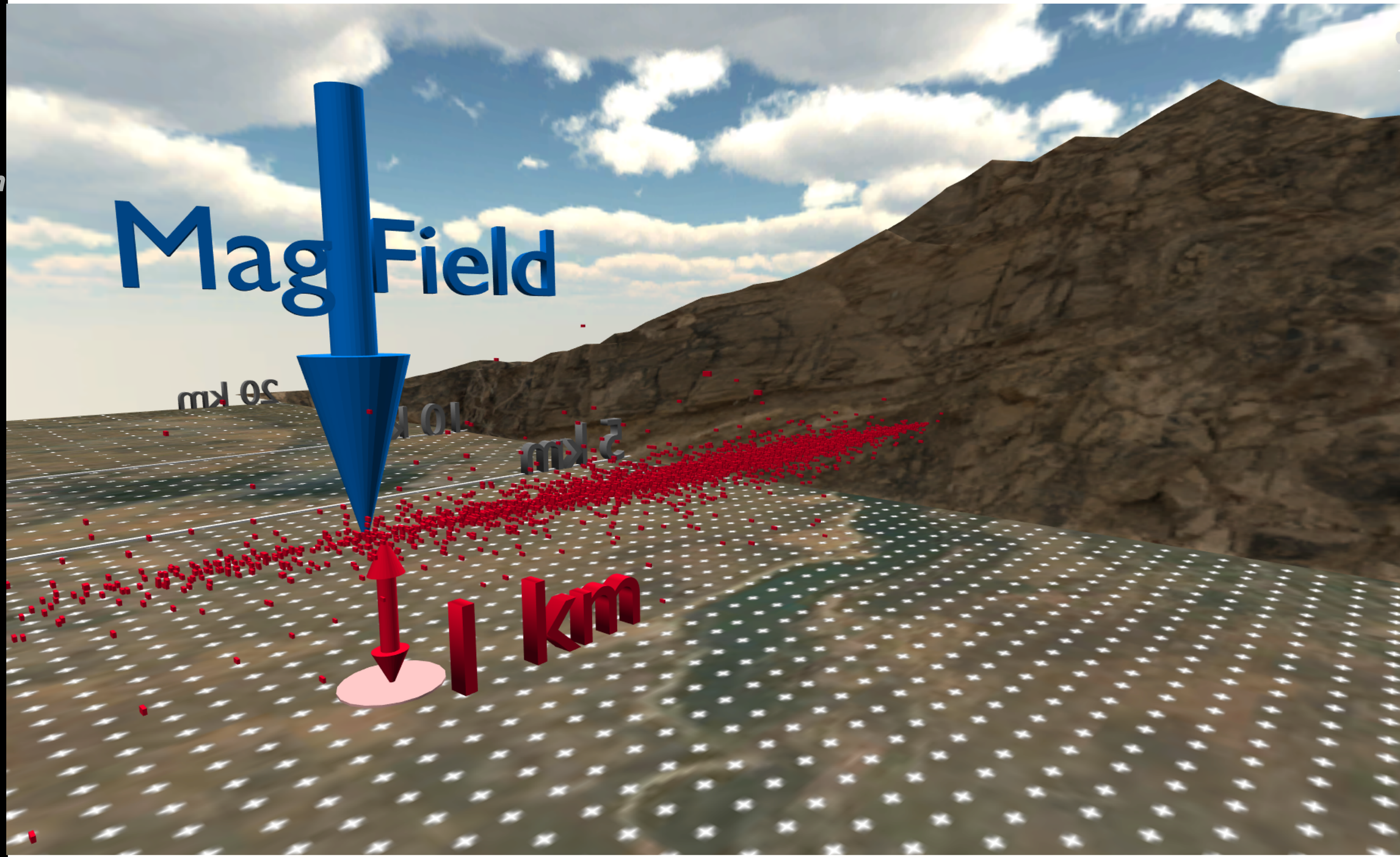


Different layers
to map the shower radio emission in 3D

35200 antennas per layer,
10 layers,

the biggest SELFAS simulation of my life…

- Concept
- Formalism
- Shower generation
- Some results...
- **Horizontal showers**
- Conclusion



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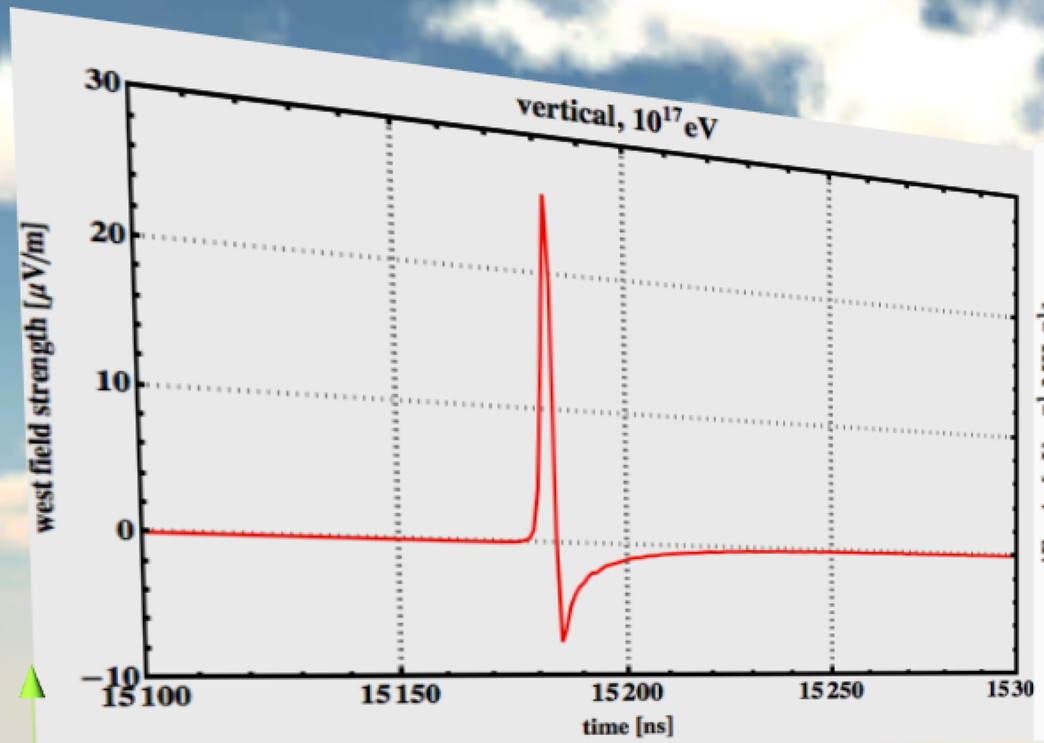

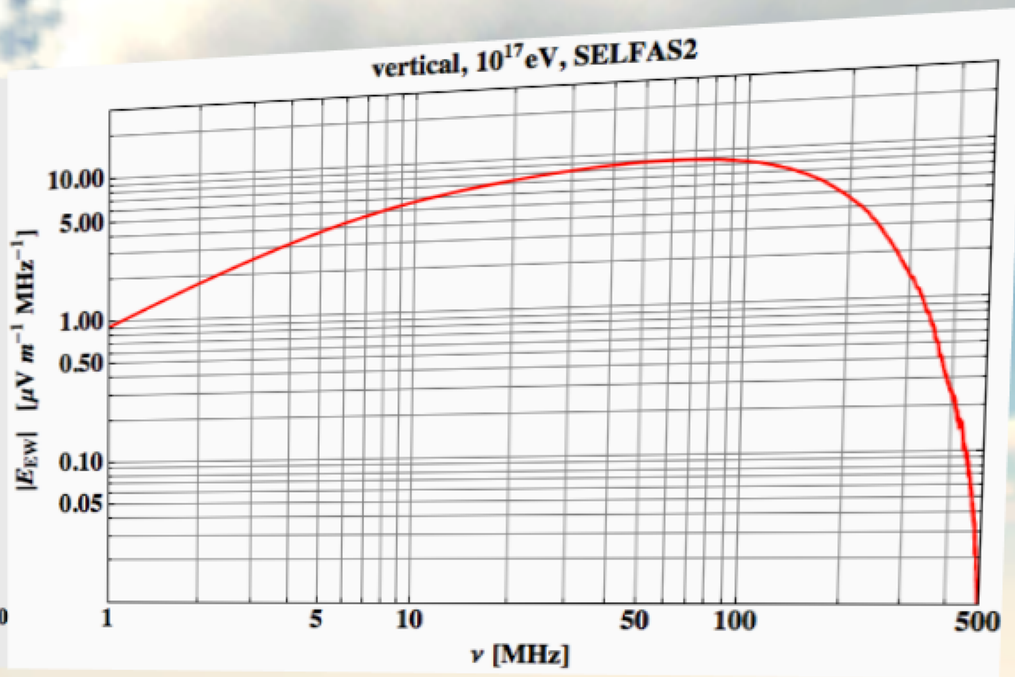

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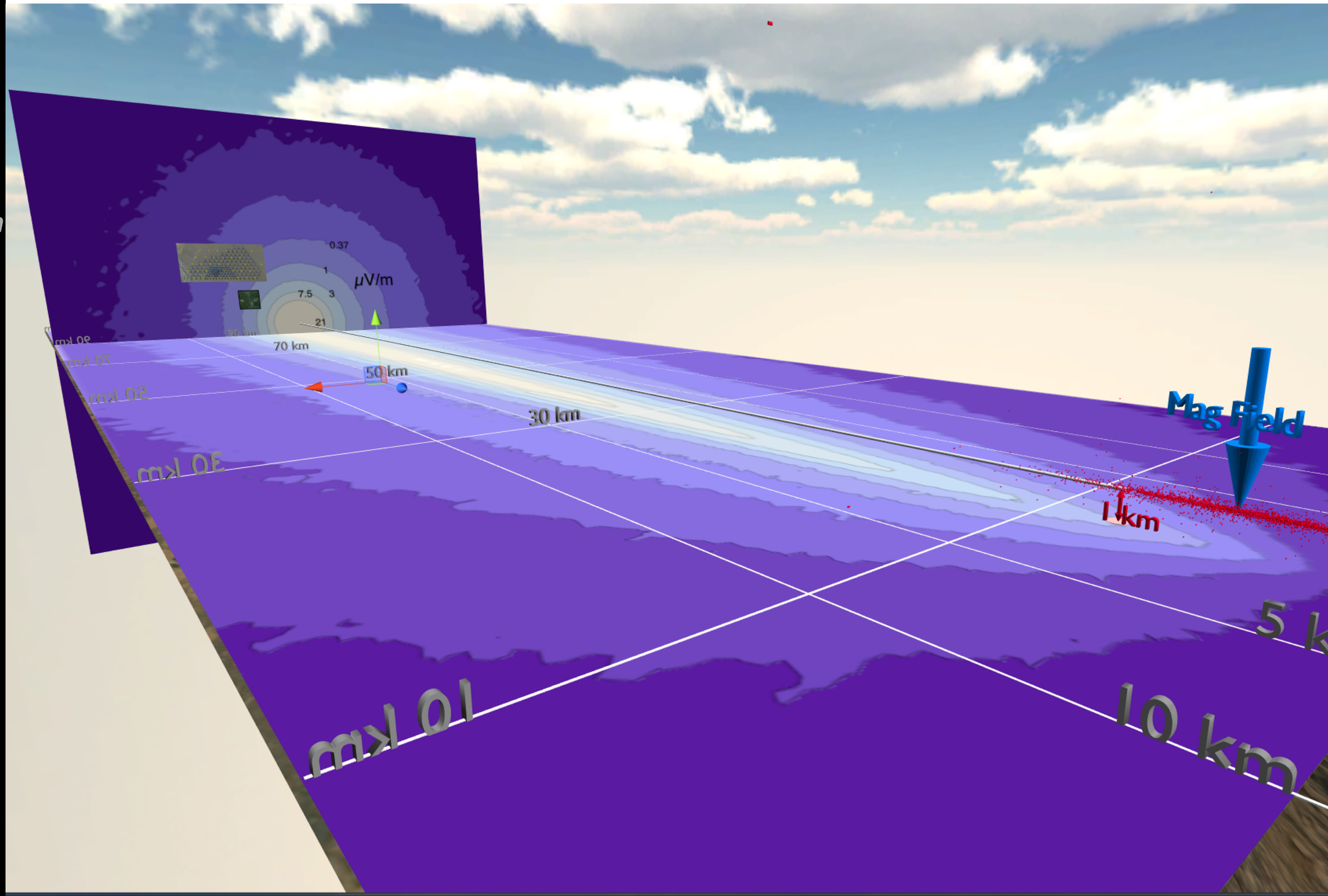

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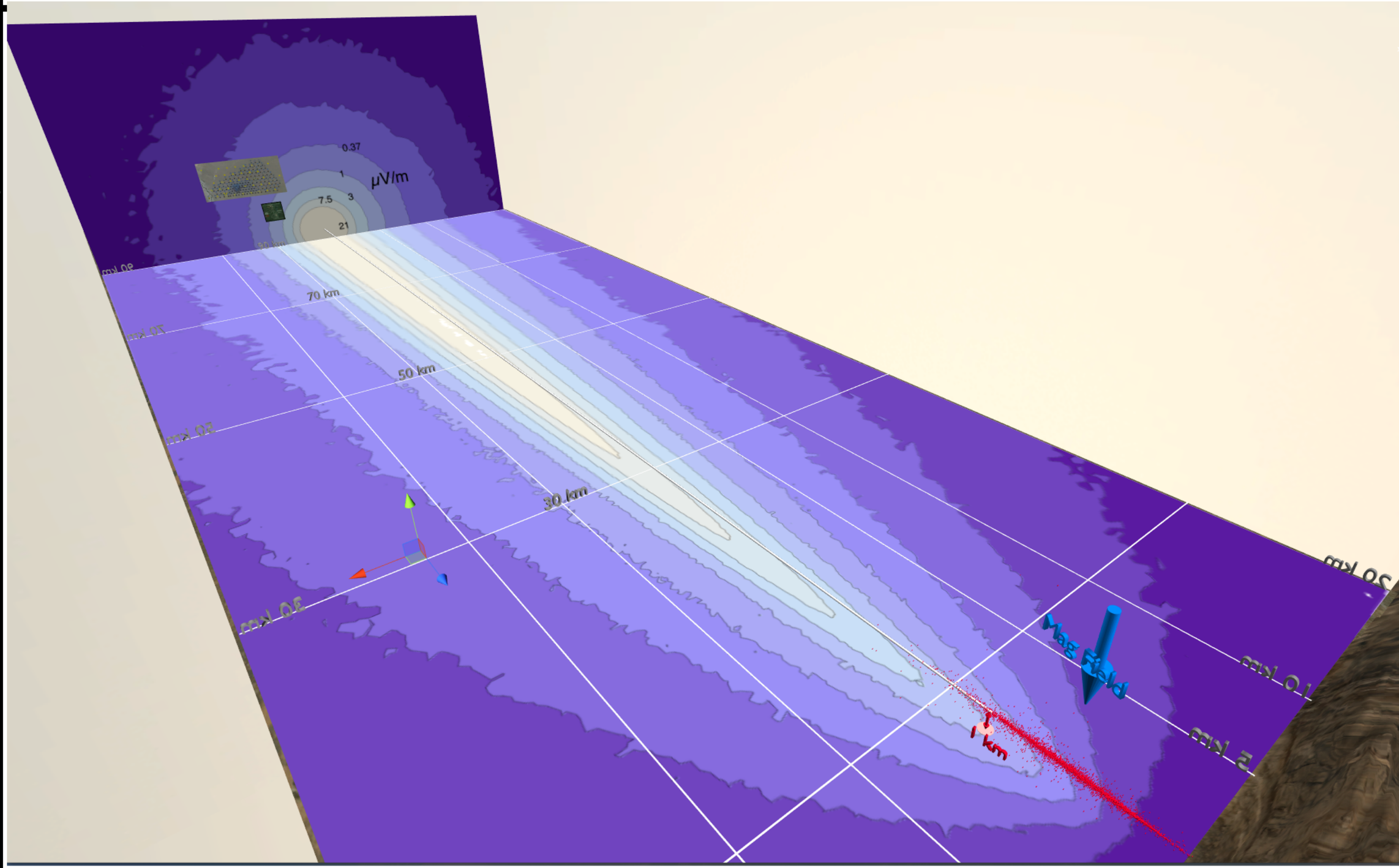

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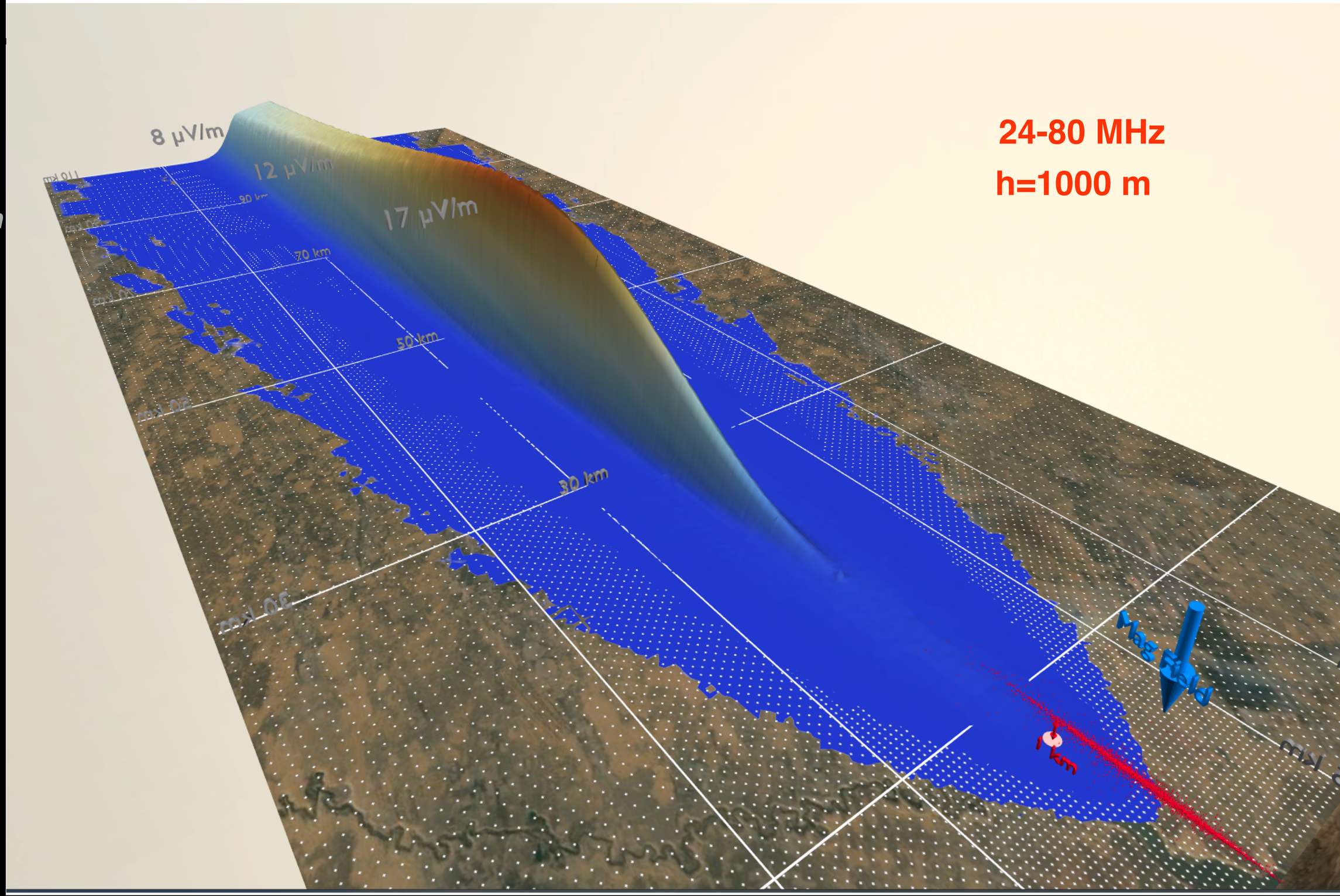

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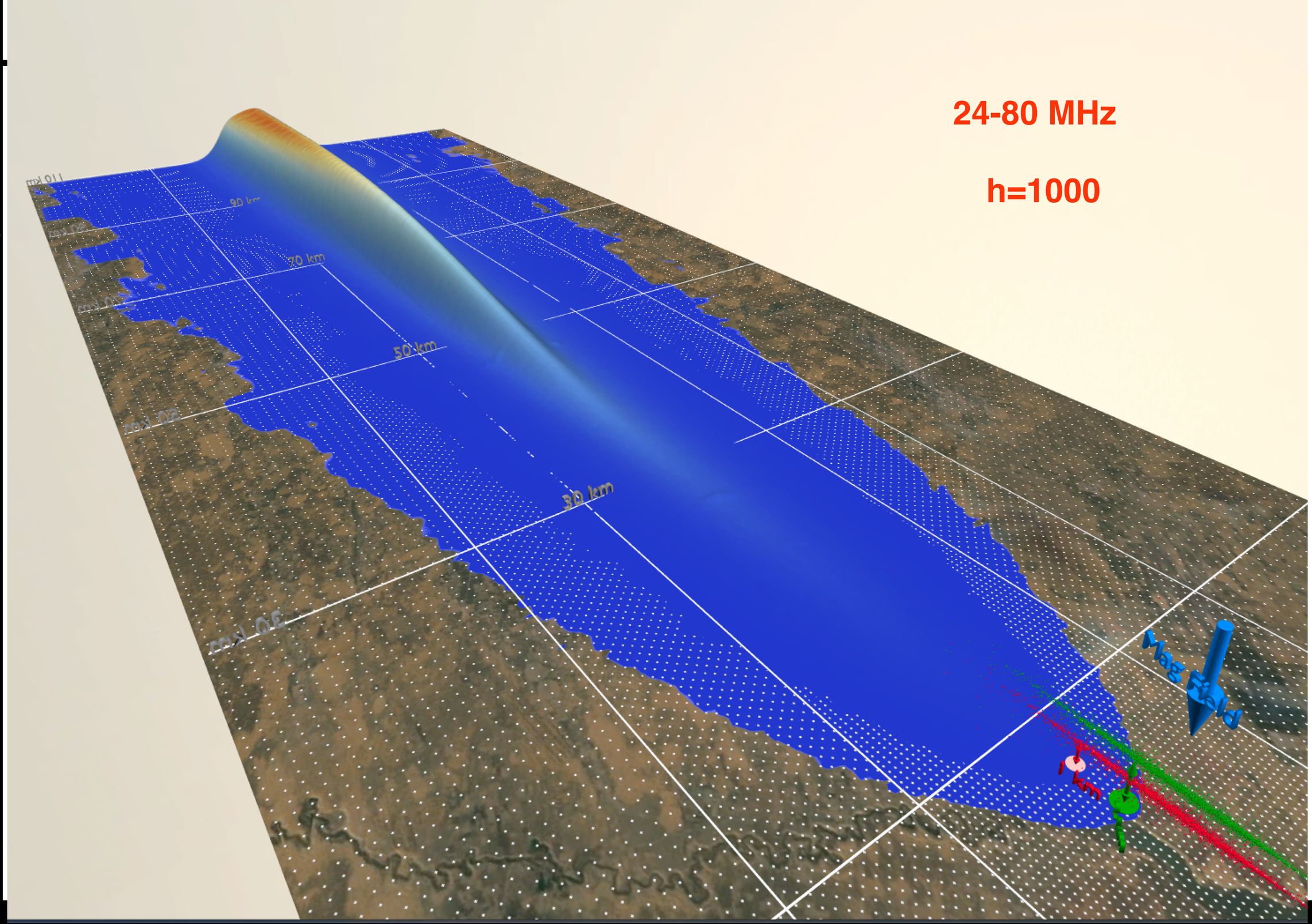

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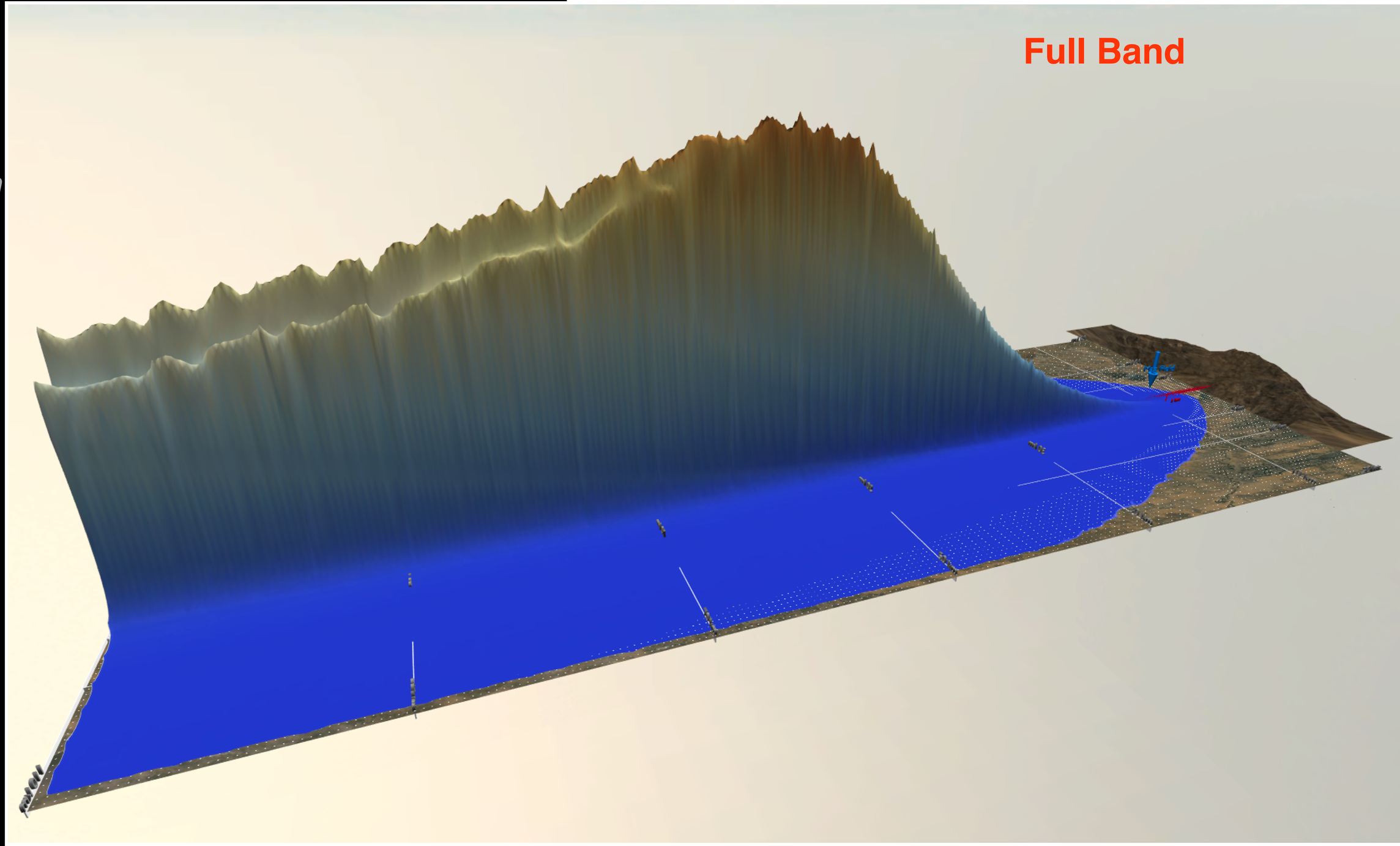

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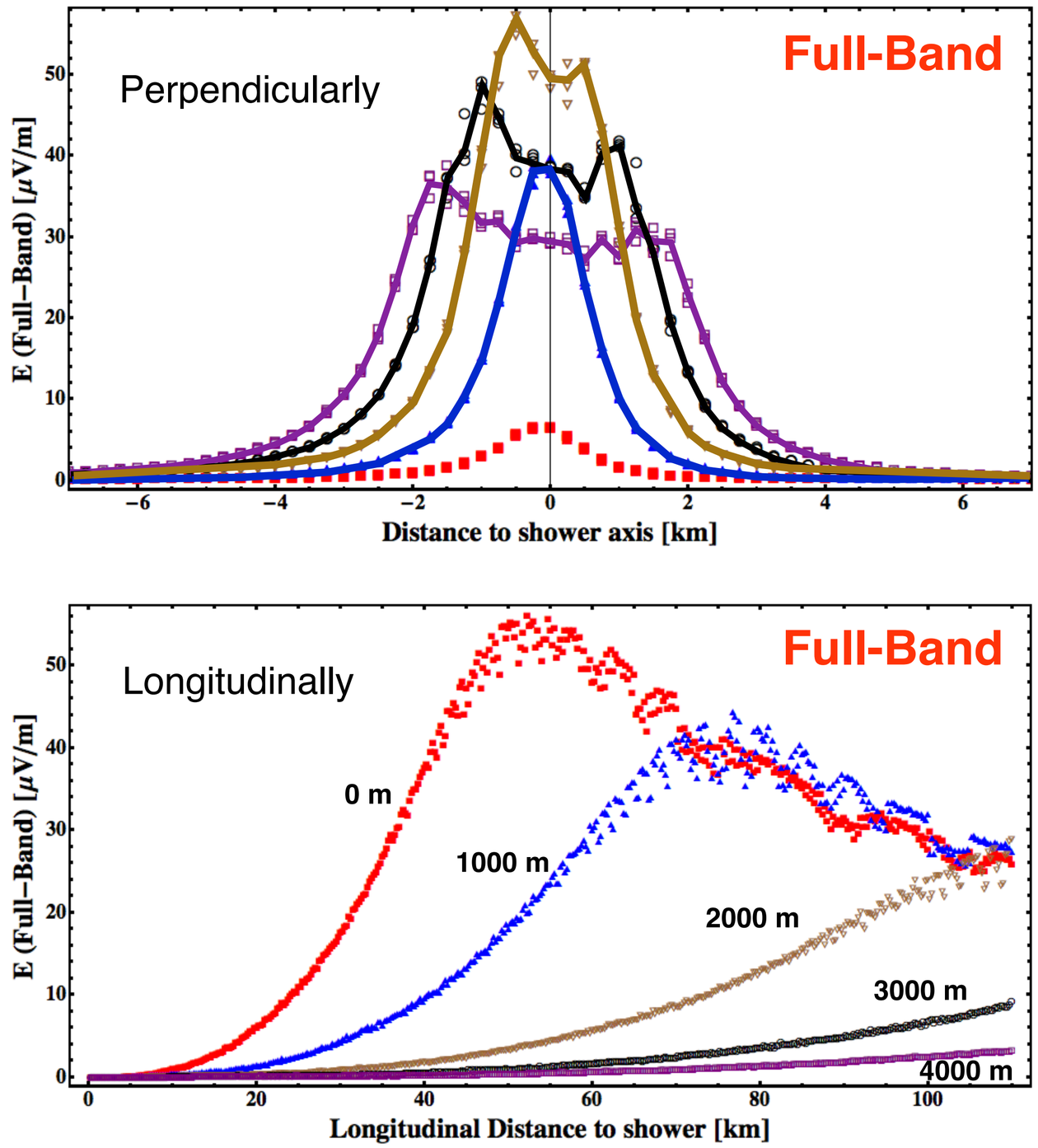
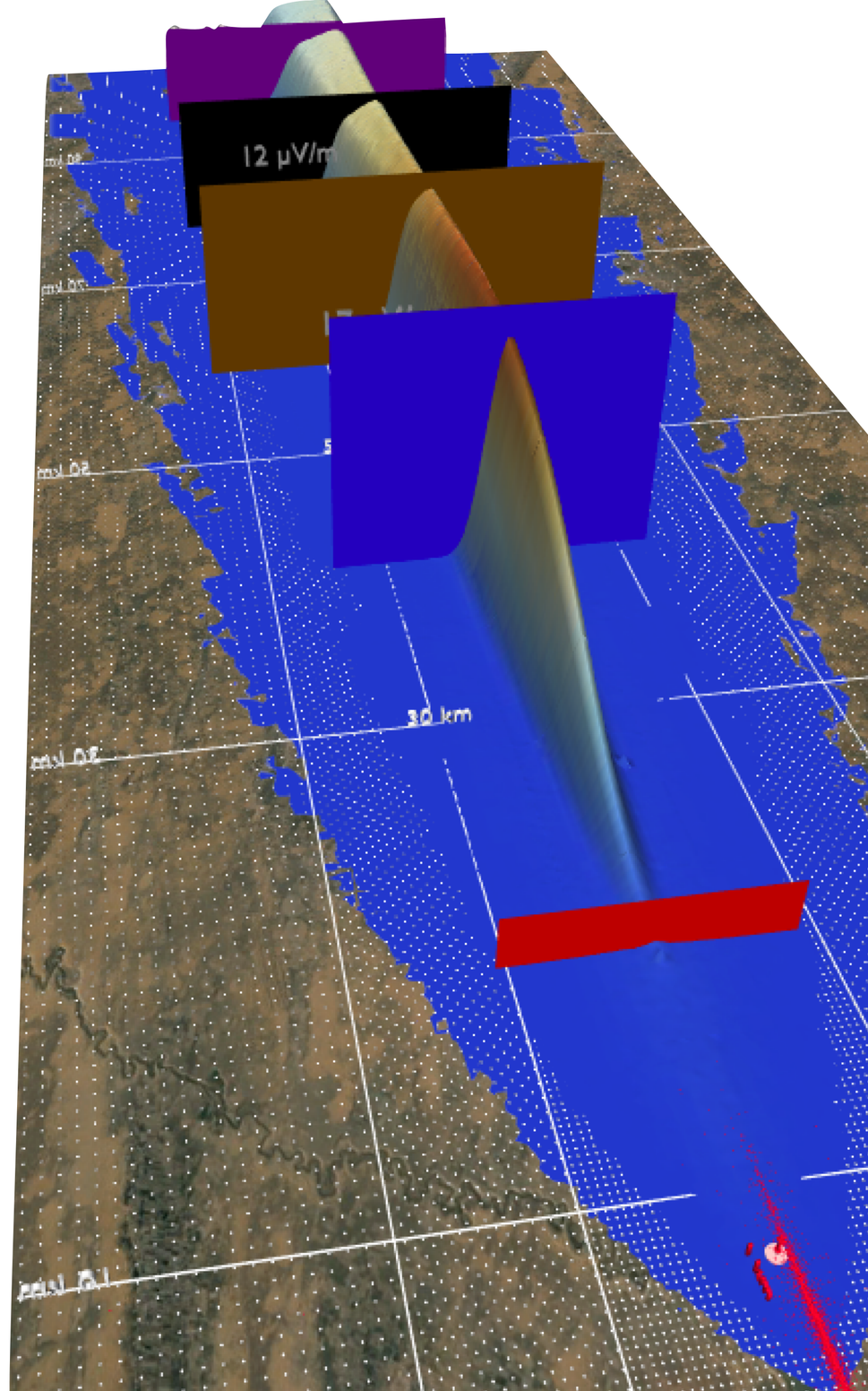


Proton induced shower
10^{17} eV



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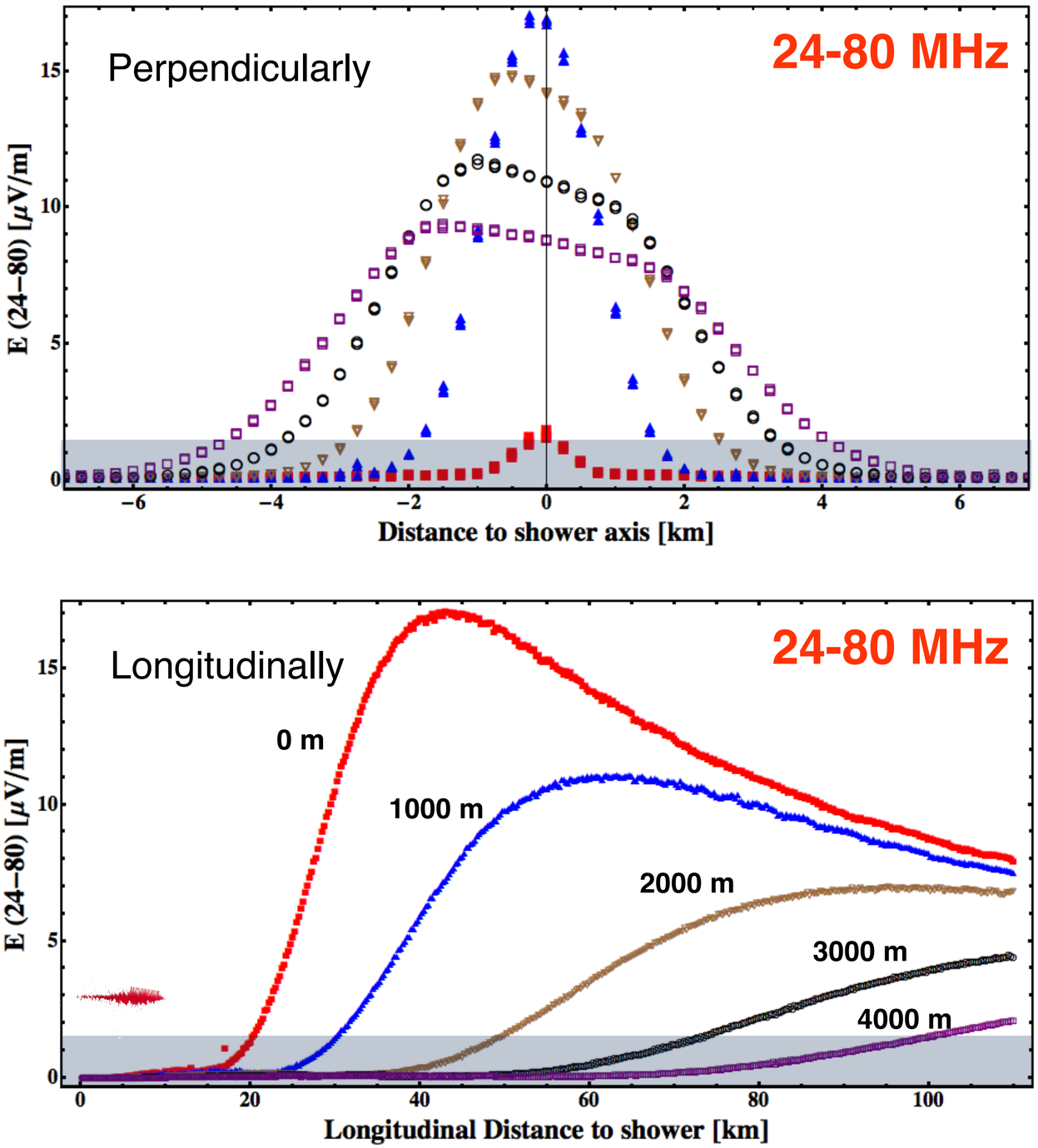

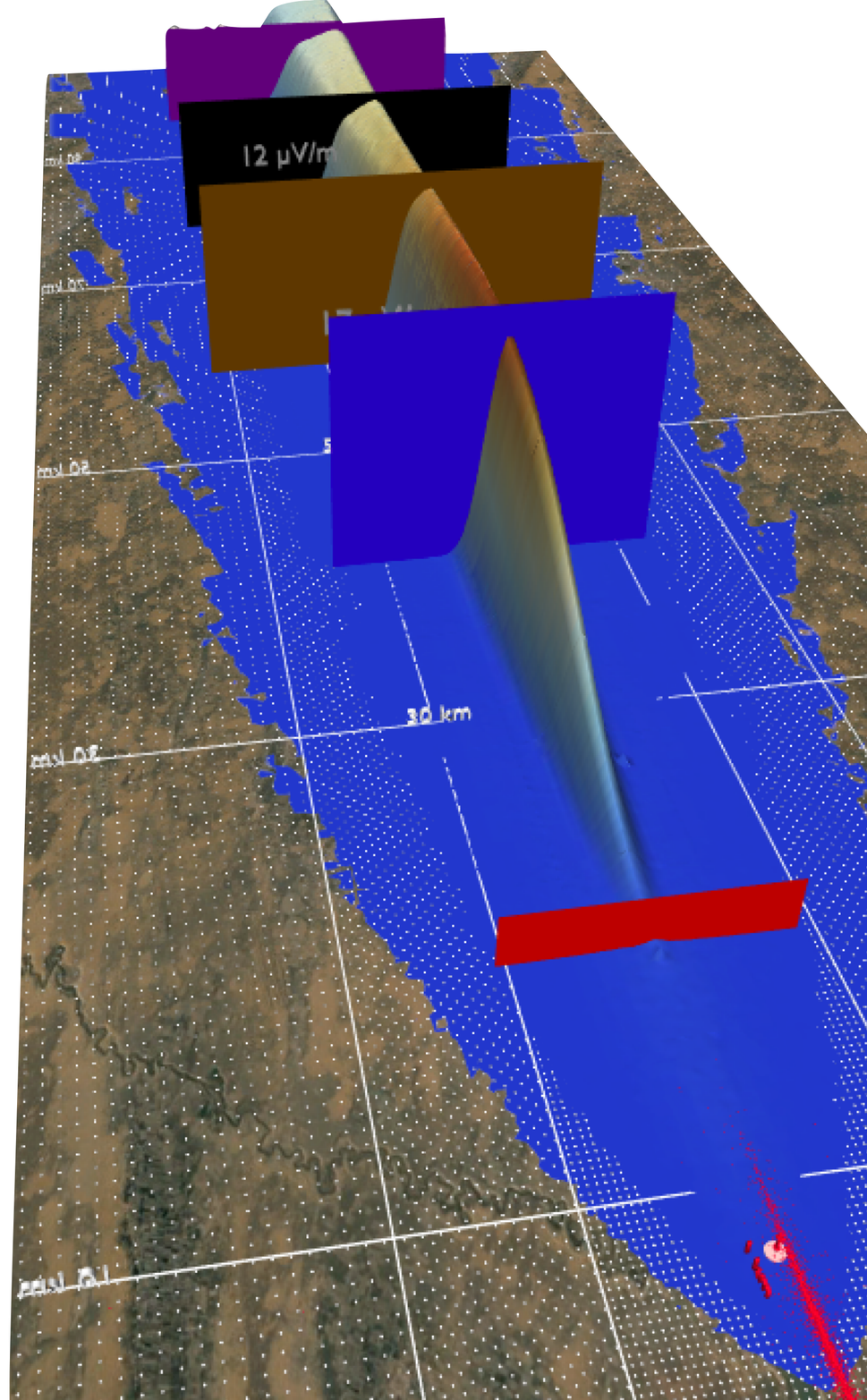

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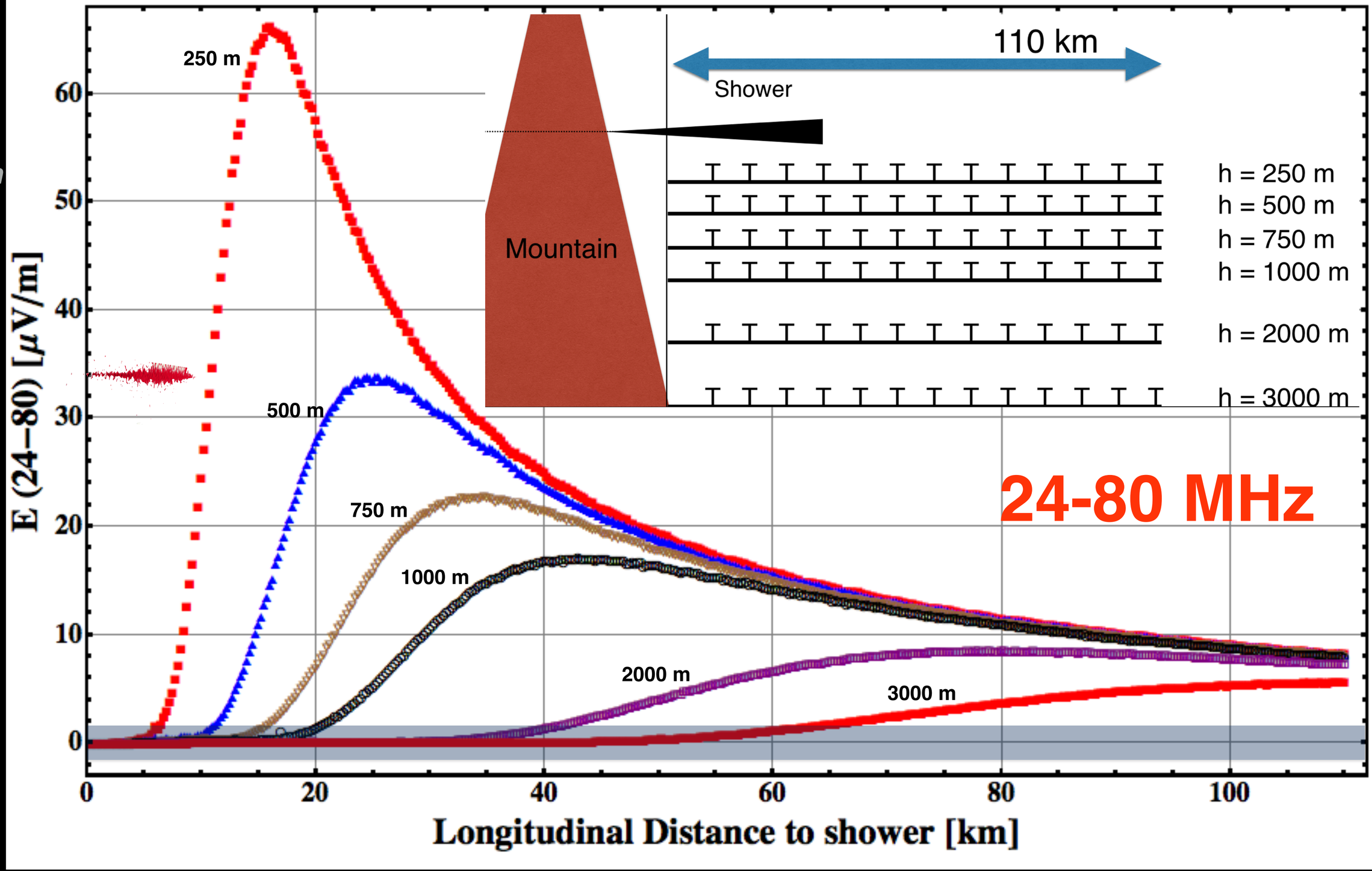


Conclusion

➡ The shower emits electric field in a strong narrow cone

➡ The radio detection could be done really far from the shower (>100 km, may be 200 km) if detectors are located along the shower direction (However caution with wave propagation… Not clear for the moment)

➡ Detectors located close to the shower are blind due to the « cone effect ».

➡10^{17} eV showers seem to be « detectable » above Galactic BG
➡10^{18} eV, field ~ x10, so better detection.

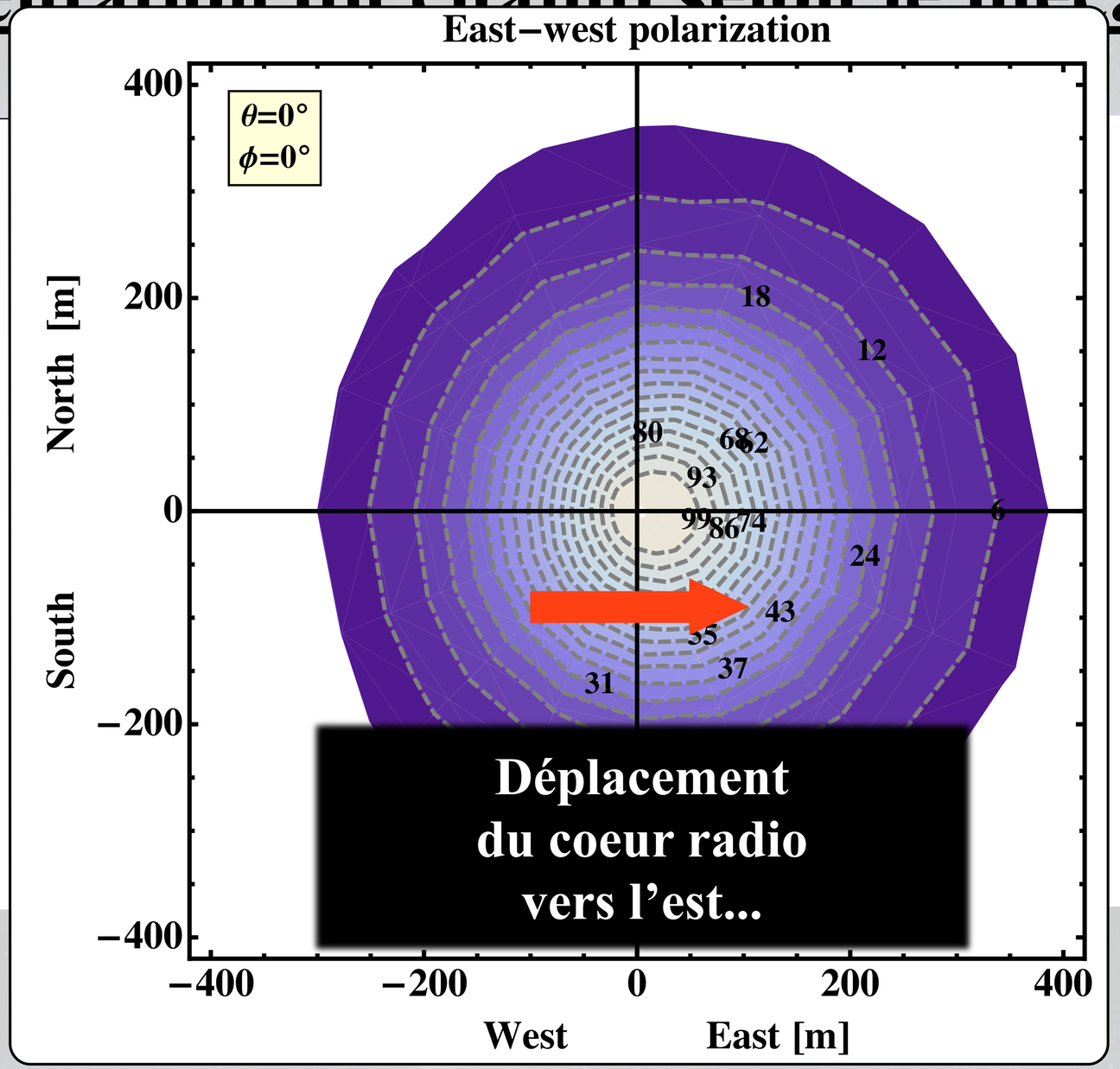
➡ Caution with wave propagation and ground effects (conductivity, permitivity dielectric…). Currently in progress in SELFAS.

➡Proton shower but what about real neutrino showers?

SEFAS2

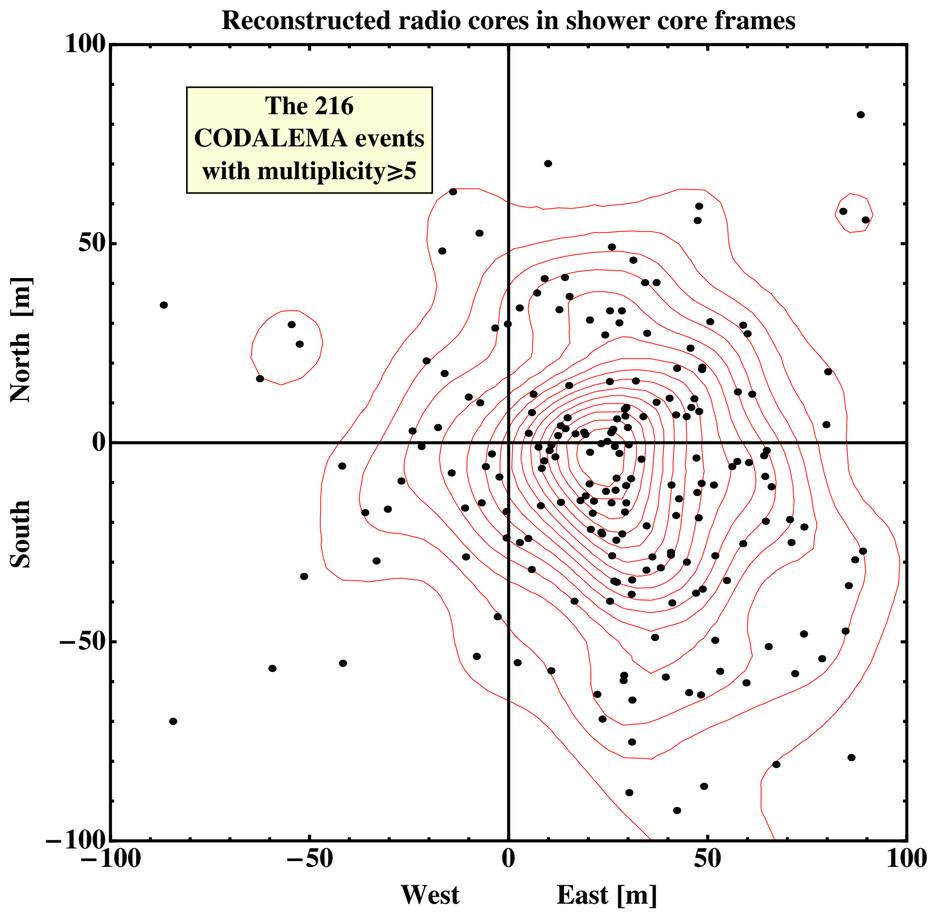
Asymétrie est-ouest du signal radio : **Conséquence de la contribution excès de charge**

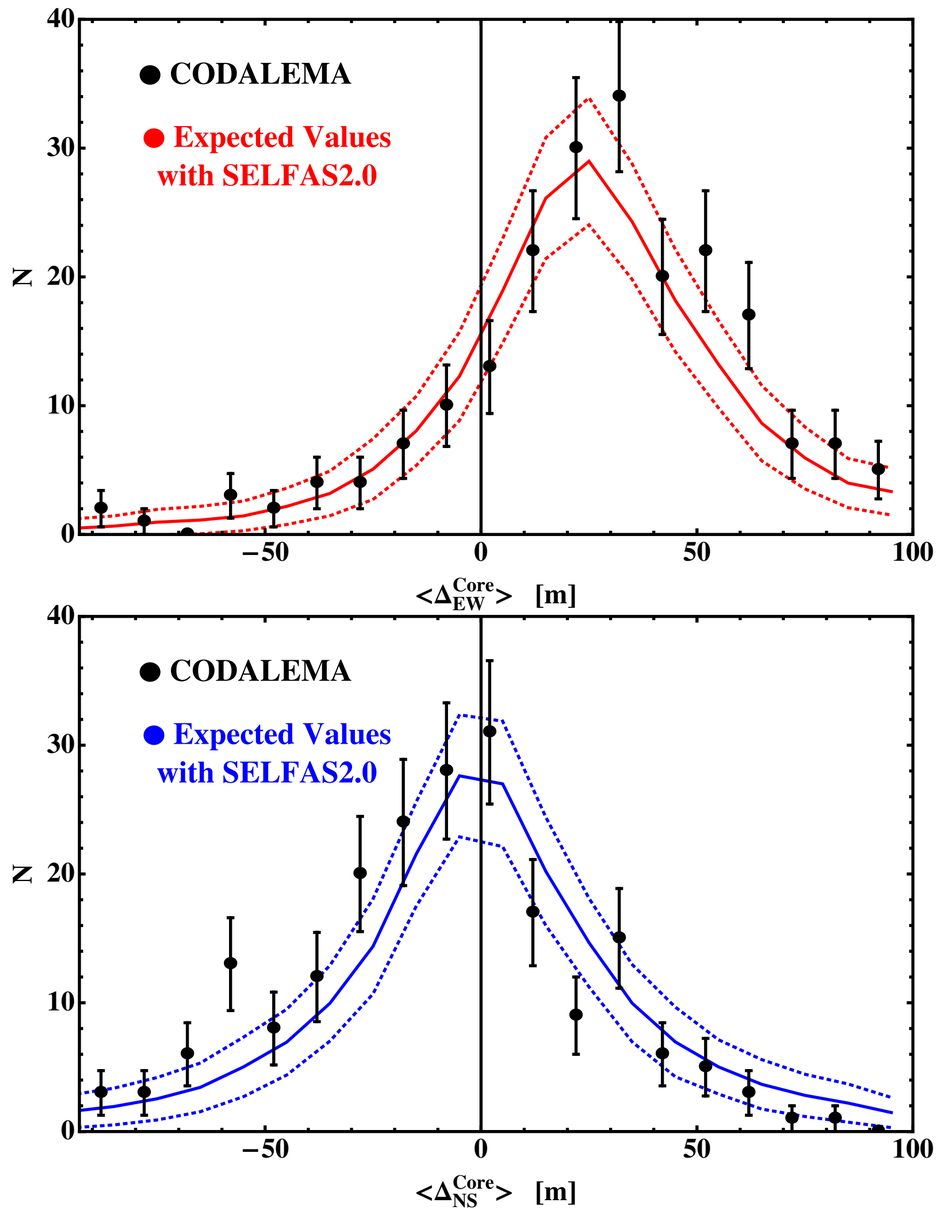
Orientation du champ selon le mécanisme



Some data comparisons…

@ CODALEMA : décalage de coeur = signature de l'excès de charge





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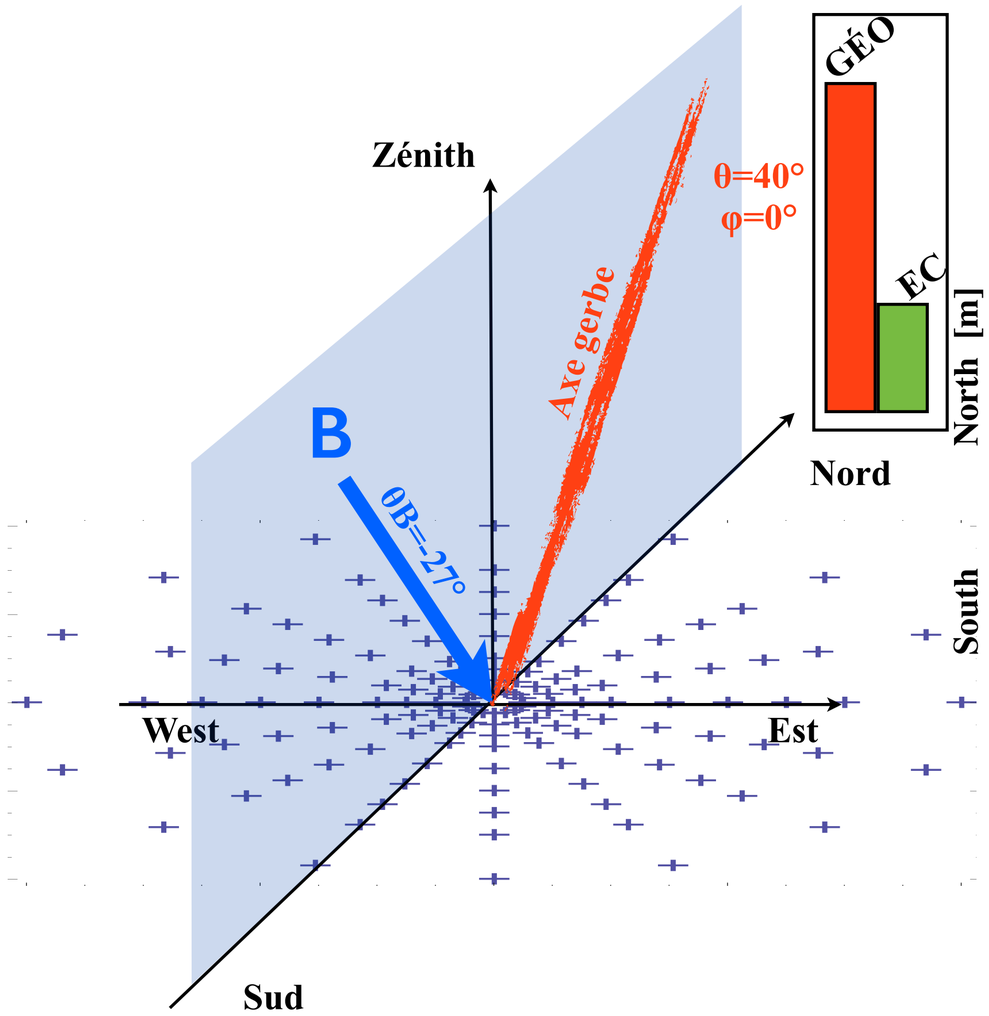
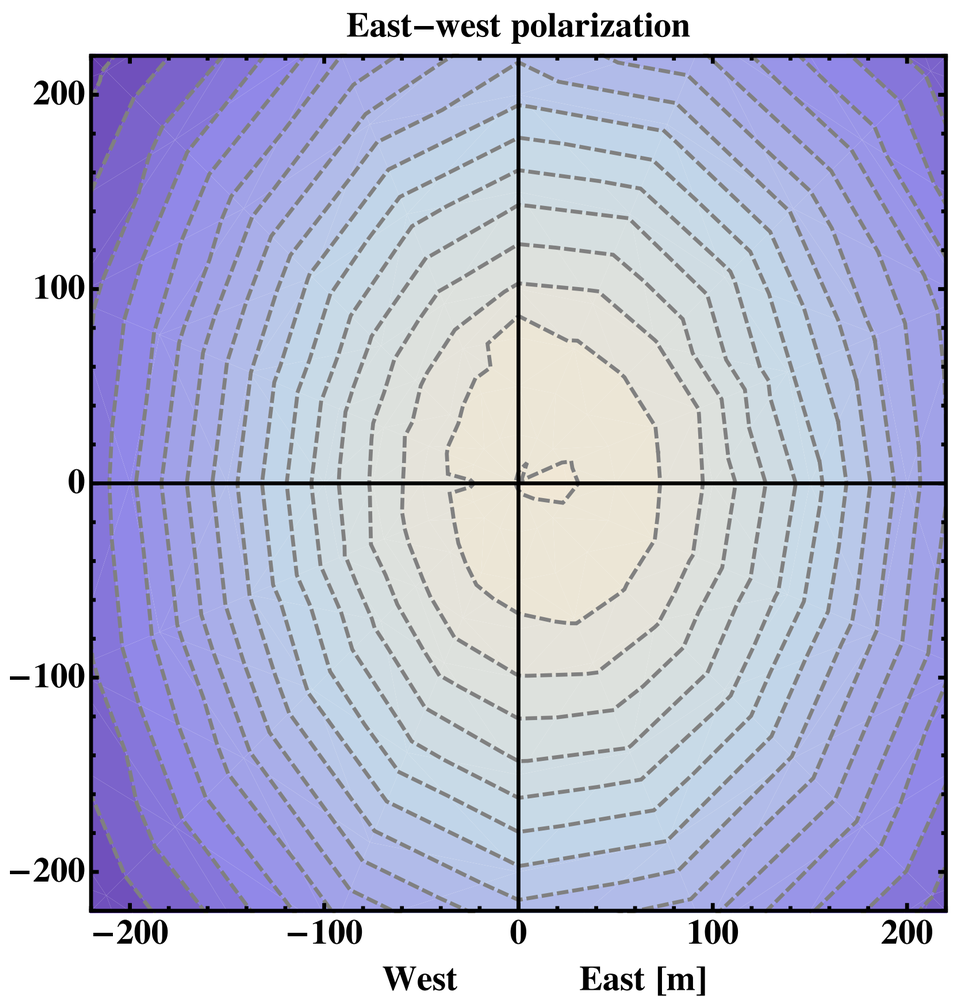
Effet pour différentes directions d'arrivée





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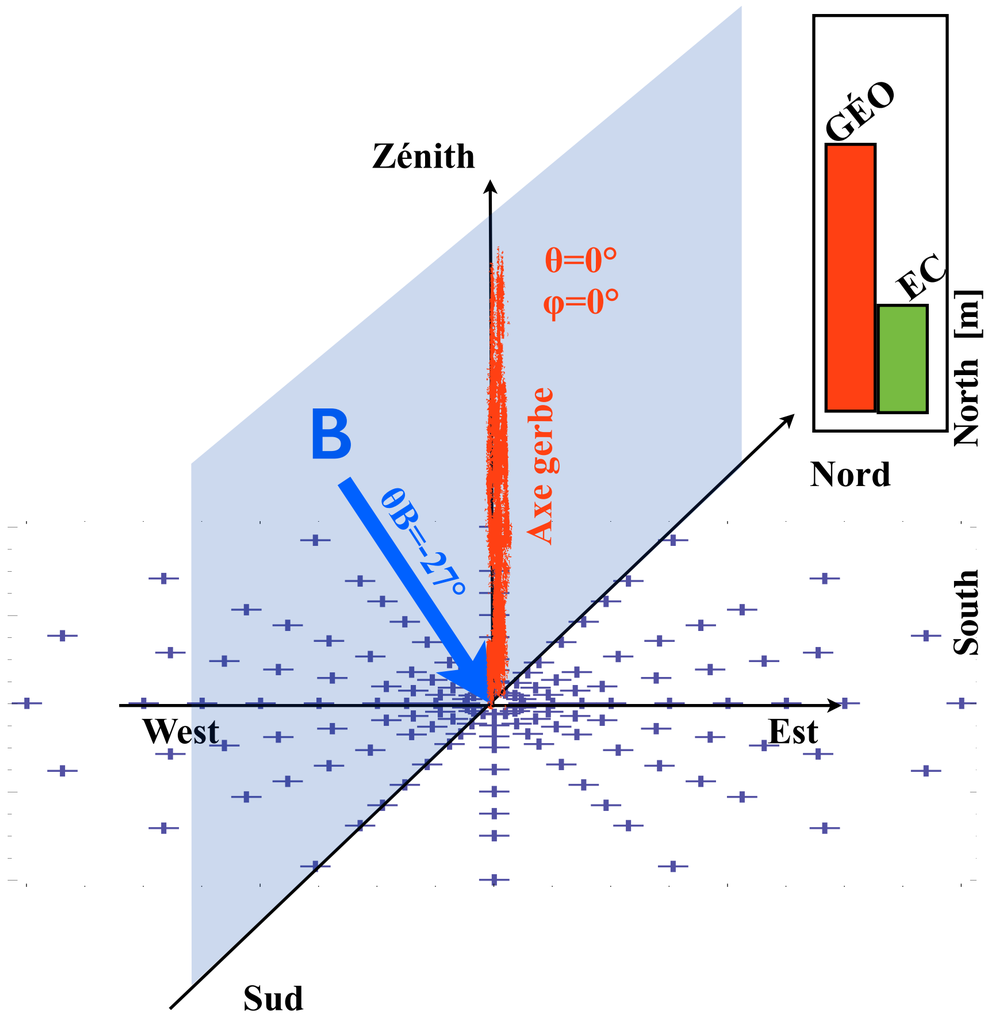

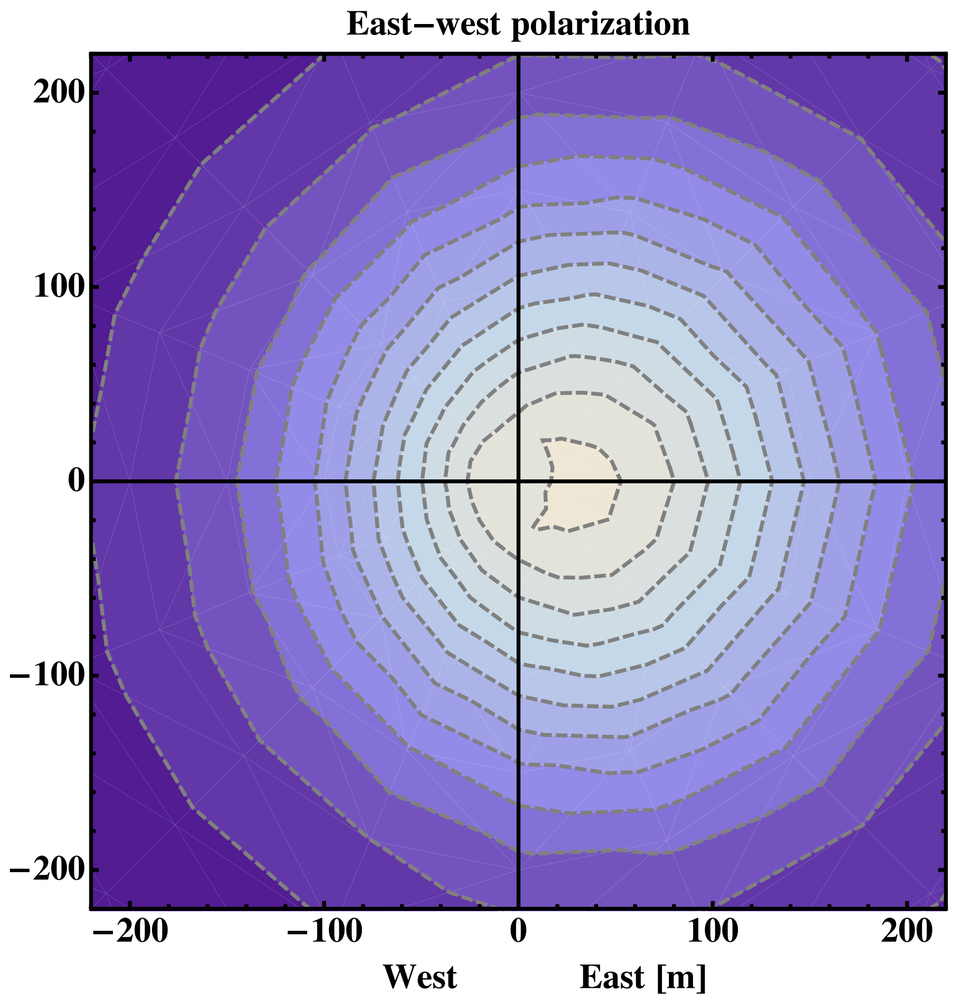

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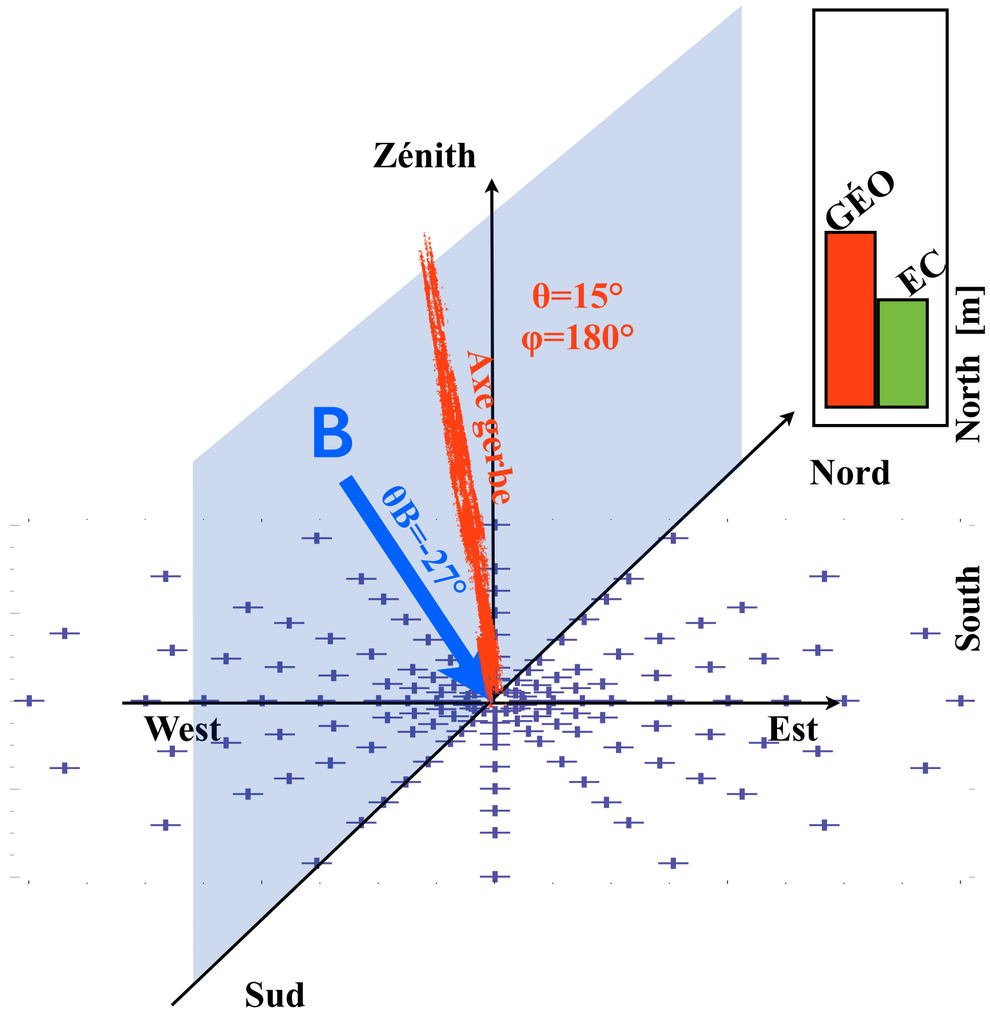

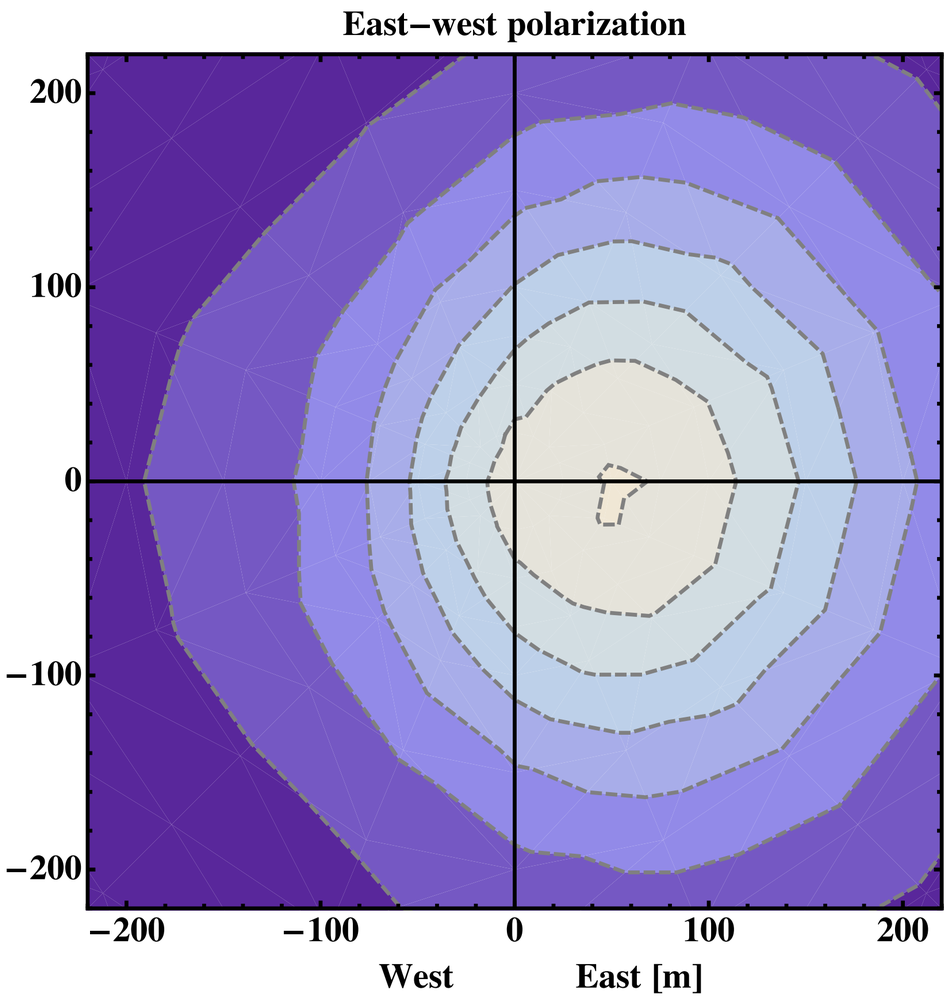

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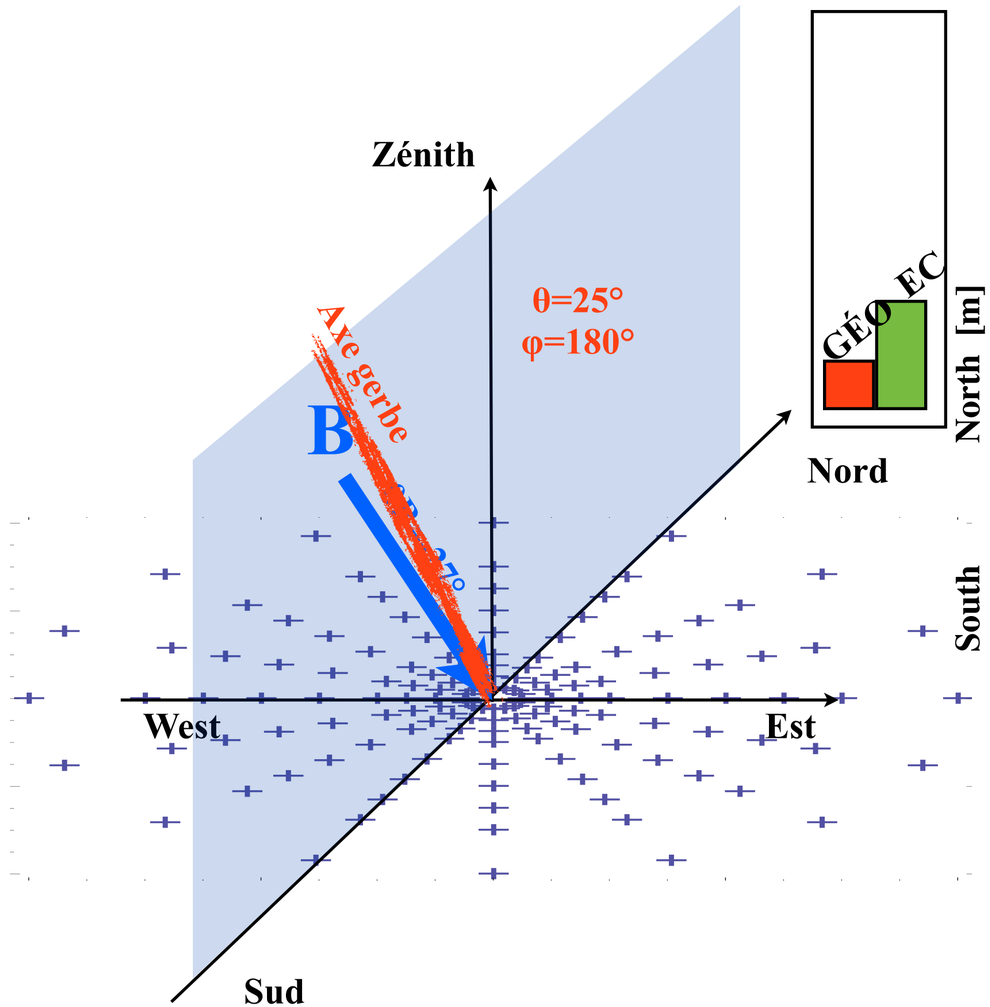

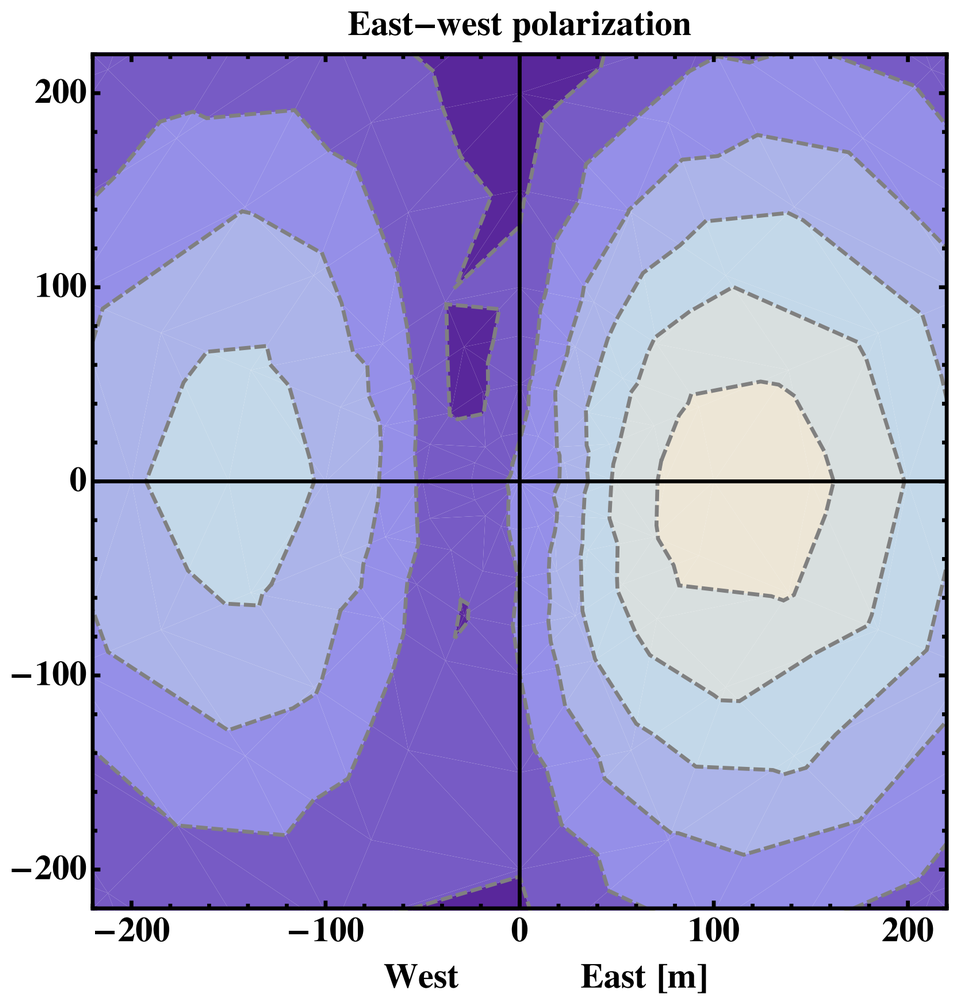

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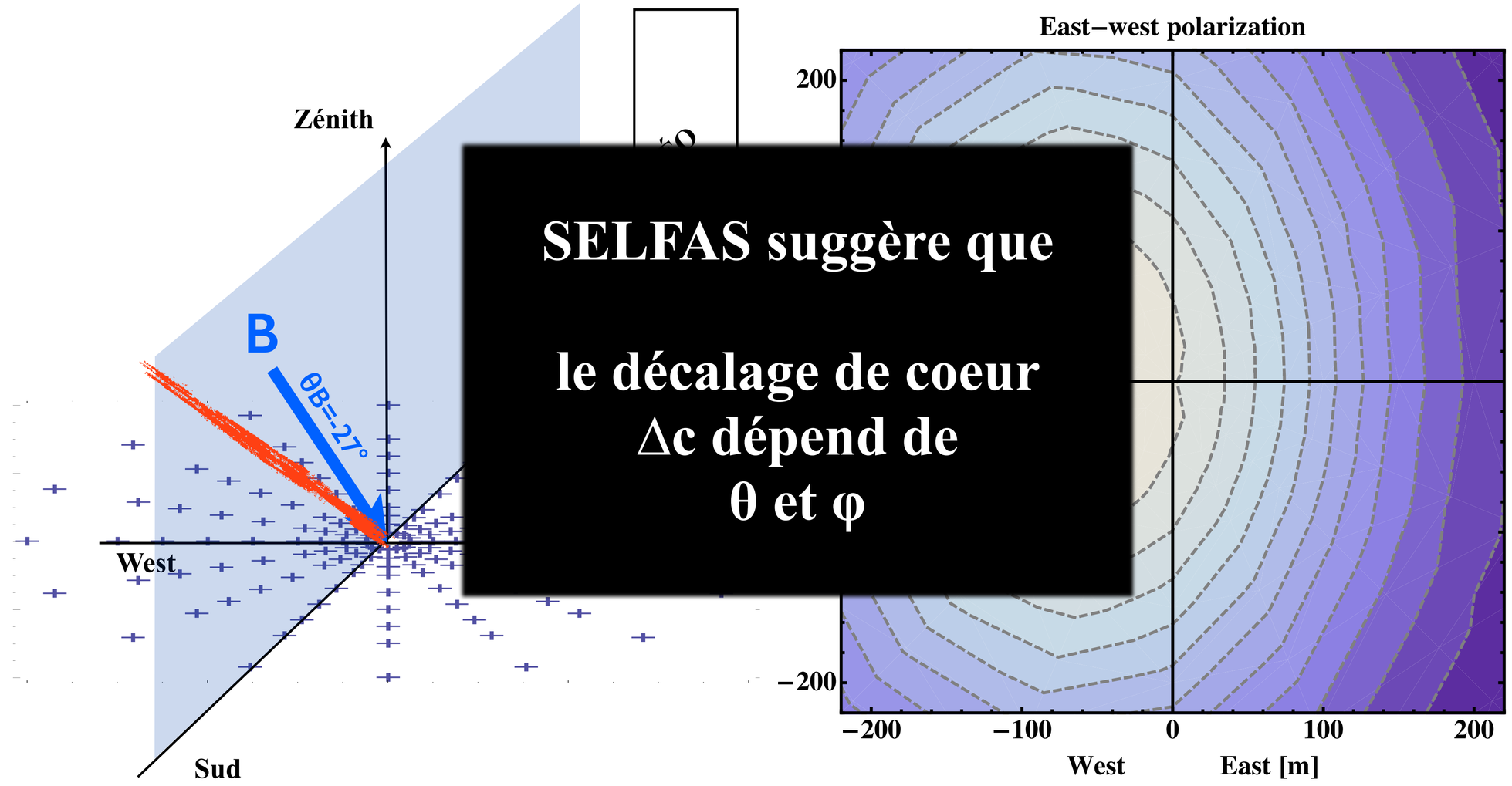

SELFAS suggère que

le décalage de coeur Δc dépend de θ et φ

Some data comparisons…

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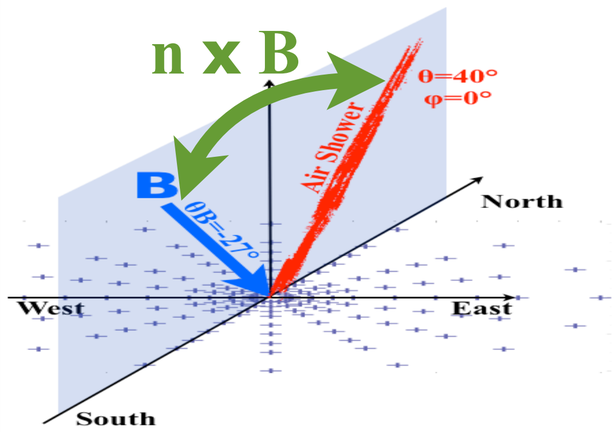

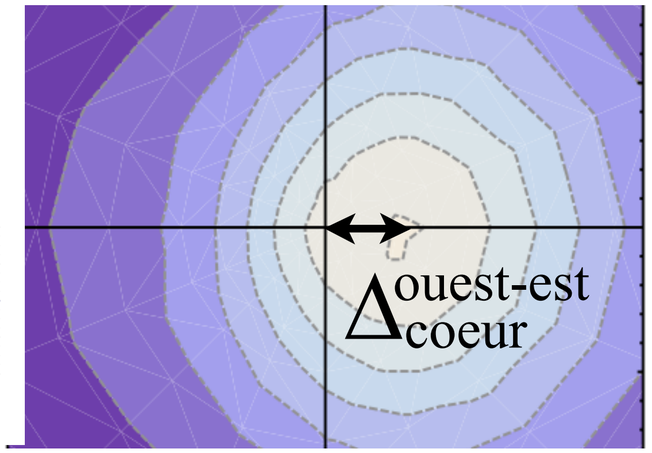

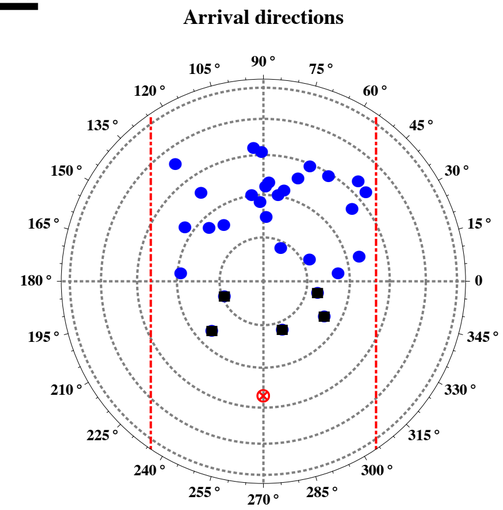

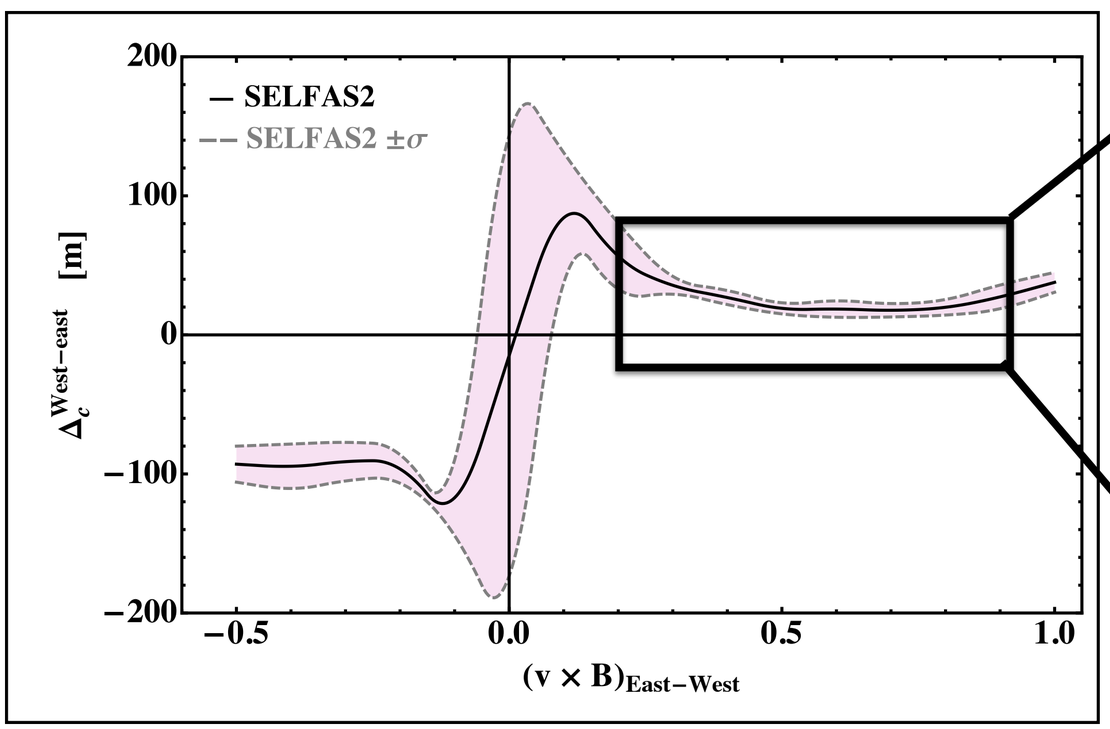

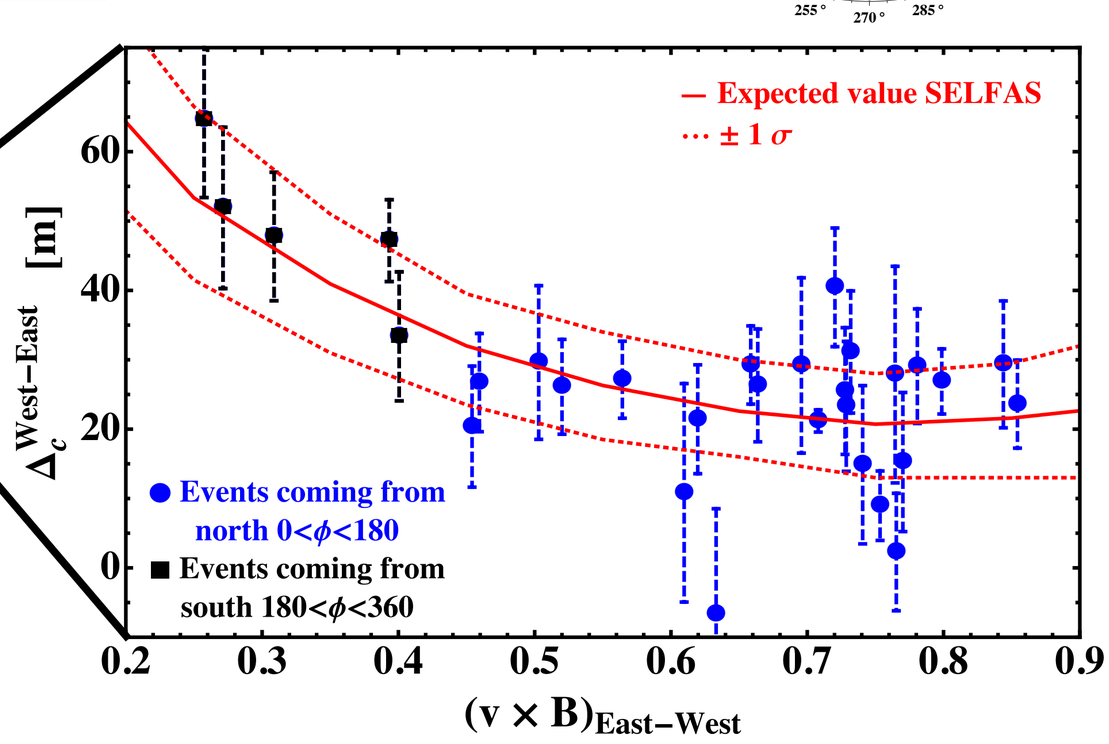

Notre compréhension au fil des Hz et des années…