SELFAS2

Simulation of ELectric Field emitted by Air Shower

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SUBATECH

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SELFAS2

➡ Dedicated to radio emission in the MHz range

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

➡ Based on air shower universality

➡ Using relevant universal distributions :

-GIL Longitudinal profile Greisen, Iljina, Linsley in Proc. of 27th ICRC
-Energy distribution
-Vertical and horizontal momentum direction
-lateral distribution
-Delay time (shower front thickness)

} Lafebre et al AP, 31(3):243–254 2009

➡ 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

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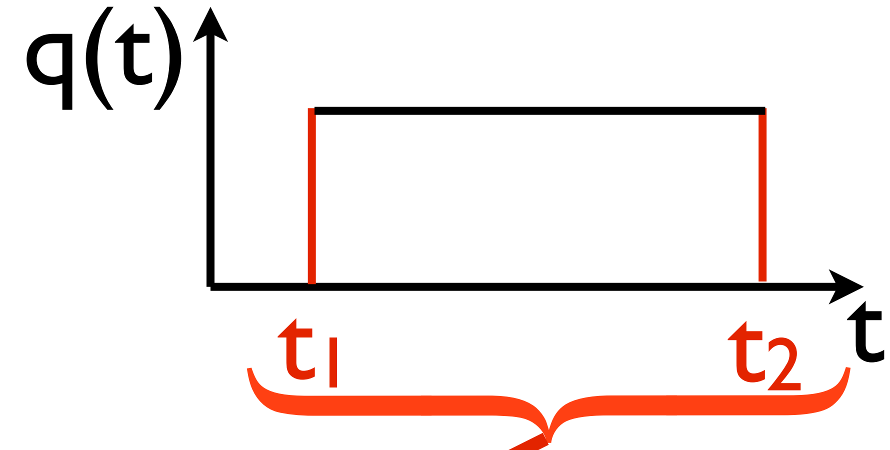
Individual charge with a finite life time

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 : (Lorenz 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 :

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

In SELFAS2 previous version :

Refractive index fixed to unity => No Cerenkov effects

At shower scale : summing up all contributions

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

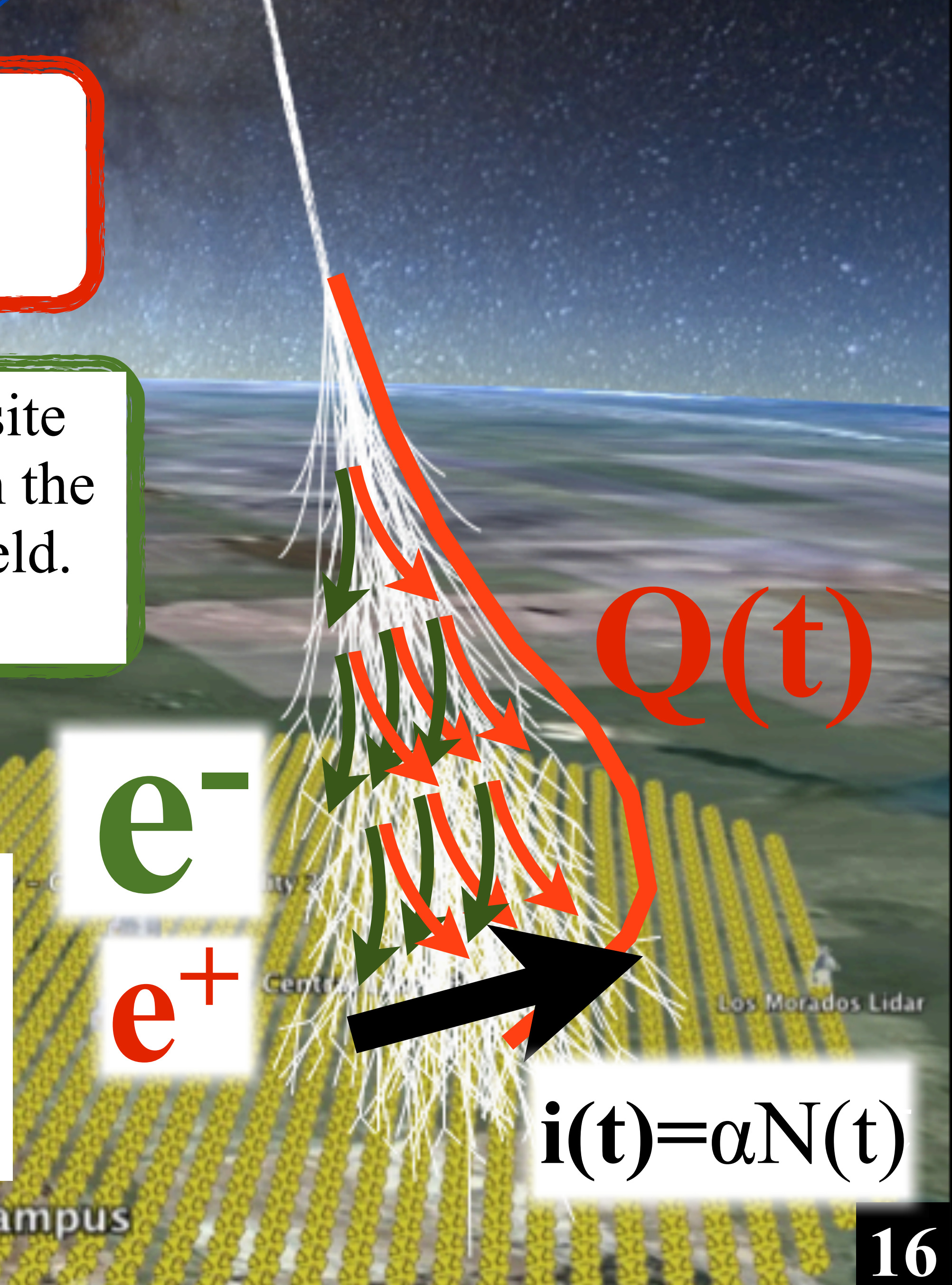
global Coulombian	Summation of all individual static contributions.

≈ 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



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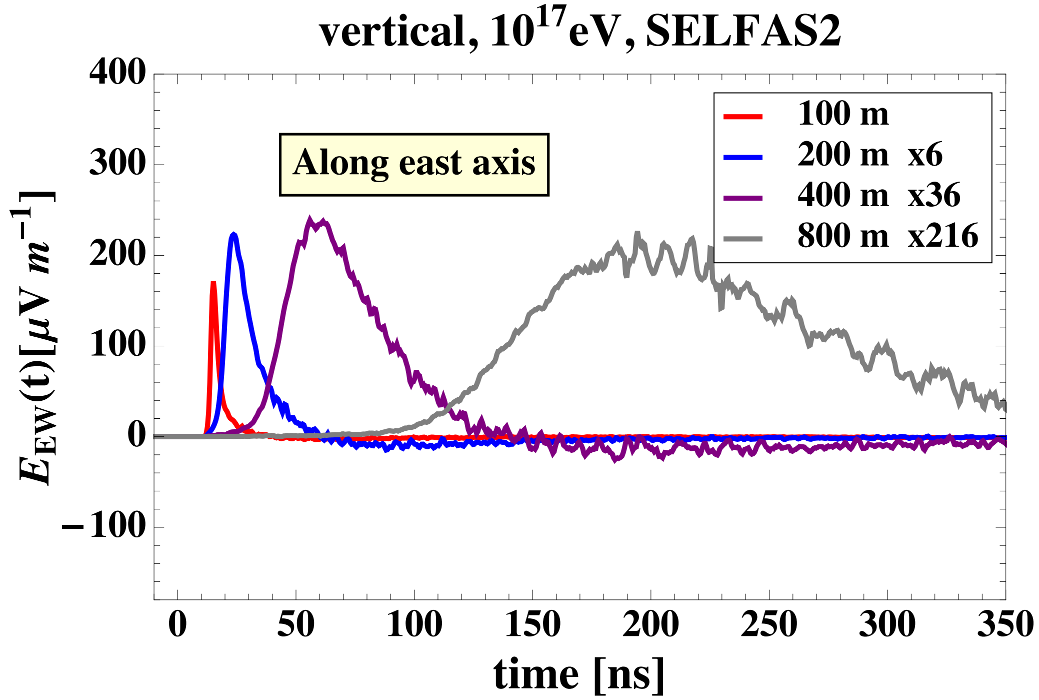
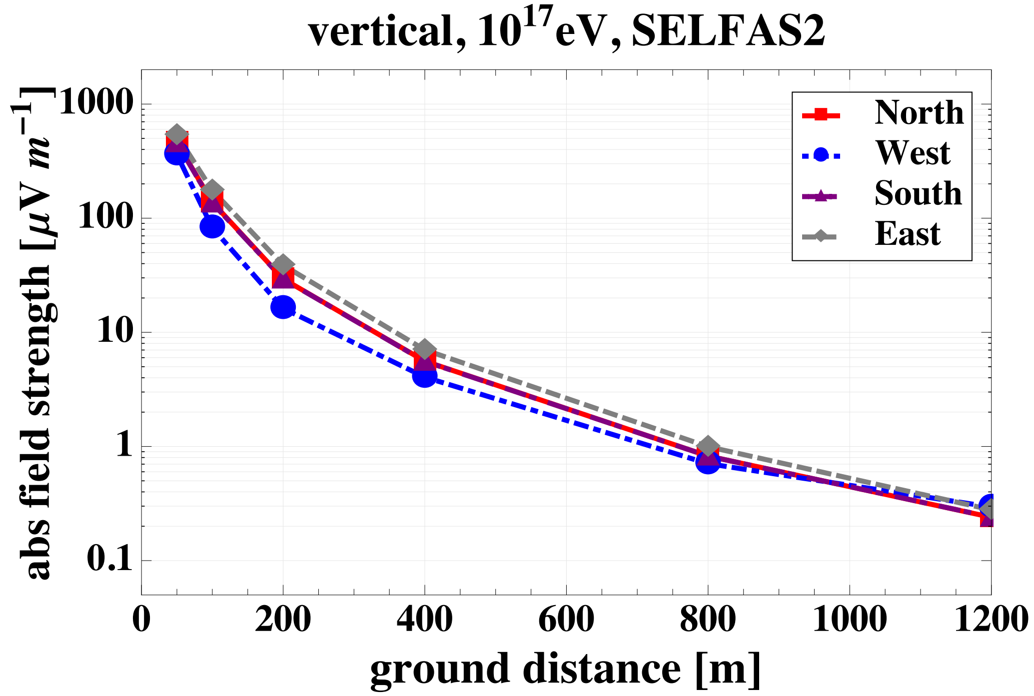
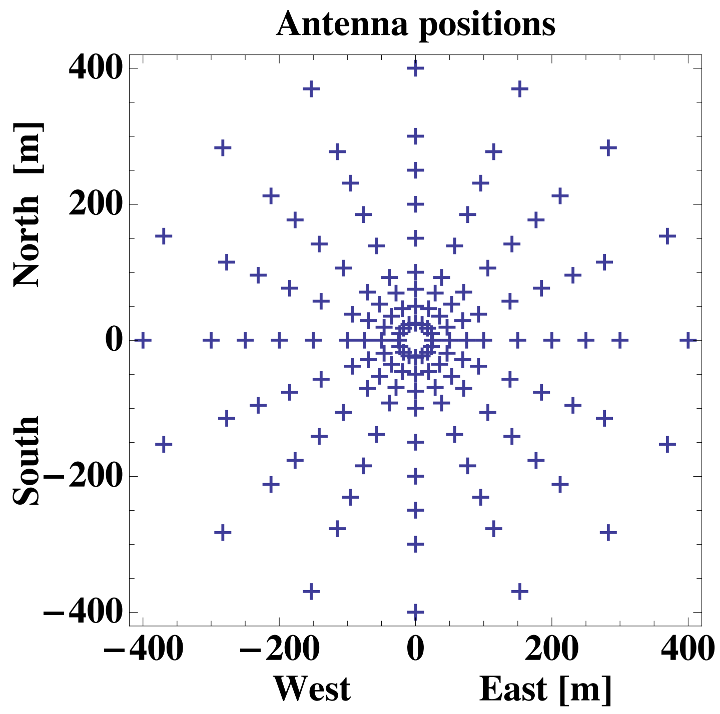
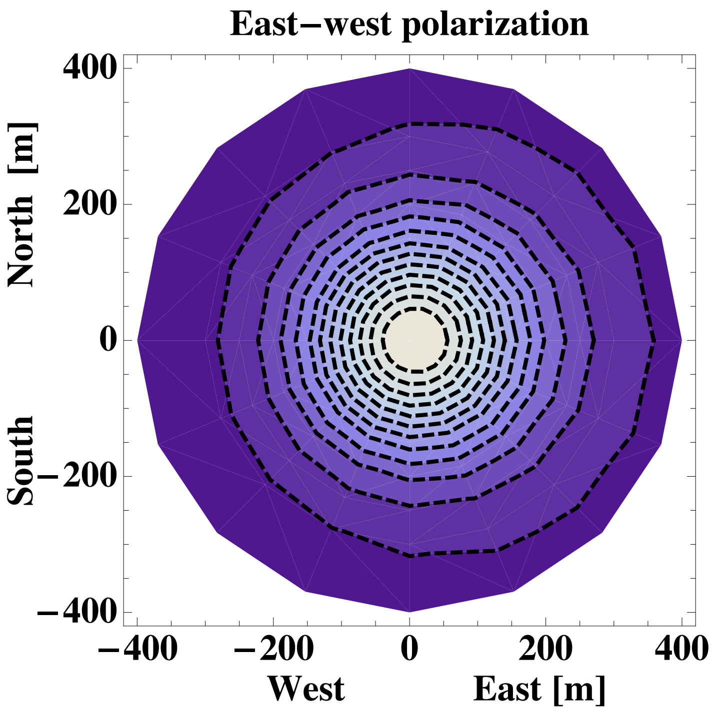
Example of a 10^{17} eV proton at Auger

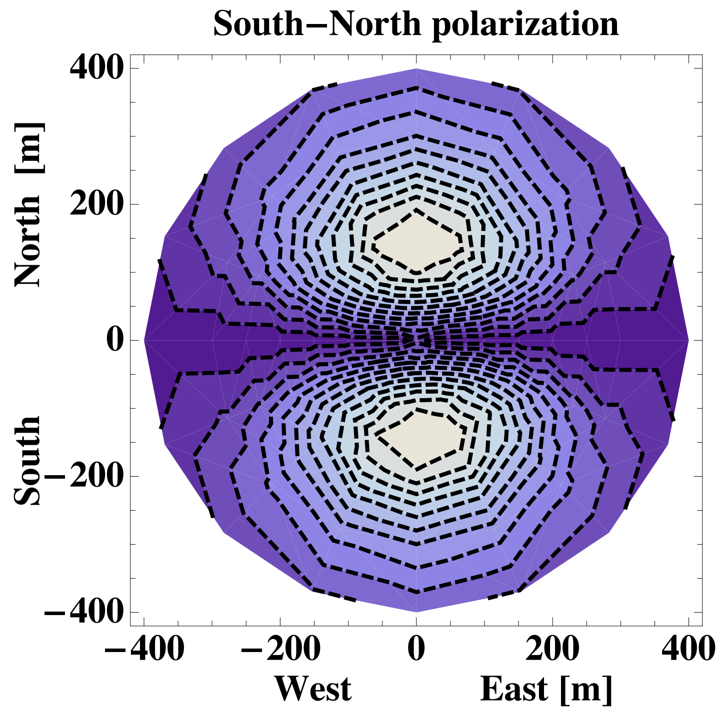
SELFAS2 at Astroparticle Physics
DOI : 10.1016/j.astropartphys.2012.03.007











East-west asymmetry due to the charge-excess contribution

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Comparison with data

SELFAS2
(with air refractive index = 1)

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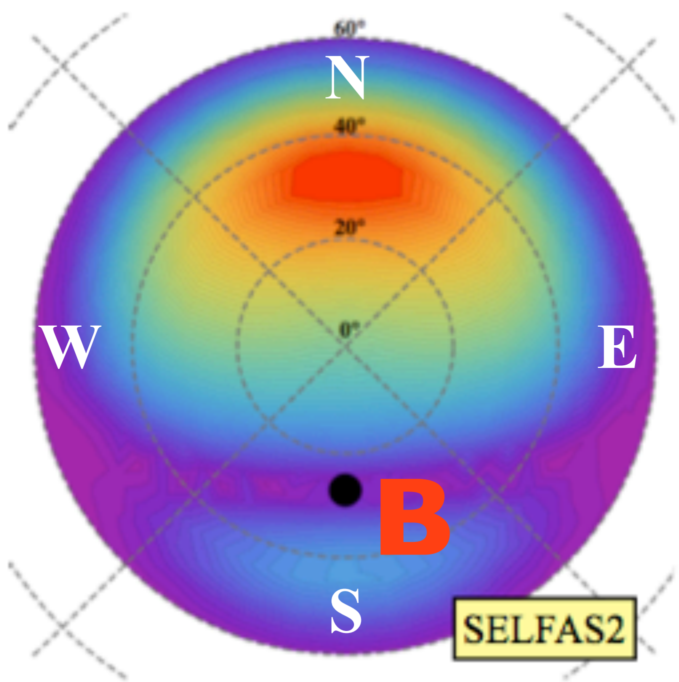
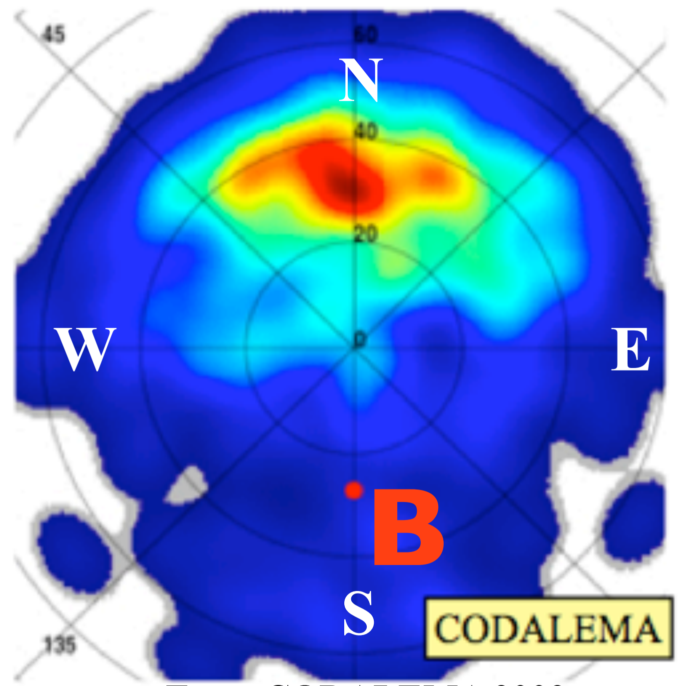
First SELFAS2 cross check with data : The arrival direction dependence

Density skymap of detected events in EW polarization for CODALEMA site

Predicted by SELFAS2

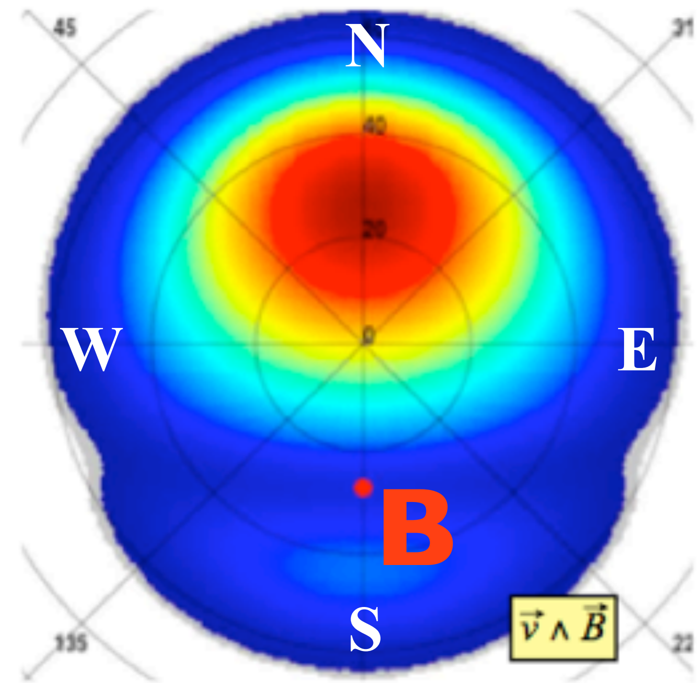


With events seen by CODALEMA-II



From CODALEMA 2009
A-P. 31, 3 (2009) 192-200.

Predicted by vxB toy model



More than 1 thousand events simulated around 10^{17} eV with SELFAS2, for various arrival directions

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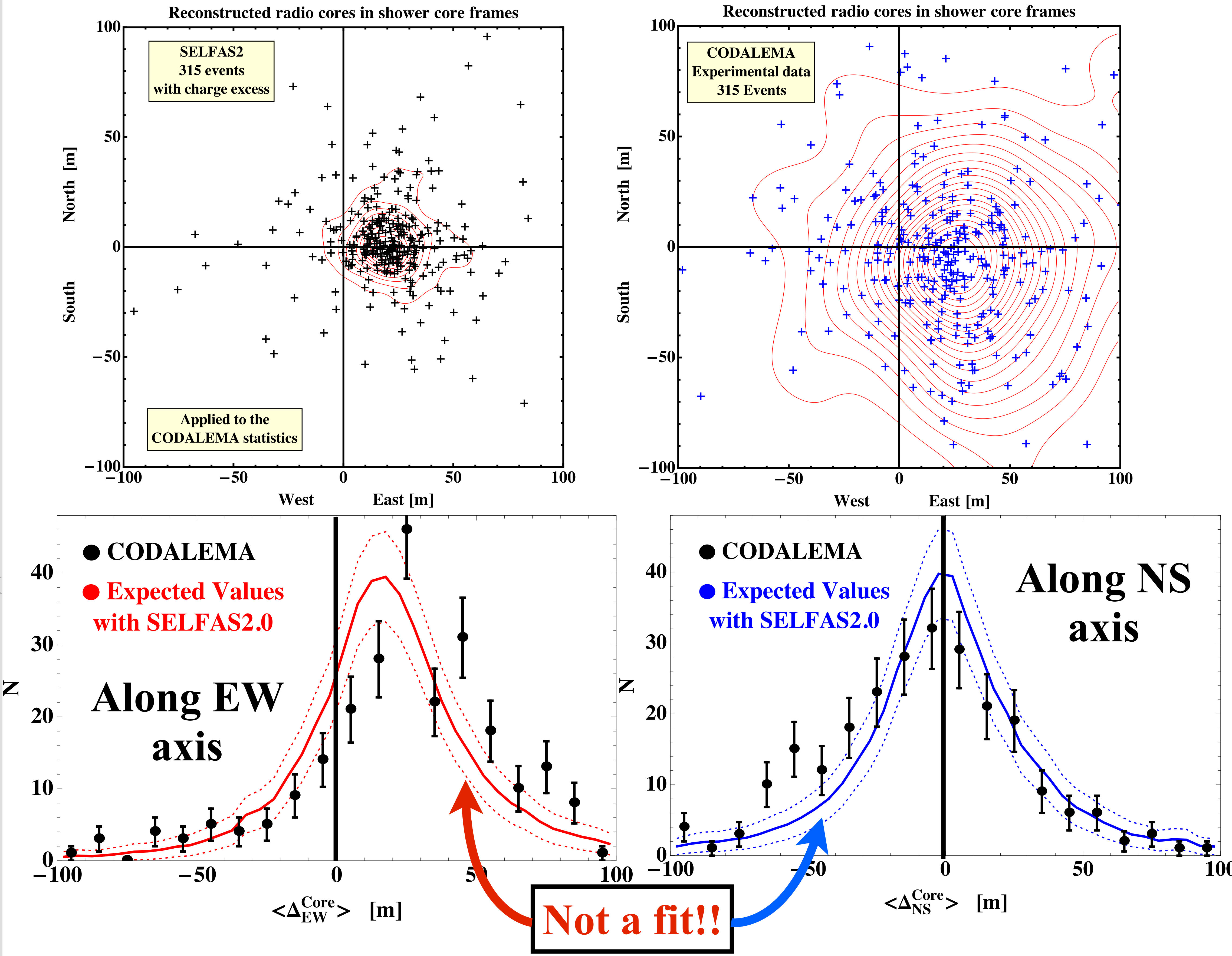
Second SELFAS2 cross check with data : Radio core shift as charge excess signature



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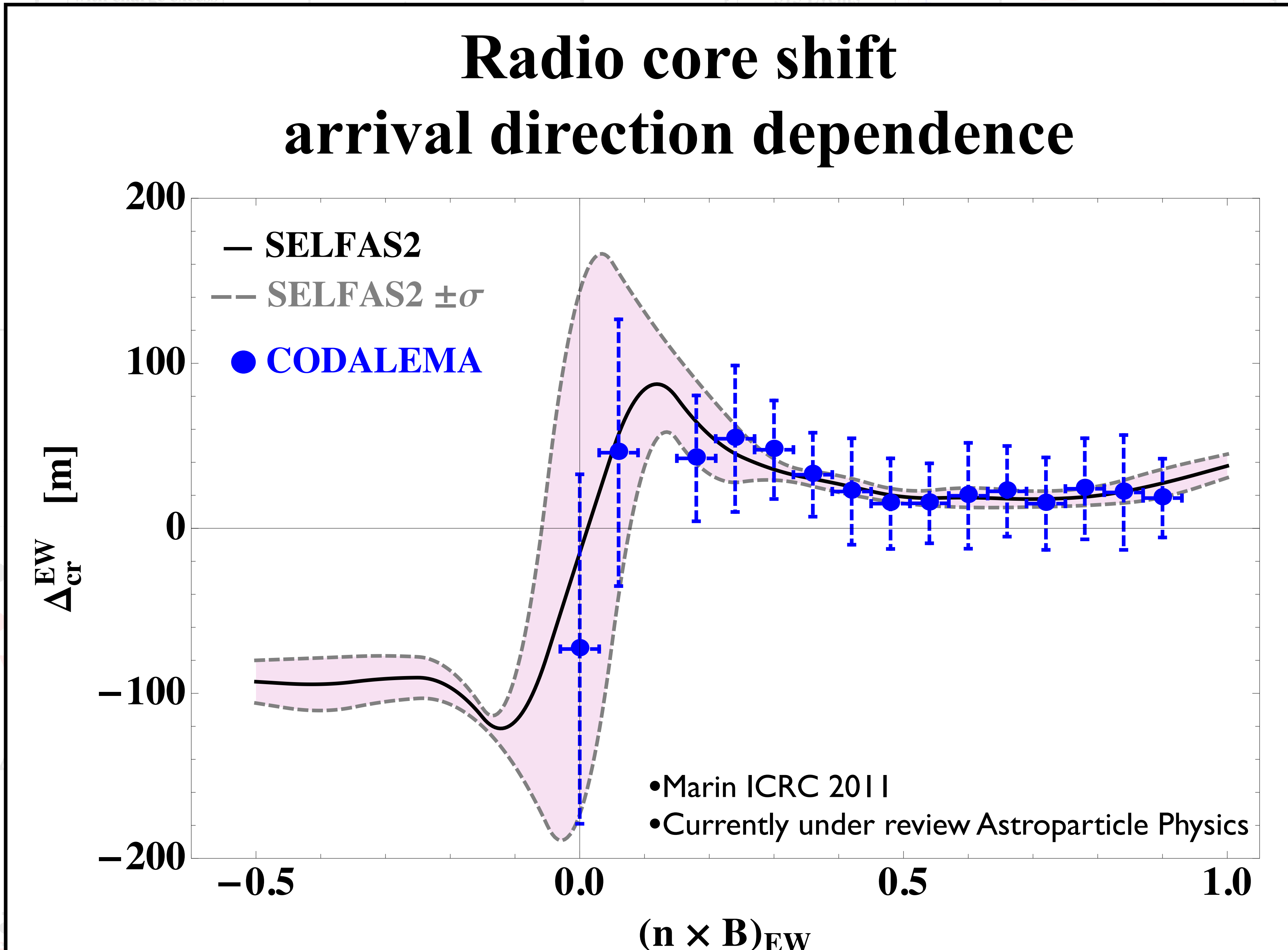

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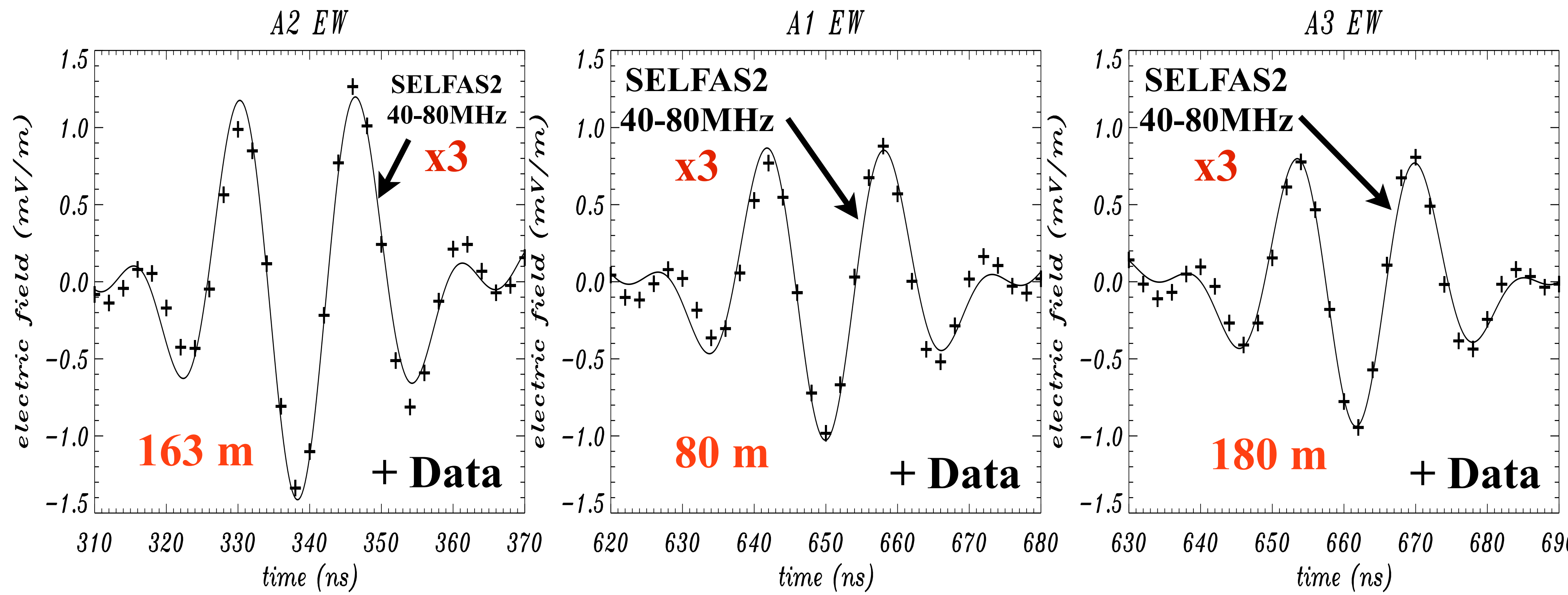
Third SELFAS2 cross check with data :

Direct comparison with a three-fold RAuger1 event deconvoluted from antenna response

Filtered-band 40-80 MHz



Scaling factor of 3??

➡Dependence to first interaction length

➡Number of particles predicted by simulation underestimated

➡Air refractive index not included in SELFAS2...
(but can't explain a factor of 3 in 40-80MHz region as we will see)

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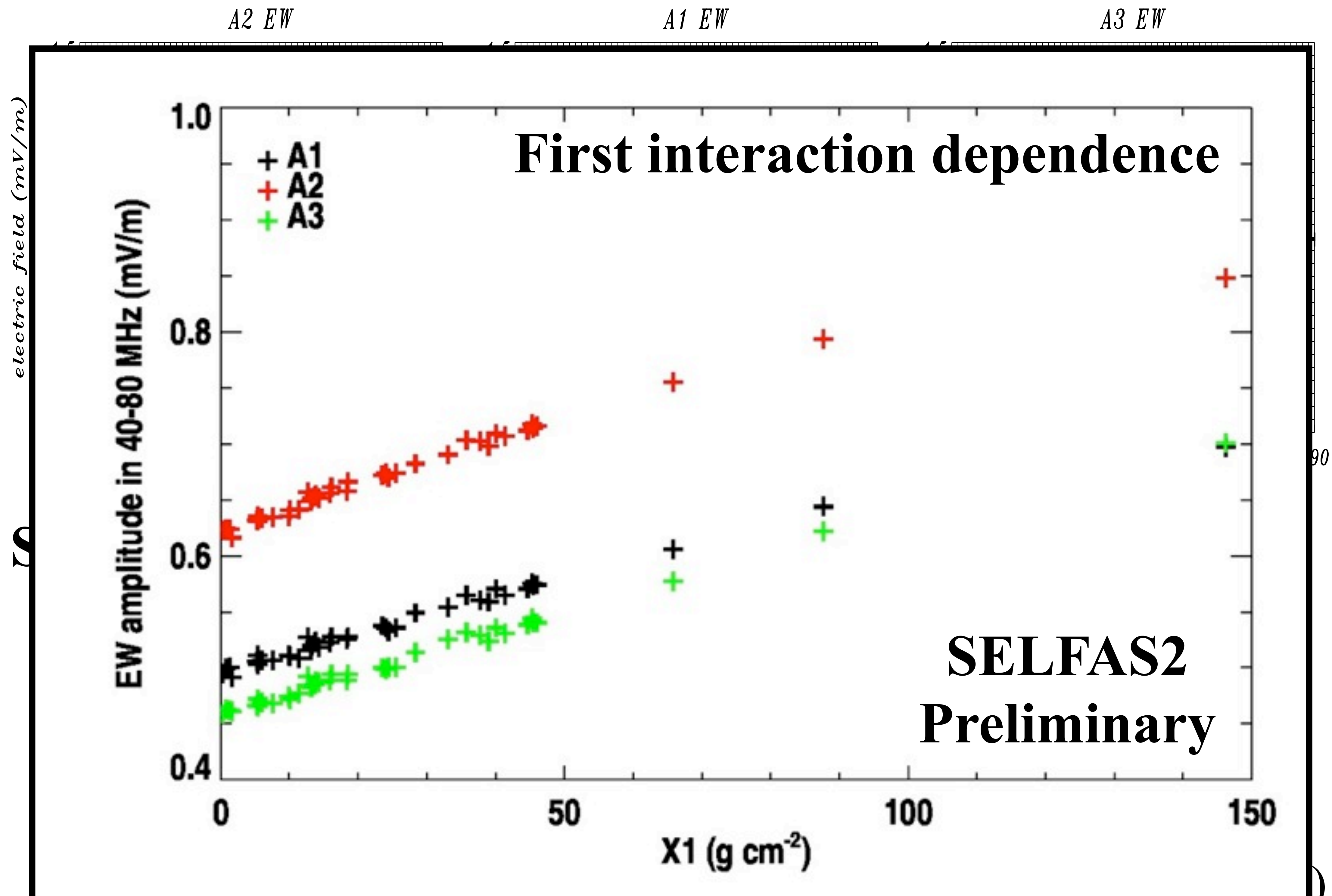

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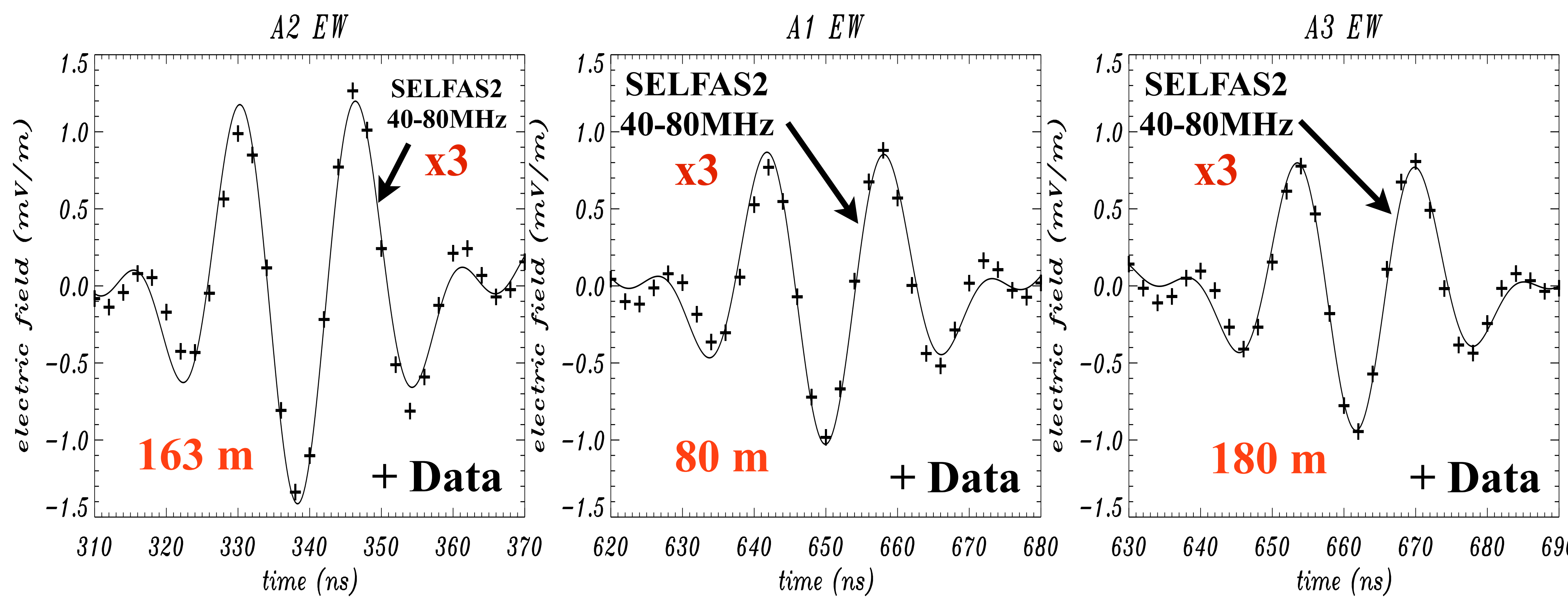

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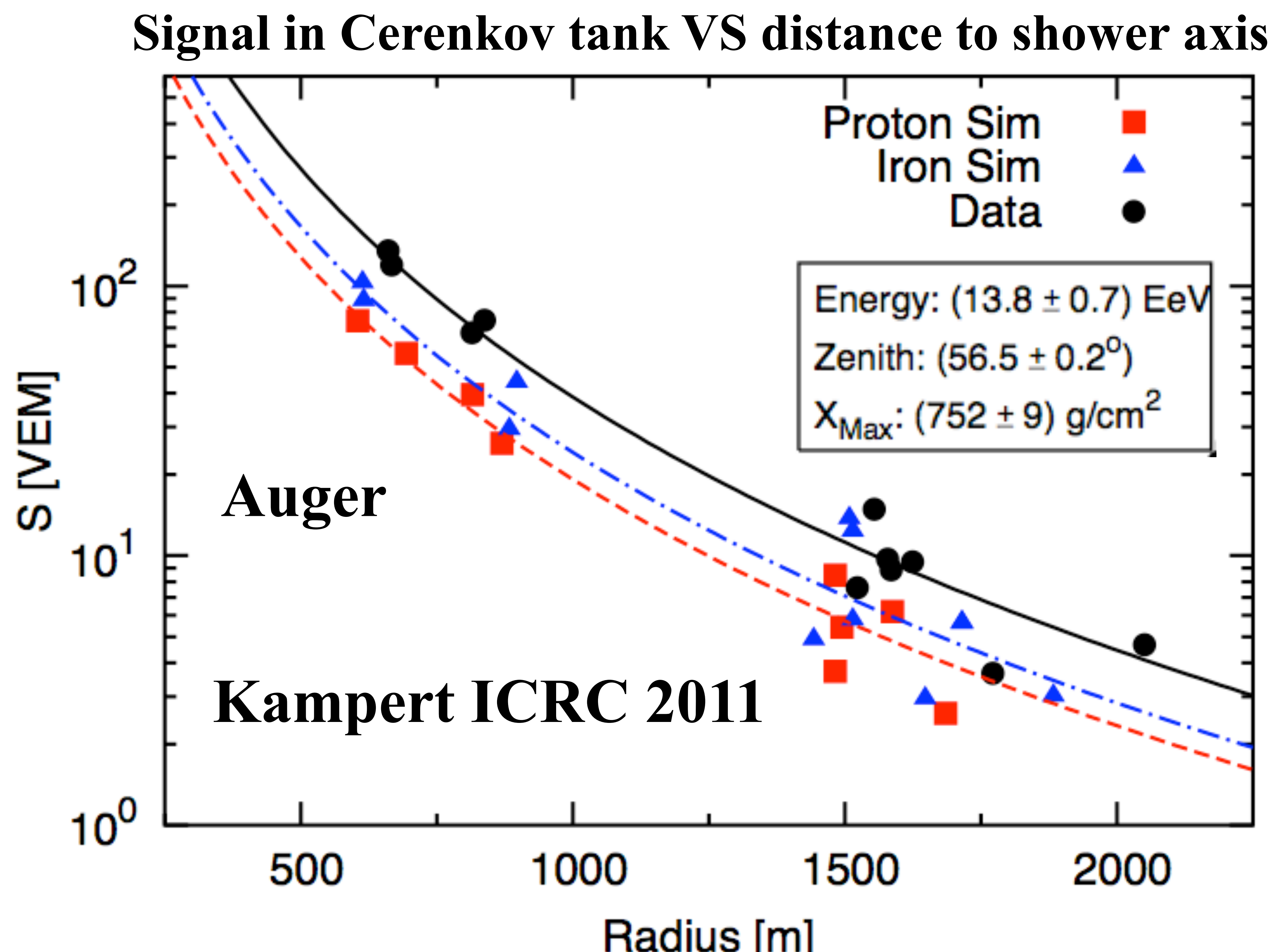

Deficit of muons predicted by simulation with respect to signal observed in the Cerenkov tank in Auger data.

Scaling factor of ≈ 2

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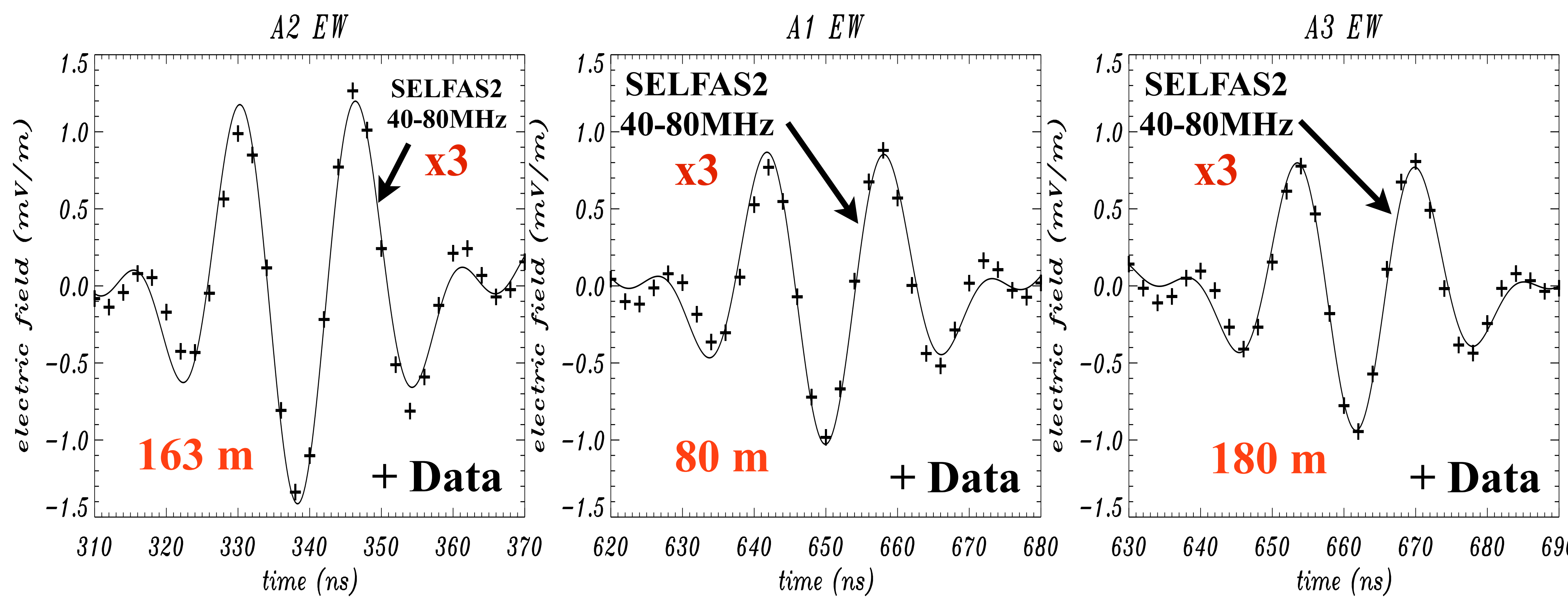

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SELFAS2 with realistic air refractive index $n=n(h)$

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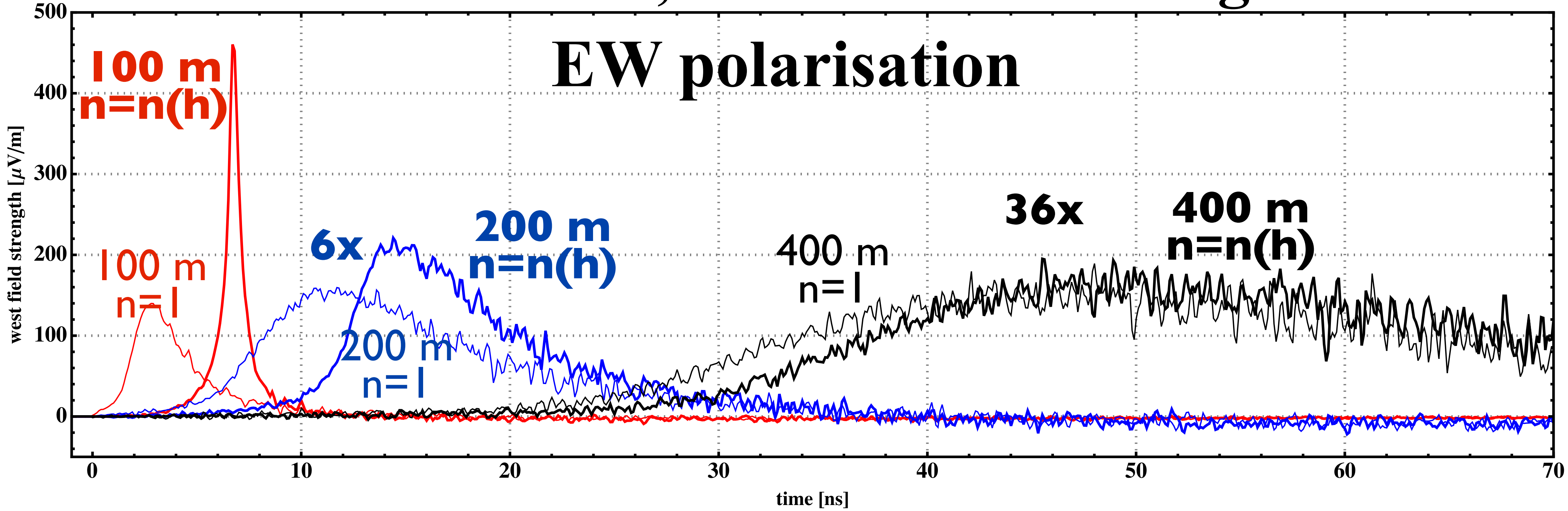
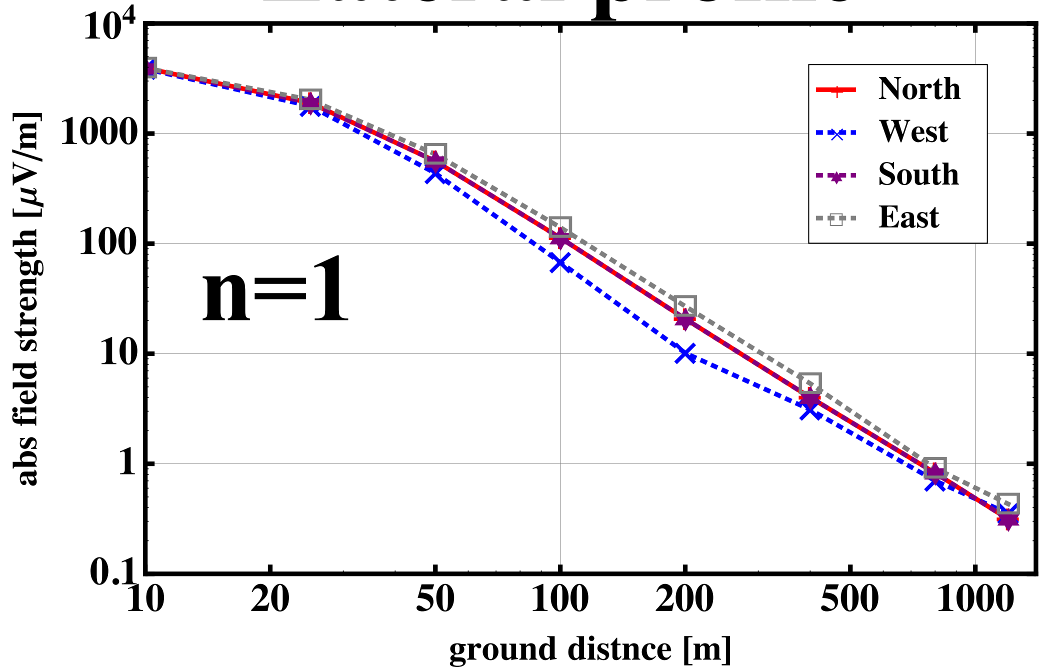
SELFAS2 + realistic air refractive index

Vertical air shower, 10^{17} eV 1400 m Auger B-field



Lateral profile



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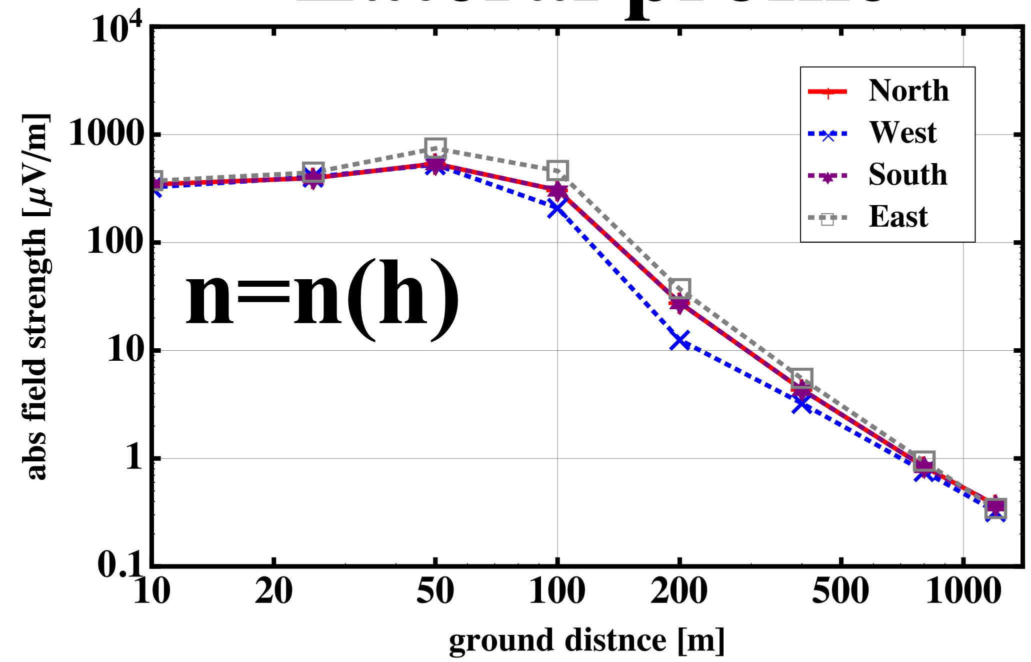

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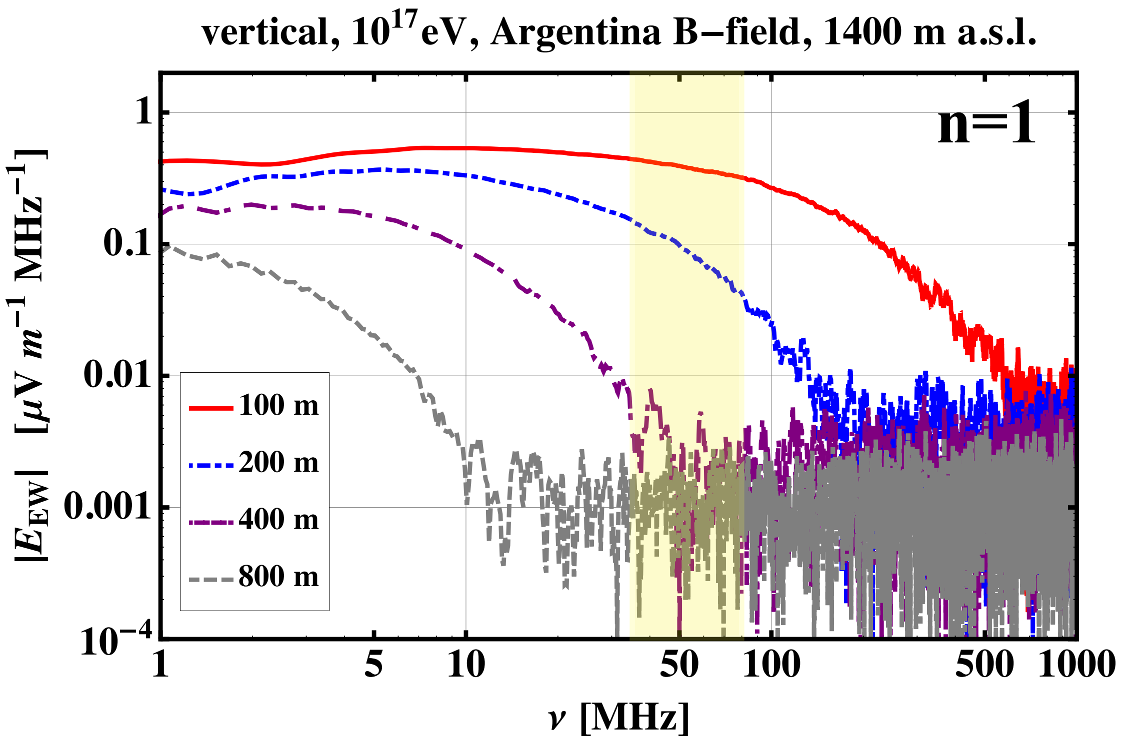

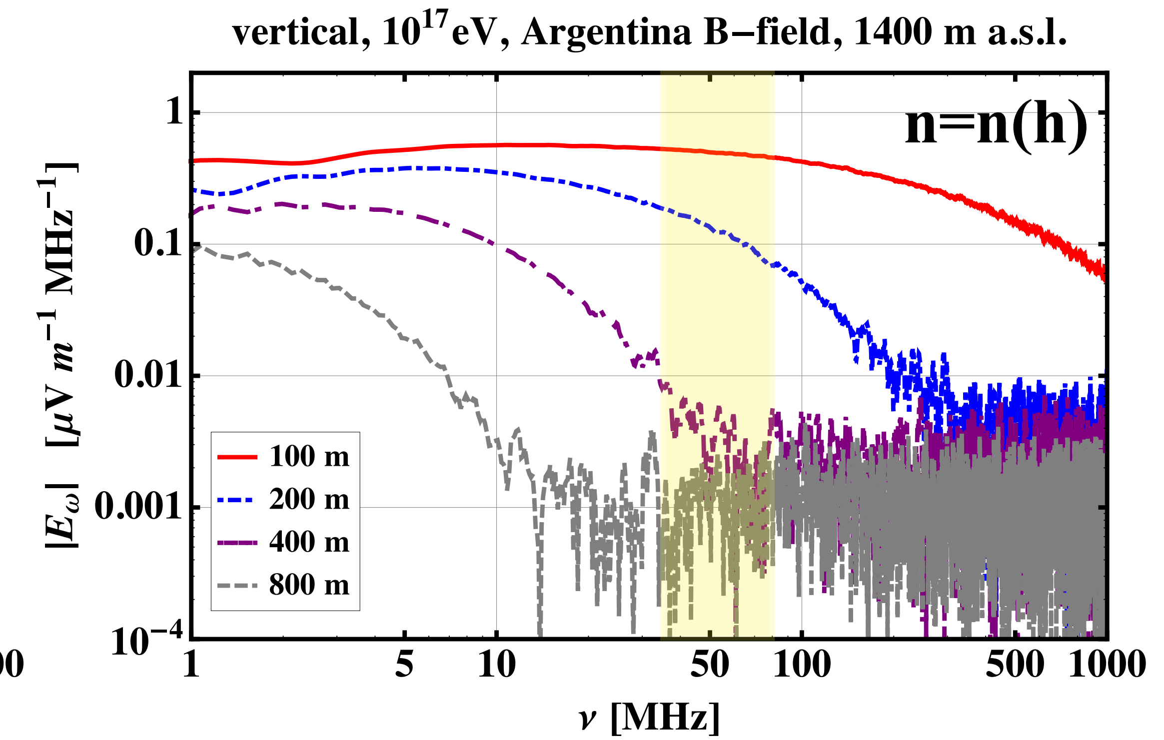

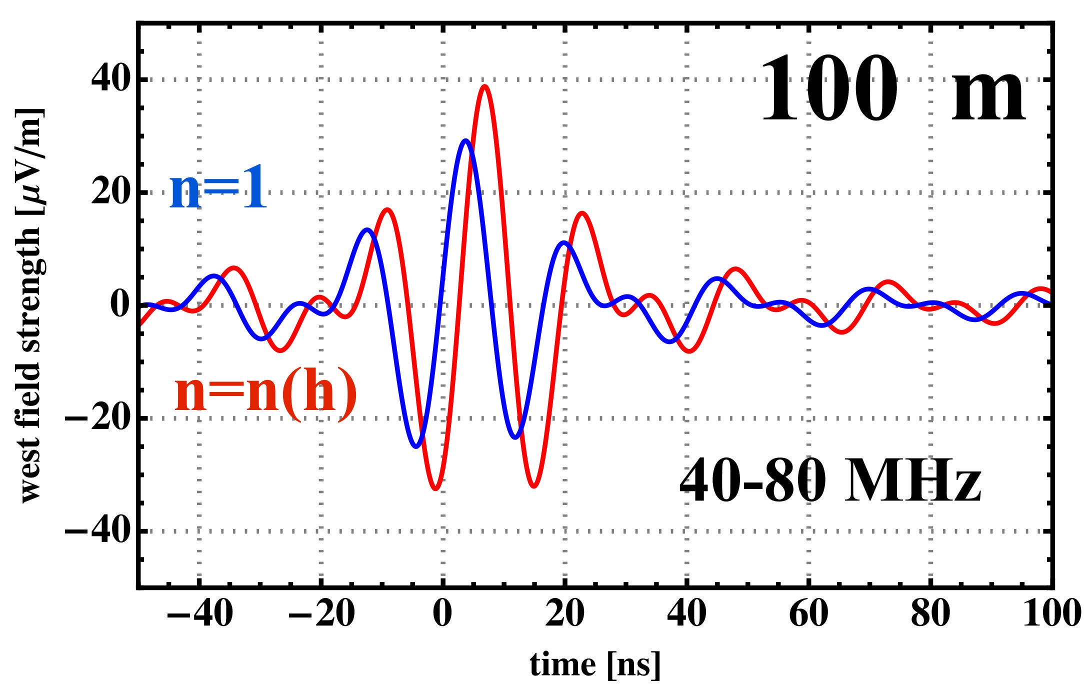

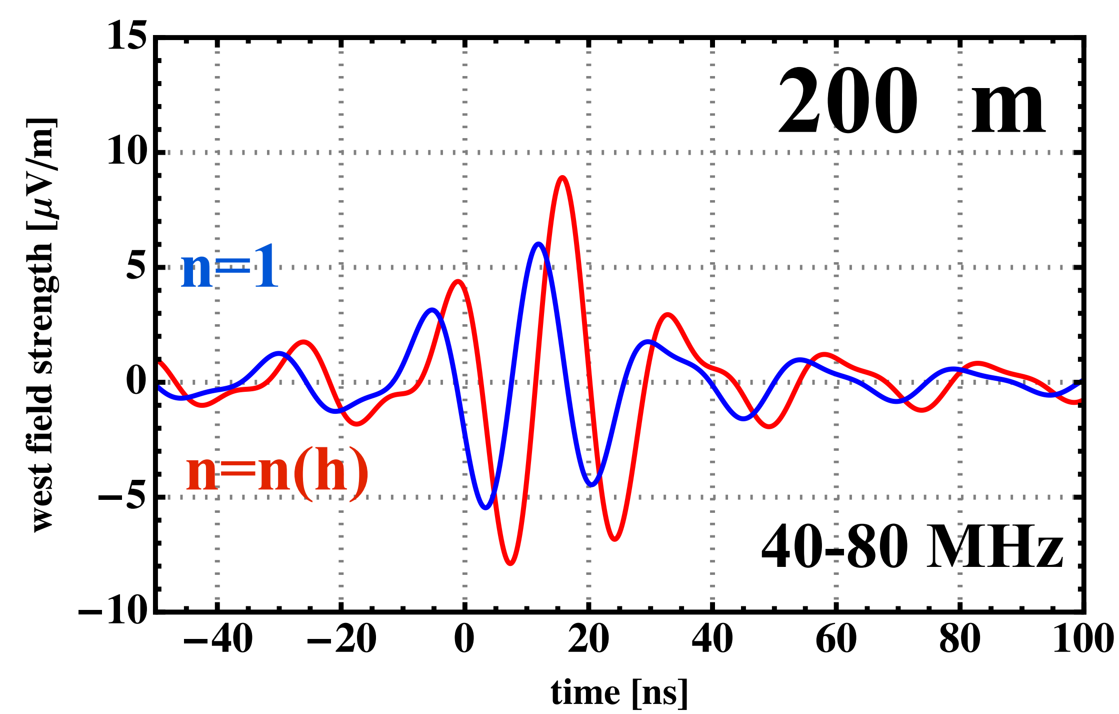

Realistic air refractive index can not explain by itself the scaling factor of 3 **(only 1.5)** observed between data and simulation in the 40-80 MHz

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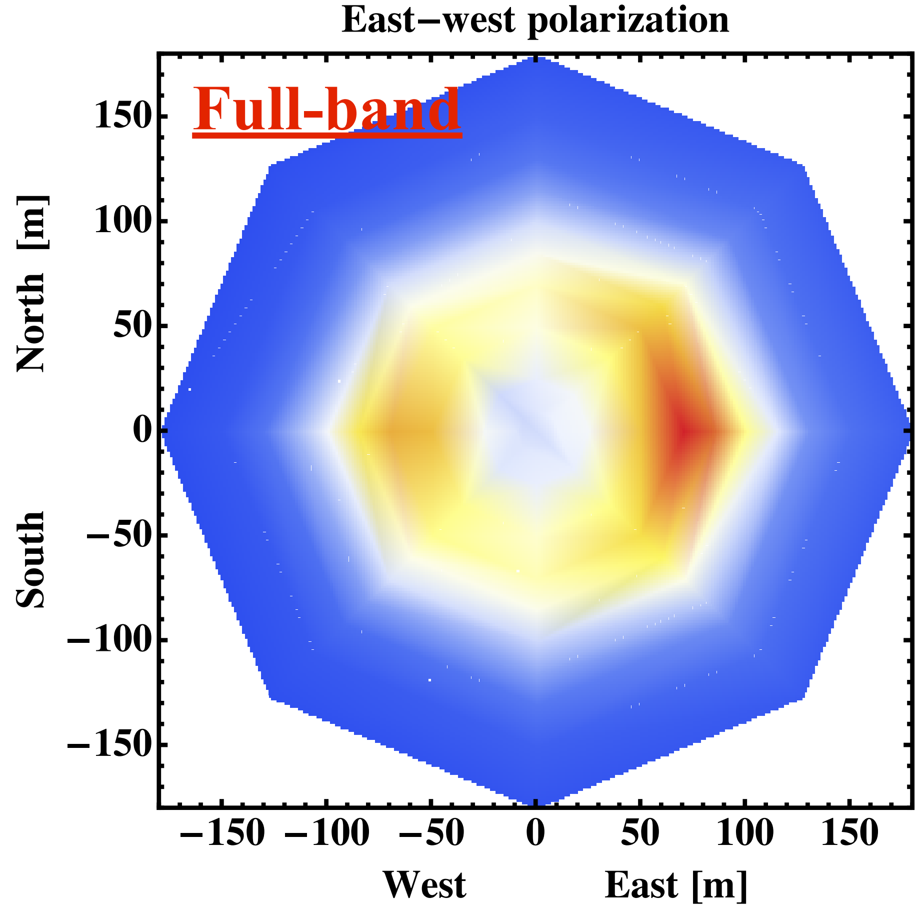

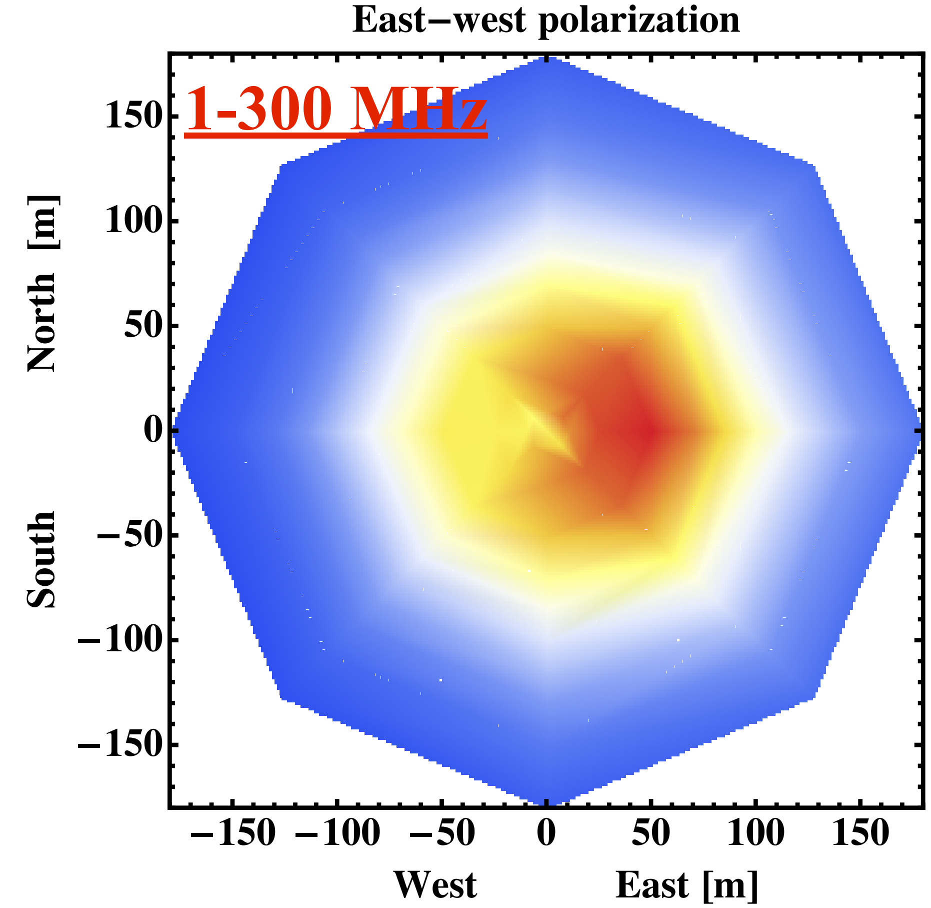

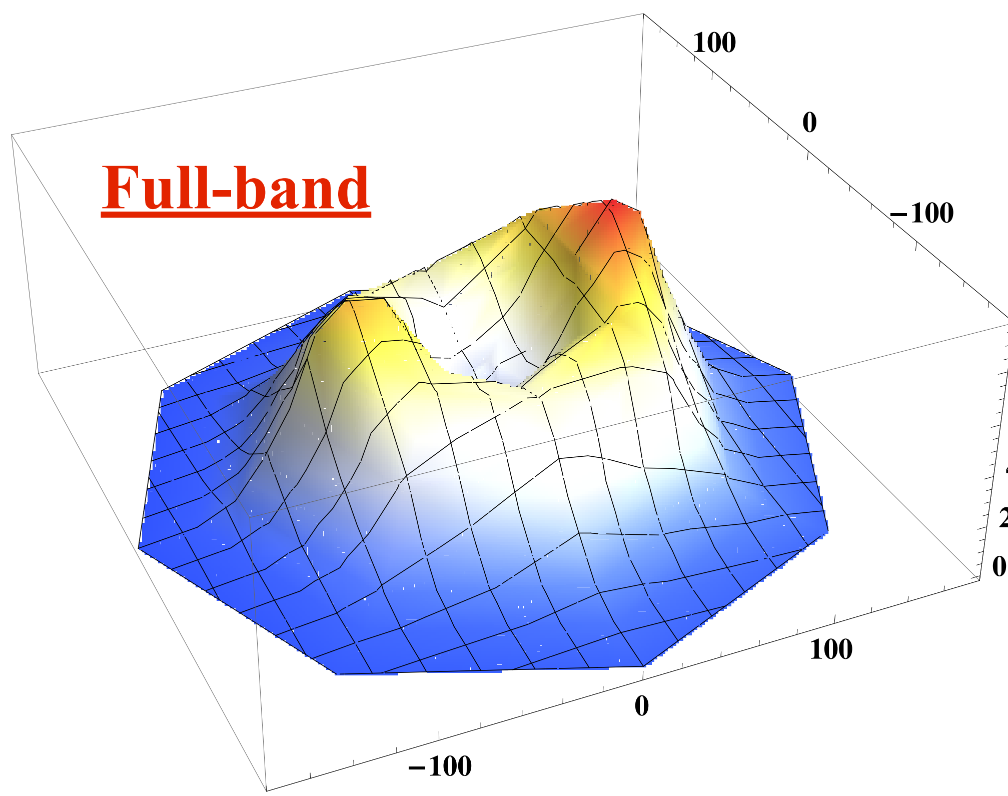

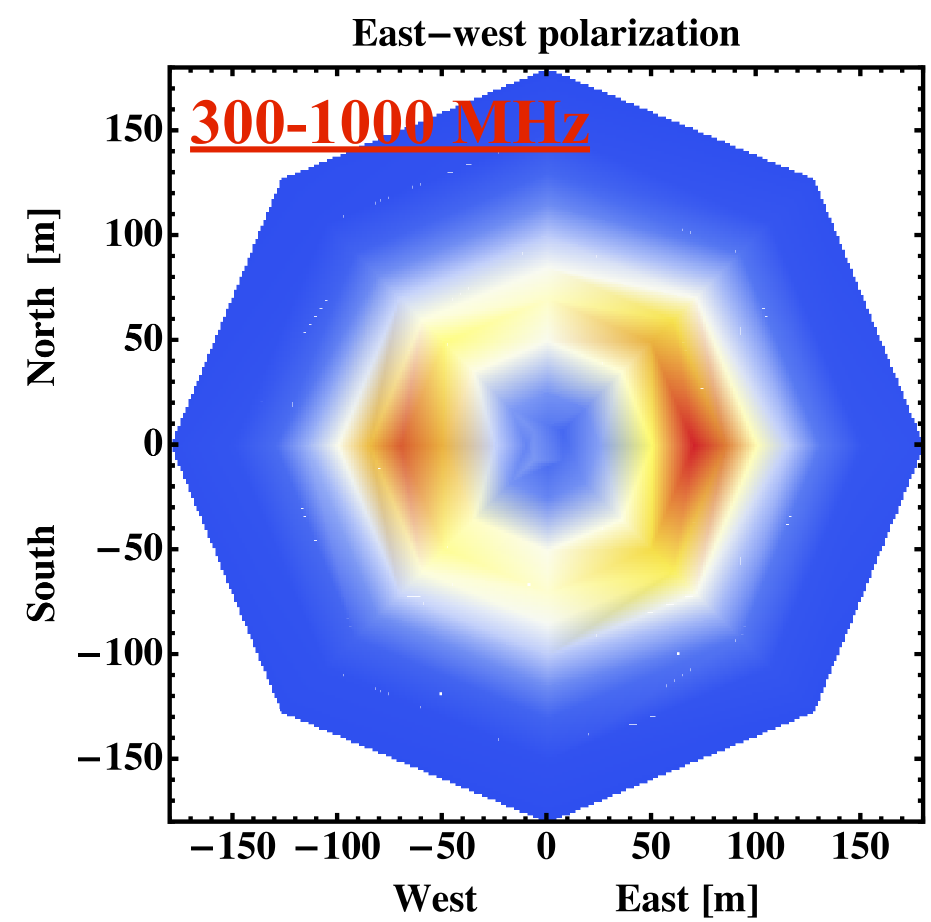

SELFAS2

➡ SELFAS is an autonomous Monte-Carlo simulation code based on universality

➡ SELFAS doesn’t need EAS generator. The geometry only is needed.

➡ Microscopic radio-emission approach permits to take into consideration the complete air shower geometry (shower front thickness, lateral distribution)

➡ Typical computation time, recent mac book pro, 10^7 particles
- one event, one antenna ≈ **13 min**

SELFAS2 *at Astroparticle Physics* **DOI : 10.1016/j.astropartphys.2012.03.007**

➡ Comparison with data give promising results:
- interpretation of the radio core shift in the CODALEMA data
Marin ICRC 2011 and currently under review in Astroparticle Physics
- reproduction of the CODALEMA skymap events
- good agreement on the individual deconvoluted events

➡ But difference between predicted amplitude and data are not fully understood yet

➡ Realistic air refractive index is now implemented in SELFAS2

SELFAS2

Available freely at :

https://sites.google.com/site/selfascode

Tanks for attention....