Coherent Cherenkov radio-emission from EeV showers in dense media through thinned simulations

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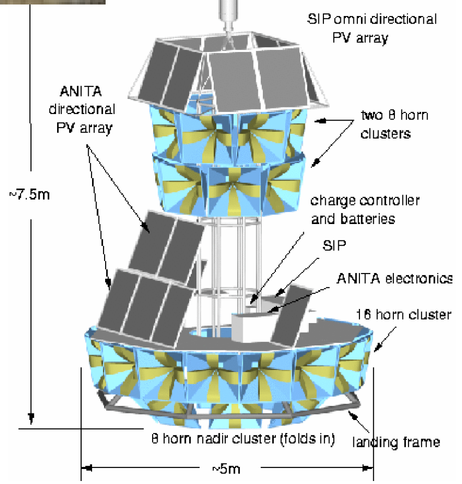
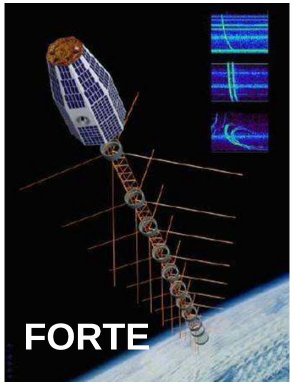
Motivation

- Detection of coherent Cherenkov radio emission in dense & transparent media, very promising technique for UHEν detection: **E**-field power ~ (Shower energy)^2
- Many experimental initiatives (mainly) in ice & the moon regolith
- Reconstruct properties of cascade from observed **E**-field → Simulations needed !!

Igor Zheleznykh

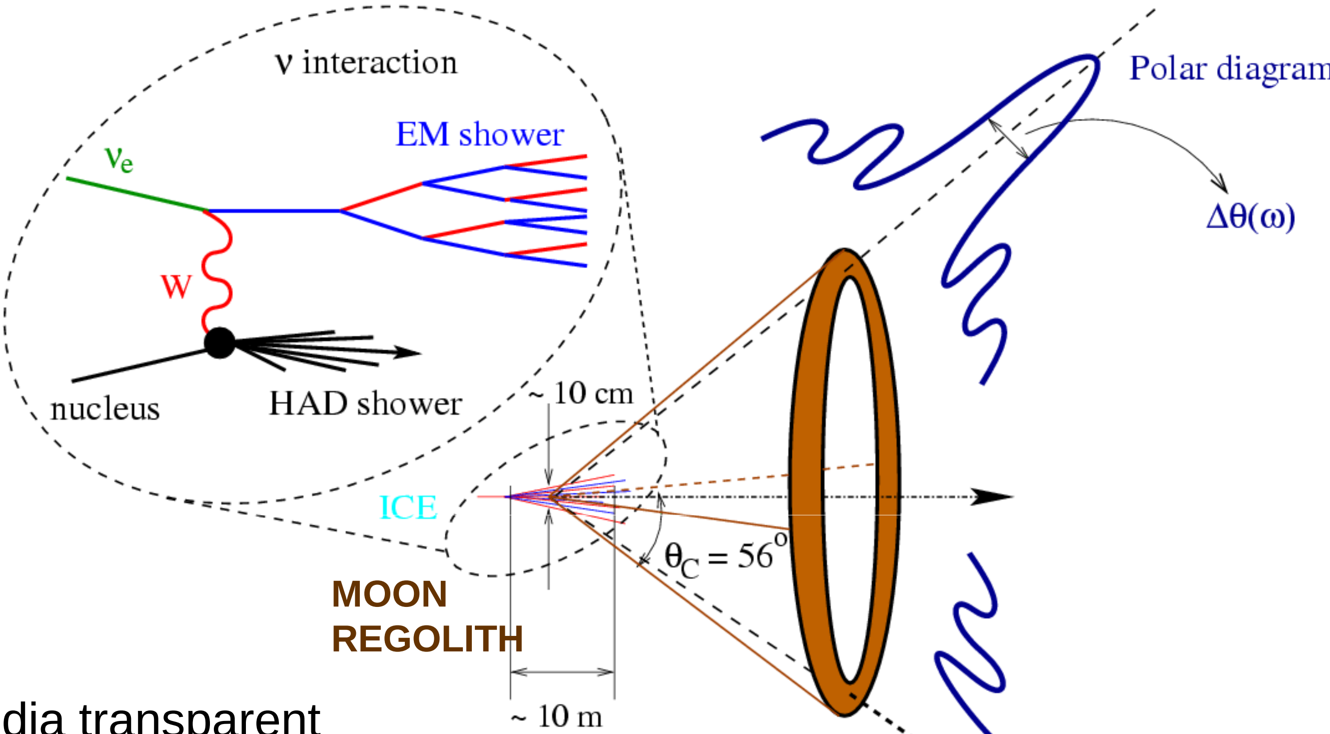
(a pioneer)

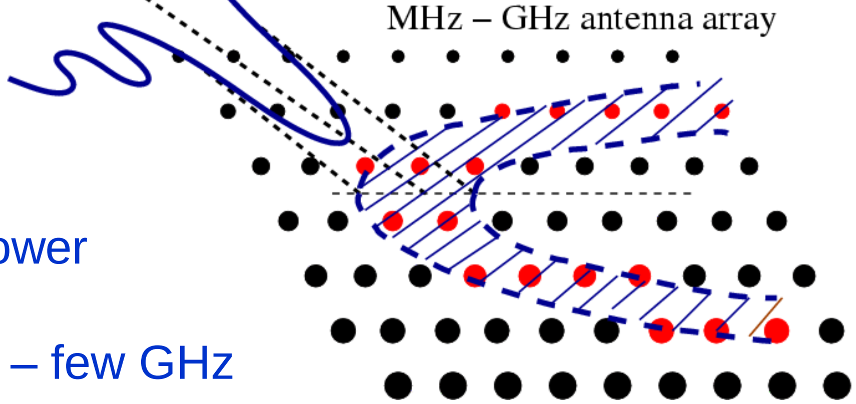




$$10^{17}\ \mathrm{eV} < E_{\mathrm{threshold}} < 10^{20}\ \mathrm{eV}$$

The radio technique in dense media





Media transparent
to radio-waves

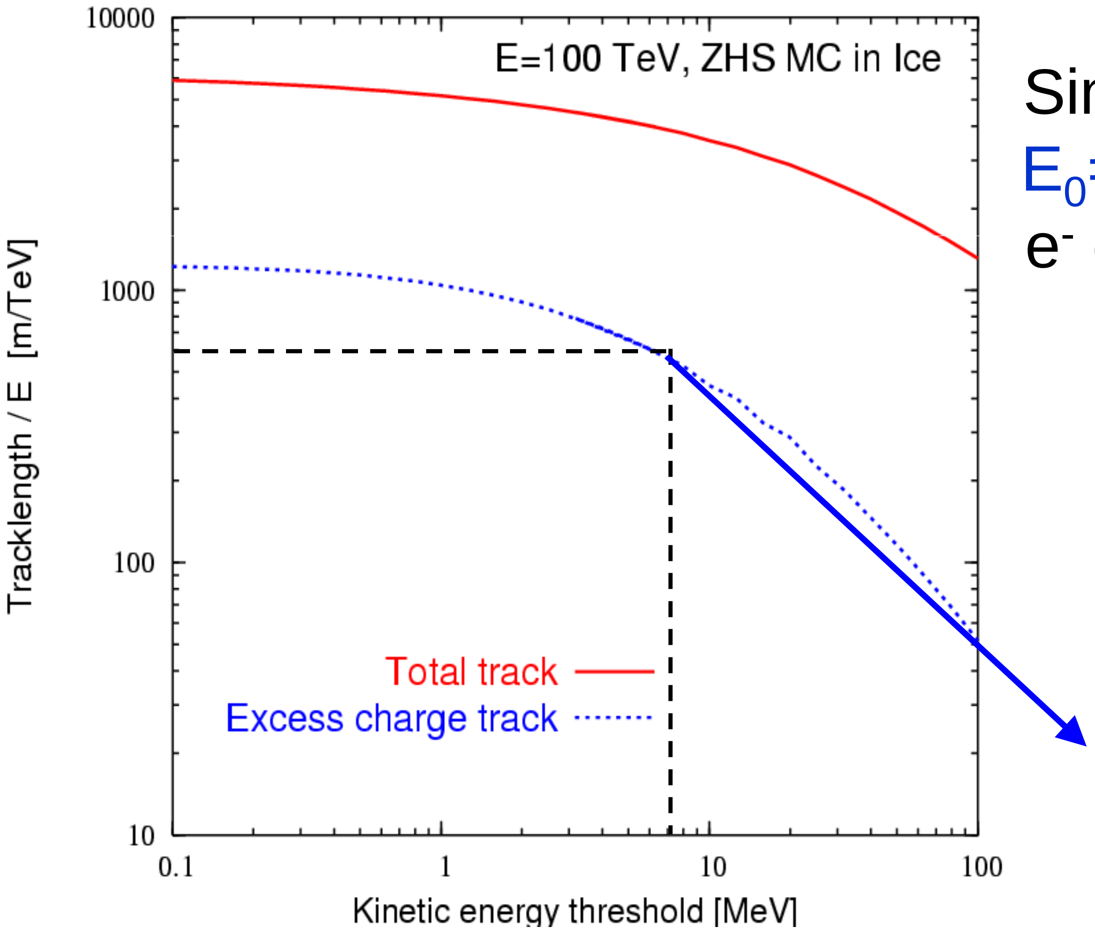
Conditions for coherent radio emission

1. Net excess charge develops in the shower
2. λ_{obs} > shower dimensions → 100 MHz – few GHz

Simulation of EeV showers in dense media: The challenge

- Coherent Cherenkov E-field in dense media is produced by sub-MeV electrons (through Compton, Moeller, Bhabha,… scattering)

(Askary´an effect measured at SLAC).



Simulation of a single shower E_0=1 EeV (10^{18} eV) following e^- down to sub-MeV energies

↓

~ years of CPU time !!

50 % of excess track due to e^- with K_e < 7-8 MeV

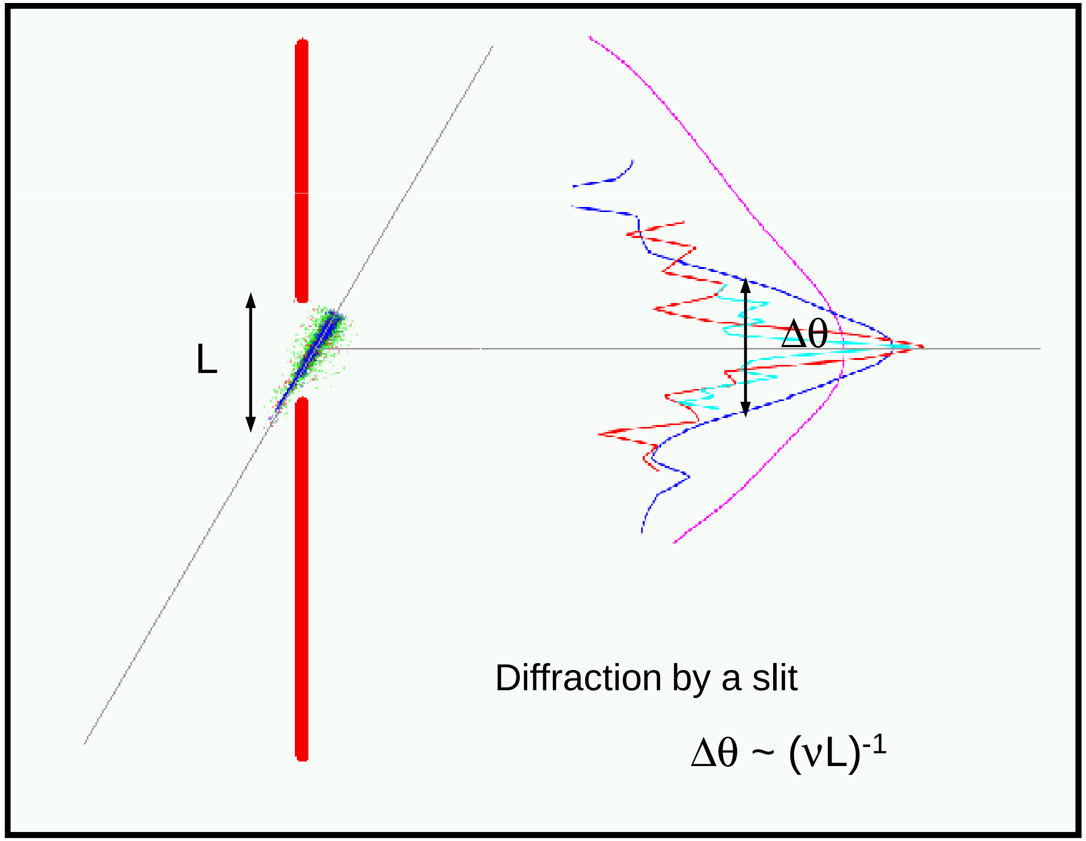
[E. Zas, F. Halzen, T. Stanev PRD 45, 362 (1992)]

Obtaining Cherenkov radiation

- “Full” simulations feasible up to E = 10^{15} - 10^{16} eV
- Coherent Cherenkov radio emission at E > 10^{18} eV was generated exploiting the analogy with diffraction by a slit

E-field can be obtained Fourier-transforming the longitudinal & lateral profile of the shower

1D simulations



Diffraction by a slit

$\Delta\theta \sim (\nu L)^{-1}$

[J. A-M & E. Zas, PRD 62, 063001 (2000)]

“Thinning” techniques

- Feasibility of applying “thinning” techniques to the simulation of electromagnetic (EM) showers in dense media for radio applications.

  - **Goals:**

    1. Reduce as much as possible CPU time
    2. Achieve accurate description of shower development & Cherenkov radiation emission.

[J. A-M, C.W. James, R.J. Protheroe & E. Zas to be submitted]

- Other approaches: hybrid techniques (work in progress)

Basics of “Thinning”

- Extensively & succesfully used for the simulation of showers in the atmosphere: **AIRES, CORSIKA, …**

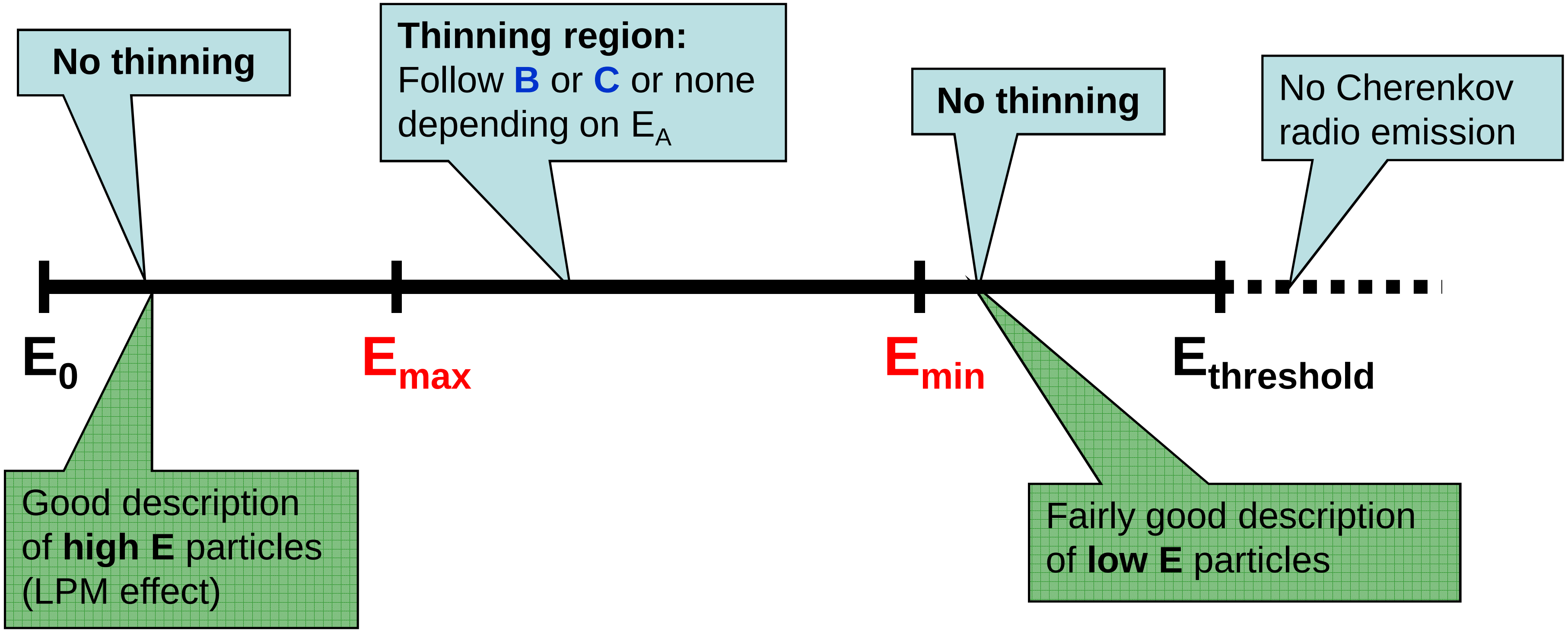
- General ideas:

1. Not all shower particles are tracked, only selected ones (CPU time saved).
2. Selection according to particle energy (thinning algorithm).
3. Assign “weights” to particles tracked to compensate for the non-selected ones.

A “thinning” algorithm for EM showers

All interactions are of the type: $A \rightarrow B + C$

2 “threshold” energies: E_{max}, E_{min}



No thinning

Thinning region:
Follow **B** or **C** or none depending on E_A

No thinning

No Cherenkov radio emission

E_0

E_{max}

E_{min}

$E_{threshold}$

Good description of **high E** particles (LPM effect)

Fairly good description of **low E** particles

Implemented in ZHS code → “ZHS-thinned” code

Optimising thinning params. (E_{min}, E_{max})

Compare thinned showers to fully simulated ones

Choose optimal (E_{min}, E_{max}) combinations so that:

- Thinned showers keep accuracy of fully simulated ones
- CPU time minimised

Extrapolate optimal combinations to highest energies:

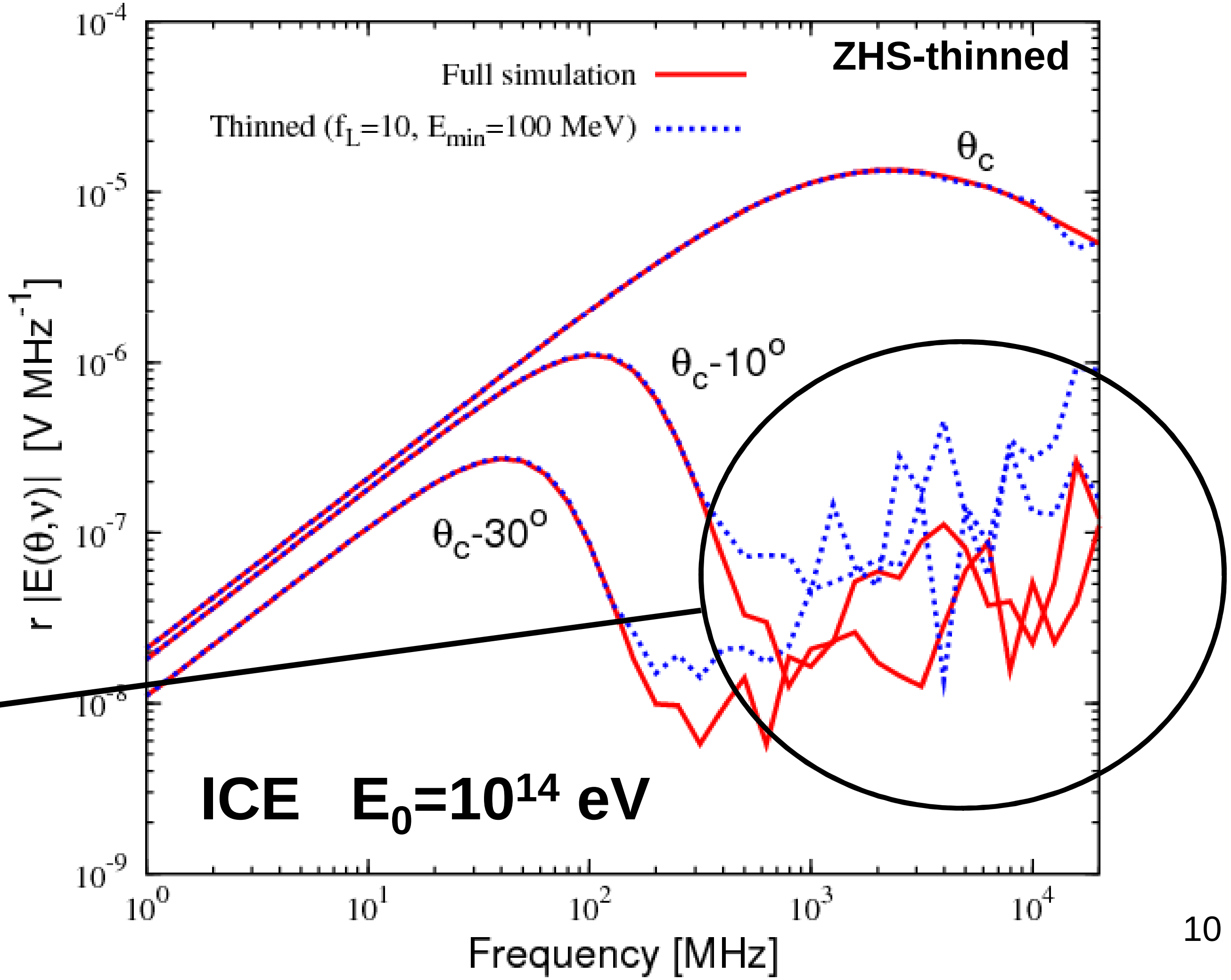
- Check stability of results under different optimal (E_{min}, E_{max})
- Compare to 1D simulations

Results: Accuracy of thinned sims.

- Accuracy of “full” simulations kept (< 10% disagreement) for **$E_{min} < 1$ GeV & $E_{max}/E_{min} \sim 10^4 - 10^5$ (Medium-independent)**

Frequency spectrum at several observation angles from shower axis

$$f_L = \frac{E_{max}}{E_{min}}$$



At small enough λ & θ away from θ_C, **E**-field sensitive to fine details of shower generally not well described by thinning.

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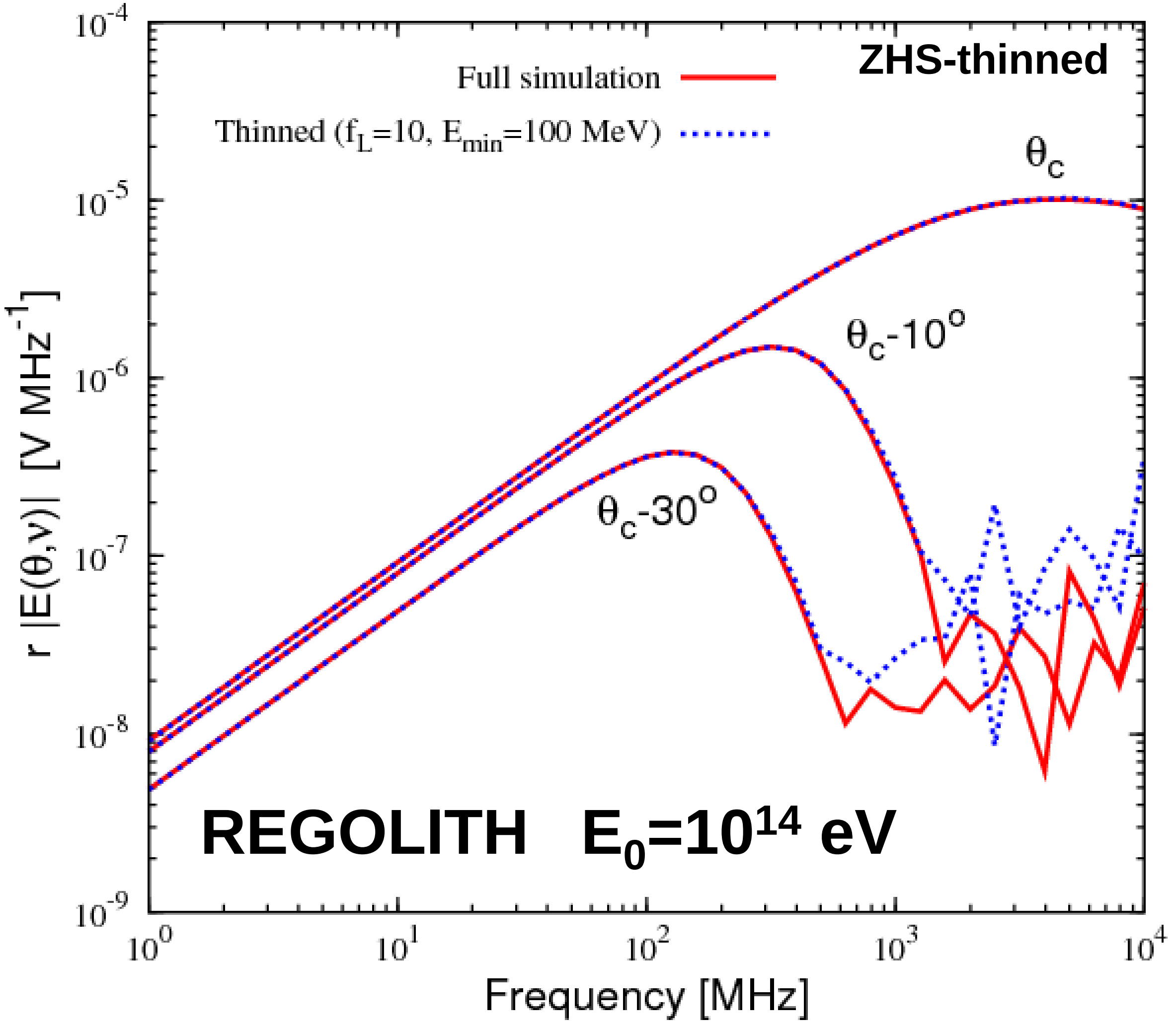
Frequency spectrum at several observation angles from shower axis

3D simulations



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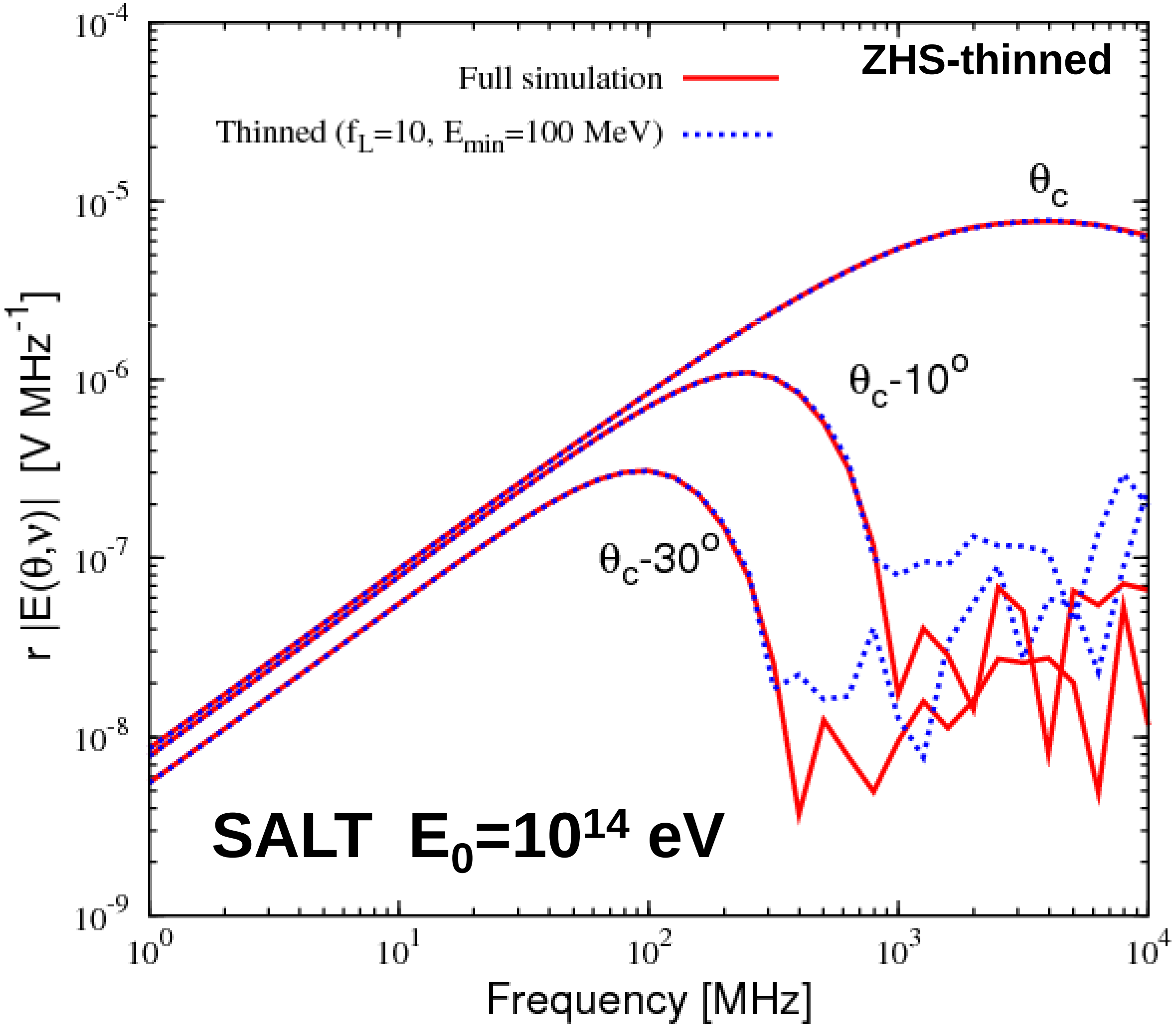
3D simulations

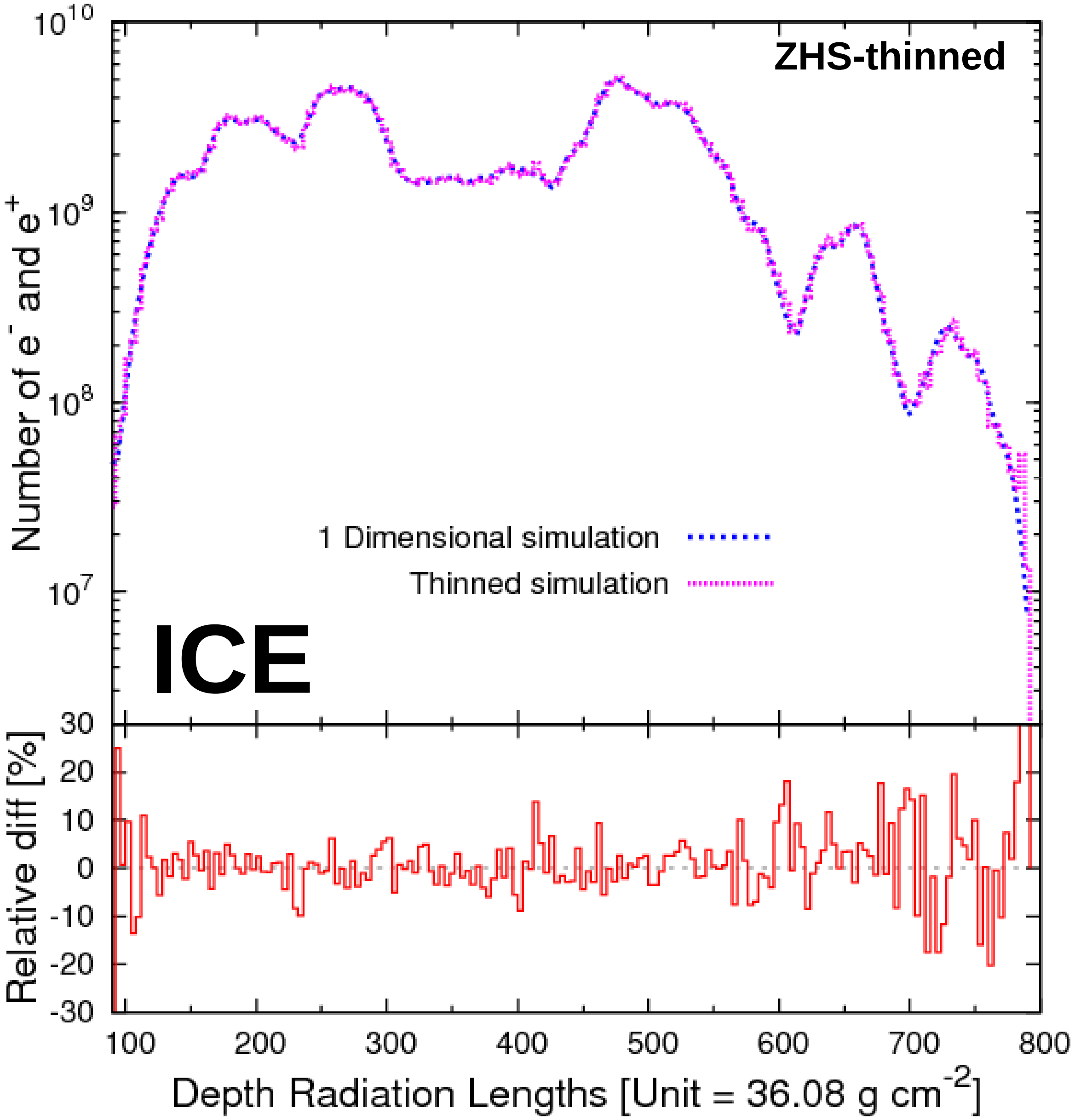


Time gains through thinning ($E_0=10^{18}$ eV)

E_{max} [eV]	E_{min} [eV]	CPU time*
Full	simulation	2.33 yr
10^{12}	10^{7}	4 hr 33 min
10^{13}	10^{8}	41.8 min
10^{13}	10^{7}	31.9 min
10^{14}	10^{8}	4.7 min

*Computed with an Intel Q6600 Quad 2.4 GHz processor

Examples of 10^{20} eV thinned showers



Longitudinal development

1 individual shower

$E \gg E_{LPM} \sim 10^{15}$ eV
Very strong LPM effect:
multi-peaked structure

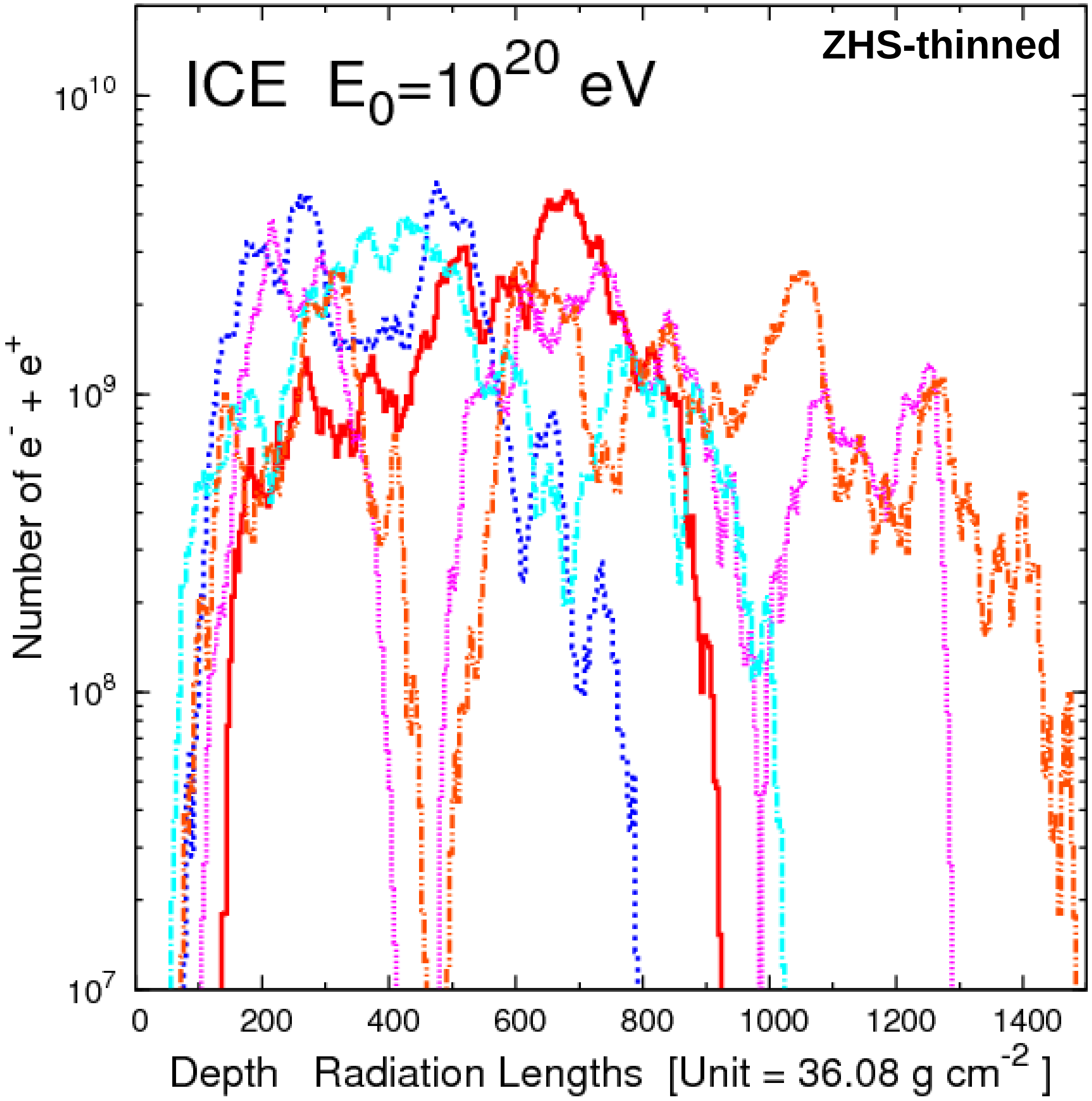
1-D "hybrid" simulation

vs

3-D "thinned" simulation

Remarkable agreement between 2 different simulation techniques

Examples of 10^{20} eV thinned showers



Longitudinal development in ice

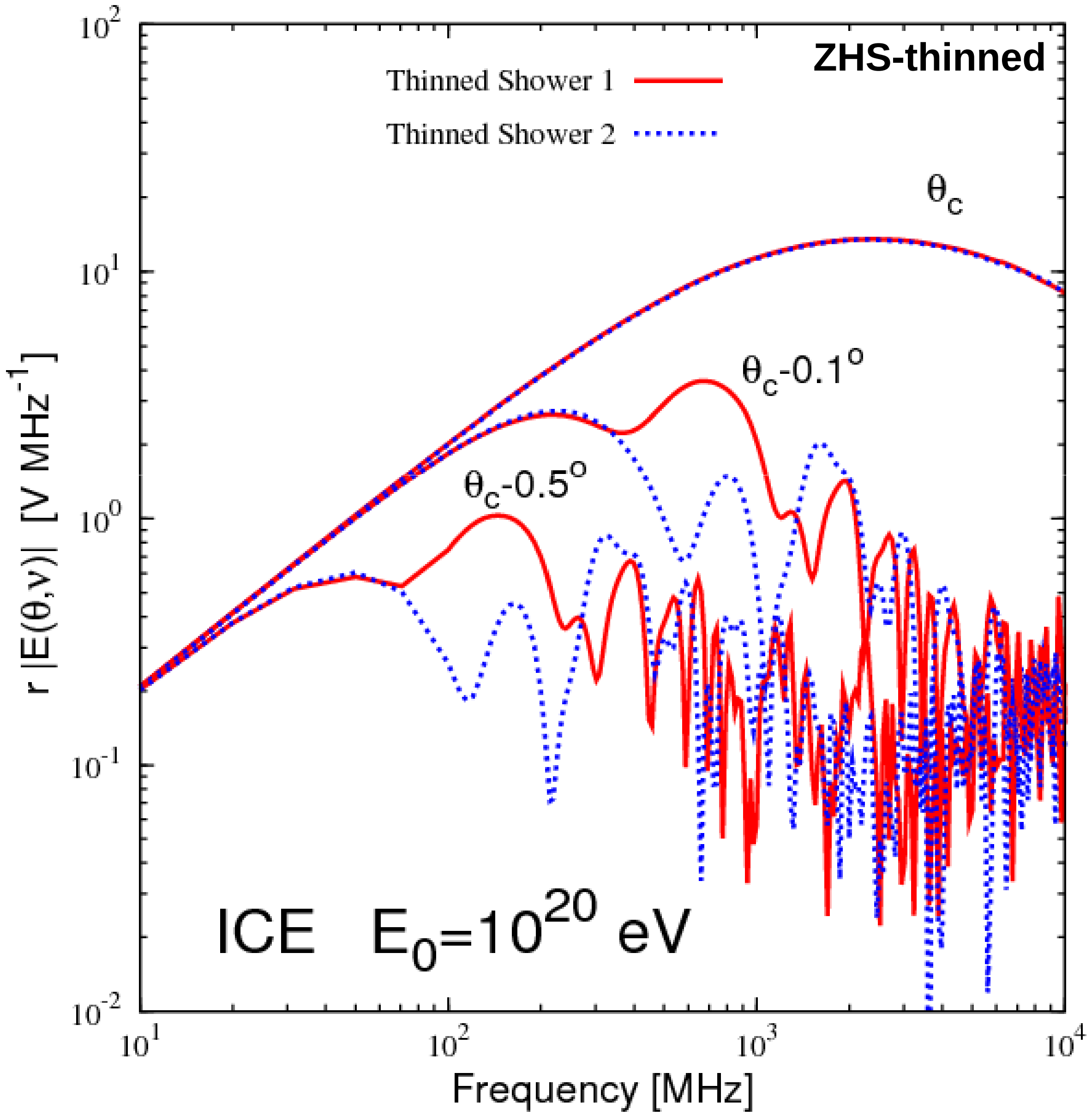
5 individual showers

$E >> E_{LPM} \sim 10^{15}$ eV (LPM effect)

Extremely large shower-to-shower variability calls for fast & accurate simulations:

→ ZHS-thinned

Examples of 10^{20} eV showers



Frequency spectrum at several observation angles from shower axis

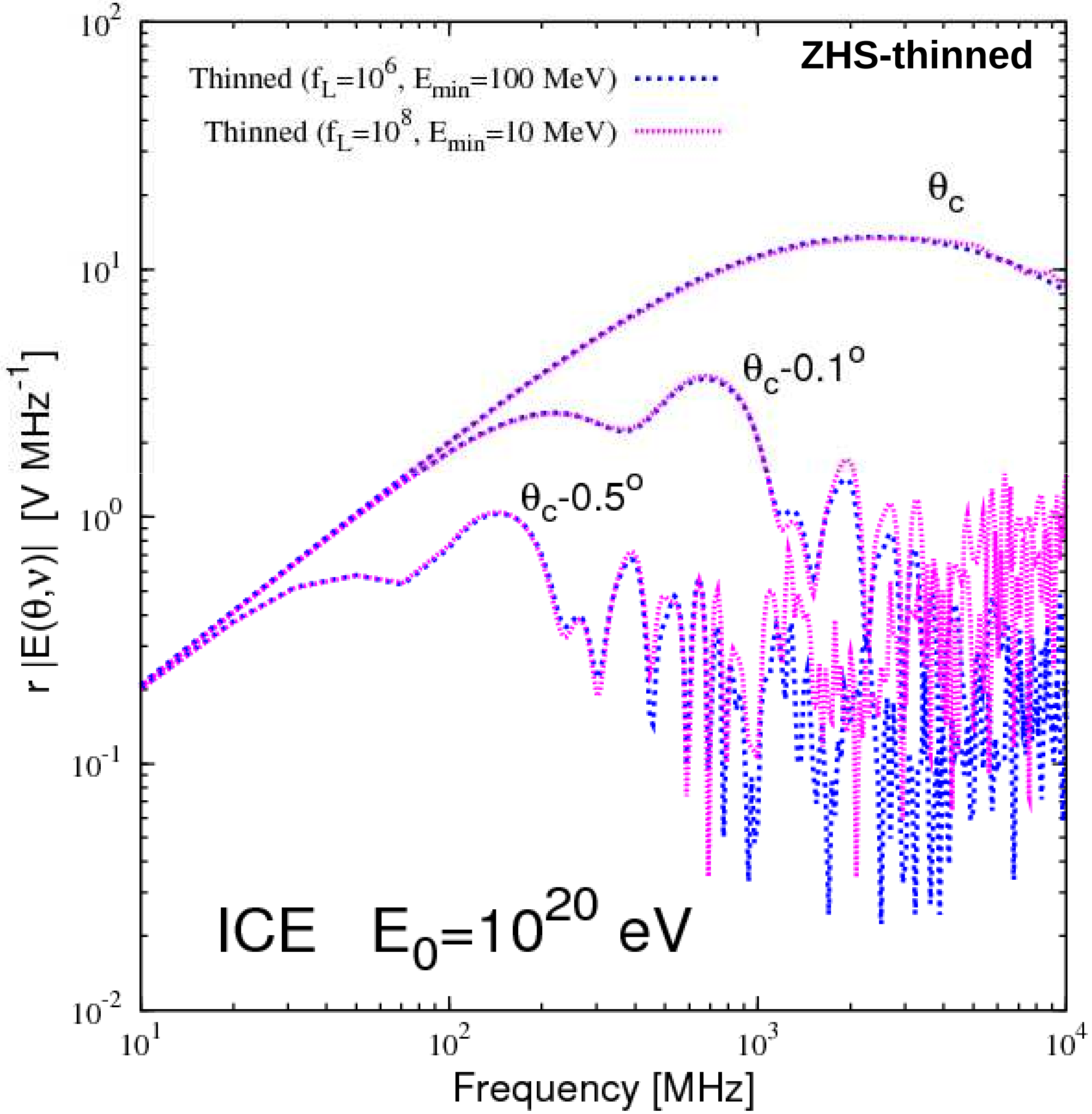
2 individual showers

$E >> E_{LPM} \sim 10^{15}$ eV (LPM effect)

Extremely large shower-to-shower variability away from θ_c

→ ZHS-thinned

Examples of 10^{20} eV showers



Frequency spectrum at several observation angles from shower axis

1 individual shower:
2 thinned (simultaneous) simulations

$E >> E_{LPM} \sim 10^{15}$ eV (LPM effect)

Secondary peaks might improve detectability of EeV electrom. showers
(work in progress)

Summary, conclusions & outlook

- "Thinning" techniques were successfully applied to the simulation of EM showers in dense media for radio applications.
  - Very large reductions of CPU time &
  - 90% accuracy achieved
- Unprecedented 3D simulations of the E-field from EM showers in ice, regolith,… up to 10^{20} eV: parameterisations for practical applications available.
- Outlook: Application to hadronic showers & actual neutrino interactions.

End of talk