# Aperture of the Tunka-Rex Radio Array

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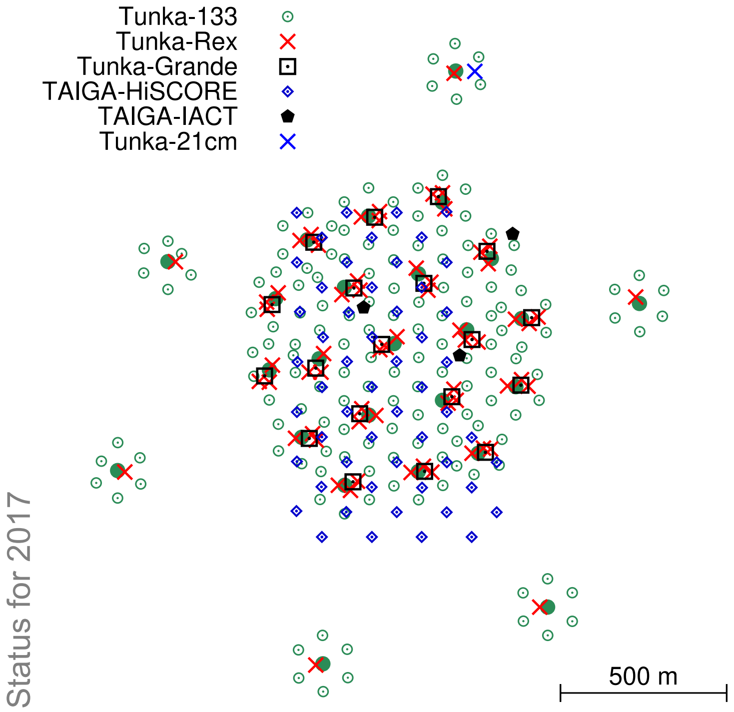
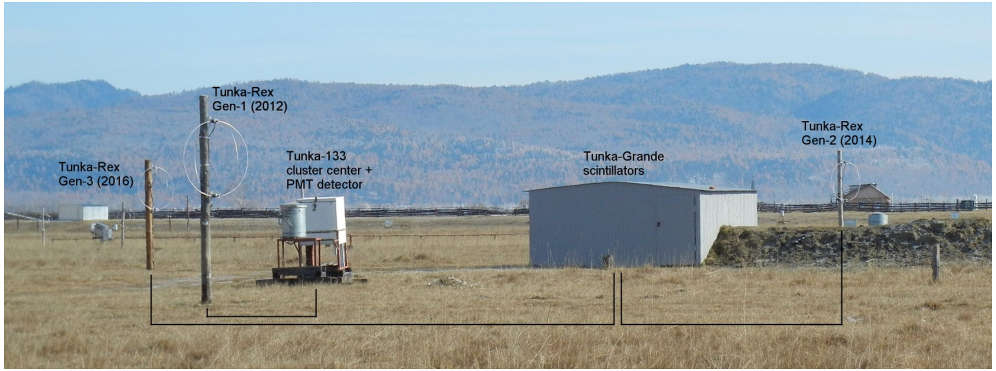
# Tunka-Rex Radio Array




- 3 antennas (2 polarizations, 30–80 MHz)
- 7 optical modules
- 8 m² (on-surface) and 5 m² (underground) scintillators

In total: 19 (dense core) + 6 (satellite) clusters

# Definition of Aperture

number of events — $N = \epsilon\, J$ — CR flux

exposure

$$\epsilon = \int_T \int_{\Omega_f} \int_{S_f} \xi \;\cos\theta\, ds\, do\, dt = \int_T A\, dt$$

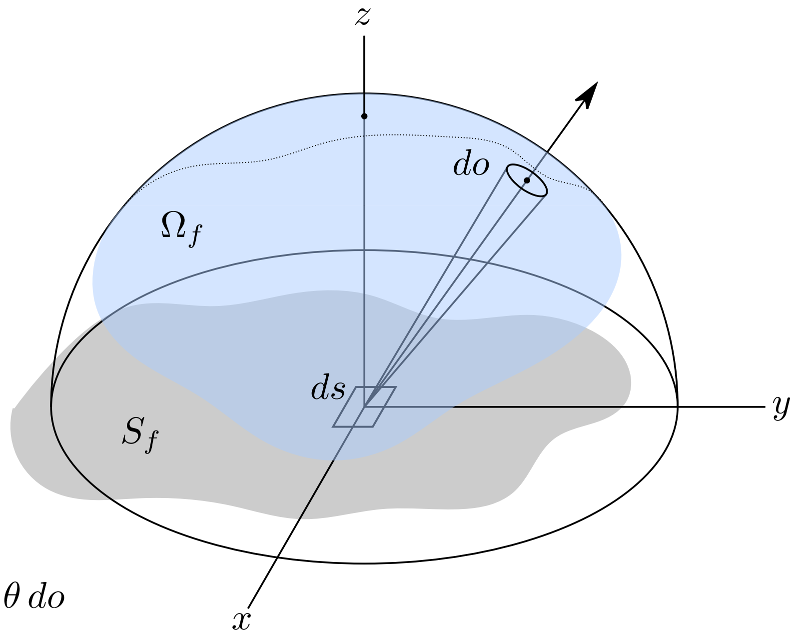
aperture

$$A = \int_{\Omega_f} \int_{S_f} \xi \;\cos\theta\, ds\, do = S_f \int_{\Omega_f} \int_{S_f} \frac{\xi}{S_f} \;\cos\theta\, ds\, do =$$

$$S_f \int_{\Omega_f} \left( \frac{1}{S_f} \int_{S_f} \xi\, ds \right) \;\cos\theta\, do = S_f \int_{\Omega_f} \langle\xi\rangle_s \;\cos\theta\, do$$

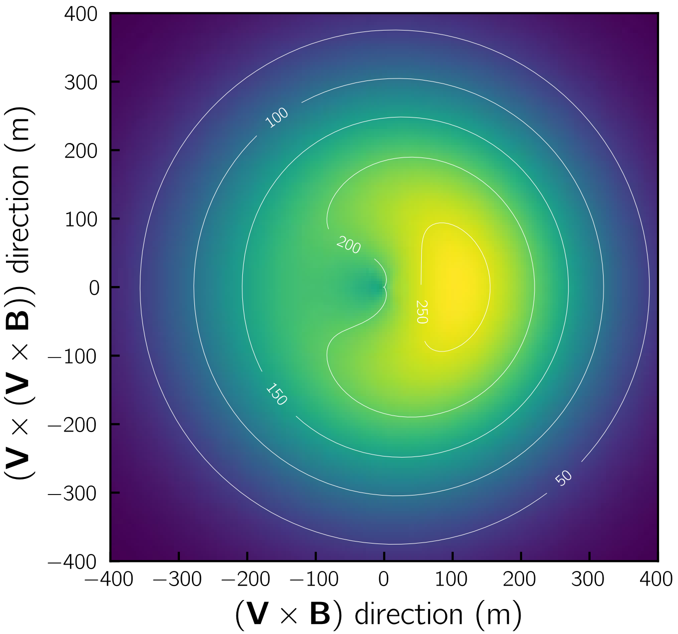
$$do = \sin\theta\, d\theta\, d\phi$$

averaged efficiency — $A_\Omega$ — angular aperture



# Efficiency Model — Full-Efficiency Region — Integration

## Electric-field distribution



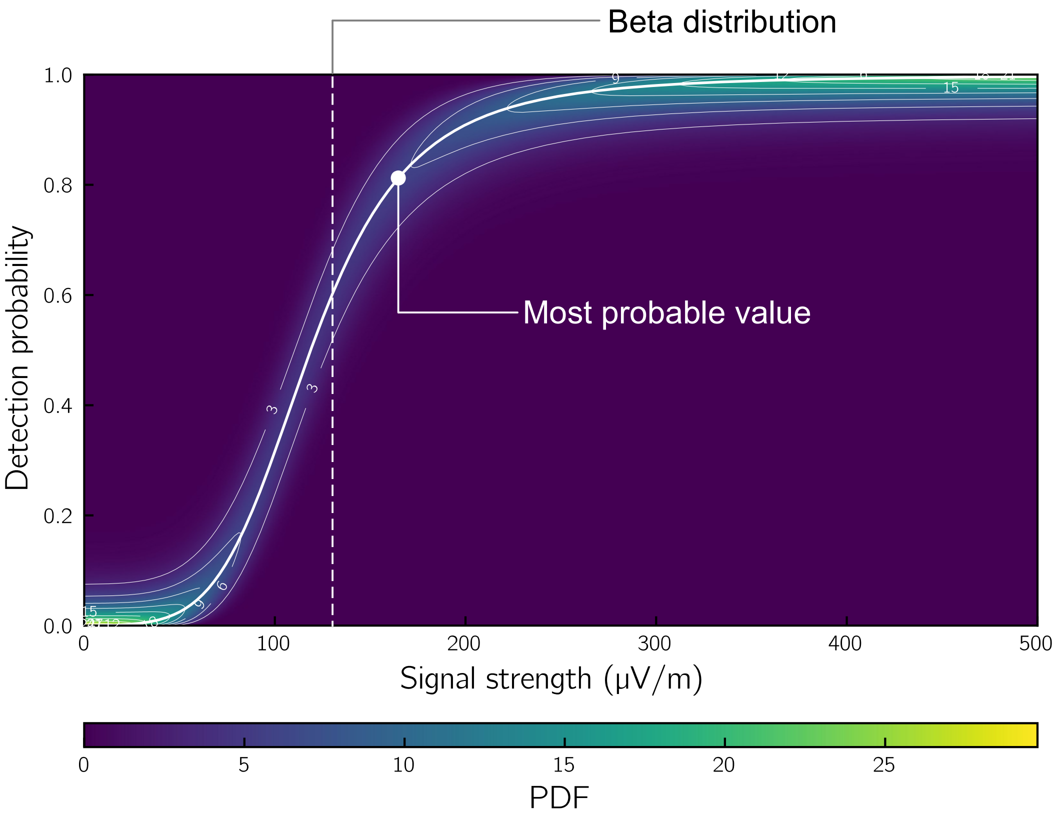

$E = 10^{17.5}$ eV, $X_{max}$ = 400 g/cm²

**Tunka-Rex radio-footprint model**

- Spatial distribution of electric field (signals on antennas)
- Depends on: E, $X_{max}$, (θ, ϕ), (x, y)

**15% of the signal uncertainty**

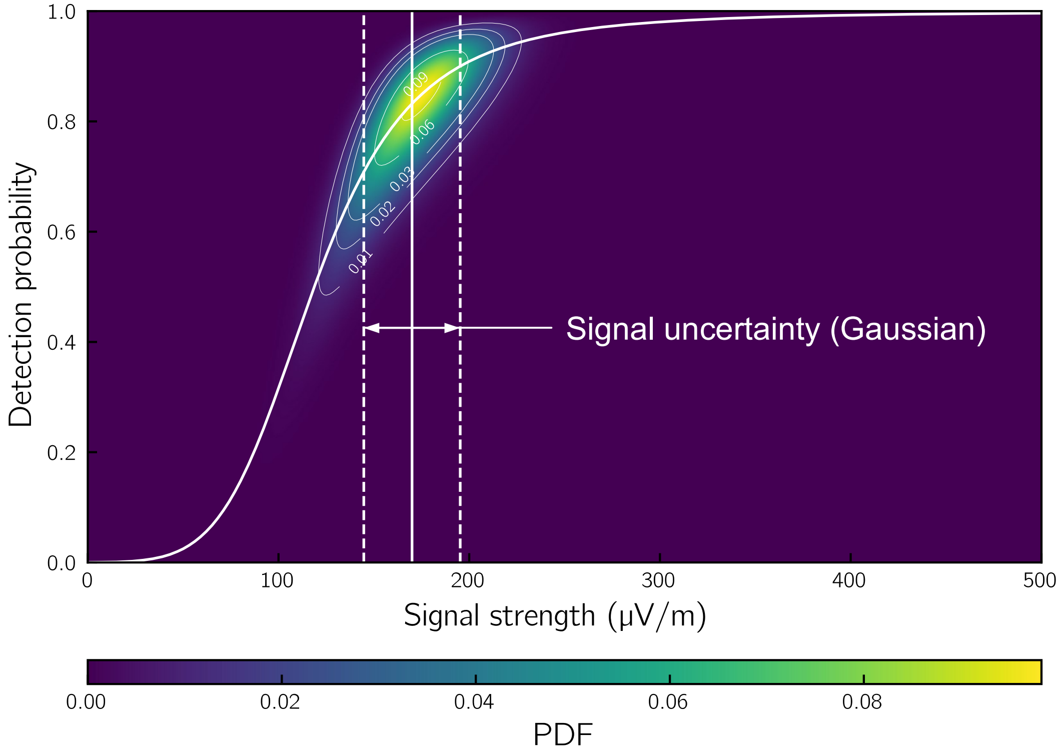
## Signal detection




Based on multiple processing of simulated signals with different noise samples

# Efficiency Model — Full-Efficiency Region — Integration

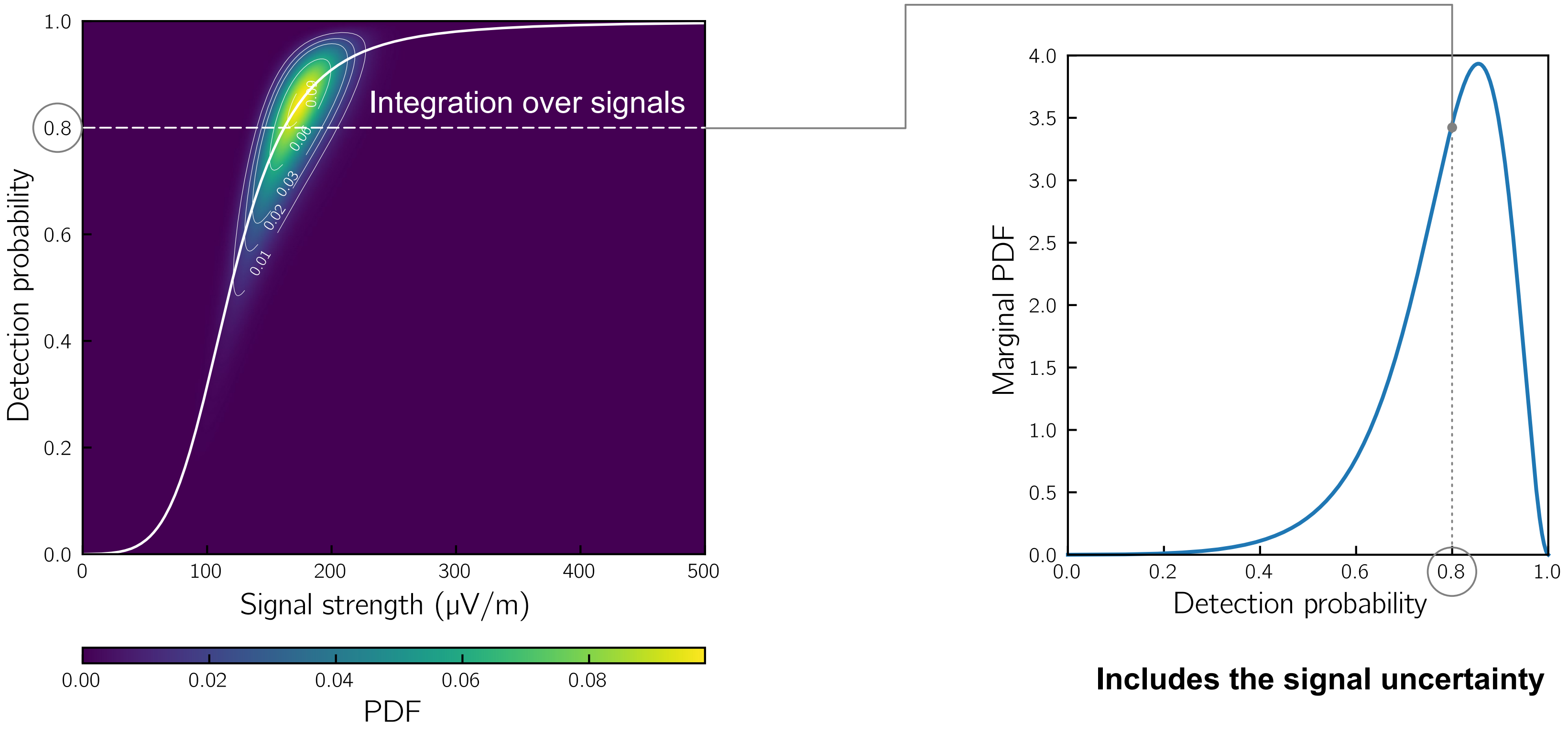
## Signal detection — Accounting for signal uncertainty




$\mu = S_0$
$\sigma = 0.15\ S_0$
($S_0$ = 170 μV/m)

# Efficiency Model — Full-Efficiency Region — Integration

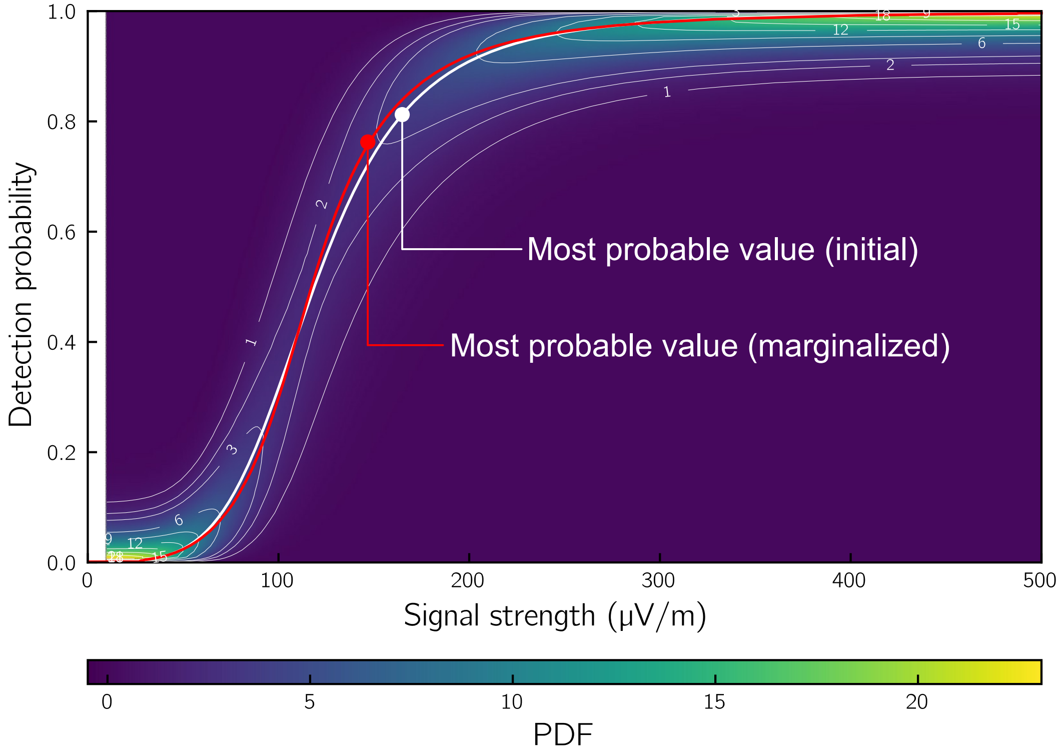
## Signal detection — Accounting for signal uncertainty — Marginalization




**Includes the signal uncertainty**

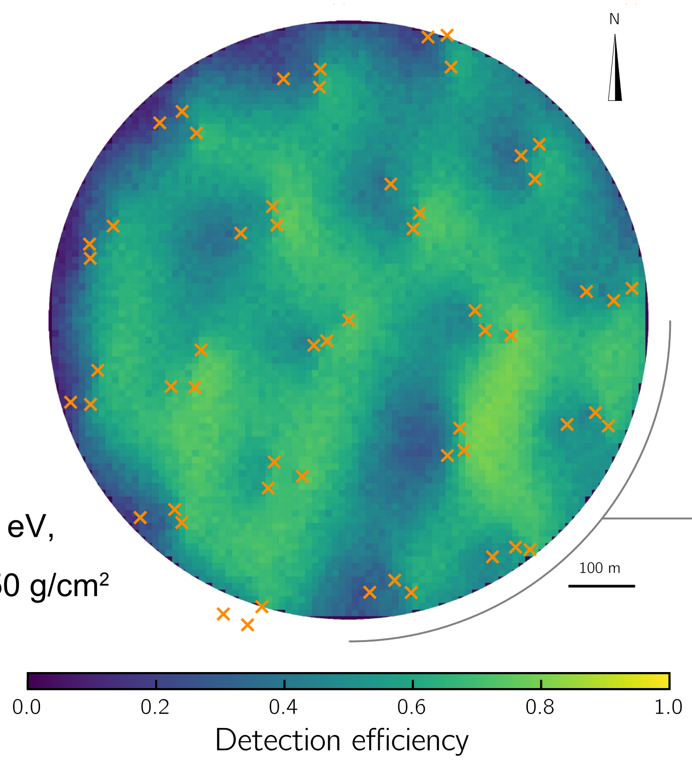
# Efficiency Model — Full-Efficiency Region — Integration

## Signal detection — Accounting for signal uncertainty — Marginalization



# Efficiency Model — Full-Efficiency Region — Integration

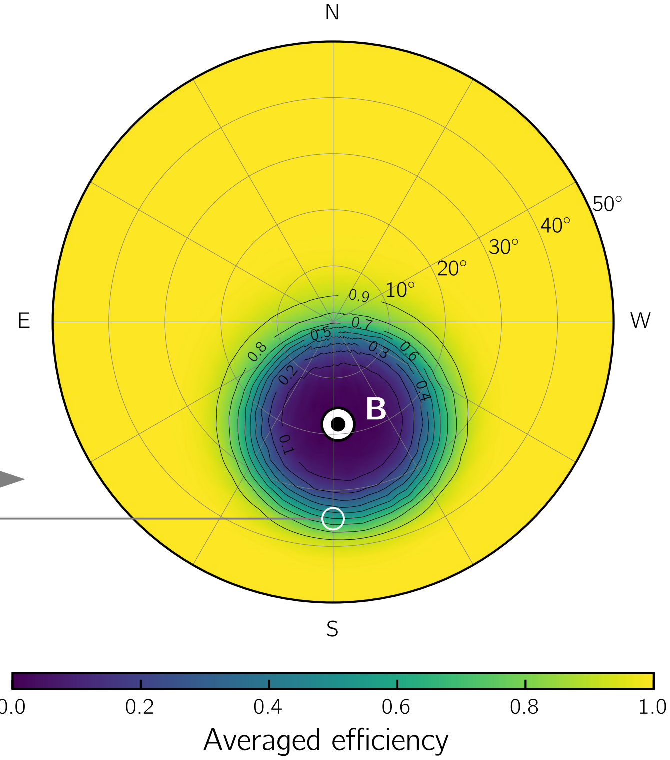
## Event detection — Probabilistic combination of PDFs (trigger probability)



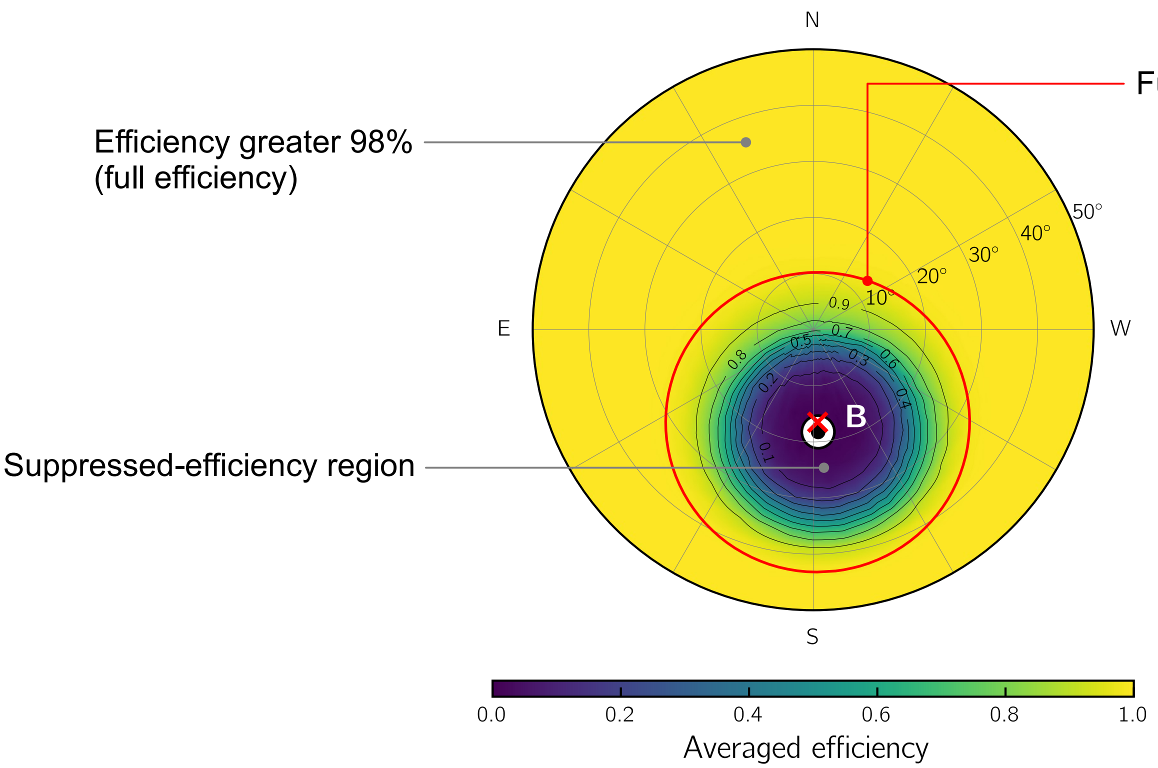

E = $10^{17.3}$ eV,

$X_{max}$ = 650 g/cm²

$\langle \xi \rangle_s$ →



## Selection scheme

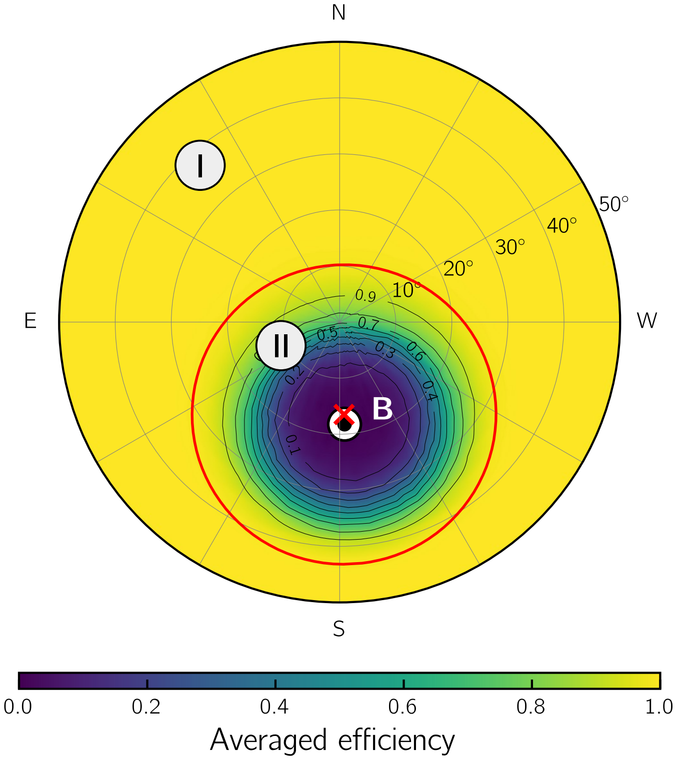



**Circle-on-sphere parametrization**

circle angular radius

$$\cos\rho = \cos\theta\cos\theta_0 + \sin\theta\sin\theta_0\cos\phi$$

circle center




angular aperture

$$A_\Omega = \int_{\Omega_f} \langle \xi \rangle_s \cos\theta \sin\theta \, d\theta d\phi$$

Jacobian

averaged efficiency (= 1)

(I) — Geometrical aperture (area up to maximal zenith)

$$\pi \left[1 - \cos^2 \theta_{\max}\right]$$

(II) — Suppressed-efficiency region

$$2 \int_0^{\theta_{\max}} \arccos\left(\frac{\cos\rho - \cos\theta\cos\theta_0}{\sin\theta\sin\theta_0}\right) \cos\theta \sin\theta \, d\theta$$

$$A_\Omega = (I) - (II)$$

# Full-Efficiency Region Evolution

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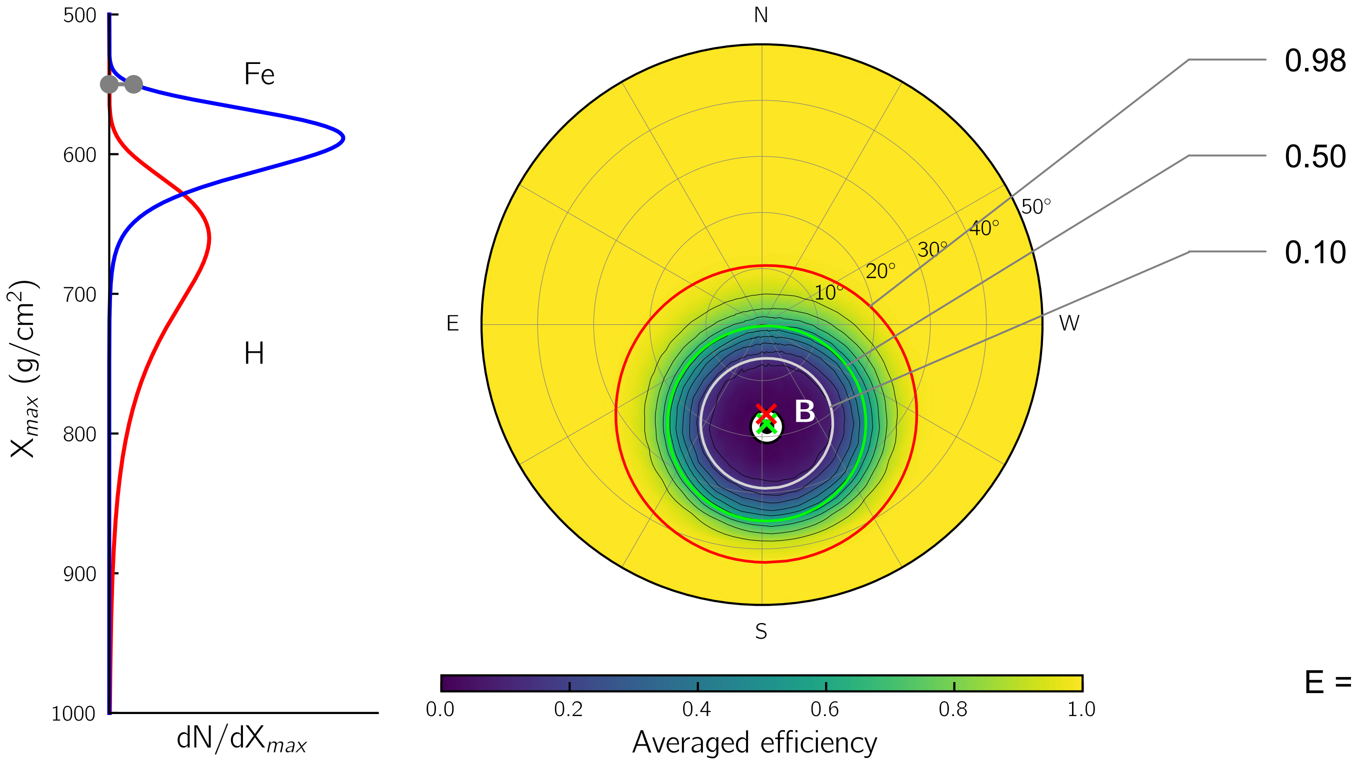
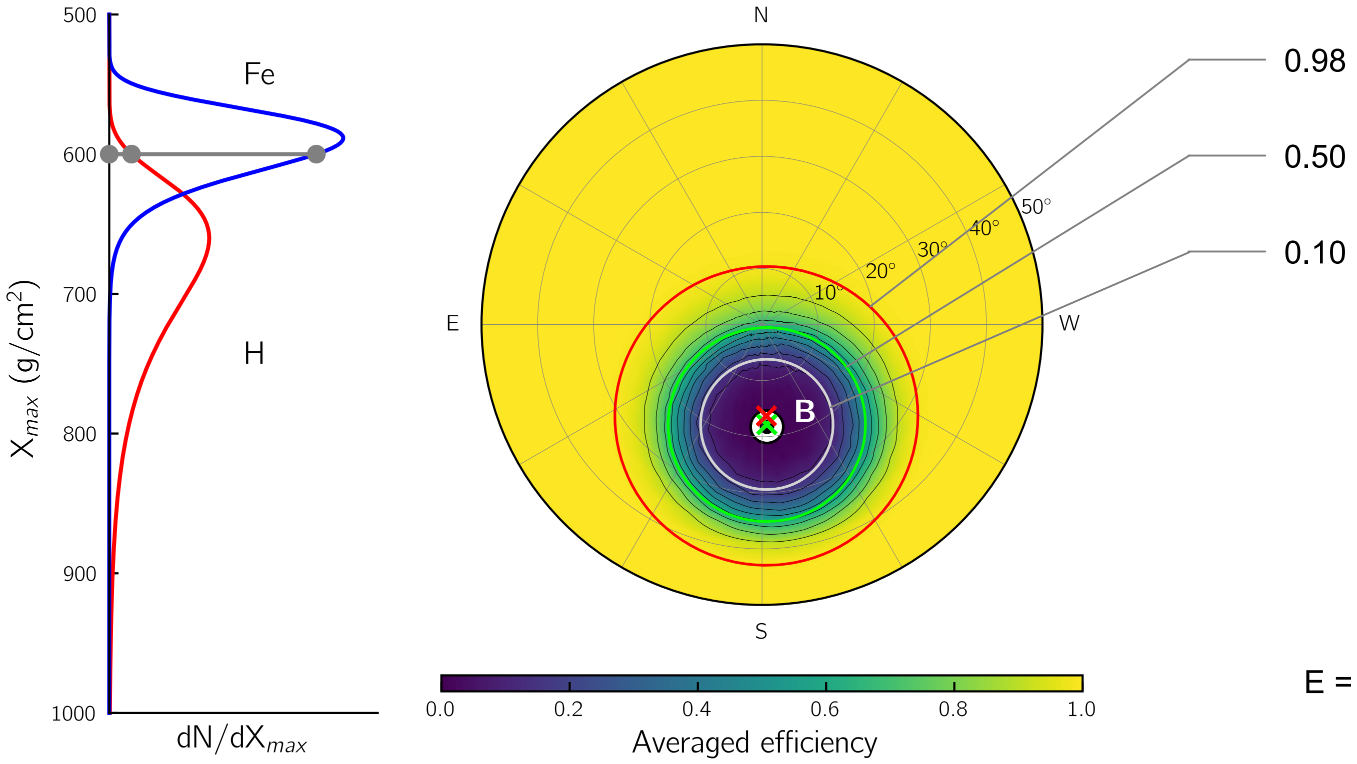



$E = 10^{17.3}$ eV

# Full-Efficiency Region Evolution



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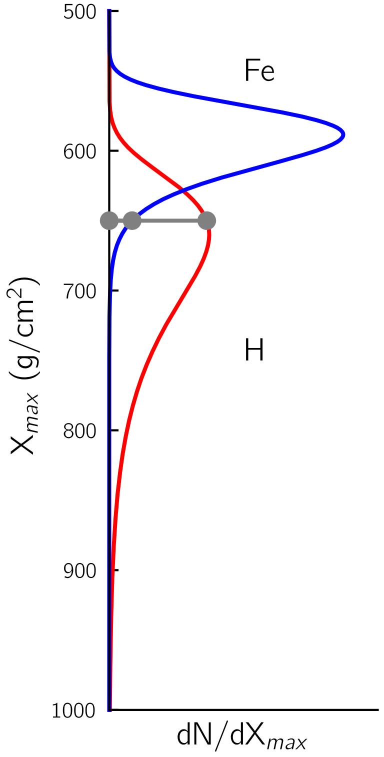


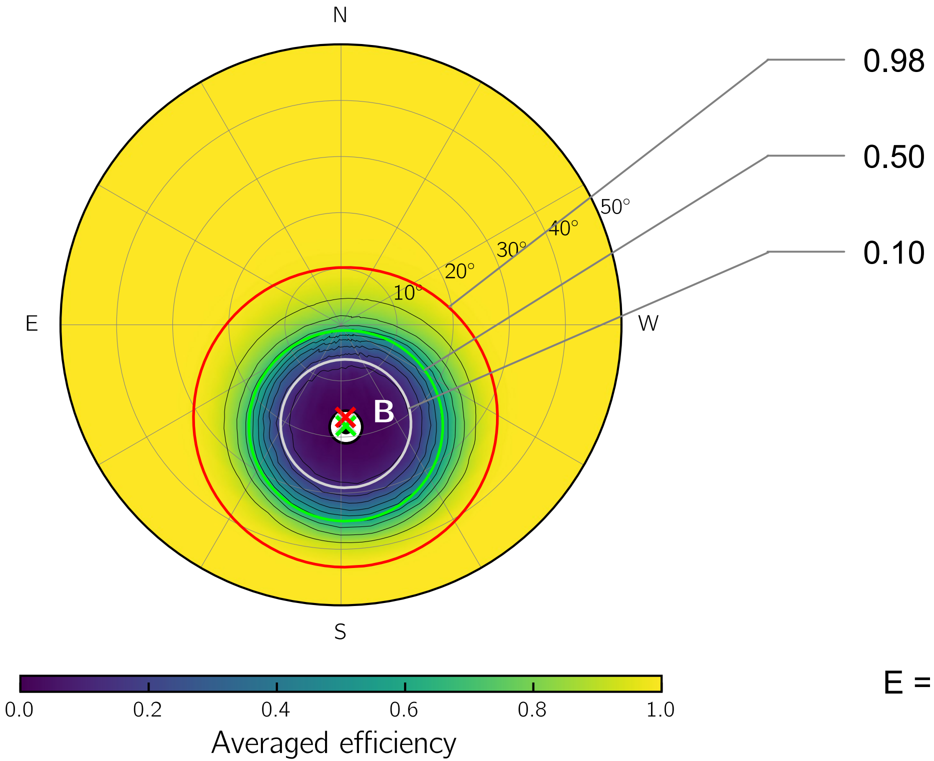


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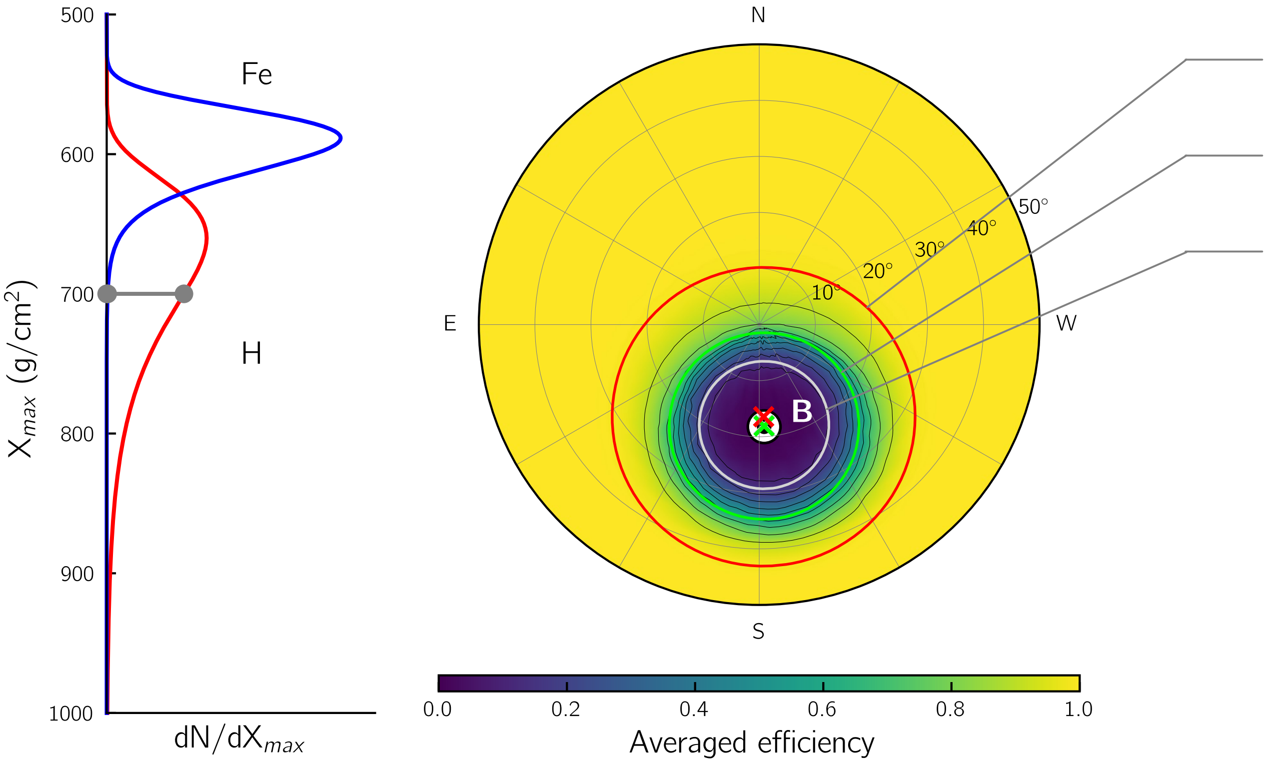


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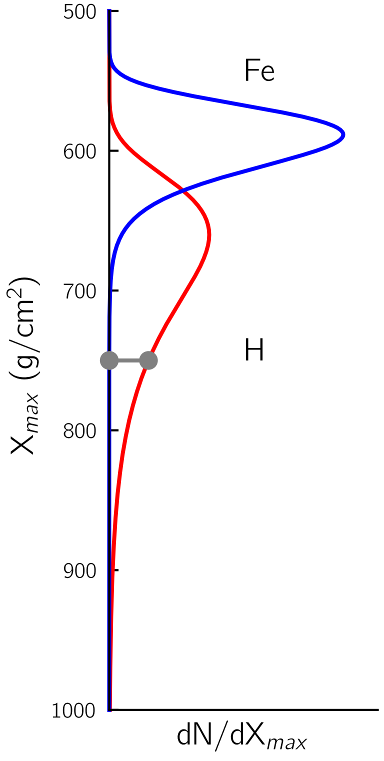


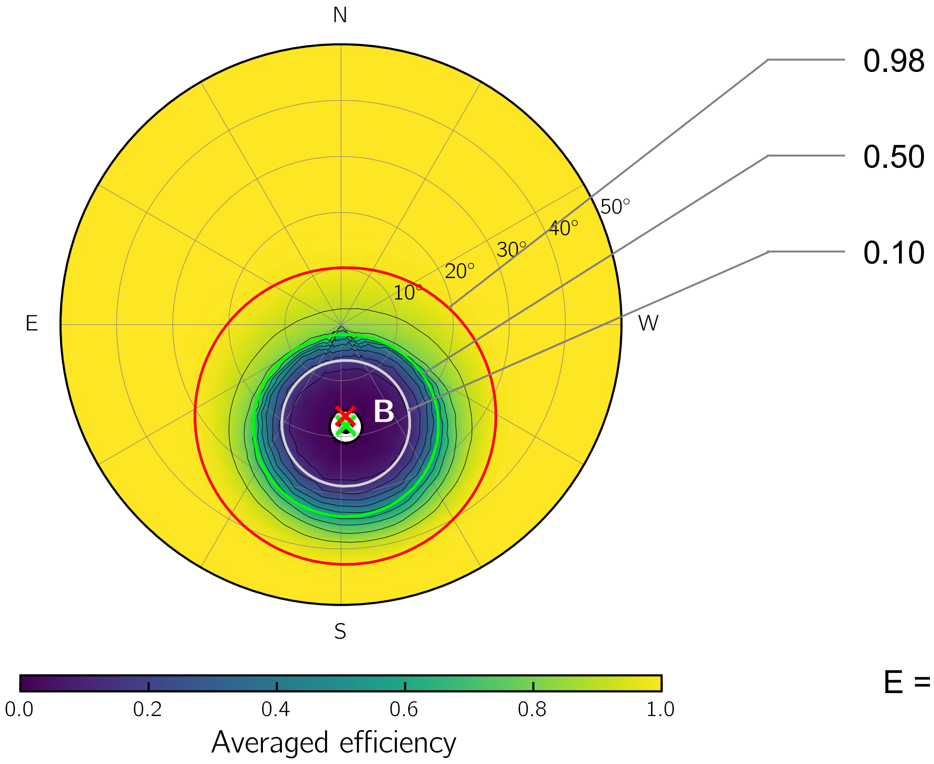


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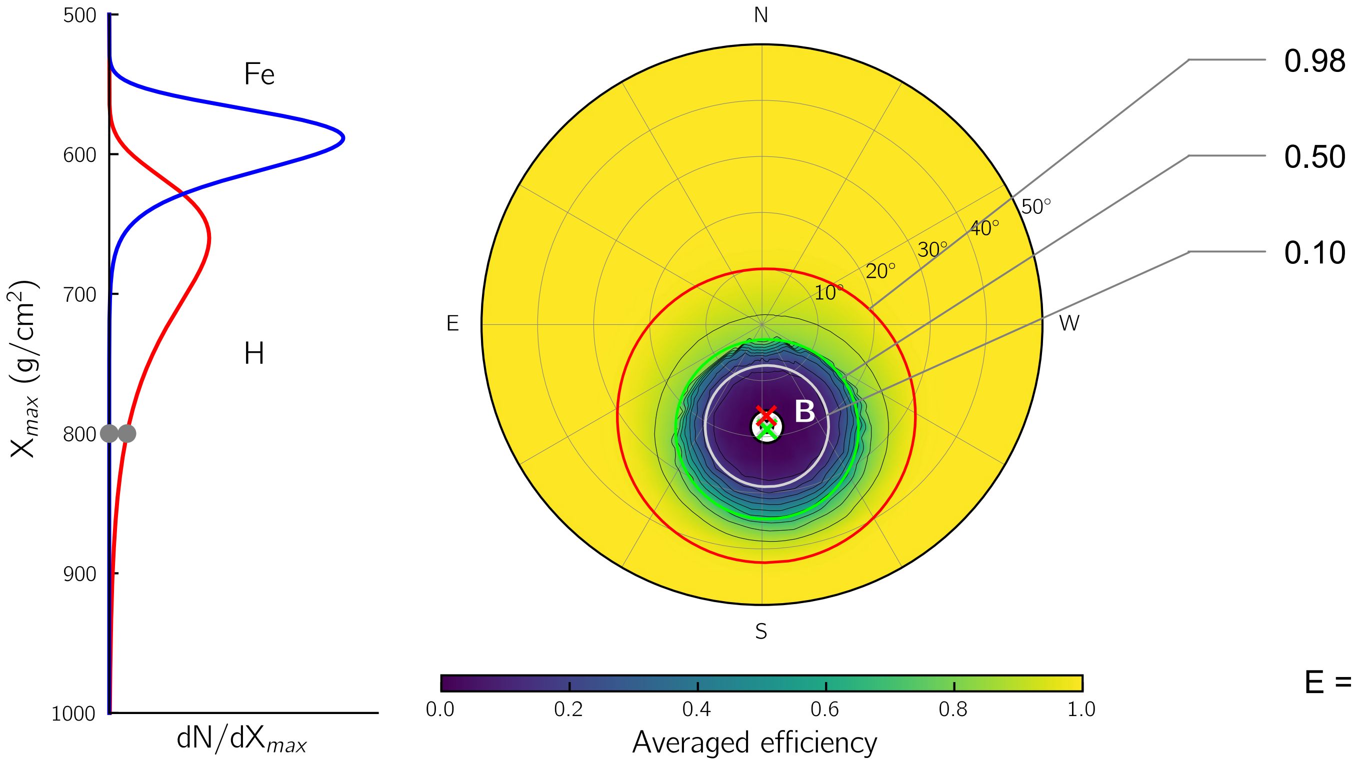


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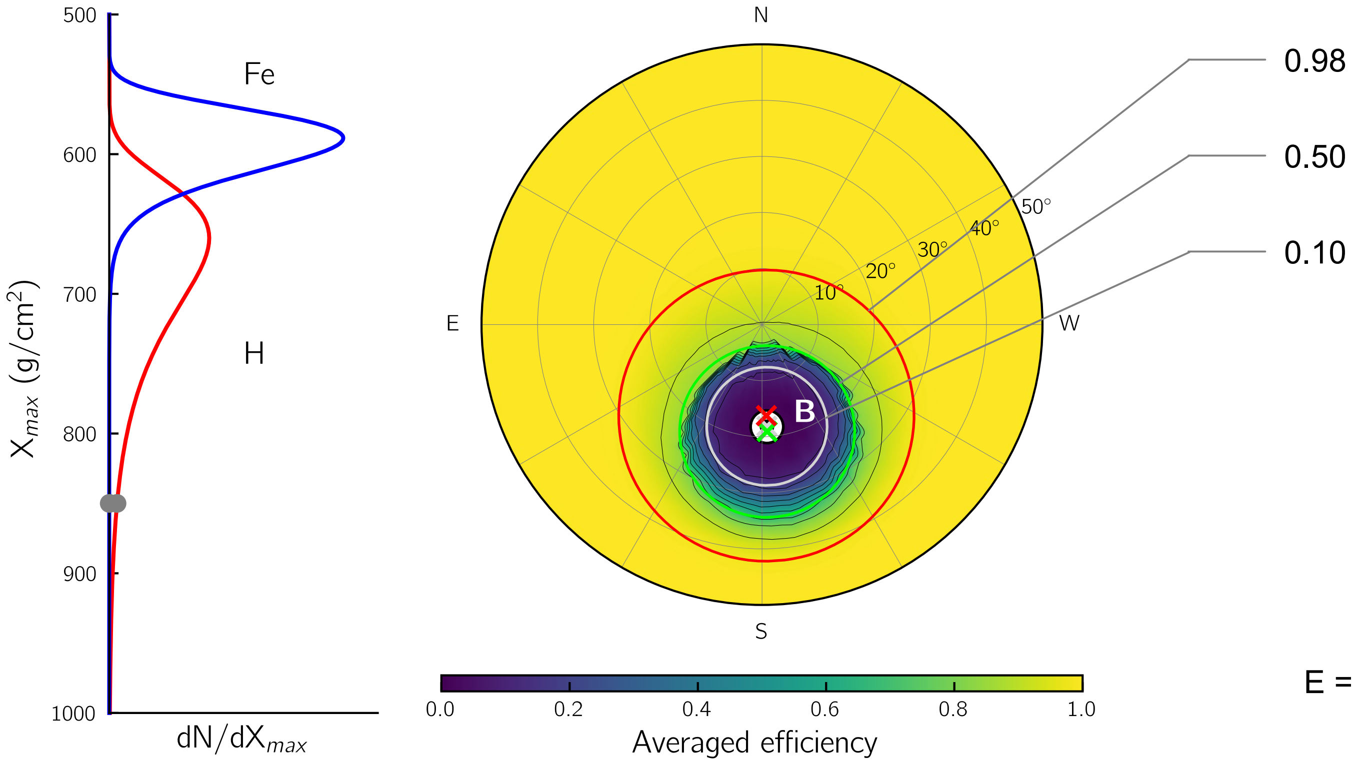


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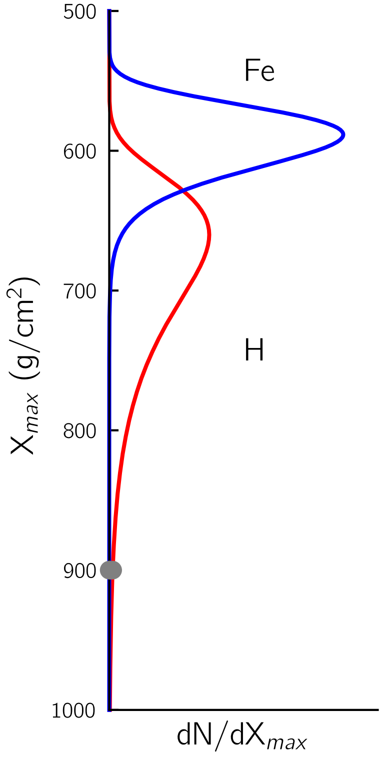


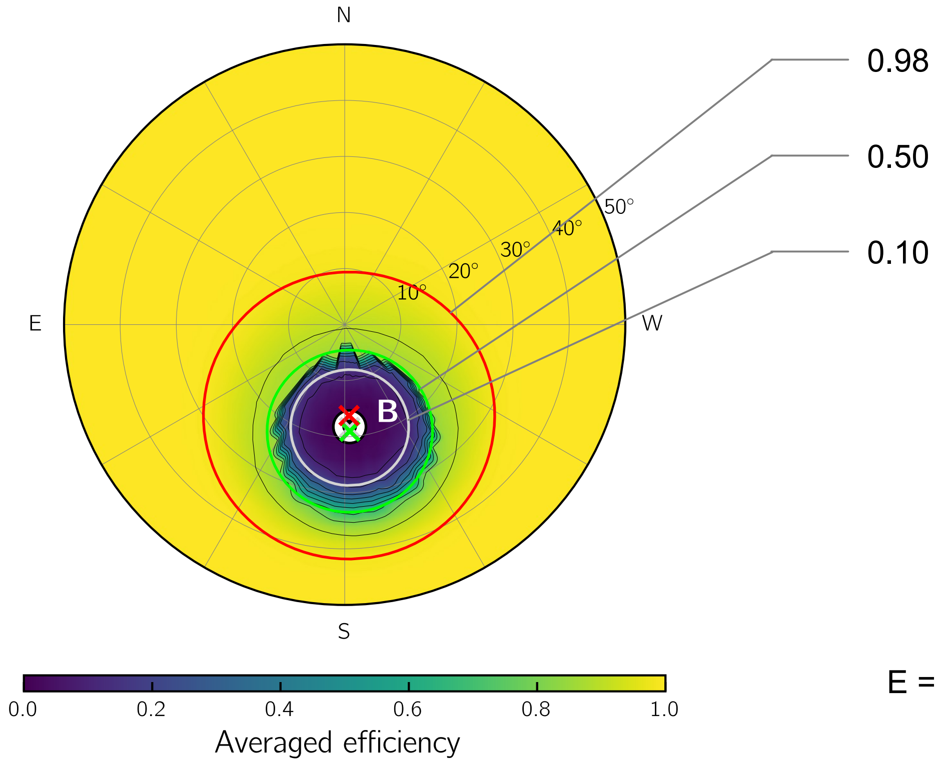


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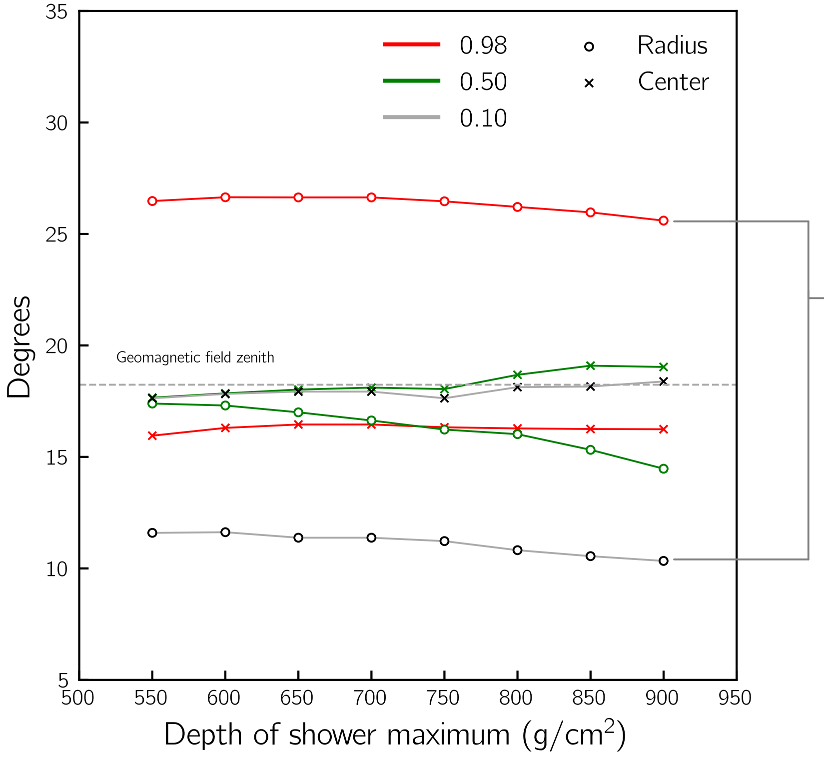
# Full-Efficiency Region Evolution




Almost no change of radii for 0.98 and 0.10 regions

# Summary

The aperture model:

- Is the key to measure CR flux's characteristics (energy spectrum and mass composition)
- Combination of two components: probabilistic model of detection efficiency and semi-analytical approach to integral estimation
- Incorporates all known uncertainties
- Can be used for studying dependence of efficiency and aperture on E and $X_{max}$
- Is generic and can be used by other radio arrays