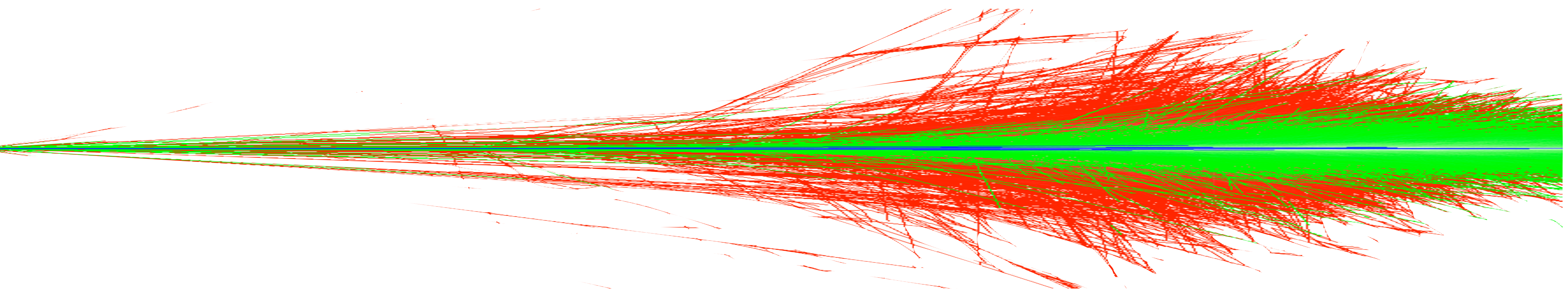
High energy cosmic particles



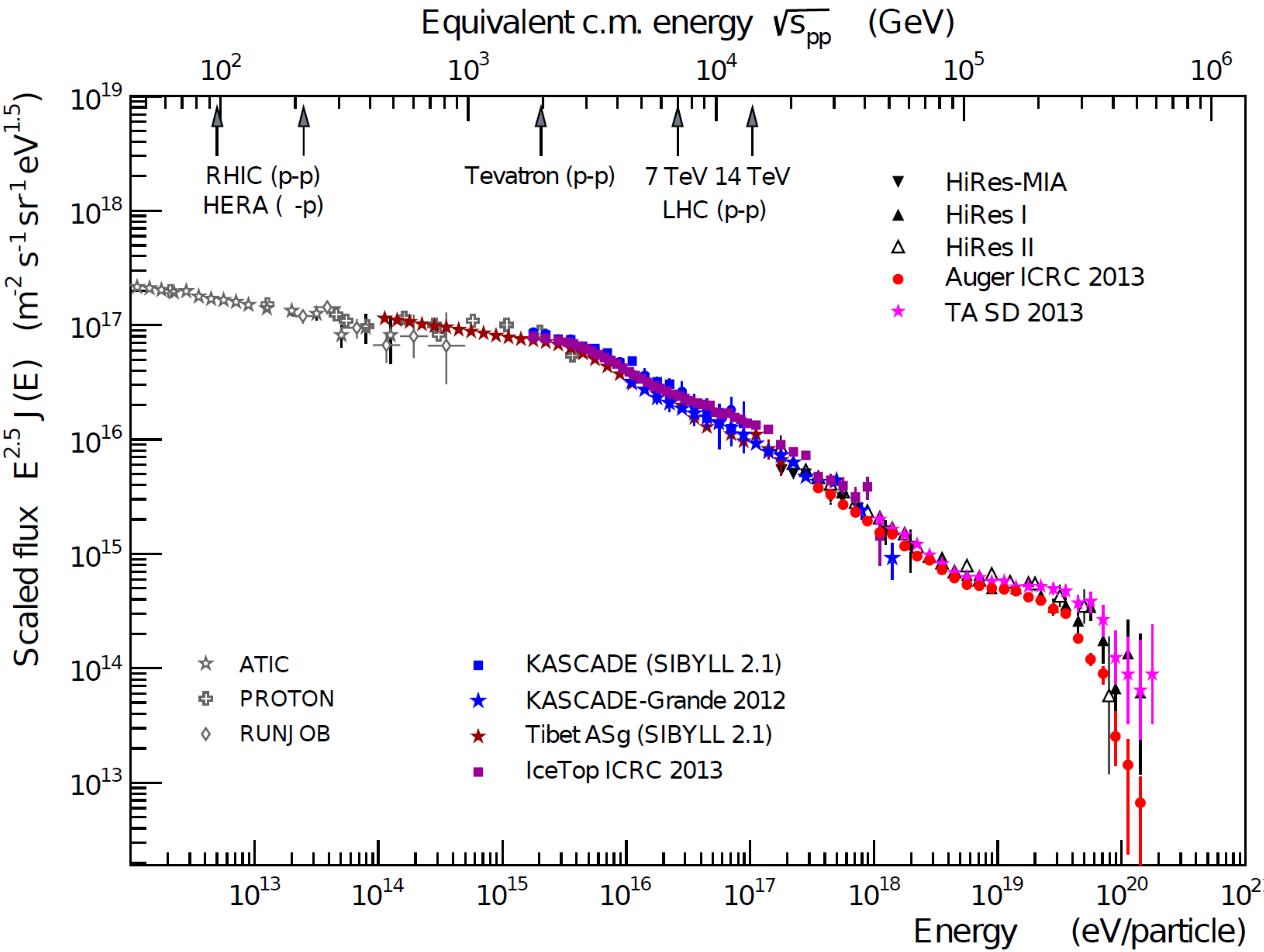
also here in Stockholm:
Justin Bray, Olaf Scholten

Stijn Buitink
for the *HECP focus group*
Aug 24 2015 - Stockholm SKA-KSP

Vrije Universiteit Brussel

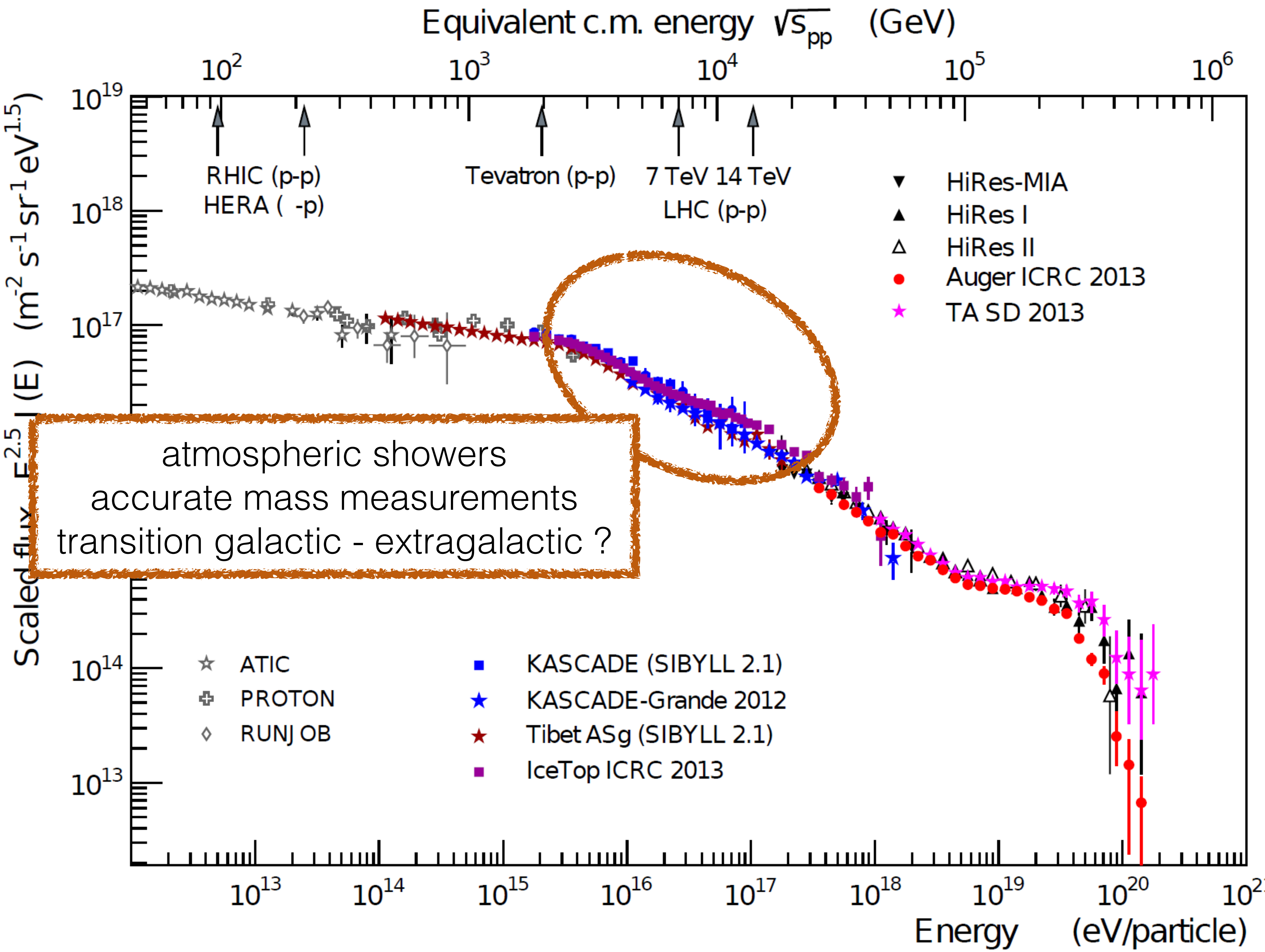
European Research Council

Cosmic ray all-particle spectrum



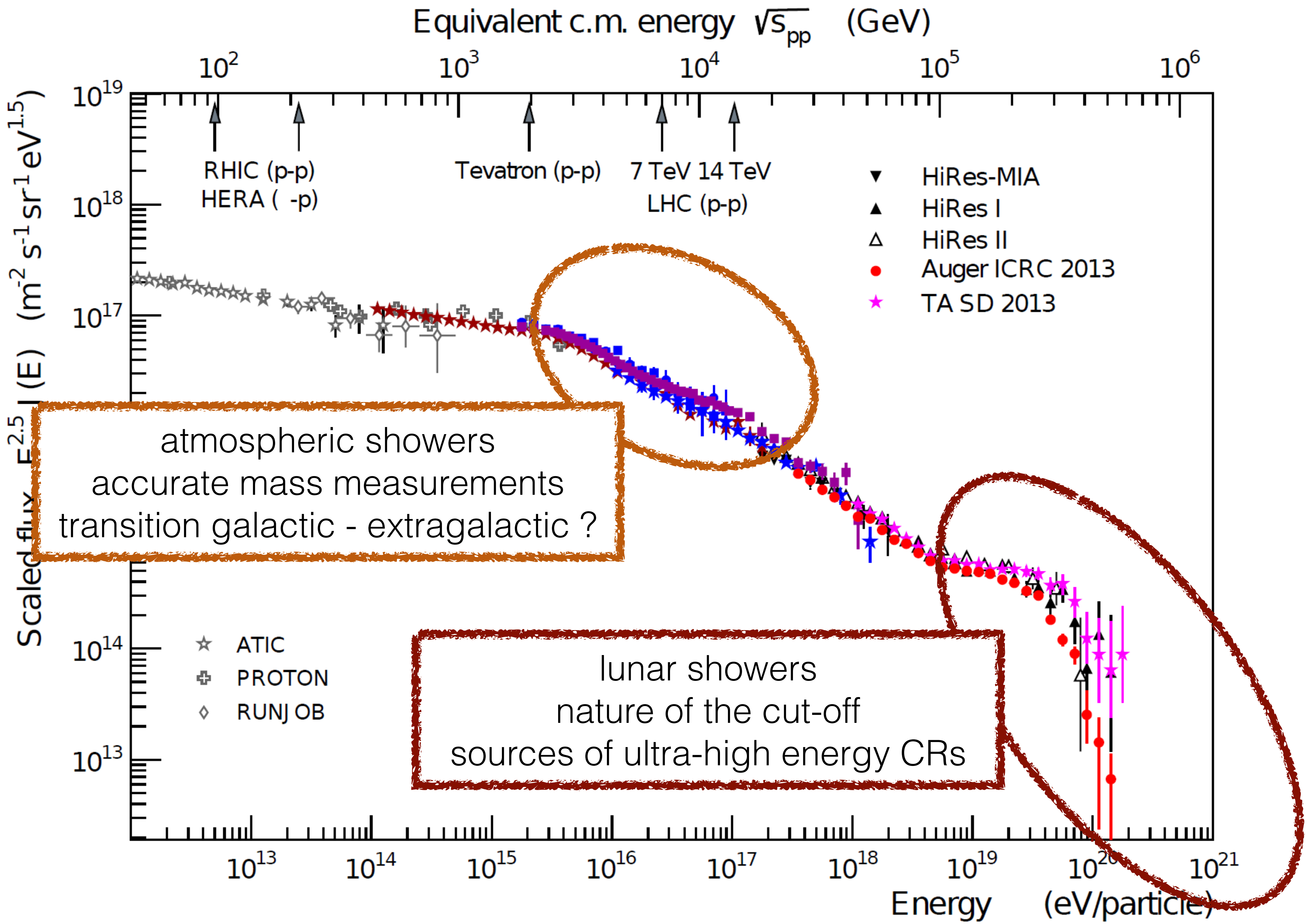
two ECPs under consideration

Cosmic ray all-particle spectrum



two ECPs under consideration

Cosmic ray all-particle spectrum



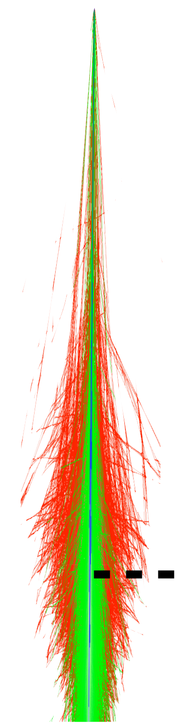
two ECPs under consideration

Atmospheric showers

Measure mass composition at 10^{17} - 10^{18} eV
to disentangle Galactic and extragalactic component

$E_{max} \sim 2\, \beta\, c\, Z\, e\, B\, r$

transition to heavier composition =
maximum source energy reached



shallow - heavy

Xmax

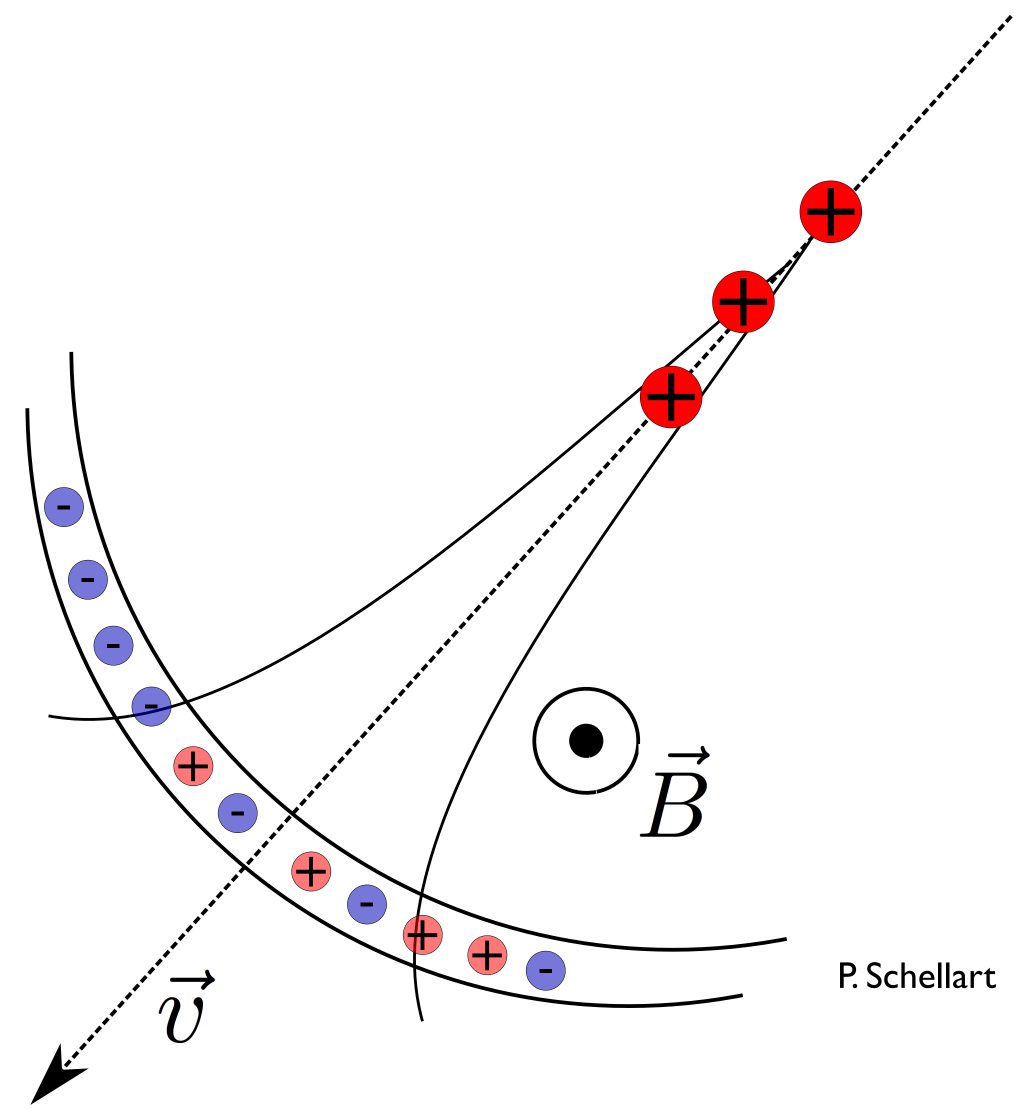
deep - light

established technique:
Fluorescence: ~ 20 g/cm^2, 15% duty cycle

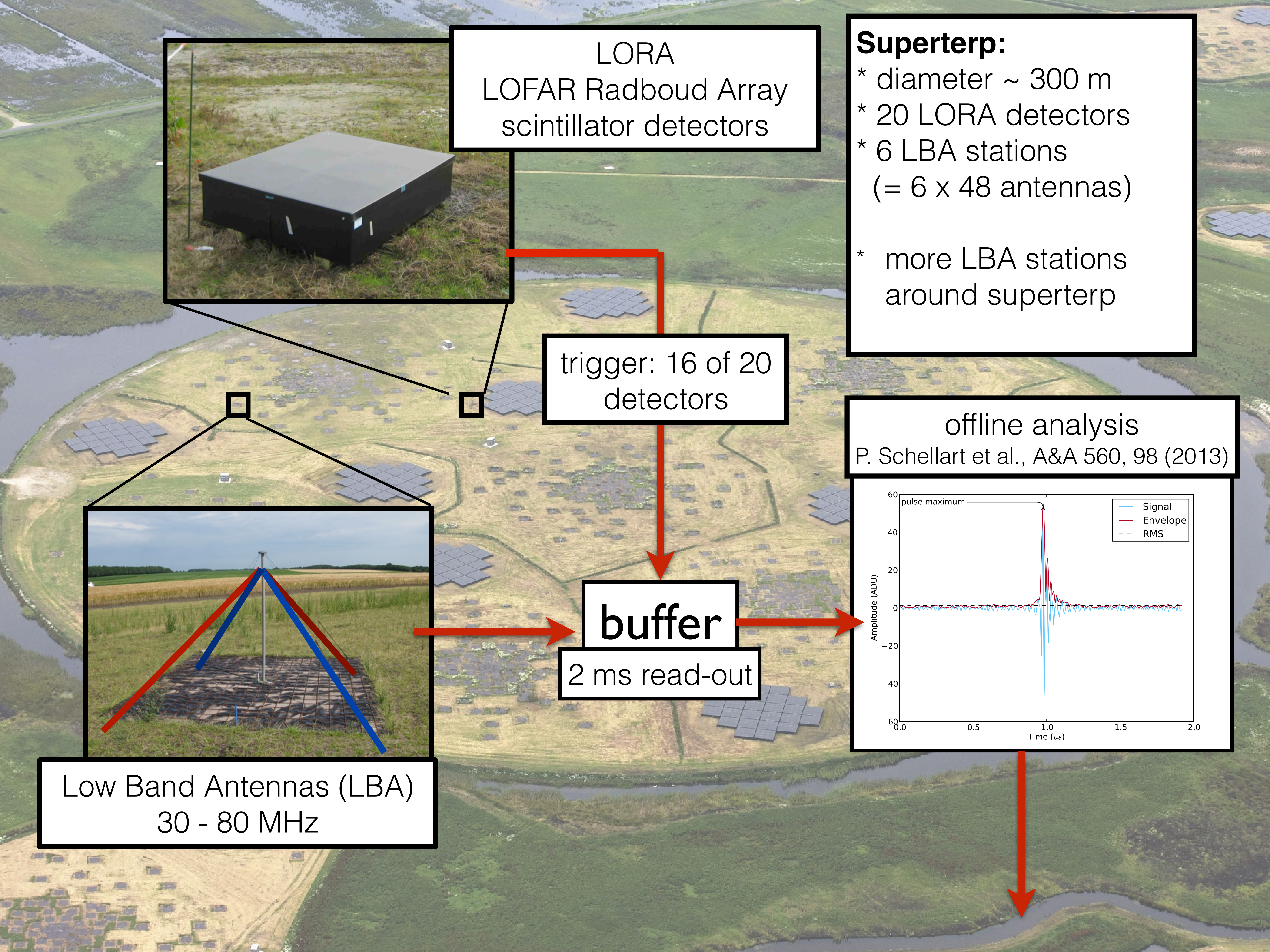
radio *method:*
LOFAR in 2014: < 20 g/cm^2, 100% duty cycle

What drives the radio emission?

- Earth magnetic field
  electrons/positrons deflected
  $E \sim dn_{ch}/dt$
- Charge excess
  negative charge due to electron knockouts
  $E \sim d(n_e - n_p)/dt$
- Non-unity index of refraction
  Cherenkov-like effects
  ring structure possible

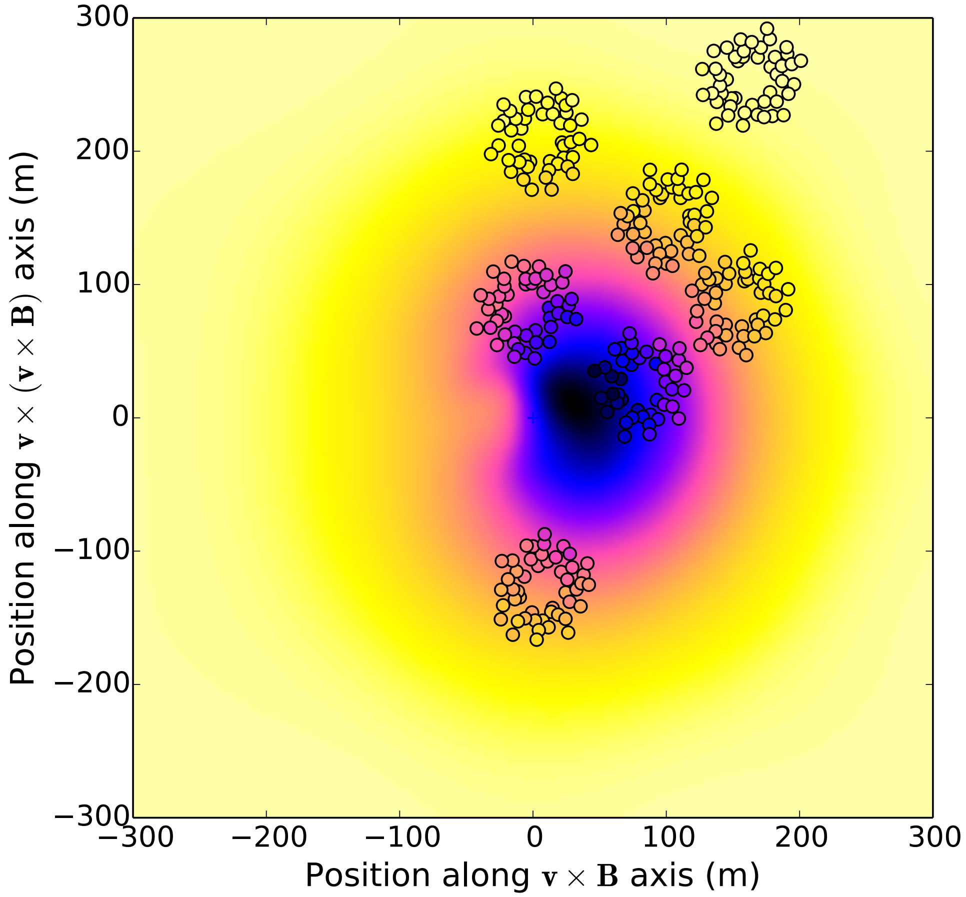


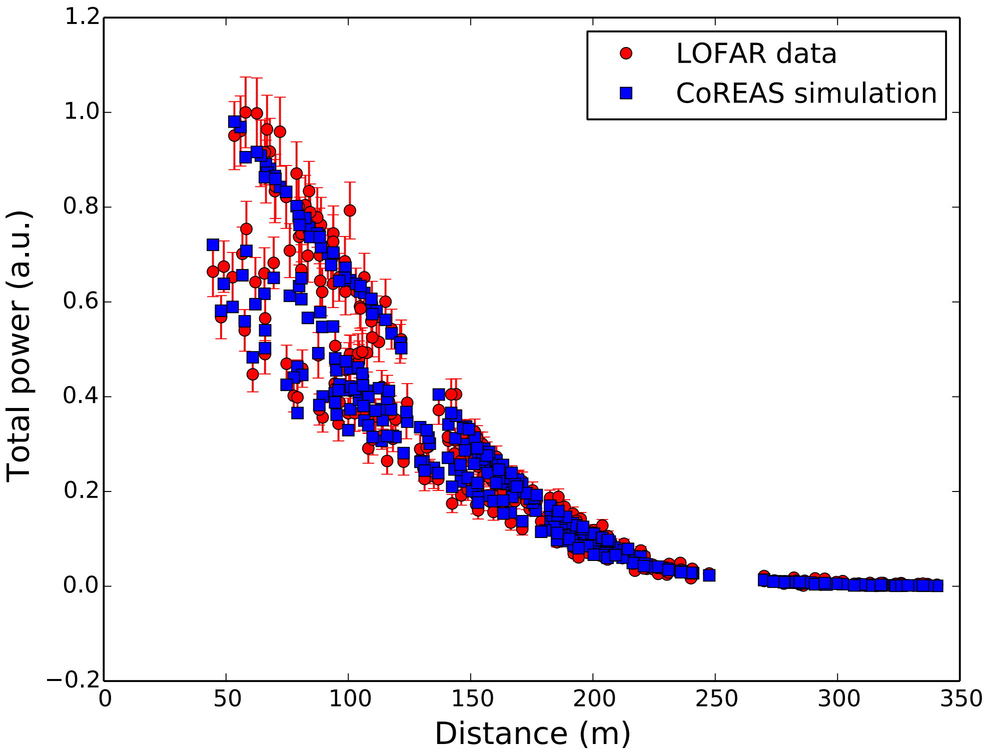
Coherent at 100 MHz (higher at Cherenkov angle!)
wavelength > shower front size
$P \sim n^2$


LORA
LOFAR Radboud Array
scintillator detectors
Superterp:
* diameter ~ 300 m
* 20 LORA detectors
* 6 LBA stations
(= 6 x 48 antennas)
* more LBA stations around superterp
trigger: 16 of 20 detectors
offline analysis
P. Schellart et al., A&A 560, 98 (2013)
pulse maximum
Signal
Envelope
RMS
Amplitude (ADU)
Time (μs)
buffer
2 ms read-out
Low Band Antennas (LBA)
30 - 80 MHz

Reconstruction of Xmax

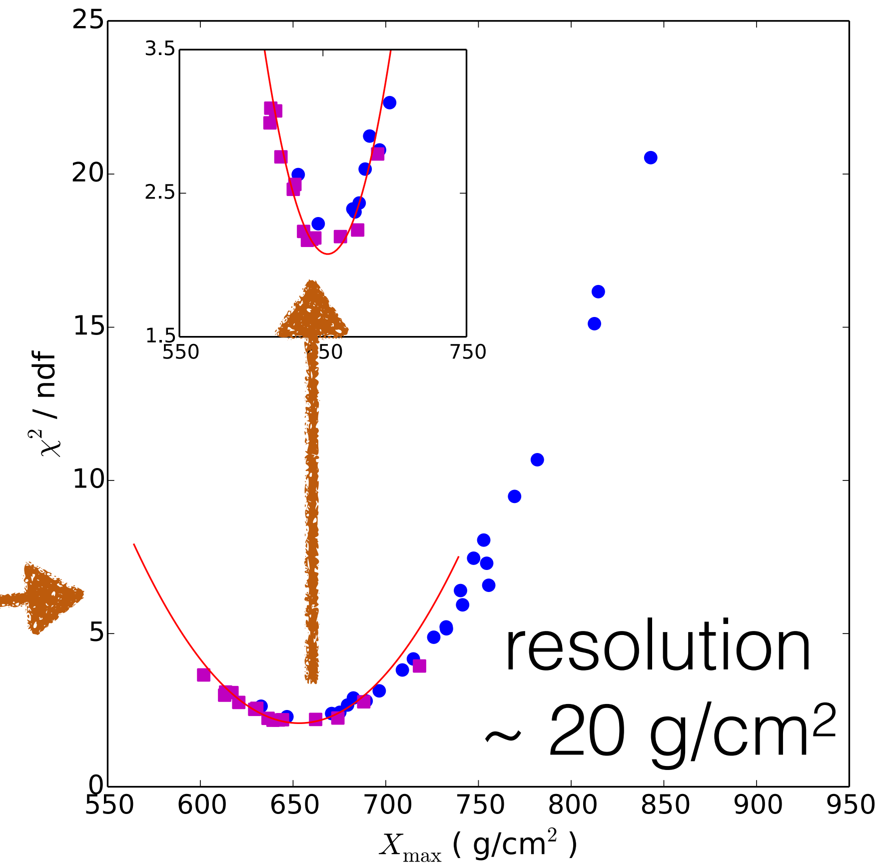
- based on fitting 2D radio profile *(S.B et al., PRD 90 082003 (2014)).*





background: CORSIKA / CoREAS
circles: data
fit: 2D radio + 1D particle

for **each** shower a **dedicated MC set** is produced:
50 p + 25 Fe
Xmax reco: use quality-of-fit
energy reco: from particles



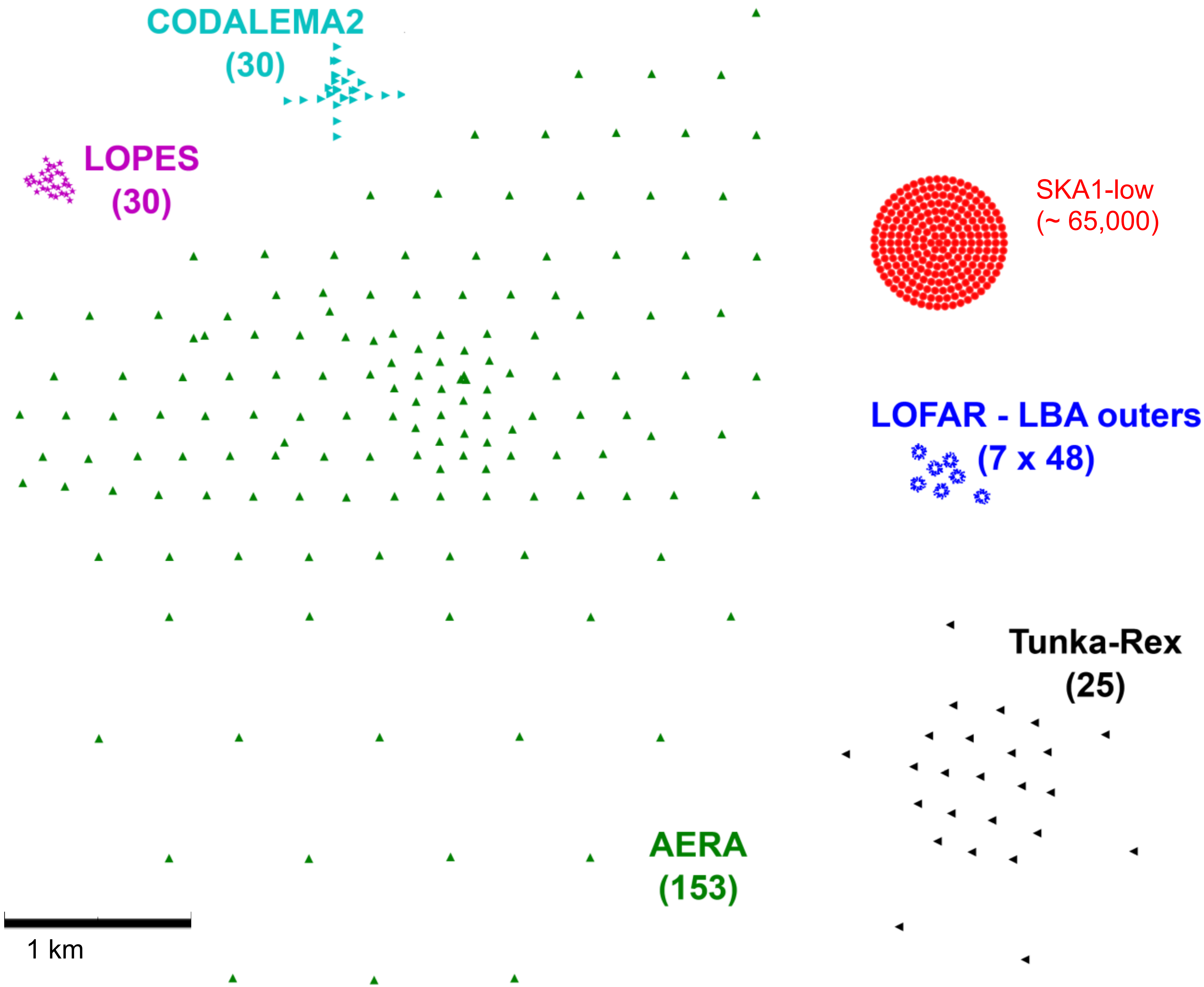
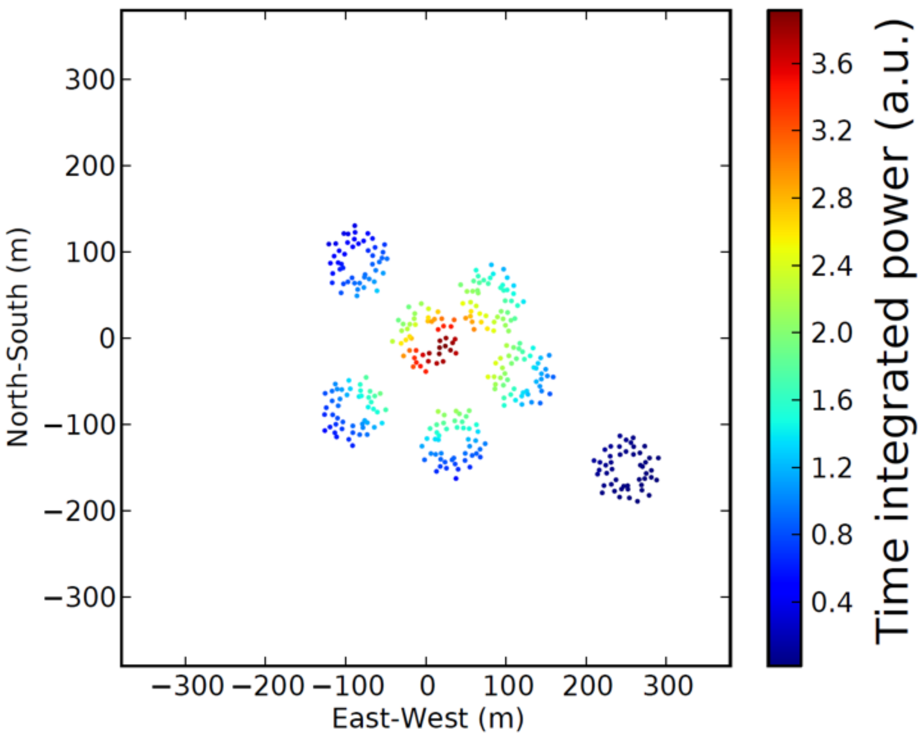
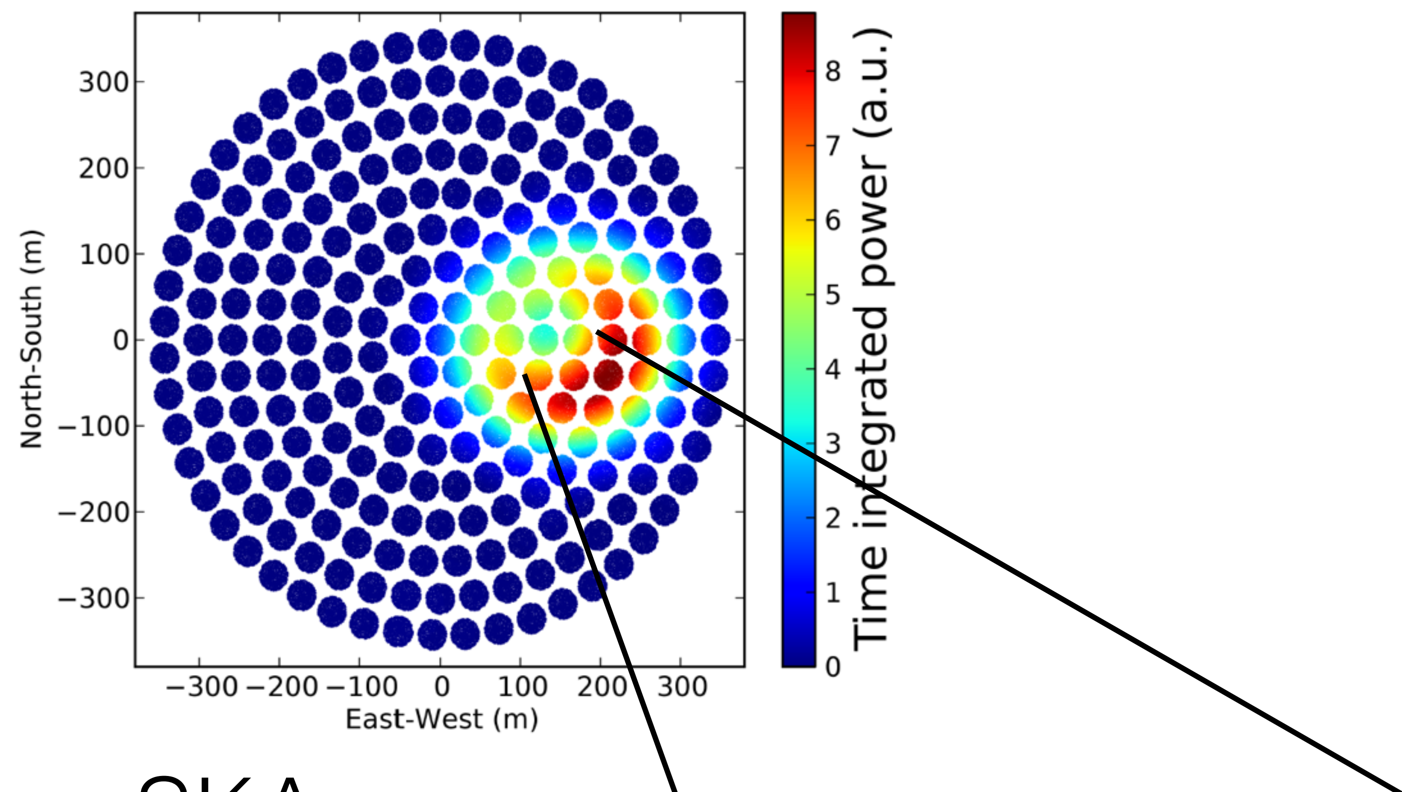


image: T. Huege, A. Zilles

SKA: ultrahigh precision measurements



LOFAR

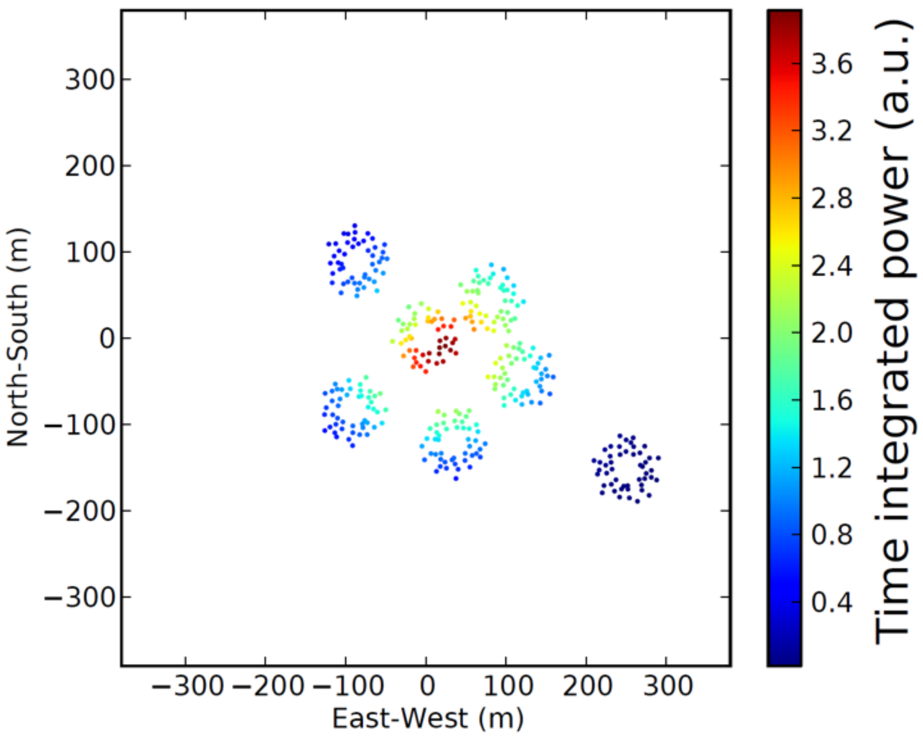


SKA

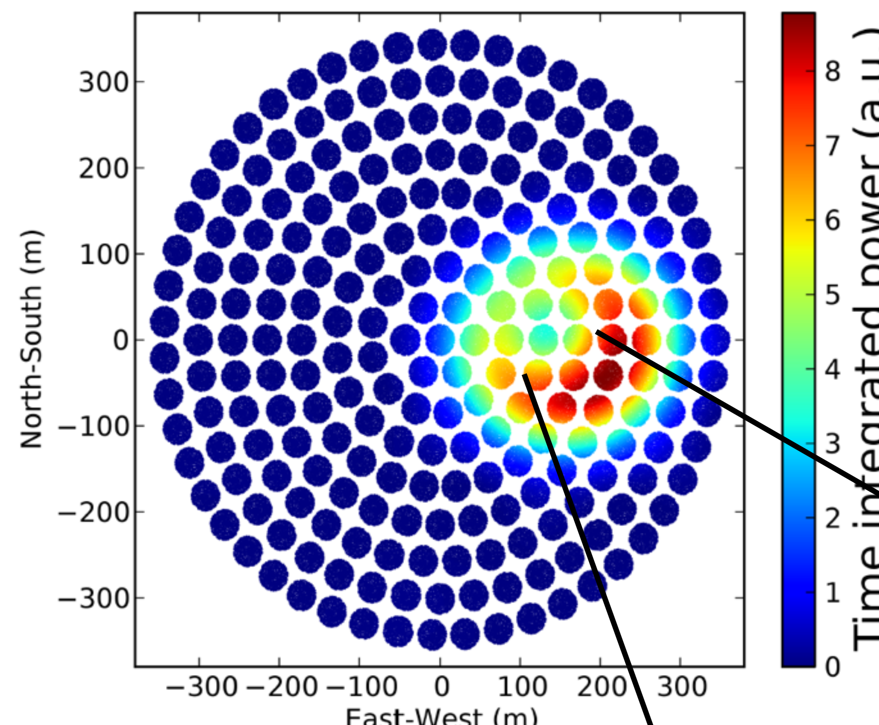
<u>Science</u>:

- **origin of CRs**
  mass composition in transition region G/XG
- **hadronic physics at super-LHC energies**
  shower tomography
- **thunderstorm physics**

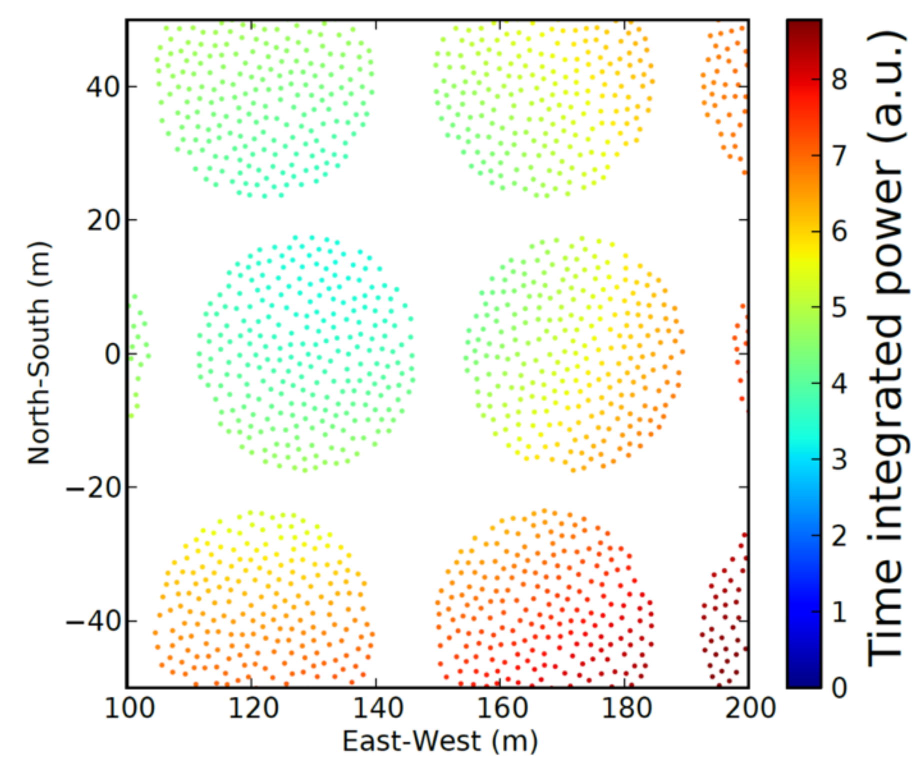
SKA: ultrahigh precision measurements



LOFAR



SKA



<u>Science</u>:

- **origin of CRs**
  mass composition in transition region G/XG
- **hadronic physics at super-LHC energies**
  shower tomography
- **thunderstorm physics**

Air showers in thunderstorms

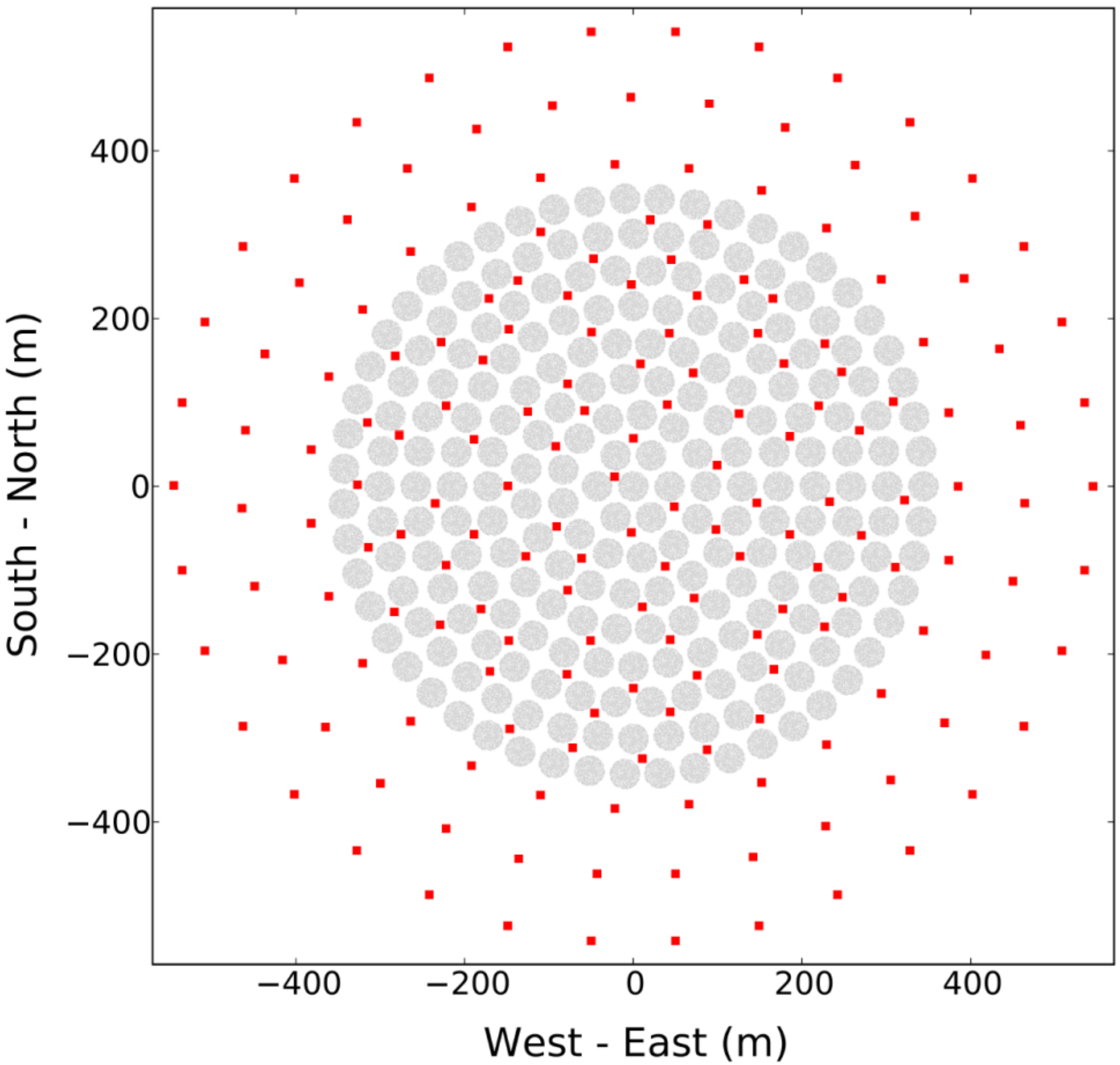
- Regular: geomagnetic field induces traverse current (vxB direction)
- Strong E-field (E ~ cB): current direction changes
- Air showers in thunderstorms: different polarisation & different intensity pattern
- Allows remote sensing of thunderstorm fields!
- Also: 4D lightning mapping lightning triggering by air showers

Schellart et al. PRL **114**, 165001 (2105)

Engineering change: buffering

- Cosmic Ray mode should run **in the background continuously**
- **Buffering** of all individual antennas: raw data
  at least 8 bit, pref. 12 bit
  buffer depth 10 ms (trigger latency)
  total 1.3 TB for 60k antennas
- **Data rate:**
  50 μs per trigger
  ~1 trigger/min.
  read out in bursts of 2.2 GB/s over 3s after trigger

Engineering change: triggering

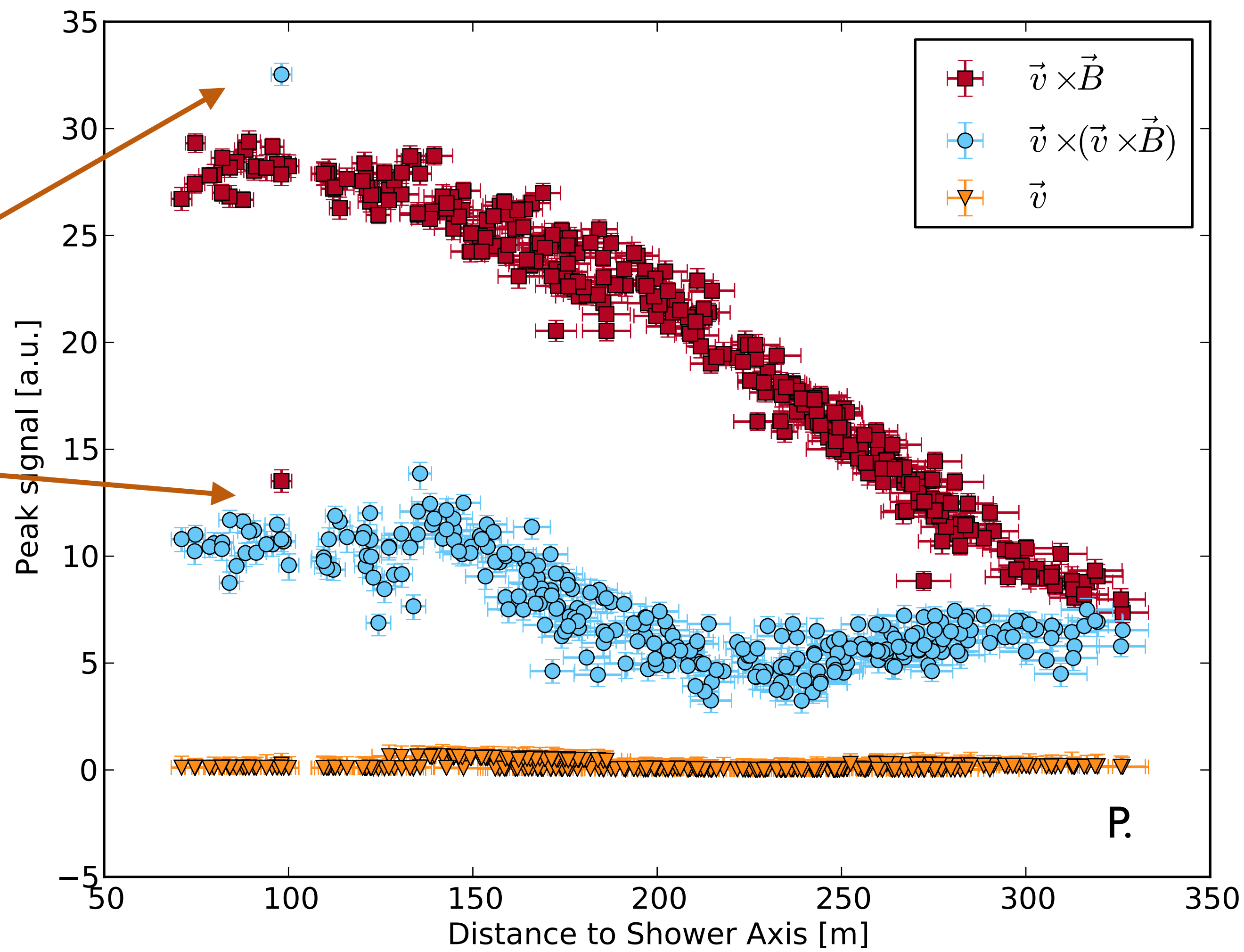


- Flat scintillator particle detectors for triggering
- Efficient at 10^{16} eV: spacing 50-100 m
- Baseline design: 180 former KASCADE detectors (3.6 m^2)
- **RFI/EMI mitigation:**
  - full shielding + possibility of burying underground
  - comm. over optical fibre
  - extensive testing planned at MWA, LOFAR sites

input from other SWGs appreciated!

System diagnostics

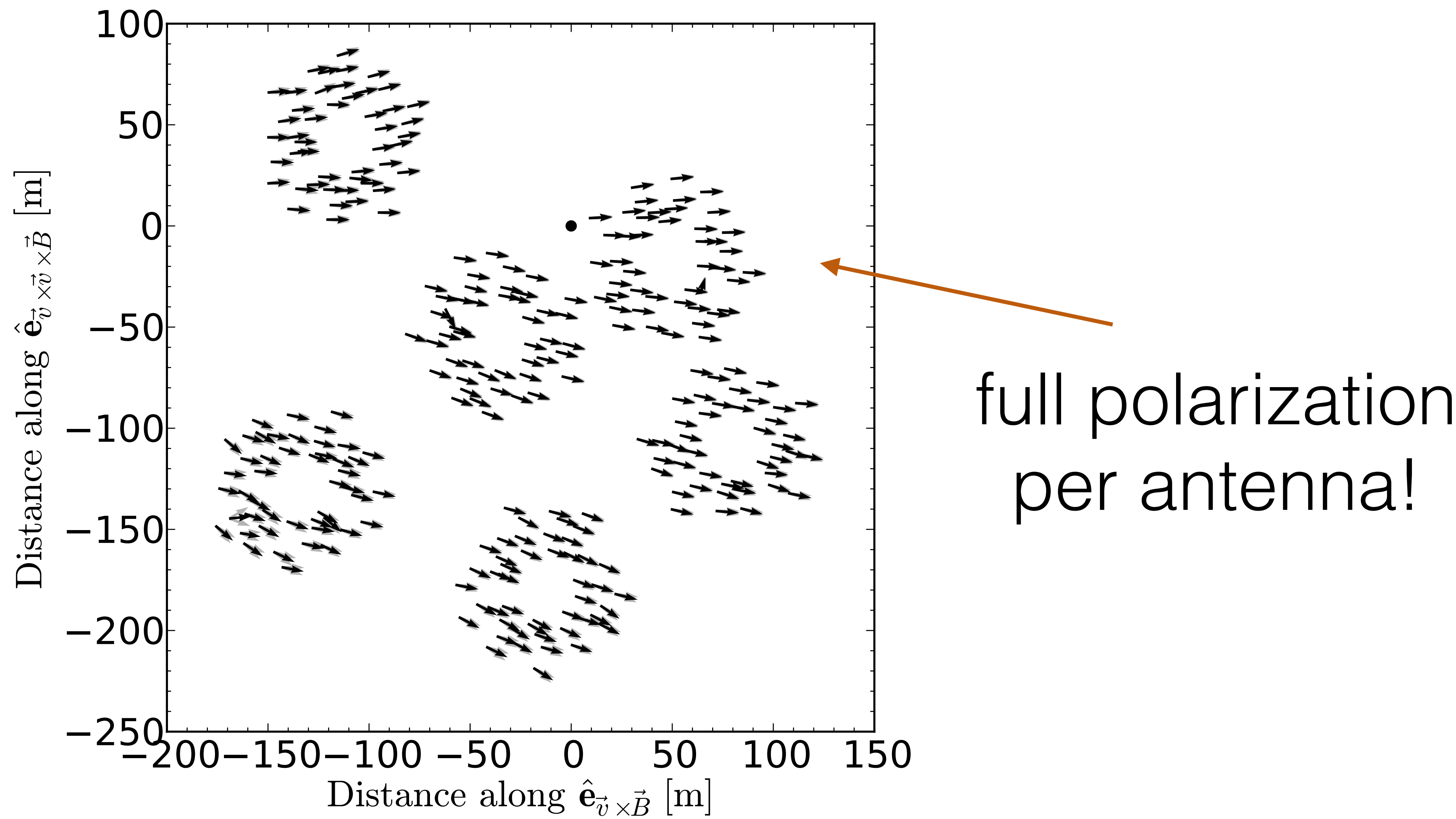
oops!



raw time-series data provide powerful diagnostic tool:

- in-situ antenna response model calibration
- bad connections, switched cables, ns timing offsets, etc.

System diagnostics

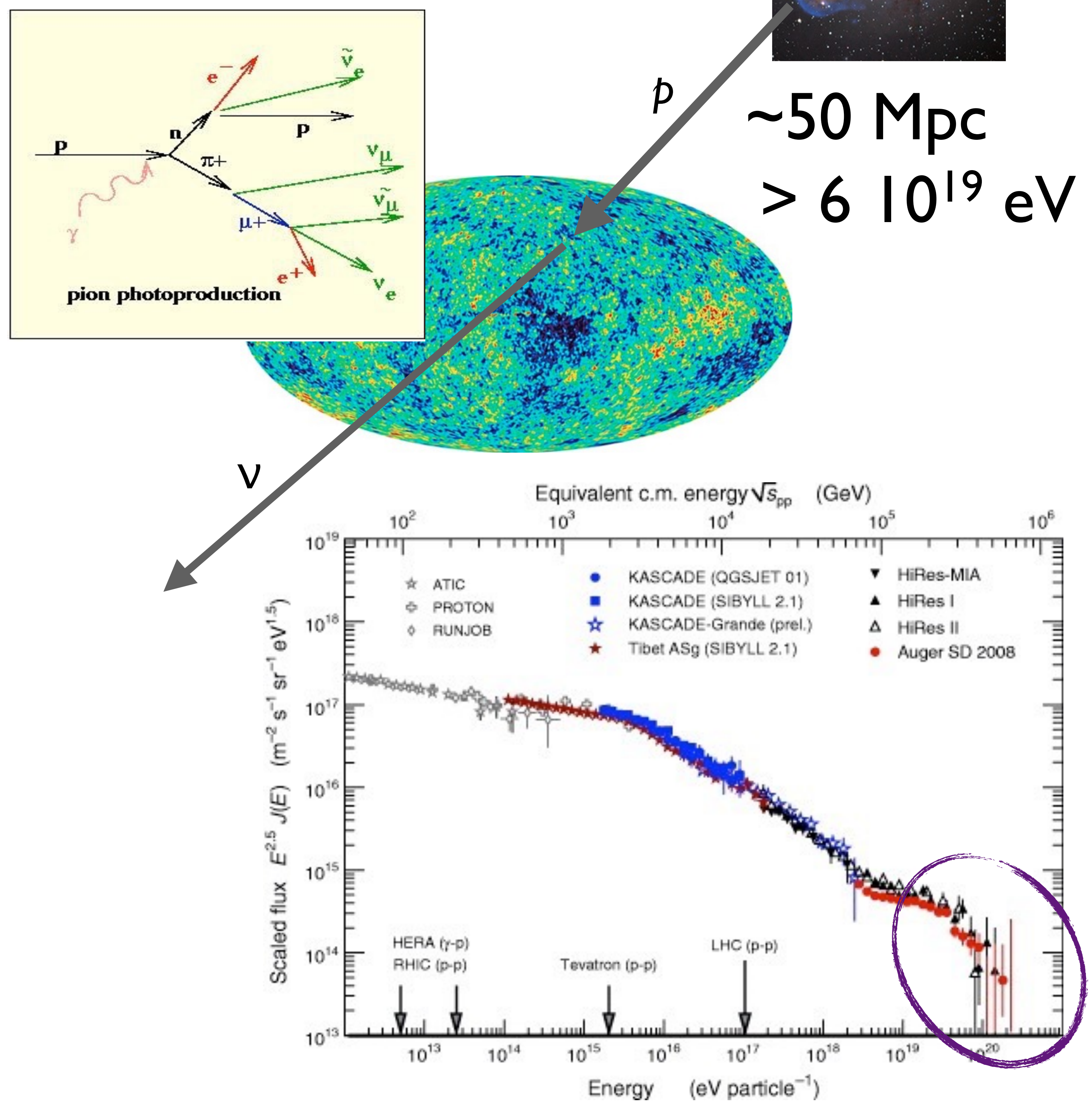


raw time-series data provide powerful diagnostic tool:

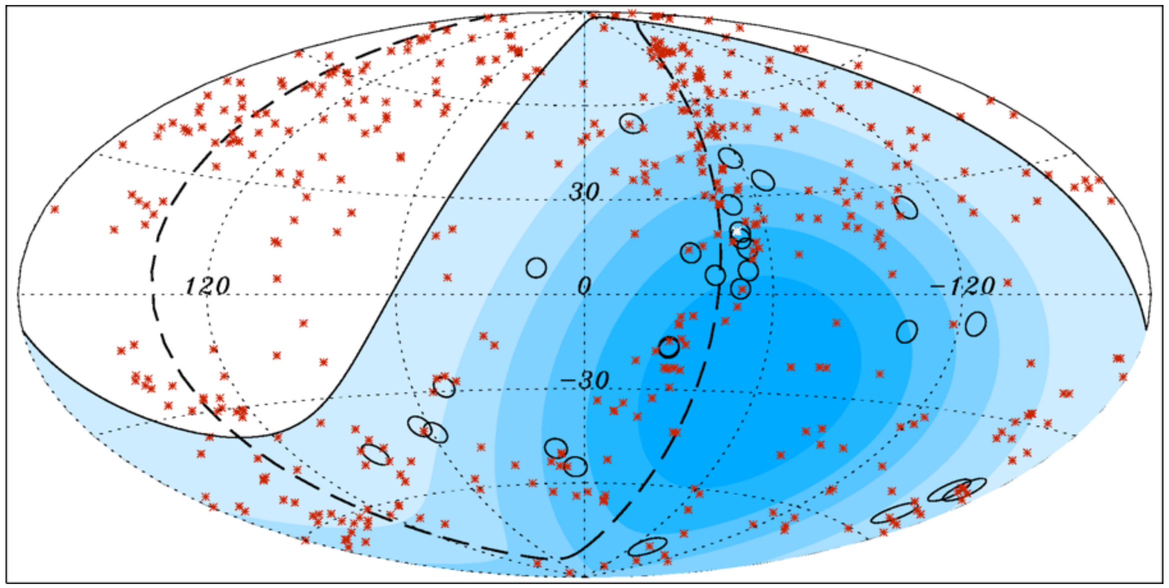
- in-situ antenna response model calibration
- bad connections, switched cables, ns timing offsets, etc.

Ultra-High energy CRs

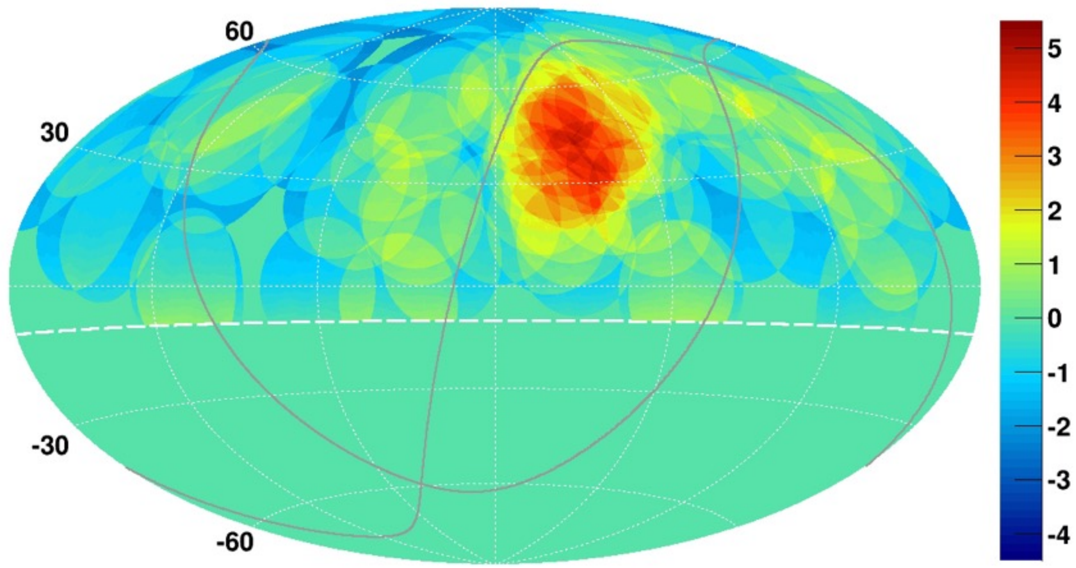
- What are the most energetic sources? (AGN, GRB, …?)
- cut-off: GZK effect or source power?
- search for top-down particles:
  decaying cosmic strings
  supermassive particles



sources above 57 EeV ?



Pierre Auger, southern hemisphere
isotropy rejected



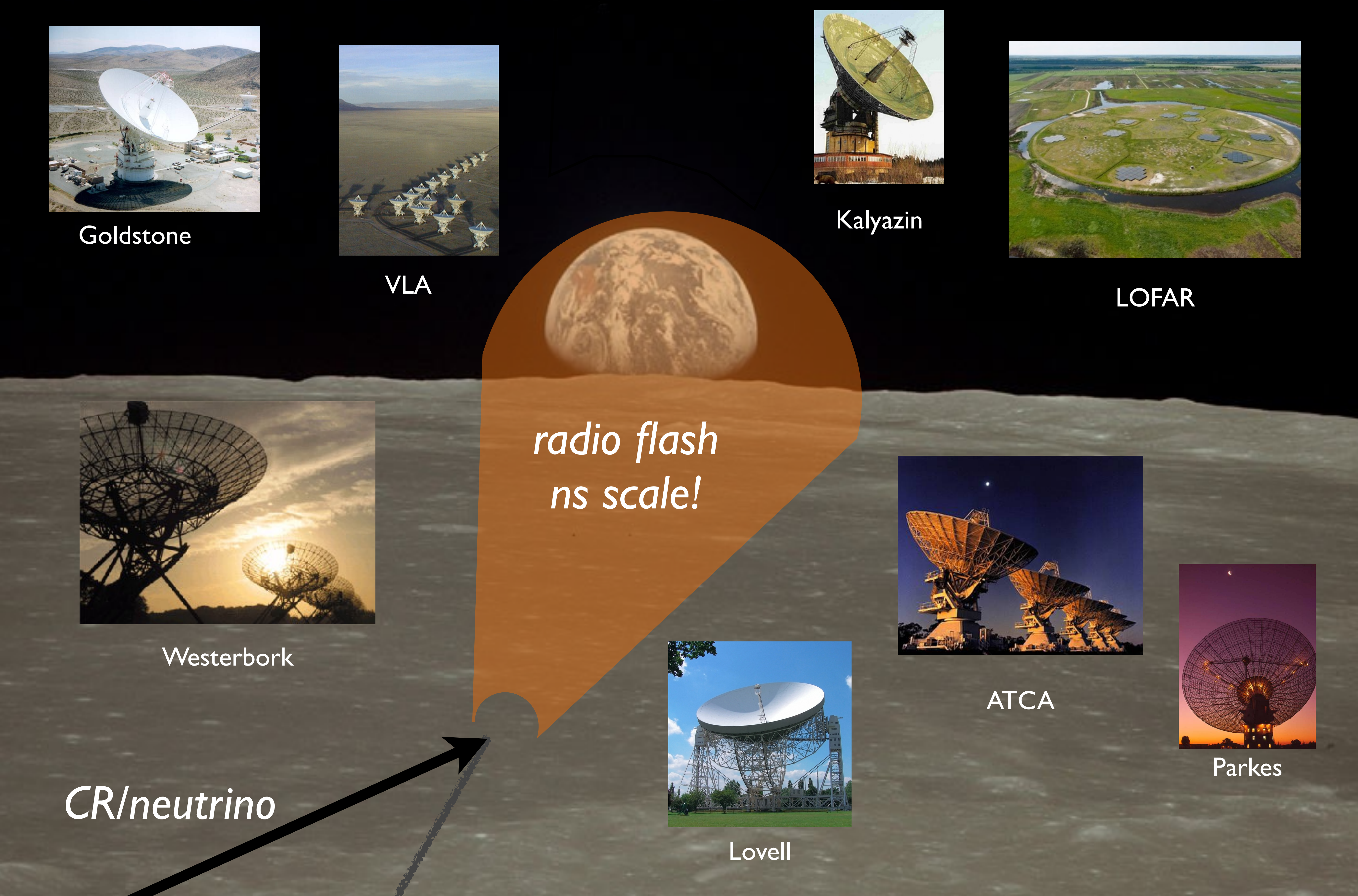
Telescope array, northern hemisphere
hotspot 3.4 sigma

More statistics needed at highest energies

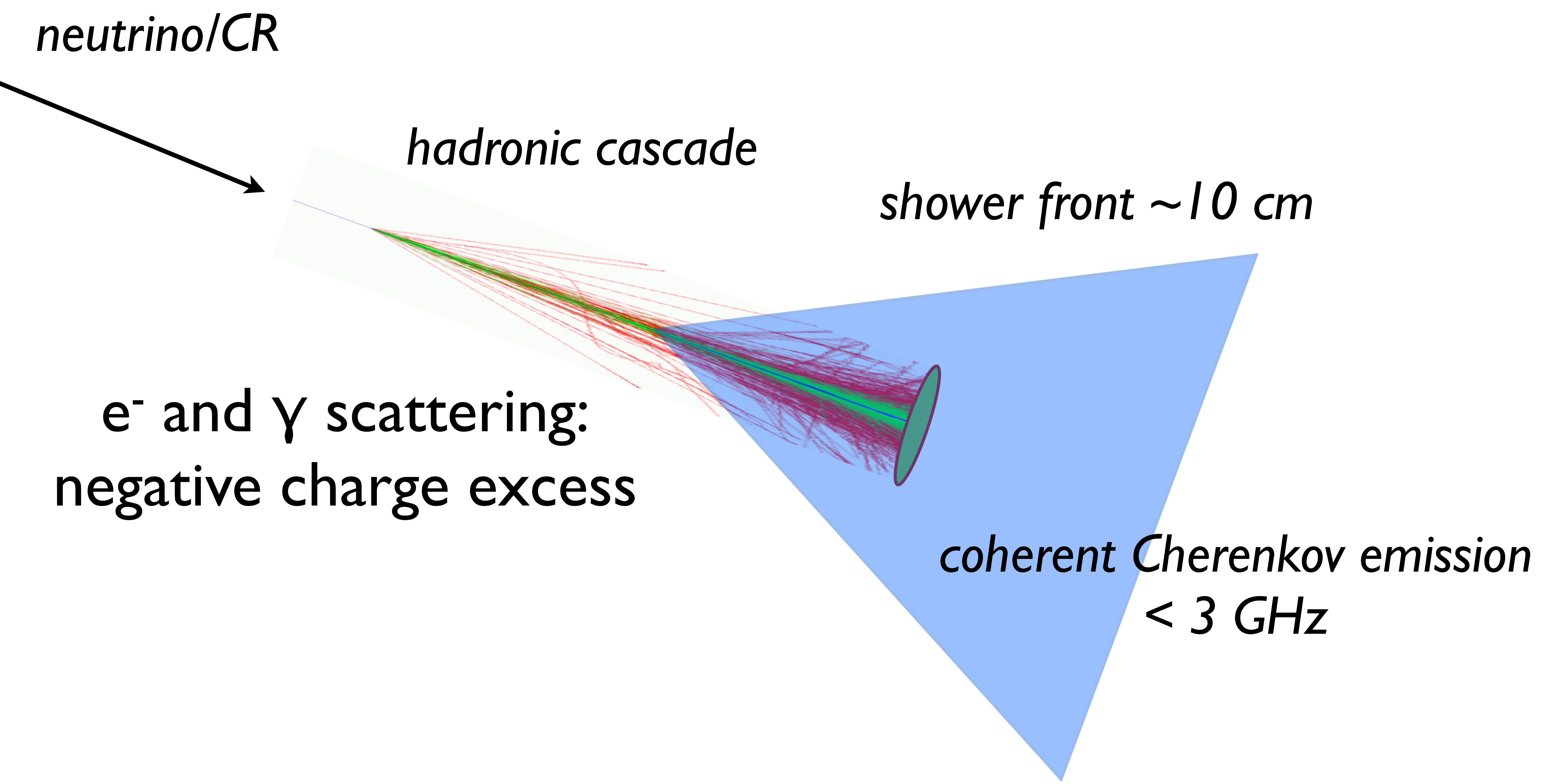
Super-Auger arrays not funded yet, space missions uncertain

SKA could be first observatory to reach sufficient aperture!

10^{20} - $10^{??}$ eV: Moon = 10^7 km^2 detector area

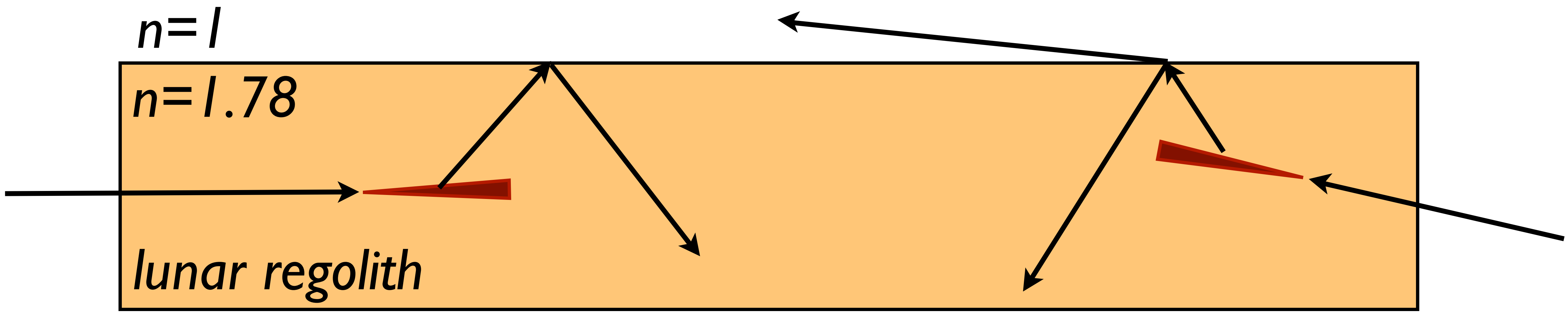


Askaryan effect



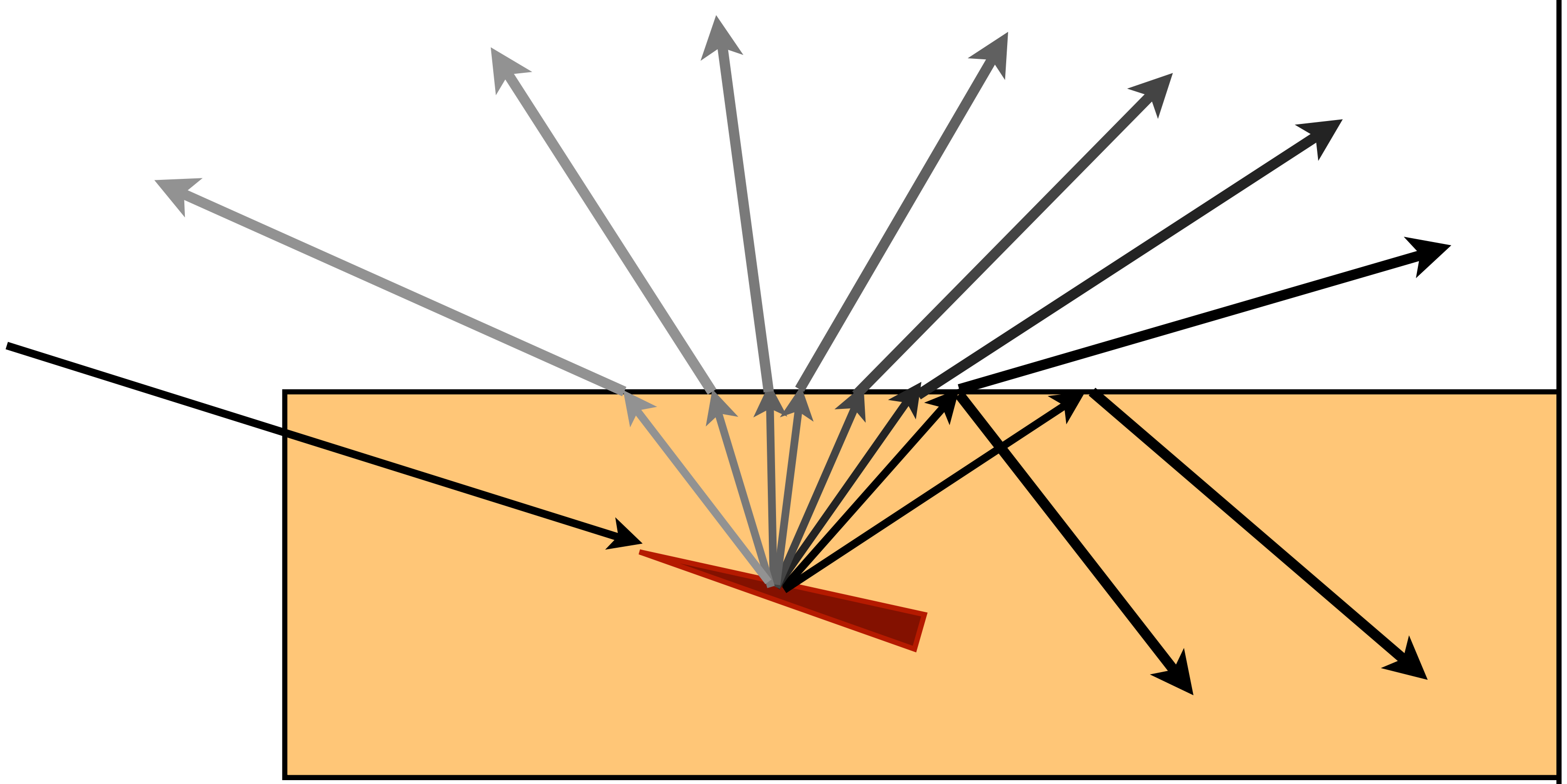
e^- and γ scattering:
negative charge excess

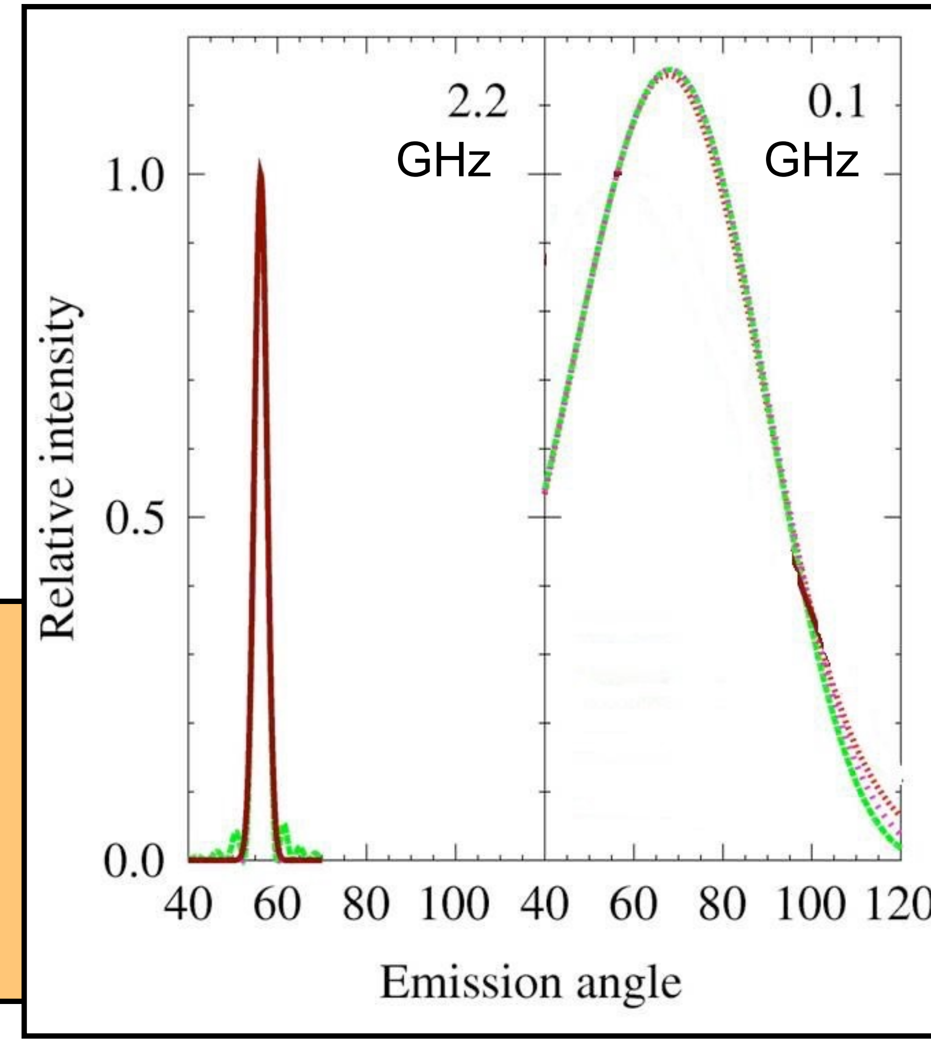
Escape from the Moon



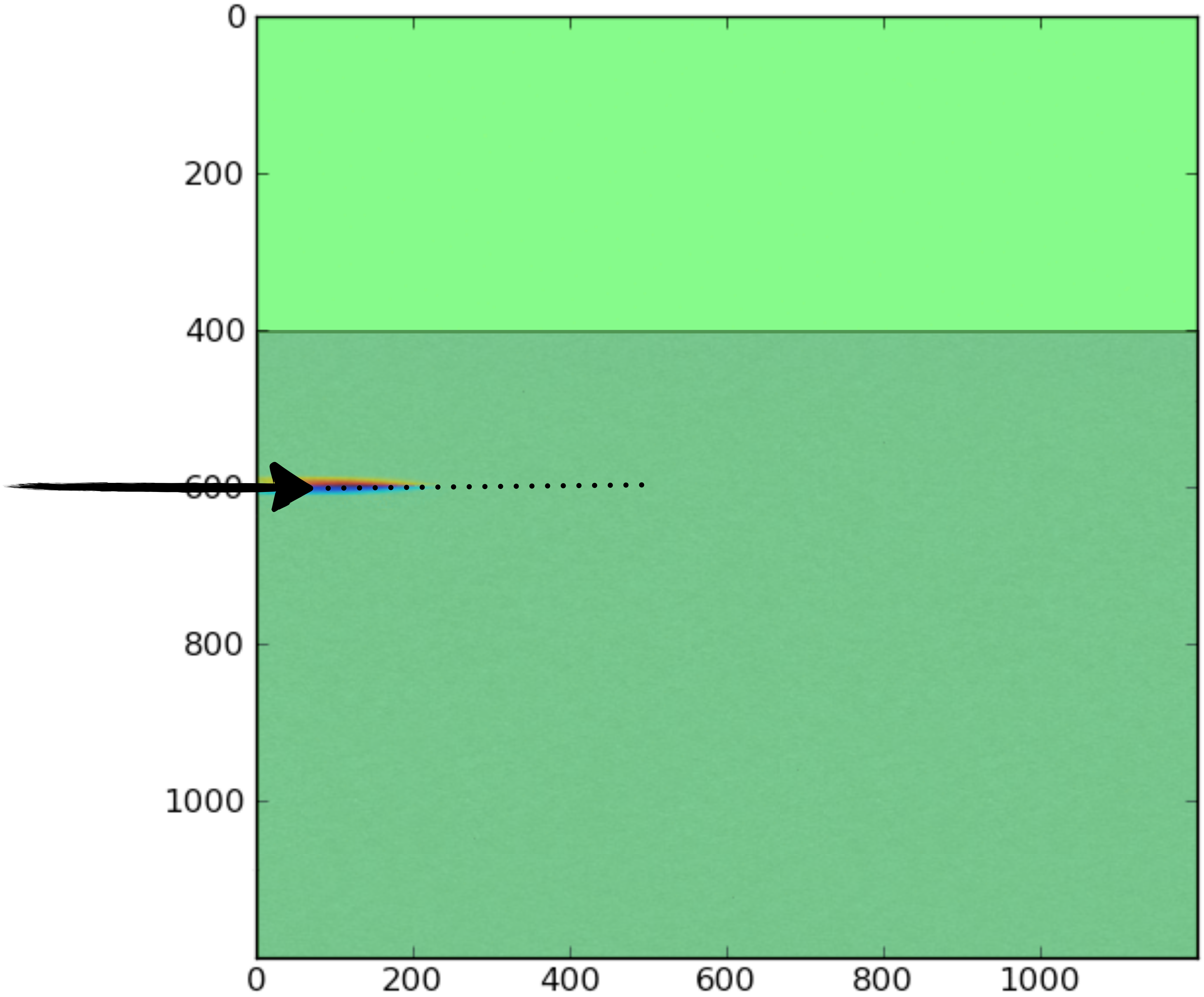
- Askaryan radiation from cascade charge excess
- Cherenkov angle = angle of total internal reflection (for cascade parallel to surface)
- Up-going showers: only at rim of Moon
- Surface roughness helps!

Low Frequency

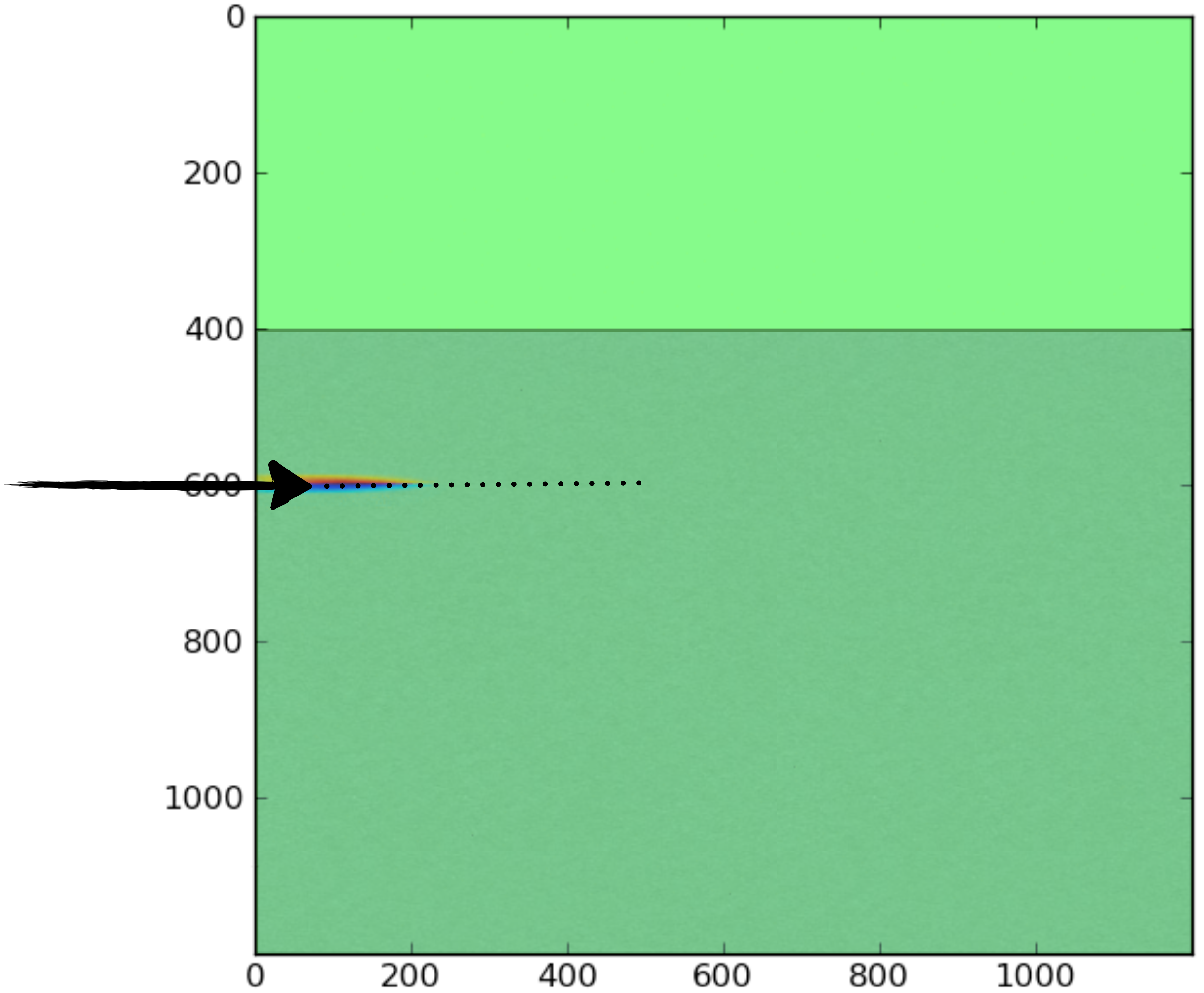




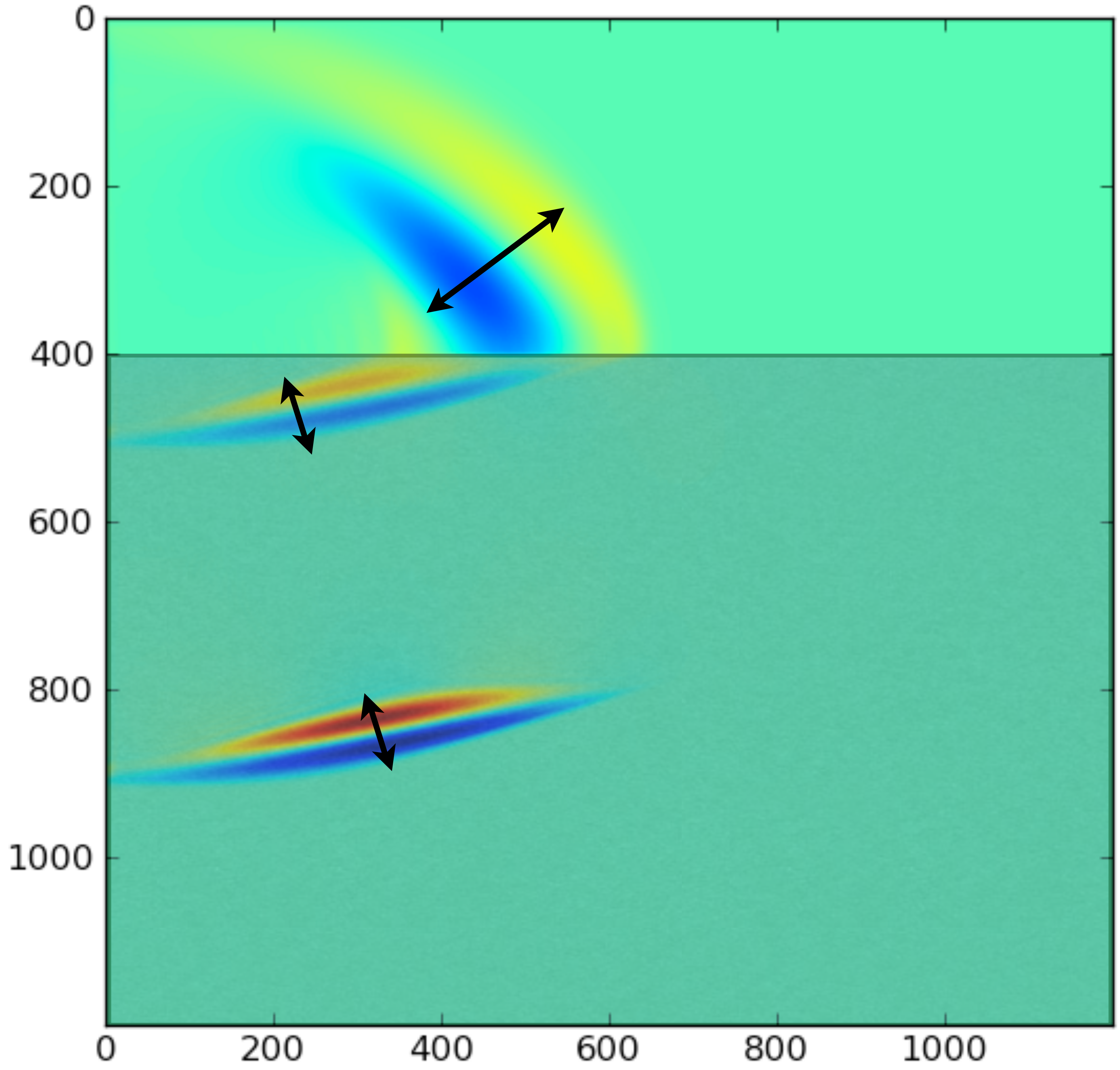
- large spread around Cherenkov angle
- also radiation for down-going cascades: whole visible Moon surface = target (~10^7 km^2)



Radio propagation simulation

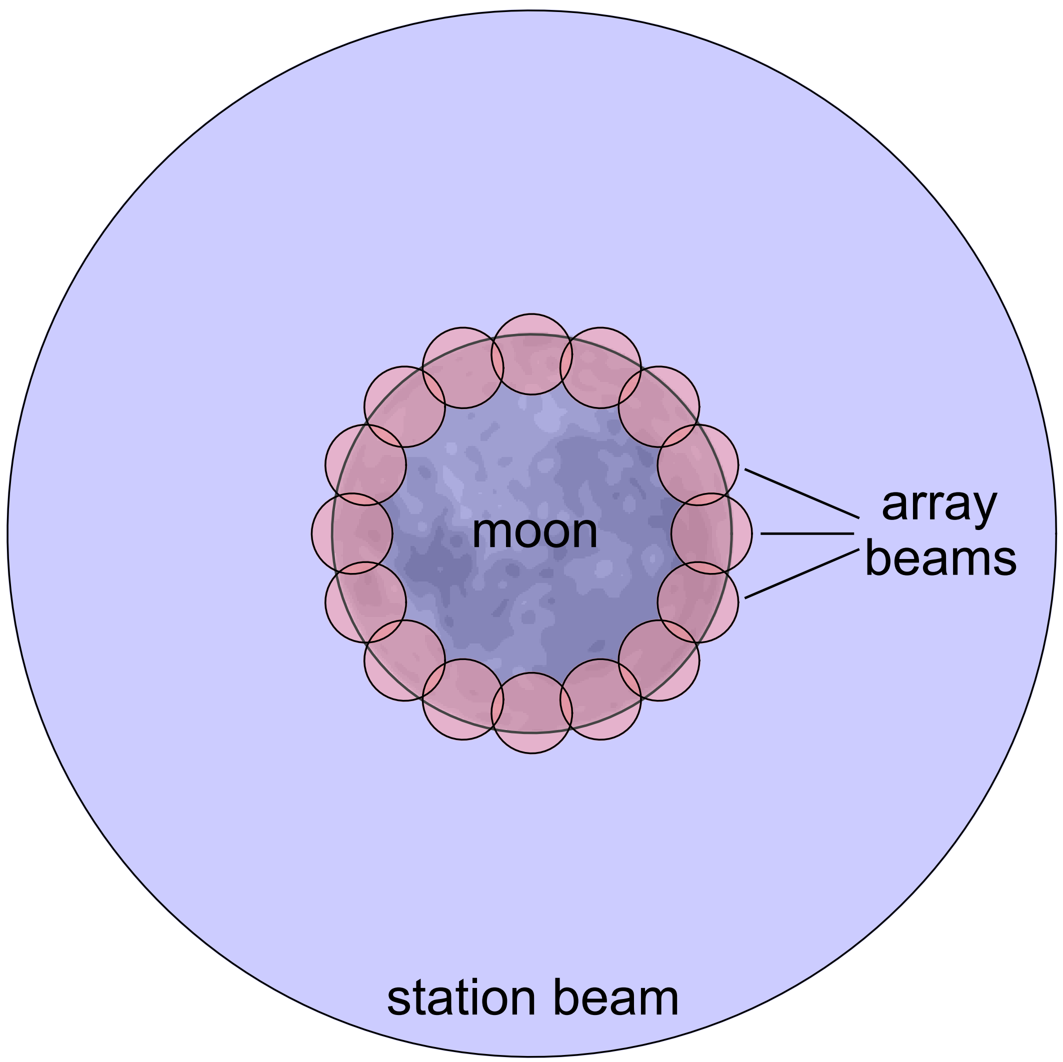


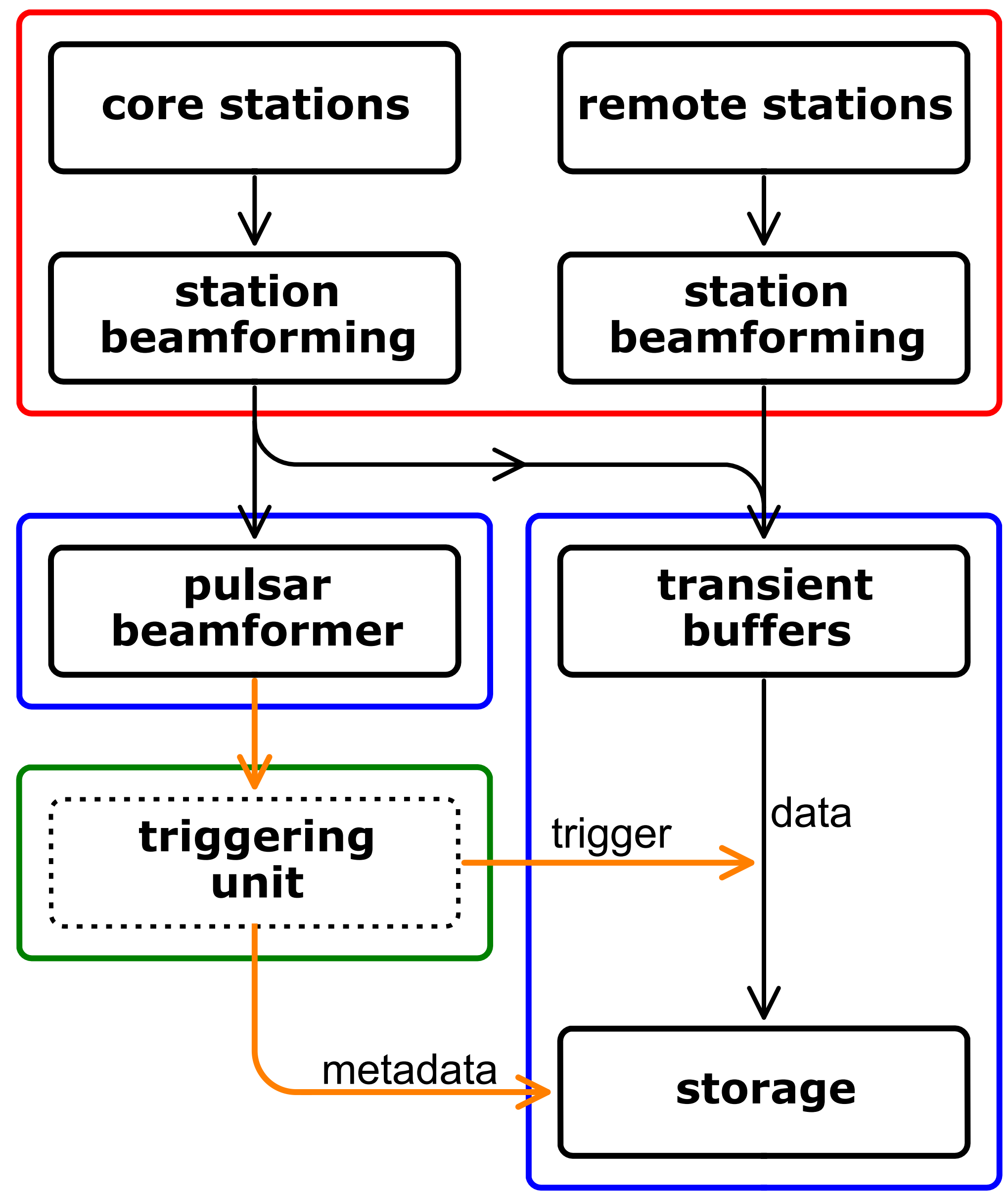
Radio propagation simulation



low frequencies can escape!

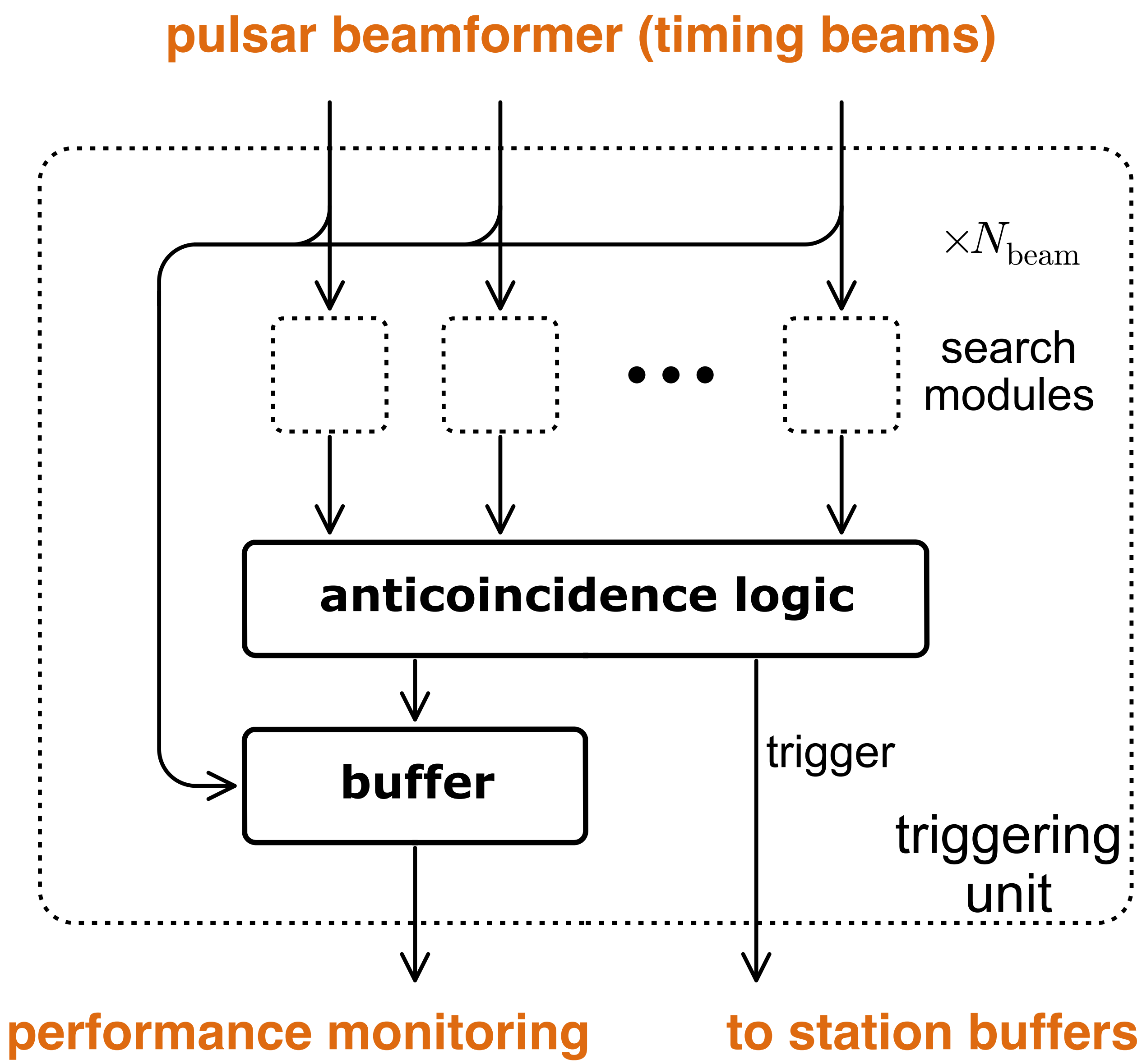
Observation strategy





trigger rate: 0.1-1 Hz
read-out: 10 μs/station

Observation strategy



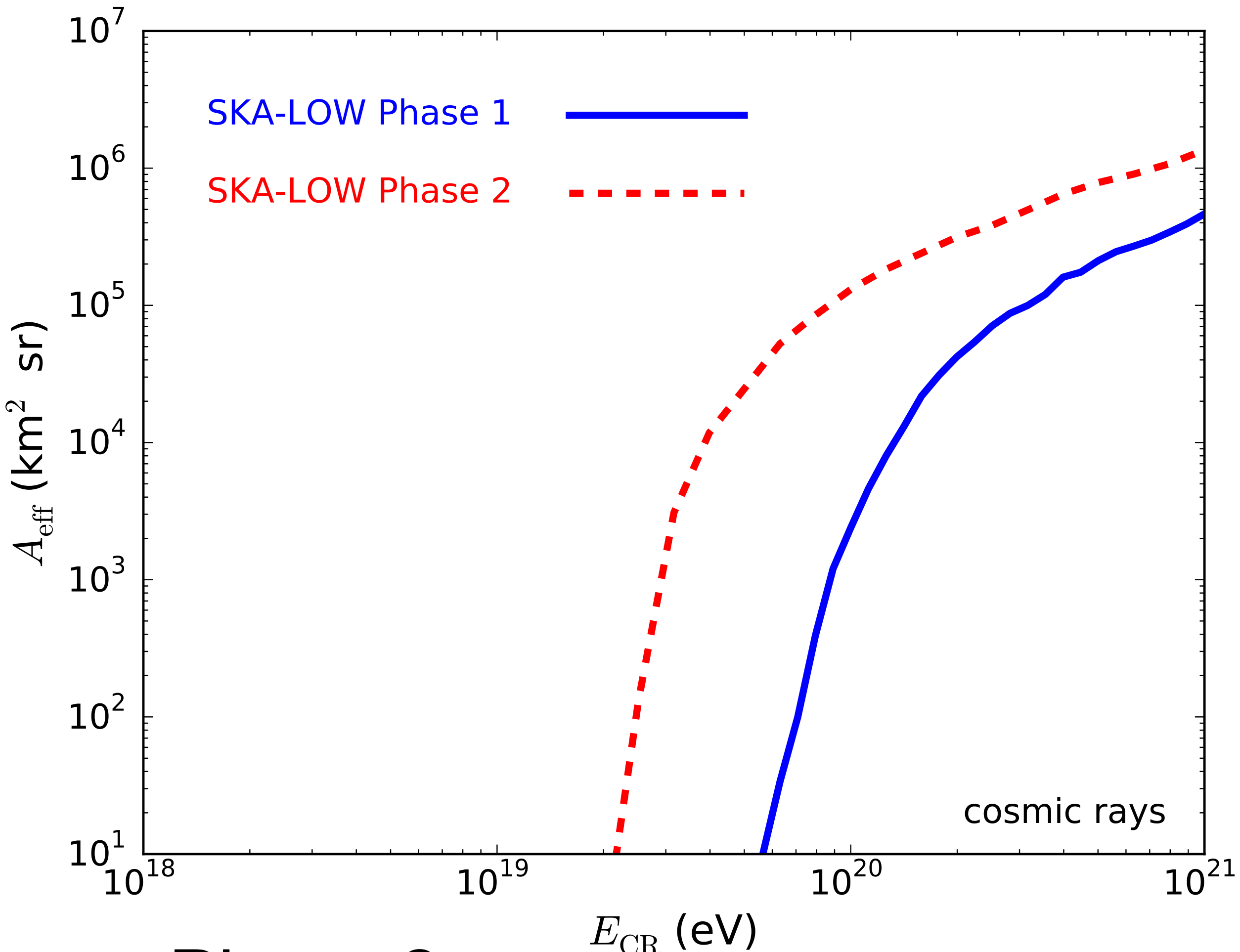
Triggering unit

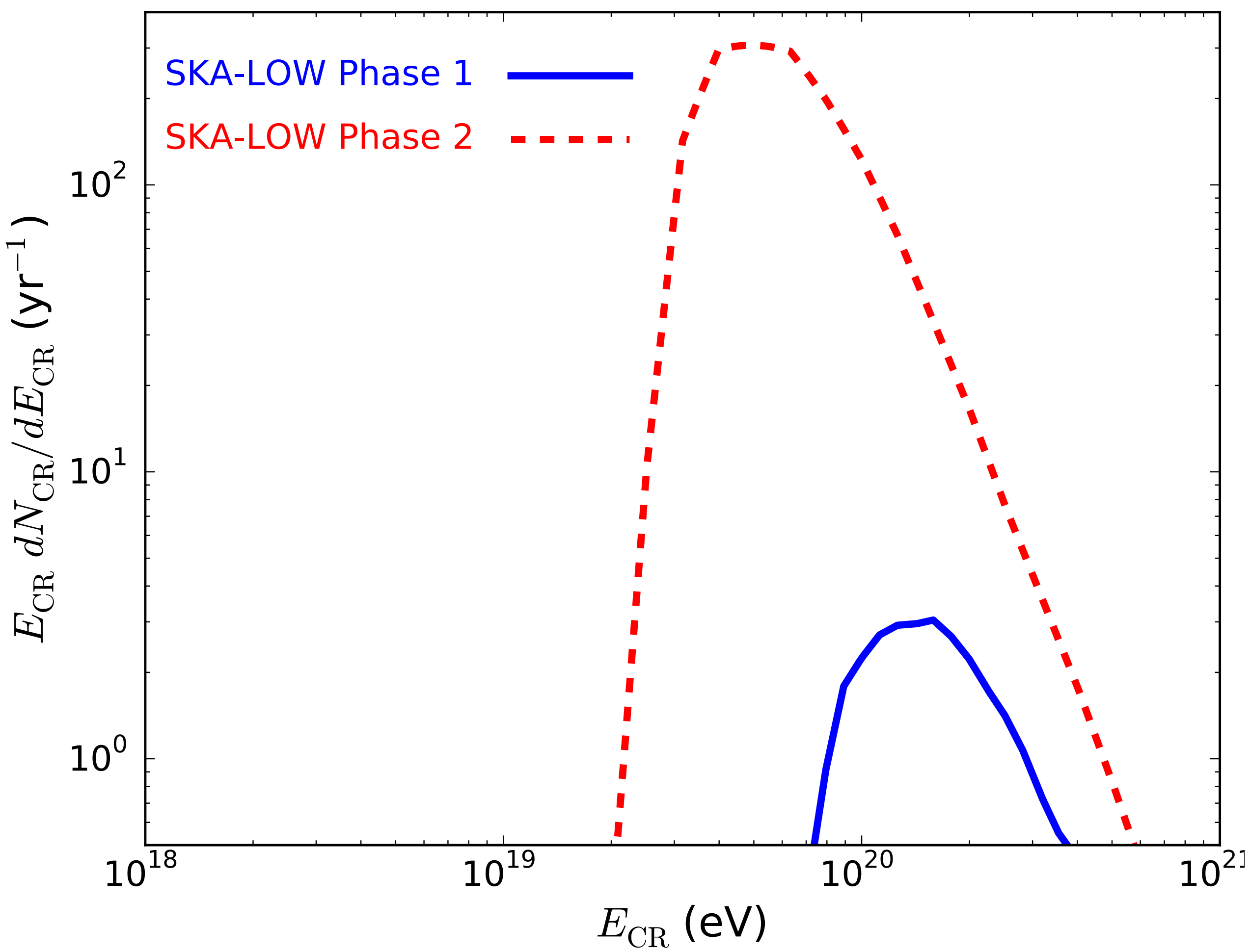
(to be provided by HECP group)

- **PFF inversion**
  subbands → timeseries data
- ionospheric **dedispersion**
- **trigger** logic
  select localised pulses

Sensitivity to UHECR

	A_{eff}/T_{sys} $m^2\ K^{-1}$	f_{min} MHz	f_{max} MHz	Beam coverage	σ_{thresh}
Phase 2	4,000	100	350	100%	10
Phase 1	250	100	350	$\sim$ 50%	7

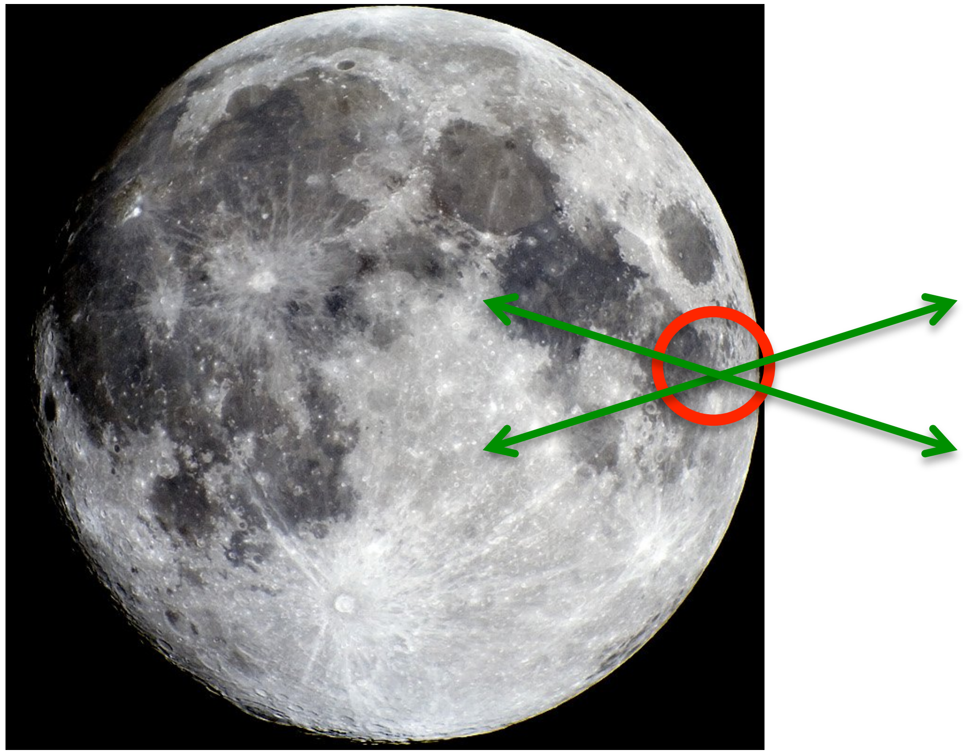


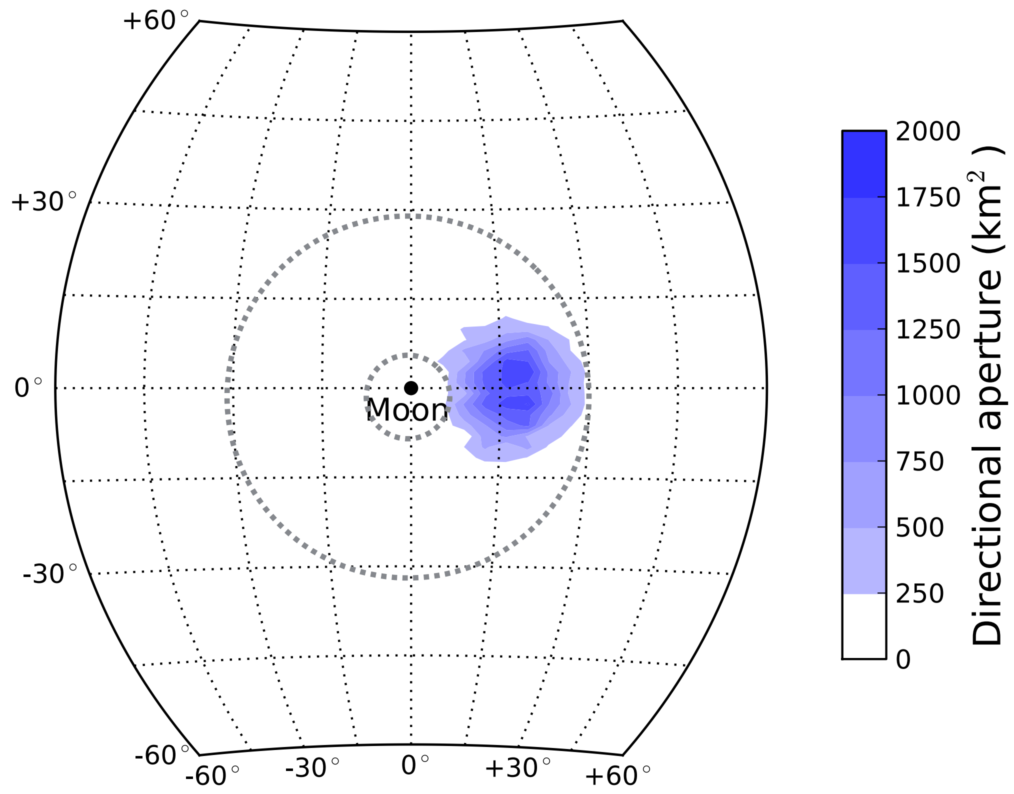


- Phase 2:
  - Aeff >100,000 km^2 sr at 10^{20} eV
  - 50 UHE CR yr^{-1} at E>56 EeV

Angular resolution

- Instantaneous sensitivity of the SKA-Moon detector



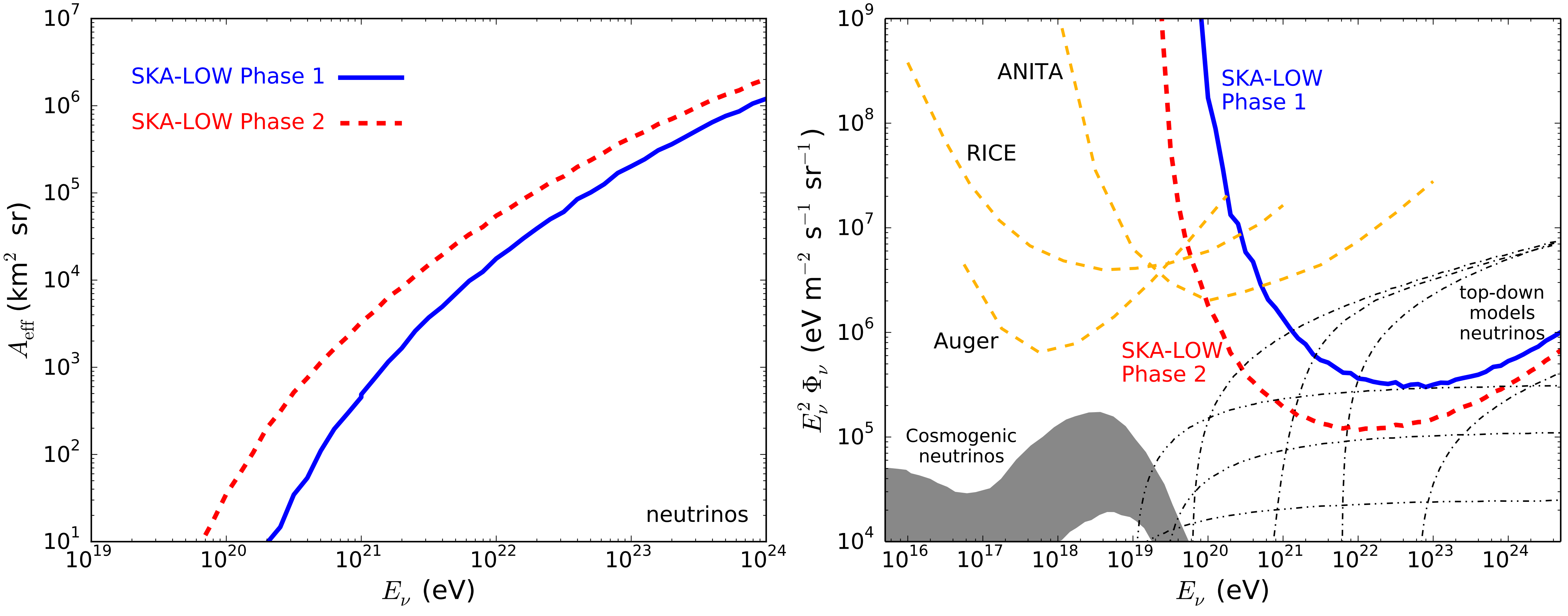


- Signal strength: 10σ (±1)
- Polarisation: 5° (asin 1σ/10σ)
- Inner 10km : 0.5’ at 100 MHz

- ‘Resolution’: ~5° region
- Any explicit reconstruction should do better!

Sources(?) in range: Cen A, Sgr A*, M87, …

Limits on UHE neutrinos with 1000 hr



- Strong constraints on remaining top-down models

summary

- **Atmospheric showers**
  - SKA aperture 10x LOFAR (+ increased freq. bandwidth)
  - Science: CR origin, super-LHC hadronic interactions, thunderstorm physics
  - Observations run continuously in background (100% commensal), raw data diagnostics could help all other observations.
  - RFI/EMI: not a problem at LOFAR; extensive testing foreseen; *input from other SWGs appreciated!*

- **Lunar showers**
  - very challenging, but potentially huge breakthrough
  - identification of ultra-high-energy sources
  - proof-of-principle SKA-phase 1; astrophysics in phase 2
  - needed ~1000 hrs observation, *commensality: CD/EoR (Vedantham et al 2015), pulsar search, FRBs, SETI, … (?)*