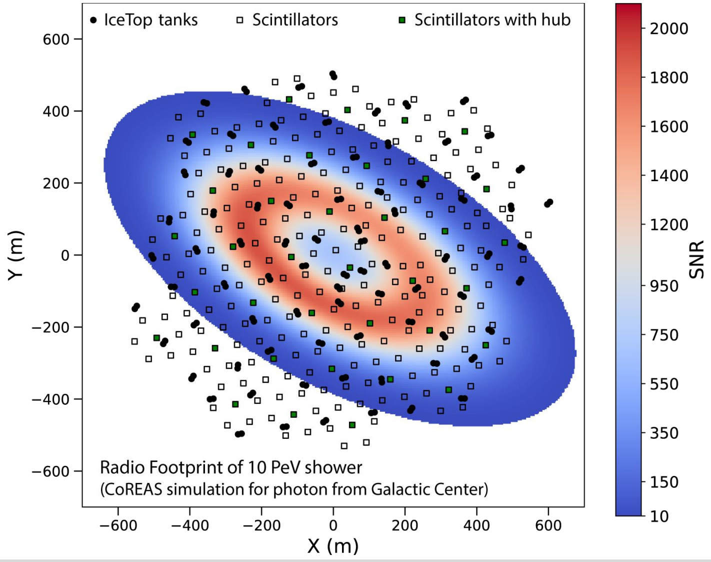
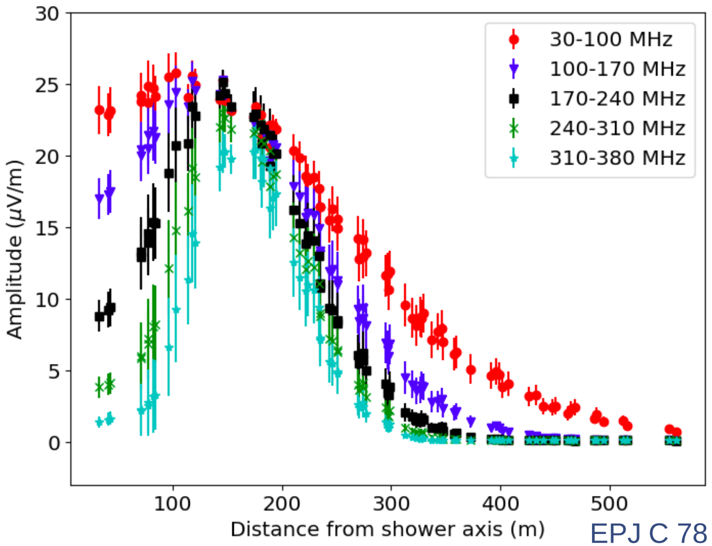
Physics Potential of a Radio Surface Array at the South Pole

Frank G. Schröder for the IceCube-Gen2 Collaboration

Karlsruhe Institute of Technology (KIT), Institute of Experimental Particle Physics , Karlsruhe, Germany (soon at University of Delaware)





EPJ C 78 (2018) 111

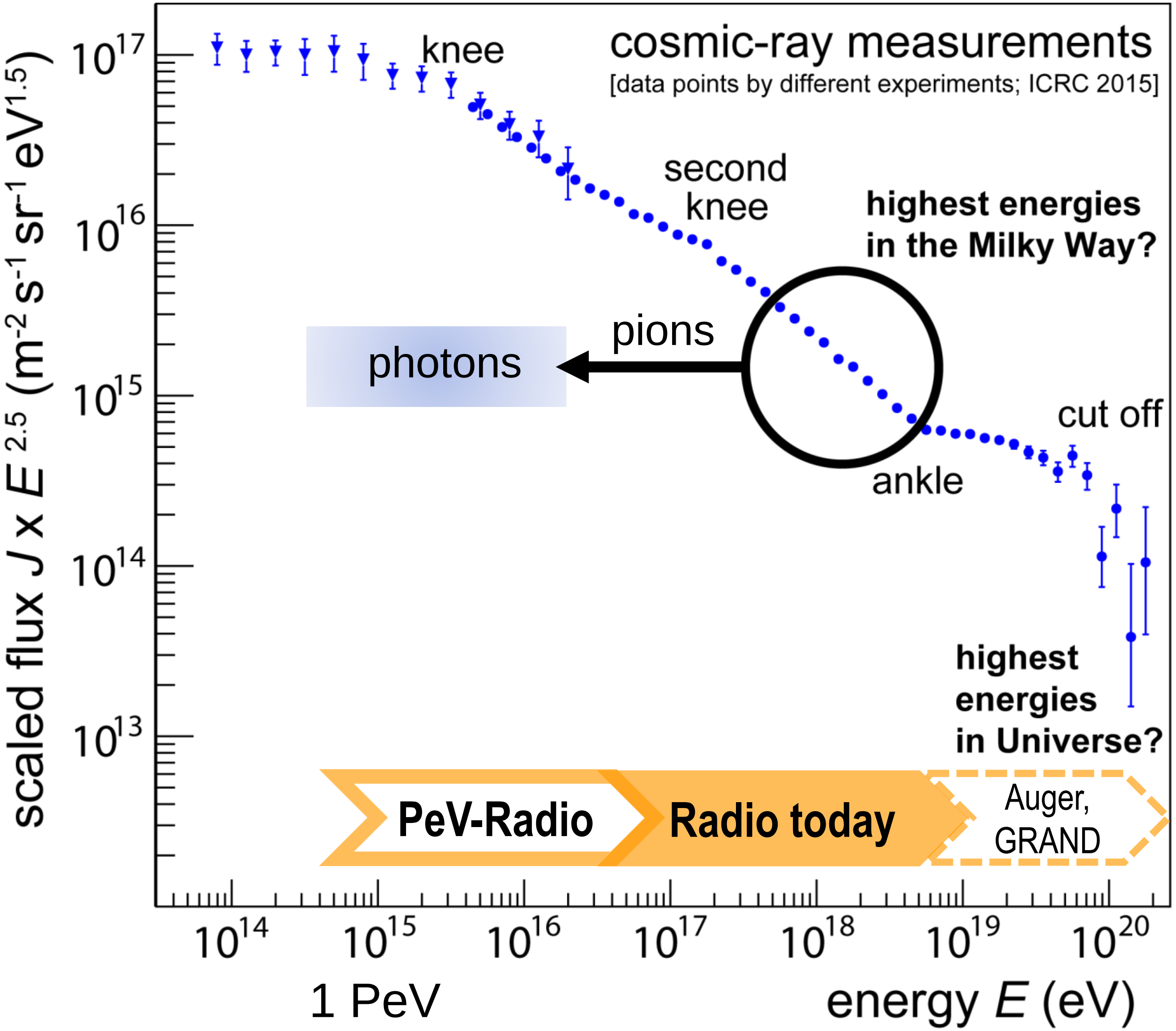
Potential of Radio Surface Array at IceTop

- Direct goal: Enhance IceTop accuracy for energy and mass of primary particle
  - CR mass composition over energy: X_{max} *and* radio/muon ratio
  - CR mass-dependent anisotropies: per-event light/heavy classification
  - PeV photon search from Galactic Center: → see talk by A. Balagopal V on Friday
  - Particle physics (air-shower physics): more thorough tests of interaction models

- Additional goal: Prototype for possible large IceCube-Gen2 radio surface array
  - Radio Surface array is *not* part of IceCube Upgrade, but useful for Gen2 studies
  - Surface veto of inclined showers and cross-calibration of in-ice radio with air showers

- Why now?
  - Sufficient accuracy of radio technique has been proved experimentally in last three years
  - Window of opportunity: antennas as cost-effective add-on to scintillator array

Big Picture of High-Energy Cosmic Rays



- Cosmic Rays are high-energy nuclei accelerated by nature
  - only access to particle physics at energies above LHC at CERN
- Sources above 10^{15} eV unknown
  - likely supernovae until second knee
  - extragalactic above ankle
- What is the most energetic accelerator in our Milky Way?
  - indirect approach by adding accuracy
  - direct by search for PeV photons

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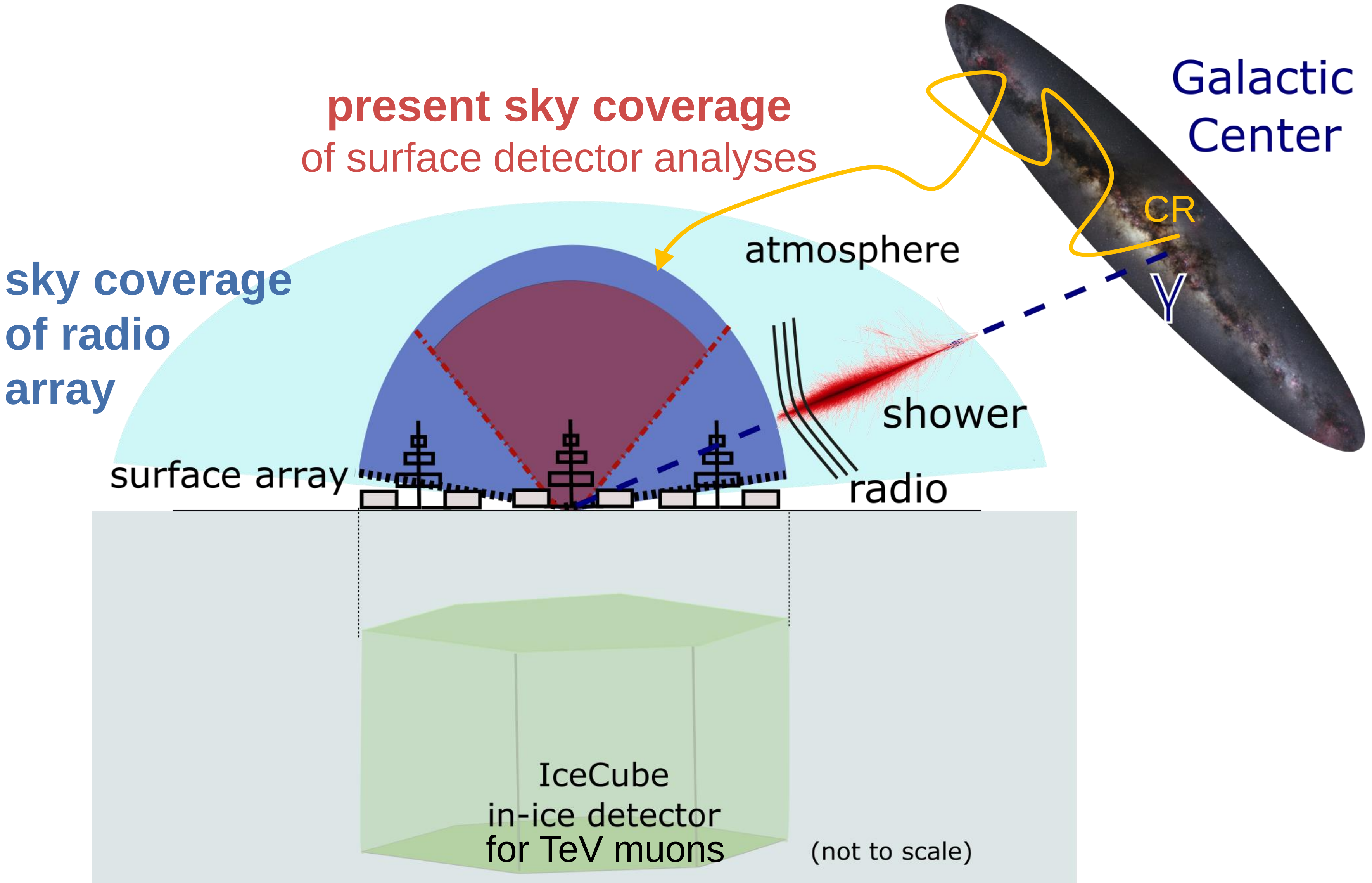
Potential of a Radio Surface Array at the South Pole



- Radio array will make IceTop the most accurate PeV air-shower detector
- Mass-sensitive, anisotropy searches at almost full sky
- PeV photon search
- Pathfinder for SKA and future Antarctic surface arrays

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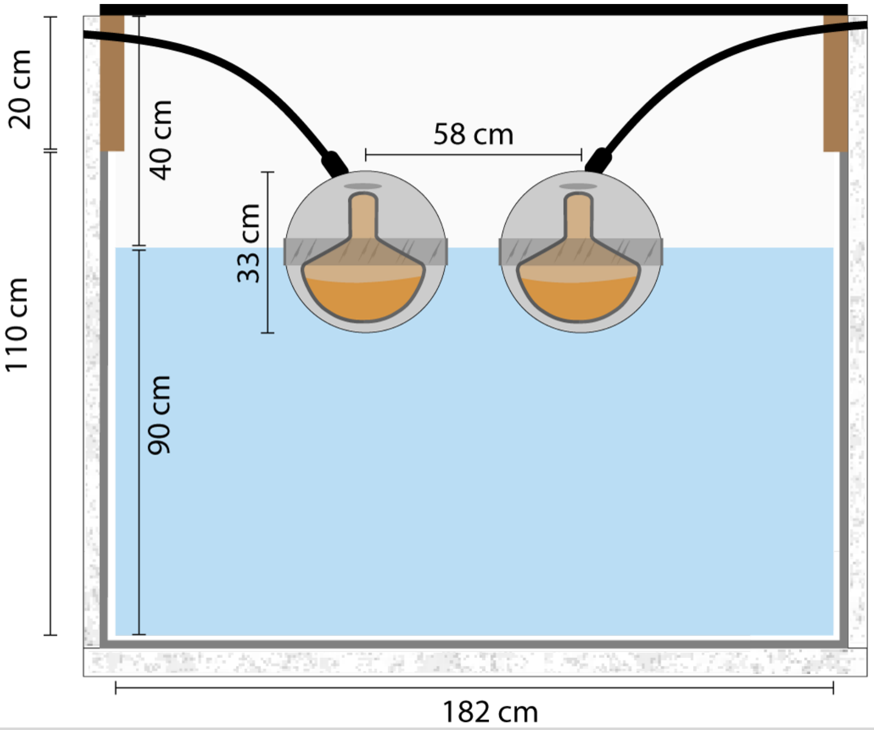
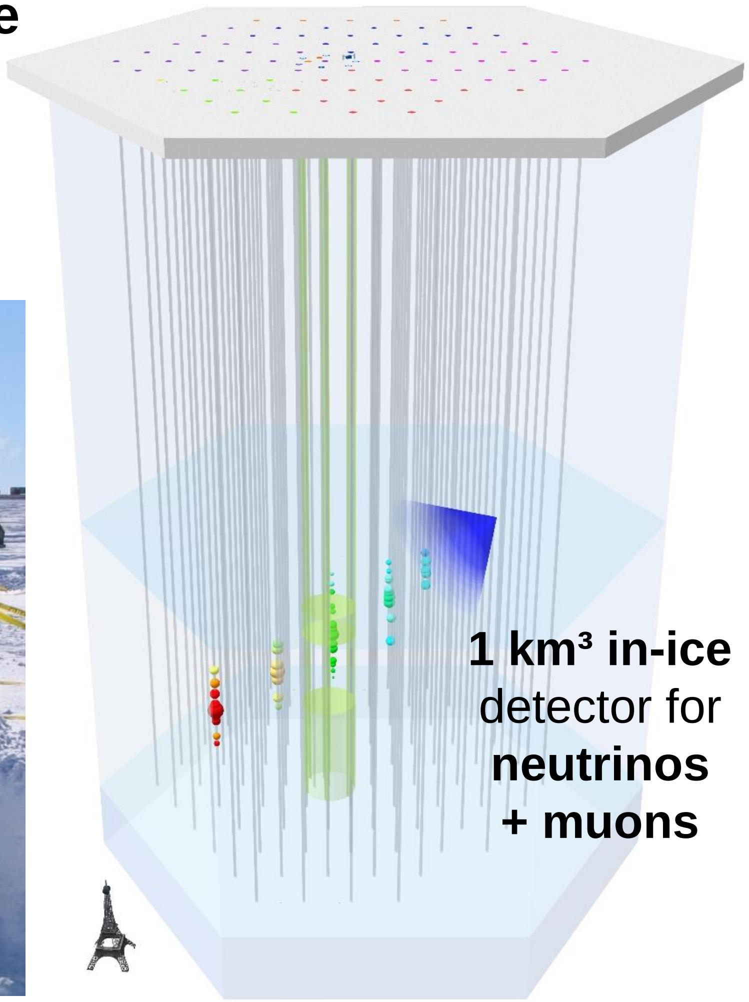
IceCube today: surface + in-ice detectors

- IceTop = surface array of ice-Cherenkov detectors
  - cosmic-ray physics
  - air-shower (particle) physics
  - veto of air-shower muons and background studies for neutrino detector in the ice



IceCube Coll., NIM A 700 (2013) 188

IceCube at the South Pole



1 km² surface detector for **air showers**

1 km³ in-ice detector for **neutrinos + muons**

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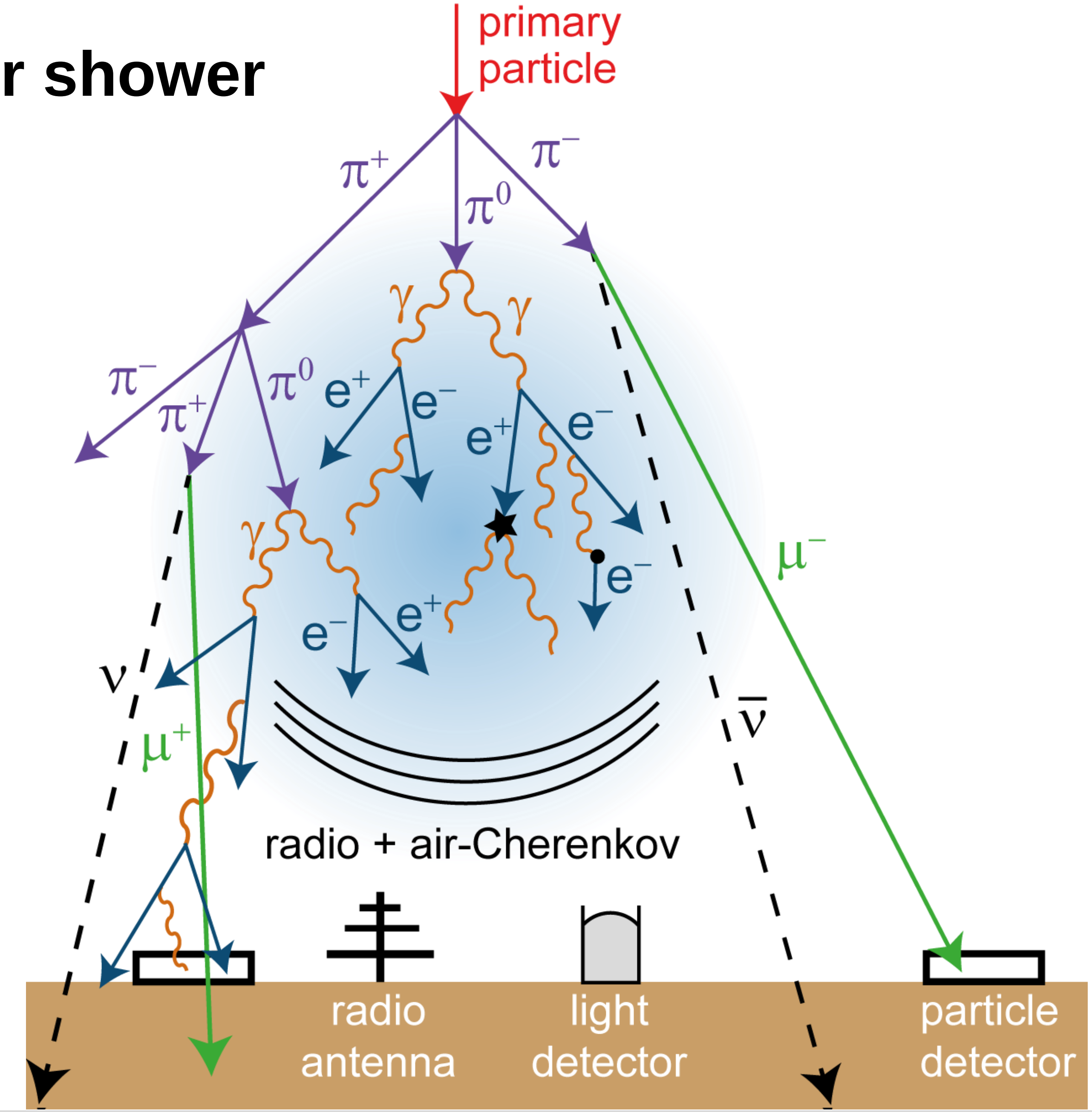
Air shower



Radio detection of air showers:

- High accuracy and duty cycle
- Sensitive to well understood electromagnetic shower component
- Radio brings complementary information to muons, but absolute number of muons lacks understanding
- IceCube: GeV muons with surface detector, TeV muons in the ice

Radio detection of cosmic-ray air showers and high-energy Neutrinos“

F.G. Schröder, Prog. Part. Nucl. Phys. 93 (2017) 1, arXiv: 1607.08781

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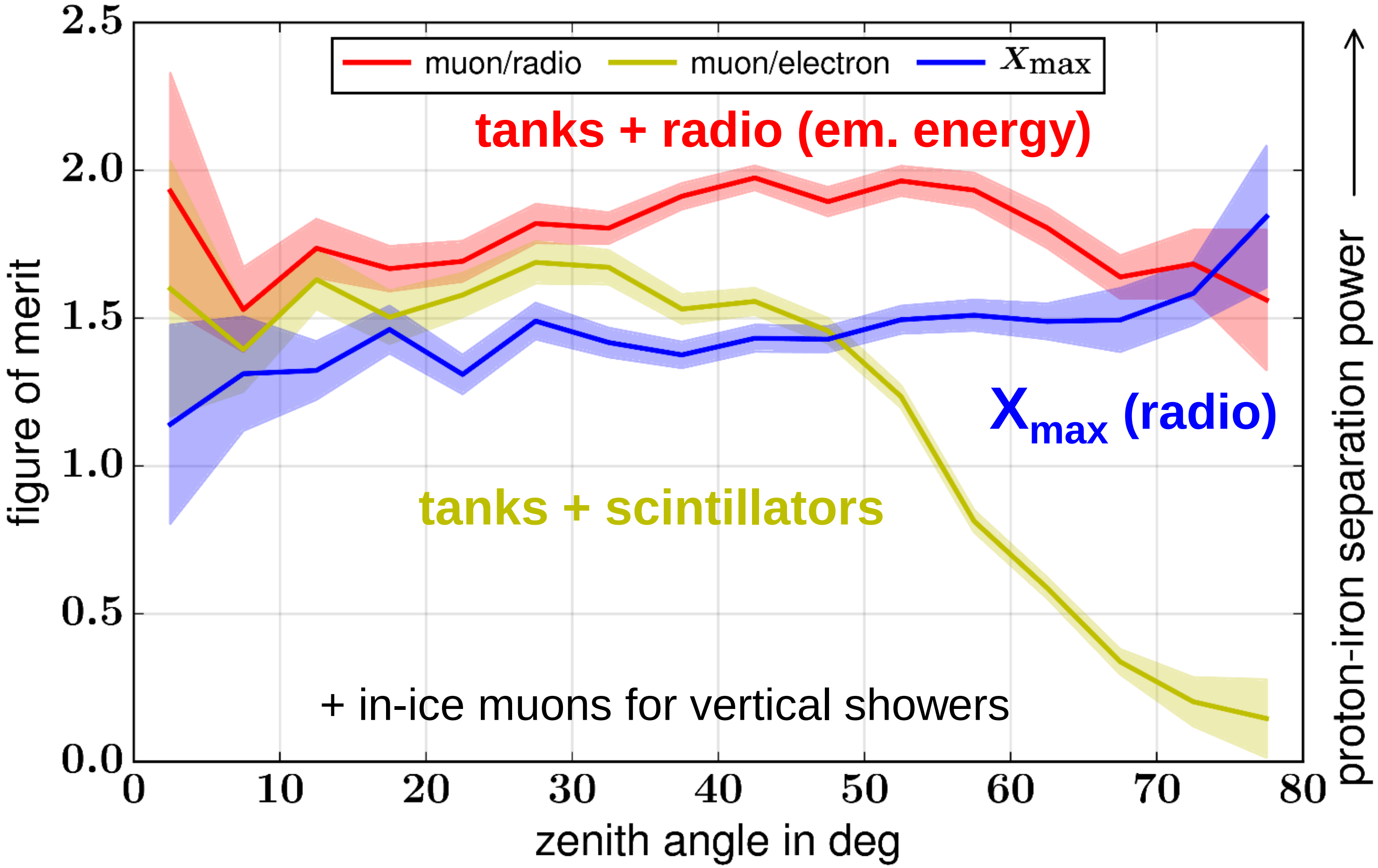
Mass separation power: Radio + Muons *and* X_{max}

- Enhance mass sensitivity for all zenith angles, in particular for inclined showers
- Goal: Make IceCube the most accurate detector for multi-PeV cosmic rays



red + blue add complementary sensitivity

simulations for 1 EeV, **Auger** altitude, detailed simulations for IceTop needed

E. Holt, PhD thesis, simulation study for Auger

→ **see talk later today**

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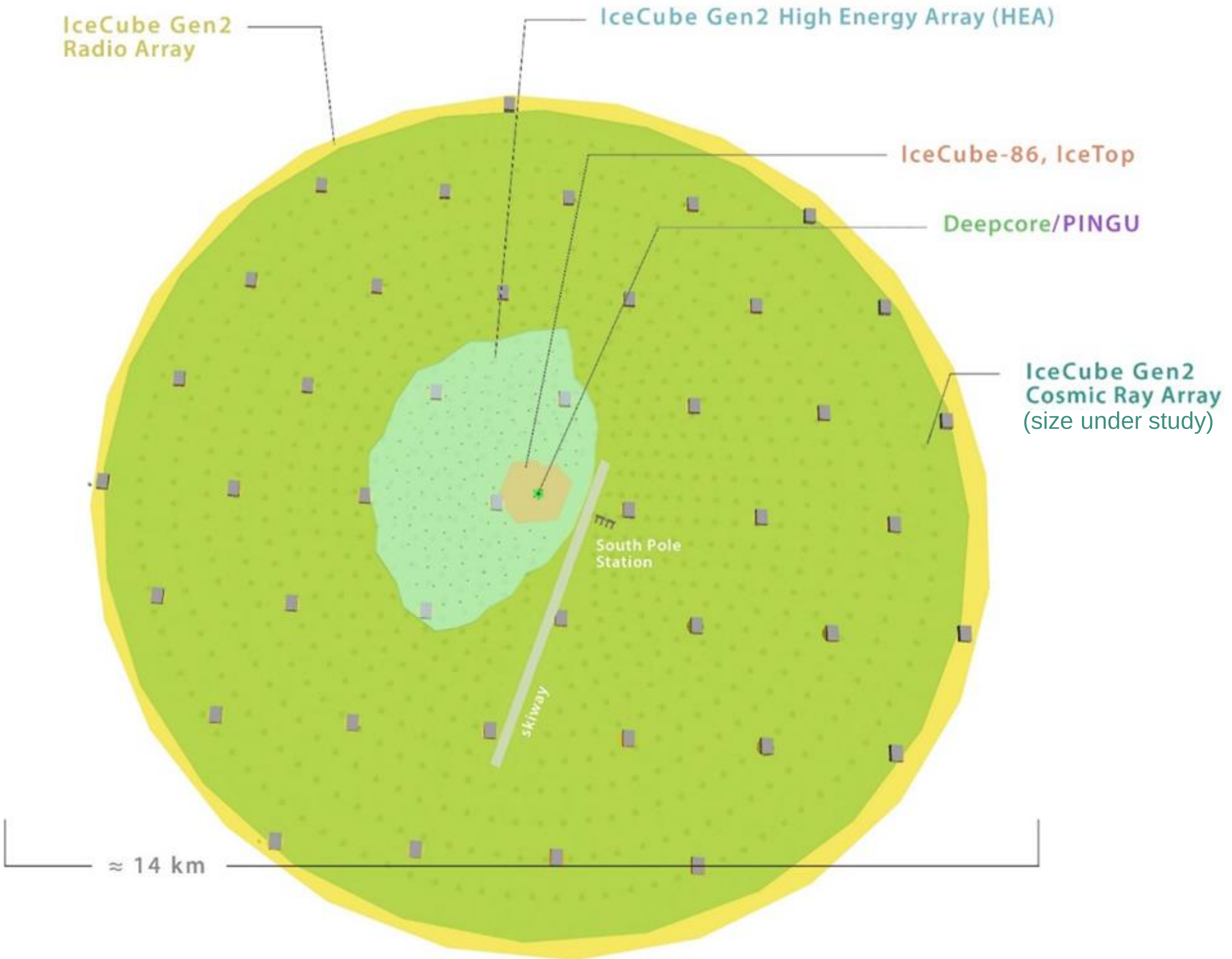
IceCube-Gen2

- Plans for in-ice and surface components
- In-Ice
  - optical
  - radio
- On-ice
  - scintillators
  - radio for veto of inclined showers and cross-calibration of in-ice radio?



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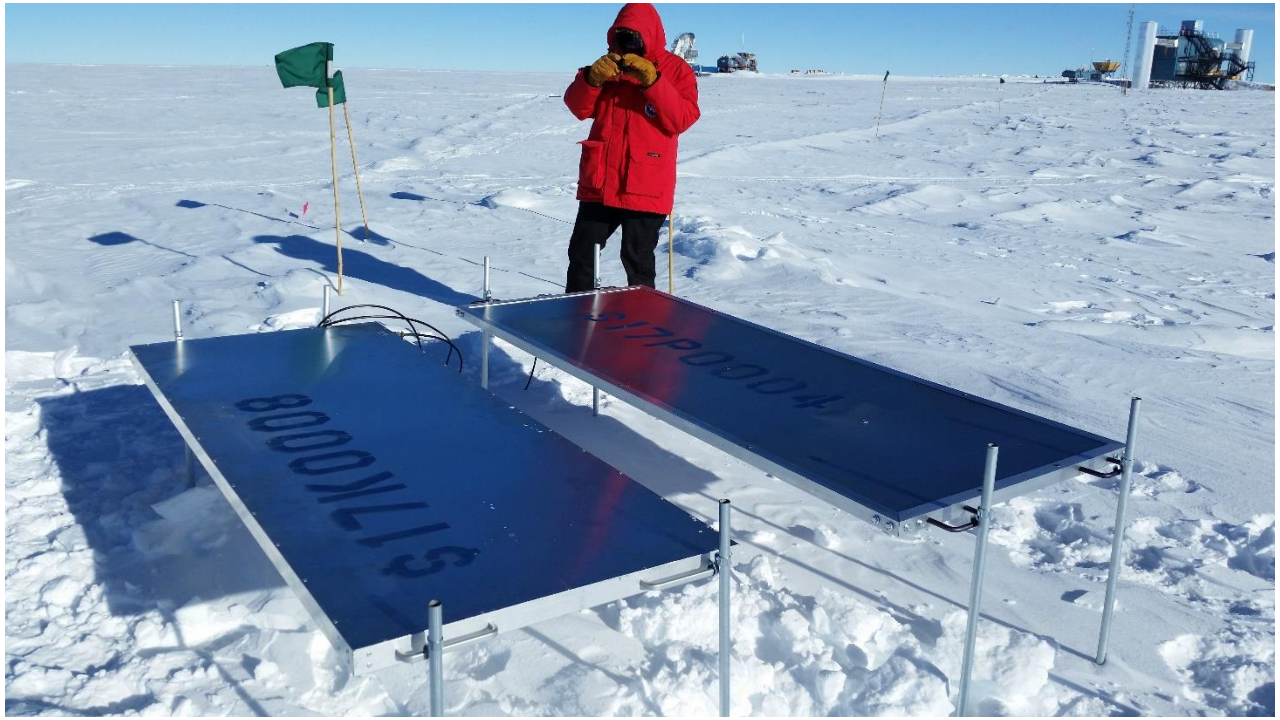
Next years: maintain and enhance performance of IceTop

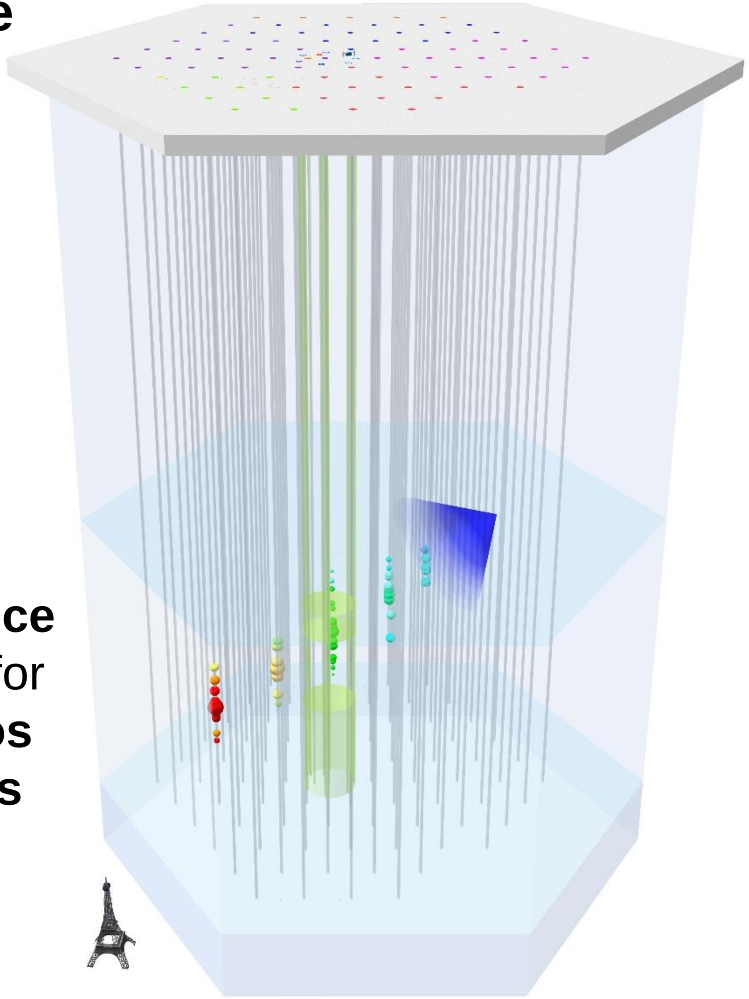
- scintillator array proposed to be built in next years in the footprint of present IceTop array
- radio array possible with reasonable investment by sharing electronics



first scintillators running since January 2018 at South Pole

IceCube at the South Pole

1 km² surface detector for **air showers**



1 km³ in-ice detector for **neutrinos + muons**

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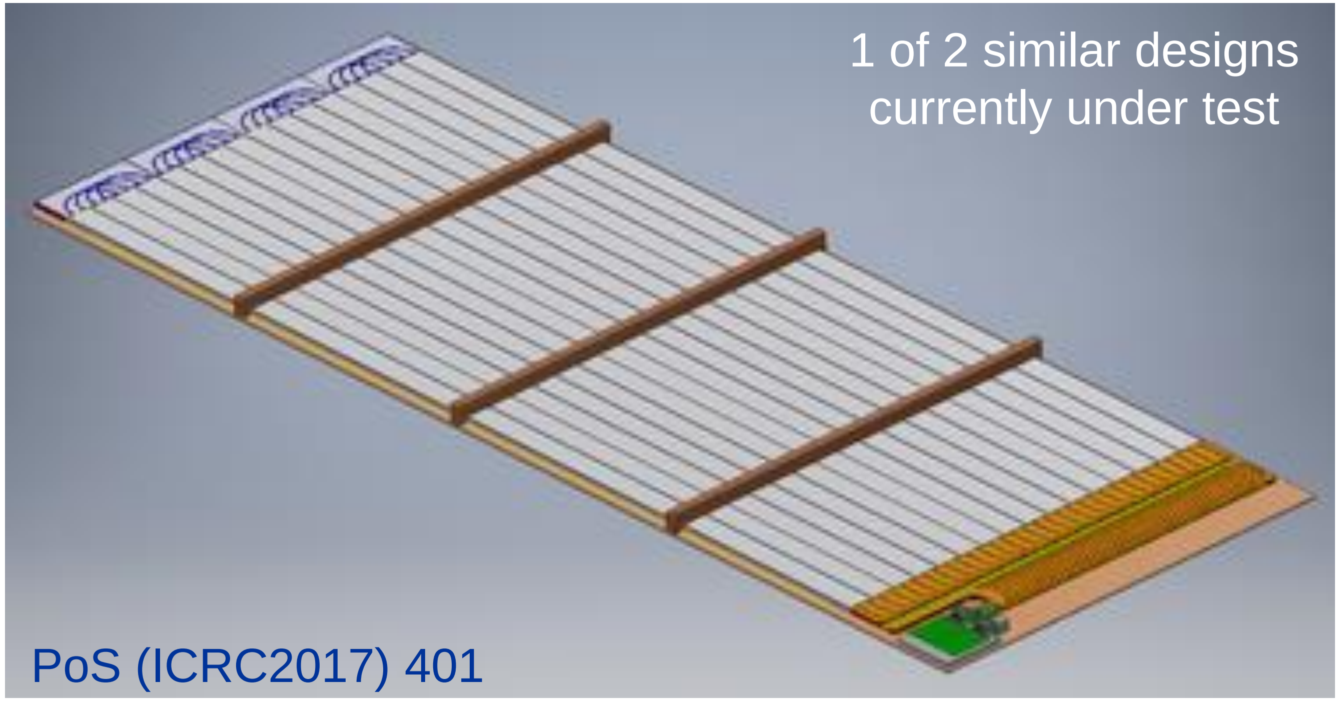
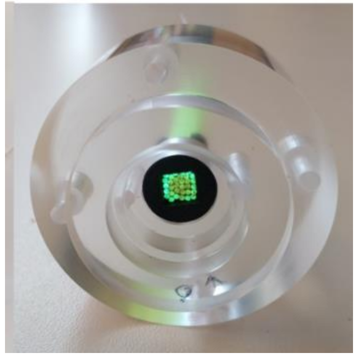
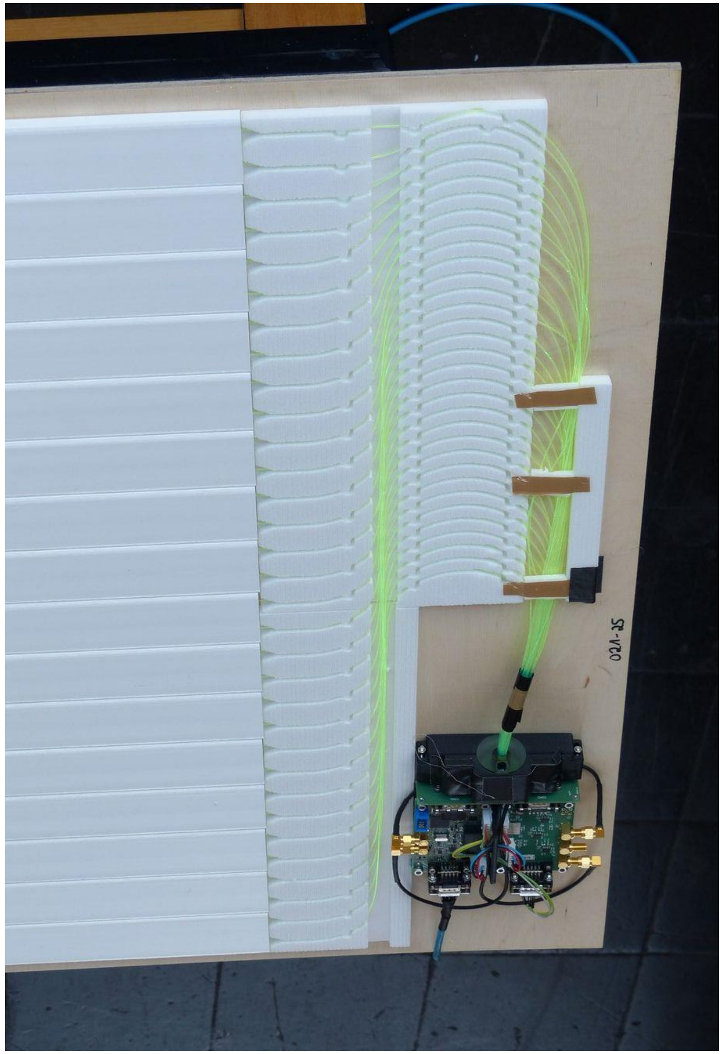
Scintillation detectors

- 1.5 m² of scintillator per detector read out by SiPMs
- scintillators provide better measurement of electrons
- muons by snow-buried IceTop and in-ice IceCube





optical coupling to silicon photomultiplier



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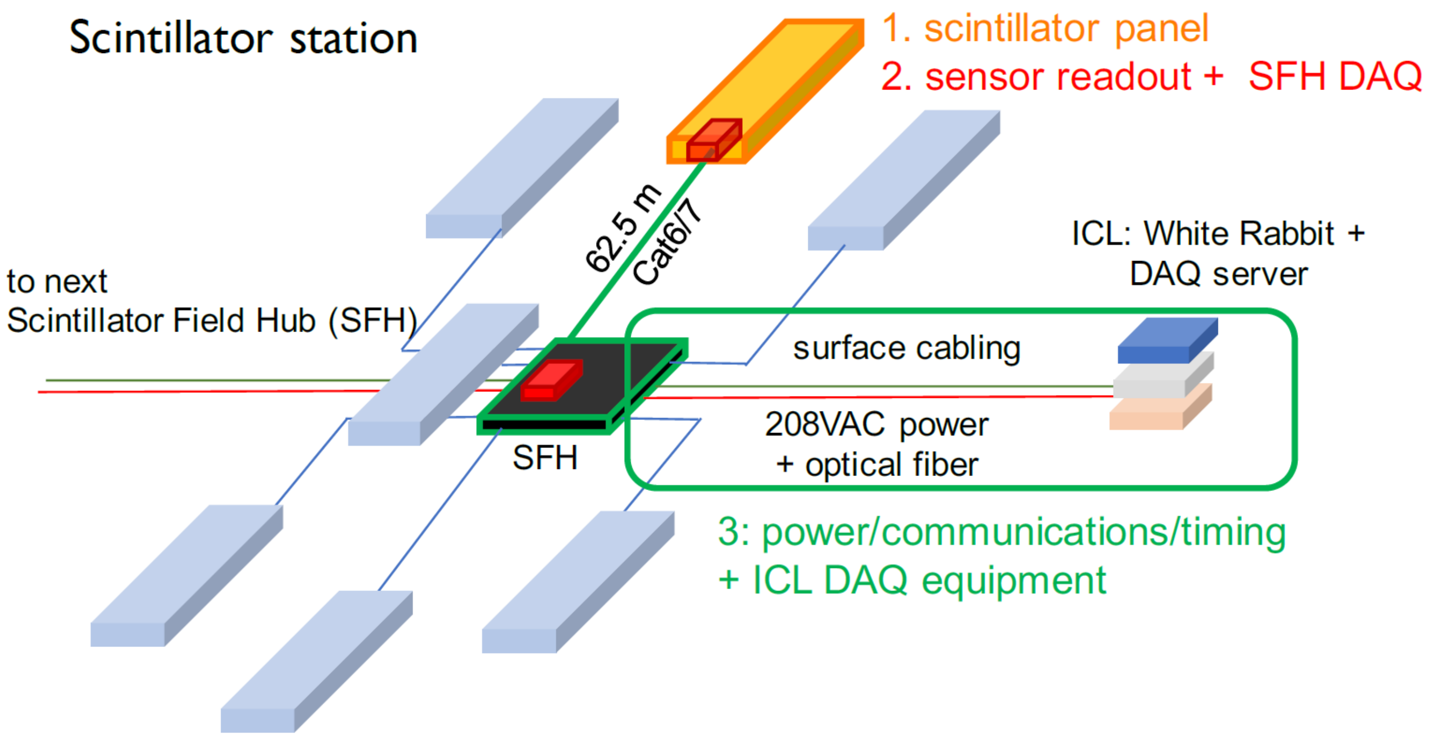
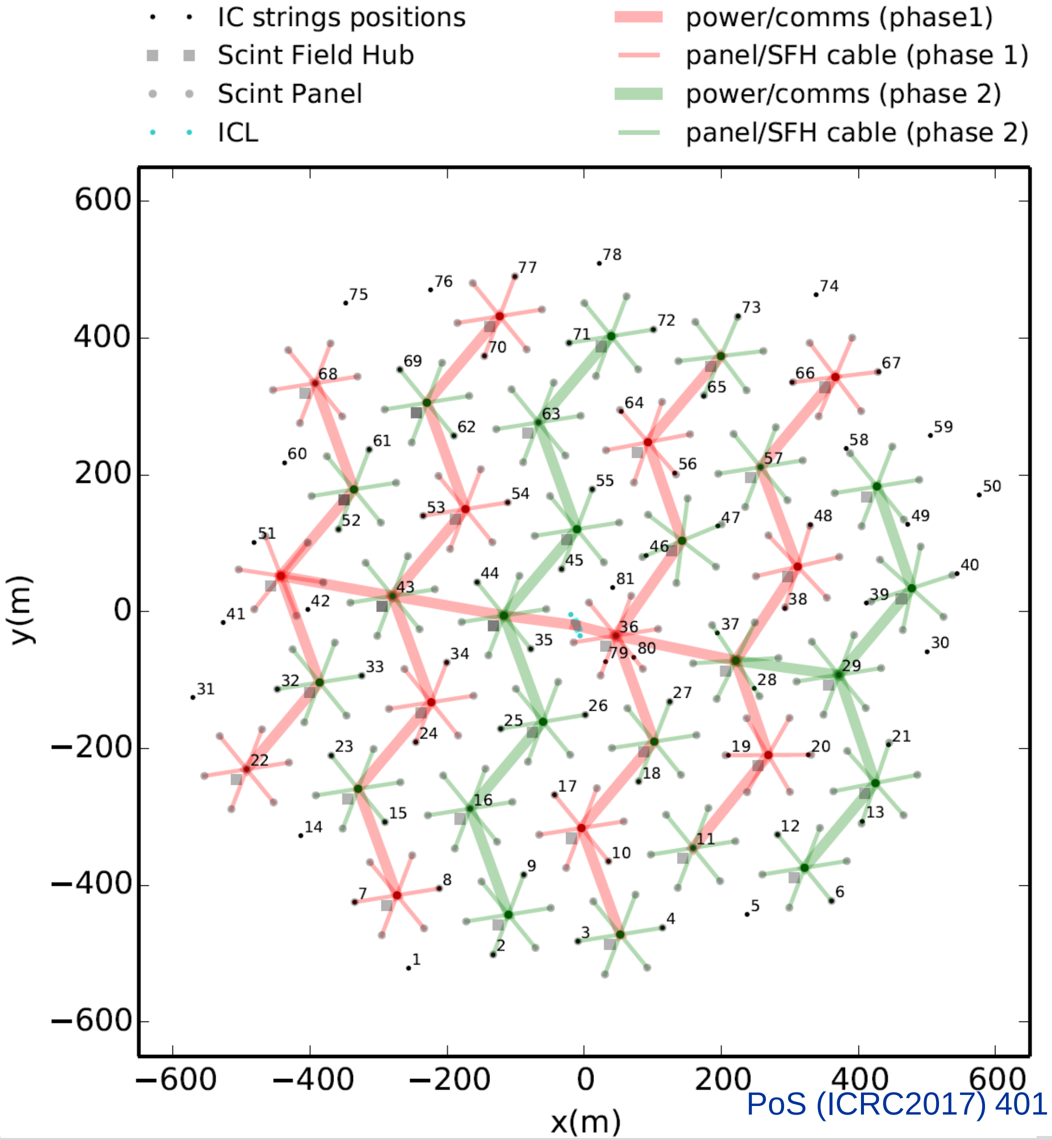
Plan for larger scintillator array (*not* to be confused with IceCube Upgrade)

- 37 stations á 7 scintillators on 1 km²
- Prototype electronics and scintillators under test





PoS (ICRC2017) 401

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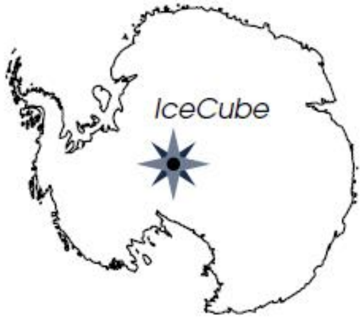
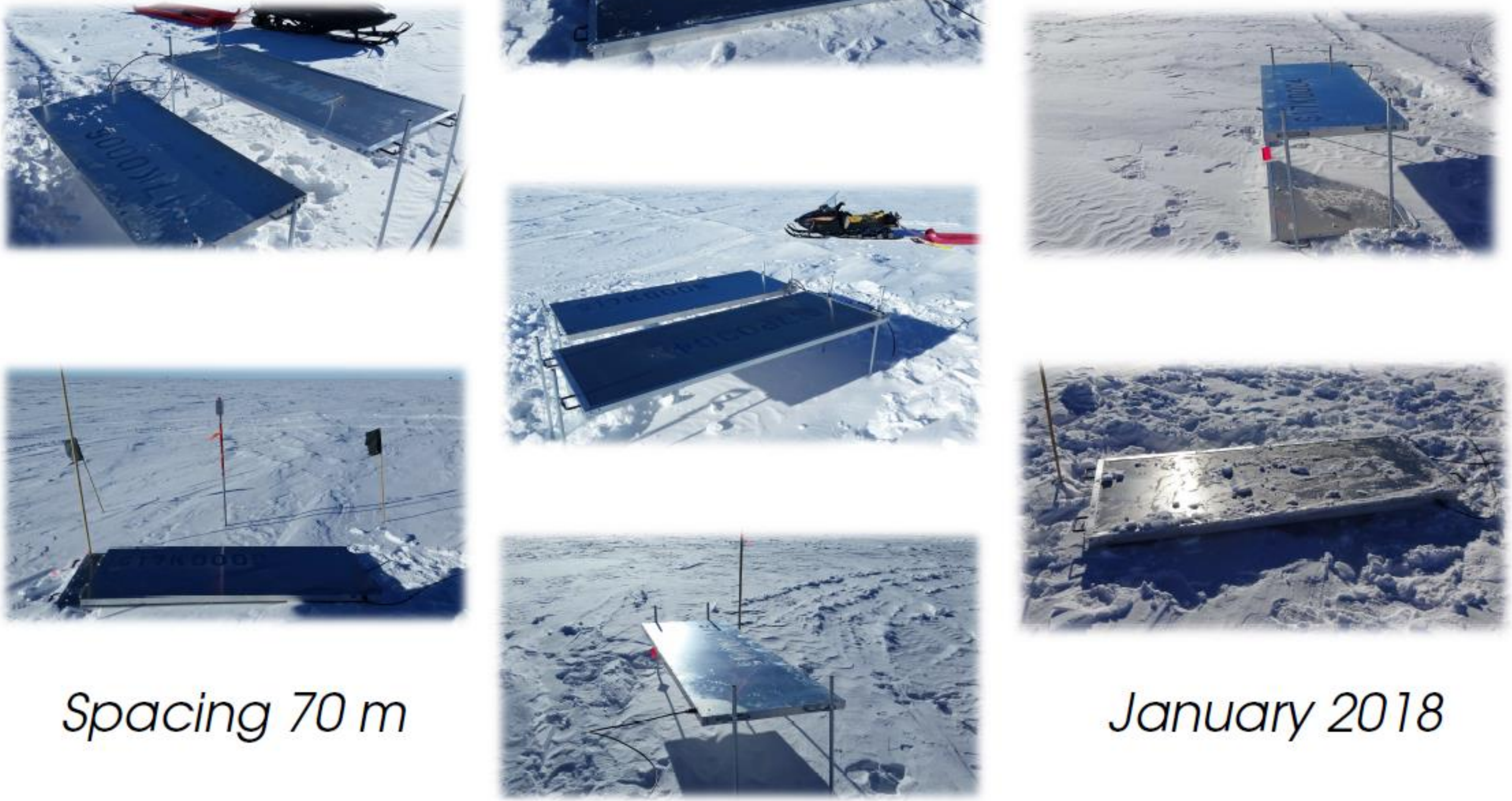
First prototype station operating at the South Pole



- Station = hexagon of 7 scintillators
- Prototype station is double station of two scintillators in each place
  - comparing different detector designs



- Idea for radio:

→ add 2 antennas per station

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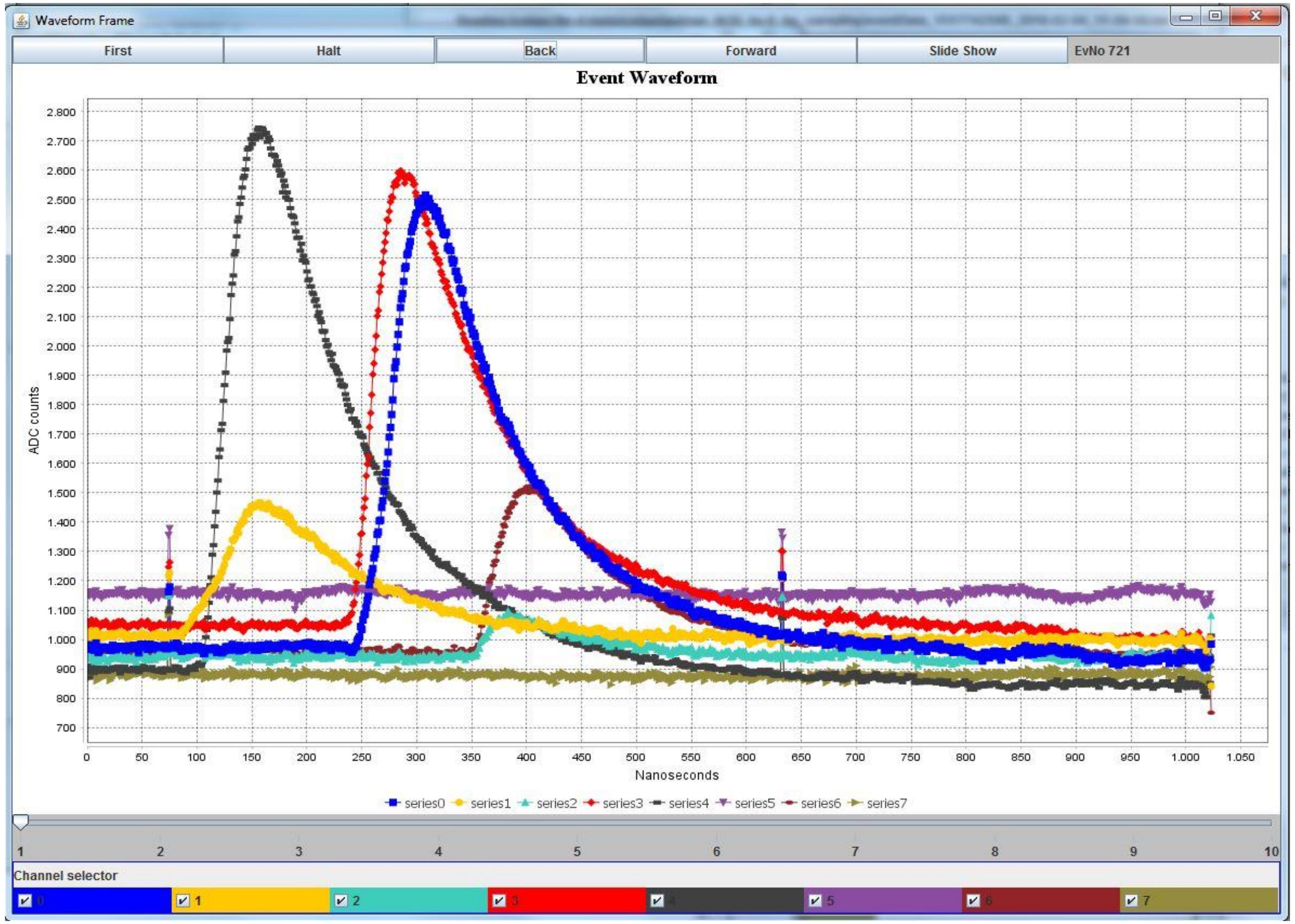
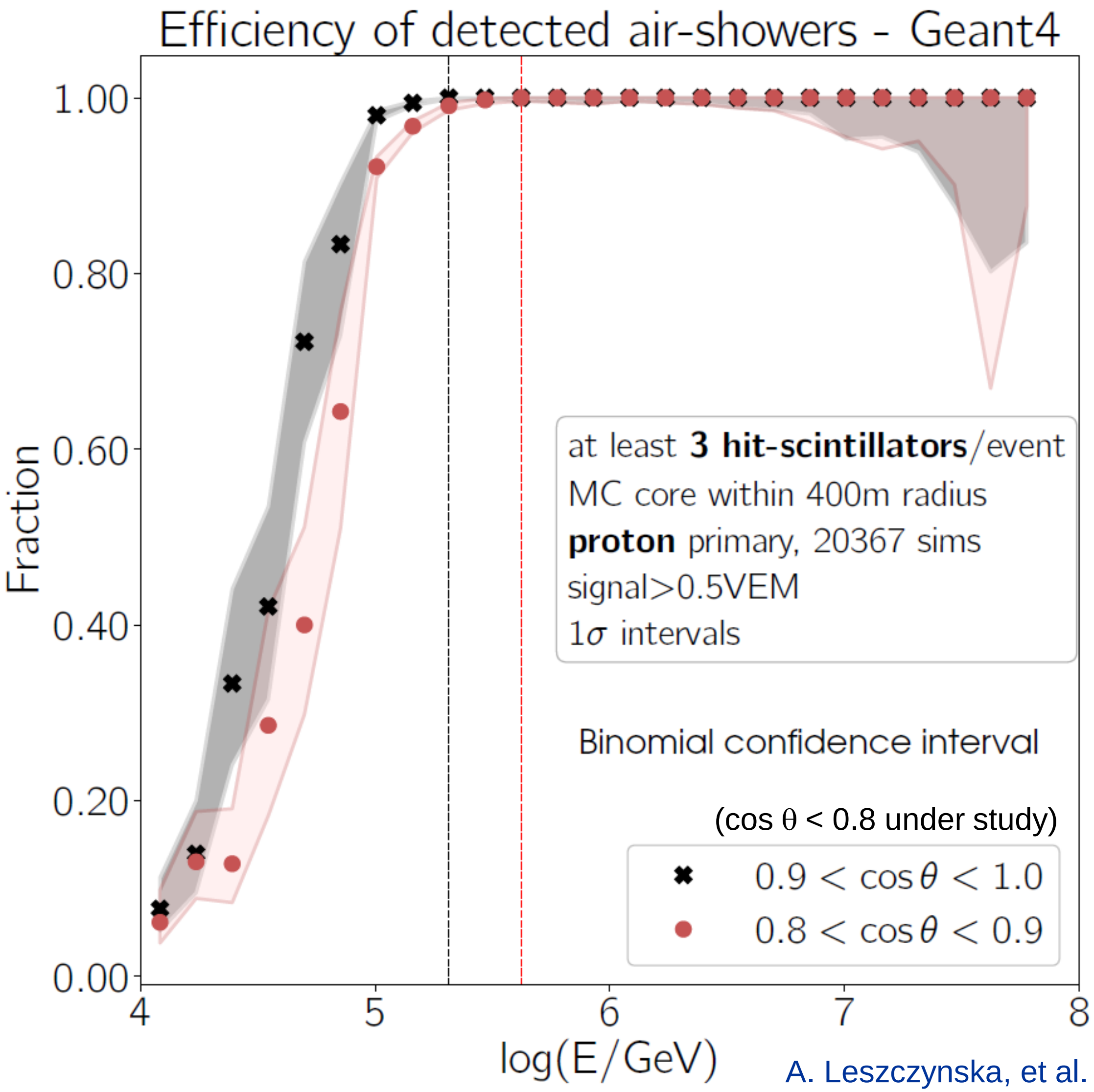
Threshold will be below 1 PeV

- First air showers measured by prototype hexagon (detailed analysis under study)





A. Leszczynska, et al.

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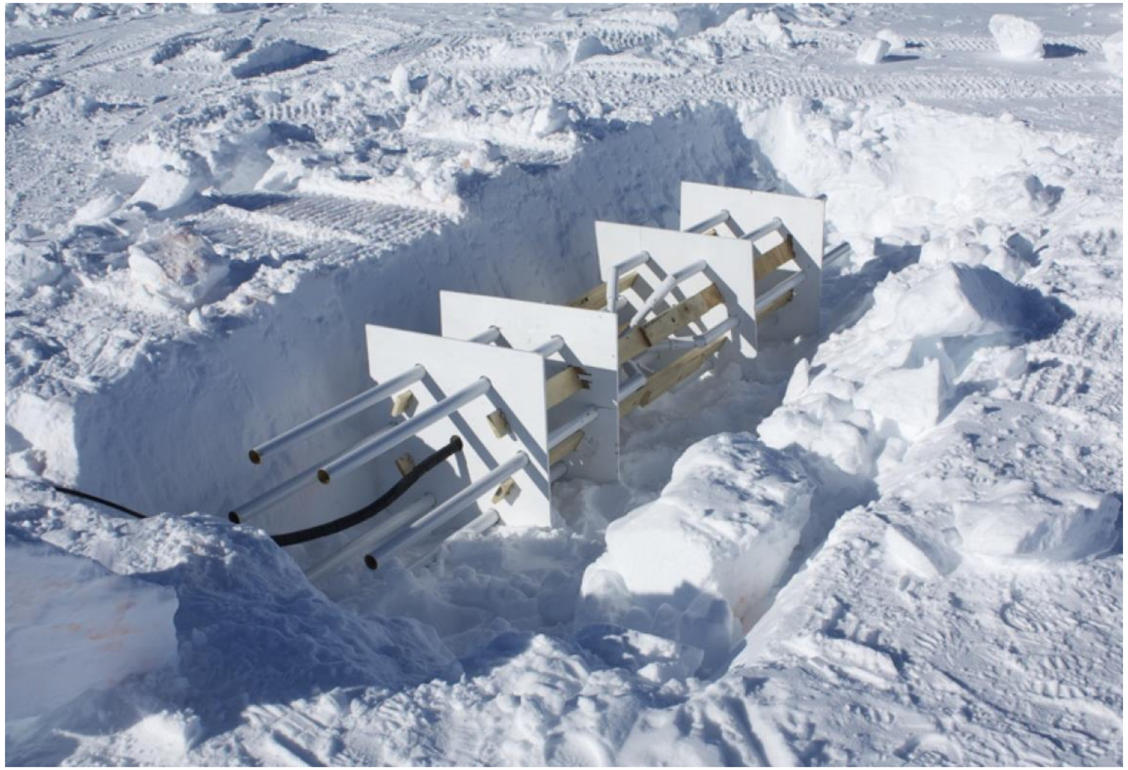
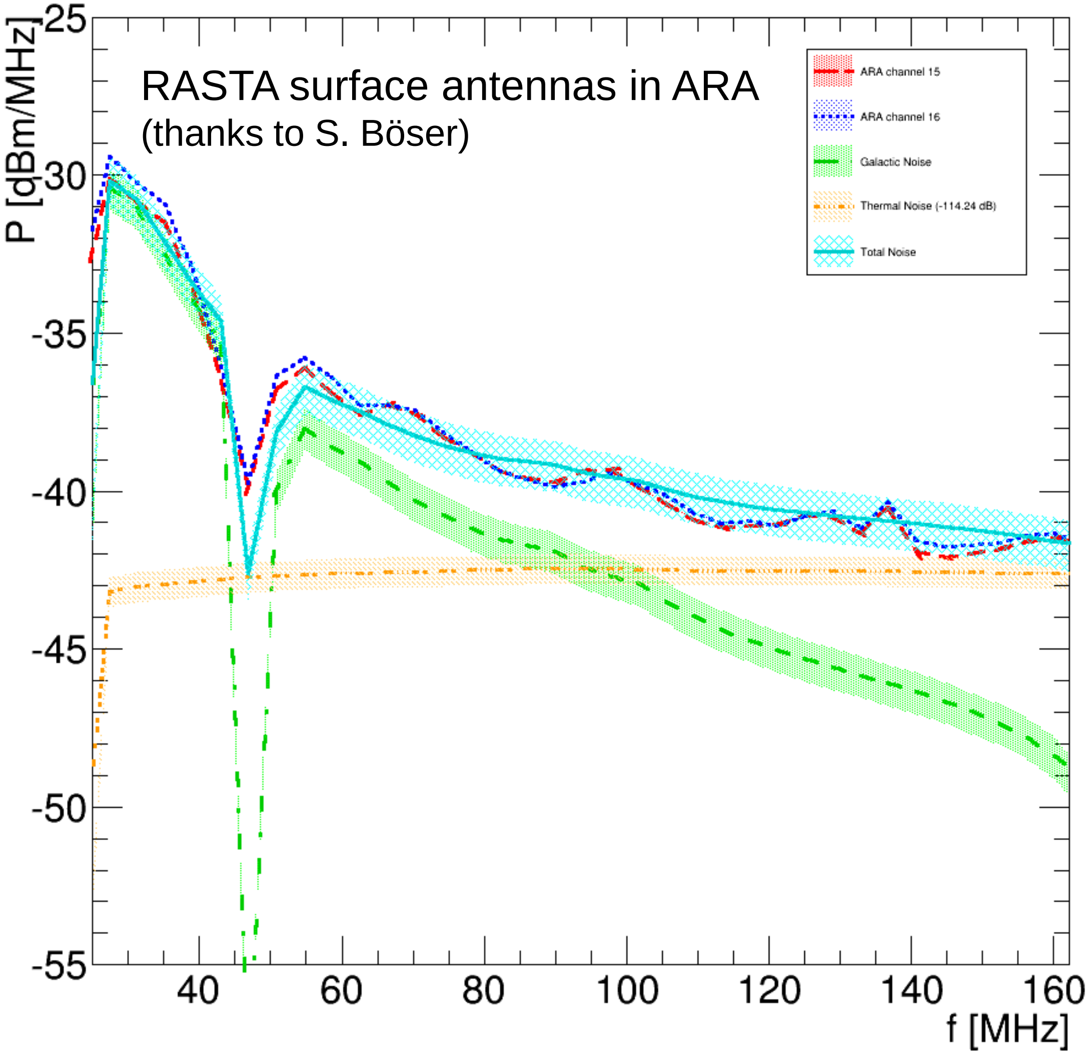
Previous Radio Experience Available at the South Pole

- Background measurements by surface antennas
  - General model of thermal + Galactic noise confirmed by RASTA antennas in ARA testbed
  - Now: pulsed background measured by ARIANNA

ARA and IceCube Coll., ARENA 2012
AIP Conf. Proc. 1535 (2013) 116





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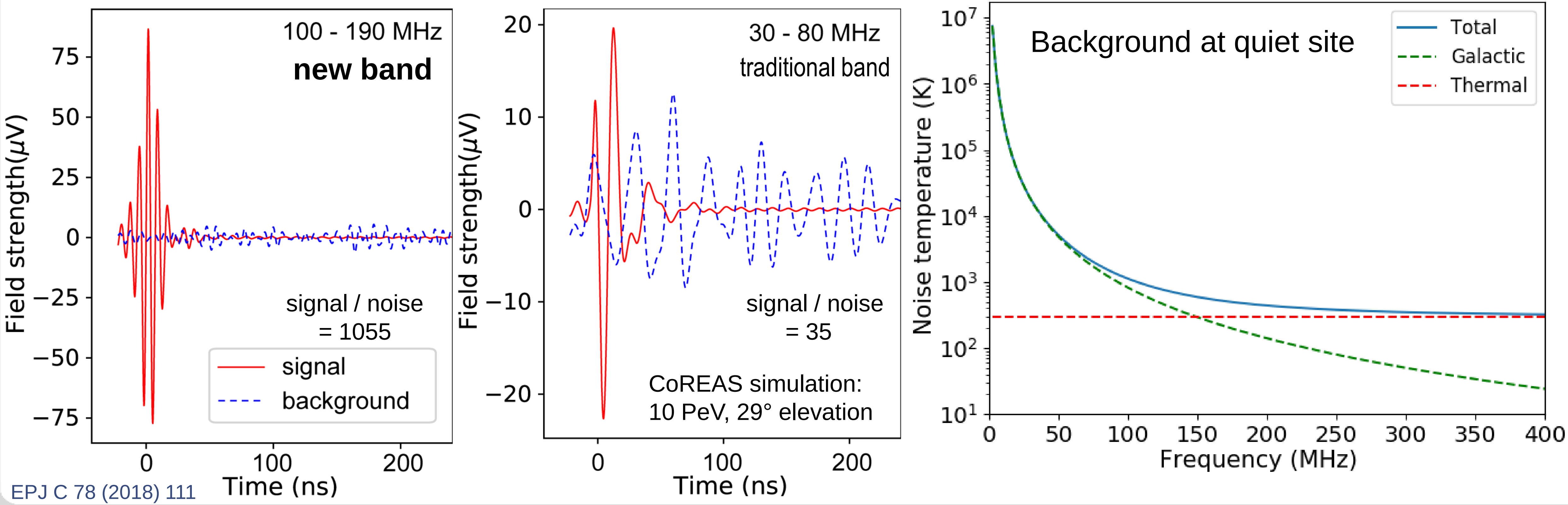
Lower threshold by higher frequencies

- Background at radio-quiet sites falls rapidly towards higher frequencies
- Signal close to Cherenkov cone extends to several 100 MHz (GHz directly at the cone)

→ PeV detection threshold for antennas close to the Cherenkov cone.



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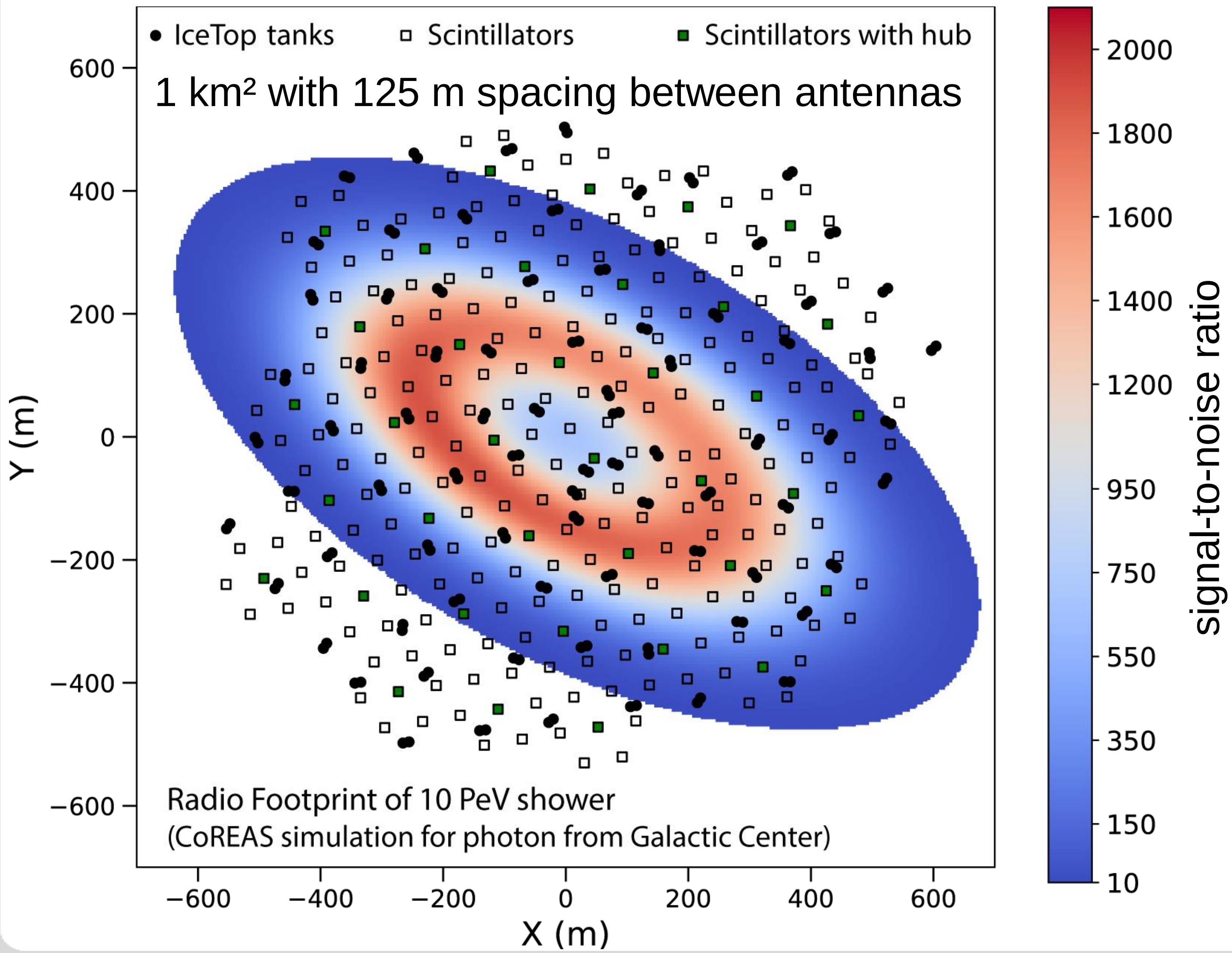
Simulation study on proposed radio array at South Pole



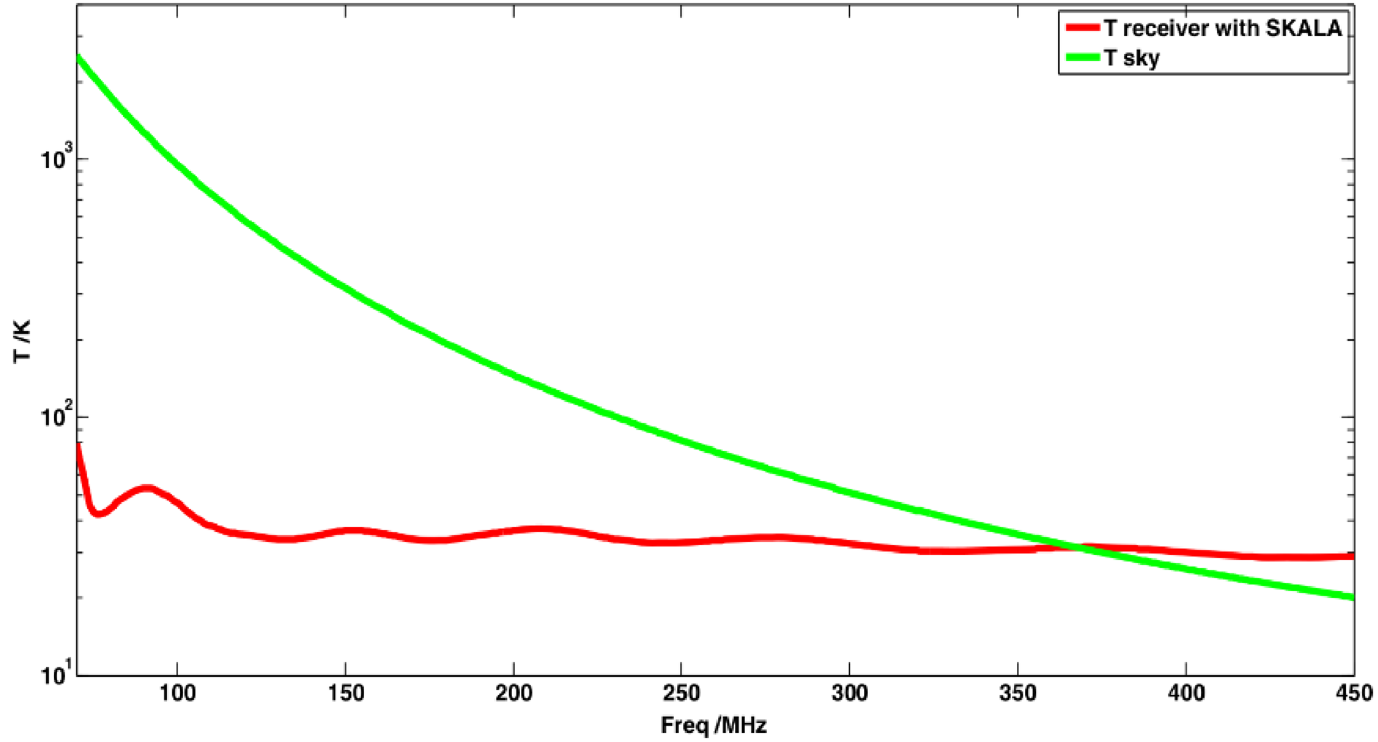
- Low threshold requires at least 3 antennas in the Cherenkov ring
- About 125 m spacing required
- About 80 antennas on 1 km² → 2 antennas per scintillator station
  - more detailed studies needed

- PeV photon search → details on Friday

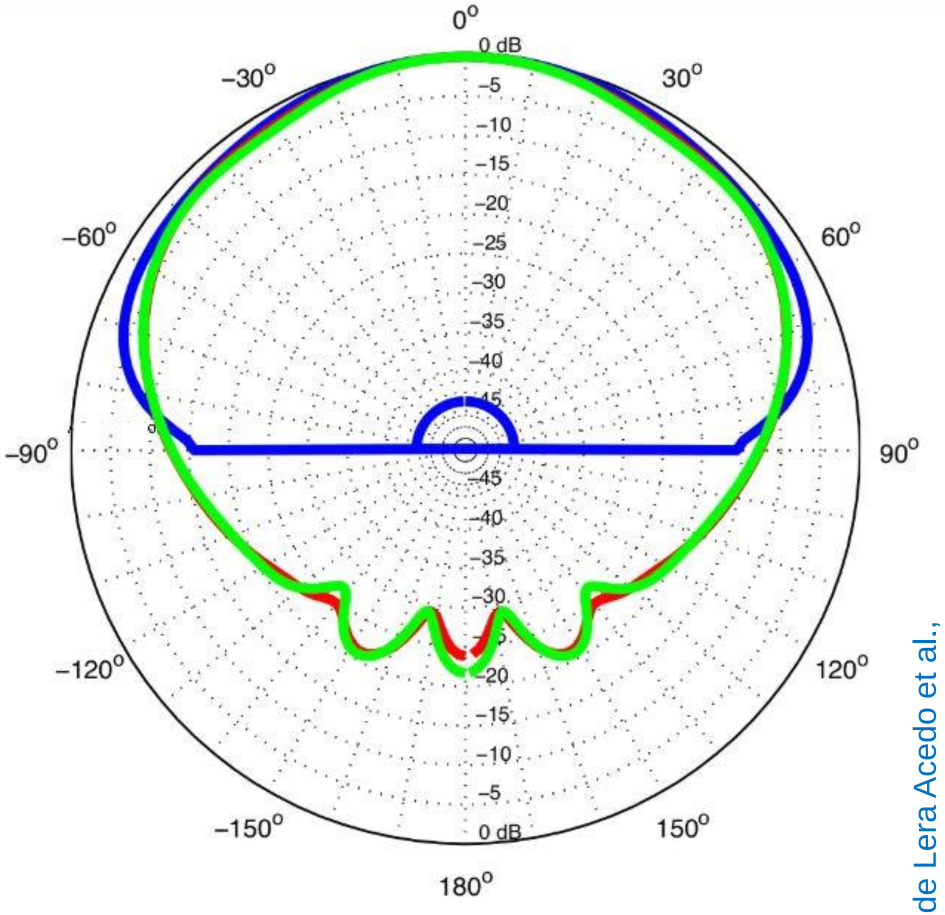
Search for PeVatrons at the Galactic Center using a radio air-shower array at the South Pole
A. Balagopal V., A. Haungs, T. Huege, F.G. Schröder,
European Physics Journal C 78 (2018) 111

Possible antenna: SKALA (LPDA of SKA-low)

- Frequency range: 50-350 MHz
- Smooth gain pattern
- Low system noise (about 40 K)



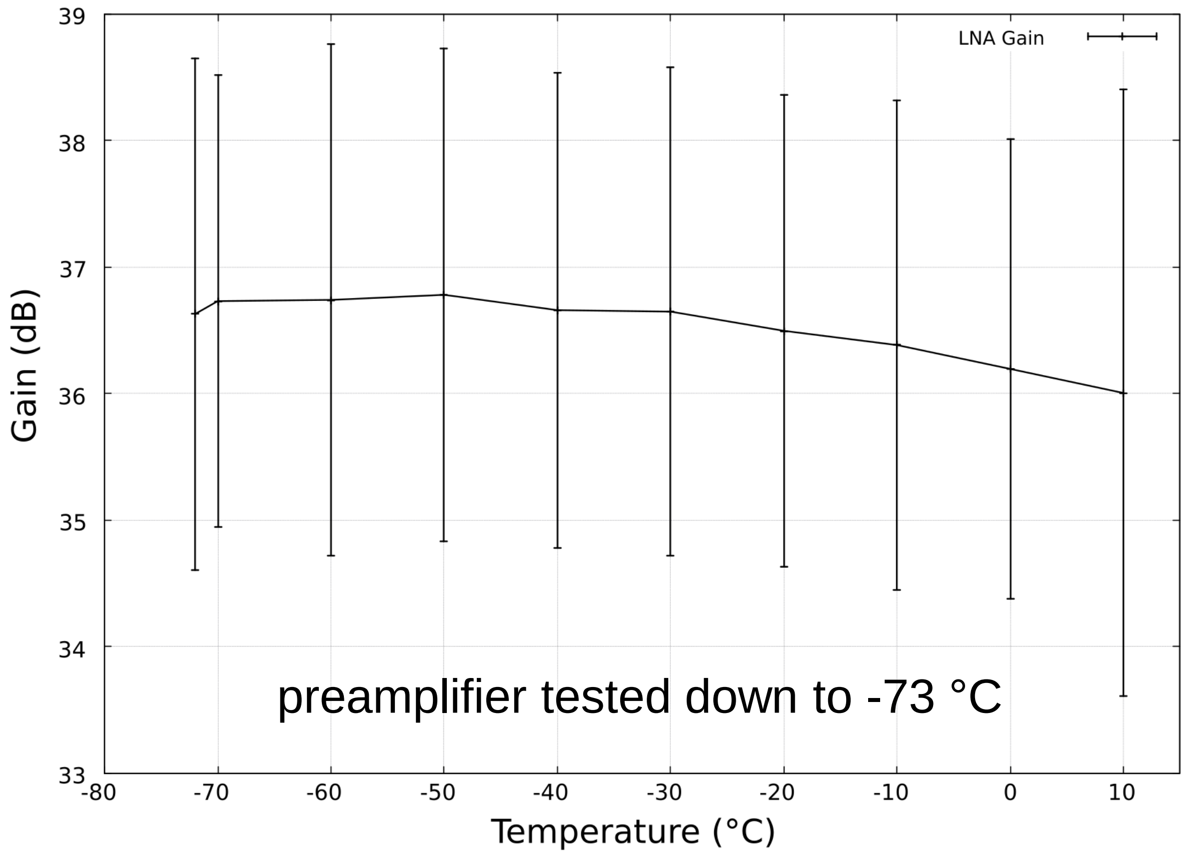
gain vs. zenith for different grounds



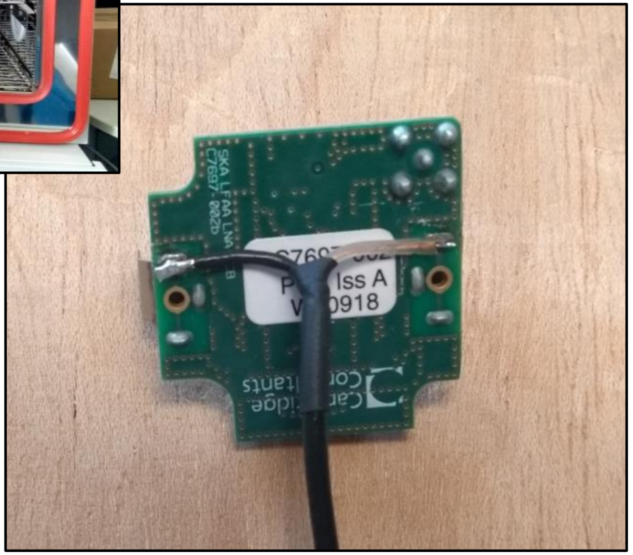
E. de Lera Acedo et al.,
Exp. Astr., 39 (2015) 567
+ IEEE, ICEAA (2015) 839

Preparative tests already started

- 3 antennas installed for first tests at KIT, low-temperature tests
- Ready to install two prototype antennas at the South Pole next January



Test of LNA and other antenna components in special fridge



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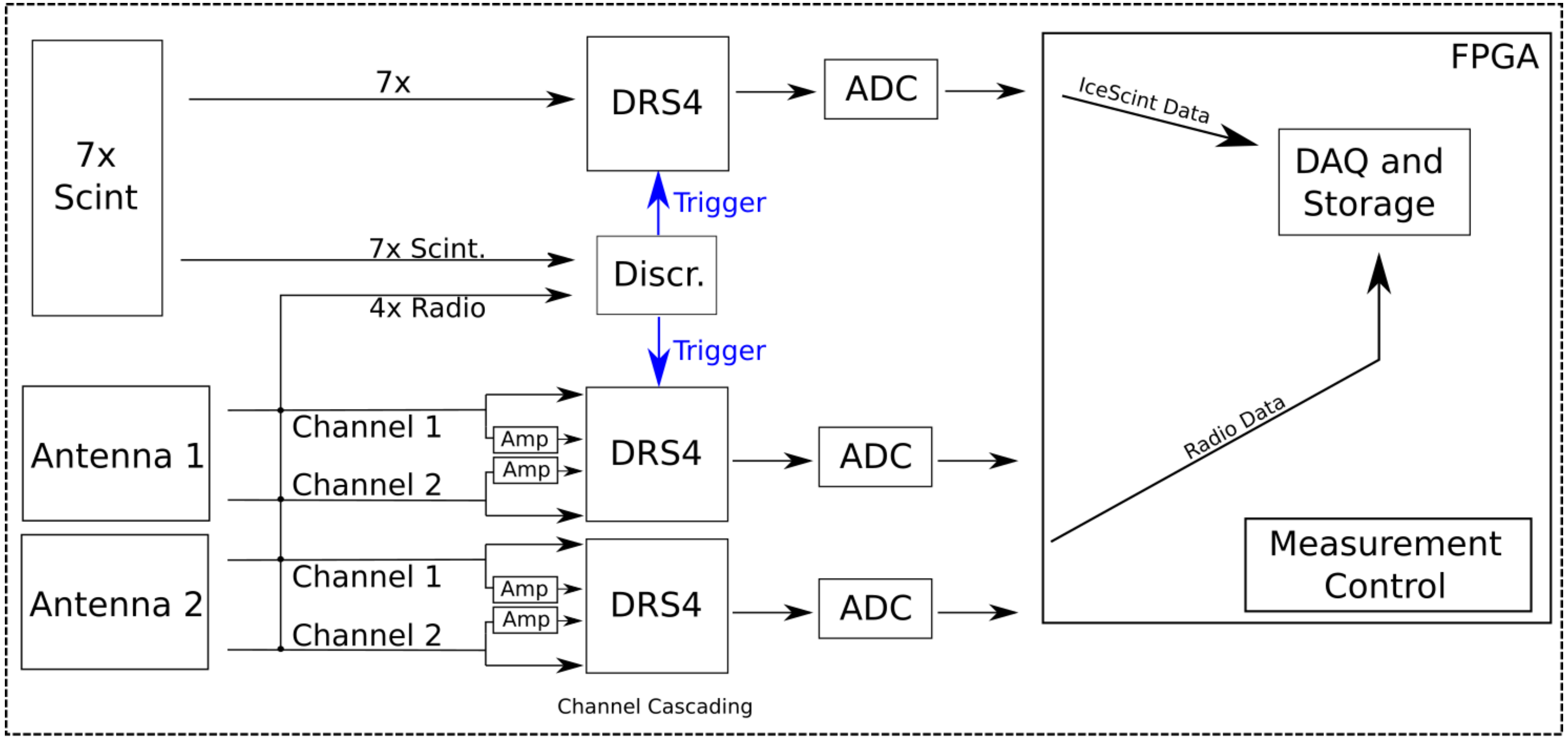
Idea: install 80 antennas on 1 km² at the South Pole

- required upgrade of scintillator electronics possible
  - straight forward in case of TAXI (see ARENA 2014; arXiv:1410.4685)
- first successful tests of antennas and amplifiers at KIT



SKA-low antenna at KIT, Karlsruhe

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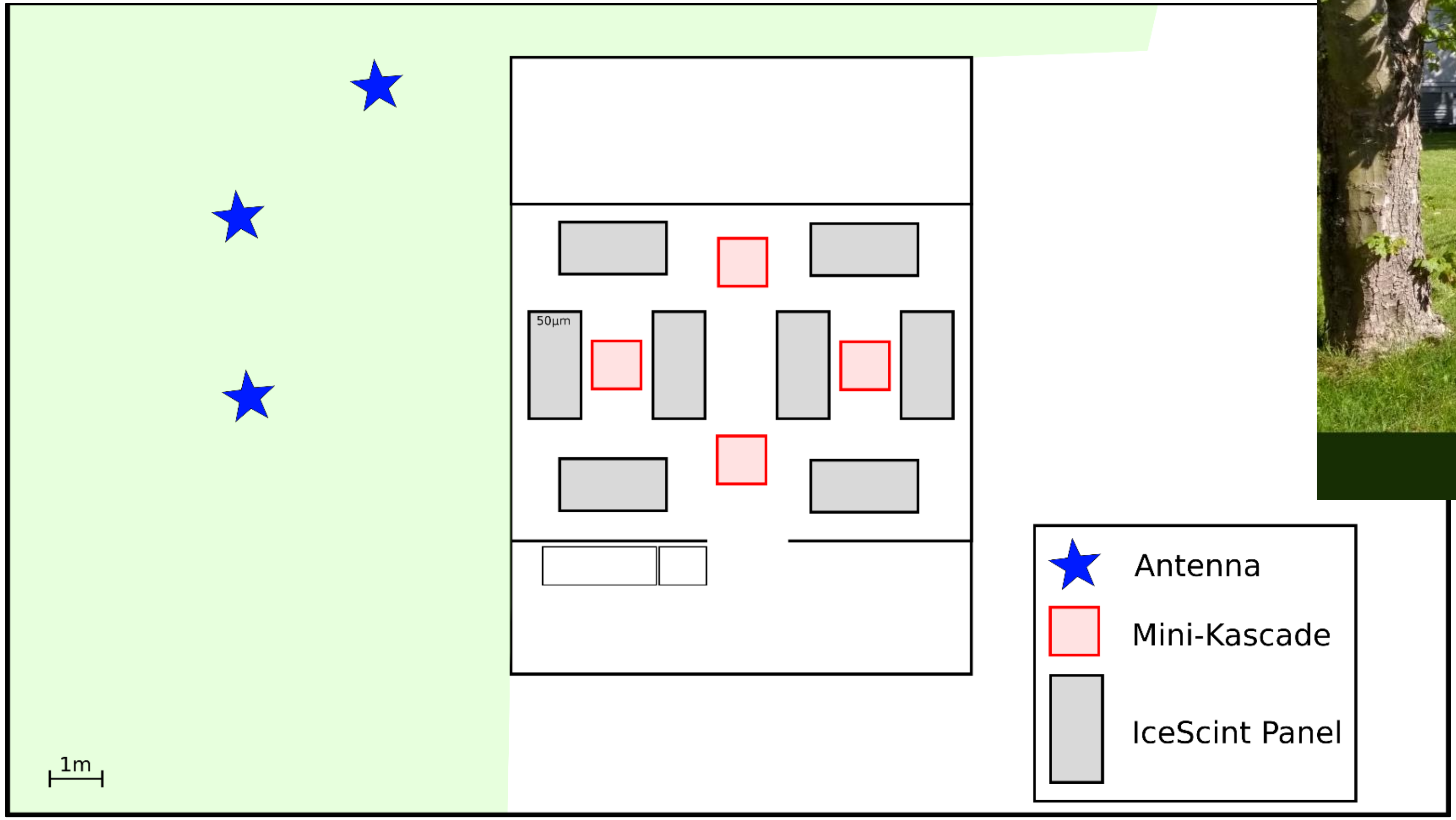
Test setup at KIT

- Test of Antennas and scintillators in very noisy environment of KIT



Mini array at KIT of

8 scintillators of IceScint type,

3 SKA-low (v2) prototype antennas

4 KASCADE scintillators for reference

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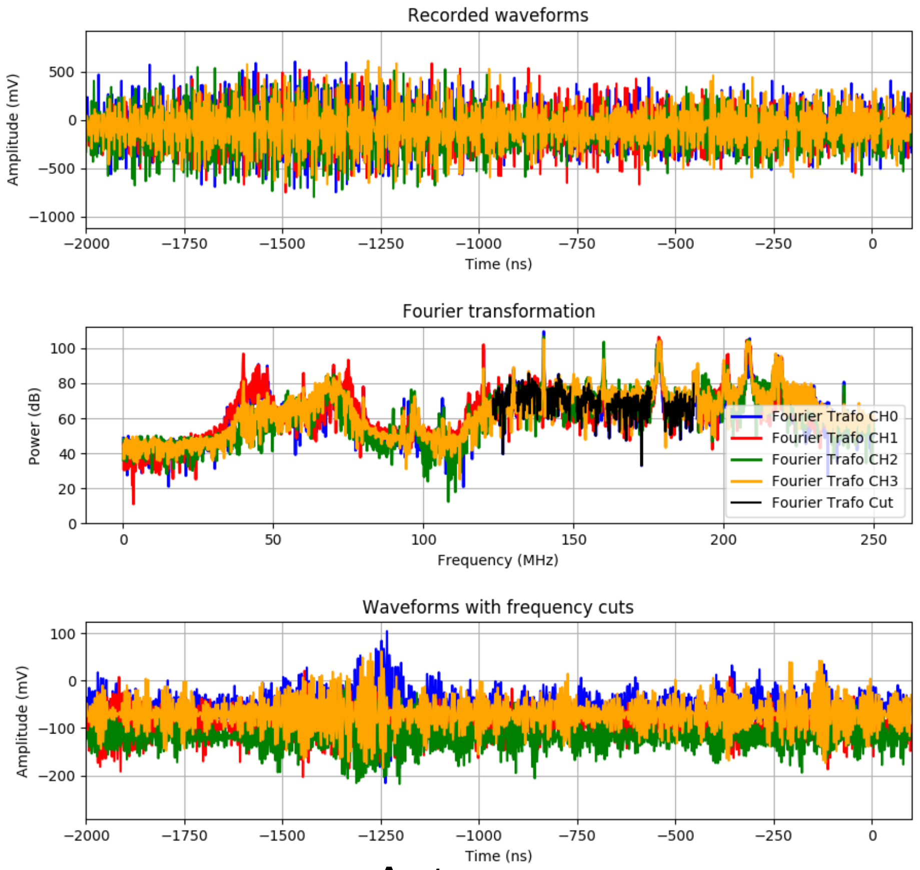
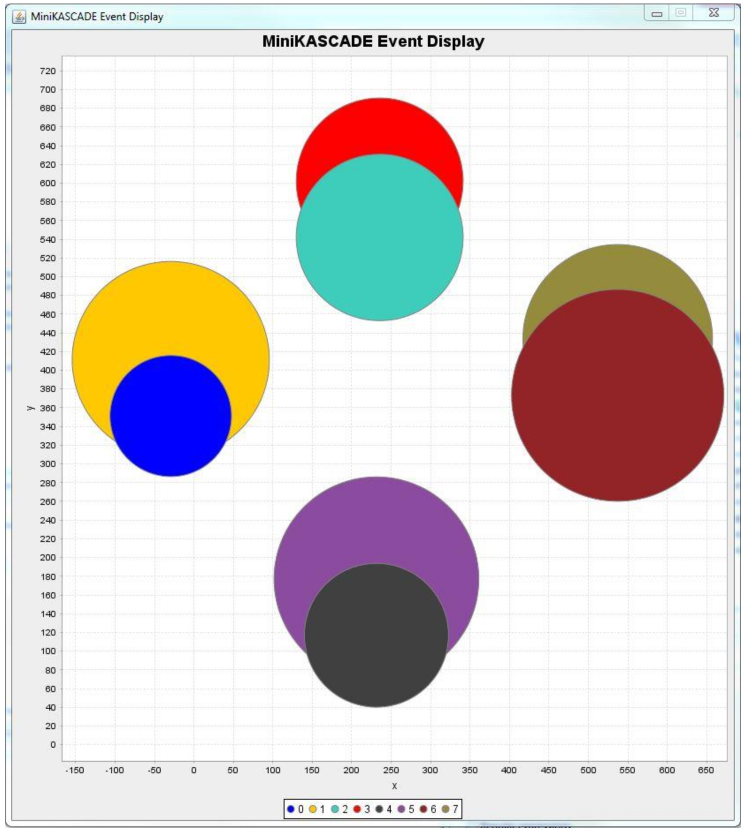
Air showers measured with scintillators trigger antennas

- Tests of technical feasibility, but radio measurement of air-showers challenging at KIT

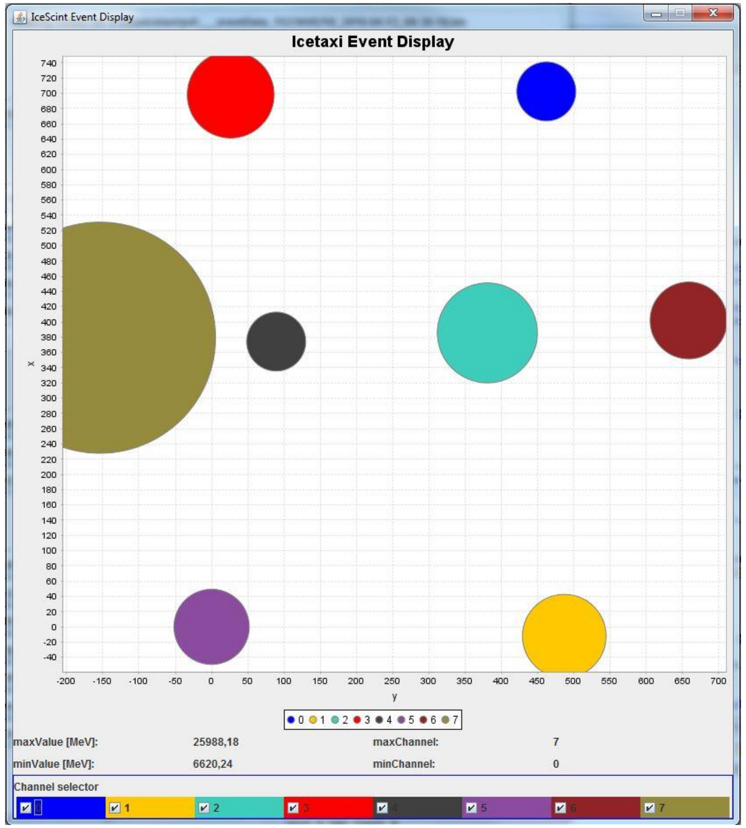
  → Realistic test of two antennas (triggered by scintillators) planned at the South Pole



Antennas



Mini-KASCADE



IceScint

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Optimistic Timeline: deployment with scintillator array

2018	2019	2020	2021	2022	2023
first antenna tests at KIT + preparations for South Pole	optimization of electronics + simulations to prepare analysis	prepare 80 antennas for full array **First Impact:** demonstrating PeV threshold	tune analysis methods *feedback to SKA-low and Gen2 plans*	**Analysis:** cosmic rays with accurate energy and composition test hadronic models	discovery of PeV photons? mass-dependent anisotropies?

South Pole

Summer 18/19	Summer 19/20	Summer 20/21	Summer 21/22	Summer 22/23
Summer 18/19: install 2 antennas at the South Pole	**Summer 19/20:** antennas with optimized design	**Summer 20/21:** deployment of full radio array	**Summer 21/22:** calibration and maintenance	**Summer 22/23:** new ideas?

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Open questions (input welcome)

- Impact of (partial) snow coverage of antenna
  - Is there any simulation code which can handle a medium changing in the near field?
- Trigger
  - Default = external trigger on station level by scintillators
  - Array trigger by IceTop and scintillator arrays?
  - Self-trigger to lower threshold for PeV photons?
- Issues we do not yet think of?

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Conclusion: Rich physics potential for radio surface array

- What is the origin of the most energetic Galactic Cosmic Rays?
  - Cosmic-ray mass composition, accurate energy, mass-dependent anisotropy
- PeV photon search from Galactic Center
  - Most sensitive at 61° zenith (in contrast to standard photon searches at IceCube)
- Air-shower physics
  - Accurate hadronic models needed to understand in-ice muons
- For free: tests for IceCube-Gen 2
  - veto and cross-calibration for in-ice radio

Open Positions:

- PhD student
- Postdoc starting Fall 2018

12 June 2018
ARENA 2018, Catania
Potential of a Radio Surface Array at the South Pole
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