

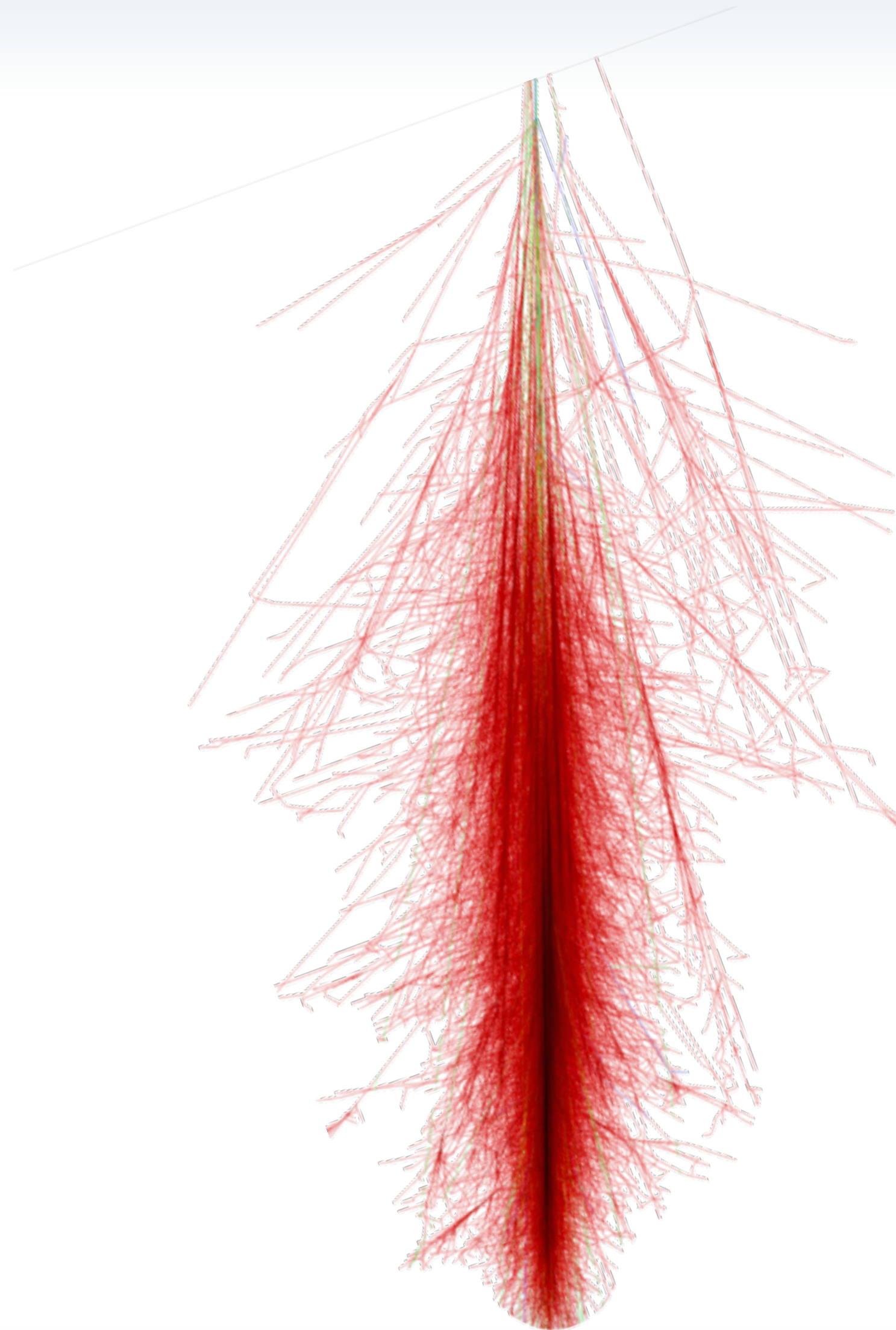
LORA: The particle detector array at LOFAR

Katie Mulrey

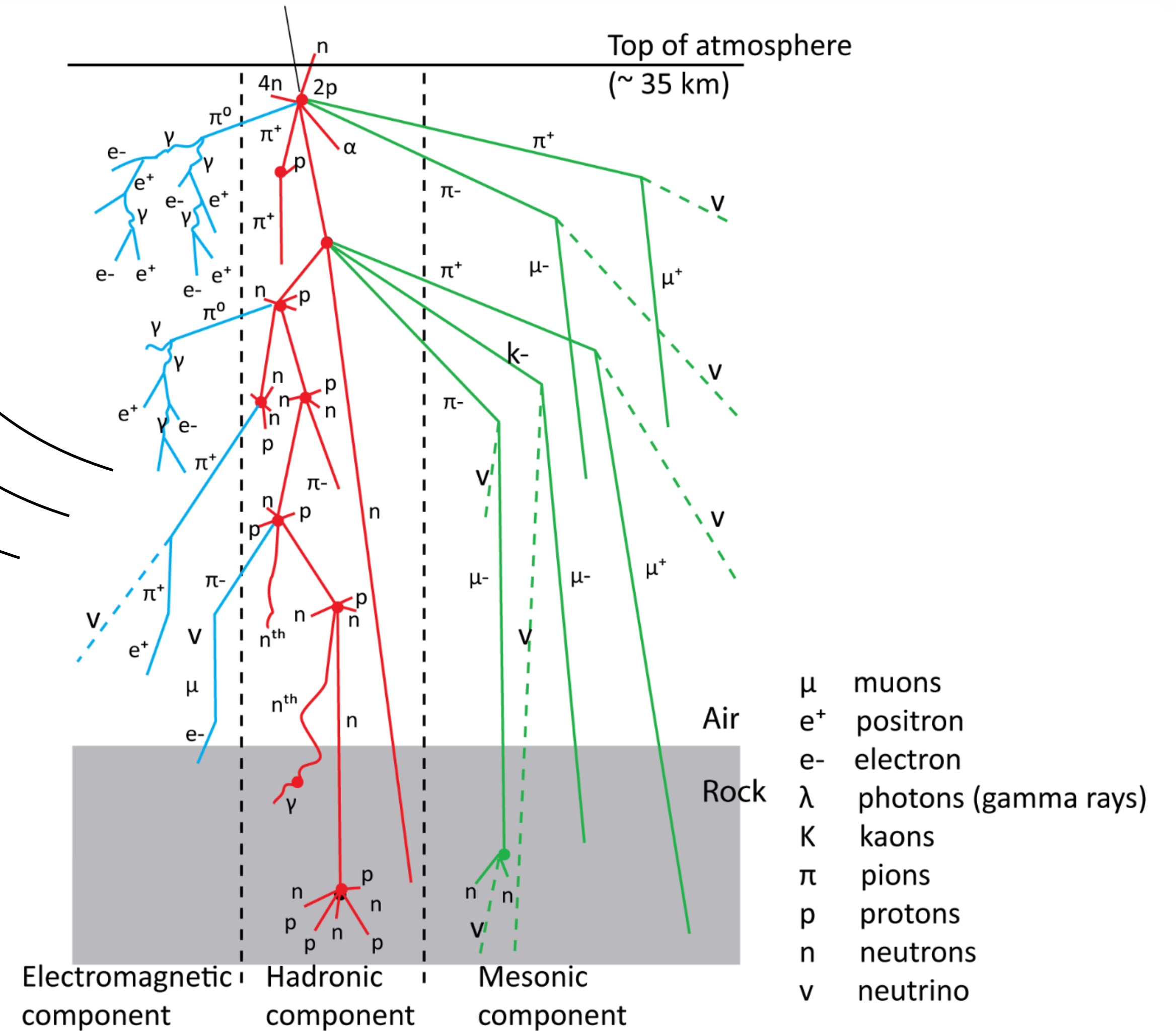
LOFAR Family Meeting 2025



What is in an air shower?

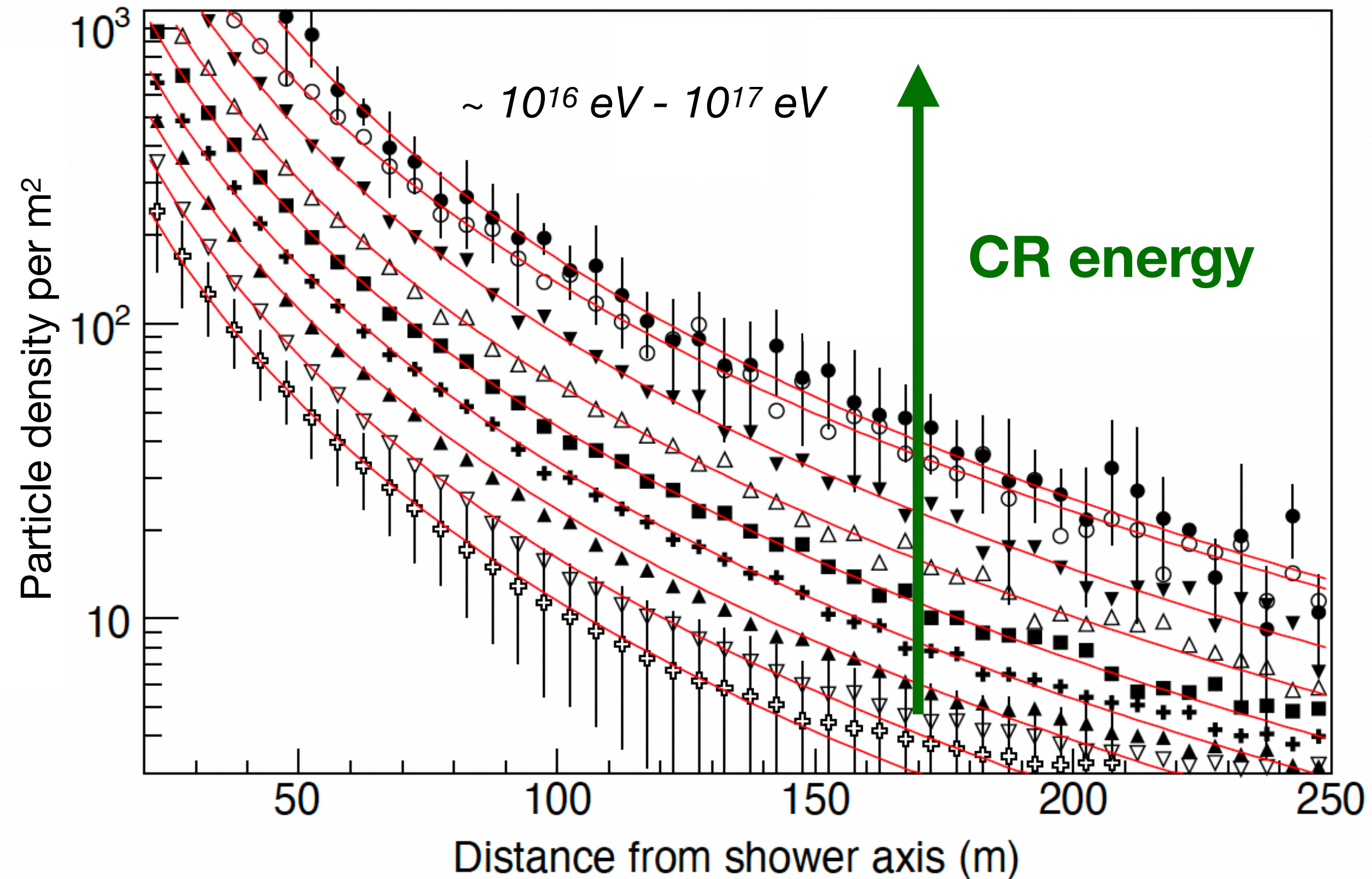


Radio emission

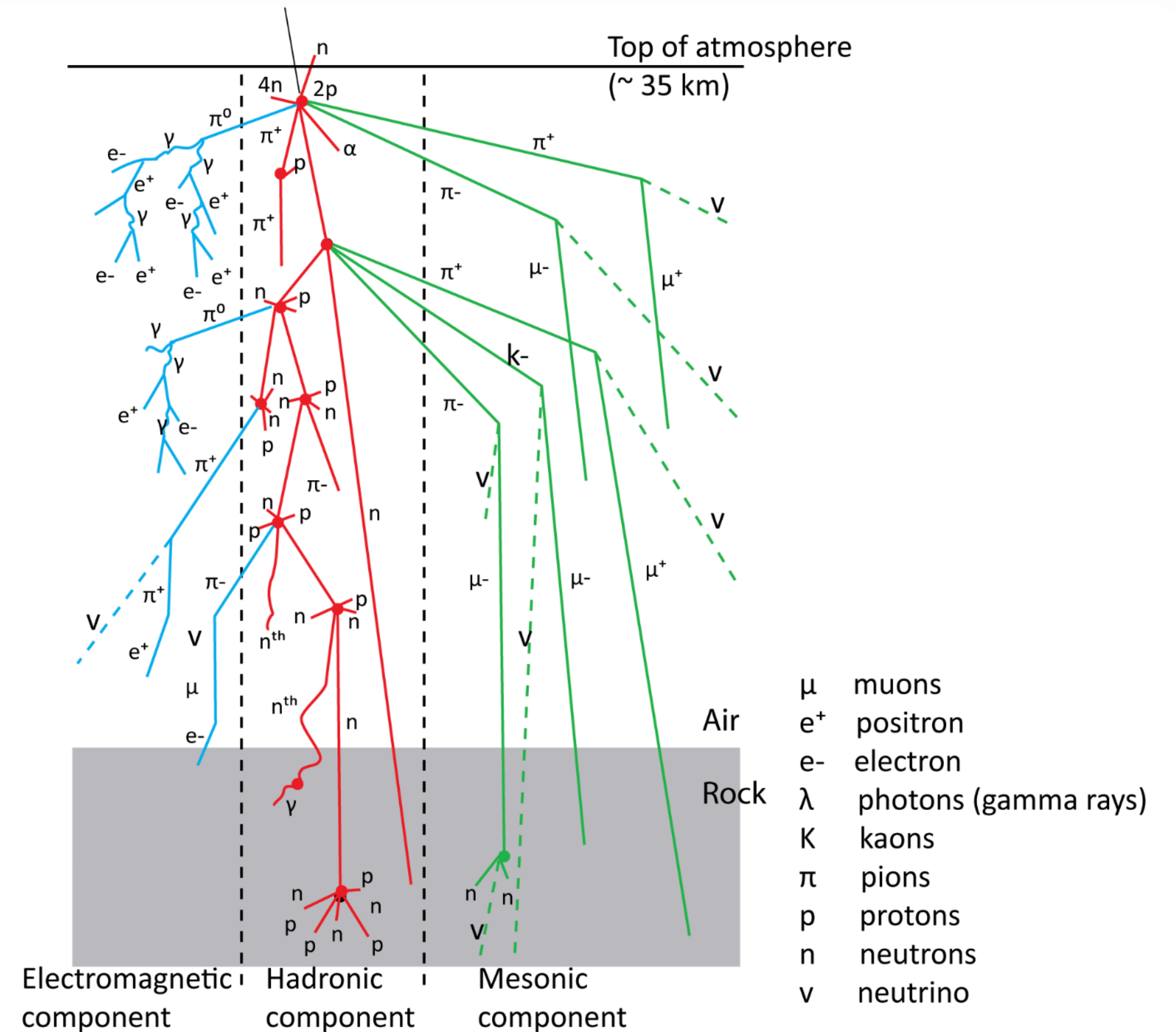


(Gosse + Phillips 2001)

What is in an air shower?

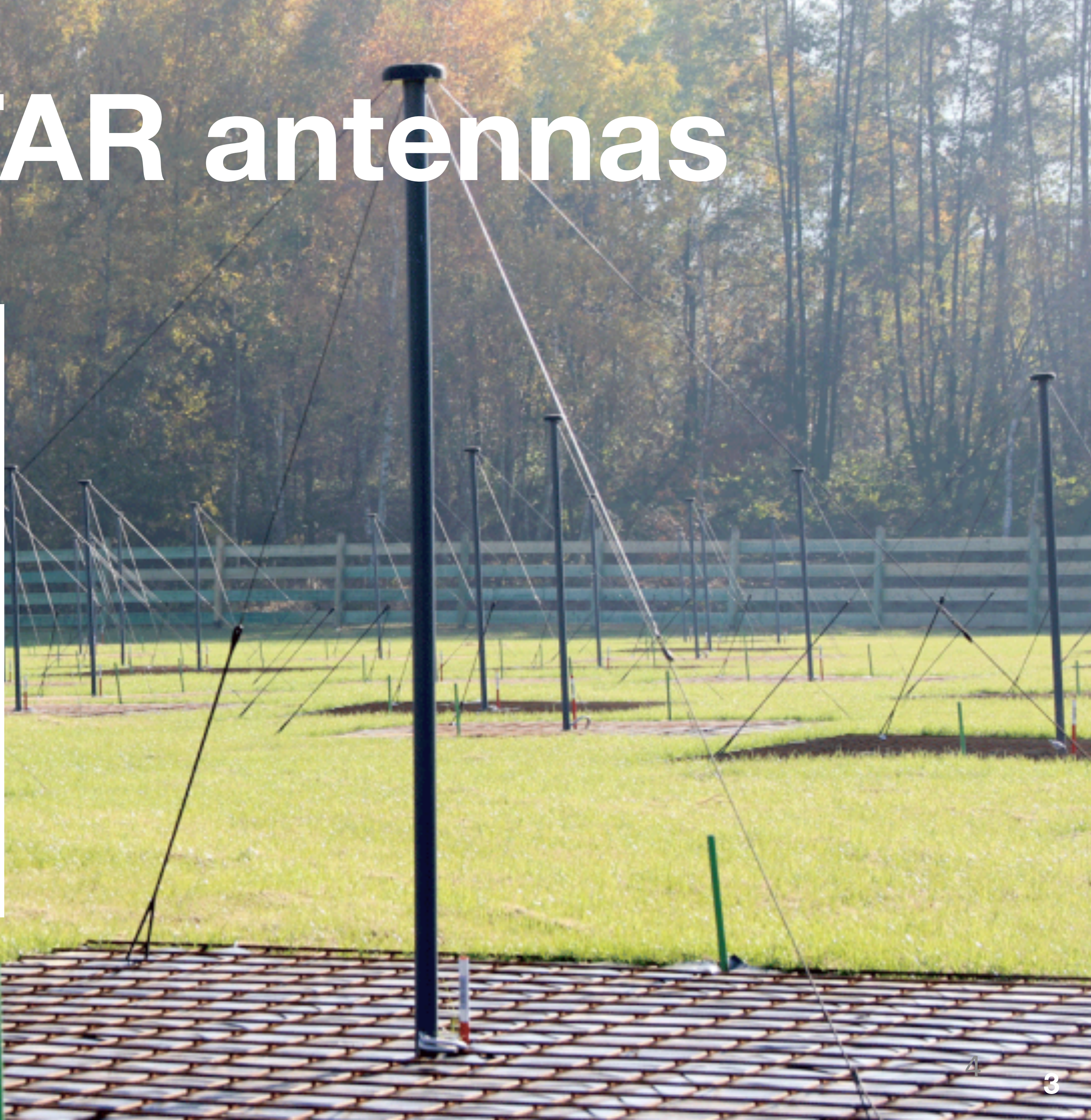
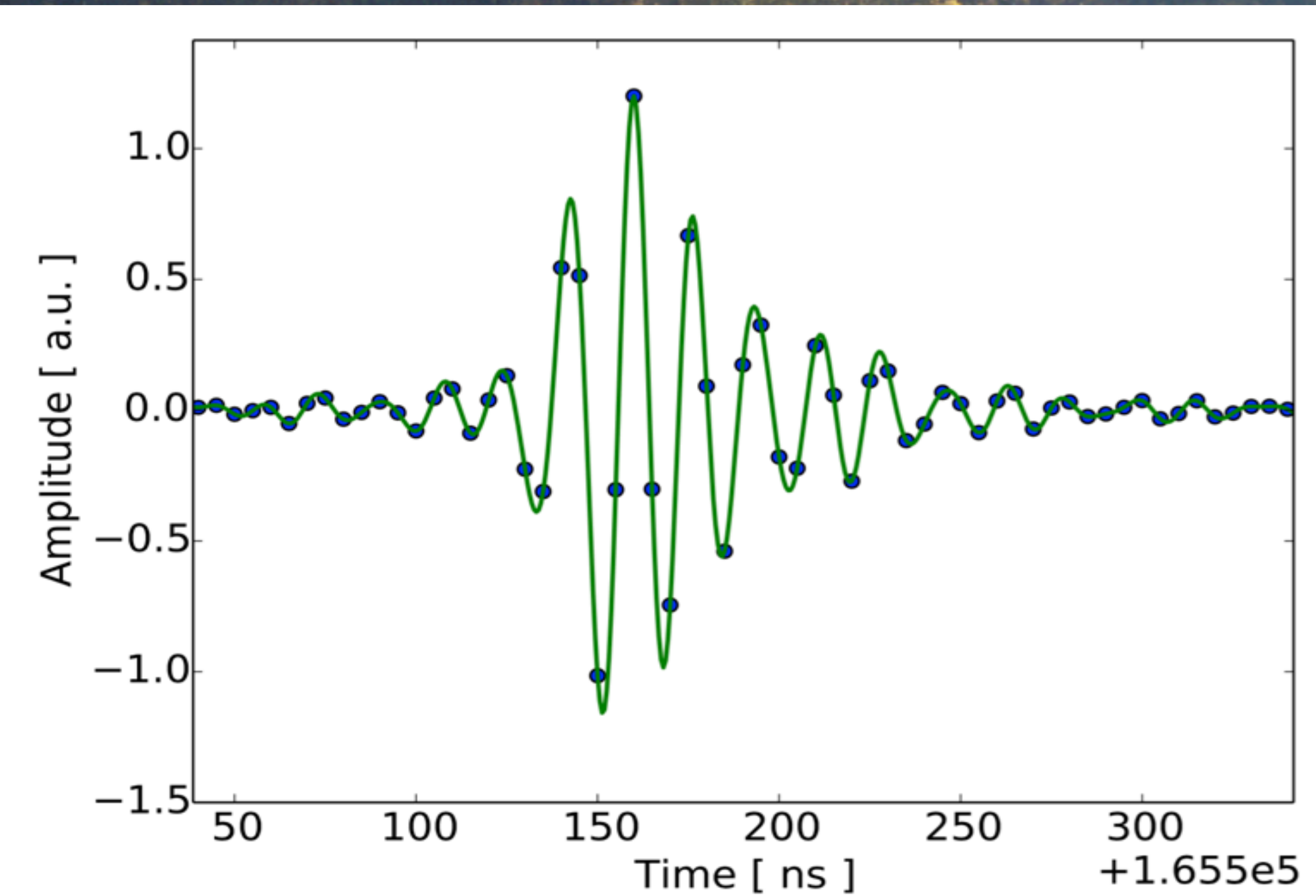


Adapted from Thoudam et al 2015

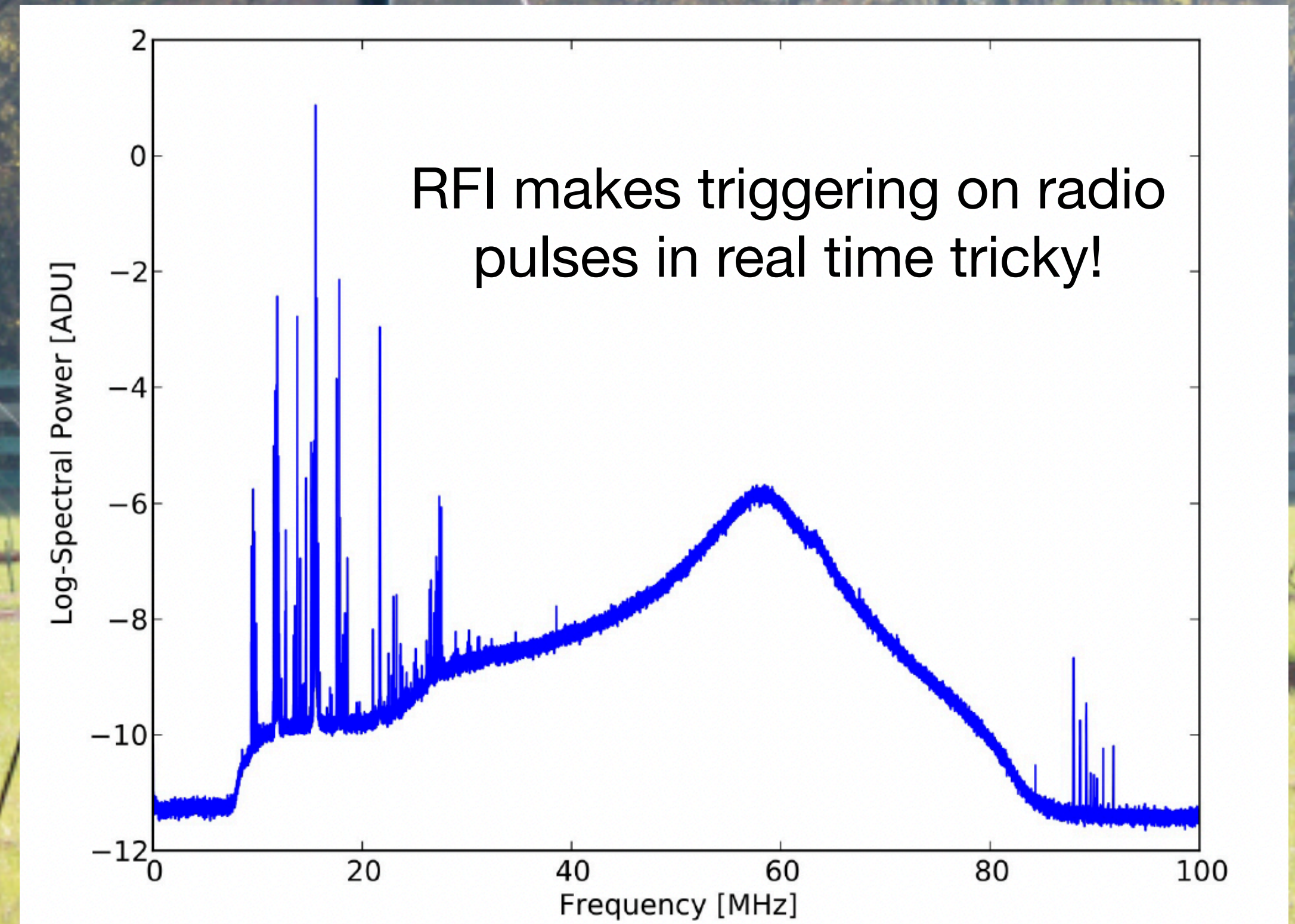
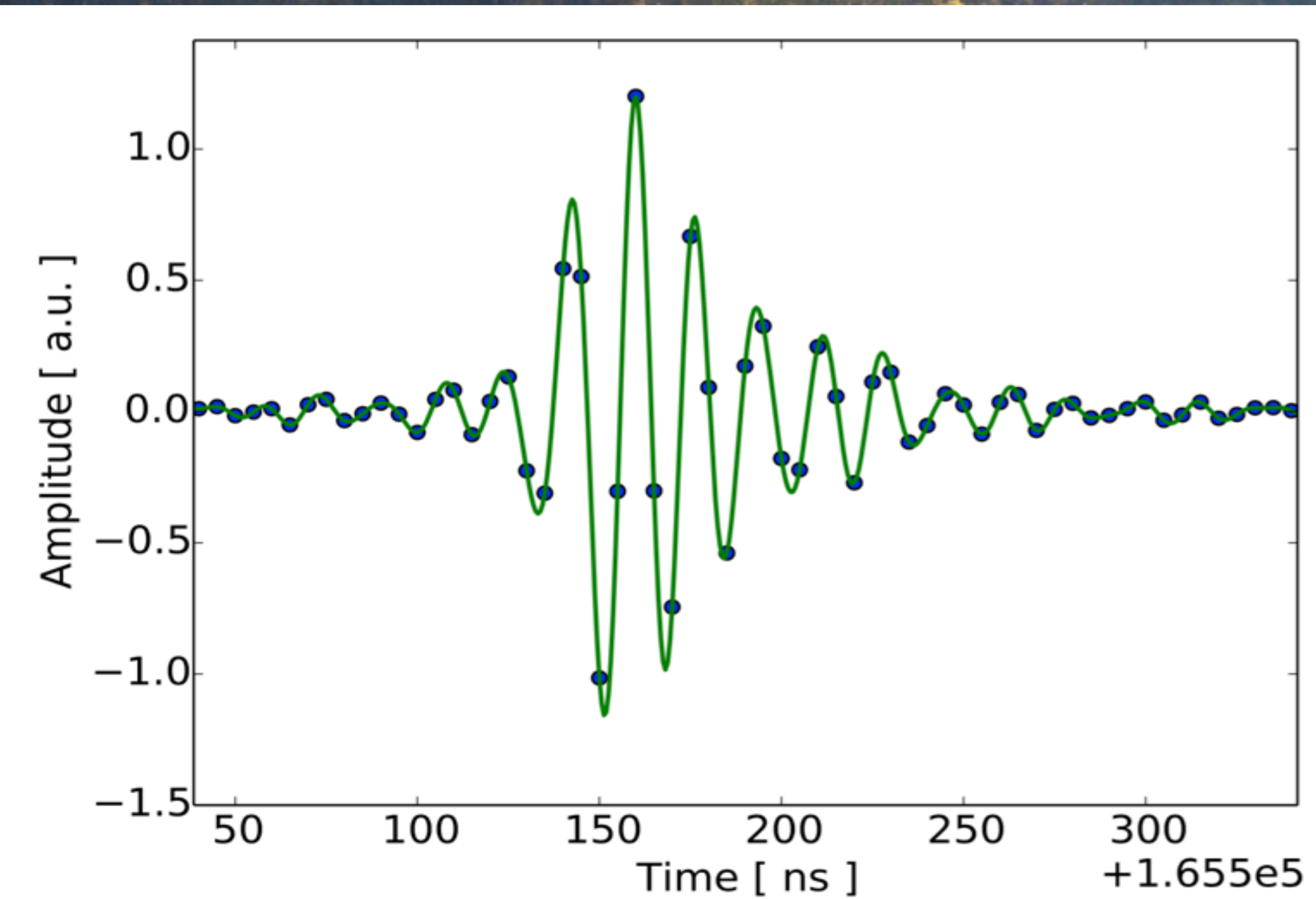


(Gosse + Phillips 2001)

Pulses in LOFAR antennas



Pulses in LOFAR antennas



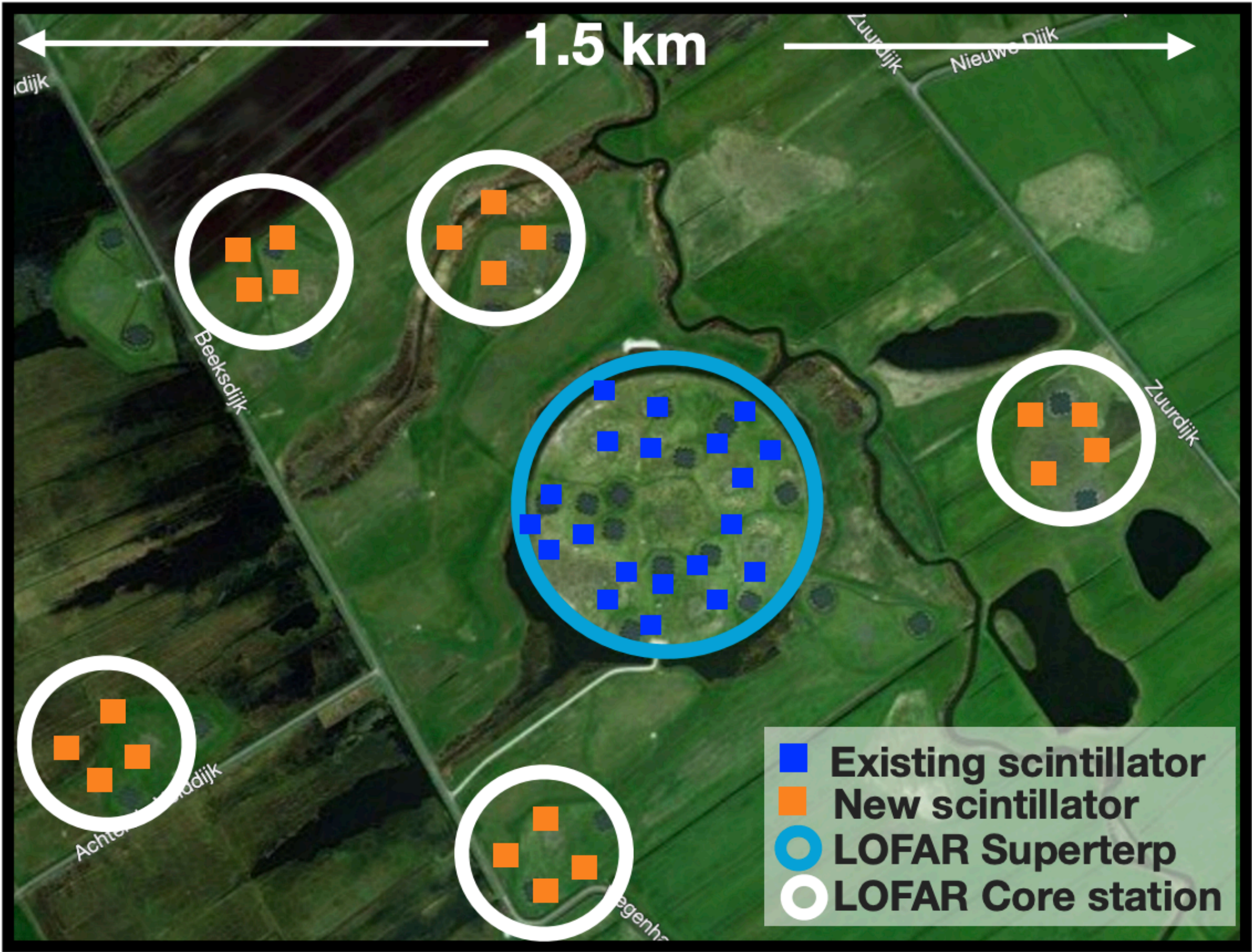
van Harlem et al 2013

Cosmic rays detection at LOFAR

Low band (30-80 MHz)



~ 100s of antennas per event

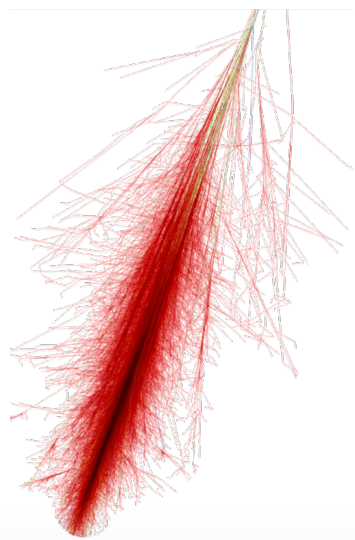


Particle detector for triggering



P. Schellart et al., A&A 560, 98 (2013)

CR event



particle trigger

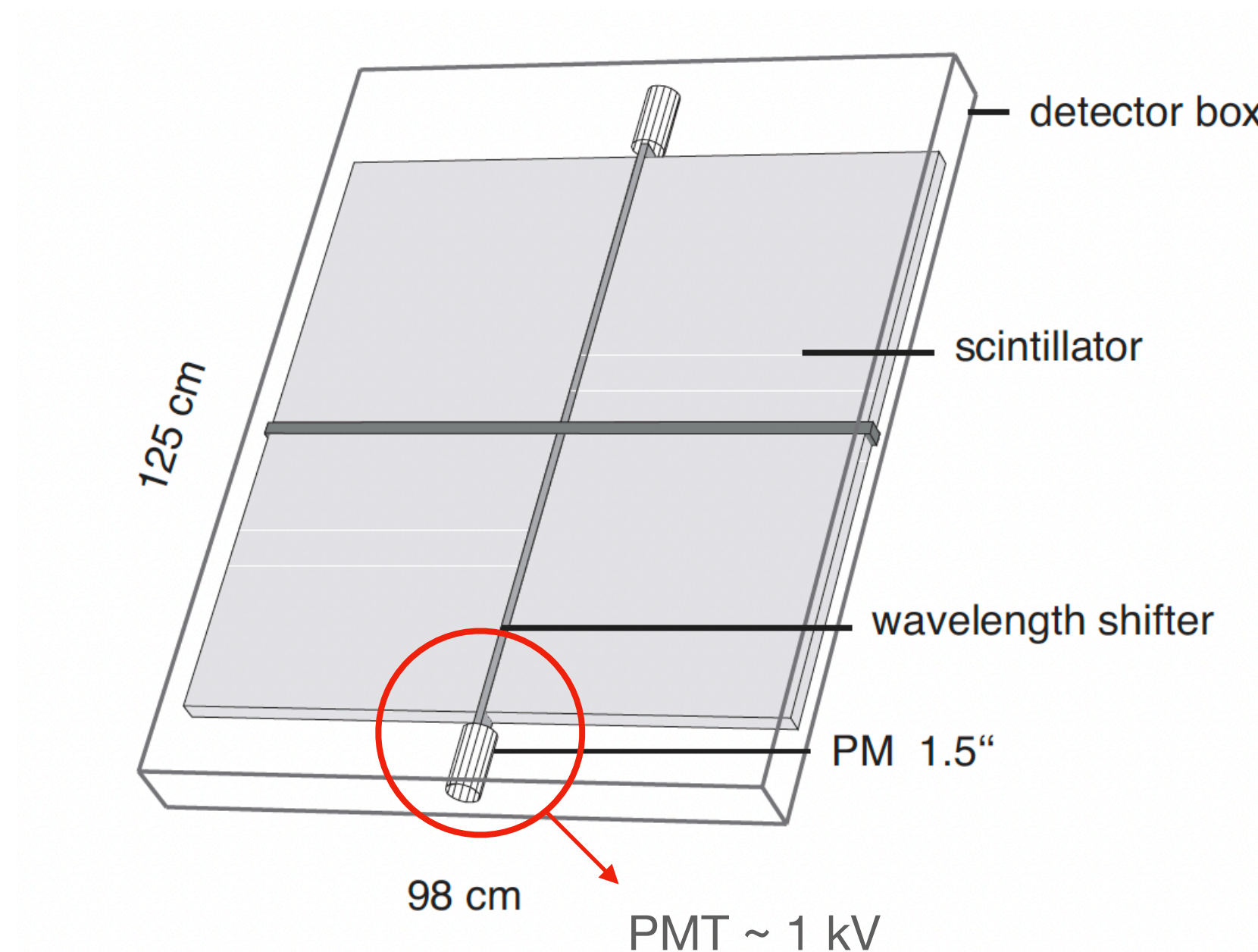
radio buffer readout

offline analysis

The particle detectors



Detector in the field



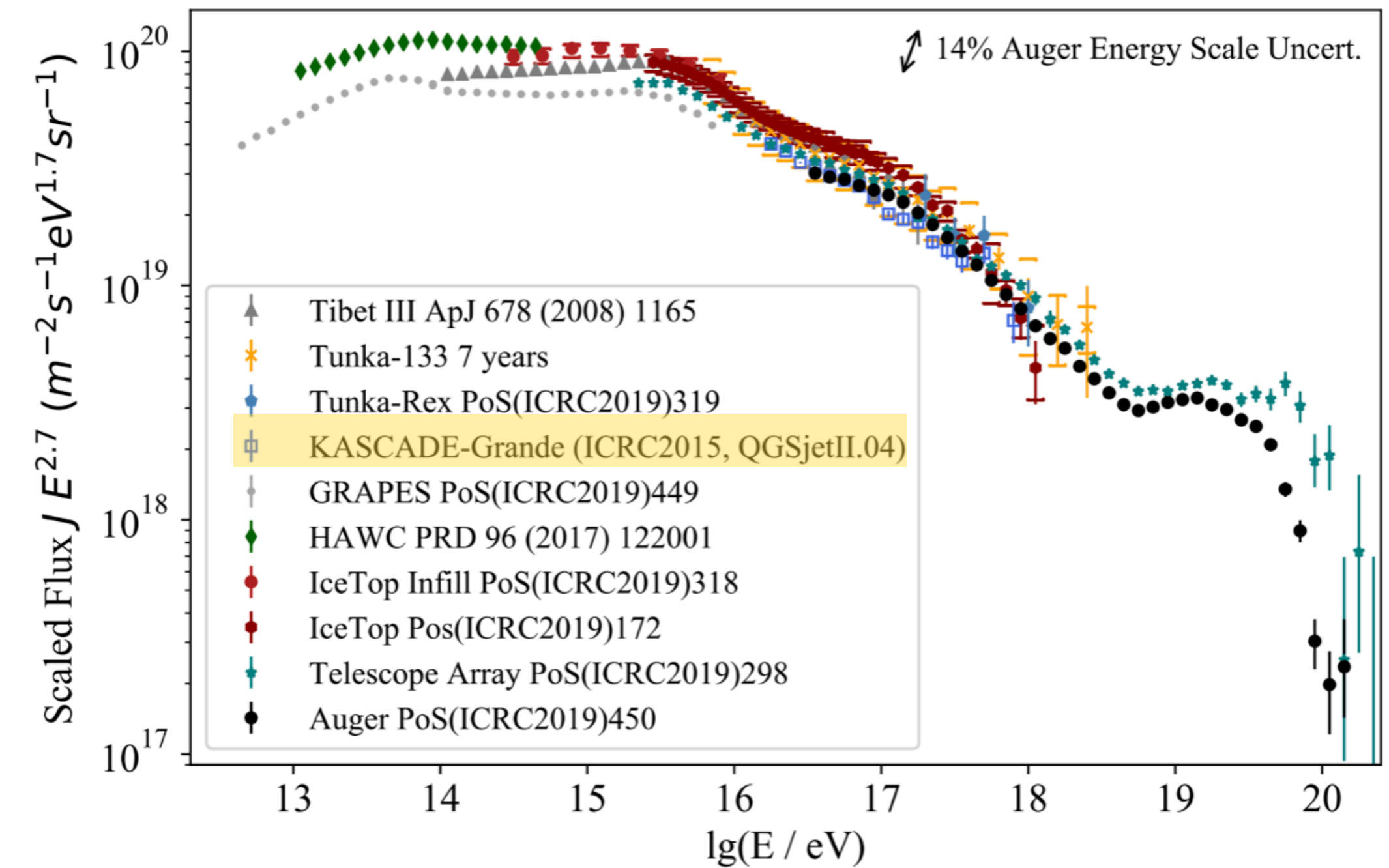
Inside the box

The particle detectors

KASCADE cosmic ray detector at KIT
1996 - 2013

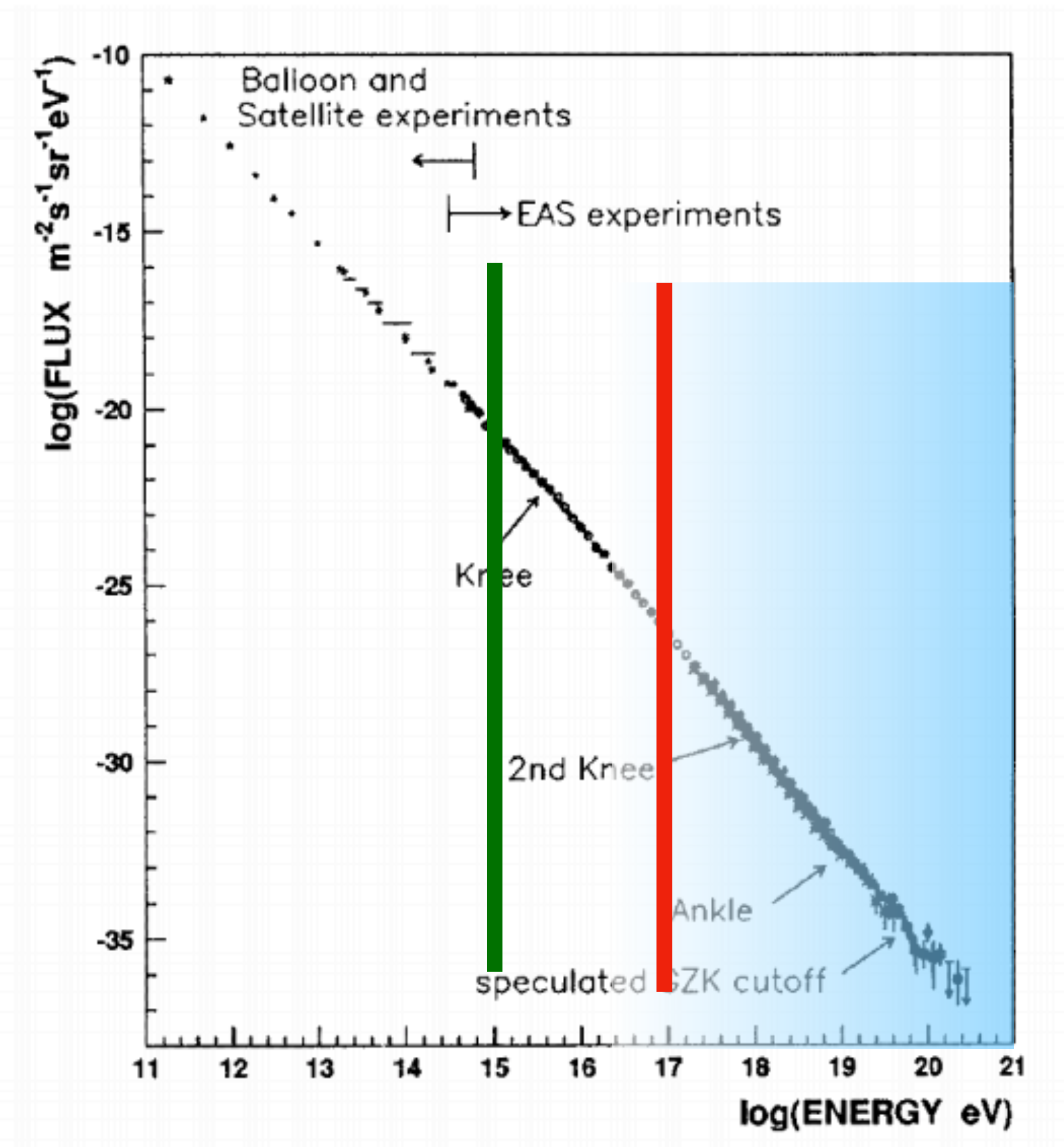
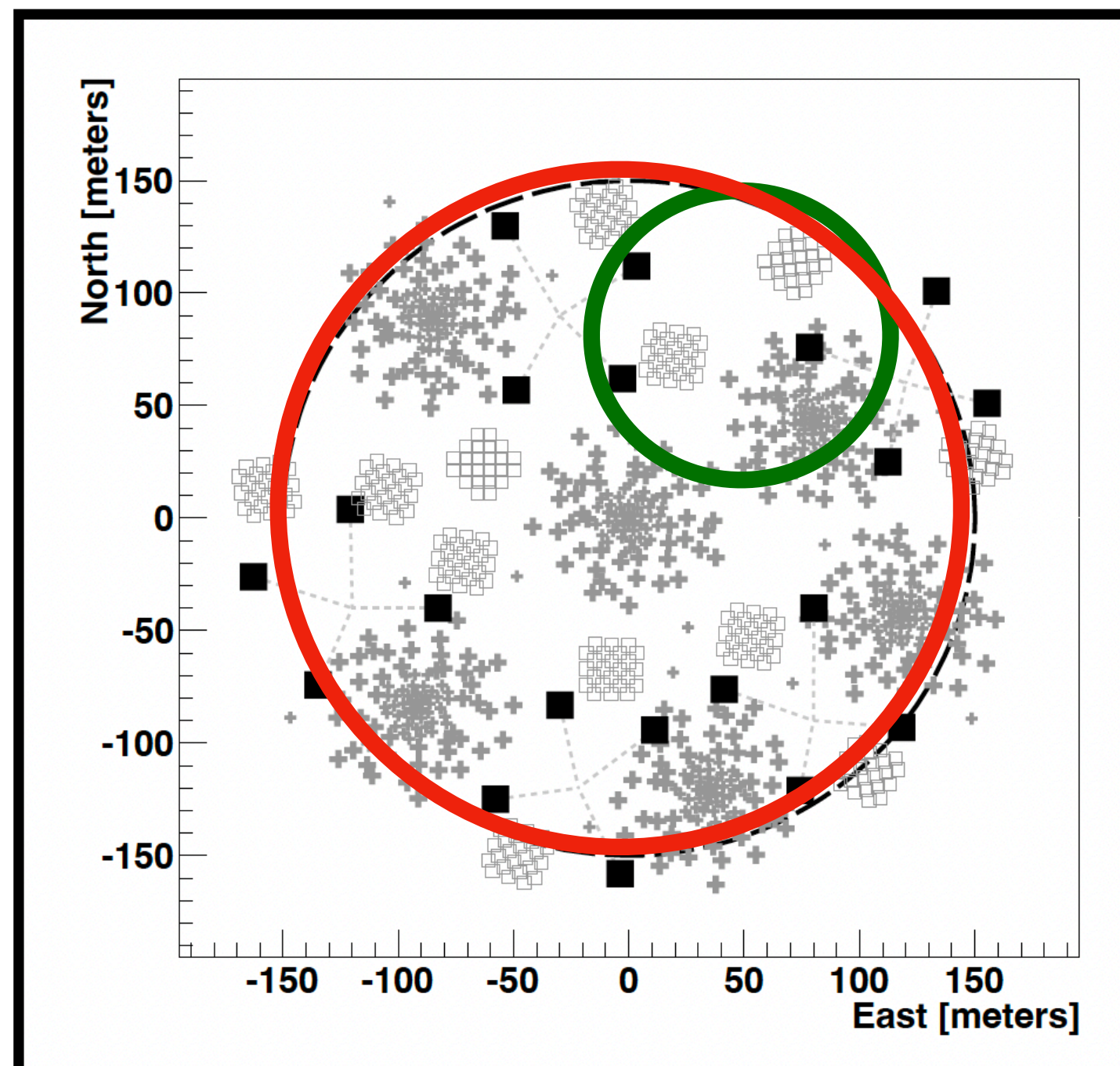


- recycled at LOFAR
- Recycled again for the LORA upgrade
- Recycled AGAIN for SKA...



F. G. Schröder, PoS(ICRC2019)030

LORA operations

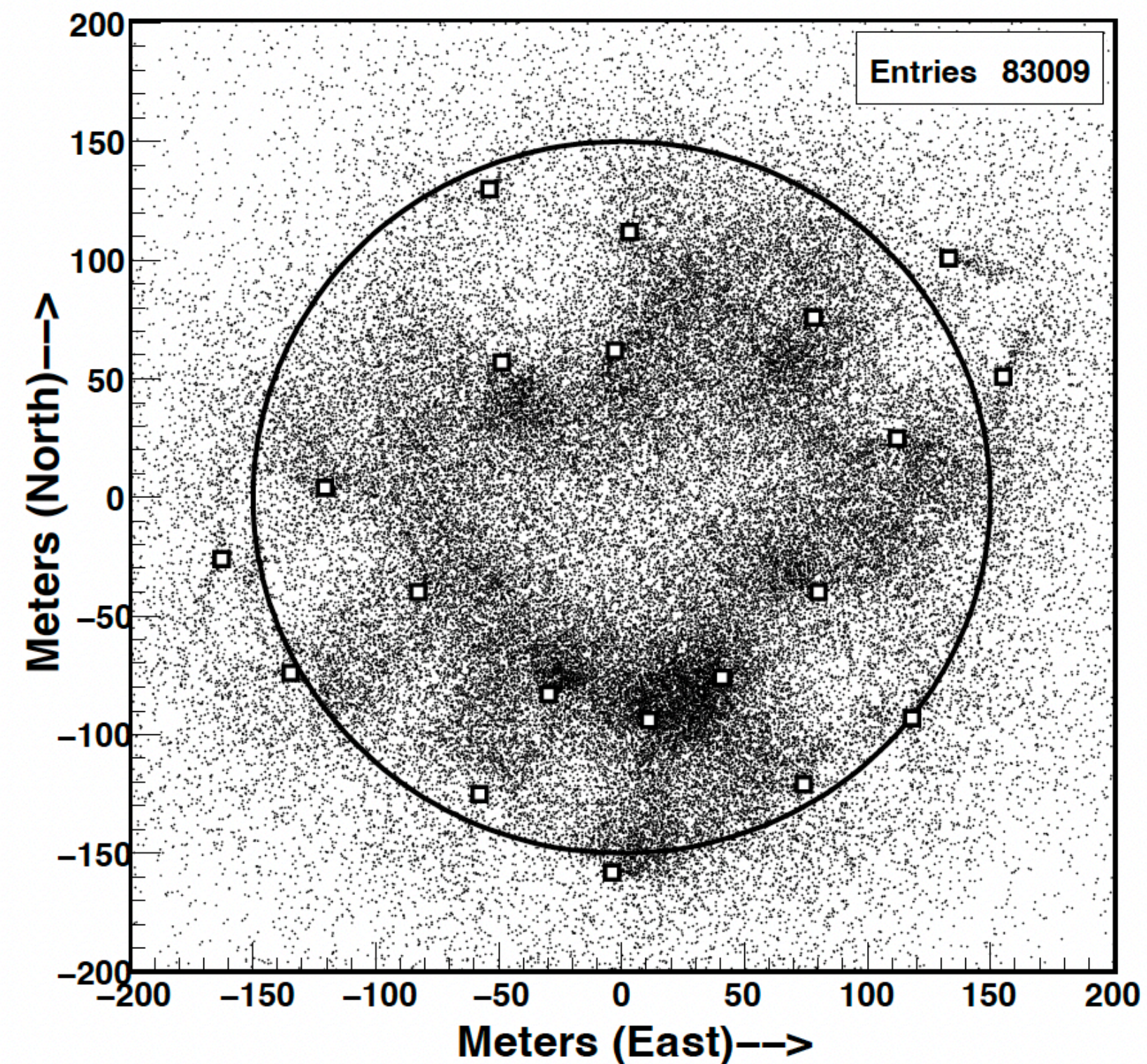


Trigger conditions (12/20 detectors):

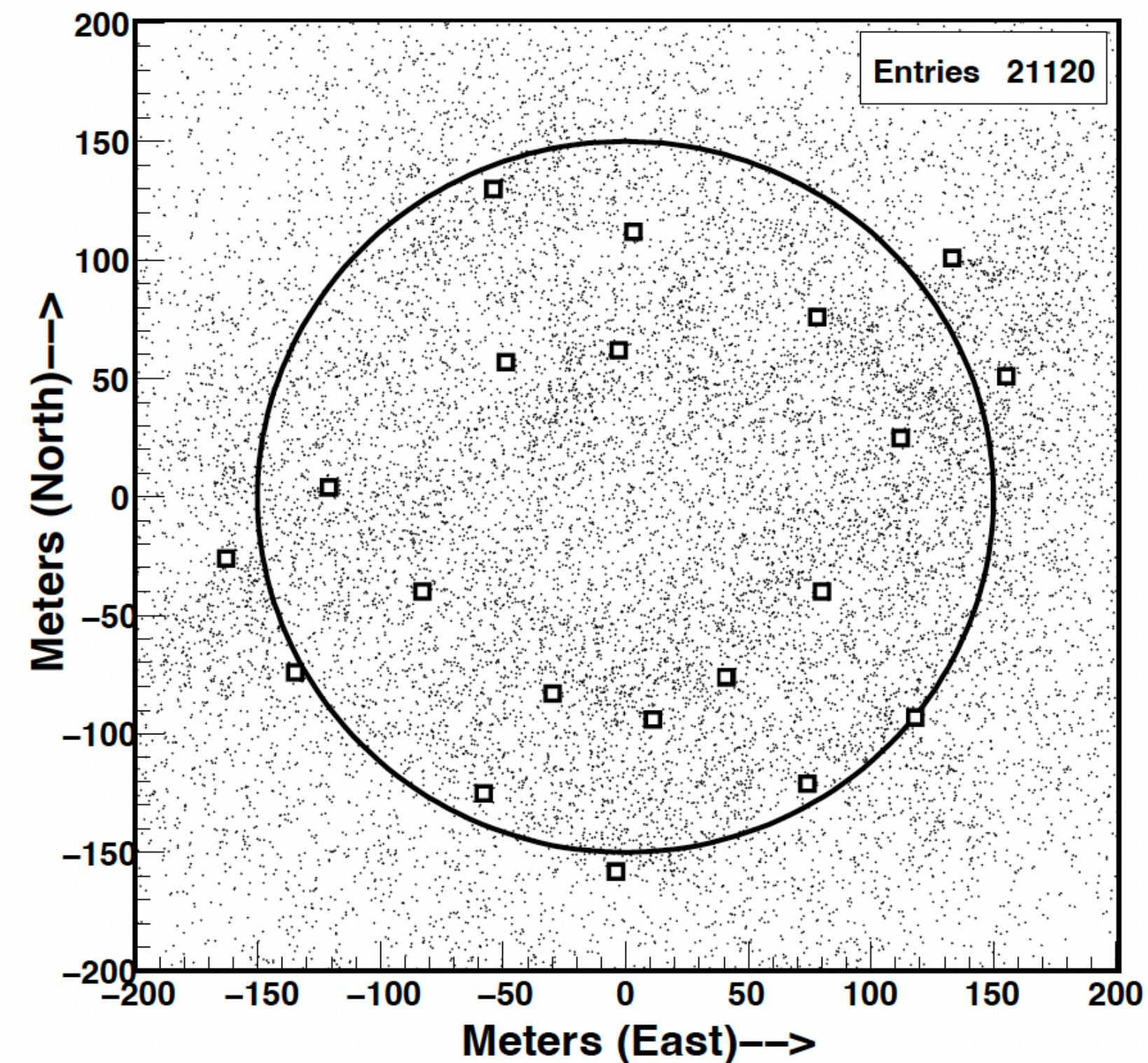
- We mostly want showers $>10^{16.5}$ eV (strong radio signal)
- We want to avoid low energy showers which are 1000s times more numerous

LORA event reconstruction

Single station triggers (once / minute)



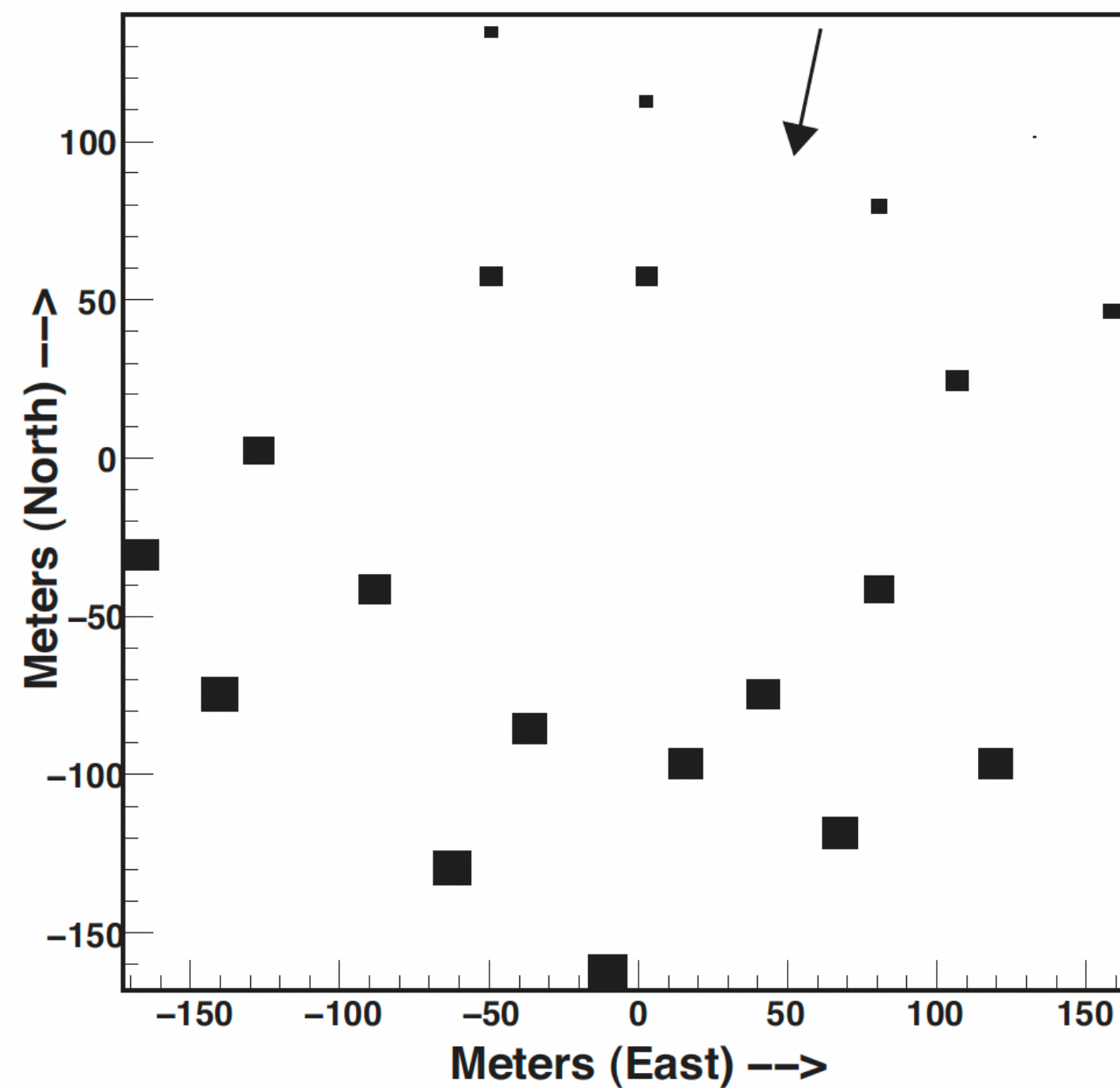
Global trigger (once / hour)



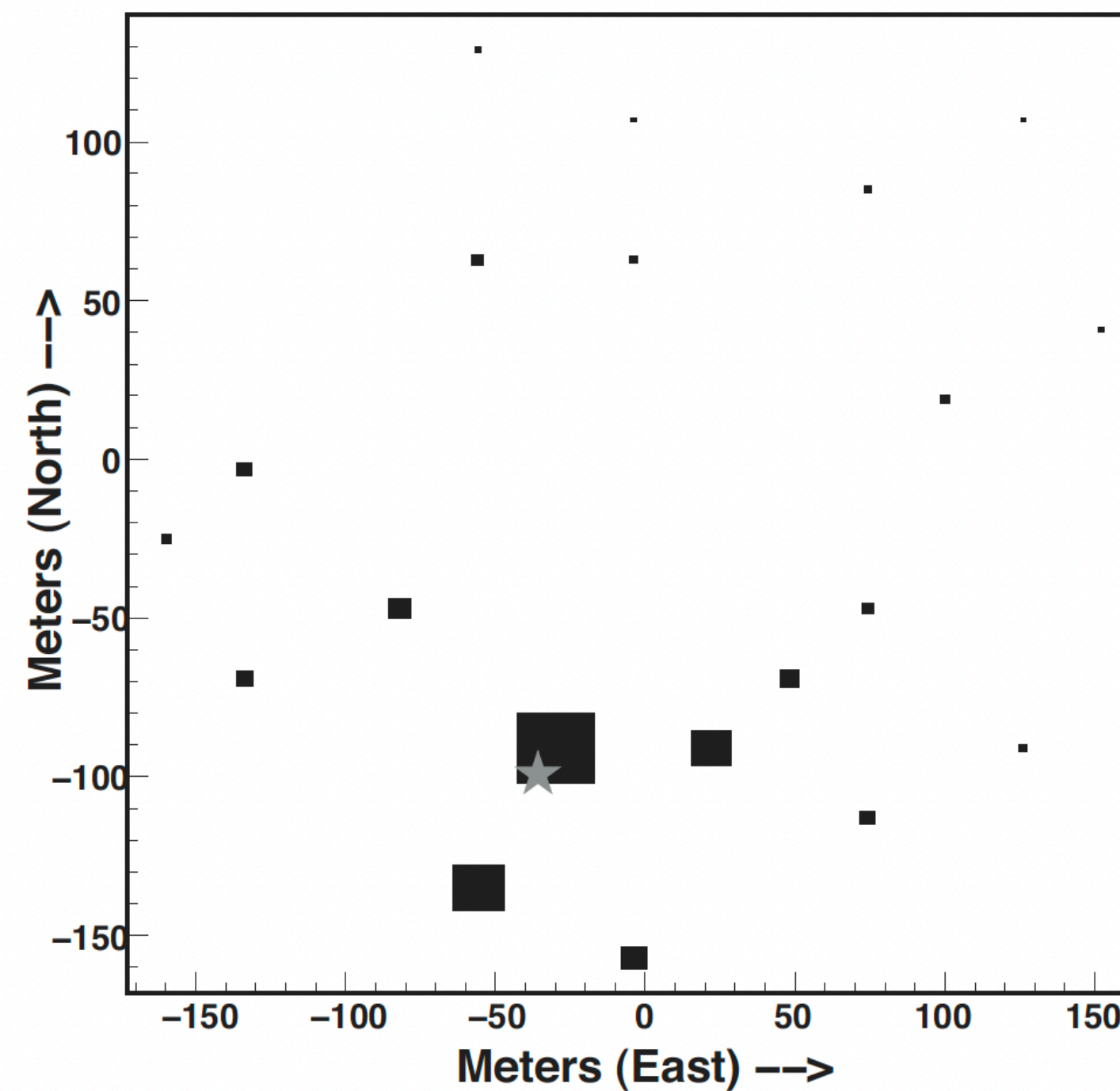
Air shower core position

LORA event reconstruction

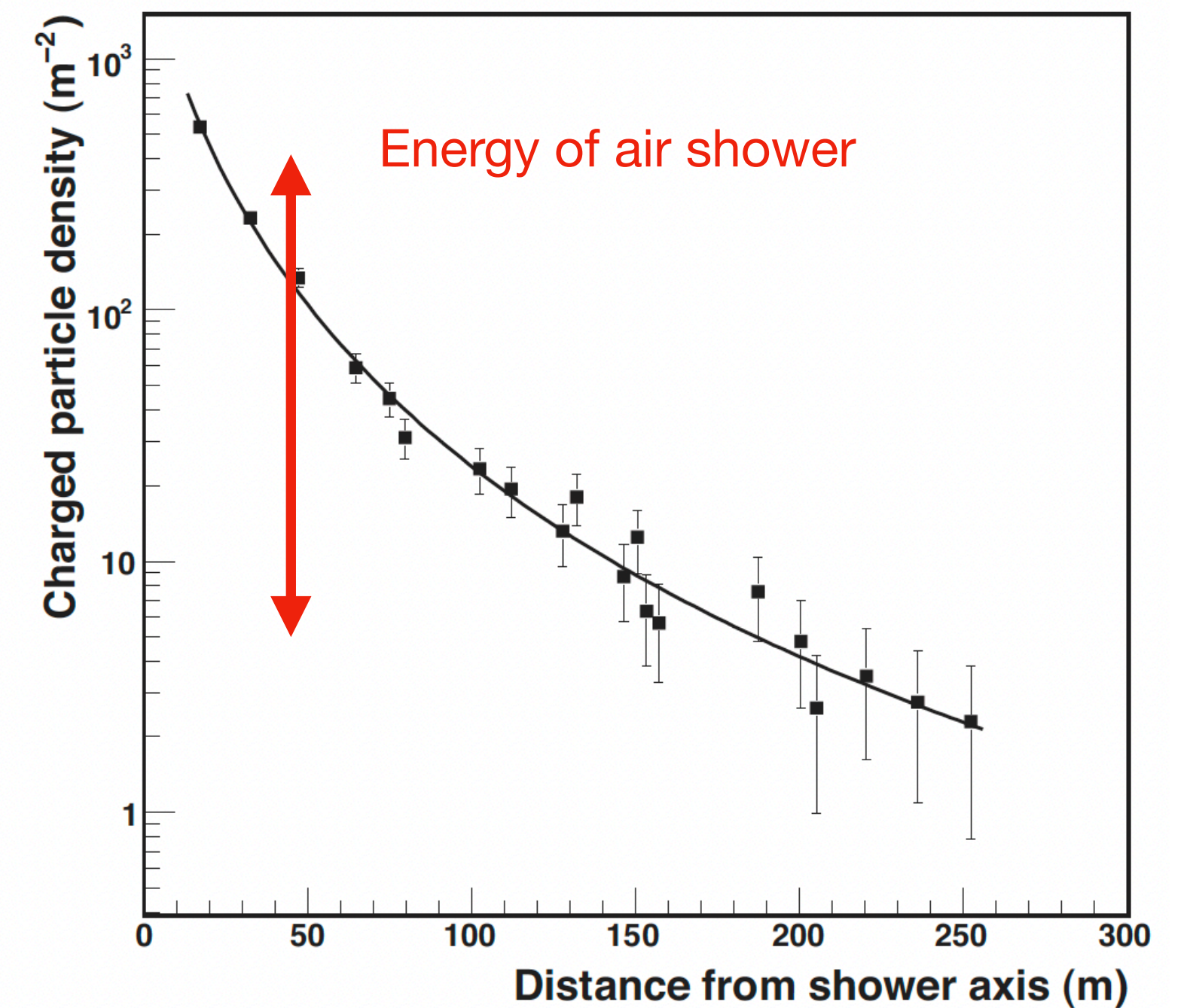
Arrival time : **direction**



Deposited energy



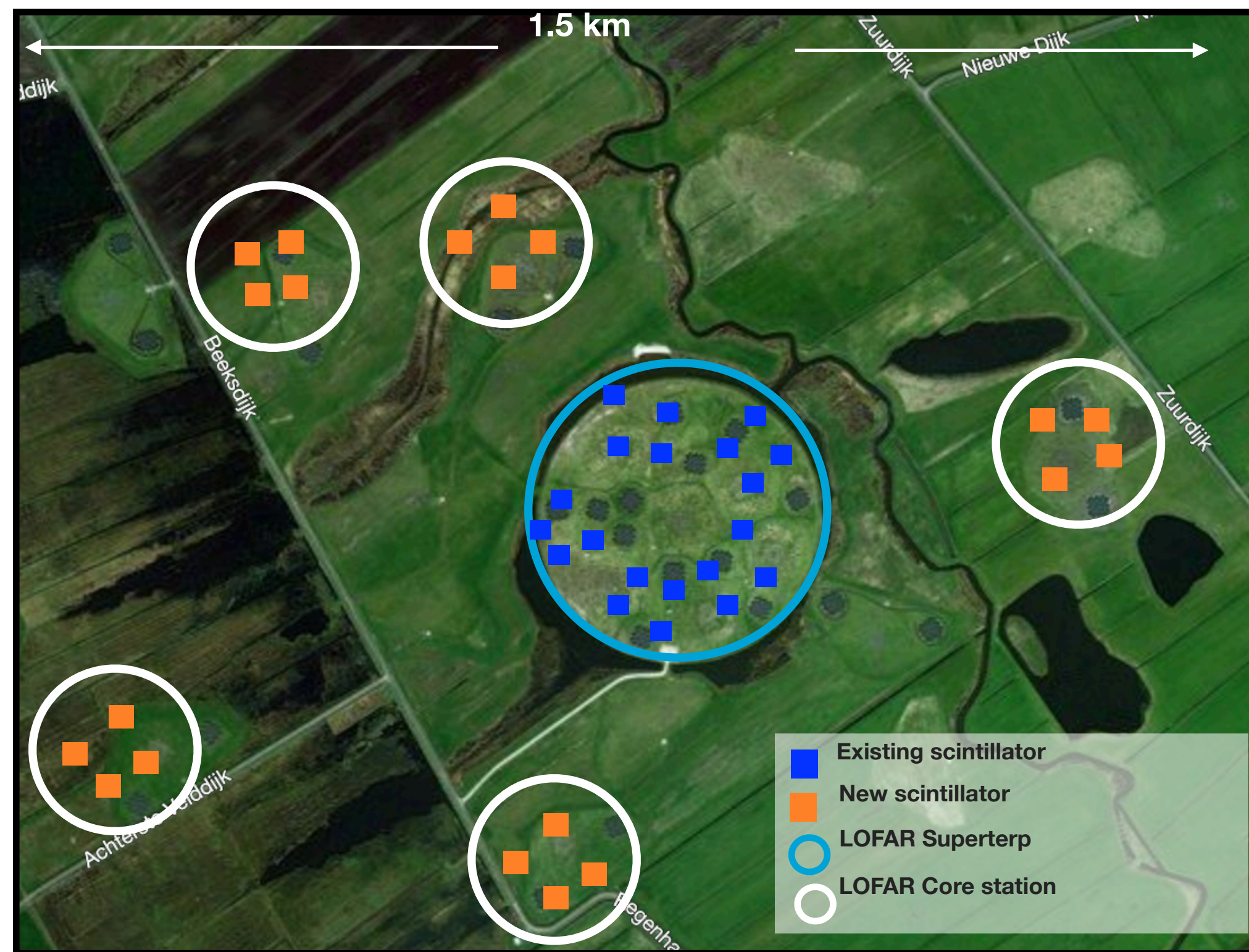
Lateral distribution of particles: **energy, core**



S. Thoudam et al. NIM 2015

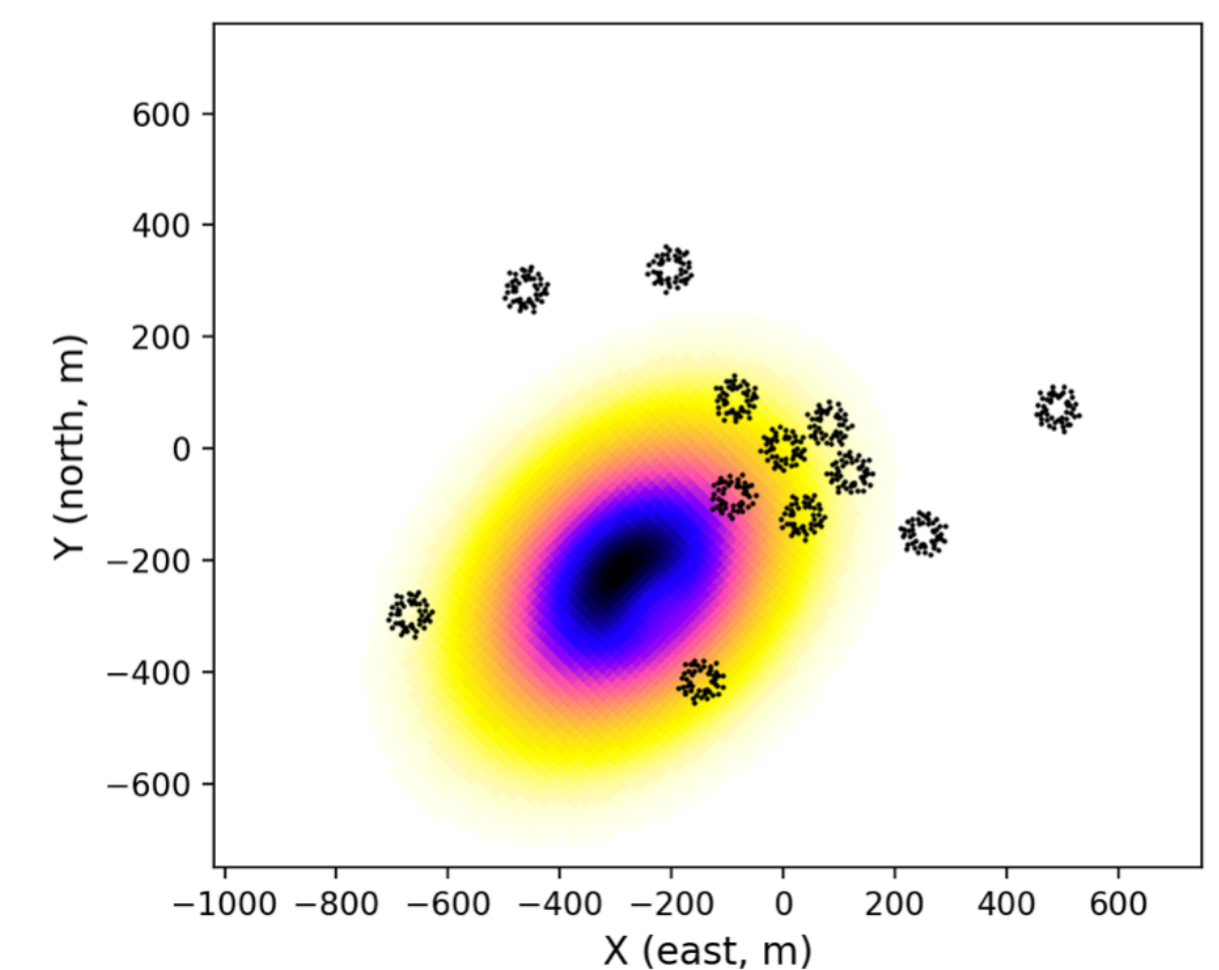
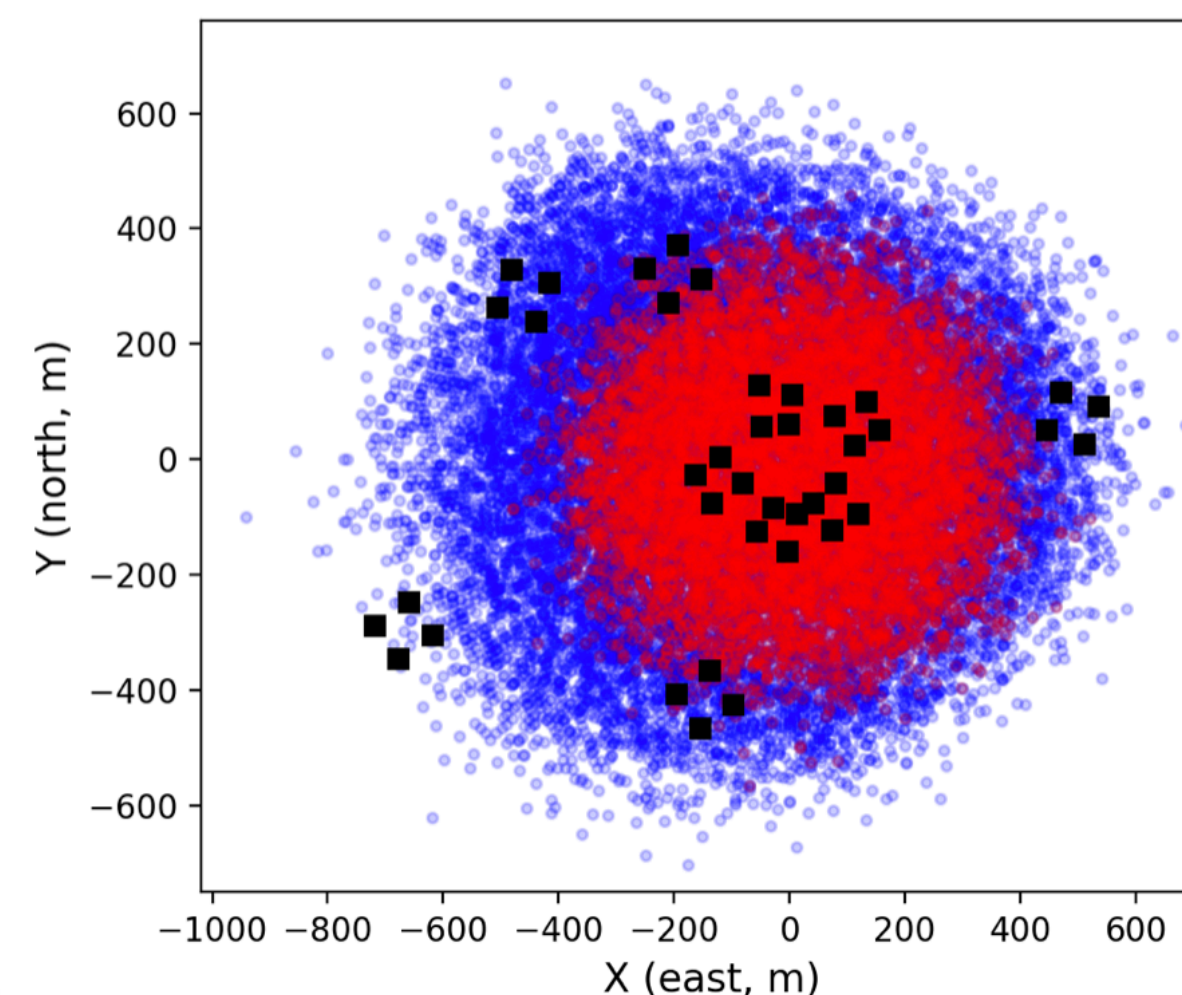
→ Initial guess for radio reconstruction pipeline

LORA Upgrade - 2019



CS001, CS013, CS017, CS021, CS032

- Added 20 more particle detectors to surrounding stations- allows us to trigger on more optimal events
- New electronics with more sustainable parts
- Detector calibration
- Rewritten central station software - flexible triggering
- In-field calibration - better event construction



LORA Upgrade - 2019

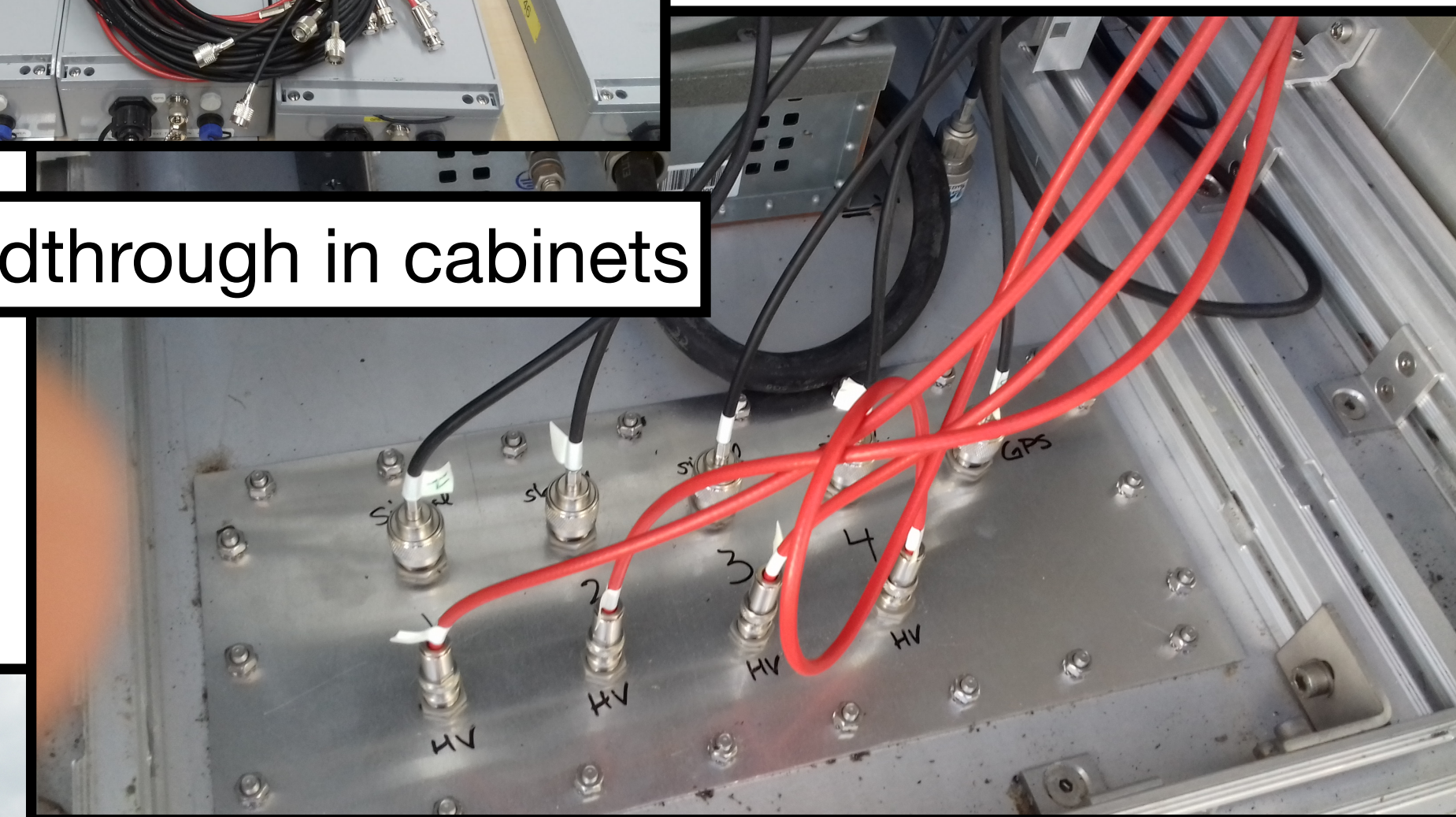


Coax cables for signal and HV

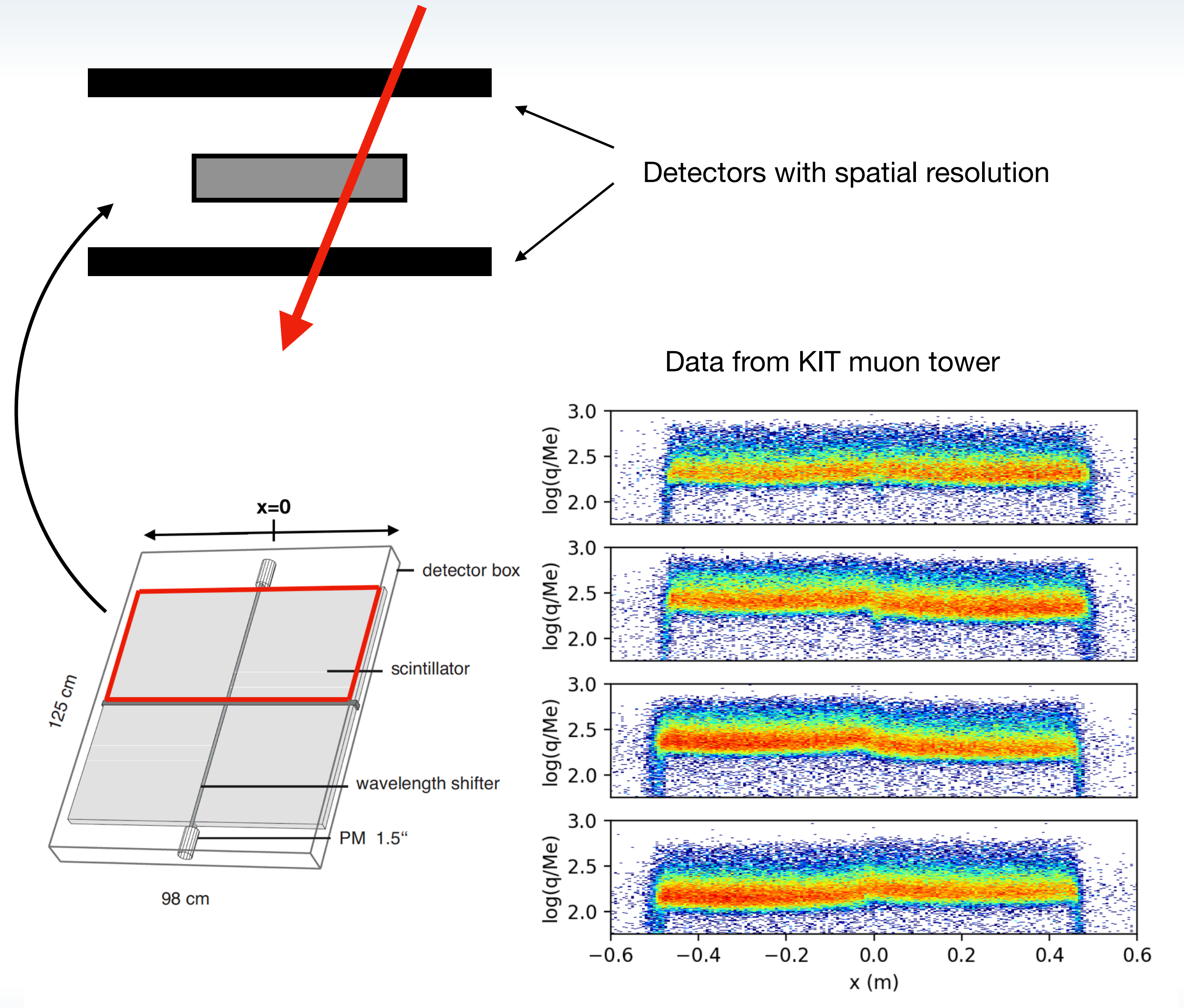
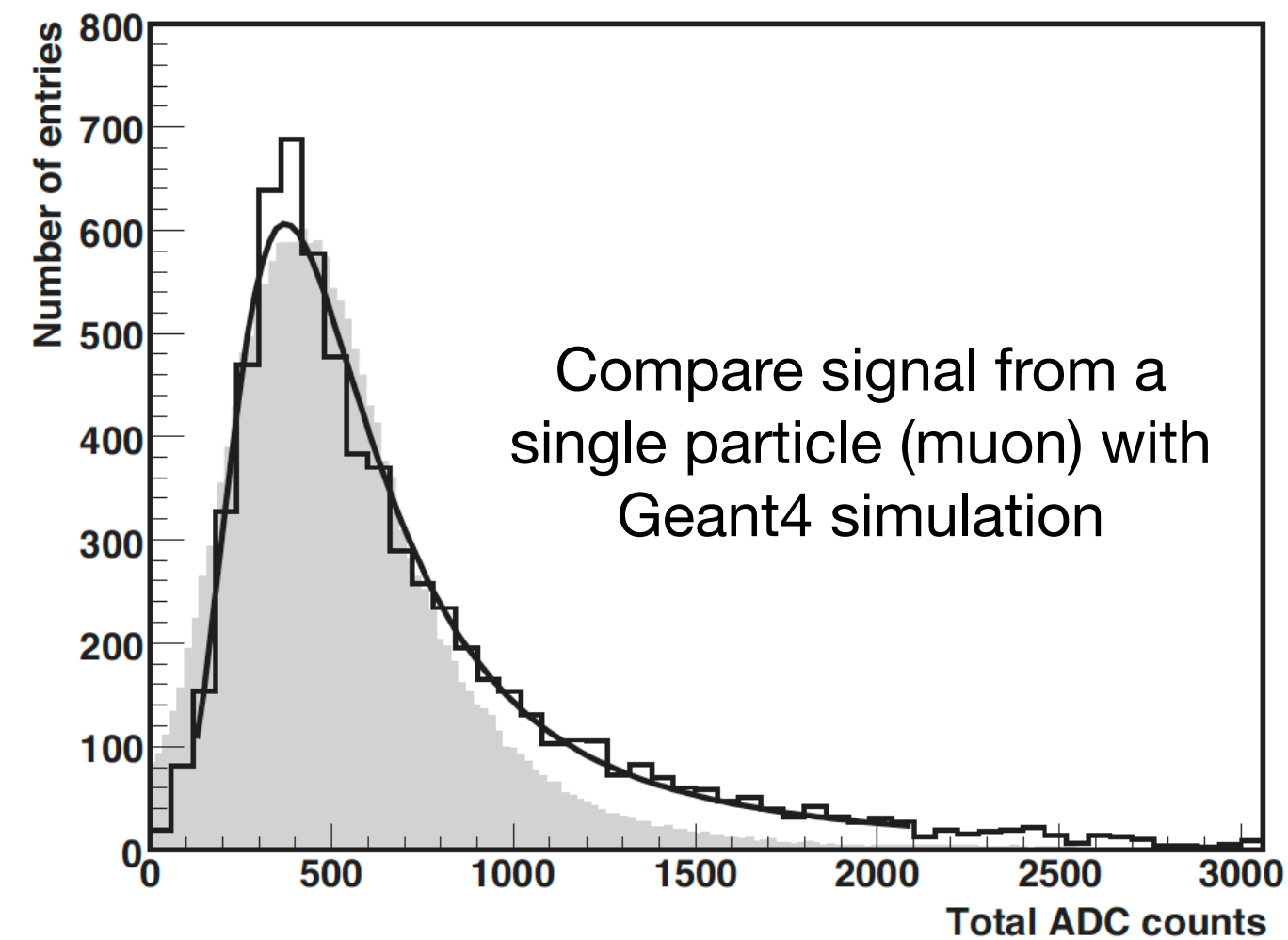
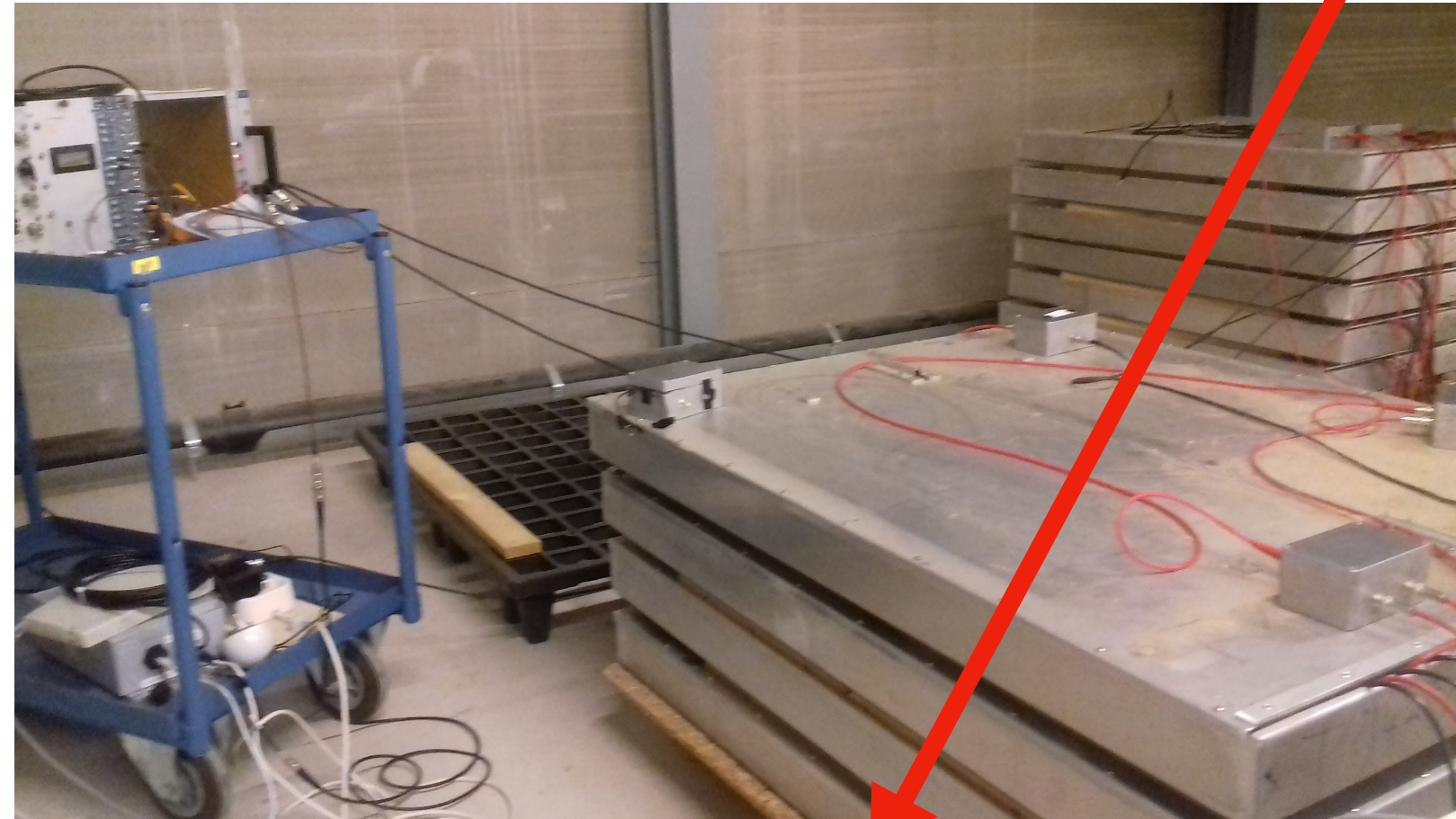


New digitizers

Cable feedthrough in cabinets

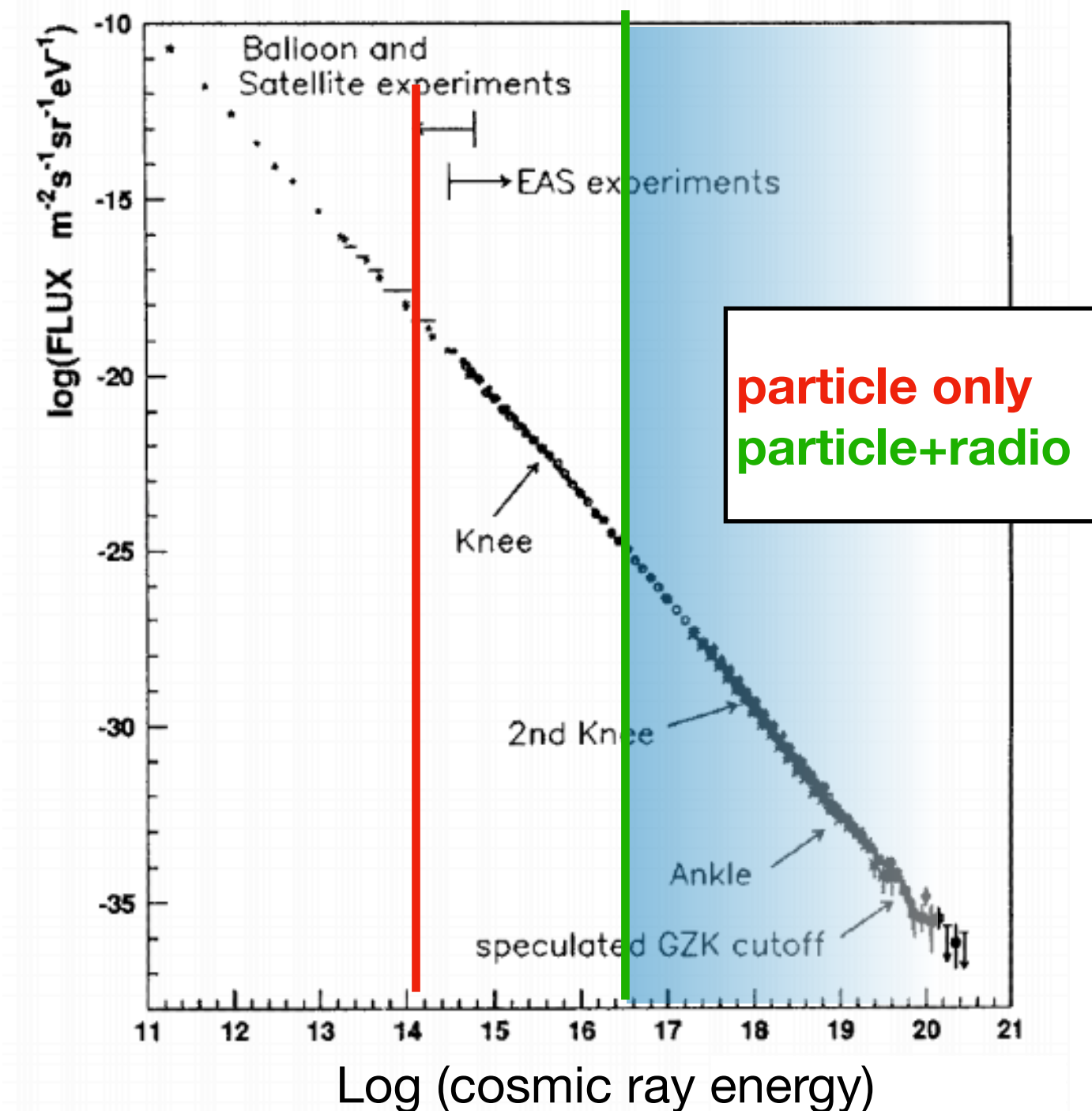
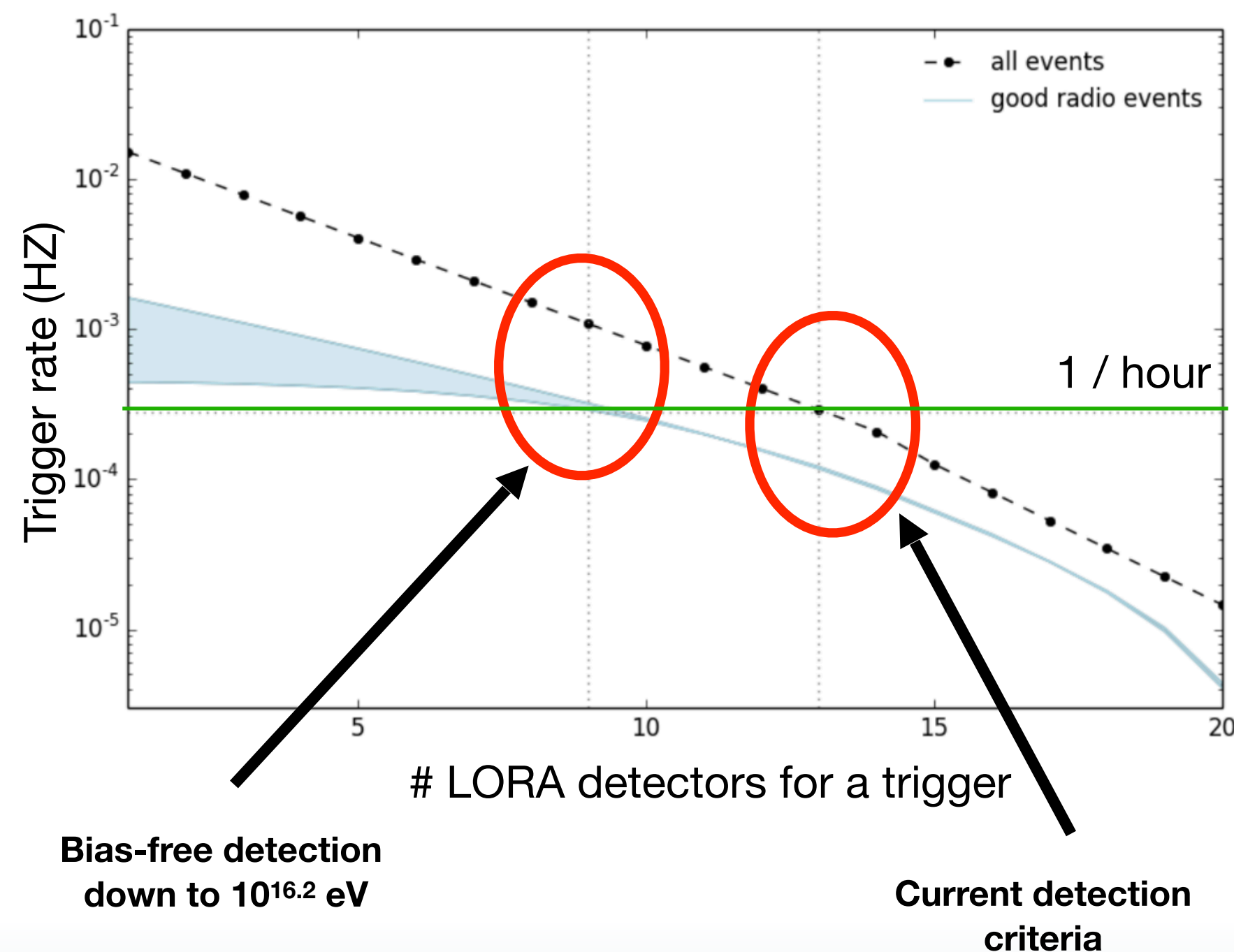


LORA Upgrade - Calibration

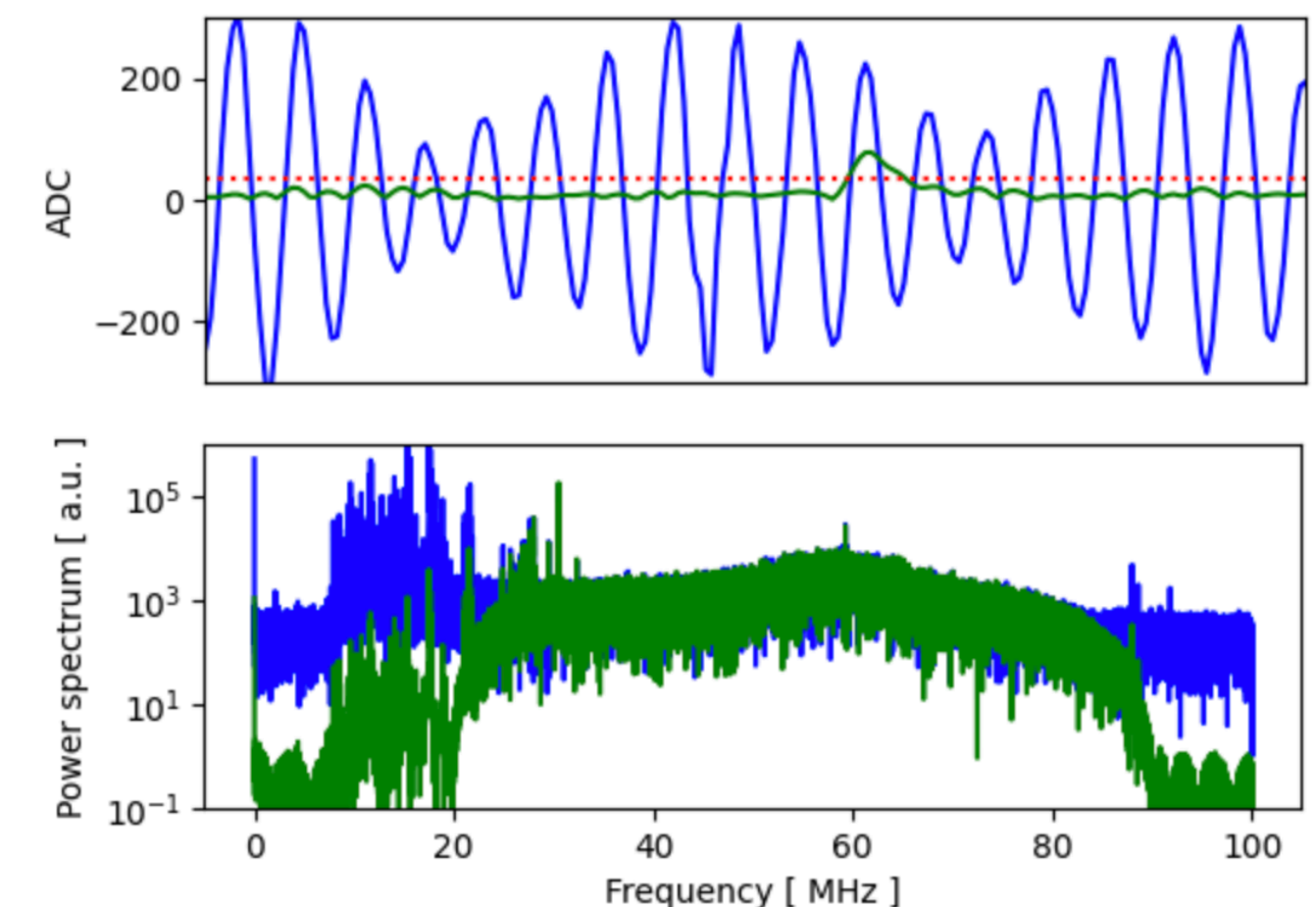


Potential extensions - hybrid trigger

- Radio only triggering is difficult due to RFI, particle detector ensures a cosmic-ray event
- We want to go to lower energies, but we have to keep the trigger threshold high enough not to overwhelm the system, only trigger on usable radio events
- Relaxed particle detector trigger + radio information = ideal trigger conditions

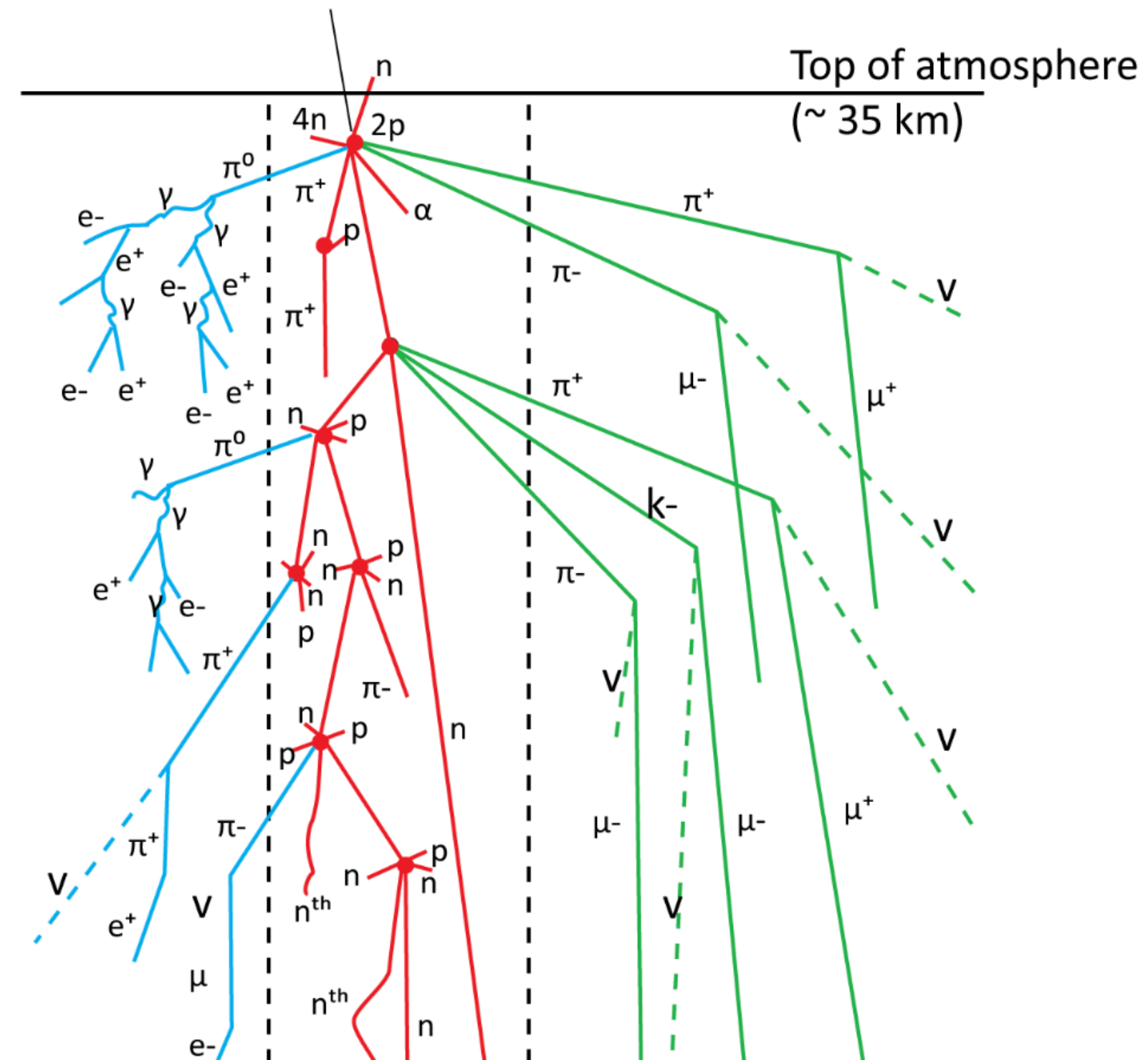
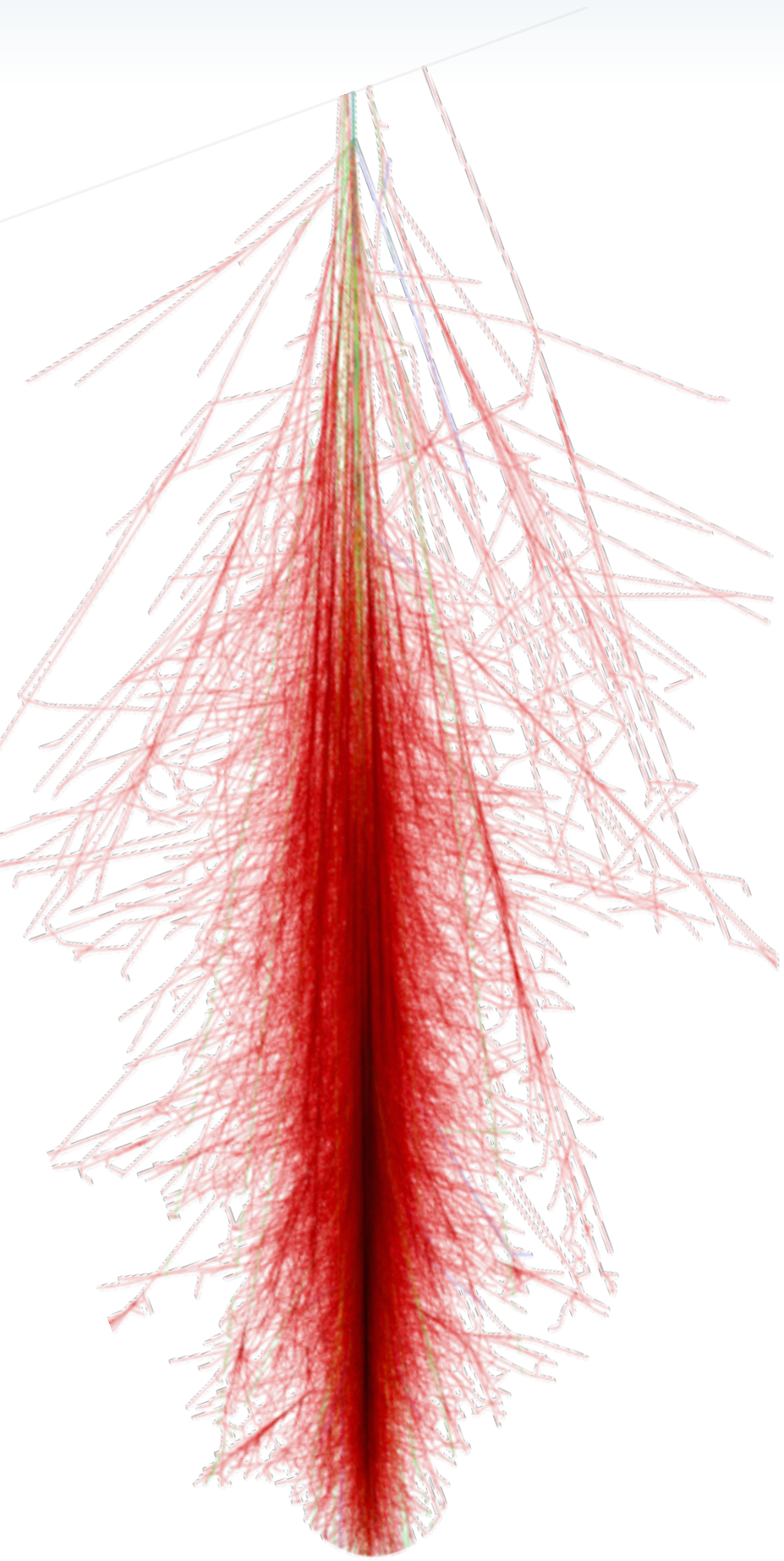


online firmware trigger

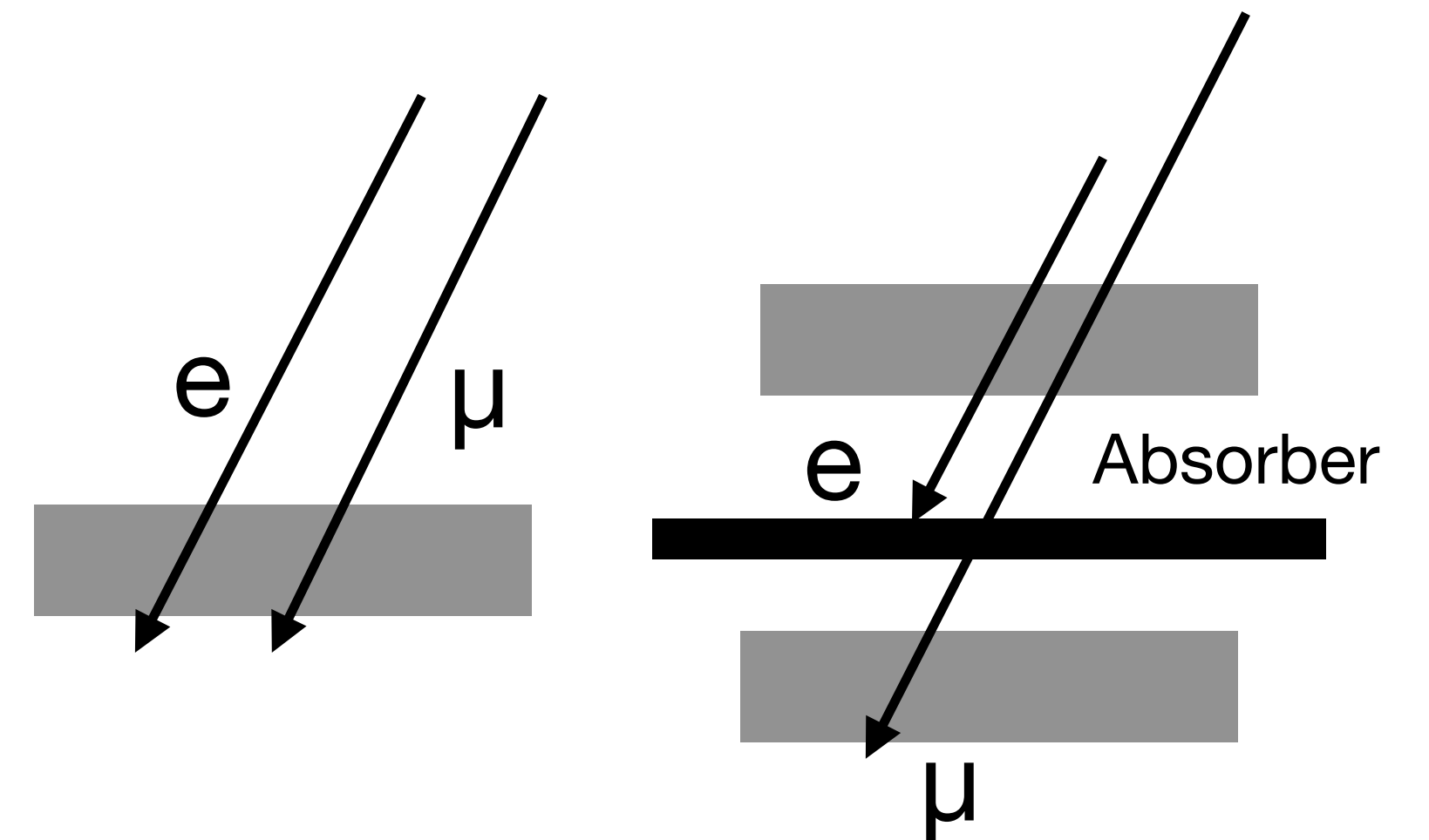


- ✓ Cosmic ray
- ✓ RFI rejection
- ✓ Good signal
- ✓ Reduced bias

Potential extensions - particle separation?



- Muon / electron separation important for serious event reconstruction with particle detectors
- Information about hadronic interaction models



Questions?

