A radio air shower array at South Pole

Sebastian Böser
on behalf of the radio air shower group

Cosmic ray Workshop

Zeuthen

February, 24th 2010

Overview

Motivation

- Composition
- Veto for IceCube
- UHE gammas

Design

- Layout
- Trigger and data flow

Roadmap

- 4-year-plan

Simulation I

- LOPES based

Simulation II

- REAS1 based

Simulation III (J. Auffenberg)

- full shower simulation

Discussion item

- fast(er) simulation

sboeser@physik.uni-bonn.de

Motivation

universitätbonn

IceCube

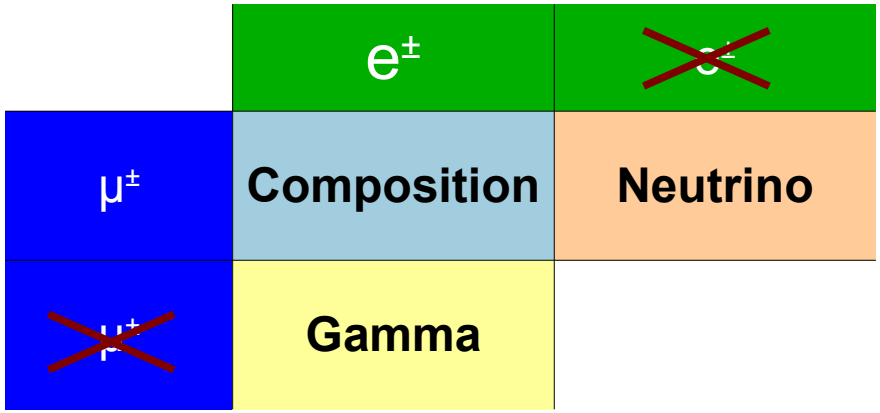
- measures muons (above ~TeV) in the ice

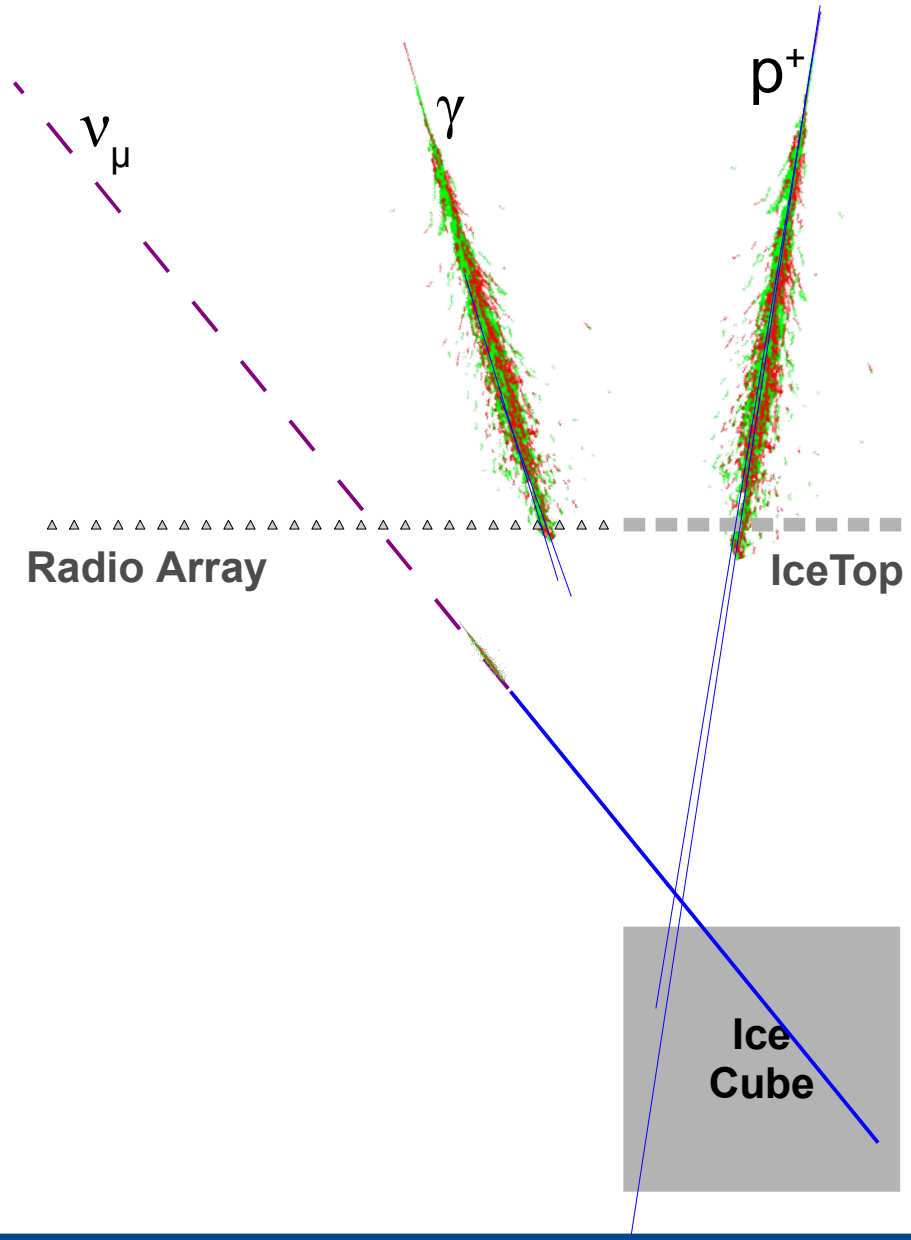
IceTop

- measures electron and muon population on the ground

Radio array

- measures total electron component (muon contribution negligible)





sboeser@physik.uni-bonn.de

Motivation: Composition

universitätbonn

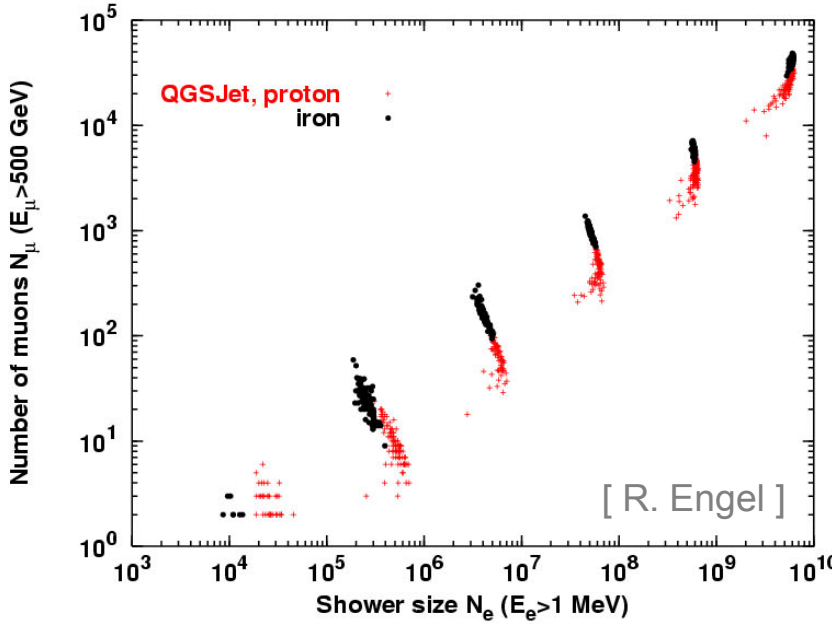
Composition measurement

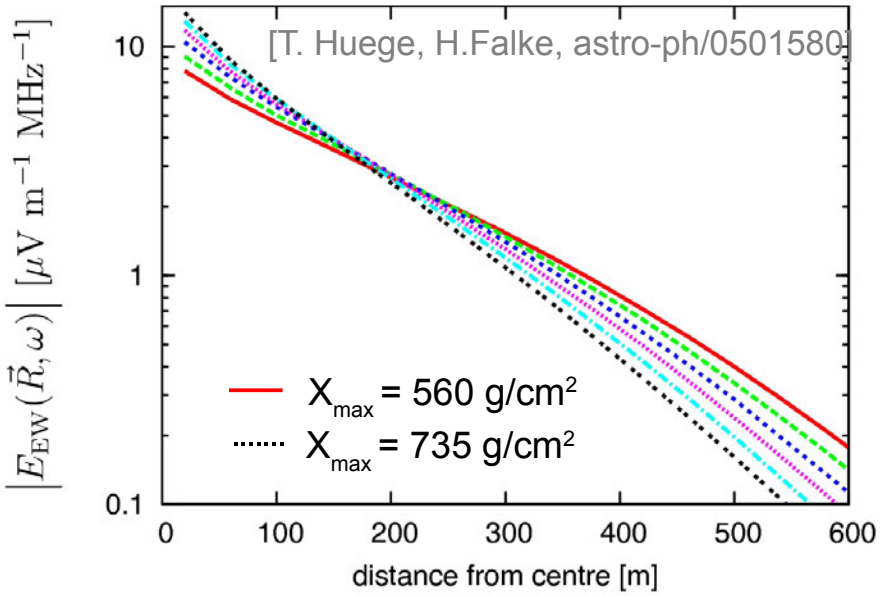
① from e-to-μ ratio

- heavy nuclei
  ➔ enhanced muon component
- IceTop: μ -Component
- IceCube: μ+e -Component
- Radio signal:
  - synchrotron emission ~ m^{-4}
    ➔ only e -Component

② from radial distribution

- steepness depends on distance to shower maximum
- will be enhanced at IceCube height (at ~750 g/cm²)





sboeser@physik.uni-bonn.de

Motivation: Neutrinos

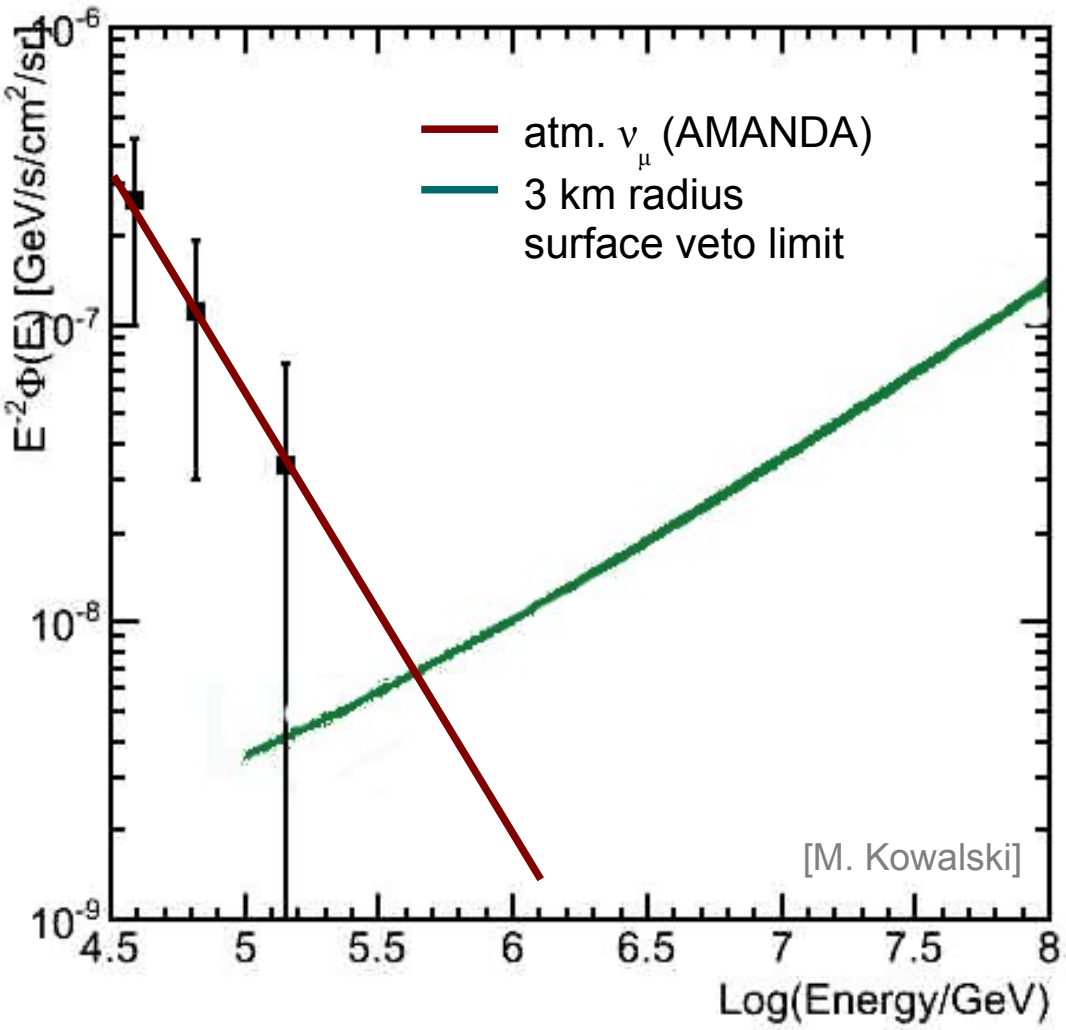
universitätbonn

Neutrino detection

- Provide a veto for air-showers above IceCube
  - ➔ increase the effective neutrino volume
- Provide a veto for an in-ice GZK radio array

Event rate estimate

- Assume E^{-2} spectrum
- 3 km radius of surface veto
- Calculate limit for one event per decade
  - ➔ need effective veto at ~ PeV energies



sboeser@physik.uni-bonn.de

Motivation: Gamma rays

Idea

- search for muon-poor showers

photon induced showers

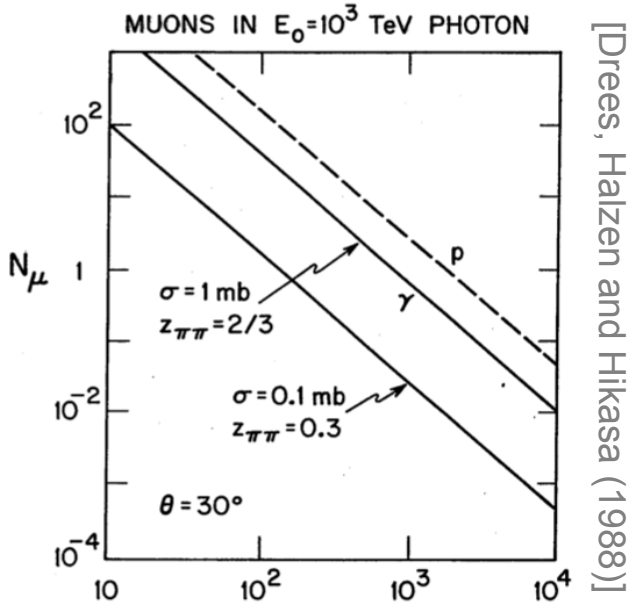
- contain 100x fewer energetic muons

➔ can be detected in radio array

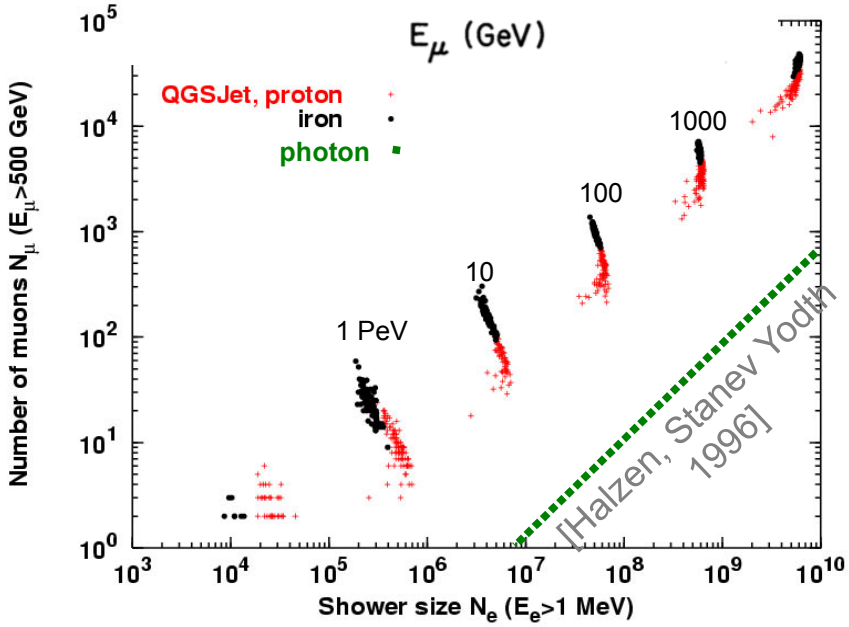
hadron induces showers

- will always contain some TeV muons
- will be detected in IceCube

➔ use as veto



[Drees, Halzen and Hikasa (1988)]



sboeser@physik.uni-bonn.de

Motivation: Gamma sources

PeV photon sky ➔ largely unexplored

Extragalactic sources

- shielded by CMB absorption

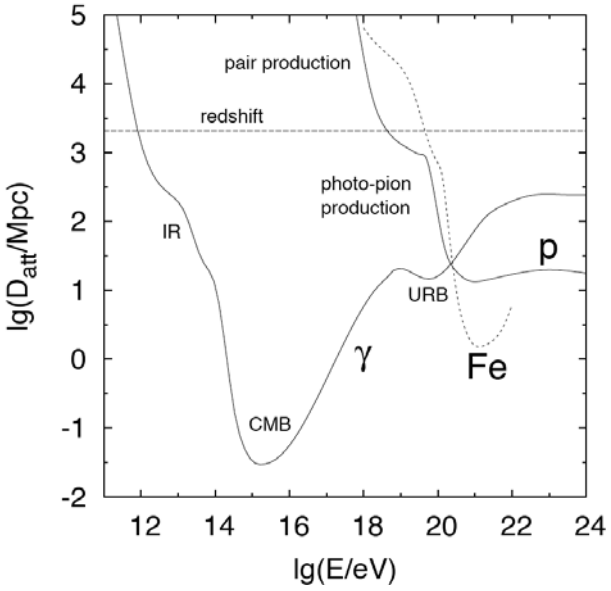
Galactic sources

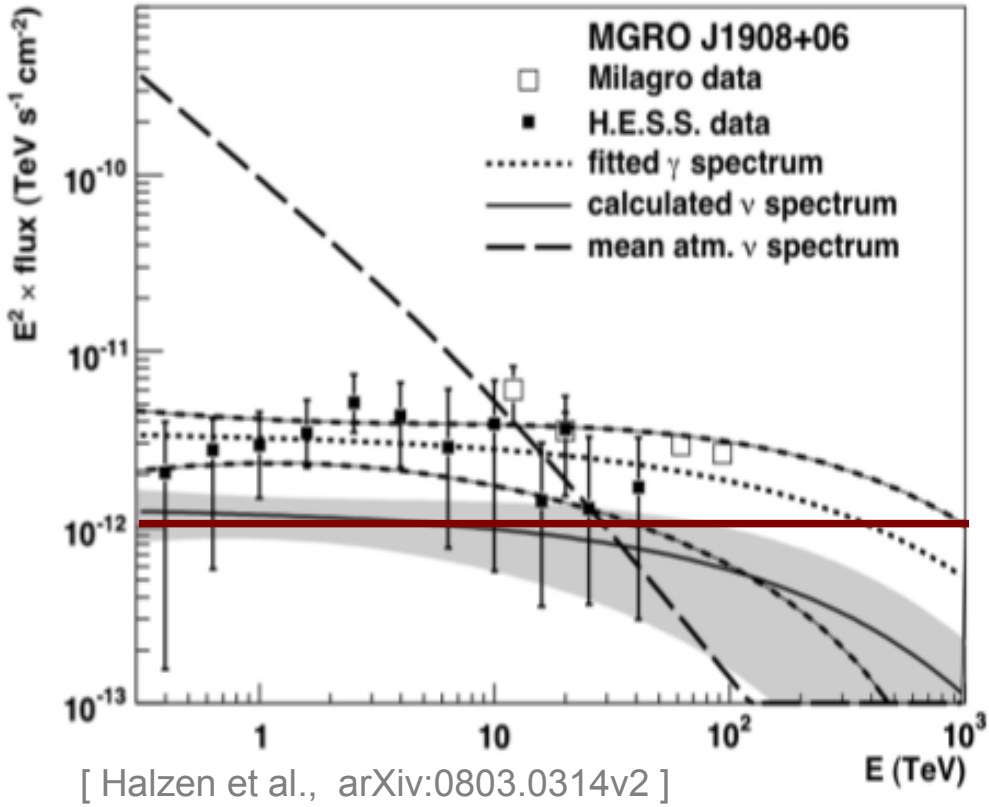
- Pevatron accelerators detected by Milagro

  ➔ no sign of cutoff

- at 10^{-12} TeV^{-1} s^{-1} cm^{-2}

  ➔ 30 events/year/km^2



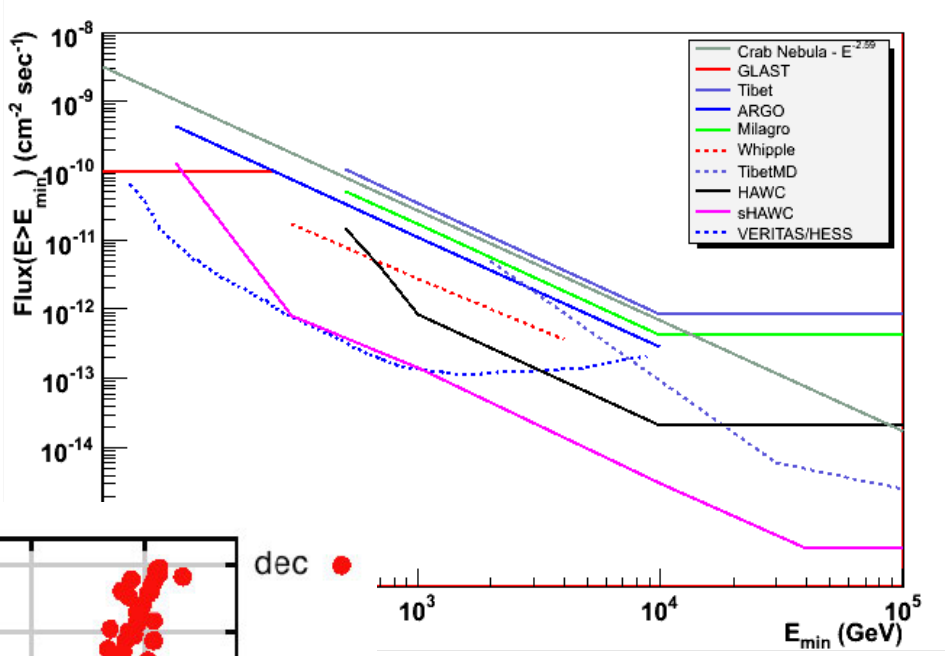


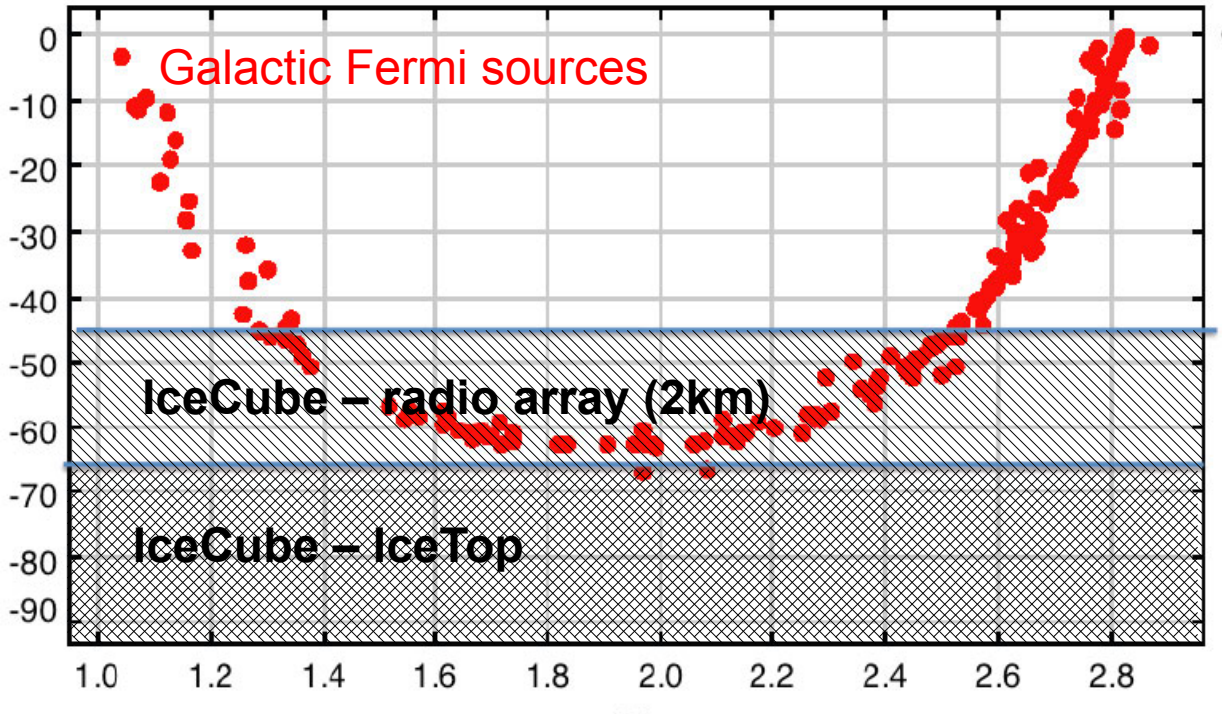
[Halzen et al., arXiv:0803.0314v2]

sboeser@physik.uni-bonn.de

Motivation: Gamma sources

Experiment	A_{eff} [m^2]	FoV [sr]
Milagro	4 x 10^3	2π
HAWC	4 x 10^4	2π
Radio array	> 10^6	> 0.7





IceTop – IceCube:

- cover 25° from vertical

Radio array – IceCube:

- at 2km extension

  ➔ cover 45° from vertical

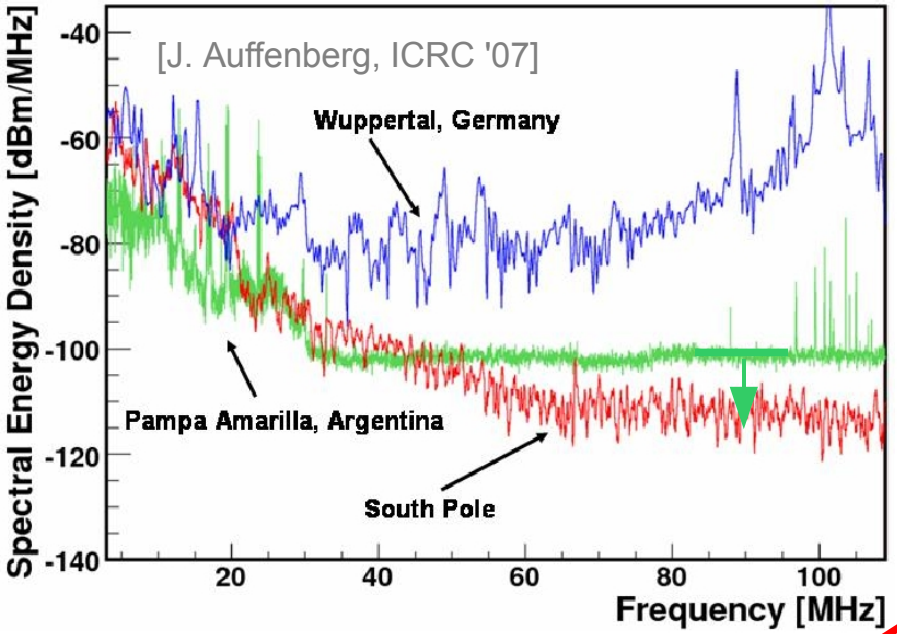
sboeser@physik.uni-bonn.de

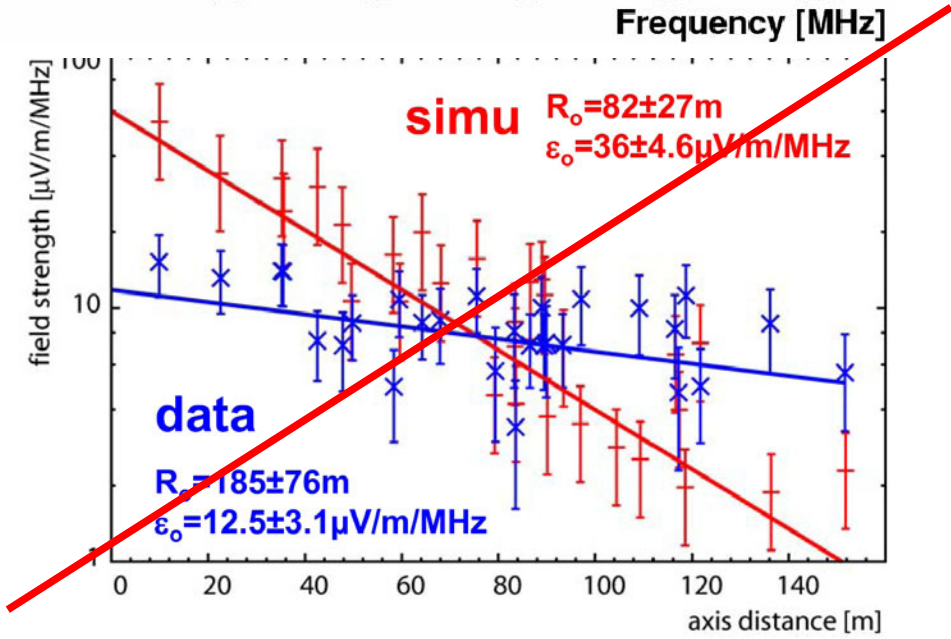
Motivation: Air-shower radio physics

universitätbonn

South pole site

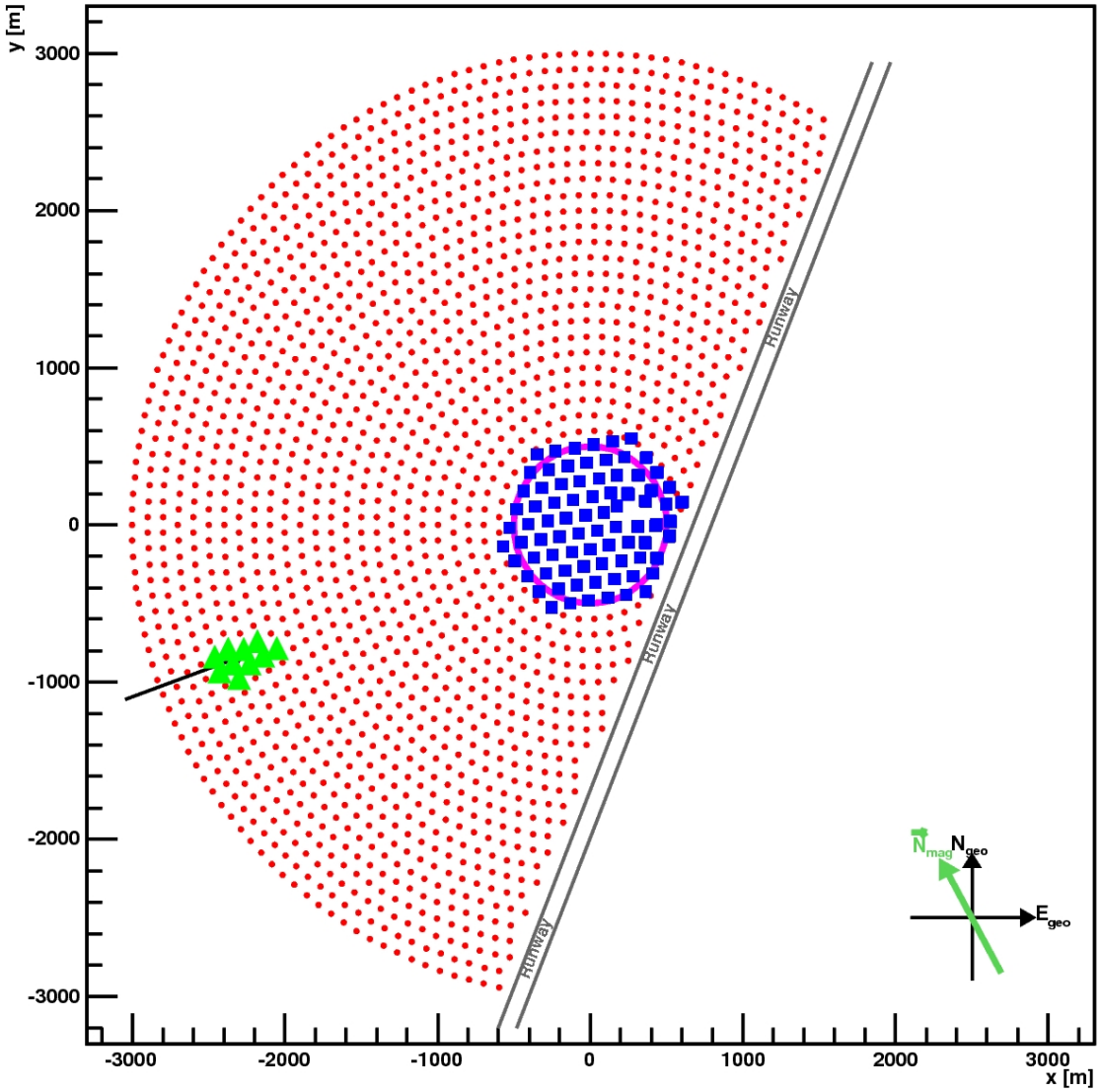
- unique in radio quietness
- unique in elevation
  - may shed light on "lateral distribution" problem
    ➔ solved by REAS3
- unique in radio impedance
  - stable ground conditions
  - firn ice is "radio-transparent"
    - negligible absorption
    - low reflection
- unique in weather conditions
  - no lightening
  - no rain





sboeser@physik.uni-bonn.de

Test layout



Magnetic field

- -72.5° inclination (upwards)
- -29.2° declination

Constraints

- IceCube side of runway
- not inside IceTop
  - blind spot
  - radio noise?
- 3km radius

Default configuration

- 1303 sensors
- 109.1 m sensor spacing

sboeser@physik.uni-bonn.de

DAQ & Computing

Input assumptions

- Sampling: f_{sample} = 500 MHz, w_{sample}=16bit
- Array: d = 6km, $N_{Antennas}=10^3$
- Event rate: R = Ø(10) Hz

Networking requirements

- cross-array time t_{cross} = c·d = 20 μs
- event size $s_{event}= t_{cross}\cdot f_{sample}\cdot w_{sample}\cdot N_{Antennas}$ = 20Mbyte (17.3 TB/day)
- total south pole bandwidth: ~45 Gb/day
  - ➔ need online reconstruction / filtering

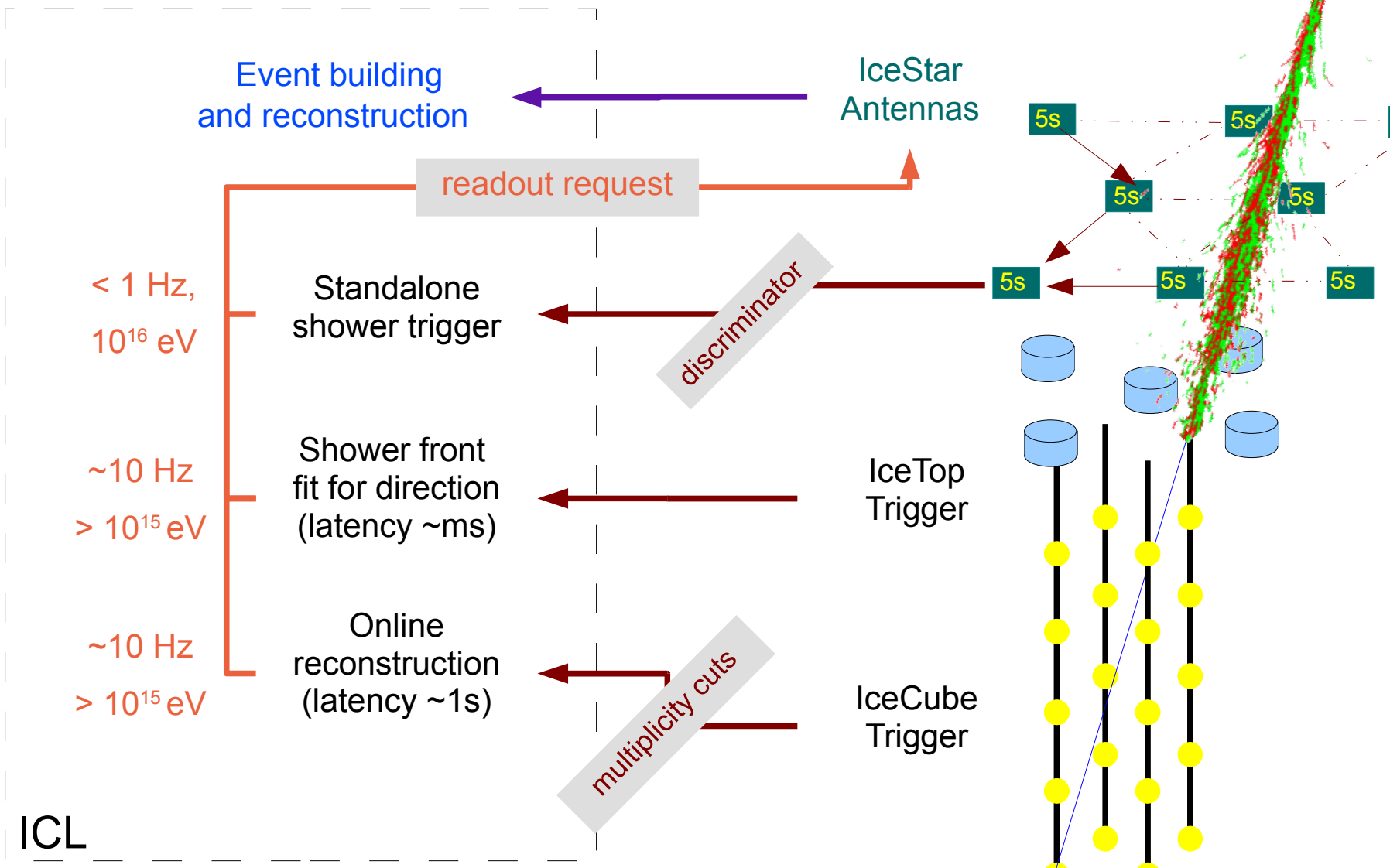
Computing requirements

- calculate N-antenna correlation function
  - N=2, all directions: 5.5 sec·CPU
  - N=1000, all directions: 0.77 hrs·CPU
  - ➔ need a core position and / or direction primer

$$R(\delta t) = \frac{\sum_t V_i(t)V_j(t+\delta t)}{\sqrt{\sum_t V_i(t)}\sqrt{\sum_t V_j(t+\delta t)}}$$

sboeser@physik.uni-bonn.de

Trigger and data flow



sboeser@physik.uni-bonn.de

Roadmap

universitätbonn

2010/2011:

- 6-8 antenna test setup
  - ➔ should be able to see some coincidences with IceTop
- independent DAQ (now using RICE DAQ)
- investigate deployment possibilities (buried antennas ?)

2011/2012:

- "intelligent" antenna development (buffered, local sampling, communication)
- finalize geometry with simulation

2012/2013:

- small scale array to verify
  - Antenna design and reliability
  - (External) triggers
  - DataFlow, CPU scaling

2013/2014:

- deploy full array

sboeser@physik.uni-bonn.de

Simulation I: LOPES parametrisation

universitätbonn

LOPES

- 30 radio antennas
- triggered by KASCADE
- 40-80 MHz bandwidth
- Calculate cross-correlation beam

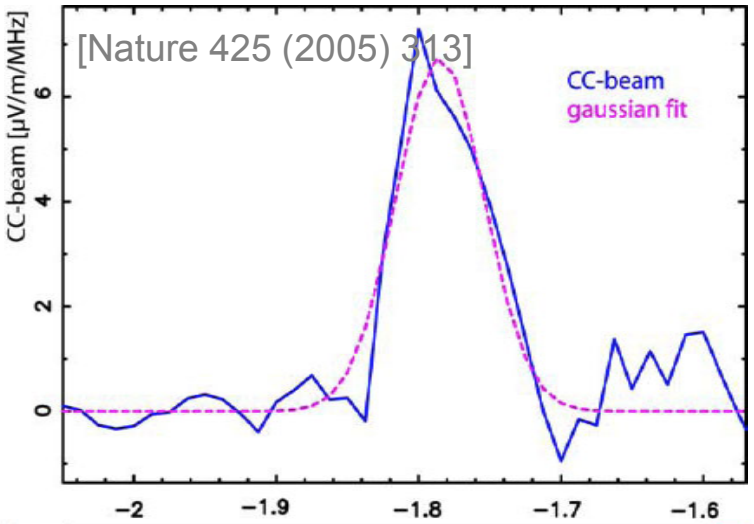
$$cc[t] = \pm\sqrt{\pm\frac{1}{N_{pairs}}\sum_{i}^{N-1}\sum_{j>i}^{N} s_i[t]s_j[t]}$$

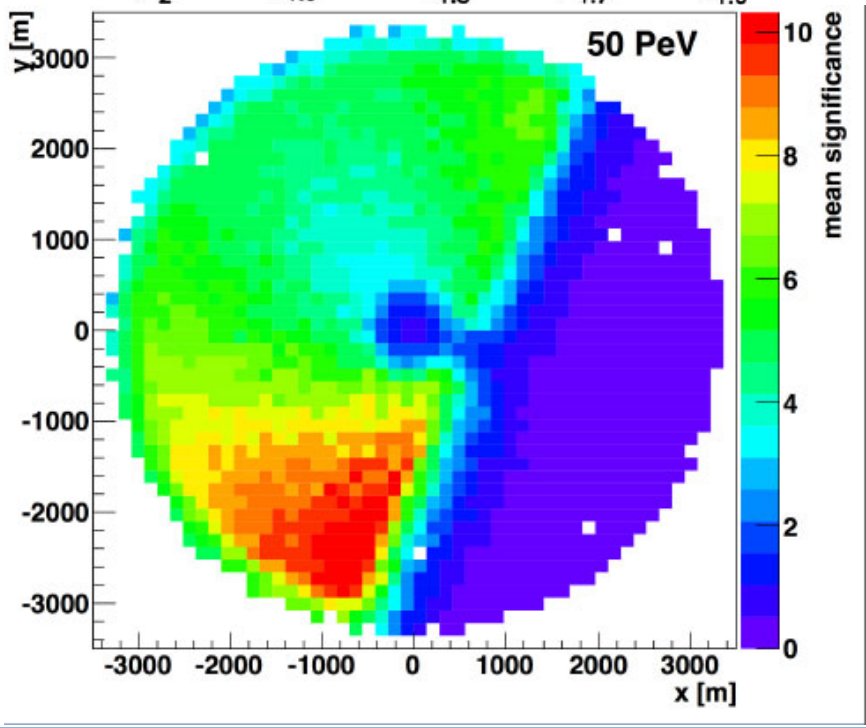
CC-beam parametrisation

$$\varepsilon_{EW} = A(1 + B - \cos\alpha)\cos\theta \; exp\left(-\frac{R}{R_0}\right)\left(\frac{E}{10^{17}eV}\right)^{\gamma}$$

Problems

- not compensated for antenna
  - ➔ **wrong angular description**
- no pulse shapes





sboeser@physik.uni-bonn.de

Simulation II: REAS1 parametrization

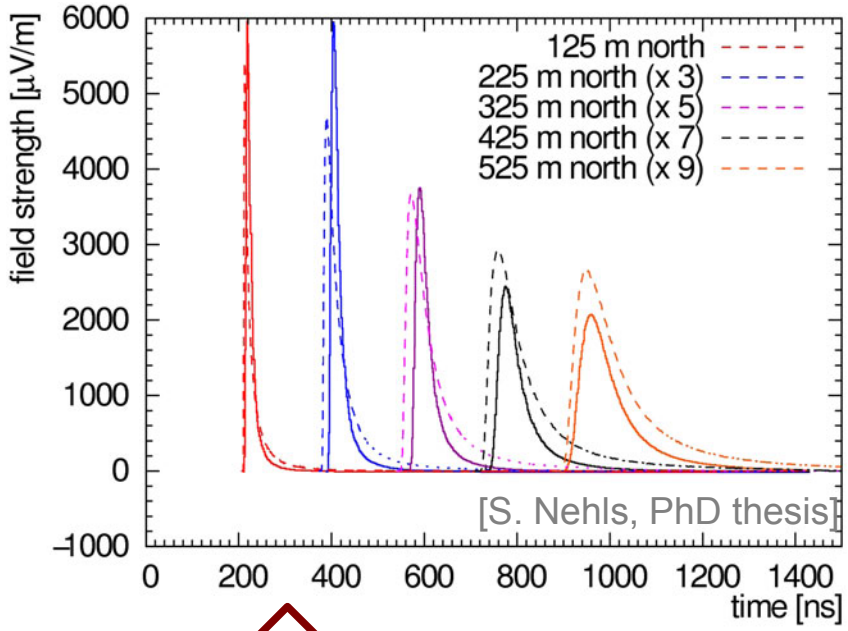
REAS1 [T. Huege, H.Falke, astro-ph/0501580]

- analytic parametrization of frequency spectrum based on parametrized showers

Time-domain information

- use landau template
- scale fourier transform to fit parametrization

  ➔ good agreement with full simulation



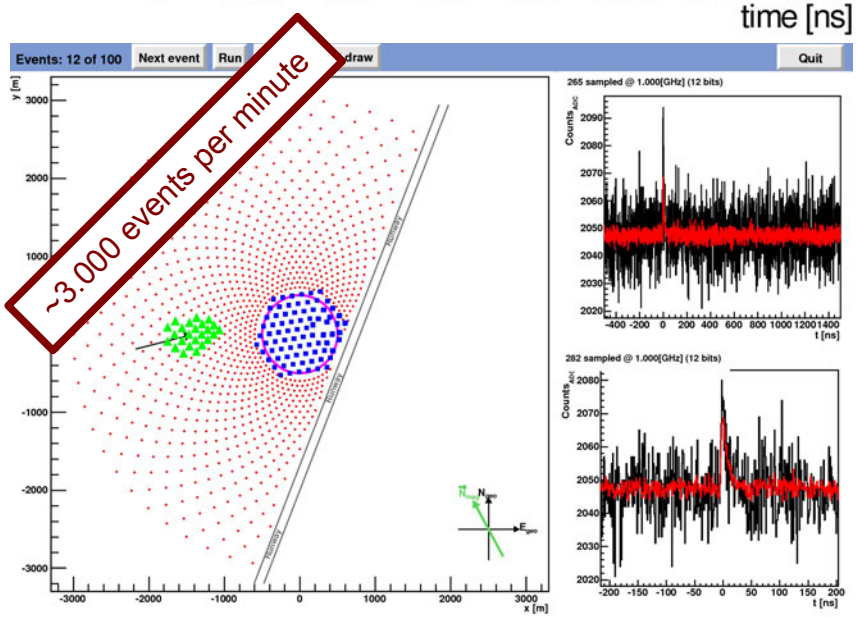
New parameters

- sampling frequency
- # of antennas
- ADC bits, range, etc.
- noise spectrum (not yet used)

Applicability

- not recommended by author

  ➔ use **only** to establish scale factors



sboeser@physik.uni-bonn.de

Veto potential

universitätbonn

Final strategy

① Calculate significance using LOPES parametrisation

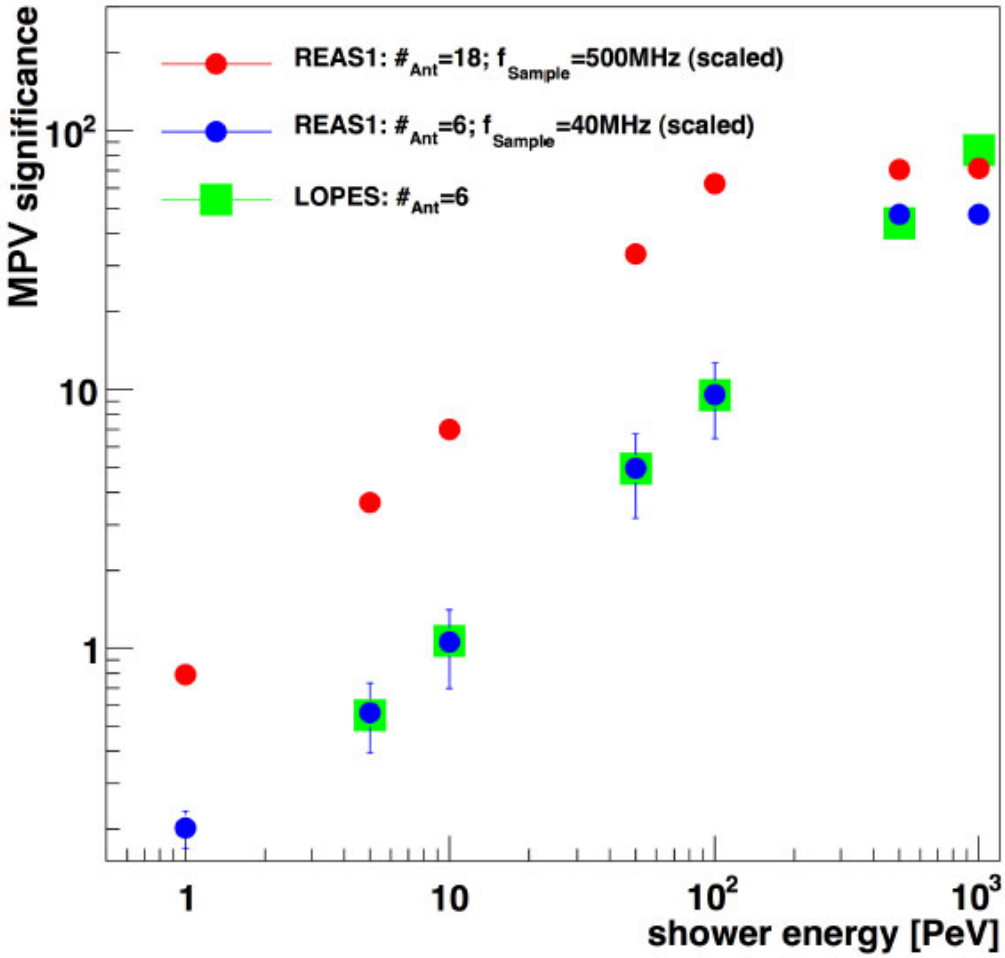
② Calculate significance using REAS1 parametrisation and

- LOPES configuration
- proposed configuration

③ Scale REAS1 results to match LOPES parametrisation

Results

- Higher sampling frequency
  ➔ increase by a factor of 10
- Strongly affected by implied LOPES antenna features



➔ We need a simulation that describes our Antennas

sboeser@physik.uni-bonn.de

Simulation III: REAS2 – Jan Auffenberg

universitätbonn

REAS2

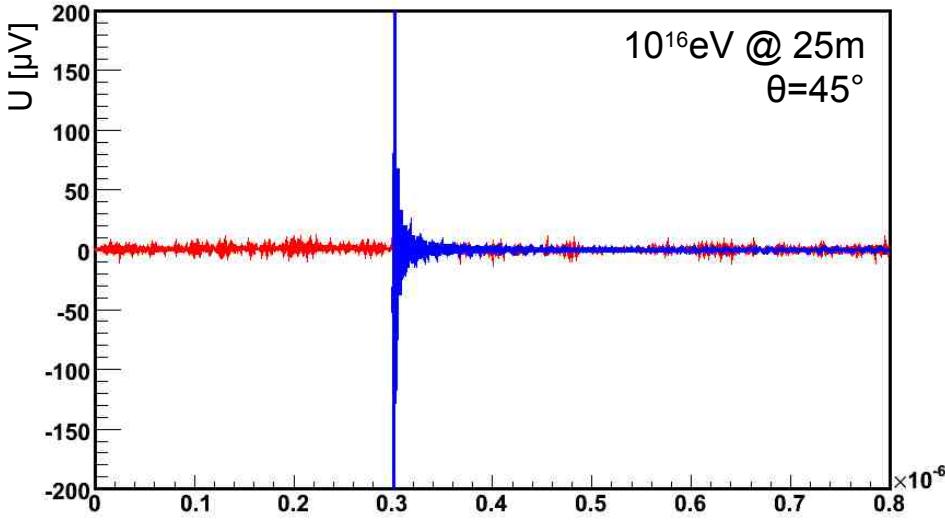
- full air shower simulation (CORSIKA)
- trace every particle and calculate radio emission
- very slow (Ø(hrs) per event)

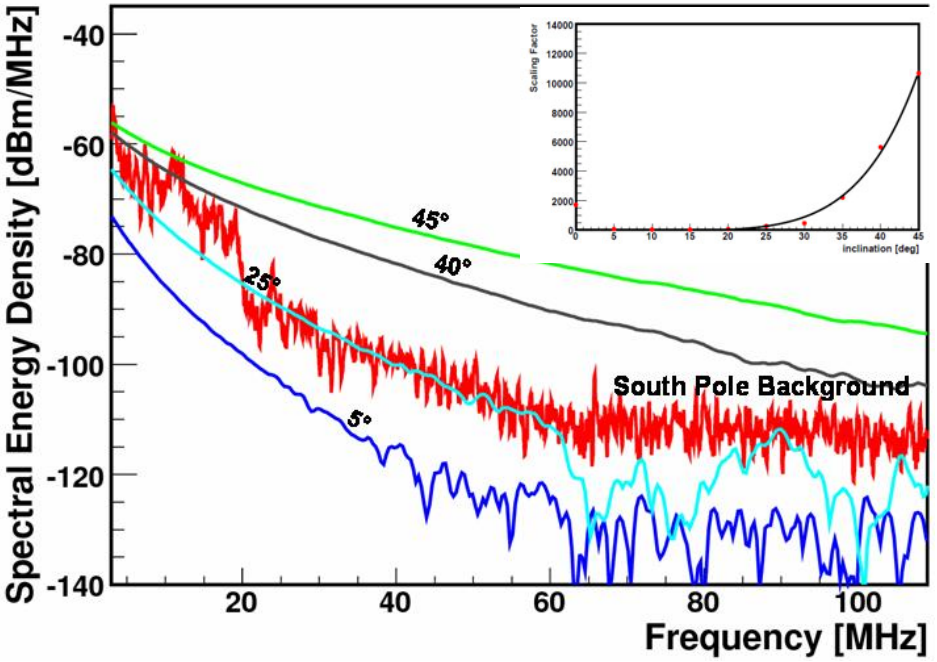
Dataset

- few events at
  - PeV – EeV energies
  - 5° – 45° zenith angle
  - various azimuth angles

Results

- profit from lower noise level at low frequencies
- should get larger signal towards the horizon for proper antennas





sboeser@physik.uni-bonn.de

Discussion item

Can we build a fast(er) simulation?

- shower simulation
  - ➔ slow due to particle tracking
- radio signal calculation
  - ➔ slow due to huge number of particles
- final radio signal
  - ➔ smooth due to large statistics
  - ➔ linear in energy

Can we use interpolation inbetween fully (REAS2) simulated showers ?

Cover parameter space with grid in

- x-y ground coordinates (denser in the center, more sparse further out)
- zenith angle (5° grid)
- shower maximum
- array elevation (two levels)
  - ➔ 10^4 showers may be sufficient

sboeser@physik.uni-bonn.de

Backup

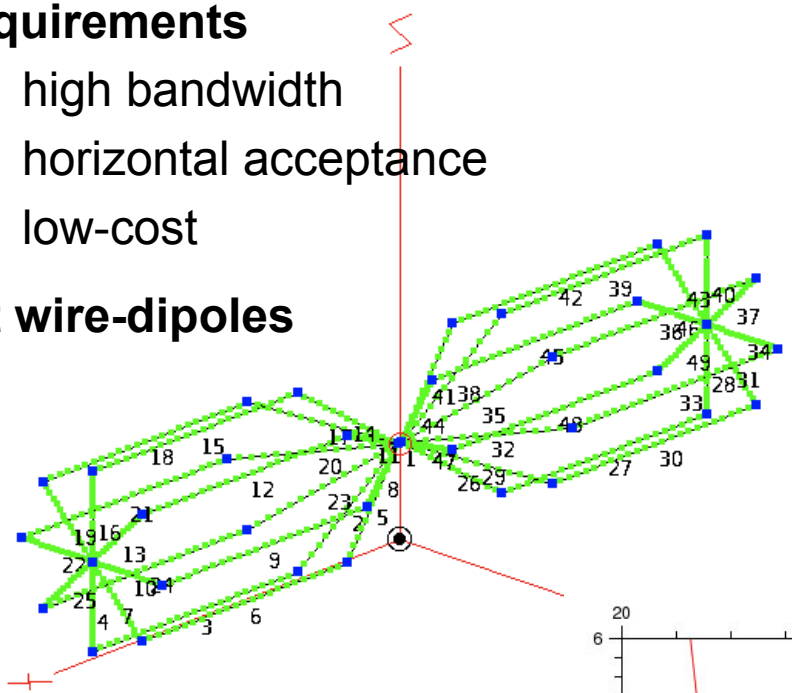
sboeser@physik.uni-bonn.de

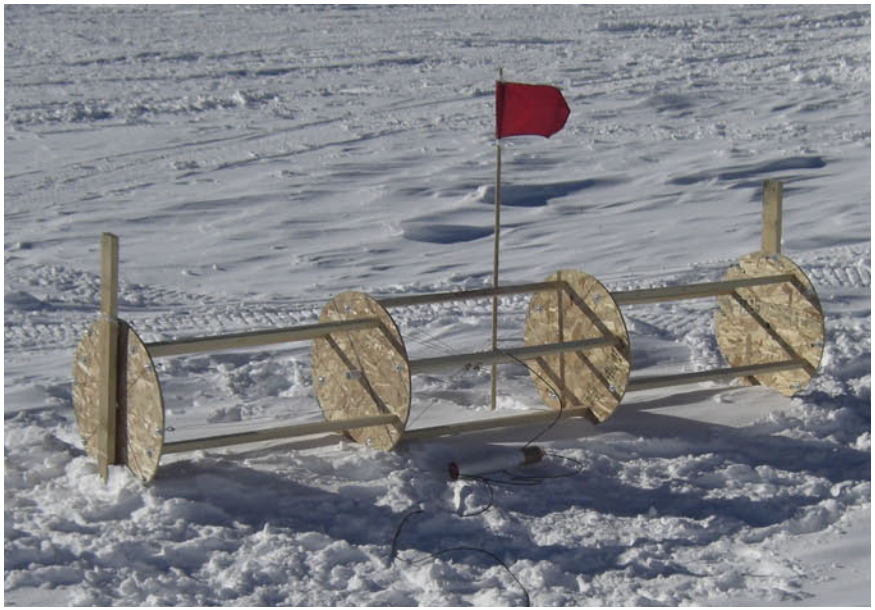
universitätbonn

Requirements

- high bandwidth
- horizontal acceptance
- low-cost

Fat wire-dipoles

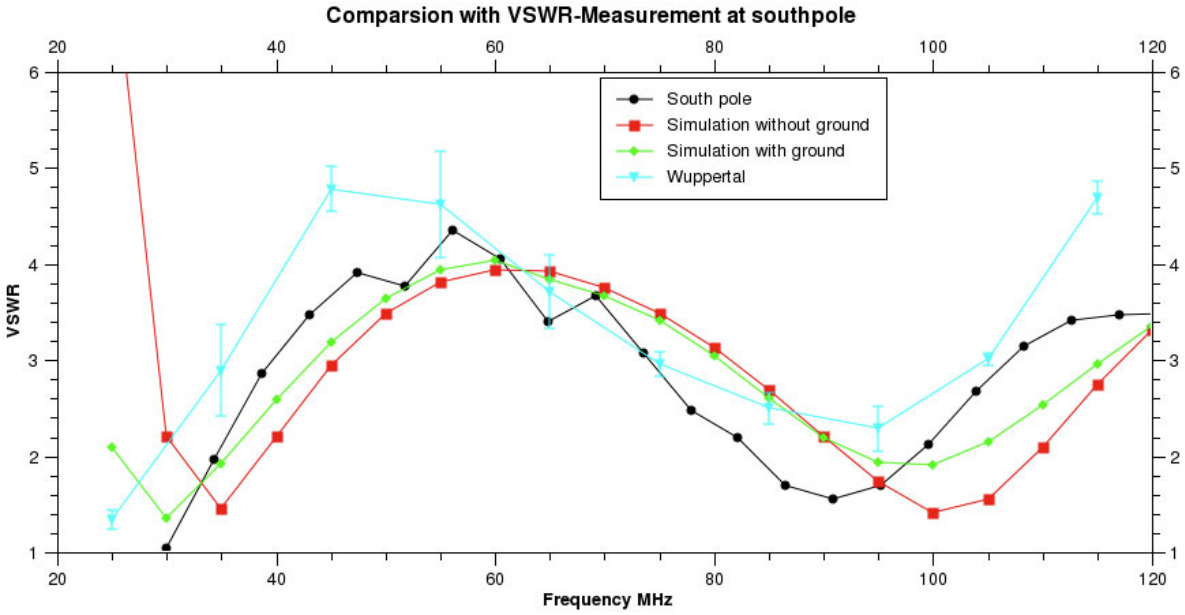




- higher bandwidth than single dipoles
- smaller group delay than log-periodic dipole

Calibration efforts

- ground effects
- environment effects



sboeser@physik.uni-bonn.de

South Pole setup – Jan Auffenberg

universitätbonn

08/09 Session

- 2 fat wire-dipoles

➔ measured background spectrum

09/10 Session

- +6 fat wire-dipoles
- trenches by Raytheon next to MAPO
- RICE DAQ (scope)
- not connected to IceCube/Top

➔ GPS timing

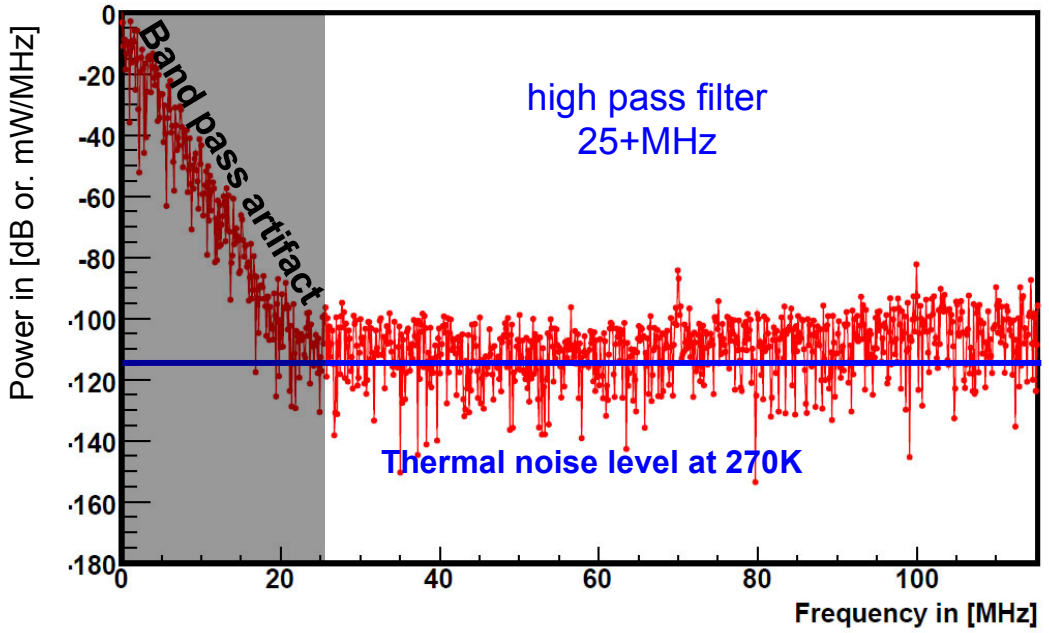
Event rate estimate

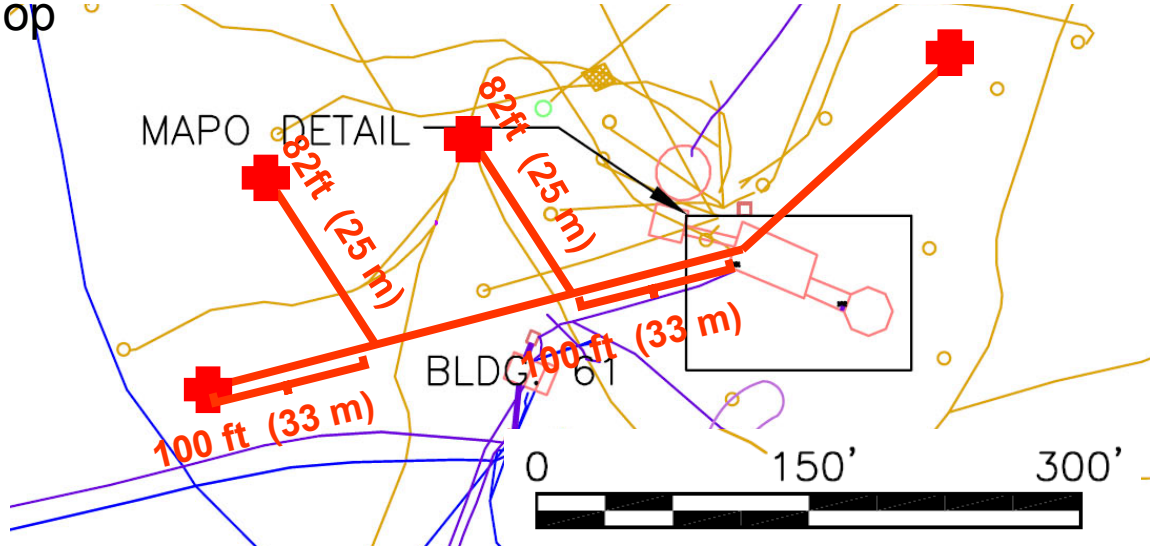
- threshold ~10PeV@125m

➔ 0.61 events/day (before trigger eff.)

- on top of IceTop

➔ Coincidences?!





sboeser@physik.uni-bonn.de