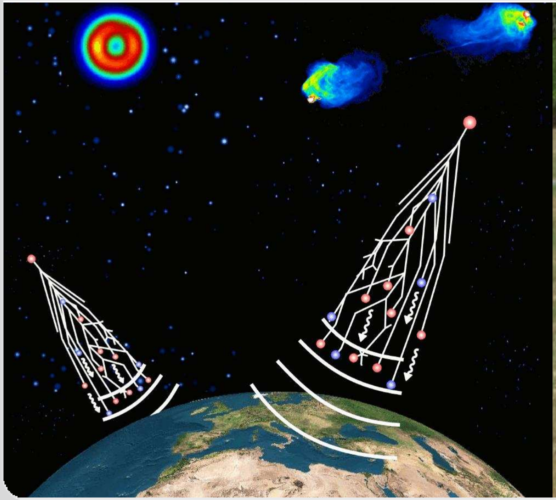
REAS: Radio emission from air showers

CORSIKA school 2010, Ooty

Marianne Ludwig, Institut für Experimentelle Kernphysik



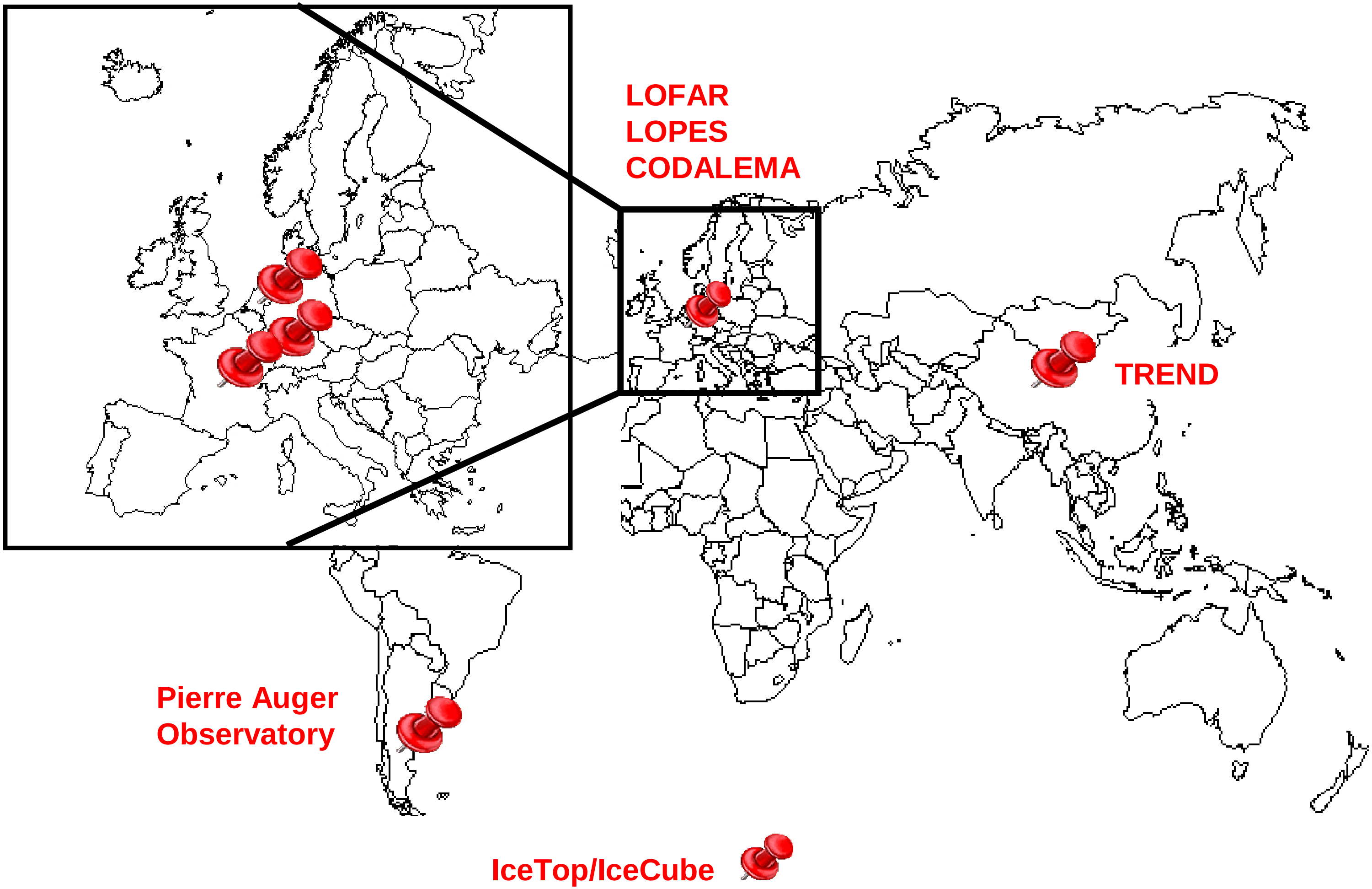
Outline

- **Radio detection and modelling radio emission from EAS**
- REAS – functionality and technical implementation
- Using REAS – a short introduction
- Using REASplot – some examples → exercises in the afternoon
- Summary

Radio detection of air showers – benefits

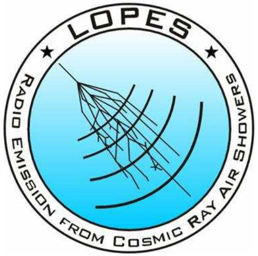
- Complementary information to particle detectors
- Duty cycle of ~ 95%
- High angular resolution (< 0.5° achievable)
- Simple detectors (in particular cheap)
  → Possibillity for large scale experiments
- Applicable to very inclined (neutrino-induced) air showers

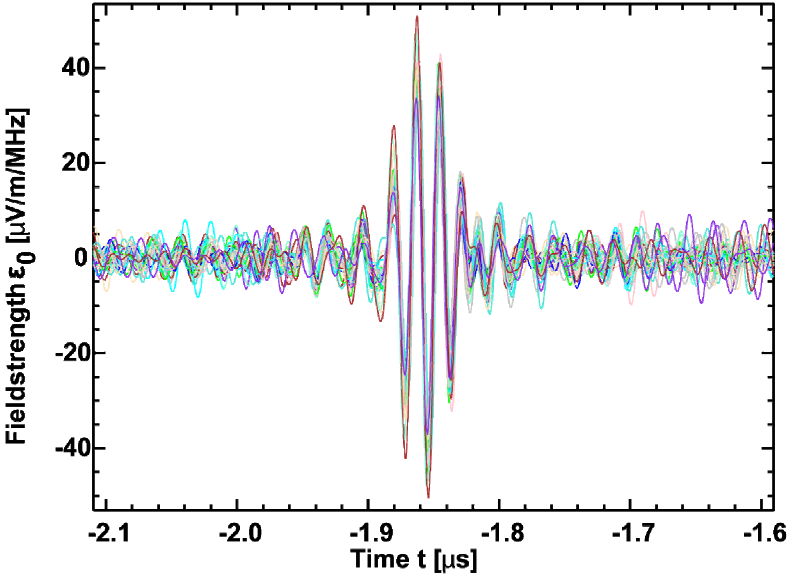
Radio detection from air showers



Radio detection – LOPES

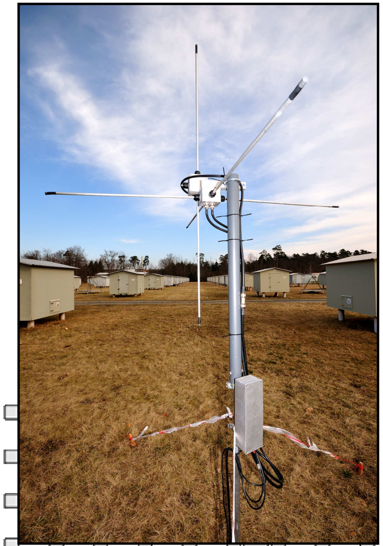
- LOPES: one of the major radio experiments
  (**LO**FAR **P**rototyp**e** **S**tation)
- Digital radio interferometer
- Integrated in KASCADE-Grande
- Measuring in the 40-80MHz bandwidth
- Effective energy range $10^{16.7}$ eV to ~10^{18} eV

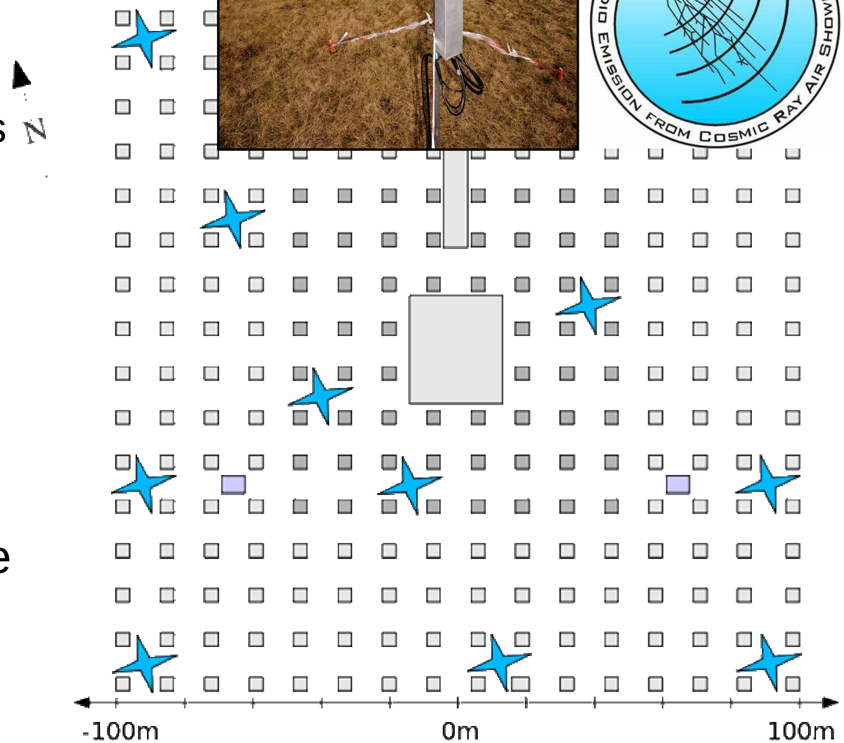




Radio detection - LOPES

- LOPES started in 2003
- Since Feb 2010:
  - 10 tripoles are installed
  - measuring all three polarizations NS/ EW / VE
- LOPES did a lot of progress in the last years
- There are several publications of the LOPES collaboration for more information





Modelling radio emission from EAS

- Understanding radio emission in detail is getting more and more important
- Several models exist:

MGMR

REAS

SELFAS

ReAIRES

and many more…

Modelling radio detection

Karlsruhe Institute of Technology

MGMR

REAS

SELFAS

ReAIRES

and many more…

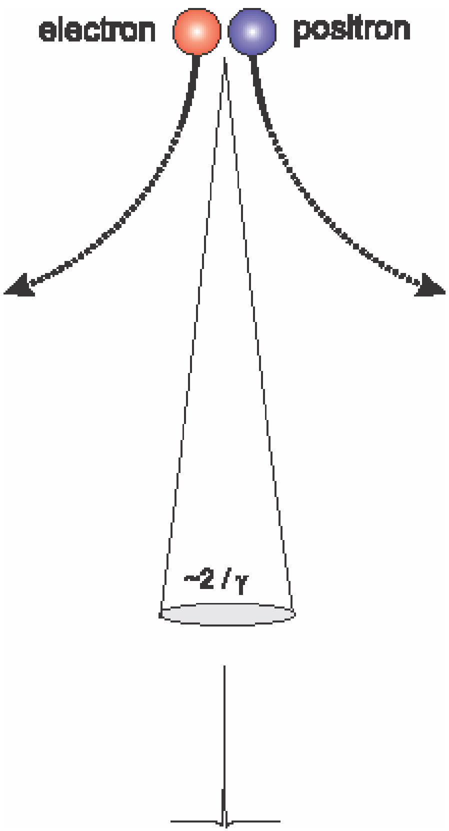
- I will introduce REAS:
  - Using CORSIKA/COAST for detailed shower information
  - No free parameters
  - Available for everybody
  - Based on an universal approach
  - Comparison with data promising

Modelling radio emission from EAS

- Secondary e- and e+ of the air shower get accelerated
  - Due to the Earth‘s magnetic field
  - Due to interactions

- Coherent radiation in the range up to hundred of MHz
  (as long as shower pancake is thinner than wavelength)

- Geomagnetic radiation (dominant effect in the atmosphere)



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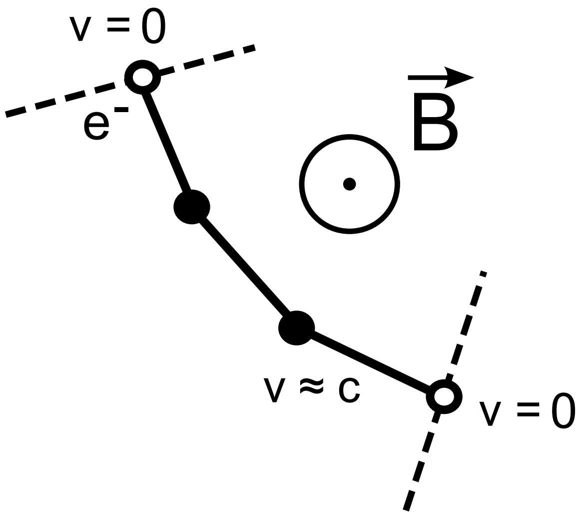
REAS – functionality

- REAS is a C++ based Monte Carlo code (written by T.Huege)
- Simulate EAS with CORSIKA → save information with COAST in histograms
- Generate shower particles (e-, e+) according to the desired distributions
- Follow each particle analytically on its track in the geomagnetic field (long trajectories are described by several short tracks)
- Superpose the radiation received from the shower particles at a given observing position

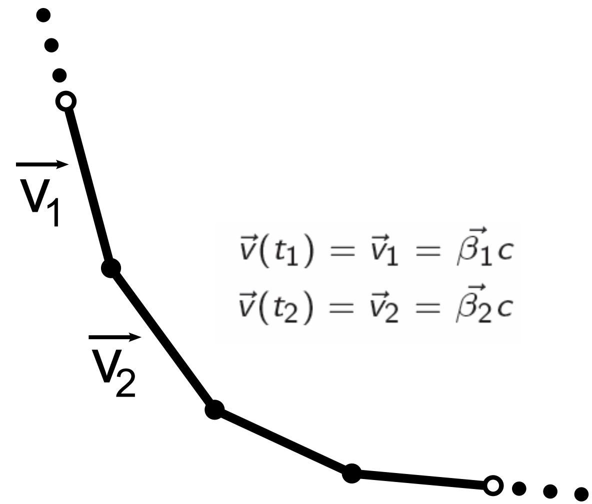
REAS3 – technical implementation

- Analytically tracks are described by straight track fragments joined by „kinks“
- Variation of the velocity (mainly direction) in kink:
  - Discrete radiation process
- Before and after being tracked analytically:
  - The particles have velocity 0
  - Radiation due to starting/stopping and due to deflection is considered



REAS3 – technical implementation

- Time averaged process of interest
- Integrated field strength from radiation formula
- Radiation contribution in one kink
- Refractive index is set to unity (so far)
- Endpoint description is completly universal



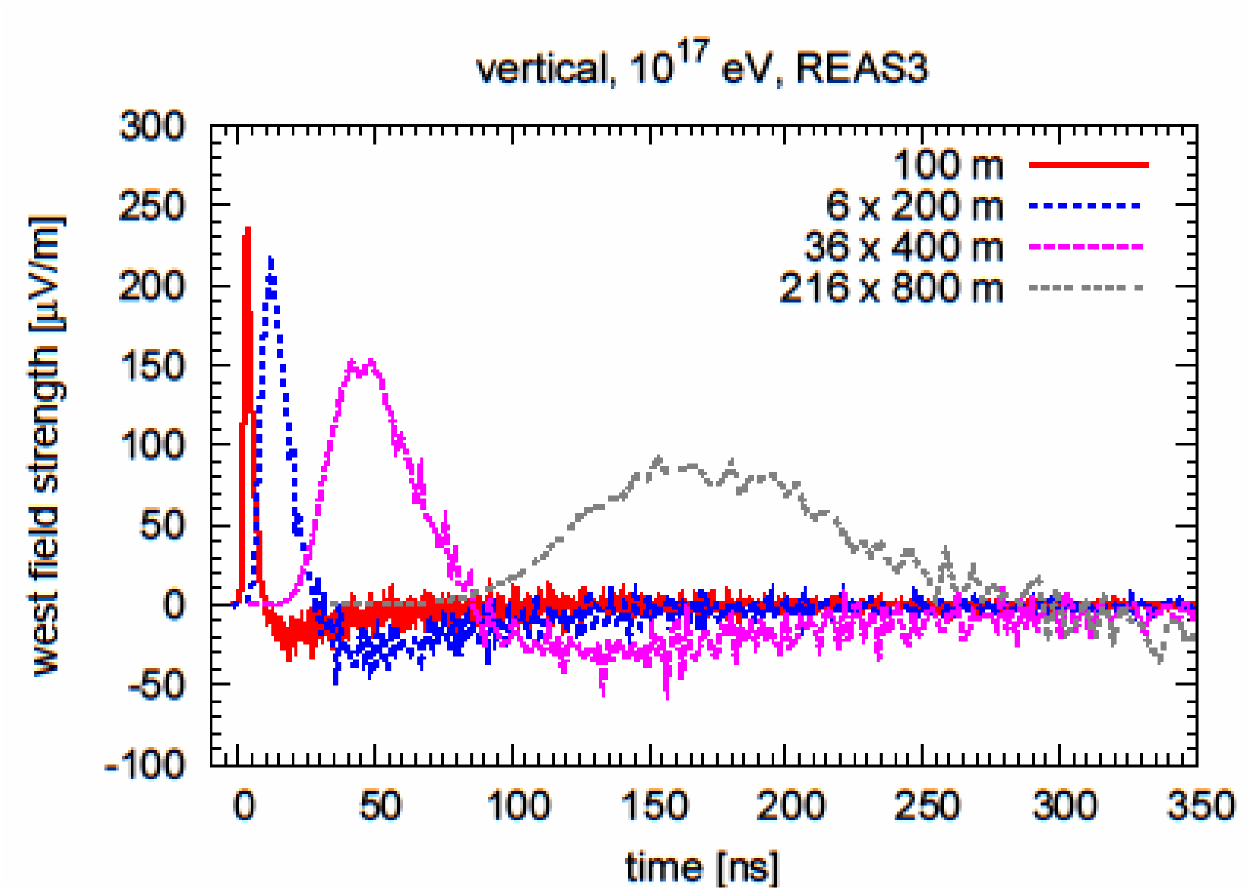
$$\vec{v}(t_1) = \vec{v}_1 = \vec{\beta}_1 c$$
$$\vec{v}(t_2) = \vec{v}_2 = \vec{\beta}_2 c$$

$$\int \vec{E}(\vec{x}, t)dt = \int_{t_1}^{t_2} \frac{e}{c} \left| \frac{\vec{n} \times [(\vec{n} - \vec{\beta}) \times \dot{\vec{\beta}}]}{(1 - \vec{\beta} \cdot \vec{n})^3 R} \right|_{ret} dt = \vec{F}(t_2) - \vec{F}(t_1)$$
$$= \frac{e}{cR} \left(\frac{\vec{n} \times (\vec{n} \times \vec{\beta}_2)}{(1 - \vec{\beta}_2 \vec{n})} \right) - \frac{e}{cR} \left(\frac{\vec{n} \times (\vec{n} \times \vec{\beta}_1)}{(1 - \vec{\beta}_1 \vec{n})} \right)$$

REAS3 – output

- The data of REAS3 is saved in ASCII-text:
  - Time-series (electric field) for each observer (in an extra folder)
  - A .log file with a copy of the on-screen output
  - Few more (not explained here but in the manual)
- Everything is given in cgs-units
- You can plot it easily, e.g., with gnuplot, root, paw
- You find for each antenna a raw_antennaID.dat file (in the extra folder)
  - Containing:
    time | E_x (NS) | E_y (EW) | E_z (VE)

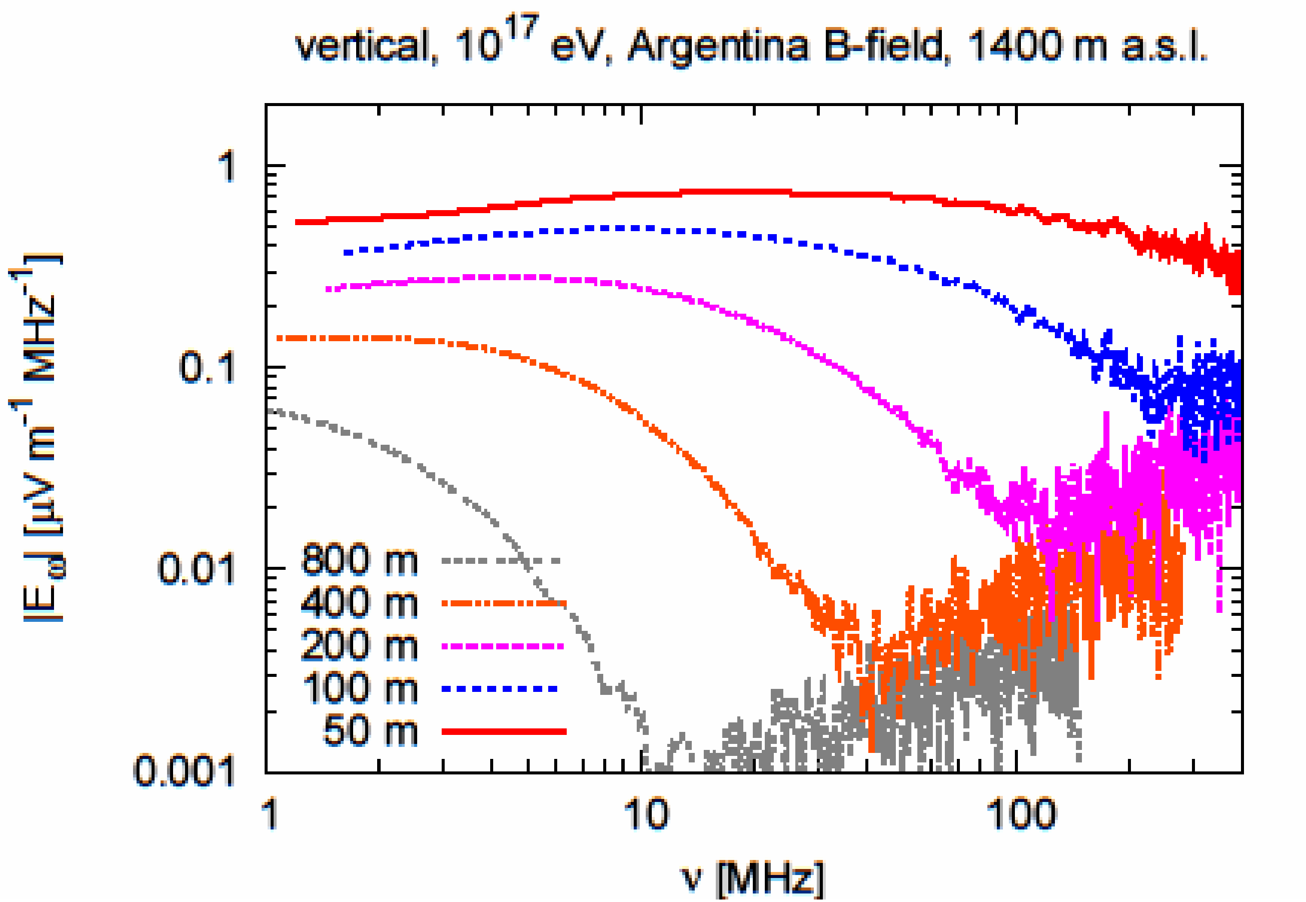
REAS3 – output – raw pulses



REAS3 – output

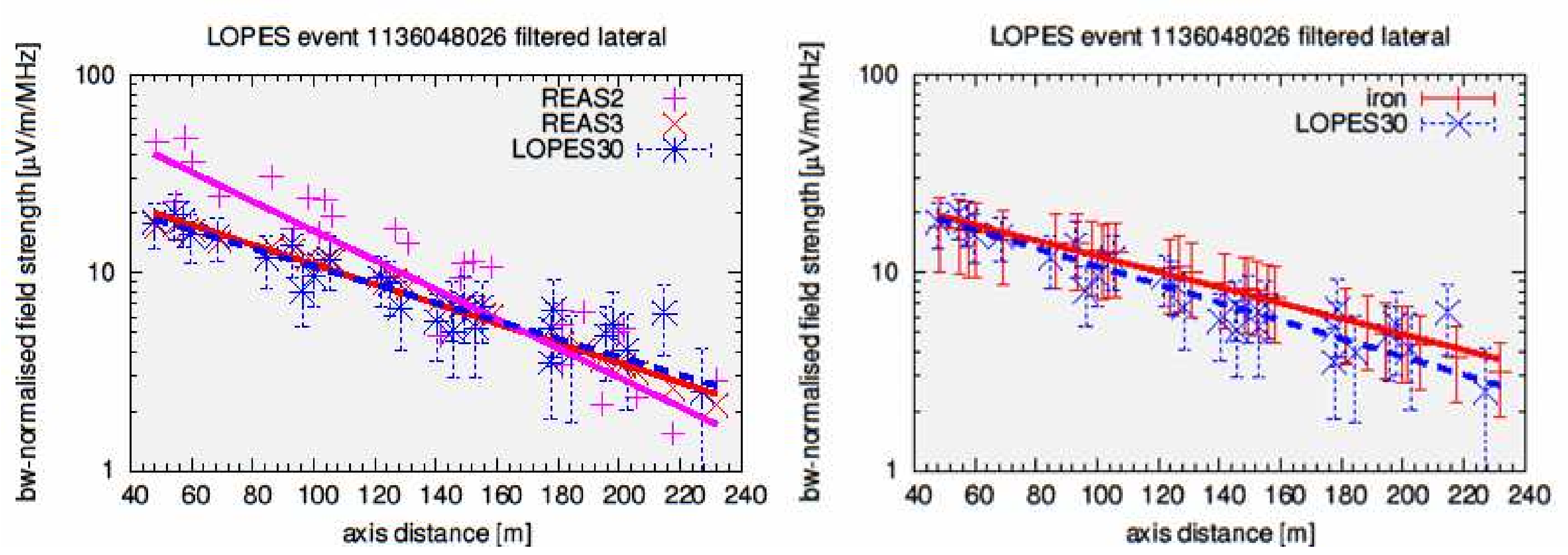
- You can also get more information on the radio signal (with REASPlot):
  - Frequency spectra
  - Lateral distributions
  - Contour plots
  - Etc.
- I will explain REASPlot later
- At this point just some examples to show you, what is possible

REAS3 – output – frequency spectra



REAS3 – possibilities for comparison with data

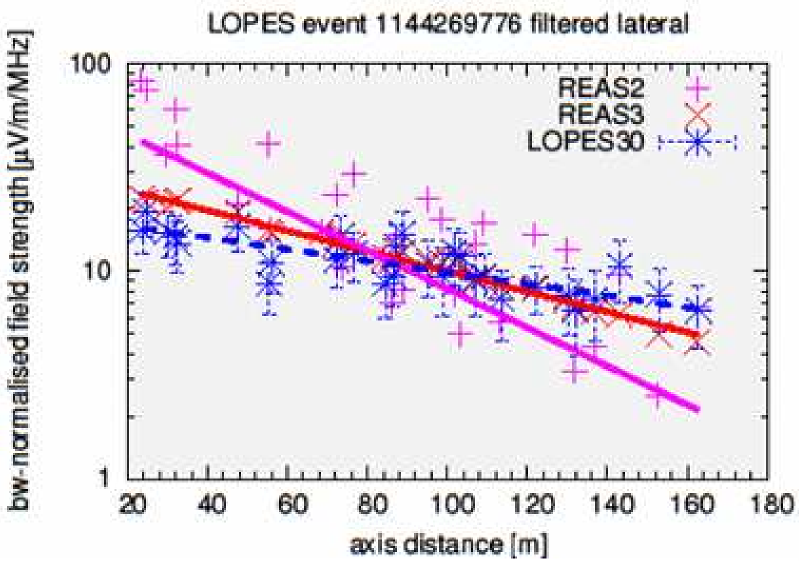
- E = 2.92*10^{17}eV, 31° zenith angle, proton primary

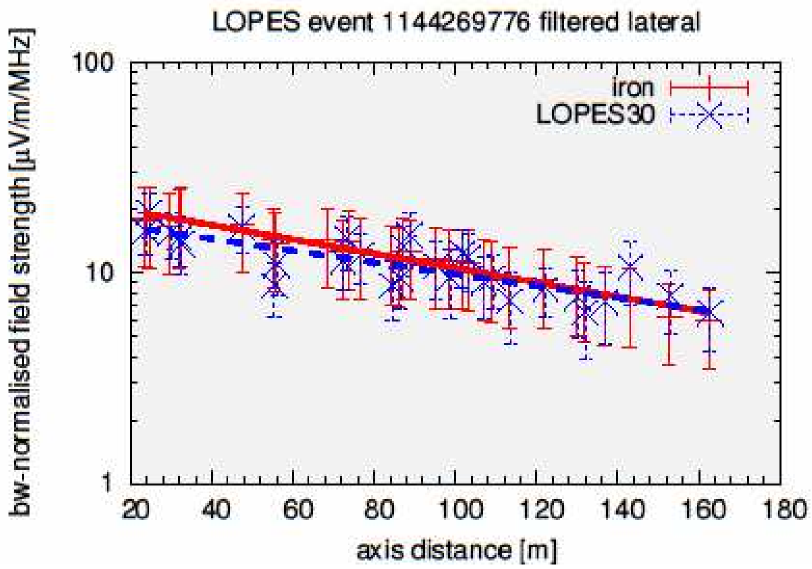


W.D. Apel et al., LOPES Collaboration - Astroparticle Physics 32 (2010) 294-303

REAS3 – possibilities for comparison with data

- E = 2.75*10^{17}eV, 24° zenith angle, iron primary





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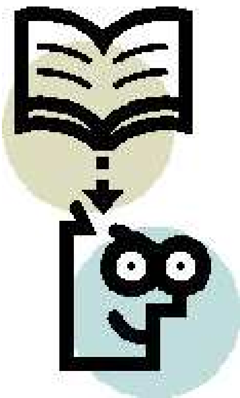
Using REAS3

- There is a REAS user‘s manual (reas-3.00-manual.pdf)
  - Specific information if you used REAS2 before
  - Step by step installation guide
  - Usage instructions



REAS 3.00 User’s Manual

Tim Huege*

November 4, 2010

1 For former REAS2 users

If you have used REAS2 before, here is an executive summary of the most important changes.

New features:

- REAS3 incorporates the “endpoint” formalism for calculating the electromagnetic radiation from moving charges. As such it in particular incorporates radio emission associated with the time variation of the number of charged particles during the air shower evolution. For a discussion of this issue, please refer to [4].

Obtaining REAS3

- The REAS source code is publicly available
  - The current version is 3.00
  - You can find it on the USB-stick for your usage
- **Please: Do NOT distribute the code by yourself!**
  - To keep a central coordination by Tim Huege
  - To get updates and information about new releases etc. (refractive index, bug fixes, …)
- Please let us know in which context you want to use REAS
- To obtain REAS contact directly me or go to the official webpage:

http://www-ik.fzk.de/~huege/reas

Using REAS

- To simulate, you need three components:

  1. CORSIKA - to simulate the air shower
  2. COAST - to save the information in histograms
  3. REAS - to calculate the radio emission

- COAST has to be installed with the extra package THRadio (as given on the USB sticks and on the REAS webpage)

- CORSIKA has to be installed with the option
  - ROOT particle TRACKing option (p)
  - SLANT should be used by default (9)

Using REAS

- How to set up CORSIKA, chosing options,… → lectures and exercises of this school

- How to set up COAST → lectures and exercises of this school

- Most features of CORSIKA are compatible with COAST and REAS

  - All interaction models
  - Thinning option
  - Preshower option for photons
  - Slant option
  - Curved option
  - …

Using REAS – Installation

- REAS binaries compiled with gcc 4.x will run twice as fast as binaries compiled with gcc 3.x

- The installation is simple (check the manual)
  – we will do it together in the afternoon exercise

- For physics details, please see

  - M. Ludwig, T. Huege, Astroparticle Physics in press (2010)
    doi:10.1016/j.astropartphys.2010.10.012

- Please cite this paper when publishing results derived with REAS

Using REAS – Few notes about setting up

- ROOT has to be installed properly (version 4.x or 5.x)
- Everything is based on GNU autotools
  - Should work on any Linux system
- Please take care when setting up the environment variables!
  - Consult User's manual for details
  - There is an example (for bash shells) to set the environments given on the USB stick:
    - CORSIKA/exercises/setenvironment
    - Load with **source setenvironment**

```
export ROOTSYS=/usr/local/root
export COAST_DIR=/home/user/coast-v4r1/install
export COAST_USER_LIB=/home/user/coast-v4r1/THRadio
export LD_LIBRARY_PATH=$ROOTSYS/lib:$COAST_DIR/lib:$LD_LIBRARY_PATH
export PATH=$ROOTSYS/bin:$PATH
```

Using REAS – a typical simulation chain

- Run one or more showers with CORSIKA (or use CONEX for this step)
  - Shower-to-shower fluctuations!
- Run CORSIKA for specific shower
- Run REAS with a defined list of desired antenna positions
- Process the REAS output (unlimited bandwidth pulses), e.g. with REASPlot

Using REAS – setup of CORSIKA

- Some values have to be „singular“
  - Energy
  - Azimuth
  - Zenith

- The energy cuts are recommanded as

```
RUNNR 1
EVTNR 1
SEED    1 0 0
SEED    2 0 0
SEED    3 0 0
PRMPAR      14
ERANGE  1.000E+8 1.000E+8
ESLOPE  0.000E+00
THETAP  0.   0.
PHIP   0.000E+00 0.000E+00
ECUTS 3.000E-01 3.000E-01 4.010E-04 4.010E-04
ELMFLG    T  T
THIN   1.000E-06 1.000E+02 0.000E+00
THINH 1.000E+00 1.000E+02
NSHOW      1
```

- You should use thinning with proper values (as given in the manual)

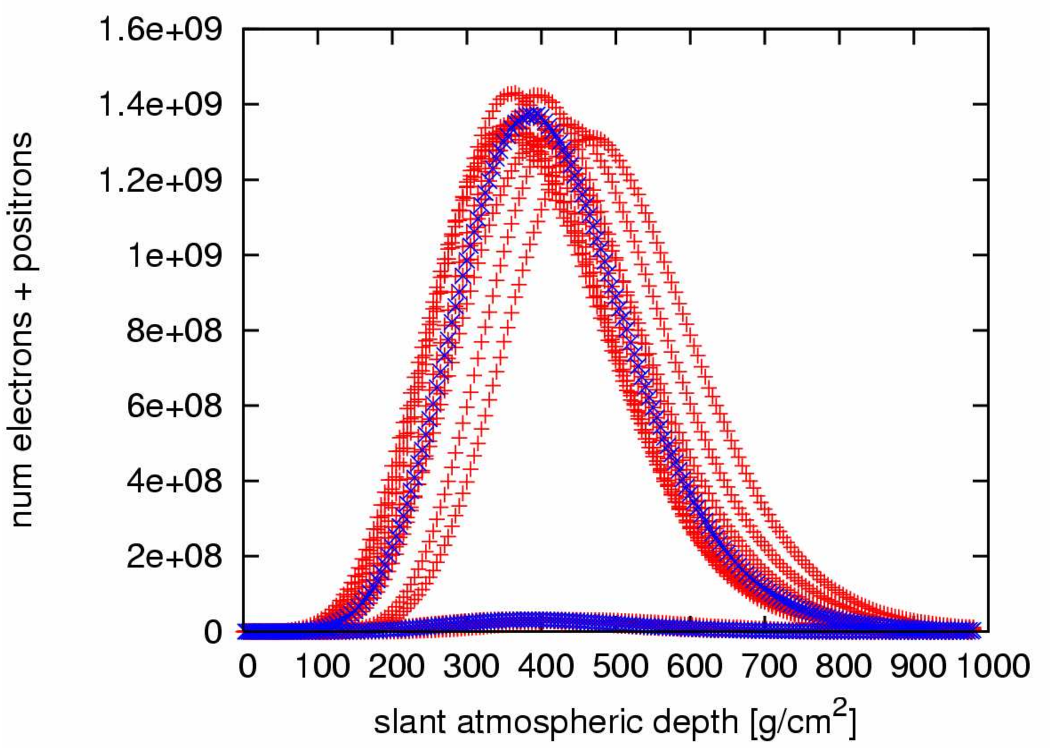
Using REAS – setup of CORSIKA

- The observer level should be below the antenna height (to avoid a loose of information for inclined showers)
- Use only one observer level
- The magnetic field has to correspond to the one at the site of the experiment
- The longitudinal output has to be activated

```
DIRECT  './'
OBSLEV  140000.0
ECTMAP  1.000E+05
STEPFC  1.000E+00
MUMULT   T
MUADDI   T
PAROUT   T  F
MAXPRT      1
MAGNET   18.37 -13.84
LONGI  T    5.   T  T
RADNKG  5.000E+05
DATBAS   F
EXIT
```

Using REAS – setup of CORSIKA

- If you run more than one CORSIKA shower (or CONEX)
- Select one shower (e.g., with average Xmax)



CORSIKA longitudinal files

Using REAS – setup REAS

- With the REAS-code you get two example files:
  - event.reas
  - all.list
- The .reas file is the input file (comparable to .inp of CORSIKA)
- Keep most information as given in the example file and same as in CORSIKA input!

```
# REAS V3 by Tim Huege <tim.huege@kit.edu> & Marianne Ludwig - parameter file
# For details see:
# Ludwig, M., Huege, T. 2010, Astroparticle Physics, doi:10.1016/j.astropartphys.2010.10.012
# Portions related to electric fields based on work of Stijn Buitink <s.buitink@astro.ru.nl>

# global parameters:

ParameterFileVersion = 22                    ; do not change manually
NumParticlesToCalculate = 10000000000
NumSimultaneousParticles = 1000000
RandomSeed = -1                              ; -1: chosen randomly, other: chosen manually
AtmosphereModel = 0                          ; 0: US Standard, 10: Argentina Winter, 20: Europe January,
CurvedGeometry = 0
EarthRadius = 637131500                      ; in cm, only used if Curved = 1
```

Using REAS – setup REAS

- You have to set a three-dimensional core position, including a height above sea level

```
# parameters setting up the spatial observer configuration:

CoreCoordinateNorth = 0                    ; in cm
CoreCoordinateWest = 0                     ; in cm
CoreCoordinateVertical = 140000.0          ; in cm


# parameters setting up the temporal observer configuration:

TimeLowerBoundary = -1                     ; in s, only if AutomaticTimeBoundaries set to 0
TimeUpperBoundary = 1                      ; in s, only if AutomaticTimeBoundaries set to 0
TimeResolution = 2e-10                     ; in s
GroundLevelRefractiveIndex = 1                   ; specify refractive index at 0 m asl
```

- For information on time-sampling:
  - See the references on REAS in the manual

Using REAS – setup REAS

- Don‘t change the optimisation strategies

```
# parameters setting the optimisation strategies:
```

- Give details where REAS will find your CORSIKA shower you want to simulate

```
# parameters specific to CORSIKA based showers - other parameters are read from the CORSIKA input file:

CorsikaFilePath = ./                    ; path to the CORSIKA files (cannot include space characters!)
CorsikaParameterFile = RUN000001.inp    ; specify CORSIKA card file
CorsikaSlantOptionToggle = 1            ; set to 1 if CORSIKA option SLANT is used
SelectedCorsikaShower = 1               ; 0: averaged, i: i-th shower
ShowerEvolutionShift = 0                ; apply slant depth shift to CORSIKA-derived shower evolution, in g/cm^2
```

- The electric field configuration is yet not active

- Auger members can use event information for Auger Offline simulations

Using REAS – the antenna file

- In the all.list file you define the positions of your antennas:
  - AntennaPosition = northcm westcm heightcm antenna_ID
  - The positions are in cm !
- Give every antenna an unique ID

```
# AntennaPosition = northcm westcm heightcm id

AntennaPosition = 5000  0      140000      pole_50m_0deg
AntennaPosition = 3535.53      3535.53     140000      pole_50m_45deg
AntennaPosition = 0     5000   140000      pole_50m_90deg
AntennaPosition = -3535.53     3535.53     140000      pole_50m_135deg
AntennaPosition = -5000 0      140000      pole_50m_180deg
AntennaPosition = -3535.53     -3535.53    140000      pole_50m_225deg
AntennaPosition = 0     -5000  140000      pole_50m_270deg
AntennaPosition = 3535.53      -3535.53    140000      pole_50m_315deg
```

Using REAS – setup REAS

- Finally: start your REAS simulation:
  - Go in the folder where your input files are
  - E.g., your parameter files are: event.reas and all.list
  - ./reas event all (where reas is your binary)

```
REAS V3 by Tim Huege & Marianne Ludwig (binary: ./reas3public)

When publishing results obtained with this code, please cite:

Ludwig, M., Huege, T. 2010, Astroparticle Physics, doi:10.1016/j.astropartphys.2010.10.012

Parameter file SIM000001.reas successfully imported!
Antenna list file rings1400m.list successfully imported!
CORSIKA file /lxdata/d21x68/huege/mgrmcomp/RUN000001.inp successfully imported! Importing parameters!
File/Program parameter version: 22/22  -->  match!

Starting calculation:

Random seed is set to: 1290777513
Importing ROOT histograms file /lxdata/d21x68/huege/mgrmcomp/DAT000001_4.hist.root ... done.
Longfile-Xmax: 680    Rootfile-Xmax: 688.786
Total number of injected particles: 4.8694e+11
Shower maximum is at slant depth: 688.786 g cm^-2
Geomagnetic angle is: 126.994 degrees
```

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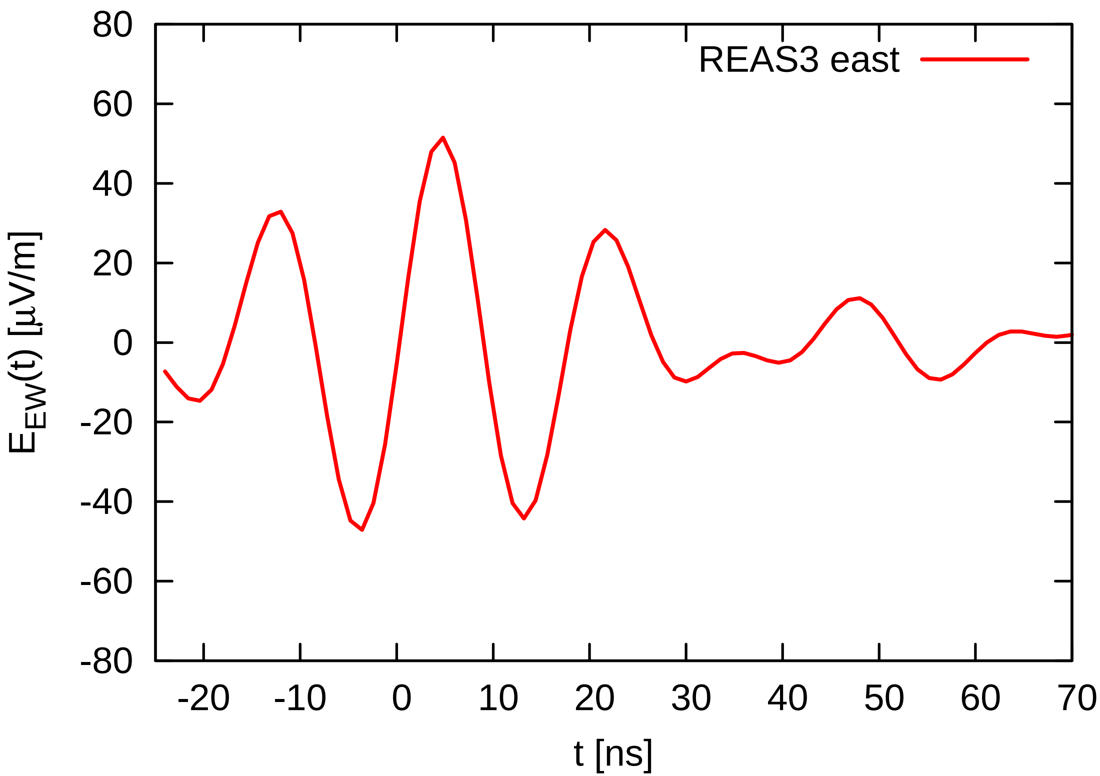
Using REASPlot – notes

- REASPlot is a helper application you get in the package with REAS3
- You can
  - Select a filter bandwidth of your interest
  - Calculate frequency spectra
  - Specify one or more frequencies to get the spectral field strengths
  - Combine simulation data from one simulation which was distributed over several CPUs
- How to use → in the exercises today

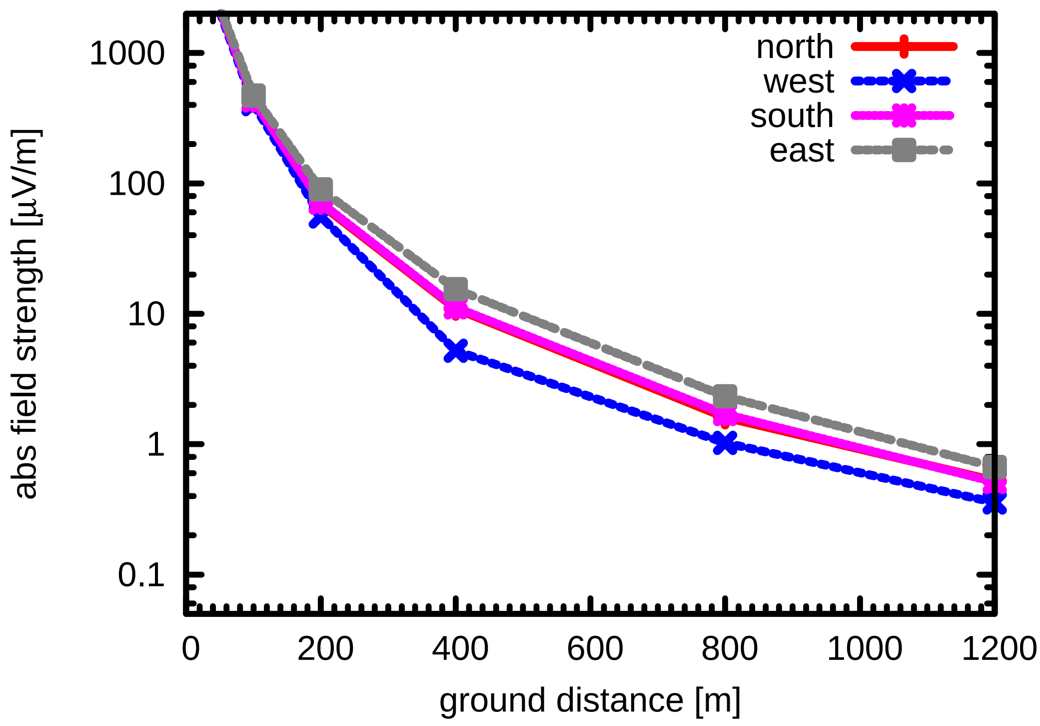
Using REASPlot – examples

- Pulses for a finite frequency bandwidth



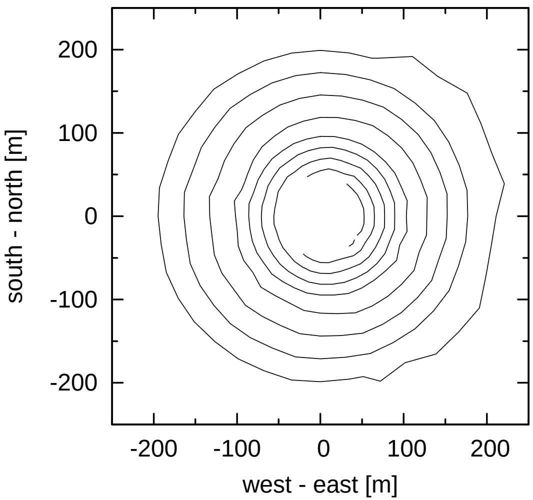
Using REASPlot – examples

- Lateral distributions

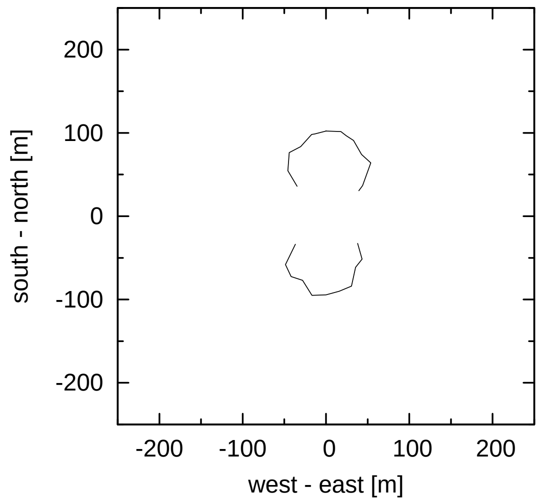


Using REASPlot – examples

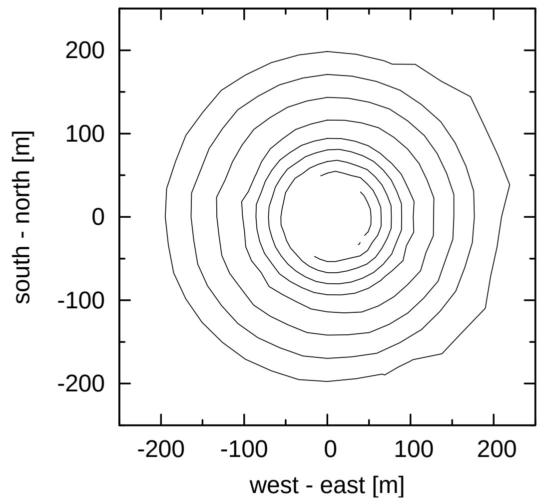
- Contour plots (60MHz field strength)



Absolute field strength



NS component



EW component

Contour levels: 0.1 $\mu Vm^{-1}MHz^{-1}$

Announcement for the REAS exercises

- For the exercises you will need another file I forgot to put on the USB
- You can get it directly from me
- Or download it (size is just 3k):
  - http://www-ik.fzk.de/~ludwig/
- The name is: **rings1400m.list**
- Please, try to get it before the exercises in the afternoon
- Sorry for the circumstances

Summary

- Secondary e- and e+ produce radio emission
  - Mainly because of the seperation in the Earth‘s magnetic field
  - Due to the variation of the charge excess of the air shower
  - …
- REAS3 is a Monte Carlo code using the universal endpoint formalism to simulate this radio emission
- REAS is based on CORSIKA using COAST histograms
- A detailed User‘s manual exists
- Please register on the official webpage if you want to use REAS3:
  - http://www-ik.fzk.de/~huege/reas
- REAS3 constitutes a widely usable radio simulation tool
- REASPlot is an useful helper application contained in the REAS package

Thank you for your attention!