

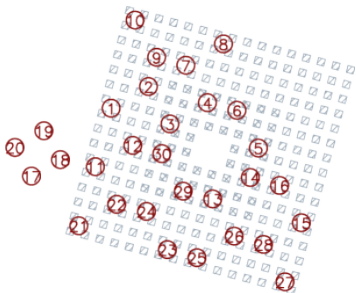
Comparison of LOPES measurements with CoREAS and REAS 3.1 simulations

ARENA conference 2012 – Erlangen

Marianne Ludwig (KIT) for the LOPES Collaboration



- LOPES measured ~ 400 events surviving quality cuts
- amplitude and time calibration existing
- in this talk:
 - events from LOPES 30 period
 - 30 antennas: east-west-polarised
 - ~ 150 events shown in this comparison



April 2003

February 2005

December 2006

February 2010

LOPES 10

LOPES 30

LOPES 30 pol

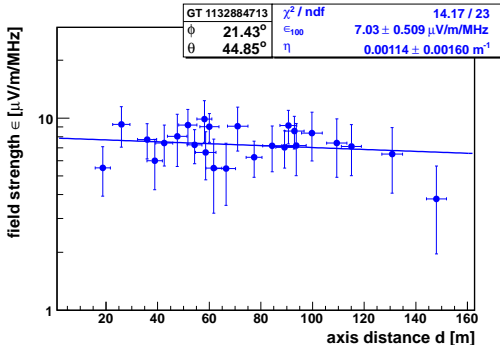
LOPES 3D

Lateral distribution function (LDF)

- exponential LDF: reasonable for LOPES distance range

$$\epsilon(d_{\text{axis}}) = \epsilon_{100} \cdot \exp[-\eta(d_{\text{axis}} - 100 \text{ m})]$$

- η, ϵ_{100} fitting parameters
- η as fitting parameter more physical than $1/R_0$
 - $\eta = 0 \Rightarrow$ flat LDF
 - $\eta < 0 \Rightarrow$ rising LDF
- for other distance ranges LDF more complicated structure



- for each individual event: KASCADE(-Grande) reconstruction

- primary energy E_p $\mathcal{O}(20\%)$
- incoming direction Θ, φ $\mathcal{O}(\ll 1^\circ)$
- core position $\mathcal{O}(\leq 7 \text{ m})$
- number of electrons and muons on ground

⇒ high quality of LOPES data & KASCADE(-Grande) reconstruction

⇒ opportunity to test models

- REAS 3.0
- REAS 3.11 (“REAS 3.0 + refractive index”)
- CoREAS (“REAS 3.11 in CORSIKA”)

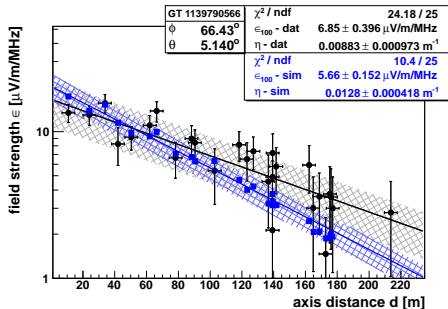
- for each individual event: KASCADE(-Grande) parameters as input
 - energy
 - direction
 - core position
- CONEX simulation
 - primary particle proton: 200 showers
 - primary particle iron: 100 showers
 - ⇒ select shower with $N_\mu(\text{CONEX}) \approx N_\mu(\text{KASCADE})$
- re-simulate selected air shower with CORSIKA plus radio emission with (Co)REAS
- ⇒ get simulated air shower comparable to measured one and its radio emission

Simulation process for each individual event

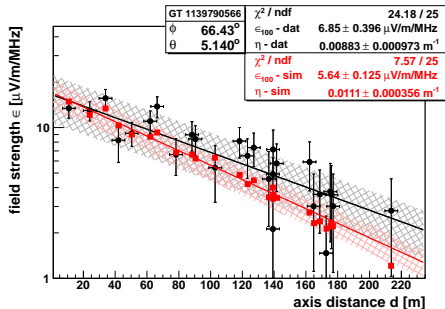
- simulations provide electric field vector in time domain
- filter signal to frequency band of LOPES
 - simple rectangular filter is used (43 - 74 MHz)
 - so far: no detector simulation (e.g. frequency dependent antenna gain)
- get east-west signal per antenna
- use same fitting function as for LOPES data

Comparison of individual LDFs – typical event

- primary energy $E_p = 2.97 \cdot 10^{17}$ eV



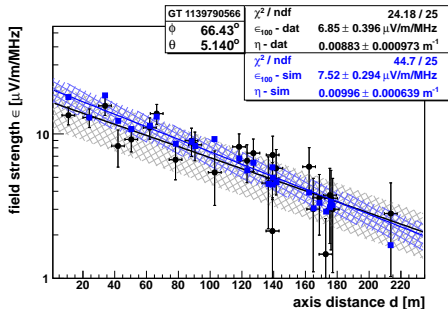
REAS 3.0 – proton



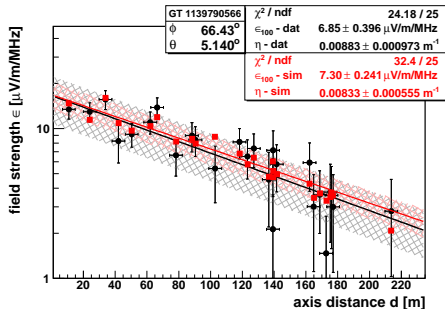
REAS 3.0 – iron

Comparison of individual LDFs – typical event

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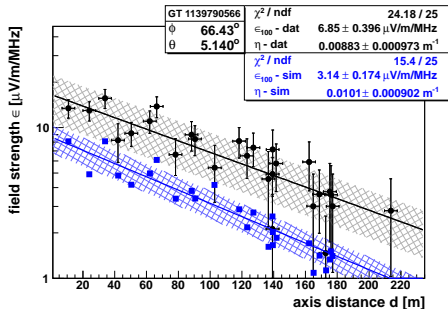
REAS 3.11 – proton



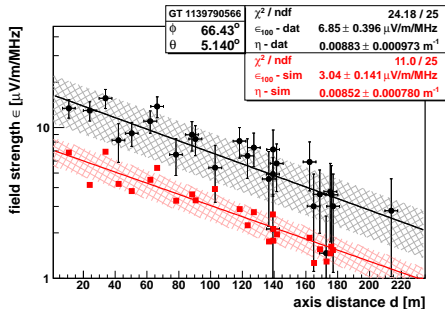
REAS 3.11 – iron

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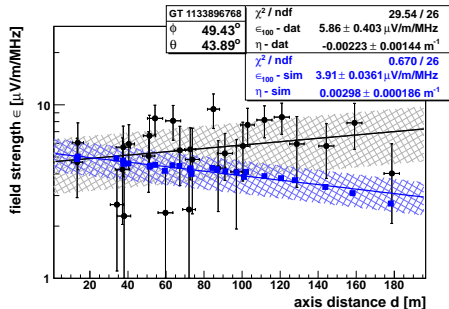
CoREAS – proton



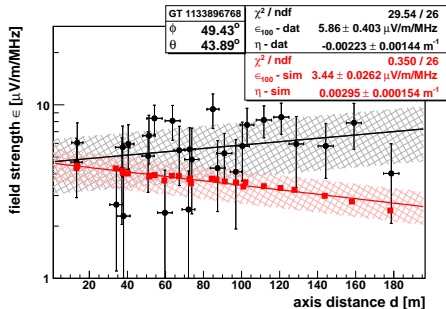
CoREAS – iron

Comparison of individual LDFs

- primary energy $E_p = 1.08 \cdot 10^{17}$ eV



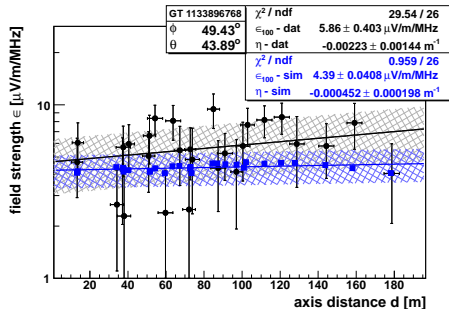
REAS 3.0 – proton



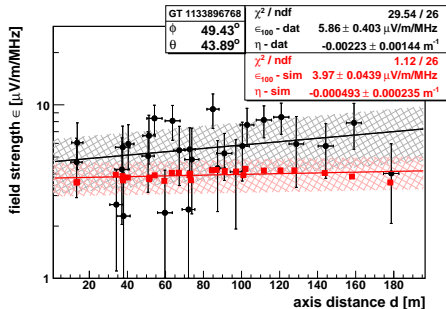
REAS 3.0 – iron

Comparison of individual LDFs

- primary energy $E_p = 1.08 \cdot 10^{17}$ eV



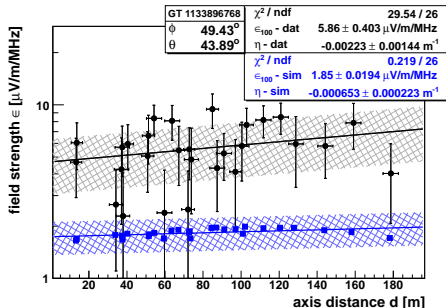
REAS 3.11 – proton



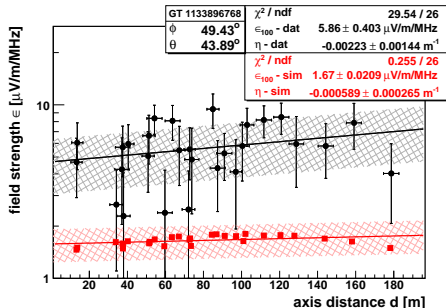
REAS 3.11 – iron

Comparison of individual LDFs

- primary energy $E_p = 1.08 \cdot 10^{17}$ eV



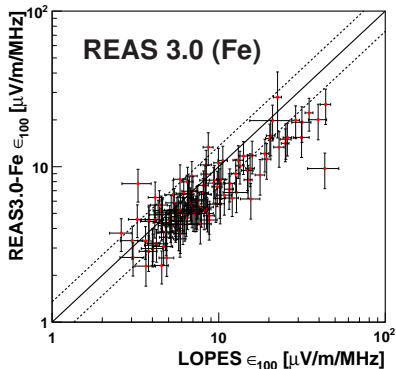
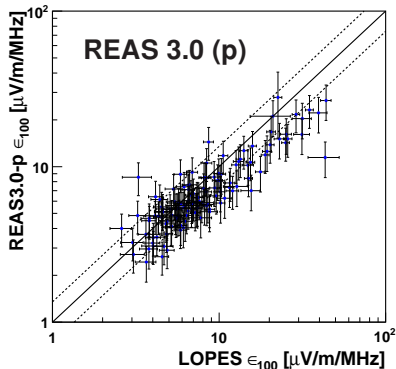
CoREAS – proton



CoREAS – iron

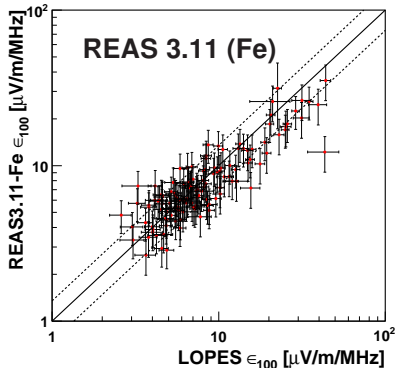
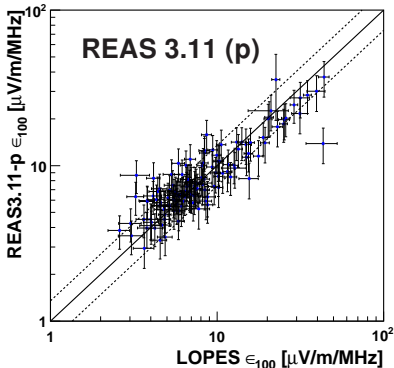
Comparison of amplitude ϵ_{100}

- amplitude at 100 m hardly affected by primary particle type
- systematic effects under investigation



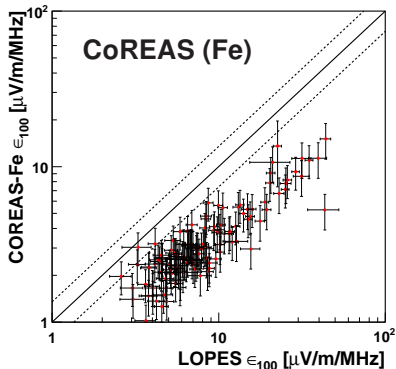
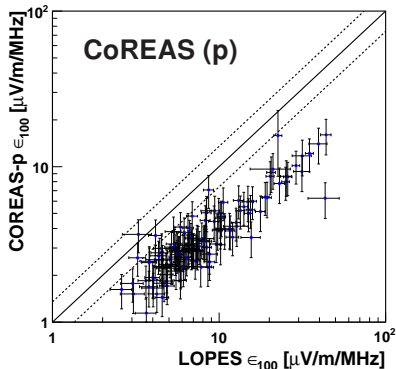
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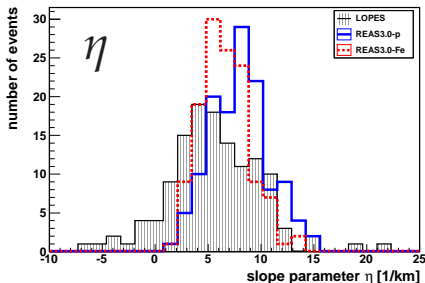
Comparison of amplitude ϵ_{100}

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Comparison of slope parameter η and ϵ_{100}

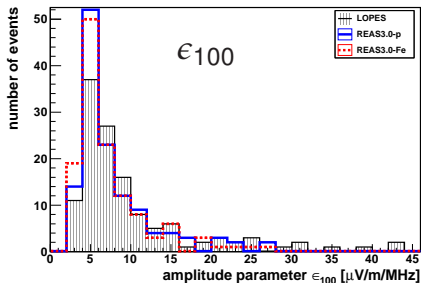
- LDF slope parameter: REAS 3.0 not compatible
- amplitude parameter: REAS 3.0 compatible within experimental scale uncertainty



Mean: 5.66 σ : 4.35

Mean: 7.91 σ : 2.78

Mean: 6.55 σ : 2.32



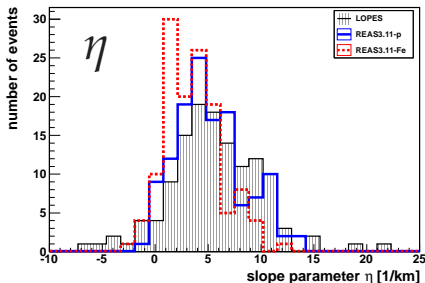
Mean: 10.03 σ : 8.17

Mean: 7.78 σ : 4.90

Mean: 7.37 σ : 4.69

Comparison of slope parameter η and ϵ_{100}

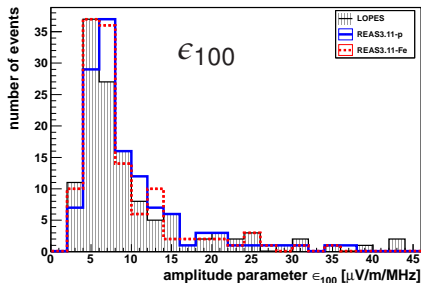
- LDF slope parameter: REAS 3.11 compatible on average
- amplitude parameter: REAS 3.11 compatible within experimental scale uncertainty



Mean: 5.66 σ : 4.35

Mean: 5.18 σ : 3.30

Mean: 3.51 σ : 2.67



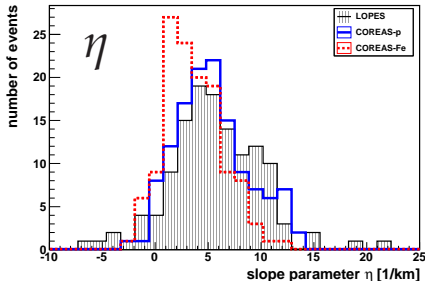
Mean: 10.03 σ : 8.17

Mean: 9.56 σ : 6.27

Mean: 8.84 σ : 5.83

Comparison of slope parameter η and ϵ_{100}

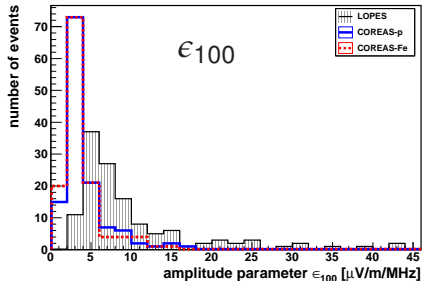
- LDF slope parameter: CoREAS compatible on average
- amplitude parameter: study effects on uncertainty due to simplifications in analysis



Mean: 5.65 σ : 4.35

Mean: 5.37 σ : 3.42

Mean: 3.64 σ : 2.77



Mean: 10.03 σ : 8.17

Mean: 4.10 σ : 2.76

Mean: 3.73 σ : 2.52

- calibrated LOPES data are suited for comparison with simulations
- so far: no simulation could describe LDF slope on average
- new simulations with refractive index describe slope properly, including rising LDFs
- REAS 3.11 shows general agreement
- CoREAS predicts smaller amplitudes than measured
 - systematic uncertainties on amplitude will be re-investigated
 - calibration uncertainty of 35% on amplitude
- detailed analysis of full data set including north-south component will follow

Thank you for your attention!