Radboud University Nijmegen

Cosmic Ray measurements with LORA: LOFAR Radboud Air Shower Array

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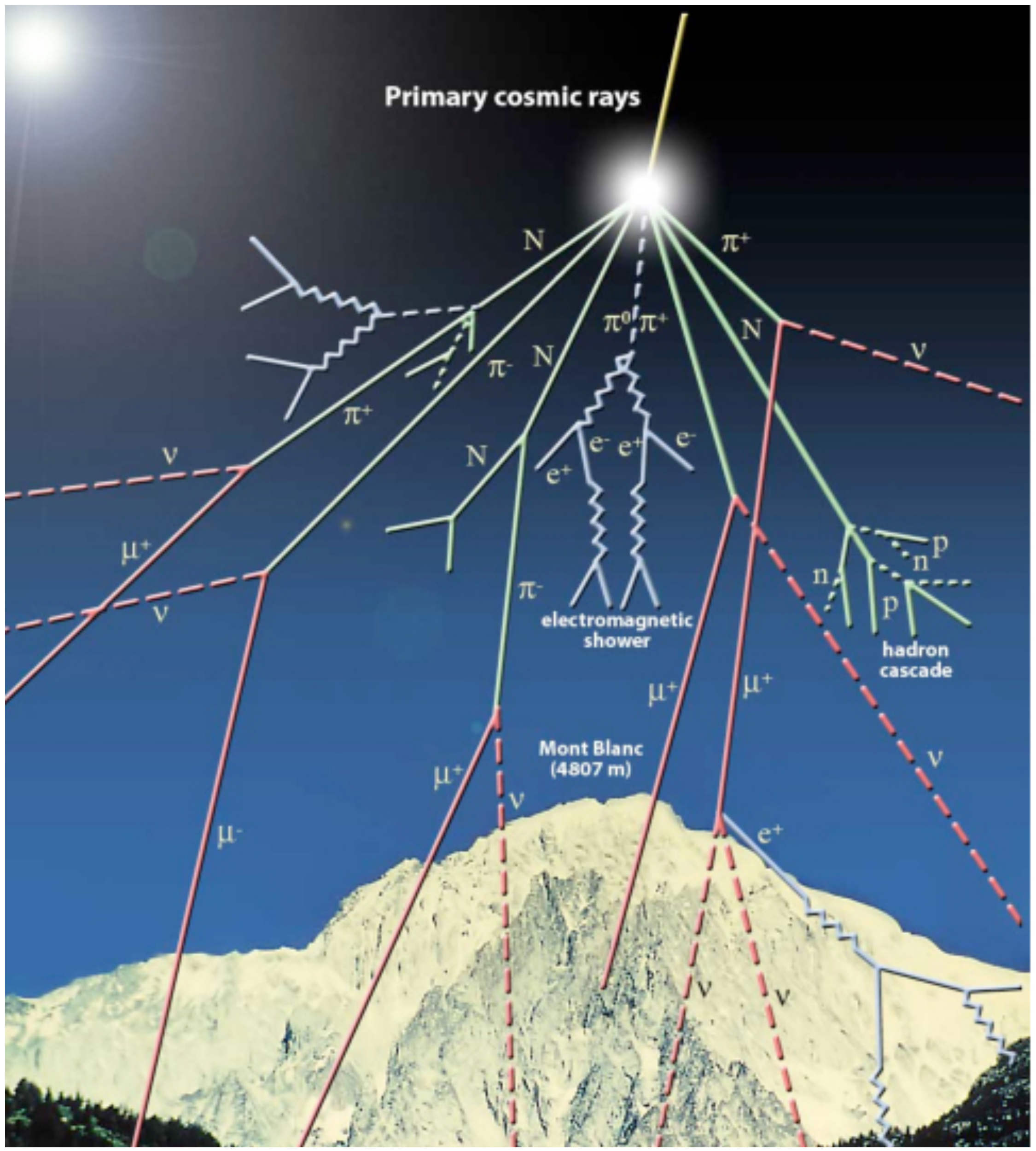
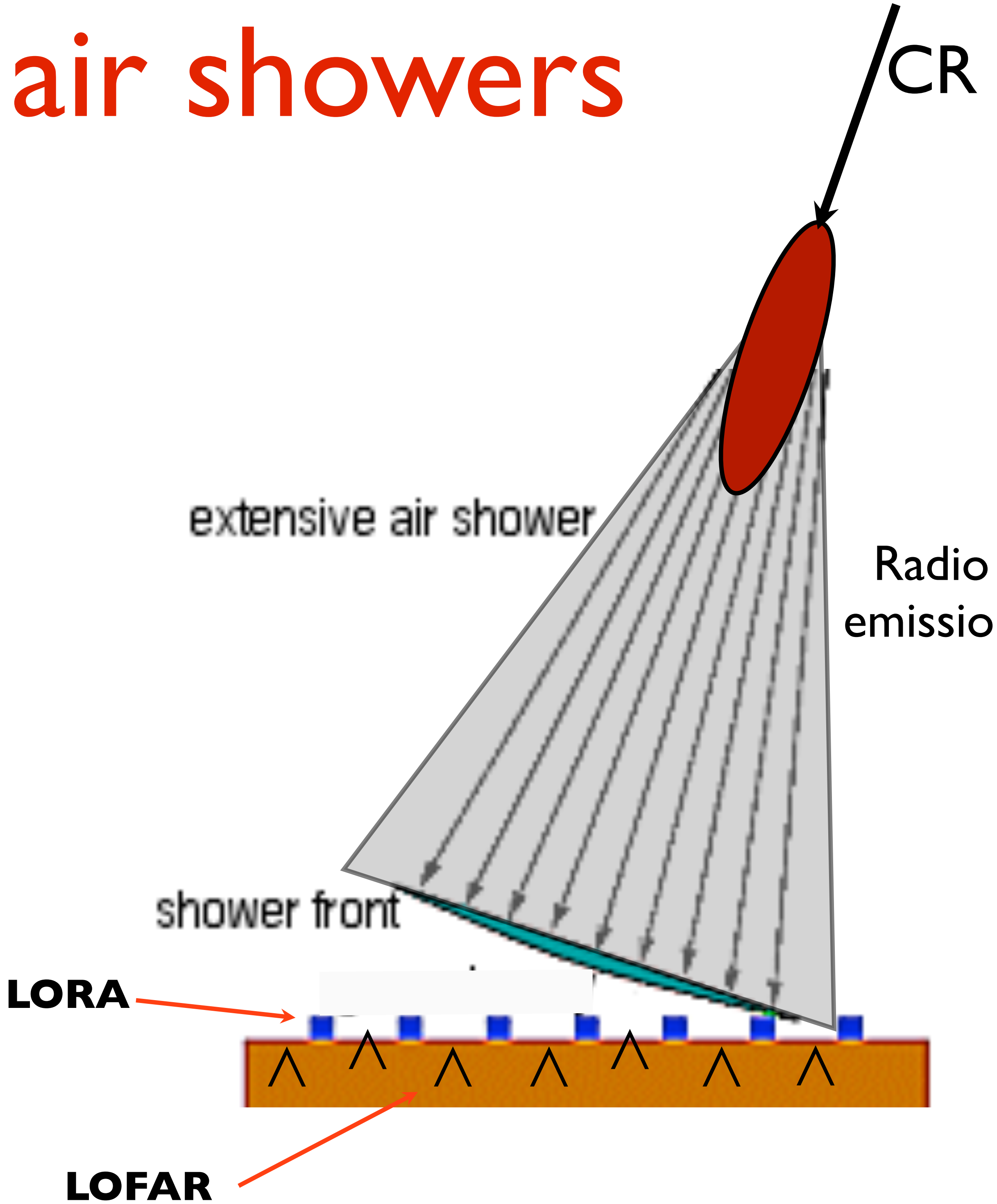
Outlines

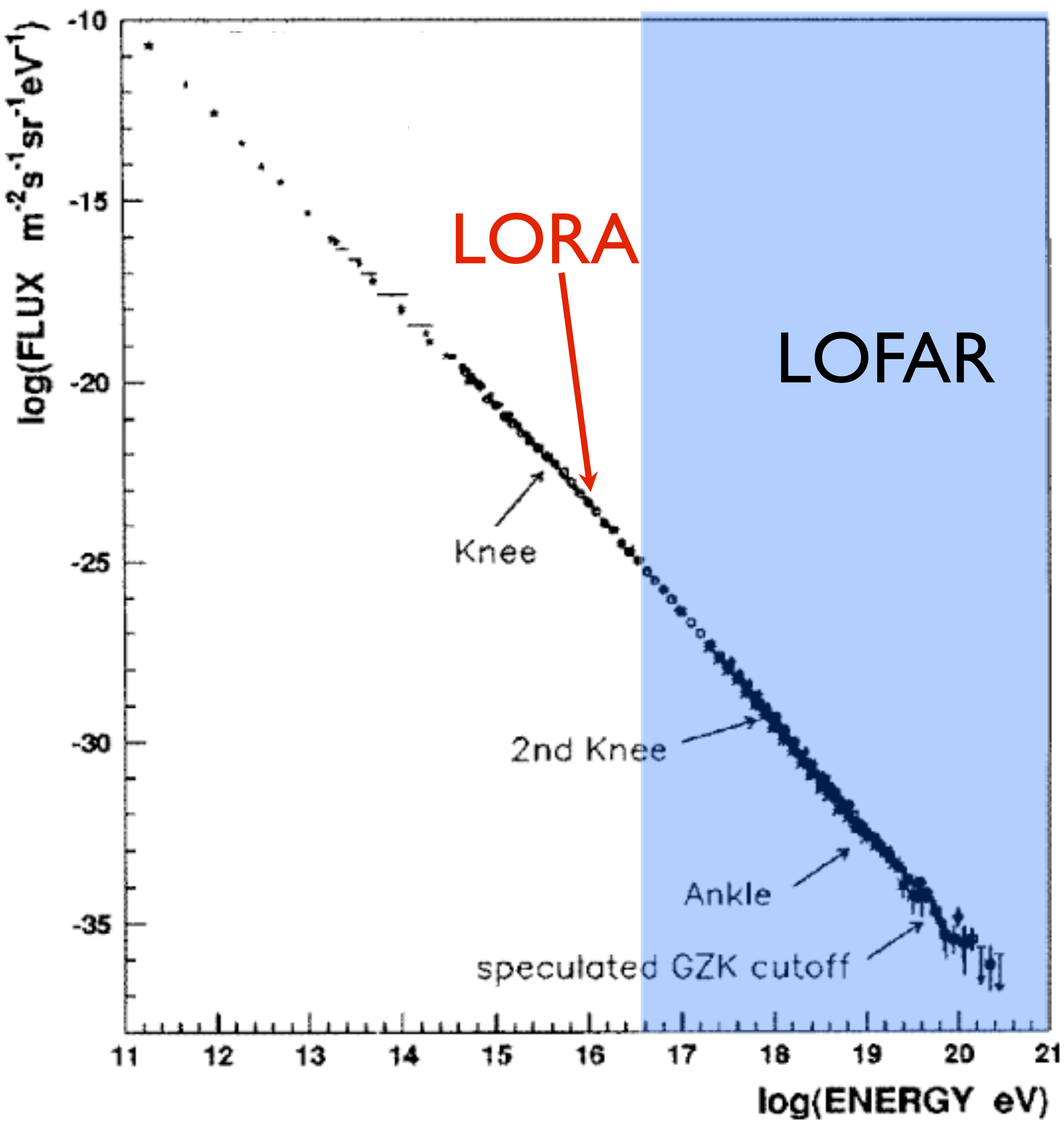
- Introduction: *Detection technique
  *Cosmic ray air showers
  *Why need LORA?
- LORA details: Experimental set-up
- Results: *Cosmic ray measurements
  *Simultaneous observation with LOFAR
- Summary

Cosmic-ray air showers





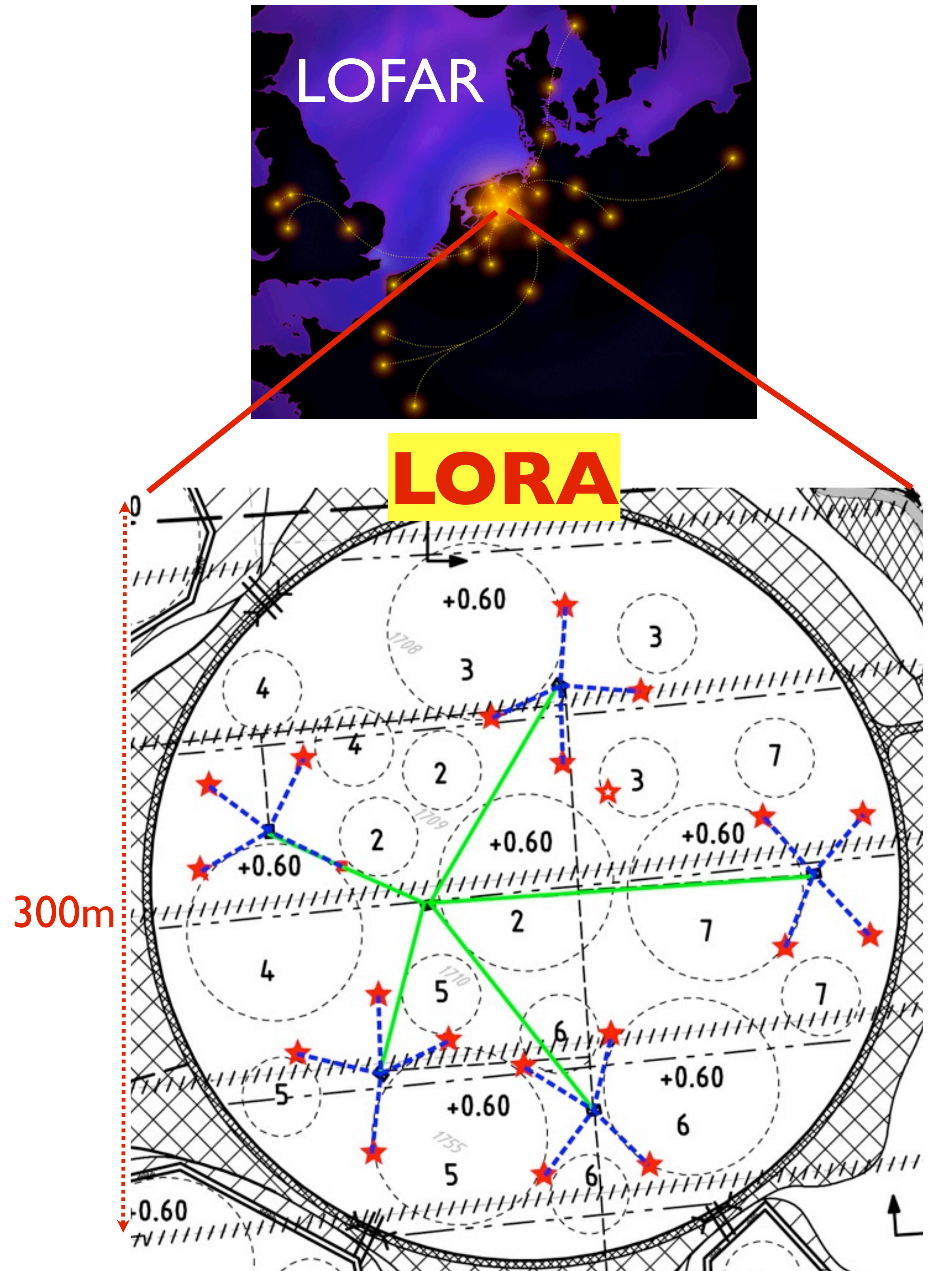
Operating energy region



Purpose: To support cosmic-ray detection with LOFAR

LOFAR Radboud Air Shower Array

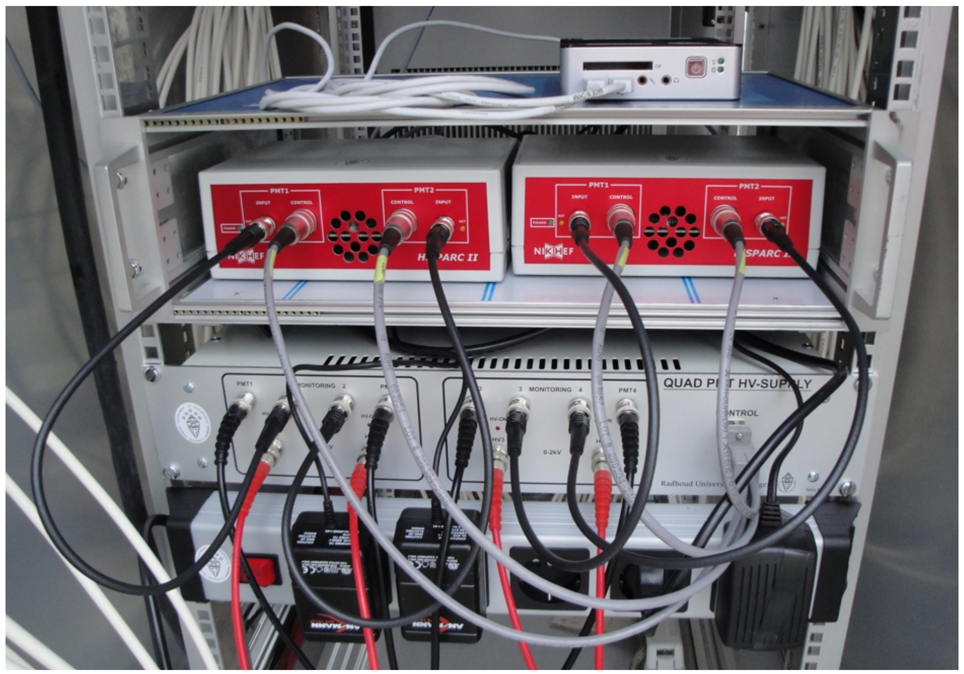
- Primary aim: To complement radio detection of CRs with LOFAR
- 5 stations with 4 detectors each
- At LOFAR stations CS003-007
- Each station is handled by a station computer
- Data processing is done on a central master computer at CS002

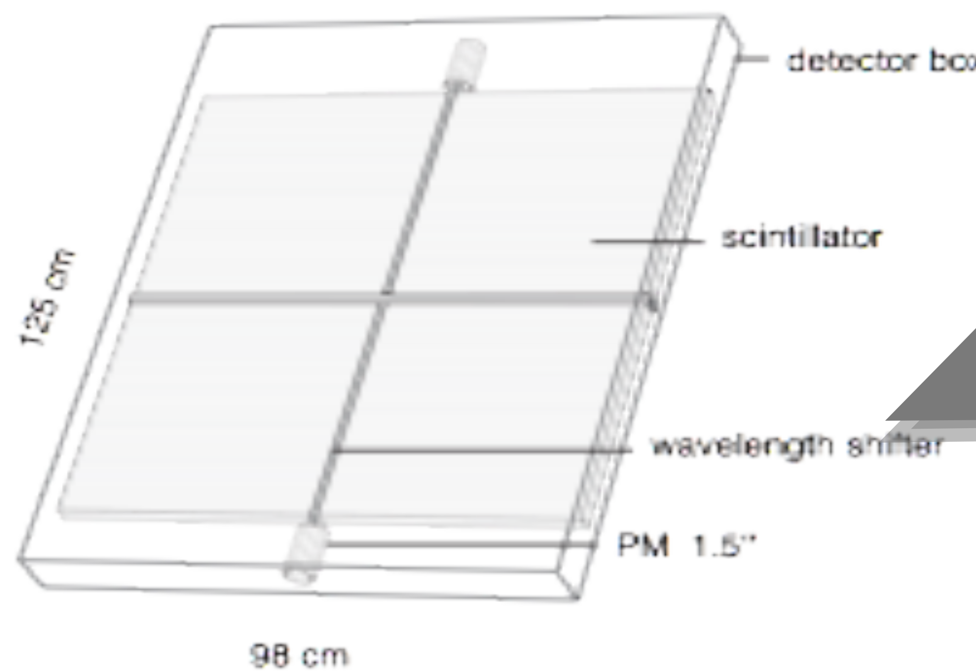


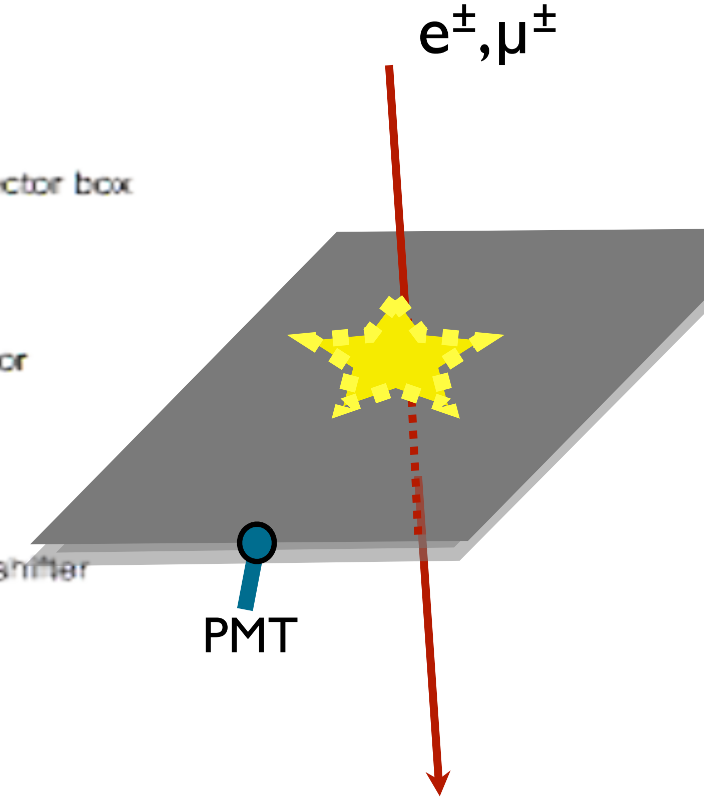
LOFAR Radboud Air Shower Array

Electronics were developed for the HISPARC experiment

Detectors are plastic scintillators from the KASCADE experiment (Antoni et al. 2003)



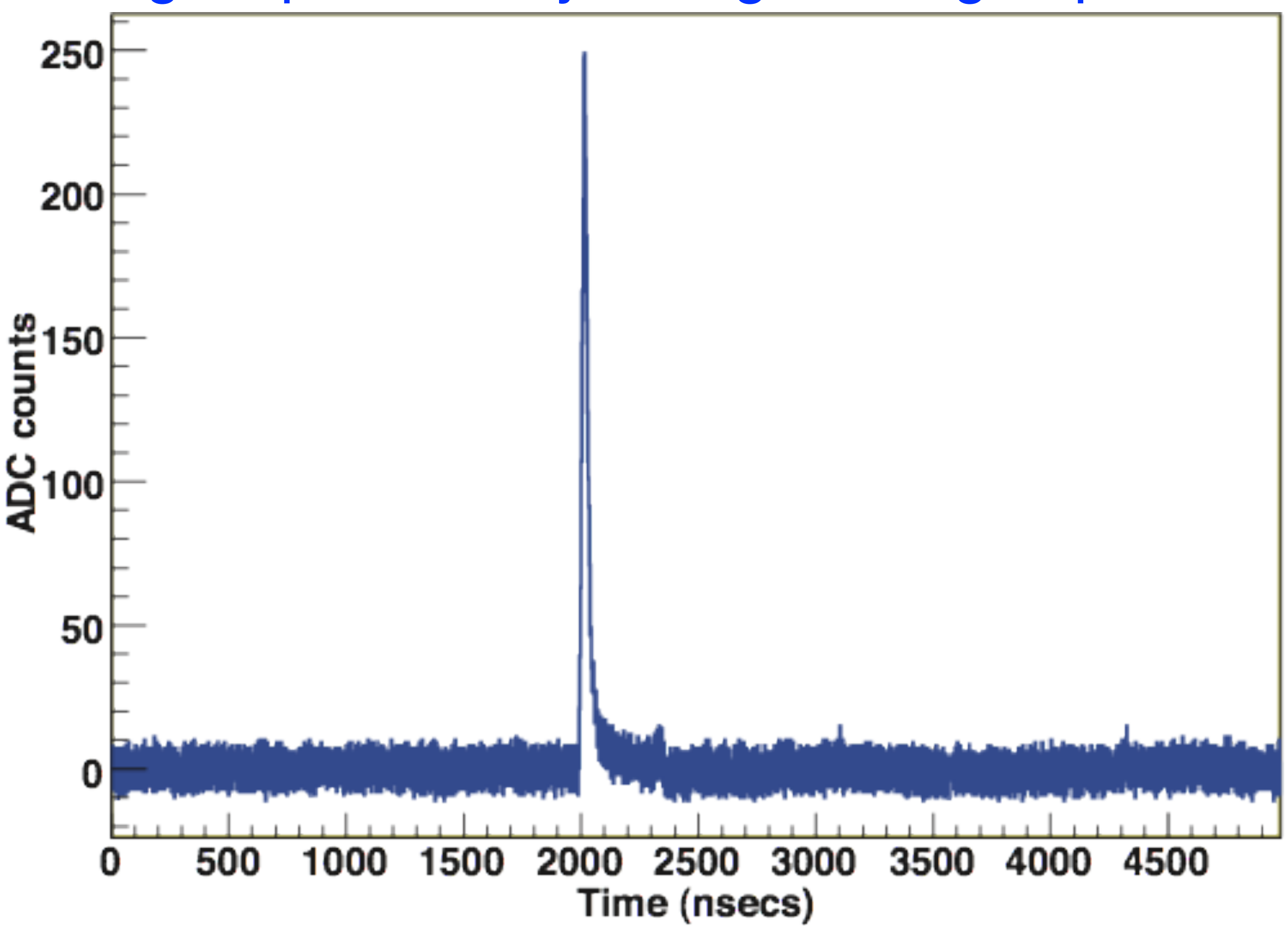




LOFAR Radboud Air Shower Array

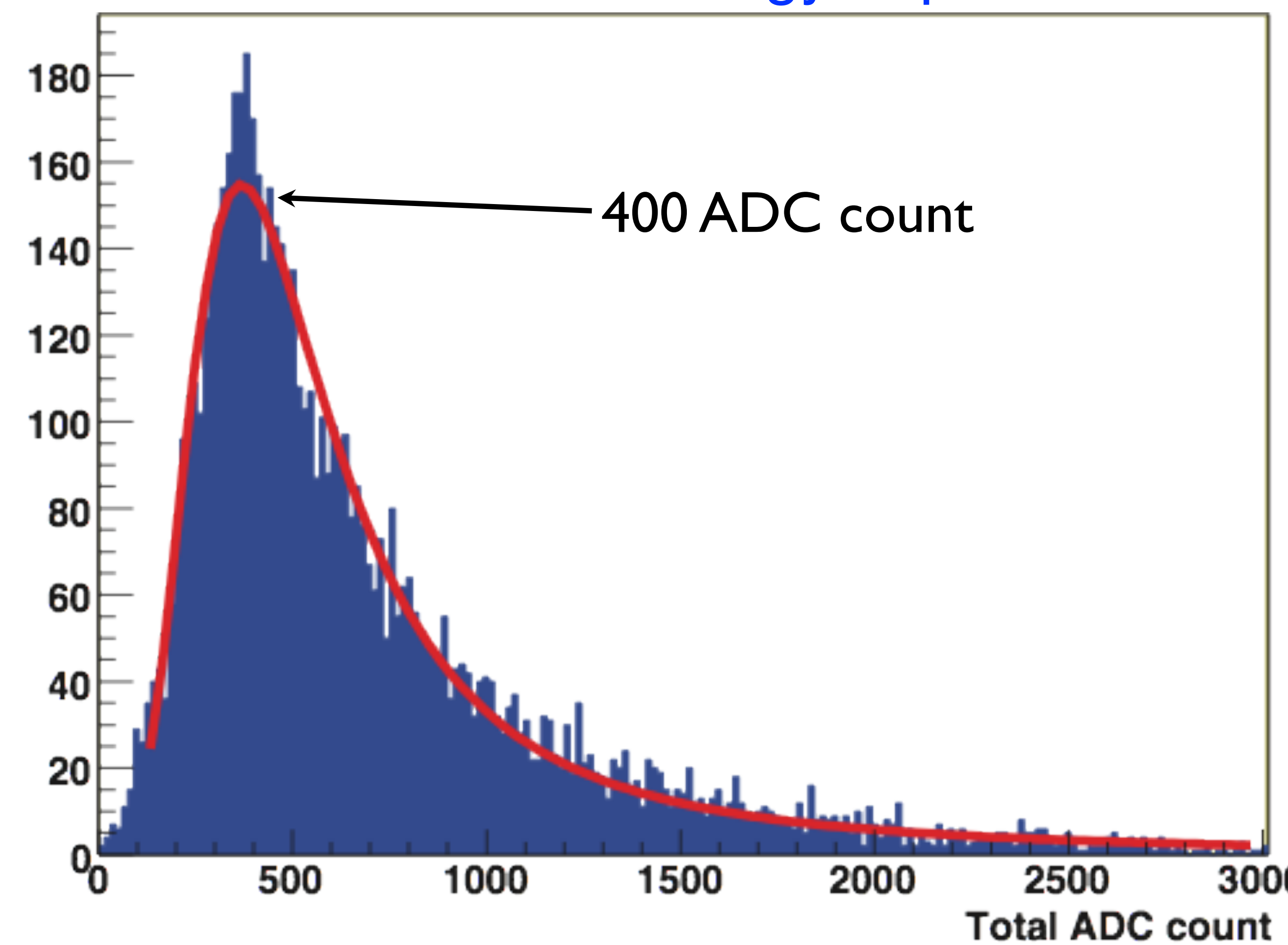
Detector calibration

Signal produce by a single charged particle



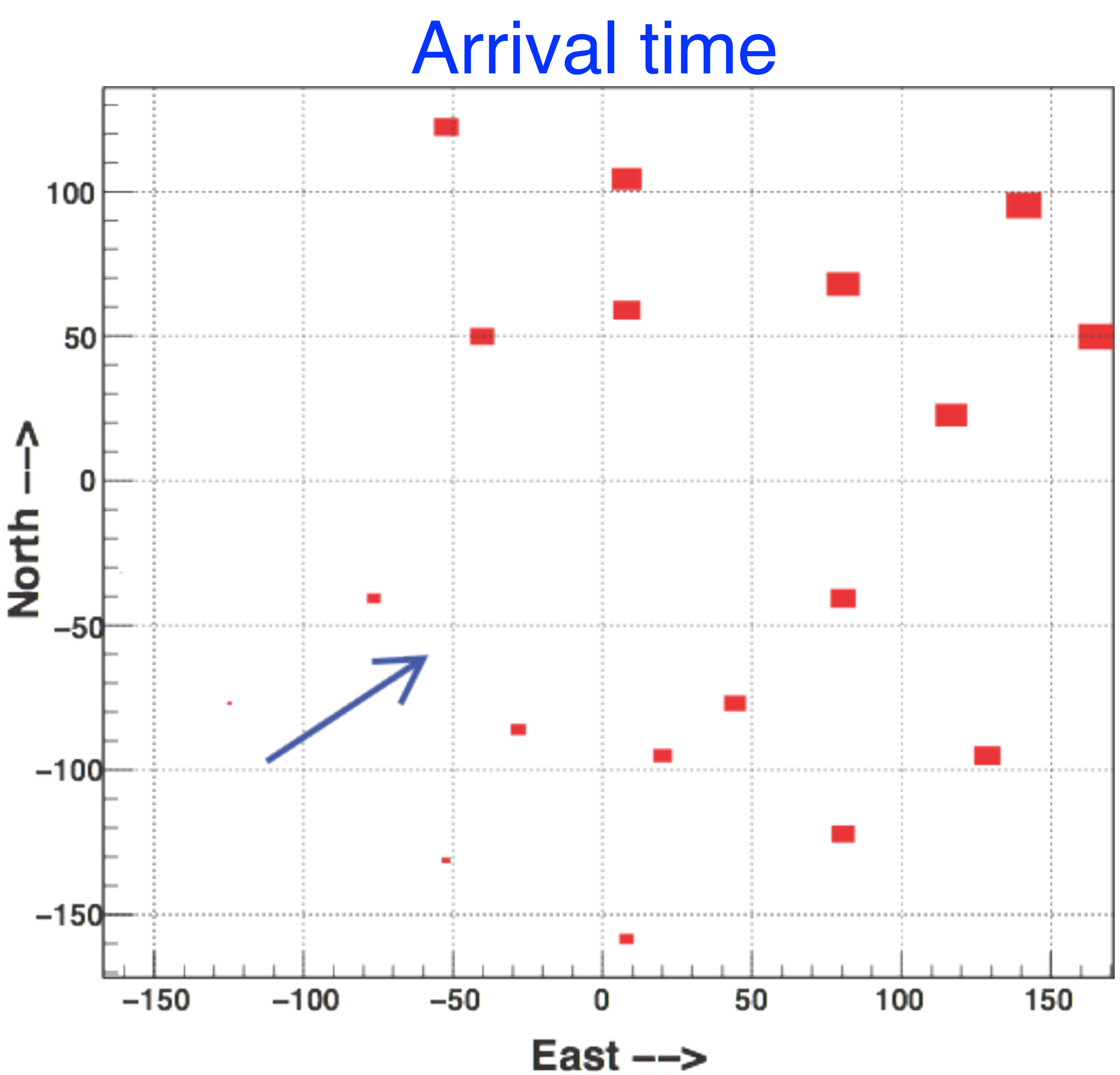
read-out window 10 μs
start 2 μs before trigger
12-bit ADC (2.5 ns sampling rate)

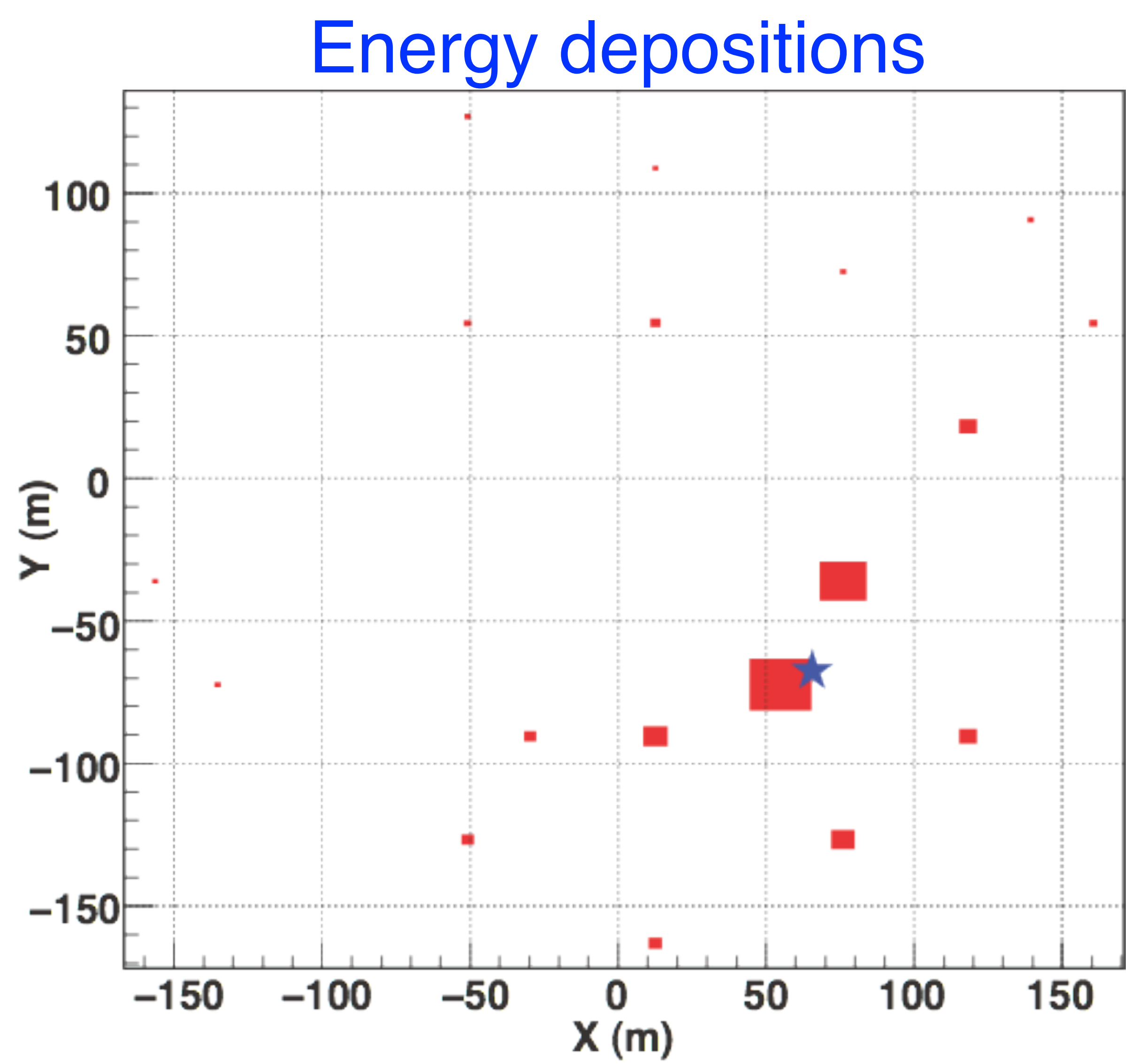
Distribution of energy deposition



Fit of Landau distribution to data
calibration: “single-muon“ peak

A measured CR air shower

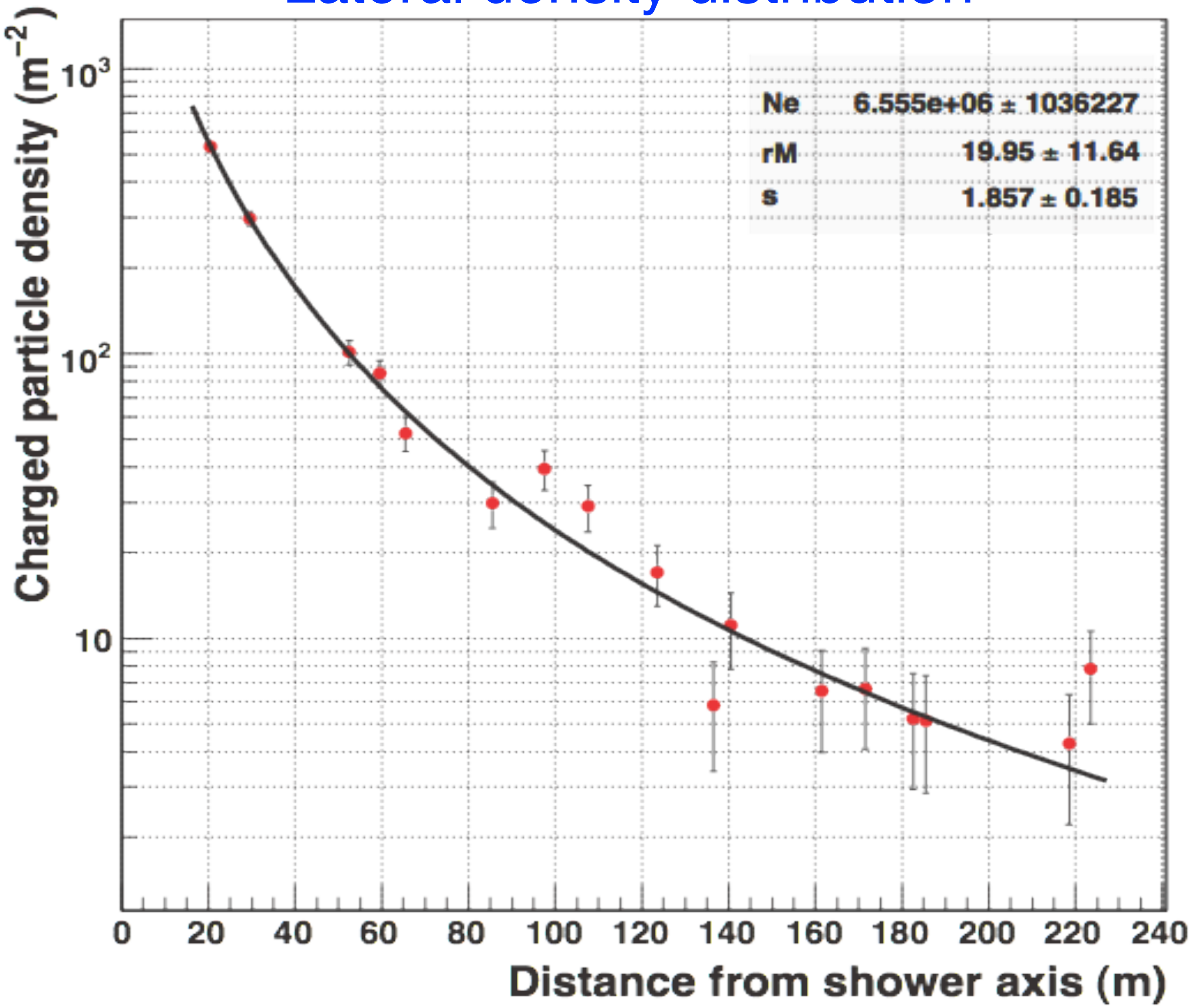




*Arrival time: From the relative time informations between the detectors

A measured CR air shower

Lateral density distribution



Fitted with NKG function:

$$\rho(r, s, N_e) = \frac{N_e}{r_M^2} \frac{\Gamma(4.5 - s)}{2\pi\Gamma(s)\Gamma(4.5 - 2s)} \times \left(\frac{r}{r_M}\right)^{s-2} \left(1 + \frac{r}{r_M}\right)^{s-4.5}$$

Ne=> Shower size ($\propto$ Energy)

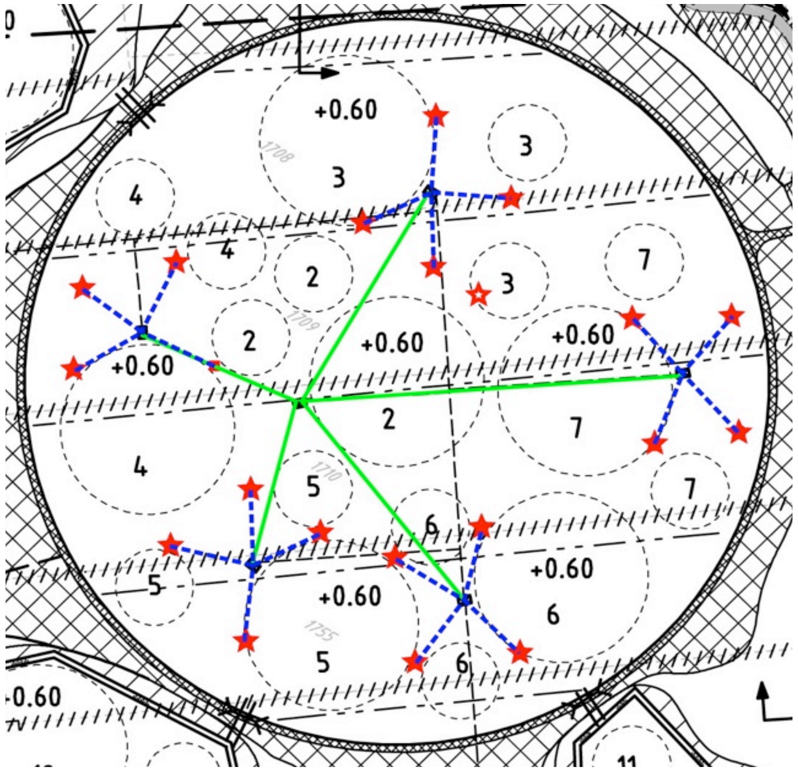
r_M => Moliere radius

s => Age parameter

r(X,Y)=> Shower core position

$(\ominus,\varnothing)$=> Arrival direction

Results from LORA

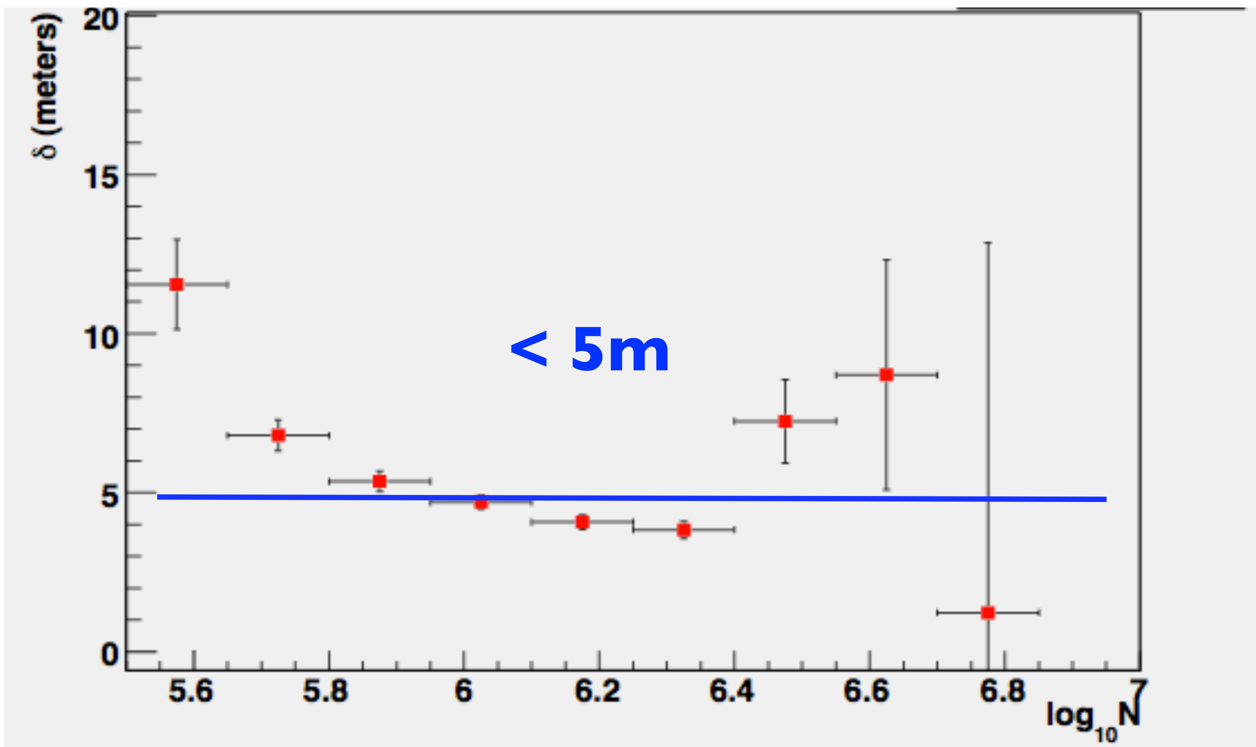


- LORA set up completed in May 2011
- Collected over 200,000 cosmic-ray events
- ~40,000 air showers triggered > 7 detectors
- For each air shower, reconstruct the core position (X,Y), arrival direction (⊖,⌀) and the shower size Ne (=> Energy)

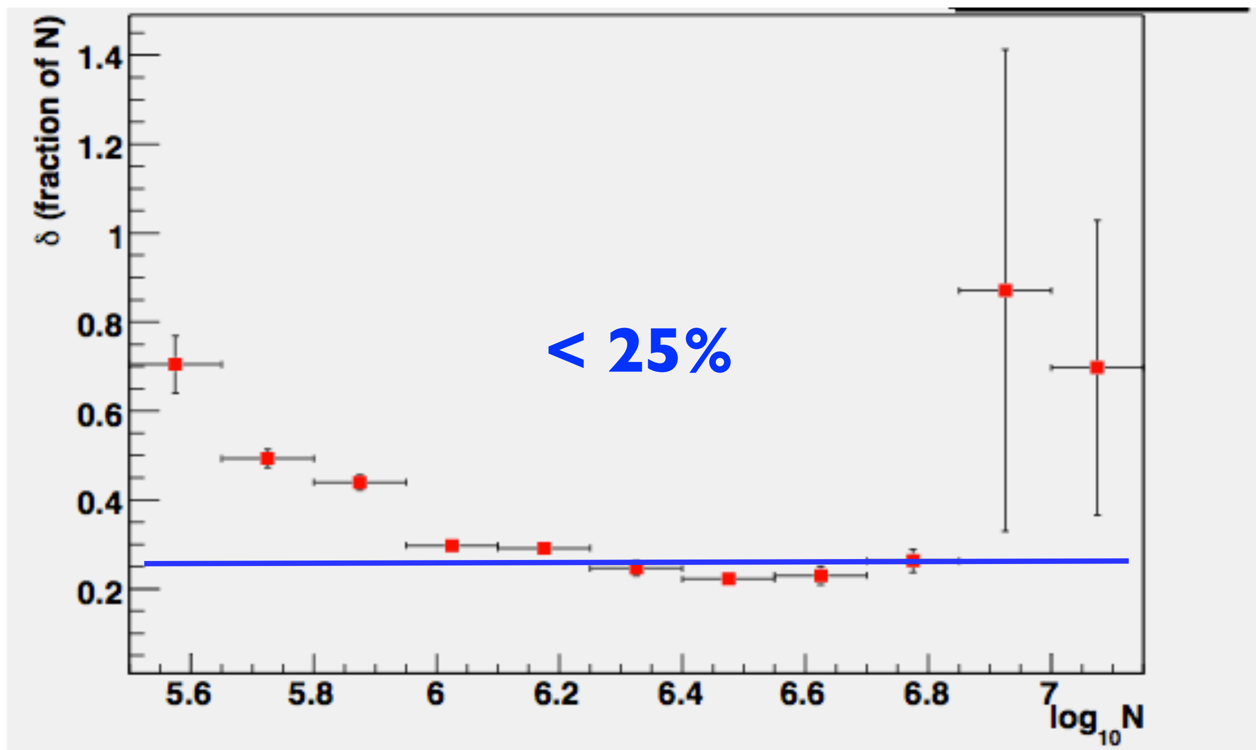
Reconstruction accuracies (from data)

using chess-board method (1/2 array vs. 1/2 array)

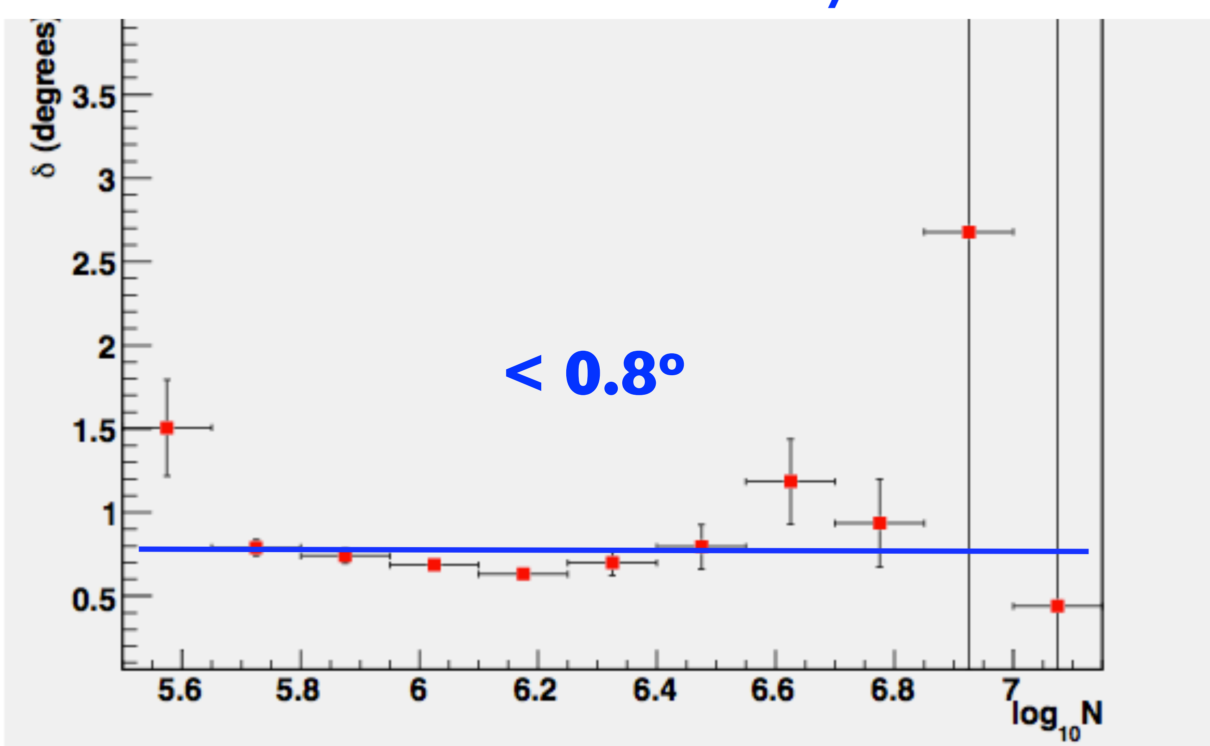
Core position accuracy



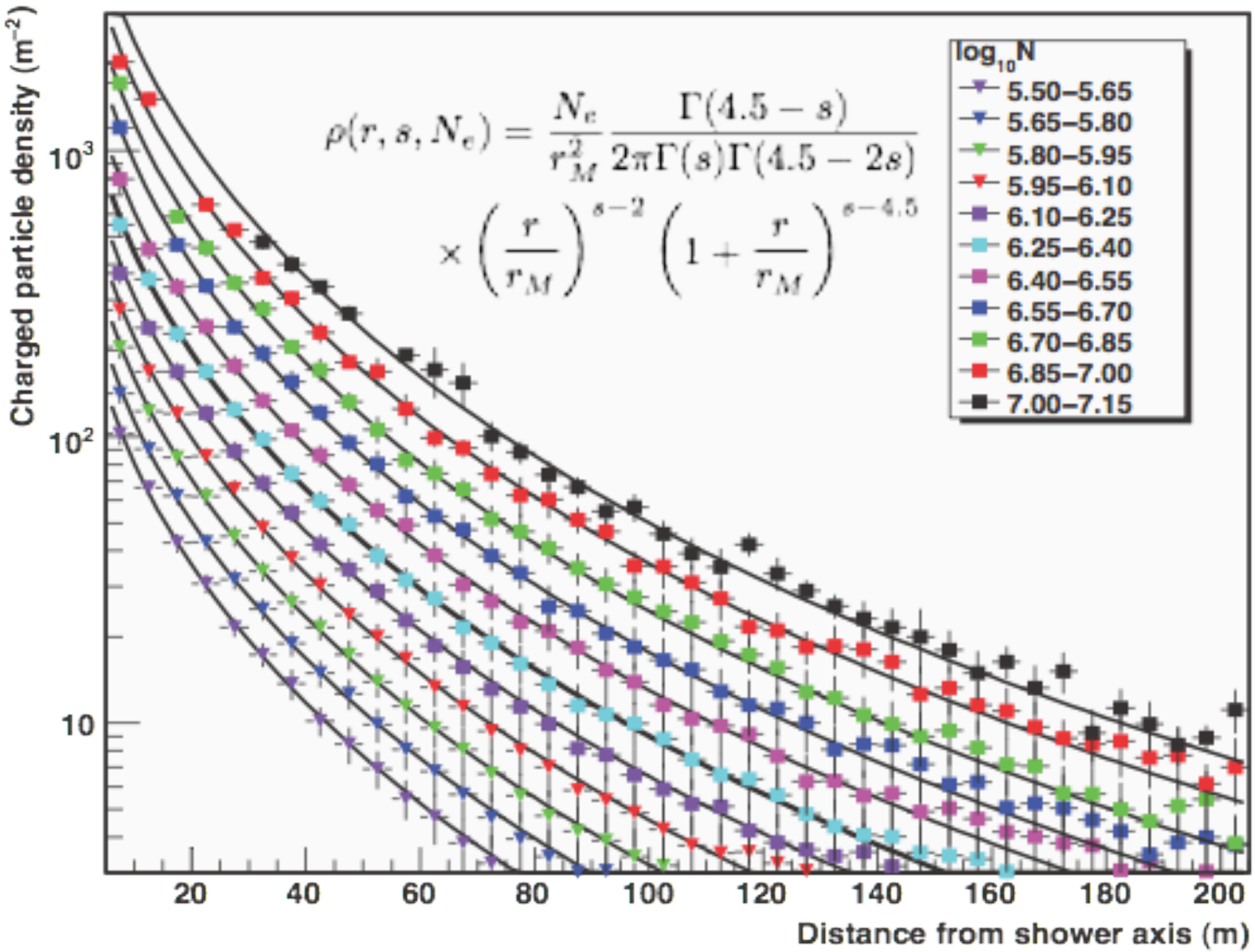
Shower size (energy) accuracy



Direction accuracy

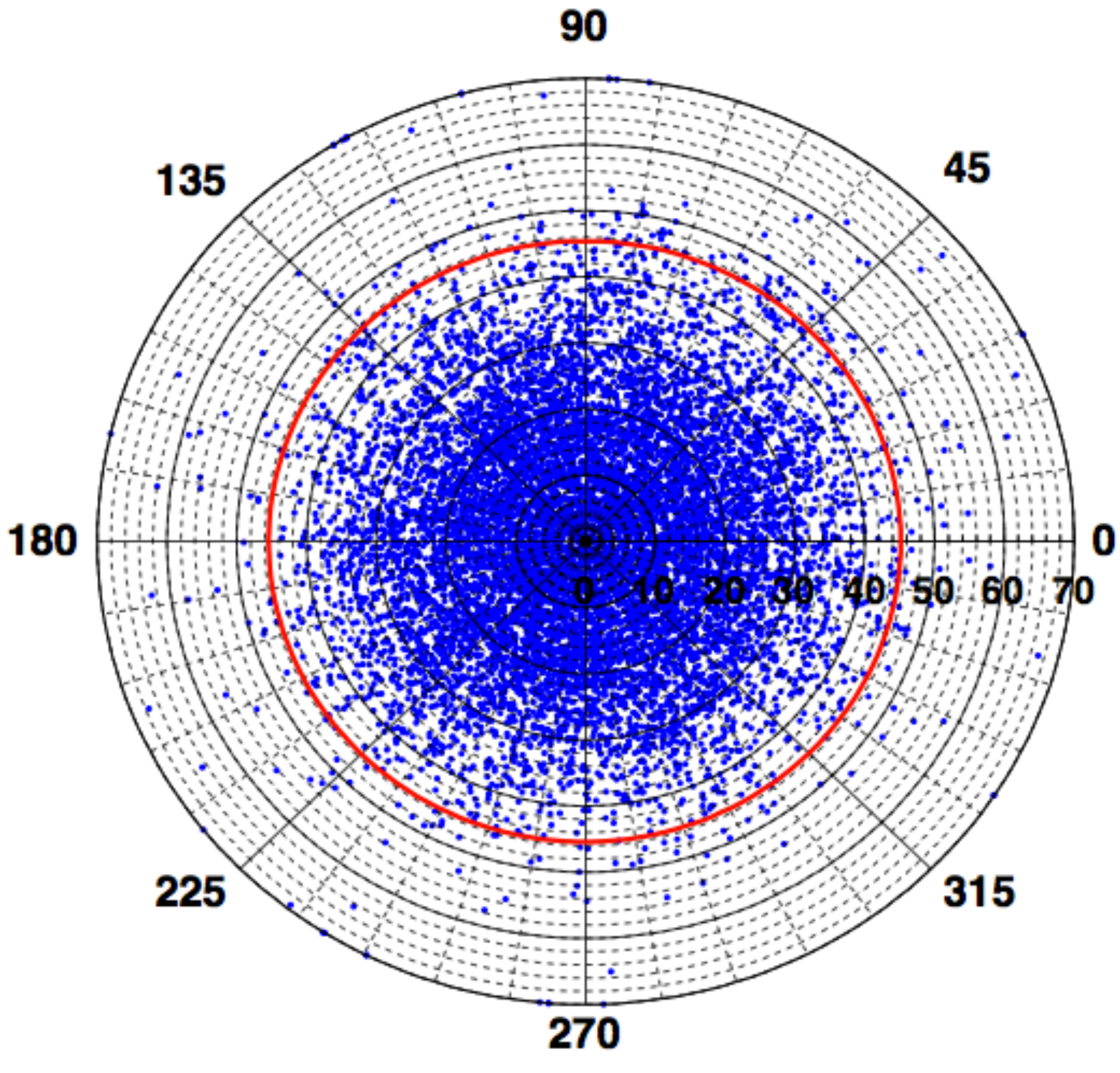


Results: Average lateral distributions

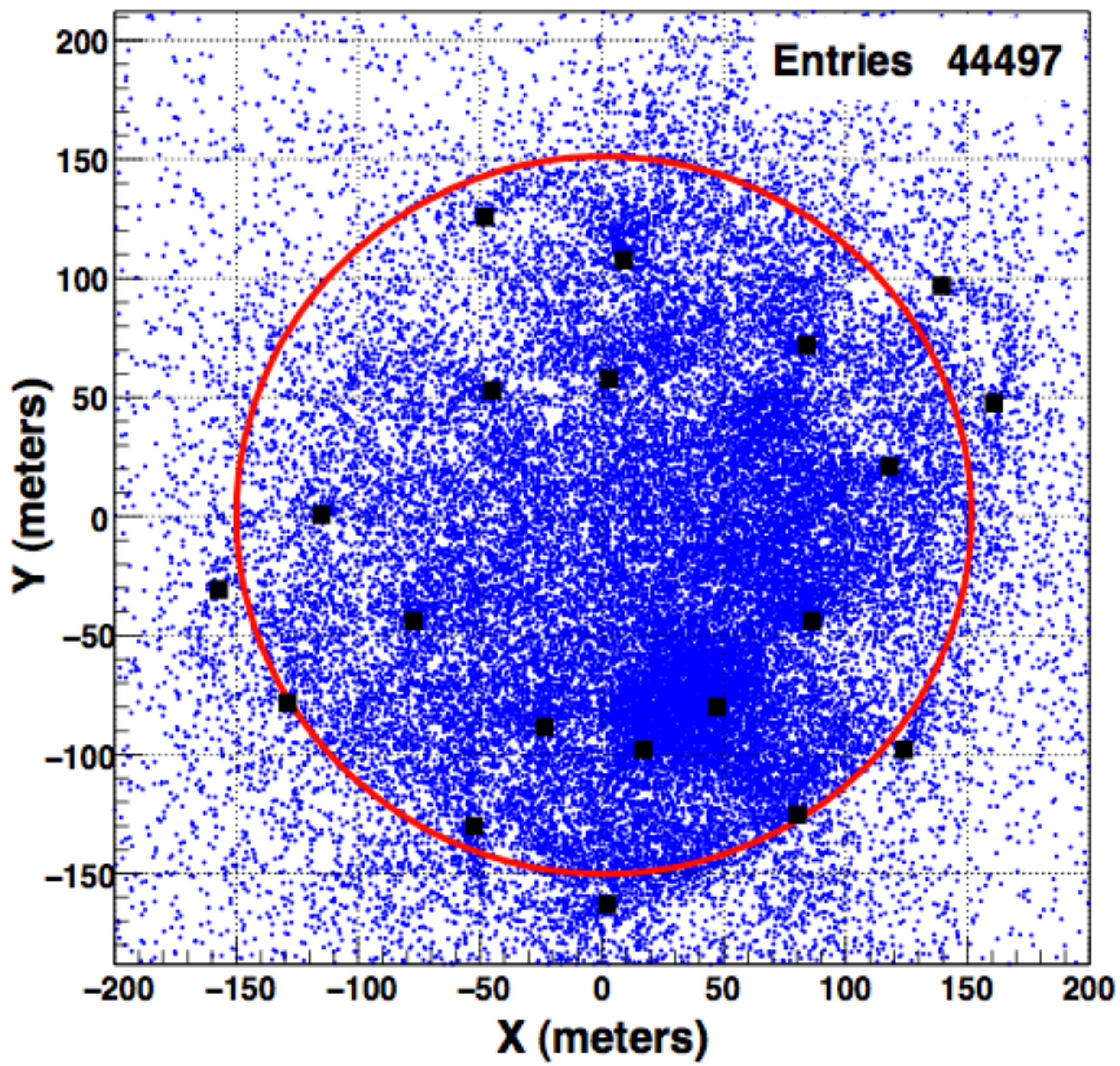


Results:

Arrival direction distributions

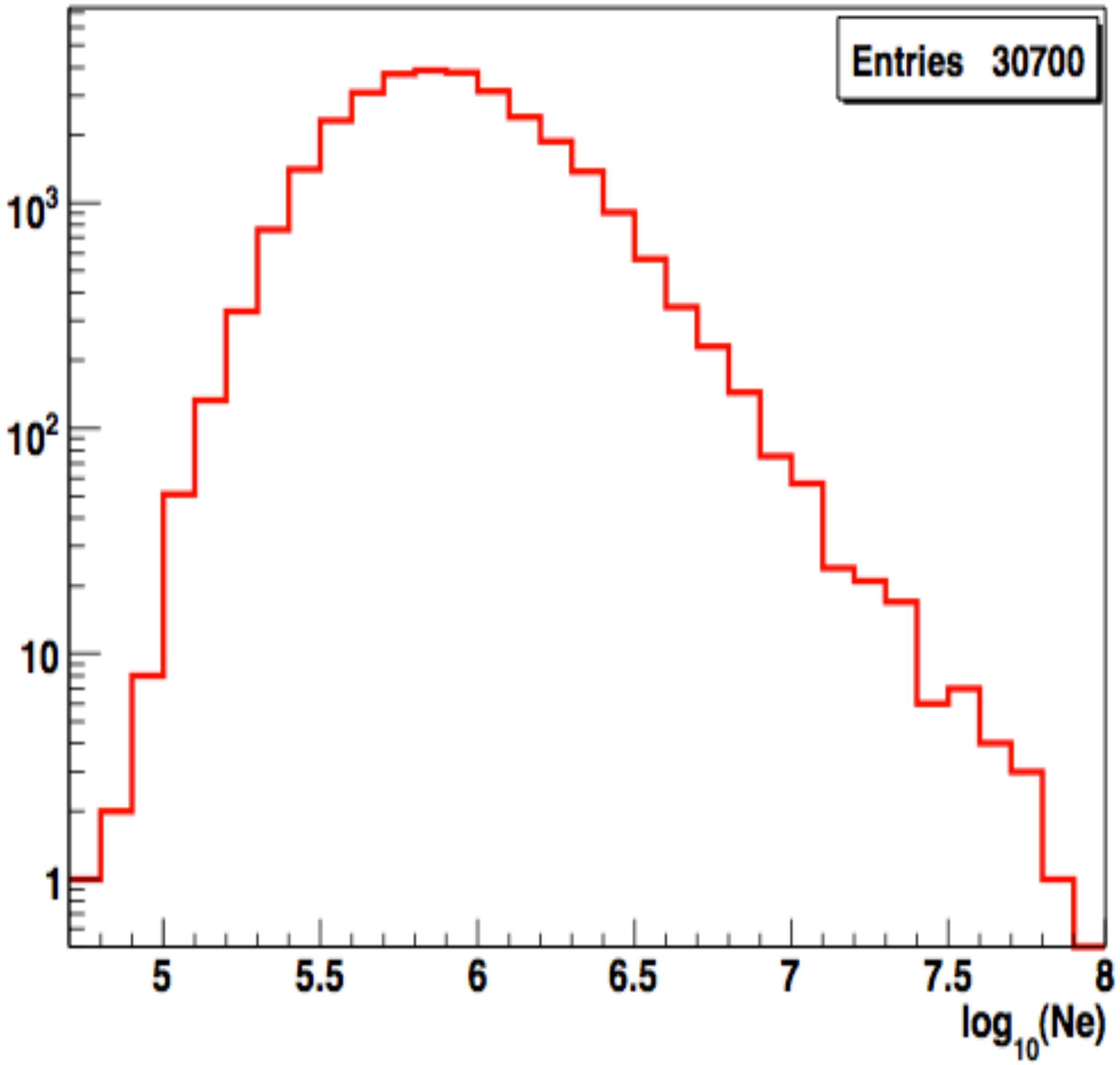


Shower core distributions

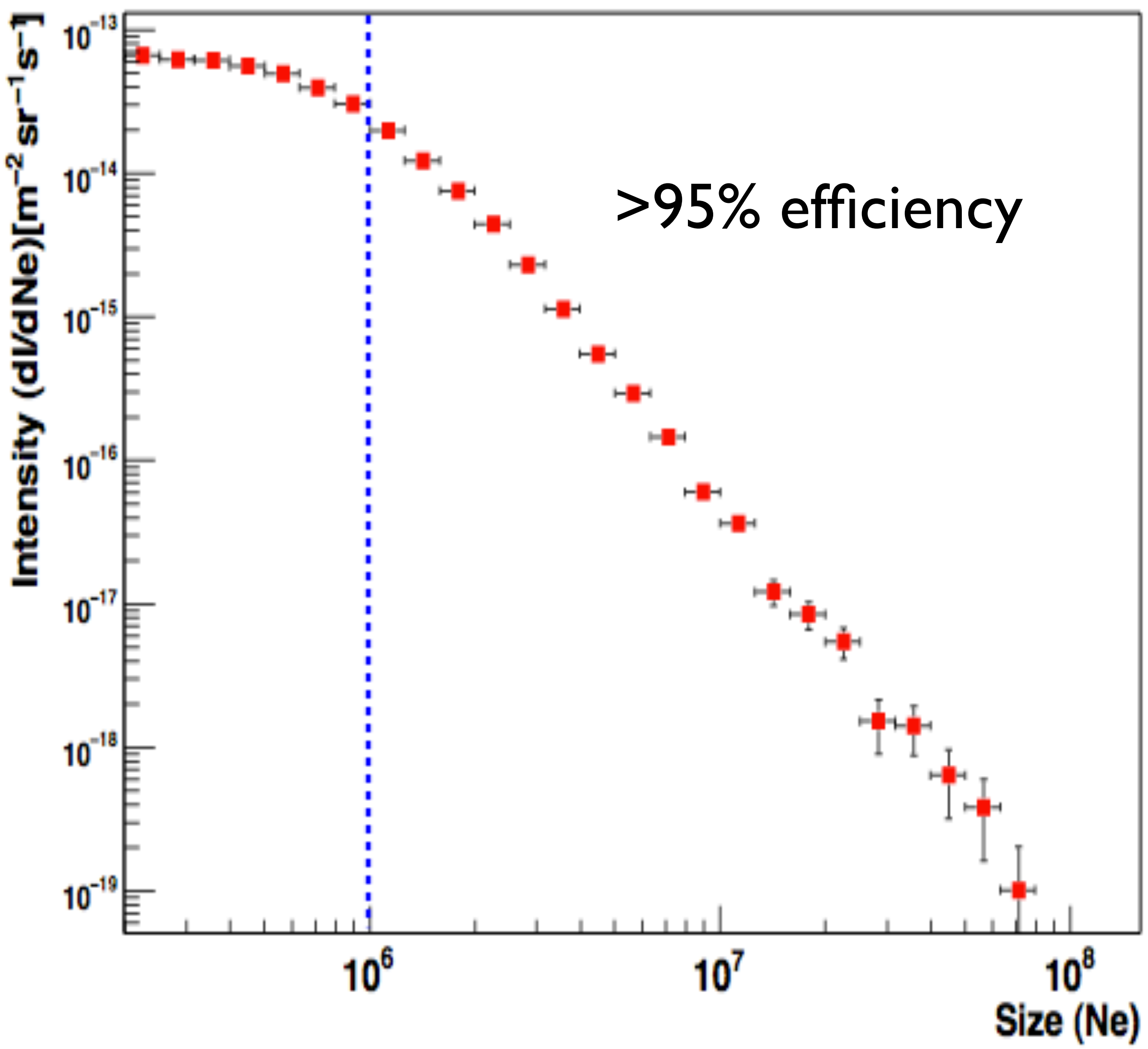


Results: Shower size Ne

Shower size distribution

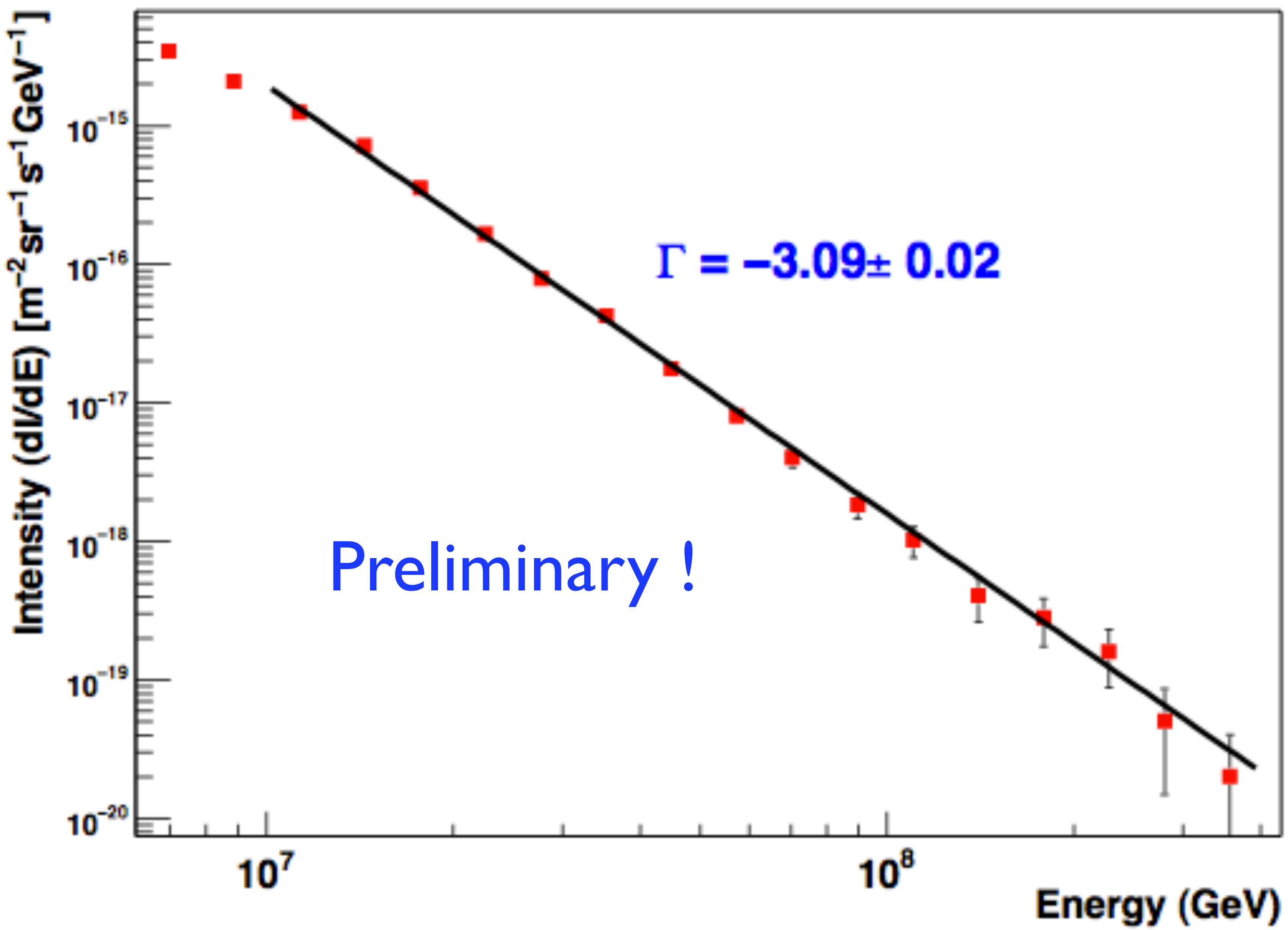


Shower size spectrum



Results: All-particle energy spectrum of cosmic rays with LORA

$\text{Energy} = \text{Ne}^{0.93} \times 10^{1.23}$ GeV (Phd Thesis 2008, KASCADE)



Simultaneous observations with LOFAR

CR event

LORA

*Online processing
*Calculate shower parameters
*Overall processing time ~ (100+30) ms

*For bright event: Send trigger to LOFAR

LOFAR

*TBB data stored for 1.3 s

Simultaneous observations with LOFAR

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LORA

*Online processing
*Calculate shower parameters
*Overall processing time ~ (100+30) ms

*For bright event: Send trigger to LOFAR

LOFAR

*TBB data stored for 1.3 s

First CR detection with LOFAR !

Summary of my talk

- LORA set-up completed in May 2011
- Measured (preliminary) all-particle energy spectrum of cosmic rays
- Started triggering LOFAR
- Led to the 1st detection of CRs with LOFAR in June 2011

We thank the KASCADE collaboration for the detectors.
Also, many thanks to Menno Norden, Klaas stuurwold, Jan Nijboer and many others for their support during the LORA installation.

Thank you!