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Cosmic-Ray Key Science Project : review on recent results and future perspective

Laura Rossetto

on behalf of the CR-KSP :

A. Bonardi, S. Buitink, A. Corstanje, H. Falcke, B. Hare, J.R. Hörandel, P. Mitra, K. Mulrey, A. Nelles, J.P. Rachen, L. Rossetto, P. Schellart, O. Scholten, S. ter Veen, S. Thoudam, T.N.G. Trinh, T. Winchen

Published papers

- → **P. Schellart et al., A&A 560, A98 (2013):** Detecting cosmic rays with the LOFAR radio telescope
- → **P. Schellart et al., NIMPA 742, 115 (2014):** Recent results from cosmic-ray measurements with LOFAR
- → **P. Schellart et al., JCAP 10, 014 (2014):** Polarized radio emission from extensive air showers measured with LOFAR
- → **S. Buitink et al., PRD 90, 082003 (2014):** Method for high precision reconstruction of air shower Xmax using two-dimensional radio intensity profiles
- → **S. Thoudam et al., NIMPA 767, 339 (2014):** LORA – A scintillator array for LOFAR to measure extensive air showers
- → **A. Nelles et al., Aph 60, 13 – 24 (2015):** A parameterization for the radio emission of air showers as predicted by CoREAS simulations and applied to LOFAR measurements
- → **A. Corstanje et al., Aph 61, 22 – 31 (2015):** The shape of the radio wavefront of extensive air showers as measured with LOFAR
- → **P. Schellart et al., PRL 114, 165001 (2015):** Probing Atmospheric Electric Fields in Thunderstorms through Radio Emission from Cosmic-Ray-Induced Air Showers
- → **A. Nelles et al., Aph 65, 11 – 21 (2015):** Measuring a Cherenkov ring in the radio emission from air showers at 110-190 MHz with LOFAR
- → **A. Nelles et al., JCAP 05, 018 (2015):** The radio emission pattern of air showers as measured with LOFAR – a tool for the reconstruction of the energy and the shower maximum
- → **A. Nelles et al., JInst 10, P11005 (2015):** Calibrated the absolute amplitude scale for air showers measured at LOFAR
- → **S. Thoudam et al., Aph 73, 34 – 43 (2016):** Measurement of the cosmic-ray energy spectrum above 10^{16} eV with the LOFAR Radboud Air Shower Array
- → **A. Corstanje et al., A&A 590, 41 (2016):** Timing calibration and spectral cleaning of LOFAR time series data
- → **S. Buitink et al., Nature 531, 70 (2016):** A large light-mass component of cosmic rays at 10^{17} – $10^{17.5}$ eV from radio observations
- → **T.N.G. Trinh et al., PRD 93, 023003 (2016):** Influence of Atmospheric Electric Fields on the Radio Emission from Extensive Air Showers

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RECENTLY published papers

→ **O. Scholten et al., PRD 94, 103010 (2016):** Measurement of the circular polarization in radio emission from extensive air showers confirms emission mechanisms
→ **T.N.G. Trinh et al., PRD 95, 083004 (2017):** Thunderstorm electric fields probed by extensive air showers through their polarized radio emission
→ **A. Corstanje et al., Aph 89, 23 – 29 (2017):** The effect of the atmospheric refractive index on the radio signal of extensive air showers

Recently published papers

Measurements of circular polarization in fair-weather events

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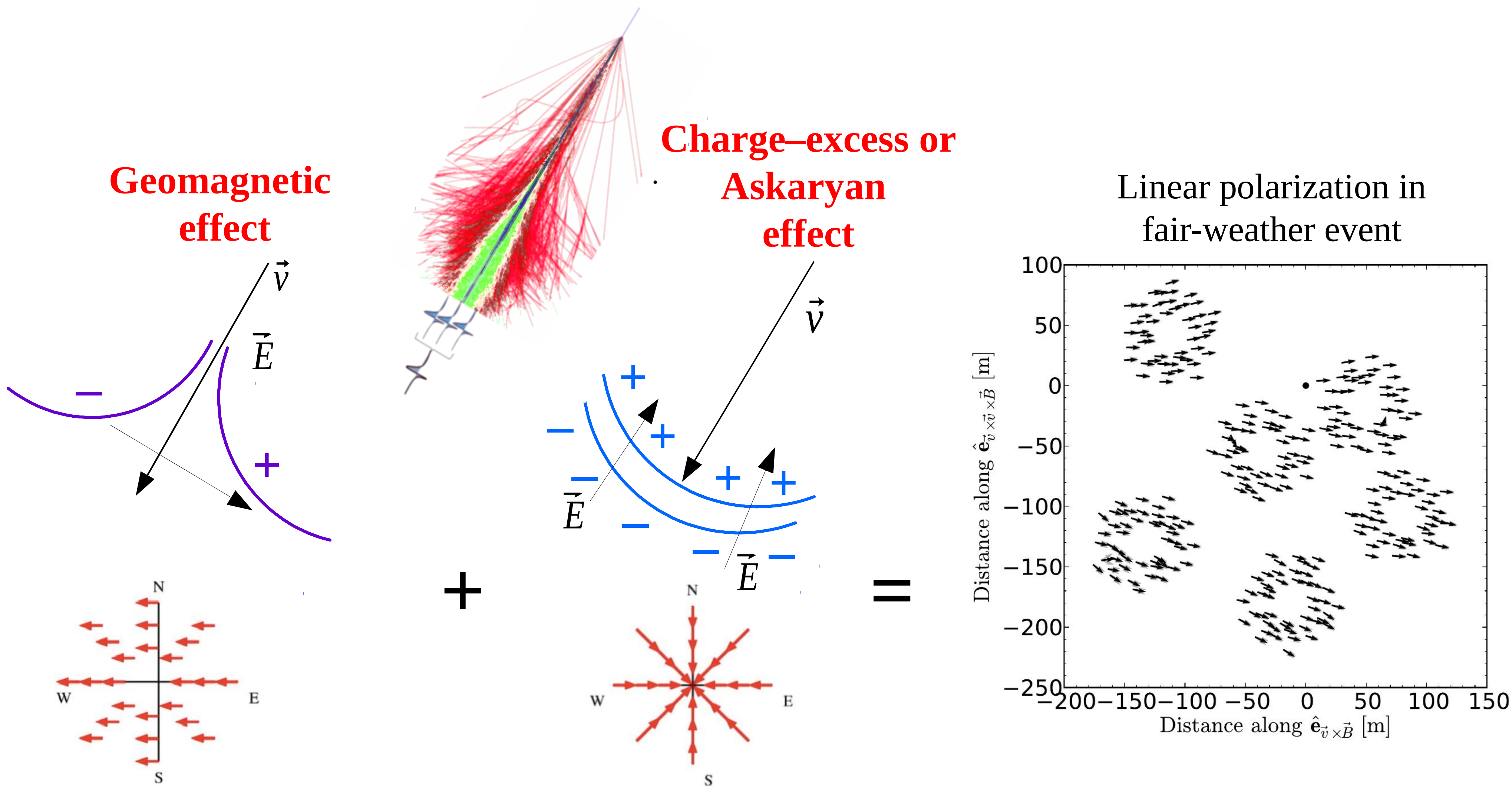

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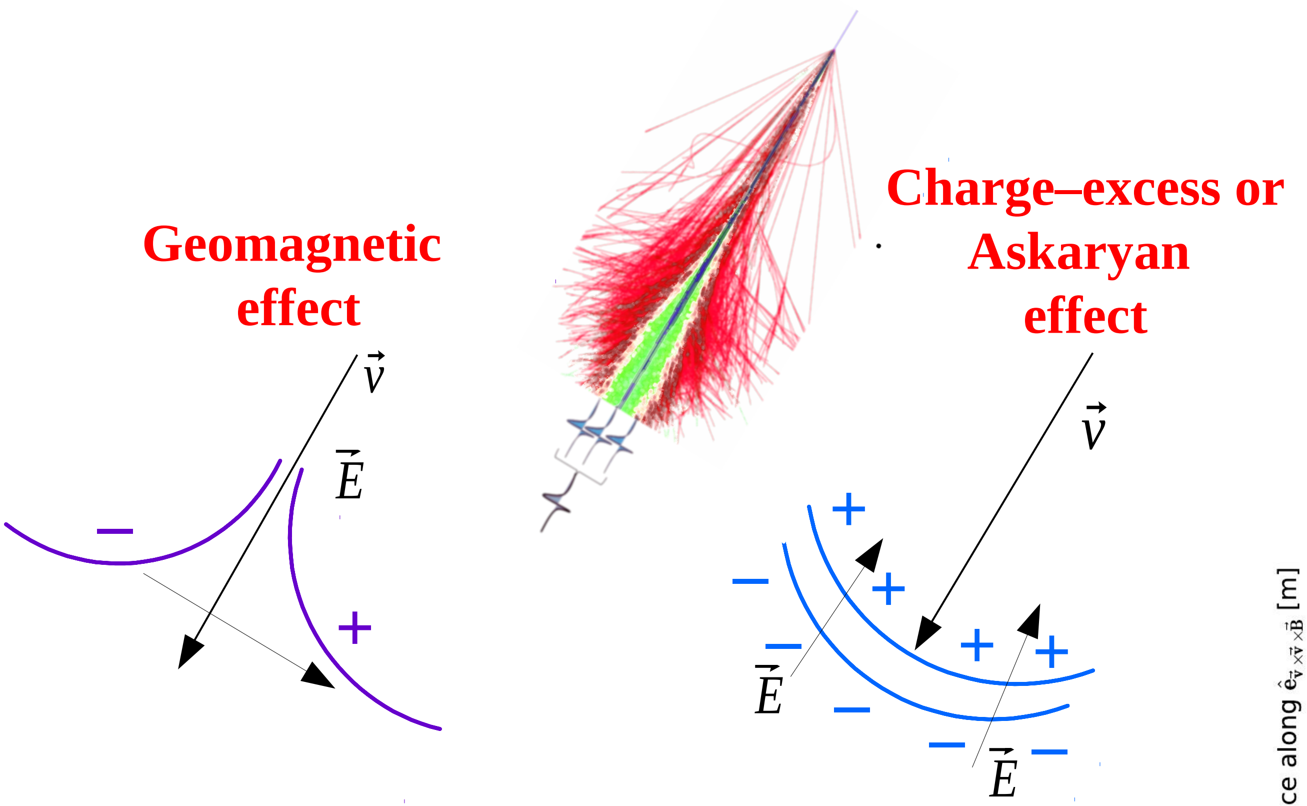


STOKES parameters:

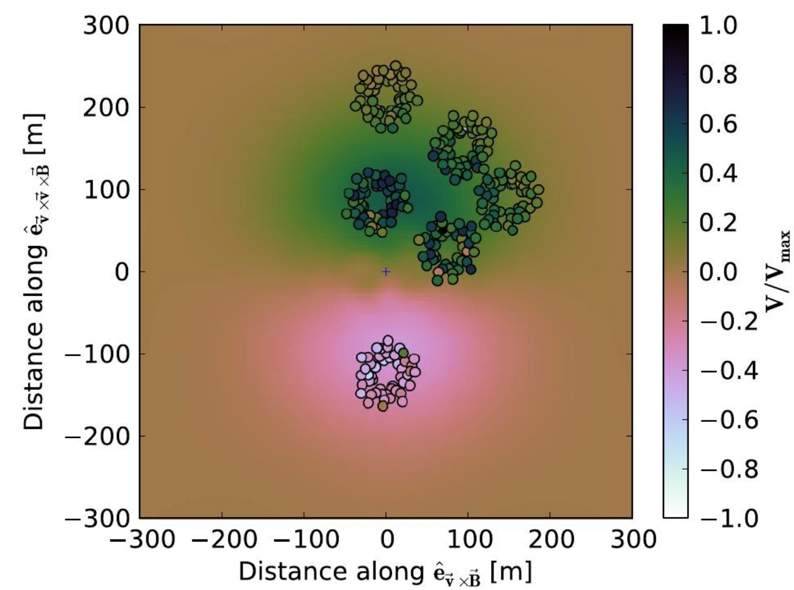
I → intensity

Q , U → linear polarization

V → circular polarization

Circular polarization due to a **time–delay** of the **Askaryan** effect of about **1 ns**

Circular polarization in fair-weather event



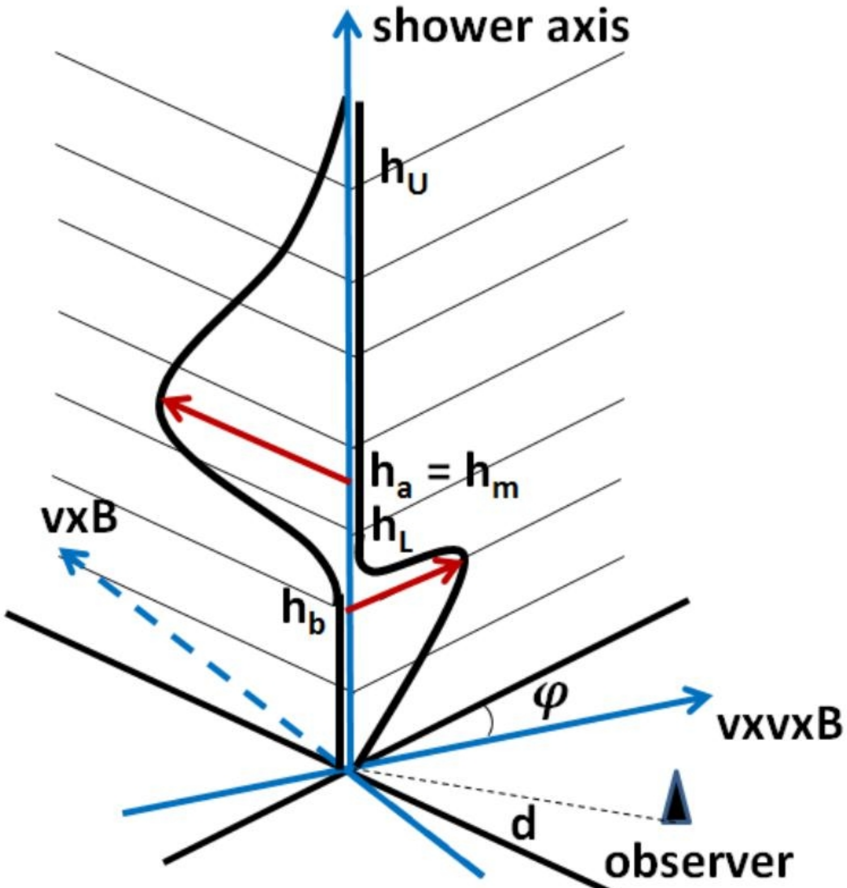
Recently published papers

Measurements of circular polarization in thunderstorm events

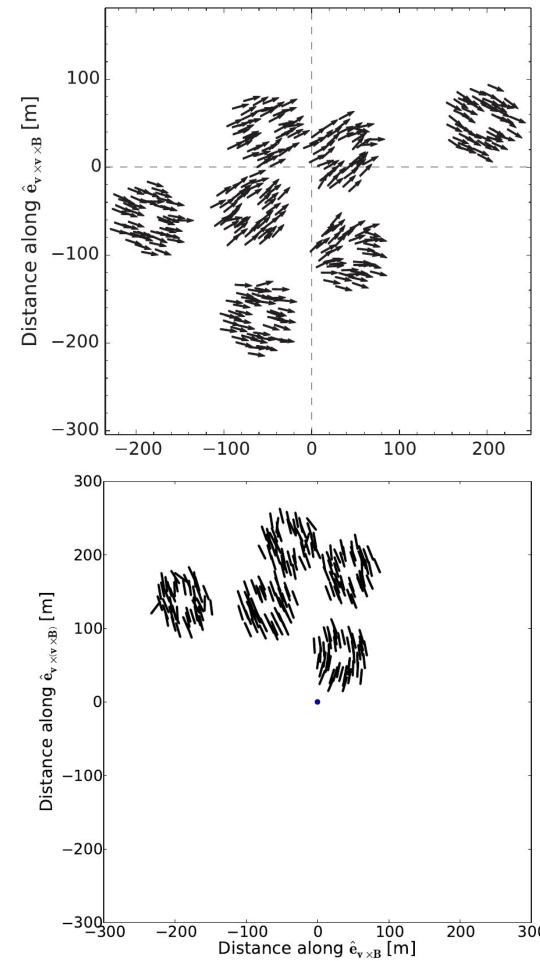
→ T.N.G. Trinh et al., PRD 95, 083004 (2017): Thunderstorm electric fields probed by extensive air showers through their polarized radio emission

The E–field changes direction at different altitudes

→ the **linear polarization** of the signal is not aligned in the V X B direction



Linear polarization in fair-weather event



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Measurements of circular polarization in thunderstorm events

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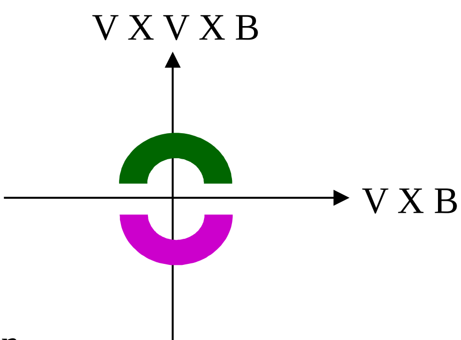
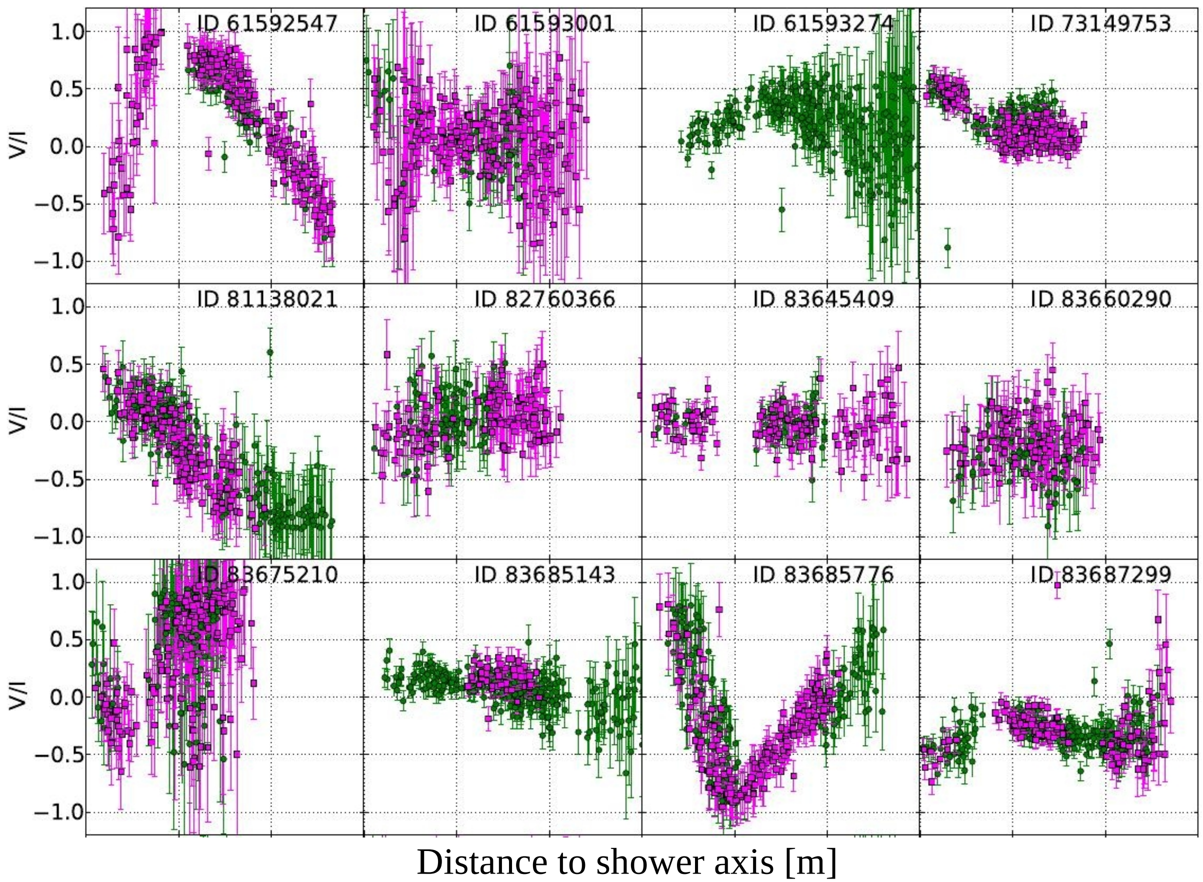
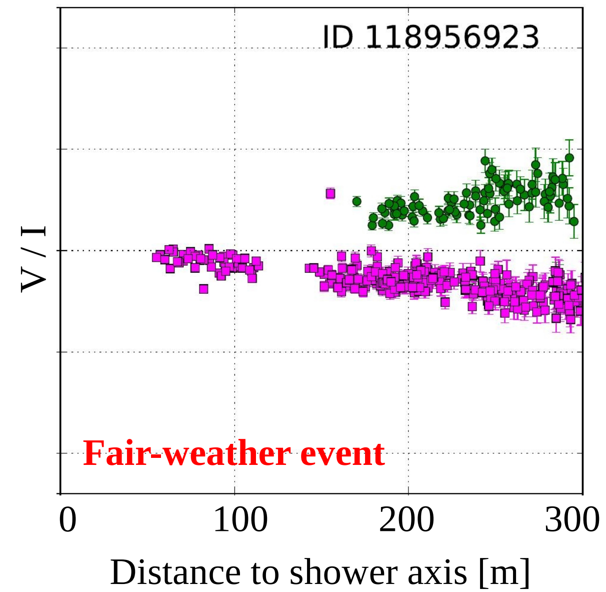
Circular polarization in thunderstorm is enhanced because of the transverse current direction changes at different altitudes



Antenna position in the shower plane
azimuth = **0 – 180 deg**
azimuth = **180 – 360 deg**

Thunderstorm events



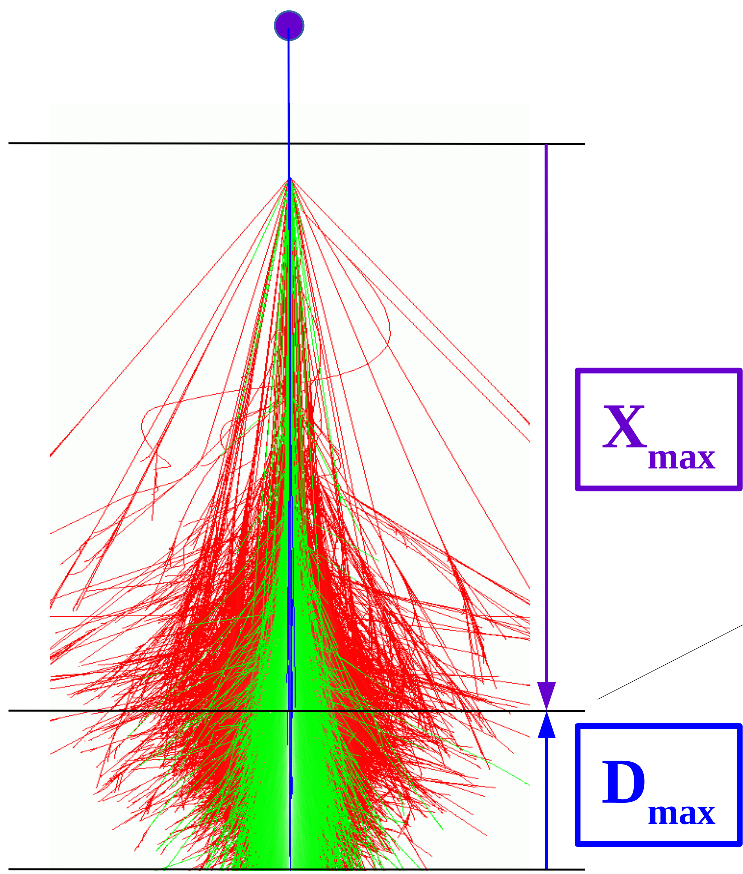


Recently published papers

Effect of atmospheric refractive index on mass composition measurements

→ A. Corstanje et al., Aph 89, 23 – 29 (2017): The effect of the atmospheric refractive index on the radio signal of extensive air showers

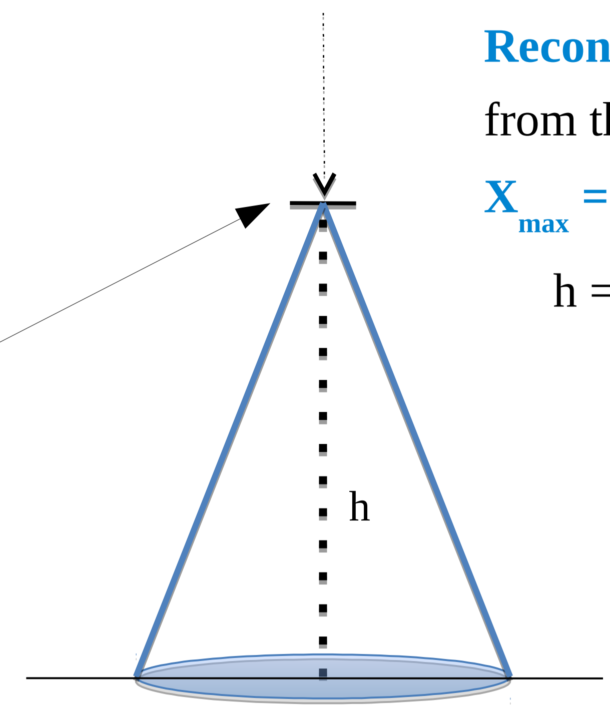
X_{max} (protons) > X_{max} (Fe)
because $\sigma_{proton} < \sigma_{Fe}$



Simple simulation model

– assuming all radiation comes from **X_{max} level**

– assuming the footprint size scales with the Cherenkov angle (Cherenkov angle model)



Reconstructed X_{max}
from the footprint

X_{max} = 670 g/cm^2

h = 3.51 km

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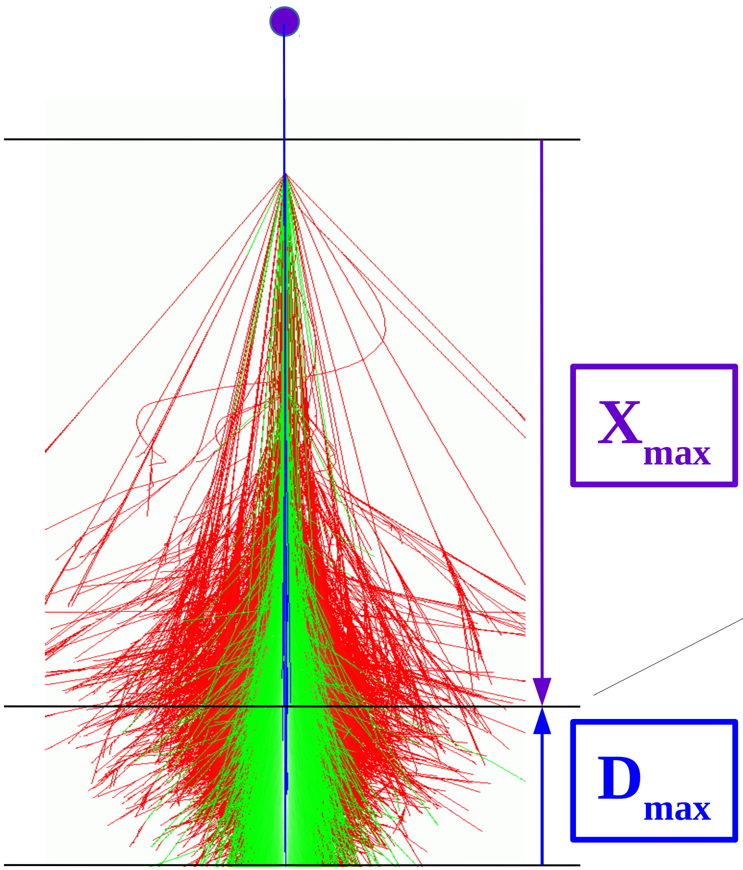
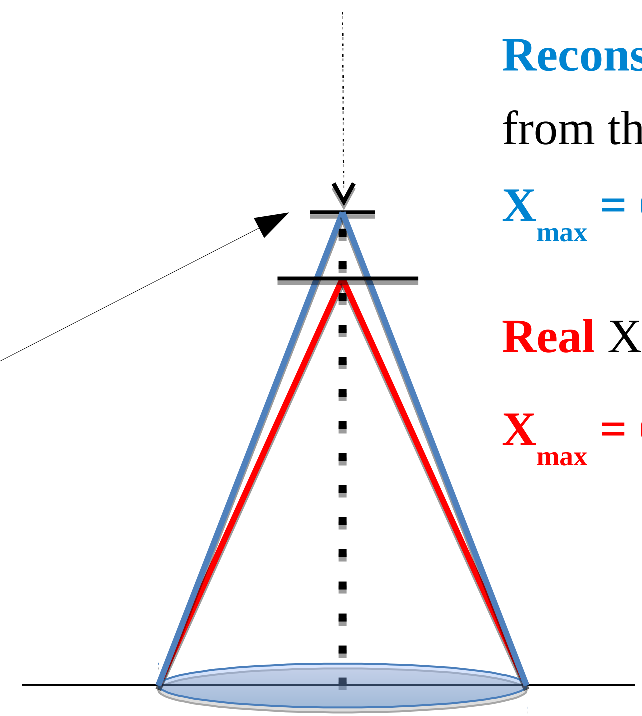


– the reconstructed X_{max} depends on the refractive index n (**higher n → smaller X_{max}**)

– the refractive index depends on temperature, humidity and air pressure



Reconstructed X_{max} from the footprint

X_{max} = 670 g/cm^2

Real X_{max}

X_{max} = 687 g/cm^2

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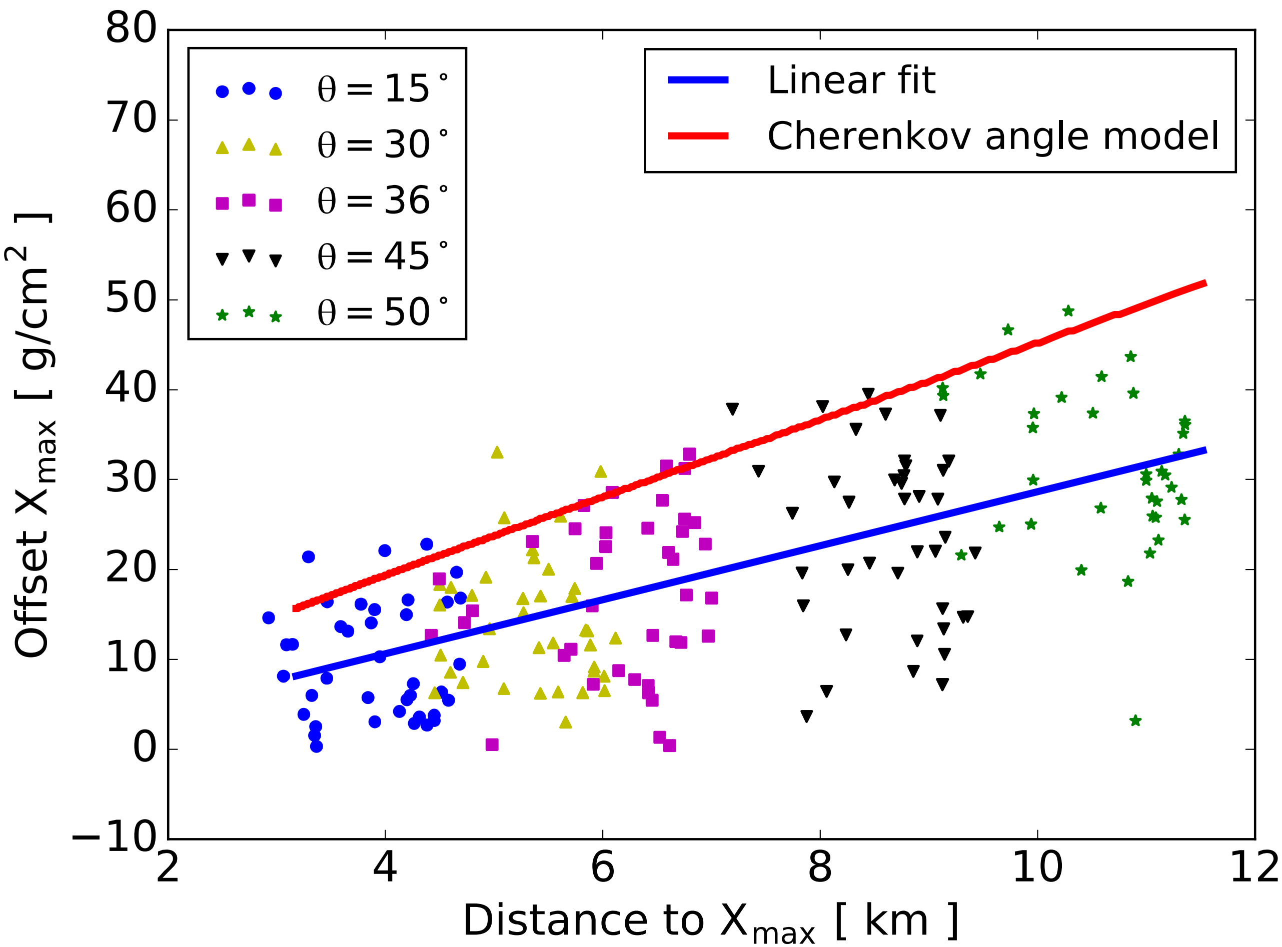


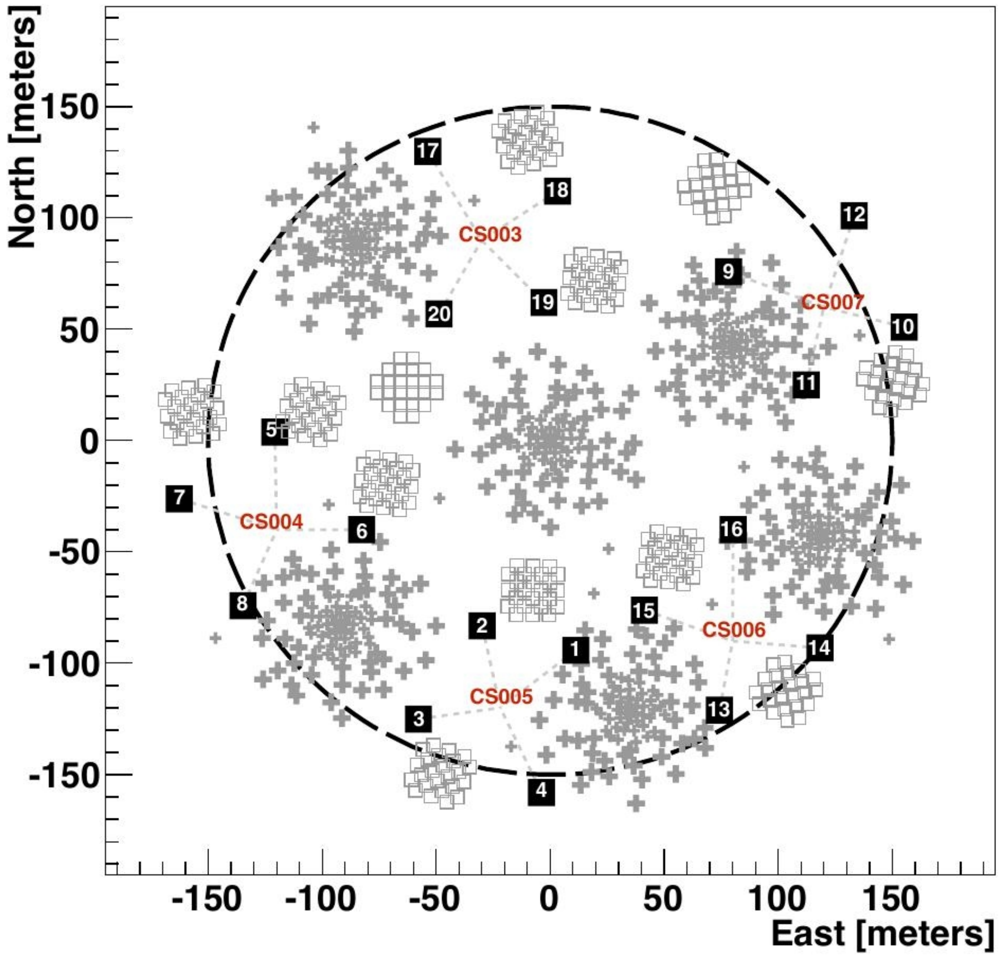
Simulation results

– a **10 % variation** of **n** gives a systematic error on the reconstructed X_{max} of about **5 – 20 g/cm^2**

– the systematic error on X_{max} depends on the **zenith angle** of the arrival direction (up to 30 g/cm^2 for very inclined showers)

– **this affects composition analysis**

LORA performances



→ **Campaign in June 2016**:

– most **connectors** of the HV and signal cables have been replaced

– HV and signal cables of detector 5 have been replaced

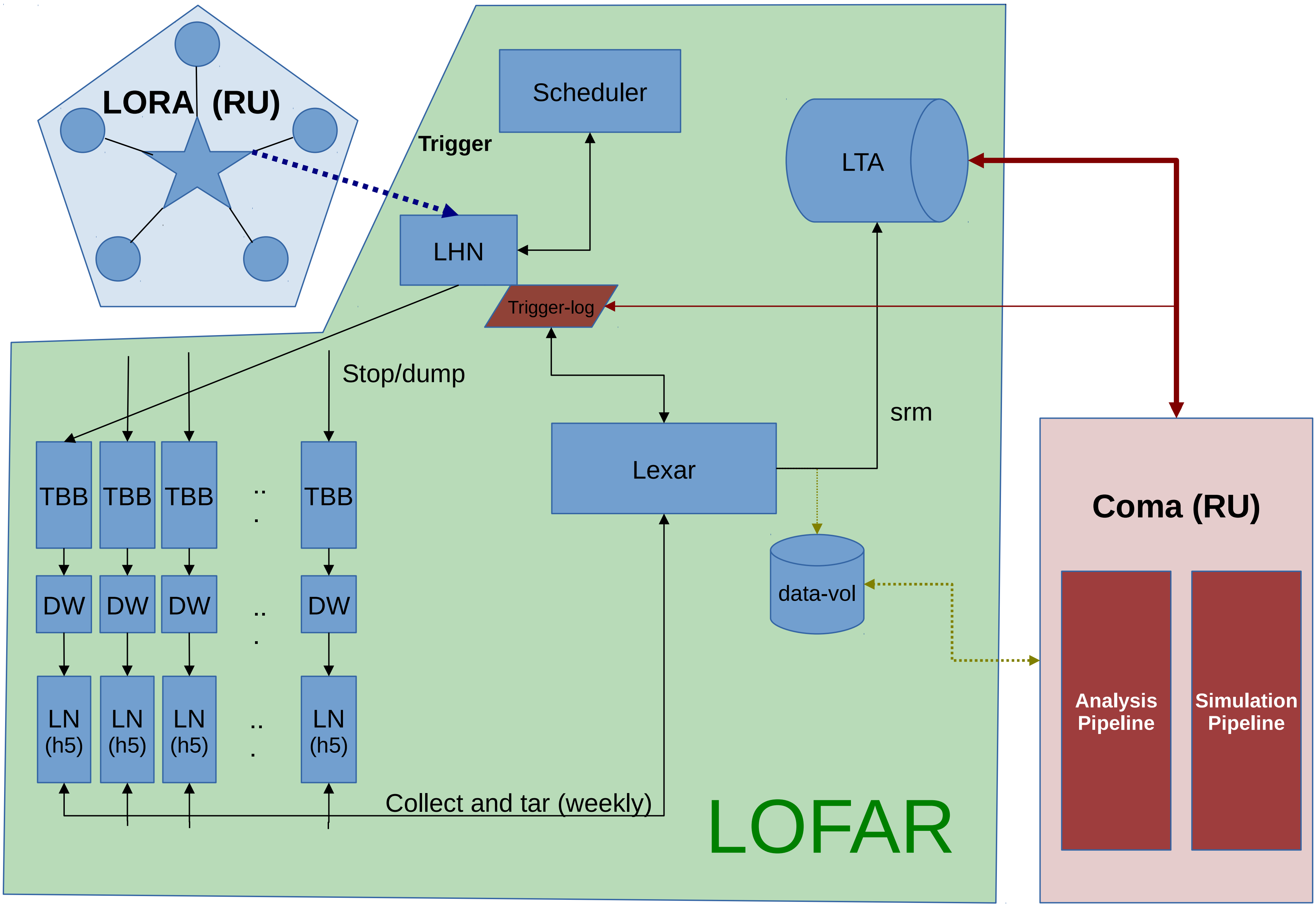
→ **since June 2016** we are back to approximately **1 trigger / hour**

→ **FUTURE plans for LORA**:

– to upgrade/expand LORA with other 20 detectors

– to implement an hybrid trigger (scintillator detectors + radio antennas)

Cosmic Rays DAQ scheme



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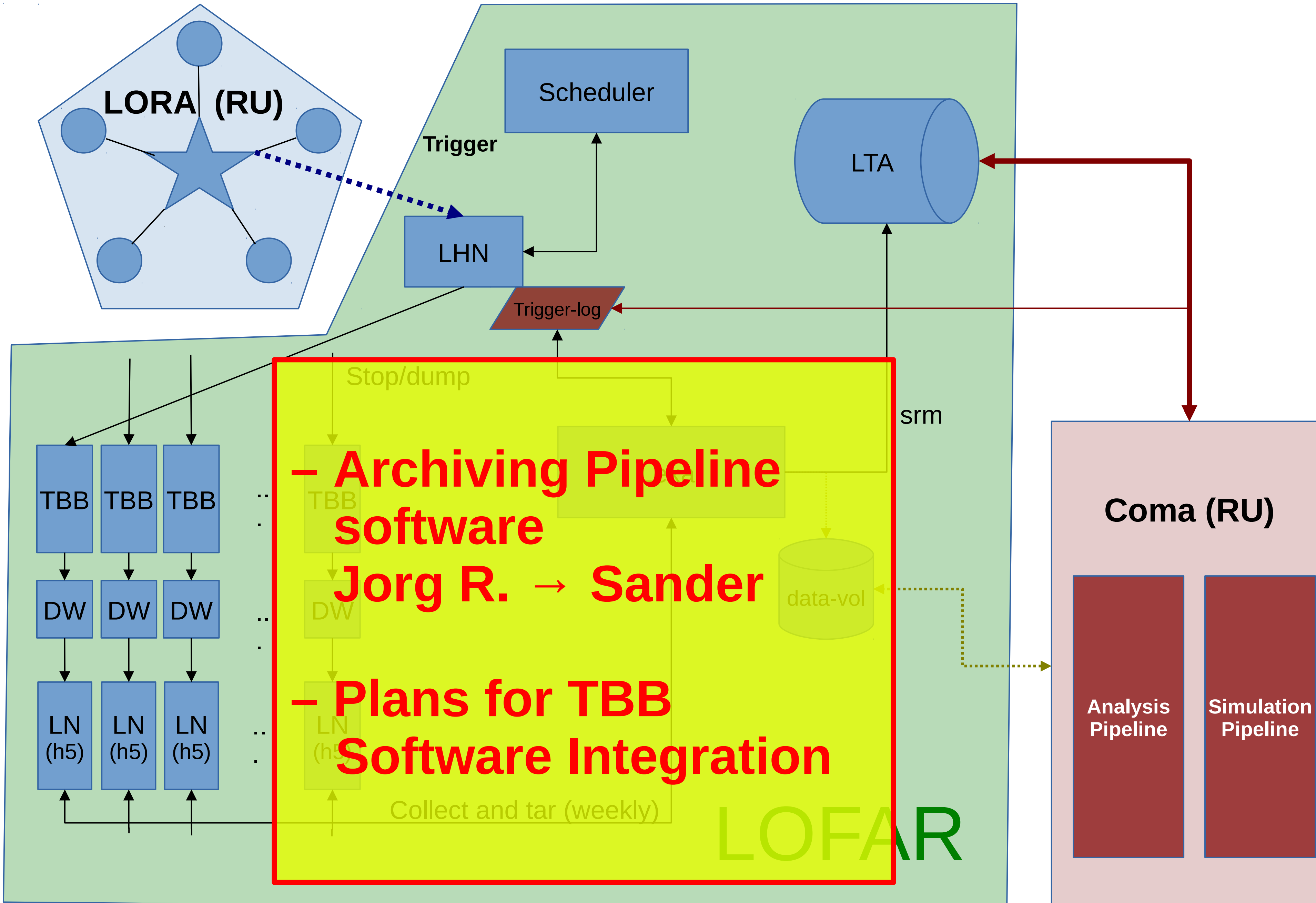
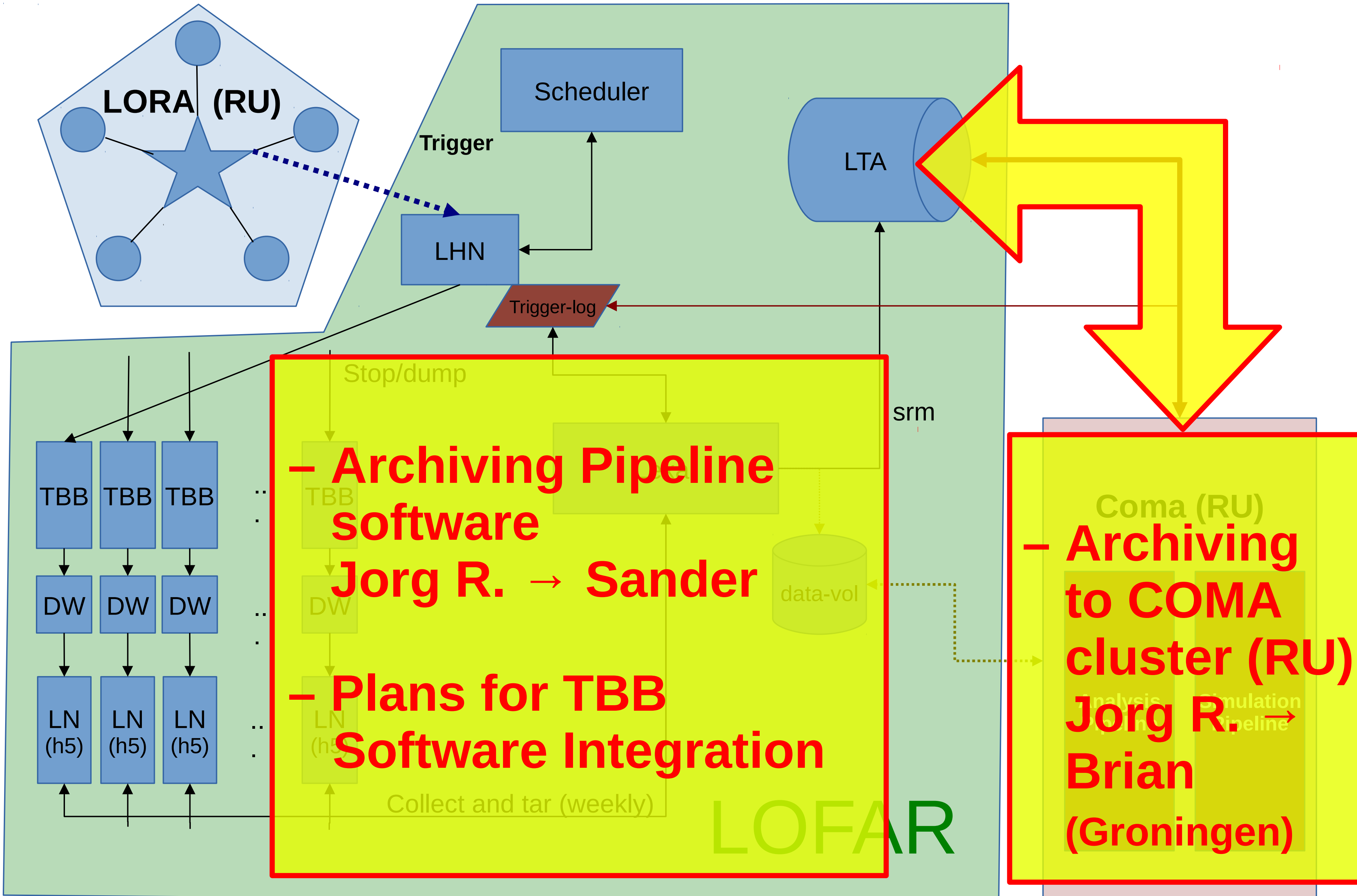


– Archiving Pipeline software
Jorg R. → Sander

– Plans for TBB Software Integration

Cosmic Rays DAQ scheme



– **Archiving Pipeline software**
Jorg R. → Sander

– **Plans for TBB Software Integration**

– **Archiving to COMA cluster (RU)**
Jorg R. → Brian
(Groningen)

Ongoing projects

Nijmegen group:

→ **Frequency spectrum analysis** (includes repeating calibration analysis of the LBA antennas) – in preparation

→ **Extended analysis on mass composition** (includes refractive index changes, atmospheric model, etc.) – in preparation

→ study of a radio self-trigger for cosmic rays detection – includes data analysis of observation with the current self-trigger (a new data acquisition should happen soon) and development of a new ROUTINE

Groningen group:

→ study of **circular polarization in fair–weather and thunderstorm events** and comparison with simulations – in preparation

→ study of lightnings and air-showers propagation in thunderclouds

Brussel group:

→ **simulation study of refractive index** using models for the whole atmosphere

→ LORA extension with other 20 detectors and implementation of an hybrid trigger (scintillators + radio)

→ NuMoon analysis – searching for radio pulses emitted by particles with energy > 10^{21} eV hitting the Moon