The Cosmic Ray Key Science Project

Status Report, LSM 22-06-16

Jörg P. Rachen for the

LOFAR Cosmic Ray Key Science Project

A. Bonaldi, S. Buintink, A Corstanje, Q. Dorosti Hasankiadeh, J.E. Enriquez, H. Falcke, J.R. Hörandel, A. Nelles, P. Mitra, K. Mulrey, J.P. Rachen, L. Rossetto, S. Thoudam, P. Schellart, O. Scholten, S. ter Veen, T.N.G. Trinh, T. Winchen

Radboud University

ASTRON

university of groningen

Vrije Universiteit Brussel

Journal papers published:

Schellart+, **A&A 560, A98 (2013): Detecting cosmic rays with the LOFAR radio telescope**

Schellart+, **NIMPA 742, 115 (2014): Recent results** from cosmic-ray measurements with LOFAR

Schellart+, **JCAP 10, 014 (2014): Polarized radio emission** from extensive air showers measured with LOFAR

Buitink+, **PRD 90, 082003 (2014):** Method for **high precision reconstruction of air shower X_{max}** using two-dimensional radio intensity profiles

Thoudam+, **NIMPA 767, 339 (2014): LORA** – A **scintillator array for LOFAR** to measure extensive air showers

Nelles+, **APh 60, 13 (2015):** A parameterization for the radio emission of air showers as predicted by **CoREAS simulations** and **applied to LOFAR measurements**

Corstanje+, **APh 61, 22 (2015):** The **shape of the radio wavefront** of extensive air showers as measured with LOFAR

Schellart+, **PRL 114, 165001 (2015): Probing Atmospheric Electric Fields in Thunderstorms** through Radio Emission from Cosmic-Ray-Induced Air Showers

Nelles+, **APh 65, 11 (2015):** Measuring a **Cherenkov ring in the radio emission** from air showers **at 110-190 MHz** with LOFAR

Nelles+, **JCAP 5, 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

Nelles+, **JInst 10, 1005 (2015): Calibrating the absolute amplitude scale** for air showers measured at LOFAR.

Thoudam+, **Aph 73, 34 (2016): Measurement of the cosmic-ray energy spectrum** above 10^{16} eV **with the LOFAR Radboud Air Shower Array**.

Corstanje+, **A&A 590, 41 (2016): Timing calibration** and spectral cleaning of LOFAR time series data.

Buitink+, **Nature 531, 70 (2016):** Radio detections of cosmic rays reveal a **strong light mass component at 10^{17} – $10^{17.5}$ eV**.

Trinh+, **PRD 93, 023003 (2016):** Influence of **Atmospheric Electric Fields** on Radio-wave Emission from Cosmic-Ray Induced Air Showers.

Papers in preparation:

Scholten+, **for PRD**: Measurement of the **circular polarization in radio emission from extensive air showers** confirms emission mechanisms.

Corstanje+: The **effect of the atmospheric refractive index** on radio detection of extensive air showers

Journal papers published:

Schellart+, **A&A 560, A98 (2013): Detecting cosmic rays with the LOFAR radio telescope**

Schellart+, **NIMPA 742, 115 (2014): Recent results** from cosmic-ray measurements with LOFAR

Schellart+, **JCAP 10, 014 (2014): Polarized radio emission** from extensive air showers measured with LOFAR

Buitink+, **PRD 90, 082003 (2014):** Method for **high precision reconstruction of air shower X_{max}** using two-dimensional radio intensity profiles

Thoudam+, **NIMPA 767, 339 (2014): LORA** – A **scintillator array for LOFAR** to measure extensive air showers

Nelles+, **APh 60, 13 (2015):** A parameterization for the radio emission of air showers as predicted by **CoREAS simulations** and **applied to LOFAR measurements**

Corstanje+, **APh 61, 22 (2015):** The **shape of the radio wavefront** of extensive air showers as measured with LOFAR

Schellart+, **PRL 114, 165001 (2015): Probing Atmospheric Electric Fields in Thunderstorms** through Radio Emission from Cosmic-Ray-Induced Air Showers

Nelles+, **APh 65, 11 (2015):** Measuring a **Cherenkov ring in the radio emission** from air showers **at 110-190 MHz** with LOFAR

Nelles+, **JCAP 5, 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

Nelles+, **JInst 10, 1005 (2015): Calibrating the absolute amplitude scale** for air showers measured at LOFAR.

Thoudam+, **Aph 73, 34 (2016): Measurement of the cosmic-ray energy spectrum** above 10^{16} eV **with the LOFAR Radboud Air Shower Array**.

Corstanje+, **A&A 590, 41 (2016): Timing calibration** and spectral cleaning of LOFAR time series data.

Buitink+, **Nature 531, 70 (2016):** Radio detections of cosmic rays reveal a **strong light mass component at 10^{17} – $10^{17.5}$ eV**.

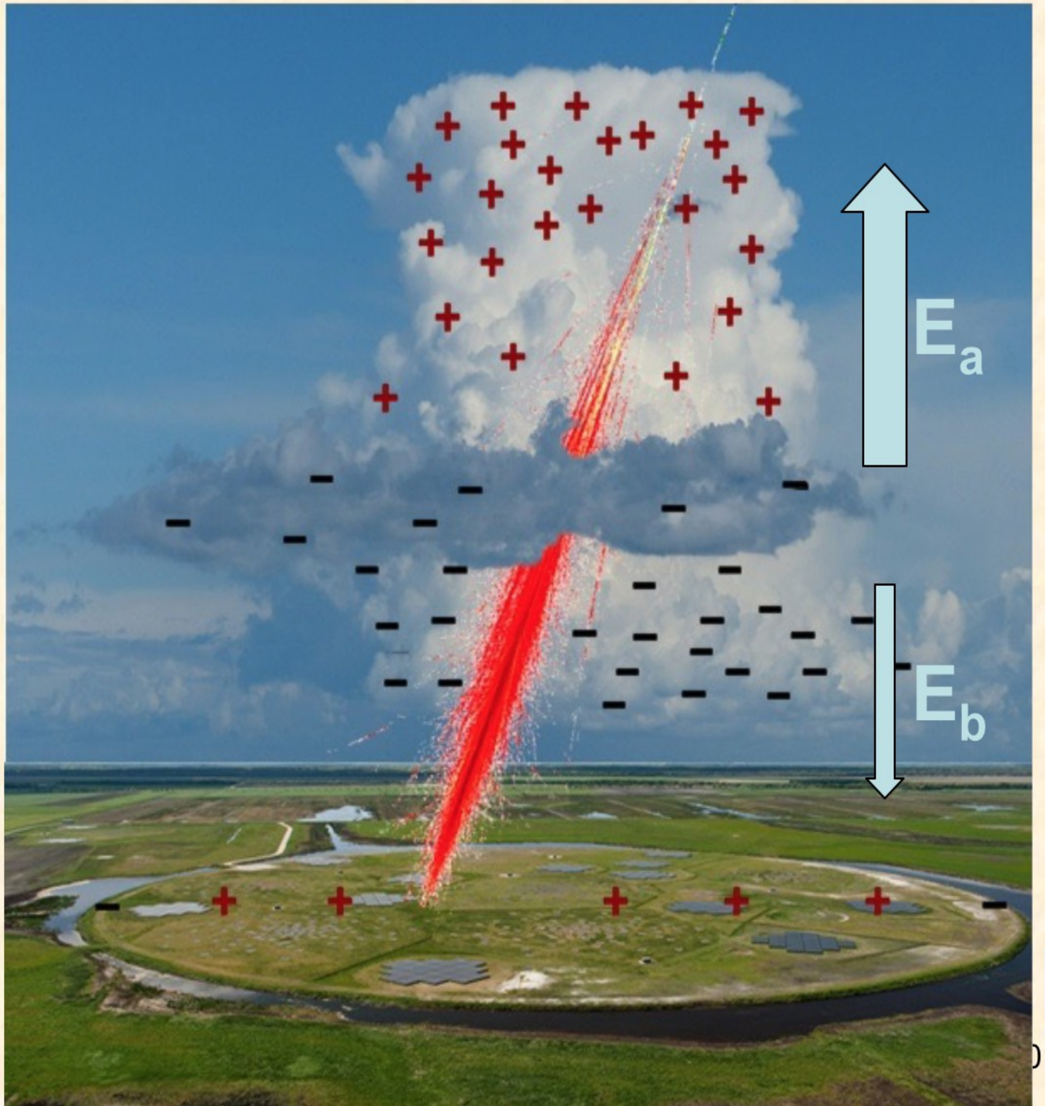
Trinh+, **PRD 93, 023003 (2016):** Influence of **Atmospheric Electric Fields** on Radio-wave Emission from Cosmic-Ray Induced Air Showers.

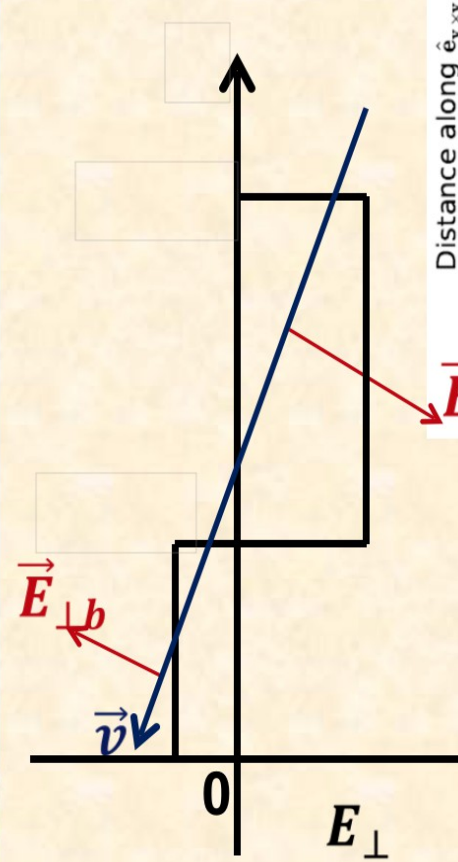
Papers in preparation:

Scholten+, **for PRD**: Measurement of the **circular polarization in radio emission from extensive air showers** confirms emission mechanisms.

Corstanje+: The **effect of the atmospheric refractive index** on radio detection of extensive air showers

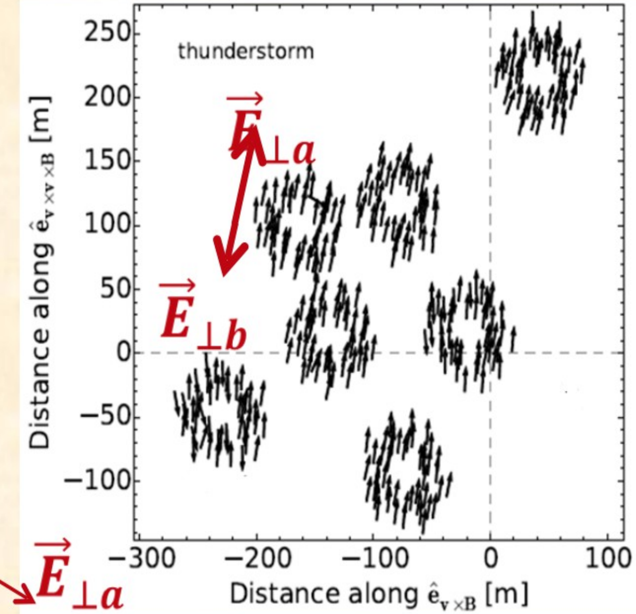
Structure E-fields

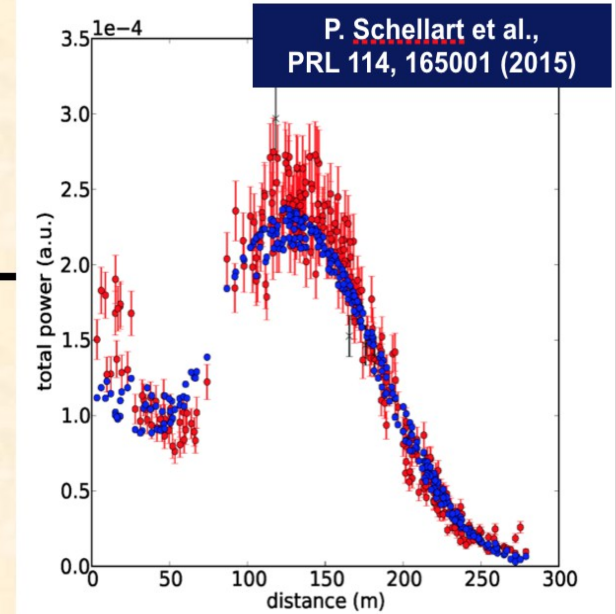




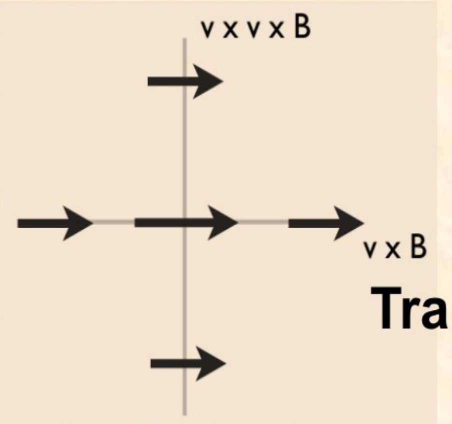
T.N.G. Trinh et al.,
Phys Rev D 93 (2016) 023003

016-Rome

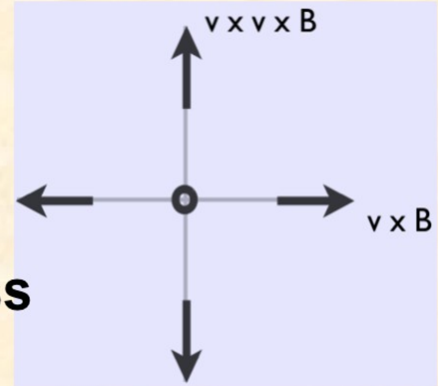




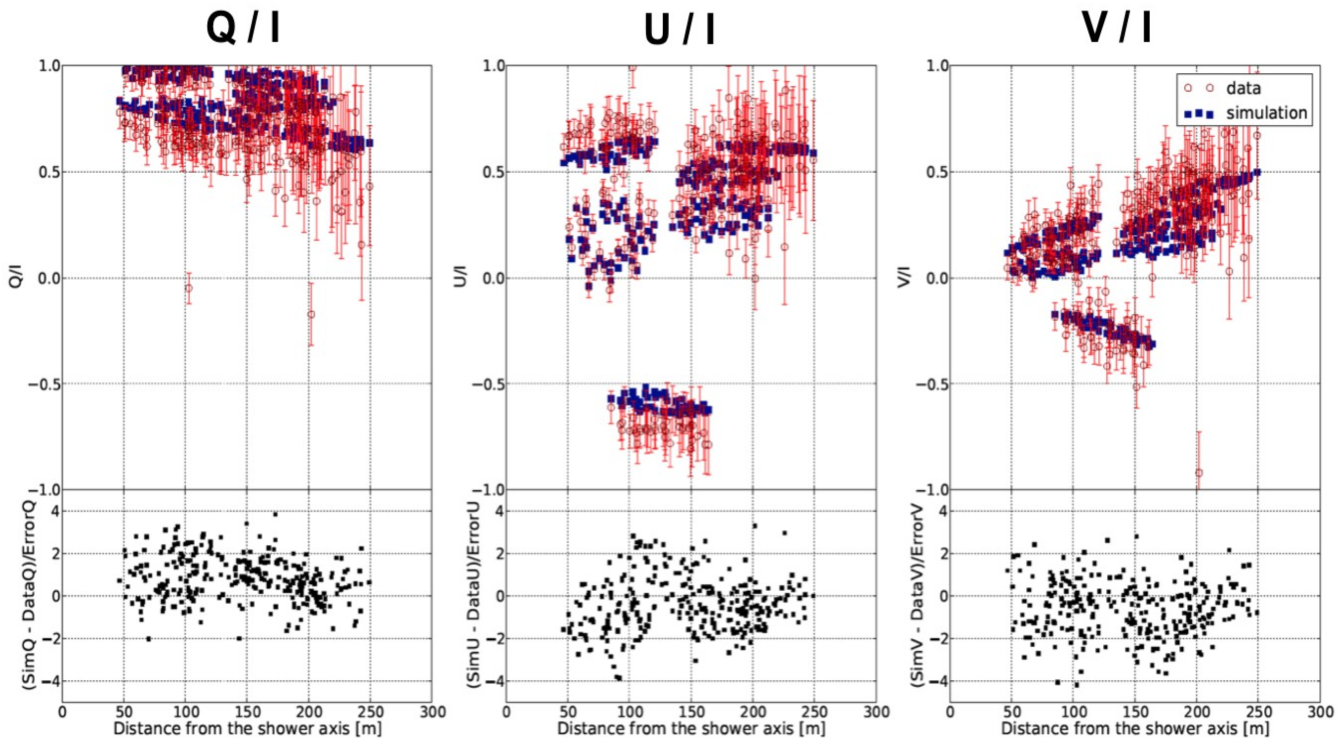
P. Schellart et al.,
PRL 114, 165001 (2015)

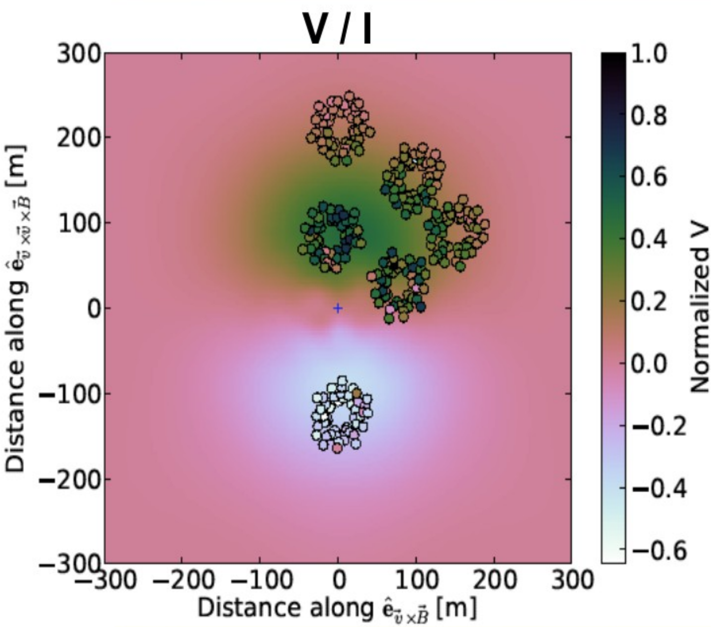


Reason for fair-weather circular polarization:

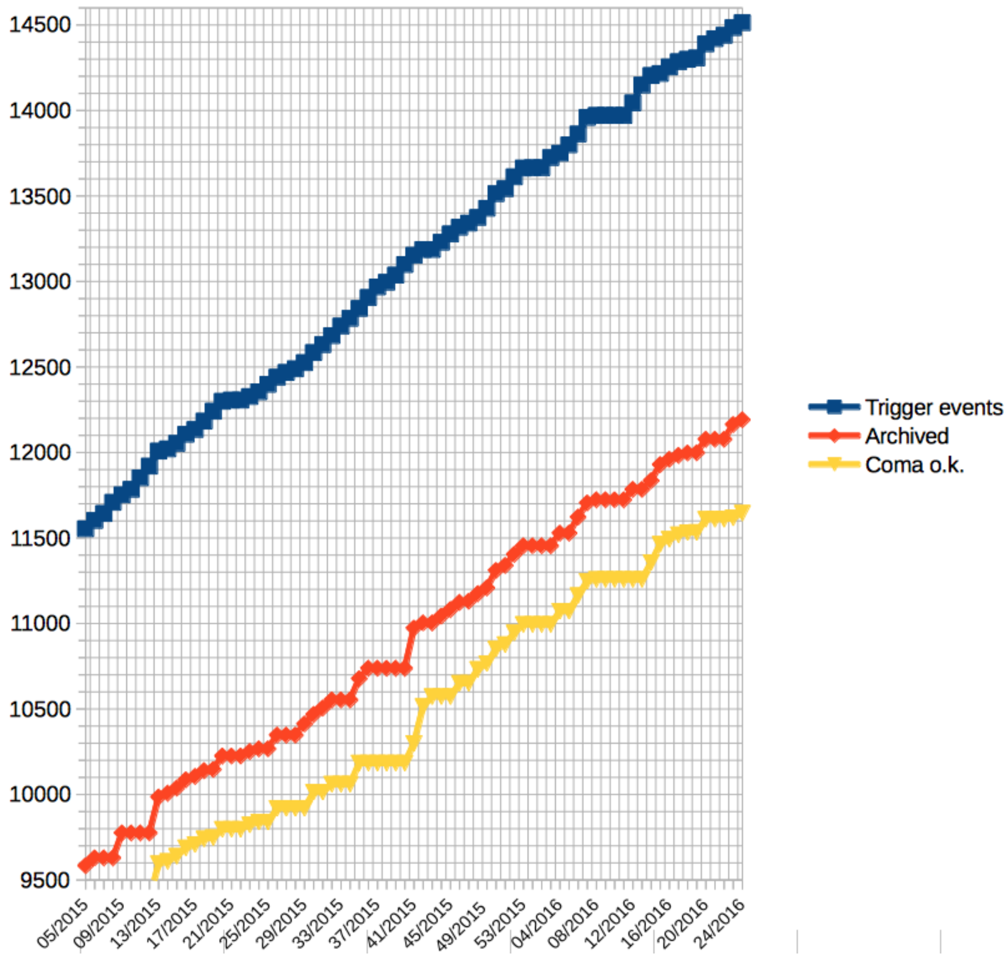


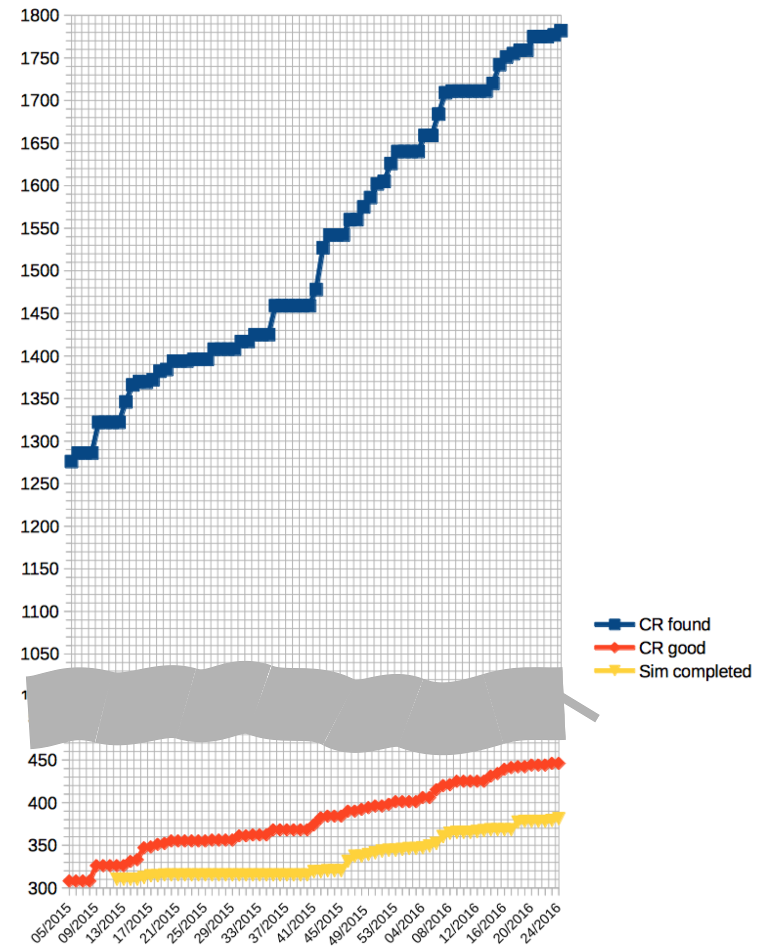
Transverse current is 1ns ahead of Charge excess pulse



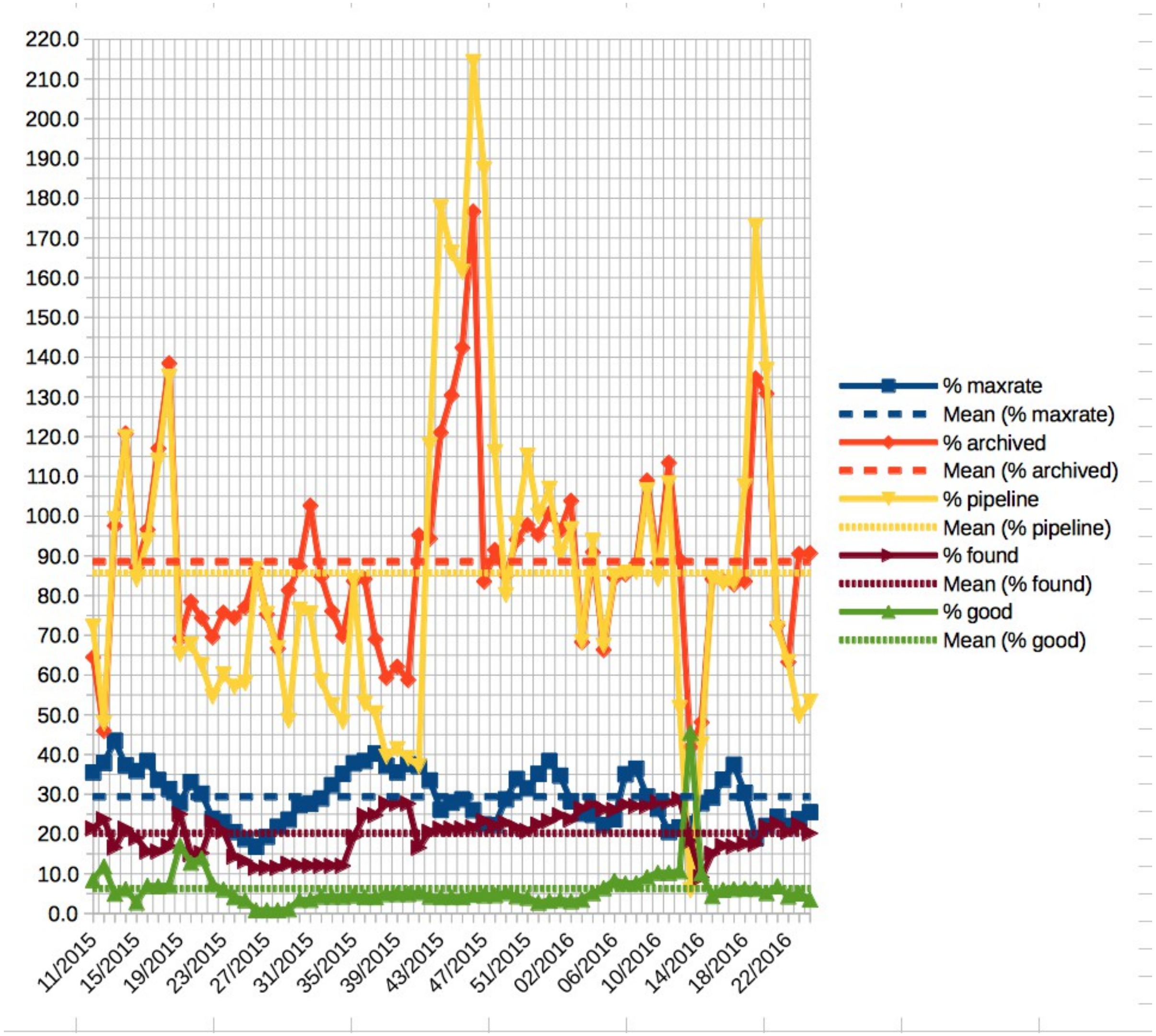


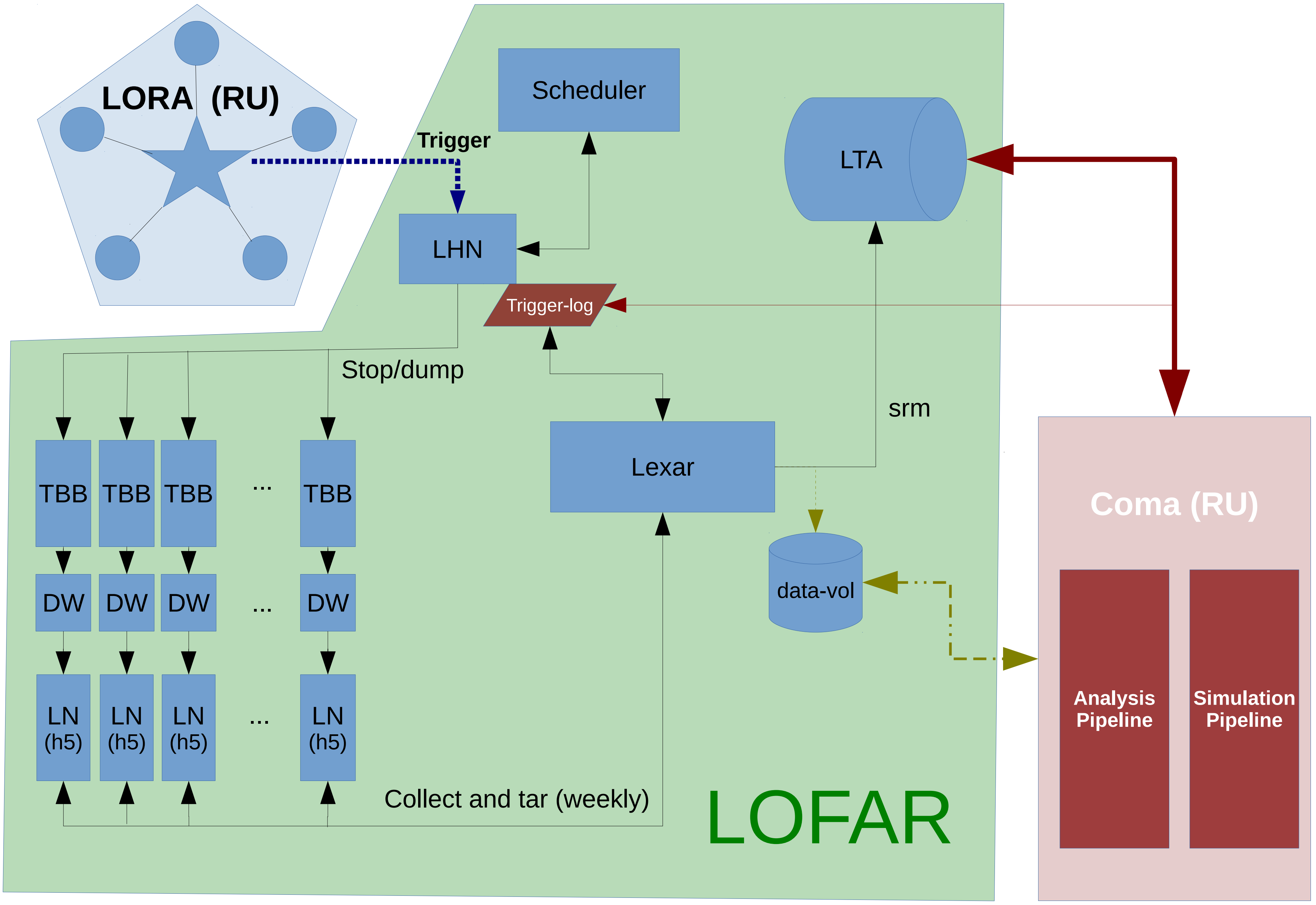
Observatory Performance





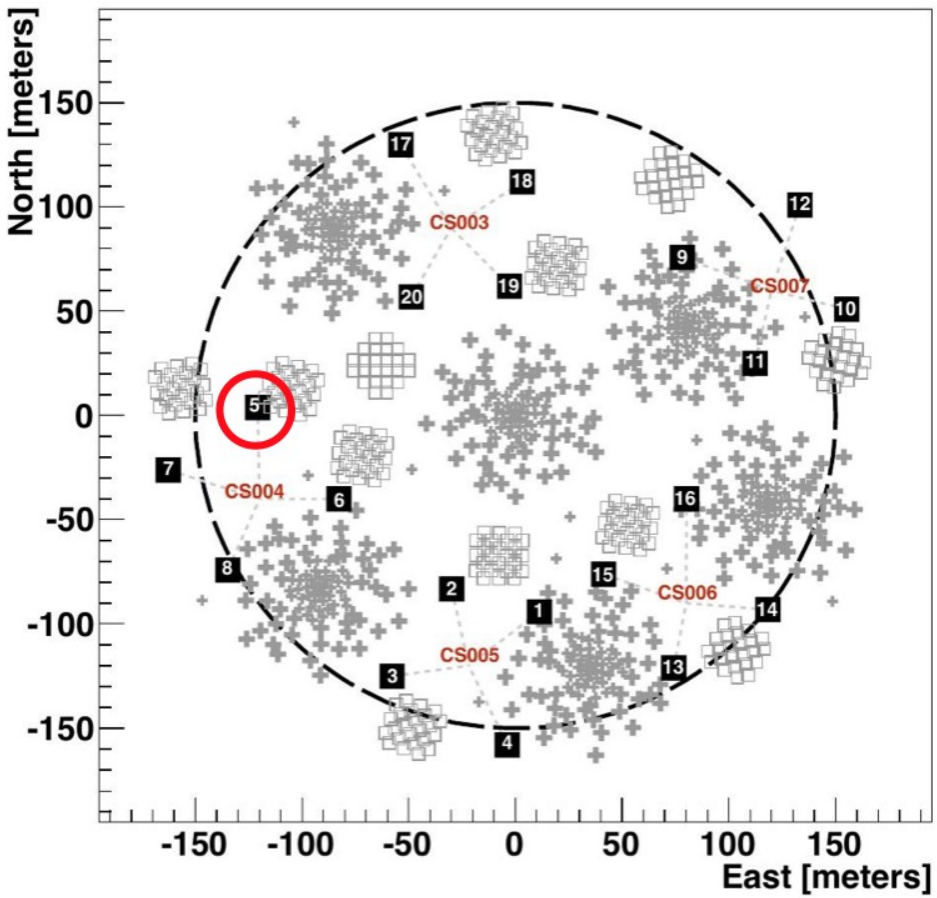
Observatory Performance





LORA (RU)
Trigger
Scheduler
LTA
LHN
Trigger-log
Stop/dump
srm
TBB
TBB
TBB
...
TBB
Lexar
Coma (RU)
DW
DW
DW
...
DW
data-vol
LN (h5)
LN (h5)
LN (h5)
...
LN (h5)
Analysis Pipeline
Simulation Pipeline
Collect and tar (weekly)
LOFAR

LORA status updates



→ **June 14th – 16th 2016**
3 working days at the Superterp

→ all the HV and signal cable connectors between LORA detectors and cabinet of stations CS003, CS004, CS005, CS006 and CS007 have been substituted

→ many cable connectors of each LORA detector have been substituted

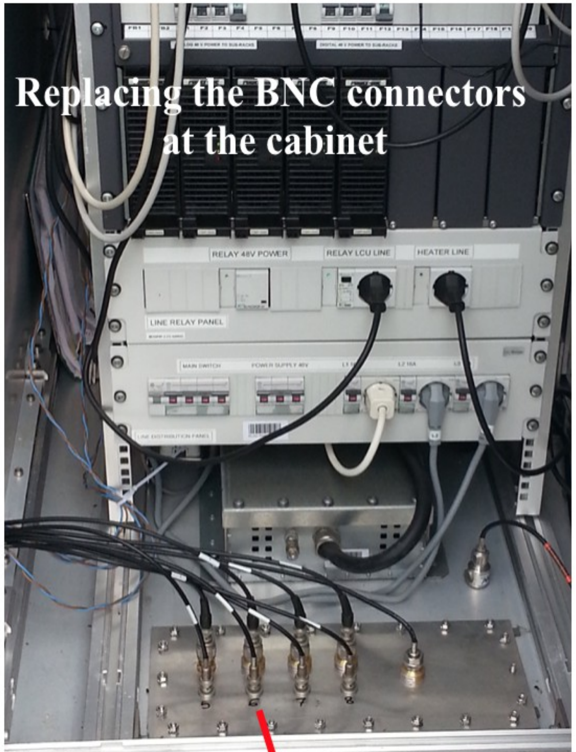
→ **cables between detector 5 and cabinet of CS004 have been replaced**
→ detector 5 works again!!!

→ **all the 20 LORA detectors are active**

LORA status updates

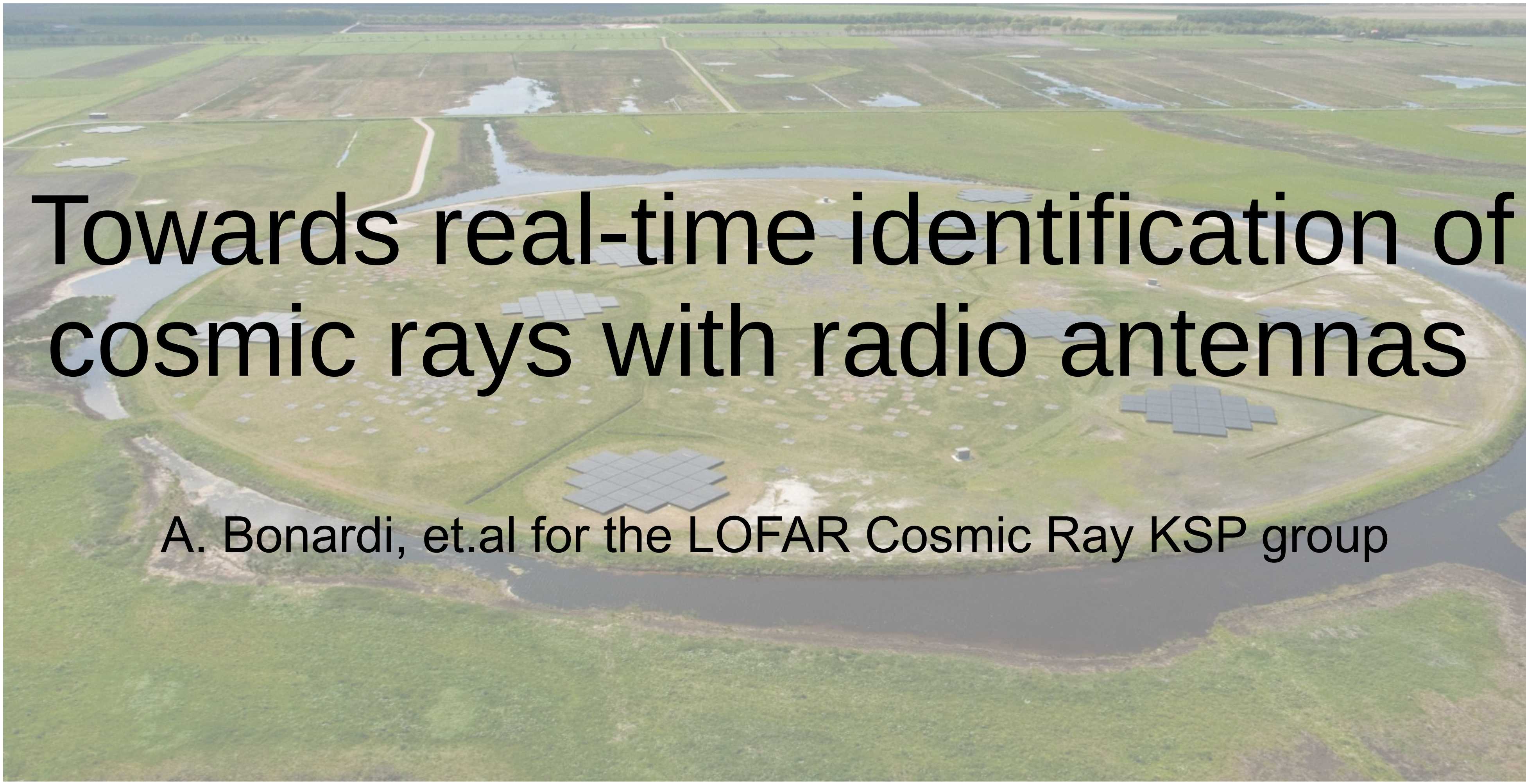
Replacing broken cable

LORA status updates



Radboud University

LOFAR



Towards real-time identification of cosmic rays with radio antennas

A. Bonardi, et.al for the LOFAR Cosmic Ray KSP group

Requirements for LOFAR self-triggering

Facts

- CR signal is very short (10-100 ns) and very rare
  by assuming an average event rate of ~1 event per hour at E > 10^{16} eV, the time window ratio is about 10^^{11}

- RFI can easily mimic CR radio signals
  strong 43 MHz FM band, electric sparks from close-by electric fences

- LOFAR capability of downloading the time buffers is limited by the data transmission bandwidth

Therefore

1) RFI suppression to less than 1 fake trigger per hour is crucial

2) High CR selection efficiency is advisable, but not crucial

3) Trigger algorithm has to be as simple as possible

LBA Self-trigger algorithm

Trigger criterion:

1) for each antenna the two polarizations are evaluated independently
2) Majority of 23 antennas along one polarization over a given threshold, on coincidence time window of 30 (LBA outer) or 20 (LBA inner) ns

RFI rejection:

1) signal time length, defined as the time distribution of the antennas majority, must be shorter than 300 (LBA outer) or 75 (LBA inner) ns
2) the ratio of I(30 MHz $< F <$ 45 MHz) and I(45 MHz $< F <$ 70 MHz) must be encompassed between 1 and 2
3) if two consecutive pulses are identified within 5 μs, both pulses are rejected
4) elevation angle of the signal must be $\theta > 30°$ (LBA inner only)

LBA Self-trigger: results

LBA outer

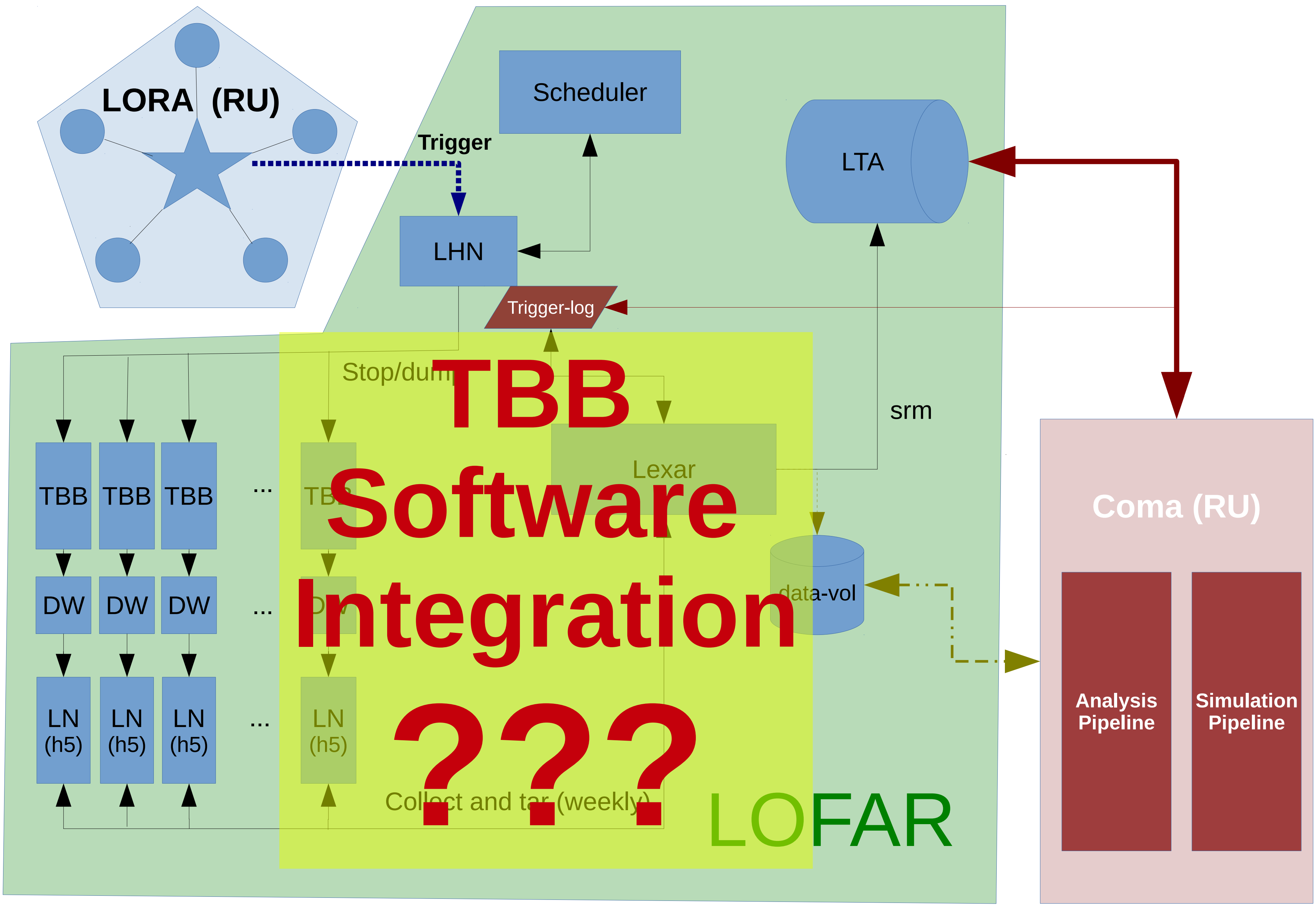
events considered: 4081 Energy: $E > 3 \cdot 10^{15}$ eV
Total independent real time: 8.9 s Total real time: 118.7 s
Antenna threshold: 4 RMS
total number of stations triggered by CR signal = 899
fraction of stations triggered by CR signal and rejected as RFI = 185 / 899 = 21%
Not-CR signal after RFI rejection in fair-weather condition = 0

LBA inner

events considered: 634 Energy: $E > 3 \cdot 10^{15}$ eV
Total independent real time: 1.7 s Total real time: 21.6 s
Antenna threshold: 4 RMS
total number of stations triggered by CR signal = 246
fraction of stations triggered by CR signal and rejected as RFI = 88 / 246 = 36%
Not-CR signal after RFI rejection in fair-weather condition = 0

Future plans

➔ Low threshold acquisitions are planned to be performed on one LOFAR test station for increasing the statistics and getting a better estimation of RFI rejection efficiency



LORA (RU)
Trigger
Scheduler
LTA
LHN
Trigger-log
Stop/dump
TBB Software Integration ???
Lexar
srm
TBB
TBB
TBB
...
TBB
DW
DW
DW
...
data-vol
Coma (RU)
Analysis Pipeline
Simulation Pipeline
LN (h5)
LN (h5)
LN (h5)
...
LN (h5)
Collect and tar (weekly)
LOFAR

Summary

- Continuing activity in improving understanding of measurement systematics for analysis of cosmic ray radio showers.
  - LOFAR is leading experiment worldwide!
- Event rate so far suffering from bad LORA performance and limitation of data taking to LOFAR observations.
  - Particle trigger LORA fixed, should improve performance
  - Dedicated observation mode in preparation (S. ter Veen)
- Studies in radio self-triggering continued
  - test observations needed, may produce large data volume (~ 100 TB)
- TBB software integration still / again open issue
  - Essential scripts still rely on availability of single people
  - Expertise is leaving **… action needed soon!**