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Review on recent results and future perspective

Laura Rossetto

on behalf of the
LOFAR Cosmic Ray Key Science project :

**S. Buitink, A. Corstanje, J.E. Enriquez, H. Falcke, 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**

- M. van Haarlem et al., *Astronomy & Astrophysics* 556, A2, 2013
- P. Schellart et al., *Astronomy & Astrophysics* 560, A98, 2013

Energy spectrum between 10^{16} – 10^{18} eV

- S. Thoudam et al., *Nuclear Instrumentation and Methods A* 767, 339, 2014
- *Measurement of the cosmic-ray energy spectrum above 10^{16} eV with the LOFAR Radboud Air Shower Array*
S. Thoudam et al., *Astroparticle Physics* 73, 34 – 43, 2015

Lateral distribution function

- A. Nelles et al., *Astroparticle Physics* 60, 13 – 24, 2014
- A. Nelles et al., *Journal for Cosmology and Astroparticle Physics* 05, 018, 2015
- A. Nelles et al., *Astroparticle Physics* 65, 11 – 21, 2015

Polarization and thunderstorm events

- P. Schellart et al., *Journal for Cosmology and Astroparticle Physics* 10, 014, 2014
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- *Influence of Atmospheric Electric Fields on the Radio Emission from Extensive Air Showers*
T.N.G. Trinh et al., *Physics Review D* 93, 023003, 2015

Wavefront shape and timing calibration

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- *Timing calibration and spectral cleaning of LOFAR time series data*
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Mass composition

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- *A large light-mass component of cosmic rays at 10^{17} – $10^{17.5}$ eV from radio observations*
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Low Band Antenna calibration

- *Calibrated the absolute amplitude scale for air showers measured at LOFAR*
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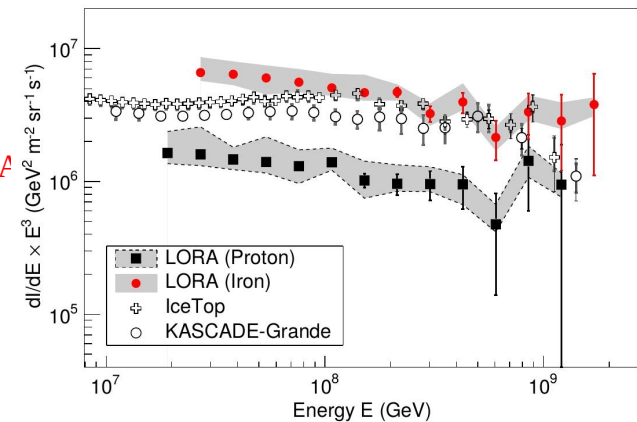
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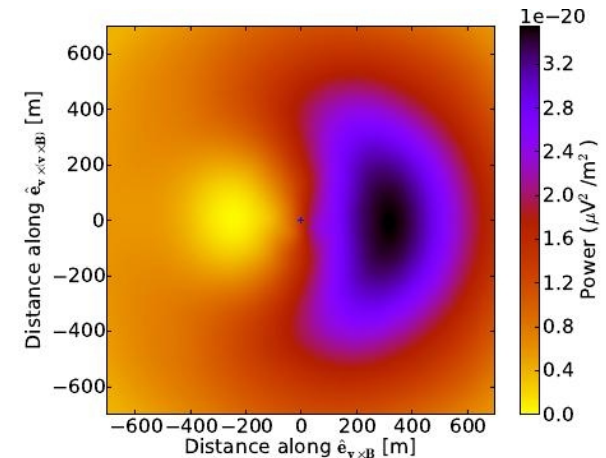
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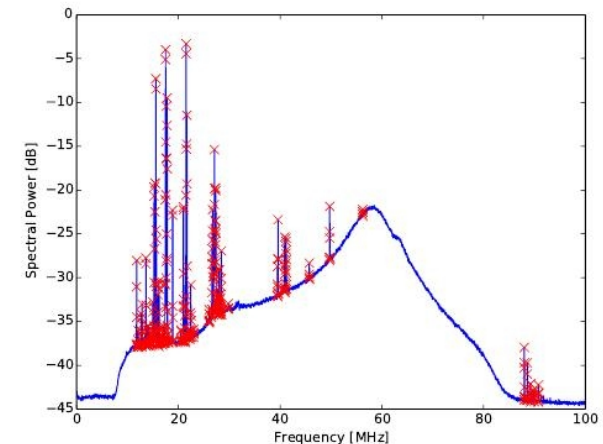
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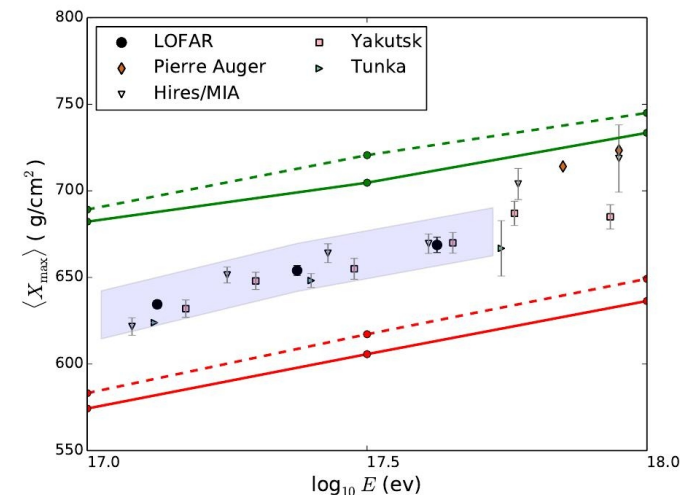
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**FIRST LOFAR paper
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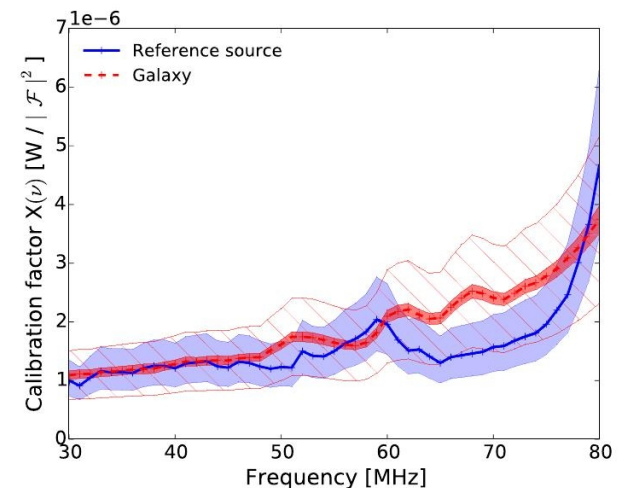
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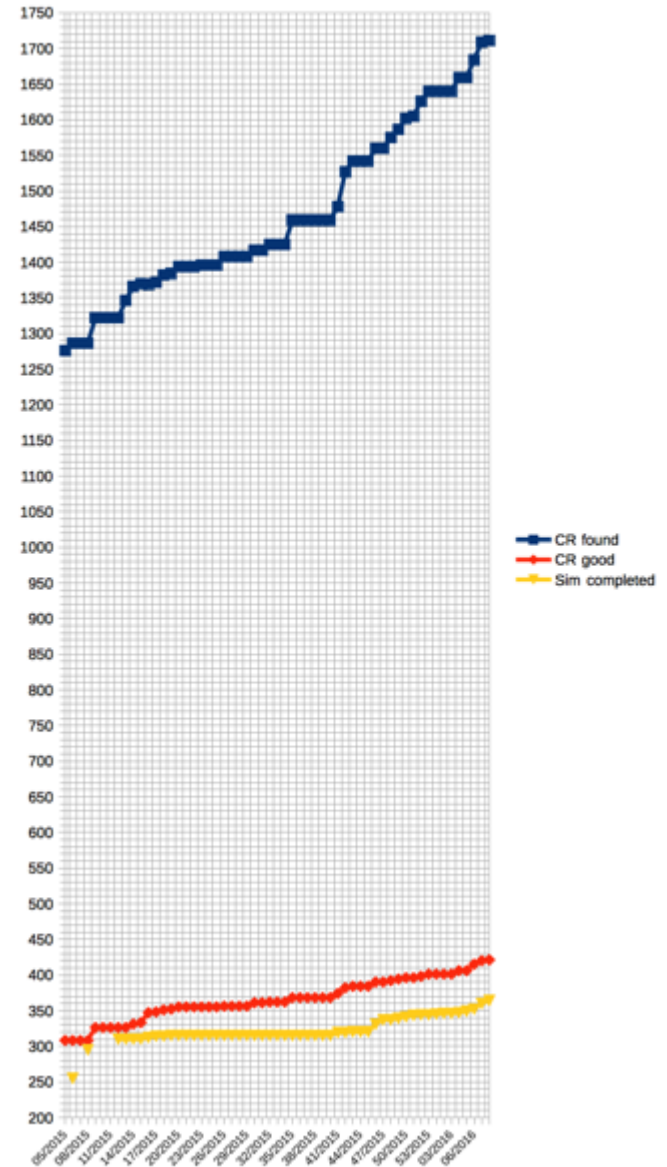
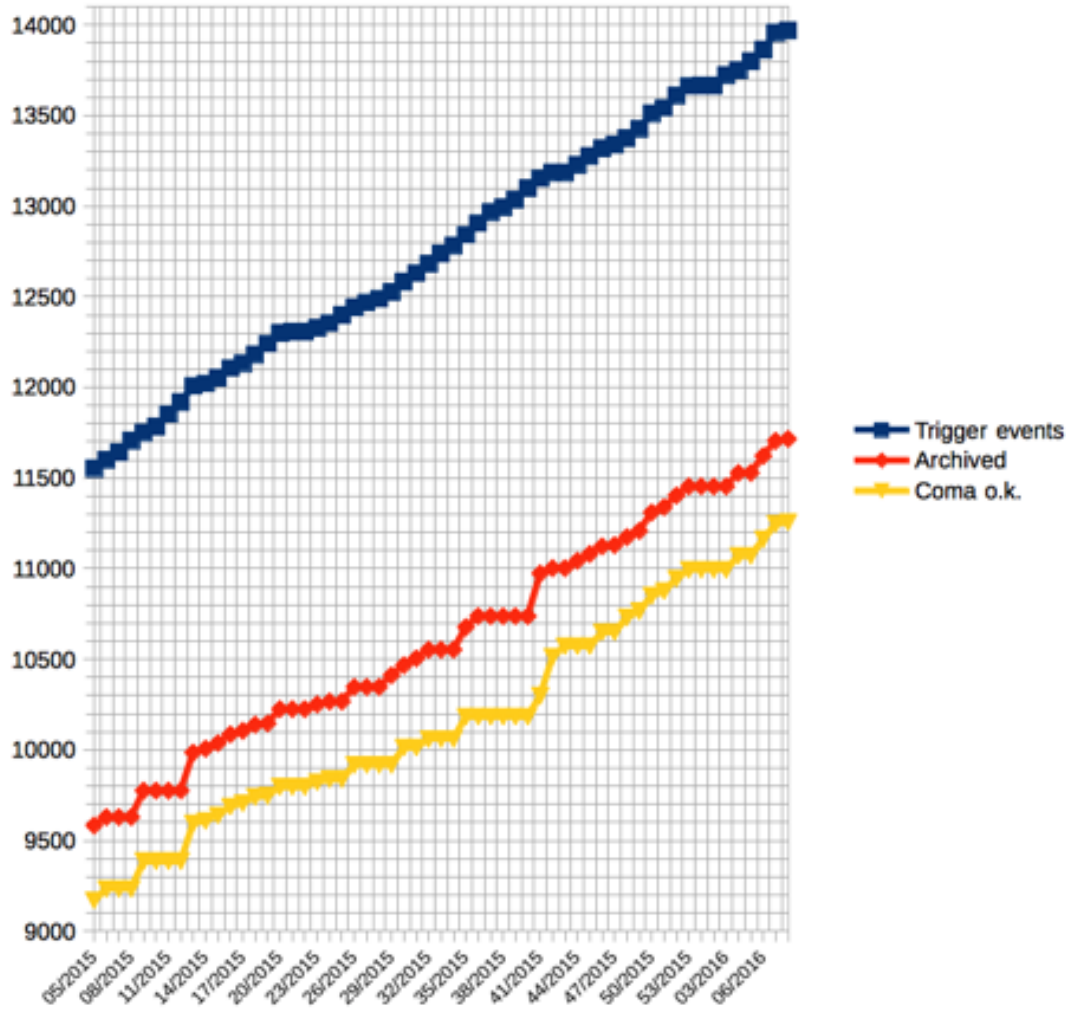
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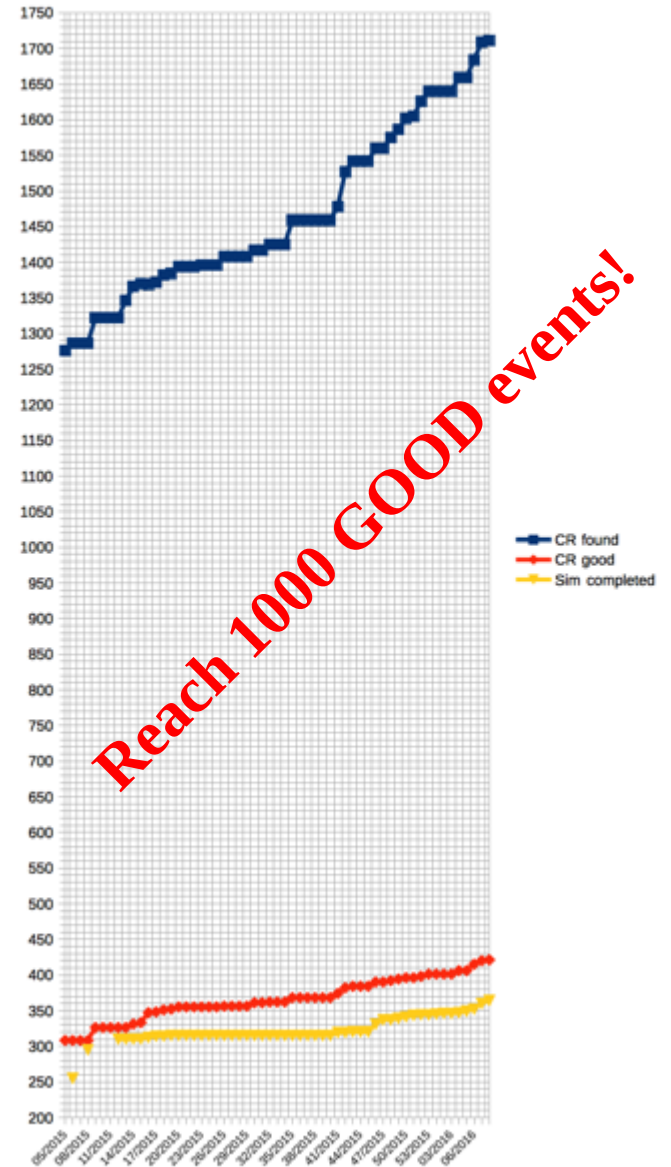
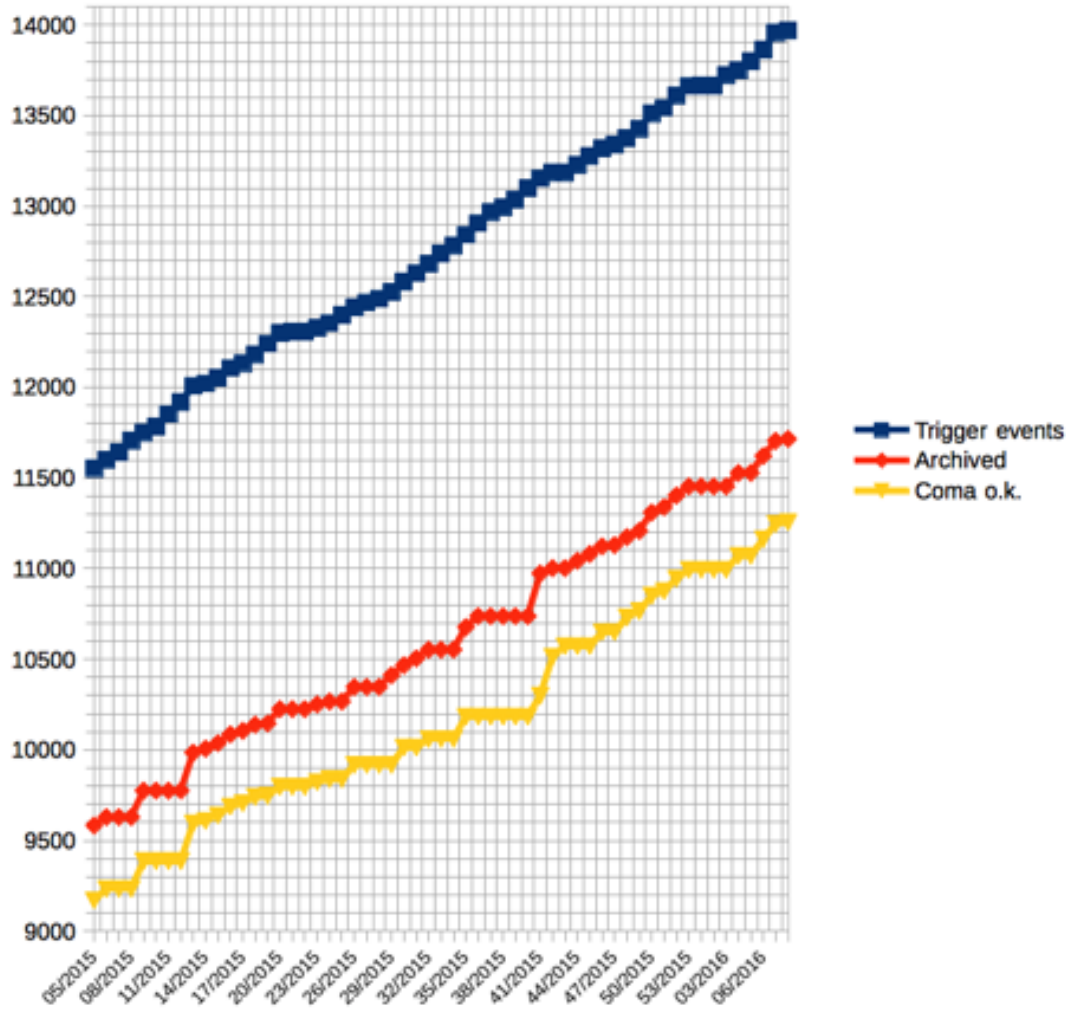
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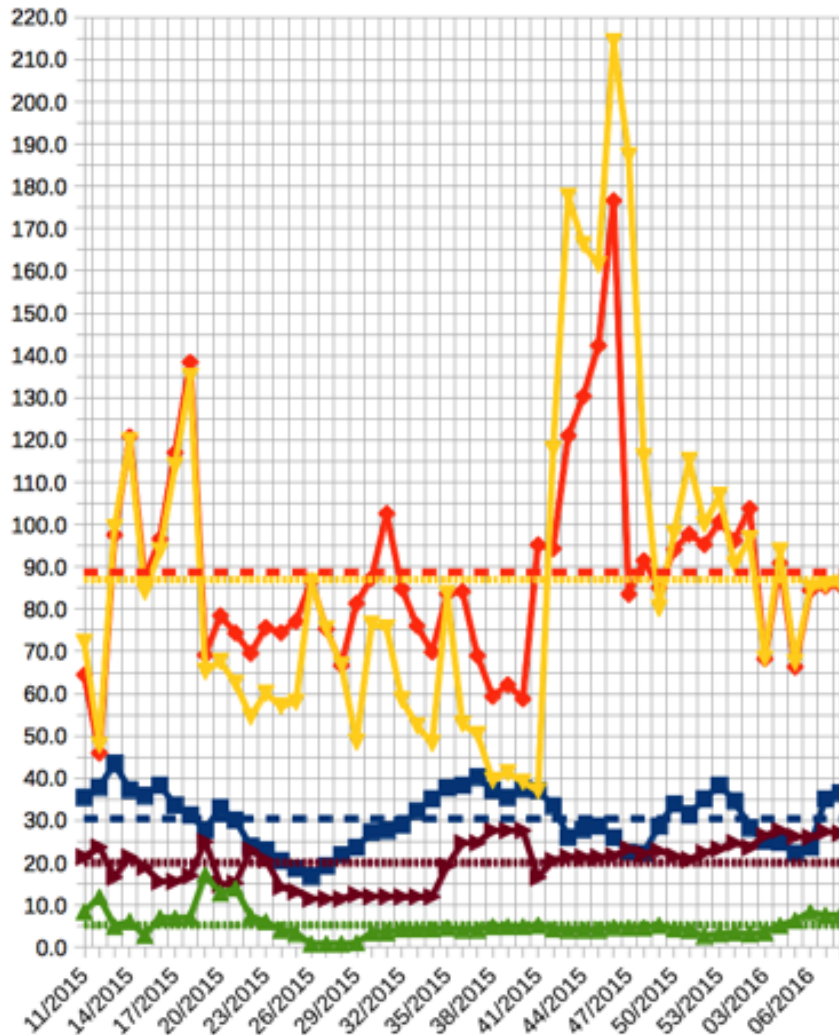
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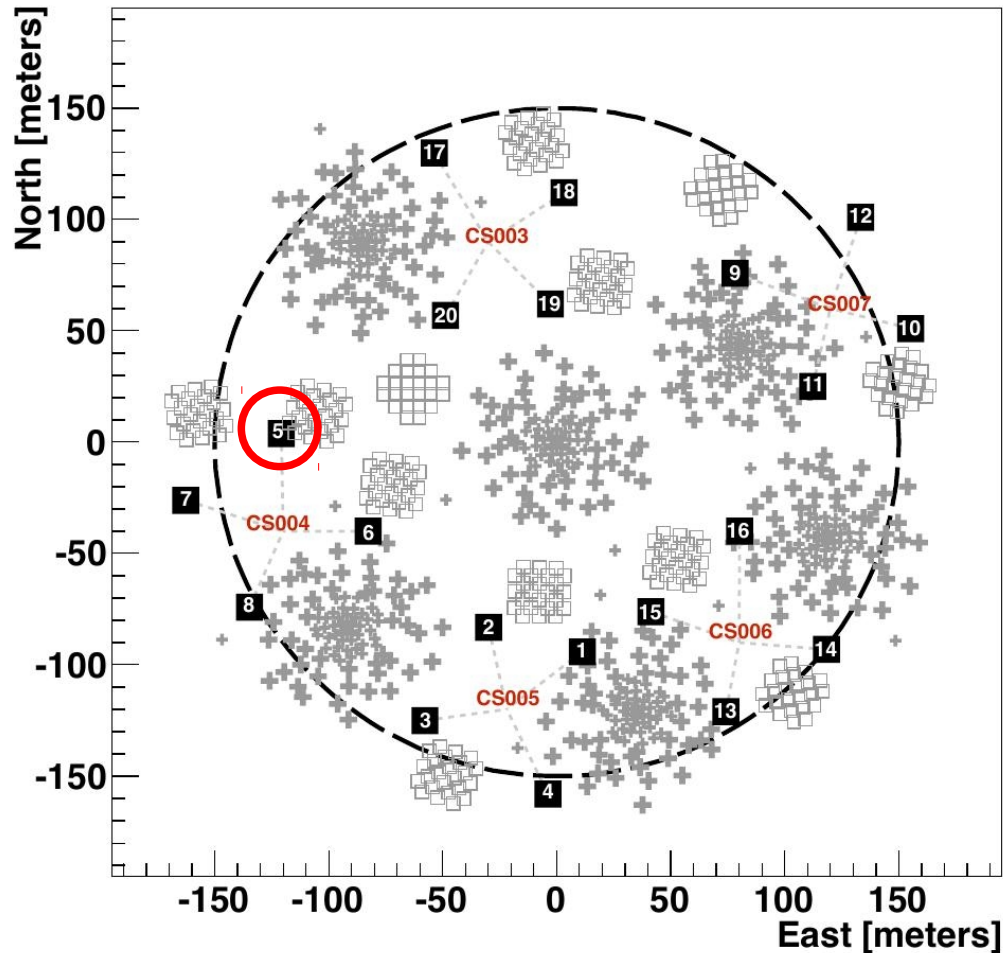




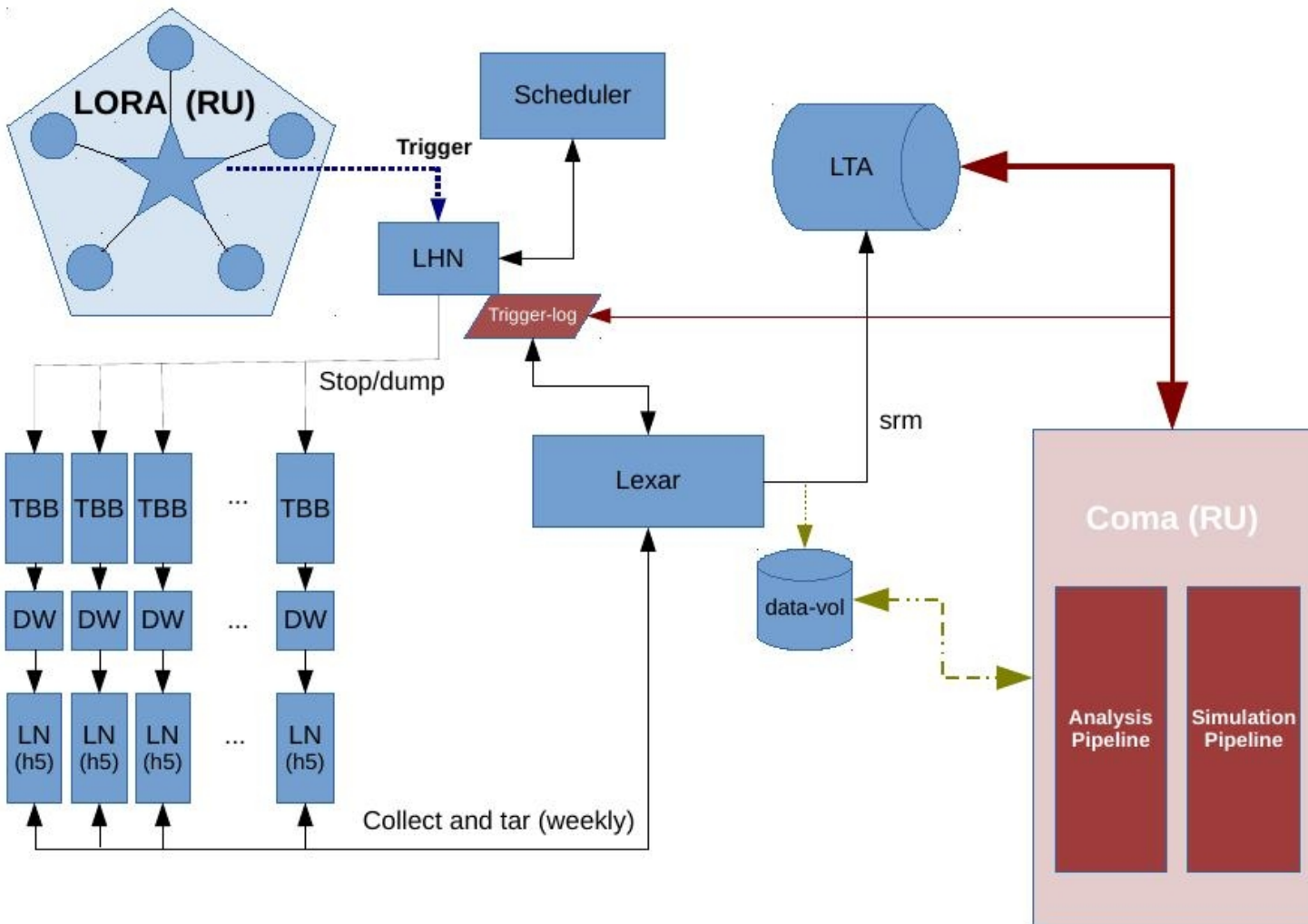


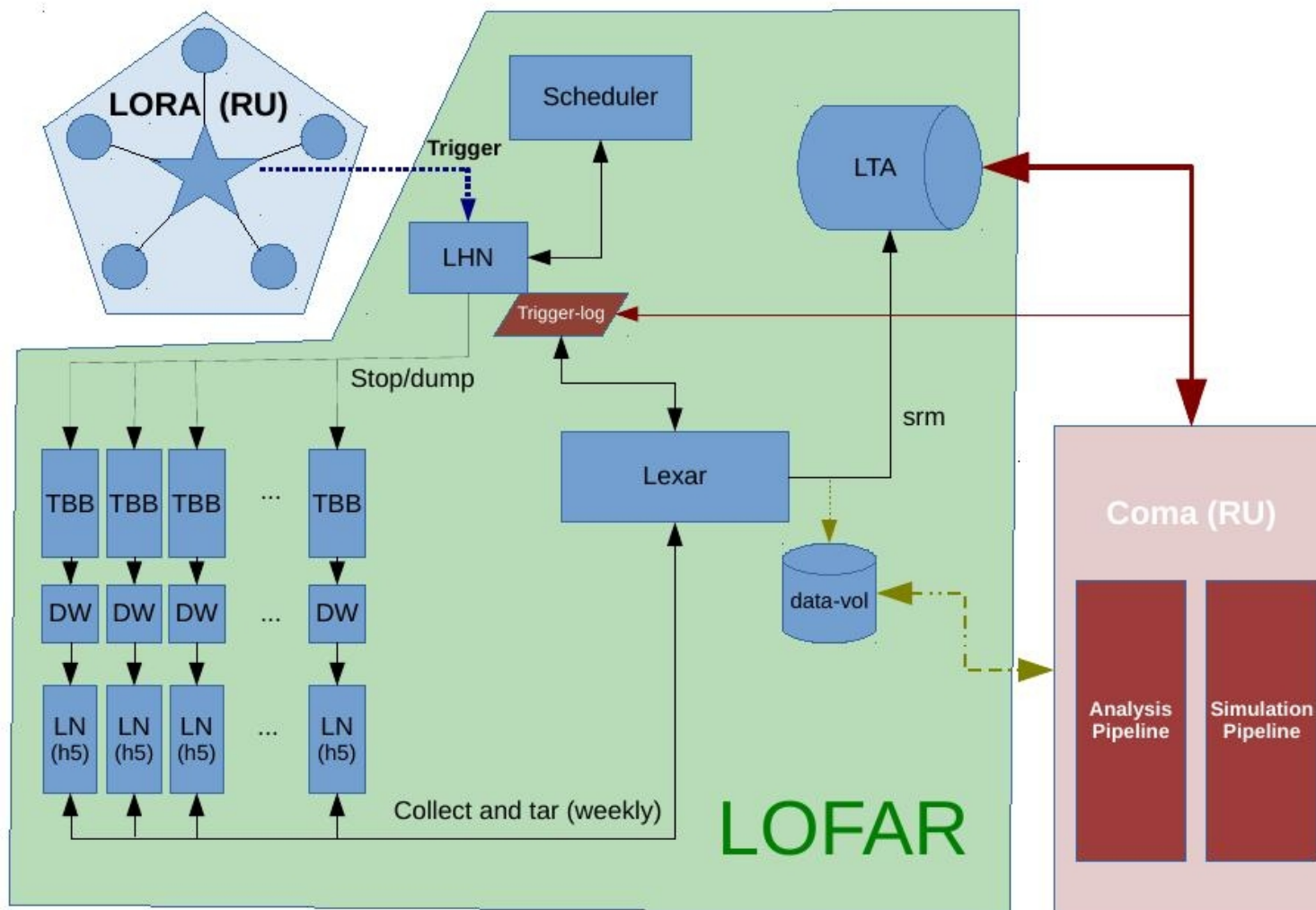


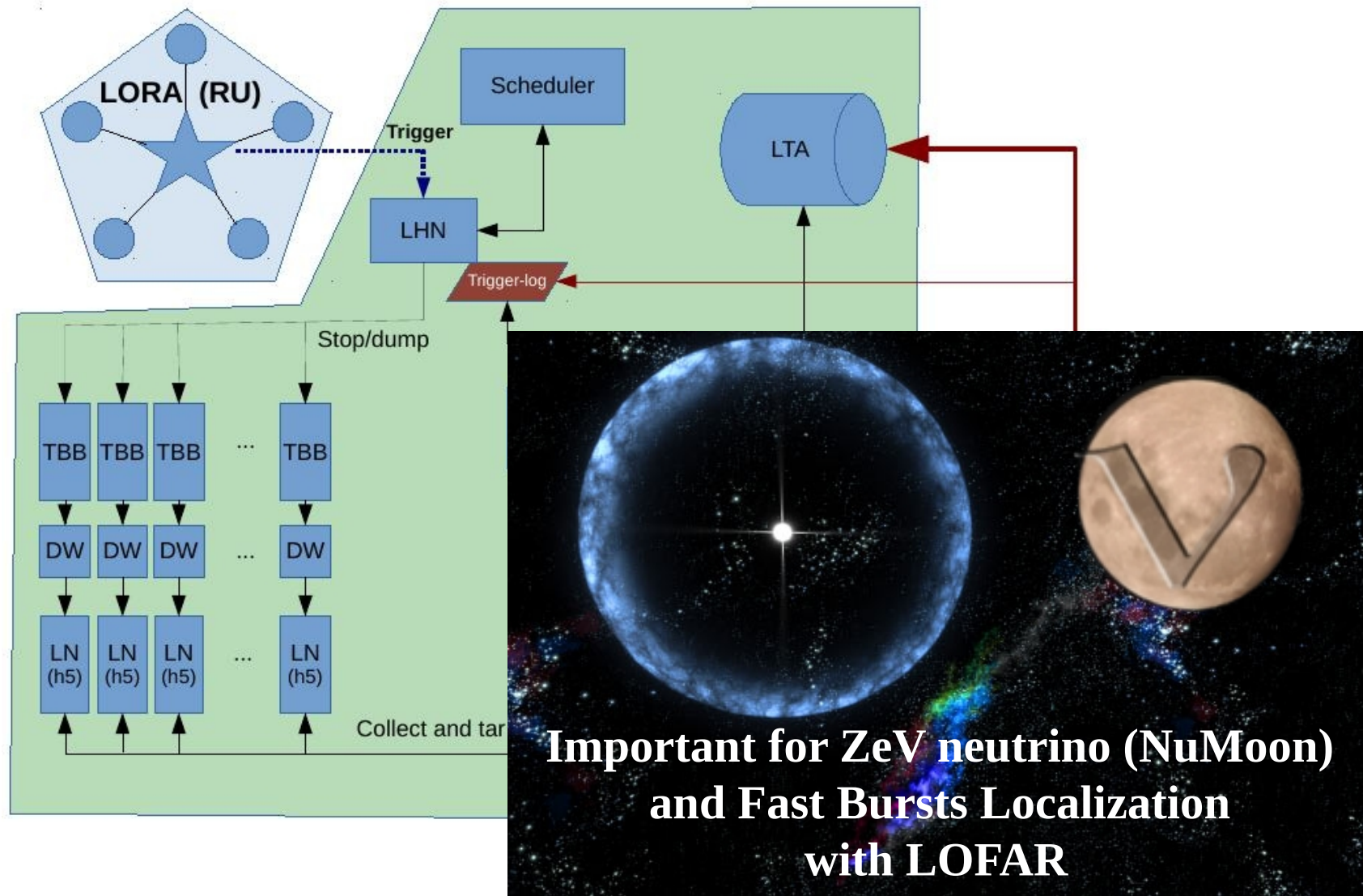
- About 90% of triggered events are archived (**orange line**) and are good events as input for our pipeline (**yellow line**) – the low rate of 2015 was due to a bug which is now fixed !
- LORA triggers are only about 30% of what we expect (**blue line**) – seasonal variations and **detector problems**
- success of our pipeline to find Cosmic Rays events is about 20% (**violet line**)
- only 10% are GOOD Cosmic rays events (**green line**)



- LORA trigger efficiency is about **30%** of what we expect
- Since April 2015 LORA is running with **19 detectors over 20**
- HV or signal cable between **detector 5** and cabinet of CS004 is not working – **these cables need to be substituted !**
- we still have many problems with the connectors of both the HV and the signal cables – This could explain the low trigger rate
- we are planning to upgrade/expand LORA with other 20 detectors







- The high density of LOFAR core antennas gives us the possibility to investigate a self-trigger for cosmic rays events – we want to achieve **1 event/hour**
- a **preliminary study** has been conducted on **RAW data** (i.e. before our pipeline analysis), total live-time about 10 s
- selection criteria involve: majority of more than 23 antennas (two polarizations treated independently) above a given threshold (3, 4, 5, 10 RMS) within 20 ns time window
- RFI rejection NOT possible by ONLY increasing the threshold
 - rejection condition is needed
- VETO criteria: elevation angle quick estimation, pulse duration, time distribution of the majority curve
- same analysis has been applied to data recorded with a **self-trigger acquisition mode** conducted on **March 14th 2012** (only 167 events available)
- good results, the method seems working in **triggering ONLY Cosmic Ray events**
- **in order to increase the statistics (about 1 hour of equivalent live-time)**
idea of conducting a new self-trigger acquisition mode

- The high density of the LOFAR core antennas is giving us the opportunity to deeply understand the radio emission of cosmic rays, and to show that radio detection of cosmic ray can compete with the well-established techniques
- this is proved by the **high number of interesting results**, paper published and contributions to conferences
- we are still affected by the **low rate of triggers sent by LORA** (only 19 detectors right now, connectors problems, LOFAR observation time)
- increasing the statistics by continuing collecting data in the following years will certainly leads to new good results
- **the integration of VHECR software into LOFAR system is crucial for a successful continuation of our data analysis**