LOFAR UHEP mode

using LOFAR as ns instrument

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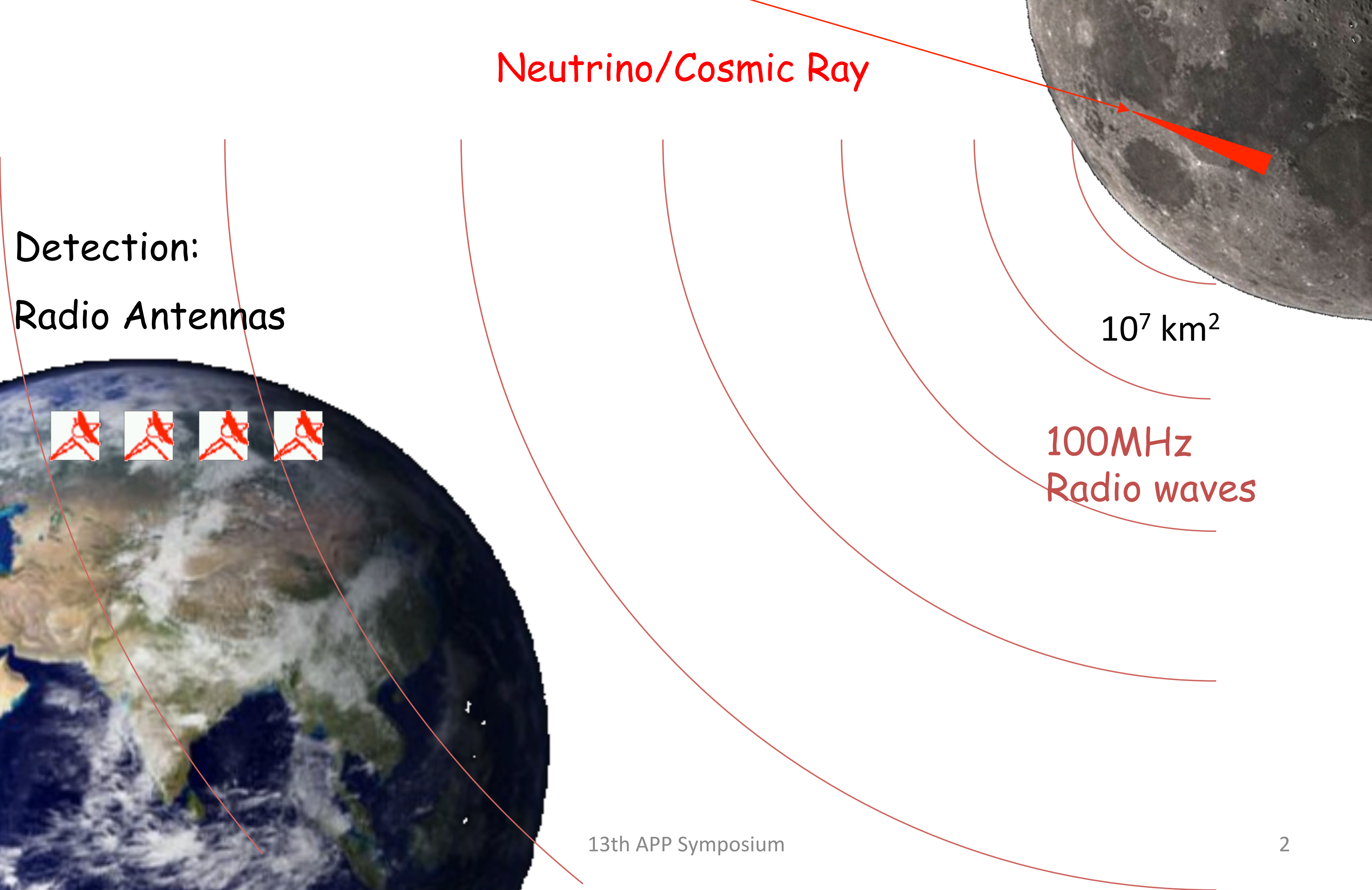
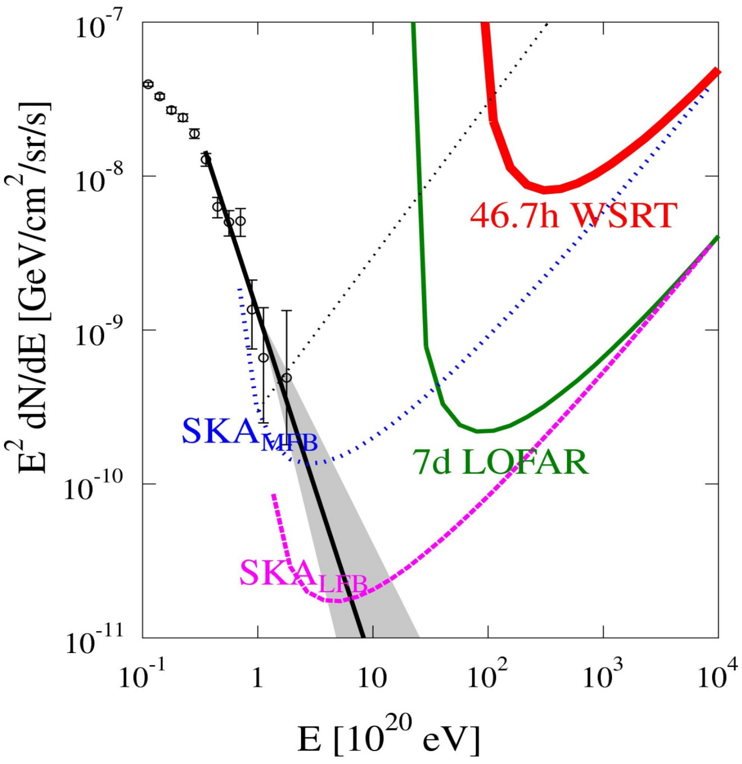
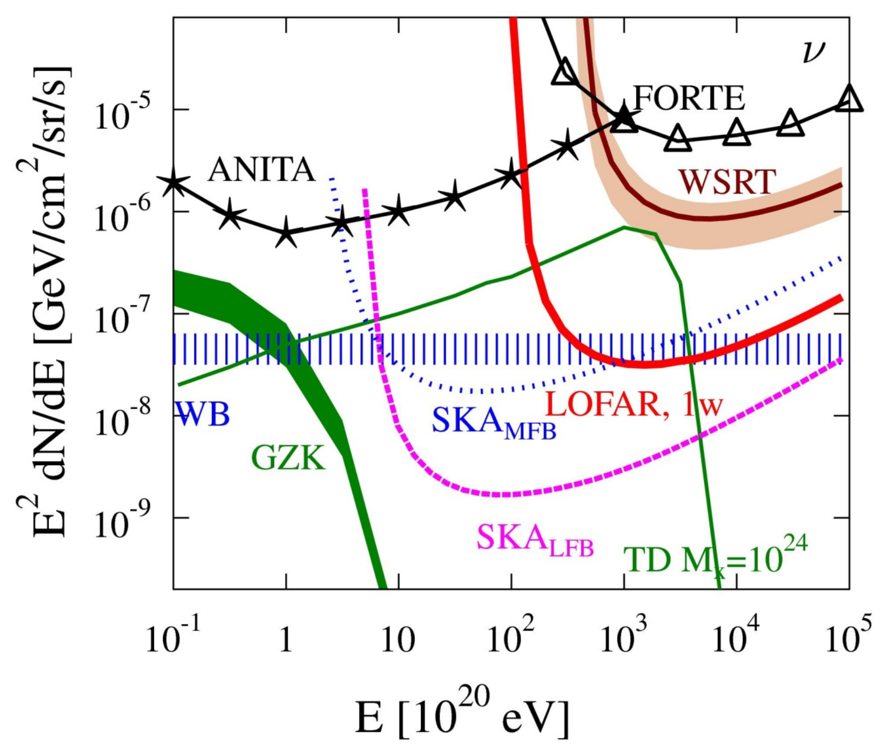
Principle of the measurement



LOFAR frequencies: highest detection probability
trade off: higher energies
Competitive flux limits possible with 1 week of LOFAR data





UHEP mode

HBA data

buffer → TBB

PPF ->freq domain

Select bands (244)

Dump data of all stations (station beamformed?)

Offline: use improved pointing + better knowledge of ionosphere to discard any remaining noise pulses

CEP:

form tied array beams

- about 50 needed
- full time resolution (bypass 2nd PPF)
- full core (single clock)

dedispersion (remove ionospheric effects)

convert to time domain:

- inverse PPF (time resolution 5 ns)

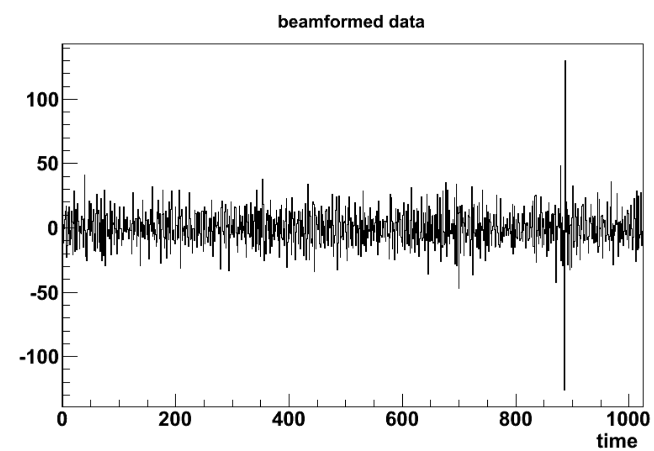
get sum of power in N consecutive bins for all beams

find pulses with power/noise > threshold

combine triggers of all beams / both polarisations:

- (anti-) coincidence

Trigger

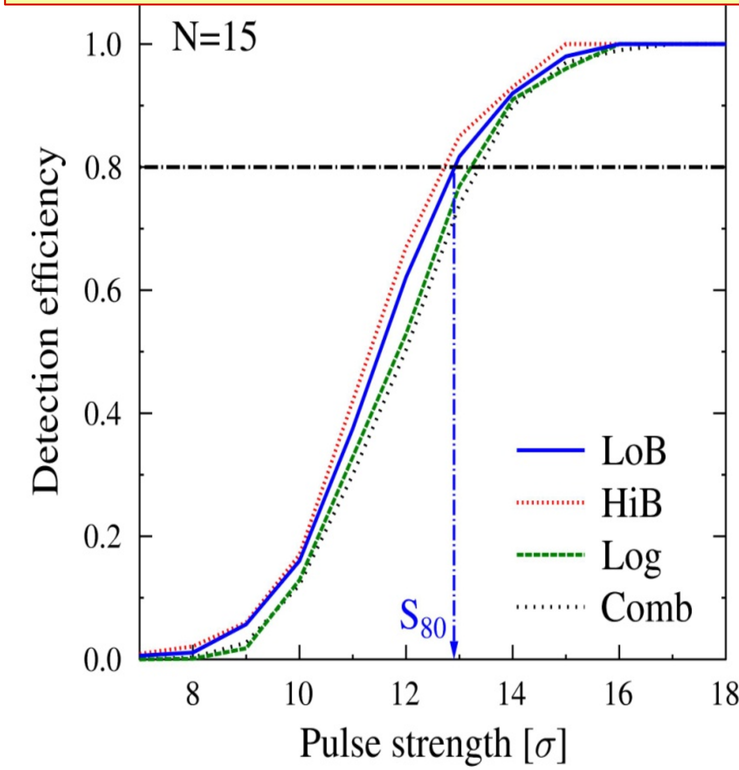


Full Simulation

Simulate full trigger chain:

- Input: Gaussian noise + bandwidth limited delta peak signal
- Determine optimal band selection
- Determine optimal number of summed bins
- Simulate ionosphere
  - estimate needed STEC accuracy
- Simulate beam effects (no dipole model)
- Determine threshold:
  assuming at most 1 trigger/min on Gaussian noise
- Determine trigger efficiency

Detection efficiency vs. Pulse strength
80% detection efficiency pulse strength determines sensitivity

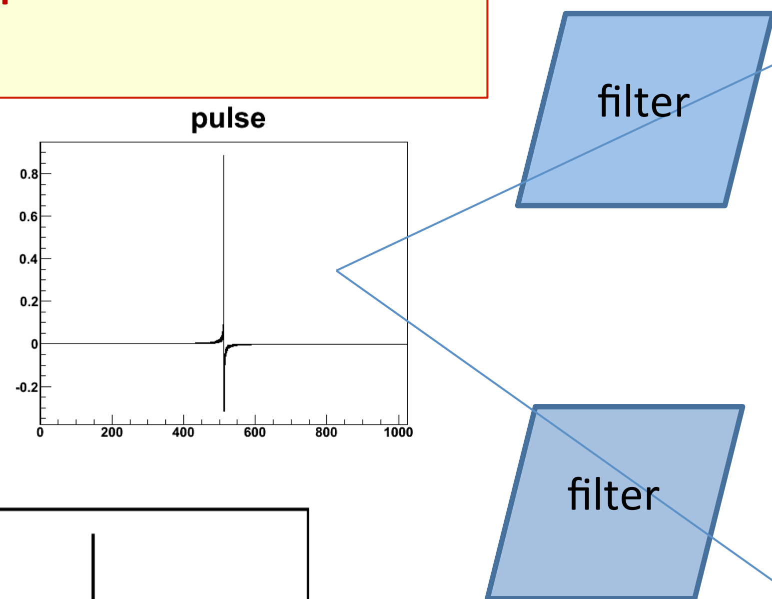


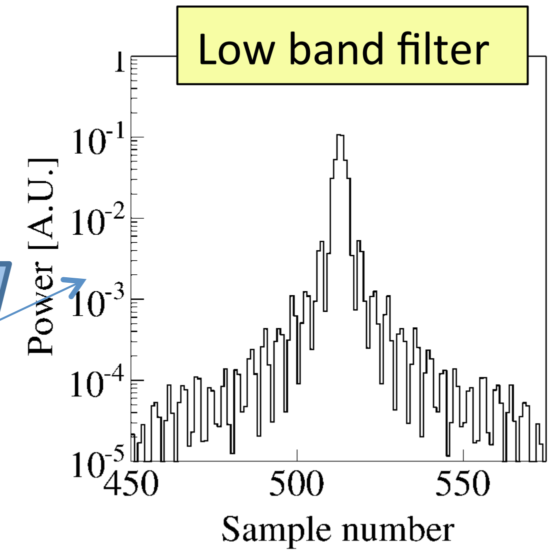
K.Singh et al. LOFAR comissioning paper
Submitted for publication to NIM: arXiv: 1108.5745

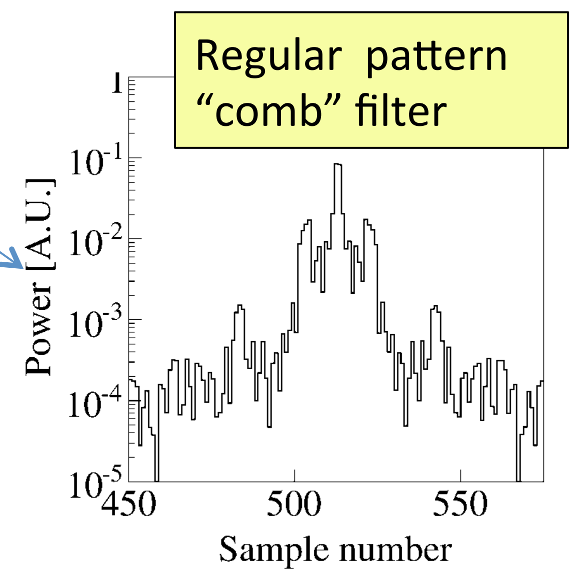
Frequency selection:

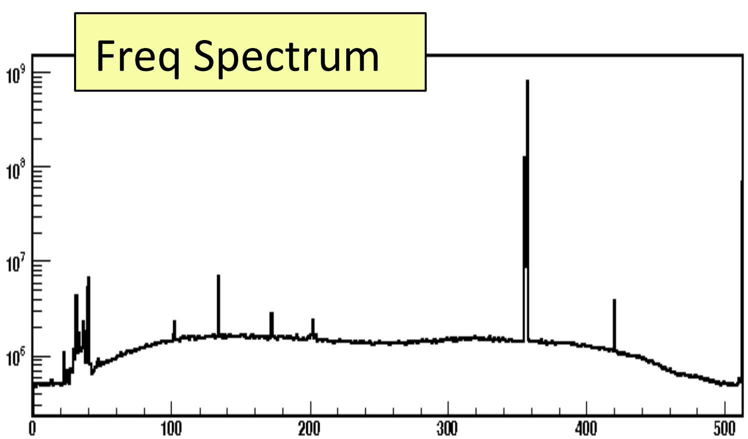
- Avoid frequent narrow band RFI
- Low band: best sensitivity
- High band: less influence ionosphere
- Avoid regular patterns in band selection

Average power distributions of pulse after filter





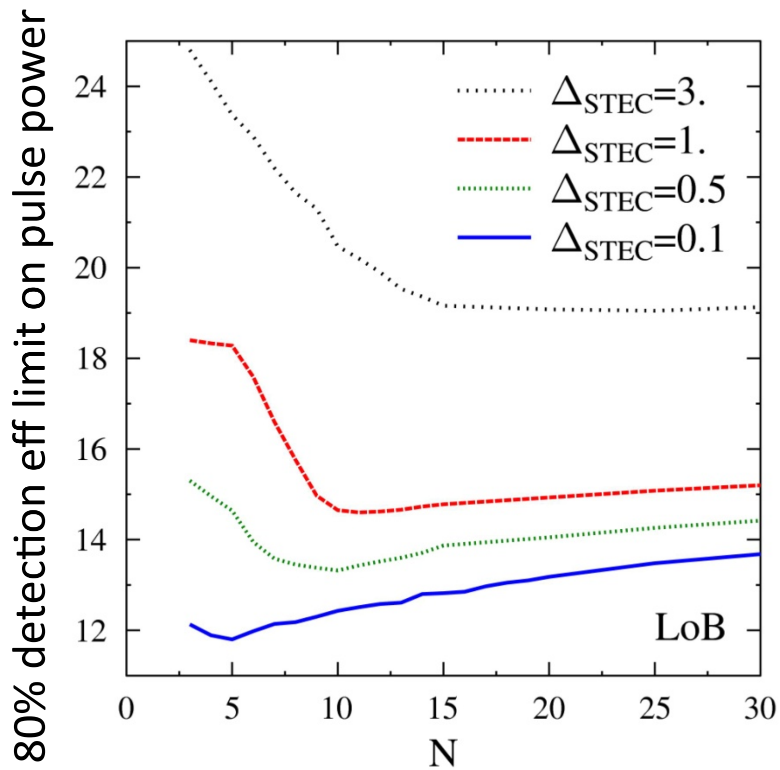




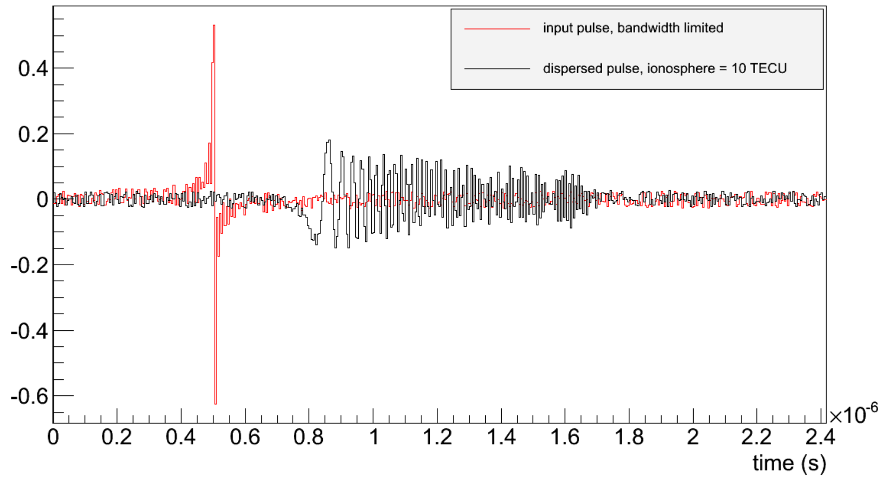
Dedispersion:

- Determine effect of STEC error on detection efficiency
- Required accuracy ~ 1 TECU

Minimal detectable pulse power for different STEC errors

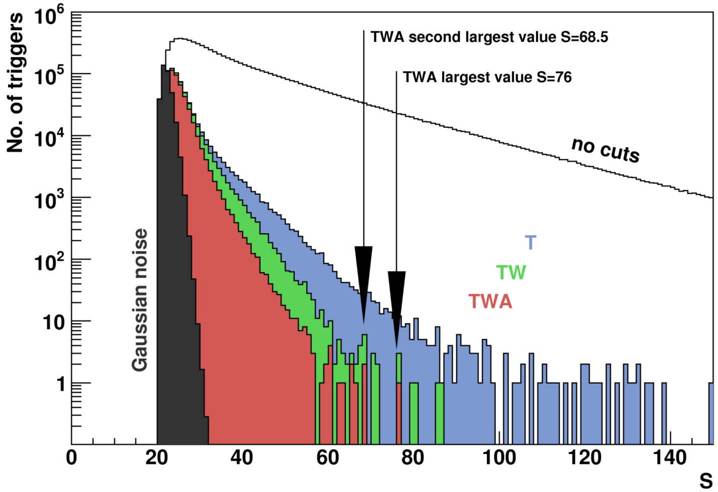


dispersed pulse 100 MHz bw, STEC=10



Data Analysis

Noise pulses: experience from WSRT



Goal:
Determine level of non Gaussian noise for LOFAR
Important to control this to keep trigger rate managable

Data Sets:
Raw Stationbeam Voltages (bypassing 2nd PPF)
61 subbands around 140MHz
Superterp only, 8 (6) half stations
Station beams pointing to Virgo A (3c196)
In brackets: specifications of earlier dataset

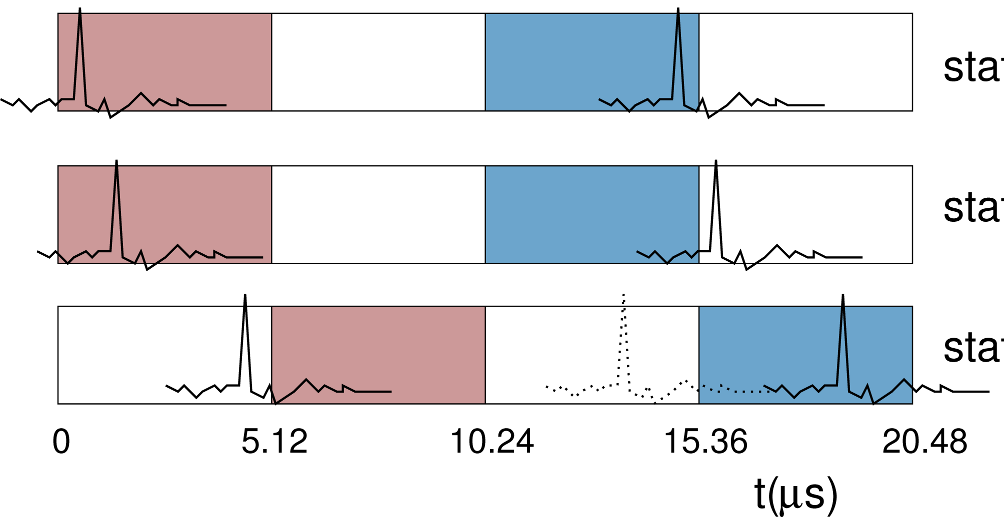
Raw voltage station beams @ CEP
Apply all remaining steps towards trigger, offline:

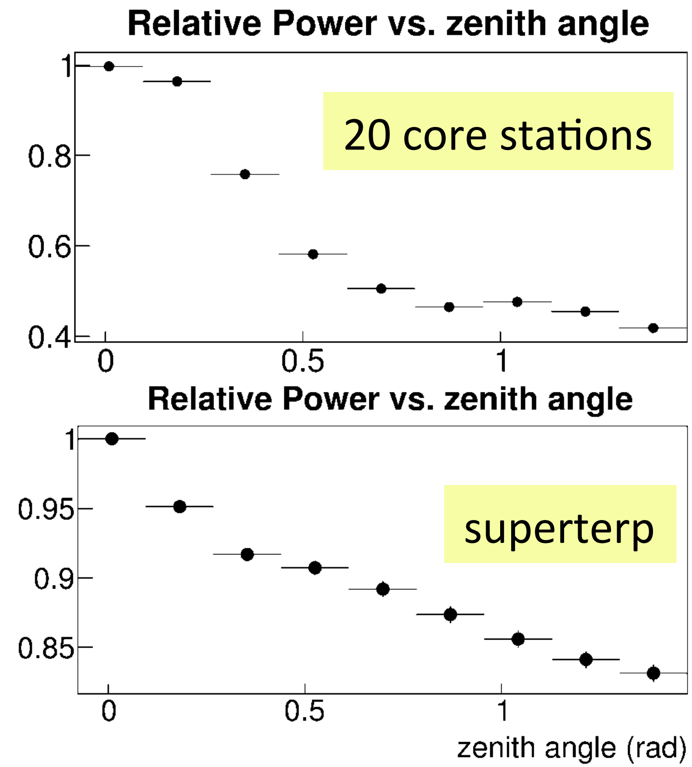
- Form tied array beams
- Oversample to 512 sb
- iFFT + inverse PPF
- Get P10 values for all beams

Verify all trigger steps on real data!

Sample shift:

- To obtain maximum sensitivity data of stations should be aligned up to 5ns level, instead of 5.12 μs
- If this is not done the short time pulse could and up in a different block for some stations, reducing the recovered power





data set under discussion:

station beams -> possible to correct offline

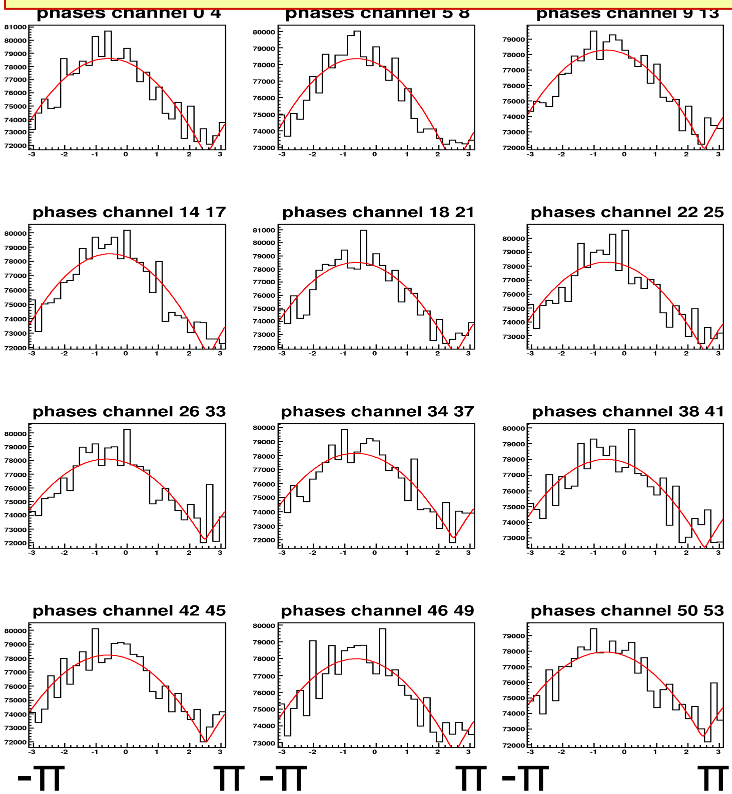
Tied array mode for short time signals:

- correction needs to be done at stationlevel
- dynamically due to changing source position

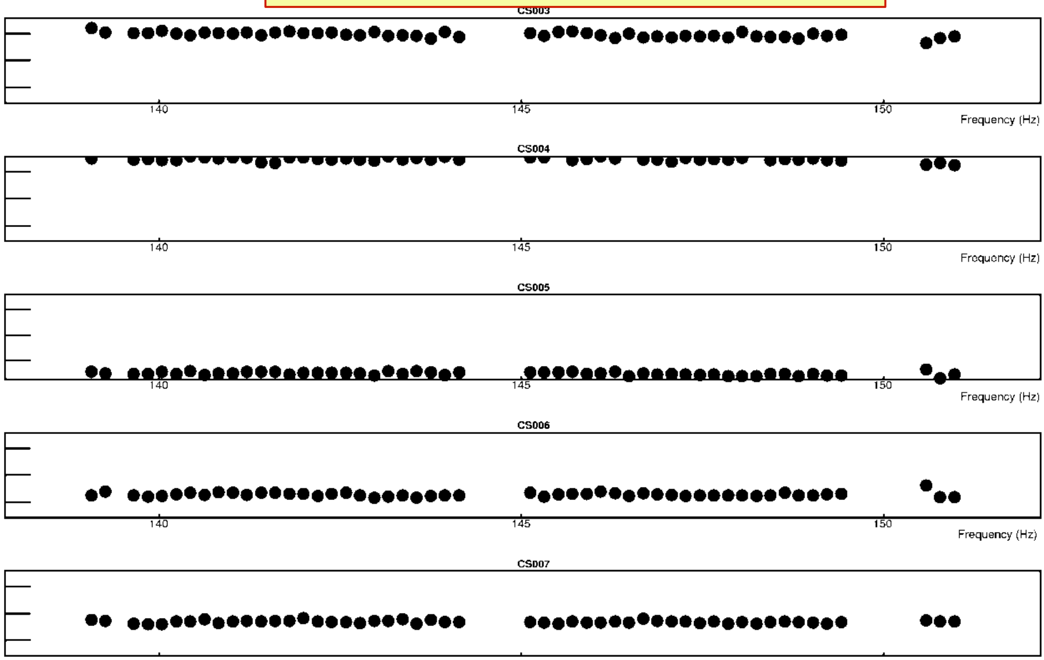
Simple Phase calibration:

- Dominant point source in center field
- Assume all phase difference on average 0
- Determine avg $\Delta\varphi$ for every frequency bin (1seconde of data)
- Fit delays + φ_0

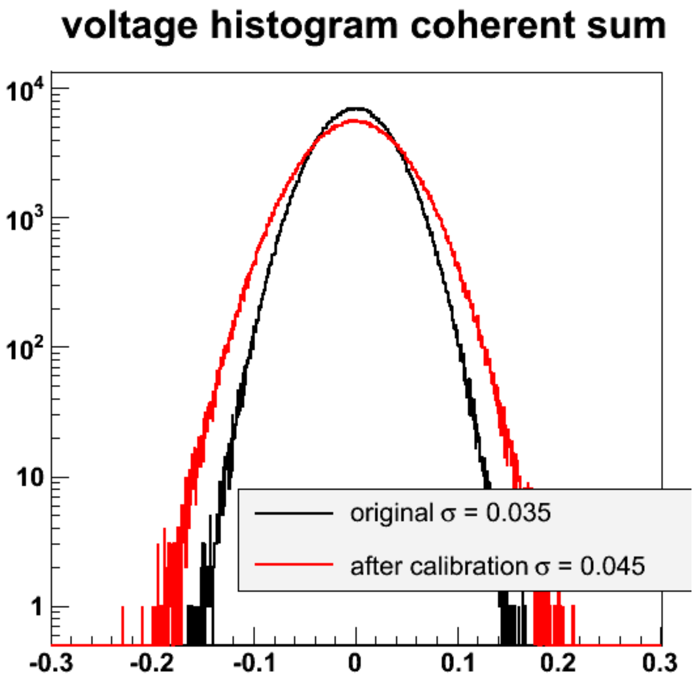
$\Delta\varphi$ histogram per frequency channel



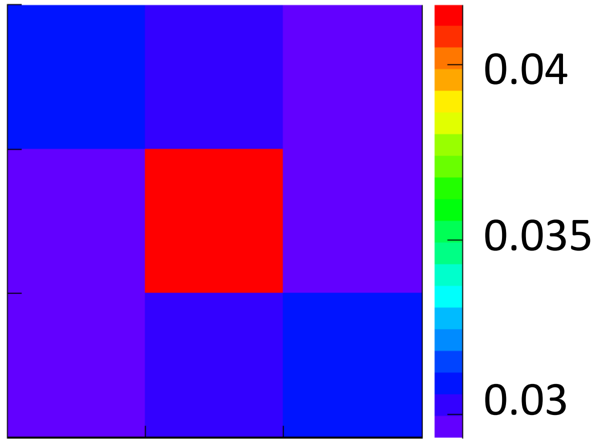
$\Delta\varphi$ vs frequency per station



Voltage histogram before and after calibration
~ 20% larger amplitude

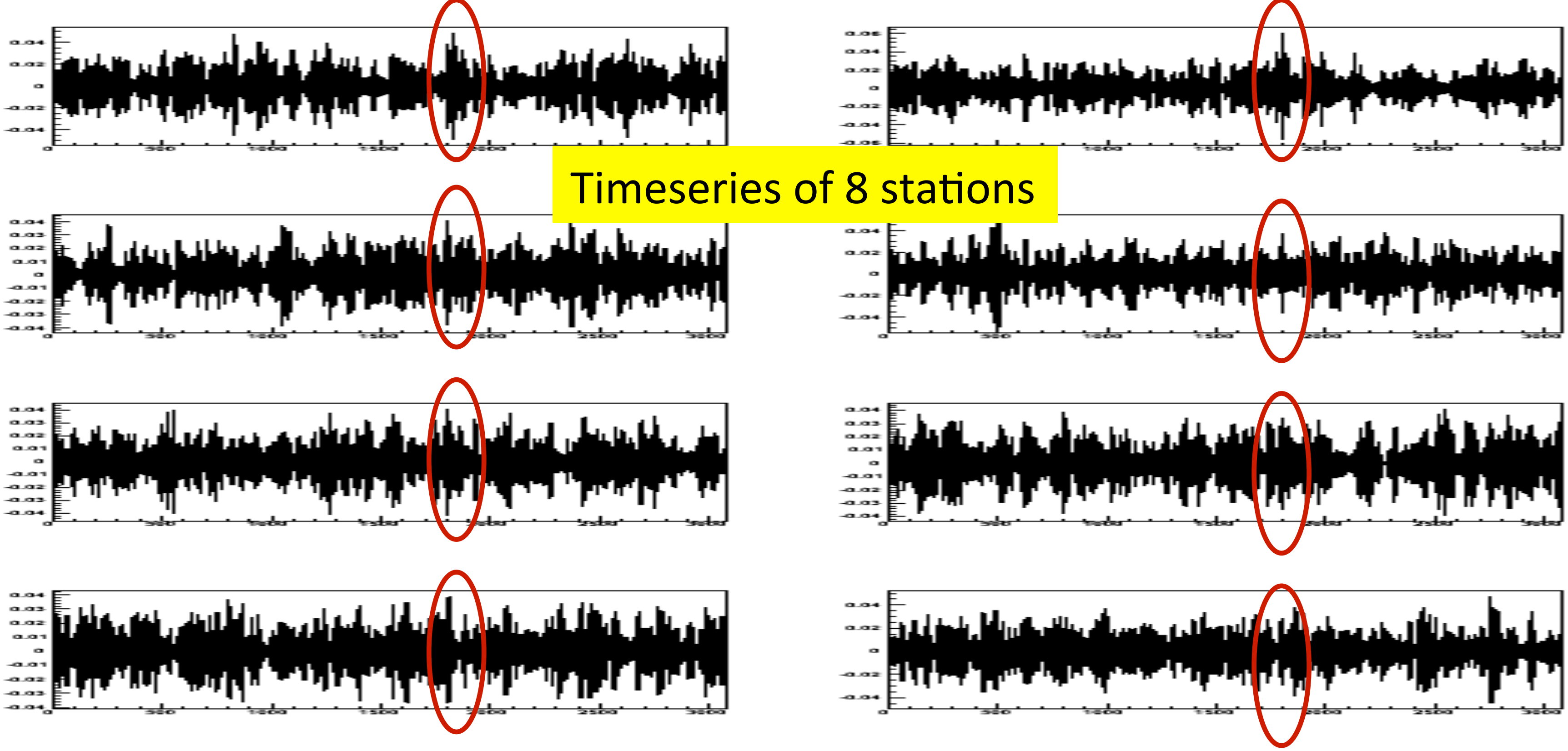


Square degree image of σ

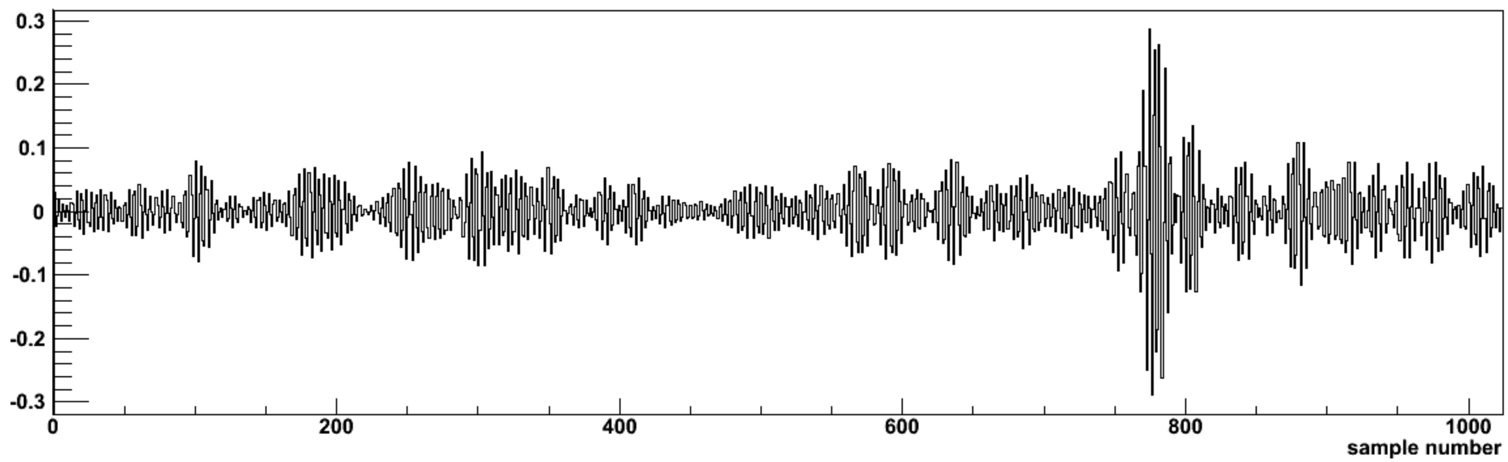


Analysis steps:

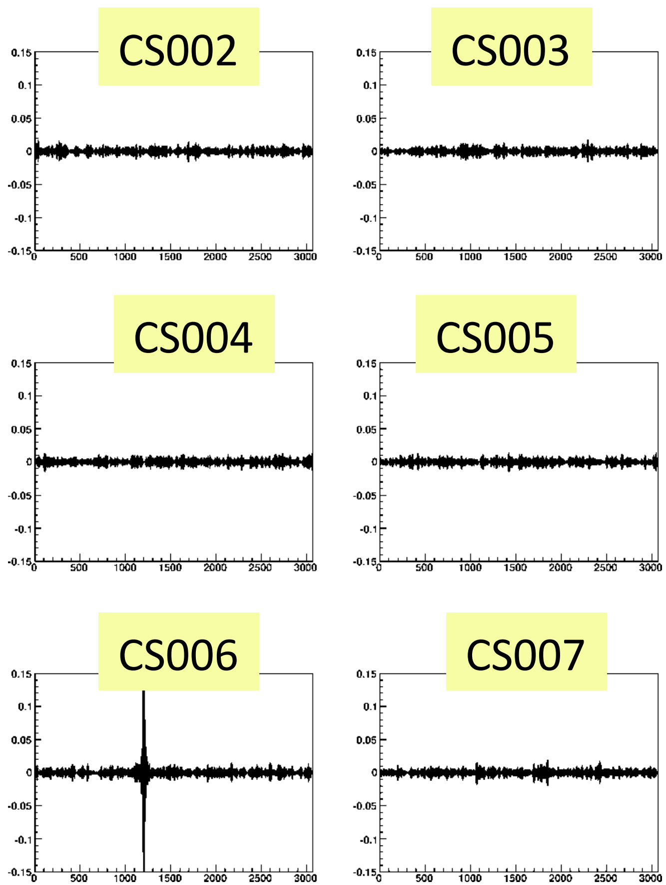
- Set power of RFI lines =0
- Oversample: 61 sb -> 512 sb
- Convert station data to time domain:
  - iFFT + inverse PPF
- Shift timeseries such that data is aligned to sample level (5ns) for central pixel
- FFT
- Apply remaing phase delays to form tied array beams in 9 (25) directions
- iFFT ->Timeseries
- Get P10 values (sum over 10 consecutive bins of power) for all beams
- Find pulses

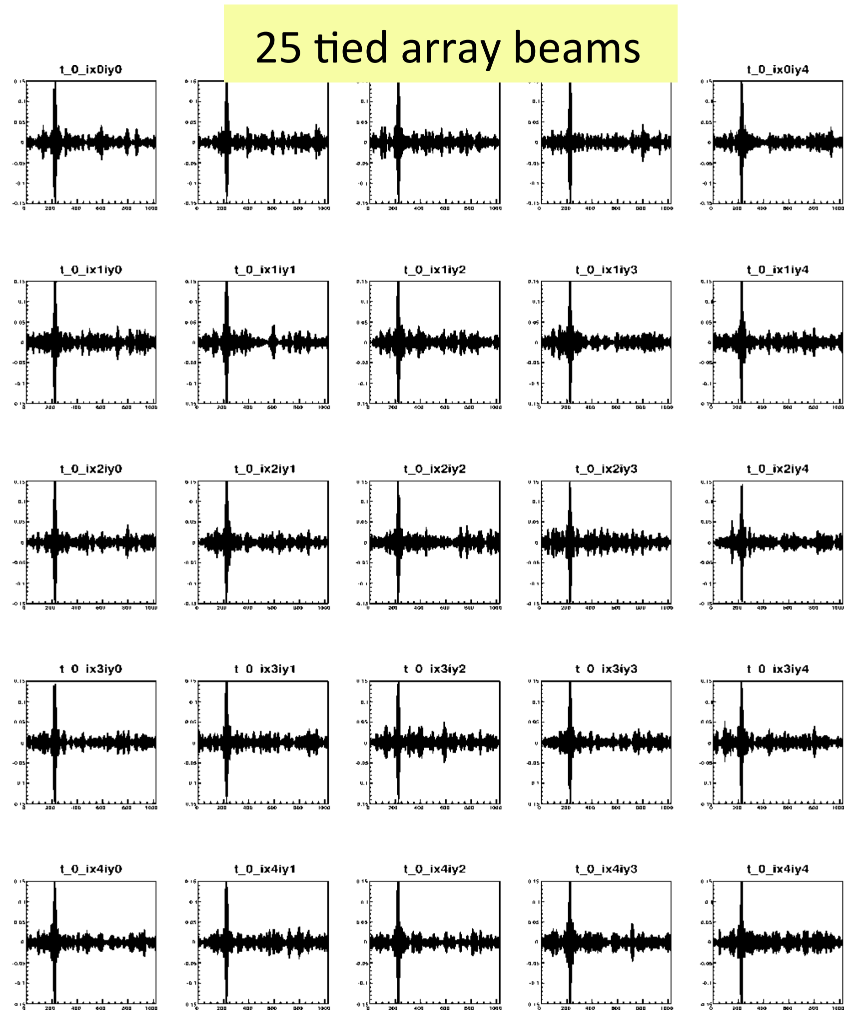


simulated pulse coherent sum

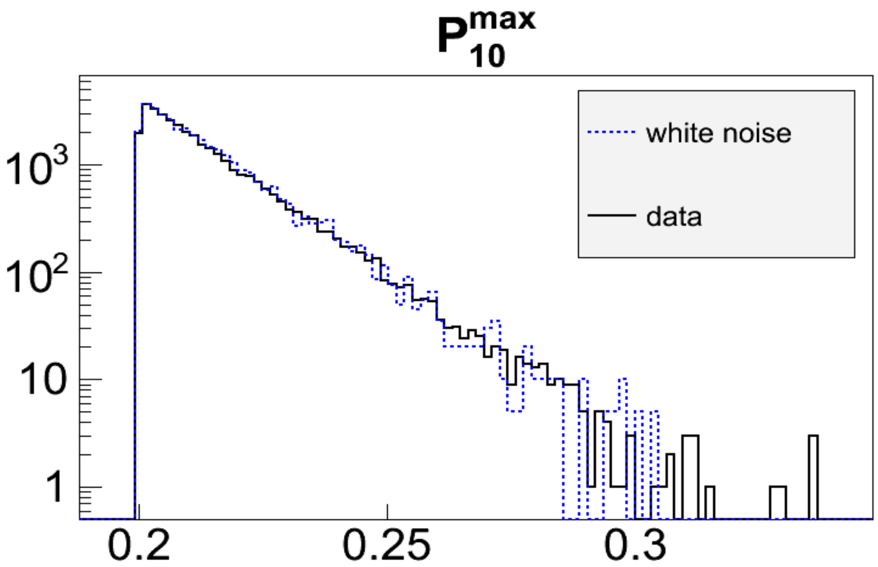


Anti-Coincidence requirement removes instrumental/local noise

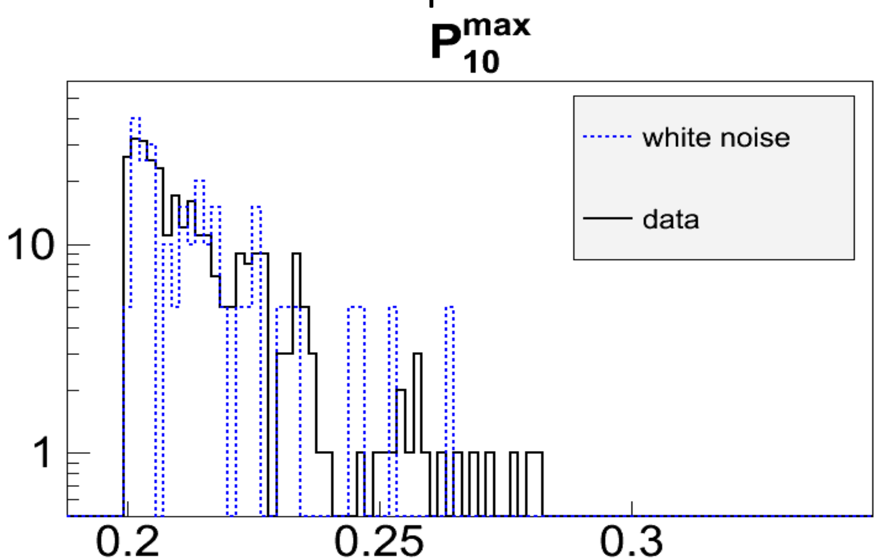




P10 distributions



After coincidence requirement



No pulses other than Gaussian noise were found in 5 minutes of data

Next steps:

- Repeat analysis on full bandwidth data
- More stations (tied array mode)
- Point one or more beams to the Moon, to check for differences
- Investigate short time structure of others sources?
- Implement simple trigger (@TBBS or CEP)

Conclusion

- Lofar can be used as ns instrument
- Competitive limits on neutrino flux using the Moon as detecting volume
- Other ns science?
- Transient (short broadband) noise levels appear no limiting factor (analysis ongoing)
- For a full online trigger implementation, perfect online timing between stations is necessary
- Online trigger algorithm defined, ready for implementation of UHEP mode Q1 2013