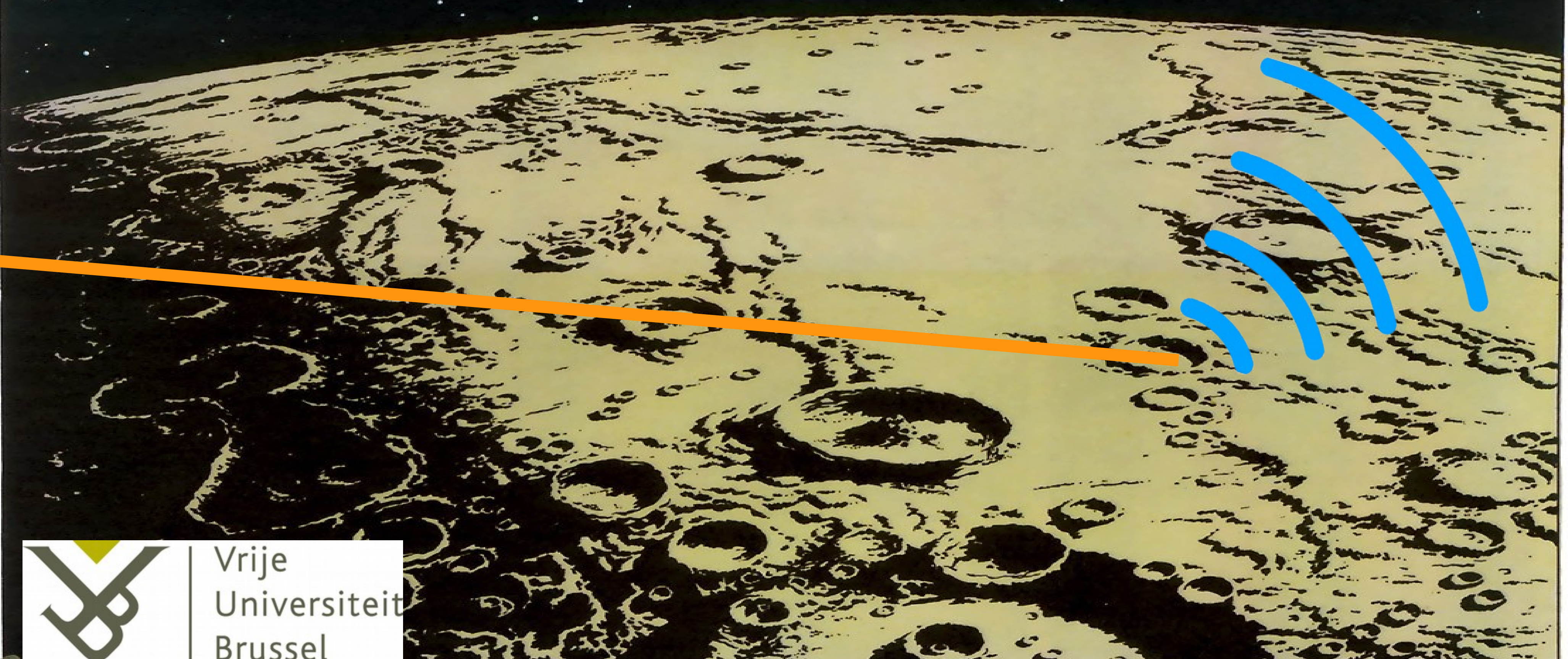
Tobias Winchen

Search for Cosmic particles With the Moon



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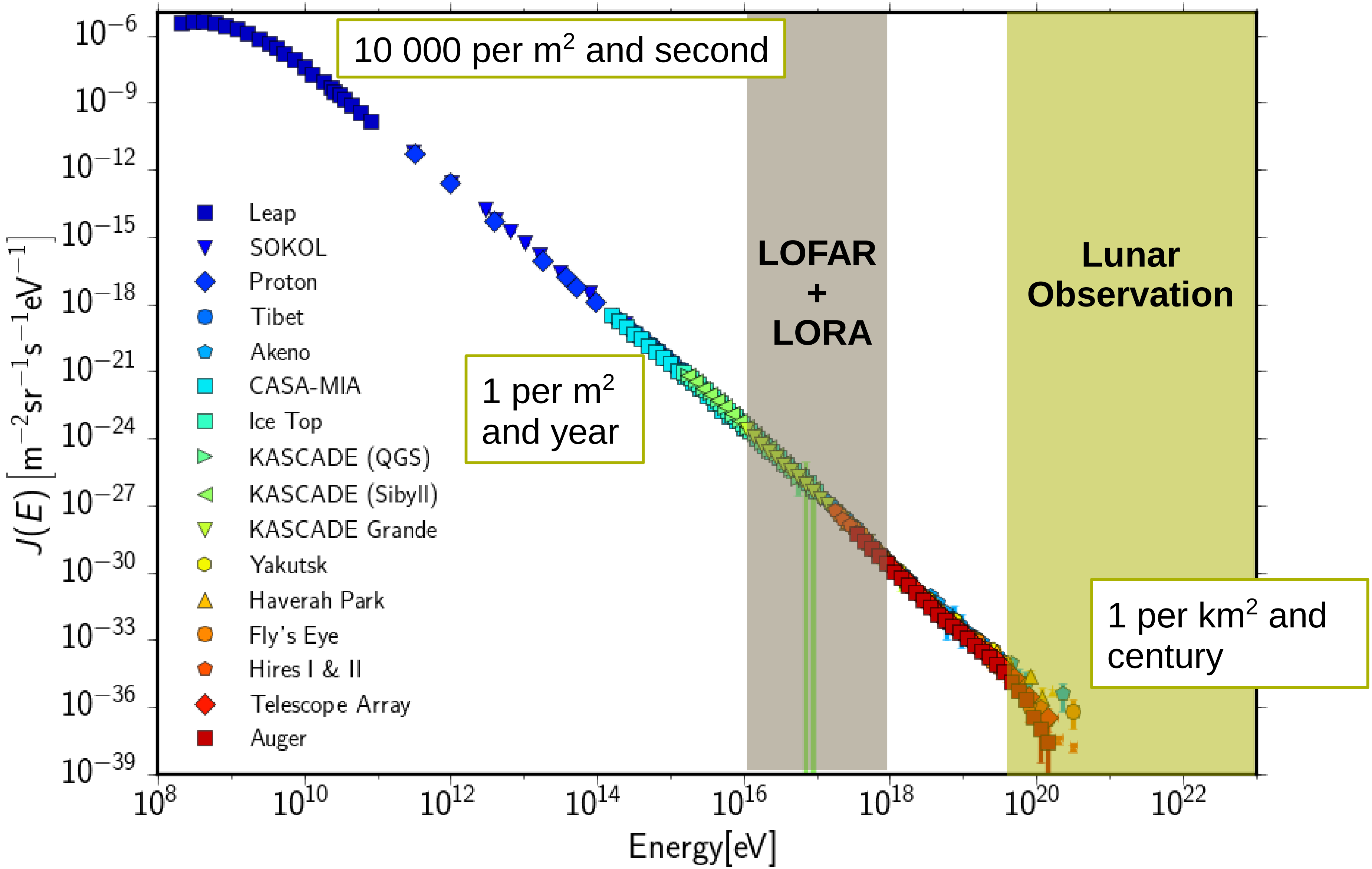
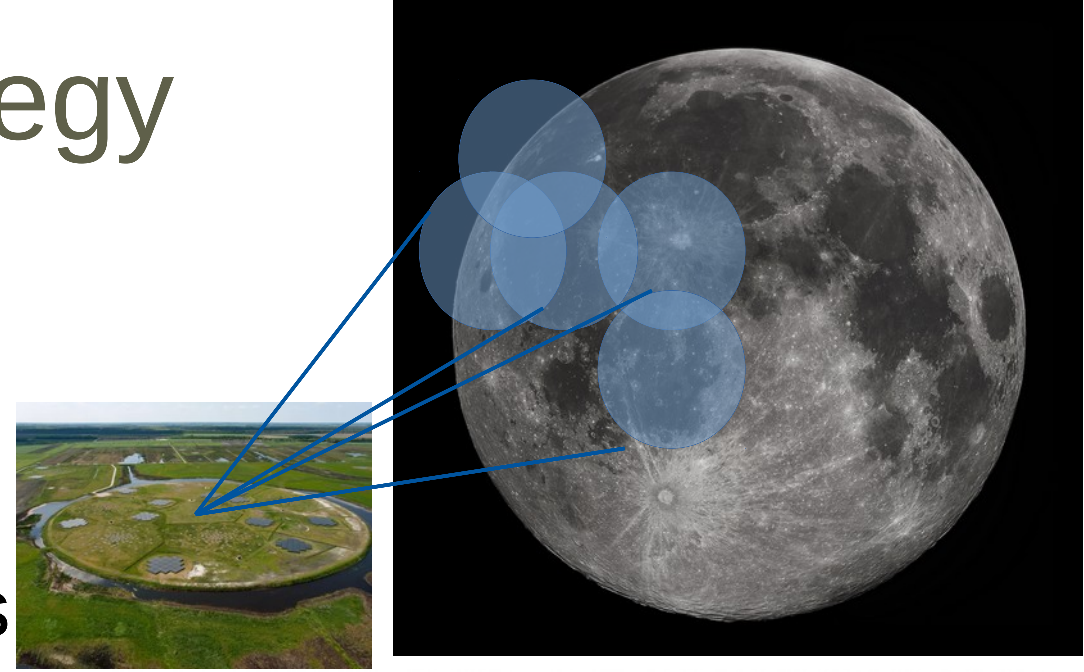
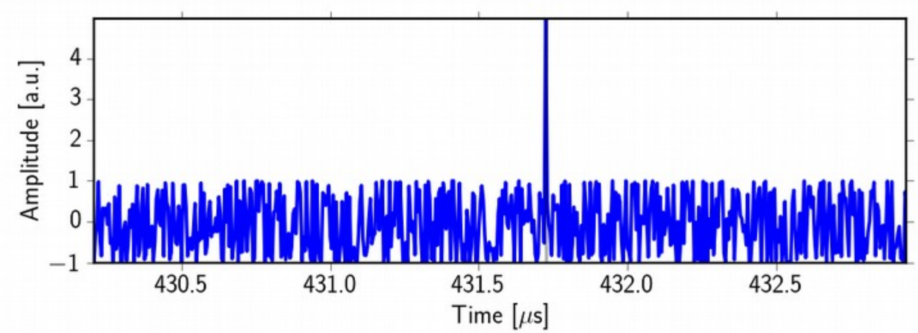
Cosmic Ray Energy Spectrum

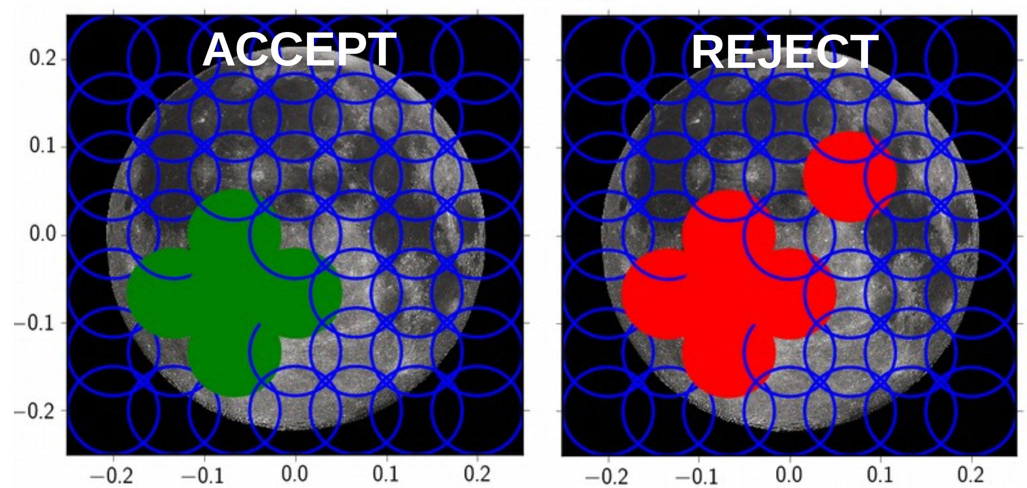


Observation Strategy

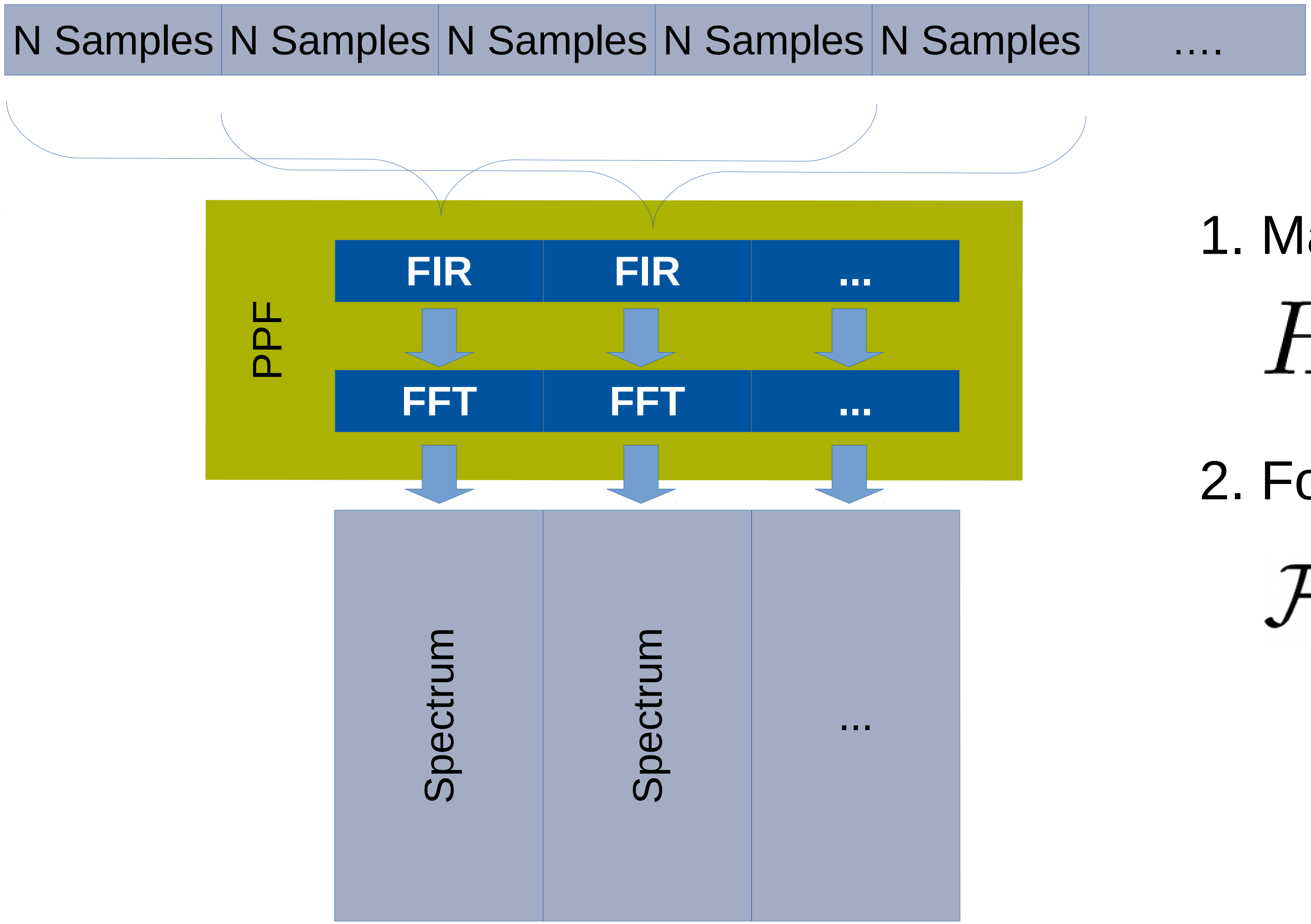
- Station beams from HBA Antennas 110 – 250 MHz
- Create tied array beams
- Correct ionospheric dispersion
- Reconstruct time series
- Search for pulses
- Anti-coincidence trigger
- Save TBB data







Polyphase Analysis



1. Matrix product

$$Hx = y$$

2. Fourier trafo

$$\mathcal{F}(y) = \tilde{y}$$

Polyphase Synthesis (PPF^{-1})

$$\mathcal{F}^{-1}(\tilde{y}) = y$$

- Direct inversion of FIR filter

$$H^{-1}y = \hat{x}$$

Inverse does not exists as H is not square

- Approximate inverse

$$Gy \approx \hat{x} \qquad GH \approx I$$

Tends to be numerically unstable

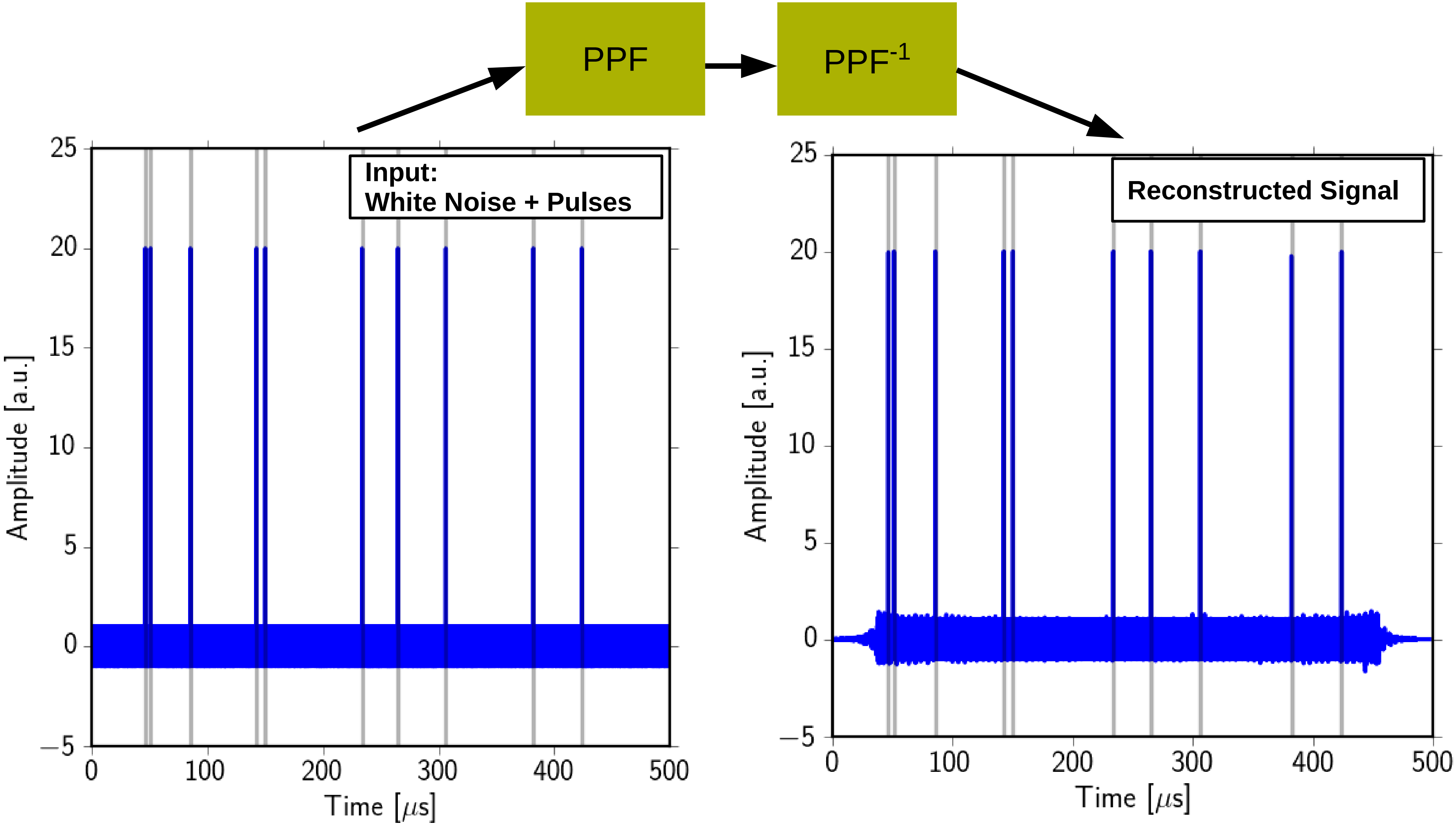
- Solve linear system

$$H\hat{x} = y$$

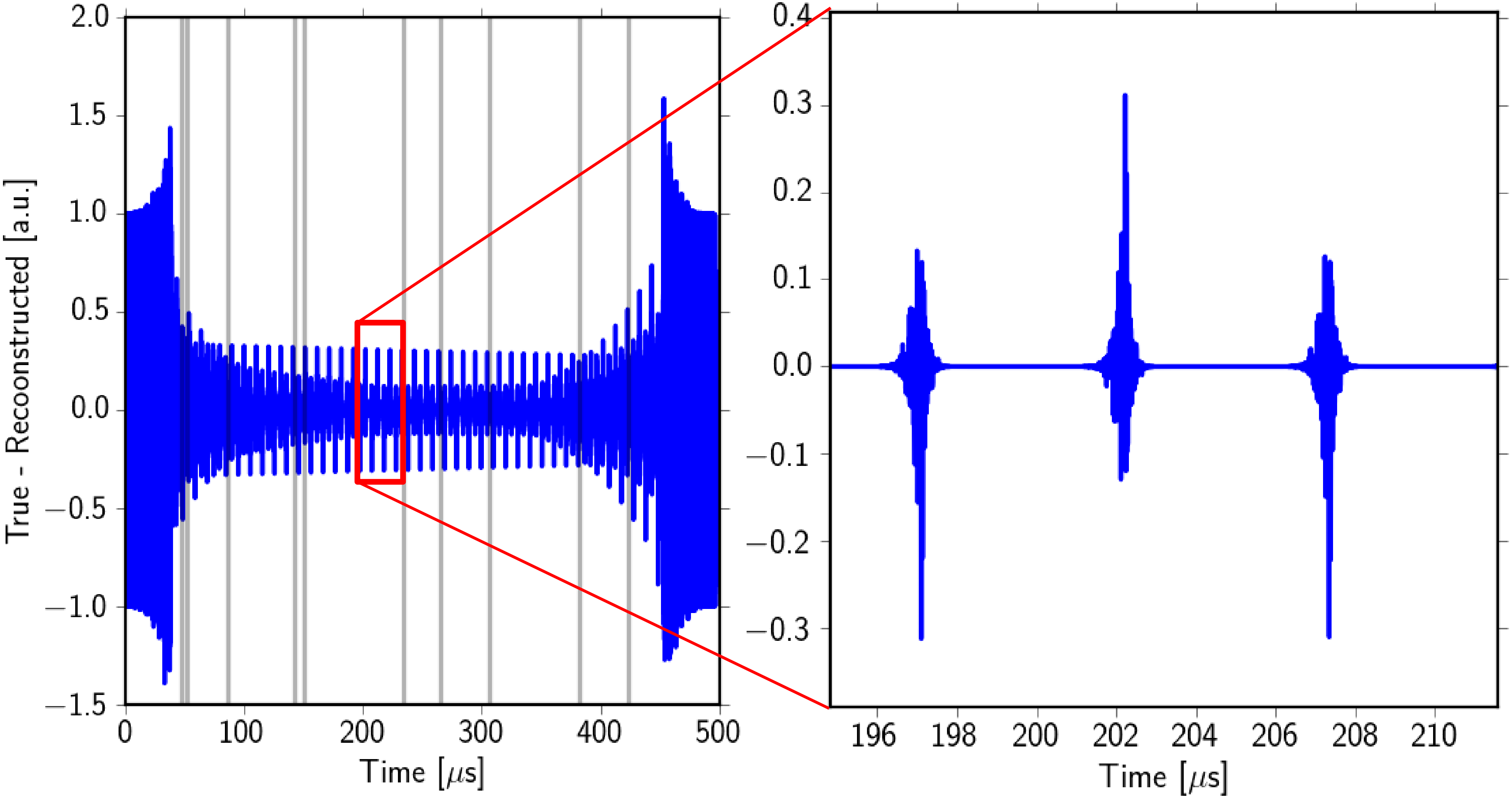
numerically using iterative least squares (LSMR) :

$$\min_{\hat{x}} ||H\hat{x} - y||$$

PPF Synthesis



Accuracy of PPF Synthesis

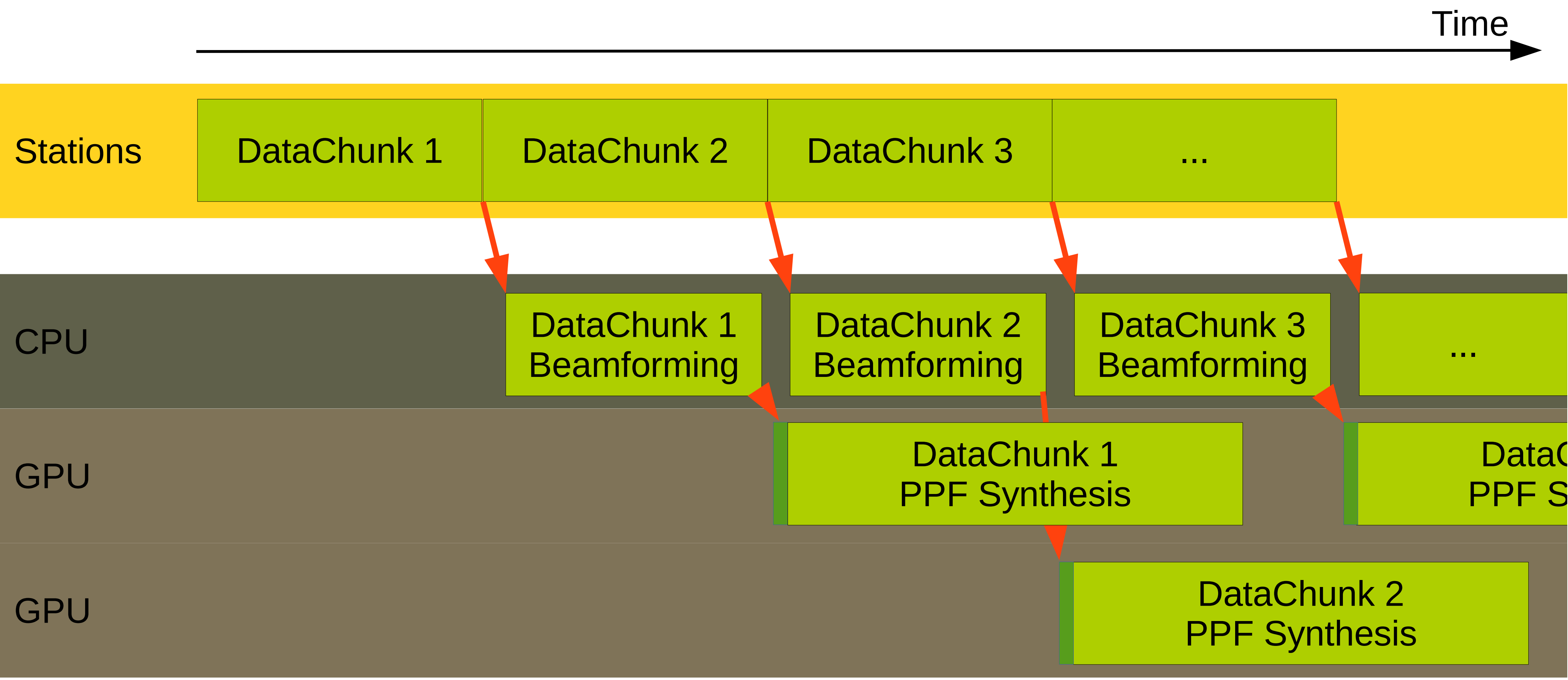


Numeric noise at ~ 30% level of white noise
Uncorrelated with pulse position

Performance Prototype Pipeline

- Beamforming < Realtime
- Dedispersion 5% Realtime, (GPU)
- PPF Synthesis 160% Realtime, (GPU)

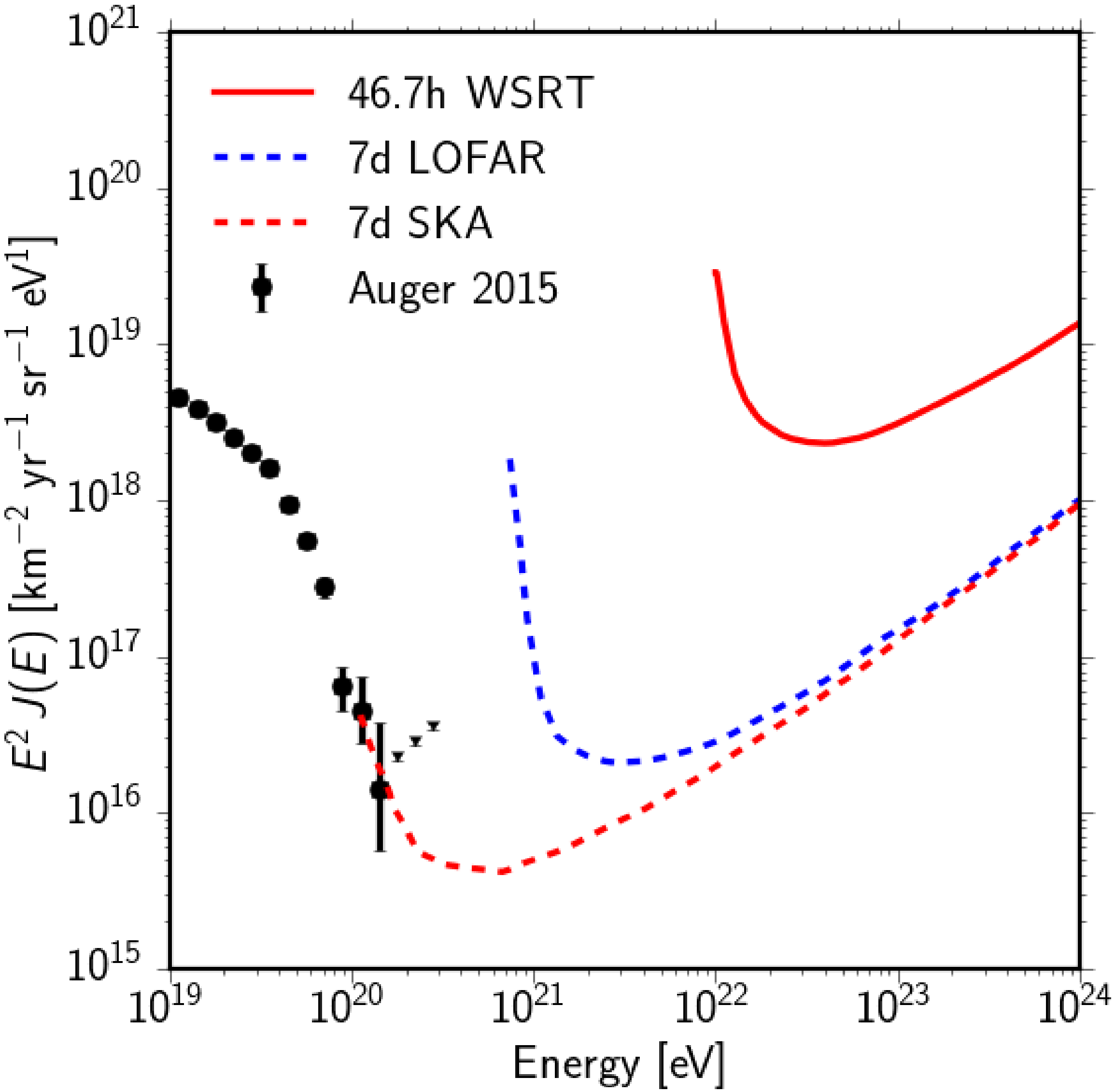
Prototype Implementation on Nijmegen cluster
CPU: Xeon-2660 (2012)
GPU: M2090



Computing on DRAGNET

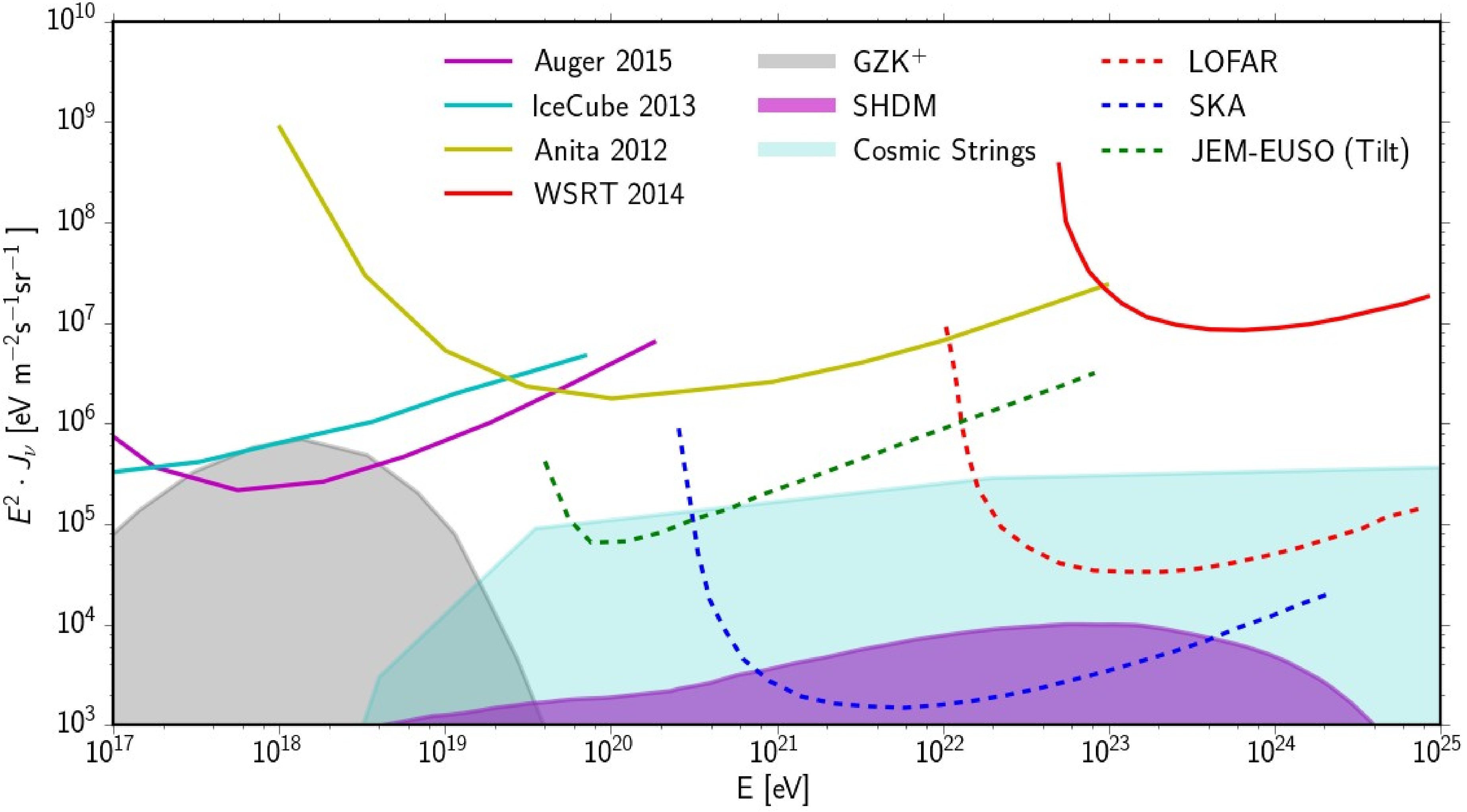
- DRAGNET cluster (J. Hessels et al., Pulsar Searches)
  - 23 Worker nodes
    - 16 CPU cores (2x Xeon E5-2630v3 (2014))
    - 128 GiB ram
    - 4x TitanX GPU
    - 56 Gbit/s Infiniband connection to LOFAR
- Estimate based on prototype implementation:
  - 2 Beams per node,
  - 46 beams total: Full coverage of the moon!

Sensitivity to Cosmic Rays



- Improve limits to ZeV particles by 10x
- Develop technology for SKA observations

Sensitivity to Cosmic Neutrinos

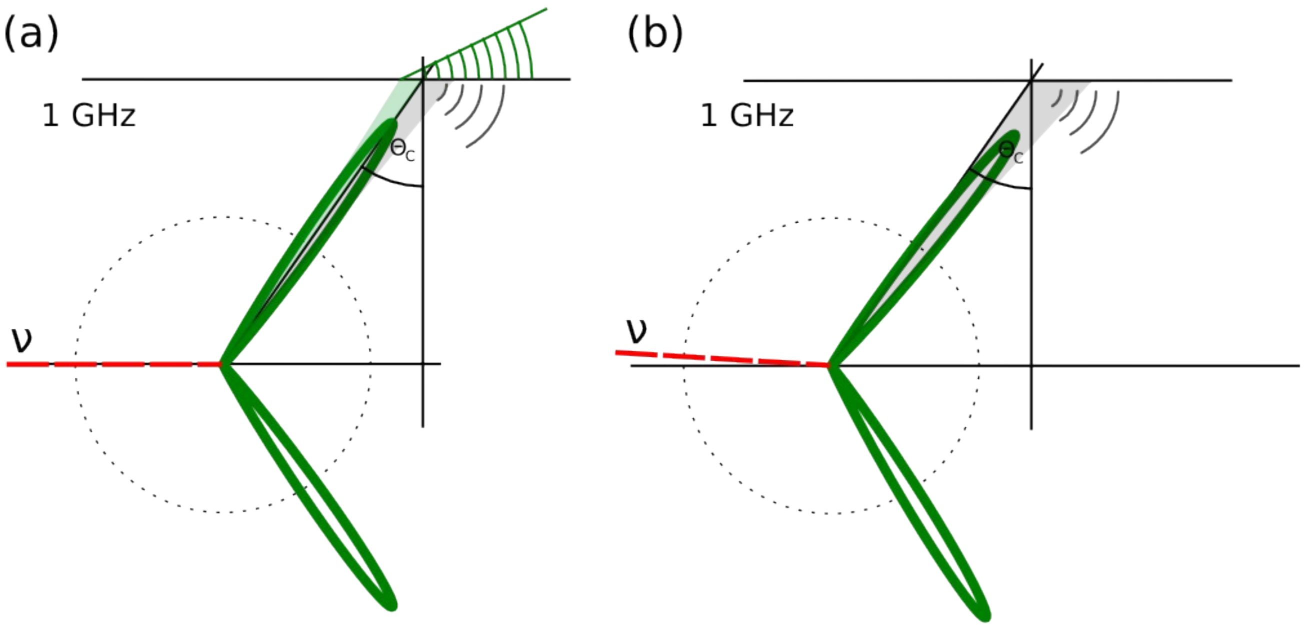


Conclusions

- Search for ns pulses from the moon
  - Improve limits on cosmic particles above 10 ZeV by a factor greater than 10x
  - Probe new physics scenarios
  - Develop technology for UHECR observations with SKA
- Prototype for online pipeline running
  - Full coverage of the Moon possible
- Integrate pipeline on DRAGNET cluster
- Measure background temperature of the moon

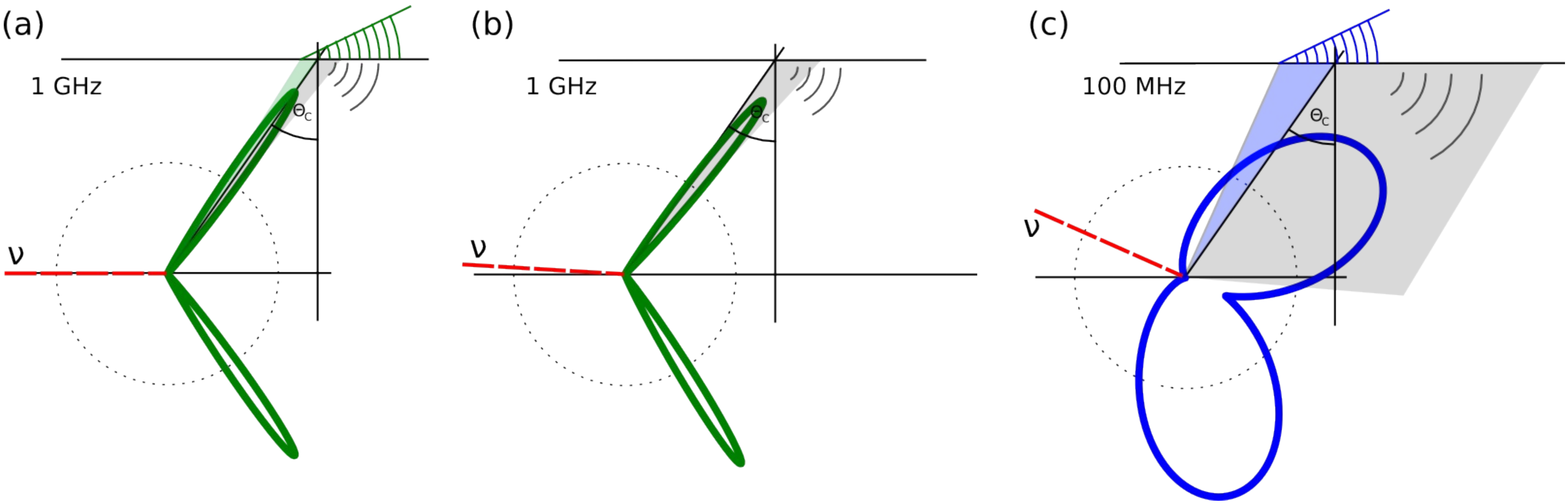
Backup

Pulse Reflection at High Frequencies



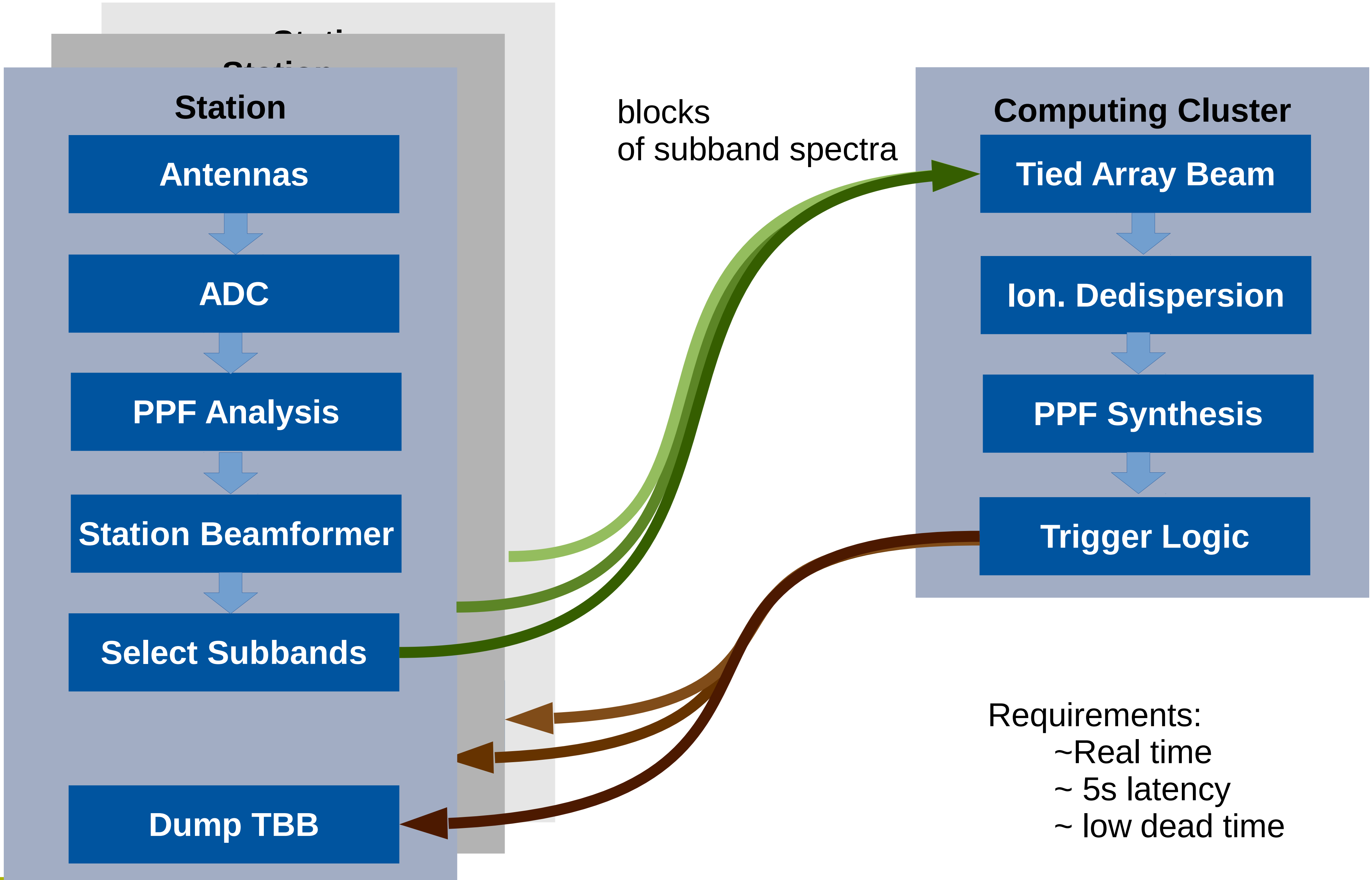
- Radiation emitted in Cherenkov cone
- Cherenkov angle == Angle of total reflection
- Upgoing shower required / rely on surface roughness

Pulse Escape at Low Frequencies



- Cherenkov cone is broader at low frequencies
- Also downgoing showers detectable
- Optimum in 100 - 200 MHz range (Scholten et al. 2006)

Online Data Analysis



Requirements:
~Real time
~ 5s latency
~ low dead time