bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

BERGISCHE UNIVERSITÄT WUPPERTAL

Prospects of GPGPU in the Auger Offline Software Framework

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for the Pierre Auger Collaboration

GPU Computing in High Energy Physics
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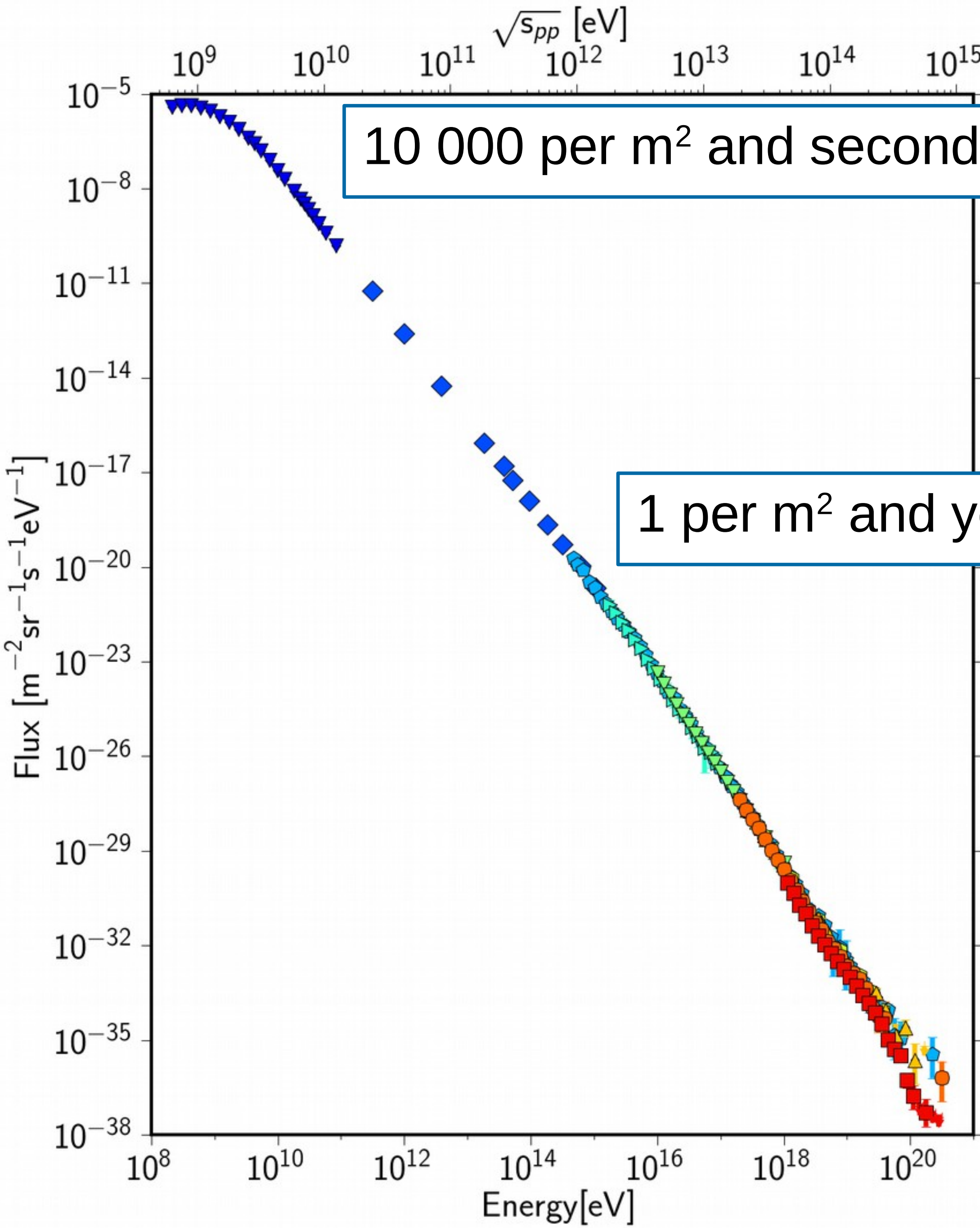
PIERRE AUGER OBSERVATORY

Cosmic Ray Energy Spectrum



10 000 per m^2 and second

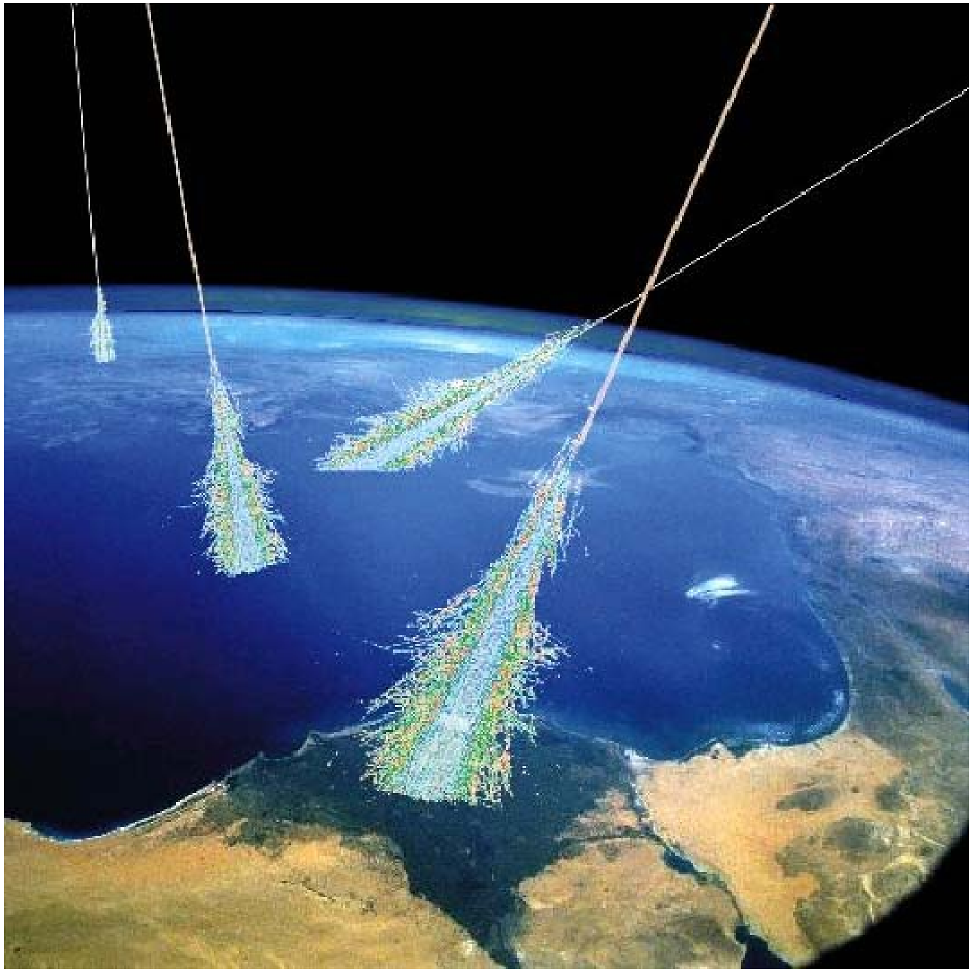
1 per m^2 and year

1 per km^2 and century

Galactic (SNR)

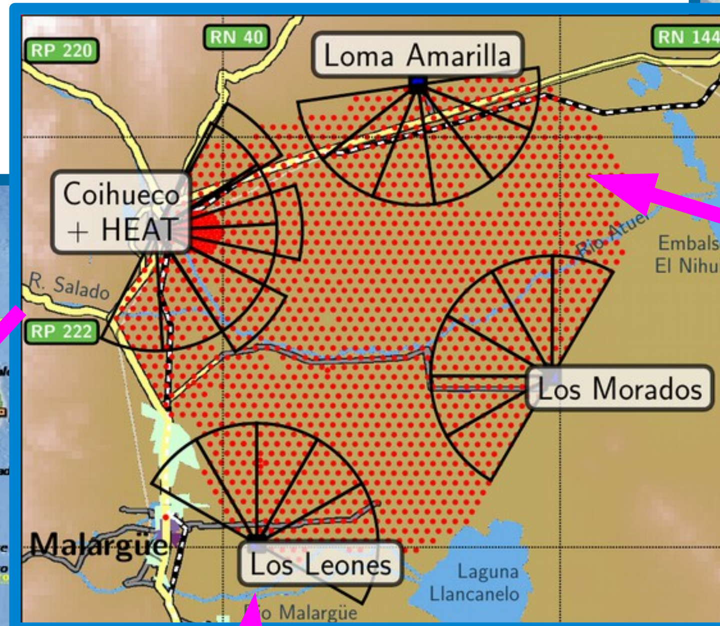
Extragalactic

Cosmic Ray Induced Air Showers



- Particle Cascade
  - ~ 10^{10} particles 10^{19} eV
  - Extend over km scale
- Electrons excite air molecules which emit fluorescence light
- Shower geometry and particle content allows conclusions on energy, direction and nature of primary particles

The Pierre Auger Observatory

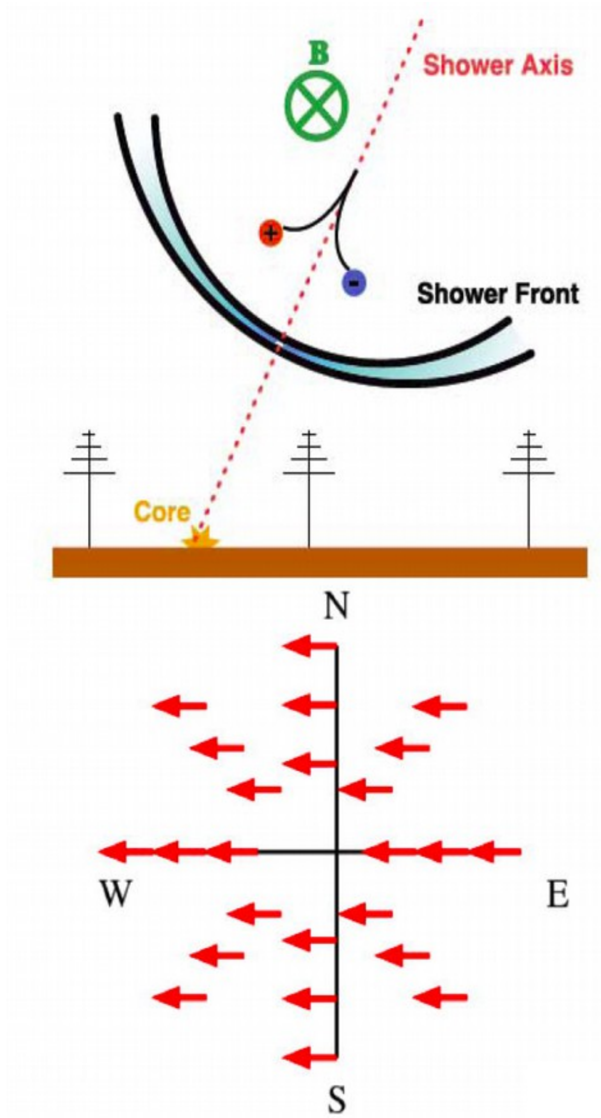


Surface Detector
1660 Water Cherenkov stations
1.5 km spacing
3000 km² covered area

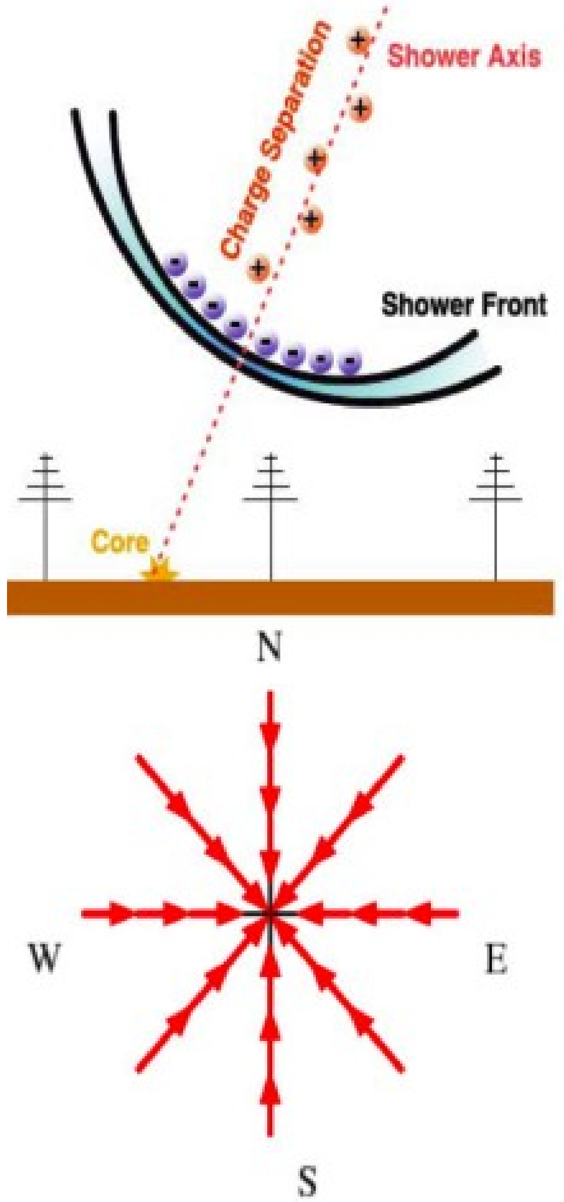
Fluorescence Detector
27 telescopes at
4 sites with 180° view

Radio Emission from Cosmic Ray Air Showers

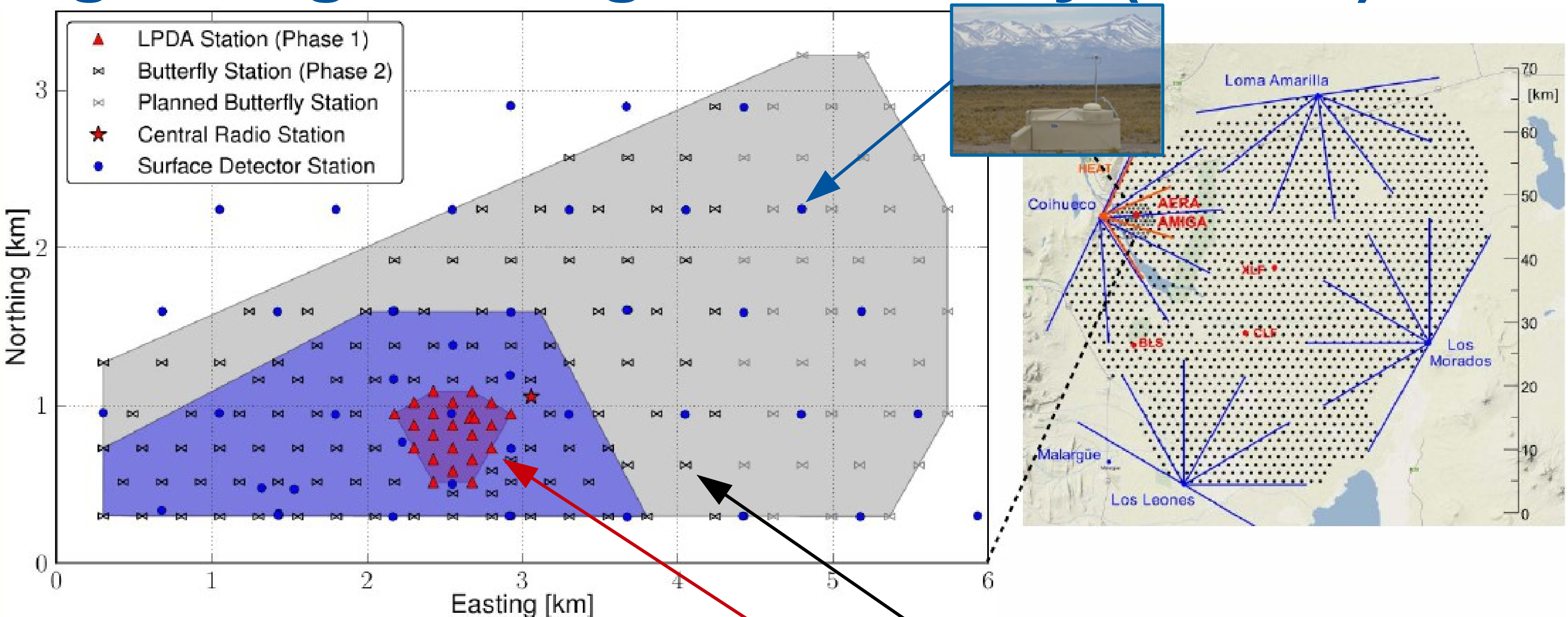
Geomagnetic Emission



Charge Excess



Auger Engineering Radio Array (AERA)

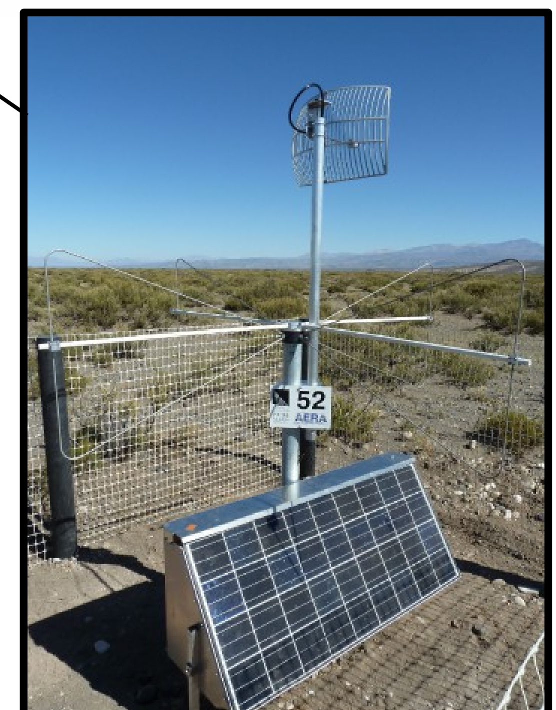


124 Stations with
2 antennas (NS, EW)

Different Antenna Types

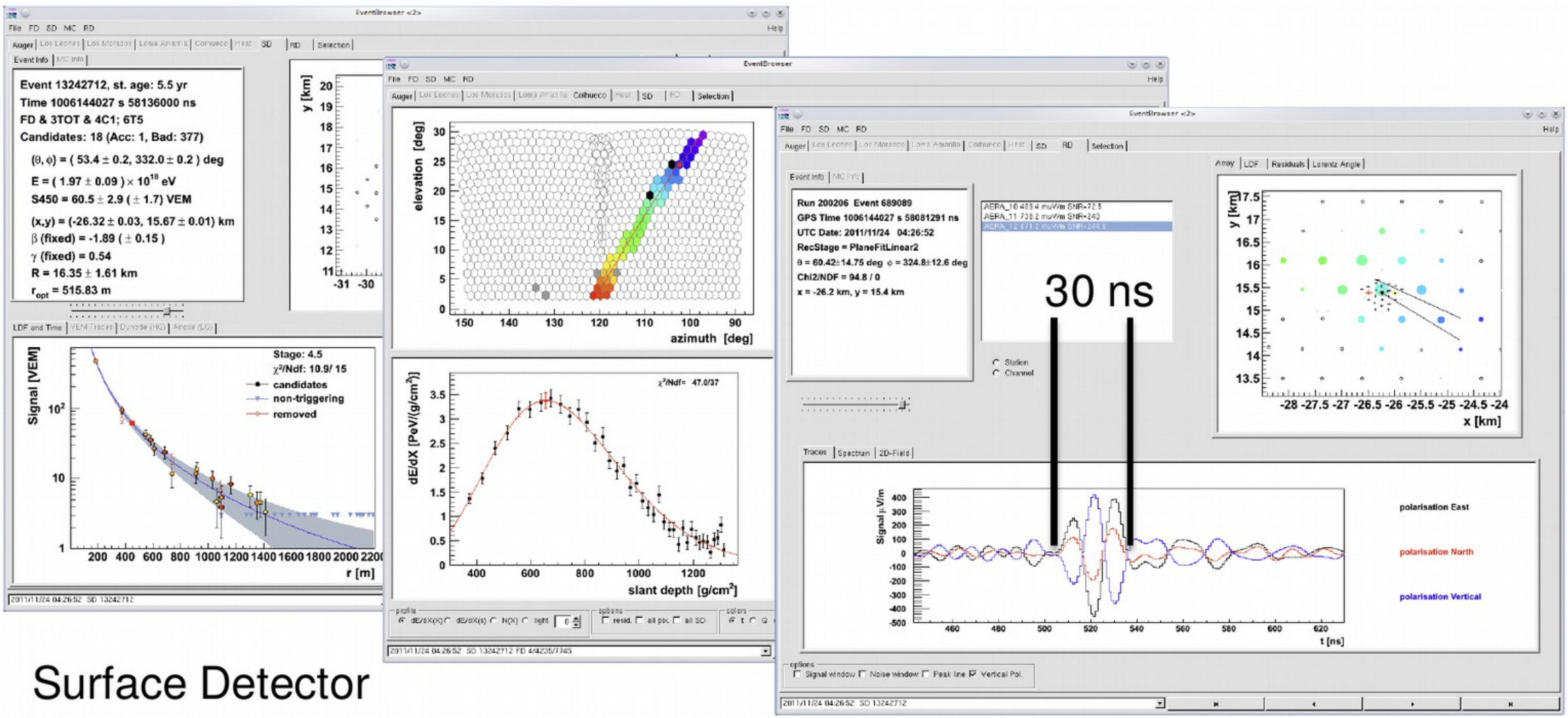
Bandwidth 30 – 80 MHz
Digitizing with 200 MHz

Science Goals:
Evaluate Radio Technology
Understand Radio Emission
Composition Measurement



(...)

Super Hybrid Events

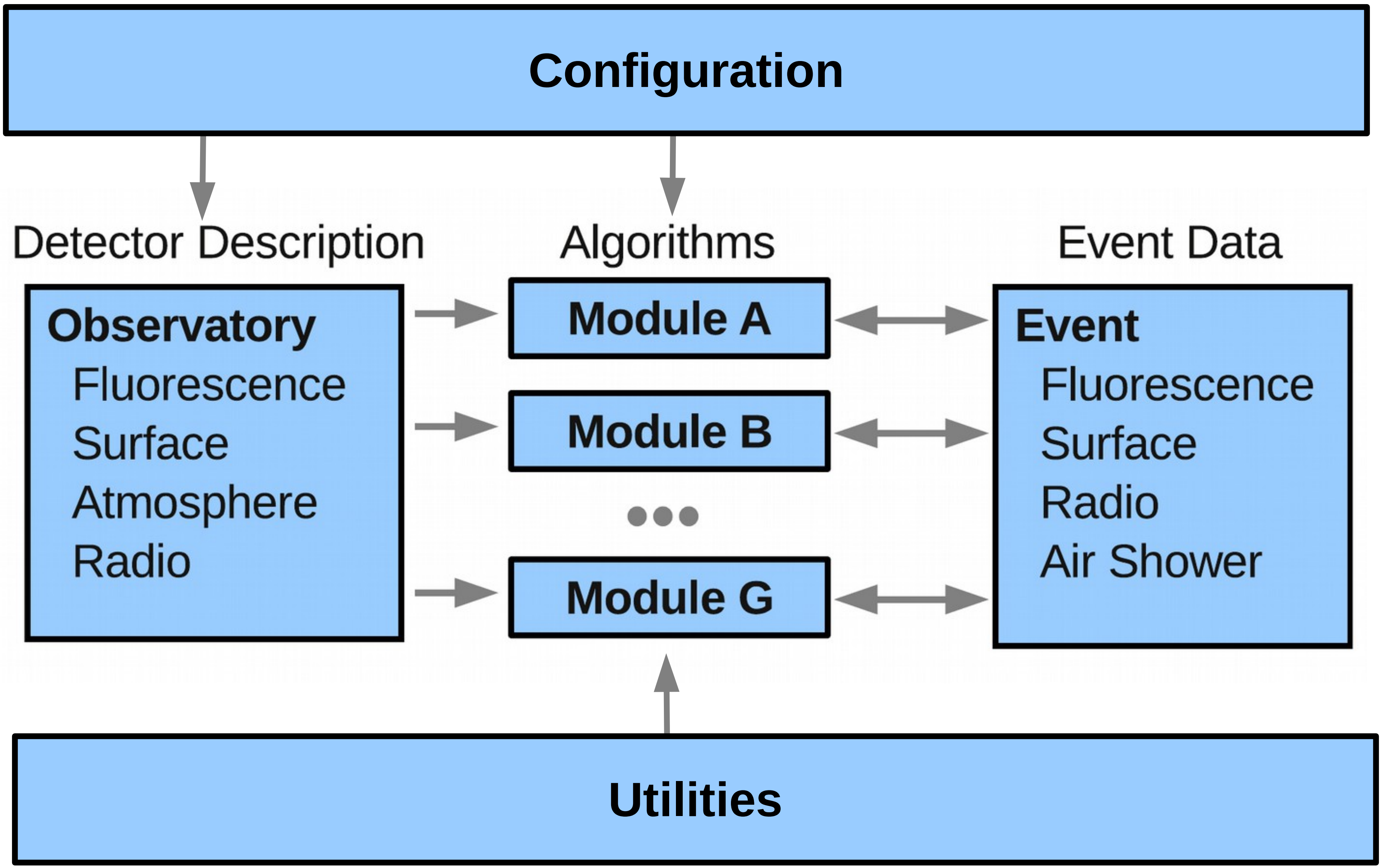


Surface Detector

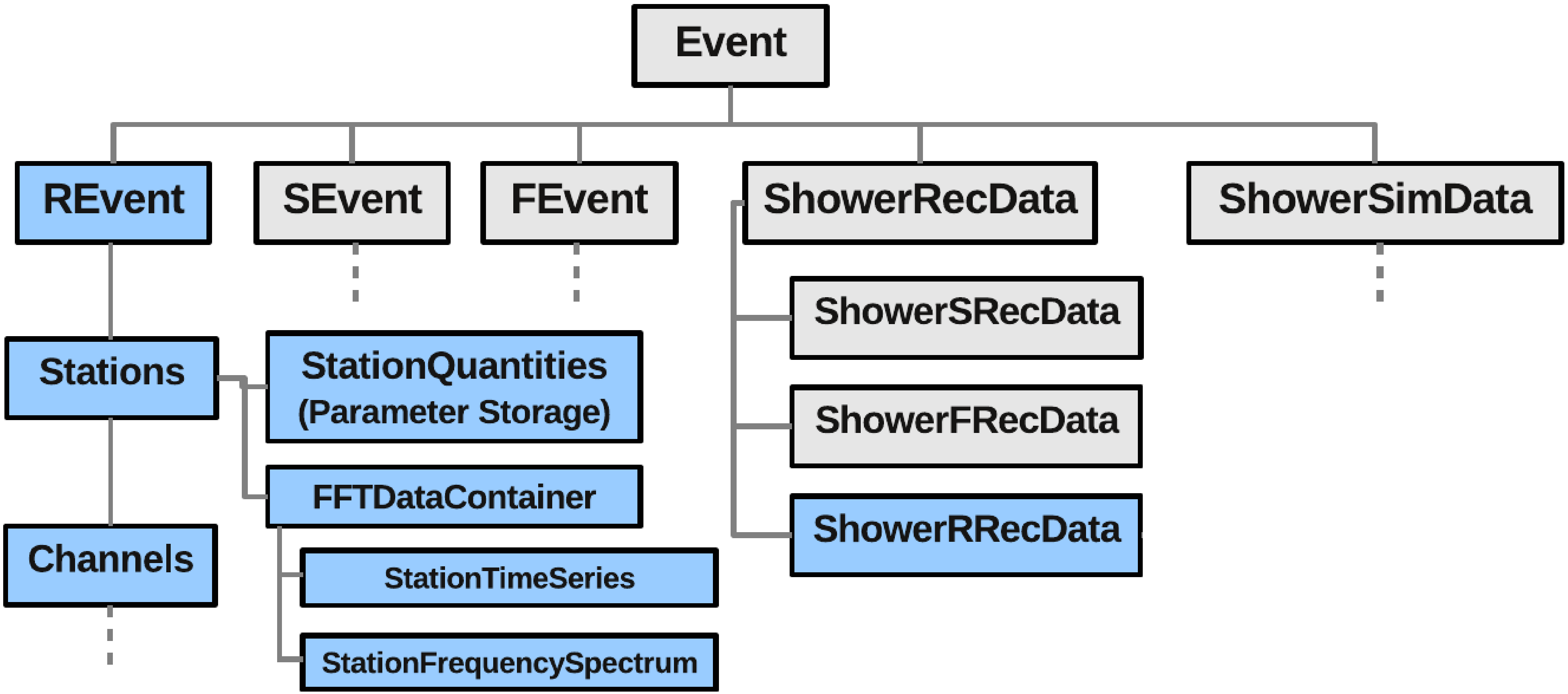
Fluorescence Detector

Radio Detector

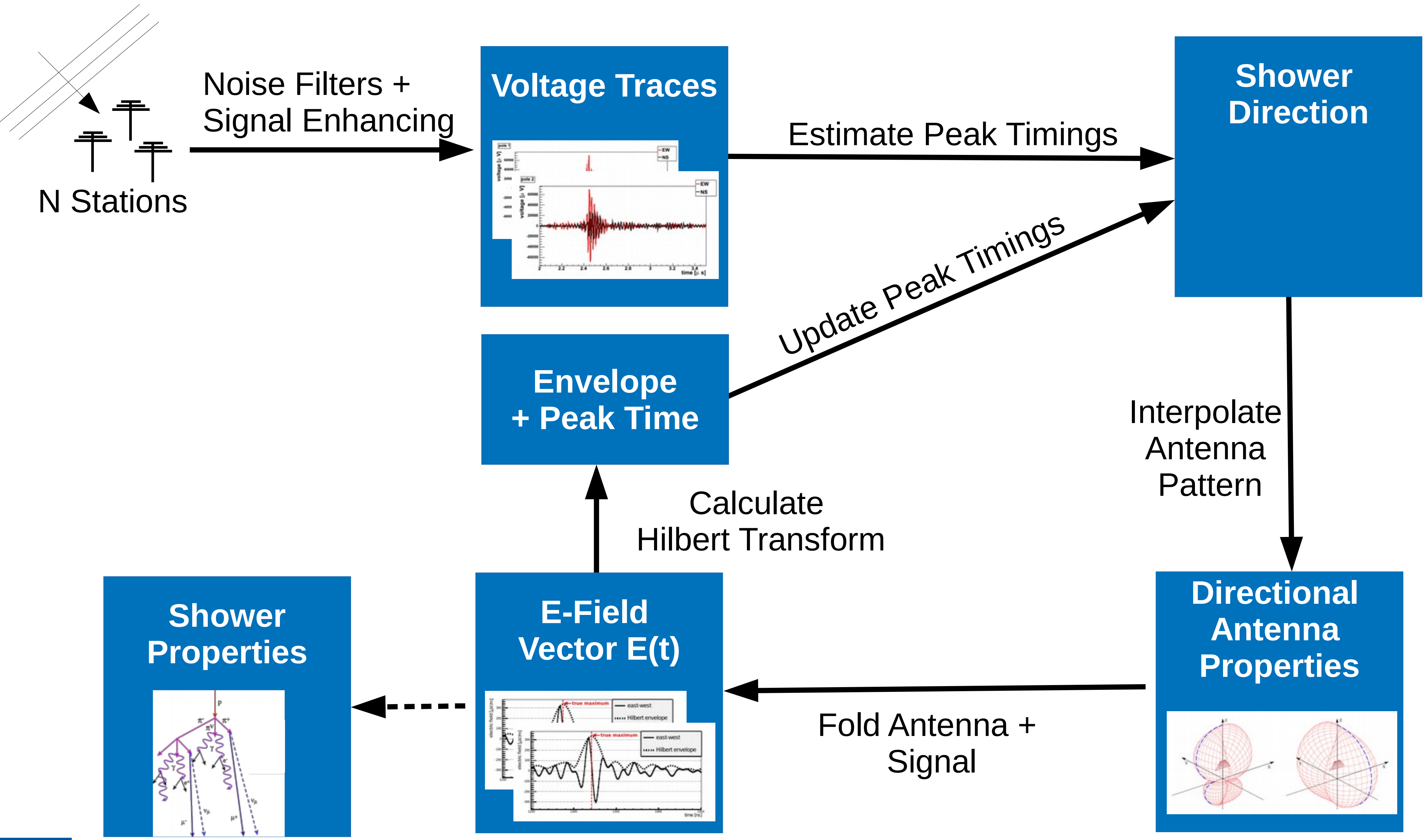
The Auger Offline Framework



Radio Integration in Offline



Reconstruction of Radio Events



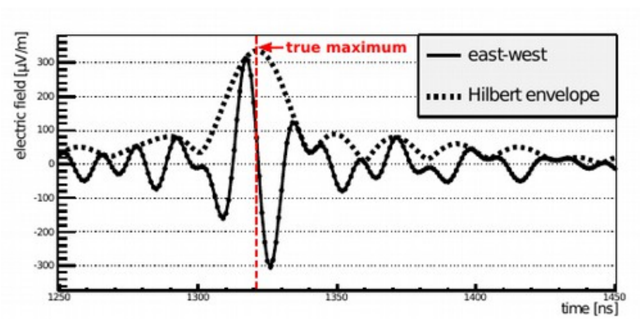
Profiling

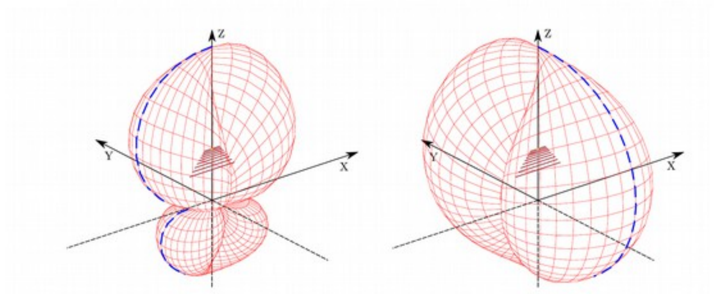
Tools	Notes
Google-perftools + kCachegrind	Free
Valgrind + kCachegrind	Free, Slow
Intel VTune	Proprietary
Linux kernel profiler (perf)	Free

No difference in conclusions **in this application**

Top Hotspots

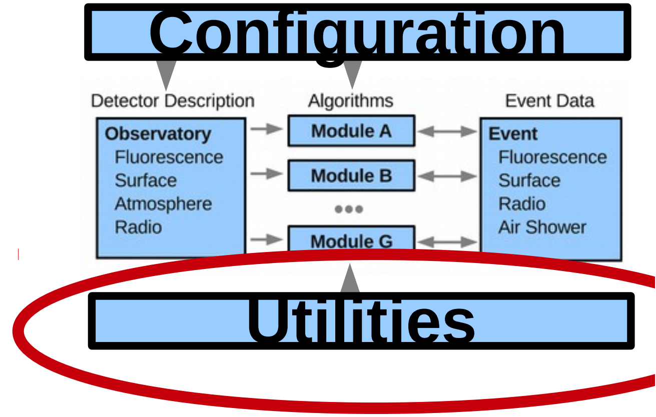
FFT	~ 15 %
Interpolation of Antenna patterns	~ 25 %
Other	(max 5%)



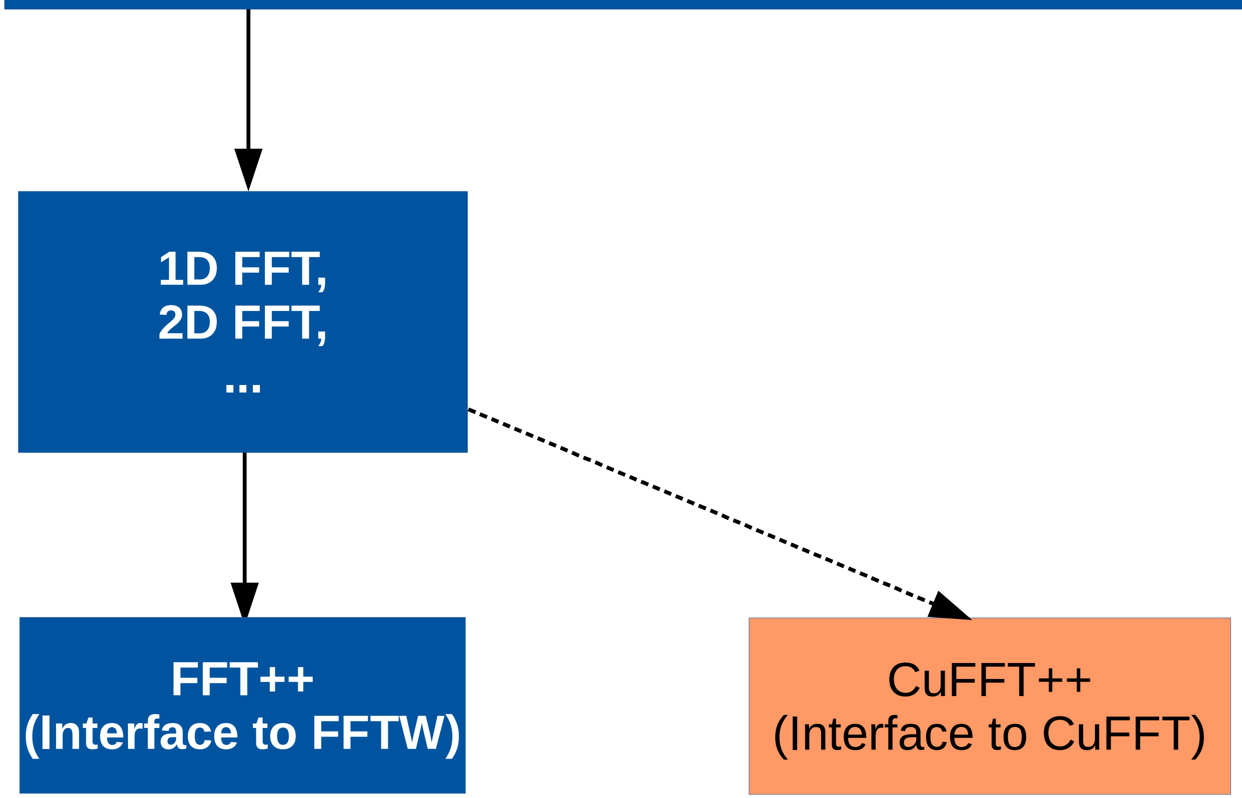


→ **Minimum invasive Approach: Move individual Hotspots on GPU**

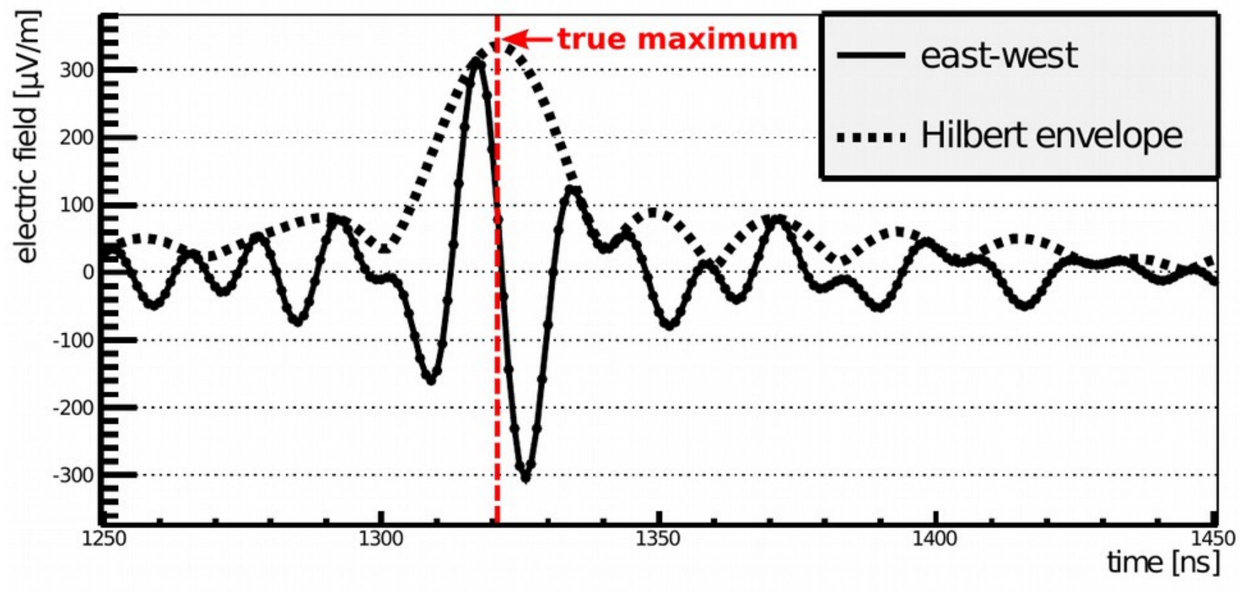
FFTW → CuFFT



Offline FFT Data Container:
- Stores data in time and frequency domain
- Lazy evaluation of FFT to update time (frequency) after modification of frequency (time)



Hilbert Envelope

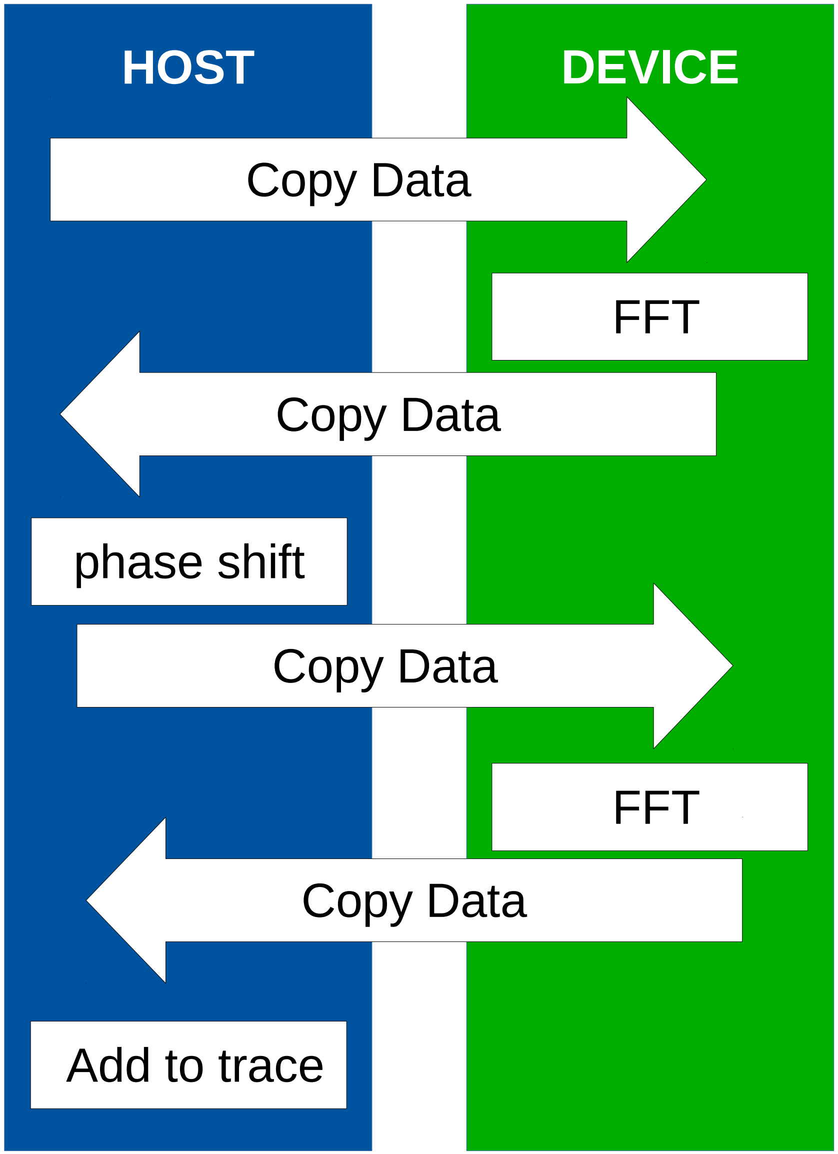


Envelope is squared sum of signal and its Hilbert Transform

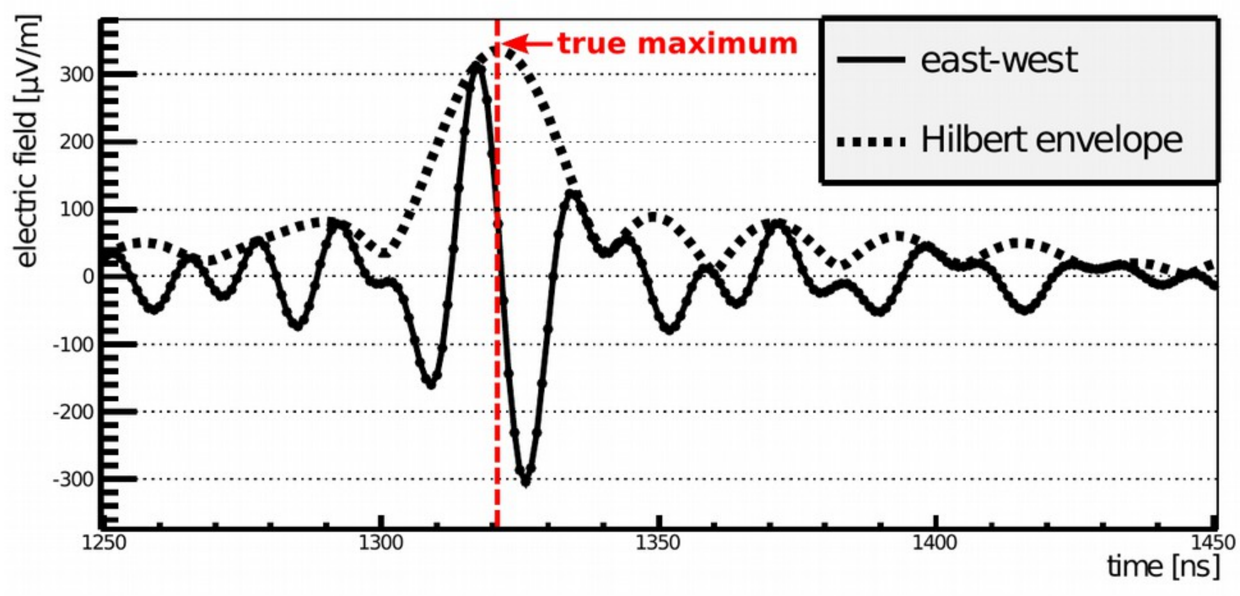
$$E(t) = \sqrt{x^2(t) + H^2(x(t))}$$

Hilbert Transform is - (+) 90 degree phase shift for first (second) half of spectrum

$$H(\omega) = -i\ \mathrm{sgn}(\omega - \omega_{\mathrm{mid}})\ x(\omega)$$



Hilbert Envelope



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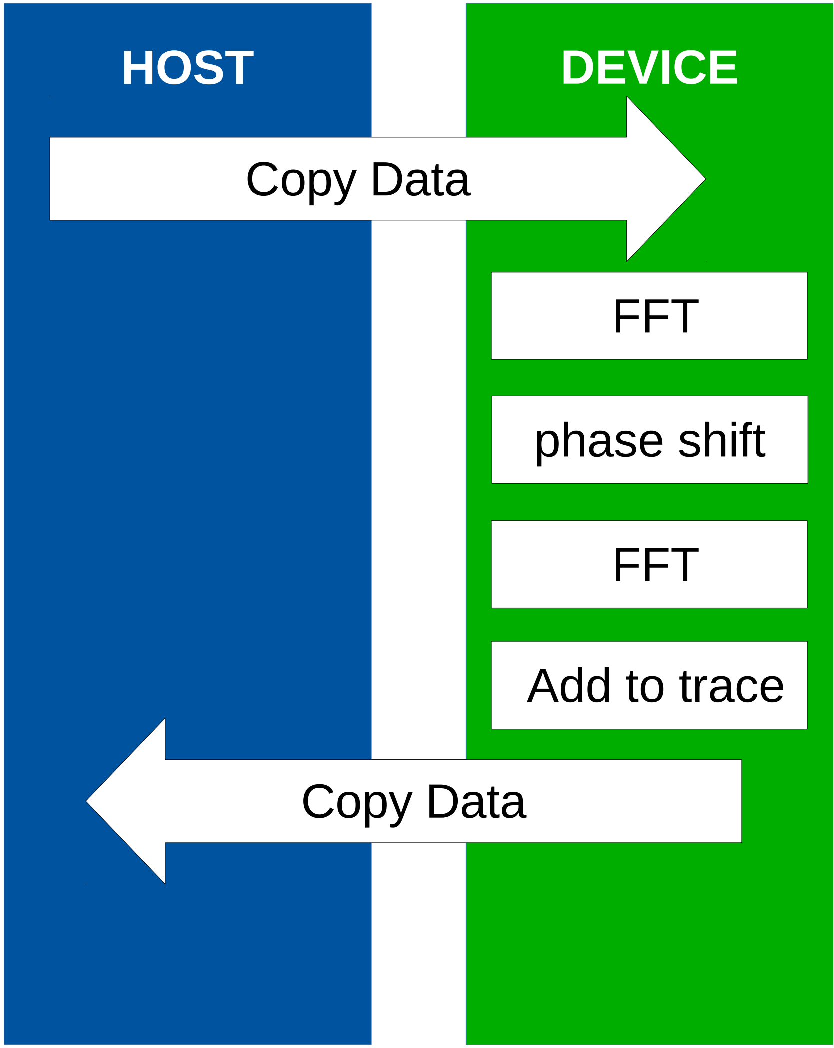
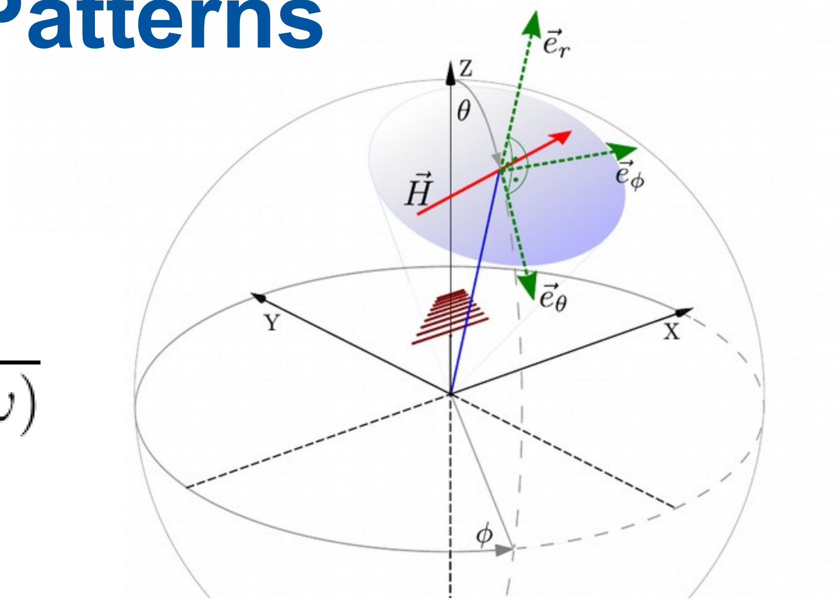


Successively Launch Kernels
operating on the same data

**=> Time spend in
FFT negligible in Cuda - Version**

Interpolation of Antenna Patterns

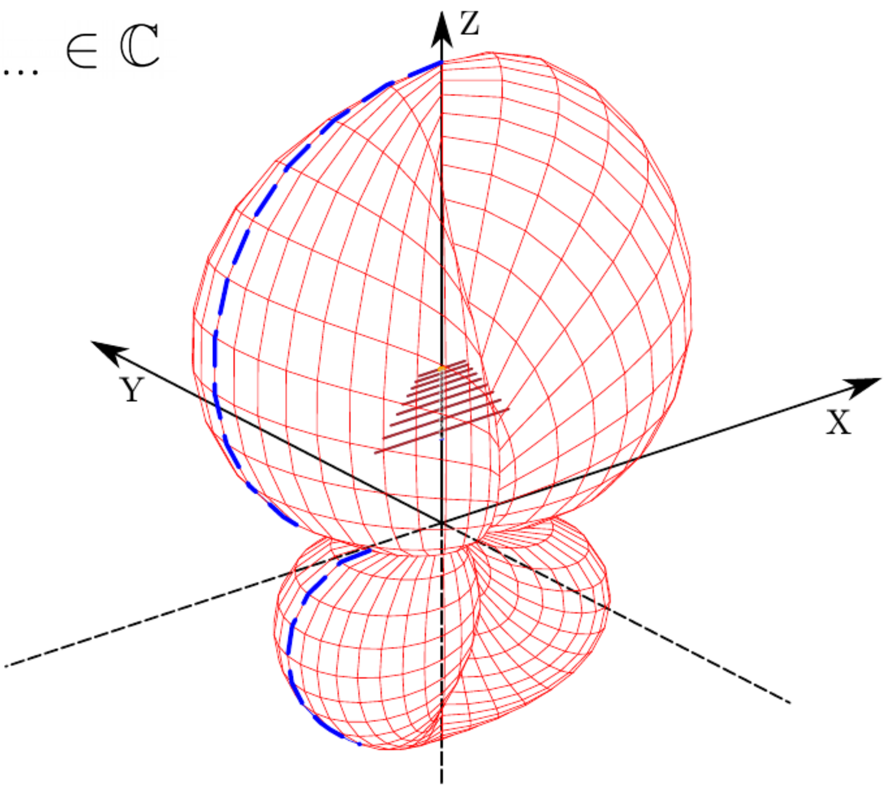


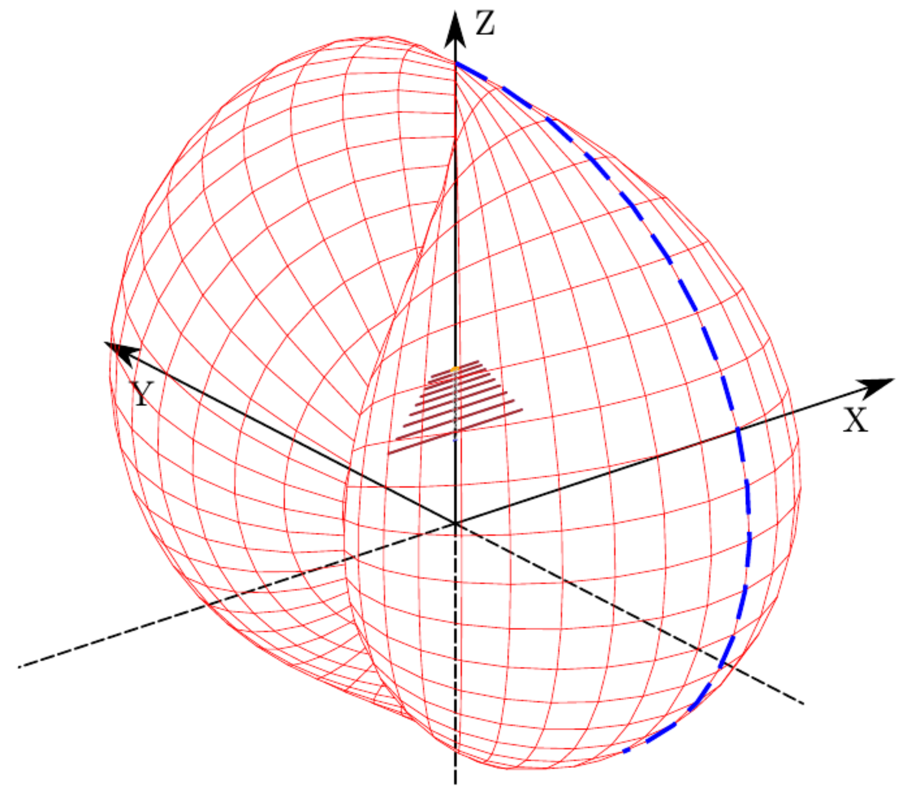
Get Efield from Voltage Traces: $U = \vec{H} \cdot \vec{E}$

$$\mathcal{E}_\theta(\omega) = \frac{\mathcal{V}_1(\omega)\mathcal{H}_{2,\phi}(\omega) - \mathcal{V}_2(\omega)\mathcal{H}_{1,\phi}(\omega)}{\mathcal{H}_{1,\theta}(\omega)\mathcal{H}_{2,\phi}(\omega) - \mathcal{H}_{1,\phi}(\omega)\mathcal{H}_{2,\theta}(\omega)}$$

$$\mathcal{E}_\phi(\omega) = \frac{\mathcal{V}_2(\omega) - \mathcal{H}_{2,\theta}(\omega)\mathcal{E}_\theta(\omega)}{\mathcal{H}_{2,\phi}(\omega)} \quad ,$$

$\mathcal{H}_{\dots} \in \mathbb{C}$

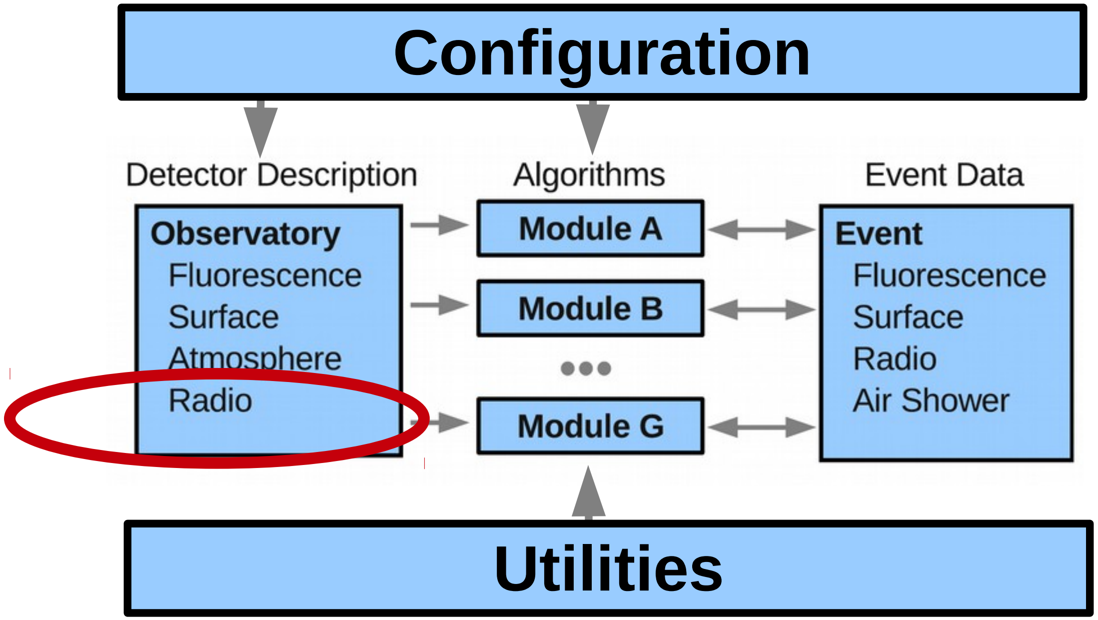




Interpolation of Antenna Patterns

- Few (~6) independent Patterns
- 2 Channels / Pattern
- ~ 80 frequencies, 180 x 90 angles
- Theta / Phi Component Complex Numbers
- Linear interpolation

- Bind Antenna Patterns as textures on GPU
- Use texture interpolation
- > 100x Speedup



Test Systems

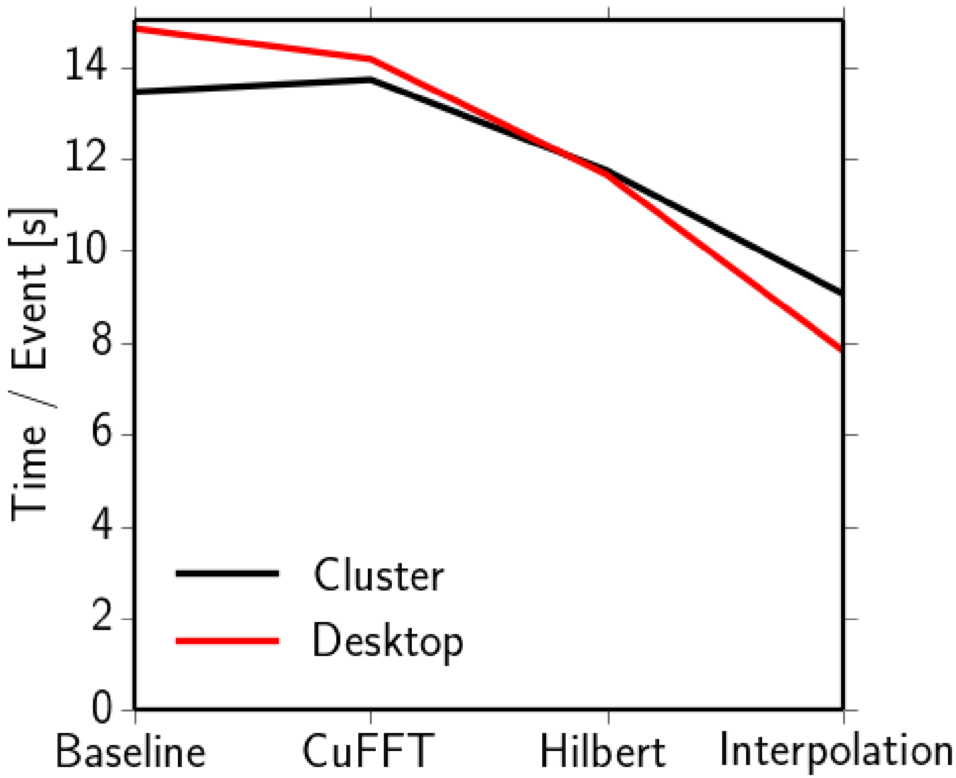
Cluster

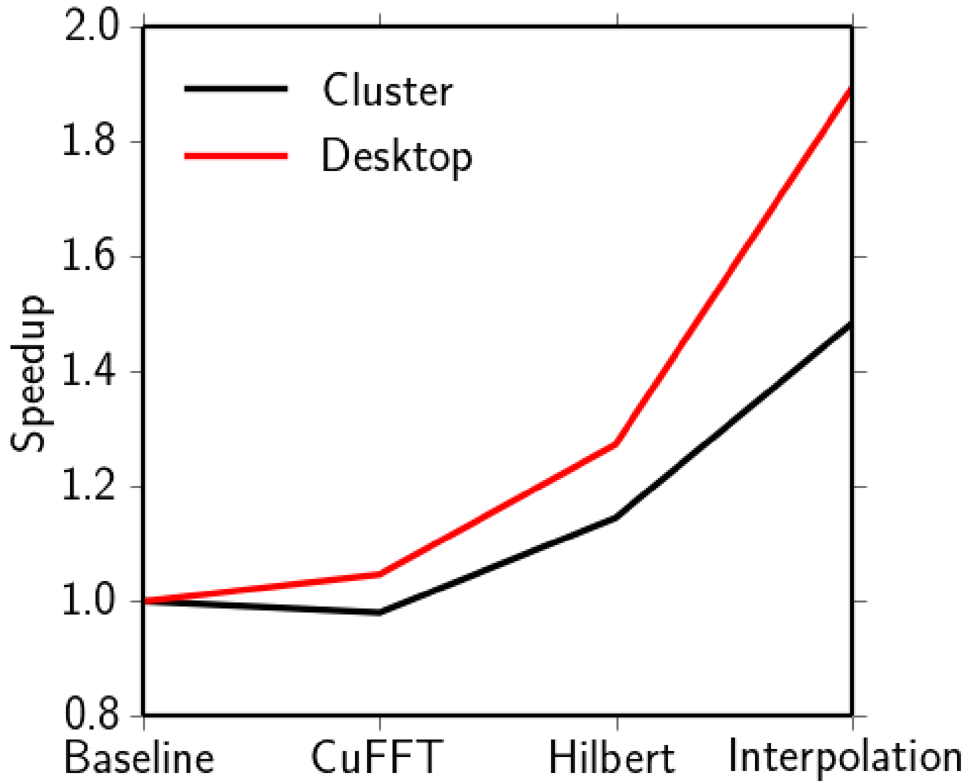
- 24x Intel Xeon X5650, 2.67GHz
- 48 GB Ram
- 4x Tesla M2090
- Debian GNU/Linux (stable)
- Cuda 4.2

Desktop

- 1x AMD A8-6600K, 3.9 GHz
- 8 GB Ram
- 1x GeForce 750 Ti
- Debian GNU/Linux (stable)
- Cuda 6.0

Performance Overview





Total Speedup ~ 1.5x on Cluster with Intel Xeon X5650 @ 2.7 GHz / Tesla M2090, Cuda 4.2
~ 1.9x on Desktop with AMD A8-6600K / GeForce 750 Ti, Cuda 6.0

Top hotspots have been eliminated

Conclusions on GPGPU in Auger Offline

- Implementation of GPU versions for selected bottlenecks in parallel to existing CPU version with minimum modifications of the code possible:
  - Replacement of FFTW with CuFFT
  - Interpolation of Antenna patterns as textures
- Implementation not optimal, but minimum invasive
- GPU implementations eliminate two main hotspots: Speedup ~ 1.9x on Desktop PC
- High benefit from GPU on Desktop with entry level GPU