bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

BERGISCHE UNIVERSITÄT WUPPERTAL

Prospects of GPGPU in the Auger Offline Software Framework

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GPU Computing in High Energy Physics
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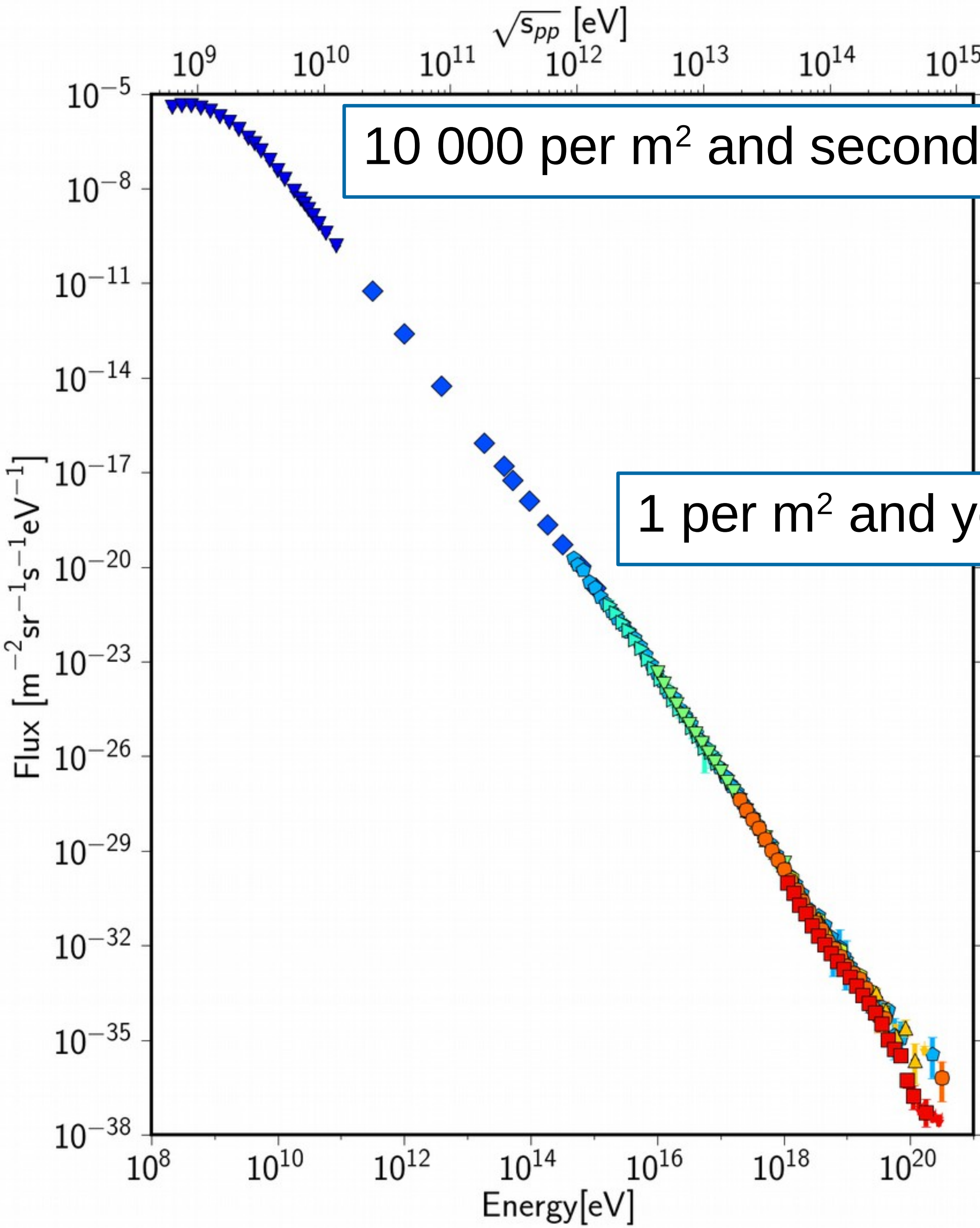
PIERRE AUGER OBSERVATORY

Cosmic Ray Energy Spectrum



10 000 per m^2 and second

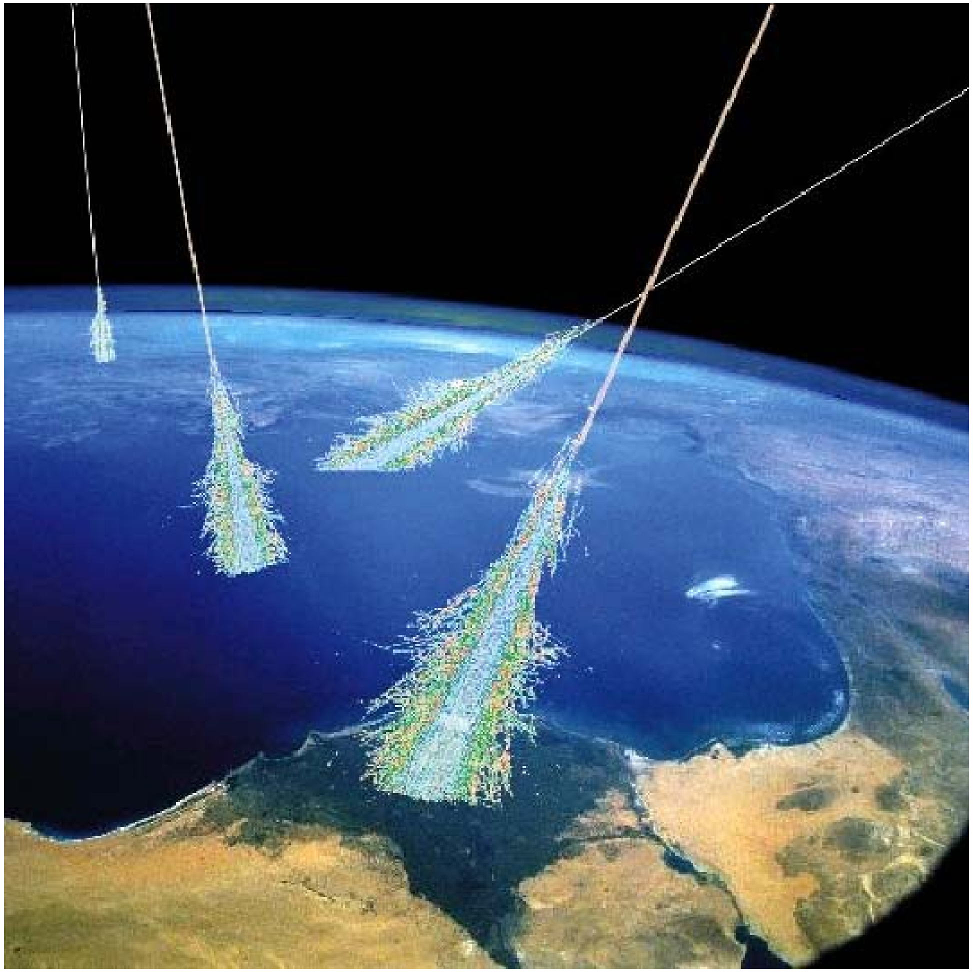
1 per m^2 and year

1 per km^2 and century

Galactic (SNR)

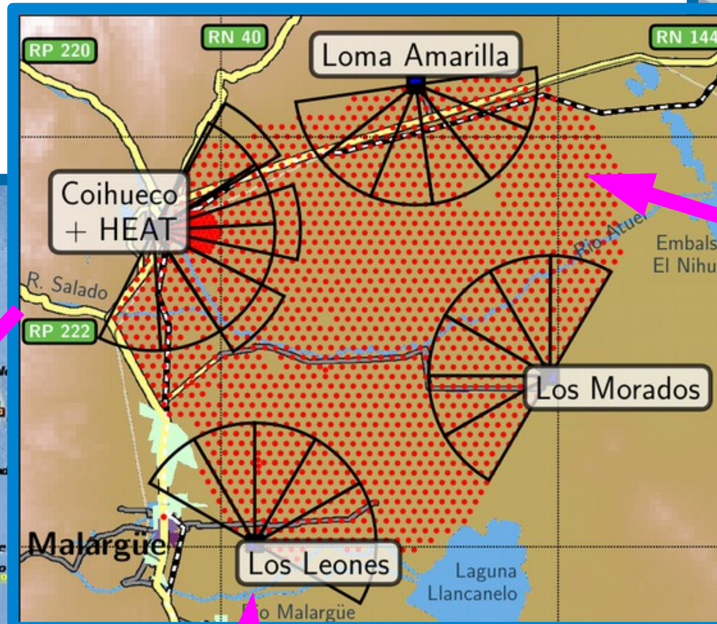
Extragalactic

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

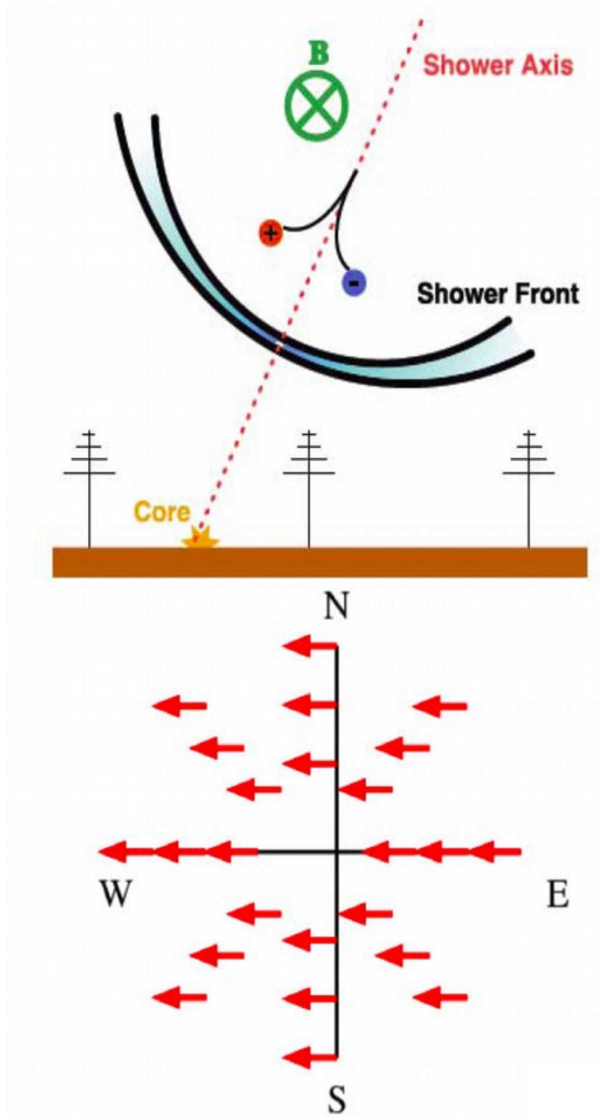


Surface Detector
1660 Water Cherenkov stations
1.5 km spacing
3000 km^2 covered area

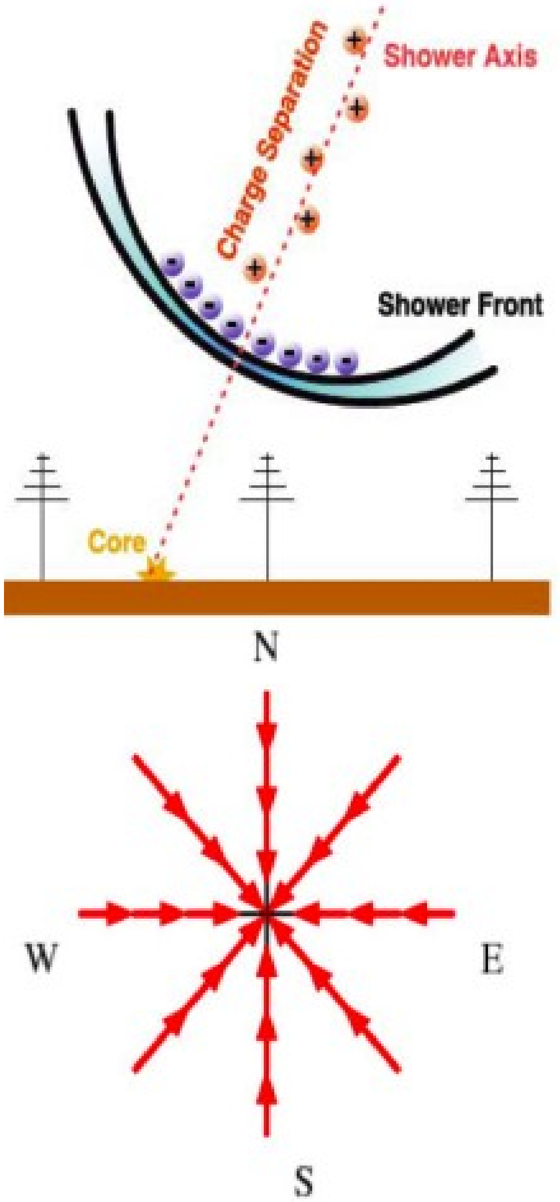
Fluorescence Detector
27 telescopes at
4 sites with 180^o view

Radio Emission from Cosmic Ray Air Showers

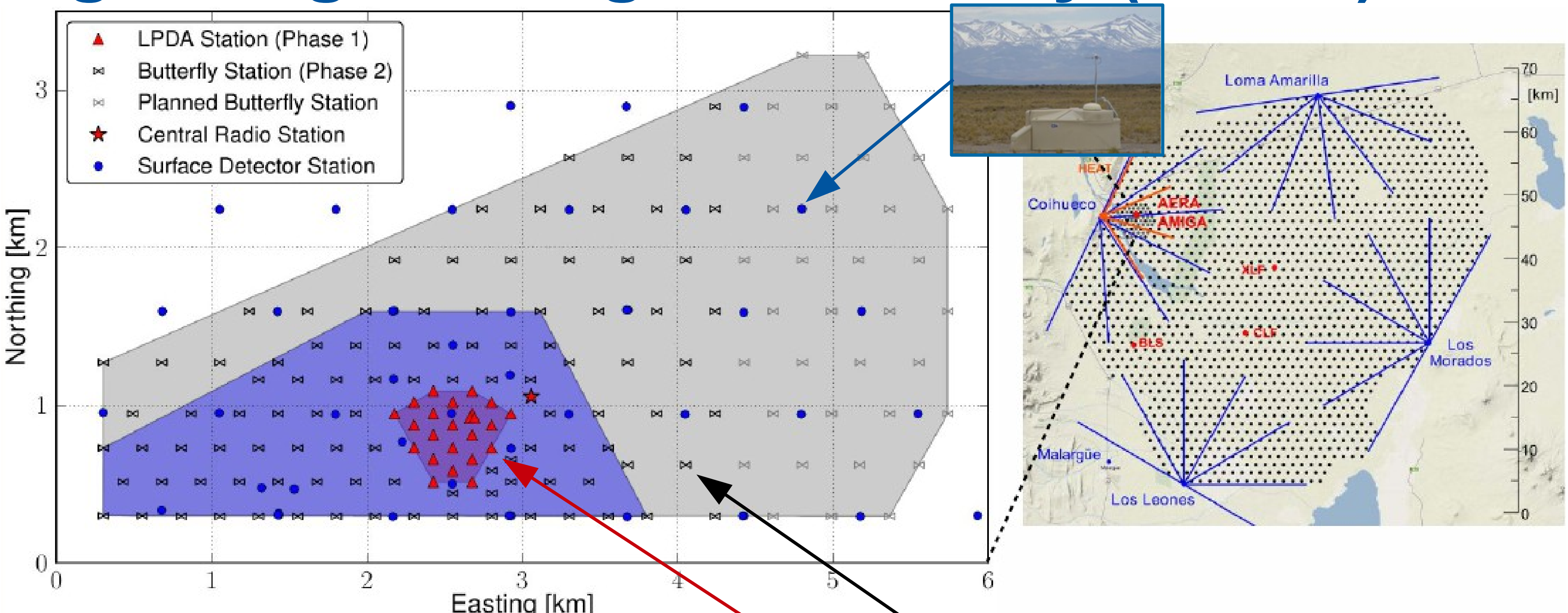
Geomagnetic Emission



Charge Excess



Auger Engineering Radio Array (AERA)

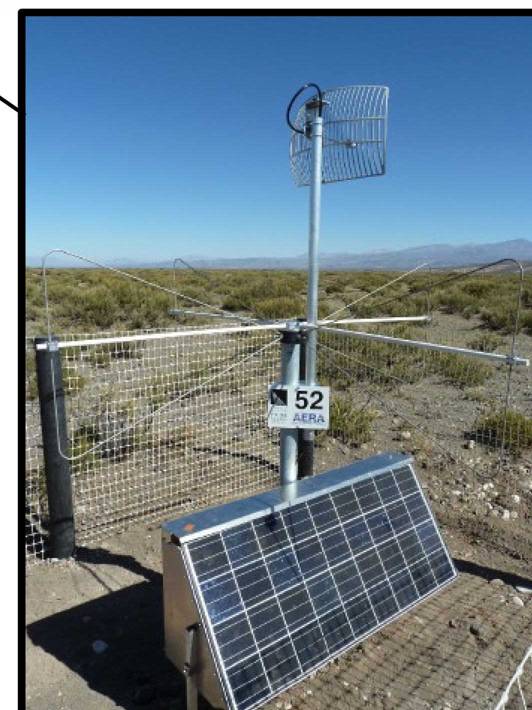


124 Stations with
2 antennas (NS, EW)

Different Antenna Types

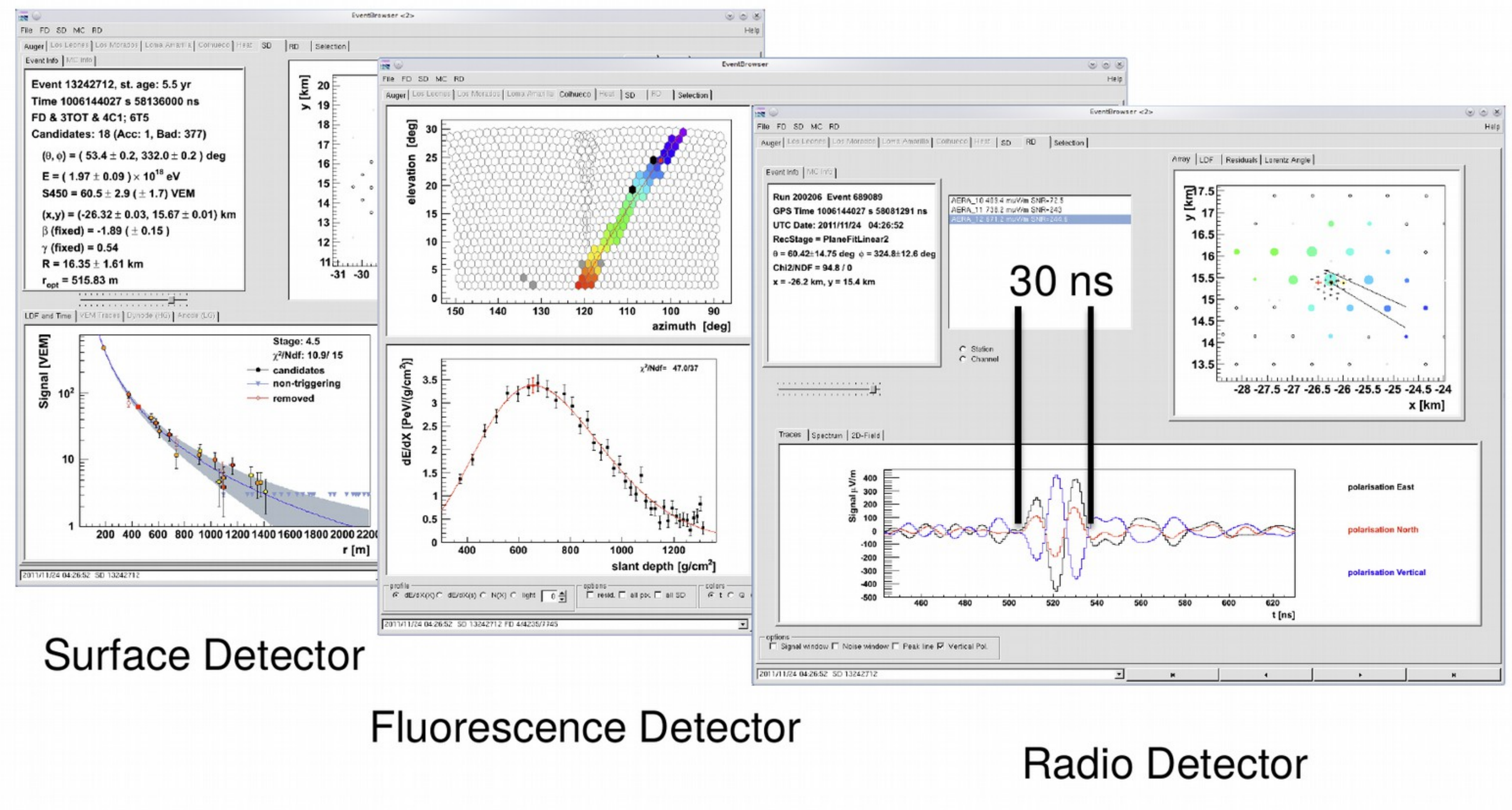
Bandwidth 30 – 80 MHz
Digitizing with 200 MHz

Science Goals:
Evaluate Radio Technology
Understand Radio Emission
Composition Measurement

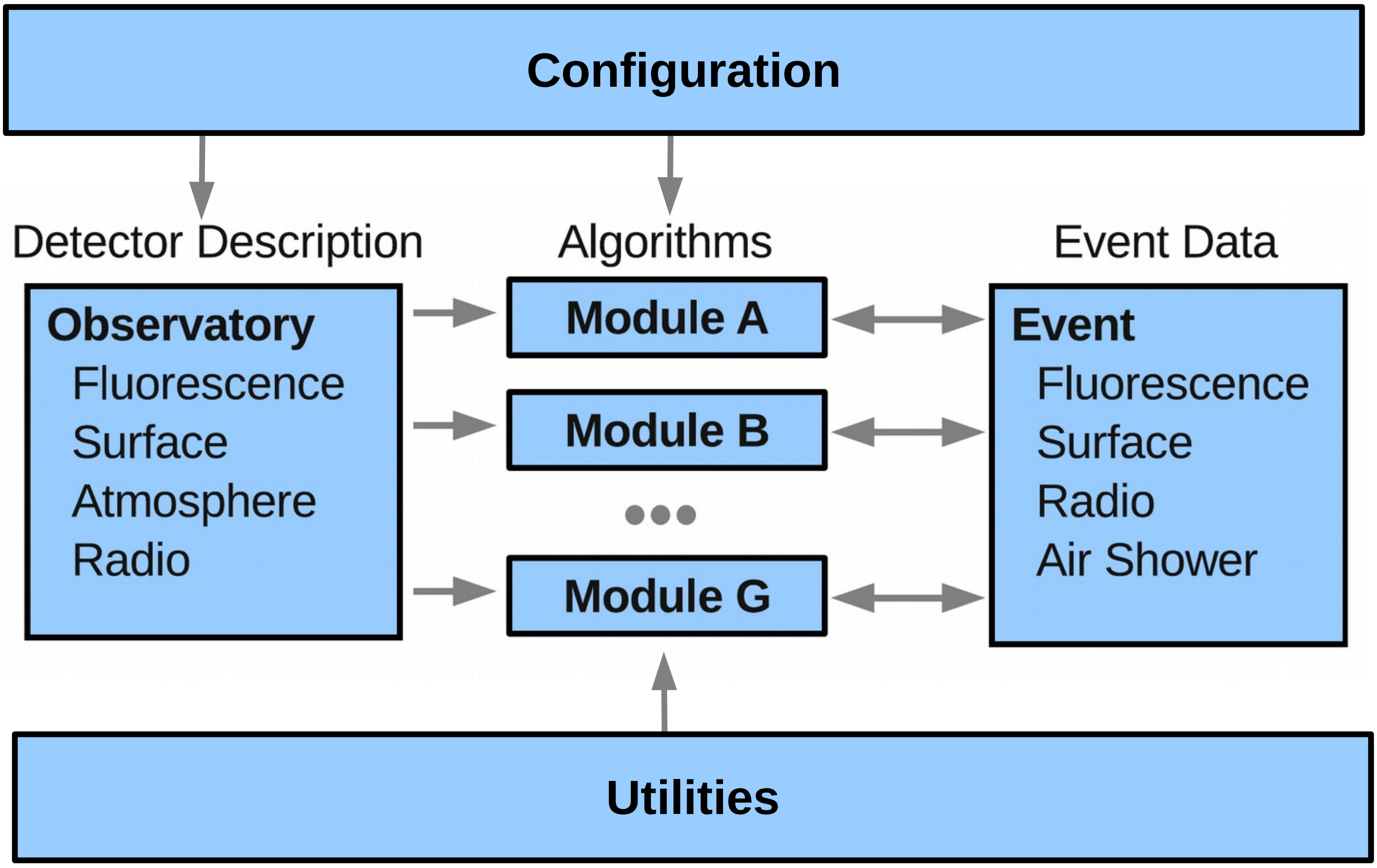


(…)

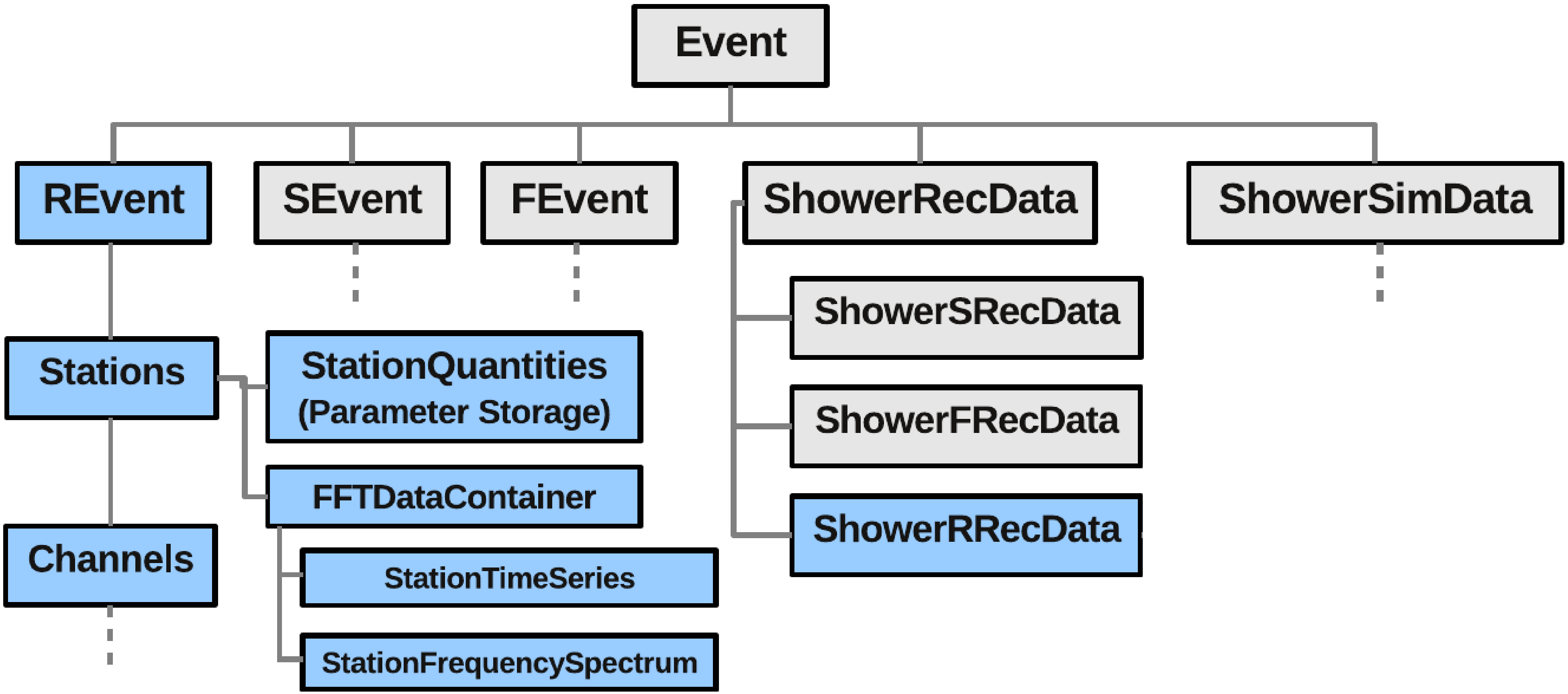
Super Hybrid Events



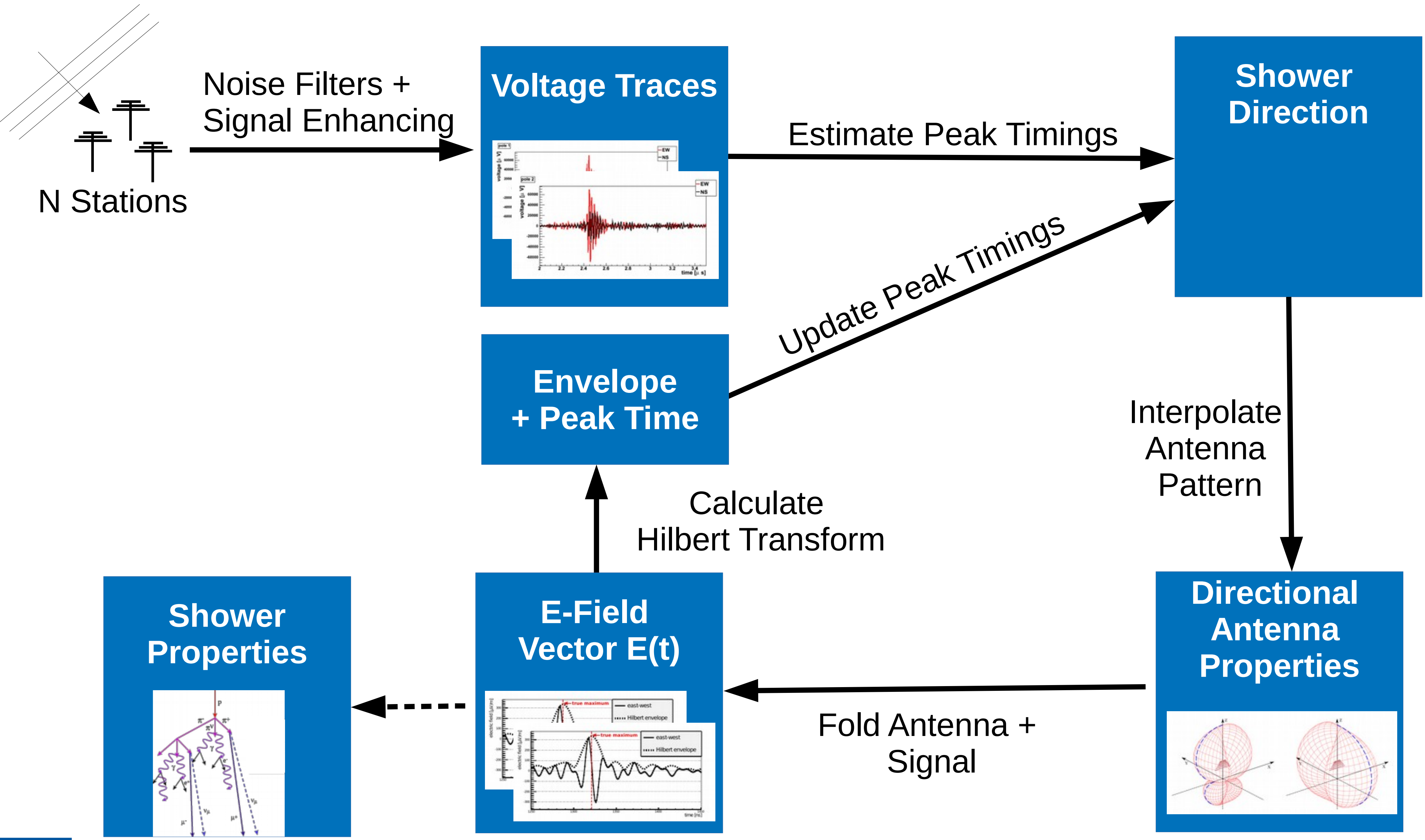
The Auger Offline Framework



Radio Integration in Offline



Reconstruction of Radio Events



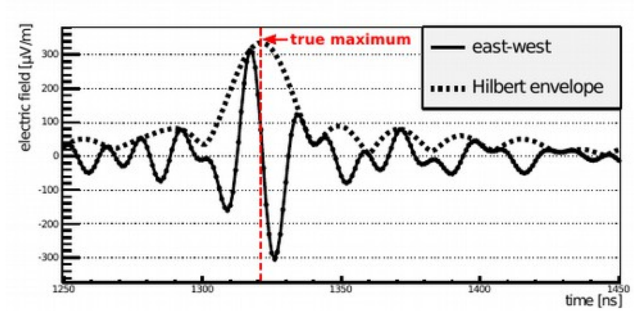
Profiling

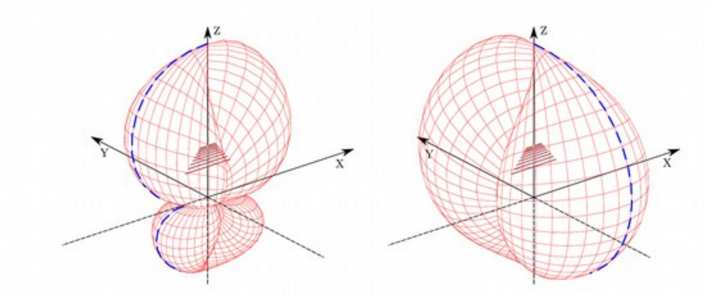
Tools	**Notes**
Google-perftools + kCachegrind	Free
Valgrind + kCachegrind	Free, Slow
Intel VTune	Proprietary
Linux kernel profiler (perf)	Free

No difference in conclusions **in this application**

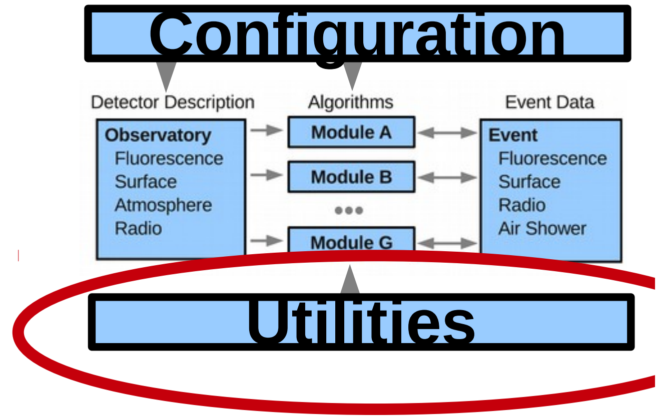
Top Hotspots

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





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)

↓

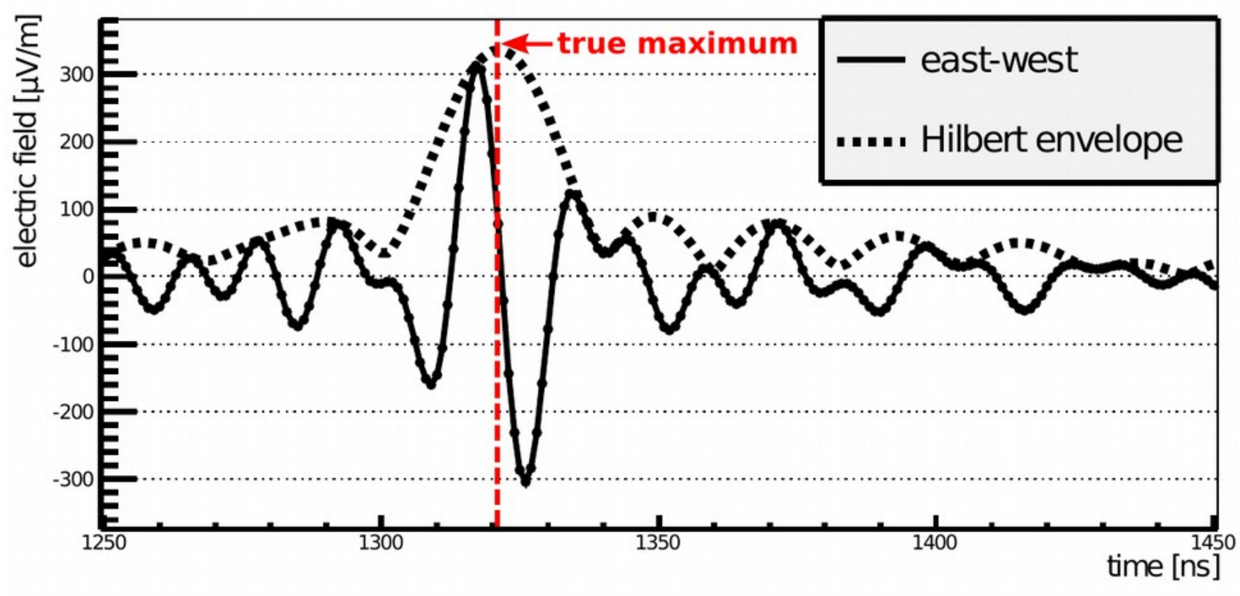
1D FFT,
2D FFT,
...

↓

FFT++ (Interface to FFTW)

CuFFT++ (Interface to CuFFT)

Hilbert Envelope

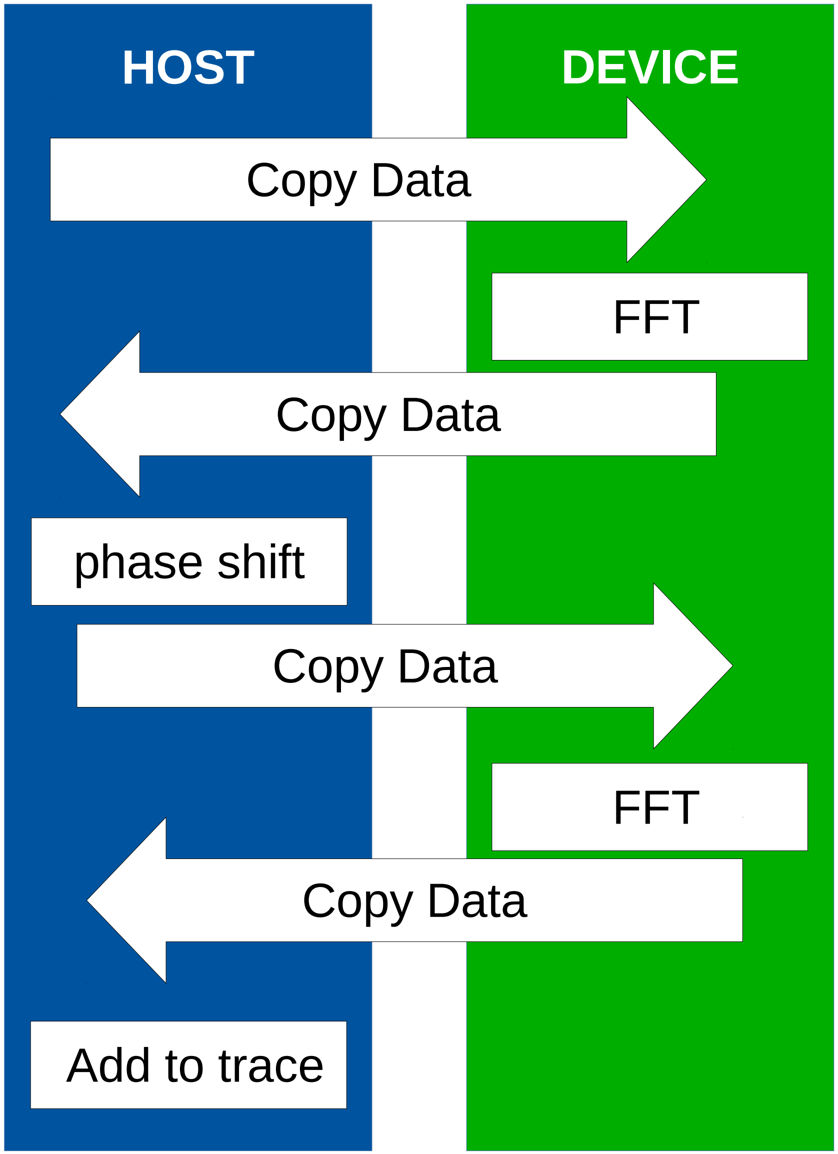


Envelope is squared sum of signal
and its Hilbert Transform

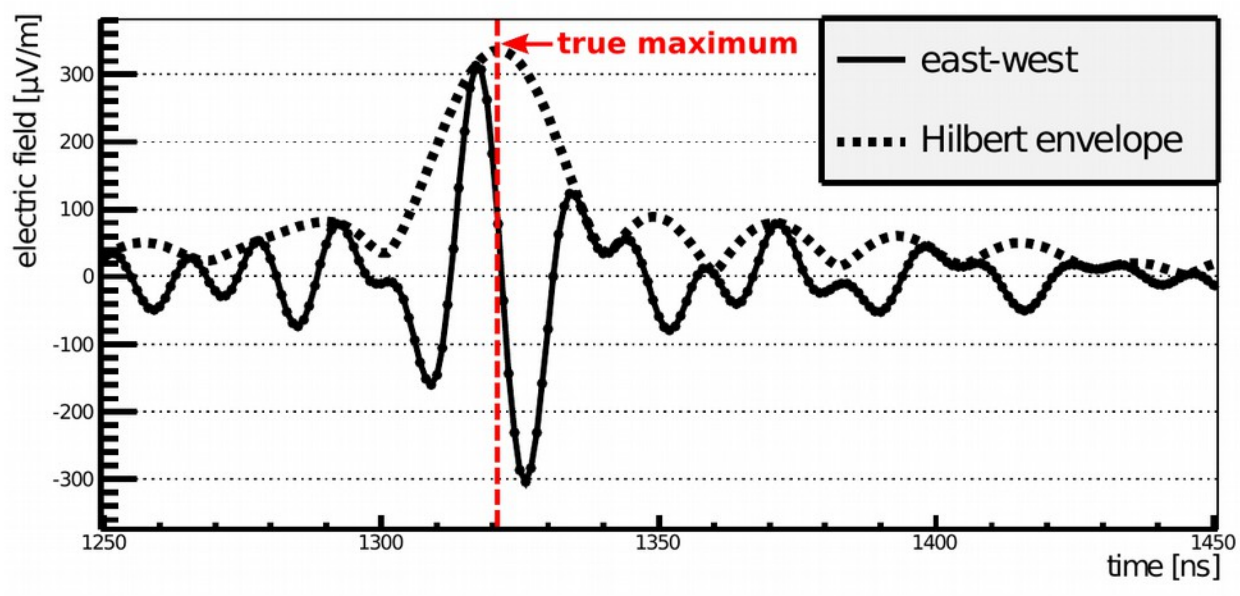
$$E(t) = \sqrt{x^2(t) + H^2(x(t))}$$

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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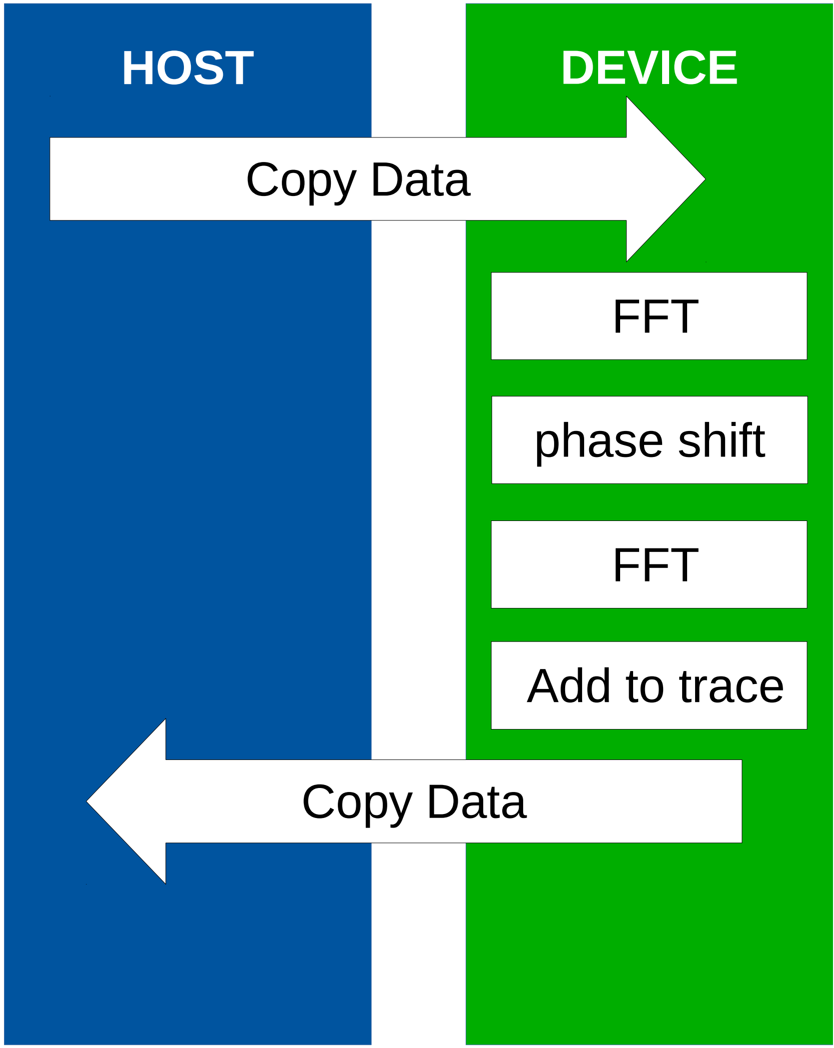
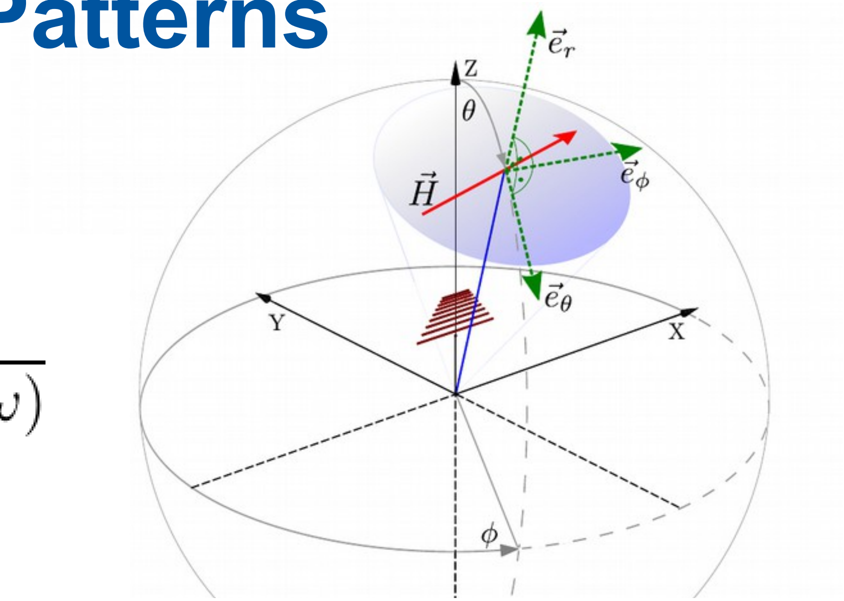


Successively Launch Kernels
operating on the same data

=> Time spend in
FFT negligible in Cuda - Version

Interpolation of Antenna Patterns

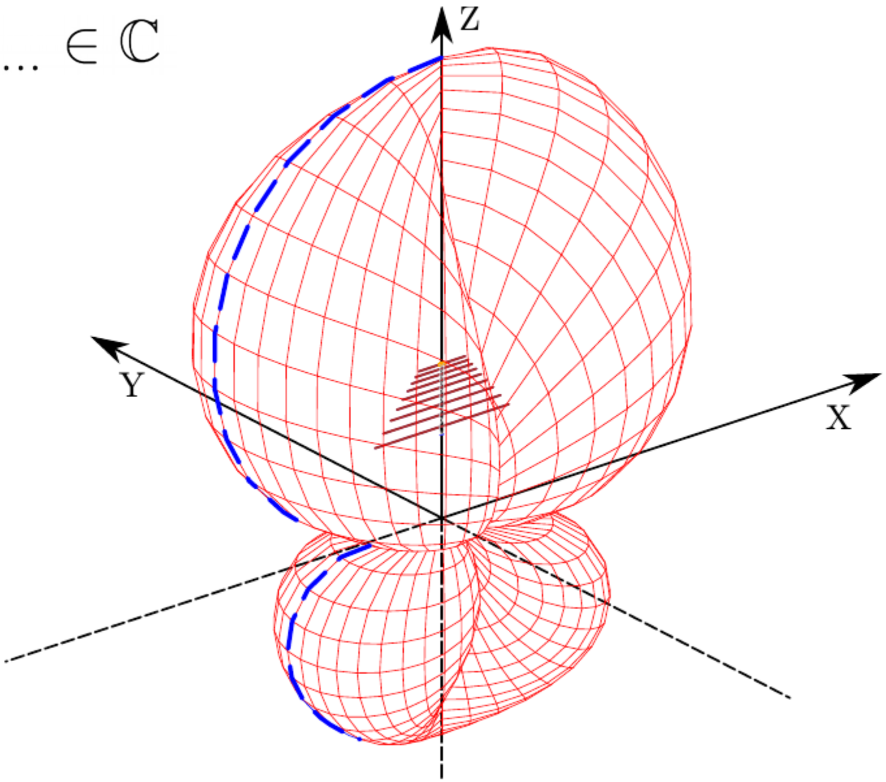


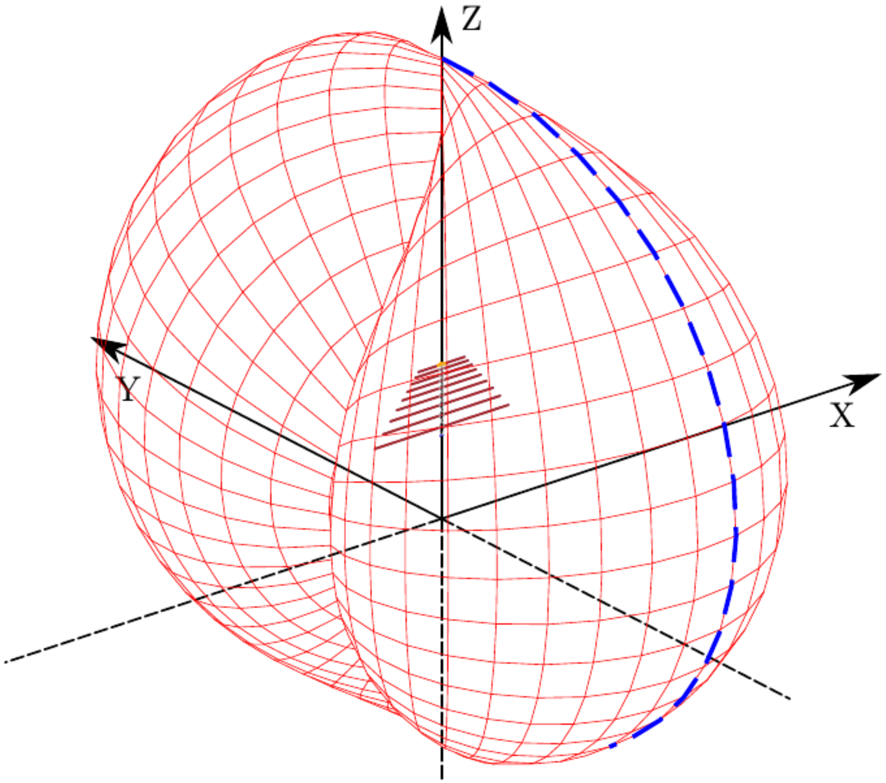
Get Efield from Voltage Traces: $U = \vec{H} \cdot \vec{E}$

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

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

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

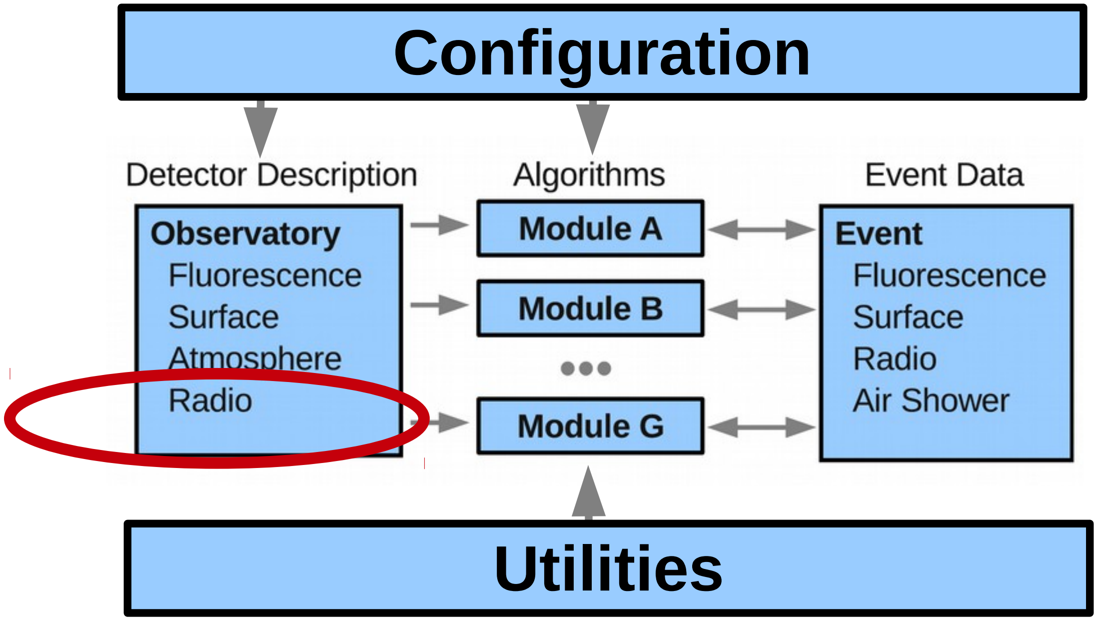




Interpolation of Antenna Patterns

- 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

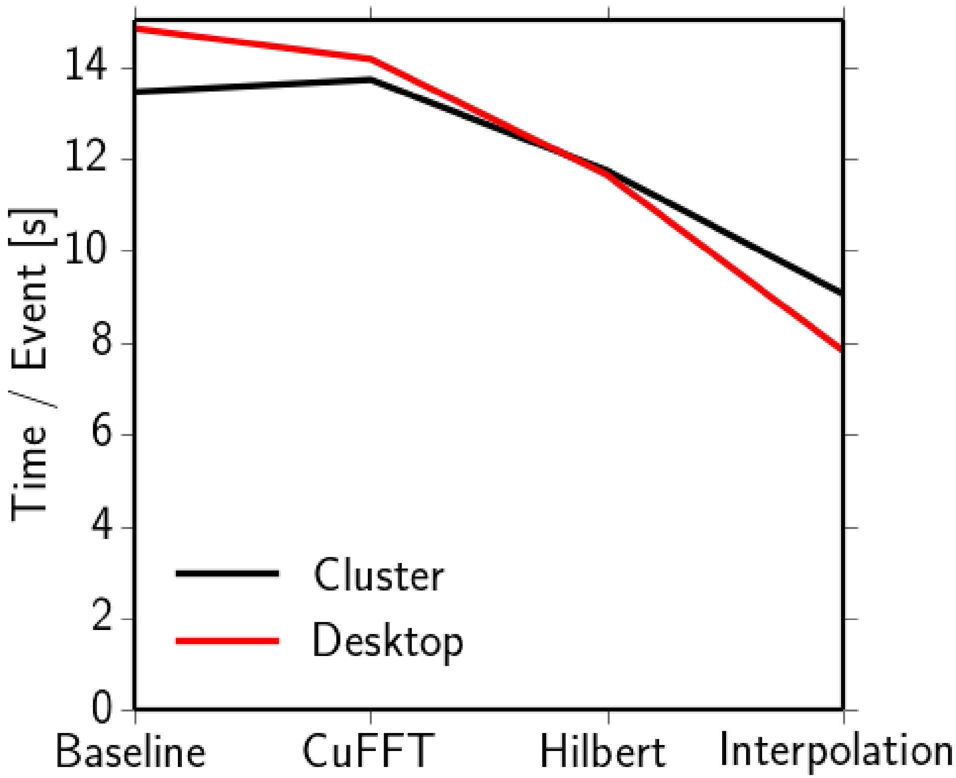
Cluster

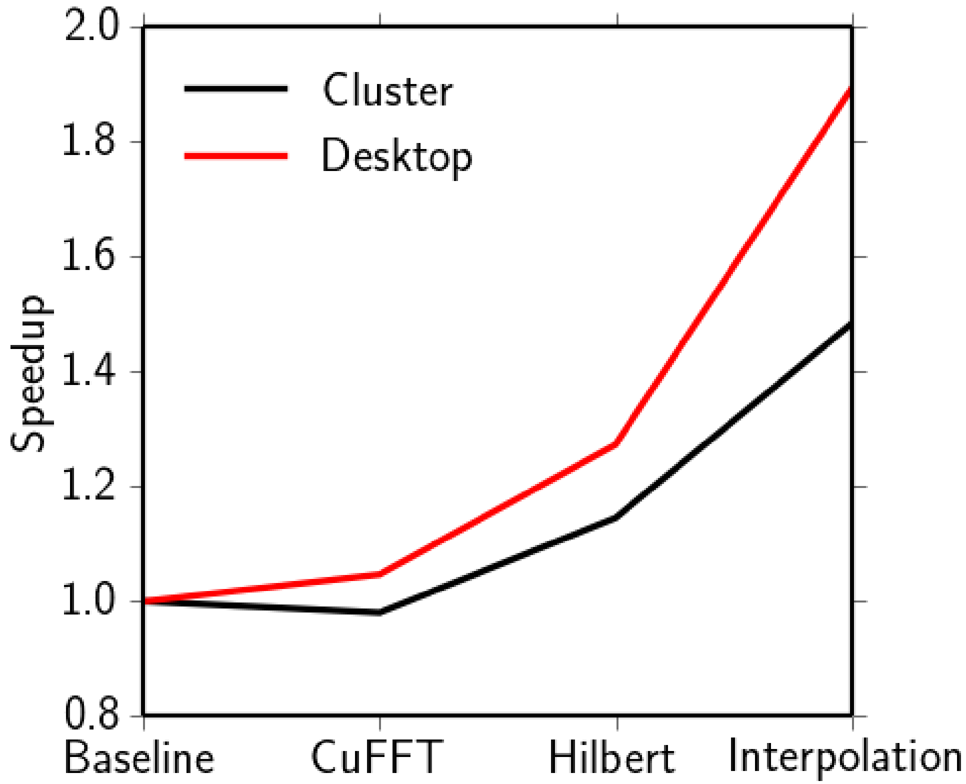
- 24x Intel Xeon X5650, 2.67GHz
- 48 GB Ram
- 4x Tesla M2090
- Debian GNU/Linux (stable)
- Cuda 4.2

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 elimiated

Conclusions

- Investigated GPU in Auger-Offline framework
- 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
- GPU implementations eliminates two main hotspots: Speedup ~ 1.9x on Desktop PC
- High benefit from GPU on Desktop with entry level GPU