International Centre for Radio Astronomy Research

Plans for the MWA Particle Detector Array

Clancy James + many others!

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Curtin University

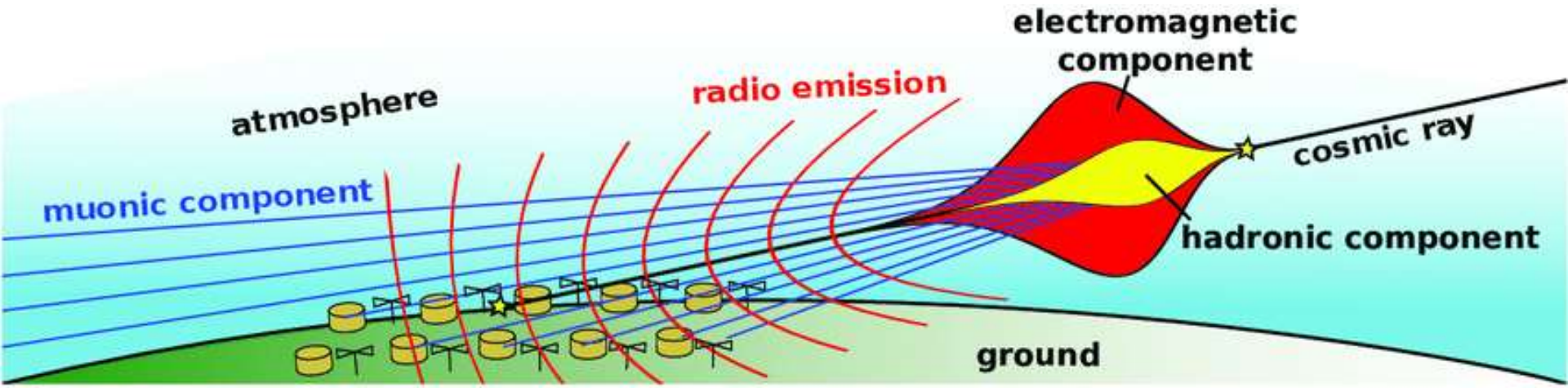
THE UNIVERSITY OF WESTERN AUSTRALIA

Government of Western Australia
Department of the Premier and Cabinet
Office of Science

Reminder: basic idea

Cosmic rays…

- Hit top of atmosphere, generate cascade of secondary particles
- Muon component travels many km (including through rock)
- Radio emission from electrons/positrons: peaks around 100 MHz



Radio Measurements

- Timing: gives incident cosmic ray direction
- Amplitude: gives height of particle cascade (related to nature of particle)

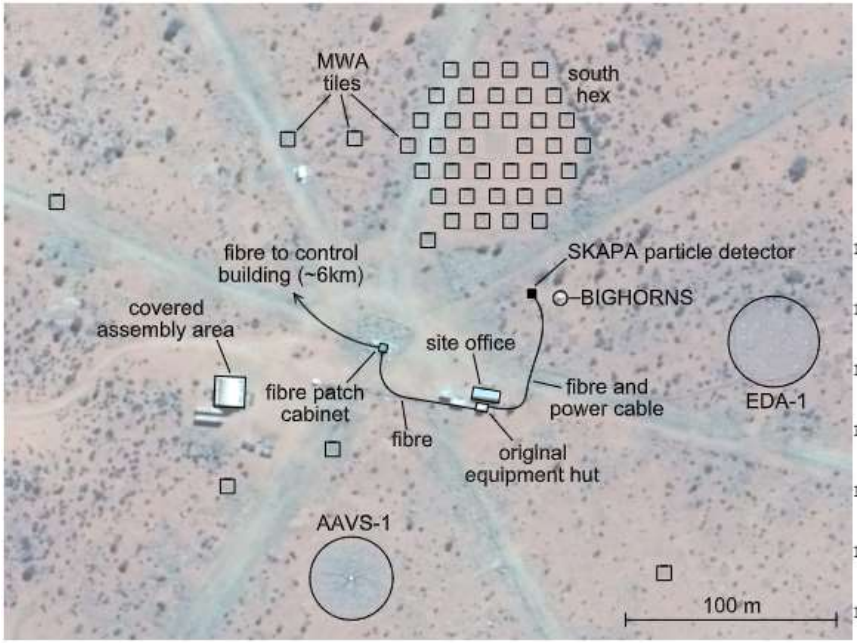
What's been done so far?

The SKA Particle Array Prototype: The First Particle Detector at the Murchison Radio-astronomy Observatory

J.D.Bray et al; Nuclear Instruments and Methods in Physics A

SKAPA (SKA Particle Array) detector

- Deployed Oct 2018, ran through 2019
- Data analysed over Nov ‘18 – Feb ’19
- Mostly sees single muons
- Rate: ~100 Hz

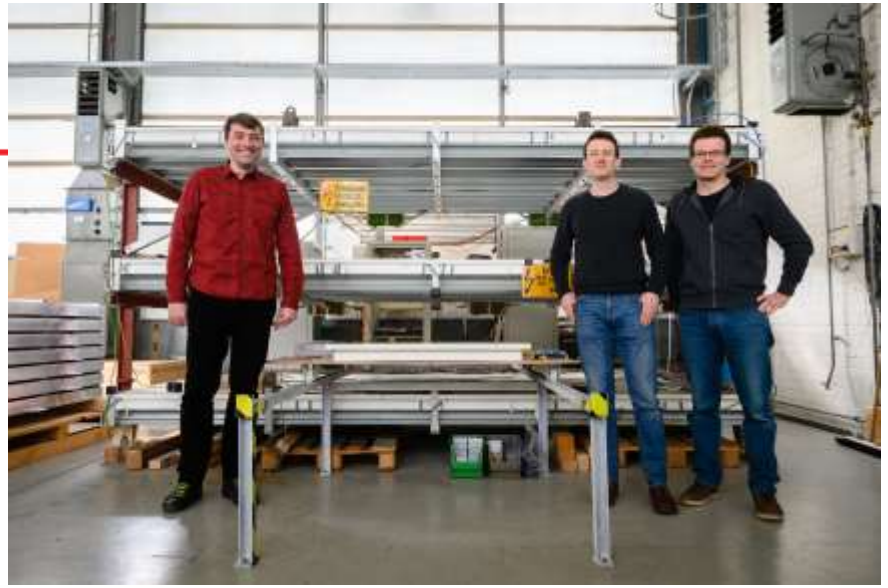


Main subject of the paper

- Q1: Do we understand how the detector is behaving?
- A1: Yes (with one little exception – hour-timescale fluctuations in sensitivity)

- Q2: Will an array of 8 of them be sensitive enough to trigger CR events?
- A2: Yes (target false event rate: O~1/day, ~CR rate)

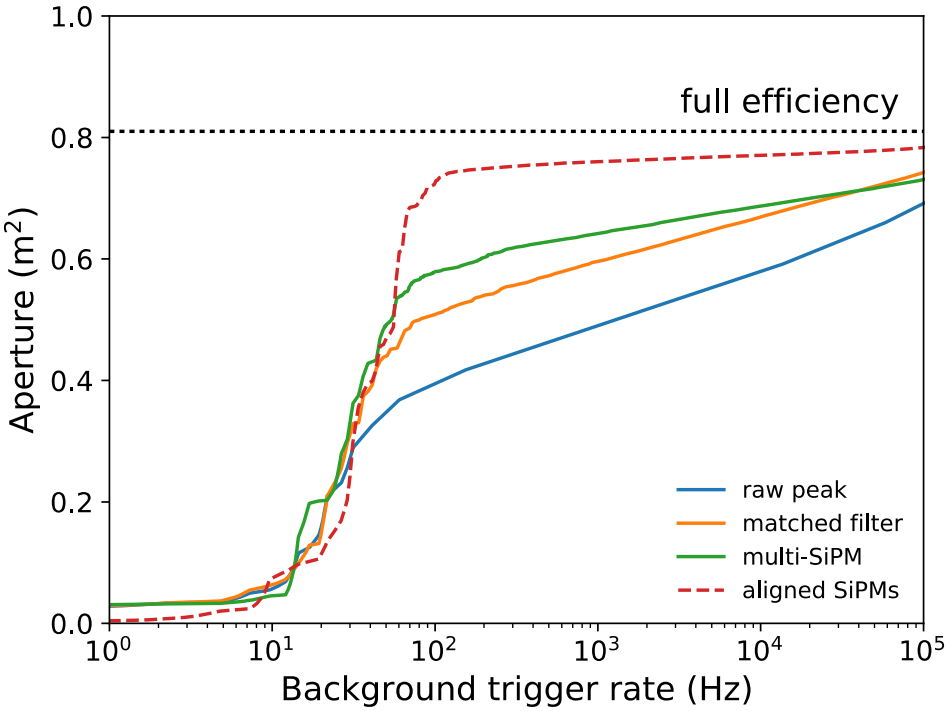
Muon tower

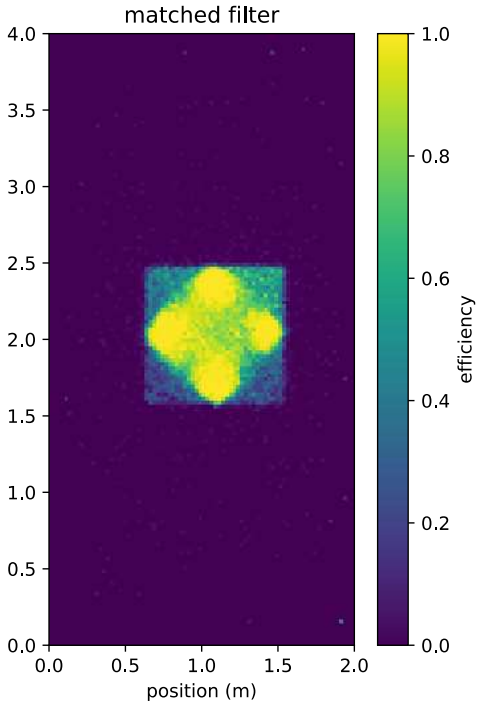


Verification at Karlsruhe

- 3 layers of detectors
- Allows precise muon tracking
- Map efficiency of detector
- Optimal configuration:

A_{eff} = 0.7 m^2 with 60 Hz background rate





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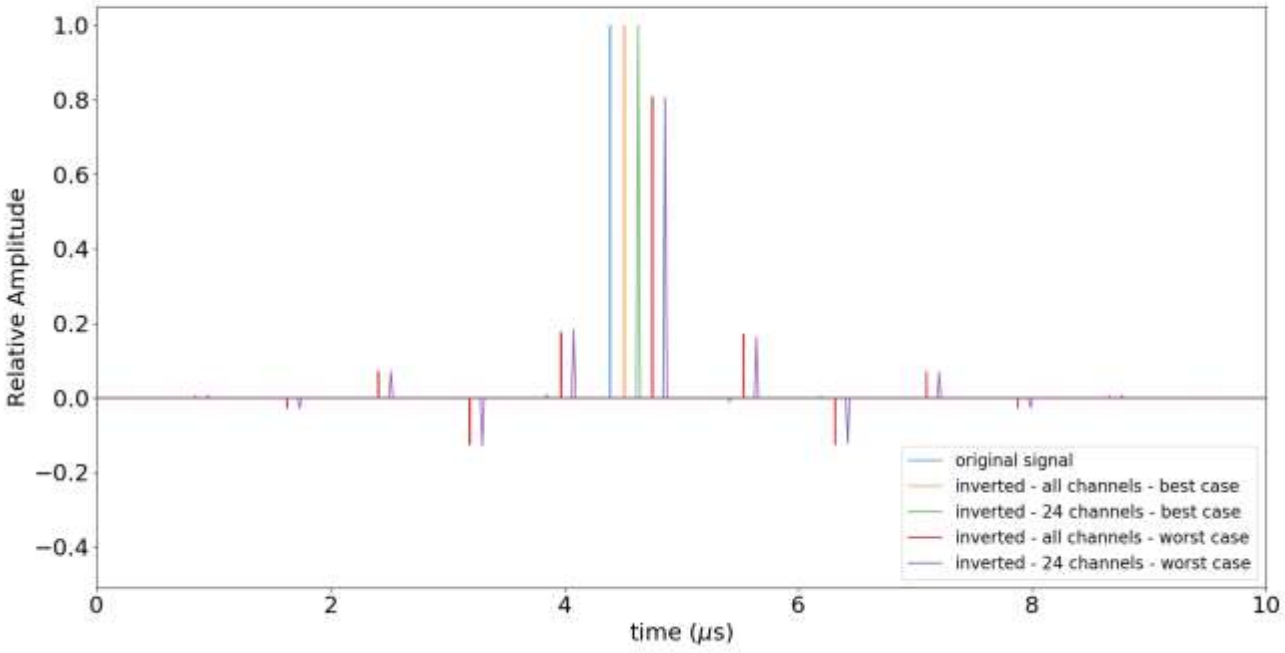
An Ultra-High Time Resolution Cosmic-Ray Detection Mode for the Murchison Widefield Array

A. Williamson, C. W. James, S. J. Tingay, S. J. McSweeney, and S. M. Ord

Polyphase filterbank inversion

- Invert 24 coarse channels to ~17ns time resolution
- Method: similar to VCS method of fine=>coarse

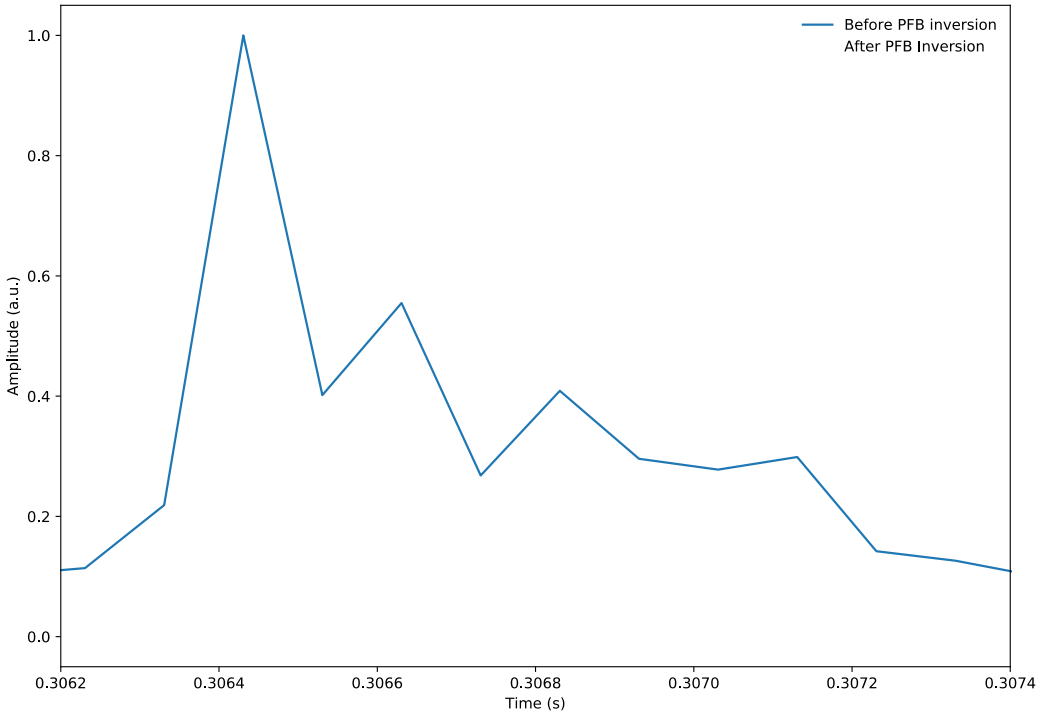


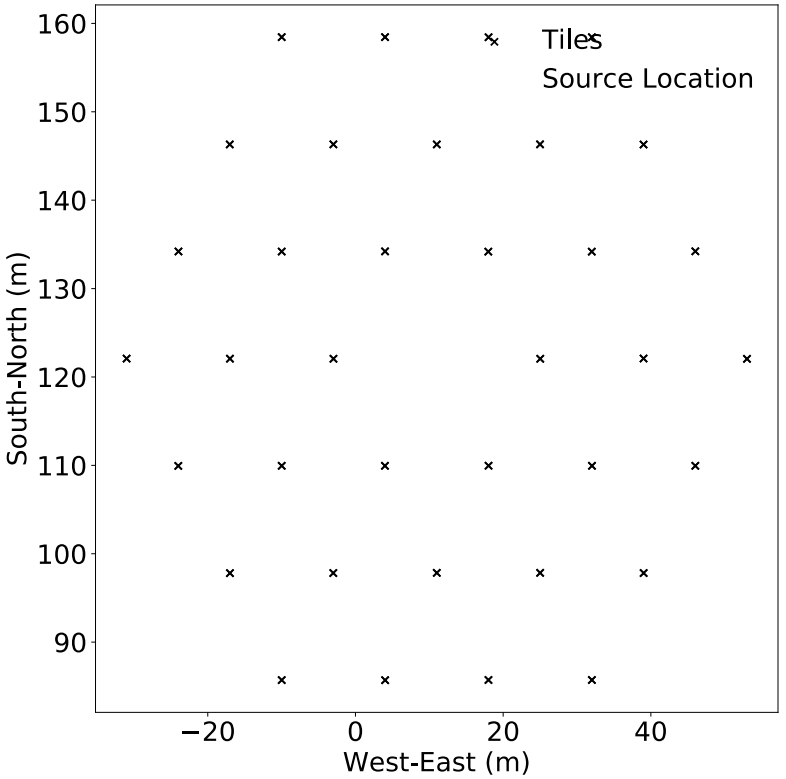
Verification

BBQ lighter test

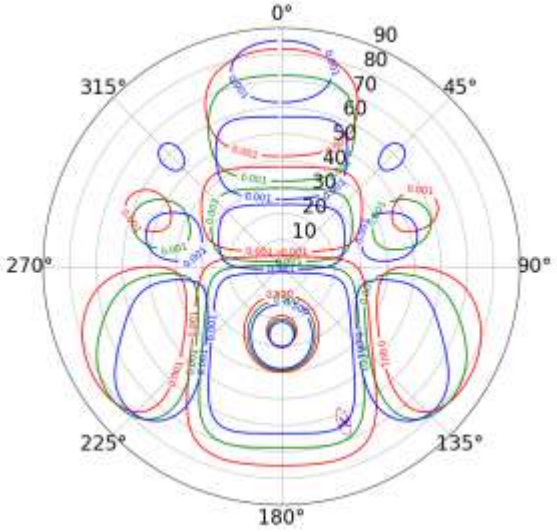
- Thanks Nichole Barry, Jack Line
- Piezo-electric sparks emit radio waves
- Great point-source for testing!
- 5m accuracy (~ c * 17ns)

At tile S26, 15 clicks over SW dipole starting at 3min 44sec
Walk NNW
At tile S19, 15 clicks over SW dipole starting at 4min 15sec
Walk NW
Jack does a dance, rapidly clicking both lighters with gusto between CRAM tile and tile S19, starting at 4min 40sec
Walk NW
At tile S13, 15 clicks over SW dipole starting at 4min 57sec



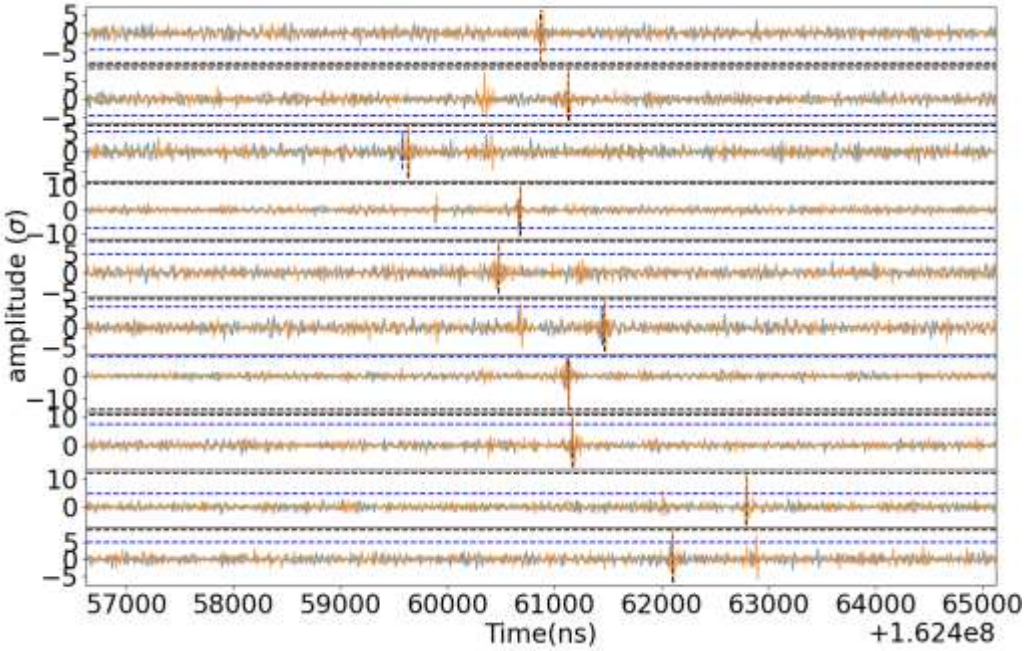


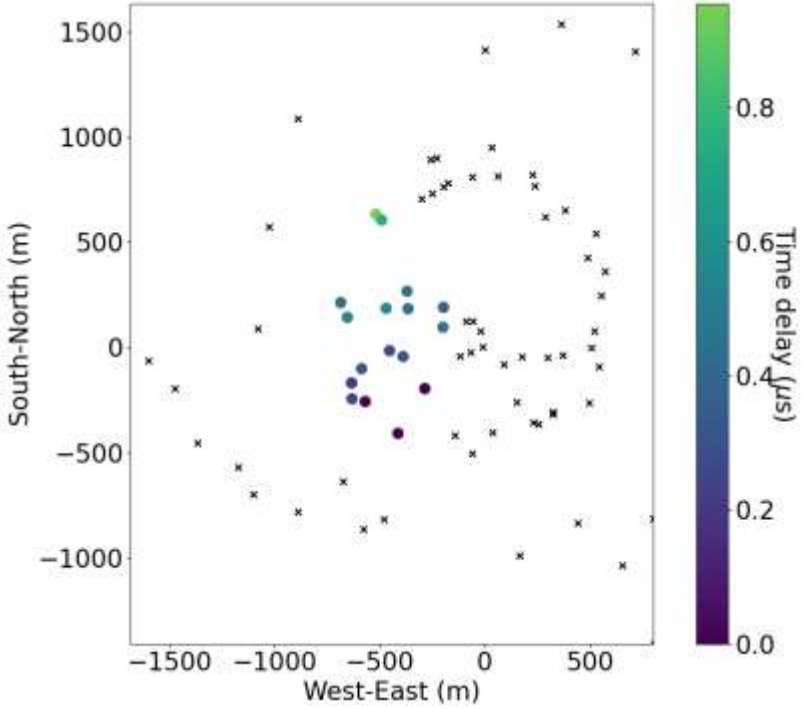
Cosmic ray search



Offline search for cosmic rays with MWA

- VCS: record 23hr of data (20 good)
- Search for cosmic rays:
  look for short, sharp pulses
- Processing: 1 week/hr at DUG/Pawsey
- 10 good CR candidates
- 1 very good event



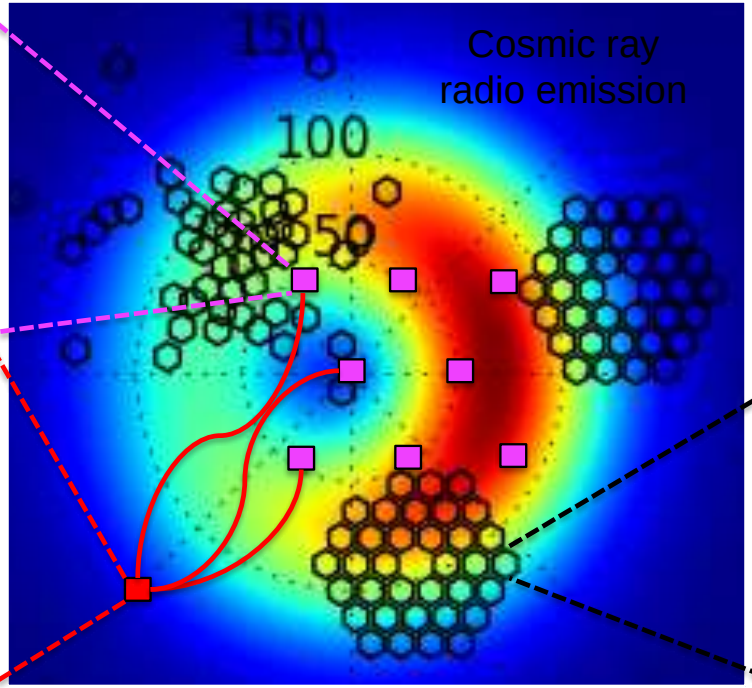


Great, what's next?

The Plan

Overview

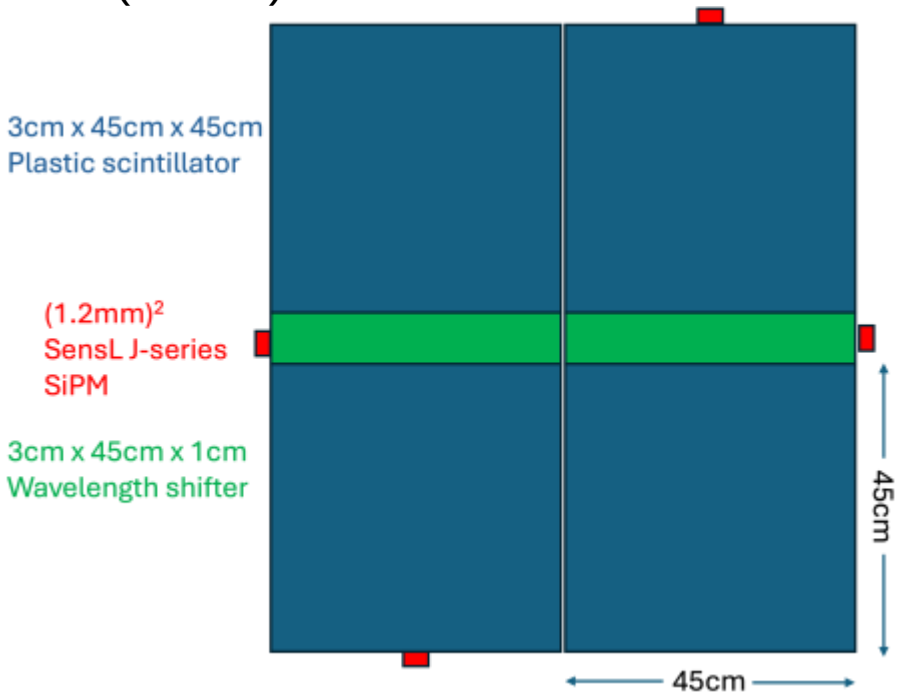
- Design, build, deploy, operate 8 particle detectors for the MWA
- Australian Research Council (ARC) LIEF Grant
- Curtin University, CSIRO, U. Manchester, KASCADE Grande Collaboration (Karlsruhe Institute of Technology)

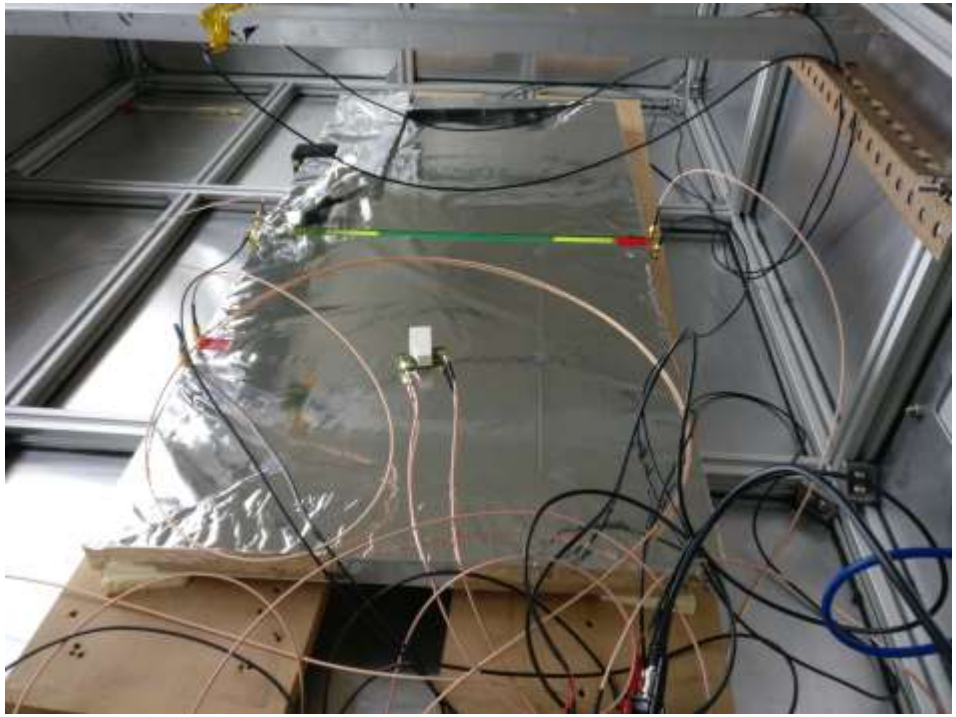


Particle detectors

Status

- Aluminium boxes
- Treated wood brackets
- 4 panels of scintillator
- 2 waveguides
- 4 silicon photomultipliers (SiPMs)



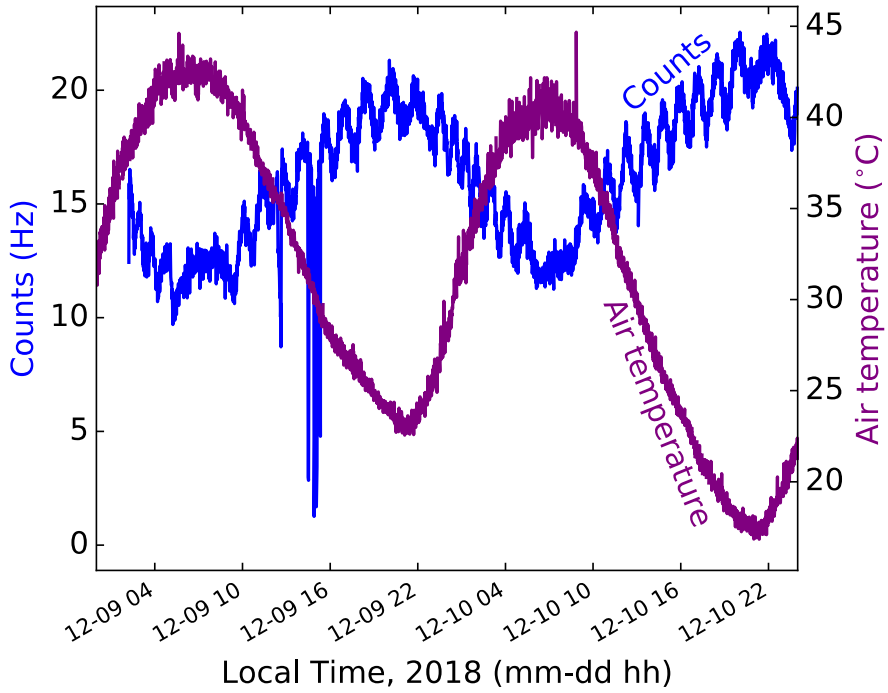


Power supply

Bob Watson
+ John Edgley

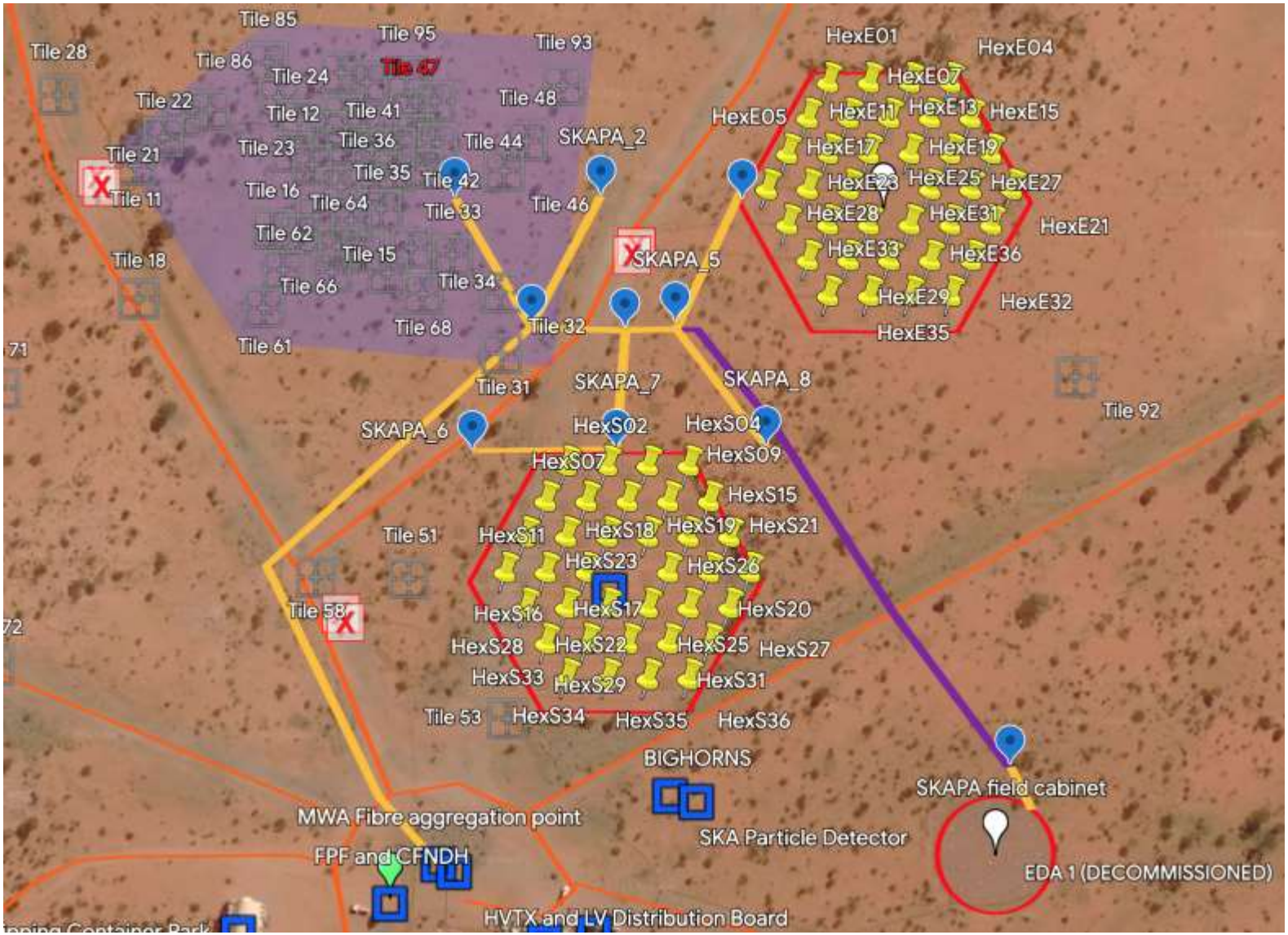
Requirements

- SiPMs: 26-30 V operating range
- Power draw: 0.012+0.072 (+0.033)A
- X8, Power supply efficiency 50%: **1.87 A**



- Temperature dependence! Voltage must be electronically adjustable

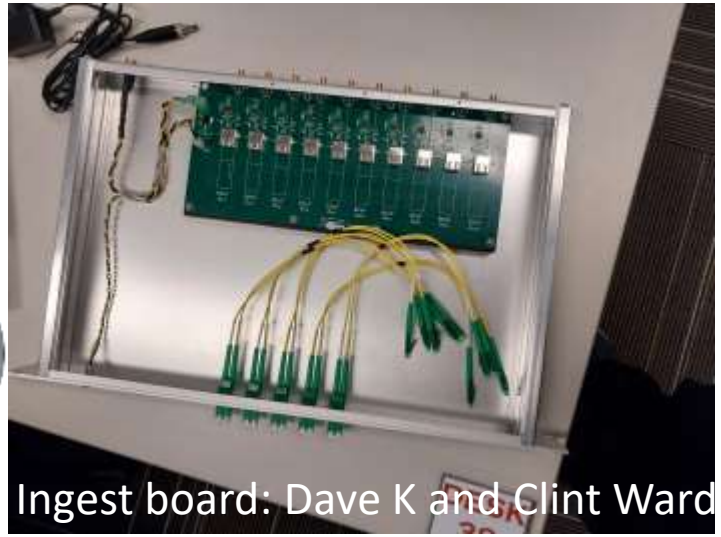
Particle detectors: construction



Data acquisition and trigger

Bedlam

- Fibre to control building
- Ingest to “Bedlam board”
- 8 x 1.024 GHz sampling, 8 bit
- Matched filtering
- Coincidence triggering: from single muons to particle cascades



Ingest board: Dave K and Clint Ward

Bedlam and control computer: Paul Roberts

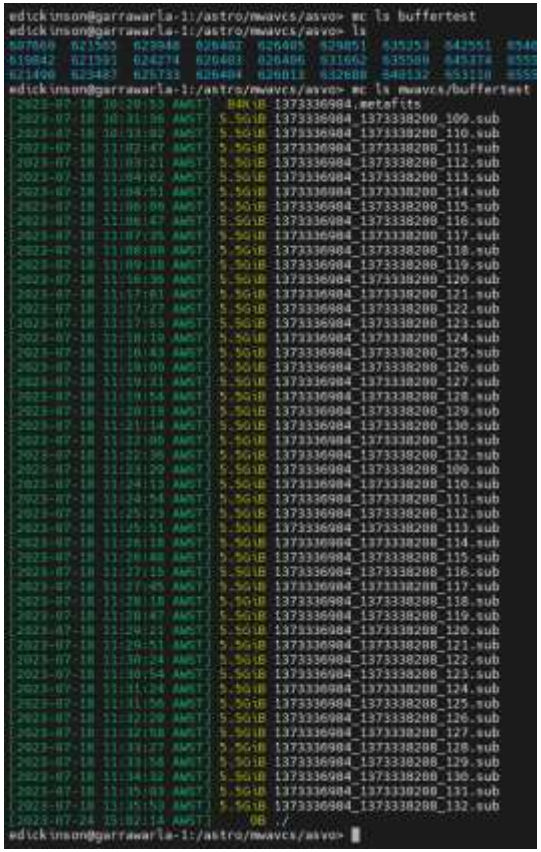
MWA trigger and data

Status



- Edwin Dickenson, Andrew Williams, Greg Sleap, Bryan Crosse
- Return 24 channels x 8s block

…	8s, 1.28 MHz	8s, 1.28 MHz	8s, 1.28 MHz	…
…	8s, 1.28 MHz	8s, 1.28 MHz	8s, 1.28 MHz	…
	…	…	…	
…	8s, 1.28 MHz	8s, 1.28 MHz	8s, 1.28 MHz	…



- Data access
  - ASVO: trigger data assigned to current observing project
  - Work-around: script from Greg to get data access
  - Work on long-term solution (ask Greg!)

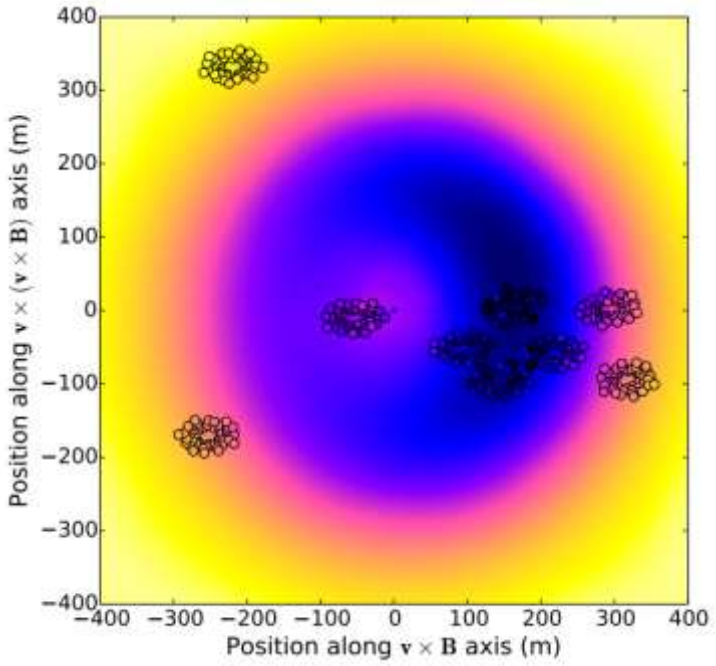
Triggering status

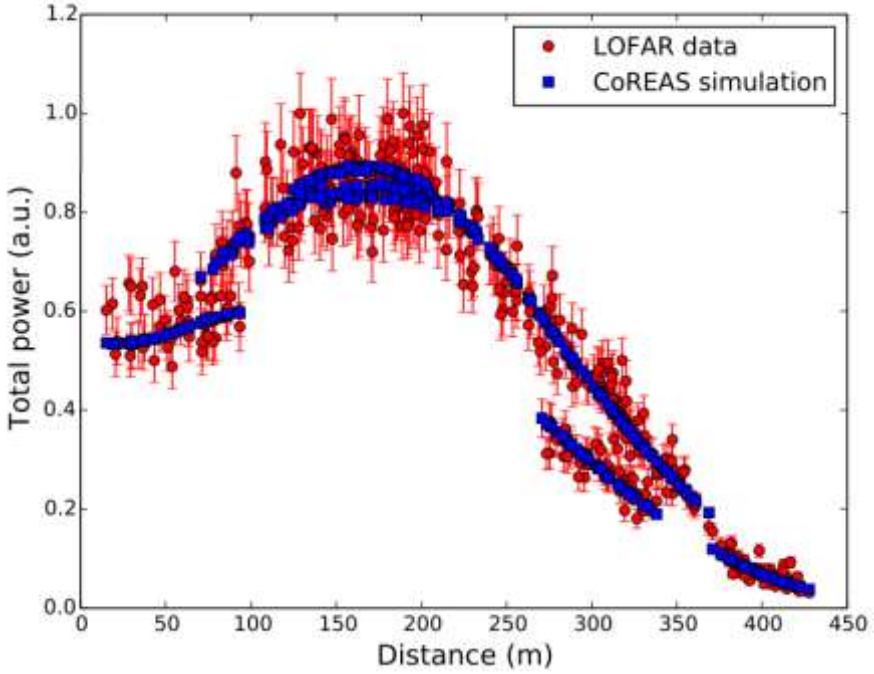
- Last week: first successful trigger sent from BCC0A to MWA! (accidentally took 16 sec)

Science!

Basics

- Plan: use LOFAR software pipeline (add MWA antenna model, adjust for bandwidth)
- Cosmic ray detectors: energy, direction and impact point
- Radio data: much better reconstruction!
- Expected energy threshold: ~10^{17} eV
- Statistical analysis: determine cosmic ray composition

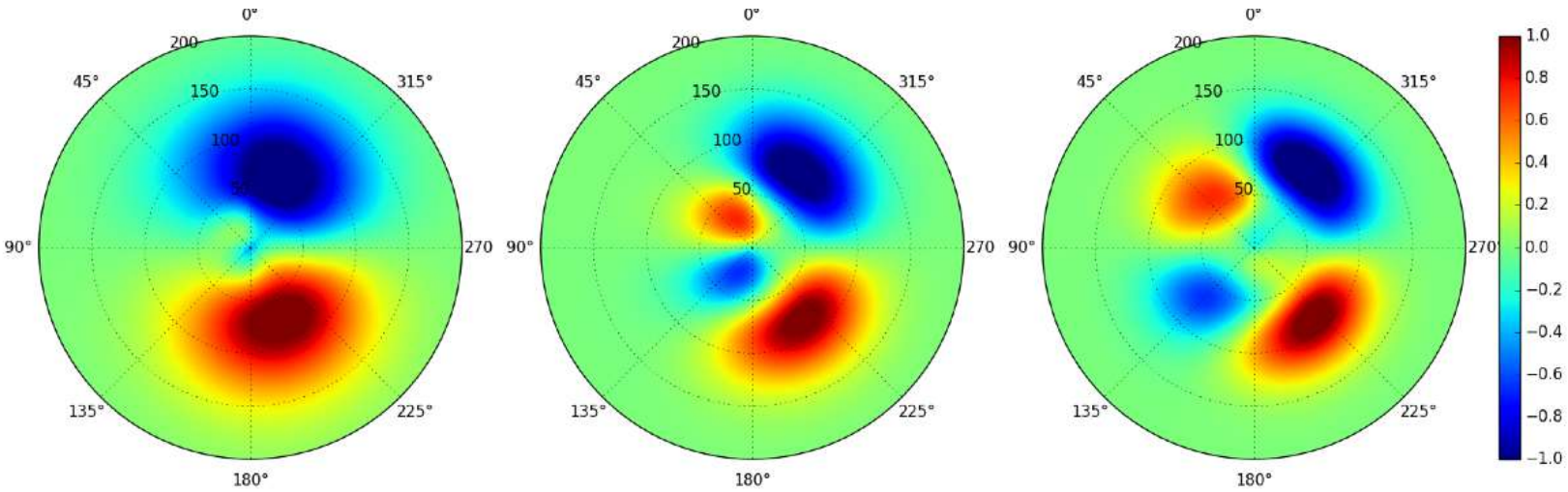




Science!

Solving an old controversy

- Charged particles moving through Earth's magnetic field: "geo-synchrotron" radiation
- Macroscopic model: "moving dipole"
- Observations at 30-100 MHz: moving dipole model correct
- Predictions (simulations and theory): should see quadrupolar signature in circular polarization near 300 MHz
- Search for this! Gives measure of the shape of the cascade



Hannan Chen, ICRAR summer research project; see also Huege, Ludwig, James

Summary

Cosmic ray detection at the MWA

- Many delays due to COVID (UK had it bad)
- Components: shipping in August
- Deployment: by end of 2023

Most critical aspect of this venture

- MWA ops and Curtin engineering teams!
- Huge amount of help regarding:
  - Design
  - Deployment
  - EMC testing
  - Triggering
  - Testing
  - …

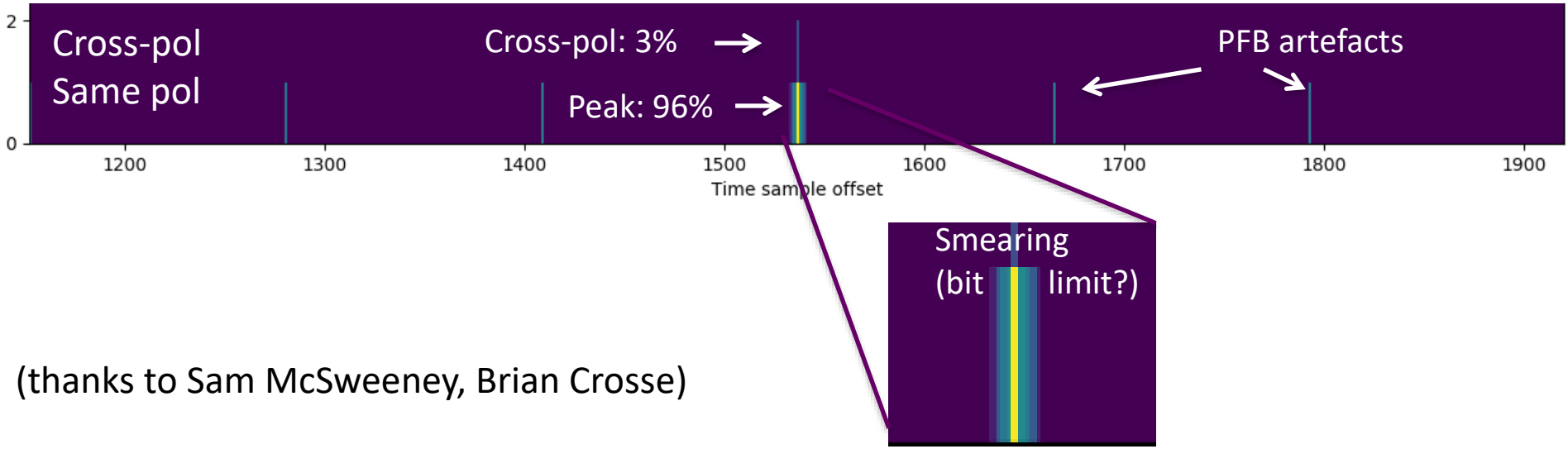
Test: fine => coarse

Check:

- Record *both* fine and coarse channels
- Resynthesise fine channels into coarse coarse
- Cross-correlate with *actual* coarse channels recorded directly

Results:

- Using FFT only: 50% correlation
- PFB 'inversion' (Alex): 96% correlation
- Time offset: full width of filterbank (half from forward, half from inversion)

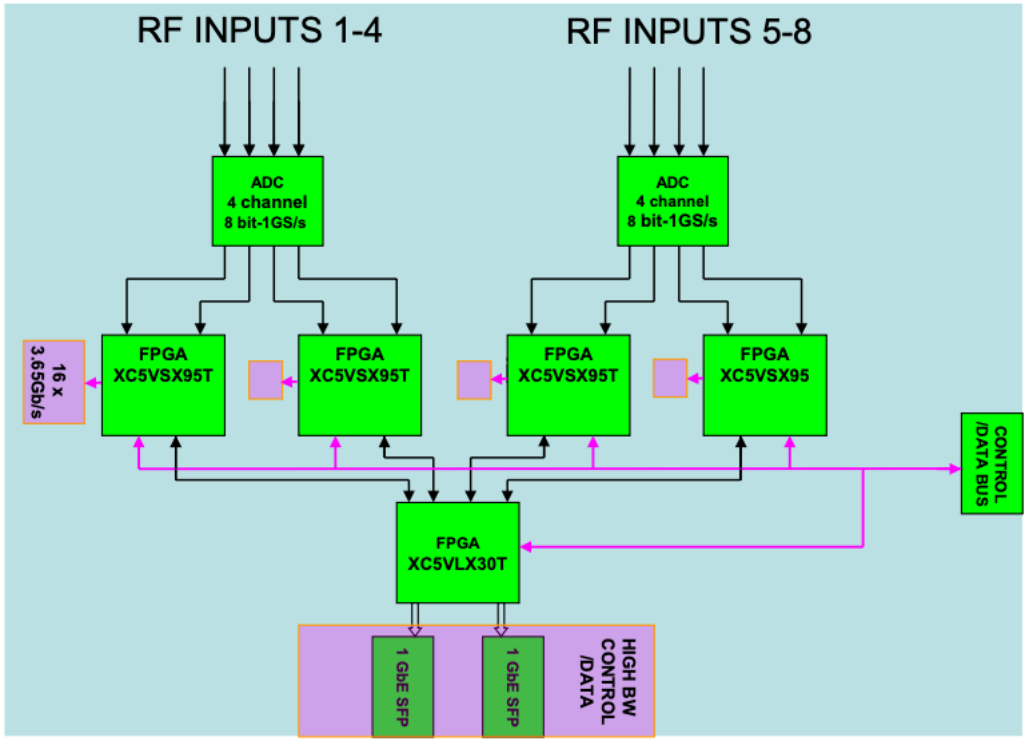


(thanks to Sam McSweeney, Brian Crosse)

Bedlam

Developer: Paul Roberts

- Cosmic ray trigger rate, direction reco from particle array and radio data
- Event reconstruction: comparison with simulation
- Statistical particle ID: protons vs iron
- Plan: use LOFAR software pipeline (add MWA antenna model, adjust for bandwidth)
- Show LOFAR rec



More photos!

Huge thanks to MWA ops team!

- Esp. Andy McPhail, Dave E.