

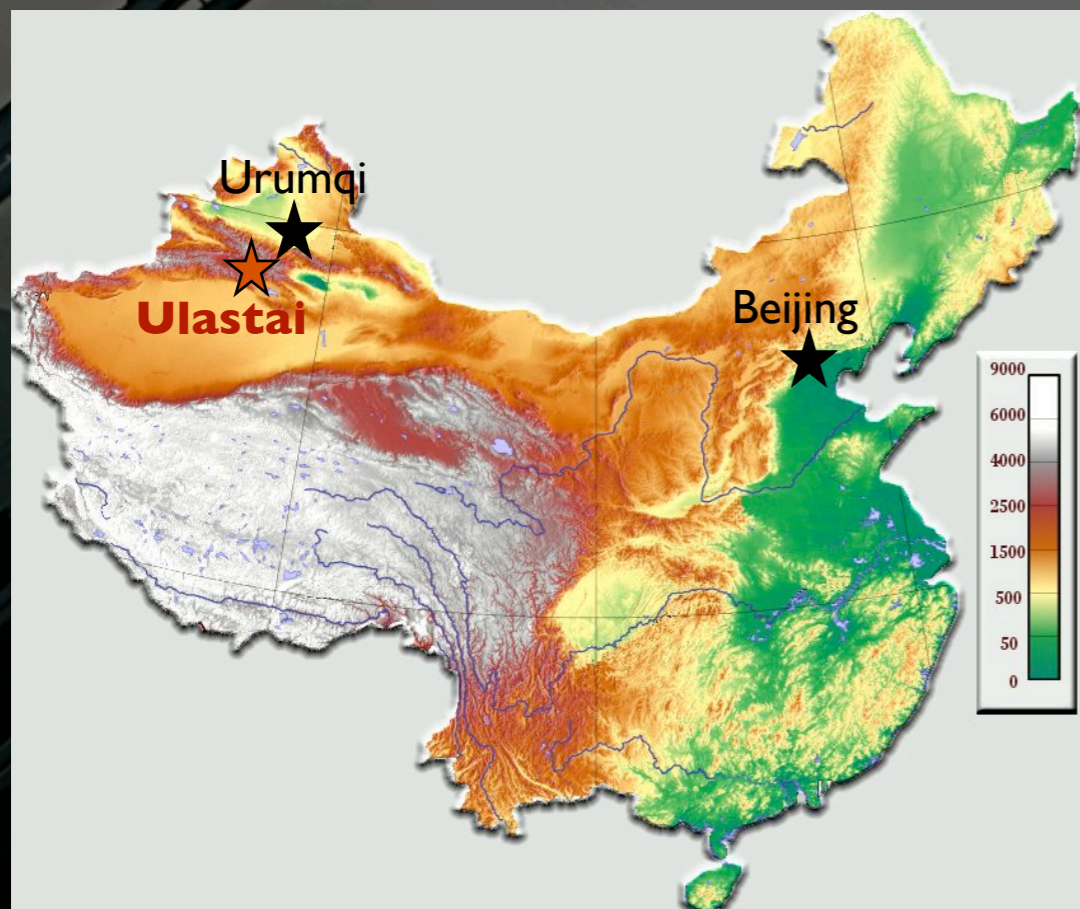


**Autonomous radio-detection of EAS
with the
TIANSHAN Radio Experiment
for Neutrino Detection**

**Olivier Martineau-Huynh
on behalf of the TREND collaboration
IN2P3 - CAS**

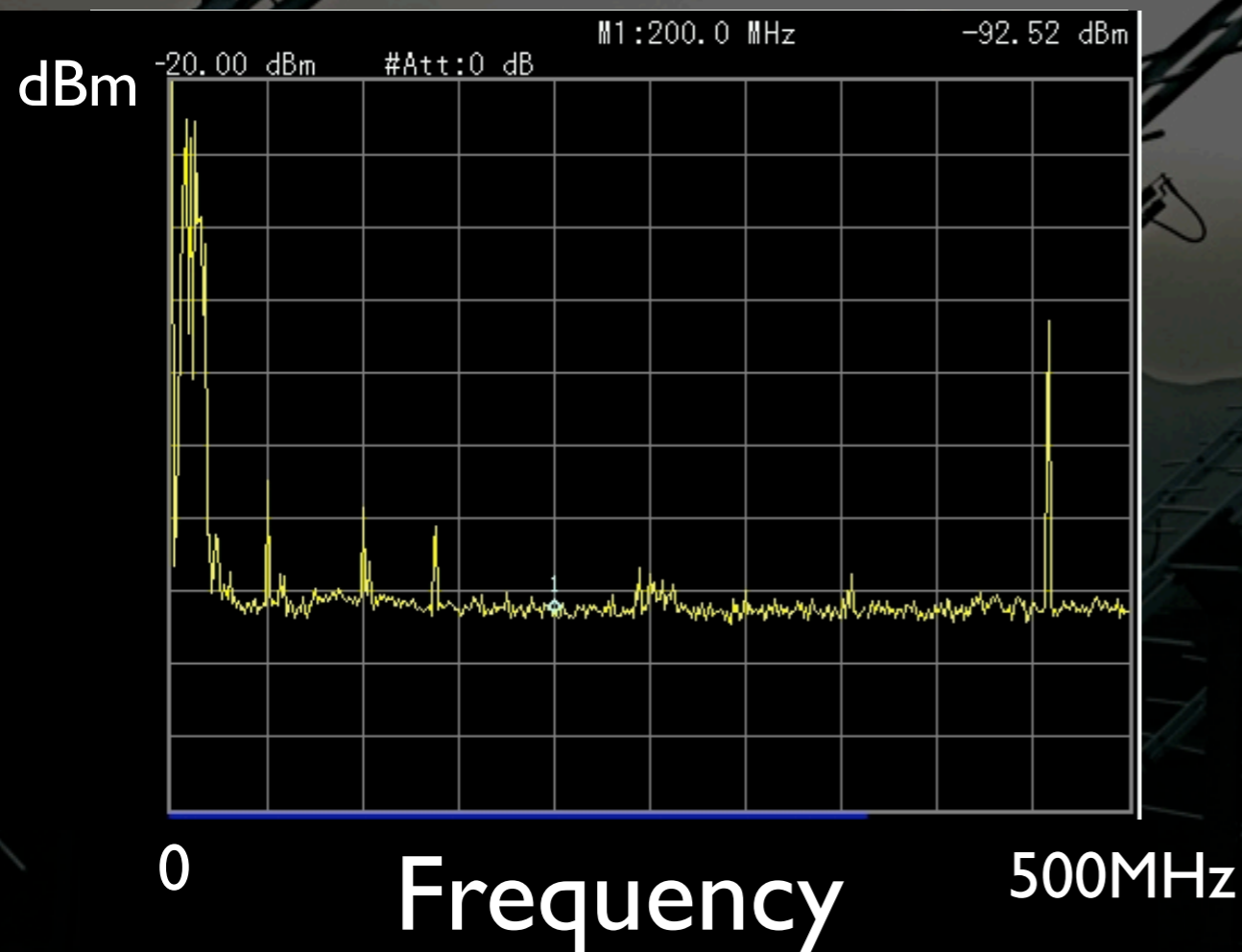
The 21 cm array

- Ulaštai, TianShan mountains, XinJiang autonomous province, China



The 21 cm array

- Ulastai, TianShan mountains, XinJiang autonomous province, China



North

The 21 cm array

a radio-interferometer for the study of the Epoch of Reionization (Wu XiangPing, NAOC)

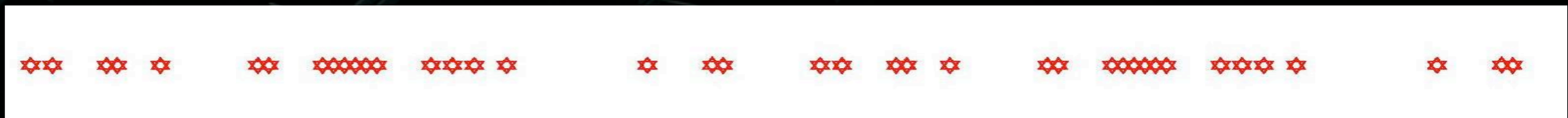
4 km



127 log-periodical antennas x 80 pods along 2 baselines



50-200MHz



3 km

West

East

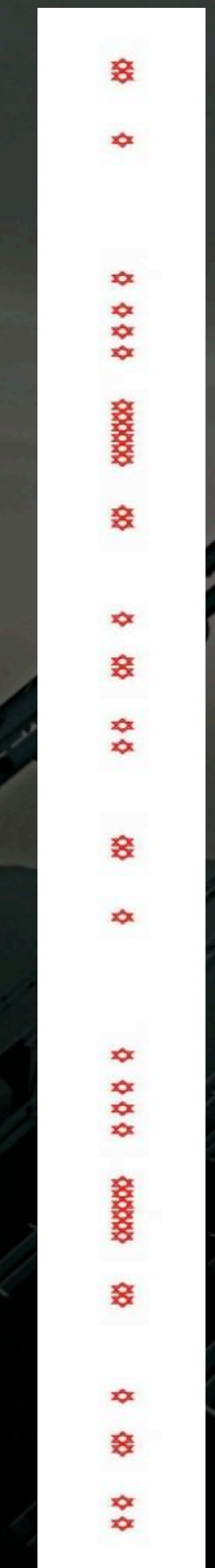
South

The 21 cm array

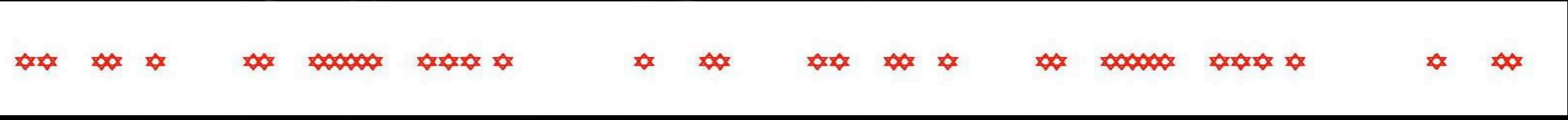
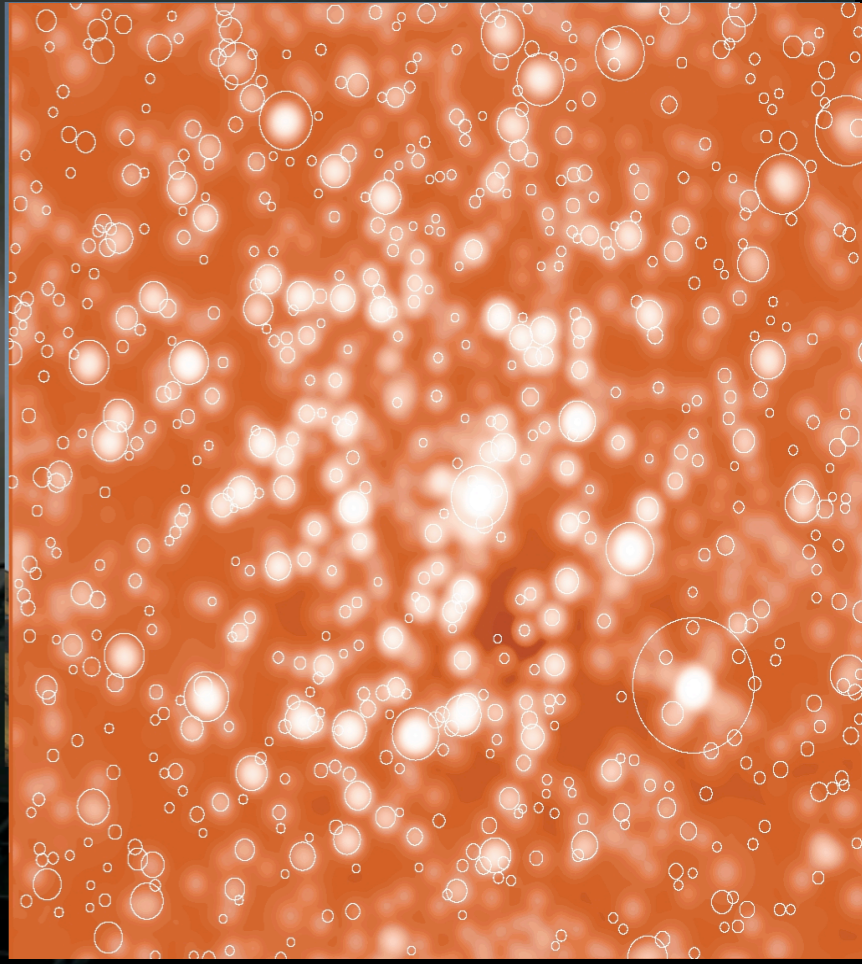
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Cosmic rays @ 21CMA?

- Is the 21CMA set-up usable for CRs detection?



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- Is the 21CMA set-up usable for CRs detection?
 - ~ Exceptional elm environment
 - ~ Adequate frequency range
 - ~ Few adaptations needed
 - ~ Mountainous environment



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- June 2008: green light for TREND project
- Quick, cheap & large set-up for CR search
 - Autonomous radio array
 - Well adaptated to neutrino search

TREND Prototype setup

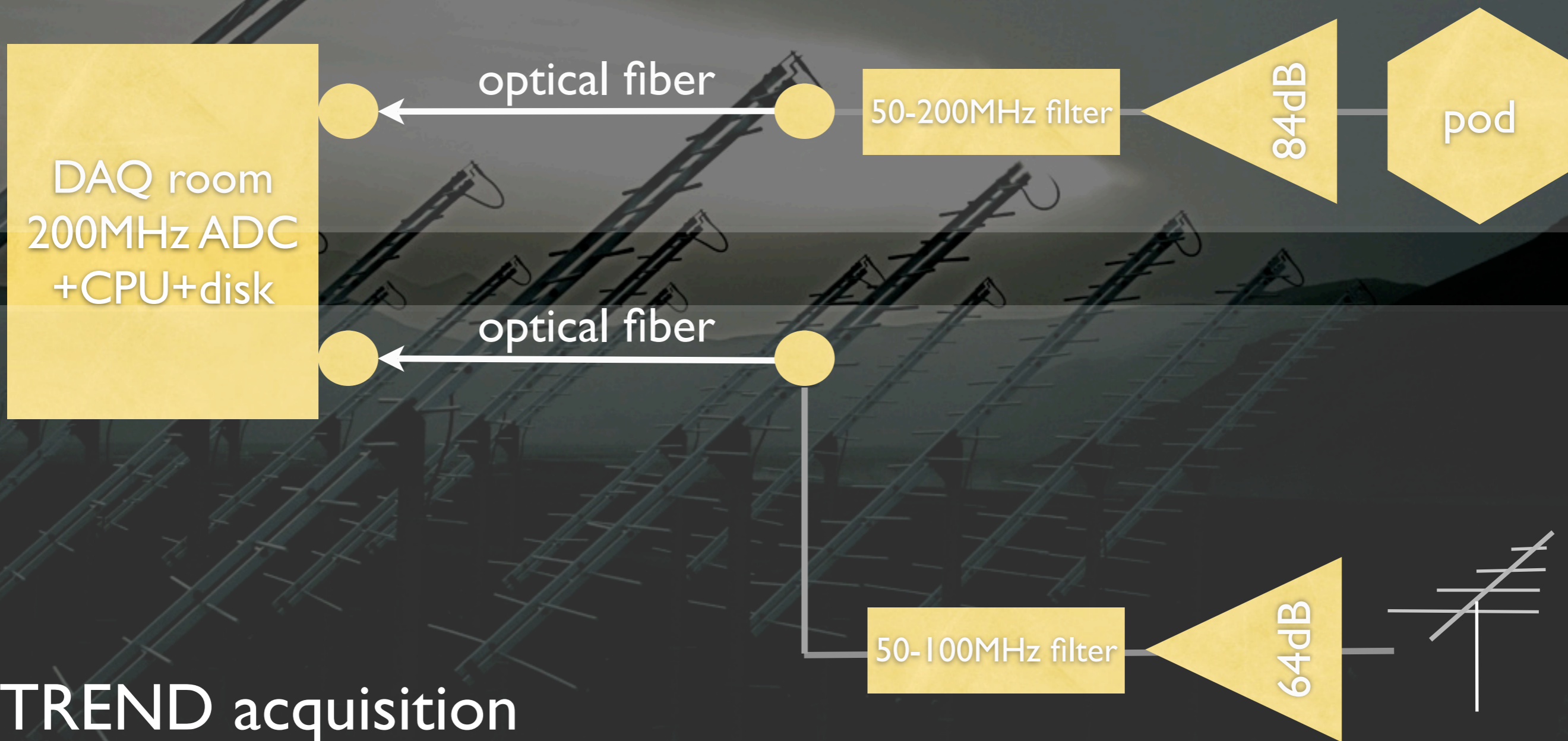
21 CMA acquisition

DAQ room
200MHz ADC
+CPU+disk



TREND Prototype setup

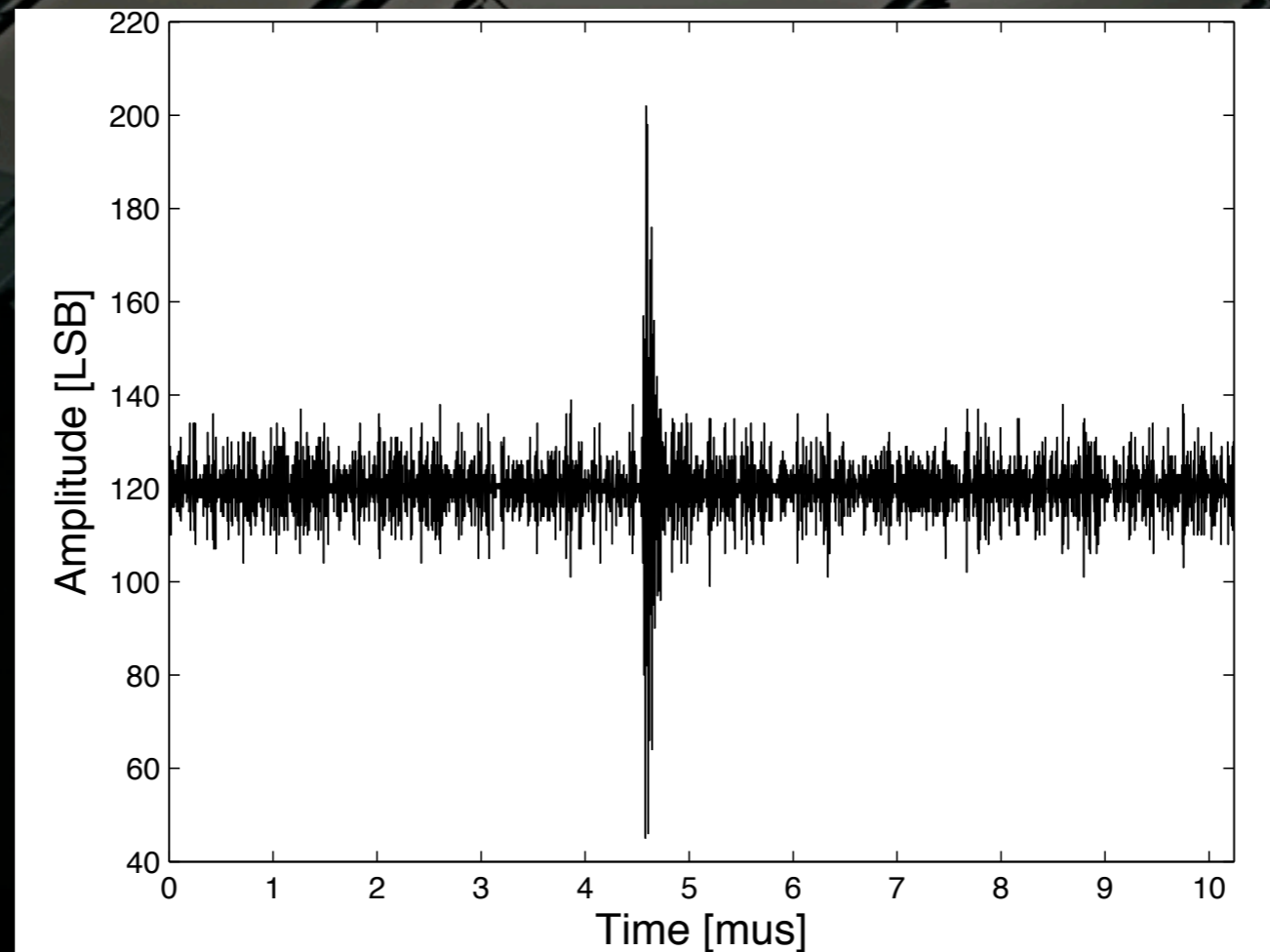
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TREND acquisition

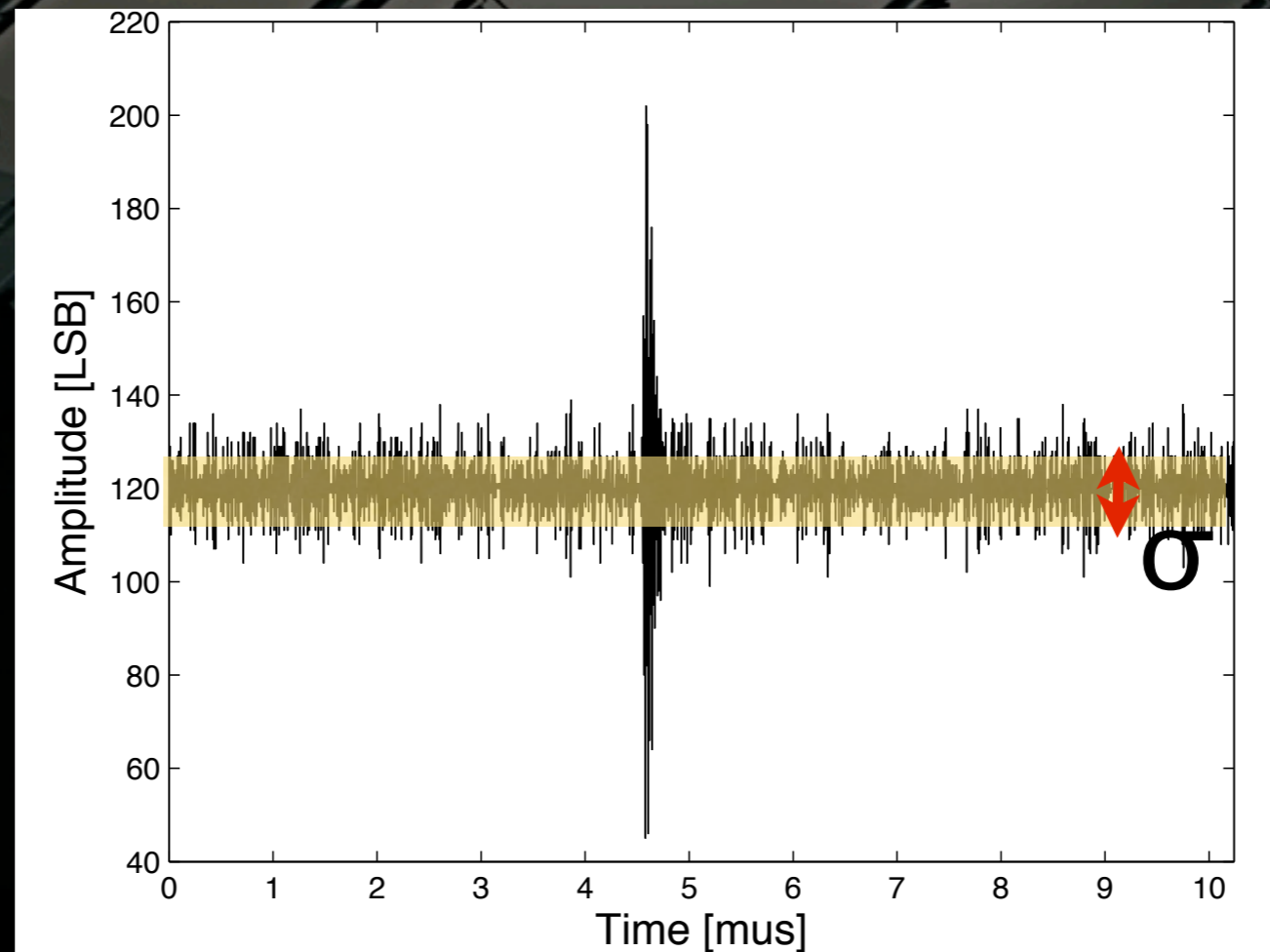
TREND acquisition

- Online (synchronized) digitization: 5 ns/sample
- Fully independent channels
- Trigger if amplitude above $N \times \sigma_{\text{noise}}$ ($N \approx 6-10$)
- 2048 samples ($\approx 10 \mu\text{s}$) written to disk



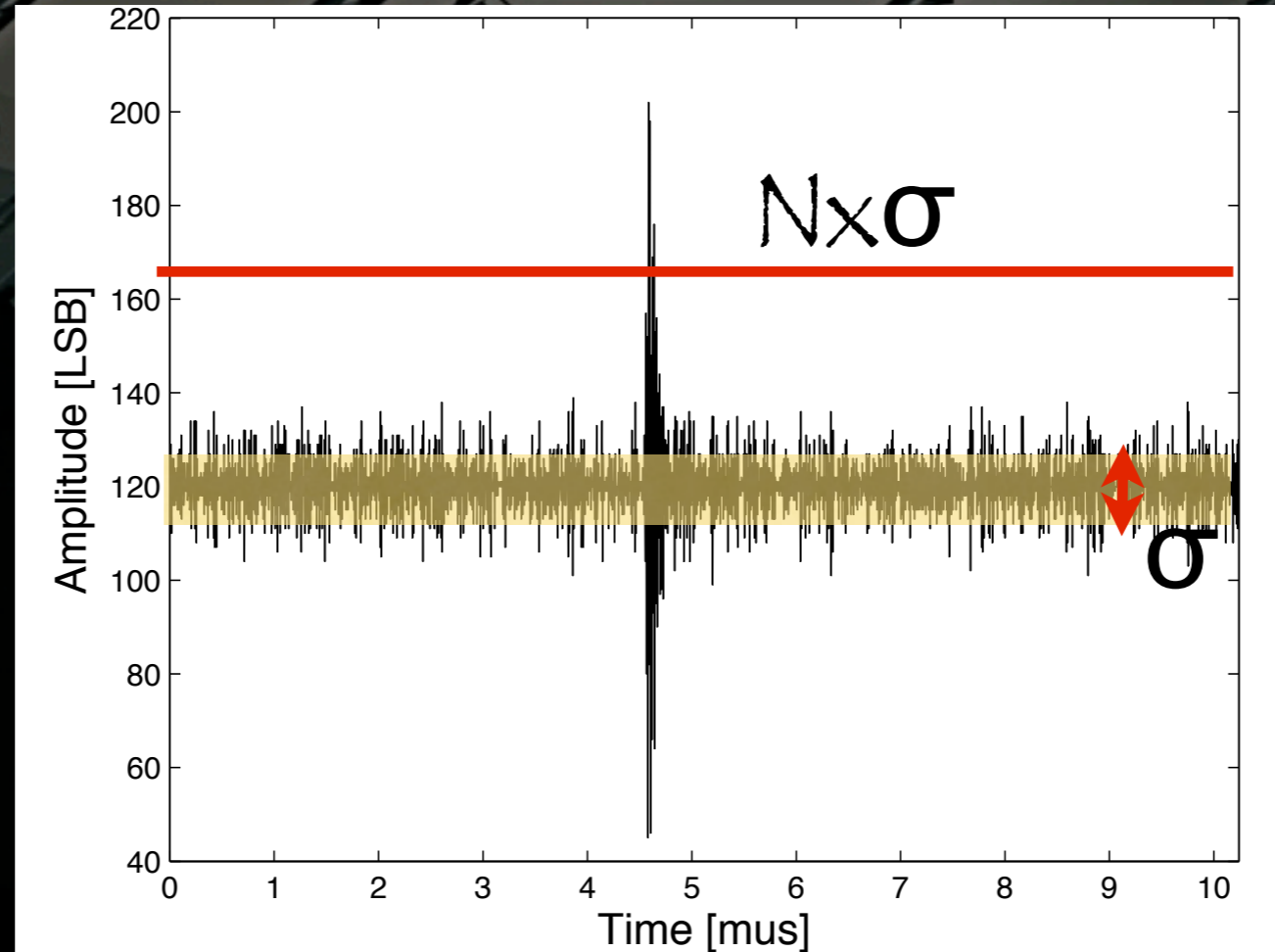
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TREND prototype

N



W

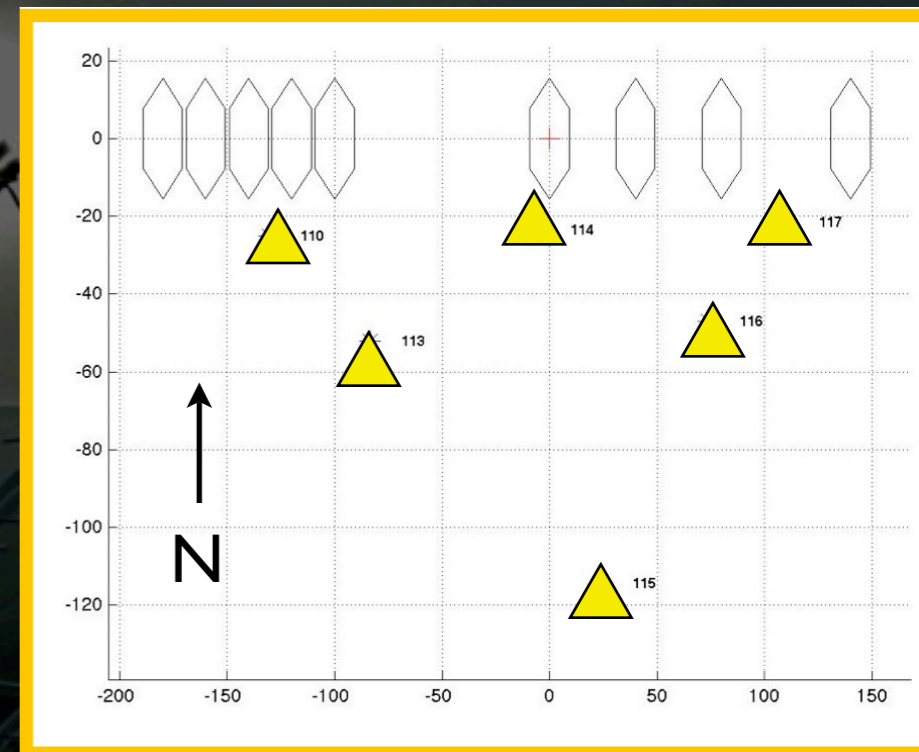
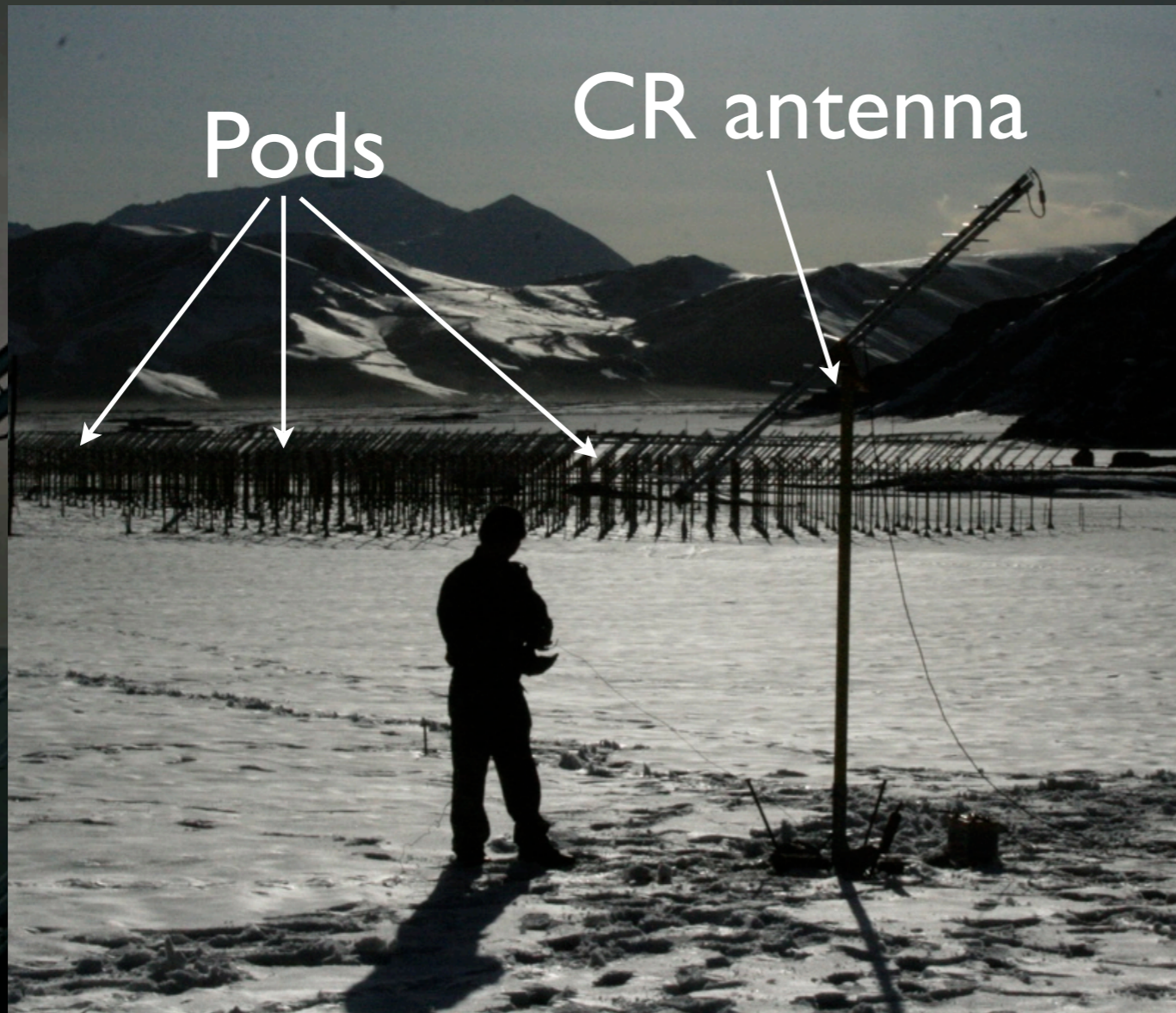
E



S



TREND prototype



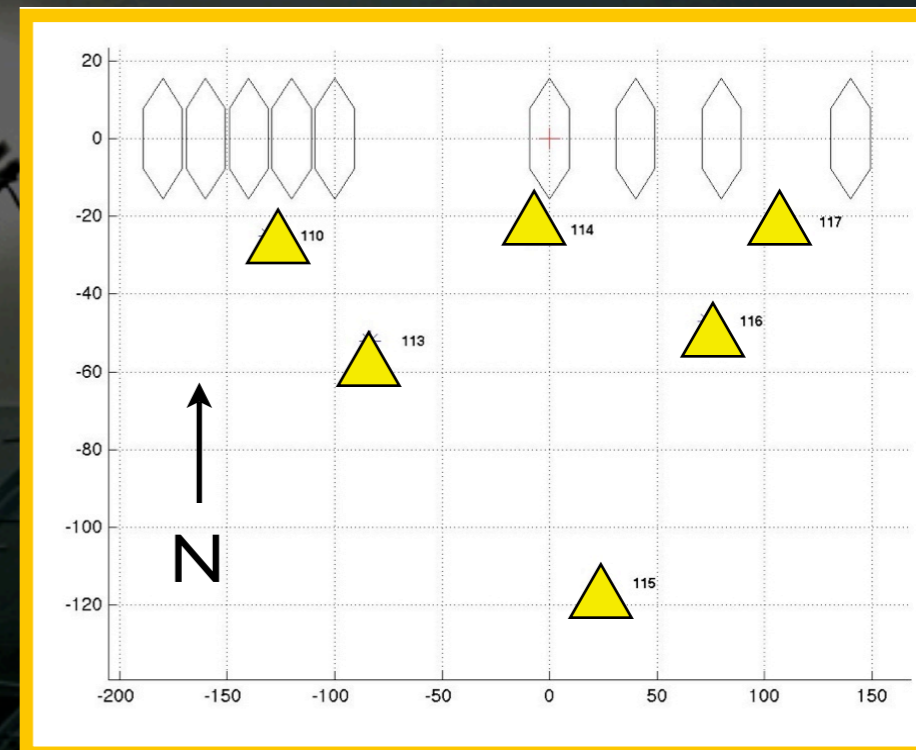
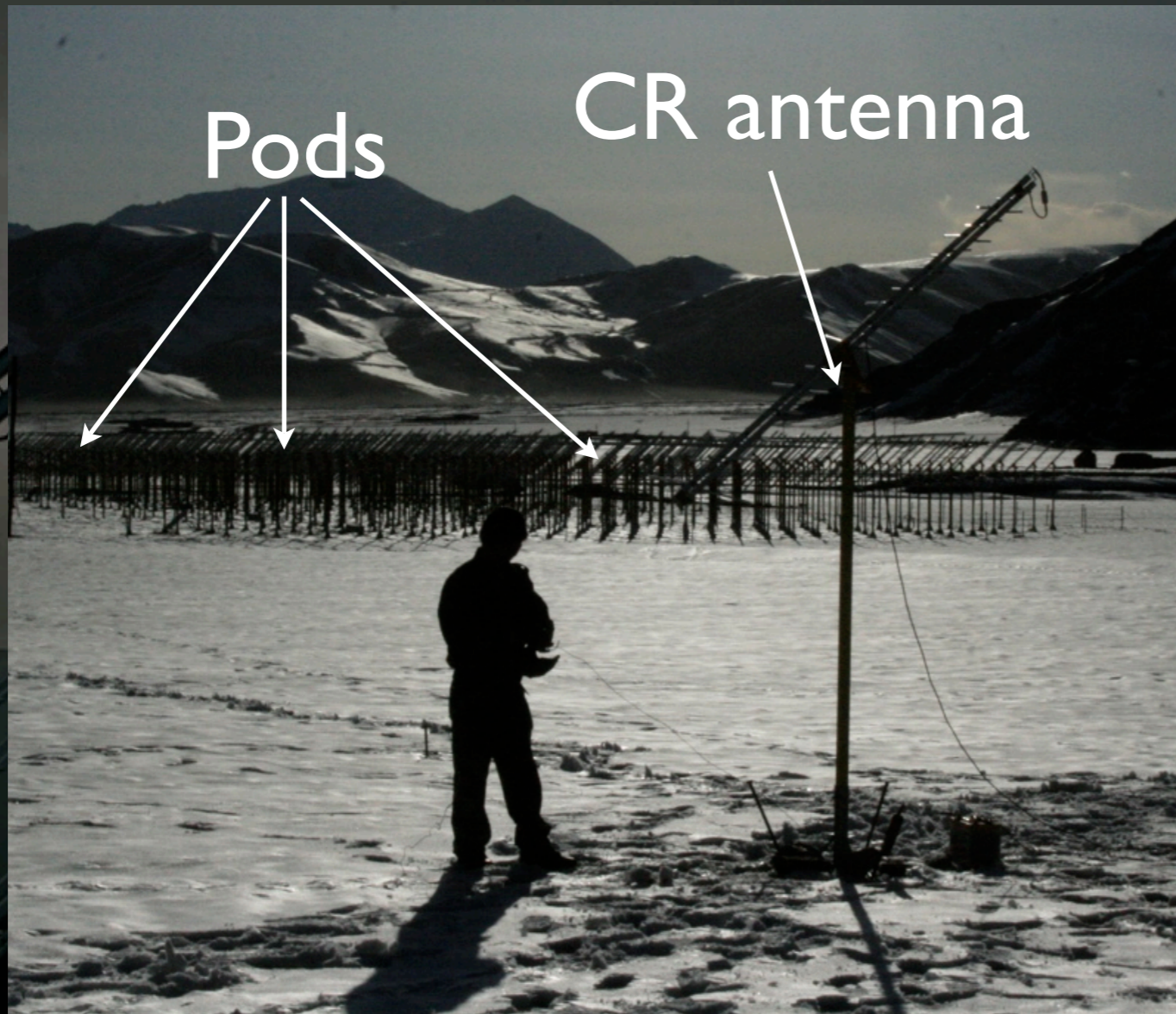
N

W

E

S

TREND prototype



Set up ready in January 2009. Ran for 24 live days.

Data analysis Reconstruction

- Plane & spherical wave front hypotheses
- Reconstruction performed on causal coincidences between 4 antennas or more.
- Antenna trigger times corrected through signal inter-correlation

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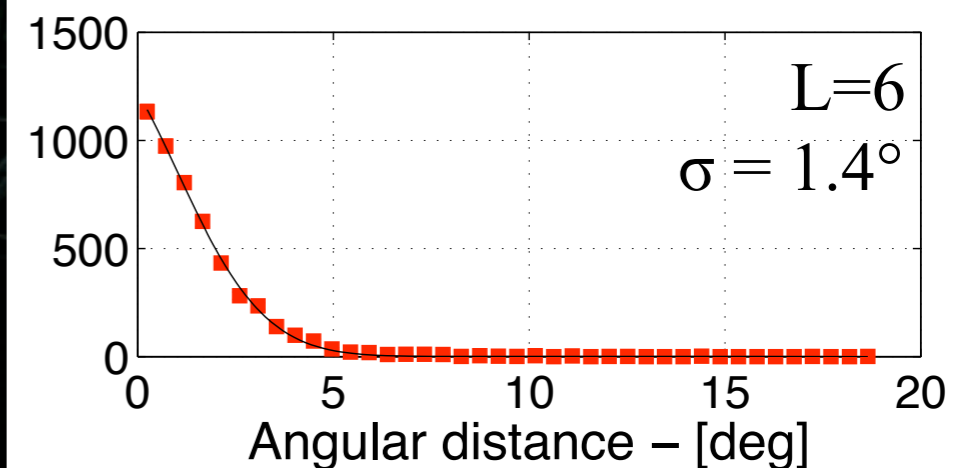
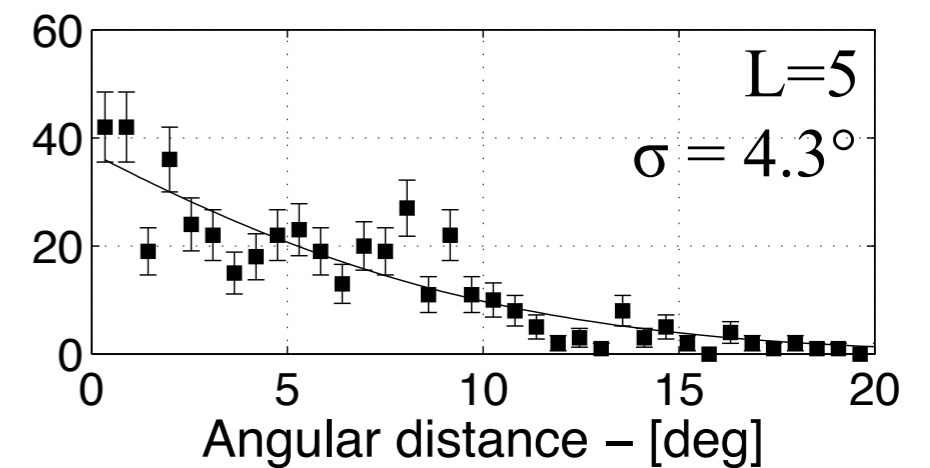
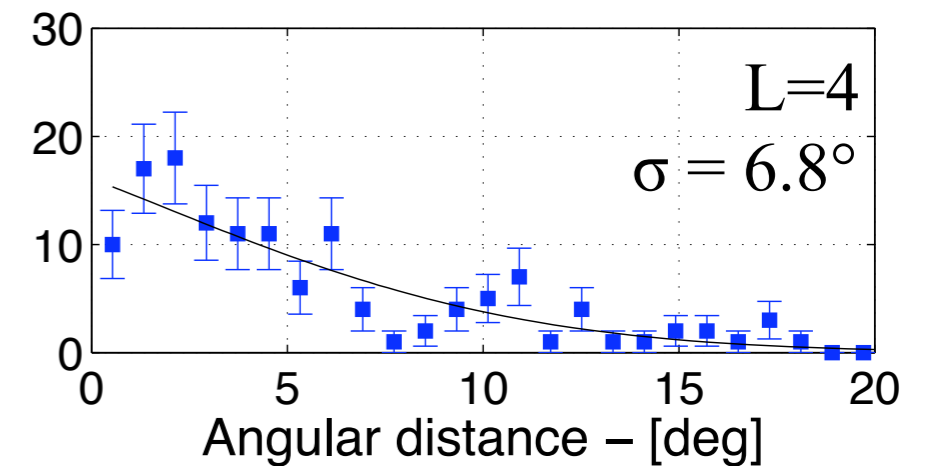
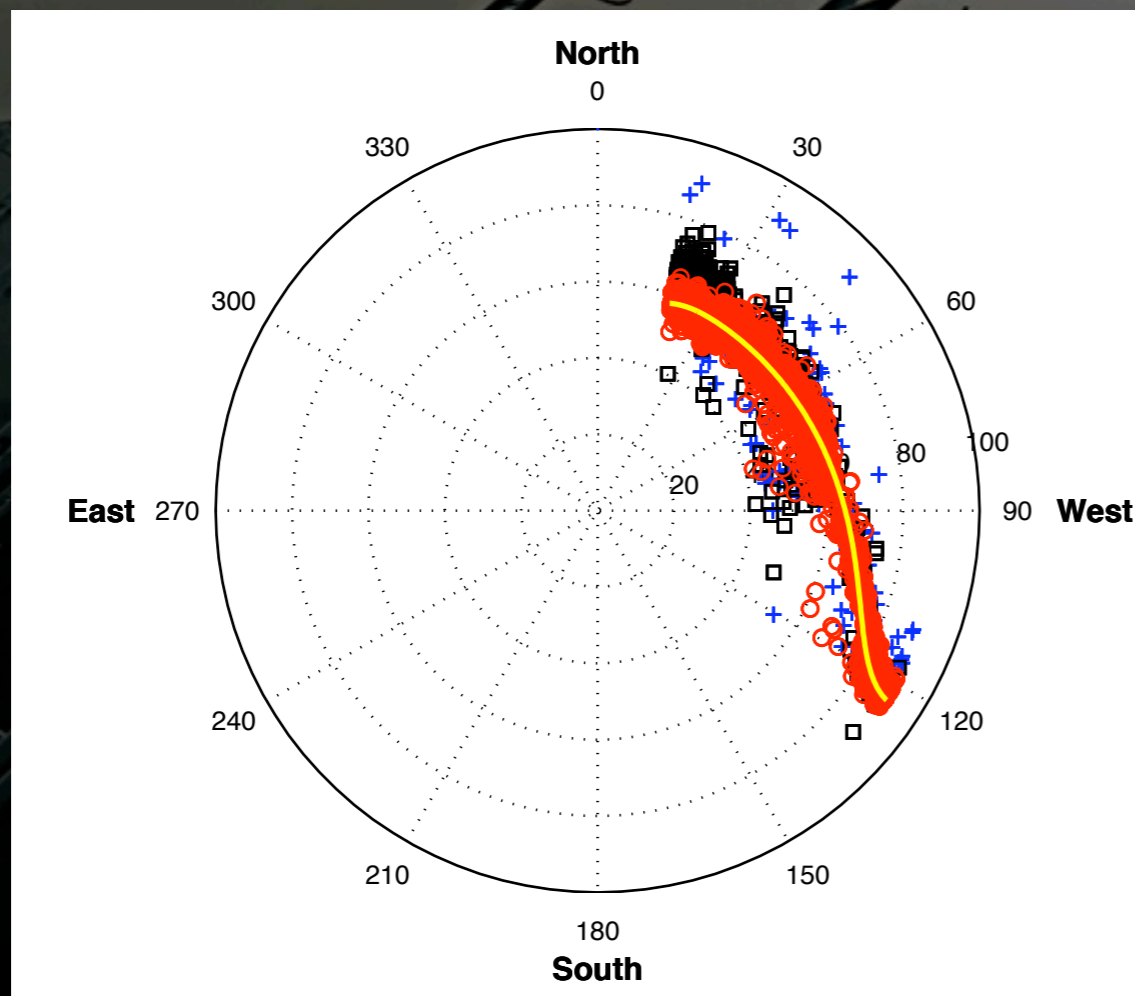
signal

background

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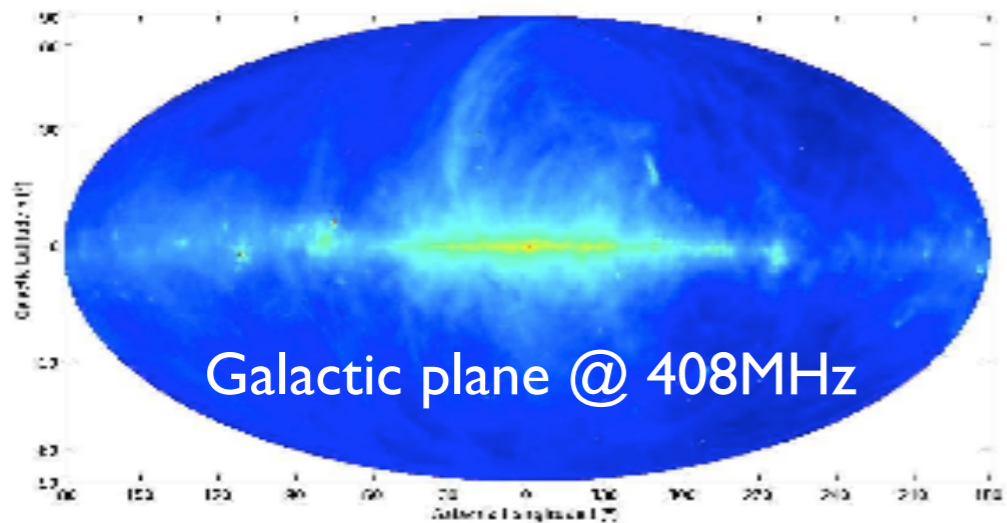
Reconstruction performances

- Estimated from transient sources crossing the sky
- Plane reconstruction: angular resolution down to 1.5°



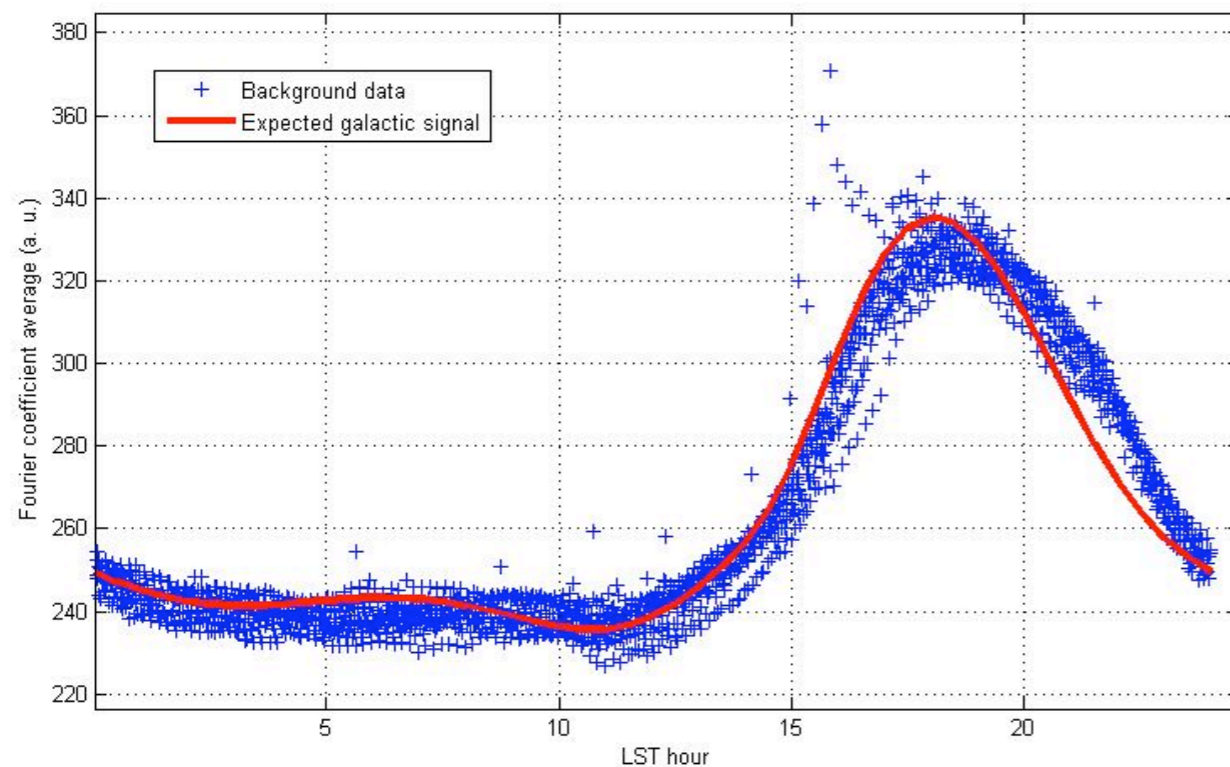
Antenna sensitivity

- Set-up sensitivity



Major radio source: thermal emission from the Galactic plane.

Visible in Ulaanbaatar sky between 15h & 23h LST.



TREND antennas clearly exhibit an increased noise level when the Galactic plane is in the sky

CR search

- CR signals

- Background signals

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 - short/symmetrical/
isolated pulses

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- ~ exponential decrease for lateral amplitude profile

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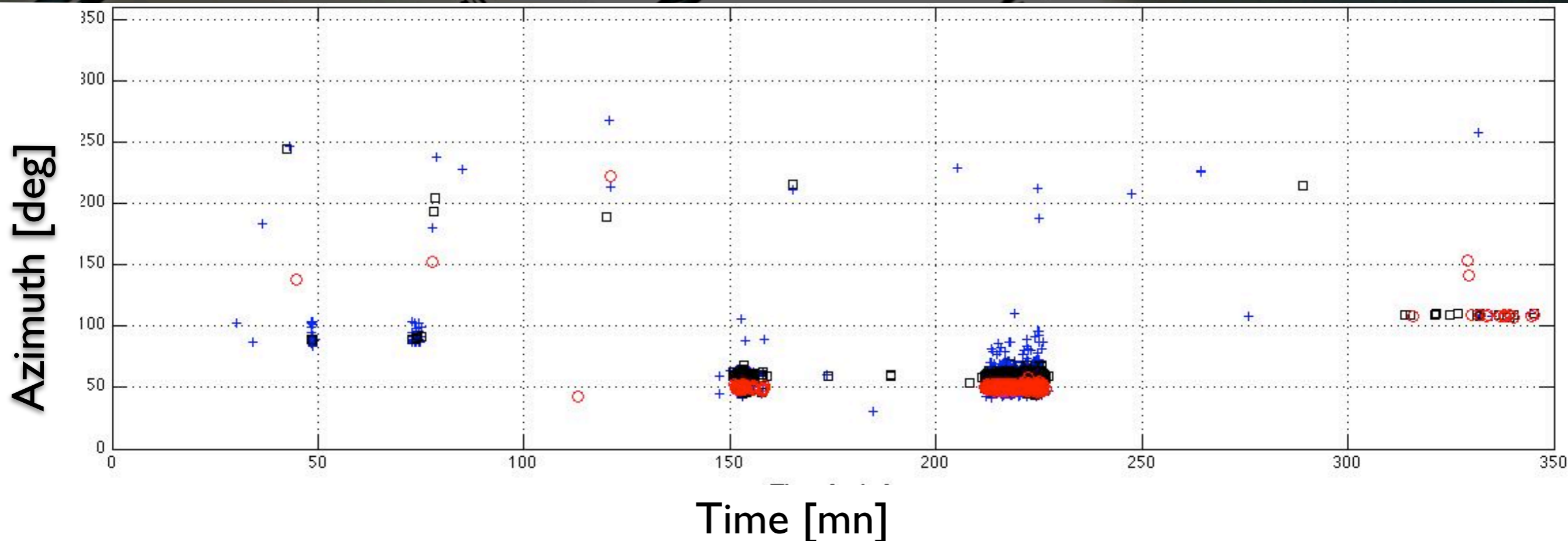
- Background signals

- ~ in general, longer & repetitive pulses
- ~ in general, localized sources or tracks
- ~ spherical wave front
- ~ $1/\text{distance}$ decrease for lateral amplitude profile

Analysis cuts (I)

Noisy periods rejection

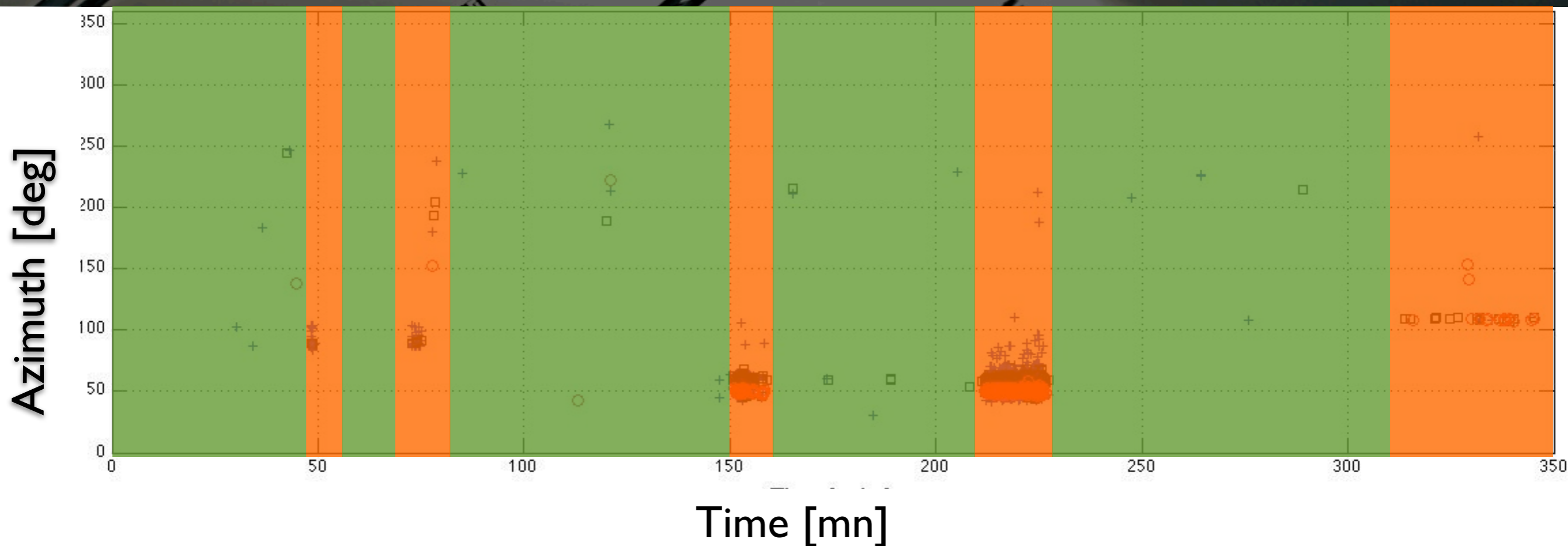
- Select quiet periods ($< 3 \text{ evts}/3 \text{ mins}$)
- 69% of 6-antennas prototype data (403h)



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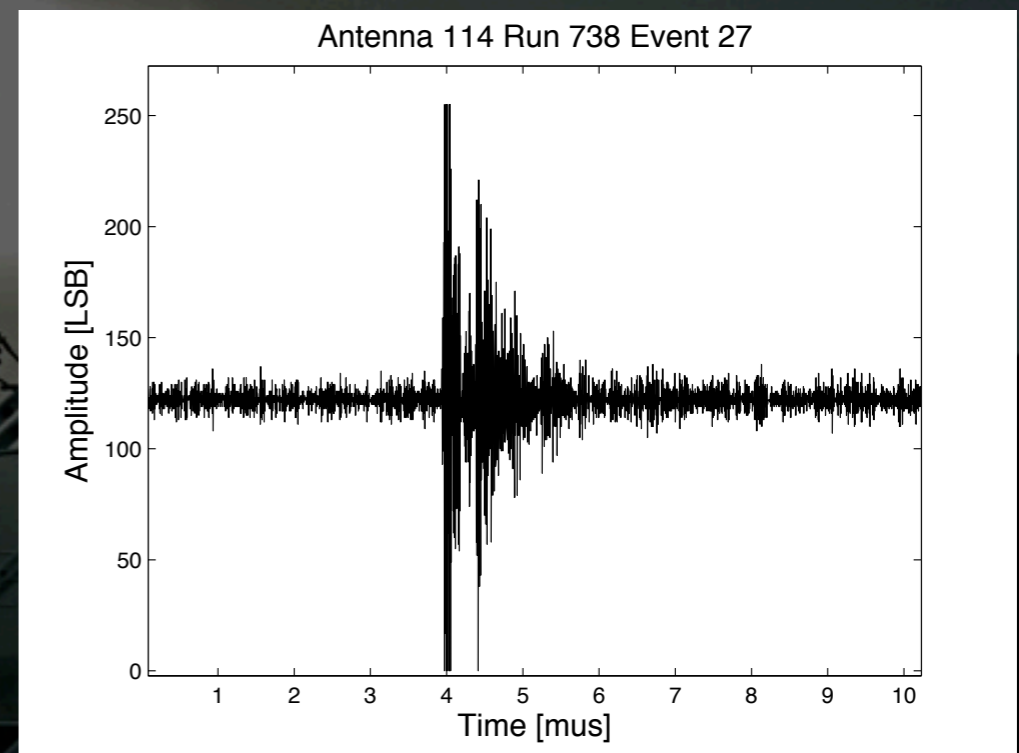
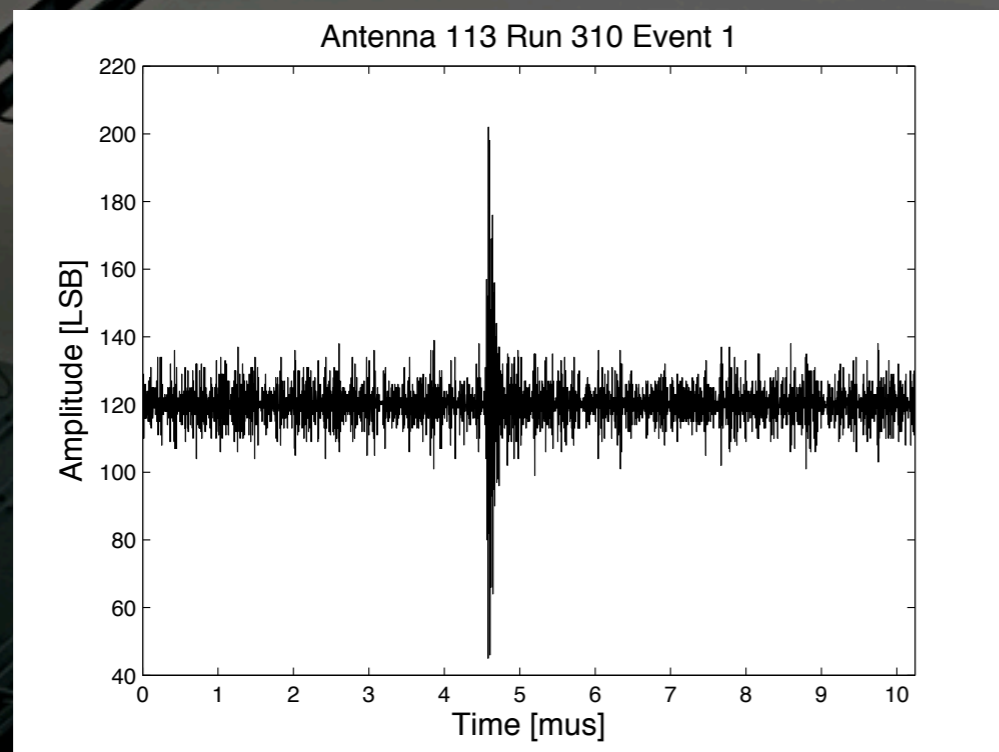
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Analysis cuts (2)

Pulse shape selection

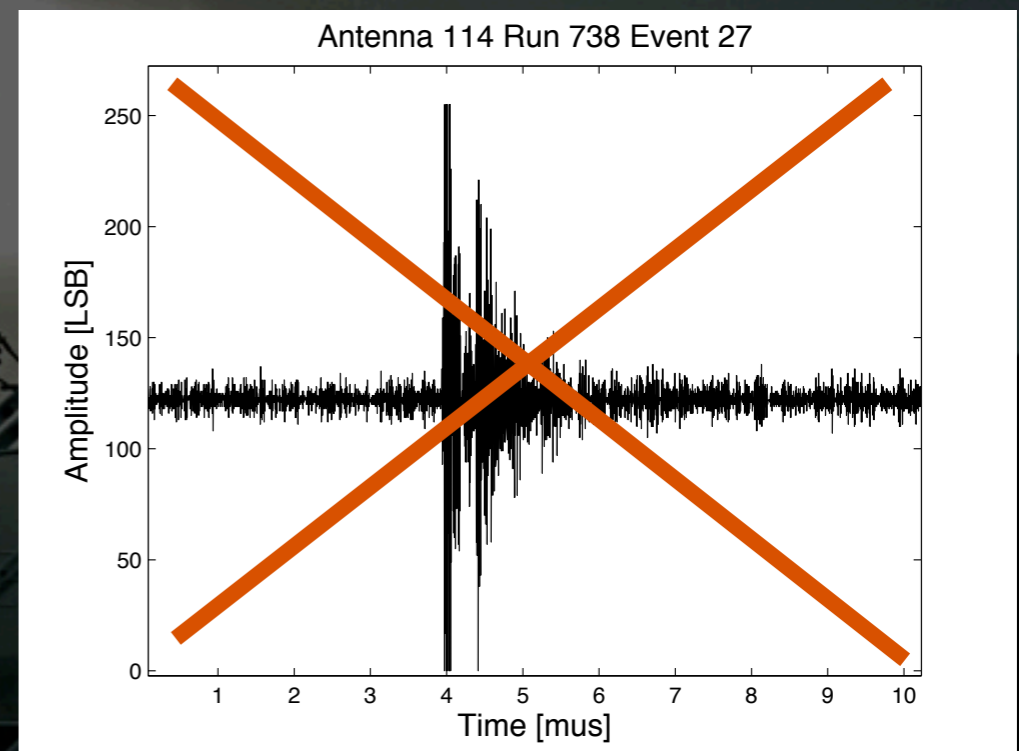
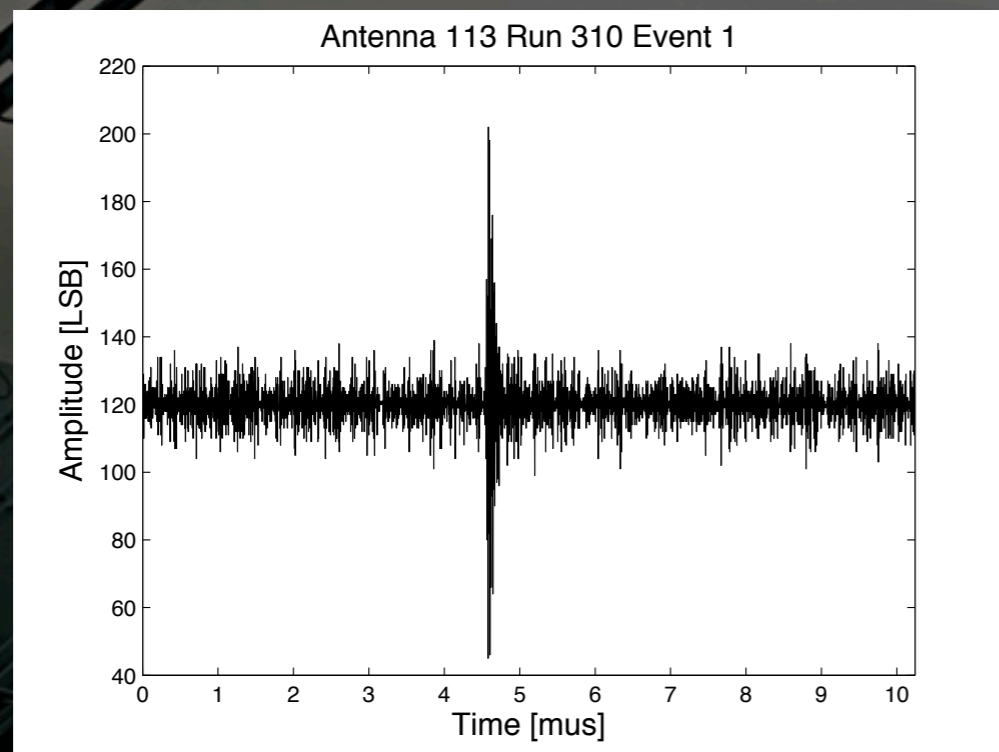
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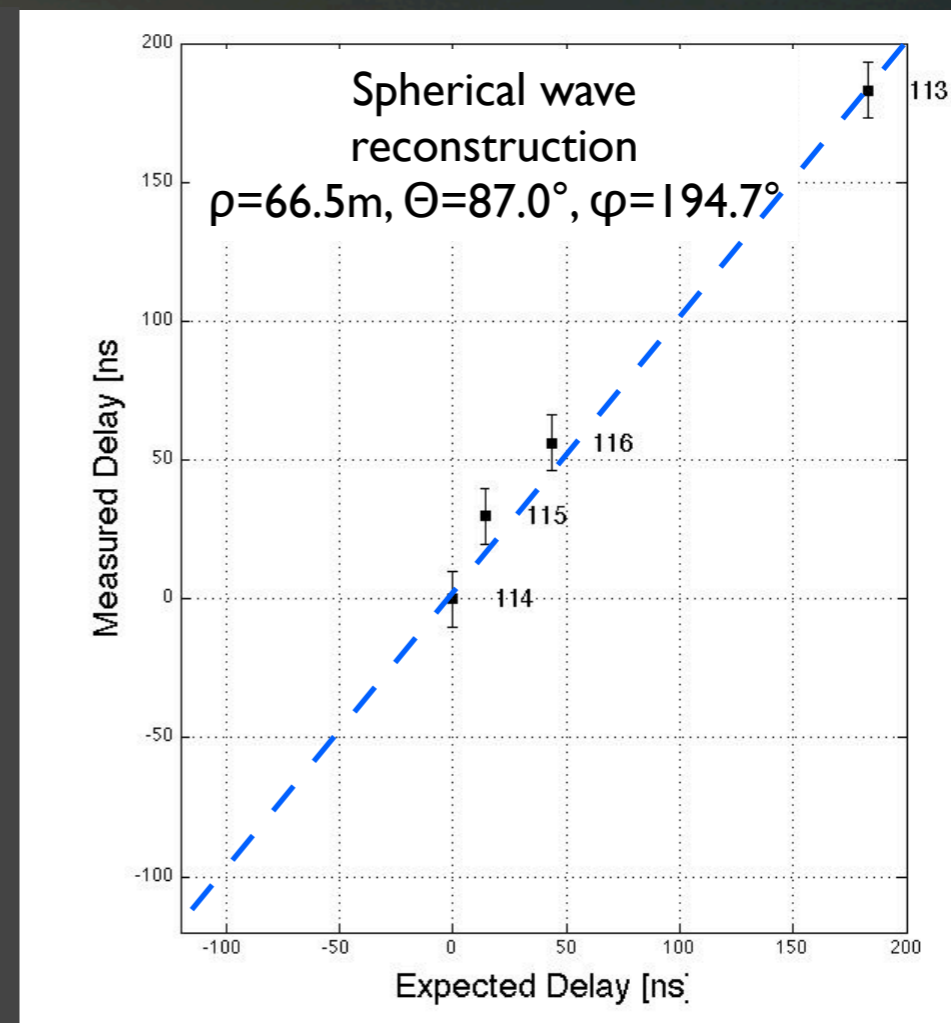


Pulses longer than 400 ns are rejected.

Analysis cuts (3)

Reconstruction quality

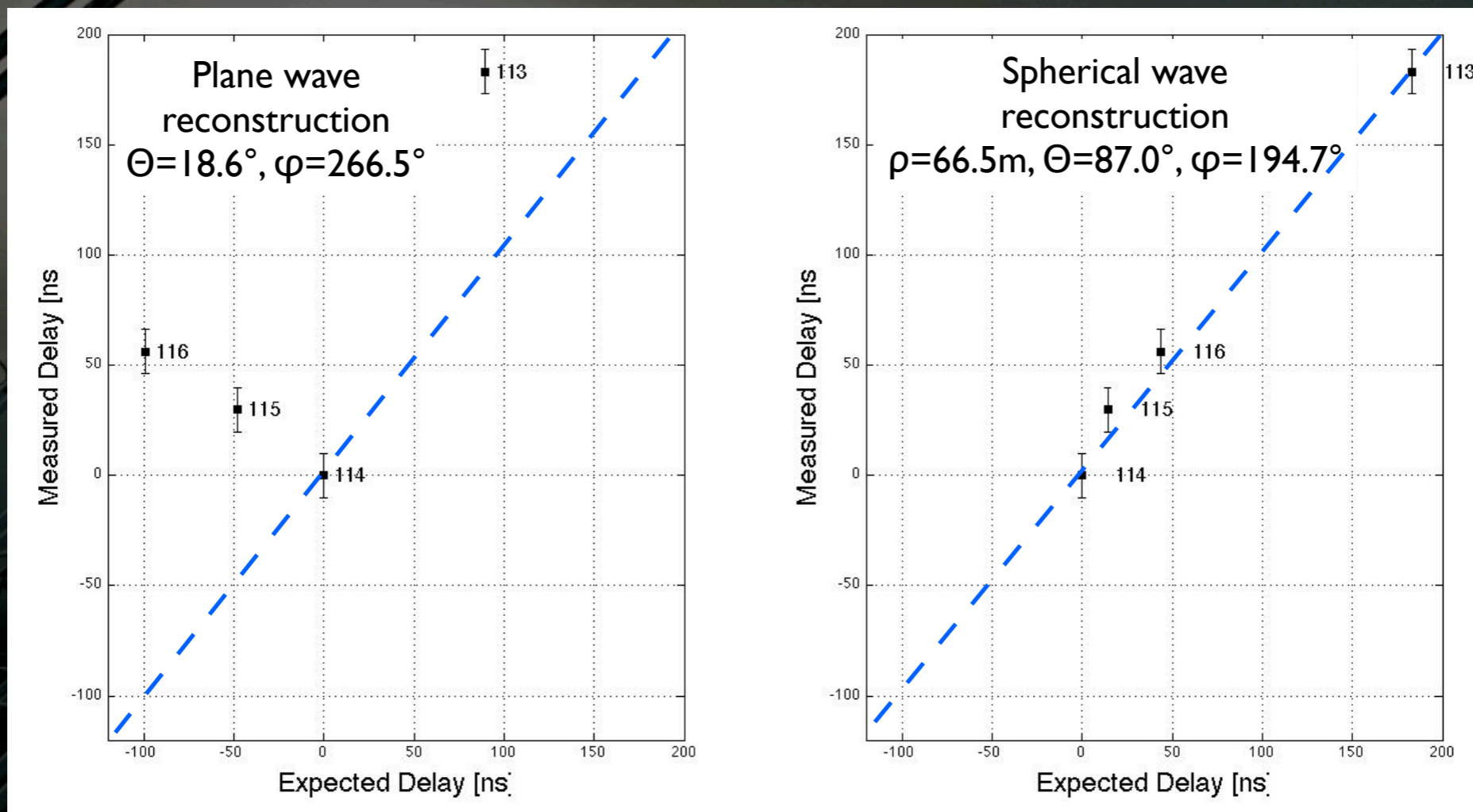
- Delay plots: measured trigger times vs values expected from reconstruction. Points should lie along 1st bissectrix.



Analysis cuts (3)

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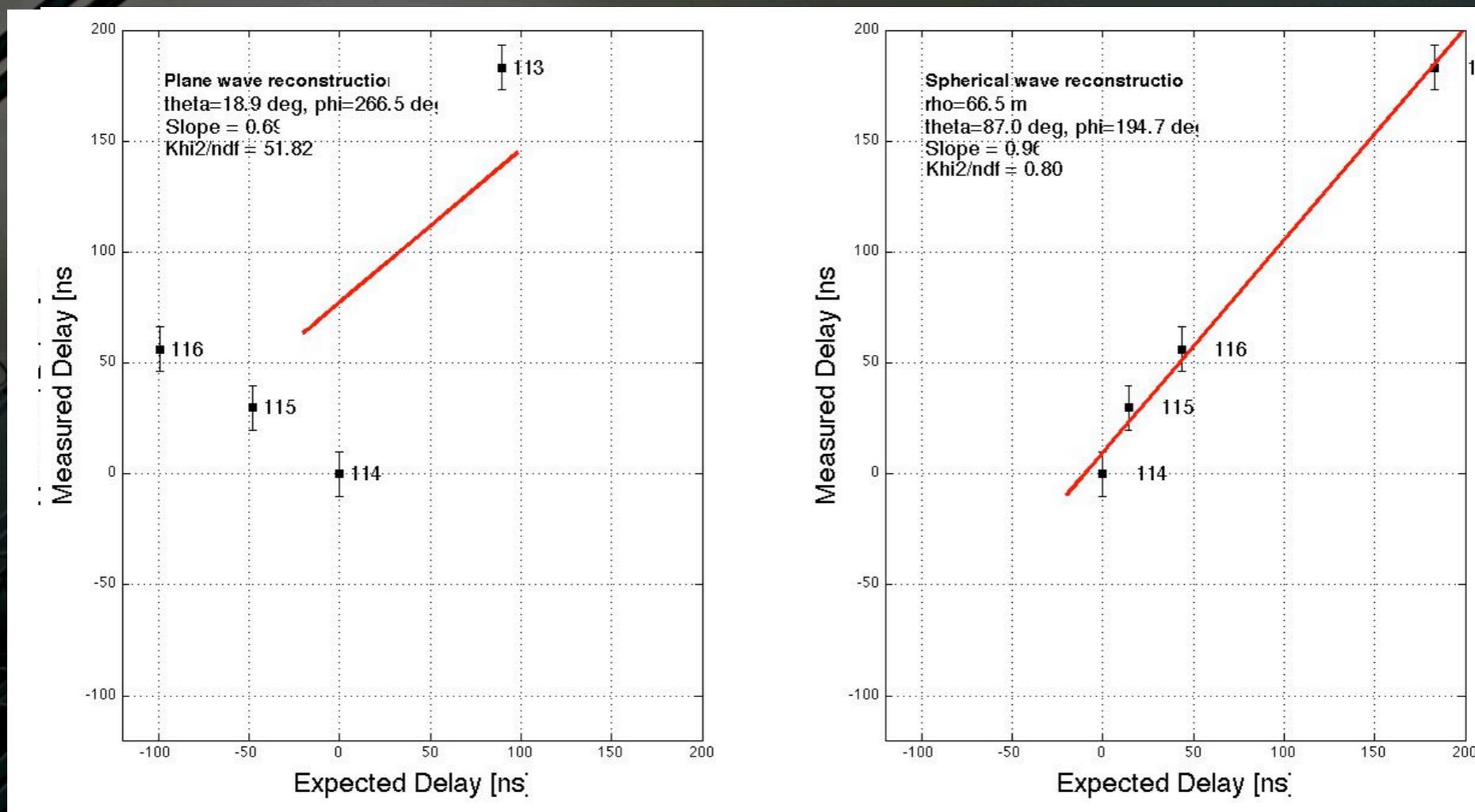
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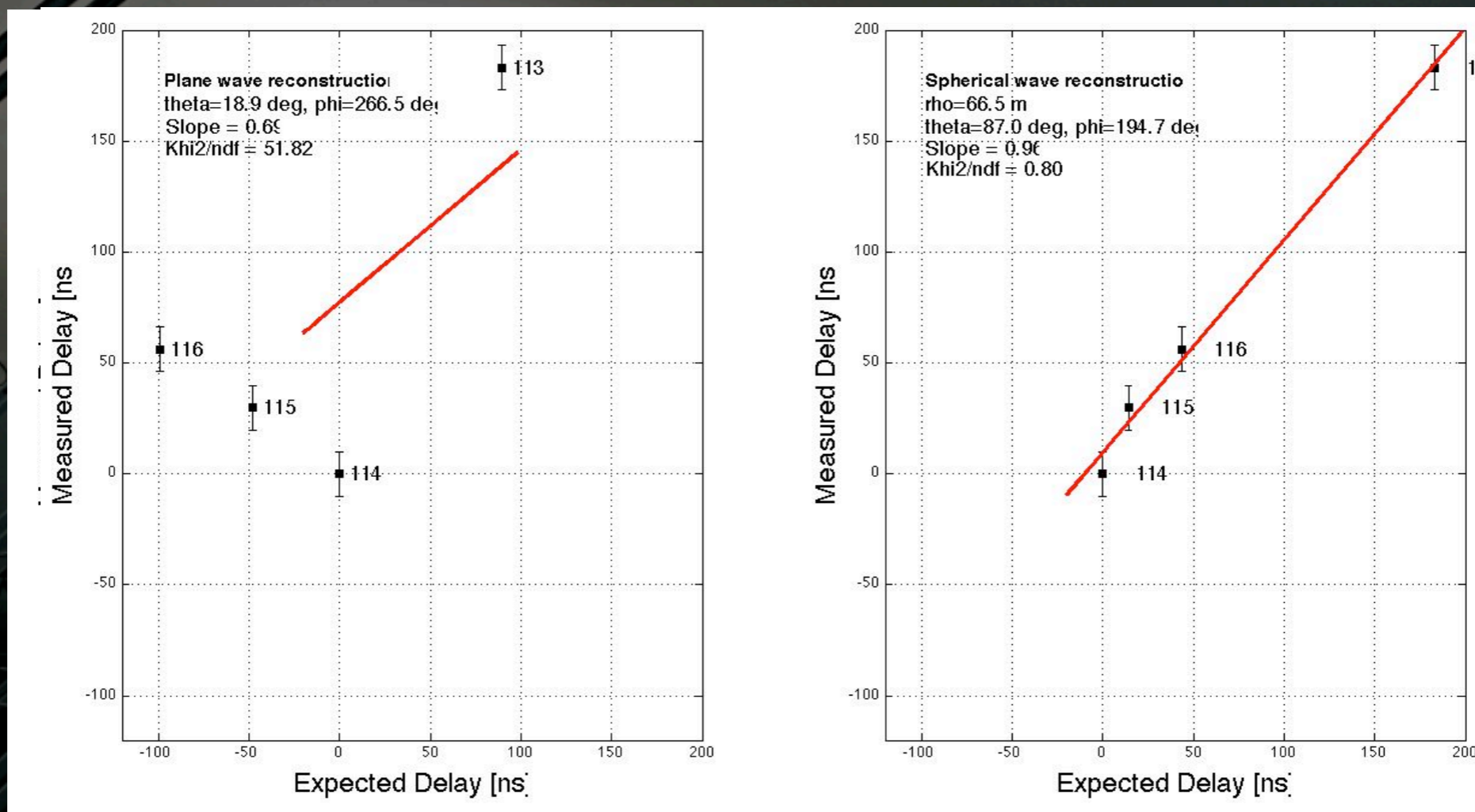


- χ^2 of linear fit provides a quantitative evaluation of the reconstruction quality

Analysis cuts (3)

Reconstruction quality

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- χ^2 of linear fit provides a quantitative evaluation of the reconstruction quality $\rightarrow \chi^2/ndf < 5$

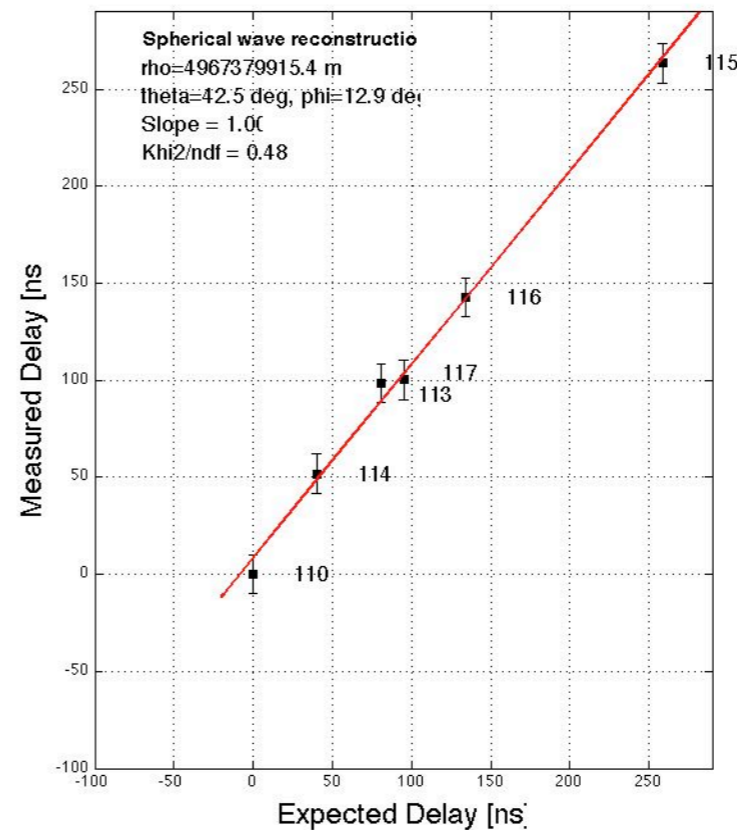
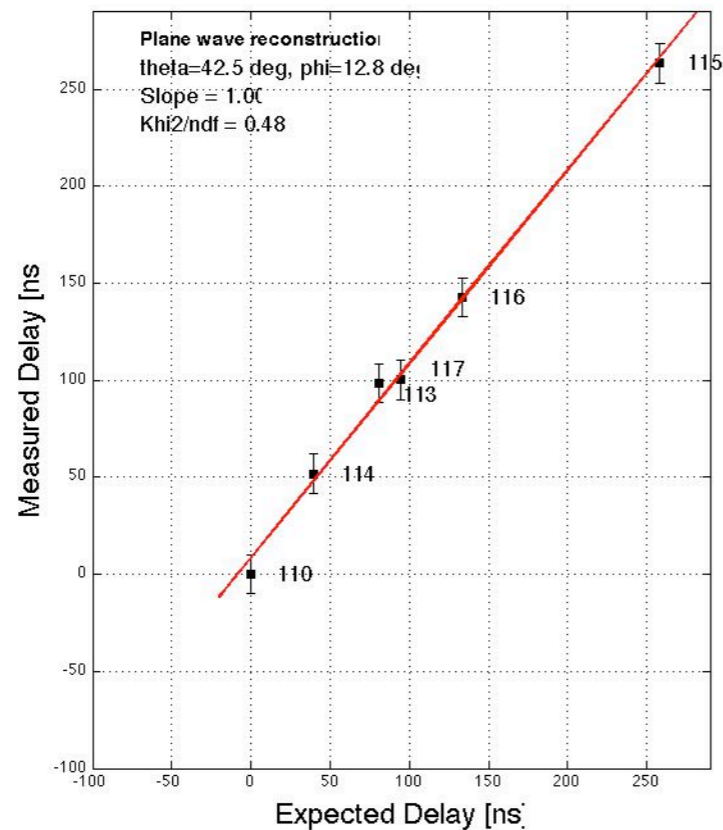
Analysis cuts (4)

Plane wave front

- Spherical & plane reconstruction should yield similar results

$$\Delta\theta^2 + \Delta\varphi^2 < d^2$$

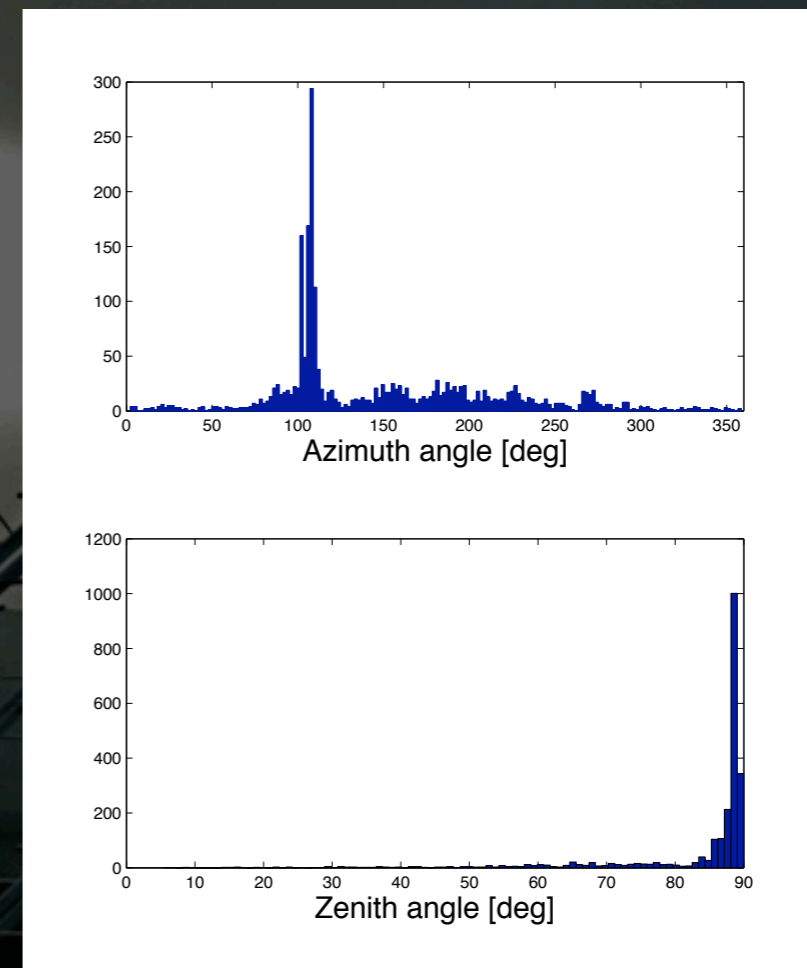
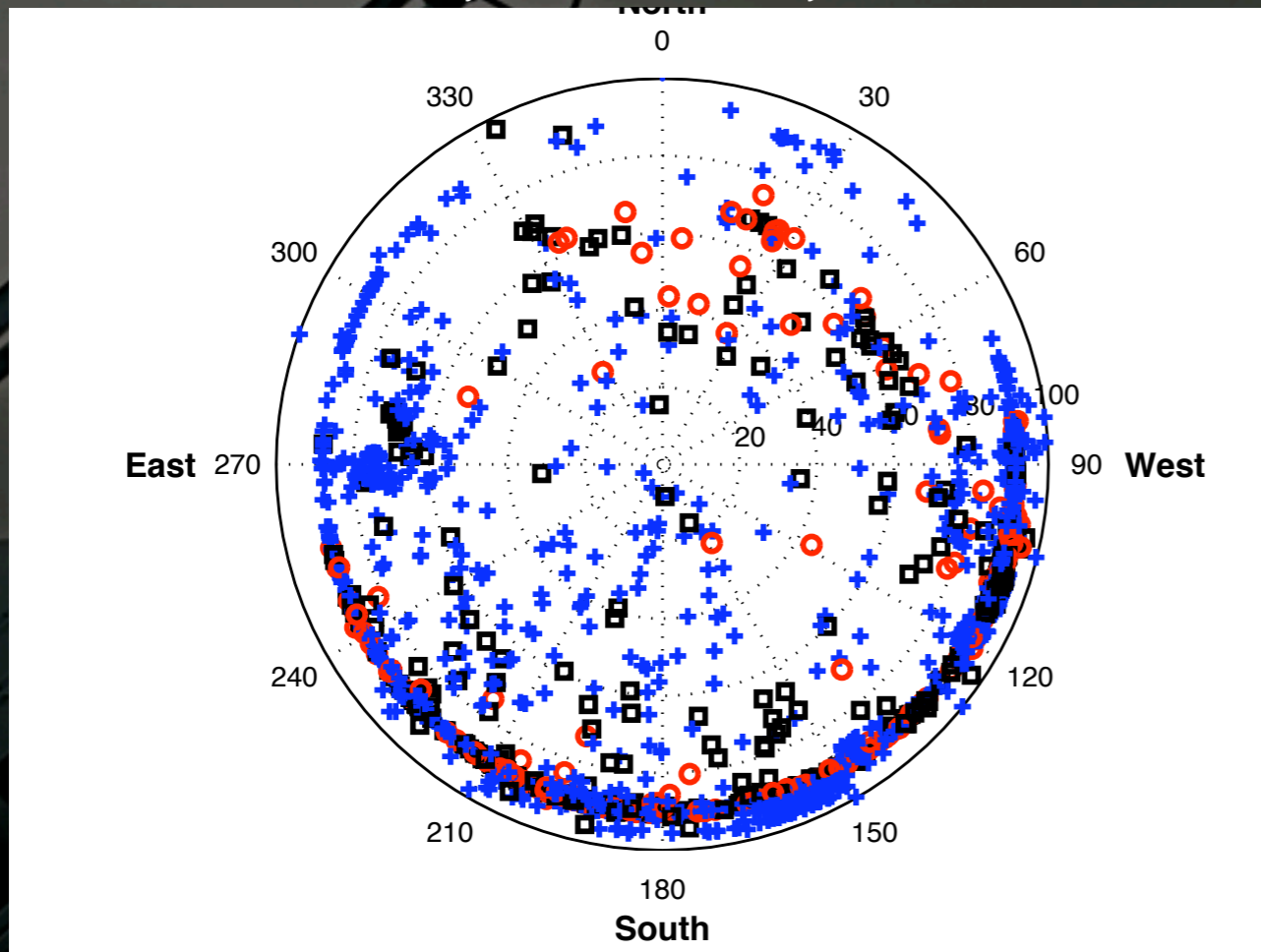
$d=10^\circ, 7^\circ, 4^\circ$ for multiplicity 4,5,6



Analysis cut (5)

Sky events

- 6-antenna prototype data : 2275 events survive cut 1

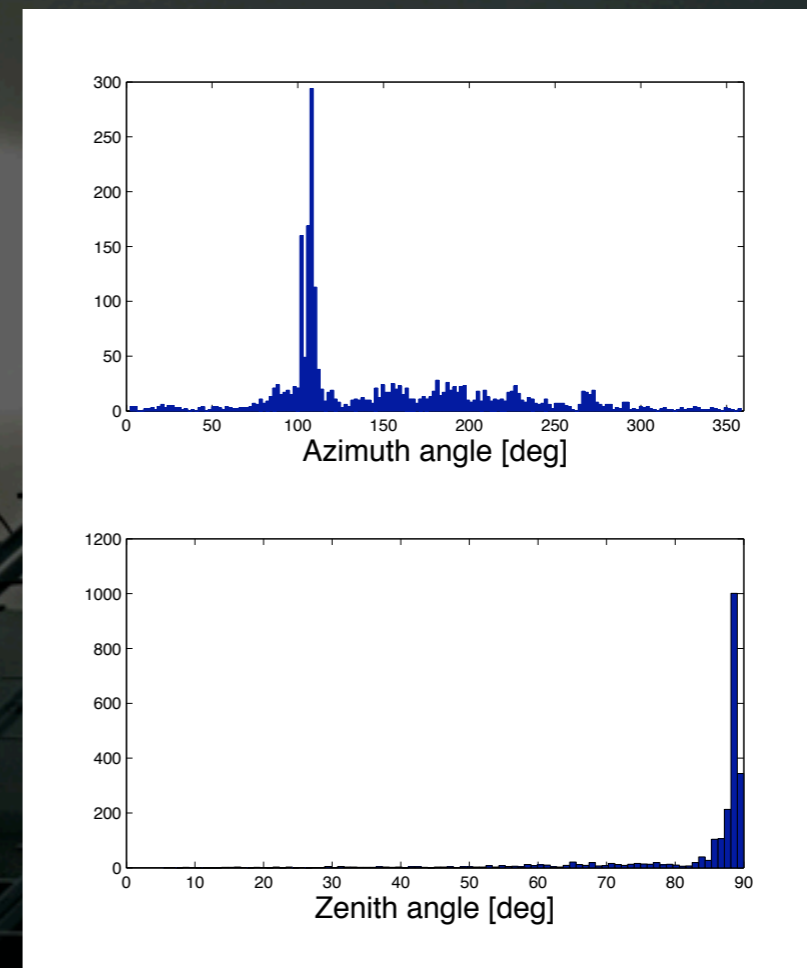
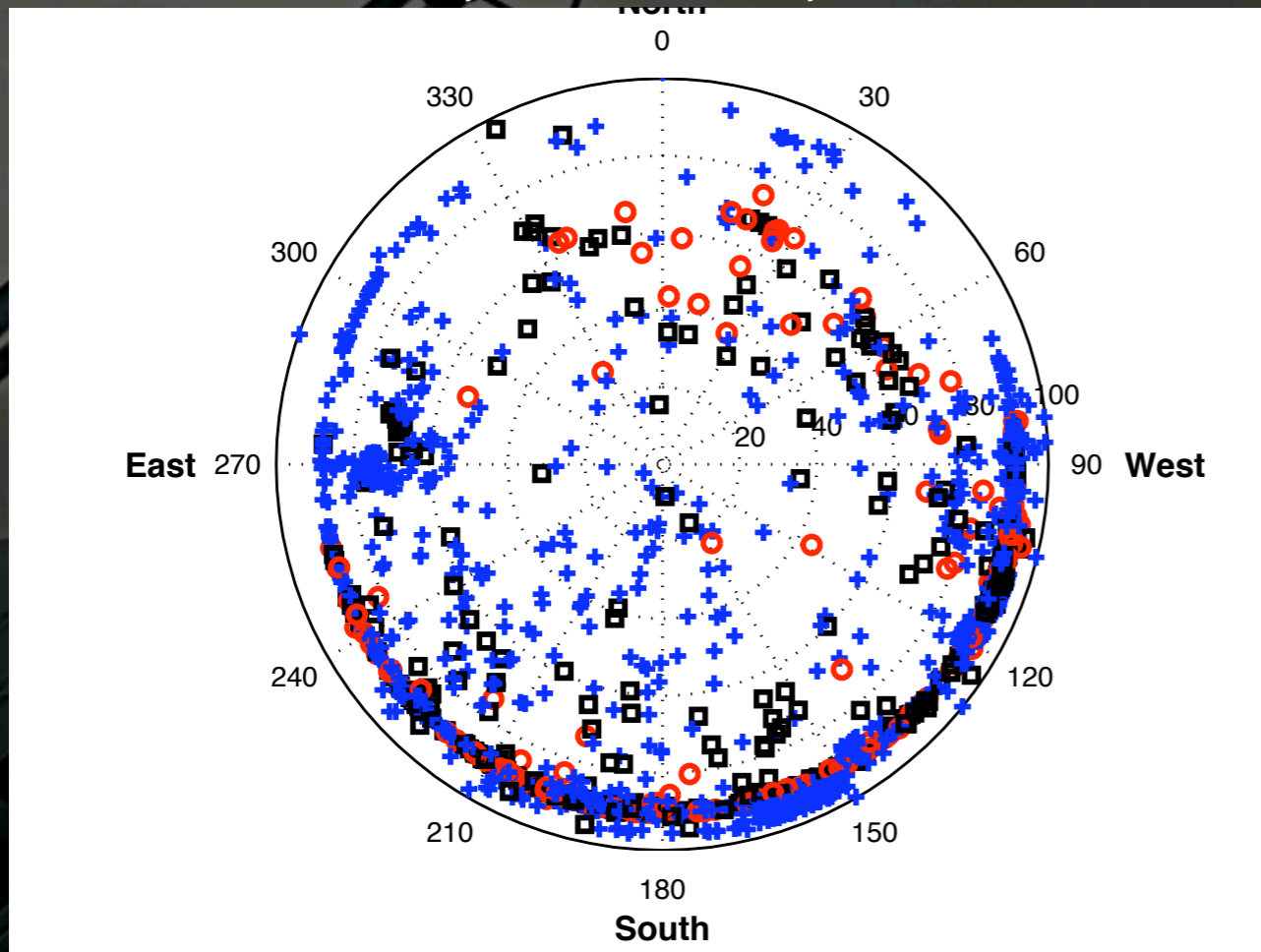


- $>95\%$ below 85° , mostly towards South.

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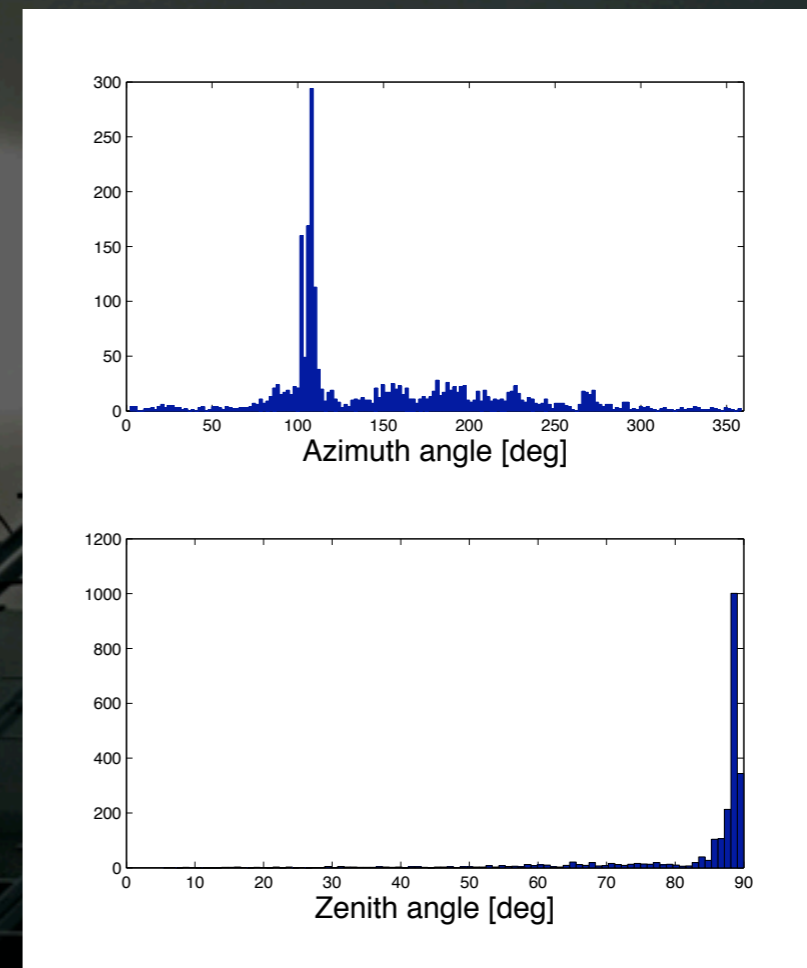
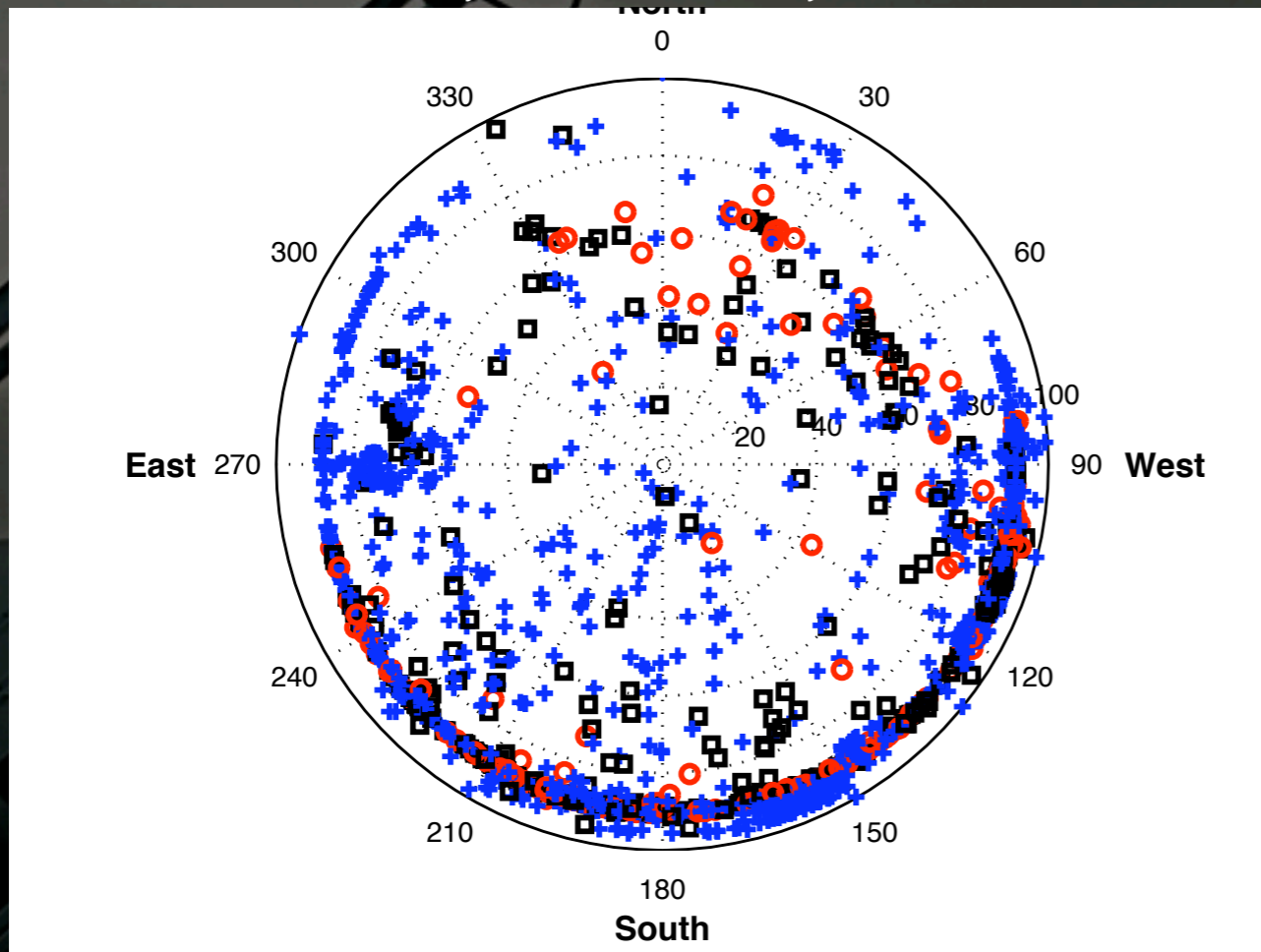


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Signal/Noise ratio increases when moving towards zenith

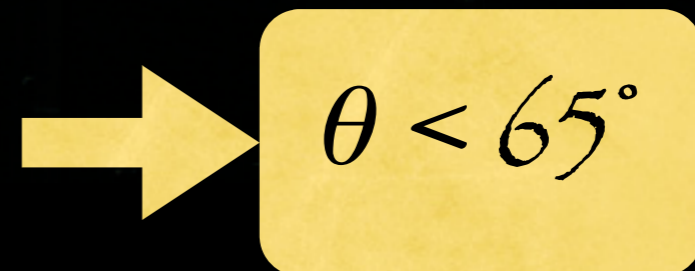
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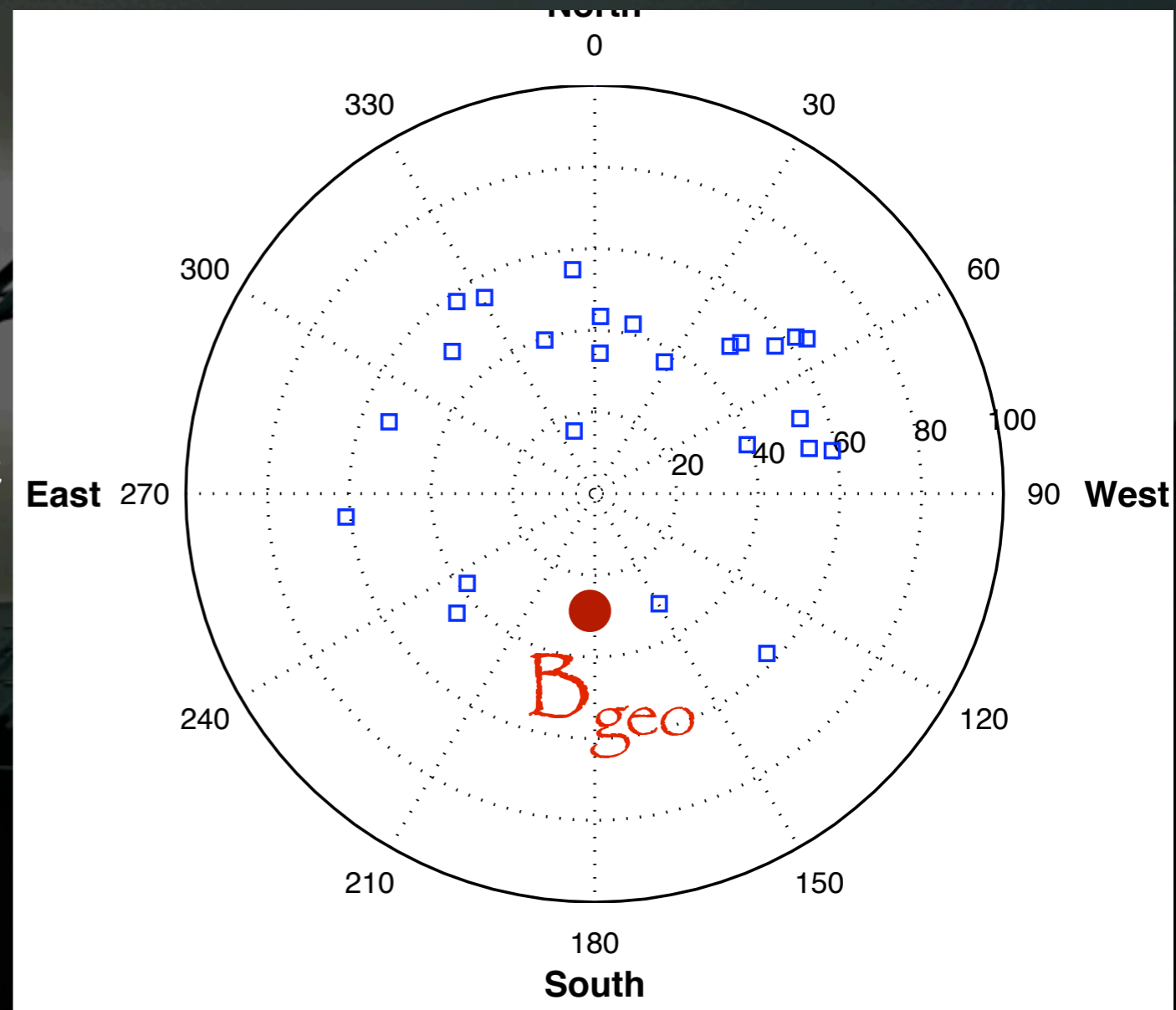


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CR candidates

- 25 candidates pass all cuts and are totally isolated in time & space from other events.



Shower profile reconstruction

- Array of limited size (200m at most)
- Limited number of antennas (6 at most)

→ No completely significant shower profile reconstruction can be performed yet

$$A = A_0 \exp(-d/d_0)$$

$d_0 = 158\text{m}$

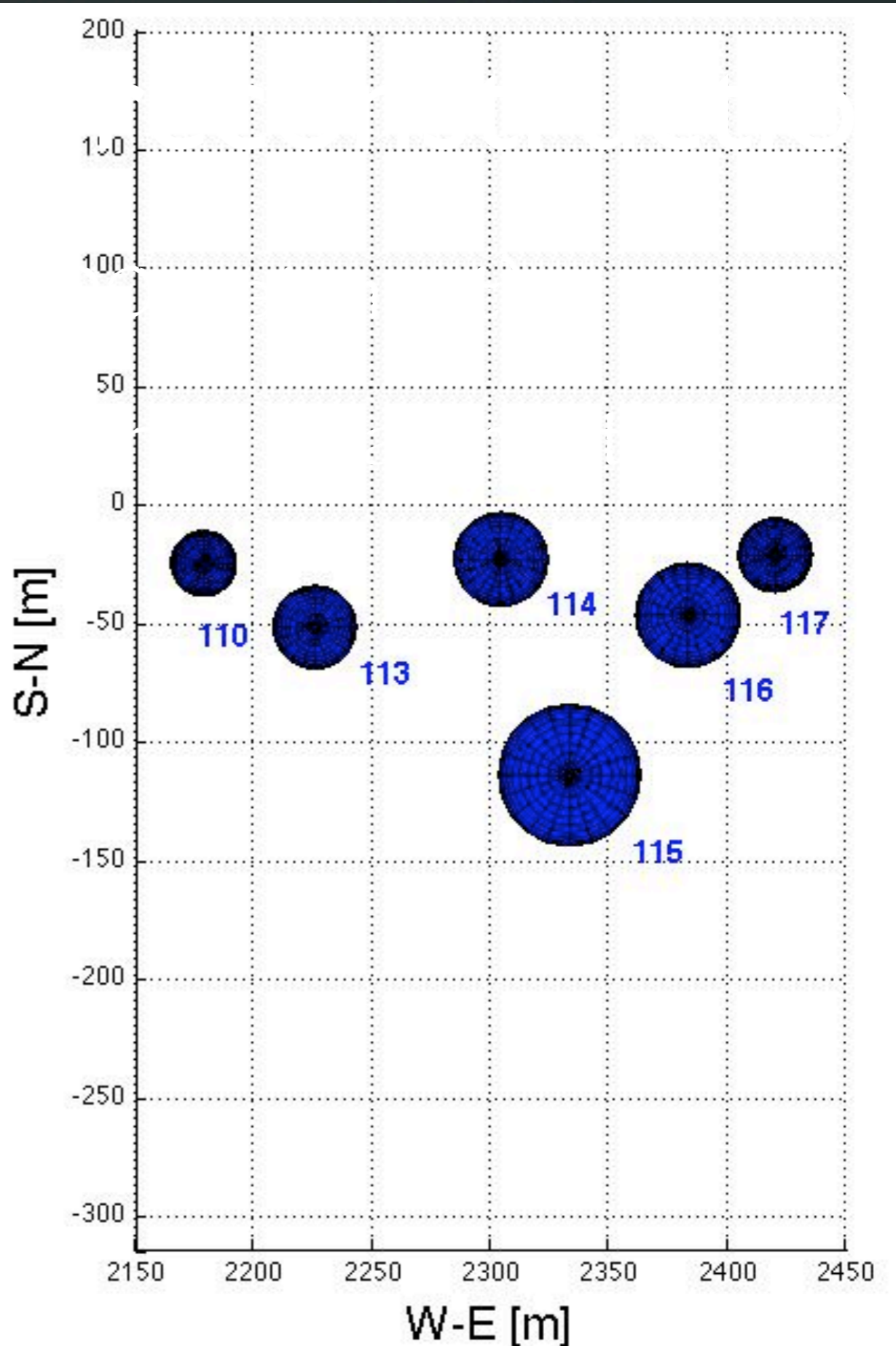
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Still, some nice reconstructions...

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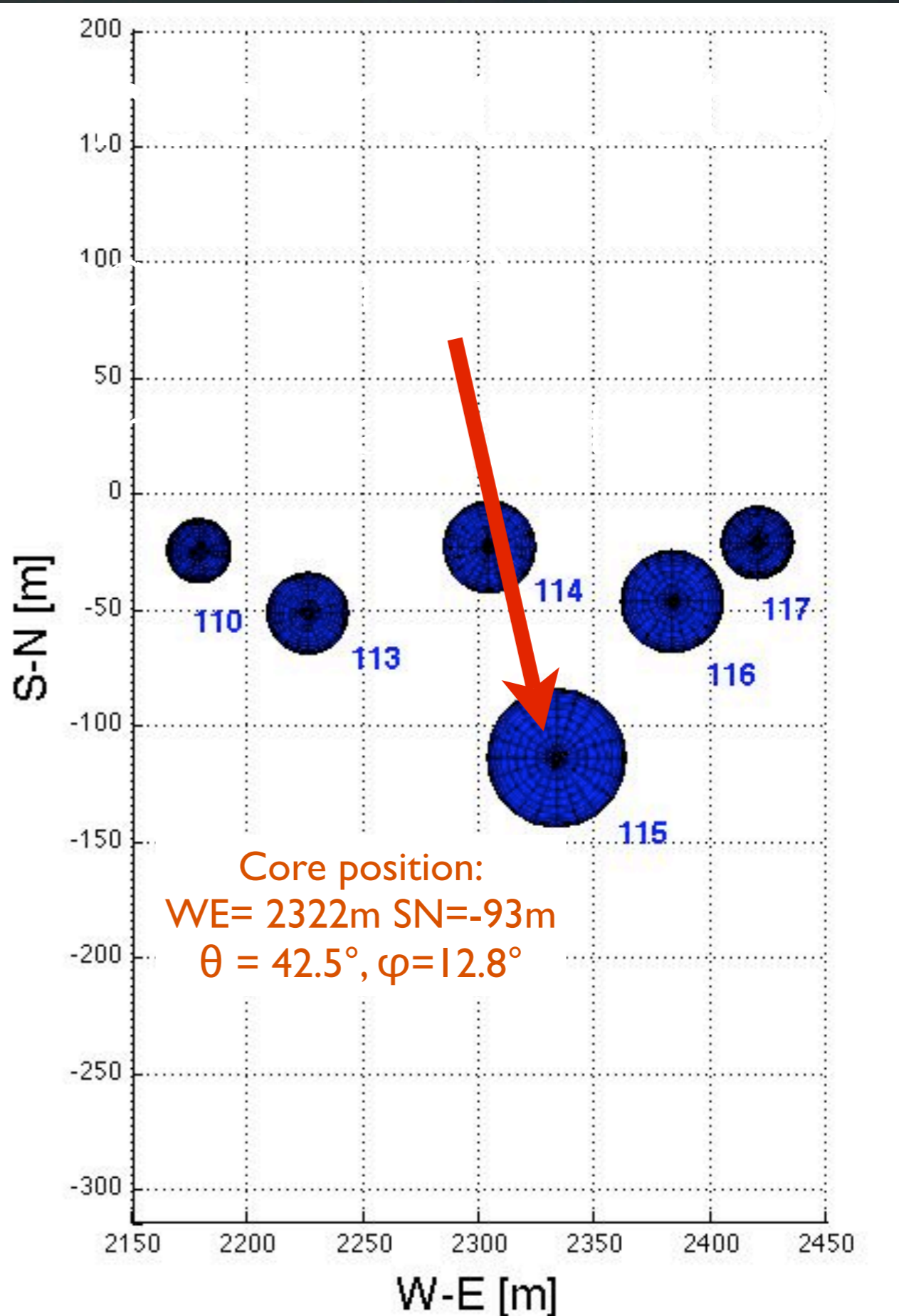
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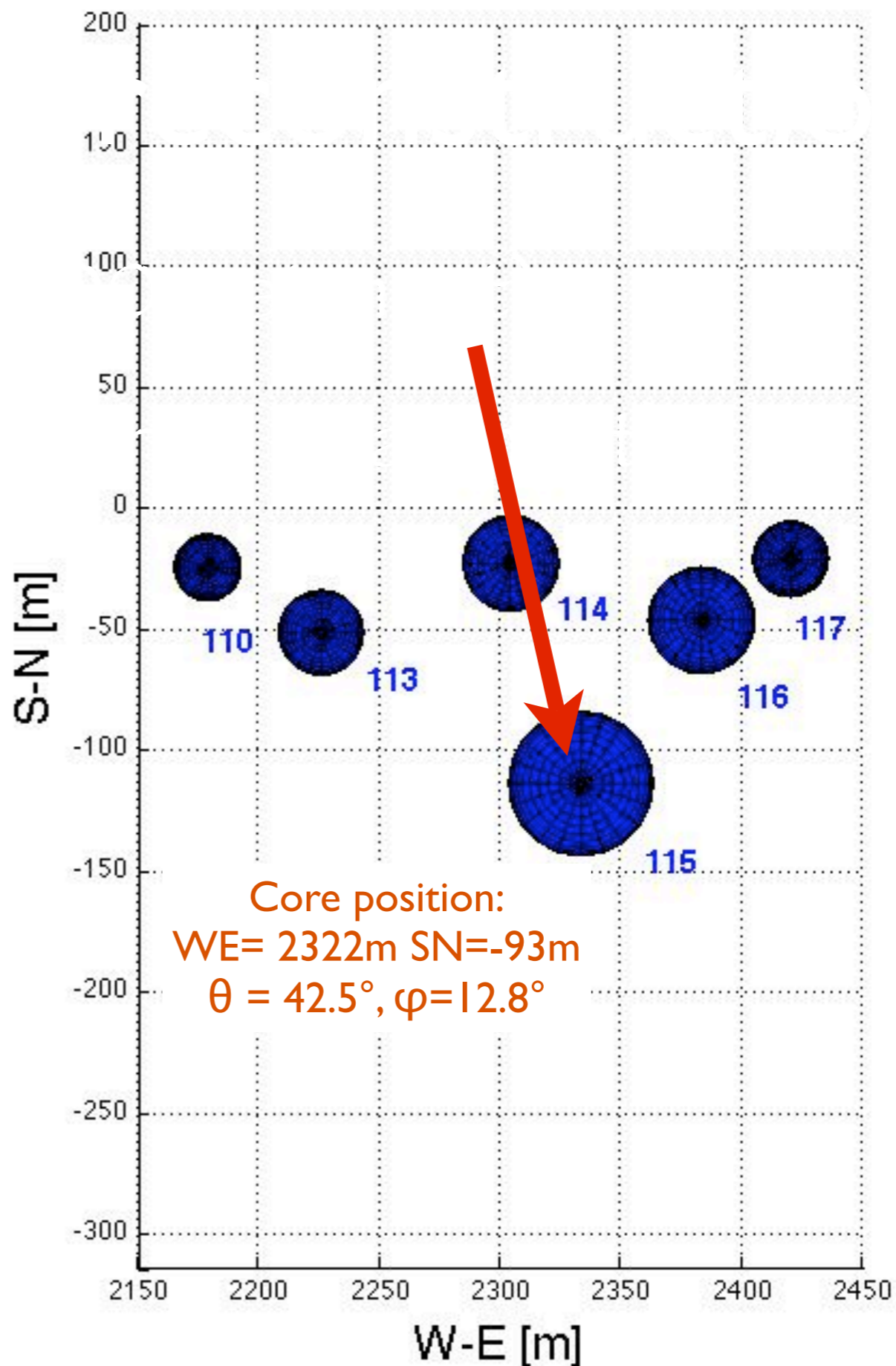
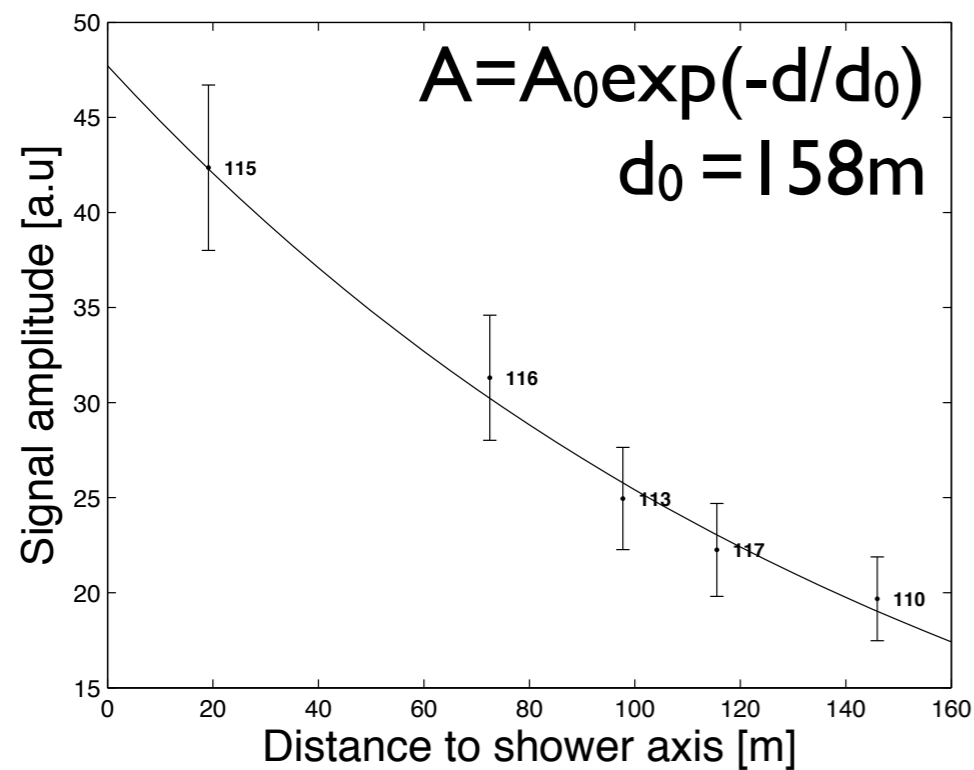
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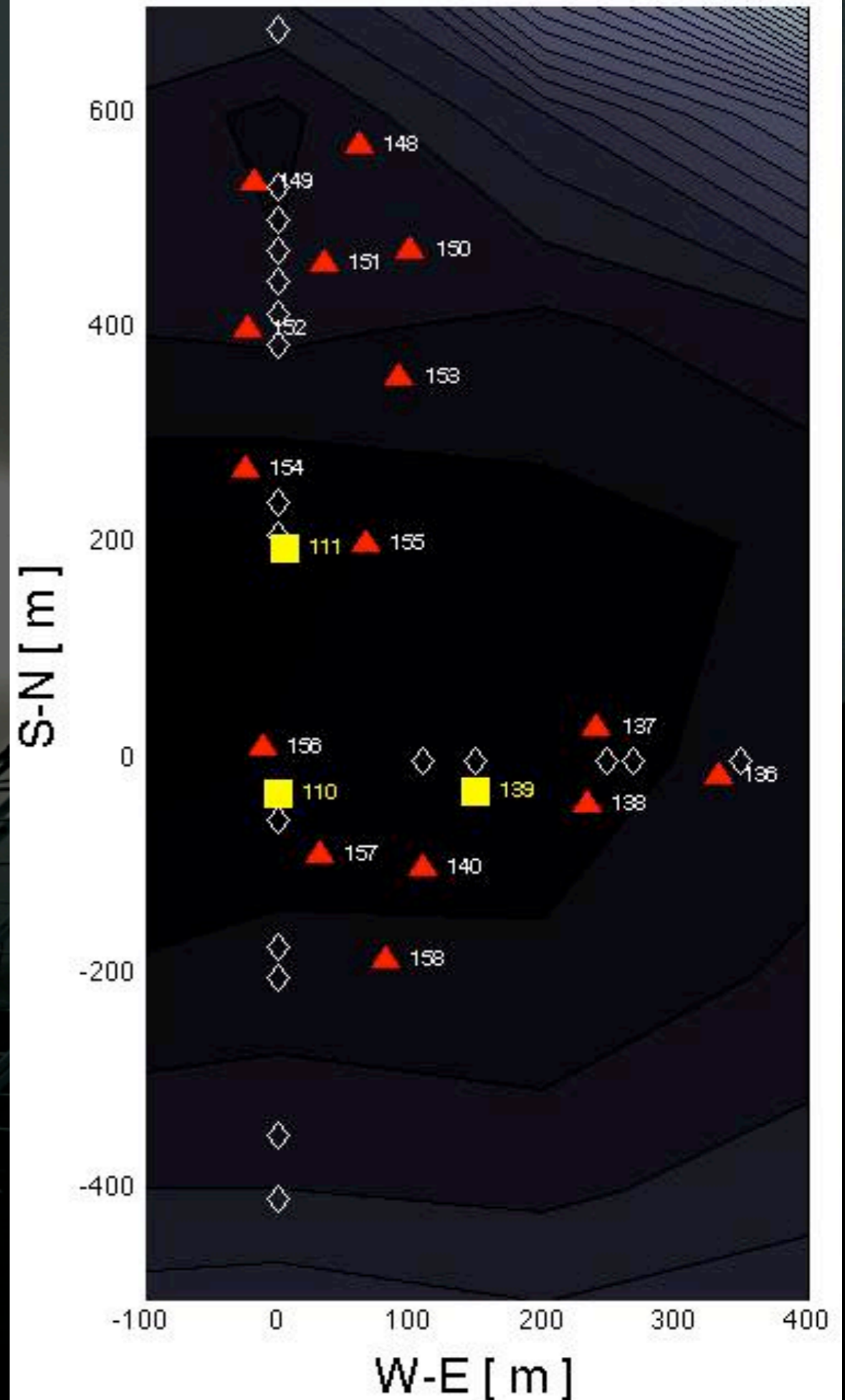
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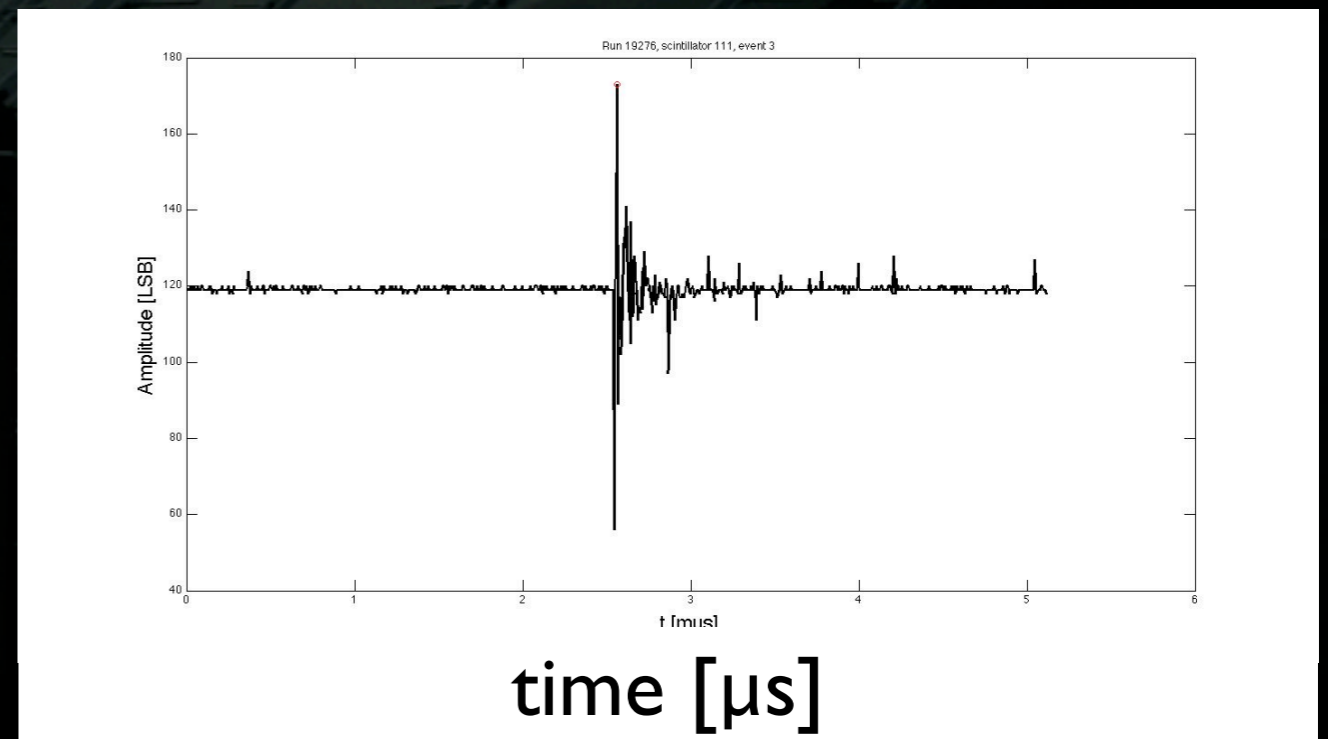
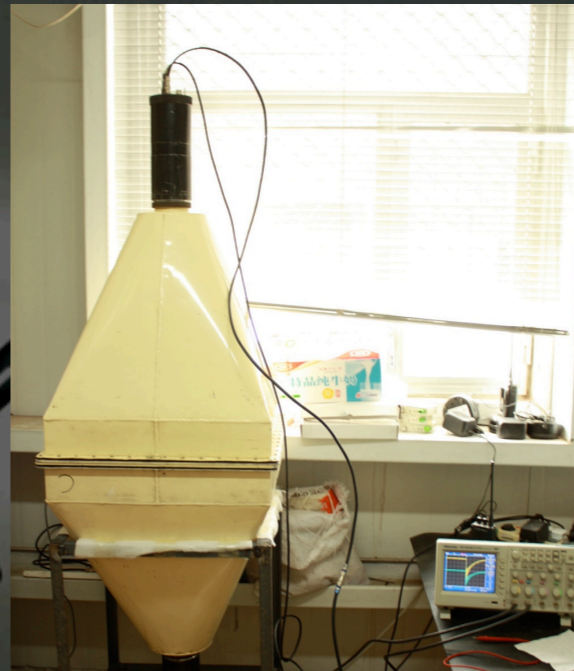
CR candidates validation

- 15 antennas array set up in January 2010 at the cross-point of the 2 baselines.
- 3 scintillators in coincidence.



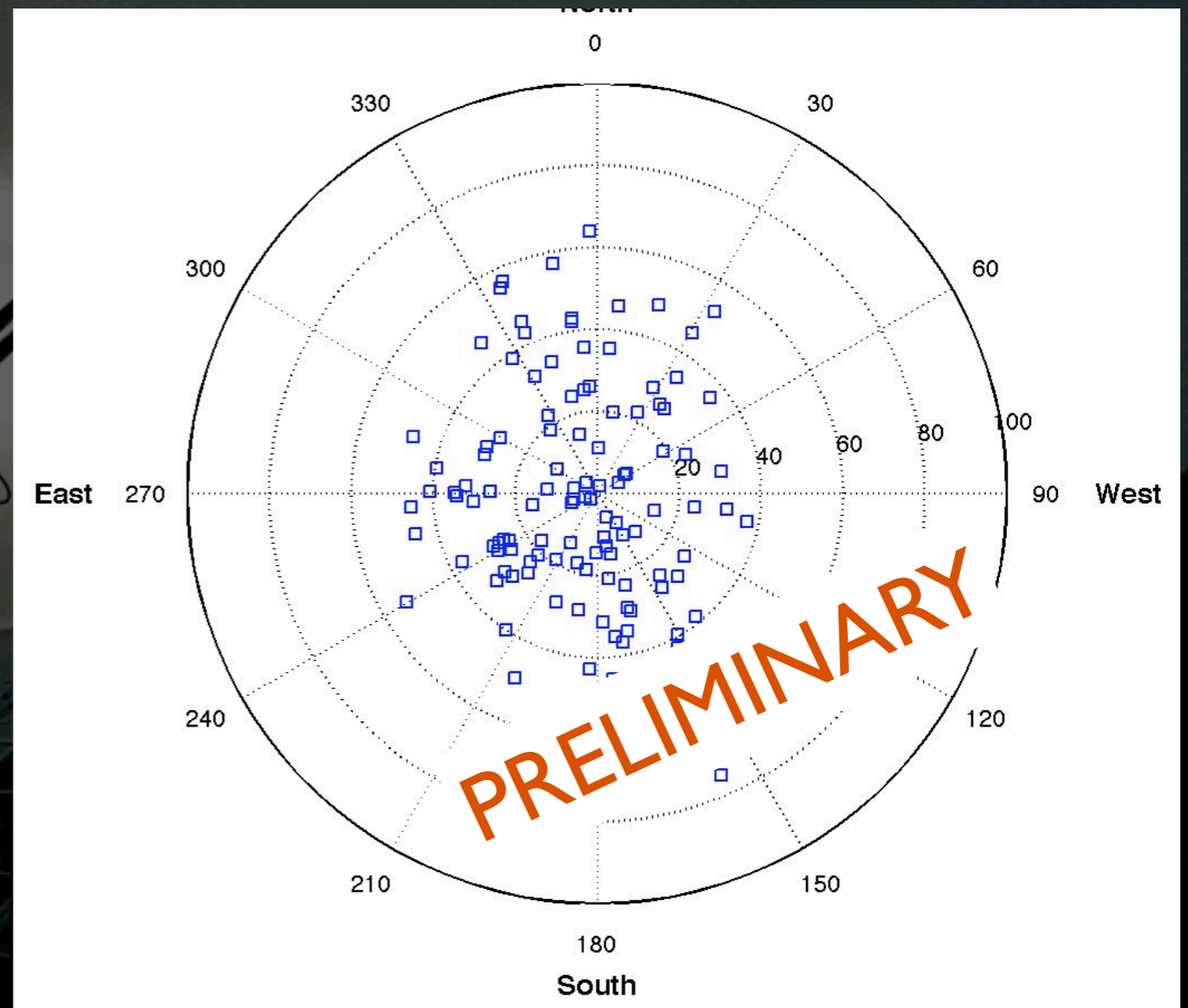
Scintillator array

- 50cmx50cmx2cm plastic scintillator + PMT
- PMT signal directly fed into optical transmitter (20-200MHz)
- Independent trigger for all detectors
- Scintillator threshold set for ~25Hz individual trigger rate.



Scintillator data

- 117 3-fold coincidences in 8 live days.
- 3-fold coincidence rate: 0.6/hour
- Expected random coincidence rate is negligible.



The 3-scintillators array is a valid CR detector.

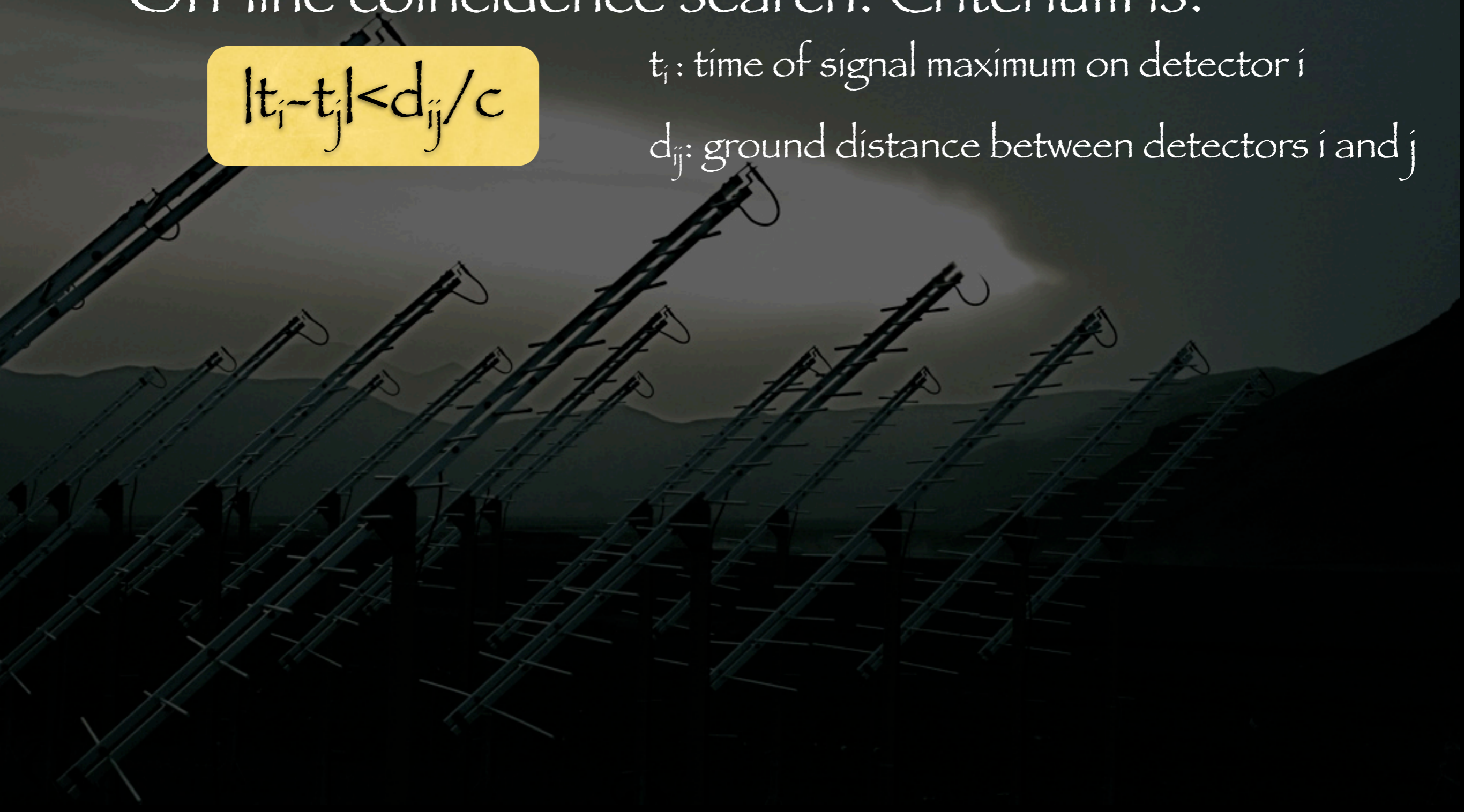
Hybrid data analysis

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$$|t_i - t_j| < d_{ij}/c$$

t_i : time of signal maximum on detector i

d_{ij} : ground distance between detectors i and j



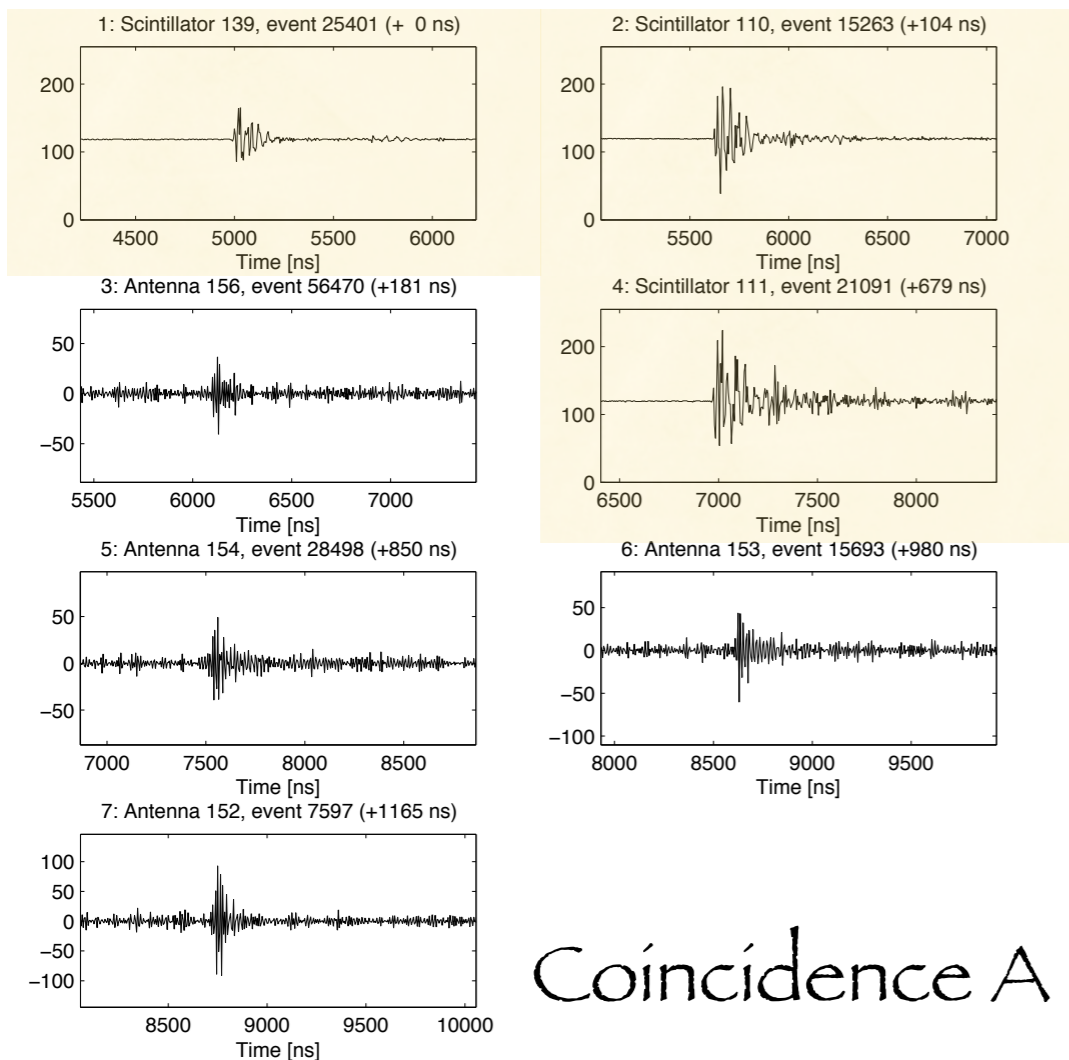
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Coincidence A

- 8 live days of data:
 - ~ 2 hybrid coincidences with 4 antennas + 3 scintis
 - ~ 1 with 4 antennas + 2 scintis

Hybrid coincidences

- Random coincidence?

- ~ Expected rate for 2 independent events given by:

$$f_{\text{rdm}} = 2 * f_A * f_B / (f_A + f_B) * (1 - \exp(-(f_A + f_B) \Delta t)) \text{ Hz}$$

Δt : time window
 $f_{A,B}$: trigger frequencies for events A&B

- ~ $f_A = 1.6 \cdot 10^{-4} \text{ Hz}$ rate of 3-folds scintillator events

- ~ $f_B < 10 \text{ Hz}$ rate of radio events ($L \geq 4$)

- ~ $\Delta t = 2 \mu\text{s}$

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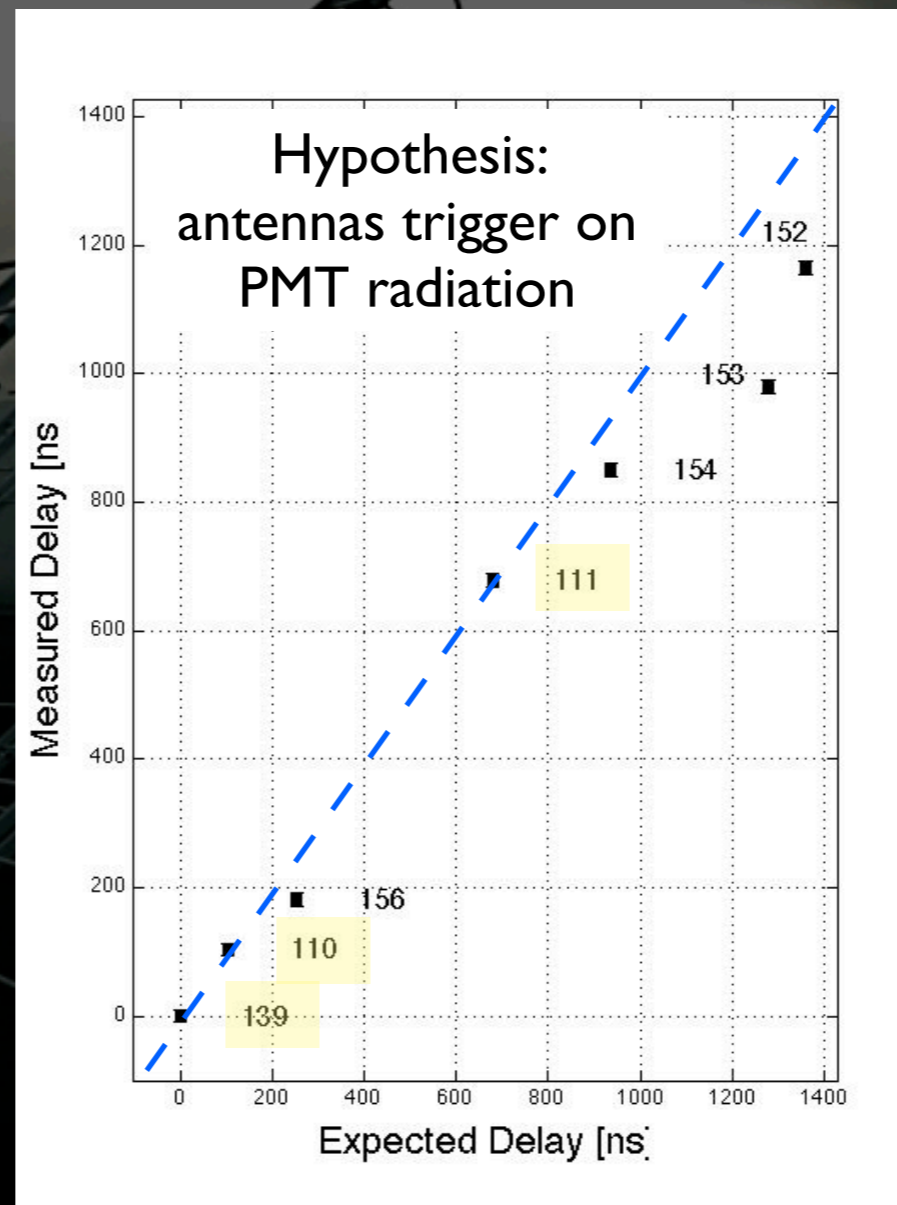
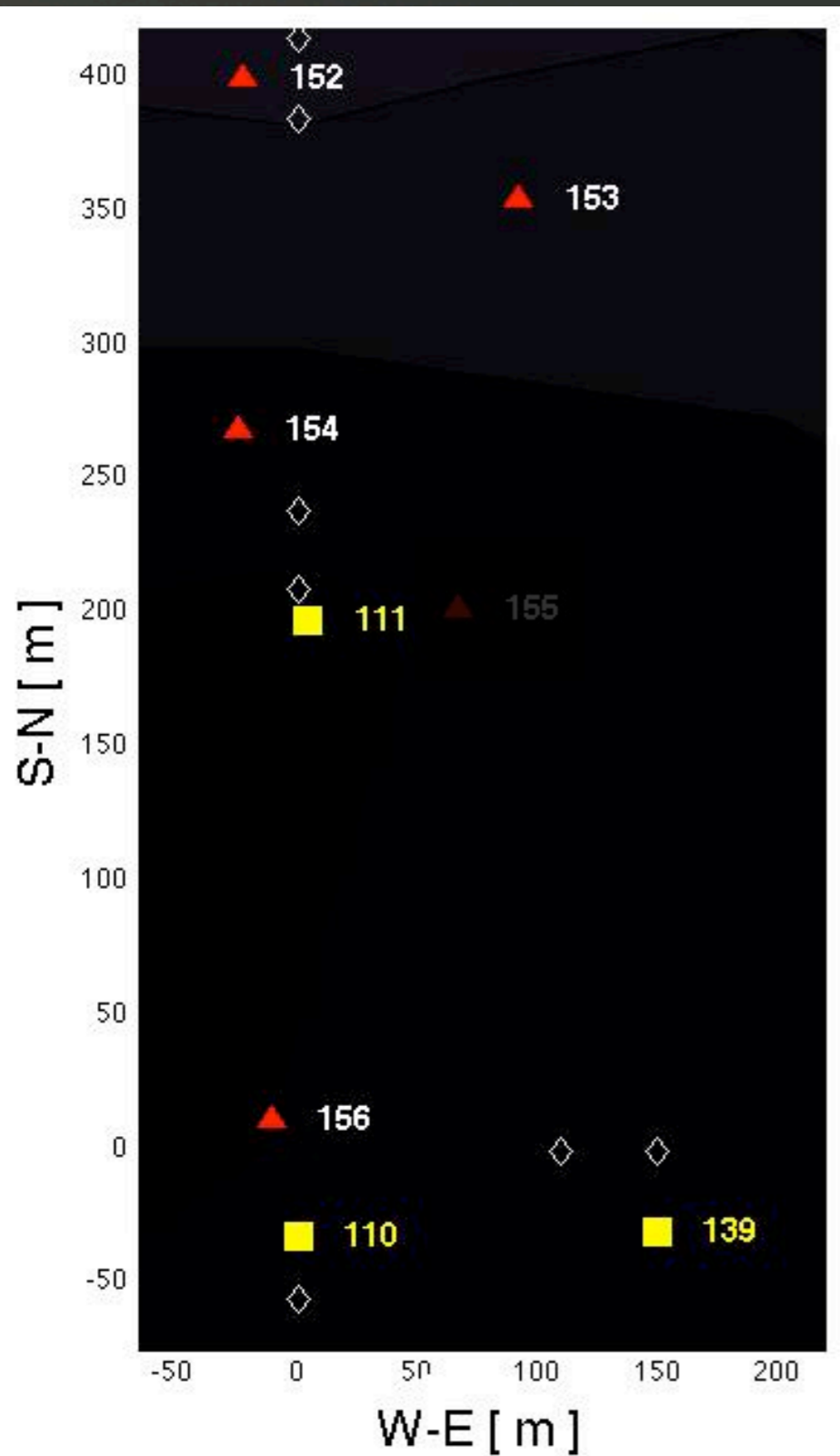
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$$f_{\text{rdm}} = 0.1/\text{year} \dots$$

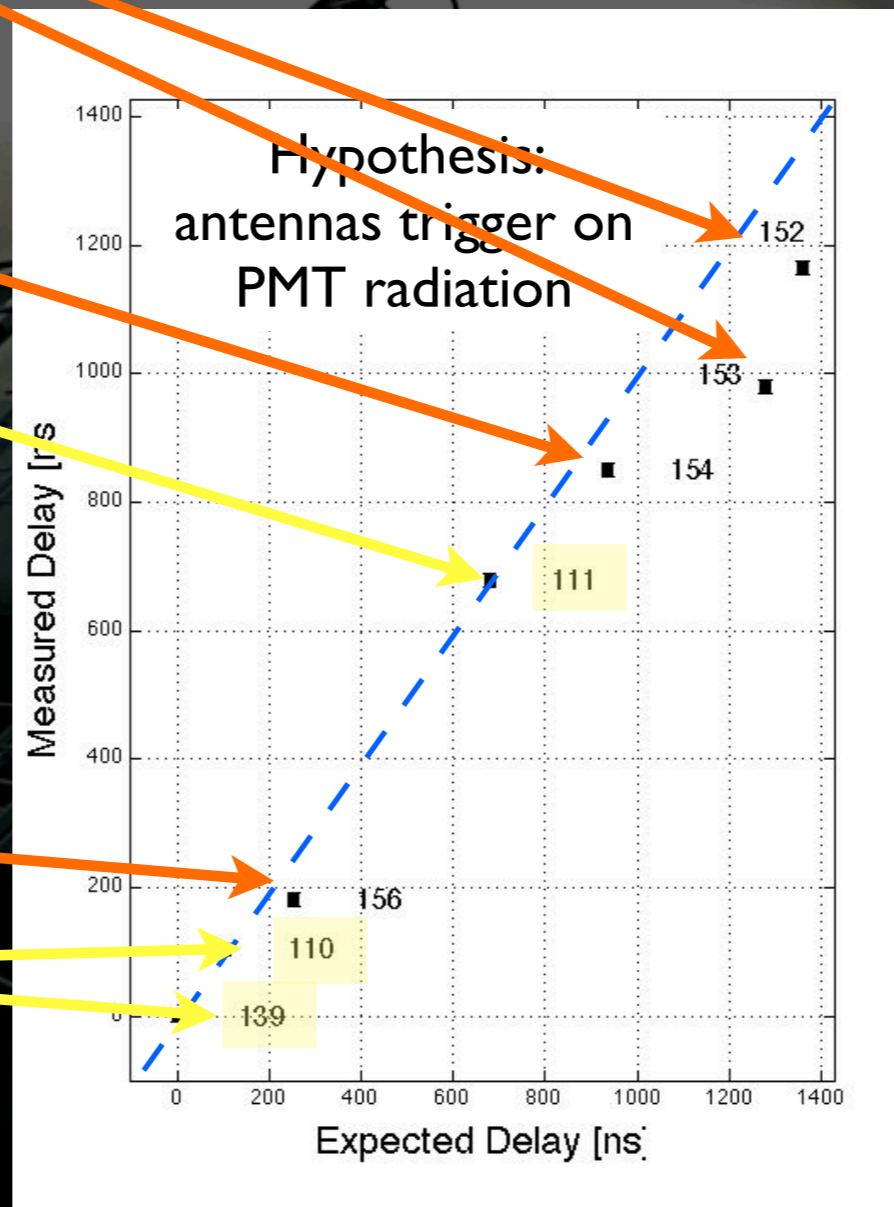
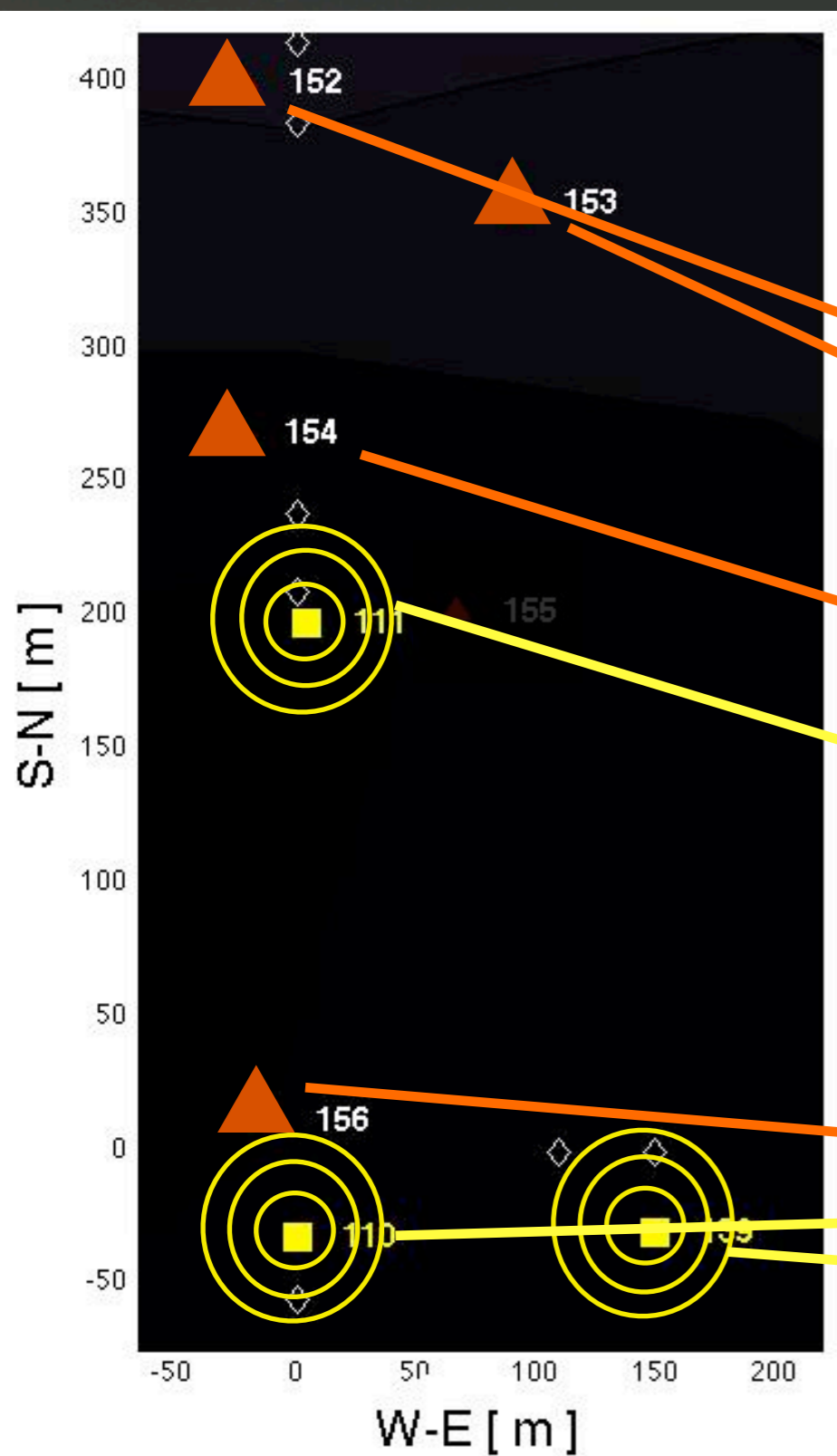
Hybrid coincidences

- Did antennas trigger on a radiation emitted by a scintillator PMT?
- exemple: Coincidence A



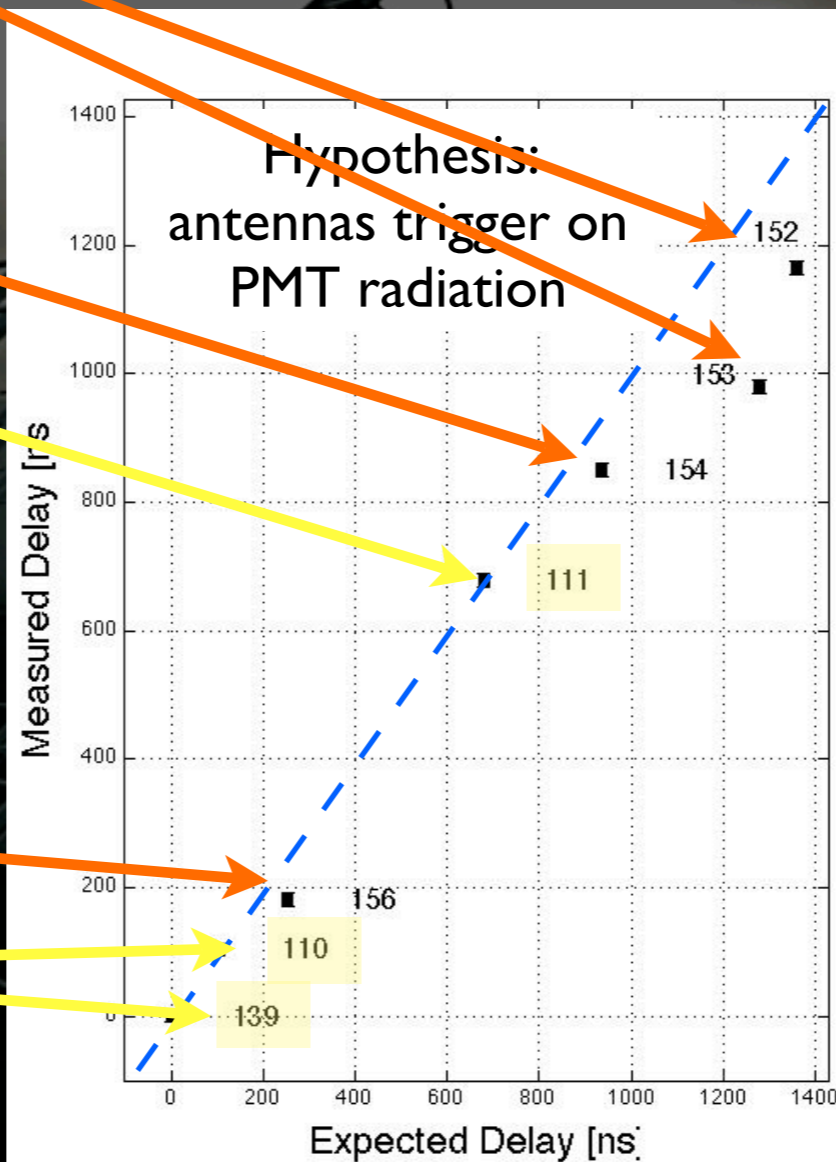
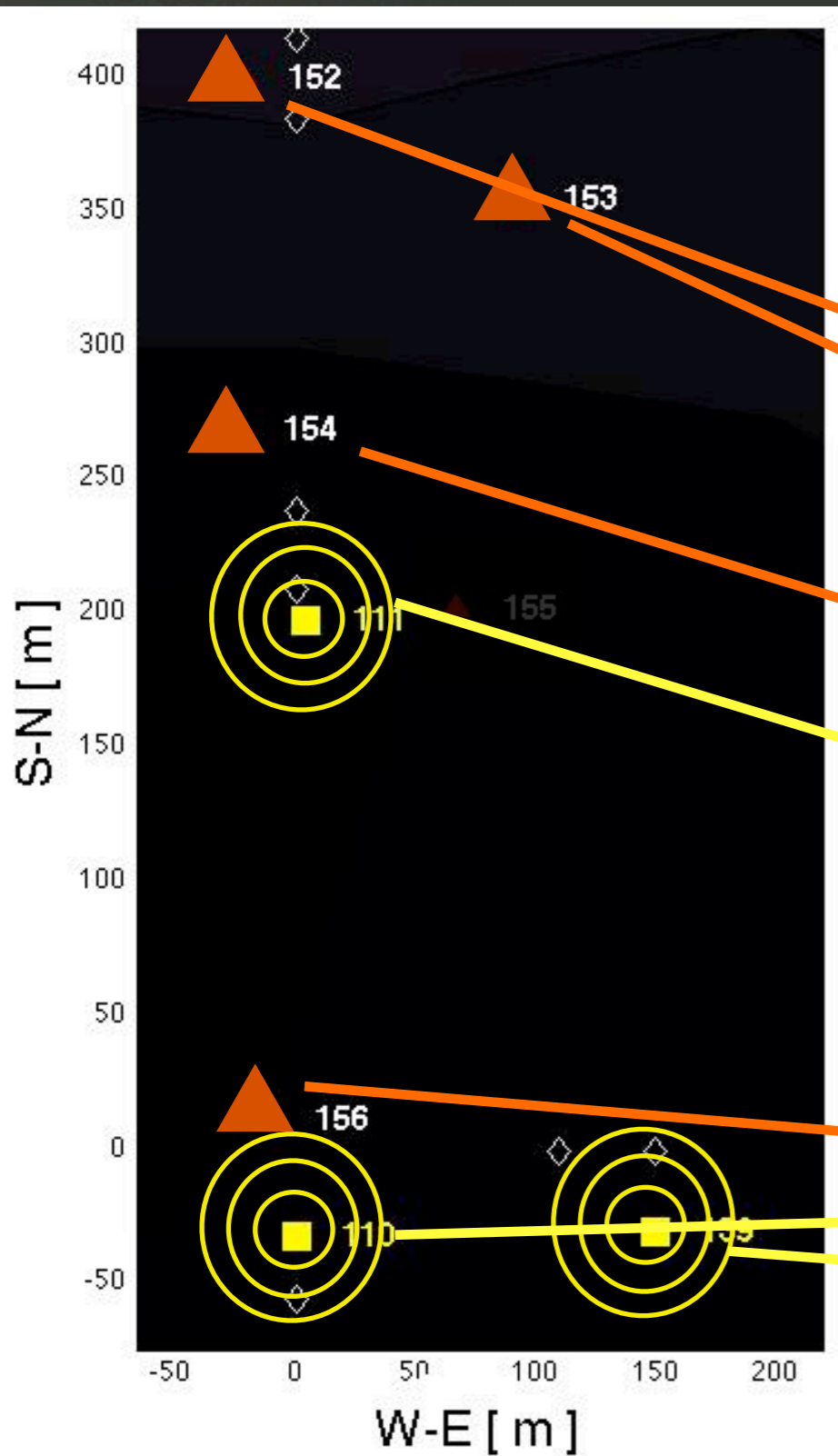
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- exemple: Coincidence A



Coincidence A was not generated by PMTs.

Hybrid coincidences

- PMT trigger?
 - ~ 2 other coins: antennas triggered BEFORE scintillators!

Coincidence B

First trigger on Ant 151

Ant 152: +170ns

Ant 153: +310ns

Ant 154: +574ns

Scint 111: +749ns

Scint 139: +1415ns

Scint 110: +1434ns

Coincidence C

First trigger on Ant 154

Scint 111: +234ns

Ant 155: +248ns

Ant 156: +721ns

Scint 110: +844ns

Ant 140: +1074ns

Hybrid coincidences

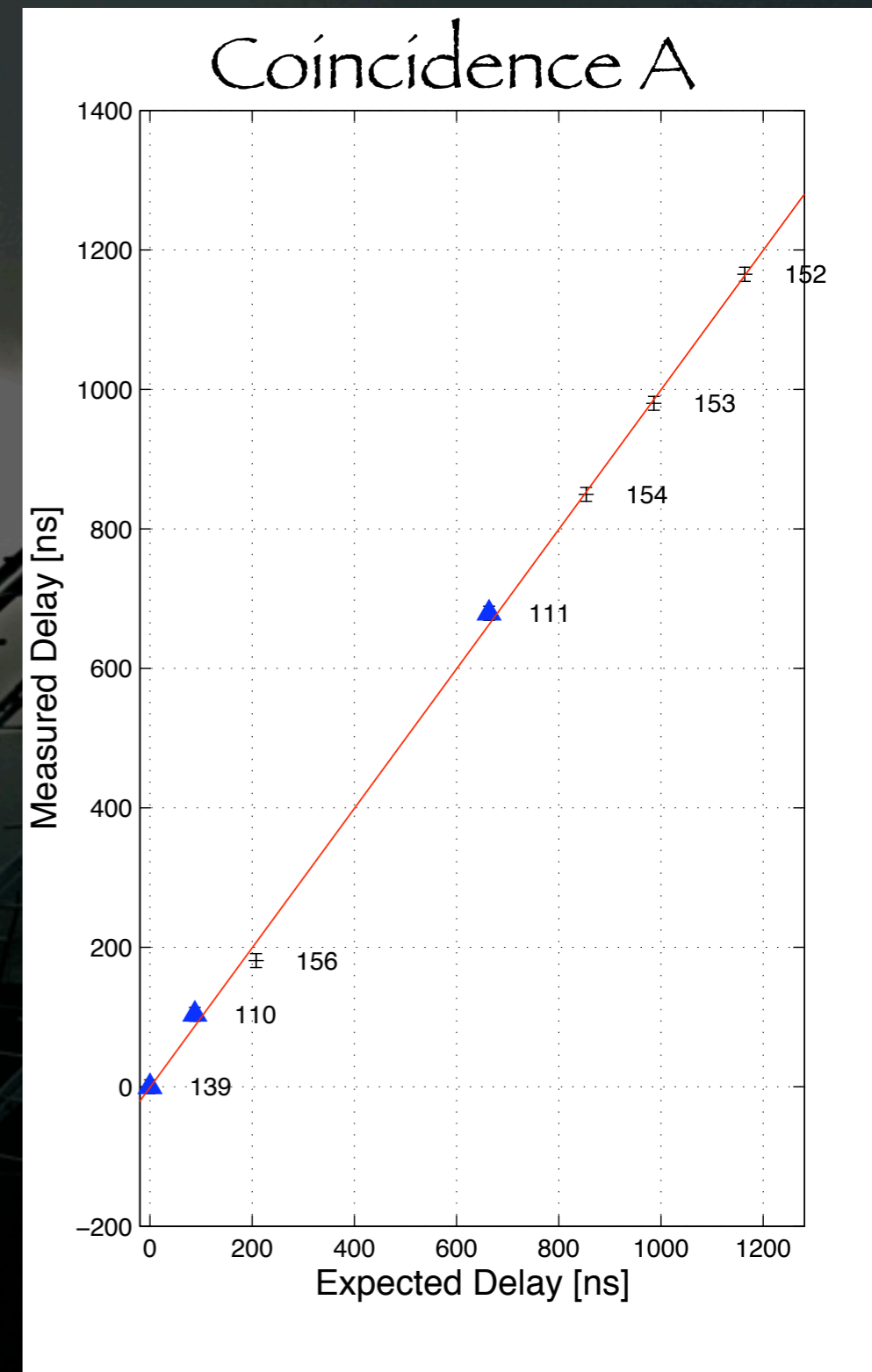
- Independent reconstruction

| | Radio recons | Scint recons | Combined |
|--------|--|--|--|
| CoíncA | $\Theta = 51.4^\circ$ $\varphi = 195.4^\circ$ | $\Theta = 51.4^\circ$ $\varphi = 196.3^\circ$ | $\Theta = 50.6^\circ$ $\varphi = 194.0^\circ$ |
| CoíncB | $\Theta = 60.6^\circ$ $\varphi = 358.6^\circ$ | $\Theta = 63.9^\circ$ $\varphi = 358.6^\circ$ | $\Theta = 61.4^\circ$ $\varphi = 358.8^\circ$ |
| CoíncC | $\Theta = 56.2^\circ$ $\varphi = 13.2^\circ$ | x | $\Theta = 56.1^\circ$ $\varphi = 12.2^\circ$ |

Hybrid coincidences

- Independent reconstruction

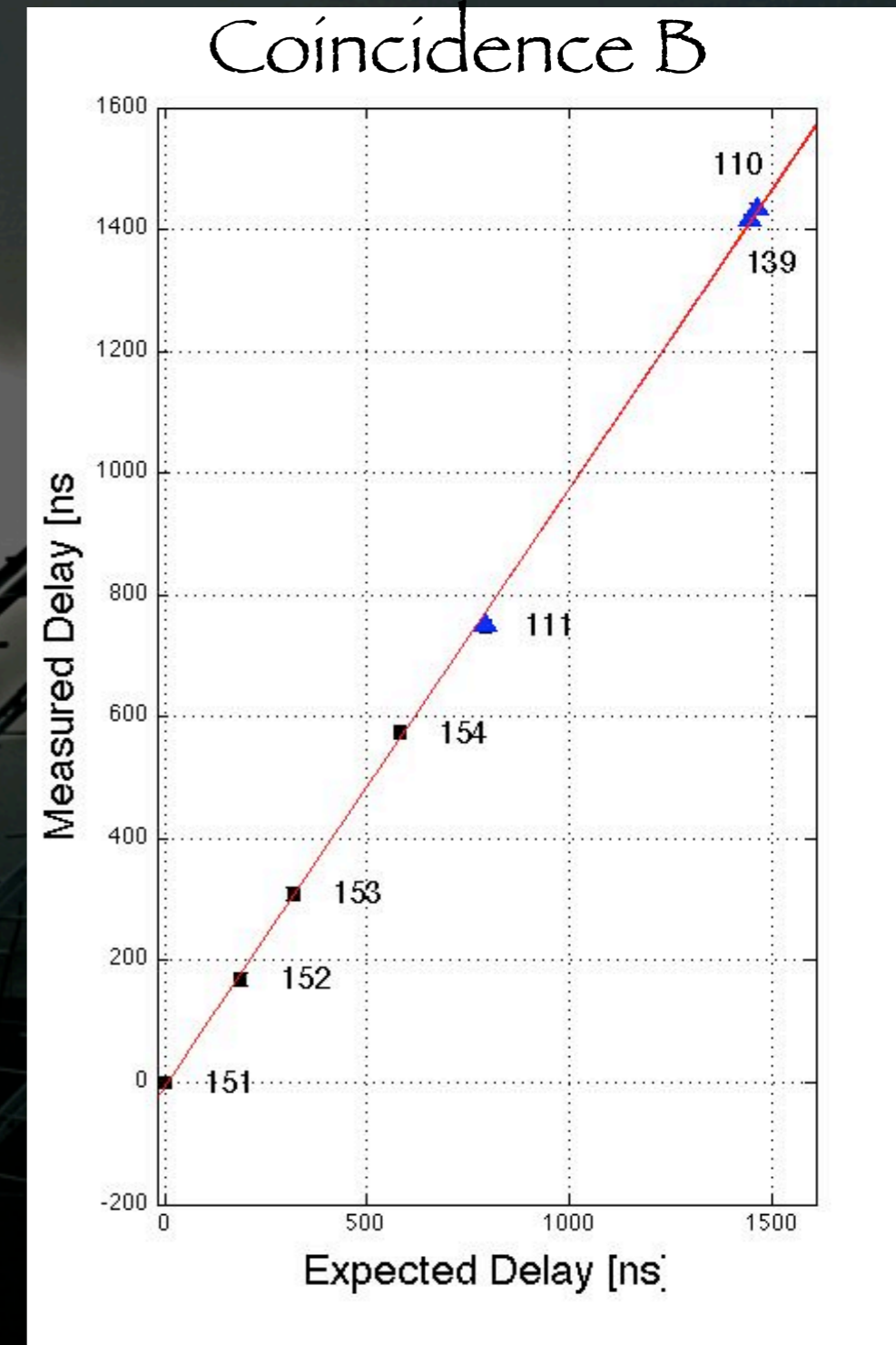
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Hybrid coincidences

- Independent reconstruction

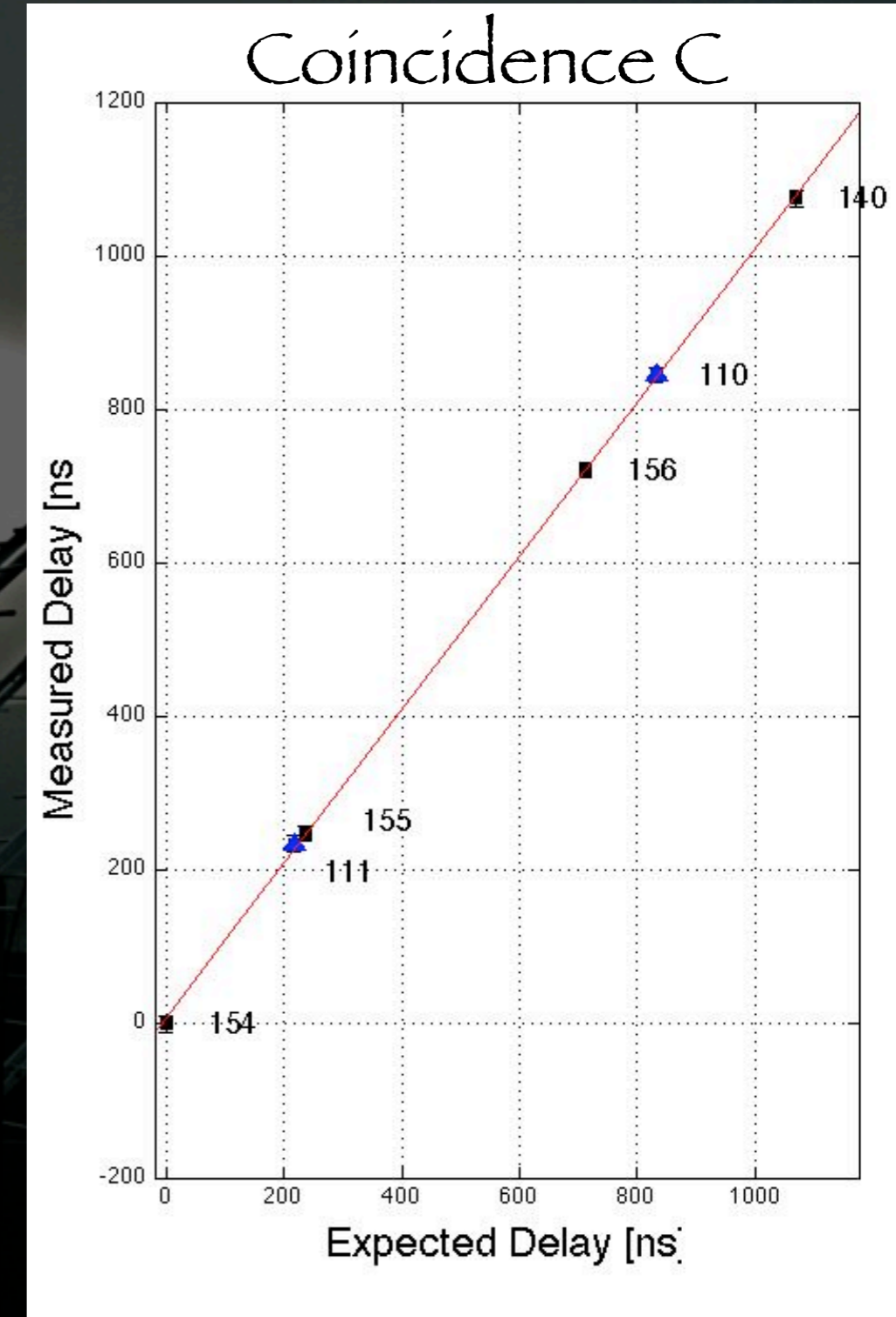
| | Radio recons | Scint recons | Combined |
|--------|--|--|--|
| CoincA | $\Theta = 51.4^\circ$ $\varphi = 195.4^\circ$ | $\Theta = 51.4^\circ$ $\varphi = 196.3^\circ$ | $\Theta = 50.6^\circ$ $\varphi = 194.0^\circ$ |
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Hybrid coincidences

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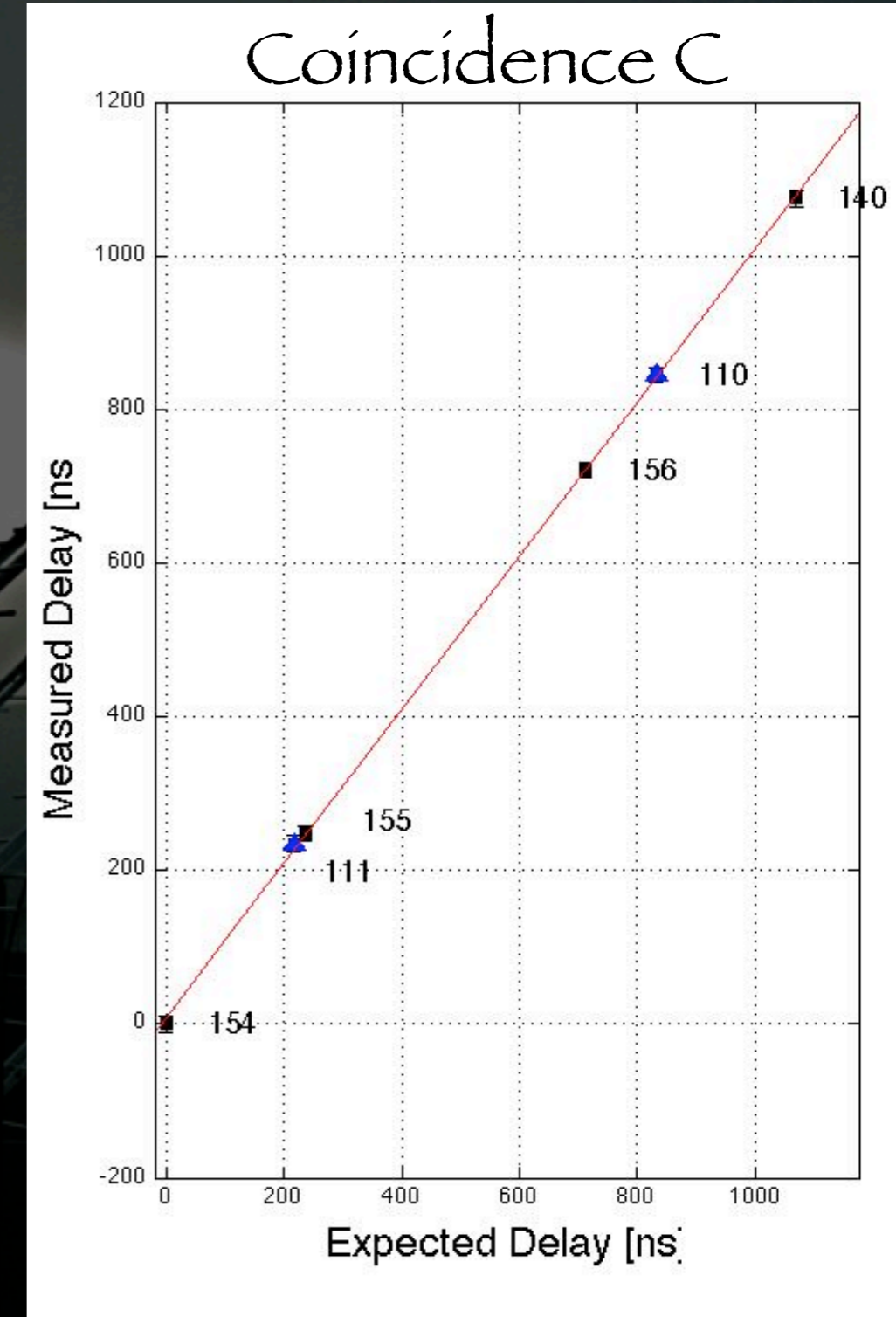


Hybrid coincidences

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CRs were detected by the TREND autonomous radio array

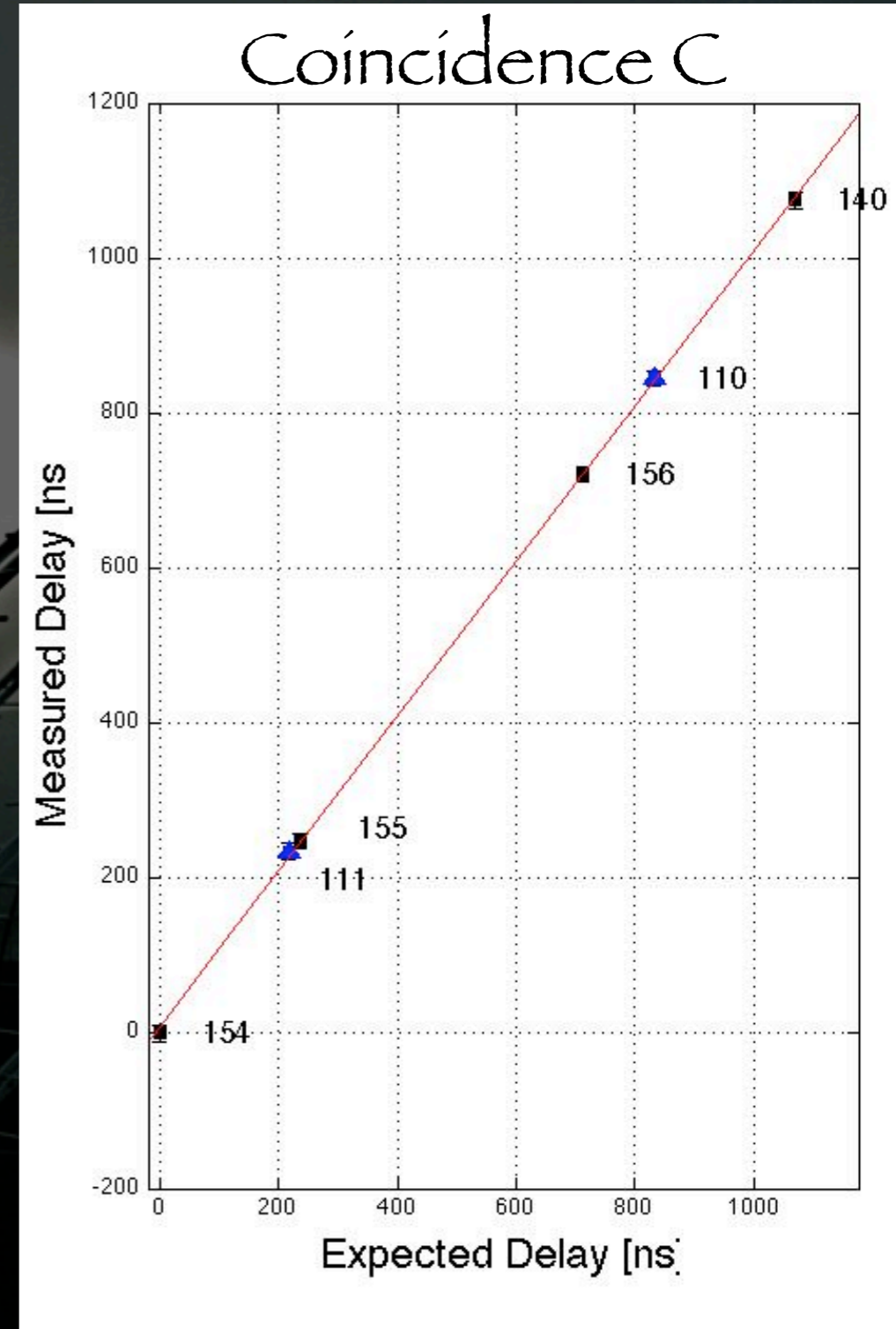


Hybrid coincidences

- Independent reconstruction

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| CoincC | $\Theta = 56.2^\circ$ $\varphi = 13.2^\circ$ | x | $\Theta = 56.1^\circ$ $\varphi = 12.2^\circ$ |

Note: these 3 events pass all CRs selection cuts!



N

Current developments

- Extension along East baseline :
50 antennas over $\approx 2\text{km}^2$

W

S

E

N

Current developments

- Extension along East baseline :
50 antennas over $\approx 2\text{km}^2$

W

E

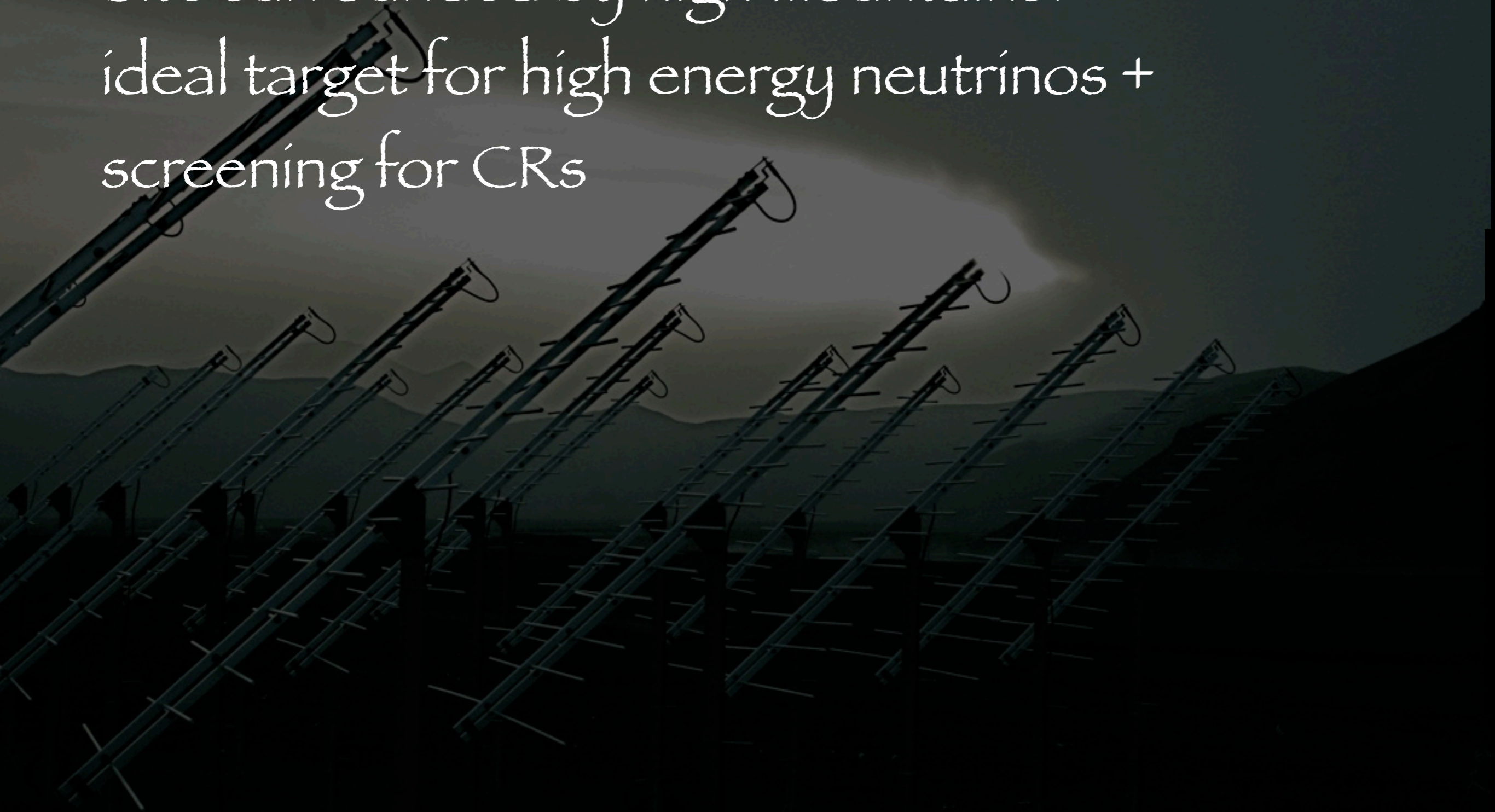
S

Next steps



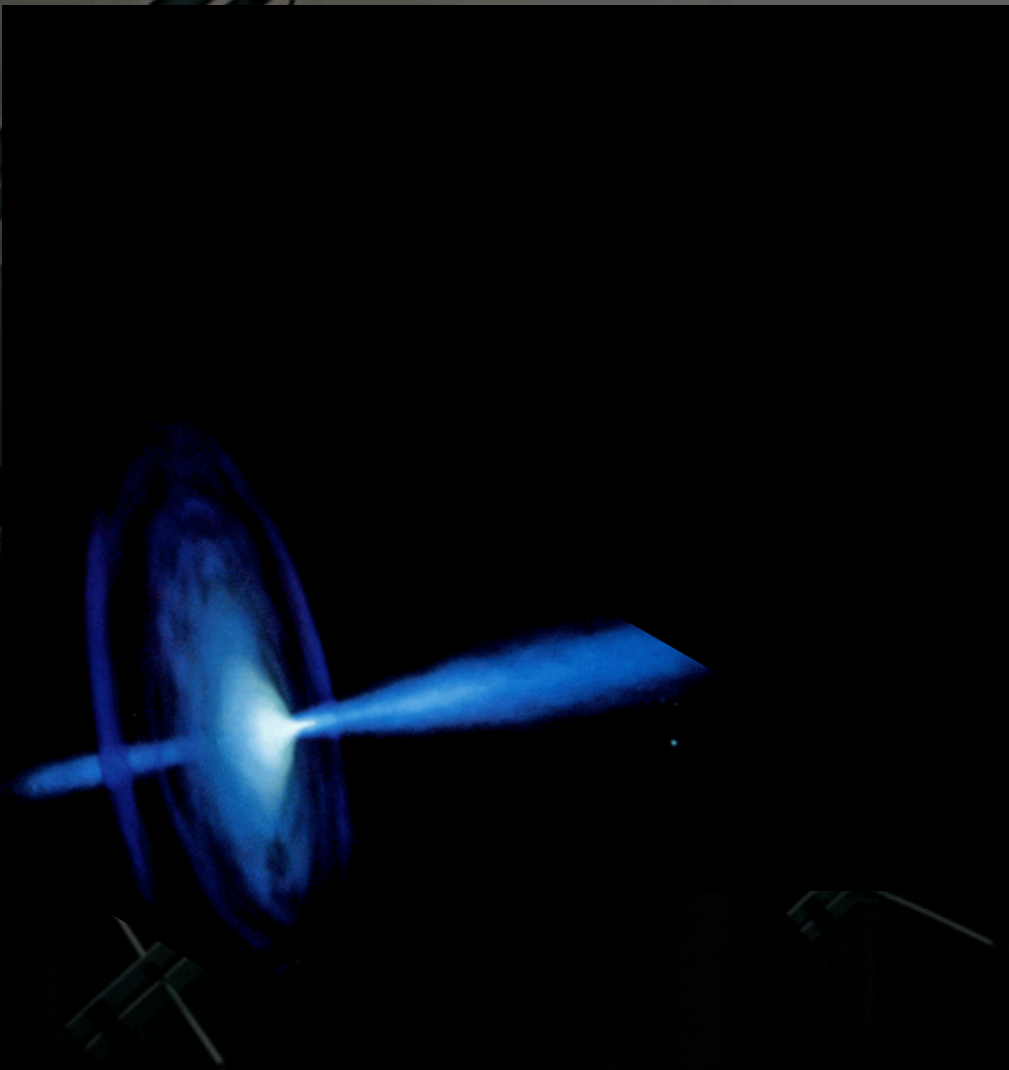
Next steps

- Site surrounded by high mountains: ideal target for high energy neutrinos + screening for CRs



Next steps

- Site surrounded by high mountains:
ideal target for high energy neutrinos +
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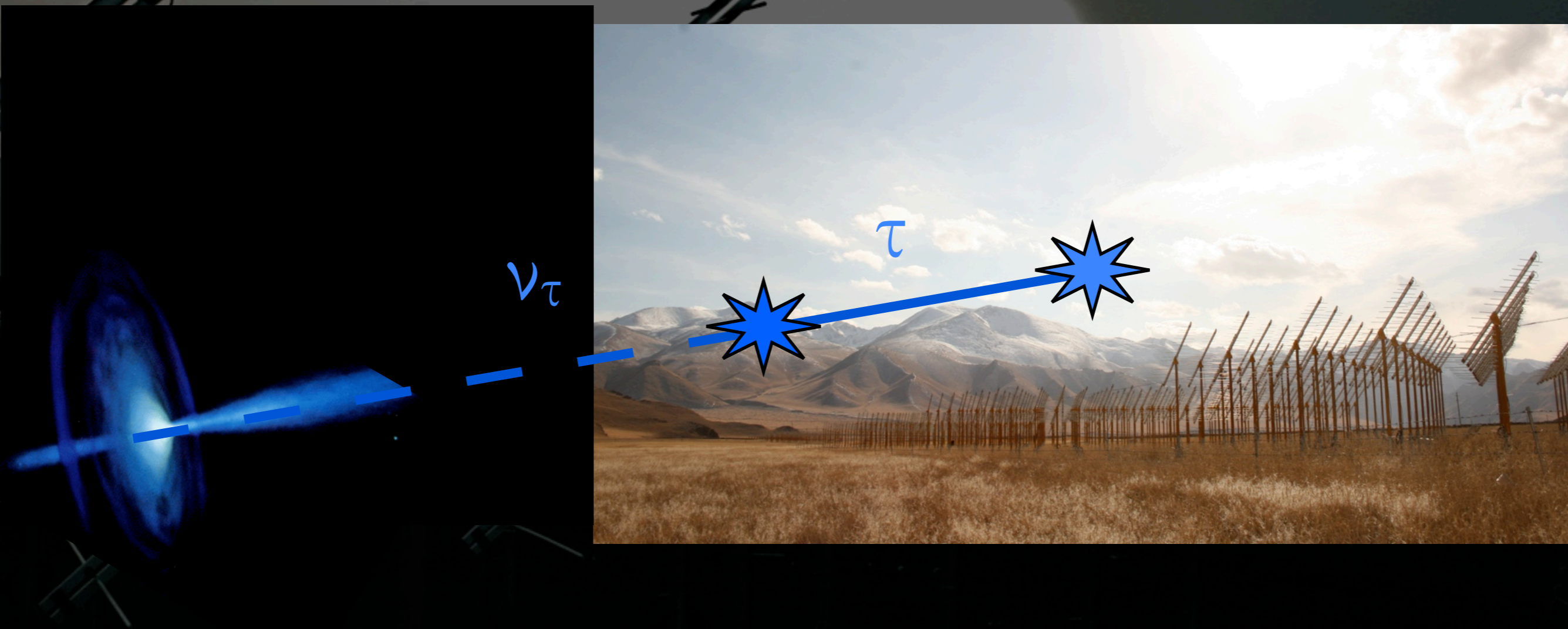
Next steps

- Site surrounded by high mountains: ideal target for high energy neutrinos + screening for CRs



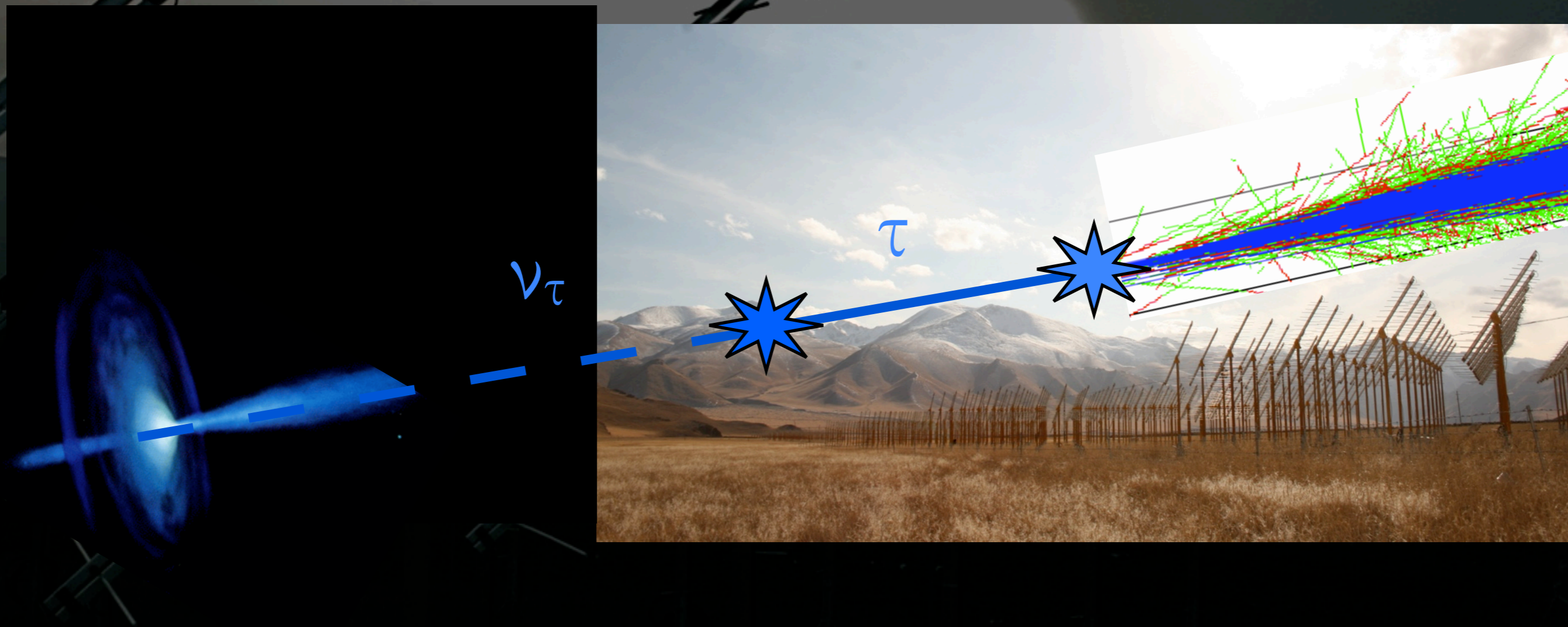
Next steps

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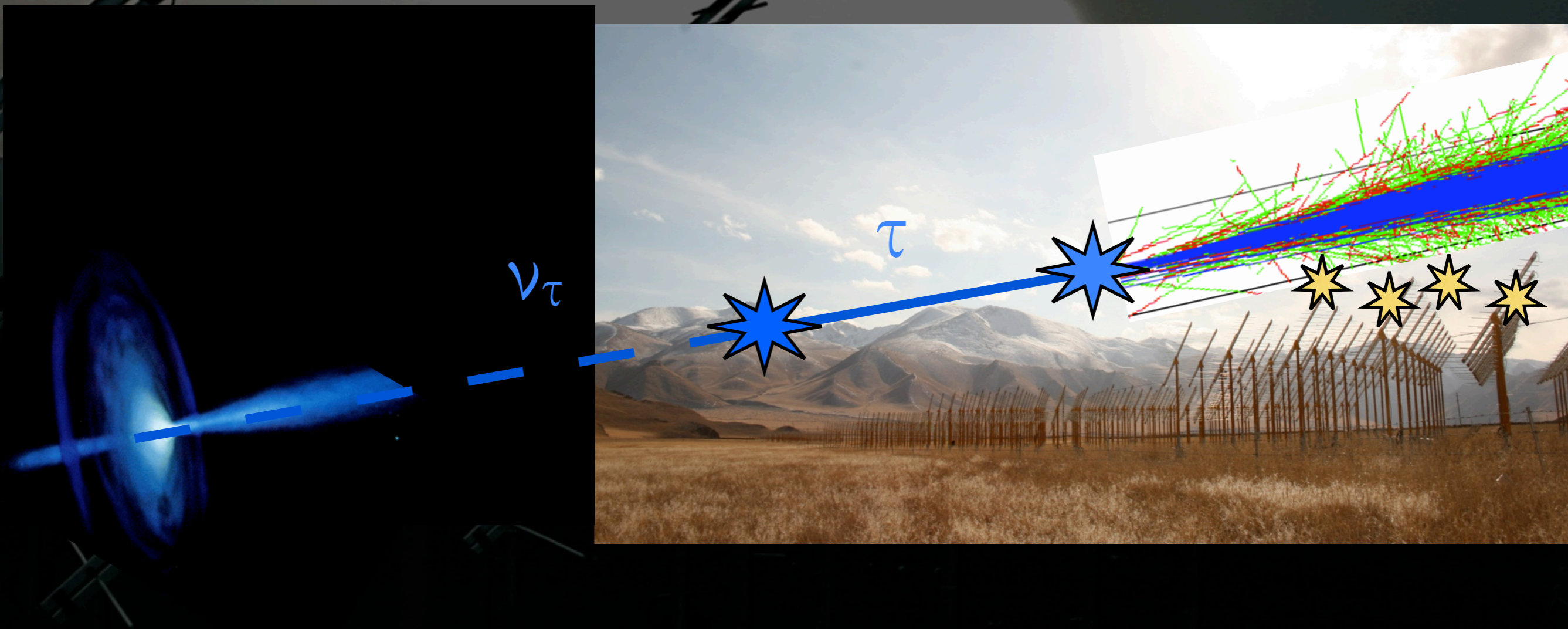
Next steps

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Next steps

- Site surrounded by high mountains: ideal target for high energy neutrinos + screening for CRs



Simulations principle

- Generate v_τ trajectory
- Generate interaction with the rock (Pythia 6.4.14)
- Tau propagation (GEANT4)
- Tau decay (TAUOLA)
- Shower detection (inclined showers!!!)

Conclusion

- TREND validated as an autonomous EAS radio detector installed on the 21CMA site.
- 6-antennas prototype has been running in 2009 for 24 live days. Analysis resulted in 25 CR candidates.
- CRs autonomous radio detection confirmed with an independent scintillator array in 2010.
- Extension to 50 antennas on 2 km² in progress
- Set-up & site optimized for UHE neutrino search.

Merci!
Thank you!
谢谢!

