The Non-Imaging CHErenkov Array (NICHE): A TA/TALE Extension to Measure the Flux and Composition of Very-High Energy Cosmic Rays

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for the TA Collaboration

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The NICHE Idea

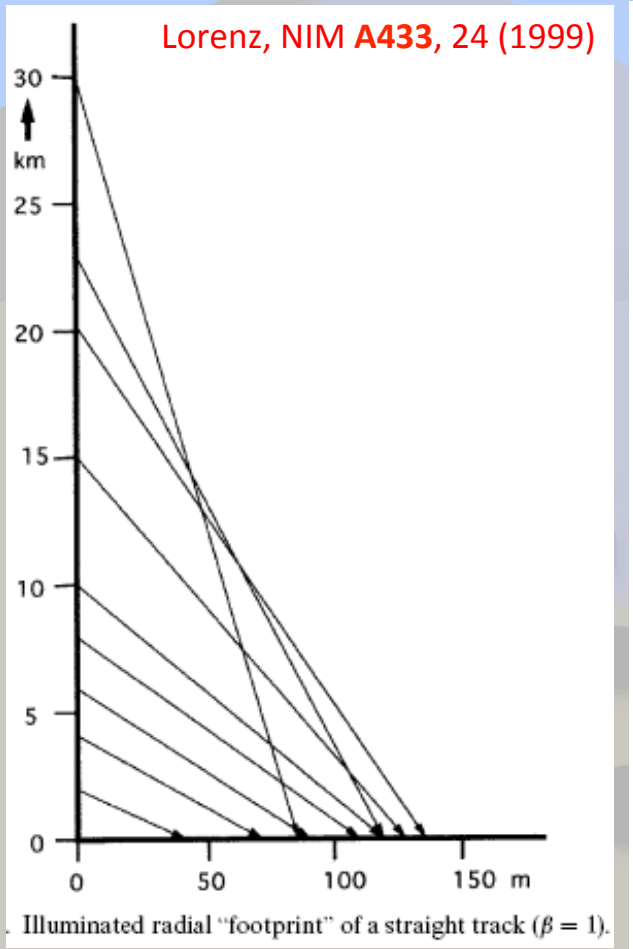
- Use non-imaging light collectors to extend the range of TA/TALE to below 10^{15} eV
  - Hybrid with TALE-Cherenkov
    - Small array, 0.16 km^2, 100-m spacing, giving a couple events per hour above 10^{16} eV in coincidence with TALE-Cherenkov
    - Important for geometrical reconstruction, allows better X_{max} reconstruction in TALE, correlate with shower front width
  - "Stand-alone" array overlapping with TALE
    - Large array, 1.5 km^2, 200-m spacing, giving one event per hour above 10^{17} eV
    - In-fill array, 100-m spacing, to push threshold down below 10^{15} eV

The NICHE Idea

- Non-imaging Cherenkov detectors sensitive to shower energy through flux of Cherenkov photons
- Sensitivity to composition
  - From lateral distribution of Cherenkov flux (need measurements within 100 m of core)
  - From time width in a single counter (measurements well beyond 120 m from core)
- Non-imaging Cherenkov is an optical detector seeing the bulk of the shower, but insensitive to the fiducial volume biases of fluorescence detectors

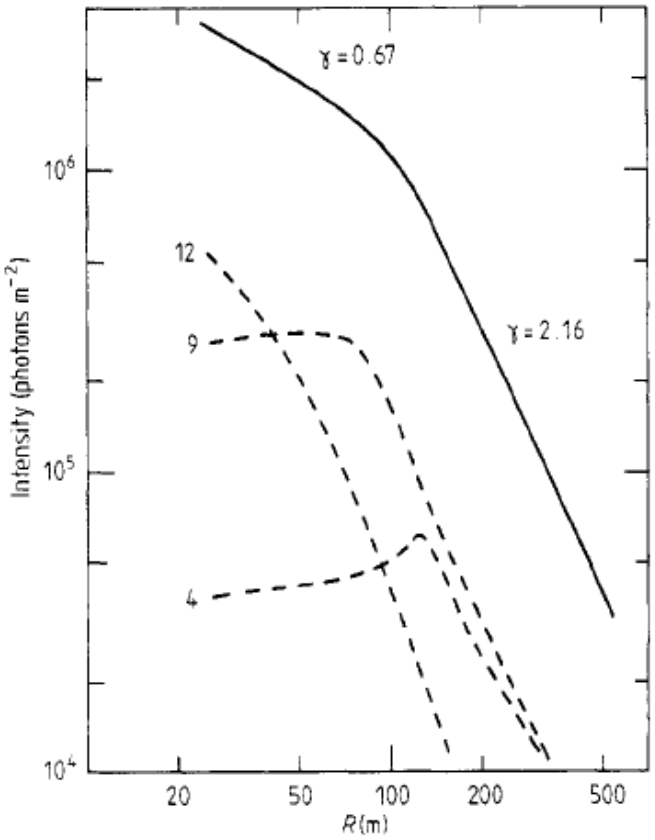
Cherenkov Phenomenology I

Lorenz, NIM **A433**, 24 (1999)



Illuminated radial "footprint" of a straight track ($\beta = 1$).

Patterson & Hillas , JPG **9**, 1433 (1983)



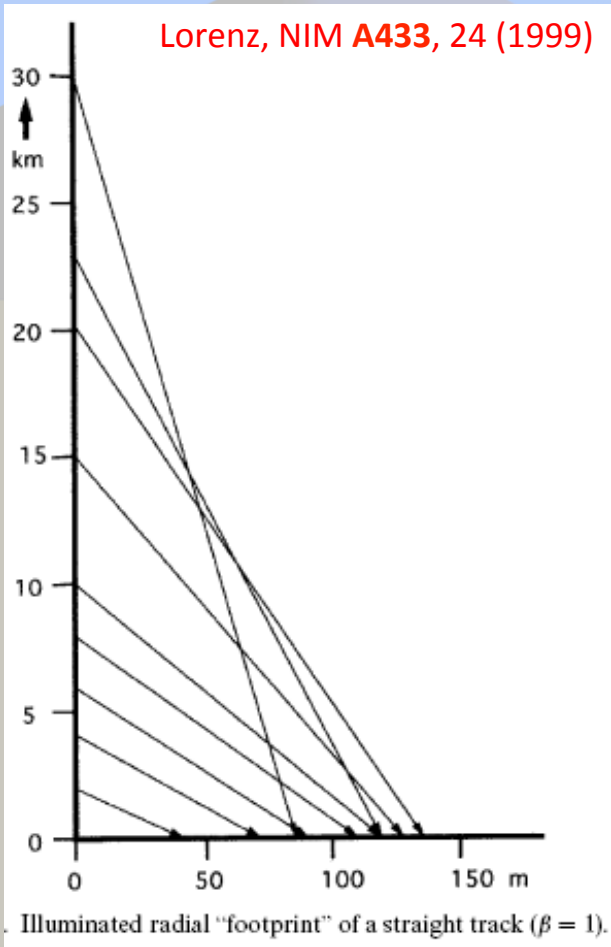
Traditionally one measures the Cherenkov Lateral Distribution.

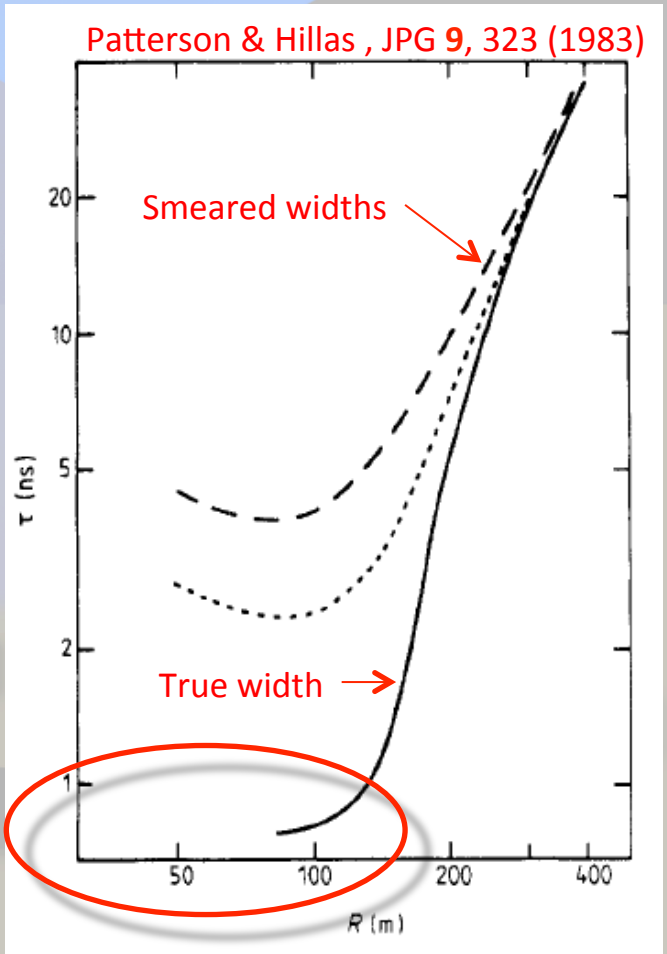
R > 120 m: Energy
R < *120 m*: X_{Max}

This requires measurements within 120 m of the shower core.

Requires large number of Cherenkov detectors for > 1 km^2 sr.

Cherenkov Phenomenology II



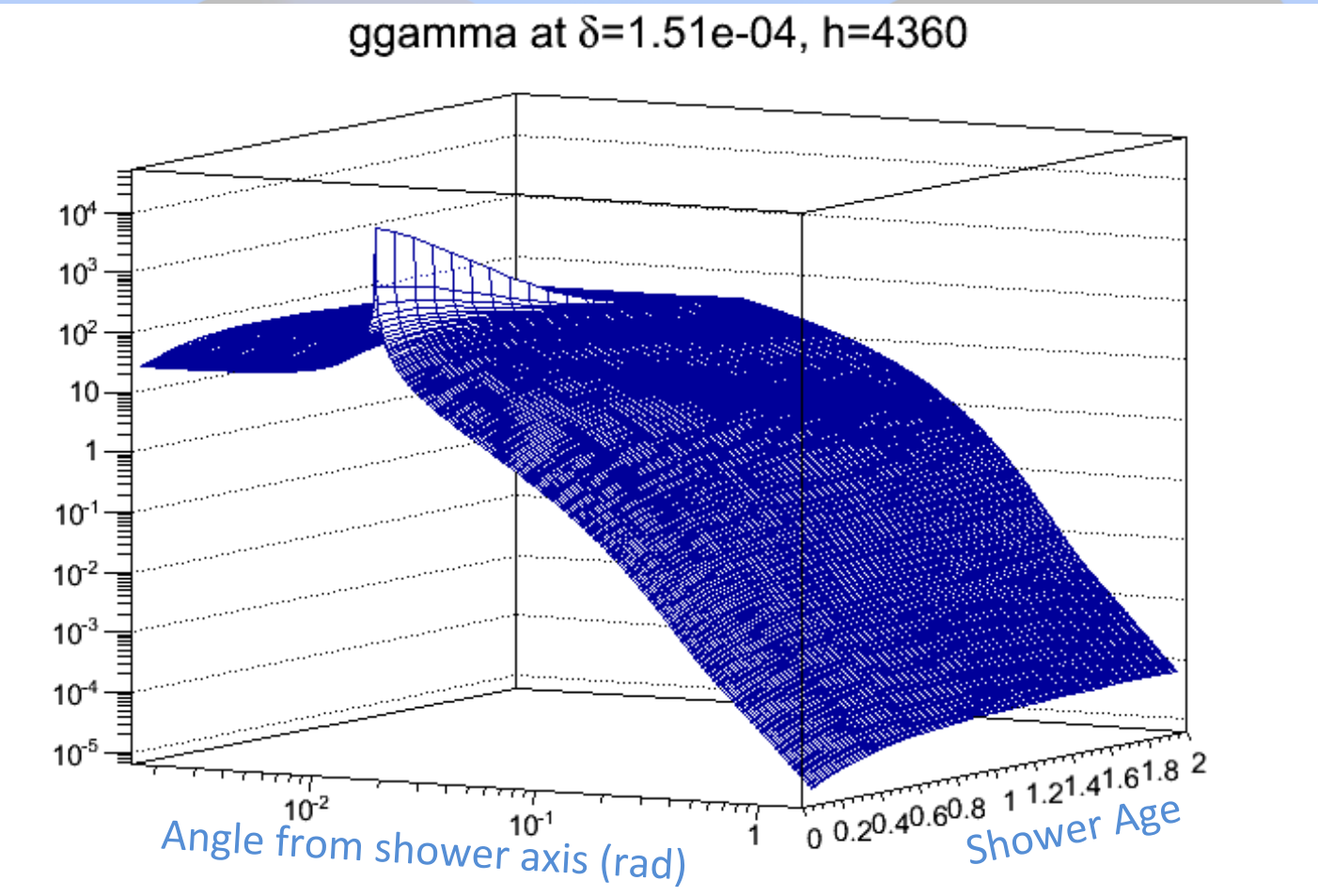


At sufficiently high energies, larger detector spacings can be used to measure the time-width at a given *R*.

At small *R:* dominated by light from lowest portion of shower.

At large *R:* get large part of shower. Many paths, wide time. The deeper the shower the wider the time.

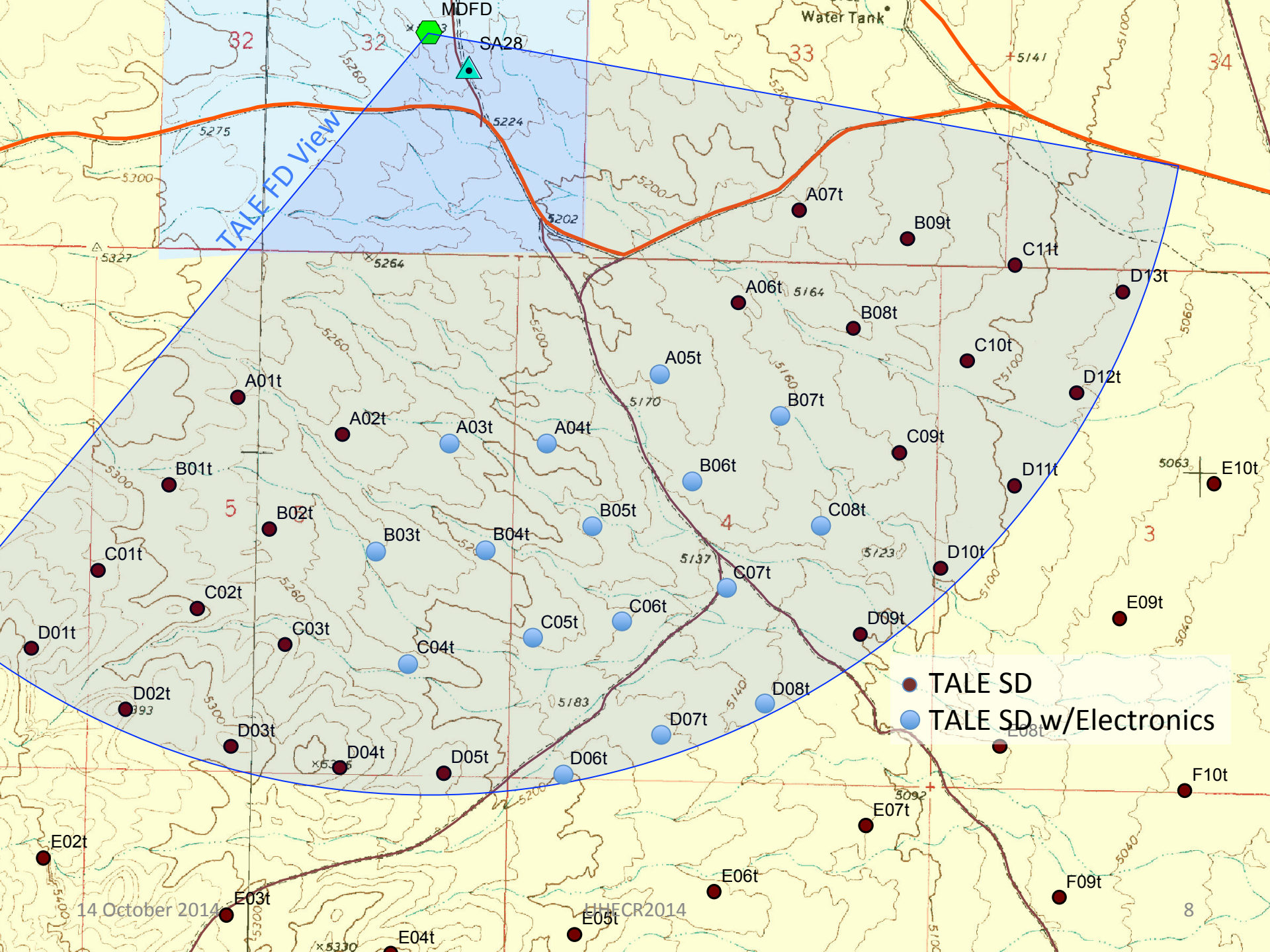
Shower Universality



Showers have universal spectrum of electron energies (at a given age) and a universal electron angular distribution (at a given energy). Convolute electron angular distribution at a given age with Cherenkov cone to get angular distribution of Cherenkov photons

NICHE Prototype

- Yoshiki Tsunesada has received ¥18.8M *Kakenhi* grant for young scientists to build the first 15 NICHE counters.
  - One 3” PMT (Hamamatsu R6233-100) per counter
  - 200 MS/s, 12-bit FADC & FPGA L1 trigger from Brains, Inc.
  - Local storage of all triggered events for one night’s data


MDFD
SA28
TALE FD View
A01t
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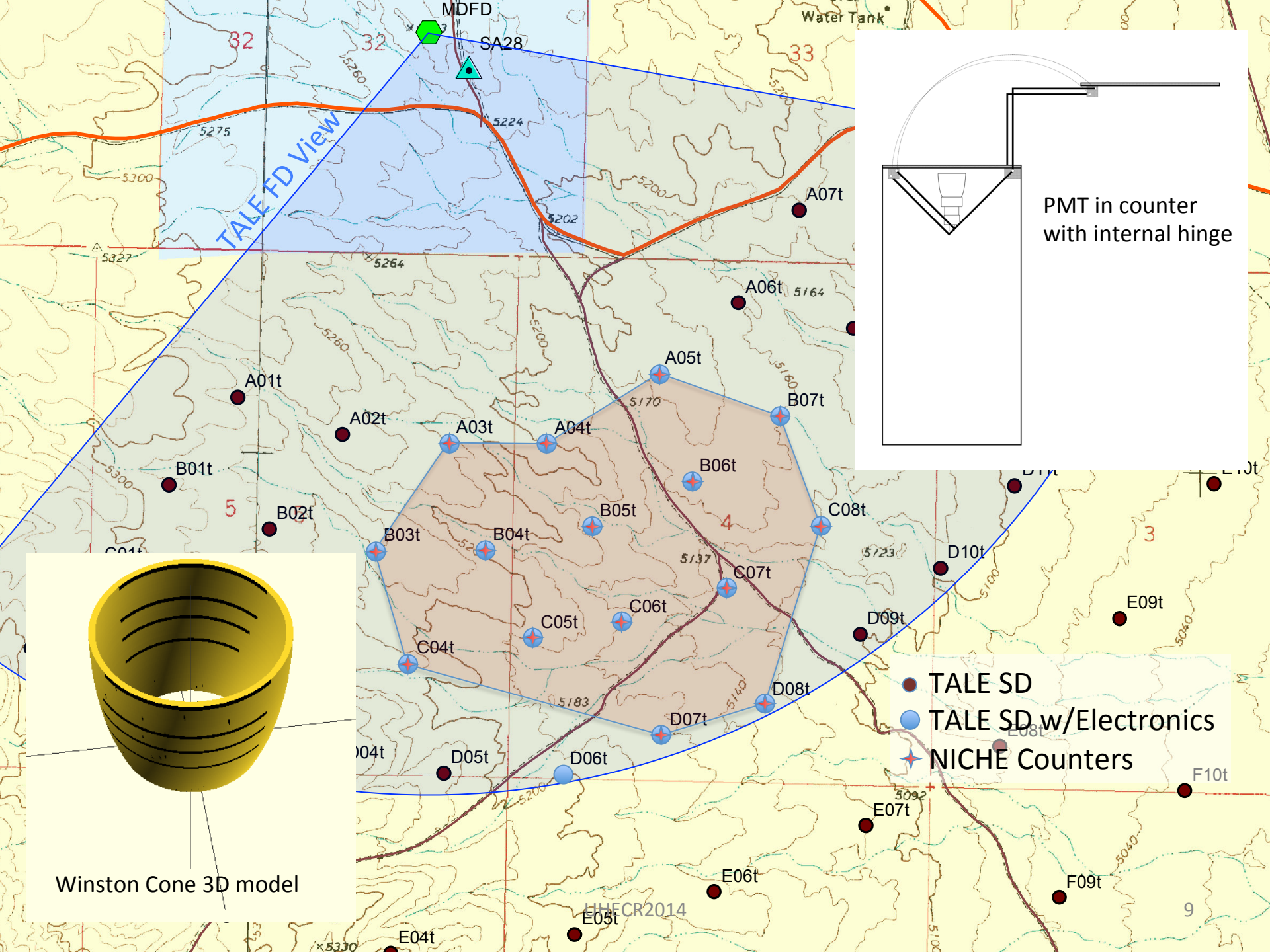
TALE SD
TALE SD w/Electronics


MDFD
SA28
TALE FD View
Water Tank
PMT in counter
with internal hinge
A01t
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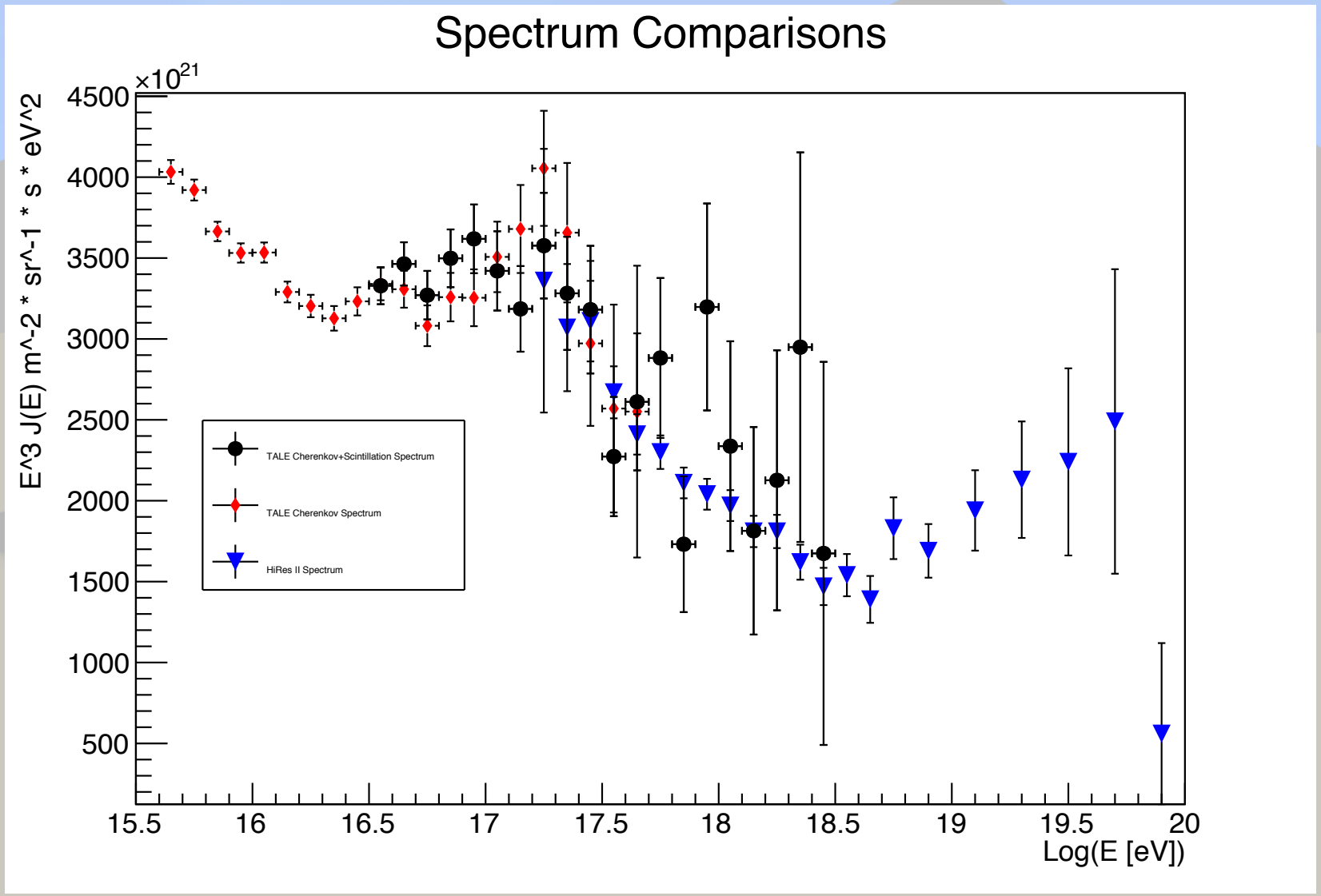
TALE SD
TALE SD w/Electronics
NICHE Counters
Winston Cone 3D model

Serendipity

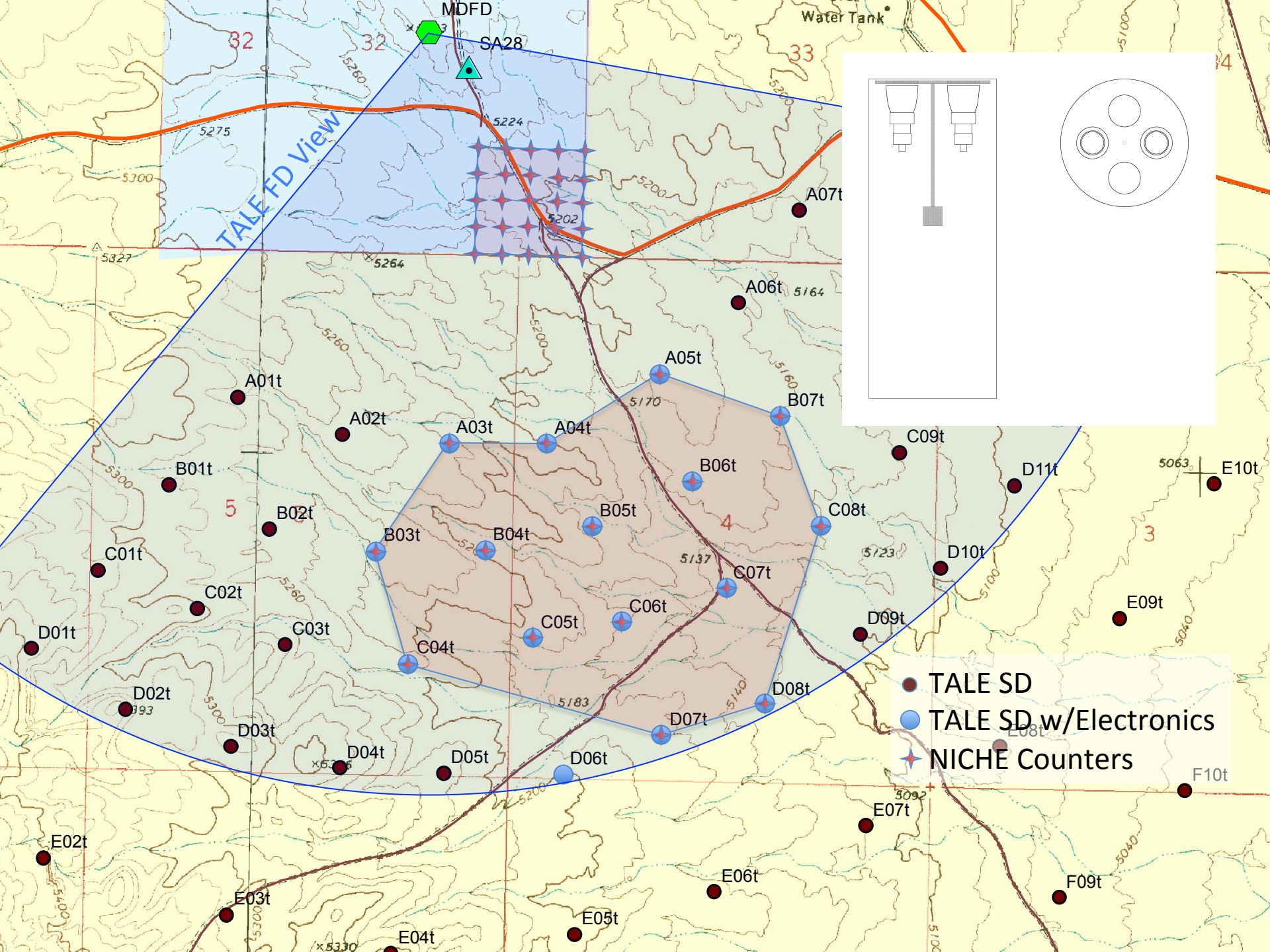
- The NICHE plan was (and still is) to make an array large enough to get an event per hour above 10^{17} eV to overlap with fluorescence
  - Push the counters far apart
  - Use time-width
- *But* if we had a direct longitudinal observation of air-showers at 10^{16} eV, life would be much easier
  - Only need 10% of the area, can put the detector close enough together to get inside-the-cone
- Well, we do …

Serendipity



NICHE-TALE Hybrid

- A NICHE array can work in hybrid with TALE-Cherenkov
  - Single NICHE counter timing can significantly constrain monocular TALE-Cherenkov geometry
  - With well known core, each NICHE counter can make a composition determination from the time-width
  - Cross-correlation of X_{max} measurements between NICHE and TALE provides confirmation of time-width technique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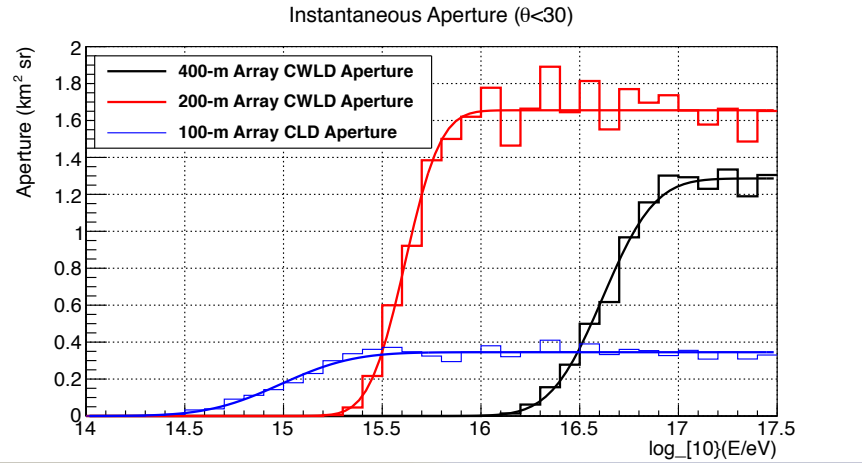
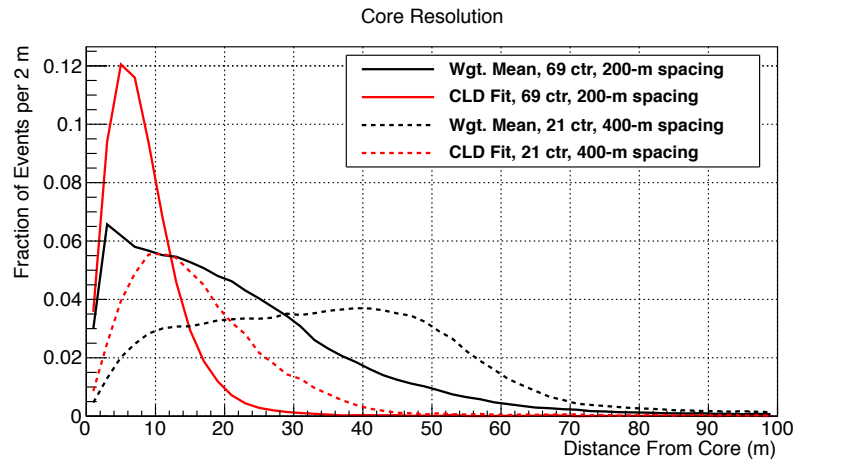
TALE SD
TALE SD w/Electronics
NICHE Counters

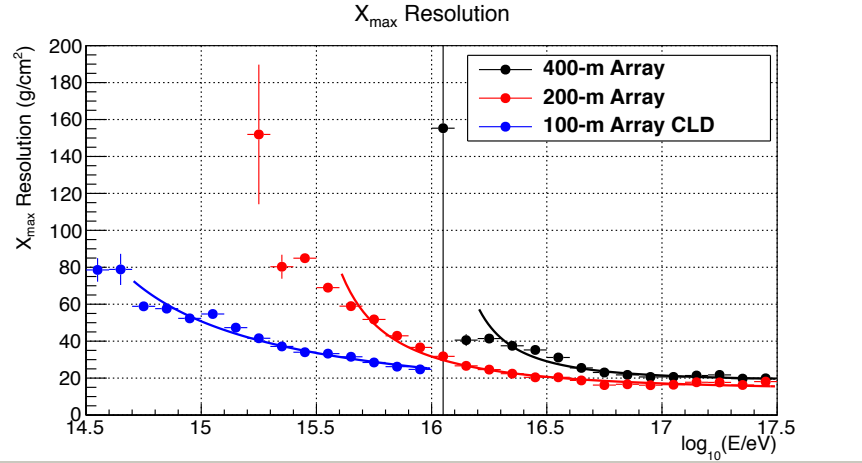
The Full NICHE Array

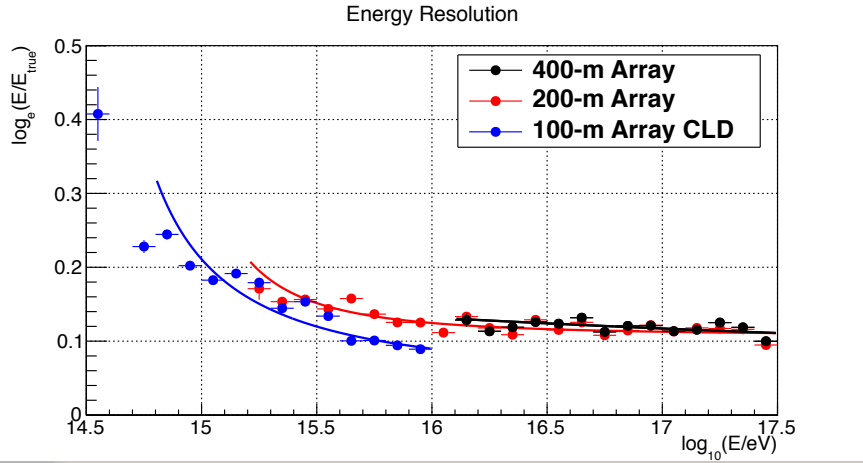
- A 68-counter array with 200-m spacing
  - Threshold just around knee
  - 25 g/cm^2 resolution above a few times 10^{16} eV
- A 25-counter infill array with 100-m spacing
  - Threshold about 10^{15} eV
  - Have to use CLD for composition (hence 100-m spacing)

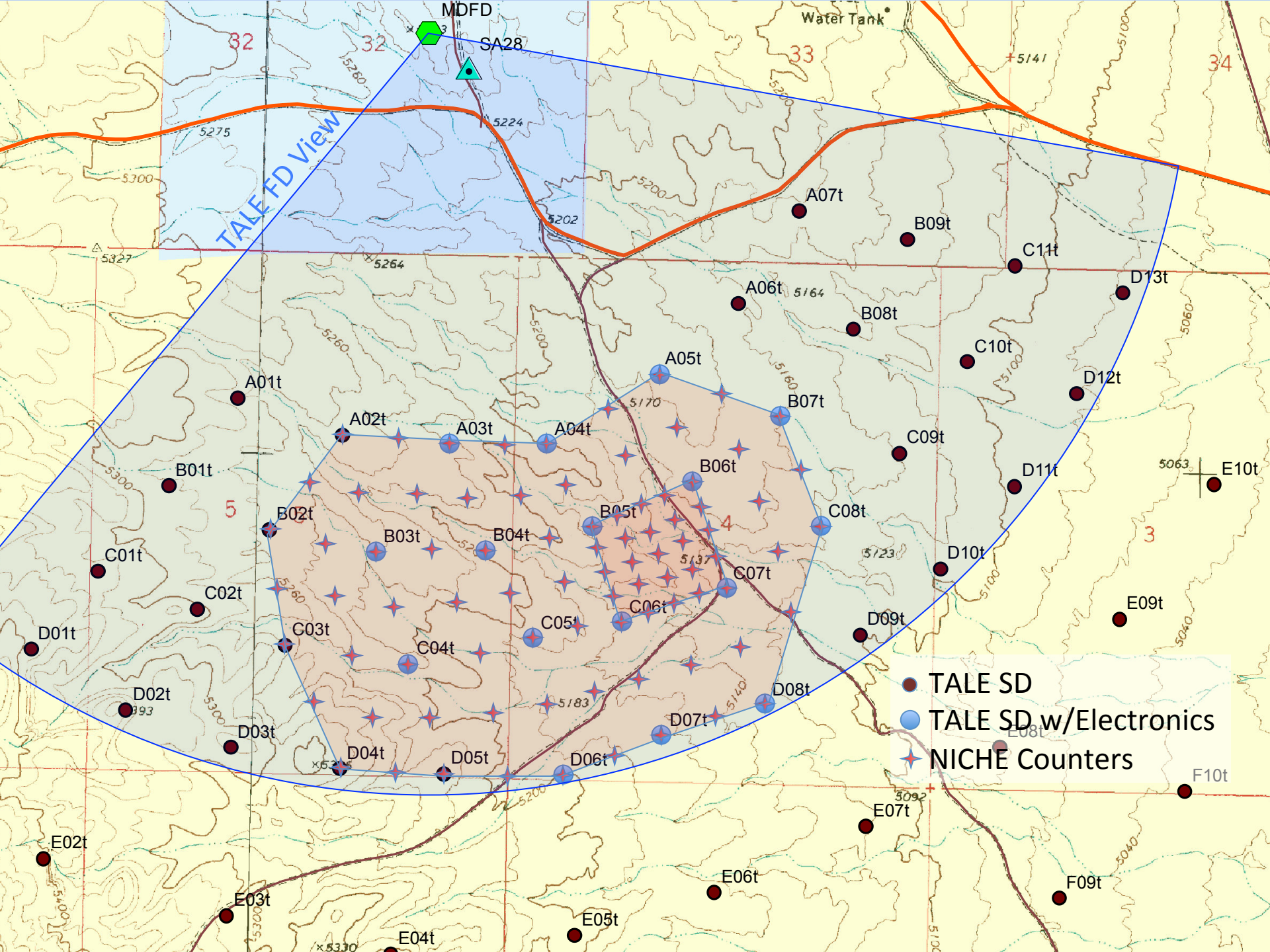
The Full NICHE Array







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TALE SD
TALE SD w/Electronics
NICHE Counters

Conclusion

- NICHE will use Cherenkov light from showers to extend the range of TA to below 10^{15} eV
- A 15-counter prototype array is currently being constructed
- A 25-counter hybrid array with TALE-Cherenkov is currently being proposed
- Eventually plan for a large 1.5–2 km^2 array