ALTO progress in Monte Carlo Simulations and Prototyping Efforts

http://alto-gamma-ray-observatory.org

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--- for the ALTO group ----
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Satyendra Thoudam - Linnaeus University (Sweden)
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The ALTO project

- Project born in 2014 at Linnaeus University after we received a research grant from the Crafoord Foundation (Sweden)

- A Wide Field-of-View (~ 2 sr) gamma-ray observatory:

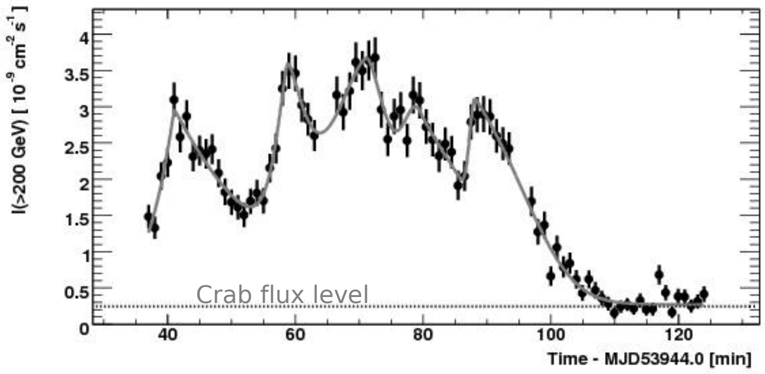
  - In the Southern hemisphere → Daily observations of Southern sources
  - At high altitude (~ 5 km) → Low threshold E ≥ 200 GeV
  - Particle detectors → Observations may be done 24h per day
  - Hybrid detectors → Improved S/B discrimination
  - Excellent timing accuracy → Improved angular resolution (~ 0.1° at few TeV)
  - Modular design → Phased construction and easy maintenance
  - Simple to construct → Minimize human intervention at high-altitude
  - Long duration → Should operate for 30 years
  - “Open Observatory” → Distribute data to the community “à la Fermi-LAT”

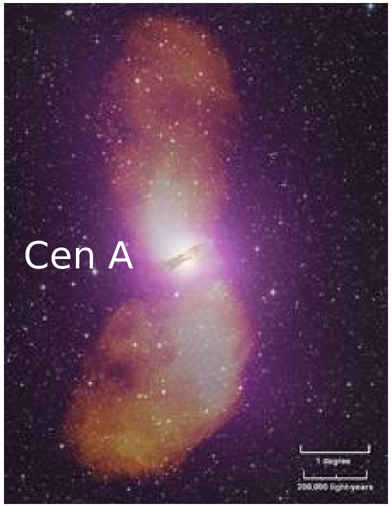
ALTO Science Goals

Daily monitoring of Southern targets:

- Transients and variable sources;
- Active Galactic Nuclei, Gamma-Ray Bursts (if spectra favourable), X-ray binaries;
- Galactic centre and central region;
- Alerts to other observatories;
- Multi-year light-curves;
- High-end of the sources’ spectra;
- Search for Pevatrons;

H.E.S.S. PKS 2155-304 (blazar) flare





Study of extended sources:

Fermi Bubbles,
Vela SNR,
AGN radio lobes;

Credit: NASA/DOE/Fermi LAT Collaboration, Capella Observatory, and Ilana Feain, Tim Cornwell, and Ron Ekers (CSIRO/ATNF), R. Morganti (ASTRON), and N. Junkes (MPIfR)

Other accessible goals:

- Search in past data if detections of:
  - gravitational waves or
  - neutrinos;
- Study of the cosmic-ray composition and anisotropy;
- Dark matter searches;
- EBL studies (if threshold low enough);
- Search for Lorentz invariance violation;
- Axion-like particles from distant AGNs.

Current Collaboration

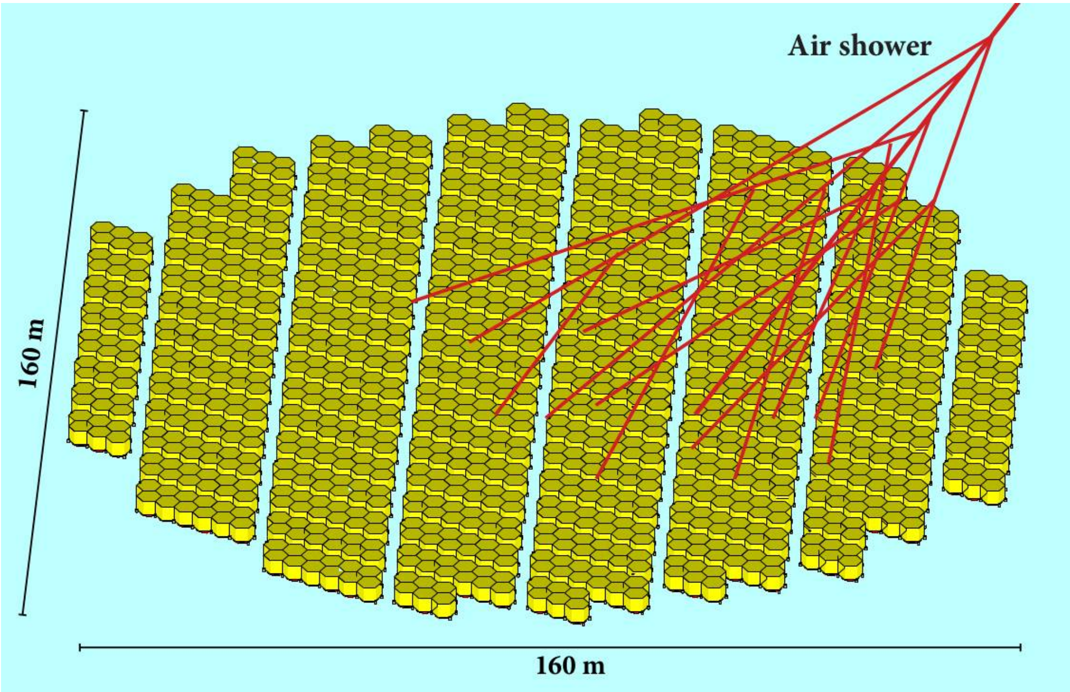
Sweden	France

• Department of Physics and Electrical Engineering, Linnaeus University, Växjö
  • PI Yvonne Becherini
  • Post-doc Satyendra Thoudam
  • Two PhD students **just started** (50%)
    • Mohanraj Seniappan: MVA Rejection
    • Tomas Bylund: DAQ & Control
• Industry: TBS Yard AB, Torsås
  • Industrial construction, responsible Lars Tedehammar
	• APC Laboratory, IN2P3/CNRS, Paris
	  • Michael Punch
	  • Contacts with Jean-Christophe Hamilton (discussions about the site)
	• Aix-Marseille University
	  • Jean-Pierre Ernenwein
	• LAL/Orsay
	  • Dominique Breton (discussions on electronics)
	• CEA/Saclay
	  • Eric Delagnes (discussions on electronics)

Discussions with other parties in Academia/Research Institutes:
- Los Alamos Laboratory, U.S.
- North-West University, Potchefstroom, South Africa

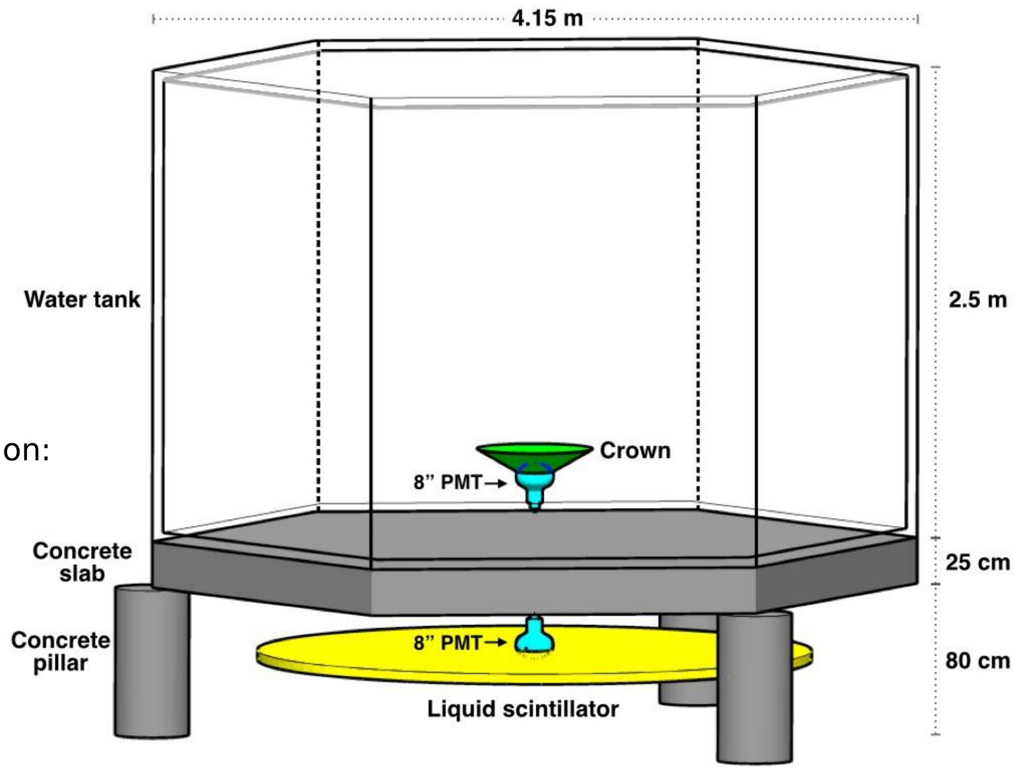
Key design characteristics of the full array

- Altitude (~ 5km):
  - For Physics goals, as a survey/alert instrument for transients
- Fine-grained array of 1242 units:
  - Smaller Water Cherenkov Detector (WCD) tanks than HAWC
  - Low dead-space ("packing factor" ~70%)
  - Improved angular resolution



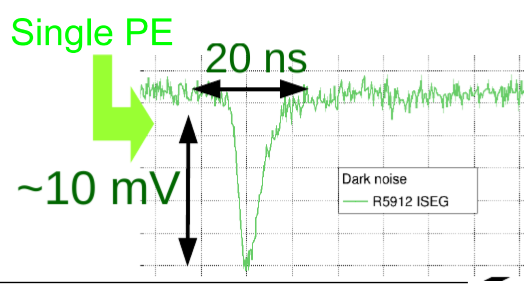
An ALTO detection unit

- Water Cherenkov tank:
  - Contains one Hamamatsu super-bialkali 8” PMT (10 dynodes) plus light-guide “crown”;
  - Similar performance to Antares 10” PMT



- Muon-detector scintillator tank for background rejection:
  - Liquid scintillator box (LAB+PPO+POPOP) (Scintillator Layer Detector, SLD) with one Hamamatsu standard QE 8” PMT (10 dynodes);

- Advanced electronics for 6-tank “cluster”, WaveCatcher + White Rabbit:
  - Trigger channel precisely time-stamped with “White Rabbit” system;
  - Analogue memories + ADCs to measure the waveform of the detector pulses;
  - No cables from central DAQ room, only fibres.



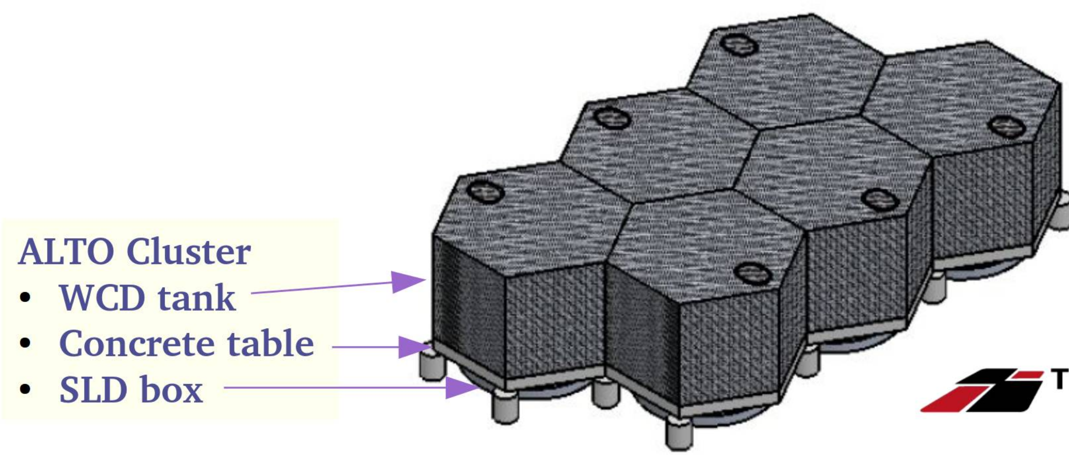
An ALTO "cluster"

Cluster = Group of 6 Units
= 6 x (WCD + SLD)

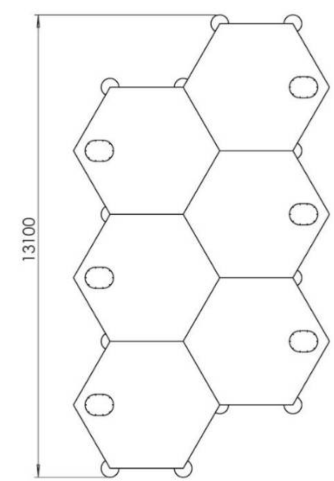
- WCDs on concrete "table"
- SLDs below "table",
  on telescopic rails

Each cluster to have common:

- Electronics readout unit
- Solar panel + battery
- Communication/data
  to central DAQ room by fibre only



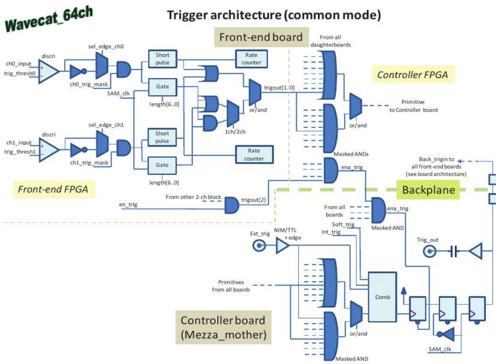
TBS

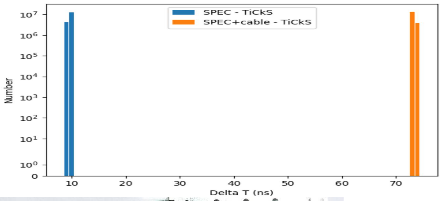


ALTO Electronics

- Readout electronics box, powered by solar panels
- Communications, by fibre-optic connections only, to central DAQ

- Electronics box containing:
  - “WaveCatcher” from CEA/CNRS
    - Analogue memory (Switched Capacitor Array)
    - 12-bit, 0.4-3.2 GS/s fast digitizers
    - 1024 samples depth/channel
    - Includes coincidence logic to start read-out
    - 12-channel version soon available
    - Low power consumption (~20W)
    - The WaveCatcher family of SCA-based 12-bit 3.2-GS/s fast digitizers: Breton et al., Real Time Conference (RT), 2014 19th IEEE-NPSS





  - Time-stamping of Read-out trigger to ns precision
    - White Rabbit node (e.g. TiCkS-SPEC board from APC)
    - “TiCkS: A Flexible White-Rabbit Based Time-Stamping Board”, Champion et al., ICALEPCS2017, Barcelona, Spain, 2017

- Probably a Single Board Computer (Arduino / BeagleBone …)
  - For local control and monitoring, autonomy in case of connection loss

ALTO Simulations

ALTO

Air shower simulation: CORSIKA (version 7.4000)

- Realistic model of Earth's atmosphere, magnetic field, refractive index, ...
- Electromagnetic and hadronic interactions based on particle physics models

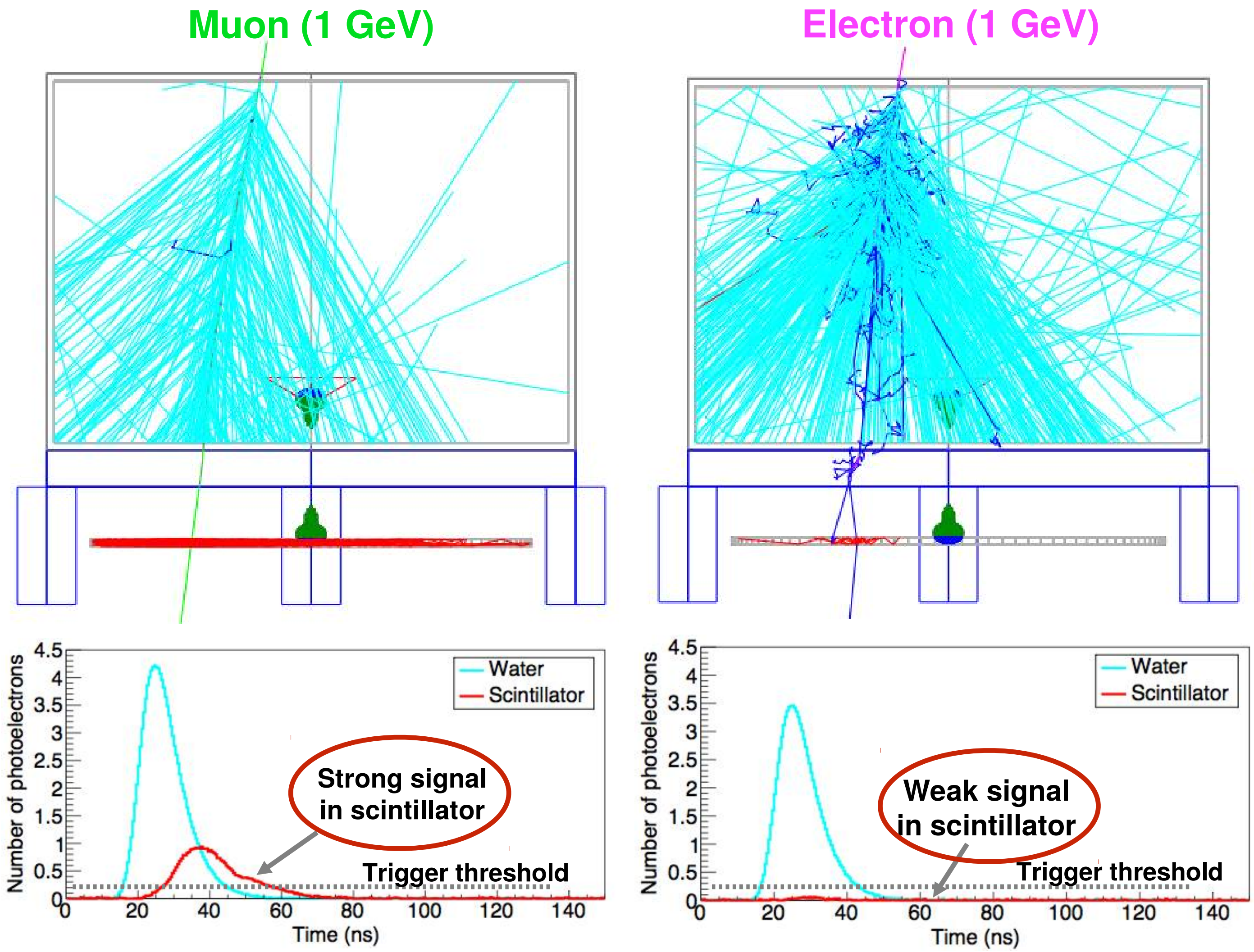
Detector simulation: GEANT4 (version 10.2)

- All material properties are included
  - Density, refractive index as function of wavelength
  - Photon reflectivity, absorption and scattering coefficients as function of wavelength

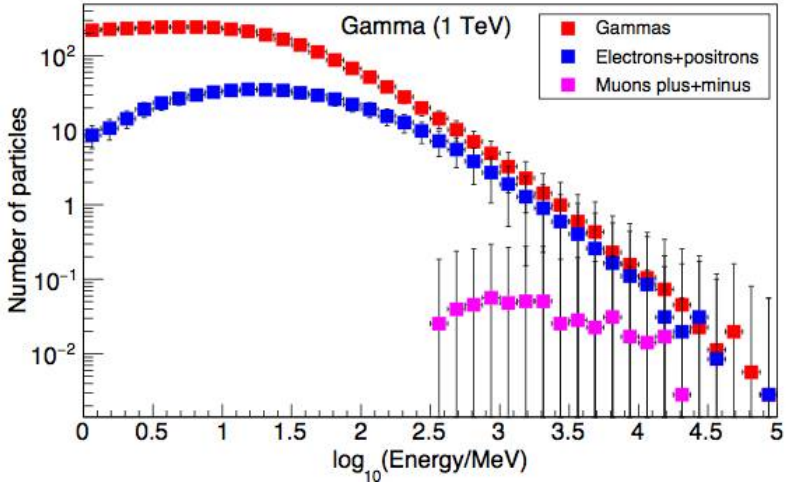
- All important physical processes are included
  - Electro-magnetic processes:
    - Y's: Photoelectric effect, Compton scattering, Pair production, Rayleigh scattering
    - $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, nuclei: Multiple scattering, ionisation, bremsstrahlung, annihilation (positrons)
    - Unstable particles: Decay
  - Optical processes:
    - Cherenkov and Scintillation photons production
    - Their emission spectrum, absorption, scattering .....

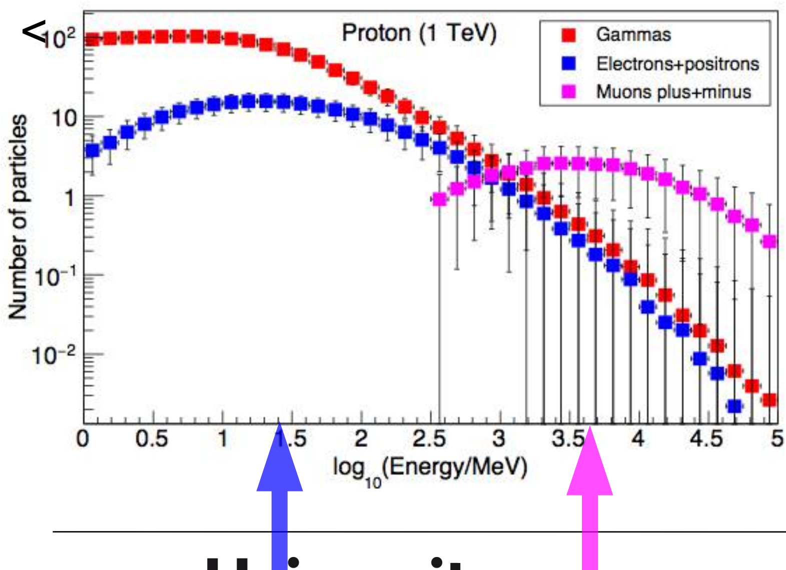
- Particle tracking
  - All particles are completely tracked by GEANT4 except for optical photons inside water tank
  - Optical photons (Cherenkov/Scintillation) are produced ~100,000 in each tank
  - For optical photons inside water tank:
    - Only those that would hit the PMT are allowed to track by GEANT4
  - For optical photons inside scintillator:
    - They are all tracked by GEANT4

ALTO Unit response to single particles



Single particles from Air Showers Energy Distribution





- Shower Muons have median energy a factor of several hundred higher than Shower Gammas/Electrons
- Factor >100 more Muons at median in Proton vs. Gamma showers

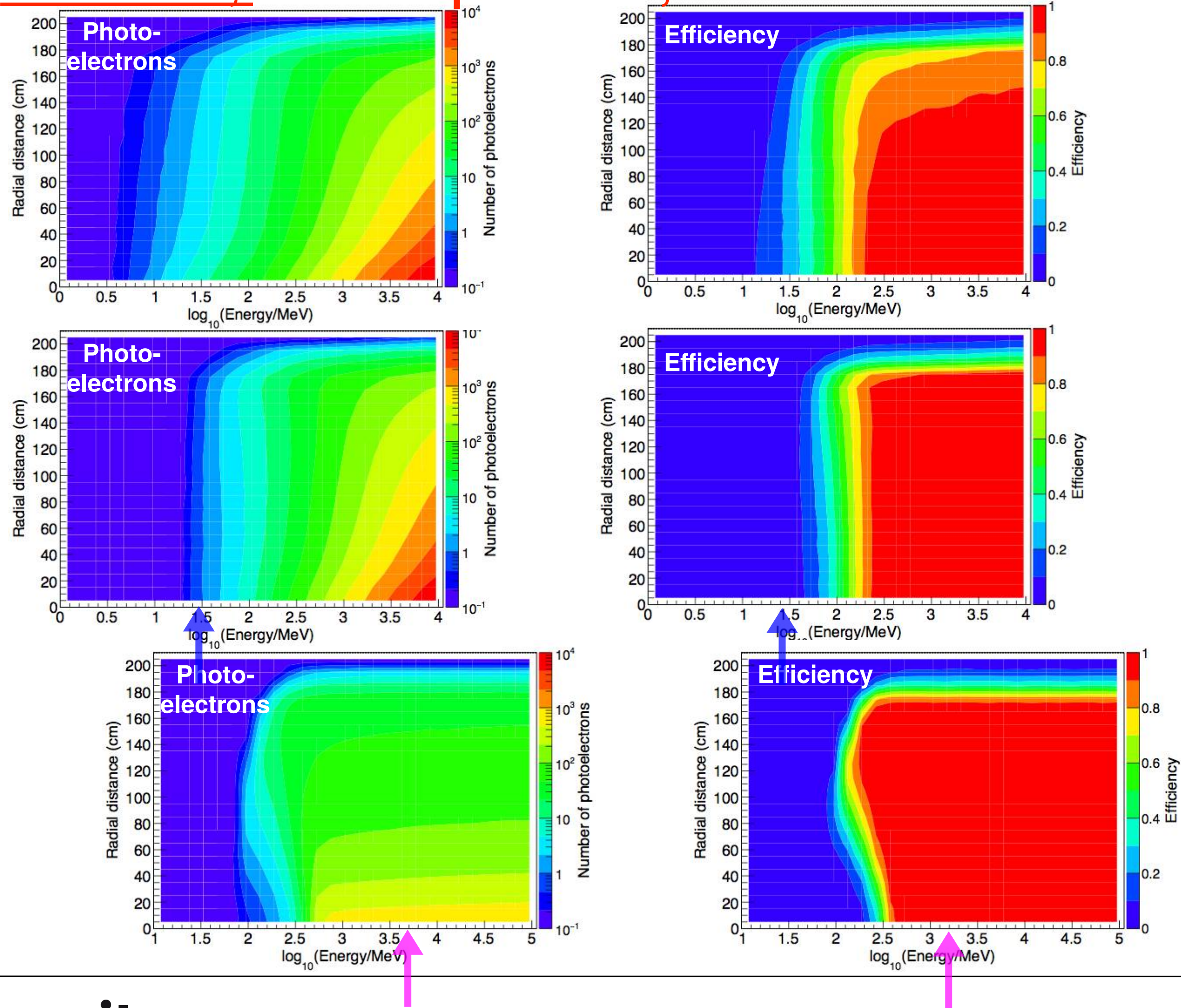
ALTO Water tank, response to Single particles

Water tank, Radial dependence, 0° incidence

Gammas

Electrons

Muons



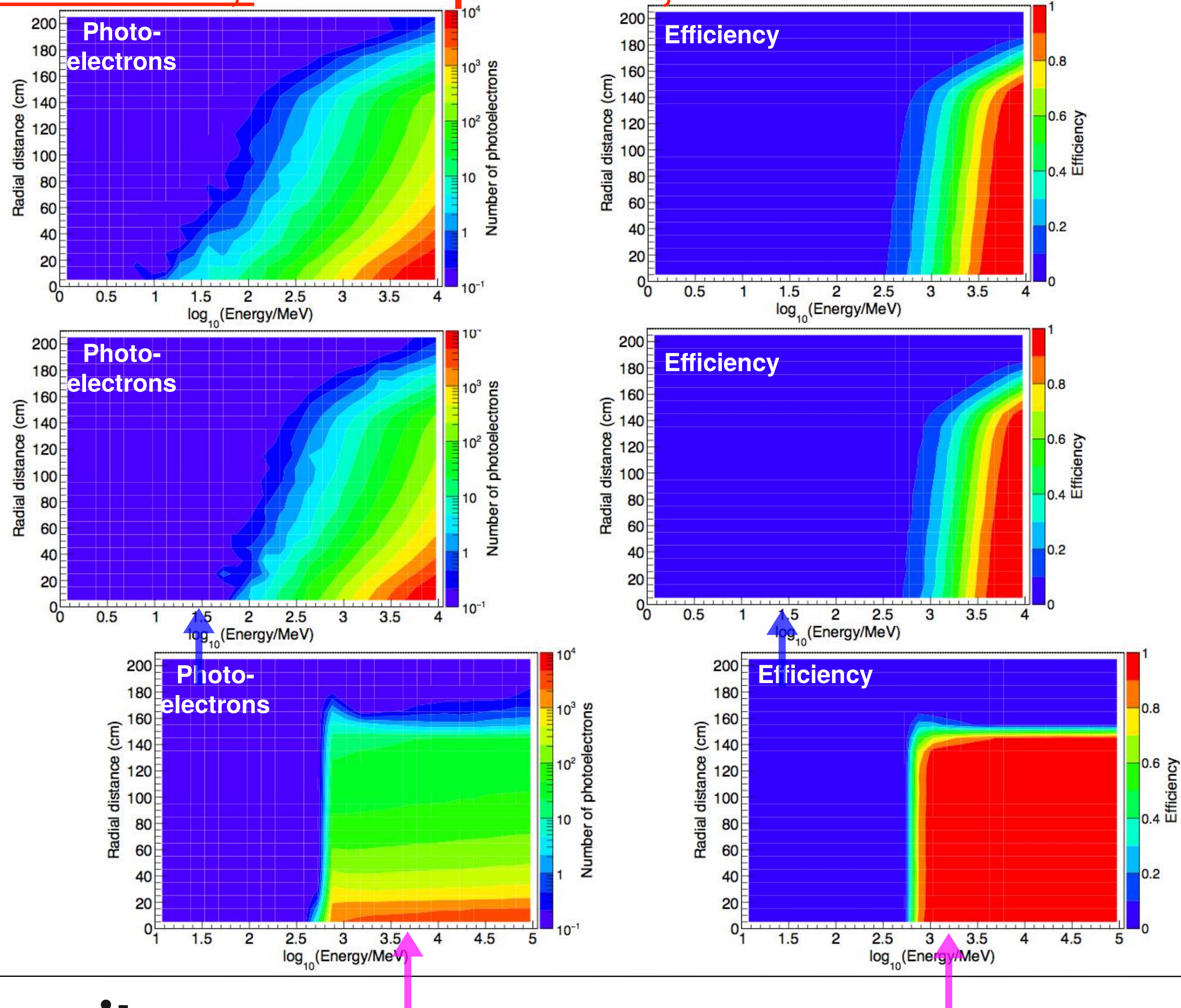
ALTO Scintillator tank, response to Single particles

Scintillator, Radial dependence, 0° incidence

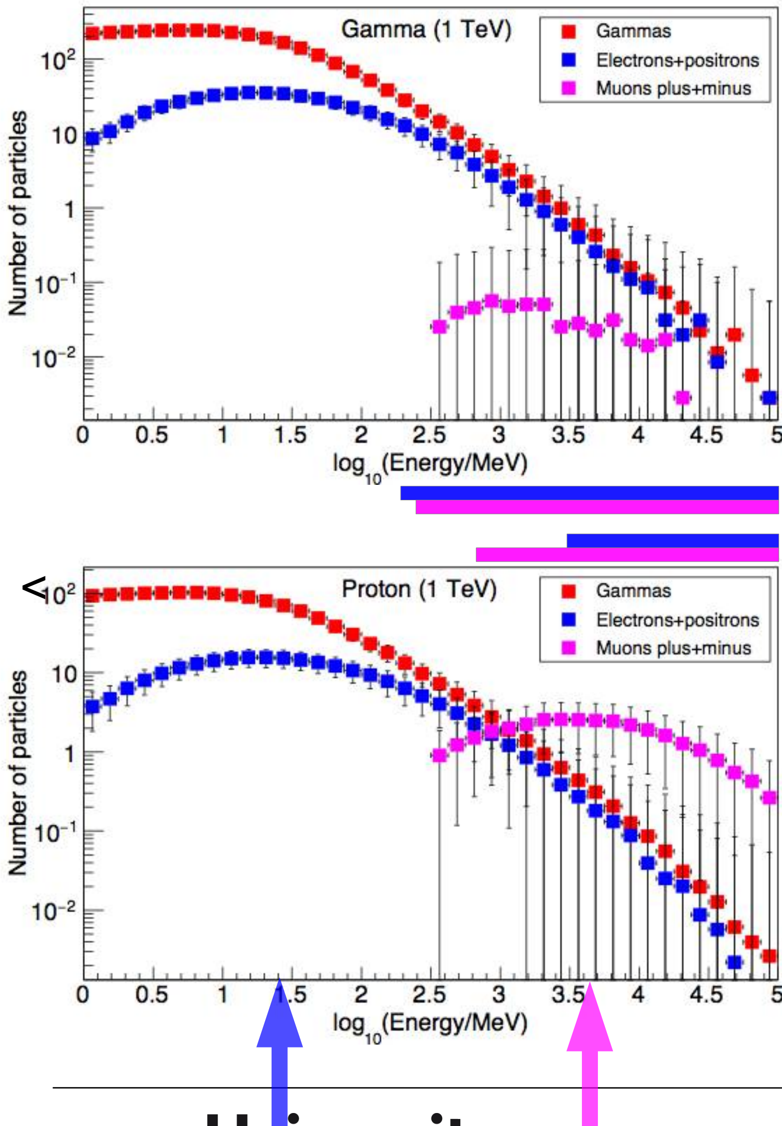
Gammas

Electrons

Muons



Single particles from Air Showers
Energy Distribution



- Shower Muons have median energy a factor of several hundred higher than Shower Gammas/Electrons
- Factor >100 more Muons at median in Proton vs. Gamma showers

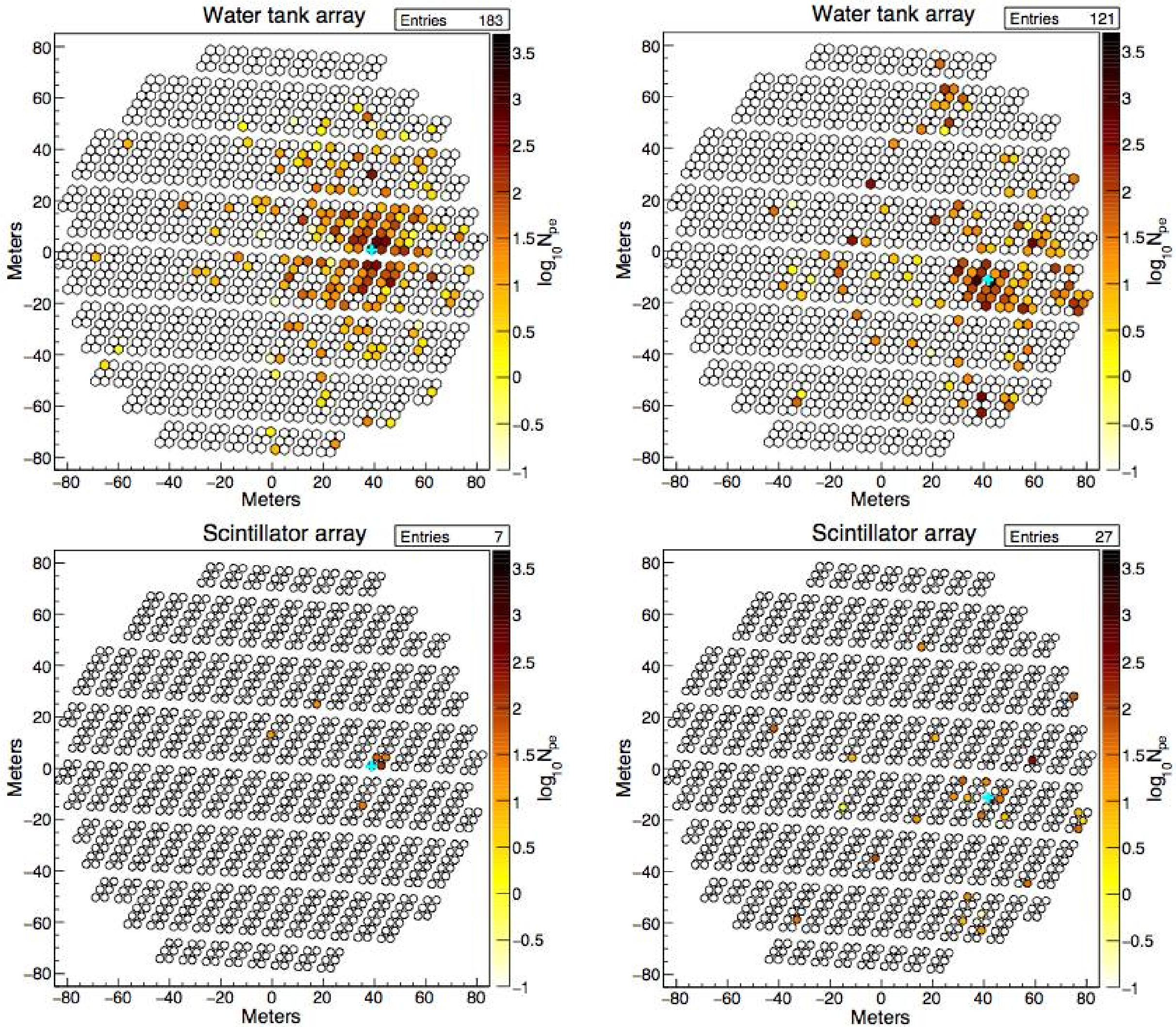
For particles injected at top of ALTO unit:

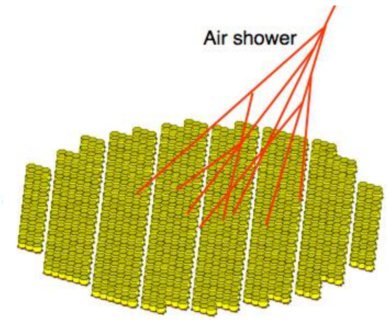
Water tank response range to electrons/muons

Scintillator response range to electrons/muons

ALTO Array response to Air Showers

Gamma ray **Cosmic-ray proton**





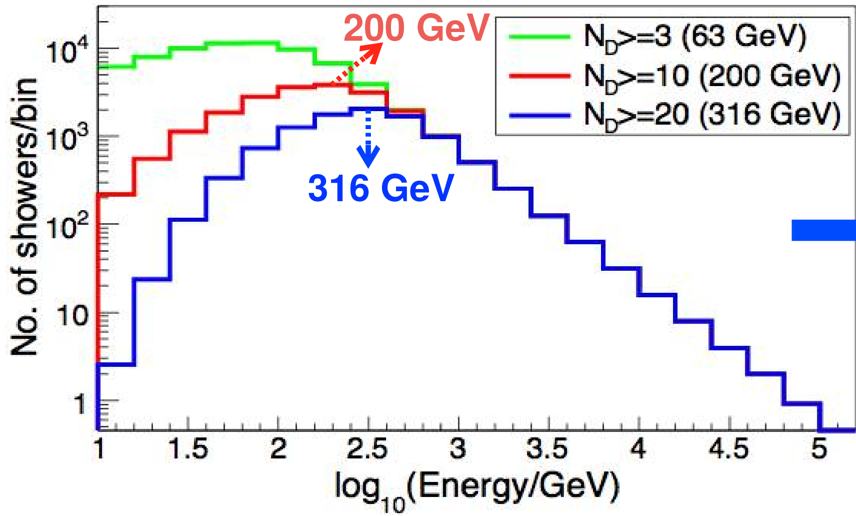
Gamma ray
- More compact
- Regular pattern

Cosmic ray
- Clumpy
- Hot spots in the scintillators at large distance from the core

ALTO Array simulated response

ALTO

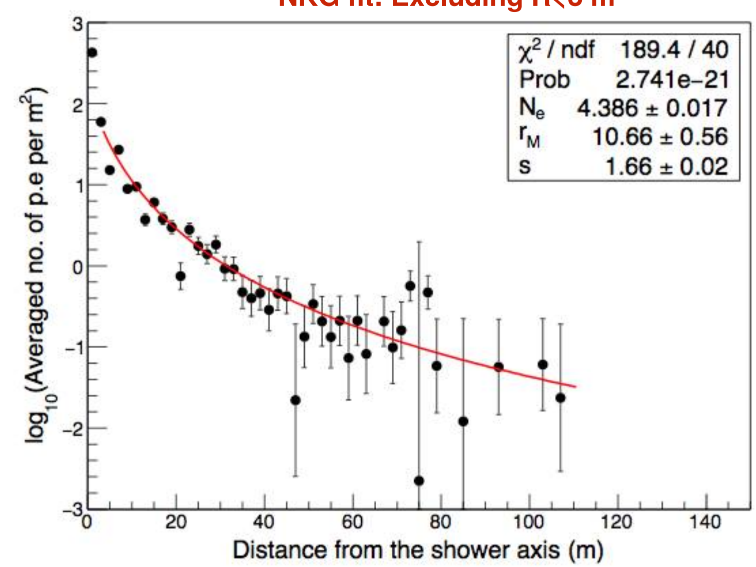
Energy distribution



Trigger
Energy threshold
~200 GeV

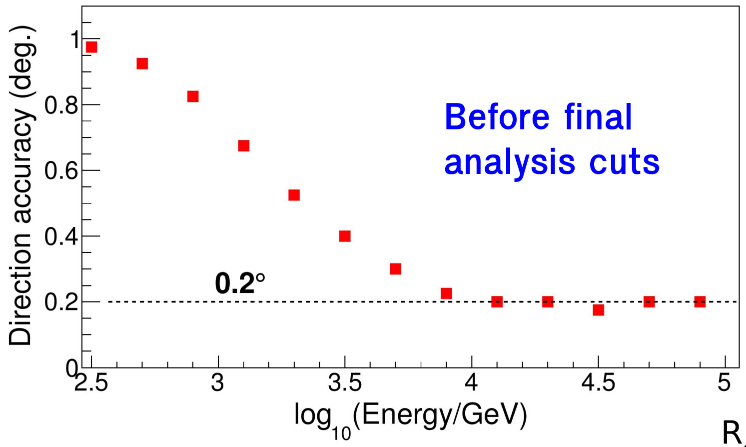
Response to Gamma-Ray spectrum with
Slope=-2.5
Zenith=18°
True core<60 m

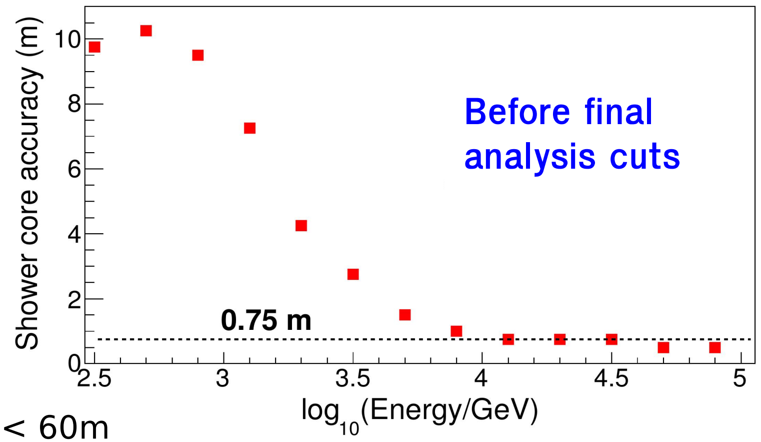
NKG fit: Excluding R<3 m



Shower reconstruction
through iterative NKG fits
(Nishimura-Kamata-Greisen)

ALTO simulated performance after simple square cuts





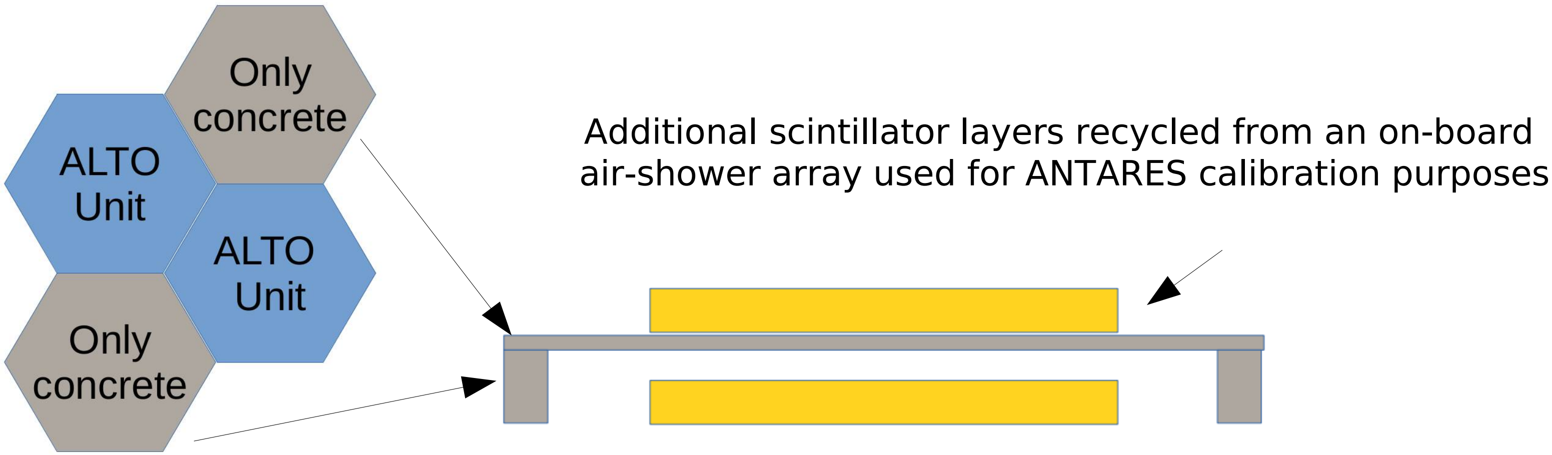
$R_{core} < 60$m

Final S/B analysis cuts still under development:

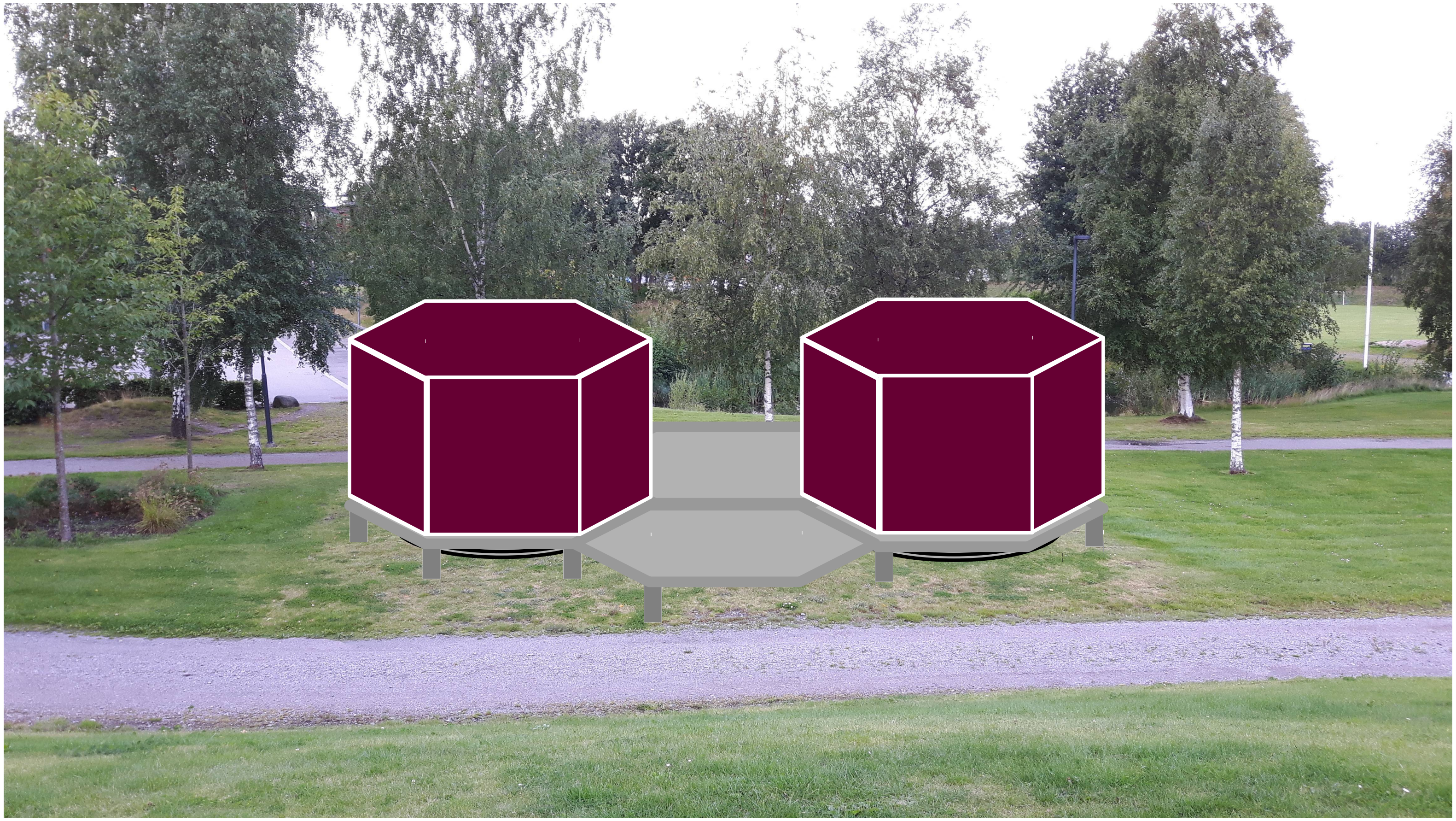
- Ideal detector would only see muons in the scintillator layer,
  but in fact some faint signal leaks beyond the concrete layer also for Gamma-ray showers;
- Several S/B parameters under investigation
  on Water-Cherenkov and scintillator tanks;
- Final S/B analysis will use Boosted Decision Trees in TMVA.

ALTO prototype at Linnaeus University in Växjö, Sweden

- Construction starts January 2nd 2018
- Several PMT solutions will be tested;
- Fully funded: construction of two full ALTO units, with 4-tank concrete layer
- The empty slots will be equipped with (smaller) additional scintillator boxes



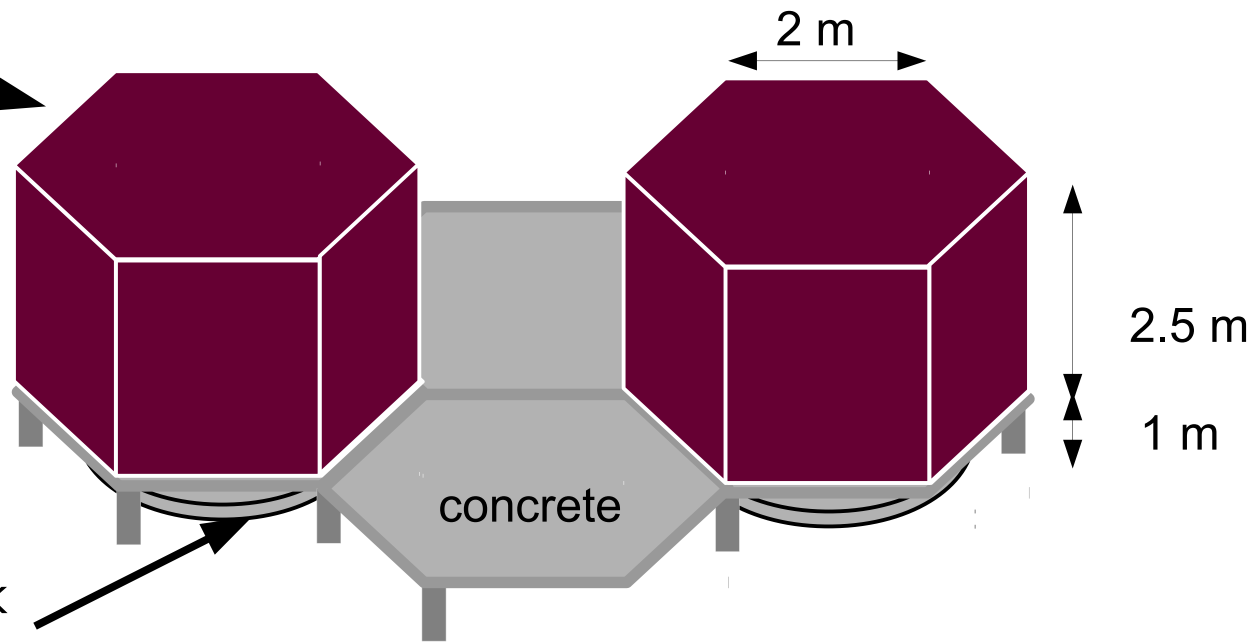
ALTO prototype setup in Växjö



ALTO prototype setup in Växjö

Water
Tank
($25\ m^3$)

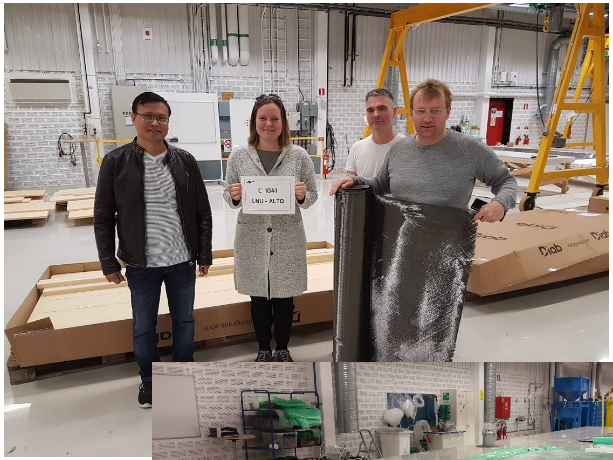
Carbon fiber
(black ”gel-coat”
painted inside)

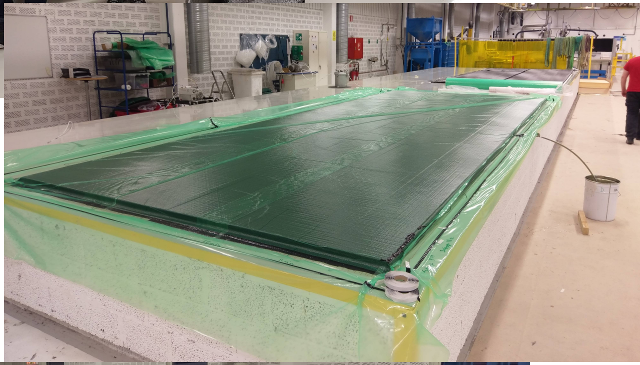


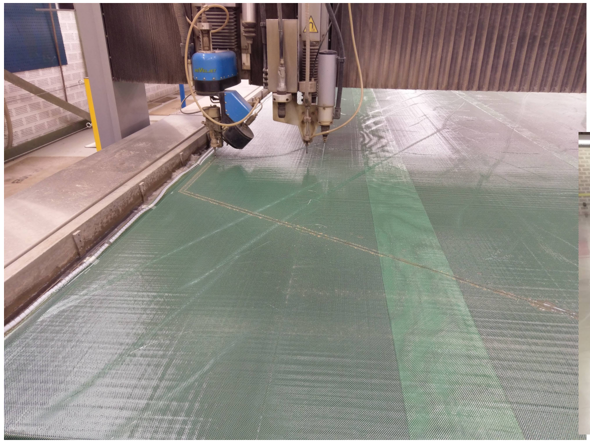
Scintillator Tank
($0.33\ m^3$)
Aluminum
(reflective inside)

ALTO prototype construction at Linnaeus University: Status

- We received the building permit
- Currently the water tanks (carbon fibre and PVC foam) being produced in Torsås by TBS Yard AB
- Aluminium SLC tanks to start when design is finalized (see “pre-protos”)
- Ground preparation starting in January, using existing pipe for fibres/poser
- Next step will be the construction of the concrete structure, installation of tanks
- Tests...







ALTO Pre-prototyping

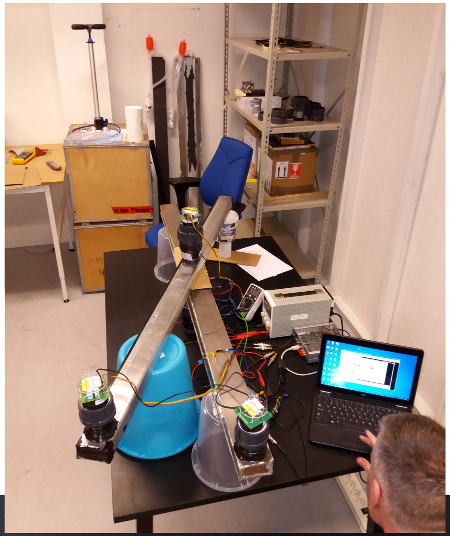
- Many test-benches, all with readout triggered
  by small (10x20cm) muon-paddles, read by "WaveCatcher"
  - All compared with GEANT4 simulations to find reflectivity, absorption, etc.

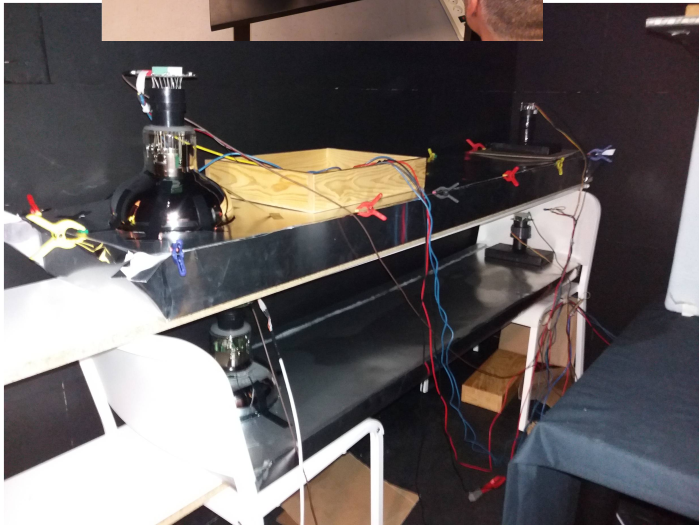
- Small water tank viewed from above by 8" PMT, to test
  - blackness of the internal "gel-coat"
  - Effects over time with strong chlorine concentration (bio-growth, leaching)
  - → 20x normal swimming pool concentration OK for now

- "Scintillator rails" read by 2" PMT
  - To test Aluminium material used in lower tank
  - Comparison of measured and expected
    (from GEANT4 simulations, adjusting reflectivity & polish)
  - → led to redesign using folded 0.5mm Al sheet
    - No welding, much simpler construction

- Large scintillator tank read by 8" PMT
  - To test aluminium material with final PMT immersed in Scintillator
  - Test of re-design → Confirmation of simplicity of construction
  - Result scalable to full-sized tank
    (factor ~x2 PE from reflections on walls)

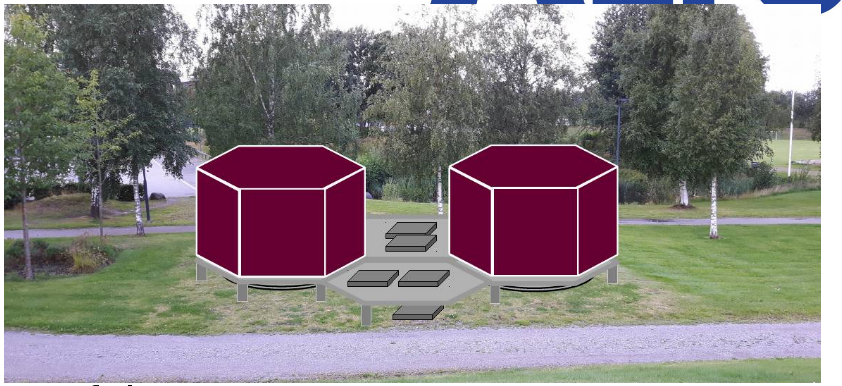
- Comparison with a deeper (10cm) tank with Water (not scintillator)
  but with liner to replace scintillator tank, currently running
  - May be able to reduce costs, avoid some radioactivity triggers





Project time-line & Next steps

- 2018 - Validation of prototype design;
  - At LnU campus, with "Antares Surface Array"



- 2019 - If design & funding requests successful:
  - Installation of one or more ALTO clusters at the site in the Southern hemisphere;
  - Flat-pack construction ("IKEA-type") assembly by local crew or "base camp"

2018-Q1 — Prototype construction

2018-Q2-Q4 — Prototype validation and operation

2019? — Installation of one or more clusters at the final site for further validation

Full deployment

ALTO site in South America

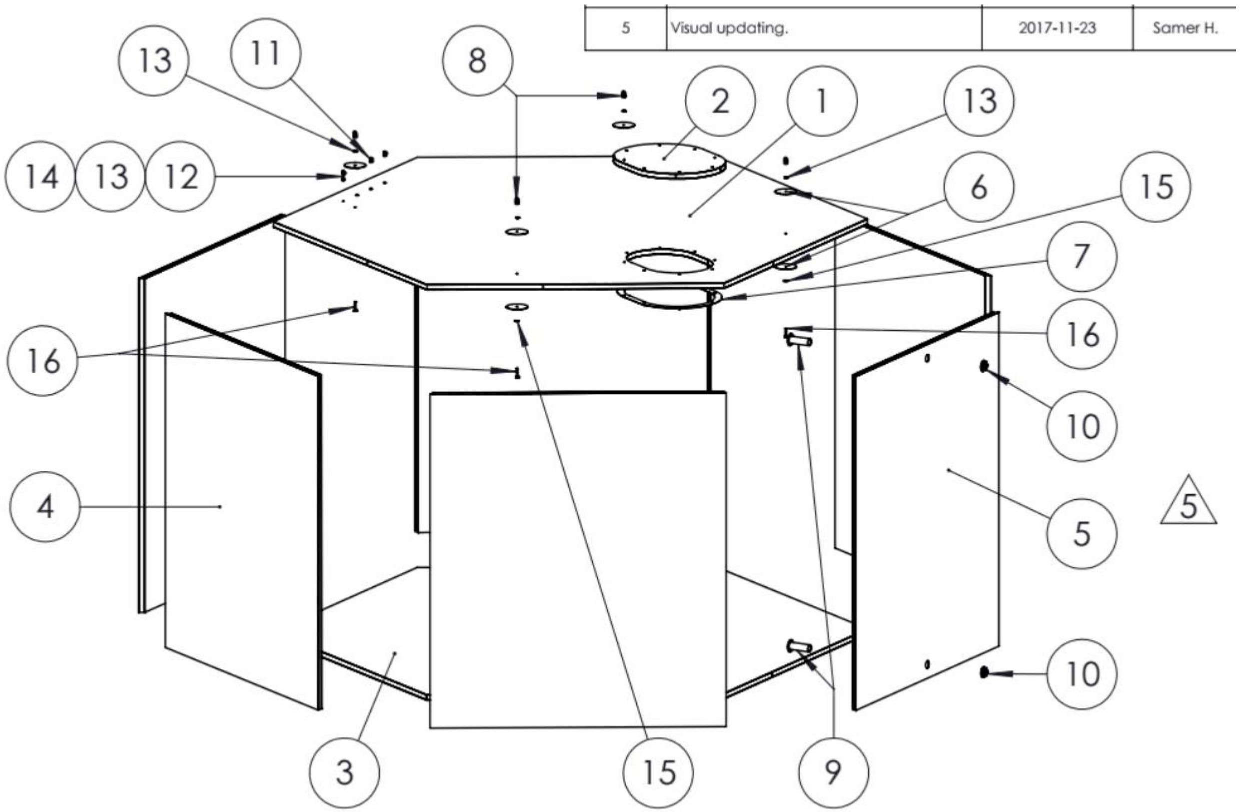
- Presence of water nearby is a key factor, to lower the costs
- In order to simplify and be quick, we are aiming for the installation of 2-3 full ALTO clusters behind the site of QUBIC/LLAMA in Argentina, at an altitude of 4850 m
  - Synergies within APC lab which is working on QUBIC
- We should be in the back lobe of QUBIC in order not to disturb the QUBIC experiment data taking
- There might also be the possibility to share infrastructure, power, network, roads
- The 2-3 cluster installation will allow us
  - To further test the construction feasibility at high altitude
  - To acquire further experience on singles and coincidence rates
  - To build partnerships with local industries

Conclusions

- ALTO is a new project, financially supported primarily by
  Linnaeus University and Swedish private Foundations for now;
- The project’s aim:
  → to build a wide FoV VHE gamma-ray observatory
  with enhanced sensitivity with respect to current WCDA technology;
- Simple design:
  → limits costs of construction in full production phase; Prototype costs higher;
- Collaboration between Academia and Industry:
  → cost-effective solutions;
  → knowledge transfer benefiting both parties;
- Possible location of the observatory:
  → Argentina, near QUBIC/LLAMA;
- Aimed investment cost for full deployment
  → ~ 20M€ excluding salaries;
- Expansion of collaboration:
  → to cover costs, expertise in DAQ, design optimisation
- Status of the project with further information can be found at the website:
  → http://alto-gamma-ray-observatory.org/
- For enquiries about the project, please contact yvonne.becherini@lnu.se

Backups

Exploded view of Water Tank



Exploded view of Scintillator Tank