Monitoring the energetic Universe with the ALTO Observatory

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

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The ALTO project

- Project born in 2014 at Linnaeus University after a research grant from the Crafoord Foundation was received

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

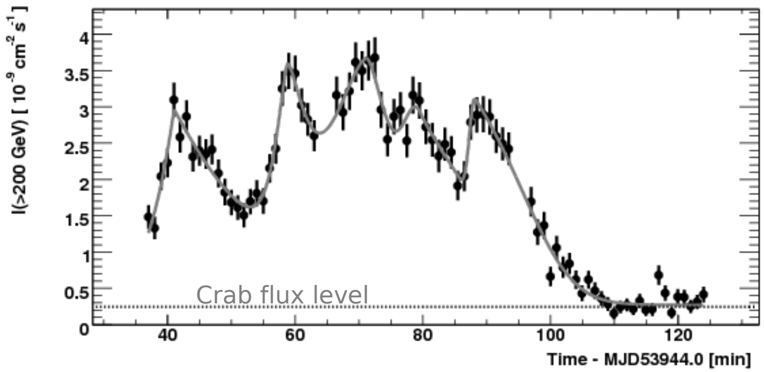
    - In the Southern hemisphere → Daily observations of Southern sources
    - At high altitude (> 5 km) → Low threshold E ≥ 200 GeV
    - Particle detectors → Observations may be done 24h per day
    - Hybrid detectors → Improved S/B discrimination
    - Excellent timing accuracy → Improved angular resolution (∼ 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”

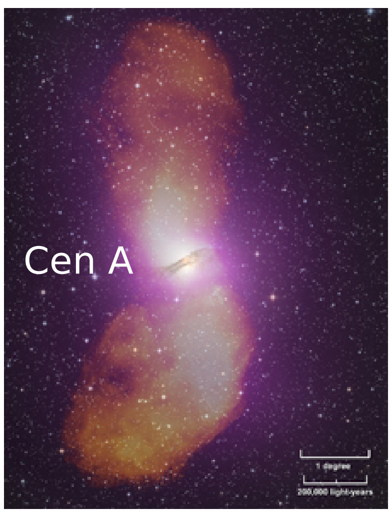
ALTO Science Goals

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 alerted to detections of:
    - gravitational waves or
    - neutrinos;
- Study of the cosmic-ray composition & 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

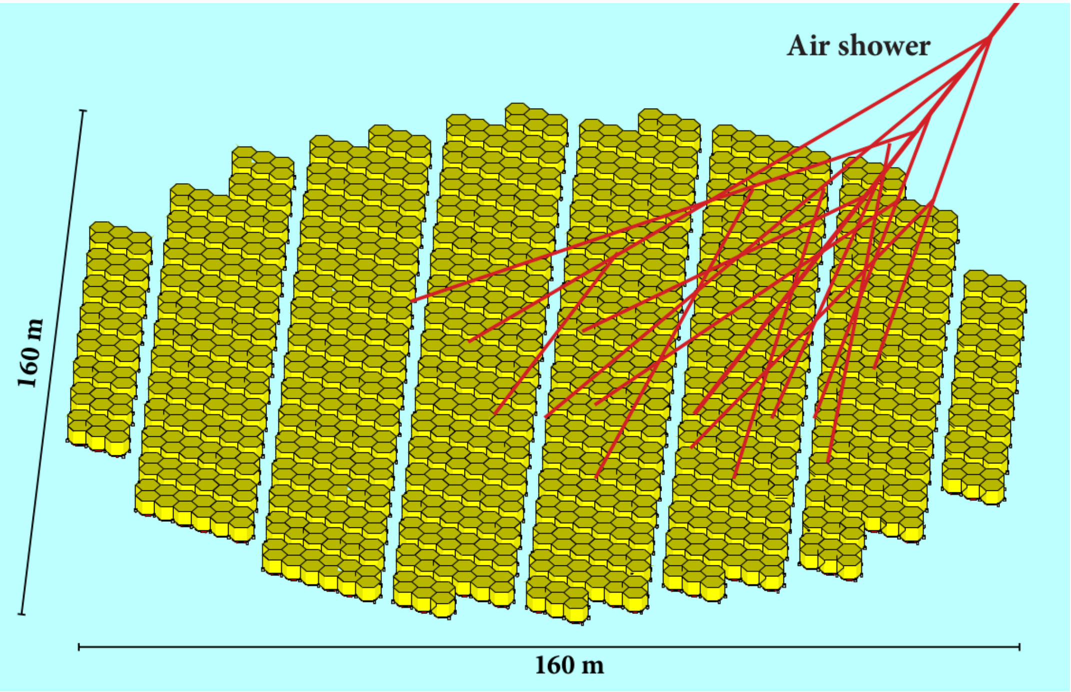
• Department of Physics and Electrical Engineering, Linnaeus University, Växjö
  • PI Yvonne Becherini
  • Post-doc Satyendra Thoudam
  • Two PhD students
• Industry: TBS Yard AB, Torsås
  • Industrial construction responsible Lars Tedehammar
	• APC Laboratory, IN2P3/CNRS, Paris
	  • Michael Punch
	  • Jean-Christophe Hamilton (discussions about the site)
	• Aix-Marseille University
	  • Jean-Pierre Ernenwein
	• LAL/Orsay
	  • Dominique Breton, Jihane Maalmi (work on WaveCatcher electronics)
	• CEA/Saclay
	  • Eric Delagnes (past discussions on electronics)

Discussions with other parties: the SGSO alliance

Key design characteristics of the full array

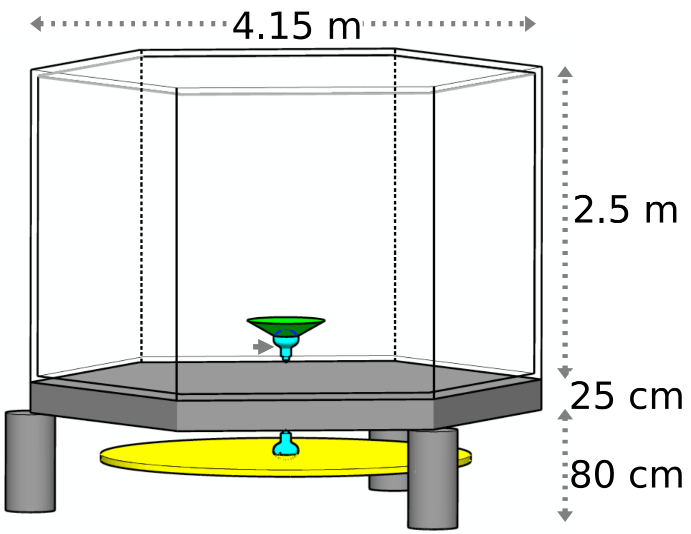
- We aim to construct and operate an array:
  - In the Southern Hemisphere (Argentina)
  - At an altitude ~ 5 km a.s.l
  - With an energy threshold of 200 GeV
  - Composed by ~ 1200 detector units

- Key characteristics wrt HAWC:
  - Advanced electronics with sub-ns timing
  - Small-sized, closed-packed WCDs
  - Low dead-space ("packing factor" ~70%)
  - Muon detectors below the Cherenkov tanks

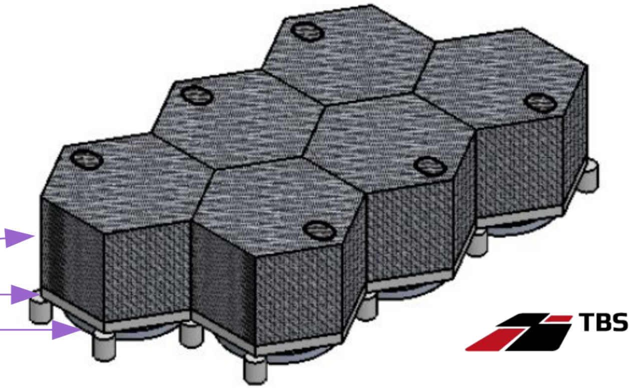


ALTO detection unit & cluster

- Water Cherenkov tank:
  contains one Hamamatsu super-bialkali 8’’ PMT;
- Muon-detector scintillator tank for background rejection:
  - Liquid scintillator box (Scintillator Layer Detector, SLD) with one 8’’ standard Hamamatsu PMT;
- Advanced electronics for 6-tank “cluster”,
  WaveCatcher + White Rabbit:
  - Trigger channel precisely time-stamped with “White Rabbit” system;
  - Analogue memories + ADCs measure the waveform of the detector pulses;
  - SBC (single board computer) for local control & acquisition
  - No cables from central DAQ room, only fibres.

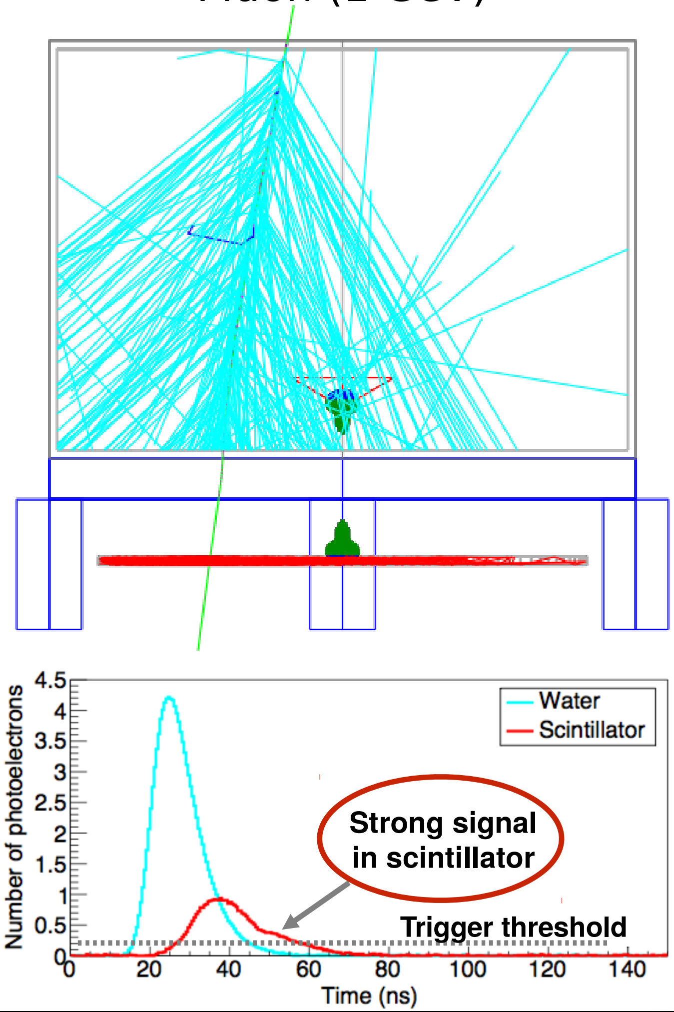


ALTO Cluster
- WCD tank
- Concrete table
- SLD box

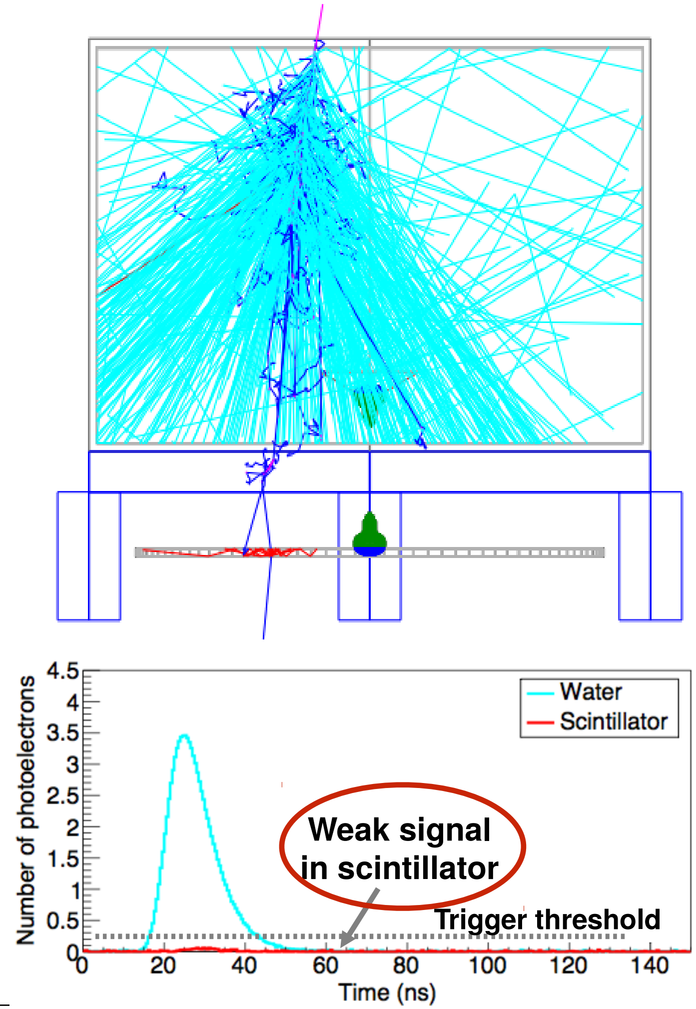


ALTO response to single particle

Muon (1 GeV)



Electron (1 GeV)



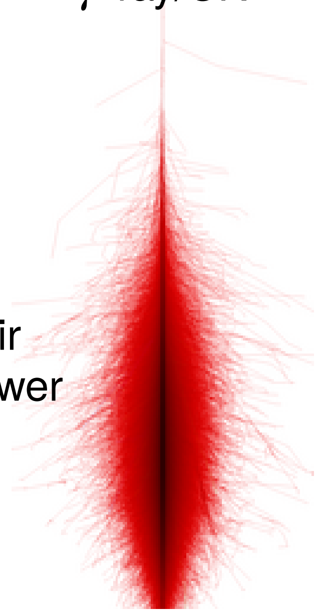
Monte Carlo simulations, reconstruction & higher level analysis

ALTO

- Corsika simulations:
  - Point-like gamma-rays (18 deg)
  - Diffuse protons (0-30) deg
- Geant4 simulations:
  - Cherenkov tank is black, so we track only photons which geometrically reach the PMT
  - Very CPU-consuming for ~ 1200 ALTO units
- Reconstruction of shower parameters:
  - Direction with hyperbola fit
  - Core position with NKG fit

- Muon tagging (new!):
  - Muon signal identification procedure (per unit)
- S/B discrimination with TMVA/BDT:
  - 9 parameters using:
    - Detected/expected water Cherenkov charge
    - Detected/expected scintillator charge
    - Number of triggered detectors
    - …
- High level analysis with Python-based book

Monte-Carlo simulations: Corsika



Air shower simulation: CORSIKA (version 7.4000)

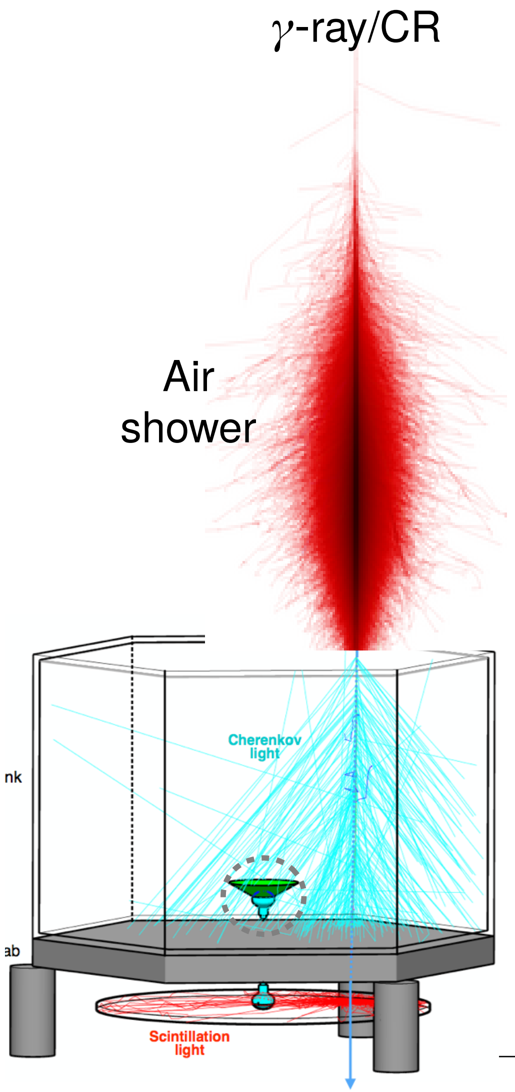
- Realistic model of Earth's atmosphere, magnetic field, refractive index, ….
- Electromagnetic and hadronic interactions based on particle physics models.

Parameter	Gamma rays	Proton
Observation height	5.1 km	Same
Energy	10 GeV-100 TeV	158 GeV-100 TeV
Spectral slope	-2.0	-2.7
Zenith angle	Fixed at 18°	0-30°
Azimuth angle	Fixed at 180°	0-360°
Magnetic field	ALMA site	Same
Core position (from array centre)	0-100 m (square)	Same
No. of showers	~17 million	~21 million (→ 12 minutes!)

Note:
- No reuse of Corsika showers currently

Future: planning for
- protons simulations up to 48°
- gamma-ray simulation at multiple zenith angles (18, 32, 41°)

Monte-Carlo simulations: Geant4



Air shower simulation: CORSIKA (version 7.4000)

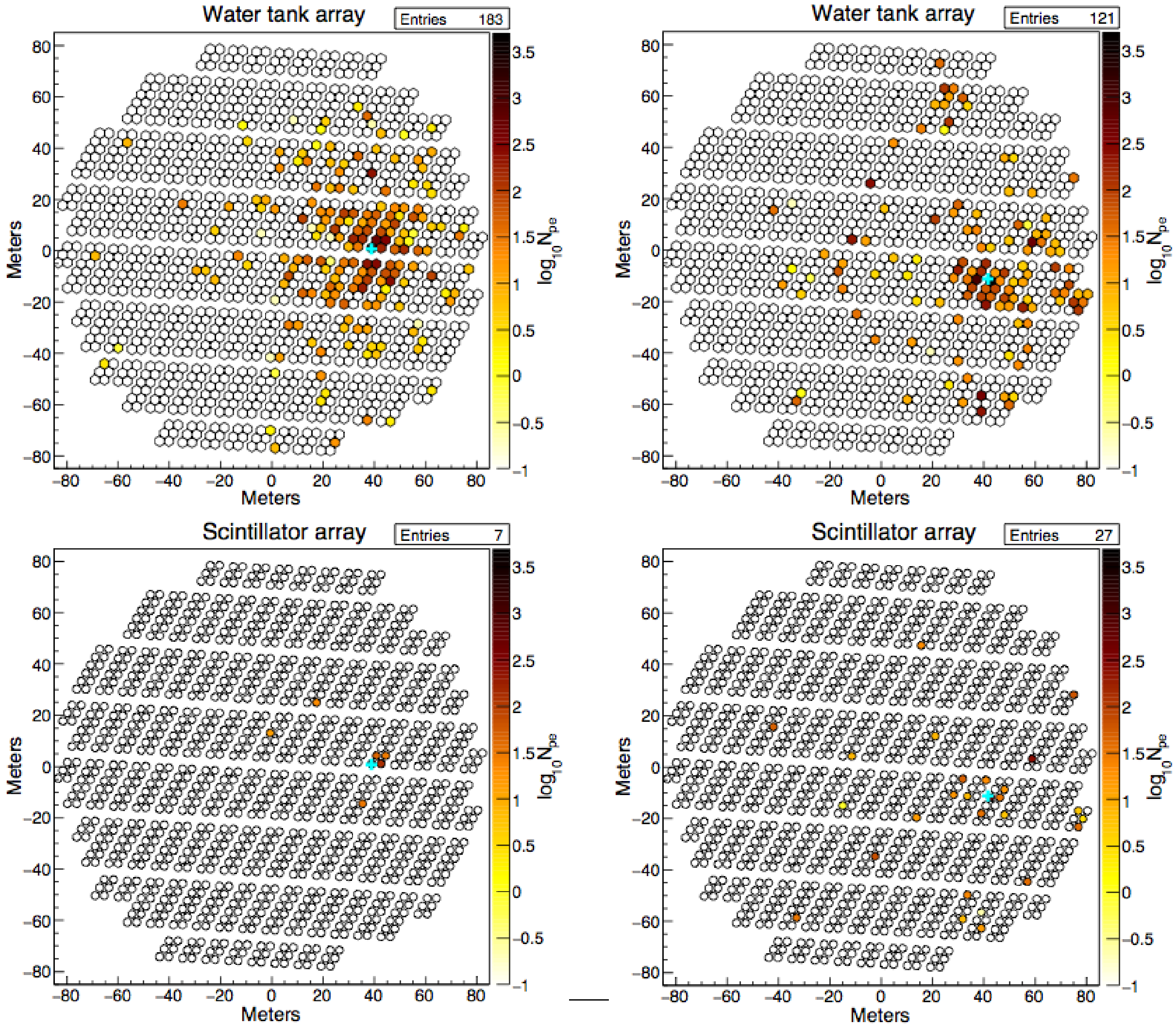
- Realistic model of Earth's atmosphere, magnetic field, refractive index, ….
- Electromagnetic and hadronic interactions based on particle physics models.

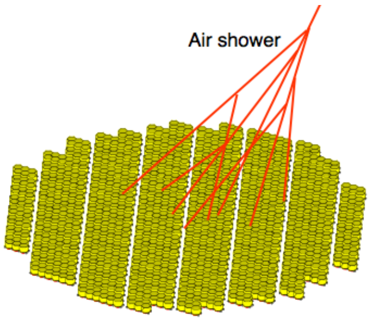
Detector simulation: GEANT4 (version 10.2)

- **All material properties included:**
  - Density, refractive index as function of wavelength.
  - Photon reflectivity, absorption and scattering coeff. as function of wavelength.
- **All important physical processes included:**
  - Electro-magnetic processes:
    - γ'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 completely tracked by GEANT4 except for photons inside WCD.
  - ~10^5 photons (Cherenkov/Scintillation) produced in each tank.
  - For optical photons inside water tank:
    - Only those that are likely to hit the PMT are tracked.
- **Signal propagation inside photomultiplier tubes:**
  - Include signal time spread (TTS) and PMT gain fluctuations.

ALTO Array response to Air Showers

Gamma ray | **Cosmic-ray proton**





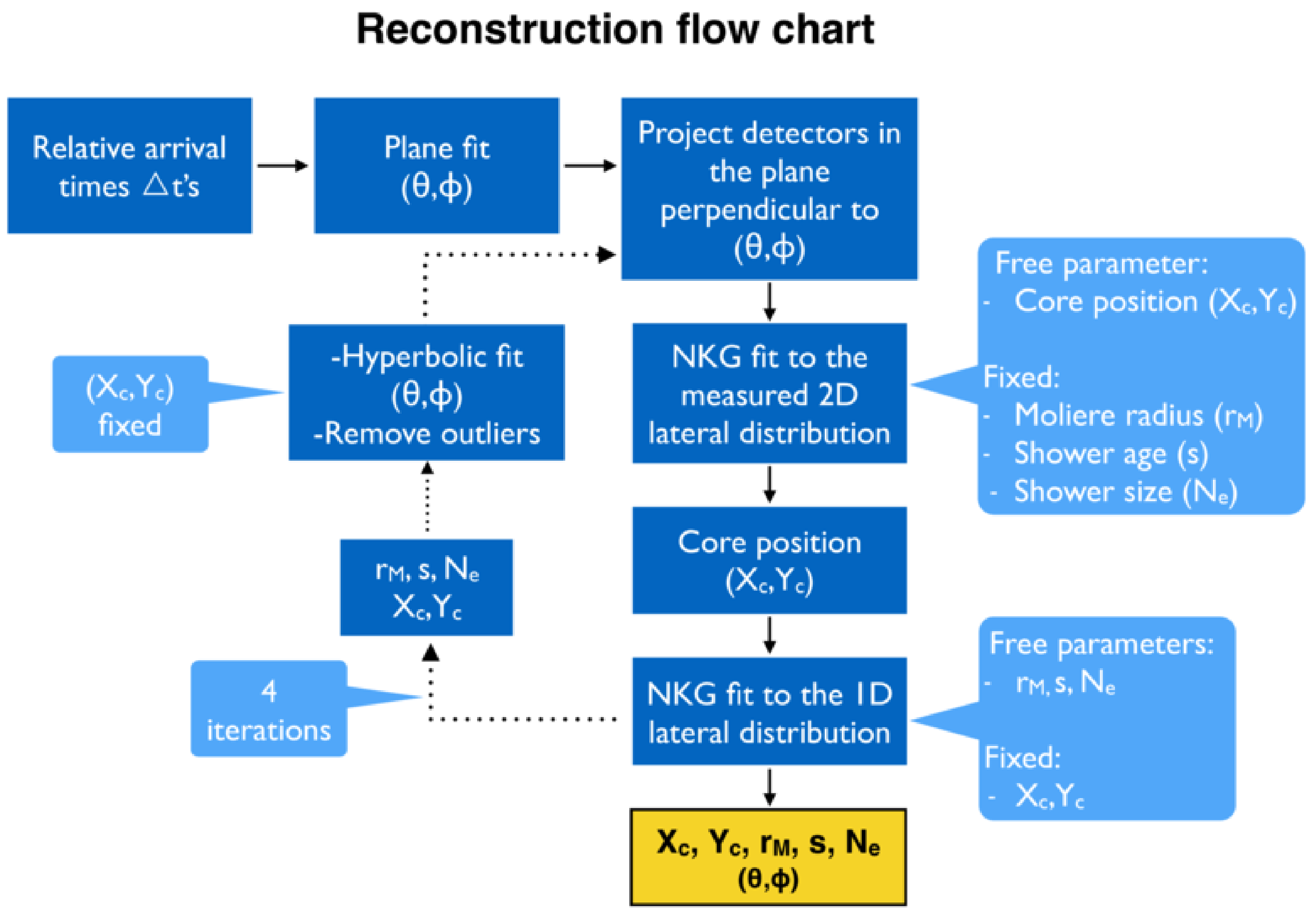
Gamma ray

- More compact
- Regular pattern

Cosmic ray

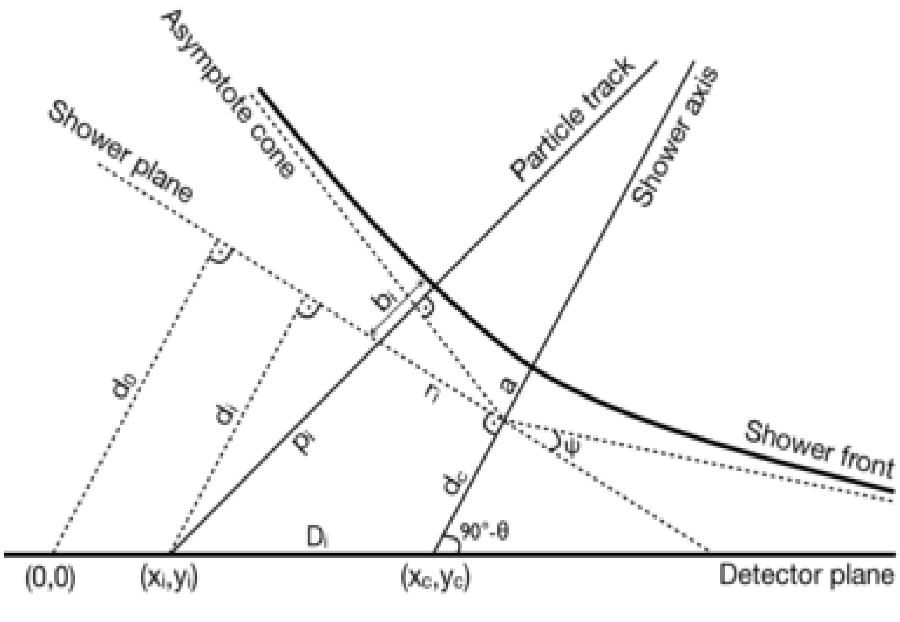
- Clumpy
- Hot spots in the scintillators at large distance from the core

A multi-fit process for core + size, direction

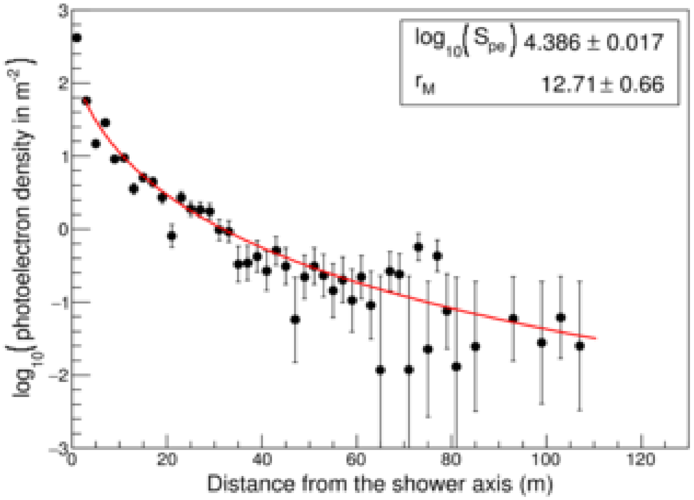


Event direction and position on the ground

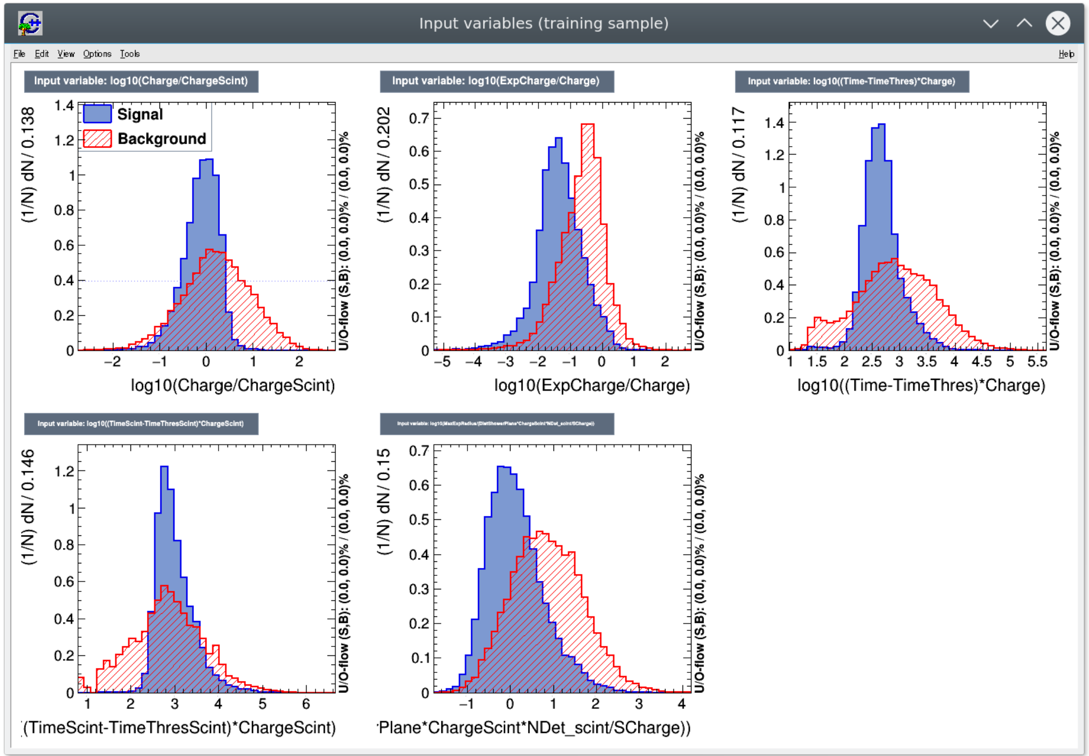
Hyperbolic fit to the wavefront

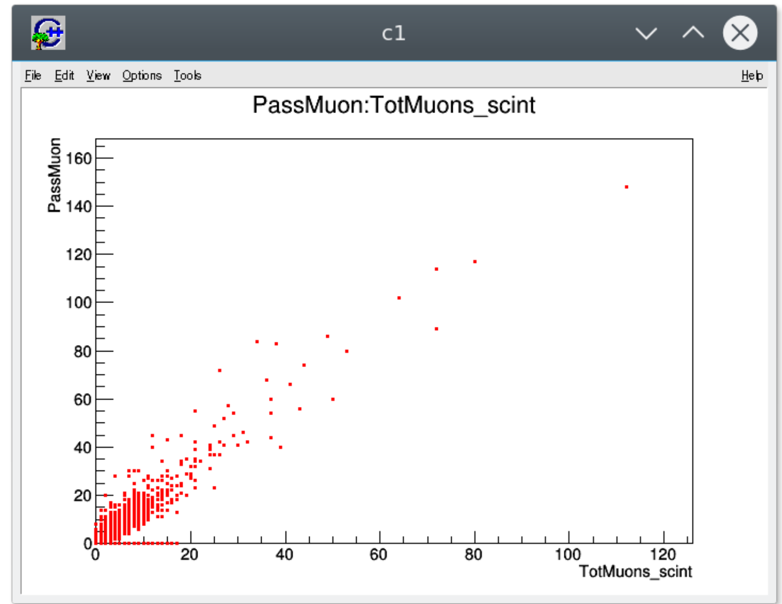


1-D Lateral distribution



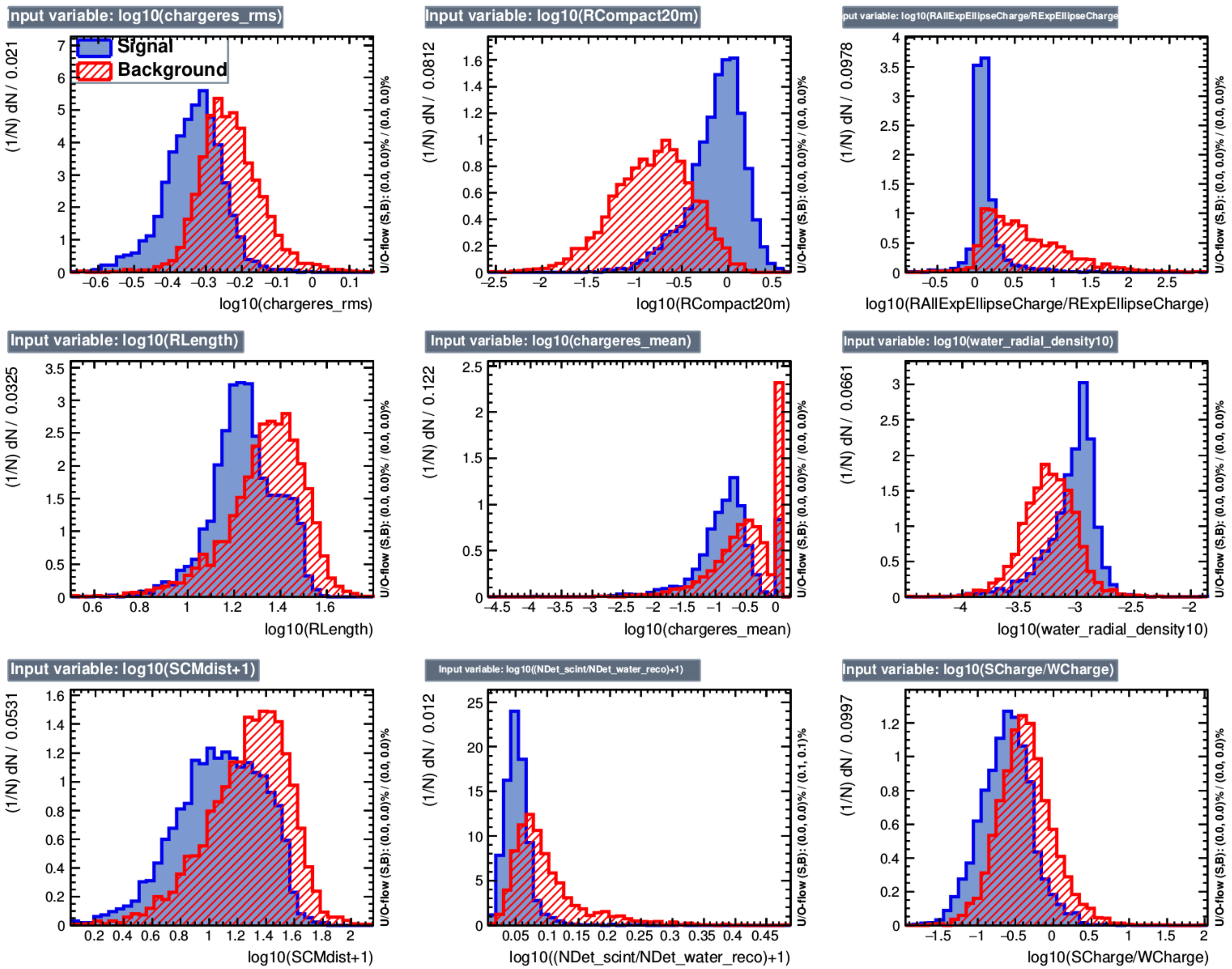
The importance of the scintillator: Muon tagging (in progress)





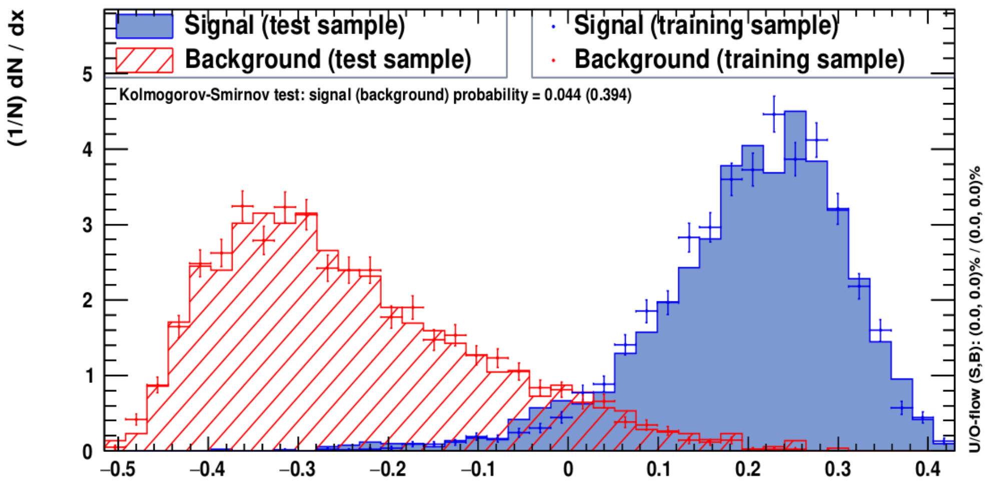
- BDT training done unit by unit
- Reconstruct a single parameter ”Muonness” for the single event
- It overestimates the presence of muons but still cuts 18% of protons and only 4% of gammas

S/B discrimination

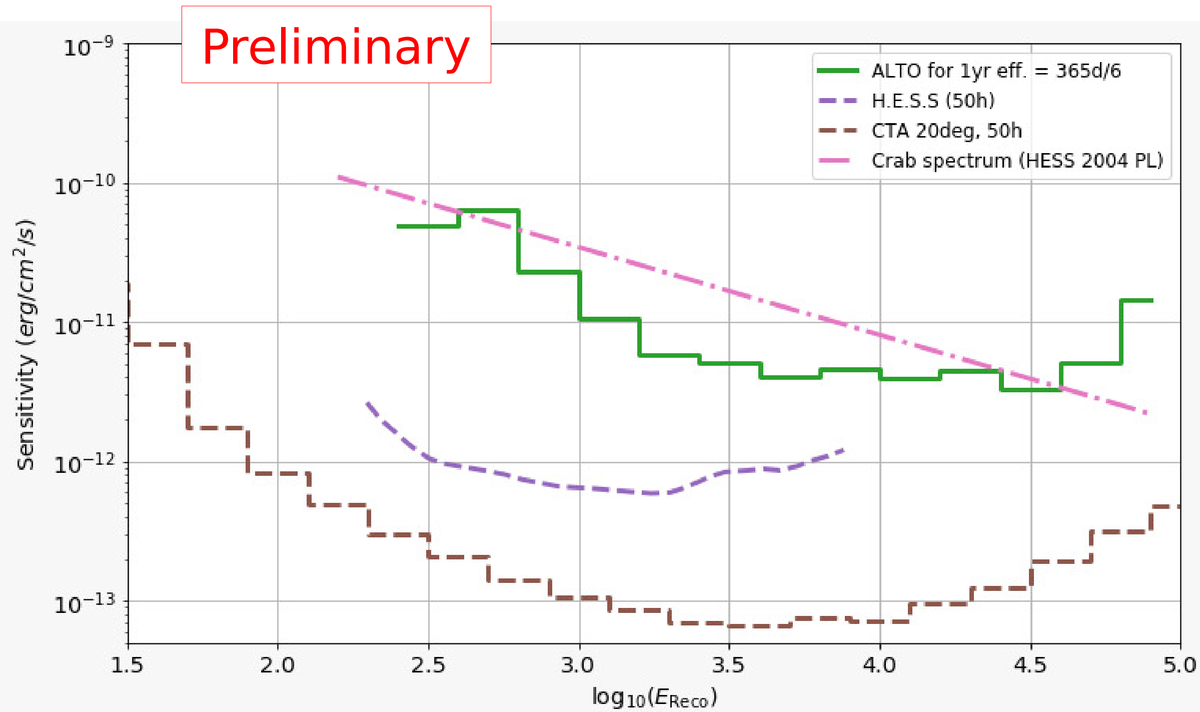


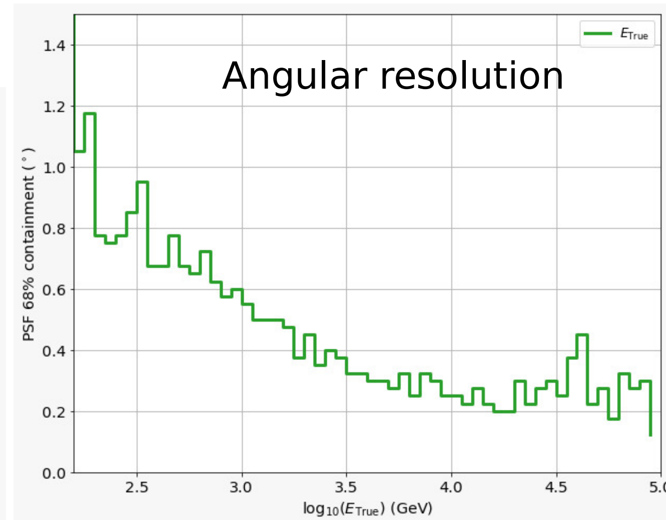
S/B discrimination

Bin number	S_{pe} limit	μ_{TE}(in GeV)	gamma efficiency	hadron efficiency
1	1.00 - 3.78	343	0.4	0.130
2	3.78 - 4.08	729	0.6	0.110
3	4.08 - 4.40	1273	0.8	0.099
4	4.40 - 7.00	4874	0.9	0.039



Sensitivity for 2 integrated months of data on a source at 18° from Zenith





Further improvements overall expected now that the software chain is complete

ALTO prototype

at Linnaeus University

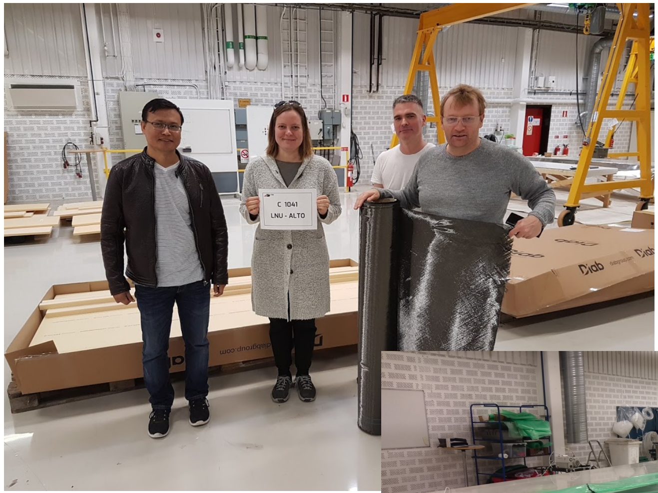
ALTO prototype construction timeline in 2018

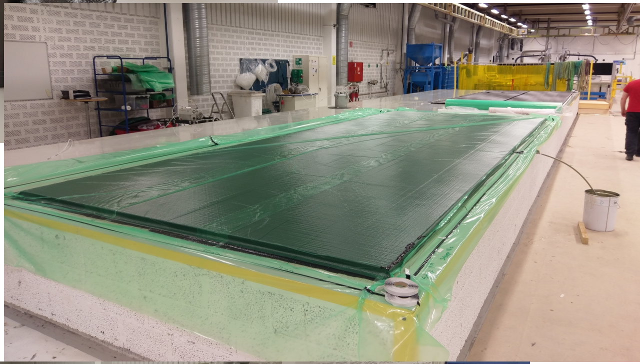
Follow our Blog on the website alto-gamma-ray-observatory.org

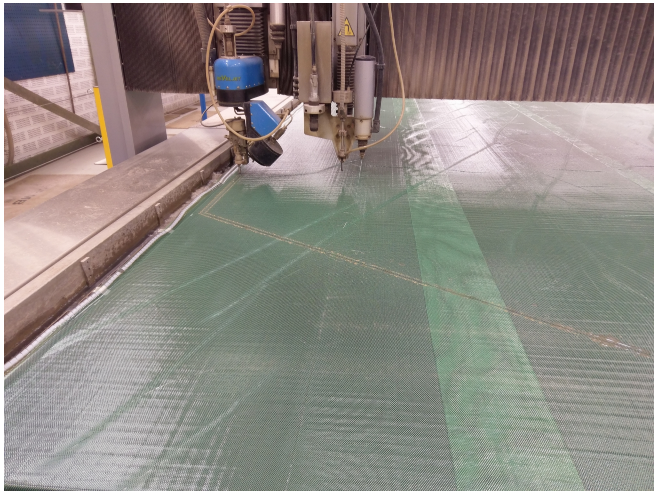
- Jan 8: Digging at the prototype site on LnU campus started
- Jan 26: Ground preparation and underground concrete base finished, columns construction well underway
- Jan 31: Concrete slab pouring
- Feb 27: Concrete structure ready, first water tank ready at TBS Yard (needed more carbon fibre for the second tank)
- Apr 7: Both water tanks ready, water resistance test
- Apr 18: Water tanks arrived at prototype site
- May 6: Photomultipliers installed in the water tanks and work on electronics and network ongoing
- May 8: First air-Cherenkov coincidence event between ALTO tanks with the full DAQ chain
- May 16: Filling of water Cherenkov tanks
- May 25: Data taking with ALTO water Cherenkov tanks started
- June 28: Added small plastic and liquid scintillators, waiting for the final ALTO scintillators
- Aug 7: Muon detectors production started
- Oct 7: Event display available
- Nov 30: Muon detector arrives at Linnaeus University
- Now: Scintillator tank inside for tests. No oil leakage, PMT installed, procedures of oil filling and installation set up
- January: Installation of the muon detector below the water tank.
- February-March: Validation and feedback on the muon detector to Industry
- Inauguration: possibly September

ALTO WCD Tank Construction (2017)

- Composite material
  - Carbon fibre and PVC foam
  - Produced in Torsås by TBS Yard AB
- Planned for “flat-pack” shipping
  - Remote assembly
  - Gluing with Carbon fibre overlaps





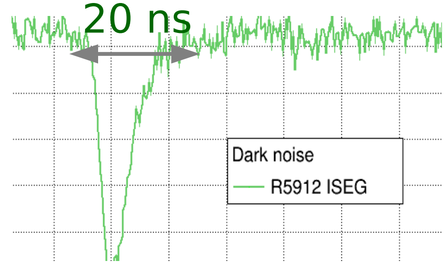


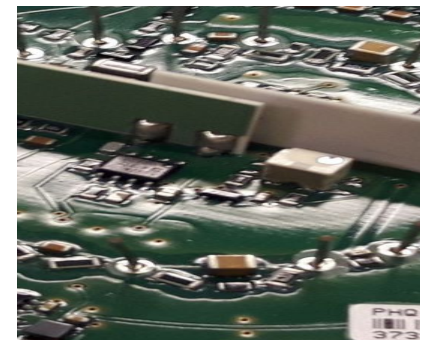
8” Hamamatsu PMT

20 cm

8 inch
photomultiplier
10 dynodes

Gain ~ 10^7

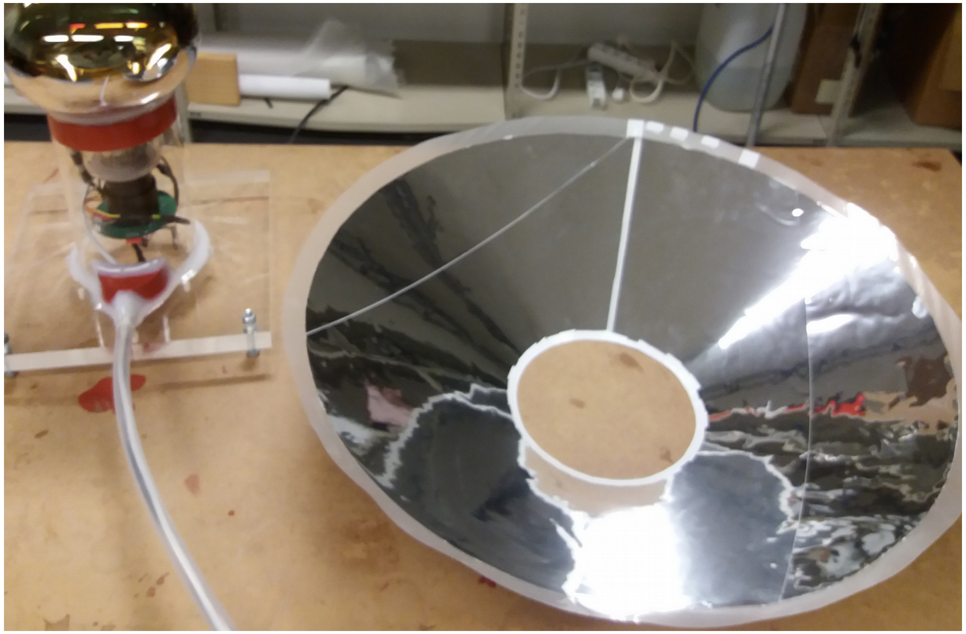


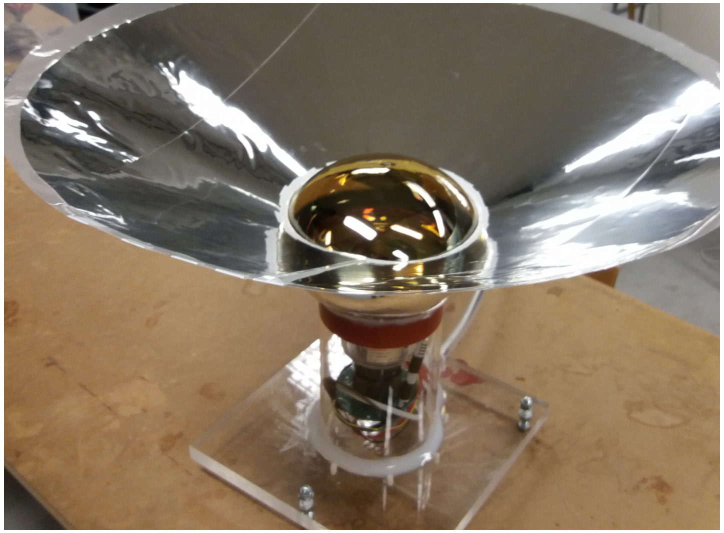


HV provided by active base ISEG PHQ 7081

- PMT and active base
  - Encapsulated in plexiglas tube,
  - Weights
  - Watertightness with Wacker RTV-ME 607
  - Signal sent over ~14m RG58 cable to WaveCatcher

Encapsulated PMT
+ Crown (mylar+lamination)

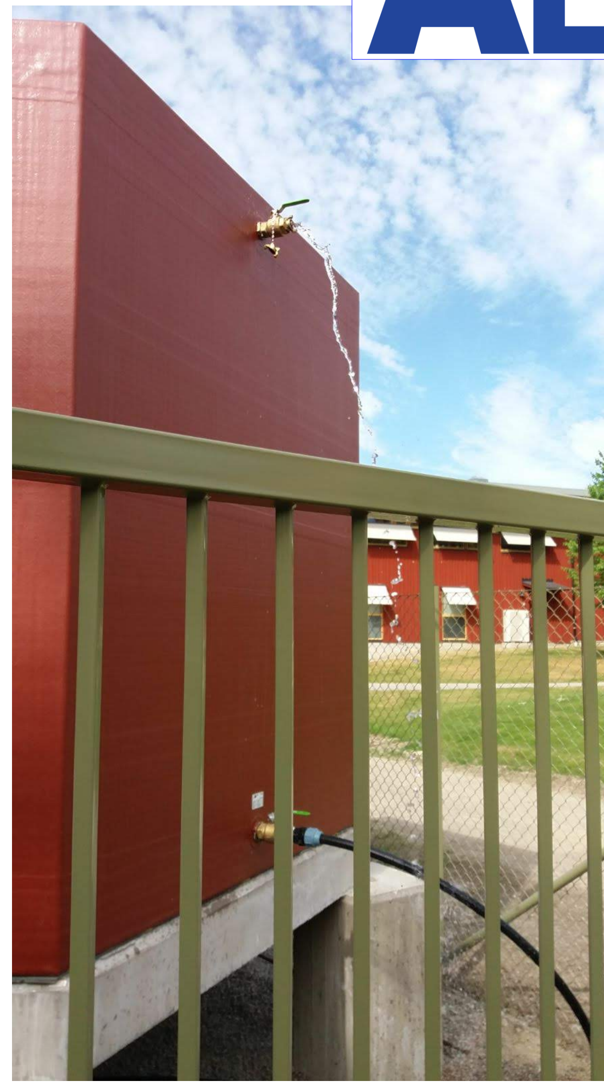




WCD tanks delivery: April 2018

ALTO WCD filling: May-June

- Using municipal water (fire hydrant)



Inside the Control Cabinet on the Cluster

LV supply for active bases of monitoring detectors

8-Channel WaveCatcher

LabJack (USB) for Slow Control of Tank PMT active bases and Sensor readout

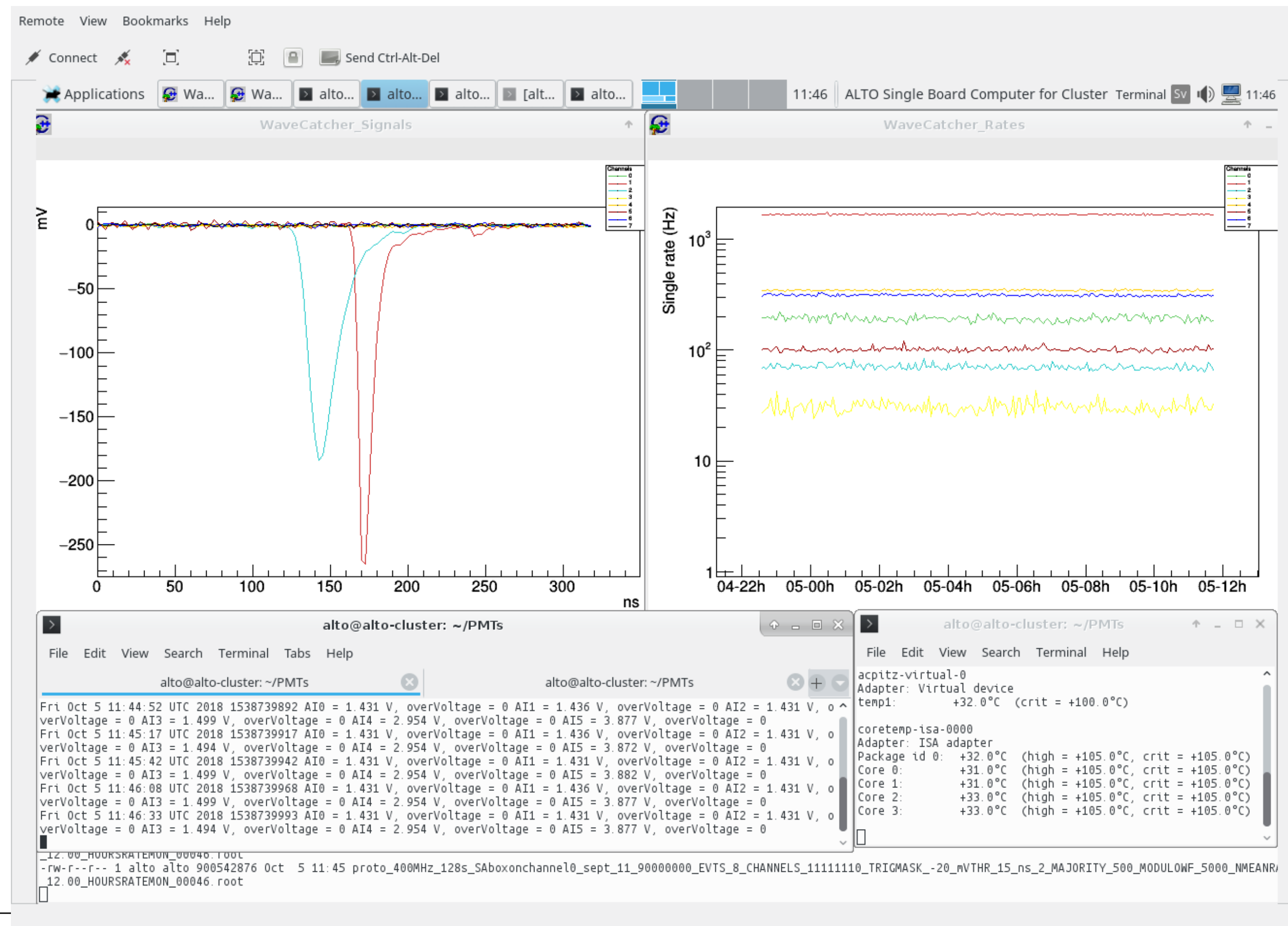
Single Board Computer (ML350G-10 Industrial Fanless, 64GB SDD)

USB ↔ Fibre convertor (to LnU network VLAN to control room)

White Rabbit Timing (SPEC) card … to be installed

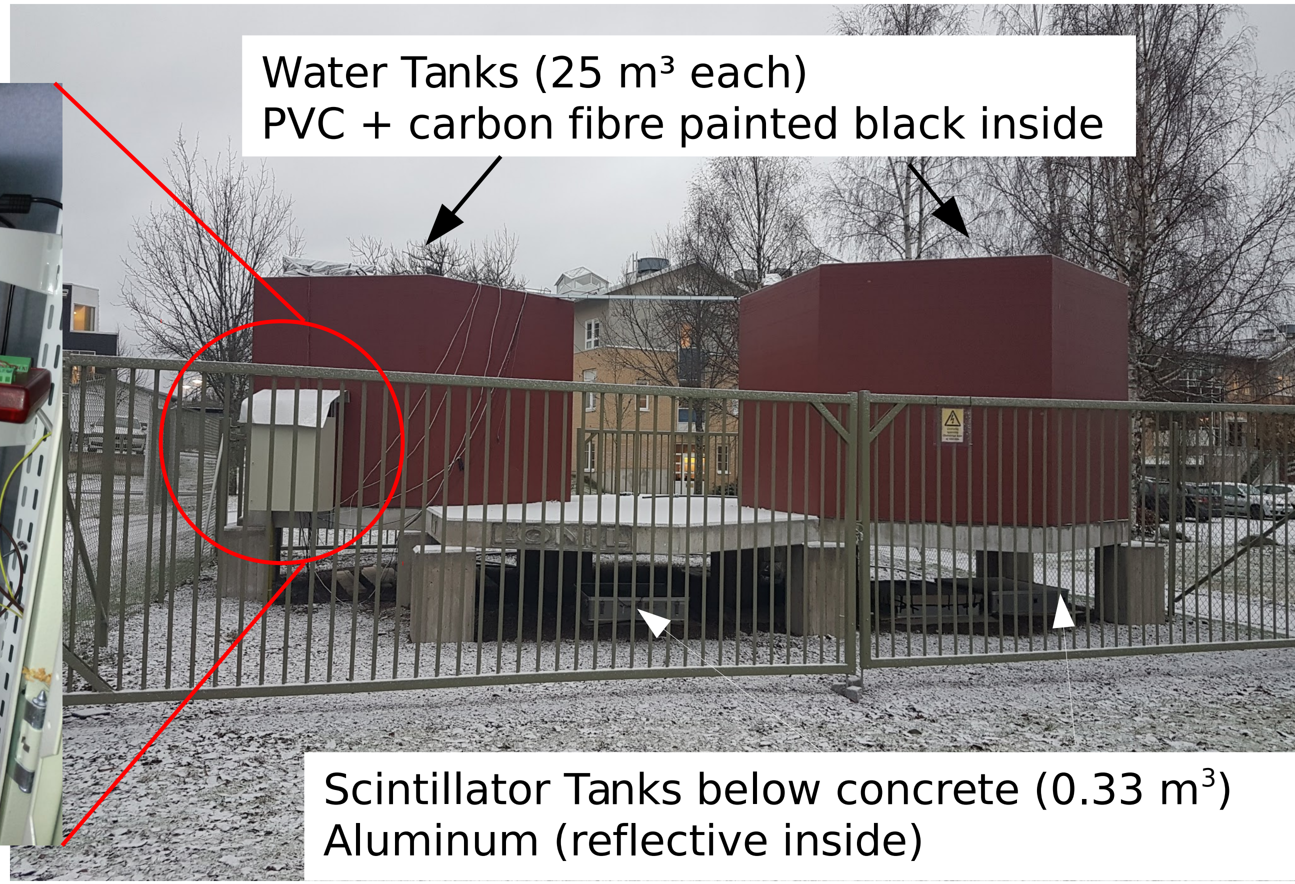
Control and Monitoring the ALTO prototype

- PC in control room, with dual display
  - Monitoring and control through VNC to SBC
  - Storage of data copied from SBC
  - Analysis
  - Event Display



ALTO Prototype array in Växjö

On site electronics

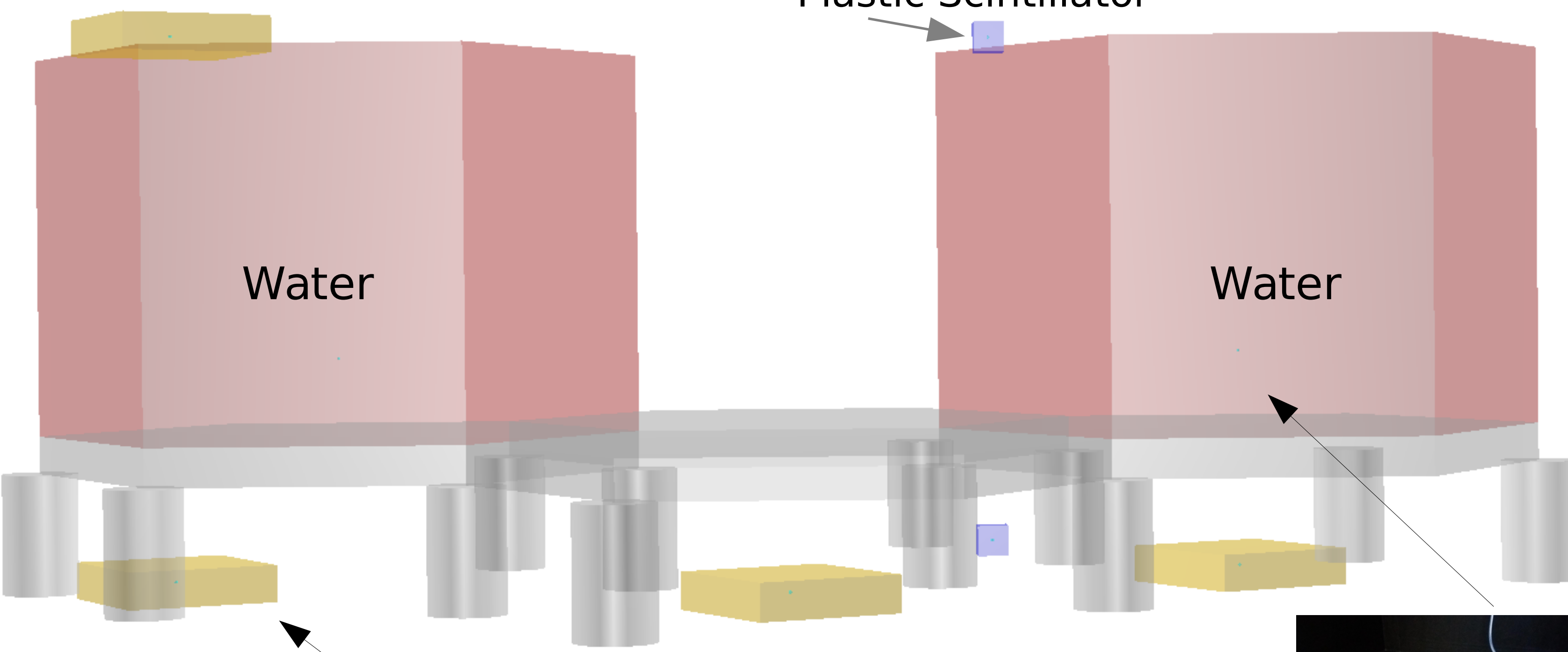


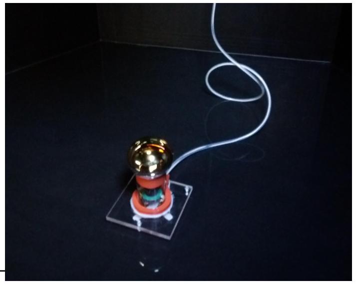
Water Tanks (25 m³ each)
PVC + carbon fibre painted black inside

Scintillator Tanks below concrete (0.33 m^3)
Aluminum (reflective inside)

Control room

ALTO Prototype array in Växjö
Current configuration

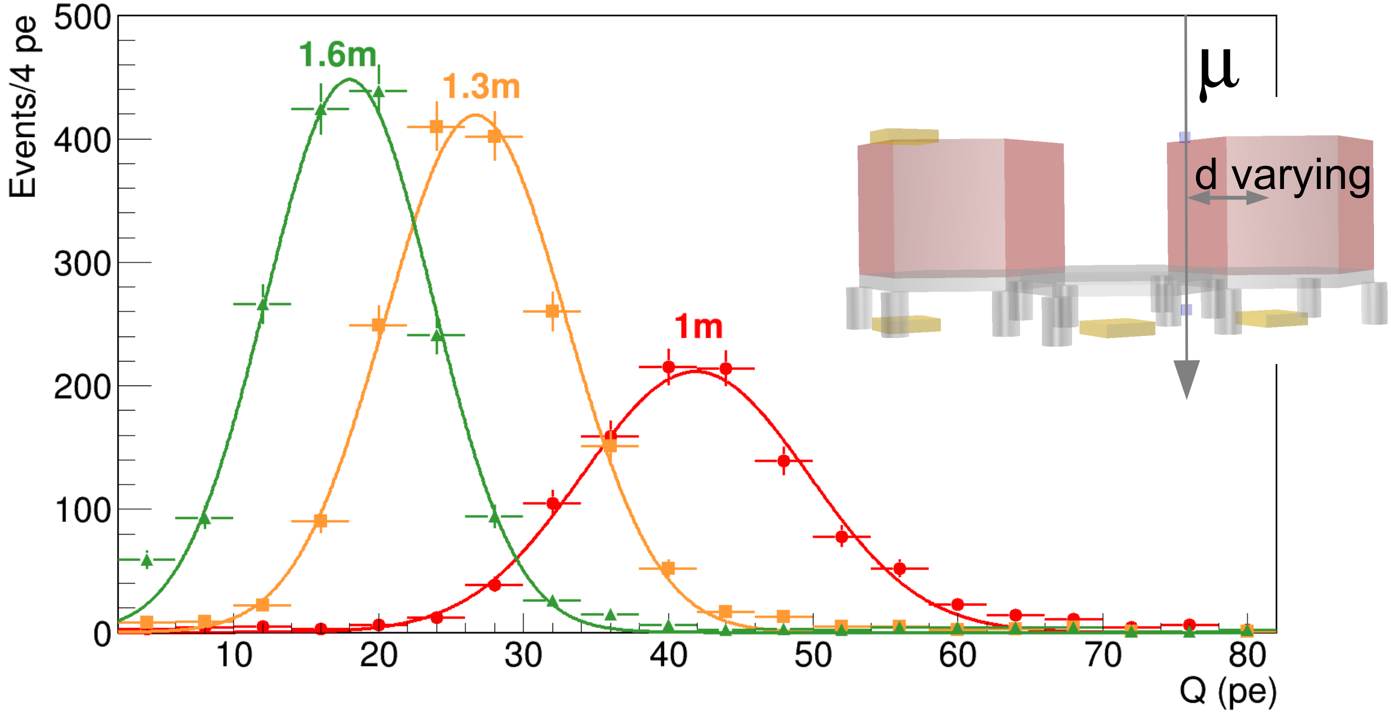




Event Display

The muon detector

Number of PE given by a single muon



Current status of ALTO & lessons learned

- ALTO simulations and Analysis now quite mature
  - We have a complete and detailed simulation of a realizable detector
  - We have completed the full chain up to the sensitivity curves
    - Many parameters developed and tested
    - MVA - BDT machinery in place and working
    - Now, some time for optimizations based on full chain

- ALTO Prototype used to learn about
  - hardware configuration (number of samples in waveform, sampling period, thresholds, PMT gain, methods for WF integration at SBC level),
  - about self-calibration &
  - about behaviour of water/crown/PMT encapsulation.

Will be pursued with Scintillator tanks.

Project time-line & Next steps

- 2018/2019 - Validation of prototype design;
- 2020 - If prototyping phase successful:
  - Installation of one or more ALTO clusters at the final site in the Southern hemisphere (our choice: QUBIC/LLAMA site in Argentina);

2017-2018
Prototype construction

2018-2019
Prototype validation and operation

2020
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
- 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

Acknowledgements

ALTO

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