WaveCatcher Electronics for **ALTO** VHE Gamma-Ray wide-field observatory:

From tests to prototypes to implementation possibilities

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

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--- for the ALTO group ----
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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”

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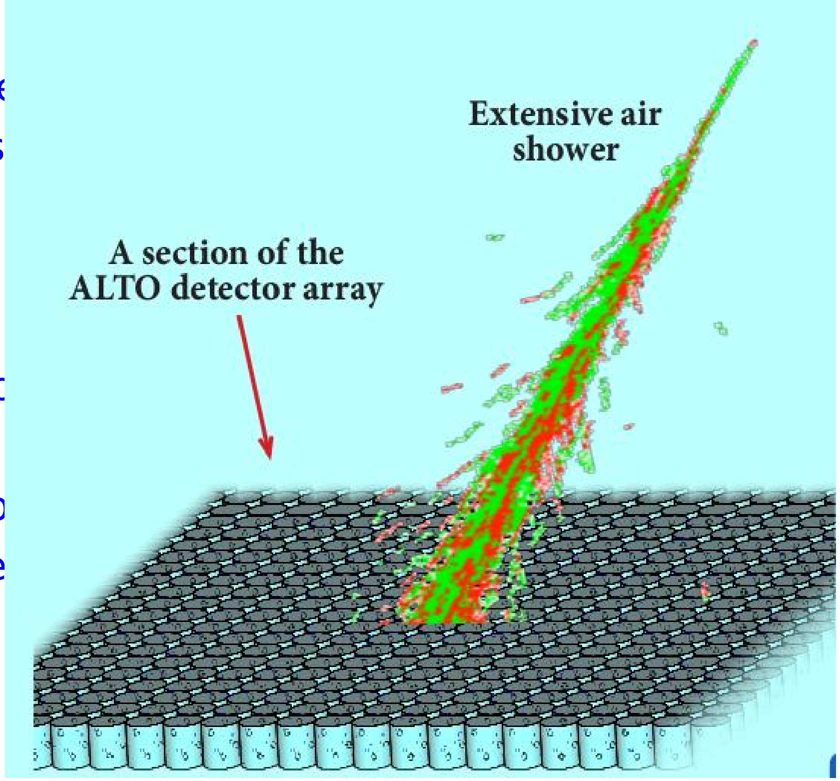
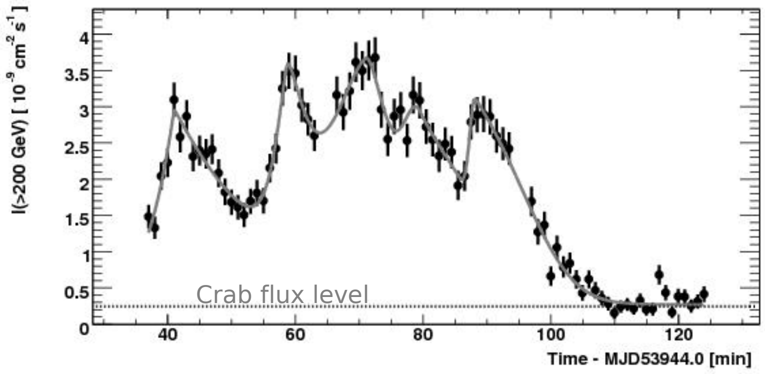


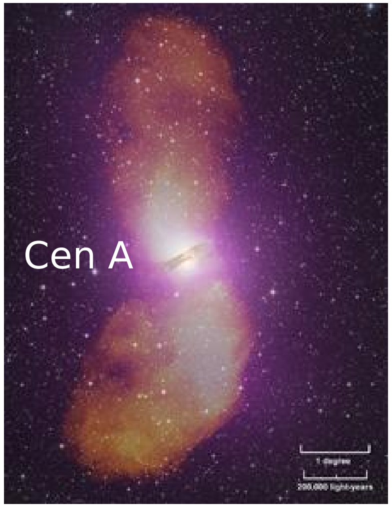
ALTO Science Goals

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

- 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

France

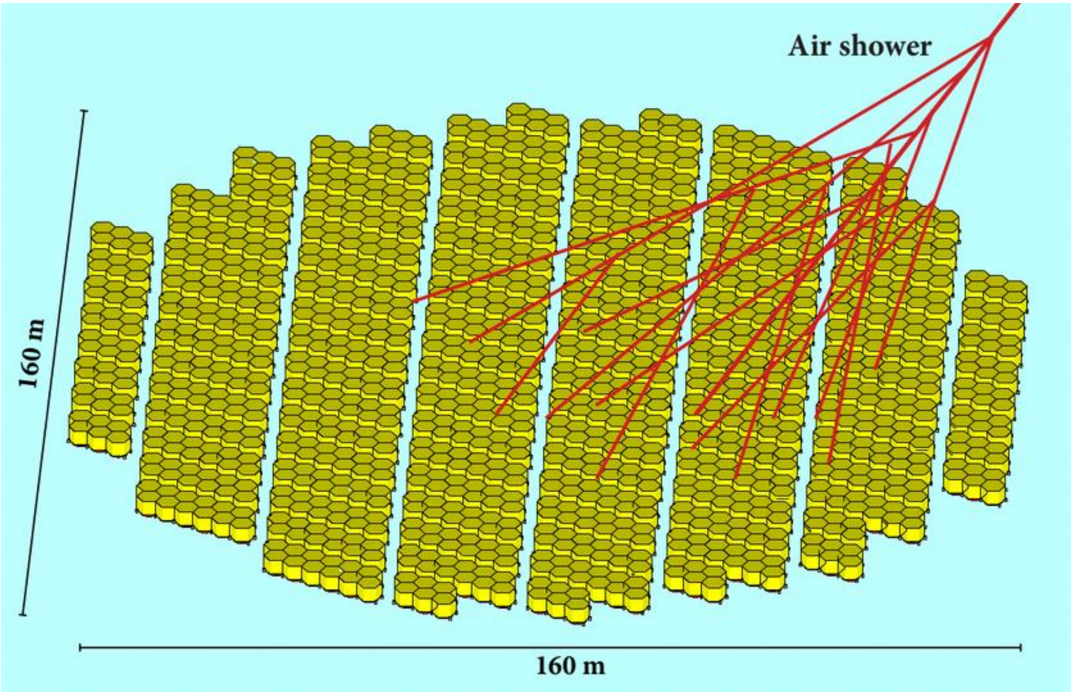
- APC Laboratory, IN2P3/CNRS, Paris
  - Michael Punch
  - Contacts with Jean-Christophe Hamilton (discussions about the site)
- Aix-Marseille University
  - Jean-Pierre Ernenwein
- LAL/Orsay
  - Dominique Breton (discussions on electronics)
- CEA/Saclay
  - Eric Delagnes (discussions on electronics)

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

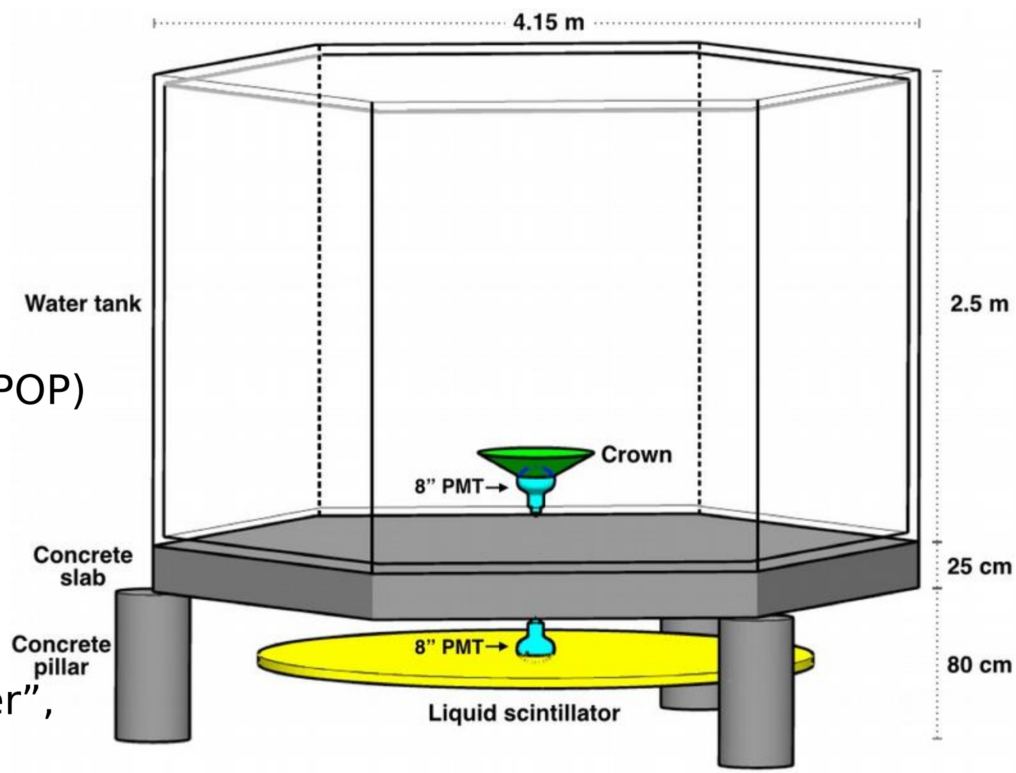
- Altitude (~ 5km):
  - For Physics goals,
    as a survey/alert instrument
    for transients
- Fine-grained array of 1242 units:
  - Smaller WCD
    (Water Cherenkov Detector)
    than existing Northern HAWC
  - Low dead-space
    ("packing factor" ~70%)
  - Improved angular resolution



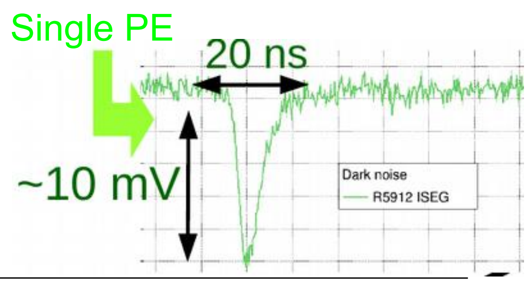
An ALTO detection unit

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

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



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



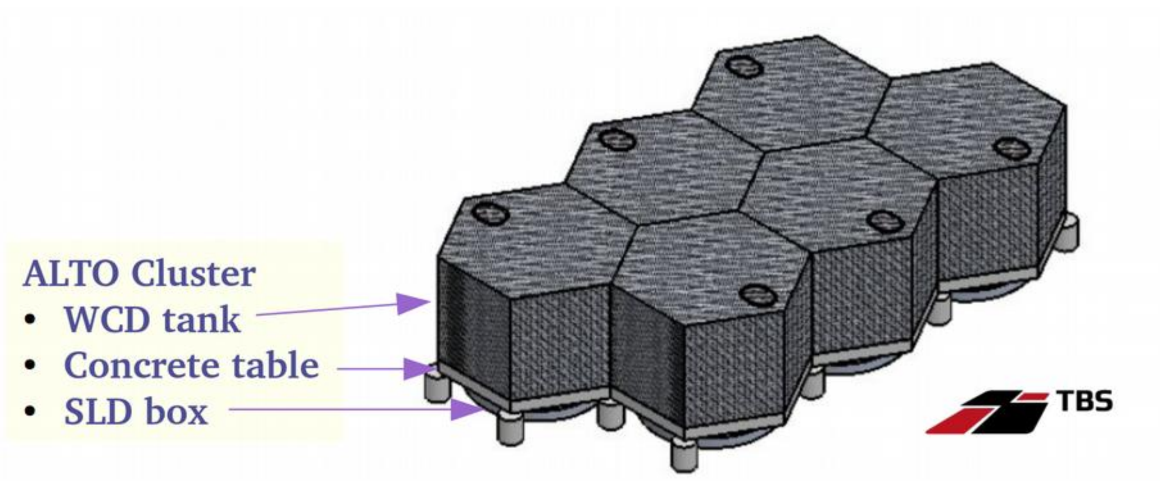
An ALTO "cluster"

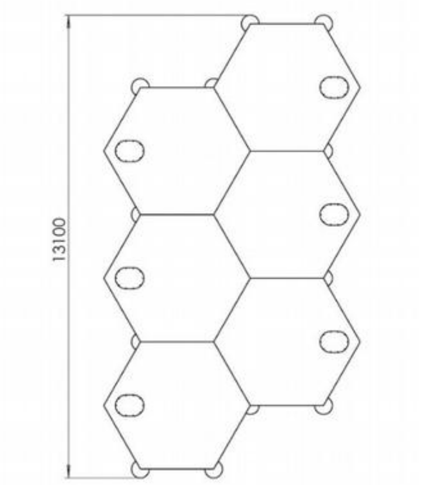
Cluster = Group of 6 Units
= 6 x (WCD + SLD)

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

Each cluster to have common:

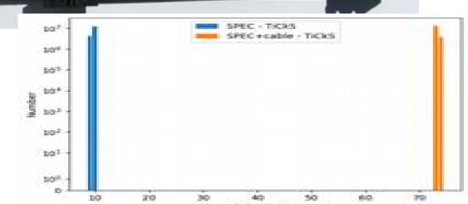
- Electronics readout unit
- Solar panel + battery
- Communication/data
  to central DAQ room by fibre only





ALTO Electronics

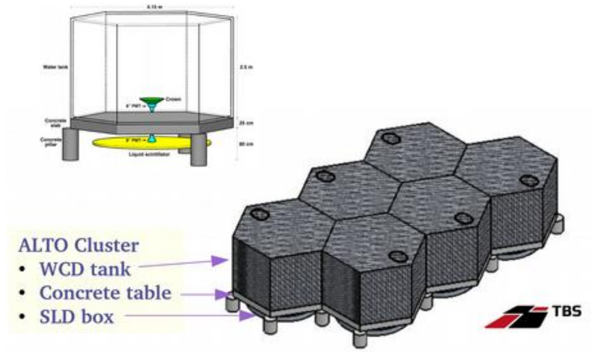
- Readout electronics box, powered by solar panels
- Communications, by fibre-optic connections only, to central DAQ
- Electronics box containing:
  - **SBC**, Single Board Computer (Arduino / BeagleBone …) or similar
    - For local control and monitoring, autonomy in case of connection loss
    - Analogue I/O for control of PMT active bases, readout of temperatures (e.g. USB LabJack)
  - “**WaveCatcher**”
    - 12-channel version, i.e. 16 minus 1 mezzanine
      - Would be well adapted for ALTO
        - BUT, majority trigger logic on all channels
      - Low power consumption (~20W)
    - Output data
      - Either copper ethernet UDP through switch to SBC
      - Or direct fibre to central DAQ
  - **TiCkS White Rabbit node** (or firmware-modified SPEC)
    - Time-stamping of WaveCatcher Read-out trigger to ns precision
    - Dedicated single-mode 1Gb optical fibre required to central DAQ (White Rabbit Switch Stack for time distribution)

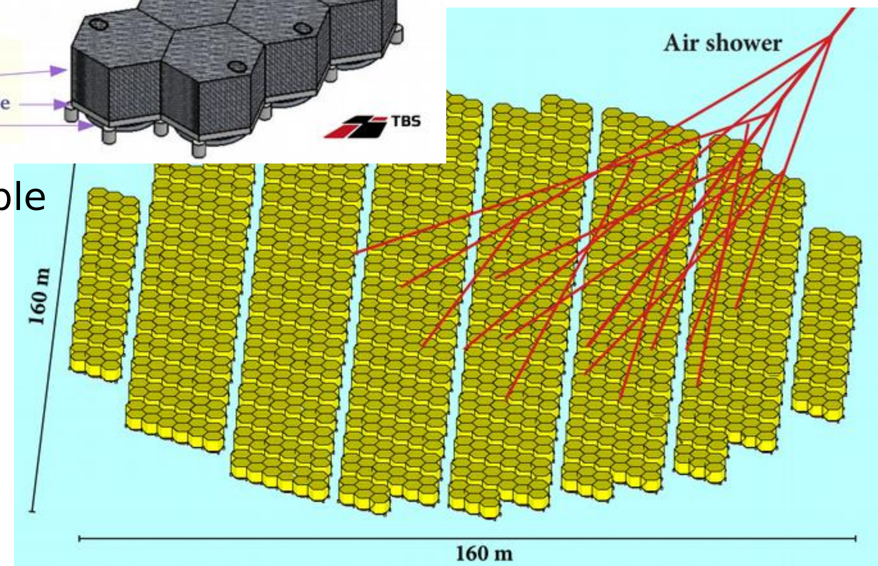


“TiCkS: A Flexible White-Rabbit Based Time-Stamping Board”, Champion et al., ICALEPCS2017, Barcelona, Spain, 2017

- In **Central DAQ**,
  - Time stamps reunited with their WaveCatcher data by their event counters
  - Coincidence logic applied to time-stamps in software gives Array Trigger (cluster multiplicity/topology)

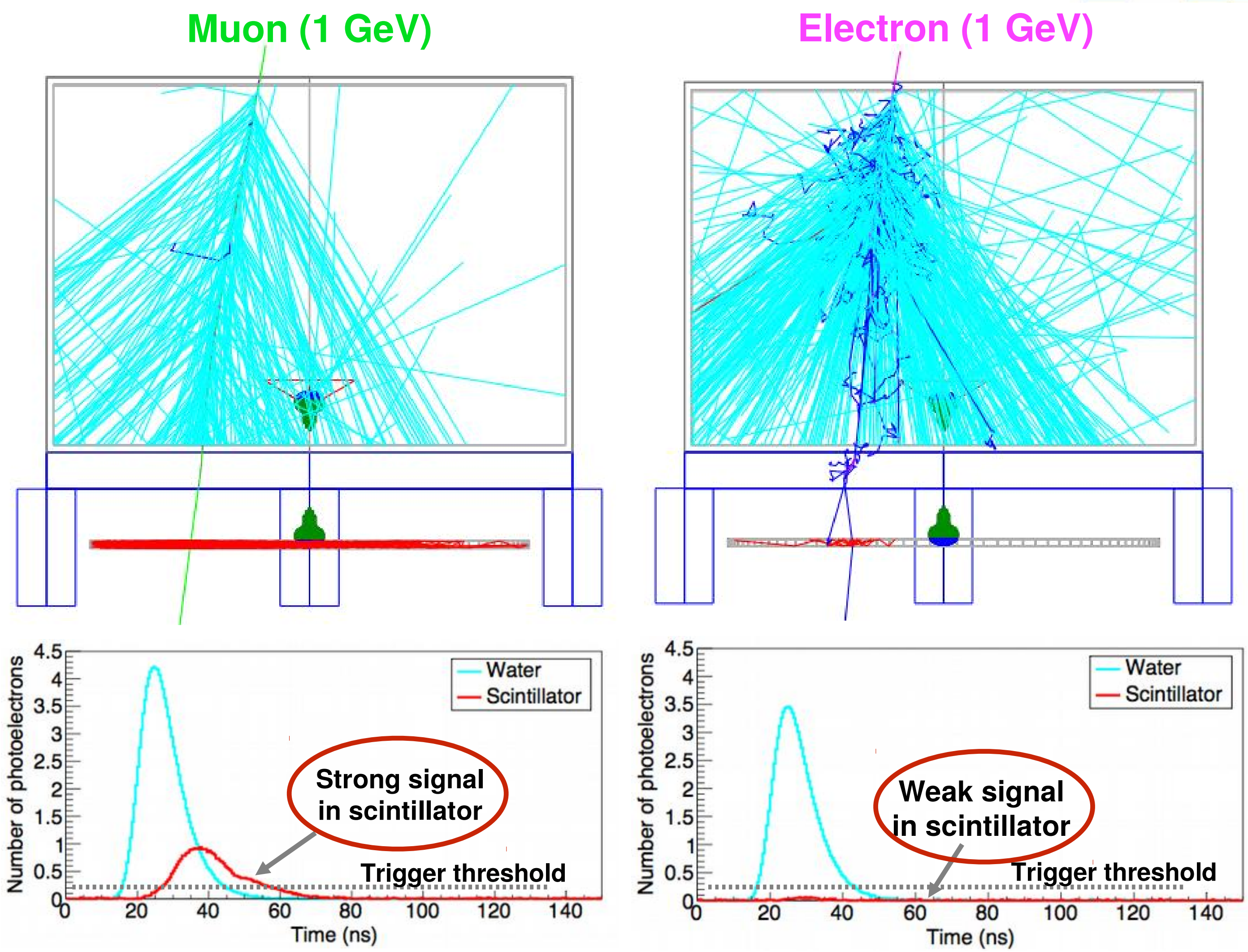
ALTO Electronics





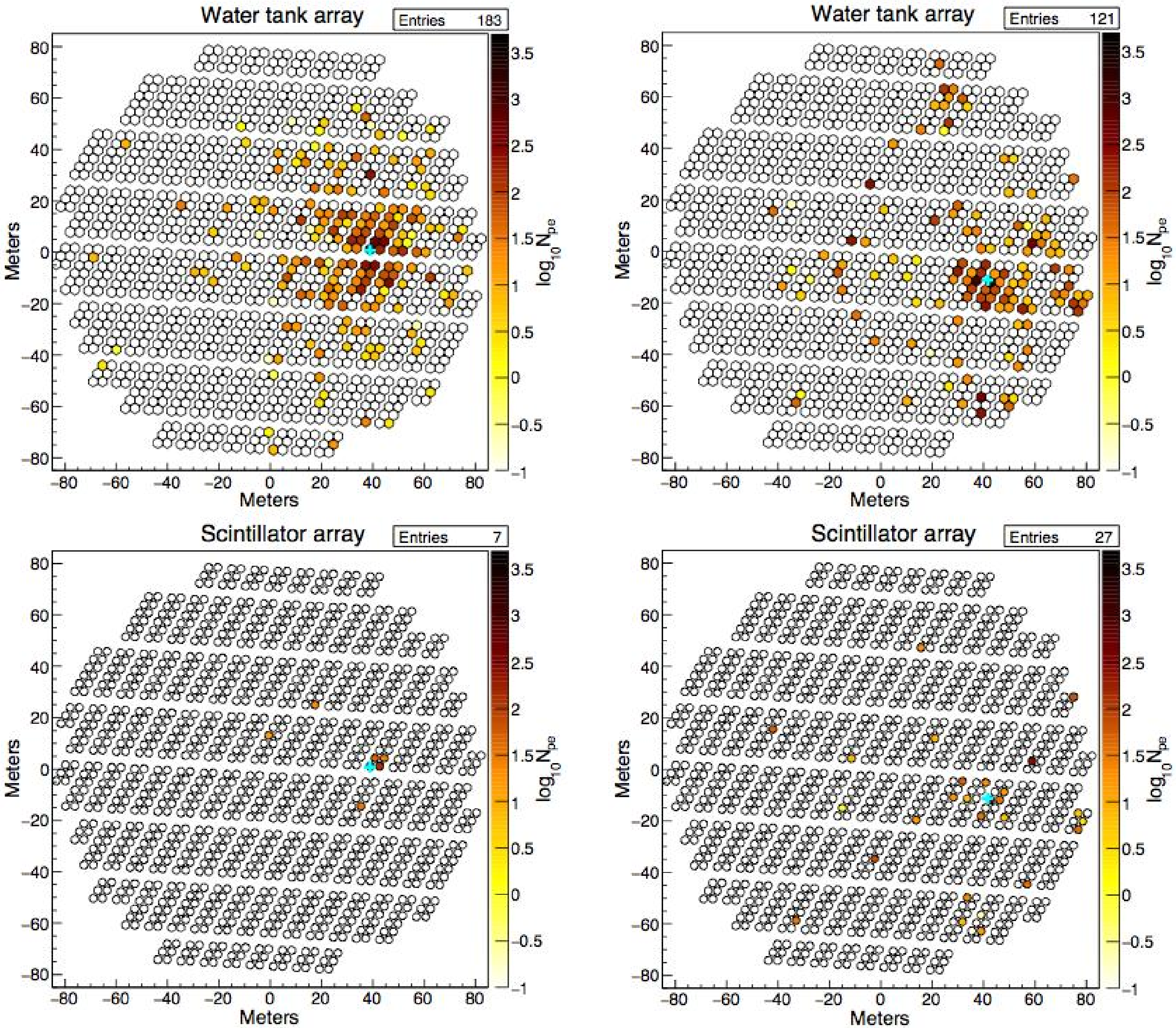
- **Per cluster**
  - 6 (Up) Cherenkov Channels
  - 6 (Down) Muon channels
- **Rates**
  - Expect << 20kHz singles rates
  - 20ns hardware coincidence window reasonable
  - 2-fold coincidence rate
    with 12 channels → 1 kHz
- **Coincidence:**
  - Ideally OR of
    - majority 2/6-Up or
    - any pair Up-Down
  - But can live with existing 2/n Majority logic
    - Maybe finer logic in 2nd step by LUT sent to FPGA to reduce data rate?
- **Read-out characteristics:**
  - Few tens of ns (maybe more pre-pulse to have baseline), lower is better for dead-time
  - GHz sampling is probably sufficient (lower would give lower dead-time)
    - Simulations re-analysis to find how coarse to go without degrading angular resolution
- *(note, full reconstruction and S/B rejection chain needed to close this loop… soon ready)*

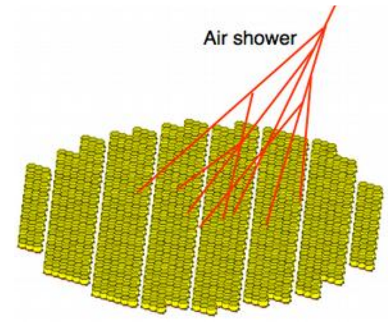
ALTO Unit response to single particles



ALTO Array response to Air Showers

Gamma ray | **Cosmic-ray proton**





Gamma ray
- More compact
- Regular pattern

Cosmic ray
- Clumpy
- Hot spots in the muon detectors far from core

ALTO Pre-prototyping: tests in laboratory

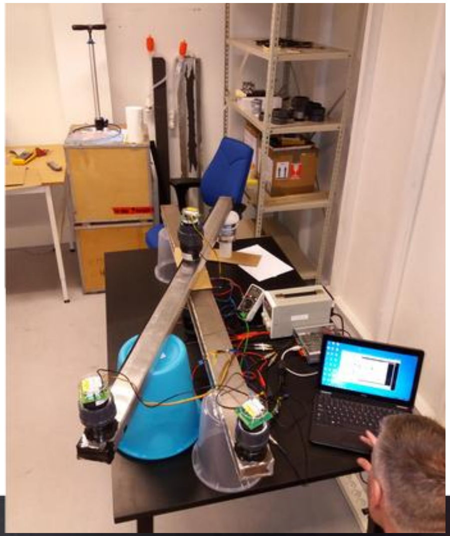
- Many test-benches, all with readout triggered
  by small (10x20cm) muon-paddles, read by “WaveCatcher”
  - All compared with GEANT4 simulations to find reflectivity, absorption, etc.

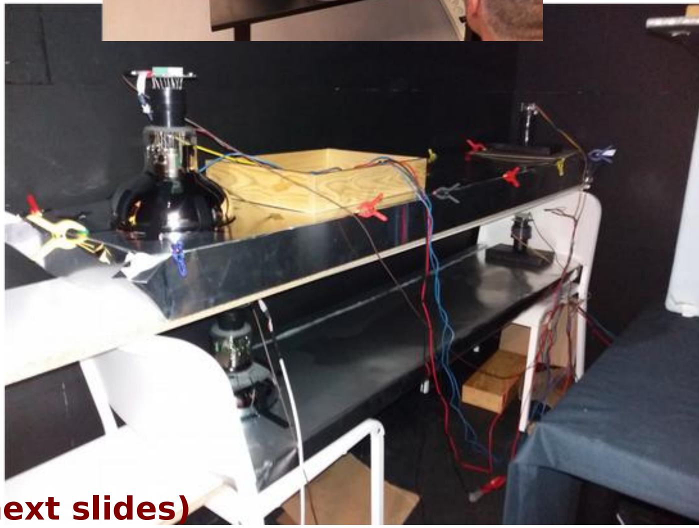
- Small water tank viewed from above by 8” PMT **(next slide)**, to test
  - blackness of the internal “gel-coat”
  - Effects over time with strong chlorine concentration (bio-growth, leaching)
  - → 20x normal swimming pool concentration OK for now

- “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)
  + Tyvek as reflector to replace scintillator tank, currently running
  - May be able to reduce costs, avoid some radioactivity triggers **(see next slides)**



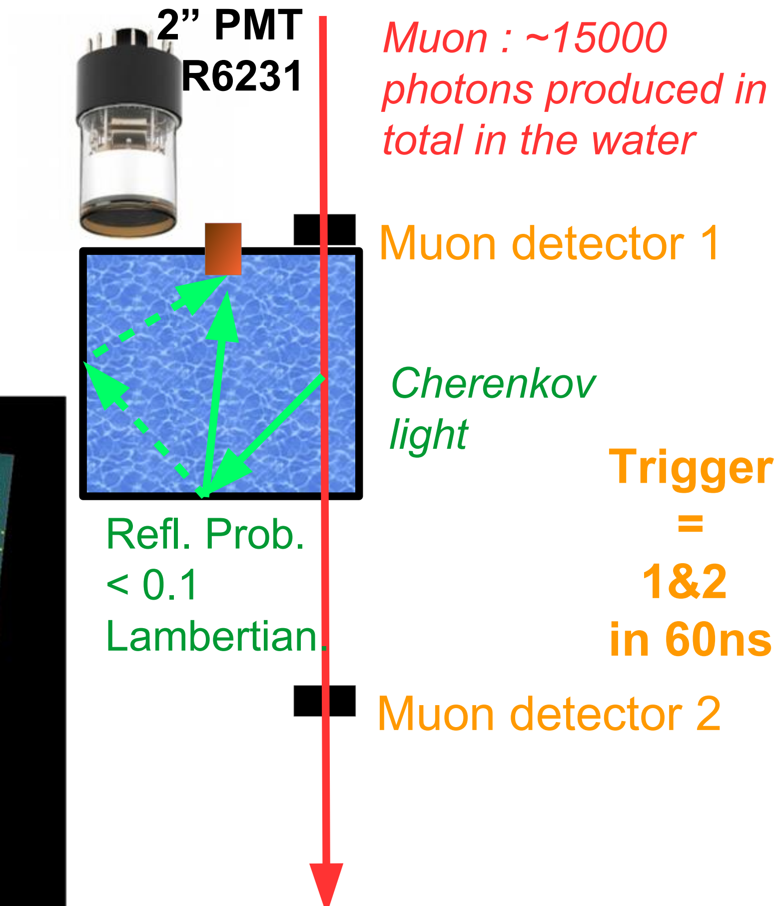


Tests in laboratory, small-scale upper tank

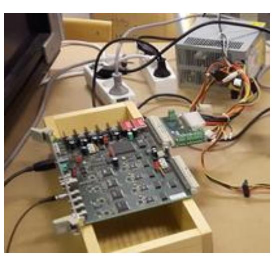
Long term test (6 months) to verify the possible interaction of water-black gel coat

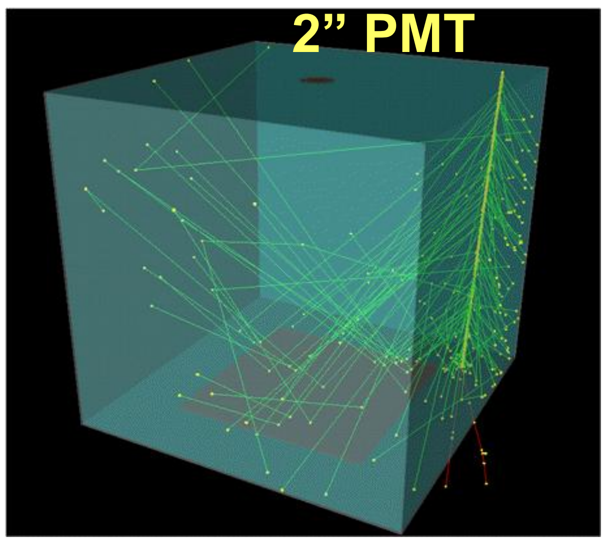
50cm x 50cm x 50cm test box with final black gelcoat.

Only ~1-2 pe seen by the PMT

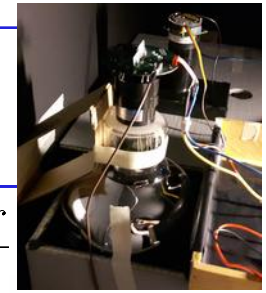


Long term tests:
- wall reflectivity/water transparency
- electronics: Matacq & WaveCatcher
- 2" then 8" PMT

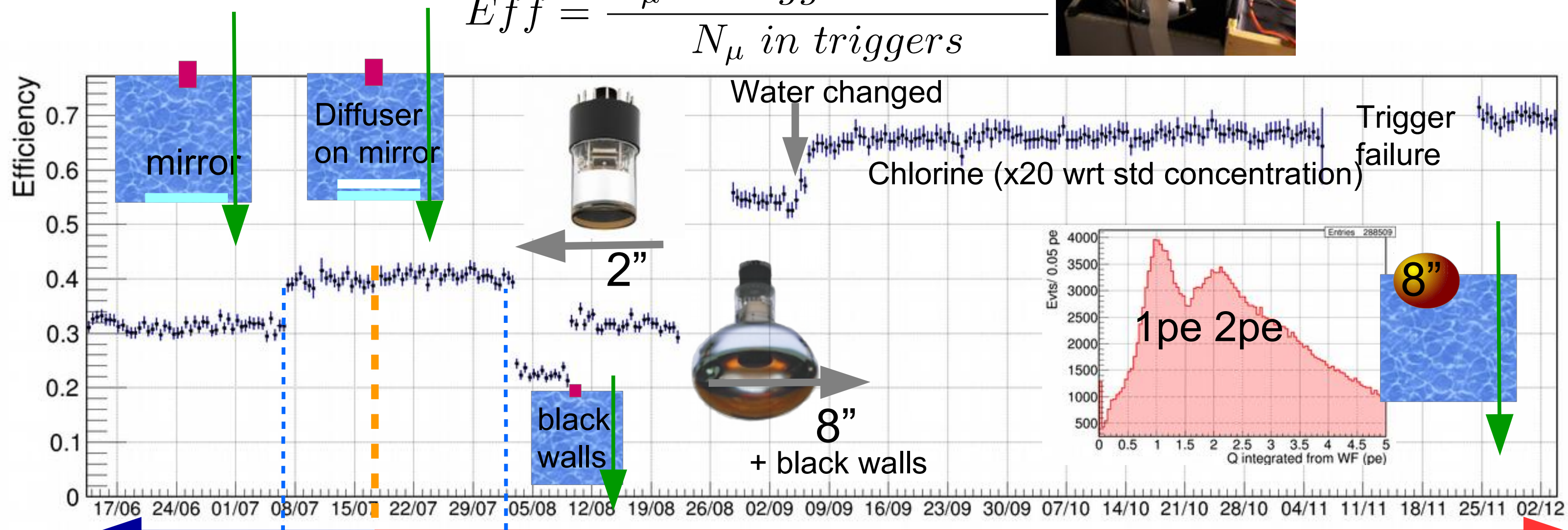




Tests in laboratory

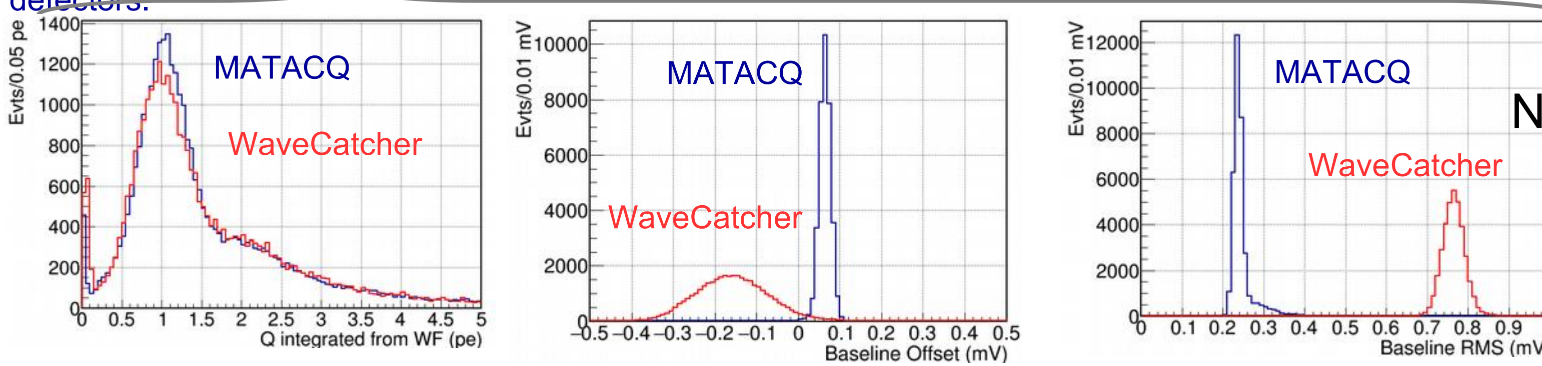


$$Eff = \frac{N_\mu \ in \ triggers \ \& \ water}{N_\mu \ in \ triggers}$$

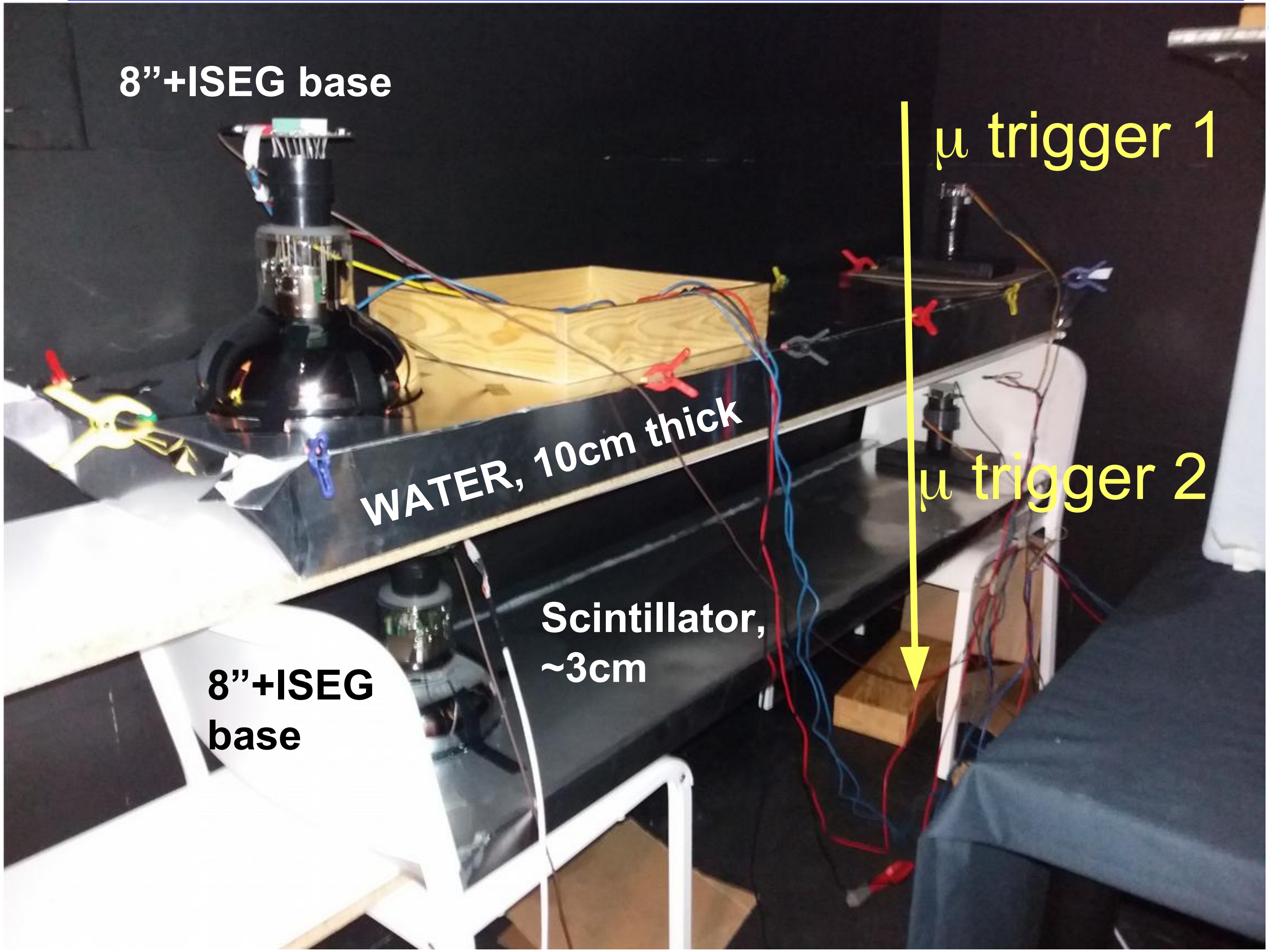


MATACQ 1 GHz
(4096 samples)+multiplicity board building a coincidence NIM signal from muon detectors.

WaveCatcher 1.1 GHz (1024 samples),
coinc. trigger built from muon detectors.



Test of small-scale bottom tank
(area=area of final tank/10)

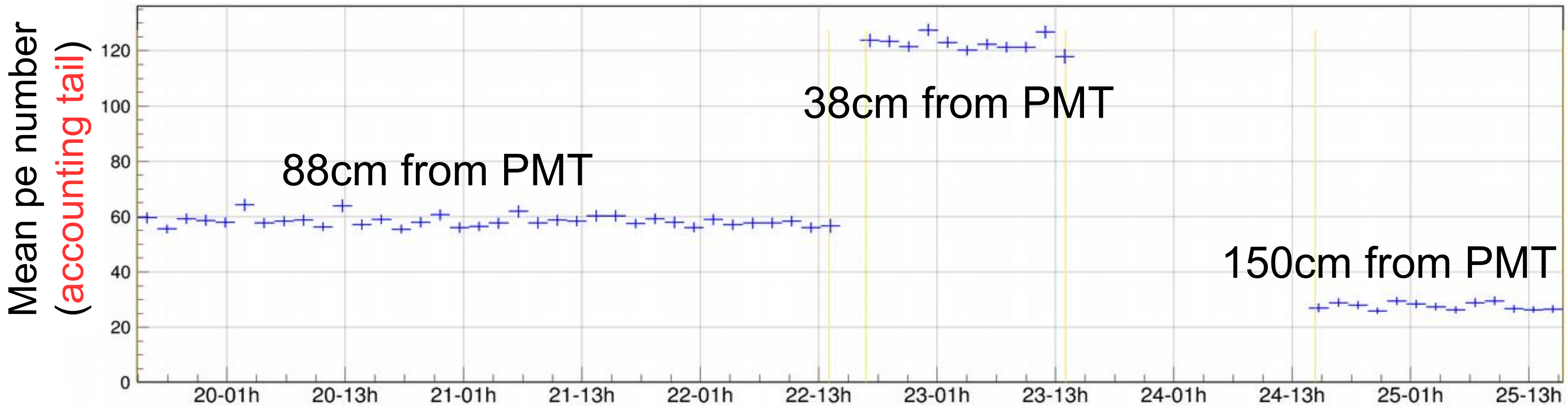


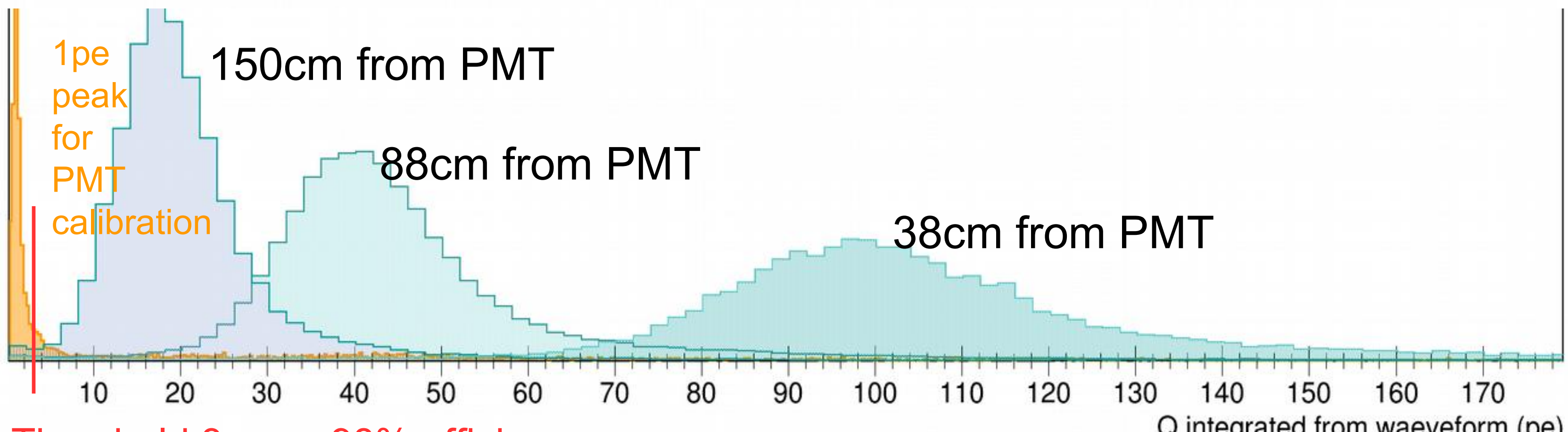
Tests of:
Water (Cherenkov) and LAB+PPO+POPOP (Scintillation)

Reflector in tanks: aluminium, Tyvek

Collected pes = f(trigger distance from PMT center)

Cherenkov case (Water+Tyvek+super bialkali R5912 Hamamatsu with gain 10^7)





Threshold 3pe → 98% efficiency
and single rate 1.3 kHz

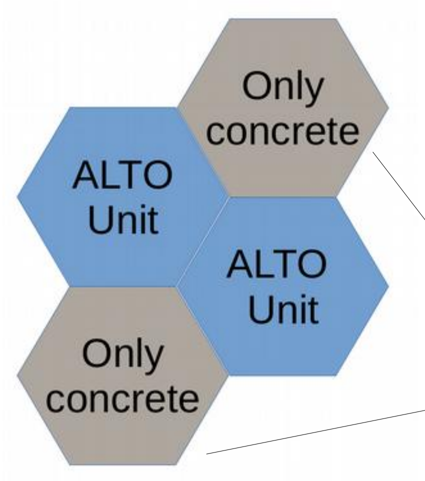
Results of tests in dark room, next steps

- R5912-SB Hamamatsu @gain 10^7 + ISEG PHQ 7081SEL_4 + WaveCatcher perfectly suitable for bottom tank in the 2 studied options: water or liquid scintillator.
- The same chain will be used in the top tank (chain is also suitable according to simulations).
- Full test will be done with the Växjö prototype.
- The test setups use Labview+USB (max rate of 1 event/s), and 1024 samples @ 1.07 GHz.
- The Växjö prototype and next steps will use a linux software+UDP (to be developed).

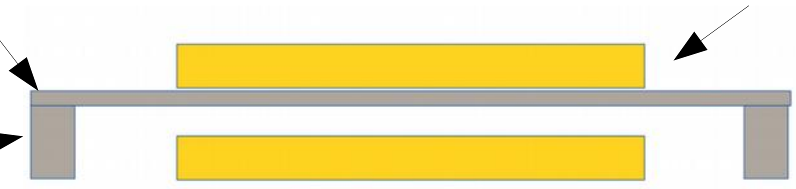
- For expected 2-fold coincidence rate with 12 channels is 1 kHz (assuming 20kHz single rate and 20ns window). ing
  → Basic tests with labview+UDP and
  48 samples @ 2GHz on 8 channels
  work up to ~3000 evts/s.

ALTO prototype at Linnaeus University in Växjö, Sweden

- Construction stared January 9th 2018
- Several PMT solutions will be tested; along with comparison scintillator/water for the lower tank.
- Fully funded: construction of two full ALTO units, with 4-tank concrete layer
- The empty slots will be equipped with (smaller) additional scintillator boxes



Additional scintillator layers recycled from an on-board air-shower array used for ANTARES calibration purposes

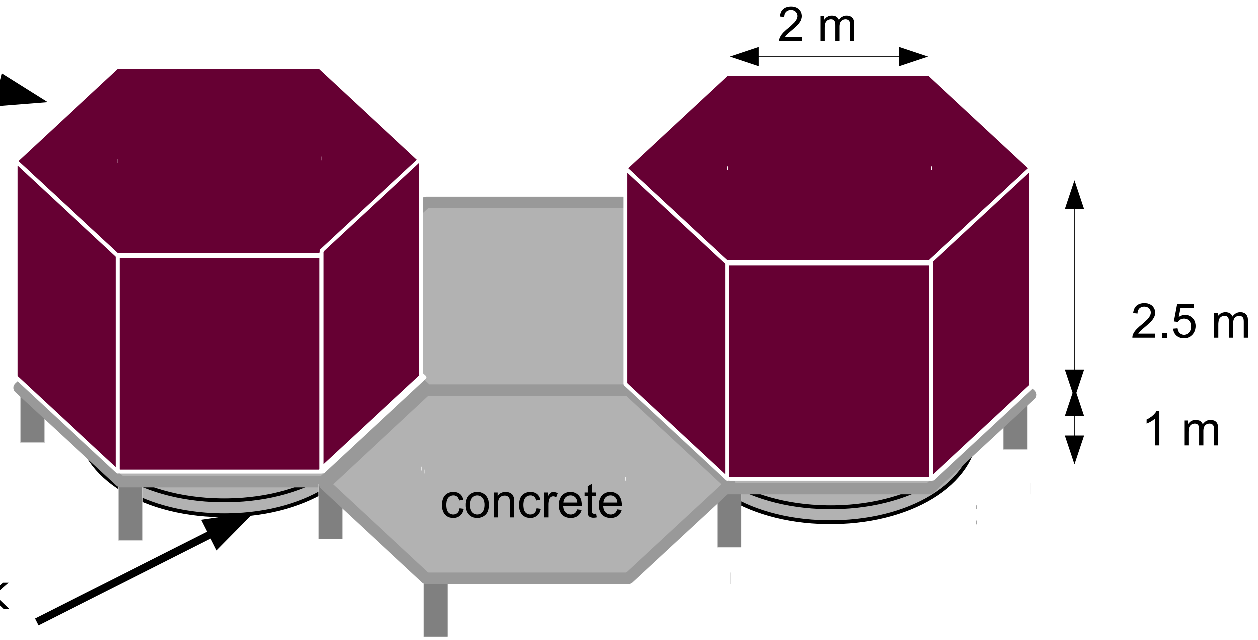


ALTO prototype setup in Växjö

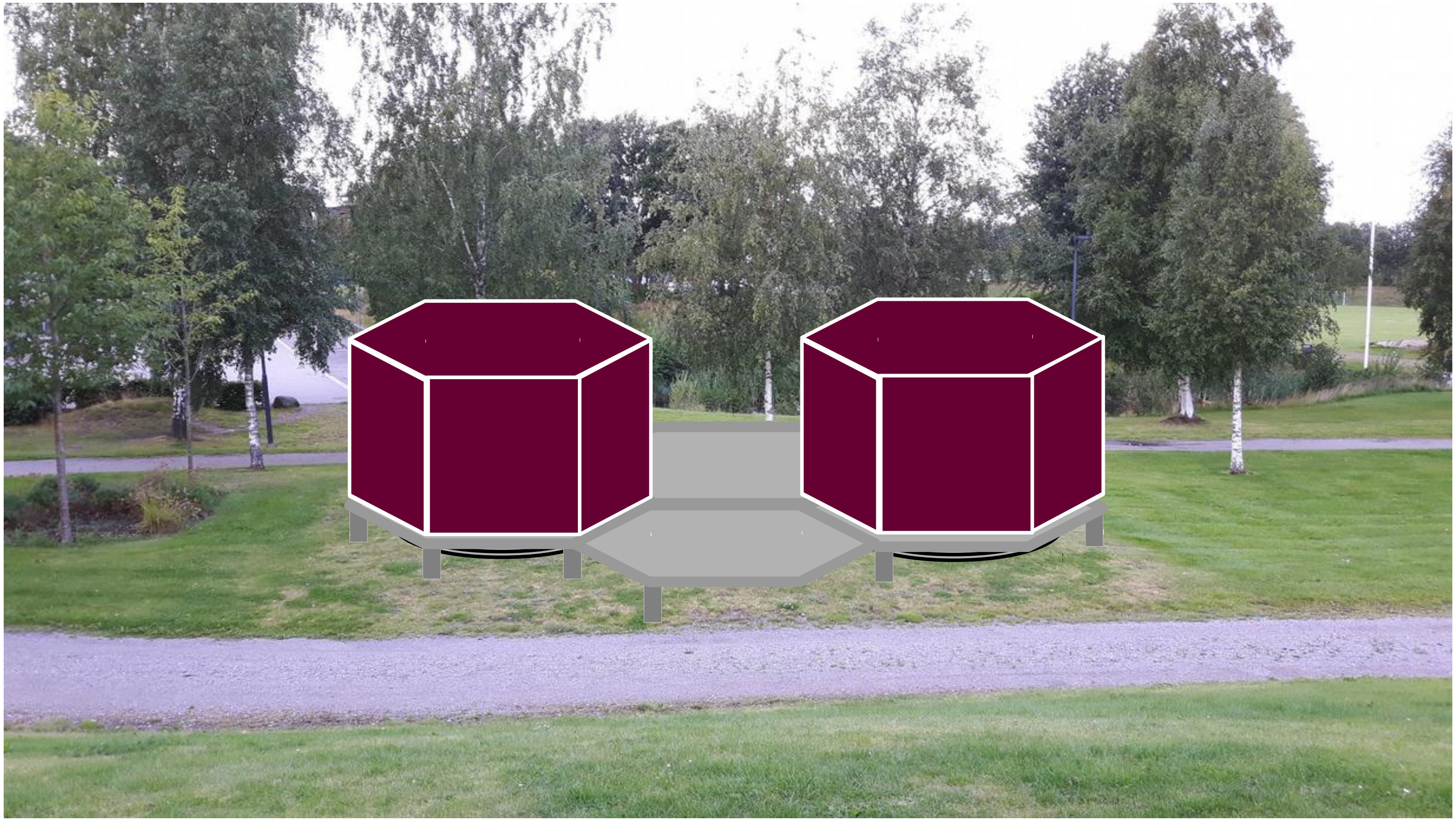
Water Tank
(25 m^3,
500kg empty)

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

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

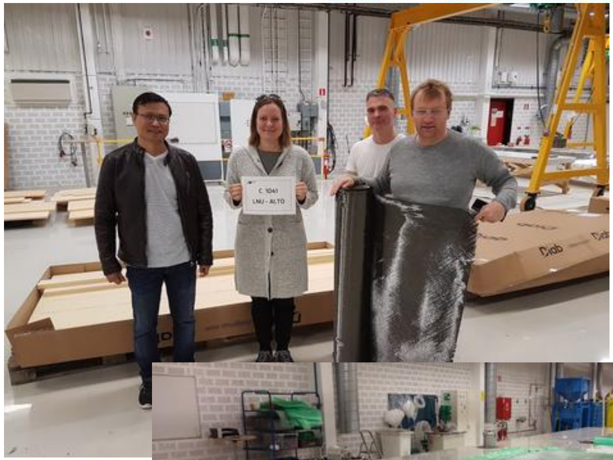


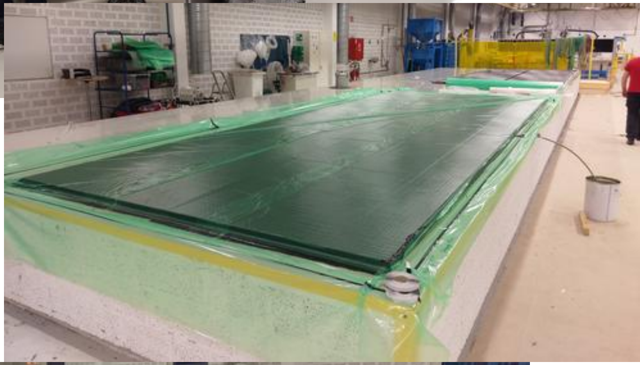
ALTO prototype setup in Växjö

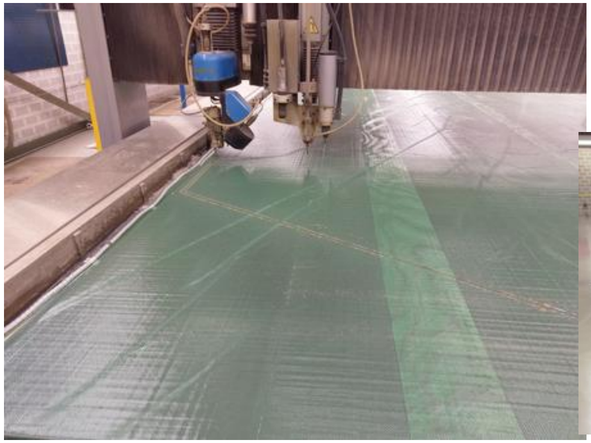


ALTO prototype construction at Linnaeus University: Status

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



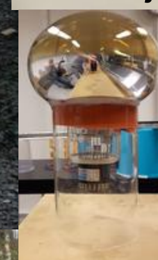




ALTO prototype construction at Linnaeus University: Status

Concrete table construction
(is completed now)

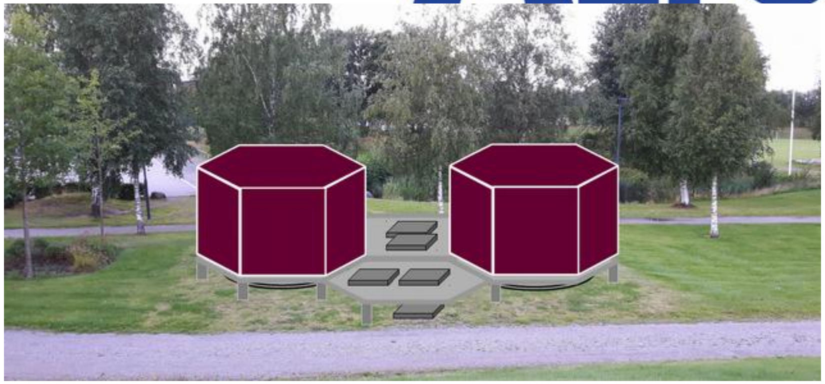

Upper tanks completed, will be moved from factory to Växjö in 4 weeks.



PMT housing: plexigass tube (housing PMT, active base). Sealing with Wacker potting. Will be placed in the center of the tank floor.

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	2018-Q2-Q4	2019?	
Prototype construction	Prototype validation and operation	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 readout electronics:
  WaveCatcher, 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

Feedback on WaveCatcher

- We are **very happy** with the WaveCatcher performance
- **Responsiveness** of Dominique and Jihane very good

- We would need:
  - For 16 (→ 12) channel wavecatcher, to have majority logic over all channels
  - Operation with Linux (Python would be nice)
  - ~200 WaveCatchers, if we get funding for full array!

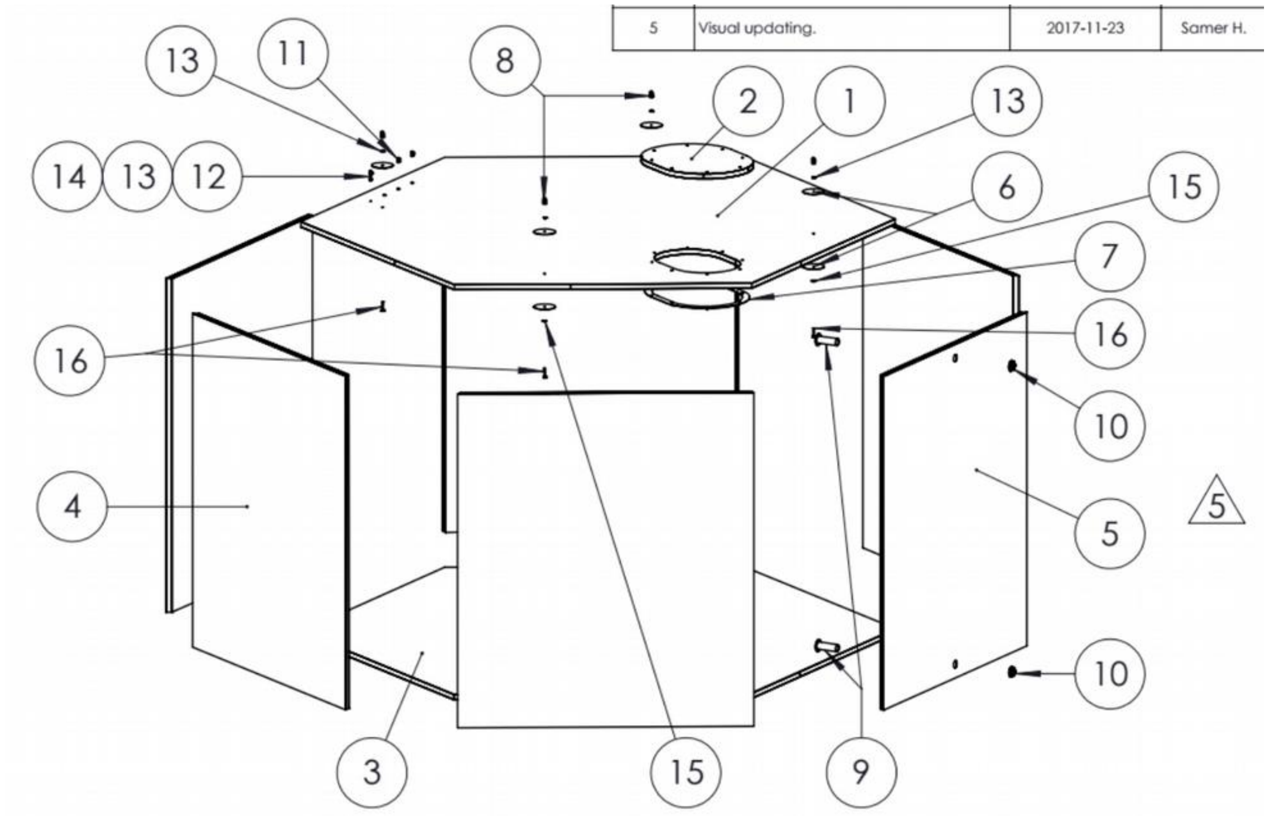
- We would like:
  - Quieter fans (only for versions in lab, in the field no problem)
  - Possibility to connect to heat-pipes for cooling (thin atmosphere at 5km)
  - Some more complex combinatorial logic to reject some events
    - Pre-trigger, to lower dead-time or
    - Post-trigger, for lower data rate
  - Separate “Read-out” and “Busy” triggers and counters,
    with corresponding outputs to go to White Rabbit node (to ensure counters stay in sync)

- Mode where only triggered channels data(discussed here), could interest us... need to look at MCs...

Photo @Miguel Mostafa

Backups

Exploded view of Water Tank



Exploded view of Scintillator Tank