Southern Gamma Survey Workshop

University of Rochester, Rochester, NY, USA
June 8-9, 2017

Welcome and Introduction, Thursday AM

Harm Schoorlemmer: organization of white paper pushing SGSO science case. Topics to be fleshed out in this workshop. M. Mostafa, S. BenZvi, and HS are writing the sections and aiming for a draft after the ICRC. Don't want to purposely farm out writing to many people, but volunteers are definitely welcome. A read/write link to the draft on overleaf will be made available upon request.

As of this workshop the white paper outline is based on observational topics, e.g.,

1. Galactic Gamma Rays: high-energy and extended emission
   a. PeVatrons (Galactic Center)
   b. Extended Emission
   c. Geminga's near or off/plane
   d. Diffuse Emission
2. Extragalactic Gamma Rays: low-energy enhancement of wide-FOV array
3. Multimessenger:
   a. GRBs: neutrino connection, GWs
   b. FRBs: current "hot topic"
4. Ancillary Topics (a.k.a. Physics we get for Free):
   a. Dark Matter
   b. Cosmic Rays

B. Dingus, P. Hüntemeyer, A. Rovero: topical breakdown is definitely not ideal. Much better to switch "Galactic," "Extragalactic," and other headings to subjects centered on science goals. For example:

1. "Studying Galactic Particle Accelerators"

2. “Monitoring the Transient Sky”
3. “Probing Physics Beyond the Standard Model”

Will result in some shuffling of subjects (e.g., both cosmic ray and gamma ray observations would fall under “Galactic Accelerators”). Consider organizing subsections using rhetorical questions along the lines of SWIFT proposal, LSST design report.

<u>Strategy: Interaction with CTA</u>

- **HS, BD, MM, all**: commenting on strategy, make sure complementary function to CTA is clear. How would our observations make CTA operate better? What can they accomplish with a wide-FOV observatory that is otherwise difficult or impossible?
- **A. Sandoval**: note that CTA funding is now getting settled (conversation with W. Hoffman) and the project also has CERN recognition. Consider integrating SGSO capability discussion with CTA WG topics, esp. after the design report is available (July).
- Caution: will complete overlap of science case negatively affect funding? E.g., CTA response: “We are already doing all of this science, but better…”
- Caution (**Michael Schneider**): several CTA groups are interested in participating in a wide FOV observatory. Electronics expertise developed for CTA have clear application in SGSO. But need to avoid perception of stealing resources from CTA!

<u>Future Workshop (Miguel)</u>

Looking into the possibility of a follow-up workshop around **December 11, 2017** in Buenos Aires.

Almost all other dates in October and November are taken up by collaboration and international meetings. Will need to start contacting people who we feel should be there and see if this date is feasible.

Community Feedback (P. Harding), Thursday AM

Informal questions posed to several CTA collaborators about interest in wide FOV observatory. Several types of feedback:

- “Theorist”: SGSO will be good for extended sources and observations off the Galactic Plane. If sensitivity is available <100 GeV then SGSO could replace Fermi-LAT as a transient factory. SGSO could provide a Southern Extragalactic catalog.
- “Optimist”: off-plane extragalactic surveys are useful. In plane observations of diffuse emission and extended sources are useful. Additional argument in favor of *orthogonal methodology*, i.e., test new discoveries with more than one kind of measurement technique.
- “Pessimist”: CTA has better low energy range, will tile observations to allow “self-discoveries,” can do extended sources with larger FOV than H.E.S.S./VERITAS/MAGIC. Large FOV not desired, but if something is built prefer a MACHETE-like instrument over a ground array.

Note: no one mentioned high-energy reach or source-finding synergies between CTA and SGSO.

Niche observations for SGSO (Pat’s opinions):

- Transients
- All-sky map: off-Plane extragalactic sources, **if sensitive at lower energies**
- Diffuse emission (Galactic Plane, maybe isotropic extragalactic)
- Spatially extended sources in GP
- Cosmic rays

<u>Studying Galactic Particle Acceleration</u>, Thursday AM

Broad group discussion about "Galactic science" but in the context of sensitivity to particle acceleration. Further attempt to formulate niches accessible to SGSO/wide-FOV instrument. Several people involved in CTA (Fabian Schüssler, Marcos Santander, Harm, et al.) asked to play "devil's advocate" and raise critical points.

1. **Galactic Center**
   a. Pros/Comments
      i. Complex region with extended emission, diffuse gamma rays. Not easy for pointed instruments.
      ii. High-energy reach needed to observe PeVatron in the GC
      iii. SGSO can characterize extended emission and tell CTA where not to look when estimating background.
      iv. Flaring. High-uptime observations are needed to test
   b. Cons/Skeptical view
      i. GC is a **major** observational goal of CTA. Will accumulate many hundreds of telescope hours in this region and easily obtain high-energy gammas.
      ii. Good angular resolution is critical to avoid source confusion. CTA resolution beats the pants off SGSO.
      iii. Improved bkd estimation techniques in IACTs (likelihood methods) means information from wide FOV array about on/off source regions is not necessary.
      iv. CTA will repeatedly return to the GC and be able to catch flares.
2. **True Diffuse Emission**
   a. Pros/Comments
      i. Sensitivity to *global properties* of the cosmic-ray environment, e.g. particle flux and diffusion well outside the solar neighborhood
      ii. Some evidence that diffusion in outer Galaxy matches local properties, but differs in inner Galaxy. SGSO observes both regions every day
      iii. Close connection to Galactic neutrino production
   b. Cons/Skeptical view
      i. CTA will be sensitive to diffuse emission via Galactic Plane survey
      ii. CTA angular resolution will identify 100s of unresolved sources, which will appear as diffuse emission to a wide FOV array
      iii. IceCube is already strongly constraining the KRA PeV nu model
      iv. HAWC will already characterize diffuse Galactic emission

3. **Hadronic vs. Leptonic Gamma-ray Production**
    a. Pros/Comments
        i. Observations of objects like RX J1713 and many Galactic supernova remnants are required
        ii. High-energy observations needed to distinguish hadronic production from Klein-Nishina effects on the spectrum. CTA cannot devote hundreds of hours to enough interesting objects (true/false?)
        iii. Many of the interesting objects will be spatially extended
    b. Cons/Skeptical View
        i. CTA can cover many more objects in its Galactic Plane survey with much higher sensitivity than HAWC
        ii. In tiling mode CTA may be able to perform deep observations of many objects with sensitivity >= current IACT measurements
        iii. Spatial extension is not a problem for CTA except for most extreme cases (i.e., a handful)
4. **Nearby Pulsars (Spatially Extended Off-Plane "Gemingas")**
    a. Pros/Comments
        i. Clear evidence from HAWC that there are at least a few such objects
        ii. Very spatially extended, will be tough for CTA
        iii. Good constraints on particle propagation and diffusion
        iv. Best sources to study for nearby sources of the Galactic cosmic ray flux in the solar neighborhood
        v. Do these sources flare? If so, high uptime is desired
    b. Cons/Skeptical View
        i. What fluence sensitivity is required for SGSO to have a real impact beyond what HAWC is already accomplishing with Geminga and B0656+14?
5. **Microquasars and Binaries**
    a. Pros/Comments
        i. Direct probe of particle acceleration in a repeating environment: "astrophysical laboratories"
        ii. Very strong and unpredictable flares occur (LS I +61 303), motivating long-term high-uptime observations
        iii. Small number of TeV observations of binaries (5 sources) motivates a wide-field survey. SGSO lacks time allocation constraints and complements CTA in this area
    b. Cons/Skeptical View

        i. Lack of observations thus far of *known* binaries with HAWC hurts the case that a ground array can observe these objects

6. **Fermi Bubbles**
    a. Pros/Comments
        i. Demonstration of recent activity in the center of the Milky Way?
        ii. Very extended emission can only be resolved by an all-sky survey
    b. Cons/Skeptical View
        i. What does an extension of the Bubble observation to TeV tell us? What are the limits worth?
        ii. Is not a qualitative improvement over what HAWC is already doing
7. **Cosmic Ray Observations**
    a. Pros/Comments
        i. Characterization of local cosmic-ray environment with high statistics
        ii. Sensitivity to CR flux in transitional energy range below the knee, in a region of the sky measured only by IceCube/IceTop
        iii. Sensitivity to CR anisotropy in a region measured only by IceCube/IceTop
    b. Cons/Skeptical View
        i. No new physics expected beyond what HAWC is already doing in the Northern sky.
        ii. CR physics “comes along for the ride” when building a ground array, but is not a reason to build the detector
8. **Star Forming Regions (Cygnus)**
    a. Pros/Comments
        i. Very spatially extended, excellent for multiwavelength observations
        ii. High-energy emission
        iii. Strong candidate for cosmic-ray acceleration and sources of Galactic neutrinos
    b. Cons/Skeptical View
        i. HAWC is already sensitive to regions like Cygnus
        ii. Source confusion is a major issue and may be better handled by CTA, which will be capable of estimating backgrounds in very extended regions
9. **Molecular Clouds**
    a. Pros/Comments
        i. Very spatially extended (> 10 degrees)
        ii. Targets for cosmic-ray interactions, can be used to characterize the CR flux well outside the solar neighborhood
        iii. Could be sources of high-energy emission

b. Cons/Skeptical View
    i. Flux expectation not known; is an array sensitive enough at the right energies?
    ii. Need to specify some targets in the Southern sky. Conversations with IR and radio astronomers are needed

10. **"Galactic Type" Particle Accelerators (LMC, Starbursts)**
    a. Pros/Comments
        i. Attractive targets to help fill in picture of CR acceleration in MW
        ii. Nearby satellites like the LMC are spatially extended
    b. Cons/Skeptical View
        i. Is the LMC going to be bright enough to be seen with a ground array?
        ii. Won't CTA be much more sensitive to starburst galaxies, which will be point sources and have cutoff spectra due to their distance from Earth? I.e., two strikes against a ground array

Summary

All of these topics can be summarized as "Properties of energetic particles in the Galaxy."

For a science case, there is a general question about the fluence sensitivity, with issues related to zenith angle/transit sensitivity in an array needing to be answered.

For complementarity to CTA, the argument that SGSO can help with telescope time allocation is *weaker* for Galactic sources because of the extensive CTA Galactic survey.

The argument that source extension is larger in the Galactic Plane than expected can help counter the claim that CTA will totally dominate Galactic observations. A reasonably careful comparison of HAWC-IACT observations is needed to demonstrate this (e.g., counts of extended vs. point sources).

Another strong point in favor of a high-uptime ground detector is the ability to search **archival data** -- e.g., new searches for dSph (to be reiterated in Dark Matter discussion). Important for flares.

<u>Monitoring the Transient Sky</u>, Thursday PM

Afternoon discussion about transients, mainly focusing on AGN and GRBs. Note that some topics already discussed, like microquasars and generic searches for flares, also apply here.

Possible physics questions:

- What are the emission mechanisms that cause extreme outbursts?
- CTA will measure short term variability, which gives information about the size of the interaction region in a source. SGSO will measure long-term variability… what does this teach us? Some conversations with astronomers could be useful.

Some skeptical points regarding source classes:

1. AGN
    a. What cosmological information can we obtain from off-plane observations of AGN?
    b. How many AGN are needed to carry out these studies? 20? 50? 100?
    c. There are already >50 AGN in TeVCat, so what can SGSO contribute to population studies that we don't already have?
    d. Skeptic: X-ray telescopes give us lots of AGN monitoring and triggering, so the demise of Fermi-LAT does not make the case for SGSO triggering of CTA.
2. GRBs
    a. A good topic, but now with 8 years of LAT/GBM data we know that large flares are rare. This was not the case in 2010 when HAWC was under construction, due to the observation of multiple huge flares soon after the launch of Fermi (h/t **Ignacio Taboada**)
    b. What sensitivity is needed?
    c. If we can guarantee 1 GRB/yr with SGSO, we expect 1 CTA follow-up in 10 years due to the 10% duty cycle. Is that a strong enough case?
3. FRBs
    a. Good: example of a recently discovered source class that can be studied with **archival data**
    b. Bad: "hot" topic today, but if these are cosmologically distant then the probability of observing them with a ground array significantly decreases, even if they produce large quantities of TeV gamma rays.
4. Gravitational Waves
    a. Almost certainly will be dominated by distant extragalactic observations for several more years, working against a ground array

   b. In favor of SGSO: GW probability contours will still be quite extended even after new detectors come on line.

Summary of points made during this back and forth conversation:

Marcos: would like to know:

1. Probability of flares with interesting science. Is merely seeing any flare enough to make a case?
2. Raw numbers of flares should be estimated if possible (need a plot here). One more flaring AGN will not be very interesting.

Adrian: disagree; physics related to particle acceleration and neutrino production could be inferred from one big flare in one source.

Robert: disagree with Adrian's disagreement; see correlation of AGN flare with Big Bird event in IceCube.

Fabian: lowered energy threshold in HAWC is likely critical for making the case for transients in SGSO. There is nothing special about the Southern sky, a point which works for and against our case.

Brenda: need to emphasize discovery over extension of existing measurements. Makes the case for why CTA <u>needs</u> this array to do certain kinds of science. Operational advantages for CTA also help.

- Long term light curve monitoring with CTA "snapshot" program could be taken over by SGSO, freeing telescope time for other sources (h/t Fabian)
- The isotropic extragalactic background is something we know we can do with HAWC, but not at low energy.
- Agree that improvements in low-energy response of HAWC need to be demonstrated (plot for paper).

<u>Physics Beyond the Standard Model</u>, Thursday PM

Note that there is some disagreement over whether or not this is a more “fringe” topic that is not central to the mission but is accessible and interesting science. As usual one’s opinion depends on one’s funding source, though US agencies like DOE have no plan to continue supporting indirect searches for DM.

Brenda: southern sky is *really* critical for DM because of the Galactic halo. Characterizing the DM and making limits could be tough for CTA depending on the density profile. Strongly peaked halo profiles like NFW allow for strong limits by H.E.S.S., but a Burkert profile could produce much worse constraints from an IACT. Many people now disfavor the NFW model.

Pat: could try to make the case that CTA and SGSO constraints are quite complementary, depending on the true density profile of the halo. Two very interesting points:

1. SGSO can more easily constrain a slowly varying profile (needs to be demonstrated and plotted).
2. Limits without strongly peaked profiles are more robust because they are less sensitive to uncertainties in the density gradient.

<u>DM Overview from Pat</u>

Pat reviewed his DM slides from the November SGSO workshop in Puebla and made the following points:

Dark Matter Halos and dSph

- We should no longer argue in favor of substructure enhancements, as theorists now argue that halo substructure will make halos more peaked (strongly favoring CTA limits over SGSO/HAWC)
- Archival data is important as new satellite galaxies are discovered, especially high M/L galaxies which can dominate limits in stacked analyses. Example:
    - MAGIC spent 50 hours on Segue I
    - Reticulum II discovered *after* and provides *stronger* DM constraints
    - Wasted time allocation for IACT, no problem at all for a ground array
- GC limits from a HAWC-like array at 29S latitude are similar to IACT limits, though this does strongly depend on the halo profile

- **Segev**: are lack of dSph observations enough to rule them out as a DM source class? **Pat**: dSph galaxies will provide the cleanest DM limits for a long time, so we should keep looking for them and not be afraid to emphasize our sensitivity

Lorentz Invariance Violation

- High-energy photons provide automatic limits on photon decay
- Huge advantage to this kind of limit over multiwavelength observations of the dispersion of photon arrival times in a flare (10x more constraining)
- Con: HAWC will already be setting very strong limits given the high-energy sky seen in the North. Counterargument: PeVatron in the GC could produce even more high-energy photons

Axions

- Solution to fine-tuning of CP violating terms in QCD Lagrangian (Peccei-Quinn symmetry) produces axions, which are pion like and <<1 eV in mass. Axions have an inverse relation between mass and coupling strength; axion-like particles (ALPs) do not.
- Couple to nucleons and photons. In strong B fields axions and photons will mix, producing observations such as:
    - Bumpy features in gamma-ray spectra due to axion-photon oscillations
    - High-energy emission from distant AGN as photons converted to axions travel unattenuated through the EBL before oscillating back to photons in the Milky Way (astrophysical “light shining through a wall” experiment)
    - “Gamma appearance” measurements in a Galactic Type II supernova. Will demonstrate axion-photon oscillations and provide 10x better constraints than any other measurement (paper by Meyer et al., 2016)
- Cons/skepticism:
    - Bumpy features in spectra require good energy resolution, ~10%. CTA can easily beat SGSO
    - Not much parameter space left in TeV transparency measurements; H.E.S.S. has already ruled out most of the allowed region (paper by D. Horns et al., 2013-2014?)
    - We are too high energy to observe SN II photons, which peak around 10 MeV (like supernova neutrinos) and cut off well below TeV range
- Pros:
    - Fermi-LAT performed its spectral irregularity measurement using the Perseus cluster, which has a strong B field. The Fornax cluster in the Southern sky could be a similar target and may be too large for CTA to easily measure.

Primordial Black Holes

- Hawking (HAWC-ing?) radiation from evaporating black holes

- These can be observed by HAWC already; what does SGSO offer?
- Effort needed to put this in context w.r.t. other topics. I.e., as direct measurements of the WIMP-nucleon cross section approach the coherent neutrino scattering background, is this becoming a more popular alternative theory of DM? Why is this worth mentioning versus some other “exotic” signal?

Design Considerations, Friday AM

Began with discussion of two ICRC proceedings on SGSO from Miguel and Harm.

1. Harm: *Baseline Design for a Next Generation Wide Field-of-View Very High-Energy Gamma-ray Observatory*
    a. Carrying out a detector optimization study based on size, altitude, station size, and detector efficiency of ground arrays
    b. Parameterization of values such as EM ground energy and ground muon count with given radius as a function of slant depth, which can be converted into altitude and zenith as needed
    c. Currently simulating a LHAASO-like layout of multiple water Cherenkov pools (~50x50 m) surrounded by several more sparse layers out to 300 m
    d. No noise in simulation, will characterize best possible performance
    e. **Andy**: think about optimizing \$/m^2 to determine the best density given particular dollar/euro constraints
    f. **Segev**: adding correlated noise is important since we expect to hit noise limits as a function of energy. Some easy ways to do this directly from CORSIKA events. **Andy's response**: yes, but beware of opening a can of worms. Toy MC can easily turn into full trigger implementation. Maybe better to pick a fixed event rate and see how it performs at different locations given some very simple noise and event models
2. Miguel: *On the Scientific Motivation for a Wide Field-of-View TeV Gamma-ray Observatory in the Southern Hemisphere*
    a. By consensus, will take salient points from this workshop with plots where available (few at the moment)
    b. All interested in authorship should contact Miguel

The Case for a Cherenkov Pool (Andy), Friday AM

Discussion centered around building large area detectors. Focus was on the water Cherenkov technique mainly because of the need to achieve large area cheaply and have height in the detectors to capture inclined events (point from Fabian).

Andy shared thoughts about why we should prefer building a Cherenkov pool over a tank array if we can do it, and how we can make it relatively modular so it can operate as an engineering array. No slides provided, but will attempt to summarize the discussion below.

Desideratum: cheapest possible way to deliver a large volume of water. Pools are good because they have a 100% fill factor, and because much of the cost of a WCD is in the perimeter (support for the weight of the water) rather than the volume. So a pool can scale to very large area more easily than an array.

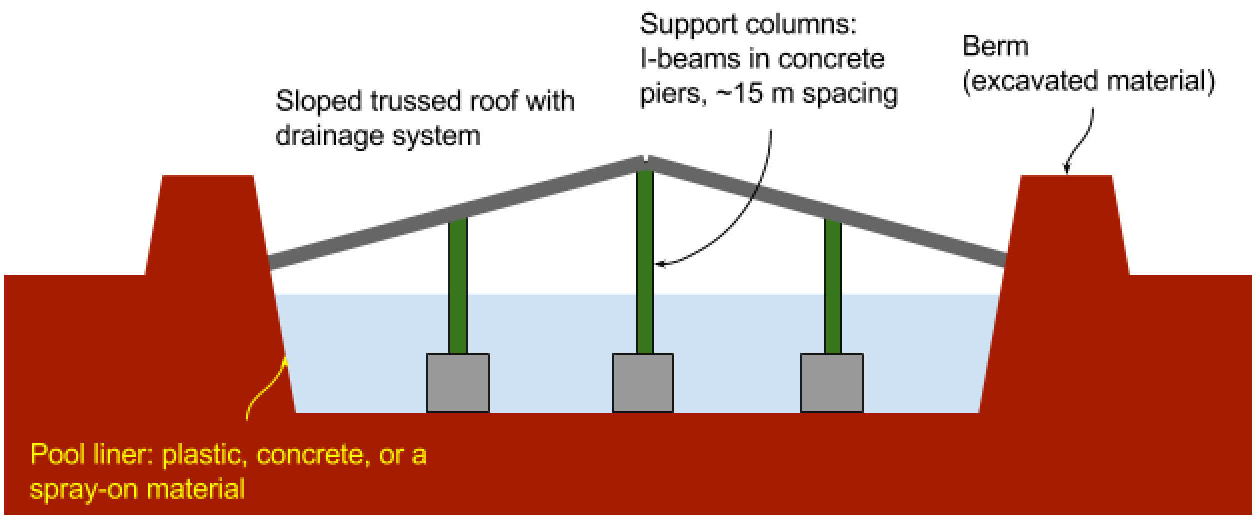
Subtext: **sensitivity scales like area rather than naive expectation of sqrt(area)**, because of gains in gamma/hadron rejection power, angular resolution, energy range, and other reconstruction parameters with area.

Problems encountered with a Cherenkov pool at Milagro: the cover was a tarp.

- Light leaks
- Difficult interior access and hard to manage, especially in high winds

Therefore, a new pool should have a roof. This may dominate the construction cost, as building a concrete pad is not particularly challenging or expensive. Possible design:

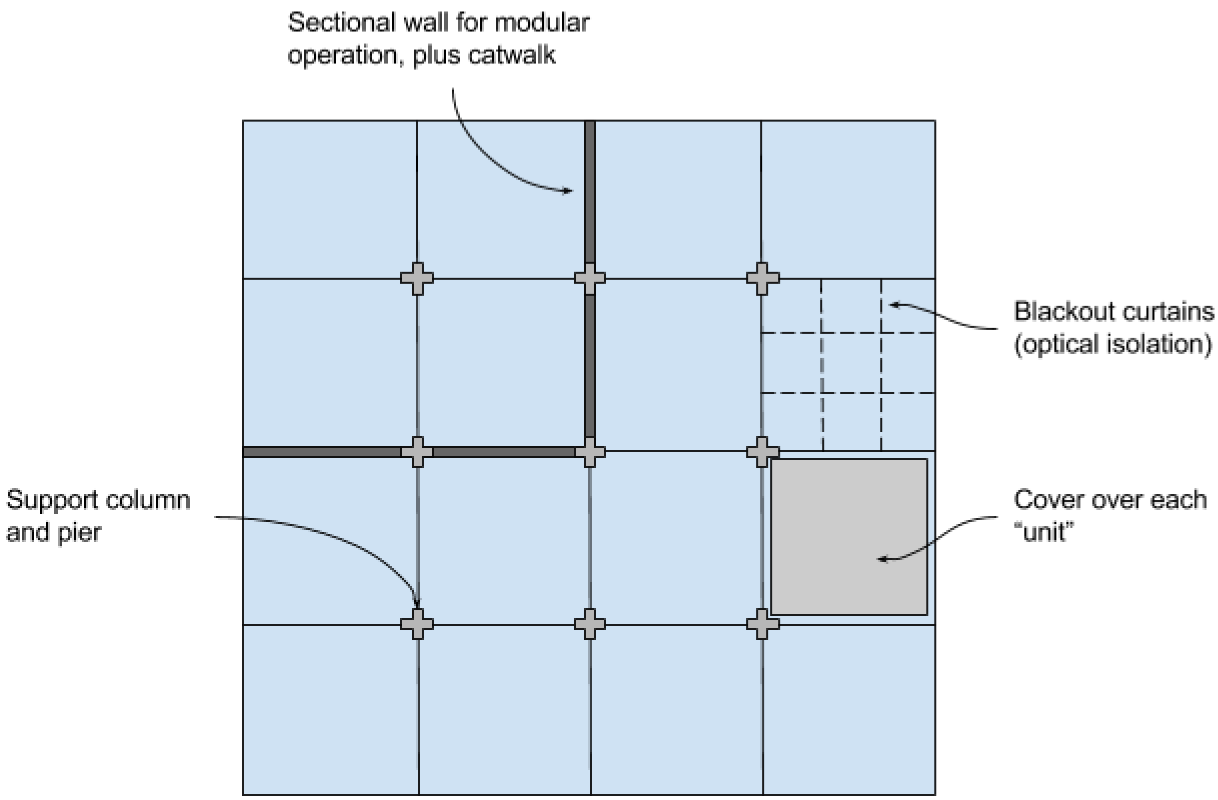
- Excavated pool ~1 m below ground level
- Berms of excavated material used for perimeter support (standard practice)
- Trussed sloped roof with drainage system
- Support columns are I-beams ~15-20 m apart, embedded in concrete piers (think of supports from a warehouse store like Home Depot)



Modularity and optical isolation are important. Possibilities:

- Sectional walls between some piers -- earth-filled concrete layers -- to allow drainage/movement of water between sections for maintenance or purification
- Within a section, blackout curtains for optical isolation

- Cover over each subsection for light leaks, further reducing stray light from roof
- Catwalks in trusses to allow access to subsections
- Modularity can be preserved (for engineering array) and PMT densities can be varied significantly within subsections



Cons:

- Engineering is much more complex than water tanks
- Cabling, feed-throughs, etc. must be pre-planned and can't be easily prototyped in the lab. Part of civil engineering, and must be planned upfront
- Large water pipeline is probably necessary; can't fill with trucks

Feasibility: could not do this in HAWC due to site restrictions. Could be possible in Llama site in Argentina. (**Marcos**: major issues with seismic loading in a pool; could raise costs significantly?)

<u>"Bagging a Lake" Concept (Discussed at LANL)</u>

Go to a lake at 4000 m to 5000 m and surround a volume below the surface with a bladder. Equal pressure inside/outside dramatically lowers expense of perimeter.

Miguel: serious problems: how to find a lake at right altitude? How to clean the water? How to secure the PMTs? How to address light leaks?

Segev: similar to concept for CHIPs from Chris Wendt (c. 2014) based on floating fish farms: large PVC rings supporting surface platforms and hanging nets.

Fabian: note that PMT motion in water is not an issue for this detector. Plenty of experience using tilt sensors and acoustic triangulation from ANTARES.

Marcos, Adrian: high-altitude lakes in Argentina are very environmentally sensitive, and also tend to be very salty in the NW. However, for the curious there is a list of lakes at highestlake.com (!)

Review of Sites in Salta (Adrian)

Overview of sites near Llama described in November 2016 workshop. The primary target site, S1, is 4850 m and is next to QUBIC. **Fabian**: QUBIC is funded and they are waiting to sign final papers so they can start building. They are eager to collaborate with us and would share infrastructure. We would be located over a hill from their detector, reducing RF interference.

The first secondary site, S2, is at 4450 m and is 300 m from route 51.

Both S1 and S2 can easily fit a 250x250m array.