Logistics, costing, photodetectors, and related matters

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SITE & LOGISTICS

Logistics experiences (in this room)

- South Pole (AMANDA/IceCube/SPT)
- Malargue, Argentina (Auger)
- Puebla, Mexico (HAWC)
- Siberia (TAIGA/Baikal)
- Namibia (HESS)
- Tibet (Tibet AS/LHAASO)
- Deep Sea (Antares/DUMAND)
- Various (Balloon campaigns)

Import/Export/Customs

- Conceptually simple, but has been a long-running problem in virtually all of these efforts
- In our sphere of interest, the European Southern Observatory has established a very comprehensive import/export regime including shipping by government entities and under (limited) diplomatic waiver; at one point HAWC had US embassy support for the shipping/customs effort
- Other projects have had success with hired customs brokers working closely with the project logistics folks
- This should be worked ahead of time, in concert with site selection ideally, and is certainly a factor in it

Altitude issues

- The road to the HAWC/LMT site is an extraordinary resource (in US, tourist roads to Mt. Evans and Pikes Peak are as high, a handful of roads in the Andes as well, out of La Paz for example) that is not to be expected elsewhere
- In the HAWC construction technique, local altitude-acclimatized workers were required (other approaches are possible, Auger for example, relied much less upon local laborers)
- Moving above 5km ASL likely leads to a completely professional work force at altitude, for example the ESO high altitude team that built ALMA down the hill and then transported it up the hill
- Costs of construction at extreme altitudes are difficult to estimate without prior local examples

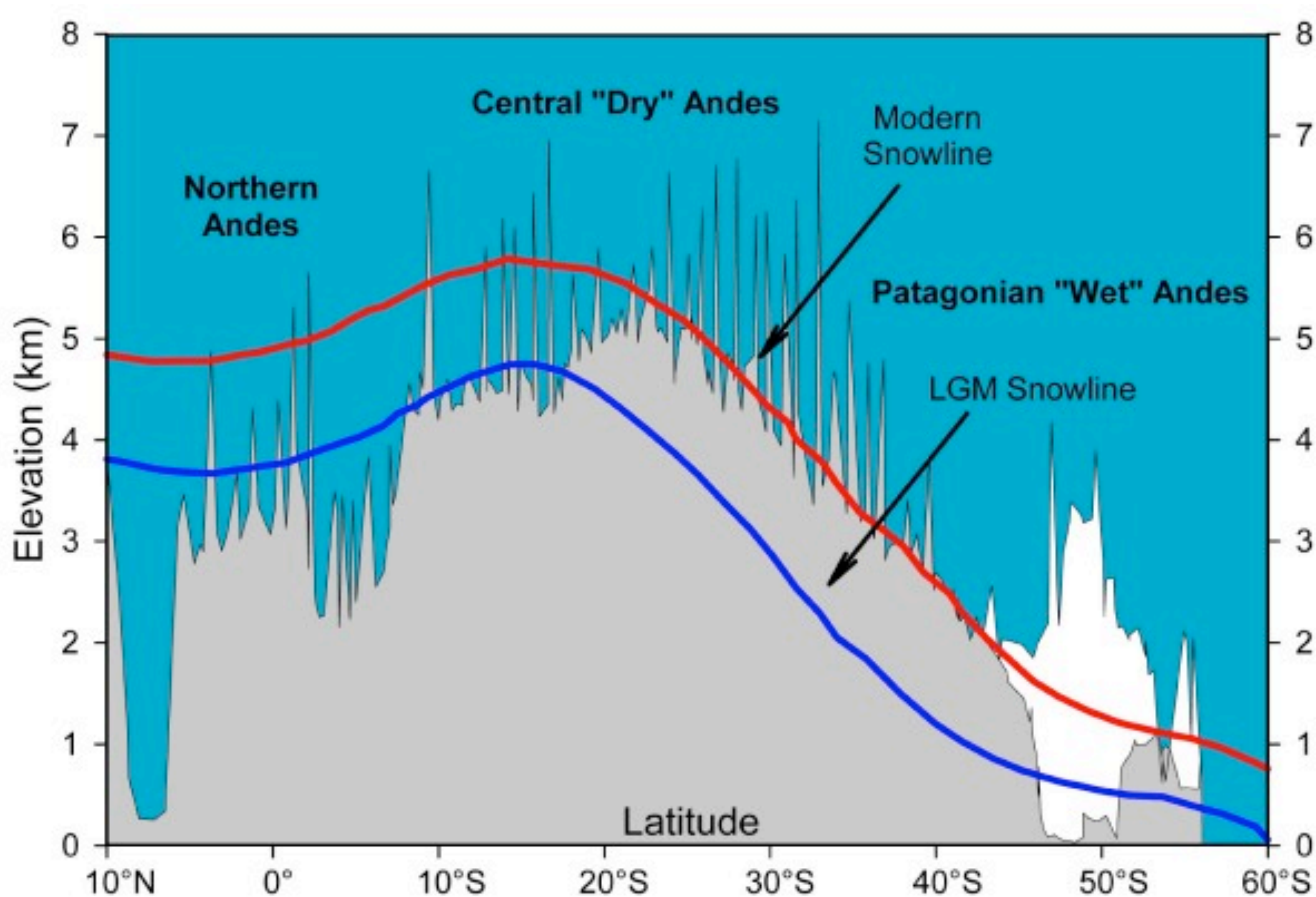
Local support

- Local academic institution(s)
- Labor force
- Hardware store (or extensive supply room)
- Plausible import scheme
- Relatively quick supply handling
- If we use academic workers, housing and transport to site become significant
- International travel time and expenses need to be kept in control

Temperature

- For a water detector, local climate is important (thermal time constants of these detectors are long)
- But not absolutely critical
  - Salts, alcohols, and liquid scintillator admixtures
  - Solar heating

Climate map



Central "Dry" Andes
Modern Snowline
Northern Andes
Patagonian "Wet" Andes
LGM Snowline
Elevation (km)
Latitude
0
1
2
3
4
5
6
7
8
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S

Site plausibility: From Wikipedia…

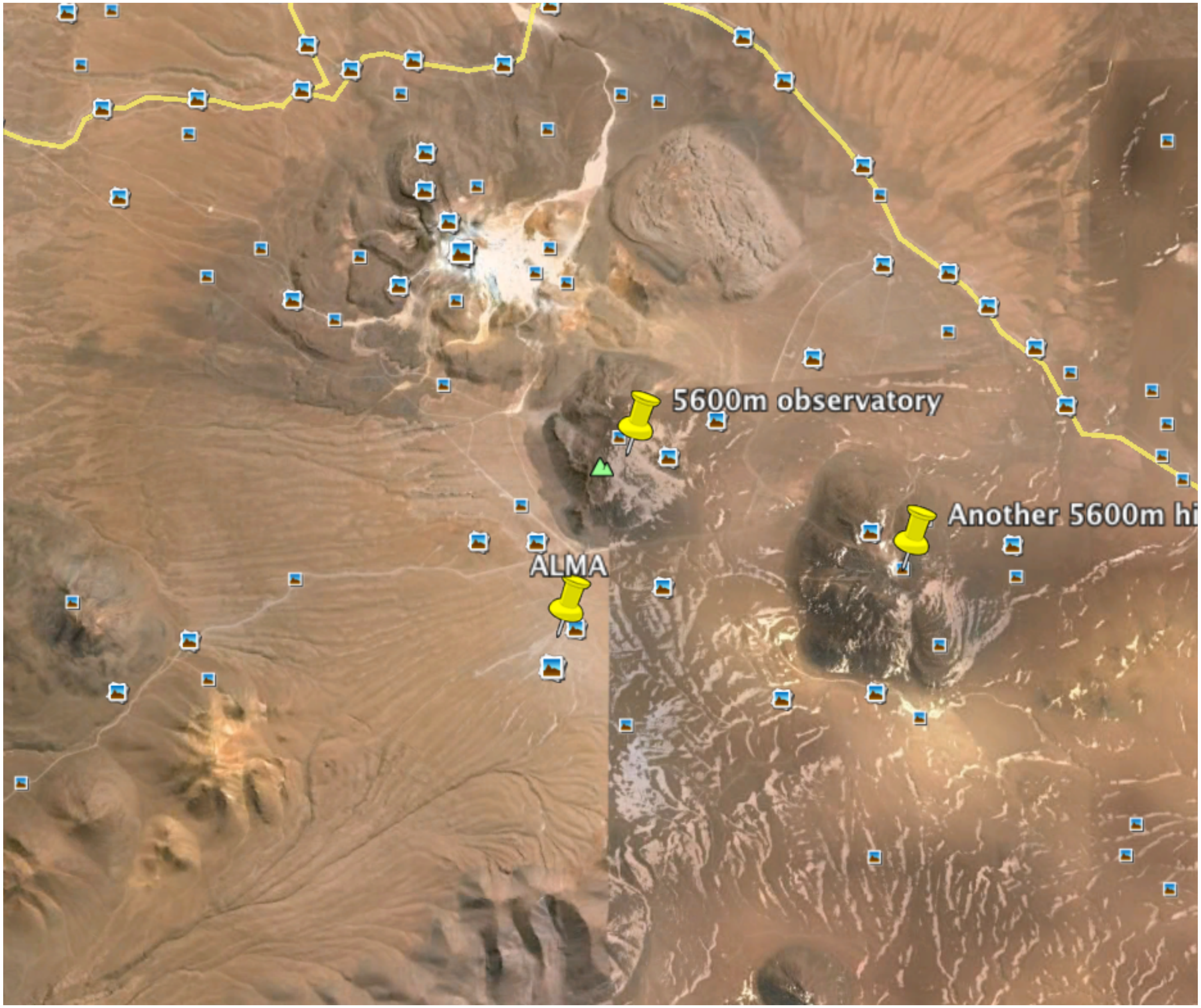
Highest permanent observatories [edit]

Permanent observatories above 3,000 m:

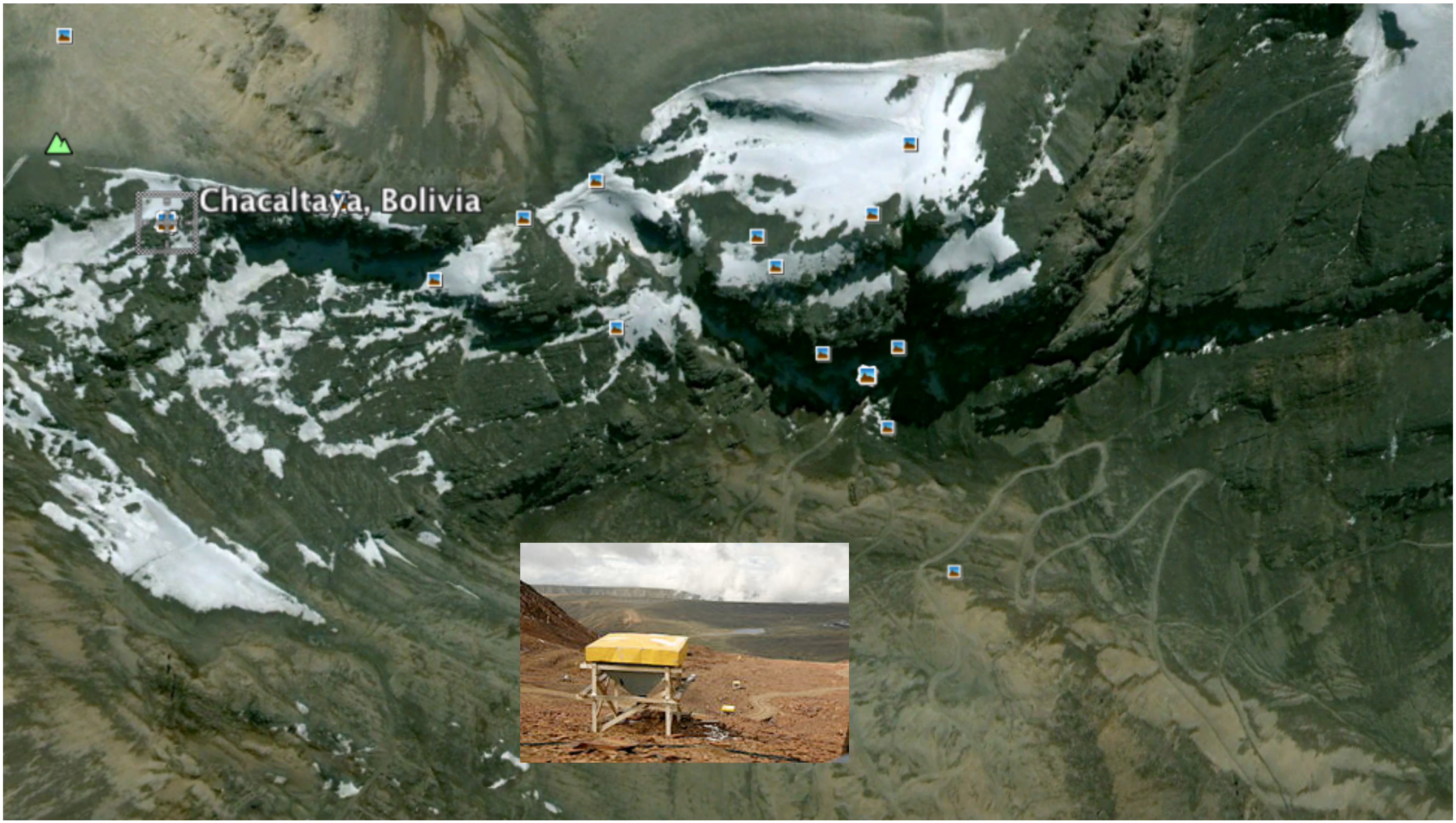
Observatory Name	Elevation	Observatory Site	Location	Coordinates	Established	Type of Observatory	Major Instruments
University of Tokyo Atacama Observatory (TAO)	5,640 m (18,500 ft)[10]	Cerro Chajnantor	Atacama Desert, Chile	22°59′12″S 67°44′32″W	2009[10]	Optical, infrared	
Chacaltaya Astrophysical Observatory	5,230 m (17,160 ft)[9]	Chacaltaya	Andes, Bolivia	16°21′12″S 68°07′53″W	1946[9]	Cosmic ray, gamma ray	
James Ax Observatory	5,200 m (17,030 ft)	Cerro Toco	Atacama Desert, Chile	22°57′30″S 67°47′10″W	2011	Microwave	POLARBEAR
Atacama Cosmology Telescope	5,190 m (17,030 ft)	Cerro Toco	Atacama Desert, Chile	22°57′31″S 67°47′16″W	2007	Microwave	
Llano de Chajnantor Observatory	5,104 m (16,745 ft)	Llano de Chajnantor	Atacama Desert, Chile	23°01′22″S 67°45′17″W	1999	Millimeter wave, submillimeter	ALMA, APEX, QUIET
Shiquanhe Observatory (NAOC Ali Observatory)[11]	5,100 m (16,700 ft)[12]	Shiquanhe, Ngari Plateau	Tibet Autonomous Region, China	32°19′N 80°01′E	2011	Optical	
Llano de Chajnantor Observatory	4,800 m (15,750 ft)	Pampa La Bola	Atacama Desert, Chile	22°58′17″S 67°42′10″W	2002	Submillimeter	ASTE, NANTEN2
Large Millimeter Telescope	4,580 m (15,030 ft)	Sierra Negra	Puebla, Mexico	18°59′06″N 97°18′53″W	2006	Microwave	
Indian Astronomical Observatory	4,500 m (14,764 ft)	Mount Saraswati[13]	Hanle, Ladakh, India	32°46′46″N 78°57′51″E	2001	Infrared, gamma ray, Optical[14]	Himalayan Chandra Telescope, HAGAR
Meyer-Womble Observatory	4,312 m (14,148 ft)	Mount Evans	Colorado, United States	39°35′12″N 105°38′24″W	1996	Optical, Infrared	
Yangbajing International Cosmic Ray Observatory	4,300 m (14,100 ft)[15]	Yangbajain	Tibet Autonomous Region, China	30°05′N 90°33′E	1990[16]	Cosmic ray	
Mauna Kea Observatory	4,190 m (13,750 ft)[17]	Mauna Kea	Hawaii, United States	19°49′28″N 155°28′24″W	1967	Optical, infrared, submillimeter	Keck, UKIRT, Gemini North, Subaru, JCMT, CSO, SMA, CFHT
High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory[18]	4,100 m (13,450 ft)	Sierra Negra	Puebla, Mexico	18°59′40″N 97°18′33″W	2013	Gamma ray	


06/01/2010

General area…



Chacaltaya: long cosmic ray history



Connections to possible sites

- Chile/ESO
  - Informal discussions, invited for visits, previously might have been complicated by CTA negotiations
- Argentina
  - Look to get a test stand/tank there, big test of how difficult it is to work there, local support available
- Bolivia
  - Chacaltaya, long history of the cosmic ray site there plus the ALPACA concept/test detector
- Other sites?

PHOTODETECTORS & ELECTRONICS

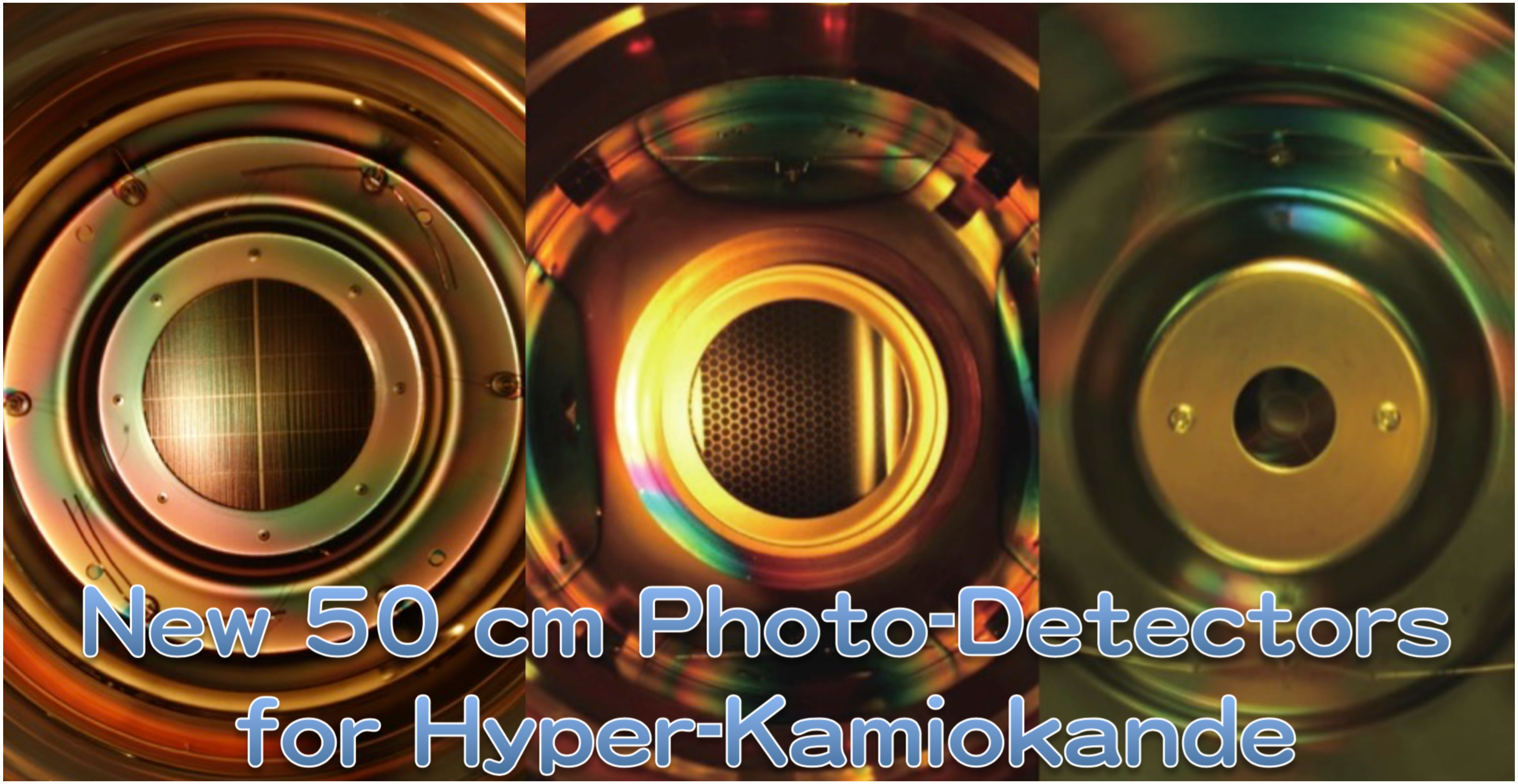
Water Cherenkov Detectors imply large area photodetectors

- Any potential improvements over the Hamamatsu 10” tubes?
- Chicago large area picosecond detectors aren’t quite at commercial scales yet
- But there are rumblings in the PMT manufacturers, largely driven by Hyper-K and Juno demands

Working with vendors on large PMTs

- HZC (Photonis IP) has provided a couple of 9" (low gain) Auger SD tubes, not suitable for SPE style calibration as in HAWC
- Waiting on delivery of HPD-PMT assemblies (in 8" form factor) from both Hamamatsu (APD-based) & HZC (MCP-based) with potential quantum efficiency times collection efficiency and angular acceptance improvements
- In parallel with other activities, will try and qualify HPD-PMT designs for use in potential IceCube or HAWC style detectors
- Factors of roughly 1.5-2.0x photon yield have been shown, along with reduced magnetic field susceptibility, and improved uniformity of gain across photocathode & from tube-to-tube
- This field has expanded significantly in the last five years (UC-Davis, Daniel Ferenc's Abalone, 2011 for example), possibly in time for a southern TeV detector
- Leveraging the large PMT orders for Hyper-K and Juno

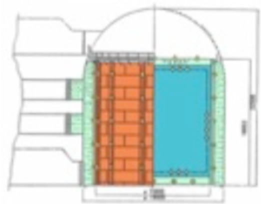
Much stolen from the Hamamatsu talk at ICHEP:



First 20-inch (50 cm) Photomultiplier Tube (PMT)

Hamamatsu R1449 (Venetian blind dynode) → IEEE milestone (2014)

For Kamiokande



(1983-1996)

1k PMTs
/ 3 kton water

Supernova ν observation!

R3600 (Venetian blind dynode, improved)

For Super-Kamiokande (Super-K, SK)

(1996-)

11k PMTs
/ 50 kton water

ν oscillation discovery!

For Hyper-Kamiokande (Hyper-K, HK)

For other experiments

42 cm (17") Box&Line PMT

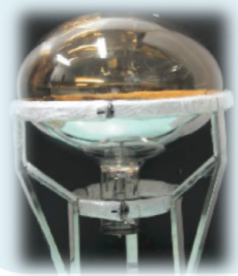
R7250

(Box&Line dynode) with 50 cm bulb of R3600

For KamLAND

50 cm MCP PMT
By NNVC, IHEP

(Micro-Channel Plate)



For JUNO

Recently developed in **China**

50 cm Box&Line PMT
R12860-HQE (Box&Line dynode)

Developed
→ Photo-detector in Hyper-K baseline design

50 cm Hybrid Photo-Detector (HPD)
R12850-HQE (Avalanche diode)

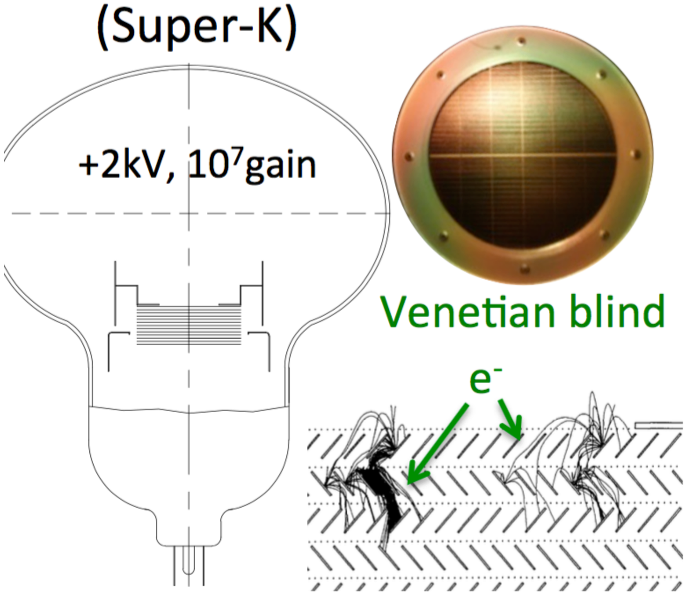
Under development
→ Possible further improvement of Hyper-K

Two types of new 50 cm photo-detectors have been developed since 2011 with much improvement for Hyper-Kamiokande.

50 cm Φ

Photomultiplier tube (PMT) | Hybrid photodetector (HPD)

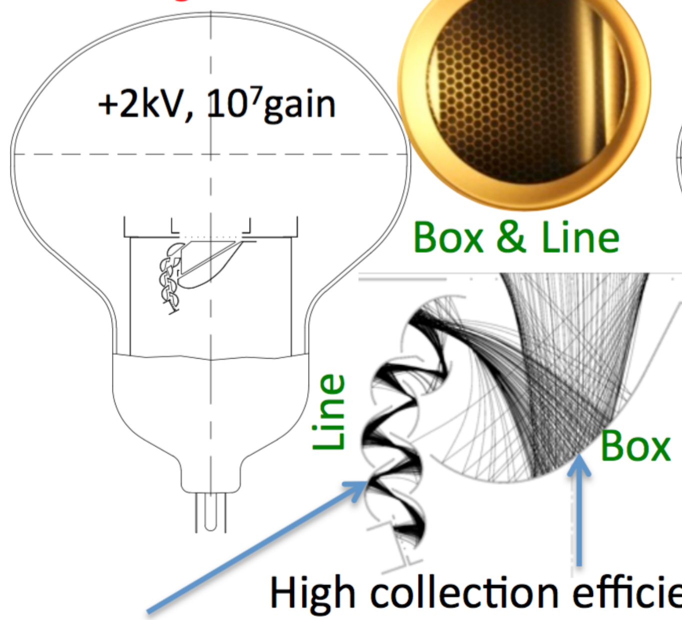
Venetian blind dynode (Super-K)



- Electron might miss dynodes → less collection efficiency
- Ambiguity of drift path limits charge and time response.

New Box & Line dynode

high QE



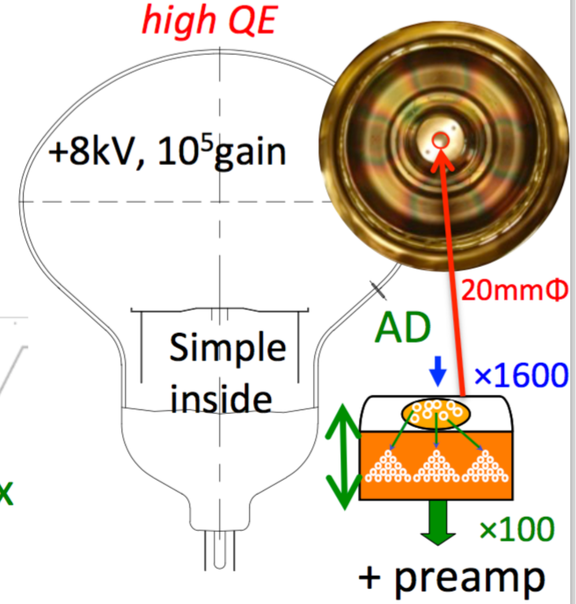
High collection efficiency (CE)

Uniform drift path

→ High charge&time resolutions

New Avalanche diode (AD)

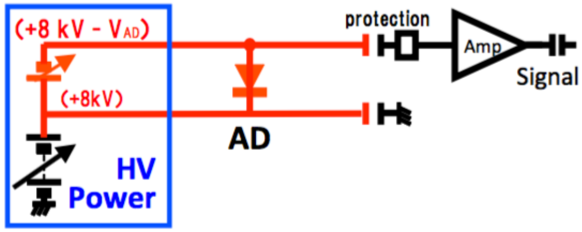
high QE

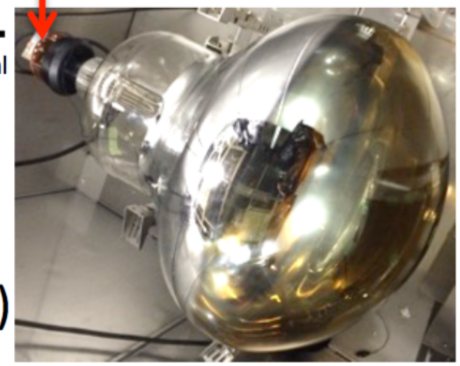


Low cost, high resolutions

HPD

Built-in HV power and preamplifier



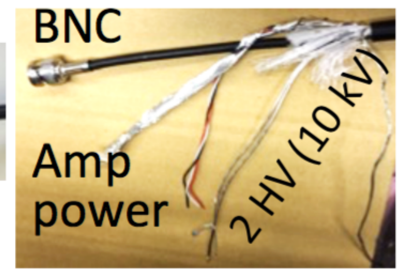


Operated by
low voltage lines (<10V)

External HV Option → Confirmed with 100 m HV extension

8 kV & signal connector

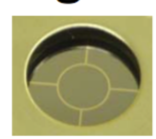
R&D, up to 100 m water



AD Segmented Option (400 pF/ 20 mmΦ)

→ 2 or 5 channels to avoid large capacitance

For amp noise reduction
and fast response

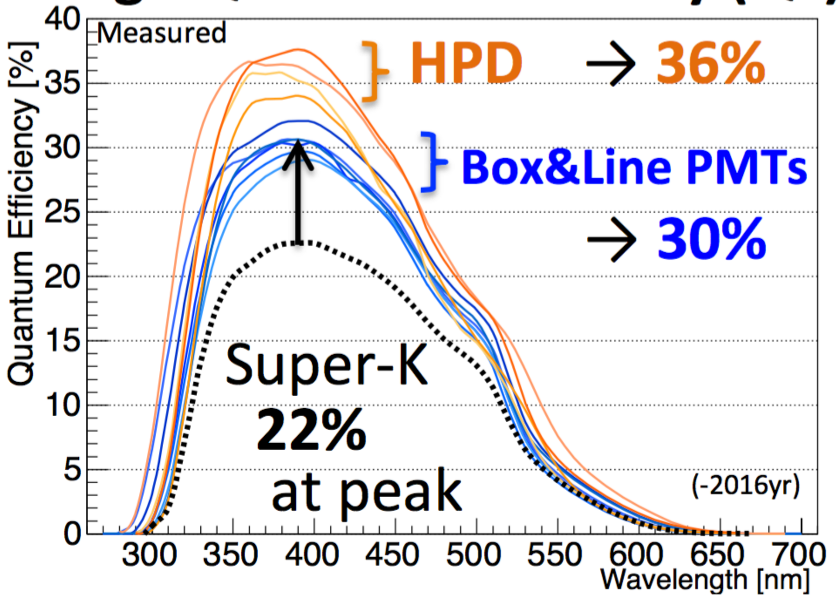


5ch AD
+ Sum amp
etc.

High pressure water test

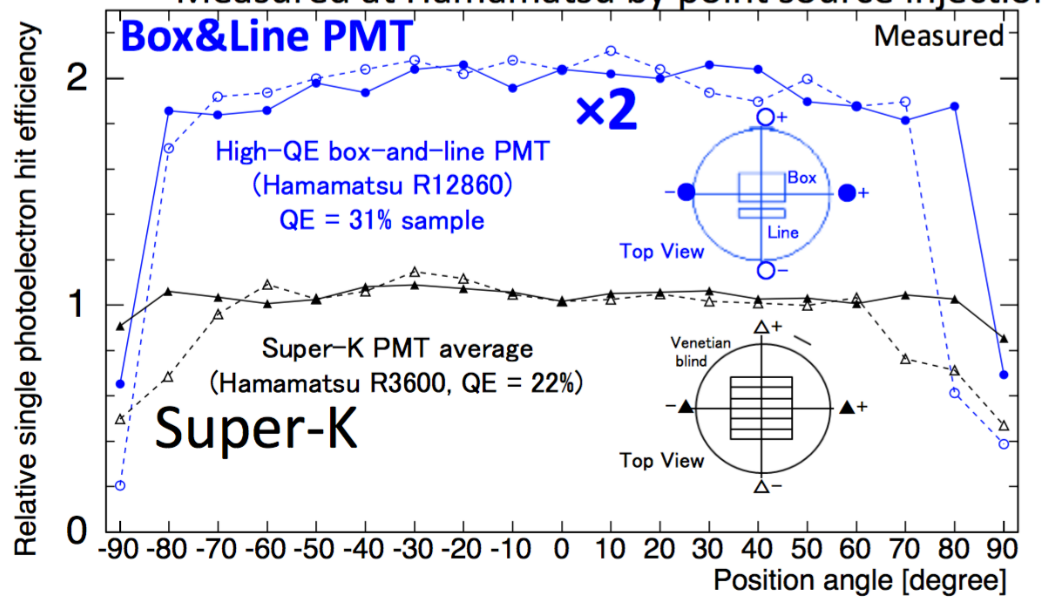
3 HPD bulbs were tested, and there is no damage up to 1.25 MPa as well.

High Quantum Efficiency (QE)



Total Detection Efficiency of 1 PE

Measured at Hamamatsu by point source injection

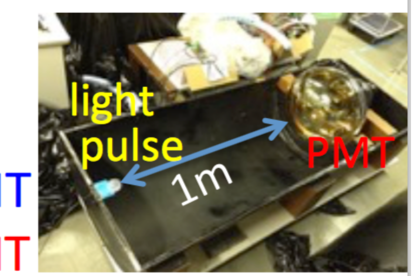


Collection Efficiency (CE)

By simulation	In 46cmΦ (50cmΦ)
Super-K	67% (61%)
Box&Line PMT	95% (85%)
HPD (1ch 20mmΦAD)	97% (80%)

Confirmation in relative hit counting

Relative comparison of single PE counting compared with SK PMT by a uniform light injection



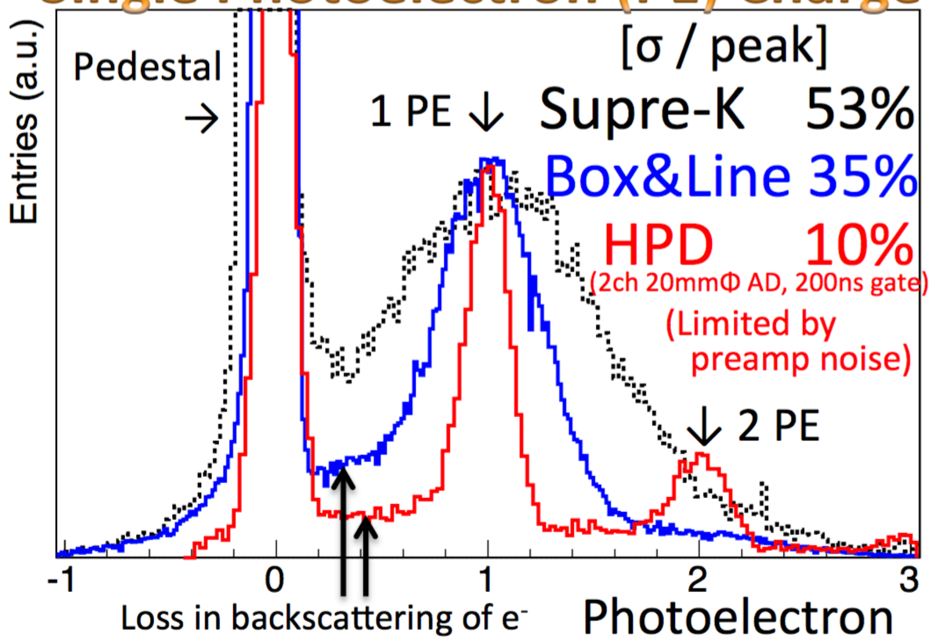
Box&Line PMT : 1.91 of SK PMT

HPD (2ch 20mmΦAD) **: 1.76** of SK PMT

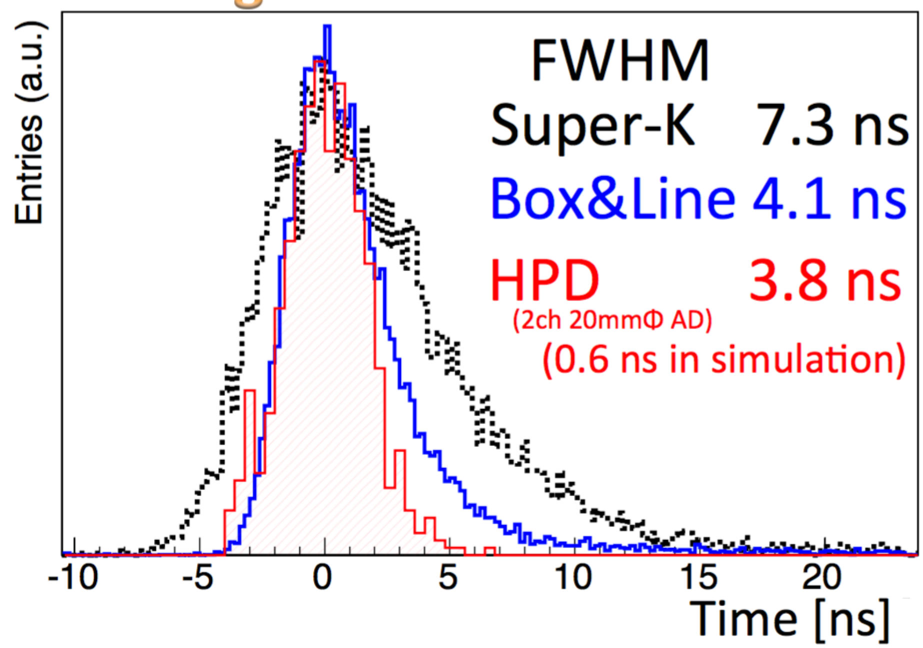
(Low due to higher threshold for 1 PE)

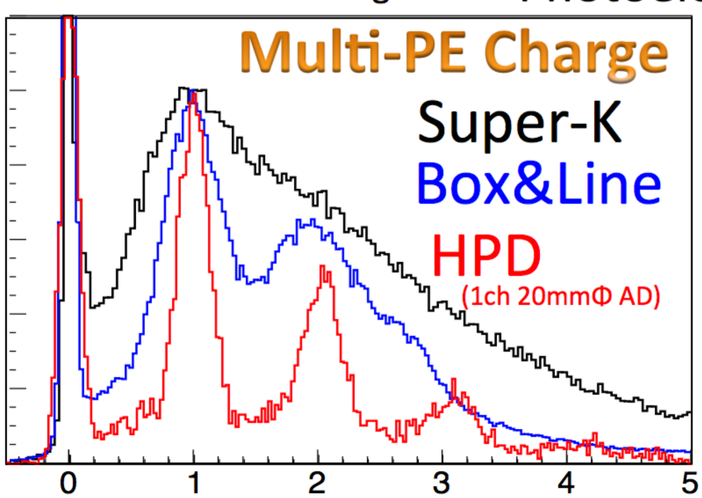
Detection efficiency was doubled in both new photo-detectors.

Single Photoelectron (PE) Charge



Single Photoelectron Time

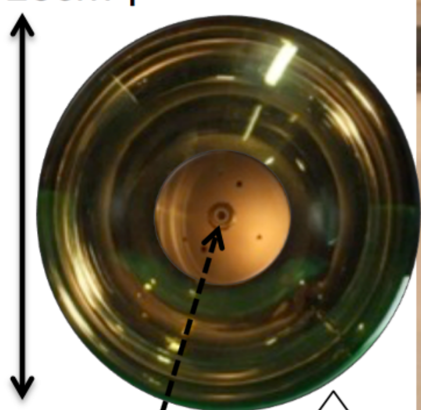


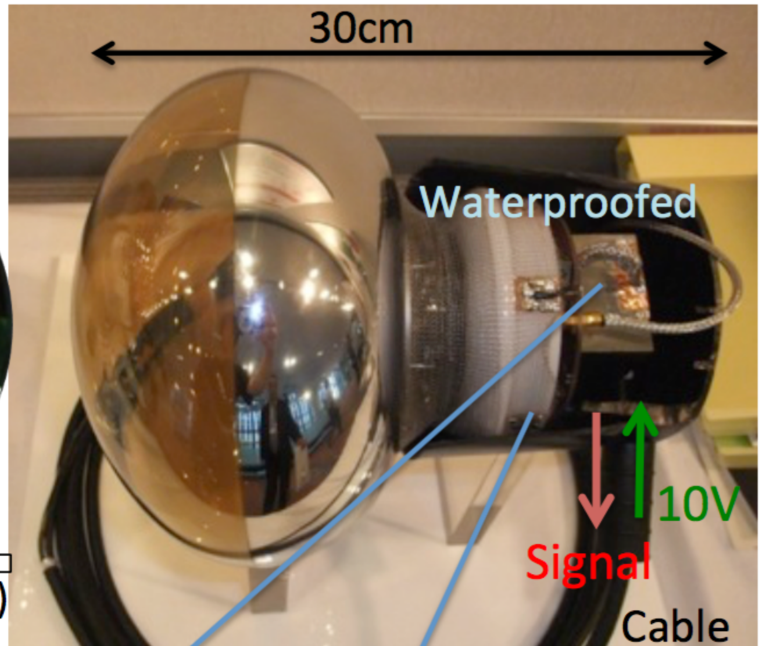


- Clear photon counting and narrow transit time spread in both new photo-detectors
  - Allow precise event reconstruction, background reduction, …
  - HPD performance is still limited by a preamplifier and to be improved.

20 cmΦ (8-inch) HPD

Size for outer detector





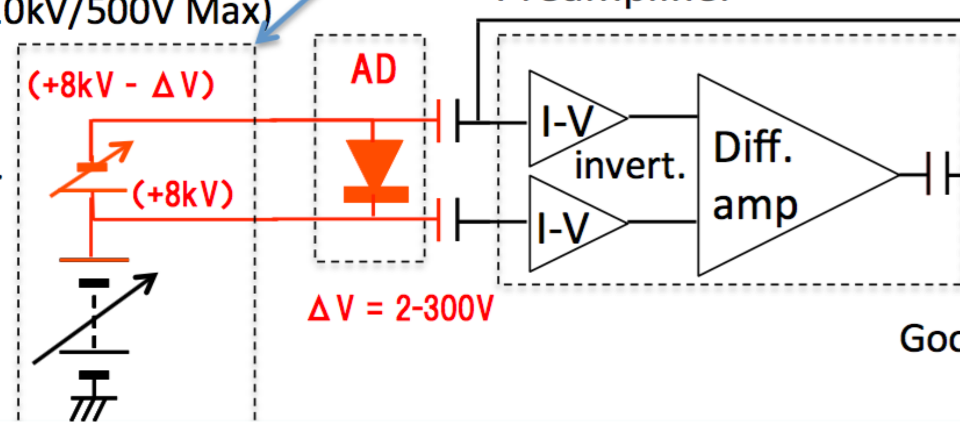
HAMAMATSU

Spectral response		300 - 650 (420 max.) nm
Photocathode		Bialkali
Window material		Borosilicate glass
Gain		4 - 9 x10^4
Time	Rise	1.7 ns
	Fall	2.7 ns
	T.T.S.	0.62 ns (σ)
Dynamic range		100 pC (1.5x10^4 p.e.)

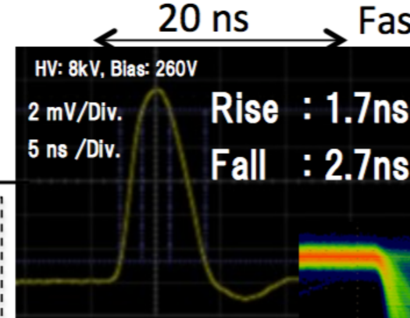
High voltage module
(2ch 10kV/500V Max)

No HV line in water

Preamplifier

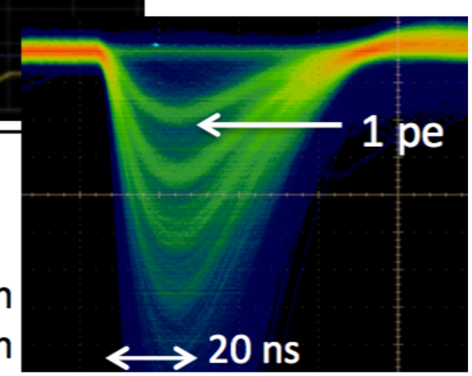


Fast intrinsic response (w/o preamplifier)

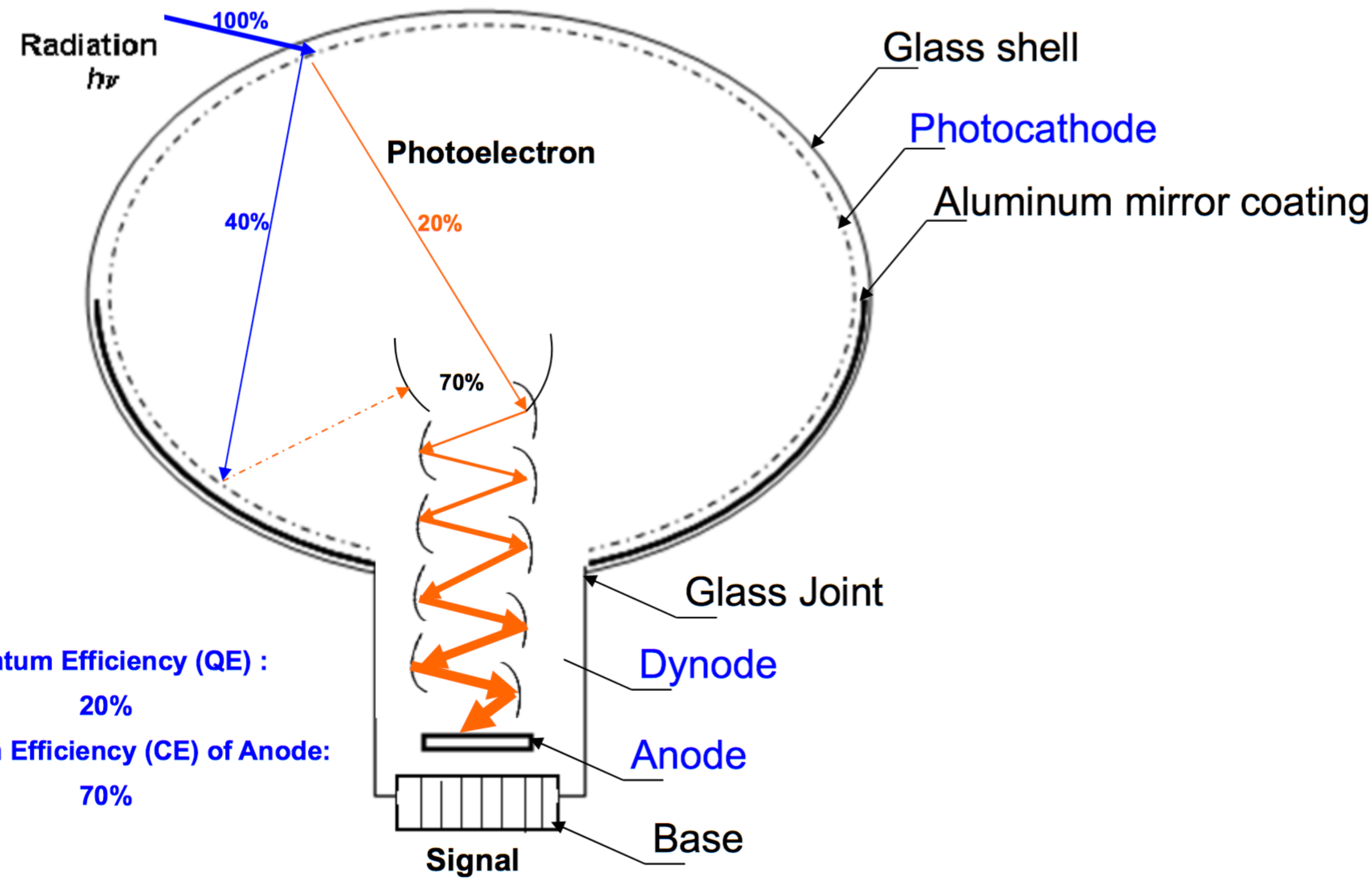


Shaped in preamplifier

Good photoelectron separation



➢ The Conventional PMT



Quantum Efficiency (QE) :

20%

Collection Efficiency (CE) of Anode:

70%

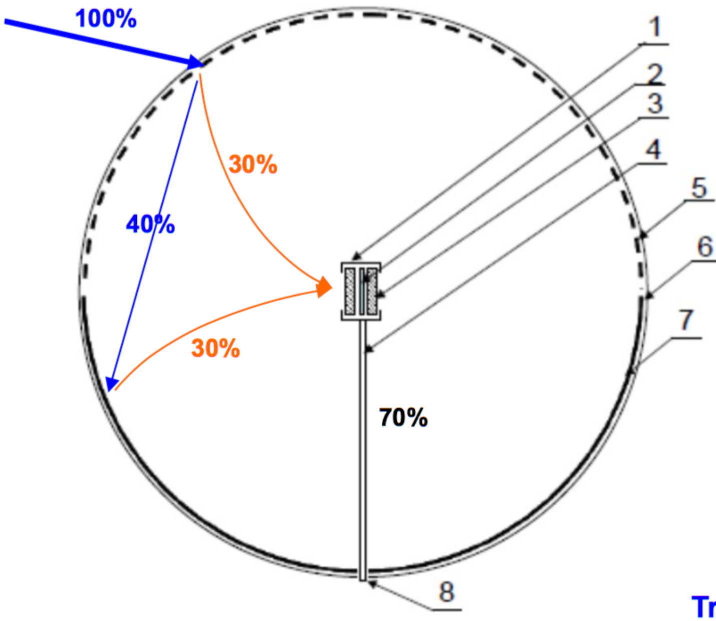
Photon Detection Efficiency (PE)= QE_{Trans} * CE = 20% * 70% = 14%

➢ The new design of a large area PMT

High photon detection efficiency + **Single photoelectron Detection** + **Low cost**

1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain

2) Using transmission photocathode (front hemisphere) and reflection photocathode (back hemisphere) } **~ 4π viewing angle!**



1.Insulated trestle table

2.Anode

3.MCP dodule

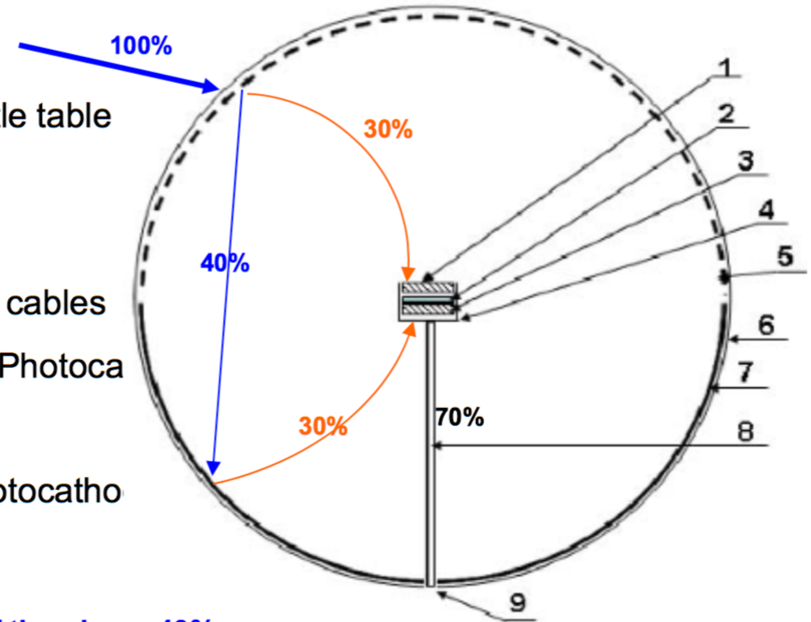
4.Bracket of the cables

5.Transmission Photoca

6.Glass shell

7.Reflection Photocatho

8.Glass joint



Transmission rate of the glass: 40%

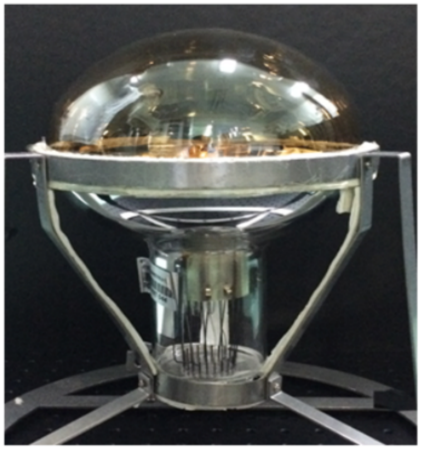
Quantum Efficiency (QE) : of Transmission Photocathode 30% ; of Reflection Photocathode 30% ;

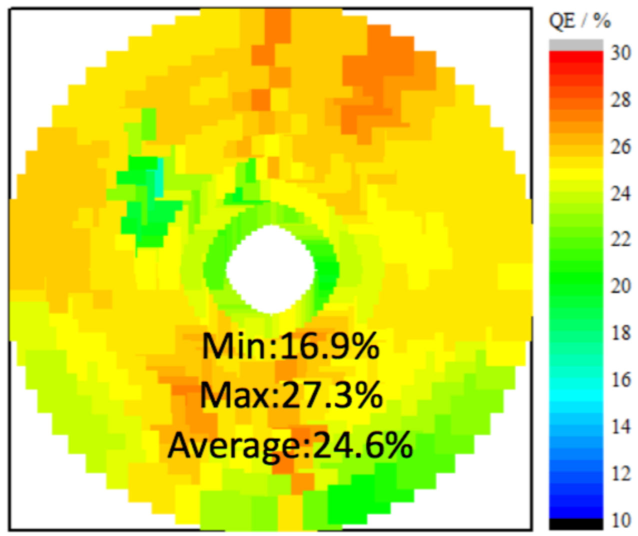
Collection Efficiency (CE) of MCP : 70%;

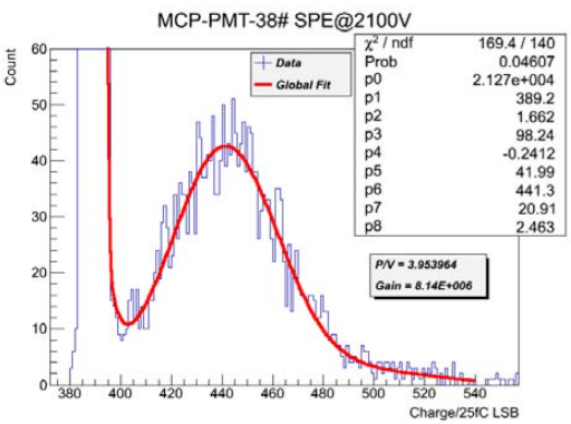
$$PD = QE_{Trans} {}^*CE + TR_{Photo} QE_{Ref} {}^*CE = 30\%{}^*70\% + 40\%{}^*30\%{}^*70\% = 30\%$$

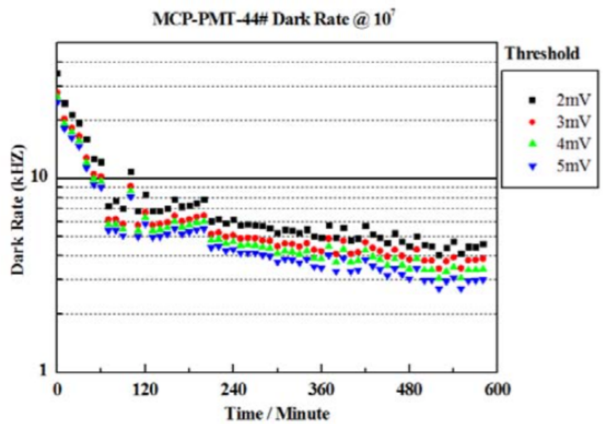
Photon Detection Efficiency: 15% → 30% ; ×~2 at least !

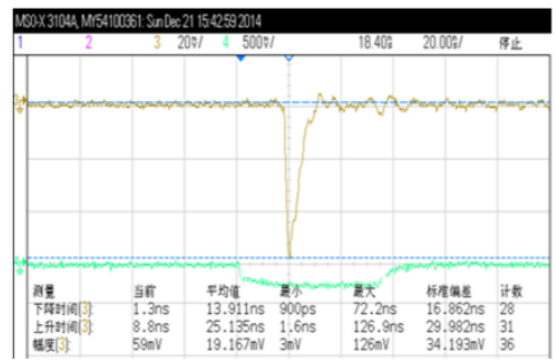
➢ 3.1 8”prototypes with normal performance--2013

8-inch IHEP MCP-PMT Vertical MCPs Sphere Glass	8-inch IHEP MCP-PMT Horizontal MCPs
	



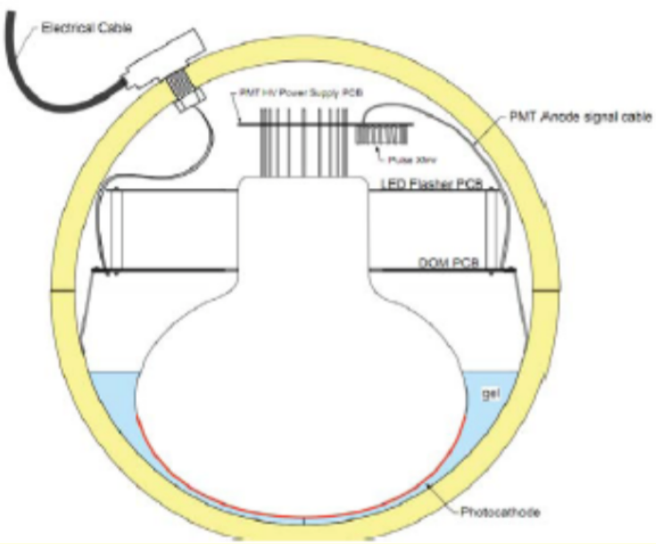




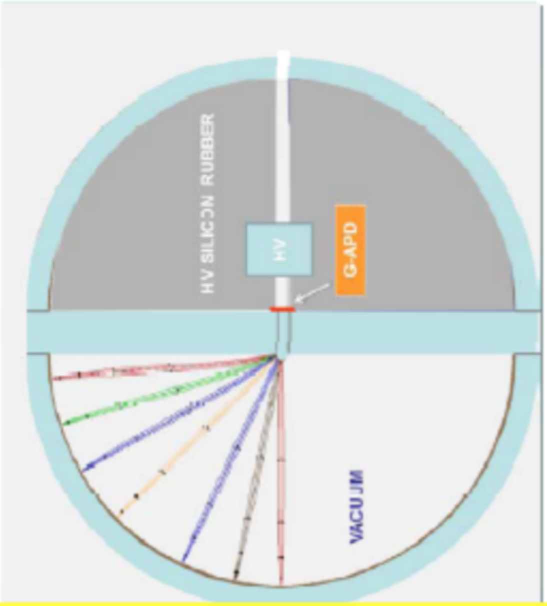


HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2100V	~1E7	~4	~1.3ns	~8.8ns	~3kHz

IceCube OPTICAL MODULE



ABALONE



NO PMT!!!

No dynodes, No voltage divider, No electrodes, No μ-metal cage, Simple means of readout (no multi-pin sockets for each pixel in PMTs)

CHEAPER!

MASS PRODUCIBLE, SCALABLE, MECHANICALLY ROBUST

FEATURES:

~100% collection efficiency, ns time resolution, Single photons resolution

Possible to build it with non-radioactive materials, Not damaged by light

High Quantum efficiency photocathode possible, Made of high purity (non-radioactive) materials

Insensitive to Earth B-field

Enclosure in Optical module or not will need tests

Electronics options

- Multiple recent options
  - Camera readouts from CTA, multiple inputs, tank clusters
  - IceCube style individual modules
  - TDC implementations
- White Rabbit timing
- Autonomous power has been mentioned at least once in this meeting

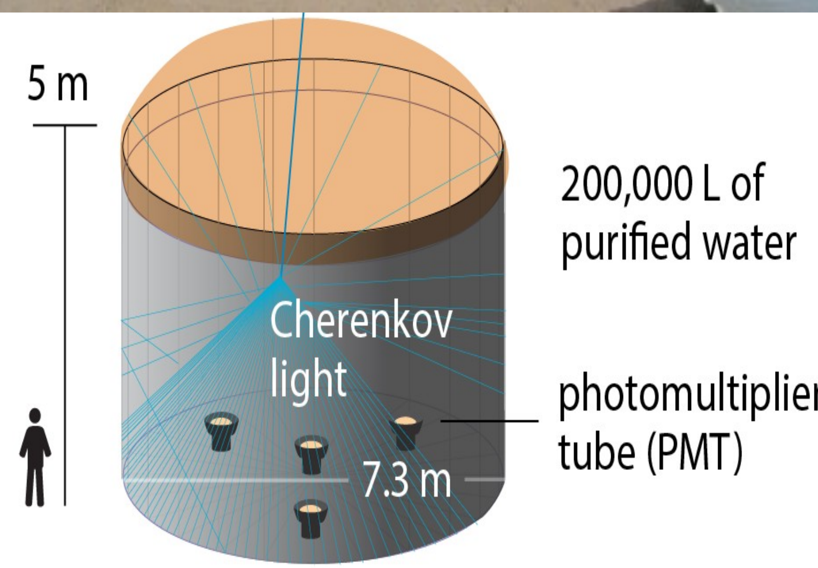
Electronics synergy with Next Generation IceCube & PINGU

- New pDOM electronics are being produced
- These are fairly general purpose, digital readouts with feature extraction, good for all environments, closely coupled to a 10” PMT, could be decoupled as well (electronics outside the tank)
- Power consumption <2W (could be <0.5W in another year)
- FPGA with hard and soft cores, local deep storage possible
- Built in communications, capable of 1Mbps over random wire + Ethernet
- FADC with >200MHz bandwidth & >14b resolution
- Timing to <5ns/<1ns via reciprocal timing over cable or via White Rabbit/Synchronous Ethernet
- Full self-calibration and built-in test equipment (BITE)

COST MODEL & COSTING

Detector construction

- Extremely site-dependent
  - Large metal tanks made sense in Mexico
  - For small tanks, rotationally molded polyethylene has been explored
  - Dense pack, rectangular or hexagonal options
  - Other extreme is a pond with dividers or bags in a lake
- Model of on-site local workers plus visiting scientists is familiar
- Totally different staffing models for different sites


5 m
200,000 L of purified water
Cherenkov light
photomultiplier tube (PMT)
7.3 m

Drive the tanks+PMTs up the hill, then fill

For-budgeting-only detector

- 40x40 array (1600 total) $10m^2$ water tanks, dense packed, solar heating gain
- 1 10” HQE-PMT in each tank
- Local electronics at each PMT
- Ethernet and power grid

- This acts as a modular costing unit, want multiples of it, but does not reflect any advances in technology (CdTe quantum dots, multiple layers, liquid scintillator, muon panels, neutron backscatter elements, etc.) and is HAWC-centric (though actually looks more like Auger densified)

Lots of knobs to tune, but this is basically a $10M detector at a moderate altitude

Strawman HAWC-like detector

N_X	40		Det type	10" HQE PMT		Tank style	RM-UHMWPE		Electronics	pDOM style		Central	Compute hub		Infrastruct	Road? Buildings?
N_Y	40		Dev / tank	1		Cost model	$909		Cost	$1,600		Cost	$400,000		Cost	$1,000,000
Total det	1600		Cost dev	$2,000		Total cost	$1,453,888		Total cost	$2,560,000		Altitude fac	0.2		Altitude fac	0.5
Det radius	1.8	m	Total cost	$3,200,000		Altitude fac	0.3	per km								
Det area	10.1736	m^2														
Det height	1.2	m														
Total area	16277.76	m^2							Water	$40	per m^3					
total vol	19533.312	m^3							Cost	$781,332						
									Altitude fac	1	per km					

Cost scaling

How big	1	time nominal
How high	4	km
Hard factor	1	times nominal

The cost

Tank	$1,890,054
"photo"	$3,200,000
Electronics	$2,560,000
Central	$480,000
Infrastruct	$1,500,000
Water	$1,562,665
total	$11,192,719

To-do list

- This open meeting is extremely important, to lead towards a White Paper for the community
- Let's be blunt: Do we want to work together on a southern all-sky TeV experiment with sensitivity significantly greater than HAWC?
- ALPACA, ALTO, and LATTE proposals/collaborations exist
- Would like to have a strawman design, is that HAWC-like? Bigger? **Matched to CTA?** Altitude? Different basic technology? ToT or waveforms? New technologies: WLS gain, scintillator panels, CdTe quantum dots, neutron sensitivity, multi-layer...
- What are our science-driven requirements and our desirements? Galactic vs. Extragalactic science?
- Then simulate, cost out/schedule, and sketch the buildability of that strawman detector. Also look at site options and establish prototypes at them.
- Do we have a science consensus? Beginnings of a collaboration? Or are there multiple collaborations?