Progress and Plans for CHIPS
CHerenekov detectors In mine Pits

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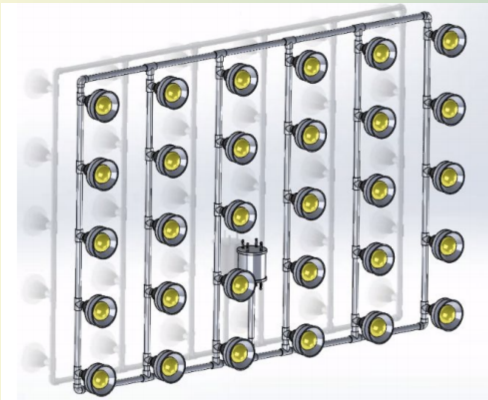
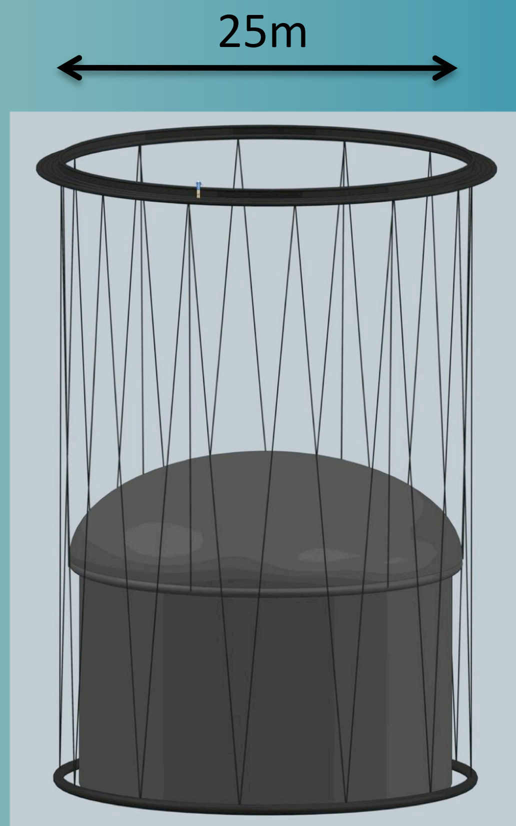
UCL and WIPAC

Orientation

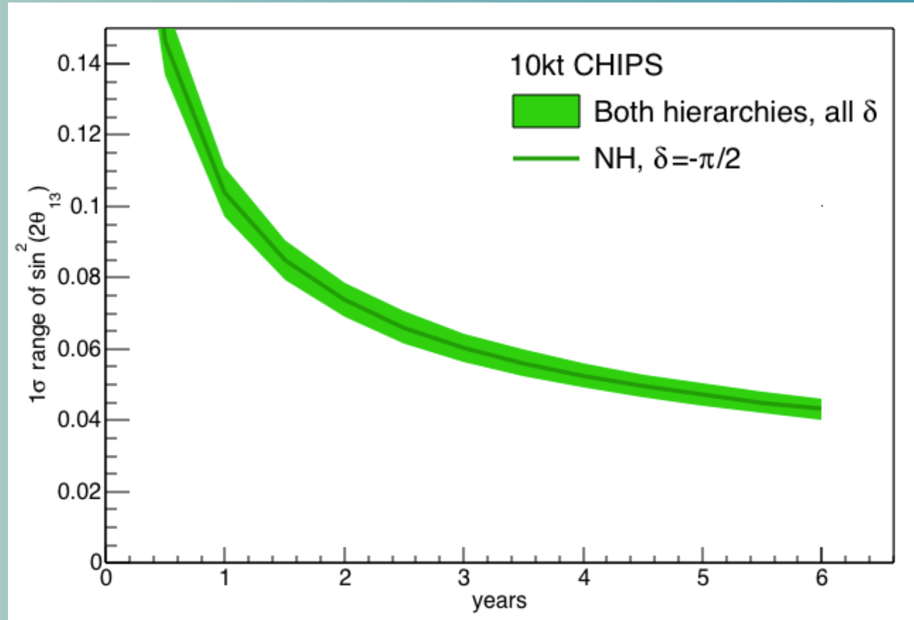
- The CHIPS goal is to prove that a water Cherenkov detector can do oscillation physics for a fraction of the cost of present neutrino detectors, and also to contribute to constraining δ_{CP} using NuMI neutrinos in the short term
  - to \$200k/kt (presently \$2-10M/kt water, \$10-20M/kt Liquid Argon)
  - These prices obviously include location/infrastructure etc
- CHIPS will be sunk in a flooded mine pit in the path of the NuMI beam
- It starts with 5 kton to be deployed in 2018, funded by ERC, Leverhulme(UK) and UCL, UW, U.Minn (small, independently owned business, newcomers welcome)

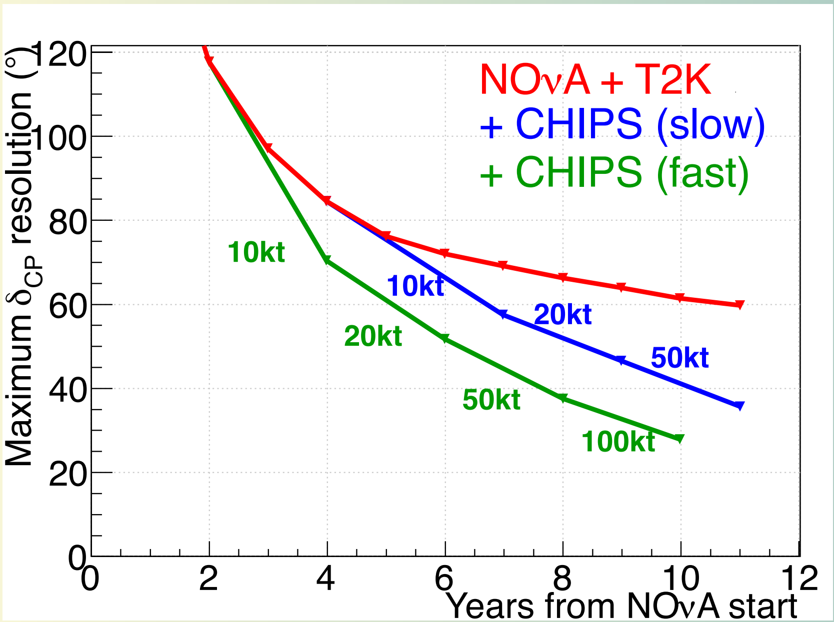


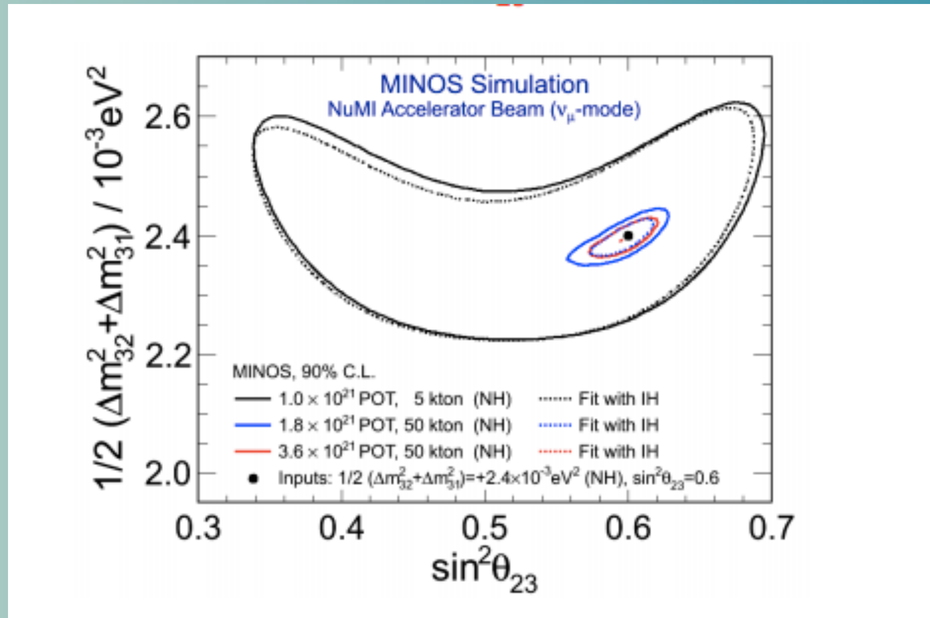


CHIPS Physics Goals

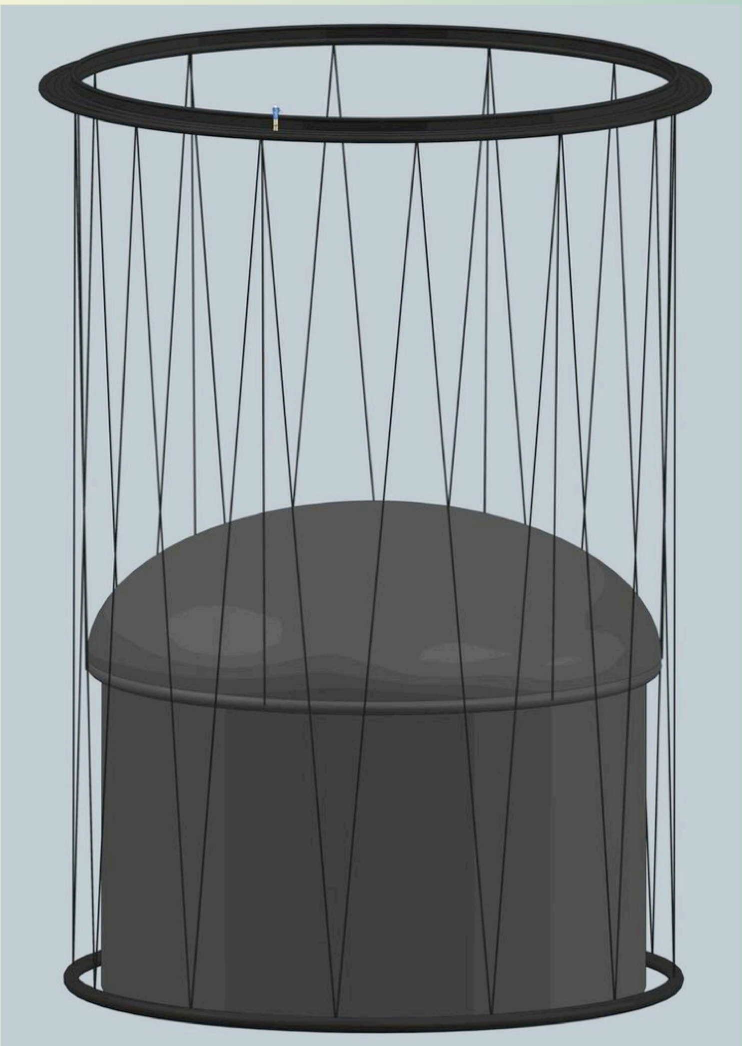
- Improve global knowledge
  - Measurement of θ_{13}
  - Measurement of θ_{23}
  - Contribution to δ_{cp} knowledge
- These plots assume SK like reconstruction ability…more later





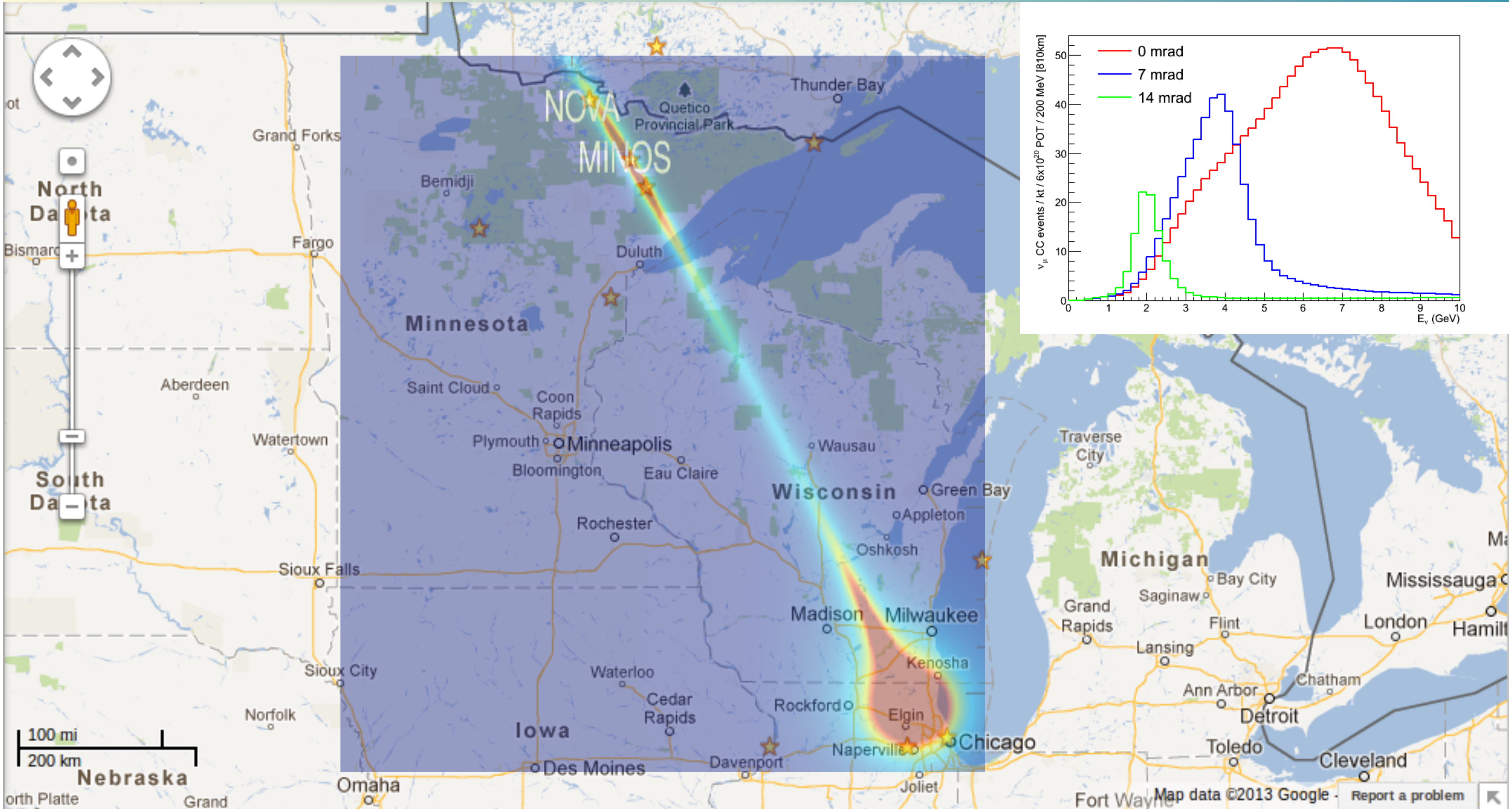


5 Steps to (cheap as) CHIPS



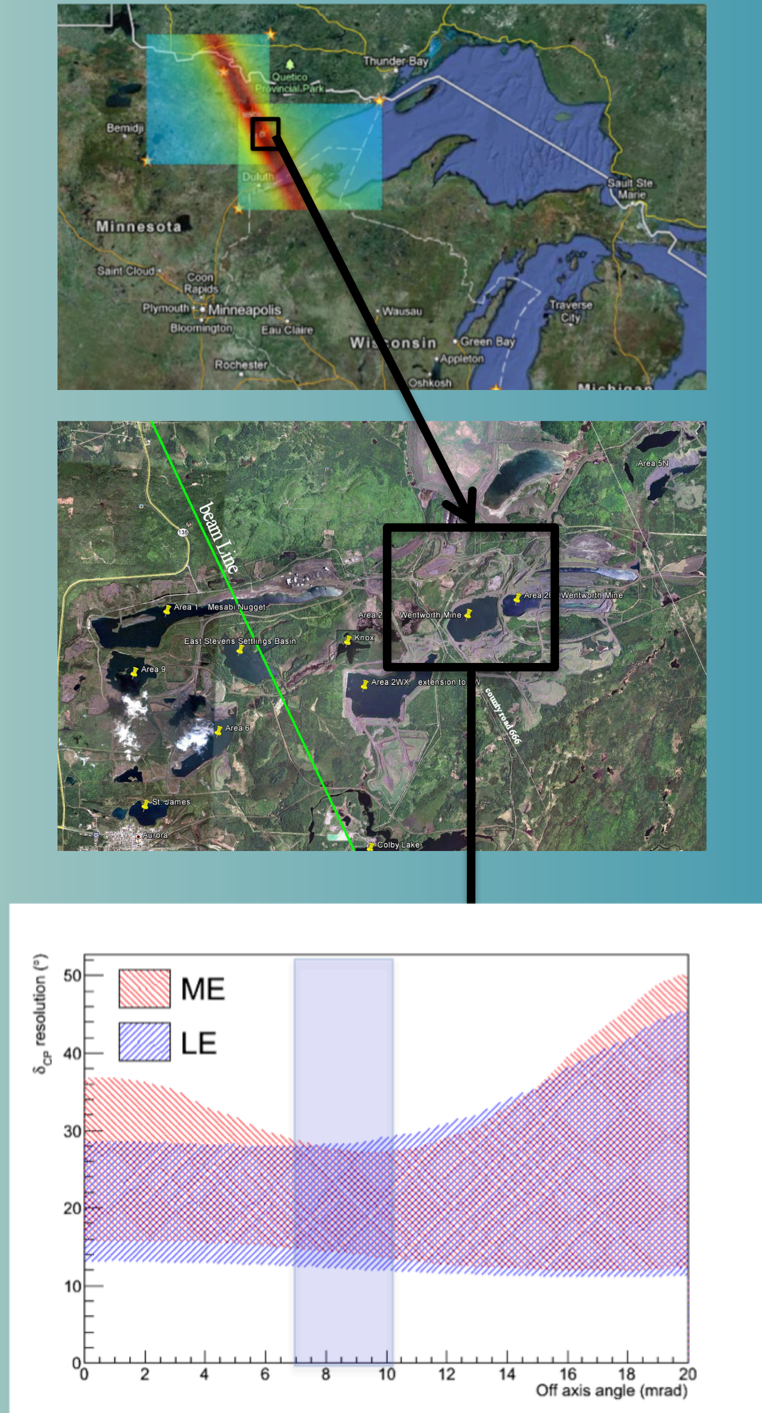
1) **Location**
   sunk in a flooded mine pit in the path of the NuMI neutrino beam, will make use of the water for cosmic overburden and mechanical support;
2) **Structure design**
   will allow it to grow in size with time but with no financial penalty beyond the instrumentation costs
3) **PMT choice and layout**
   3” PMT’s good position and time resolution and beam optimized layout
4) **Electronics**
   will make use of ubiquitous mobile phone and communications technology and already developed KM3Net Solutions
5) **Simple water purification plant**
   will use straightforward filtering to maintain water clarity.

1. CHIPS location location location



CHIPS : Location

- Deep lake or body of water on mining site: Wentworth 2W
  - 60m depth, cosmic overburden (later)
- High energy neutrino beam
- At 7mrad off axis
  - Between signal and background extremes
- CHIPS-M (mini) prototyped in 2014 and 2015

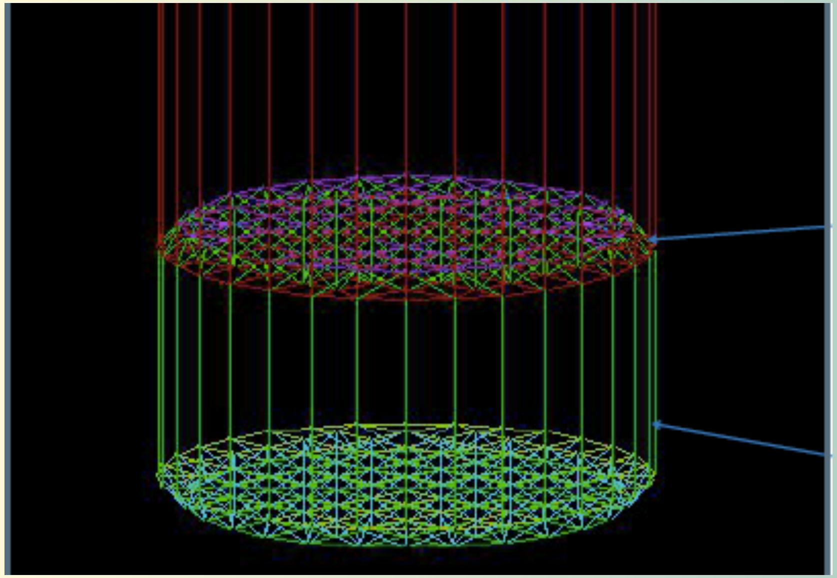


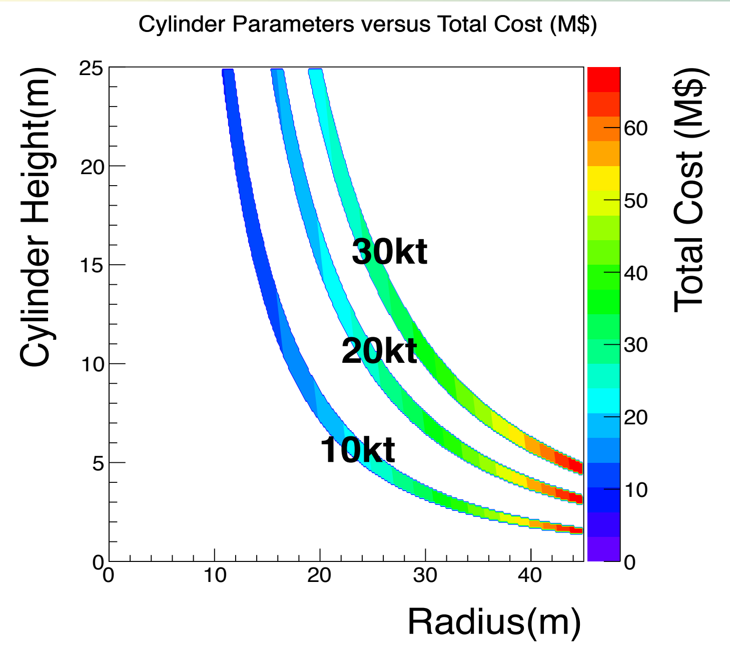
CHIPS-M prototype 2014/15

- Being submerged in ←←←←2014
- After one year under the water in 2015 →→→

- Liner is robust, light-tight and mostly pristine after a year under the water
- Sealing method is robust
- Winter defence worked well, water continued to circulate, nothing broke!

2. CHIPS Structure Design





- Hang bottom truss end cap from top one with Dyneema ropes (used in KM3Net)
- Allows volume to grow if more PMTs are available
  - Recovery and ability to further instrument is designed in
- Saves 50% cost of the space frame sides
  - Pushing on 25% of orignal estimate
- PMT planes attached to ropes
- Make footprint large enough: bang for buck is impressive for walls
  - ~100k/kt for additional volume

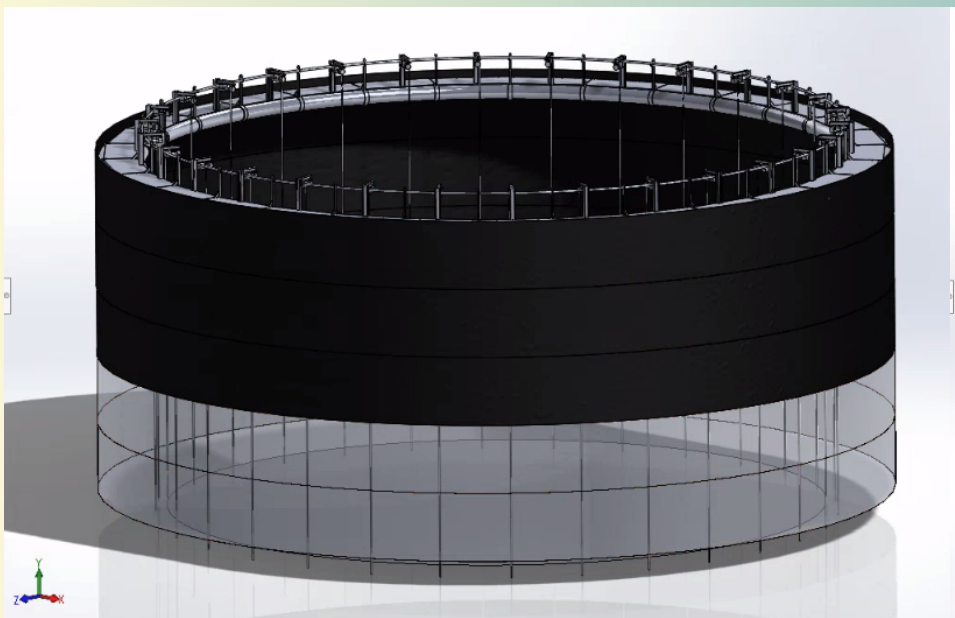
CHIPS Deployment

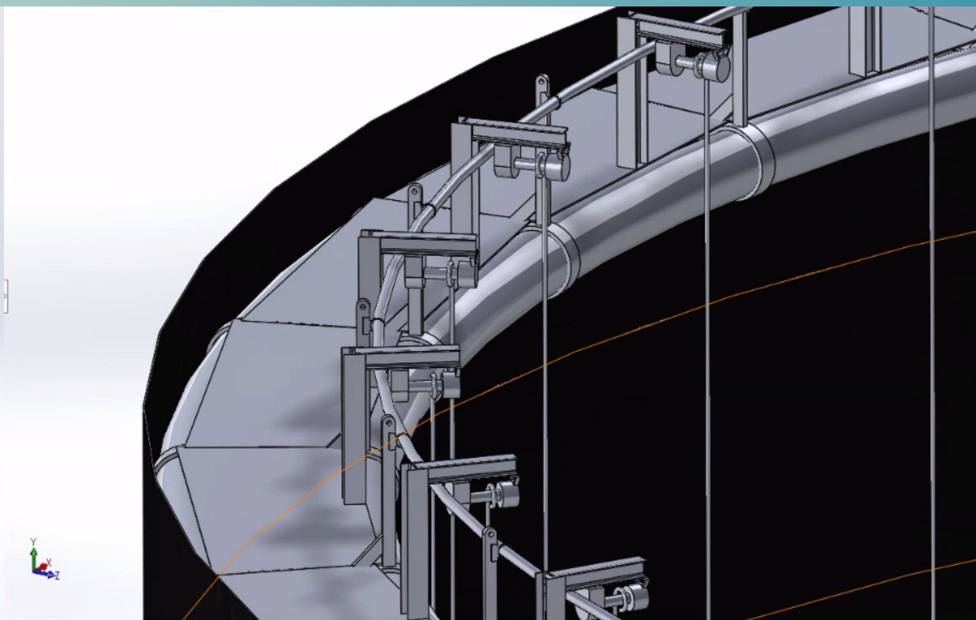
Coffer Dam technology can prepare area for building

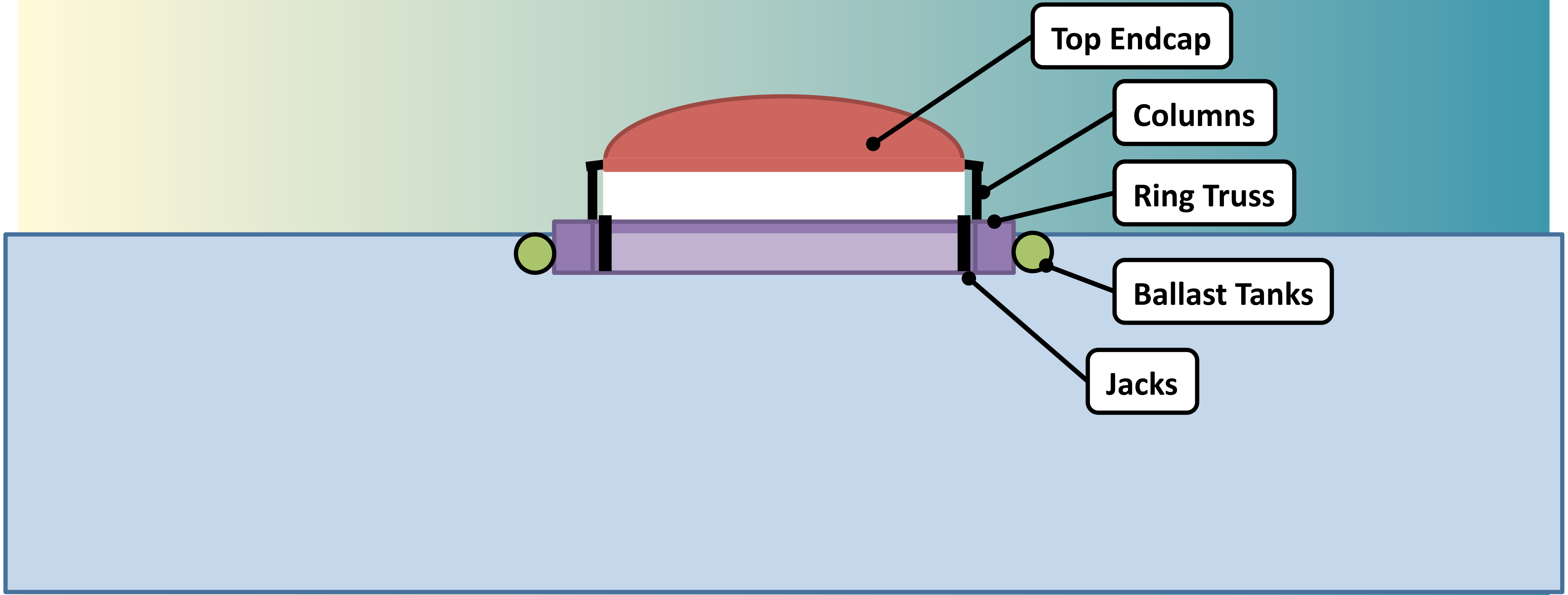
Build Structure on “dry land”
Float by allowing in water, minimal stress on end cap structure
Both top and bottom end caps will be floated together

CHIPS Deployment

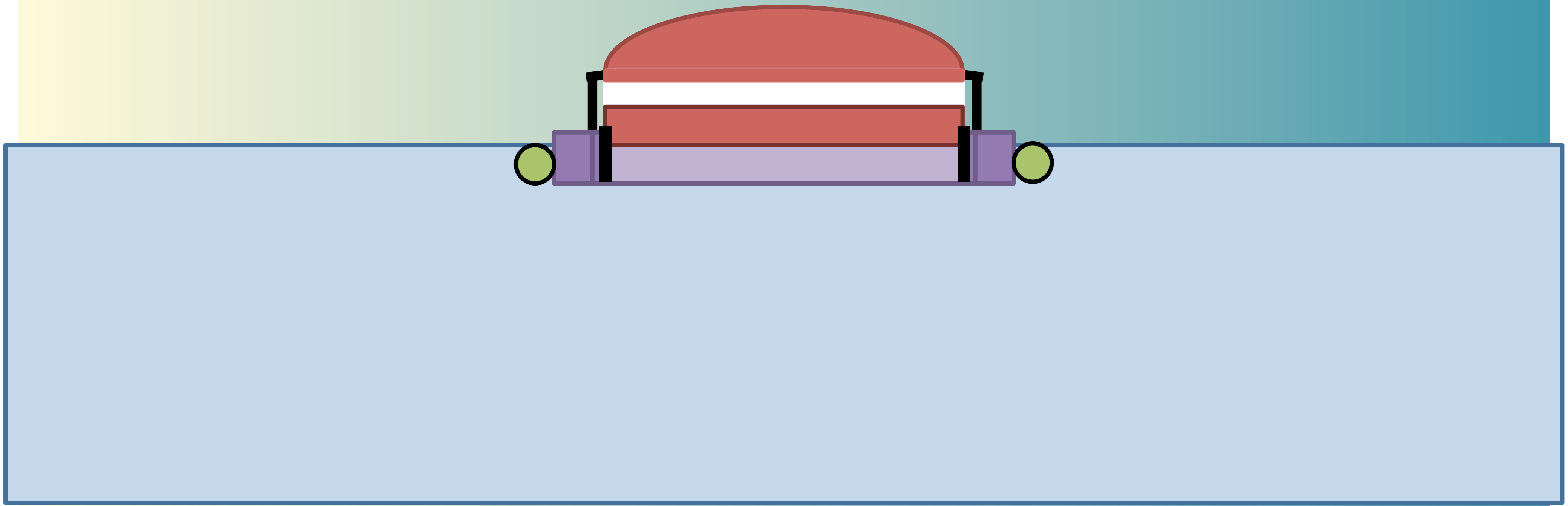
- Intense work on-going, not all issues are resolved
- Liner wrapped on a bobbin placed on a float to be attached to the floating dock
- Winches lower dyneema ropes as planes are attached to them
- Not all ropes are bottom-endcap weight bearing





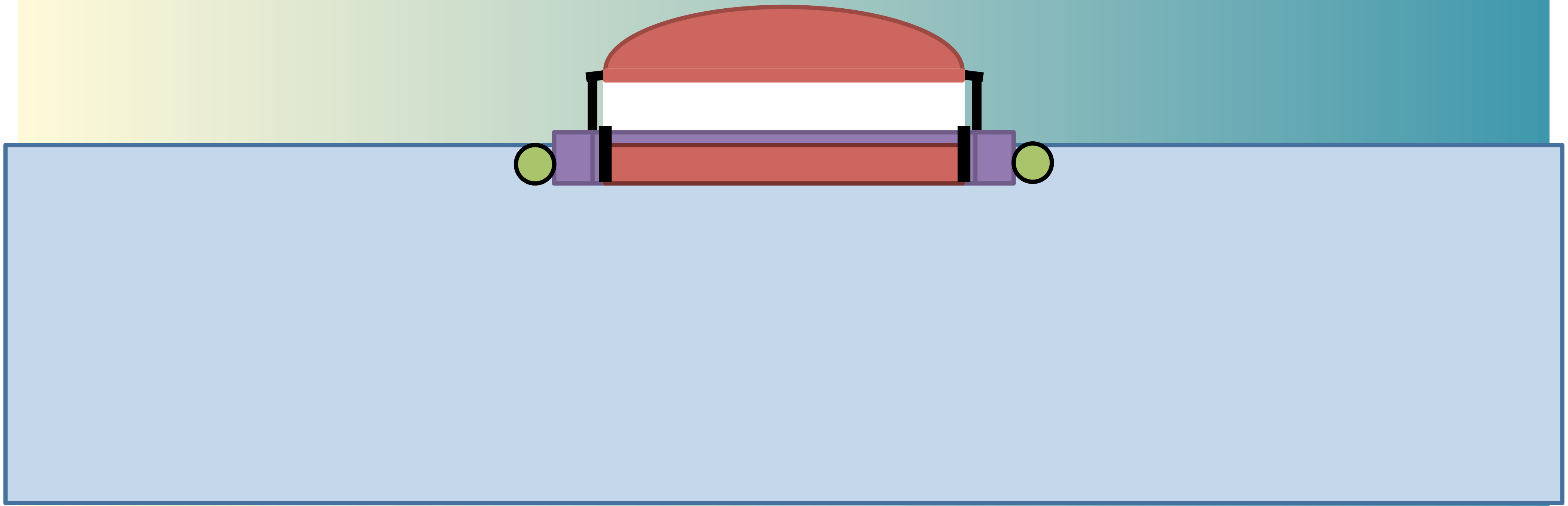


- Domed roof self-supporting in air
- Supported by circumferential columns
- Columns supported by floating ring truss equipped with ballast tanks
- Entire assembly built next to shore with crane support
- Floating ring truss provides work surface
- Temporary curtain around circumference to keep inside of detector clean
- Dome's roof could be equipped with a radial crane



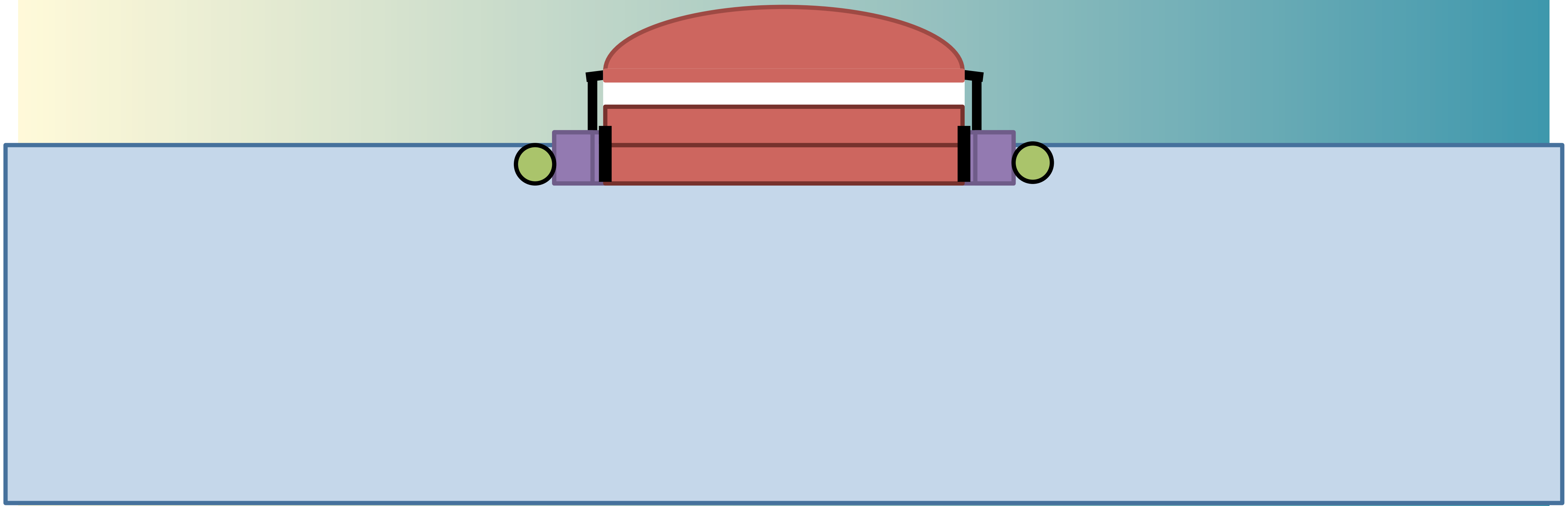
Assembly sequence on water

1. Build floor and first wall layer. The wall layer also attaches to the floating ring jacks.



Assembly sequence on water

1. Build floor and first wall layer. The wall layer also attaches to the floating ring.
2. First wall layer “climbs” down the floating ring into the water as it is filled.



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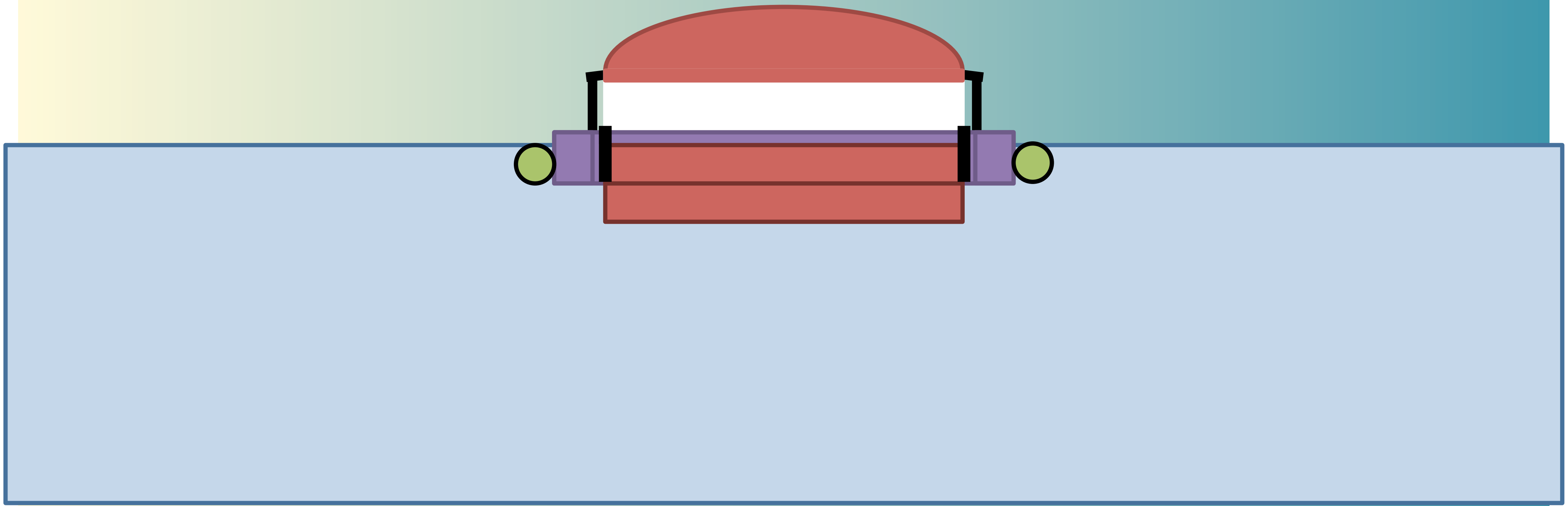

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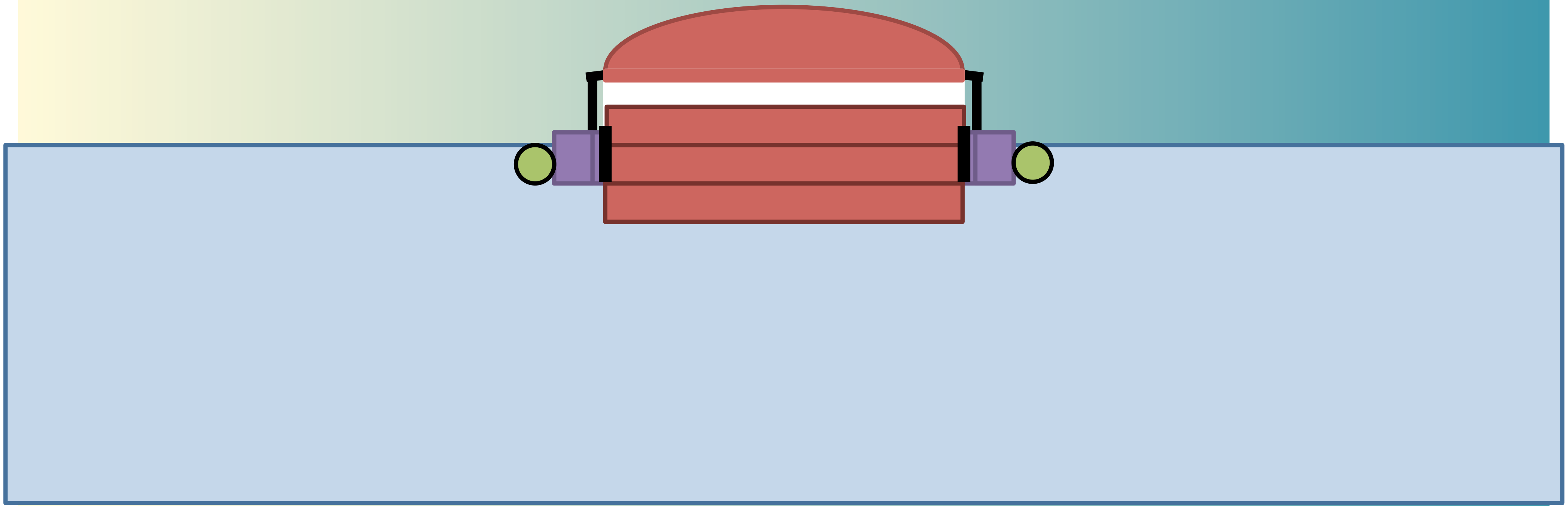

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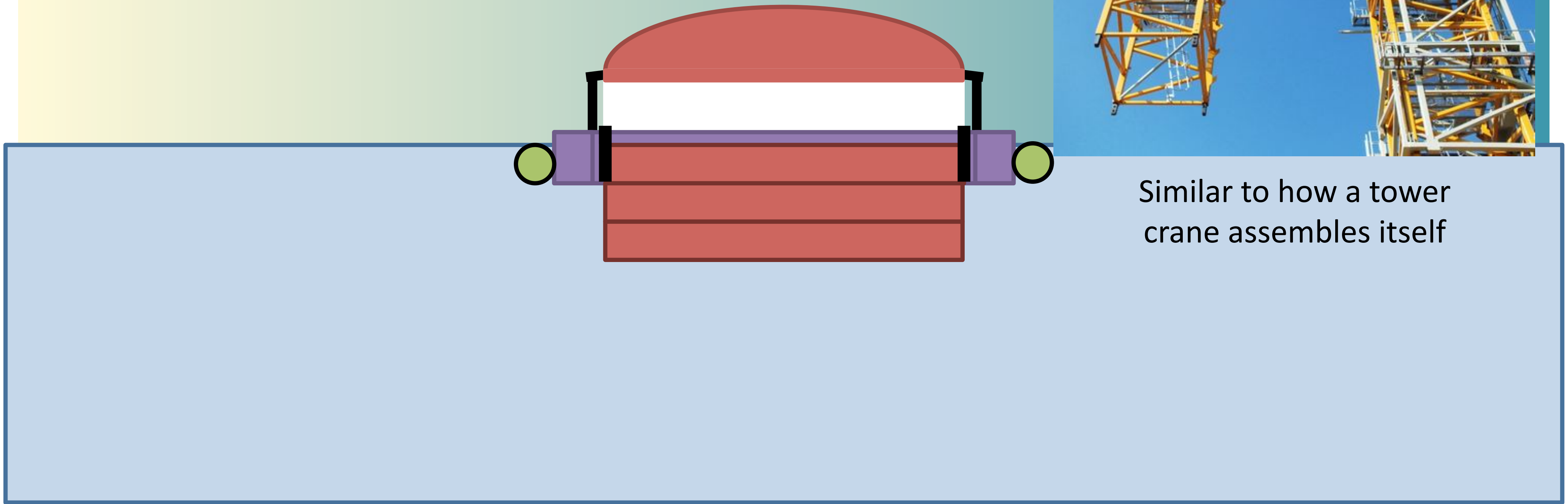

Similar to how a tower crane assembles itself

Assembly sequence on water

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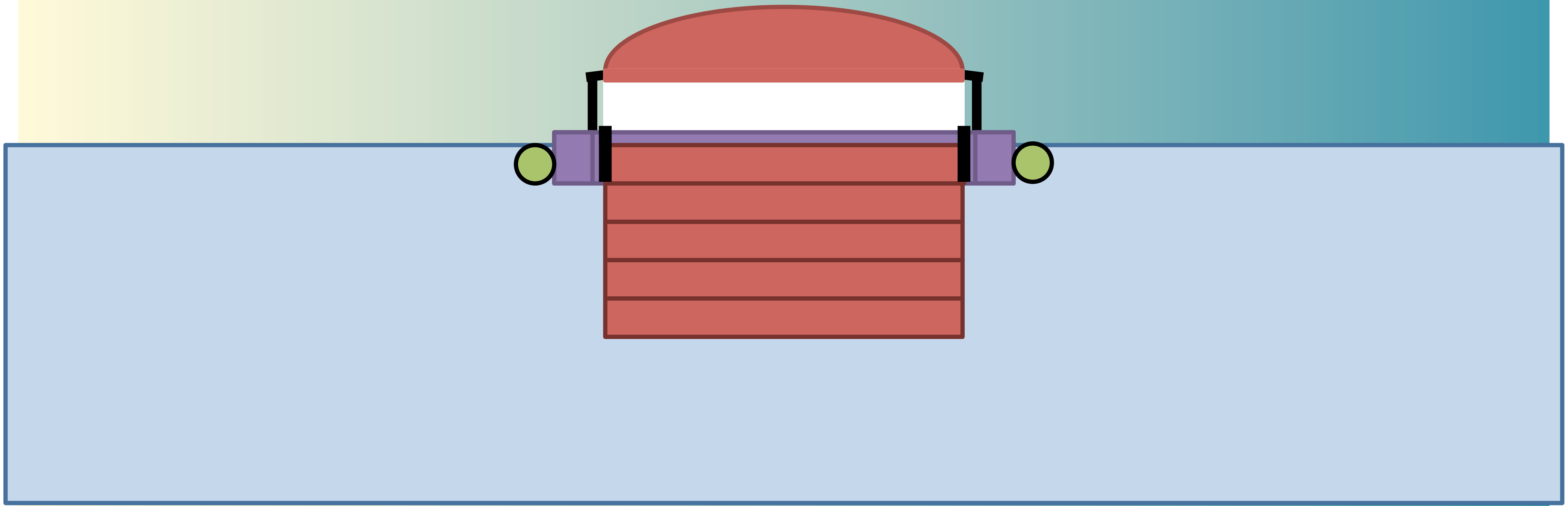

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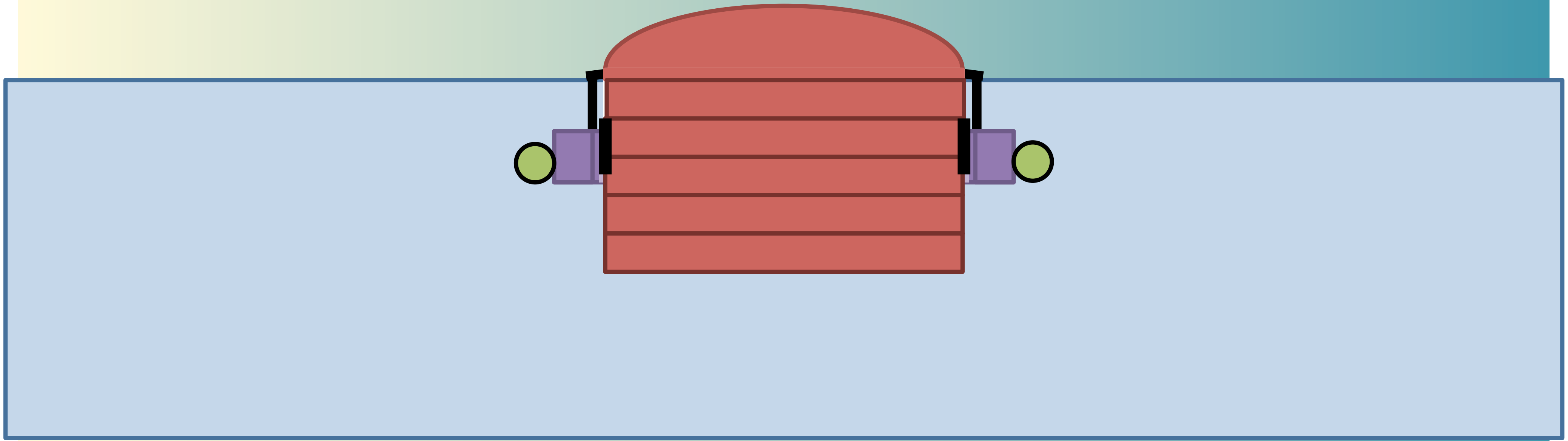

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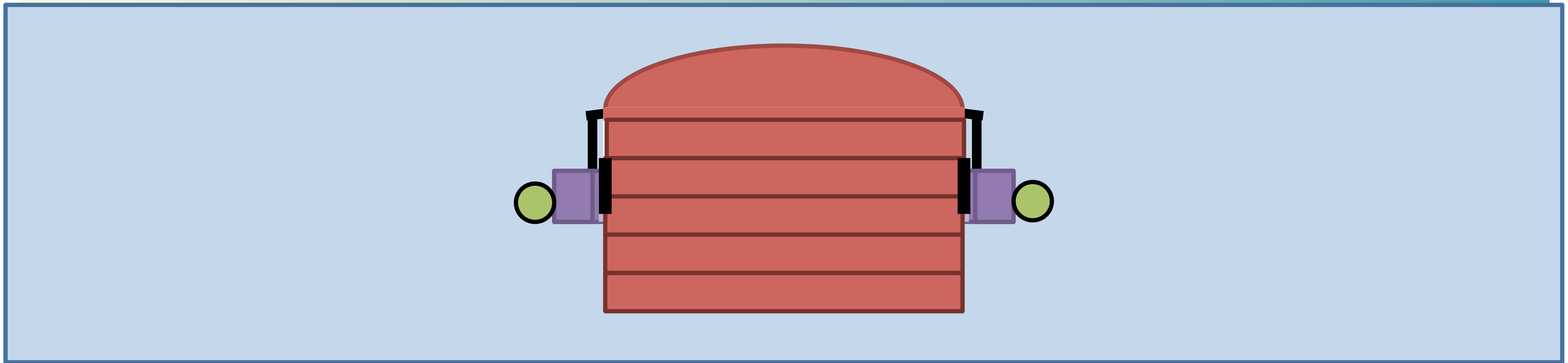
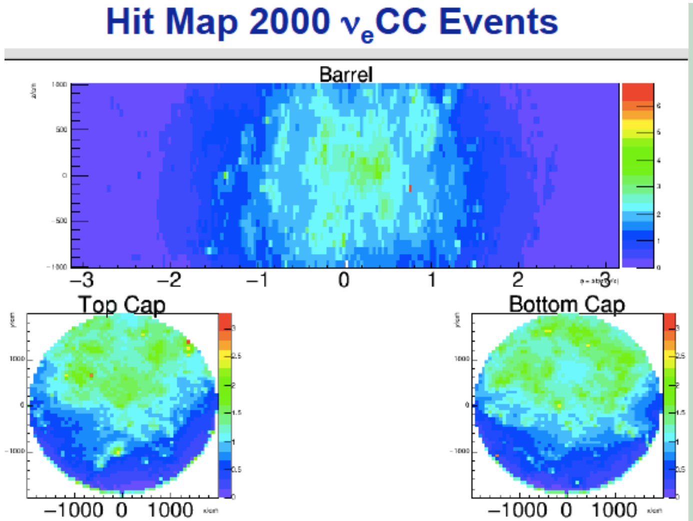
4. As layers are added the floor and wall assembly successively climbs down.
5. After all wall layers are assembled, ballasts are adjusted and the ring and top climb down the wall. A seal is made at the perimeter seam.

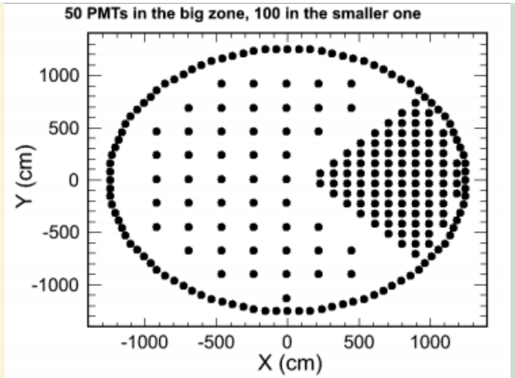


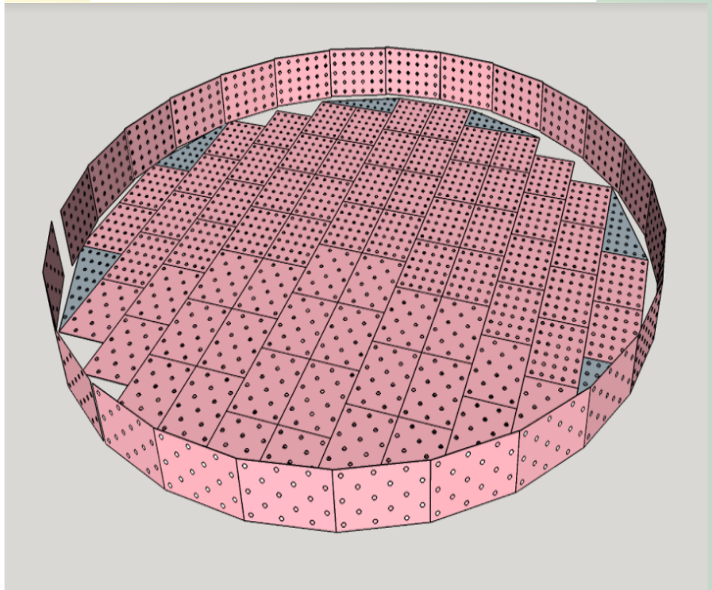
(Lowering)

Additional comments

- The ring truss may also be used for rigging and mooring.

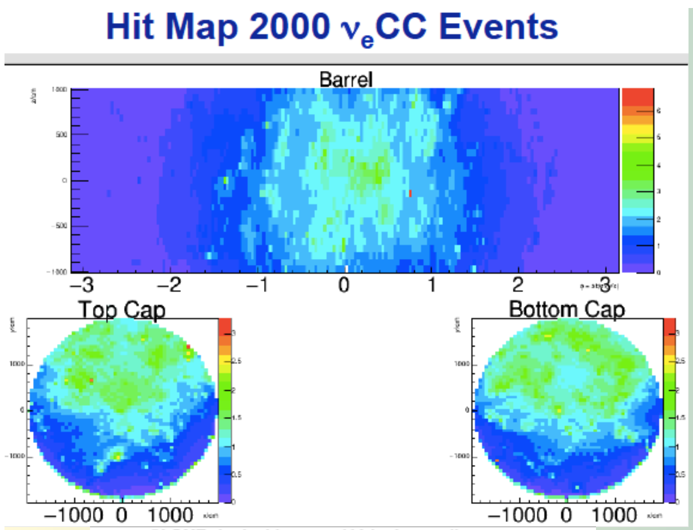


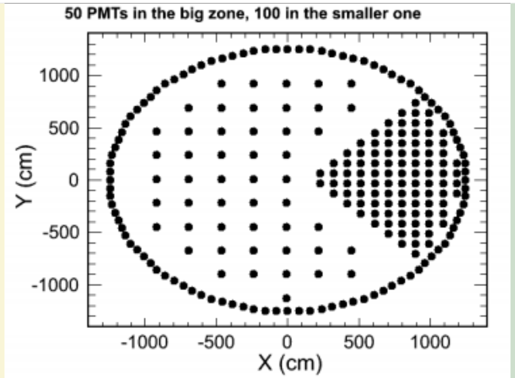


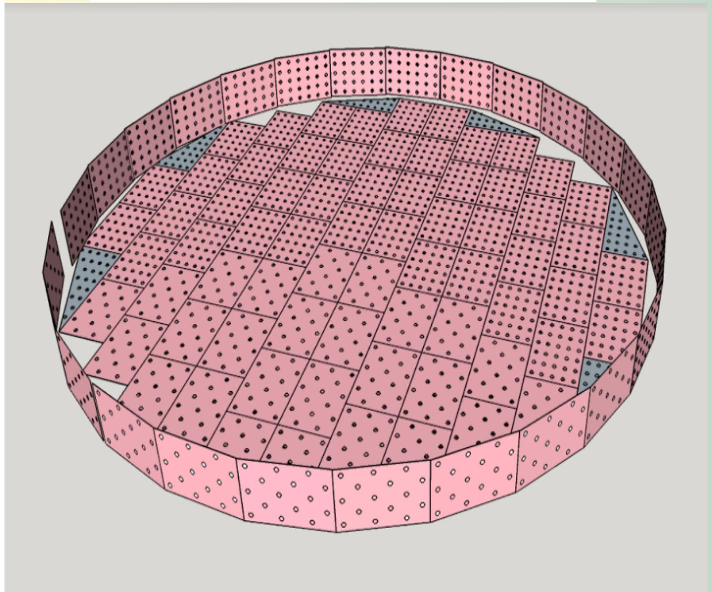


3. PMT Choice and Layout

- CHIPS-M design will be carried forward
- Layout will involve high and low density planes
- A big part of the instrumentation will just implement KM3Net technology
  - New 3" PMTs at 6% coverage in front and end caps, and 3% coverage back end cap region
- Low density wall planes will be made with NEMO-III 3" PMTs and Madison electronics.
  - Old 3" PMTs at 3% coverage in back







3. PMT Choice and Layout

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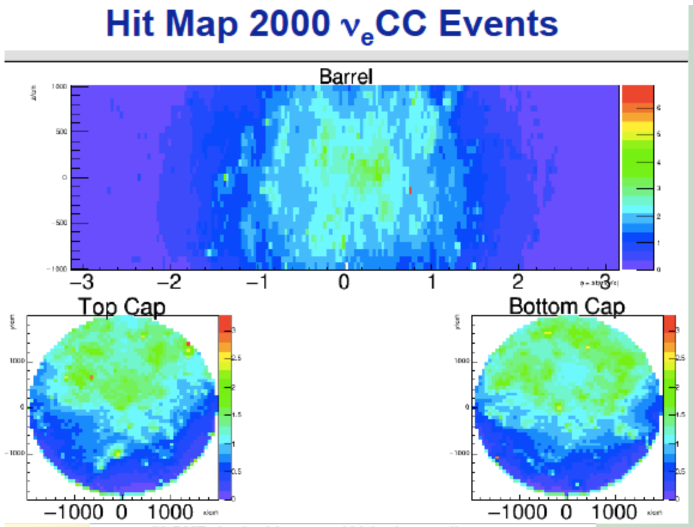
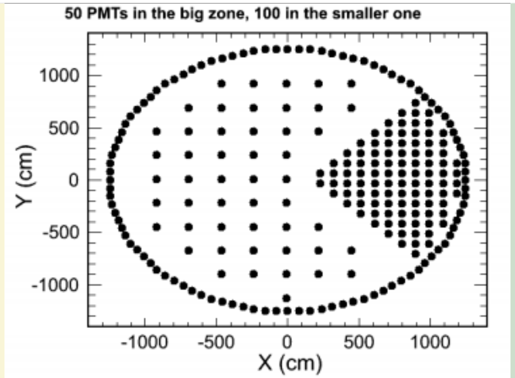
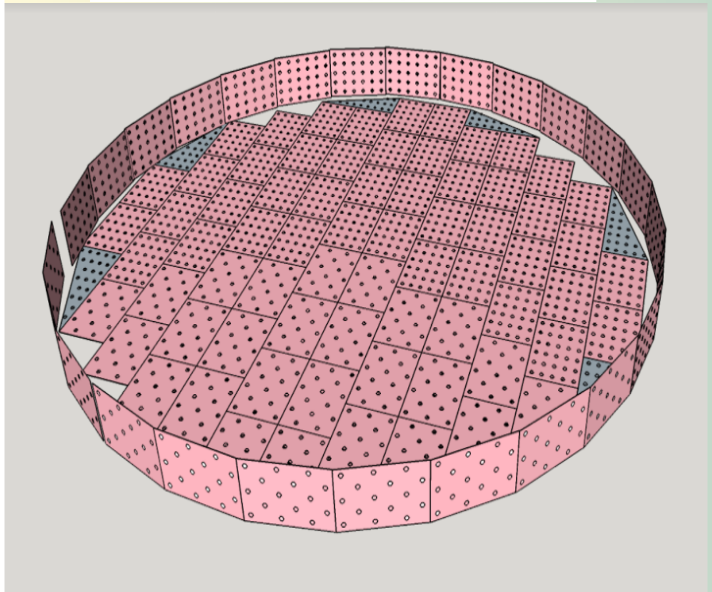
  - New 3" PMTs at 4% coverage in front and end caps, and 3% coverage back end cap region
- Low density wall planes will be made with NEMO-III 3" PMTs and Madison electronics.
  - Old 3" PMTs at 2% coverage in back







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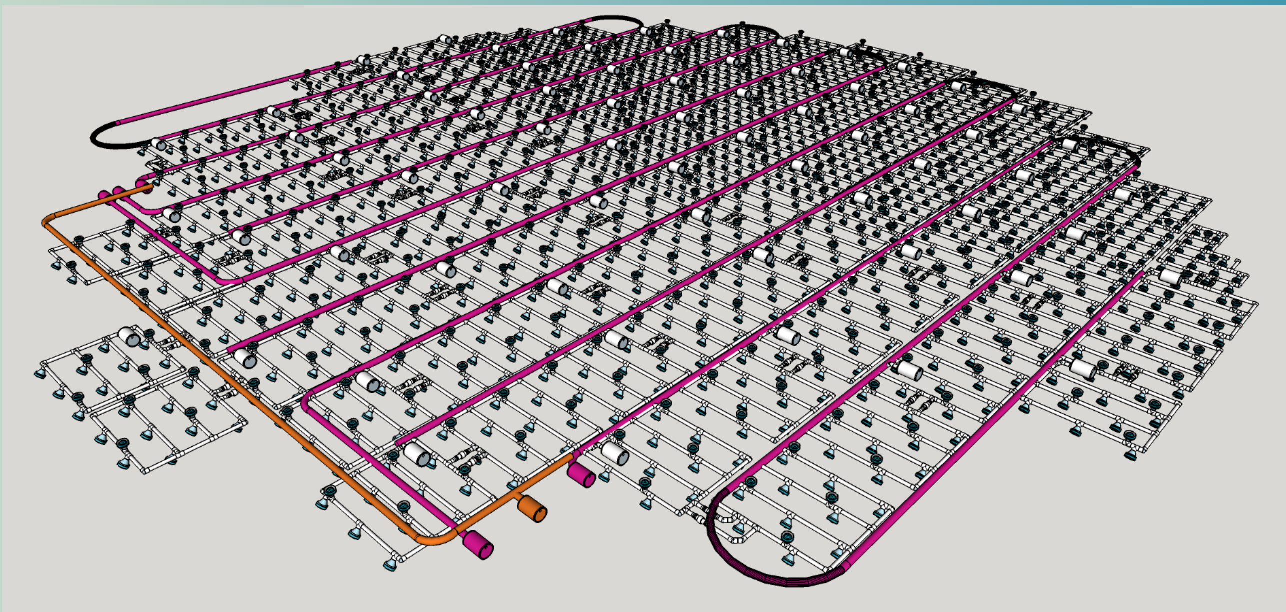
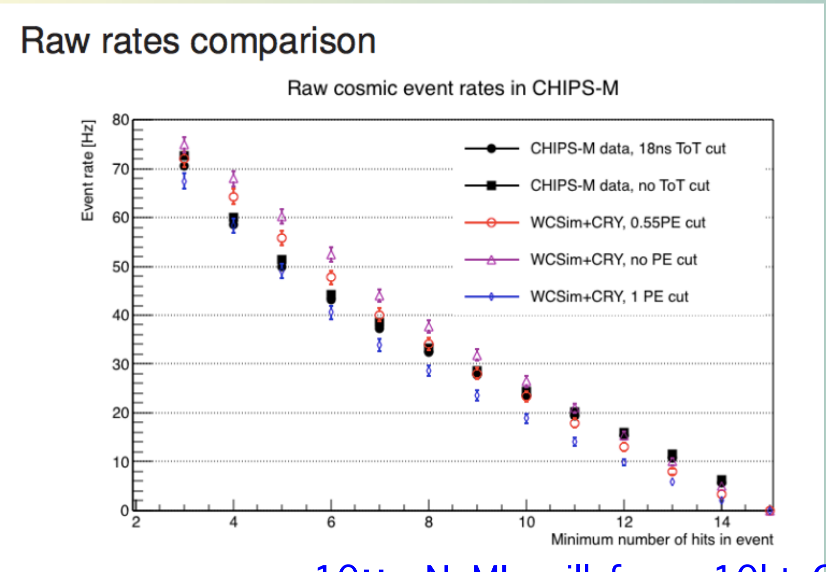
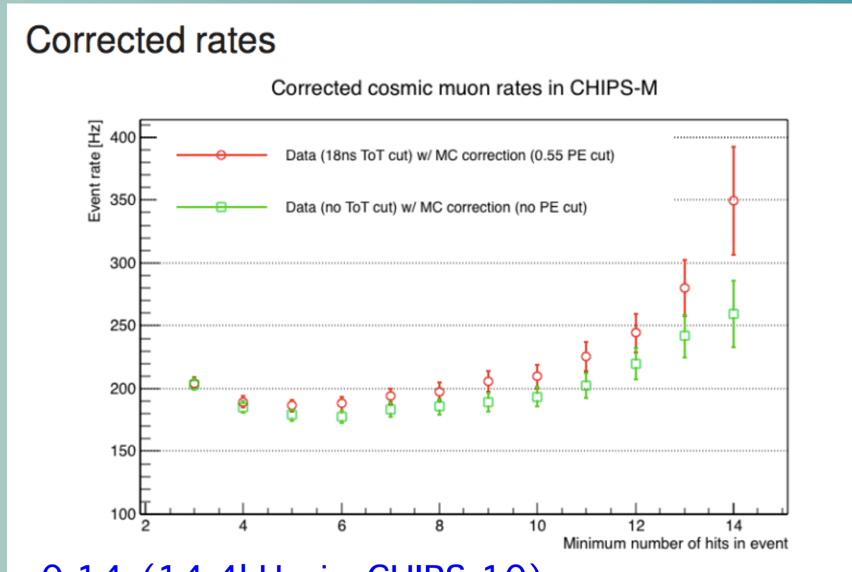


CHIPS-M Detector Plane Data

- Event window is 30ns with at least 5 hits
- Use events to compare with CRY simulation
- Verify cosmic rate prediction from MC at OUR 50m depth





10μs NuMI spill for a 10kt CHIPS = 0.14 (14.4kHz in CHIPS-10)

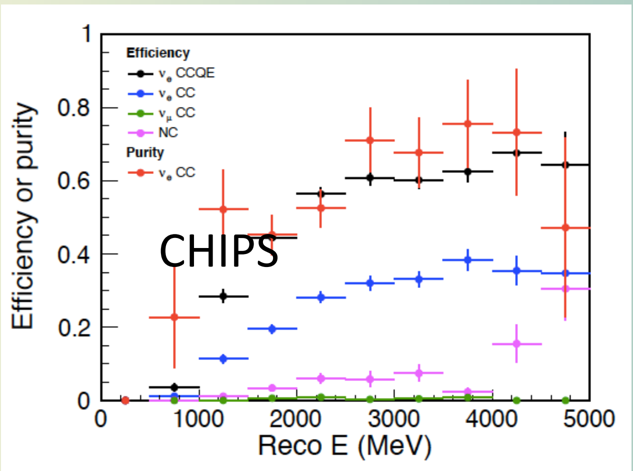
- PMT dark rate 200-800 Hz so cosmic rate dominates
- Cosmic rate for 10kton (25mx20m) is 14 kHz
- 14kHz used to calculate dead time/electronics speed etc

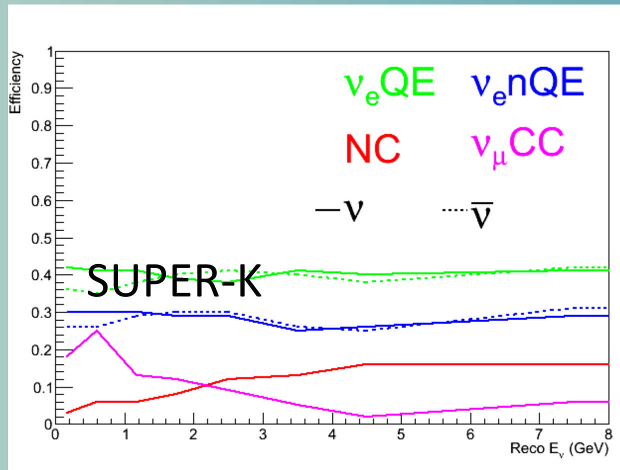
Less than 1% dead-time in 10kt detector during spill

Reconstruction

Table 1. The resolutions of various reconstructed parameters from single ring electron (muon) track fits to a sample of CCQE ν_e (ν_μ) interactions with energies following those expected from the NuMI beam.

Sample	Geometry	Reconstruction Resolution Position (cm)	Time (ns)	Direction (°)	Energy (MeV)
	10 inch, 10%	35	0.9	2.1	208
CCQE ν_e	3 inch, 10%	35	0.84	1.9	210
	3 inch, 6%	38	0.89	2.1	211
	10 inch, 10%	47	1.35	2.6	113
CCQE ν_μ	3 inch, 10%	44	1.14	2.7	110
	3 inch, 6%	51	1.28	3.0	113

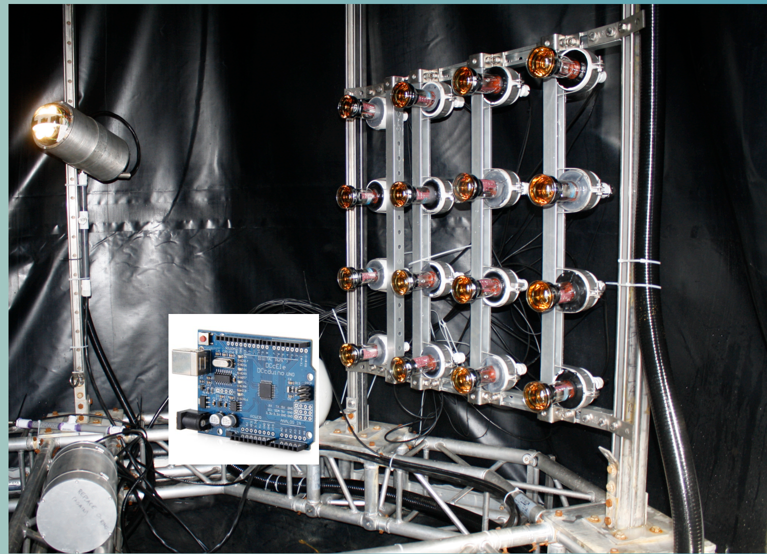


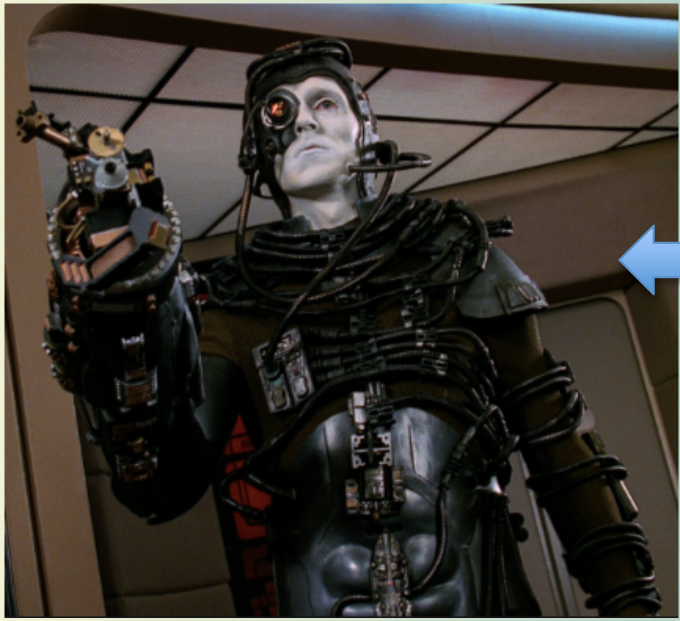


- Originally based on MiniBOONE approach, several innovations from that point (time)
- Neural Nets, Fourier transform analysis and even deep learning all being studied
- Pretty good basic bottom line so far, more improvements on the way

4. Electronics: iPHONE and ARM

- We are riding a revolutionary wave in development
- $20 for a BBB to collect signals and transmit to Ethernet
- Reduce cost to minimum
- Microprocessors on each PMT provide ToT and receive clock from WR system

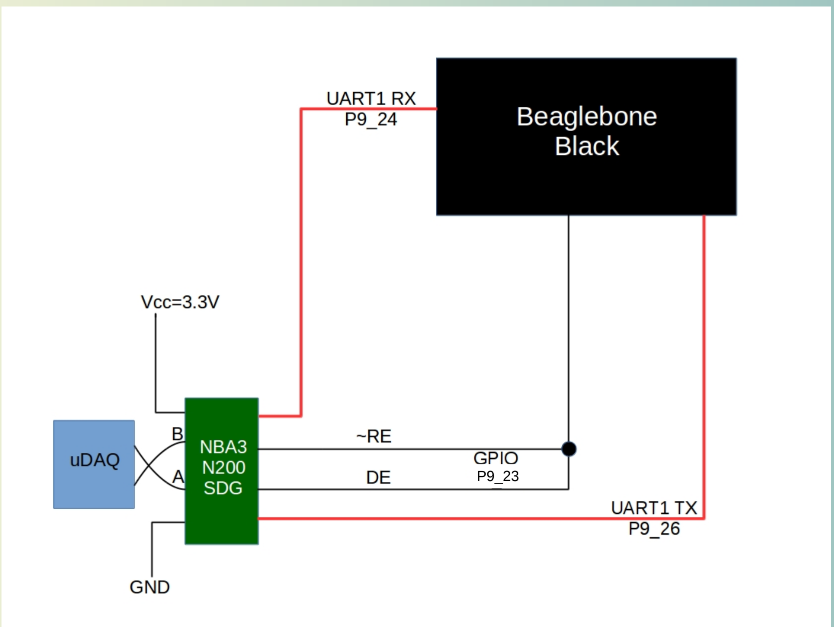


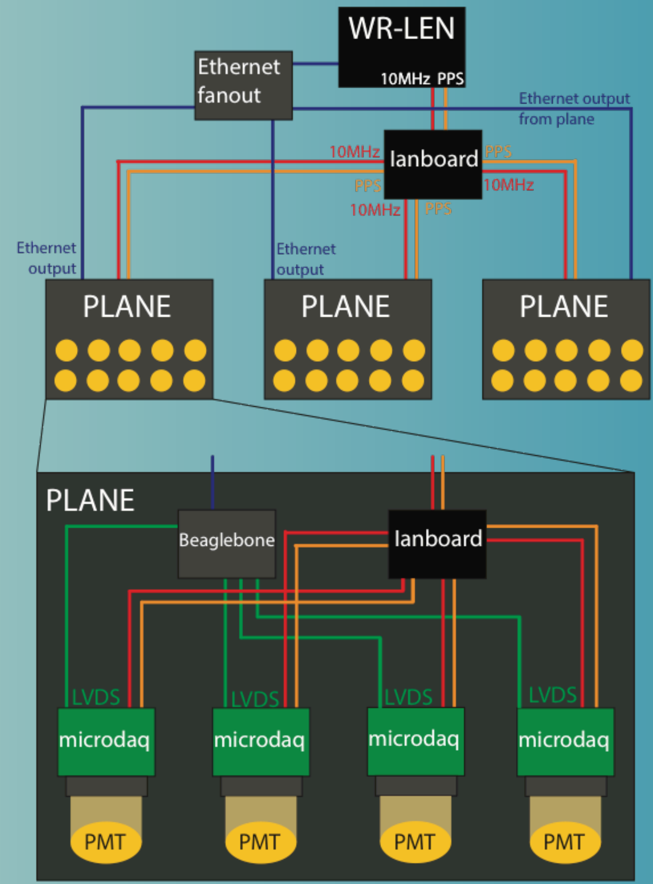


- Side comment: Industrially available ASICs in version 100 (ish): home grown electronics is typically in version 2-5the combination of cheap processors such as Raspberry Pi, BeagleBone and Arduino combined with the WWW means progress goes incredibly fast as solutions are known instantaneously
- Developers are like the Borg: and **resistance is futile..**

Status of Design

- Communication software between BBB and micro-daq demonstrates 1Mbps on RS485
- Rate of 1-10kHz per tube means scope for local filtering (maybe) or at least buffering during spills

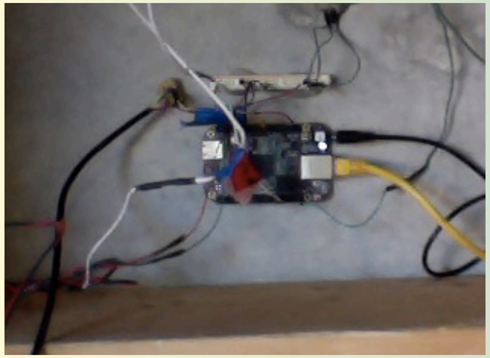




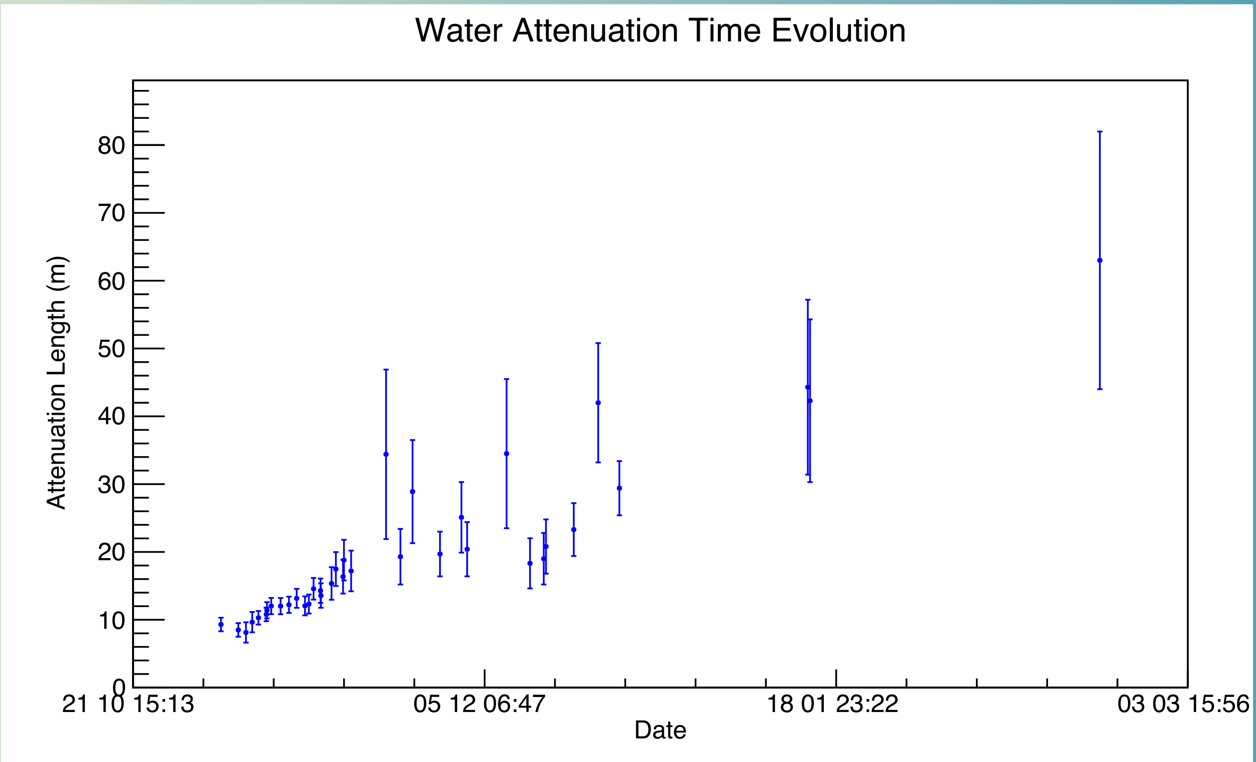
5. Water Clarity

- CHIPS has advantage of being under about 6 bar pressure and at 4-8^{o}C :
  - Good for crushing bubbles and bacterial blooms respectively
- Filters provide
  - a raking of the particulates in the water down to 0.2 micron
  - A UV sterilizer to eliminate life + a carbon filter to make sure
- We used a small model of CHIPS-M (micro-CHIPS) on surface
  - Using 405nm laser and 3m upright column, we watched the water clarity over 6 months
  - This is likely worse than in reality because it is not pressurized or cold
- Needed to know how clear we can make the water with simple filtering, for simulation benchmarking, and for system design

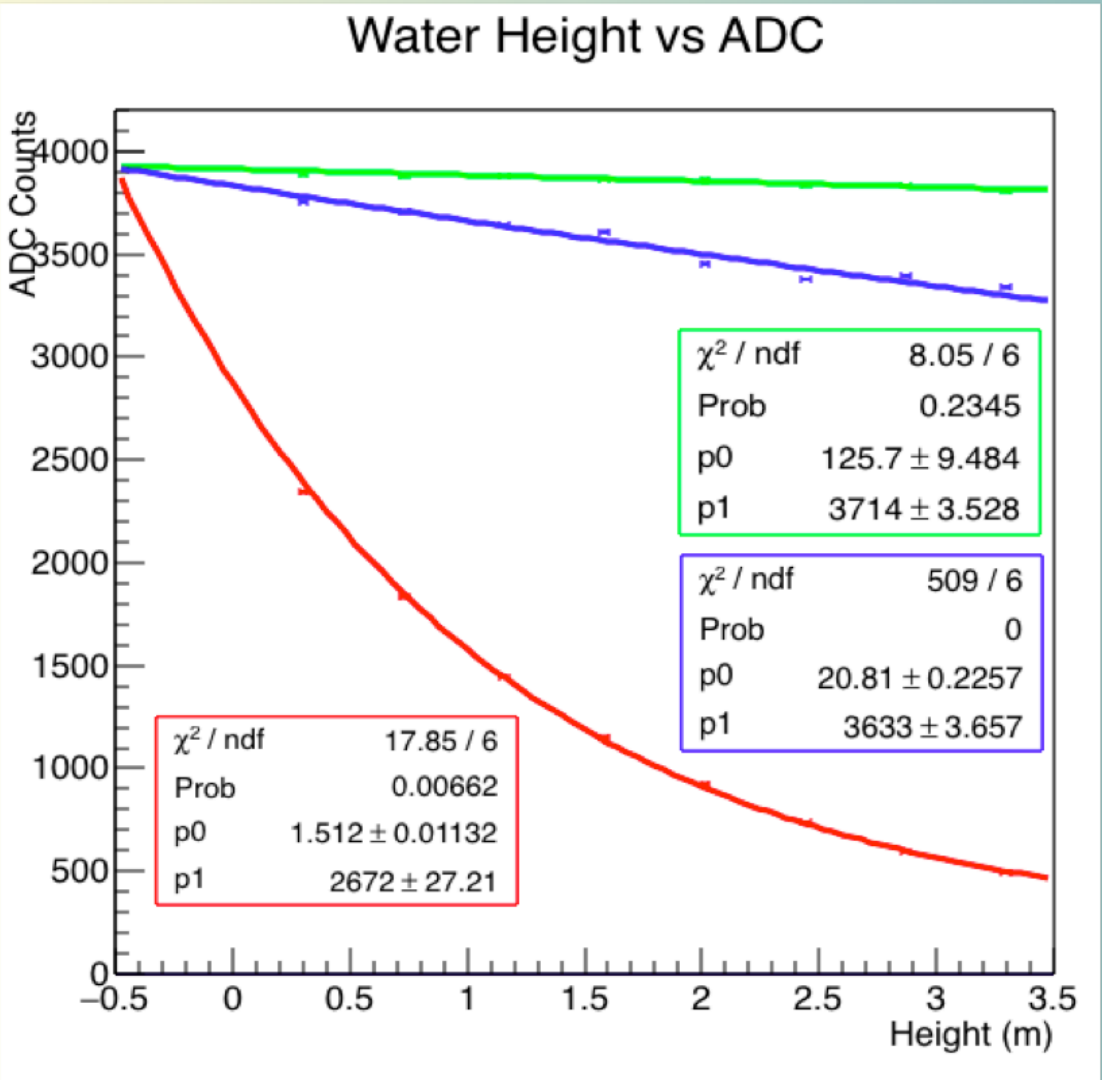
Water Studies



- Automated attenuation length measurements using BeagleBoneBlack, servos, relays, ADCs
- Photodiode at top and 405nm laser at base provide the baseline : simple op-amp circuit to get correct voltage for the BBB
- 50 gallons of RO'd water circulated at equivalent of 4gpm in CHIPS-M
- UV sterilizer, 0.5μm + carbon, 0.2μm filters
- Full recycle time of about 10 days
- System is the equivalent of what was in CHIPS-M : straightforward and cheap but without the low temperature which keeps bacteria better under control at the bottom of the lake and pressure which reduces bubbles



Water : conclusions



- Published NIMA59451
- Simple filtering can clean the water to ~100m at 405nm
- Means dissolved solids do not cause bad attenuation at this wavelength
- Check with other wavelength light
- Implication is for cost of water plant and strength of structure

Schedule

- Deployment of as many kt as possible will happen in Summer 2018
  - This is driven by ERC schedule, already a year late due to small funding delay pushing past onset of winter
- Factory setup will happen in Summer 2017 and plane construction/testing will start then
- PMT procurement will commence this month
  - ~~Hamamatsu (76mm, very motivated)~~
  - CKZ (86mm, very good price and larger PC area)
  - ~~ETL (no information as yet)~~
- Stainless Steel Frame will be ordered this year
  - Likely will be mostly constructed at the pit starting spring 2018

Summary

- We do have a big task ahead of us, but progress is steady
- All being well, the 5kton detector will be deployed before the snow in 2018
- 10 kton detector footprint, so small extra money needed to deploy 5kton more (<$1M)
  - If deployment successful, we will be asking for further funds, but lets wait and see
- Greater masses could be possible in the future
  - FNAL plans for PIP-2 upgrade until 2025 to 1MW
  - Factor 2 in footprint brings factor 4 in volume
- Detector could be recycled if successful, to a lake in the path of the LBNF beam in S.Dakota to increase speed of knowledge take up