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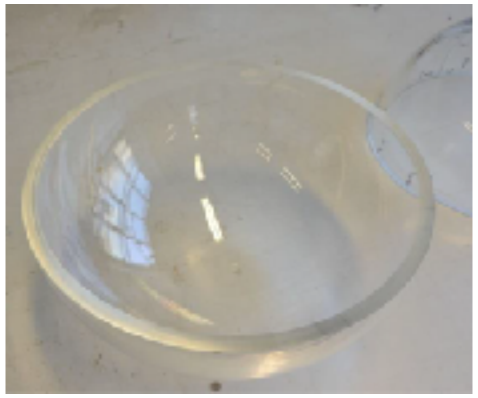
# MPMTS FOR HK

A PERSONAL PERSPECTIVE

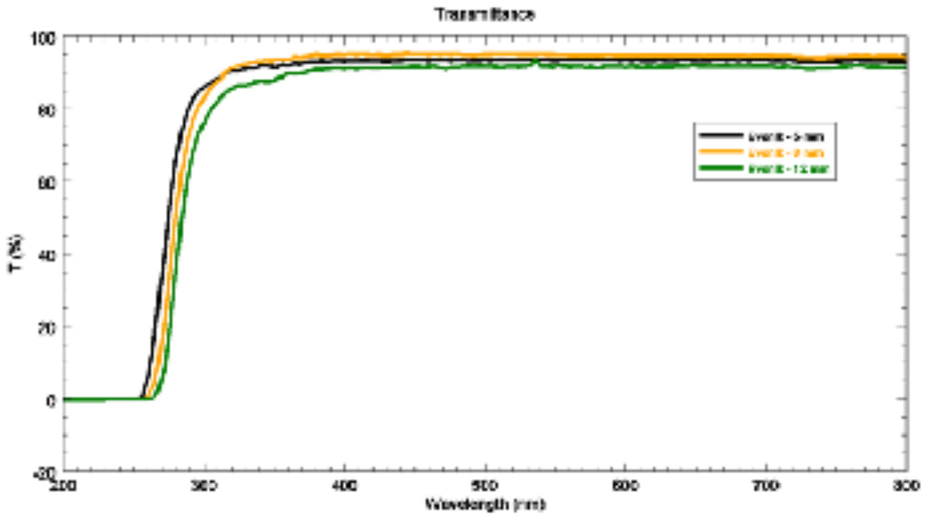
# MPMT:

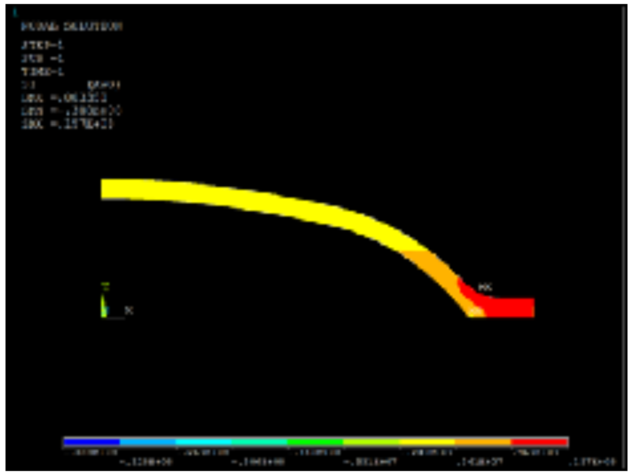
- Essential features:
  - Vessel providing water-proofing and protection against pressure
    - in additional to photosensors, readout electronics, monitoring, calibration devices can be placed in the vessel
  - Array of small (~3”) photosensors rather than one large photosensor
    - if using one or a few large photosensors (>8”) than we are back to “DOM”
- Possible applications of the mPMT in HK have introduced a few times over ~2 years
  - intermediate detector/TITUS (G. de Rosa) and NuPRISM
  - within HK (T. Feusels)

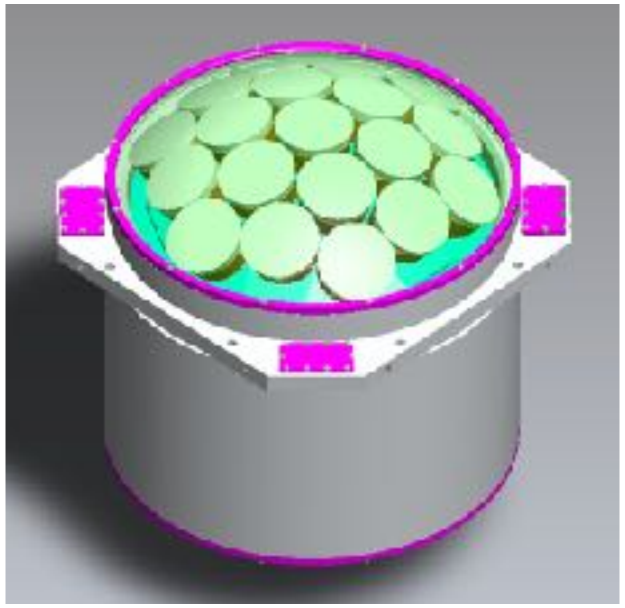
# MPMTs IN HK

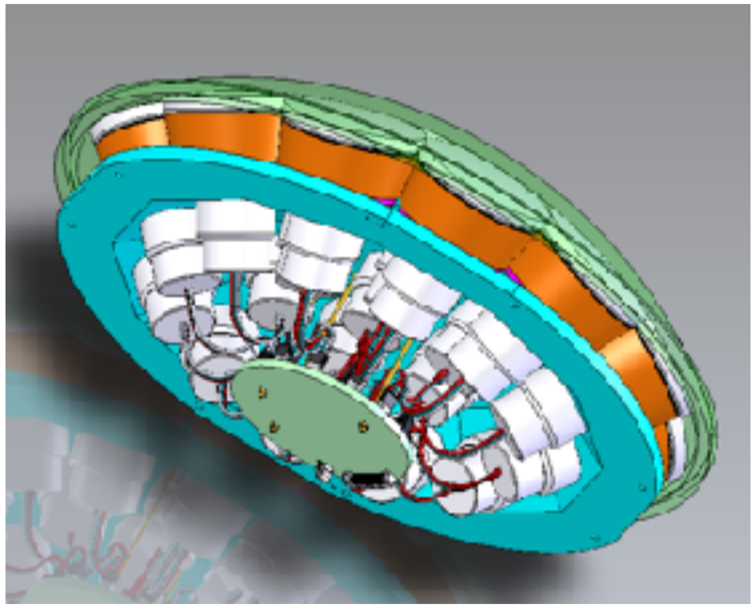


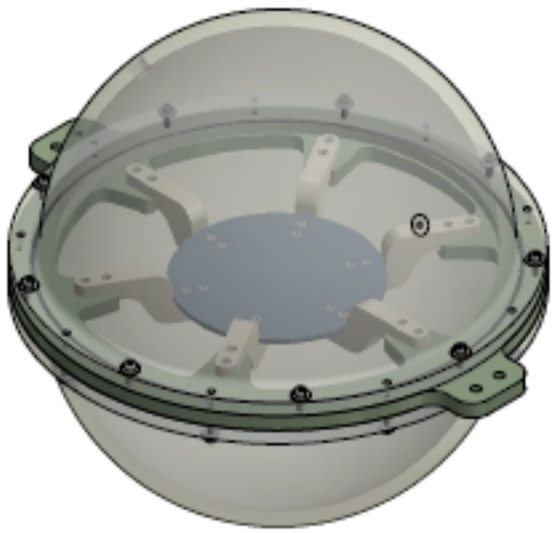
- There has been significant technical progress in advancing various aspects of a HK mPMT (Canada, Italy, Japan, Poland)
- Acrylic vessel:
  - optical, stress, testing
- Electronics
- 3” PMTs
- optical gel
- Overall design:
  - Adapting KM3NET design
  - “bottom-up” design for NuPRIS

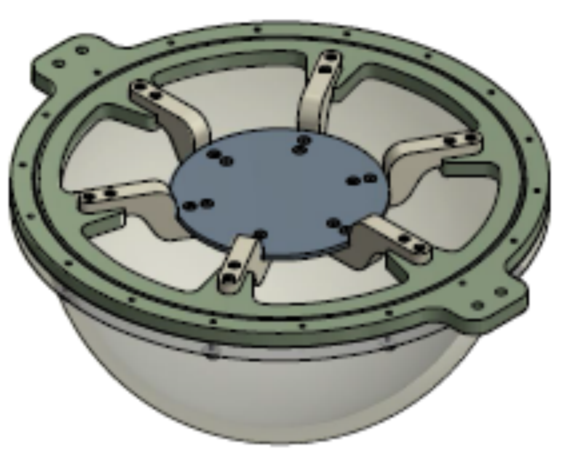










enormous effort and progress, but it is not my purpose to review it here . . .

# CURRENT EFFORT

- Simulation studies and mPMT design optimization
- Acrylic studies
- Vessel design
- Cooling system design
- PMT read-out optimization
- HV system
- Optical gel studies
- Final design mPMT prototype construction

- Final design mPMT test
- PMT support studies
- PMT selection

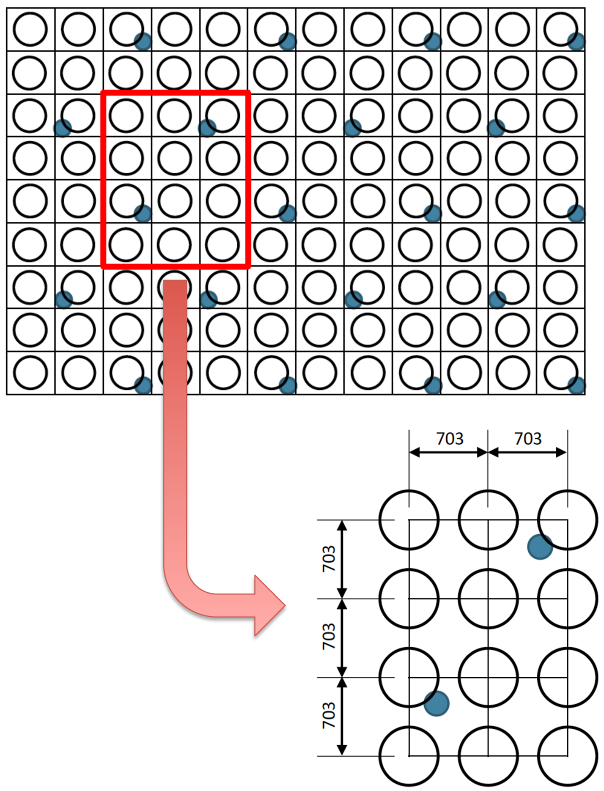
# PROGRESS AND LACK THEREOF

- We have made a lot of progress understanding how to build an mPMT
  - also costing, components, assembly
  - it is already understood as an attractive way to increase photo coverage in HK with broad participation.
- But it is still not clear from a physics stand point why we want mPMTs in HK
  - why is this advantageous relative to 20” PMTs?
  - are there complementary capabilities/features?
- Still, we have managed to identify where we **may** profit:
  - *increased granularity in imaging Č rings*
  - *better timing resolution (due to improved Hamamatsu and HZC 3” PMTs)*
  - *directional information*
  - *integration of ID/OD (potentially less “dead” space)*
  - *opportunity to add calibration devices in mPMT vessels*
  - *containment of radon emanation within vessel*
- However, we have not produced anything resembling a “bottom line” for how HK would profit from the mPMT concept.
  - advantages of integration mean that the design considerations are more complicated . . .
  - organizationally, it presents challenges as what were separate efforts must now be considered at once:
    - photosensor, readout electronics, support structure, calibration, (DAQ, software)

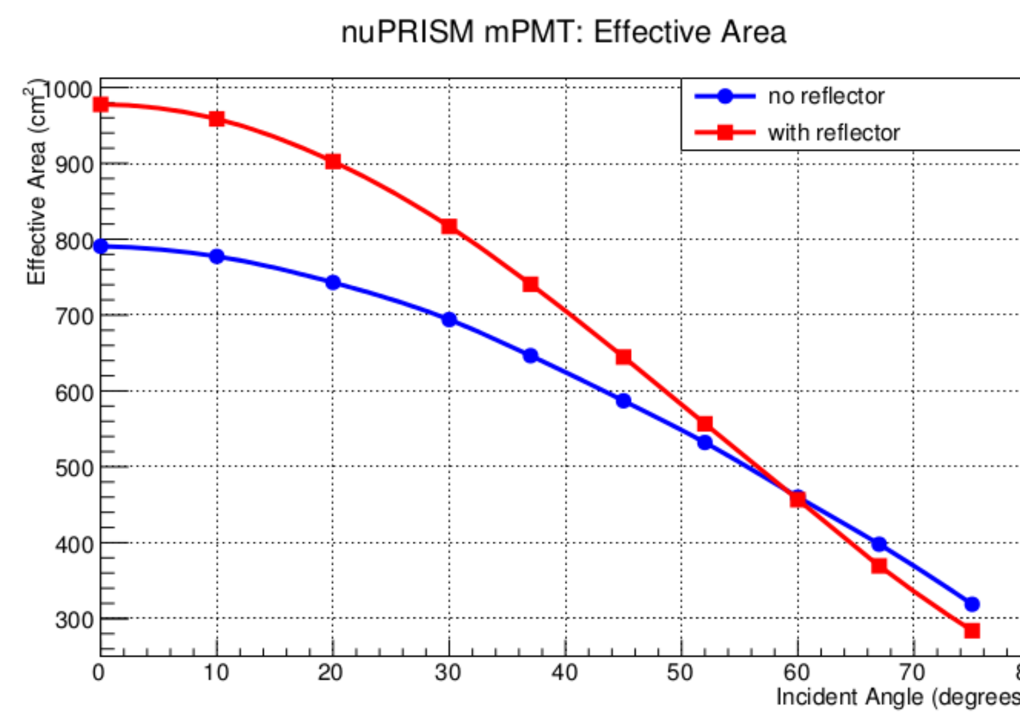
# WHY NOT?

- Depends on which point:
  - Information content:
    - *increased granularity in imaging Č rings*
    - *better timing resolution*
      - now making good progress in NuPRISM with detailed simulation/reconstruction
    - *directional information*
      - qualitatively new capability the we do not know how to exploit yet, both in reconstruction and calibration
  - Overall HK design:
    - *integration of ID/OD (potentially less "dead" space)*
      - this requires us to go beyond just the mPMT design to the global detector design.
      - how do ID/OD, 20" PMTs, and mPMTs coexist within HK?
  - Calibration:
    - *opportunity to add calibration devices in mPMT vessels*
      - depends on global calibration strategy
  - Containment:
    - *containment of radon emanation within vessel*
      - needs testing/measurements
      - needs detailed design with this goal in mind? (*won't say more about this for now*).

# OVERALL PHOTODETECTION




- Photodetection has been the primary metric to evaluate photosensor coverage
- in baseline design, with 40% coverage, 20" PMTs are nearly maximally packed on the wall
- Naively, each have π x (25 cm)$^2$ ~ 2000 cm$^2$ effective area




- Consider 50 cm diameter mPMT with 19 ID 3" PMTs
  - Effective area is ~1000 cm$^2$
- Geometrically, replacing one 20" PMT with mPMT of the same diameter reduces photocoverage by 1/2.
  - in addition to the dead space between the modules there is dead space between the PMTs within the module.

- **Motivation for mPMTs in HK must be something other than "raw" photdetection**
  - even if cost/area is less, equivalent photocoverage to 20" PMT is difficult to achieve geometrically without a radical (innovative) departure in the concept
  - (radical but not innovative: make hexagonal modules or PMTs that can improve packing)

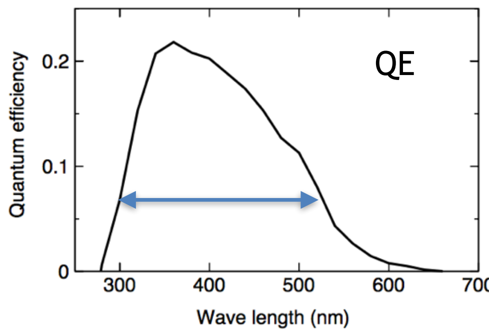
# TIMING RESOLUTION

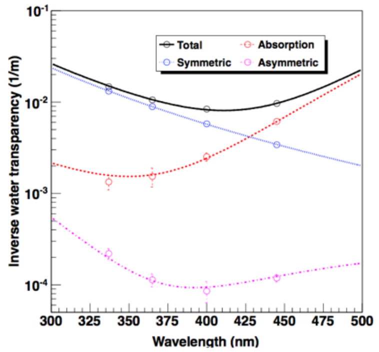
- new Hamamatsu 3″PMTs are showing excellent timing resolution (1.3 ns FWHM)
  - promoting developments also at HZC
- How can we study the impact of this?
  - Again, we can directly simulate the configuration and return reconstruction, etc.
    - may take some time?
  - Can we decouple granularity from time resolution?
    - simulate 20″ B&L PMT with 1.3 TTS of 3″ PMT as a starting point
    - we can easily address issue such as chromatic dispersion effects.
    - is it easier to return reconstruction in this case?

- Perform physics studies:
  - vertex resolution for low E?
    - solar, relic neutrino
    - $p \rightarrow K+\nu$?
  - applications where darknoise, etc. are critical
    - e.g. n-tagging

**Timing limitation due to chromaticity?**

- 300nm (n=1.349) — 525nm (n=1.334):
  - $\Delta n/n=1.1\%$ => $\Delta t=0.05$ nsec/m (full width)
  - $\Delta t=1.3$ nsec (TTS of the new 3” PMT) for 26m path
    - TTS dominates up to ~20m of light path for the new 3” PMT
    - UV side of light are absorbed for longer light path, shrinking $\Delta t$
  - TTS dominates for 20” box-and-line PMT’s

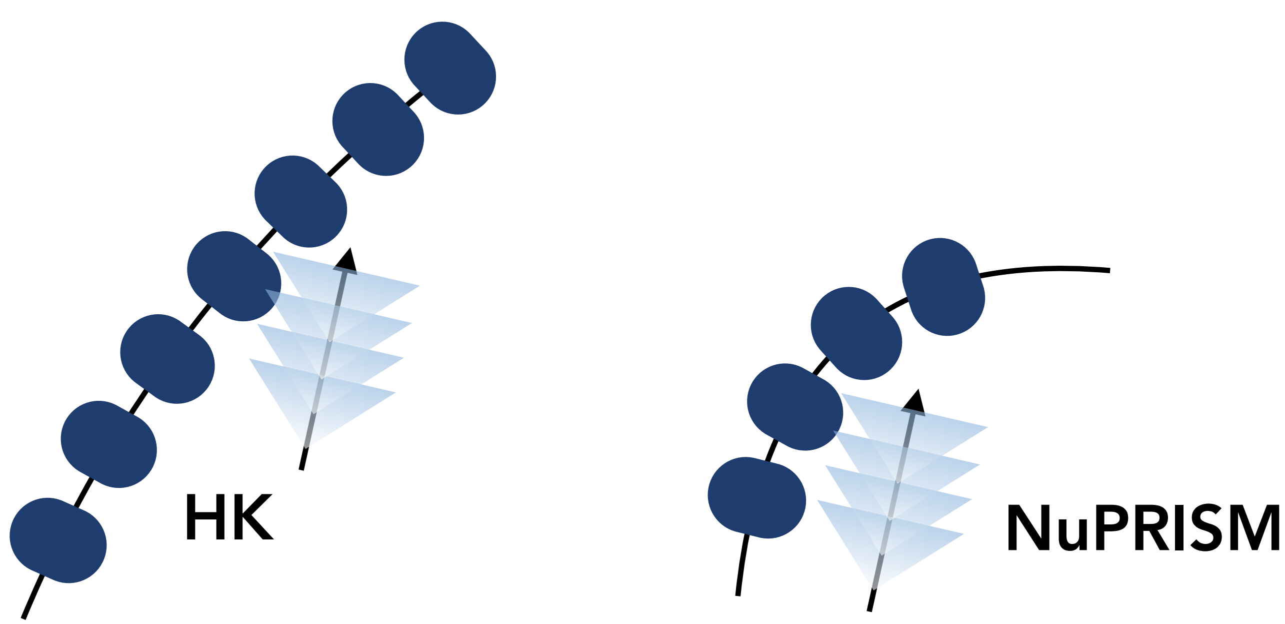


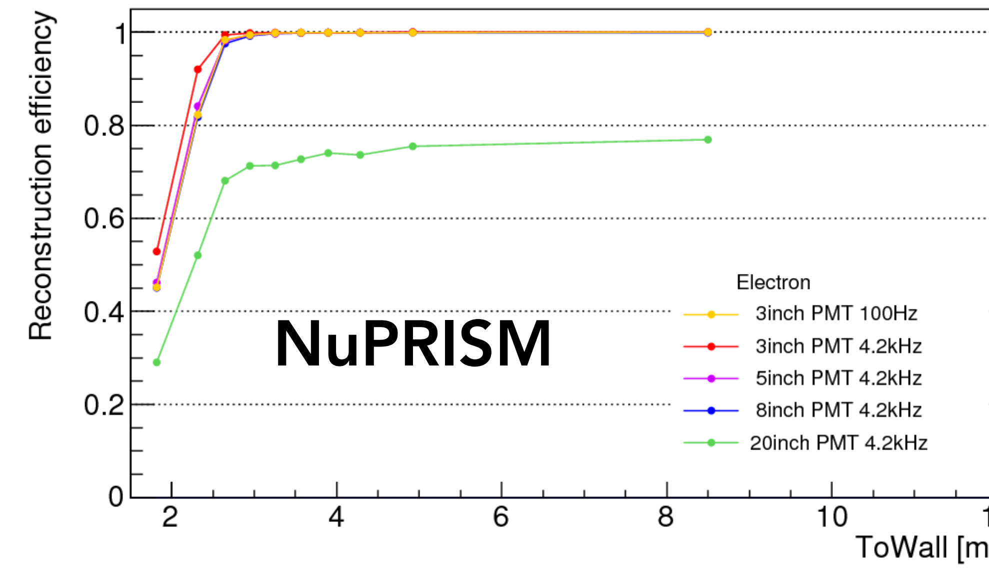



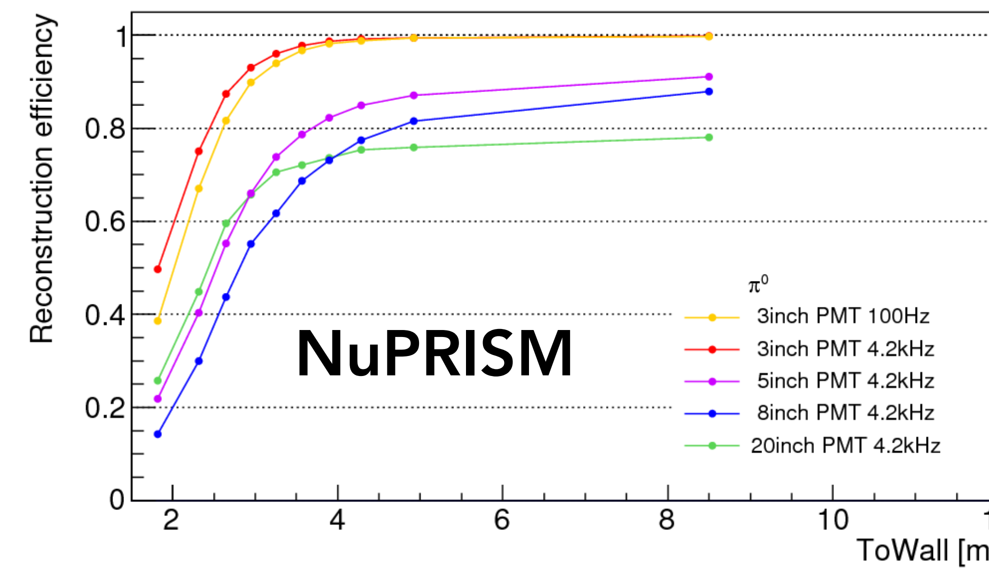

| λ(μm) | n |
|---|---|
| 0.300 | 1.349 |
| 0.325 | 1.346 |
| 0.350 | 1.343 |
| 0.375 | 1.341 |
| 0.400 | 1.339 |
| 0.425 | 1.338 |
| 0.450 | 1.337 |
| 0.475 | 1.336 |
| 0.500 | 1.335 |
| 0.525 | 1.334 |
| 0.550 | 1.333 |
| 0.575 | 1.333 |
| 0.600 | 1.332 |

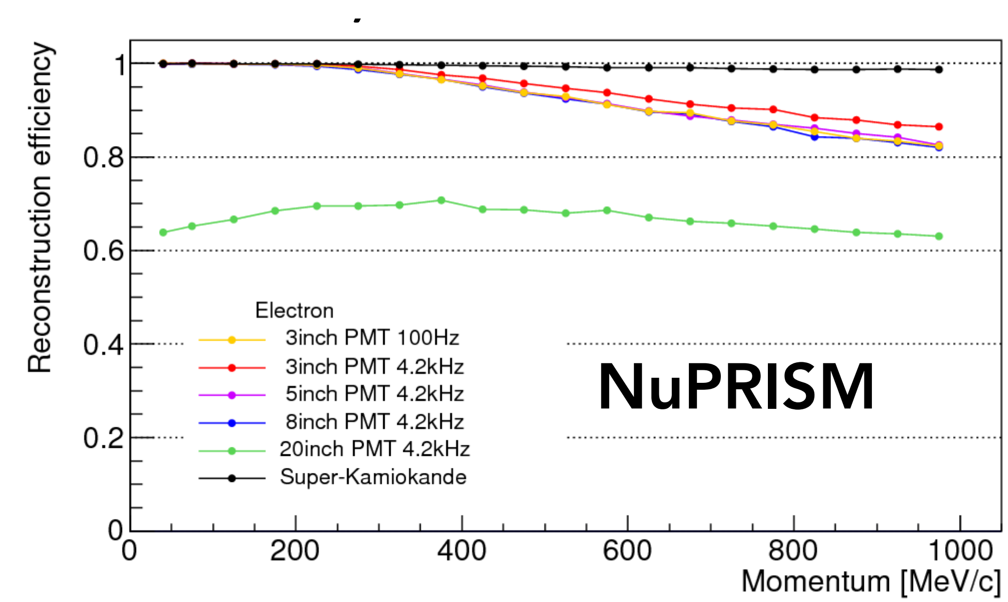
# GRANLUARITY

- NuPRISM studies show clear gain in vs. *toWall* for 3” PMT
  - N.B.: uniform array (not mPMTs)
- How can we study this in HK?
  - do it directly (simulate in HK, tune reconstruction, study performance)
    - may take some time?
  - Bootstrap NuPRISM studies to understand implications for HK?
    - small d/toWall are where we expect improvement due to granularity
    - if *d*, *toWall* are << tank diameter, we may expect that NuPRISM, HK perform similarly, assuming the same mPMT configuration.
    - if we control *toWall*, momentum, and *angle-to-wall*, we may be able to translate NuPRISM performance in this region to HK.



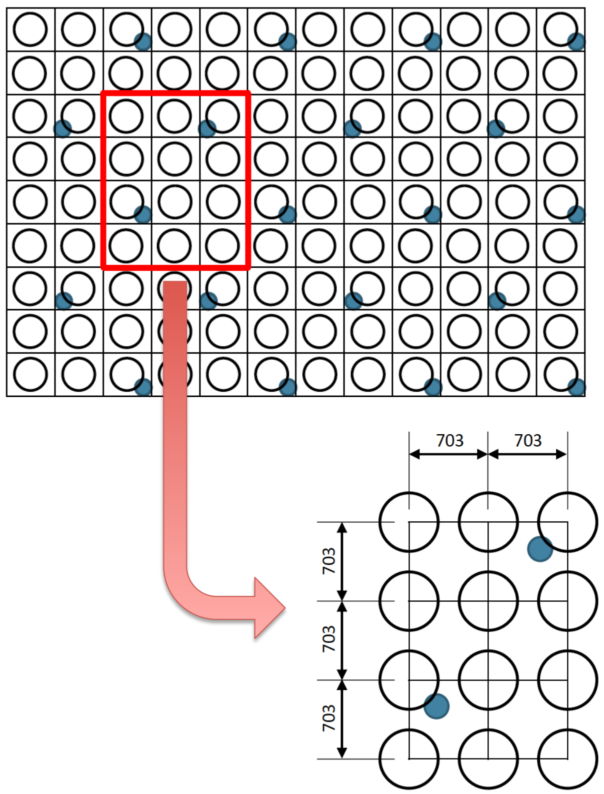



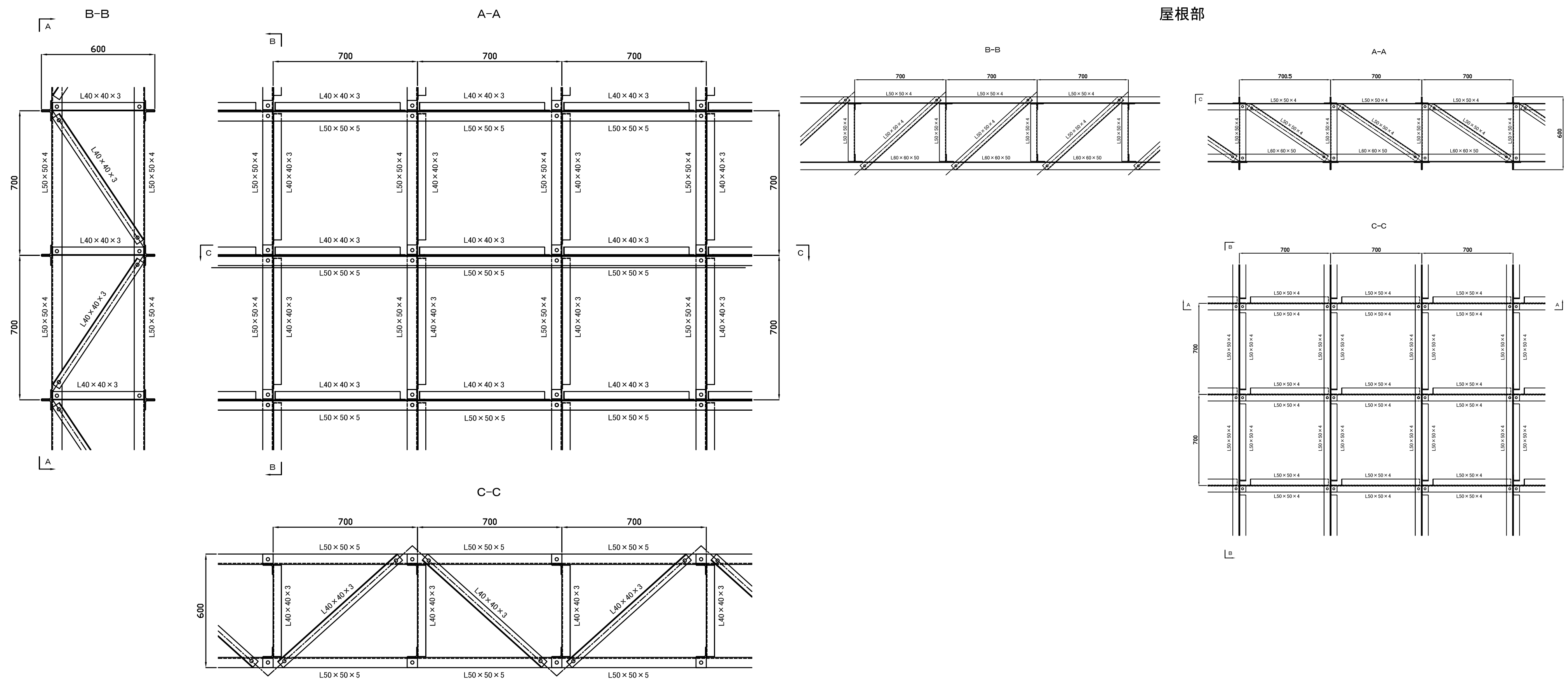



# DIRECTIONALITY:

- The most complicated since it is a qualitatively new capability
  - Probably needs actual mPMT implementation in MC
- For high energy, incorporation into a reconstruction algorithm is probably needed to study this
  - qualitatively new information that may be difficult to incorporate into fiTQun
  - this is probably the most challenging aspect
- For low energy:
  - rejection of light produced from PMT-related backgrounds (e.g. photon emission, etc.)
    - produce low energy tracks from PMT surface
    - see if light can be rejected by PMT directionality or if aperture occludes light
- Calibration:
  - decoupling angular/position information may allow position-dependent water parameters to be (more easily) determined
  - this needs to couple to a more general calibration strategy

# INTEGRATION OF ID/OD




- Potential savings in dead/OD region to increase ID is tied to design of PMT support structure
- If we are to profit from this, we have to immediately consider how PMTs and mPMTs coexist in the same detector
- Can we consider a "universal" interface that allows either an mPMT and PMT to be mounted in a given location?
    - this would then define mechanical requirements for both the 20" and mPMT assemblies
    - it will also define "height" requirements on mPMT to result in net reduction of dead region.

# OBSERVATIONS (I):

- We have made a lot of progress over the last two years understanding existing mPMT designs and issues
  - much of the initial discussion was focussed on cost/photodetection.
- Photodetection with mPMT relative to 20" PMT is limited due to simple geometry
  - we must make a case based on something else
- We can make a technical schedule for mPMT development
  - this is relevant, but a physics design study must proceed (precede to some extent) in parallel
  - what performance metrics are relevant for the mPMT?
- Whatever the design, it will be a substantial production endeavour
  - sourcing/testing of components
  - assembly of modules and subsequent QA/testing
    - difficult/non-standard processes such as optical gel formation and application
  - how to manage supply chain of incoming components and outgoing modules?
    - one feature we are looking to is "global" participation in the production . . . . .
    - additional hurdles in managing distributed production
  - *can we manage this in a reasonable time and with high reliability?*

# OBSERVATIONS II

- The phase space of "mPMT" designs is enormous.
  - but we know where we are seeking advantage in physics
    - what granularity is desired? (3" is okay? or can we use larger PMTs?)
    - what timing resolution is needed? (impacts timing resolution of individual PMTs, electronics requirements)
    - how much directional information is needed (impacts light collector design, PMT direction)
    - how to minimize dead space (impacts "height" of design and support structure design)
    - what calibration devices do we need to incorporate?
    - what level of Rn containment is needed for real physics impact?
  - Can we converge on a few (2?) concepts, study, and optimize?
  - Can we profit as much as possible in the short from:
    - NuPRISM studies and "simplified/shortcut" studies
    - to inform whether we are benefitting from the mPMT concept and to guide the optimization.