Hyper-Kamiokande
proto-Collaboration

NINETEENTH LOMONOSOV
CONFERENCE August, 22-28, 2019
ON ELEMENTARY PARTICLE PHYSICS
MOSCOW STATE UNIVERSITY

Photodetection & shockwave-arresting PMT cover systems for the HyperK ν detector

David **Bravo-Berguño,** on behalf of the HyperK protoCollab.
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MARIE CURIE ACTIONS

H2020-MSCA-RISE-2014-GA641540, SKPLUS

Hyper-Kamiokande protoCollaboration

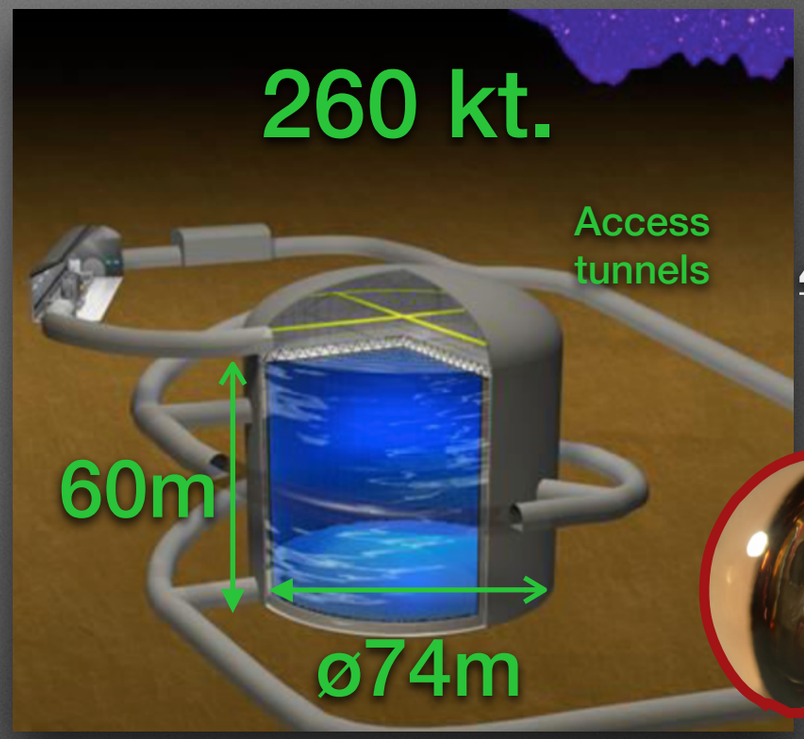
300+ member (proto)Collaboration, comprising 17 countries in Asia, Europe and the Americas, inscribed in 82 institutes (75% international)

March 2018 protoCollaboration meeting in UAM (Madrid, Spain)

Hyper-Kamiokande project in a nutshell

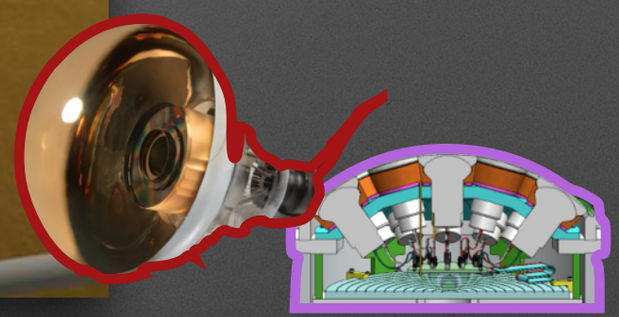
- UTokyo ratified funding to continue design and start construction next April, to **start DAQ in 2027**. One of Japan's Ministry of Education and Science (MEXT)'s highest priority large-scale projects in Japan.

- Published Design Report last year. (arXiv: *phys.inst-det:1805.04163*). Several internal Technical Reports published (see backup references).



40% ID photocoverage

40,000 new 20" PMTs
— or option for —
20" PMTs + multiPMTs

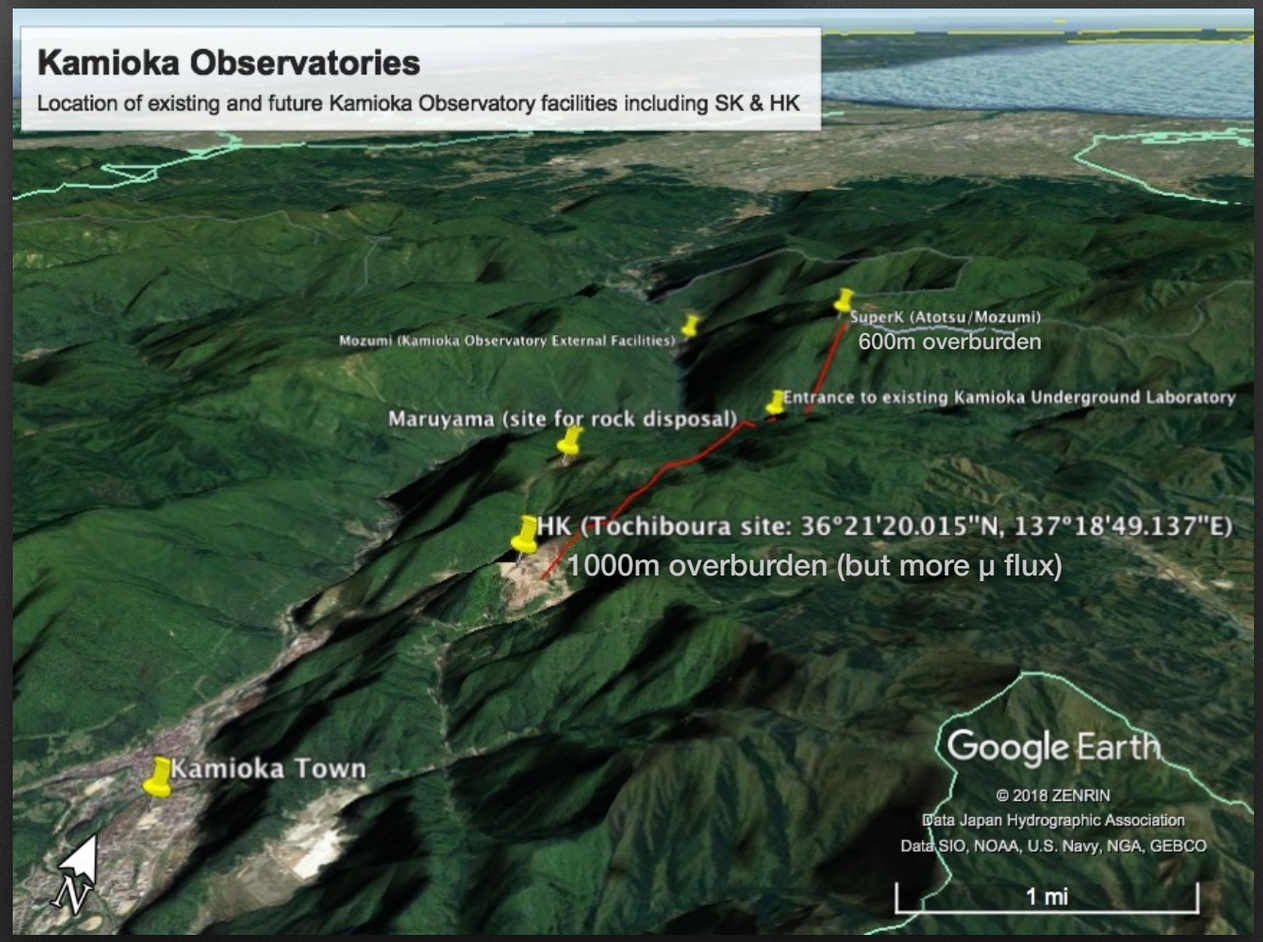


- Intermediate Water Cherenkov Detector (IWCD) CDR released.

- Enlarged, improved version of SuperK (10x statistics!) aiming for low background, and therefore low threshold.

- Second tank under detailed consideration (preferred location in Korea: HKK).

- Same beam oscillation possibilities as with SuperK through J-PARC's T2HK(K) beam.



Hyper-Kamiokande's physics

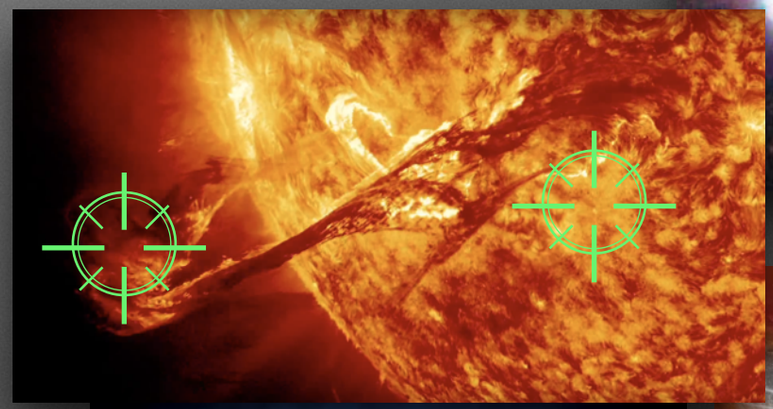
- Multipurpose detector with a wide breadth of physics reach; unparalleled projected sensitivity in many areas:

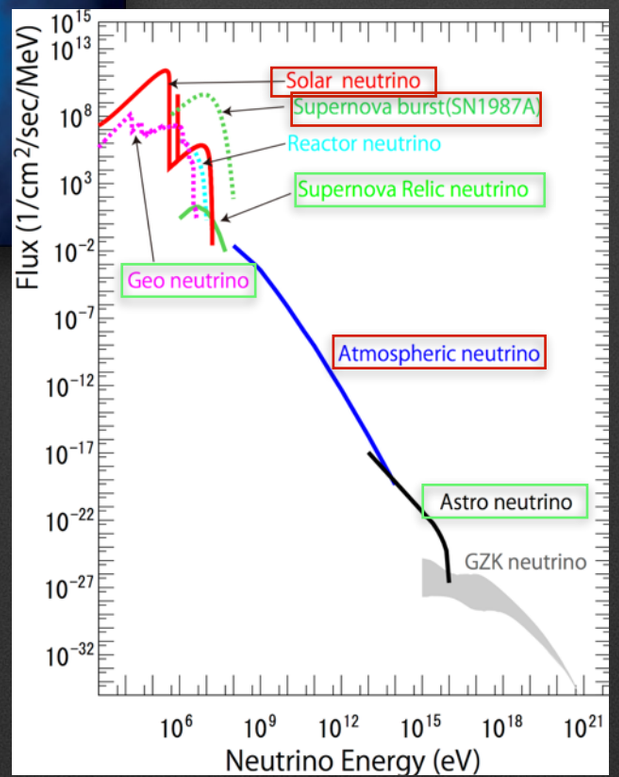
  √ Neutrino oscillations (MH, δ_{CP}, PMNS)
  - Long-baseline beam (T2HK)
  - Atmospheric
  - Solar

  √ Neutrino astrophysics
  - Solar (spectrum and flare)
  - Supernova (burst and DSNB)
  - Dark matter searches
  - Other sources (AGN, GRB, GW…)

  √ Neutrino geophysics

  √ Nucleon decay





Higer statistics than any other next-generation experiment, while keeping **directionality** and sensitivity to **low energies (beyond ν_e mode)**.

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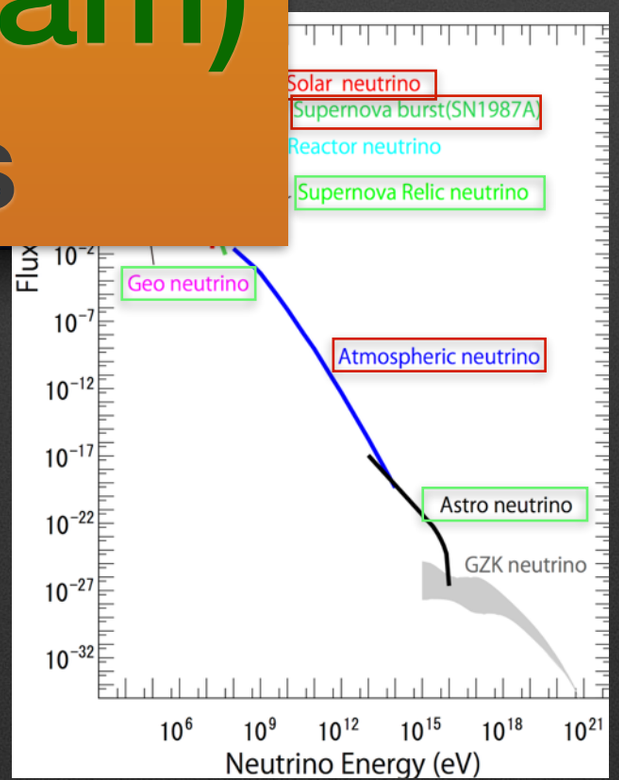

Please see

M. Yokohama-san's

presentation on

Monday 26th (11:30 am)

for more on HK physics

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How will HK achieve this?

- A superior energy resolution in a wide dynamic range is the critical factor in achieving HyperK's planned objectives.
- This will pair with the much enhanced statistics collection.
- Projected energy resolution relies on achieving high precision calibrations, as well as background suppression (esp. ^{222}Rn), in line with SuperK's SK-IV period (2009-18).

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- NEW high-quantum-efficiency 50cm box-and-line (B&L) PMTs: **R12860-HQE**.
  - √ **Commonality** with SK's shape and dimensions (133 already working in SK for ~1 year)
  - √ **~40% faster** time response
  - √ **+8% Q.E.** @ peak
  - √ Greater Sb-K-Cs **collection area and efficiency**
  - √ Improved SPE **resolution**
  - √ Linear response **resilience to saturation**

	R12860-HQE (HK)	R3600 (SK)
Rise time	6.7 ns (SPE)	10.6 ns (SPE)
FWHM (w/o ringing)	13.0 ns	18.5 ns
Timing res.	2.6±0.1 ns	~5 ns
QE (peak)	30%	22%
Area w. CE>50%	49.2 cm	46 cm
CE within ph.c.	87%	73%
Sigma res.	35%	50%
Output linearity	470 p.e.	250 p.e.(specs) 700 p.e.(measured)
Dark rate	*~6 kHz (reducing)*	*4.2 Khz*
Pressure rating	80 m	50 m

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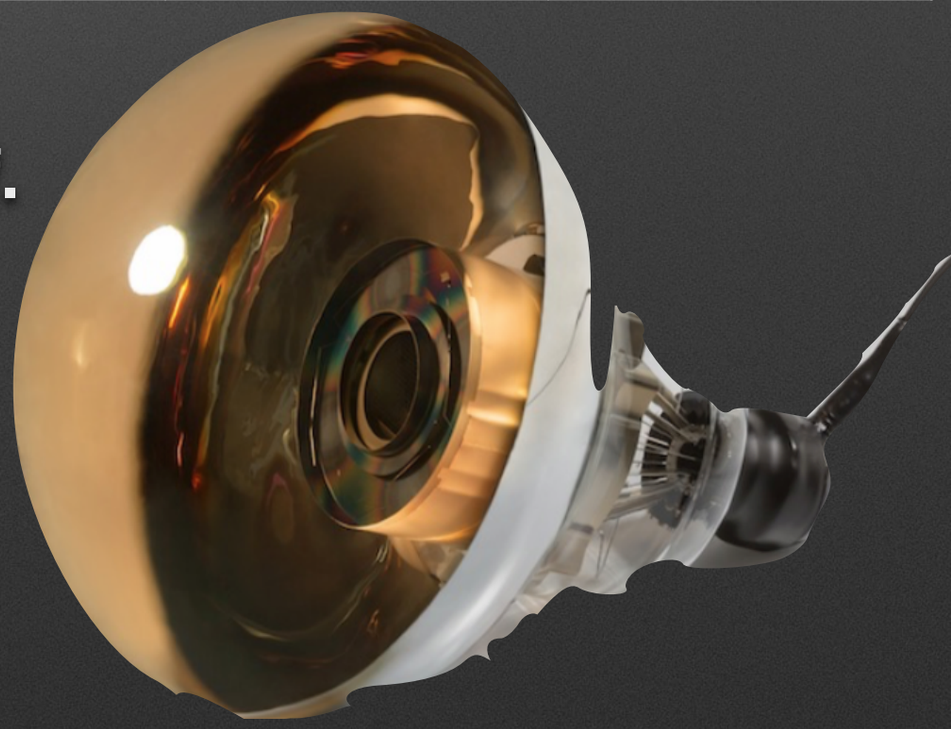
26% PMT detection eff.

<=>

10% overall HK photon detection eff.

(2x SK's)



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  - √ **Improved shockwave prevention PMT covers** ->
    -> ***Spanish contribution***

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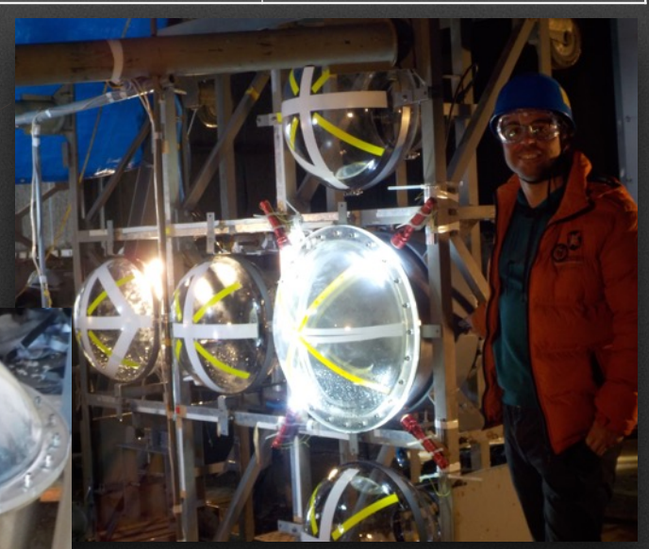

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  - √ **Dark rate** reduction effort ongoing
  - √ Possibility to include **multi-PMT** modules (19 3" PMTs) for increased granularity: advanced R&D program, benefitting ICWD too
  - √ Also discussing possibility of **MCPs** for increased detection efficiency (but limited by timing resolution and dark noise for now)…

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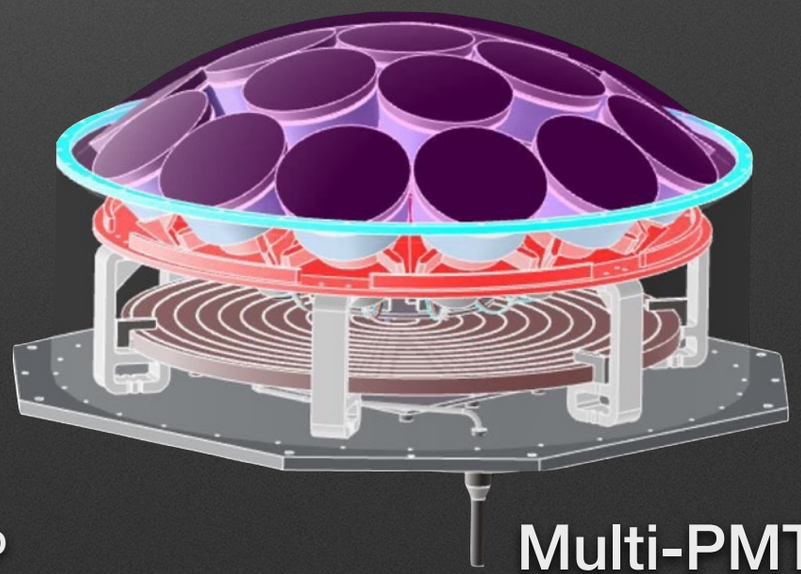
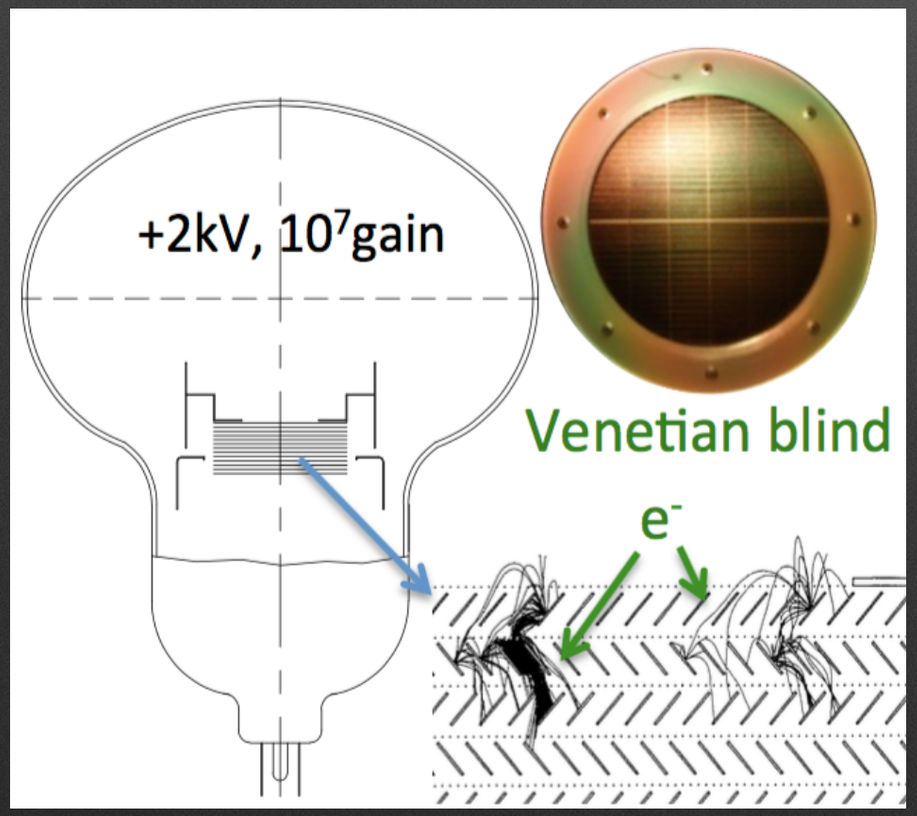


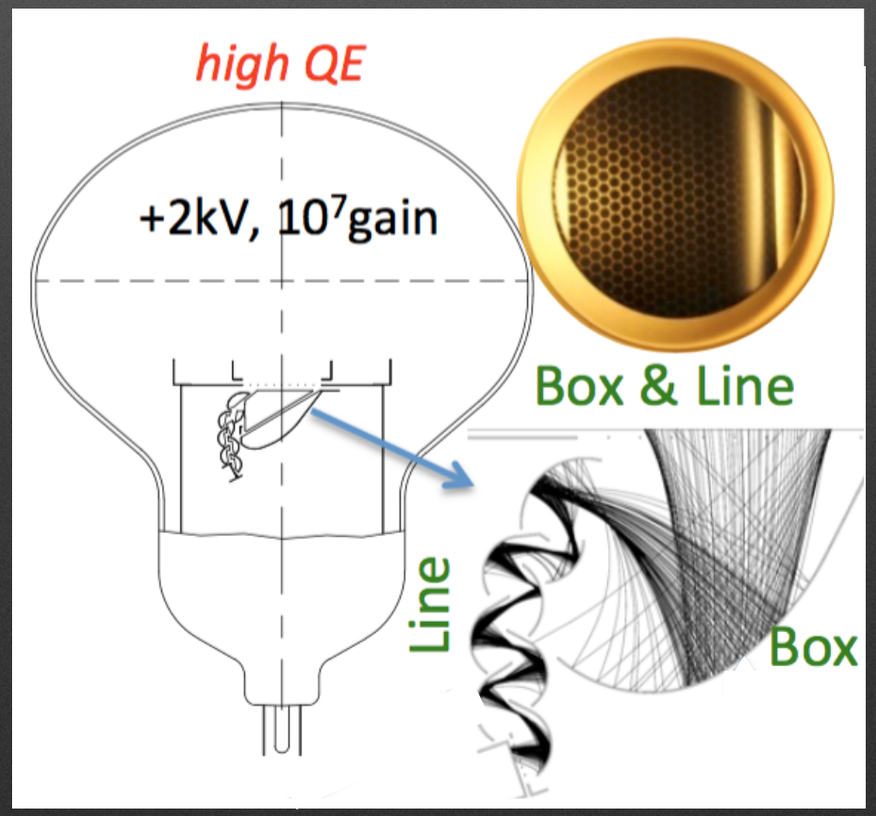
Multi-PMT module

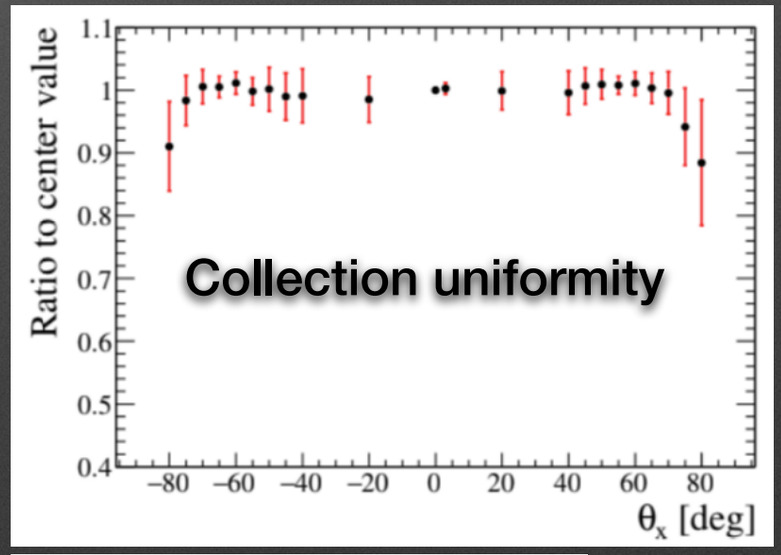
[(3" R12199-02) x 19]

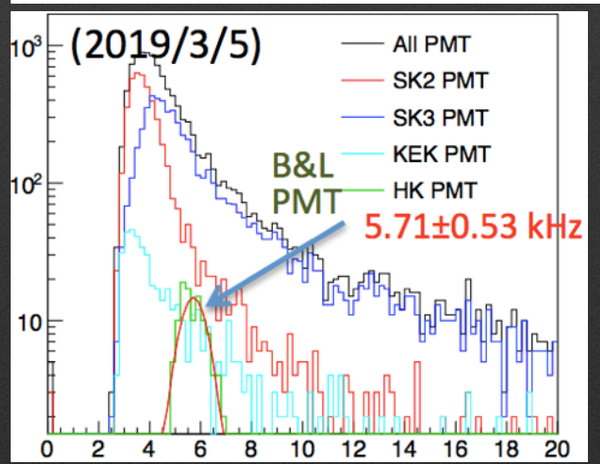
PD System details

- Move from venetian blind dynode structure (SK) to box-and-line dynodes (HK) minimizes chance of photoelectron to miss collection nodes.
- Drift path is uniform, decreasing timing resolution spread.
- Uniformity (±5%) of response over most of collection surface, sharp drop at edges (±70°).
- Reduction in dark rate lead by improvement in radioactive isotope contamination in the PMT glass — details proprietary for now.





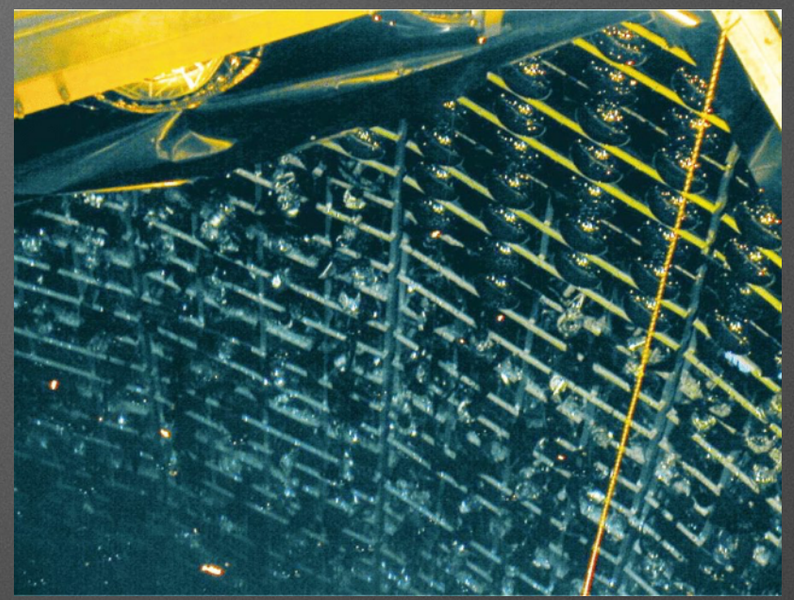




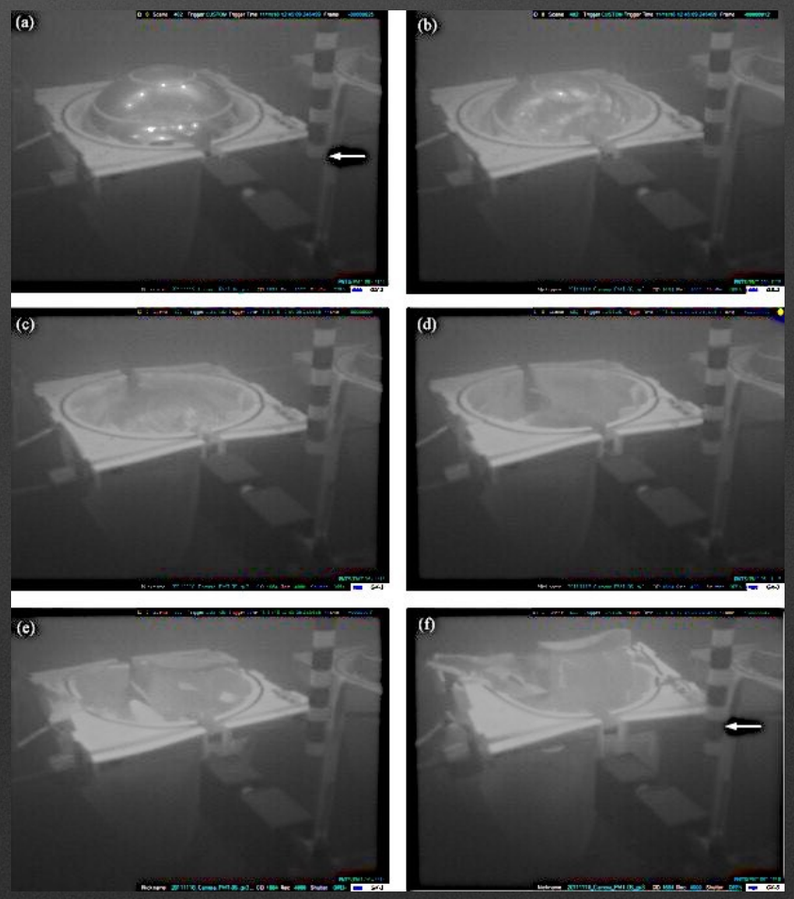
Dark rate

Underwater vacuum in glass: handle with (lots of) care

- PMTs = mostly **vacuum** (~60 L)
- Vacuum vessel = relatively fragile, handcraft blown borosilicate **glass**.
- Small (even microscopic) cracks or imperfections in glass can lead to sudden bulb failure -> -> underwater IMPLOSION.



- Water incompressibility = water hammering effect.
- Single PMT bulb failure = chain reaction propagation of shockwave through water to all other PMTs.
- Precedent: SK-I to -II upgrade (during filling, 2001). All submerged PMTs (~2/3rds) lost, including most smaller OD PMTs.
- Solution found: fiber-glass polymer (FRP) covers for SuperK (40m) . Could be improved w.r.t. performance (60-80 m) and cost?



Shockwave-arresting (a.k.a. anti-chain reaction) PMT covers

- Steel truss structure will line HK's tank (+ top & bottom), providing optical and physical separation between the ID and OD, as well as support for all PMTs, cabling, etc.

- Covers basically conceived as an **unpressurized** design.
  √ High-transparency (>90% @>400 nm; >77% @>300 nm), low-background (<10 mg(TOC)/m^2) spherical **acrylic dome**.
  √ Low-background (<4 Bq(U/Th), <10 Bq(K), <10 mBq(Rn)…), low-cost, high-strength **body**.
  √ PMTs operate at **local pressure**.
  √ In event of failure, pressure wave and debris must be **attenuated and contained** below harmful levels for neighboring PMTs.
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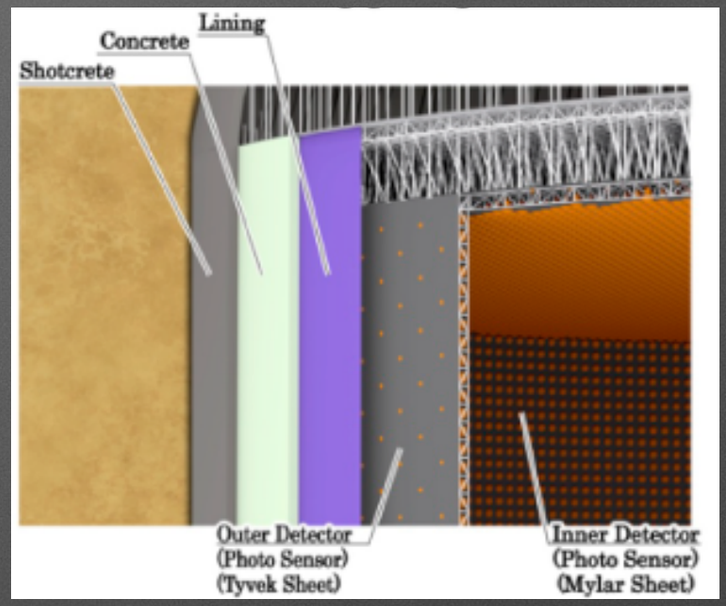

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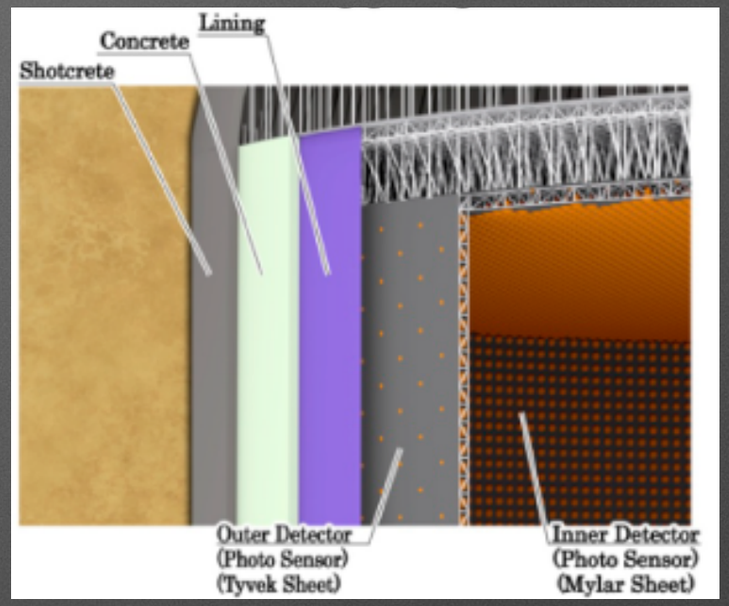

- 3 main designs being considered for HK; all of them well into final R&D and prototype testing:
  – Conical stainless steel ("Japanese SUS")
    √ Deepest rated pressure (80 m)
    √ Most studied and tested
    √ Baseline design

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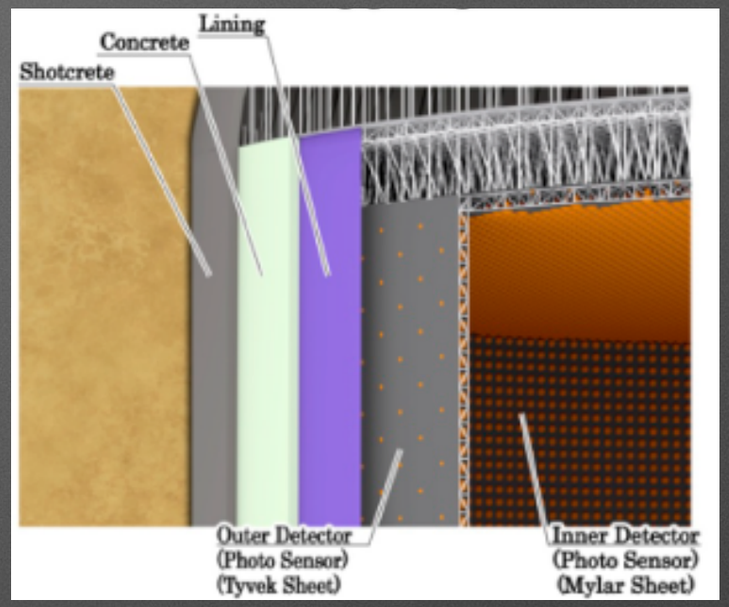

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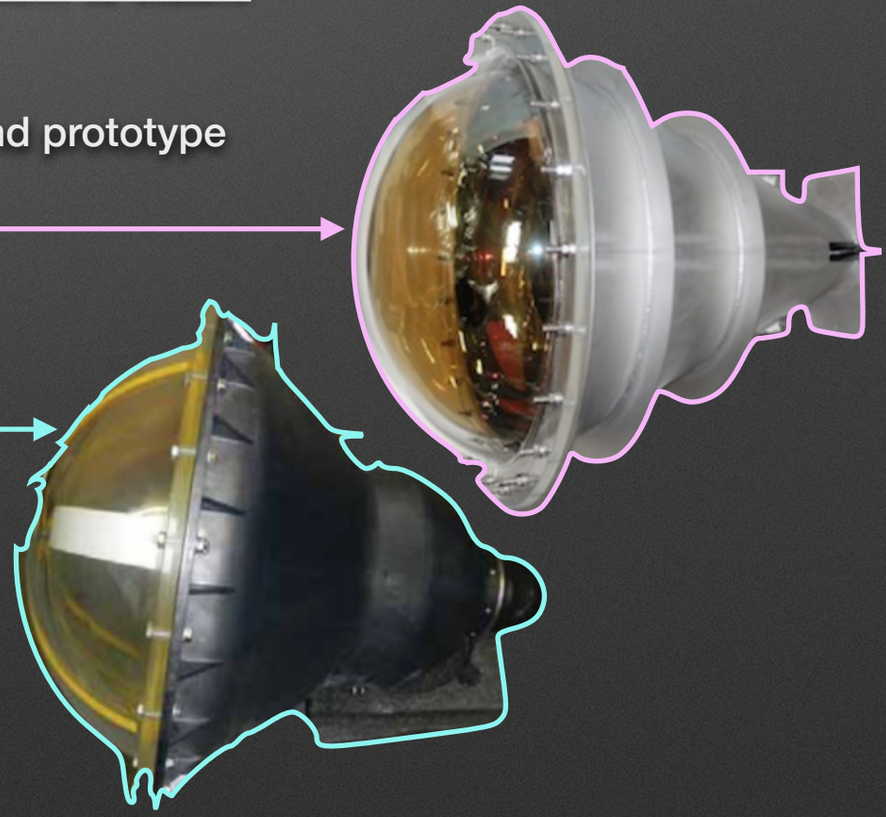

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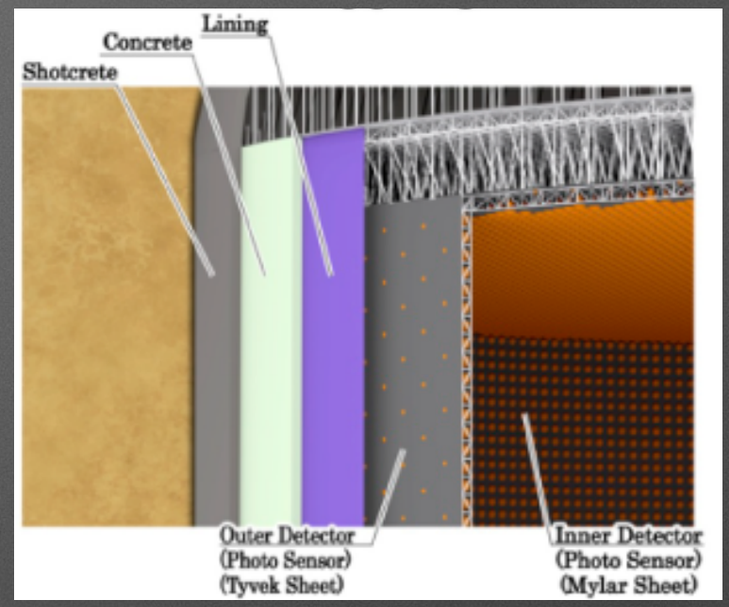

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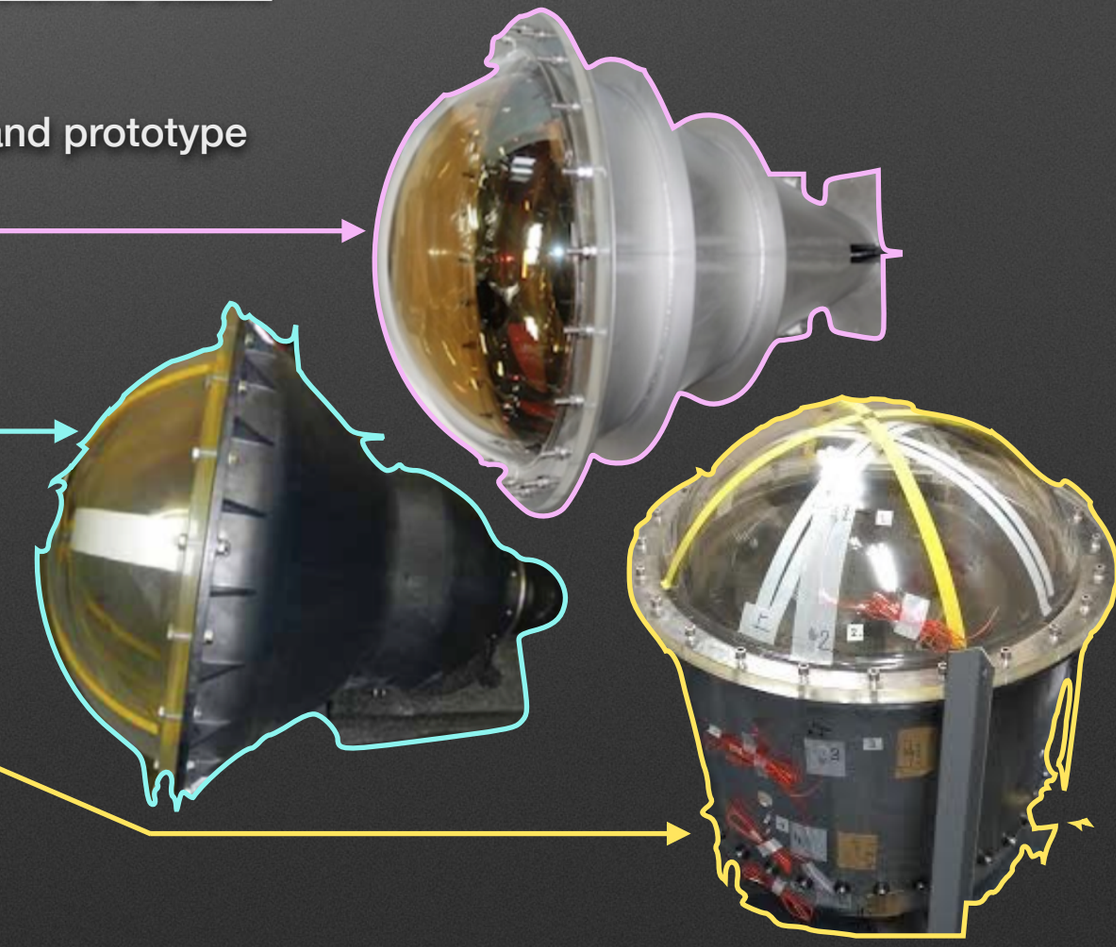
  - Cylindrical stainless steel ("Spanish SUS")
    - √ Lowest cost
    - √ Successfully (but not as thoroughly) tested



Could be used in parallel (i.e. different depths or areas) or uniquely.

- Mass production start in ~1 year to stockpile for HK outfitting (~2026).

UAM-Aratz “Spanish” PMT cover

- Conceived as a non-conformal, high pressure tolerance, simplified (& consequently cost-effective) stainless steel cover design.

- Started out with bare minimum: cylindrical two-piece body, hemispherical bottom, flat flange for acrylic interface.

- Testing showed single-piece, pseudo-conical body better. Kept slightly modified (5º-inclined) bottom and flange.

- Handcrafted pieces for prototype stage:
  embossing (<<$$$$ overhead for molds and machinery).
  —>Introduces larger tolerances and less constrained defects that mass-produced units wouldn’t have.
  —>Work around that during qualification testing.

- Baselined common flanged acrylic window with the other Japanese cover designs.

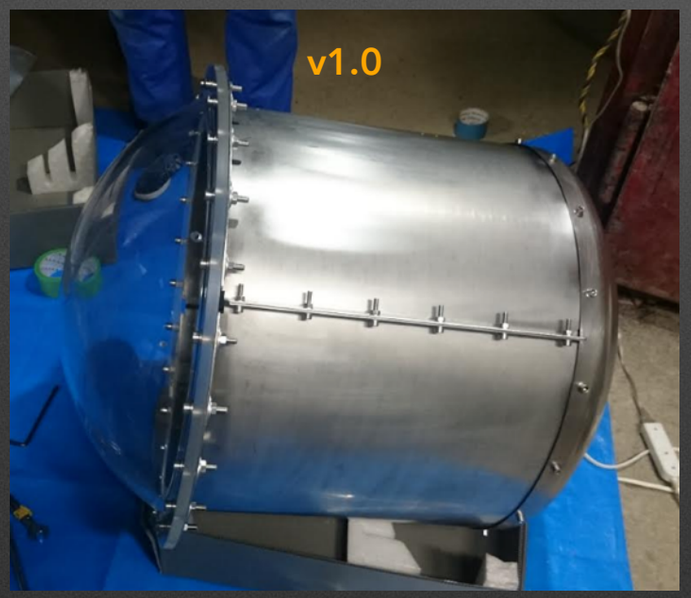
- Other variants possible, including pressurized version (just bottom + acrylic) for mPMT modules - under definition.

Live testing:
from v1.0 to v2.2

- Three rounds of testing for each design:
  - i. FEM acceptance and refinement (< 1MPa): several companies in Japan & Spain.
  - ii. Hydrostatic testing (~0.7-0.8 MPa): Kamioka Underground Laboratory, Aratz (Vitoria, Spain)
  - iii. Implosion testing (40-80 m depth): ex-JAMIC facilities (Kami-Sunagawa, Japan)

- Material selection (esp. radiopurity) throughout subdesign iterations. LSC (Canfranc Underground Laboratories) assist with that effort.

- Allows to weed out suboptimal designs and make refinements.
  Example: “Spanish cover”



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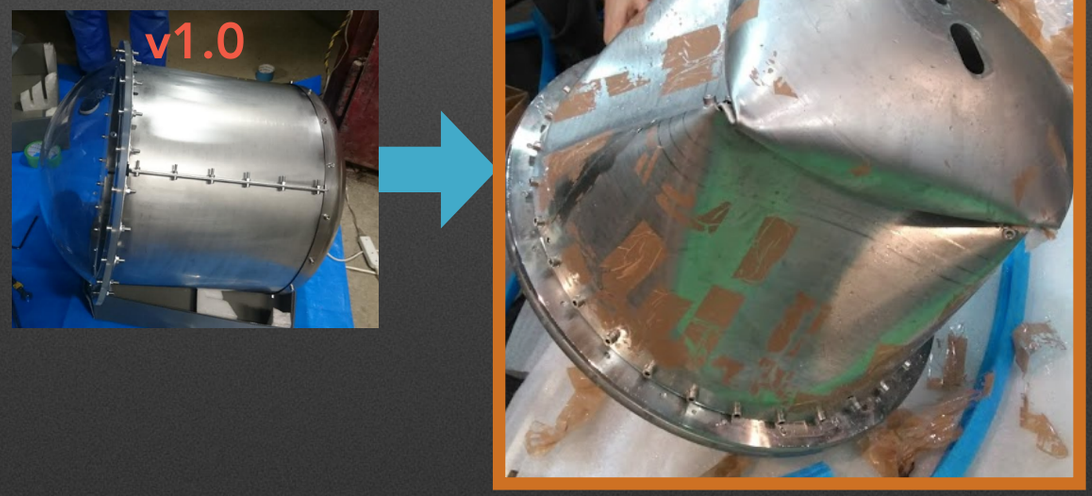

Live testing:
from v1.0 to v2.2

- Three rounds of testing for each design:
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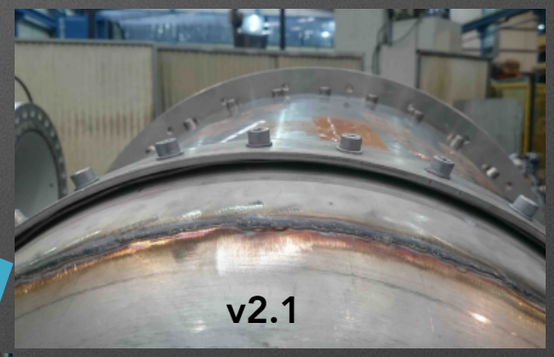

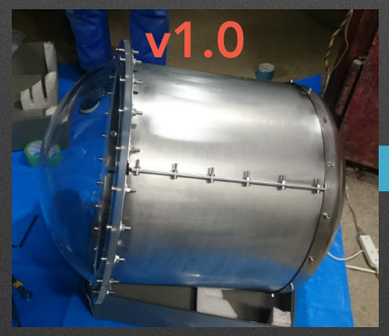

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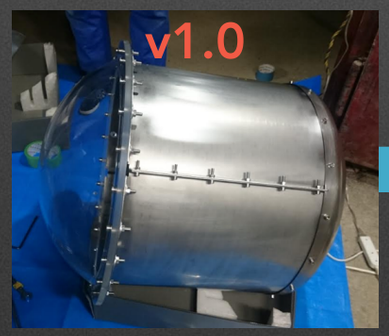

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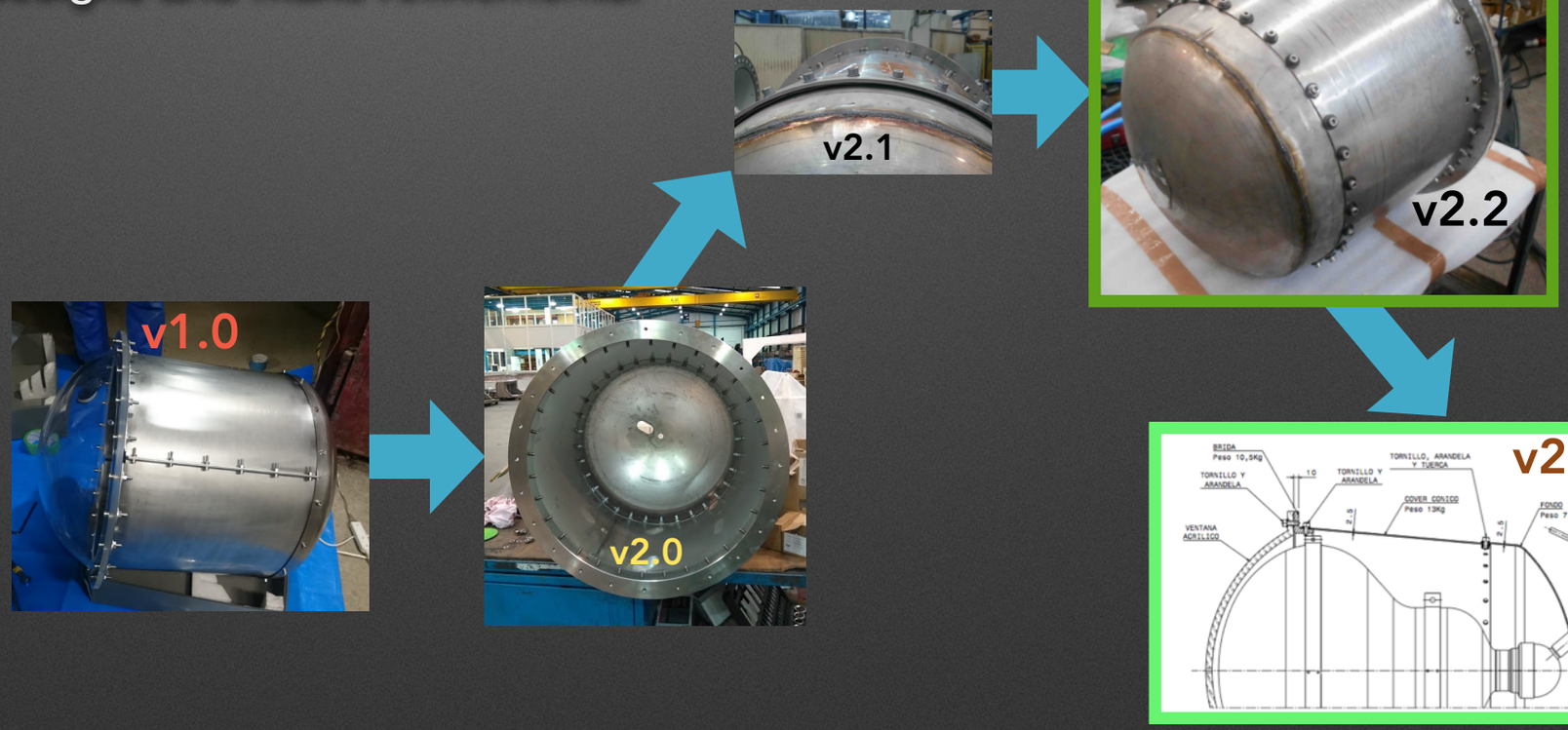

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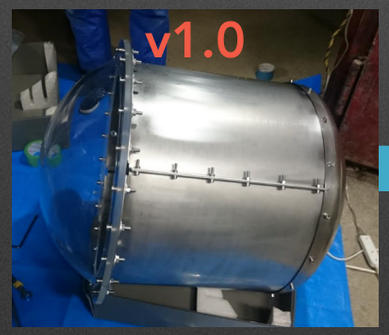

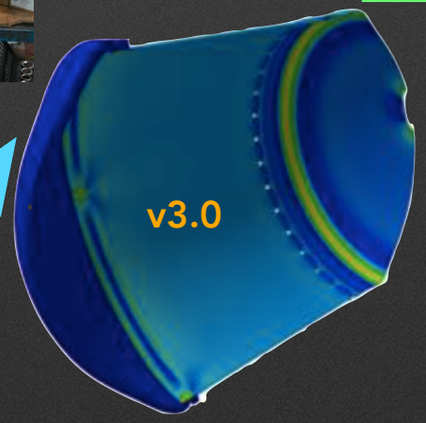

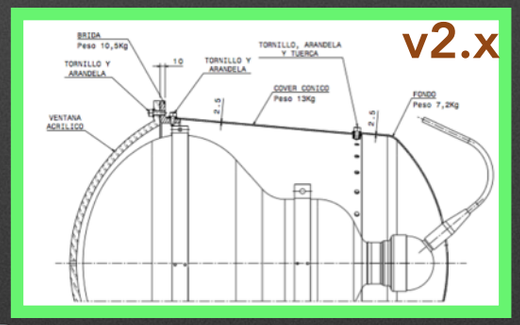

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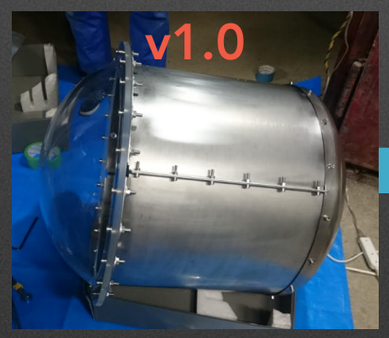

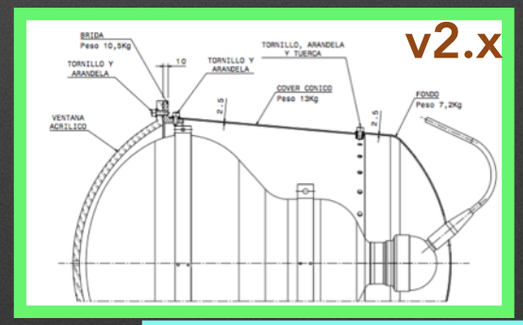

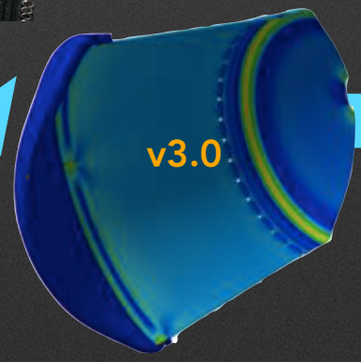

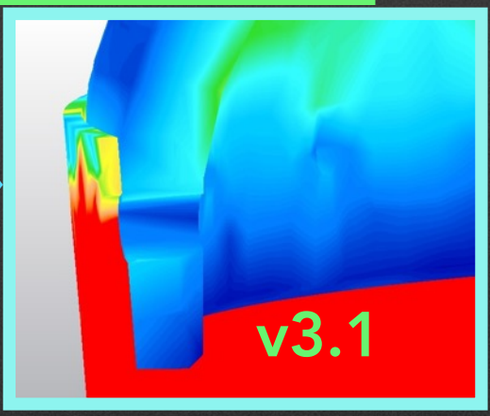

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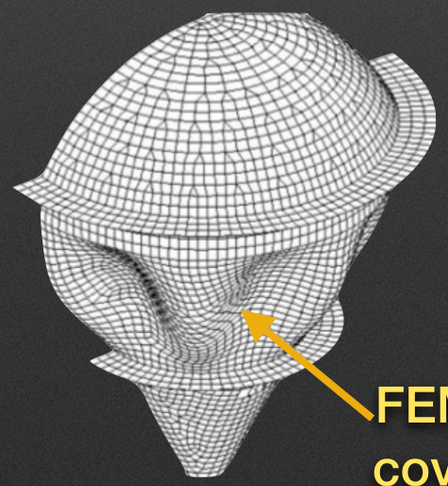
- Main industry subcontractors and collaborators:
  - Mitsui Co.
  - Hamamatsu
  - Nippon Marine Enterprises Ltd.
  - Kuraray Co.
  - Talleres Aratz S.A.
  - Evonik Italy S.p.A.
  - Liras S.p.A.



FEM testing of “Japanese SUS” cover at ~1.3 MPa (beyond req.)

Live testing: implosion tests

- The refined prototypes of all designs, after hydrostatic testing, passed final acceptance tests in realistic conditions

- **Ex-Japanese Microgravity Center (JAMIC)** facilities in Kami-Sunagawa (Hokkaido, Japan) provide a controlled, stable 12ºC environment at various pressures in a flooded 700-meter (!) shaft.

- **Baseline "Japanese SUS"** cover design fully certified for HK use (≤80 m).
  -Moving from prototype to mass production:
  polishing details like areas of tension in acrylic-to-stainless flanged interface (cracks), cost reduction…

- Prototype "Japanese resin" cover design tested successfully for ≤40 m use.
  - Need strengthening for deeper areas. More testing for final certification at shallow depth.
  - Cost reductions?

- Prototype v2.2 "Spanish SUS" cover design teste successfully for ≤60 m use.
  - Need more implosion tests and depths for certification.
  - Baselined flanged variant for use in HK. Now repeating tests for flangeless variant (**v3, see next slide**).
  - Aiming to fully certify (<80 m) both versions in early JFY'20 — then downselect to best performance+cost.

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Bare cover buildup
(v2.2 Spanish)

Dummy PMT + acrylic + support hw
Strain & pressure gauges

Full cover + witness dummy PMTs
on support truss + instrumentation

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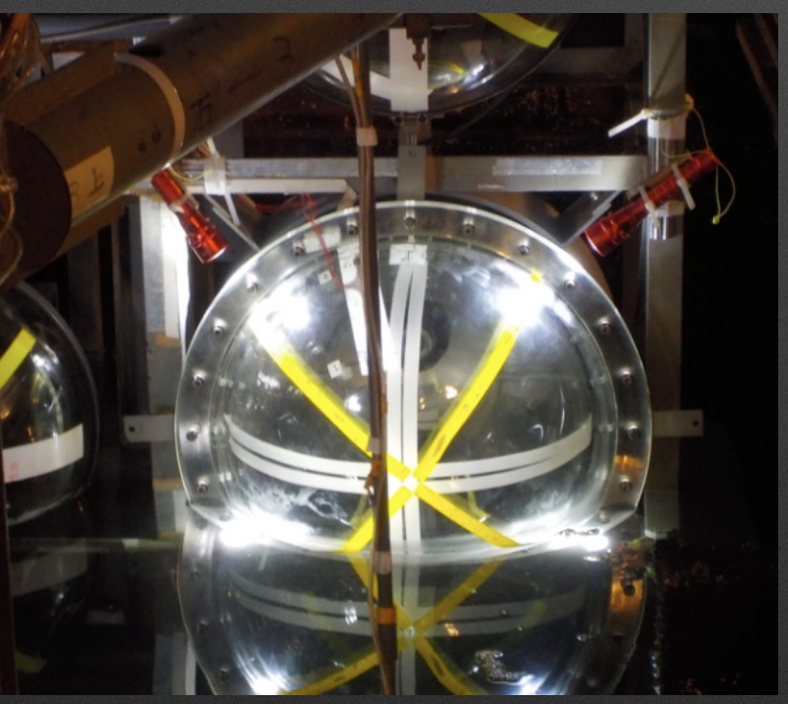
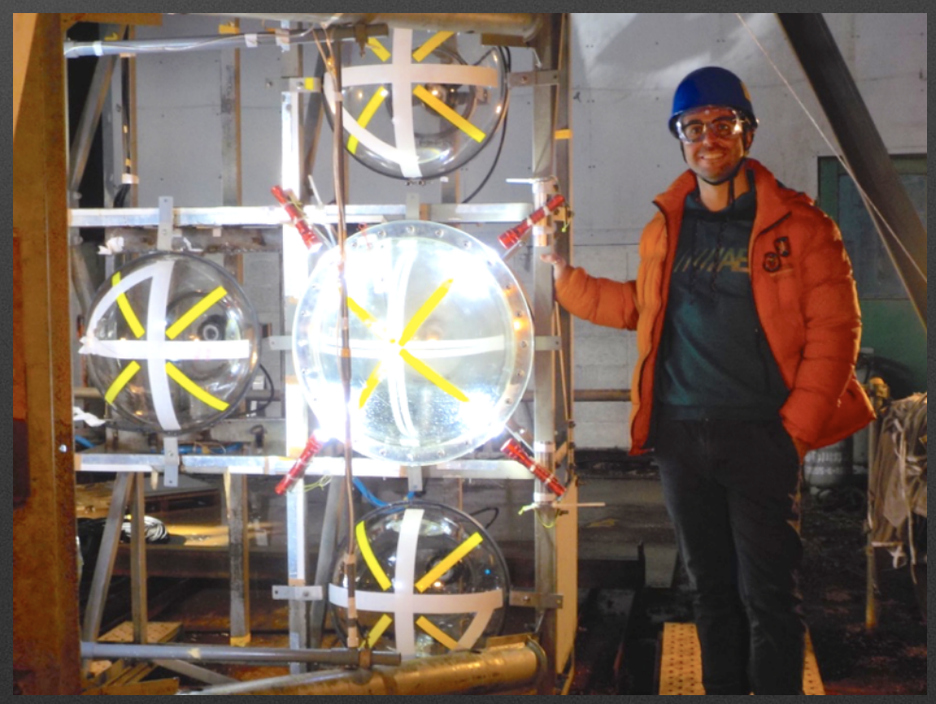


Immersion & implosion (video?)

Retrieval of surviving items (all)



Cleanup, inspection and analysis

Live testing: implosion tests

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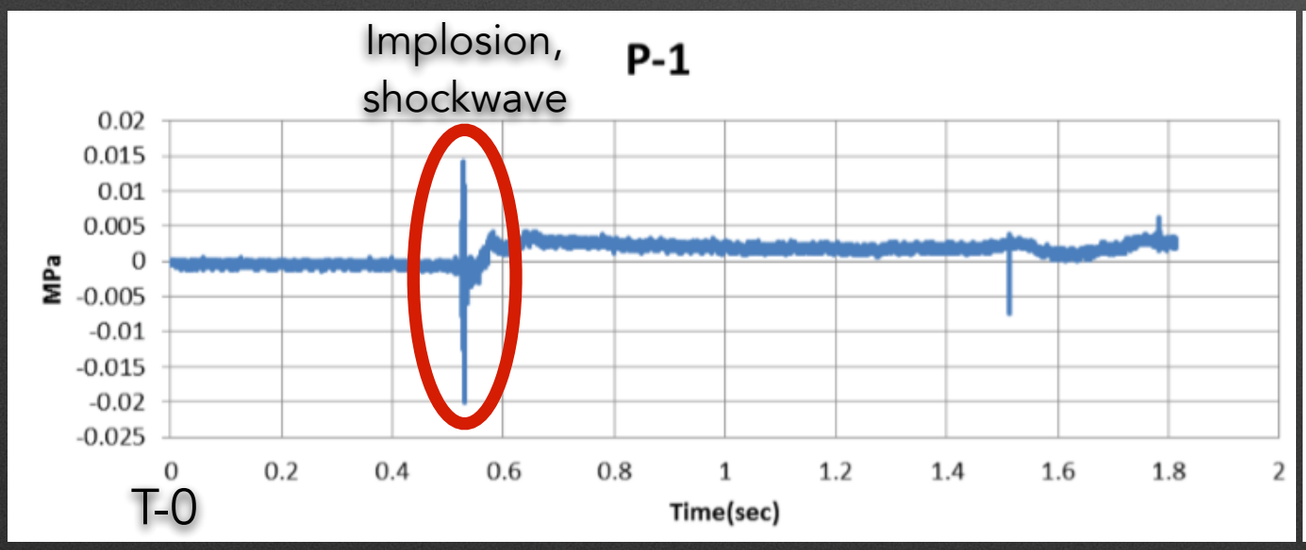
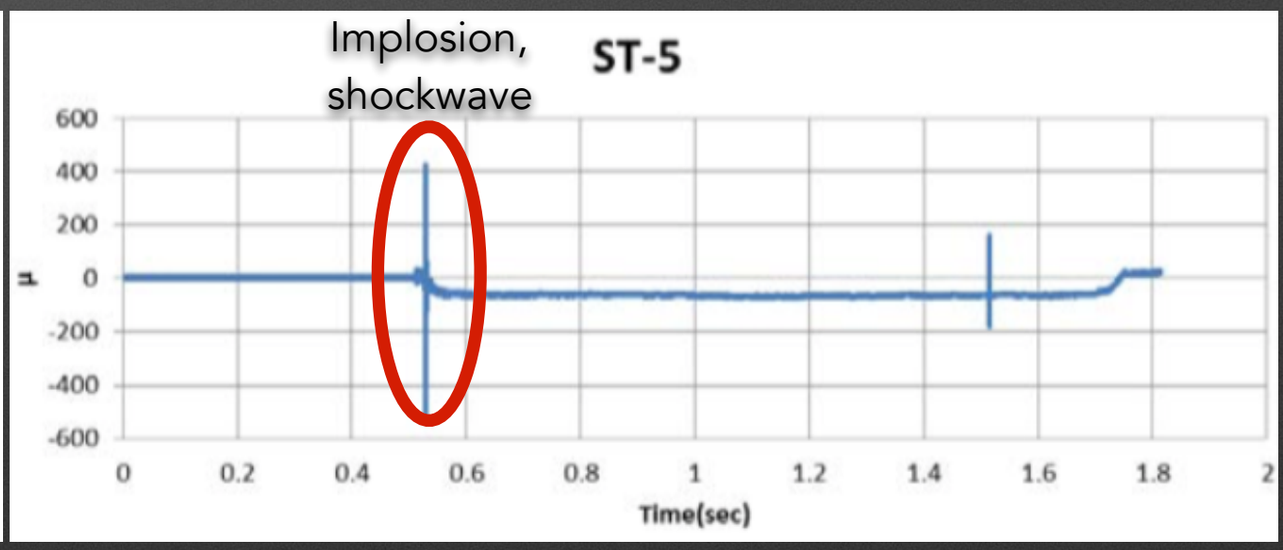


(break trigger)

Good shockwave produced inside Spanish v2.2 cover
Good attenuation outside
(bare implosion ~5 MPa amplitude; registered <1%)



Sample strain on Spanish v2.2 cover body

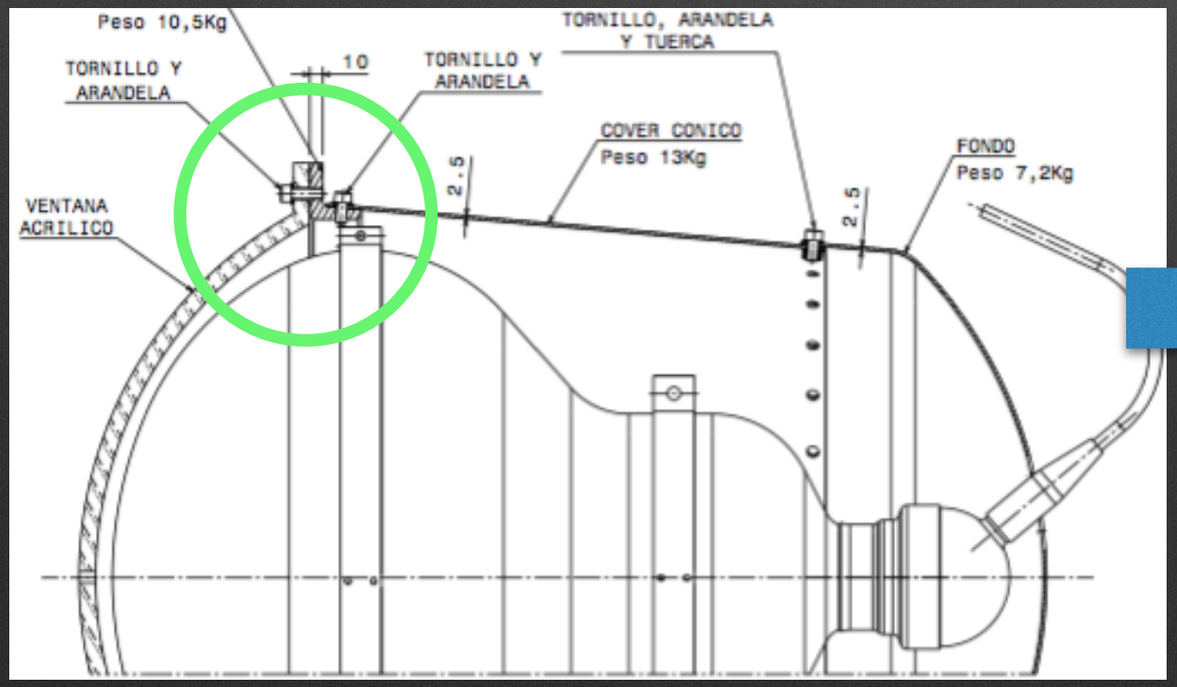
New developments: v3

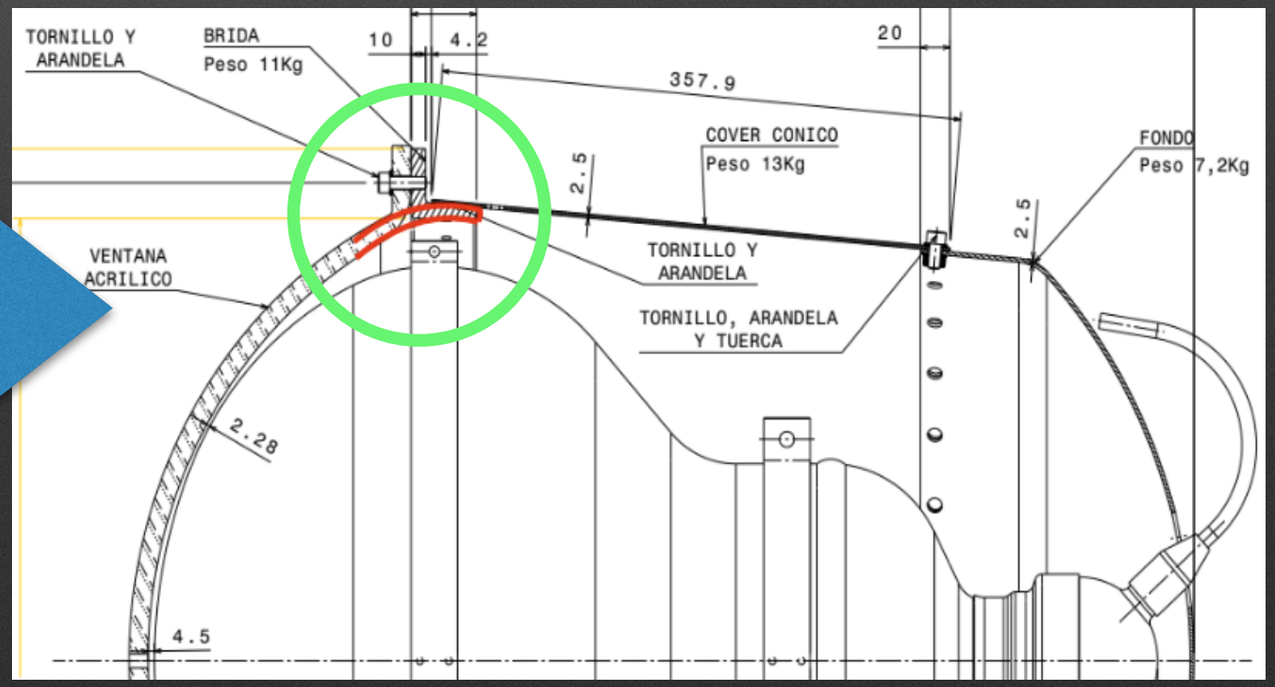
- "Spanish" cover prototypes conceived as "***battleship***" units from the start.
  Optimization expected: both in weight (~32 kg —> ≤20 kg) and cost (~100€/unit?)

- Combine acrylic's elasticity + pressure tolerance to steel's sturdiness + traction resilience?

- **Largest strains** at **bottom** steel pieces — NOT at window edge. Room for improvement?

- **Flangeless** cover version: **v3**
  - √ **Removes flat flange** interface (10 kg, 1/3rd of cost)
  - √ **Direct wall-to-acrylic** interface (possibly riveted)
  - √ **Retains body+bottom steel** pieces (commonality with the baselined & tested, flanged v2.2), including areas of highest stresses.
  - √ Considered acrylic-over-steel (v3.0), but further study leaned us toward **steel-over-acrylic** (v3.1).





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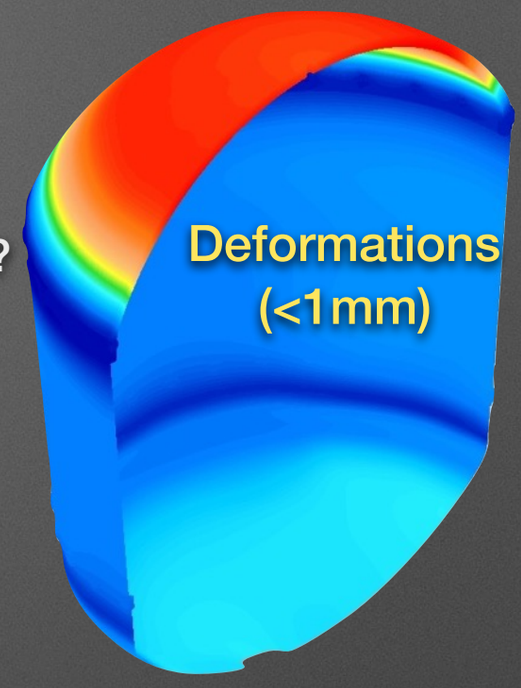
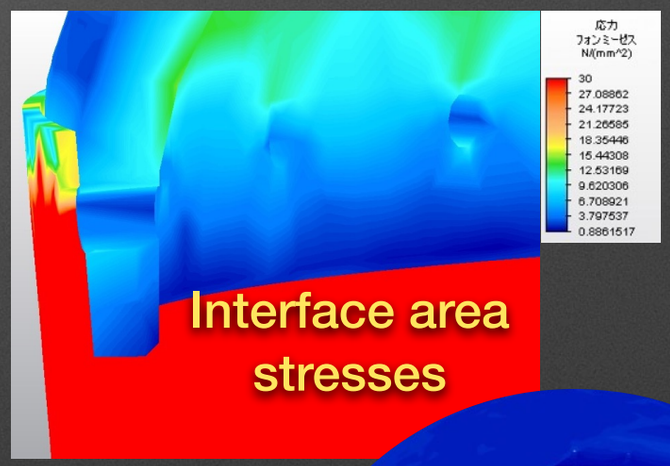
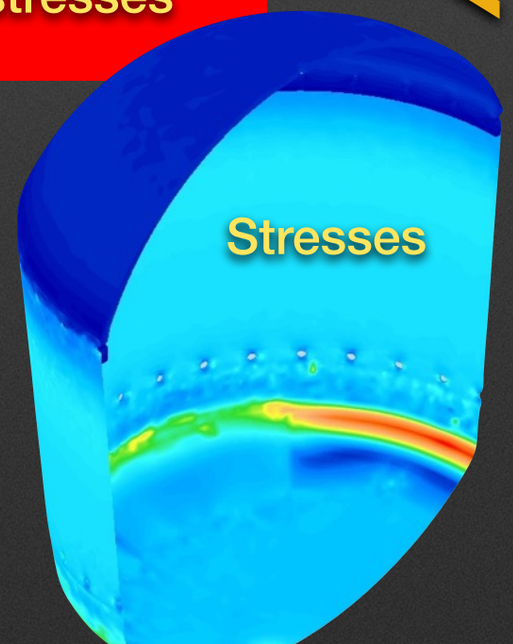
- ***Very preliminary*** FEM testing shows expected performance (modified v2-v3 interface region = low criticality area in stresses).

- **First prototypes fabricated**, into assembly and initial testing:
  v2.2 bodies (minus ring flange), brand new acrylic and joint hardware.

- **More delicate interface** design:
  - very tight tolerances (+0%, or won't fit!)
  - machined "lip" (thinner, source of manufacturing weaknesses? trying annealing after machining)
  - no bolt tightening once assembled (need rivets or other solution)
  - extra height needed at fabrication can lead to too much thinning at apex (new manufacturing technique: thermoforming vs feedback pressure air blowing)







PRELIMINARY

Timeline and outlook

- Hyper-Kamiokande will be in the forefront of the neutrino oscillations, astroparticle physics and nucleon decay research, thanks to its unprecedented size, resolution and sensitivity.

- Photodetector system leads these improvements — but also needs protection against itself: need to arrest any possible shockwave. Strict quality control + protective PMT covers.

- **Three main cover designs** under advanced R&D and prototype testing. Possibility to use one, several or all together.

- High-performance, low cost stainless steel cover (now in third main iteration, “v3.1”) as Spanish contribution (UAM, LSC, contractors).

- **Close to cover mass production** initiation (~2020), well into prototype testing (>3 years of detailed, extensive testing).

- **On track for late 2027 HK DAQ start**!

HK proto-Collaboration (and myself) thank you for your attention.

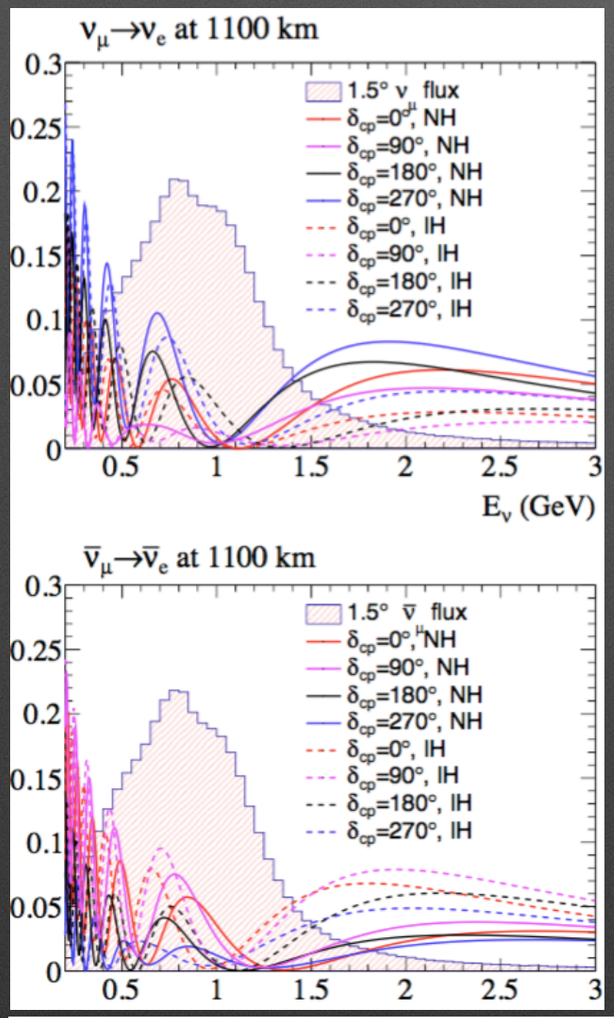
Hyper-Kamiokande Let's enjoy LomCon'19 !

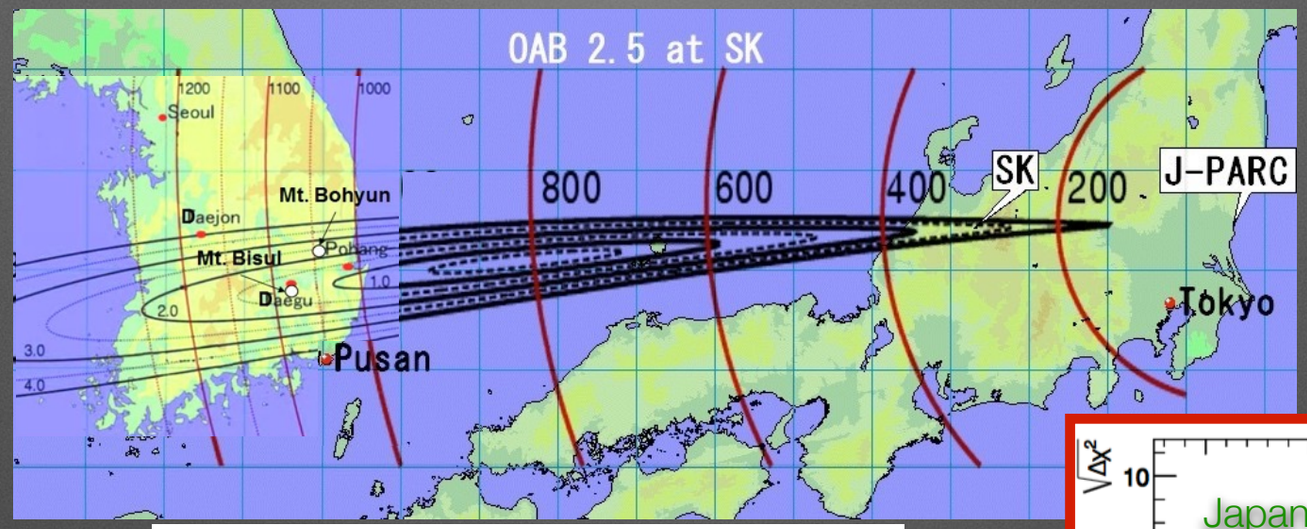
Questions, comments?
New collaborators?

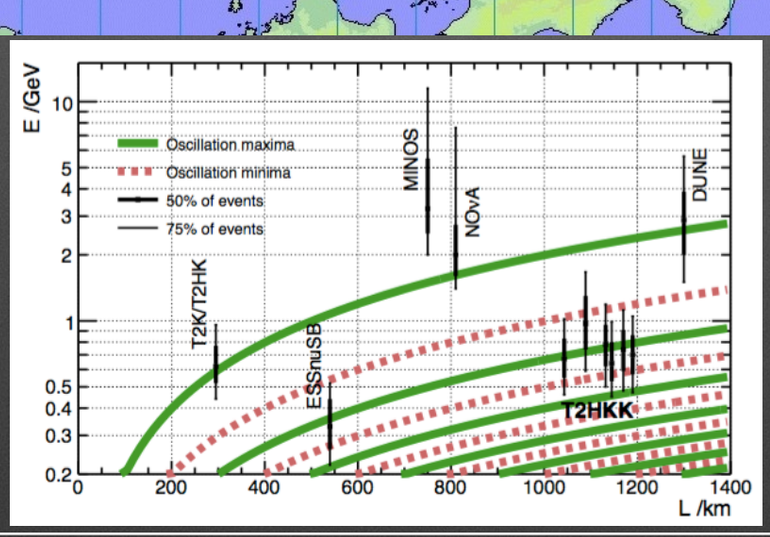
Even more  Hyper-Kamiokande ?

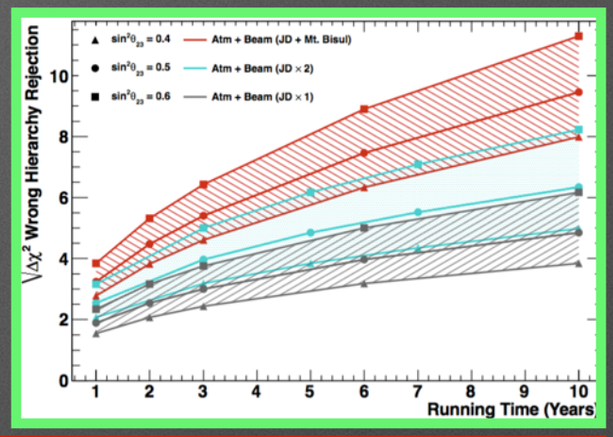
Backup slides

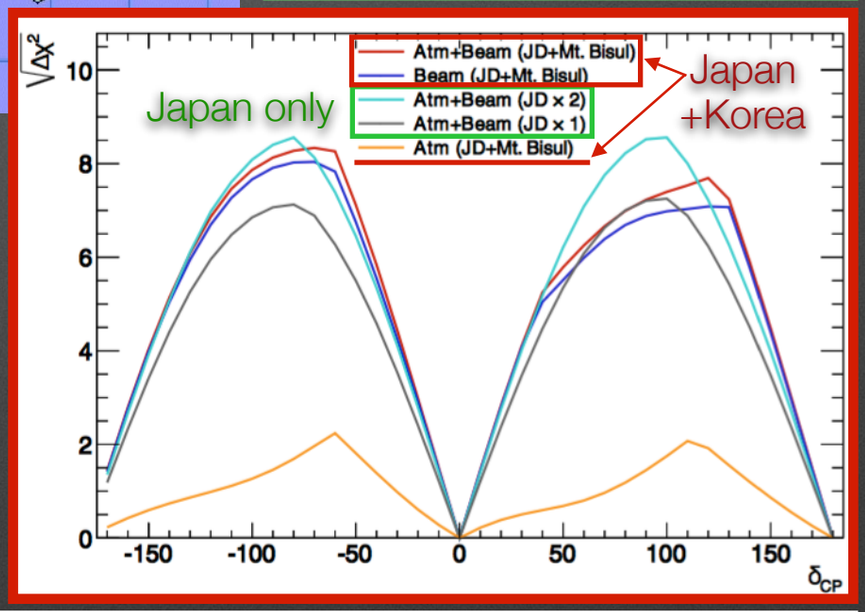
HK-Korea and sensitivity reports











Sensitivity reports

Letter of Intent - arXiv:1109.3262

HK LBN - Prog. Theor. Exp. Phys. 053C02 (2015)

HK Design Report - arXiv:1805.04163 (public: May 9th'18)

Option for 2nd tank in Korea (HKK) - arXiv:1611.06118