TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Multi-PMT system for E61 and HK

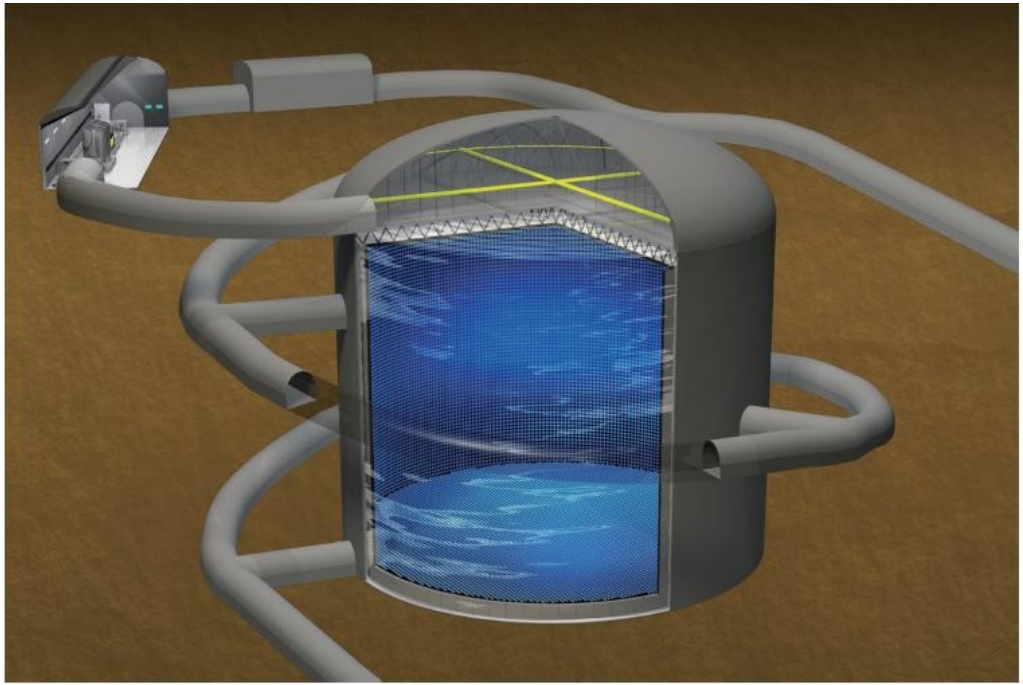
Mark Scott

Neptune Workshop

20th July 2018

Hyper-Kamiokande

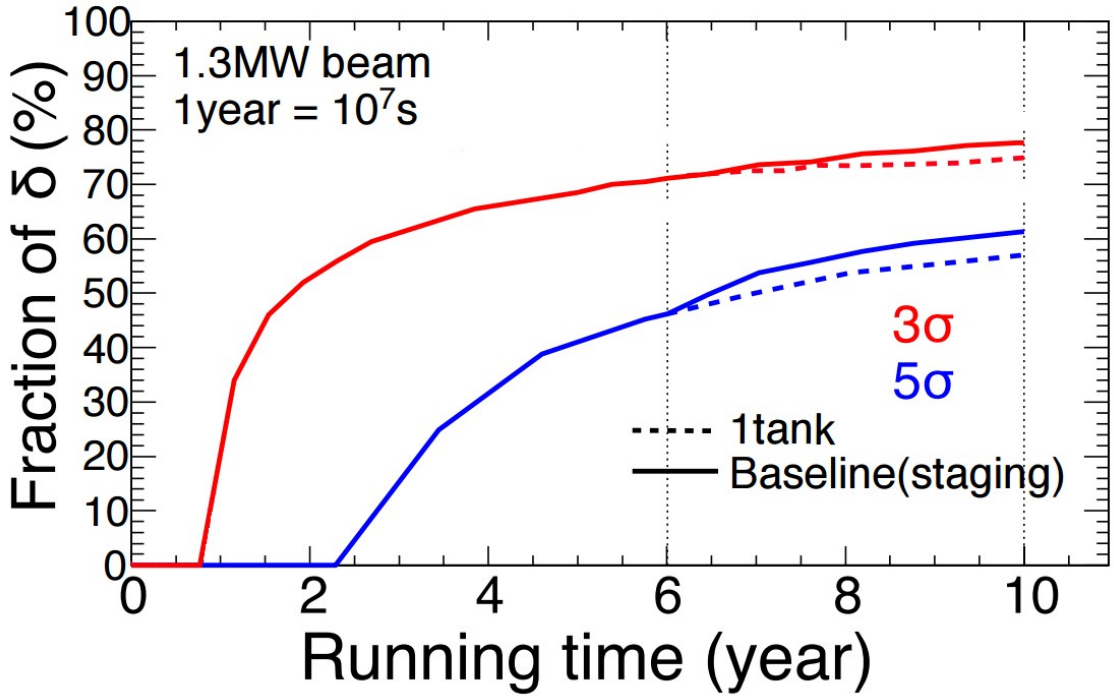
- Next generation neutrino oscillation experiment
- Upgrade of Super-Kamiokande – increased fiducial volume by factor ~8



Hyper-Kamiokande

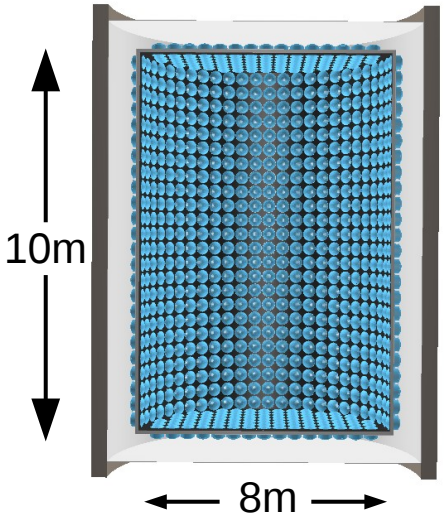
- Next generation neutrino oscillation experiment
- Upgrade of Super-Kamiokande – increased fiducial volume by factor ~8

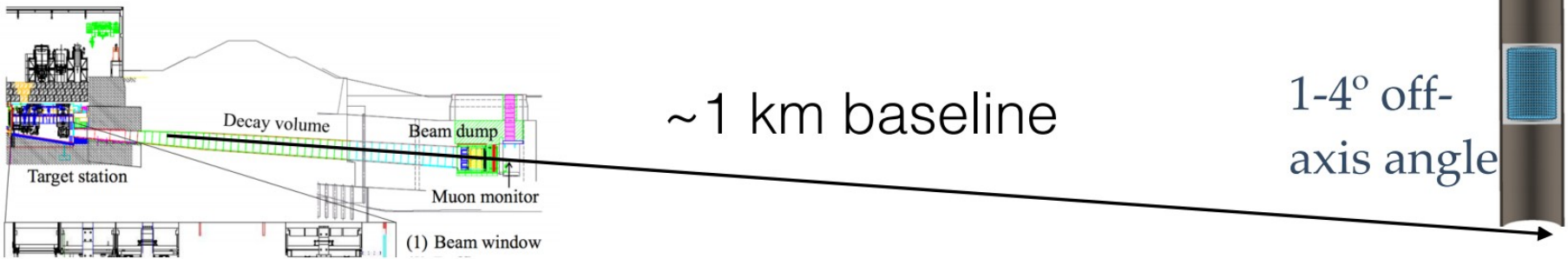
- Physics goals:
  - 5σ discovery of CP violation over 60% of values of δ_{CP}
  - Proton decay searches
  - Atmospheric + solar neutrinos



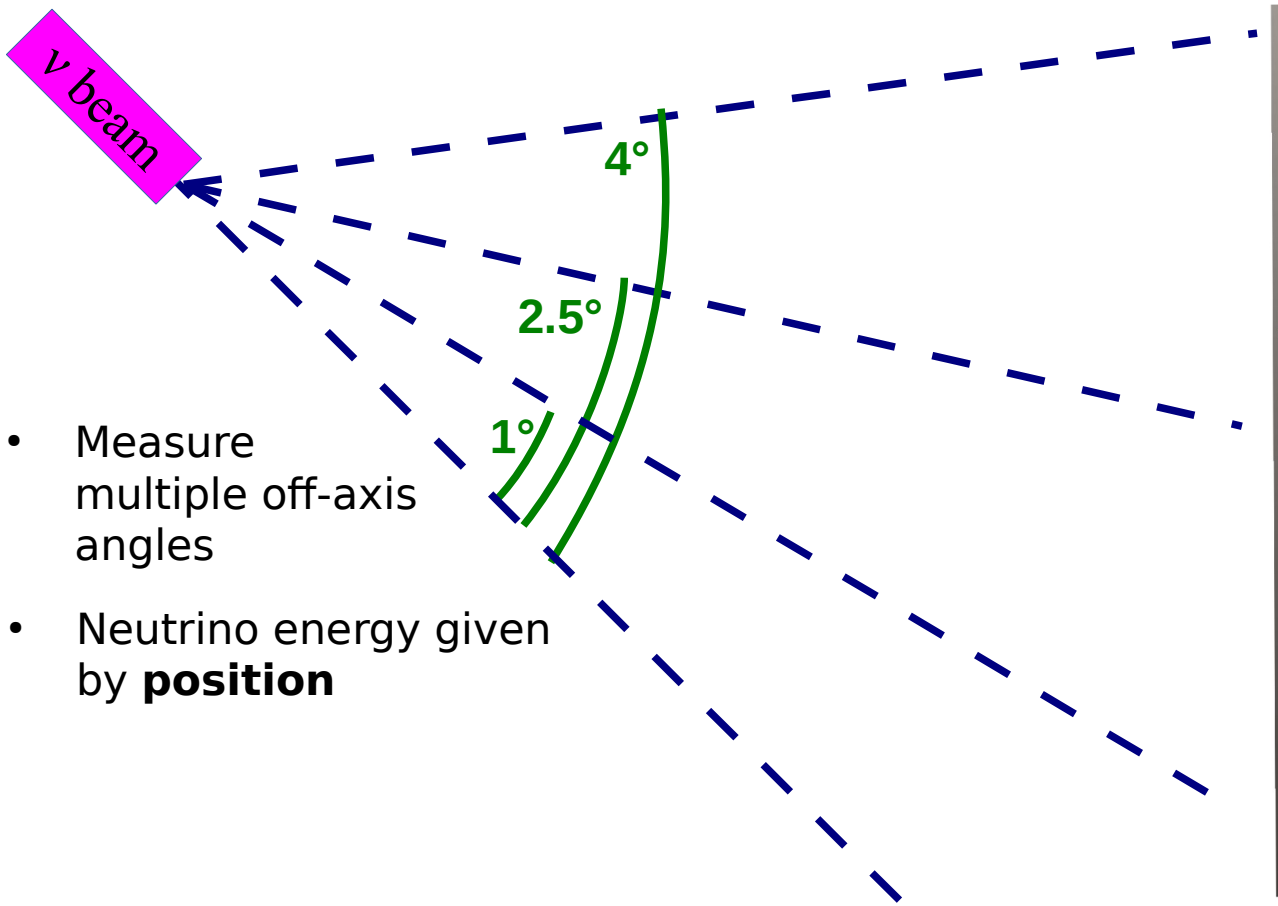
E61 (NuPRISM) detector

- Hyper-Kamiokande limited by systematics, not neutrino statistics
- E61 intermediate detector:
  - Kilo-ton scale water Cherenkov detector
  - Located ~1km from neutrino production point
  - Same technology as far detector
    - Increased cancellation of systematics
  - Measure neutrino beam at different off-axis angles

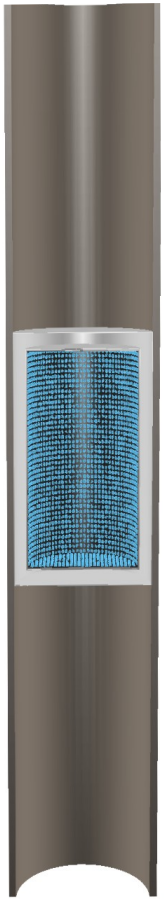


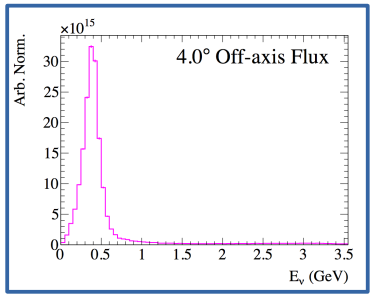


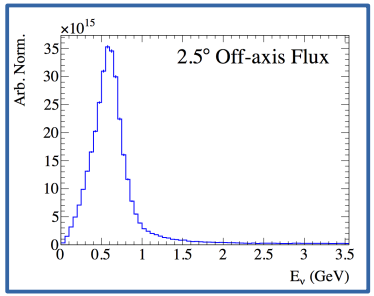
E61 concept

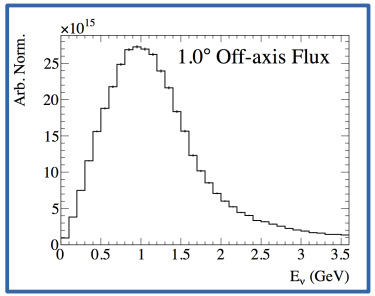


- Measure multiple off-axis angles
- Neutrino energy given by **position**









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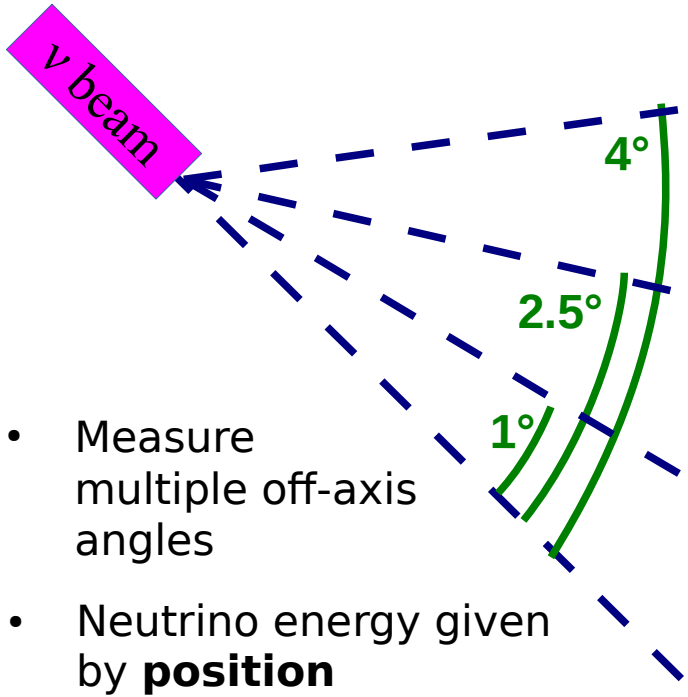
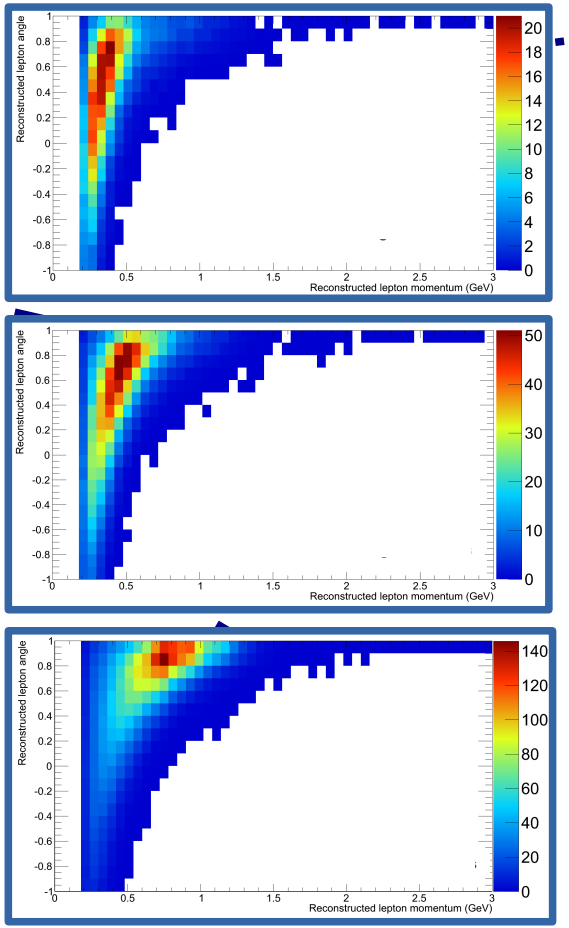
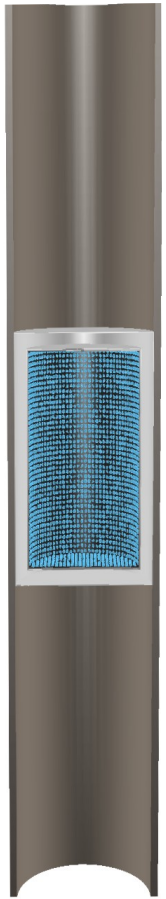
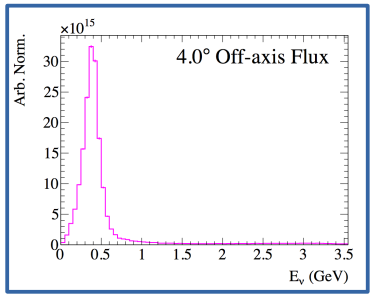
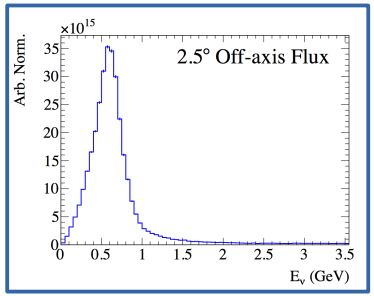


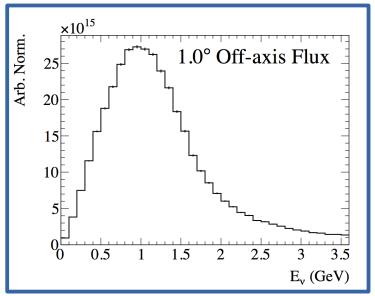
- Measure multiple off-axis angles
- Neutrino energy given by **position**
- Measure relationship between neutrino energy and lepton kinematics



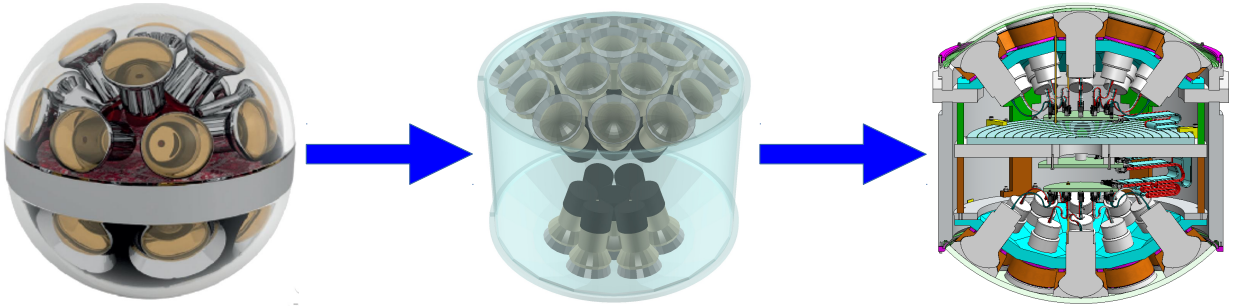


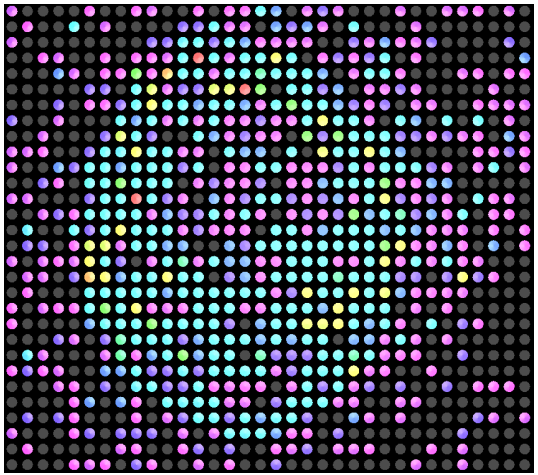


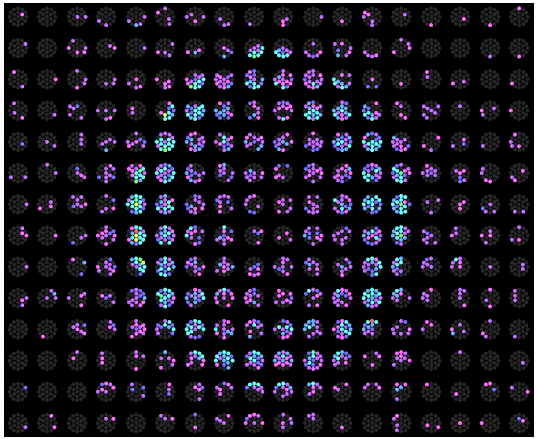




Multi-PMTs for E61 and HK



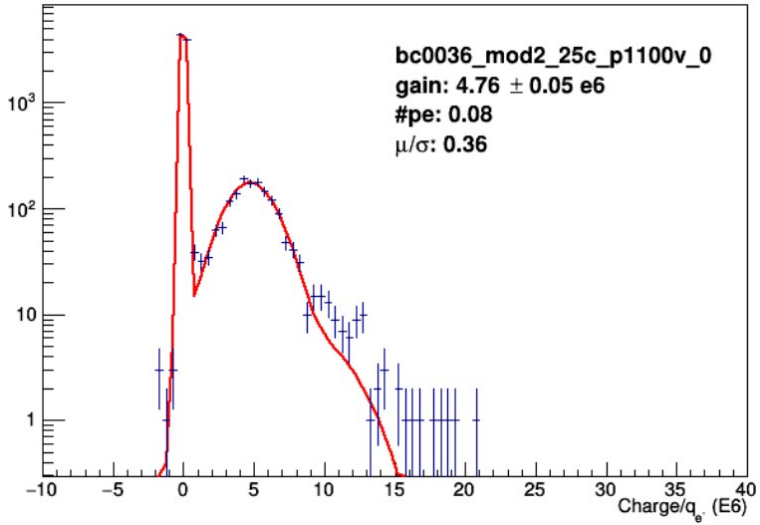


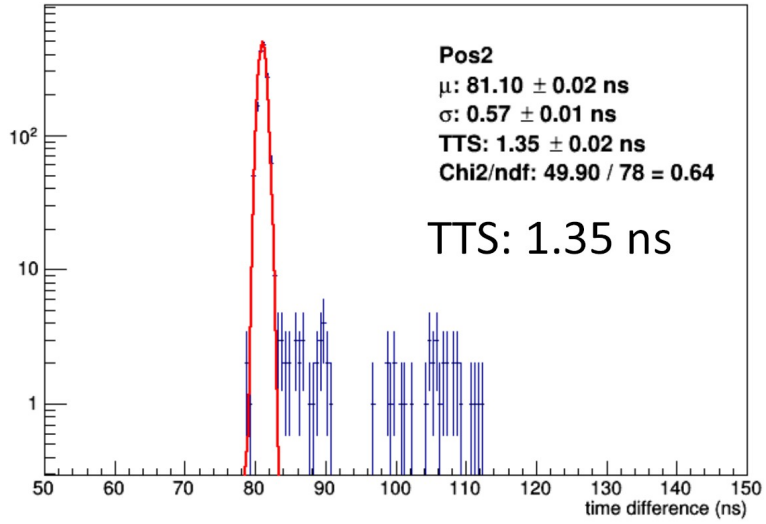


- Ongoing development in Italy (A. Ruggeri yesterday) and Canada for E61 and Hyper-Kamiokande (HK)
  - Started from KM3NeT concept
  - Will instrument E61, may make up some fraction of the HK photosensors
- Trade photo-coverage for finer granularity + improved PMT performance
  - Event displays show electron neutrino event comparing 8” PMTs (top) to mPMTs (bottom)

Improved 3” PMTs

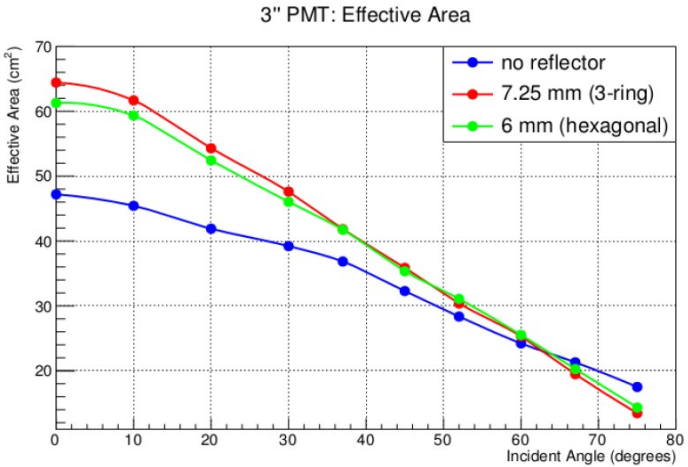
- Improved performance 3” PMTs from Hamamatsu and HZC
  - Talk by M. Ziembicki yesterday
- Reduced transit time spread by >1ns
  - FWHM <1.5ns for Hamamatsu PMTs

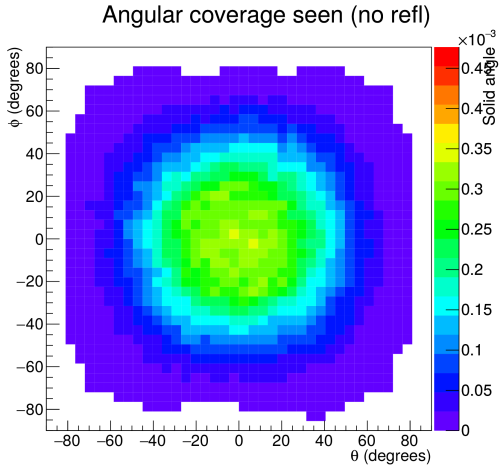


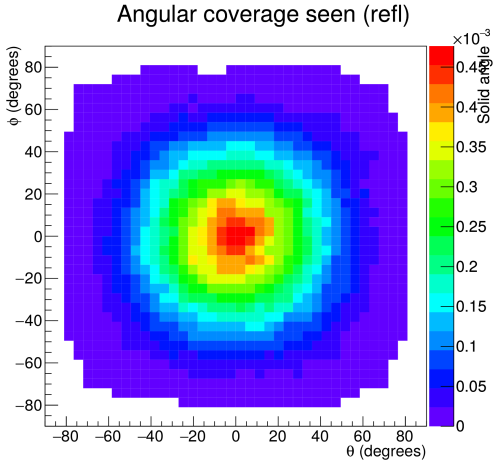


mPMT directionality

- Silver coated aluminium reflector surrounds 3” PMT
  - Angled at 40° to plane parallel to cathode
  - Increases effective area of each PMT by ~25%
  - 'Focuses' PMT towards forward direction
  - Effect scales with width of reflector
- Improved performance through:
  - Reduced combinatorial noise
  - Directional information for reconstruction
    - Optimisation ongoing

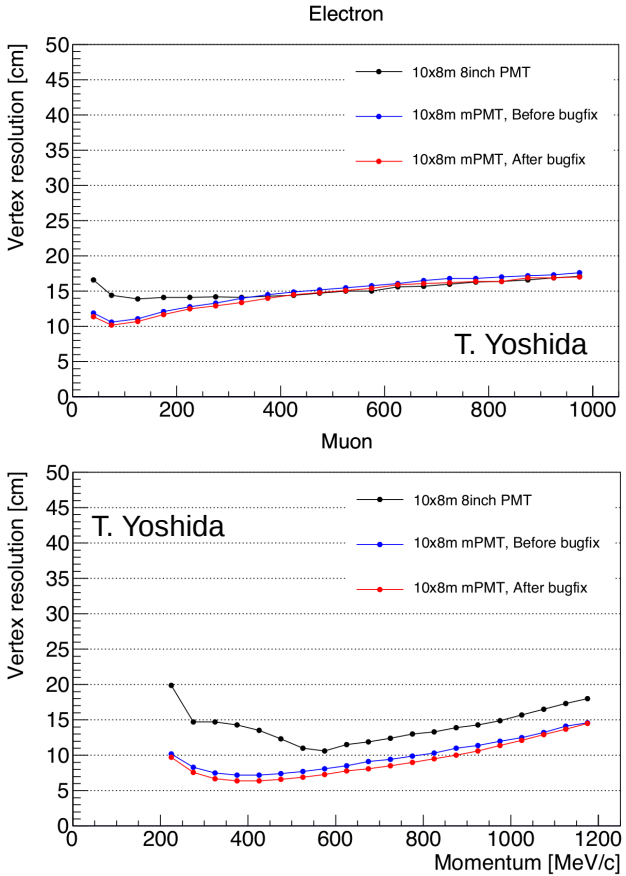






mPMT performance

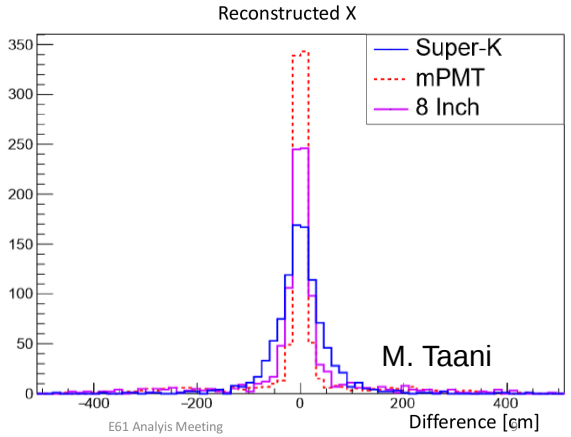
- Studied using E61 detector simulation and reconstruction algorithms
  - mPMT configuration: 832 modules over 10.4m x 7.4m tank, with an effective coverage of ~24%
  - 8” PMT: 40% coverage 10m x 8m tank
- Plots show vertex resolution for muons (top) and electrons (bottom)
  - Compare red line (mPMT) to black (8” PMT)
  - Improved performance for mPMT compared to 8” PMT
    - See talks by B. Quilain and T. Yoshida for more details

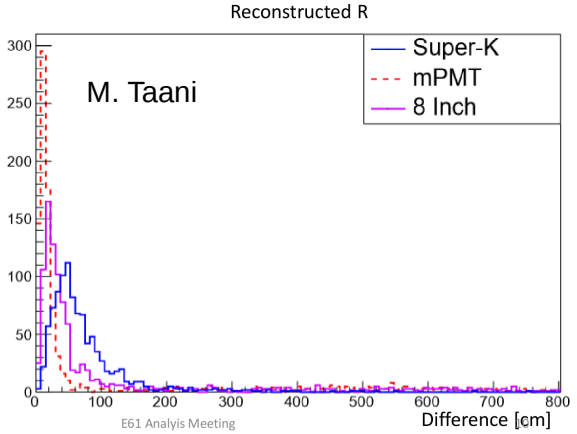


mPMT performance – low energy

- Work at Univ. of Edinburgh using BONSAI algorithm
  - Same mPMT configuration as fiTQun tuning
  - 10 MeV electrons, isotropic and uniform across tank, 1m from walls
  - Nominal BONSAI algorithm, based on timing information only, no directionality
- *Both fiTQun and BONSAI do not use full information from mPMT → Reconstruction performance will improve*

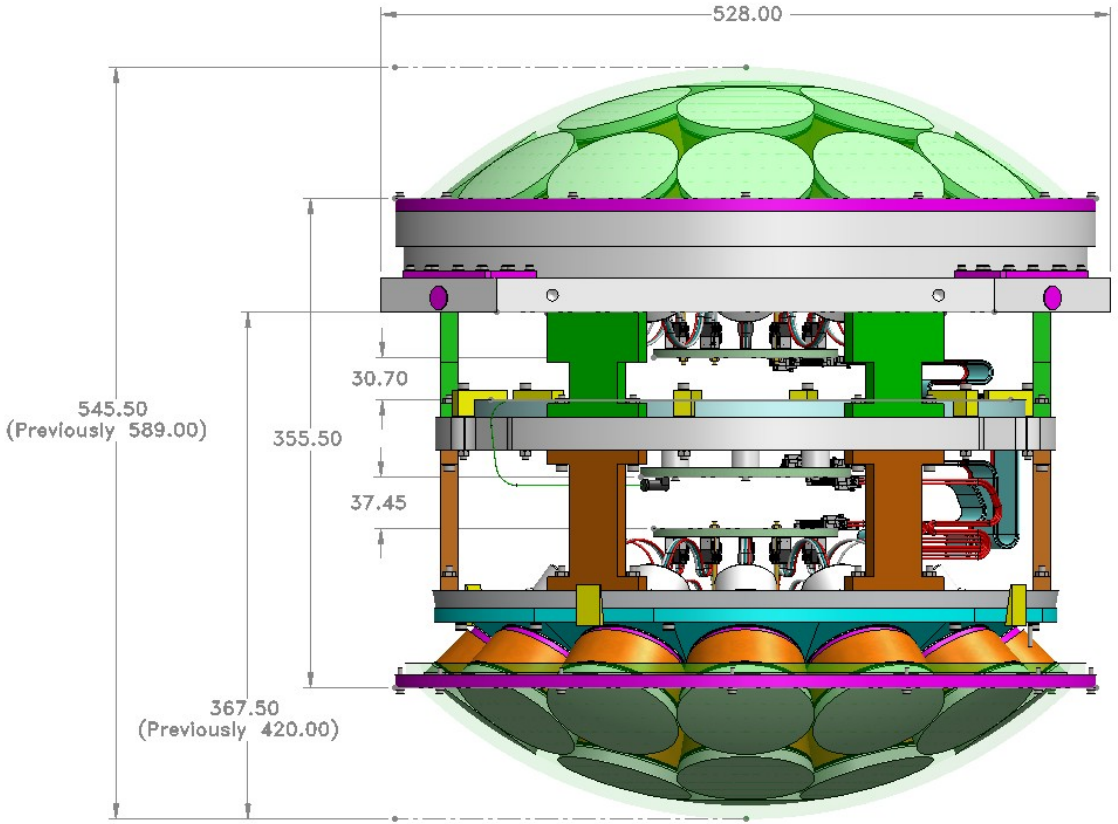
Detector	Coverage [%]	Num PMTS	Resolution [cm]
SK	40	10994	76
mPMT	25	15808	28
8 Inch	40	3888	60
3 Inch	25	16052	26



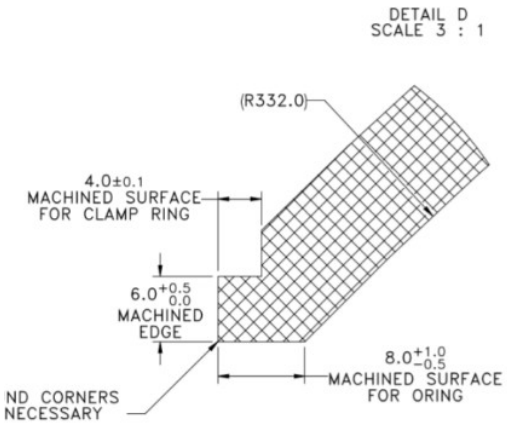


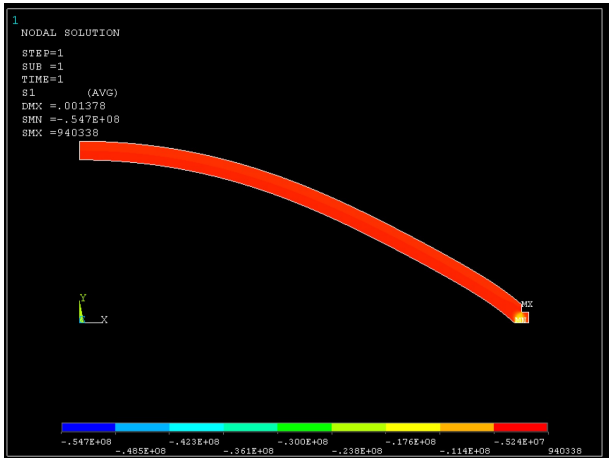
Canadian mPMT design

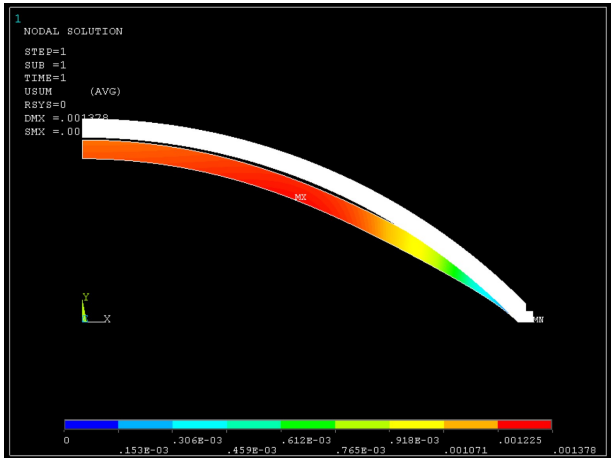
- Modular design – view to mass production
  - Aluminium outer structure
  - Inner support frame / heat transfer
  - Optional scintillator disc
  - 3” PMT sub-assemblies + support
  - Acrylic dome
  - Motherboard + daughter boards



Acrylic dome design and FEA



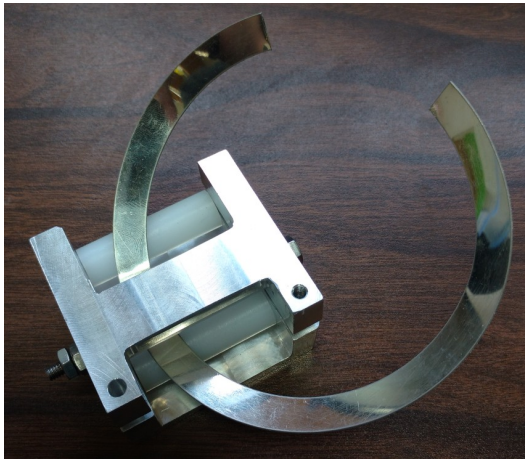




- Designed with machined surface for clamp ring
- FEA analysis assuming 8 atm. external pressure and vacuum internally
- Maximum stress of 0.94 Mpa and max displacement of 1.378mm
  - Stress concentrated on inner corner, must ensure retaining wall supports edge of dome
  - Clamping force has negligible effect on stress
  - All looks good!

Reflectors and acrylic domes

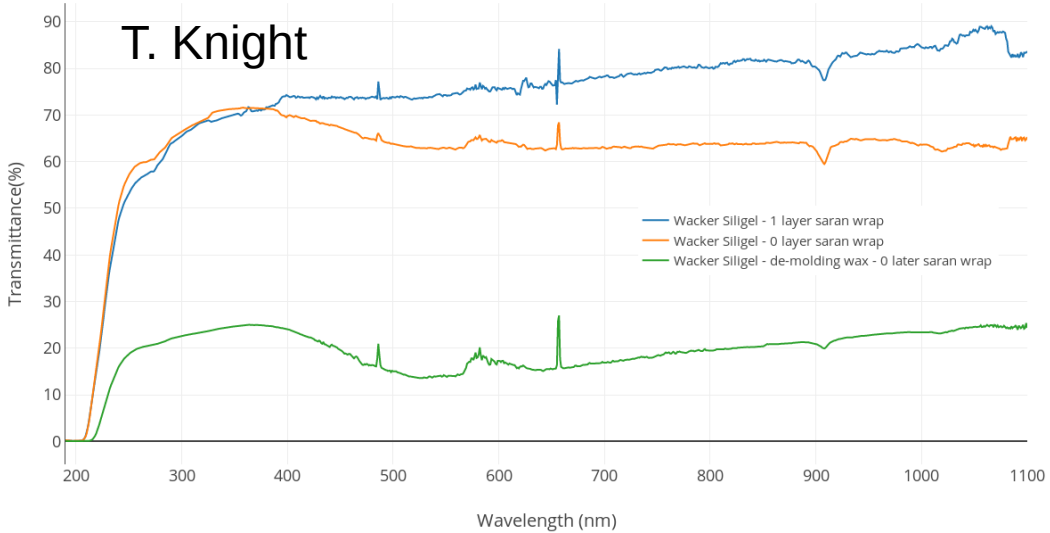
- 20” diameter acrylic dome sourced from Italian company (Liras + Evonik acrylic)
  - 12mm thick initially, 10mm final thickness at dome centre
  - Uniform radius of curvature – expected accuracy of 0.1mm
- First domes arrived last week – currently measuring to confirm accuracy

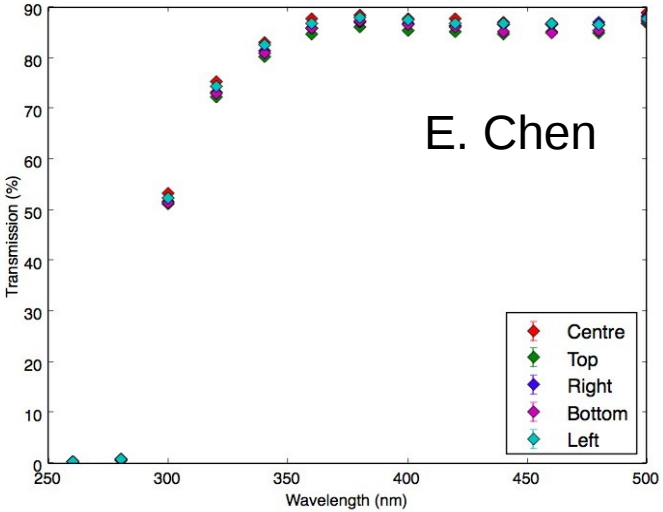


- Waterjet cutting of Anomet MIRO Silver reflector
  - Degrades surface, CNC machining for large scale
- Roller based on KM3NeT design
  - Affects surface finish of reflector
  - Works reasonably – few minutes per reflector

Optical gel studies

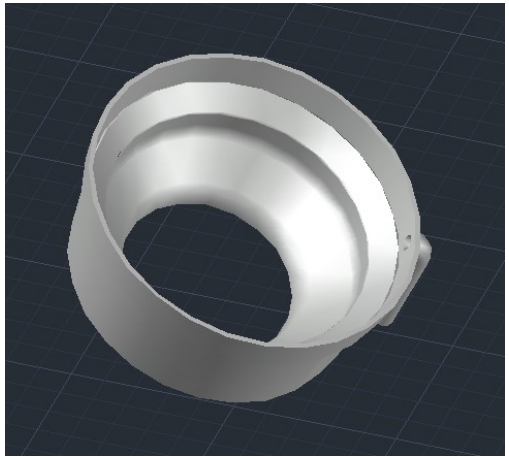
- Tested different optical gel compounds – Wacker SilGel 612 (KM3NeT), Elastosil 604 and Elastosil 601, Momentive RTV 615 (cured in 7 days – not suitable), Shin-Etsu gels
- Shin-Etsu gel – one very soft, other too hard, slight yellow colour, ongoing development with company
- Wacker 601/604 de-mould well but cure too hard – not enough compression
- Wacker 612 transmits down to 250nm, uniform over puck, good mechanical properties





Optical gel casting

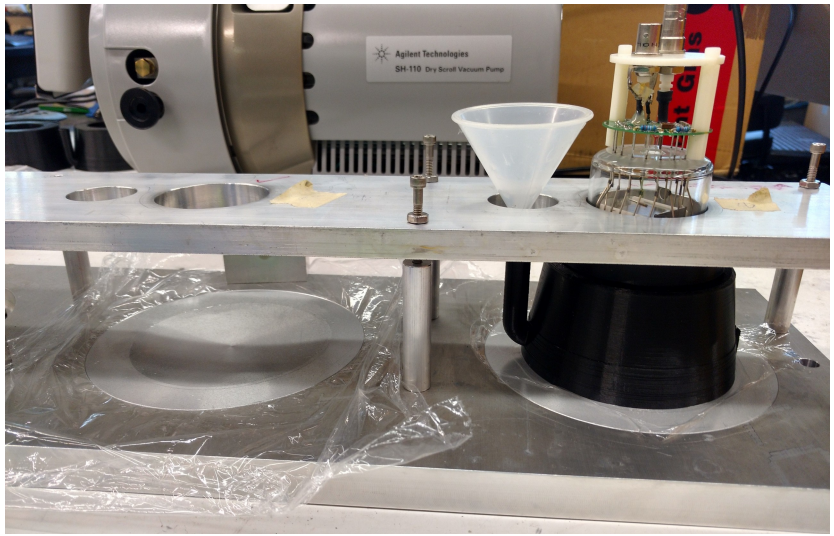
- Developed molding process for gel pucks
  - 3D print PMT holder with thin lip and spout
  - Lip fits over porous aluminium disk machined to the correct curvature
  - Holder (with PMT + reflector) and acrylic clamped together, fill with activated gel
  - Peel lip/spout from PMT holder



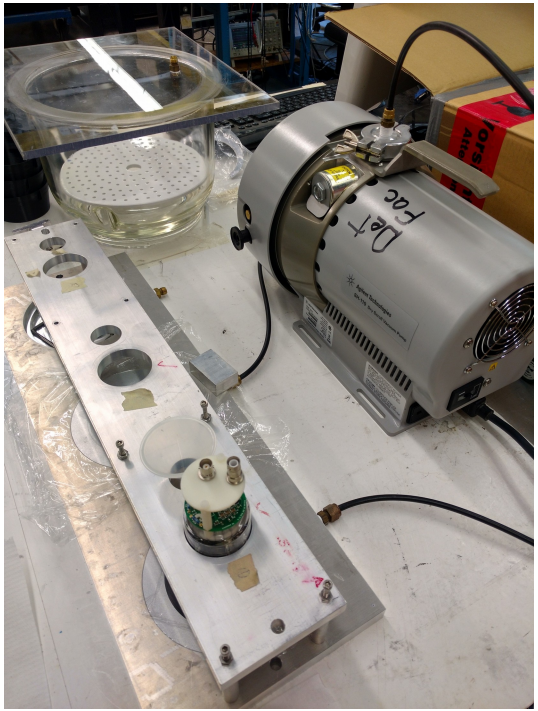
3” PMT sub-assembly

PMT holder + reflector with clamp ring

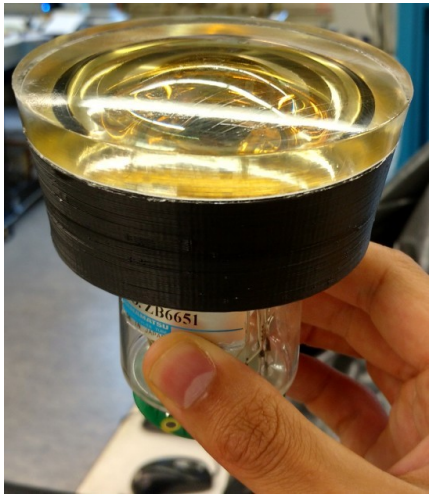
Holder + PMT in gel casting jig



Vacuum applied to hold plastic wrap onto casting surface

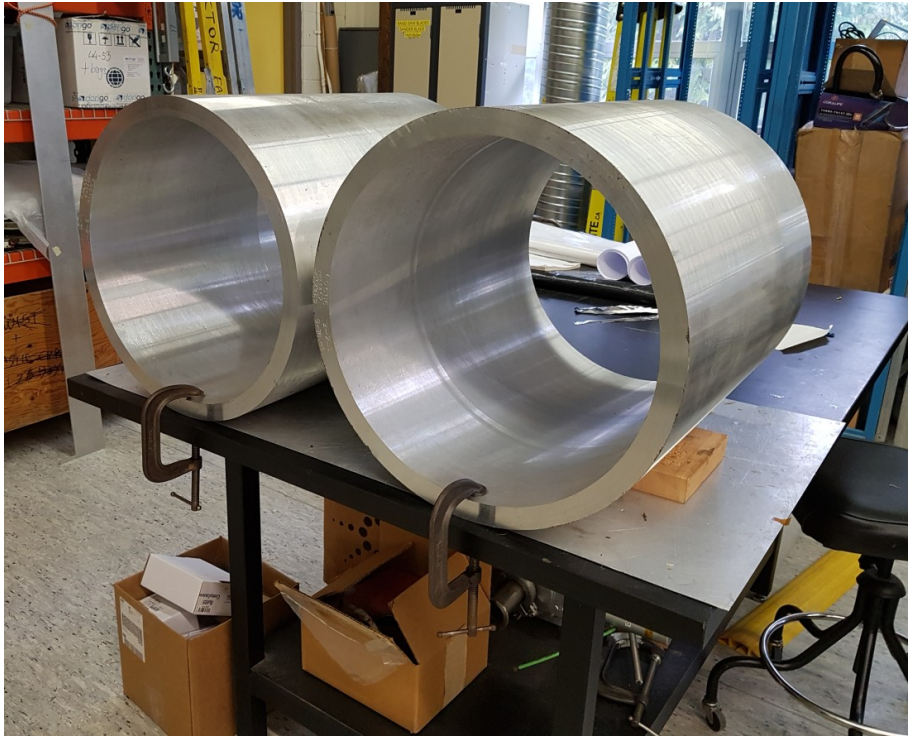


Final PMT sub-assembly



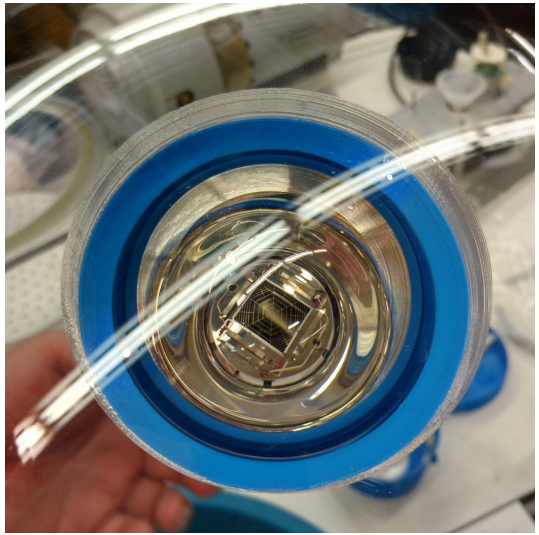
3D support and aluminium

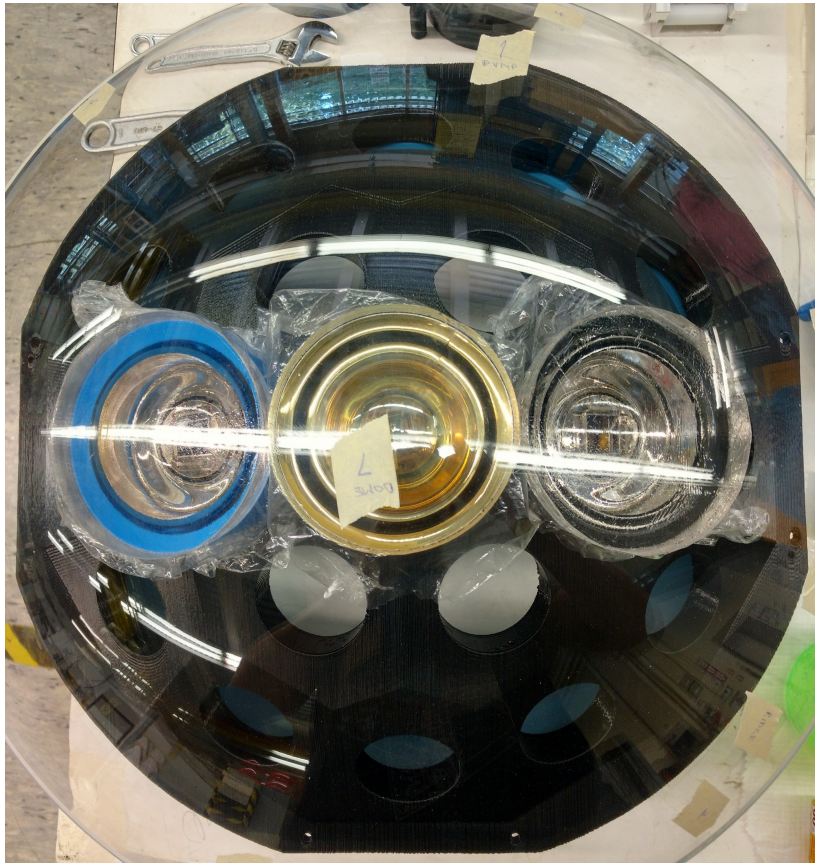
- 3D printed support produced (working with AON3D) – injection mold for mass production
- Aluminium cylinders for mPMT body – 20” diameter, machining underway to create pressure vessel



TRIUMF mPMT prototype

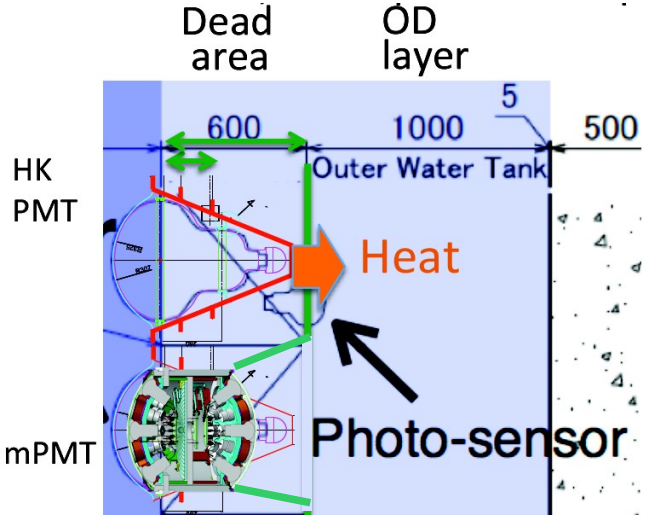
- Fifteen 3” PMTs (R12099) from KM3NeT at TRIUMF
  - Including readout boards from University of Alberta
- Timeline:
  - Molding of optical gel pucks started
  - Aluminium cylinder machining started
  - Assembly beginning next week
  - First operation in early August!

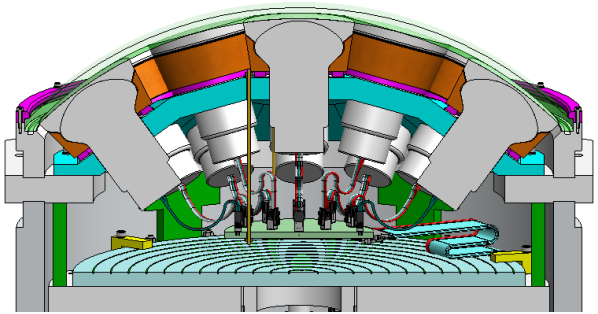




Updating the design

- 20” PMTs protrude by 60cm into outer detector (OD), mPMTs protrude by < 40cm
  - Reflective sheet separates OD from dead region
- Weight – 20” PMT with cover has a mass of ~40kg, mPMT is currently ~80kg
- OD PMTs are not essential to mPMT design – could remove one side of detector
  - No issues with OD sheet
  - Reduced mass
  - Simpler cable penetrator
  - Cheaper
  - More compact for E61
    - Offset OD PMTs, readout through mPMT electronics





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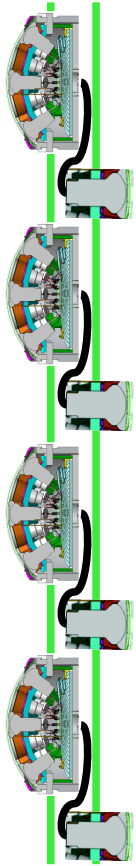
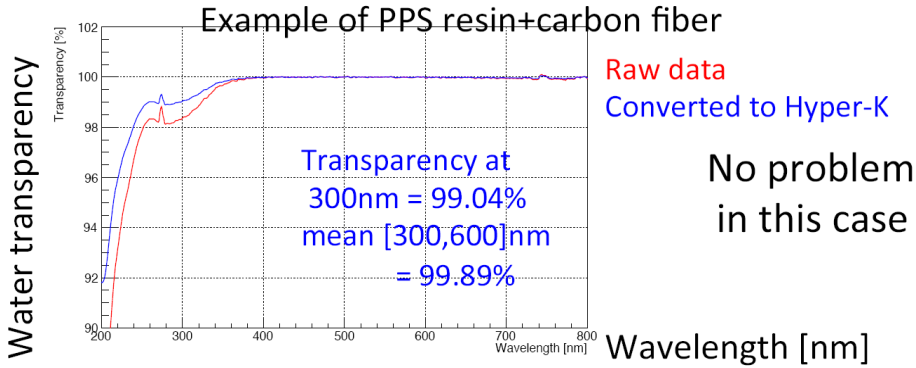


Pressure vessel material

- Anodised aluminium in SK observed to 'rust'
  - White powder covered light injector window
- Using aluminium may not be acceptable for HK



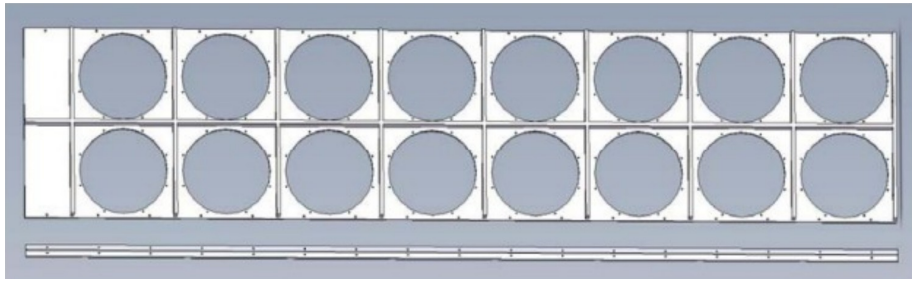
- Polyphenylene sulfide (PPS) will be used for 20” PMT covers
  - Compatibility test already performed
- Strong, light, cheap
- Injection molding possible, including internal support
- TRIUMF engineers working on PPS design
- Prototypes will be made at TRIUMF for pressure testing

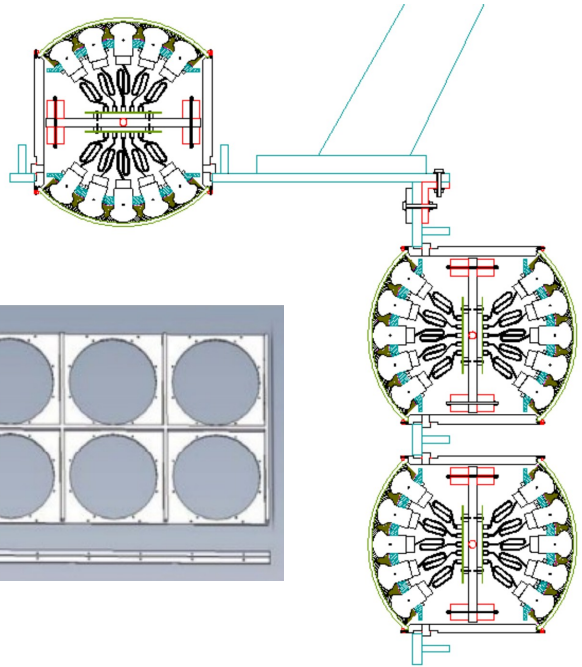
Summary

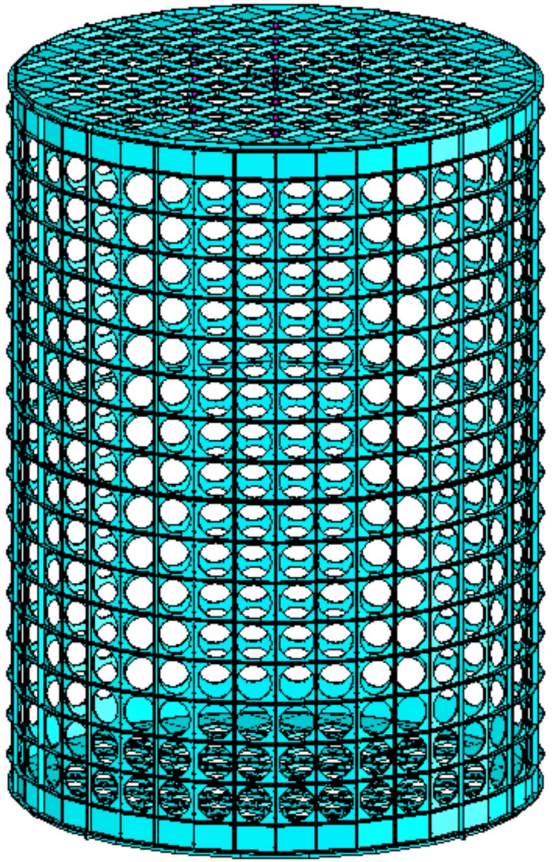
- mPMTs offer several benefits compared to 20” PMTs
  - Modular construction
  - Smaller PMTs
    - Improved timing resolution, lower dark noise, less magnetic field sensitivity, pressure tolerance
- Reconstruction studies show improvement with respect to 8” PMTs for the E61 detector
  - Optimisation of reflector design for physics underway
  - Studying impact of 5000 mPMTs on HK physics
- All components for first prototype are now at TRIUMF
  - Expect this will be finished in the next few weeks
  - Funding secured for second round of prototypes (electronics, pressure testing, PPS) in fall / 2019

mPMT installation

- Panels made of aluminium, 20” diameter holes for mPMTs
- Bolt mounting plate to frame
  - Should work for HK too
  - Concept only, need full engineering design







Multi-PMT studies in Italy

Work based on experience with KM3NeT mPMT modules – adaptations for Hyper-K

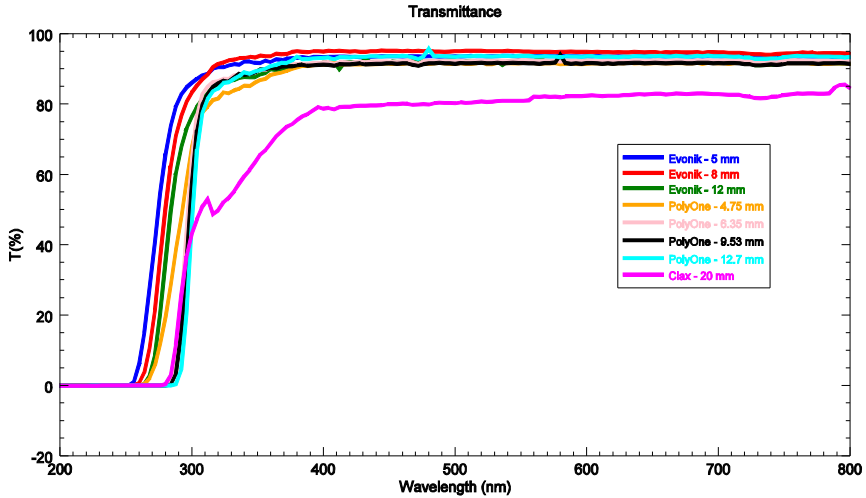
Goals of the project:

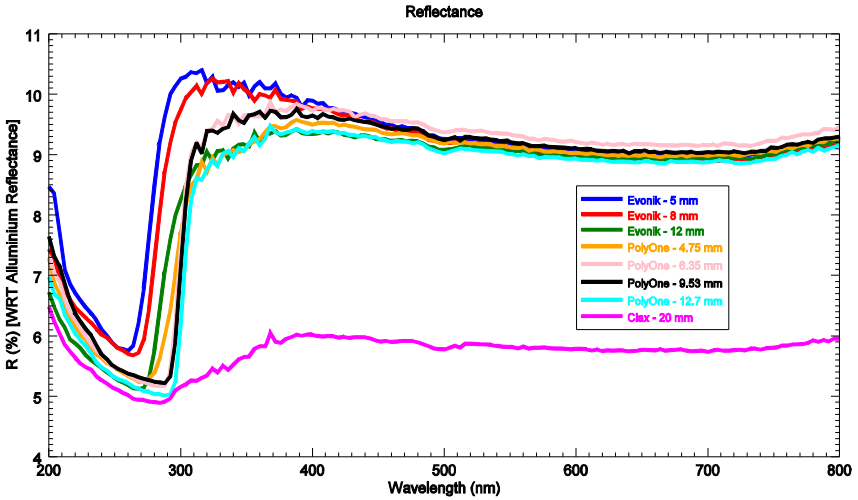
- Demonstrate the effectiveness of a vessel system based on acrylic
- Define a better solution for the PMT Read-out system

Team:

- INFN – Naples: G. De Rosa, A. Boiano, A. Evangelisti (Student), C. Riccio (Post-Doc), A.C. Ruggeri (Post-Doc) + support from INFN technicians on mechanical design and construction
- INFN – Bari: V. Berardi, M. Mongelli
- Politecnico – Bari: V. Berardi, R. Spina

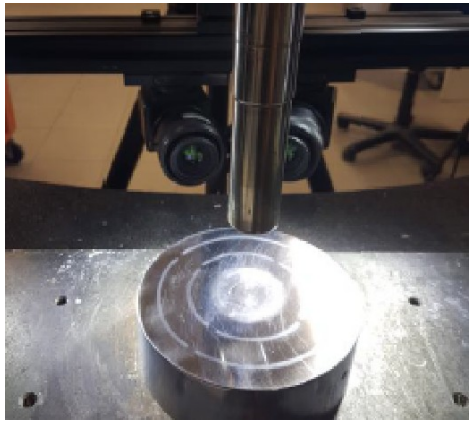
Acrylic properties



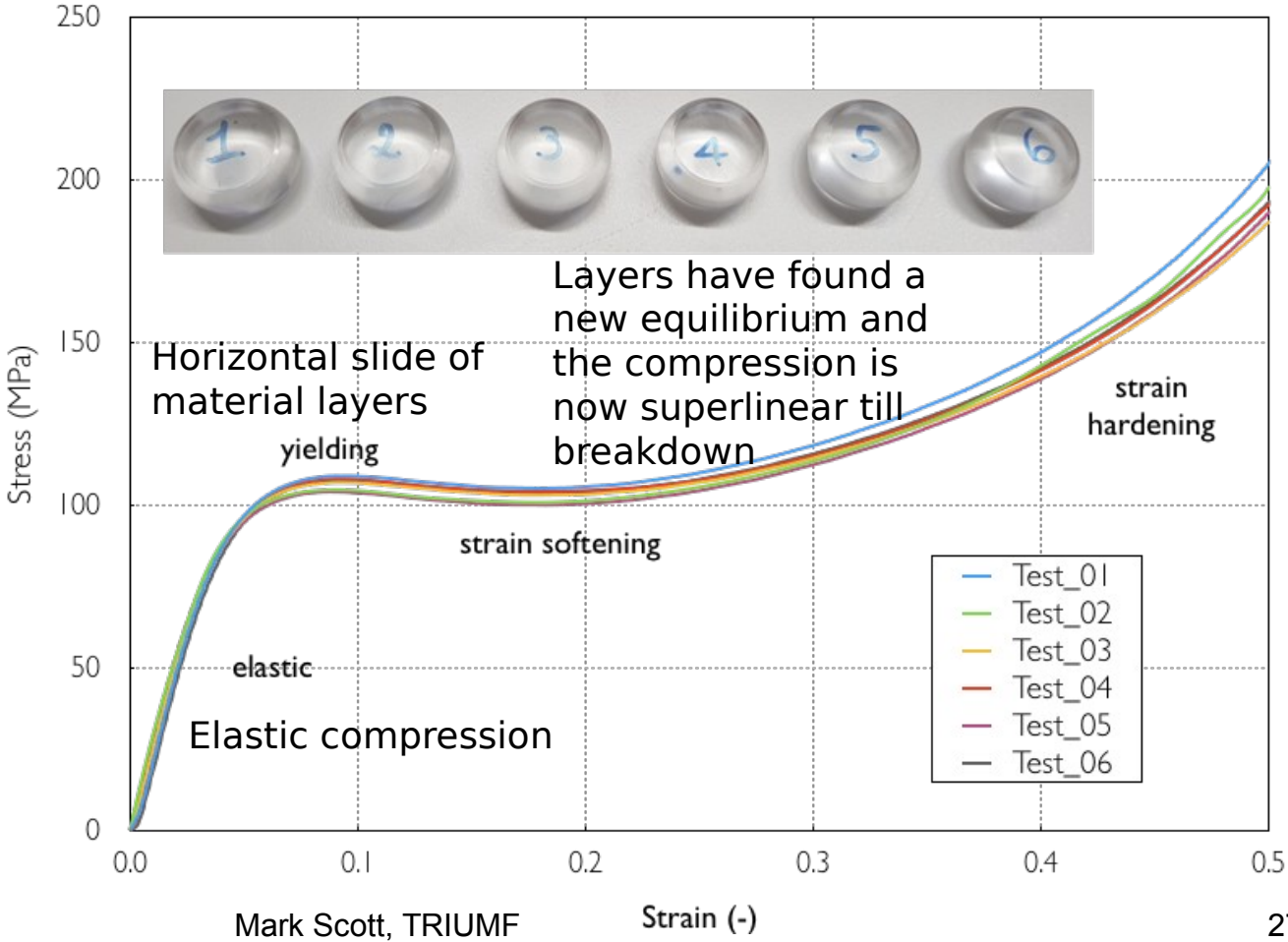


- Investigated transmission and reflectivity of different acrylic samples from Evonik, PolyOne and Clax
- Evonik performs best for transmittance

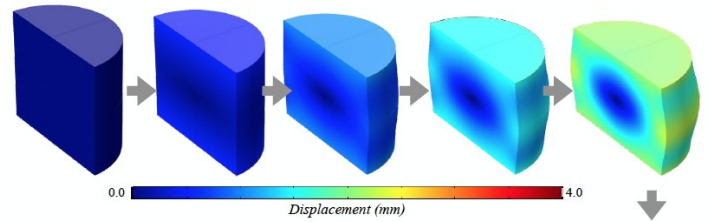
Acrylic mechanical testing

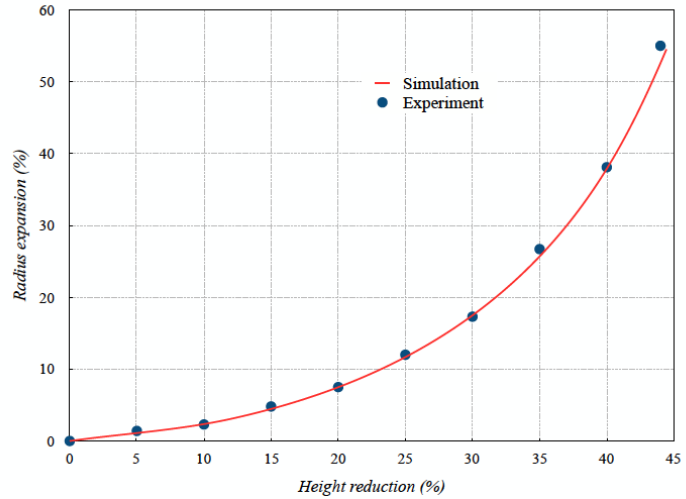


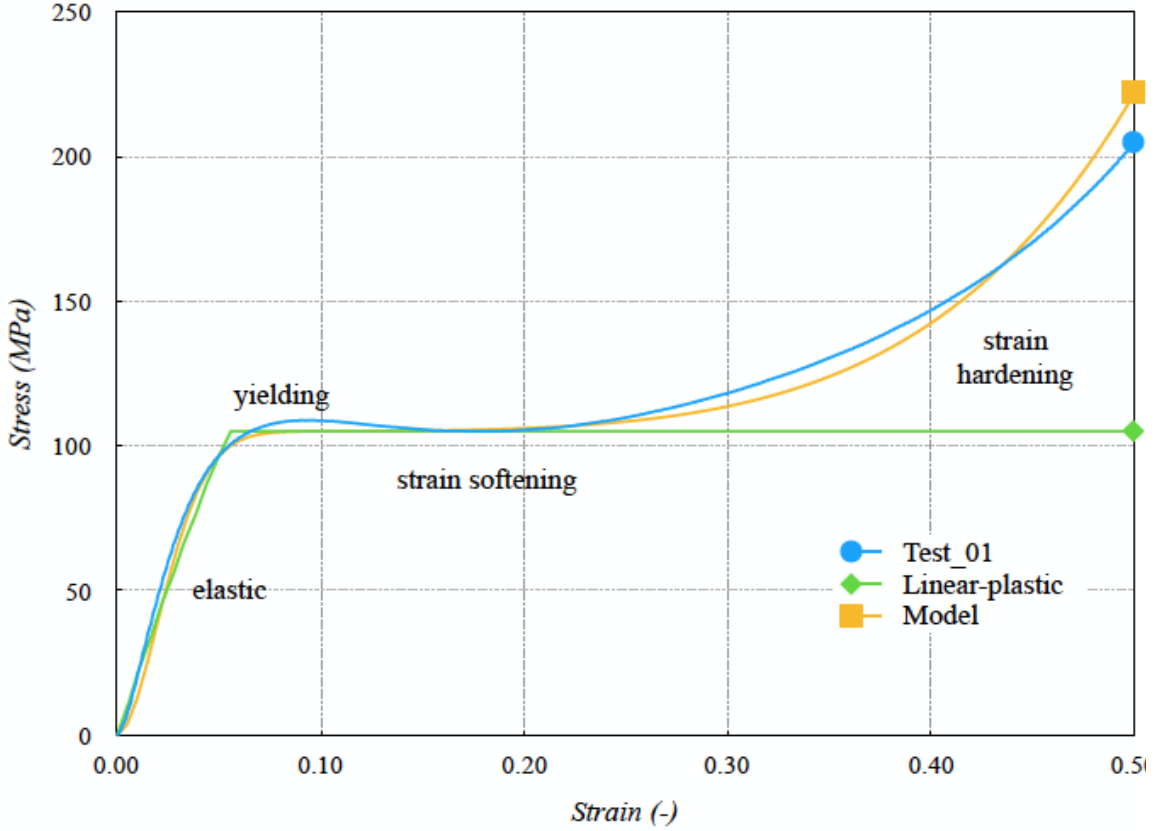
- Mechanical tests of acrylic performed at INFN Bari
- Tensile and compression tests according to ISO 527



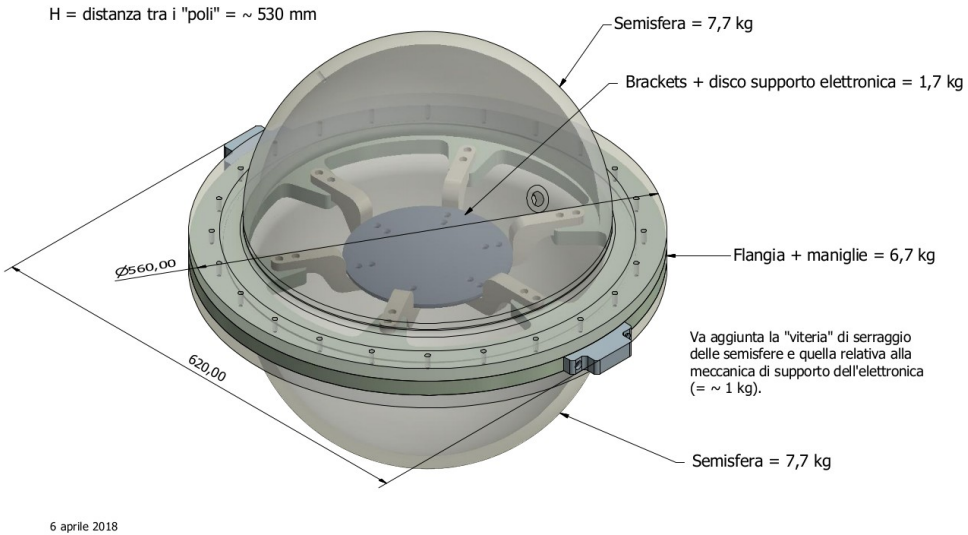
Acrylic mechanical simulation

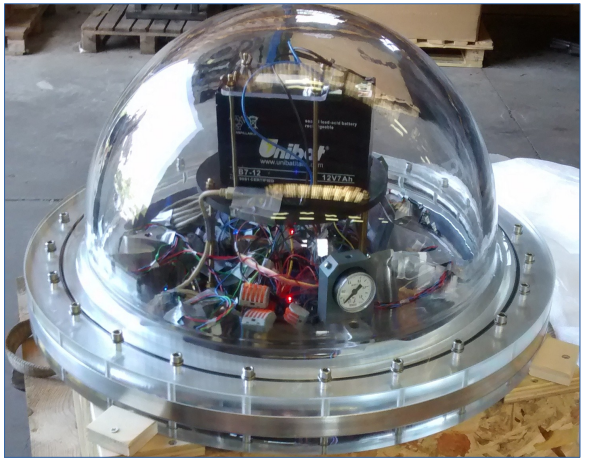


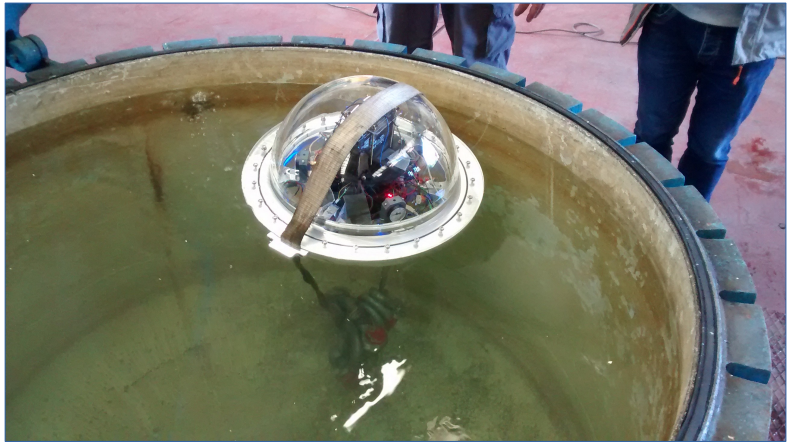




Pressure testing



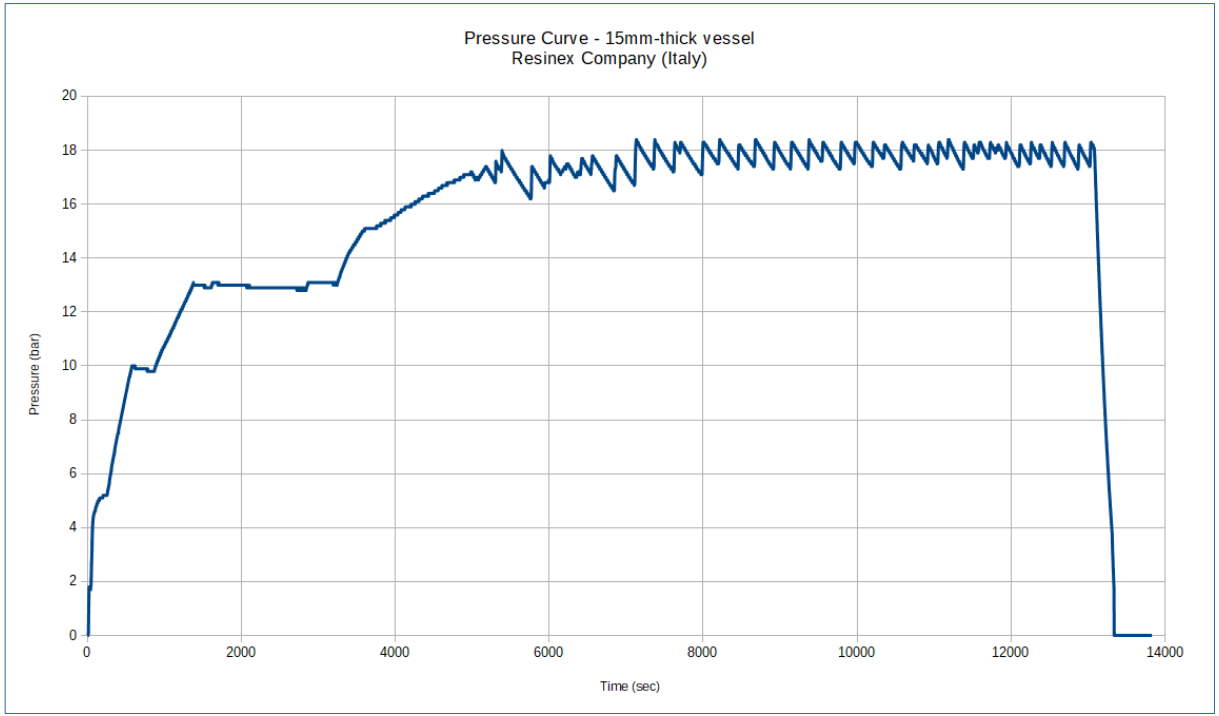




- 15mm or 20mm thick acrylic vessel
- Metal flange with O-ring seal
- Pressure valve and dummy penetrator
- 25 bar pressure tank with 15mm acrylic

Pressure profile

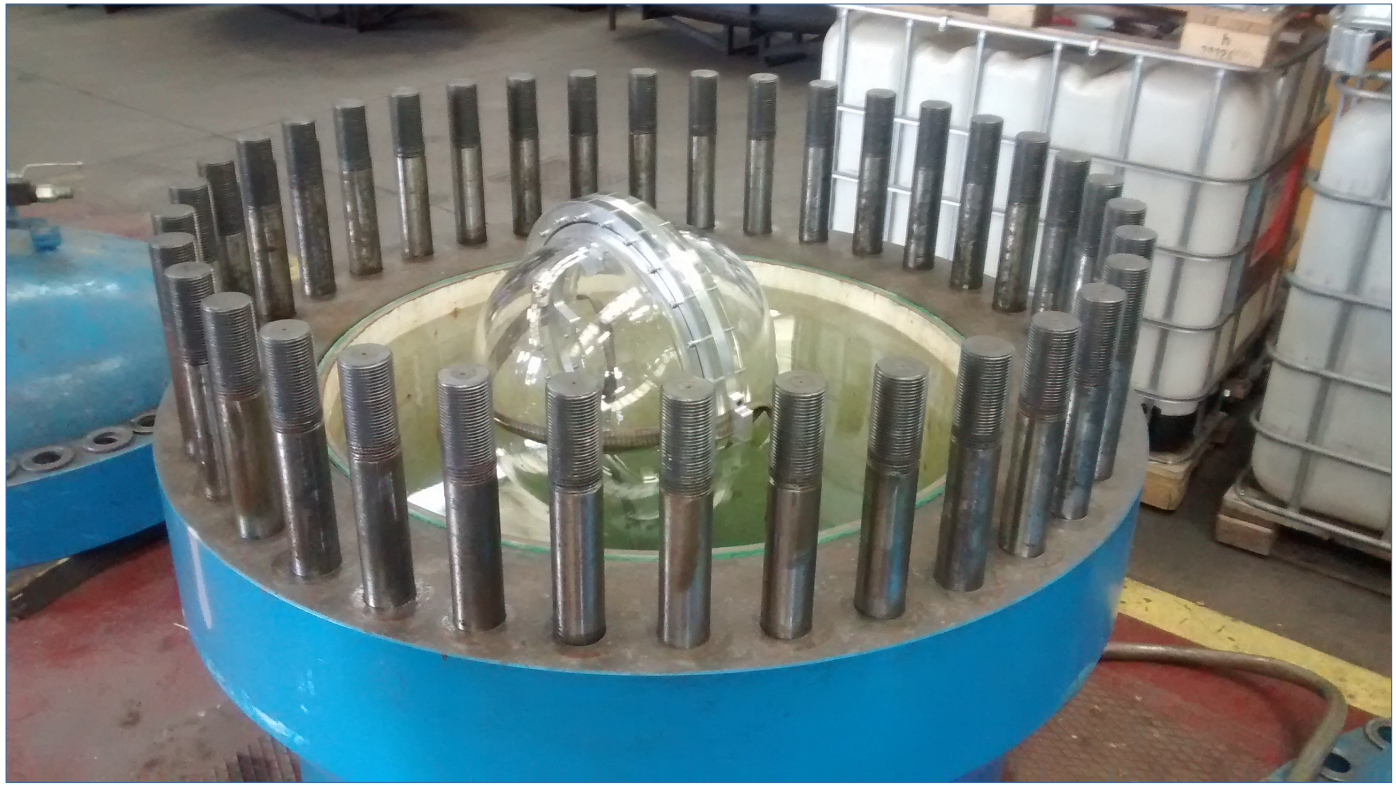
- 15mm thick acrylic easily survives test at 18 bar for two hours



High pressure tests

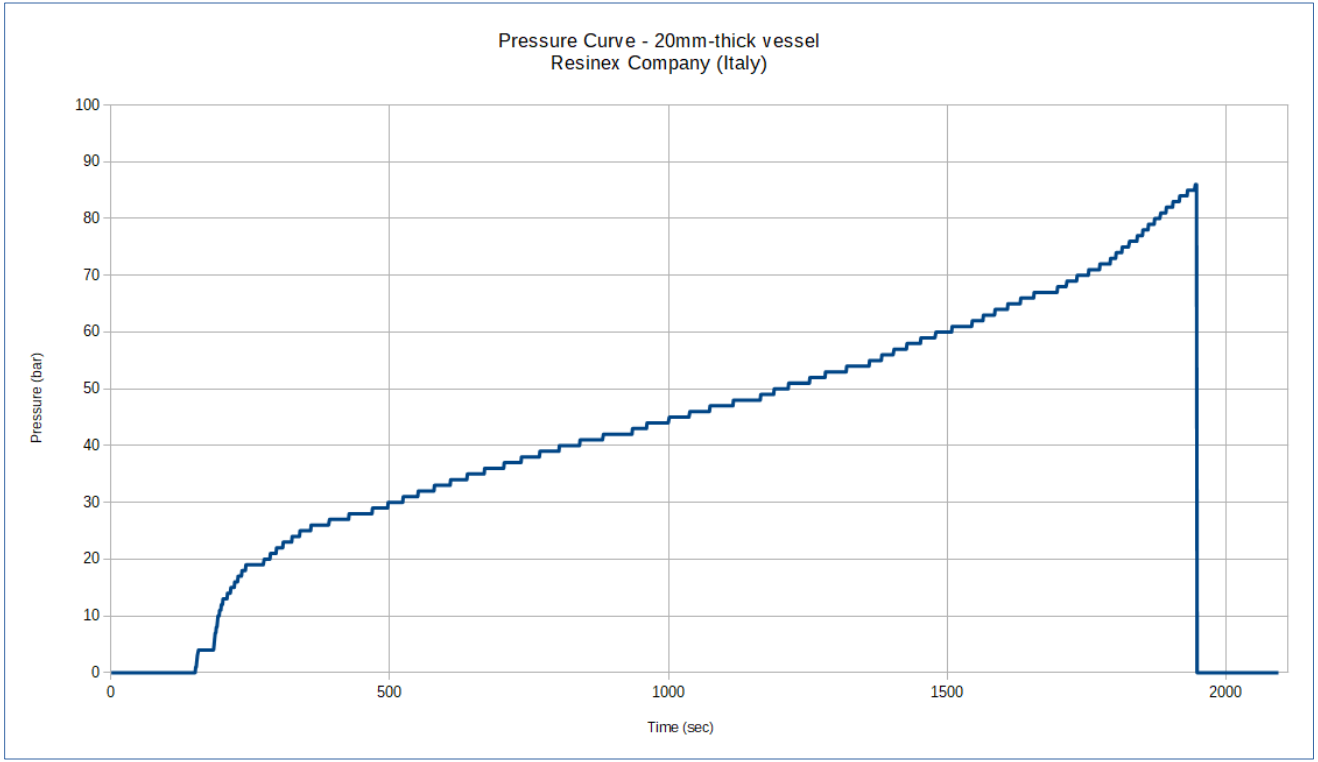
Second test in the 400bar tank:

Crash test of the 20mm-thick vessel

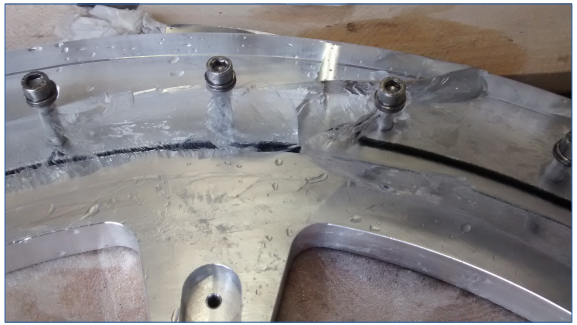


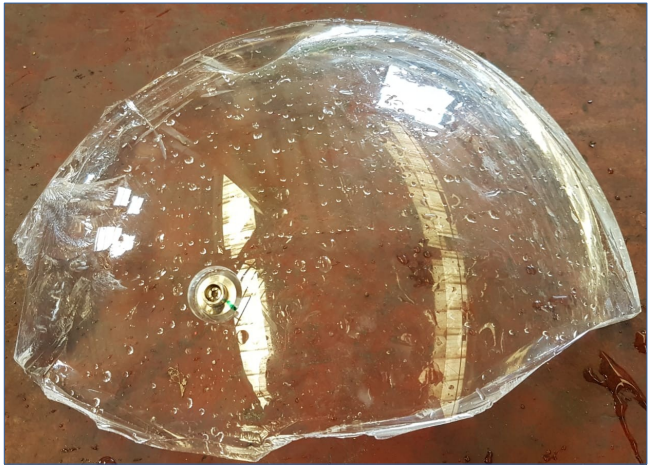
Increasing the pressure...

- 20mm acrylic vessel
- Steady increase in pressure
  - Two 'noises' at ~50bar
  - Implosion at 86 bar



...to destruction



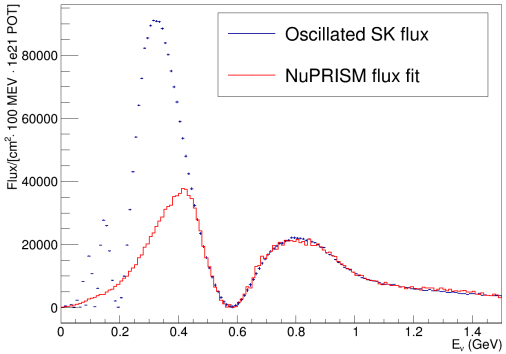


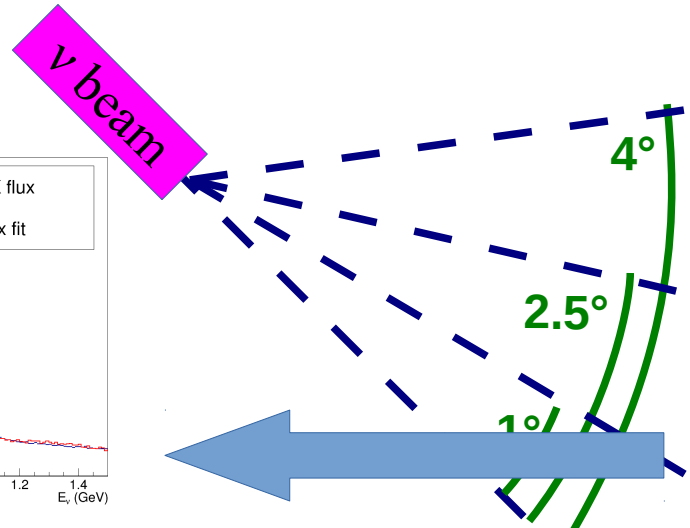
One half completely destroyed...

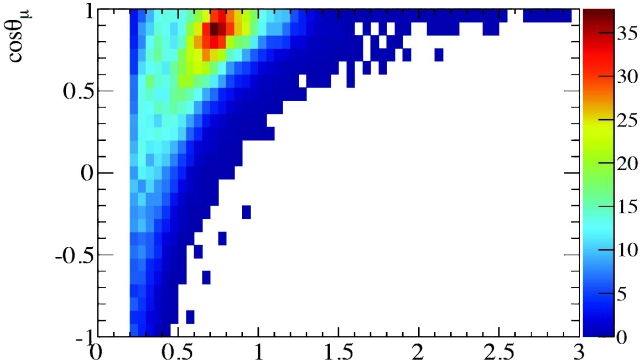
Pressure valve + dummy penetrator survived

Further testing at INFN

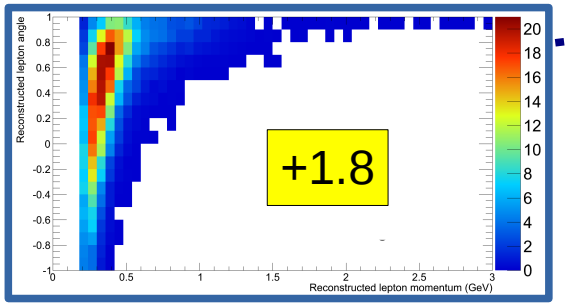
E61 concept - oscillation

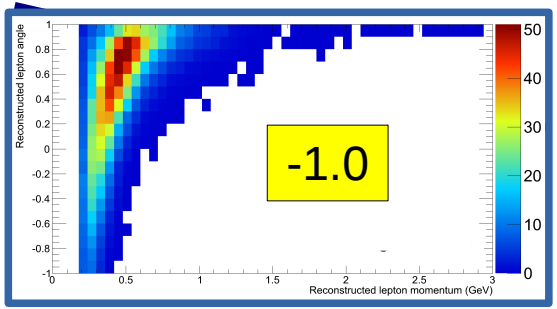


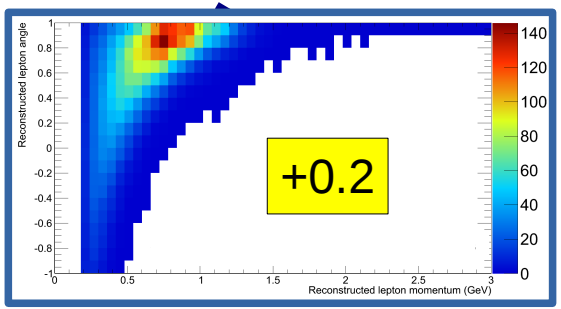


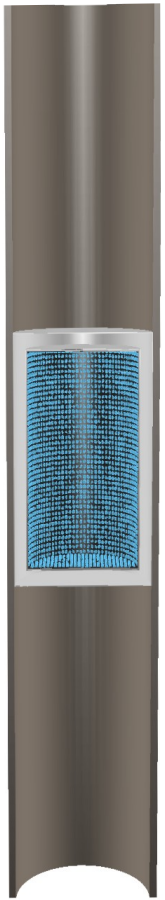


- Weight and combine different off-axis slices
- Create **oscillated** flux

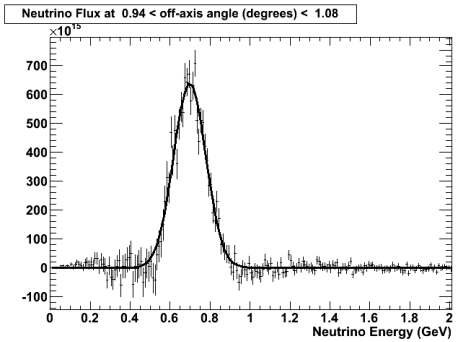


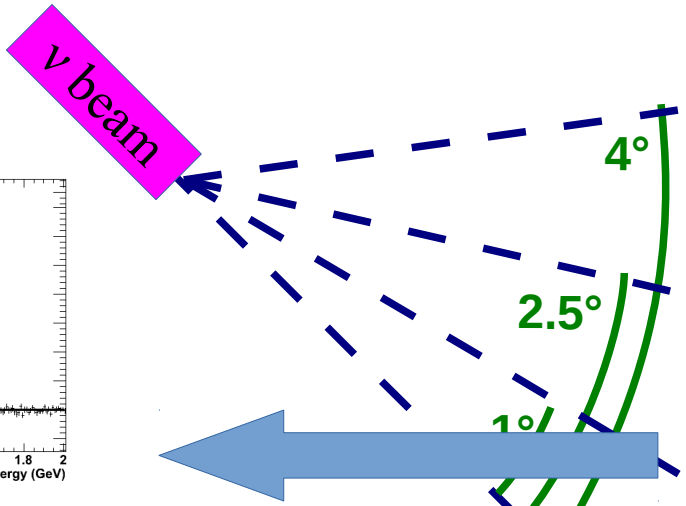


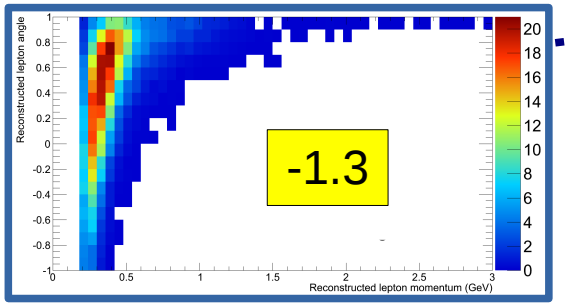


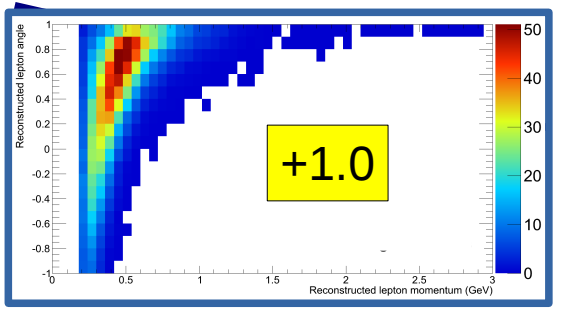


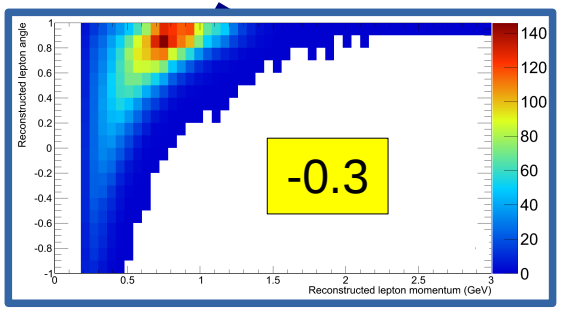
E61 concept – cross sections

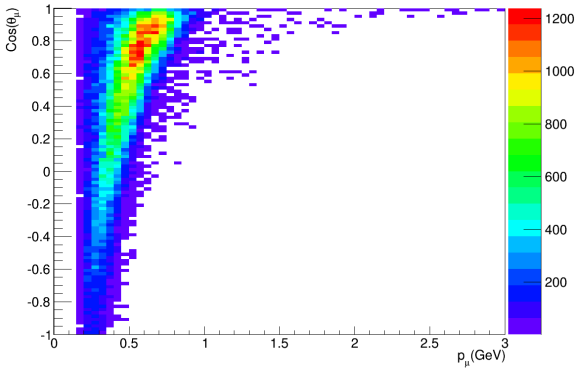












- Weight and combine different off-axis slices
- Create **Gaussian** flux