CALIBRATION FOR HYPER-K

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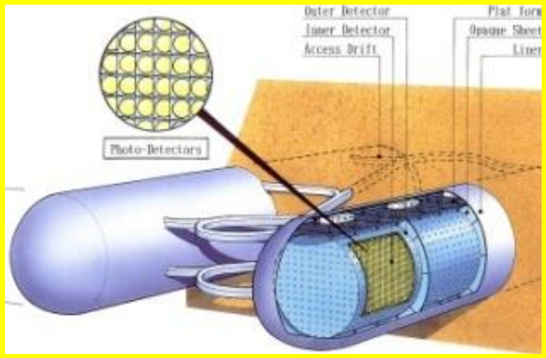
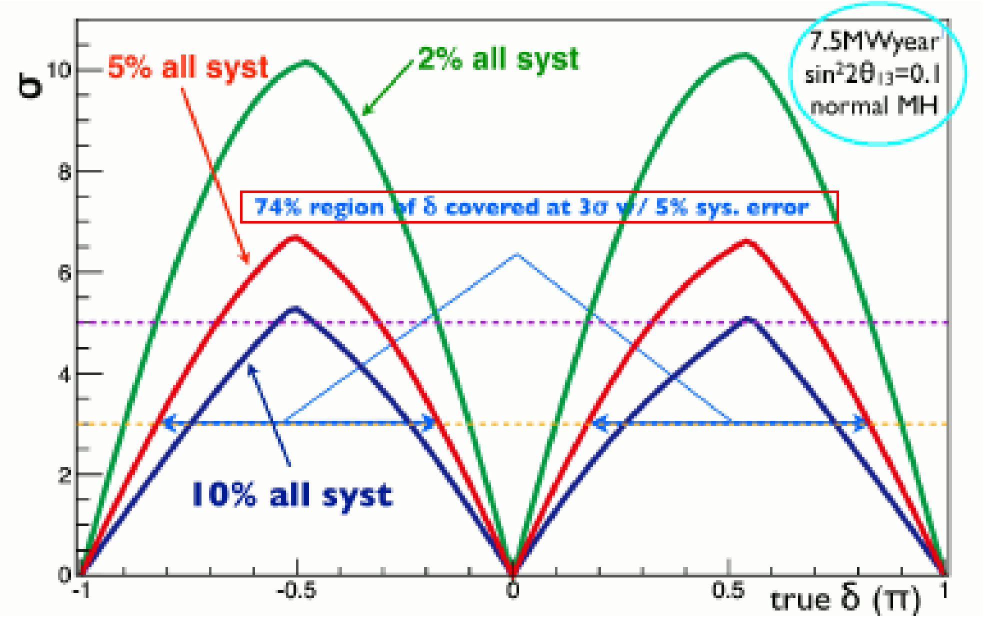


Measurement of oscillation parameters

- Sensitivity of HK dependant on total systematic uncertainty
- SK detector systematics are significant for T2K
  - We will need to do better in HK.



Source of error for ν_e appearance
arXiv:1311.4750

Error source [%]	$\sin^2 2\theta_{13} = 0.1$	$\sin^2 2\theta_{13} = 0$
Beam flux and near detector	2.9	4.8
(w/o ND280 constraint)	(25.9)	(21.7)
ν interaction (external data)	7.5	6.8
Far detector and FSI+SI+PN	3.5	7.3
Total	8.8	11.1

Source of error for ν_μ disappearance
PRL, 111, 211803

Source of uncertainty (number of parameters)	$\delta n_{SK}^{exp} / n_{SK}^{exp}$
ND280-independent cross section (11)	6.3%
Flux and ND280-common cross section (23)	4.2%
Super-Kamiokande detector systematics (8)	10.1%
Final-state and secondary interactions (6)	3.5%
Total (48)	13.1%

What do we need to measure?

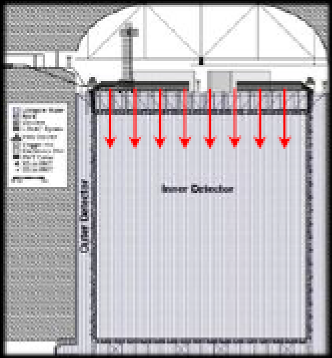
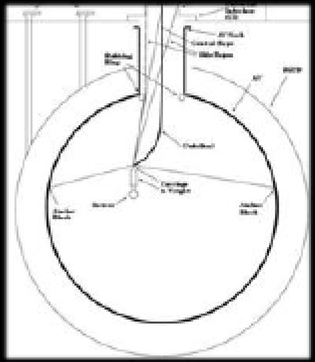
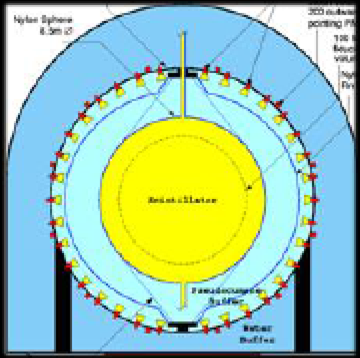
- Electronics
- PMT Response
  - Timing
  - Gain
  - Angular Response
  - Faulty PMTs
  - Relative PMT efficiency
  - Overall detector gain
  - Multi and single photon effects
- Detector Properties
  - Water Attenuation/Extinction
  - Scattering
  - Reflections from surfaces
- Physics sources
  - Energy scale
  - Reconstruction
  - Event shapes

Calibration Strategies

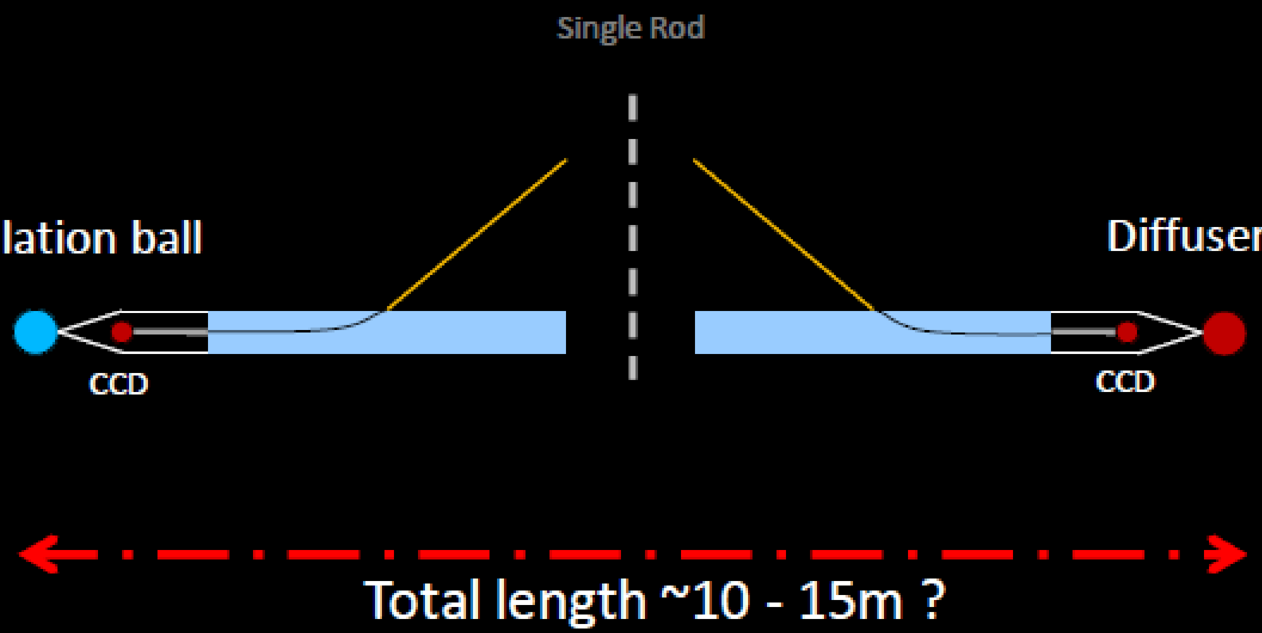
- Deploy sources
  - Light sources
  - Radioactive sources
- Collect data for calibration insitu
  - Michel Electrons
  - Cosmic muons
  - Atmospheric neutrinos
- Build sources into the detector
  - Optical fibres
  - Embedded sources
- Precalibraton
  - Careful measurements before/during assembly

Deploying sources

Current Deployment Systems

Super-K	SNO	Borexino
		
Semi-automatic	Semi-automatic	Fully manual
1D calibration System (manual)	2D calibration System (manual)	3D calibration System (manual)
Volume Calibrated: ~ 50k m^3	Volume Calibrated: ~ 1k m^3	Volume Calibrated: ~ 0.3k m^3

Deploying sources



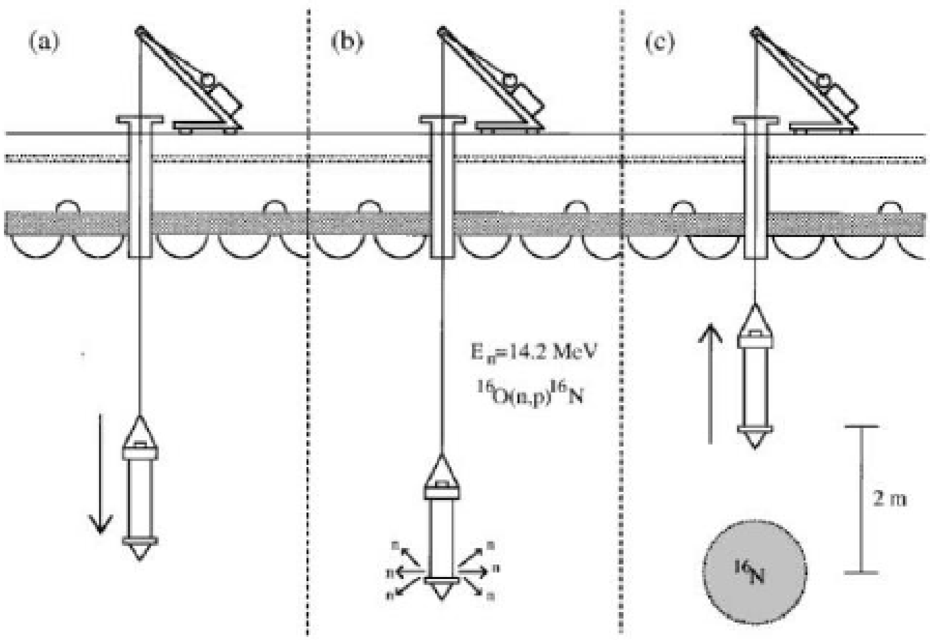
Similar to KamLAND: a solution with one rod, all sources mounted

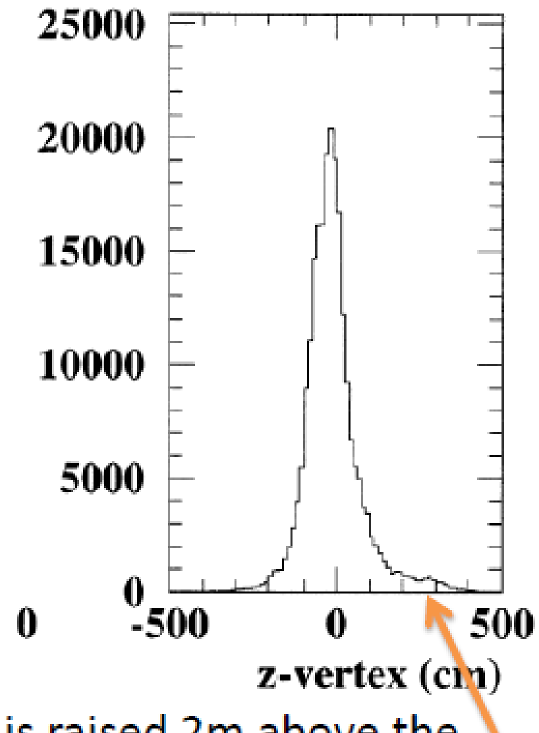
Problem: where to store such a long rod ?

Sources under discussion

- ^{16}N two options 6MeV γ + βs
  - DTG neutron source deployed directly into the detector.
    - SK Style
  - Activate CO_2 with DTG neutron source and flow gas into detector.
    - SNO style.
    - Tagged γs
- Cf – Ni source (9 MeV γ)
  - Self triggered
  - R&D still required
- Other sources discussed
  - pT source 19.8 MeV γ. Deployed once in SNO.
  - LINAC source.
    - Expensive option (multiple units required)
    - Not currently considered.

The Super-K D-T generator : In action



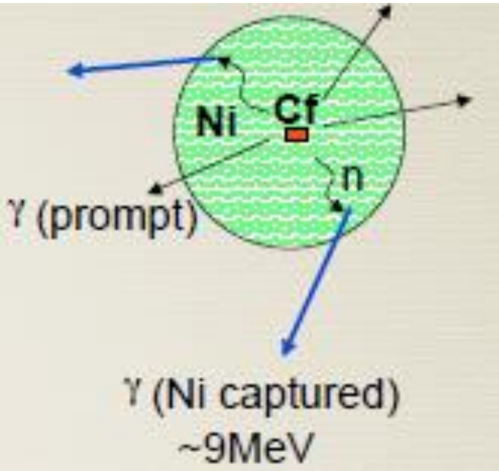


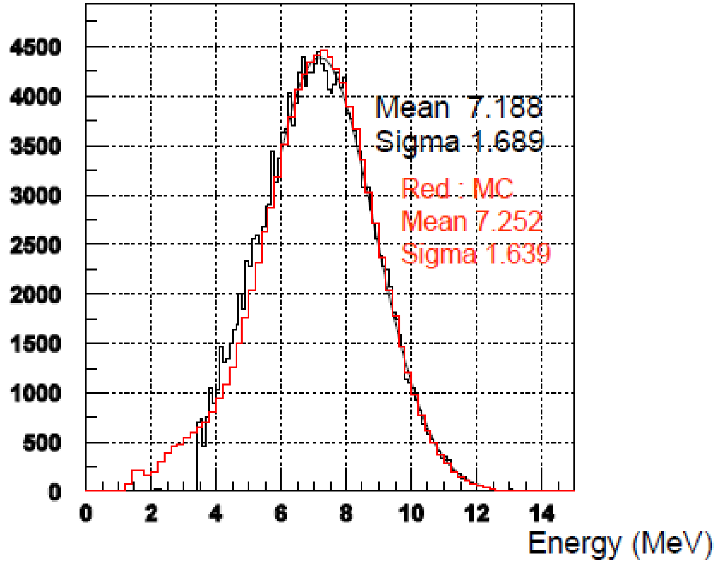
- During the calibration process the DT generator is raised 2m above the original fire position to reduce shadowing/interaction with the device
  - Basically unavoidable
- Causes diffusion of events along axis of this motion as water is displaced
- Range of utility in the vertical direction is limited
- Device is not so mobile

R. Wendell

Nickel source

- Capture of thermal neutrons by nickel
  - Produces 9 MeV γ-ray.
  - Typically ^{58}Ni (n:γ) ^{59}Ni reaction.
- Ni source with ^{252}Cf fission source embedded.
- R&D Ongoing





LED Pulsers

- Use an LED rather than a laser as a light source.

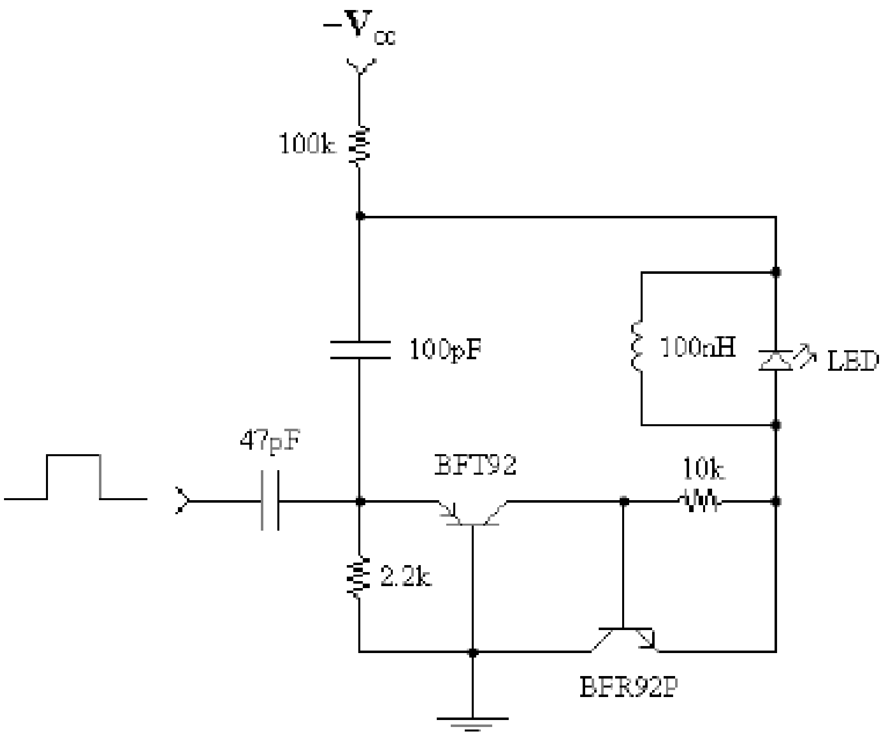
- Advantages
  - Cheap per channel cost. (~£10 for LED and basic driver electronics)
  - Compact device possible
  - Stable wavelength distribution ~ 10 nm spread
  - Wide range of wavelengths available
  - ~1 ns pulses possible.
  - Simple coupling to fibres
- Disadvantages
  - Higher current requirements
  - Large light loss into fibres.

ANTARES Beacon

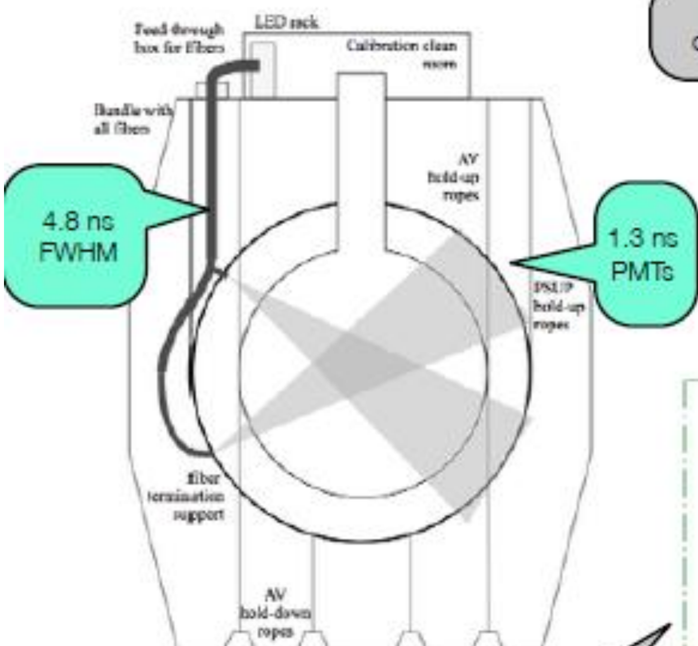
- Developed to provide a light source on each ANTARES photo-module.
- Permanently deployed.
- Can flash single or multiple LEDs at once, depending on calibration required
  - Different systems to do this.

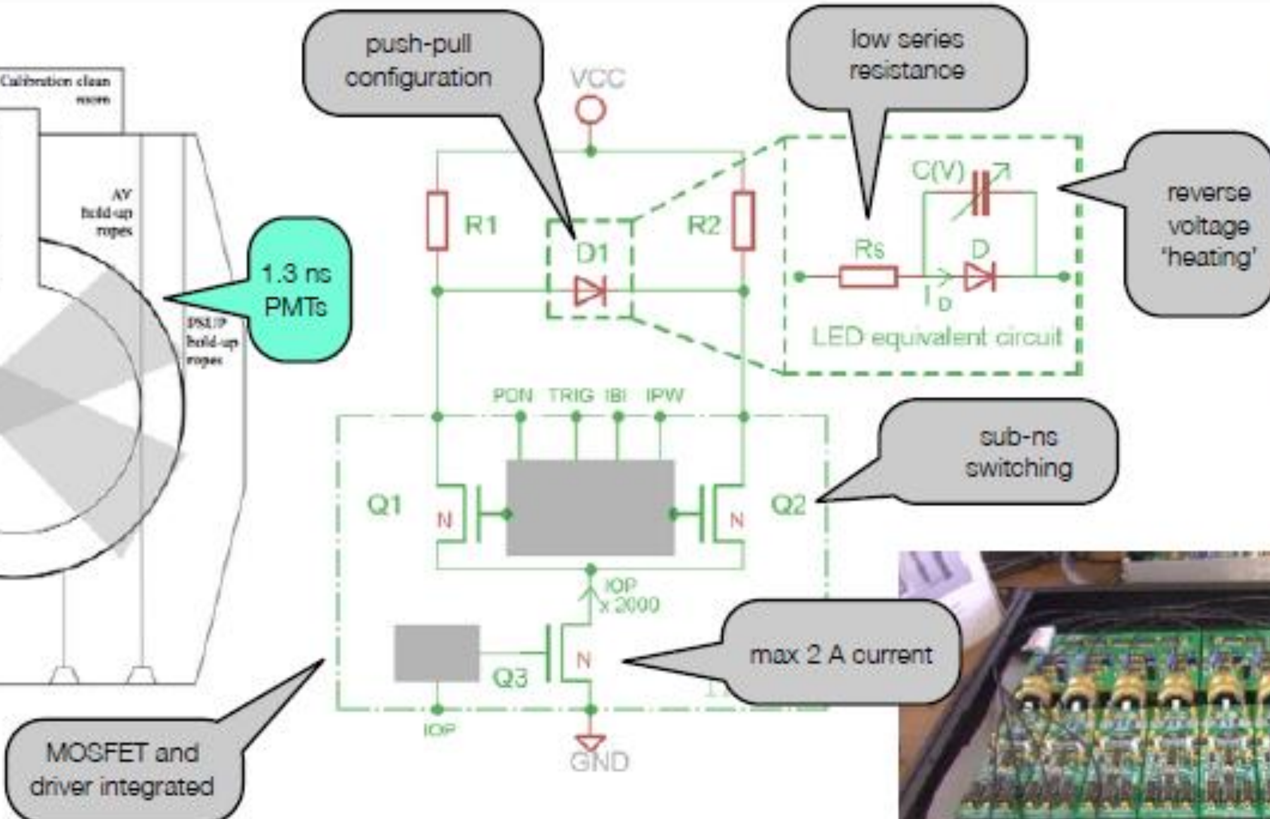
Basic design of ANTARES system

- Use a modified Kapustinki design.
- Discharge a capacitor into LED.
- Uses a fast 2 transistor switch.
- Inductor to "sweep out" charge.
  - Reduced tail.



LEDs in SNO+





Original design requirement (LED end):
- > **10^6 photons per pulse**
- – **1 ns optical pulse width**

Later additional requirement (wet end):
10^3 photons per pulse (stable) at
1 pulse per second repetition rate

Updated LED drivers for HK

- We plan to develop an updated driver circuit for HK exploiting what we’ve learn from ANTARES and SNO+
  - Include the best of both systems with new improvements
  - Update electronics to more modern standards, use FPGAs for example
- Need to finalise targets for
  - Pulse width
  - Number of photons
  - Decision on number of LEDs to drive simultaneously (>1?)

Possible uses for LED

- Embedded light source on PMT support
- Potted in a diffuser ball as an isotropic light source
- As a beacon on other calibration sources
- As the light source for a “muon source”.

Embedded Light Sources

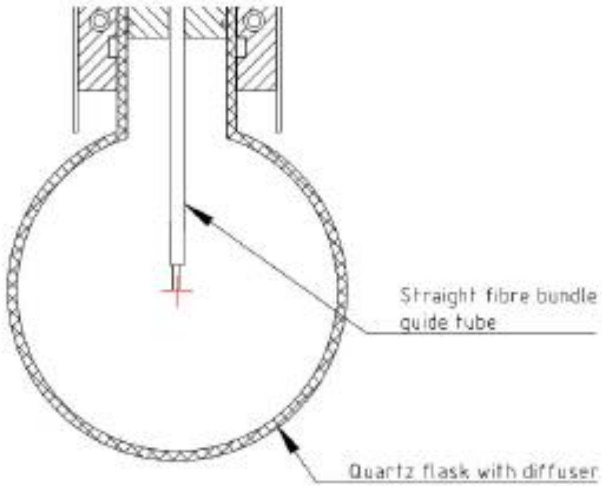
- Source for embedded light source in HK PMT support
  - Similar to SNO+ fibre system.

- Could be deployed as a fibre system as in SNO+
- Alternatively could be deployed directly in detector
  - Particularly interesting if we have “wet-end” electronics.

- Useful for measuring/monitoring
  - PMT timing
  - Attenuation/extinction
  - Scattering

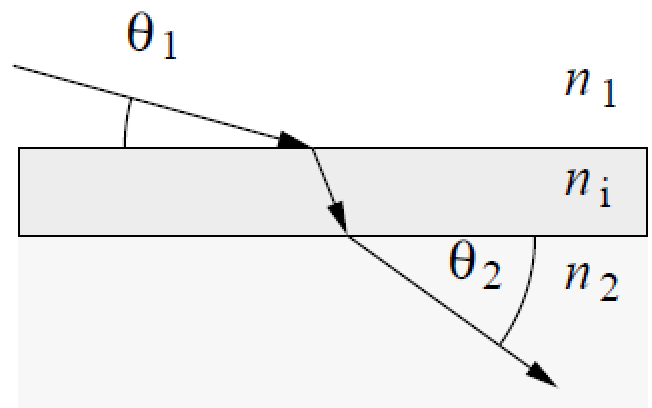
For an isotropic source

- Adapt the laserball design from SNO.
  - Fibre in the centre of a quartz ball filled with beads potted in a gel.
  - Provides isotropic light.
- Replace fibre with LEDs.
  - Will be more isotropic as the light from a LED is more isotropic than from a fibre.
- Can potentially stay in the detector
  - Can run calibrations without running the laser system.



A fake muon source

- A source to simulate muons and test reconstruction.
- A narrow transparent tube with a light source producing almost parallel light at one end.
- Light emitted at the Cherenkov angle.

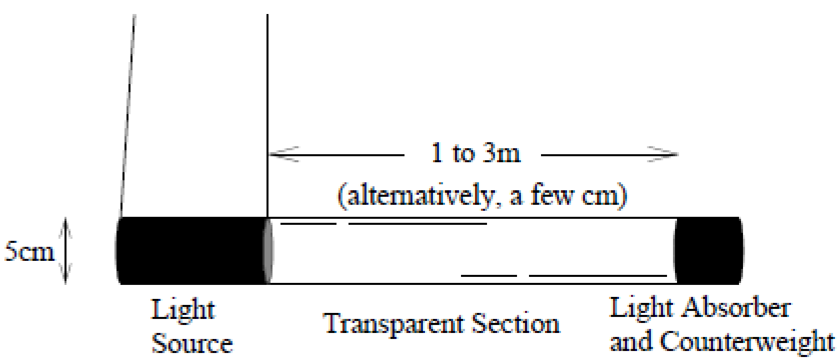


$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

independent of n_i

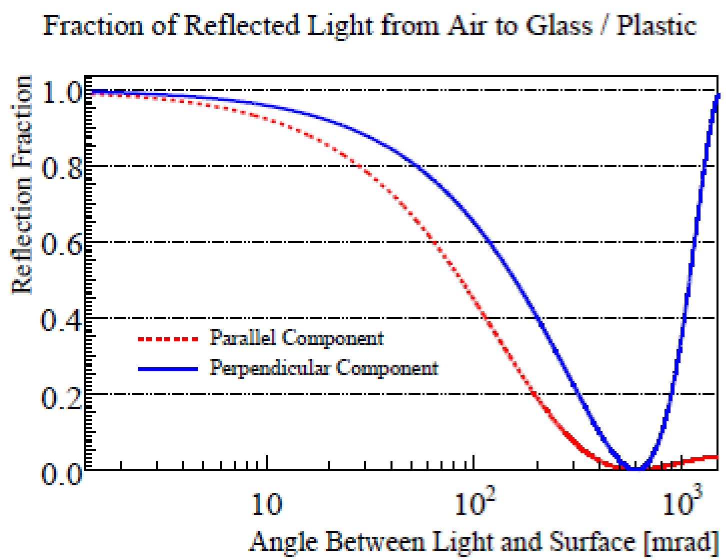
As $\theta_1 \rightarrow 90^\circ$ $\sin(\theta_2) \rightarrow 1/n_c$

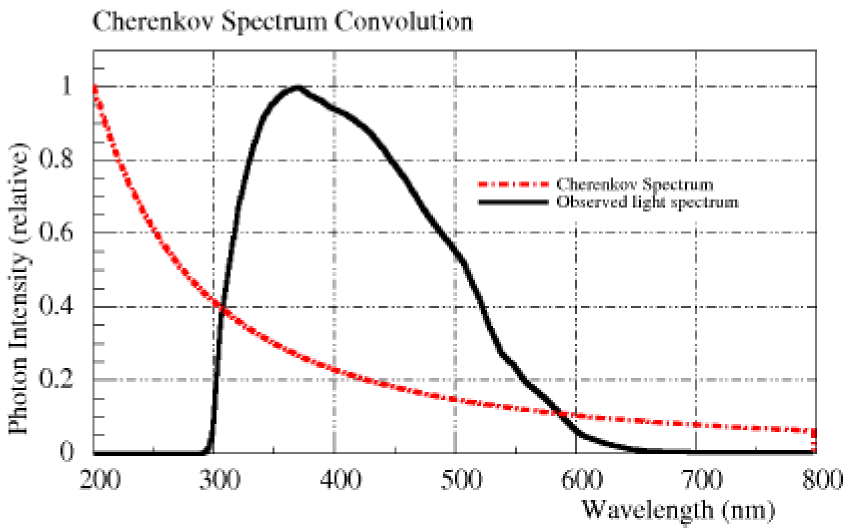
Light emitted at Cherenkov angle.



Plans for muon source

- We plan to pursue this as an R&D project in the UK
- Produce a short source for testing.
- Use multiple LEDs to “cover” range of Cherenkov spectrum
- Plan to
    - Test angular distribution
    - Tune LED intensity
    - Test light deployment and absorption methods.





Source Beacon

- LED source is small and compact and could be attached to any calibration source.
  - Or to the source deployment system

- Can therefore use as a beacon to determine the position of the source in the PMT co-ordinate system.
  - Collect multiple pulses – determine mean PMT time for direct light.
  - Reconstruct position of LED
  - Determines source position independent of source effects.

- Could also act a as light source for a camera system if one is deployed.
  - Flash LED at a high rate.

Conclusions

- Calibration will be critical to meet the physics goals of HK
- A wide a varied program will be required
- Light sources
  - LED pulsers being pursed in the UK
- Radio active sources
- Calibration infrastructure
- Plenty of scope for European involvement.