Energy response characterisation of the SoLid detector

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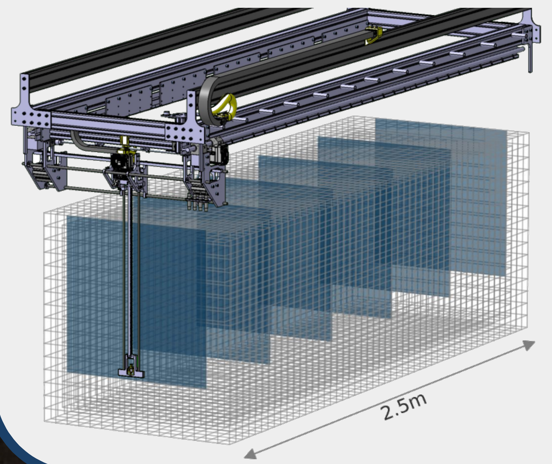
Light, generated in a scintillator cube and sheet, is guided by a grid of fibers to sensors. With 12800 cubes and 3200 fibers and sensors, energy calibration does not come easy.

Detector calibration



Calibration challenge

- Accurate energy response needed to reconstruct $\bar{\nu}_e$ energy
- Highly segmented detector gives complex calibration:
  - Inhomogeneities in detector response need to be determined, i.e. cube light yield, sensor gain, fiber attenuation and coupling (> 20000 parameters)
  - Multiple cubes are read out by same channel. Results in complicated disentanglement of correlated effects.

Calibration campaign

- Periodic calibration campaigns are performed on site
- Automated robot can lower neutron and gamma sources in 6 gaps between modules of 10 planes

Source	AmBe	^{252}Cf	^{22}Na	^{207}Bi	^{137}Cs
Type	$n+\gamma$	n	γ	γ	γ
Energy [MeV]	<4.2> (n) + 4.4 (γ)	<2.1>	1.27 + 0.511	0.57 +1.06	0.667

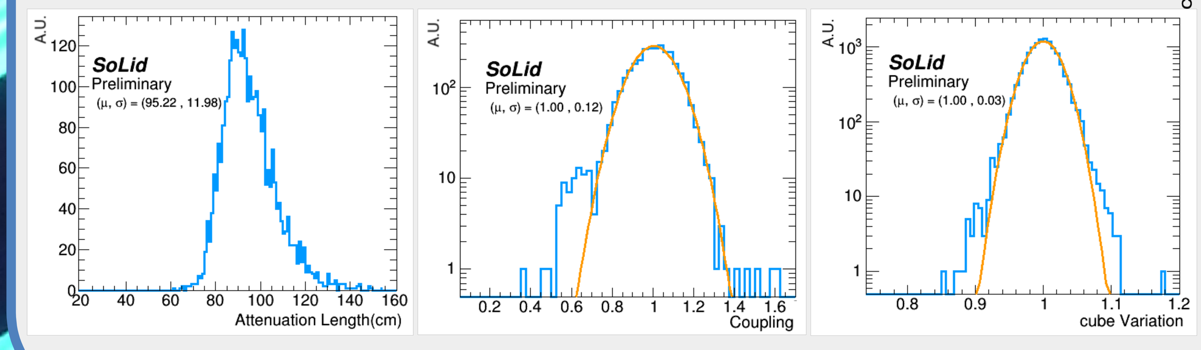
Calibration parameters

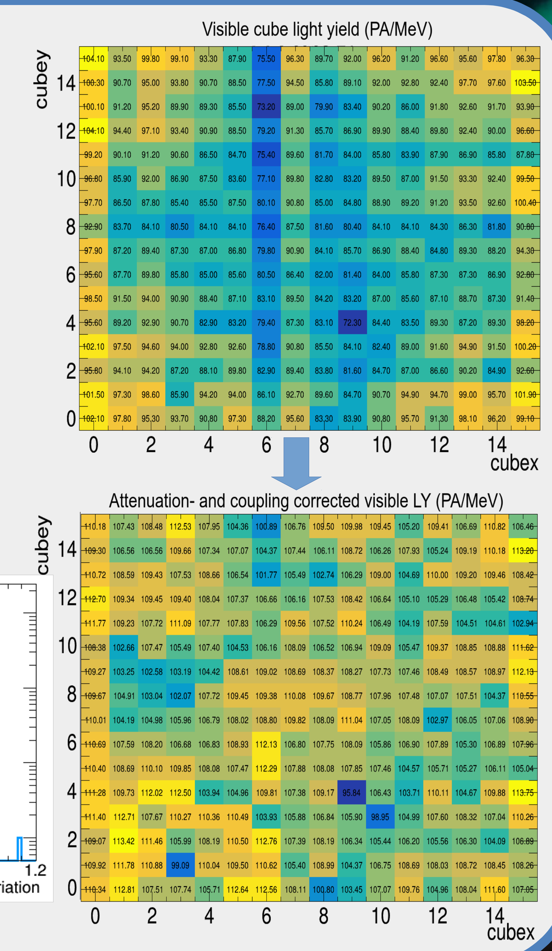
Inhomogeneities in light yield pattern

- Fiber specific attenuation gives gradient towards sensors
- Fiber specific coupling to sensor affects LY collection of row

Correction

- 19200 parameters determined for all fibers and sensors
- After correction, 3% spread in cube LY over 12800 cubes

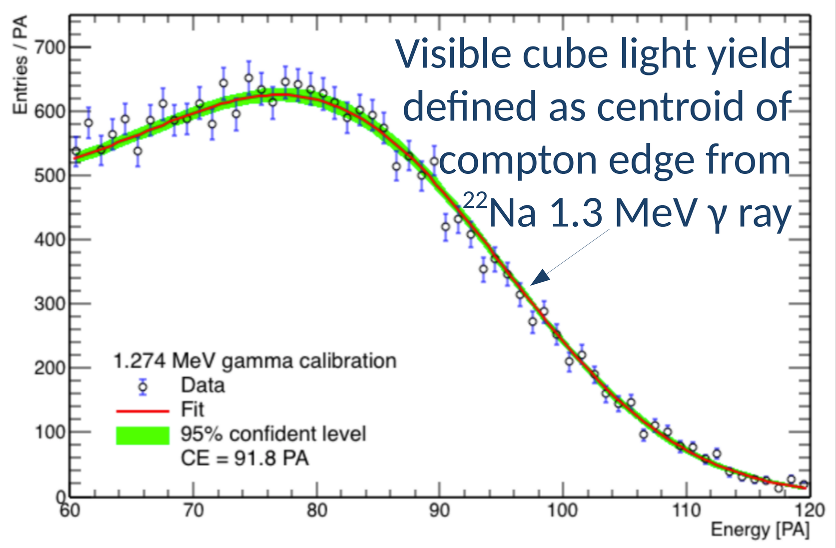




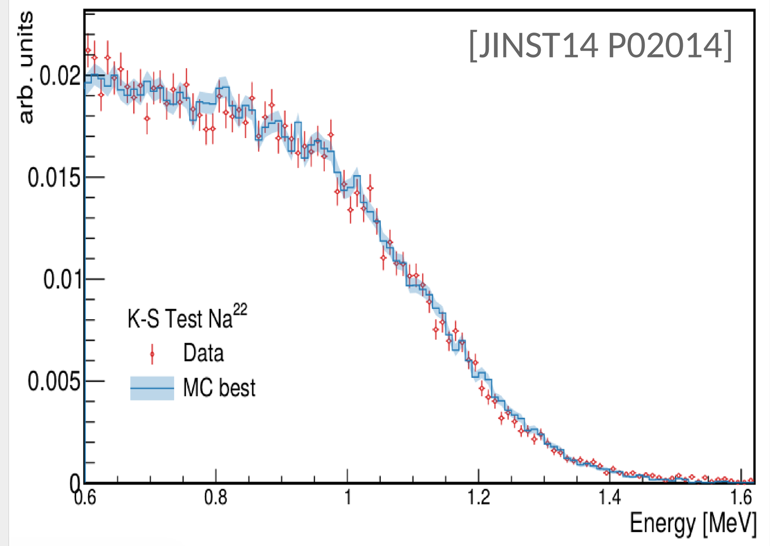
Energy response calibration

Calibration gamma ray has no clean photo peak. Complex energy distribution fitted by two methods to extract cube light yield from Compton edge spectrum (2% agreement)

Analytical fit method
Gaussian convolution of cross section model (based on Klein-Nishina formula) with energy dependent resolution.



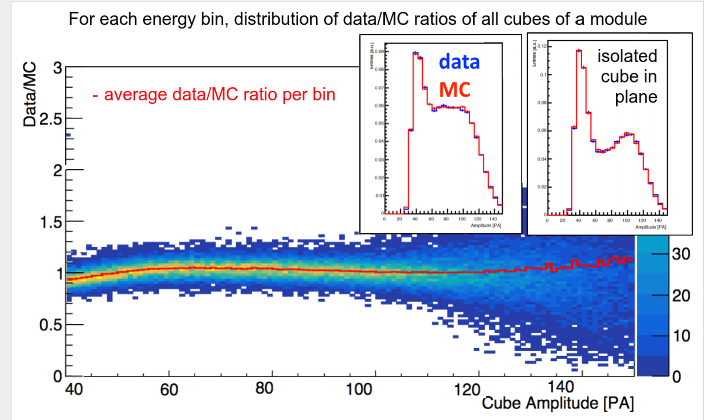
Kolmogorov test method
True energy spectrum (GEANT4) smeared with different resolutions and light yields. Comparison between data and simulation.

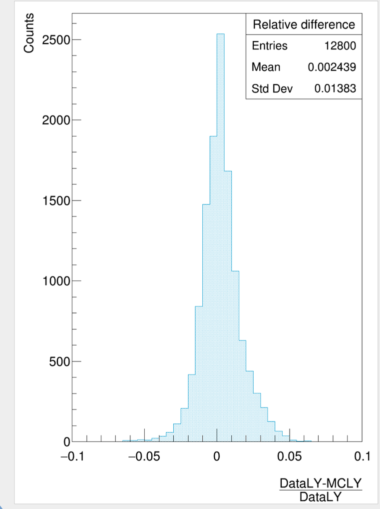


Energy response simulation

Simulation chain

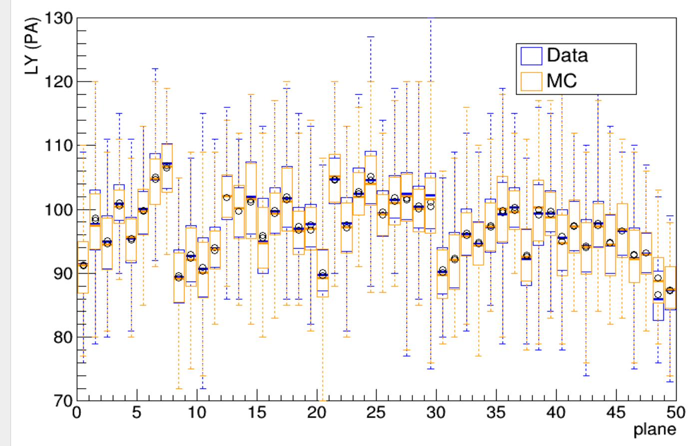
- GEANT4 simulation of reactor building and detector. Particles generated and tracked through volumes.
- Readout simulation of scintillators, sensors, trigger system, readout and full detector inhomogeneity.



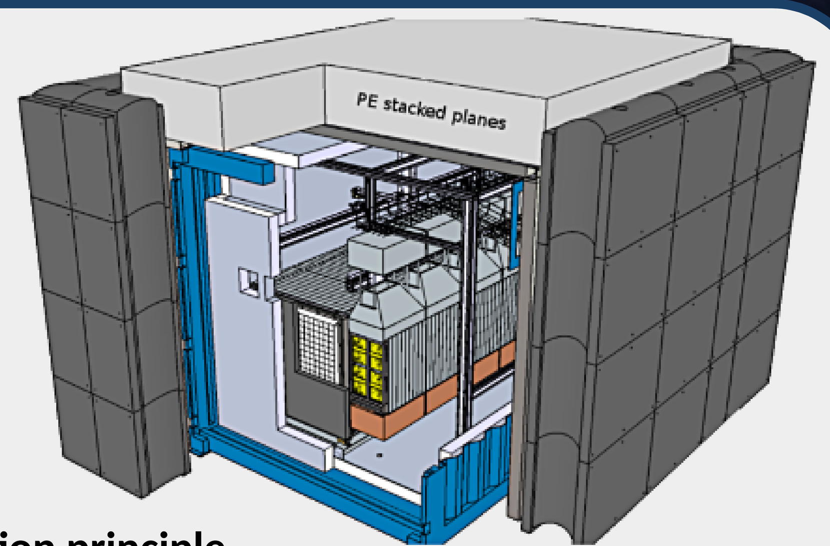


Data/MC agreement

- For all cubes in a module, agreement of reconstructed energy spectrum at 10 % around 1 MeV
- For each plane, good agreement in spread of cube light yields



SoLid - reactor neutrino experiment



Physics goal

- Assess Reactor Antineutrino Anomaly
- Investigate the sterile neutrino hypothesis
- Measure $\bar{\nu}_e$ oscillation in position and energy
- Measure ^{235}U energy spectrum precisely

Detector [JINST12 P04024]

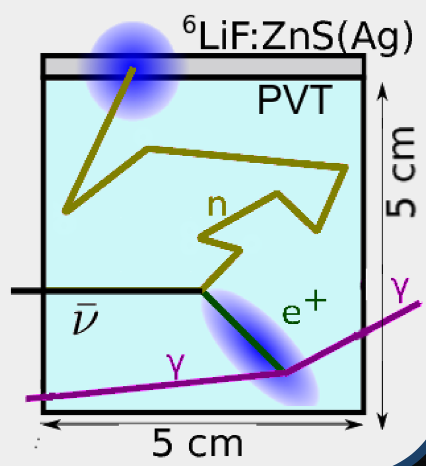
- 1.6 tonnes fiducial volume
- 50 planes of 16 x 16 cells (5 cm^3)
- In container, cooled to 10°C
- Shielded by 50 cm water/HDPE

Research reactor

- Located at SCK-CEN, Belgium
- 93% HEU fuel in compact core
- Short baseline (6 m - 10 m)

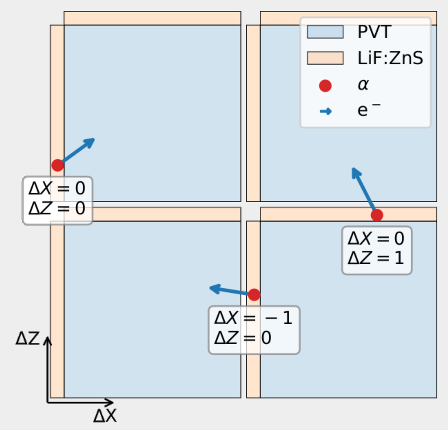
Detection principle

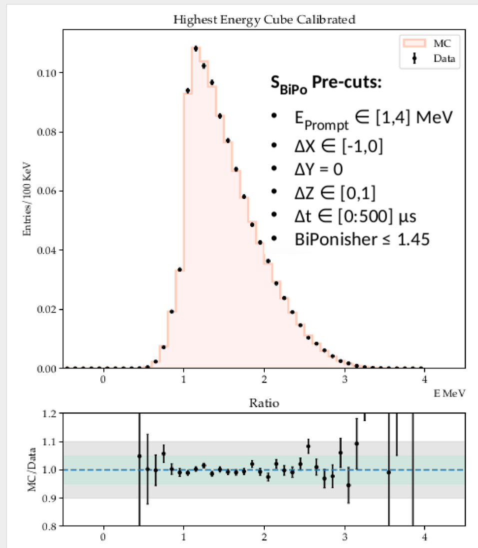
- $\bar{\nu}_e$ are detected via inverse beta decay $\bar{\nu}_e + p \rightarrow n + e^+$
- Hybrid scintillators:
  - e^+ and γ interaction in PVT
  - neutron capture in LiF:ZnS
- IBD selection based on spatial- and time correlation and topology

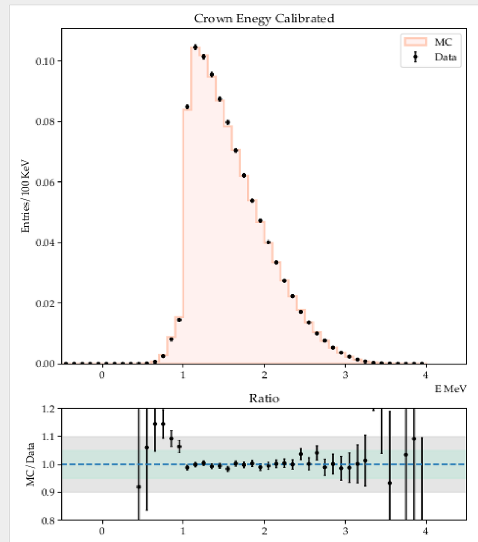


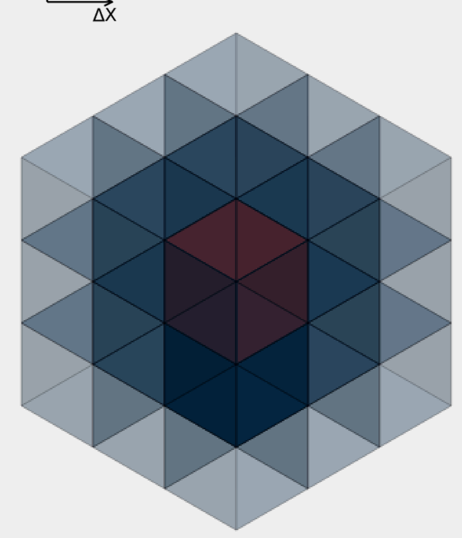
Data/MC performance

- ^{214}Bi → ^{214}Po decay exploited to control energy response
- SoLid geometry allows extracting cube to cube light yield (10 %) and LiF:ZnS light yield (1 % w.r.t. PVT)
- β signal resembles IBD e^+ signal and occurs in all cubes
- Data MC agreement at 10 % level for highest energy in central cube (red) and crown energy in nearest cubes









Conclusion

- Calibration and simulation of SoLid detector energy response are crucial to correct detector inhomogeneities and perform a precise neutrino oscillation measurement
- The detector is composed of 128000 unit cells (5 x 5 x 5 cm^3) and read out by a network of 3200 wavelength shifting fibers and MPPC sensor, making the calibration very challenging
- Two methods have been developed to extract the light yield of each cube from Compton edge spectrum with 2% agreement
- 22400 parameters are derived to describe the detector response and are implemented in the simulation
- The agreement in data and simulation is controlled using periodic calibration runs and the decay energy spectrum of ^{214}Bi → ^{214}Po decay, that is present throughout detector. We obtain an agreement within 10%.

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