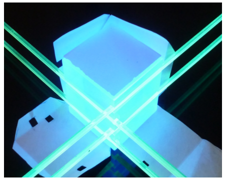
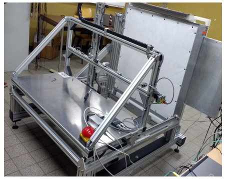
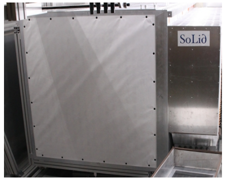
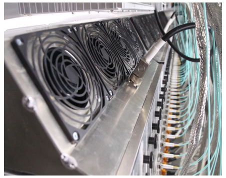







Observation of reactor antineutrinos with the SoLi∂ experiment

Petra Van Mulders

21st of November 2019
annual IIHE meeting

Credit: many slides recycled from Valentin Pestels presentation at "GDR neutrino" 3 weeks ago

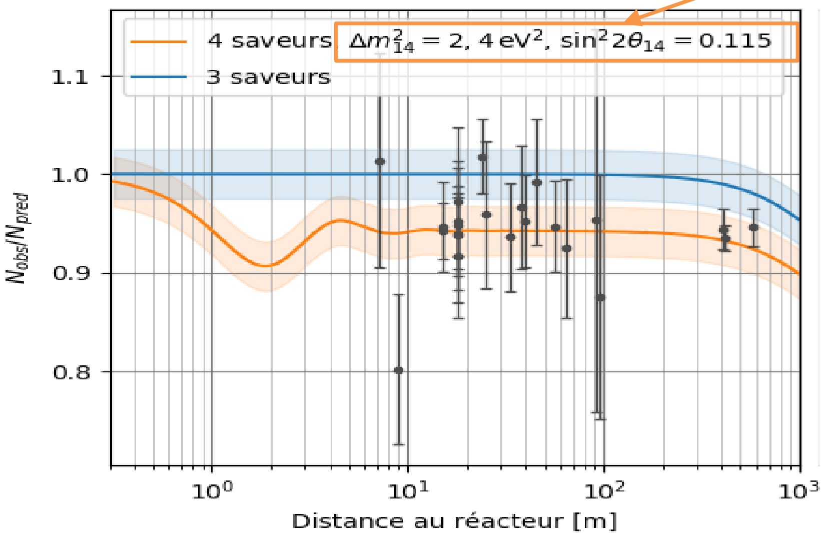
Goal of the SoLid experiment

- Measure the neutrino flux at very short baseline (< 10 metres) to understand the reactor antineutrino anomaly (RAA)

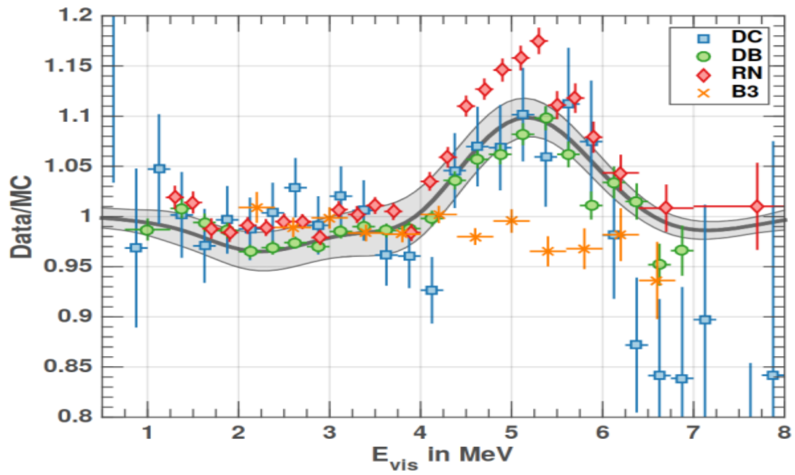
  → deficit of the observed number of antineutrinos with respect to the predicted number: new physics (e.g. oscillation to sterile neutrino) or issue with the prediction?

- Resolve the discussion on the spectral features observed by previous reactor experiments (so-called “5 MeV bump”)

RAA best fit

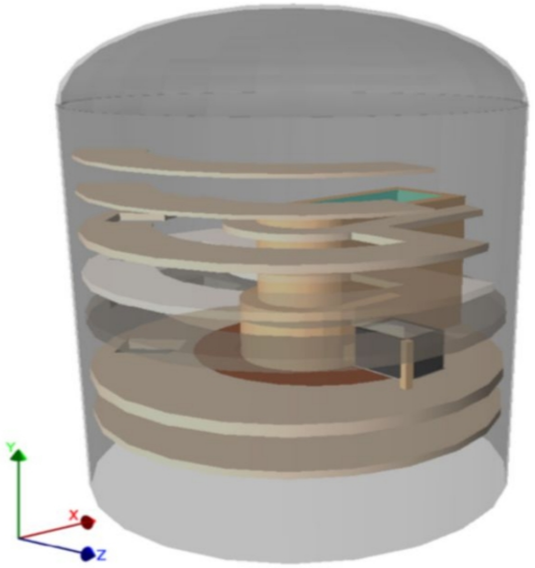


[G. Mention et al. Phys. Rev. D, 83 : 073006, Apr 2011.]

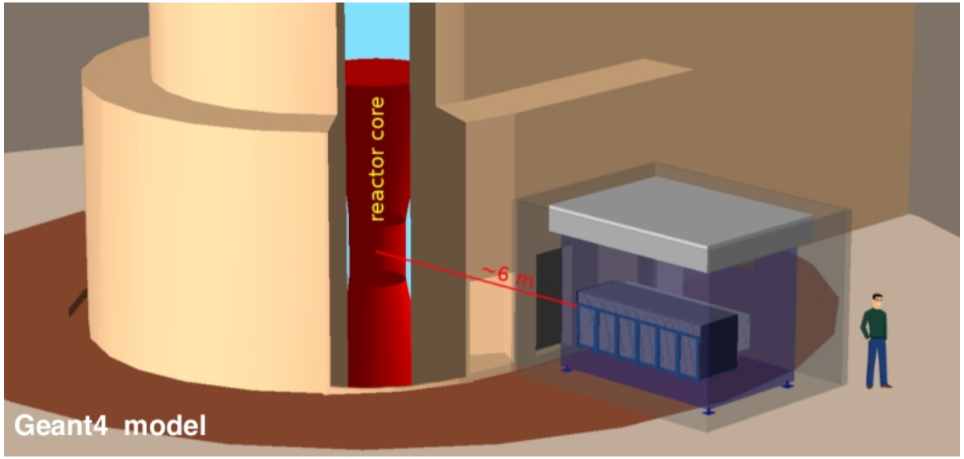


[G. Mention et al. Physics Letters B, 773 :307 – 312, 2017.]

BR2 reactor @ SCK·CEN



- Specifications of the research reactor
  - Thermal power: $P_{th} \approx 60$ MW
  - Antineutrino flux: 10^{19} $\bar{\nu}_e$/s
  - Fuel: 95.3% ^{235}U (99.7% of $\bar{\nu}_e$)
  - Compare core: Ø = 50 cm, h = 90 cm
  - Duty cycle: 50%



- SoLid experiment design goals
  - ~1000 $\bar{\nu}_e$ interactions / day
  - Energy resolution < 14 % @ 1 MeV
  - Baseline of 6 – 9 metres

SoLid detection technology

- The antineutrinos are detected through inverse beta decay (IBD)

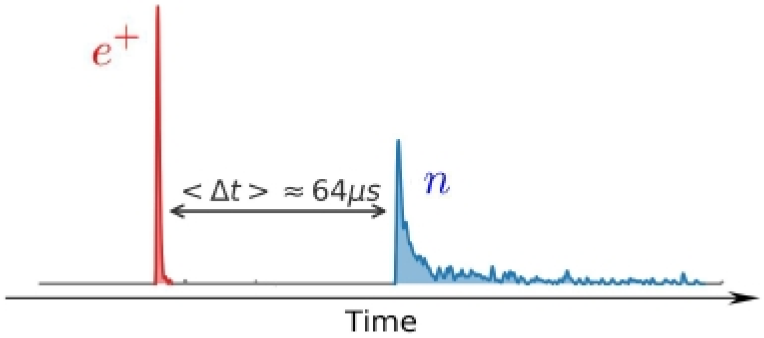
$$\bar{\nu}_e + p \to e^+ + n \quad (Q = -1,8\,\mathrm{MeV})$$

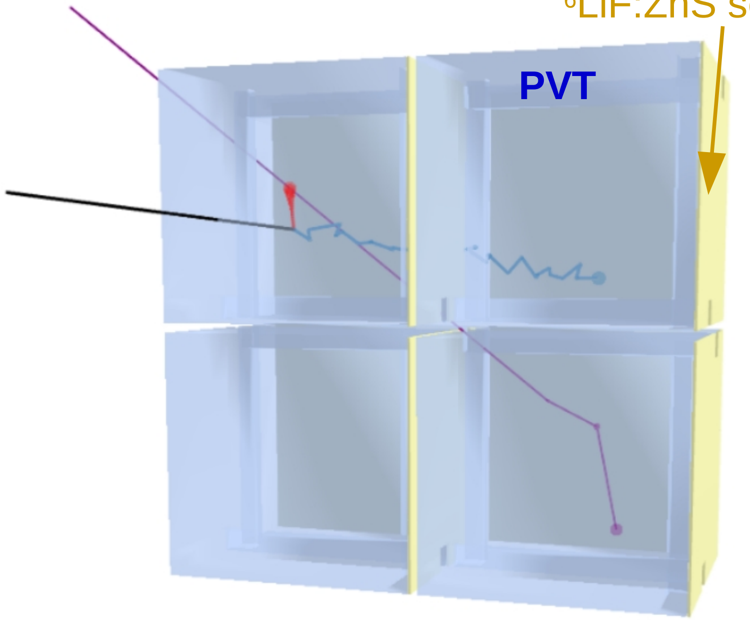
$$E_{\bar{\nu}_e} \approx E_{e^+} + 1,8\mathrm{MeV}$$

$$\vec{p}_{\bar{\nu}_e} \approx \vec{p}_n$$

- The neutron is absorbed by the ^{6}Li

$$n + {}^6\mathrm{Li} \to {}^3\mathrm{H} + \alpha \quad (Q = 4,8\,\mathrm{MeV})$$

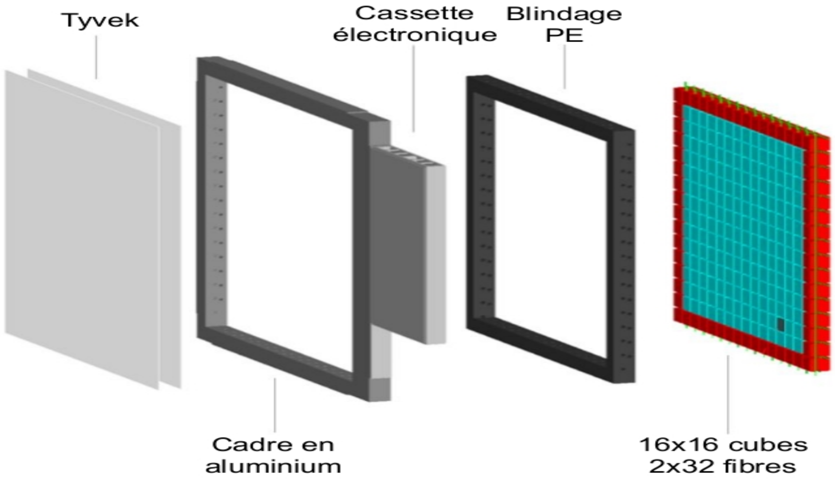


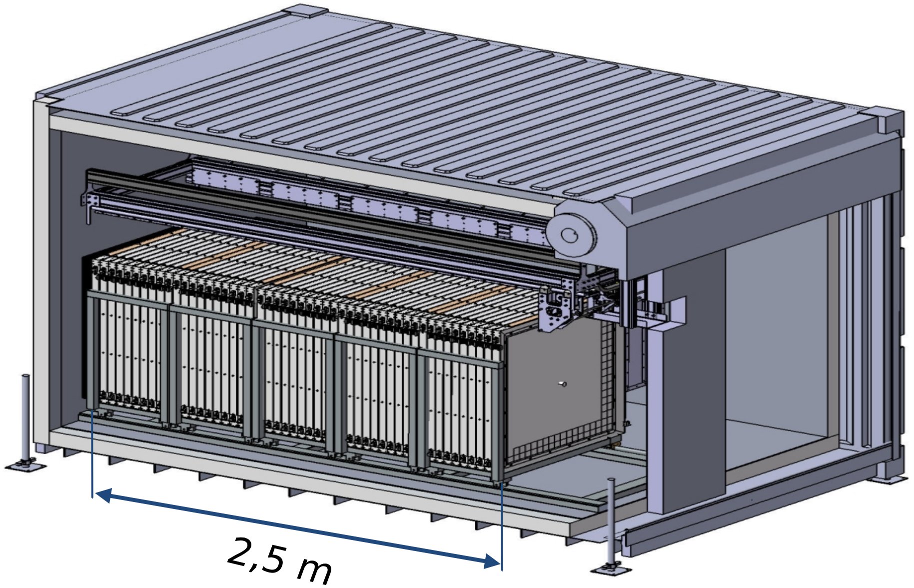


- ZnS and PVT pulse shape discrimination
  → positron and neutron discrimination
- Time and space coincidence
  → background rejection

SoLid Phase 1 detector

- 1,6 ton; 12800 cubes; 50 planes
- Each plane is composed of:
  - 256 cubes (16x16), optically isolated
  - 64 readout fibres + photon counters (MPPCs)





- 5 modules of 10 planes
- Positioned on rails in cooled container (10 °C)

History of the SoLid Phase 1 detector and publications

December 2016

STARTED CONSTRUCTION

JINST 12 P04024 technology

November 2017

DETECTOR SHIPMENT & INSTALLATION AT BR2

December 2017

DETECTOR COMMISSIONING AT BR2 WITH 4 MODULES

JINST 13 P05005 Results of the full-scale prototype

April 2018

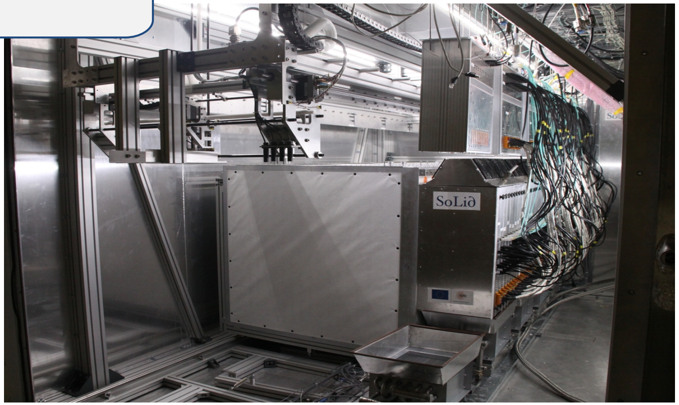
START DATA TAKING WITH FULL PHASE I DETECTOR

JINST 13 P09005 Light yield and uniformity

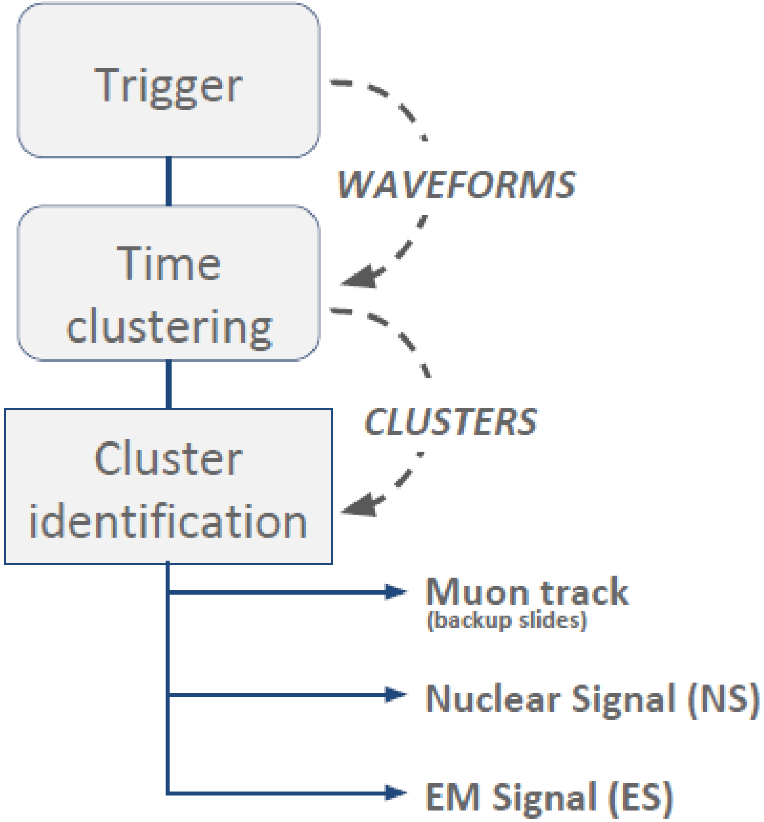
JINST 14 P02014 Quality assurance

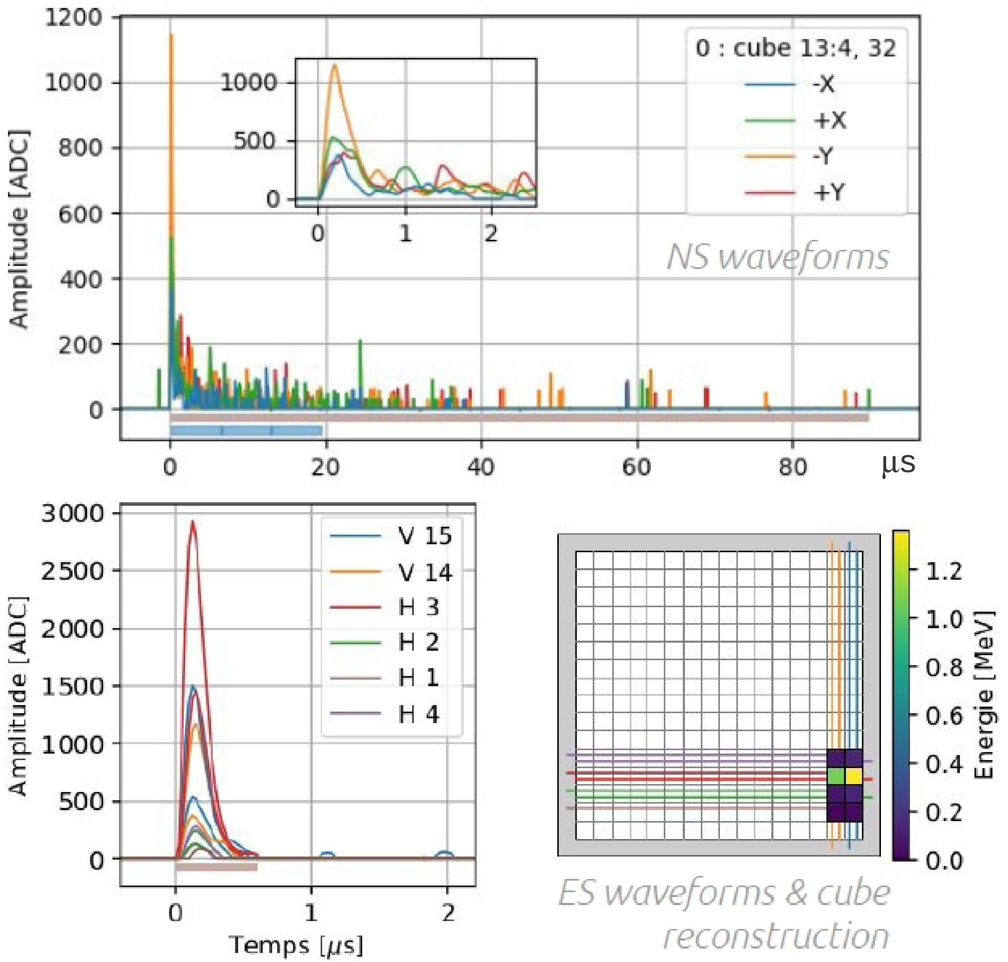
Up to today

DETECTOR RESPONSE AND BACKGROUND UNDERSTANDING

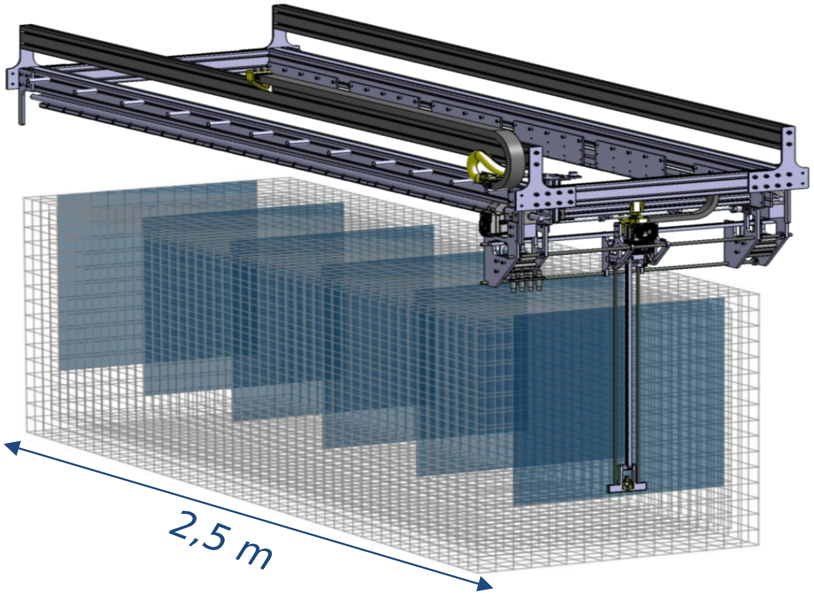


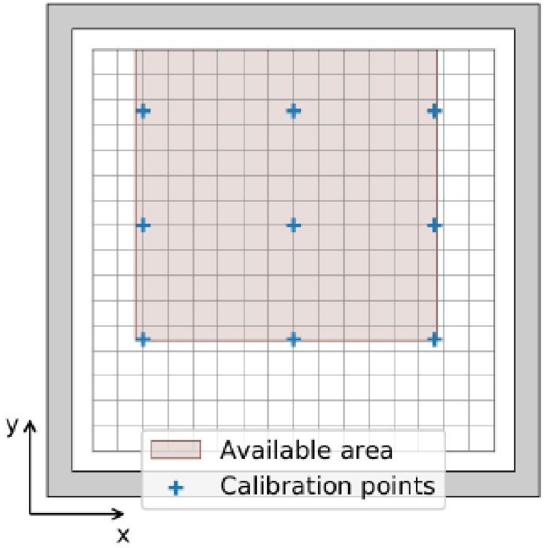
Data reconstruction





Calibration system: CROSS





CROSS:

- 3D calibration arm holding a radioactive source for calibration
- Can move over modules and lowered between two modules
  (i.e. 6 locations where it is lowered)

Very good coverage of the detector volume:

9 measurement points for every gap

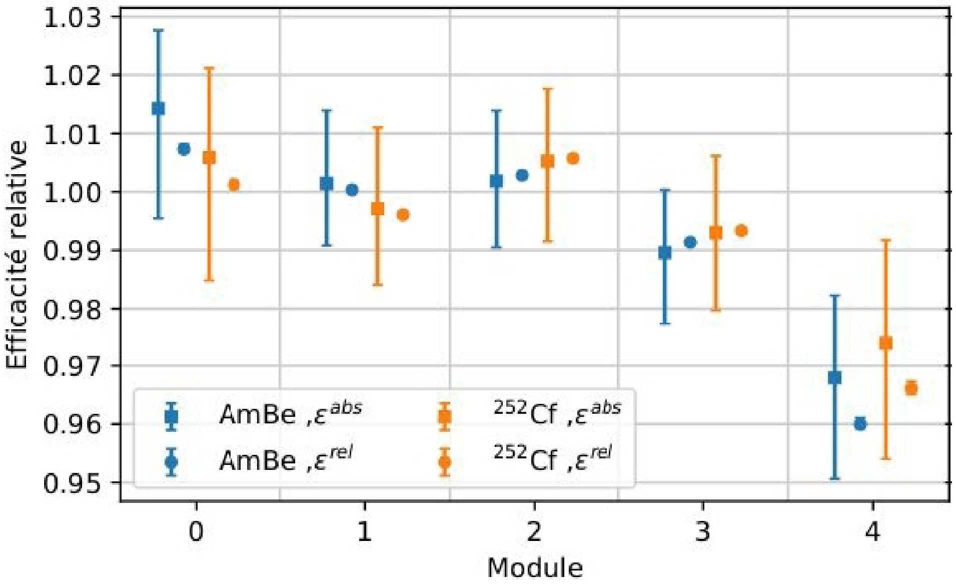
Calibration results

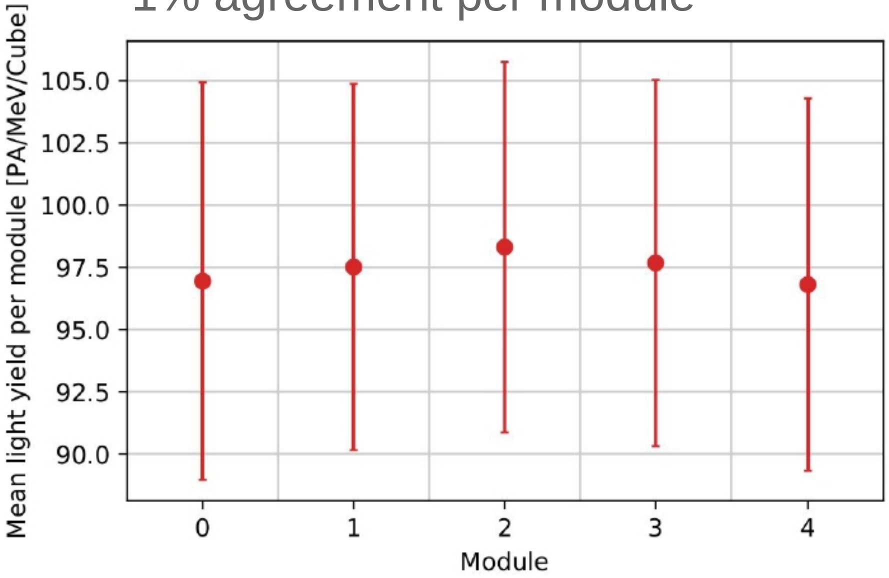
Neutron detection efficiency:

- 2 radioactive sources: AmBe & ^{252}Cf
- Absolute measurement (comparison with MC): $\epsilon_{n\,IBD}^{det} \approx 52\,\%$

Relative measurement:

- 1% agreement per module



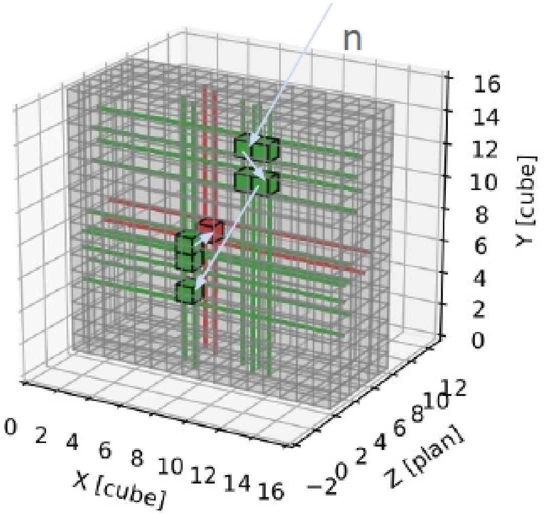


Light yield measurement:

- Compton edge fit (data/MC)
- Mean light yield of 97 PA/MeV/cube
- Energy resolution of ~12% at 1 MeV

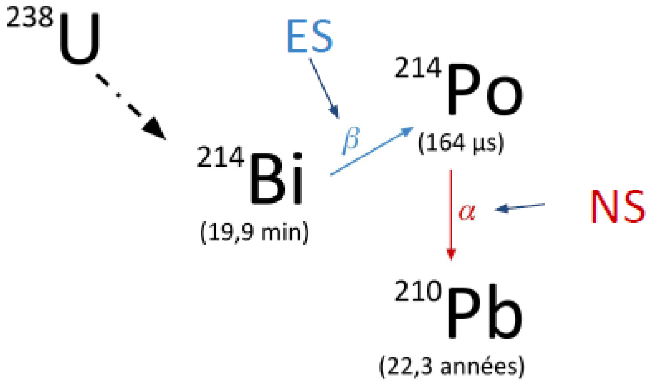
Time correlated backgrounds

Fast neutrons



- Fast neutrons entering the detector
- $\Delta t_{NS\text{-}ES}$ ~ 65 µs
- Rate varies with atmospheric pressure
- Broad range of possible topologies and energies

BiPo cascade



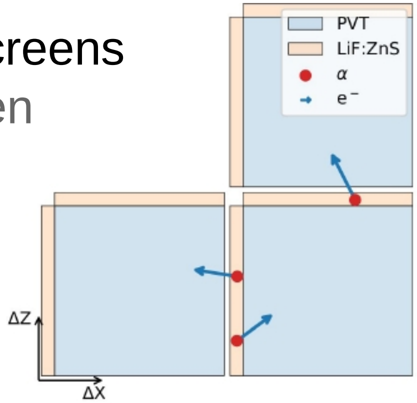
- Natural radioactivity
- $\Delta t_{NS\text{-}ES}$ = 164 µs
- Endpoint energy Q_β = 3.3 MeV

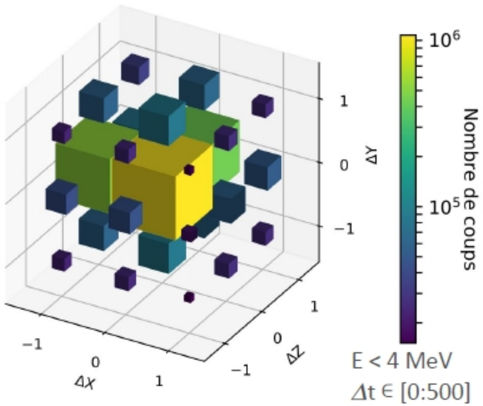
BiPo rejection: discrimination between α and neutron

- Radioactive contamination of LiF:ZnS screens

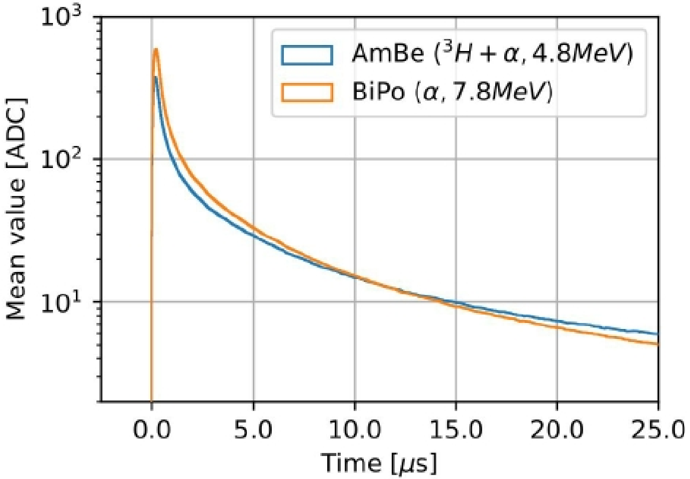
  NS signal comes from the α in the screen

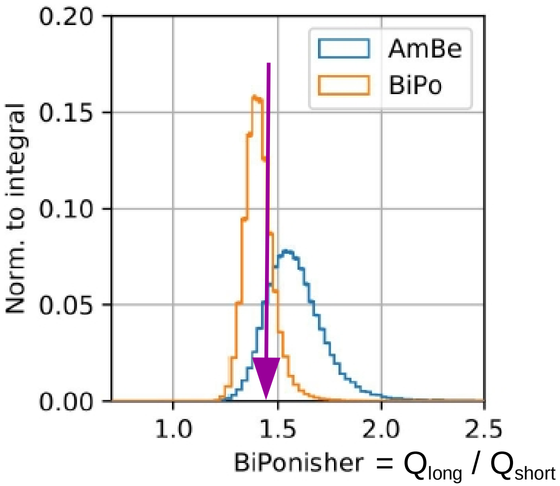
  → 3 main topologies





- α-n discrimination using the pulse shapes: BiPonisher = $Q_{long\ (0\text{-}87.5\ \mu s)}$ / $Q_{short\ (0\text{-}7.5\ \mu s)}$



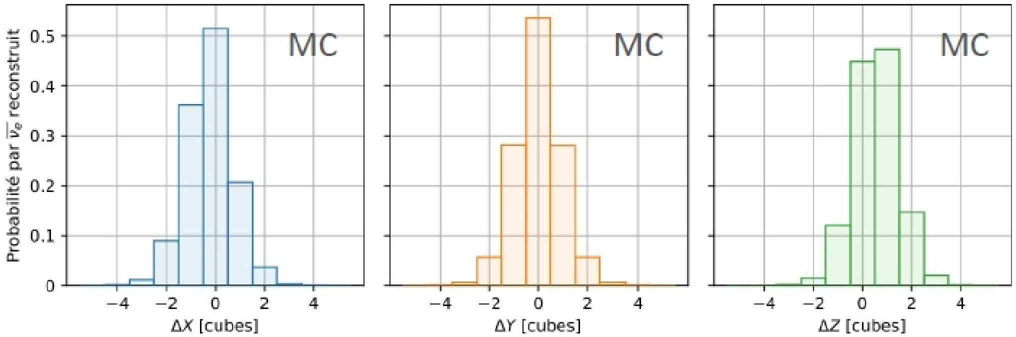


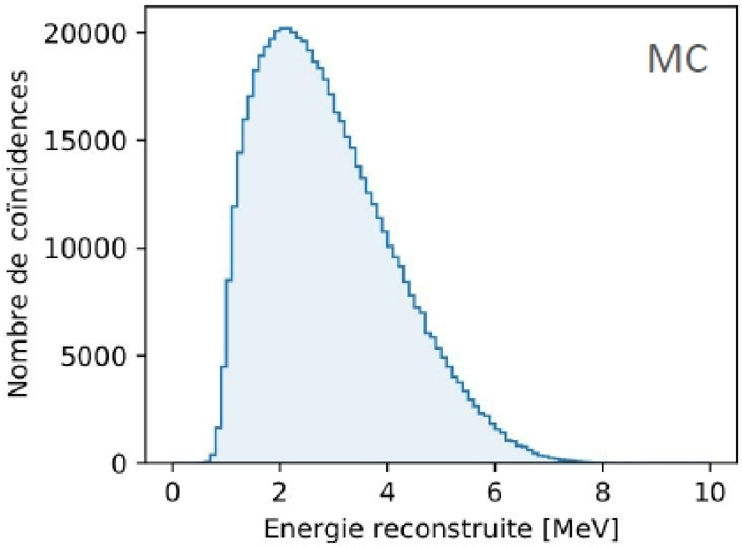
BiPonisher > 1.45:

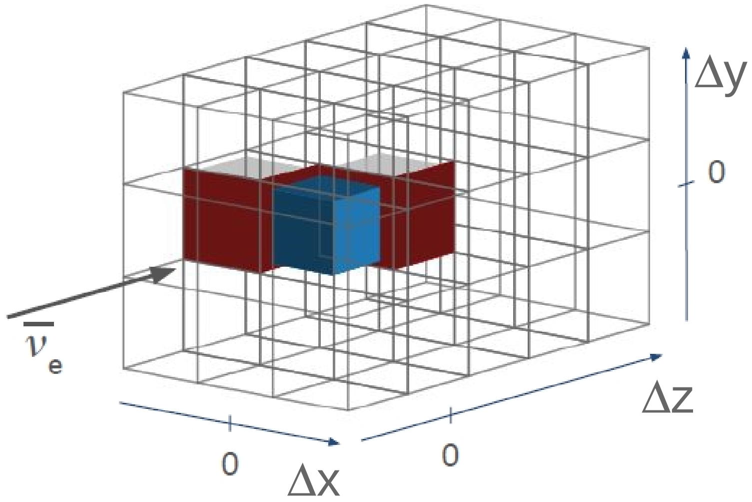
- Reject 75% of α
- Keep 85% of n

Main event selection requirements

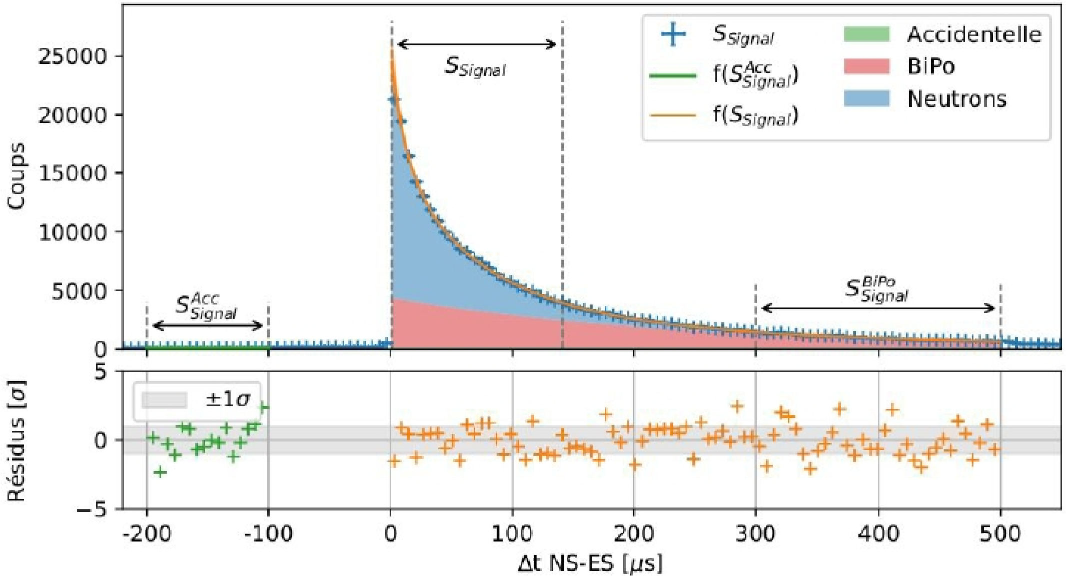
- Δx, Δy and Δz requirements optimized using simulation to reject topologies dominated by BiPo
- BiPonisher > 1.45
- Energy between 2 and 8 MeV





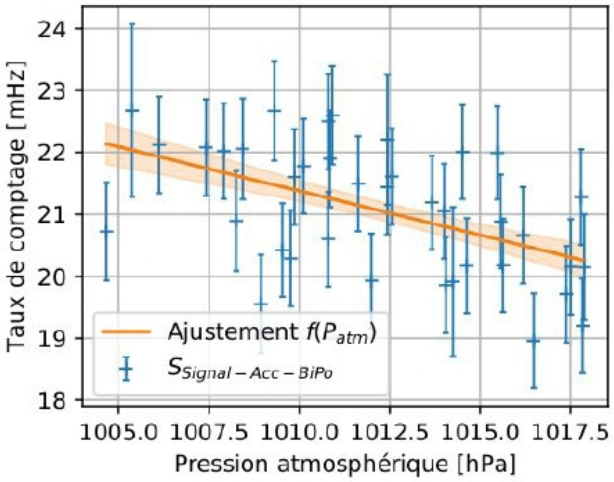


Background monitoring using the $\Delta t_{NS\text{-}ES}$ distribution



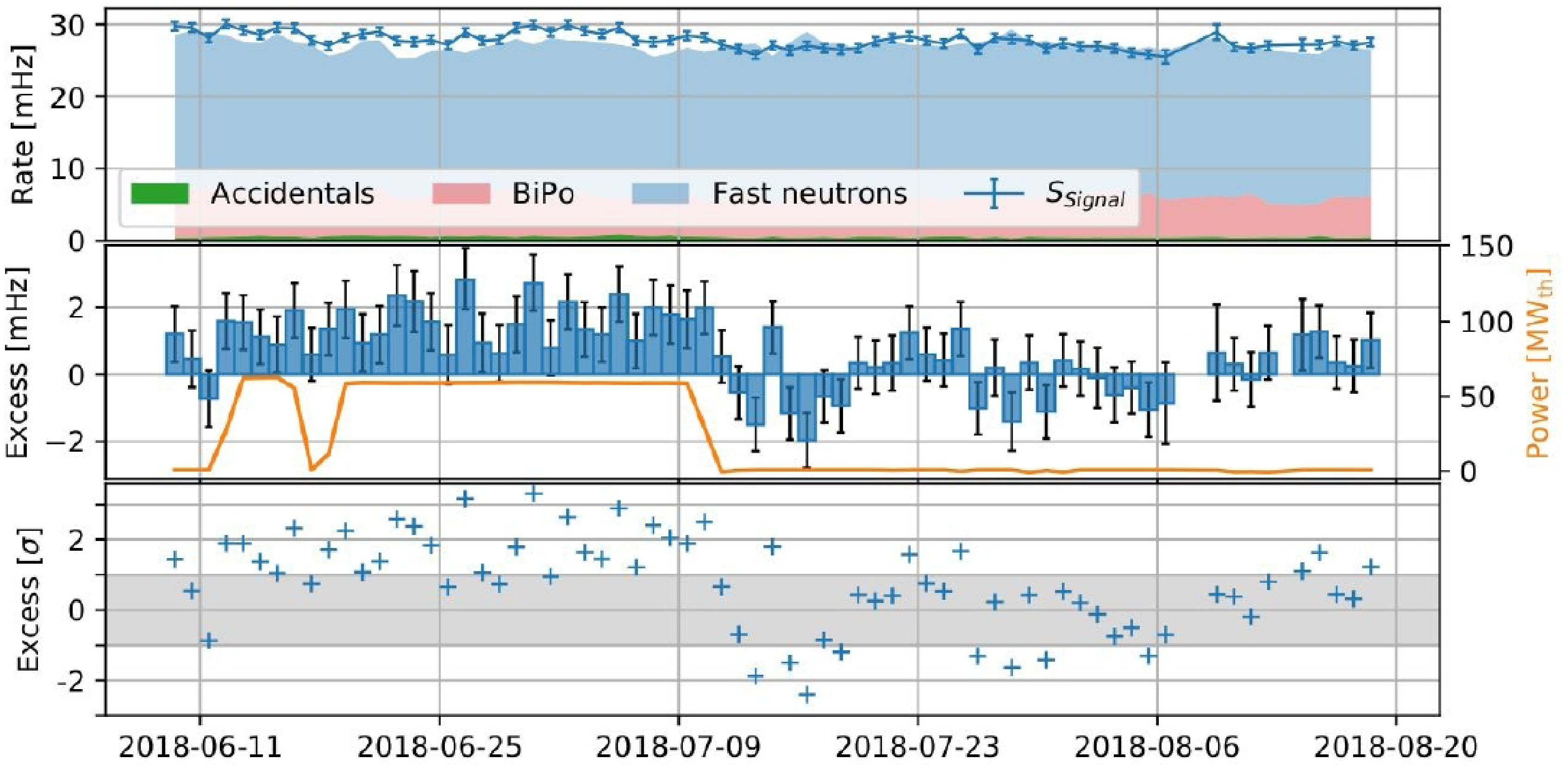
- Different $\Delta t_{NS\text{-}ES}$ windows for background monitoring:
  - IBD signal: [1,141] µs
  - BiPo: [300,500] µs
  - Accidentals: [-200,-100] µs

- Fast neutron estimation in the signal $\Delta t_{ES\text{-}NS}$ range:
  - Total reactor off – BiPo – accidental = fast neutron
  - Depends on the atmospheric pressure → fit the relation using reactor off data
  - Use this relation to predict the fast neutron rate when the reactor is on



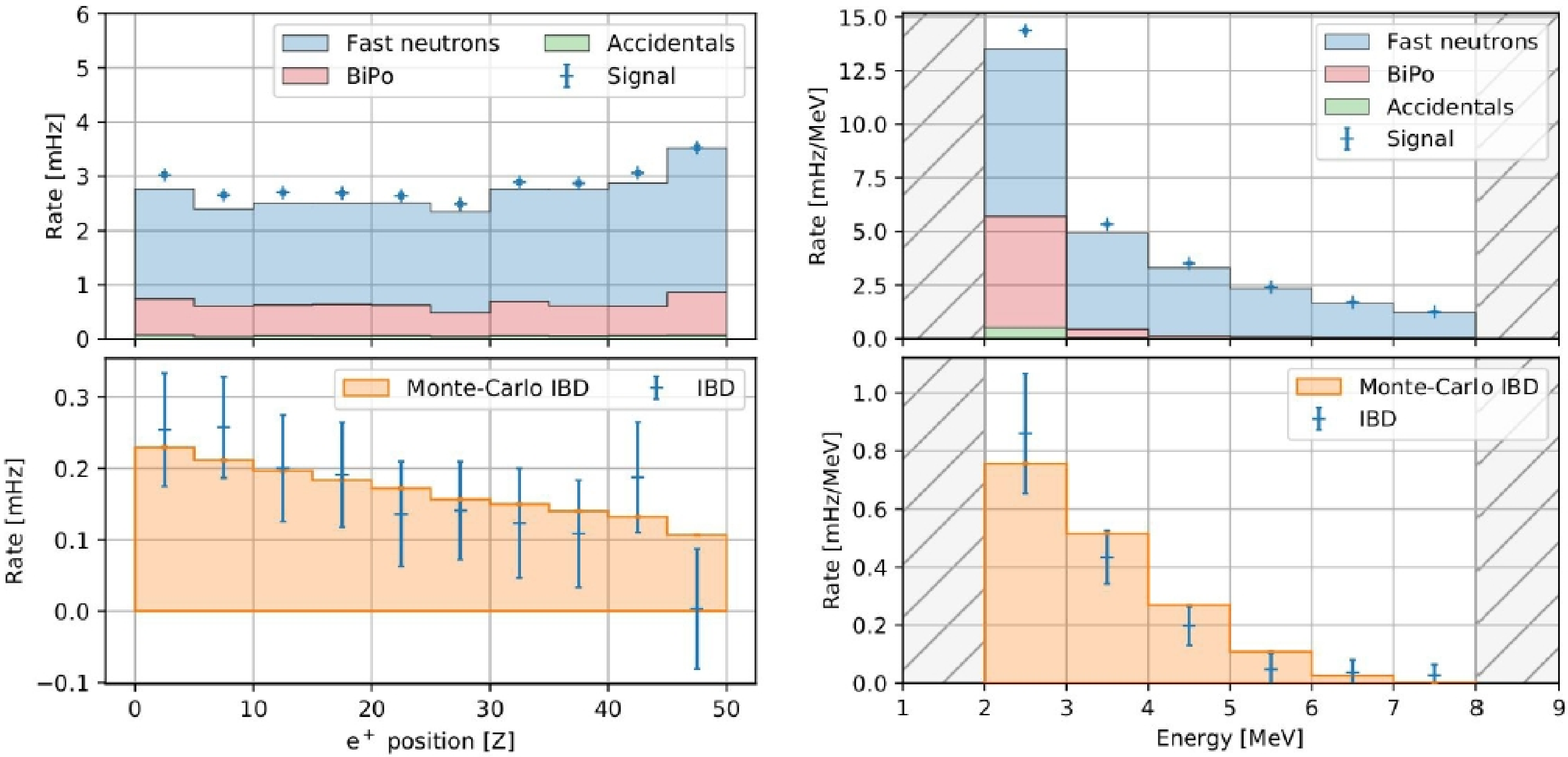
Test of the background model with the open dataset

Open dataset : 21,5 days reactor On 34,5 days reactor Off



Excess of ~140 events/day → 5.4σ significance over the whole period using open dataset

IBD signal position and energy distribution



Agreement with the simulation → optimize analysis further and open more data

IIHE contributions

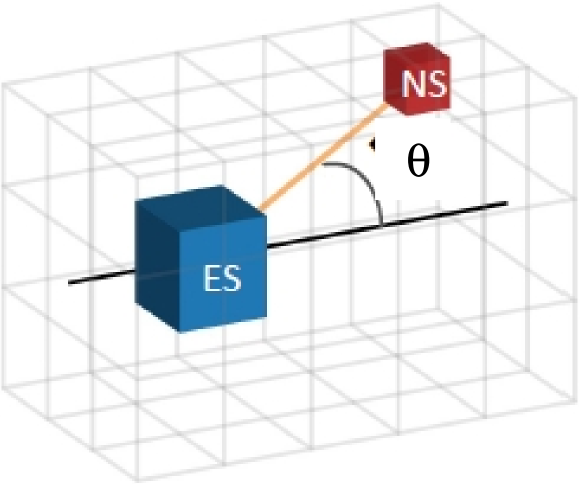
- Physics
  - Data reconstruction, muon and neutron identification
  - Lead the initial background studies and oscillation analysis
  - Procedure for fast neutron estimation and relation with environmental parameters
  - Contributions to the optimization of the event selection requirements for the first observation of the reactor $\bar{\nu}_e$ with the SoLid experiment
  - Publication & conference committee (reviewing the publications and public material)
- Construction (→ *Annemie and Jan*) / commissioning / shifts
- Computing → *IIHE computing team*
  - T2 used as primary data storage, raw data processing, MC production, data analysis, ...
  - Host of the website for internal documentation
- Hosted two collaboration meetings at the IIHE (→ *Marleen*)

SoLid Collaboration meeting @IIHE in September 2019

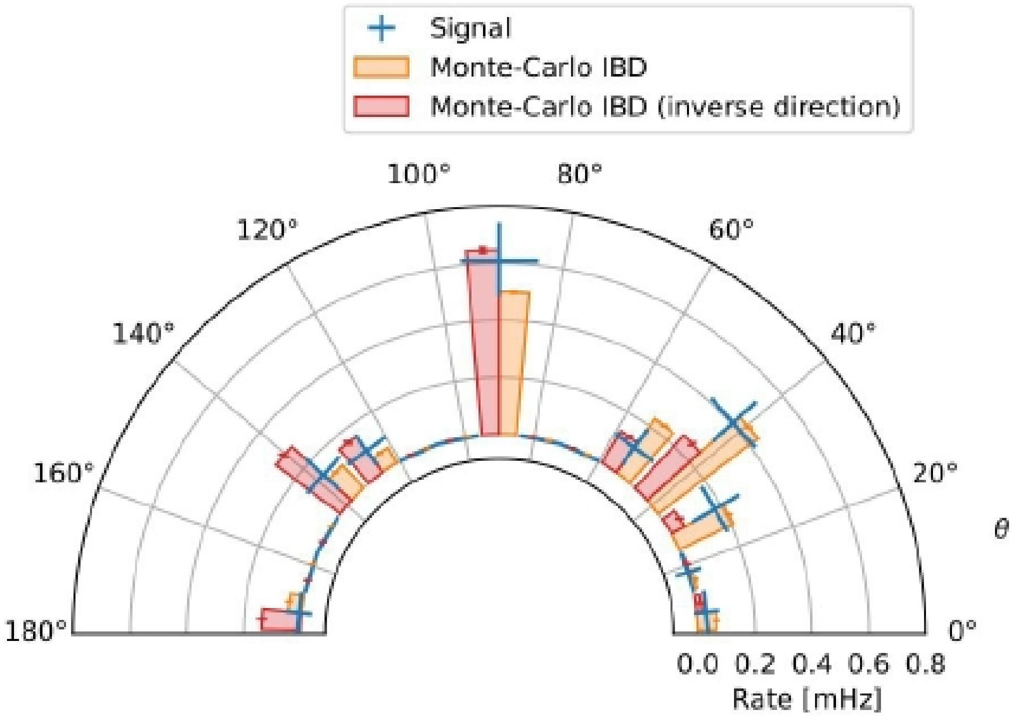
Summary and outlook

- Taking data with the SoLid experiment since April 2018
  - Good understanding of the detector response and stability
  - Calibration under control
- Preliminary analysis with only 1 cycle:
  - Enough knowledge about the background to develop predictive models
  - Ability to extract an antineutrino signal
  - Good agreement with the simulation (acceptance, energy, topology)
- Preparing the next steps:
  - Optimize the selection requirements (higher efficiency, better background rejection)
  - Open a larger dataset
  - Perform the first oscillation analysis with the SoLid experiment

IBD signal: directionality

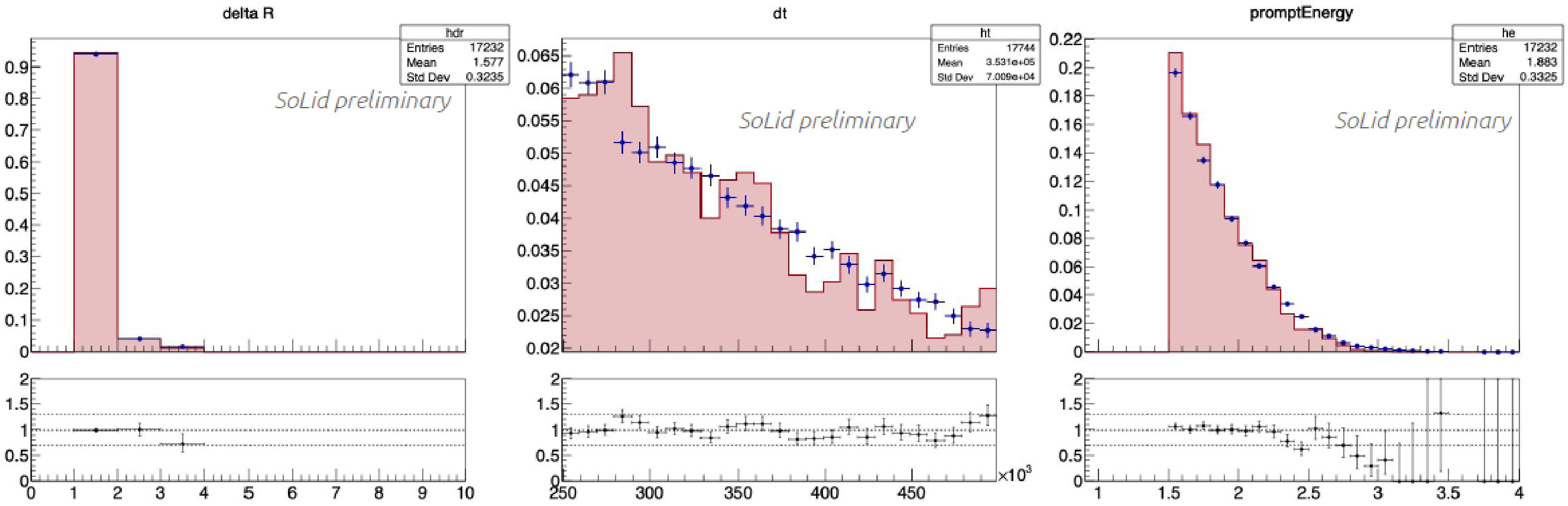


Neutron keep the $\overline{\nu_e}$ momentum



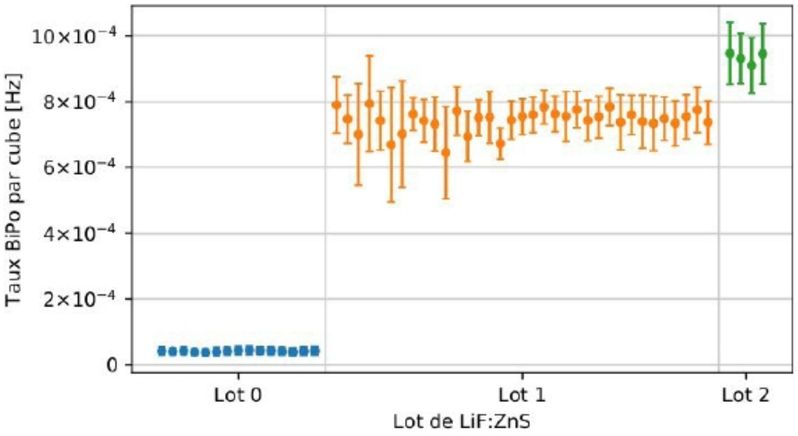
SoLid technology sensitive to $\overline{\nu_e}$ directionality

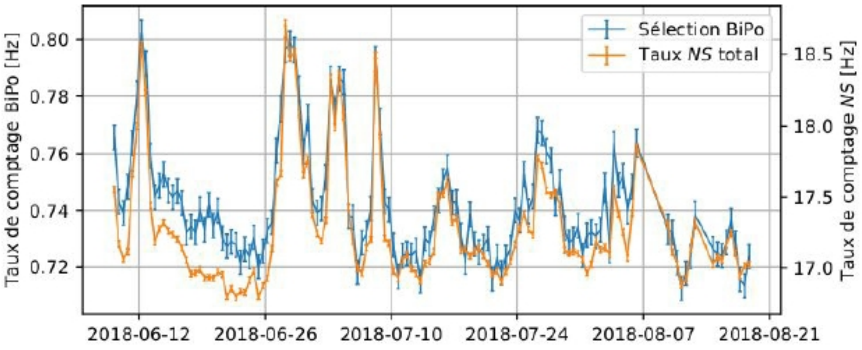
Data/MC comparison for BiPo

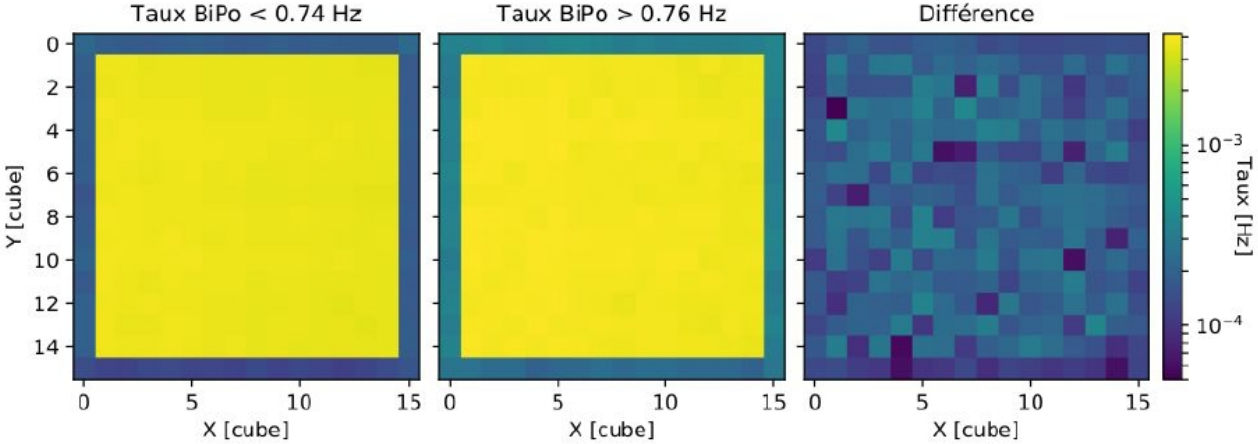


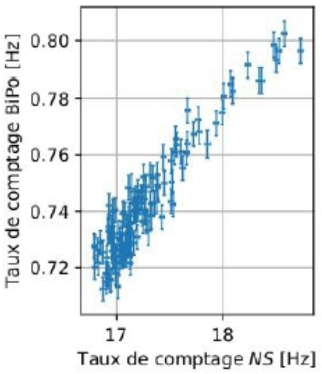
MC/Data comparisons of Δt, Δr and prompt E distributions show BiPo background is well understood.

BiPo contamination

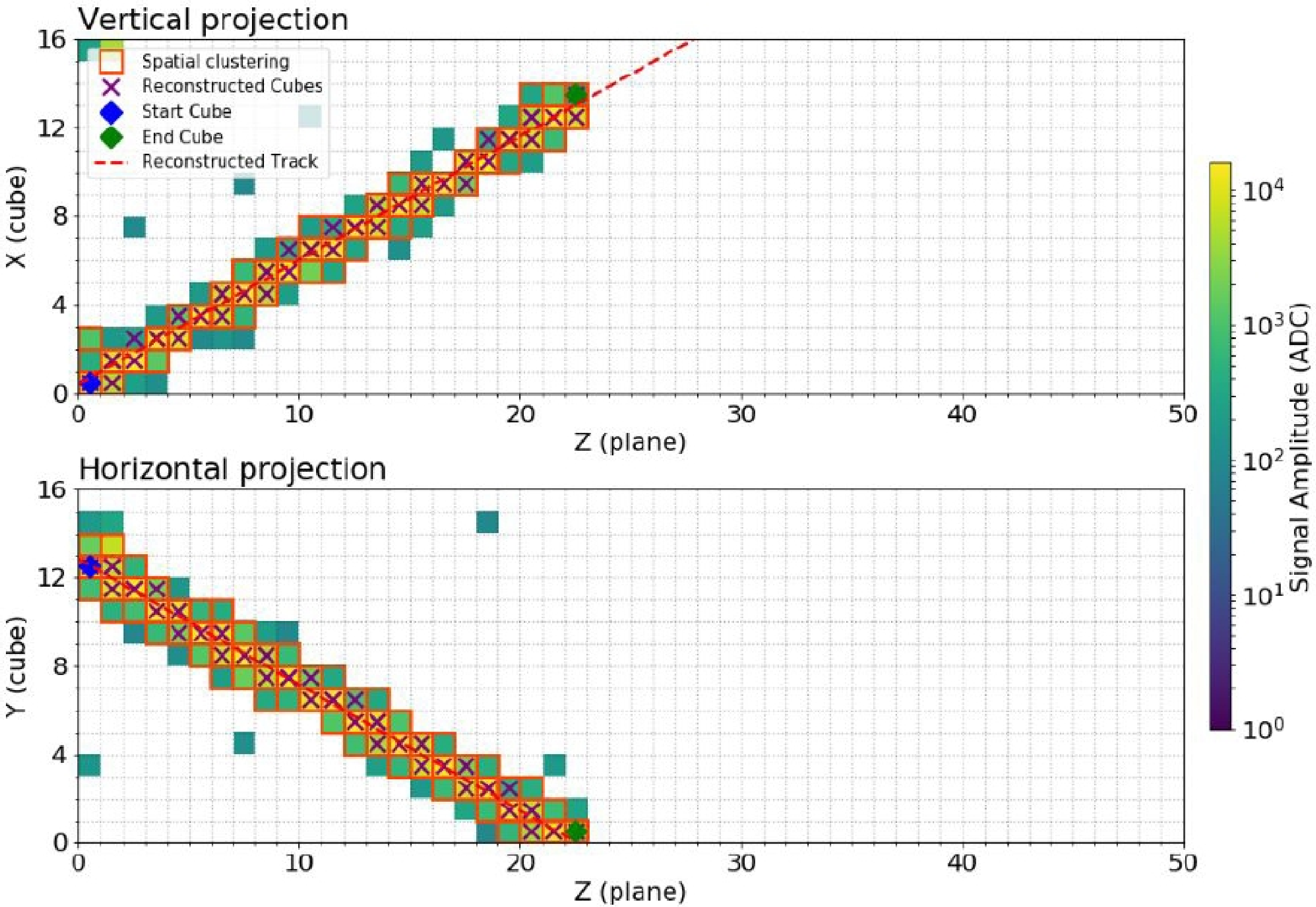








Muon track example



Light yield calibration

Light yield measurement :

- Compton edge fit (data/MC)
- Mean light yield of 97 PA/MeV/Cube
    - Energy resolution > 12% at 1 MeV