# Commissioning and calibration of the SoLid experiment

Nick van Remortel
University of Antwerp, Belgium
On behalf of the SoLid Collab.

Neutrino 2018, Heidelberg
June 8, 2018

# The SoLid Collaboration

4 countries 12 institutes ~50 people

Universiteit Antwerpen

lpc caen

Vrije Universiteit Brussel

LPC Laboratoire de Physique de Clermont

Universiteit Gent

Laboratoire de l'Accélérateur Linéaire

SCK•CEN Studiecentrum voor Kernenergie Centre d'Étude de l'Énergie Nucléaire

Subatech

University of Bristol

Imperial College London

University of Oxford

VirginiaTech Invent the Future

EOS The Excellence of Science

Belgian Science Policy Office belspo

foundation of public utility HERCULES STICHTING

Agence Nationale de la Recherche ANR

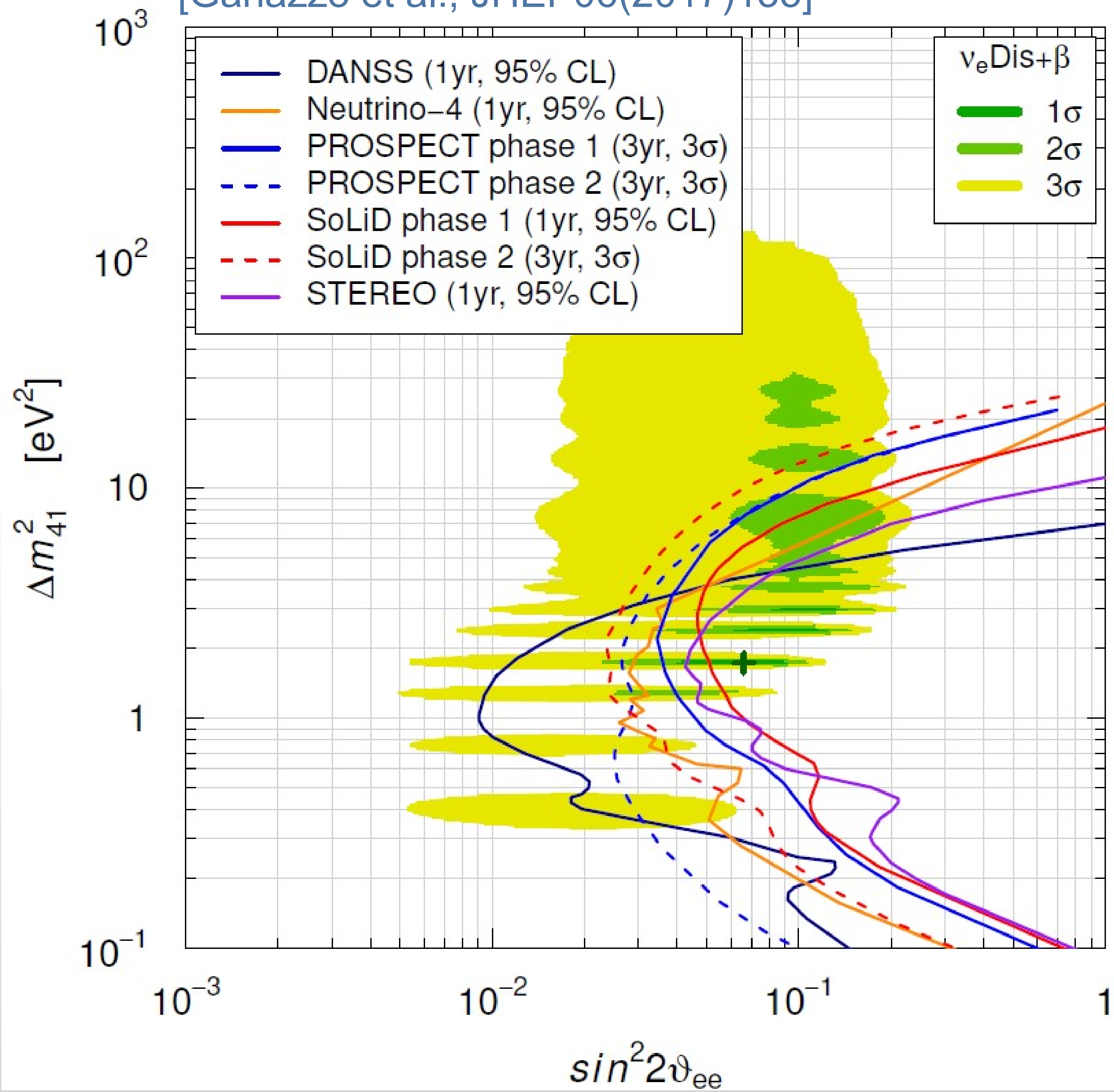
erc

PI A. Vacheret
CoG 682474 SOLID

# Motivation

- Establish or disprove new neutrino eigenstates at $\Delta m^2 \sim O(1\ eV^2)$, see also reactor- and gallium anomaly

[Gariazzo et al., JHEP06(2017)135]



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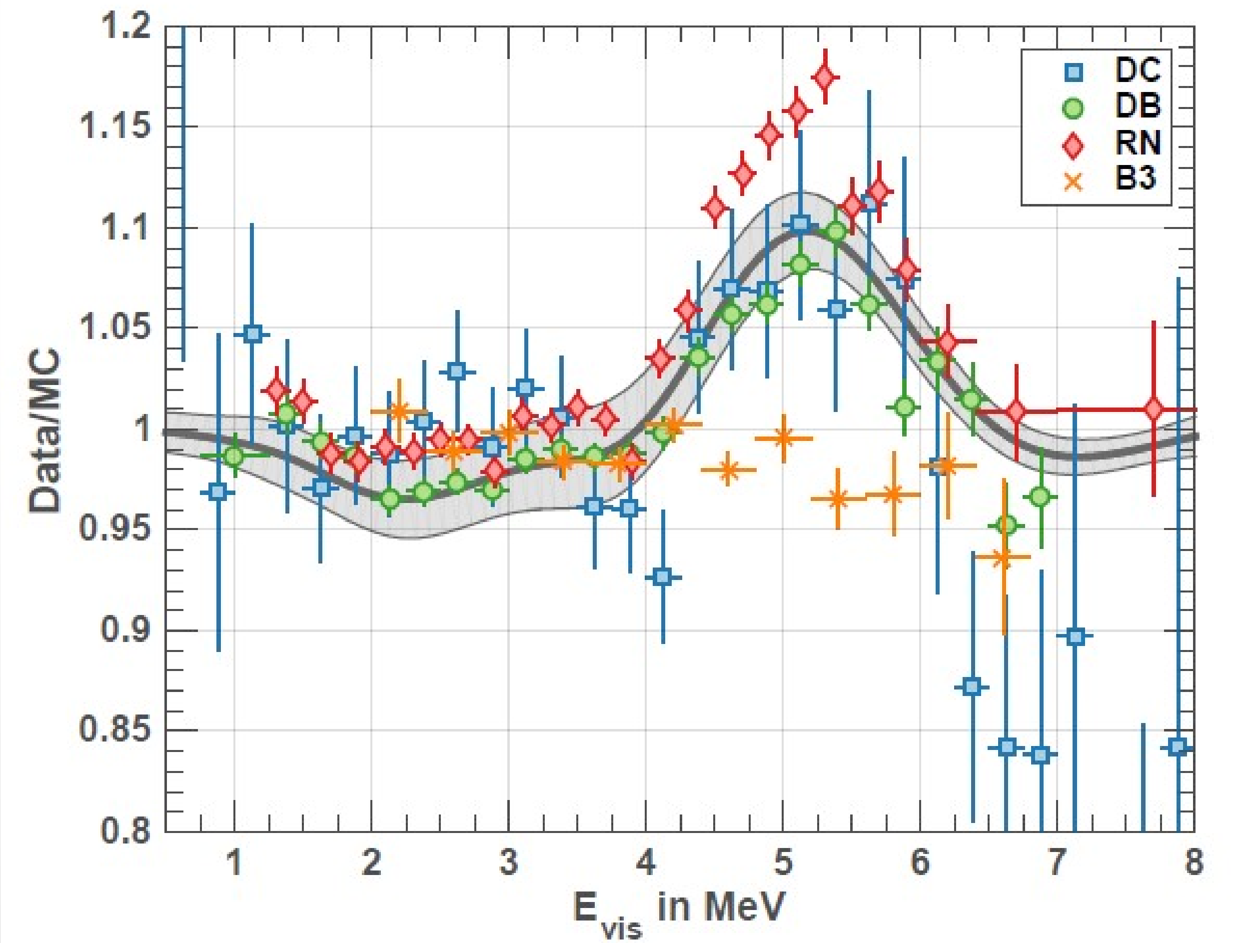
- Establish or disprove new neutrino eigenstates at $\Delta m^2 \sim O(1\ eV^2)$, see also reactor- and gallium anomaly
- Resolve discussion on spectral features observed by long baseline reactor expts using common fuels ($^{235}U$, $^{238}U$, $^{239}Pu$, $^{241}Pu$)

[G. Mention et al., Phys. Lett. B773(2017)307]



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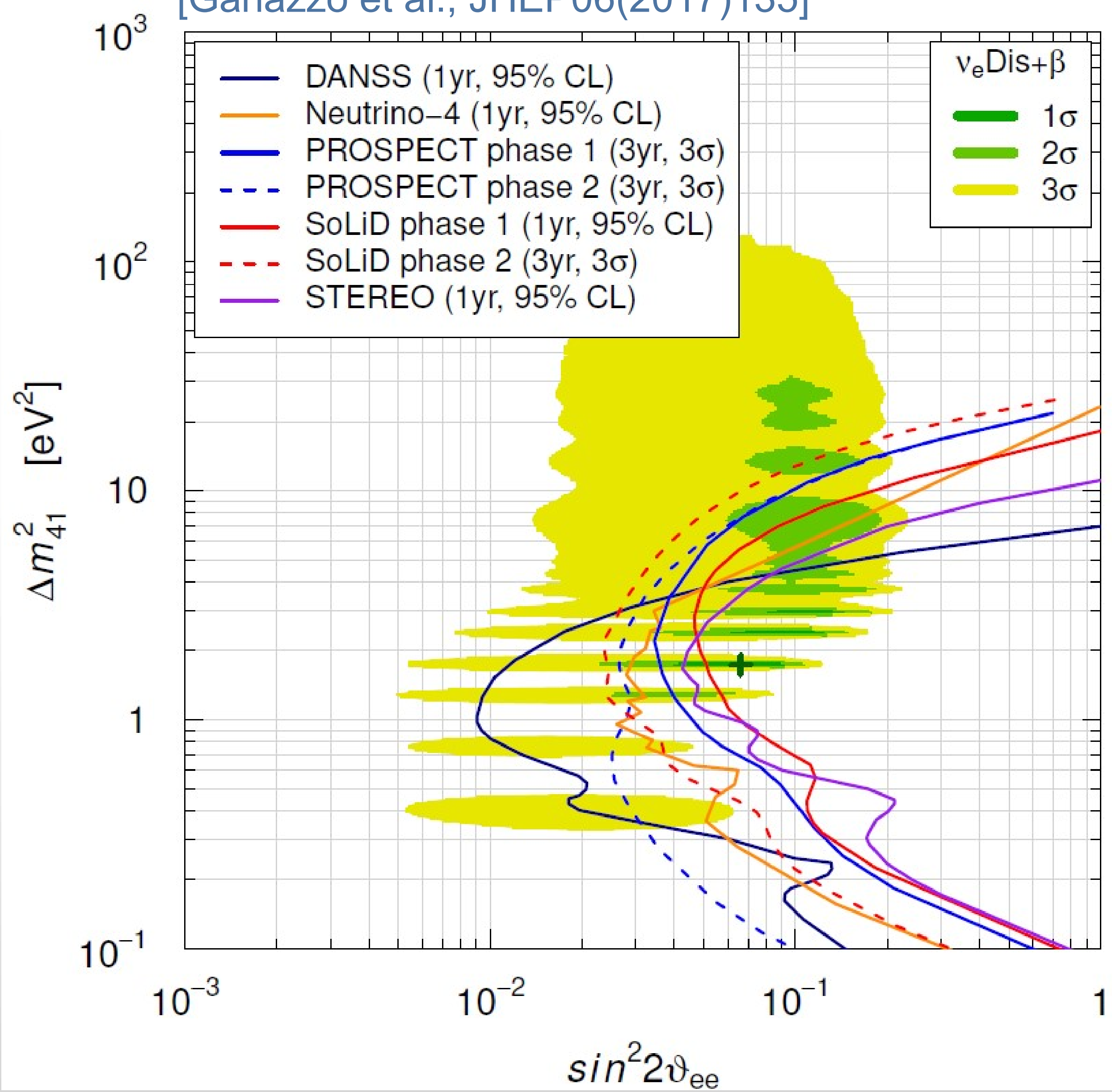
- Resolve discussion on spectral features observed by long baseline reactor expts using common fuels ($^{235}U$, $^{238}U$, $^{239}Pu$, $^{241}Pu$)
- Several experiments taking data since 2018!
- SoLid approach:
  - $\bar{\nu}_e$ energy measurement with plastic scintillator: Linear energy response (see eg. ESCAPE 2018)
  - Very small segmentation:
    - Topological event information & Bg reduction
    - 2D Oscillometry in E and L
  - Using highy enriched $^{235}U$ reactor fuel

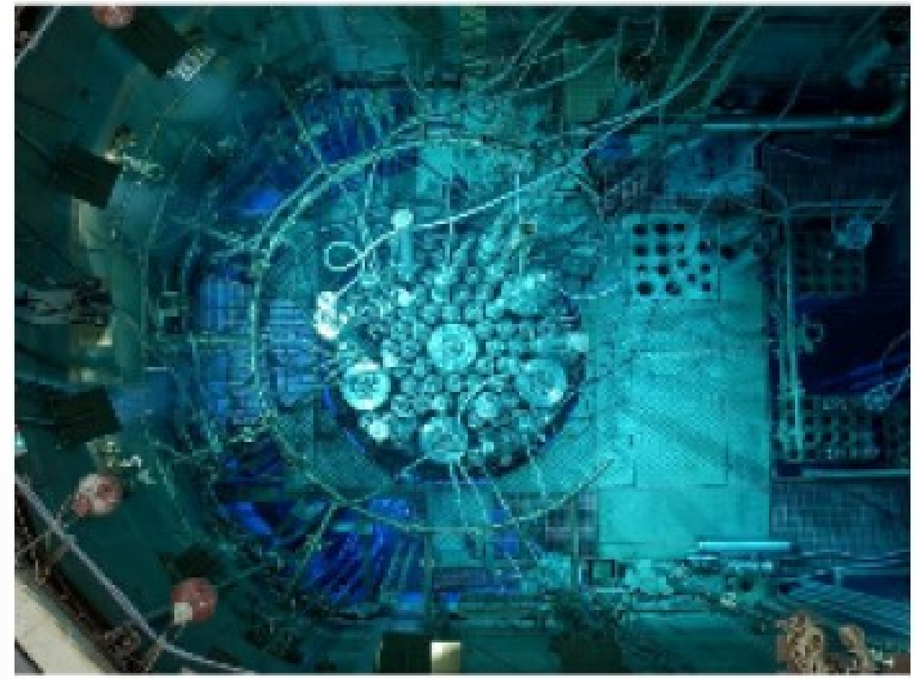
[Gariazzo et al., JHEP06(2017)135]

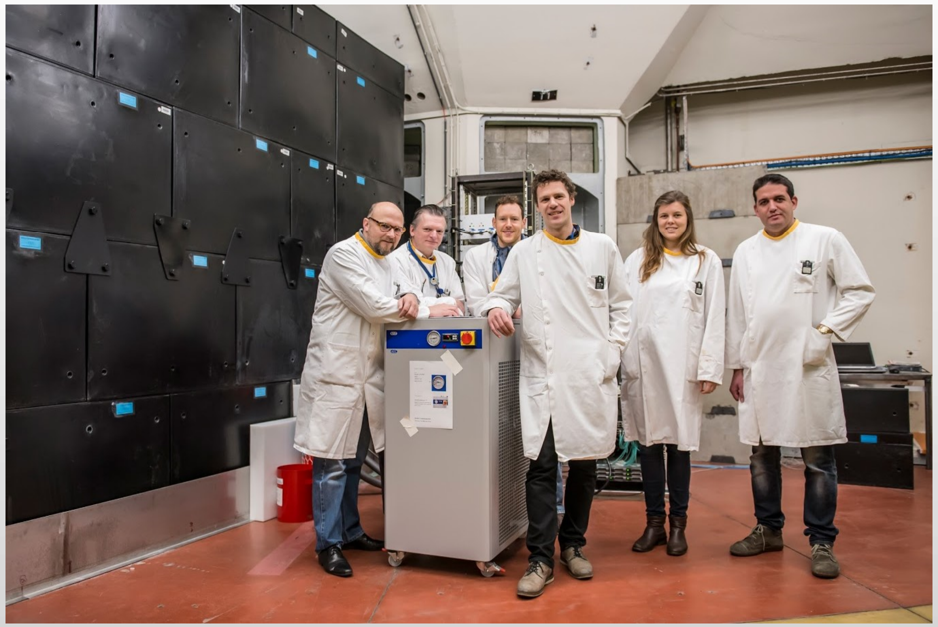


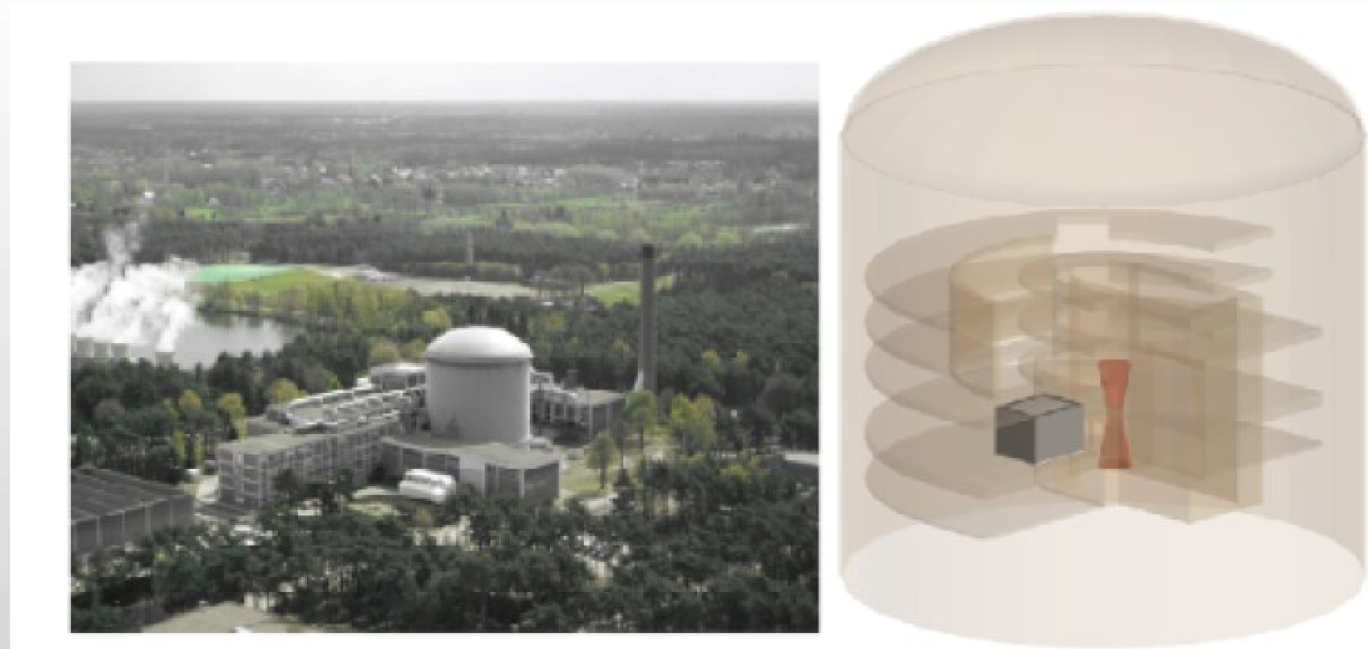
# BR2 nuclear site

- Compact research reactor
  - ∅ 50 cm and height 90 cm
  - Fuel 93.5% $^{235}$U
  - Thermal power 50-80 MW
  - Duty cycle 150 days/year (~ 1 month cycles)
  - SoLid at baseline 6-9 m

- At ground level
  - Overburden 10 mwe
  - Muon rate: O(250 Hz)
  - Cosmogenic neutrons
  - Natural radioactivity



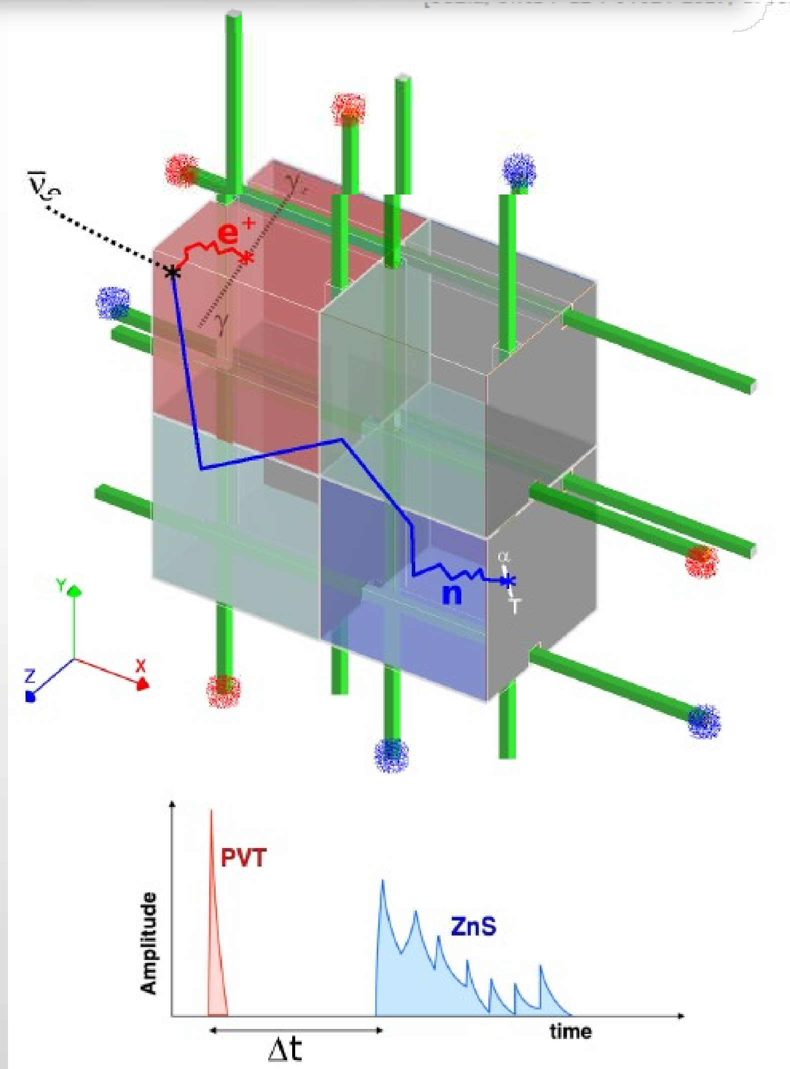




# SoLid detection principle

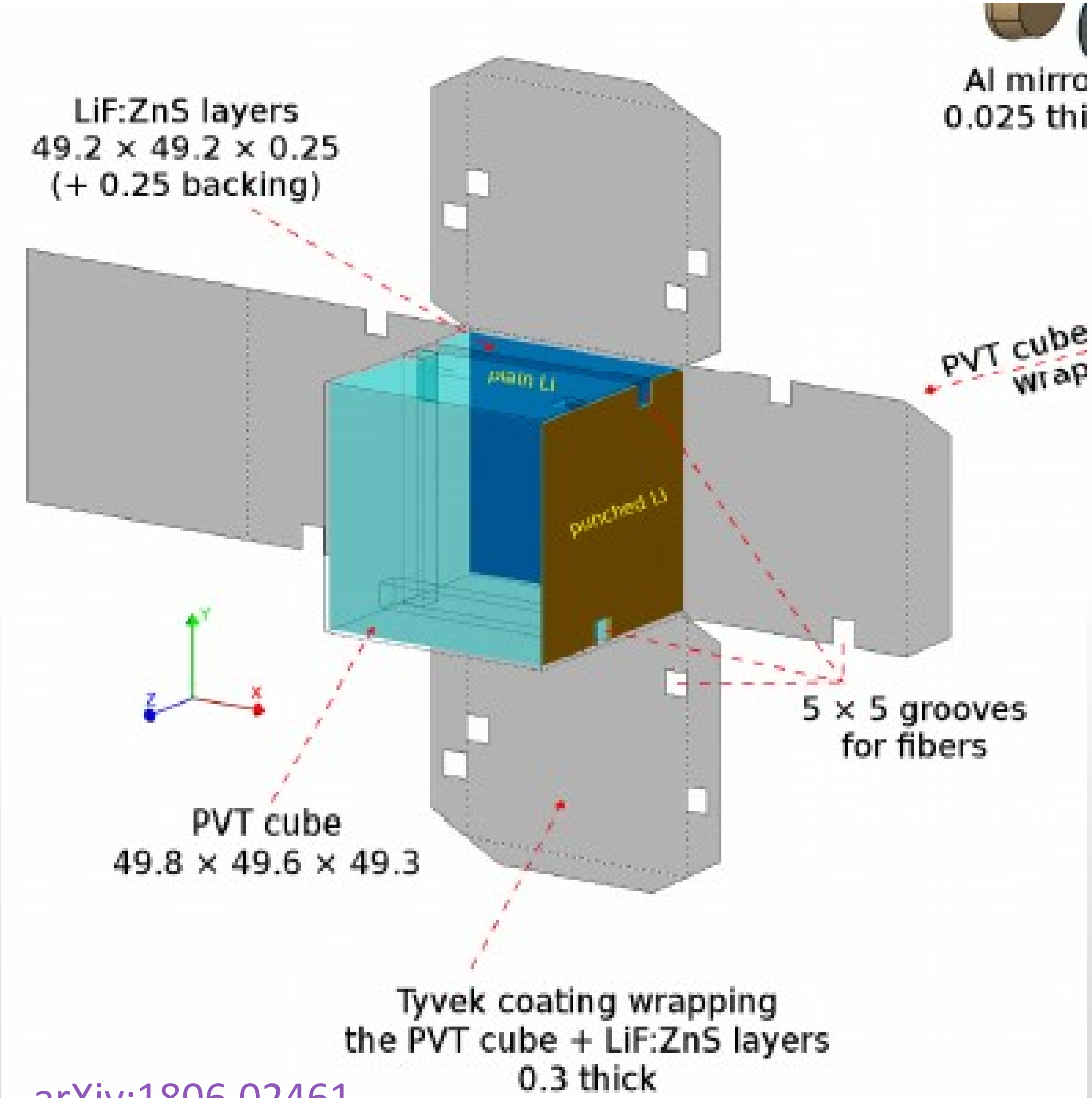
JINST 12 (2017) no.04, P04024
JINST 13 (2018) no.05, P05005

- Anti-electron-neutrinos detected through inverse beta decay (IBD) in the composite (PVT + $^{6}$LiF:ZnS) scintillator element
  $\bar{\nu}_e + p \rightarrow n + e^+$ $(E_{\bar{\nu}_e} > 1.8$ MeV)
- Prompt positron signal
  - Positron energy contained in one/two PVT cubes
  - Allows precise localisation of IBD interaction
  - Provides seed for anti-neutrino energy
- Delayed neutron signal
  - Neutron captured in $^{6}$LiF:ZnS close by
    $n + {}^{6}Li \rightarrow {}^{3}H + \alpha$ + 4.78 MeV
  - Capture time O(60 μs)
- Both signals
  - Collected by WLS fibers in X and Y directions and transported to MPPC for readout
  - Discrimination (ES – NS) based on pulse shape



# SoLid phase 1

- SoLid detector cells: Cubes
  - PVT cubes of 5x5x5 $cm^3$ with 2 $^6$LiF:ZnS neutron screens
  - Optically isolated with Tyvek wrapping




arXiv:1806.02461

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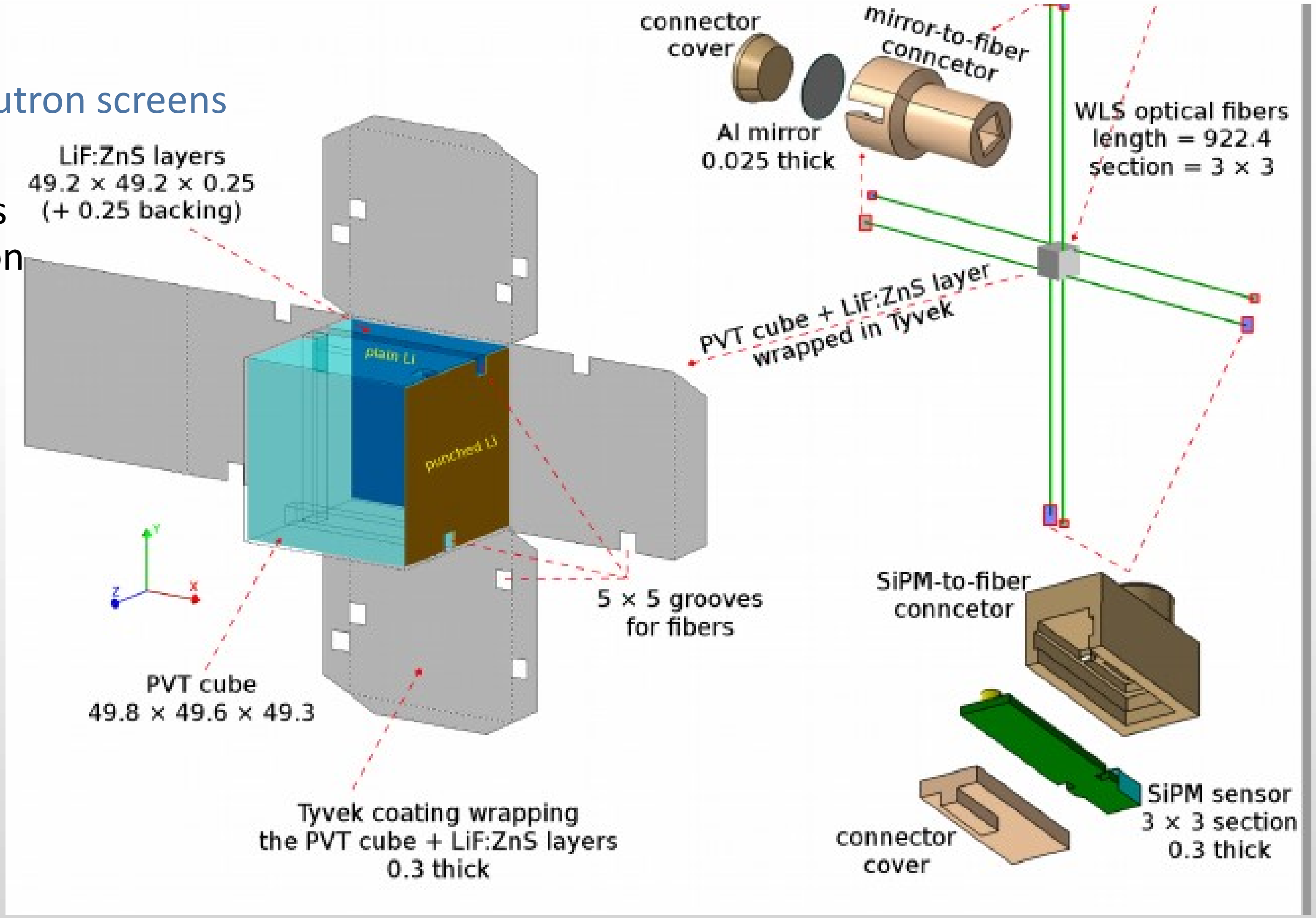

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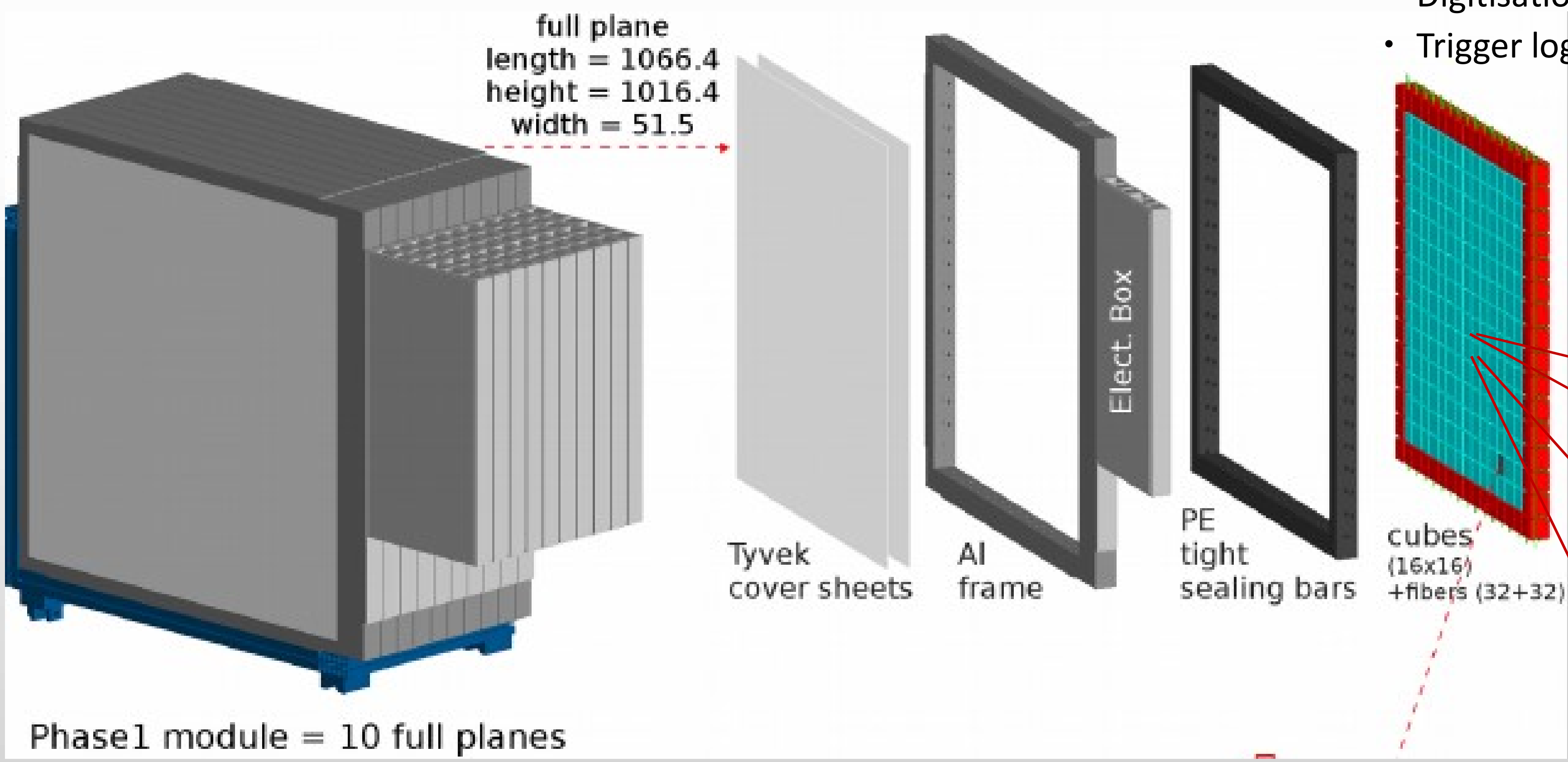
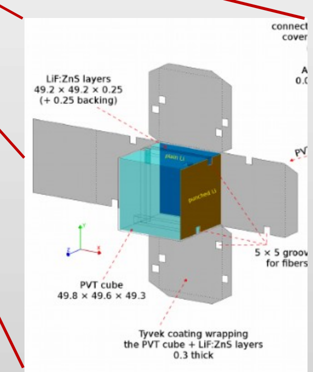
- SoLid detection planes
  - Planes of 16x16 cubes = 64 RO channels give 3D topological information
  - Plane readout & trigger:
    - amplification& shaping
    - Digitisation at 40 MHz - 2 Tb/s output for full detector
    - Trigger logic in FPGA
- SoLid detection Modules
  - 5 modules of 10 planes each
  - 1.6 ton sensitive mass

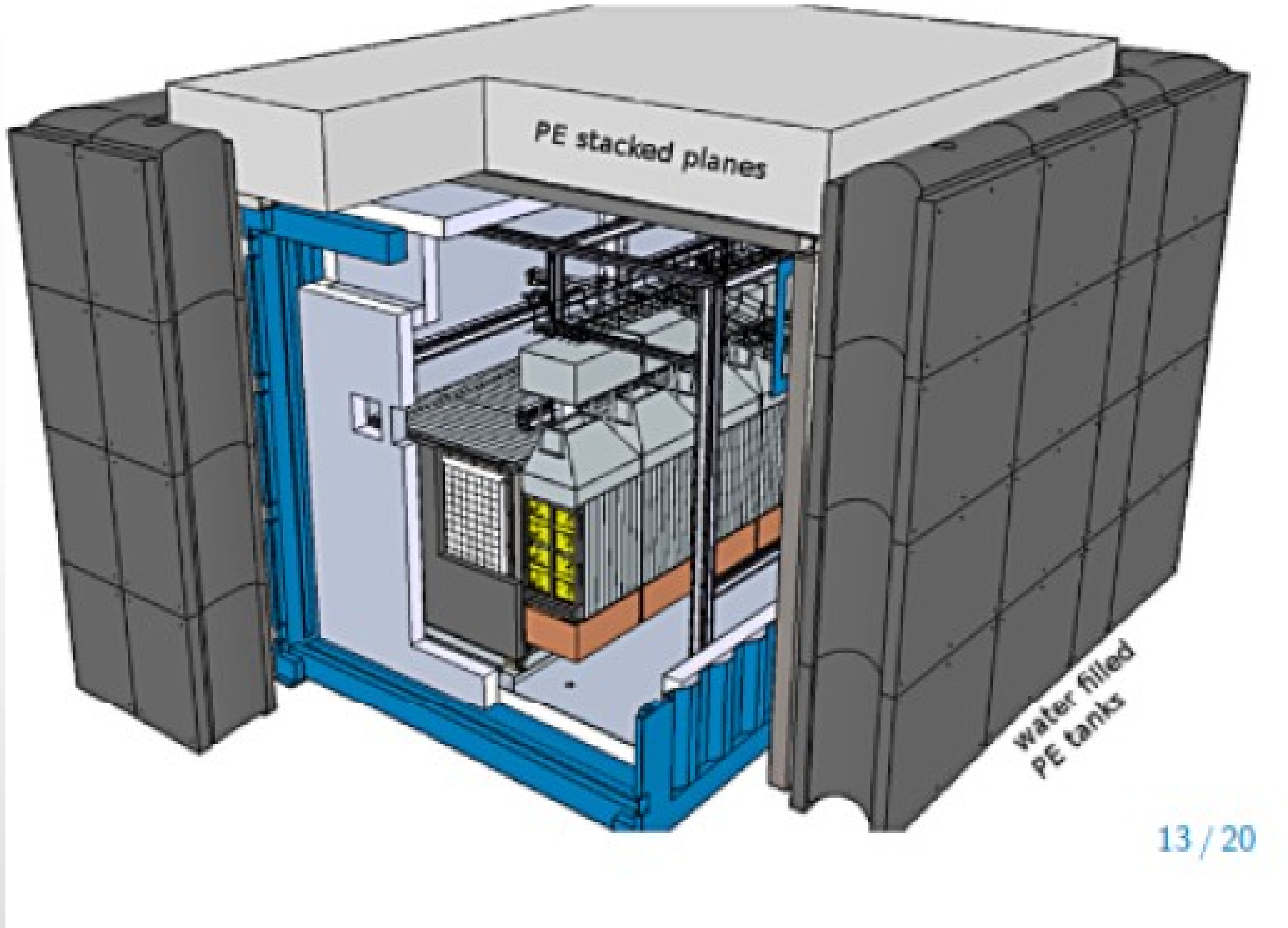


# SoLid Phase 1

- Container 2.4x2.6x3.8 $m^3$
  - Cooled to 10°C to reduce MPPC dark count rate (1/3)
- Shielding
  - Water enclosure 50cm thick, 3.4 m high, 28ton
  - Polyethylene ceiling 50cm thick, 6ton
  - Cadmium lining
- Automated calibration system for absolute efficiency and energy scale calibration at % level ($^{207}$Bi, $^{60}$Co, $^{137}$Cs, $^{22}$Na, AmBe, $^{252}$Cf)

  → Full G4 simulation



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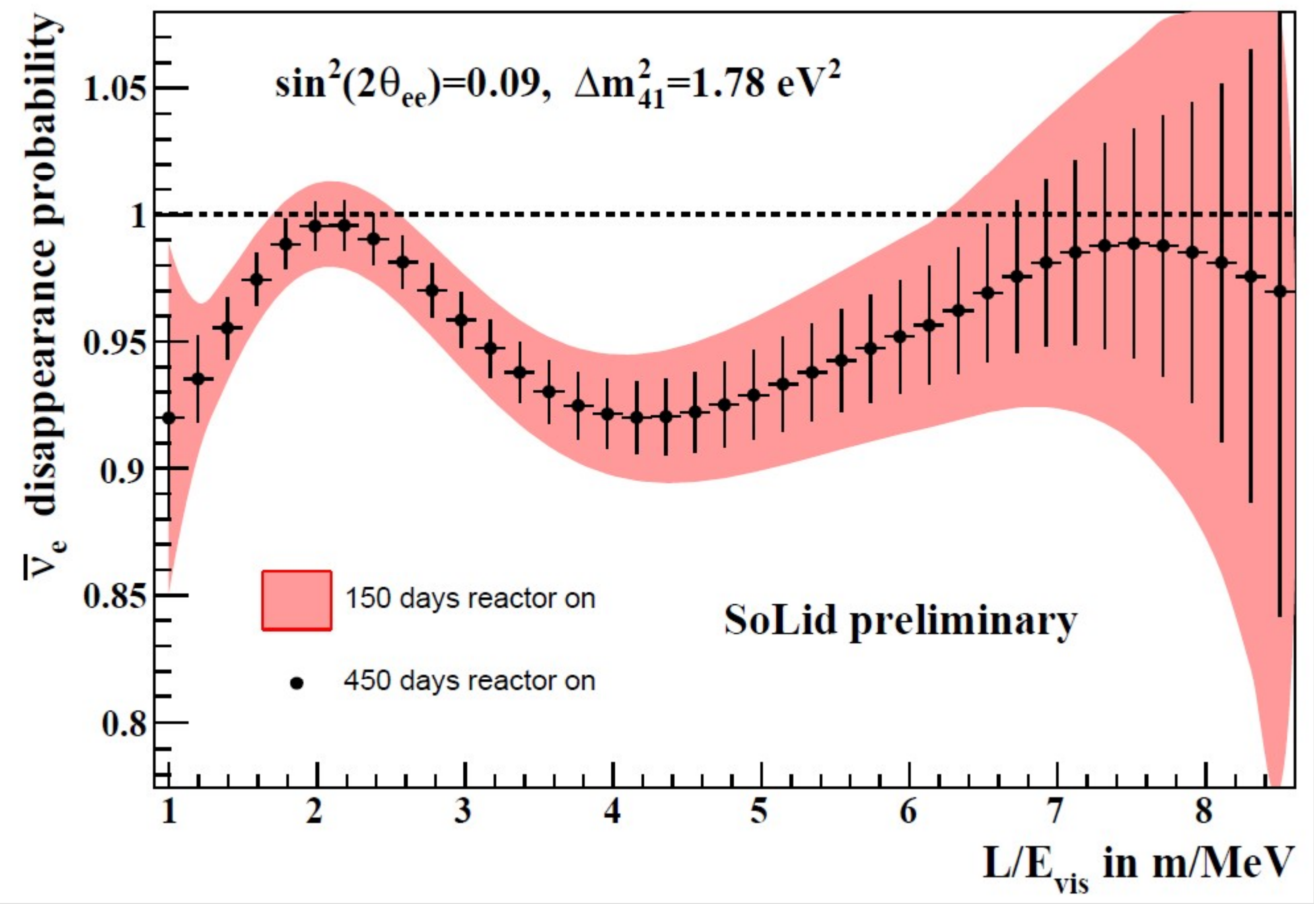
  → Full G4 simulation

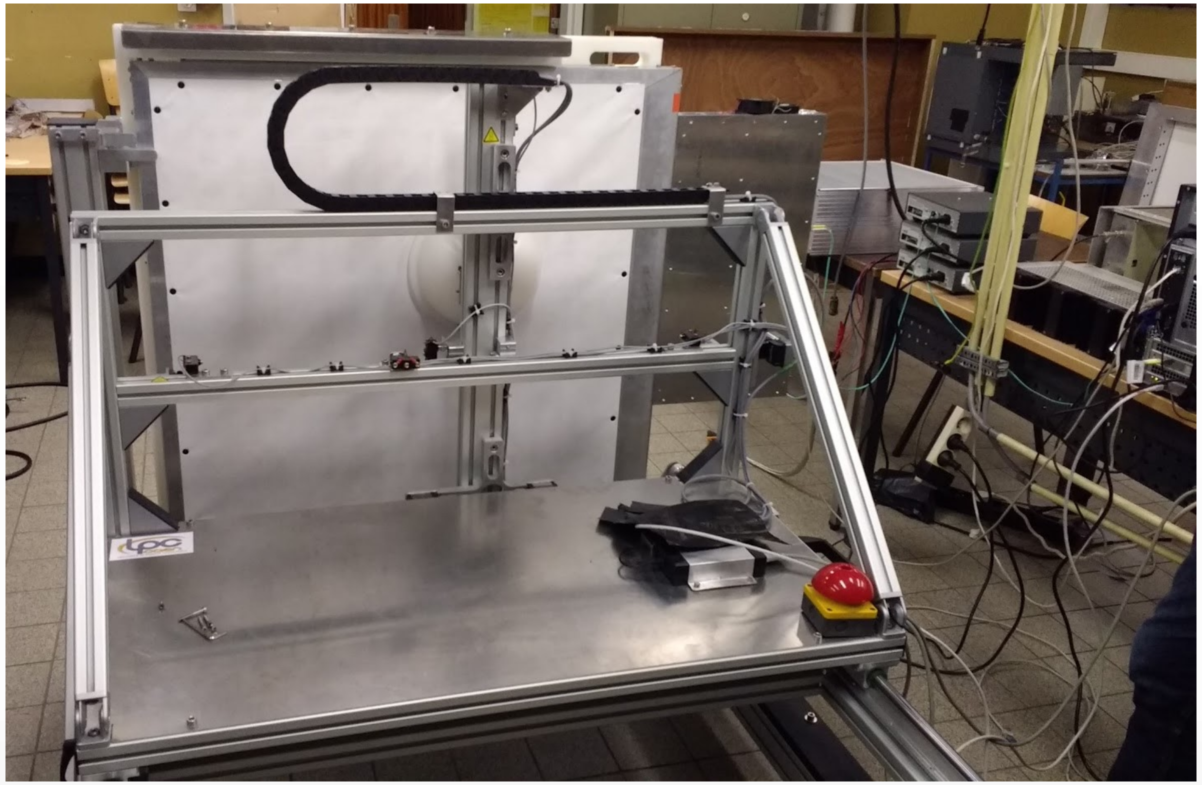
- Target sensitivity
  - Energy resolution $\frac{\sigma_E}{\sqrt{E\ (MeV)}} = 14\%$
  - IBD efficiency 30%
  - Signal-to-Background 3:1

$$P_{ee} \sim 1 - \sin^2(2\theta_{14})\sin\ (1.267\Delta m_{14}^2\ L[m]/E[MeV]\ )$$

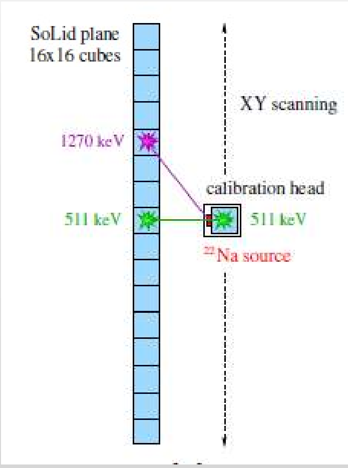


# Quality control: CALIPSO

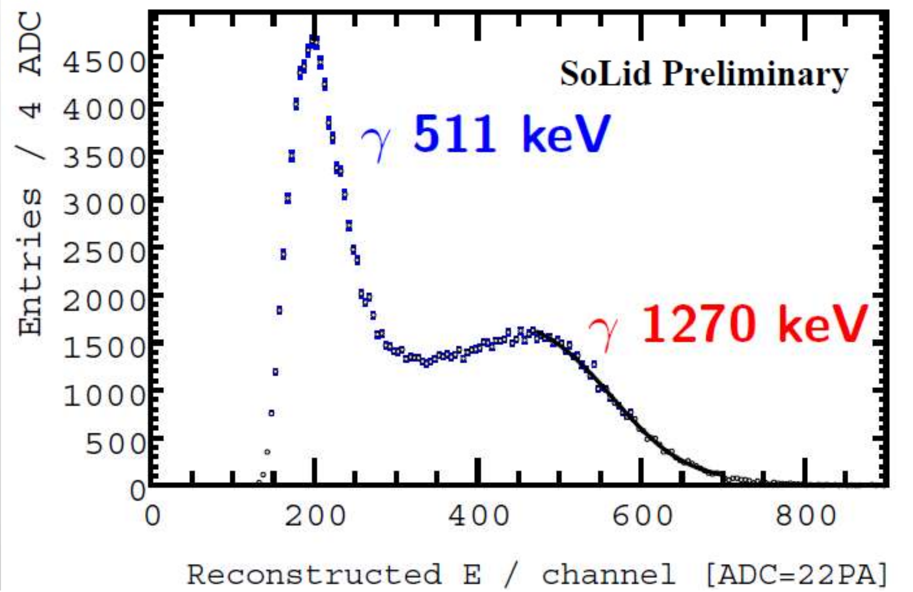
- Automated scanner with active calibration head accommodating various neutron, electron/gamma sources:
  - $^{207}$Bi, $^{22}$Na, $^{137}$Cs, $^{60}$Co, …
  - $^{235}$Cf, AmBe
  - 16x16 cell plane in 4 hours
- Employs same readout&DAQ as full detector



Poster: L. Manzanillas
Monday #171 (Ballroom)




$^{22}$Na Compton edge of 1270 keV gamma used for LY measurement



# Construction & Integration:


Nov 2017

# Optical performance

- 99% of channel gains equalized to 1.4% spread
- Linear energy response over wide range
- Will add more sources/energies: Including conversion $\gamma$'s from $^{207}$Bi
- Exploit muons for real-time monitoring

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And
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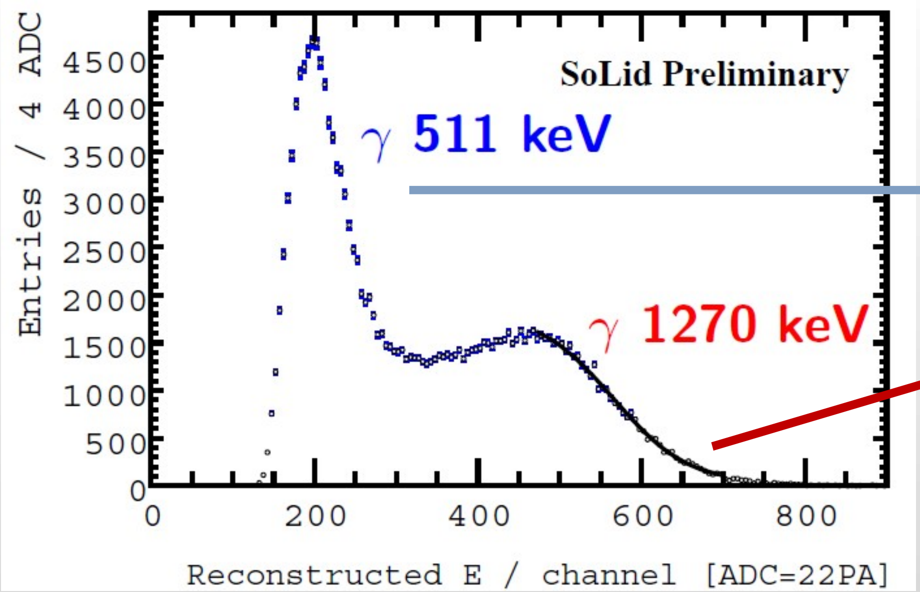


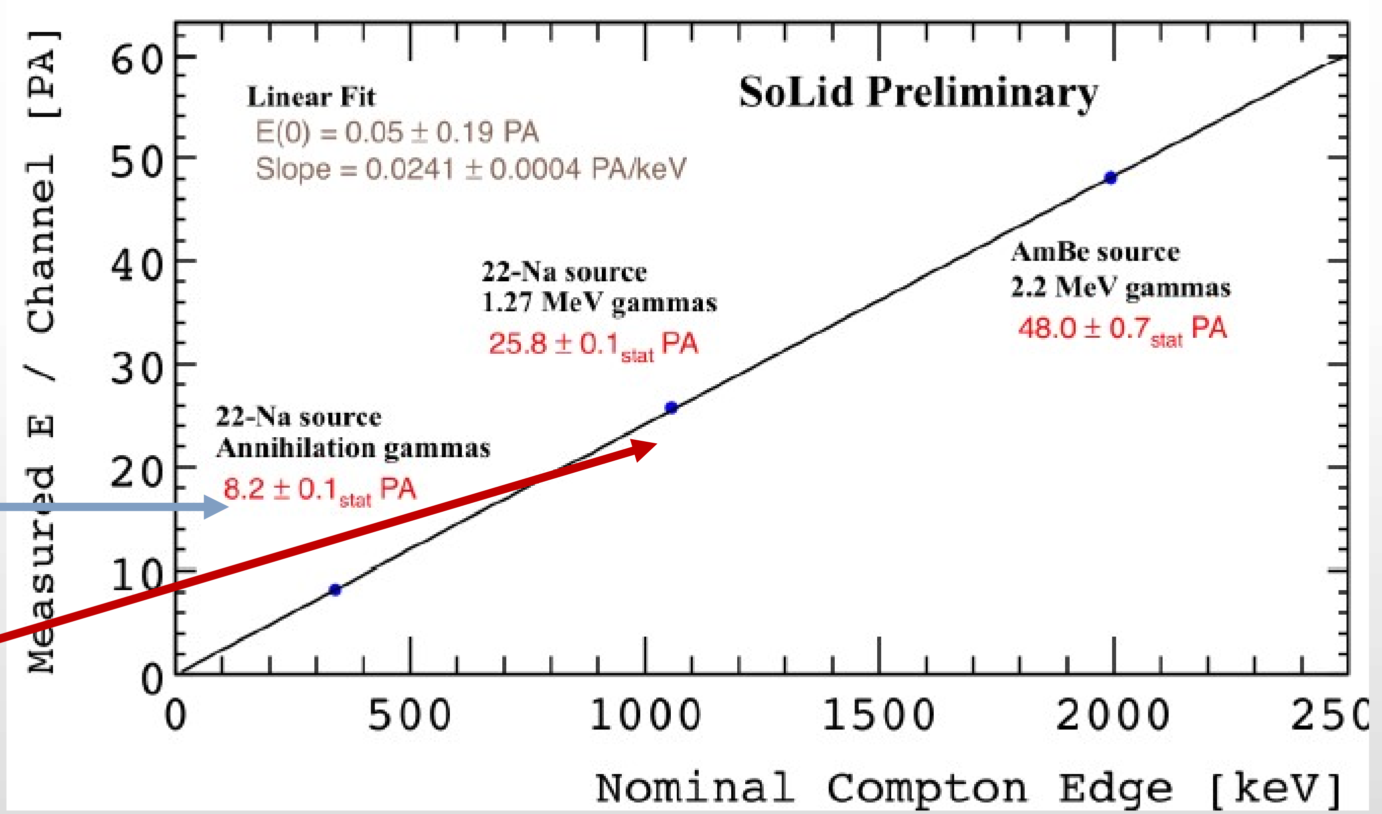

# Optical performance

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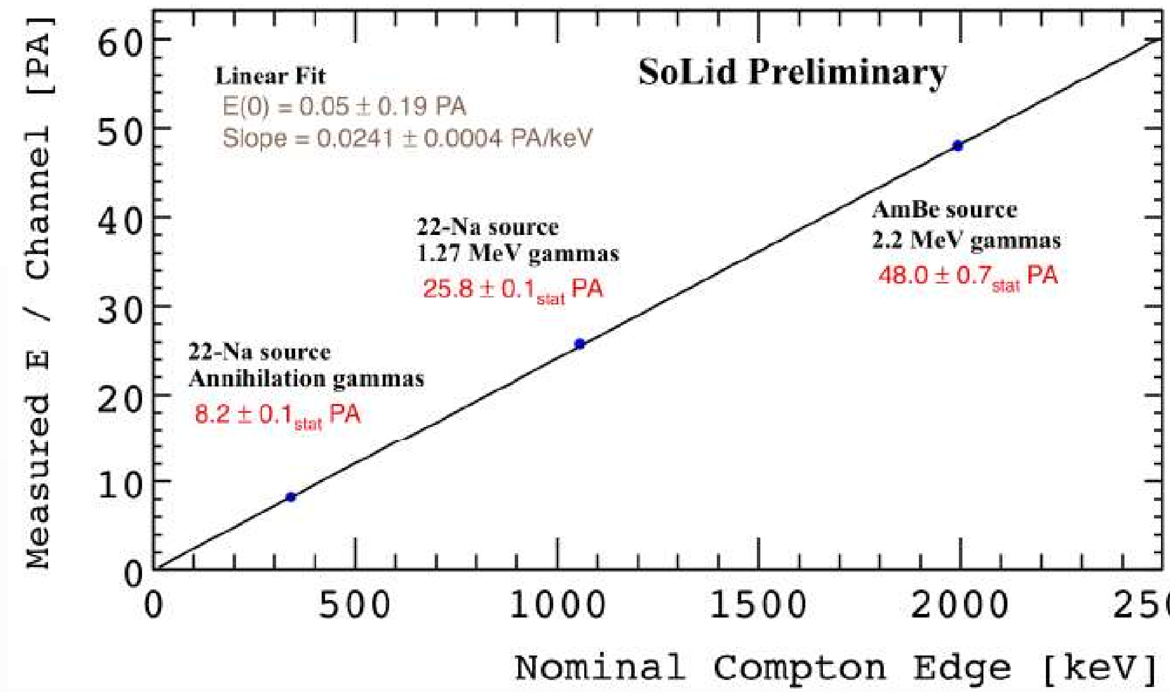
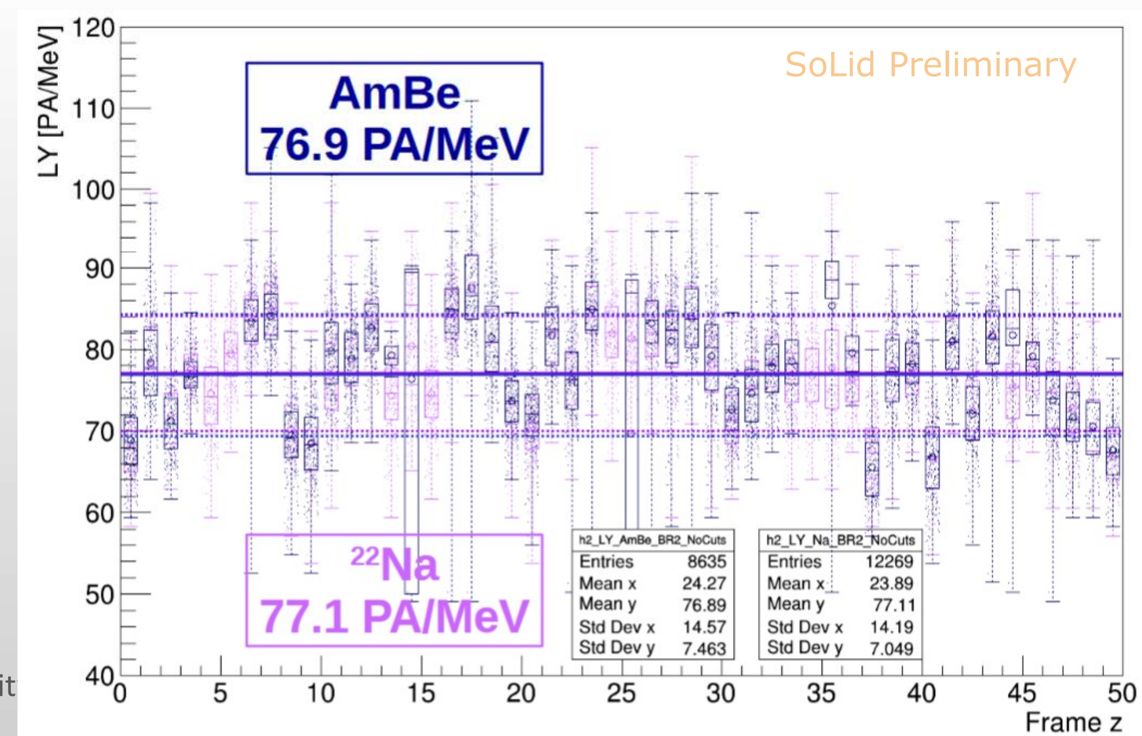
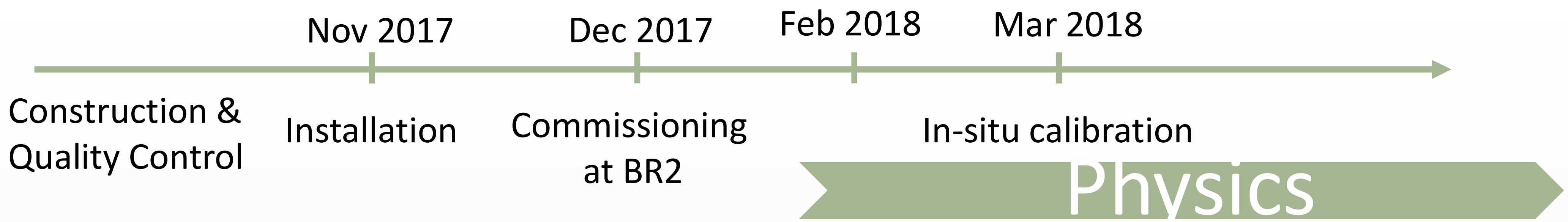
- Channel gains equalized to 1.4% spread
- Linear energy response over wide range
- Will add more sources/energies and exploit muons for real-time monitoring
- Pre-integration calibration crosschecked & complemented by in-situ calibration
- Light yield: 77 PA/MeV/cube $\rightarrow \sigma(E)/\sqrt{E}$ = 12% at 1 MeV
- Very good consistency between $^{22}$Na and AmBe

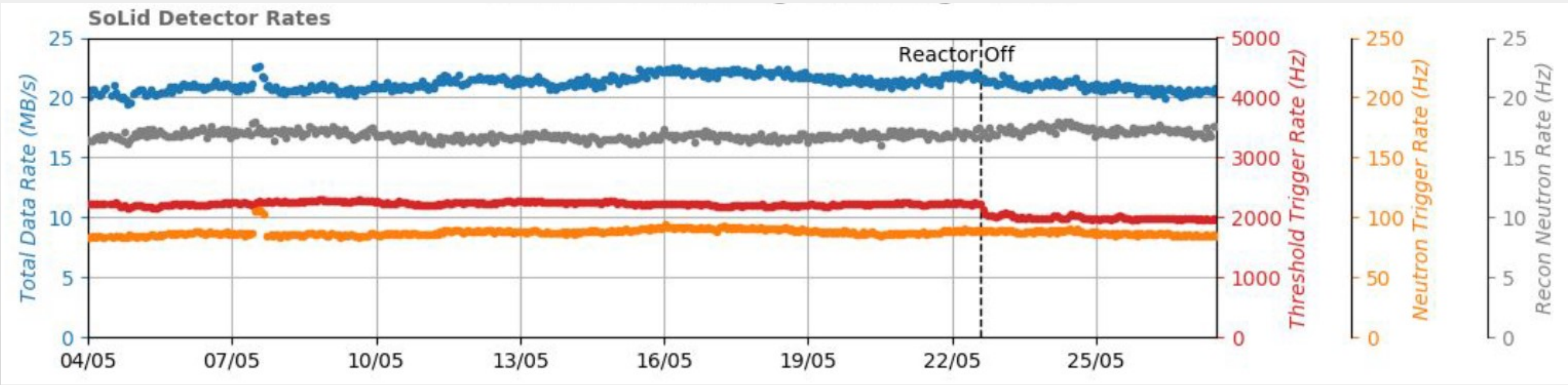


# Trigger and DAQ




| Random | Threshold | Neutrino |
|---|---|---|
| Full detector readout at 1 Hz. Non zero-suppressed waveforms for SiPMs monitoring. | Require XY coincidence > 2 MeV. Muon and high electromagnetic event tagger. | PSD algorithm for neutrons. Past time buffer & *multiplane* readout →**Unbiased prompt detection.** |



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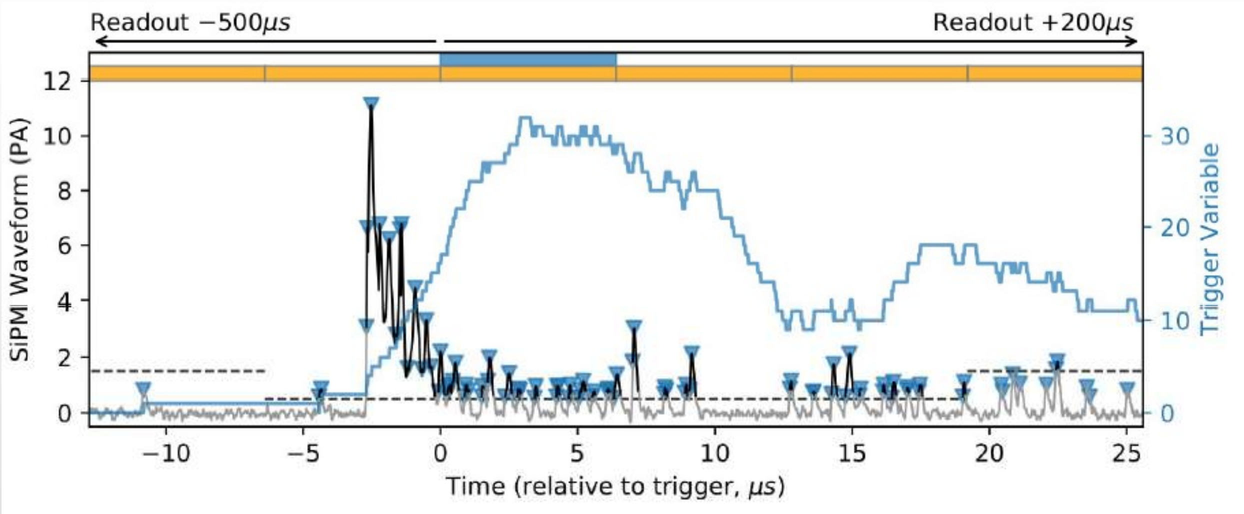
- Neutron trigger implemented in FPGA
  - Based on scintillation signal induced in 6LiZnS: lots of secondary peaks

    → Count number of peaks over treshold in sliding time window
  - Read out long time buffer around NS: [-500 µs, +200µs]

See D. Saunders’ poster: #151 (Hölderlin-Room)



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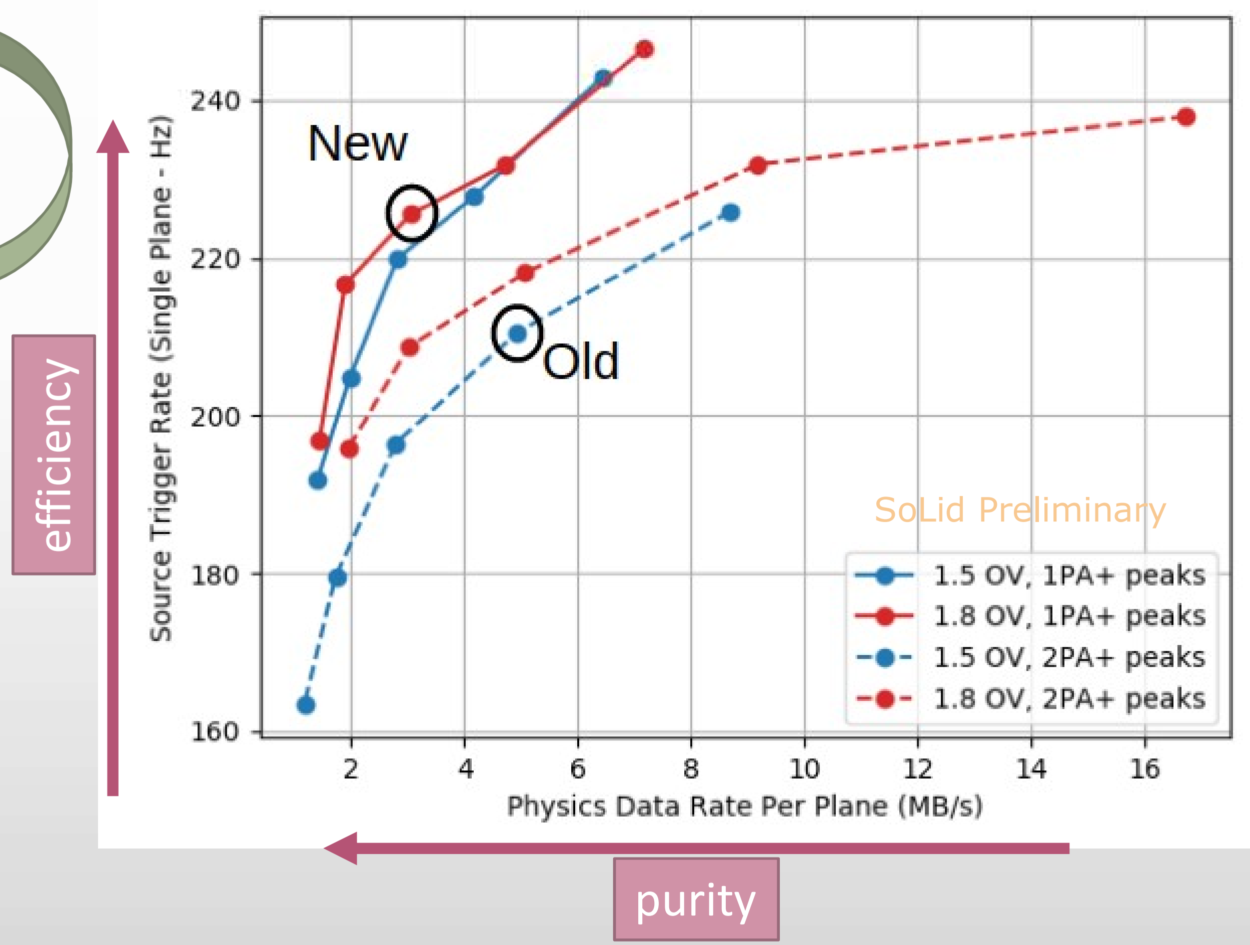
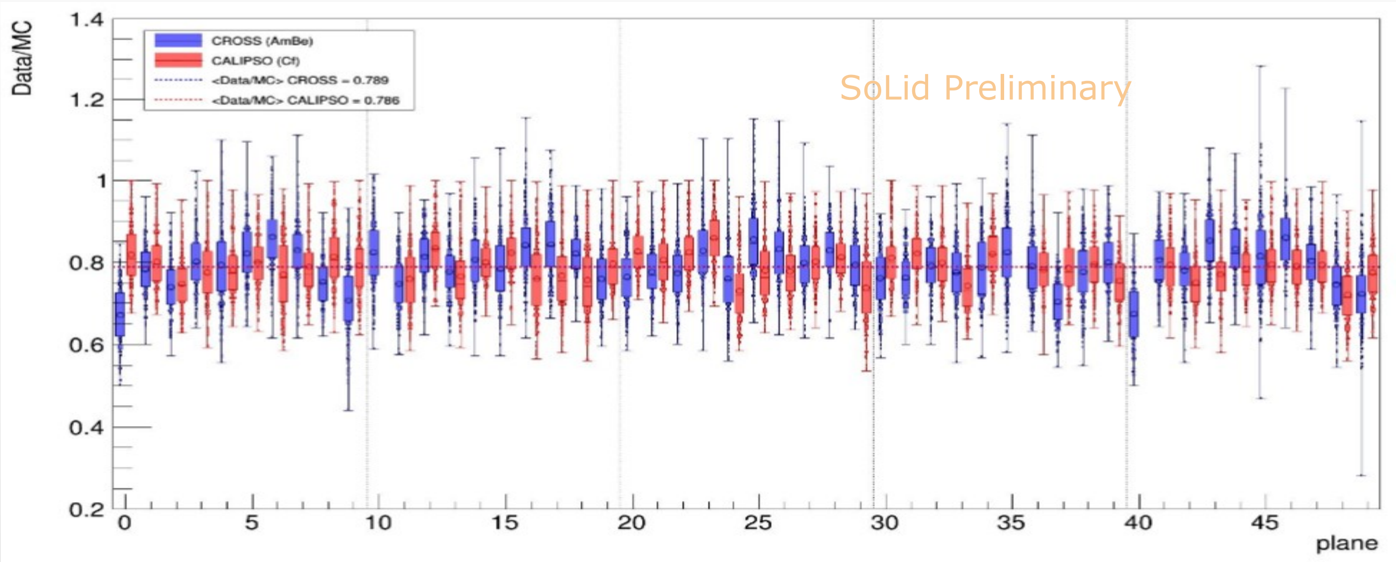
    → Count number of peaks over treshold in sliding time window
  - Read out long time buffer around NS: [-500 μs, +200μs]
- Performance
  - Trigger&PID efficiency 79 ± 3 % (trig dominated)
  - Trigger purity ~20%
  - DAQ efficiency > 90%

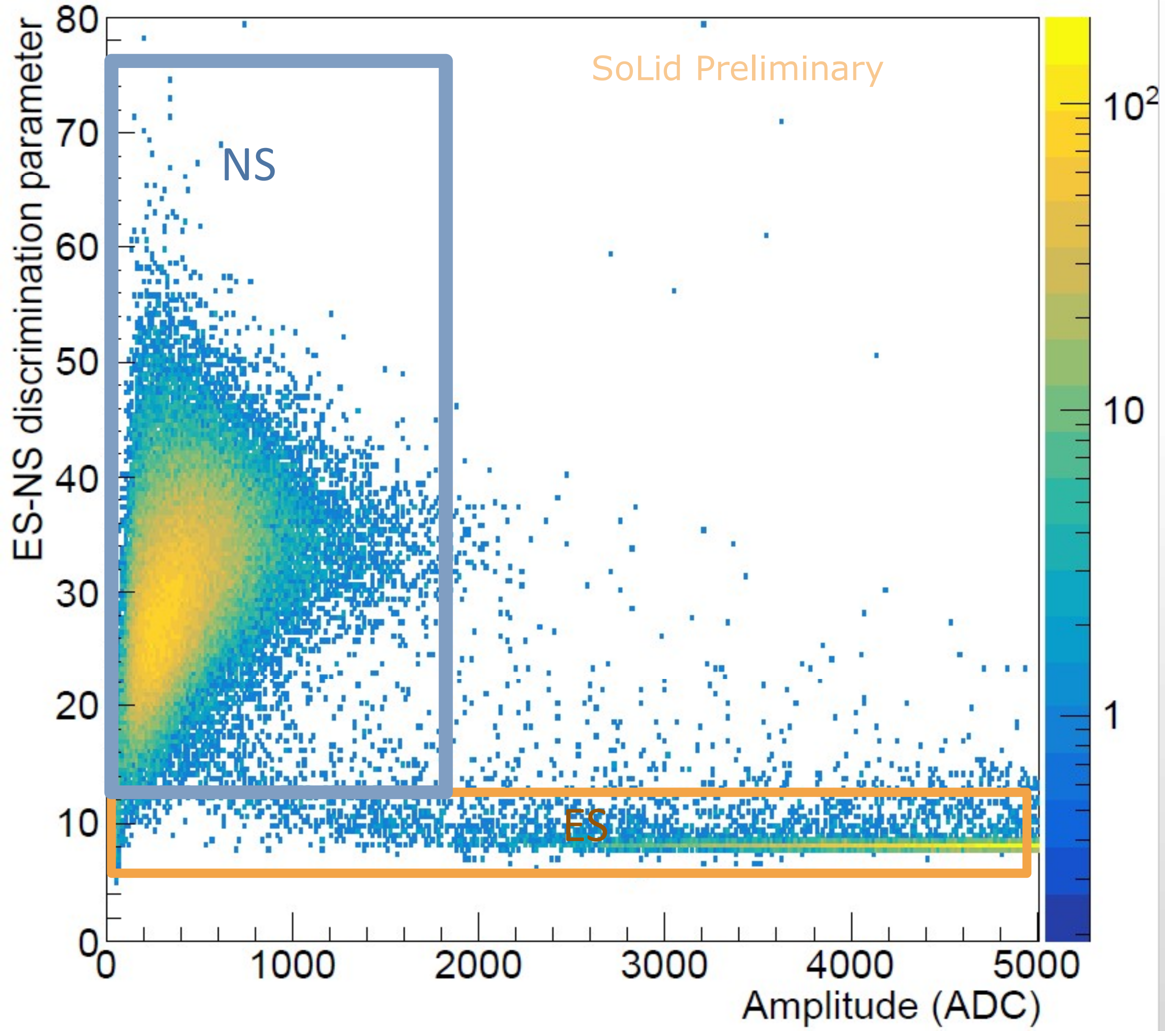
**Neutron trigger performance**



# Neutron reconstruction

- Validated in-situ with AmBe and $^{252}$Cf sources:
  $\rightarrow$ neutron detection efficiency per cube!
- Average trigger $\otimes$ reconstruction efficiency:
  Improved from
  75.8% to 79.4% $\pm$ 0.03% (stat) $\pm$ 3.1% (syst)

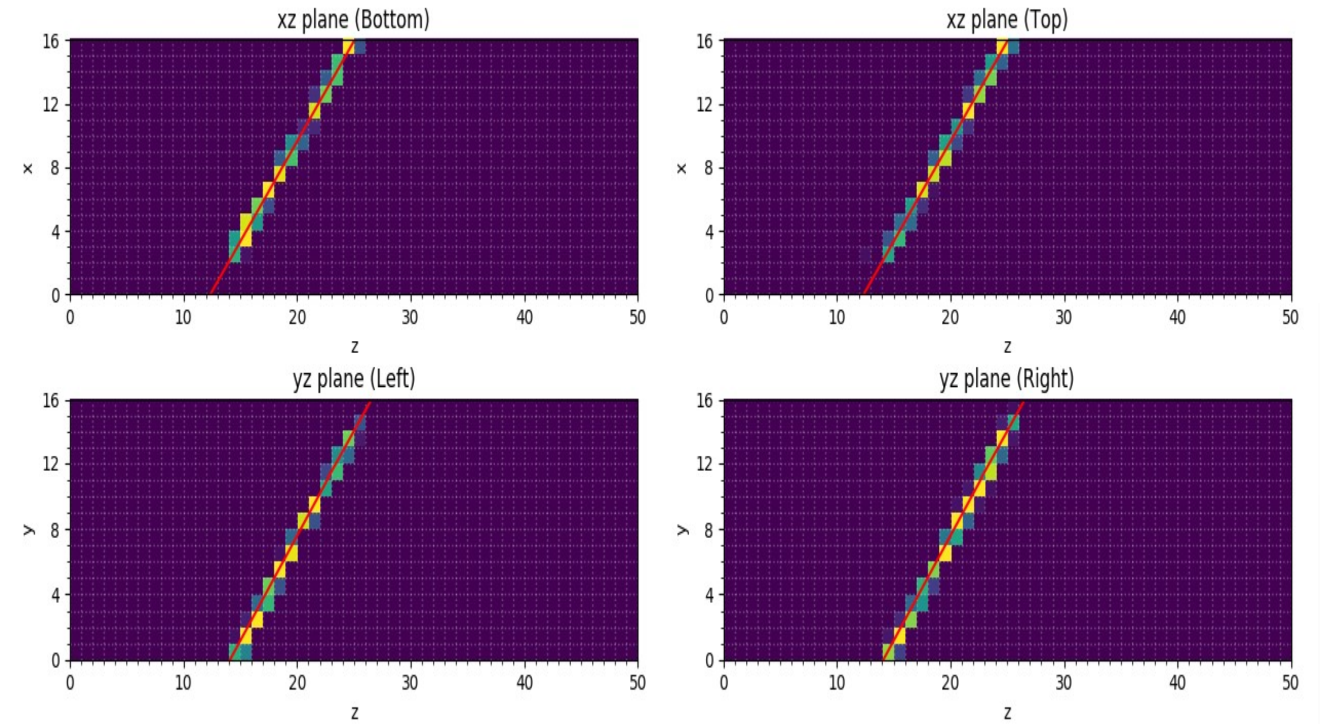


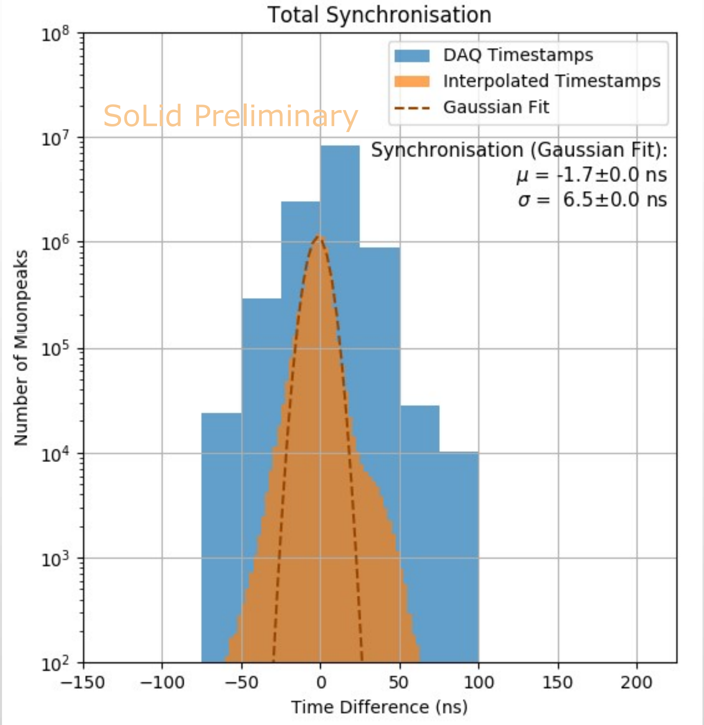



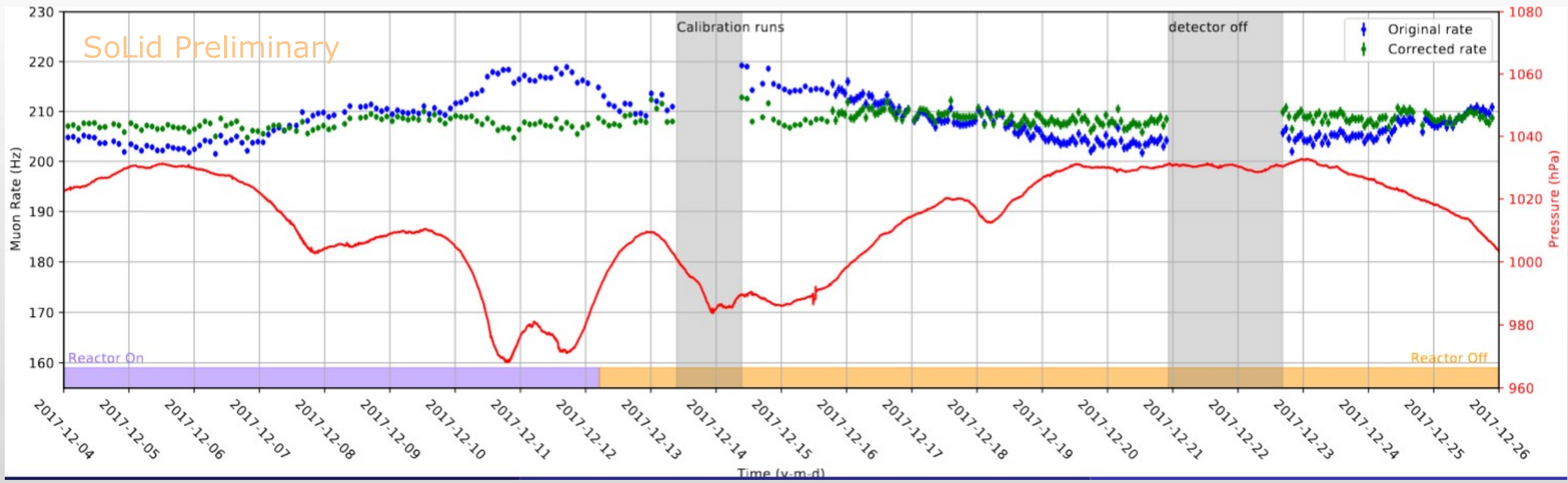
# Event Topologies: Muons

Exploit temporal AND spatial event information:

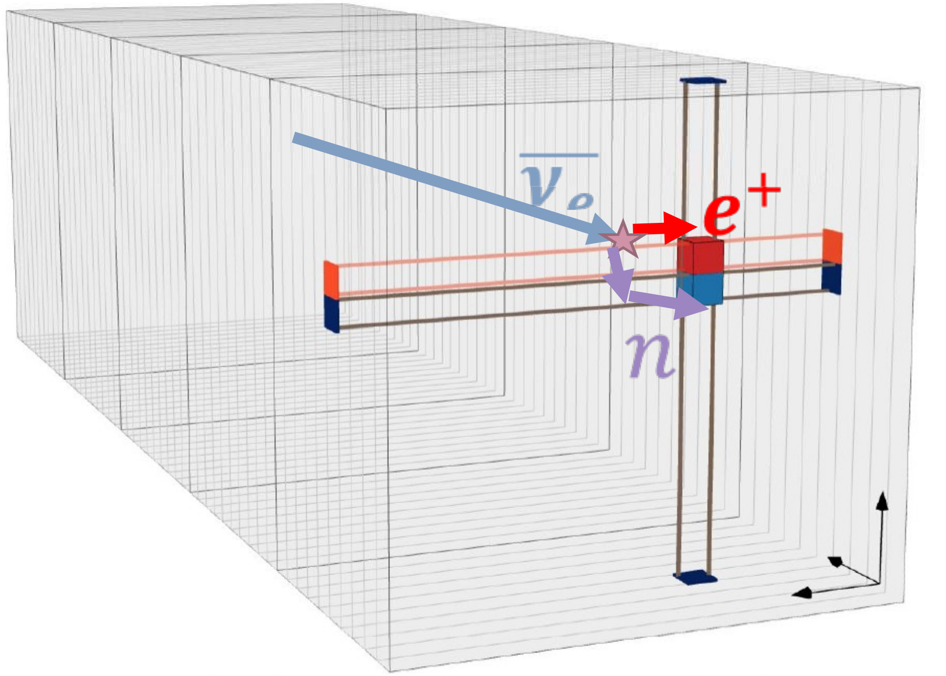
- Muons: Tracking and dE/dx
- Time Synchronisation Validation
- Monitoring and pressure correction



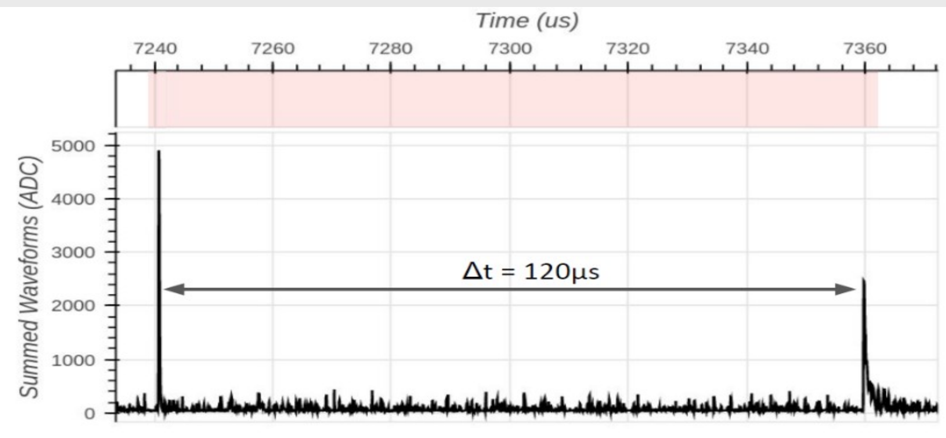



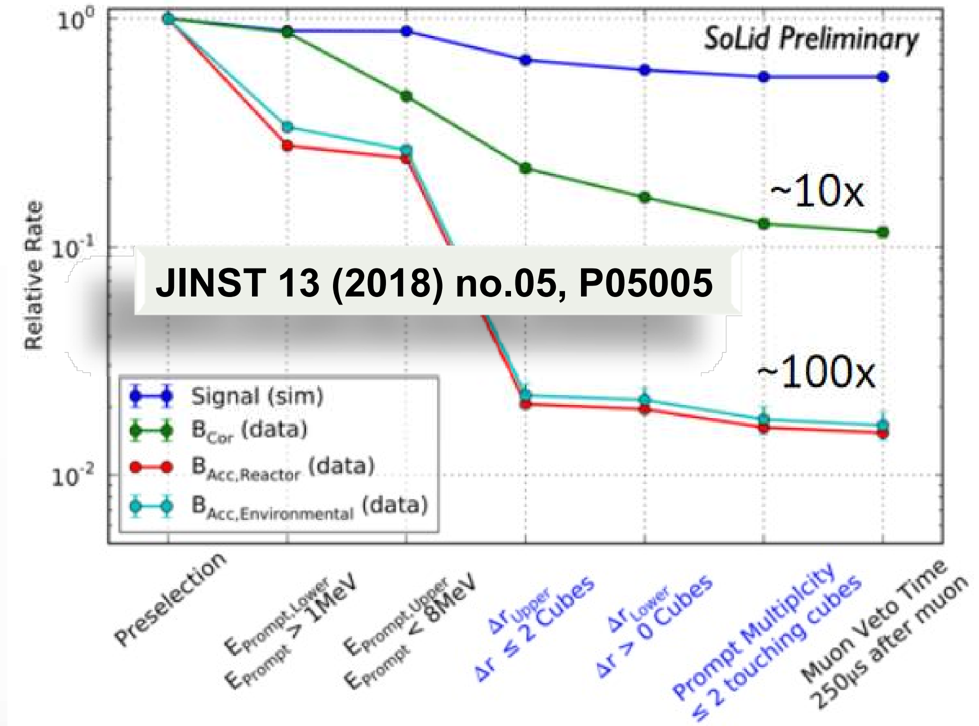



# Event Topologies: IBD-like




**Prompt**-**Delayed** Coincidence Candidate - 2017/12/05, 00:07:26



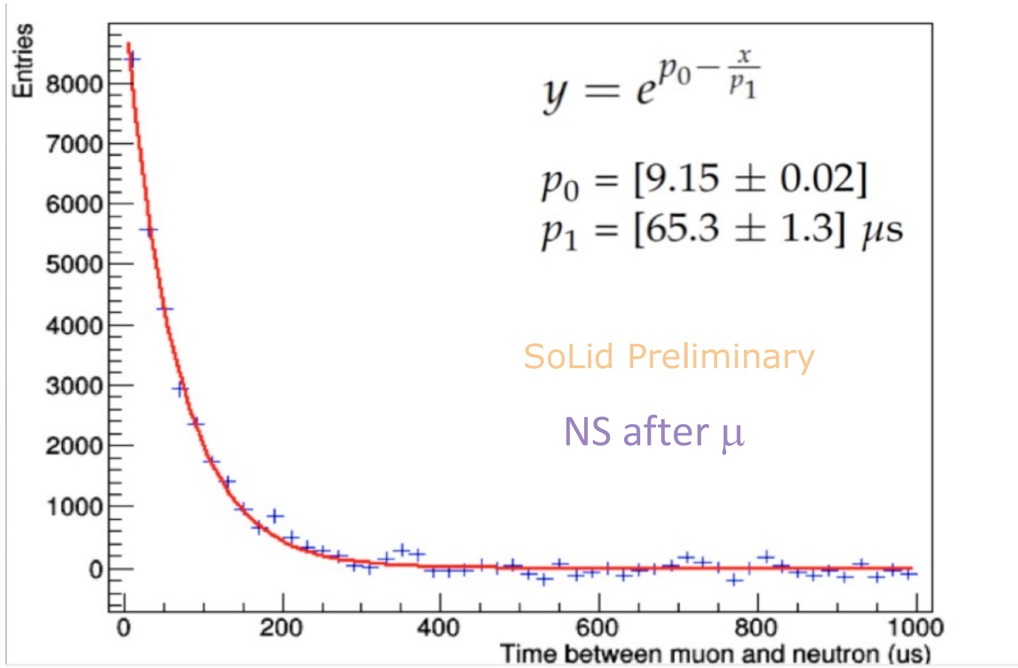



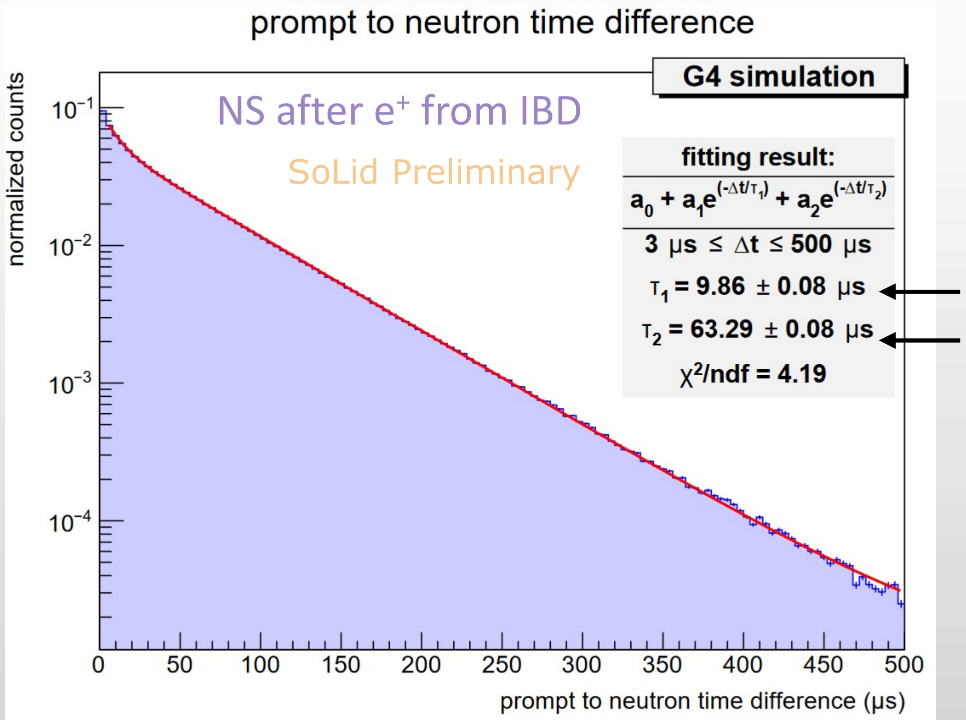

Suppression of :

- Accidentals:
  - Distance prompt – NS: > 2 cubes
- Fast neutrons:
  - Recoils: high Energy & multiplicity
- Muon induced NS:
  - Muon veto time window
- Intrinsic radio-contamination:
  - $^{214}$Bi->$^{214}$Po and Rn:
    - Energy
    - timing
    - Same-cube events

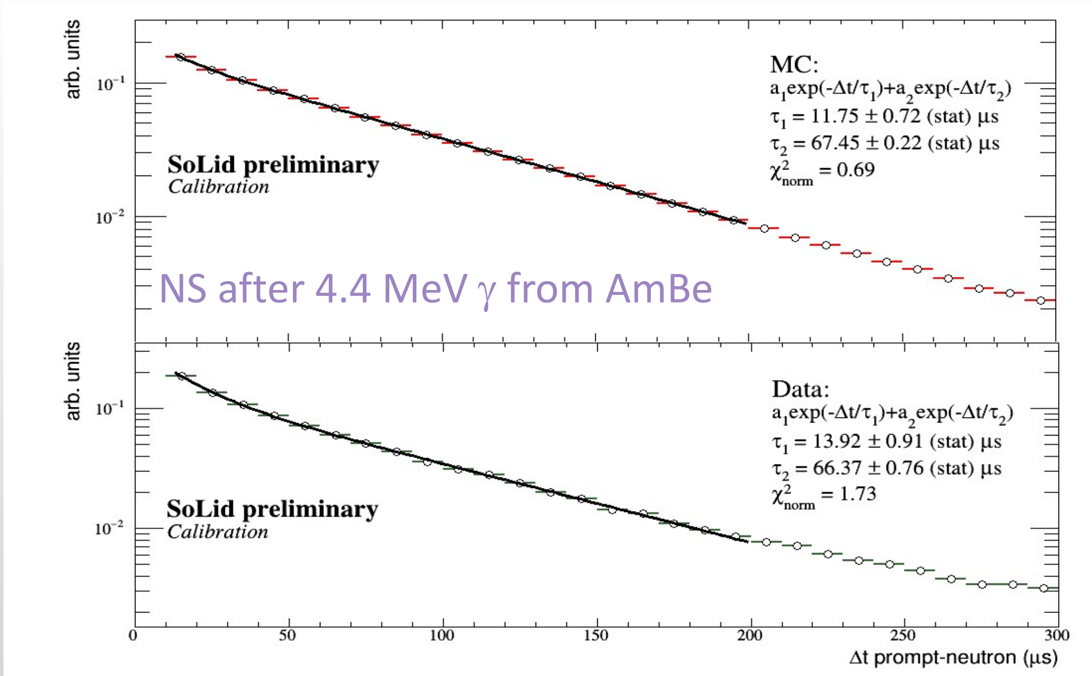
# NS-ES Time correlation

| Reaction | Fitted capture time (μs) |
| --- | --- |
| Spallation (NS after μ-track) | 65.3 ± 1.3 (stat) |
| AmBe Calibration (NS after γ) | 66.4 ± 0.8 (stat) |
| IBD Simulation (NS after e⁺) | 63.3 ± 0.1 (stat) |



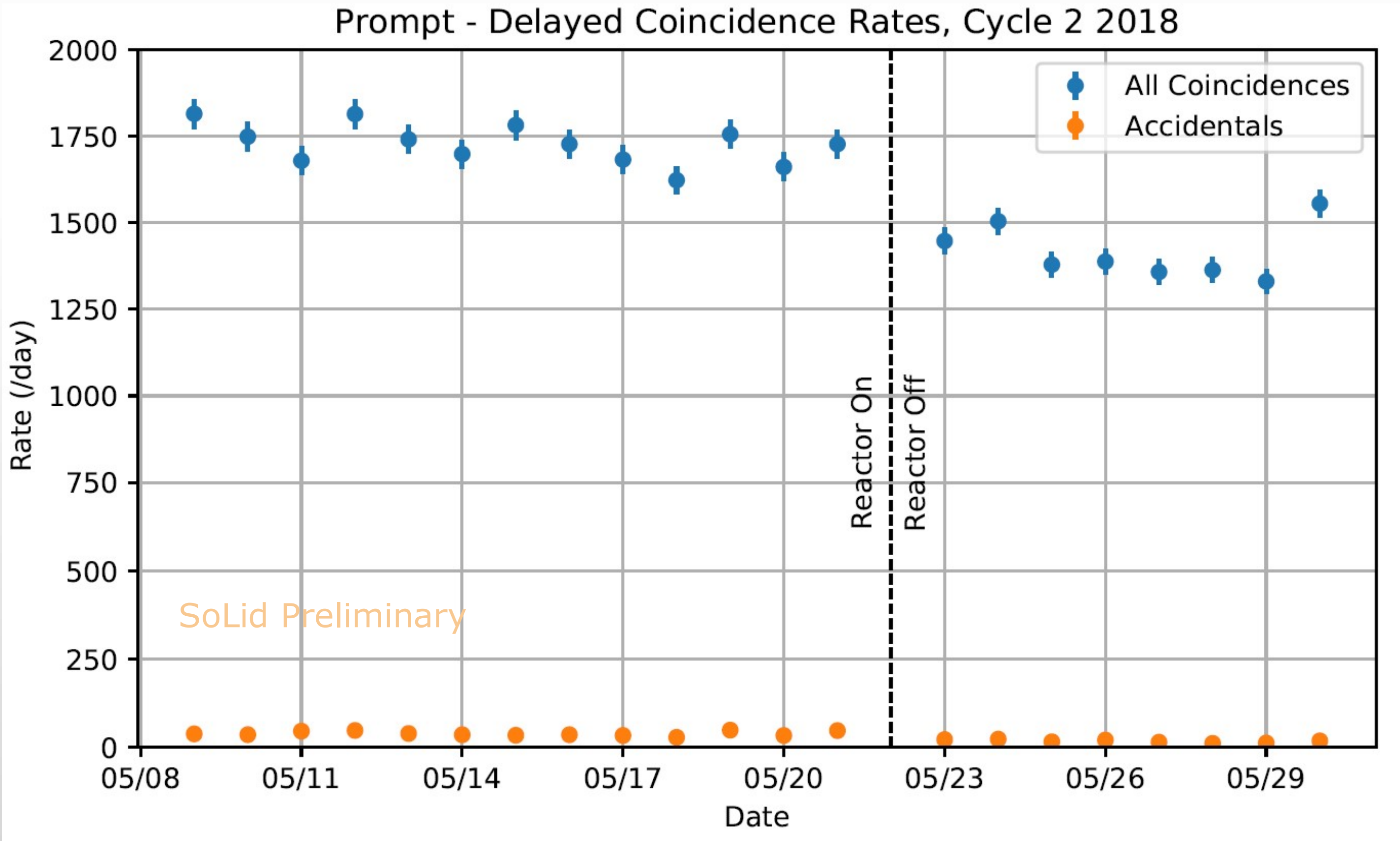




epithermal
thermalised



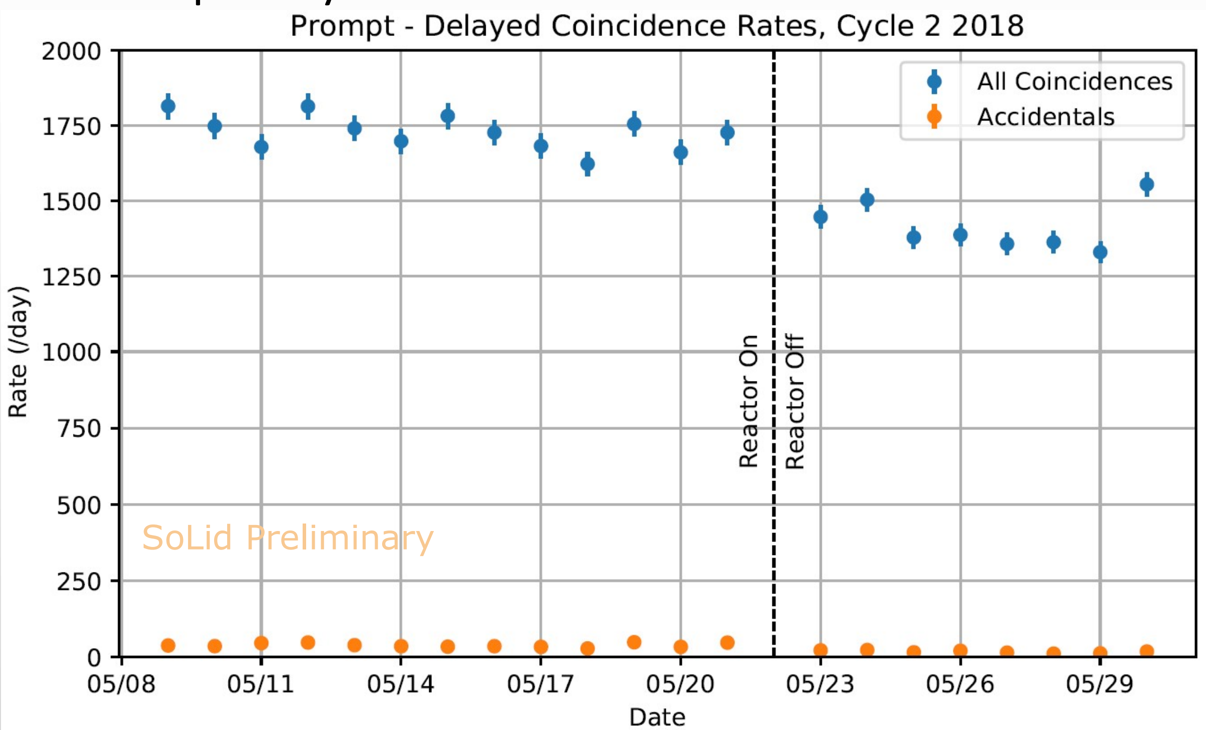
# IBD-like Rates

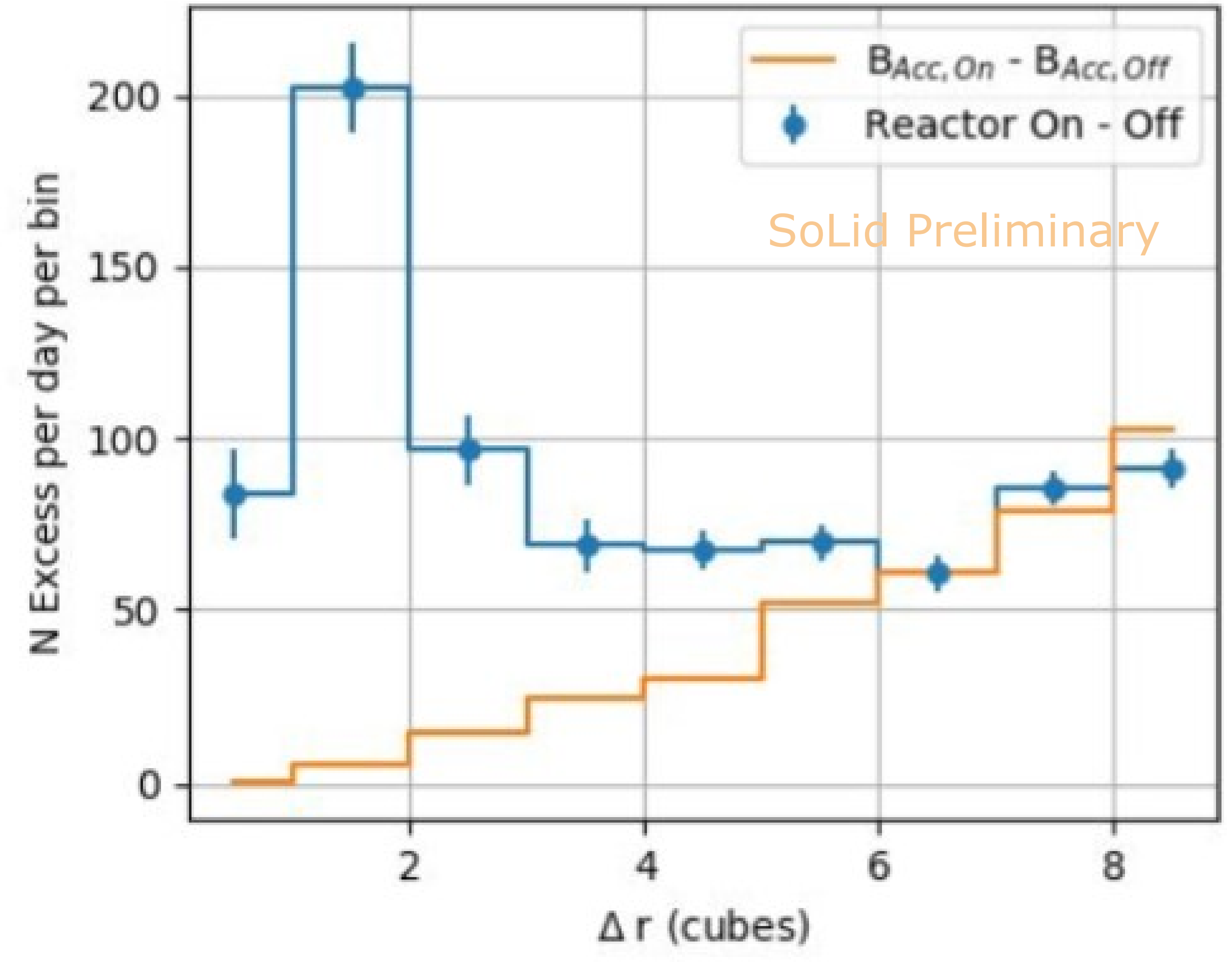
- Preliminary rate monitoring, based on:
  - Timing, Topology, Muon veto, Energy selection
- Significantly higher IBD-like rate during reactor ON
- Very low accidental rate
- How does it behave?



# IBD-like Events

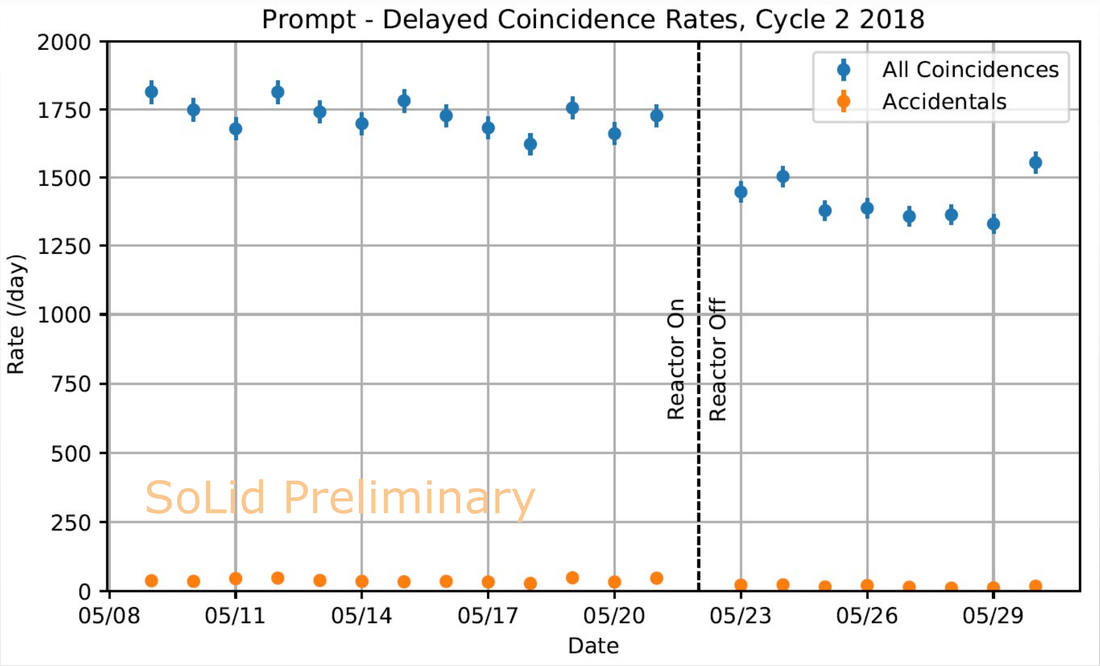
- Preliminary rate monitoring based on:
  - Timing, Topology, Muon veto, Energy selection
- Significantly higher IBD-like rate during reactor ON
- How does it behave?
  - Spatially confined ✓

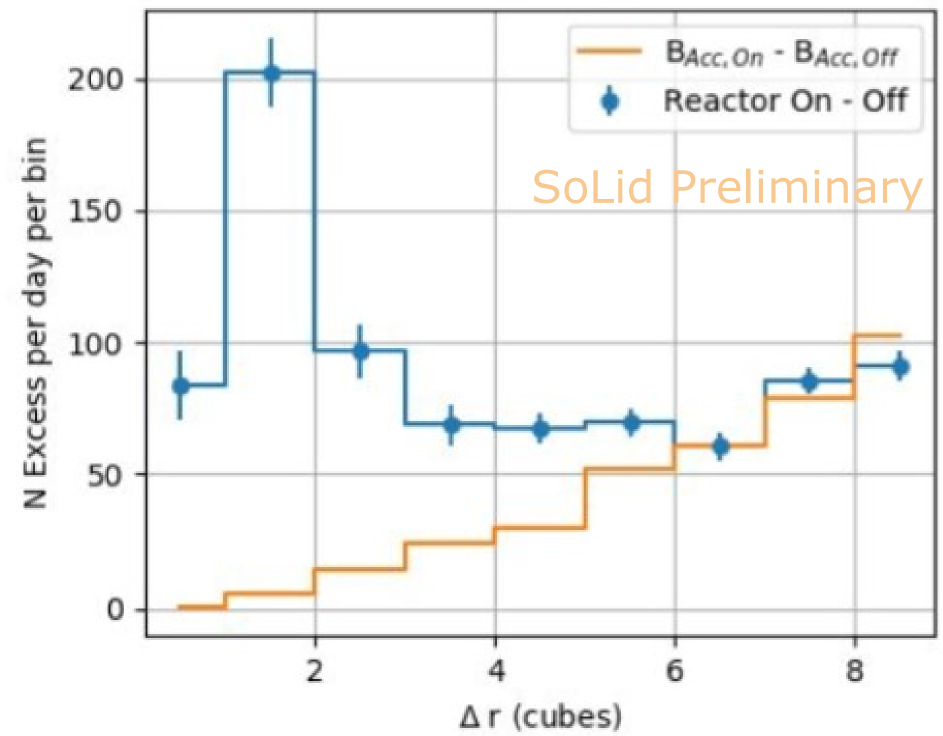


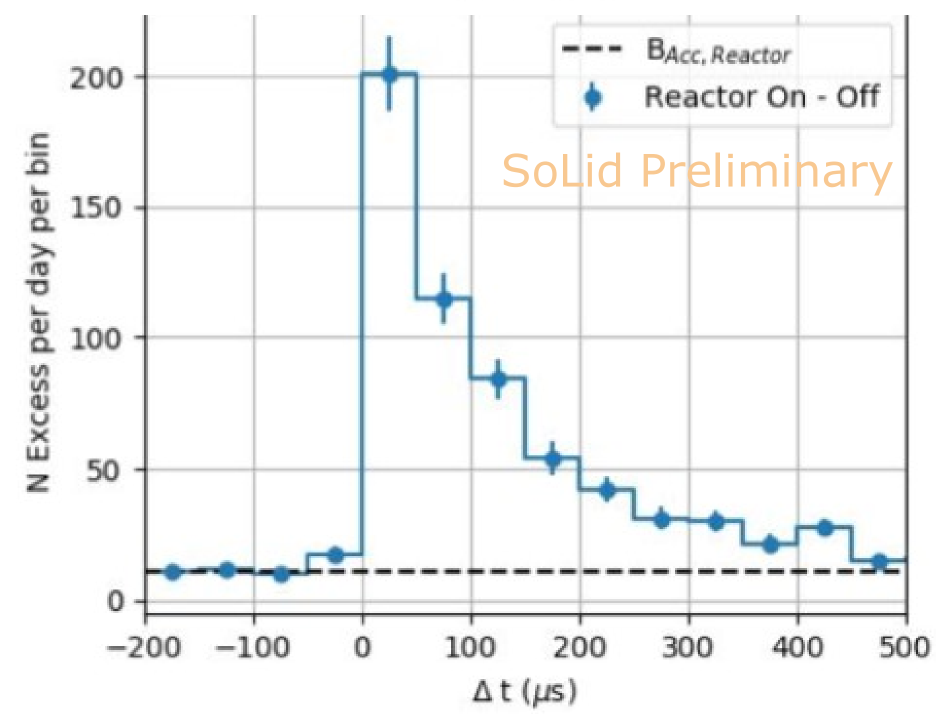



# IBD-like Events

- Preliminary rate monitoring based on:
  - Timing, Topology, Muon veto, Energy selection
- Significantly higher IBD-like rate during reactor ON
- How does it behave?
  - Spatially confined ✓
  - Time difference: consistent with thermalised n-capture ✓



# Conclusion

- Solid improved design after evaluating performance of full scale prototype module in 2015-2016
- Constructed a 1.6 ton detector (Phase1) in 2017 and commissioned it in Nov-Dec 2017
- Validated performance with calibration & commissioning data
- SoLid is now taking good quality physics data and observes IBD-like events
- BR2 will provide us with 6 reactor cycles this year
- Physics triggers and DAQ operations are being optimized
- Object reconstruction under continuous development and being validated
- Backgrounds being measured and IBD selection criteria optimized
- First physics results coming real soon!

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→ Full G4 simulation

| Parameter | Value |
|---|---|
| **Reactor** | |
| Thermal power ($P_{th}$) | 60 MW |
| Fissile isotopes | $^{235}U$ only |
| **Baseline** | |
| Point of closest approach | 6.2 m |
| **Detector** | |
| Density | 1.023 gr/cm$^3$ |
| Proton density | 5.17 $10^{22}$ H per cm$^3$ |
| Dimensions | $0.8 \times 0.8 \times 2.5$ m$^3$ |
| Active mass | 1.6 tons |
| IBD efficiency ($\epsilon$) | 30% |
| Energy resolution | $14\%/\sqrt{E_{vis}}$ |
| **Background** | |
| S:B | 3 |
| Spectrum | Taken from SM1 data |