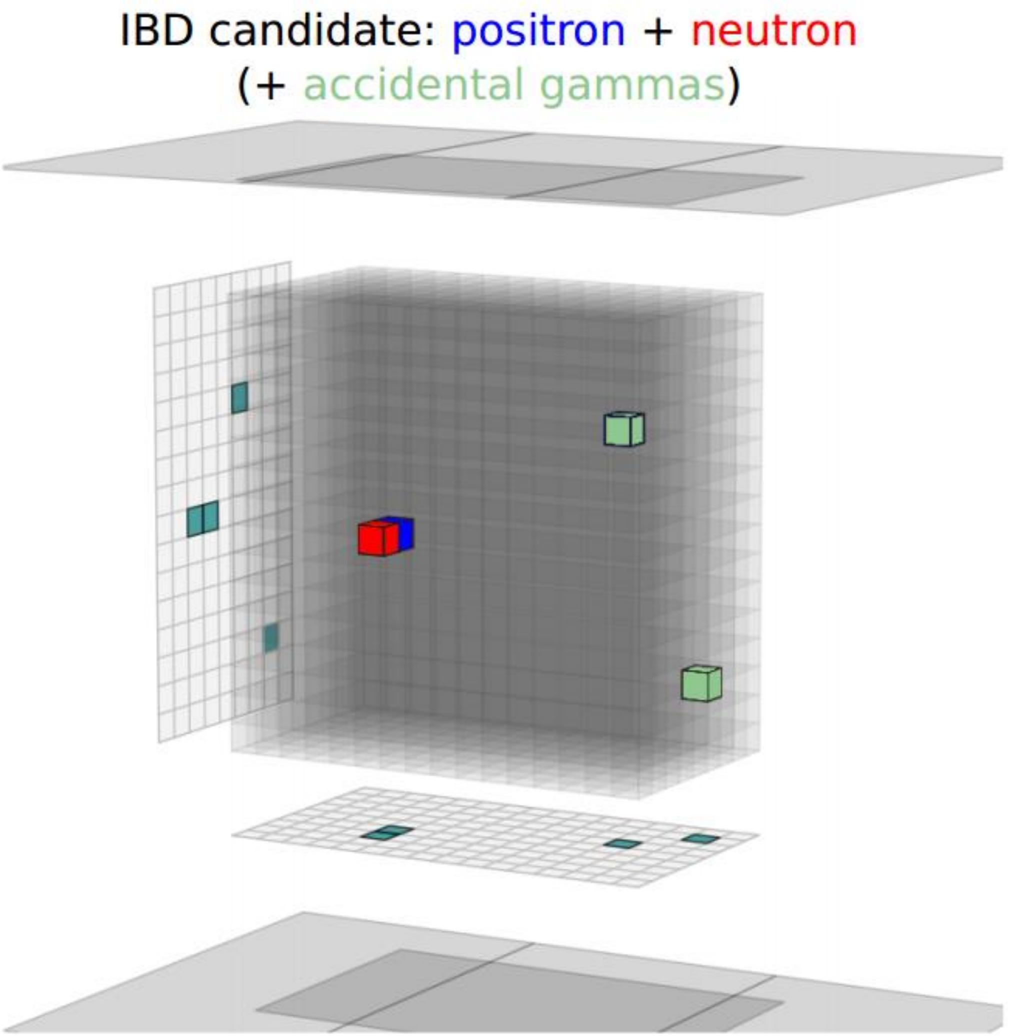


SoLid: a new short baseline neutrino experiment

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

51st Rencontres de Moriond EW
March 12-19 2016

fwo Research Foundation Flanders Opening new horizons
foundation of public utility HERCULES STICHTING
Belgian Science Policy Office belspo
Fundamental Interactions .be

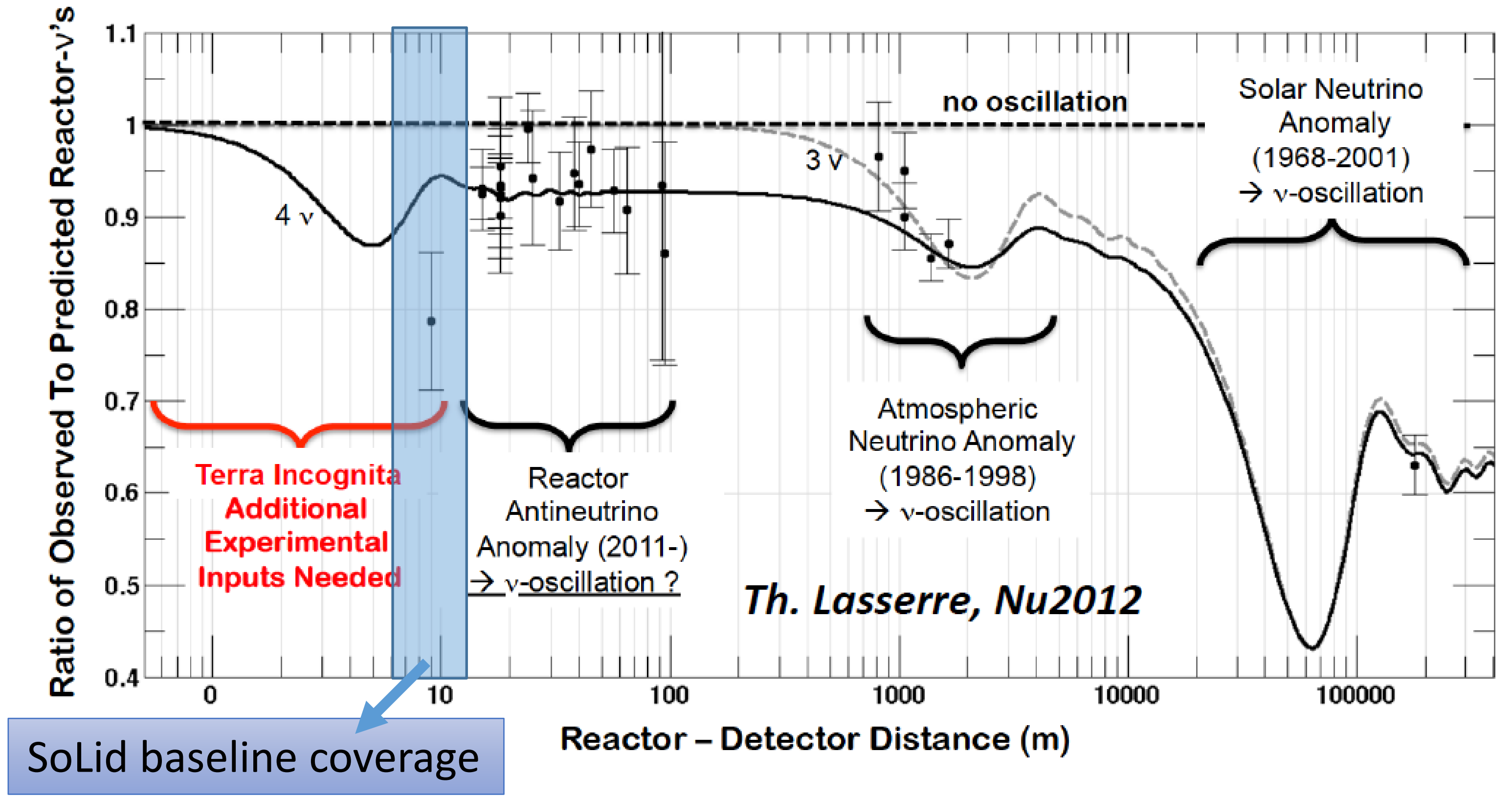
Motivation

- B. Kayser @ Moriond EW 2012:arXiv: 1207.2167
  "Not all of the neutrino data are successfully described by the standard three-neutrino paradigm. …
  …there are hints, coming from a variety of sources, that nature may contain more than three neutrino mass eigenstates, and squared-mass splittings significantly larger than the measured $|\Delta m^2_{21}|$ and $|\Delta m^2_{32}|$. Whether individually or taken together, these hints are not convincing. However, they are interesting enough to call for further, hopefully conclusive, investigation"

- Deficits in measured neutrino rates wrt. Expectations from standard neutrino oscillation predictions:
  - Gallium anomaly in radiochemical (solar) neutrino detectors: 2.9 σ effect
  - Reactor neutrino anomaly in short baseline reactor neutrino experiments: 2.7 σ
  - LSND and MiniBoone short baseline accelerator neutrino experiments
- For comprehensive overview, see e.eg.
  - K. N. Abazajian et al., arXiv:1204.5379 [hep-ph]
  - Kopp, Machado, Maltoni and Schwetz, JHEP05(2013)050

Motivation

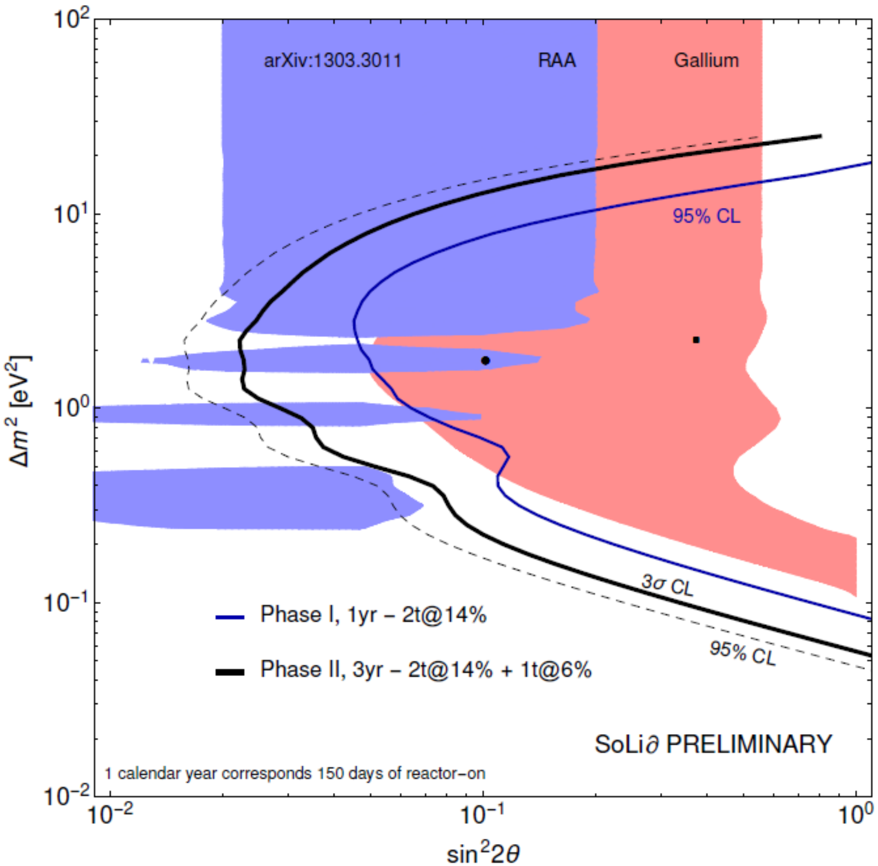
- Reactor anomaly (Mention et al., Phys. Rev. D 83 073006 (2011))
  - Origin: Re-evaluation of reactor $\bar{\nu}_e$ flux calculations in 2011 (T.A. Mueller et al., Phys. Rev. C83, 054615 (2011).) increased the predicted rate of $\bar{\nu}_e$ for reactors
  - All short baseline reactor $\bar{\nu}_e$ rates systematically fall below new rate predictions: 6% deficit (2.7 σ)
- Several explanations possible to explain each individual anomaly, but hard to reconcile them all: consider the option of extra (sterile) neutrino flavors
- Challenging task for new experiments



Introduction of 1 extra(sterile) neutrino

- See eg. Kopp, Machado, Maltoni and Schwetz, JHEP05(2013)050
- Key strategy to probe new physics: Measure oscillation spectrum (in Energy and distance) over very short distances (metres) using the same source

$$P_{ee}^{\mathrm{SBL},3+1} = 1 - 4|U_{e4}|^2(1-|U_{e4}|^2)\sin^2\frac{\Delta m_{41}^2 L}{4E} = 1 - \sin^2 2\theta_{ee}\sin^2\frac{\Delta m_{41}^2 L}{4E}$$



Necessary requirements to probe these parameters

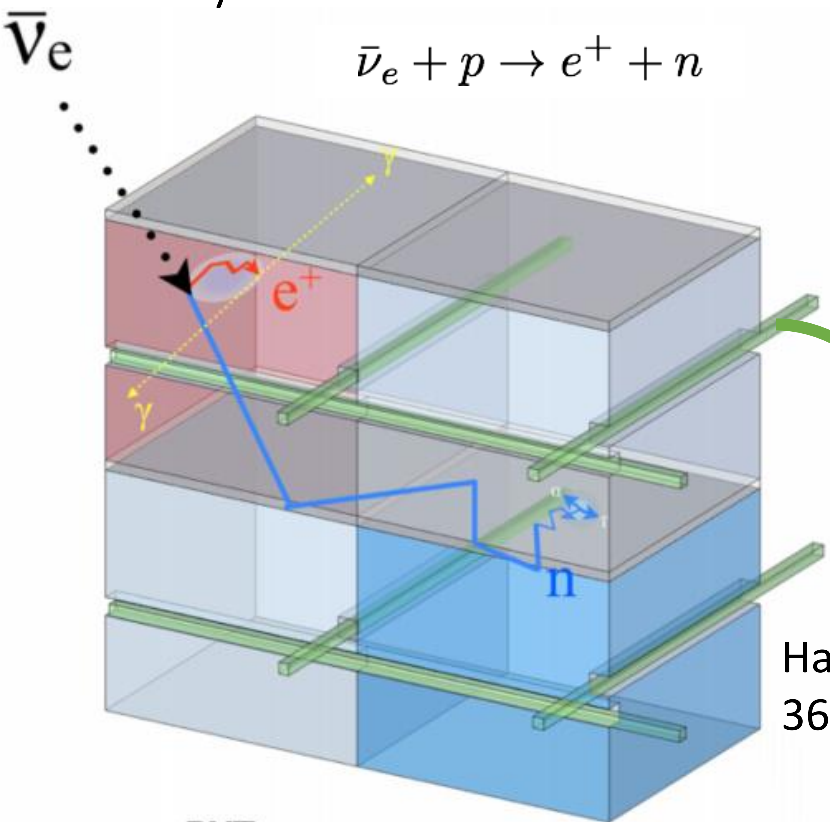
- Reactor and reactor facilities:
  - Power * duty cycle ∝ integrated neutrino flux
  - Fuel: Simple composition, HE ^{235}U preferred
  - Compact core: effective diameter <1m
  - Detector-to-core distance: 1m – 10m
  - Low Reactor background: accidental rate
  - Large overburden or effective shielding: cosmic or cosmic induced bg
- Antineutrino detector:
  - Target mass and acceptance: >1T on-axis with reactor core
  - High $\bar{\nu}_e$ detection efficiency
  - Position and energy resolution: $\Delta(x,y,z)$=O(cm), $\sigma_E/E<15\%/\sqrt{E}$

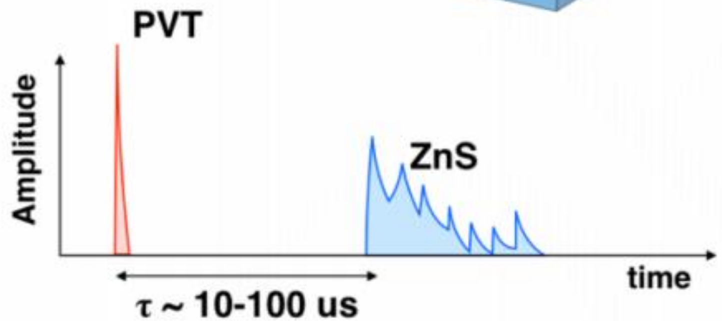
SoLi∂ at BR2

SoLid detector technology

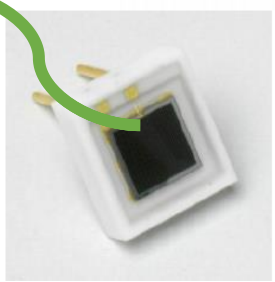
Key detection mechanism: IBD

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

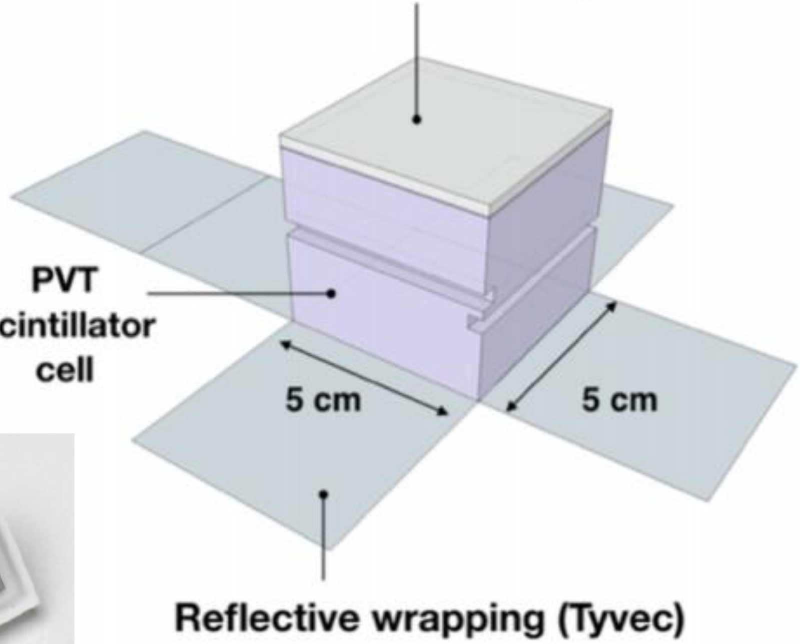


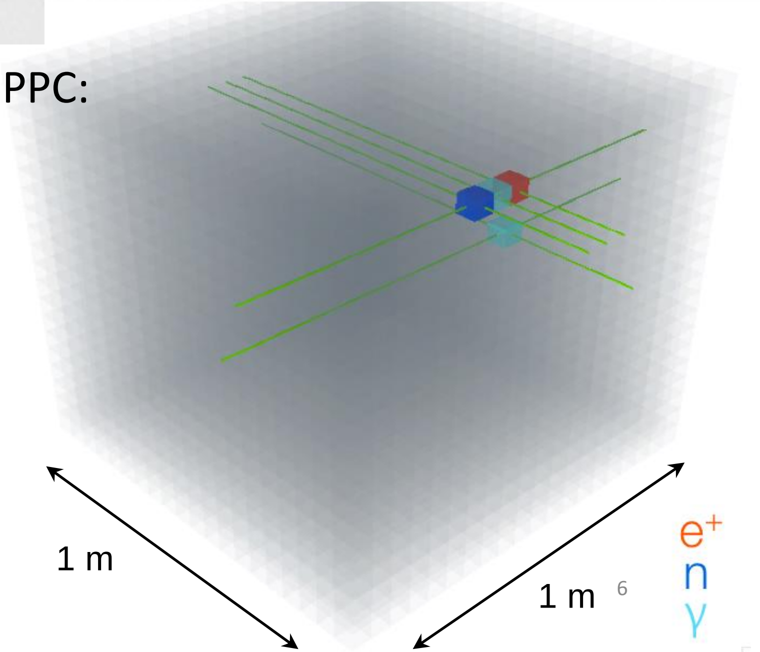


$$^6_3Li + n \rightarrow {}^4_2He(2.05\ MeV) + {}^3_1T(2.75\ MeV)$$



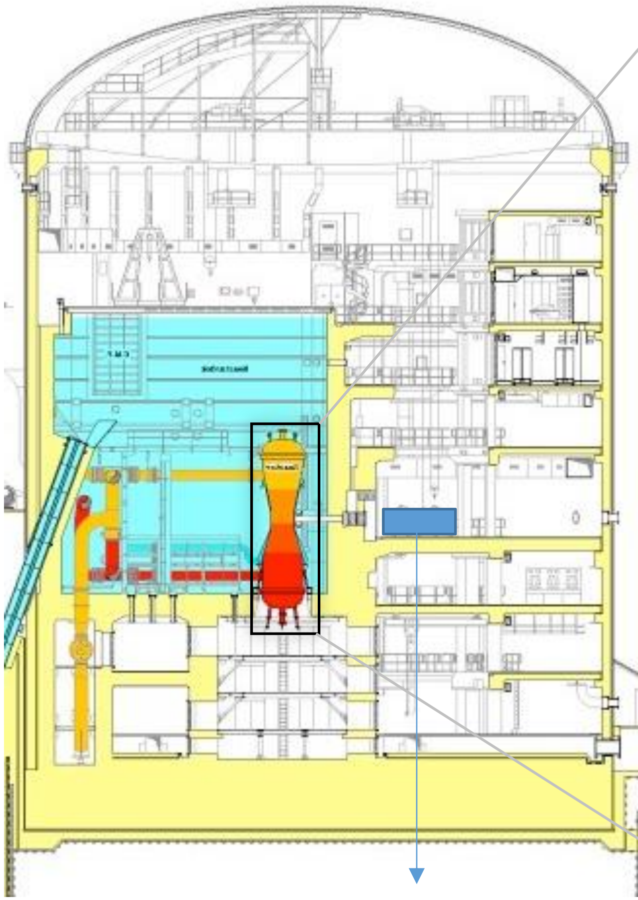
Hamamatsu MPPC:
3600 pixels



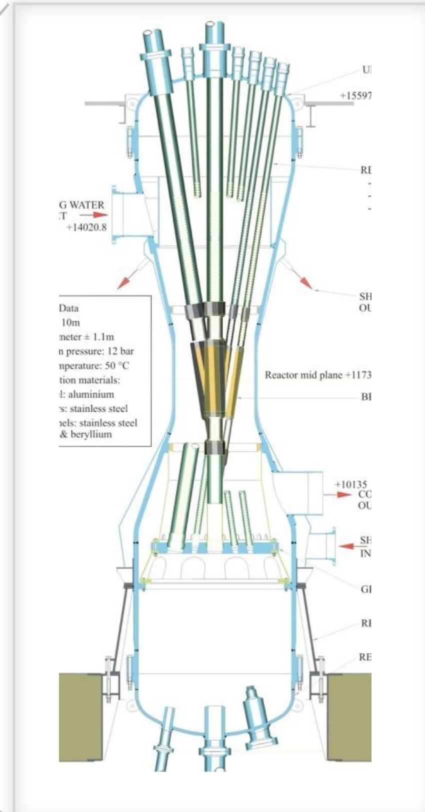


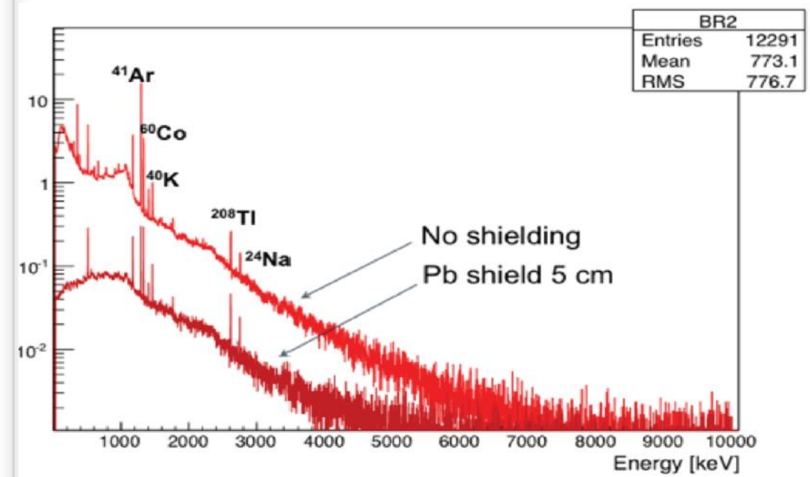
Belgian Reactor 2 (BR2)@ SCK•CEN

BR2 Confinement building



Aluminum pressure Vessel
Twisted core





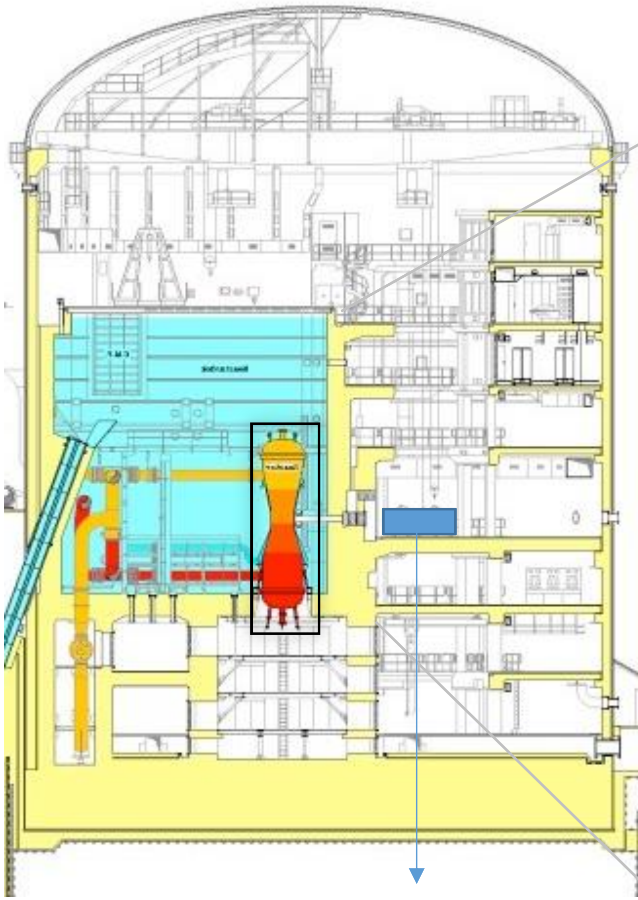
SoLid $\bar{\nu}_e$ detector:

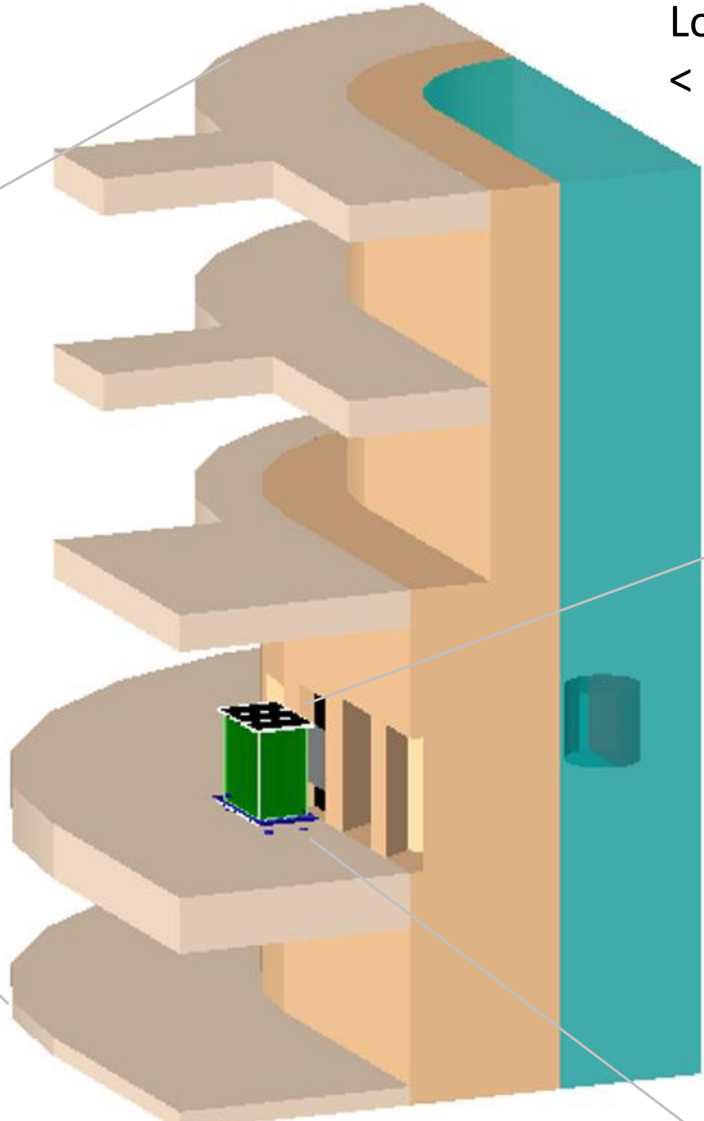
- 1.5 T fiducial
- Baseline: 5.5 – 12m
- On-axis with reactor core

- 95% Enriched 235U
- Effective core diameter d=0.5m
- Peak power: 70-80 MW_{th}
- Duty cycle: ~ 150 days/year
- Low accidental background

Belgian Reactor 2 (BR2)@ SCK•CEN

BR2 Confinement building





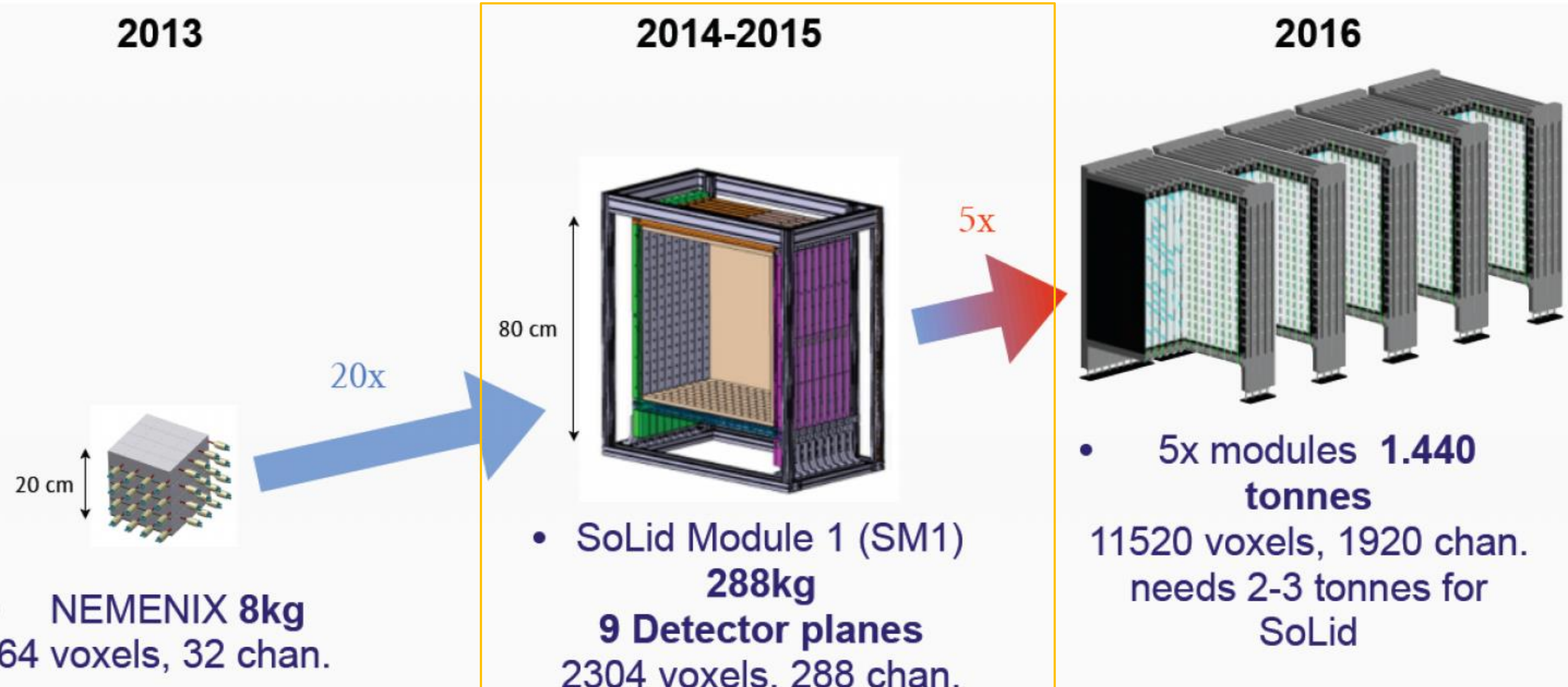
Low vertical overburden
< 10m WE

<u>SM1:</u>
Full scale module
300 kg
2300 voxels

SoLid $\bar{\nu}_e$ detector:

- 1.5 T fiducial
- Baseline: 5.5 – 12m
- On-axis with reactor core

Detector construction and operation …a staged approach



Proof of Concept

1. Demonstrate neutron PID
2. Measure Backgrounds
3. Measure Coincidence Rate

Real Scale Systems Test

1. Demonstrate scalability
2. Test Production (schedule & procedures)
3. Demonstrate Power of Segmentation
4. Do Some Physics (?)

Physics Scale Detector

1. Implement Neutron Trigger
2. Optimize Production
3. Optimize Performance
4. Do Initial Oscillation Search

EM Energy response

<u>Energy Scale& resolution</u>

Laboratory test bench

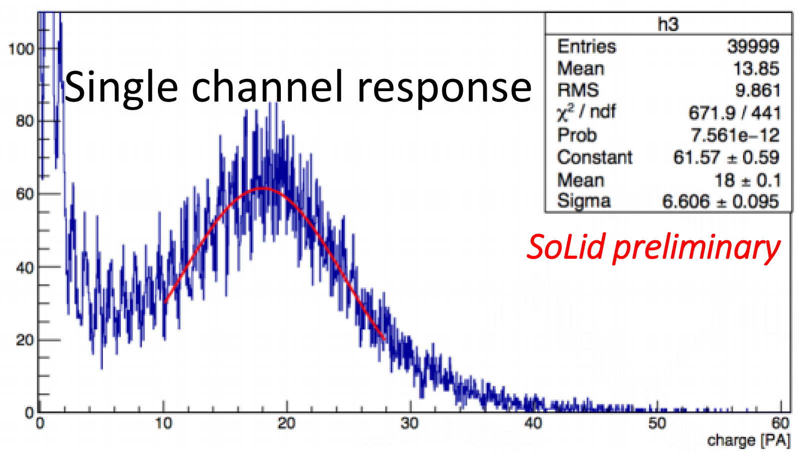
Using 1MeV conversion electron

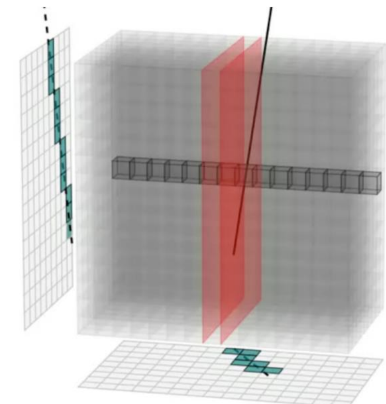
From ^{207}Bi

With 4-channel readout/cube ≥40 PA/MeV

$15\%/\sqrt{E}$ at 1MeV Achievable !

1 MeV peak



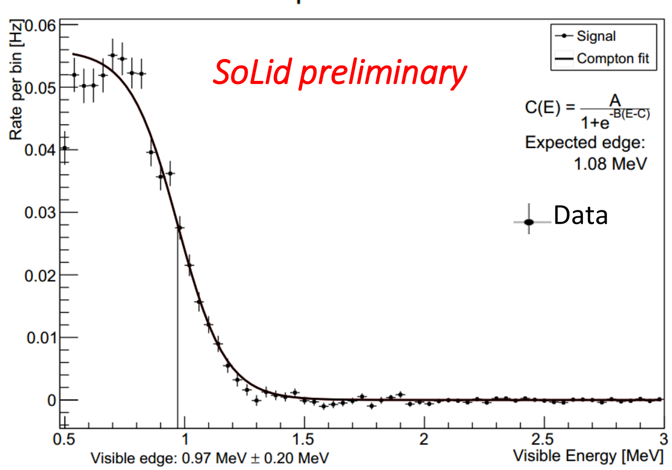


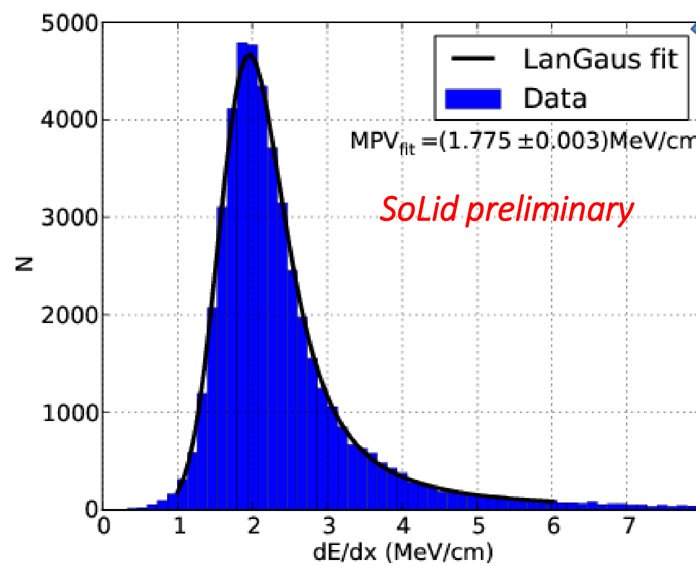
Crossing muon event

<u>Inter-channel calibration</u>

Using reconstructed muon tracks

In situ: ^{60}Co-spectrum in a cube



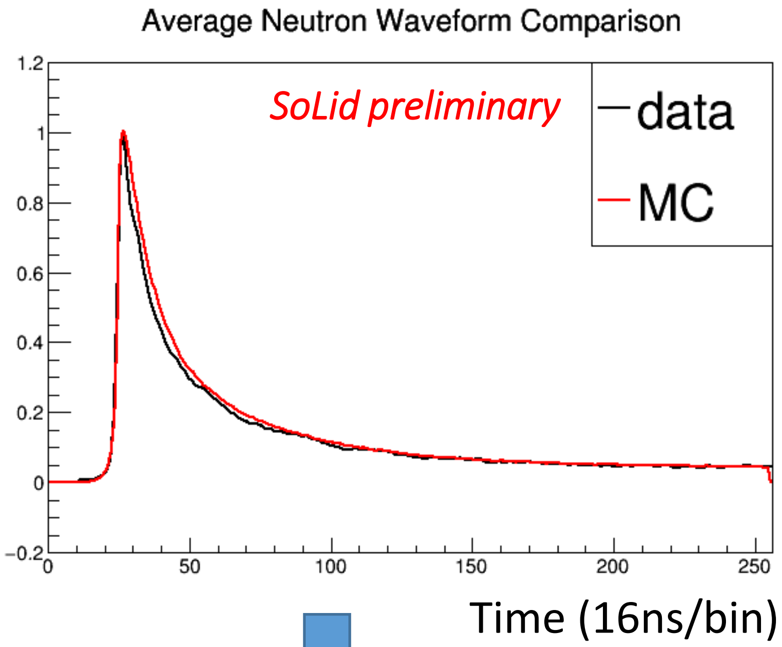


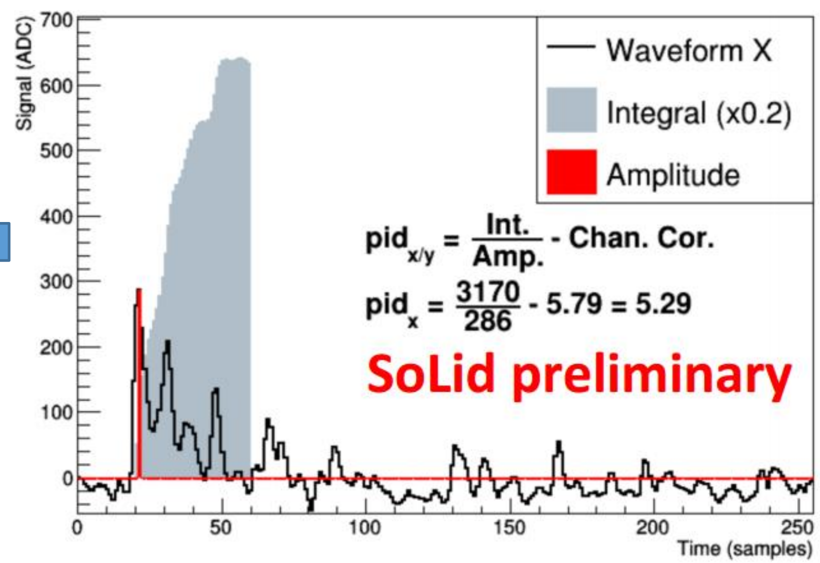
Neutron reconstruction

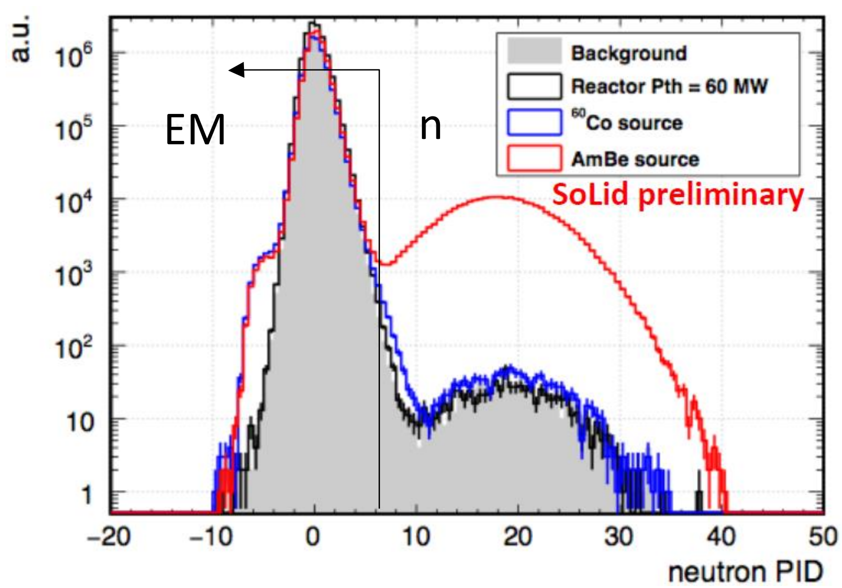
- Capture on ^6Li and excitation of ZnS(Ag) scintillator

$$^6_3Li + n \rightarrow {}^4_2He(2.05\ MeV) + {}^3_1T(2.75\ MeV)$$

- Capture efficiency for IBD neutrons using single (double) ^6LiFZnS per cell: 65% (80%)
- Distinct pulse shape allows separation from EM signals
- Validated with ^{60}Co and AmBe sources

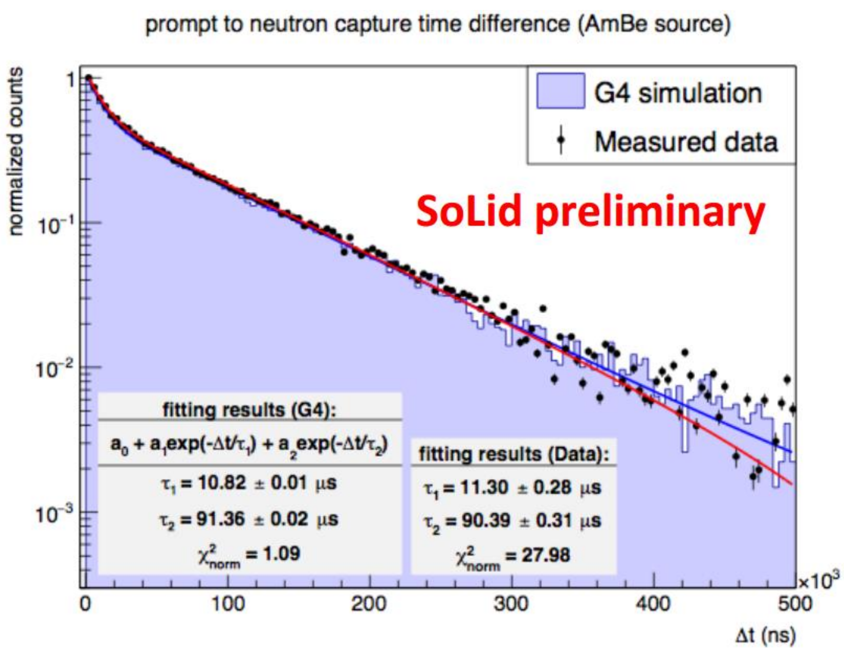


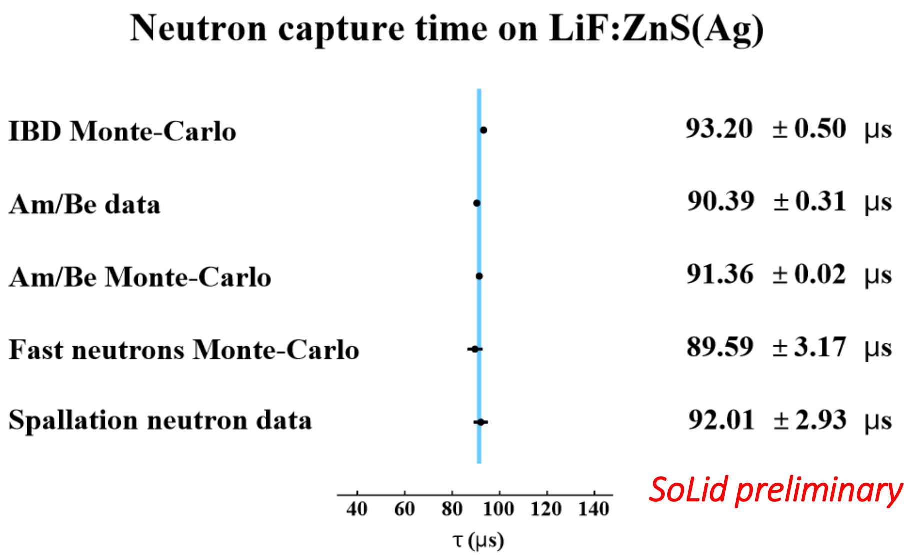




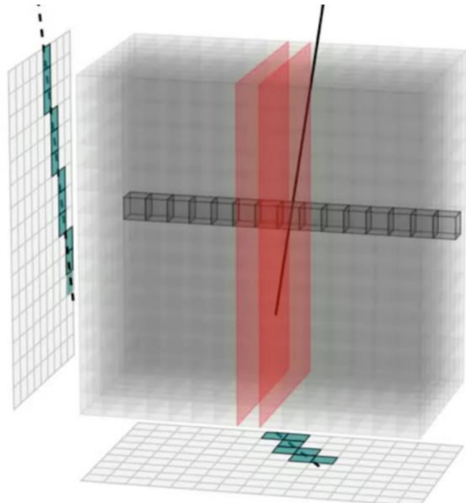
Neutron reconstruction

- Neutrons thermalize over distance of < 10cm: $\rightarrow$ Confined topology of IBD events
- prompt-neutron time difference determines IBD search window
- Simulation validated with Calibration sources (AmBe)

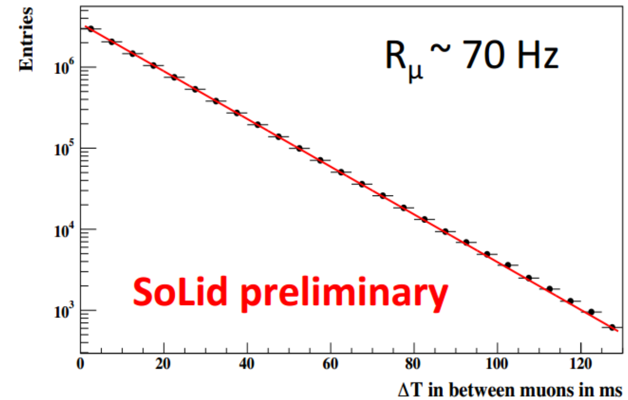


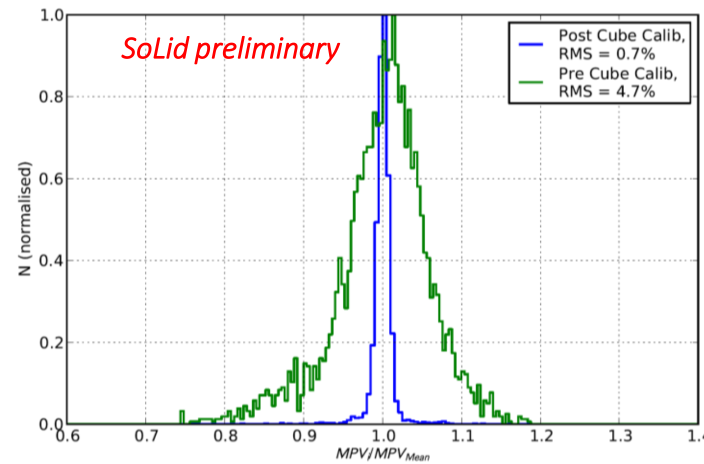


Muons

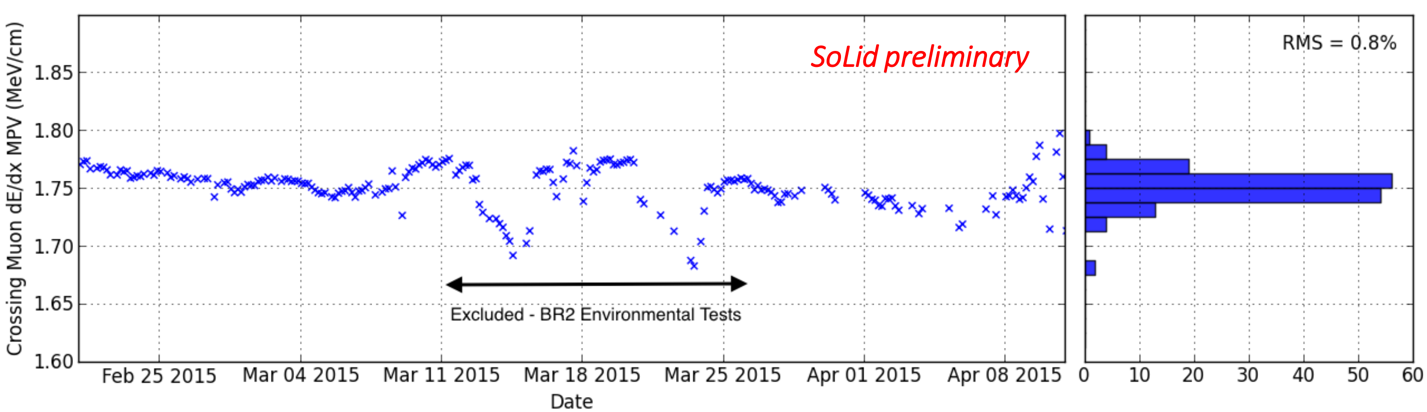


Crossing muon event





- SoLid is excellent Muon tracker
- dE/dx exploited for
  - Energy scale and inter-channel calibration
  - Veto muons by outer shell : 96% eff!
- Monitor detector stability over time: ~1%

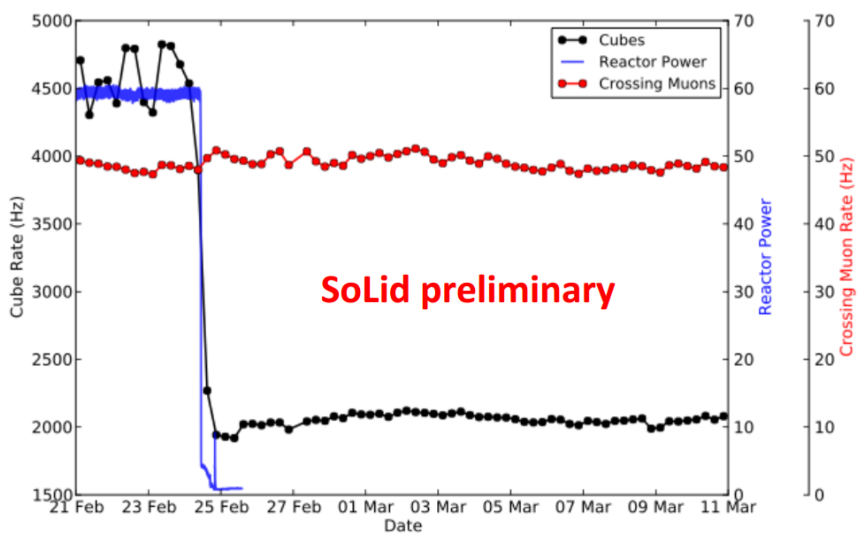


SM1 data taking & operational stability

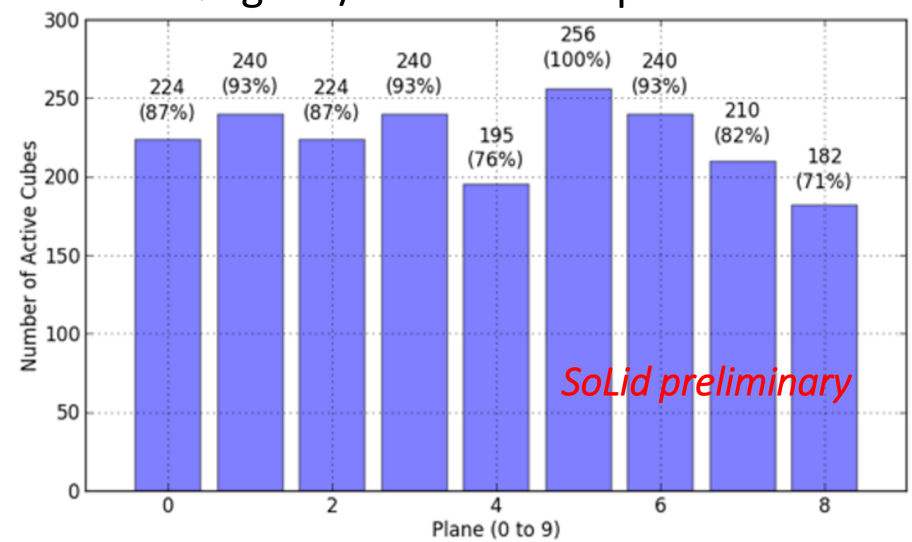
	Period	Exposure Time
Reactor On	00:00 21 Feb → 08:00 24 Feb	50.9 hours
Reactor Off	00:00 01 Mar → 00:00 13 Mar and 00:00 01 Apr → 12:00 11 Apr	428.8 hours

+ Dedicated calibration campaigns with sources: 60Co, AmBe, 252Cf

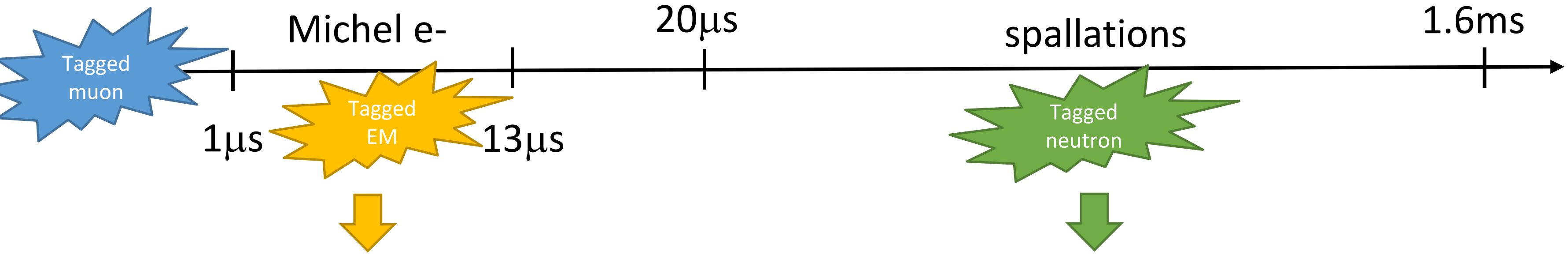
Stable rates of EM signals



87% good/stable cube operation

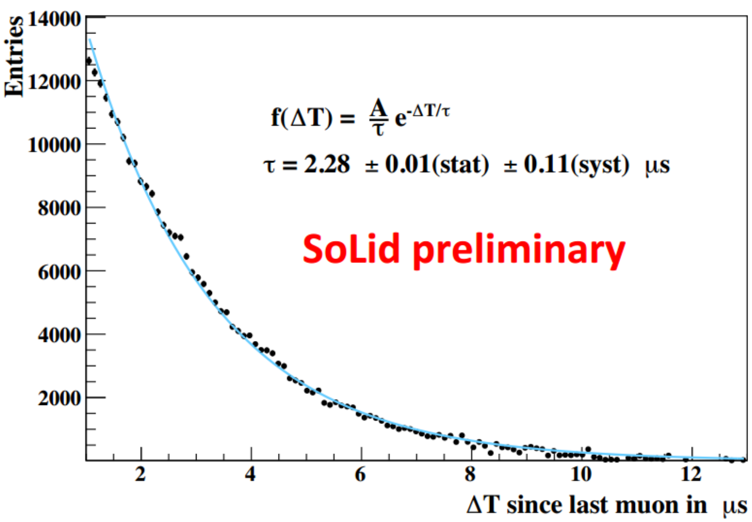


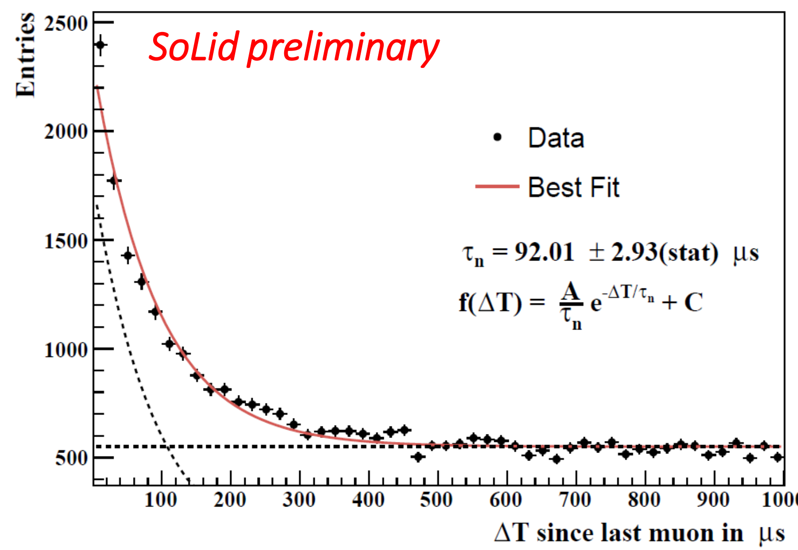
Time correlated signals: Muon Tagged



$$\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$$

$$\mu + N \rightarrow \mu + N^* + n$$

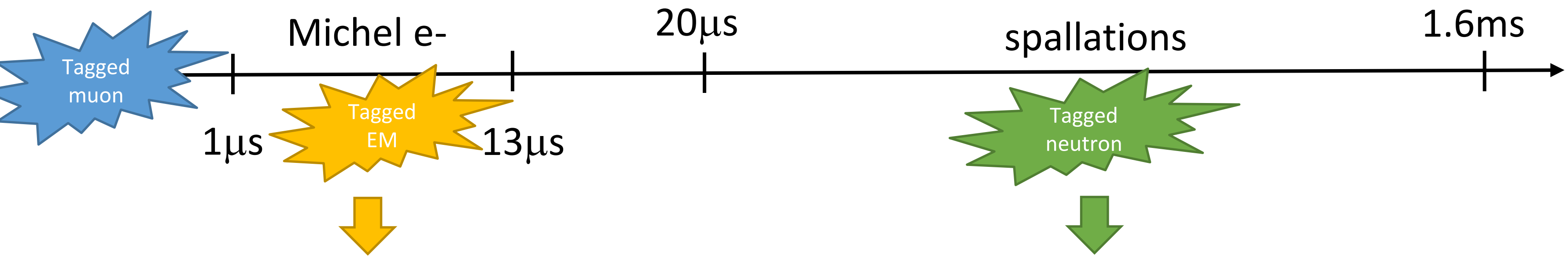




- Validation of Muon tagging
- Timing crosscheck
- Neutron contamination of EM signals: < 0.01% of Michel electrons tagged as neutrons

Capture time compatible with results from AmBe data and simulation
→ Muon induced spallation neutrons
→ Investigate directionality
→ Neutron-like Control sample

Time correlated signals: Muon Tagged



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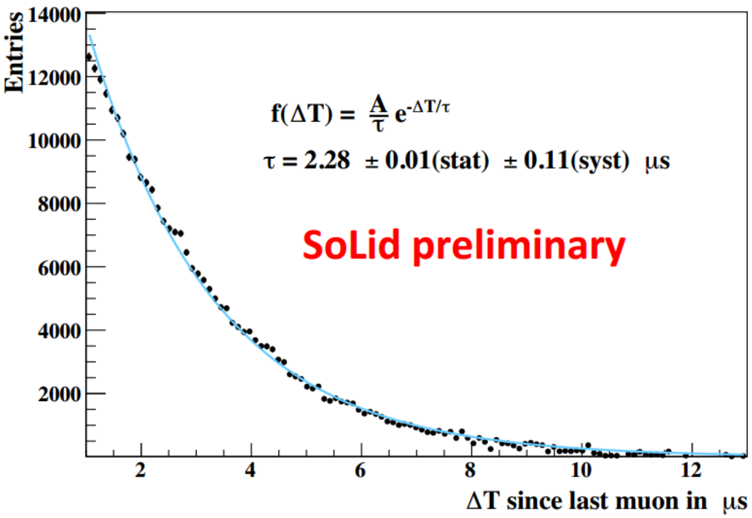

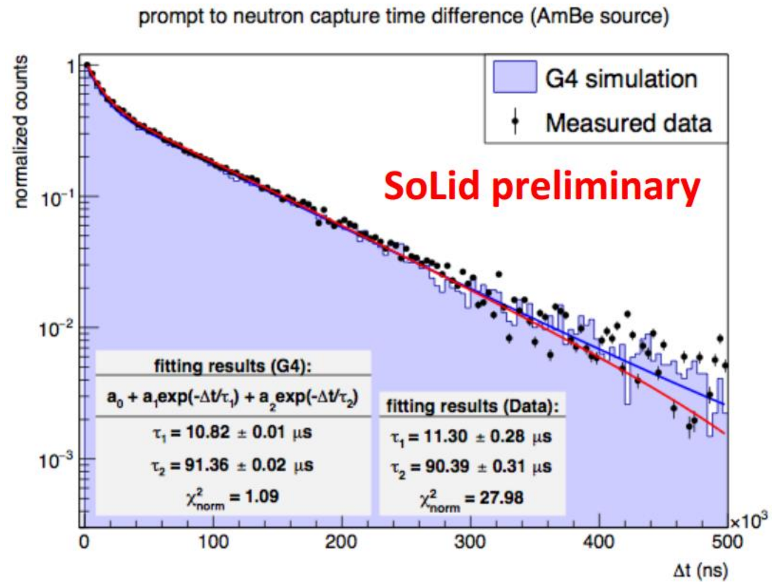

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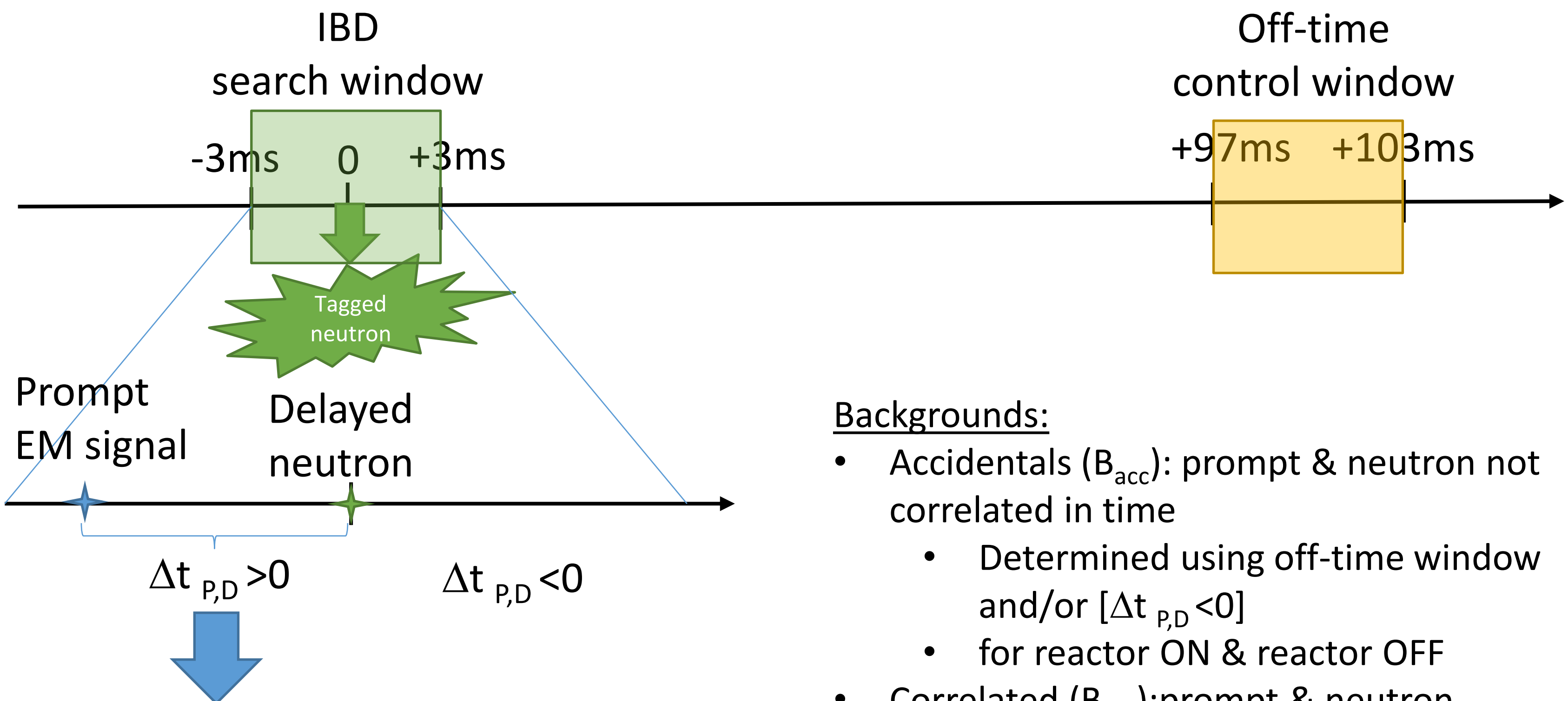
Capture time compatible with results from AmBe data and simulation

→ Muon induced spallation neutrons

→ Investigate directionality

→ Neutron-like Control sample

Time correlated signals: IBD-like



<u>Backgrounds:</u>

- Accidentals (B_{acc}): prompt & neutron not correlated in time
  - Determined using off-time window and/or [$\Delta t_{P,D} < 0$]
  - for reactor ON & reactor OFF
- Correlated (B_{cor}):prompt & neutron correlated in time
  - Determined using reactor OFF data in [$\Delta t_{P,D} > 0$] window

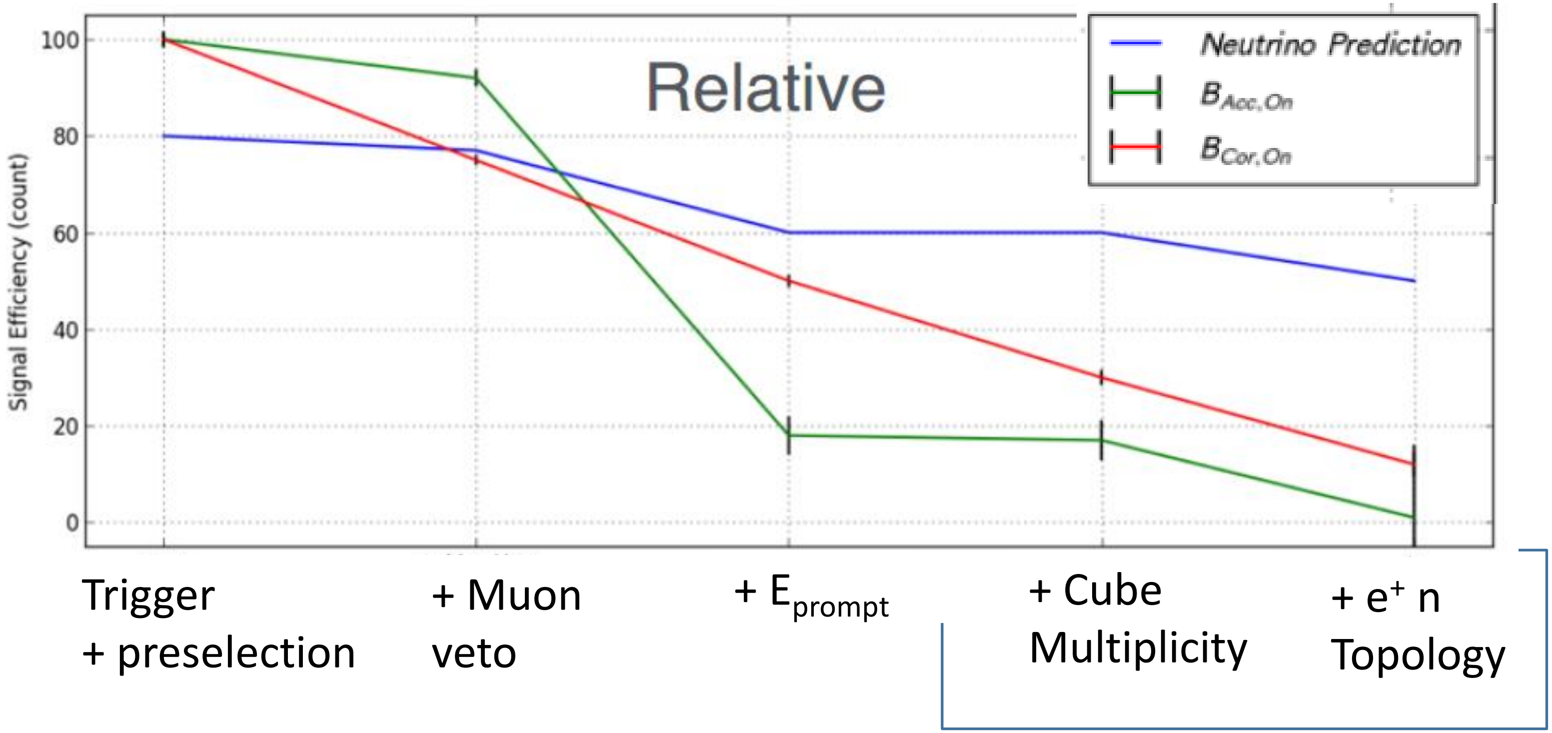
<u>IBD signal</u> region:

$0.1\ \mu s < \Delta t_{P,D} < 250\ \mu s$

Purified by:

- Muon veto (fast n from μ)
- Energy thresholds (Gamma bg)
- Hit Multiplicity (fast n)
- Topological cuts (accidentals)

IBD Analysis performance



- Data-driven background determination
- Accidental background can be significantly reduced
- Time-correlated background reduced by 90% due to our unique segmentation feature
- High IBD efficiency achievable in future analyses

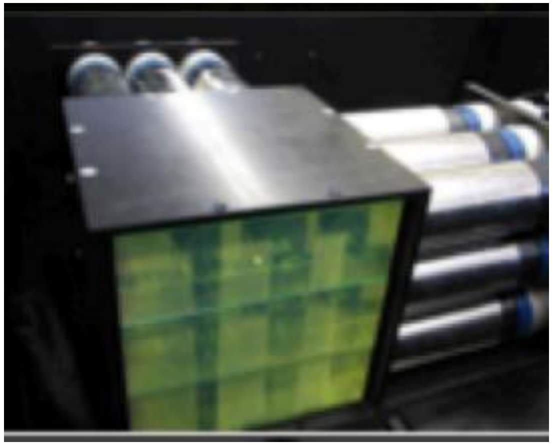
Short term plans

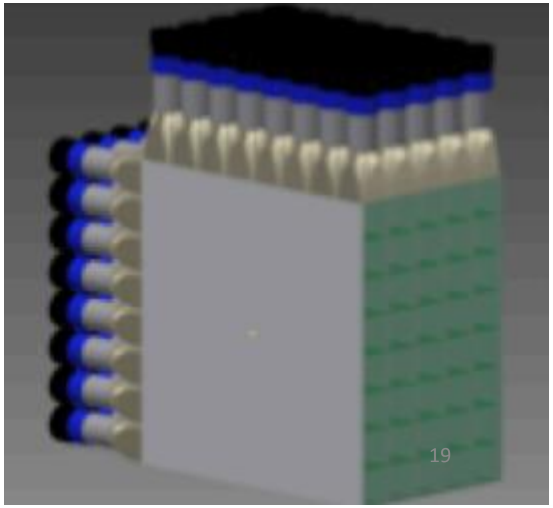
- Implemented small design changes to:
  - Increase light yield: improve energy resolution and operate at lower tresholds
  - Improved front-end electronics and DAQ: lower noise levels and cope with increased trigger rate
  - Double amount of ^{6}Li based neutron screens
  - Dedicated neutron trigger
  - Supplementary passive shielding for cosmogenic bg
  - Possibility to add active muon veto
- Construction started in phased approach
- Start next data taking run second half of 2016
- Ready to undertake sensitive search for reactor antineutrino disappearance
- Provide precise measurement of ^{235}U $\bar{\nu}_e$ spectrum

Long term plans

- Complement SoLid with 1m3 HiRES (6% σ_E/E) CHANDLER near-detector module
- 8x8x5 voxel module currently under construction
- See eg. J. Link at Aspen 2016

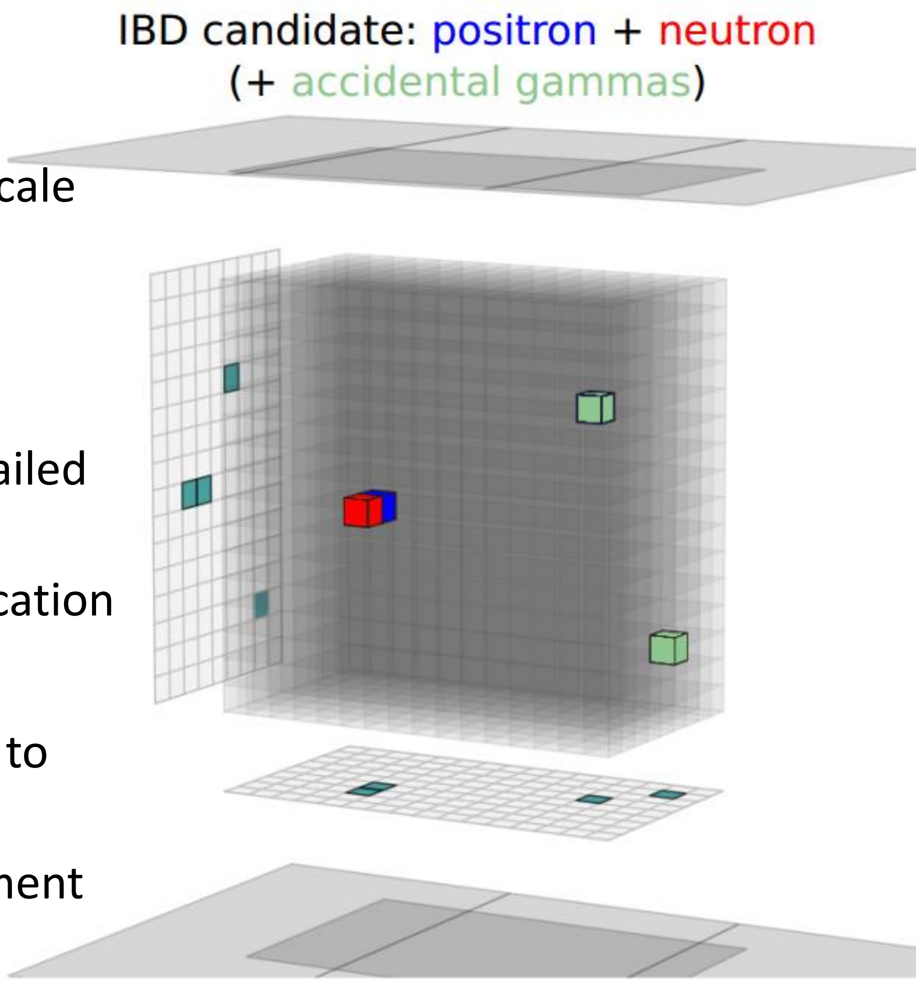
https://indico.cern.ch/event/473000/session/2/contribution/10/attachments/1213996/1771830/Aspen_2016.pdf





Conclusion

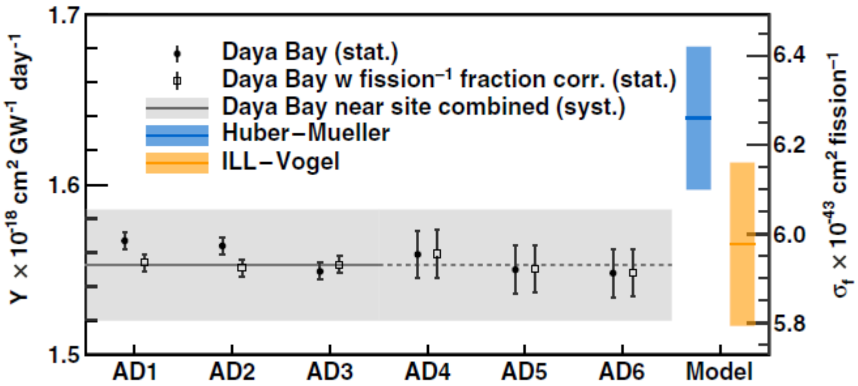
- Commissioned, operated and calibrated full scale detector module
- In realistic reactor conditions
- Very good stability over time
- Developed many analysis tools, including detailed detector + environment simulation
- Optimizing object reconstruction and identification
- Study of various backgrounds
- First hints of IBD candidates appearing: More to come
- Currently staging a scale-up to a 1.5 T experiment
- Data taking starting 2nd half 2016

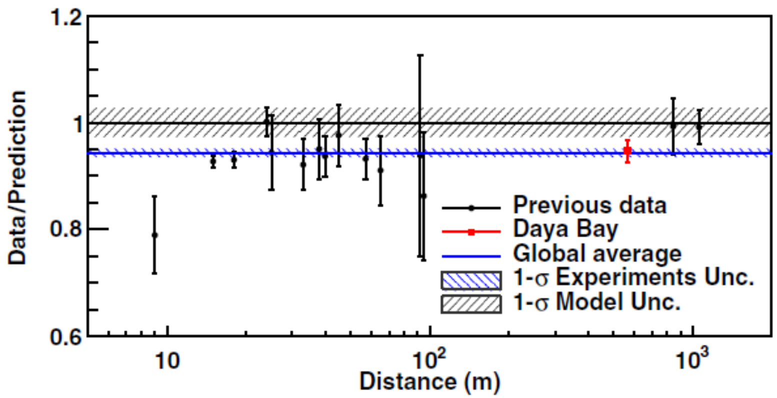



Thank You !

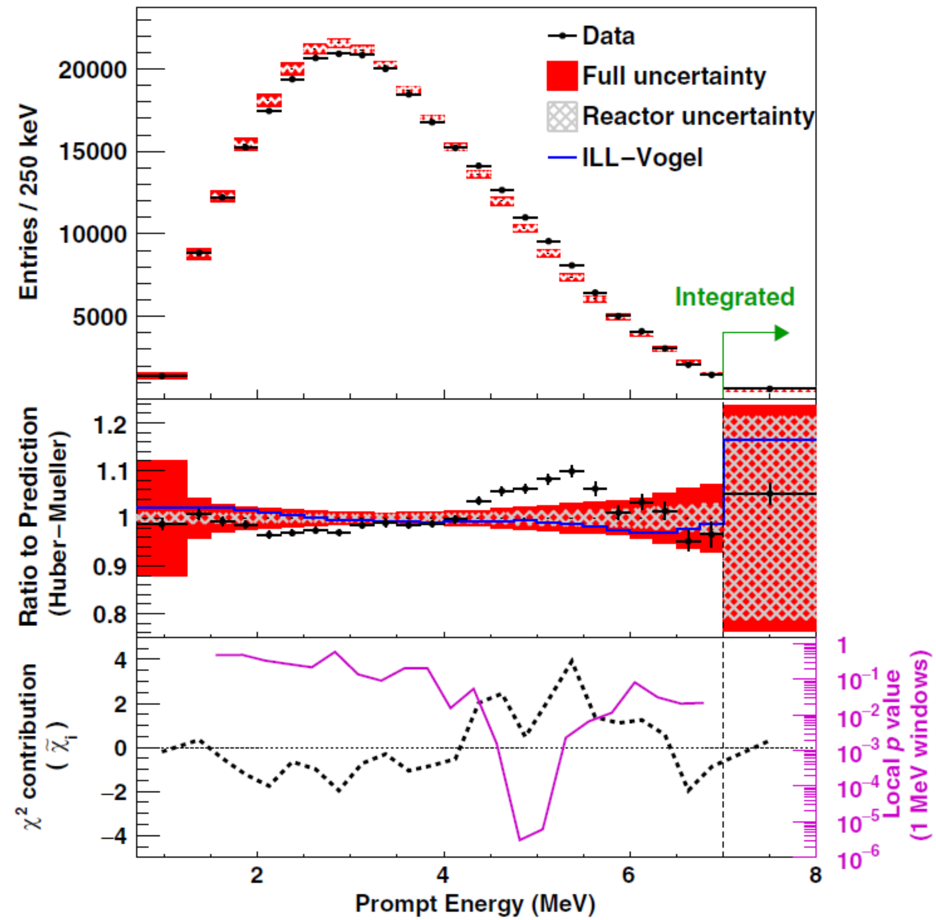
Backup

- Daya-Bay flux and spectrum measurements



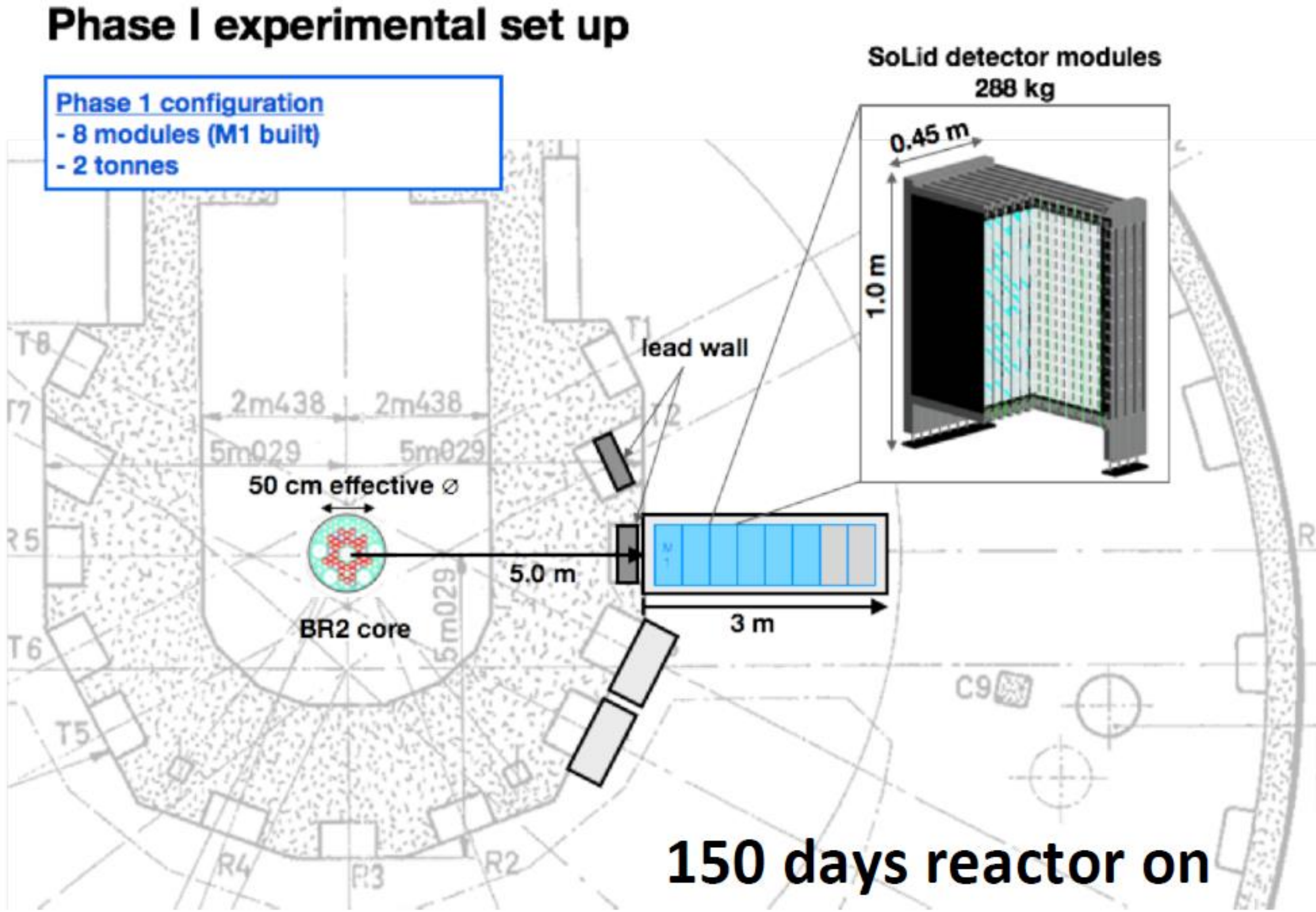


$$R_g = 0.943 \pm 0.008(\mathrm{expt}) \pm 0.025(\mathrm{model}).$$

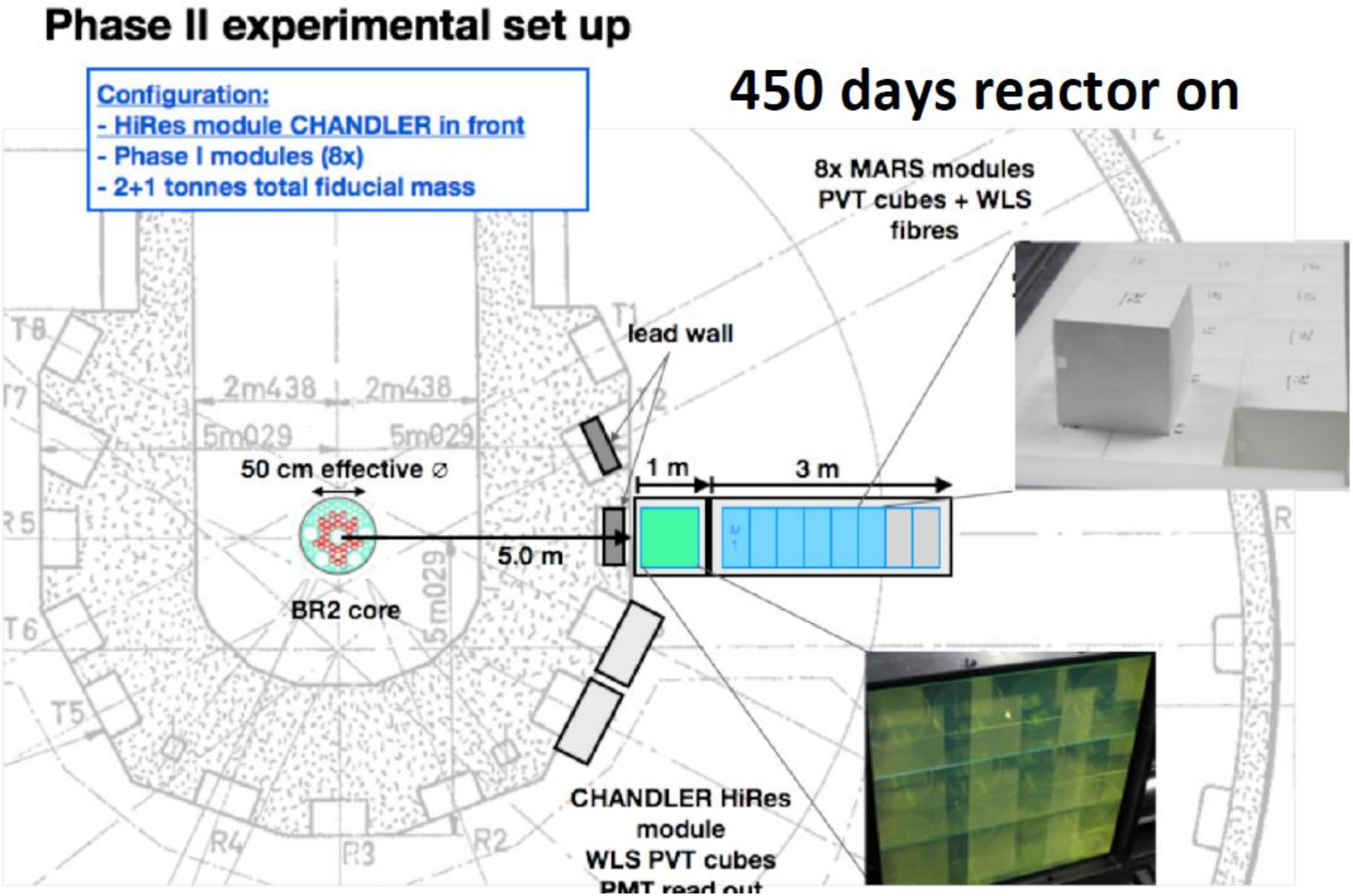


- Very interesting to confirm the existence of the 5MeV bump for pure ^{235}U and at L=5meter !

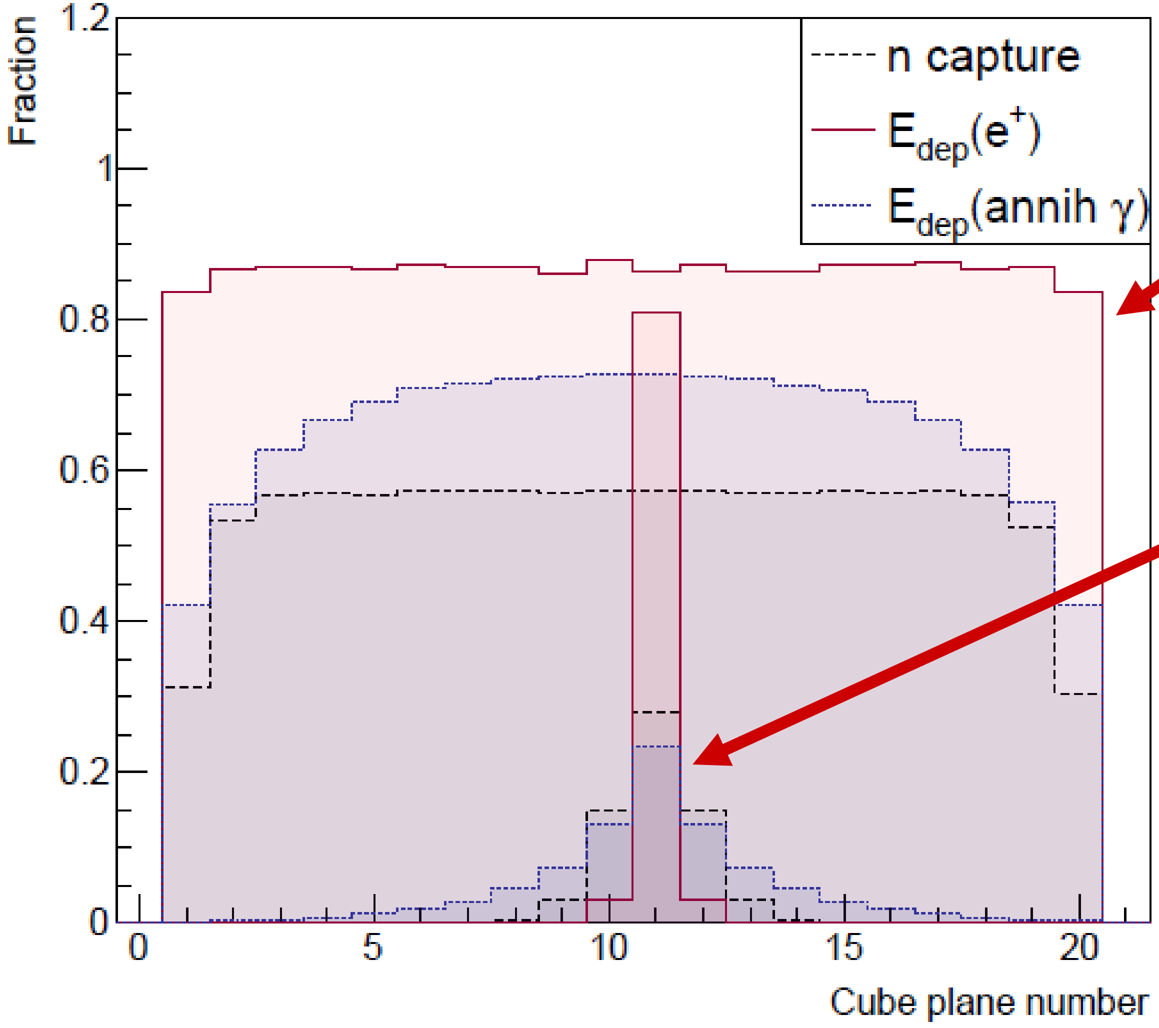
Phase 1 configuration



Phase 2 configuration



Neutron and EM energy containment



Averages over whole detector

Total efficiency

Generated in detector center

Containment of IBD event