Status of the SoLid experiment

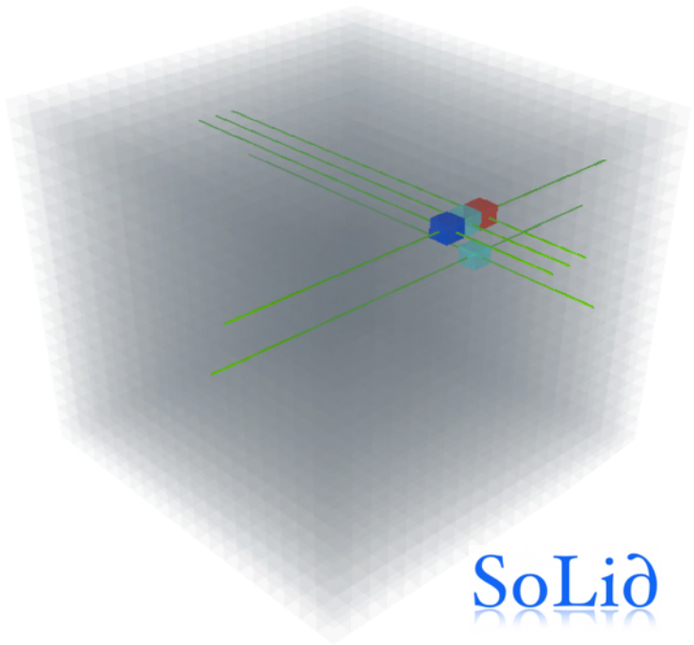
Benoît GUILLON

guillon@in2p3.fr

for the SoLid Collaboration

Normandie Univ, ENSICAEN, UNICAEN, CNRS/IN2P3, ***LPC Caen****, 14000 Caen, France*

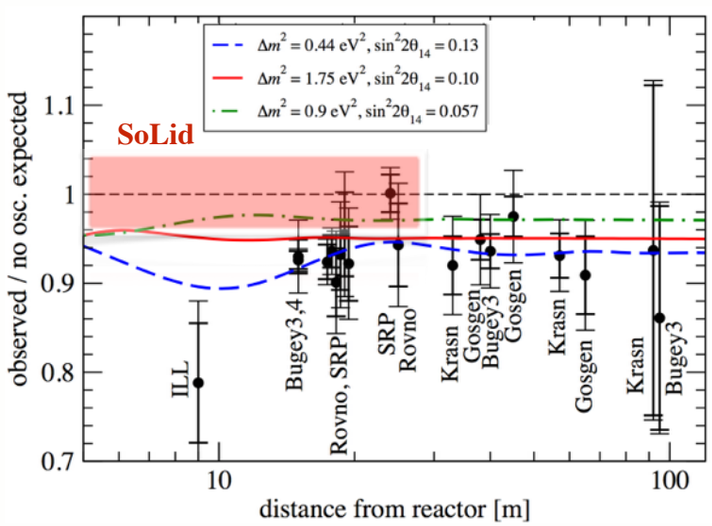
GDR Neutrino - 06/2016

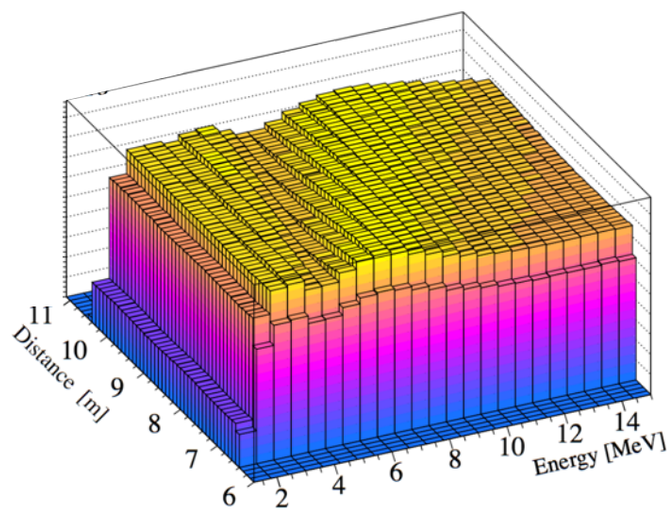


Physics Motivations

- Search for Short-Baseline Oscillation (RAA) ⇢ Light sterile neutrino ($\Delta m^2 \sim eV^2$)

J. Kopp et al., JHEP 1305:050 (2013)

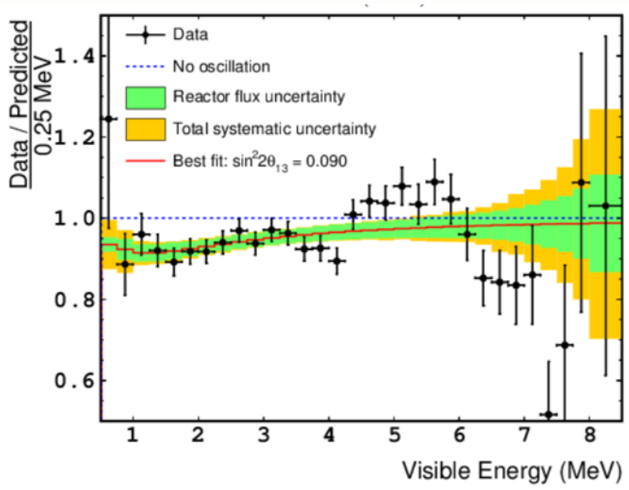




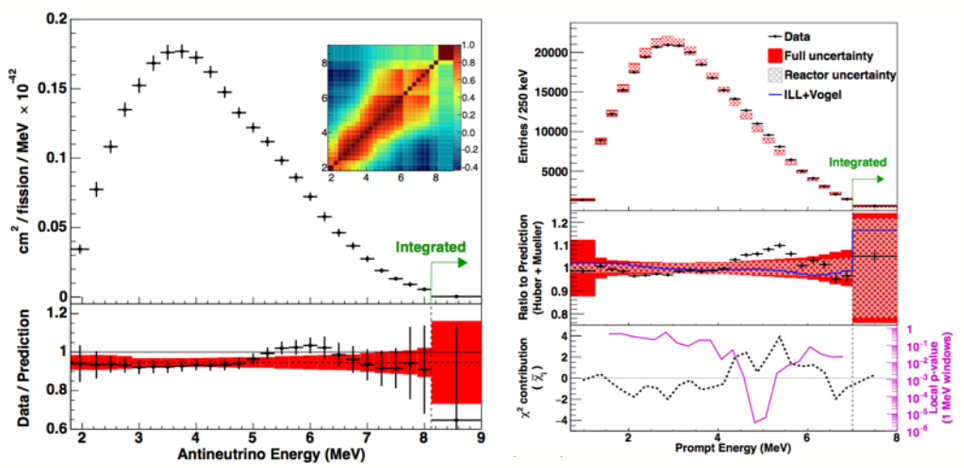
Energy spectrum distorsion vs distance

- ^{235}U ν_{e}- spectrum measurement ⇢ Insight for predictions

Y. Abe et al., JHEP 10, 086 (2014)



F. P. An et al., Phys. Rev. Lett. 116, 061801 (2016)



All 3 θ_{13} reactor experiments observes an excess ('bump') between 4 and 6 MeV

- New Segmented Solid neutrino detector … Against background (close reactor core @ sea-level)

  … Neutron detection, non-proliferation

SoLid overview

- Detector : 1.6 → 3 t fiducial

  Composite solid scintillators (PVT / ^{6}LiF:ZnS)

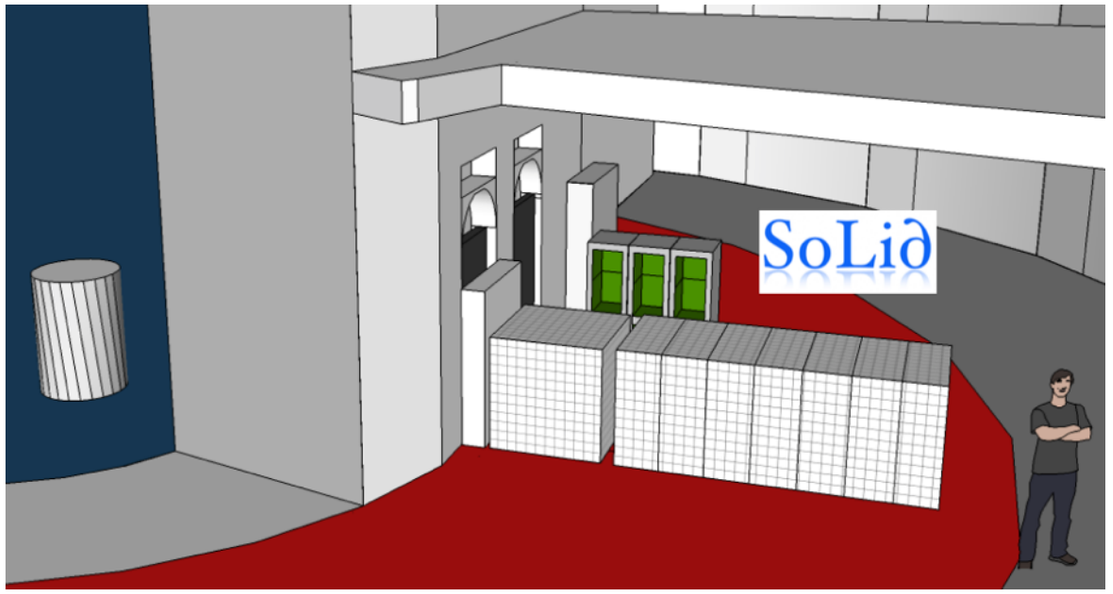
  Highly Segmented (8 000 voxels/m^3)

- BR2 @ SCK-CEN (Mol, Belgium)

  HEU(^{235}U) : P_{th} = 50 - 80 MW

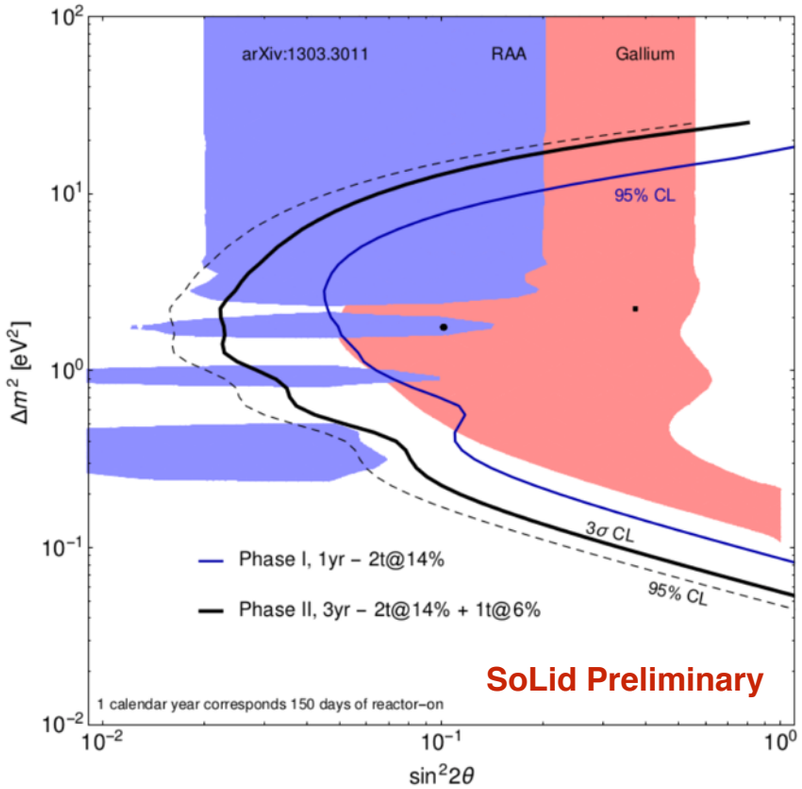
  SoLid @ 5.5 → 12 m

  Low background (neutron, γ)



- Physics run scheduled end 2016

Parameters	Objectives
Total mass	1.6 ~ 3t
IBD efficiency	41 %
Threshold	200 - 500 keV
Anti-neutrinos	~1200 d^{-1}
Signal/Background	~3
Energy resolution	14 % à 1 MeV
Systematic uncertainty	2.5 - 4.5 %

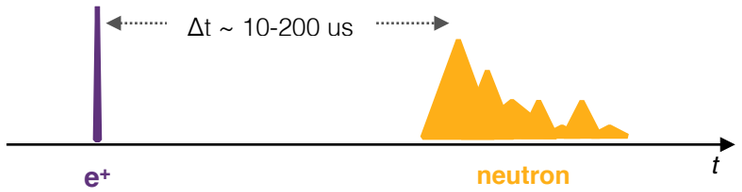


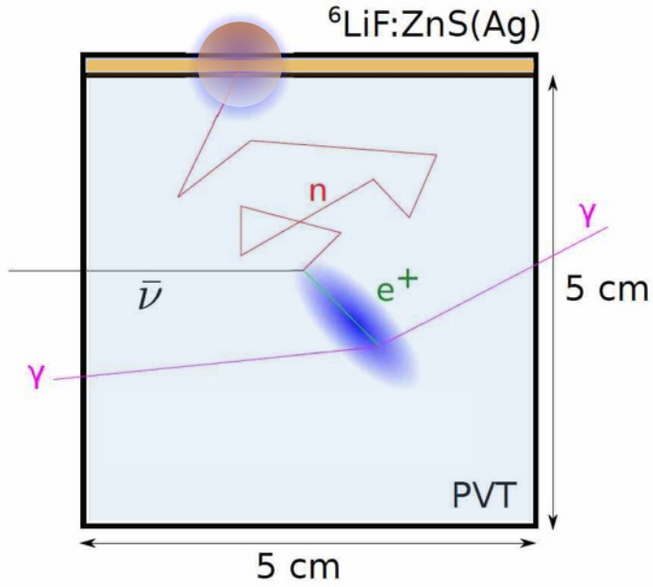
SoLid collaboration

	Oxford University	*A. Weber, S. Ihantola, N. Ryder*
	Bristol University	*D.Newbold, D.Cussans, K.Petridis, G.Pommery, J.Rademacker, D.Saunders*
	Imperial College	***A. Vacheret*** *(new group being formed)*
	SCK-CEN	*B. Coupé, S. Kalcheva, E. Koonen, L. Ghyrs*
	Antwerp University	***N van Remortel,*** *Y. Abreu, A. De Roeck, X. Janssen, I. Piñera,*
	Vrije University Bruxel	*J. D'Hondt, P. Van Mulders, S. Vercaemer, L. Kalousis*
	Gent University, B	*M. Labare, C. Moortgat, D. Ryckbosch, I. Michiels*
	LPC Caen	*G. Ban, D. Durand, B. Guillon, G. Lehaut*
	Subatech Nantes	***F. Yermia****, M. Fallot, L. Giot, B. Viaud*
	LAL Orsay	*M. Bongrand, L. Simard, M-H Schune, Y. Amhis, D. Boursette*
	Virginia-Tech	*J. Link, P. Huber, C. Mariani, J. Park*

Detection Principle

- Inverse Beta Decay **(PVT)** : $\bar{\nu}_e + p \rightarrow e^+ + n$
- Delayed neutron capture **(^{6}LiF:ZnS)** : $n + {}^6Li \rightarrow {}^3H + \alpha$ (4.8 MeV)
  - PSD and $\triangle$T coincidence windows





- Highly-segmented (8 000 voxels/m^3)

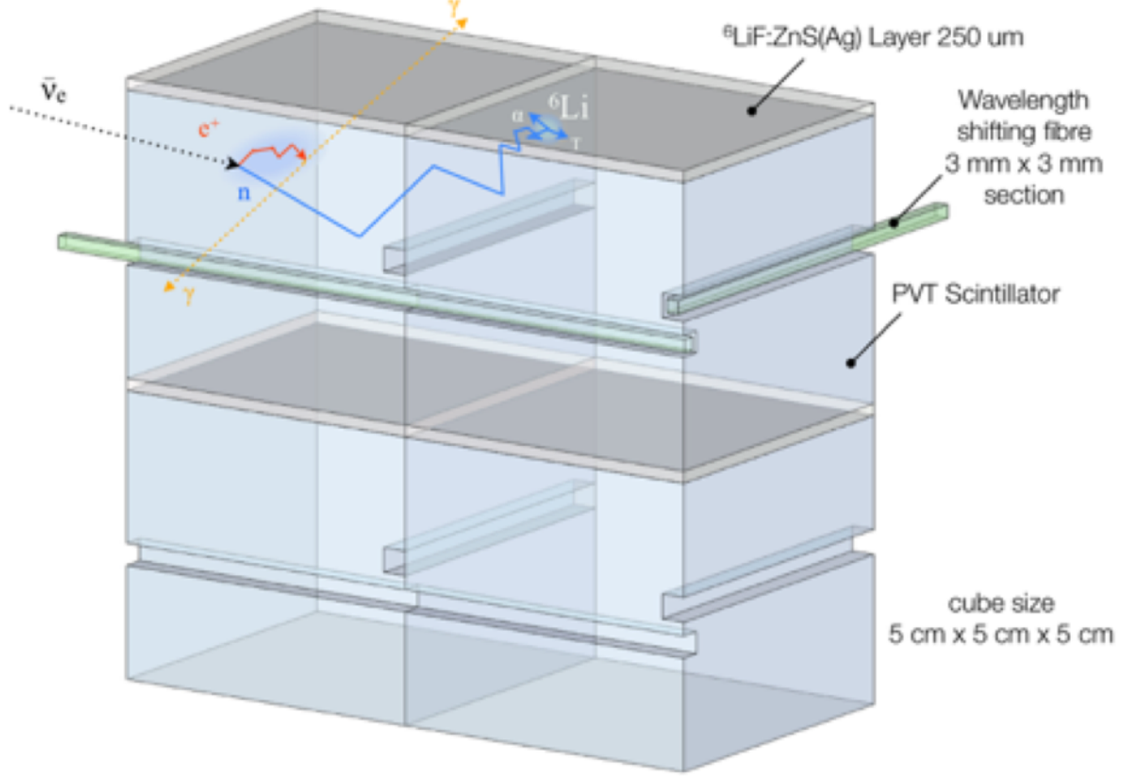
  Cube detection elements (5x5x5cm^3)

  Optically isolated by Tyvek wrapping

  16x16 cubes lattice - plane (80x80 x5 cm^3)

  Light collection by (2 →4) WLS (3x3 mm^3)

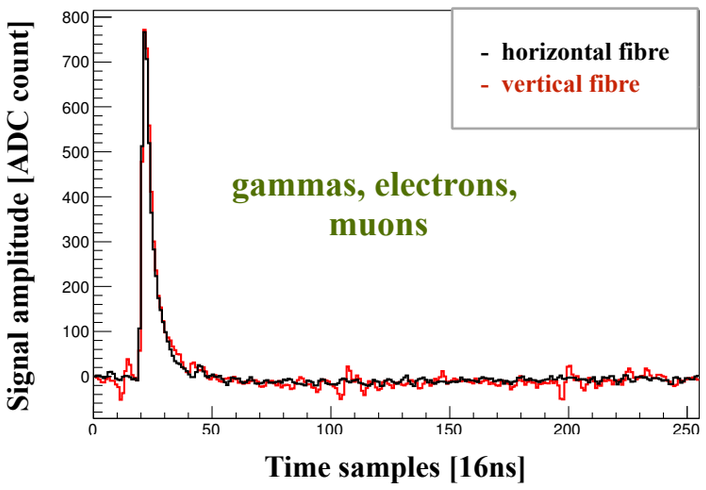
  Read-out by (2 →4) MPPC (Hamamatsu S12572-050P)

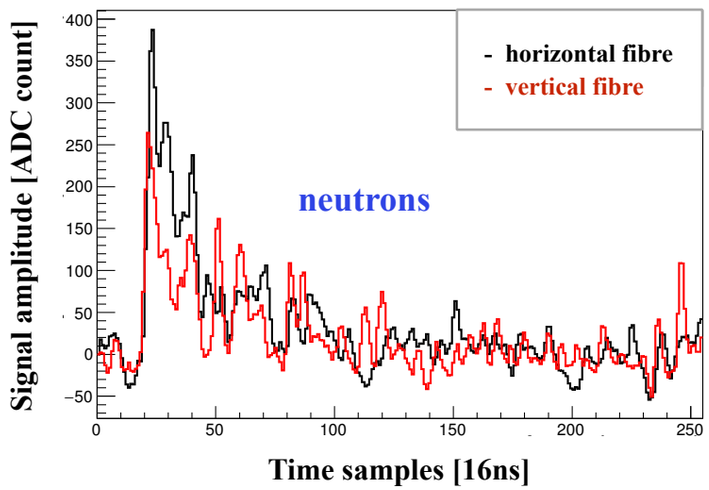


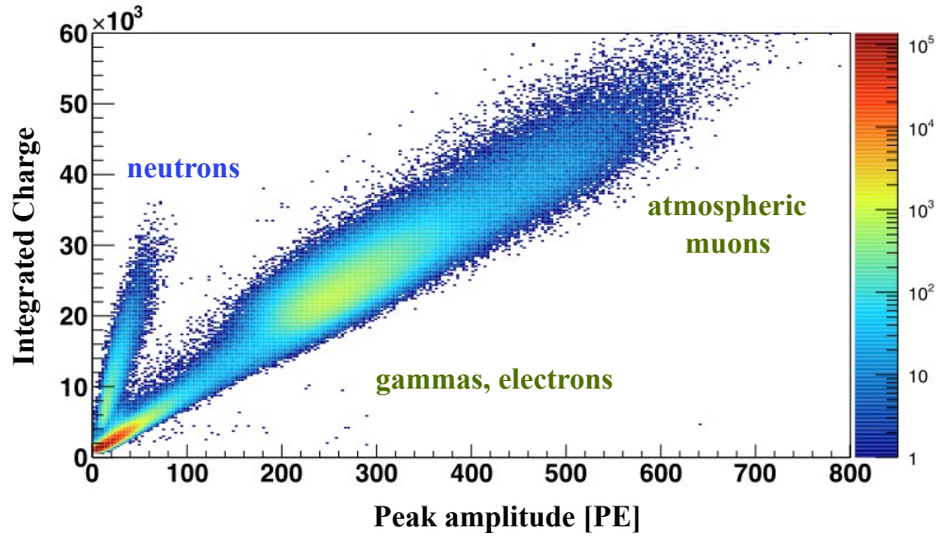
- Good light yield : $\delta E / \sqrt{E} \sim 20 \rightarrow 14\ \%$

SoLid unique features

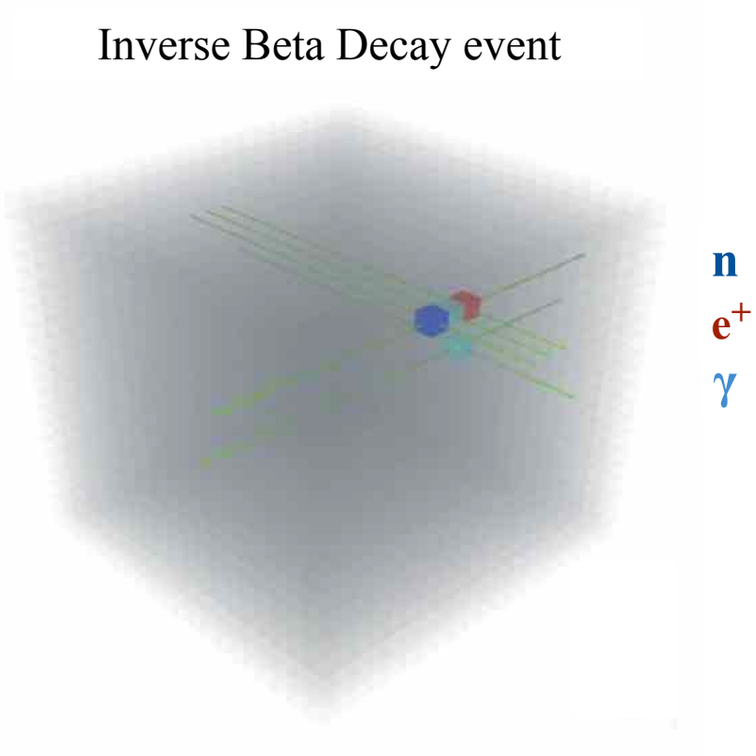
- Pulse Shape Analysis ⟶ Neutron Tag (trigger) !

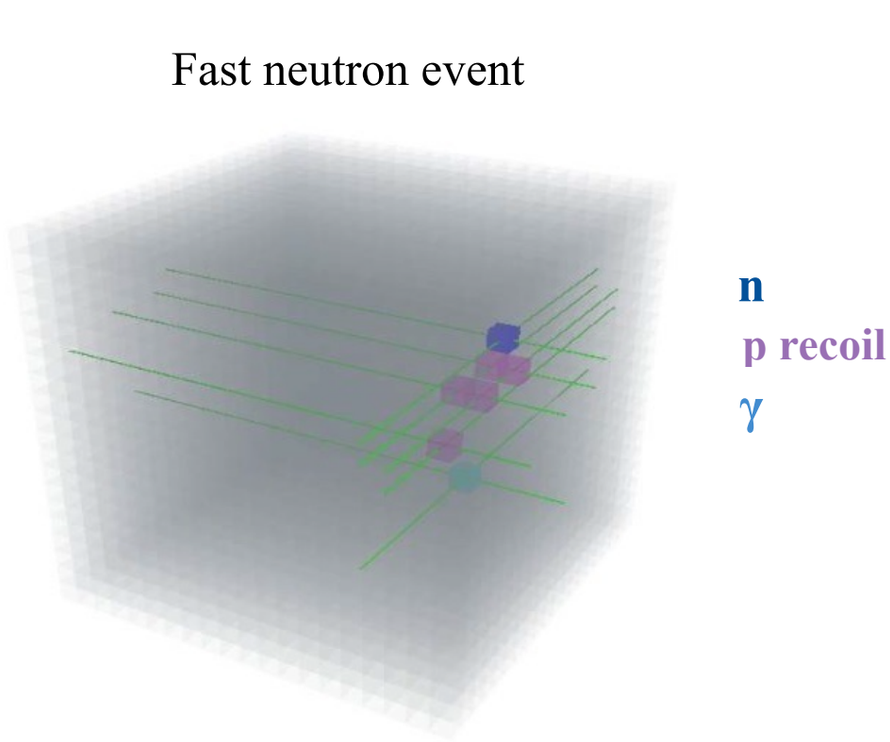






- 3D topology reconstruction ⟶ Background identification/rejection !





Belgian Reactor 2 @ SCK-CEN

- Major MTR-type reactors

  Material testing/Isotopes production…

  No others project in fondamental/particle physics

  Non-proliferation : statutory tasks

- SCK-CEN collaboration

  Support, funding (shielding, source,…)

  Reactor calculation expertise

  Large working area & No time limitation

- Neutrino parameters

  Operating power : $P_{th} \sim 65\ (125)\ MW_{th}$

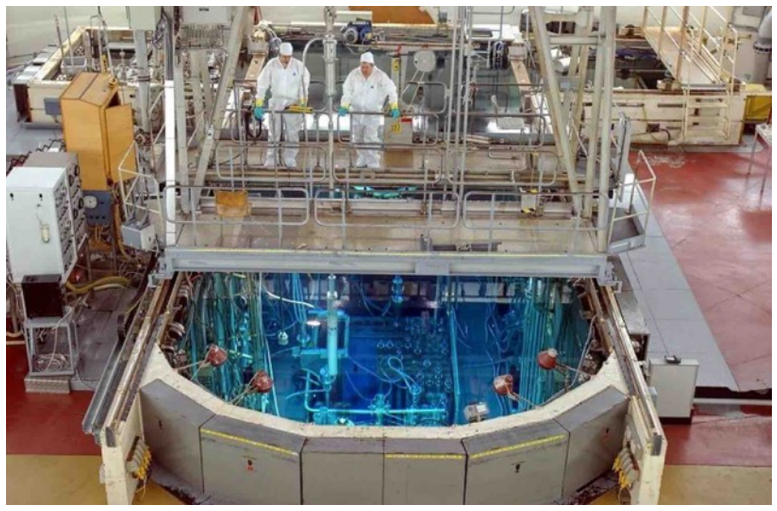
  Highly Enriched Uranium : 93% ^{235}U

  Neutrino flux : $\sim 10^{19}\ \nu_e$ /s

  Compact : $\Phi_{eff} = 50$ cm, h = 90 cm

  Duty cycle : 150 days/year

⇢ Critical after 1.5 year refurbishment (1/06/2016)
Power operation resumed in July 2016



SoLid @ BR2

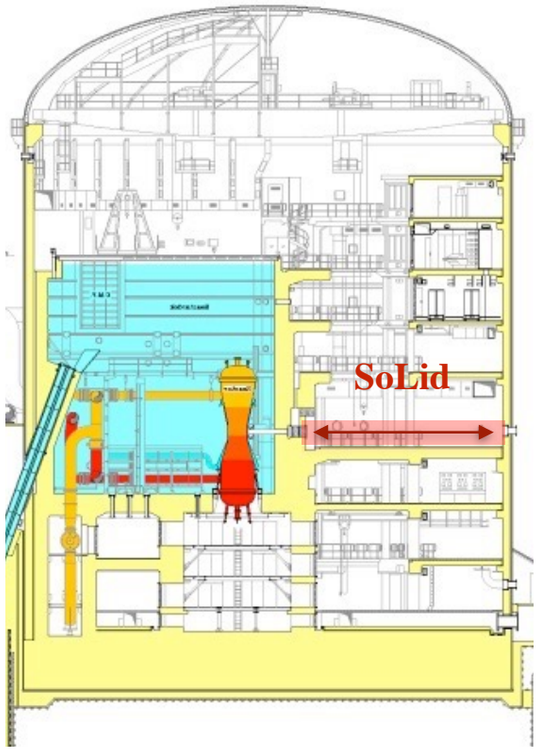
- Adjustable Base-Line

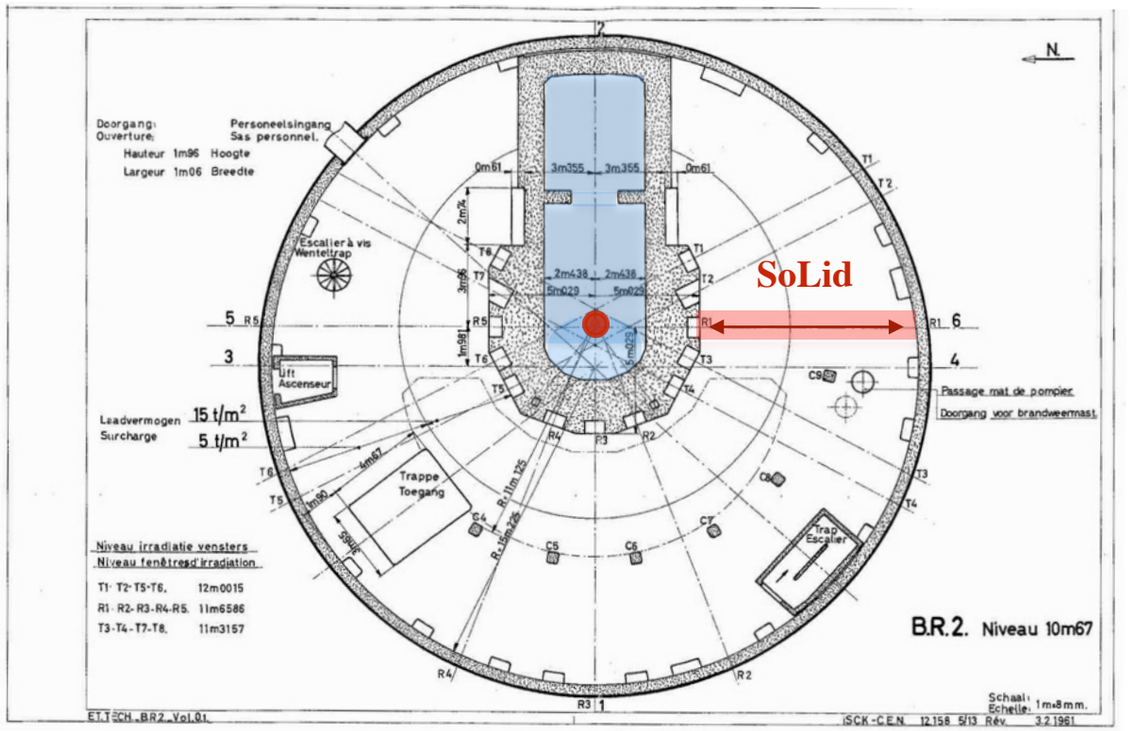
  SoLid @ 5.5 → 12 m

- Reactor On-Axis

- Low vertical overburden

  < 10 m WE





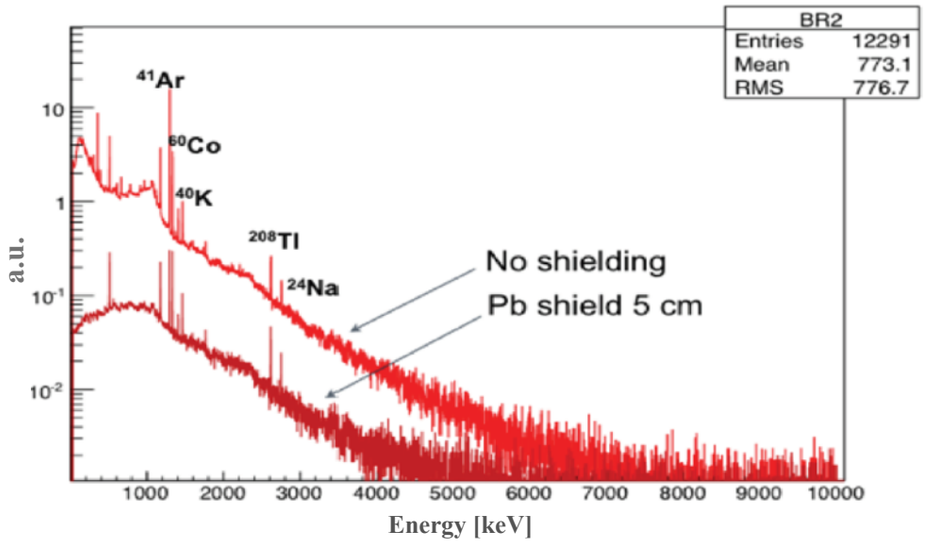
- Low level of Reactor core background (no beam-pipe (bio-shielded), concrete)

  Background measurement campaign … confirmed by NEMENIX and SM1 results

BR2 HPGe detector

BR2 neutron detector

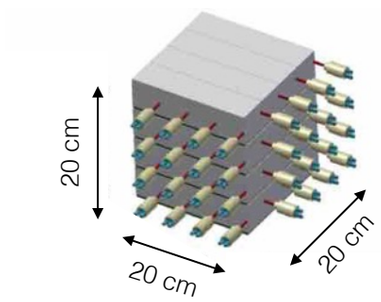
Oxford neutron detector (MARS)



Project Timeline … a staged approach

NEMENIX

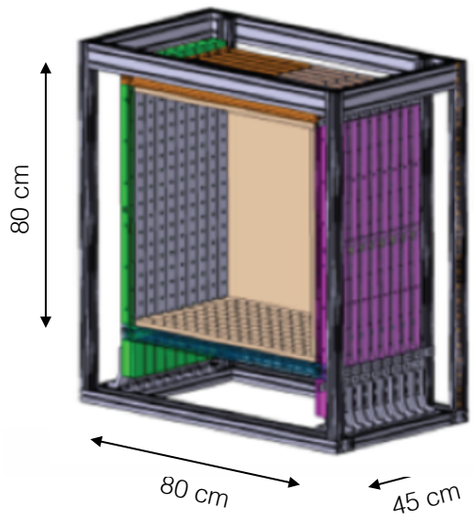
8kg - 64 voxels
32 channels



x 40

SM1

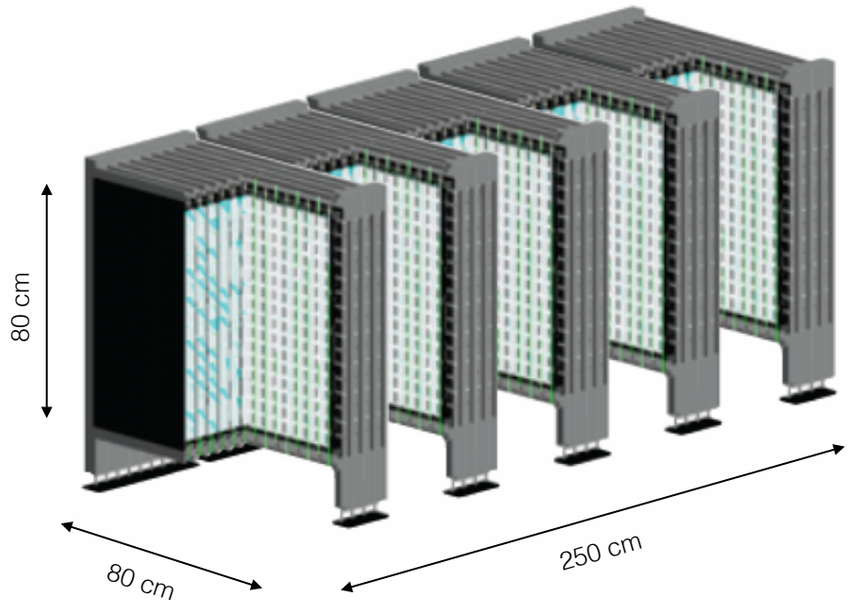
288kg - 9 planes
2304 voxels - 288 channels



x 5

SoLid Phase I

1.6 t (need 2-3 t) - 50 planes
12 800 voxels - 3200 channels



Proof of Concept

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

2013

Real Scale Systems

1. Demonstrate scalability
2. Production/Assembly test
3. Demonstrate segmentation capabilities
4. Physics and Background studies

2014-2015

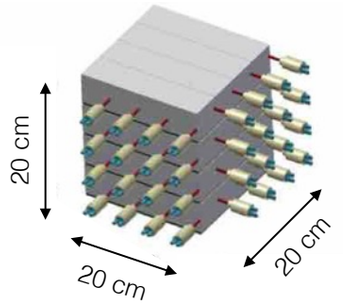
Physics Scale Detector

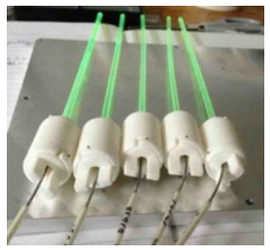
1. Optimize Performance
2. Implement Neutron Trigger
3. Optimize Production/QA
4. Spectrum measurements
5. Oscillation Search

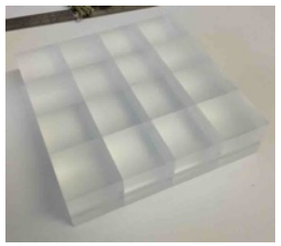
2016

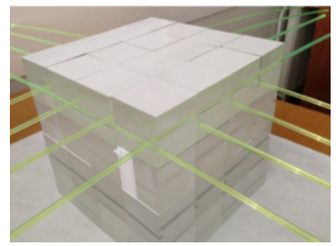
NEMENIX prototype

8kg
64 voxels
32 channels

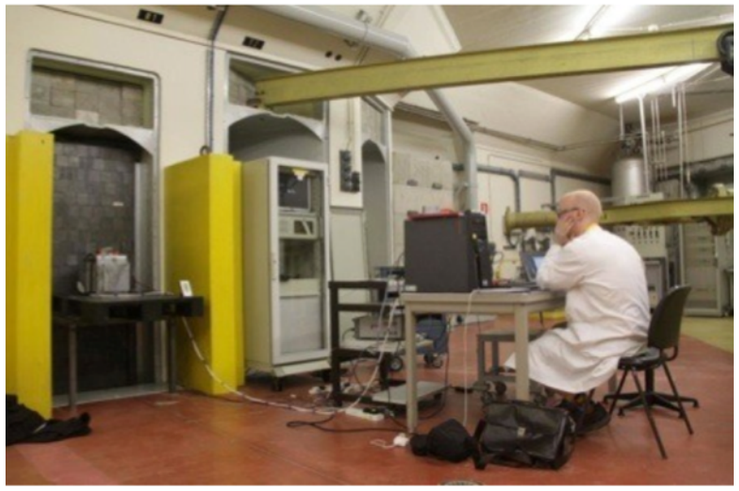




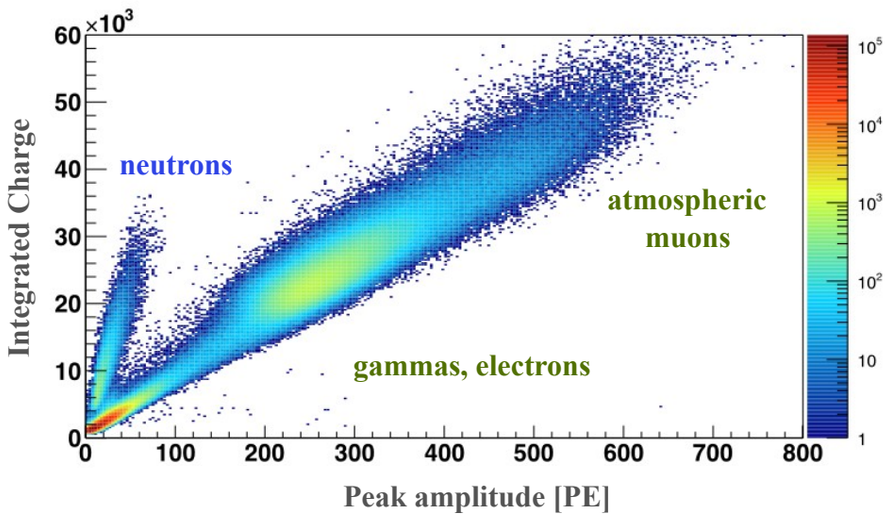


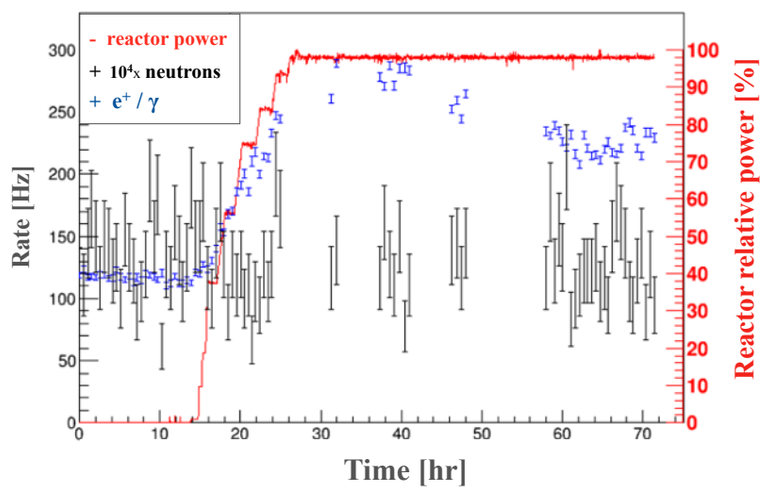


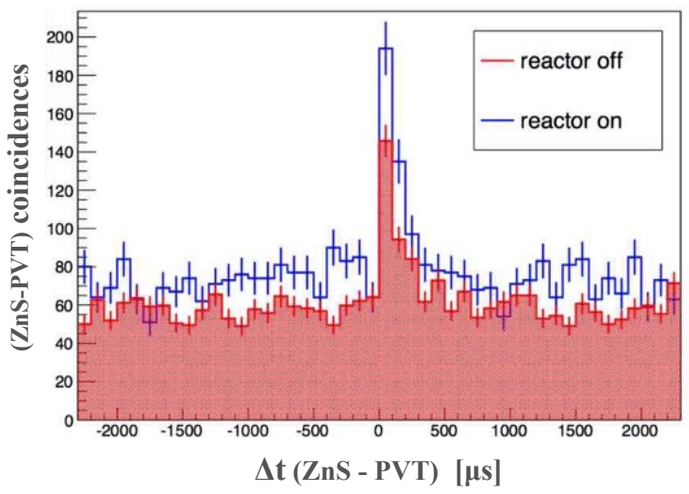
- Moved @ 5.5 m from BR2 [08/2013]
  - ⇢ **30 (19) days reactor ON (OFF)**
- Neutron Calibration @ NPL [2015]
- BiPo measurements @ Boulby [2016]



- Detection principle approved *... technical paper in preparation*



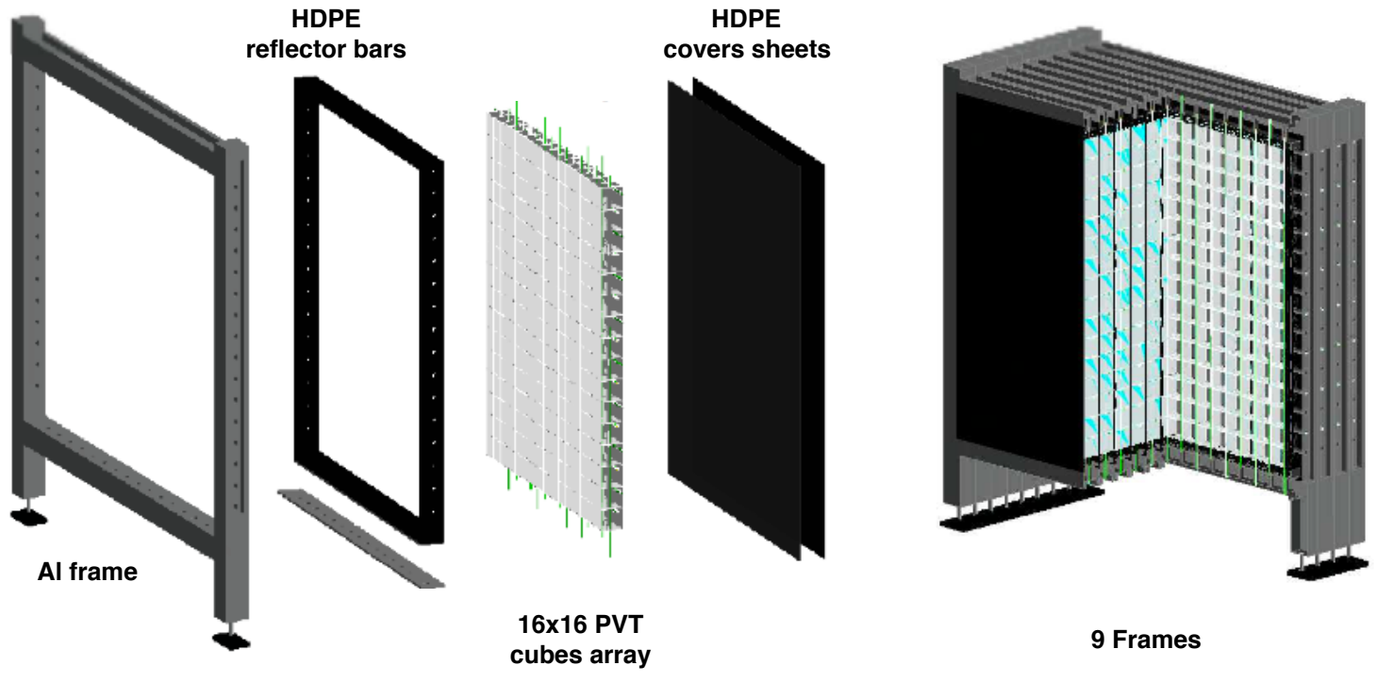




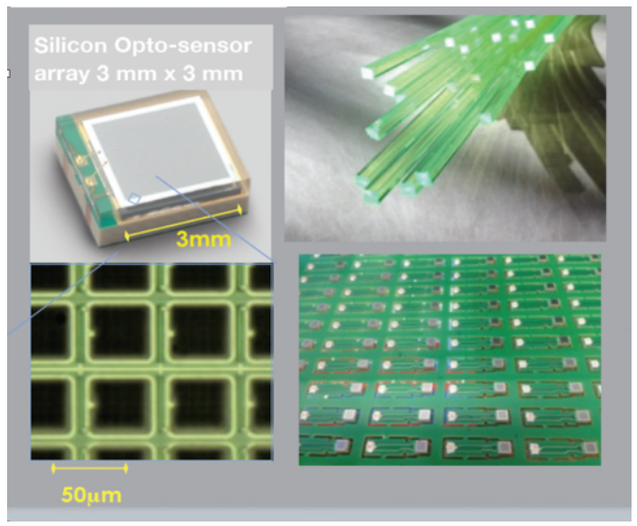
SM1 detector

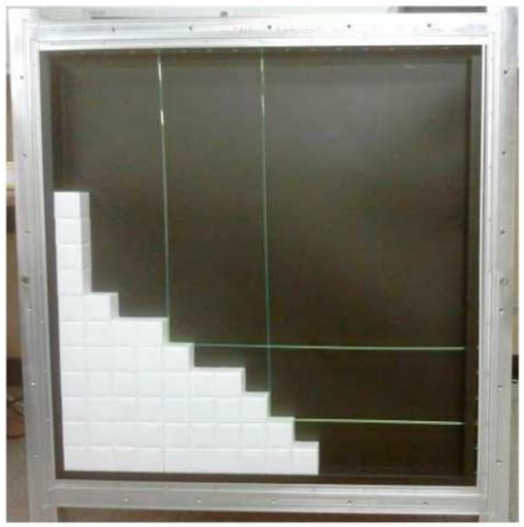
- Full scale prototype
  - 288kg
  - 16x16 lattice plane
  - 2304 voxels / 288 channels

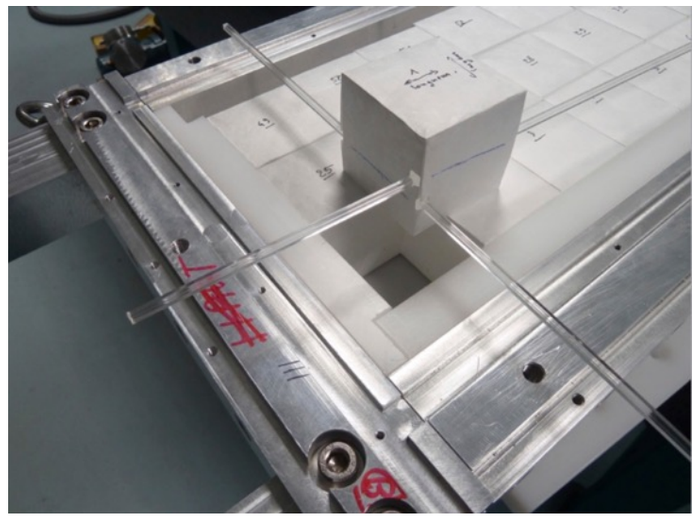
- Mechanical design @ **Subatech**
  - 9 frames (Al, HDPE Polyethylene)



- Assembly and Built @ Gent/Antwerp (~6 month)
  - 300 cubes machined, assembled, wrapped with tyveck
  - Carefully weighted : # of protons determined with better than 1 % accuracy







SM1 detector

- Deployement @ BR2 [12/2015]

  ADC : 62.5MHz rate (16 ns sample)

  Light yield : 25 PA/MeV (X+Y)

  Energy resolution : $\delta E / \sqrt{E} \sim 20\%$

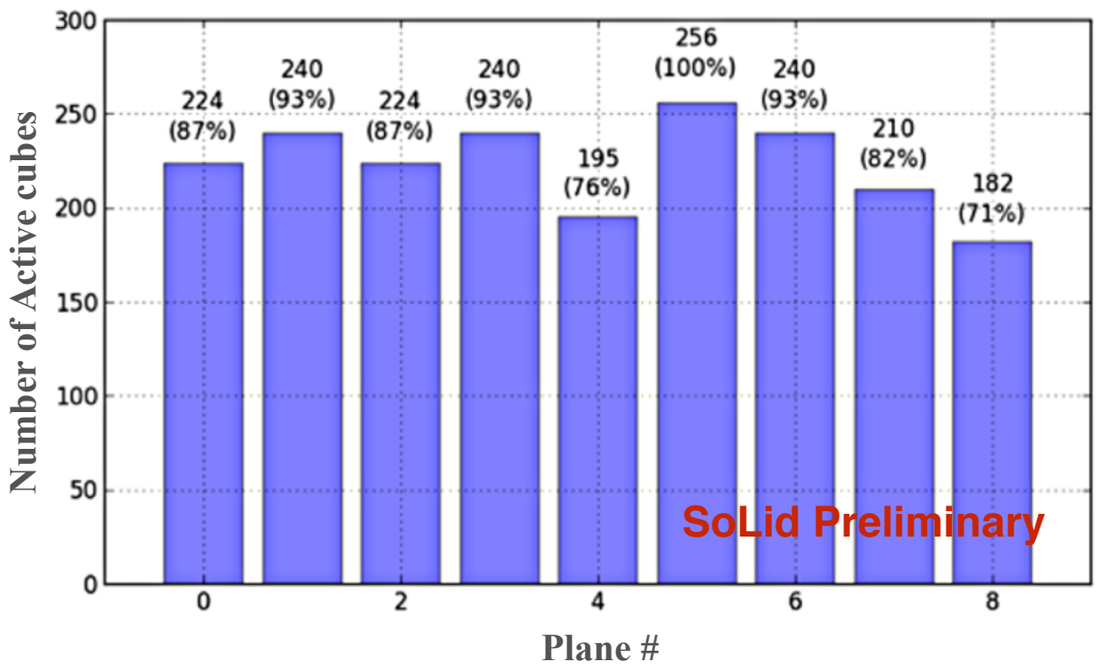
  50 ns (XY) coincidence window

  600 keV threshold

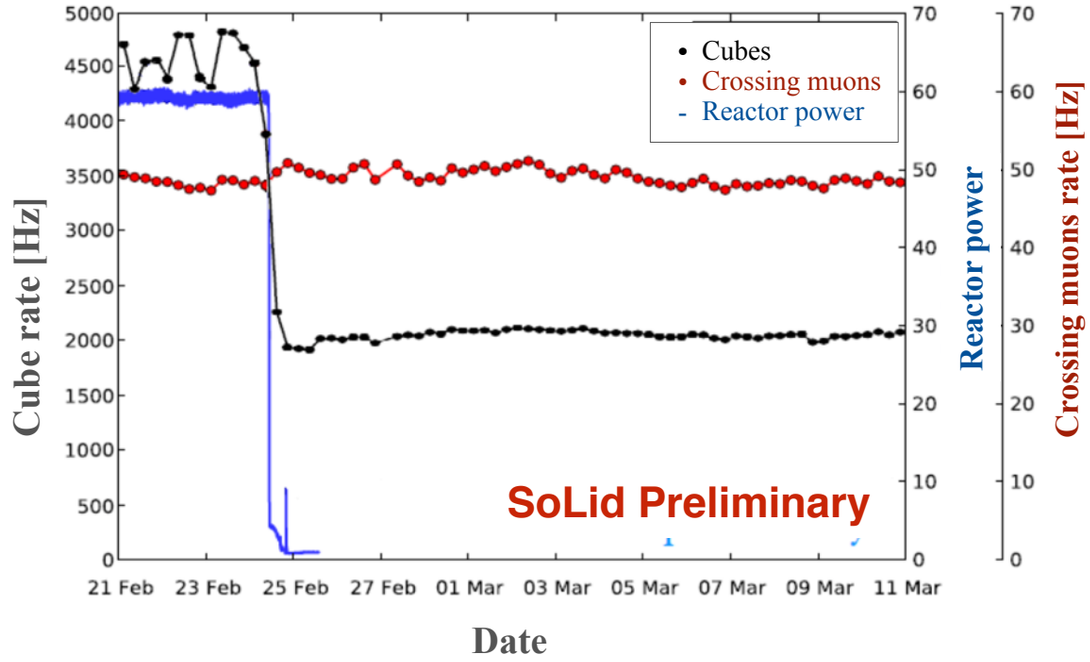
SM1 data taking

- Data from February to April 2015 : ~ 2 days reactor ON / ~ 1 month reactor OFF

Period	Dates	Exposure Time (h)
Reactor ON	00:00 21st Feb to 08:00 24th Feb	50.91
Reactor OFF	00:00 27th Feb to 00:00 13th Mar, and 00:00 27th Mar to 00:00 11th Apr	525.51
	Exposure time ratio (ON/OFF)	0.0969



- 87% good/stable cube



- Data over time

+ dedicated calibration runs : ^{60}Co, ^{137}Cs, AmBe, ^{252}Cf

SM1 Neutron ID

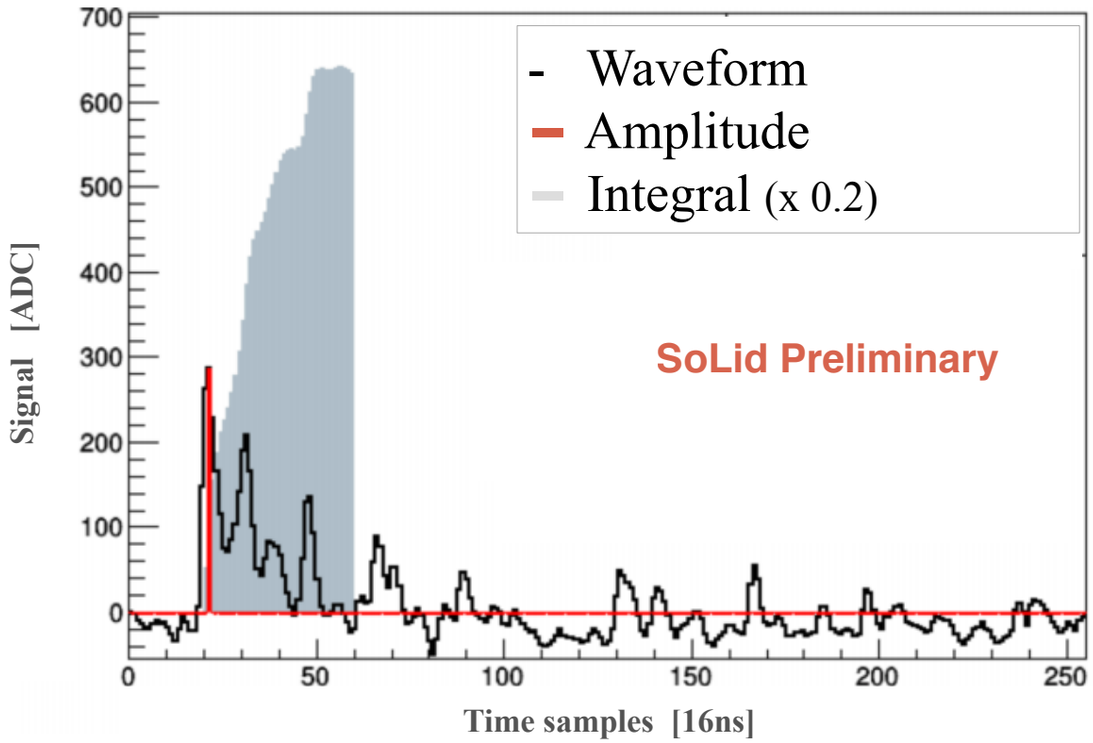
- IBD neutron capture efficiency ~ 65%

  MCNP/Geant4 benchmark

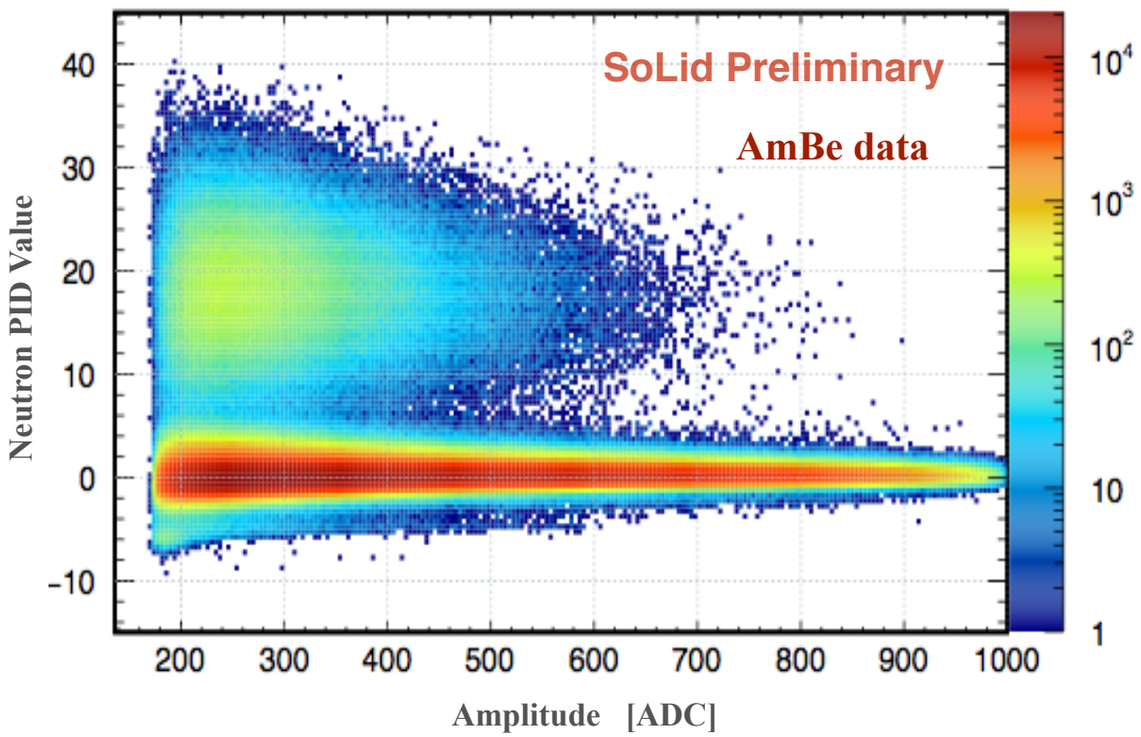
- Pulse shape analysis to tag neutrons

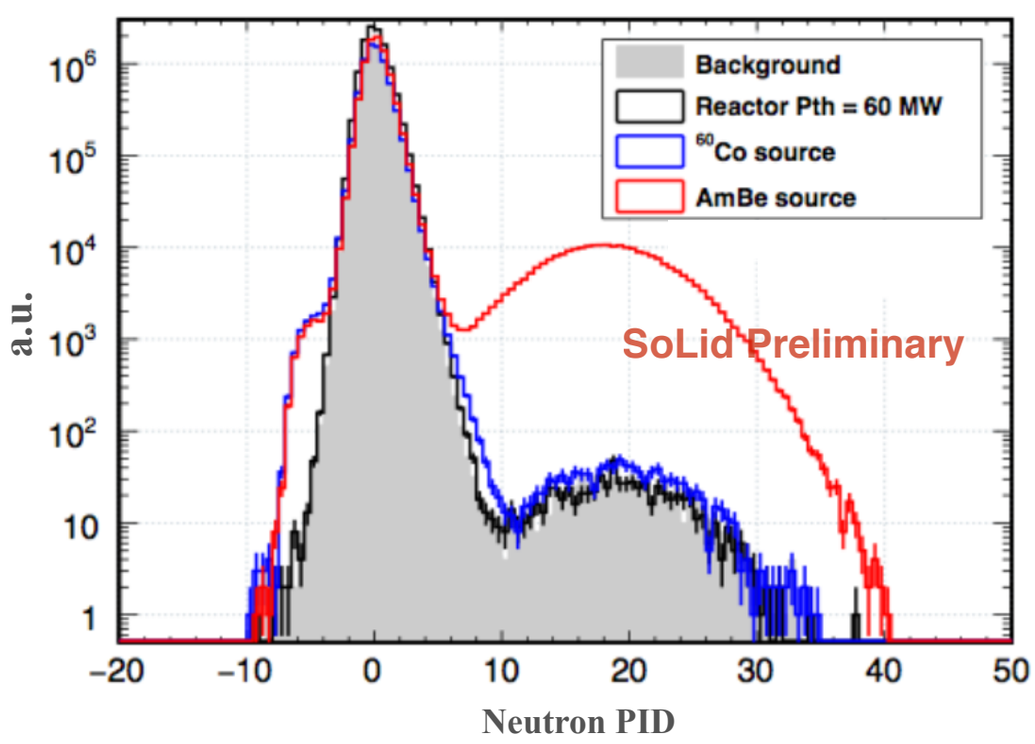
  PID = Integrale/Amplitude ± Cor_{chan}

  Coincidence X/Y



- PID cuts validated by ^{60}Co and AmBe data

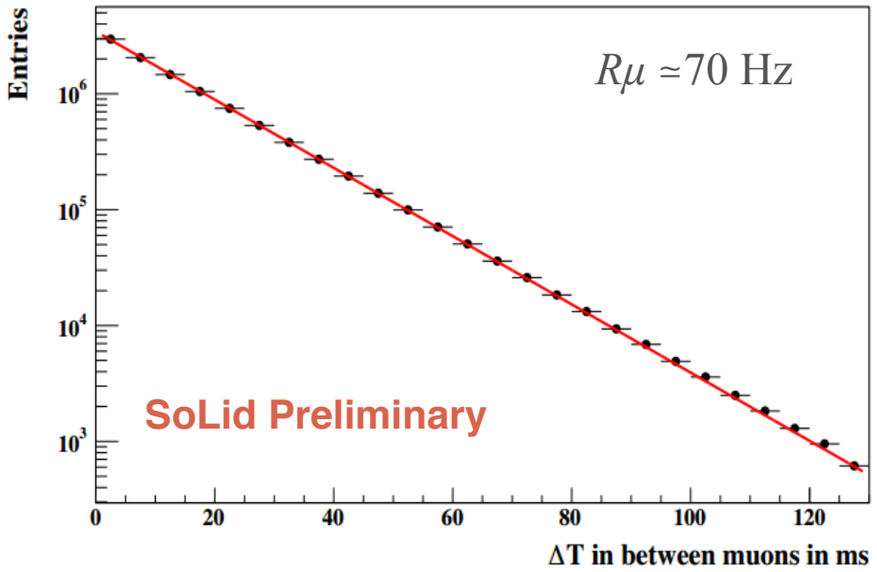


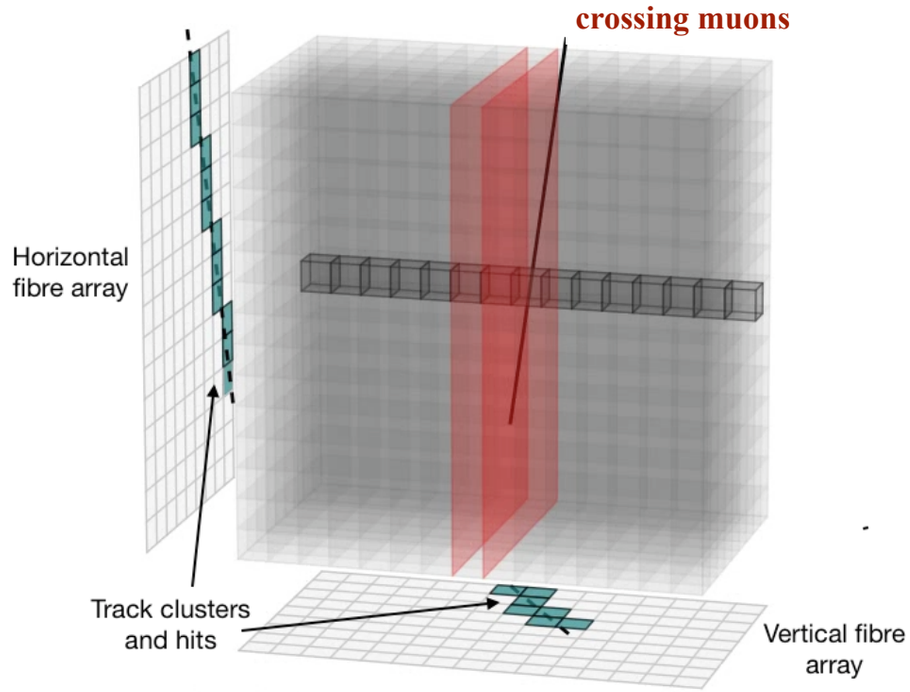


SM1 Cosmic muons response

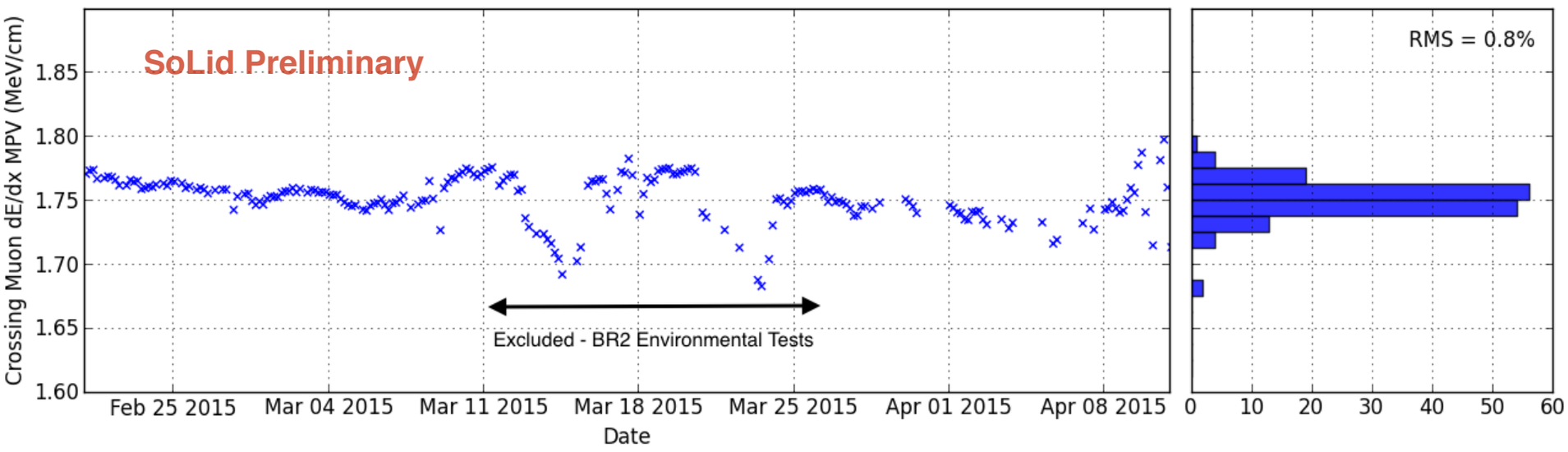
- Excellent muons tracker (>95% efficiency)

  PSD, deposit energy, topology, timing





- Monitor detector stability over time (@ % level)



Energy-scale and resolution

- Cube inter-calibration (fibre attenuation correction)

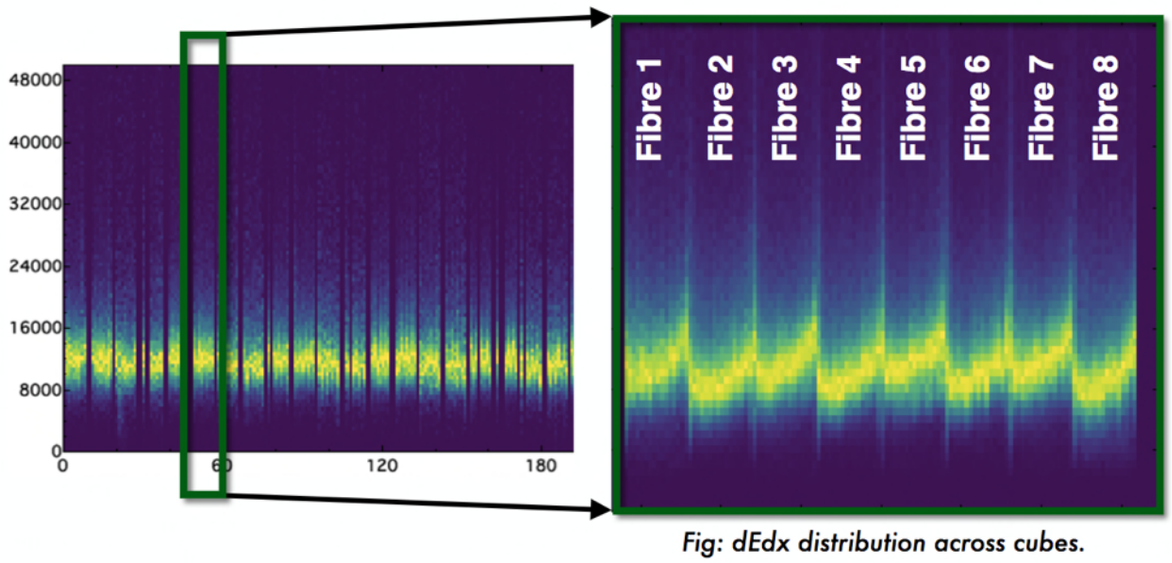
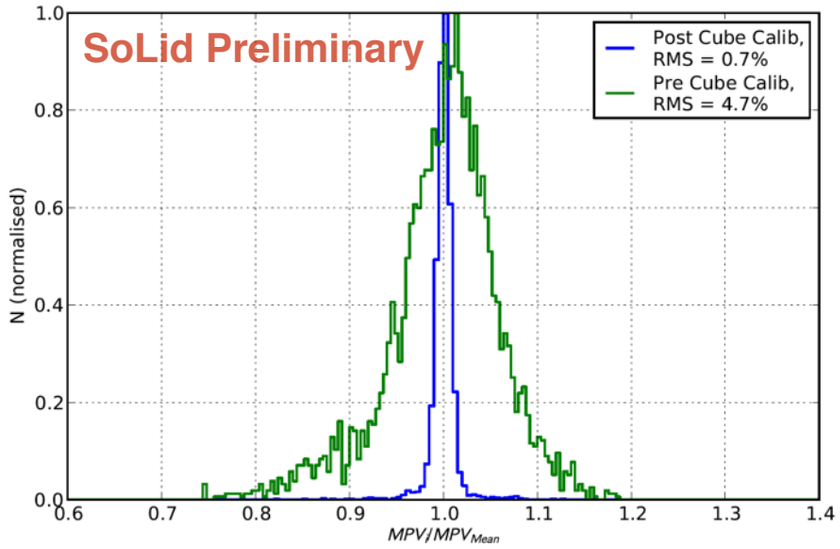
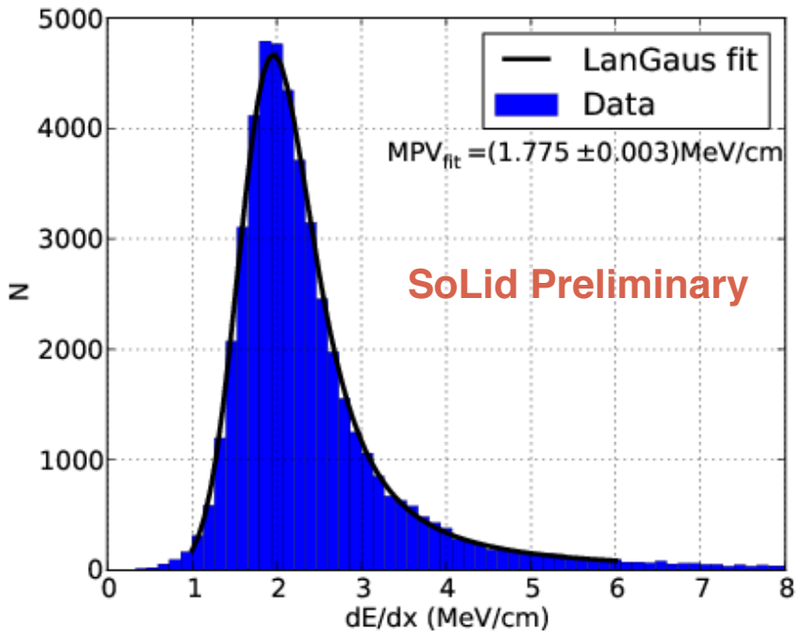


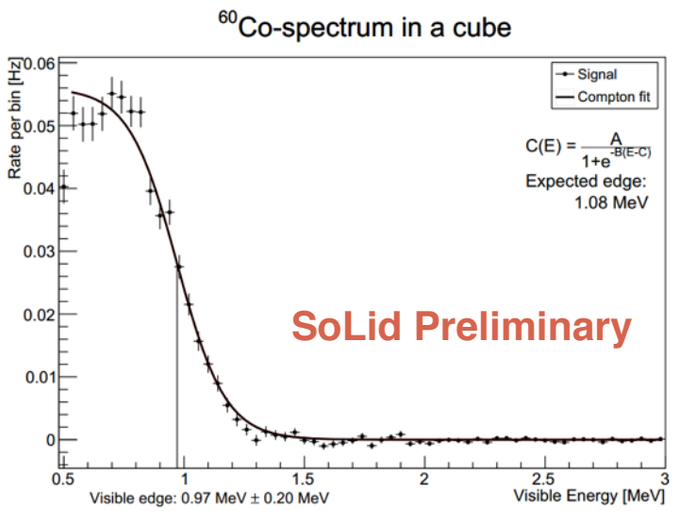
Fig: dEdx distribution across cubes.

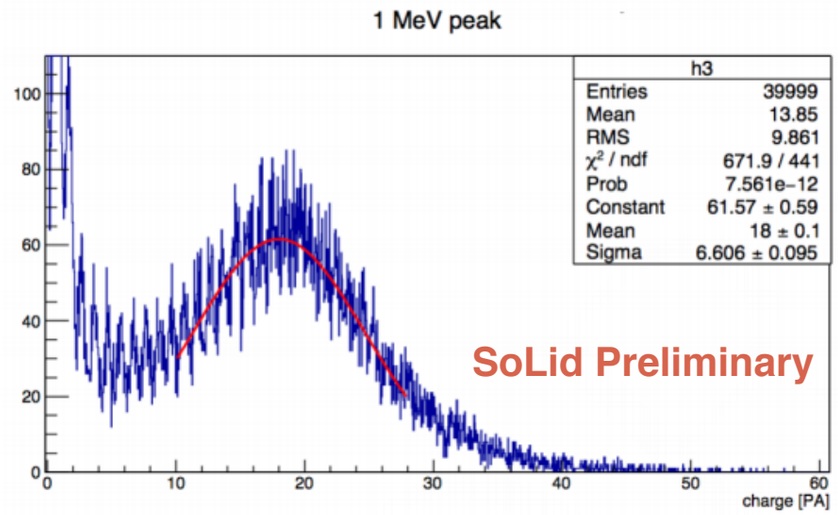


- dE/dx : $\delta E / \sqrt{E} \sim 20\ \%$



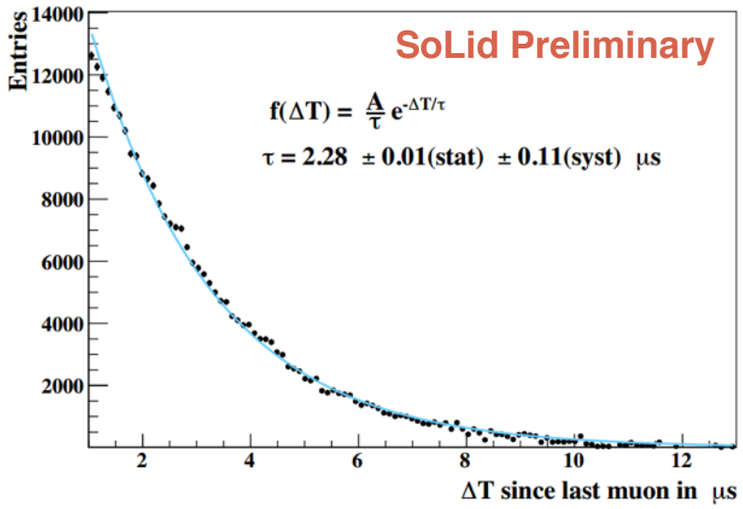
- In agreement with ^{60}Co run, ^{207}Bi test-bench and AmBe data (4.4MeV γ)

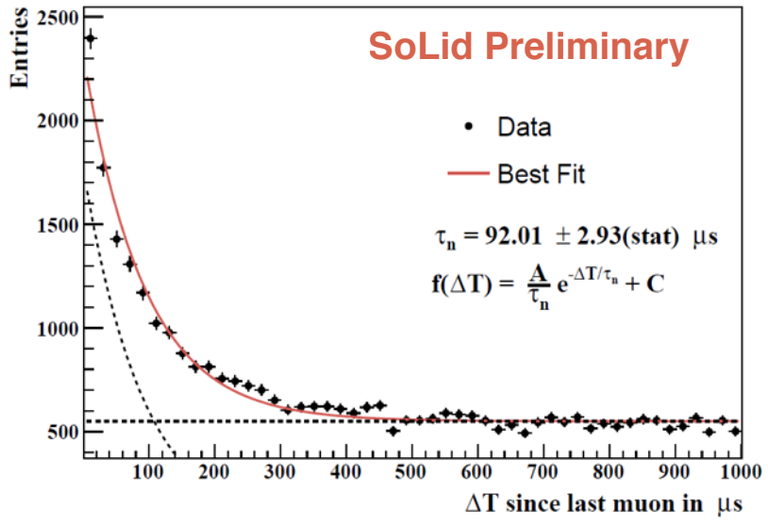




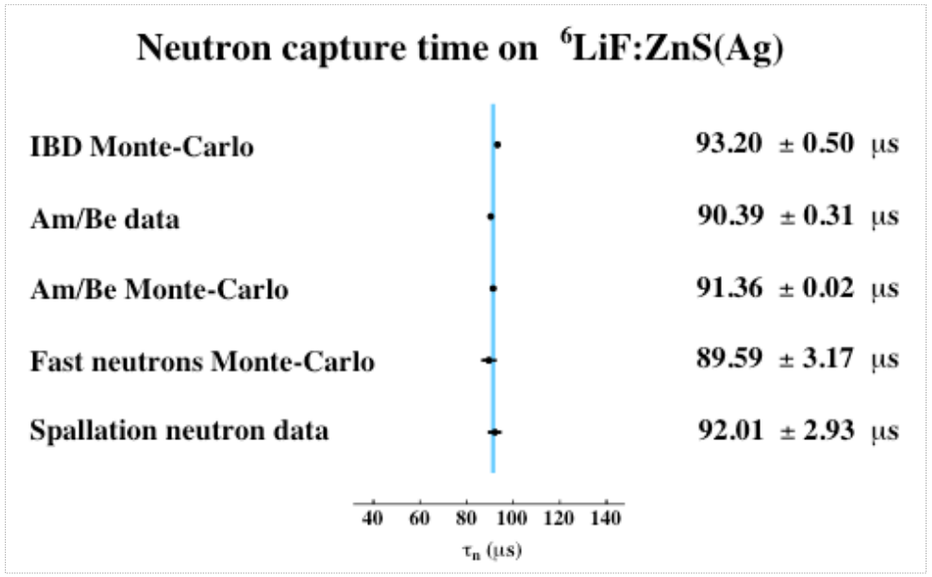
Time-correlated signal

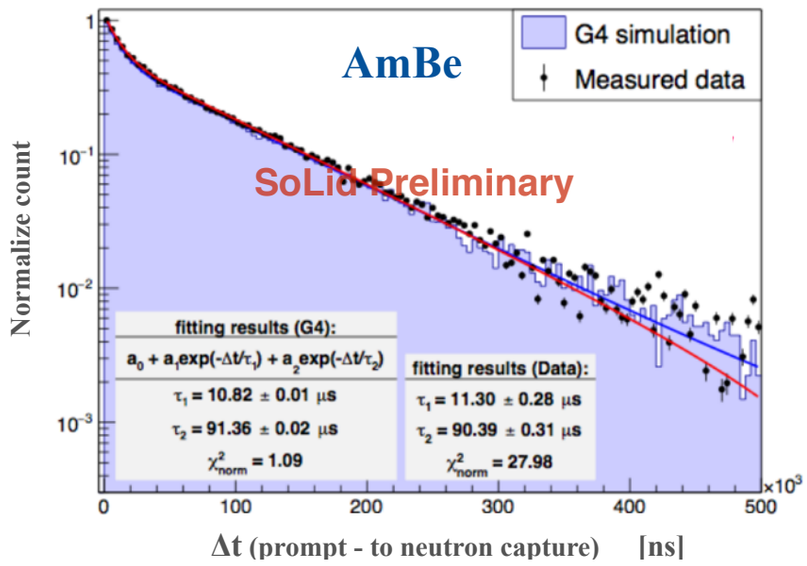
- Muon correlated time signals





- IBD-like neutron capture time



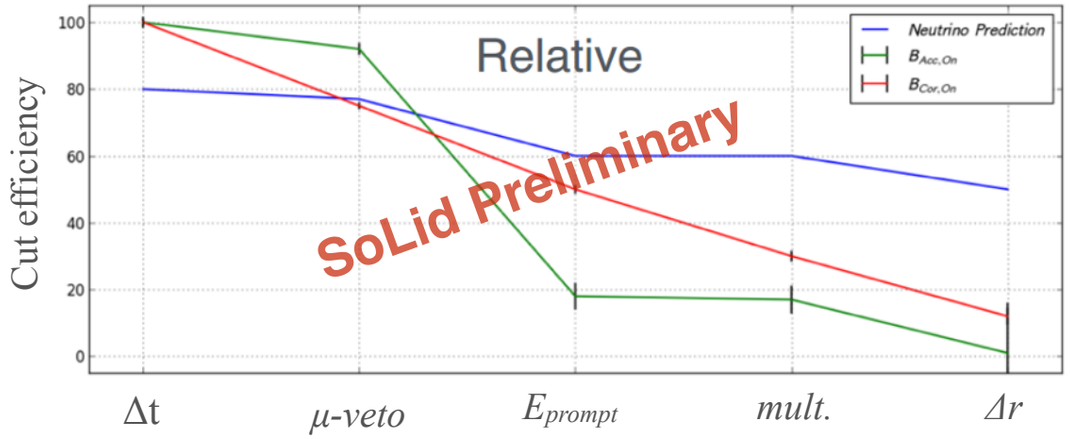


SM1 IBD analysis

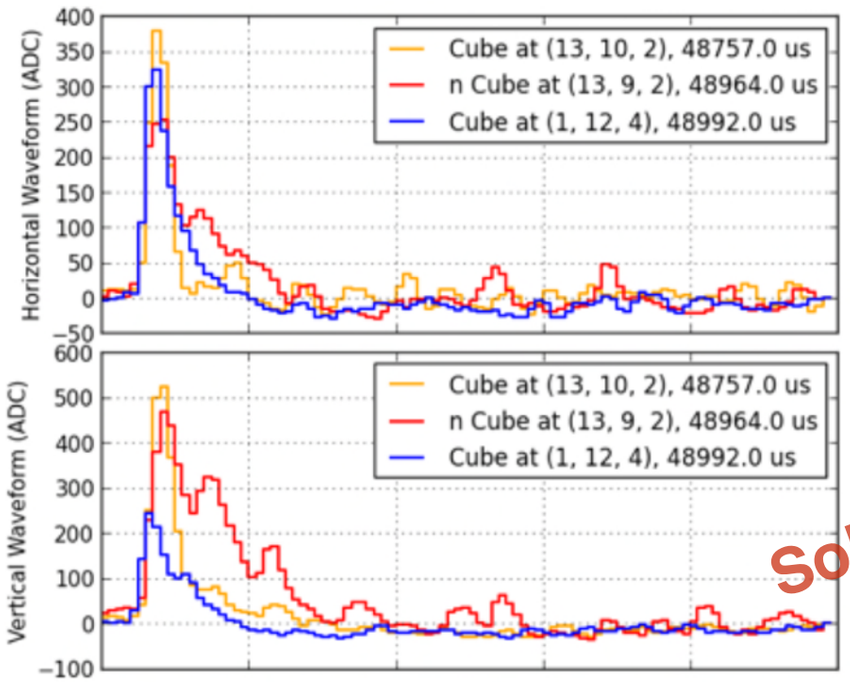
SoLid Preliminary

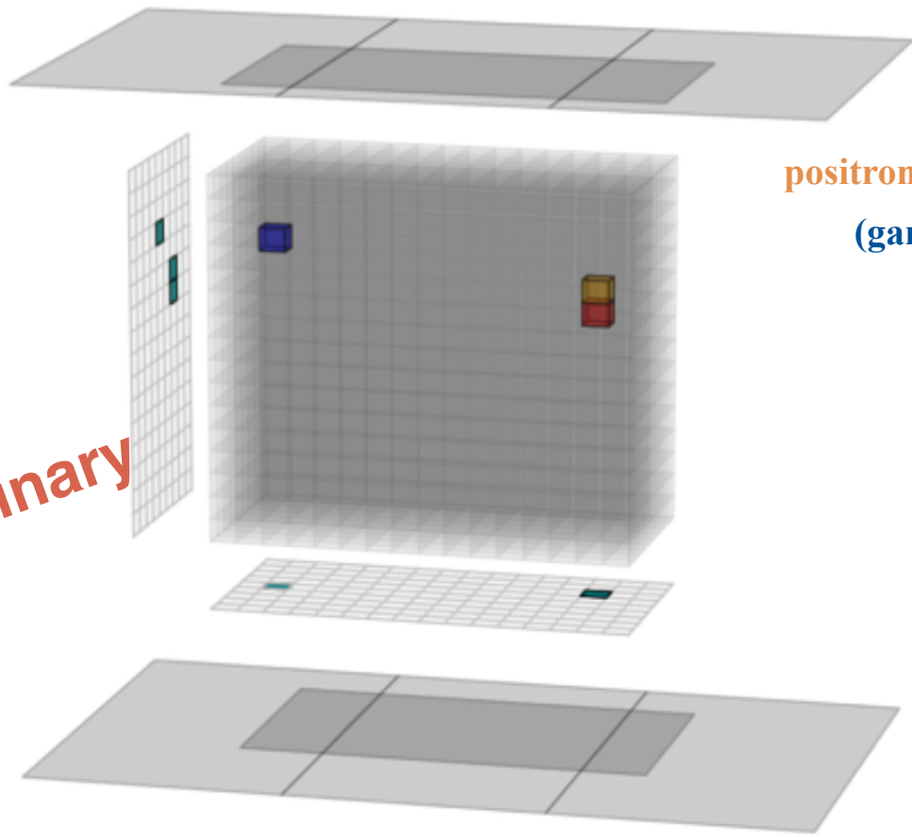
- IBD selection cuts
  - $0.1 < \Delta t\ (\mu s) < 250$
  - Muon veto
  - Multiplicity
  - $1.5 < E_{Prompt} < 8$ MeV
  - $0 < \Delta r$ (Cube side) ≤ 2

.... other non-cut technique under study (e.g. likelihood rejection)



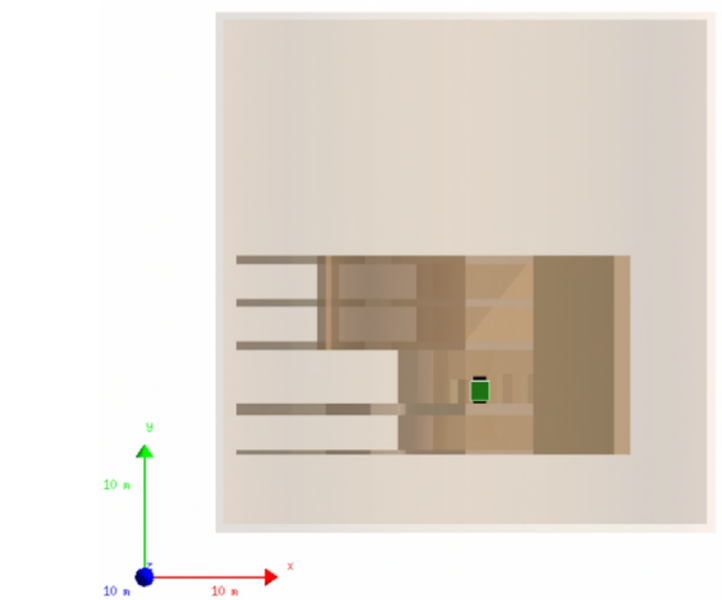
- Example of IBD candidate

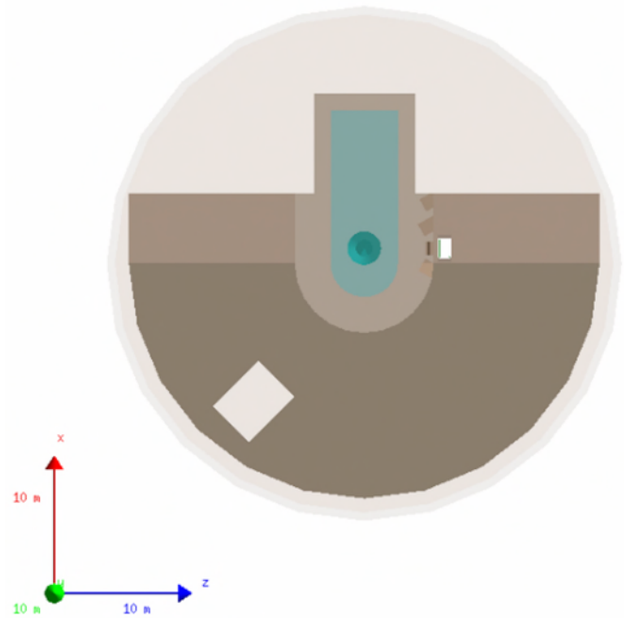


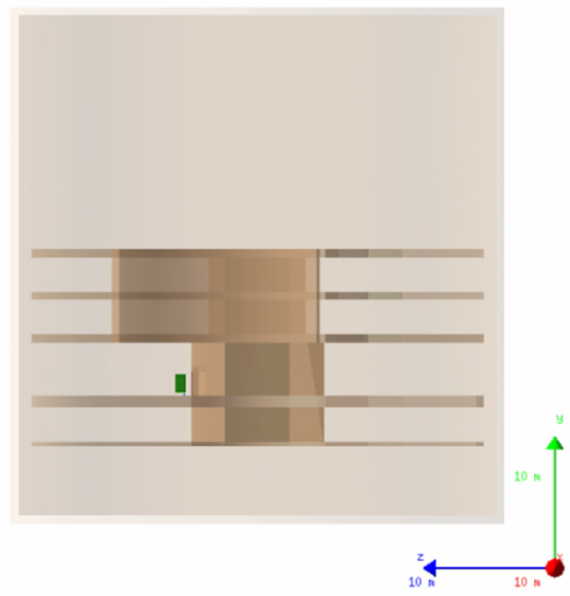


Cosmic simulation - neutron generation

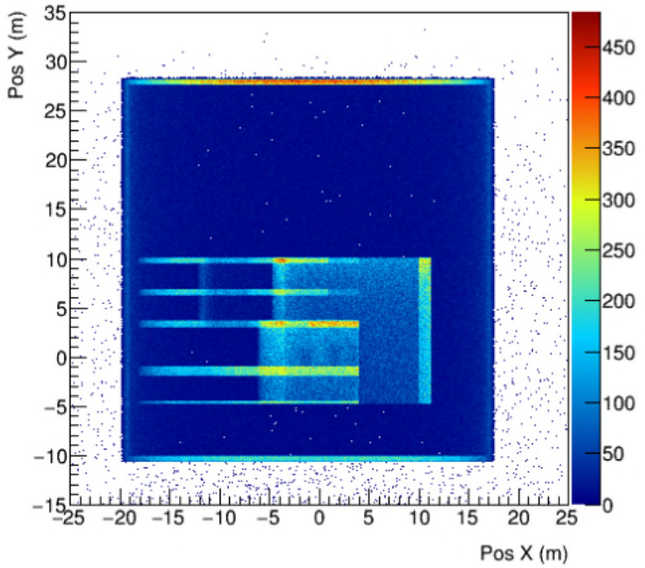
- Full Geant4 BR2 model implemented & 3 independent muons generators (CRY, Reyna, Guang)

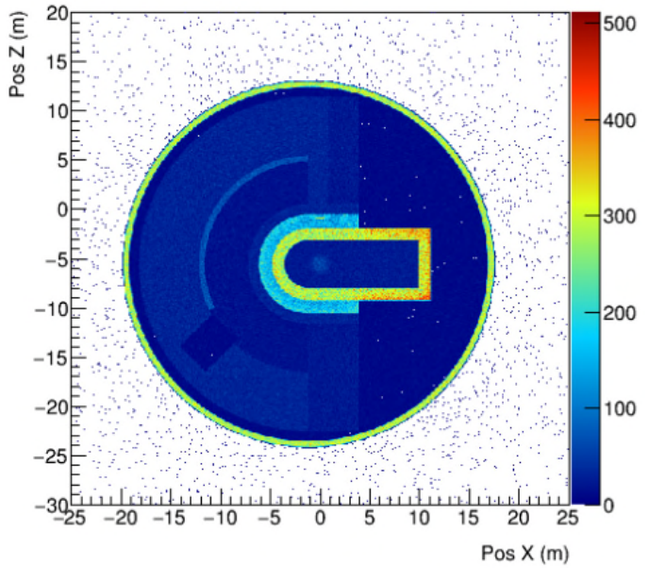


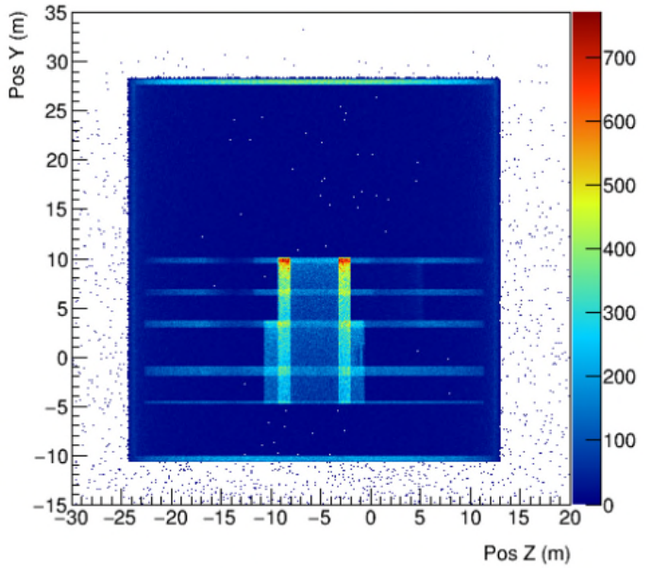




- Neutrons generation (CRY & Gordon)



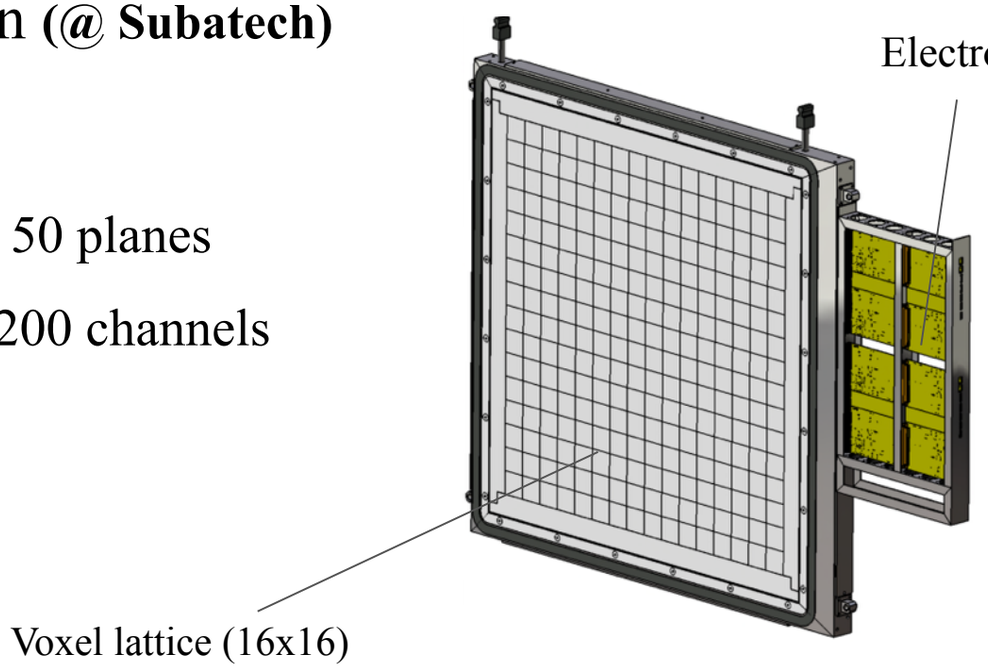


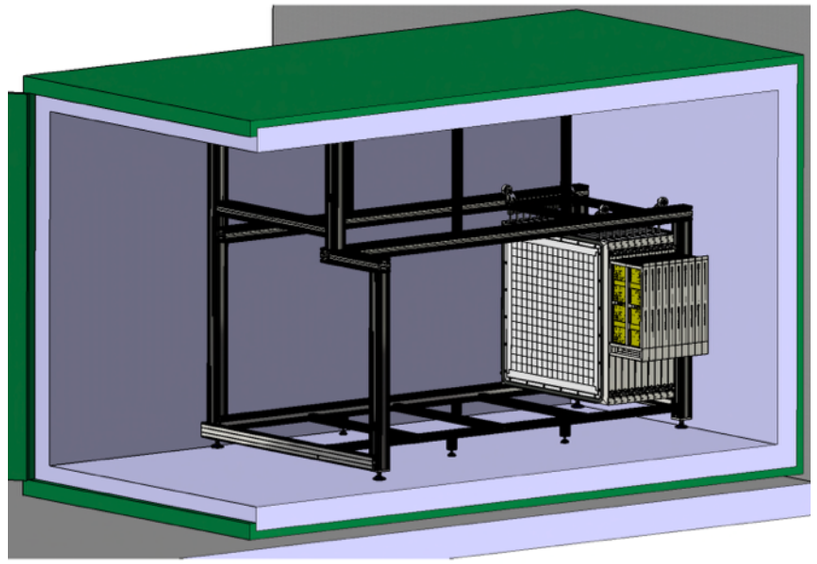


Vol name	n generation (%)
other	0.080362
LiFZnS	0.000000
PVT	0.000444
PPL shielding	0.000752
n reflector	0.000051
HDPE in plane	0.000051
Al frame	0.001760
Air	0.254757
NORCAN	0.000376
Iron table	0.002153
Al plate	0.000051
Pb wall	0.059613
Concrete wall	32.877433
Concrete other	64.930263
Reactor core	0.153938
Water pool	1.637994

SoLid Phase I

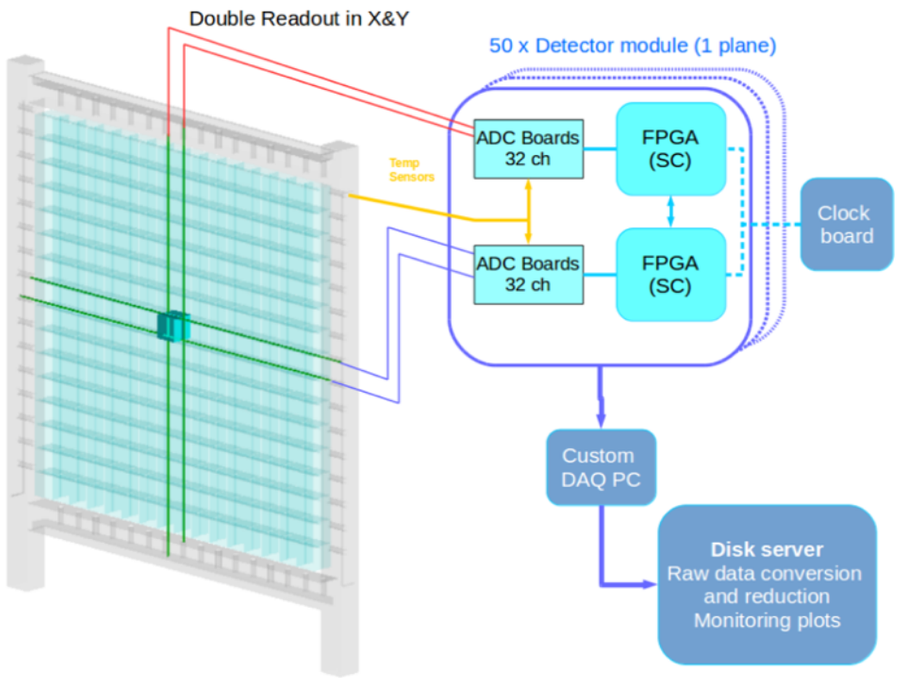
- Mechanical design **(@ Subatech)**
  - Plane modularity
  - 1.6 t (need 2-3 t) : 50 planes
  - 12 800 voxels & 3200 channels





50 planes inside cooled container (5°C)

- New dedicated read-out/electronics (**@ Oxford/Bristol**)



- Double electronic readout compared to SM1 (32 000)
- Reduce dark count rate (noise) …. cooling & faraday box
- Dedicated trigger algorithm**s** :

  Neutron waveform trigger (zero suppression)

  Threshold trigger

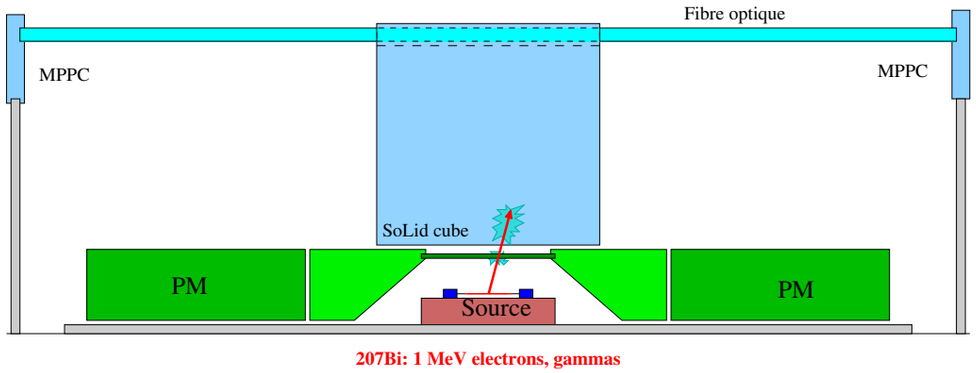
  External trigger, Random...

SoLid Phase I

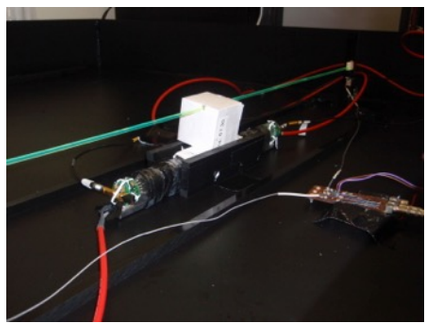
- Light-yield/Resolution improvement **(test-bench @ LAL)**

  Unique test bench with peaked signal & systematic uncertainty < 5 %

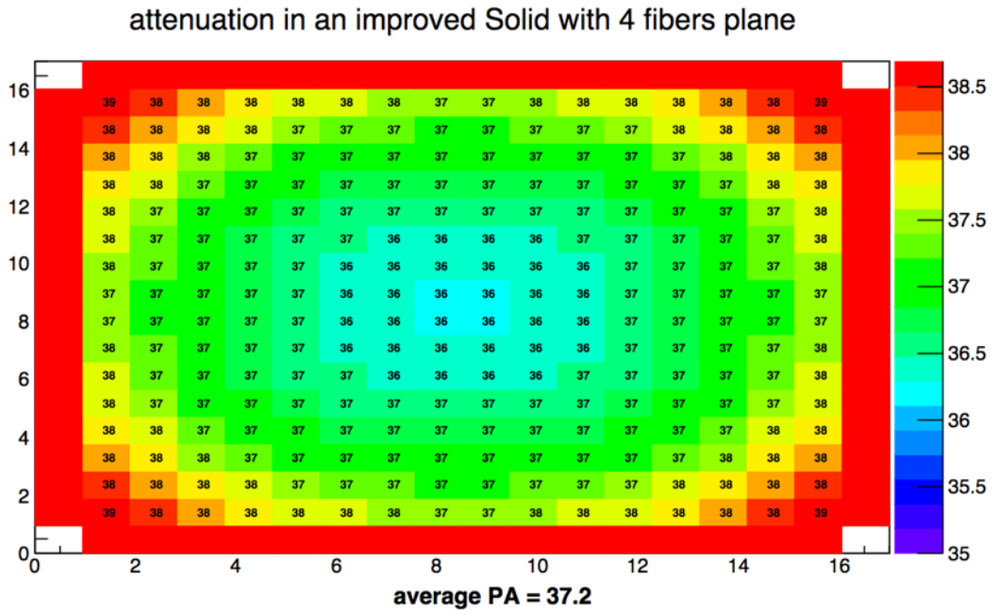
  Using 1MeV conversion electron from ^{207}Bi



207Bi: 1 MeV electrons, gammas



- Read-out (double) :
  - 4 multi cladding fibre/cube
  - 4 MMPC/cube
- Thick tyvek wrapping
- Aluminized mylar mirror
- Cube polishing
- 2 LiF:ZnS sheets/cube

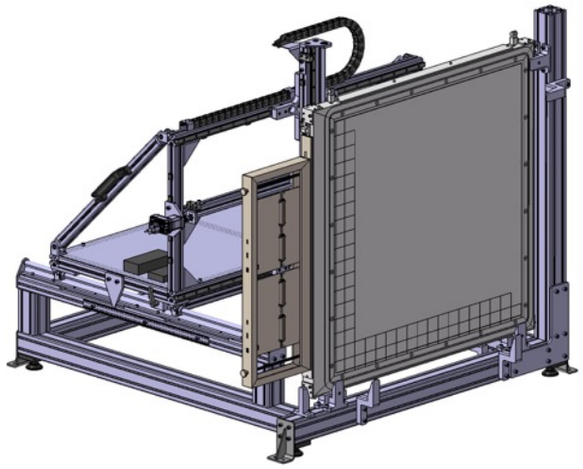


⇢ SoLid Phase I (double readout) will have energy resolution $\delta E / \sqrt{E} < 16$ %

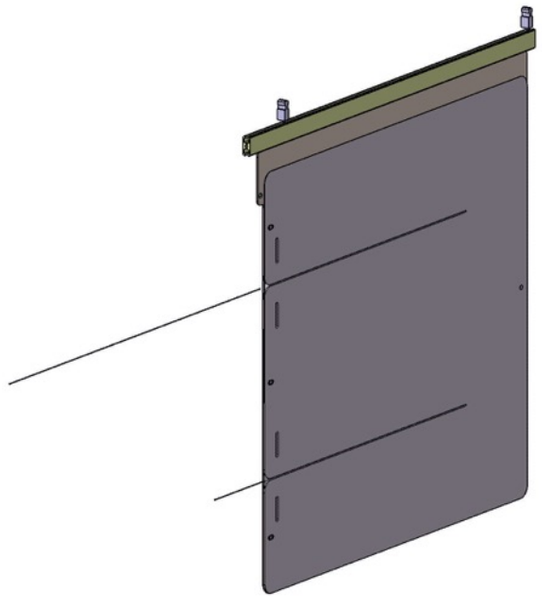
SoLid Phase I

- Calibration systems : ^{137}Cs, ^{60}Co, … AmBe, ^{252}Cf **(mechanics @ LPC-CAEN)**

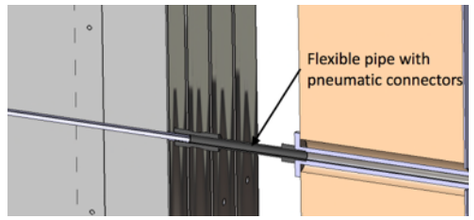
Individual automated X-Y scanning of plane/cube @ Gent **(QA)**



In-Situ calibration plane @ BR2



source insertion through thin guide tube

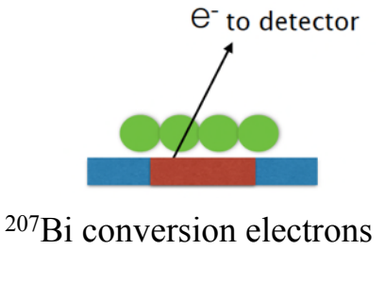


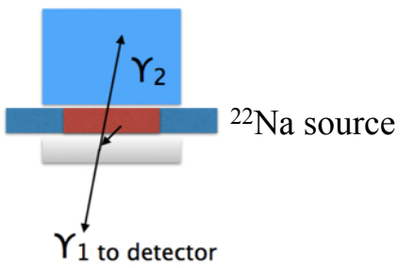
- Energy Calibration (% required)

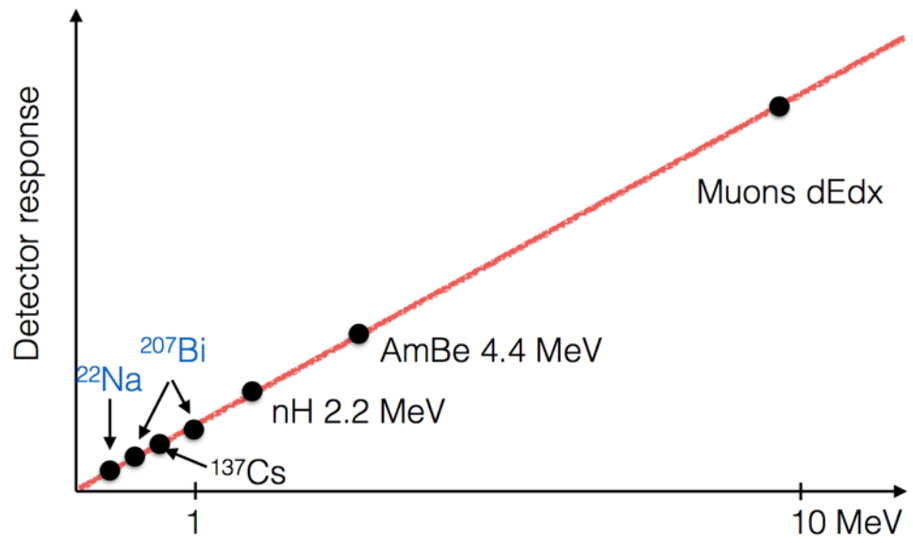
PVT response linear in range [0.1-20] MeV

Source : Muons, ^{137}Cs, ^{60}Co, … AmBe, n(H)

R&D on dedicated trigger system (purity) : ^{207}Bi, ^{22}Na







French SoLid involvement

F. Yermia, M. Fallot, L. Giot, B. Viaud …

Analysis **(F. Yermia, coord.)** - Mechanical design - Reactor flux **(M. Fallot, coord.)…**

M. Bongrand, L. Simard, M-H Schune, Y. Amhis, D. Boursette (Phd) …

Analysis/Simulation - Light yield test/Bench - Mechanical design …

B. Guillon, G. Ban, D. Durand, G. Lehaut…

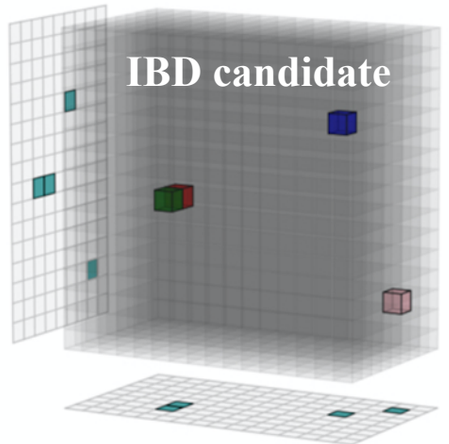
Reactor flux - Analysis - Calibration **(B. Guillon, coord.)** - Mechanical design …

Funding (2014) MINES-CARNOT (subatech) : Most part of SM1 module
(2016) IN2P3 + own ressources : 300kg fiducial mass + part of the calibration system

⇢ Apply for **ANR-2016** : 300 kg + 3 x 2years Post-Docs

Summary

- Successful NEMENIX and SM1 runs
  - Excellent neutron ID
  - Muons tracking opportunities
  - Background studies & rejection capabilities
  - IBD analysis ongoing … *2 papers in preparation*



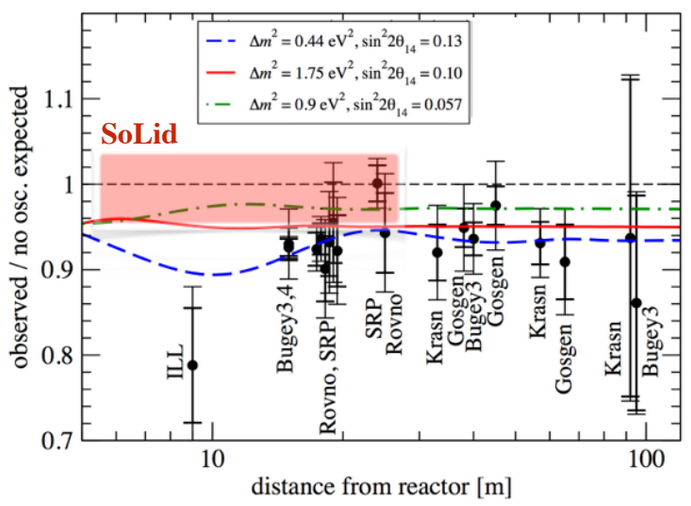
positron + **neutron**

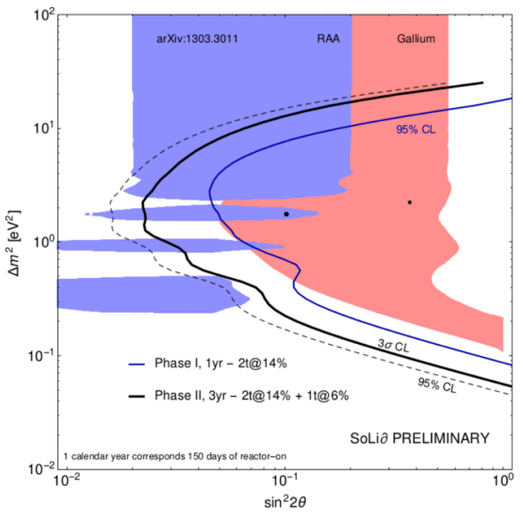
(accidental gammas)

- SoLid Phase I under construction (1.6 t / 50 planes modular)
  - Better light yield/energy resolution
  - Read-out improvements : cooling, DAQ/electronics, triggers
  - In-situ calibration (γ, neutron, e^-)
  - Passive shielding & cosmic veto umbrella … under studies

- Deploiement for phase I data taking at the end of 2016

J. Kopp et al., JHEP 1305:050, 2013





- Intense activities of the french collaboration for next ~3 coming years

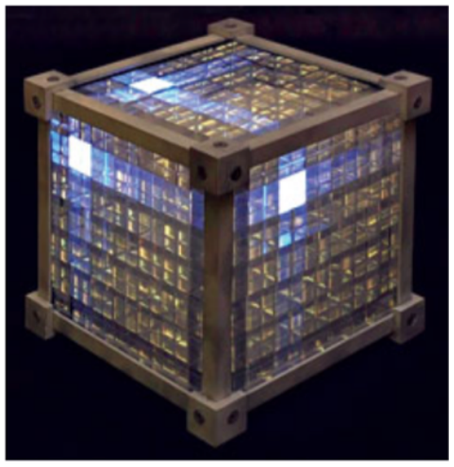
Backup

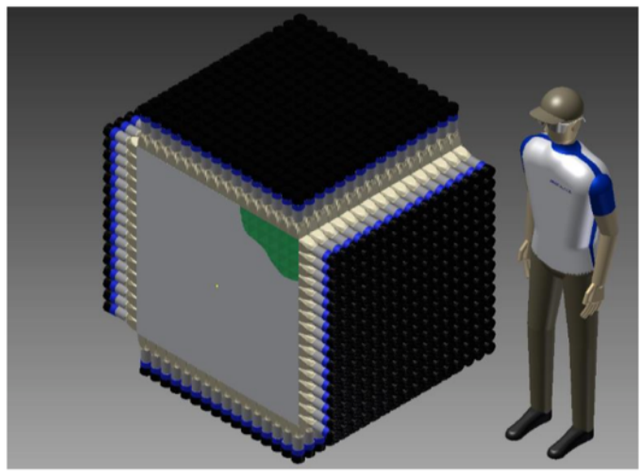
SoLid Phase II

- Call for US collaborators to build 1 t module (~2018)

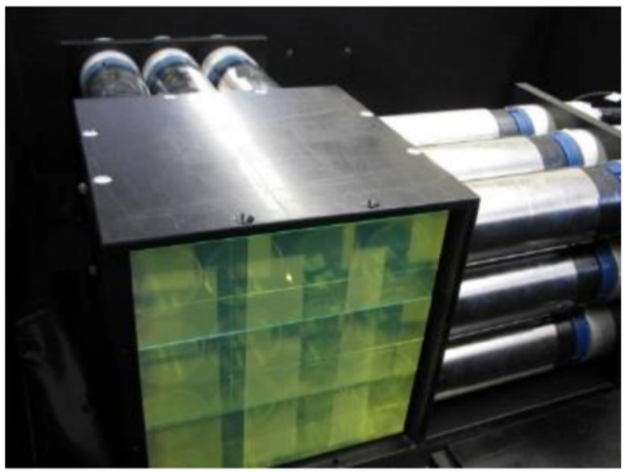
Combining LENS
and SoLid technologies

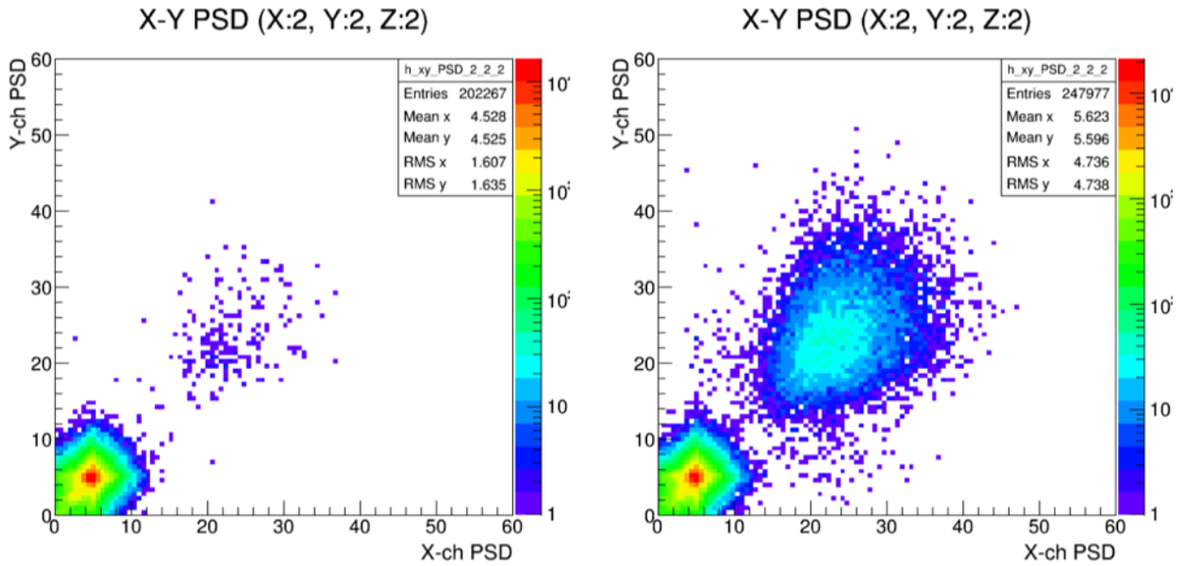
$\delta E / \sqrt{E} \sim 6\ \%$





- Chandler prototype (3x3x3) under test at Virginia Tech





- Mini-Chandler (8x8x5) under construction … operational winter 2016 near power reactor

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