Search for eV Sterile Neutrinos

The Stereo Experiment

Stefan Schoppmann

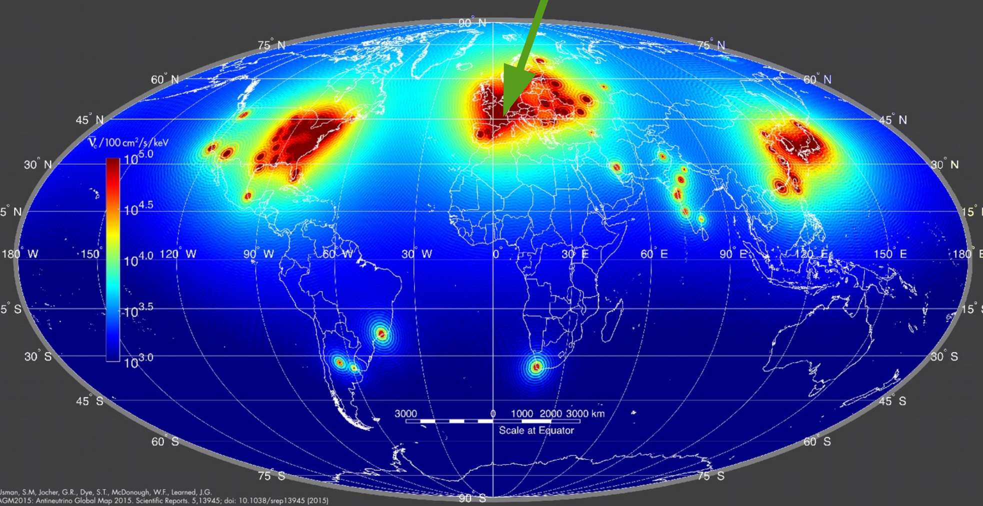
for the Stereo collaboration

Supported by:

Outline

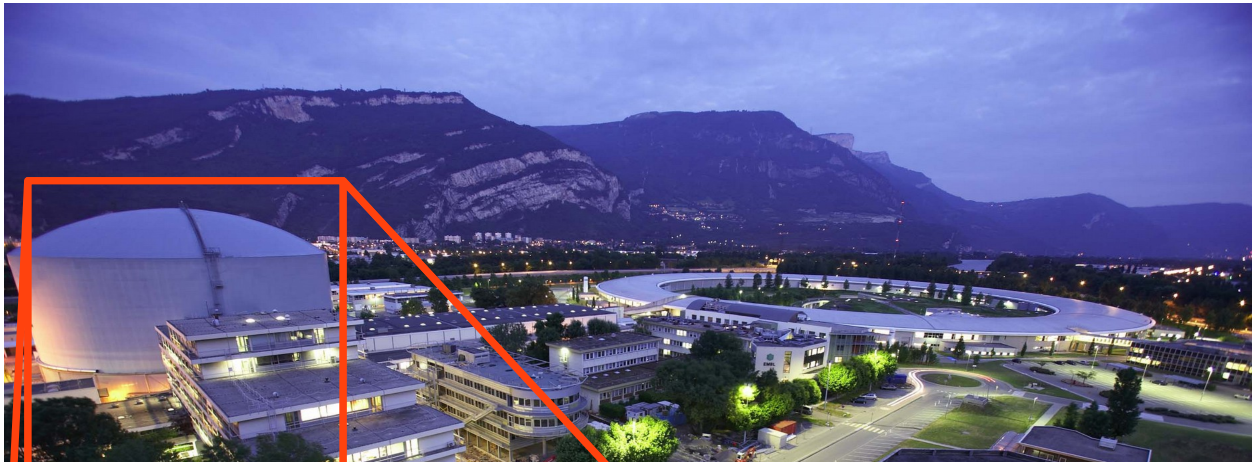
- Experimental Setup
- Calibration and Energy Reconstruction
- Signal and Backgrounds
- Summary/Outlook

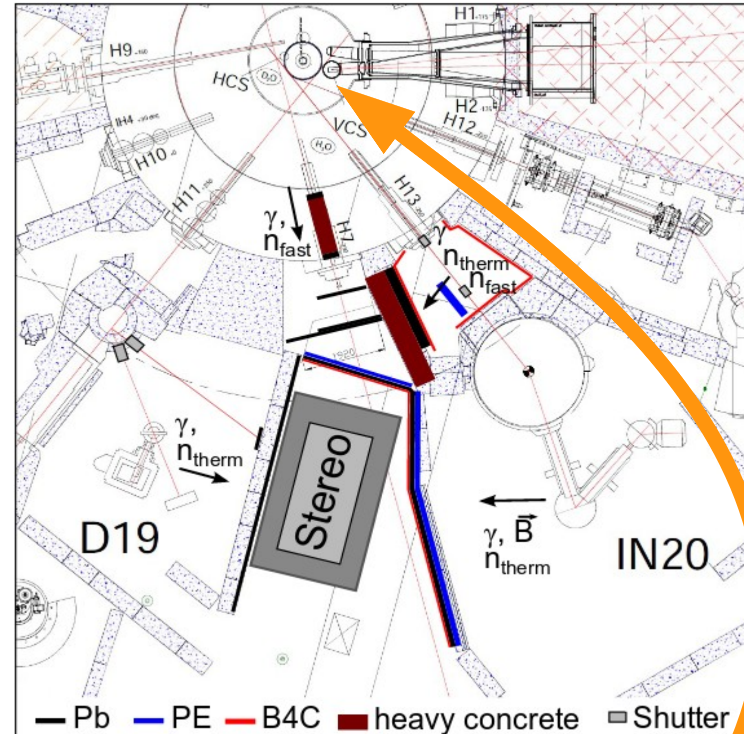
3 MeV reactor antineutrino flux worldwide:

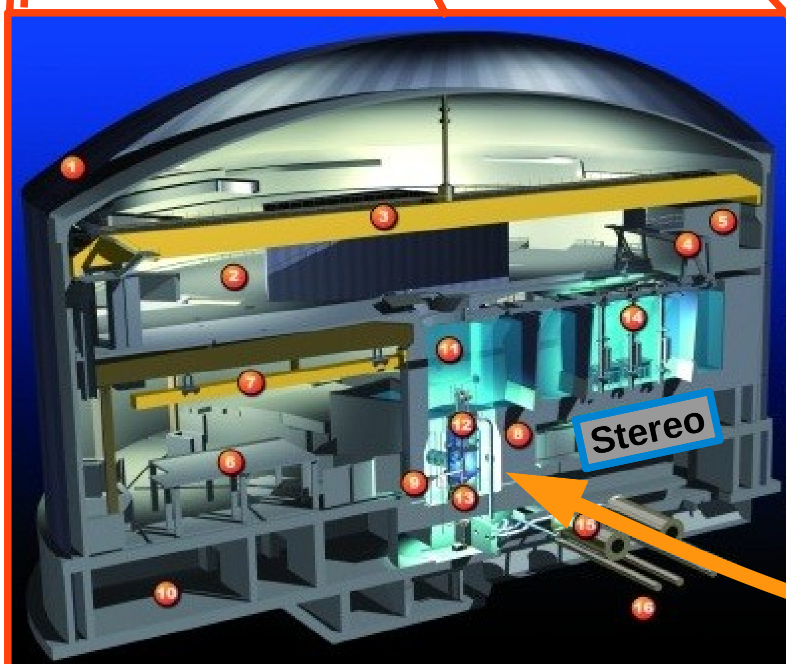


Antineutrino Global Map 2015, Sci.Rep. 5 (2015) 13945

Experimental Setup







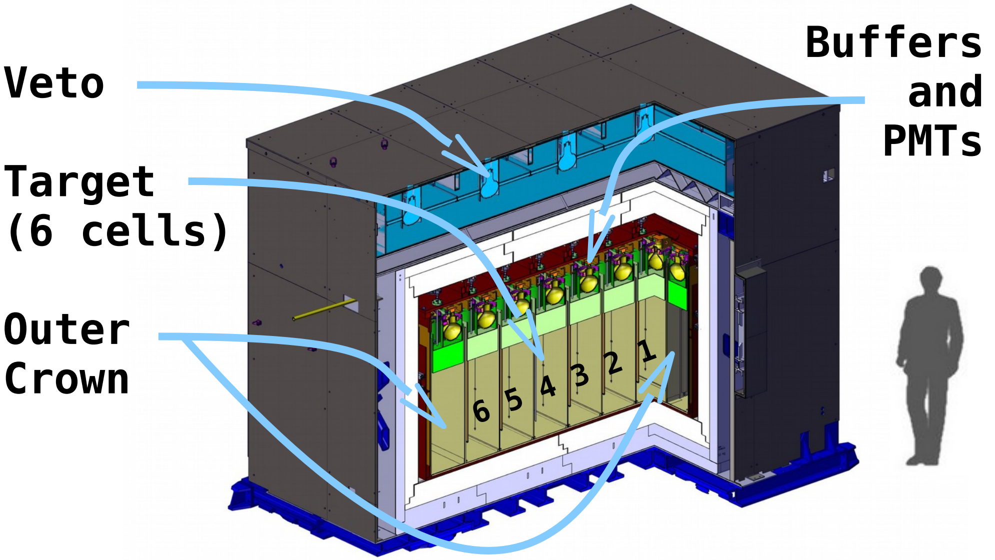
Neutrino source:

- reactor at ILL Grenoble
- 58.3 $MW_{thermal}$
- Height: 80cm
- Diameter: 40cm
- Highly enriched in ^{235}U (93%)

Baseline: 9 - 11 m
Overburden: ~15 m.w.e.

Detector/Measurement Idea

- Target segmented in 6 cells
  → 1800 l of Gd-loaded liquid scintillator
- Surrounding outer crown to capture gammas
- 48 PMTs of 8 inch diameter
- Layers of acrylic and oil as buffer
- Water Cherenkov veto on top
- About 90 tons of shielding material
  → lead, polyethylene, B_4C, iron



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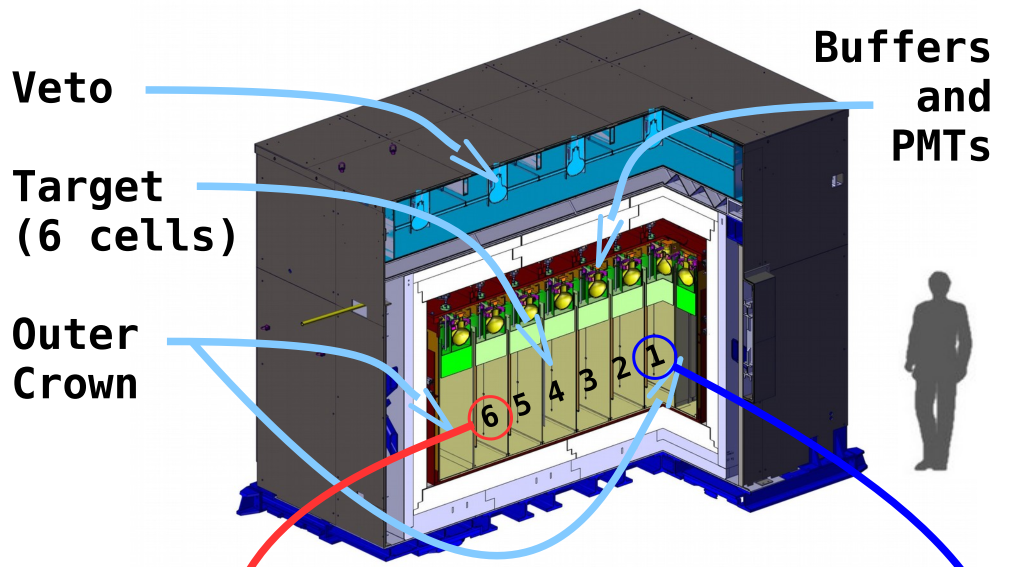
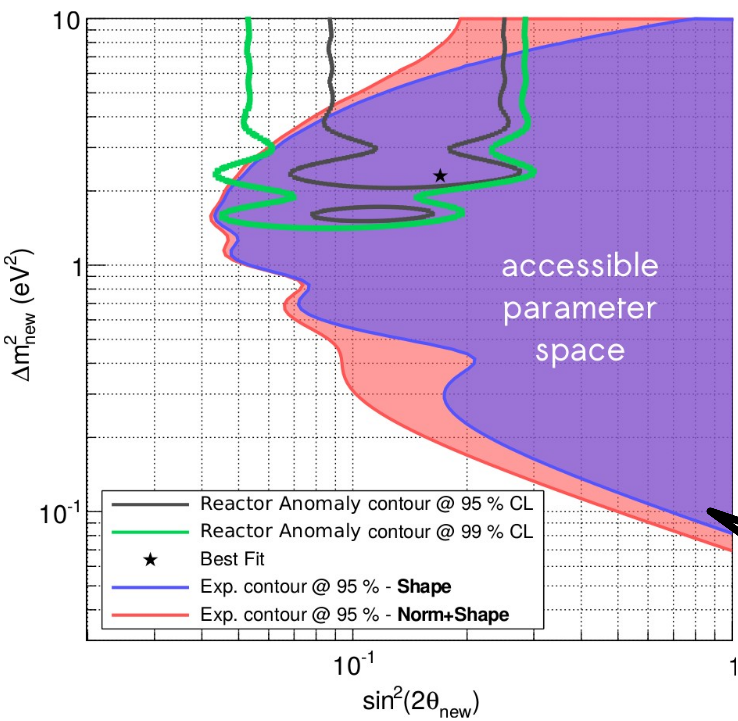
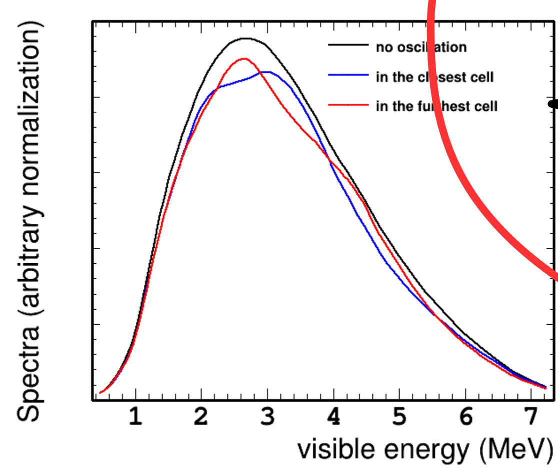
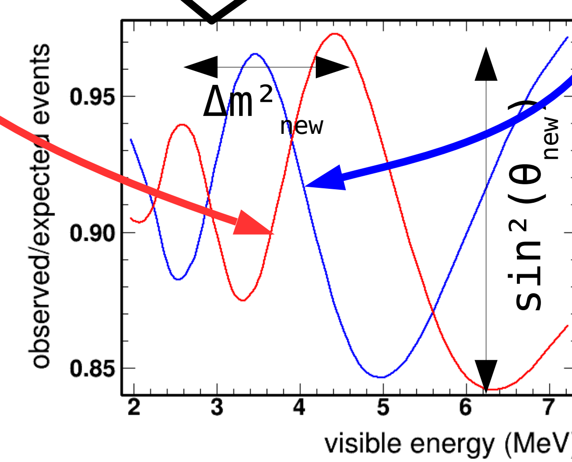




sensitivity after 1 year

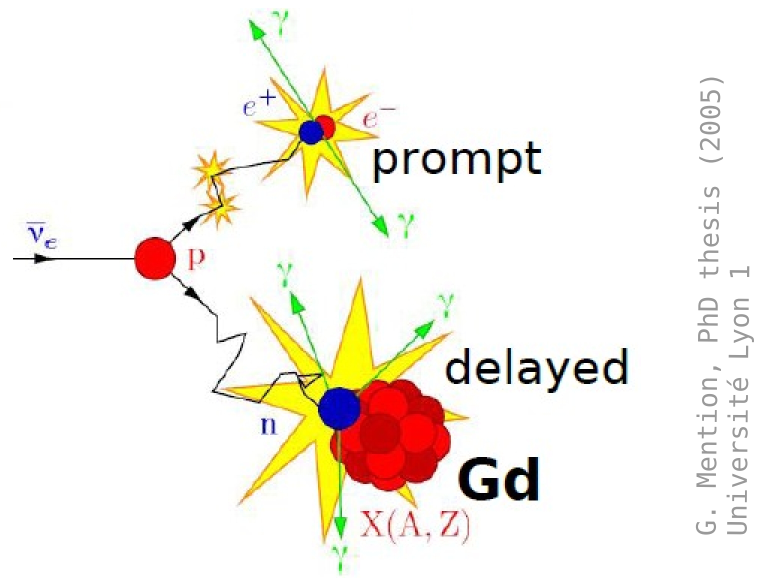


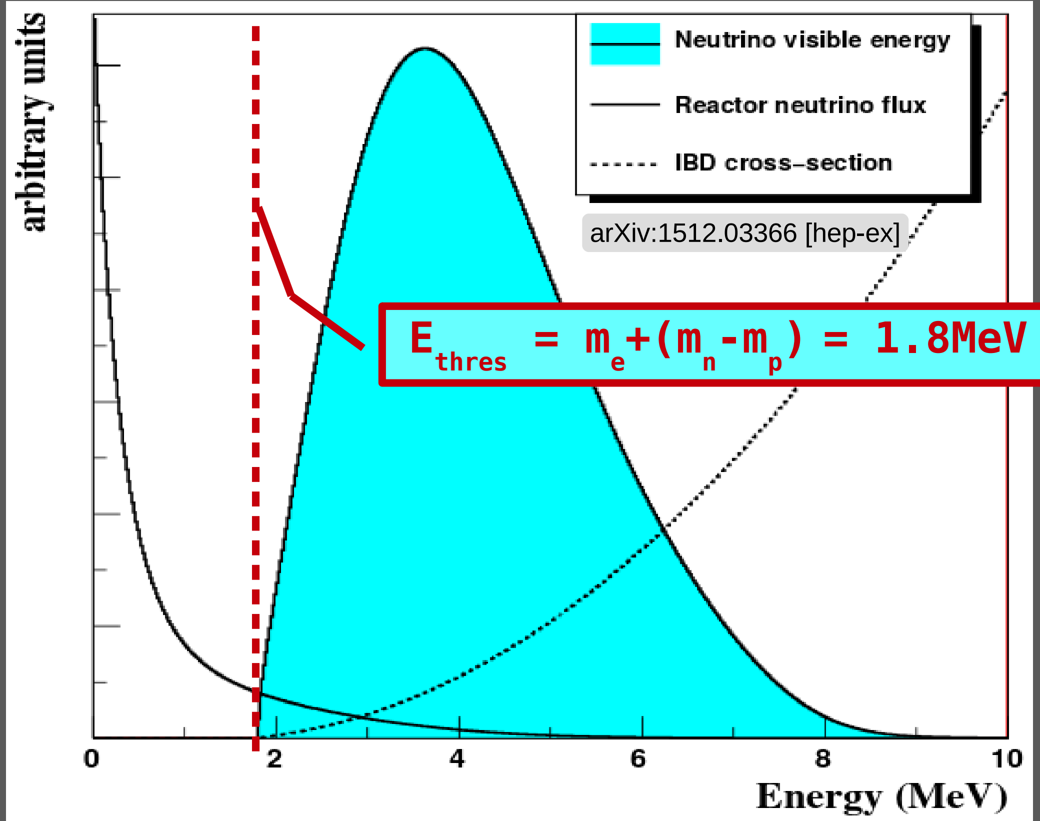
Visible shape effects in energy



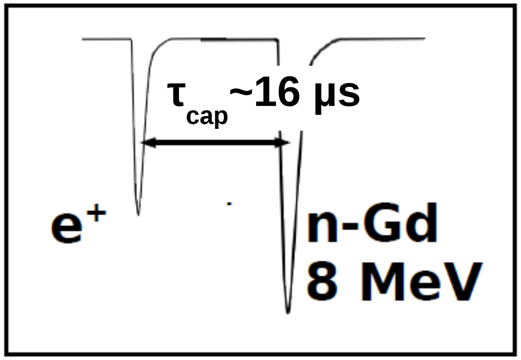
Inverse beta-decay (IBD):

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





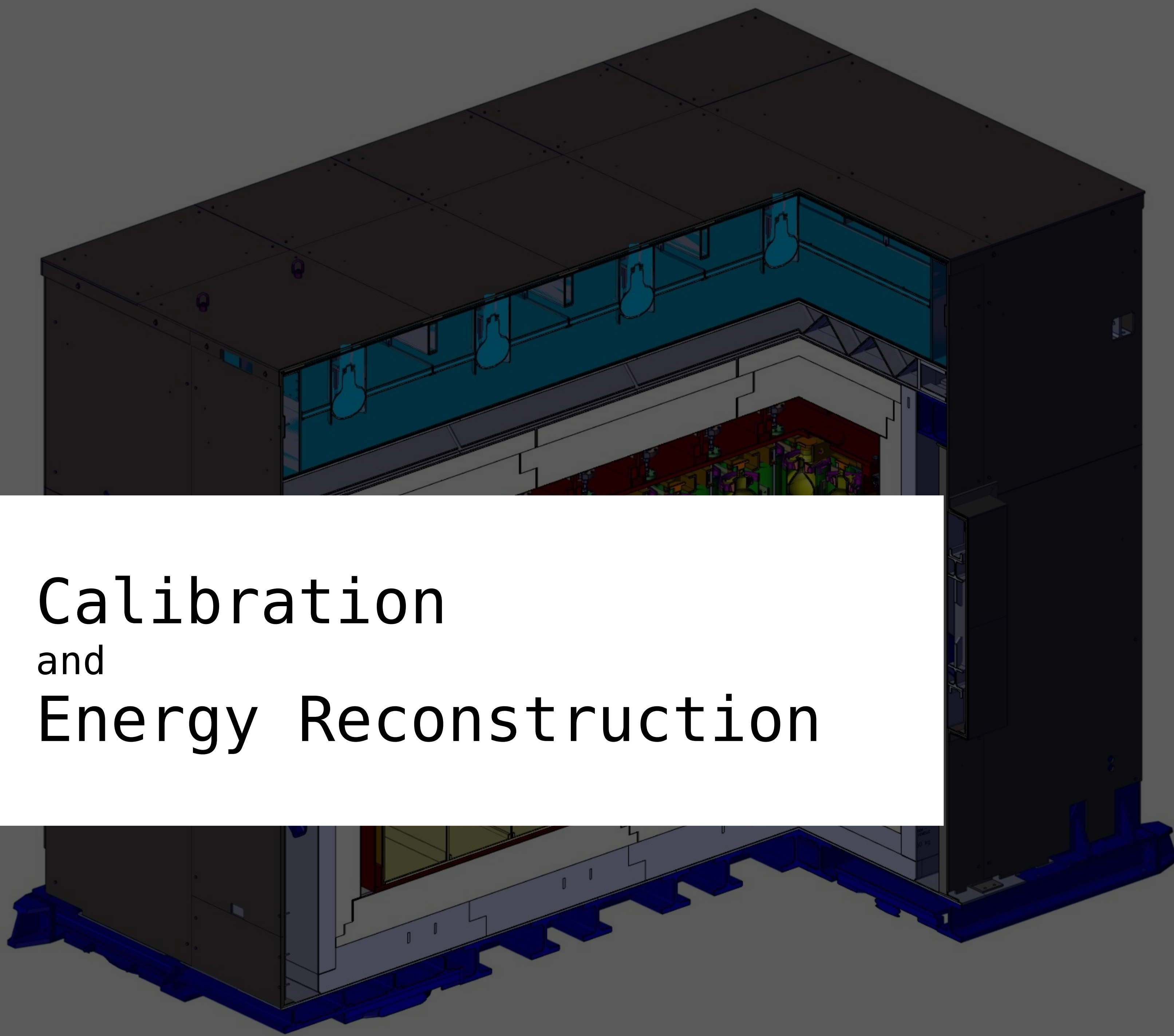
Delay due to:
thermalisation of neutron before capture
+
time constant of the capture process



Visible prompt energy = neutrino energy + corrections

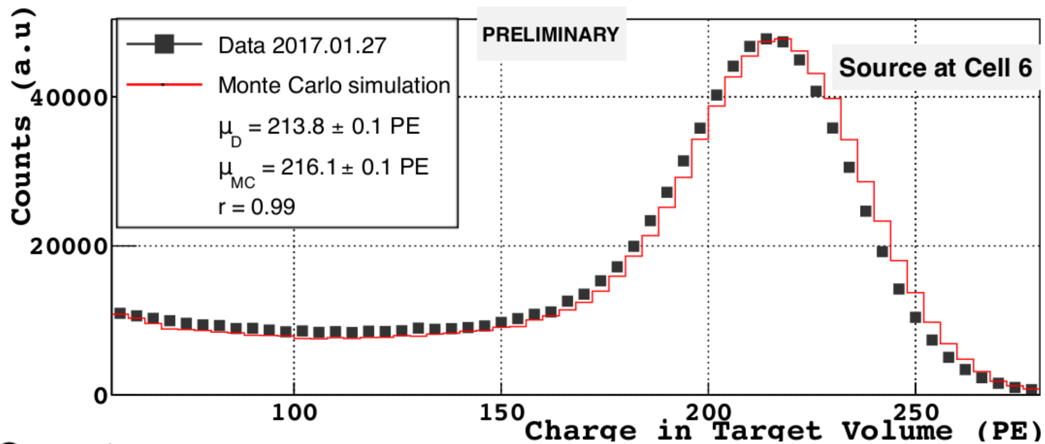
$$E_{\bar{\nu}_e} = E_{e+} + (m_n - m_p) + \mathcal{O}(E_{\bar{\nu}_e}/m_n)$$

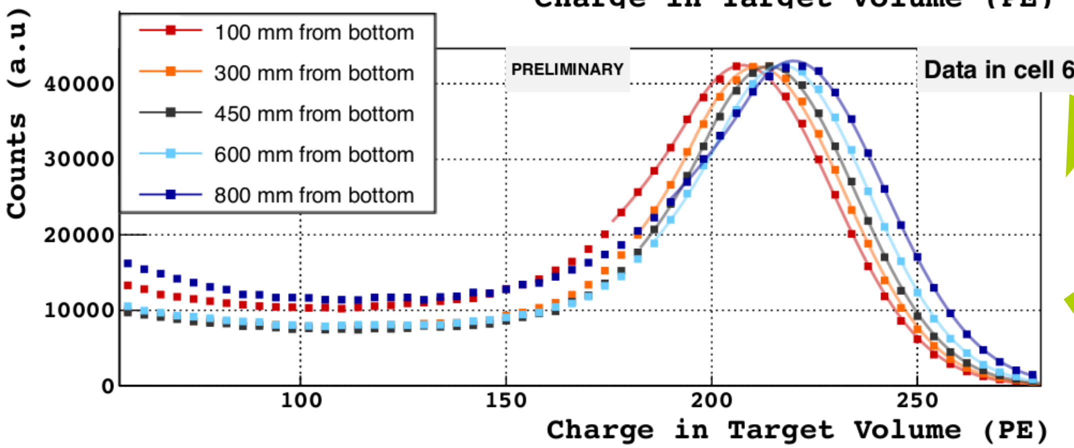
$$E_{vis}^{prompt} = E_{e+} + m_{e-}$$

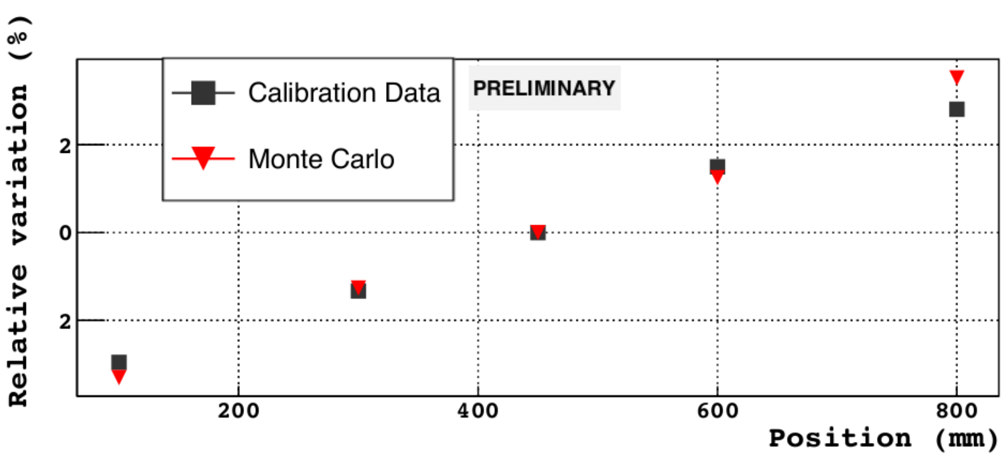


Calibration
and
Energy Reconstruction

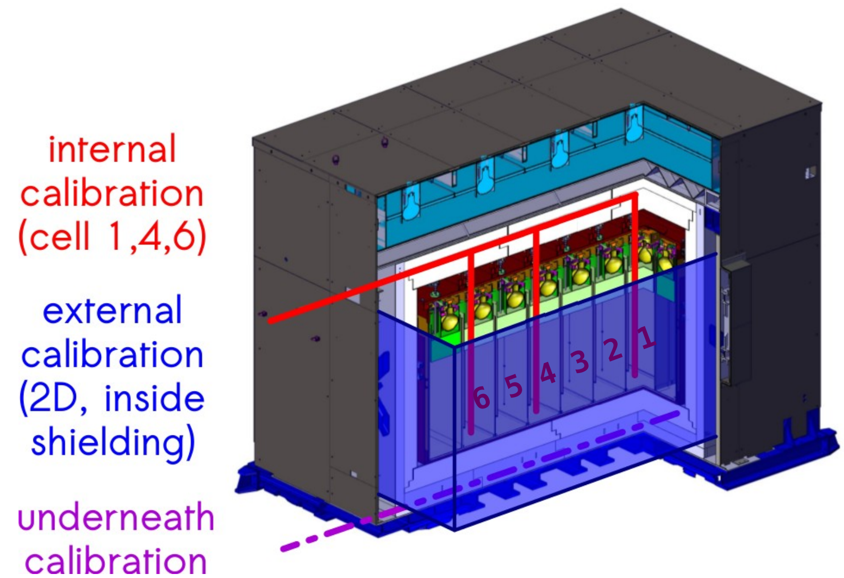
Homogeneity







→ three calibration systems
→ various γ+n sources



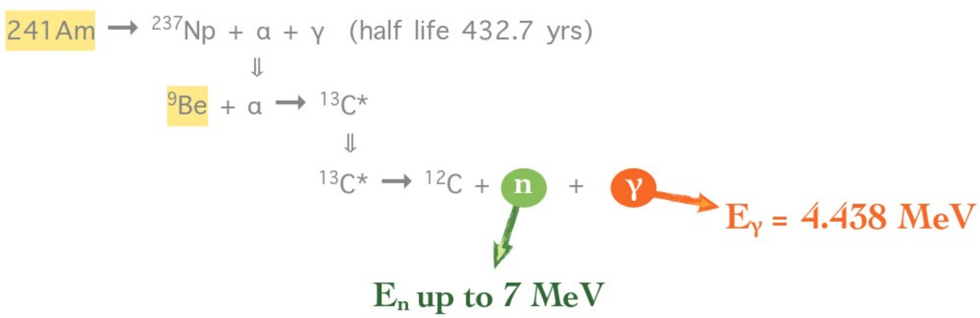
Mn-54 source at different heights in one cell shows:

→ low z-dependence

→ excellent MC to data agreement at current stage of analysis

Detection Efficiency

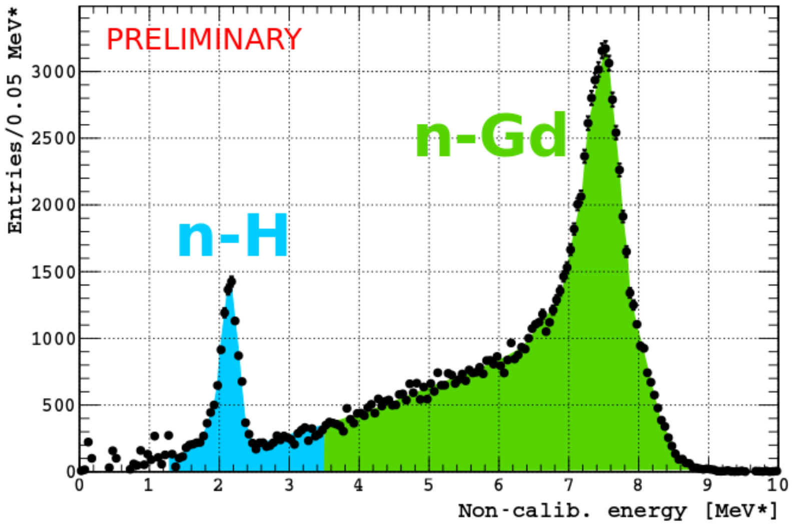
Using γ+n events of an AmBe source



→ study delayed event energy

→ study delay time

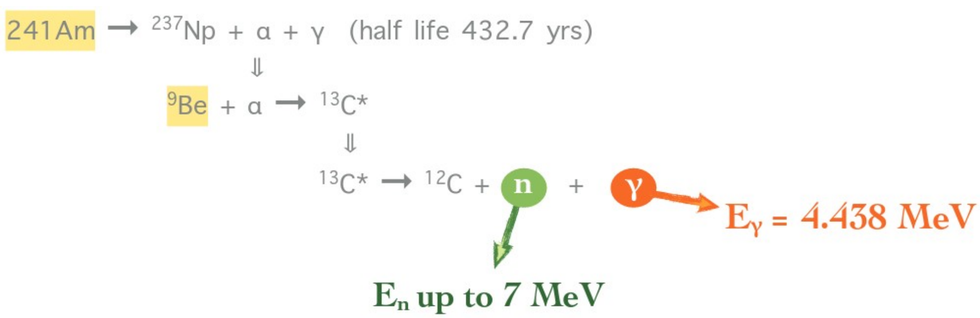
Source at centre of cell 6



⇒ n-Gd capture fraction ~86%

Detection Efficiency

Using γ+n events of an AmBe source



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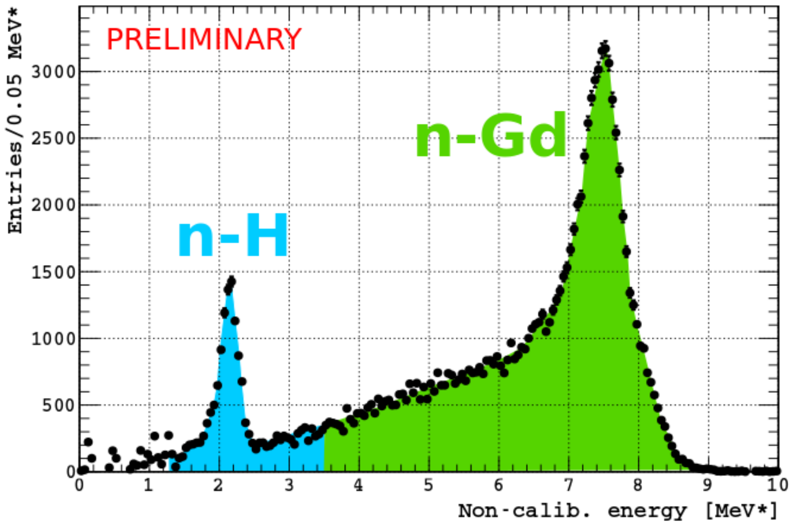

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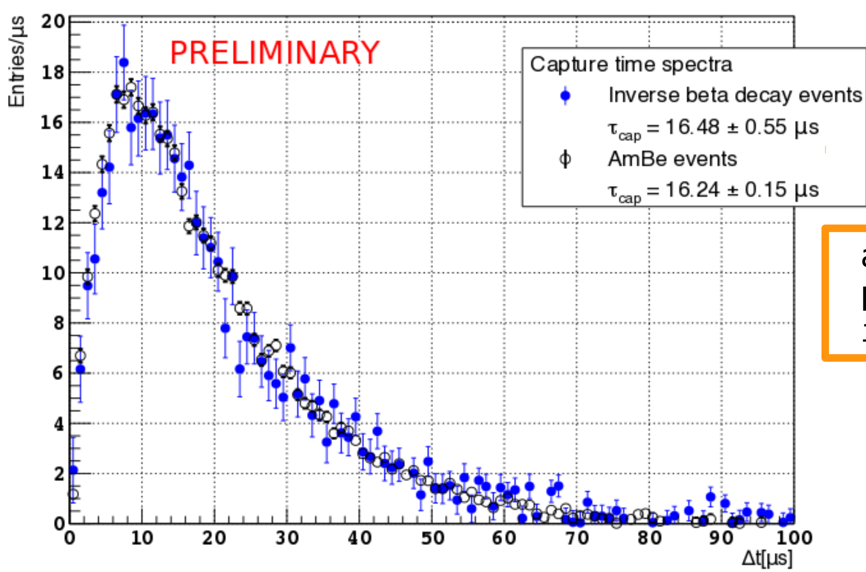
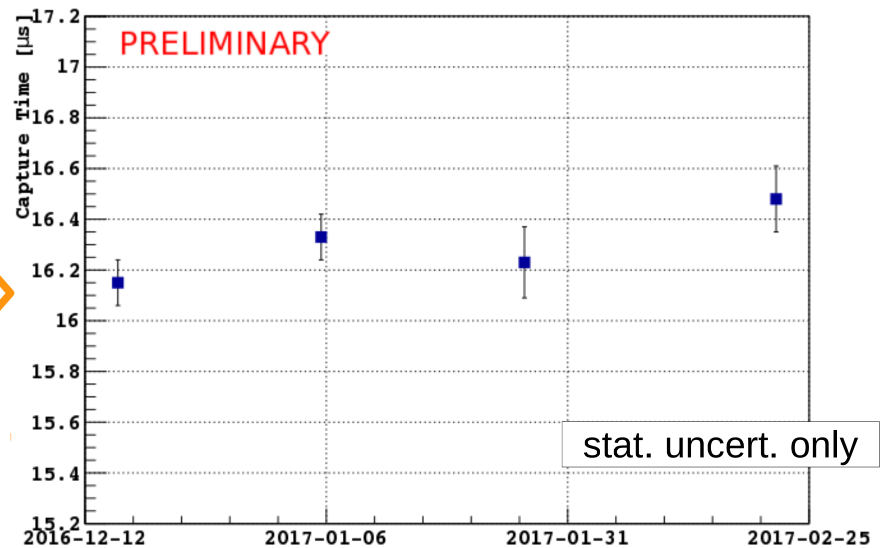
Neutron capture time comparison



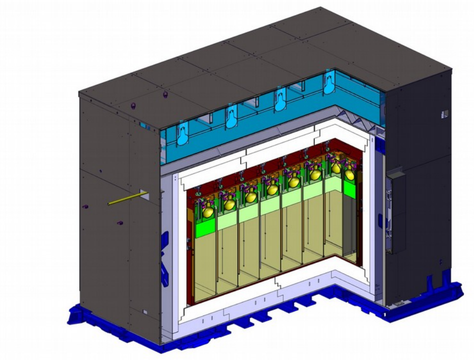
at many points in time

Capture time stability



Energy Reconstruction

Collected charge in one target cell given by
- light produced in that cell and
- light cross-talking from neighbouring cells j:



$$Q_i = \alpha_i^{\mathrm{geom}} \sum_{j=\mathrm{cells}} E_j^{\mathrm{dep}} \times f_j \times L_{j \to i}$$

photon acceptance cell i

deposited energy in cell j

photons per MeV

light crosstalk between cells

→ Conversion factors obtained simultaneously and in-situ from calibration data

$$Q_i = \sum_{j=Cells} E_j^{dep} C_j L_{j \to i}$$

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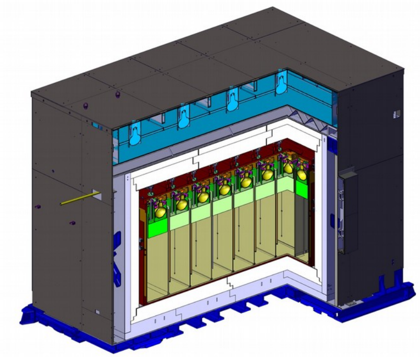

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- α_i^{geom}: photon acceptance cell i
- E_j^{dep}: deposited energy in cell j
- f_j: photons per MeV
- $L_{j \to i}$: light crosstalk between cells

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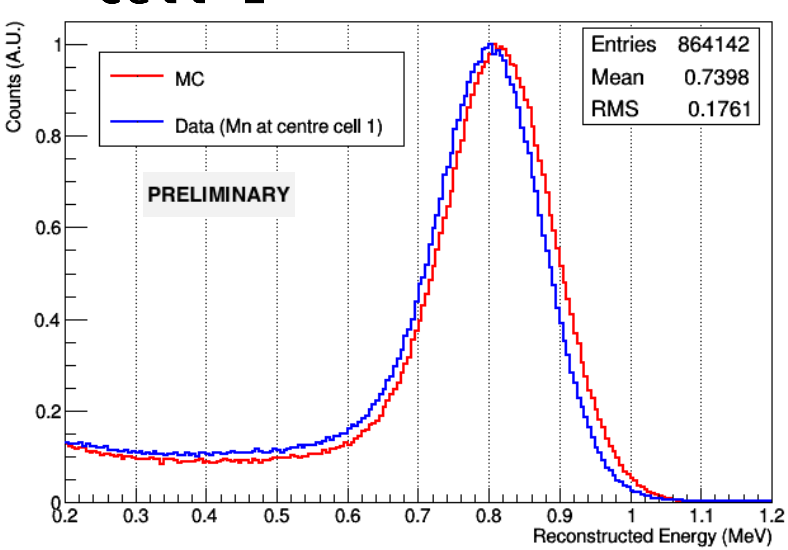
Cell 1

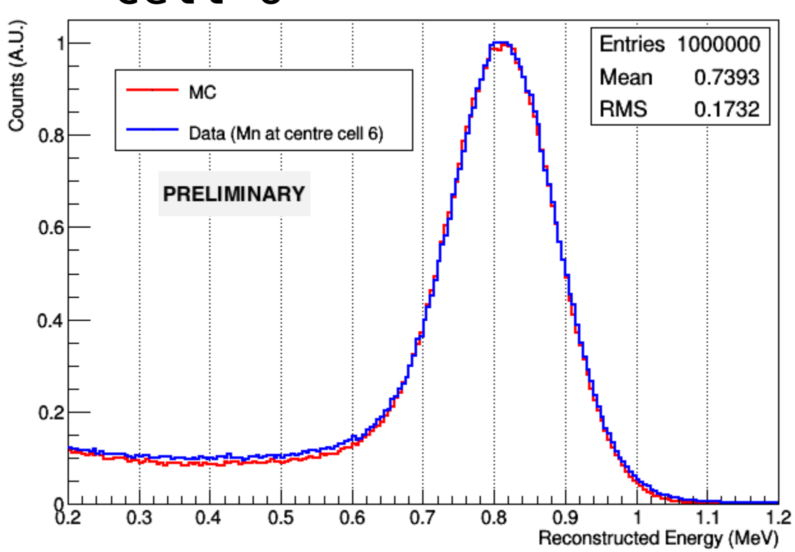


Mn-54 source at centre of different cells:

→ Data-MC agreement goal: 2%

⇒ already achieved

Cell 6

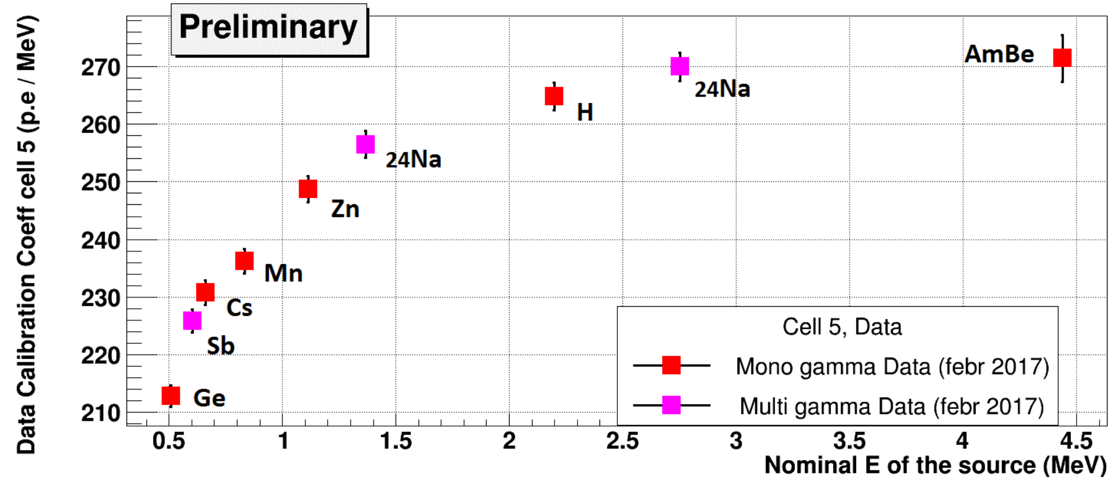


Energy Reconstruction

Energy response function

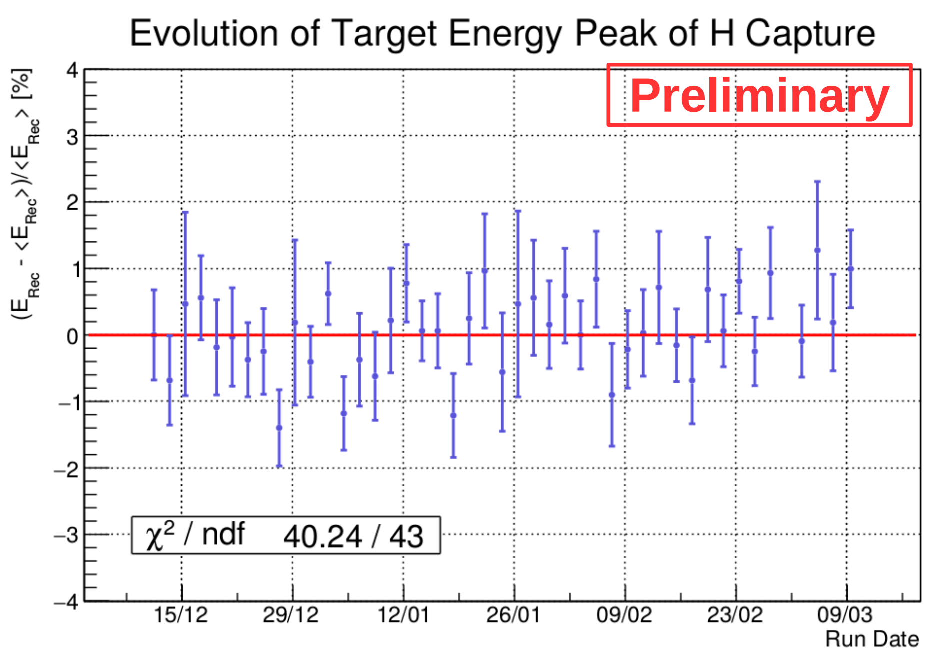
→ quenching curve
→ gamma sources
→ single gamma lines

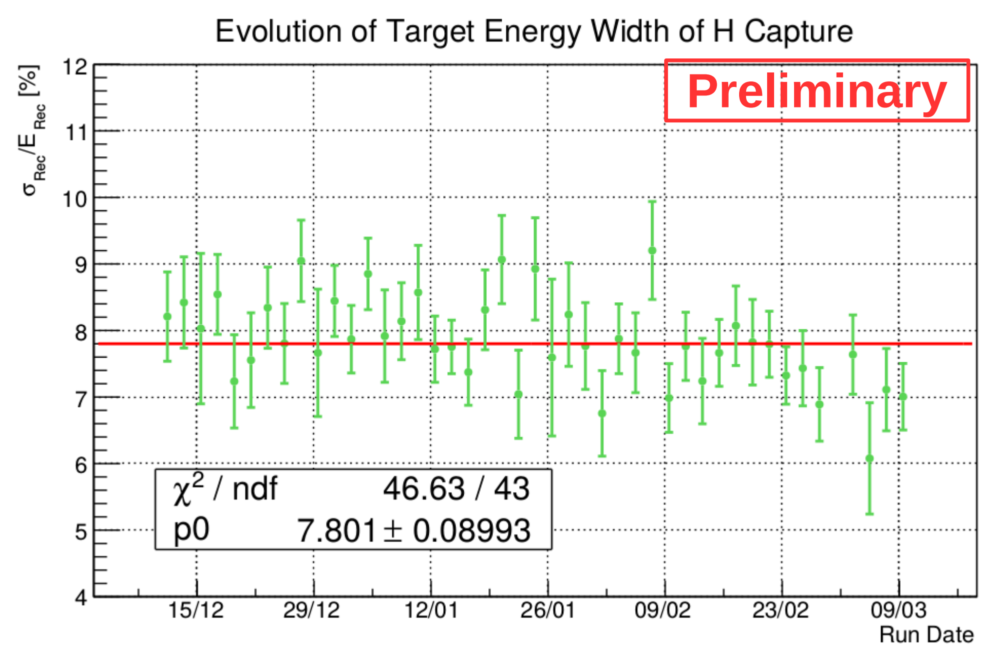
⇒ expected behaviour of liquid scintillator ionisation quenching (Birk's law)

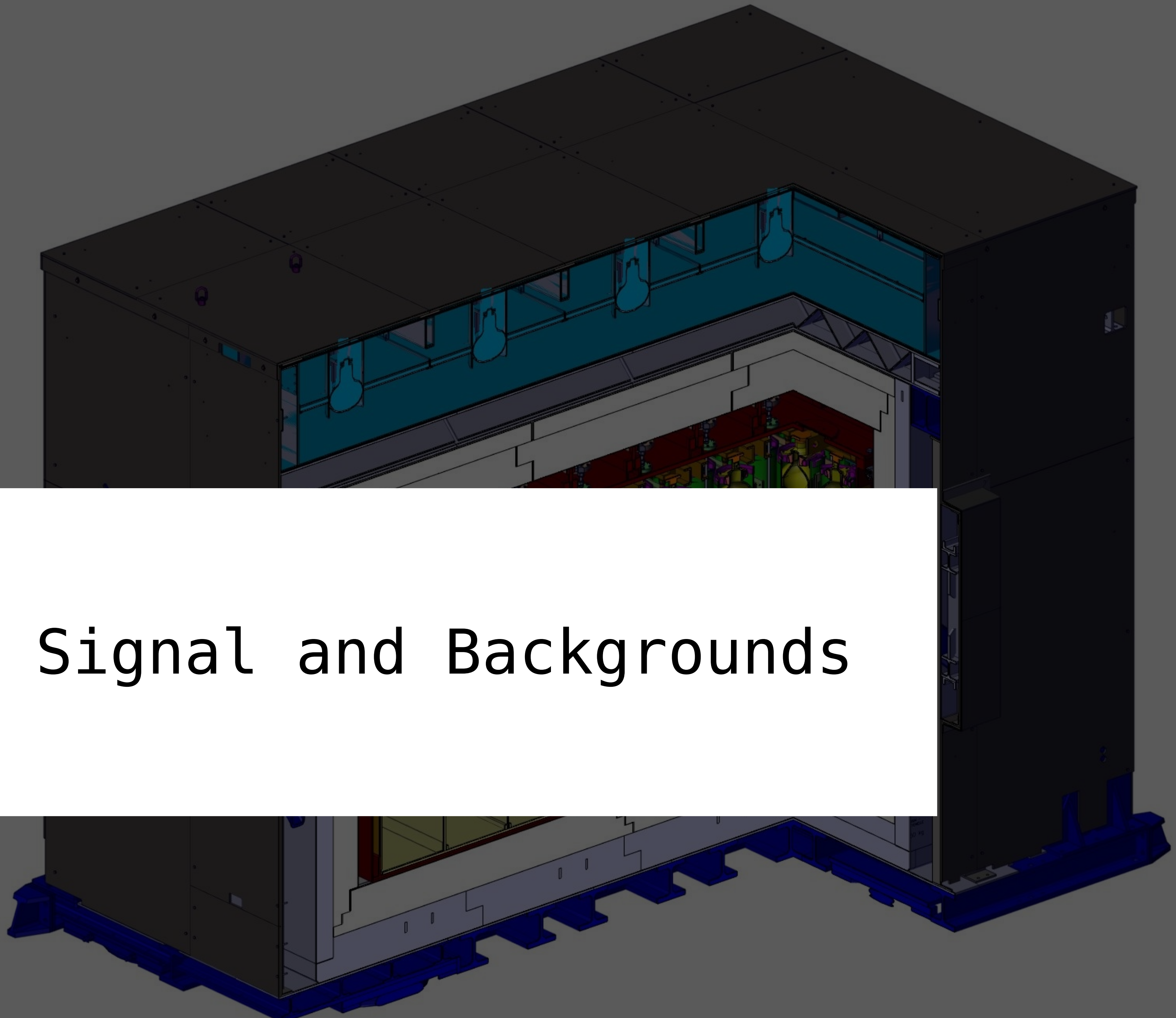


Energy stability from n-H captures of spallation neutrons

⇒ in good agreement with stable behaviour







Signal and Backgrounds

Backgrounds

© NSF/J.Yang

Muon induced

Examples:
- fast neutrons
- stopping muons

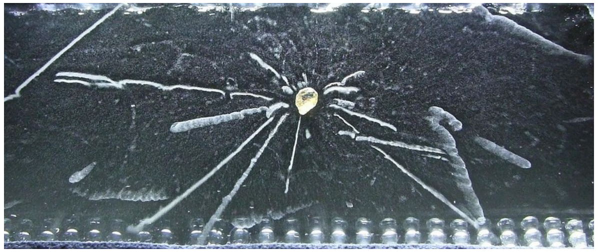
Counter measures:
- water pool
- active veto
- pulse shape discr.
- PMT cut

Courtesy of J.Haser

Reactor induced

Examples:
- neutrons
- γ-radiation via neutron capture

Counter measures:
- shielding
- pulse shape discr.
- event topology



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Radioactive decays

Examples:
- thorium/uranium
- radon/argon
- potassium

Counter measures:
- shielding
- event topology
- precise measurement

Backgrounds

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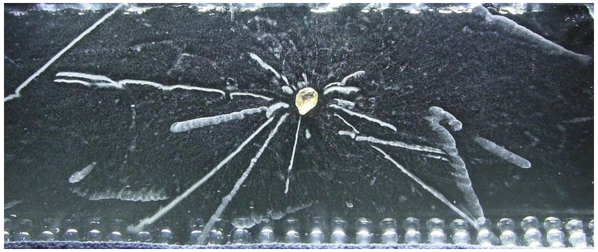

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Radioactive decays

Examples:
- thorium/uranium
- radon/argon
- potassium

Counter measures:
- shielding
- event topology
- precise measurement

Neutrino Candidate Search

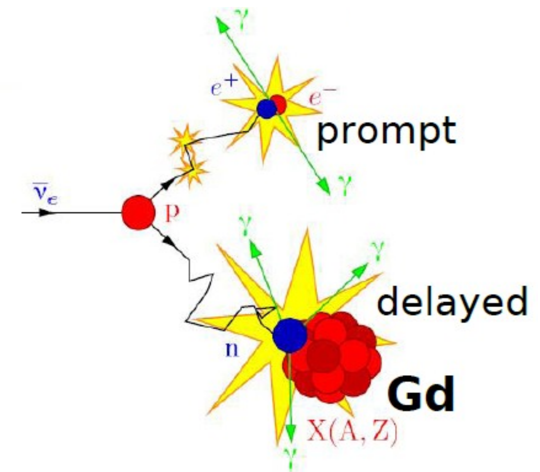
Signal selection (proposal cuts):

	Cut 1	Cut 2	Cut 3
E_{prompt}	1.5 MeV < E_{tot} < 8 MeV	E_{GC} < 1.1 MeV	2.5 σ PSD
$E_{delayed}$	5 MeV < E_{tot} < 10 MeV	E_{TG} > 1 MeV	
T_{delay}	< 70 µs		

+ after muon veto
+ additional cleaning cuts

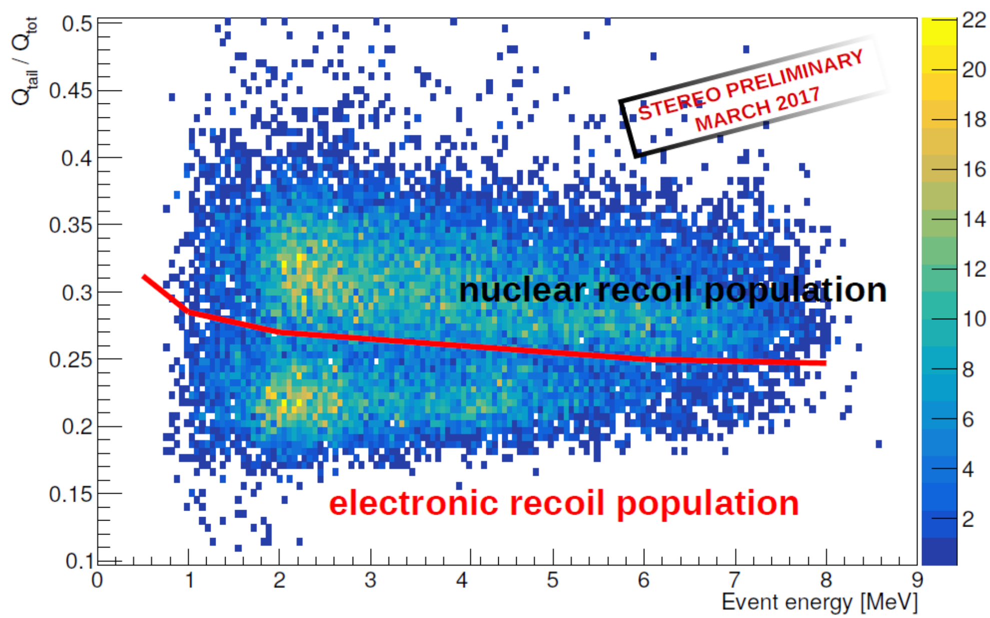
Inverse beta-decay (IBD):

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

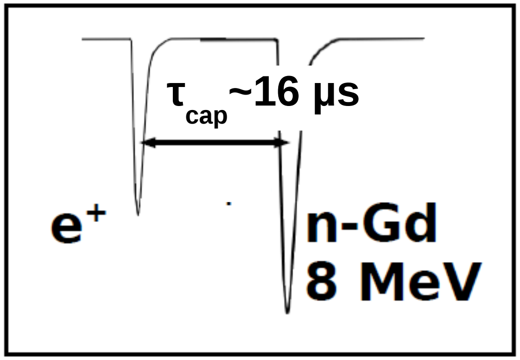


G. Mention, PhD thesis (2005)
Université Lyon 1

Background rejection by Pulse Shape Discrimination (PSD)



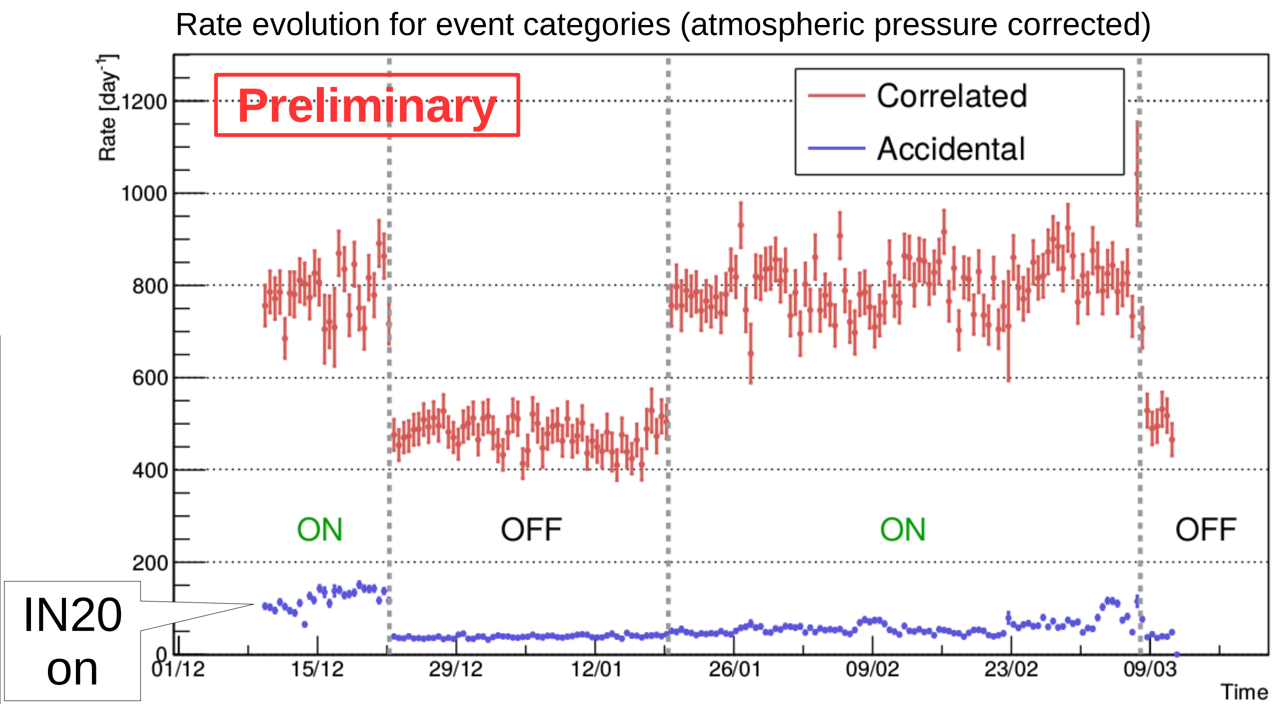
IBD seen by detector:

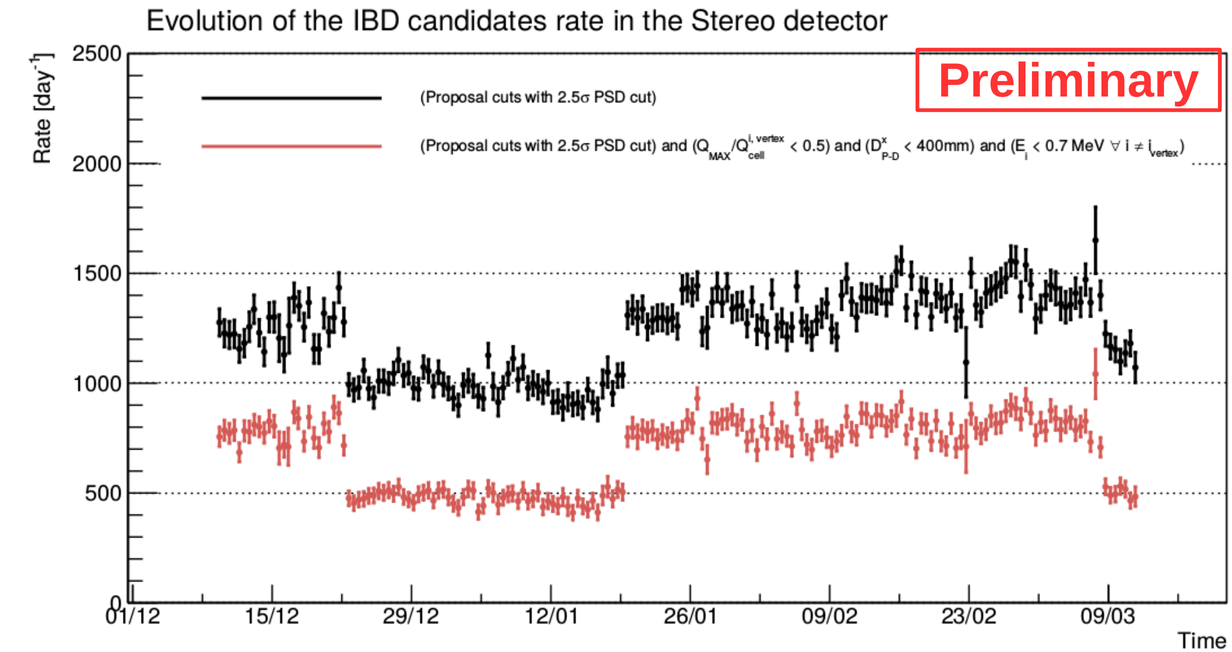


Neutrino Candidate Rates

Neutrino candidate rate by comparing rates at reactor-on (75 days) vs. reactor-off (28 days):

~300/day
(with current proposal cuts)





Neutrino Candidate Rates

Neutrino candidate rate by comparing rates at reactor-on (75 days) vs. reactor-off (28 days):

~300/day
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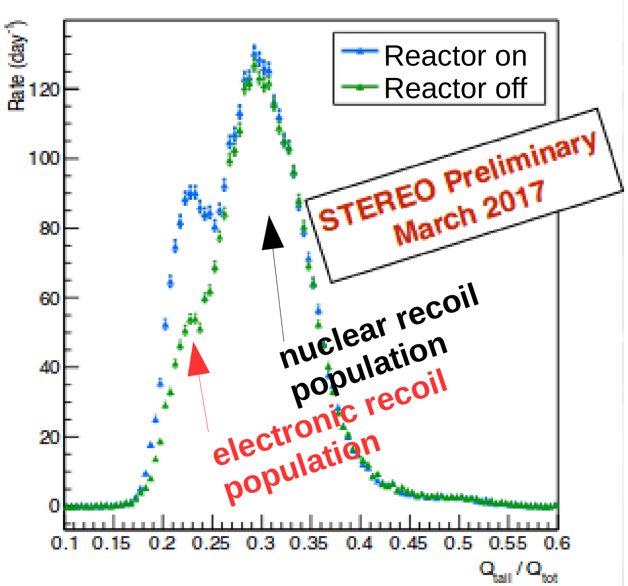
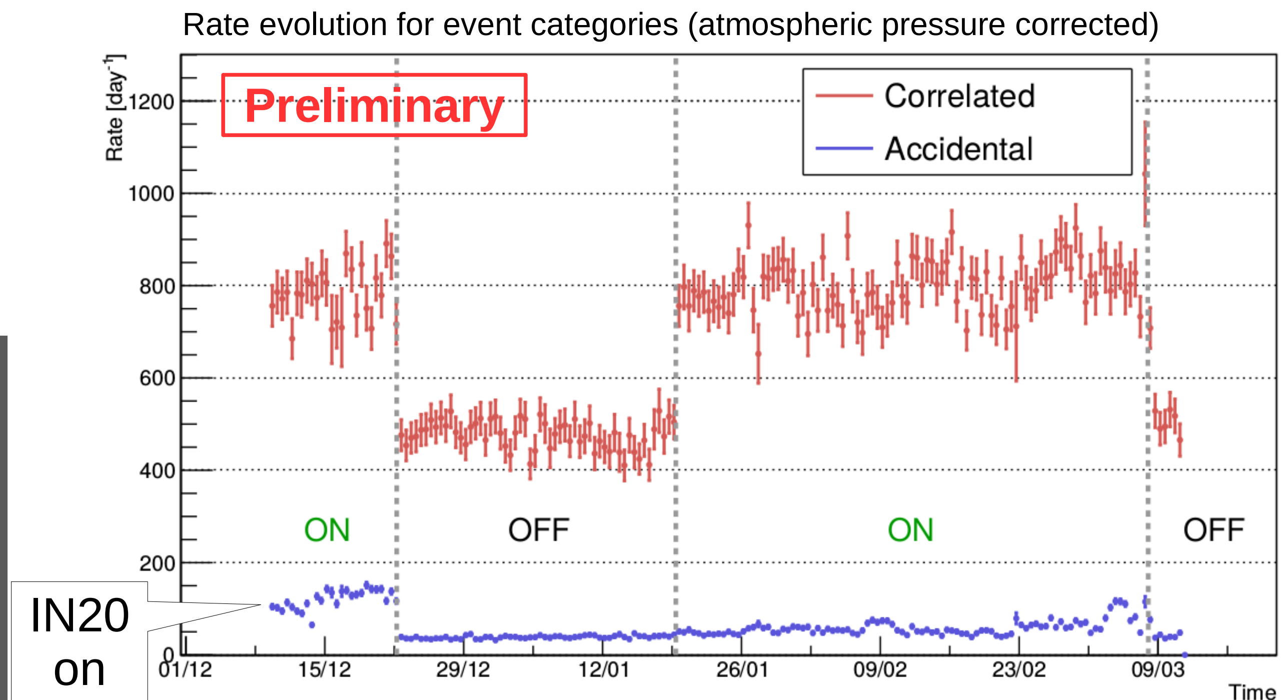
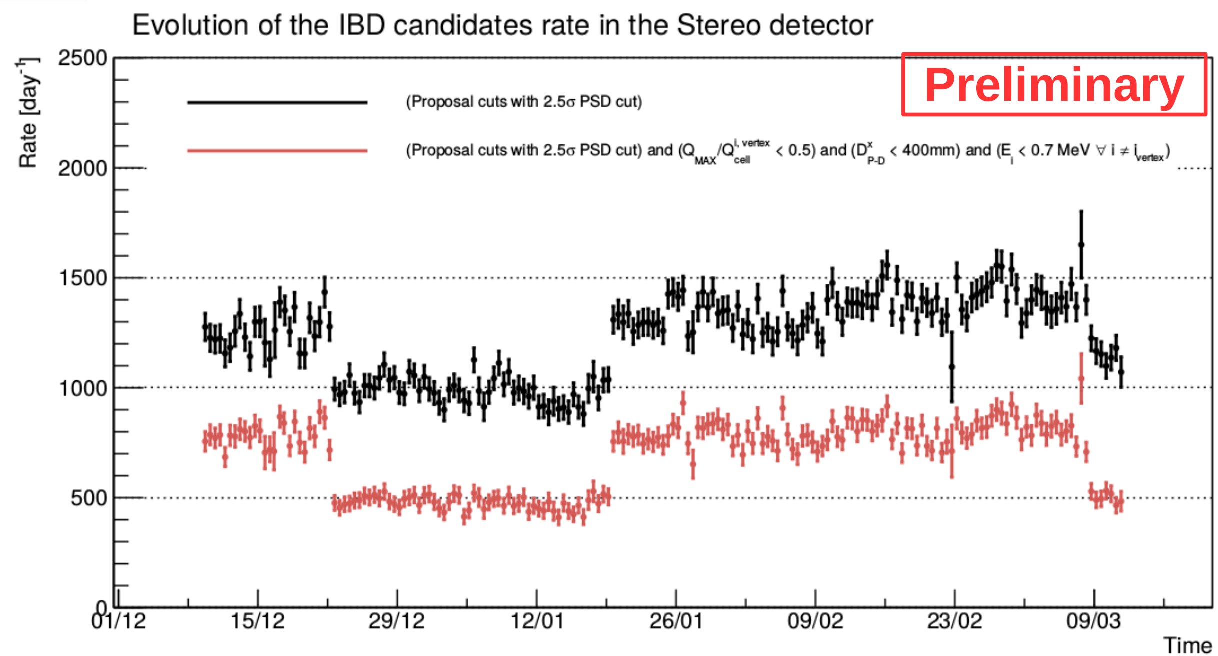
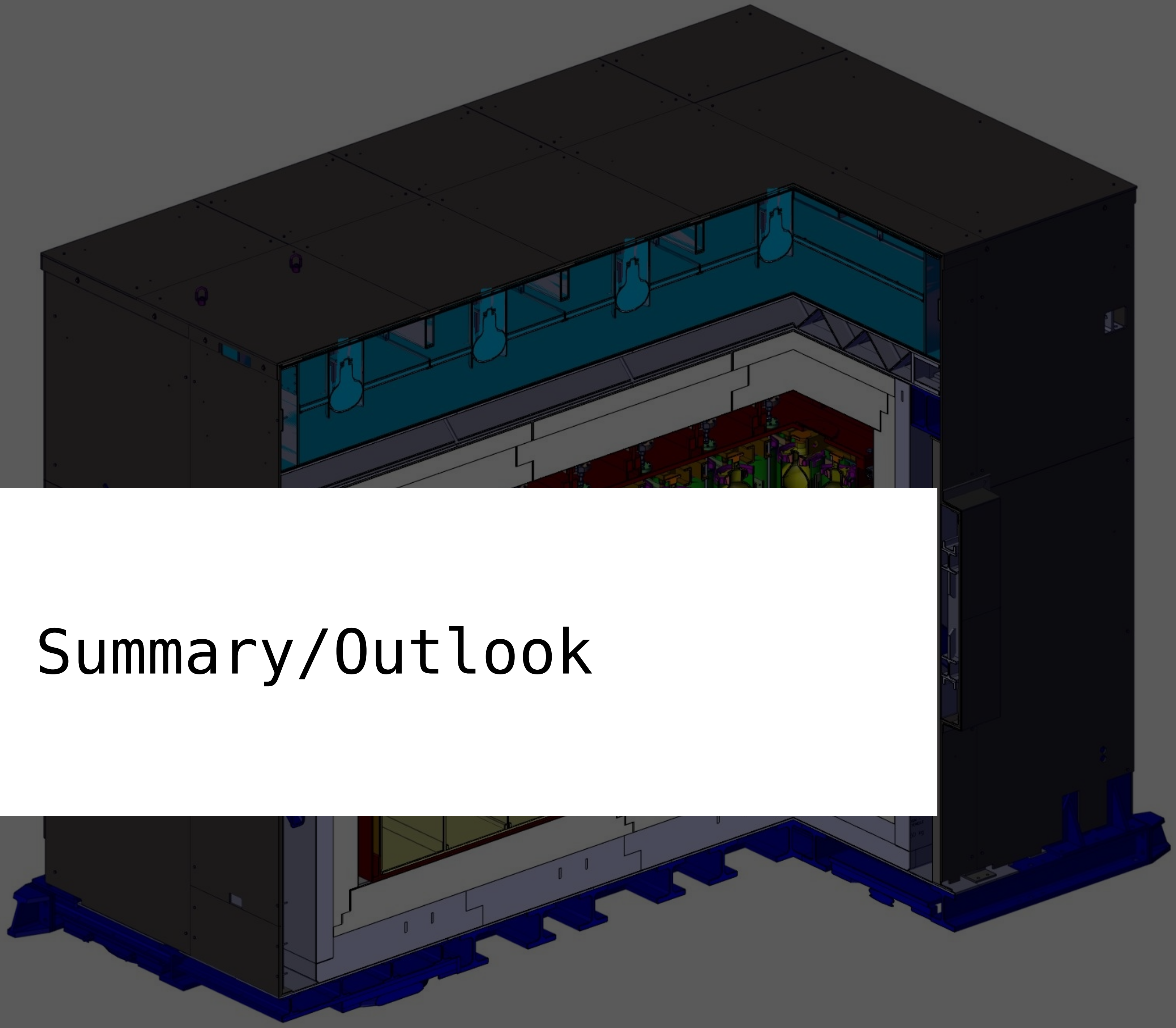
Comparison reactor-on vs. reactor-off via PSD
→ additional contribution only in signal region
→ shielding against reactor-induced background sufficient









Summary/Outlook

Summary/Outlook

Summary

→ first data taking phase completed (75 days reactor on + 28 days reactor off)

→ detector shows well-understood/stable response

→ first signal and background selections yield promising results

Outlook

→ cut optimisation

→ finalisation of energy reconstruction
→ for spectral shape oscillation analysis

→ studies of backgrounds + systematics

→ re-installation of detector (currently maintenance at reactor site)

→ further data taking → 2017: + 60 days reactor on
→ 2018: + ~150 days reactor on

The Stereo Collaboration

LAPP

LPSC Grenoble

ILL NEUTRONS FOR SOCIETY

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

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PROJET FINANCÉ PAR L'ANR – ANR – PROJECT FUNDED BY THE ANR

Enigmass

P2IO Physique des 2 Infinis et des Origines

MAX-PLANCK-GESELLSCHAFT

Appendix

The Stereo Timeline

Spring-Autumn 2016:
Mounting and installation of the STEREO detector and its shielding

9th November 2016:
ASN approval
⇒ detector filled and commissioned (2 weeks)

Winter 2016-2017:
Data taking of
75 days reactor ON +
28 days reactor OFF

3rd March 2017:
Reactor shutdown
(up to October 2017)
⇒ End of the first data acquisition phase

March-August 2017 :
STEREO retracted for reactor works, used for detector maintenance

Shielding types:

- 6 tons of borated polyethylene
- 65 tons of lead
- B_4C sheets all around the detector
- Magnetic shielding (soft iron + µ-metal)
- Casemate reinforcements (lead + borated polyethylene)