Very short distance neutrino oscillations

Antonin Vacheret
University of Oxford, Oxfordshire, UK

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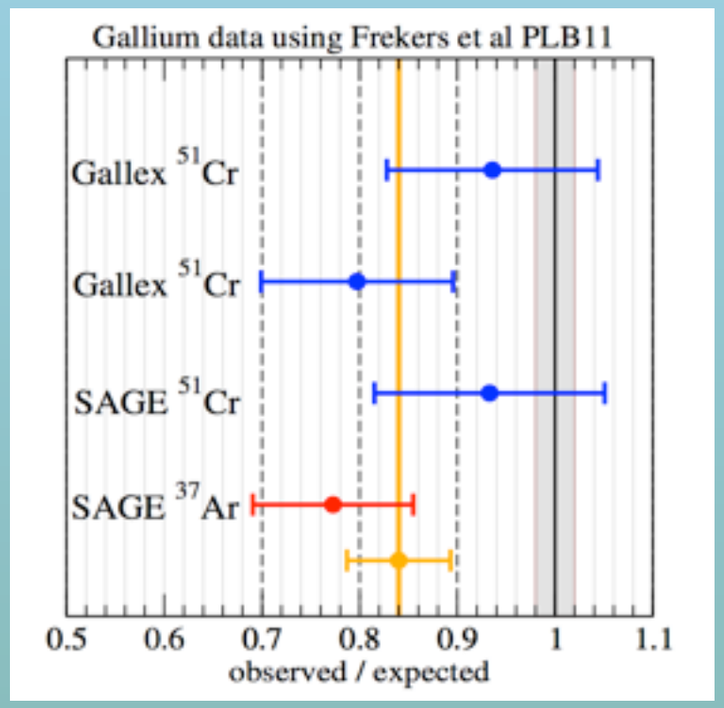
Xth Rencontres du Vietnam
Quy Nhonh, Vietnam

Recent anomalous results

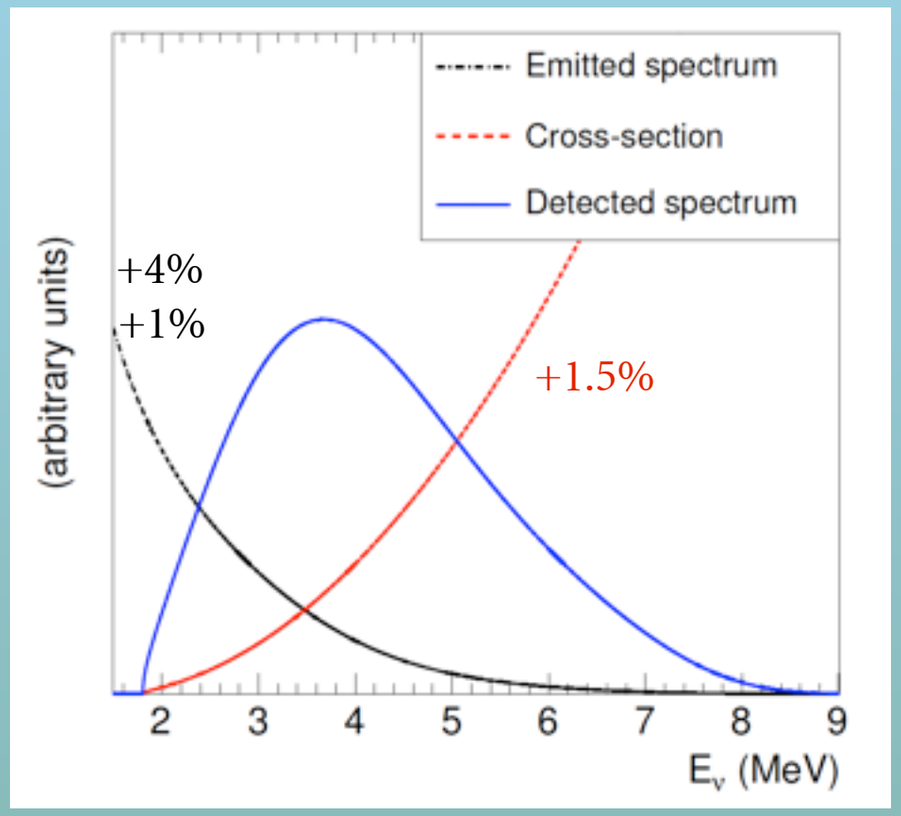
$$\nu_e + {}^{71}\mathrm{Ga} \rightarrow {}^{71}\mathrm{Ge} + e^-$$



Giunti Laveder 1006.3244
J. Kopp et al., hep/ph:1303.3011

- re-analysis of calibration source data
  - (L/E ~1m/0.1MeV)
- rate deficit of 14 ± 6 %
  - *Gallium anomaly*

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

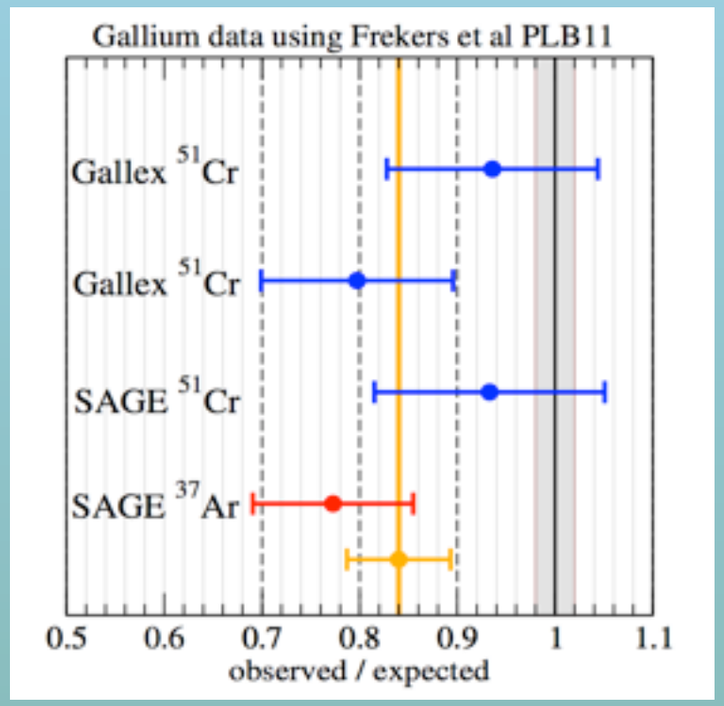


- 2011 re-evalatation of reactor antineutrino flux and update on cross-section parameters
  - 3.5% new conversion of ILL beta spectra
  - 1.5% off-equilibrium
  - 1.5% neutron lifetime τ_n
- rate deficit 6.5 %
  - *Reactor anomaly*

Recent anomalous results

G. Mention et al., Phys. Rev. D83, 073006 (2011)

$$\nu_e + {}^{71}\mathrm{Ga} \rightarrow {}^{71}\mathrm{Ge} + e^-$$



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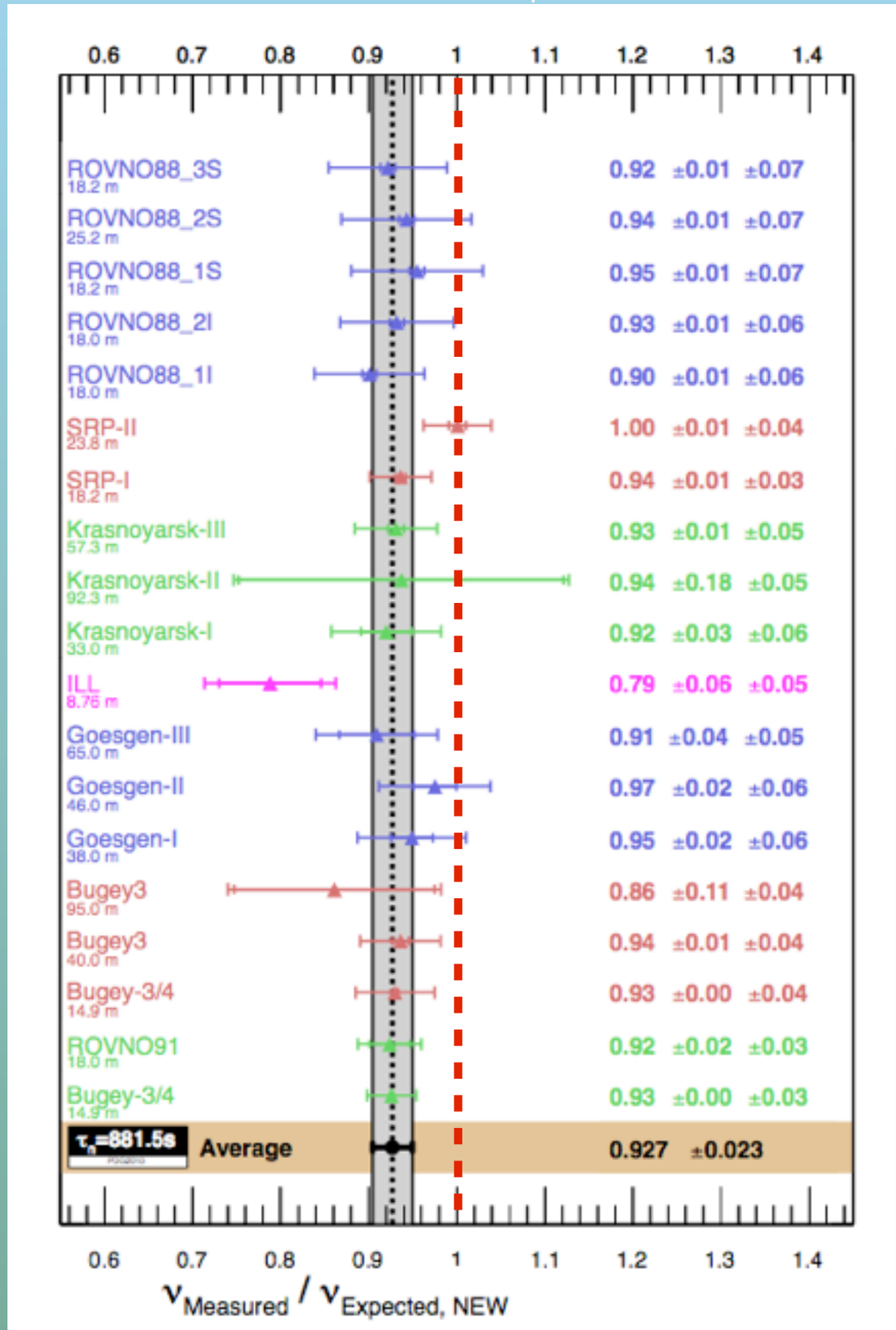
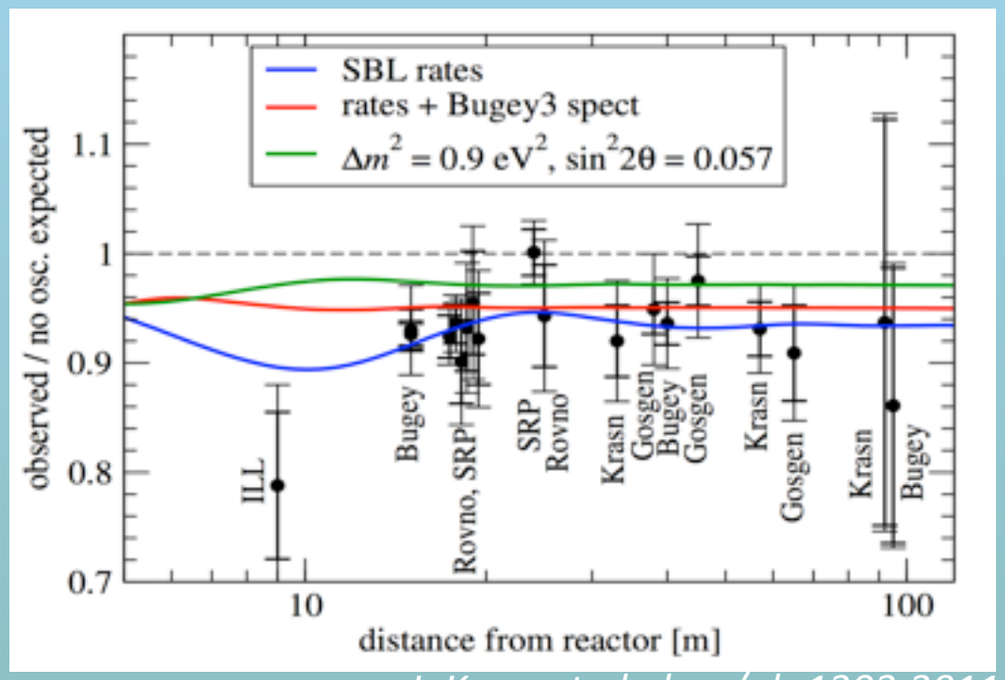


- re-analysis of calibration source data
  - (L/E ~1m/0.1MeV)
- rate deficit of 14 ± 6 %
  - *Gallium anomaly*

Sterile neutrino hypothesis

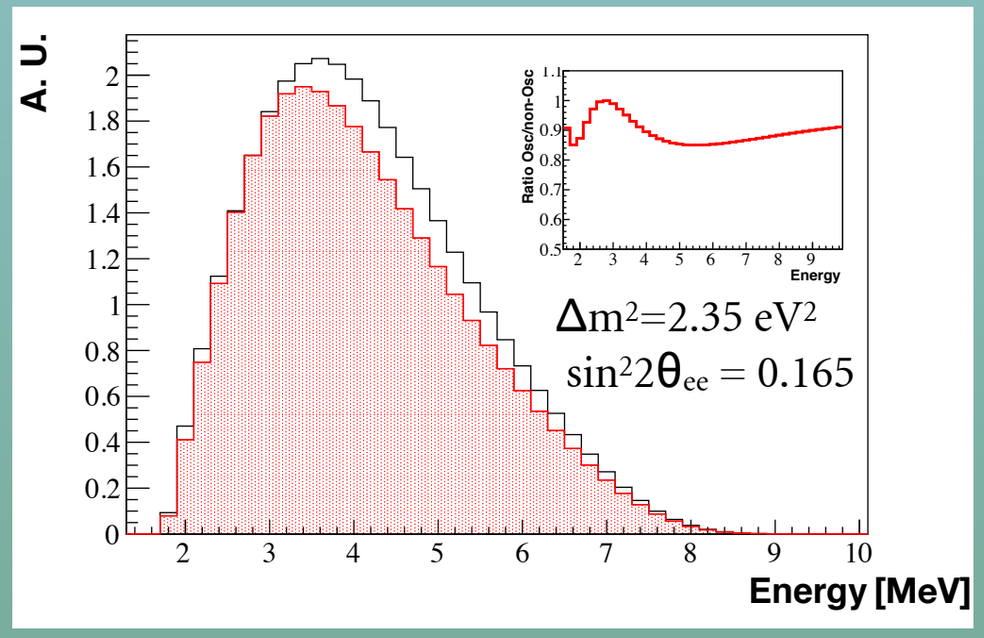
- current rate anomalies due to unknown effect or to new physics ?
- additional(s) light fermion mixing with active neutrinos could be one explanation
  - a generic extension of SM
  - help with phenomenology (connection to DM is possible)
  - tension exists between oscillation data sets
  - in modest tension with PLANCK data

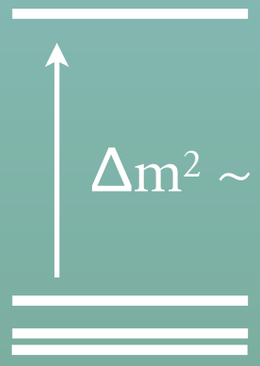
Effect as a function of distance



J. Kopp et al., hep/ph:1303.3011

Effect as a function of energy

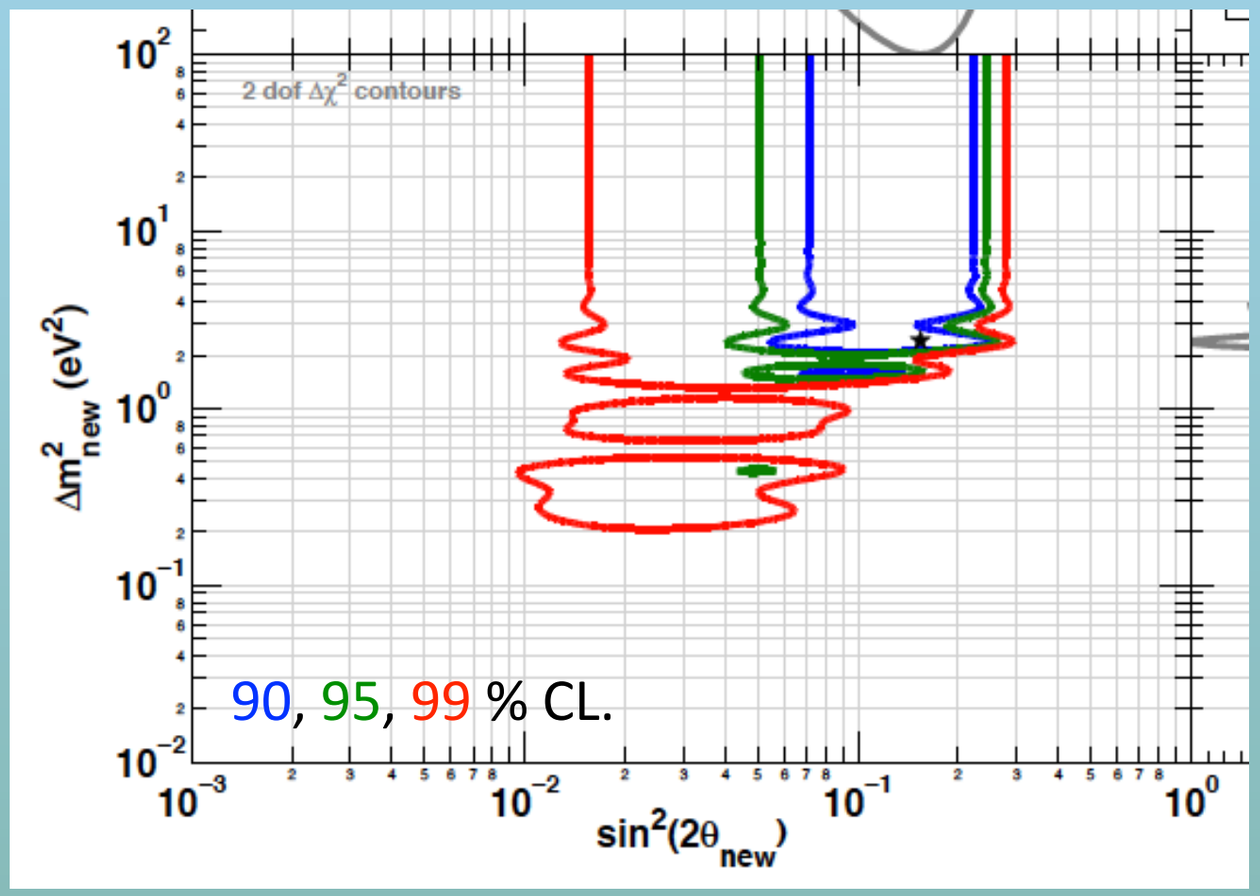




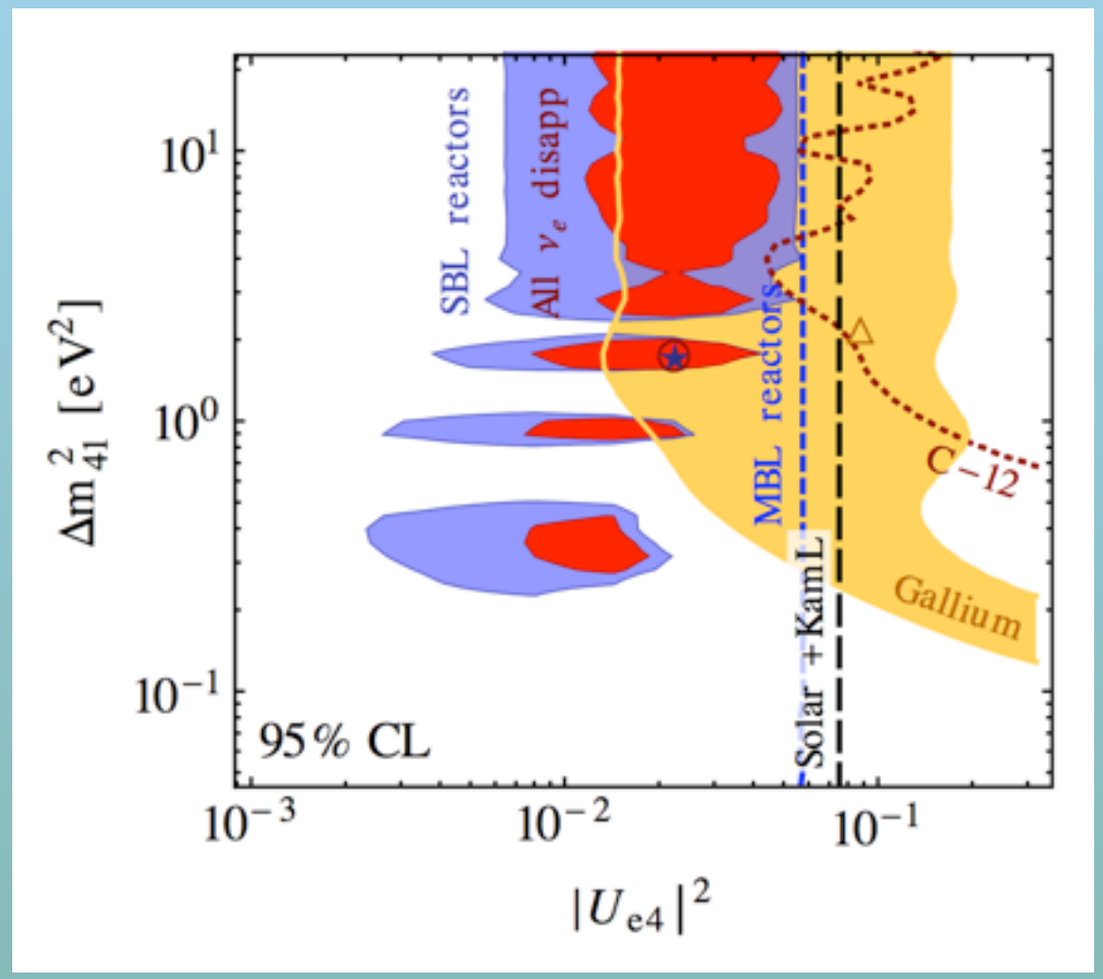
$$\bar{\nu}_e \rightarrow \nu_s$$

$$P_{ee} = 1 - 2|U_{e4}|^2(1 - |U_{e4}|^2)$$

Allowed region



Sterile neutrino white paper arXiv:1204.5379

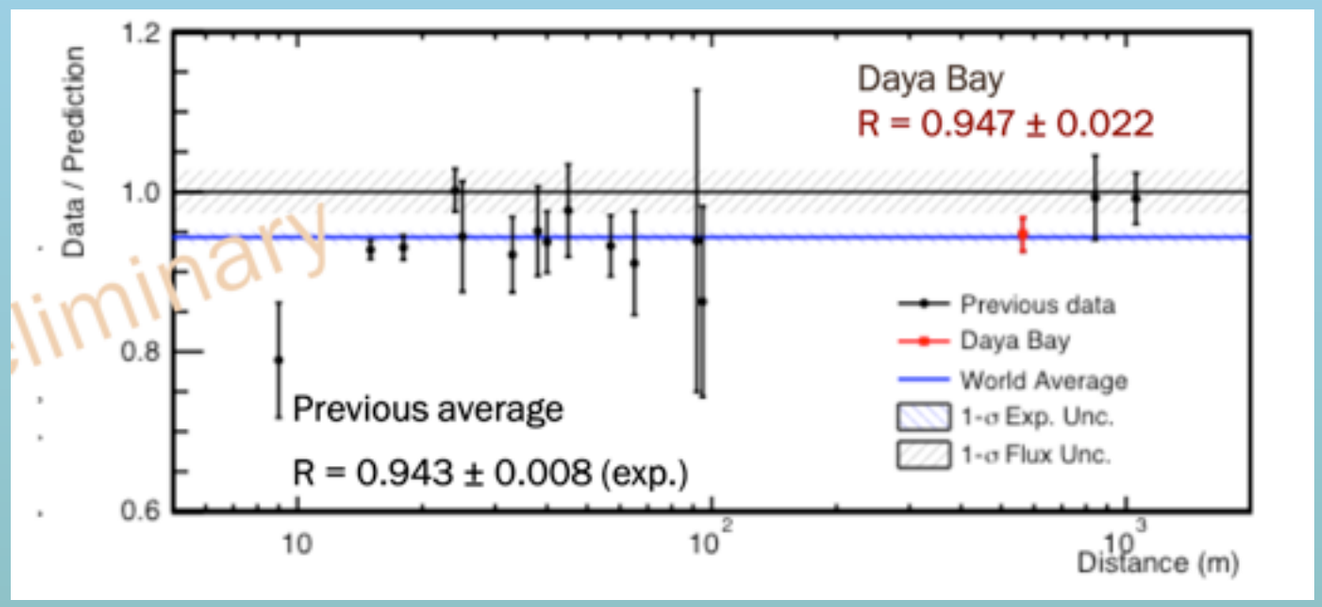


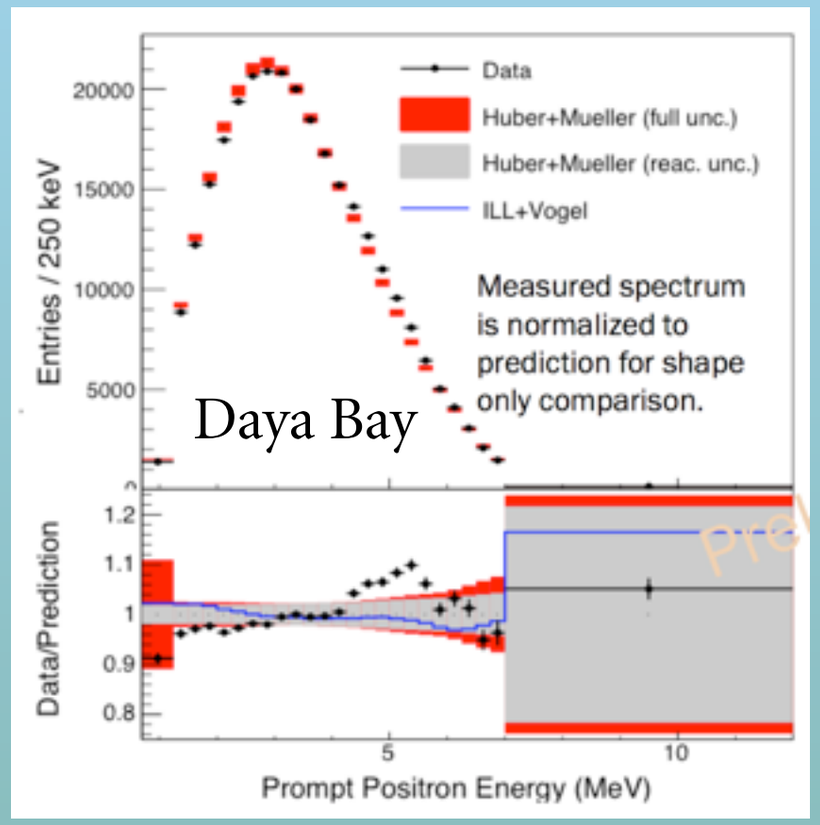
J. Kopp et al., hep/ph:1303.3011

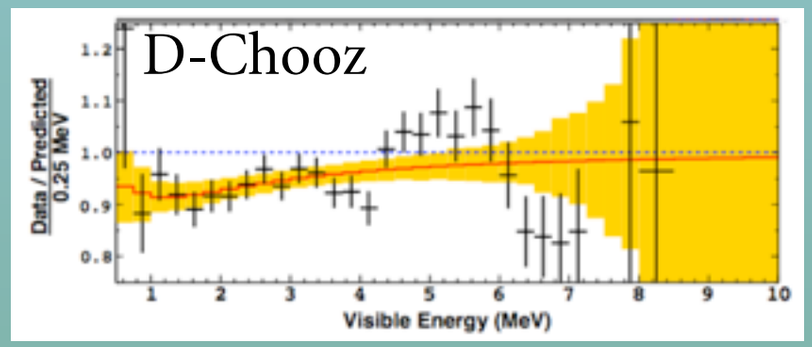
- Combined no oscillation disfavored at more than 99.9% C.L. (3.3σ)
- Two techniques in ν_e disappearance to address this on a short timescale:
  - Large source, large detector experiments
  - very short baseline [5-20] m reactor experiments

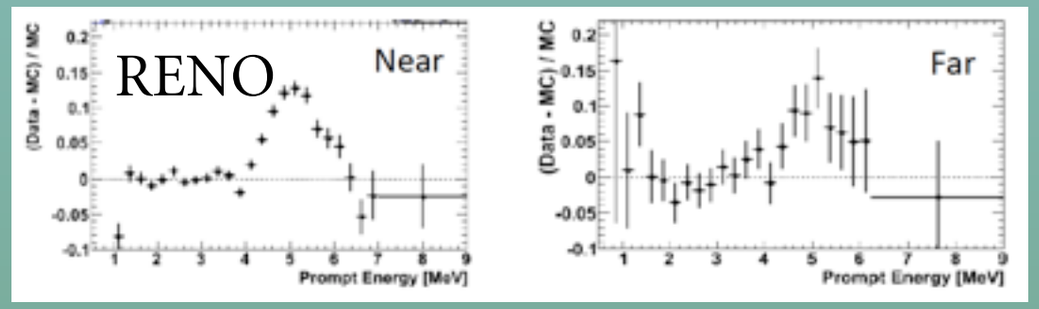
Recent reactor data

$E_\nu \simeq E_{e^+} + m_n - m_p$





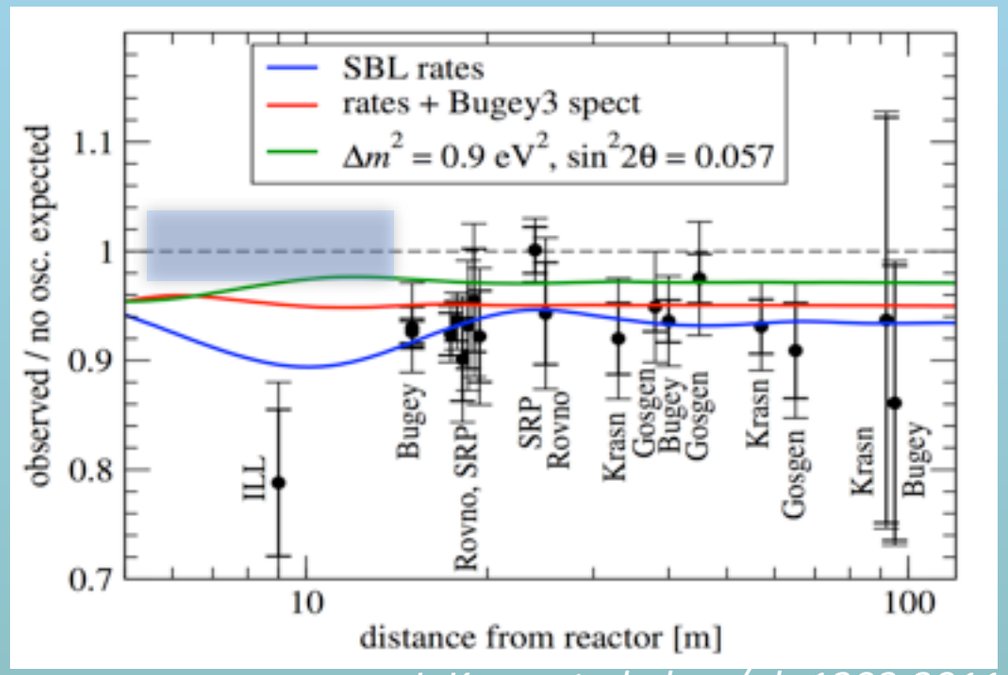




- Total rate measurements compatible with other experiments
  - 2.4σ sigma deficit including Daya Bay nu2014 result
- Deviation in e+ spectrum observed at all three experiments (D-CHOOZ, RENO, Daya Bay)
  - 4σ excess in [4,6] MeV window in Daya Bay data
  - no effect on θ_{13} measurement

New experiment at short distance

- $\Delta m^2 \sim 1\ eV^2 \sim 1\text{-}3$ m oscillation length
  - require compact reactor core
- remeasure at very short distance using two distance measurement ratio
  - no assumption on shape of spectrum
- similar precision to θ_{13} search needed
- challenging above ground / near reactor measurement
  - large gamma-ray and neutron backgrounds expected



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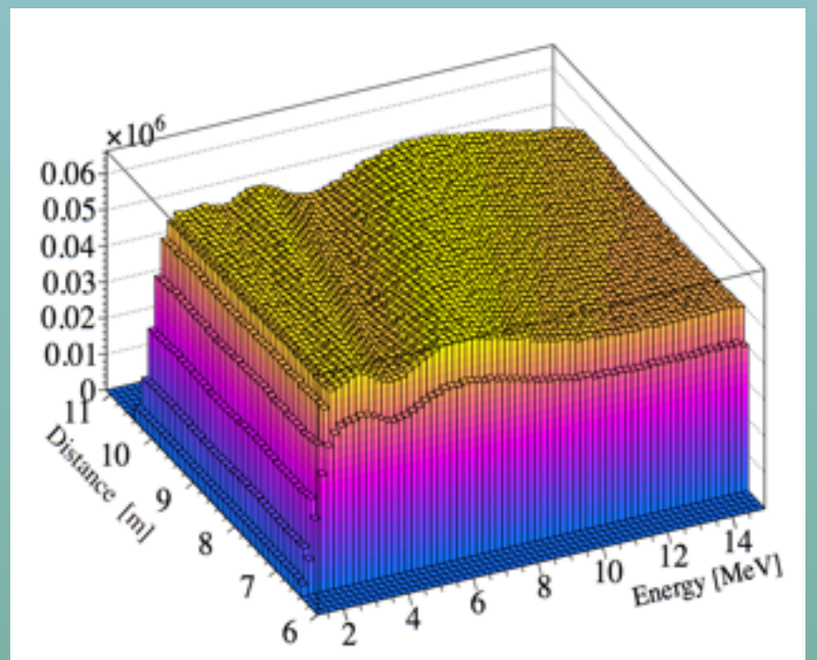
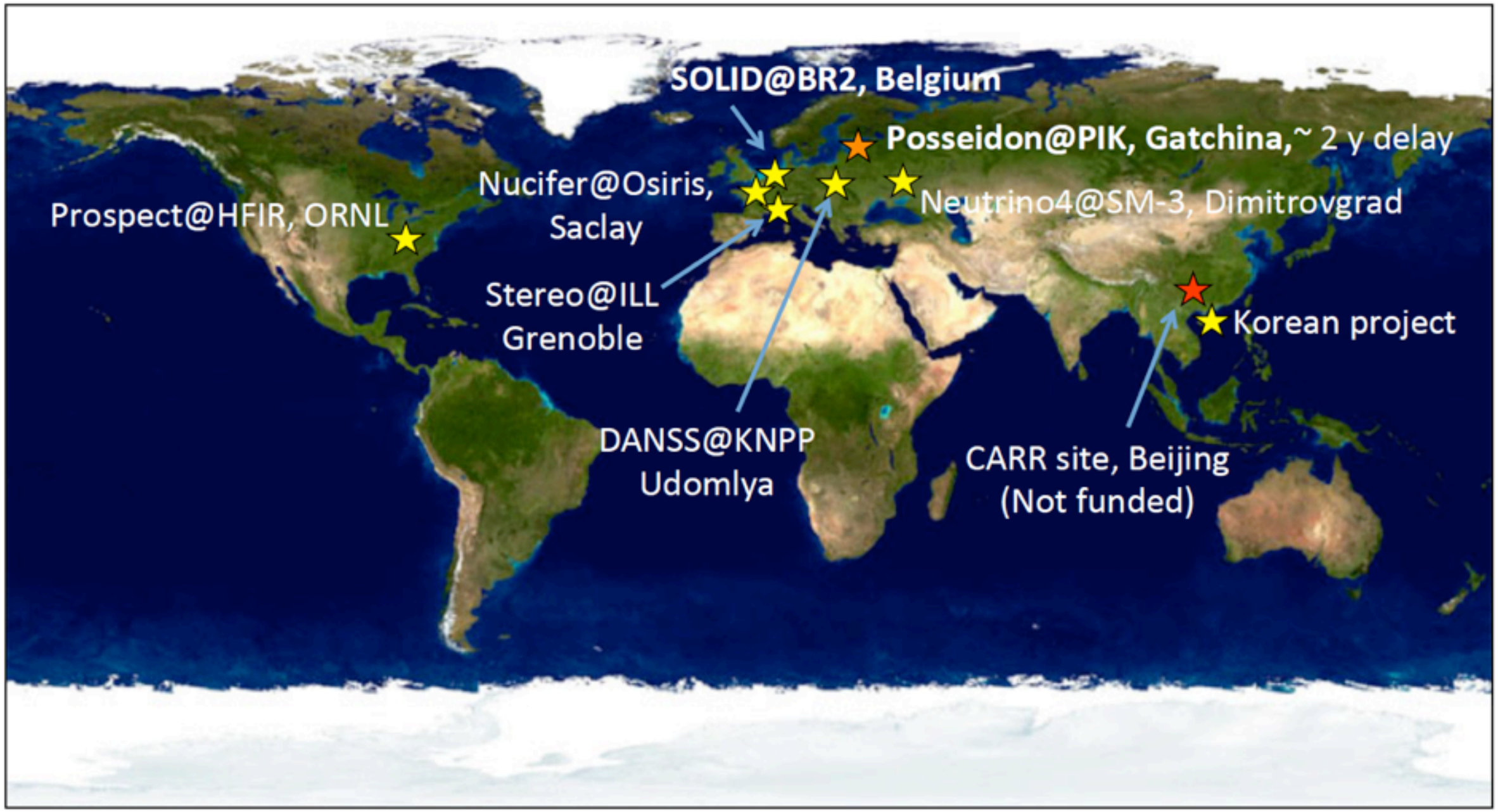


$\Delta m^2 = 2.35\ eV^2$ $\sin^2 2\theta_{ee} = 0.165$

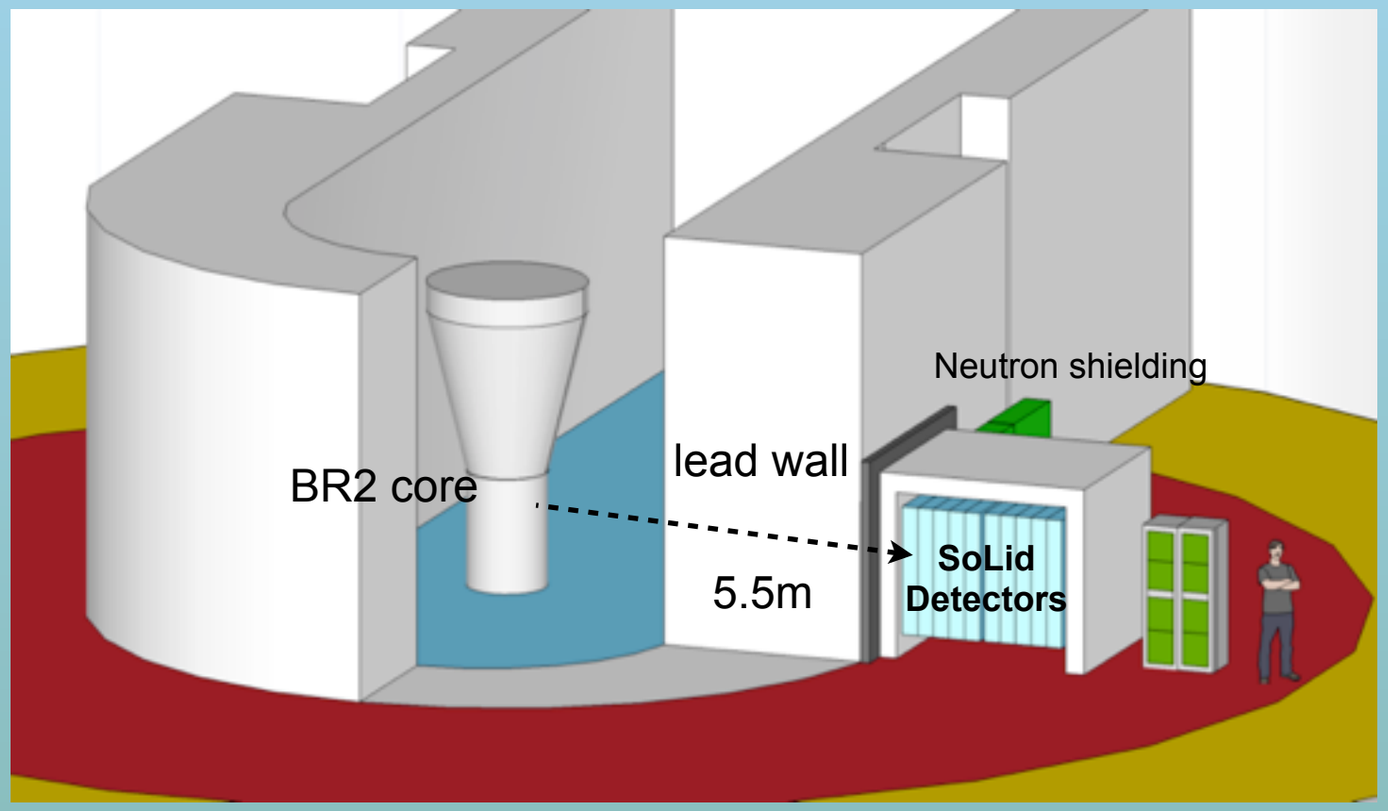
New reactor experiments

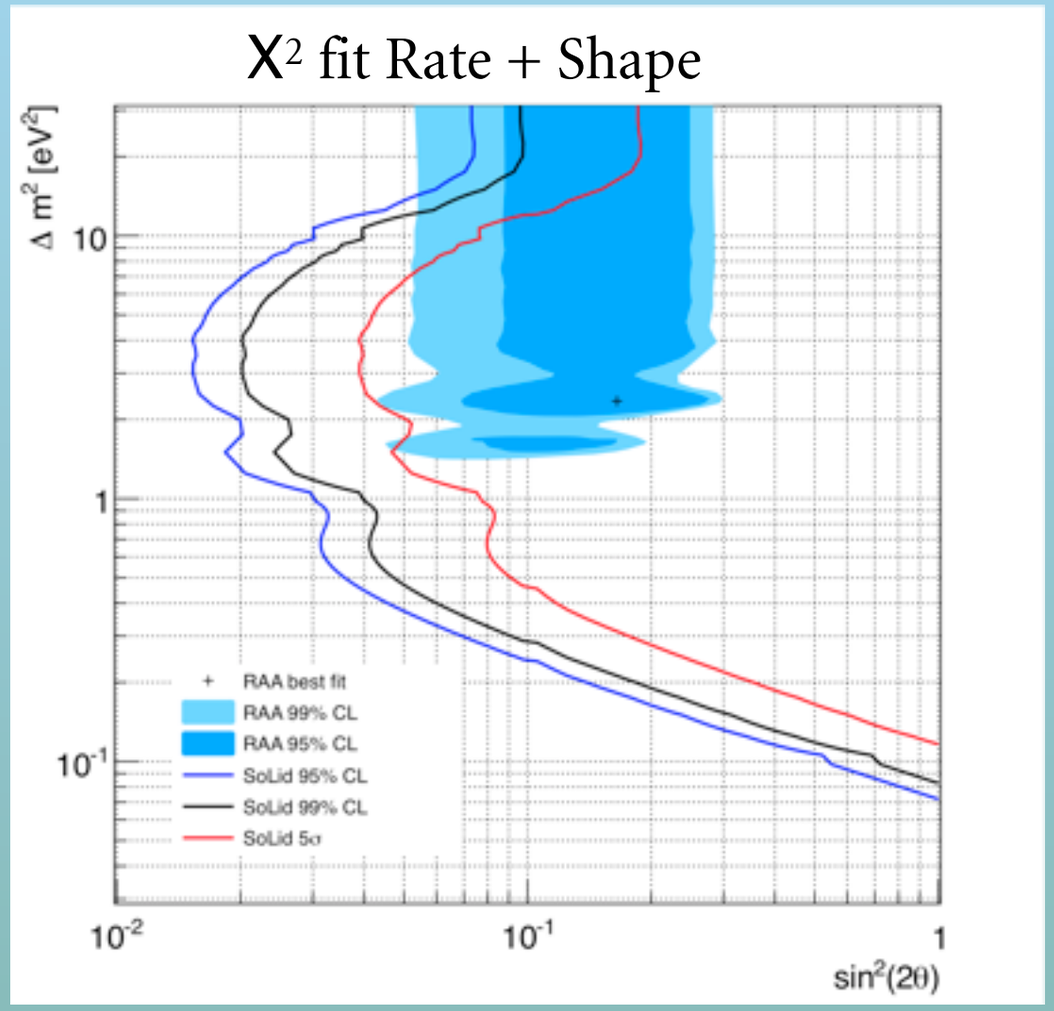


New reactor experiments

	Tech	Reactor	P [MW]	L (m)	M (tonnes)
Nucifer (Fr)	LS+Gd	OSIRIS	70	7	0.8
POSEIDON	LS+Gd	PIK	100	5-8	~3
STEREO (Fr)	LS+Gd	ILL	57	8.8-11.2	1.75
Neutrino-4 (Ru)	LS+Gd	SM3	100	6-12	1.5
PROSPECT (US)	LS + Gd/^{6}Li	ORNL HFIR	85	7-18	1 & 10
SoLid (UK/B/Fr)	PVT + ^{6}LiF:ZnS	SCK•CEN BR2	45-80	5.5-11	1.44/2.88
DANSS (Ru)	PS + Gd	KNPP	3000	9.7-12.2	0.9
Hanaro (KO)	PS + Gd/^{6}Li	Hanaro/ Younggwang	30-2800	6-?	~1

SoLid experiment overview





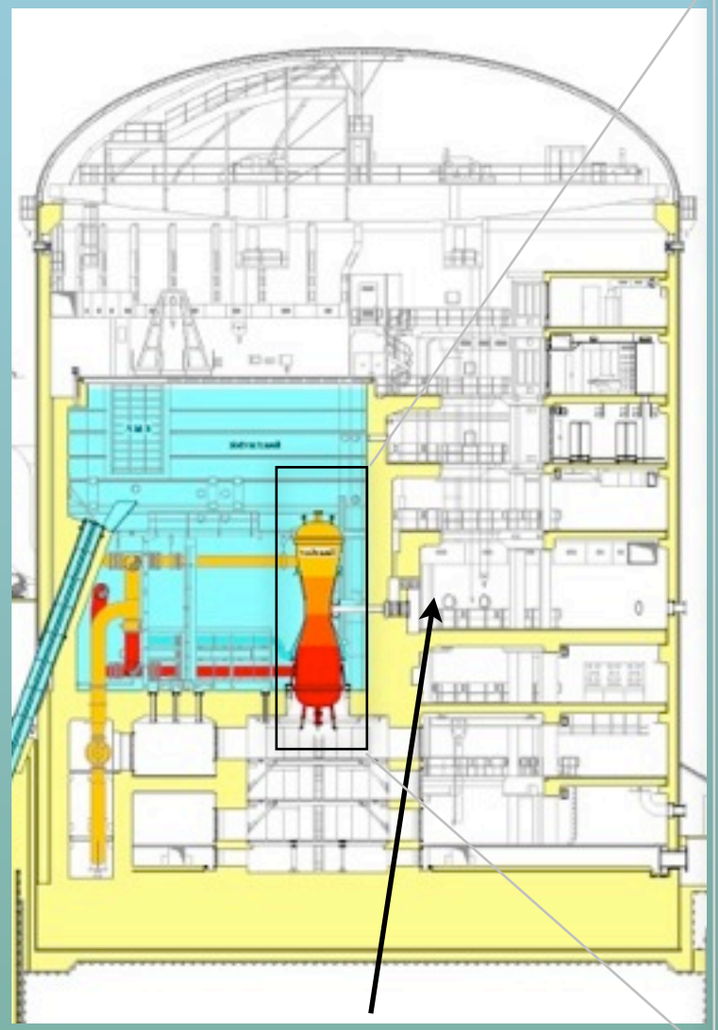
- Source: SCK-CEN BR2 MTR reactor
  - 45-70 MWth power, 150 days/year
  - Relatively low level of reactor background
- Baseline L = 5.5-11 m
- 2.88 tonnes fiducial mass
- Modest passive shielding
- Data taking in early 2016

- IBD efficiency 41% (416ν/day/tonne)
- 300 days running at 6.8m baseline
- flux normalisation (4.1%), detector efficiency (2%) systematics and backgrounds (S:B ~ 5-6)
- large bins to account for energy smearing effects

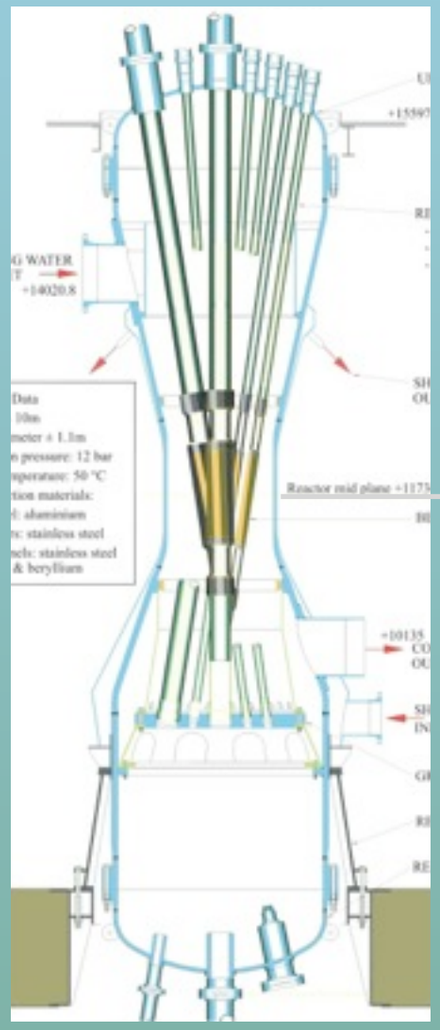
SCK•CEN BR2

- Tank in Pool MTR research reactor
- Licensed to run at power up to 100 MW
  - variable operating power
  - 5/6 cycles per year
  - low reactor backgrounds

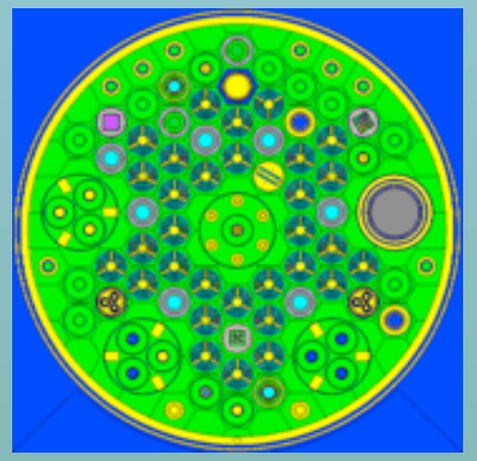
Confinement building



Level 10m67
on axis with reactor



Aluminum pressure Vessel
Twisted core

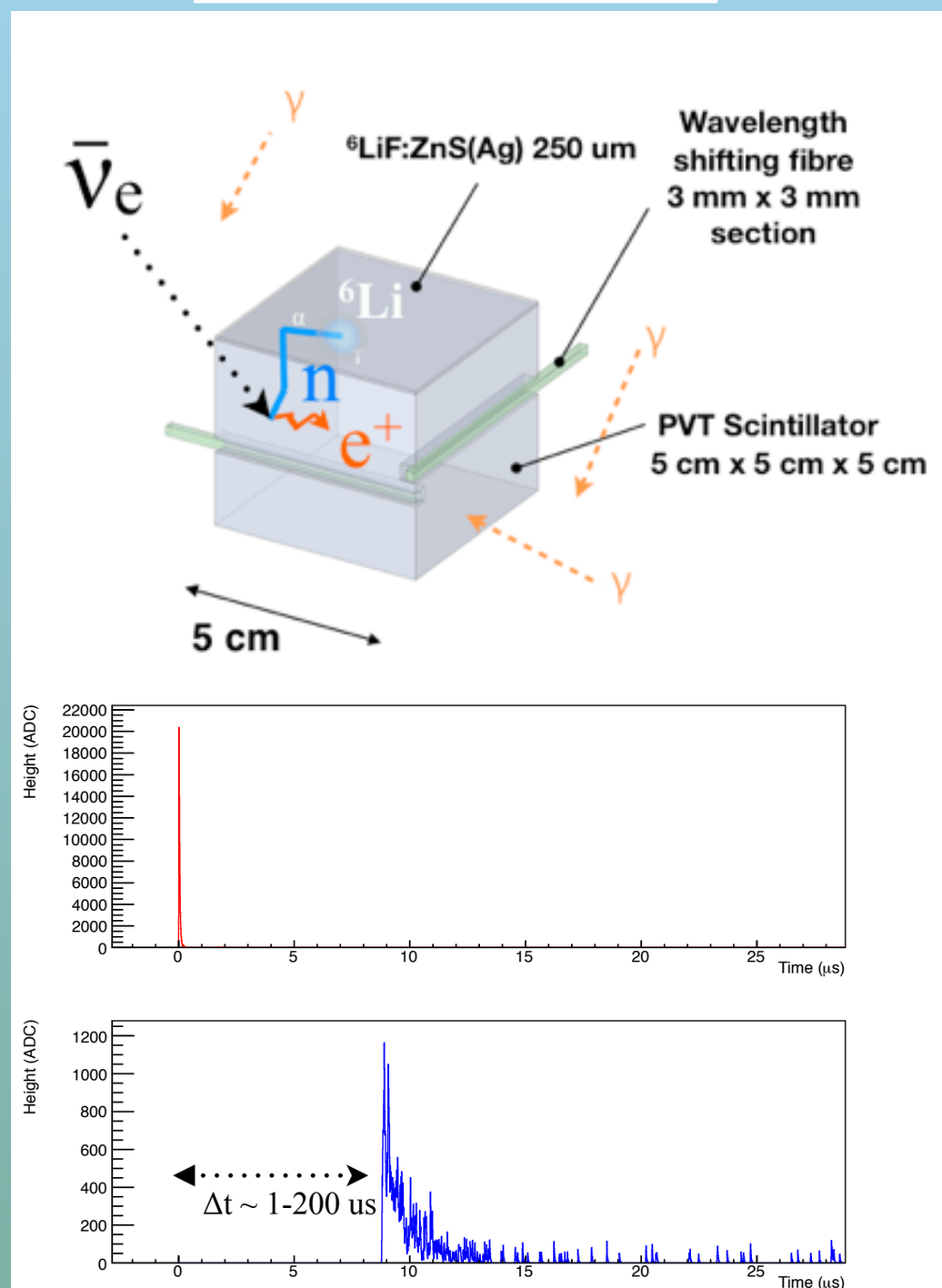


1.0 m

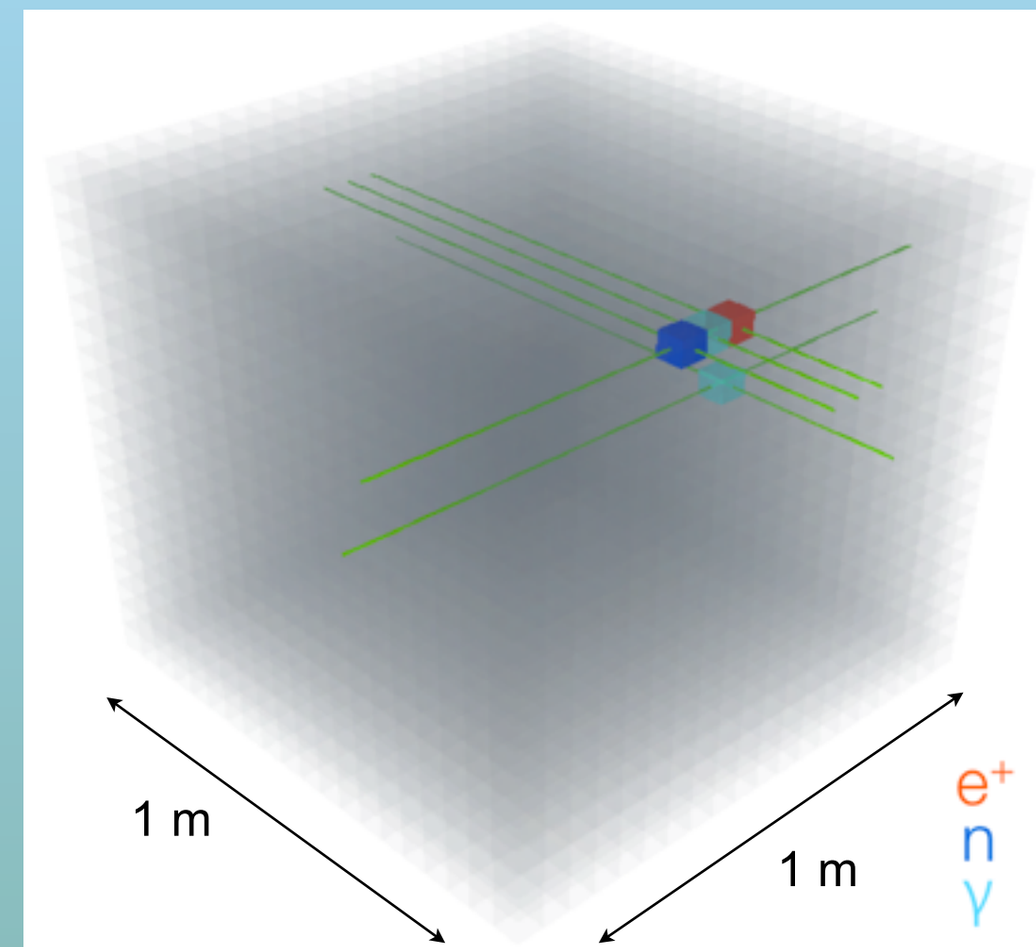
Beryllium matrix
and assemblies

Detector principle

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

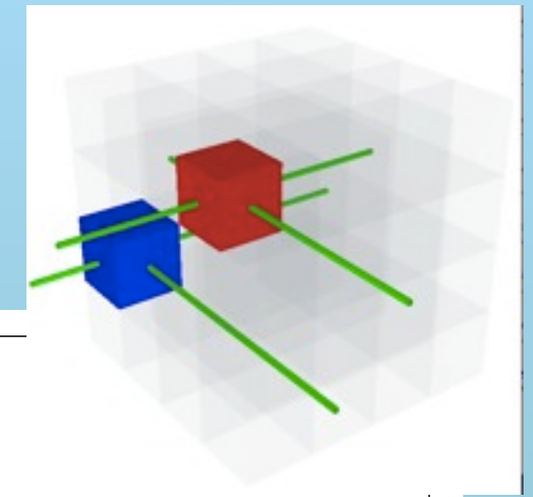


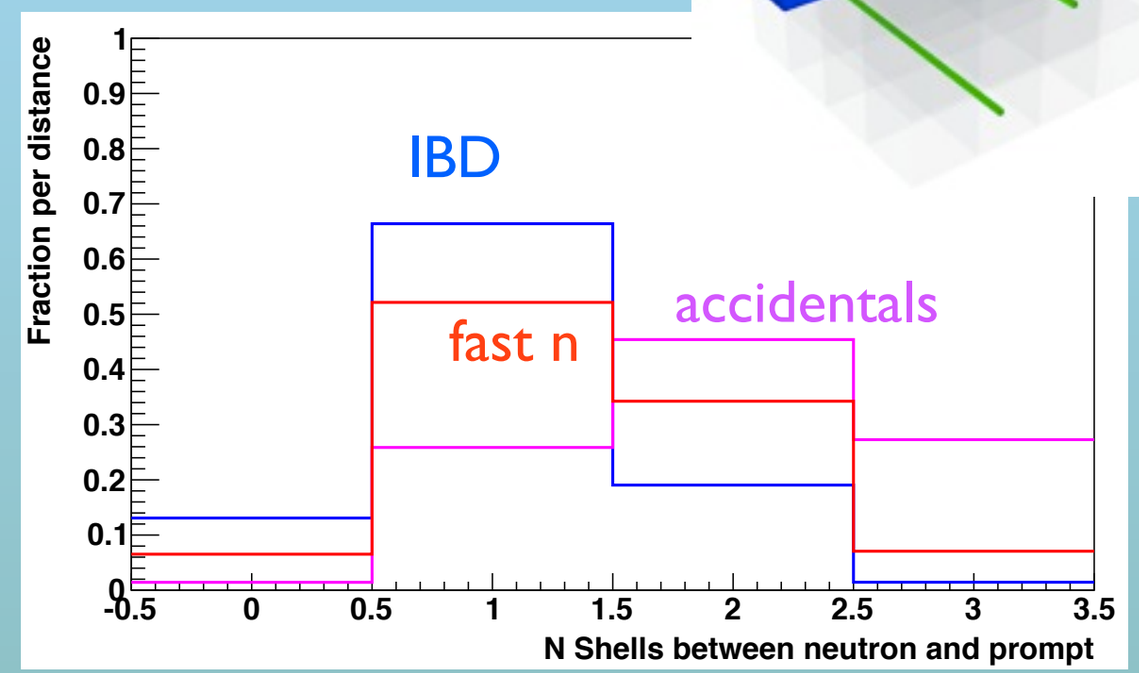
$$^6_3\mathrm{Li} + \mathrm{n} \rightarrow ^2_4\mathrm{He}\ (2.05\ \mathrm{MeV}) + ^1_3\mathrm{T}\ (2.75\ \mathrm{MeV})$$



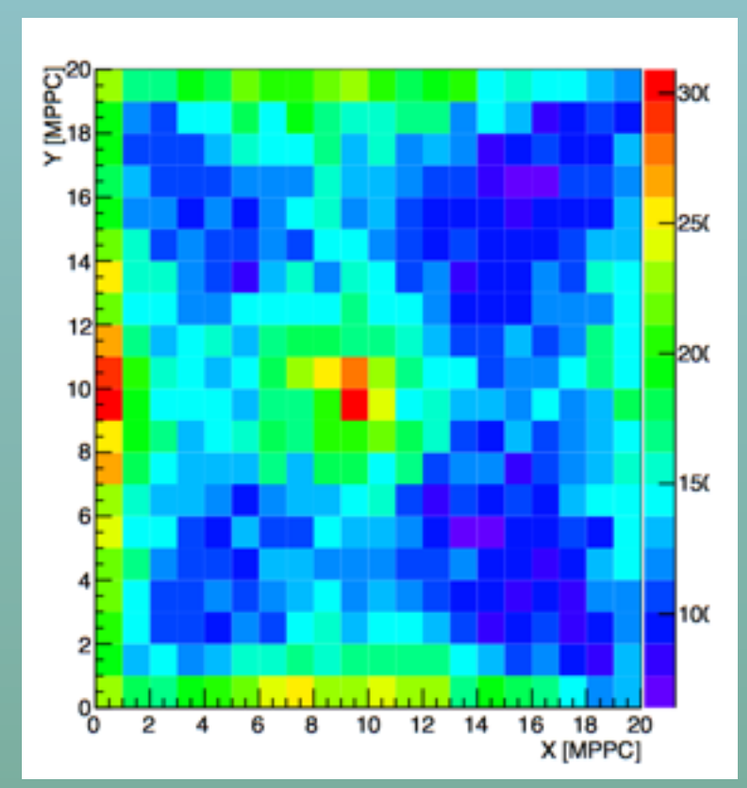
- Neutron / gamma-ray discrimination from pulse
  - distinctive response for prompt and delayed signal
  - neutron used to trigger event read out
- Voxelisation of target volume
  - neutron captured in neighboring cube increasing localisation of IBD event

Advantages



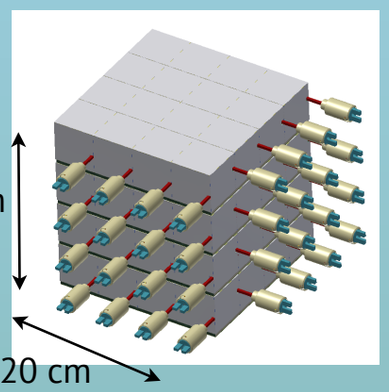


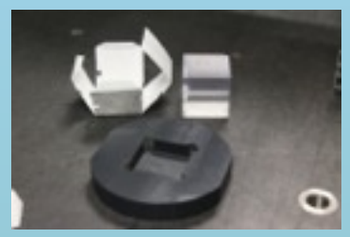
- Use of topology to discriminate between antineutrino events and others
- Flexibility to choose size of target volume selection
  - handle external backgrounds
  - monitor background
- Effective Compton scattering cuts possible
  - further reduction of accidentals

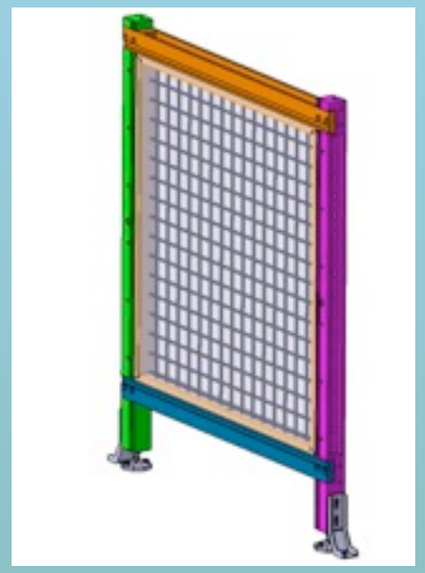


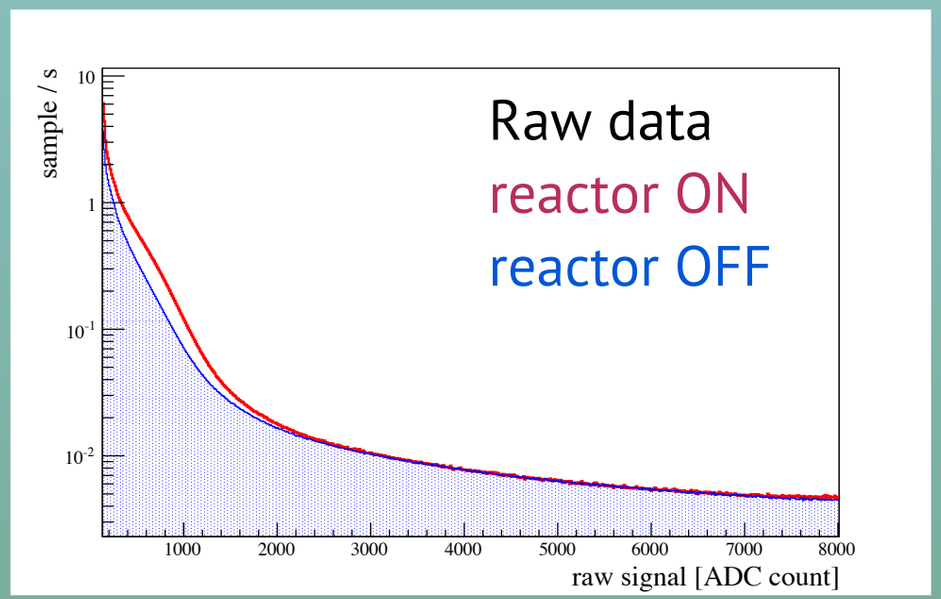
Status of technology

- NEMENIX (8 kg, 64x cubes) prototype upgrade
  new DAQ + muon veto
  demonstrate expected response
  study background rate and IBD analysis
- mars-may 2014 cycles analysis in progess

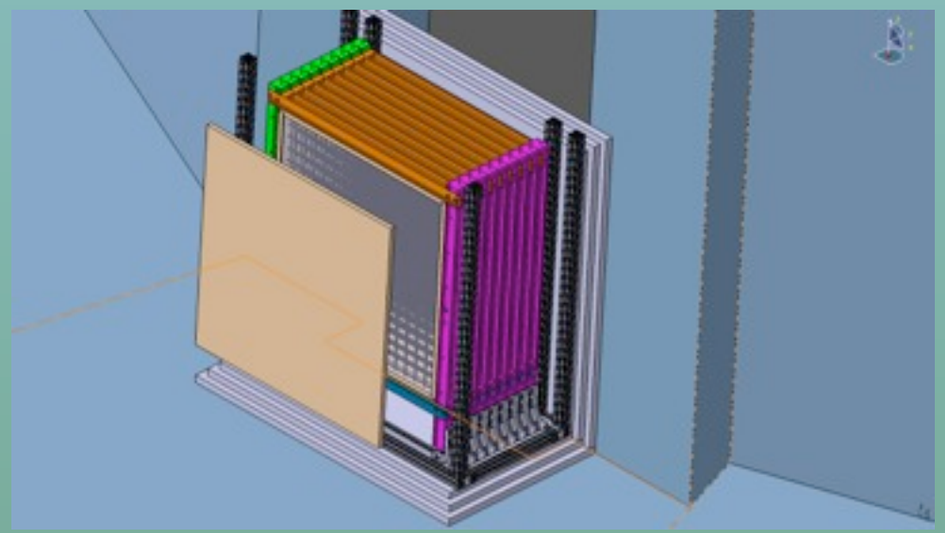




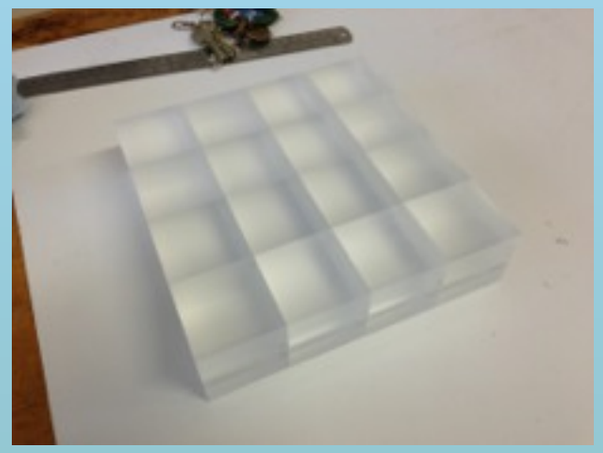


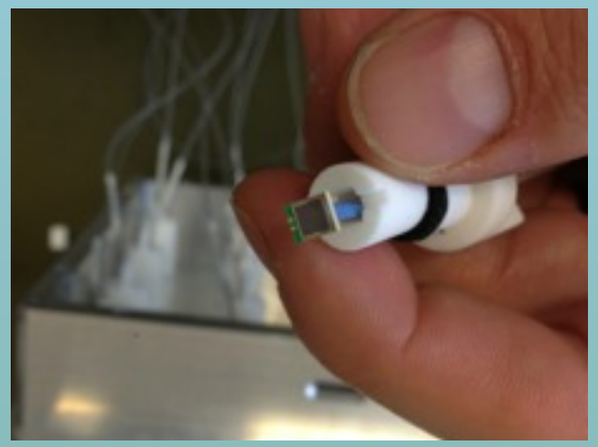


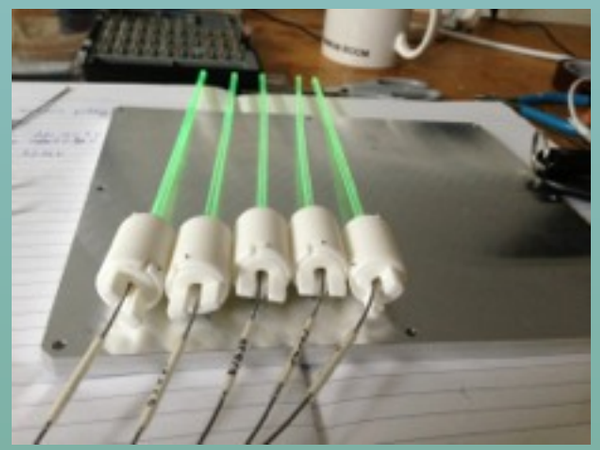
- 288 kg module (2304 cubes) construction started
  (1.2 m H x 1.0 m W x 0.4 m D)
- deployment planned before end of year 2014 at BR2



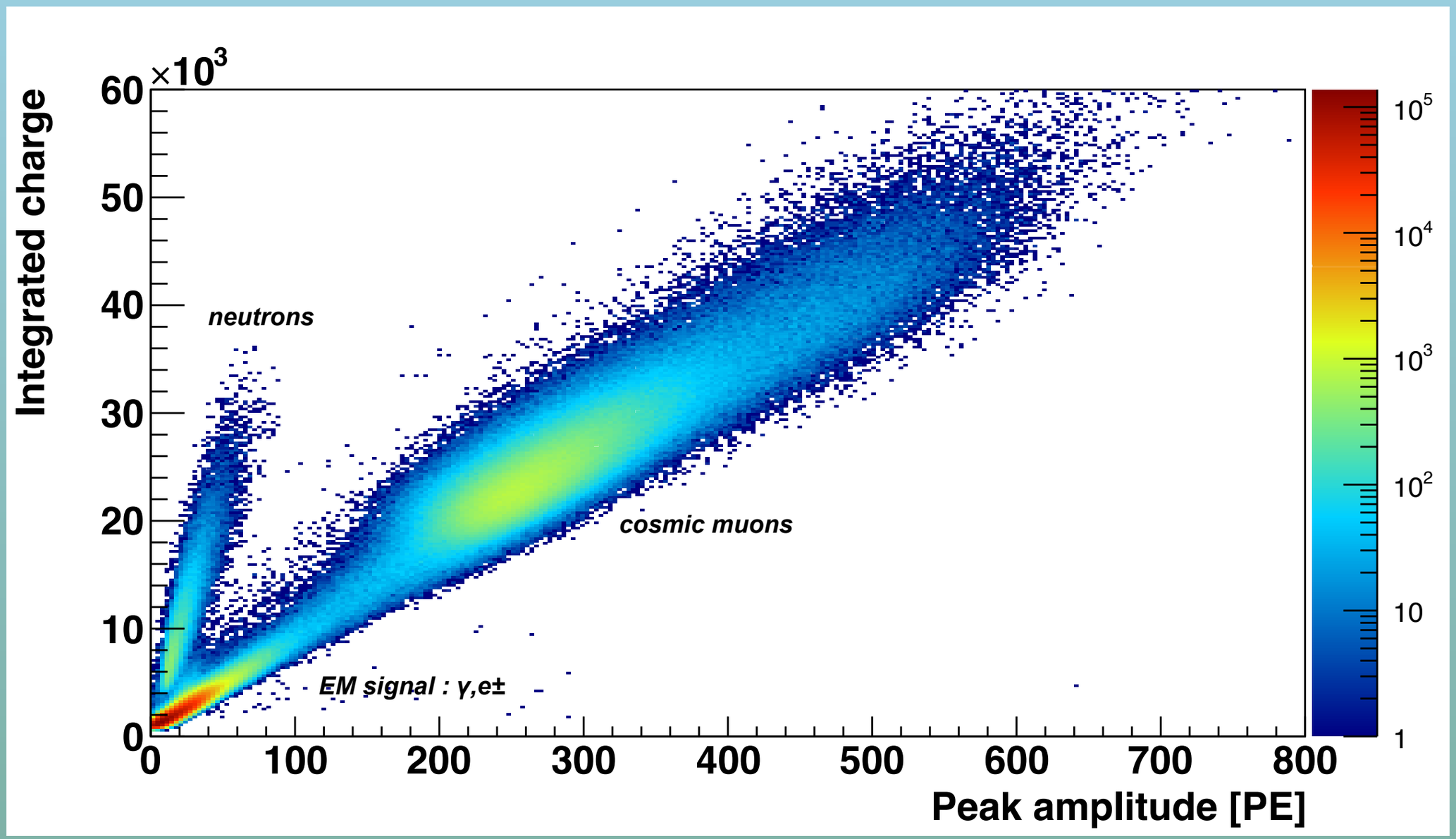
NEMENIX Construction



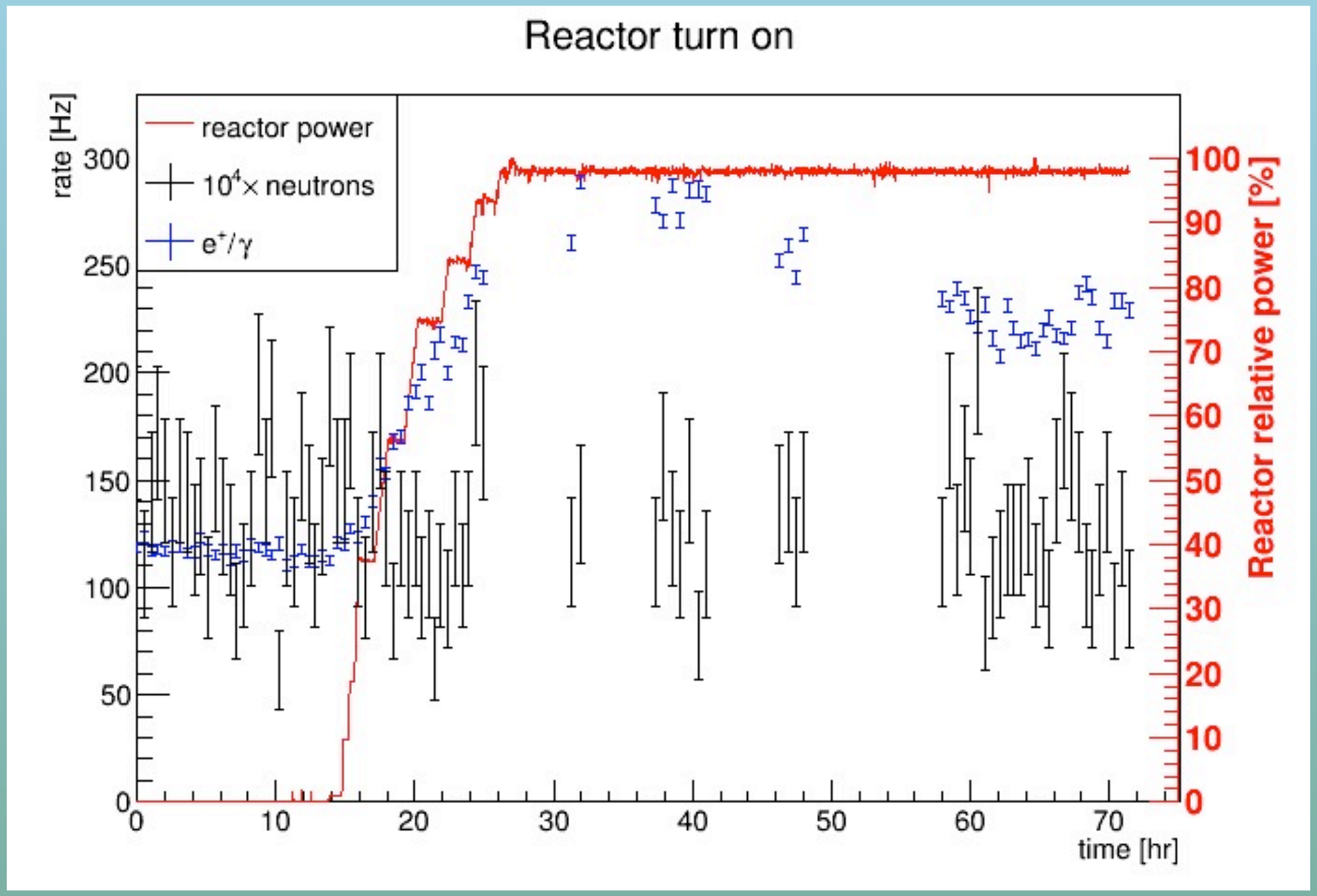




Detector response



Monitoring reactor ramp up



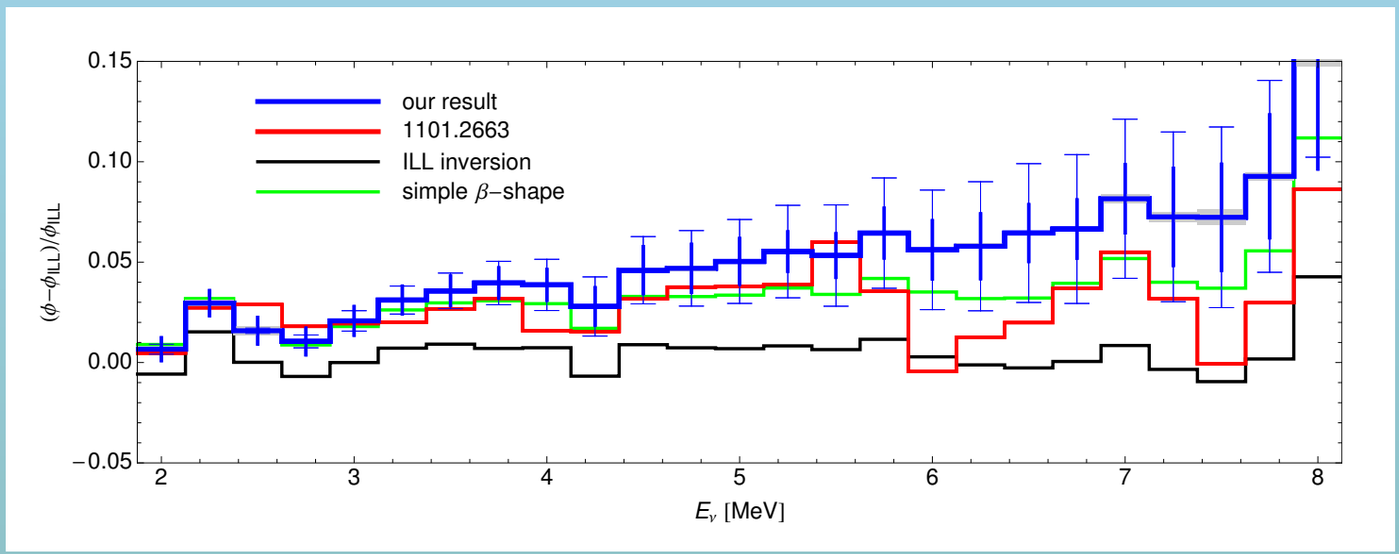
Summary

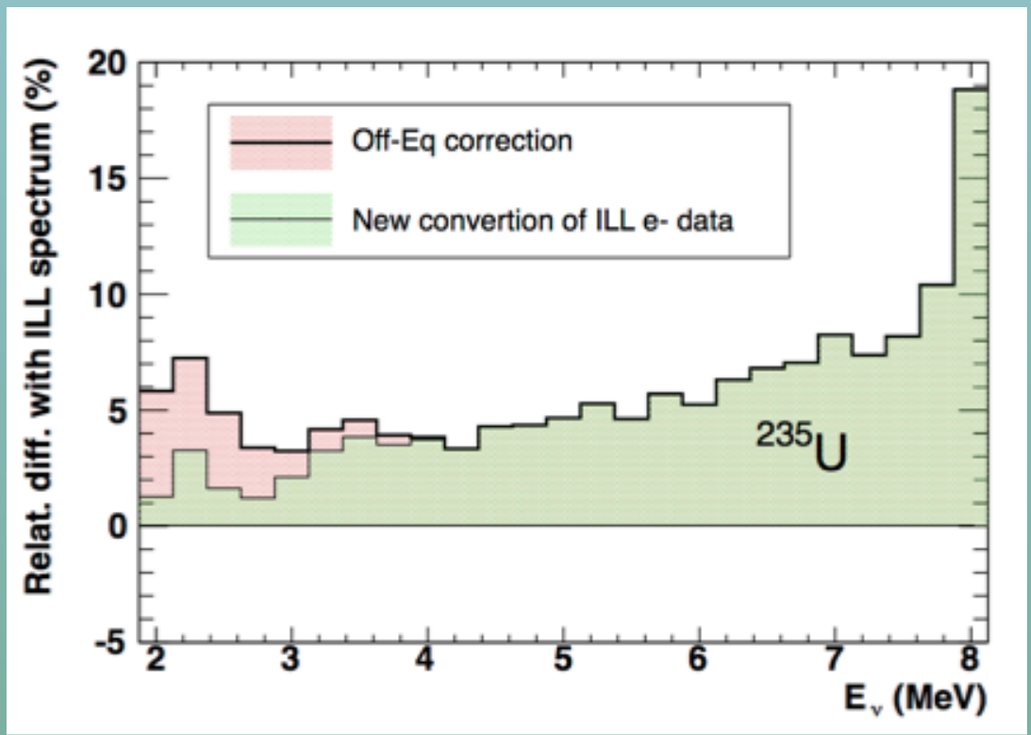
- Recent anomalies in neutrino sector need to be addressed
  - more precise data at very short distance
  - Results from high precision reactor data show interesting features but no obvious hint for explanation yet
- percent level measurement at ~10 m baseline would severely constraint sterile neutrino hypothesis
  - but challenging environment at reactor and above ground
- The SoLid experiment proposes to do a precise measurement using a novel technique and low background site
  - BR2 MTR reactor in Mol, Belgium
  - Voxelisation of target volume with specific signature for neutron
  - use of topology to handle backgrounds
- One of several proposals with planned results as early as 2016 !

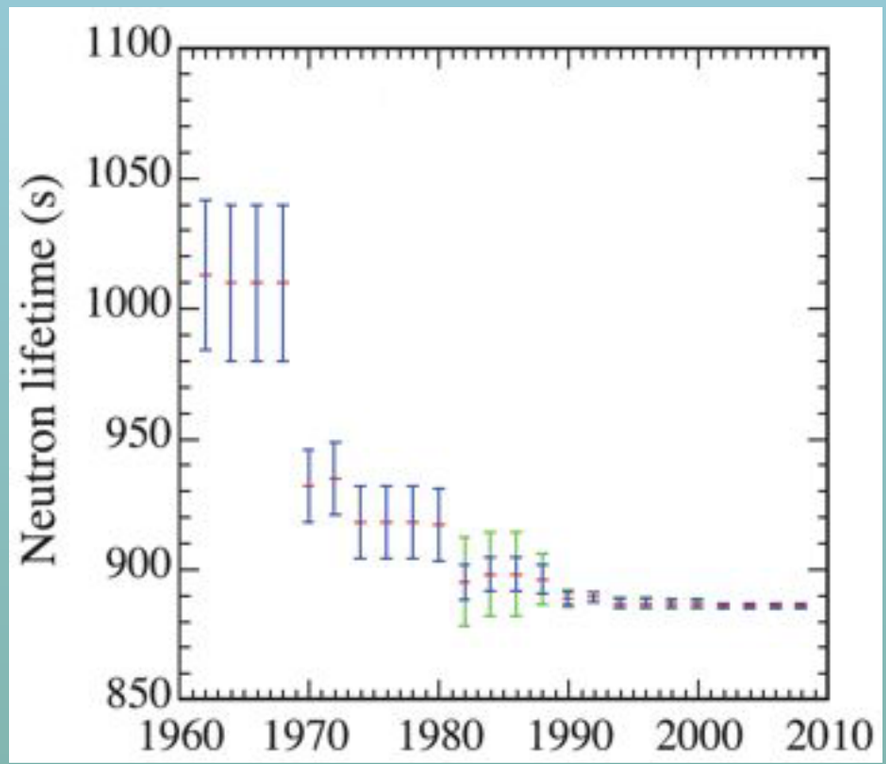
Thank you

Back up

New flux conversion







$$\sigma_{\text{V-A}}(E_\nu) \propto 1/\tau_n$$

SoLid detectors

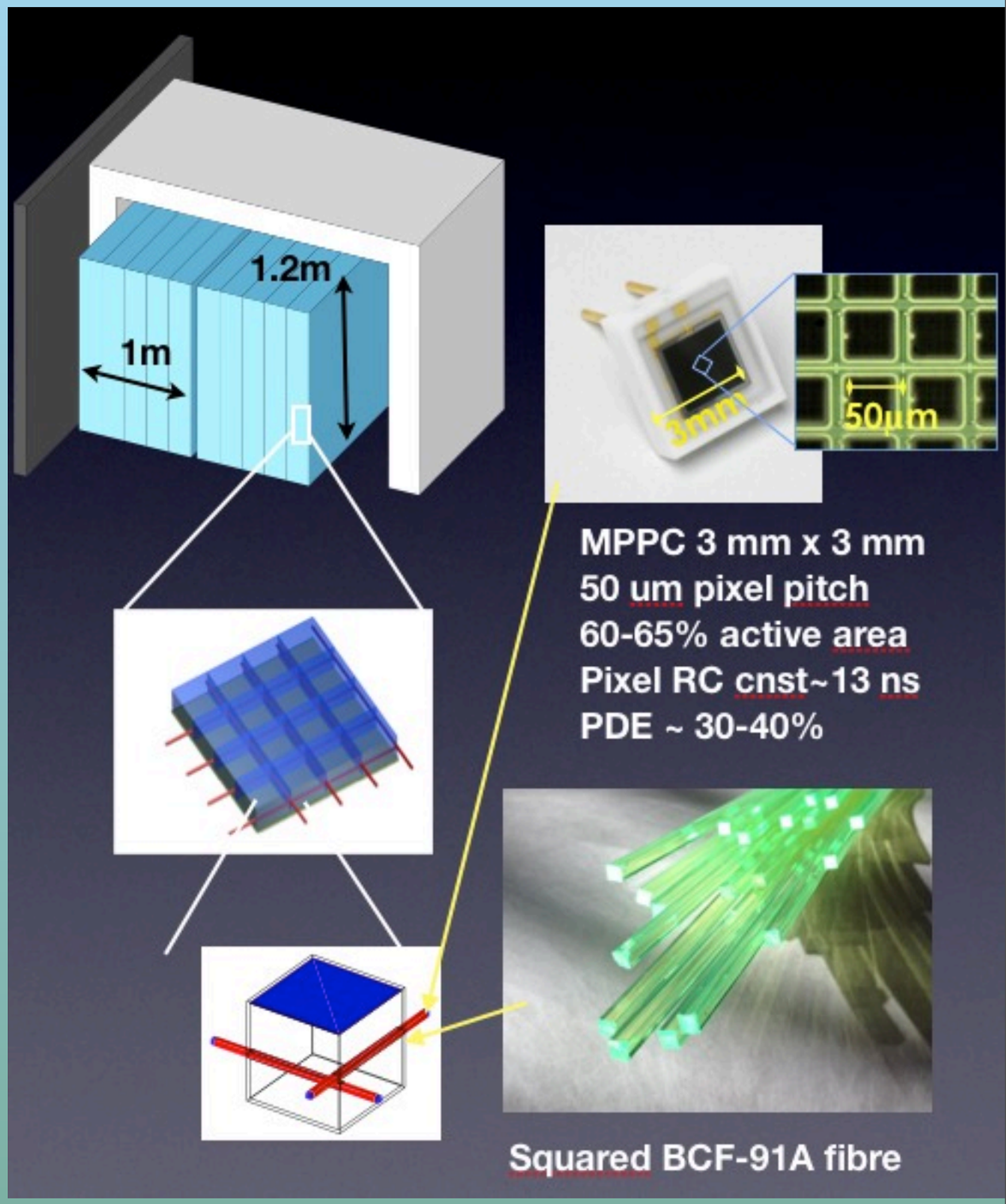
- Based on MARS detector technology (patent)
  - Segmented detector (2.88 t) divided in 10 sub-modules (1.2x1.2x0.2 m^3)

➢ Robust to background, mitigate better background than passive shielding

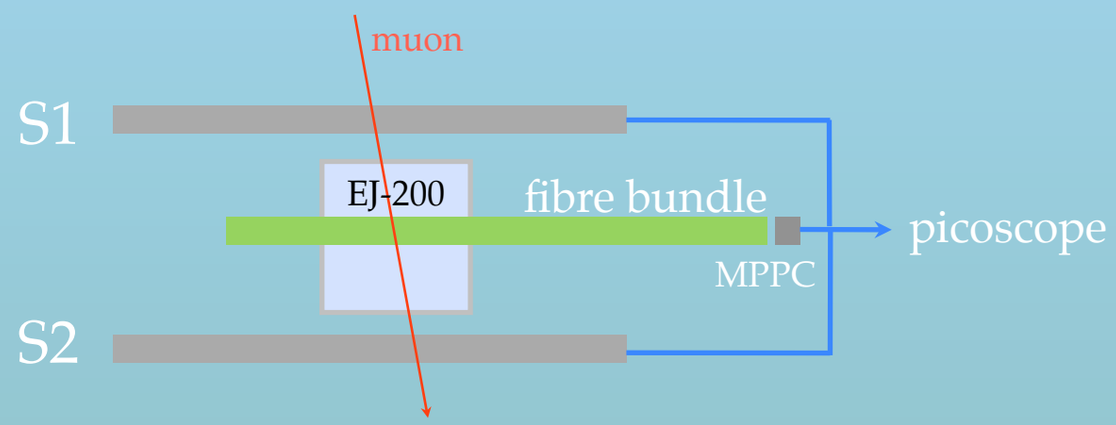
- Detector element :
  - EJ-200 PVT cubes 5 cm x 5 cm x 5 cm
  - 6LiF:ZnS(Ag) screens 5 cm x 5cm x 250um
  - Covered with Tyvec sheets
  - Carbon fibre tray to hold cubes in layer
  - Scintillator light collected by fibre
  - MPPC read out at one end of fibre
  - Detector read on X et Y

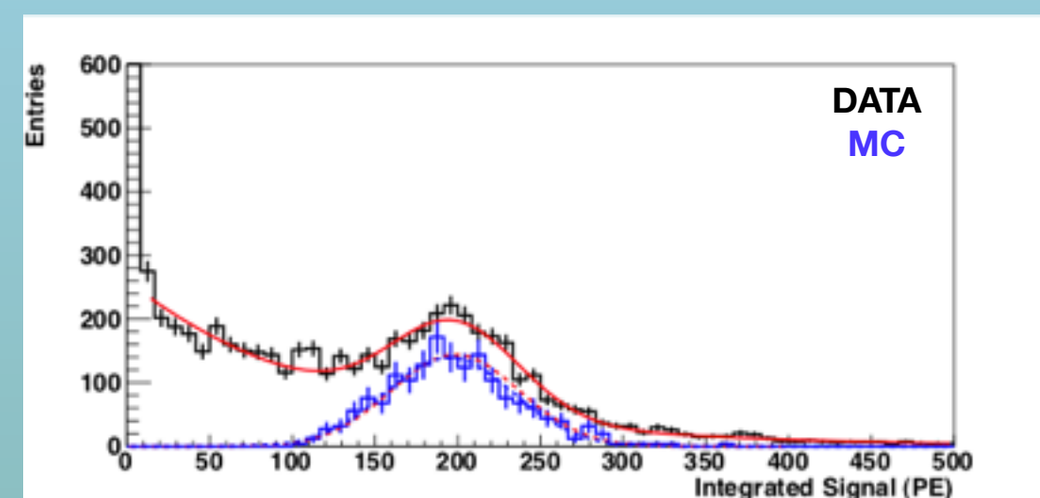
(10 sub-modules = 23040 cubes, 1920 read out channels)

- Electronics developed by Oxford / Bristol / Antwerp

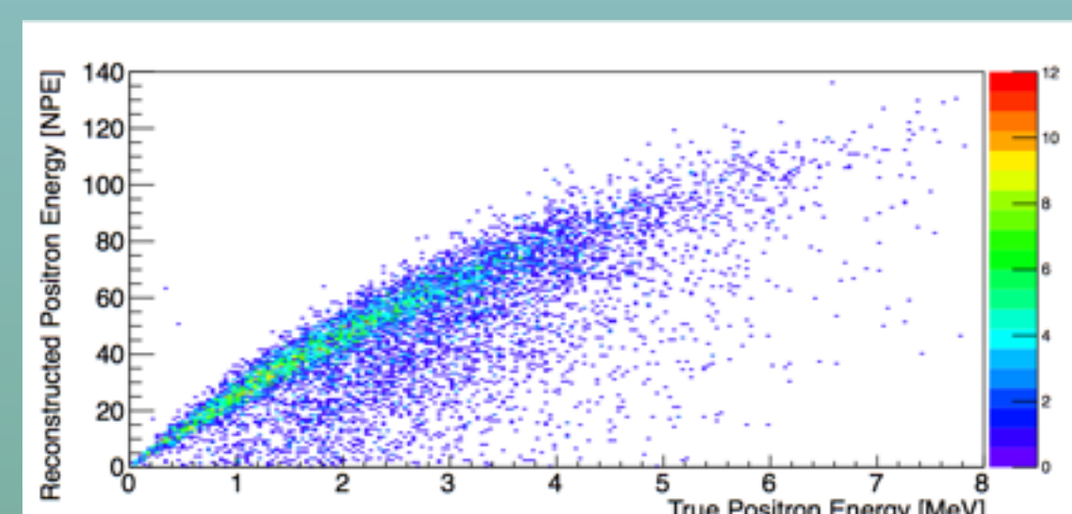


Energy response





- Tested light yield for 5cm cube with 3mm2 MPPC read out using cosmics setup
- Large light yield based on real dimension PVT cubes with BCF-91A fibre and MPPC read out
  - 40-50PE @ 1 MeV (2 MPPC)
  - dE/E ~ 17%
  - Optical model tuned on data
- High IBD reconstruction efficiency
  - Flat in energy both for e^+ and neutron



Correction of MPPC linearity response not included

Backgrounds at BR2

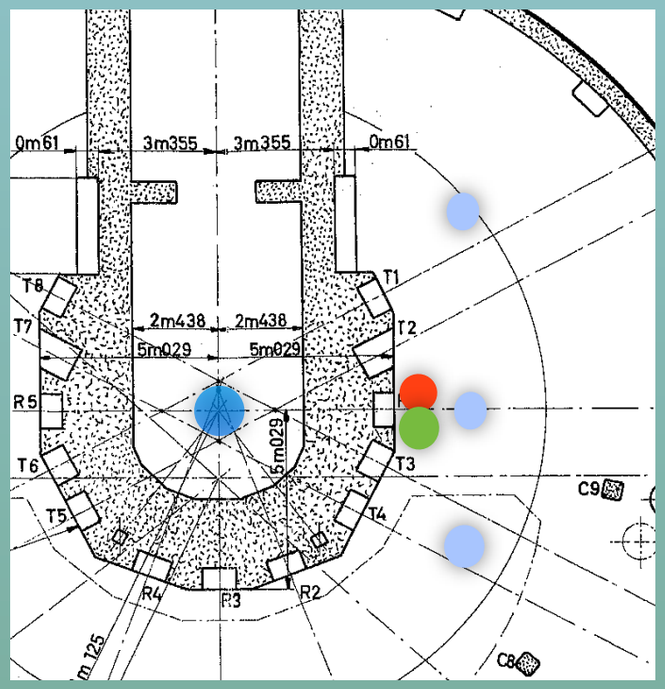
Background rates

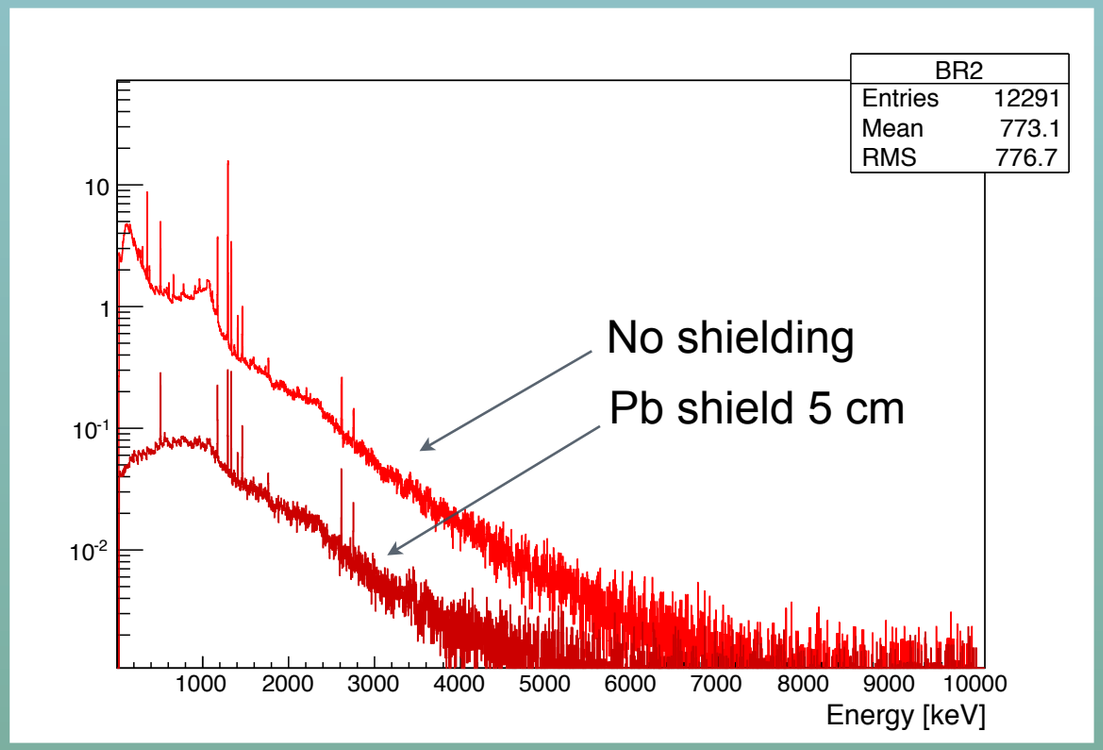
- Neutrons
  - Large system to measure atm neutrons
  - Reactor ON : small neutron counter : Rn < 10^{-5} Hz
- Reactor ON gamma-rays
  - HPGe detector w and w/o shielding
  - Rgam ~ 41 Hz/cm^2 (> 500 KeV) Pb 5cm

BR2 HPGe detector

BR2 portable neutron detector

Oxford Large neutron detector



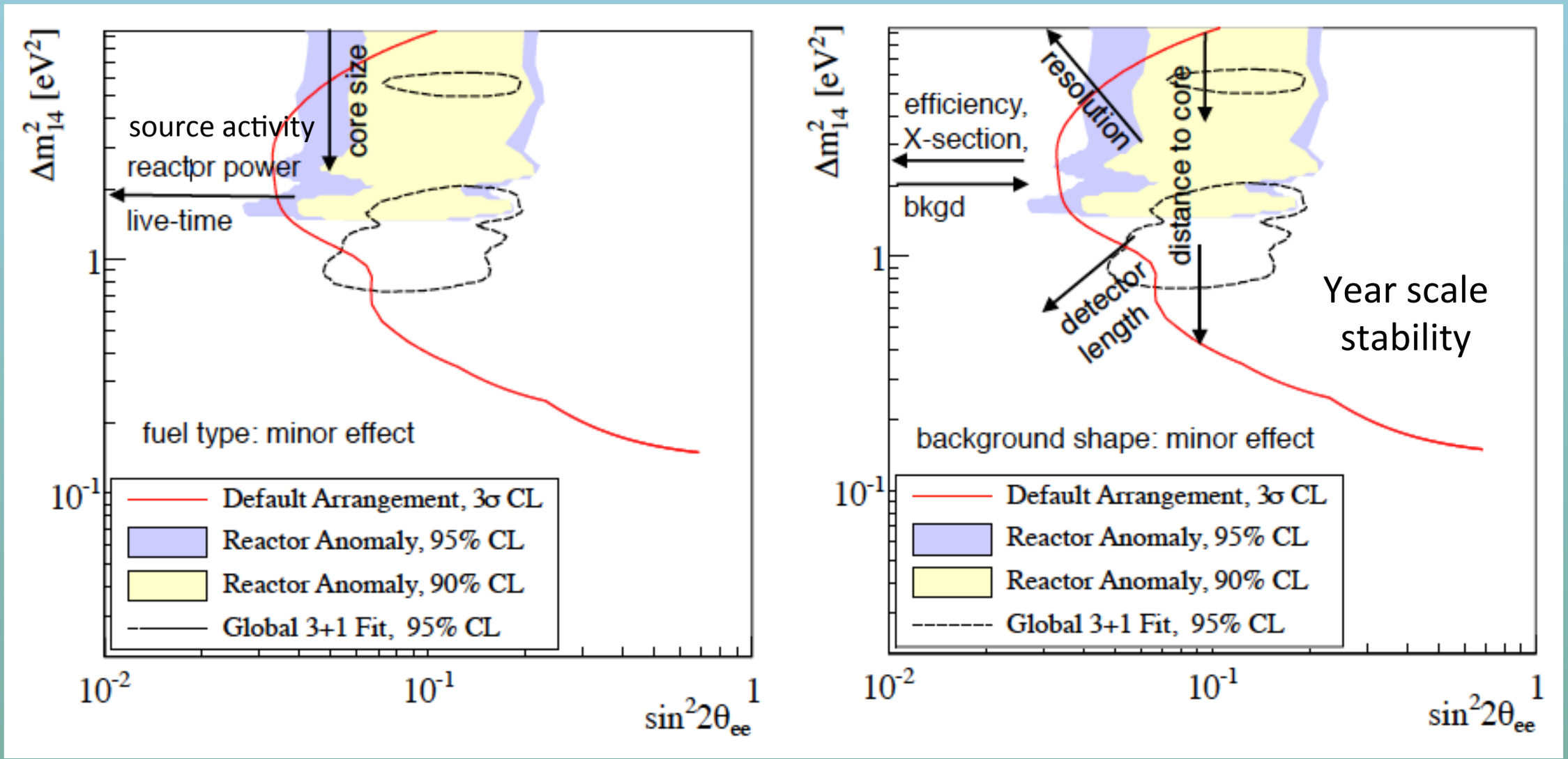


IBD efficiency

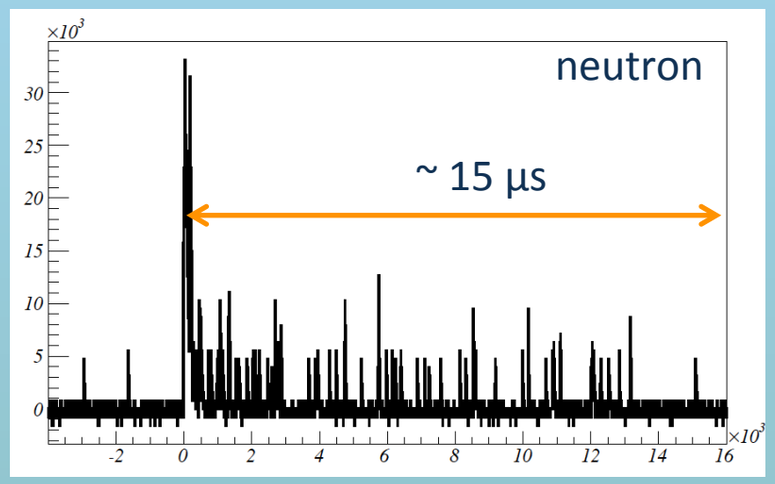
- Simple IBD selection
- Look for a neutron trigger
- apply time cut 300 ns < Δt < 100,000 ns
- Select MPPC pair E > ~600 keV around trigger
- apply position cut (2 cubes max around trigger)

cut	Efficiency
n trigger	0.71
coincidence	0.58
Energy cut (20PE/600keV)	0.48
spatial cut	0.47
multiplicity cut	0.45

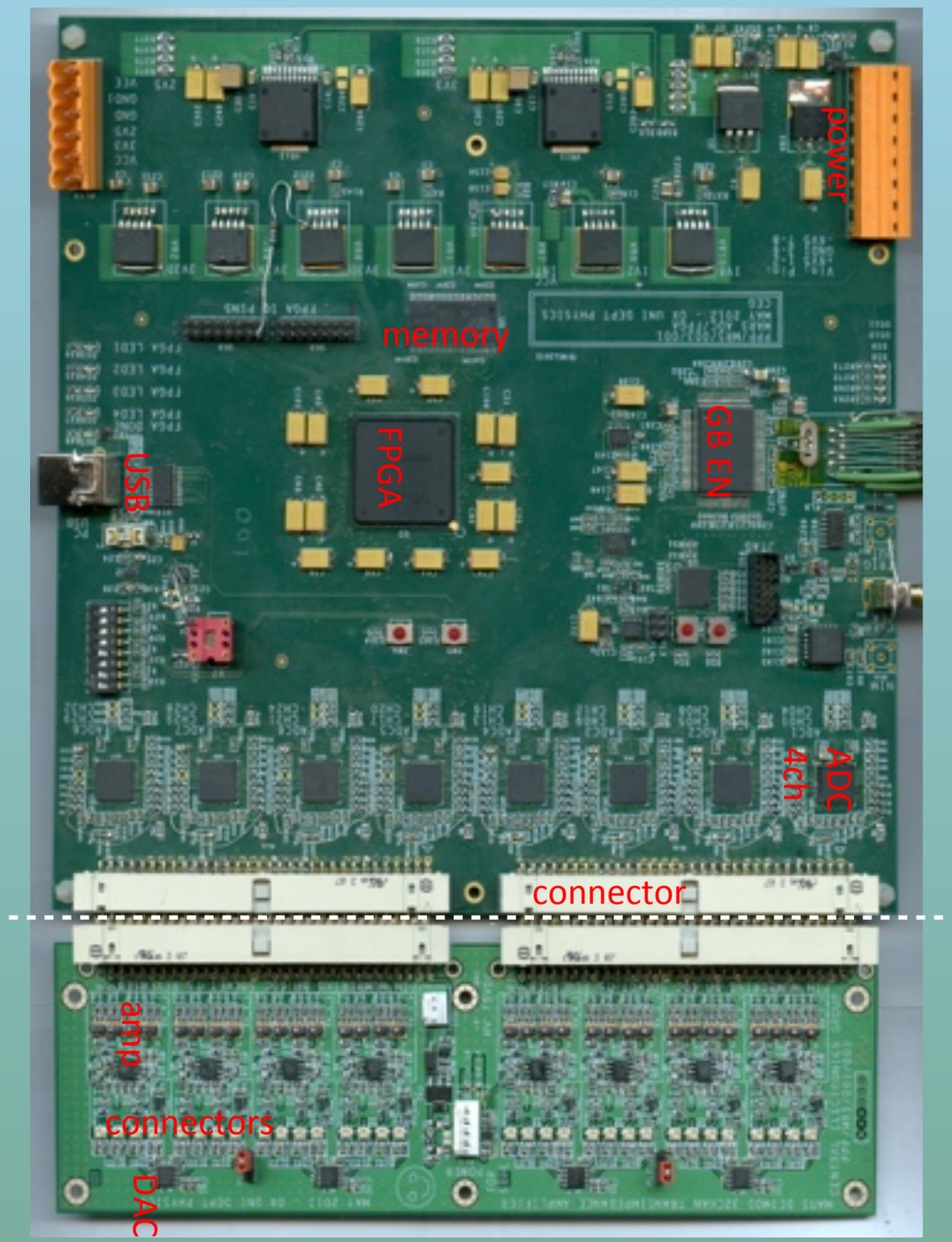
Experimental parameters and



SoLid electronics



First version of Digitiser Board : DPC



- Developed in Oxford / Bristol
- Front-end cards : **DEIMOS 32chan amplifier card**
  - first board produced and under tests
- Back-end card : **DPC 32chan Digital Processing card**
  - fast digitisation : 80MS/s 12bit cADC
    - 200-400 us memory buffer
  - dead-timeless
  - on board digital processing : pedestal suppression, readout threshold, PSD etc..
  - use neutron signal features to trigger on IBD event
  - version 0 of card used to develop basic functionalities