Status of the STEREO experiment : search for a sterile neutrino

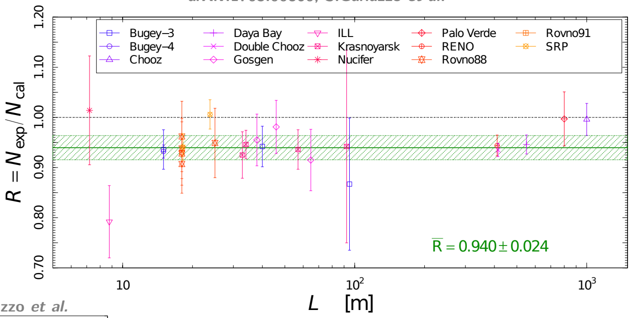
Thomas Salagnac
on behalf of the STEREO collaboration

LPSC, Grenoble

GDR Neutrino 2017

Short distance neutrino anomalies

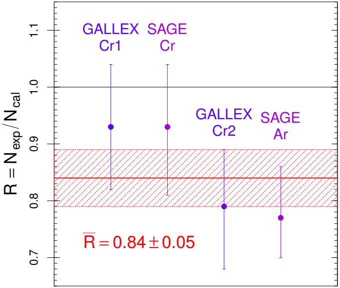
arXiv:1703.00860, S.Gariazzo *et al.*



Reactor antineutrino anomaly (RAA) :

deficit at $3\,\sigma$ in $\overline{\nu}_e$ flux measured by several experiments at different distances from reactors

arXiv:1507.08204, S.Gariazzo *et al.*



"Gallium" anomaly : ν_e deficit at $2.7\,\sigma$

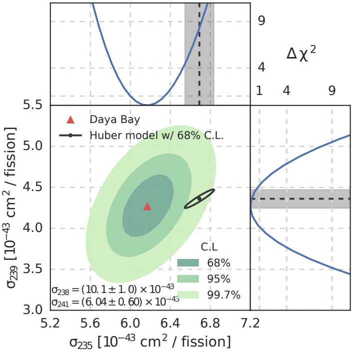
in ν_e counting with calibration sources inside the SAGE and GALLEX solar neutrino detectors

Possible explanations : sterile neutrino vs bias in flux prediction

New ν flavor inducing short distance oscillation : a **light sterile neutrino**

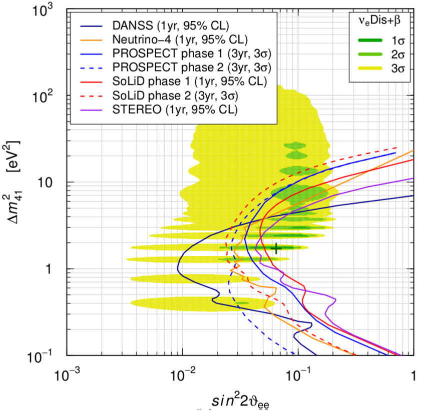
$$P_{e\to e} \simeq 1 - \sin^2(2\theta_{ee}) \times \sin^2\left(1,27 \cdot \frac{\Delta m^2_{41}[eV^2]\cdot L[m]}{E_{\bar{\nu}_e}[MeV]}\right)$$

arXiv:1704.01082, The Daya Bay Collaboration



(see G.Mention talk)

arXiv:1703.00860, S.Gariazzo *et al.*



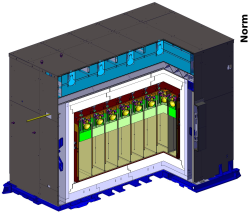
Bias in the predicted reactor $\overline{\nu}_e$ fluxes :

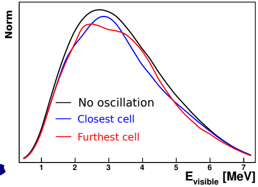
- Spectral distortion (bump around 5 MeV) in θ_{13} experiments shows that $\overline{\nu}_e$ spectra are not perfectly predicted
- Discrepancy between observed and predicted ^{235}U yield by Daya Bay suggests ^{235}U may be the primary contributor of the RAA

1st Objective : Probe sterile neutrino parameter space at the ILL research reactor (Grenoble)

- Measure the distortion of the $\overline{\nu}_e$ spectrum between cells, at [9-11] m from ILL core

Segmented detector

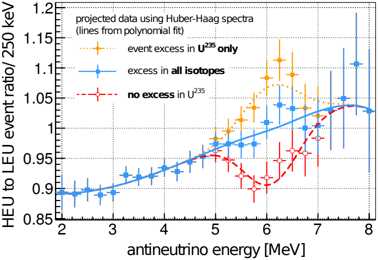


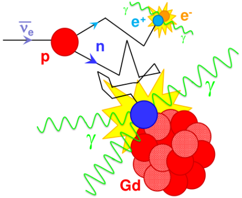


2nd Objective : Improve reactor $\overline{\nu}_e$ spectrum understanding

- Measure a quasi-pure ^{235}U $\overline{\nu}_e$ spectrum

arXiv:1512.06656,J.Haser *et al.*





ν detection via IBD in liquid scintillator : $\overline{\nu}_e + p \rightarrow e^+ + n$

Prompt signal - e^+ thermalization + annihilation

$$\Rightarrow E_{vis}^{\text{Prompt}} = E_\nu - 0.782\,\text{MeV}$$

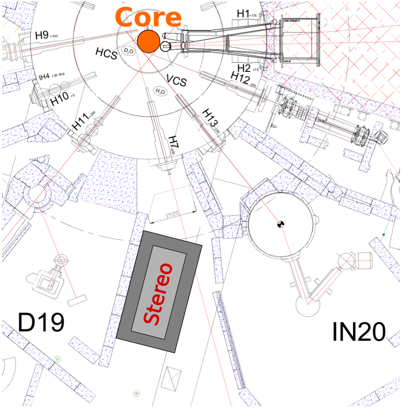
Delayed signal - n-capture on gadolinium (Gd), induce $\sim 3\,\gamma$ emission for a total of 8 MeV, few μs after prompt signal

Reactor :

- Nominal reactor power ∼ 57 MW
- Highly ^{235}U-enriched fuel (93%)
- Compact core (diameter = 37 cm) prevent oscillation signal being washed out

Detector position :

- STEREO detector covers $[8.9 - 11.1]$ m from core
- Overburden of water channel (15 m.w.e.) ⇒ shielding against muons



Drawbacks :

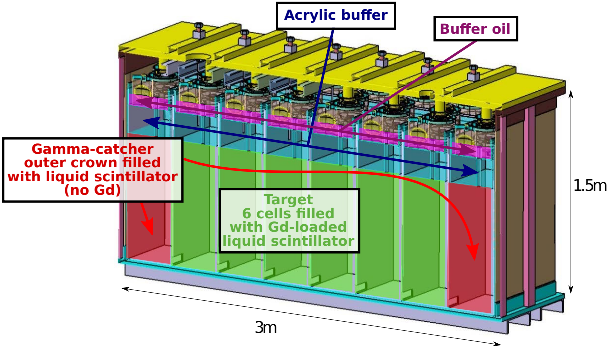
- High level of background $(n,\ \gamma)$ from neighbouring experiments and reactor

STEREO detector

Two sub-volumes : filled with liquid scintillator

Target (for IBD) segmented in 6 identical cells

Gamma-catcher to collect escaping gamma, improve efficiency and energy resolution

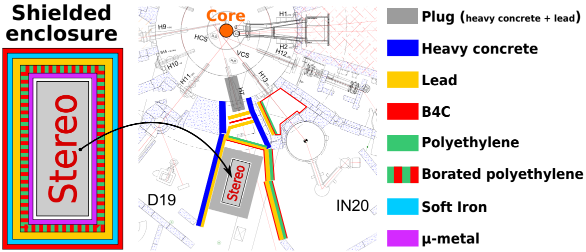


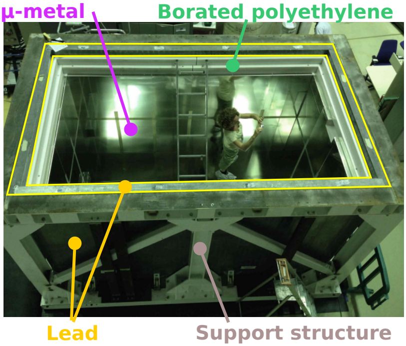
- 48 PMTs : 4 PMTs per Target cell and 4 or 8 PMTs per Gamma-catcher cell

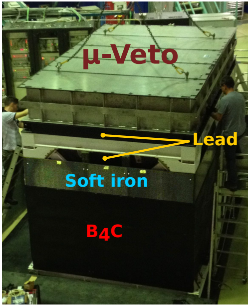
Shielding

Shielded enclosure :

- 6 tons of borated polyethylene
- 65 tons of lead
- B_4C sheets all around the detector structure
- Magnetic shielding (soft iron + μMetal)



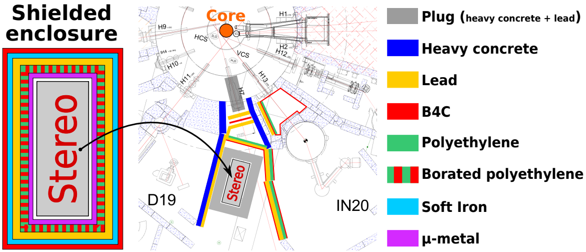


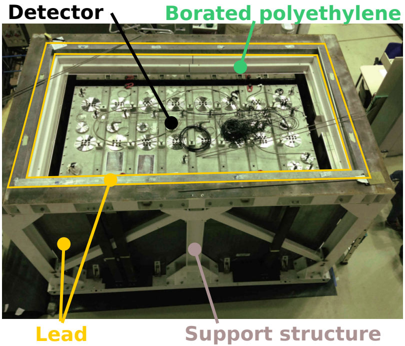


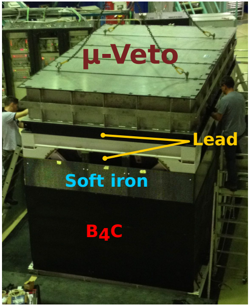
Shielding

Shielded enclosure :

- 6 tons of borated polyethylene
- 65 tons of lead
- B_4C sheets all around the detector structure
- Magnetic shielding (soft iron + μMetal)



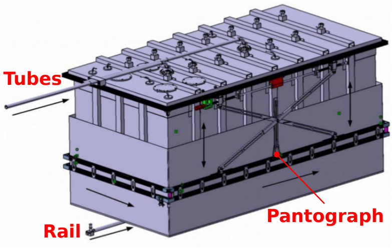




Calibration

Calibration sources :

- Gamma sources (^{54}Mn, ^{60}Co, ...) : energy scale (quenching curve)
- Neutron sources (AmBe, ^{252}Cf) : neutron efficiency, PSD characterization



Calibration systems :

- Tubes to deploy sources inside 3 of the 6 target cells at different heights
- Pantograph to deploy source all around the detector at different heights
- Rail to deploy source underneath

Regular calibration runs : calibration are done regularly to follow coefficient evolutions

- $\times 3$ per week : internal calibration with ^{54}Mn
- Once per week : external calibration with γ and n sources
- every 3 weeks : full calibration campaign with all sources

Between calibrations : LED light injected in the detector at different heights (every hour)

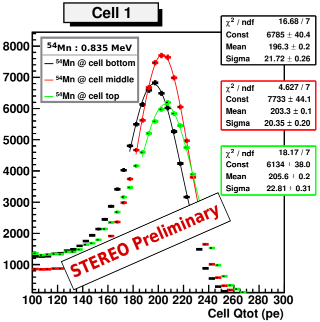
Status

STEREO timeline :

- **Spring-Fall 2016 :** Mounting and installation of the STEREO detector and its shielding
- **9th November 2016 :** ASN approval ⇒ detector filling and commissioning (2 weeks)
- **Winter 2016-2017 :** **Data taking** of 75 days reactor ON + 28 days reactor OFF
- **March 2017 :** Reactor stopped on March 8th (up to October 2017)
  ⇒ **End of the first data acquisition phase on March 12th**
- **March-September 2017 :** STEREO retracted for reactor works, used for detector maintenance

Analysis of first data

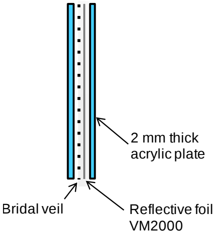
- 95% neutrino data, 5% calibration, negligible losses
- No acquisition dead time with a trigger rate up to few kHz
  $\rightarrow$ low trigger threshold (250 keV)
- Light yield as expected ($\sim$300 PEs/MeV)
- Homogeneity as expected (small top/bottom effect)



Problem encountered :

- Buffer oil leaking in one TG and one GC cell
  $\Rightarrow$ halved light collection in these cells
- Liquid scintillator seeped into the air gap of cell walls
- Cross talk (light leaks) between cells larger than expected, need to deploy a correction procedure

Acrylic wall

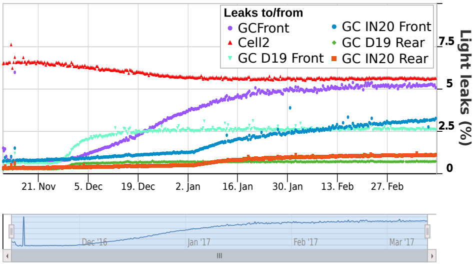


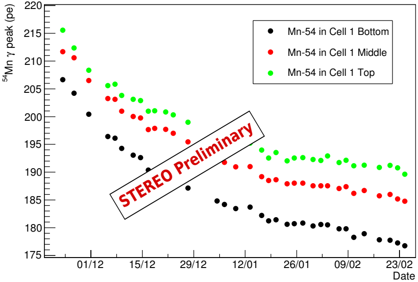
Light leaks

- Light leaks measured and monitored in 2 ways :
  - using vertical muons
  - using ^{54}Mn radioactive source
- Few percent [1%-15%] of light leaks between cells (cell with buffer leak ~30%)
- Light leaks vary with time : buffer leaking, LS slowly seep into the air gap between acrylic plates

  ⇒ Impact on the collected light in cells, need to take into account light leaks in the energy reconstruction

Light leaks from Cell1 To other cells





Energy reconstruction

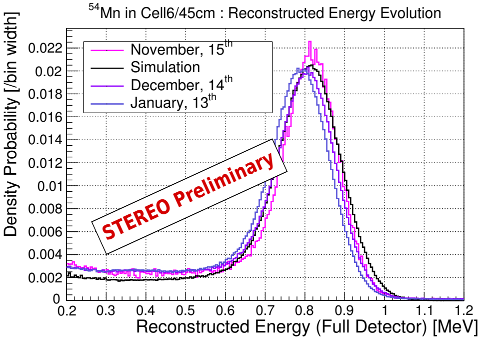
- The charge collected in a cell i is proportional to the light produced in that cell and the light leaks from neighbouring cells j :

$$Q_i = \sum_i E_j^{dep} \times C_j \times L_{ij} = \sum_i E_j^{dep} \; M_{ij}$$

- C_j are the conversion coefficients (PEs/MeV) and L_{ji} are the light leaks. Both are obtained from calibration data as M_{ji}
- Inverting M_{ji} and solving the equation gives the final E_{dep} as a sum of contributions of all cells

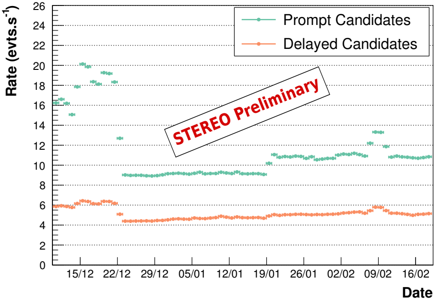
Benefits of E_{dep} :

- Stabilise detector response over time
- Direct comparison Data vs MC
- Use topological cuts (barycenter, dispersion, ...)



IBD candidate search

- **IBD candidates (pairs) :** Search for a coincidence between two signals (prompt, delayed) in a 70μs window
  - Prompt (e^{+} thermalization + annihilation) :
    $2\,\text{MeV} < E^{dep} < 8\,\text{MeV},\ E^{dep}_{GC} < 1.1\,\text{MeV}$
  - Delayed (n-capture) :
    $5\,\text{MeV} < E^{dep} < 10\,\text{MeV},\ E^{dep}_{TG} > 1\,\text{MeV}$

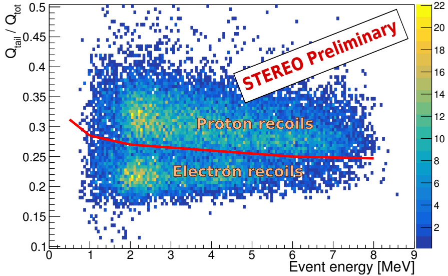


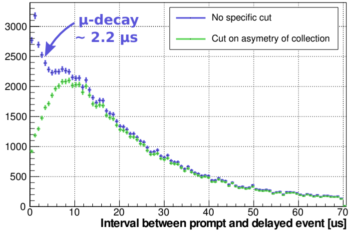
- **Accidentals :**
  - estimated online by shifting the delayed window from 2 ms (repeat n-times to decrease the statistical uncertainty)
  - contribution subtracted to obtain only the correlated contribution

- **Correlated background :**
  - Cosmic origin : measured with reactor OFF, then subtraction ON-OFF

μ-decay : μ-stop (prompt) and Michel-e (delayed)

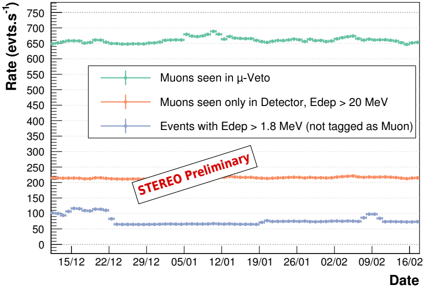
- μ-stops that mimic IBD occur at the cell top near PMTs
  $\Rightarrow$ reject events with strong asymmetry of the collected light in the vertex cell





Fast-n : p-recoil (prompt) + n-capture (delayed)

- PSD cut : separate electronic from proton recoils



Multi-neutrons : n-captures and p-recoils

- Isolation cut : no event above 1.8 MeV (muons excluded) in 100 μs before and after a pair

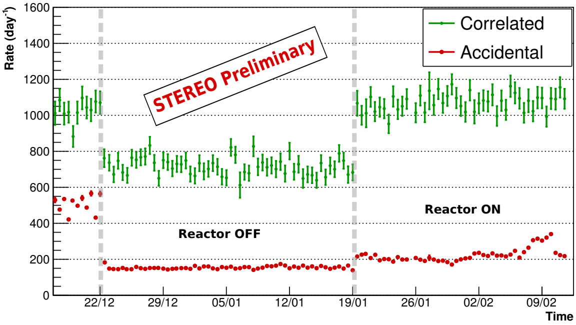
μ-induced background : μ-decay, fast-n, multi-n, ...

- μ-veto cut : 100 μs veto after a muon

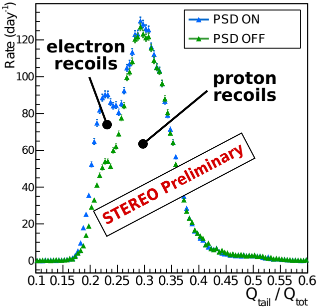
First results : IBD candidates

IBD candidate rates :

corrected from dead time (hard + soft) and atmospheric pressure



IBD candidate prompt signal, PSD ON - OFF :



- Low accidental background level mainly from reactor and neighbouring experiment
- No evidence for fast neutron from reactor inducing pair
  $\Rightarrow$ Shielding meets the specifications
- Remaining background is induced by cosmic rays

Conclusion and perspectives

Achievements :

- STEREO detector collected more than 100 days of data :
  75 days reactor ON + 28 days reactor OFF
- Light yield in agreement with expectation
- Working at low threshold with very small deadtime
- Evolution of detector response required regular calibration and development of dedicated tools to account for cross-talk
- S/B ratio close to specifications

Next steps :

- Work in progress to refine topological cuts and increase S/B
- Currently re-assembling the detector during long reactor shutdown (ends in October 2017)
- Expect more than 100 days of reactor ON by the end of 2017
- Plus $\sim$150 additional days of reactor ON in 2018

Thanks for your attention !

funded by :