Energy calibration in the STEREO experiment

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LAPP-IN2P3

on behalf of the STEREO collaboration

12/06/2018 GDR Neutrino meeting
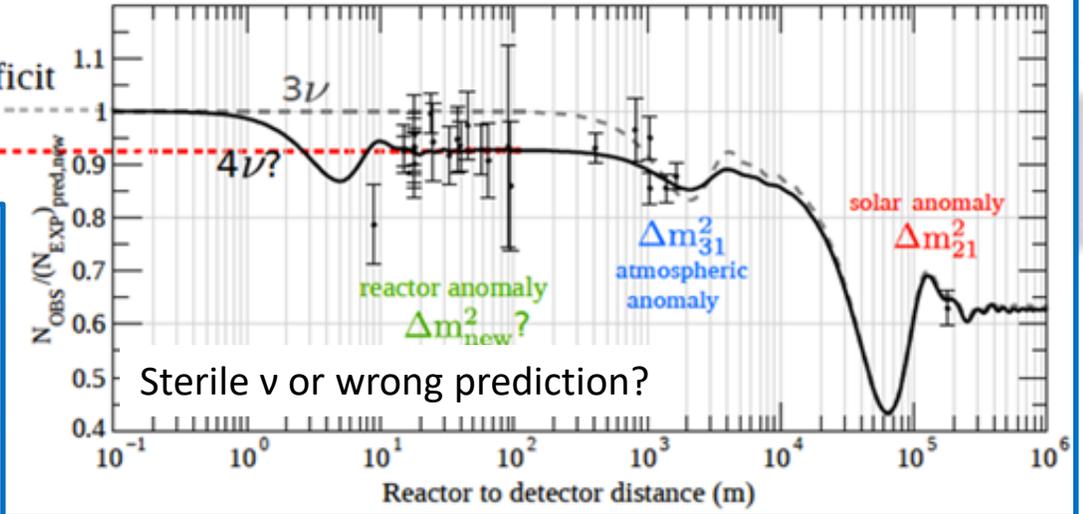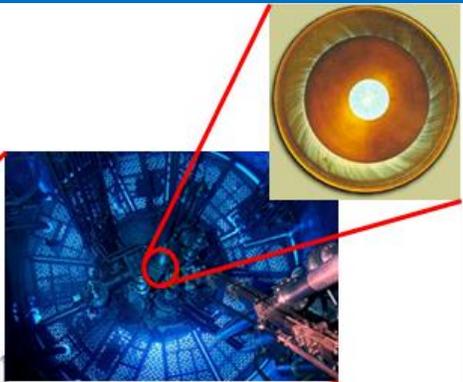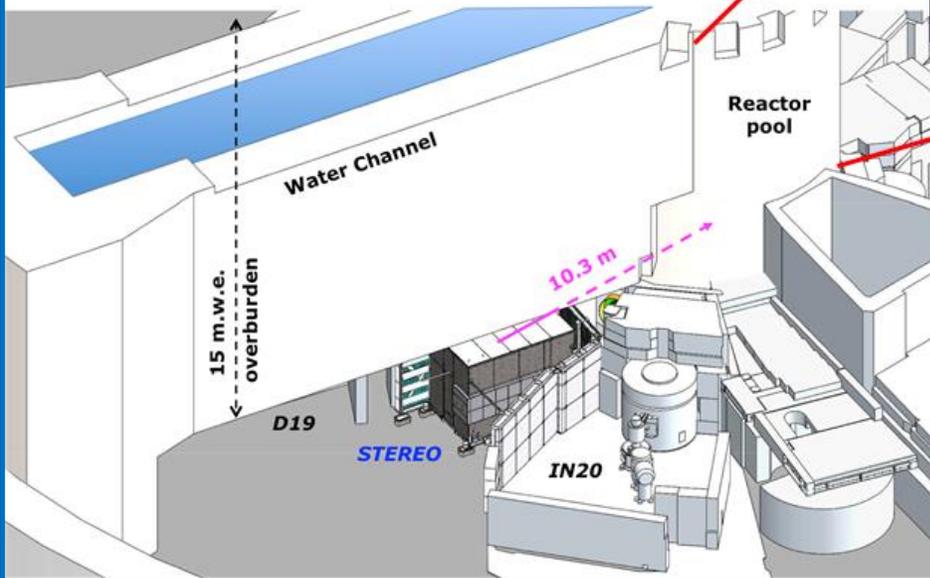
Summary

- ➢ **General STEREO features**
  - • **Motivation, ILL site & data taking**
  - • **Detector & instrumentation**

- ➢ **Light cross talk & Calibration Coefficients**

- ➢ **Internal calibration**
  - • **Detector response inhomogeneity in Z**
  - • **Time stability and Quenching**

- ➢ **External calibration**
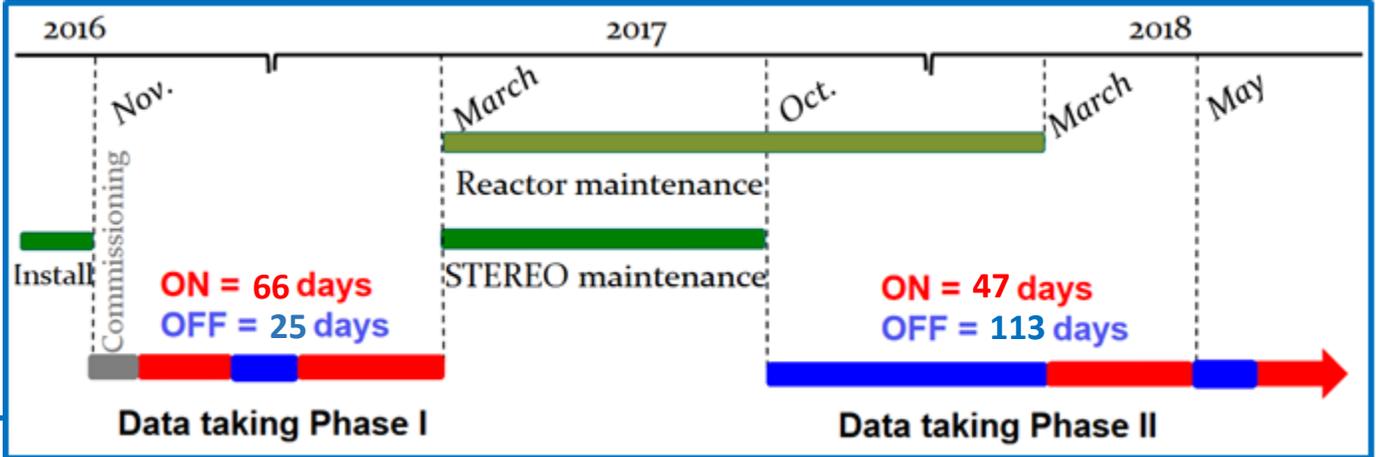 - • **Spatial inhomogeneity of detector response**

- ➢ **Outlook**

Generalities

ILL Site (Grenoble)
Compact core $\emptyset$40 cm × 80 cm
93% ^{235}U fuel
~58 MW$_{thermal}$
3-4 cycles/year each of 50 days
10^{19} s^{-1} pure $\bar{\nu}_e$ flux

~ 6 % deficit

3ν

4ν?

$N_{OBS}/(N_{EXP})_{pred,new}$

Sterile ν or wrong prediction?

reactor anomaly Δm^2_{new}?

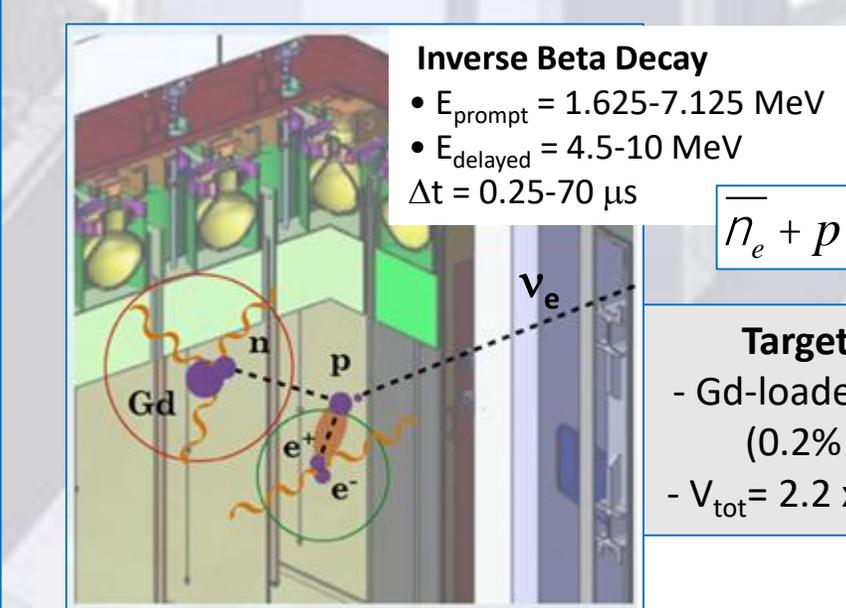Δm^2_{31} atmospheric anomaly

solar anomaly Δm^2_{21}

Reactor to detector distance (m)

* For more detailed introduction, please, see Aurélie Bonhomme's talk "STEREO results" during GT1 session.

Water Channel

Reactor pool

15 m.w.e. overburden

10.3 m

D19

STEREO

IN20

2016   2017   2018

Nov.   March   Oct.   March   May

Commissioning

Install

Reactor maintenance

STEREO maintenance

ON = 66 days
OFF = 25 days

ON = 47 days
OFF = 113 days

Data taking Phase I

Data taking Phase II

STEREO detector

Shielding
- Cosmic rays → Water Cerenkov Muon veto (+ water channel & reactor building)
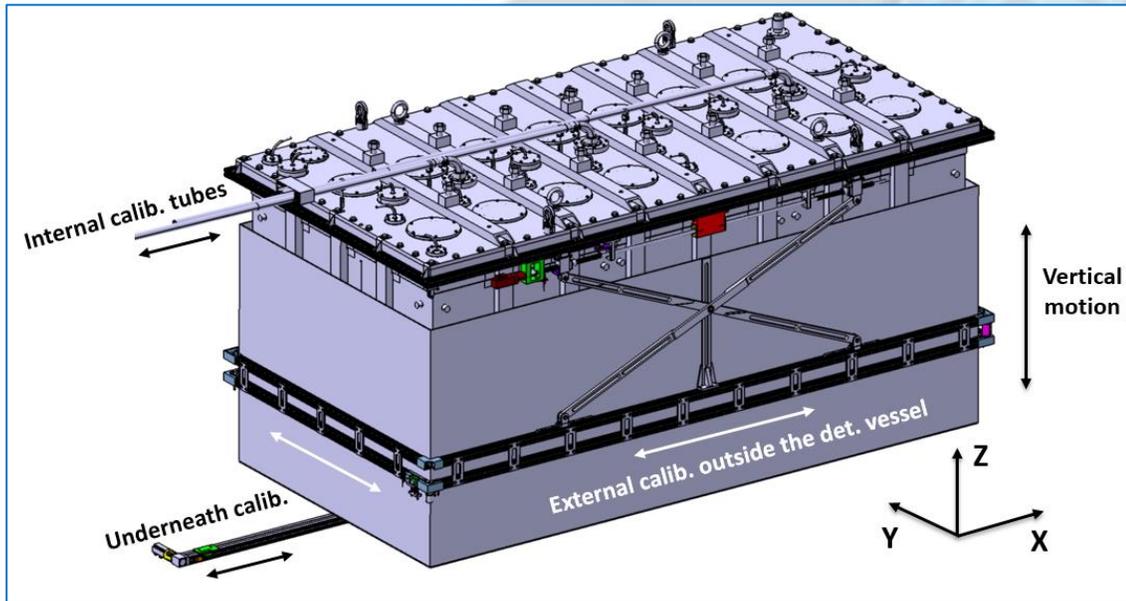- Neutrons & γ → Pb, borated polyethylene & B rubber

Soft iron + B4C

Water Cerenkov Muon veto

1.5 mm mumetal layer

Inverse Beta Decay
- E_{prompt} = 1.625-7.125 MeV
- $E_{delayed}$ = 4.5-10 MeV
- Δt = 0.25-70 μs

$$\overline{n_e} + p \rightarrow e^+ + n$$

ν_e

Gd   n   p

e+

e-

Target = 6 cells
- Gd-loaded scintillator (0.2% in mass)
- V_{tot}= 2.2 x 0.9 x 0.9 m³

Gamma Catcher
(unloaded scintillator)
- Vetoes ext. background
- Captures escaping γ's

Polyethylene   Lead

Support structure

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* All selection cuts presented by A. Bonhomme in "STEREO results" during GT1 session.

STEREO instrumentation

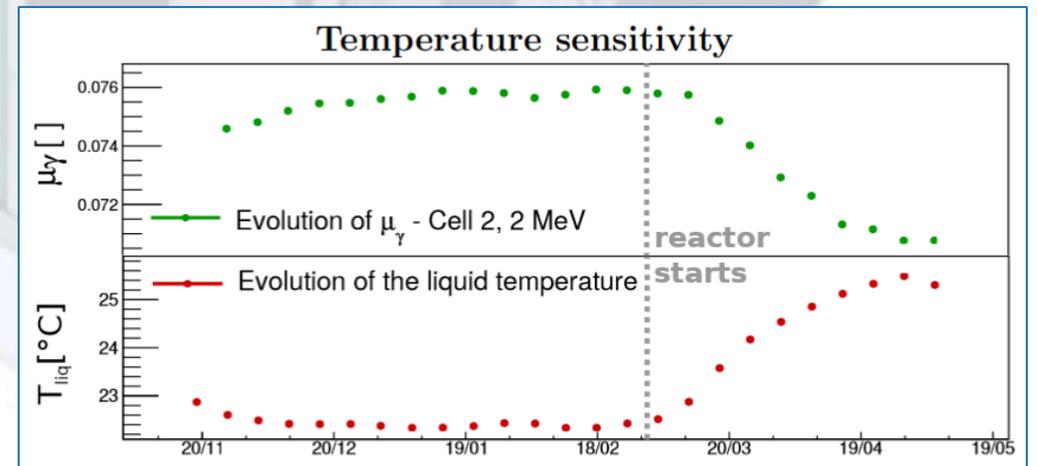- **Calibration instrumentation for source deployment inside & outside the target**

Find more on
arXiv:1804.09052

- **Monitoring & control instrumentation**

Sensors for:
pressure, temperature
B field (due to neigbour experiments)
Reactor power and neutron rate near detector
PMT voltage
...
→ To check the detector stability
→ To follow the data taking environmental conditions
→ Online detector monitoring

$*\mu_\gamma$: e$^-$ recoil bckg component from PSD [Qtot/Qtail]

Light cross-talk

→ Light cross-talk coefficients from cell i to cell j, $L_{ij} = \dfrac{Q_j}{Q_i}$, are necessary for the correct energy reconstruction.
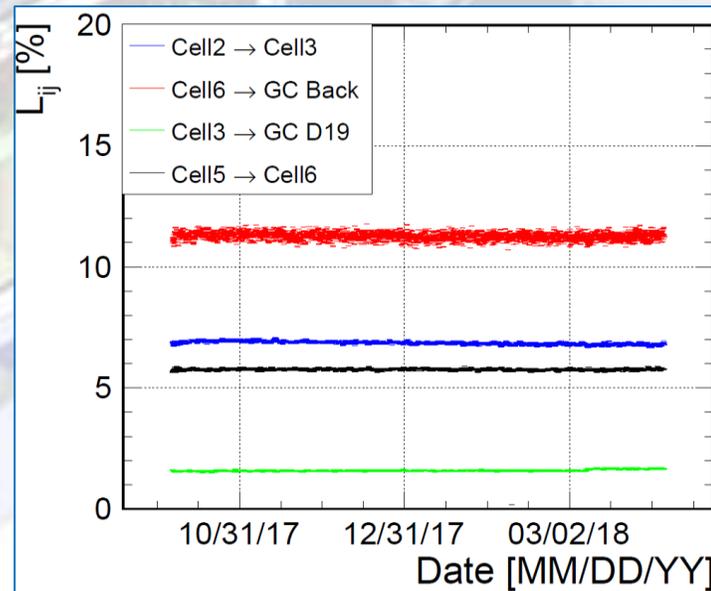
→ 2 independent methods to measure these light cross-talk coefficients.
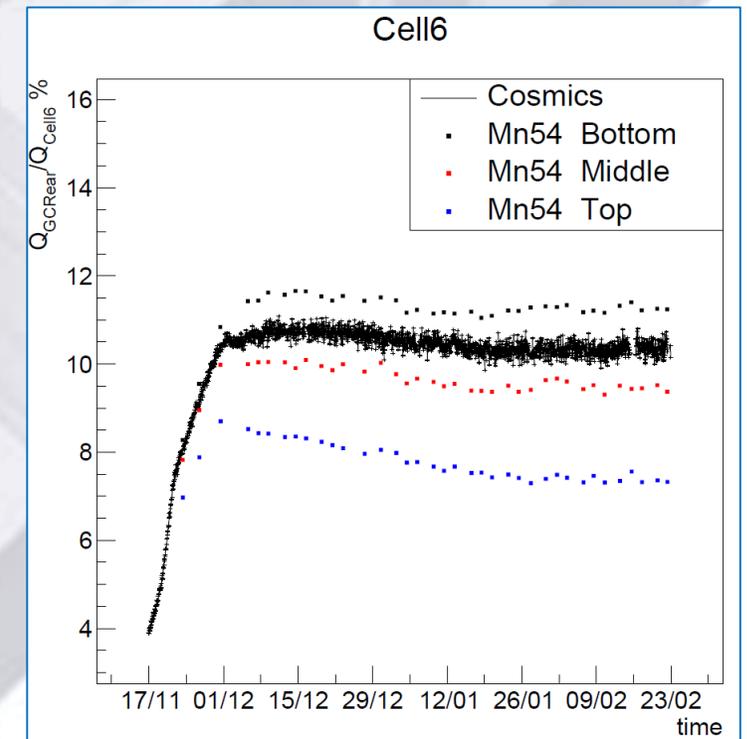
→ Consistent results

- Using ^{54}Mn calibration inside the target cells (0,835 MeV γ)
- Using high energy events from cosmic rays during standard runs (10-40 MeV)

Phase I

Phase II

Cell6
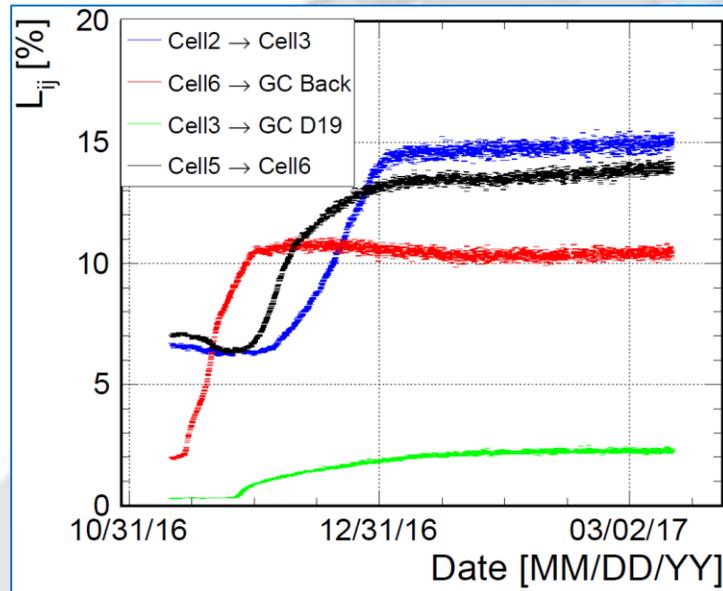
- Deficient optical coupling in the 4th target cell & front γ-catcher
- Evolving light cross-talk was repaired during the reactor long shut down

- Largest cross-talks were reduced
  - Stability in time

Calibration coefficients

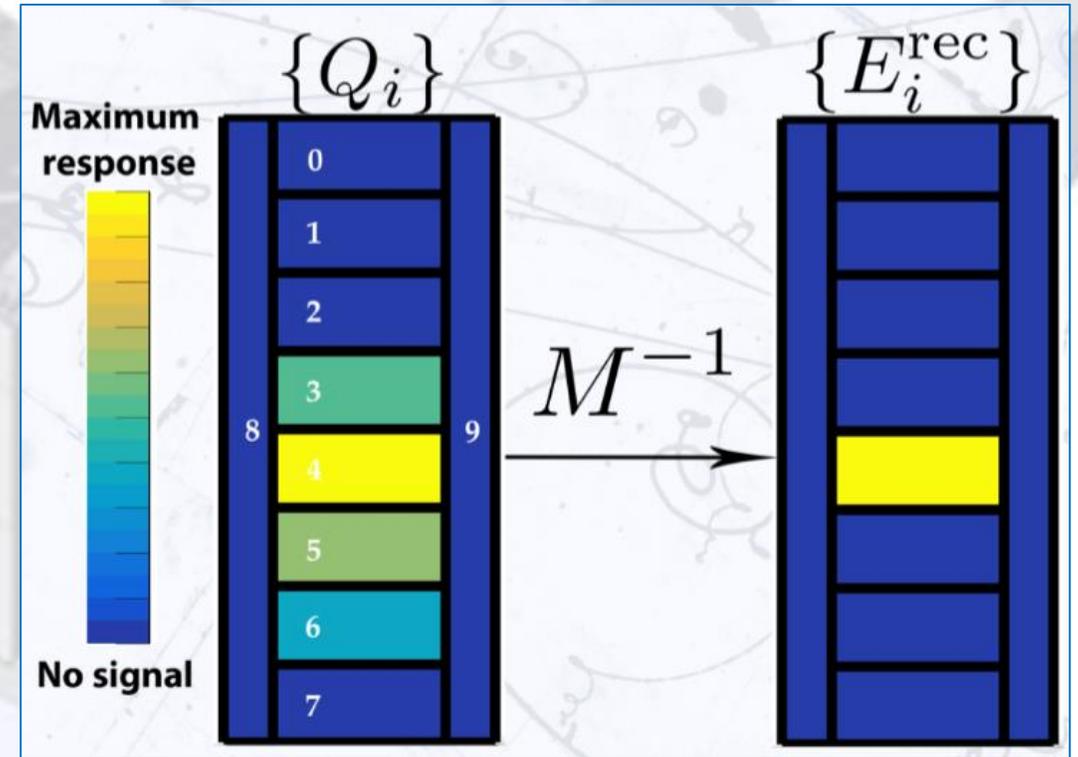$$Q_j = \sum_{i=\text{cells}} E_i C_i L_{ij} = \sum_{i=\text{cells}} E_i M_{ij}.$$

Collected photons/ MeV from calibration runs in target and γ-catcher cells

$$C = \frac{Q_{DATA}}{E_{MC}}$$

Light cross-talk cells j→i Measured online + Mn calibrations

Reconstructed E

$$\begin{pmatrix} E_0^{\text{rec}} \\ E_1^{\text{rec}} \\ \vdots \\ E_9^{\text{rec}} \end{pmatrix} = M^{-1} \begin{pmatrix} Q_0 \\ Q_1 \\ \vdots \\ Q_9 \end{pmatrix}$$
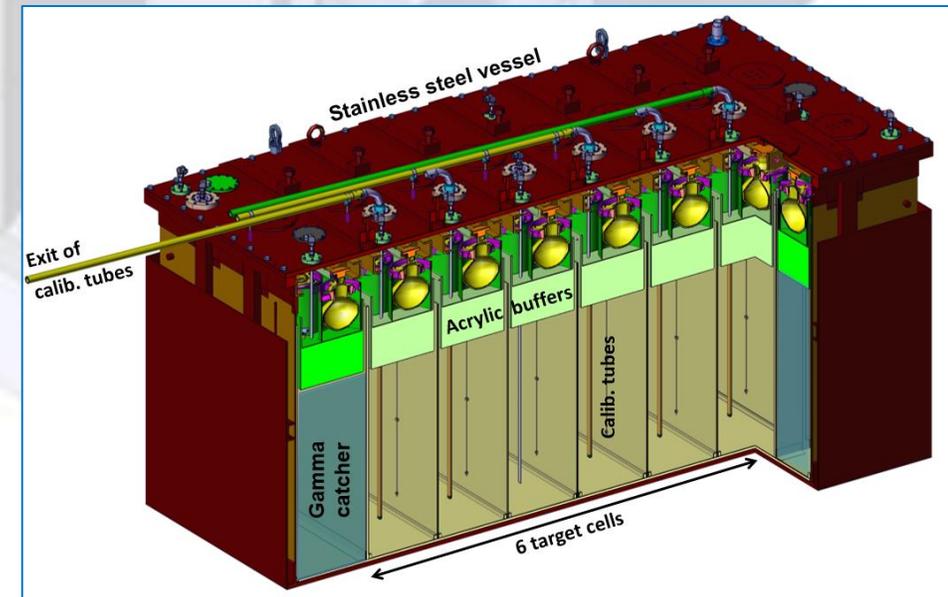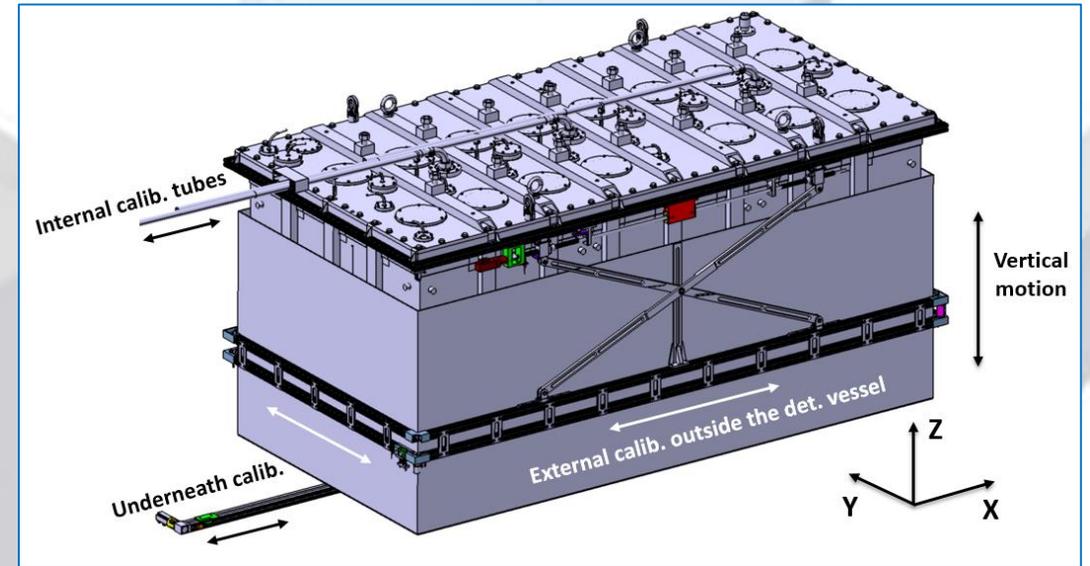

https://www.mpi-hd.mpg.de/nu2018/contributionindex
A. Blanchet "Energy reconstruction in the STEREO experiment" poster, NEvTRINO2018.

GDR. Working Group GT4: Accélérateurs, Moyens de détection, R&D et valorisation. V. Sergeyeva, LAPP.

STEREO calibration

Detector response studied with radioactive sources and a LED system

Source	Eγ (MeV)
^{68}Ge	0,511 x2
^{124}Sb	0,603 & 1,69
^{137}Cs	0,662
^{54}Mn	0,835
^{65}Zn	1,11
^{60}Co	1,17 & 1,33
^{24}Na	1,37 & 2,75
AmBe	2,22; 4,4 + neutrons

- **External calibration**

- Underneath the target
- Around the detector perimeter, outside the γ-catcher
  - Several positions in Z

- **Internal calibration**
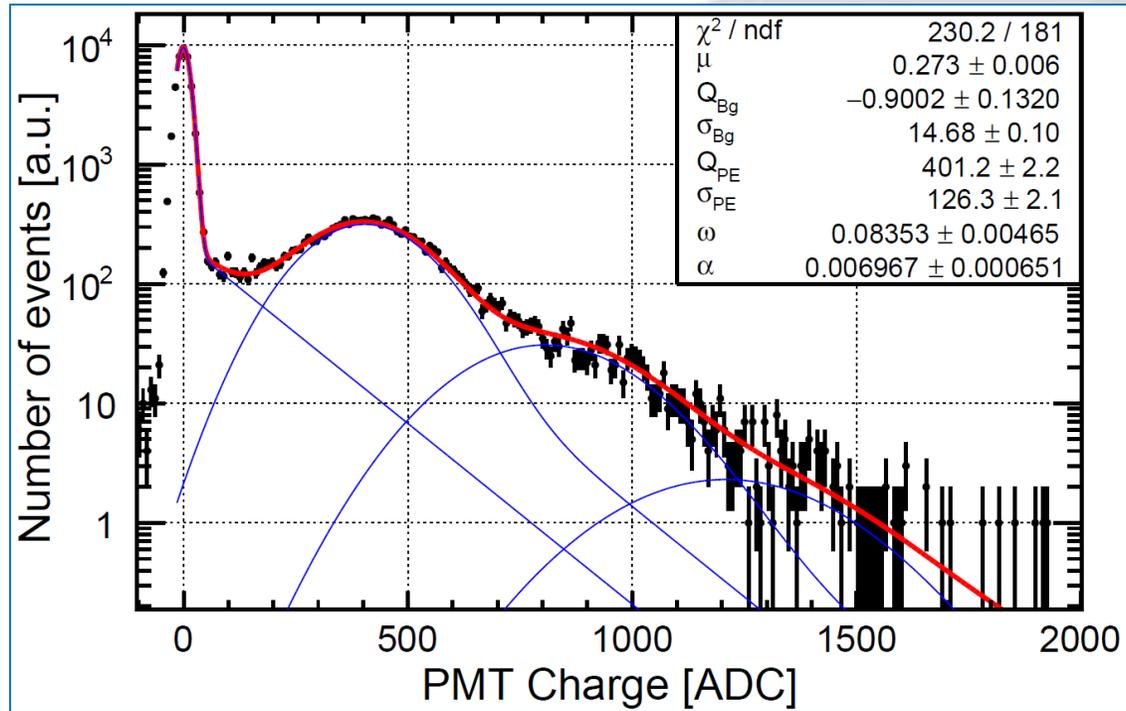
- Access to all the target cells
- Several positions in Z

12/06/2018

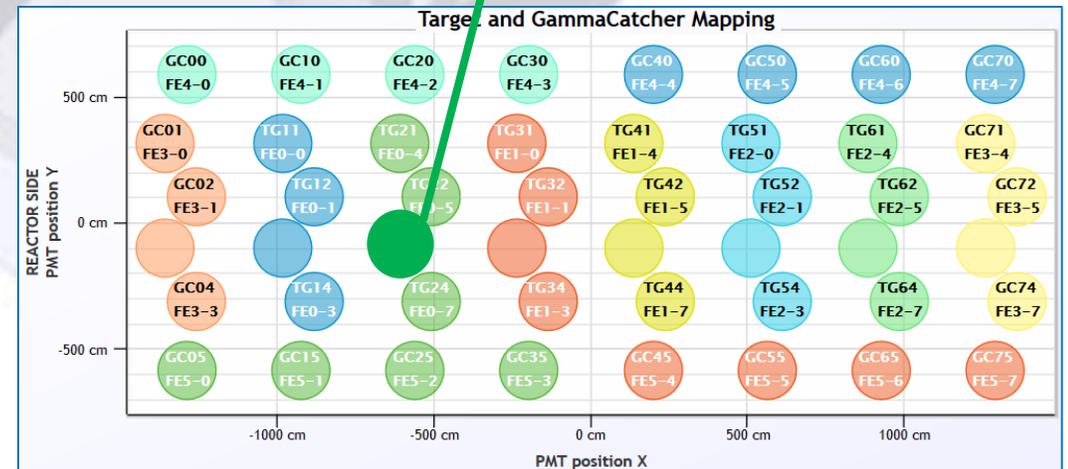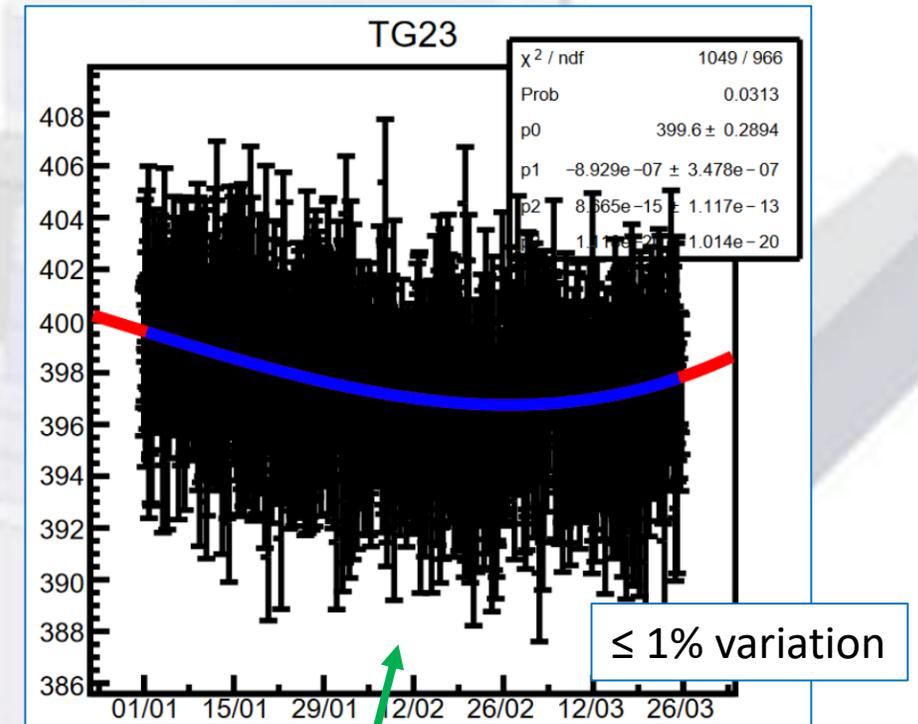GDR. Working Group GT4: Accélérateurs, Moyens de détection, R&D et valorisation. V. Sergeyeva, LAPP.

8

STEREO LED calibration

Combinations

Optical fiber

References
Only one LED is on

Combinations
Several LED are on

PMT

Acquisition system

Computer
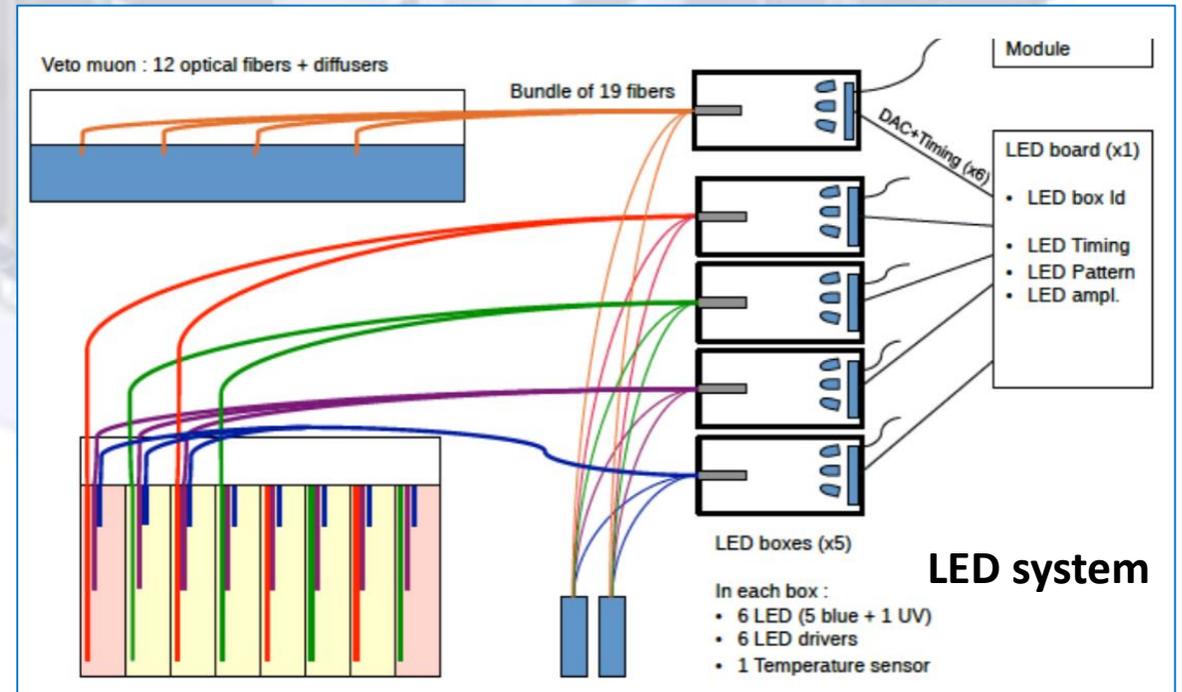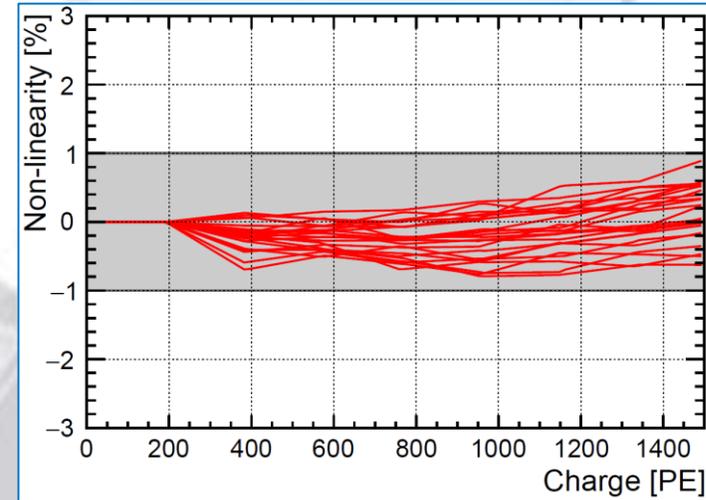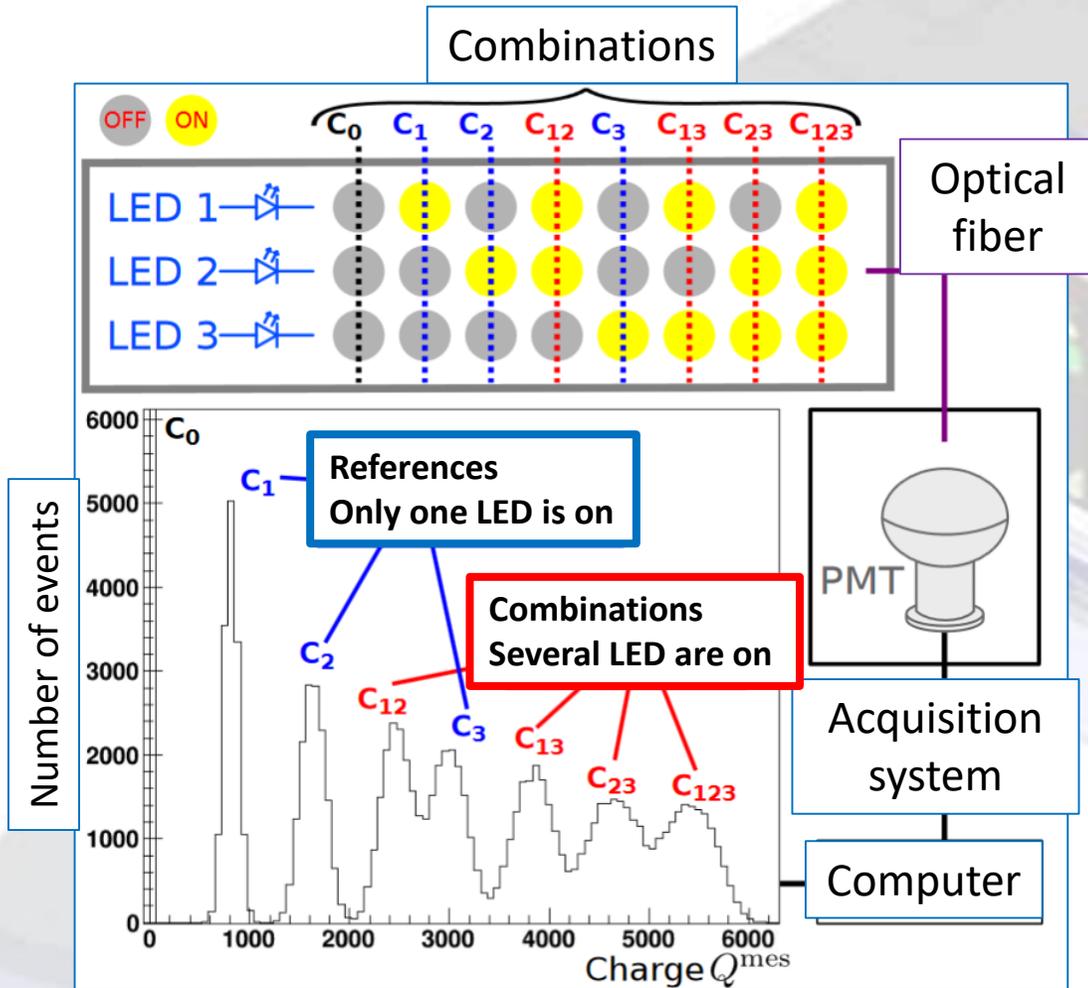
Fore more info arXiv:1804.09052

LED system

STEREO PE calibration

Typical single and multi PE spectra from a Hamamatsu R5912-100 PMT in a TG cell fitted with a sum of functions which parametrize the noise and the PMT response.

≤ 1% variation

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STEREO internal calibration

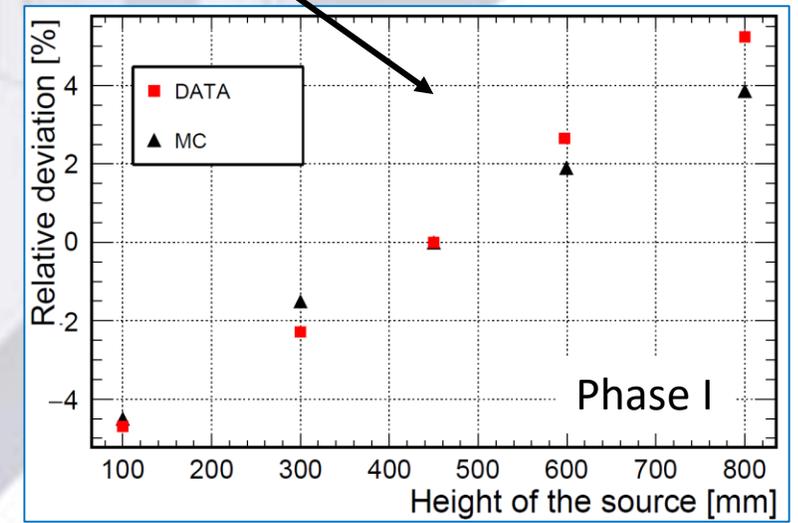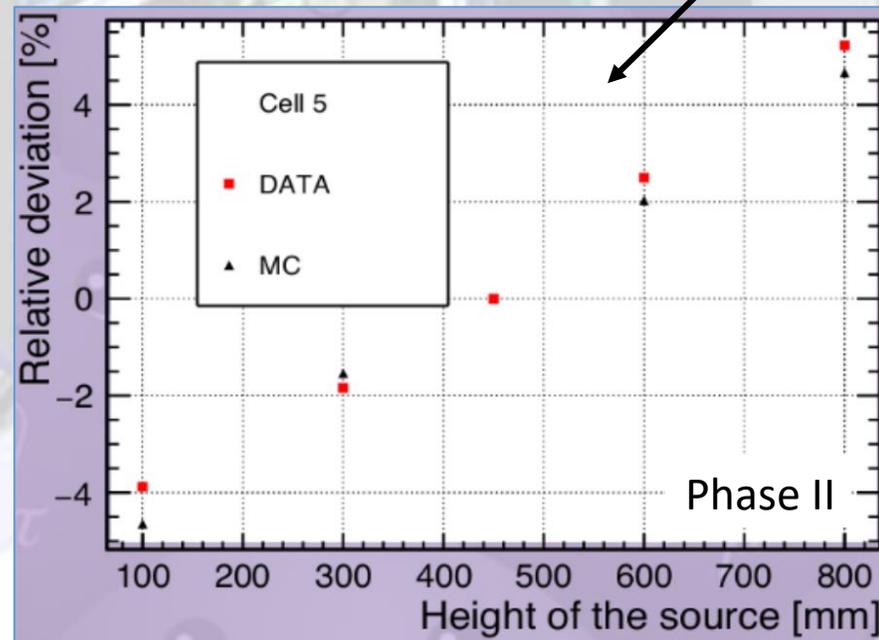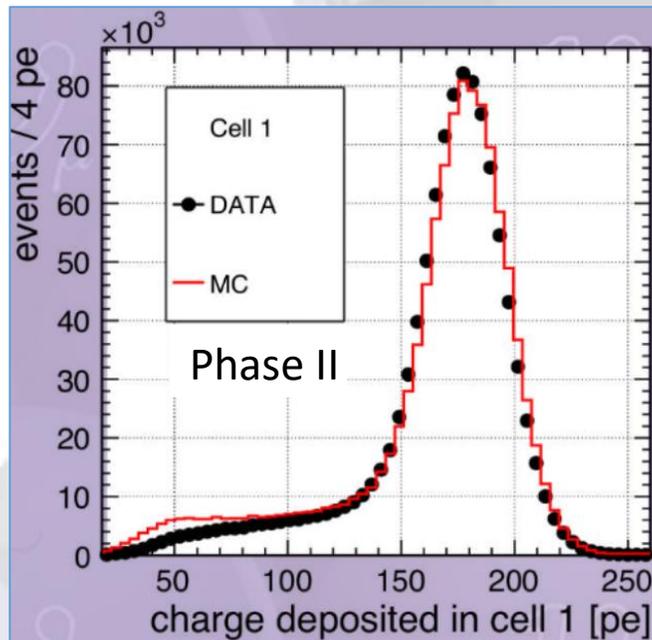- **Weekly calibration with ^{54}Mn source**
  - All target cells
  - 5 different heights middle, top and bottom Z

➤ Allows to follow the **light cross-talk evolution**
➤ Check of charge collection **asymmetry with Z**
➤ **Monte Carlo tuning**
+ *Light cross-talk in MC match inhomogeneous cross-talk from data at % level.*

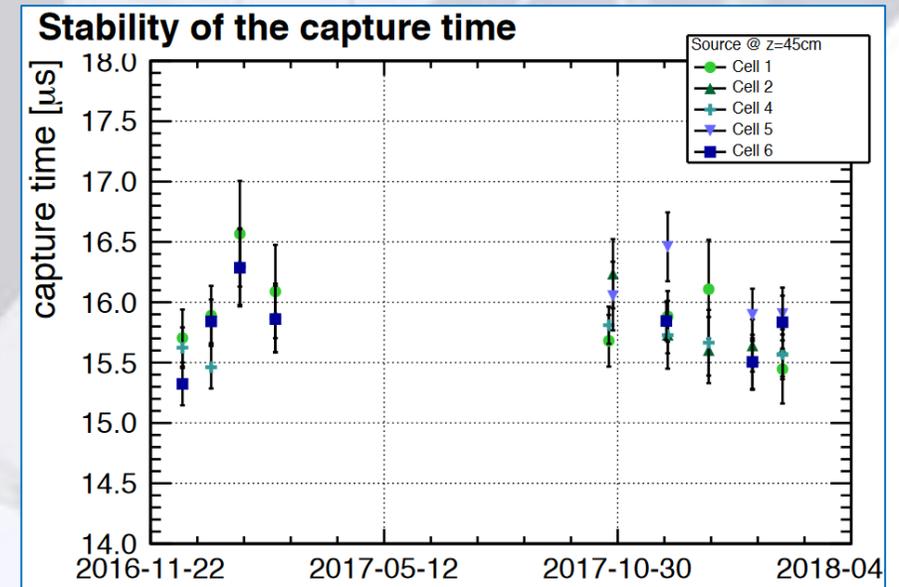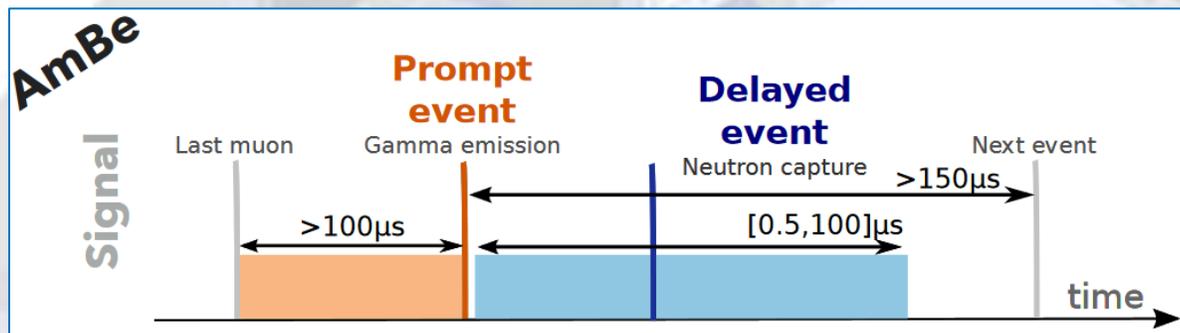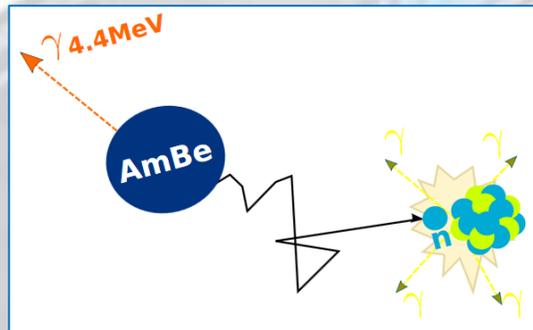Z asymmetry slightly changed between the 1st & 2nd phases.
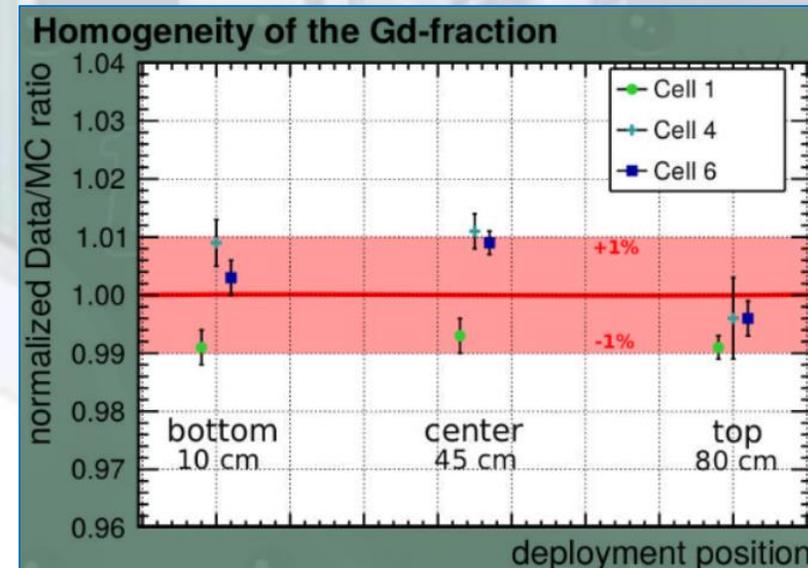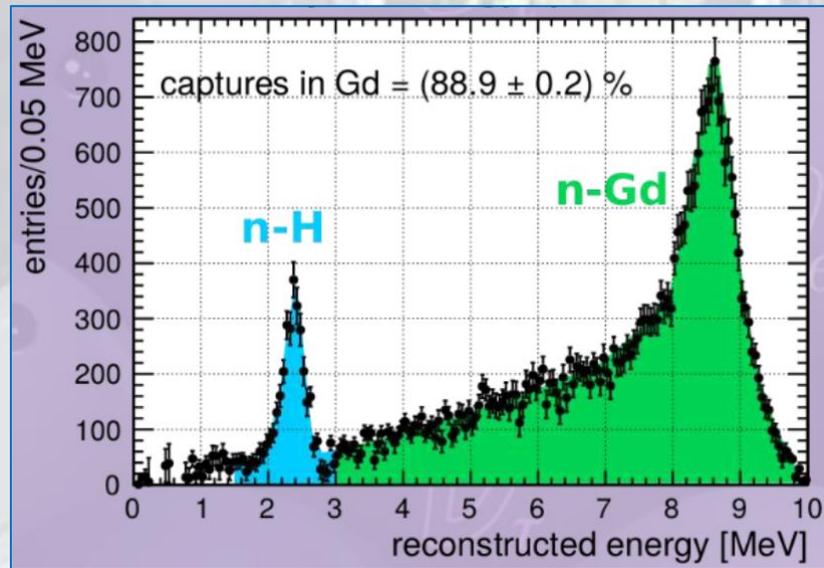
STEREO internal calibration

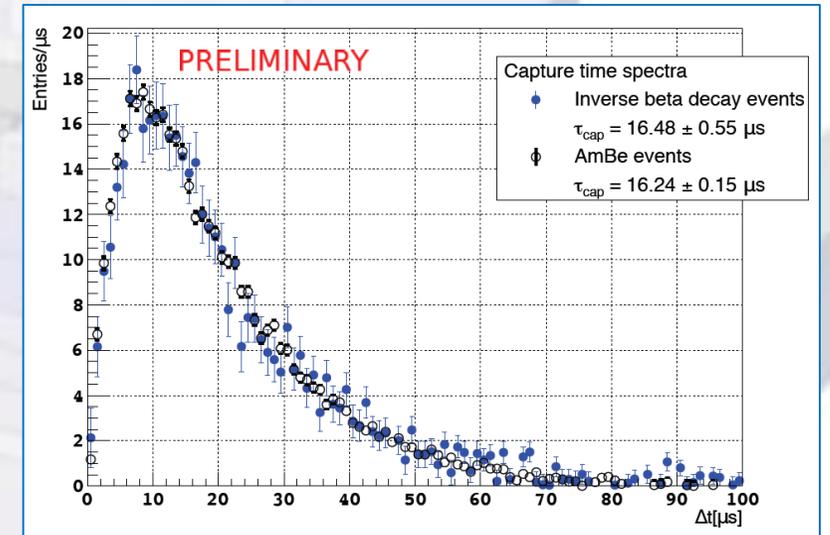- **Monthly calibration with AmBe source**
- 3 target cells (phase I) and 5 target cells (phase II)
  - 3 different heights
  middle, top and bottom Z

➢ Allows to study neutron capture peaks in H and Gd
➢ Allows to study neutron capture time
➢ Monitor the stability in time

https://www.mpi-hd.mpg.de/nu2018/contributionindex
Ch. Roca & H. Almazan "Response of the STEREO detector"
poster, NEvTRINO2018.

STEREO internal calibration

- **Monthly calibration with AmBe source**
- ➤ n-capture time from Am-Be in agreement with IBD candidates
- ➤ Relative variations of n efficiency in agreement between MC and data.
- ➤ Absolute fraction of Gd-capture fine-tuned in MC

https://www.mpi-hd.mpg.de/nu2018/contributionindex

Ch. Roca & H. Almazan "Response of the STEREO detector"
poster, NEvTRINO2018.

STEREO internal calibration

- **Several "quenching" calibration campaigns**
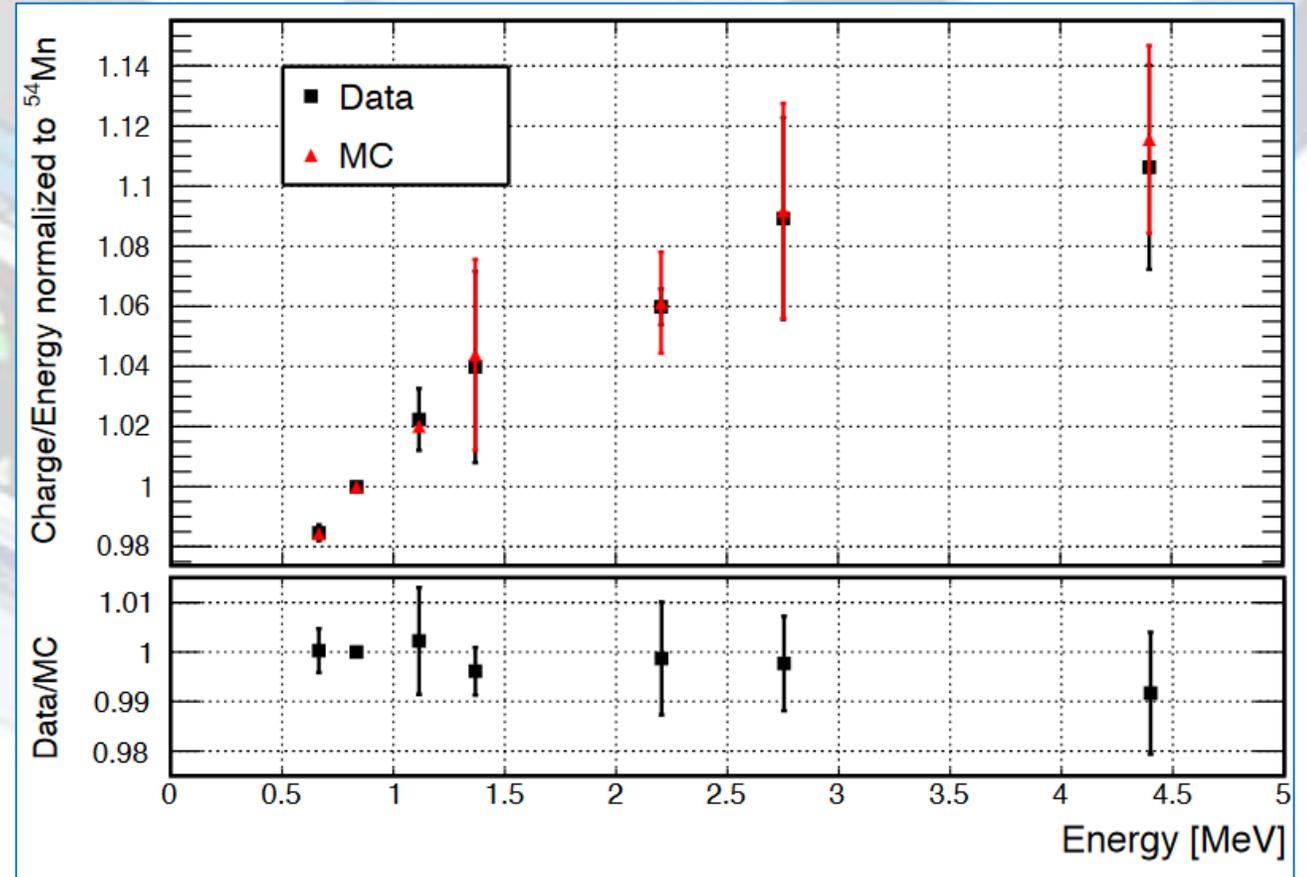 - ➢ At least 1 campaign / phase
  - ➢ Inside different target cells

Energy non-linearity in the liquid scintillator
  - ➢ Birk's law

$$\frac{dL}{dx}(E) = S_{ef} * \frac{\frac{dE}{dx}(E)}{1 + K_{Birks} * \frac{dE}{dx}(E)}$$

Scintillation ↔ energy loss
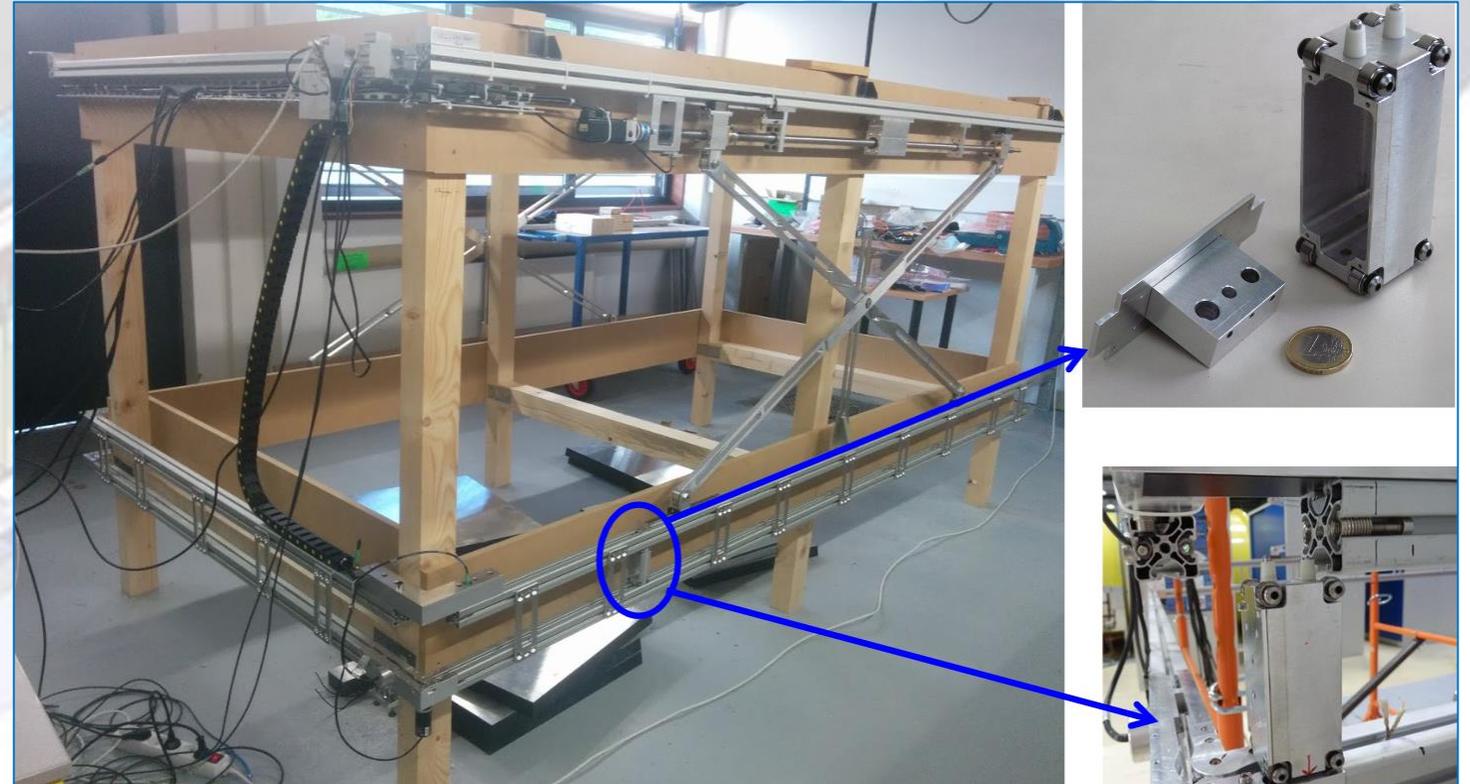

^{54}Mn is an anchor point

STEREO calibration

K$_{Birks}$ tuning in Monte Carlo

➤ Use experimental quenching curve from source runs, Data(E)

➤ Obtain MC quenching curve for a set of **K$_{Birks}$** values, MC(E, K$_{Birks}$, LY). First large set [0.202, 0.010]

   ➤ Compute ratio of Data/Monte Carlo
R(E, K$_{Birks}$, LY) = Data(E) / MC(E, K$_{Birks}$, LY)

➤ Determine the optimal **K$_{Birks}$ ±δ K$_{Birks}$** from the shape of R(E, K$_{Birks}$, LY) → **0.096±0.007 mm/MeV**

   ➤ Use of ^{54}Mn energy anchor point removes the dependence on LY!
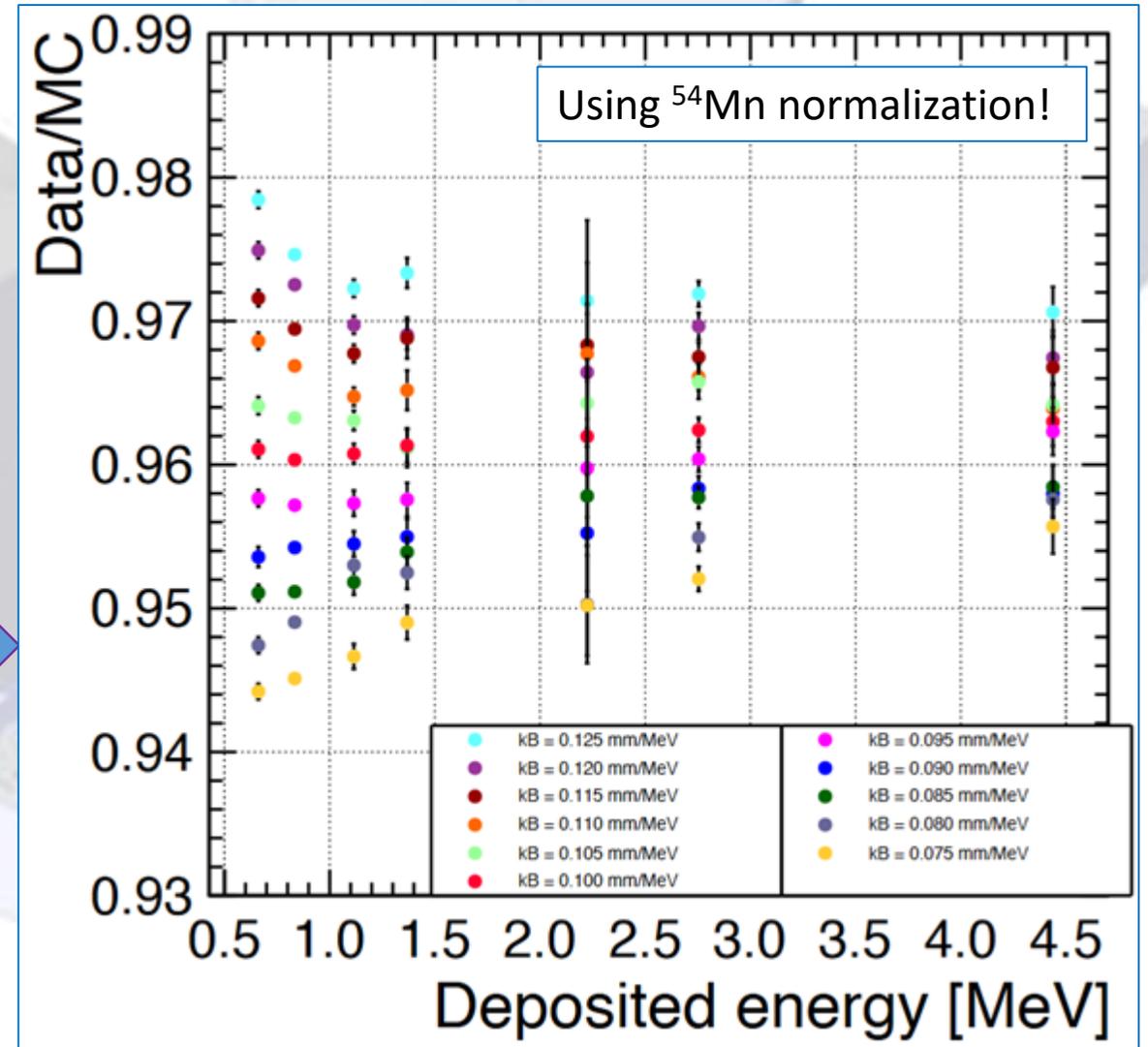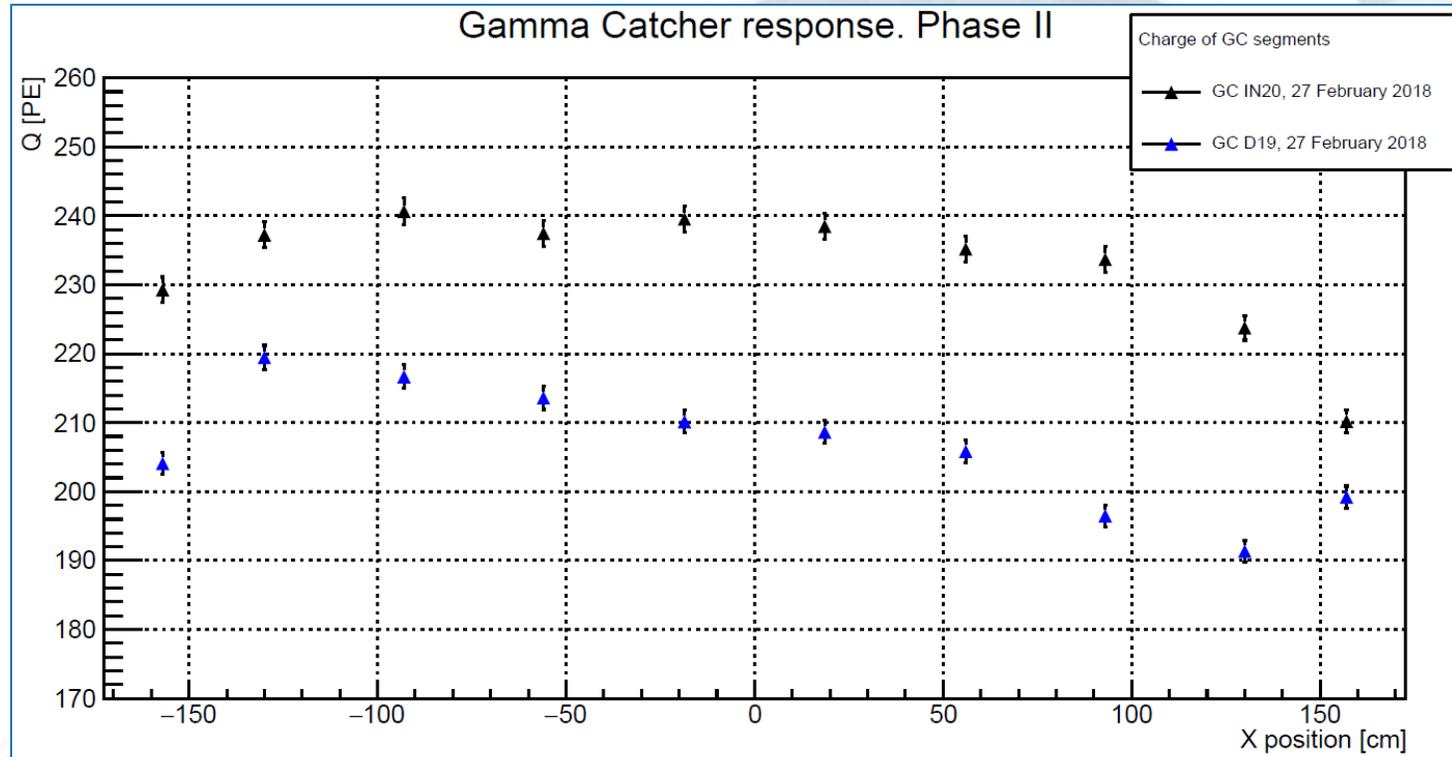
STEREO external calibration

- **Frequent calibrations with ^{54}Mn source**
  - Along the γ-catcher perimeter
    - 3 different heights middle, top and bottom Z

- ➢ Verify charge collection asymmetry with (X, Y, Z) position

    - ➢ Time stability

STEREO external calibration

Gamma Catcher response. Phase II

Charge of GC segments
- GC IN20, 27 February 2018
- GC D19, 27 February 2018

Response of two GC long segments to different positions of ^{54}Mn source

External source positions

IN20

Front

Back

D19

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STEREO external calibration

Gamma Catcher response. Phase I

Gamma Catcher response. Phase II

Gamma Catcher response. Phase II
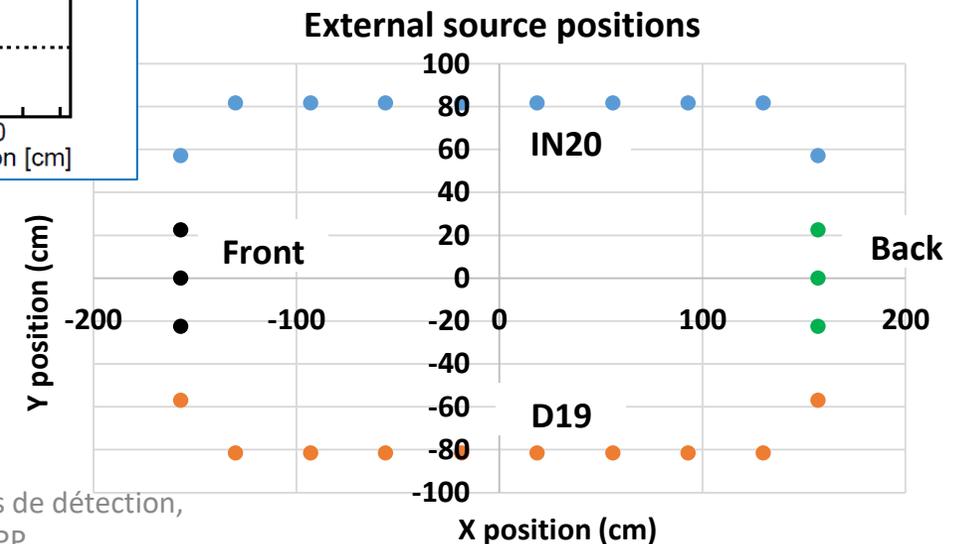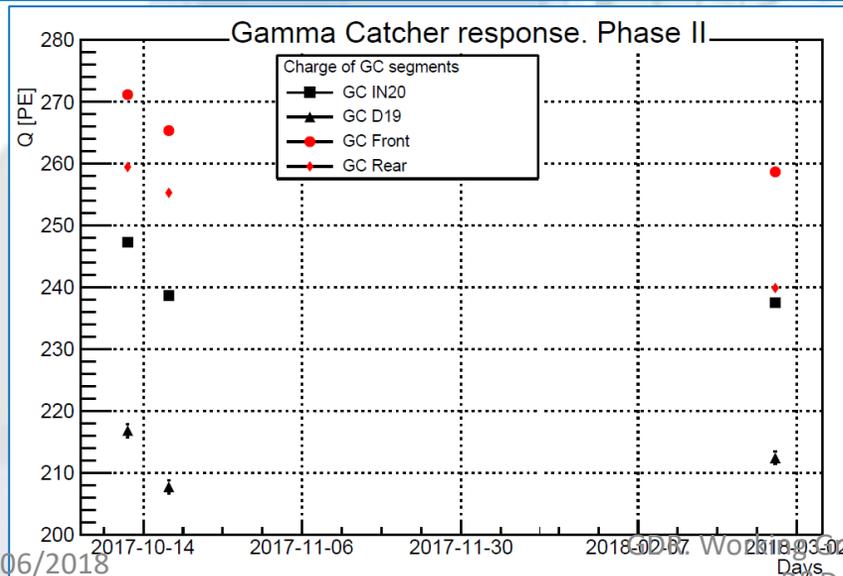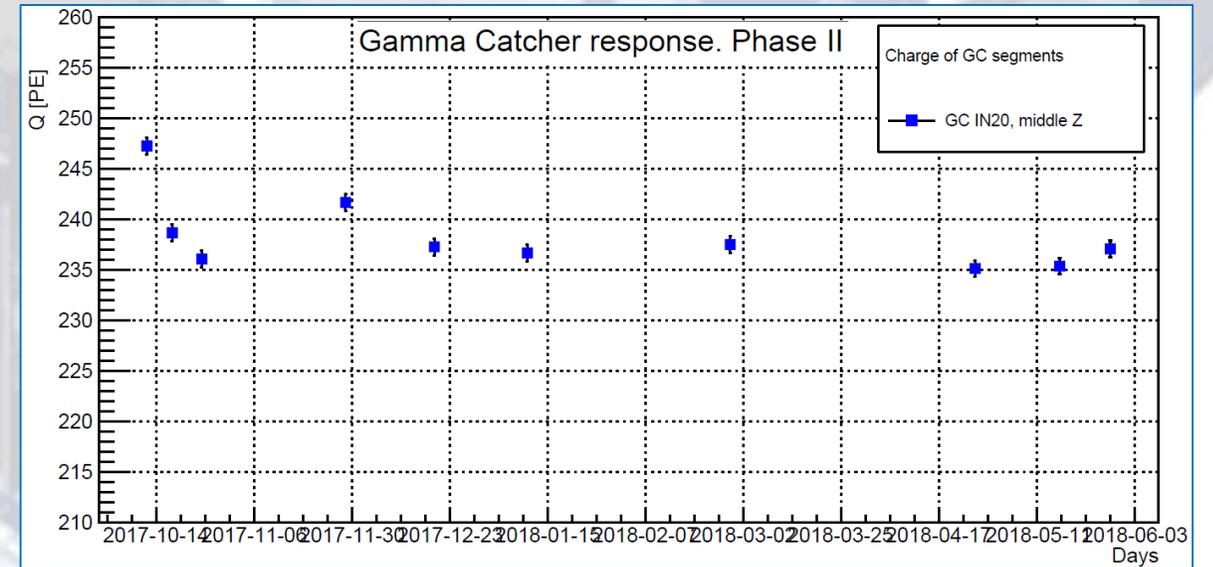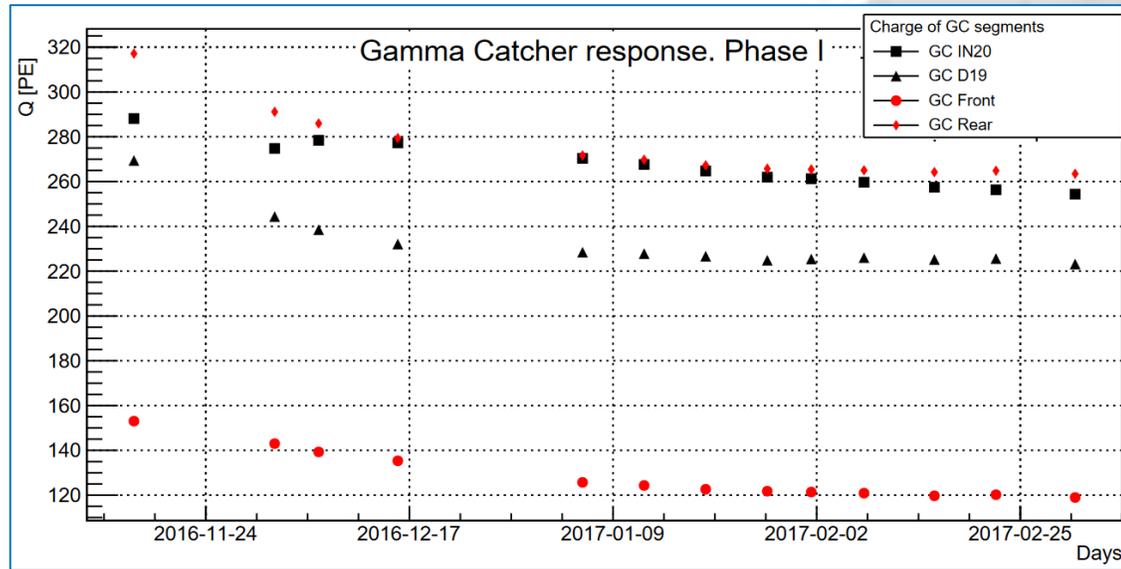
Charge evolution in time for GC segments during external ^{54}Mn calibration

Unstable at the beginning of phase II (liquid filling) & stable behavior afterwards

Outlook

➢ Complex light cross-talk during phase I is taken into account and was fixed for phase II data taking.

➢ Regular calibration runs with ^{54}Mn allow to follow the detector evolution and stability in time.

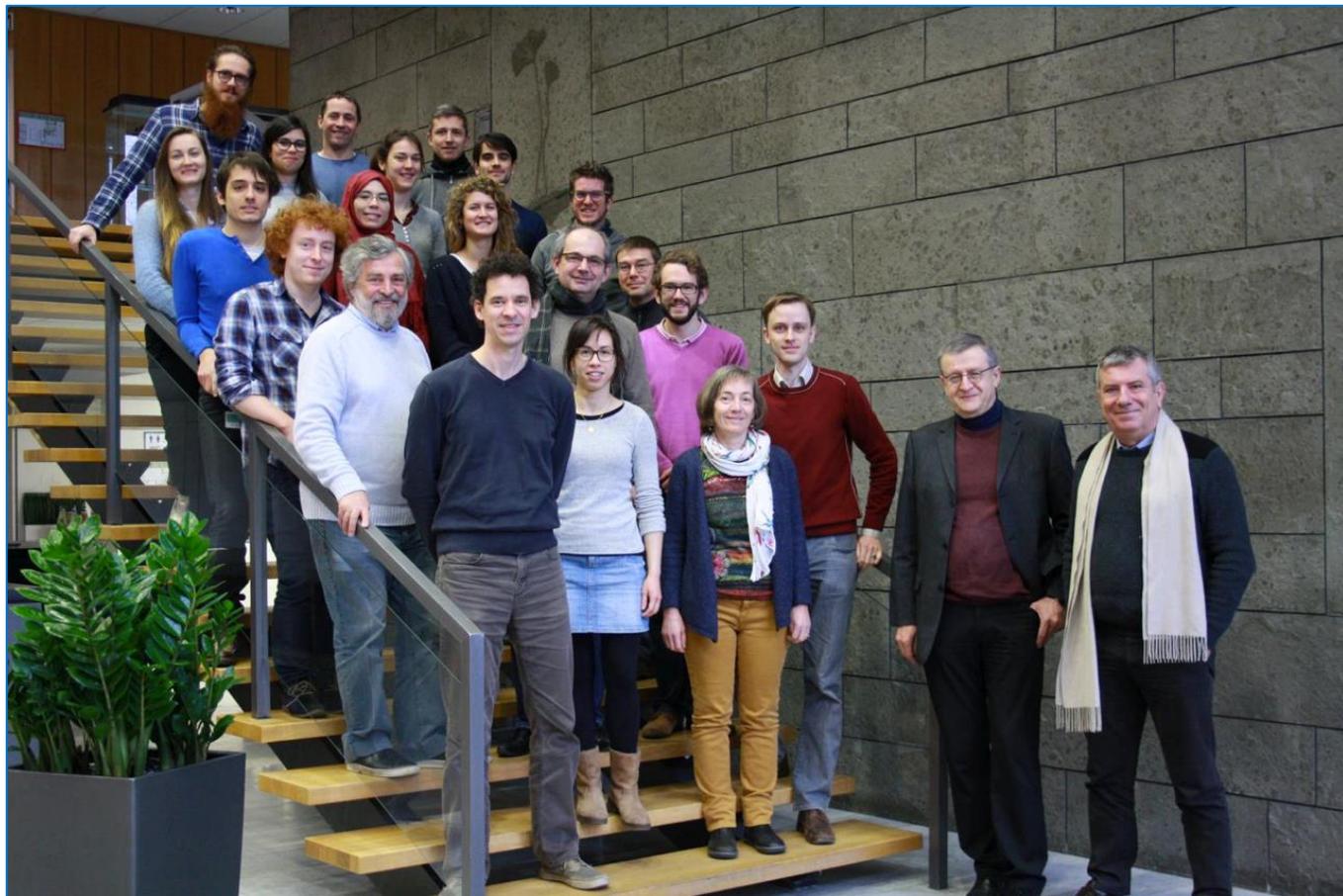➢ AmBe calibrations allow to study and follow the time stability of neutron capture.

➢ Target and γ-catcher are regularly calibrated with several sources.

➢ A large set of sources allows to obtain and tune (MC) the LS quenching effect.

➢ Spatial inhomogeneity in detector response is well reproduced by Monte Carlo (*attenuation length, refractive indices, light yield, …*).

➢ Finally, total energy scale uncertainty at 1% level.

➢ Data taking will continue until end of 2019.

Energy scale at 1% level	Source	Cell-to-cell correlated	Cell-to-cell uncorrelated
	E^{ref}	-	0.20%
	^{54}Mn anchor	-	0.30%
	Time stability (n-H)	0.35%	-
	Cell-wise Data-MC comparison (from calib. sources + n-H)	-	1.00%
Total		**0.35%**	**1.06%**

Source	Detection efficiency syst	Contrib to $\sigma_{Cell}^{NormUncor}$
Cell volume		0.85 %
n-capture efficiency		1.20 %
Other selection cuts efficiency		0.90 % (3.1 % cell4)
TOTAL		**1.7 % (3.4 % cell4)**

Thank you for your attention!

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R&D et valorisation. V. Sergeyeva, LAPP.