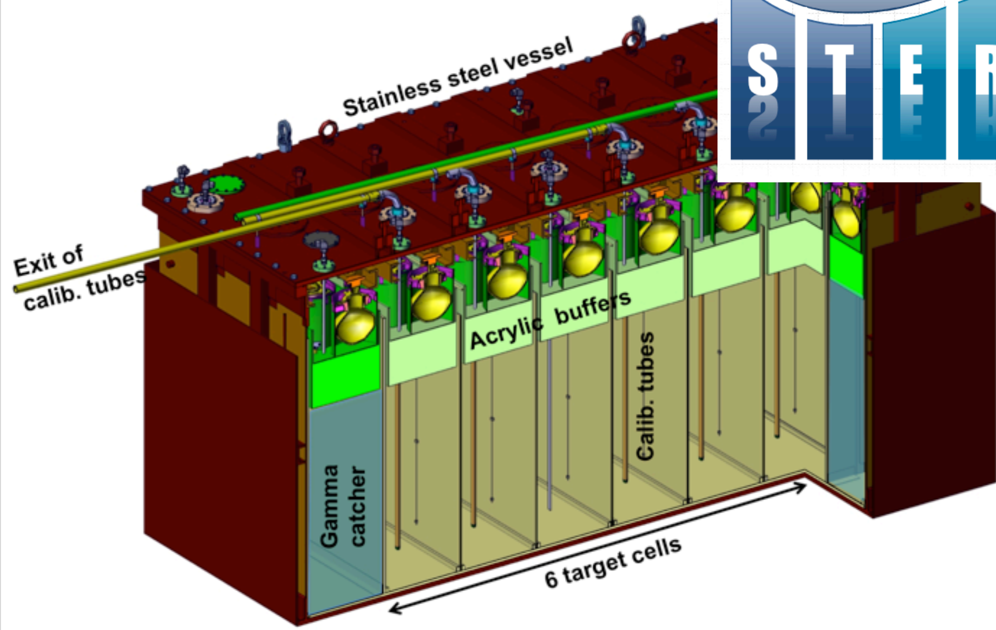
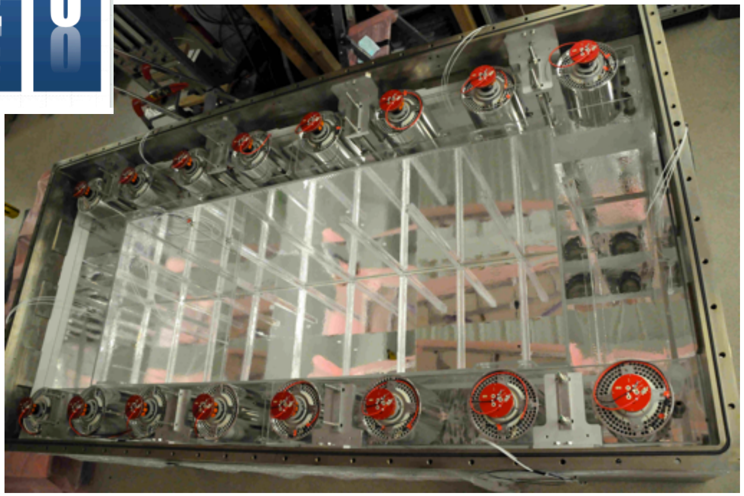
# Calibration and energy scale in STEREO



Pablo del Amo Sánchez ESCAPE 2018 01/06/18 cea Irfu

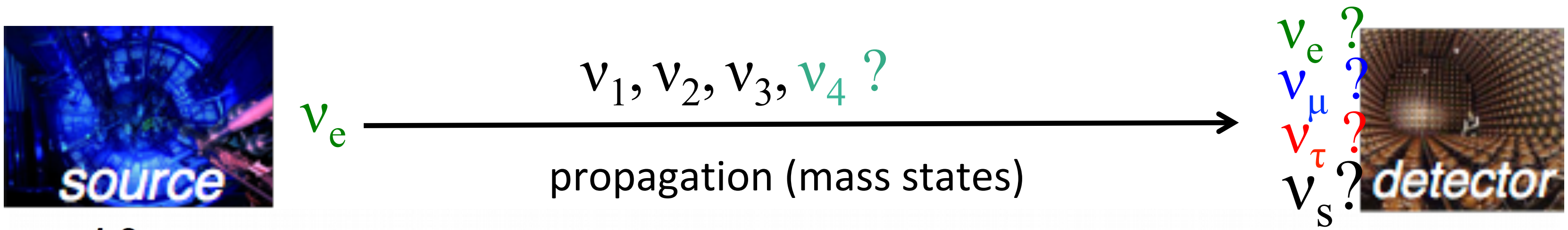
NEUTRONS FOR SOCIETY

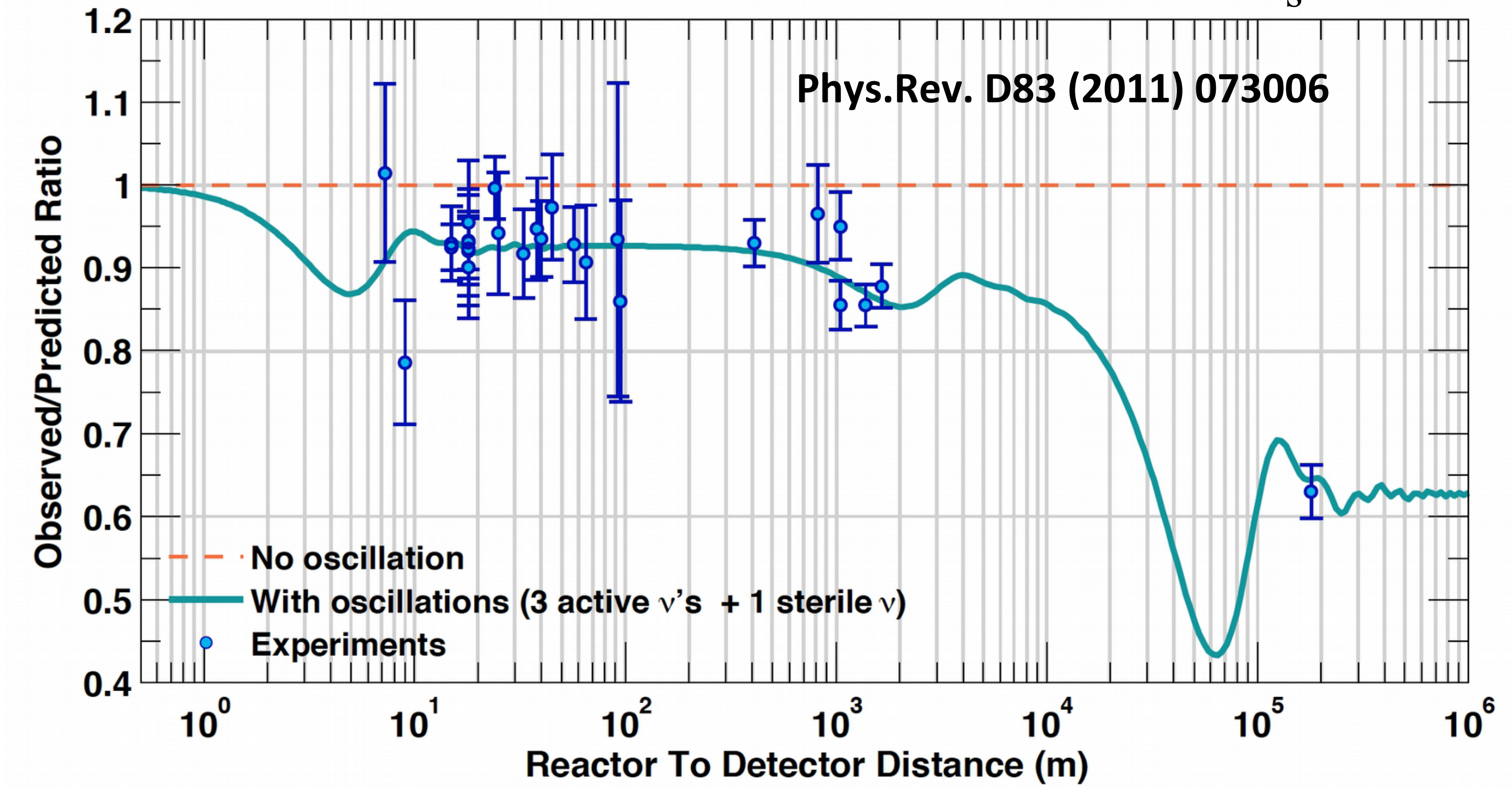
LAPP

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

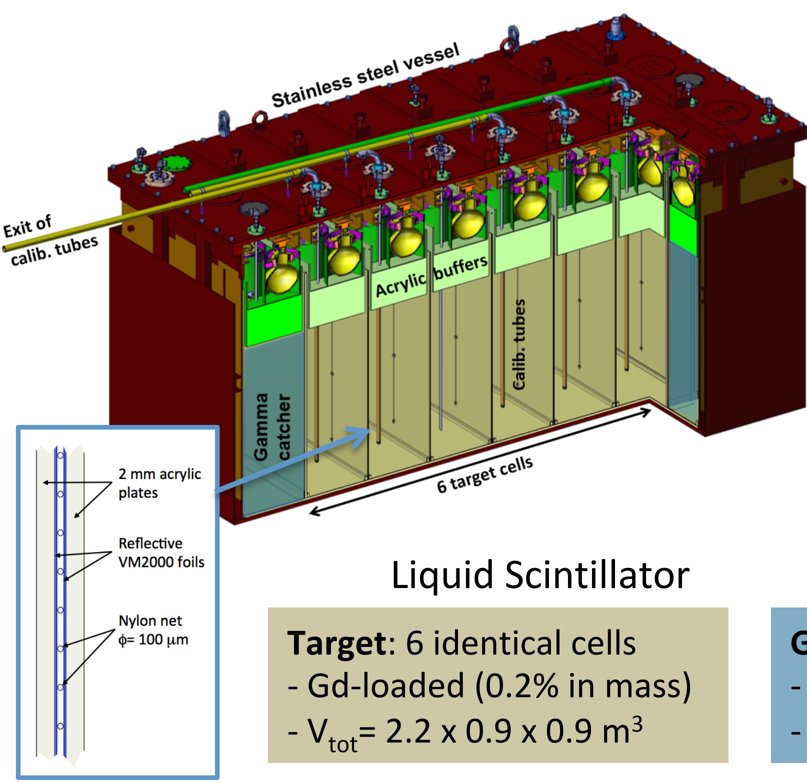
# Reactor Anti-ν Anomaly



# STEREO detector

- Compare 6 target cells to measure oscillation-driven distortions in the $E_{\bar{\nu}_e}$ spectrum.
- Mitigate sensitivity to predicted spectrum.




Reactor →

20 cm thick acrylic buffers for homogeneous detector response. PMT coupling via oil bath.

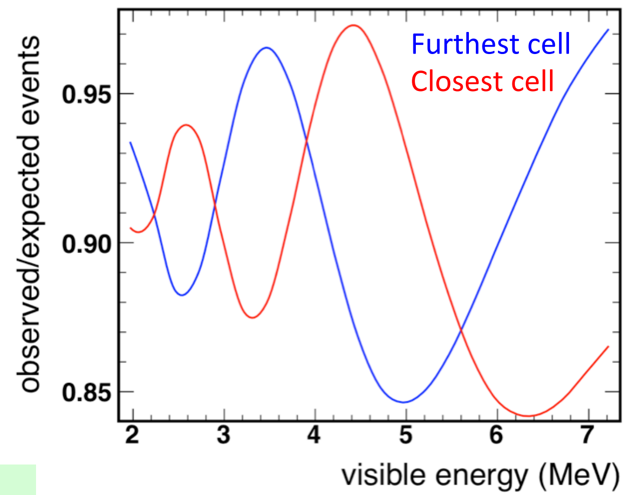
The STEREO experiment, ([arXiv:1804.09052](arXiv:1804.09052)).

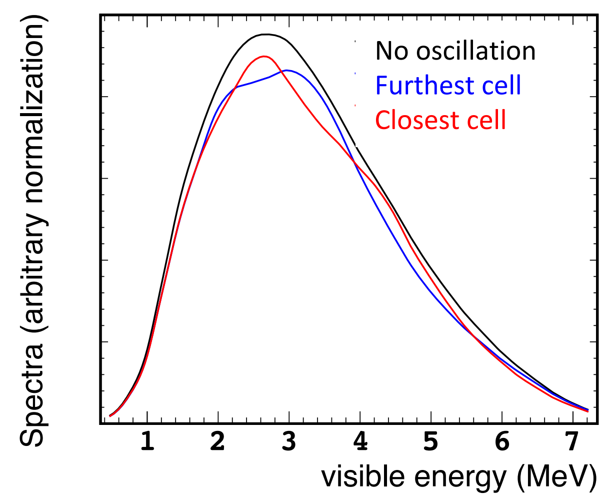
Liquid Scintillator

**Target**: 6 identical cells
- Gd-loaded (0.2% in mass)
- $V_{tot}$= 2.2 x 0.9 x 0.9 $m^3$

**Gamma catcher** (unloaded):
- Vetos ext. background
- Captures escaping γ's

**$\sin^2(2\theta)$=0.14, $\Delta m^2$=2.4 $eV^2$**



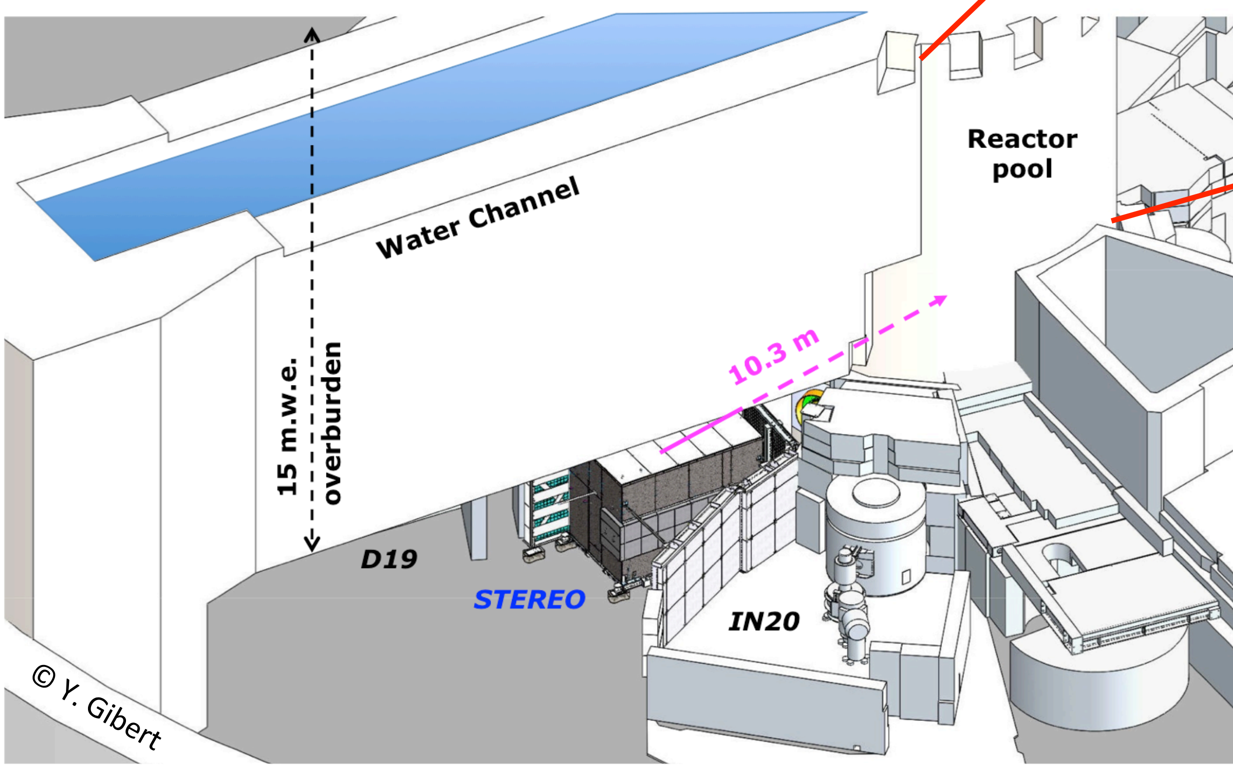



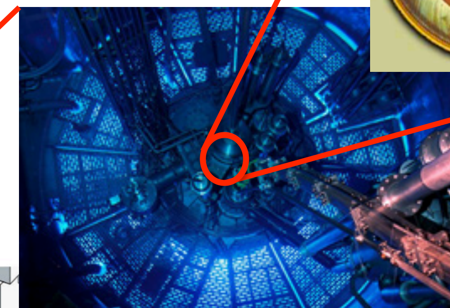
# ILL Site

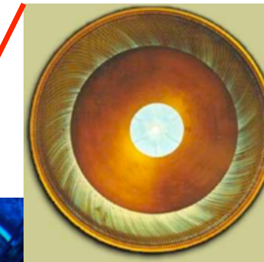
**Compact core**

- 58.3 MW_thermal
- Ø40 cm × 80 cm
- Highly enriched: 93% $^{235}U$

- 3-4 cycles/year each of 50 days
- $10^{19}$ $s^{-1}$ pure $\overline{\nu}_e$ flux



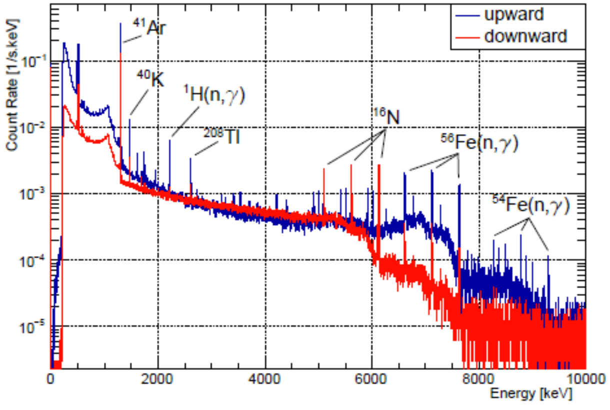





**Challenging mitigation of the background generated by:**
**- Neighboring experiments.**
**- Cosmic-rays.**

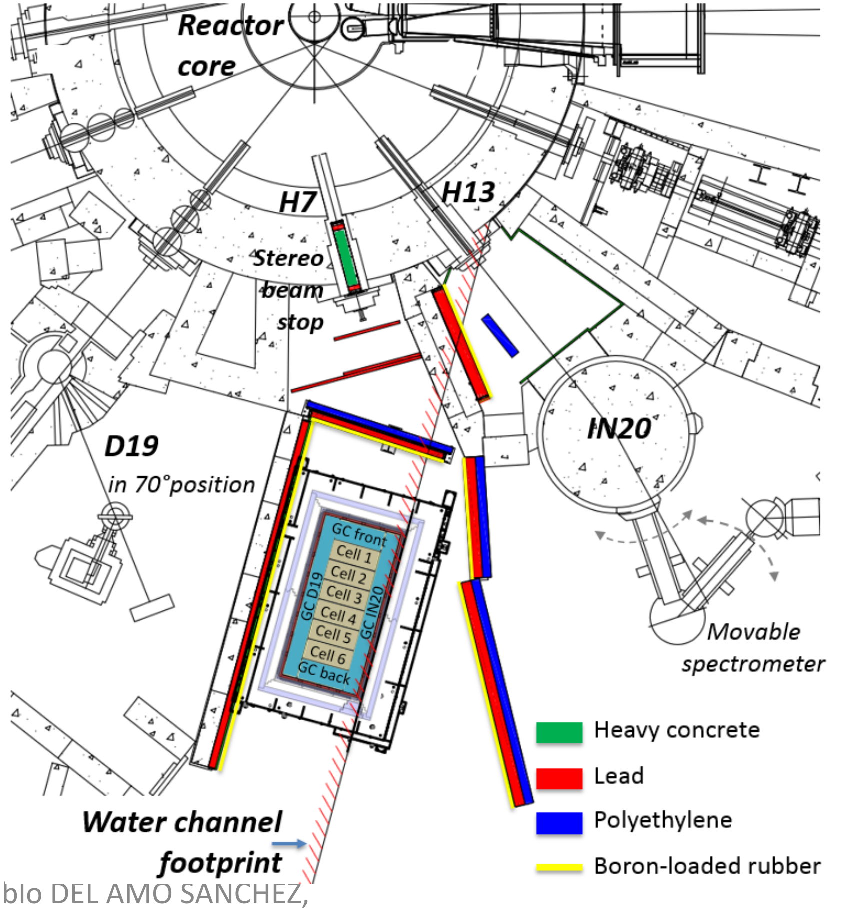
# Reactor sources of background

- Extraction of neutron beams for neighboring experiments.
- Extensive campaigns of characterization of n and γ sources before shielding design.




- High E γ's from n-capture on metals, $^{41}$Ar in and $^{16}$O in primary water circuit
- Stray magnetic fields from IN20 magnets.

Heavy passive shielding added on front and side walls



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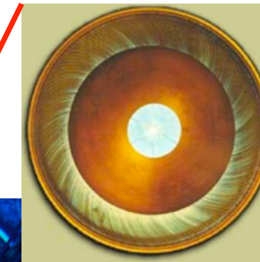
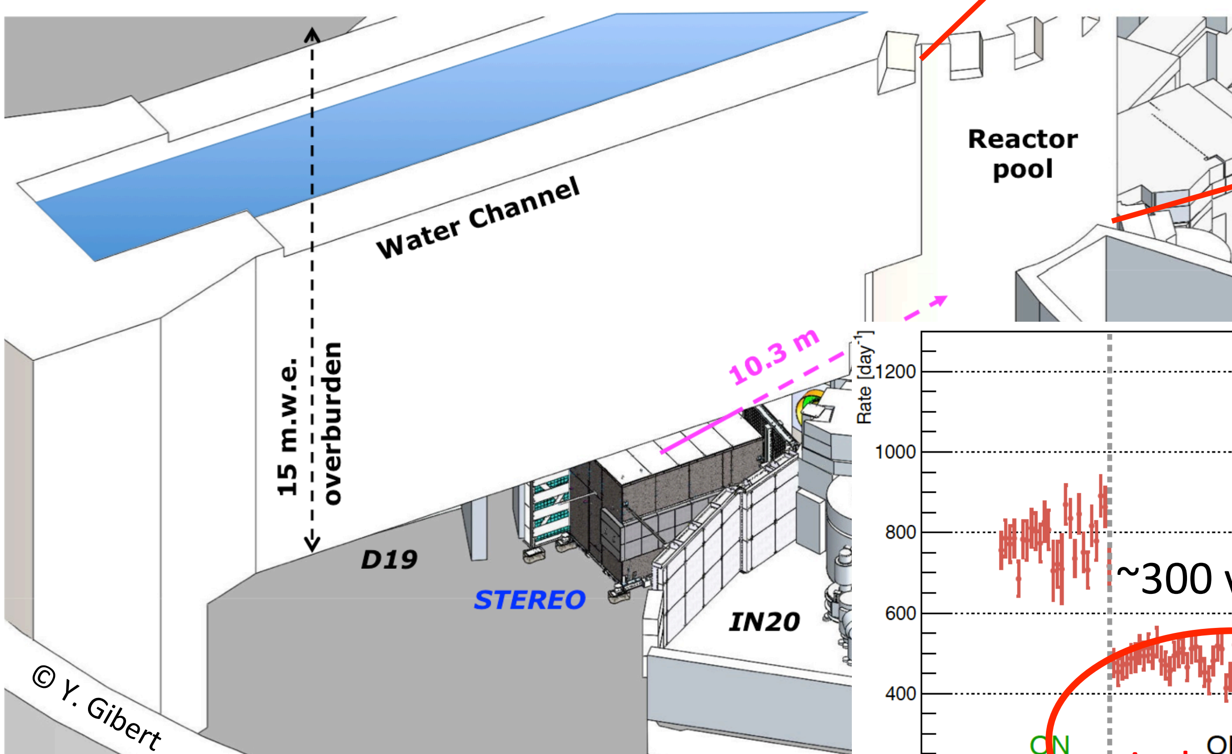
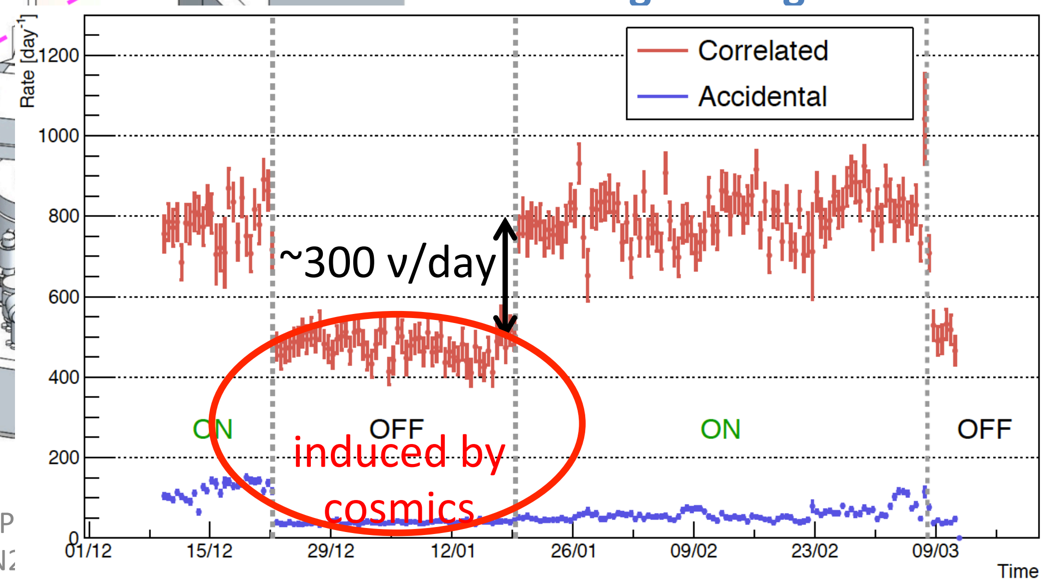




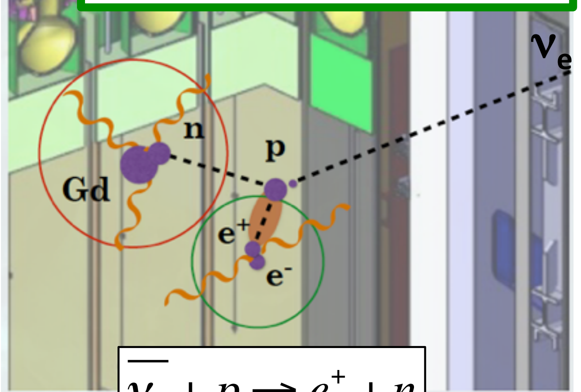

Challenging mitigation of the background generated



# Selection cuts

## Neutrino selection

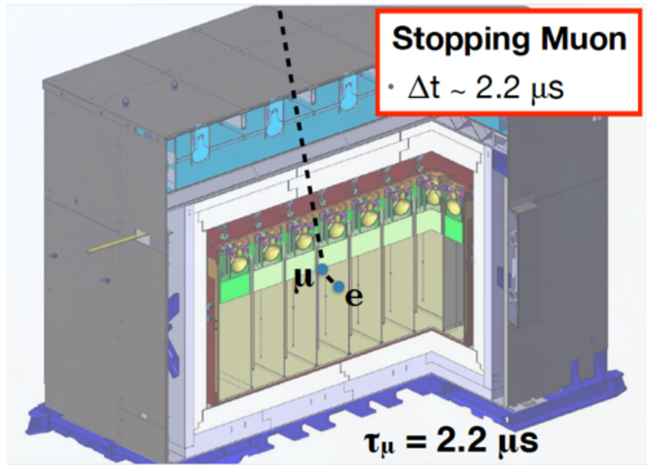
**IBD**
- $E_{prompt}$ = 1.625-7.125 MeV
- $E_{delayed}$ = 4.5-10 MeV
- $\Delta t$ = 0.25-70 μs




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

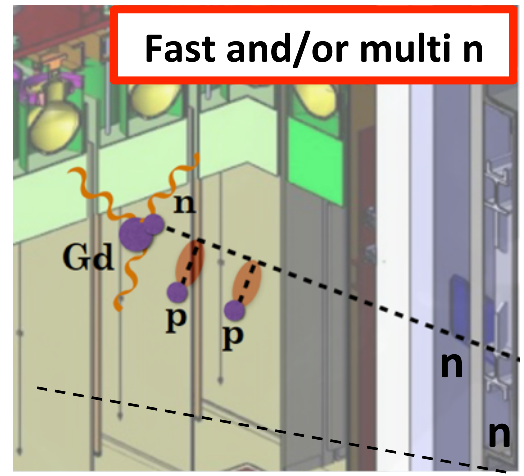
## Background rejection (cosmic rays)

**Stopping Muon**
- $\Delta t \sim 2.2$ μs




- Charge asymmetry per cell: $Q_{max}/Q_{tot} < 0.50$

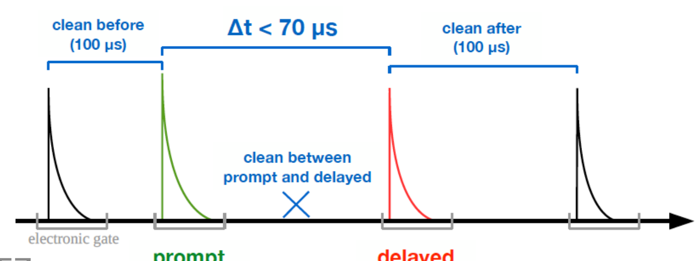
**Fast and/or multi n**



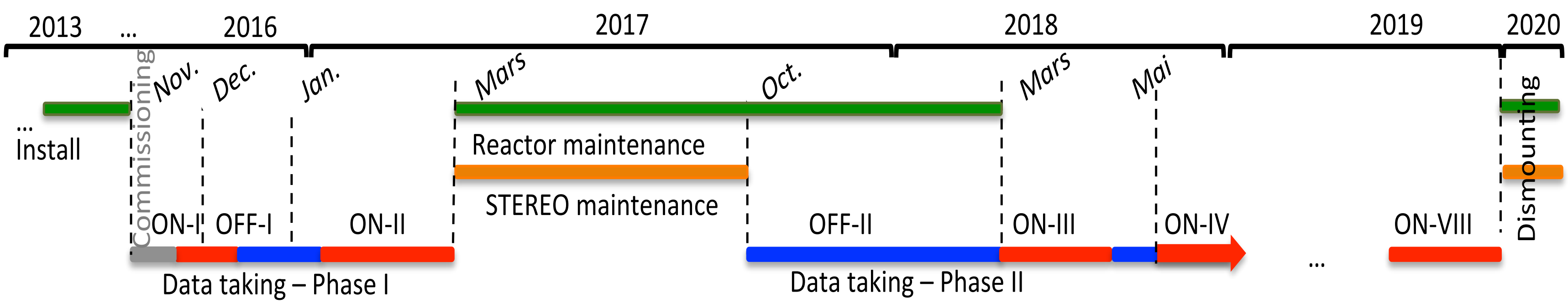

- $\Delta t_{last\text{-}\mu} > 100$ μs
- Isolated prompt-delayed pair

Topology cuts:

- $E_{prompt}$ in γ-catcher < 1.1 MeV
- $E_{prompt}$ in neighboring cell < 0.8 MeV
- $E_{delayed}$ in target > 1 MeV
- $D_{prompt\text{-}delayed} < 60$ cm



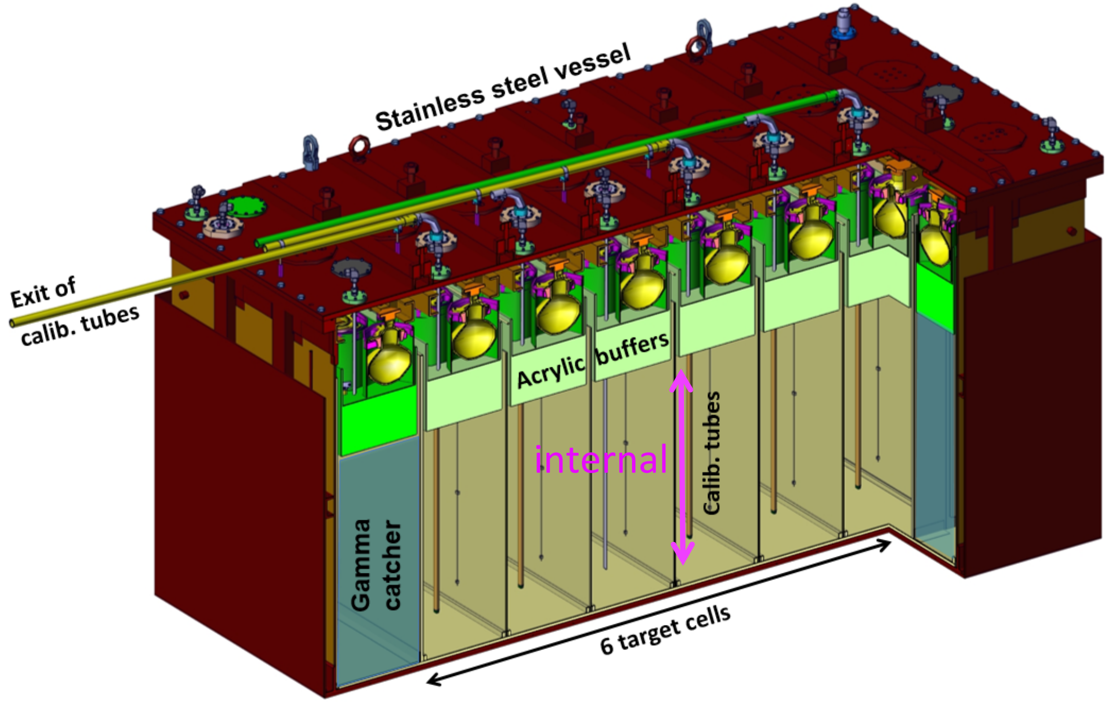
# Timeline




- Data taking started in Nov 2016
- Registered 66 days reactor ON + 28 react OFF before reactor shutdown for maintenance (Phase I)
- Back to data-taking in Oct 2017 – plenty of reactor OFF data to study cosmic-induced backgrounds

# STEREO calib systems

Need to calibrate every (small) active volume independently




3 different ways to expose active volumes to radioactive sources:

- internal calib tubes (Target only, 5 cells)
- outside steel vessel, around GC
- outside steel vessel, below central axis

| Source | $^{68}$Ge | $^{124}$Sb | $^{137}$Cs | $^{54}$Mn | $^{65}$Zn | $^{60}$Co | $^{24}$Na | AmBe |
|---|---|---|---|---|---|---|---|---|
| $\gamma$-ray energies (MeV) | 0.511<br>0.511 | 0.603<br>1.69 | 0.662<br>- | 0.835<br>- | 1.11<br>- | 1.17<br>1.33 | 1.37<br>2.75 | 2.22 (H(n,$\gamma$))<br>4.43 |
| Initial Activity (kBq) | 90 | 2.4 | 37 | 90 | 3.3 | 50 | 5.9 | $250 \cdot 10^3$ ($^{241}$Am) |

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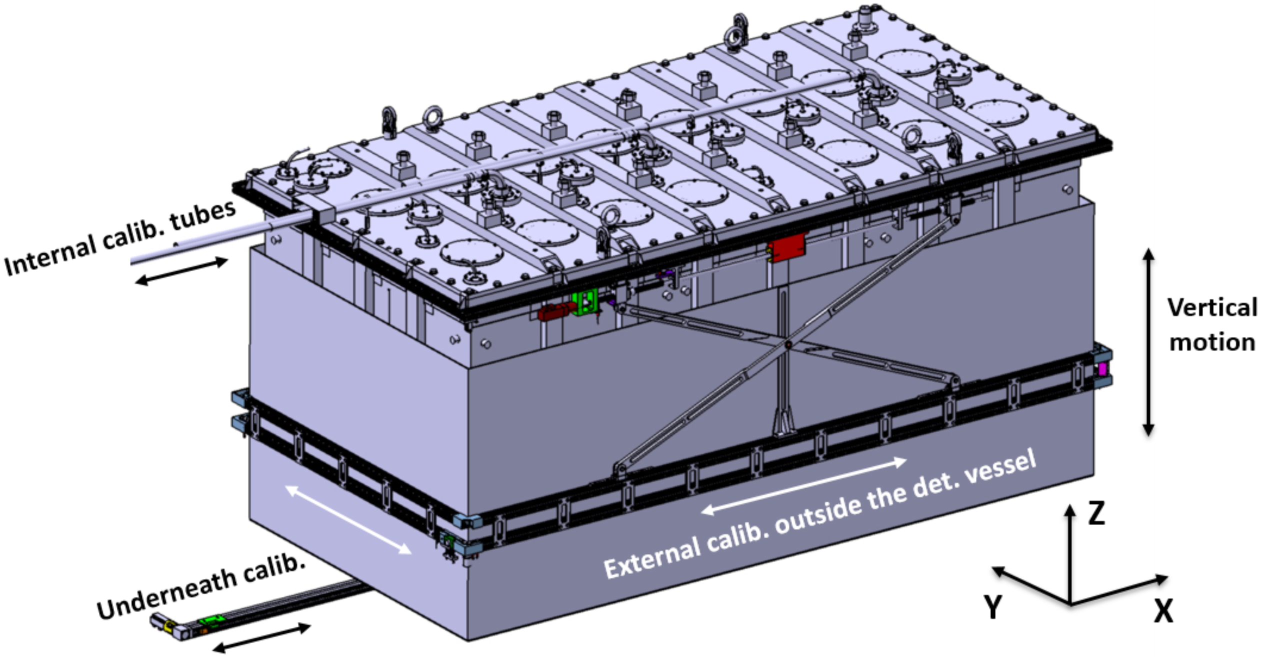


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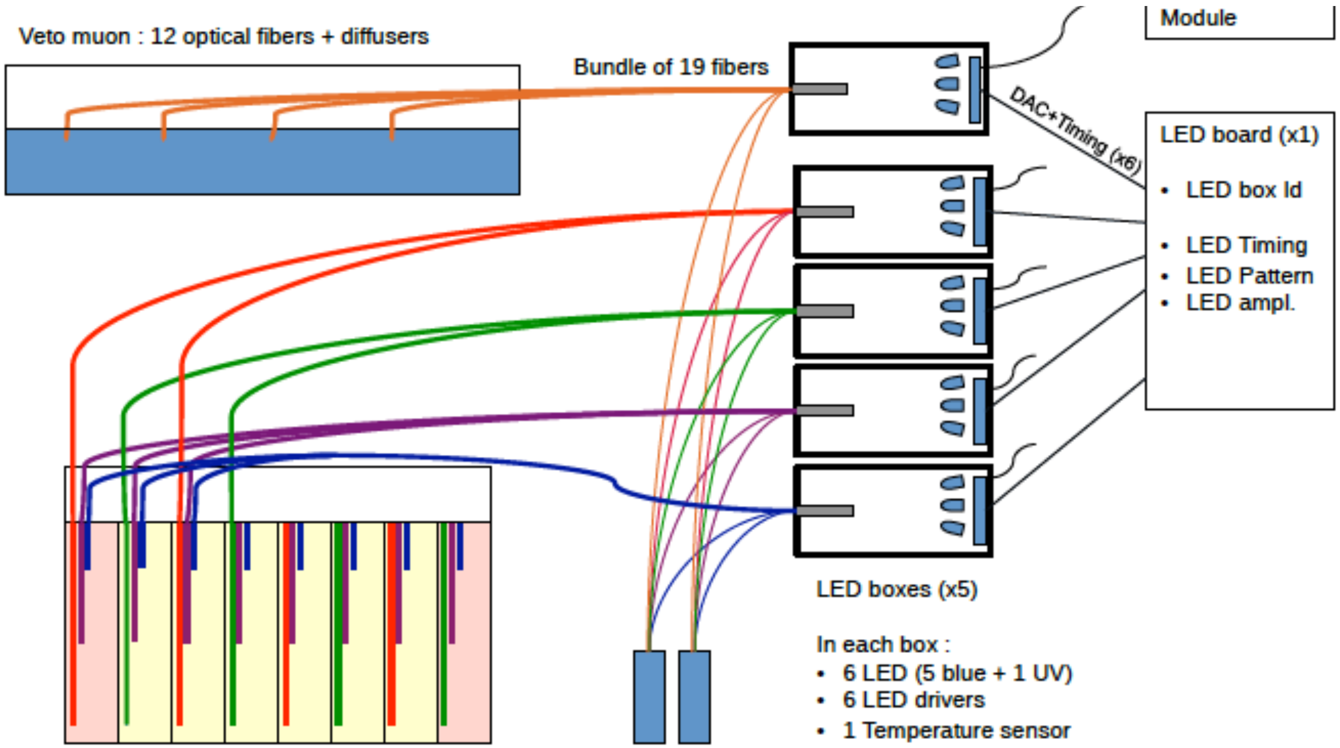
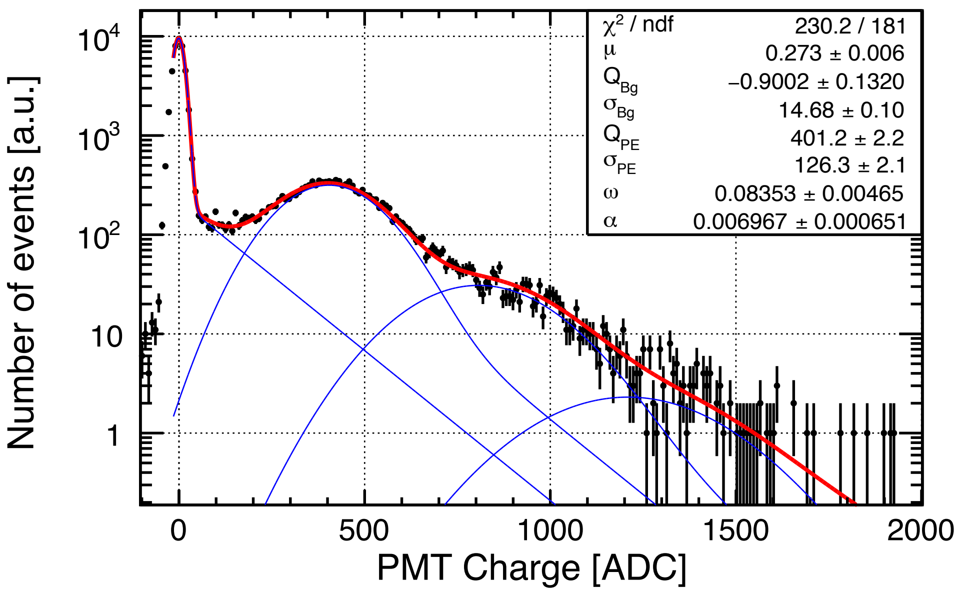
# STEREO calib systems

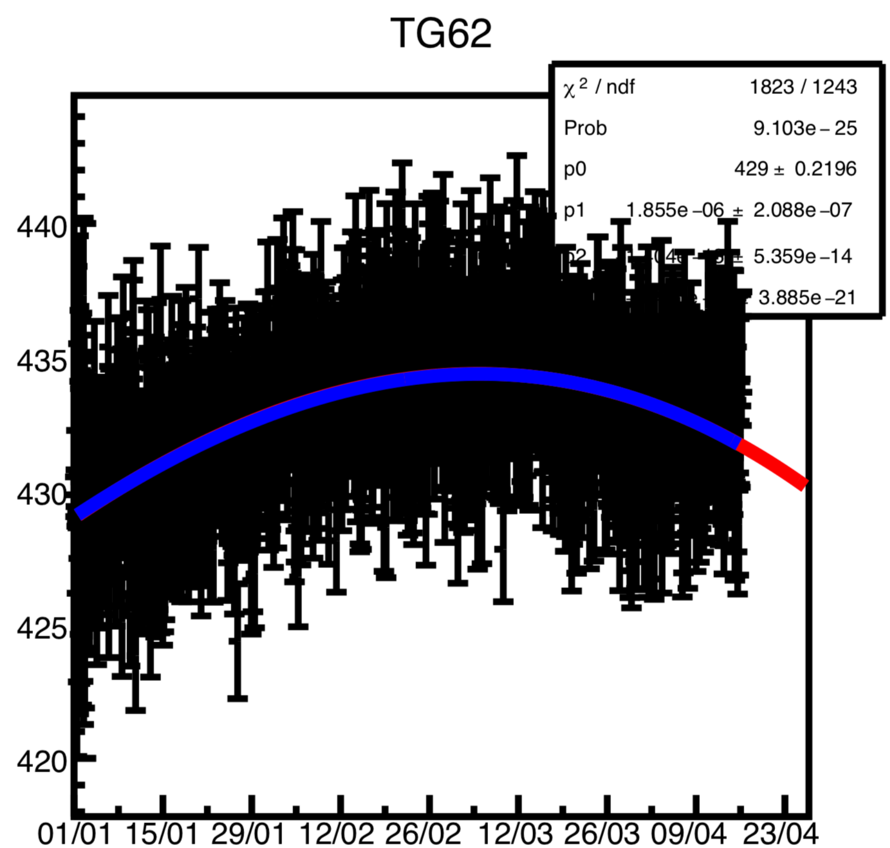
- 465nm wavelength LED coupled to 3 optic fibers/cell ending in diffusive teflon balls
- Monitoring of light attenuation, collection; PMT gain calibration; electronics non-linearities



# PE gain calib

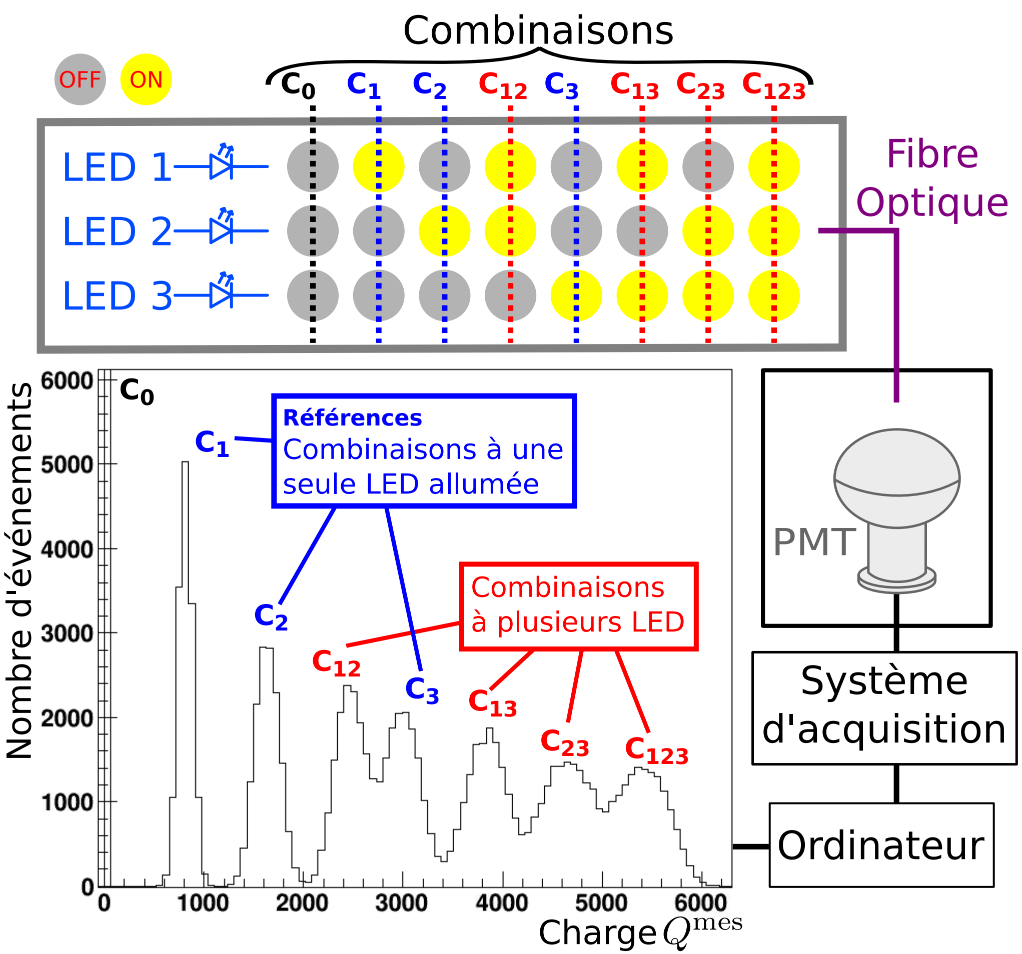



- Single PhotoElectron gain calibration several times a day

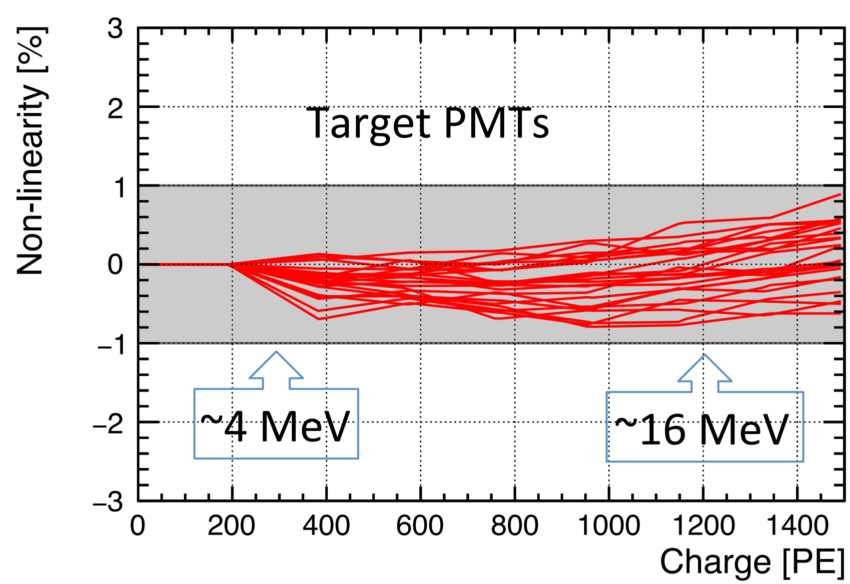



- Gain interpolated to smooth out fluctuations
- Target & GC PMTs ~ 1% variation

# Electronics non-linearities




- Switch LEDs on simultaneously and compare with LEDs one at a time
- Target PMTs non-linearity well below 1%





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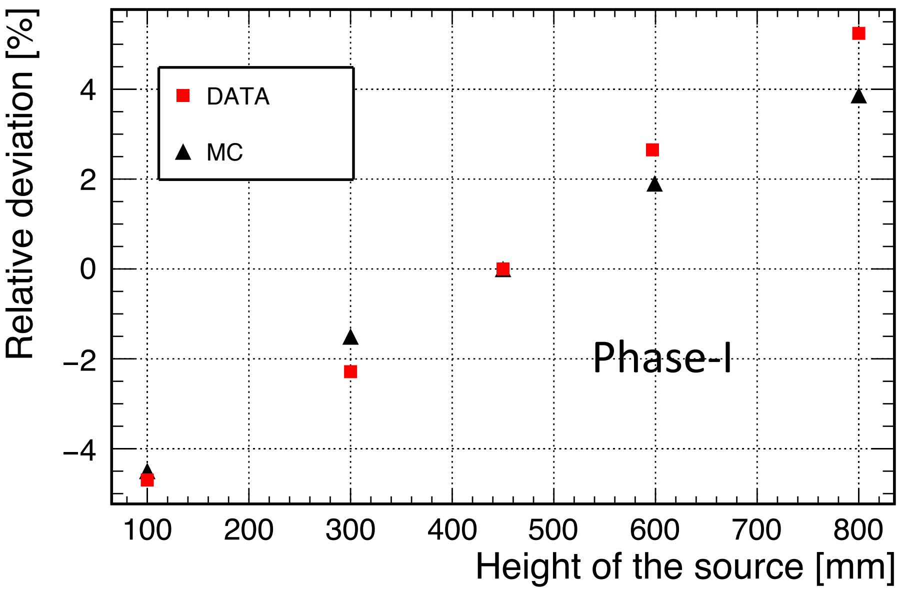
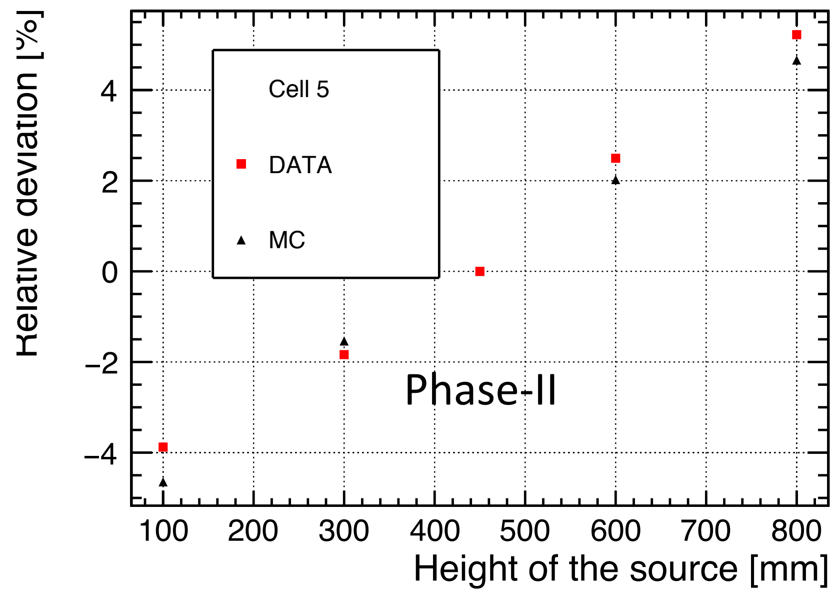
# Light collection in MC

- Inhomogeneous light collection within a cell
- Little chance of correcting for it (reflection scrambles photon trajectories, localisation within a cell impossible)
- But: model accurately height dependence in MC to match rad sources data
  (attenuation length, wall reflectivity, refractive indices)

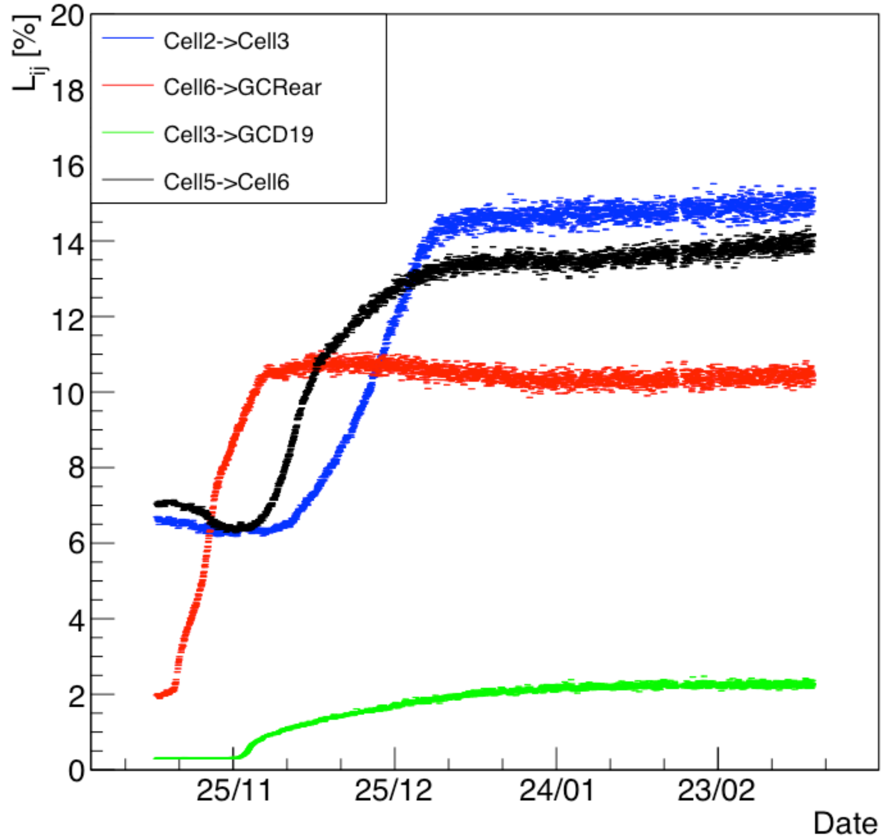


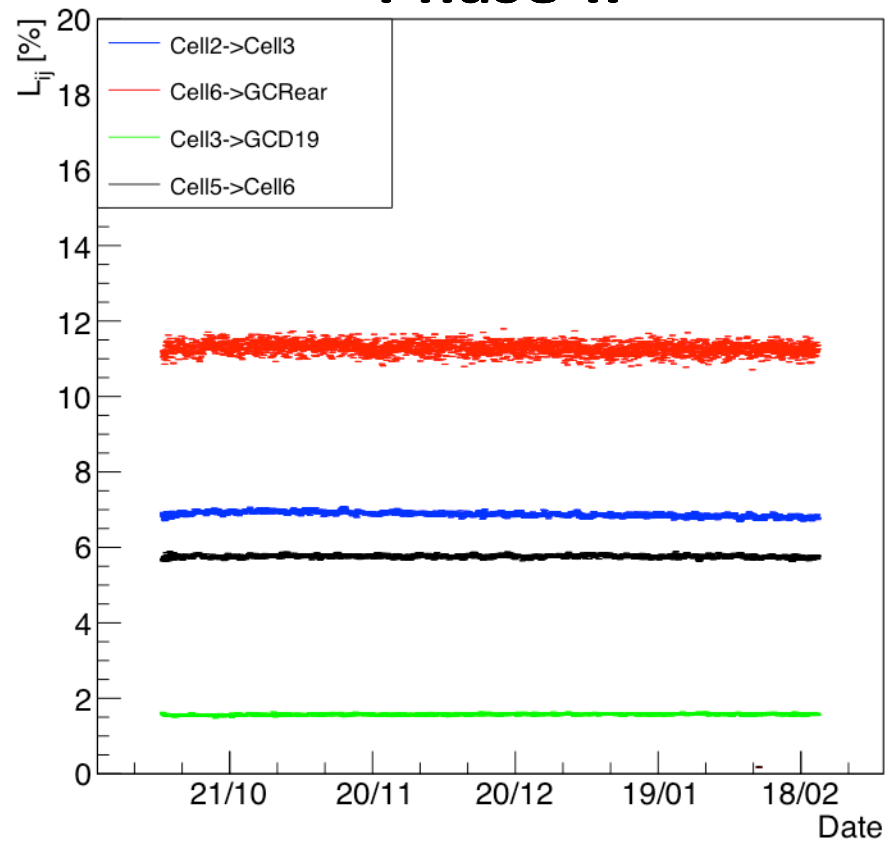
# Light Crosstalk between cells

- "Bumpy" first physics run from a light-collection point of view:

**Phase-I**




**Phase-II**



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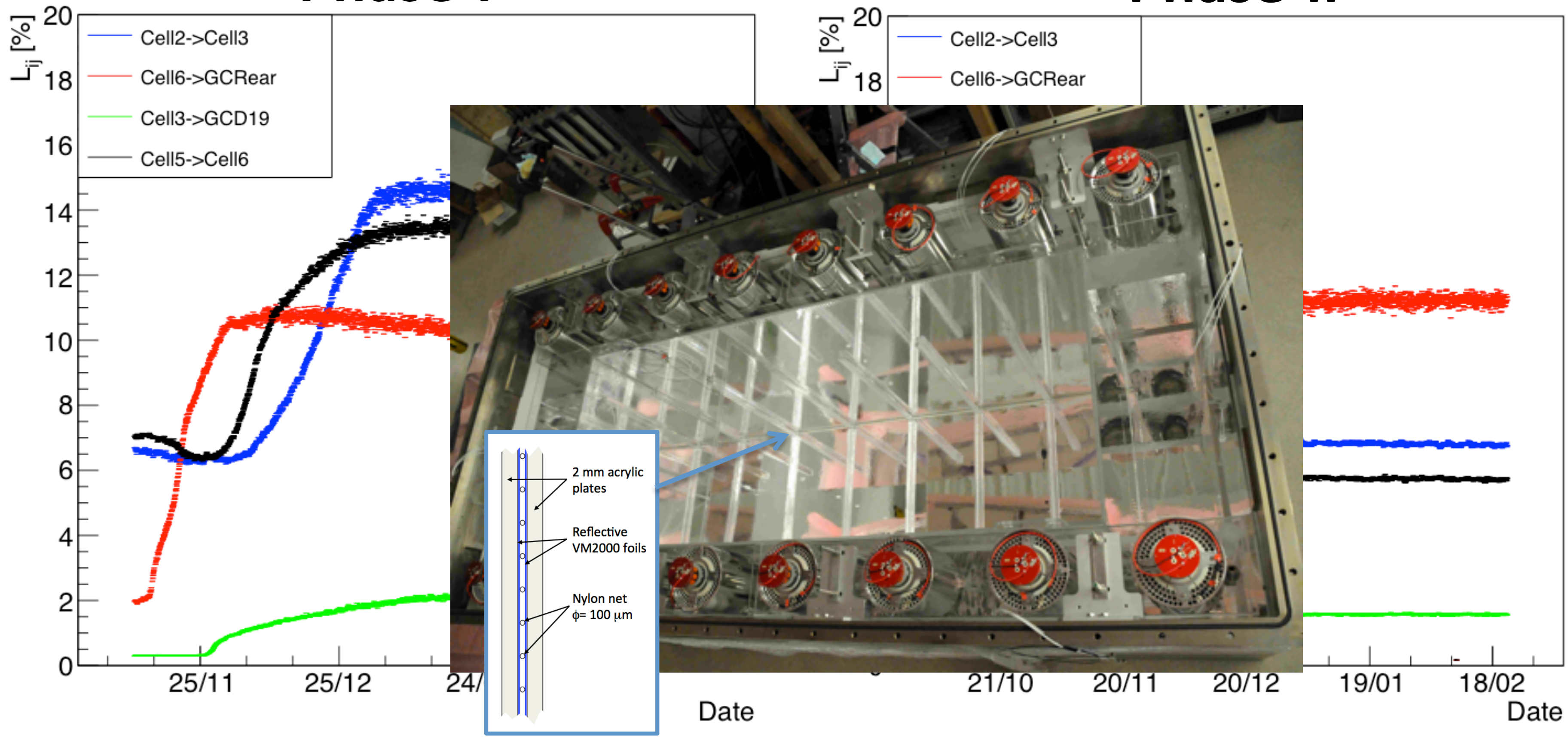
**Phase-I** **Phase-II**





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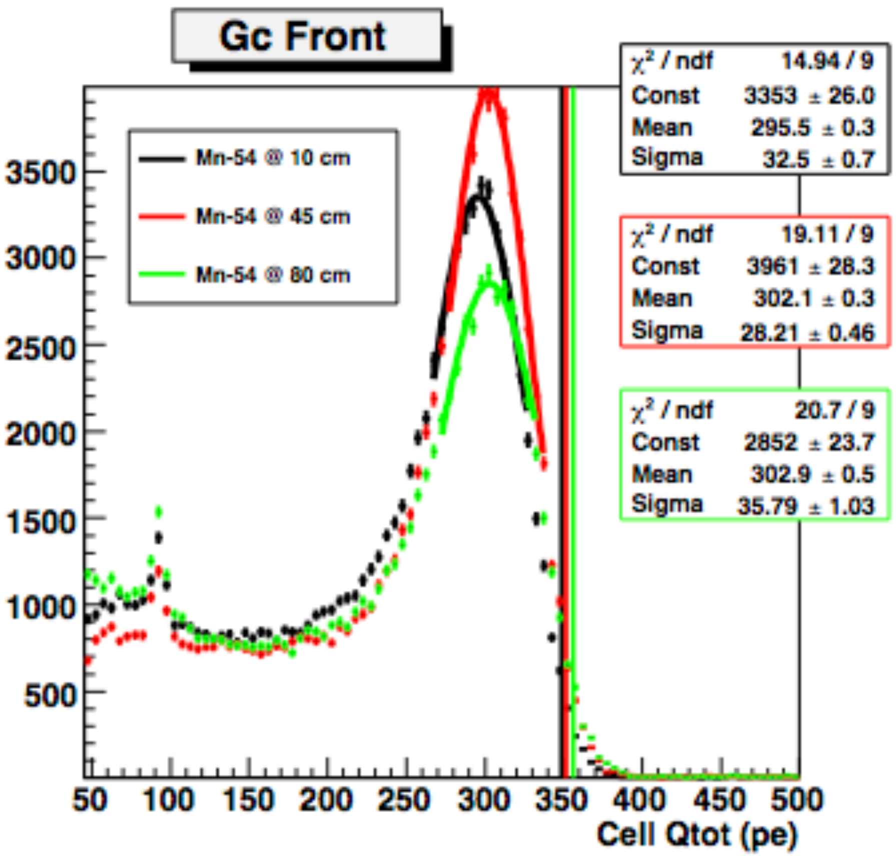
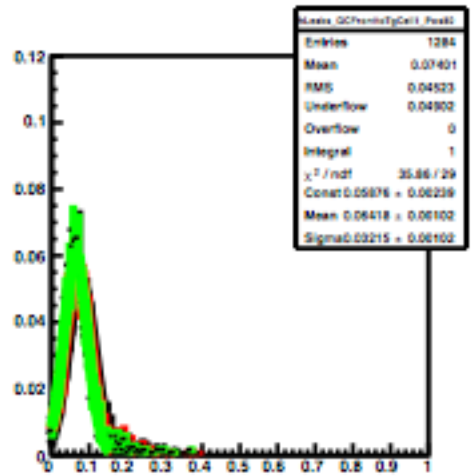
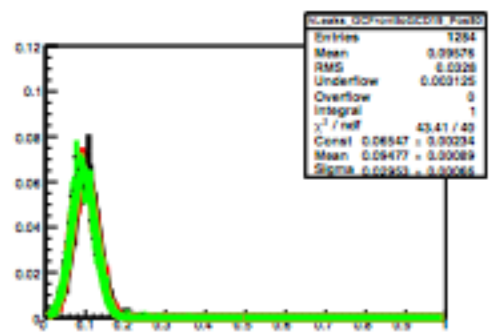
# Crosstalk – Rad sources

Precisely track light crosstalk with frequent internal, low energy source ($^{54}Mn$) calibs



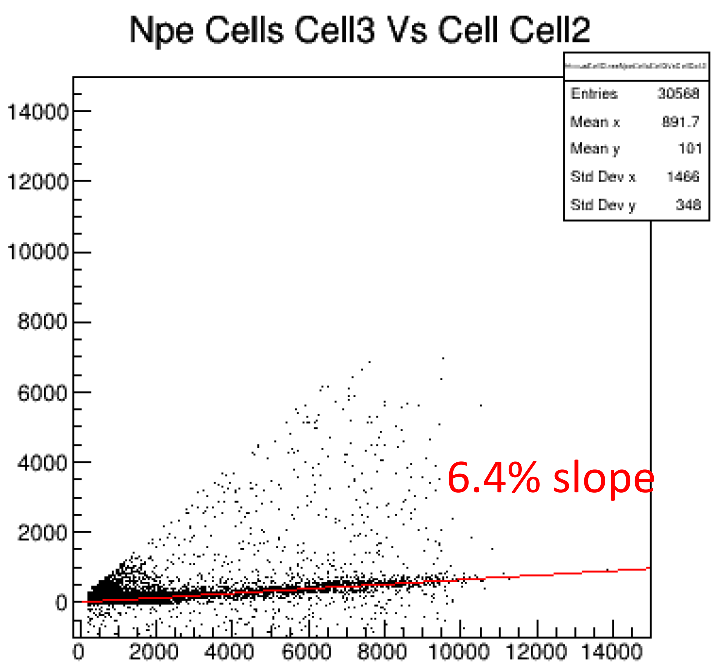



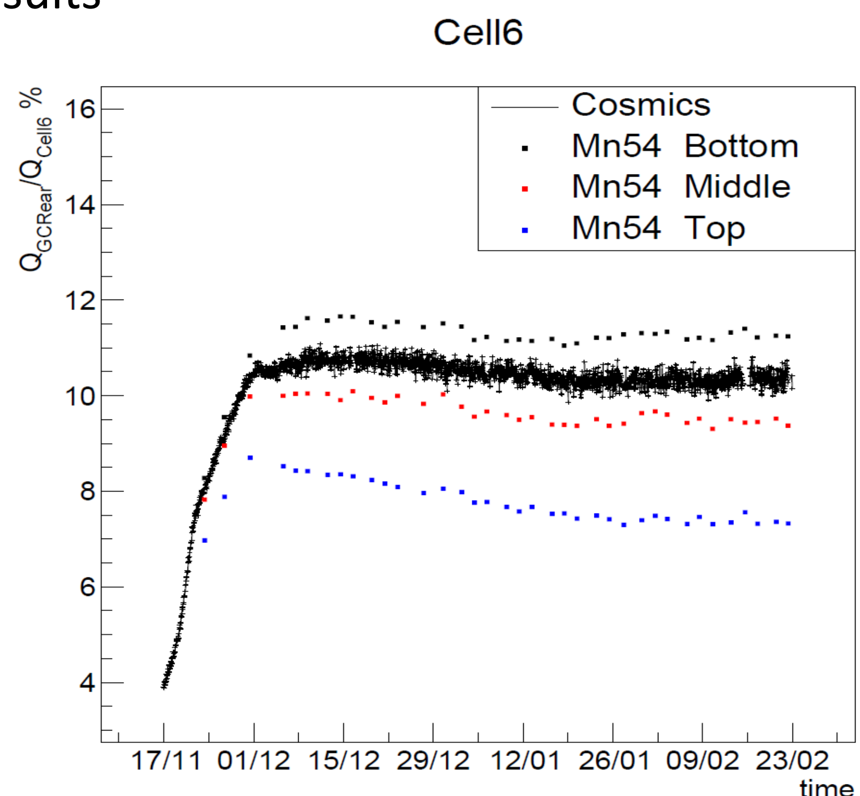


- Avoid energy deposition in nearby volumes: select only events in right-hand tail
- Height dependence of crosstalk observed

# Crosstalk – Cosmics

- Independent method: look at correlation of charges in different cells in single triggers (mostly cosmics)
- "Online" measurement
- In good agreement with source results



# Crosstalk-correcting E reco

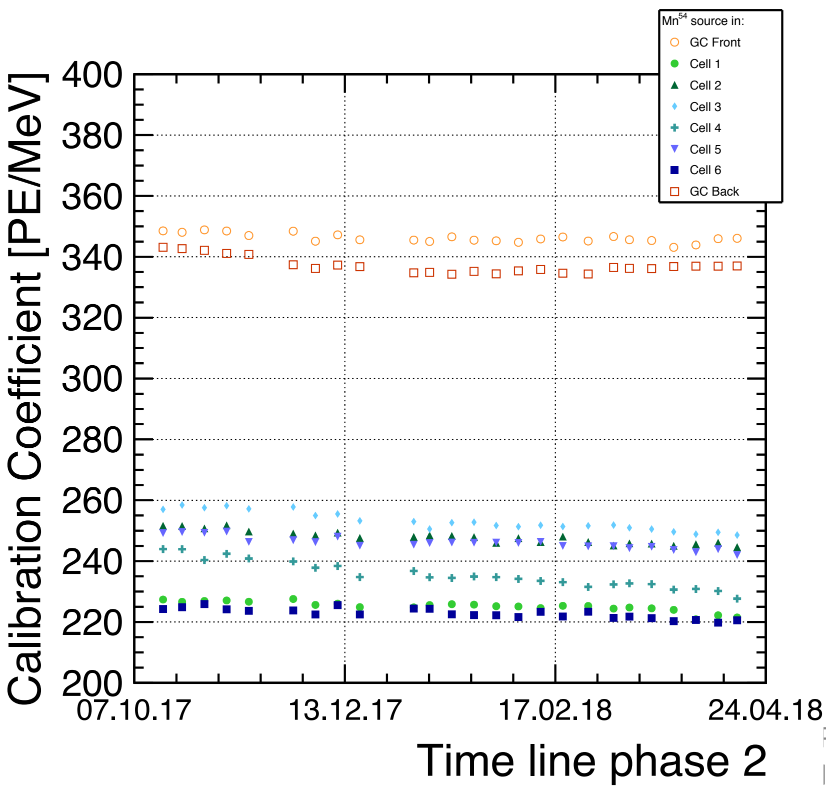
- Correct for cross-talk in energy reco algorithm – greatly simplifies Data/MC comparison

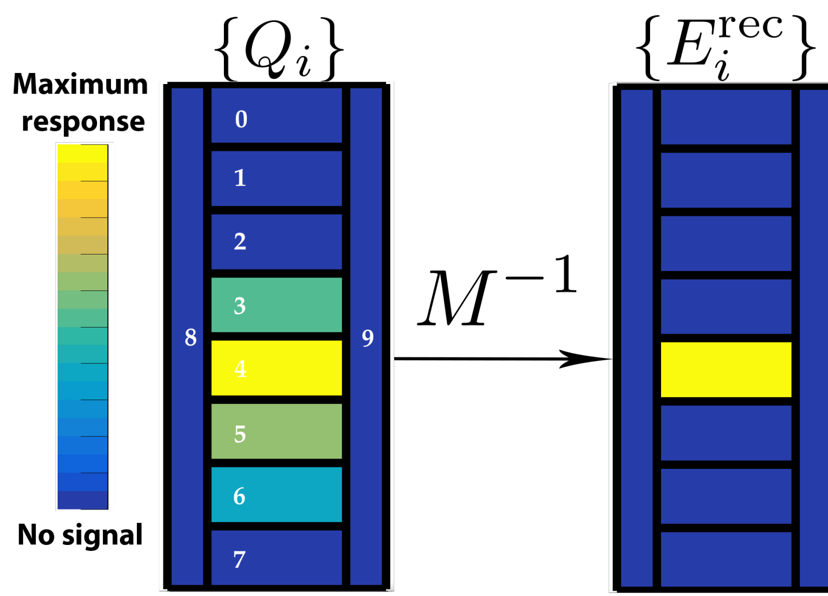
Light crosstalk

$$Q_i = \sum_j E_j^{dep} \times C_j \times L_{ji} = \sum_j E_j^{dep} M_{ji}$$

Calib coeffs

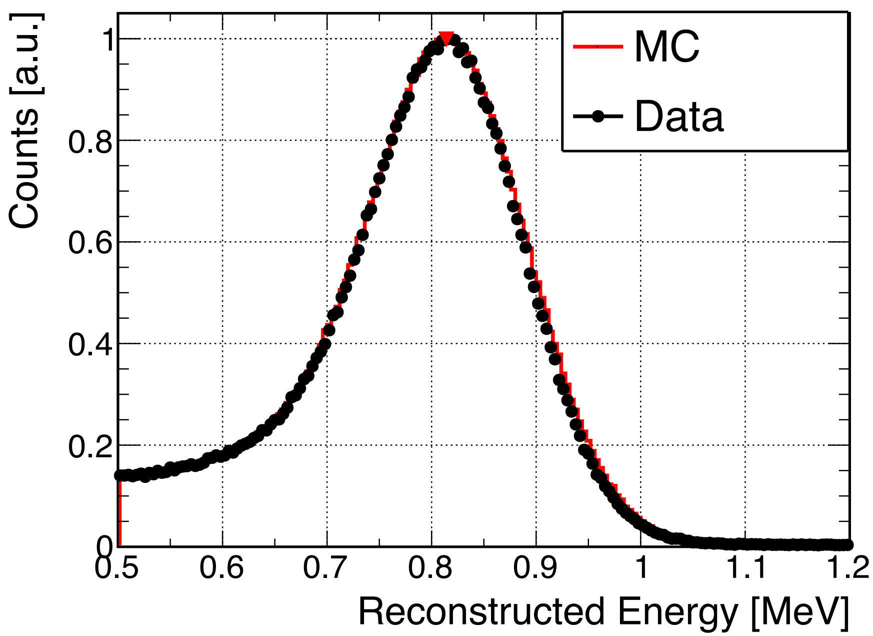
$$M^{-1}\begin{pmatrix} Q_0 \\ Q_1 \\ \vdots \\ Q_9 \end{pmatrix} = \begin{pmatrix} E_1^{rec} \\ E_2^{rec} \\ \vdots \\ E_9^{rec} \end{pmatrix}$$

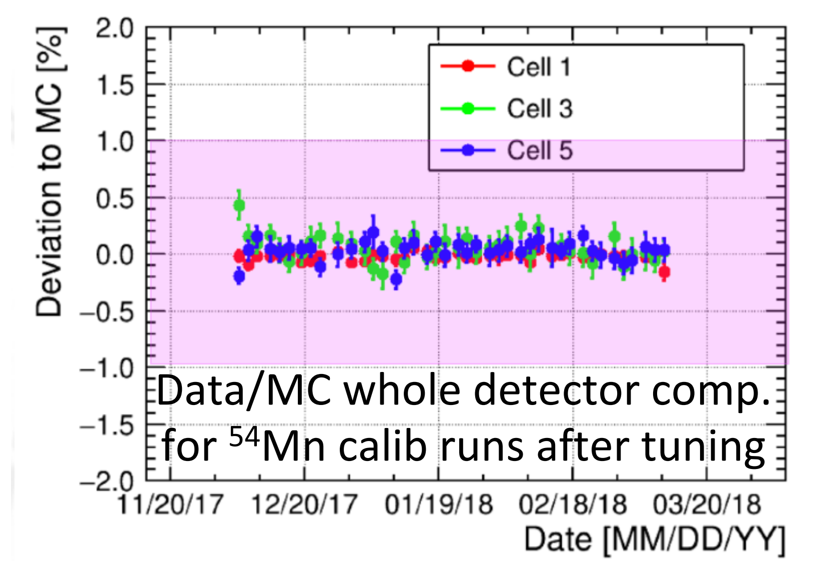


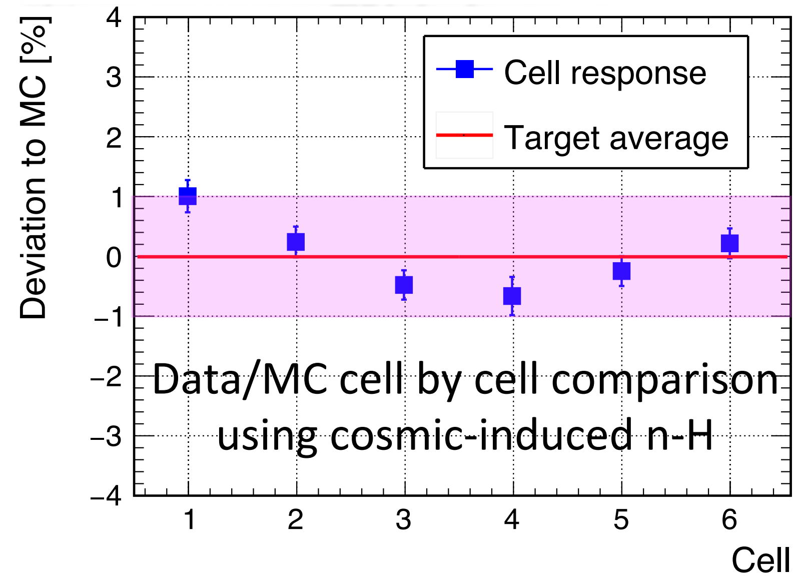



# Calibration coeffs tuning

- Energy scale anchor 0.835 MeV ($^{54}Mn$)
- Iteratively tune $C_i$ and $L_{ij}$ so that energies reco'ed in Data and MC match
- 9.4% energy resolution at 0.835 MeV
- 0.2% systematics from true E deposit
- 1% cell-to-cell uncorrelated systematcs

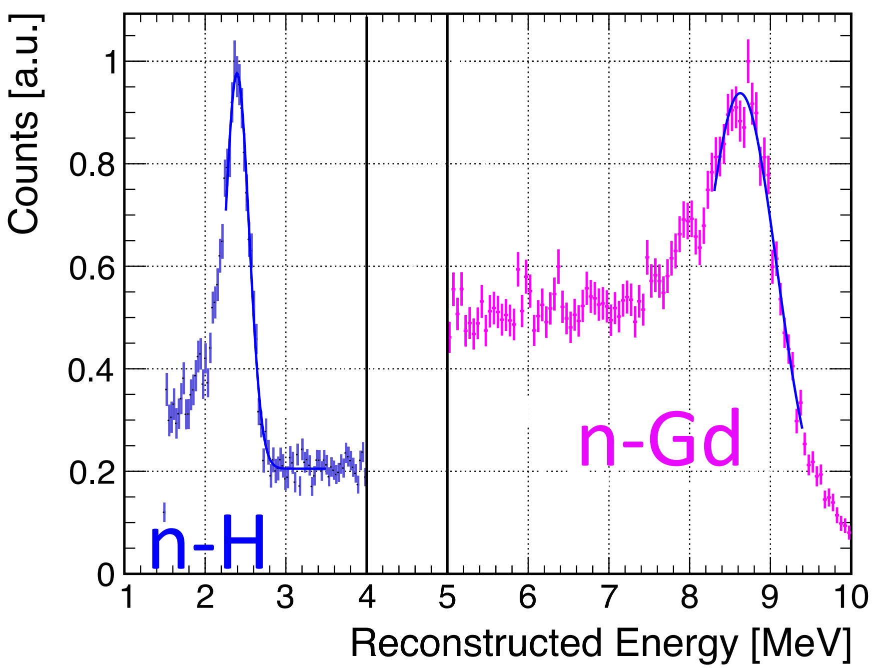


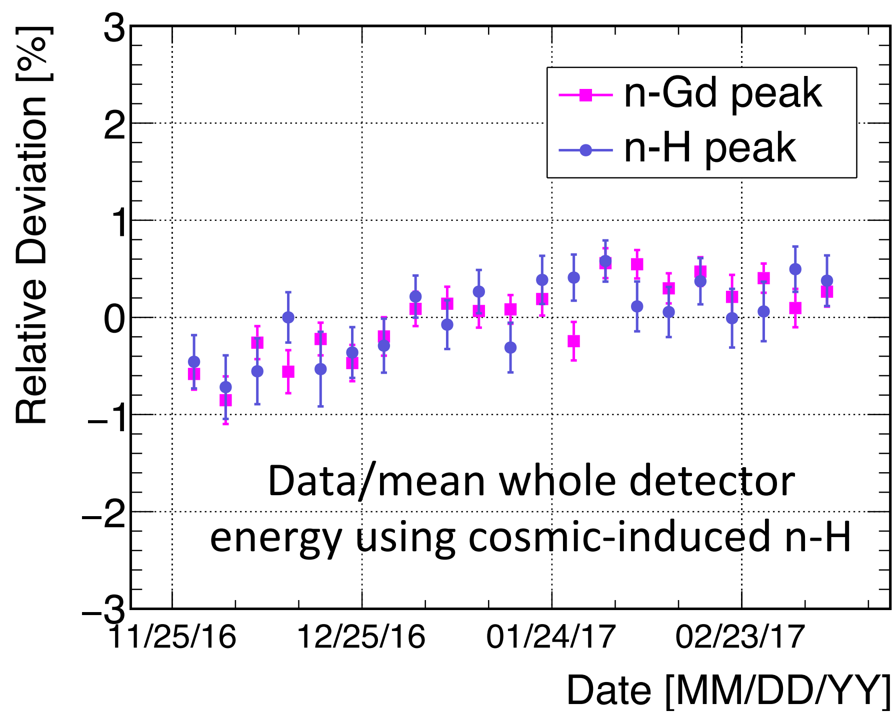



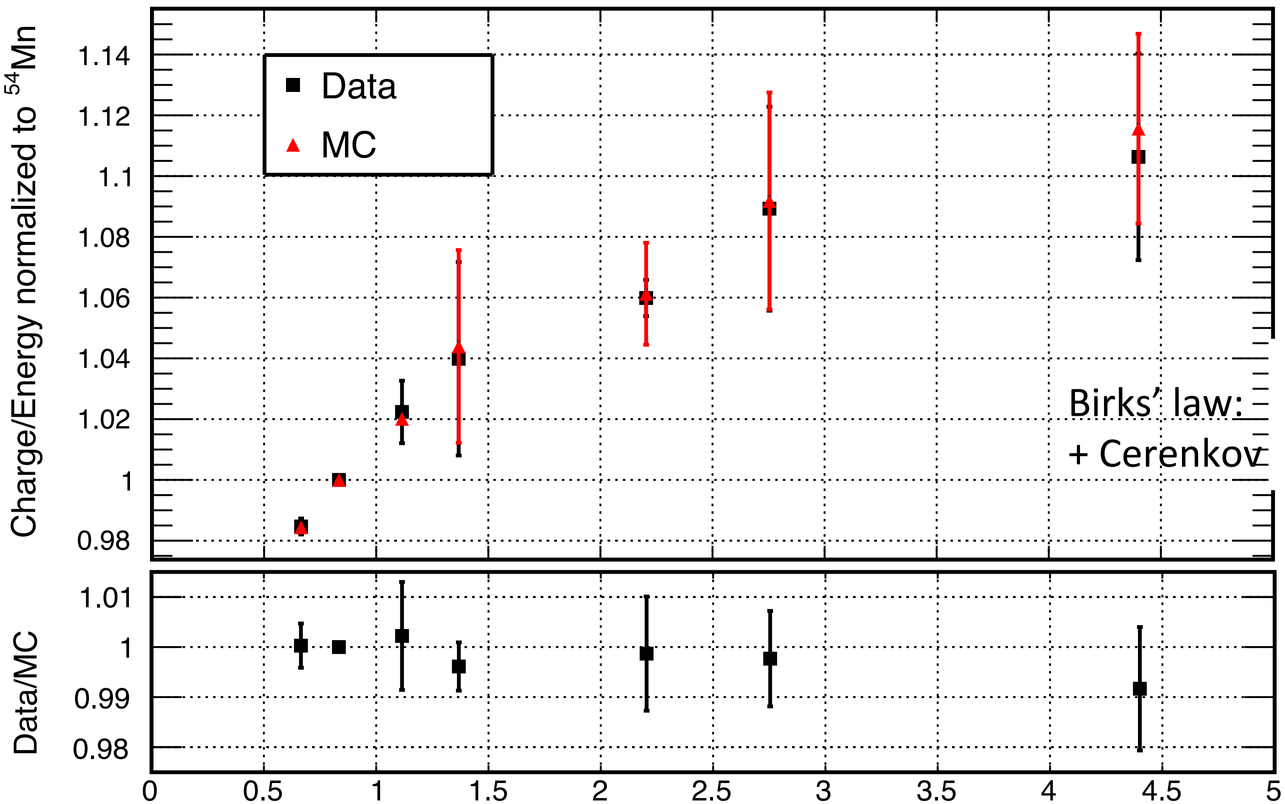
# E scale time stability

- Use n captures from cosmic spallation to monitor energy scale time stability
- 0.35% variation in Phase I



# Quenching




Precisely determined LS non-lineariy (1% level)

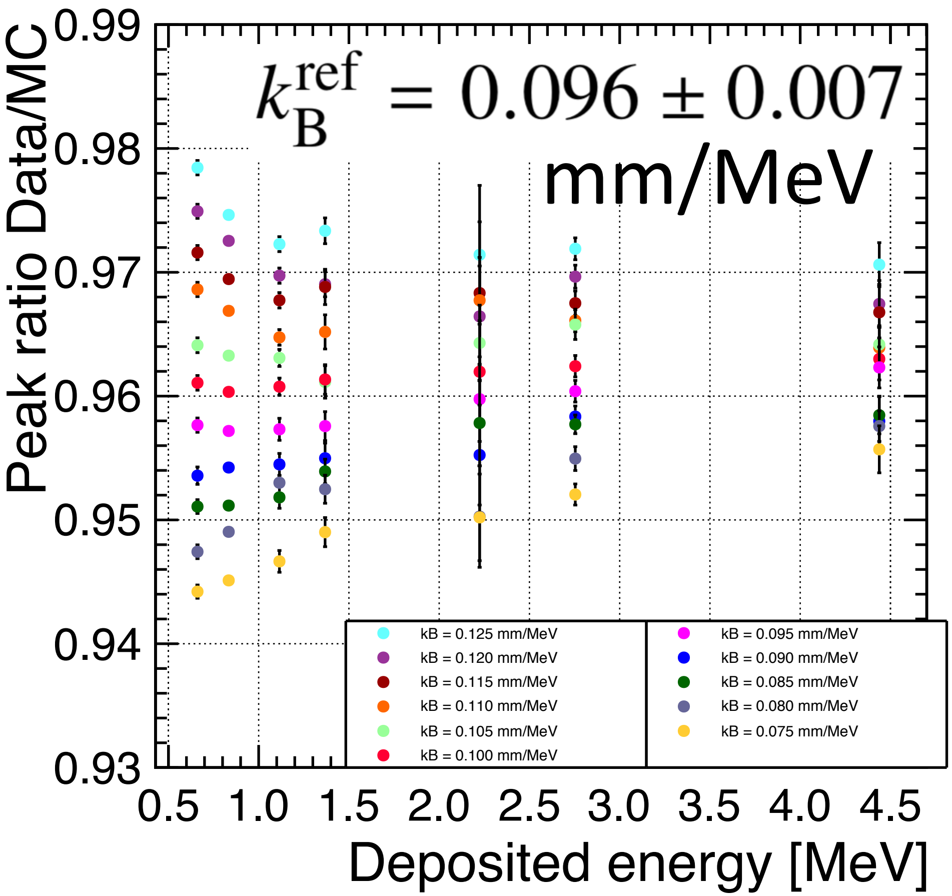
$$\frac{dL}{dx} = S \frac{\frac{dE}{dx}}{1 + K_{Birks}\frac{dE}{dx}}$$

Very good Data/MC agreement after $k_B$ tuning

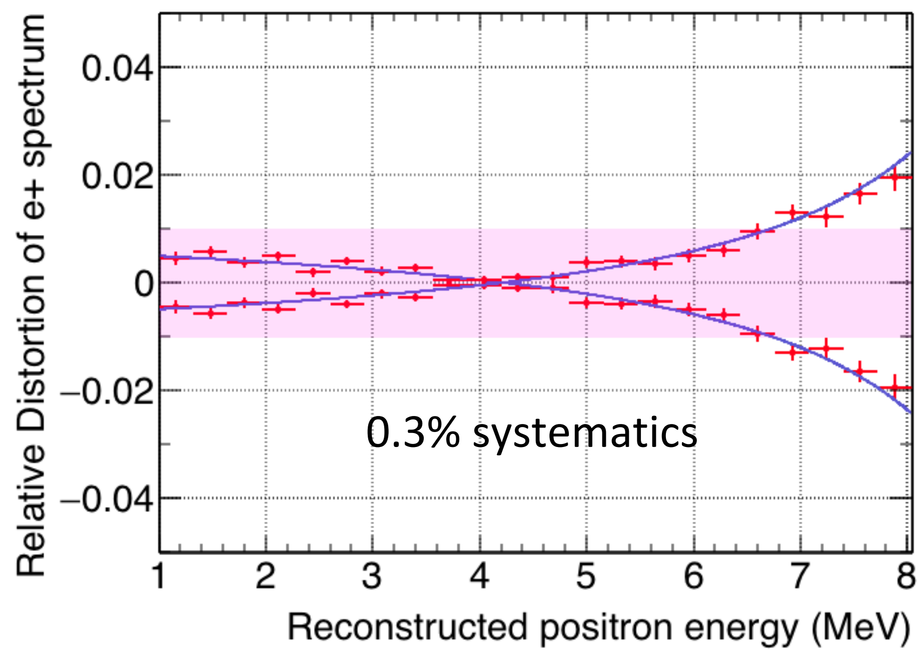
| Source | $^{68}$Ge | $^{124}$Sb | $^{137}$Cs | $^{54}$Mn | $^{65}$Zn | $^{60}$Co | $^{24}$Na | AmBe |
|---|---|---|---|---|---|---|---|---|
| $\gamma$-ray energies (MeV) | 0.511<br>0.511 | 0.603<br>1.69 | 0.662<br>- | 0.835<br>- | 1.11<br>- | 1.17<br>1.33 | 1.37<br>2.75 | 2.22 (H(n,$\gamma$))<br>4.43 |
| Initial Activity (kBq) | 90 | 2.4 | 37 | 90 | 3.3 | 50 | 5.9 | $250 \cdot 10^3$ ($^{241}$Am) |

# Quenching tuning in MC

- Fit to Data/MC ratio for source peak means for different MC kB values yields




Ratio of reco'ed positron energies generated using $k_B \pm 1\sigma$





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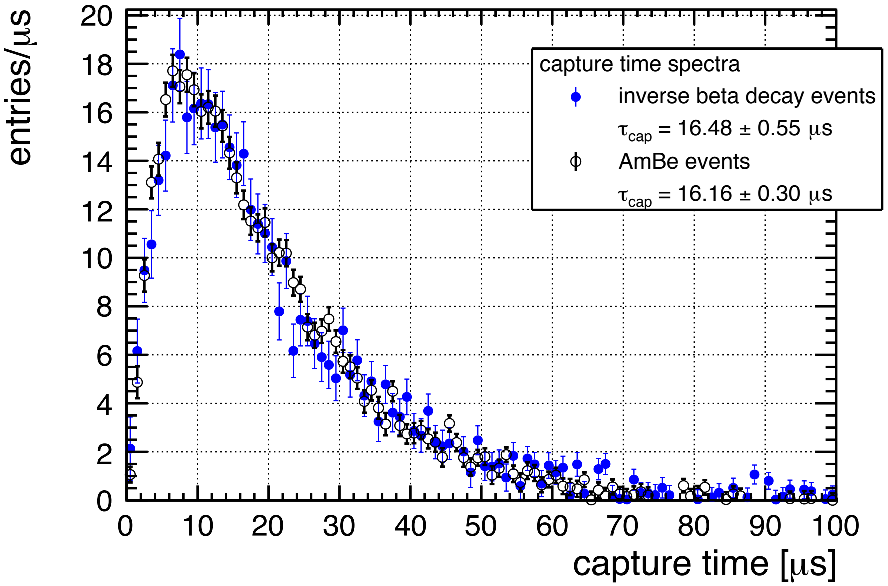
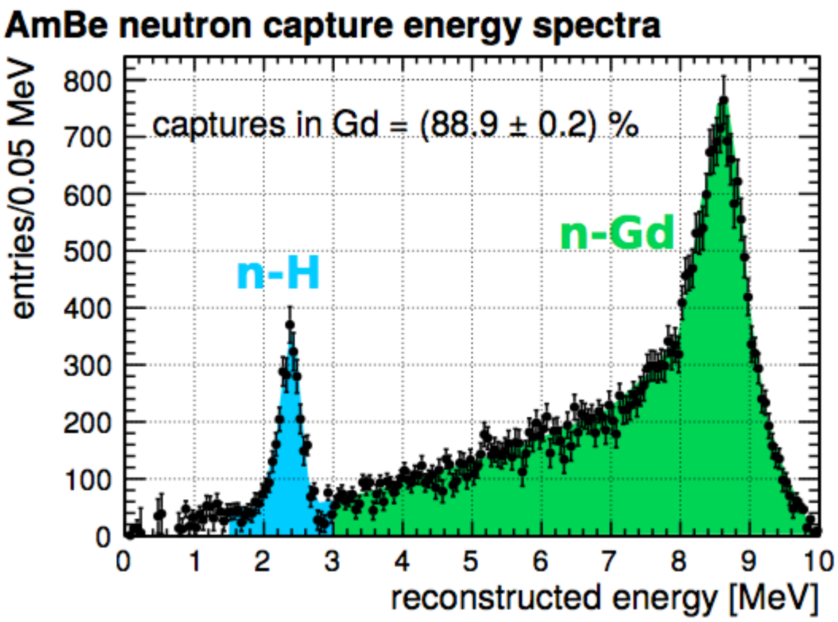
# Neutron capture efficiency

- Thoroughly studied with AmBe internal calibrations



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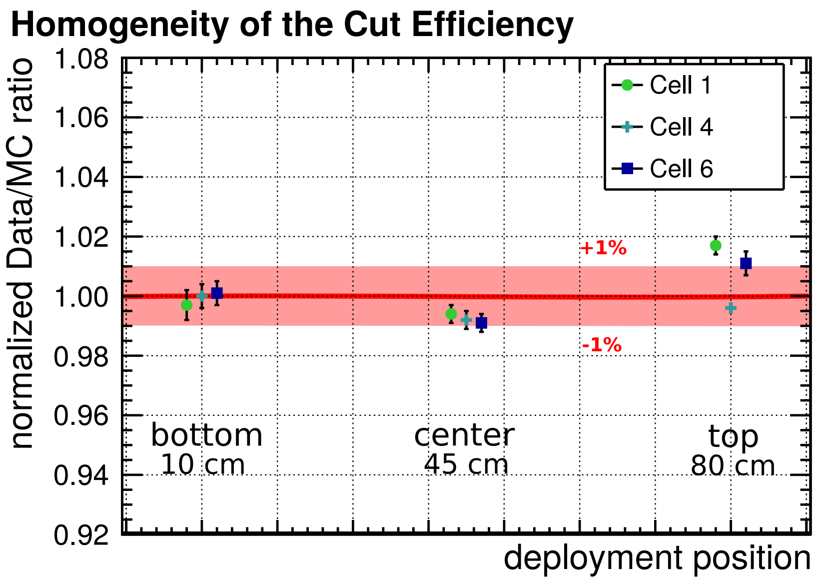
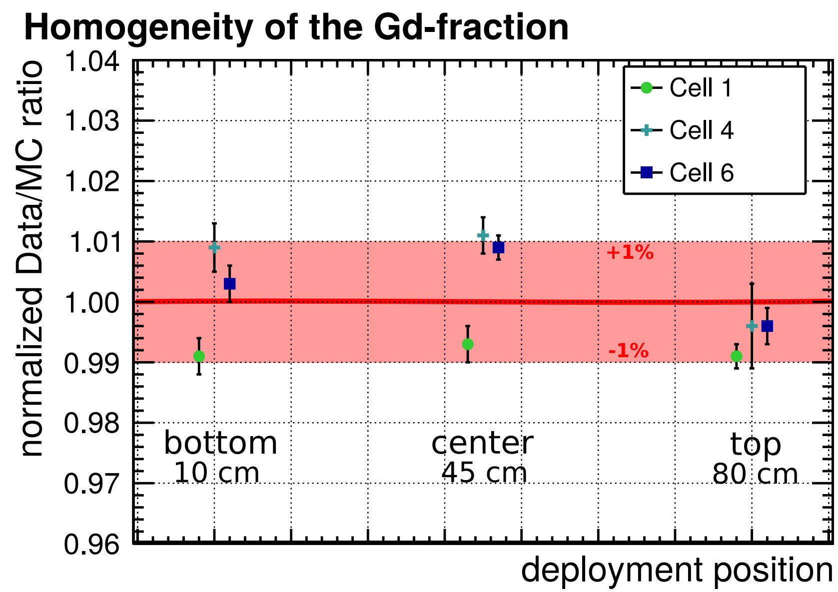


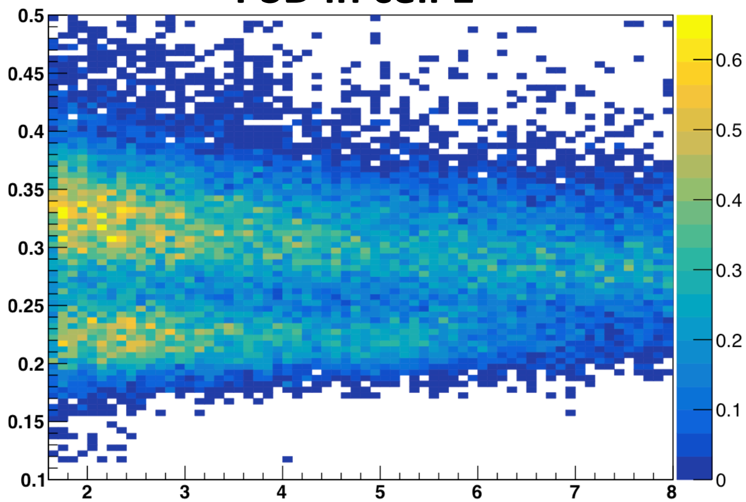




| Source | | Contrib $\sigma^{NormUncor}$ |
|---|---|---|
| n-capture eff. | 0.961 ± 0.008 (stat+syst) | 0.81% |
| IBD cut efficiency (energy + DeltaT | 0.981 ± 0.009 (stat+syst) | 0.88% |
| **TOTAL neutron eff.** | **0.943 ± 0.012 (stat+syst)** | **1.2%** |

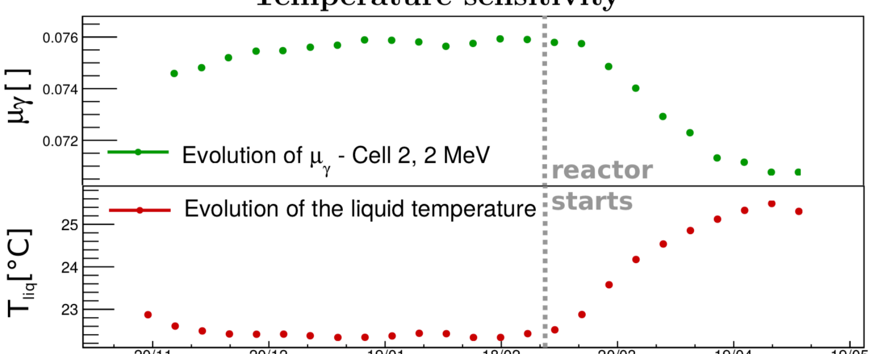
# Pulse Shape Discrimination

- Pulse Shape Discrimination response sensitive to temperature. Cosmics rate depends on atmospheric pressure ➔ not just an ON-OFF subtraction
- **In-situ PSD calibration**, PSD parameters fitted and allowed to vary with time

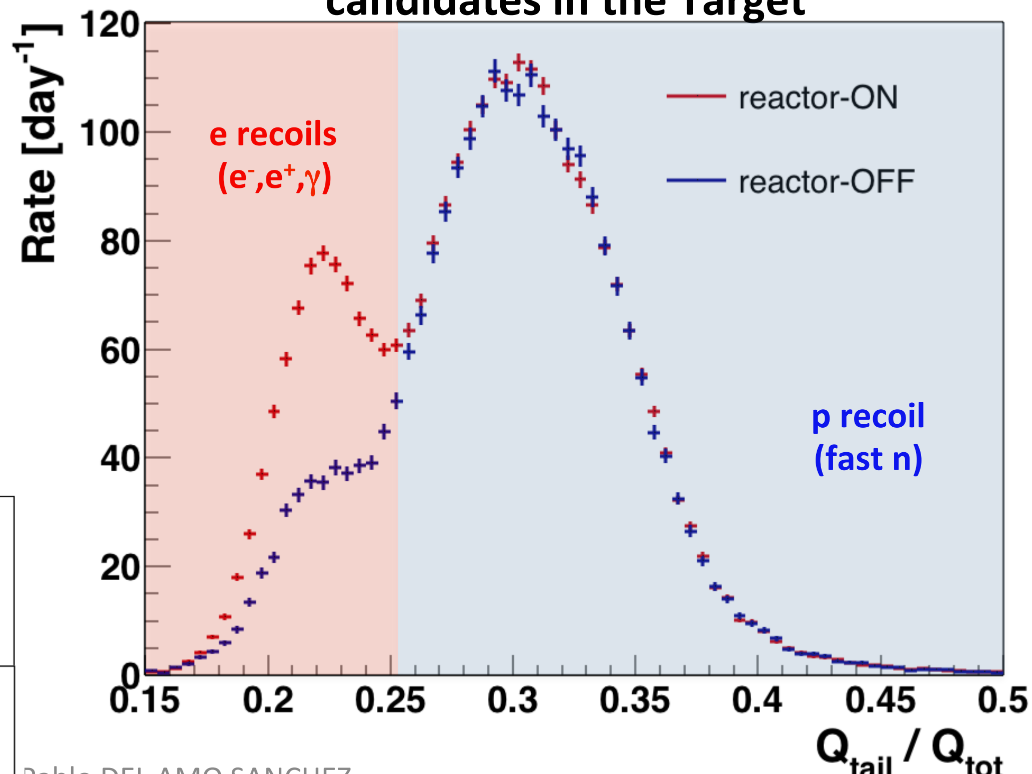
**PSD in cell 1**




Temperature sensitivity



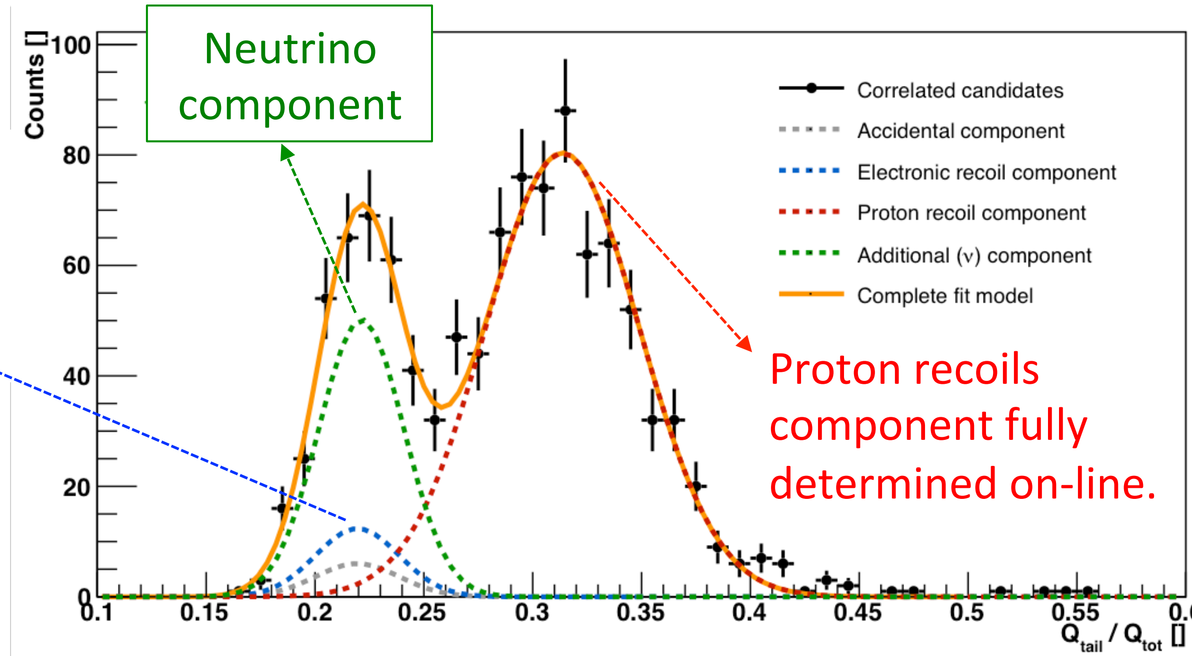

**Projected PSD distribution of all IBD candidates in the Target**



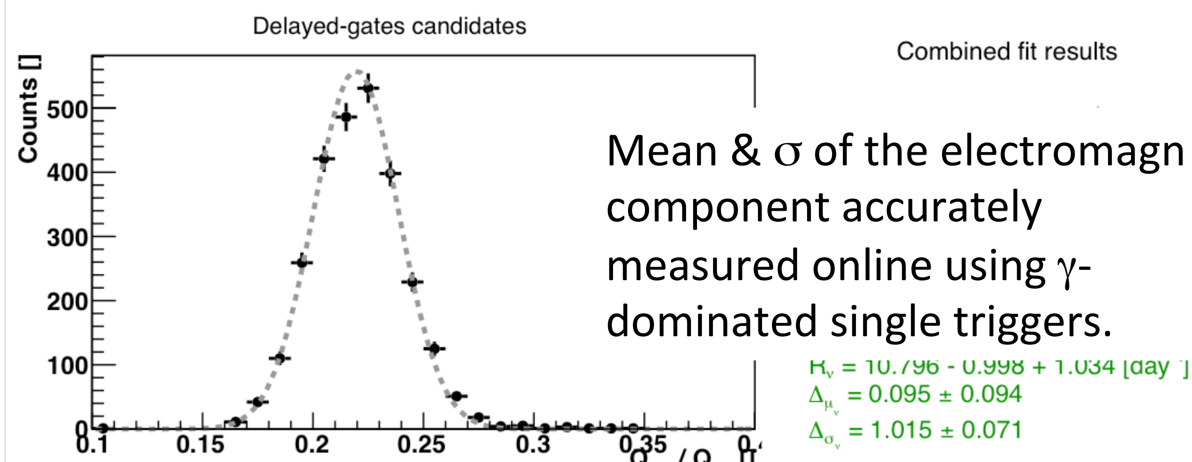
# Pulse Shape Discrimination

Amplitude of the electromagn. cosmic background fixed by the $A_\gamma$ / $A_p$ ratio measured during OFF periods.

Amplitude of the accidental background determined by off-time windows.




Proton recoils component fully determined on-line.




Mean & σ of the electromagn component accurately measured online using γ-dominated single triggers.

# Putting all together

During Phase I:

- Energy scale systematics already at the 1% level

| 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%** |

- Detection efficiency systematics at the ~2% level

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

See related posters # 195, 196 & 197 at Neutrino2018!

BACK UP