The muon veto system of the EDELWEISS dark matter experiment

from EDW-II towards EDW-III

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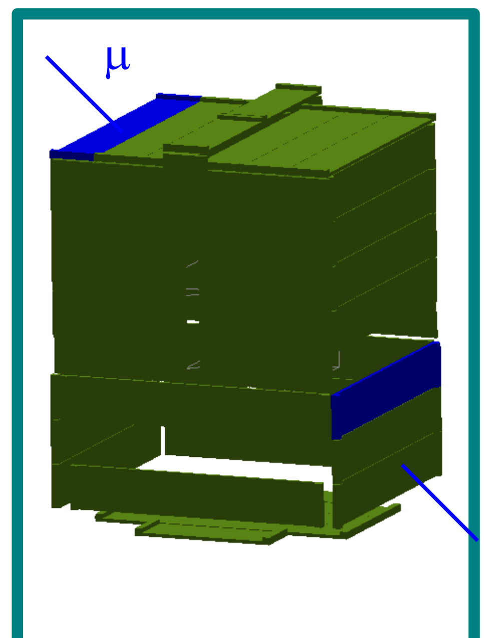
Journées des jeunes chercheurs, 5/12/2013

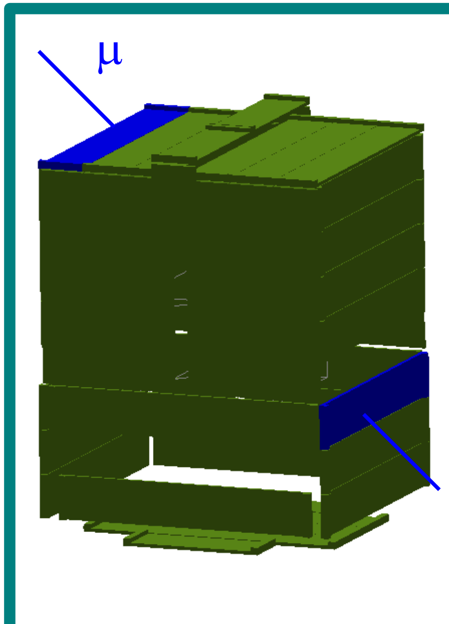


What you are going to hear about

1) The EDELWEISS experiment

2) Muon veto system : working principle

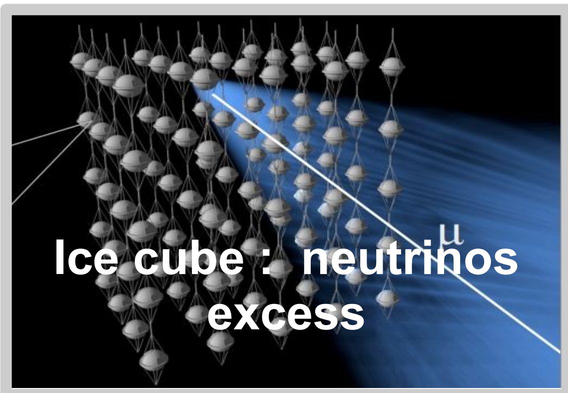
3) Residual muon-induced neutron background in EDW-II



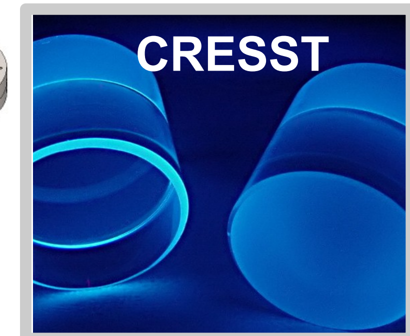
4) Improving the muon veto efficiency

How to detect dark matter

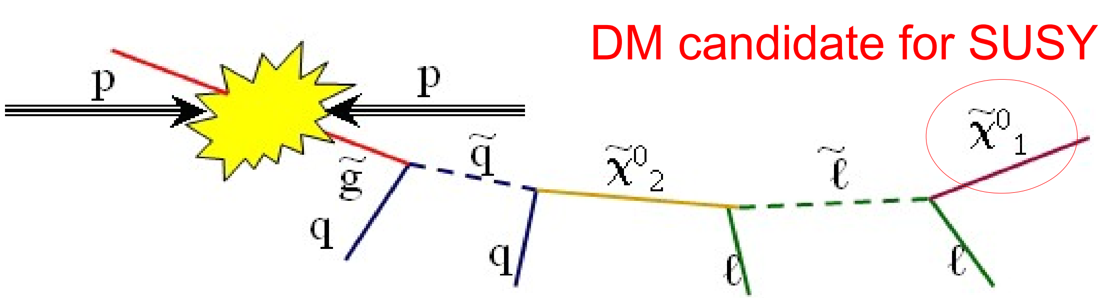
Detection of annihilation products of DM at high energy

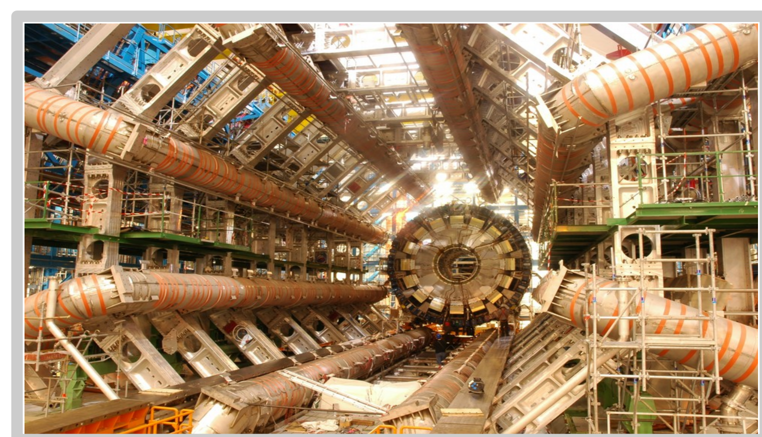


Detection of a DM particle scattering inside a detector

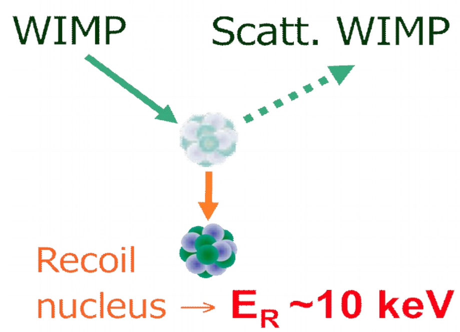


Production and detection of DM at LHC





Direct dark matter search in EDELWEISS



Extremely rare event
< 0.01 evt/kg/j

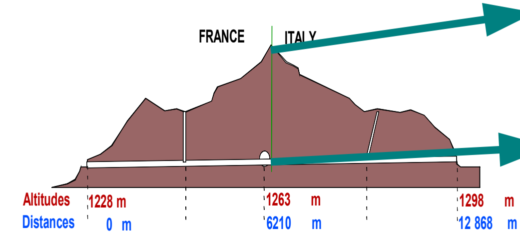
<<<

- Low energy radioactivity α, β, γ
- Neutrons from radioactivity
- Cosmic rays

Ways to protect bolometers from the background :

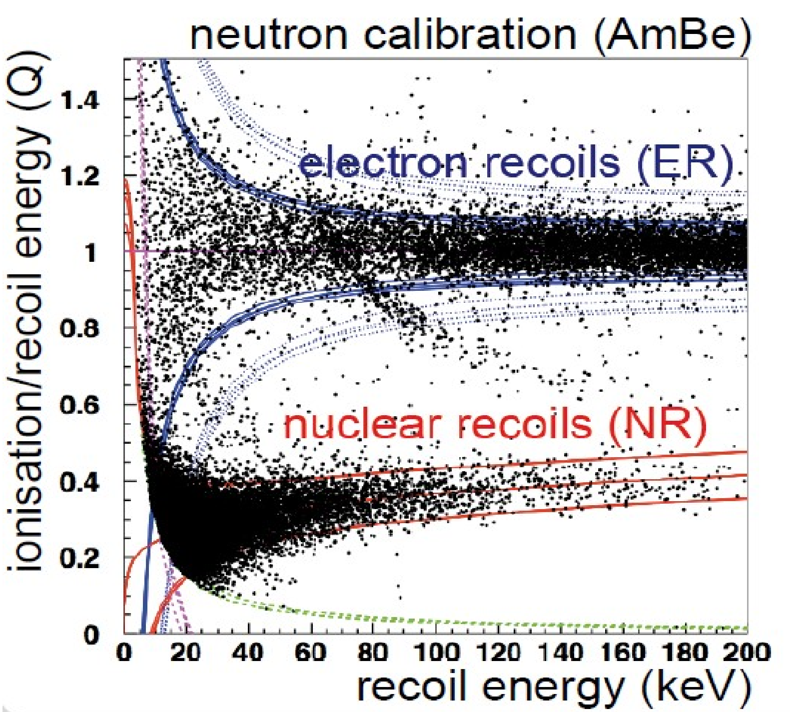
- different layers of shielding + mountain
- selection of low radioactivity materials
- double measurement detectors

to discriminate γ,β background



10^7 μ/m²/day

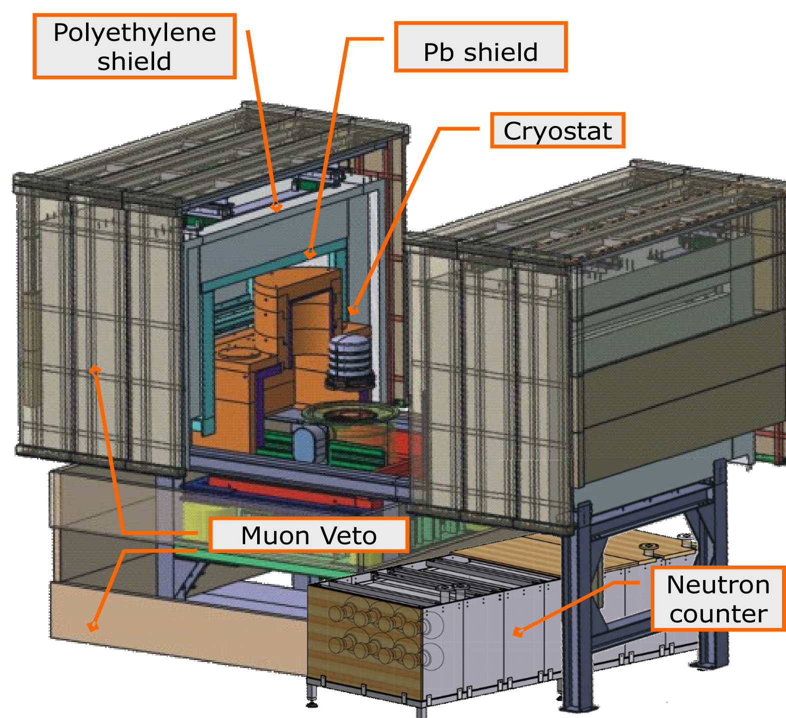
5 μ/m²/day



γ
β

WIMPS
Neutrons

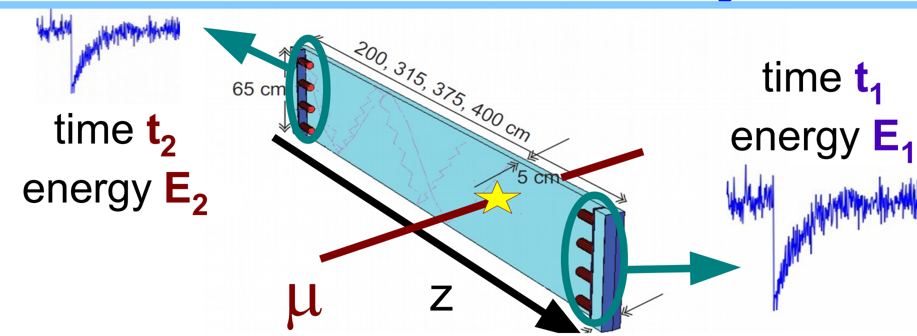
→ radioactivity
→ **cosmic μ**

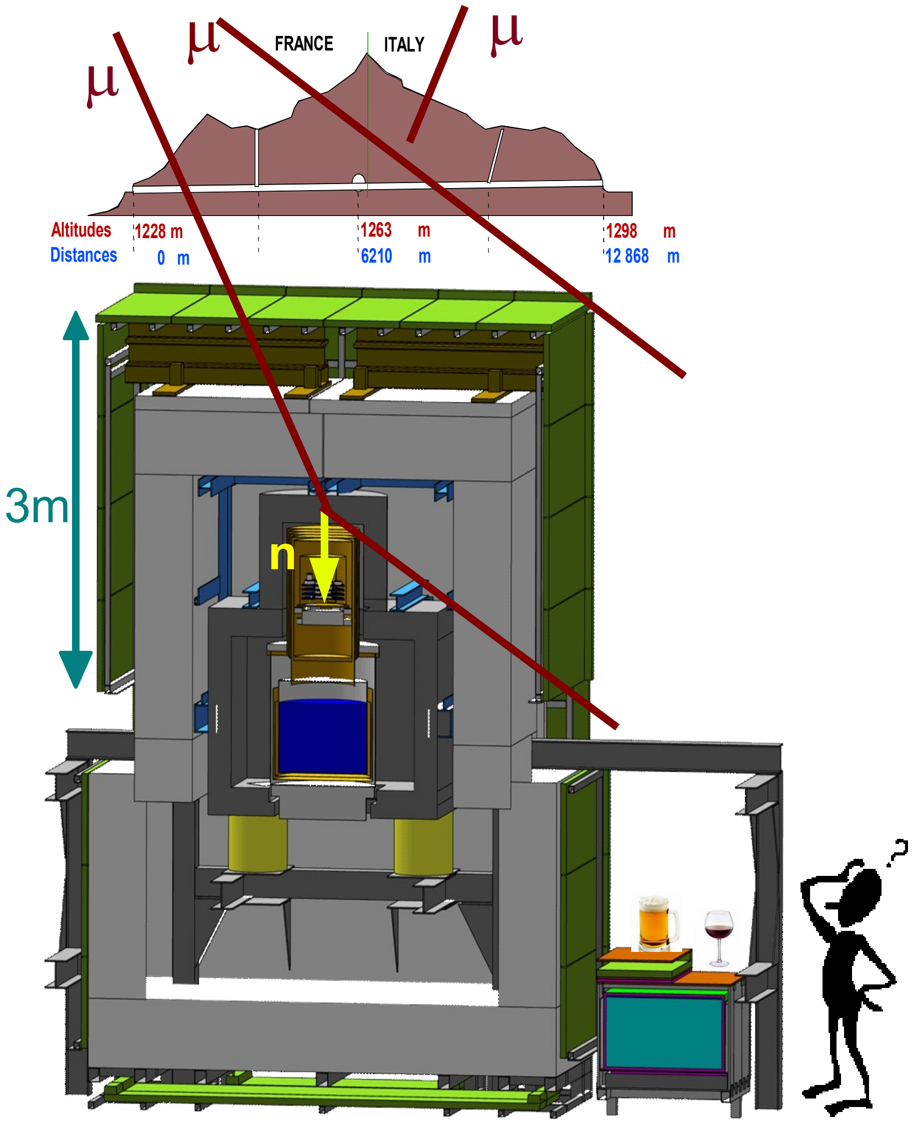


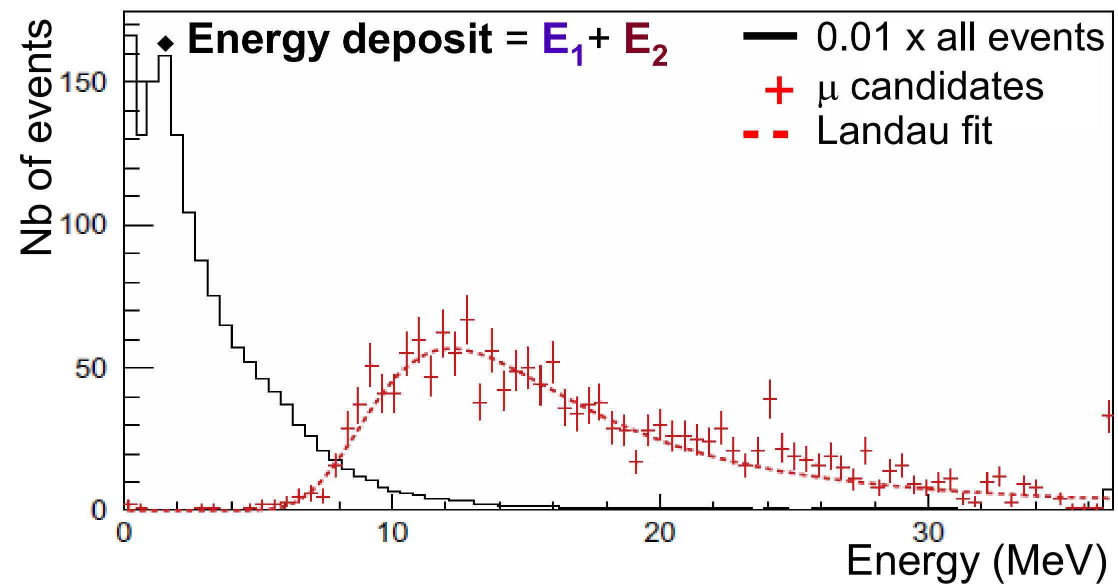
The functioning of the muon veto system

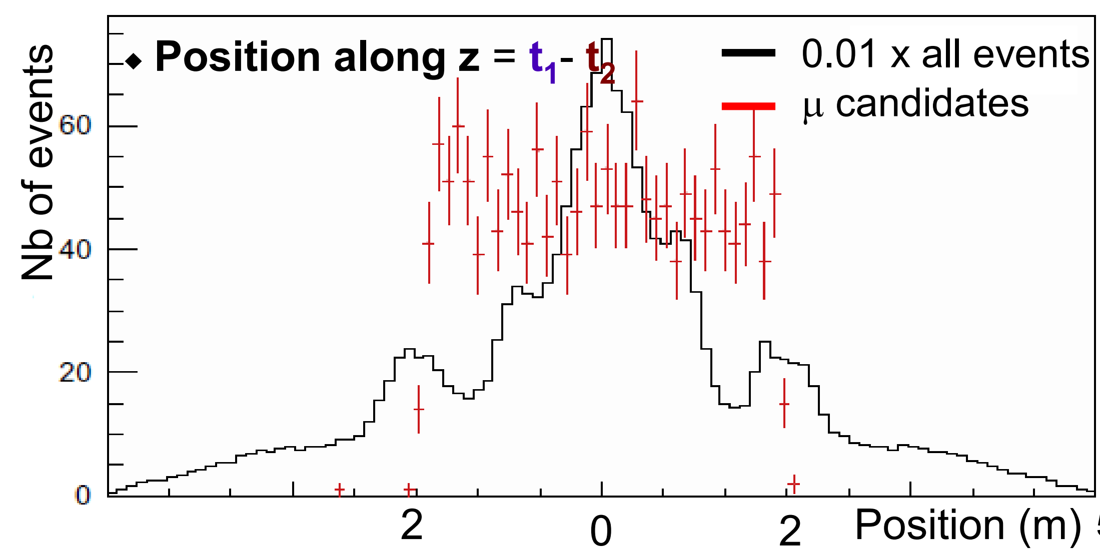
Muon Veto (MV) :

48 modules from 2 up to 4 m covering 100 m²
used to reject nuclear recoil in coincidence with the detection of a μ







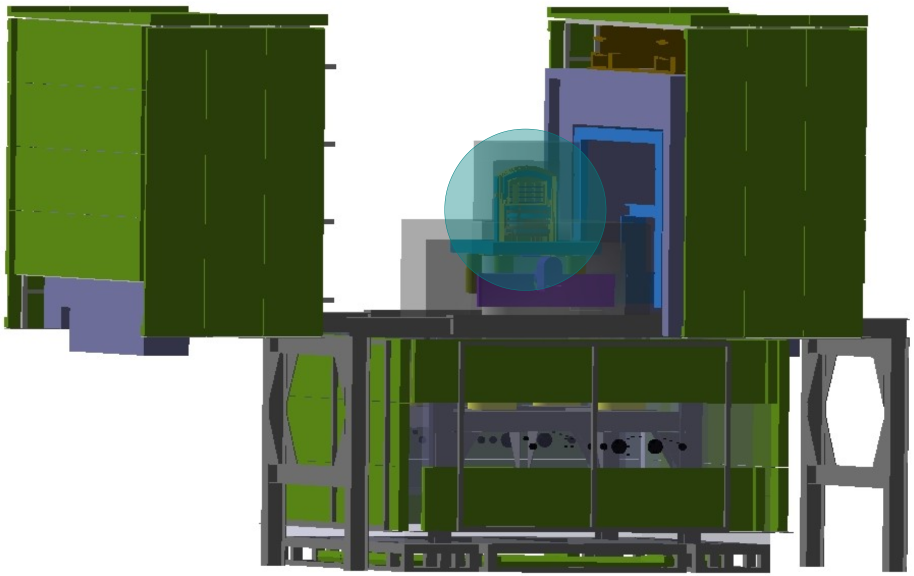


Estimation of the MV detection efficiency in EDW-II

B.Schmidt et al, Astroparticle Physics 44 (2013) 28-39

2 methods to derive muon veto efficiency ε_{MV} :

1) From determination of individual modular efficiency and detailed MC simulation of μ interactions



- volume defined by the μ-veto:

$\varepsilon_{\text{tot, MC veto volume}}$ **= (93.6 ± 1.5)%**

6.4% efficiency loss due to:.
- 2.4% gaps
- 0.9% a module malfunctioning
- 3.1% trigger inefficiencies of individual modules

- sphere 1m radius centered on the cryostat, more adapted to WIMP search

$\varepsilon_{\text{tot, MC central sphere}}$ **= (97.7 ± 1.5)%**

2) From bolometer data only identified as μ-induced events: $m_{bolo} \geq 2$ and $E_{heat} > 7$ MeV

→ 34 events from March 2009 to May 2010, all detected in the muon veto

From binomial distribution $P(k,n,p)=\binom{n}{k} p^k (1-p)^{(n-k)}$ with $p=\varepsilon_{MV}$ and $k=n=34$

$\varepsilon_{\text{tot,data}} \geq$ 93.5% at 90% CL

method only limited by low statistics

Muon-induced neutron background in EDW-II

Number of expected unvetoed μ-induced single scatter neutron events = irreducible bckg

$$N^{\mu-n} = M_{\exp}^{B+V}\,\Gamma^{\mu-n}(1-\varepsilon_{tot}) + M_{\exp}^{B}\,\Gamma^{\mu-n} = 0.40$$

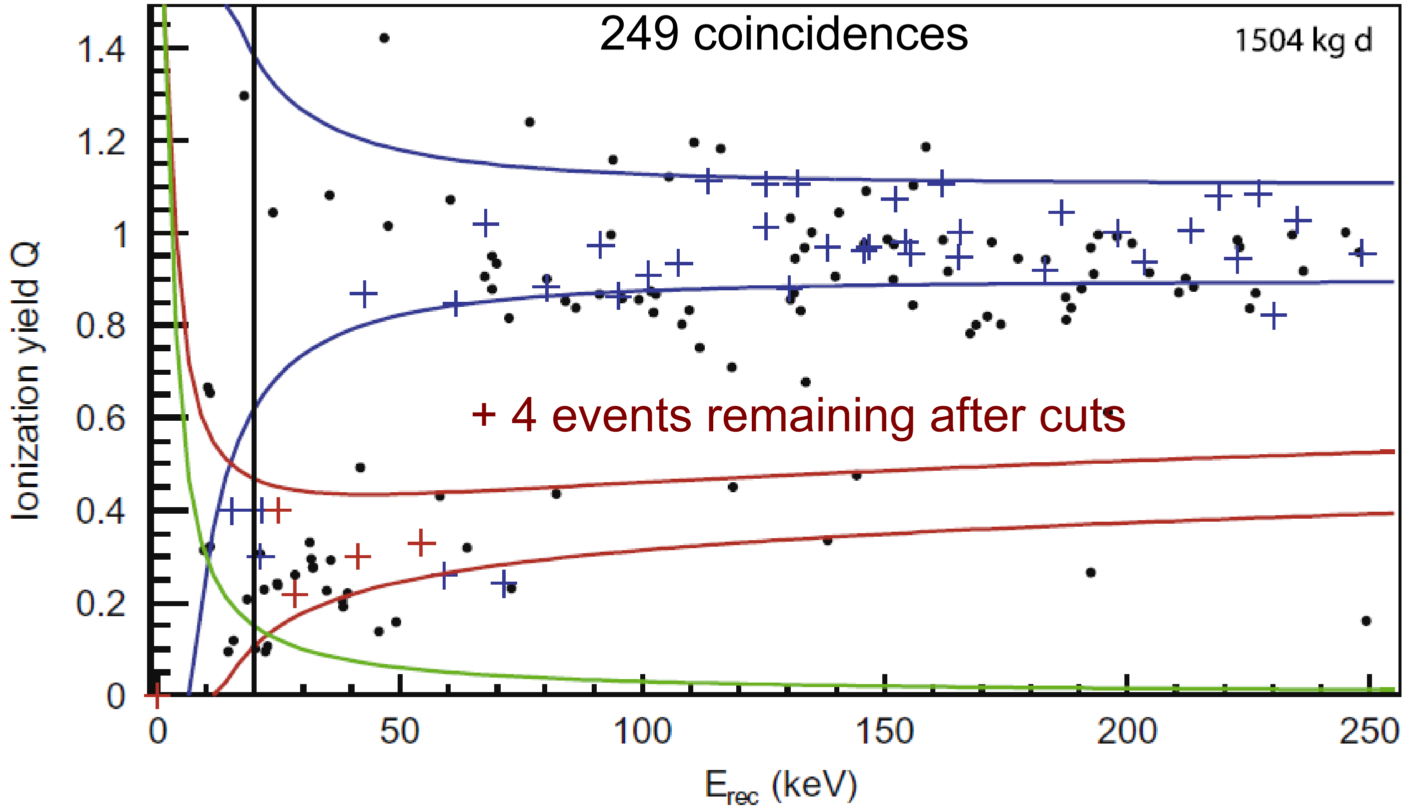
upper limit: $N^{\mu\text{-}n} < 0.72 \rightarrow$ 15% WIMP-search bkg

$M_{\exp}^{B+V} = 384\,kg.d - M_{\exp}^{B}$: good synchronisation detectors/MV

$M_{\exp}^{B} = 38 \pm 11\,kg.d$: malfunctioning synchronisation detectors/MV → ε_{MV} = 0

$\varepsilon_{tot,\,data} = 93.5\,\%$ (very conservative value)

$\Gamma^{\mu\text{-}n}$: rate of μ-induced WIMP-like events



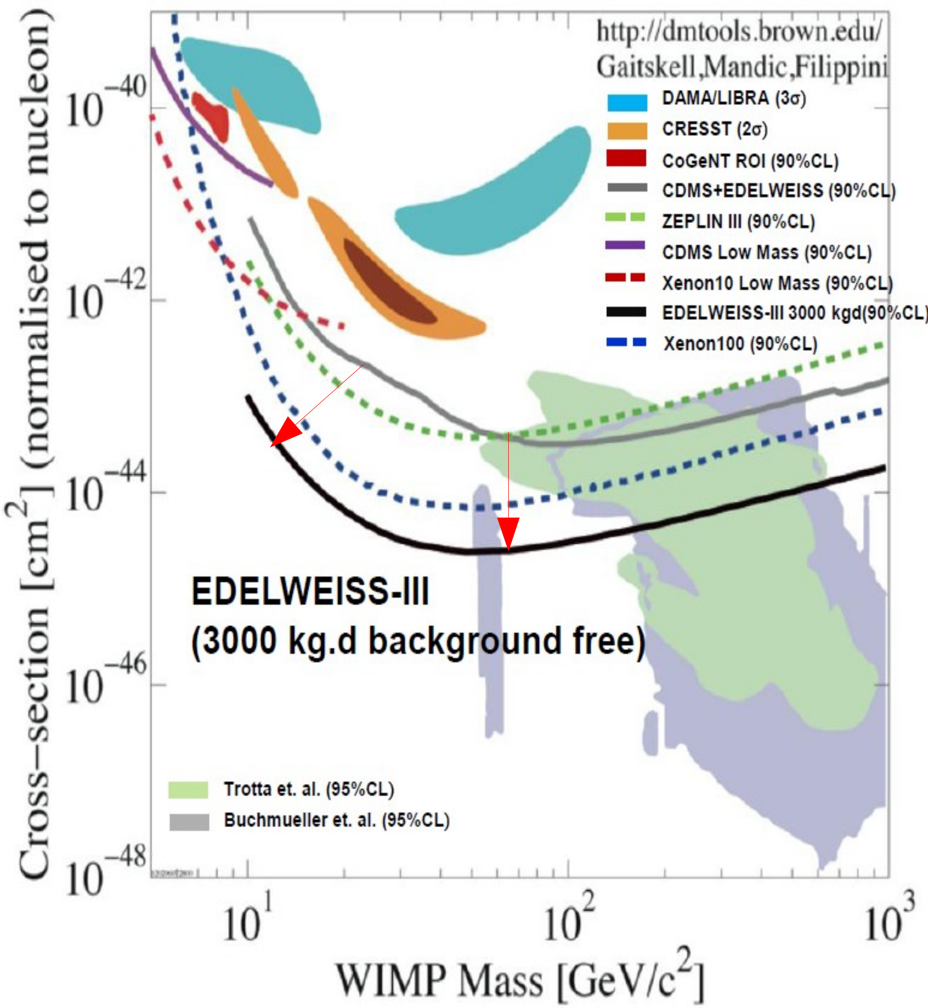
Ongoing phase of the experiment: EDELWEISS III

Goal : increase of sensitivity > x10

- **Increase of the fiducial detection mass :**
 from 10 x160 gr to 40 x 600 gr

- **Decrease of background interacting in detectors :**
addition of PE shield + MV additional modules

- **Better discrimination of residual background**
new cryogenic structure + new electronics



Muon veto :

- **At least maintaining its efficiency by:**
✔ studying of the increase of the gap between the 2 chariots of the MV
✔ correction of ageing effects

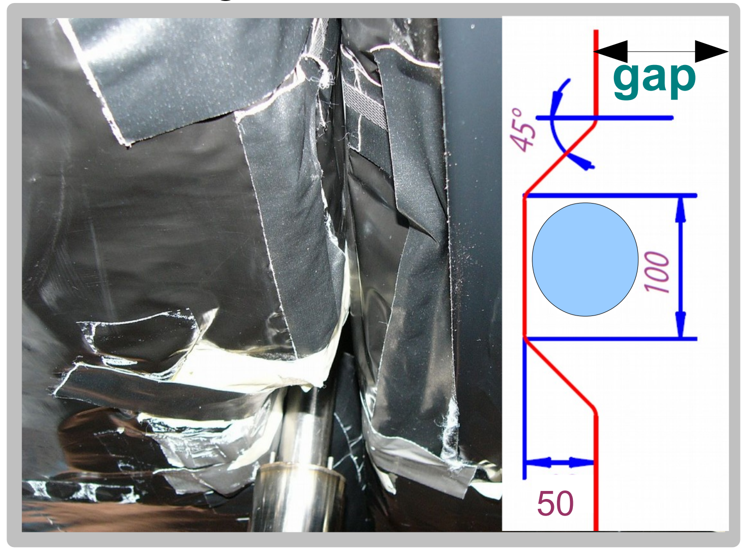
- **Improving its efficiency by :**
✔ additional modules to cover part of the gaps
✔ better knowledge of the module response at low energy

EDW-III upgrades impacting the muon veto detection efficiency

Muon Detection efficiency loss due to new cryoline ?

Installation of a new cryoline with a larger diameter in October 2012

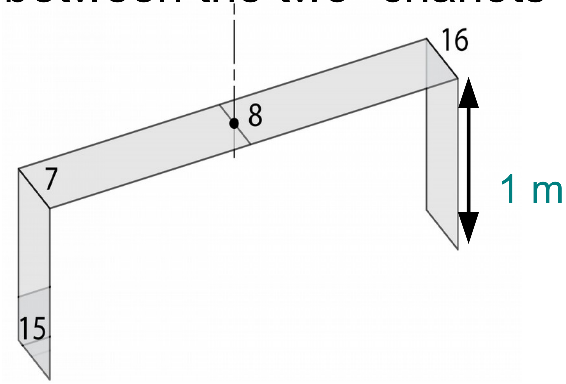
From the cryostat...

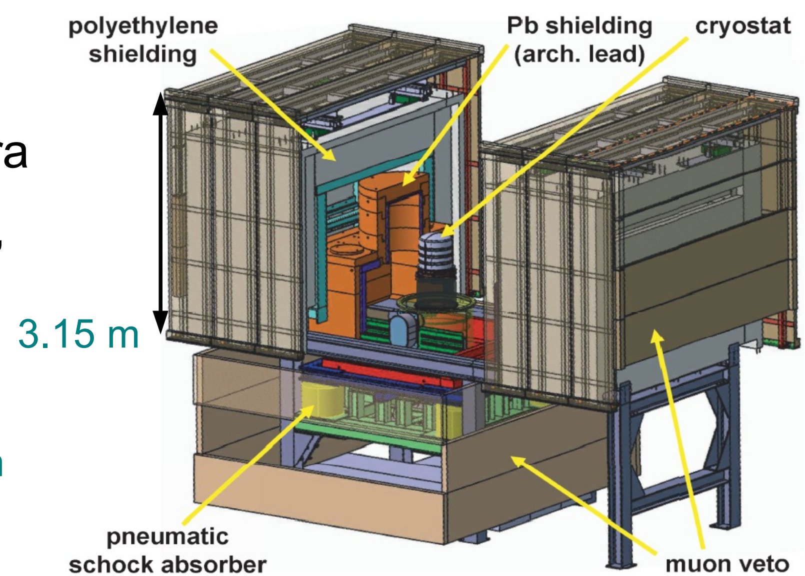


...through the Muon Veto...

… to the thermal machines.

2010 : installation of 4 extra modules to cover the gap between the two "chariots"



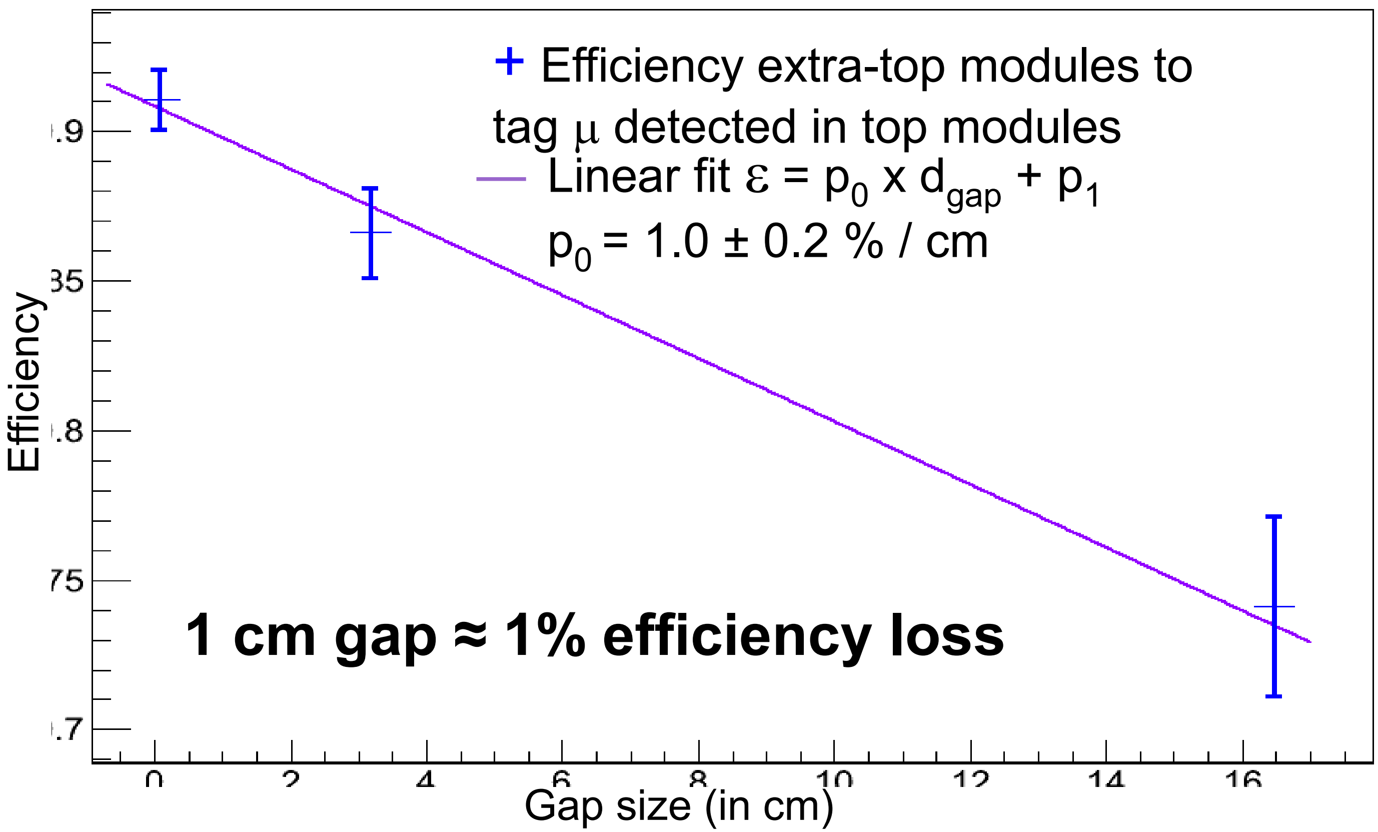


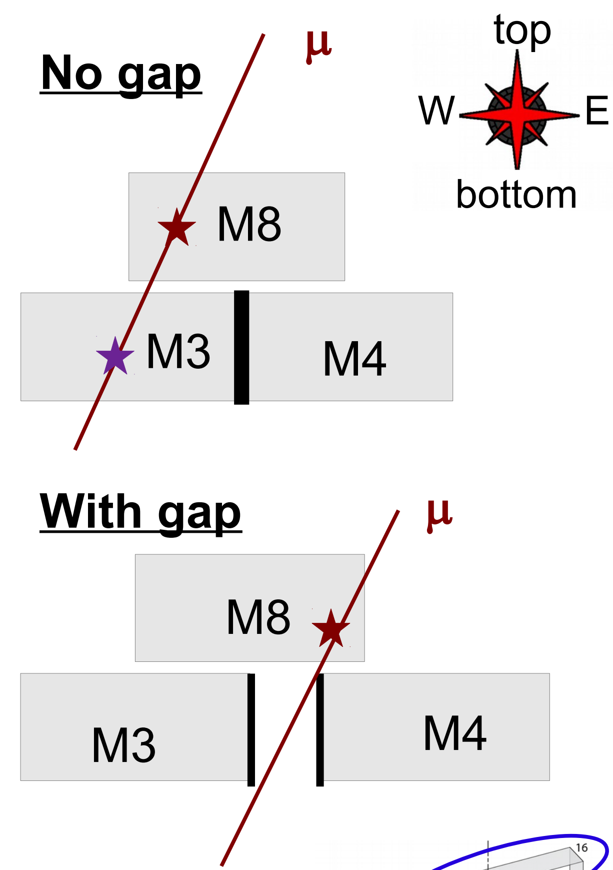
BUT detection efficiency of a module ε < 100 %

Goal : estimation of the loss of muon detection efficiency **due to the enlarged gap**

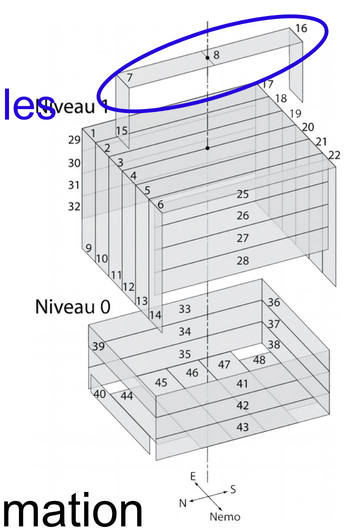
Estimation of ε_{MV} decrease due to enlarged gap

→ need estimation from data only of $\varepsilon_{\mu\text{-veto}}$ loss due to enlarged gap by using extra-top modules





extra-top modules



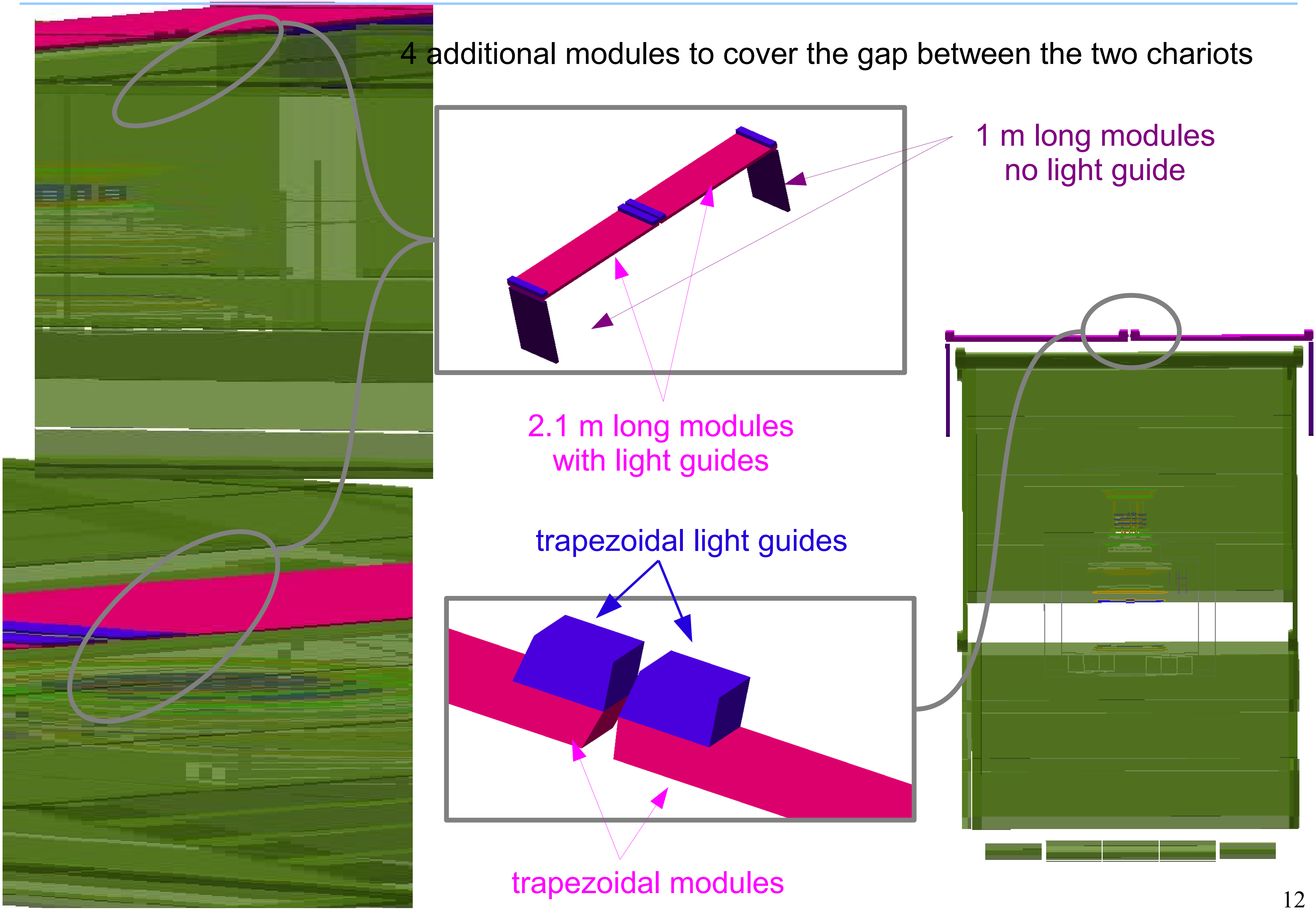
Conservative probability of a μ missed in top module to be detected in another module: P_μ = 75 %

Increase of unvetoed WIMP-like events/(kg.d):

- 50% augmentation without extra-top modules
- **≤ 5% with extra-top modules** → need simulation for more precise estimation

Implementation of new modules in G4 simulation

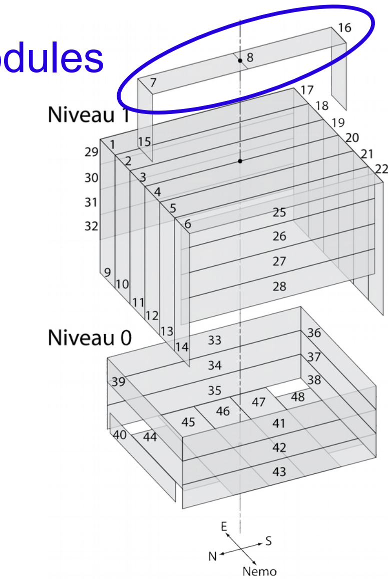
4 additional modules to cover the gap between the two chariots



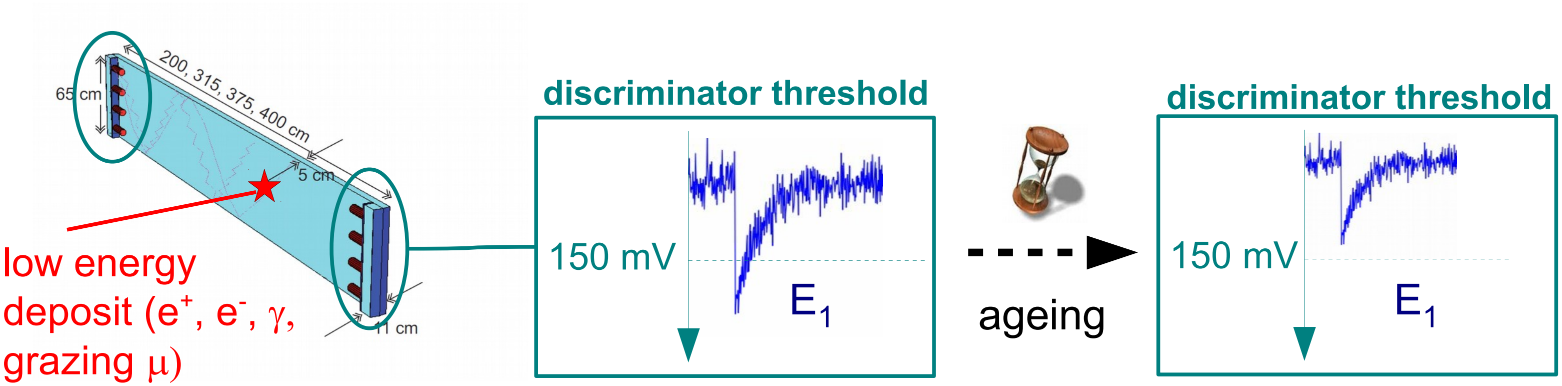
Module ageing correction

Module ageing and its consequences

- **2005**: installation muon veto system
  module calibration at Earth's surface with cosmic muons
- **2010**: installation of extra-top modules (EDW-III upgrade)



- Since this time, **module ageing**:
  - less scintillation light produced (oxidation)
  - increase of light absorption (micro cracks)
  - worse signal amplification (PMT vacuum less good)

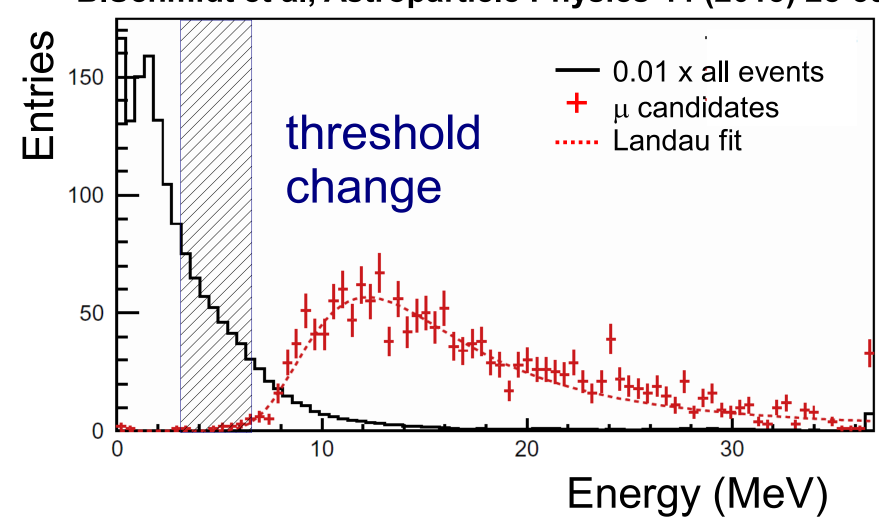


→ **increase of the effective threshold because of ageing**

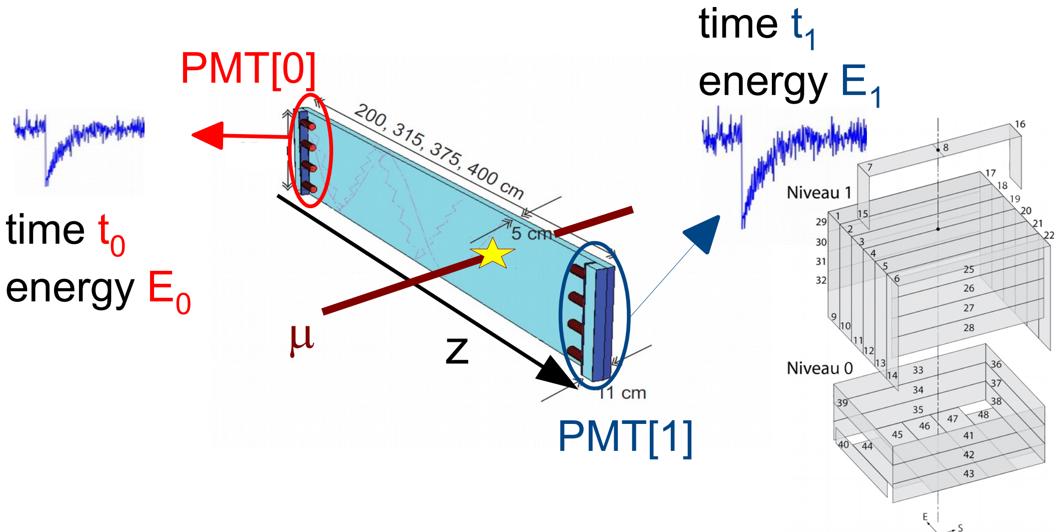
- Ageing of the module impacts mainly detection efficiency of secondaries

→ **no significant decrease of measured muon rate due to ageing**

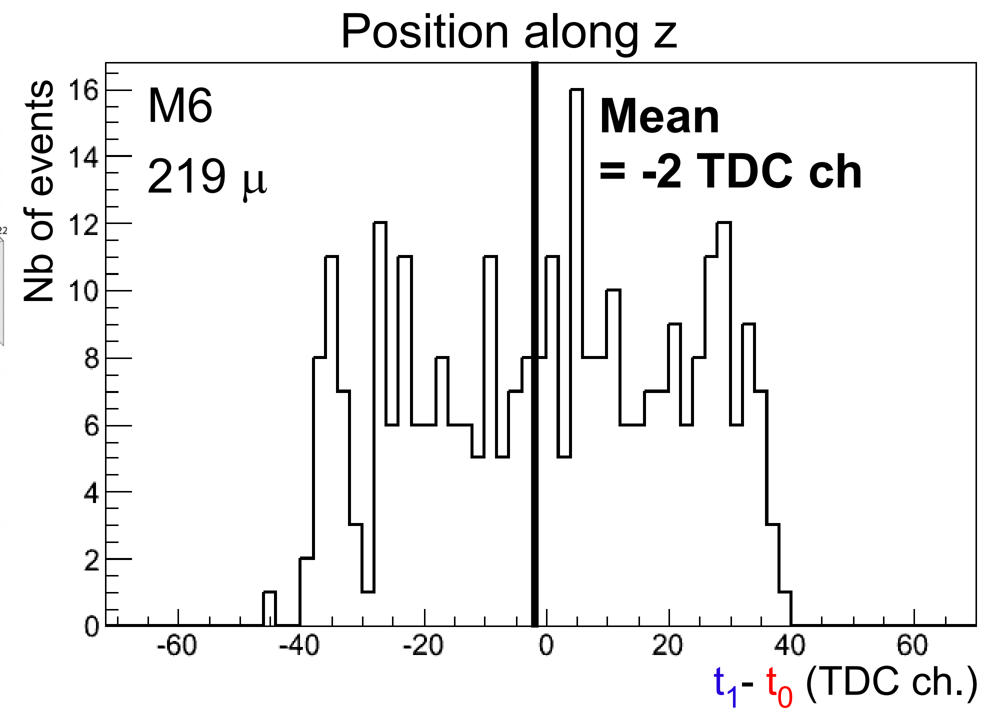
B.Schmidt et al, Astroparticle Physics 44 (2013) 28-39

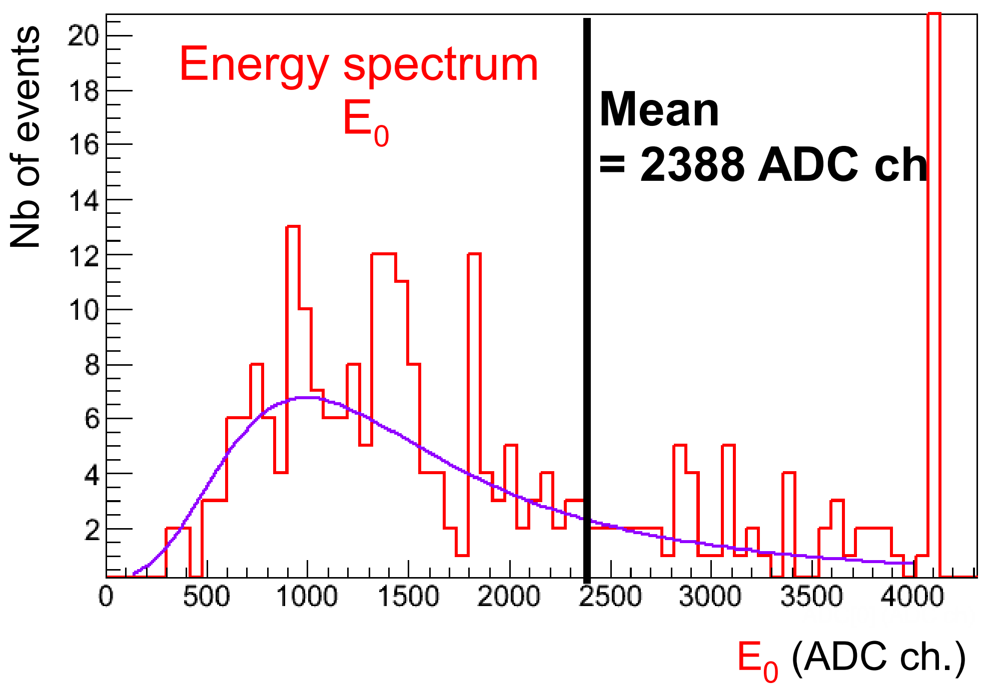


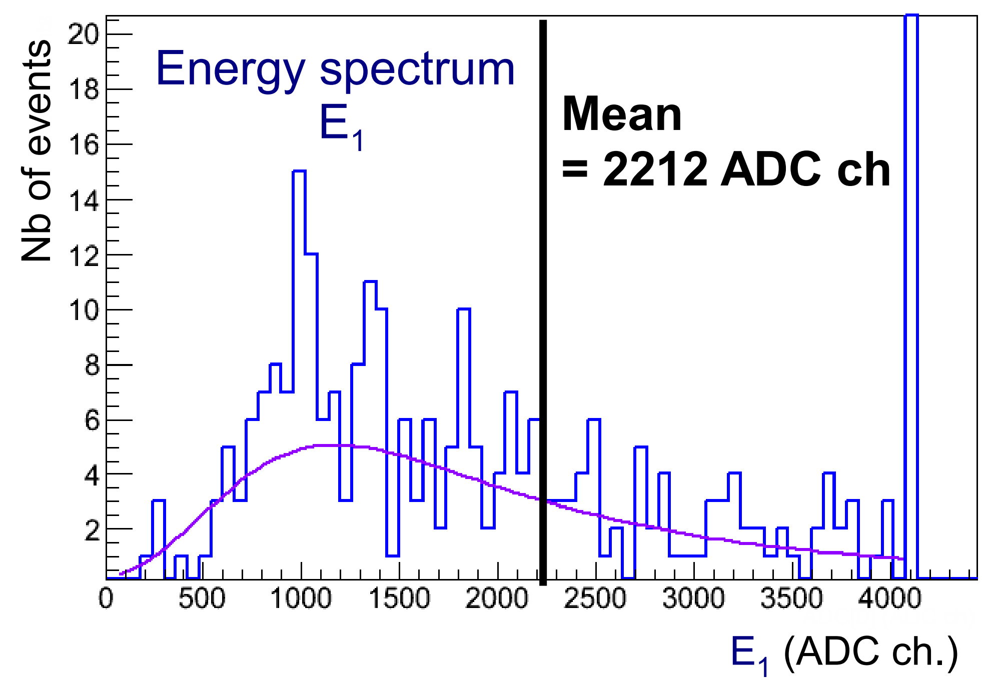
Expected module response to μ-induced events



- **Position along z** = t_1- t_0 ~ flat spectrum
- **Energy deposit** = E_1+ E_0 ; E_0 ~ E_1



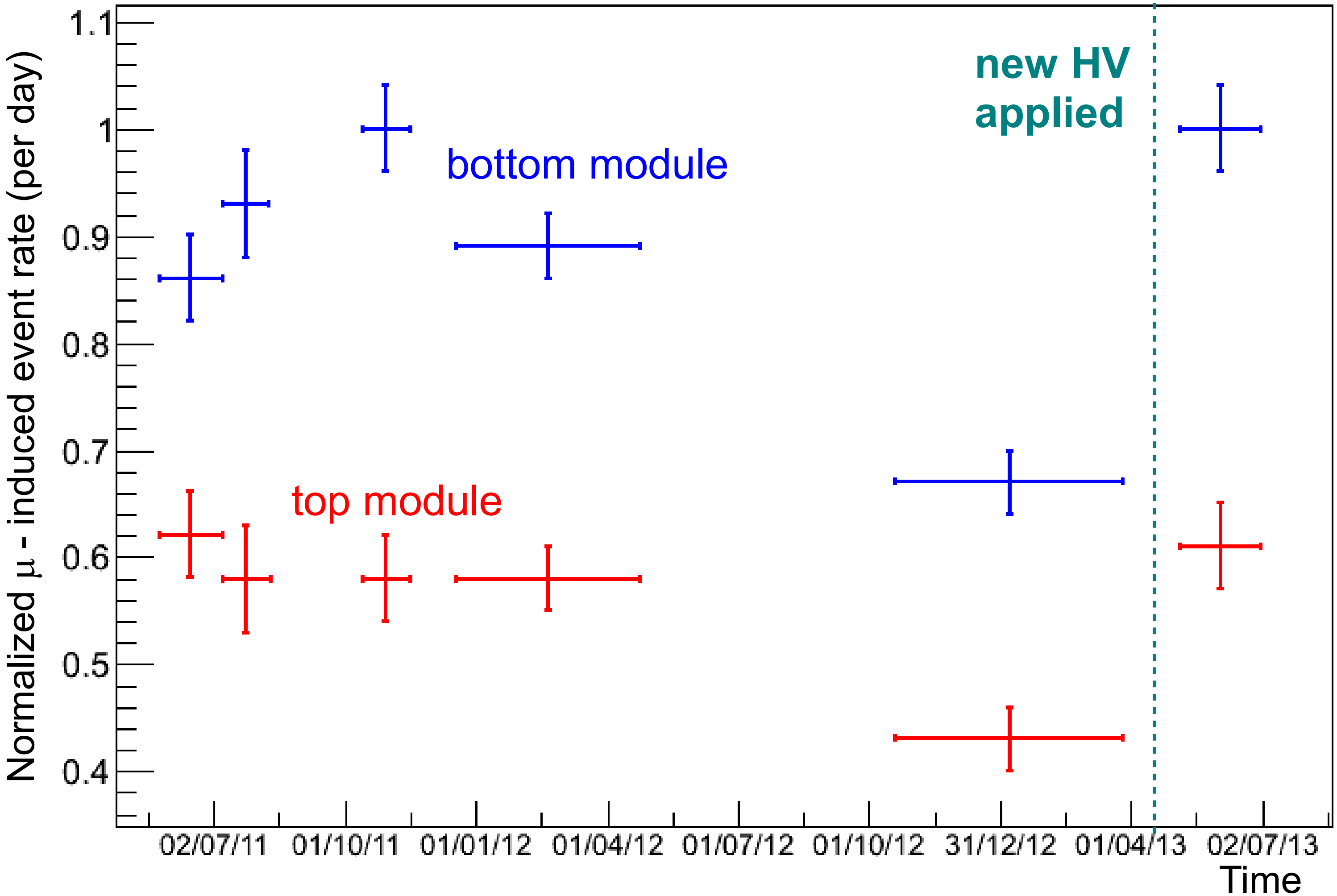




μ-induced event rate over two years

→ 40% of the HV values were increased

after applying new HV setting, μ-induced event rate back to its value of two years ago



Is the measured rate **=** simulated rate x module response ?

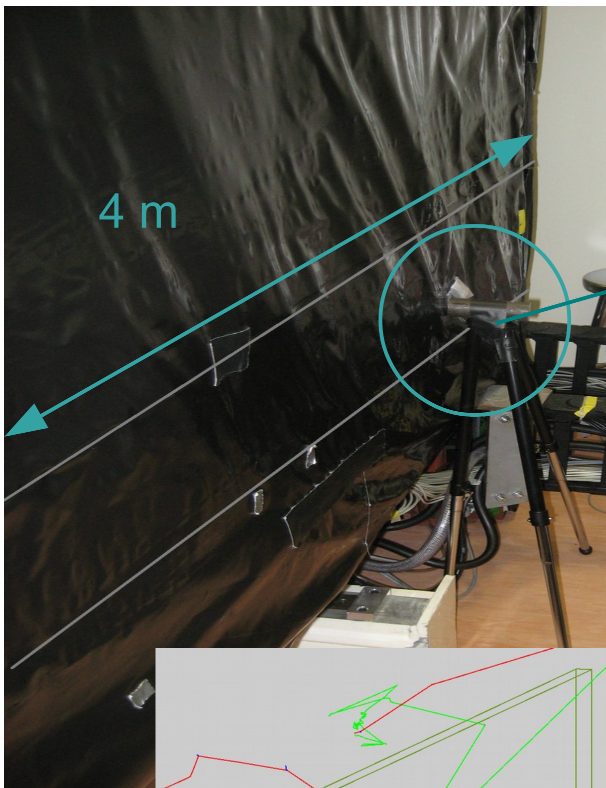
→ need to know the module response at low energy...

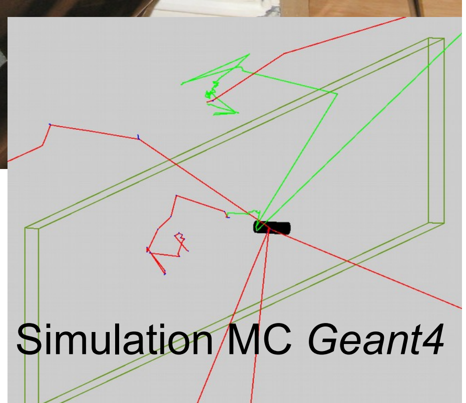
Module response at low energy

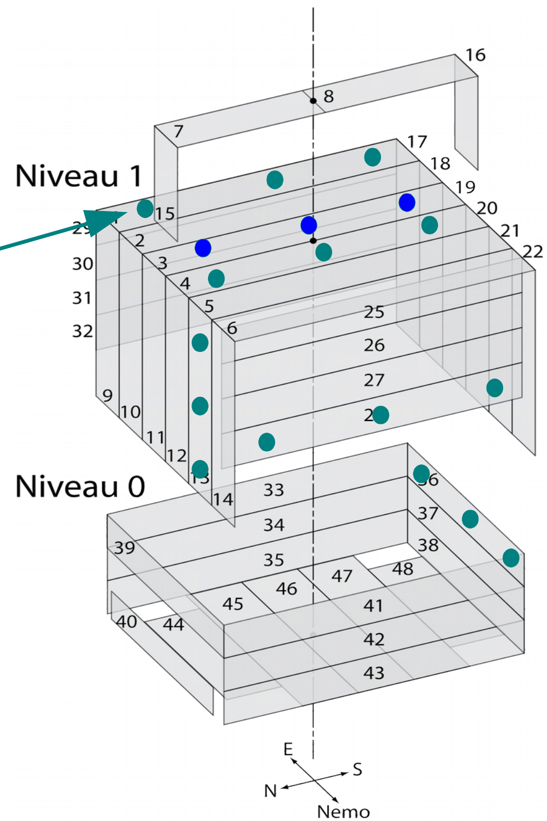
Deriving module response from AmBe calibration

- Necessity of knowing the module response at low energy
  - to get a better comparison simu/data at low energy
  - to derive a more realistic and precise muon veto detection efficiency (going from averaged threshold along the module axis to a position-dependent threshold)

- Calibration started one year ago (master thesis)







$\alpha(^{241}Am)+^{9}Be \rightarrow {}^{13}C$

$^{13}C \rightarrow {}^{12}C + n$ (40%)

$^{13}C \rightarrow {}^{12}C^{*} + n$ (60%)

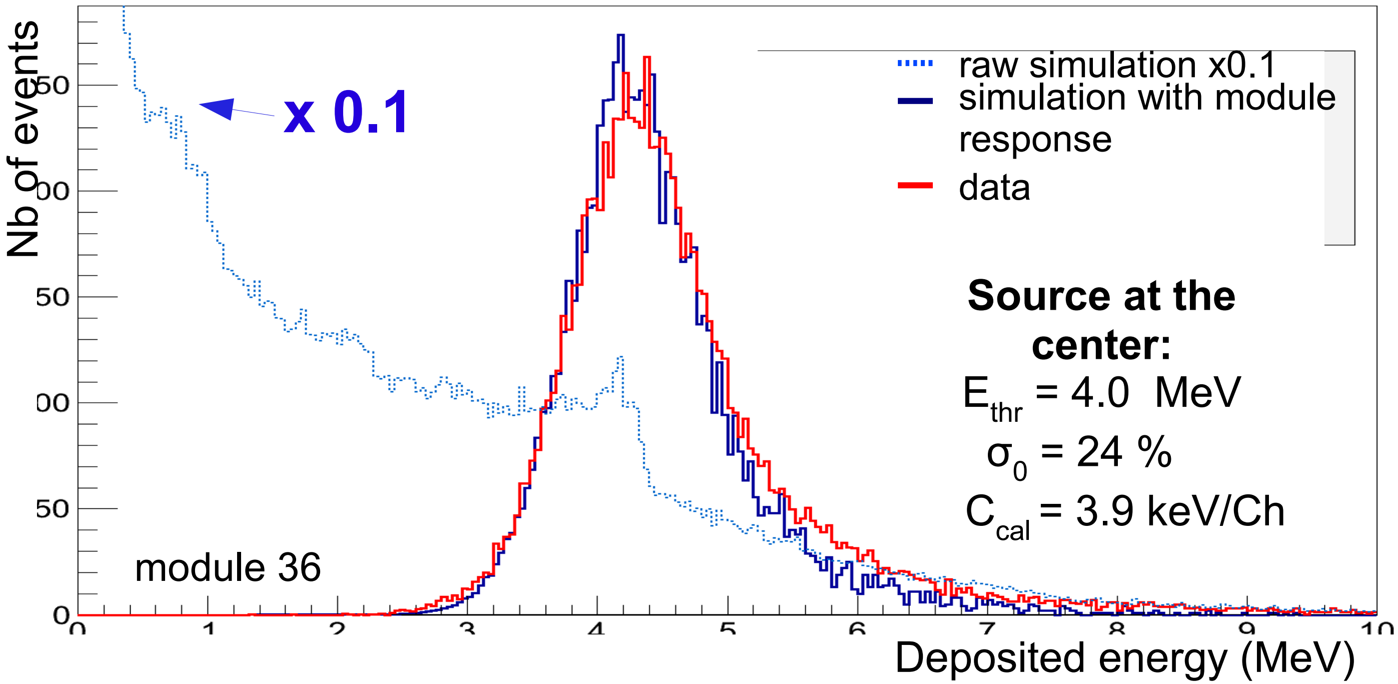
$\quad \rightarrow {}^{12}C + \gamma$ (4.4 MeV)

Module response parametrized by:
- energy treshold E_{thr}
- energy resolution σ_0
- calibration coefficient C_{cal}

Until now:
- 6 modules calibrated (5 before HV change, 1 after HV change)
- 1 module analysed

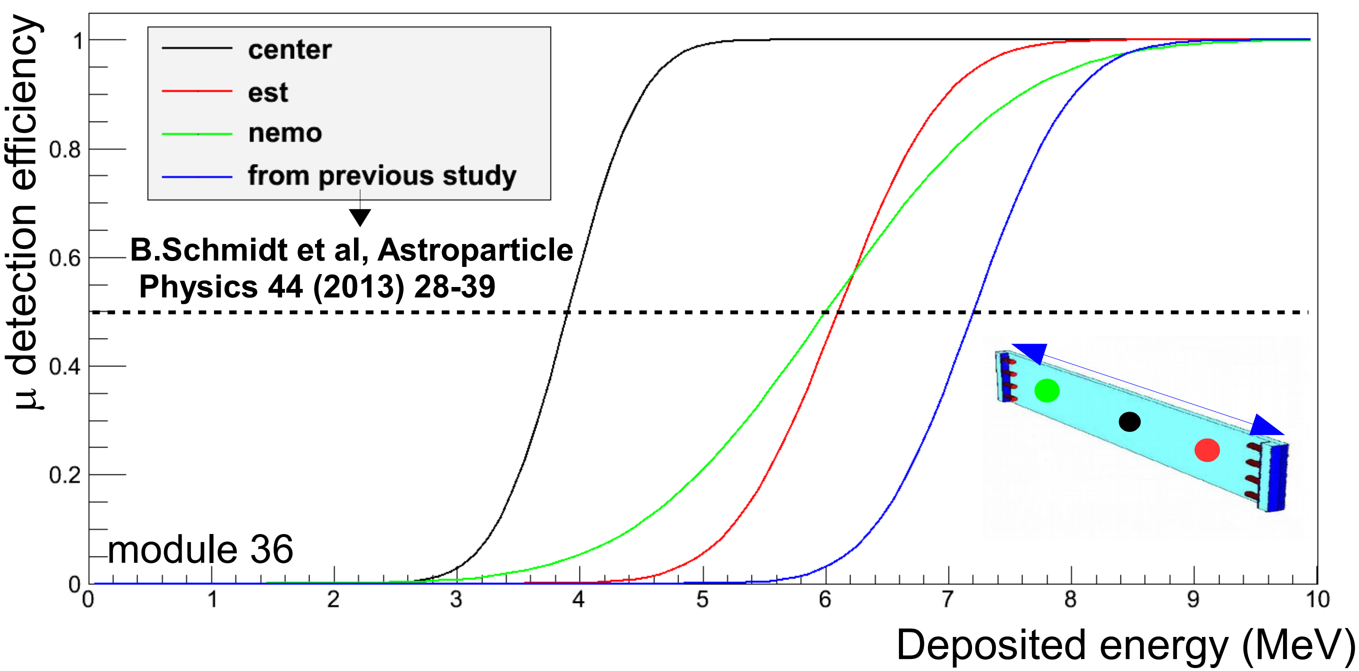
20 n/s AmBe source ~ 2 weeks per module

Method to derive module response already set up



✔ Method of estimation of module parameters already set up

→ applied for each position of the source along the module axis



New approach is questioning the previous one

To be continued...

Conclusion and outlook

Improvements on the MV towards EDW-III

- installation of new modules to cover gaps
- correction of module ageing
- maintenance of the muon veto system
- tested spare material ready to use in case of failure
- determination of a more realistic ε_{MV} (AmBe calibration)

Muon veto in EDW-III

no major dead time expected

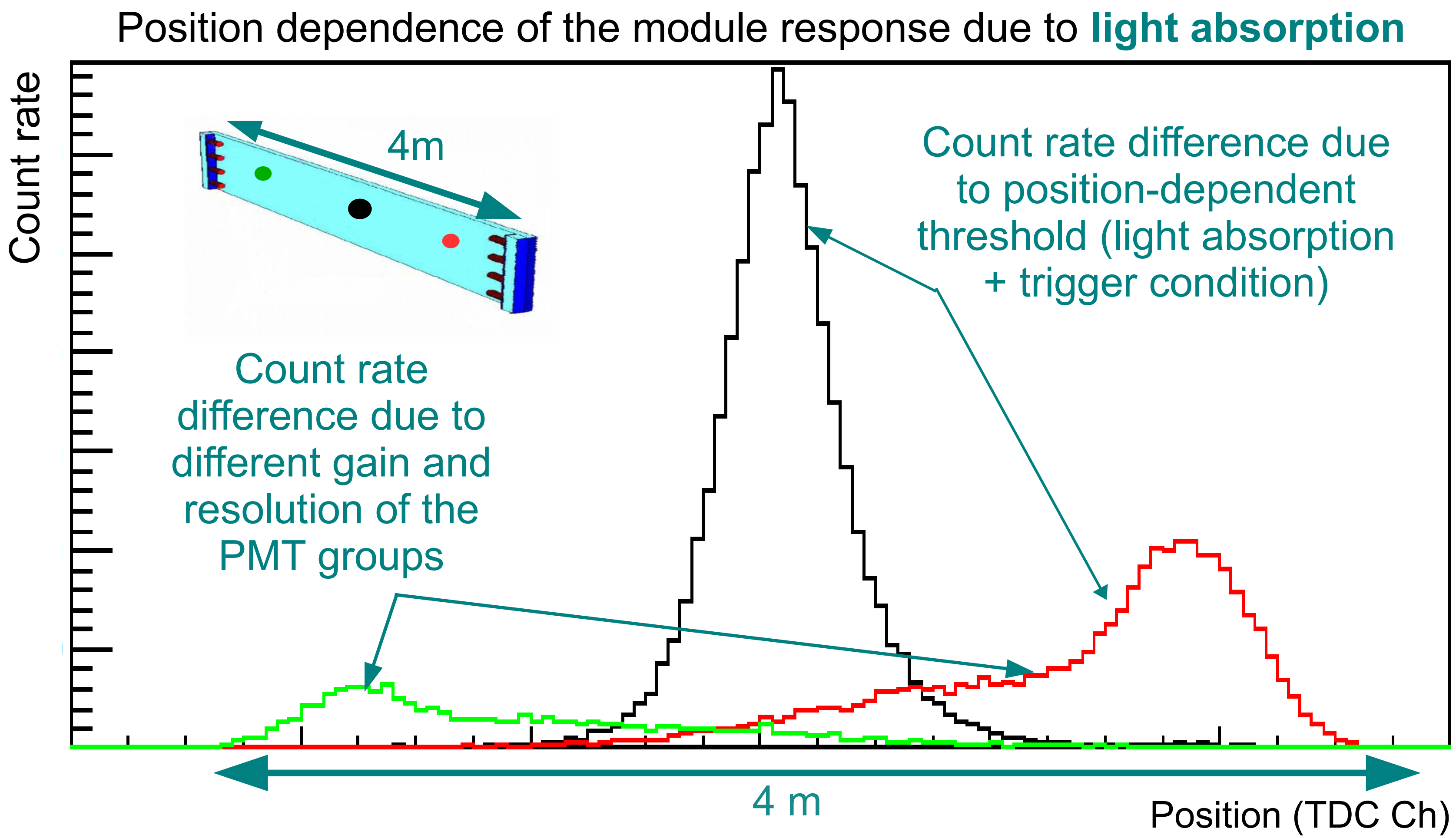
- muon veto run almost constantly
- good synchronisation between detectors/MV

In the future

- Study of muon-induced event topology in bolometers in EDW-III configuration
- Study the best configuration of the detectors in the cryostat
- Get first results on muon-induced neutron background in EDW-III

Backup slides

Position dependence of the module response



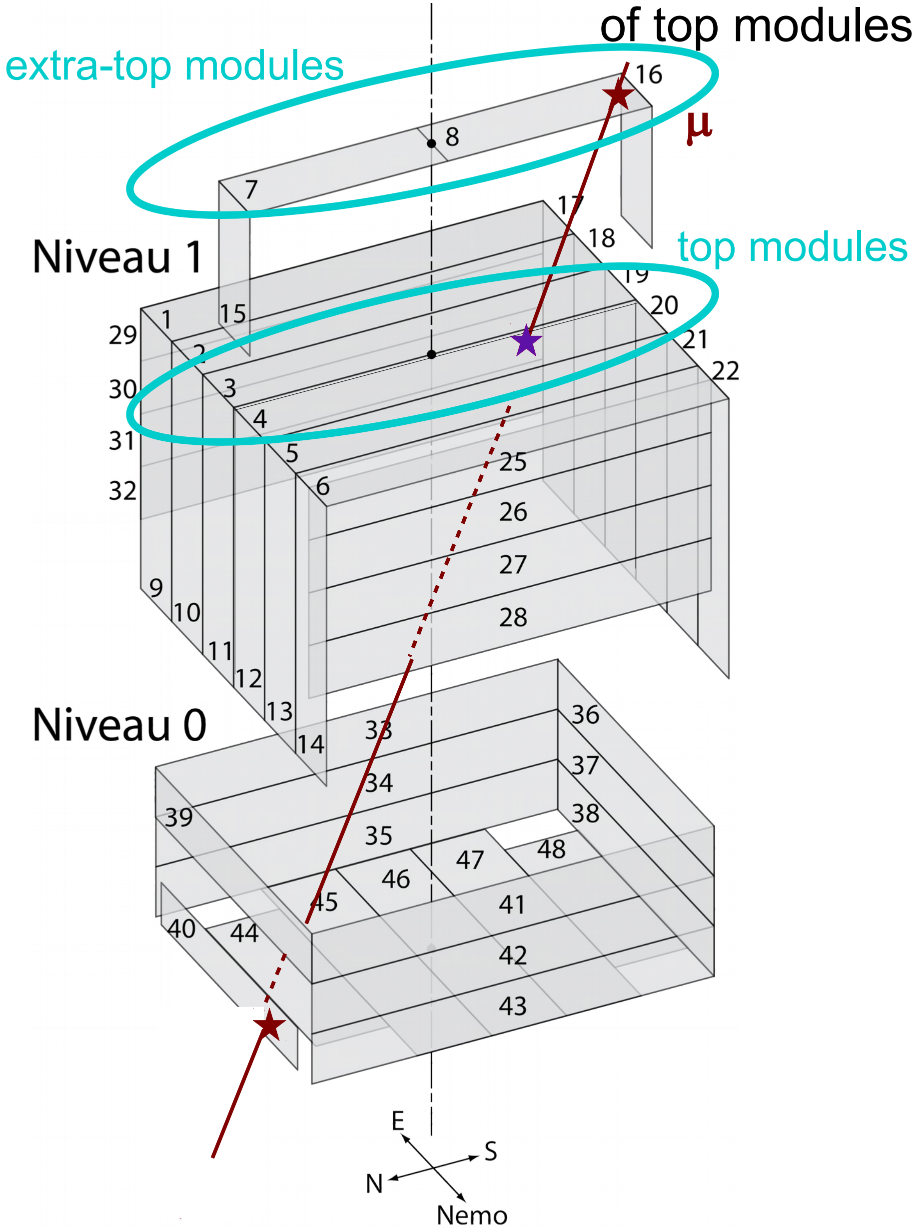
For an E_{dep} to be stored : signal at BOTH module ends > discriminator threshold

➡ the most distant PMT group is responsible of the data acquisition

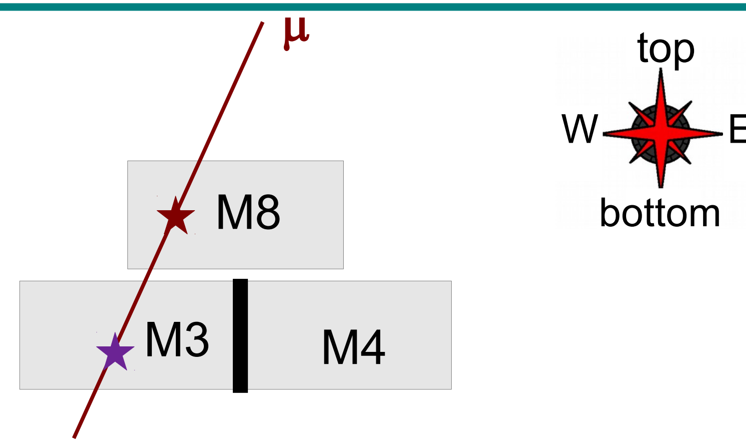
Module response depends on :
- position of the interaction
- group of PMT's which triggers

Getting efficiency loss from data

Method : using extra-top modules to get an estimation of the muon detection efficiency loss of top modules with the increase of the gap

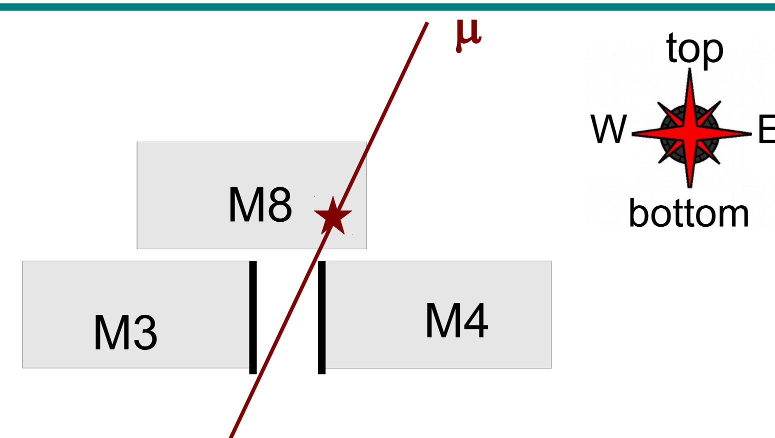


No gap



n_{μ}[extra-top AND top] = n_{μ}[extra-top] x ε(top)

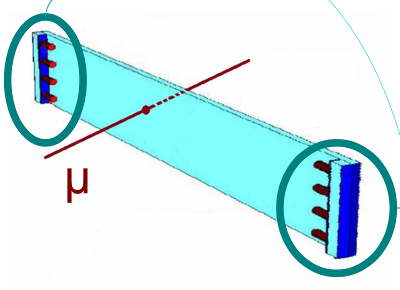
Gap



n_{μ}[extra-top AND top] = n_{μ}[extra-top] x ε(top) x **ε(Gap)**

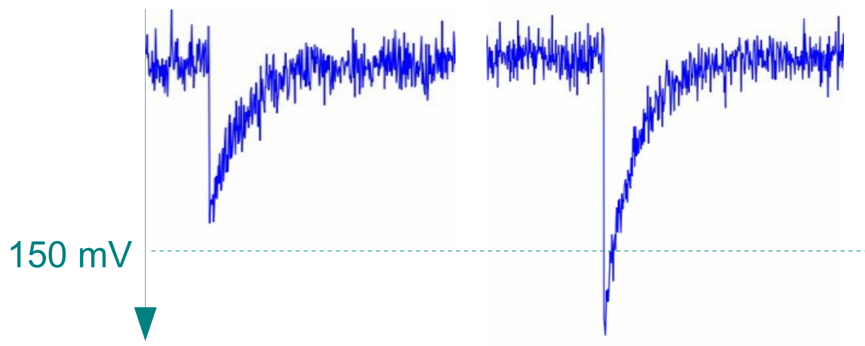
→ **comparison of n_{μ}[extra-top AND top] and n_{μ}[extra-top] for different sizes of the gap**

Acquisition of MV and double threshold effects



delay

Discriminator threshold



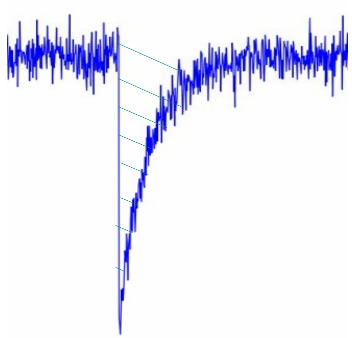
Scalar cards

Time-to-Digital Converter (TDC)

Logic unit

If two PMT group signals above threshold in 100 ns time window

Analog-to-Digital Converter (QDC) threshold : **conversion** threshold



If Q < 110 channels
→ QDC = 0

If Q > 110 channels
→ QDC ≠ 0

Storage :
of all the signals in the muon veto in ± 125 ns around trigger time
Notably :
→ TDC of each PMT group
→ QDC of each PMT group

→ Low energy events which trigger can have null QDC information