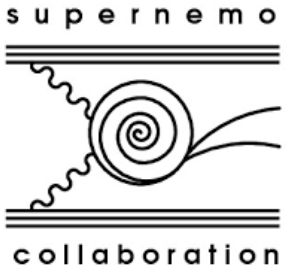
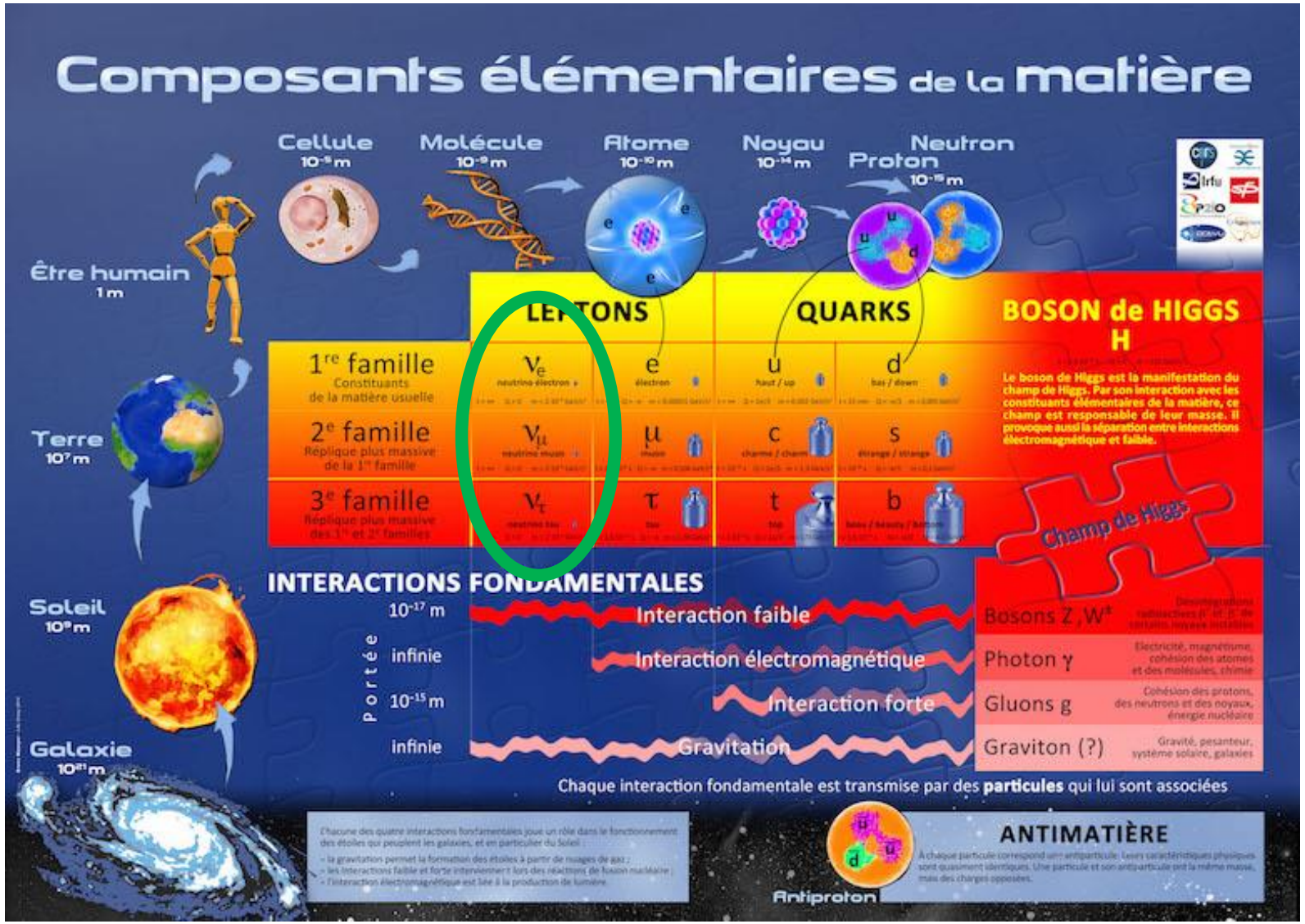


Study of the nature of the neutrino with the SuperNEMO experiment and the LiquidO project

Axel Pin, Emmanuel Chauveau, Christine Marquet

State of the art



- Most abundant particle in the Universe
- Lepton, 3 savours
- Fermion (spin $\frac{1}{2}$)
- Mass < 1eV
- Φ = 70 $\bar{M}$/cm²/s
- That's all!

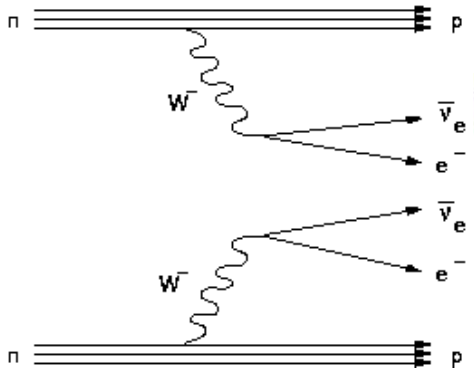
Researches

- Measure of the mass and determination of the mass hierarchy
- Search for the nature : Dirac ($\bar{\nu} \neq \nu$) or Majorana ($\bar{\nu} = \nu$)
- Measure of oscillation parameters and the δ_{CP} phase
- Search for sterile neutrinos
- Leptogenesis
- …

SuperNEMO and LiquidO

Double beta disintegrations …

… with neutrinos emission



$2n \rightarrow 2p + 2e^- + 2\bar{\nu}_e$ → $T_{1/2} = [10^{18} - 10^{20}]$ans

Rarest radioactivity ever observed

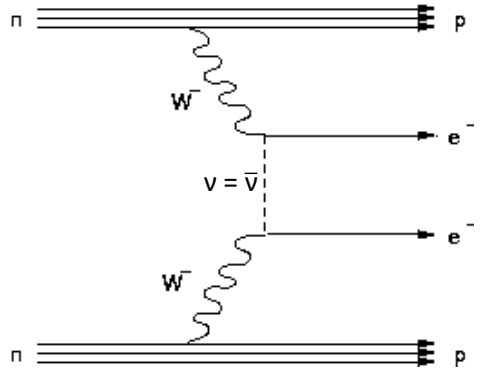
Exist whatever the nature of the neutrino

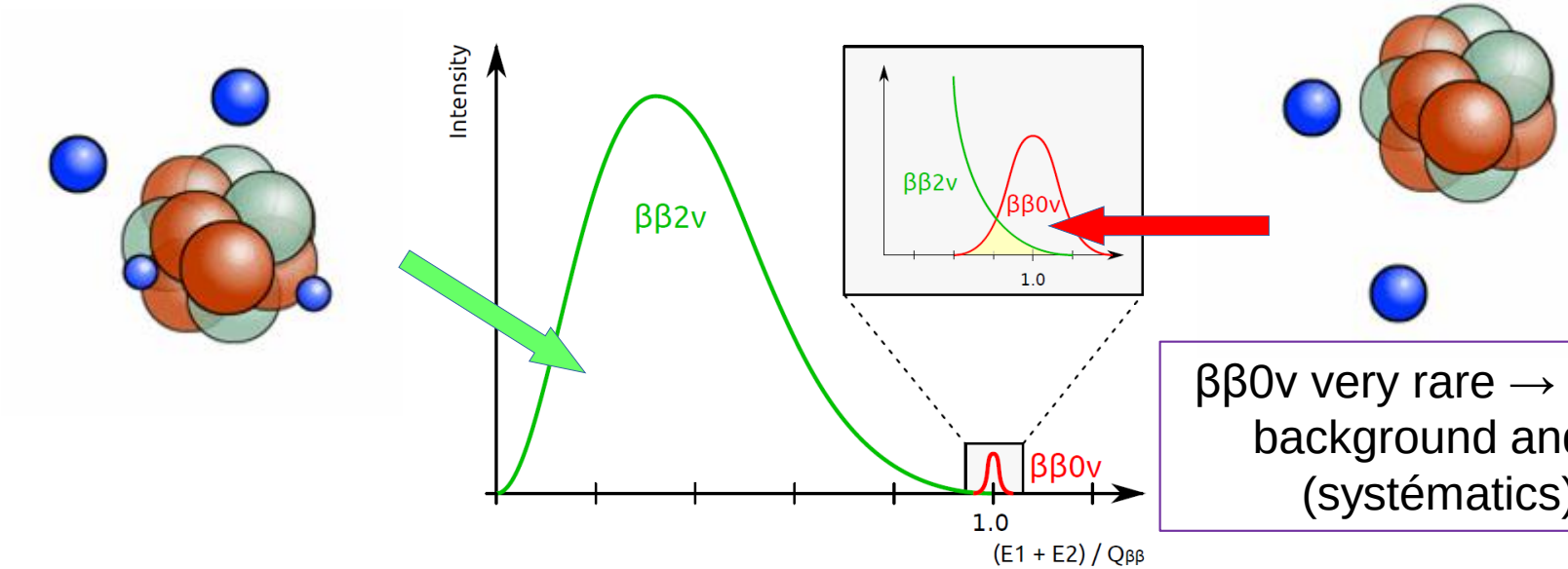
… without neutrinos emission

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

$2n \rightarrow 2p + 2e^-$ → $T_{1/2} > 10^{26}$ ans

Forgiven by the Standard Model
Not observed yet
Will prove that $\nu = \bar{\nu}$ **(Majorana** ν**)**





ββ0ν very rare → need to contrôle the background and so the measure (systématics) on the energy

The SuperNEMO experiment : description and optimisation of the demonstrator’s calorimeter

SuperNEMO : the detector

Demonstrator = 1/20 SuperNEMO
Installation at Laboratoire Souterrain de Modane

The source foil

7 kg de Sélénium 82
($Q_{\beta\beta}$=2,998 MeV)

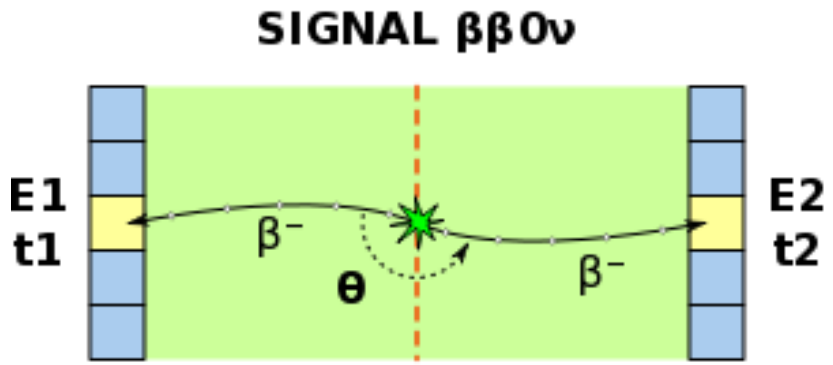
The tracker

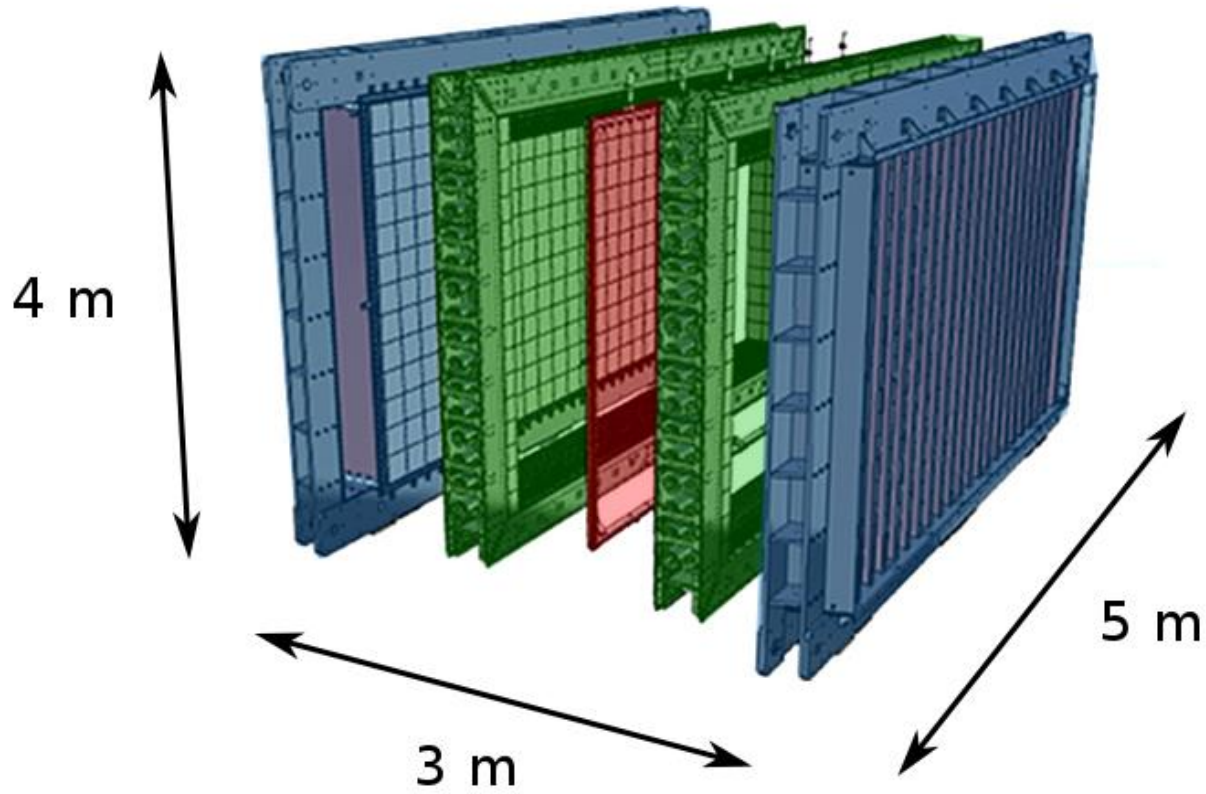
2034 Geiger cells (14970 wires)
→ reconstruction of the trajectory
→ particules identification

The calorimeter

712 optical modules
→ measure of the energy
→ measure of the time of flight

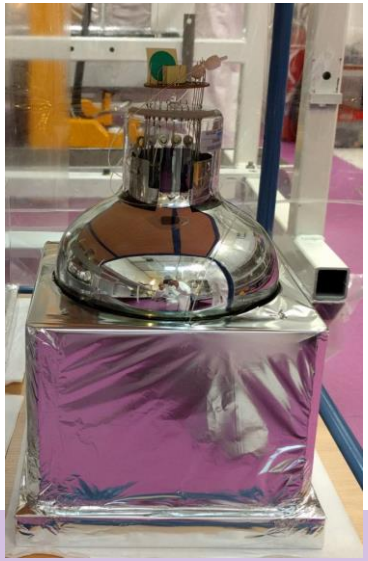
My thesis : to caracterise and to optimise!





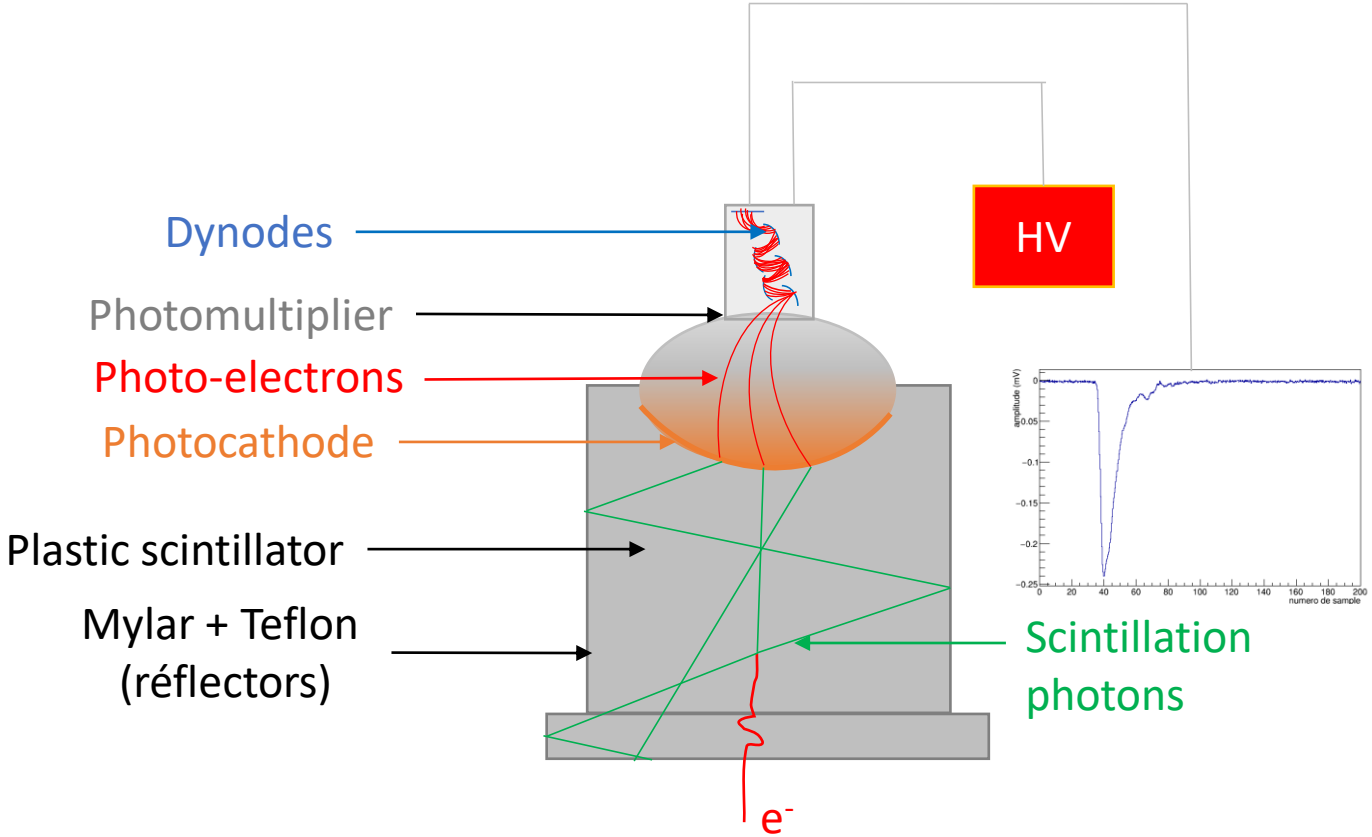
The calorimeter

Main wall



x520

Optical Module



~~**Signal (charge) ∝ nb photons ∝ deposited energy**~~

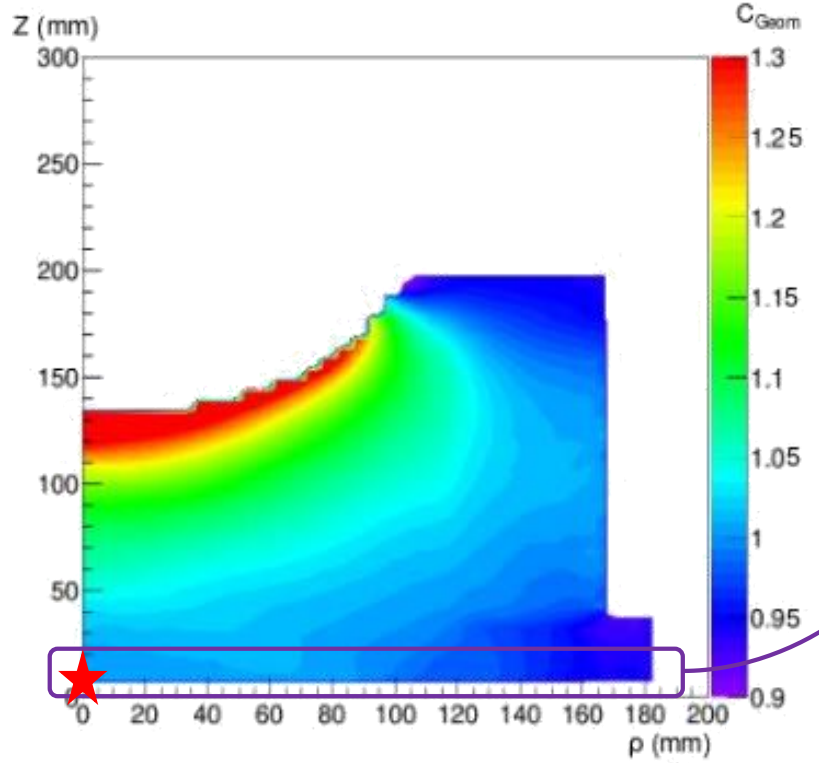
<u>SuperNEMO</u> : mastery the energy at 1%!

- Precision of the calibration
- non-linéarity of light production and response of the photomultiplier
- non-uniformity of the scintillator and the photocathode.

Effects on the energy to take into account

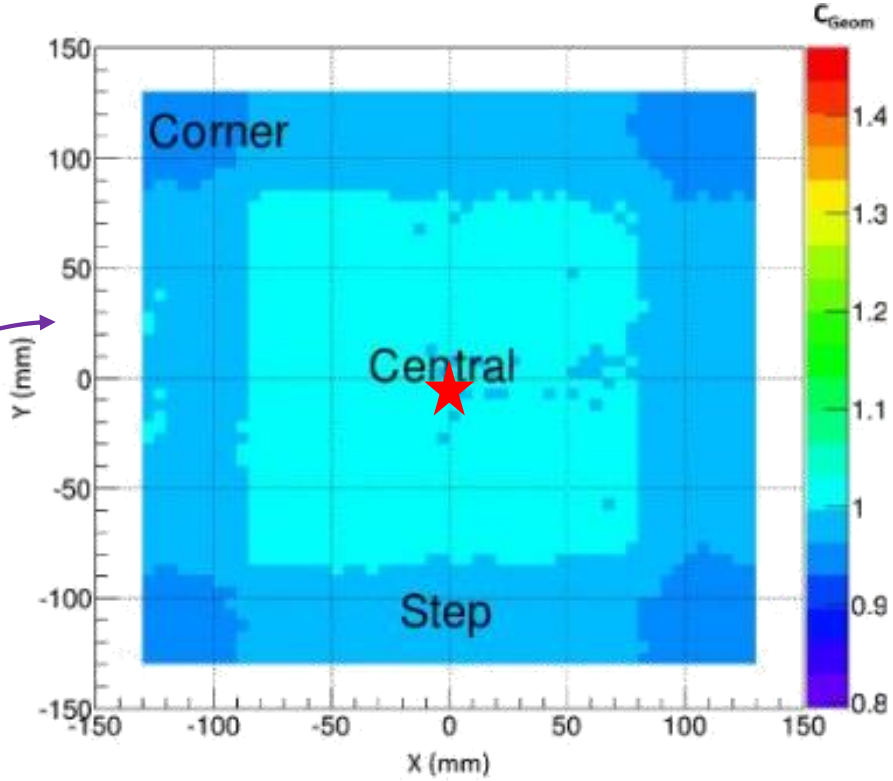
- Geometrical effects : difference on the energy measurement of a particle depending on the interaction point (non-uniformity of light collection)

Correction factor for the full volume of the scintillator



★ Normalisation

Correction factor for the front face of the scintillator



Results from A. Huber

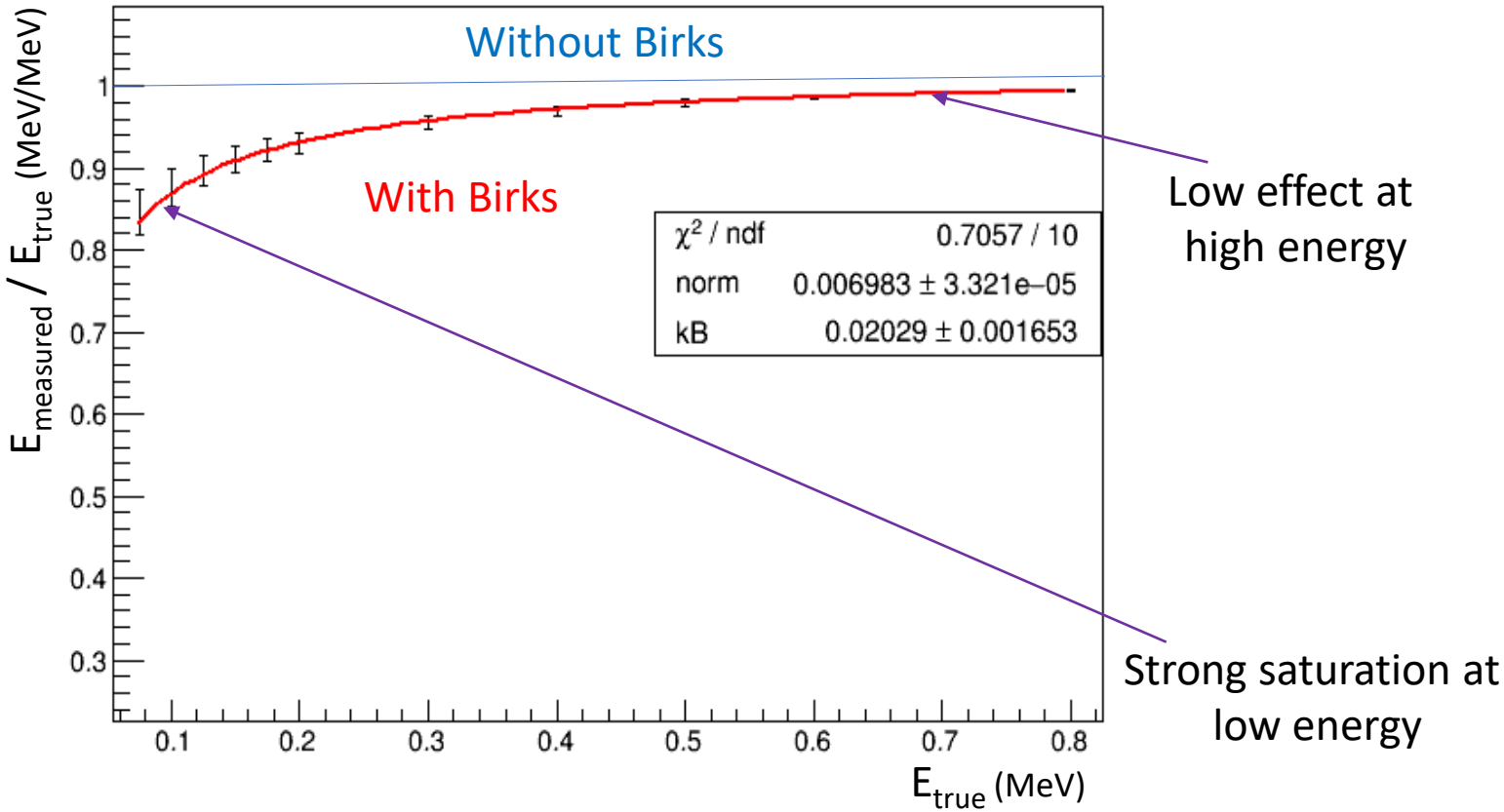
- Birks effect
- Cerenkov effect

Effects on the energy to take into account

- Geometrical effects
- Birks effect: local saturation of the scintillation (non-linéarity of light production)

$$LY(E_0) = SE_0$$

$$LY(\mathbf{E_0}) = S \int_0^{\mathbf{E_0}} \frac{1}{1 + \mathbf{k}_B \frac{dE}{dx}} dE$$



- Cerenkov effect

Effects on the energy to take into account

- Geometrical effects
- Birks effect
- Cerenkov effect : more light is produced when $v_{part}^{scint} > v_{light}^{scint}$

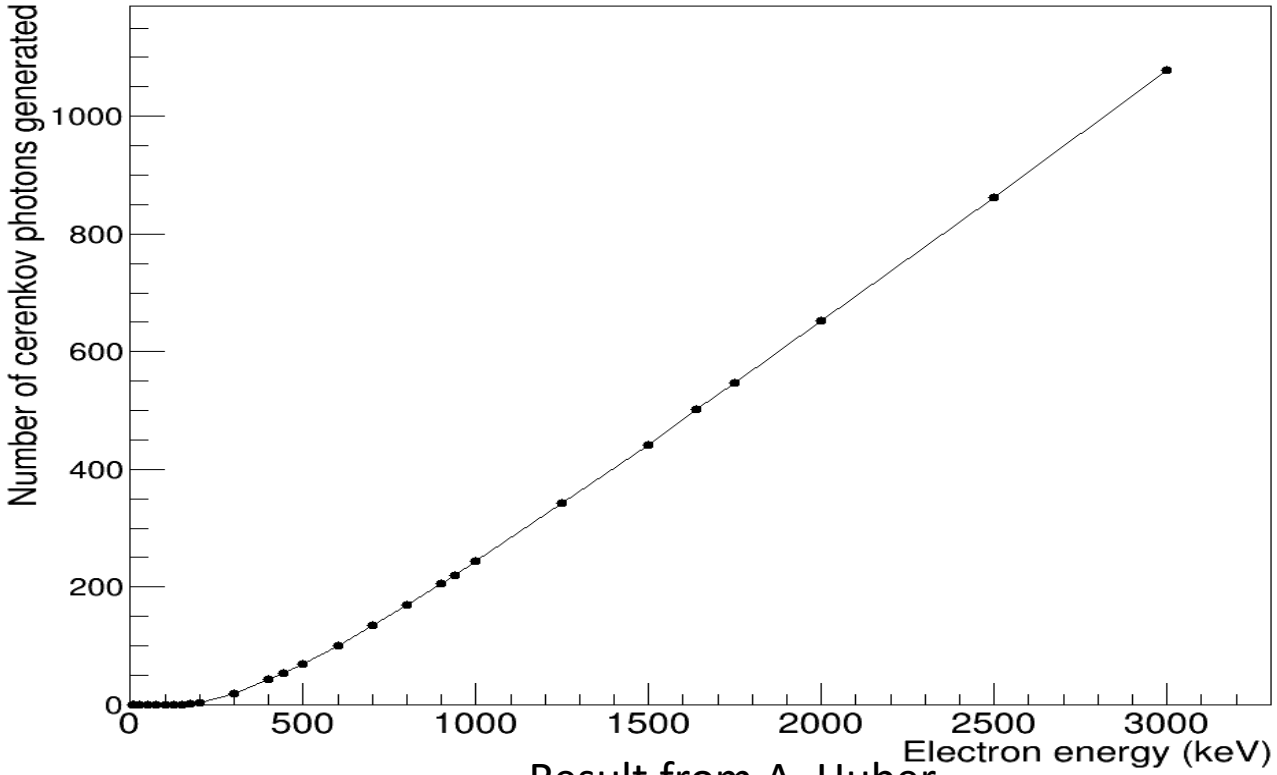
n = 1.59 for the SuperNEMO scintillators

→ $v_{light}^{scint} = \frac{c}{n}$ = 0,63c

→ $E_{thresh} = \frac{m_0 c^2}{\sqrt{1-\frac{1}{n^2}}} - m_0 c^2$ = 146 keV

→ $N_\gamma = 2\pi\alpha x Z^2 \left(\frac{1}{\lambda_{min}} - \frac{1}{\lambda_{max}}\right) sin^{2\theta_C}$

$= 217$ more photons @ 1MeV



Result from A. Huber

Effects on the energy to take into account

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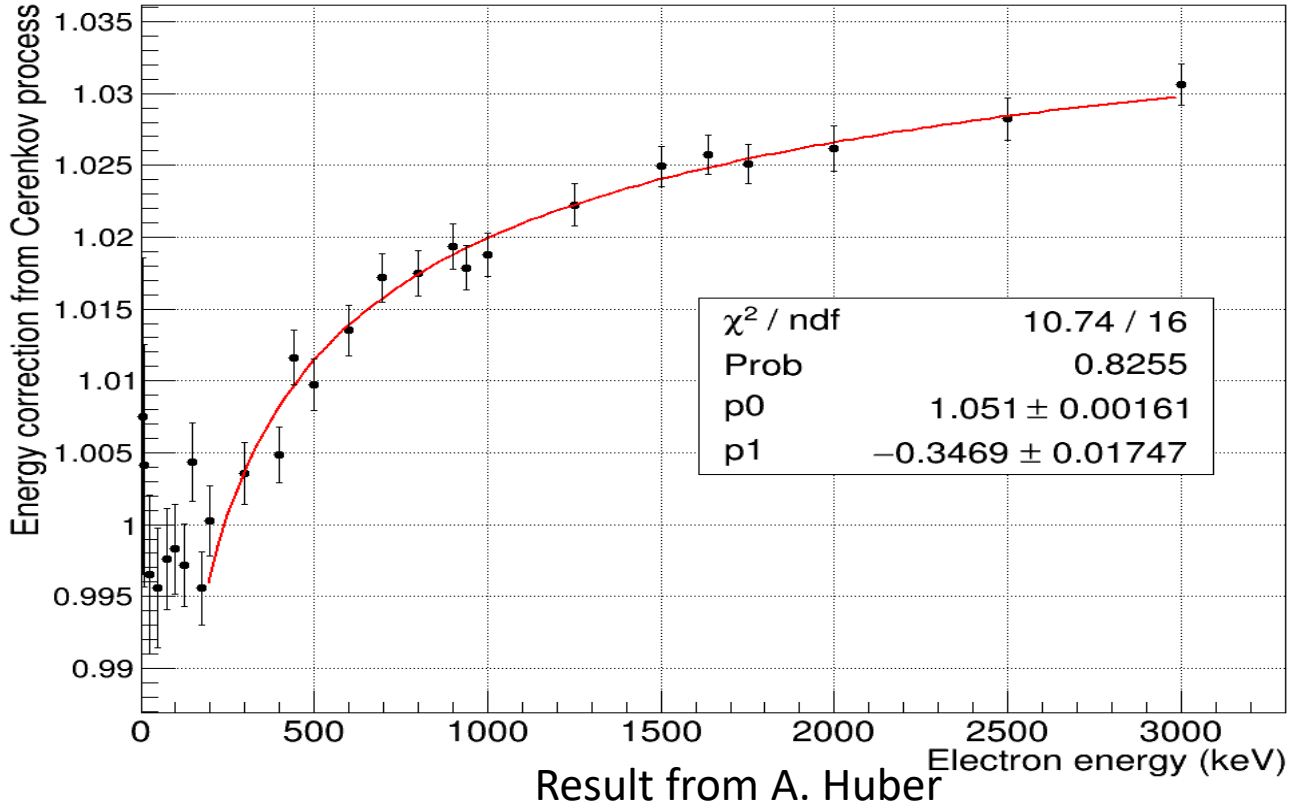


Result from A. Huber

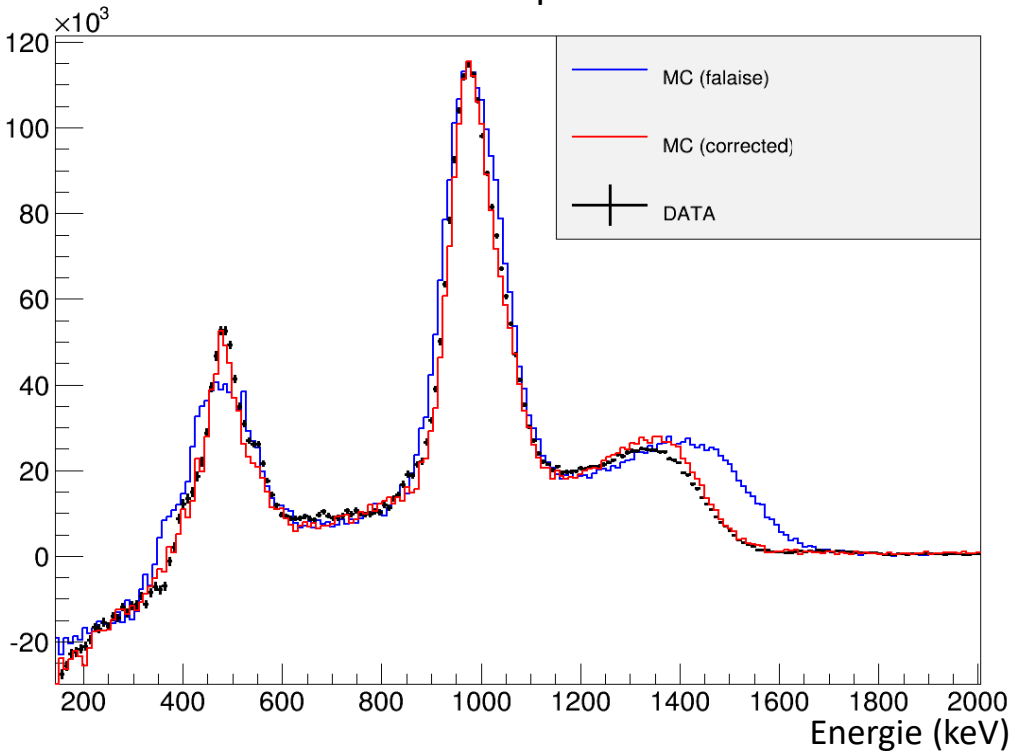
Effects on the energy to take into account

- Geometrical effects
- Birks effect
- Cerenkov effect

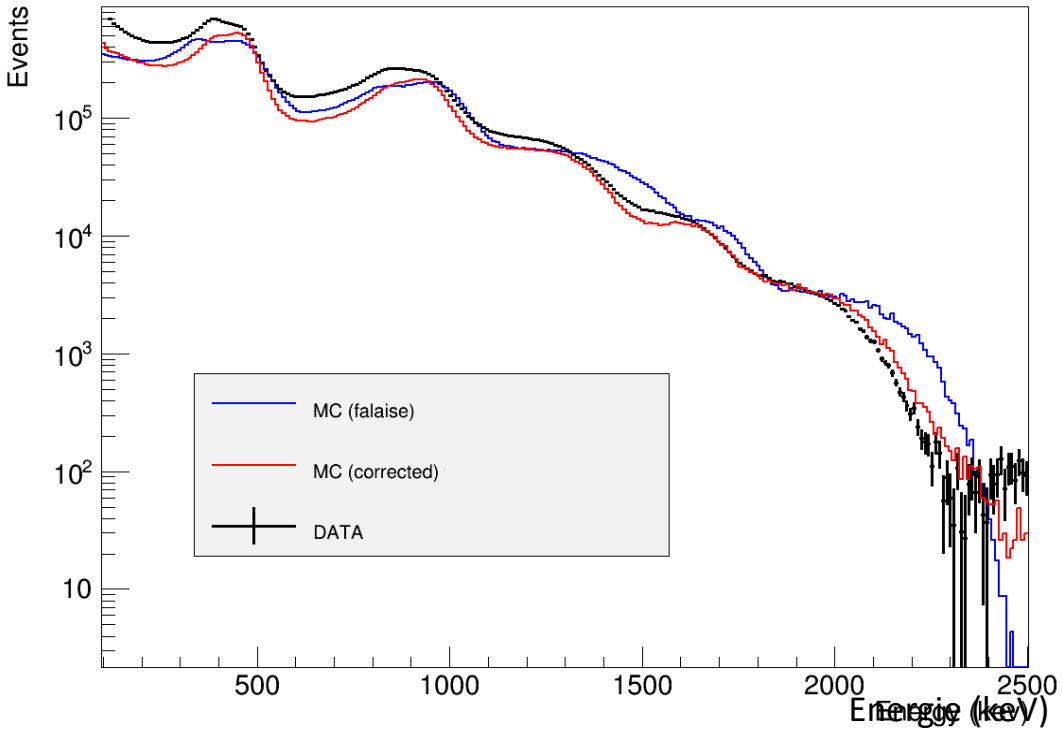
} Impact on the spectrum: distorsion + enlargement

Exemple : ^{207}Bi (EC + γ) spectra (calibration sources of SuperNEMO)

^{207}Bi electron spectra



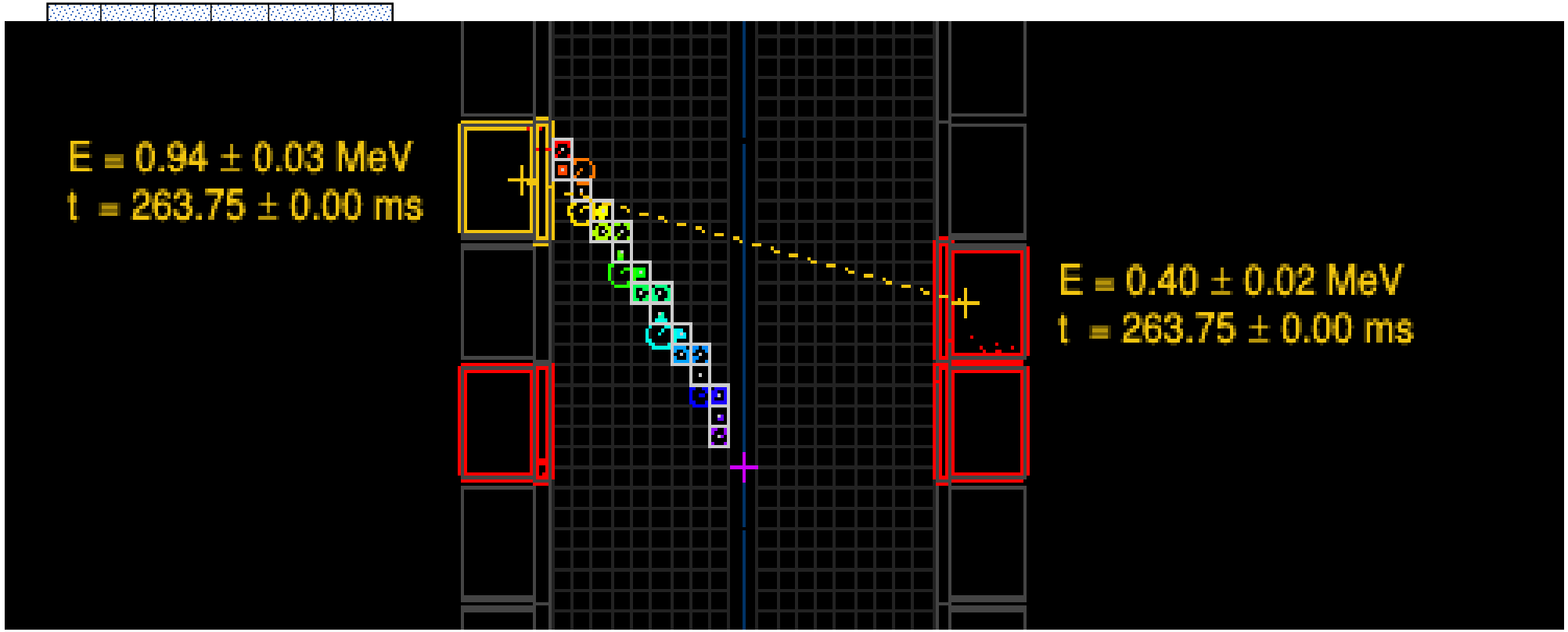
^{207}Bi gamma spectra



Results from A. Huber

Implementation of corrections in the simulation

- 1st step : Measurement of corrections

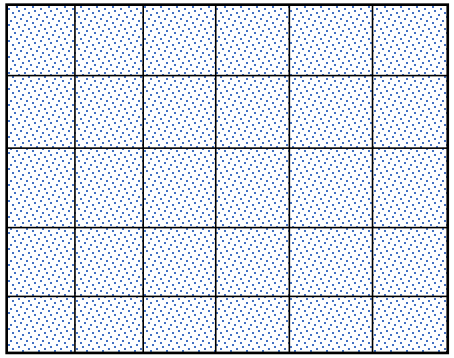


SuperNEMO simulation : ^{207}Bi events

- 2nd step
- 3rd step
- 4th step

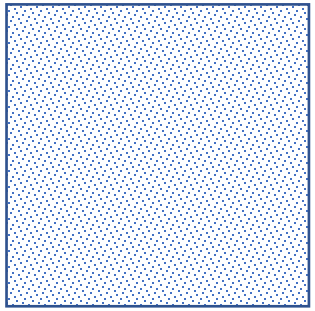
Implementation of corrections in the simulation

- 1st step : Measurement of corrections

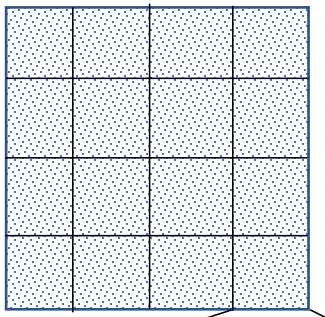


Main wall : ^{207}Bi e- simulation

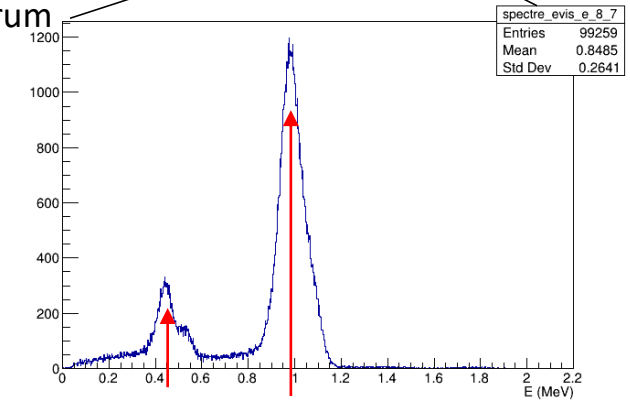
All events are placed in the same referential



Division in little surfaces

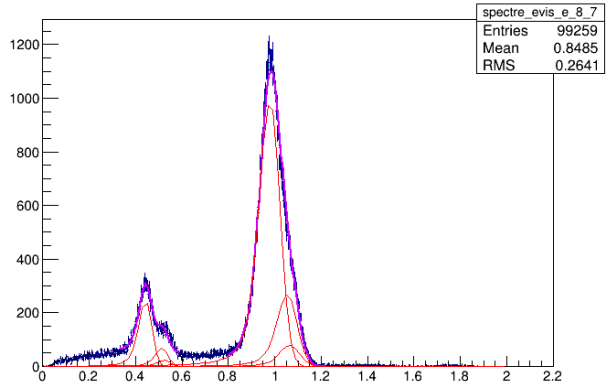


Draw of the corresponding e- spectrum



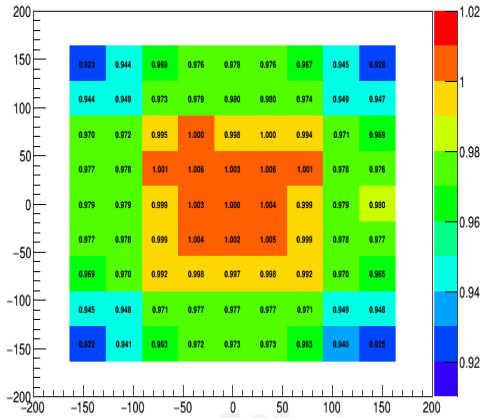
482 keV 976 keV

Fit → $E_{masured}$



Correction = $\frac{0{,}976\ (MeV)}{E_{masured}}$

Job done for each little surface



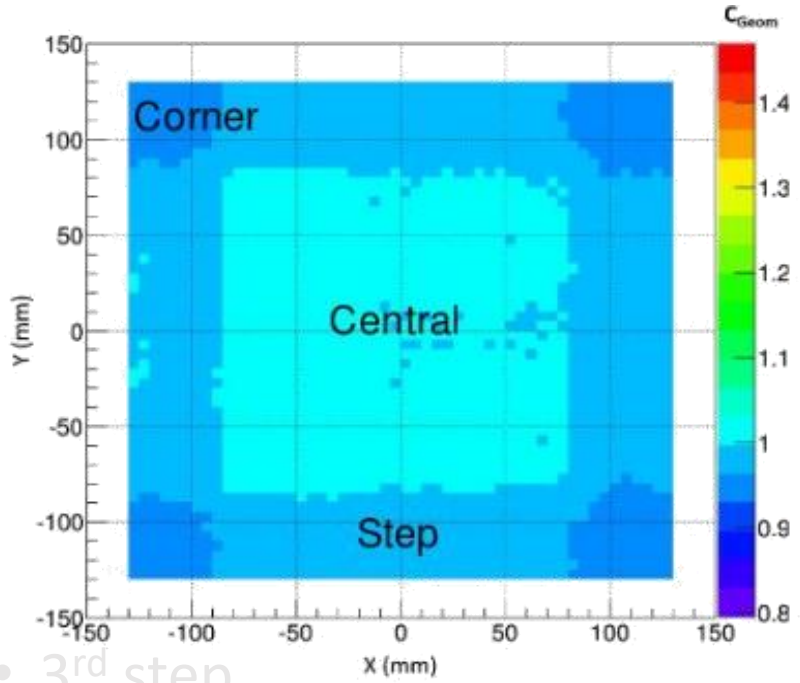
Reconstructed corrections

- 2nd step
- 3rd step
- 4th step

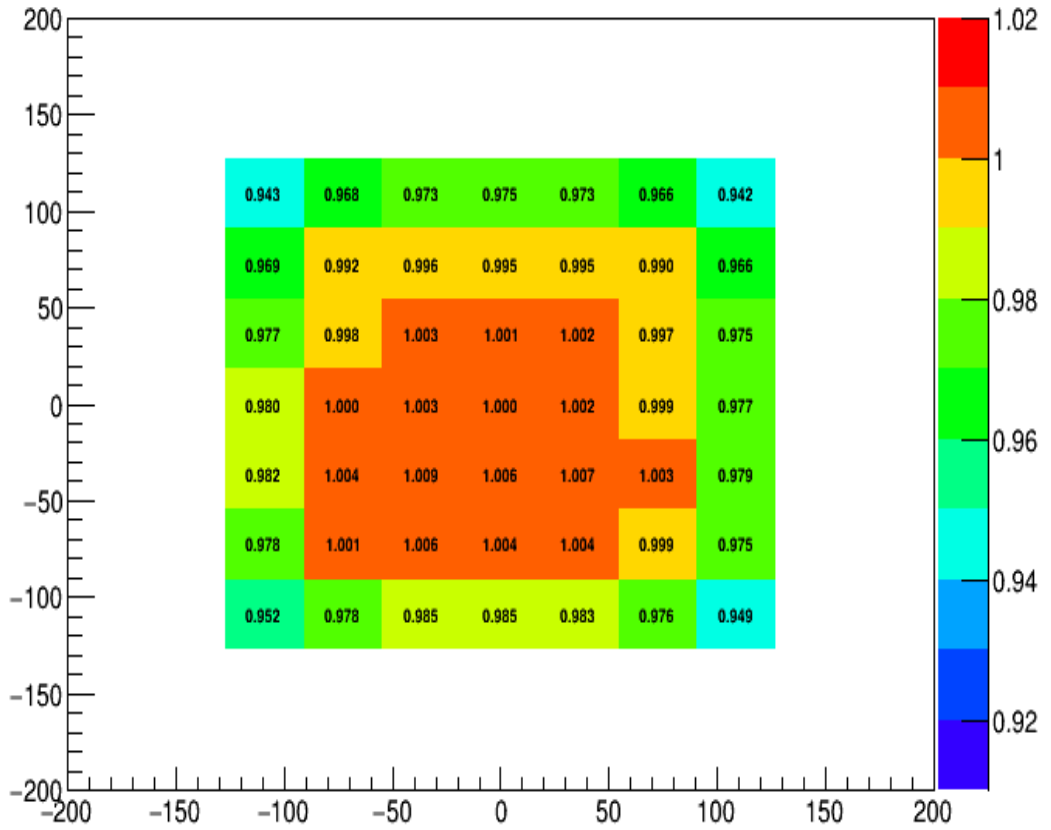
Implementation of corrections in the simulation

- 1st step
- 2nd step: Discretisation of geometrical corrections
- 3rd step
- 4th step

Correction factor for the front face of the scintillator



Discretisation

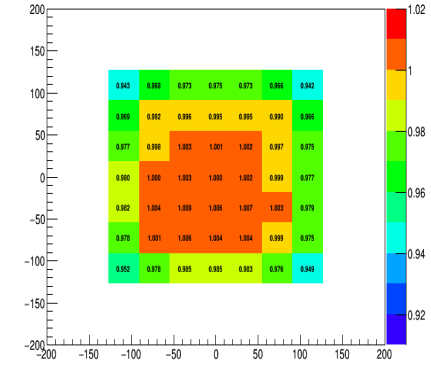


True corrections

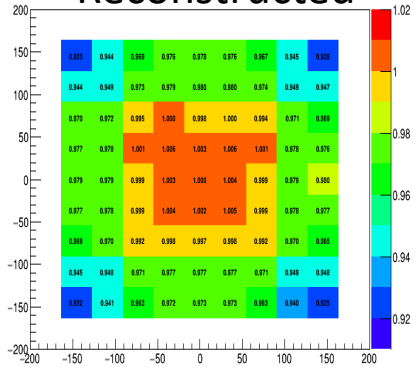
Implementation of corrections in the simulation

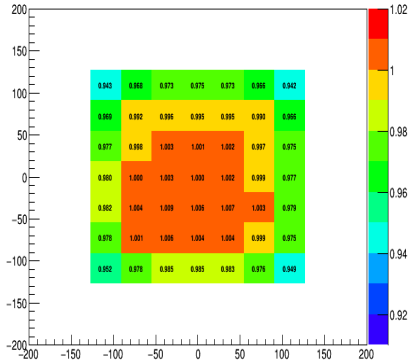
- 1st step
- 2nd step
- 3rd step: Comparison true/recontructed corrections

True

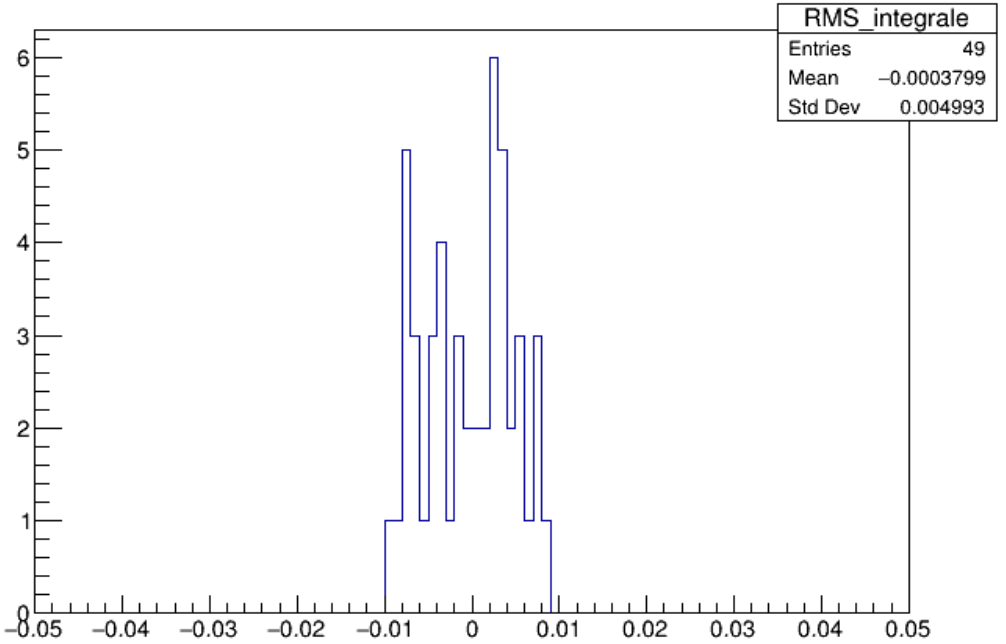


Reconstructed





True



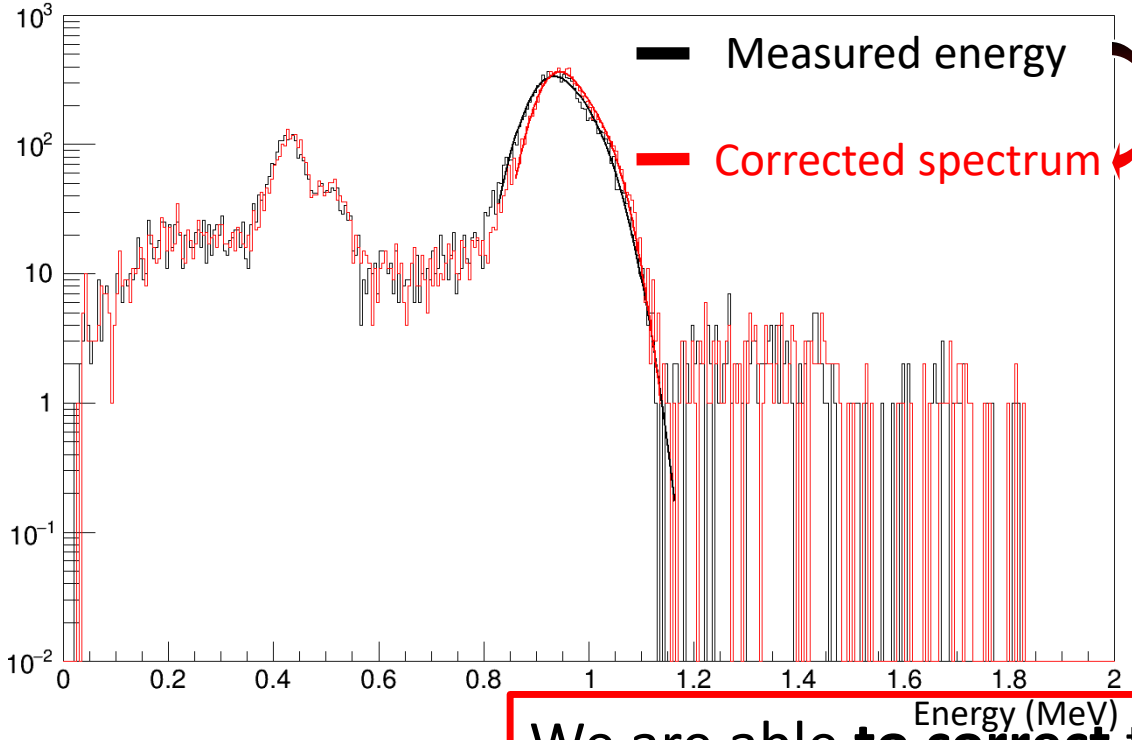
Difference < 5 ‰

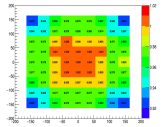
We are able **to measure** the effects on energy

- 4ème étape

Implementation of corrections in the simulation

- 1st step
- 2nd step
- 3rd step
- 4th step: Use of corrections to correct effects on energy





$\sigma_{976} = 5{,}0 \pm 0{,}1\ \%$ → $\sigma_{976} = 4{,}4 \pm 0{,}1\ \%$

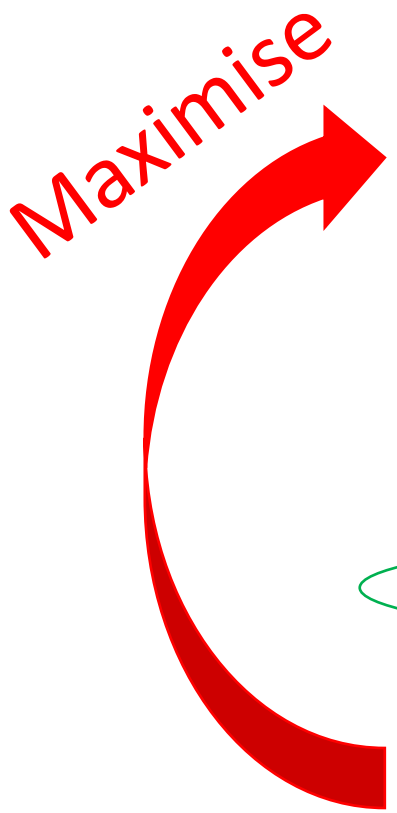
Improvement on resolution : 12%

We are able **to correct** the effects on energy

The LiquidO project : R&D for a multi-ton double beta experiment

Motivation

$$T_{1/2}^{0\nu} > \frac{N_A ln(2) m t \varepsilon}{M N_{excluded}}$$



N_A = Avogadro cte = 6.02×10^{23} mol^{-1}

m = mass of exposed isotope (kg)

t = exposure time (year)

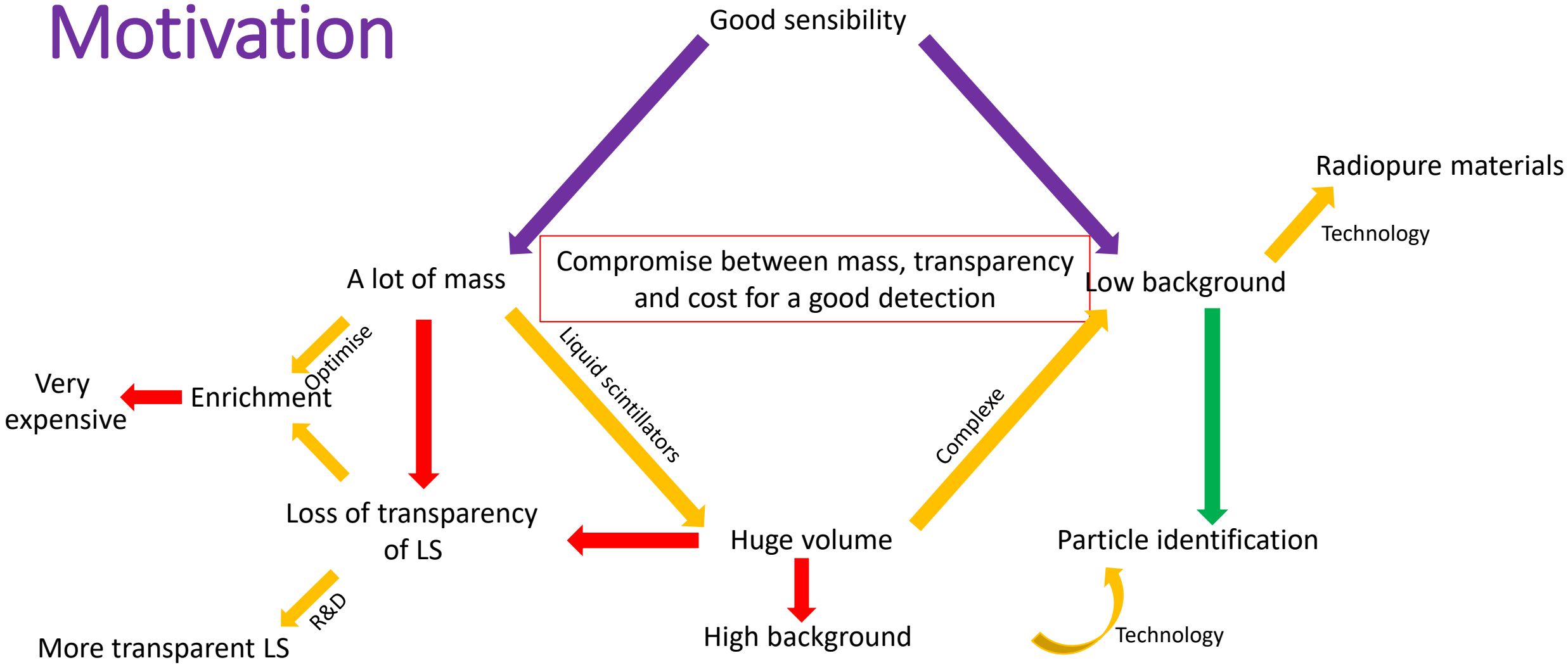
ε = selection efficiency of the ββ0ν signal

M = Molar mass (kg/mol)

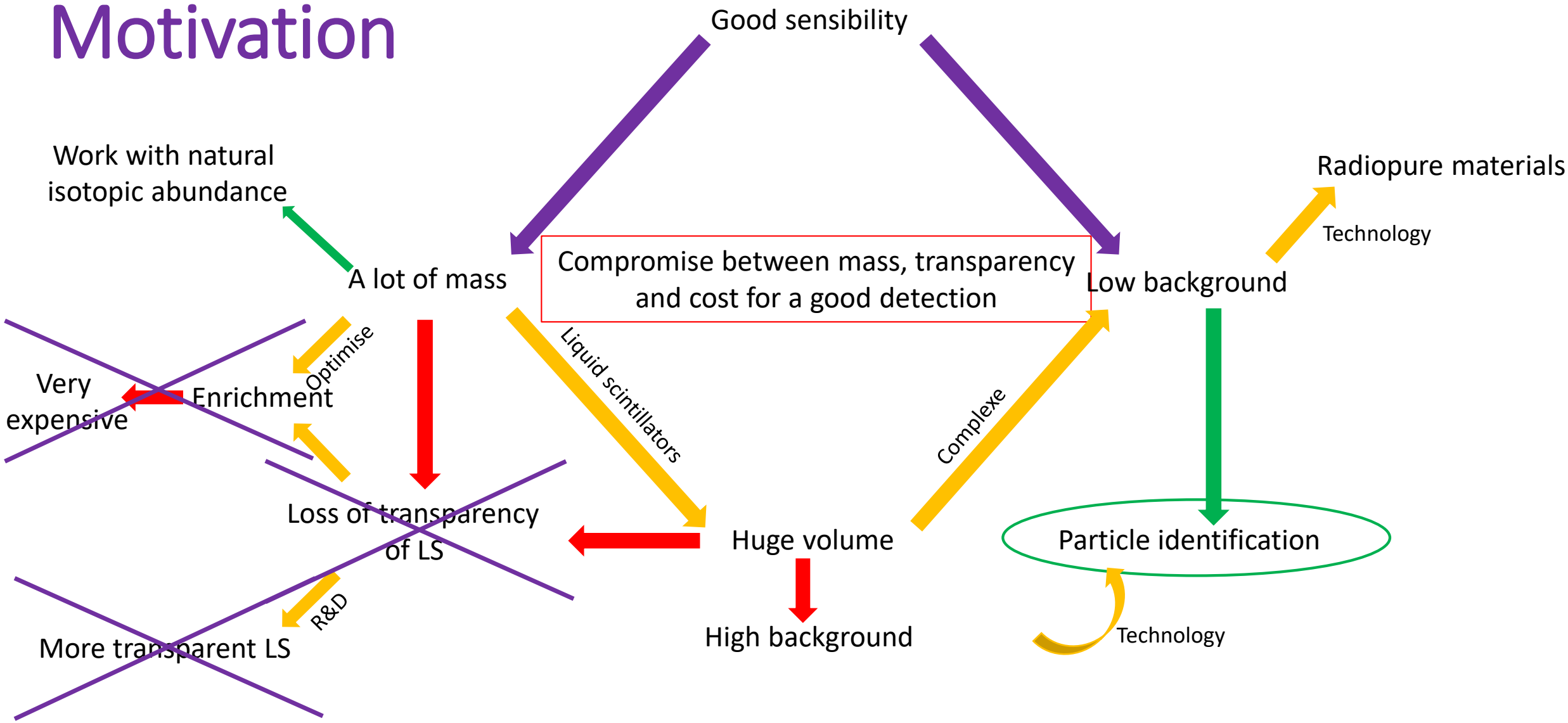
$N_{excluded} \geq 2.3$ (background dependant)

LiquidO

Motivation


Good sensibility
Compromise between mass, transparency and cost for a good detection
A lot of mass
Low background
Radiopure materials
Technology
Optimise
Very expensive
Enrichment
Liquid scintillators
Complexe
Loss of transparency of LS
Huge volume
Particle identification
R&D
More transparent LS
High background
Technology

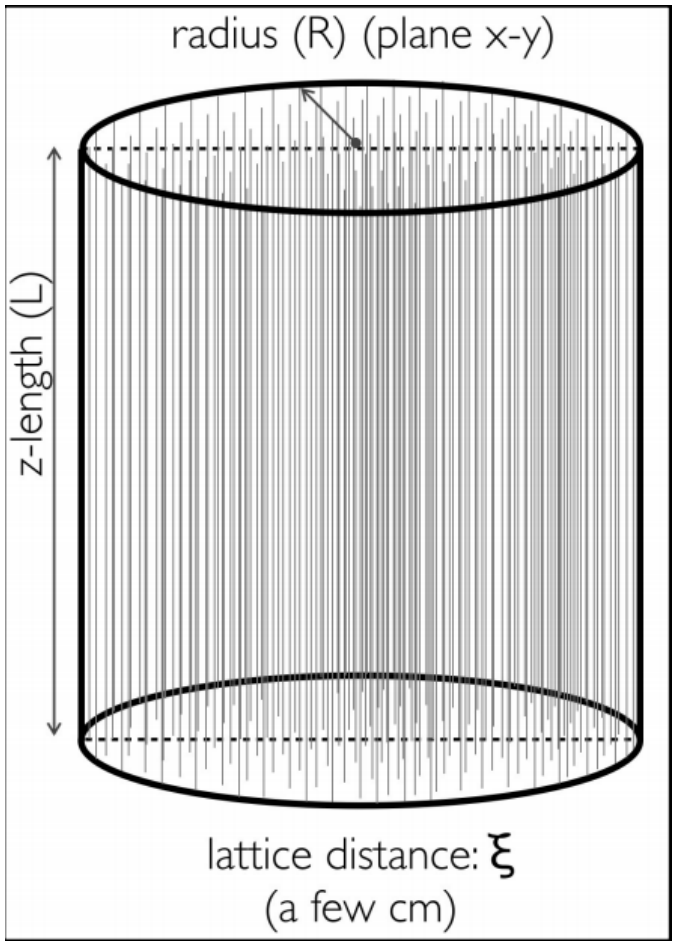
Motivation

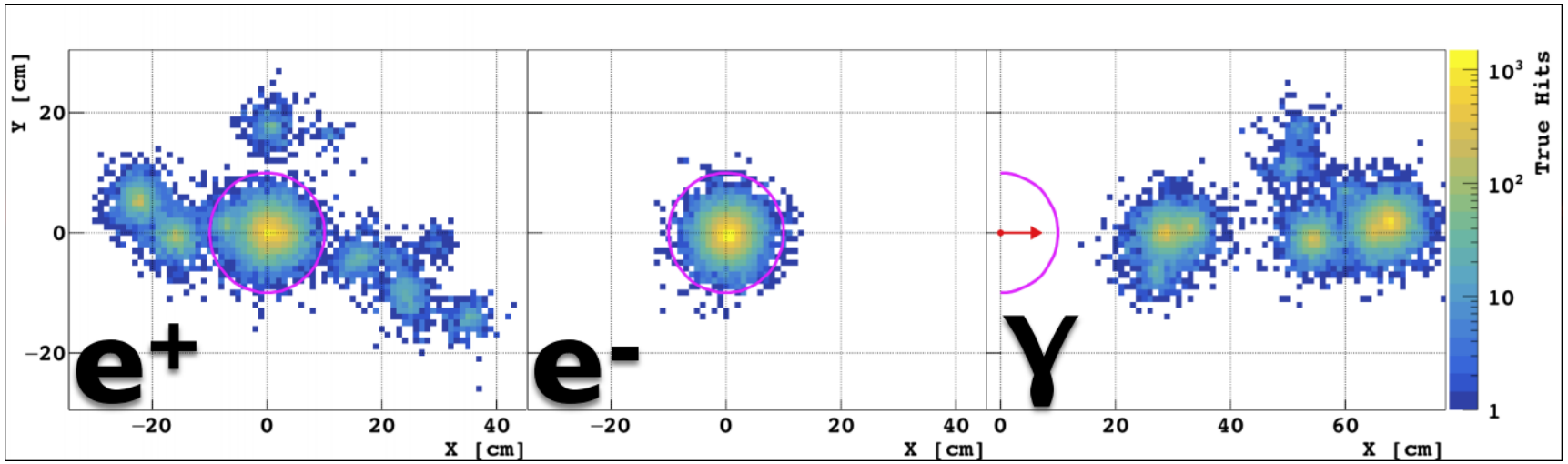


LiquidO : use of an opaque liquid scintillator!

Detection principle

Opaque liquid scintillator **to confine** the light + **optical fibers to collect** trapped scintillation photons

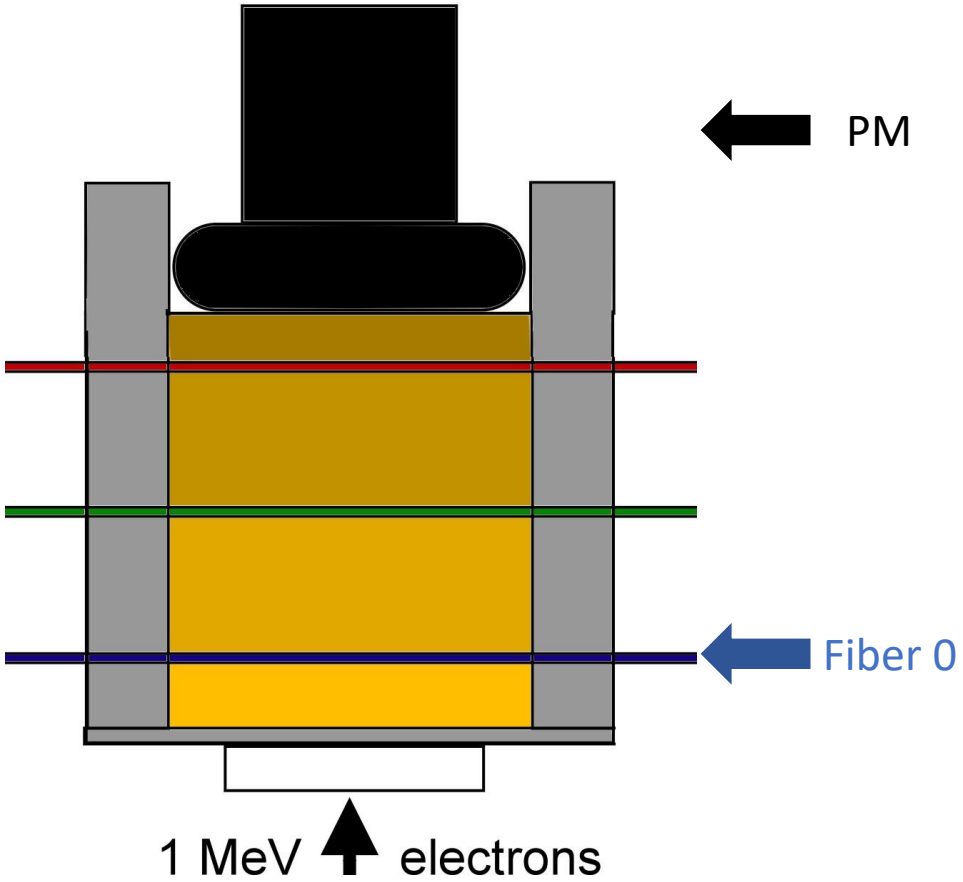


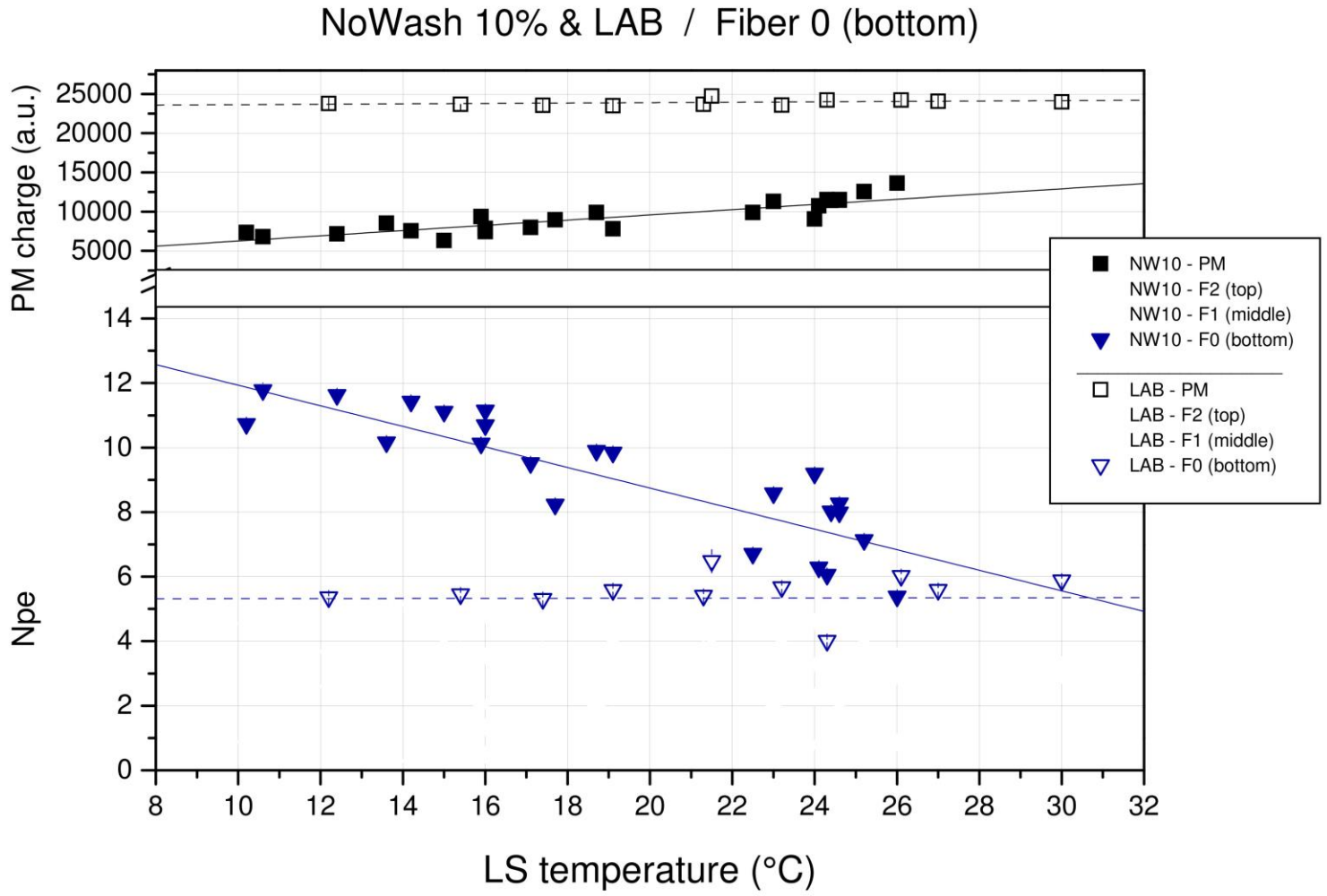


Particle identification with LiquidO (simulation)

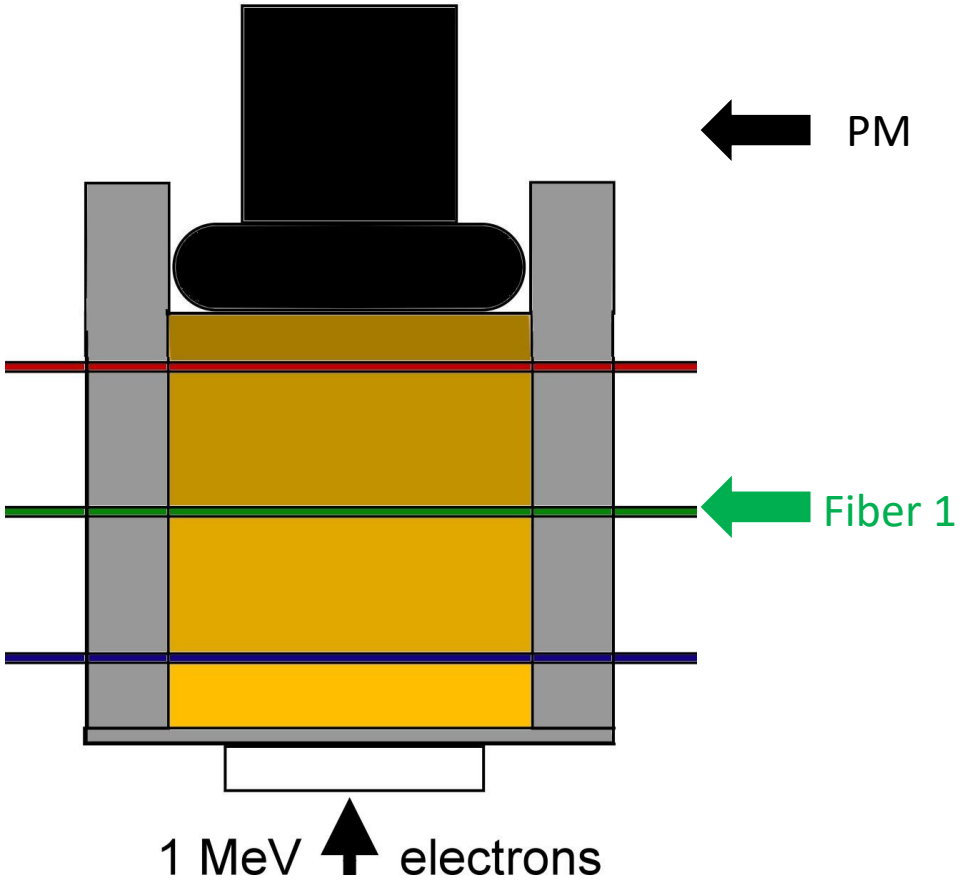
Pictures from Anatael Cabrera

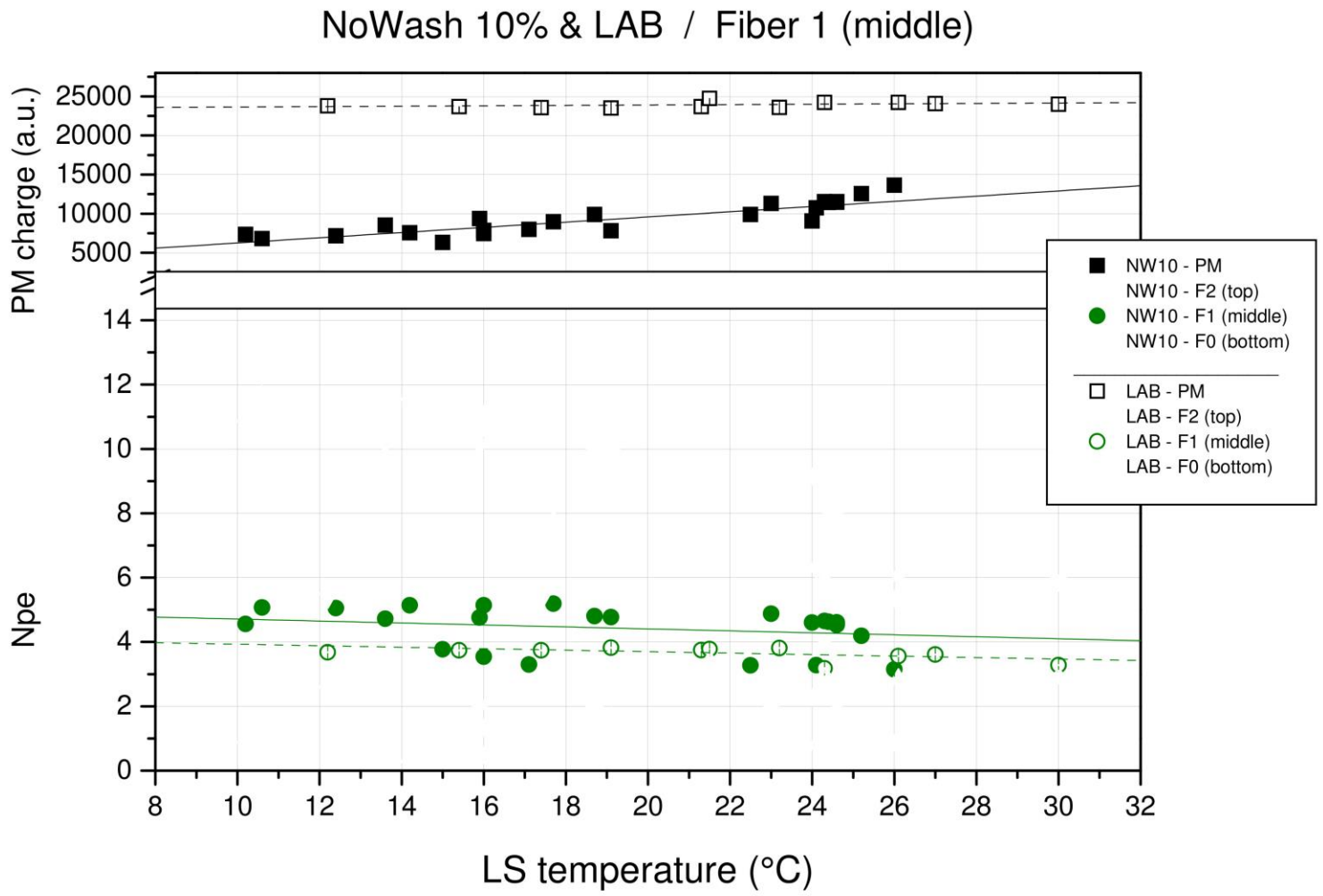
R&D first results with opaque liquide made in CENBG



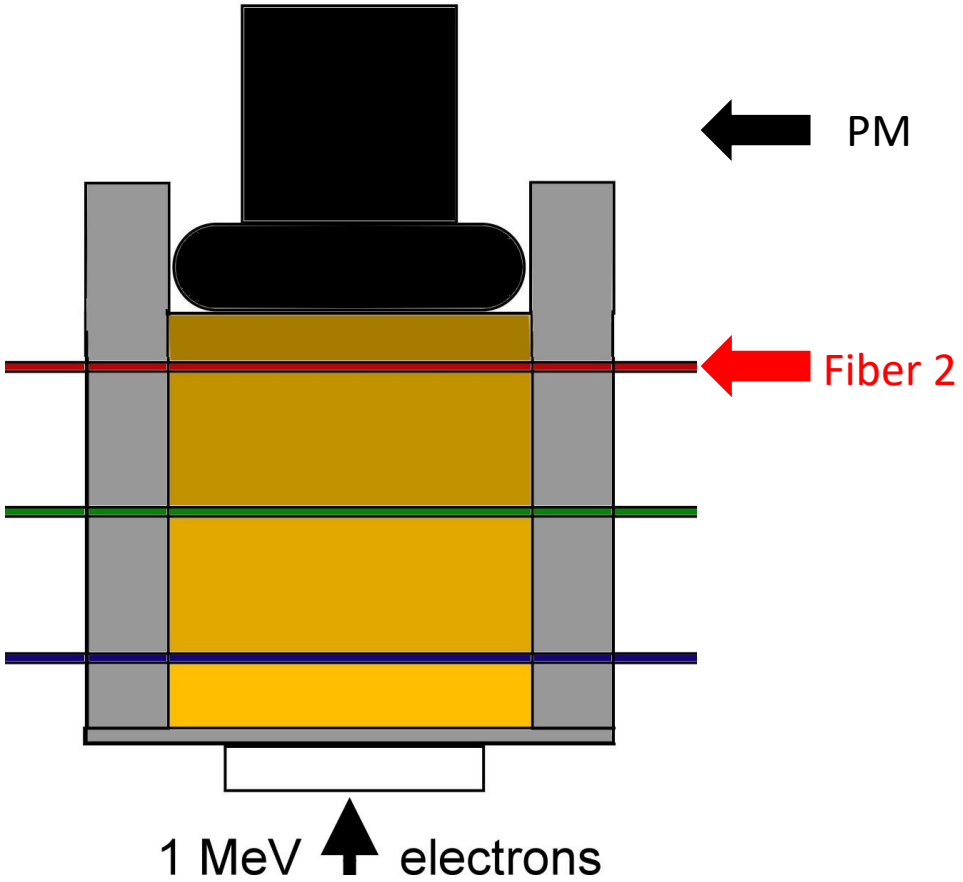


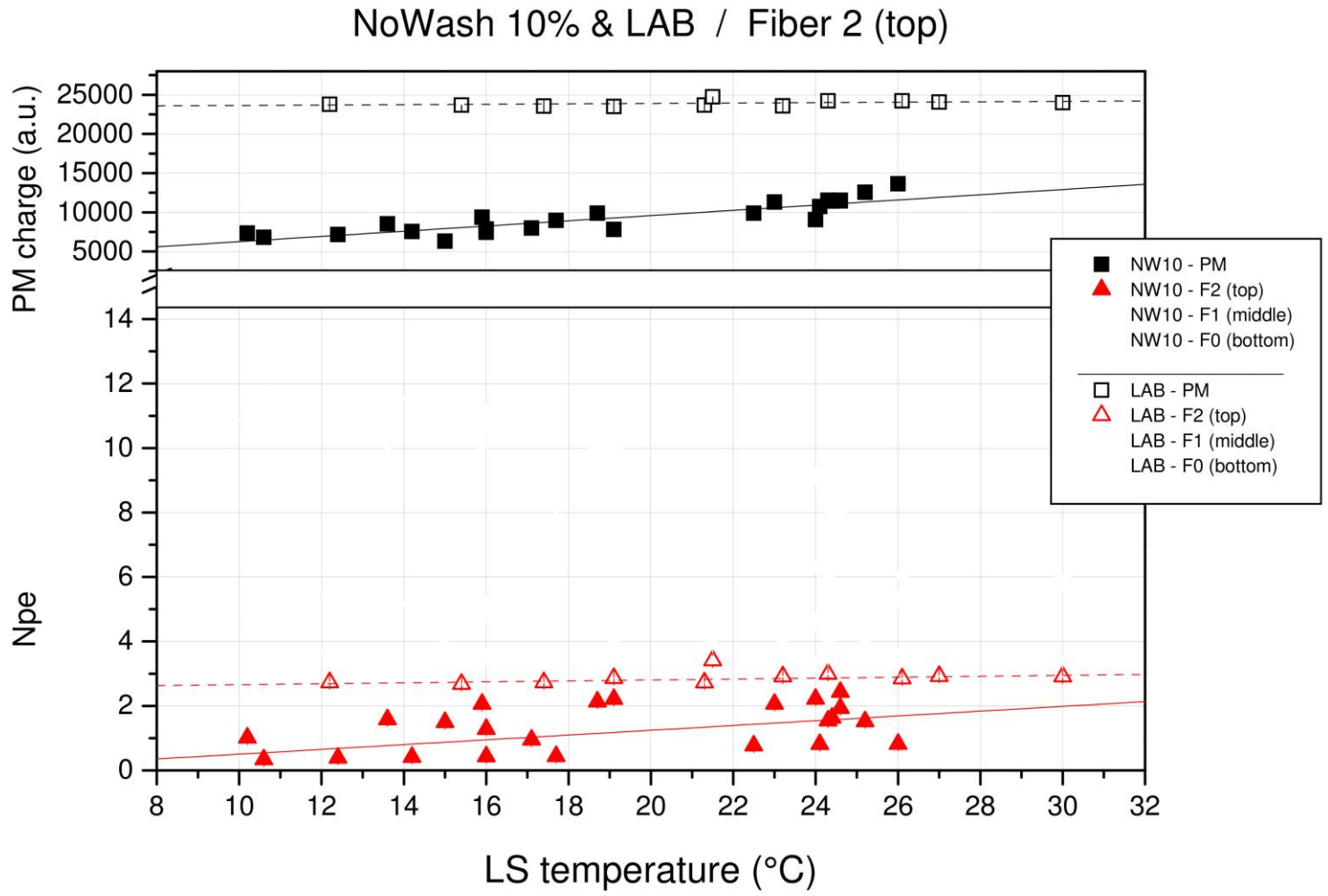
R&D first results with opaque liquide made in CENBG





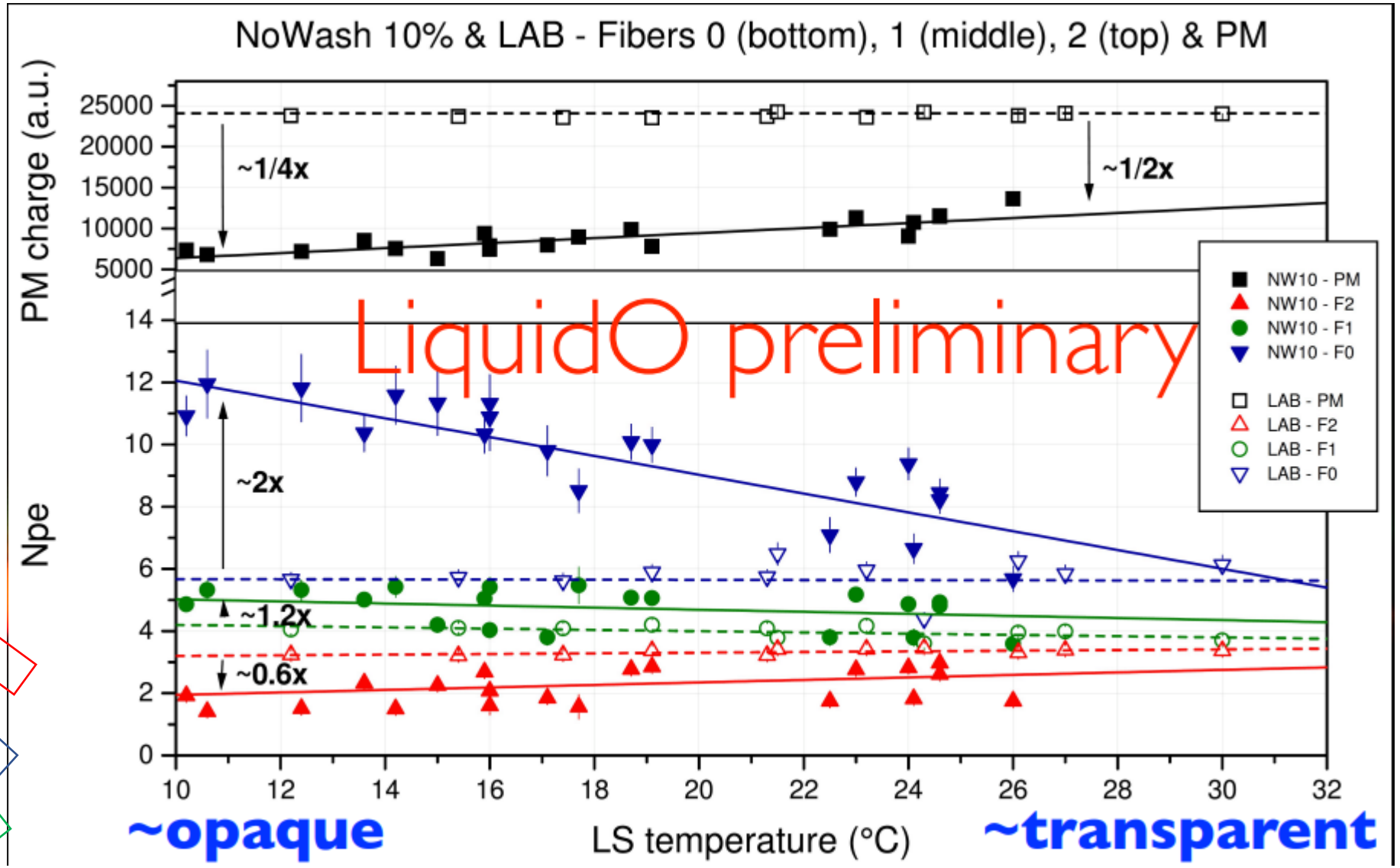
R&D first results with opaque liquide made in CENBG





R&D first results with opaque liquide made in CENBG

1 MeV electrons



Conclusions

- Neutrinos are very badly known
- The discovery of the neutrinoless double beta decay will help us to know about their nature

- SuperNEMO :
  - Unique technology to detect the ββ0ν and to study the involved mechanisms
  - Need to control all systematics on the measurement on energy
  - We are able to correct these systematics

- LiquidO :
  - Potential to be a multi-to experiment
  - Still in R&D
  - Very promising results