# SuperNEMO

## within the labex ENIGMASS

## (and few words on $0\nu\beta\beta$ physics)


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# Is there any Majorana particles?

In 1936 E. Majorana:

- A *real* wave equation to describe massive & electrically neutral fermion:
  - **particle** == **antiparticle**

In 1957 B. Pontecorvo:

- Set the basis for the neutrino flavour oscillation

In the last 15 years:

- Huge experimental effort → confirm **neutrino oscillation** and measure parameters

The neutrino is a **fermion**, is **electrically neutral** and is **massive**

- **Is it a Majorana particle?**

Interesting implication for particle physics:

- Lepton number violation must occur ($0\nu\beta\beta$ decay)
- GUT, Leptogenesis model, See-Saw mechanism

**$0\nu\beta\beta$ decay is the only practical way to test Majorana nature of neutrinos**

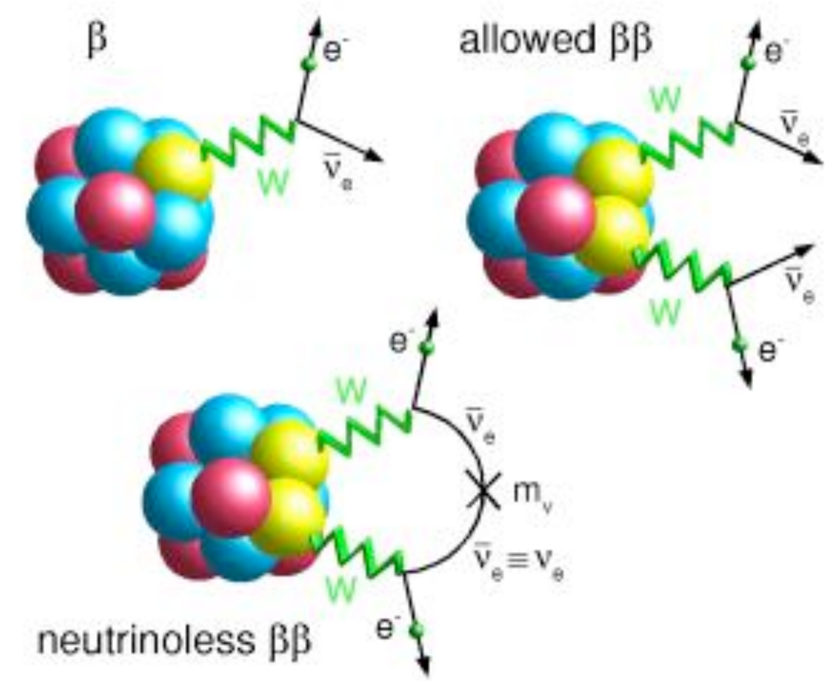
# The neutrino-less double beta decay

2νββ decay: $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$

- 2nd order process **allowed** in the SM
- Single β decay forbidden (energy & angular momentum)

0νββ decay: $(A, Z) \rightarrow (A, Z+2) + 2e^-$

- process **forbidden** in the SM




$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)|M_{0\nu}|^2\eta^2$$

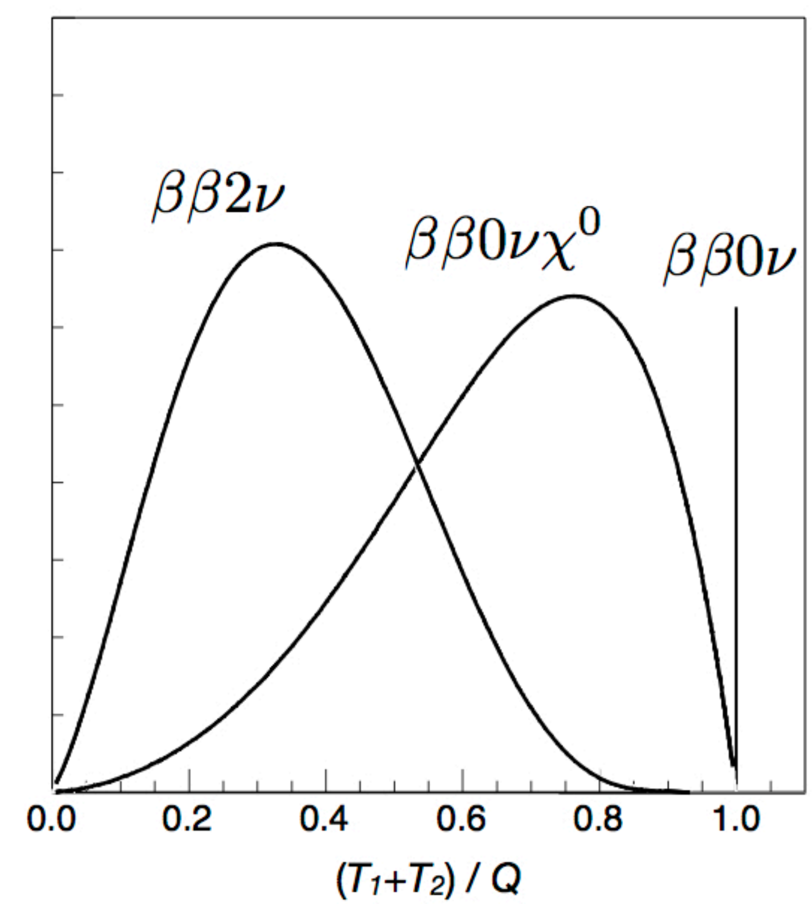
**$G_{0\nu}$**: Phase space term (atomic physics)

**$M_{0\nu}$**: Nuclear matrix element (nuclear physics)

**η**: decay mechanism (particle physics)

- **Light Majorana neutrino exchange**
- Right-handed current (V+A), SUSY, I Majoron, etc.

Different event topology in the final state

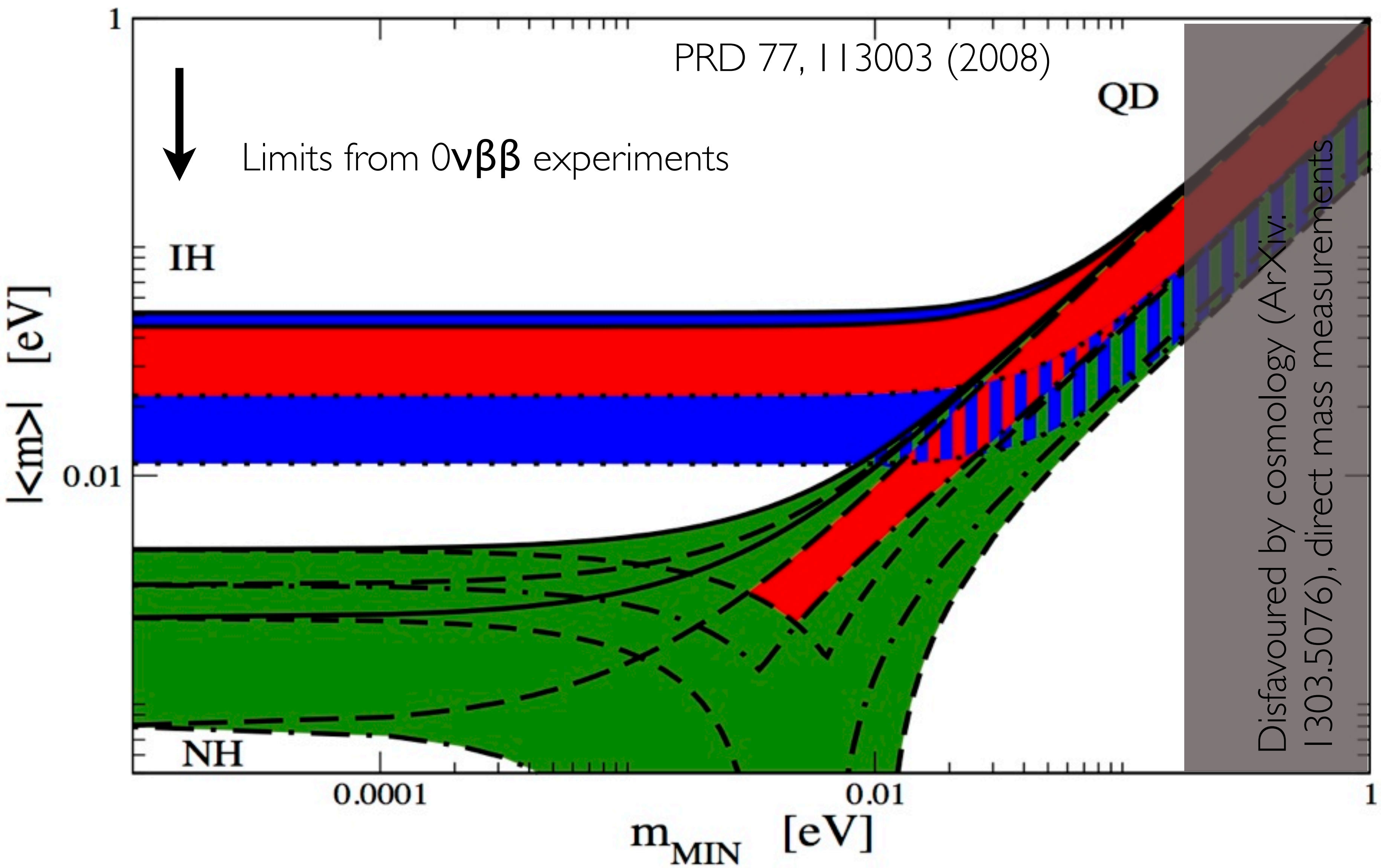


# Sensitivity on neutrino mass scale

$$\left(T_{1/2}^{0\nu}\right)^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2 \frac{\langle m_{ee}\rangle^2}{m_e^2}$$

Effective mass term:

$$\langle m_{ee}\rangle = \left|\sum_i U_{ei}^2 m_i\right|$$

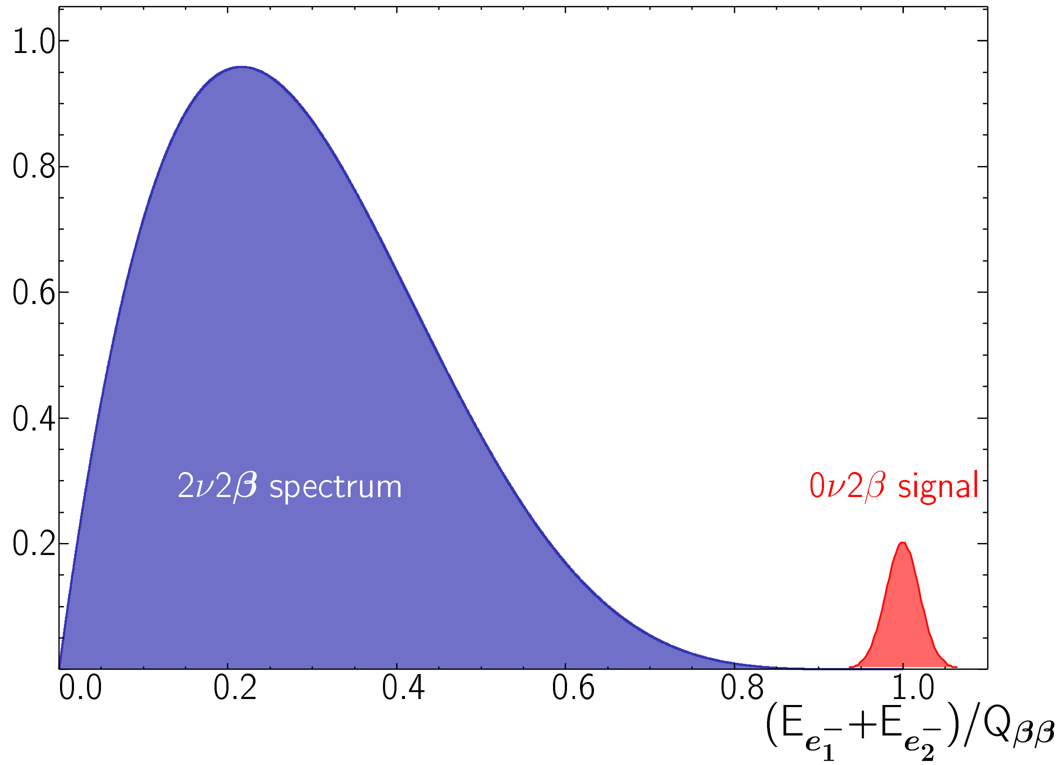



Related to neutrino oscillation

Sensitive to the neutrino mass scale ($m_{min}$)

**CP violation**
**Normal Hierarchy**
**Inverted Hierarchy**

# Searching for 0νββ process




Measure the 2 e⁻ energy spectrum

- 2νββ signature → Broad spectrum
- 0νββ signal signature → **Peak** @ $Q_{\beta\beta}$

If no signal → set a **limit** on half life

$$T_{1/2}^{0\nu} > \frac{N_A \ln 2}{n_\sigma} \times \frac{\epsilon}{A} \times \sqrt{\frac{M \times t}{B \times \Delta E}}$$

- Detection efficiency → $\epsilon$
- ββ emitter mass → $M$
- Exposure time → $t$
- Excluded events at a given C.L. → $n_\sigma$
- Atomic mass → $A$
- Bkg. index → $B$
- E res. @ $Q_{\beta\beta}$ → $\Delta E$

# Some general remarks

Rare process ($T_{1/2} \gtrsim 10^{25}$ y) → Long **exposure**, high isotopic **mass**

Low energy process ($Q_{\beta\beta} \lesssim 5$ MeV):

- **Natural radioactivity** is an issue ($^{232}$Th, $^{238}$U, ...)
  - $\gamma$ (up to 2.6 MeV, $^{208}$Tl) and $\beta$ (up to 3.2 MeV, $^{214}$Bi Q-value)
  - Ultra **high radio-purity material**, dedicated shielding
- Cosmic muons are an issue → **Deep underground** lab

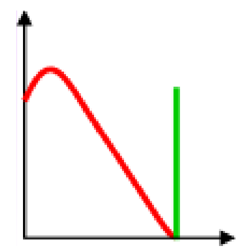
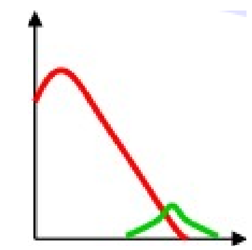
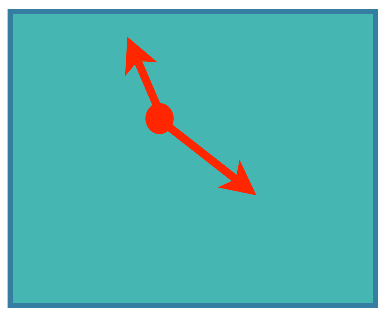
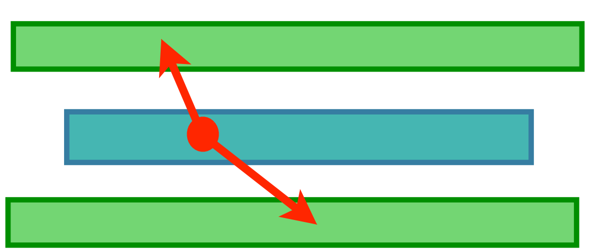
Distinguish $0\nu$ from $2\nu$ mode → the ultimate background

- Good detector **energy resolution**
- Long $2\nu$ mode half life (less $2\nu$ background @ end point)

Many available isotopes → **multiply** experimental efforts

- Adopt different detection techniques
- **Independent** measurements

# Experimental technique

| **En. resolution** / **Technique** | **< 1 %**  | **> 1 %**  |
|---|---|---|
| **Calorimeter**  **Detector = Source** | **Ge diodes**<br>• Efficiency, PID<br>$^{76}$Ge | **Liquid scintillators**<br>• Mass<br>$^{136}$Xe, $^{150}$Nd, $^{48}$Ca, $^{100}$Mo |
| | **Bolometers**<br>• Efficiency, (PID)<br>$^{130}$Te, $^{82}$Se, $^{100}$Mo | **Liquid Xe TPC**<br>• Mass, PID<br>$^{136}$Xe |
| **Electron Tracking**  **Source** **Detector** | **Gas Xe TPC**<br>• (PID)<br>$^{136}$Xe | **Tracko-Calo**<br>• PID, Full kinematic<br>$^{82}$Se, $^{150}$Nd, $^{48}$Ca, ... |
| | | **Pixelized Scintillator**<br>• PID<br>$^{116}$Cd |

# What's the status?

1993 - 2000:

- **HdM** (~11 kg) & **IGEX** (~2 kg), $^{76}Ge$
  - $T^{0\nu}_{1/2} > 1.9\ 10^{25}$ y @ 90% C.L.
- **HdM claim**: $\langle m_{ee} \rangle = 0.32$ +/- 0.03 eV

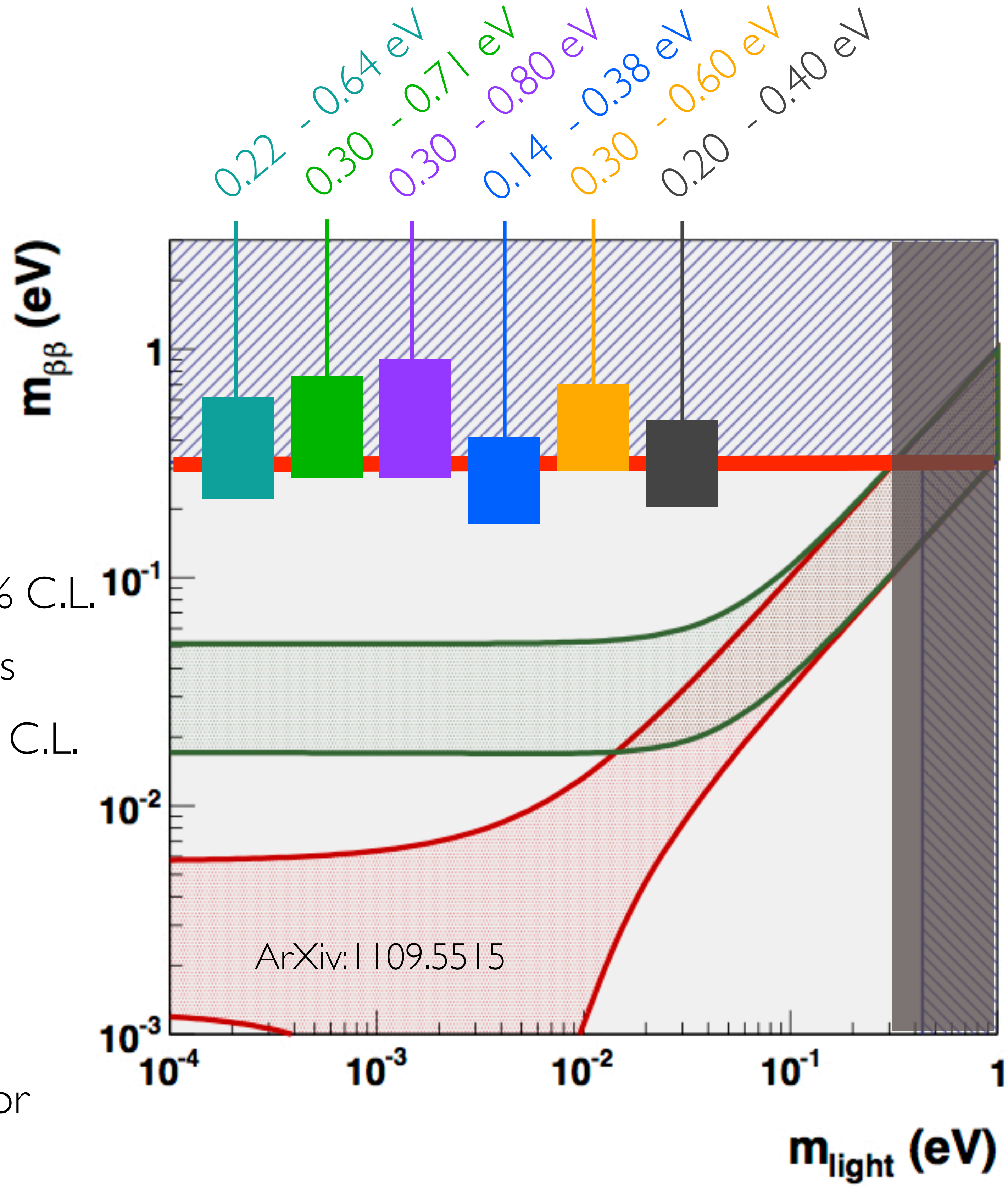
2000 - 2010:

- **Cuoricino**: $TeO_2$ bolometric detector
  - ~11 kg $^{130}Te$: $T^{0\nu}_{1/2} > 2.8\ 10^{24}$ y @ 90% C.L.
- **NEMO3**: Tracko-Calo, 7 different isotopes
  - ~7 kg $^{100}Mo$: $T^{0\nu}_{1/2} > 1.1\ 10^{24}$ y @ 90% C.L.

Since 2011: new generation

10 - 100 kg, R&D for future scaling

- **EXO200** ($^{136}Xe$): Liquid TPC
- **Kamland-ZEN** ($^{136}Xe$): Liquid Scintillator
- **GERDA** Phase I ($^{76}Ge$): Ge diodes



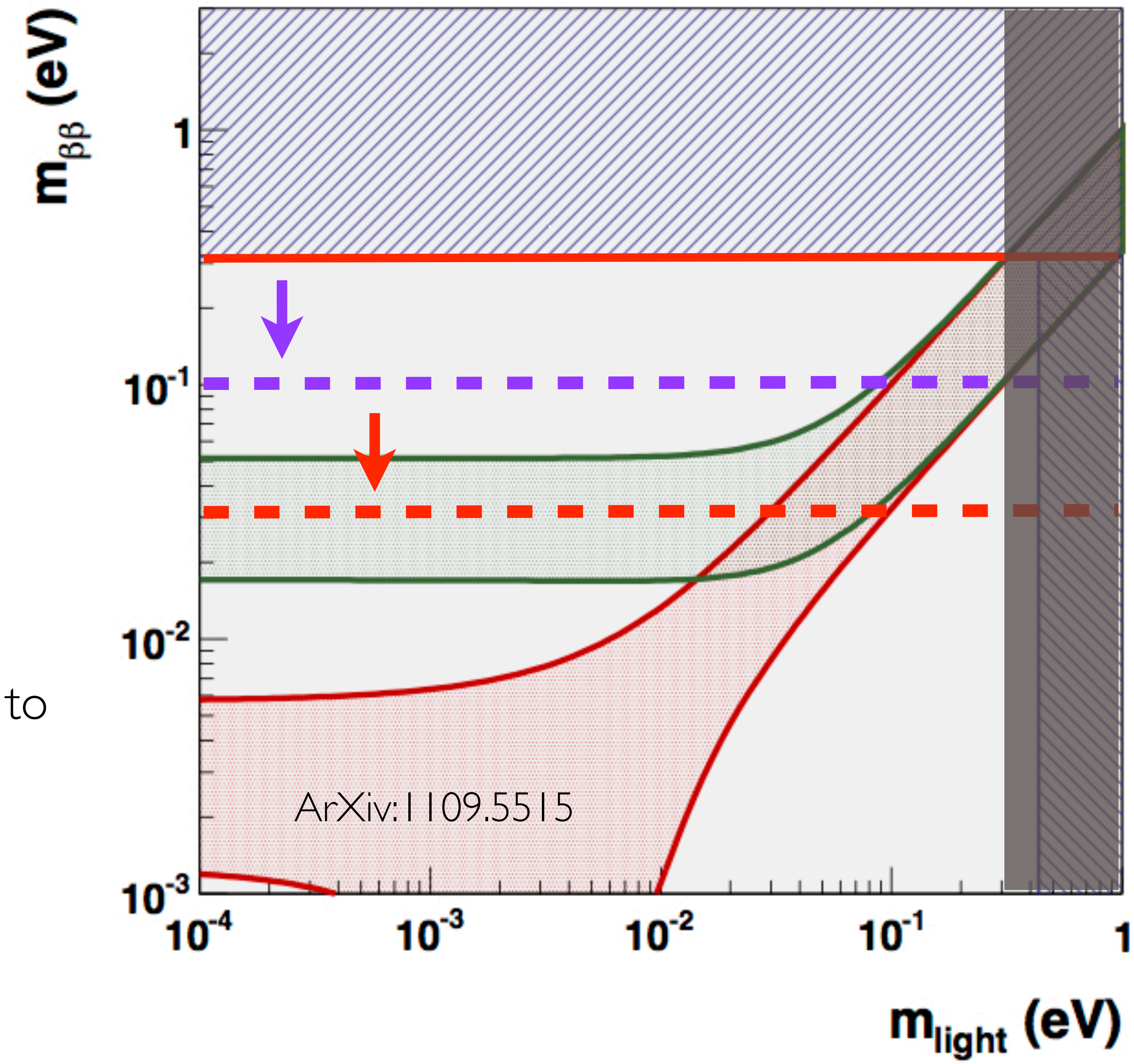
# Future projects

**5 years time scale:**

- M ~ 10 - 50 kg of ββ isotope
- Background level $10^{-3}$ cts. /(keV kg y)
- Explore quasi-degenerate region

**10 years time scale:**

- M ~ 100 kg - 1t of ββ isotope
- Background level $10^{-4}$ cts. /(keV kg y)
- Approach Inverse Hierarchy region




- Extended R&D: Energy resolution, particle ID, radio-purity
- Multi-phase approach: demonstrate scalability to higher mass and background levels

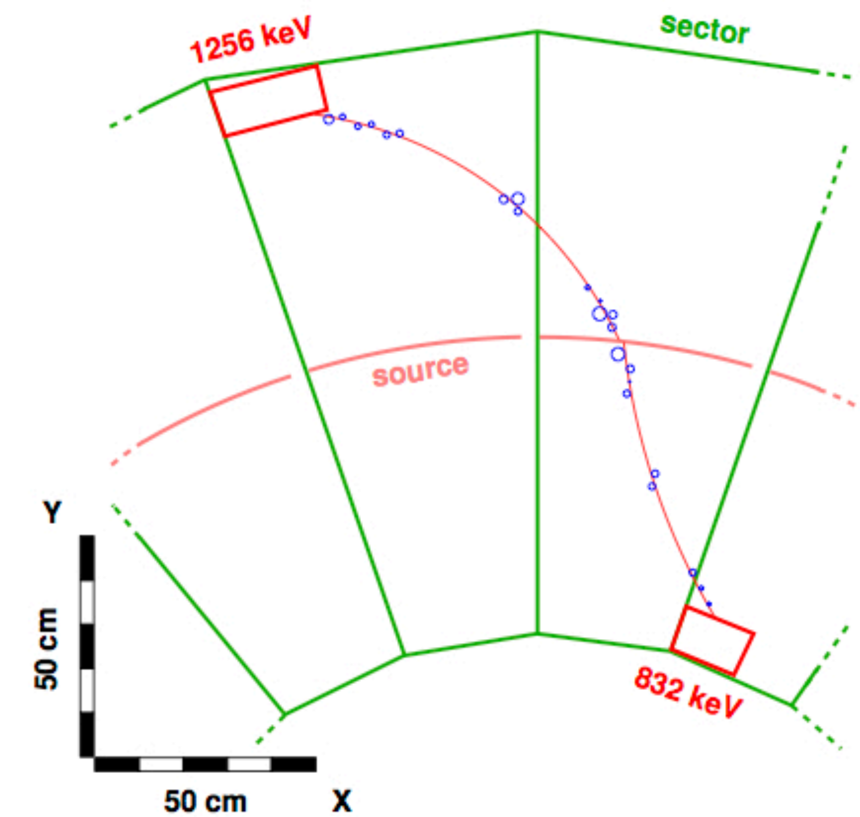
CUORE, Gerda, Majorana, Lucifer, AMORE, NEXT, COBRA, EXO, SNO+, KamLAND-Zen, Candels, **SuperNEMO**, MOON, DCBA, ...

# NEMO3 and the Tracko-Calo technique

Running @ LSM 2003 - 2011

**Full** reconstruction of $2e^-$ kinematics (unique!)

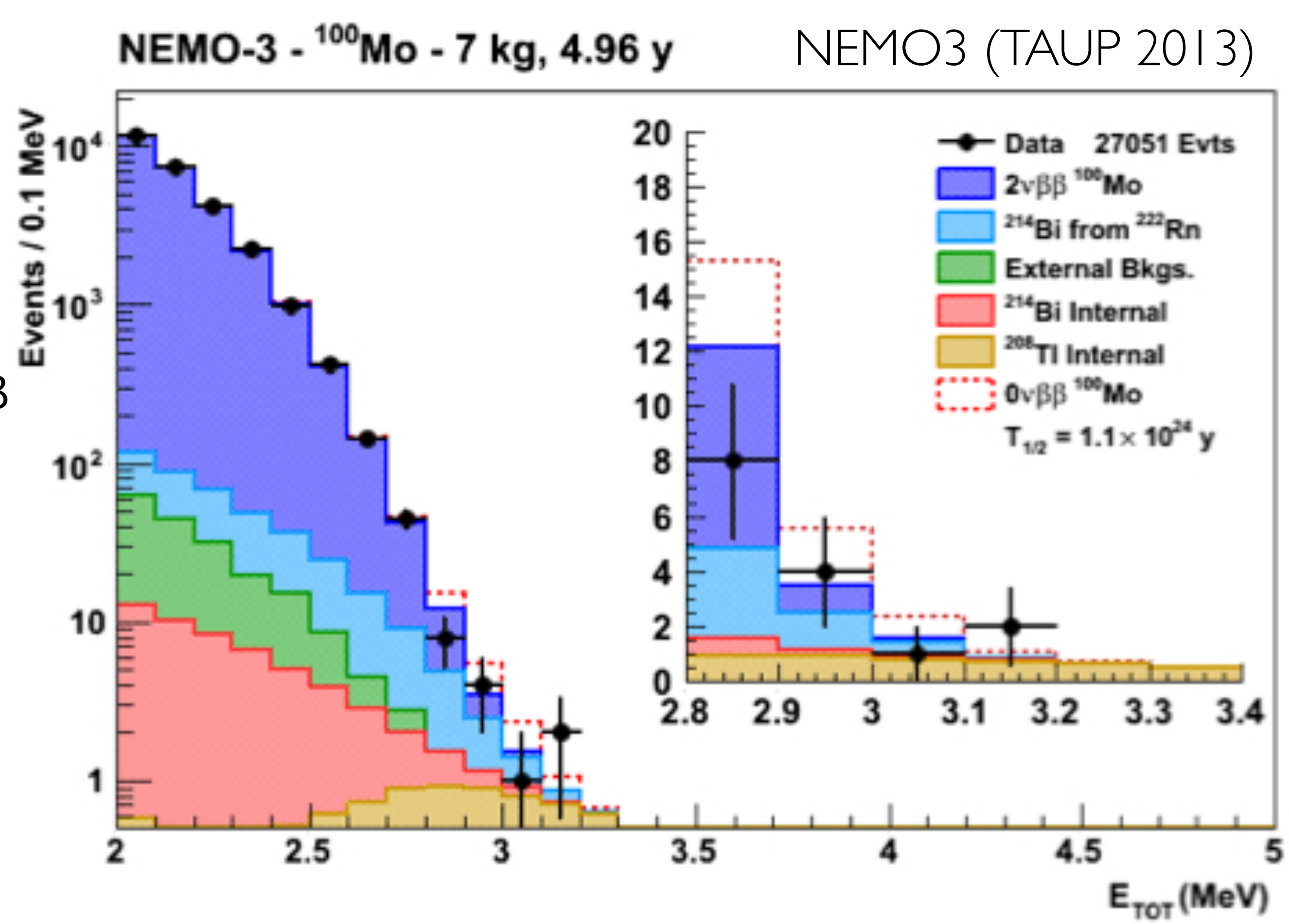
- Individual e- energy, arrival time, track curvature in magnetic field, emission vertex and tracks angle
- Low energy resolution: [14 - 17] % / Sqrt(E)
- **Excellent** background rejection
- **Equivalent** to best calorimetric experiment




Recent results with full $^{100}$Mo exposure 34.7 kg y

- $T^{0\nu}_{1/2} > 1.1\ 10^{24}$ y @ 90% C.L.
- Background level ~ 0.02 cts. / (keV kg y) @ $Q_{\beta\beta}$
- No background event > 3.2 MeV

NEMO3 (TAUP 2013)




Potential background **free** technique for high energy $Q_{\beta\beta}$ isotopes ($^{48}$Ca, $^{150}$Nd, $^{96}$Zr)

# The next step: SuperNEMO

Exploit a well known technique:

- 20 detection module 5 kg ββ emitter each

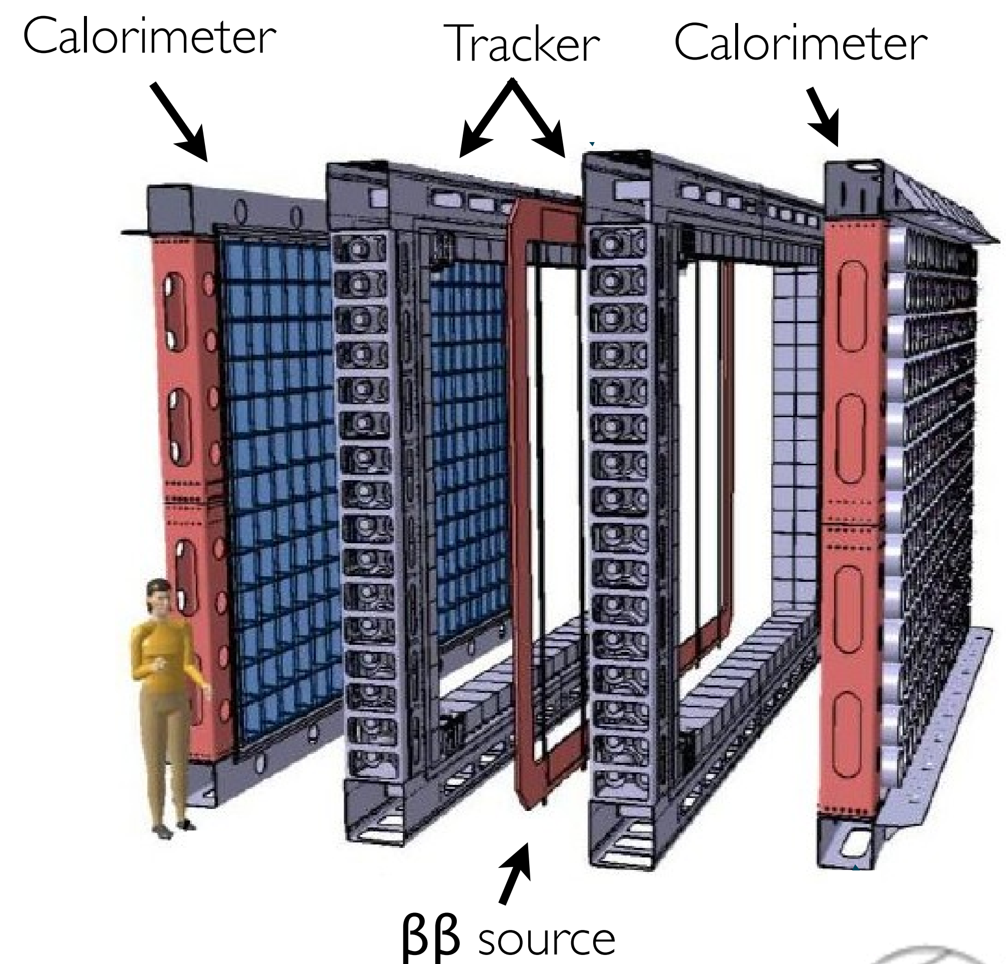
Goal:

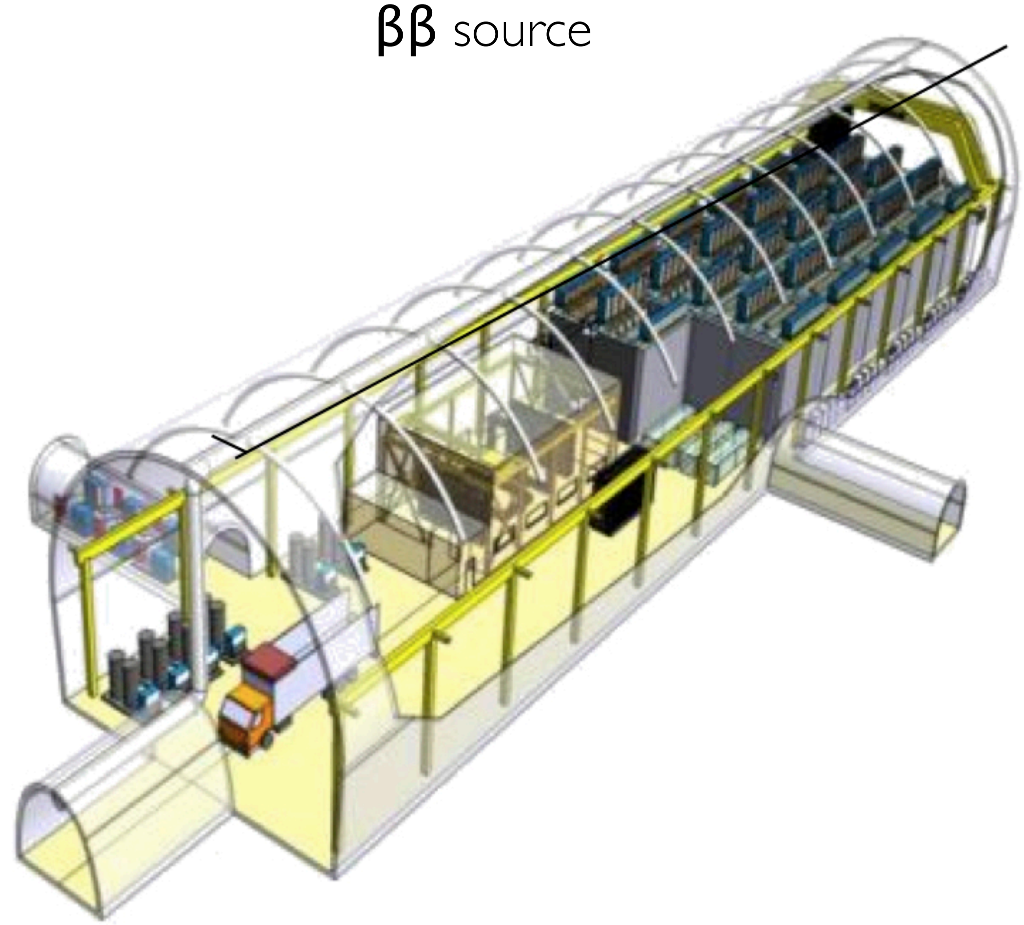
- Bkg. level: $10^{-4}$ cts./(keV kg y)
- Approach IH region

A **challenge** under many aspects:

| | NEMO3 | SuperNEMO |
|---|---|---|
| Efficiency | 18% | ~30% |
| Isotope | 7 kg $^{100}$Mo | ~100 kg $^{82}$Se |
| Exposure | 35 kg y | ~500 kg y |
| Energy res. | 8% @ 3 MeV | 4% @ 3 MeV |
| $^{208}$Tl | ~100 μBq/kg | < 2 μBq/kg |
| $^{214}$Bi | > 300 μBq/kg | < 10 μBq/kg |
| $T_{1/2}$ | 1 $10^{24}$ y | 1 $10^{26}$ y |
| ⟨$m_\nu$⟩ | 0.31 - 0.79 eV | 0.04 - 0.1 eV |

- Require LSM extension
- First step → demonstrator module



# The SuperNEMO demonstrator

One SuperNEMO module → **7 kg $^{82}$Se running ~2.5 y**

- To be installed @ LSM (replacing NEMO3)

Match SuperNEMO requirements

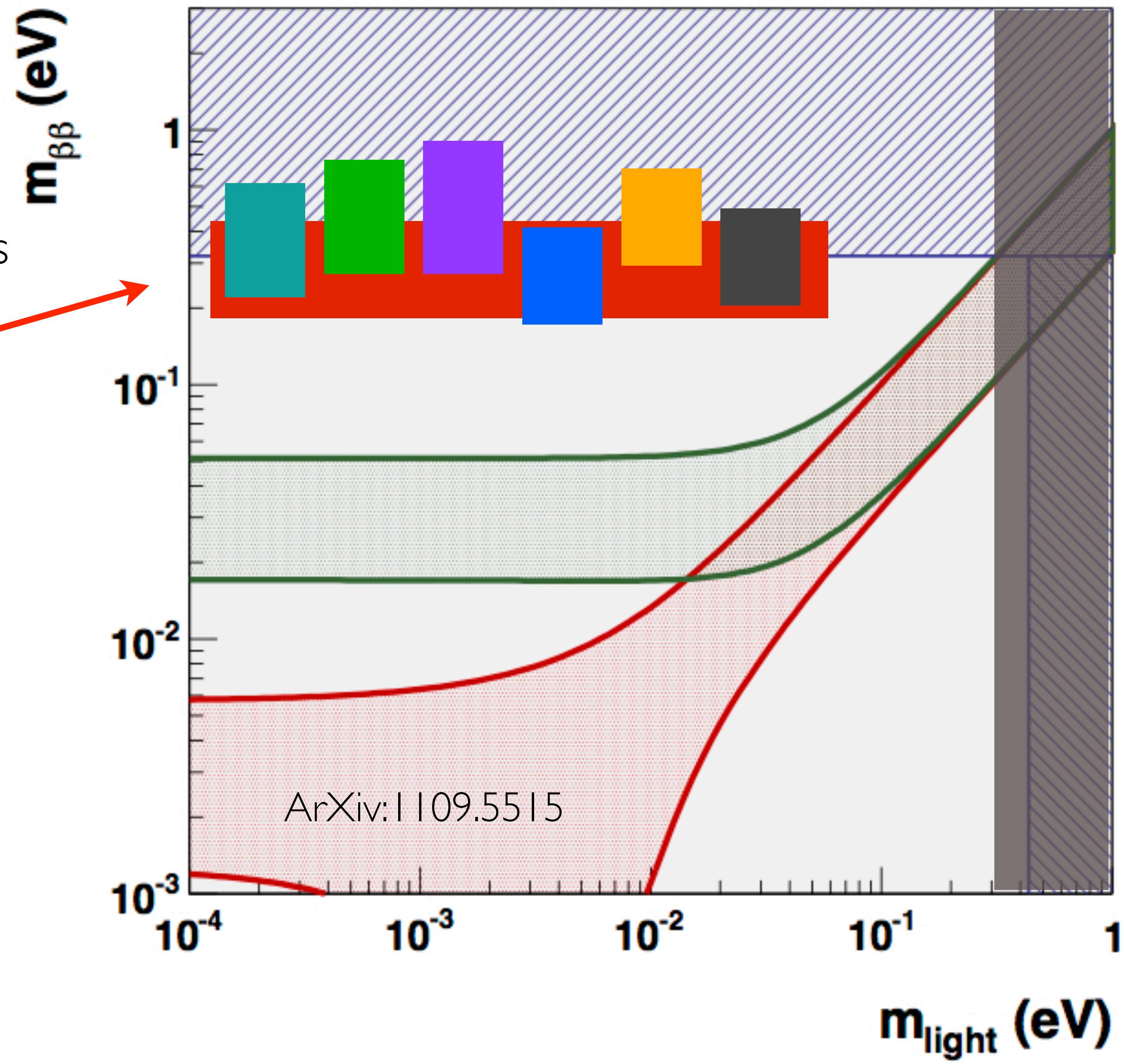
- Less than **0.2 bkg. events** in ROI

Reach NEMO3 ($^{100}$Mo) sensitivity in 4.5 months

- Sensitivity: $\langle m_{ee} \rangle$ ~ **0.20 - 0.40 eV**
  - Test HdM claim with $^{82}$Se

Schedule:

- Installation & commissioning 2014
- First **physics data in 2015**



# Contributions from the labex

- Laboratories: **LSM** & **LAPP**
- Period: 2012 - 2016
- Activities: Development & installation of the SuperNEMO demonstrator module

**1) R&D and production of $^{82}$Se foil source**

**2) Monte Carlo studies for the foil design optimisation**

**3) Development of the Slow Control system**

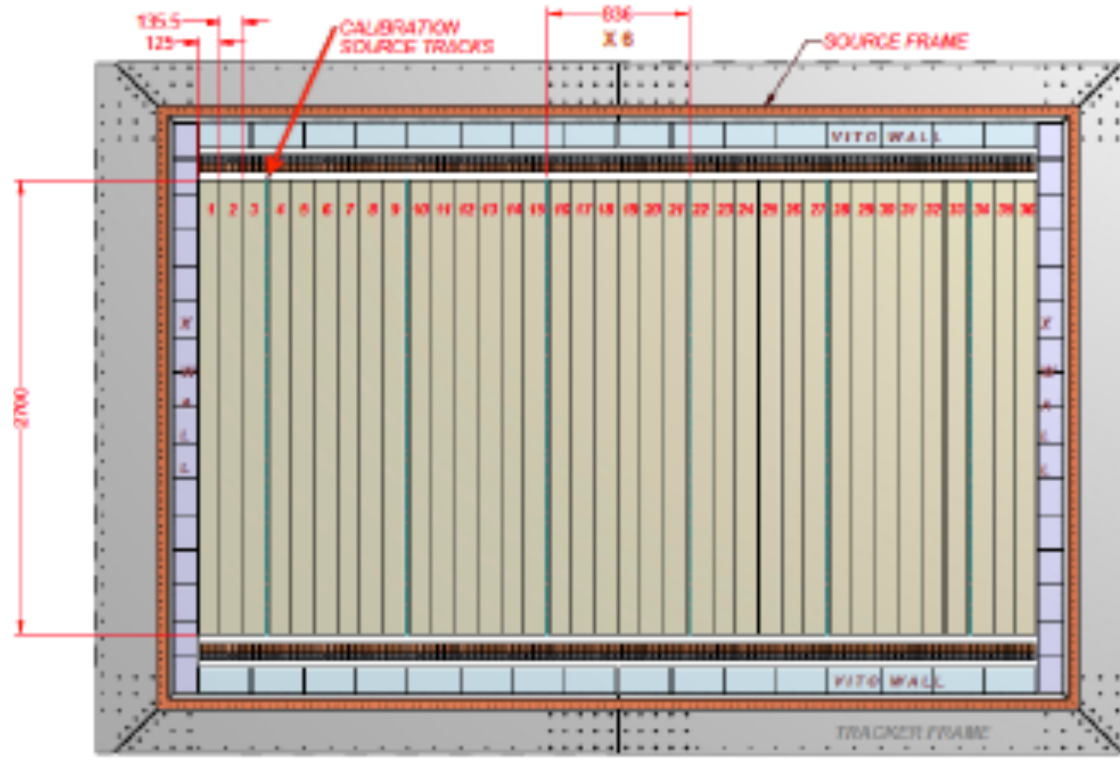
4) Detector installation + commissioning + running (2014 - 2016)

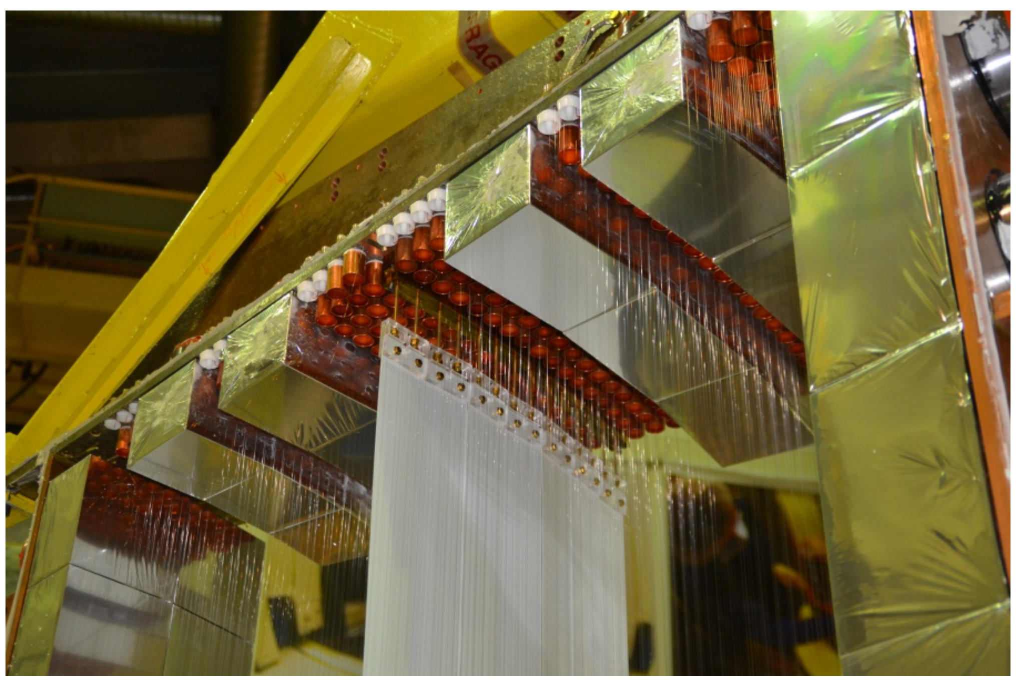
5) Physics data analysis (2015 - 2016)

# Foil Source R&D

SuperNEMO **ββ** source:

- 36 strips 3 long, ~200 um thick (50 mg/cm$^2$)
- Strong material radio-purity constrain



NEMO3 foil production experience:

- Se + PVA glue + Mylar film
- Mylar is **not radiopure enough** for SuperNEMO
- A($^{208}$Tl) ~ 9 +/- 3 uBq/kg (limits is 2 uBq/kg)

An **alternative strategy** is necessary:

- Mechanical department @ LAPP in collaboration with LSM
- 3.5 kg of $^{82}$Se available in France → **produce 1/2 demonstrator foils**

# Foil Source R&D



**Set up a test bench:**

- ISO 5-6 clean room

**R&D for PVA glue**

- Samples for radio-purity measurement
  - Ge (LSM): ~1.5 kg PVA powder
  - BiPo (LSC): 20 thin foil → 30x30 cm 200 um thick

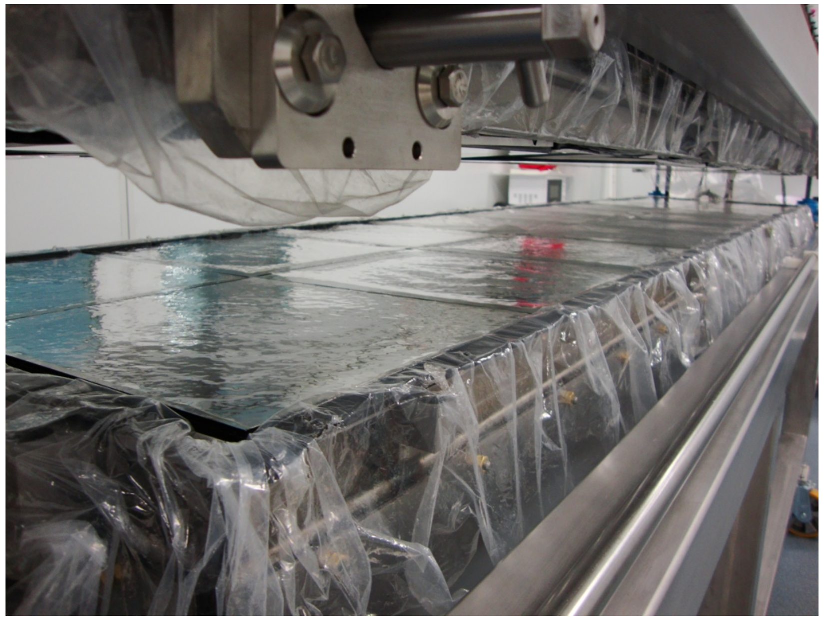
**R&D for new mechanical support**

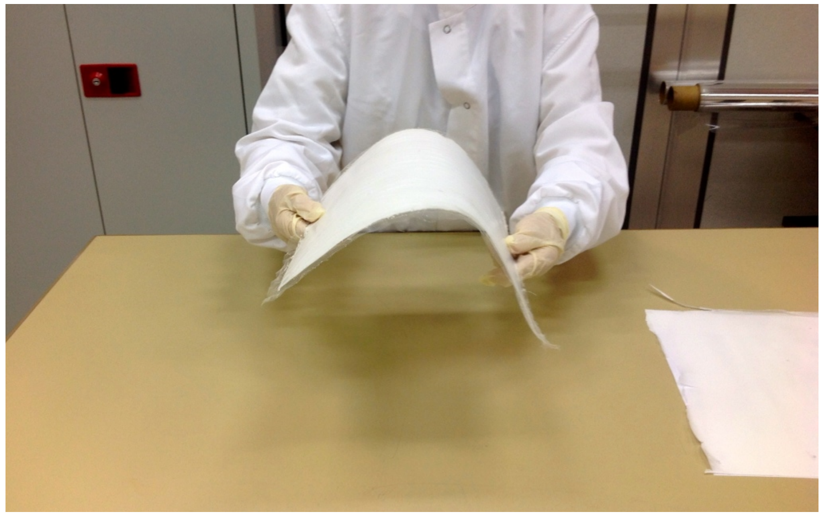
- Fine mesh fabric (Tulle) as central backbone
- Flexible foil with smaller support mass (~ 1 %)
- Setting up 30 $m^2$ for radio-purity measure

**Se powder processing (grinding/purification)**

- Choose suitable materials w.r.t. radio-purity requirements
- Purification strategy under study @ LSM

**Full foils production expected by the end of 2014**

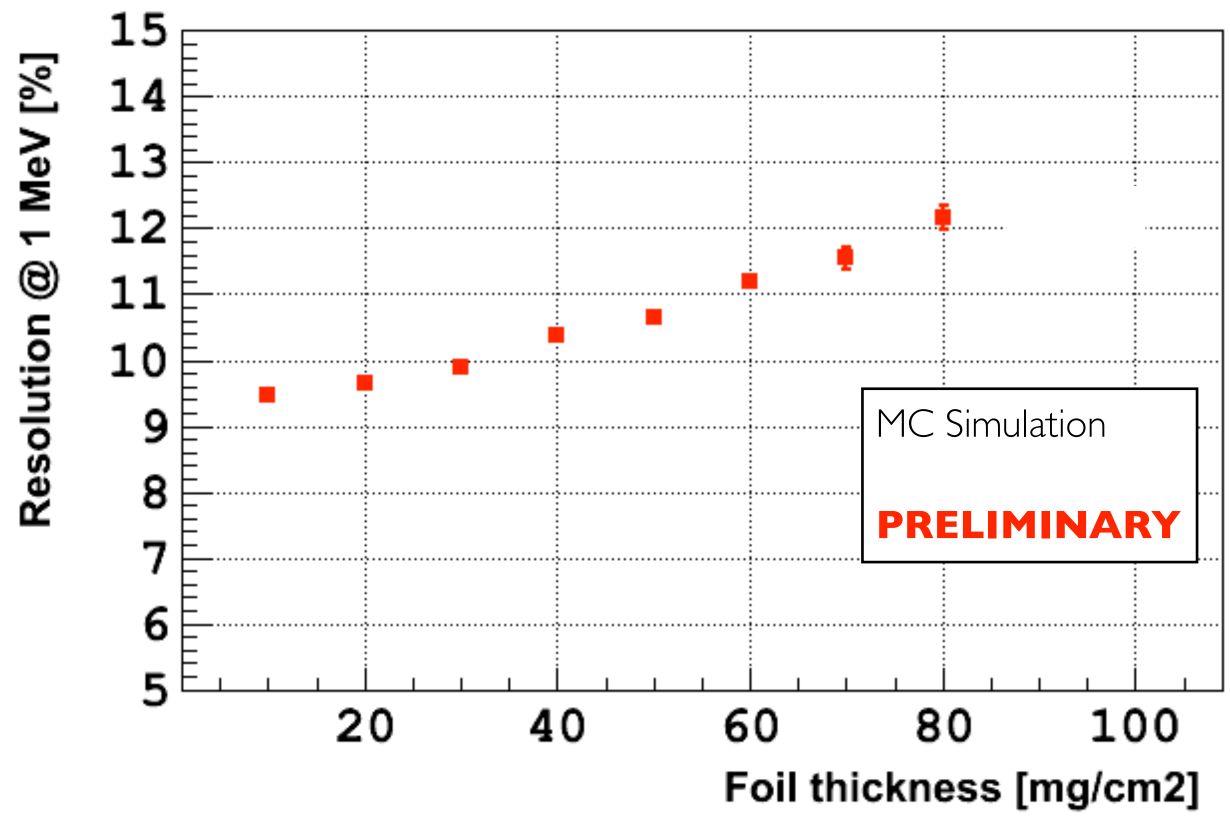




# Foil Source MC studies

**Optimise** detailed **foil design** & composition:

- Test different foil design
  - Mylar film / Tulle, PVA fraction, foil thickness, ...




- Tune foil parameter w.r.t. $T^{0\nu}_{1/2}$ sensitivity → guideline for best foil production

Setting up MC production + Analysis code for full sensitivity study

- **Submit a Master 2 project on the subject (January/June 2014)**

# Slow Control system

Computing + electronic departments @ LAPP

Develop dedicated software system to:

- **Control/monitor** environmental parameters, detector subsystems (local & remote)
- Operate **heterogeneous** devices

Proposed solution:

- Common choice with CTA project → Take advantage of **existing experience**
    - OPC UA **specification** → A standard issued by HW & SW industrial vendors
    - Generic solution **independent** from context (experiments, technical strategy, devices)
- Definition of a **Interface Control Document** (ICD) to collect devices infos/specifications
- First prototype of integrated hardware to be tested next spring
    - From ICD → to web interface management

**Implement device & user Interfaces by the end of 2014 / beginning 2015**

# Conclusions

- World wide interest on $0\nu\beta\beta$ searches → answer a fundamental question
  - Rich experimental program for the next 5 & 10 years
- SuperNEMO aims to explore the IH region with a Tracko-Calo detector
  - The Demonstrator module is the first step towards the full detector
  - In 2 years time scale will reach sensitivity to test HdM claim with $^{82}Se$
- Key contributions from ENIGMASS groups
  - R&D and production of a $\beta\beta$ emitter source with a new design
  - Slow control system development
  - We're on the front line for the detector installation/commissioning/running

# Backup slides

# Choosing the ββ isotopes

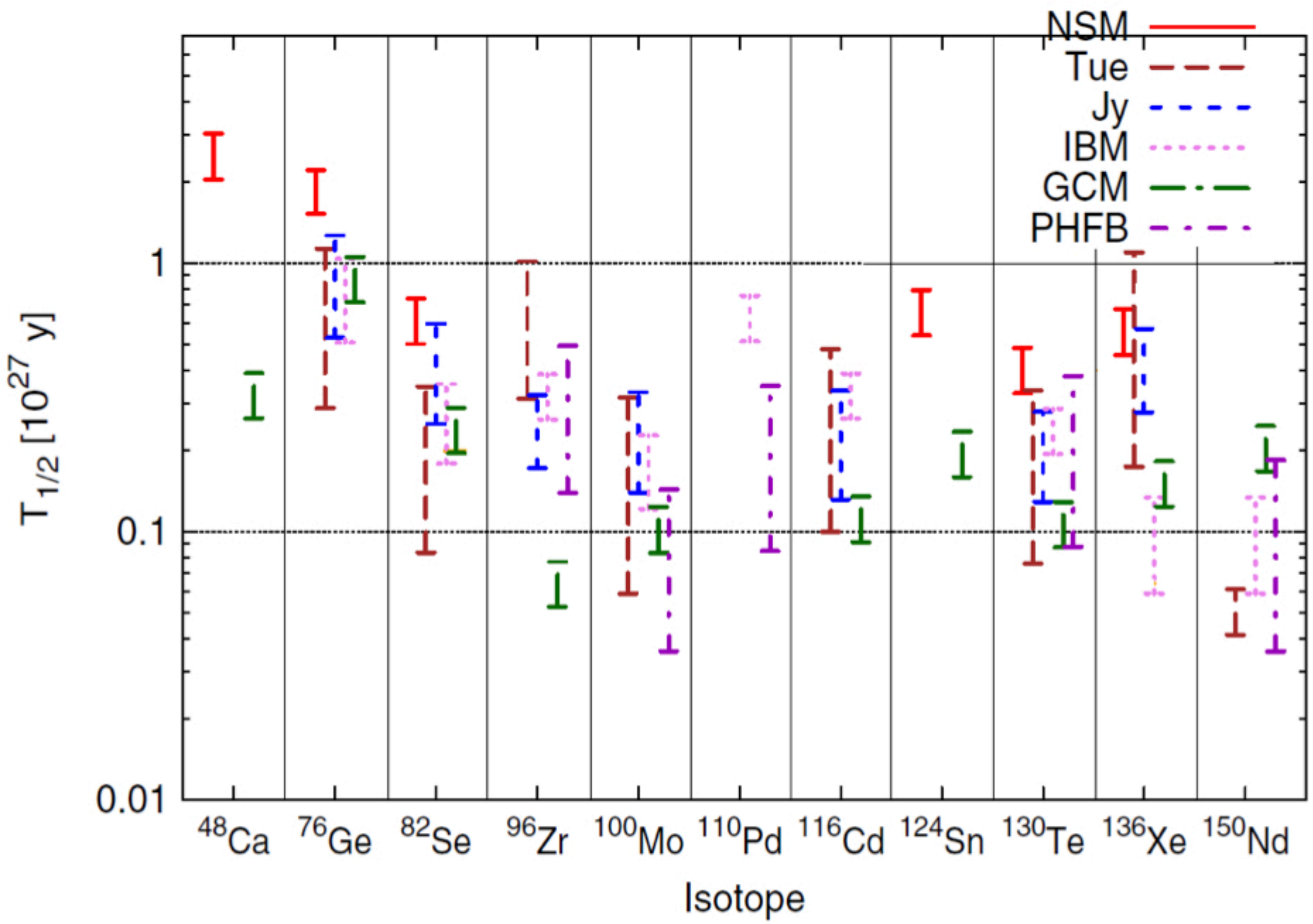
| Isotope | $Q_{\beta\beta}$ [keV] | Nat. abund. (enrich.) [%] | $G_{0\nu}$ [$10^{-14}$ $y^{-1}$]$^{(*)}$ | $T^{2\nu}_{1/2}$ [$10^{19}$ y] | Experiment |
|---|---|---|---|---|---|
| $^{48}Ca$ | 4270 | 0.187 (73) | 6.35 | $4.2^{+2.1}_{-1.0}$ | NEMO3 |
| $^{76}Ge$ | 2039 | 7.8 (86) | 0.623 | 150±10 | HM |
| $^{82}Se$ | 2995 | 8.7 (97) | 2.70 | 9.0±0.7 | NEMO3 |
| $^{96}Zr$ | 3350 | 2.8 (57) | 5.63 | 2.0±0.3 | NEMO3 |
| $^{100}Mo$ | 3034 | 9.6 (99) | 4.36 | 0.71±0.04 | NEMO3 |
| $^{116}Cd$ | 2802 | 7.5 (93) | 4.62 | 3.0±0.2 | NEMO3 |
| $^{130}Te$ | 2527 | 34.5 (90) | 4.09 | 70±10 | NEMO3 |
| $^{136}Xe$ | 2480 | 8.9 (80) | 4.31 | 238±14 | KamlandZEN |
| $^{150}Nd$ | 3367 | 5.6 (91) | 19.2 | 0.78±0.7 | NEMO3 |

Isotopes enrichment and $T^{2\nu}_{1/2}$ from respective experiment

# Nuclear Matrix Element

Contain nuclear structure effects → only **approximative** theoretical calculation

Required $T^{0\nu}_{1/2}$ sensibility for $\langle m_{ee} \rangle$ ~ 0.05 eV (IH)

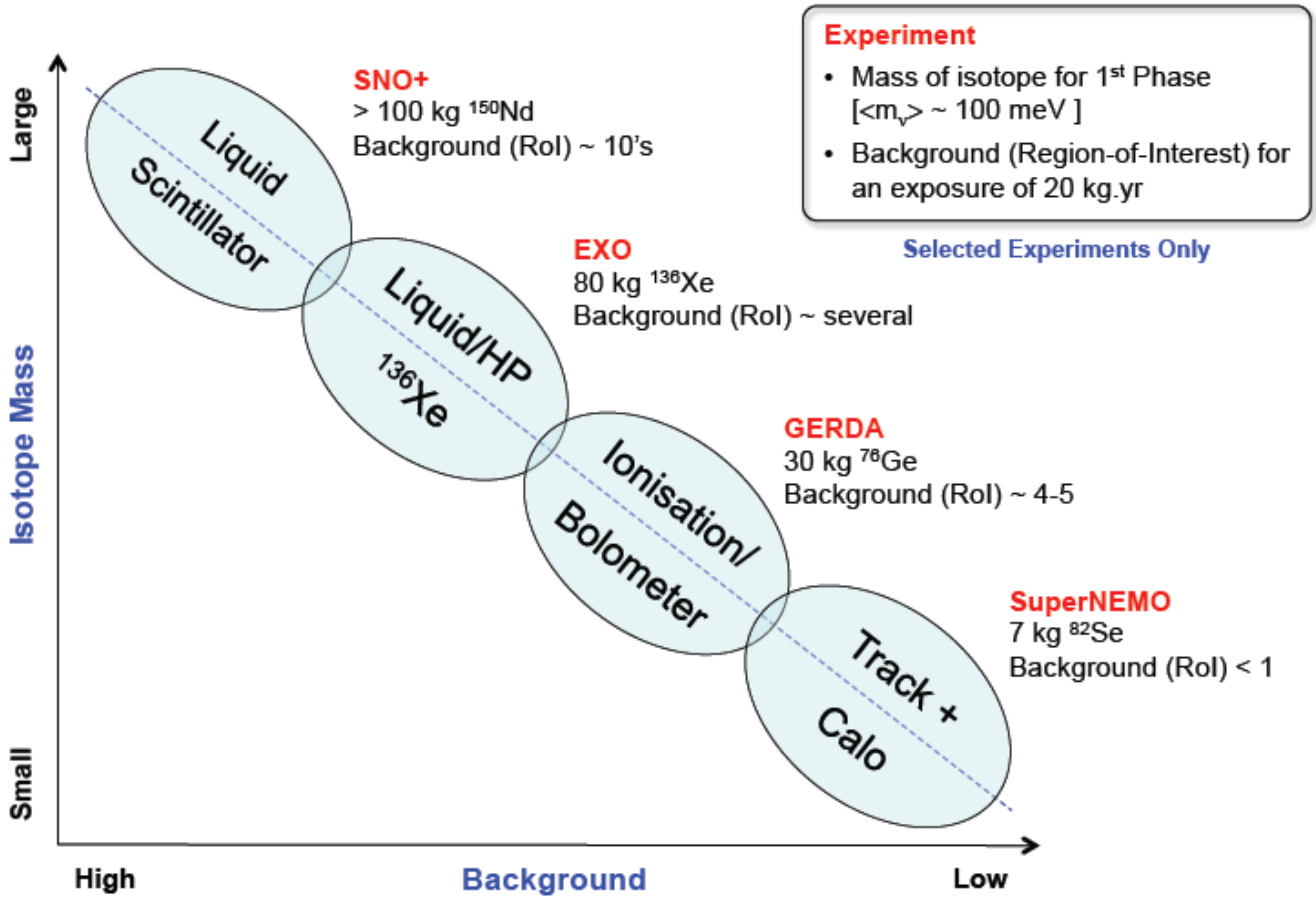



PRD 83, 113010 (2011)

- Many approximation methods
- Variation up to factor ~10
- Different among isotopes
- Up to factor 10 on required mass! ($^{150}$Nd, $^{100}$Mo w.r.t. $^{76}$Ge)

Main **limitation** in interpreting result & comparing among different isotopes

# Comparison of Current Techniques



# SuperNEMO demonstrator: status

Most R&D completed

Radio purity measurements of materials ongoing

- HPGe, Radon emanation chamber, BiPo

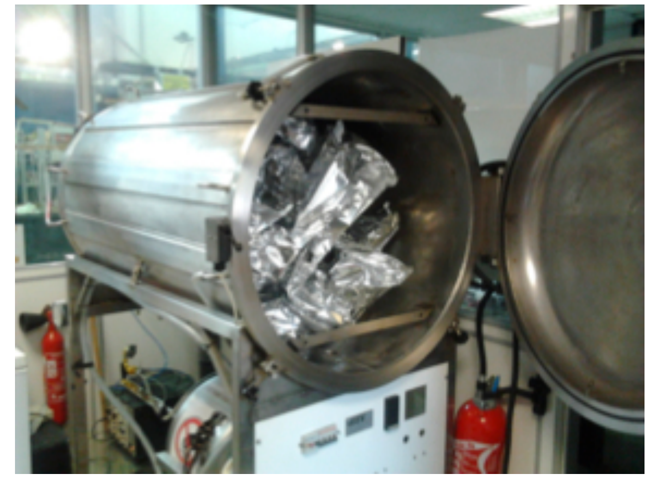
Calorimeter: main wall under construction

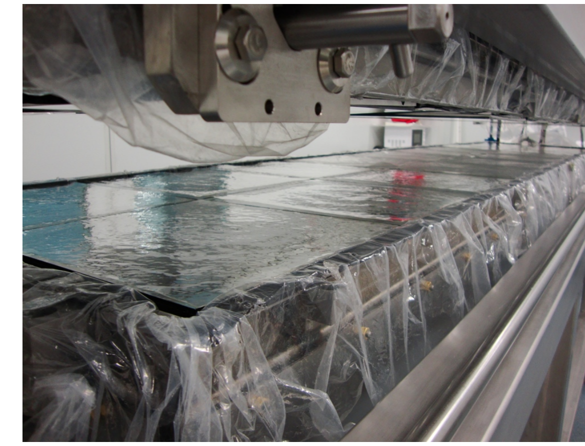
- Scintillator block under production
- 8'' Hamamatsu PMT by February 2014
- Electronic (FE digitiser & trigger board) under production

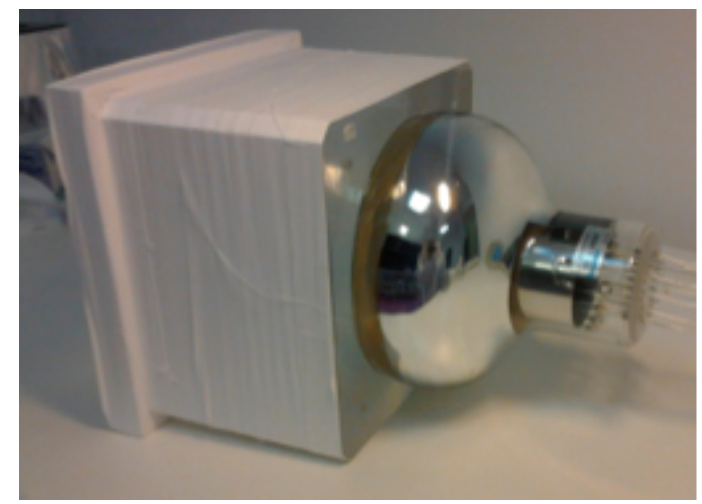
Tracker: C0 under construction.

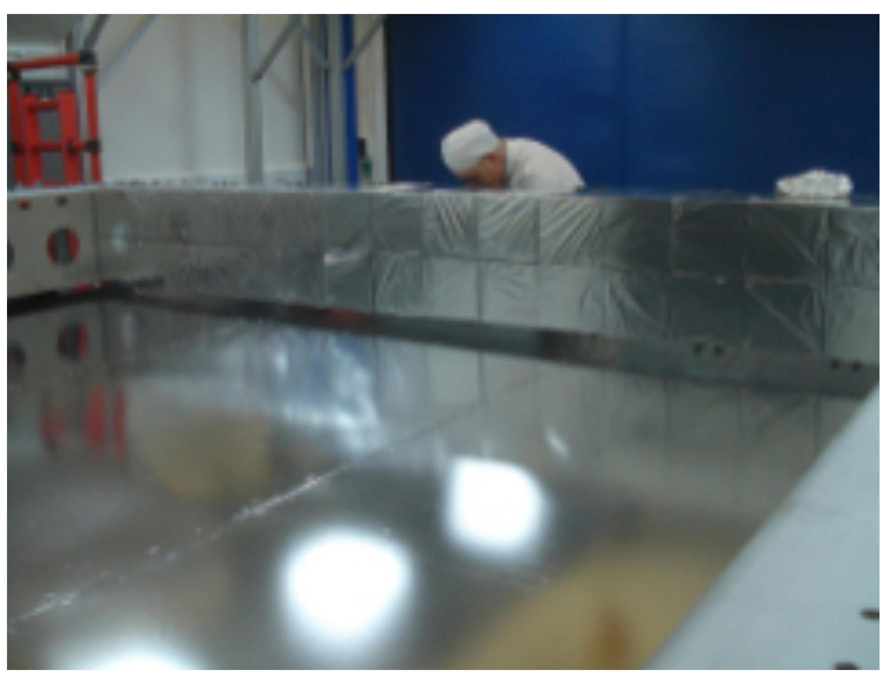
- Commissioning end 2013 (surface) 2014 (underground)

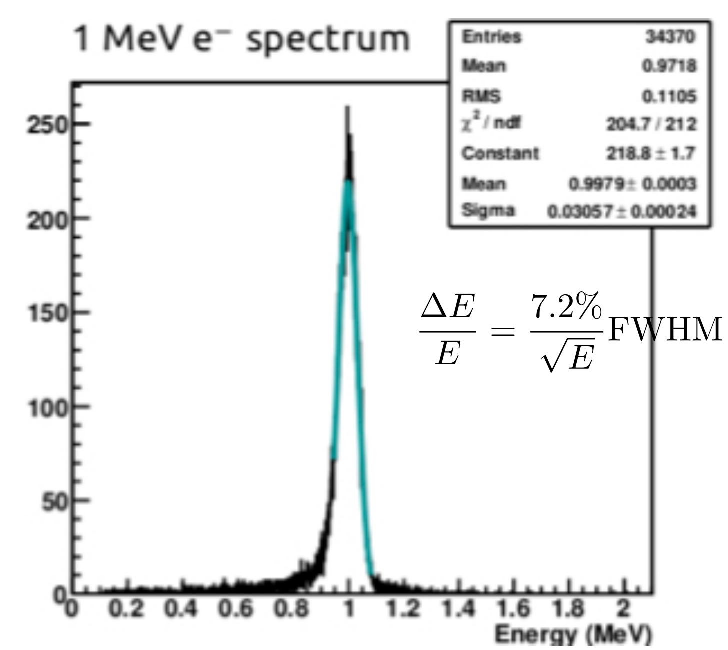
Source: more detail later...



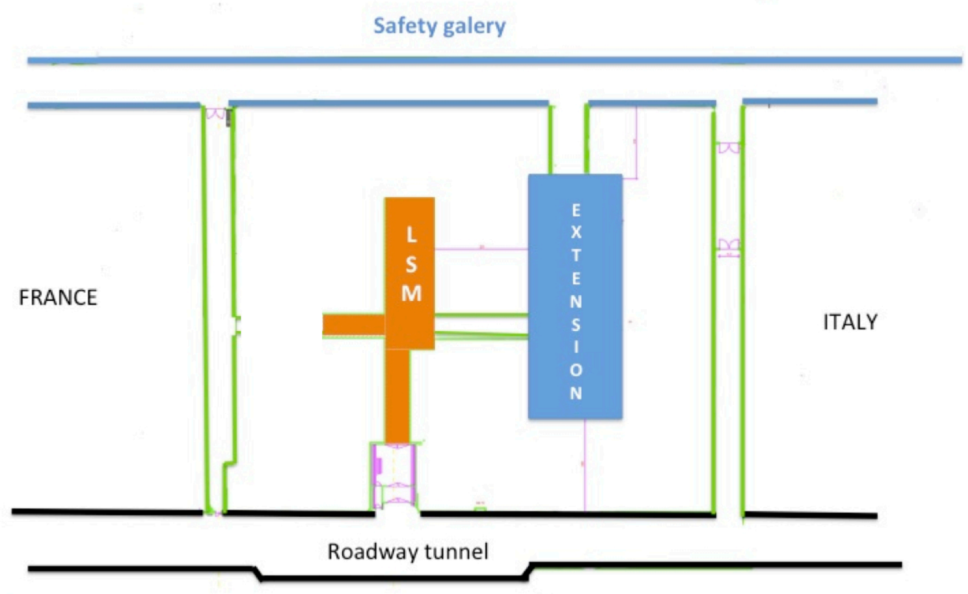








# LSM Extension: DOMUS




From F. Piquemal (TAUP2013)

- Project accepted by Ministery of Research and programmed by CNRS
- Cost estimated by project supervisor of safety galery :
- 7 M€ including 20% hazards
- Funding secured from CNRS, Rhône-Alpes region, Savoie department, FEDER
- Technical studies completed
- Negociations with the civil work company in October
- Digging Spring 2014 or end 2015 depending of the company schedule
- 6 months for excavation, 10 months for outfittings
- Extension in operation 2016 -2017