Neutrinoless double beta decay search using ^{136}Xe: The *NEXT* experiment.

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next

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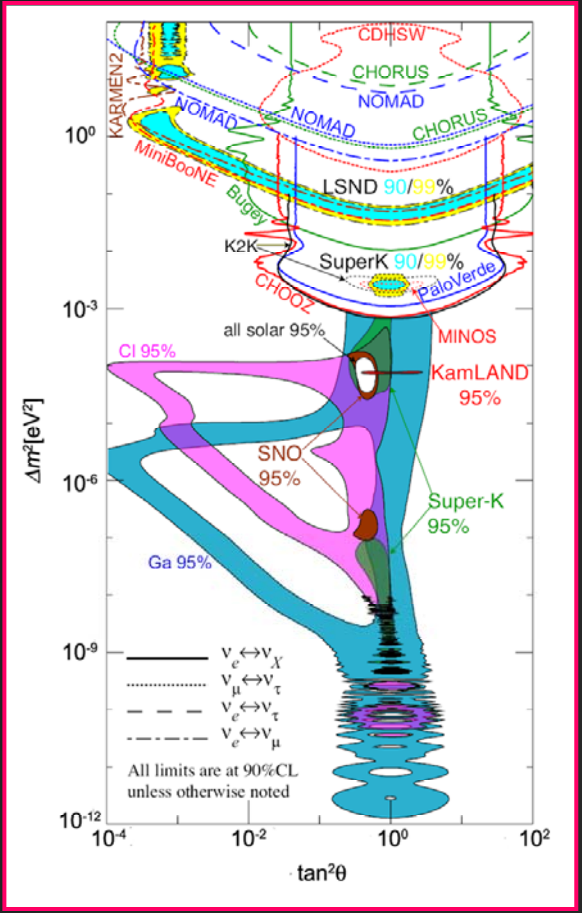
OUTLINE

- ✓ Neutrino and double beta decay.
- ✓ The Experiment.
  - ✓ Why HP Xe TPC?
  - ✓ The SOFT concept.
- ✓ Present Status.
  - ✓ Prototypes.
    - ✓ NEXT-μM.
  - ✓ NEXT-100.
- ✓ Outlook.
- ✓ Summary.

NEUTRINO AND DOUBLE BETA DECAY

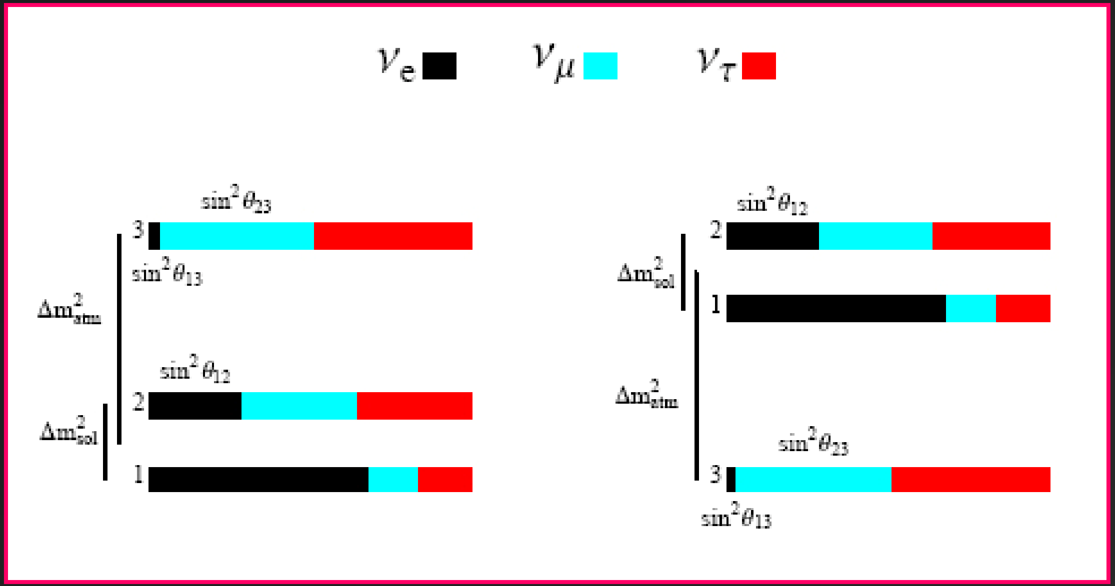
✓ Neutrino oscillation experiments have shown that neutrino is a ***non-zero*** mass particle, implying the existence of Physics beyond the Standard Model of Particles.



NEUTRINO AND DOUBLE BETA DECAY

✓ Neutrino oscillation experiments have shown that neutrino is a ***non-zero*** mass particle, implying the existence of Physics beyond the Standard Model of Particles.

✓ It is also known that neutrino mass could have two different mass hierarchies: ***normal*** and ***inverse***.



Normal hierarchy:
$m_1 \sim m_2 << m_3$ → ***$(\Delta m_{23})^2 > 0$***

Inverted hierarchy:
$m_1 \sim m_2 >> m_3$ → ***$(\Delta m_{23})^2 < 0$***

NEUTRINO AND DOUBLE BETA DECAY

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✓ It is also known that neutrino mass could have two different mass hierarchies: ***normal*** and ***inverse***.

✓ Unfortunately, neutrino oscillation experiments can only measure $(\Delta m_{ij})^2$.

HOW TO MEASURE THE ABSOLUTE MASS VALUE OF THE NEUTRINO?

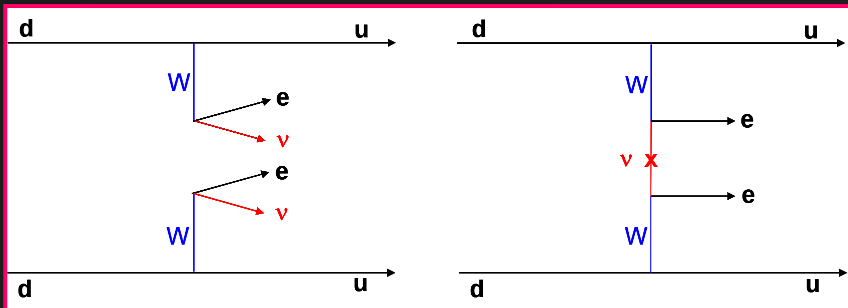
End point study of the ^{3}H decay energy spectrum (***KATRIN***)

Upper limits from Astrophysical Observations (***SN 1987-A***)

NEUTRINOLESS DOUBLE BETA DECAY DETECCTION ($0\nu\beta\beta$)

NEUTRINO AND DOUBLE BETA DECAY

✓ Double beta decay processes:



$$2\nu\beta^-\beta^-:(A,Z)\rightarrow(A,Z+2)+2e^-+2\bar{\nu}_e; \quad (\Delta L=0)$$

$$0\nu\beta^-\beta^-:(A,Z)\rightarrow(A,Z+2)+2e^-; \quad (\Delta L=2)$$

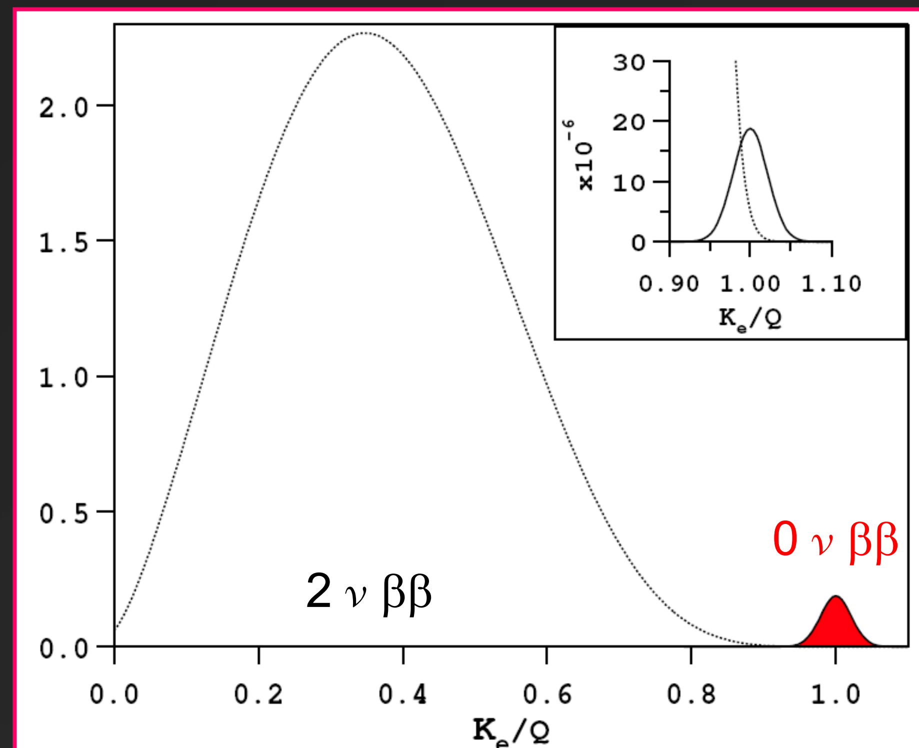
$\nu=\bar{\nu}\Rightarrow$ Majorana ν

✓ *$0\nu\beta\beta$* process detection:

$$T_{1/2}^{0\nu}(0^+\rightarrow 0^+)^{-1}=G_{0\nu}\left|M_{GT}^{0\nu}-\frac{g_V^2}{g_A^2}M_F^{0\nu}\right|^2\frac{\langle m_\nu\rangle^2}{m_e^2}$$

$$\langle m_\nu\rangle=m_e\left(F_N T_{1/2}^{0\nu}\right)^{-1/2}$$

$$\langle m_\nu\rangle=\sum_j U_{ej}^2 m_j$$



NEUTRINO AND DOUBLE BETA DECAY

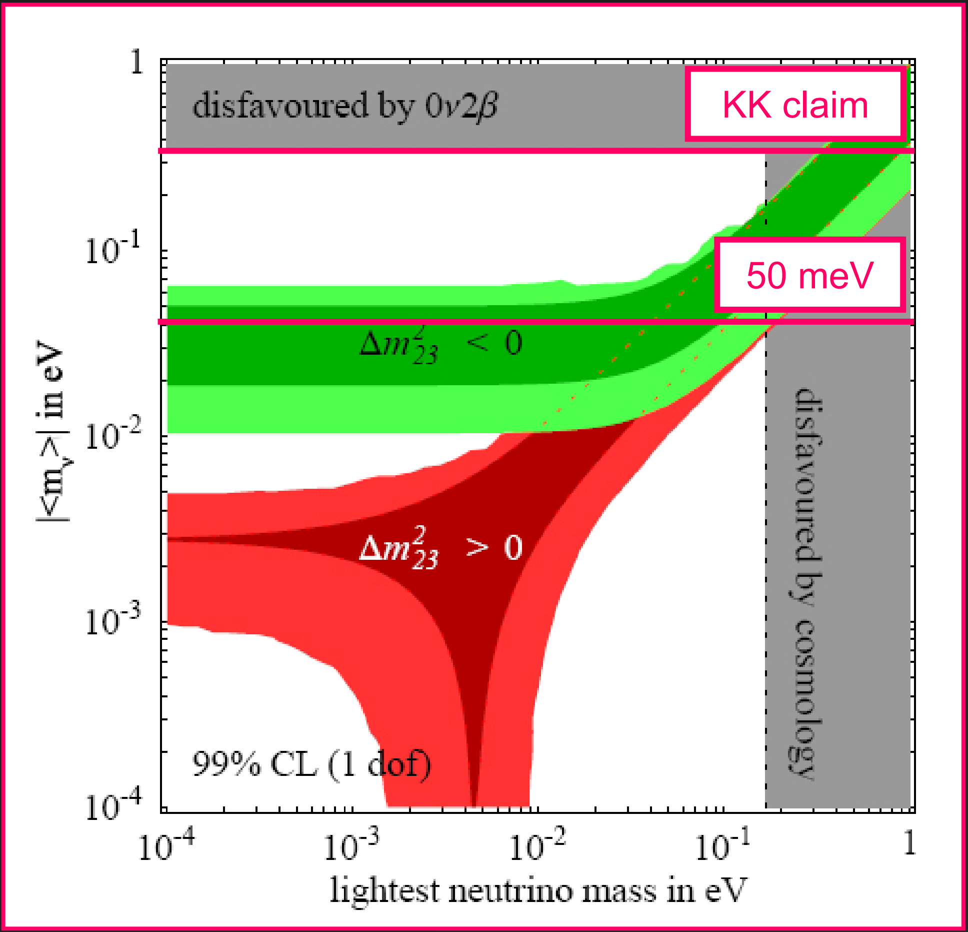
✓ Study of the ***$0\nu\beta\beta$*** decay for almost 20 years. Some ***experiments*** already ***finished***:

Experiment	Isotope	Technique	Laboratory	Results	
				$T_{1/2}^{0\nu}$ (y)	$\langle m_\nu \rangle$ (eV)
IGEX	^{76}Ge	Ge Diodes	Canfranc	≥ 1.57 10^{25}	≤ 0.33-1.35
HEIDELBERG-MOSCOW	^{76}Ge	Ge Diodes	Gran Sasso	≥ 1.55 10^{25}	≤ 0.35
HEIDELBERG-MOSCOW*	^{76}Ge	Ge Diodes	Gran Sasso	1.20 10^{25}	0.44
MIBETA	^{128}Te	Bolometers	Gran Sasso	≥ 8.60 10^{22}	≤ 1-2
	^{130}Te			≥ 1.44 10^{23}	
CUORICINO	^{130}Te	Bolometers	Gran Sasso	≥ 3.00 10^{24}	≤ 0.19-0.68
NEMO 3	^{100}Mo	Track + Calorimetry	Modane	≥ 1.00 10^{24}	≤ 0.31-0.96
	^{82}Se			≥ 3.2 10^{23}	≤ 0.94-2.60

*H.V. Klapdor-Kleingrothaus et al. Phys. Lett. B 578:54 & 586:198 (2004)

NEUTRINO AND DOUBLE BETA DECAY

✓ Where are we going now? ***New generation*** experiments.



✓ Trying to reach sensitivities to explore ***$<m_\nu> \sim 50$ meV***.

✓ Some requirements are mandatory:

- Big amount of $\beta\beta$ emitter mass.
- Radiopure materials.
- Placement underground.
- Background events discrimination.
- …

✓ Klapdor's claim could be checked.

NEUTRINO AND DOUBLE BETA DECAY

✓ If ***no signal*** is found:

$$\langle m_\nu \rangle = m_e \left(F_N T_{1/2}^{0\nu} \right)^{-1/2} \rightarrow \langle m_\nu \rangle < m_e \left(F_N F_D \right)^{-1/2}$$

$$F_D = 4.17 \times 10^{26} \frac{f}{W_{at}} \varepsilon \sqrt{\frac{MT}{b\Gamma}}$$

- Isotopic abundance ↑↑
- Atomic weight ↓↓
- Detection efficiency ↑↑
- Exposure ↑↑
- Background level ↓↓
- Energy resolution ↓↓

Several techniques, isotopes and detectors proposed trying to ***optimize F_D***.

NEUTRINO AND DOUBLE BETA DECAY

✓ Some new generation $0\nu\beta\beta$ experiments:

Experiment	Isotope	Technique	Main Strength
CANDLES	^{48}Ca	CaF_2 Scintillation	Background, Efficiency
CARVEL	^{48}Ca	$CaWO_4$ Scintillation	Mass, Efficiency
COBRA	^{130}Te, ^{116}Cd	ZnCdTe Semiconductors	Resolution, Efficiency
CUORE	^{130}Te	Bolometers	Resolution, Efficiency
CUORICINO	^{130}Te	Bolometers	Resolution, Efficiency
DCBA	^{150}Nd	Gaseous TPC	Bkg Rejection, Efficiency
EXO	^{136}Xe	TPC Ionization + Scintillation	Mass, Efficiency, Final State Signal
GERDA	^{76}Ge	Ge Diodes	Resolution, Efficiency
MAJORANA	^{76}Ge	Ge Diodes	Resolution, Efficiency
MOON	^{100}Mo	Tracking + Calorimetry	Compactness, Bkg Rejection
NEXT	^{136}Xe	Tracking + Calorimetry	Bkg Rejection, Efficiency
SNO++	^{150}Nd	Nd Liquid Scintillation	Mass, Efficiency
SUPERNEMO	^{82}Se, ^{150}Nd	Tracking + Calorimetry	Bkg Rejection, Isotope Selection
XMASS	^{136}Xe	Liquid Xe	Mass, Efficiency
YANGYANG	^{124}Sn	Sn Liquid Scintillation	Mass, Efficiency

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THE EXPERIMENT

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WHY A HP XENON TPC?

✓ Let's try to find the answer in these equations:

$$\langle m_\nu \rangle < m_e \left(F_N F_D\right)^{-1/2}$$

$$F_D = 4.17 \times 10^{26} \frac{f}{W_{at}} \varepsilon \sqrt{\frac{MT}{b\Gamma}}$$

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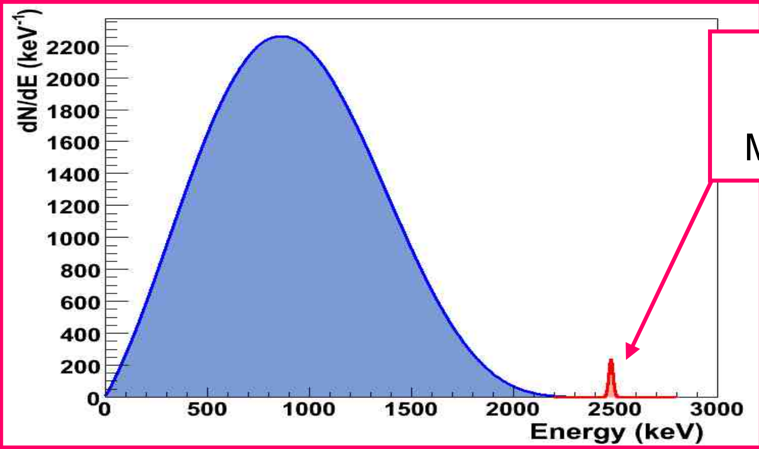
- ✓ High $Q_{\beta\beta}$ value (2457.83 keV).



$Q_{\beta\beta}$ (^{136}Xe) = 2457.83 keV

M. Redshaw *et al*, PRL 98 (2007) 053003

THE EXPERIMENT

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- ✓ Long $T_{1/2}^{2\nu\beta\beta}$ (2.11 ± 0.048(stat.) ± 0.21(sys.) x 10^{21} y).

Observation of Two-Neutrino Double-Beta Decay in ^{136}Xe with EXO-200

We report the observation of two-neutrino double-beta decay in ^{136}Xe with $T_{1/2}$=2.11±0.04(stat.)±0.21(sys.)×10^{21} yr. This second order process, predicted by the Standard Model, has been observed for several nuclei but not for ^{136}Xe. The observed decay rate provides new input to matrix element calculations and to the search for the more interesting neutrino-less double-beta decay, the most sensitive probe for the existence of Majorana particles and the measurement of the neutrino mass scale.

arXiv: 1108.4193v2 [nucl-ex]

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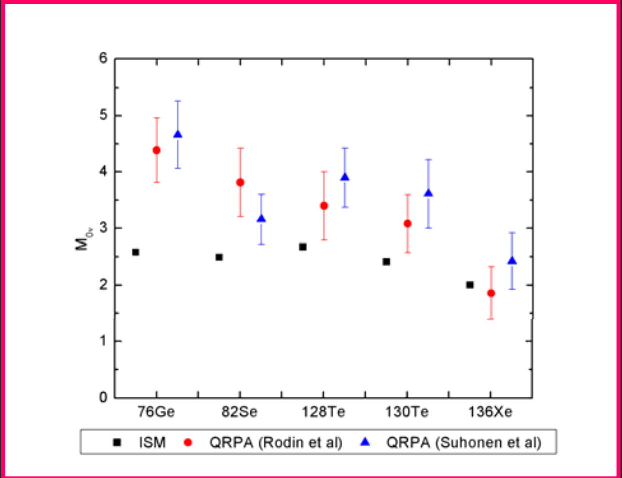

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- ✓ Possibility to detect Ionization/Scintillation and to study Tracking.
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- ✓ F_N is worse if compared with other isotopes.

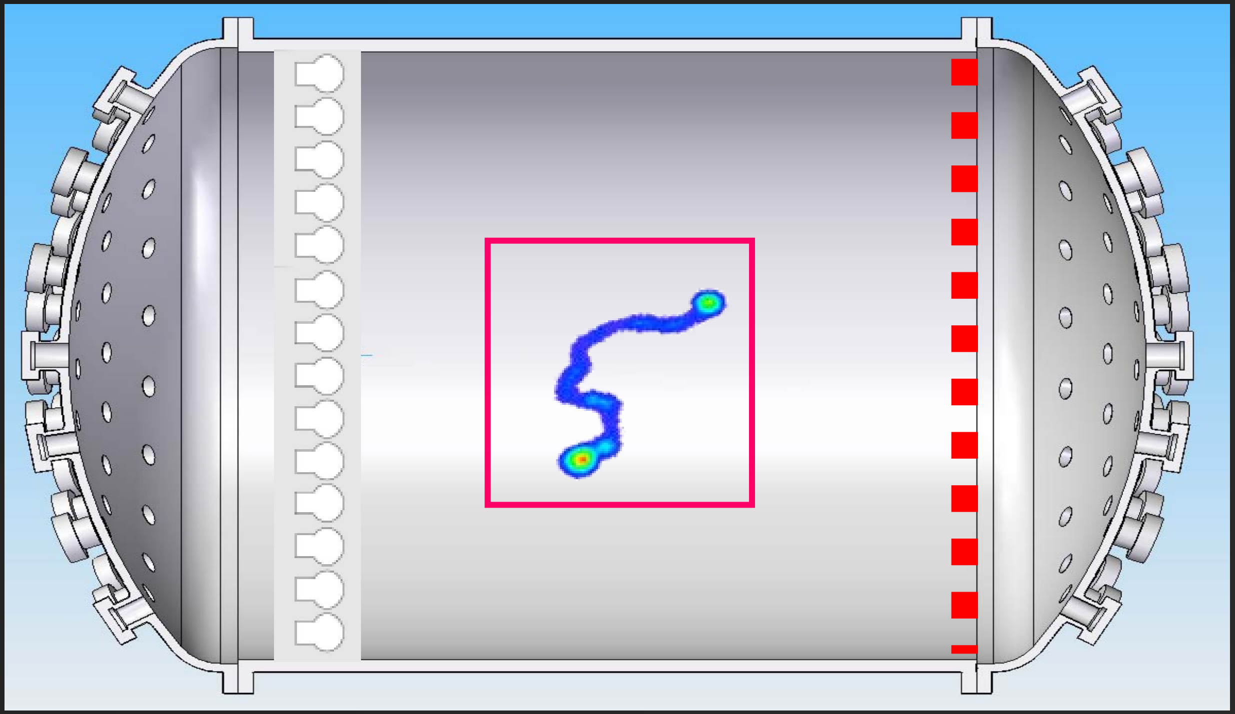
- ✓ Difficulty to design a compact experiment.
- ✓ Typical problems coming from working at High Pressure (~10 bars).

THE EXPERIMENT

✓ The ***NEXT*** (***N***eutrino ***E***xperiment with a ***X***enon ***T***PC) experiment expects to measure the $0\nu\beta\beta$ decay of ^{136}Xe using a high pressure Xenon TPC.

✓ Events detection is based on the ***SOFT*** TPC concept.

- ✓ ***S***eparated-***O***ptimized Energy ***F***unction from ***T***racking



THE EXPERIMENT

✓ ***SOFT*** TPC: Separate-Optimized Energy Function from Tracking.

✓ The experiment will have a ***better sensitivity*** if we are capable to obtain as accurate as possible:

- ✓ ***Energy*** of the event (with good resolution).
- ✓ Time of the event (t_0, related to z position).
- ✓ ***Track*** of all the particles of the event.

✓ These characteristics will allow not only to determine the energy of the event, but also to reconstruct it in order to apply ***pattern recognition*** to ***discriminate*** background events from $0\nu\beta\beta$ ones.

THE EXPERIMENT

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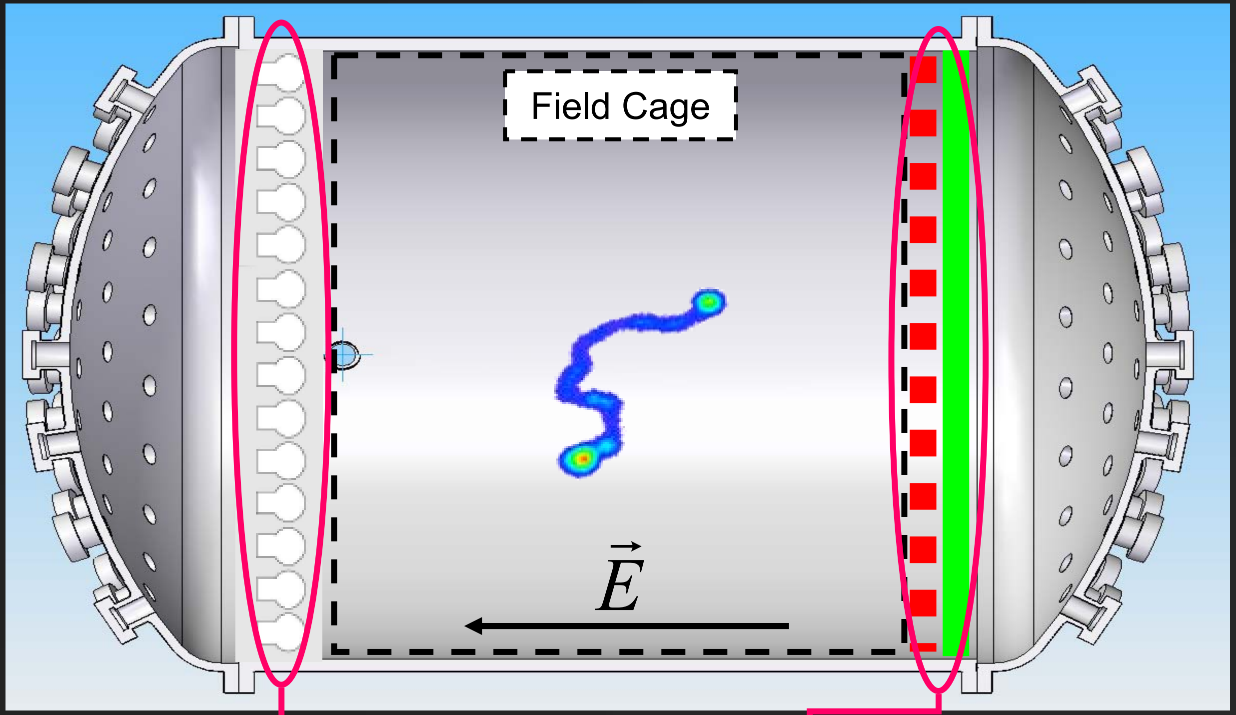

PMT plane

Electroluminescence region (higher *E*)
SiPM plane

THE EXPERIMENT

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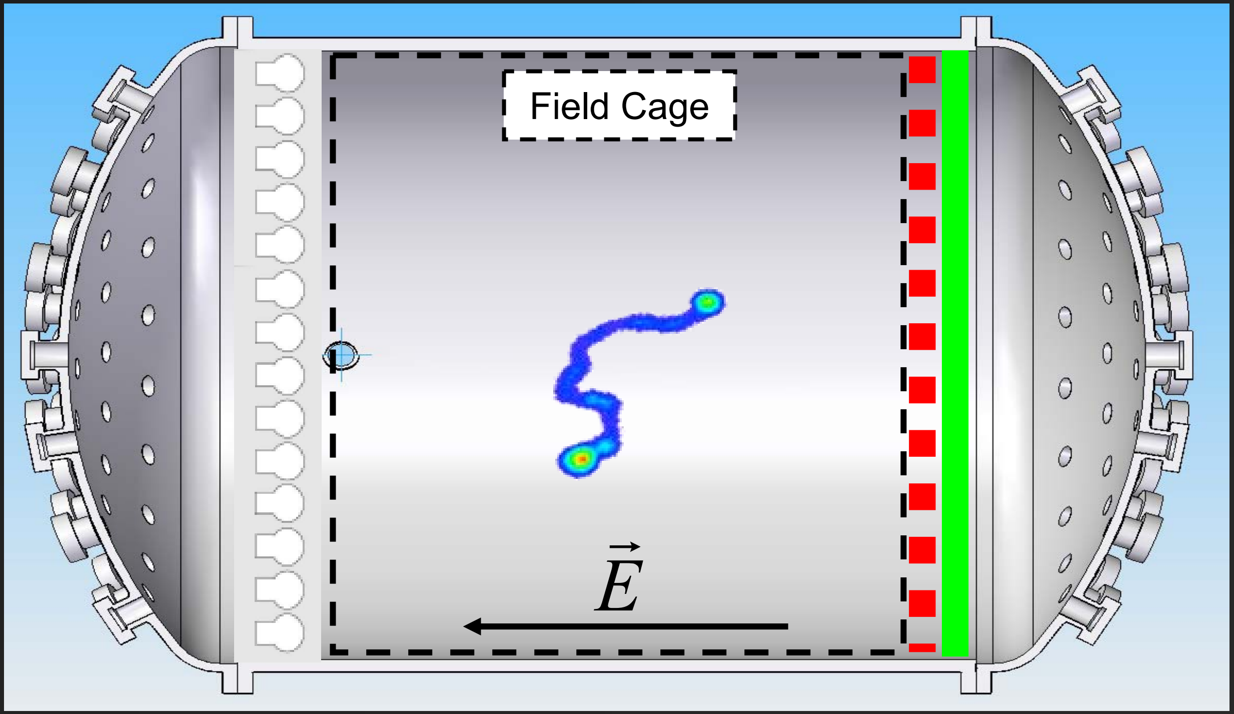


PMT plane:
Primary scintillation → t_0
Electroluminescence Light → ***Energy***

SiPM plane:
Electroluminescence Light → ***Tracking***

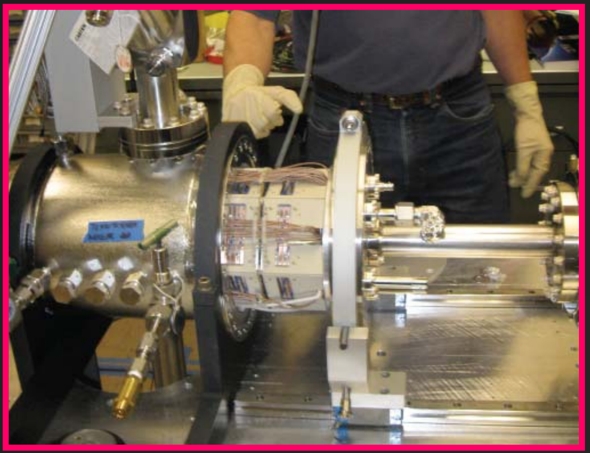
PRESENT STATUS: PROTOTYPES

✓ Different small and medium size TPCs to test and improve elements that will be used in the final setup.

- ✓ Detectors: Energy Resolution, Time Stability…
- ✓ Vessel and internal components: Outgassing, Leak rates…
- ✓ DAQ

✓ There are still decisions to be taken about some features of NEXT-100.

NEXT DBDM

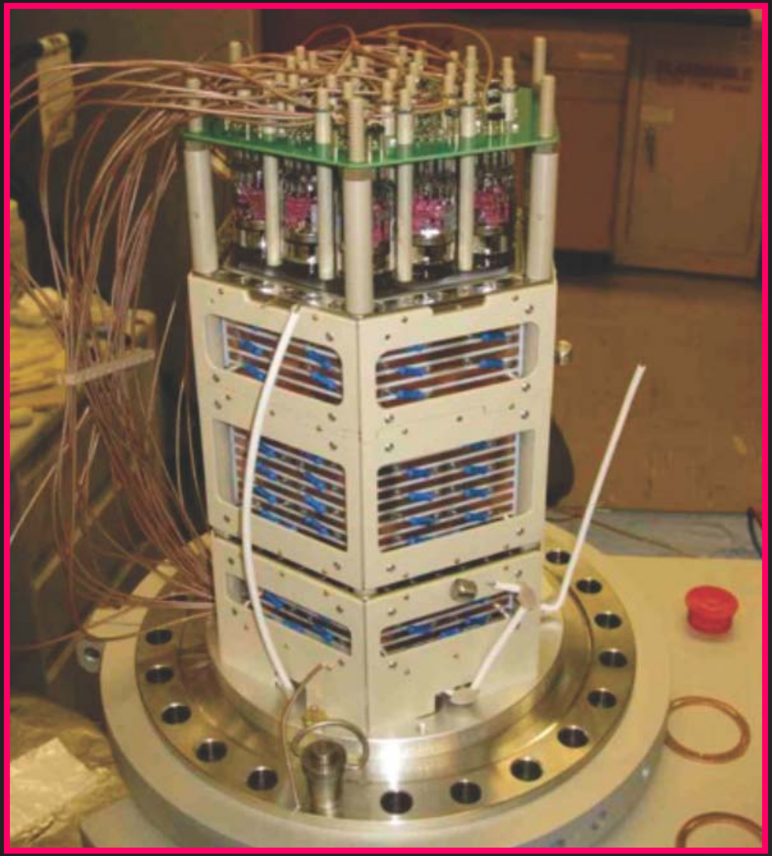


NEXT DEMO

NEXT μM

PRESENT STATUS: PROTOTYPES

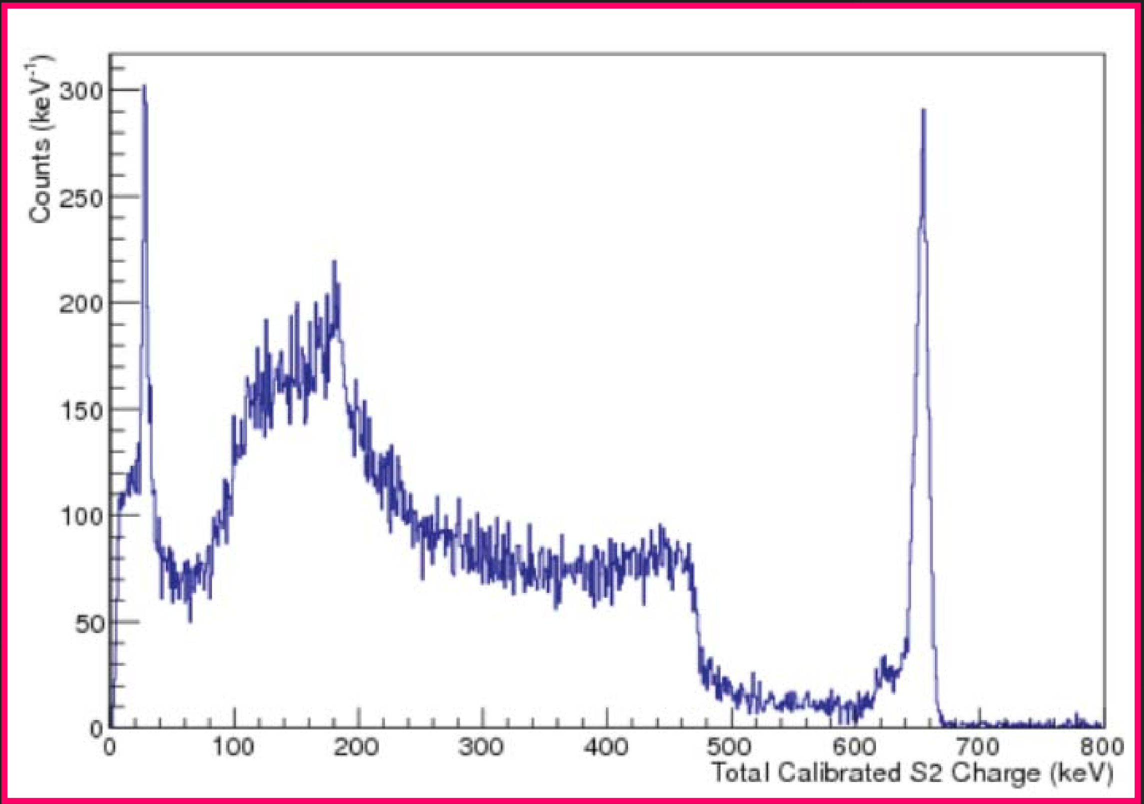
- ✓ ***NEXT DBDM***:
  - ✓ Test PMTs energy resolution in HP Xe (up to 15 bar).



PRESENT STATUS: PROTOTYPES

✓ **NEXT DBDM**:

- ✓ Test PMTs energy resolution in HP Xe (up to 15 bar).
- ✓ Promising results.



✓ 1% FWHM @ 662 keV

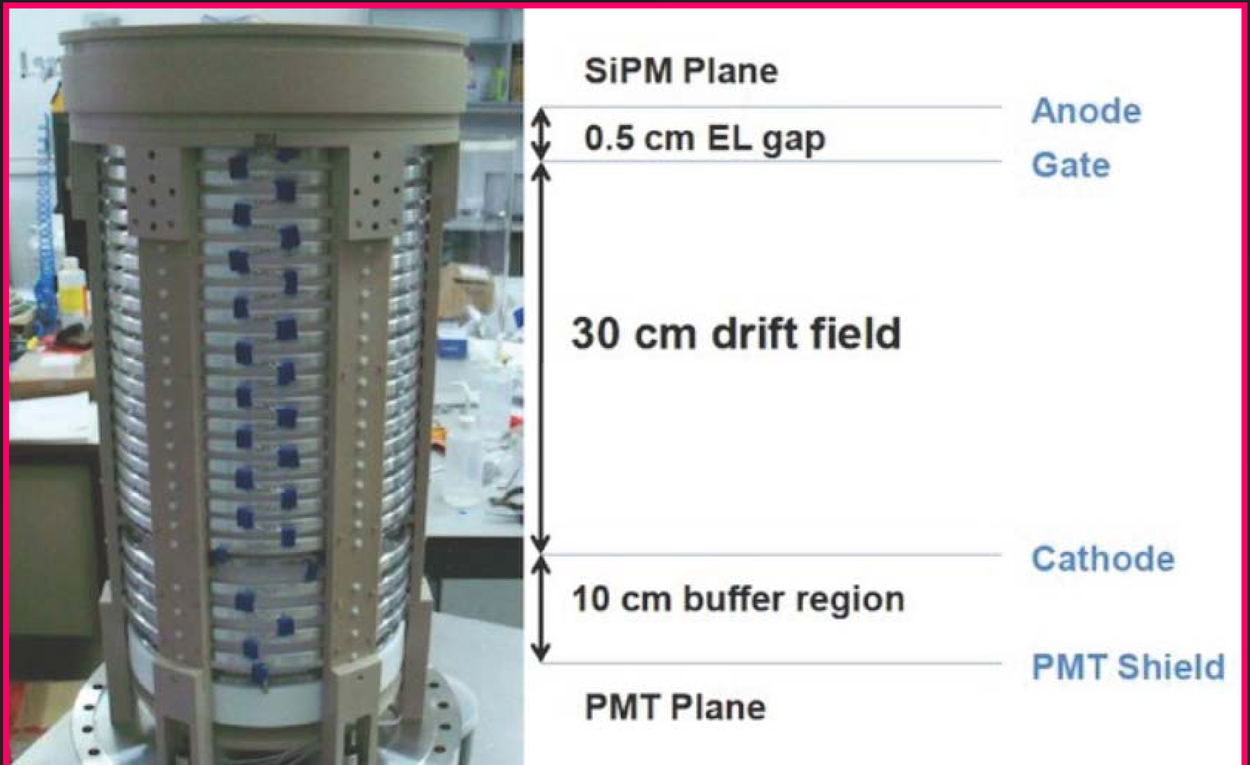
- Drift Field: 0.05 kV/cm/bar
- EL Field: 2 kV/cm/bar

✓ Primary Scint. also observed

- Work with higher Drift Fields.
- Radial dependence and other points to clarify.

PRESENT STATUS: PROTOTYPES

- ✓ ***NEXT DEMO***:
  - ✓ Analog to the NEXT-100 baseline detector concept.



Ø = 16 cm → SV ~ 6 l

m_{Xe} ~ 0.34 kg @ 10 bar

PRESENT STATUS: PROTOTYPES

✓ ***NEXT DEMO***:

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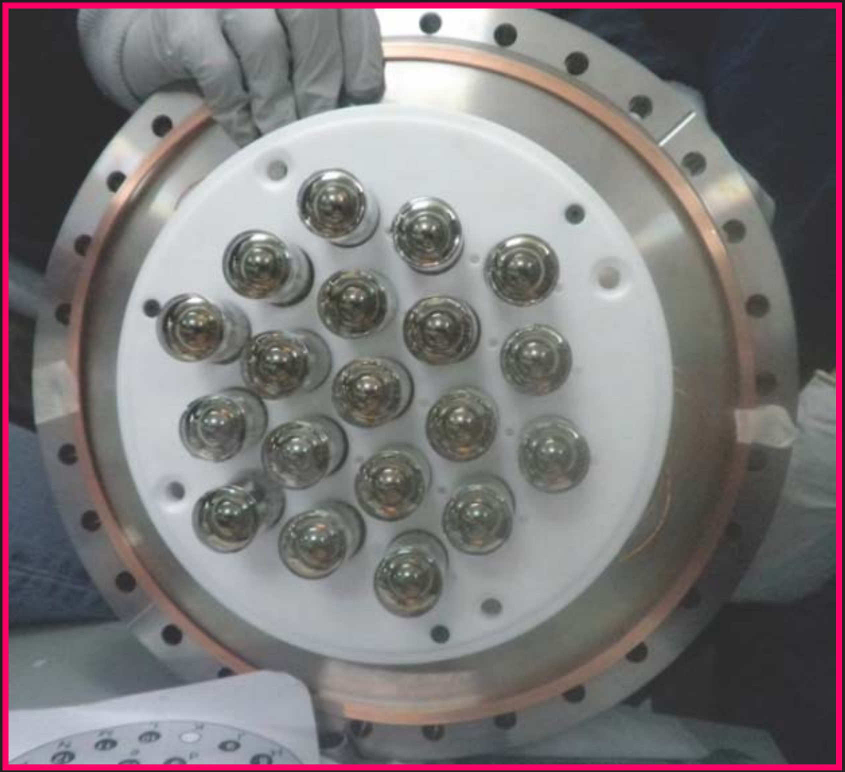
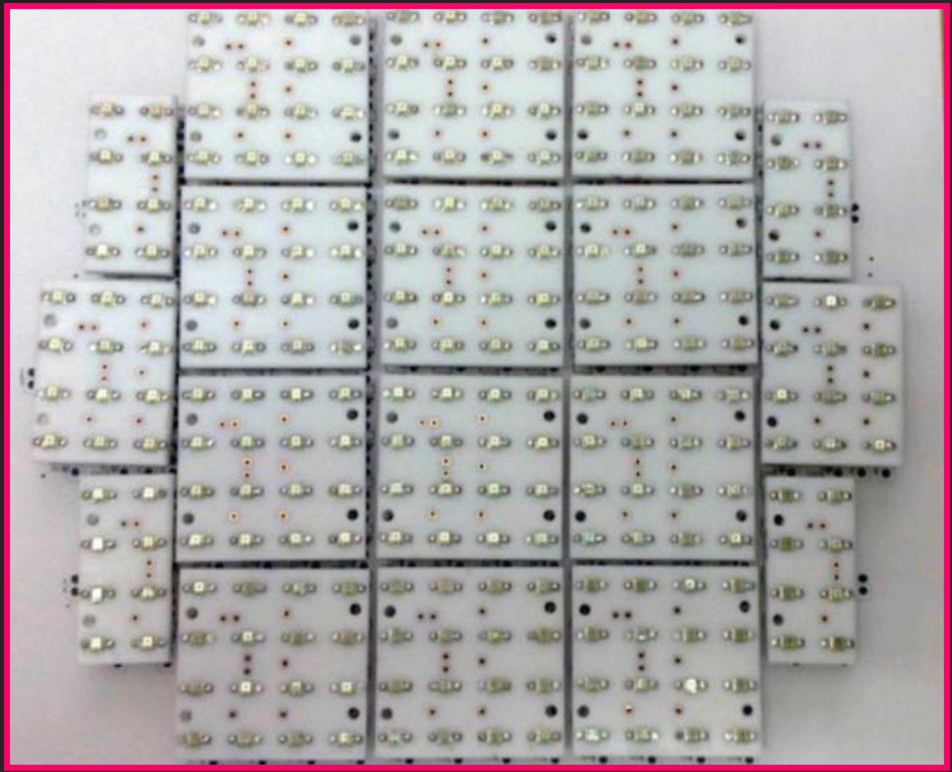


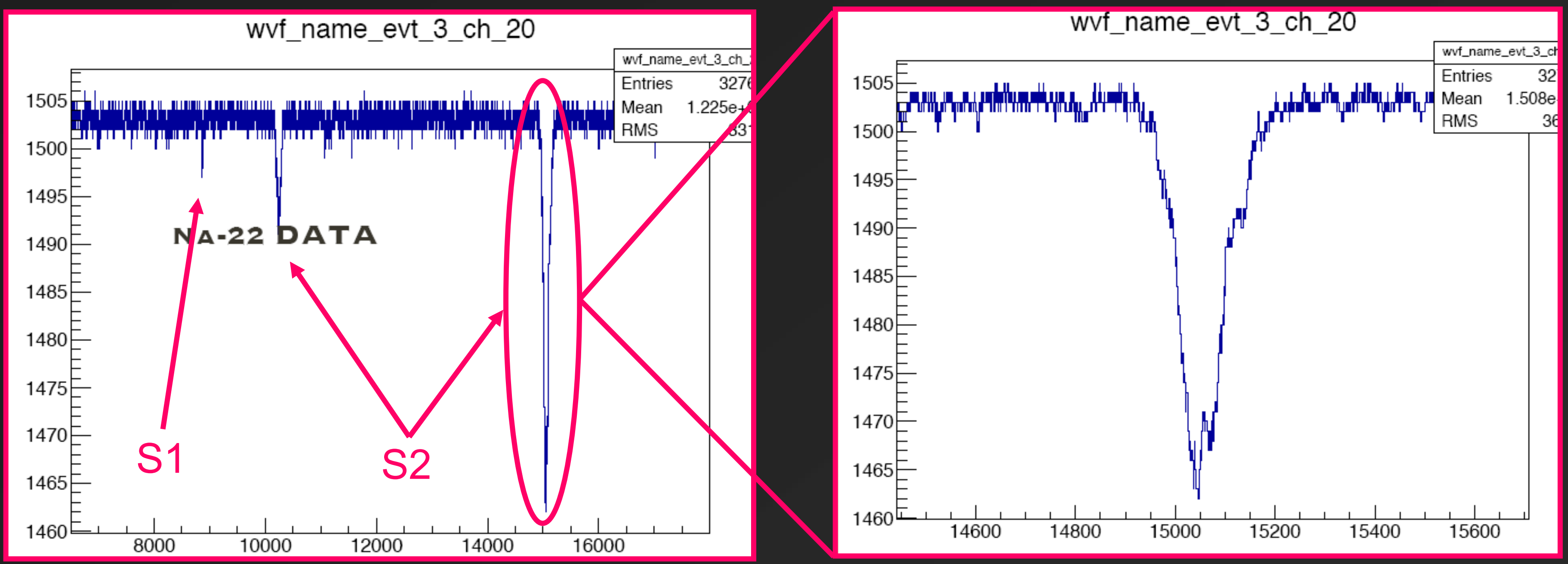
PMT Plane (t_0 and ***Energy***)



SiPM Plane (***Tracking***)

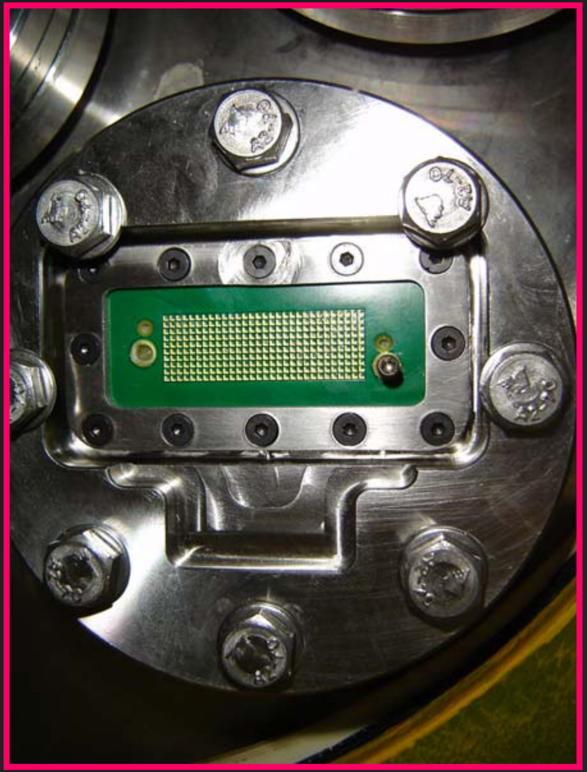
PRESENT STATUS: PROTOTYPES

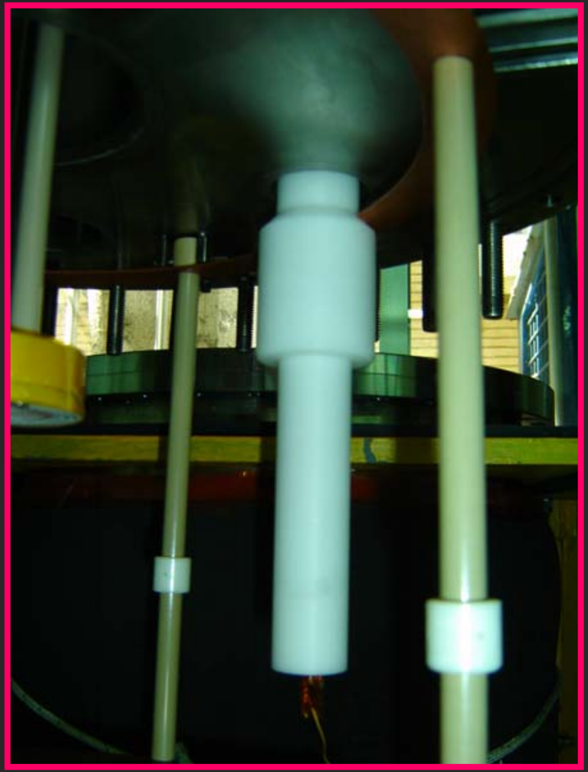
- ✓ ***NEXT DEMO***:
  - ✓ Analog to the NEXT-100 baseline detector concept.
  - ✓ Prototype just commissioned (only preliminary calibrations done).



PRESENT STATUS: PROTOTYPES

- ✓ ***NEXT μM***:
  - ✓ Testing of different Xe-base mixtures (effects on the energy resolution).
  - ✓ Outgassing and Leak Rates for Feedthorughs and internal components.
- ✓ ***But Also***…





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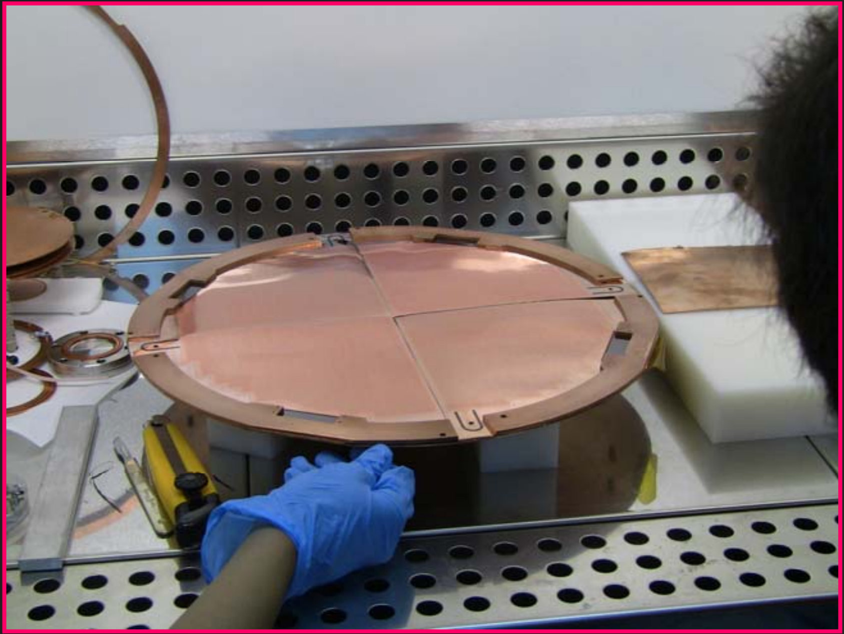

- ✓ No operational problems in HP
- ✓ Long term stability
- ✓ Radiopure solution
- ✓ Capable to register energy and tracking
- ✓ Ongoing studies to see EL
- ✓ …

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- ✓ No operational problems in HP
- ✓ Long term stability
- ✓ ***Radiopure solution***

S. Cebrián et al, Astrop Phys 34 (2011) 354-359

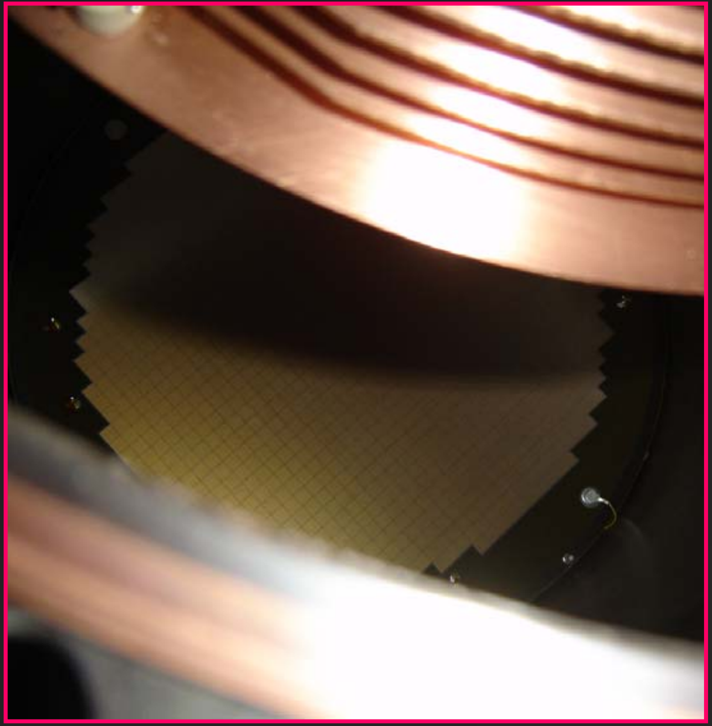
Table 2
Radioactivity levels (in µBq/cm^2) measured for a Micromegas without mesh, a *microbulk*-Micromegas, a kapton–copper raw material foil, a copper–kapton–copper raw material foil and those in a PMT used in XENON experiment, taken from [30].

Sample	^{232}Th	^{235}U	^{238}U	^{40}K	^{60}Co
Micromegas without mesh	4.6 ± 1.6	<6.2	<40.3	<46.5	<3.1[a]
Microbulk-Micromegas	<9.3	<13.9	26.3 ± 13.9	57.3 ± 24.8	<3.1[a]
Kapton–copper foil	<4.6[a]	<3.1[a]	<10.8	<7.7[a]	<1.6[a]
Copper–kapton–copper foil	<4.6[a]	<3.1[a]	<10.8	<7.7[a]	<1.6[a]
Hamamatsu R8520-06 PMT [30]	27.9 ± 9.3	–	<37.2	1705.0 ± 310.0	93.0 ± 15.5

[a] Level obtained from the minimum detectable activity (MDA) of the detector [31].

PRESENT STATUS: PROTOTYPES

- ***NEXT μM***:
  - Testing of different Xe-base mixtures (effects on the energy resolution).
  - Outgassing and Leak Rates for Feedthorughs and internal components.
- ***But Also***…
  - Study of Micromegas detector as alternative to the baseline.



- No operational problems in HP
- Long term stability
- Radiopure solution
- Capable to register energy and tracking
- Ongoing studies to see EL
- …

PRESENT STATUS: PROTOTYPES

- ✓ **NEXT μM**:
  - ✓ ~ 79 l Stainless Steel Chamber.
  - ✓ Ø = 28 cm and 35 cm Drift Length for 21.5 l of sensitive volume.

    → Up to ***~1.2 kg of Xe @ 10 bar*** in the sensitive volume.

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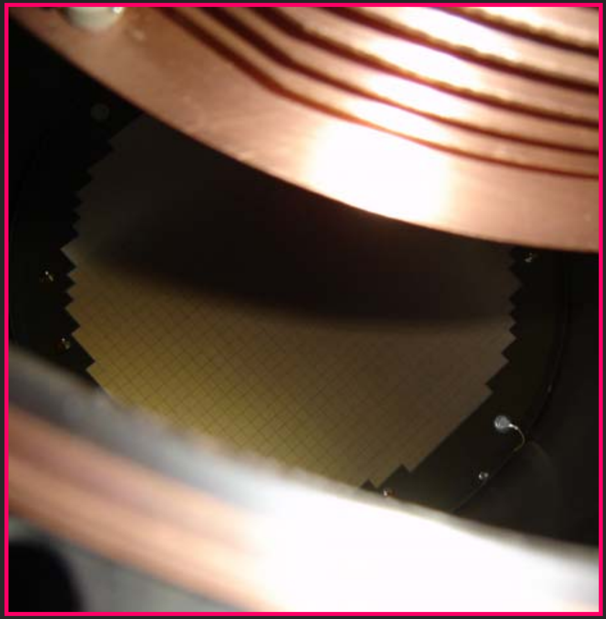
  - ✓ ~ 79 l Stainless Steel Chamber.
  - ✓ Ø = 28 cm and 35 cm Drift Length for 21.5 l of sensitive volume.
    - →Up to ***~1.2 kg of Xe @ 10 bar*** in the sensitive volume.
- ✓ In a first step the prototype was fully equipped with:
  - ✓ Bulk mM detector Ø ~ 30 cm.
  - ✓ Copper + Peek + Cirlex Field Cage.
  - ✓ Teflon + Copper HV Feedthrough.
  - ✓ Readout Feedthrough.



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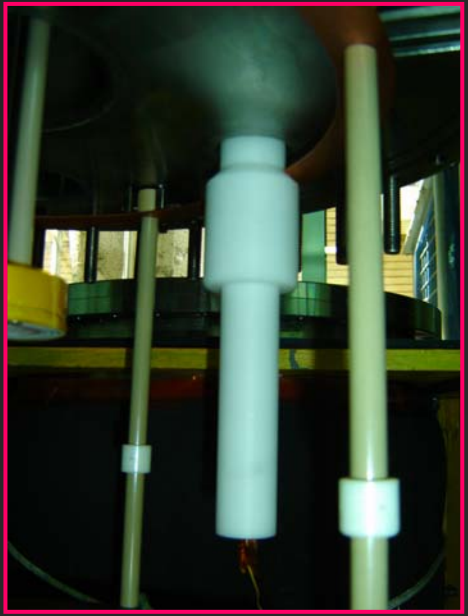

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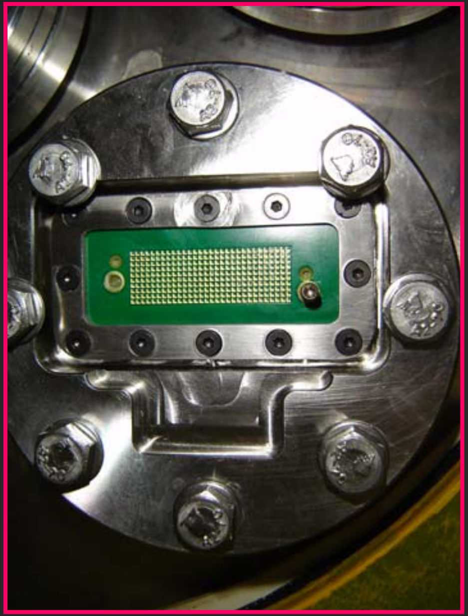

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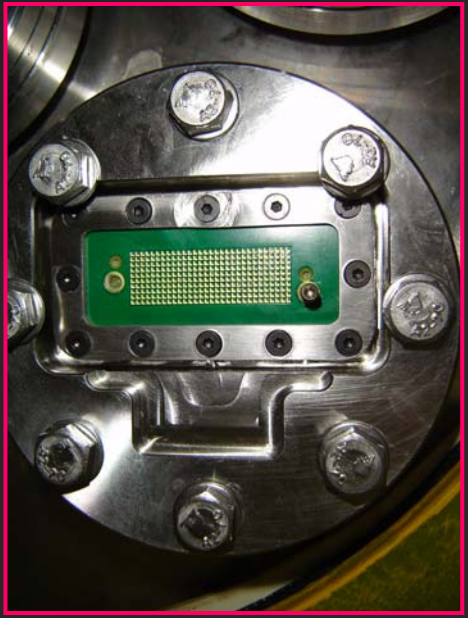
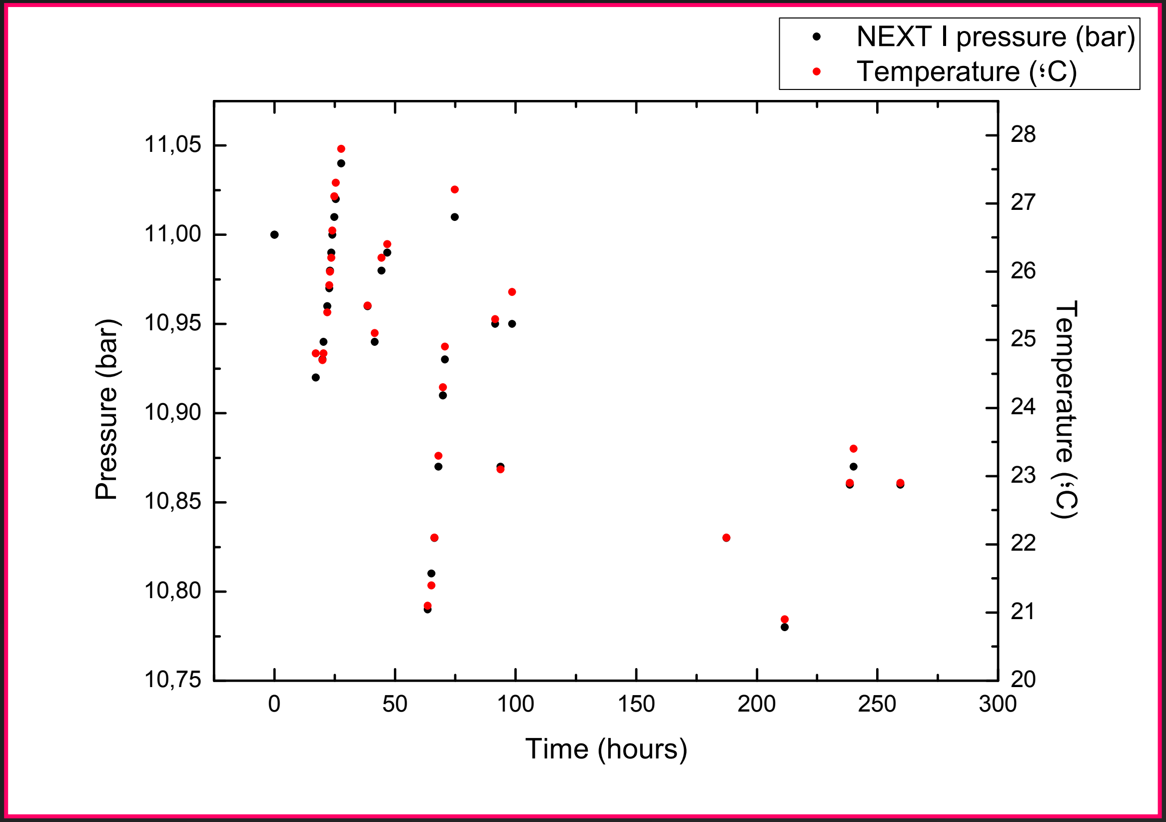
  - ✓ Bulk mM detector Ø ~ 30 cm.
  - ✓ Copper + Peek + Cirlex Field Cage.
  - ✓ Teflon + Copper HV Feedthrough.
  - ✓ Readout Feedthrough.
- ✓ Before to measure:
  - ✓ ***Pressure*** Tests
  - ✓ ***Vacuum*** and ***Outgassing*** measurements
  - ✓ ***HV*** and many others…



PRESENT STATUS: PROTOTYPES

- ✓ **NEXT μM**: Pressure Tests.
  - ✓ Useful to test the vessel but also the Gas System to put the gas inside the vessel (valves, flowmeters, …)



- ***11*** bar of ***Ar***
- Monitoring of ***P*** and ***T***

PRESENT STATUS: PROTOTYPES

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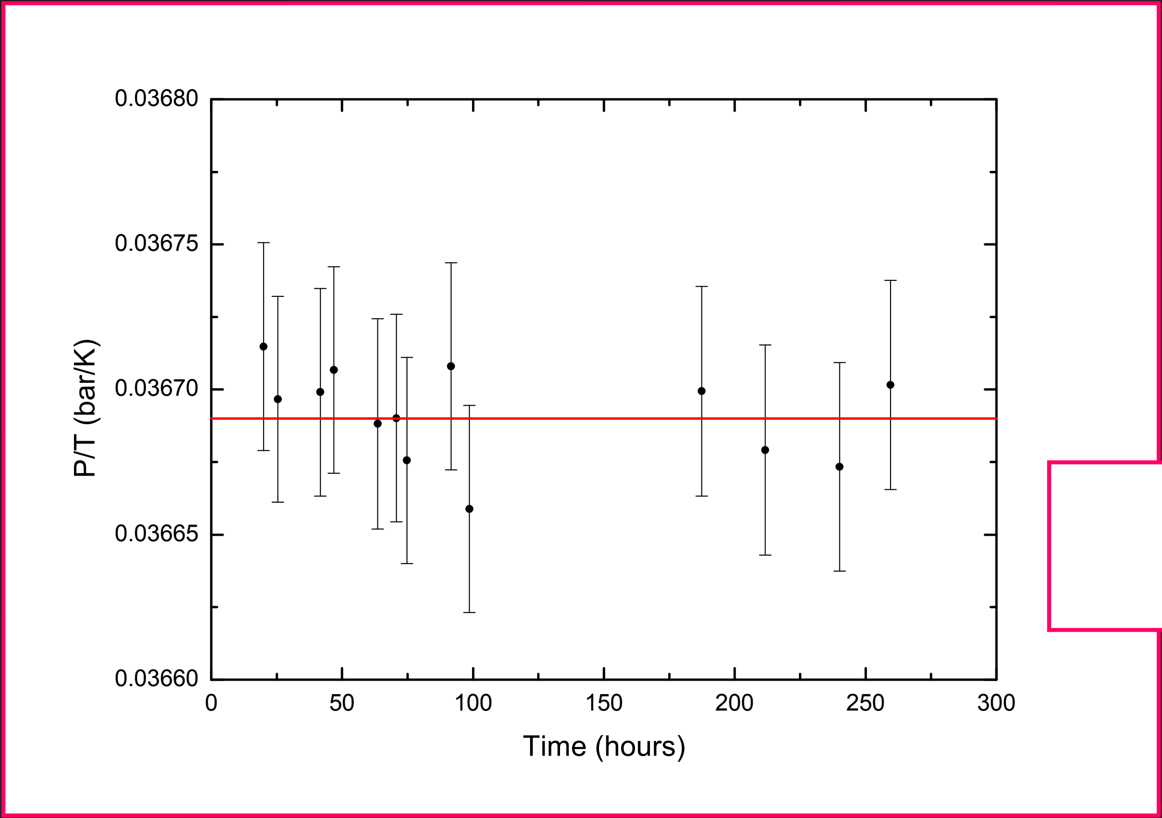
  ✓ Useful to test the vessel but also the Gas System to put the gas inside the vessel (valves, flowmeters, …)



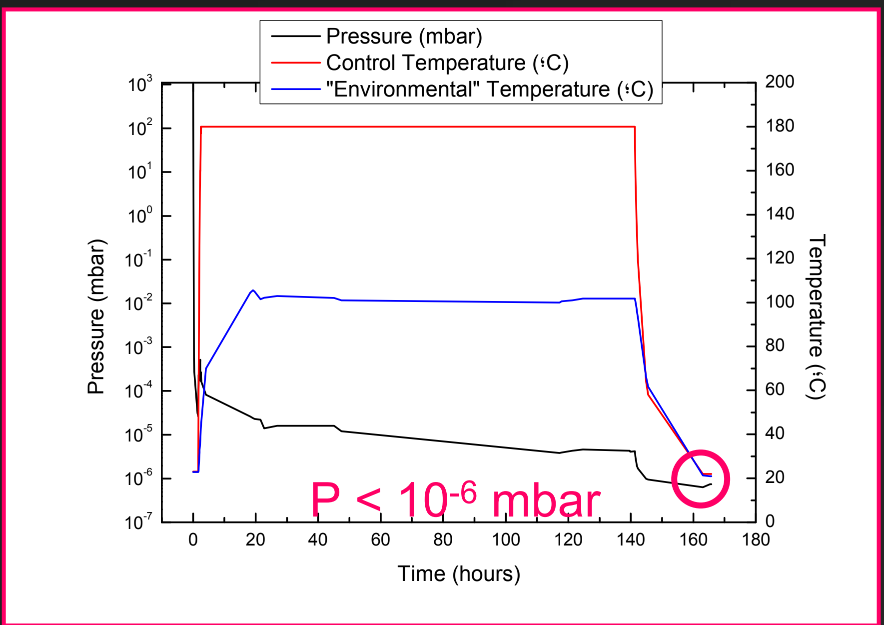
- ***11*** bar of ***Ar***
- Monitoring of ***P*** and ***T***

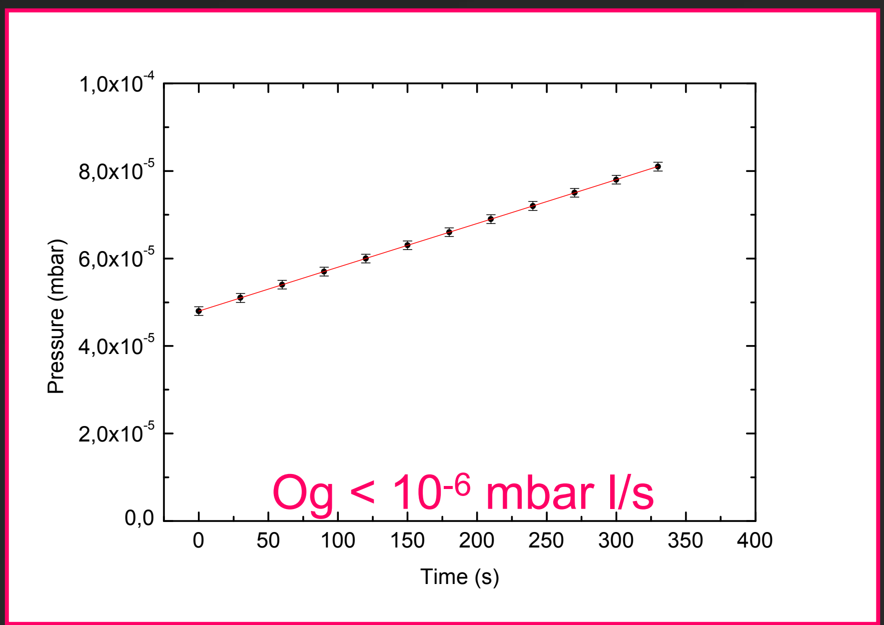
11 *bars* constant during more than 10 days

PRESENT STATUS: PROTOTYPES

- ✓ ***NEXT μM***: Vacuum and outgassing measurements.
  - ✓ To keep the purity of gas, elements in contact must not emanate any contaminant.
  - ✓ In principle the inner materials were chosen with this purpose.
  - ✓ Bake-out cycles → To “clean” possible impurities.

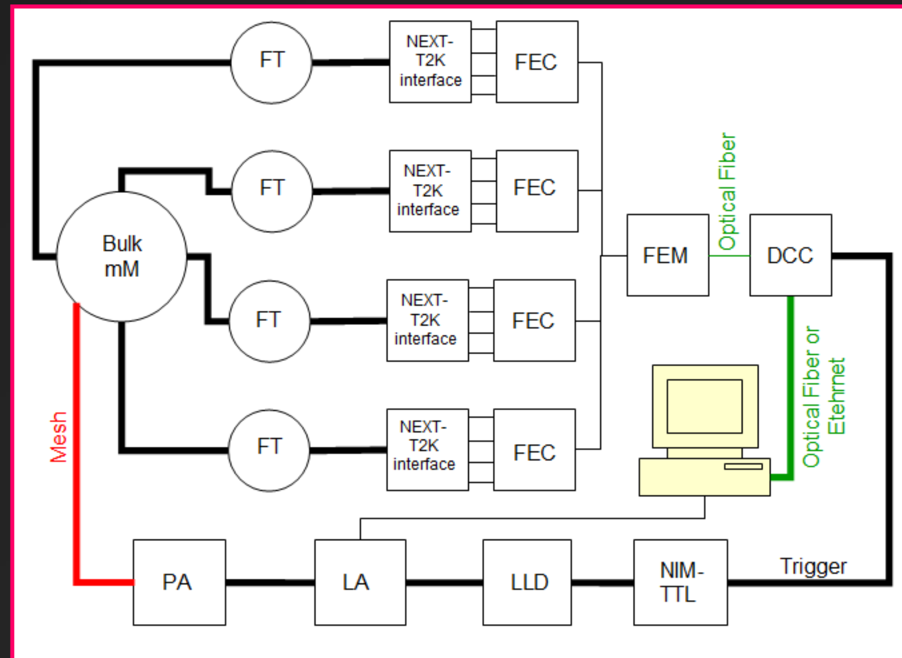
$$\text{Outgassing}\left(\frac{\text{mbar}\times\text{l}}{\text{s}}\right)=\frac{(P(t)-P_0)\times\text{Volume}}{t-t_0}$$





PRESENT STATUS: PROTOTYPES

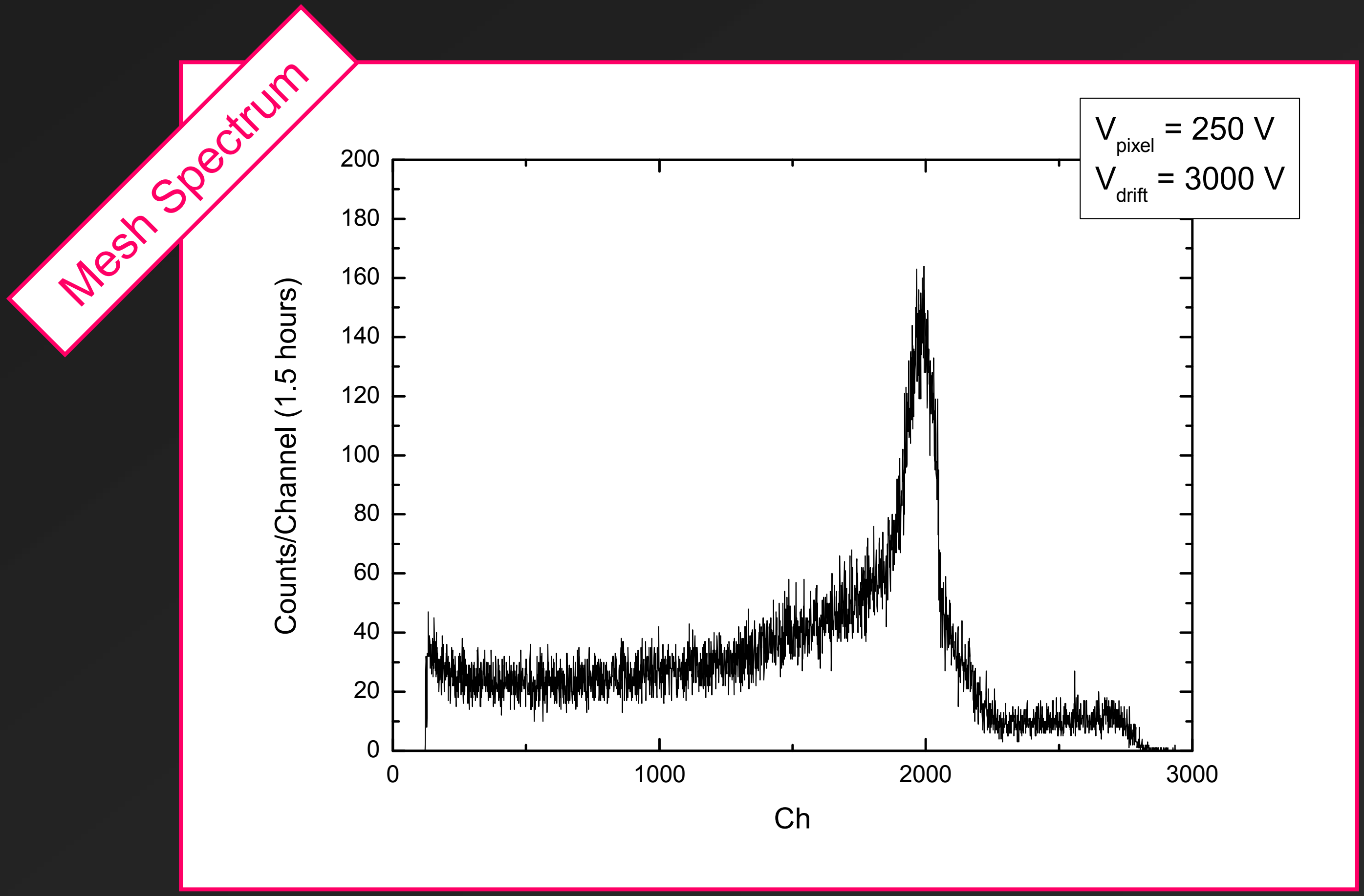
- ✓ ***NEXT*** μ***M***: Other tests.
  - ✓ HV tests to check that Electric Field needed for the Drift is reachable.
  - ✓ Installation of the electronics close to the vessel.



- ✓ DAQ based on ***AFTER*** chip.
- ✓ Possibility to read mesh (***E***) and pixels (***track***) of the μM ***simultaneously***.

PRESENT STATUS: PROTOTYPES

- ✓ ***NEXT μM***: First measurements.
  - ✓ ^{222}Rn source diffused in the gas (Ar-iC_4H_{10} 5%)
  - ✓ ~ 6 MeV α inside the sensitive volume.



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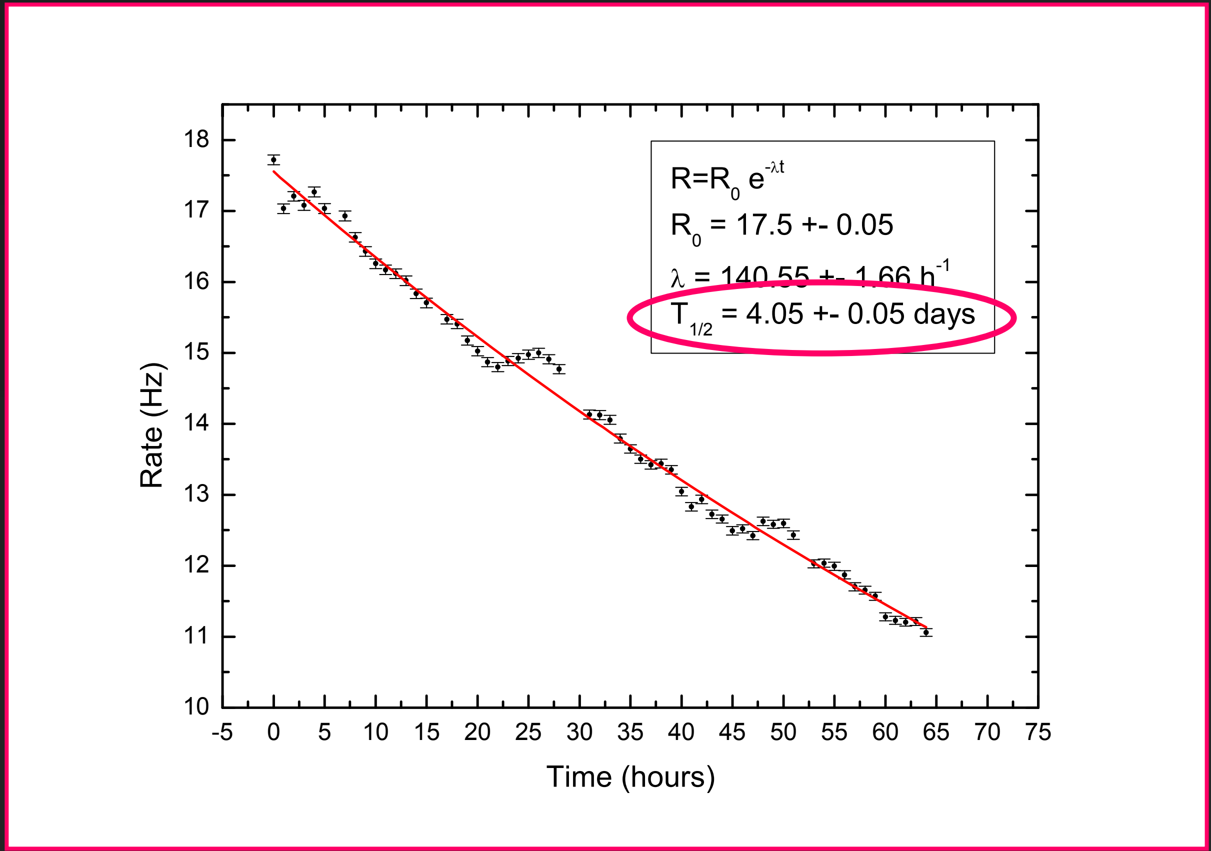

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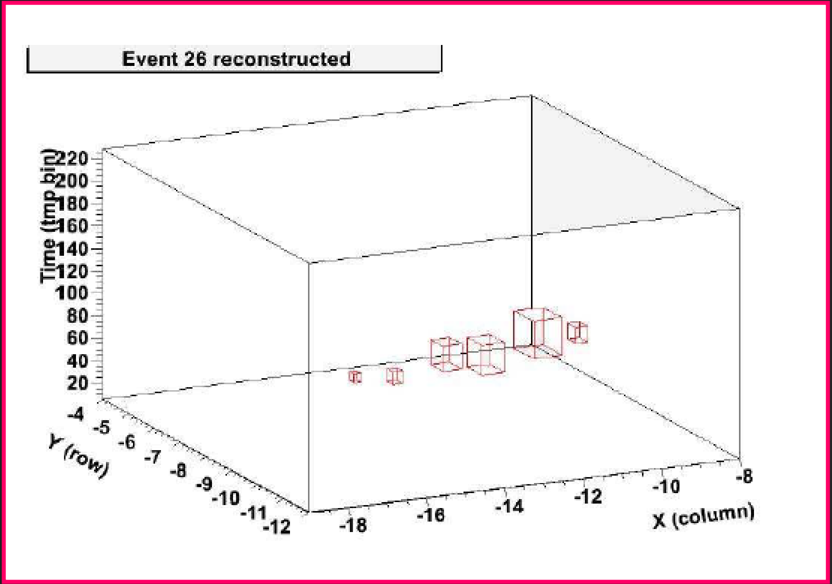
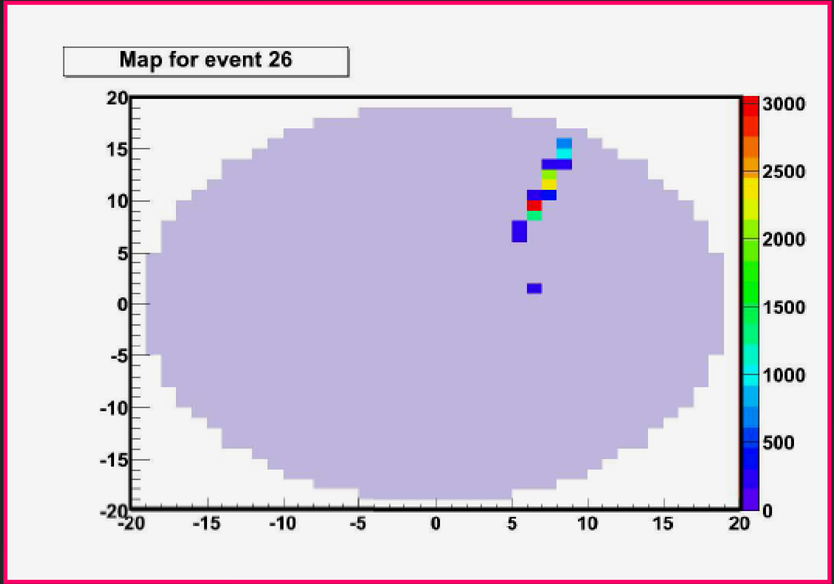


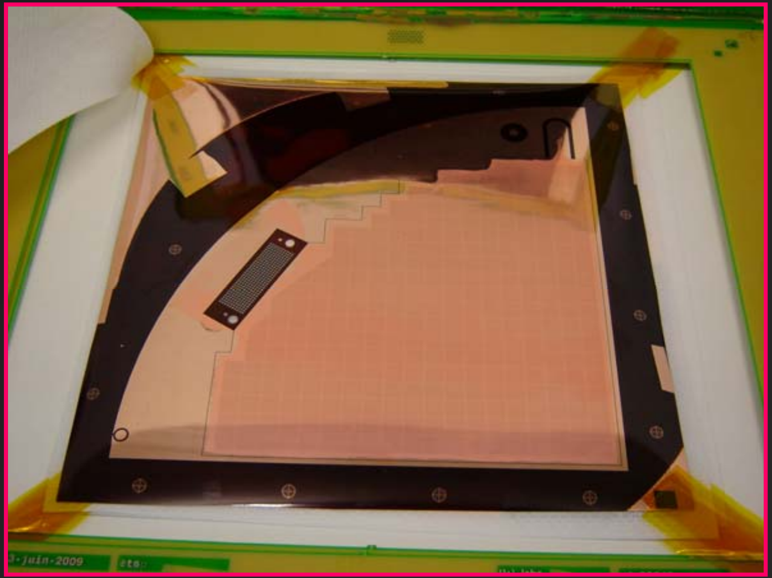
3-D Energy Distribution

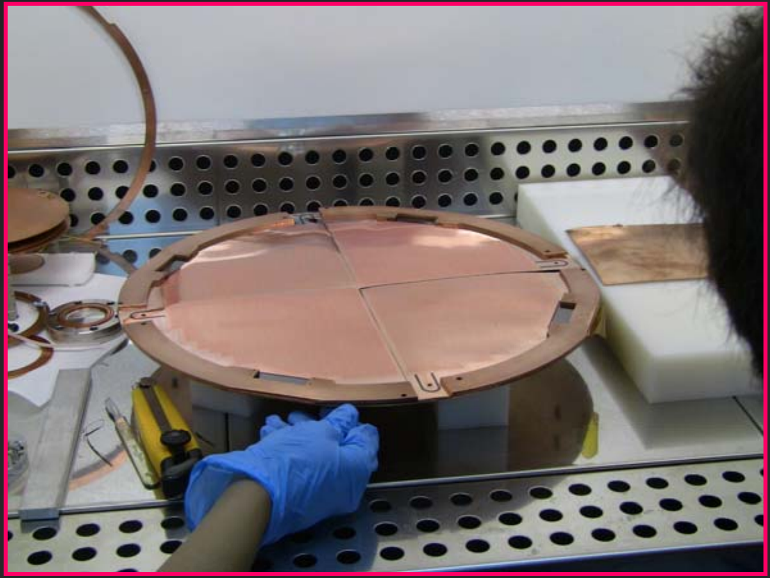


2-D Event Reconstruction

PRESENT STATUS: PROTOTYPES

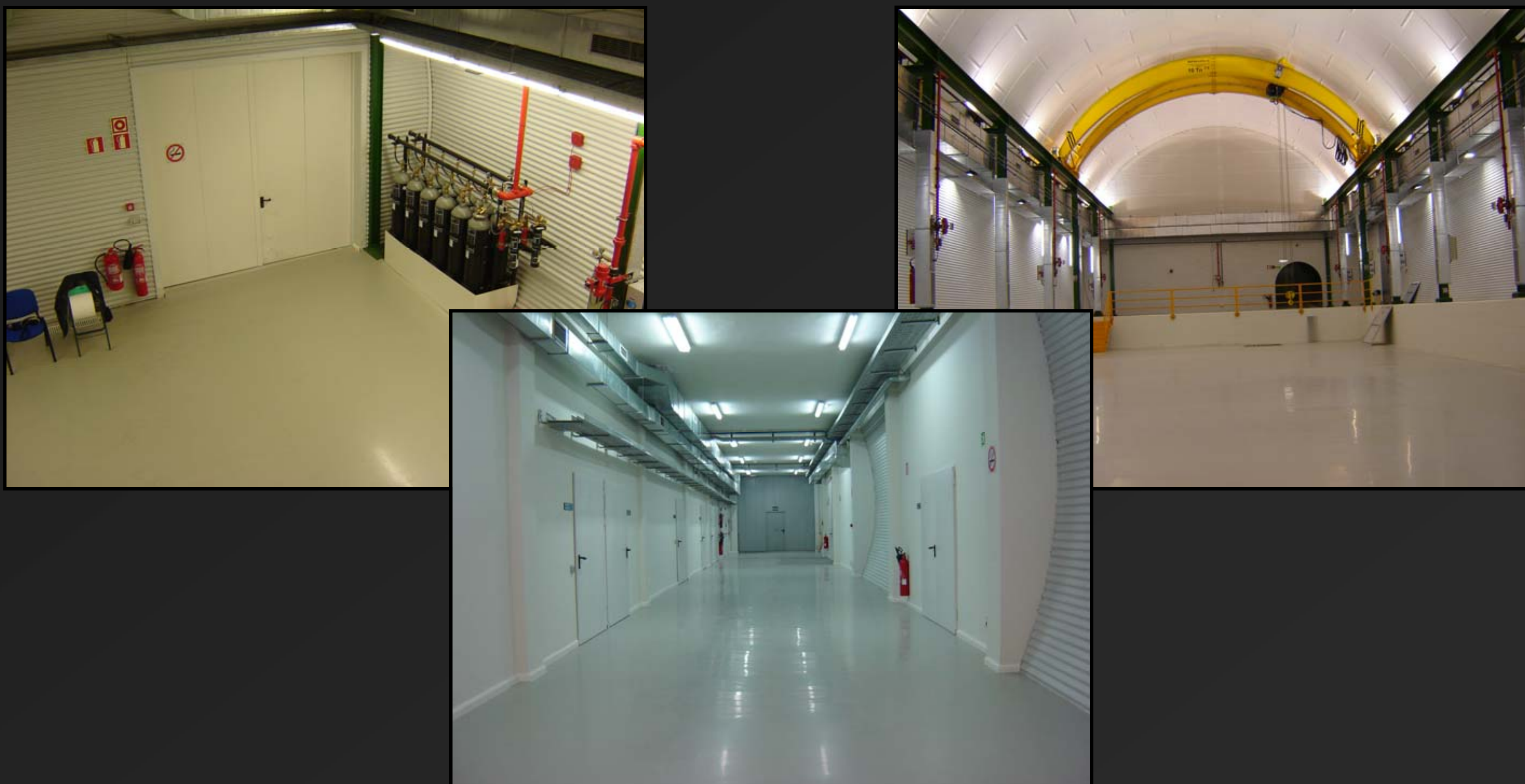
- ✓ ***NEXT μM***: Presents Status.
  - ✓ Prototype fully operative with ***Bulk μM***.
  - ✓ Possible to register ***Energy*** and ***2-D tracks***.
- ✓ Next steps:
  - ✓ Installation of ***microbulk mM*** → LARGEST SURFACE COVERED
  - ✓ Complete the system to register t_0 → 3-D tracks





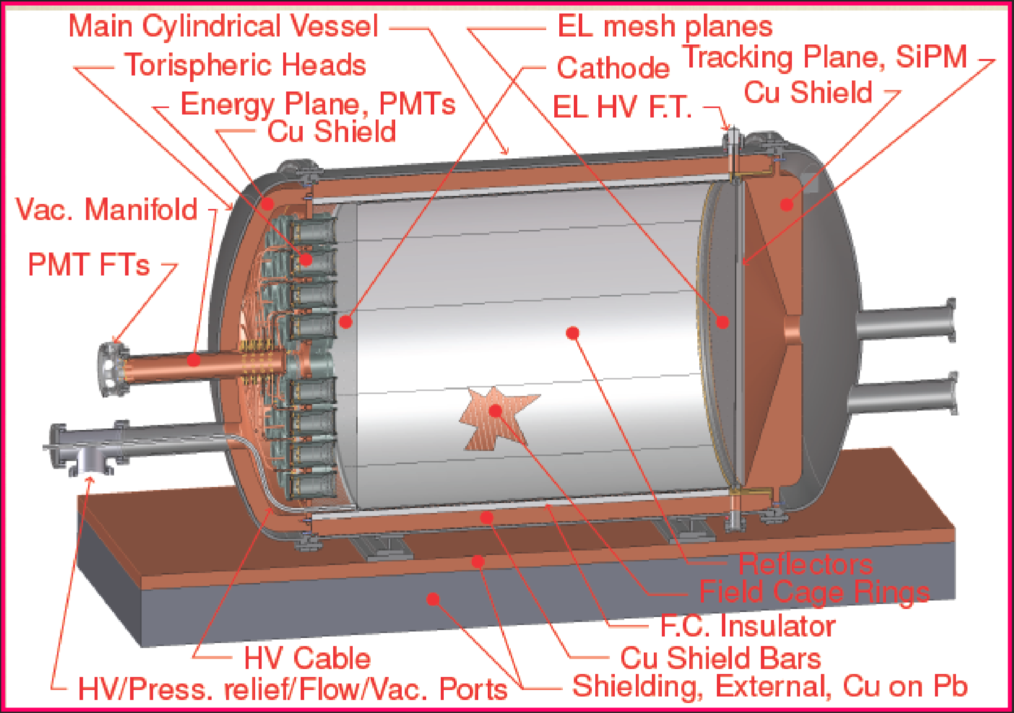
PRESENT STATUS: NEXT 100

✓ ***NEXT 100*** will be placed at Canfranc Underground Laboratory (***LSC***), in the Spanish Pyrenees (***2450 m.w.e.***).



PRESENT STATUS: NEXT 100

- ✓ ***NEXT 100*** time schedule:
  - ✓ Commissioning of the detector along ***2013***.
  - ✓ Start data taking in ***2014***.
- ✓ Technical Detector Report (TDR) finished:
  - ✓ Pressure Vessel (SS + internal Cu shielding)



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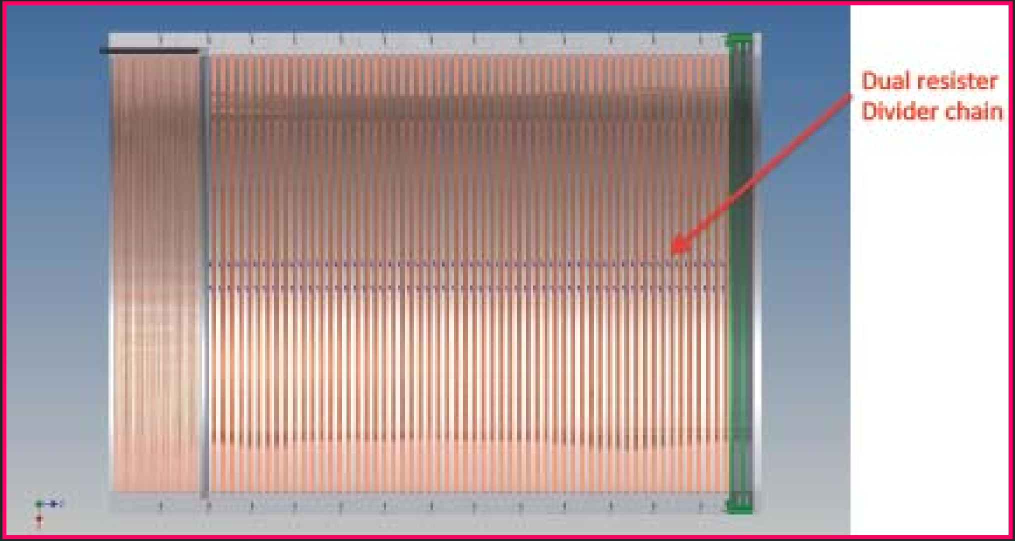
  - ✓ Field Cage



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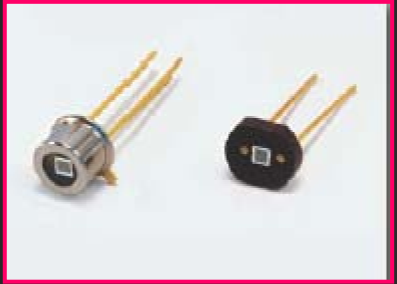

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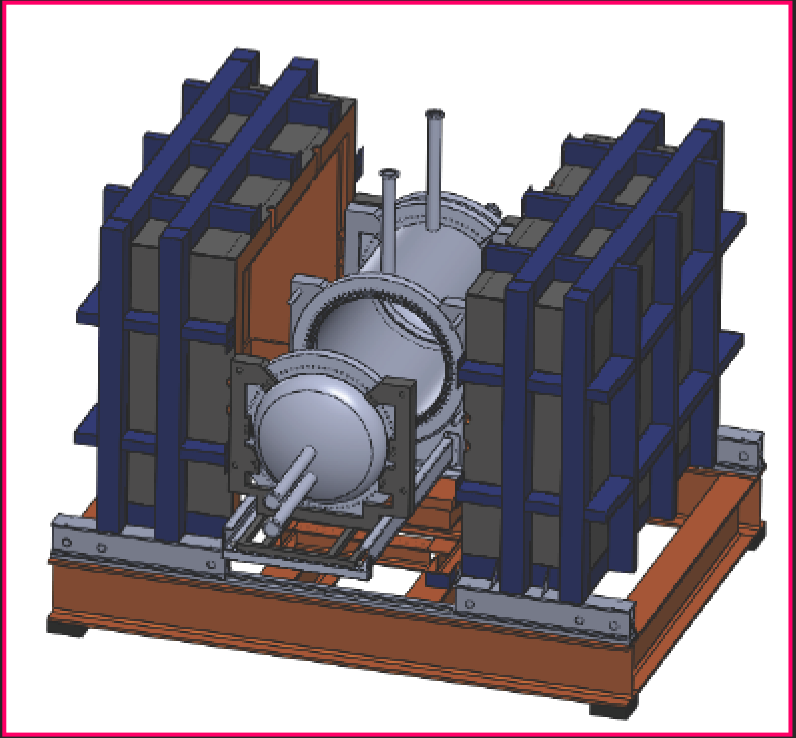

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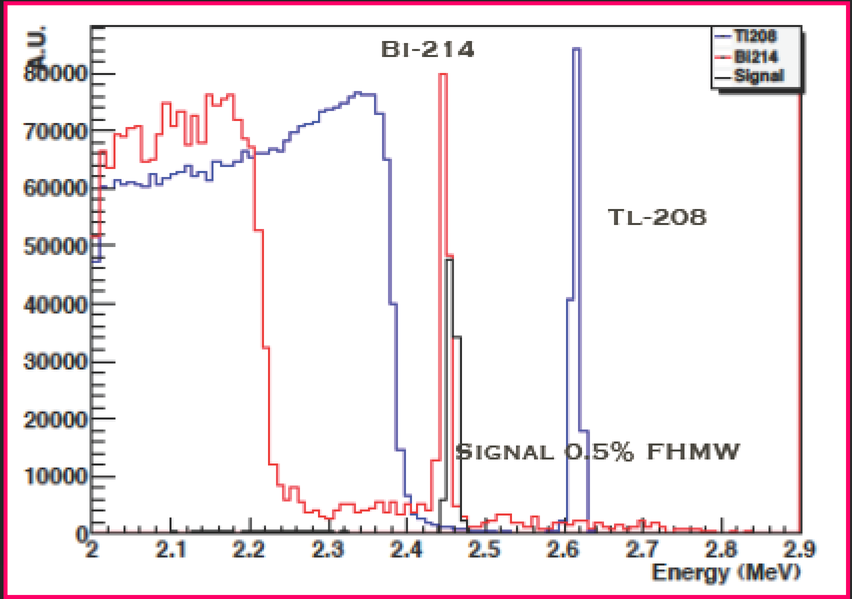
  - ✓ Start data taking in *2014*.
- ✓ Technical Detector Report (TDR) finished:
  - ✓ Pressure Vessel (SS + internal Cu shielding)
  - ✓ Field Cage
  - ✓ PMTs and MPPCs
  - ✓ Shielding
- ✓ Radiopurity measurements → Bkg Model
- ✓ Simulations
- ✓ …

EXPECTED TO REACH THE $\langle m_\nu \rangle$ ~ 50 meV SENSITIVITY



OUTLOOK

- ✓ ***PROTOTYPES***:
  - ✓ Data taking and test of different element and techniques that will be used in NEXT 100.
- ✓ ***NEXT 100***:
  - ✓ Construction and Commissioning of Shielding and Gas System (***2012***).
  - ✓ Final Design and Manufacture of Pressure Vessel (***2011-2012***).
  - ✓ Construction and Characterization of Detector Planes (***2012***).
  - ✓ Construction of Field Cage and HV Feedthroughs (***2012***).
  - ✓ Commissioning of NEXT 100 at LSC (from ~ ***June 2013***).
  - ✓ Start Data Taking (***2014***).

SUMMARY

✓ ***$0\nu\beta\beta$*** is a hot topic in Particle Physics.

✓ ***New generation*** experiments aim to explore new regions for the neutrino effective mass around ***50 meV***.

✓ ***NEXT*** experiment expects to reach this sensitivity using a ***HP Xe TPC***.

✓ NEXT ***prototypes*** are showing that the technology chosen could be suitable for this objective.

✓ ***NEXT 100*** design is already finished and works to construct the setup will start in ***2012***.

✓ The goal is to ***start*** the data taking in ***2014***.

IS A REALLY AMBICIOUS TIME LINE…
BUT LET'S TRY IT

Neutrinoless double beta decay search using ^{136}Xe: The *NEXT* experiment.

Héctor Gómez Maluenda

gomez@lal.in2p3.fr

LAL Seminar, December 2011.