A **NE**utrino **X**enon gas **T**PC for ββ decay searches

Igor G. Irastorza

Universidad de Zaragoza

On behalf of the NEXT Collaboration

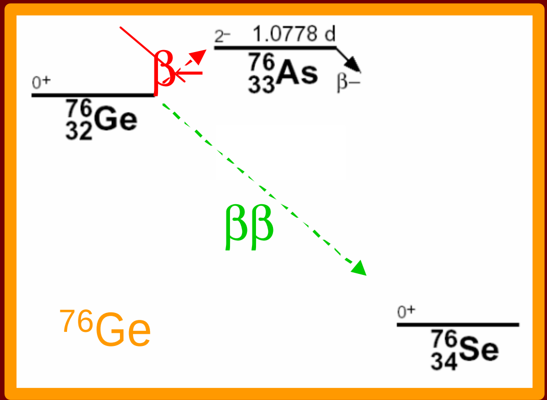
IRFU Seminar, Saclay 30/09/08

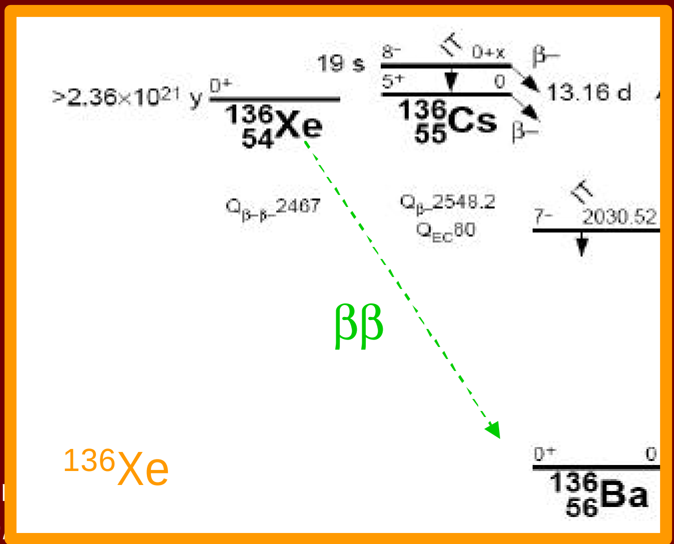
Outline

- Neutrinoless double beta decay: motivation, challenge, brief current status
- Merit of a Gas Xe TPC for double beta decay searches.
- NEXT: new initiative. Motivation, proposal. Expresion of Interest to Canfranc.
- New Canfranc Underground Laboratory.
- Some recent R&D results (E resolution with Micromegas)
- Signal and backgrounds (preliminary)
- Expected next 5-year plan. Funding.
- Conclusions

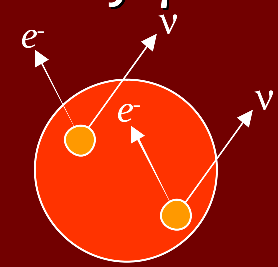
Neutrinoless Double Beta (0νββ)

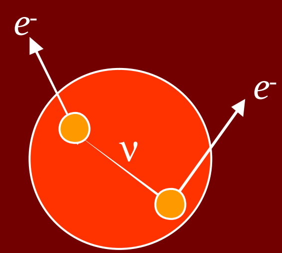
- ββ decay is relevant when the nucleus cannot decay β.





  - ✓ With emission of 2 ν (2νββ). Standard process, observed in a number of isotopes.
  - ✓ With no neutrino (0νββ). Only possible if neutrino is massive and Majorana. Not yet seen(*).

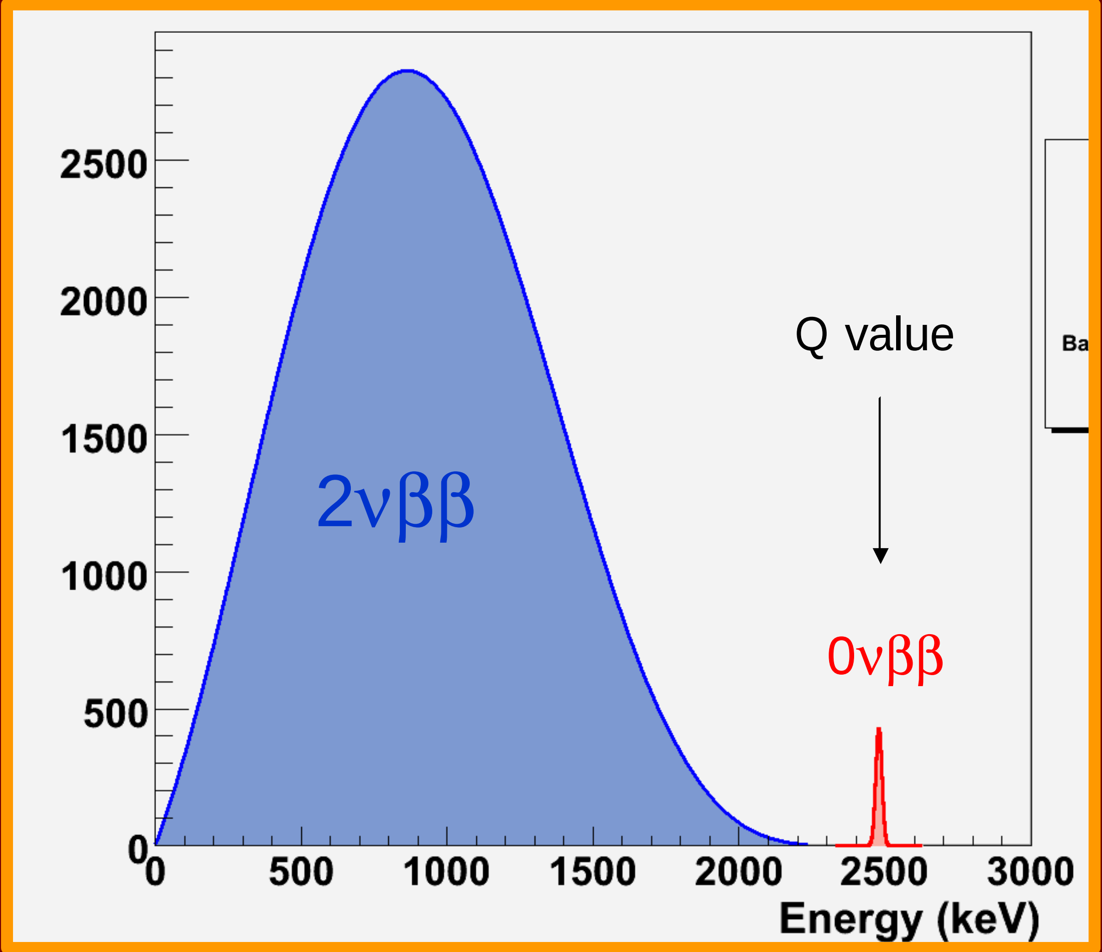


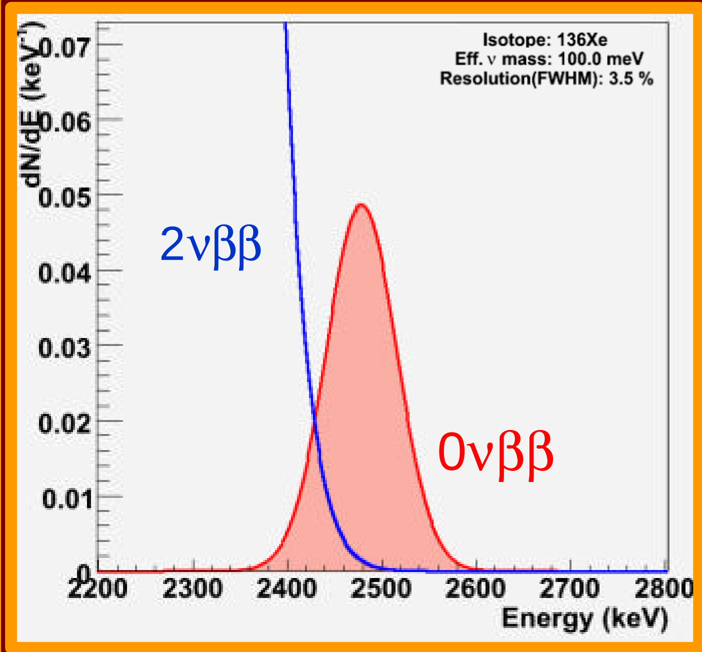


- Precious information on neutrino properties (mass scale, Majorana/Dirac nature,…)

Neutrinoless Double Beta ($0\nu\beta\beta$)

- "Visible" energy (i.e. the 2 e^-) spectrum:

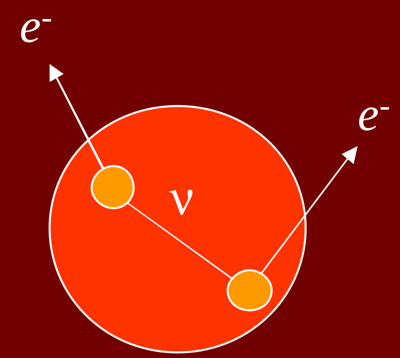




- Energy resolution very important. **Only way to distinguish between both processes**

Neutrinoless Double Beta (0νββ)

- (A,Z) → (A,Z+2) + 2 e⁻
- Lepton number violation (ΔL =2)
- Neutrino must be Majorana (equal to its antiparticle)
- Decay rate:



Phase space factor

Nuclear Matrix Element

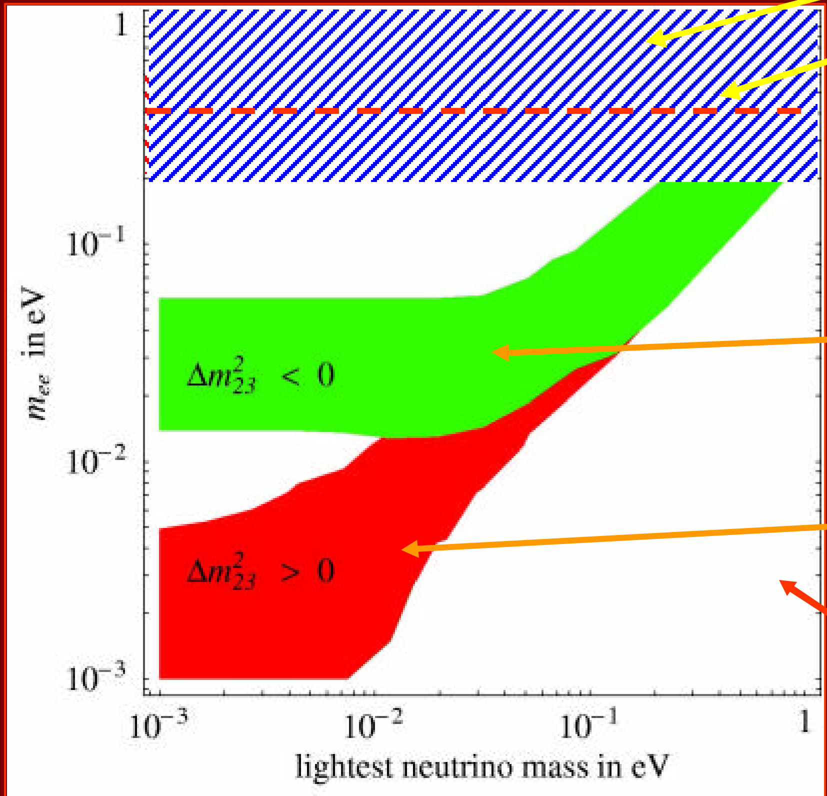
$$\Gamma = G|M|^2|m_{\beta\beta}|^2,$$

- Effective neutrino mass is the underlying quantity (assuming light neutrino exchange as fundamental process, others possible)

$$m_{\beta\beta} = \sum_{i=1}^{3} m_i U_{ei}^2.$$

Neutrino mass scale and 0νββ

- IGEX (^{76}Ge) $<m_\nu>$ < 0.33 – 1.35 eV PRD65(02)092007
- NEMO-3 (^{100}Mo) $<m_\nu>$ < 0.6 – 1.3 eV PRL95(05)182302 & talk @ TAUP07
  expected soon < 0.3 – 0.7 eV
- CUORICINO (^{130}Te) $<m_\nu>$ < 0.2 – 1.1 eV PRL95(05)142501



Region being explored by present experiments

Claimed evidence (0.2-0.6 eV)
PLB586(04)092007

"quasi" degeneracy
$m_1 » m_2 » m_3$

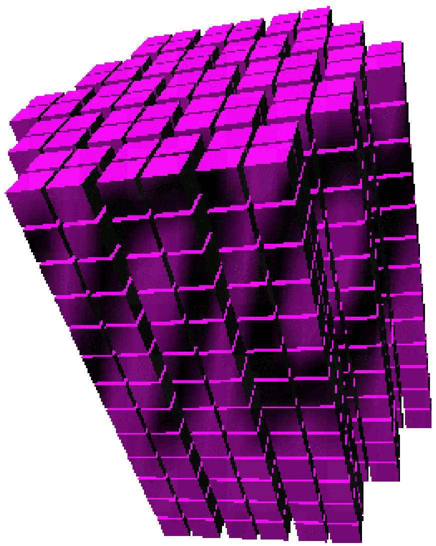
Inverse hierarchy
$Dm^2_{12} = Dm^2_{atm}$

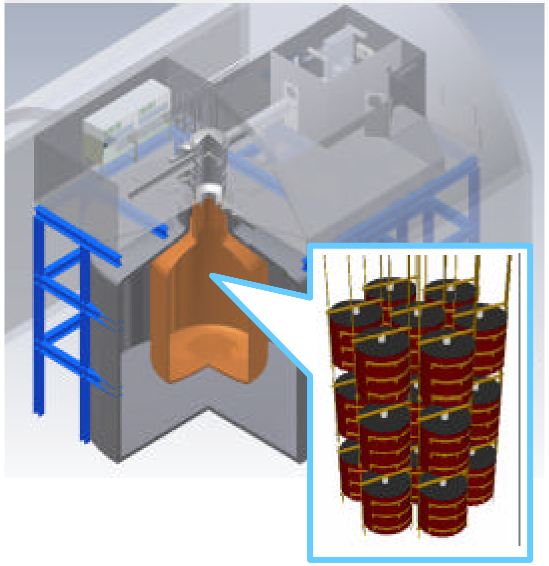
Direct hierarchy
$Dm^2_{12} = Dm^2_{sol}$

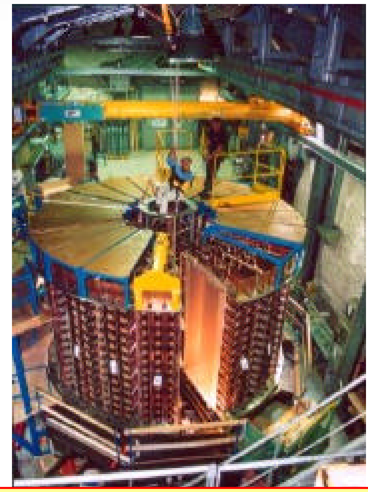
Cosmological disfavoured Region

Current generation ββ experiments

- Source = target
- Source ? target







CUORICINO/CUORE

GERDA

NEMO/SUPERNEMO

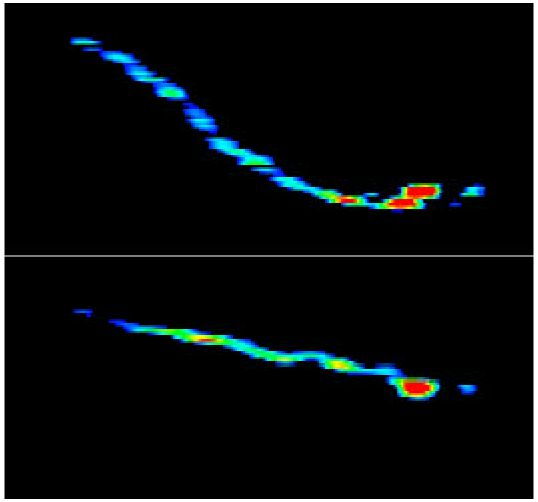
•Good E resolution
•Good scaling-up
•BUT, modest background discri.
→strong requirements on radiopurity and shielding

•Event topology information
•BUT, moderate energy resolution and difficult scaling up

Gas Xe TPCs for ββ?

Are they competitive in the race towards ton or multiton scale exp's?

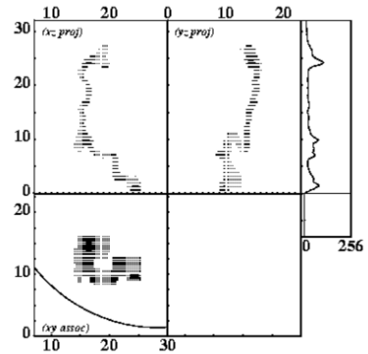
- Gas TPCs offer in principle the advantages of both previous approaches: topological signature & scaling-up
- But also:
  - Xe easy to enrich
  - No long lived isotope to activate
  - Very weak 2νββ mode (still to be measured!)
  - Single homogeneus medium (no surfaces/boundaries)
  - Ba++ taging, as proposed by EXO (R&D needed)



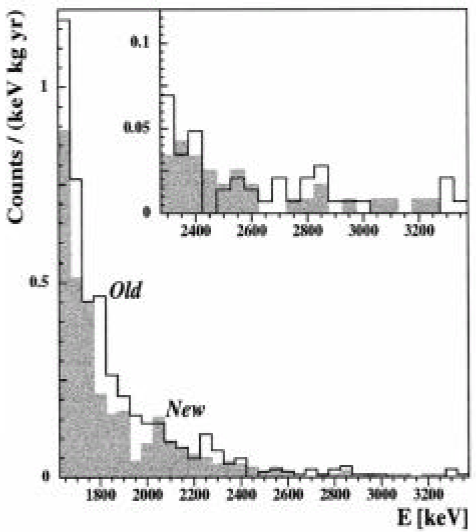
870 keV e- in the MUNU TPC

Gas Xe TPCs for ββ?

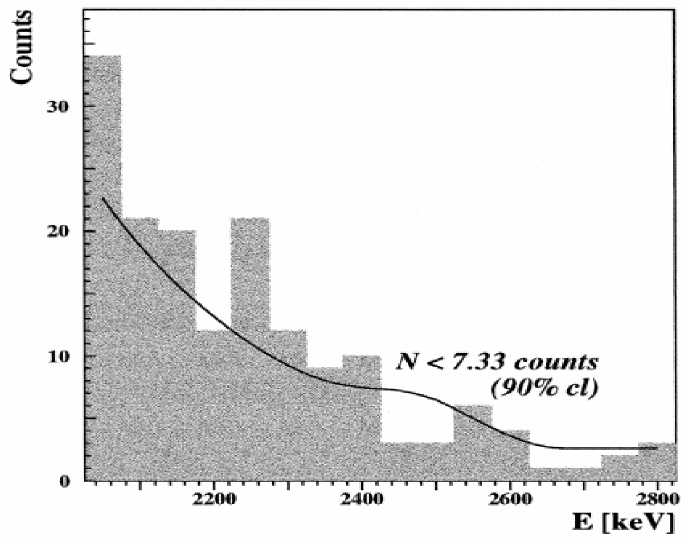
- Not presently comtemplated in present projects (EXO: liquid TPC)
  Why?:
  - Energy resolution: Fano factor, gain stability
  - homogeneity, equalization, ballistic deficit,...
  - Complex detectors. Specially for large V needed.



Typical double beta decay candidate. The x-z and y-z projections are measured, as well as the anode signal to the right. The x-y projection is reconstructed. Lengths are in cm.

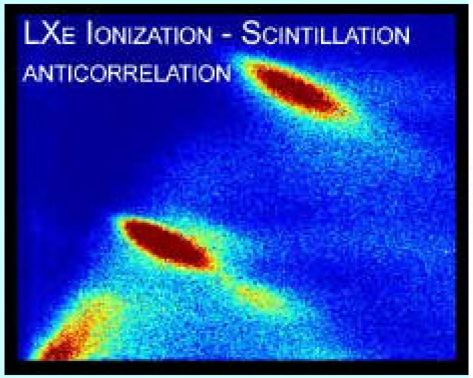


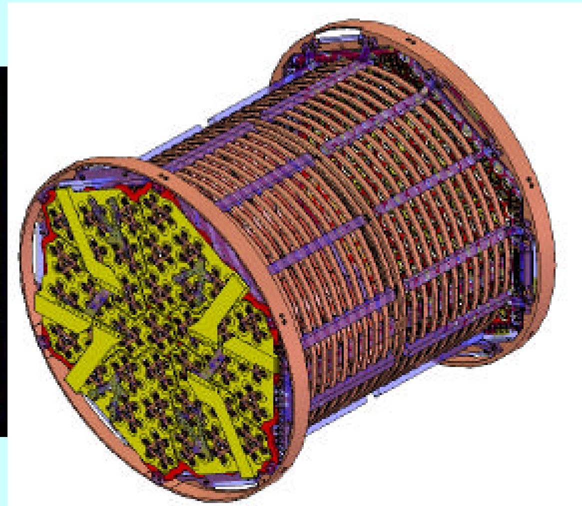
- Gothard TPC in the 90´s
  PLB 434 (98) 407
- **180 l** @ **5 bar** = **3.3 kg** Xe^{136}
- **6.6% FWHM** E resolution at Qββ
- **96.5%** topological rejection of single e-
- Background limited (environ. gammas)
- $T_{1/2}^{0\nu}$ > 4.4 x 10^{23} years



Liquid vs. Gas

- EXO experiment:
  - Liquid Xe TPC
  - Energy measurement by ionization + scintillation
  - No single e- identification → poor background rejection
  - R&D for Ba ion tagging in progress (136Xe → 136Ba++ + 2e-)
  - EXO200 being built in WIPP, without Ba tagging

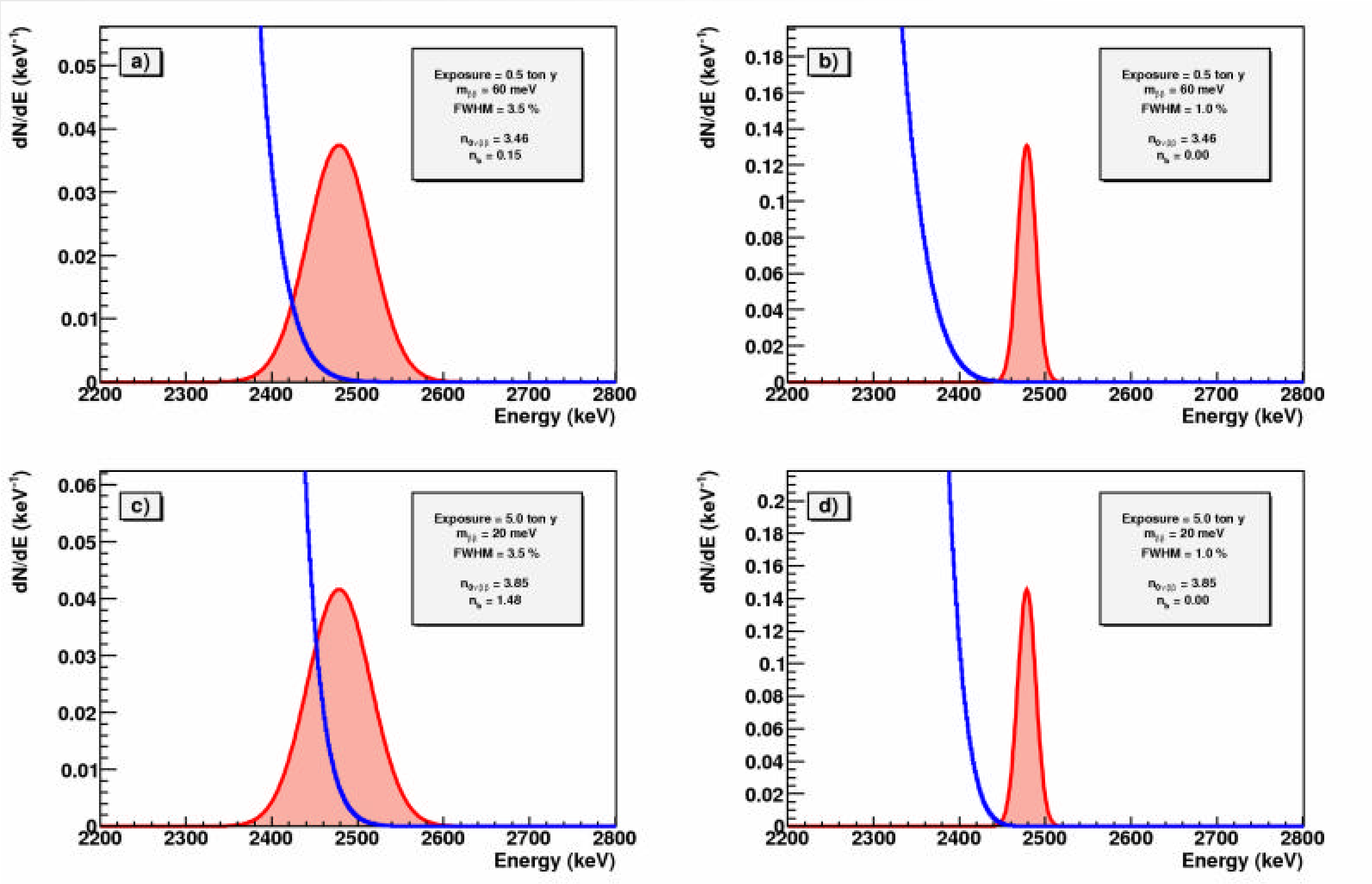




Liquid Xe		Gas Xe
✓	Scalability	✓
✓	Compact	✗
Cryogenics	Complexity	High P
✗	Topology	✓
✓	E resolution	✓

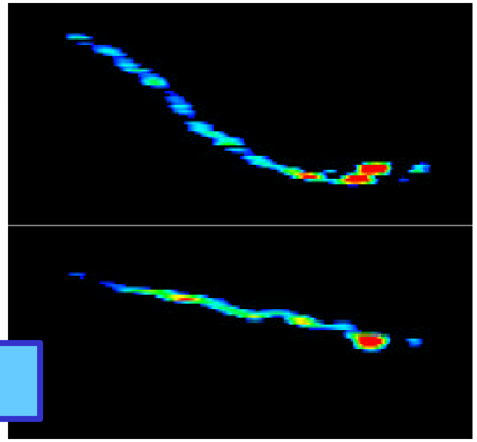
+ And Ba tagging can be done better in gas

The role of E resolution @ the ton scale

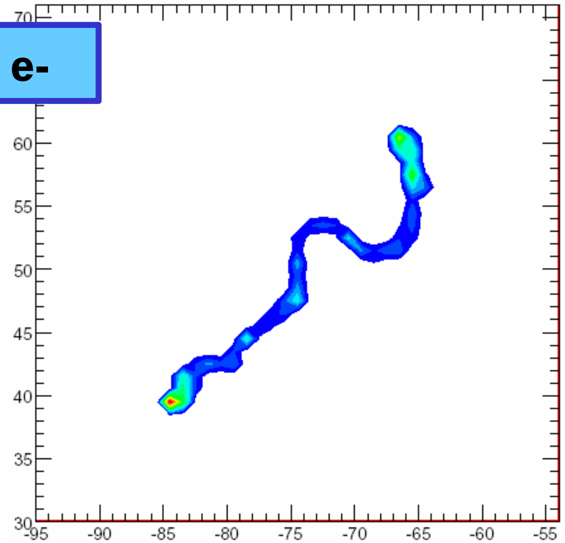


The topological signature

- A gas TPC have access to the “image” of the event.
- 1 e$^-$ events and 2 e$^-$ events have different topologies. This can be used to reject gamma background (1 e$^-$)
- Gothard demostrated that this can be done. They achieved a 96.5% efficiency in rejecting single e$^-$ events. We may do better.
- **A gas TPC would have an extra handle to reduce background by a factor of at least 10^2 (most probably more?).**



1 e-



2 e-

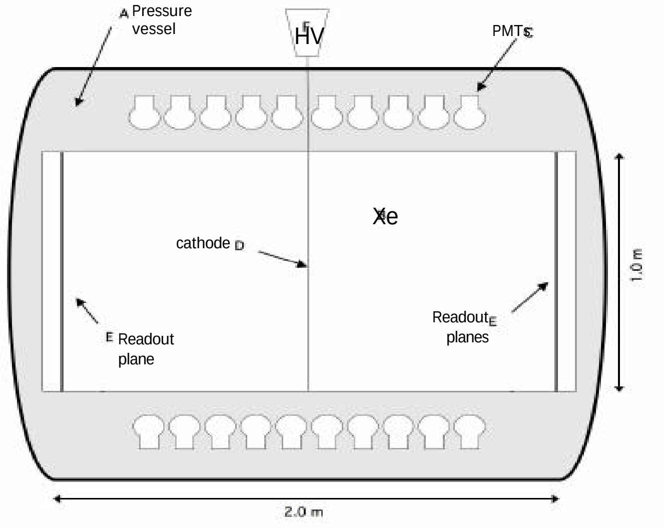
A new initiative: NEXT

- We consider...

  A **N**eutrino **E**xperiment with a gas **X**e **T**PC may:

1. Have all advantages of a Xe monolithic detector (like EXO)
2. Outdo Liquid Xe by getting topological info
3. Override tradicional limitation of gas TPCs (Gothard) by applying the latest developments on TPC readouts

- Competitive option for the next (ton scale) generation of experiments



Initiative pushed by spanish groups *(Barcelona, Ciemat, Santiago, Valencia, Zaragoza)* for 100 kg detector construction in Canfranc (+ eventually “jump” to 1 ton). Interest and support by other groups. Especially *Saclay (Y. Giomataris), Berkeley (D. Nygren), Livermore (A. Bernstein), Canadian groups (R&D)*, ...

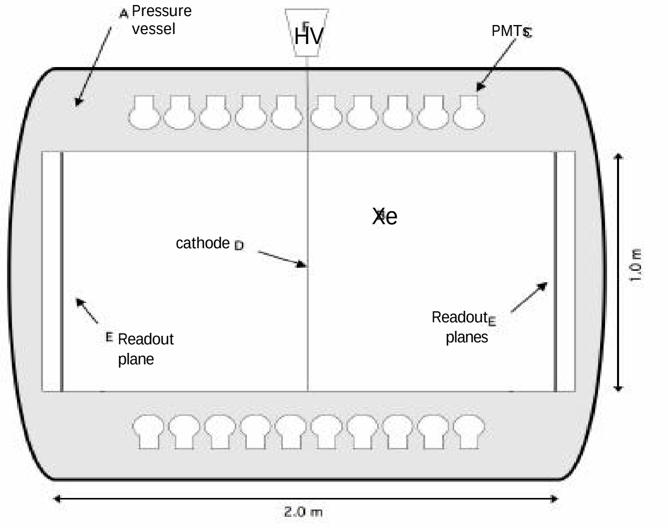
A new initiative: NEXT

- We propose...

1. To define all technical aspects of a 100 kg Xe gas TPC.
   - By doing some R&D, and building a demostrator of 10 kg, **NEXT10**, to operate underground in a timescale of 2-3 years.

2. **To build a 100 kg detector, NEXT100,** already with physics interest. (in a timescale of 5 years)

3. To assess the option of scaling up to 1 ton, NEXT1000, and eventually build it.



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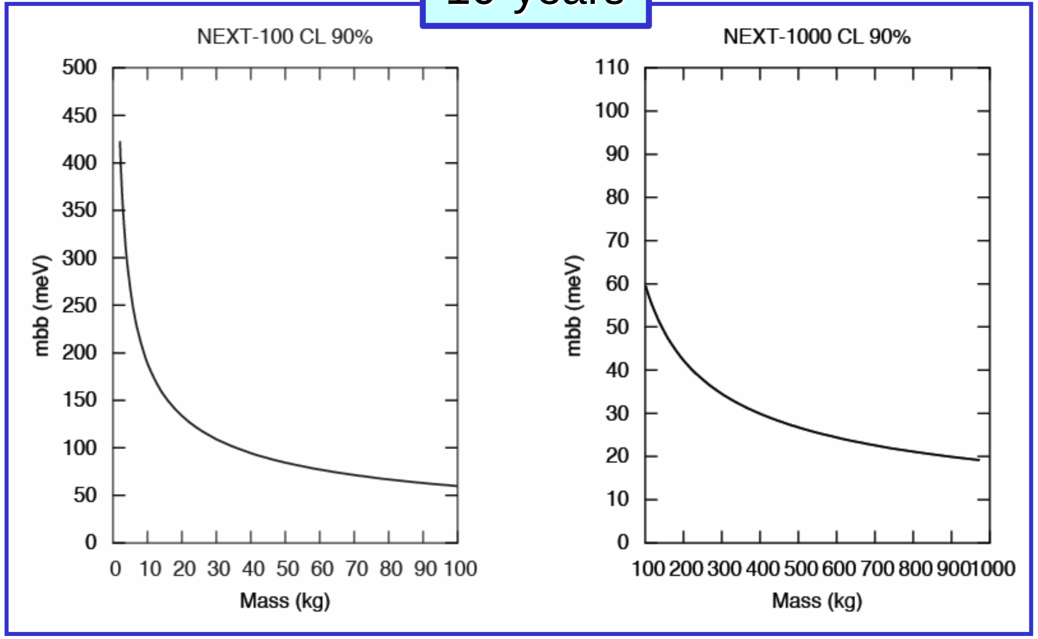
NEXT expected sensitivity

- A sensitivity down to 60 eV (for NEXT-100) and 20 eV (for NEXT-1000) is a priori reachable:

Of course, IF

- Low enough resolution is achieved (~1% FWHM)
- Low enough backgroung after topology cuts (i.e. not background limited)
- We believe this is possible after last developments on TPC readouts
- A dedicated R&D is needed now to demonstrate these issues (as well as other technical ones)
- Very encouraging first steps

10 years



Expresion of Interest to Canfranc

Expression of Interest to the Canfranc Scientific Committee

NEXT: A proposed Neutrino Experiment with a Xenon TPC

F. Nova, F. Grañena, T. Lux, F. Sánchez,
Institut de Física d'Altes Energies, IFAE, Barcelona, Spain

D. Nygren
Lawrence Berkeley Laboratory, Berkeley, USA

I. Giomataris, E. Ferrer-Ribas
CEA/Saclay, Paris, France

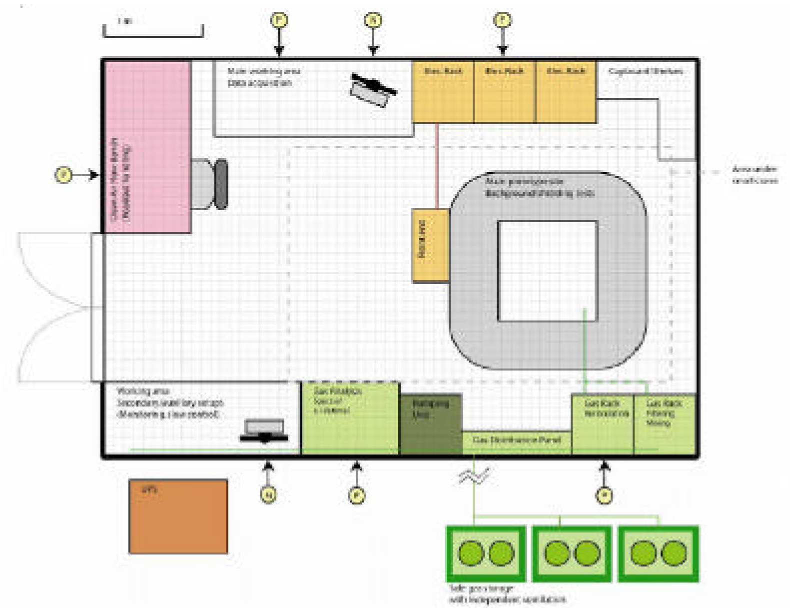
M. Ball, J. Catala, A. Cervera, J. Díaz, A. Gil, J. J. Gómez-Cadenas,
C. Hansen, J. Martín-Albo, F. Monrabal, L. Monfregola,
J. Muñoz-Vidal, P. Novella, M. Sorel, N. Yahlali
Instituto de Física Corpuscular, IFIC, CSIC - U. Valencia, Spain

R. Bravo, R. Palma, J. L. Pérez, R. Ripoll
U. Politécnica de Valencia, Spain

J. M. Carmona, S. Cebrián, Th. Dafni, J. Galn, H. Gómez,
F. J. Iguaz, I. G. Irastorza, G. Luzón, J. Morales,
A. Rodríguez, J. Ruz, A. Tomás, J. A. Villar
U. Zaragoza, Spain

EoI approved by LSC scientific committee on April08

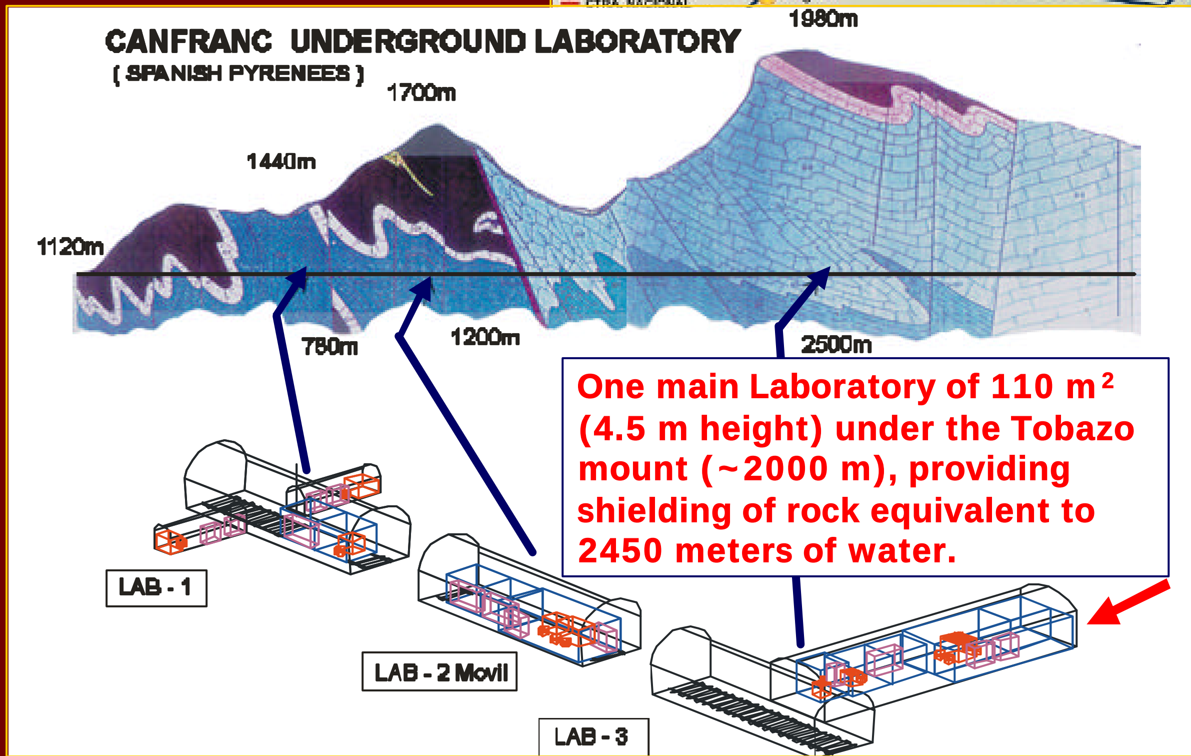
- Footprint of 30 m2 area requested to LSC to perform R&D and operate the prototype NEXT10



- 100 m2 in the hall A is anticipated for the construction of the NEXT100 detector

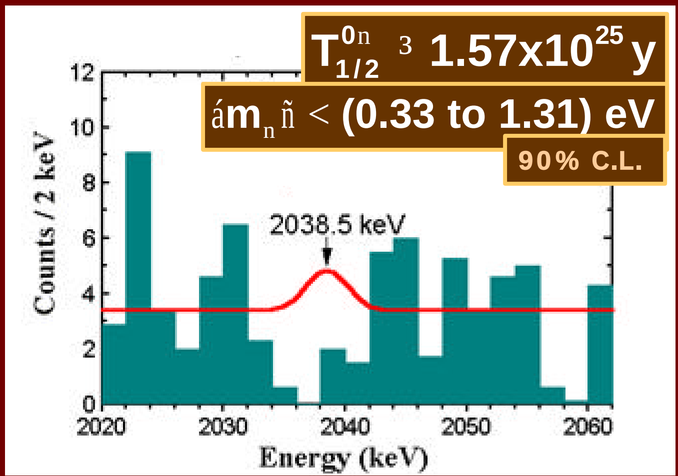
Canfranc Underground Lab
Laboratorio Subterráneo de Canfranc (LSC)

- Old laboratory existing since 1985.
- Created and operated by Zaragoza group.
- Several sites along unused railway tunnel.
- Largest one of 110 m2
- 2450 m.w.e.



Canfranc Underground Lab

- Important tradition of double beta decay searches.
- IGEX experiment (1991-2000).
- Still one of the best limits
- Crystals currently in GERDA setup.

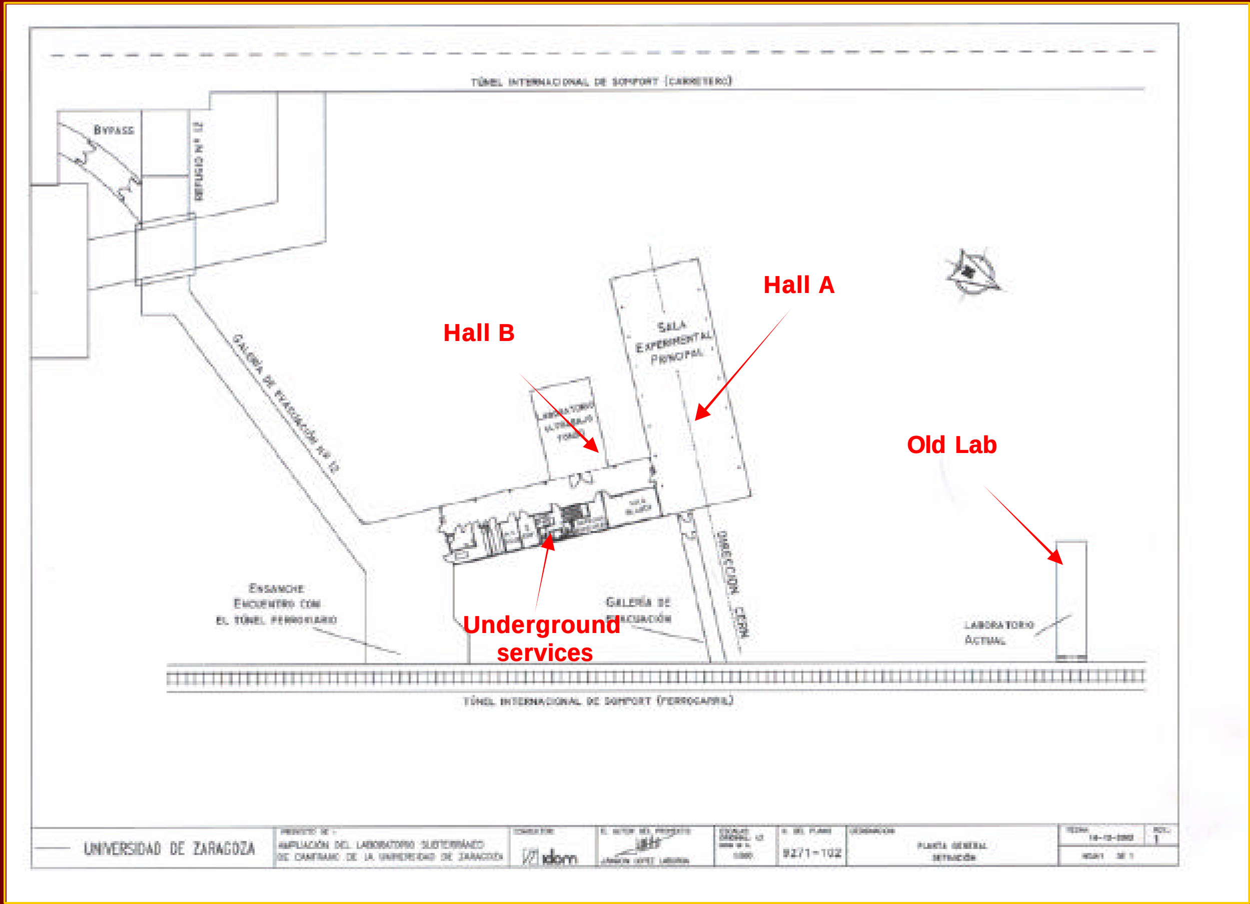


NEW Canfranc Laboratory

- 2006: new laboratory constructed expanding x10 old lab's underground space
- Institutional structure created to manage new laboratory (Zaragoza University, Regional Government, Science Ministry)
- International dimension of the laboratory stressed:
  - International Scientific committee created
  - Open call for proposals
- Director appointed in 2007 (Sandro Bettini)
- Zaragoza is the host group of the Laboratory

NEW Canfranc Laboratory

- The Main Hall (Hall A) has 40 x 15 x 12 m^3 and it is oriented towards CERN
- A Hall B of 150 m^2 of surface and 8 m height constitutes the ultralow background Lab. for dark matter studies and other needs.
- In the access corridor, one has a clean room, offices and workshops for more than 1000 m^2.



NEW Canfranc Laboratory

Access from road tunnel

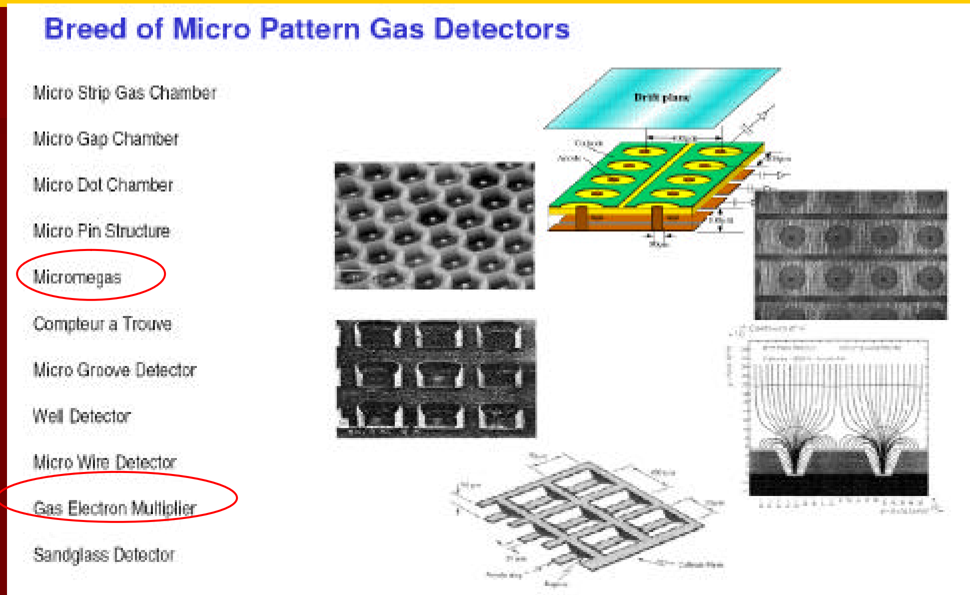
Gallery

Hall A

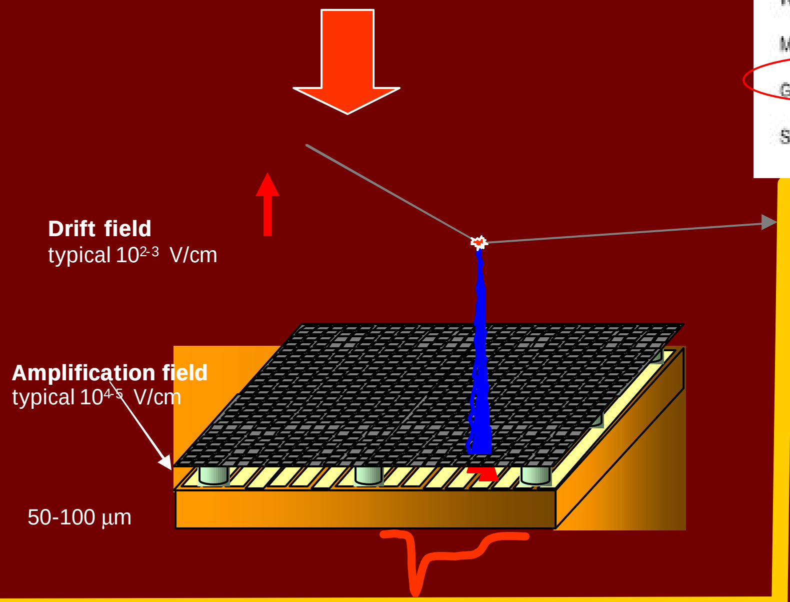
Hall B

Novel concepts on TPC readouts

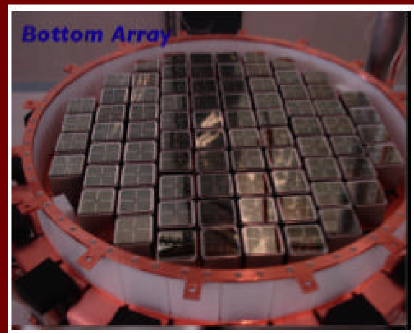
Micropattern detectors: seminal idea is atributed to Oed (88)



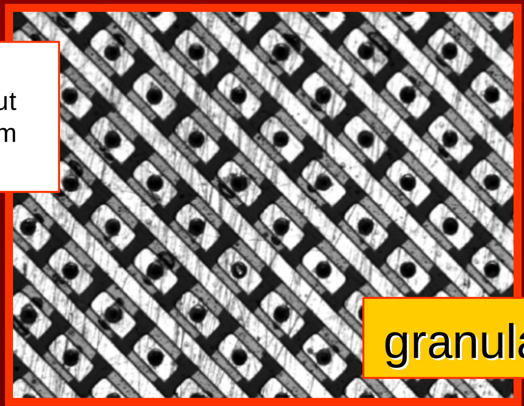
e.g. MICROMEGAS
Giomataris, Charpak (96)



Gas Proportional Scintillation Counter (XENON dark matter exp.)

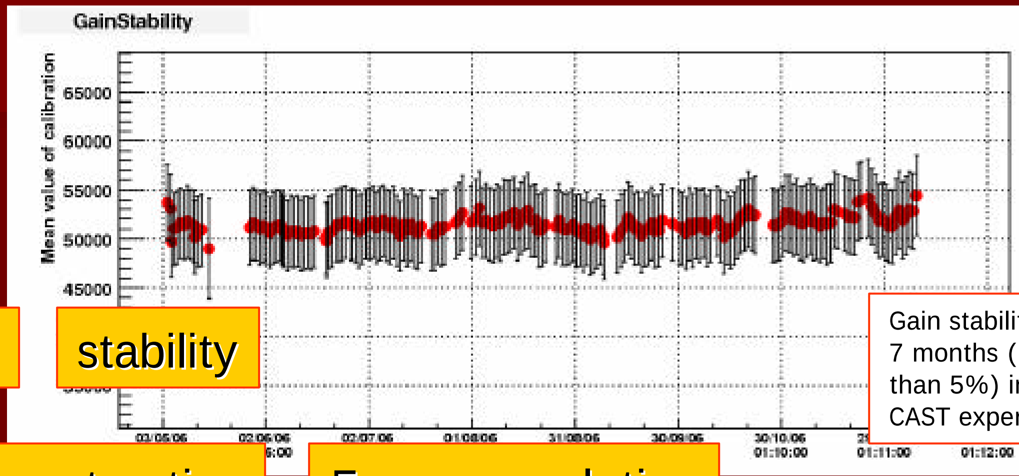


Micromegas: latest developments



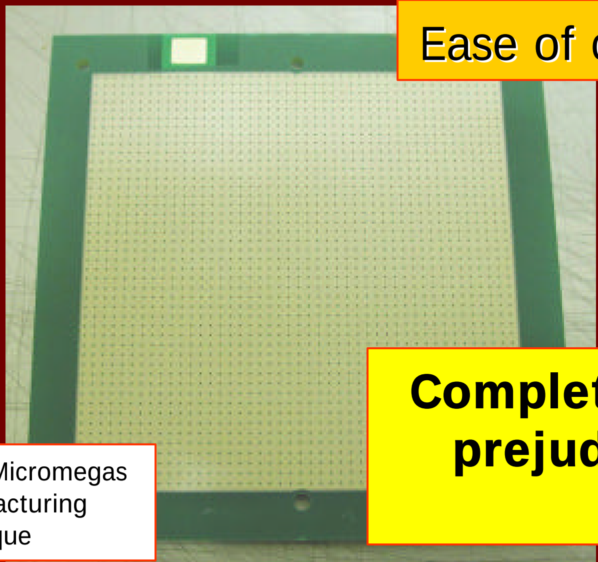
CAST readout 300 µm pitch

granularity



stability

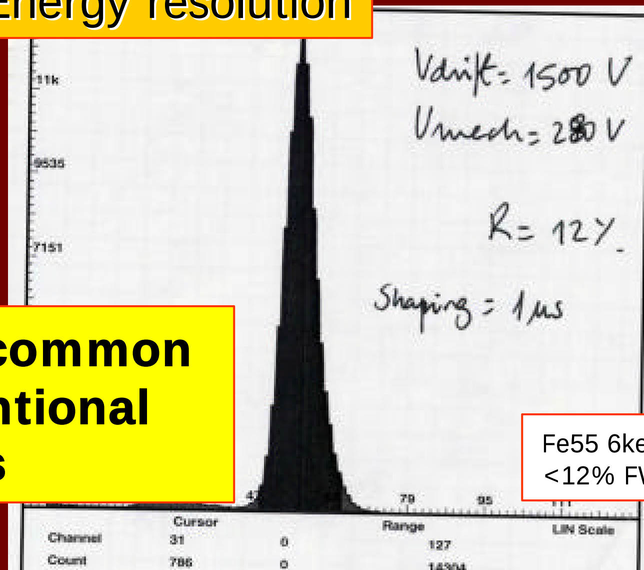
Gain stability over 7 months (less than 5%) in the CAST experiment



Ease of construction

BULK Micromegas manufacturing technique

Energy resolution



Fe55 6keV source <12% FWHM

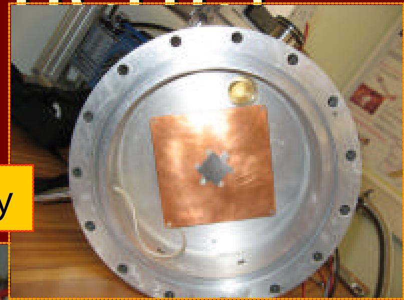
Completely overrides common prejudices on conventional multiwire TPCs

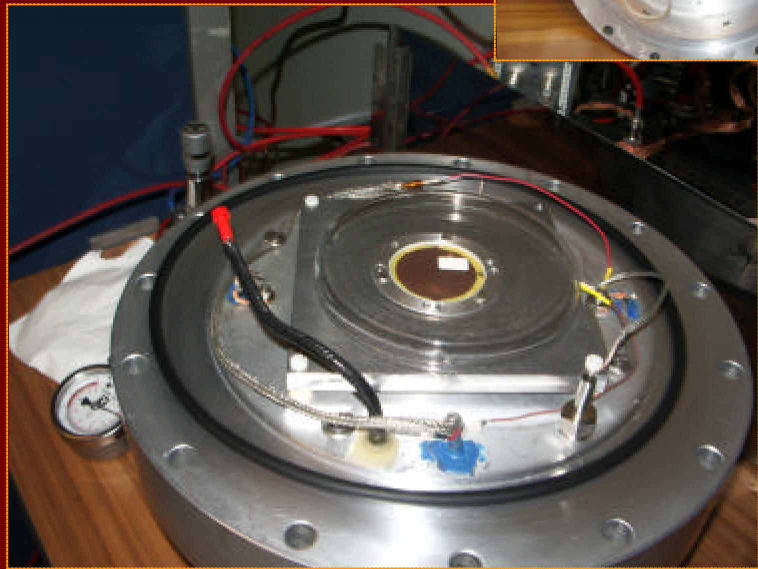
Energy resolution measurements

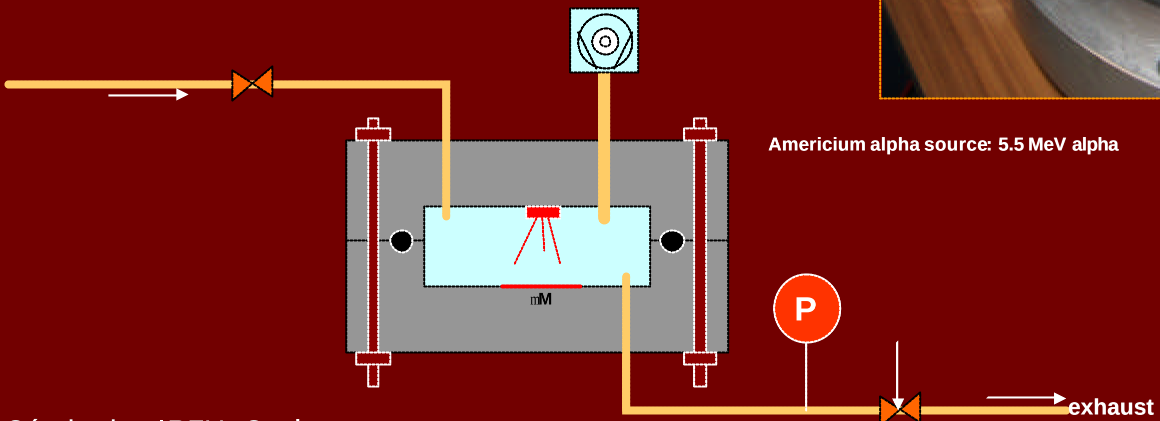
- Measurement of E resolution at high energies:
  - High pressure Ar+Isob small setup, read by new generation Micromegas readout (*microbulk*) non-pixelized anode

- Mixtures testes: Ar + Iso 2%, Ar + Iso 5%
- Pressures tested: from 1 to 5 bar

HELLAZ setup at Saclay





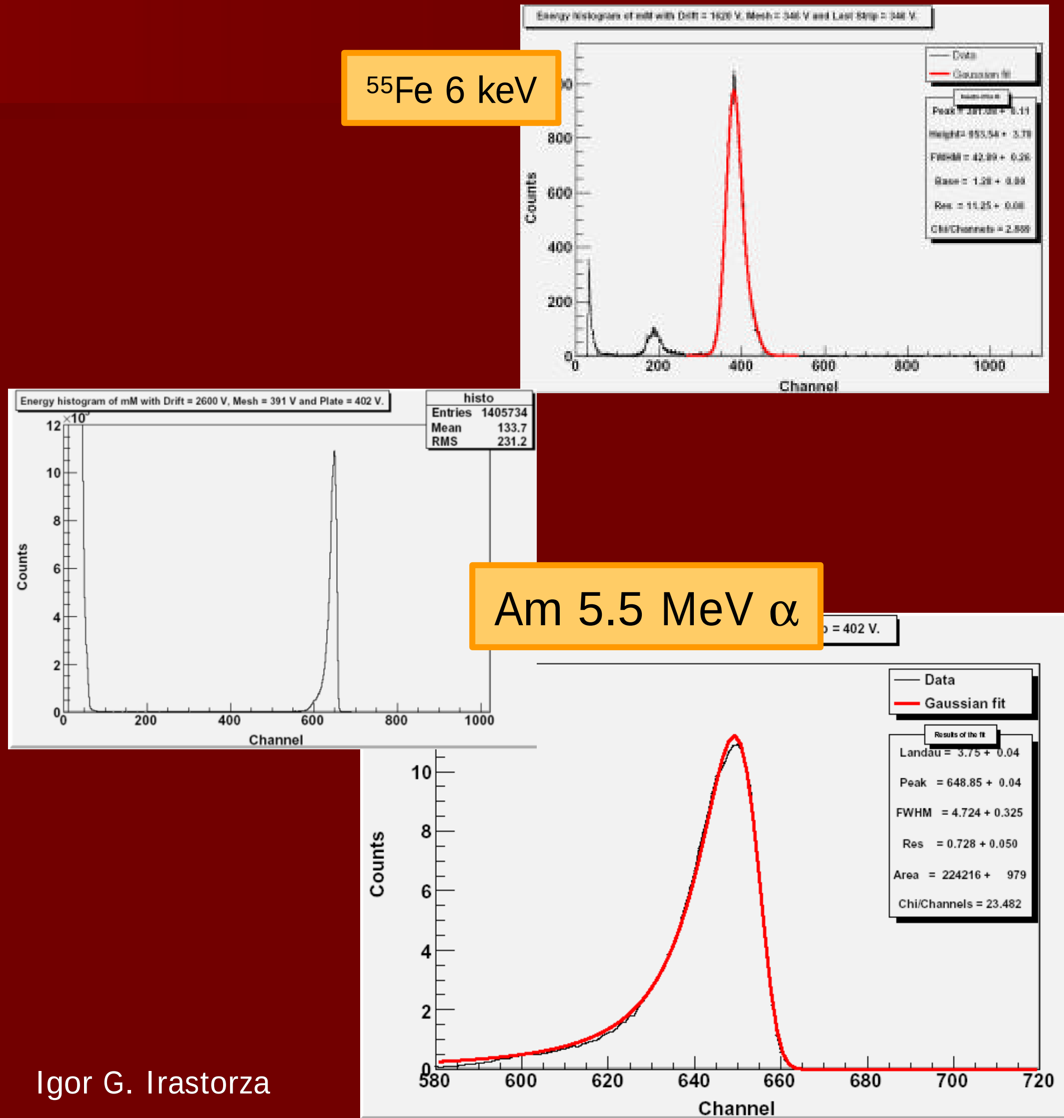


Energy resolution measurements

- Obtained resolutions in Ar/Isob :

  1.5 – 2 % (FWHM) in Ar/Isob

  in a wide range of parameters (mesh and drift V, P, etc...)
- Landau deconvolution analysis indicate possible intrinsic Micromegas energy resolution of 0.7 % FWHM.



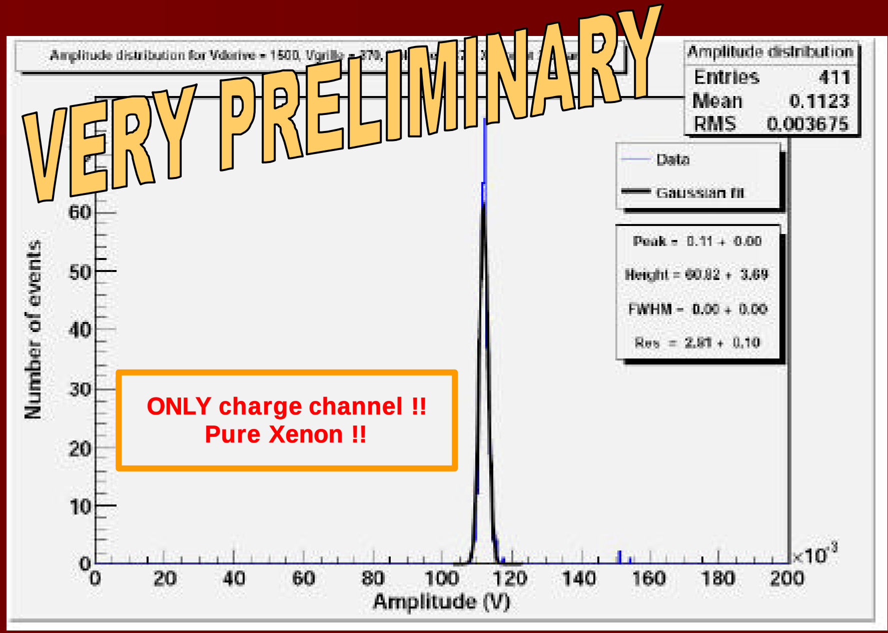
Energy resolution in Xe

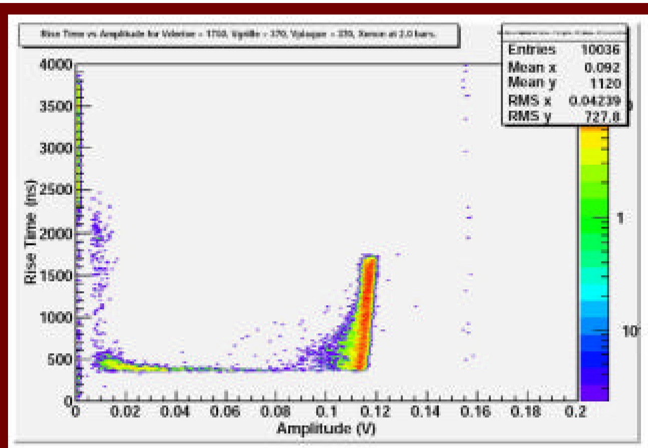
- **Preliminary**: resolution measured in pure Xenon:

  > • at 2 bars: 2.8 % FWHM
  > • at 4 bars: 4.5 % FWHM

- Gains well above 100
- Further improvements expected from:
  - Better gas system quality
  - Quencher
  - Addition of Light readout
  - Micromegas geometry

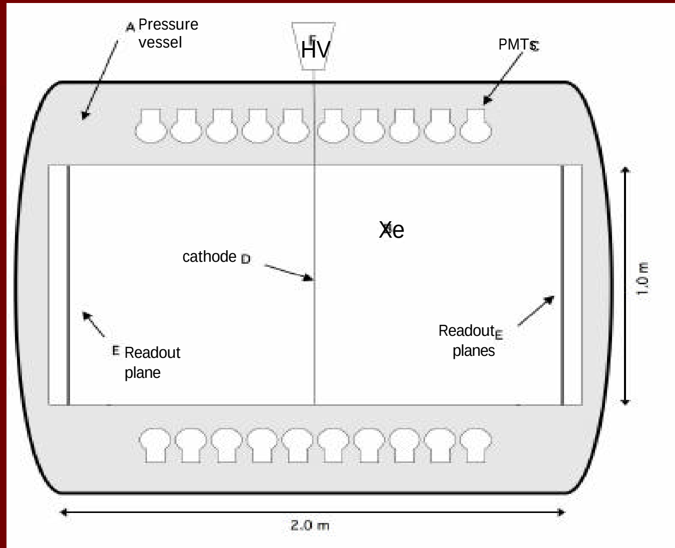
- BUT, already enough for NEXT100 requirements on E resolution
- Lessons on gas system





NEXT R&D

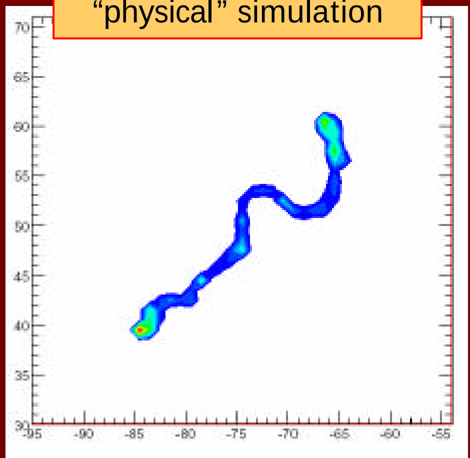
- Energy resolution and gas mixture
  - Demonstrate in Xe
  - Role of quencher. Compromise with scintillation signal.
- T0 measurement (UV light)
- Software: simulations
  - Best use of topology information
  - Backgrounds
- Mechanics (high P issues)
- Background
  - Needed radiopurity measurement program
  - Needed shielding? Active/pasive? Selfshielding?
- Readout type and design
  - Which is best for NEXT?
  - Implications to radiopurity



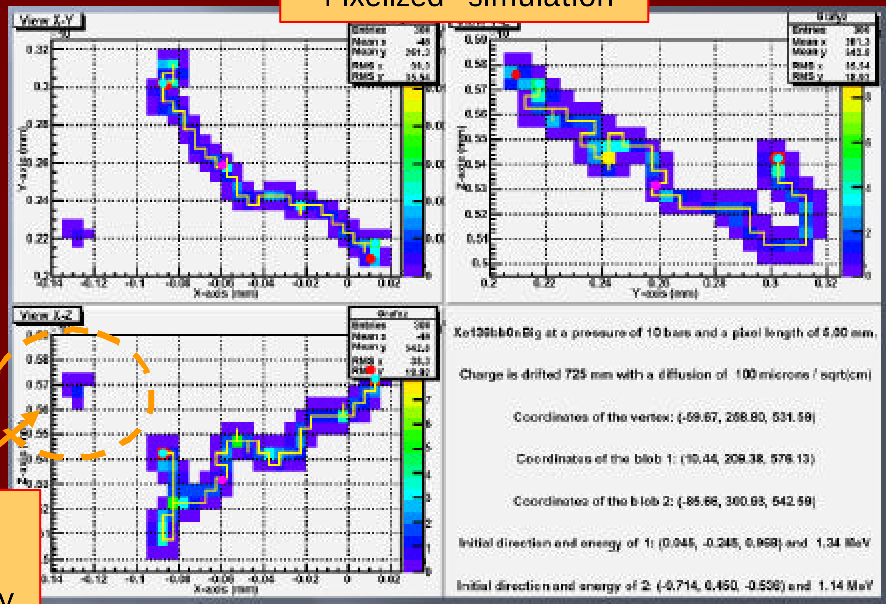
NEXT signal

- Very characteristic topology of ββ event in a gas TPC: 1 single twisted track of about 20 cms (if P=10 atms) with blobs at each end.
- Bremstrahlung (50% of the times) can produce disconnected tracks/clusters. But most of them are very low energy → very close to the main track.

"physical" simulation



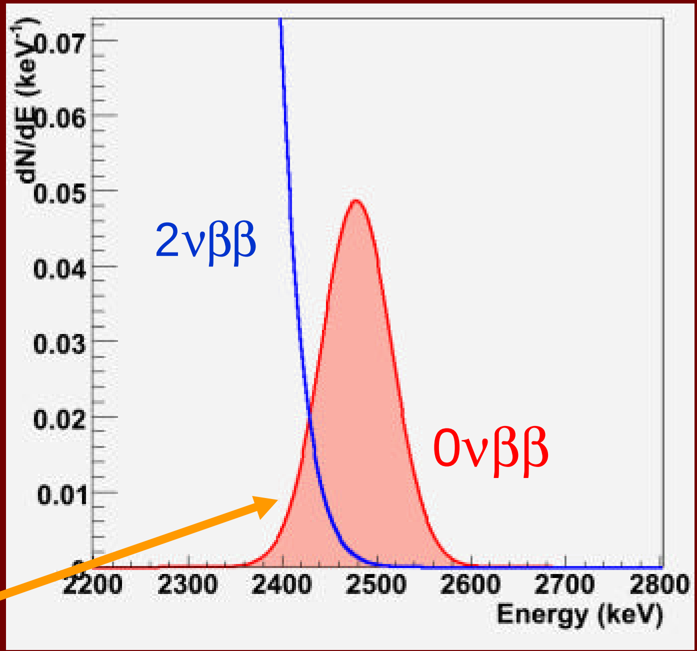
"Pixelized" simulation



Disconnected clusters (few cms away) of substantial energy (>10%) produced only rarely (few % of cases)

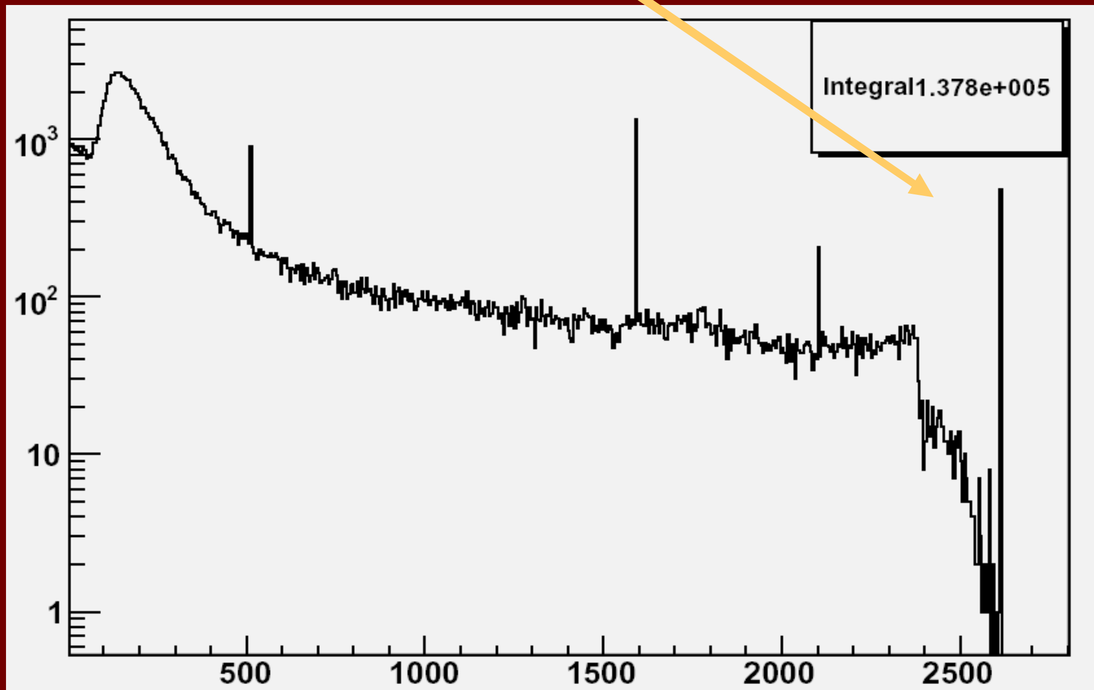
NEXT background

- Goal background for NEXT100 is <10^{-3} c/keV/kg/year
  - $2\nu\beta\beta$: Negligible if good energy resolution (< 5% FWHM)
  - Environmental (gamma) backgrounds:
    - External: environmental radioactivity (can be shielded)
    - Intrinsic: radioactivity of detector components and inner shielding
  - Energy deposit must be in the E window determined by detector resolution. Only sources above 2480 keV are of concern



NEXT backgrounds

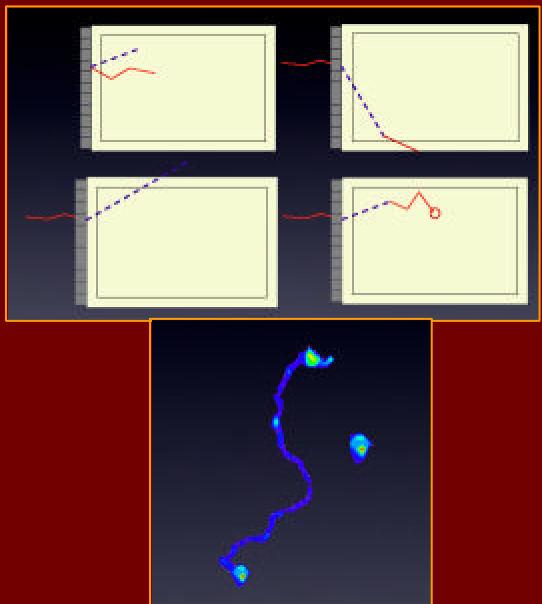
- ^{208}Tl is the main gamma line of natural radioactivity above $Q_{\beta\beta}$.
- Illustrative ^{208}Tl raw spectrum (no cuts).
- Xe $Q_{\beta\beta}$ falls between Compton edge and photopeak.

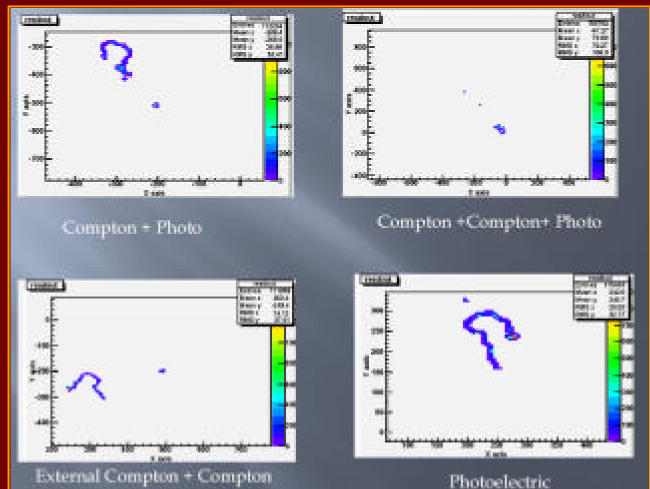


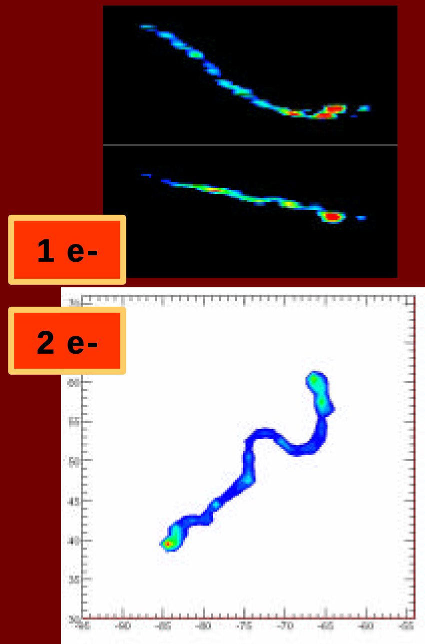
Discrimination by topology

- Only a fraction of gammas (few %) produce single track
- Most of them linked with edge effects (photoelectic with radiative losses that escape the chamber). Fiducial cut.
- Single track topology (two blobs versus one blob). Extra factor >100 discrimination.

Overall discrimination factors can reach up to 10^6 - 10^7 with respect to raw (no topology) background levels







NEXT background budget

- ***Work under progress*** to quantify with precision all possible contributions.

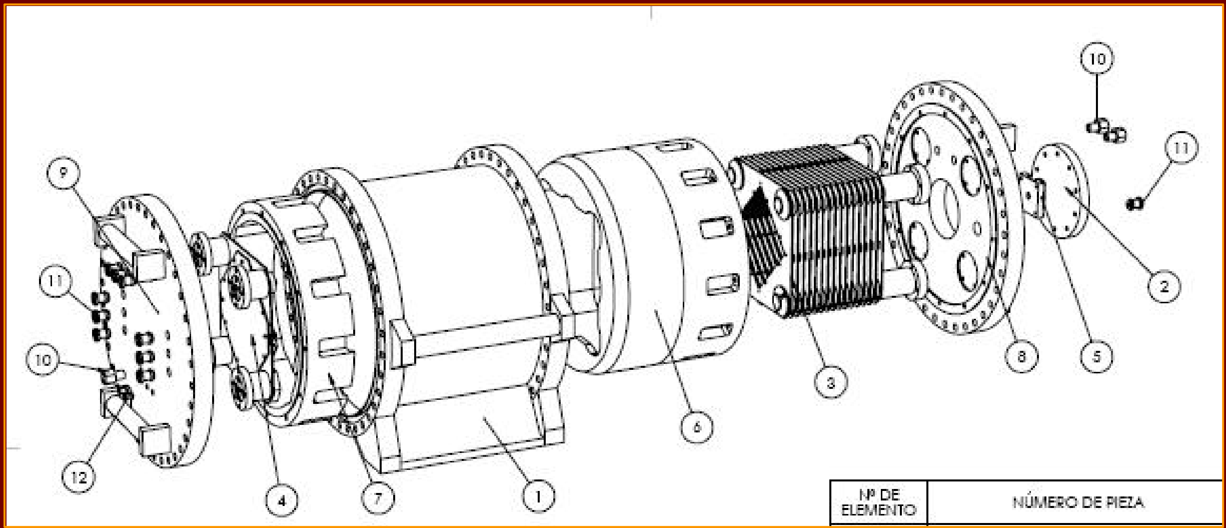
	Origin	gamma	Beta
Tl208	Laboratory, detector materials, shielding	2614 keV (99 %)	
Bi214		~~1764 keV (16%)~~ +	3272 keV (18%) ~~1507 keV (16%)~~
Co60	Cosmogenic activation	~~1173.24 keV + 1332.5 keV (100%)~~	
Xe137	Neutron capture		3717 keV (30%) 4173 (67.3%)
muons	shielding	Energetic ?	

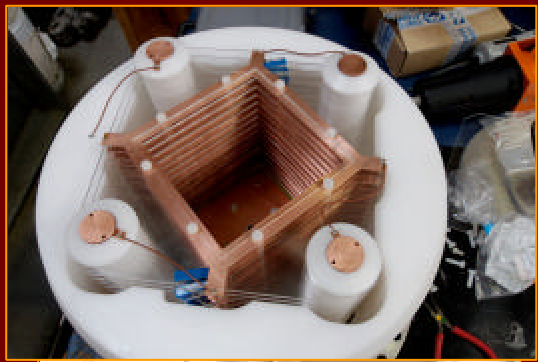
- External → shielded
- Internal → radiopurity + topological cuts
- Negligible
- Negligible
- Negligible?

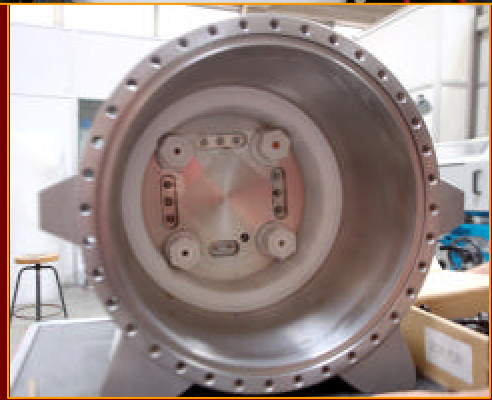
- Very preliminary results indicate that background goal may be reached with moderate shielding and selected efforts on radiopurity of detectors components

NEXT-0 : R&D, prototyping

- Several 0-generation prototypes under construction to perform R&D (test different options for light/charge readout, trigger, E resolution, electronics, etc...)







Design and pictures of NEXT0 @ IFAE

NEXT-0 : R&D, prototyping

- 3 independent test benches being set up with gas systems for prototype testing and R&D.

Gas detector Lab at Zaragoza University being refurbished

Gas system and test bench at IFIC

"CUP" CONSOLIDER

- CONSOLIDER: Program of the Spanish Ministry of Science and Innovation, to fund large specific projects of international scientific excellence.
- CUP (*Canfranc Underground Physics*) proposal, including NEXT as main activity, approved recently and funded with **5 million euros**.
- Project **period**: 5 years
- Main **milestone**: the contruction of NEXT100 at Canfranc.
- Contract arrangements under progress, project officially to start soon.

- NEXT Spanish groups signing CUP:
  - CIEMAT, Madrid.
  - **IFAE Barcelona**
  - **IFIC Valencia**
  - U. Politecnica Valencia.
  - U. Santiago Compostela.
  - **U. Zaragoza**
- External collaborators from
  - CEA/Saclay
  - LBL Berkeley
  - LLNL Livermore