NEXT: a Neutrino Experiment with Xenon gas TPC

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on behalf of the NEXT collaboration

Frontiers detectors for frontiers Physics
La Biodola, Isola d'Elba, 24-30 May 2009

Who we are ?

We are several spanish institutions :

- IFIC CSIC-University of Valencia
- Universidad politecnica Valencia
- IFAE - Barcelona
- University of Zaragoza
- CIEMAT - Madrid
- Universidad Santiago de Compostela

and three foreign institutions :

- Universidade de Coimbra, Portugal
- IRFU - Saclay. France
- LBNL, Berkeley USA

Others may join …..

NEXT is a new double beta experiment

funded and approved in july 2008 for operation in the new Canfranc underground facility

Our leading idea

The leading contemporary experiments in WIMPs and ββ0ν searches use Time Projection Chambers (TPC) filled with very large masses of liquid xenon (LXe) :

- **XENON → talk of K.L. Giboni**
- **EXO-200 → talk of Razvan Gorvec**

The knowledge gathered during the last decade on the response of xenon in gas and liquid phases to the energy deposition, have shown that an ultra-high energy resolution is possible with xenon gas at density < 0.55 g/cm^3. The gas phase offers in addition the possibility to record the 3D track topology of the particles which gives a crucial handle for background rejection.

A High Pressure xenon gas TPC could offer the possibility of an optimized and robust ββ0ν experiment.

The NEXT project

Our goal : **build and operate a TPC filled with 100 kg HPGXe enriched with ^{136}Xe isotope, to measure its $\beta\beta0\nu$ decay. This TPC so-called NEXT-100 will be hosted in the new underground facility of Canfranc (LSC) in the spanish Pyrenees.**

Institutional supports :

✓ NEXT has been approved by the Scientific Committee of the LSC (2008)

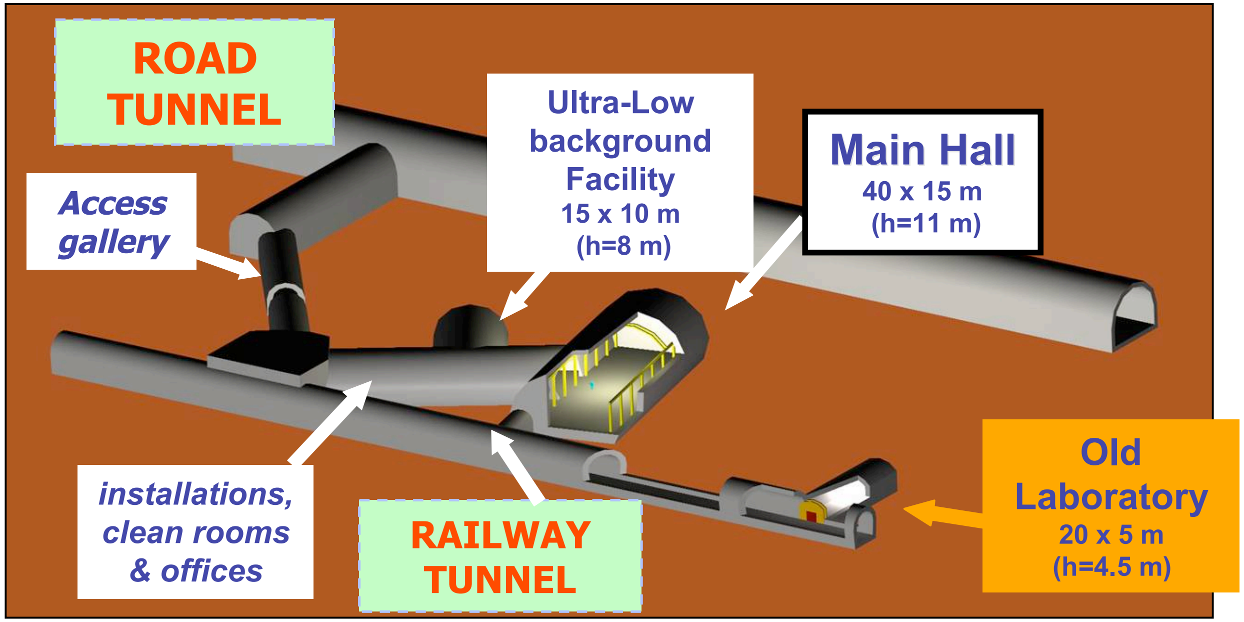
✓ NEXT has been partially funded by the Ministry of Science and Innovation (MICINN) with the approval of the project CUP (Canfranc Underground Science) and the funding program CONSOLIDER-INGENIO in calendar-year 2008.

Time schedules :

✓ 2 years from now for the 1:10 prototype NEXT-10 to prove feasibility

✓ 5 years for NEXT-100 with full operation in the LSC.

The experiment site : the new Canfranc underground Laboratory (LSC)



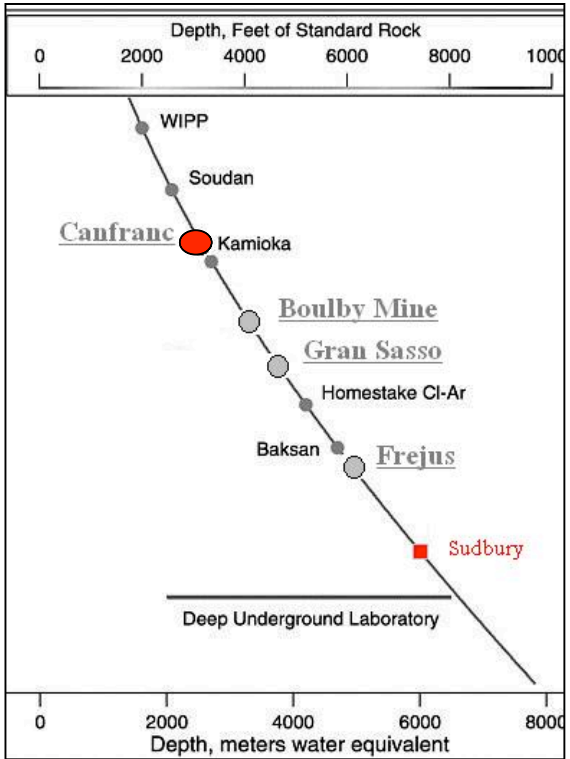
Depth: 2400 m.w.e.

Surface: 1000 m^2

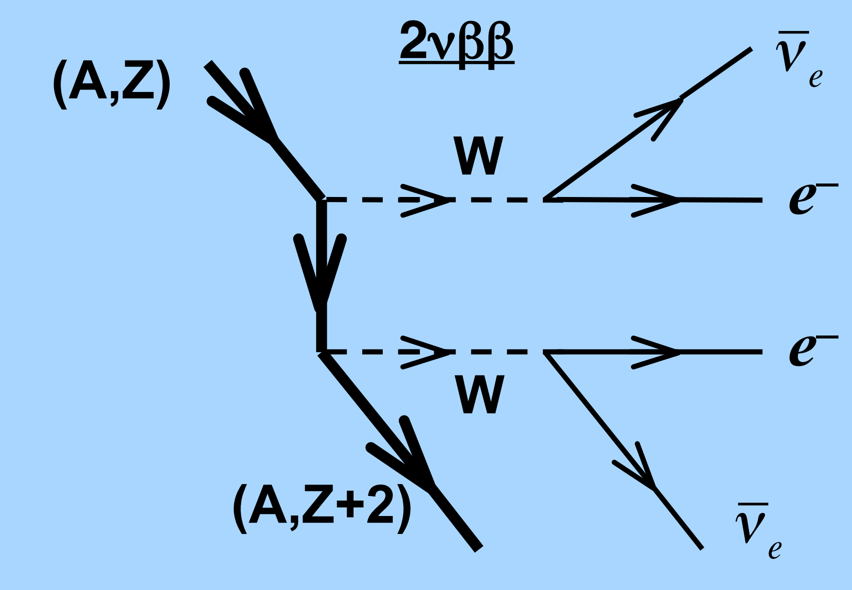
Muon flux $2.4\ 10^{-3}\ \mu.m^{-2}.s^{-1}$

Neutrons: $2\ 10^{-2}\ n.m^{-2}.s^{-1}$

Radon: 50 - 80 Bq/m^3



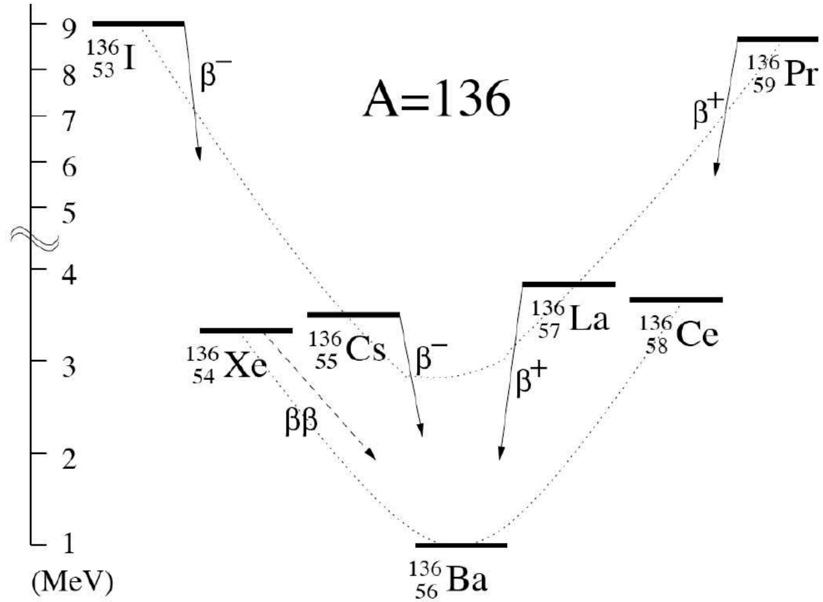
The double beta decay : ββ2ν



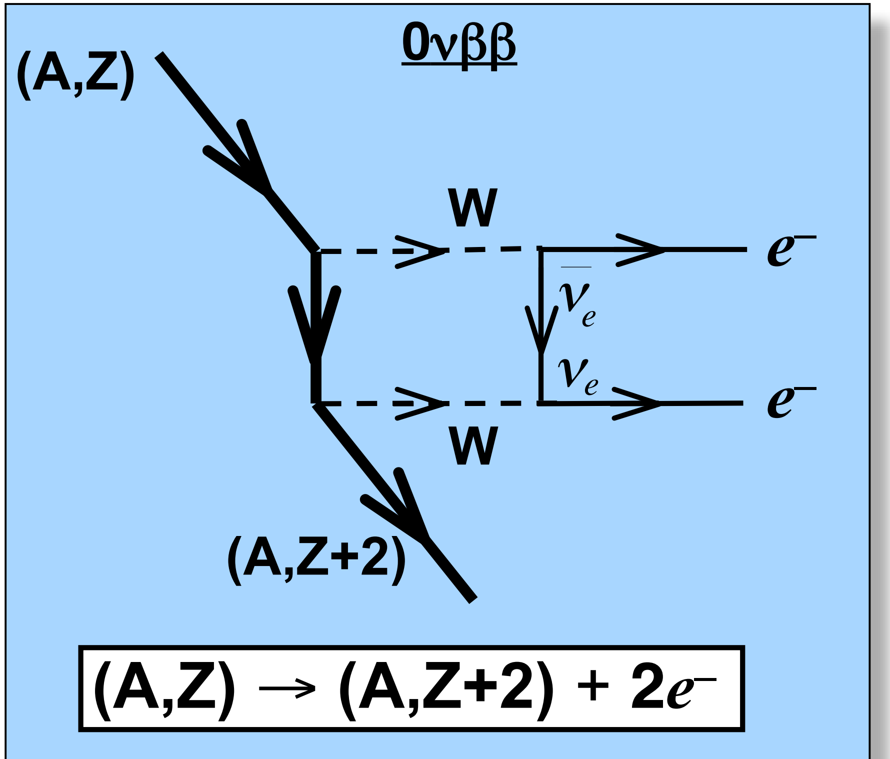
$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$$

- Not observed yet for the ^{136}Xe

- Double weak interaction ⇒ rare process
- only possible to observe if β decay forbidden.
- allowed in the Standard Model
- experimentally confirmed for several isotopes



The double beta decay : ββ0ν



- Forbidden in the SM because of Lepton number conservation
- Only possible if the neutrino is a Majorana particle

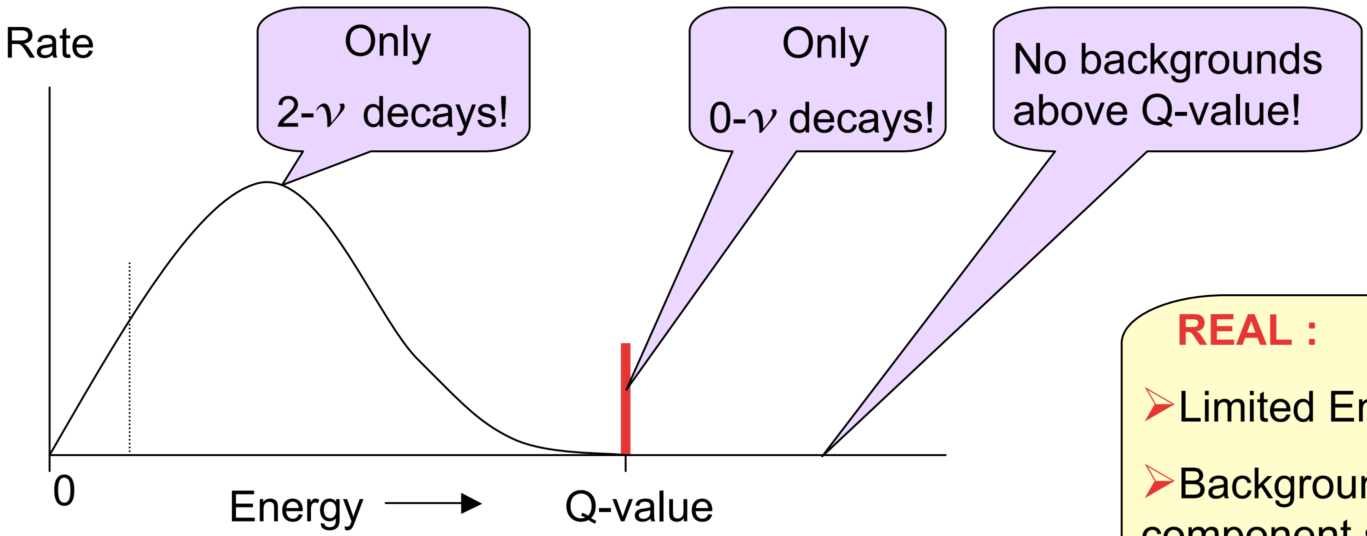
  ⇒ **neutrino = anti-neutrino**

- Lepton number violation
- Not observed/confirmed until now

The observation of a positive signal would reveal the nature of the neutrino and set an absolute scale to it mass.

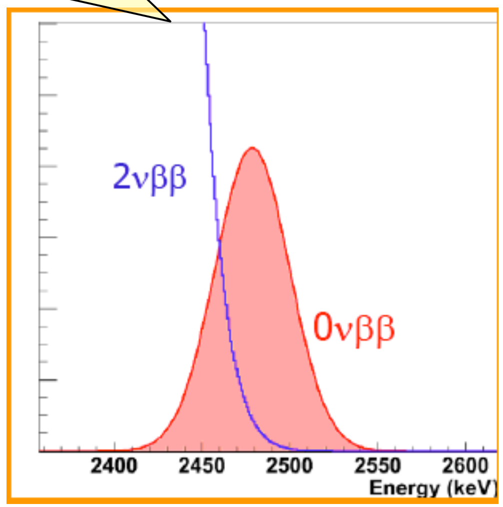
The experimental evidence should be robust !!

A robust evidence



REAL :

- Limited Energy resolution
- Background in detector component sand surroundings



IDEAL :

- Optimal separation of ββ-2ν and ββ-0ν populations
- No background

Background

Sensitivity to active mass M strongly depends on energy resolution and background level :

✓ $m_{\beta\beta} \sim \{1/MT\}^{1/2}$ — ideal

✓ $m_{\beta\beta} \sim \{(B\delta E)/MT\}^{1/4}$ — real

B = number of background events/unit energy

δE = energy resolution of the detector system

T = detection time

MT = exposure (Mass x Year)

Why xenon ?

isotope	$Q_{\beta\beta}$	Abundance %
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

Advantages of ^{136}Xe

- ✓ only noble gas that has a $\beta\beta$ decaying isotope
- ✓ high $Q_{\beta\beta}$
- ✓ High natural abundance
- ✓ can be easily enriched
- ✓ no long-lived radioactive isotope
- ✓ prompt scintillation λ_{max}= 175 nm

Liquid versus Gas

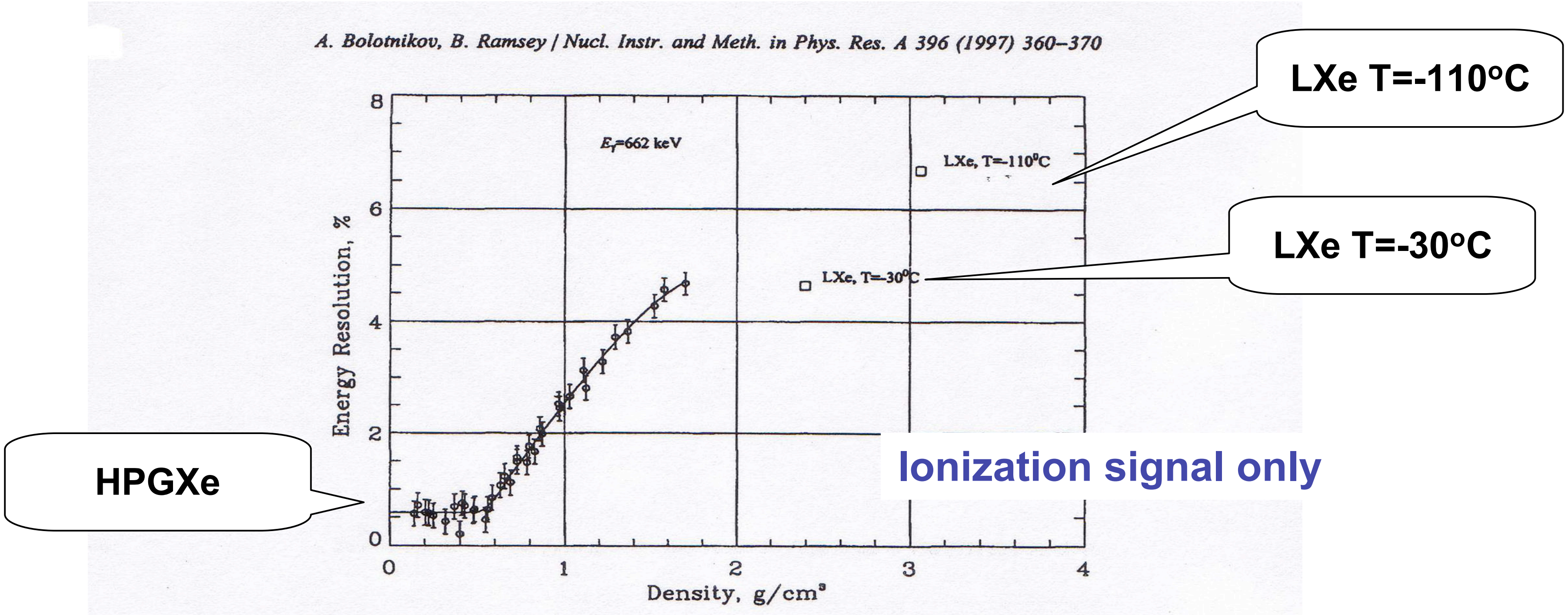


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

At densities < 0.55 g/cm^3 the energy resolution in the xenon is "intrinsic".

For ρ >0.55 g/cm^3, energy resolution deteriorates rapidly

Bolotnikov et al. Nucl. Inst. and Meth A 396 (1997) 360-370.

“Intrinsic” Energy Resolution for Ionization at ^{136}Xe Q-value

$\delta E/E = 2.35 \times (FN)^{1/2} = 2.35 \times (FW/Q)^{1/2}$

$\delta E/E \sim 2.8 \times 10^{-3}$ FWHM @ 2480 keV*

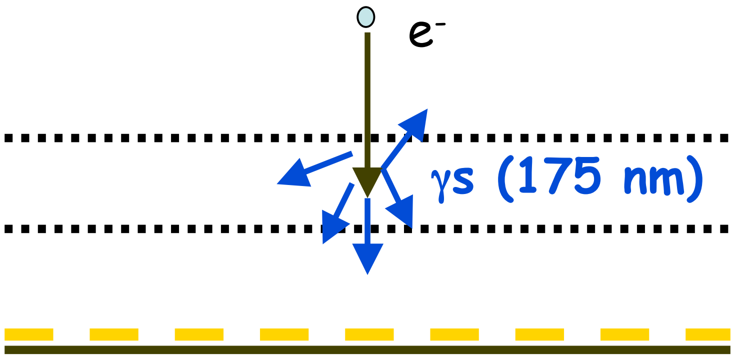
(xenon gas - ionization intrinsic fluctuations only)

*This **ideal** result is ~ same as that achieved with germanium diodes, in **practice.**

Technical factors contribute also to the energy resolution :
Attachment of electrons to electronegative ions in the gas,
Lost of charge in the grids, electronic noise,..

An energy resolution better than 1% is possible in HPXe xenon gas if these technical factors are controled and if EL is used to amplify the ionization proportionally

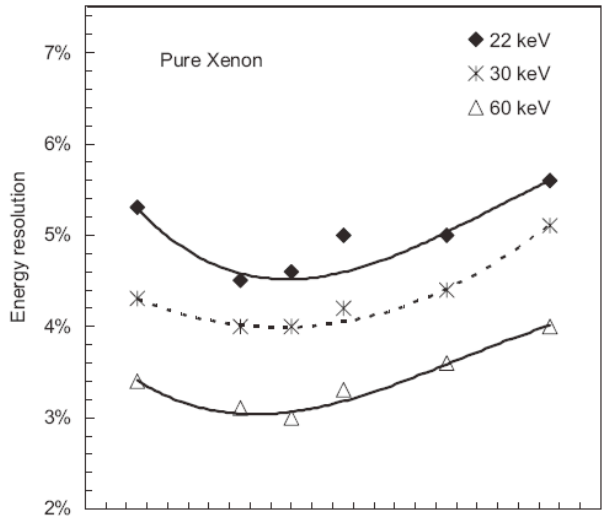
Electroluminiscence (EL)



EL is a linear process while the charge amplification is an exponential process. The fluctuations in the light are extremely small

L.C.C. Coelho et al. NIM A 575 (2007) 444-448

3% FWHM at 5 bar for 60 keV : only a factor ~2-3 worse than results with solid state detector



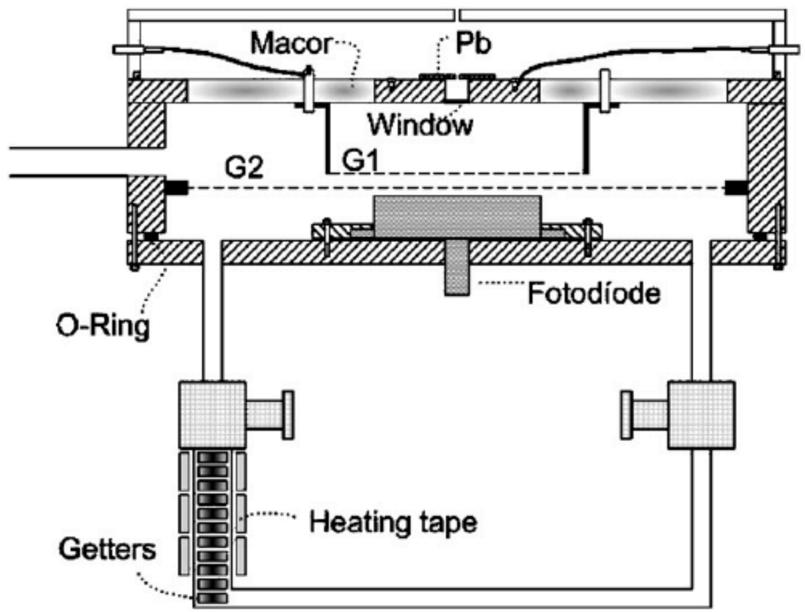
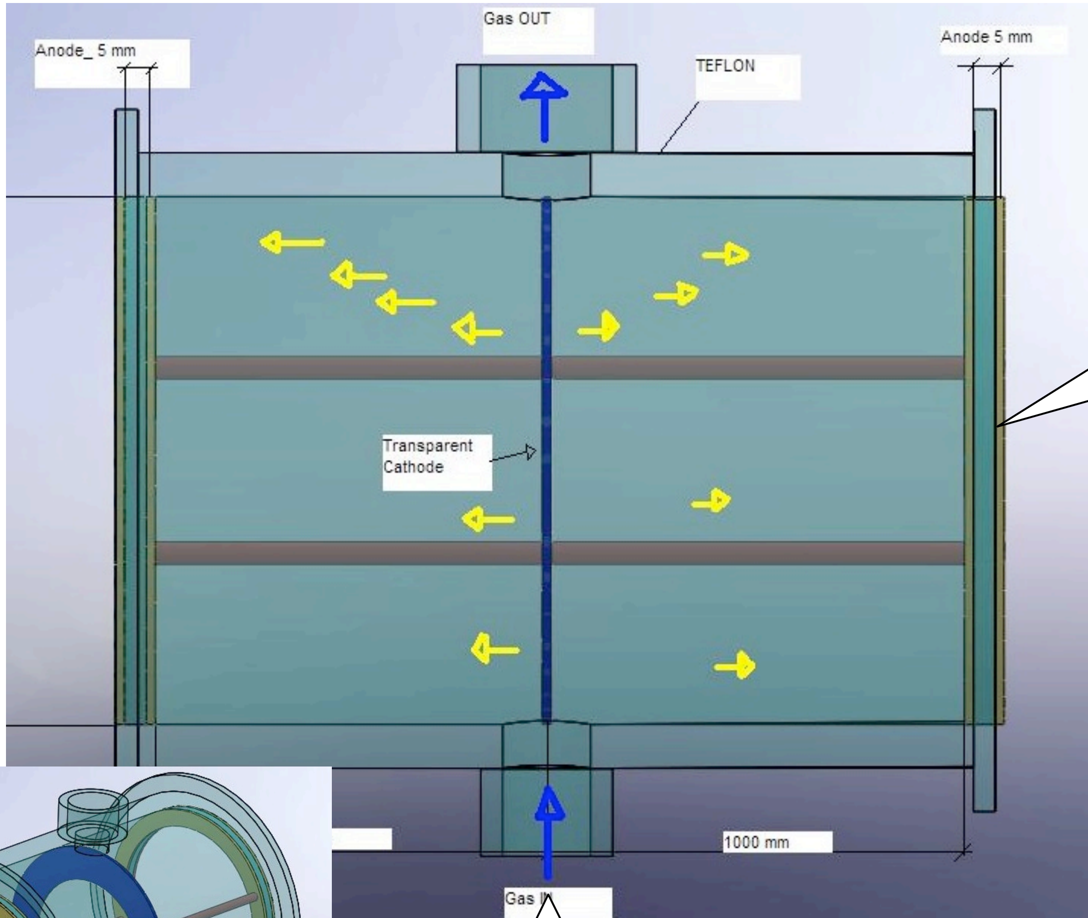
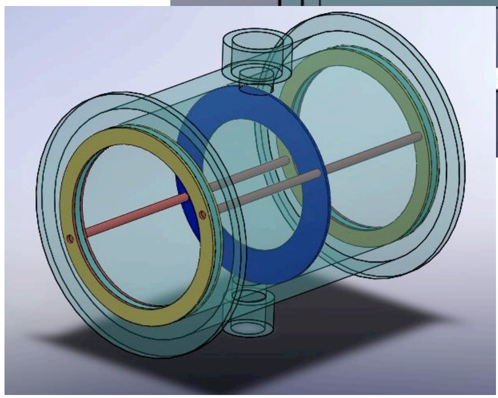


Fig. 1. Schematic of the present GPSC instrumented with a LAAPD photosensor substituting for the PMT.

Conventional EL TPC





Anode : wire grid
UV PMT readout
At eah endcap

Cathode -HV

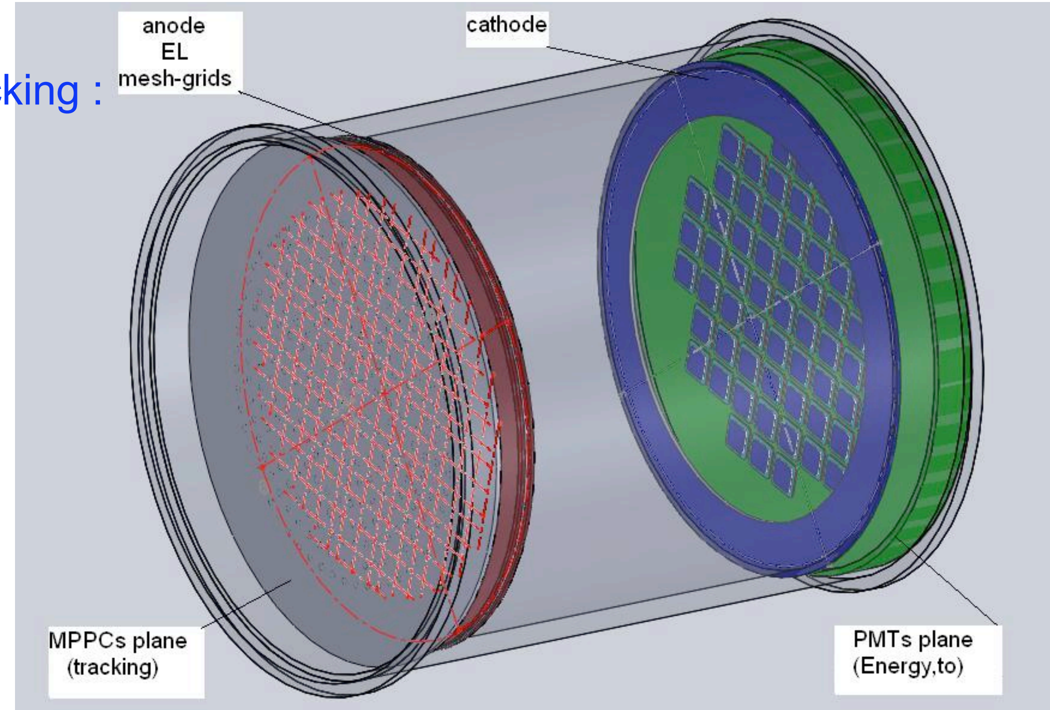
Drawbacks

- Low optical gain ≈ 300
- Number of PMTs too large (2500, cost, radioactivity)
- Large dynamic range for PMT readout

NEXT conceptual design : SOFT TPC

Separate-Opimized Function for Tracking :

- ✓ Uses EL mesh-grid (3-5 kV/cm) at the anode
  to convert ionization into proportional UV Light
- ✓ high optical gain with voltage tuning in the
  EL gap
- ✓ One volume totally active
- ✓ separate technology for energy and tracking :
  PMTs behind the cathode for energy, t0
- ✓ SiPM (MPPC) behind the anode
- ✓ gain in the tracking cells can be set
  lower than in energy cells



Dimensions :

- ✓ drift length : 140 cm
- ✓ diameter : 140 cm
- ✓ xenon mass : 108 kg (10 bar)

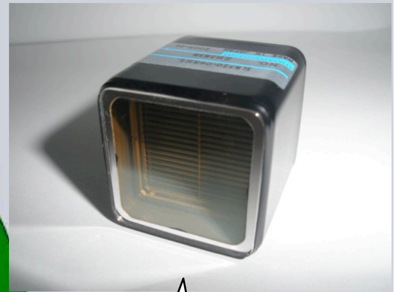
SOFT TPC : Energy function - PMTs

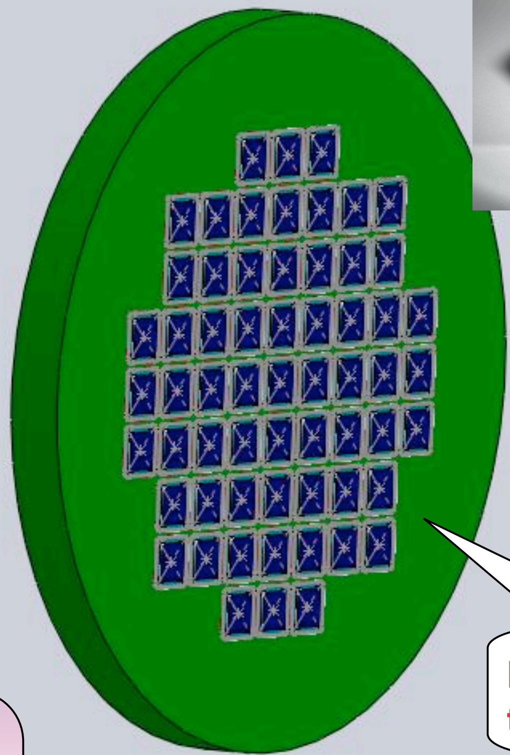
NEXT PMT: **R8520-06SEL from Hamamatsu**

This is a modified version of XENON PMT R8520-06-AL

Main characteristics:

- ✓ Radioactivity: **0.5 mBq for U and Th chains**
- ✓ Pressure resistance **: 5 bar**
- ✓ Spectral response : **160 - 650 nm**
- ✓ Quantum efficiency **: 30% at 175 nm**
- ✓ Gain : **1.0×10^6**
- ✓ Window material : **fused silica**
- ✓ Anode dark current: **2 to 20 (max) nA**





R8520-06SEL
Hamamatsu

PMTs plane behind the TPC cathode

What we expect from Hamamatsu ? :

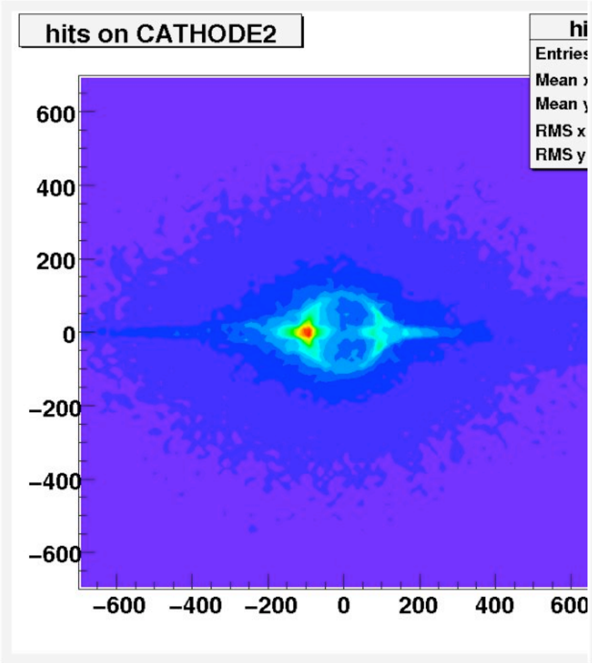
- ✓ increase pressure resistance up to 10 bar
- ✓ increase size → optimize coverage at lower number of channels and lower price

What we have to develop? : HV dividers

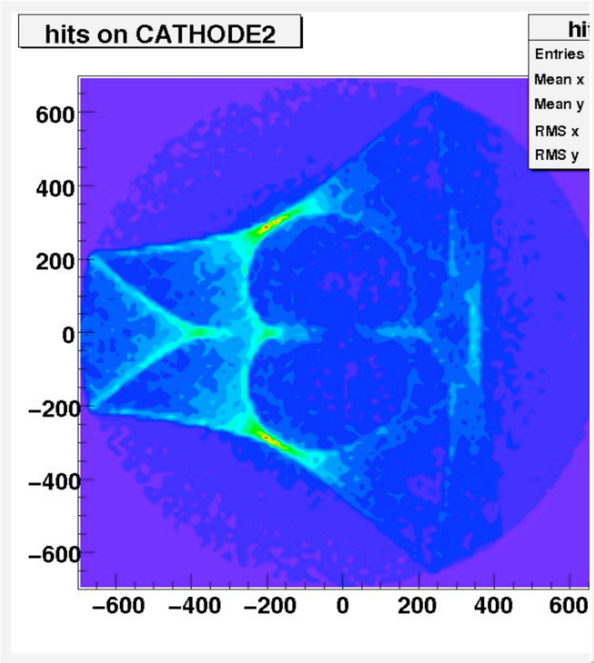
Hamamatsu has no expertise

- ✓ radio-pure
- ✓ pressure resistant up to 10 bar

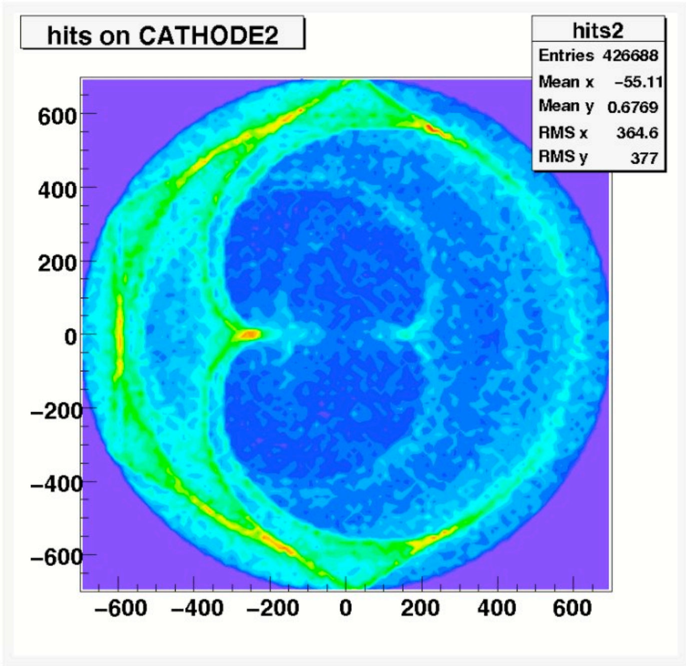
SOFT TPC : Energy function - simulations



D=70 cm



D=45 cm



D=20 cm

Light distribution in the NEXT100 PMT plane :

Internal vessel reflectivity is assumed **R=97%**

Total drift length : **160 cm**, diameter : **140 cm**

D : distance light emission-point — cathode

PMT coverage should match the Light distribution

Best compromise should be found : high coverage — low nbr PMTs

Accurate calibration of the multi-PMT system is necessary

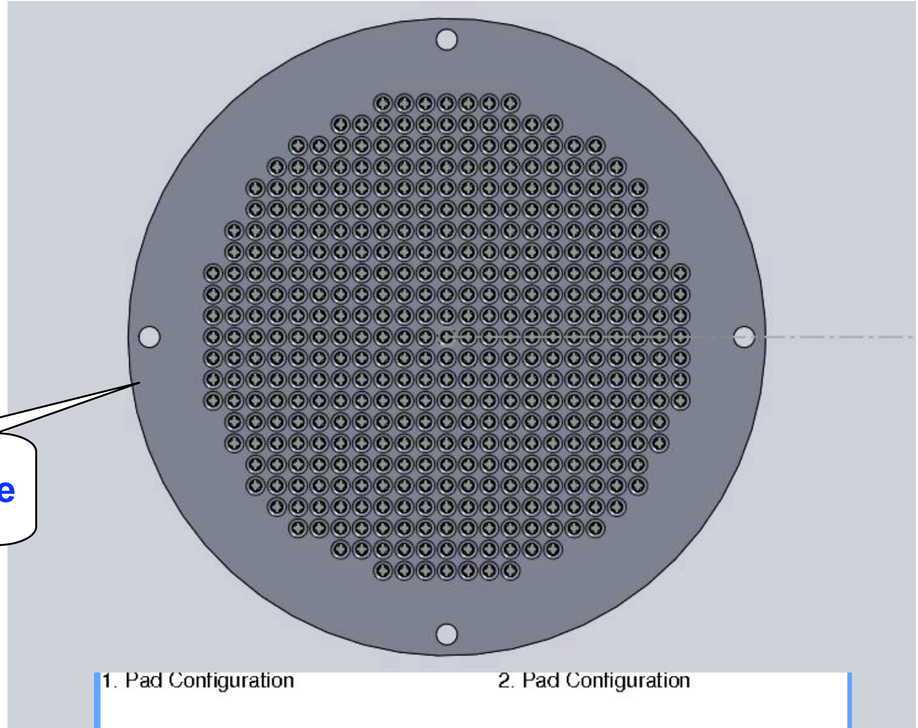
SOFT TPC: Tracking function - SiPMT

Main advantages :

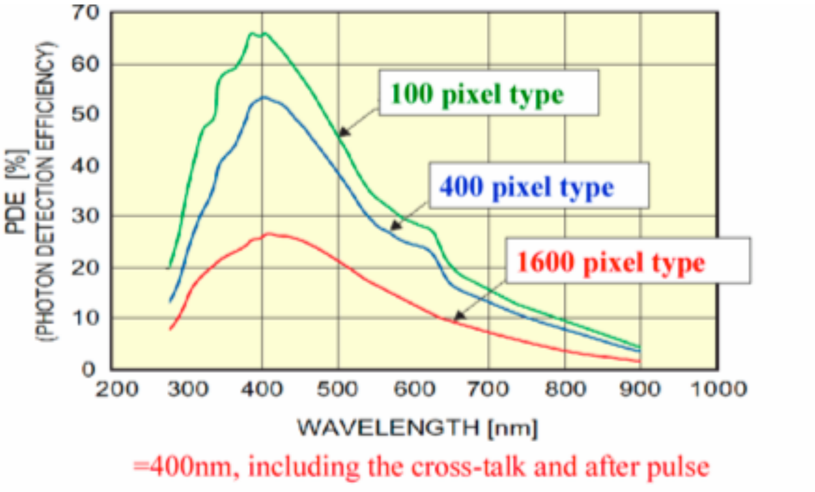
- ✓ Radio-pure device
- ✓ low cost per unit sensitive area
- ✓ small size suitable for tracking
- ✓ High PDE
- ✓ High Gain : 10^5 - 10^6

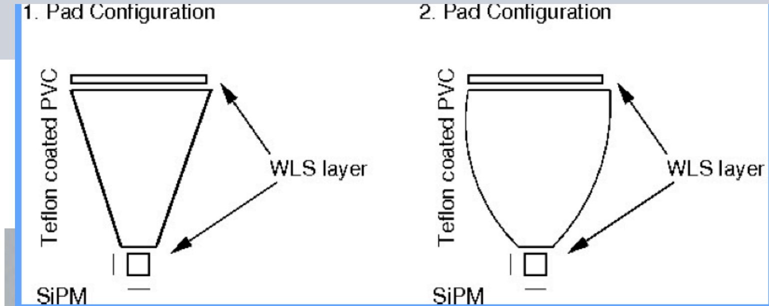
Drawback :

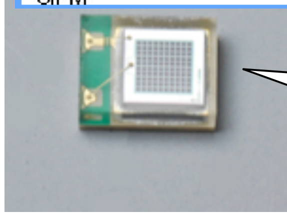
- ✓ High sensitivity to temperature



SiPM plane







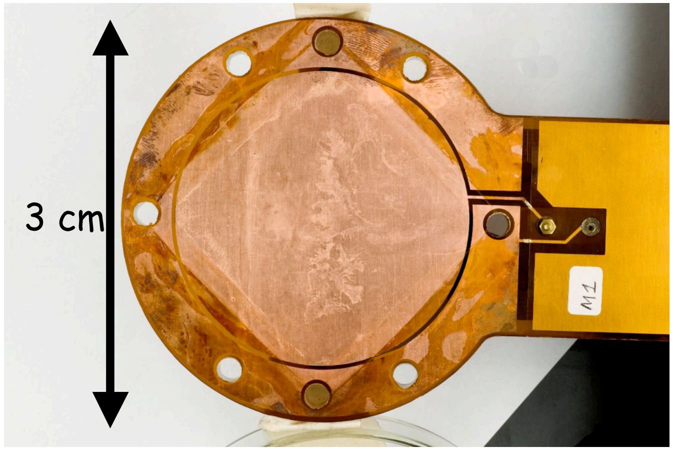
S10362-11-025p
Hamamatsu

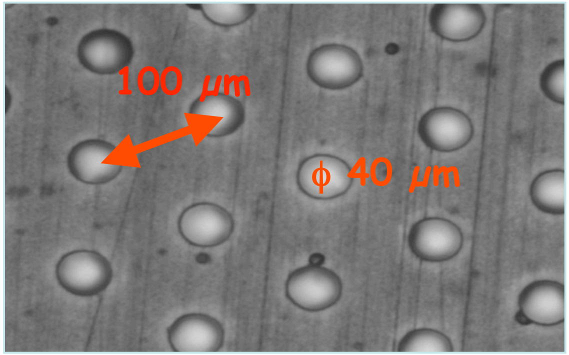
SOFT TPC: Tracking function - MM

Tracking with micromegas is also investigated as a competitive alternative to the baseline choice of SiPM.

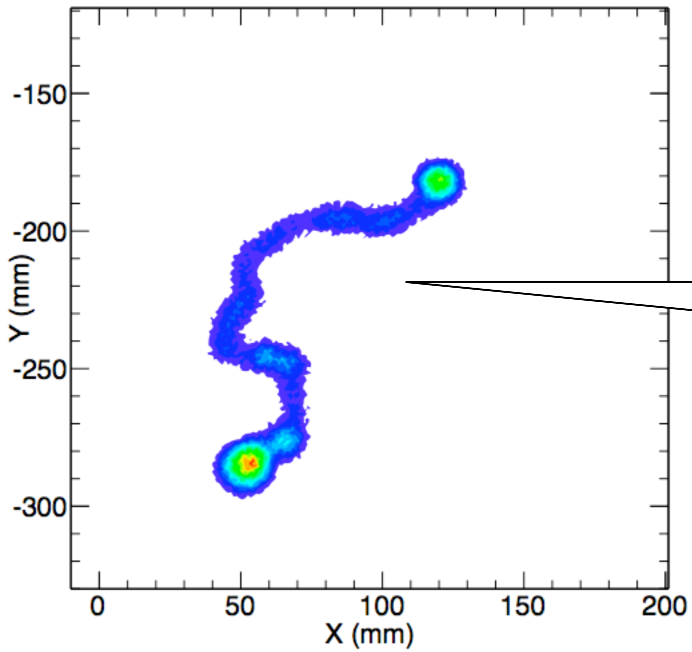
Expertise at the University of Zaragoza with collaboration of Saclay.

Many questions related the operation of MM in a EL TPC are addressed : gain, quencher, presence of EL grid ..

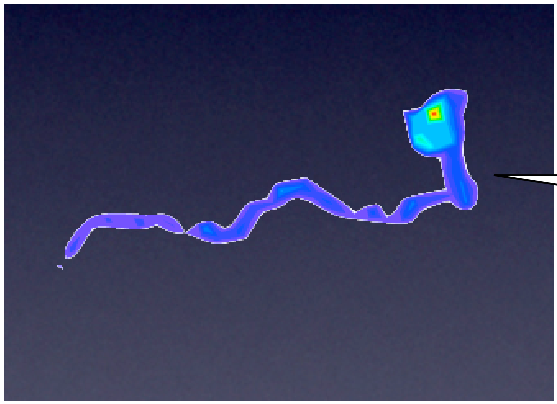




SOFT TPC: Tracking function - topology



Double beta



One beta

The track length at 10 bar is 30 cm. The ββ event track is a tortuous cord because of the multiple-scattering. The cord is ended by two blobs of energy.

This pattern is distinguishable from the one electron track with energy near Qββ

LXe cannot resolve blobs

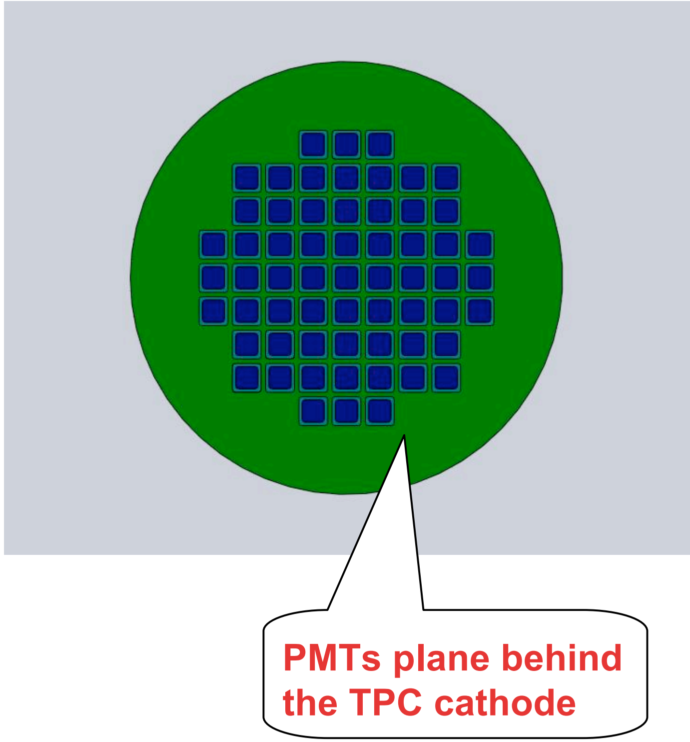
SOFT TPC: Start-of-event time t0

- The primary xenon scintillation (λ_{max}= 175 nm) readout provides the start-of-event time t0.

- t0 is necessary to place the event in the drift direction and to provide a complete 3D track-topology.

- Such faint optical signal (150 pe expected at $Q\beta\beta$ have to be recorded by high-gain, high-sensitivity and low-noise devices : **PMTs**

❖ The PMT plane will perform the primary scintillation readout. This occurs several μs prior to the secondary scintillation (EL) for the energy measurement.



- **PMTs gain should be high to record light of a few pe per PMT**

- **Scintillation attenuation in the HPXe should be studied.**

- **A near 100% reflectivity in the vessel walls is required.**

Radio-purity

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

Only Background sources with an energy higher than the Q value can contribute to the region of interest !

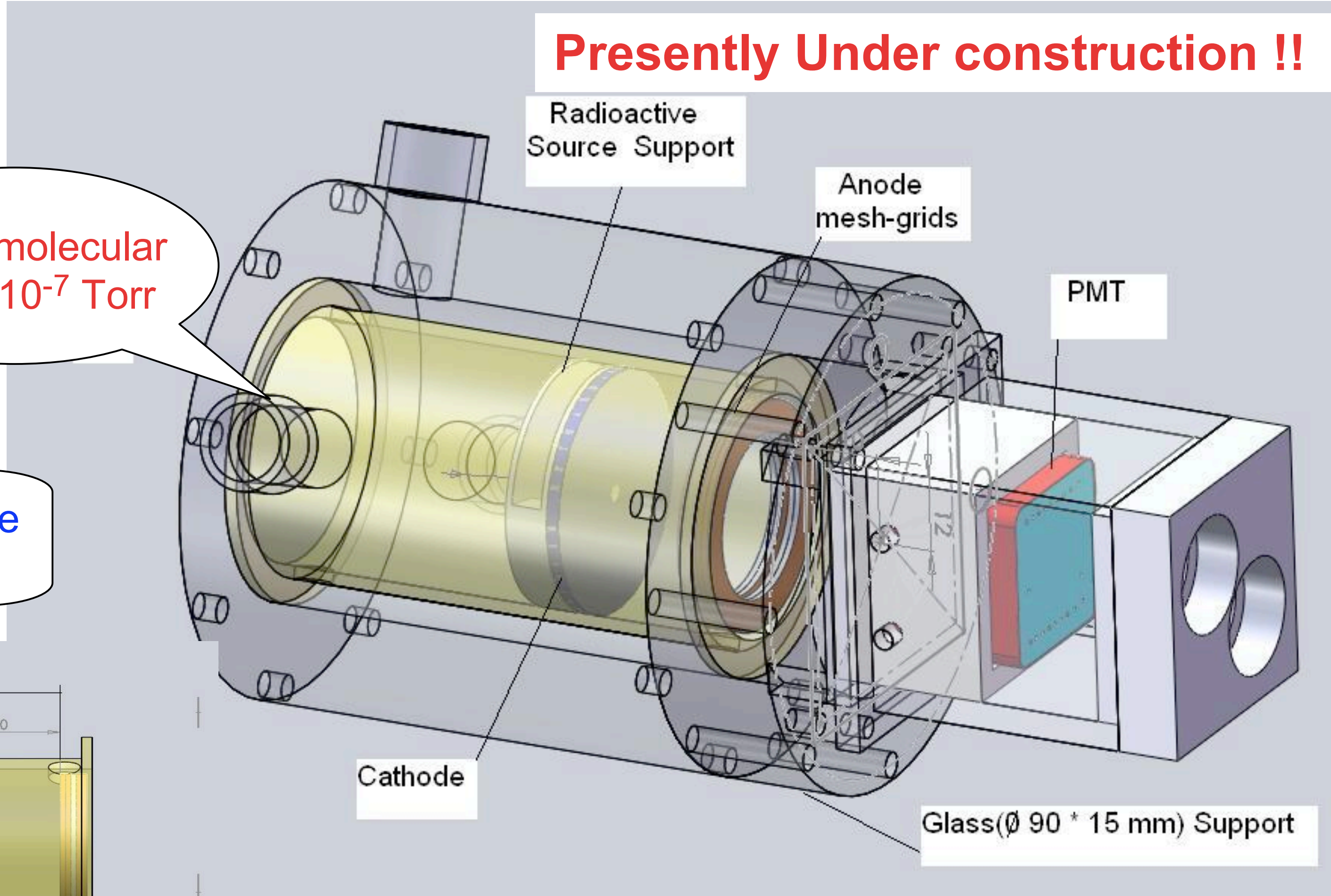
Major contribution to the Background : ^{208}Tl

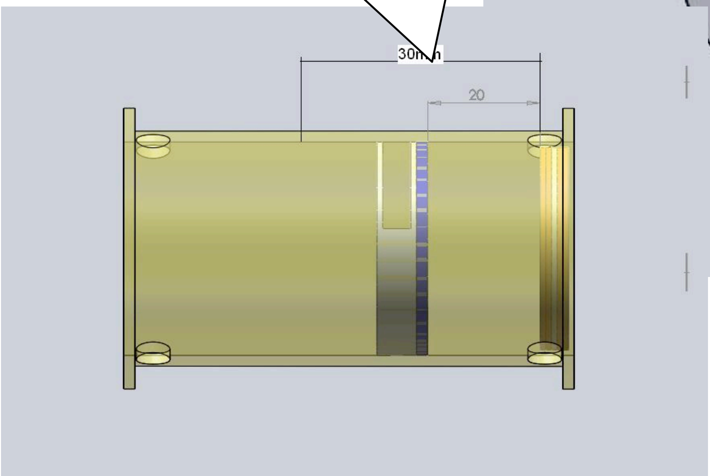
R&D Prototypes : NEXT-0-IFIC

Rotary-vane pump
10^{-3} Torr

Turbo-molecular
pump. 10^{-7} Torr

Variable drift distance
Max = 3 cm

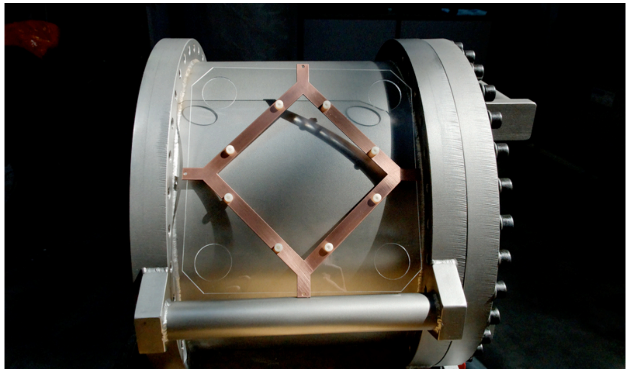


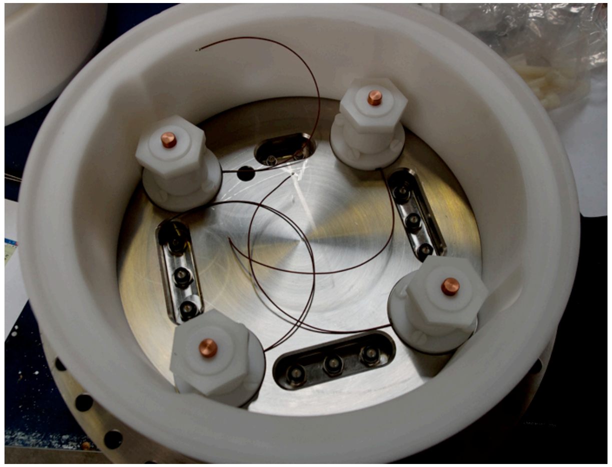


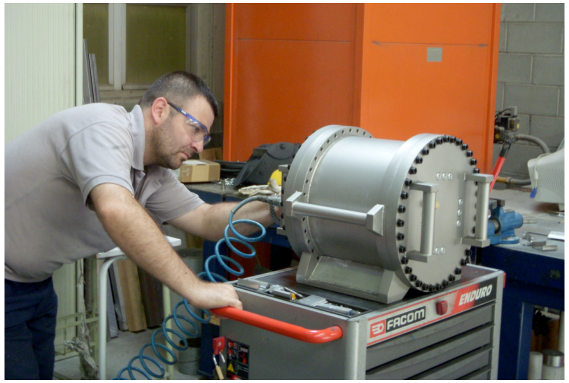
Objectives: energy resolution at 5, 10 bar pressure.

Prototypes : NEXT-0-IFAE

- IFAE Barcelona provided a design of a HP TPC. Stainless steel vessel
- ~30 cm long, ~30 cm diameter
- design for up to 10 bar
- modular approach: readout technology can be "easily" exchanged and even cross-institute exchanges possible
- pressure test was successful: chamber did lose less than 0.1 bar over 1 month at 8.7 bar
- APDs readout is being studied







NEXT-10 : the demonstrator

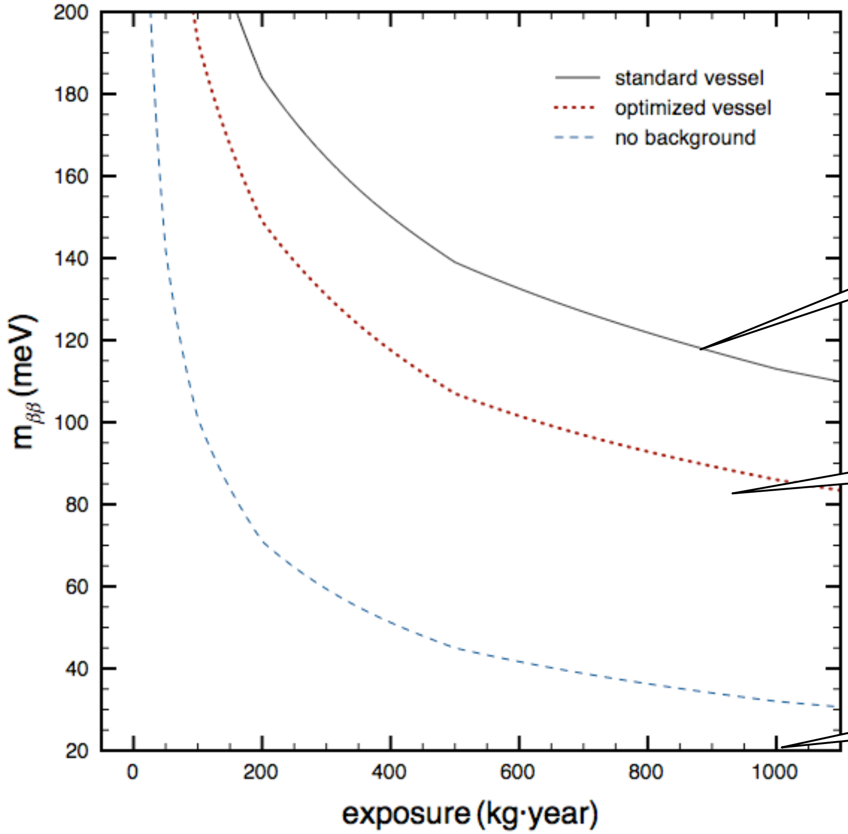
NEXT-10 is the 1:10 scale prototype of NEXT-100

which should demonstrate feasibility of the project and solve all the relevant issues of the experiment :

readout, electronic, radio-purity, gas purification gas pressure system etc…

Schedule :   2 years

SOFT TPC sensitivity : simulations



stainless steel vessel : 1 mBq

Stainless steel vessel 0.1 mBq

Negligible background

Sensitivity down to 50 meV is possible

If objectives of energy resolution and Bkg rejection are met.

Sensitivity to $m_{\beta\beta}$ at 90% CL

of the NEXT TPC as a function of exposure.

Energy resolution is assumed 1%

Summary

- NEXT is a new double beta decay experiment using a TPC filled with 100 kg high pressure xenon gas enriched in ^{136}Xe

- Ultra high energy resolution - close to intrinsic - is expected in HPGXe

- 3D-Topological signature of the event is possible in gas and not in liquid

- The conceptual design of NEXT is a SOFT EL TPC :Energy and tracking are performed with different technologies

- Small prototypes with single and multiple readout are under construction
- Everything to be done : electronics, radio-purity, gas system, … Intense R&D is conducted at different institutions

NEXT is the last newborn child of the double beta community

Exciting is the infancy …

BUT

wants to grow up fast and needs expert collaborators from all over the world …