NEXT: a Neutrino Experiment with Xenon gas TPC

Nadia Yahlali
IFIC (Valencia)

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 ….
Our leading idea

The leading contemporary experiments in WIMPs and $\beta\beta_{0\nu}$ searches use Time Projection Chambers (TPC) filled with very large masses of liquid xenon ($\text{LXe}$):

- 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 $< 0.55 \text{ g/cm}^3$. 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 $\beta\beta_{0\nu}$ experiment.
The NEXT project

**Our goal**: build and operate a TPC filled with 100 kg HPGXe enriched with $^{136}$Xe isotope, to measure its $\beta\beta^{0}\nu$ 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)

- **Main Hall**: 40 x 15 m (h=11 m)
- **Ultra-Low background Facility**: 15 x 10 m (h=8 m)
- **Old Laboratory**: 20 x 5 m (h=4.5 m)

**Installations, clean rooms & offices**

- Access gallery
- Railway tunnel
- Road tunnel

**Depth**: 2400 m.w.e.

**Surface**: 1000 m²

- Muon flux: $2.4 \times 10^{-3} \mu m^{-2} s^{-1}$
- Neutrons: $2 \times 10^{-2} n m^{-2} s^{-1}$
- Radon: 50 - 80 Bq/m³
The double beta decay: $\beta\beta 2\nu$

- Double weak interaction $\Rightarrow$ rare process
- Only possible to observe if $\beta$ decay forbidden.
- Allowed in the Standard Model
- Experimentally confirmed for several isotopes

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

- Not observed yet for the $^{136}\text{Xe}$
The double beta decay: $\beta\beta^0\nu$

- Forbidden in the SM because of Lepton number conservation
- Only possible if the neutrino is a Majorana particle
  \[ \Rightarrow \text{neutrino} = \text{anti-neutrino} \]
- Lepton number violation
- Not observed/confirmed until now

\[
(A,Z) \rightarrow (A,Z+2) + 2e^- + 0\nu\beta\beta
\]

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

The experimental evidence should be robust!!
A robust evidence

**IDEAL:**
- Optimal separation of $\beta\beta$-2$\nu$ and $\beta\beta$-0$\nu$ populations
- No background

**REAL:**
- Limited Energy resolution
- Background in detector component sand surroundings
Background

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

$\sqrt{m_{\beta\beta}} \sim \{1/MT\}^{1/2}$  \hspace{2cm} \text{ideal}

$\sqrt{m_{\beta\beta}} \sim \{(B\delta E)/MT\}^{1/4}$  \hspace{2cm} \text{real}

- $B$ = number of background events/unit energy
- $\delta E$ = energy resolution of the detector system
- $T$ = detection time
- $MT$ = exposure (Mass x Year)
Why xenon?

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

Advantages of $^{136}\text{Xe}$

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

Pisa 24-30 May 2009
Nadia Yahlali
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

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

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

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

(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 controlled 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.
Conventional EL TPC

Anode: wire grid
UV PMT readout
At each endcap

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-Optimized 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: $1.0 \times 10^6$
- Window material: fused silica
- Anode dark current: 2 to 20 (max) nA

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

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

D=70 cm

D=45 cm

D=20 cm
**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

---

1. Pad Configuration
2. Pad Configuration

---

Pisa 24-30 May 2009

Nadia Yahlali
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..
The track length at 10 bar is 30 cm. The $\beta\beta$ 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 $Q_{\beta\beta}$.

$\text{LXe}$ cannot resolve blobs.
SOFT TPC: Start-of-event time $t_0$

- The primary xenon scintillation ($\lambda_{\text{max}} = 175$ nm) readout provides the start-of-event time $t_0$.
- $t_0$ 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 $\mu$s 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

<table>
<thead>
<tr>
<th>Origin</th>
<th>gamma</th>
<th>Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL208 Laboratory, detector materials, shielding</td>
<td>2614 keV (99 %)</td>
<td>3272 keV (18 %)</td>
</tr>
<tr>
<td>Bi214</td>
<td>1764 keV (16 %)</td>
<td>1507 keV (16 %)</td>
</tr>
<tr>
<td>Co60 Cosmogenic activation</td>
<td>1173.24 keV + 1332.5 keV (100 %)</td>
<td></td>
</tr>
<tr>
<td>Xe137 Neutron capture</td>
<td>3717 keV (30 %)</td>
<td>4173 (67.3 %)</td>
</tr>
<tr>
<td>muons shielding</td>
<td>Energetic ?</td>
<td></td>
</tr>
</tbody>
</table>

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

Major contribution to the Background: $^{208}$TI
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

Pisa 24-30 May 2009
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

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 …