

# *XENON and GERDA: low background experiments for the research of Dark Matter and $0\nu\beta\beta$ decay.*



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CIEMAT - Madrid 26/10/09



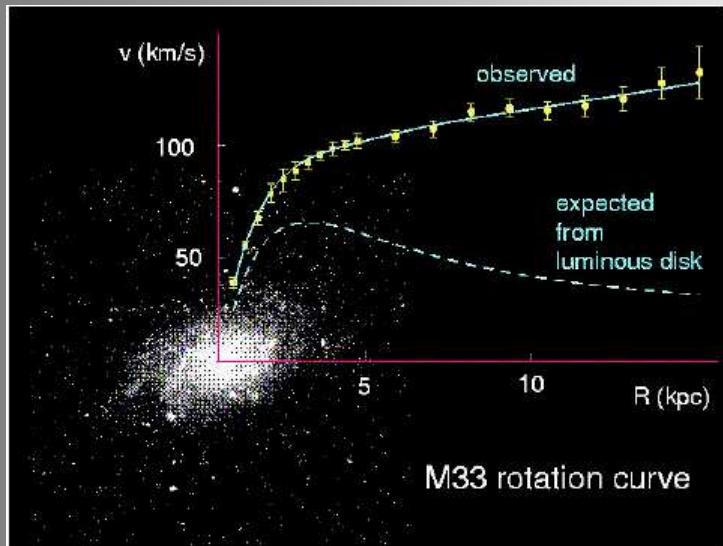
# *OUTLINE*

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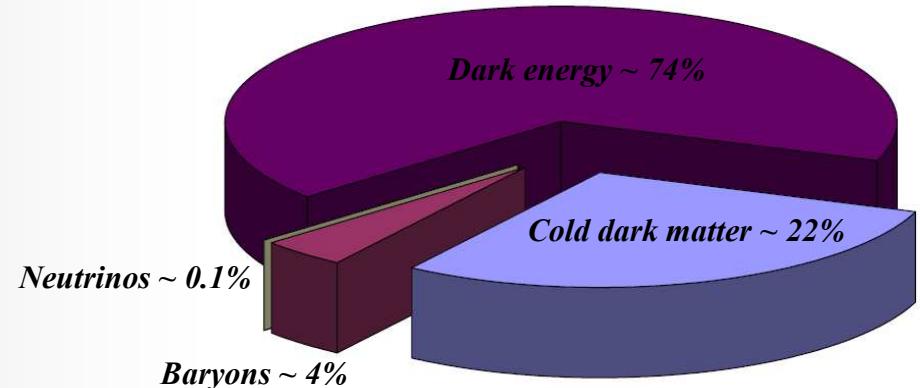
- *LXe detectors for DM direct research*
- *The XENON project*
- *Status & plans*
- *The GERDA experiment*
- *Calibration*
- *Conclusions*

# DARK MATTER RESEARCH

- most DM is non-baryonic
- cold
- dark



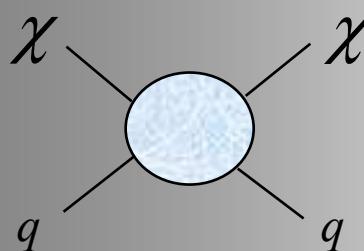
Roughly spherical galactic structure local density of  
 $\sim 0.3 \text{ GeV/cm}^3$ .



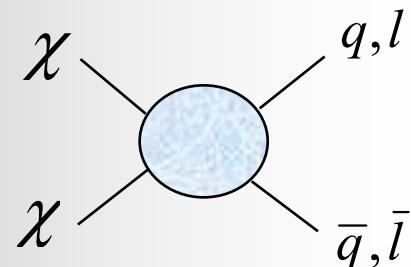
## Weakly Interactive Massive Particle

- stable
- slow
- relic from the Big Bang
- part of a motivated theory

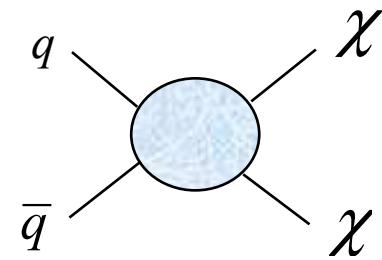
### **UNDERGROUND**



### **ABOVE GROUND**



### **ACCELERATORS**



# DIRECT DETECTION EXPERIMENTS

*GOAL: Detection of the elastic (inelastic) collisions with atomic nuclei*

$$\text{Recoil energy} \quad E_r = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2 V^2}{m_N} (1 - \cos \theta) \leq 50 \text{ keV}$$

$$|\vec{q}| = 2\mu^2 V^2 (1 - \cos \theta) \quad \text{momentum transfer}$$

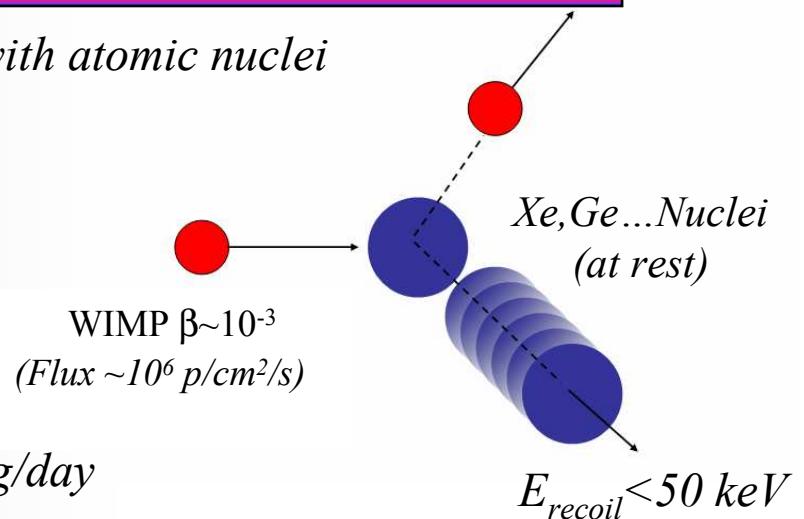
$$\mu = m_\chi m_N / (m_\chi + m_N) \quad \text{reduced mass}$$

$$\text{Rate } R \propto N \frac{\rho_\chi}{m_\chi} \sigma_{\chi N} \cdot \langle V \rangle < 1 \text{ evt/100 kg/day}$$

N = number of target nuclei in detector

$\rho_\chi$  = local WIMP density  $\rho_\chi \sim 0.3 \text{ GeV/cm}^3 \rightarrow 3000 \chi/\text{m}^3$  ( $m_\chi = 100 \text{ GeV}$ )

$\langle \sigma_{\chi N} \rangle$  = scattering cross section ( $\leq 10^7 \text{ pb}$ )



Scattering non relativistic :  
coupling spin-dependent / spin-independent

## Experimental signatures:

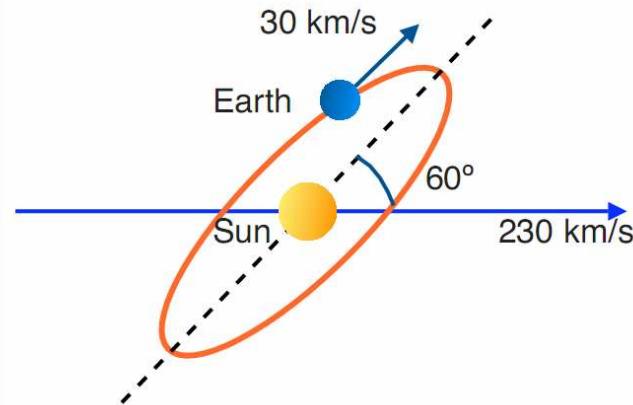
- Nuclear recoils
- Featureless recoil spectrum (no bump)
- Single scatters  
(uniform throughout the detector volume)

## Backgrounds:

- $\alpha$  : higher energy depositions
- $\mu$  : underground + veto
- $\gamma, \beta$  : ER  $\rightarrow$  shielding + discrimination
- $n$  : NR  $\rightarrow$  shielding + multiple interactions

*Extremely low background technique required and good discrimination NR-ER  
(bkg rate > 10<sup>6</sup> higher)*

# ANNUAL MODULATION → DAMA/LIBRA



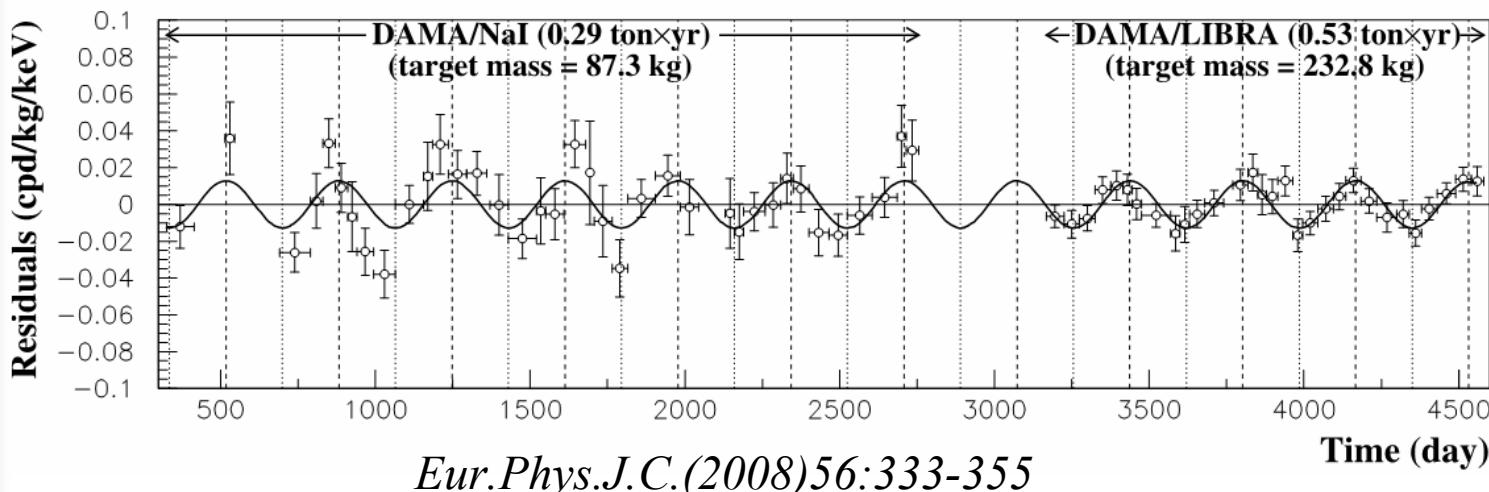
*Annual modulation (<3%) → Additional signature*

*DAMA/NaI : 100 kg NaI(Tl)  
0.29 ton/y over 7 annual cycles  
DAMA/LIBRA: 250 kg NaI(Tl) – 25 crystals  
0.53 ton/y over 4 annual cycles*

*Total exposure : 0.82 ton/y*

*Modulation in the range 2-6 keV*

**2-6 keV**



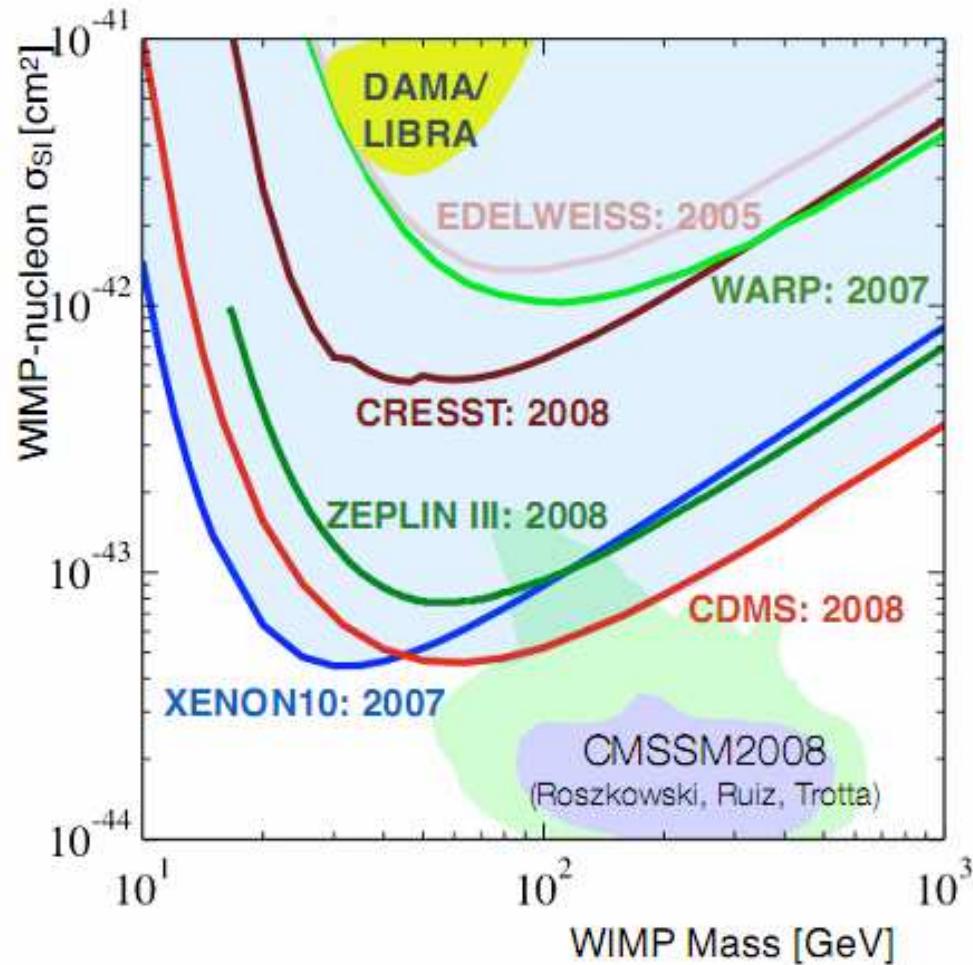
$$R(t) = A \cos \omega(t-t_0)$$

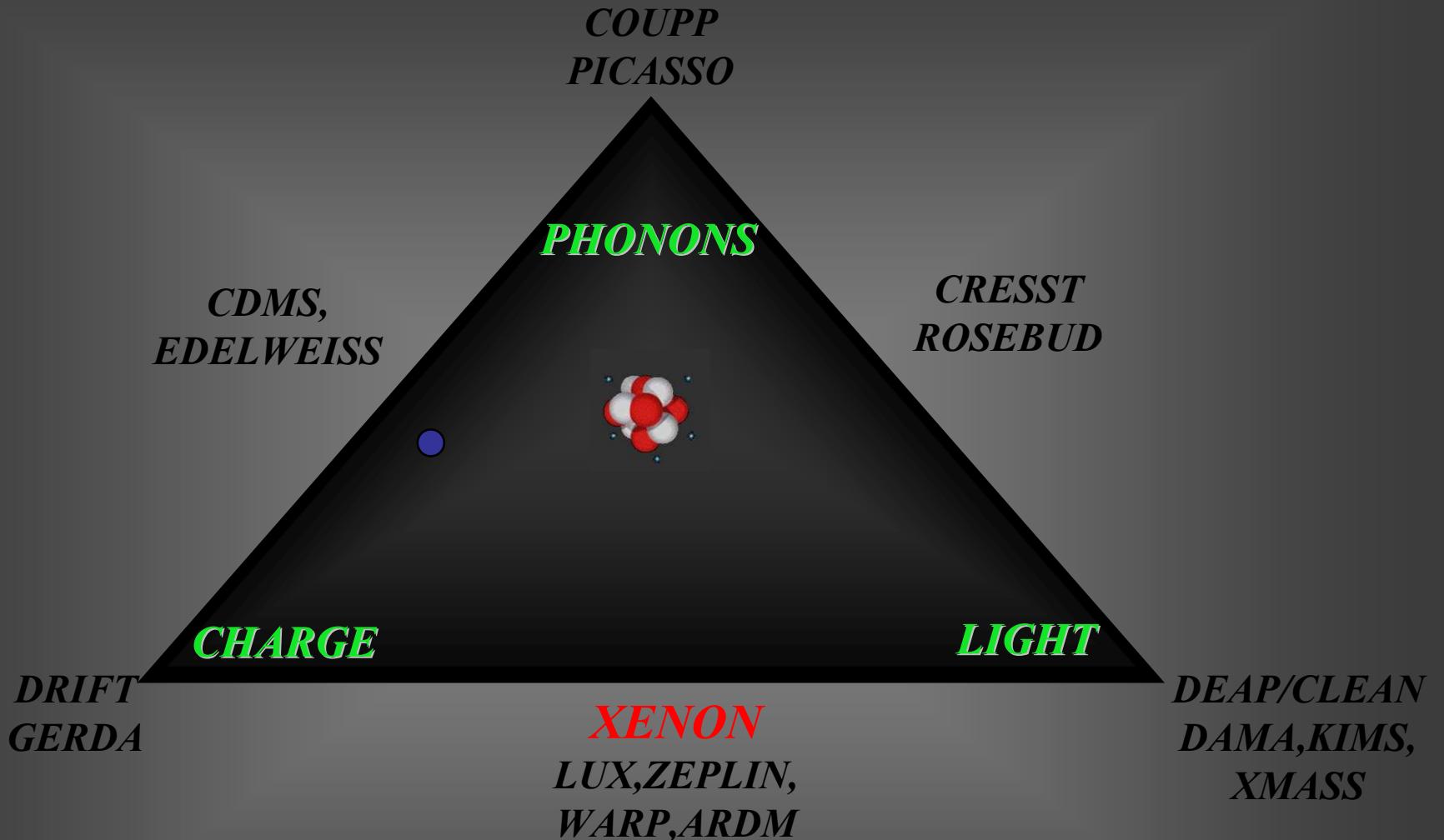
$$T = \omega/2\pi = 1y$$

$$t_0 = 152.5d$$

$$A = (0.0215 \pm 0.0026) \text{ cpd/kg/keV} (8.3\sigma \text{ CL})$$

## *PRESENT STATUS*

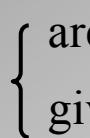




# *NOBLE LIQUIDS AS DETECTOR MEDIUM*

*Experimental requirements for DM experiments:*

- *low energy threshold*
- *large mass*
- *ultra low background*
- *good event discrimination*

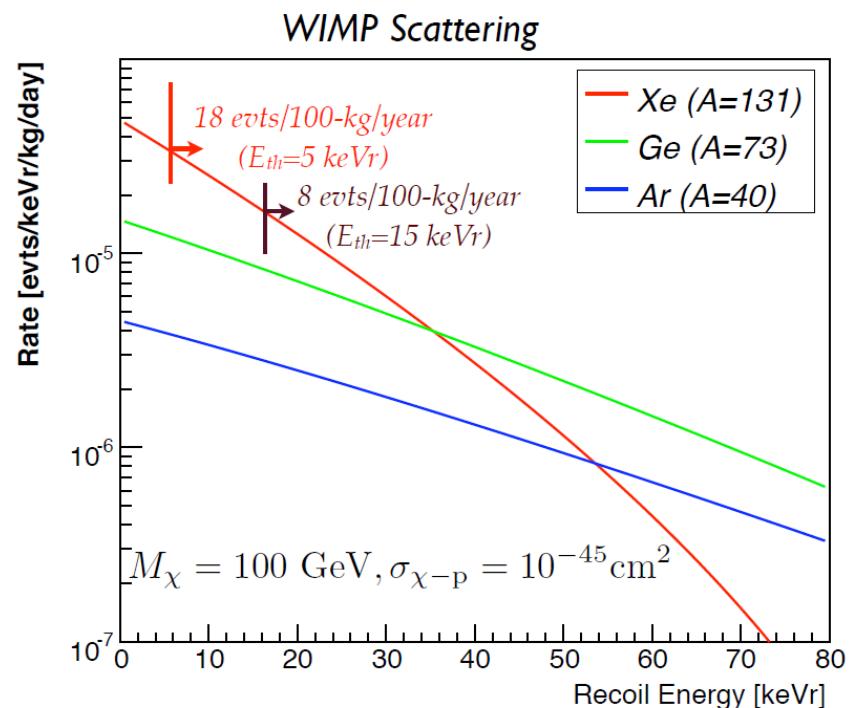
Liquid nobles elements  *are available in large quantity*  
*give both scintillation and ionization signals → Bkg discrimination*

<i>Element</i>	<i>Z(A)</i>	<i>Boiling point (T<sub>b</sub>) @ 1bar [k]</i>	<i>Liquid density @ T<sub>b</sub> [g/cm<sup>3</sup>]</i>	<i>Energy loss dE/dx (MeV/cm)</i>	<i>Radiation length X<sub>0</sub>(cm)</i>	<i>Collision length λ(cm)</i>	<i>Ionization [e<sup>-</sup>/keV]</i>	<i>Scintillation [γkeV]</i>	<i>Cost</i>
<i>Ne</i>	10(20)	27.1	1.21	1.4	24	80	46	7	
<i>Ar</i>	18(40)	87.3	1.40	2.1	14	80	42	40	
<i>Kr</i>	36(84)	119.8	2.41	3.0	4.9	29	49	25	
<i>Xe</i>	54(131)	165.0	3.06	3.8	2.8	34	64	46	

# LIQUID XENON FOR DARK MATTER DETECTION

Liquid Xenon properties:

- **High atomic number (Z=54,A~131) and density ( $r=3\text{g/cm}^3$ )**
  - compact detectors
  - good stopping power (i.e. self shielding active volume)
- ~50% odd isotopes ( $^{129}\text{Xe}$ ,  $^{131}\text{Xe}$ ) for spin dependent interactions
- **No long-lived radioactive isotopes.**  $^{85}\text{Kr}$  contamination reducible to ppb level or less
- **High scintillation (W~22 eV) yield with fast response (yield ~80% of NaI)**
- **High ionization (W=15.6eV) yield and small Fano factor for good  $\Delta E/E$**
- **Background discrimination** → different charge/light ratios for electron/nuclear interactions
- Available in large quantity and “easy” to purify with a variety of methods (~10k\$/kg).

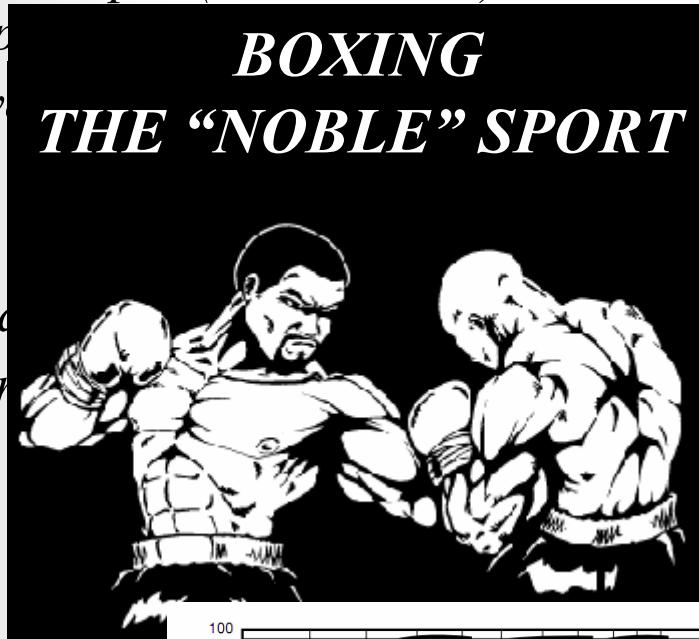


- LXe:**
- ✓ *Density*
  - ✓ *~50% odd isotopes ( $^{129}Xe, ^{131}Xe$ ) for spin dependence*
  - ✓ *No long-lived radioactive isotopes*

✗ *Price*

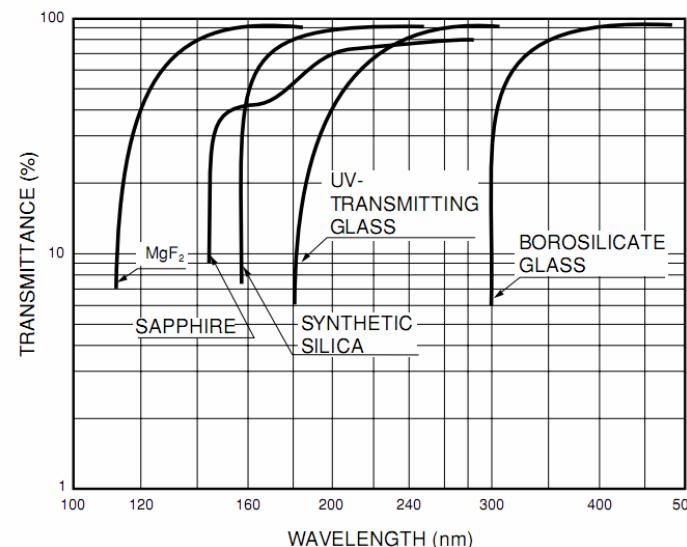
- LAr:**
- ✓ *Background*
  - ✓ *Available in large volumes*

*Radioactive isotopes*  
 $^{39}Ar \rightarrow 1.01 \text{ Bq/kg}$   
 NIM-A 574 (2007) 83–88



*Additionally: Scintillation wavelength*

$$\left\{ \begin{array}{l} \lambda_{LXe} \sim 175 \text{ nm} \\ \lambda_{LAr} \sim 128 \text{ nm} \\ (\lambda_{LN\!e} \sim 77.5 \text{ nm}) \end{array} \right.$$



LXe : No need for wavelength shifter!

Hamamatsu:  
 " Photomultipliers tubes "  
 3<sup>rd</sup> edition

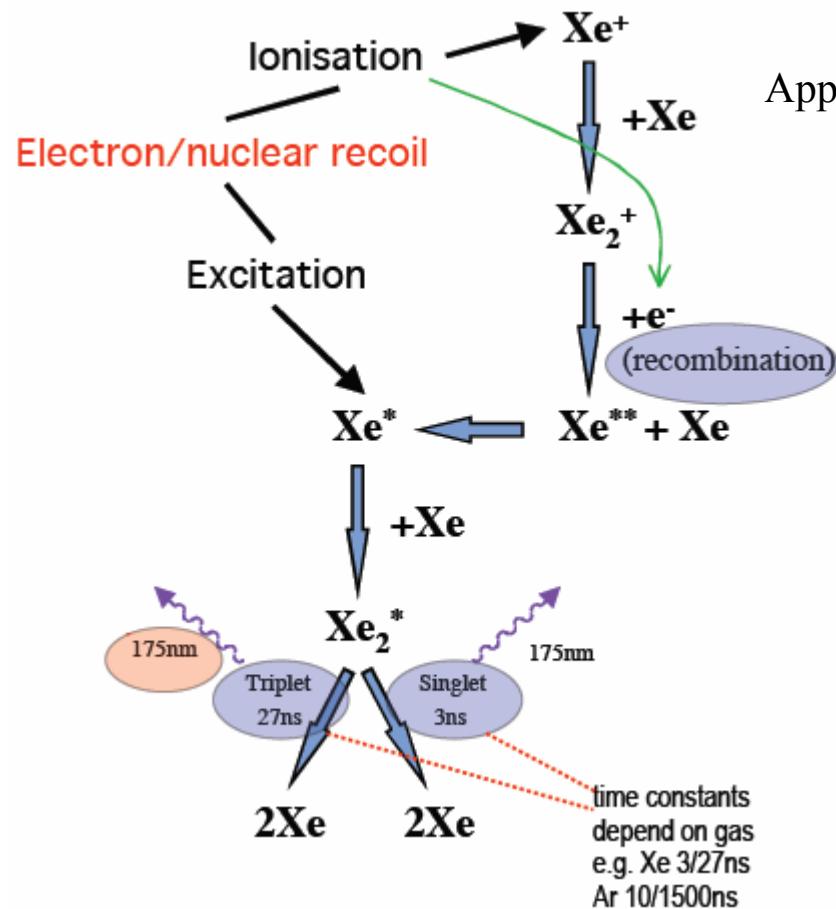
# **THE XENON DARK MATTER PROGRAM**

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LXe **double-phase TPC**, 3D position sensitive detector

- **XENON10** first implementation of the concept. Data taken in 2006/2007.  
(Reached sensitivity  $\sim 10^{-43} \text{ cm}^2$  at 100GeV WIMP mass)
- Event by event discrimination ( $>99.5\%$ ) by simultaneous charge and light detection
- Low energy threshold ( $\sim 5 \text{ keV}_R$  with 89 PMTs readout - light yield  $\sim 3 \text{ pe/keV}$ )
- **XENON100** currently operating at Gran Sasso laboratory  
Goal: gamma background reduction by  $\sim 100$  and fiducial mass increase by  $\sim 10$   
Sensitivity: up to  $\sim 2 \times 10^{-45} \text{ cm}^2$  ( $M_W = 100 \text{ GeV}$ ) -  $\sim 2 \times 10^{-46} \text{ cm}^2$  projected 2012
- Ultimate goal **XENON1T** ->  $\sigma_{\text{SI}} \sim 10^{-47} \text{ cm}^2$  ( $M_W = 100 \text{ GeV}$ )

# THE DOUBLE PHASE XeTPC:



Wimps (or neutrons) → Slow nuclear recoils

$\gamma, \text{e}^-$  etc → Fast electron recoils

Applying a drift field fewer and fewer electrons recombine with the parent ions : **recombination light suppressed**.

Different track structures of recoiling electron and nuclei  
→ **two different amount of quenching**



Different ionization/scintillation ratio for electron and nuclear recoil

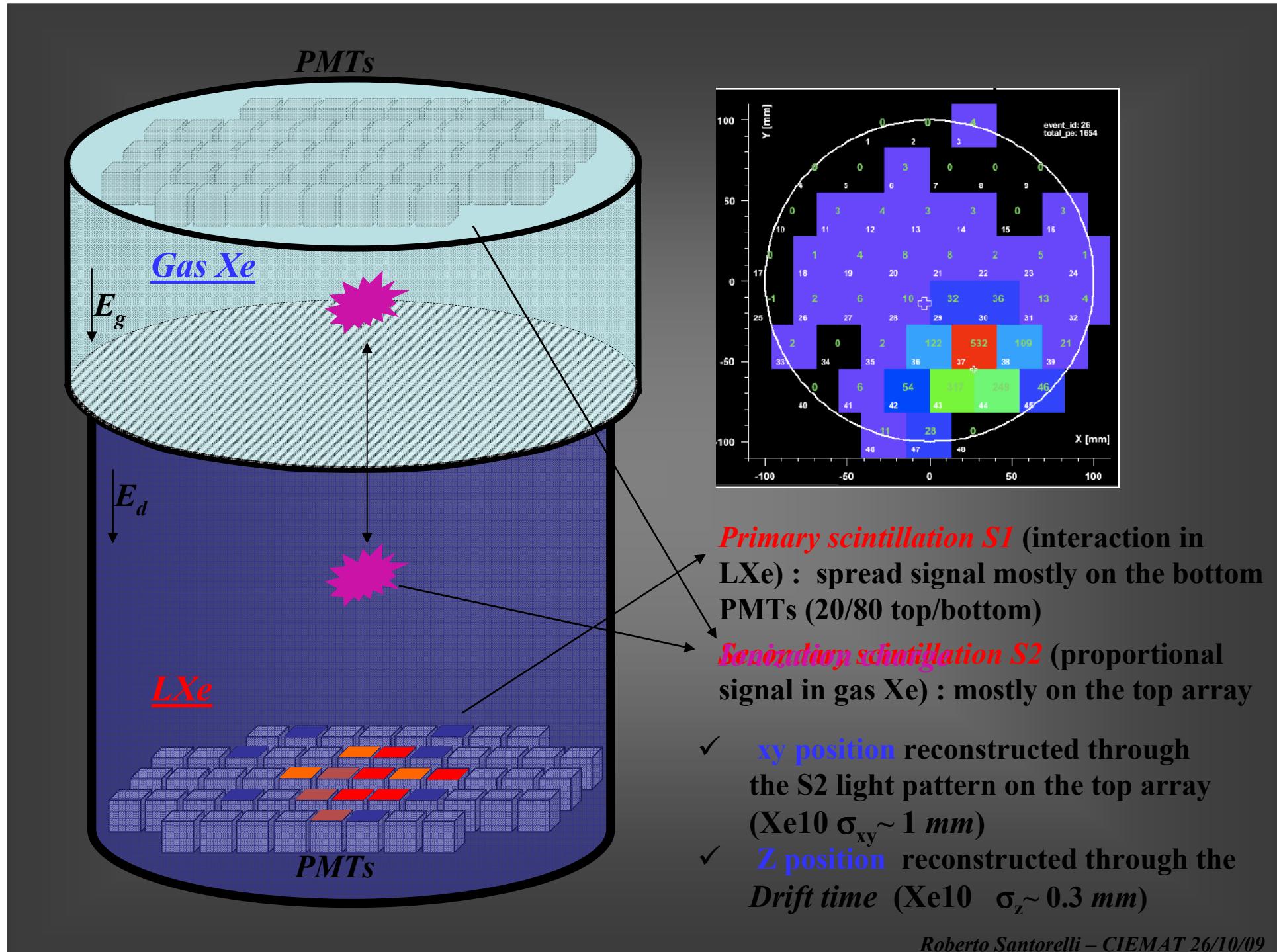
→ **Event by Event discrimination**

Ionization signal from nuclear recoil too small to be directly detected



**DUAL PHASE DETECTOR**

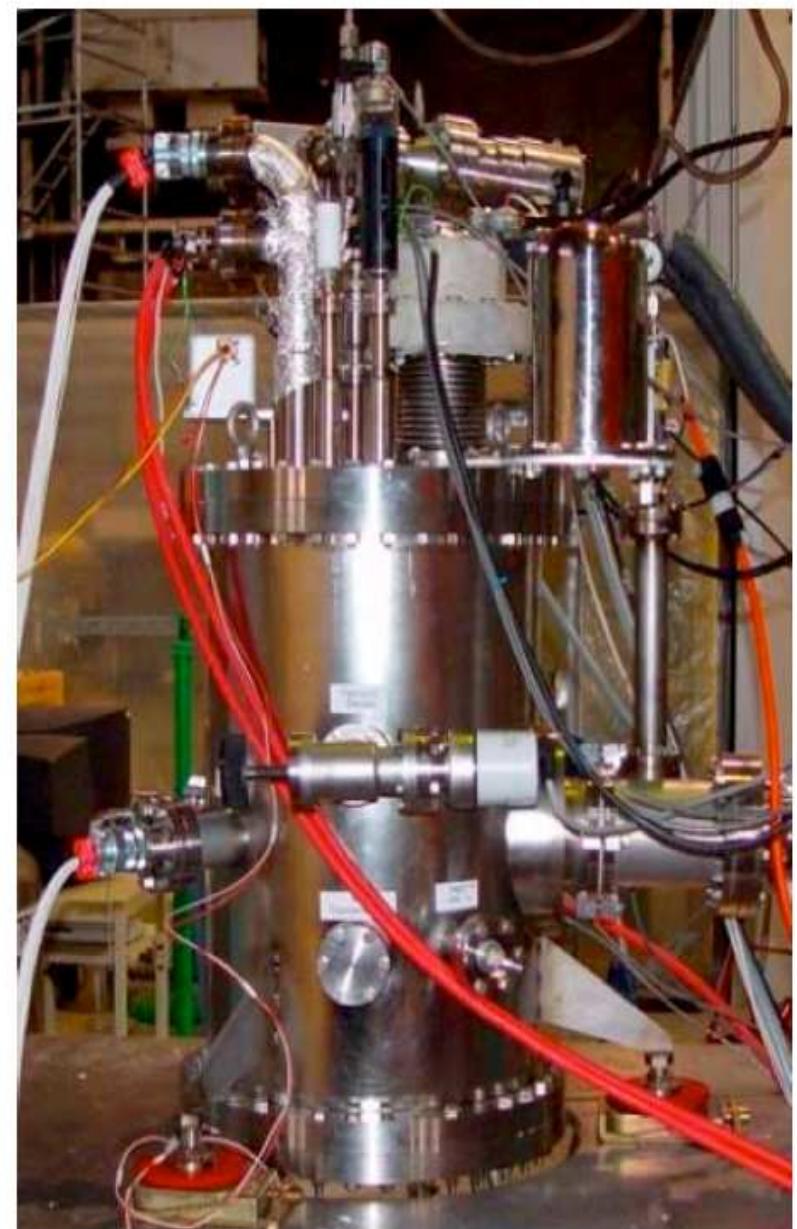
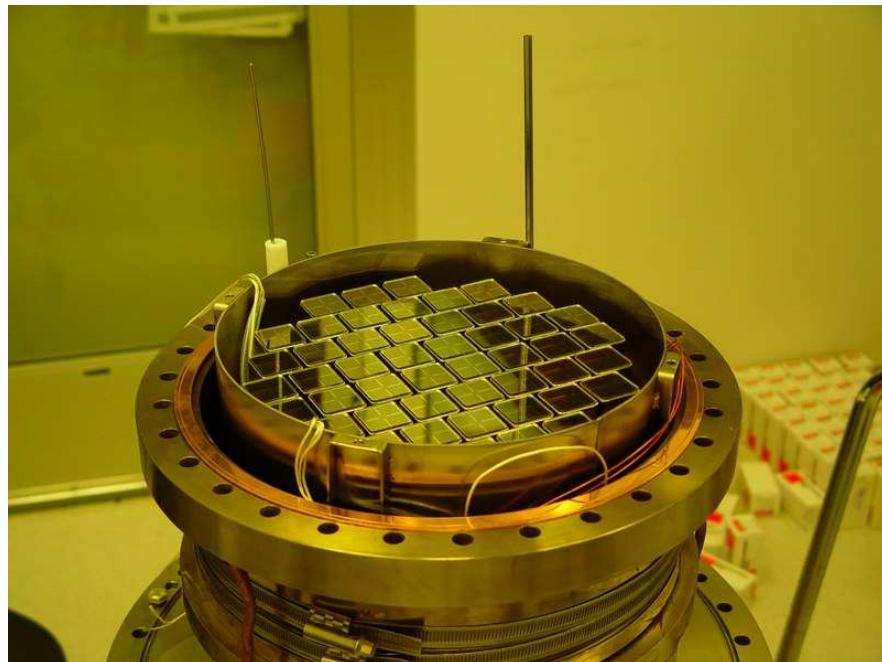
Ultra pure liquid necessary to preserve small electron signal ( $\sim 10$  el)

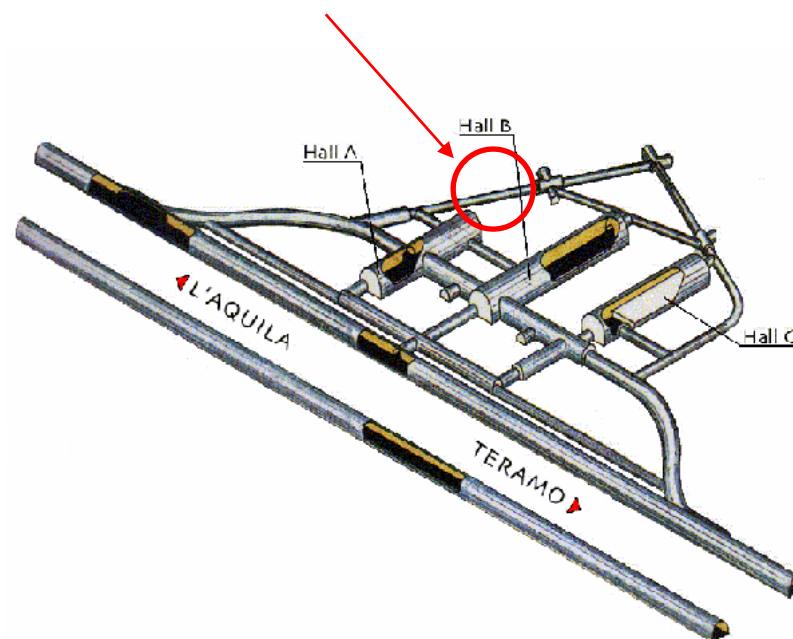


## **REMINDER: XENON10**

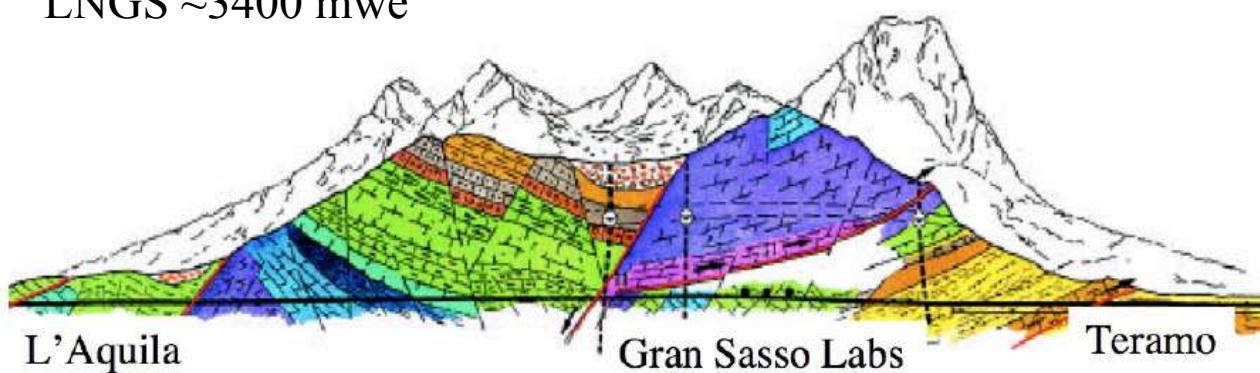
In operation at LNGS 2006-2007

- Physical **active region** : cylinder r=10cm z=15cm  
22 kg LXe, 15 kg active, 5.4 kg fiducial
- **Shielding** 20 cm poly + 20 cm lead
- **Readout** : 89 PMTs Hamamatsu R8520 (48T+41B)  
1"- Al body  
Bialkali photocathode Rb-Cs-Sb  
Quantum efficiency > 20% @178 nm



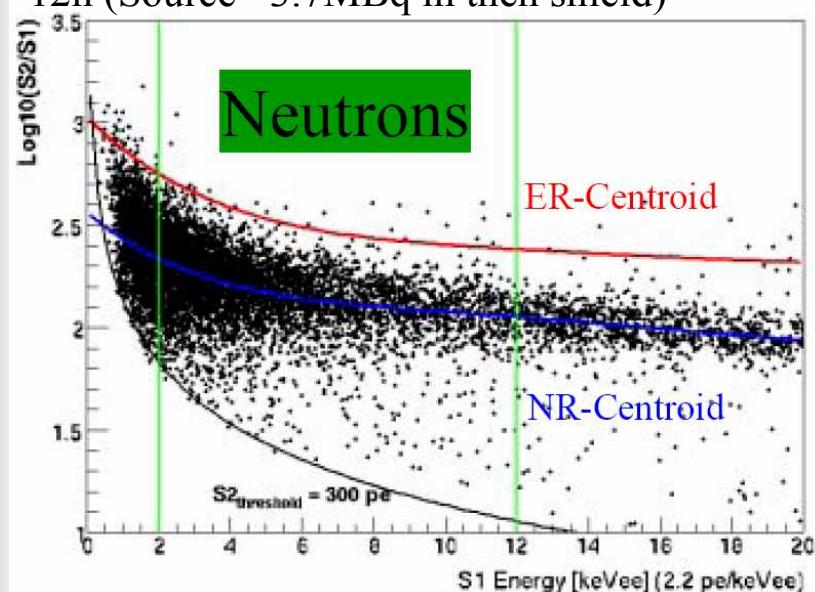


LNGS ~3400 mwe

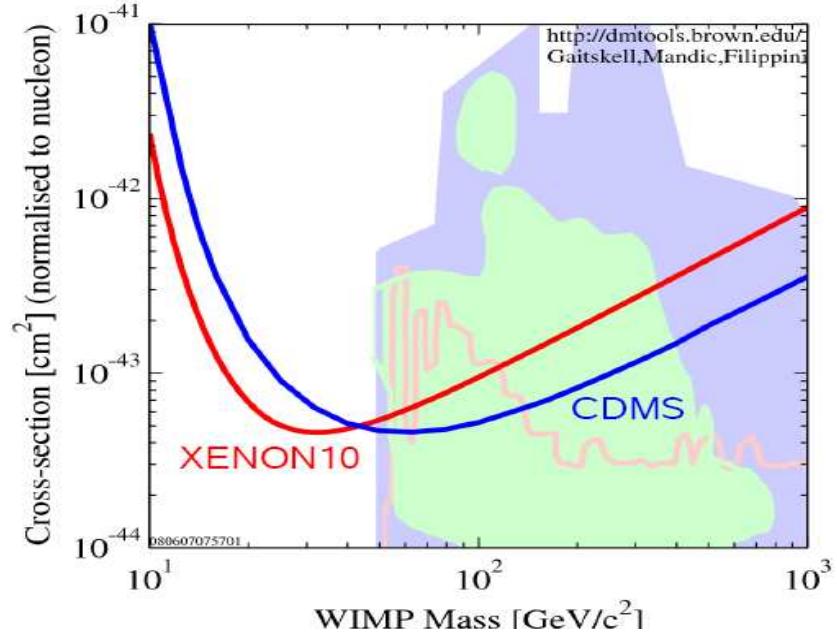
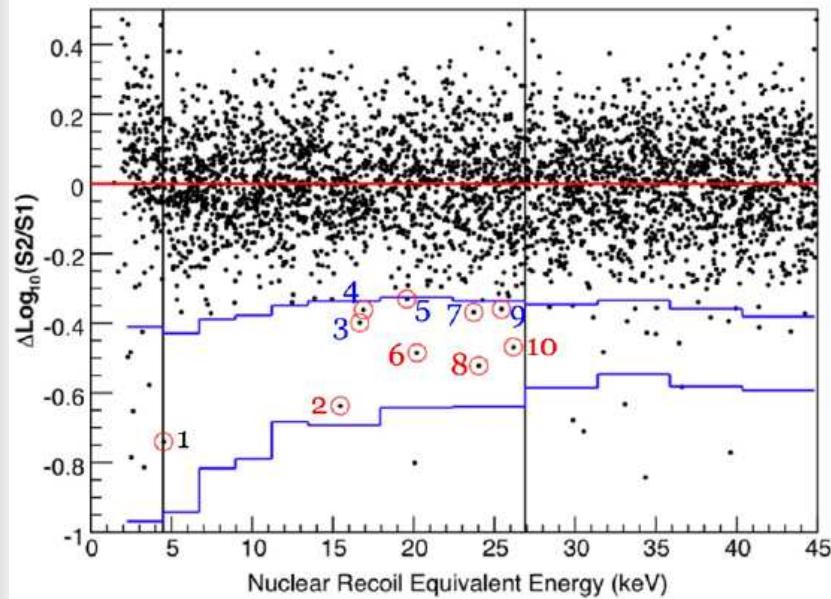
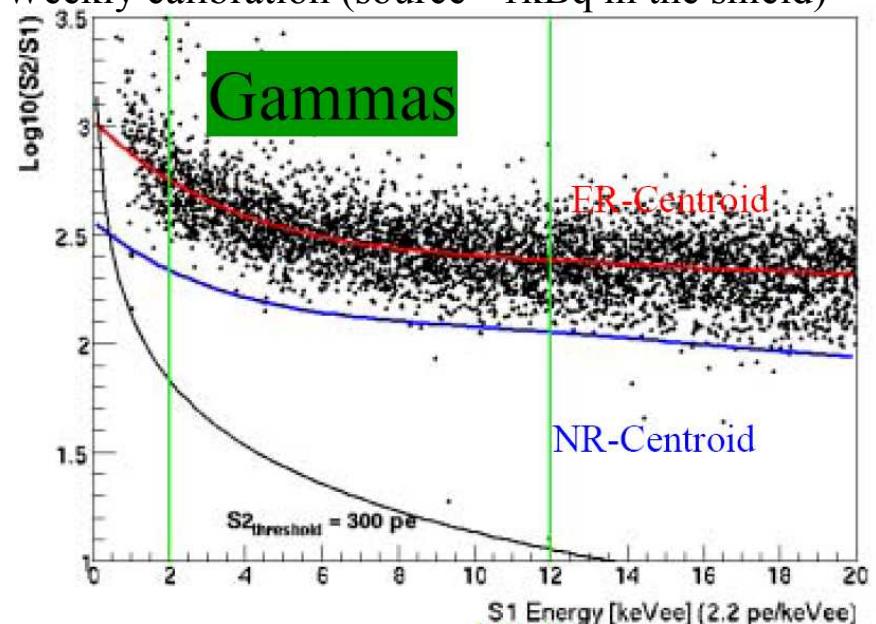


# XENON10: background rejection power

AmBe neutron calibration (NR-band)  
12h (Source ~3.7MBq in then shield)



Cs-137 Gamma Calibration (ER-band)  
Weekly calibration (source ~1kBq in the shield)



# *XENON100 collaboration*

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*UCLA*



*Columbia*



*Rice*



*Zurich*



*Coimbra*



*Gran Sasso*



*MUENSTER*



*SUBATECH*



*WASEDA*



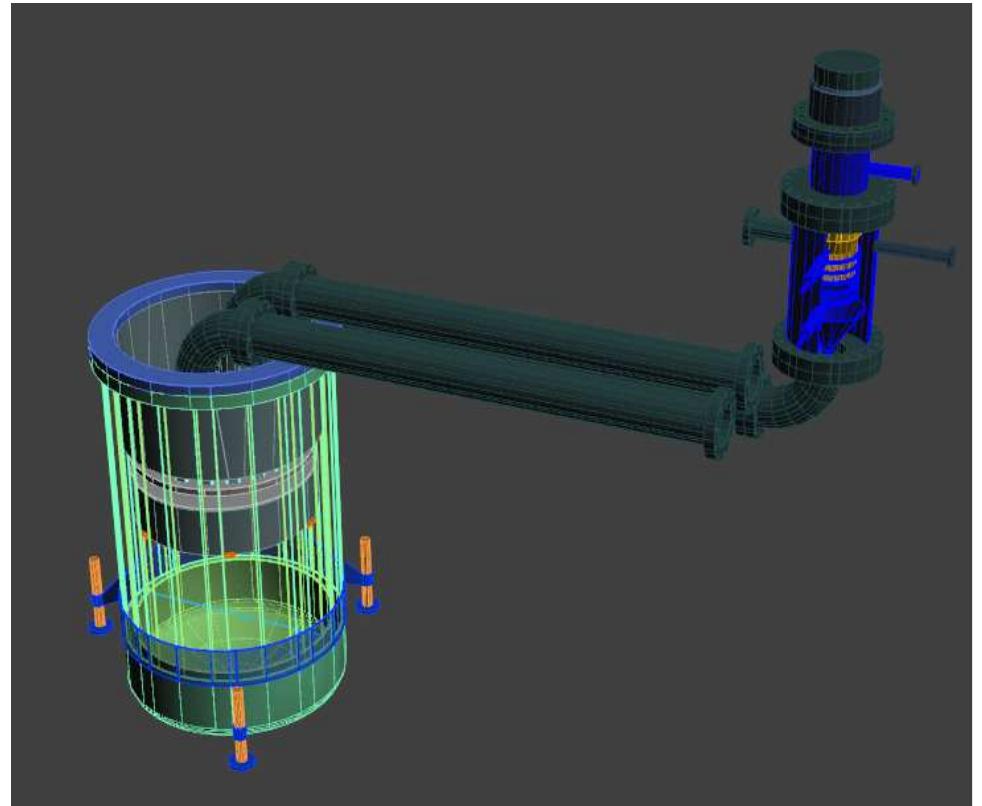
*SJTU*

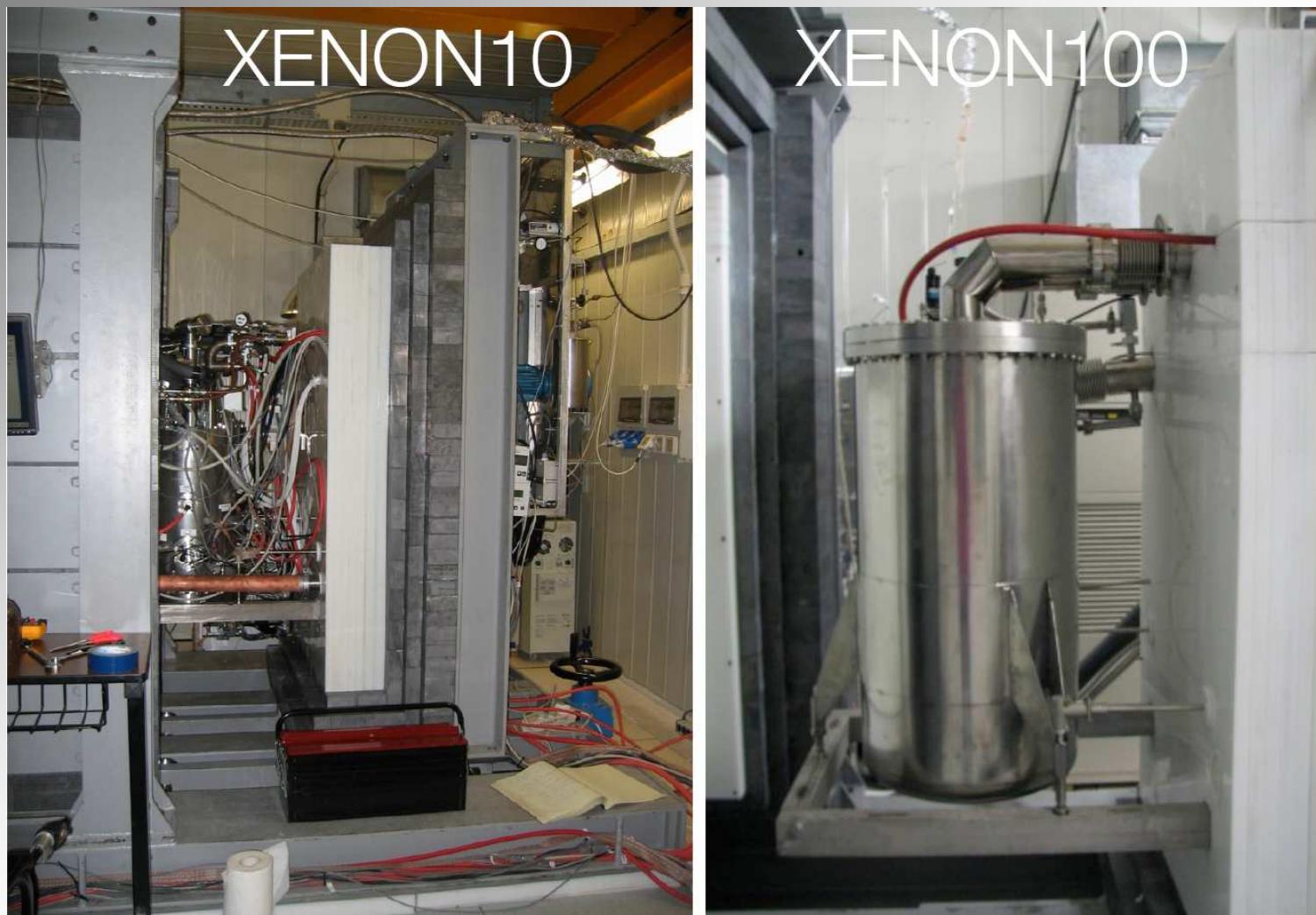
***Goal:*** gamma background reduction by  $\sim 100$  and fiducial mass increase by  $\sim 10$  respect to XENON10

# XENON100 DETECTOR

New detector in the same location at LNGS (moved UG on spring 2008)

- ~170 kg total / ~65 kg target LXe (15 cm radius , 30 cm drift)
- Cryocooler and feed-through outside the shield
- Active LXe veto – improved shield (Pb,Poly,Cu,N<sub>2</sub> purge)
- New high QE (>32%@175nm) low activity 1" R8520 PMTs (total 242 PMTs)
- Material screening facility at LNGS (gamma background reduction ~100))





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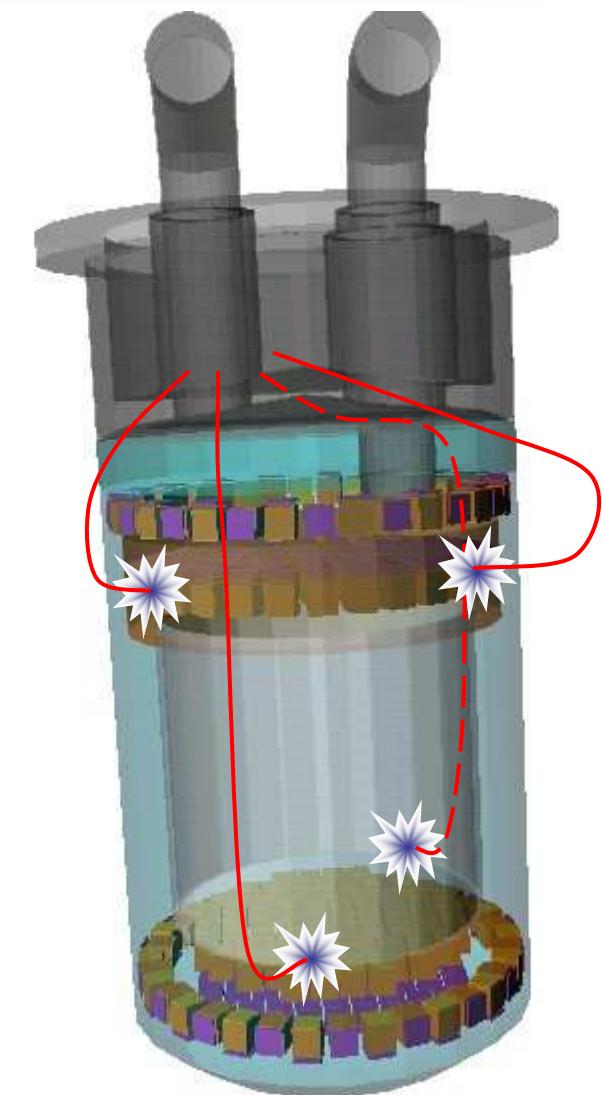
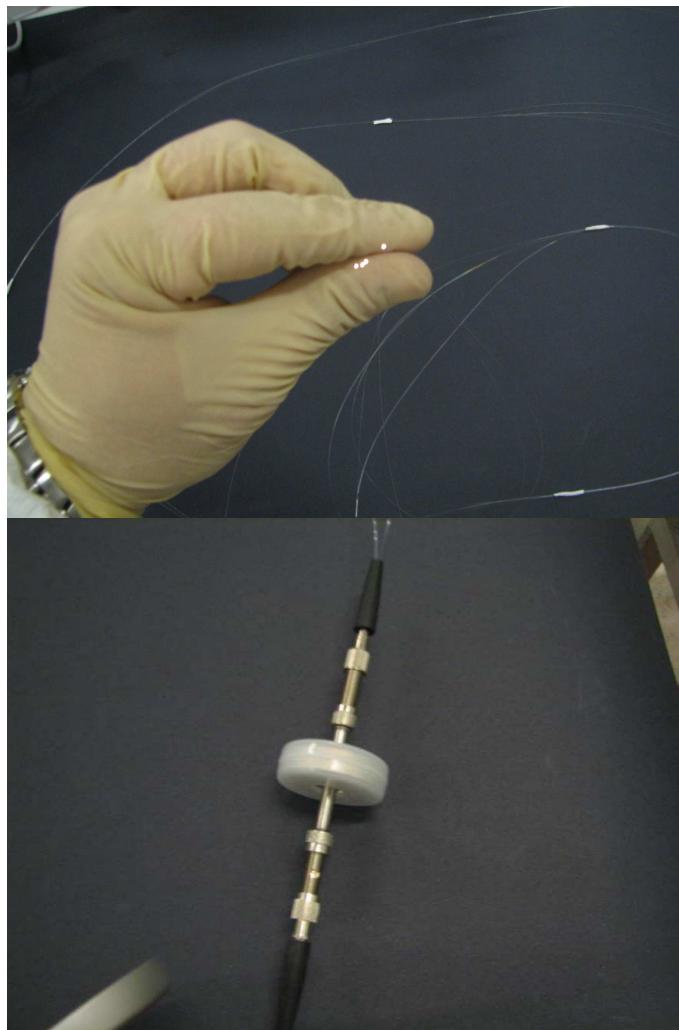
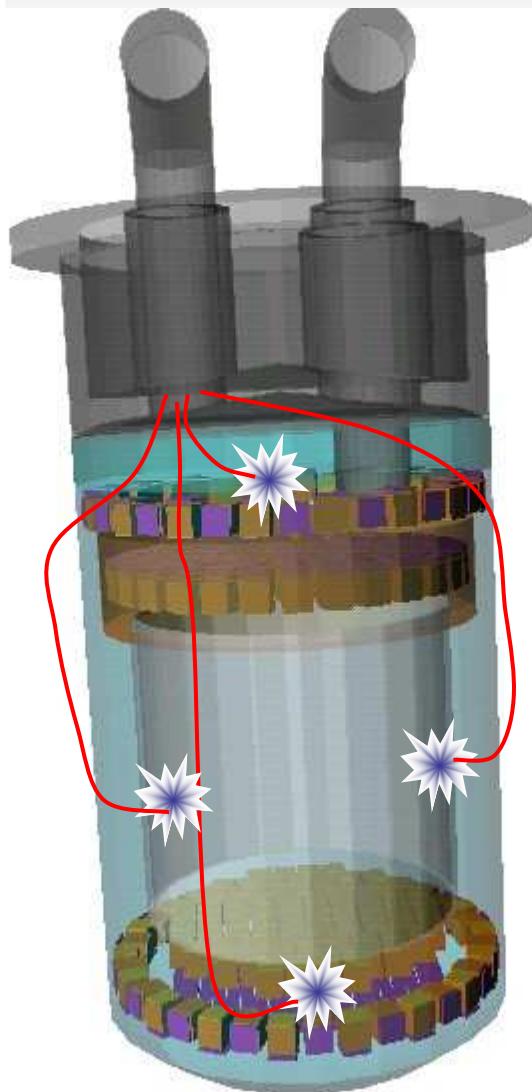
## ***DETECTOR: COOLING AND PURIFICATION***

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- 200 W PTR cryocooler
- Continuous Xe purification (Getter) —> •  $H_2O$  level < 1 ppb
- Kr distillation column
- 10 slpm recirculation (5 slpm Xe10)
- Electron drifted through the full gap



# *LIGHT CALIBRATION SYSTEM*



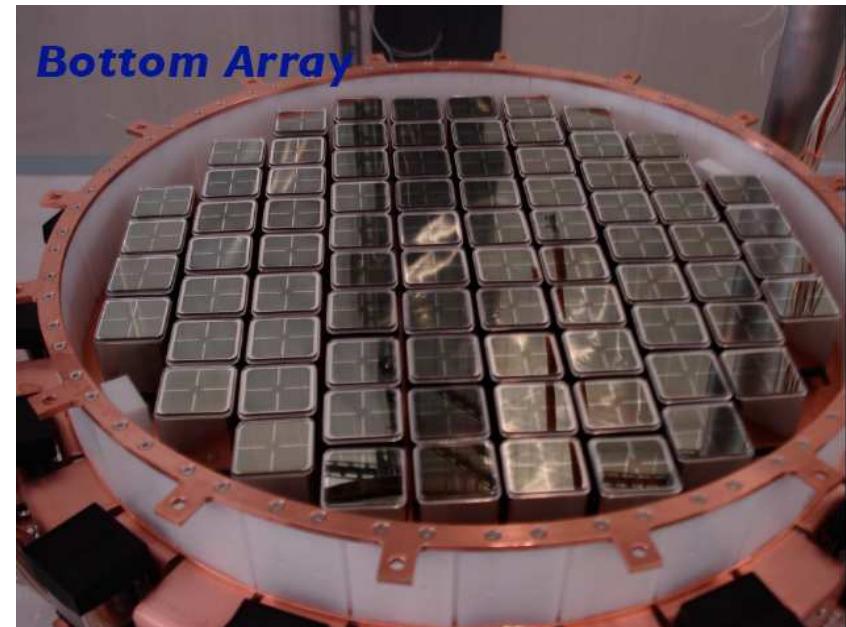
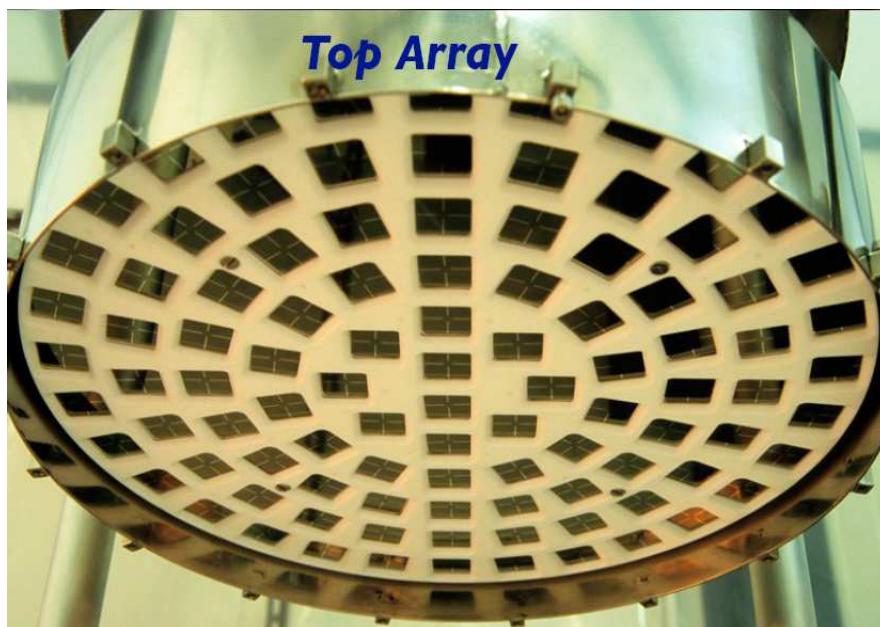
# DETECTOR: PMTs

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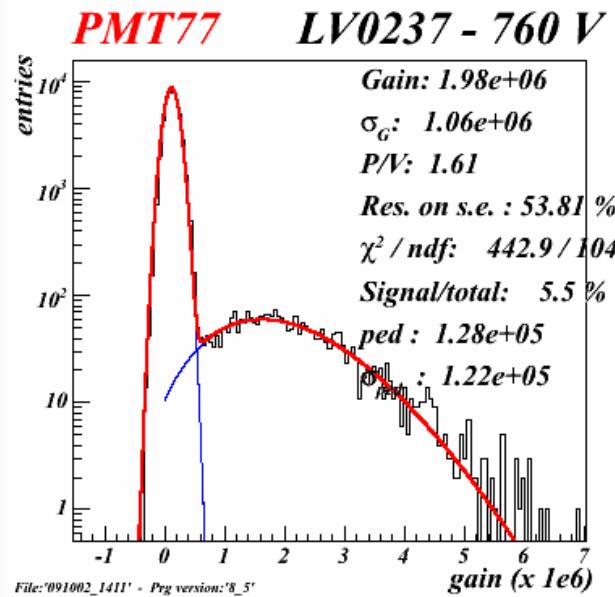
**242 Hamamatsu R8520 :**  
*1" x 1" active area,  
low radioactivity,  
high QE (~ 33% @ 175 nm)*



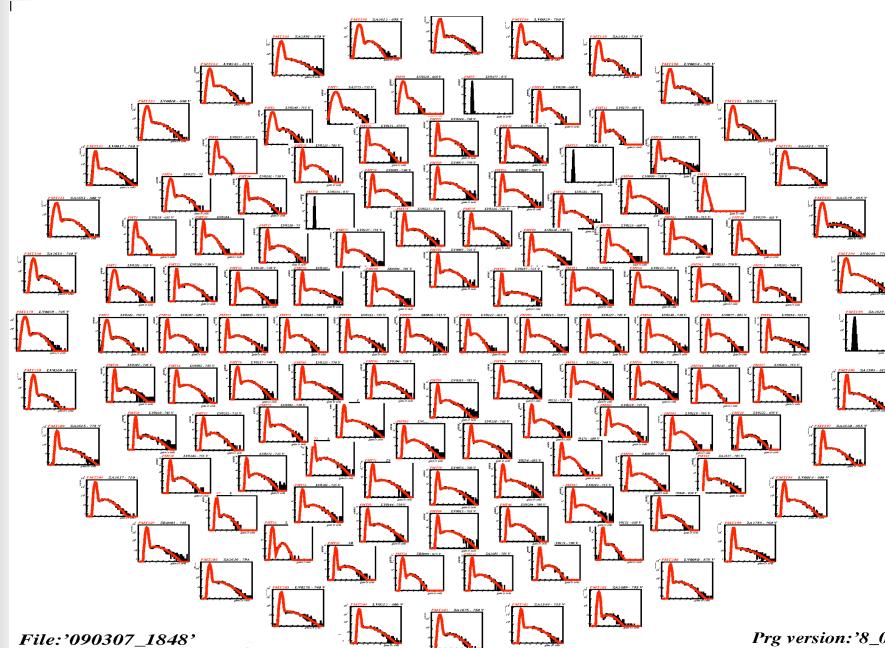
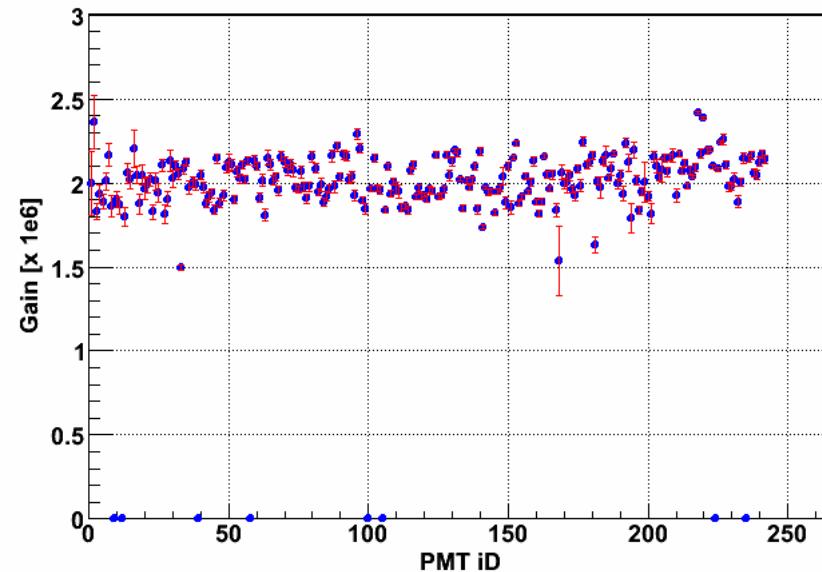
- 98 PMTs top array: selected for good position reconstruction (fiducial volume)
- 80 PMTs bottom array: selected for optimizing S1 light collection (low threshold)
- 64 PMTs active veto: Average LCE 4.7%    trigger efficiency in veto ~90% at 50 keVee



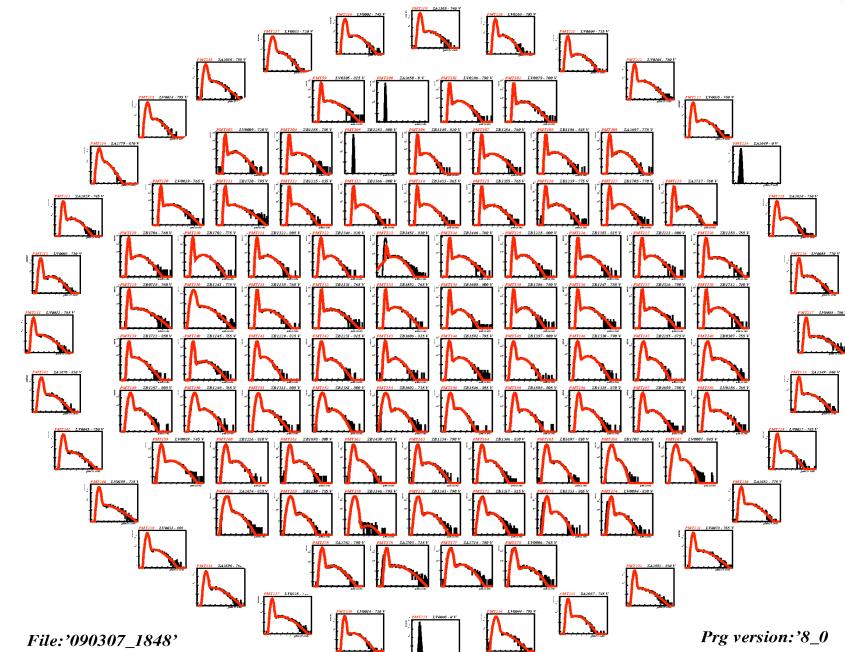
# PMTs: GAIN (AND QE) ESTIMATION



PMT 1-242, 091002\_1411

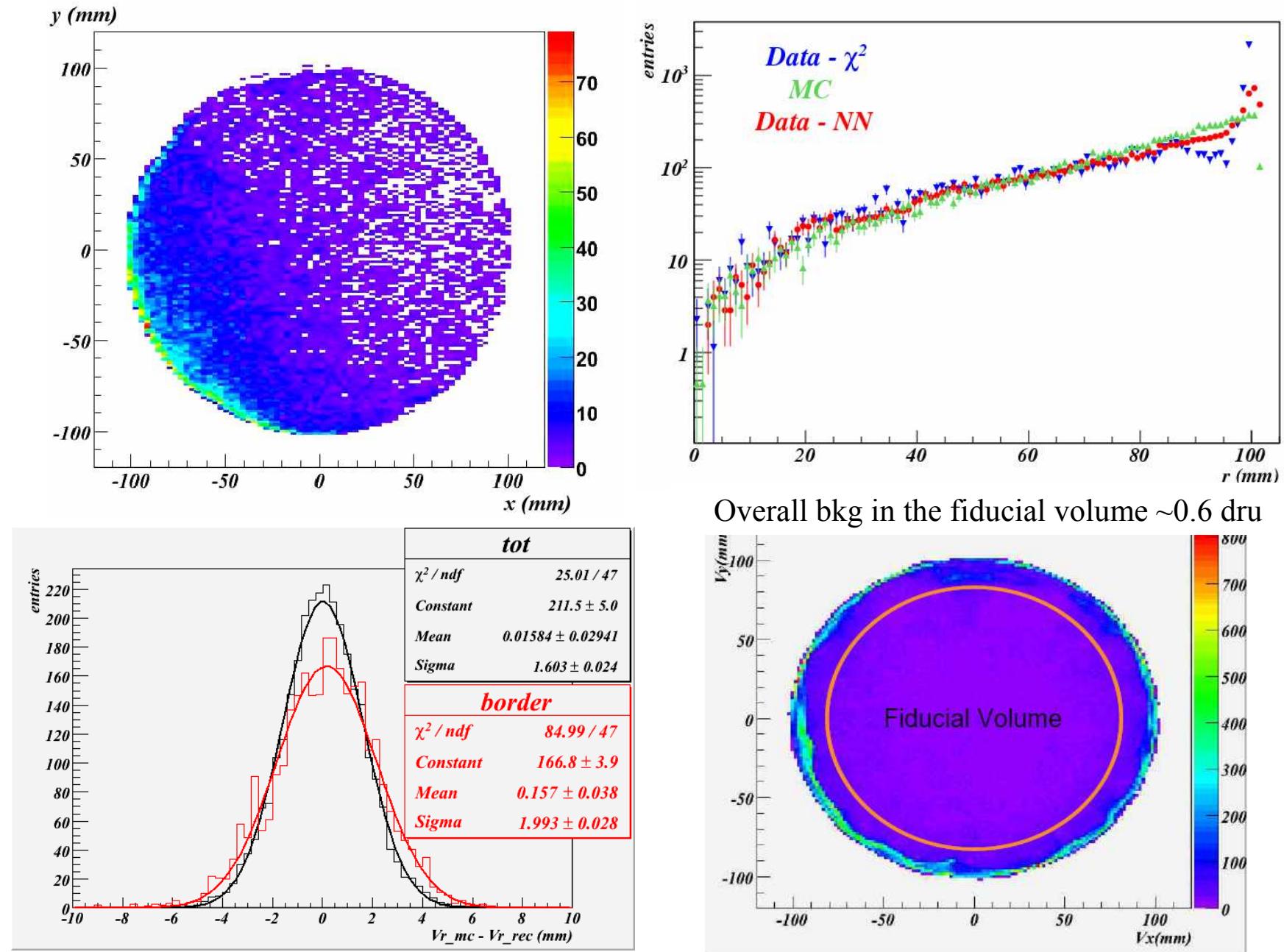


Prg version: '8\_0'



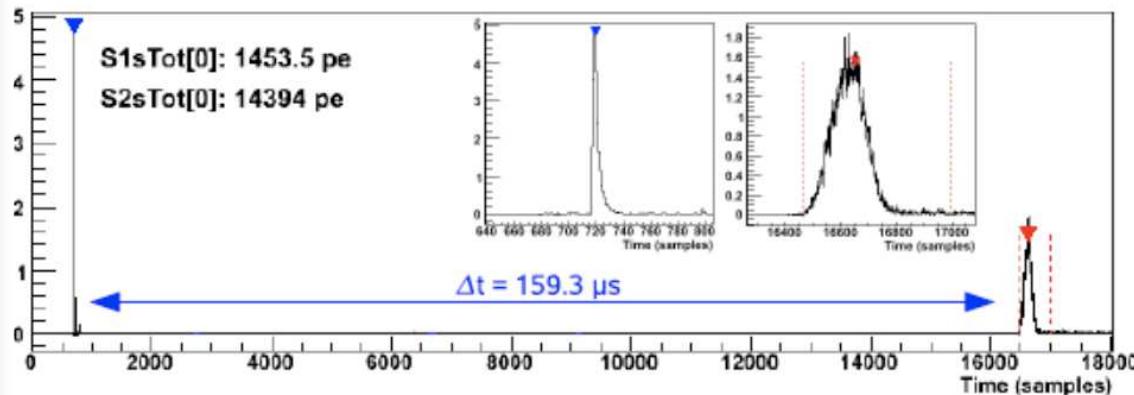
Prg version: '8\_0'

# POSITION RECONSTRUCTION

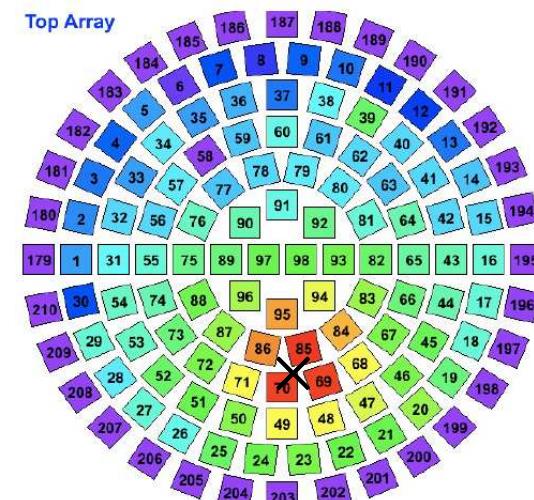


# CALIBRATION: ENERGY

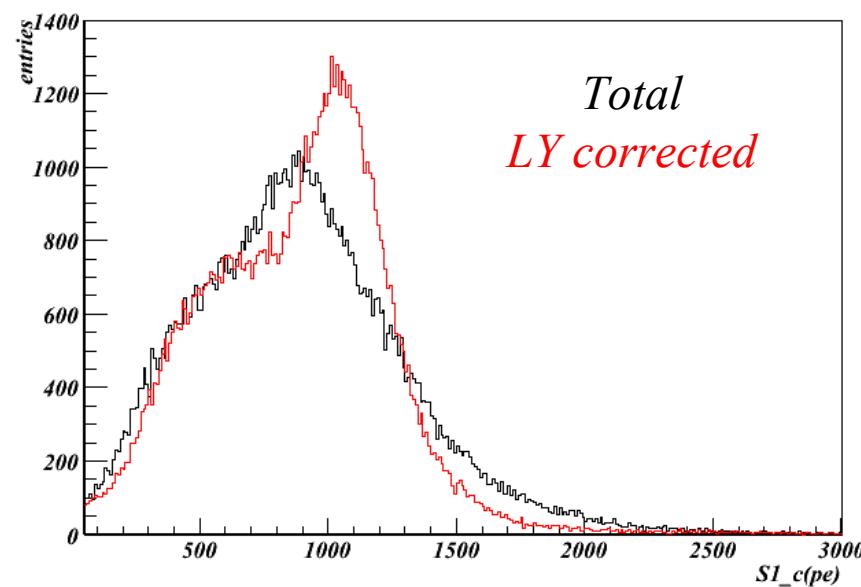
## *Cs<sup>137</sup>source*



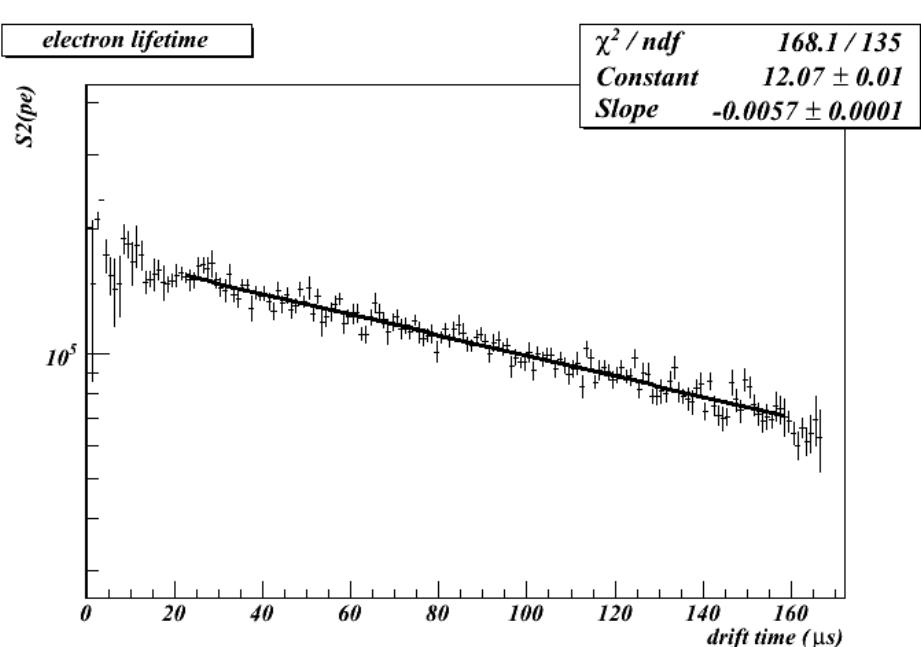
## *S2 light pattern*



## *S1 corrected - <sup>137</sup>Cs*



## *electron lifetime*

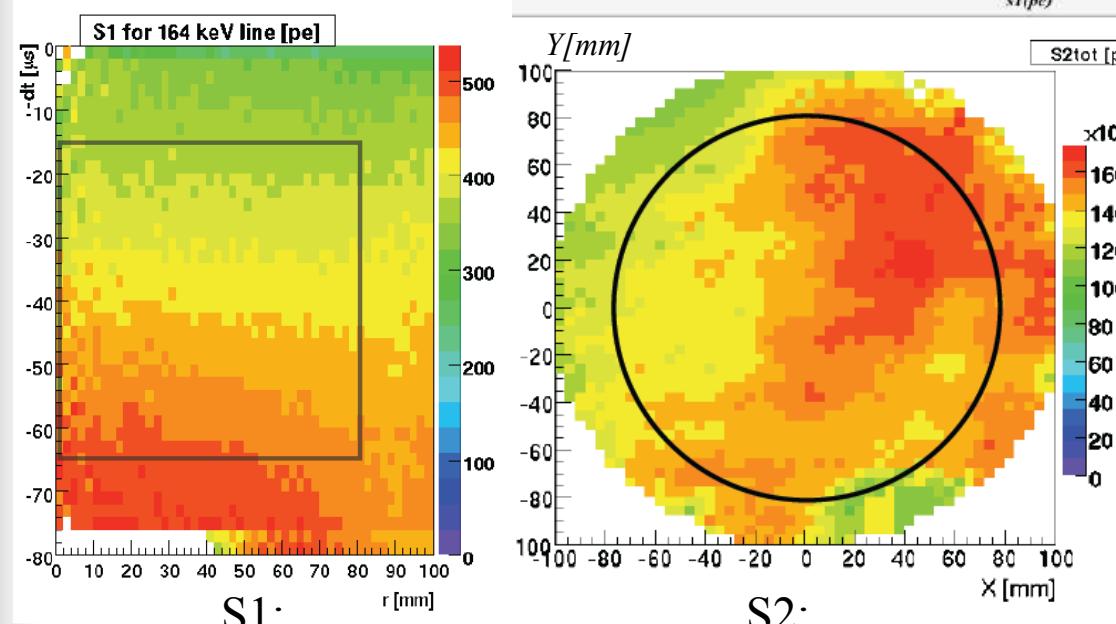
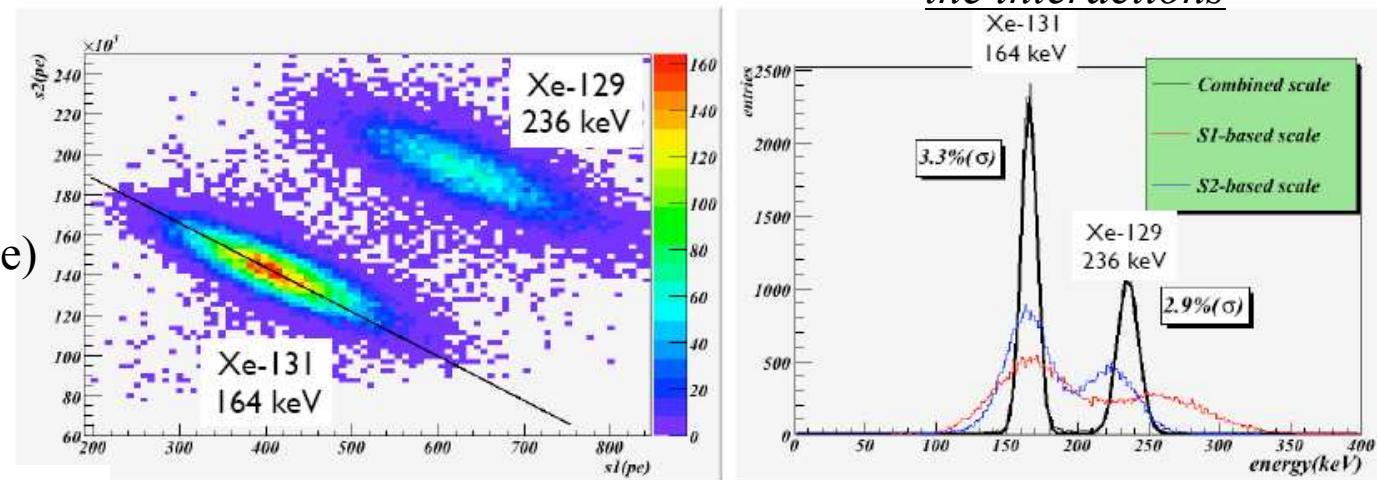


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# CALIBRATION: ENERGY

- Calibration with gamma sources ( $^{57}\text{Co}$ ,  $^{60}\text{Co}$ ,  $^{137}\text{Cs}$ ,  $^{228}\text{Th}$ ) → Non uniform distributions of the interactions

Gamma ray peaks  
164 keV – 236 keV  
(from  $^{129m}\text{Xe}$  and  $^{131m}\text{Xe}$ )



S1:  
20% variation across z  
~constant with r

S2:  
20% variation on xy

Not the proper calibration for our energy range of interest:



$^{83m}\text{Kr}$  lines at 32 keV and 9.4 keV  
Produced by the decay of  $^{83}\text{Rb}$ .

arXiv:0908.0616 [astro-ph.IM]

# CALIBRATION: NUCLEAR RECOIL BAND

Nuclear recoil energy calibration

$$E_{nr} = \frac{S_1}{L_y L_{eff}} \times \frac{S_e}{S_r}$$

$S_1$  = signal in pe

$L_y$  = light yield @ 122 keV (pe/keV)

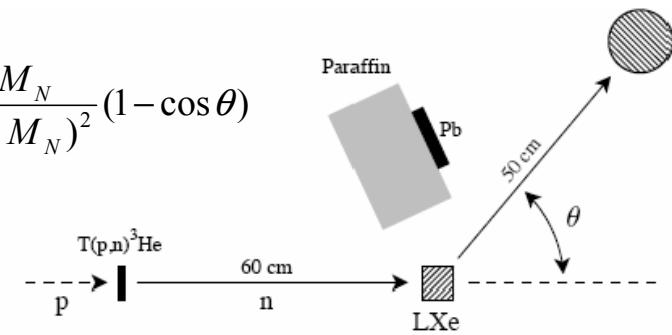
$L_{eff}$  = NR scintillation efficiency rel. to 122 keV (0 field)

$S_e$  = quenching of scintillation yield @ 122 keV due to the field

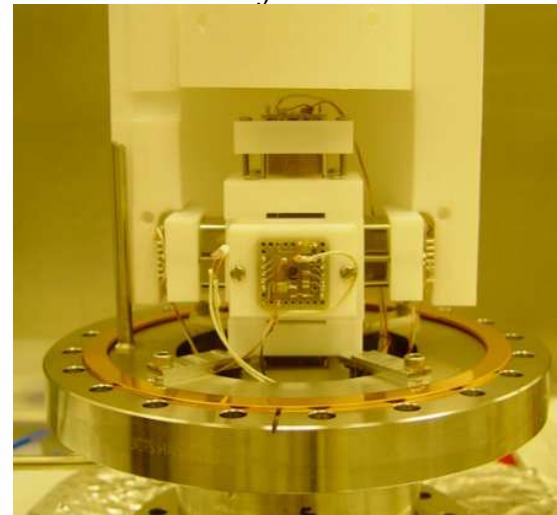
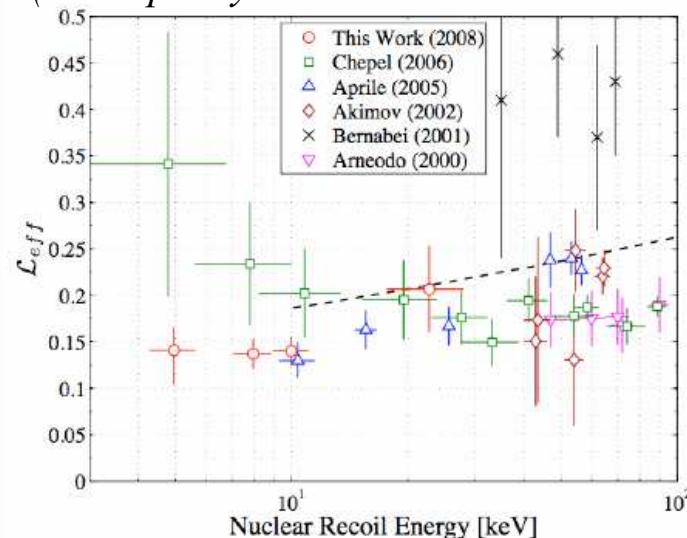
$S_r$  = " " " for NR

Single-phase LXe scintillation detector  
(>95% light coll efficiency – 25pe/keV)  
→ Neutron scattering experiment

$$E_{nr} \cong E_n \frac{m_n M_N}{(m_n + M_N)^2} (1 - \cos \theta)$$



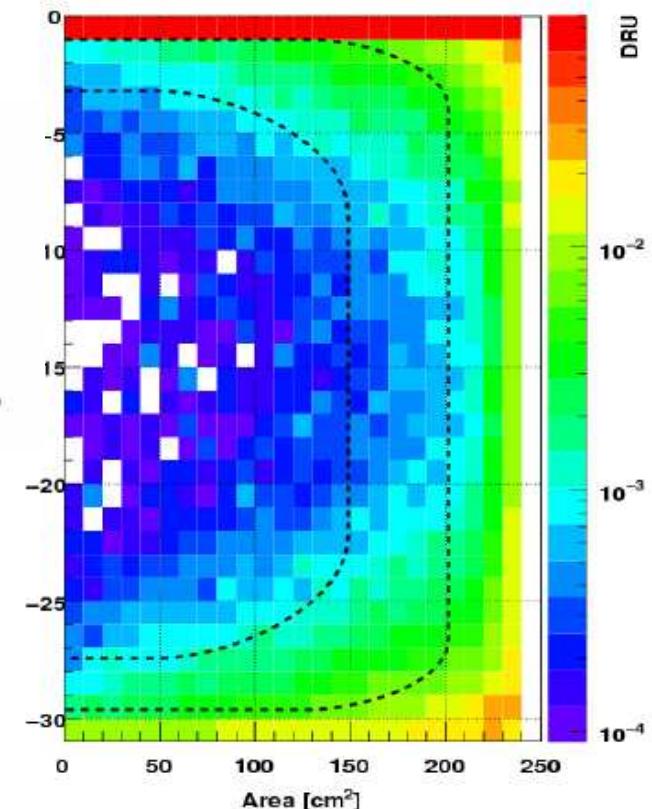
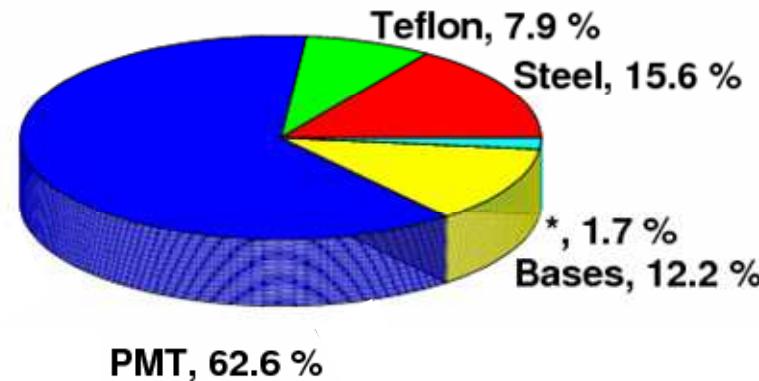
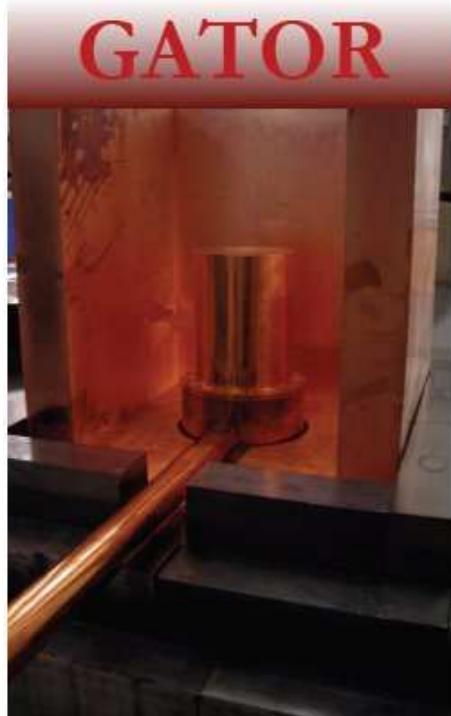
- Results consistent with previous data for  $E > 10$  keV
- Average value  $E < 10$  keV:  $L_{eff} = 0.14$   
(discrepancy with other data but consistent with the best fit on Xe10 neutron calib.)



Phys.Rev.C 79-045807

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## BACKGROUND: GAMMA



*Single scatter event rate in  
the region of interest (0-100keVee)*

Material	Rate[m dru] 50kg FV	Rate[m dru] 30kg FV
SS	3.98	1.68
Teflon	0.24	0.09
PMT	14.55	5.21
PMT Bases	1.61	0.49
Polyethylene	0.07	0.005
Support Bars	0.28	0.12
Copper	0.04	0.02
<b>Total</b>	<b>&lt;20.92</b>	<b>&lt;7.69</b>

*Factor 2-3 reduction with active veto cuts*

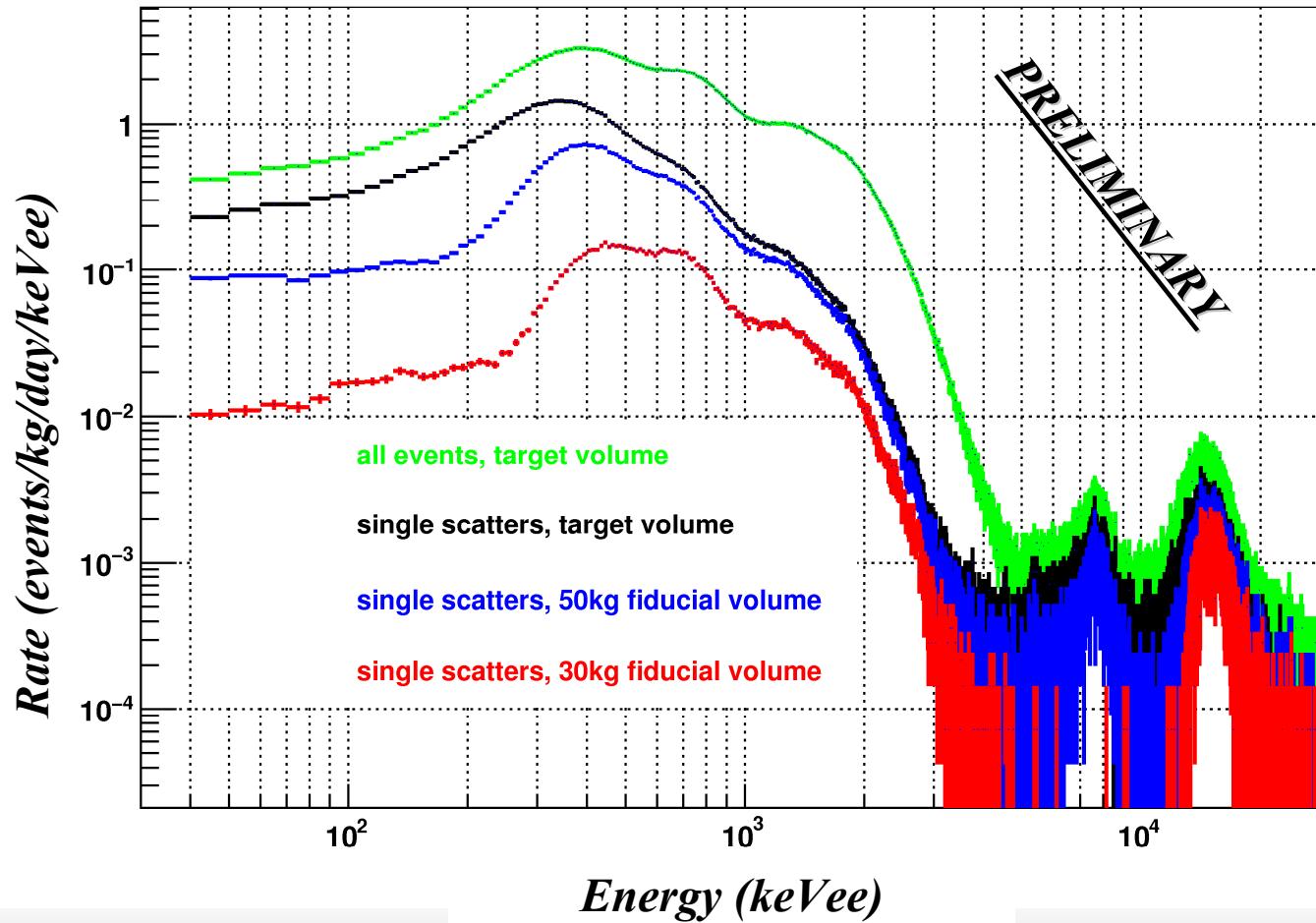
## *BACKGROUND: NEUTRON*

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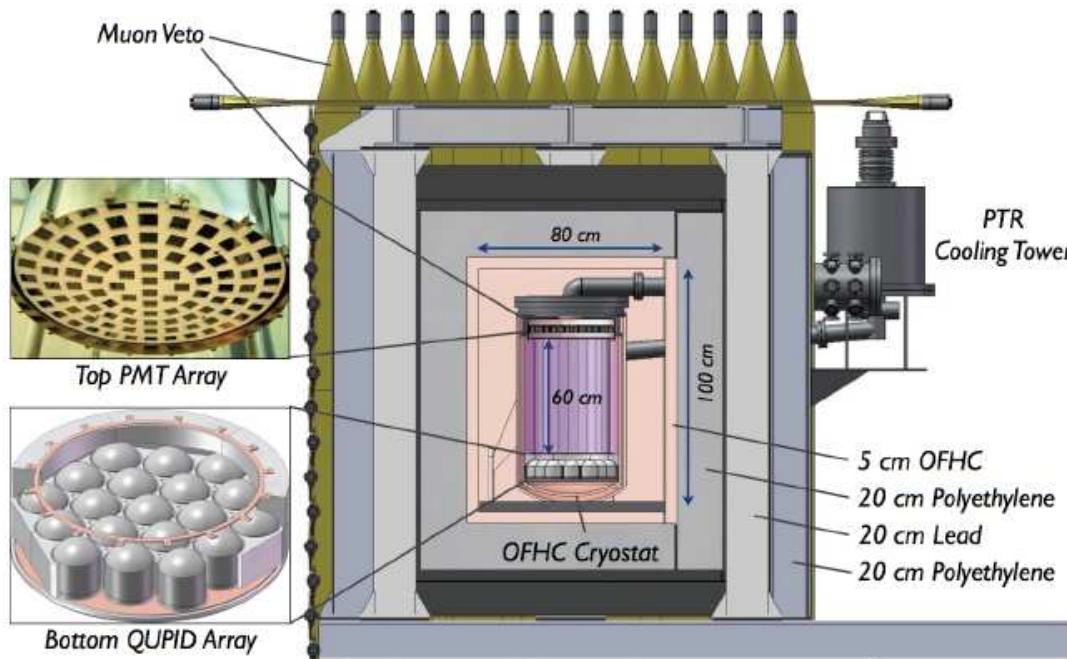
*Single nuclear recoil rated in WS region (4.5-26 keVnr)*

<b>Materials</b>	<b>Rate [per year] in 50 kg FV mass</b>	<b>Rate [per year] In 30 kg FV mass</b>
Stainless Steel	0.078	0.035
PMTs	0.255	0.108
Teflon	0.241	0.097
Lxe	0.002	0.001
Copper	0.105	0.048
Lead	0.004	0.002
Polyethylene	0.002	0.0006
Total material radioactivity	0.69	0.29
Rock-Concrete*	0.49 +/- 0.15	0.25 +/- 0.11
Muon-induced neutrons	0.54 +/- 0.24	0.10
<b>Total neutron background</b>	<b>1.72</b>	<b>0.64</b>

## *BACKGROUND : PRELIMINARY DATA*

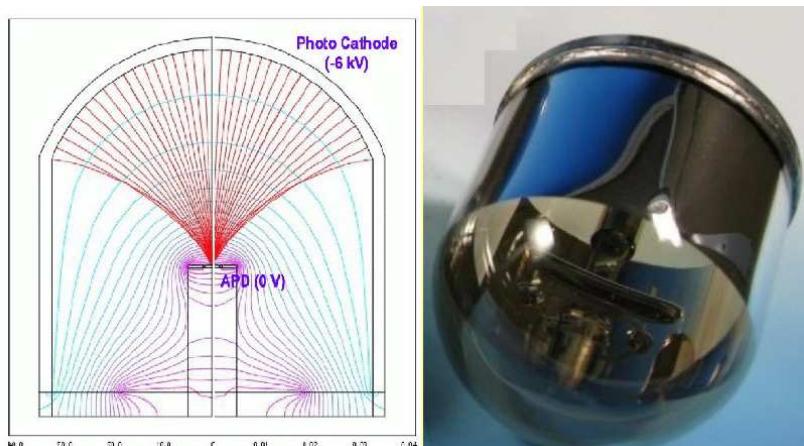


# XENON100+ (2010 - 2012)



- Fiducial mass  $> 100 \text{ kg}$
- Decrease background by a factor 10
- Increase sensitivity by a factor 10

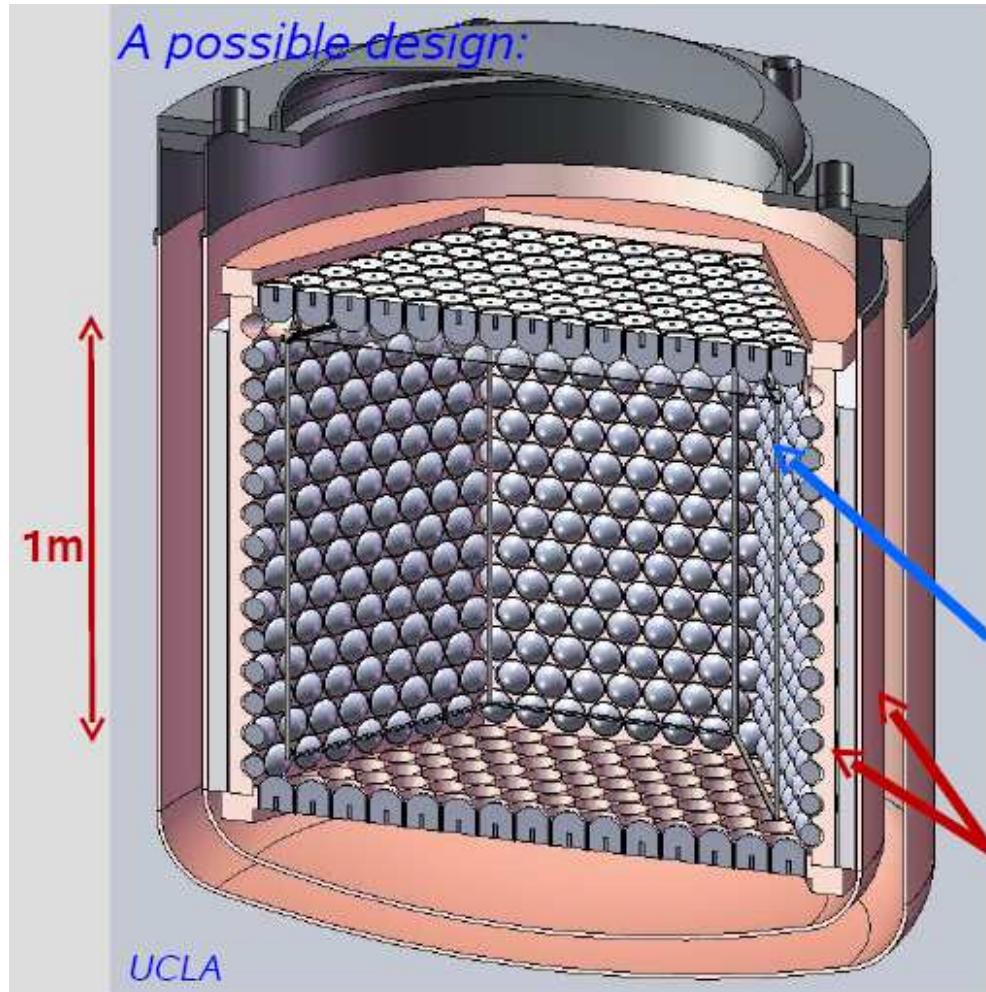
Funded by NSF



## Quartz Photon Intensifying Detector

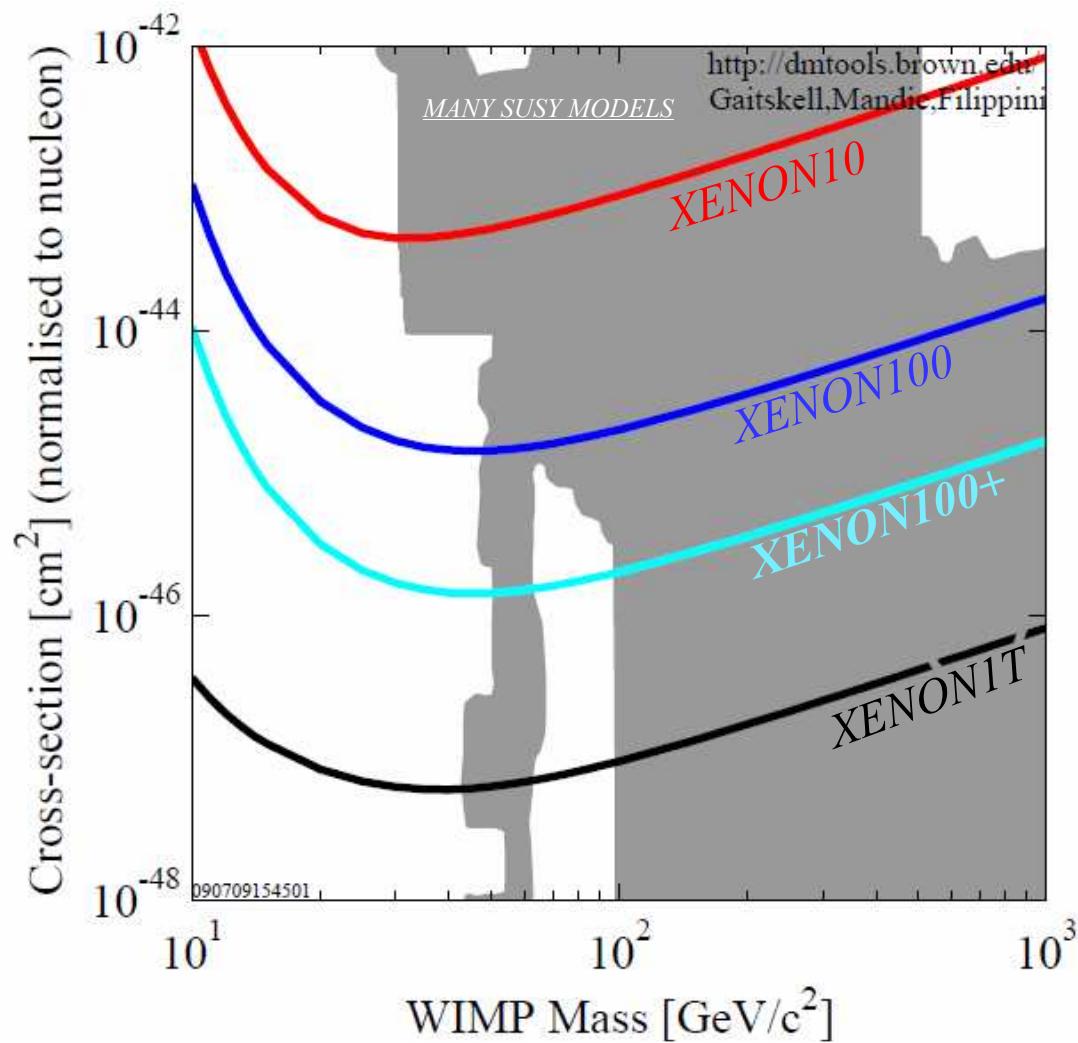
- Low radioactivity ( $< 1 \text{ mBq}$ )
- Large area (3")
- High QE ( $> 30\%$ )
- High spe resolution

## ***ULTIMATE GOAL: XENON 1t***



- *3t LXe total, 1t fiducial*
- *MC studies on going*
- *Timeline: 2013 - 2015*

# PROJECTED SENSITIVITY

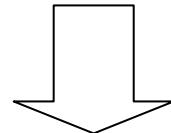


**Section II:**  
**GERDA experiment**  
**A search for neutrinoless double beta decay**

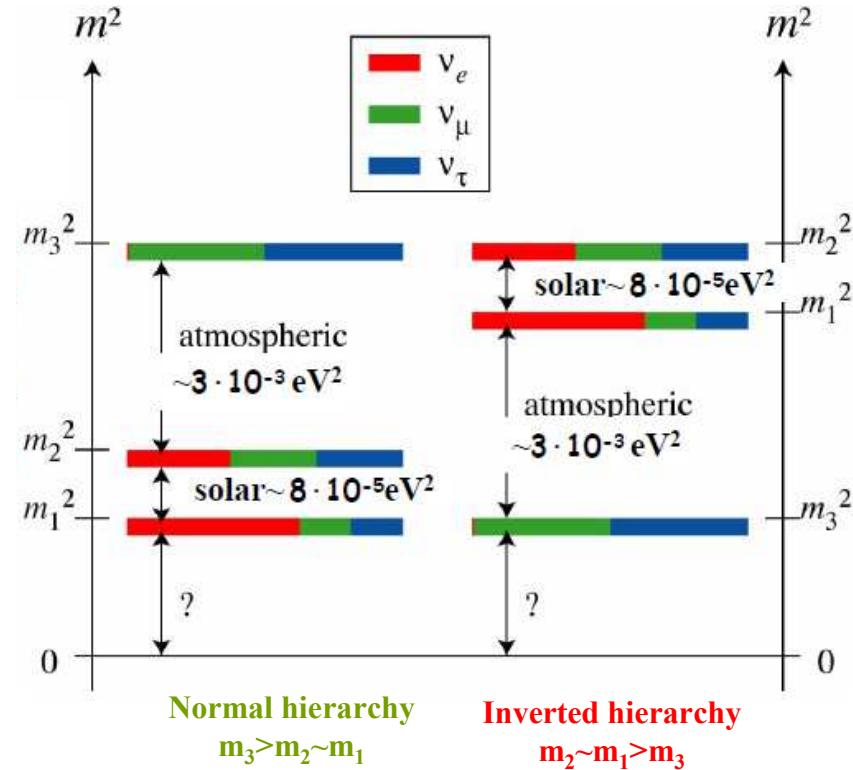
## MOTIVATIONS

Neutrinos mixing matrix  $U_{ij}$   
characterized by:

Three mixing angles  $\theta_{12}$   $\theta_{23}$   $\theta_{13}$   
One Dirac phase  $\delta$   
Two Majorana phases  $\phi_2 \phi_3$



$\theta_{12}$   $\theta_{23}$  measured – limits on  $\theta_{13}$   
Mass scale  $\Delta m^2_{12}$   $|\Delta m^2_{13}|$

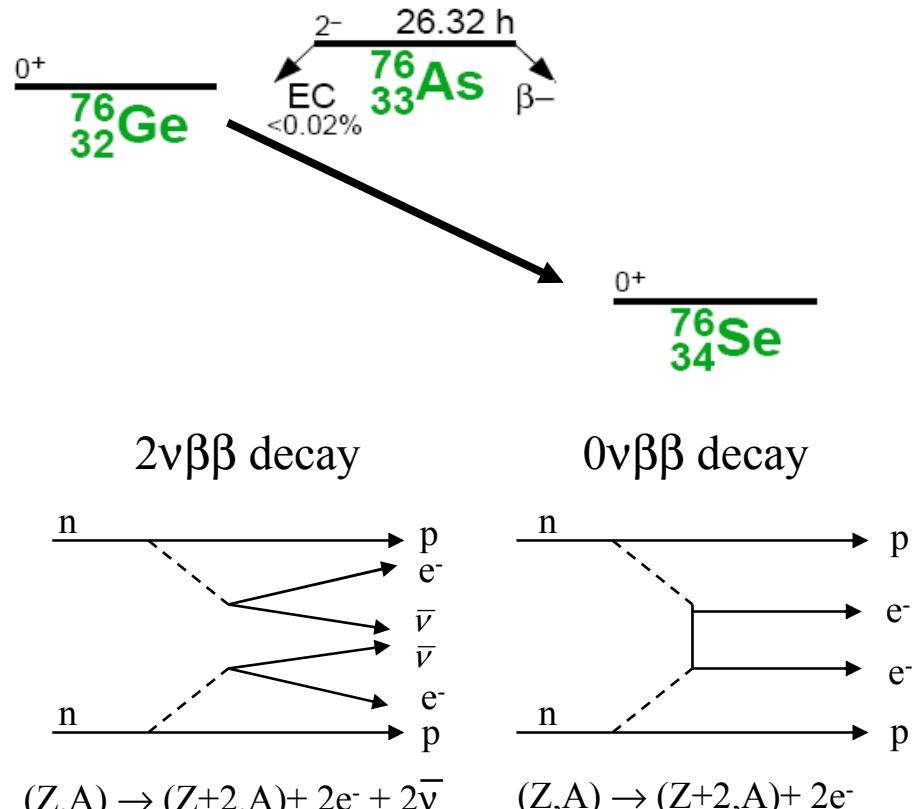


### Next challenges in neutrino physics:

- Majorana or Dirac nature of the particle
- Mass hierarchy
- Absolute mass scale

## DOUBLE BETA DECAY

Second order process detectable if the first order process is energetically forbidden



$$T_{1/2} \sim 10^{21} \text{y}$$

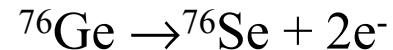
$$T_{1/2} > 10^{25} \text{y}$$

0ν mode forbidden in the SM

$\Delta L = 2$   
Possible only for  $\left\{ \begin{array}{l} \nu = \bar{\nu} \\ m_\nu \neq 0 \end{array} \right.$  (Majorana particle)

Candidate      Q(MeV)      Abund(%)

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



$$Q_{\beta\beta}(^{76}\text{Ge}) = 2039 \text{keV}$$

## EXPERIMENTAL SIGNATURE

$2\nu\beta\beta$  in  $^{76}\text{Ge}$ :  $T_{1/2} \sim 1.5 \pm 0.1 \cdot 10^{21} \text{ y}$

Peak at  $Q_{\beta\beta} = E_{e1} + E_{e2} - 2m_e$

2 electrons from the vertex + daughter isotope

$$\frac{1}{\tau} = G(Q_{\beta\beta}, Z) |M_{nucl}|^2 \langle m_{ee} \rangle^2$$

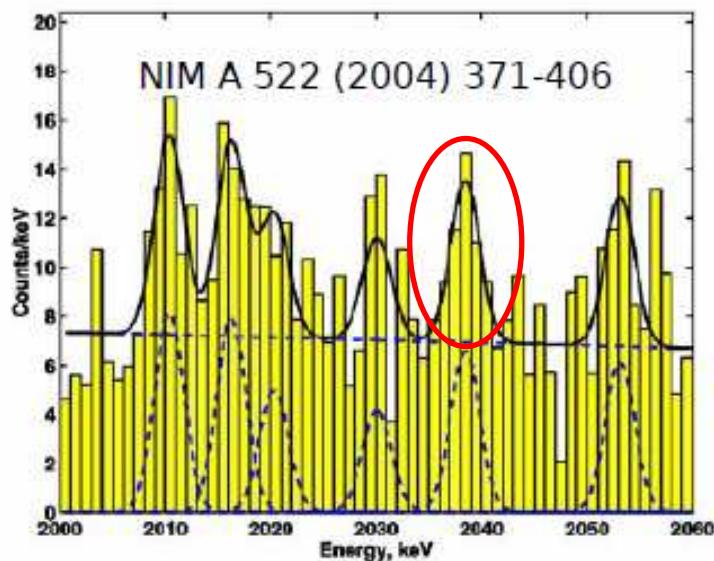
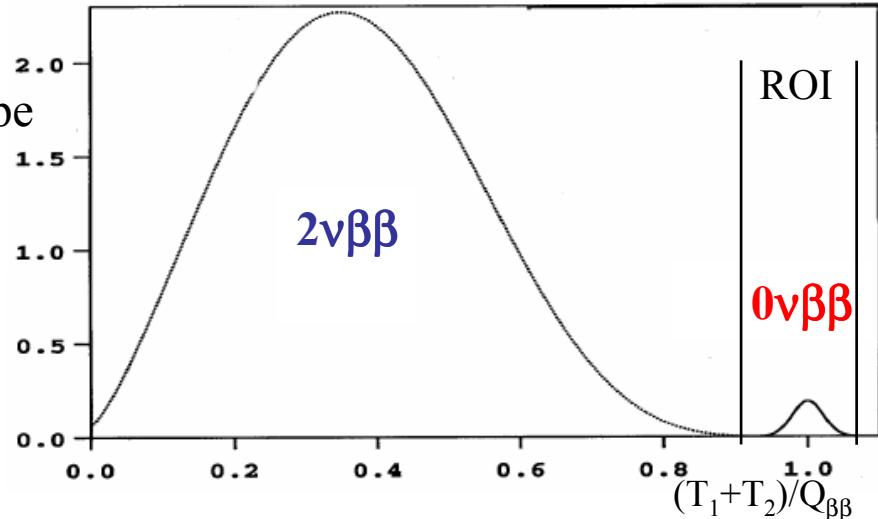
↓                      ↓                      ↓

Nucl. matrix element      Effective Majorana mass

Phase space  $\propto Q_{\beta\beta}^5$

Effective Majorana mass

$Q_{\beta\beta}(^{76}\text{Ge}) = 2039 \text{ keV}$



Heidelberg-Moscow experiment:

- 5 enriched Ge p-type crystals
  - background index  $\sim 0.1 \text{ cts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$
  - $71.7 \text{ kg} \cdot \text{y}$
  - $T_{1/2} = (0.69 - 4.18) \cdot 10^{25} \text{ y}$
- Claim of a signal by part of the collaboration

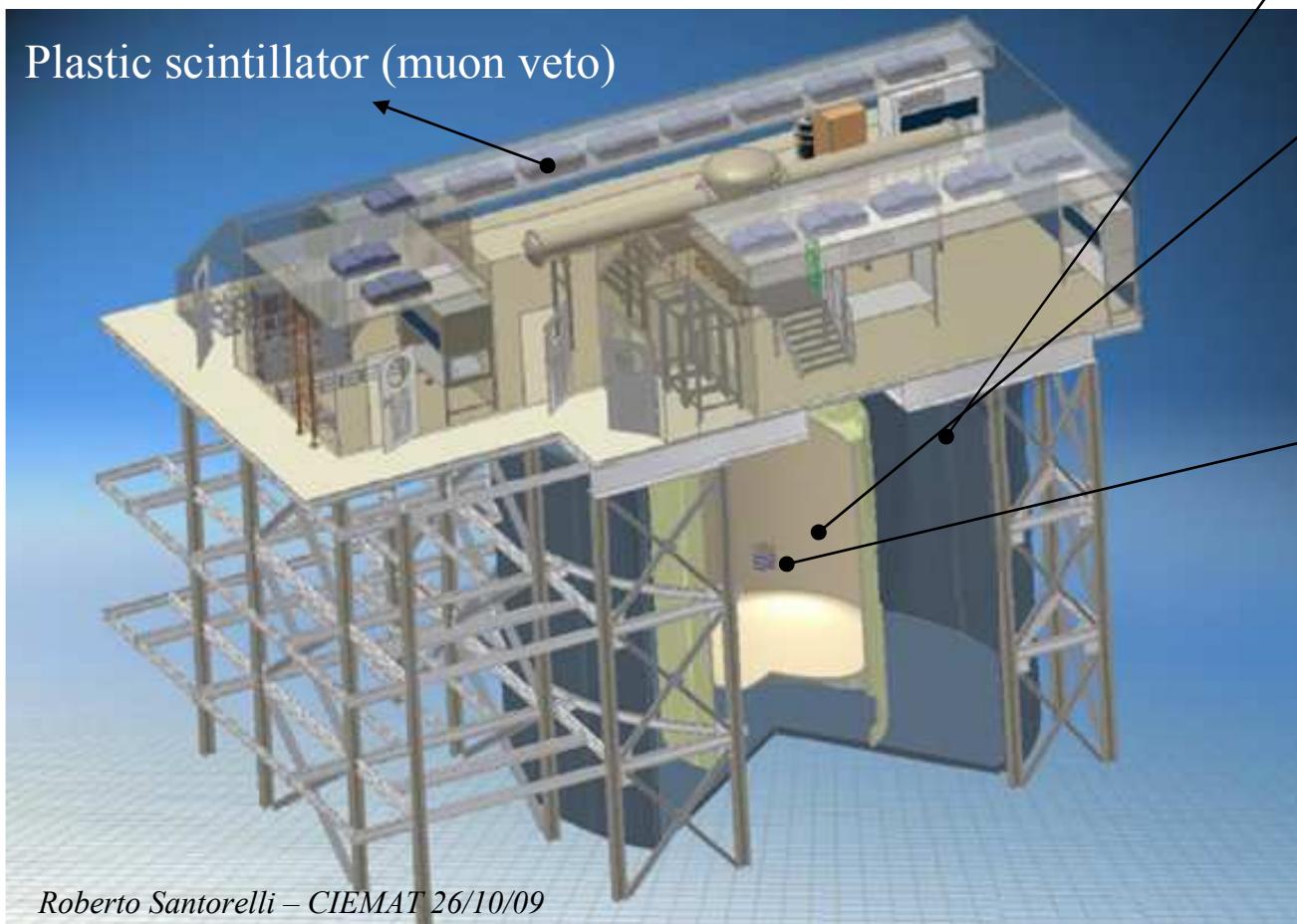
Klapdor-Kleingrothaus et al., Phys. Lett. B 586 (2004) 198.

## EXPERIMENTAL REQUIREMENTS

- Large amount of  $0\nu\beta\beta$  isotopes
- Good energy resolution
- Extremely low background

## GERDA →<sup>76</sup>Ge detectors for 0νββ

- High Q-value
- Very pure detectors → natural radioactivity contribution reduced
- Large target mass → Enrichment in <sup>76</sup>Ge (86%)
- Very good energy resolution → ΔE/E ( $Q_{\beta\beta}$ ) ~ 0.2%
- LAr as cooling and shielding
- Surrounding materials minimized



**Water tank**  
(r=5.0m h=9.0m)

- n shield
- Cherenkov veto

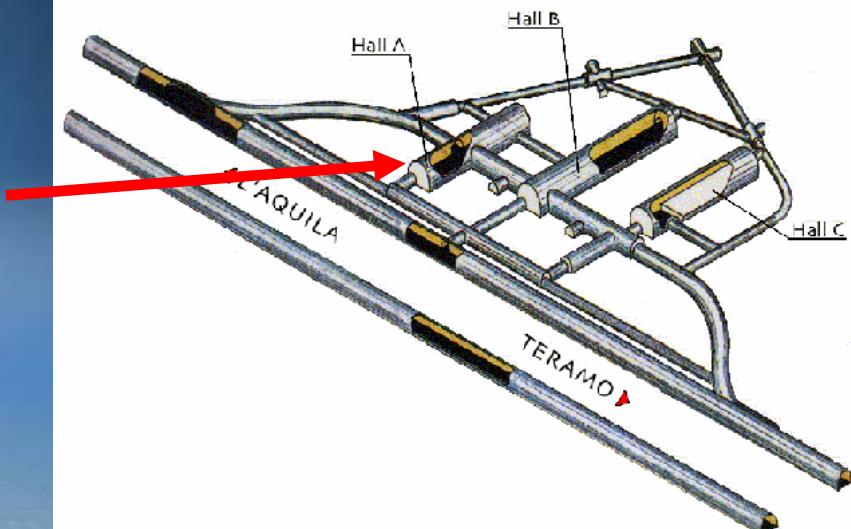
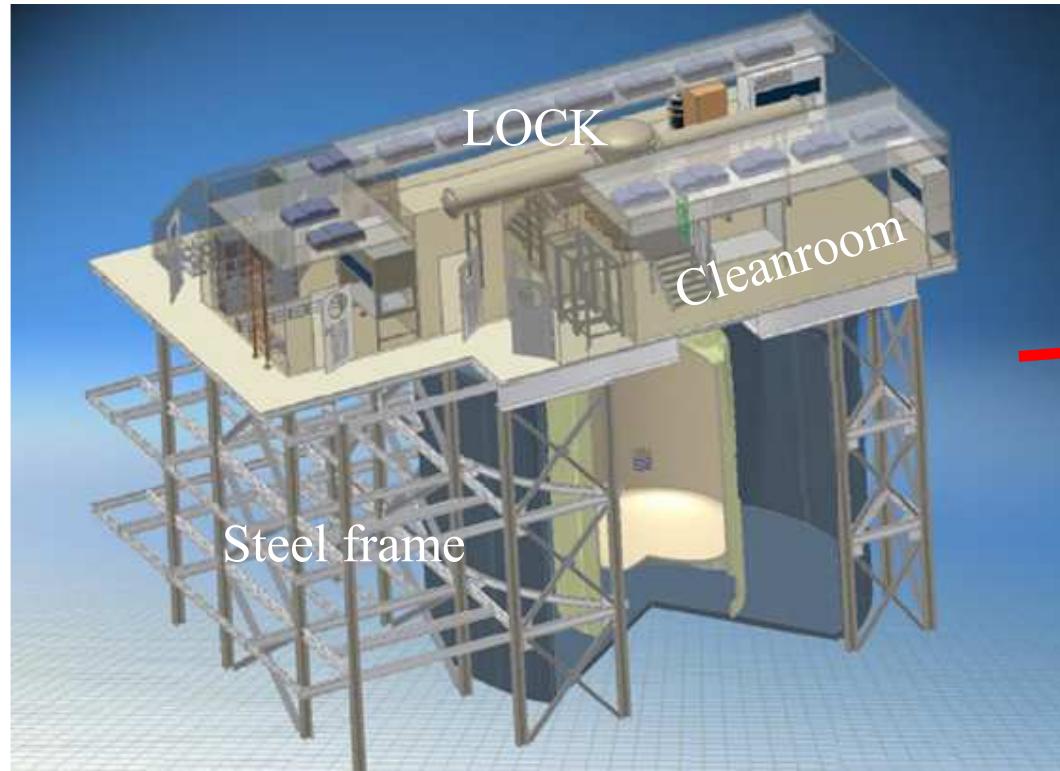
**Cryostat**

- (r=2.1m h=5m)
- cooling medium
  - passive/active shield



Up to 16  
strings

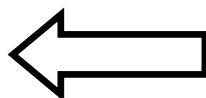
Detector loaded from top of  
the tank  
through a clean room area



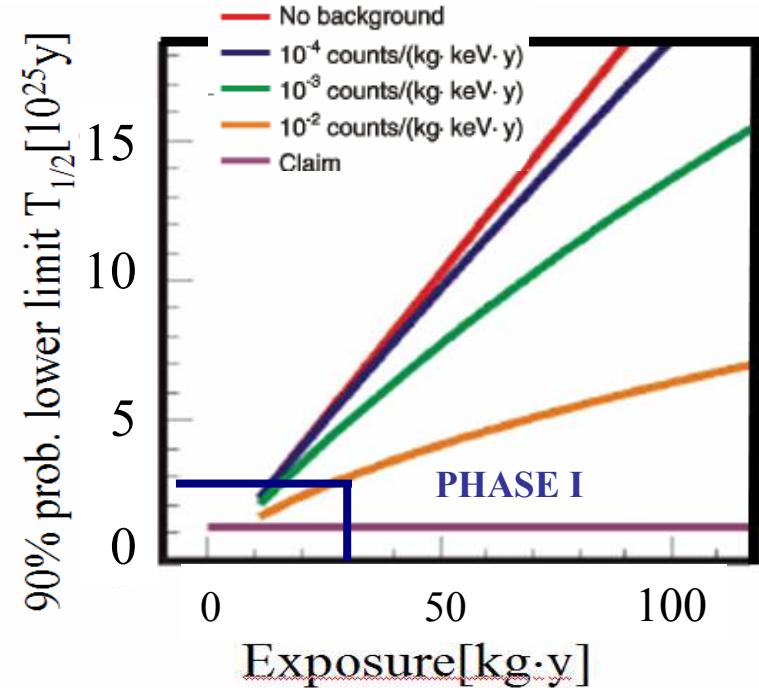
## PHASE I



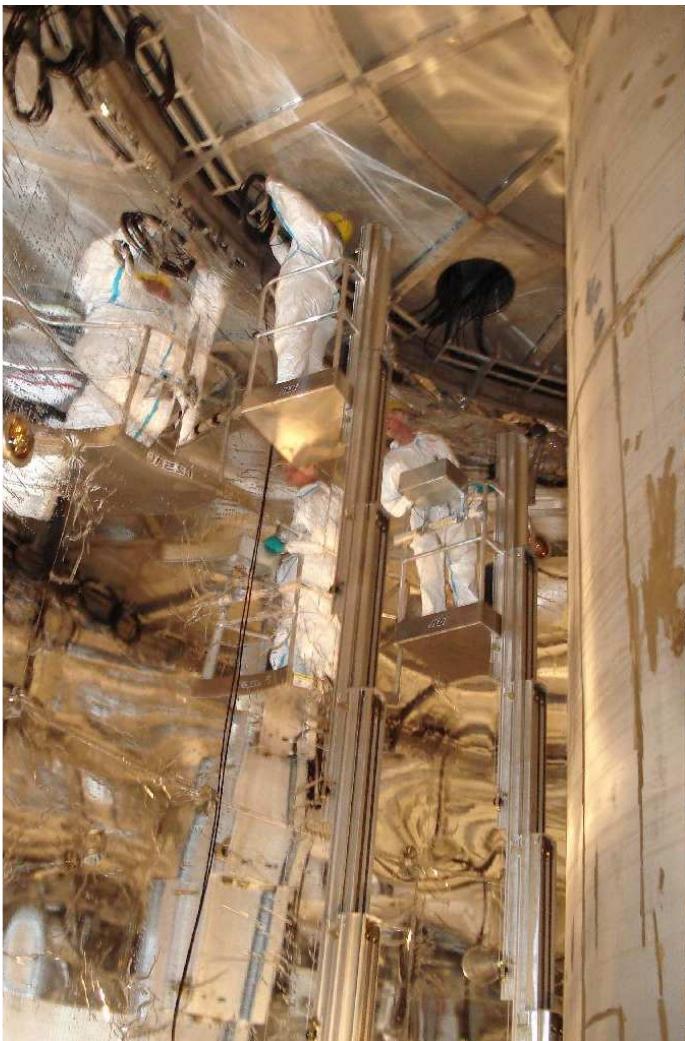
Check claim of Hd-Mo



- p-type coaxial detectors
- 5 He-Mo detectors
- 3 IGEX
- Refurbished by Canberra and tested in LAr
- Total 17.9 kg enriched Ge
- Exposure  $\sim 30 \text{ kg} \cdot \text{y}$
- bck:  $0.01 \text{ cts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$
- $T_{1/2} \rightarrow 2 \cdot 10^{25} \text{ y}$



## **PRESENT STATUS**



- Installation of the clean room (May 09)
- Mounting of the muon veto PMTs (Aug 09)
- Cryostat filling (Sep 09)
- Temporary commissioning lock for Phase I completed by the end of the year
- Phase I detector reprocessed and tested in LAr
  - FWHM (1.33MeV) ~ 2.5 keV
  - leakage current stable
- Phase II R&D ongoing



Cryotank (Mar. 08)

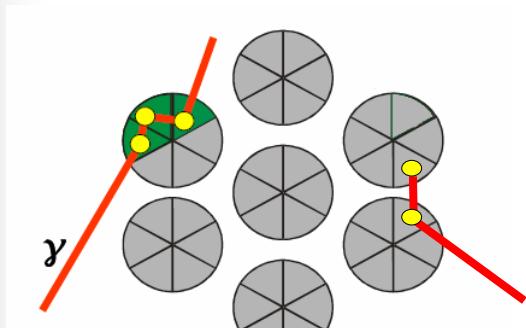


Water tank (Aug. 08)

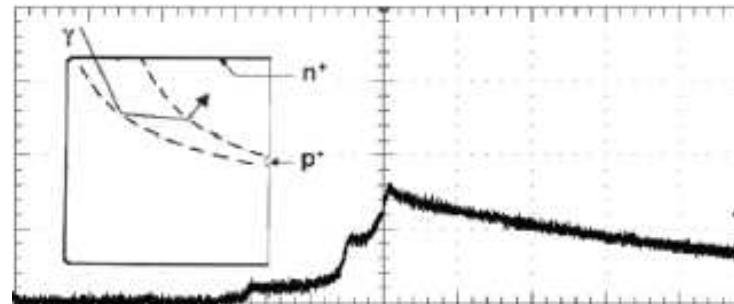
## PHASE II

- PHASE II** : add new p/n-type coaxial detector
- 86% enrichment
  - 37.5 kg already available
  - segmentation? unsegmented Broad Energy det?  
(R&D on ongoing)
  - Exposure  $\sim 100 \text{ kg} \cdot \text{y}$
  - bck:  $0.001 \text{ cts}/(\text{keV} \cdot \text{kg} \cdot \text{y})$
  - $T_{1/2} \geq 15 \cdot 10^{25} \text{ y}$

Single and Multi-site event discrimination:



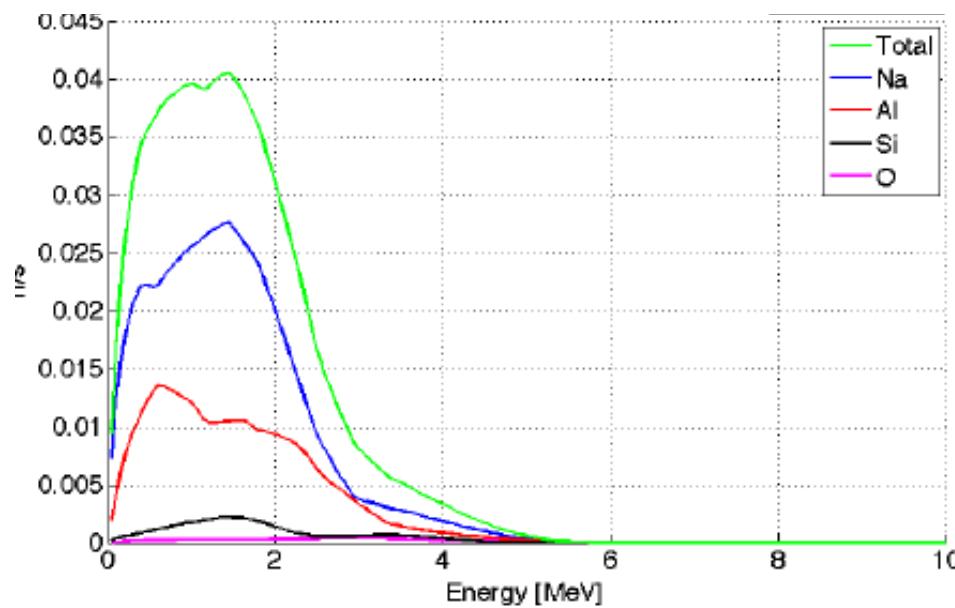
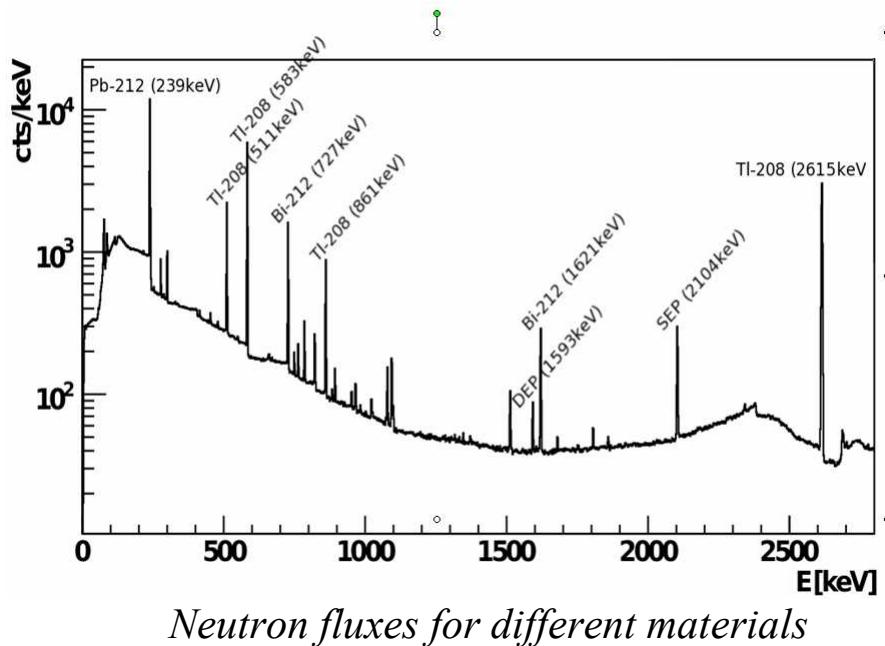
- segmented detectors



- point contact BEGe detector

Effective bkg reduction

## *$^{228}\text{Th}$ calibration source*



Roberto Santorelli – CIEMAT 26/10/09

- Sufficient number of lines
- Energy calibration in the region of interest (SEP –  $^{208}\text{Tl}$ )
- Pulse shape discrimination
- $^{228}\text{Th} \rightarrow \alpha$  emitter  $\bar{E}(\alpha) \sim 6.5 \text{ MeV}$   
 $E_{\max}(\alpha) = 8.8 \text{ MeV}$   
 $\Rightarrow$  neutrons produced through  $(\alpha, n)$  with the ceramic pellet of the commercial sources

$$\text{Neutron Rate} = 3.8 \cdot 10^{-2} \text{ n}/(\text{s} \cdot \text{kBq})$$

$$E_{\text{mean}} = 1.45 \text{ MeV}$$

MC simulations:

350 cm LAr attenuation

$6.7 \cdot 10^7$  neutrons considered



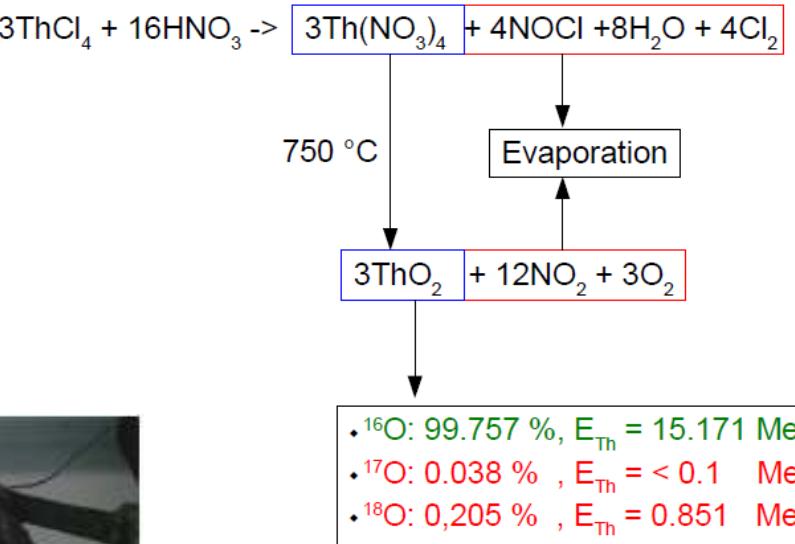
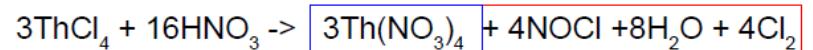
- Mean interaction probability  $\sim 4 \cdot 10^{-4}$
- $1.0 \times 10^{-5} \text{ cts}/(\text{keV} \cdot \text{kg} \cdot \text{y} \cdot \text{kBq})$
- $6.0 \times 10^{-4} \text{ cts}/(\text{keV} \cdot \text{kg} \cdot \text{y}) @ 3 \times 20 \text{ kBq}$

## New low-*n* rate source development

Aim: reduction of the neutron flux through  
the development of a new setup

Gold: no oxidation

Threshold for  $(\alpha, n) \sim 9.94$  MeV



### *Collaboration with PSI*



200 °C



750 °C

### *MC simulations:*

Neutron flux  $\sim 5.0 \times 10^{-4}$  n/(s · kBq)

$$B = 8.6 \times 10^{-8} \text{ cts}/(\text{kg} \cdot \text{keV} \cdot \text{y} \cdot \text{kBq})$$

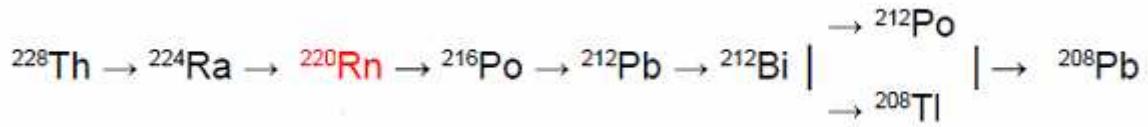
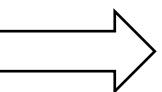
$E_{\text{mean}} = 2.5$  MeV

$$B = 5.1 \times 10^{-6} \text{ cts}/(\text{keV} \cdot \text{kg} \cdot \text{y}) @ 3 \times 20 \text{ kBq}$$

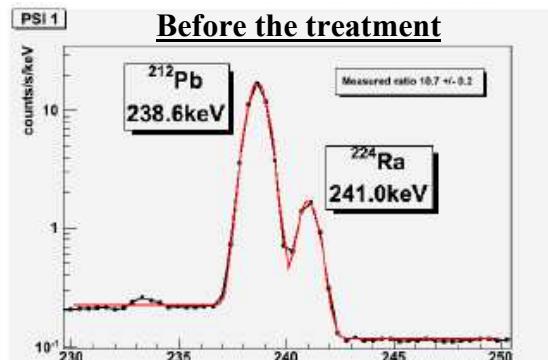
$$\sum \rightarrow \phi \sim 0.01 \text{ n/s} @ 20 \text{ kBq}$$

## RESULTS I

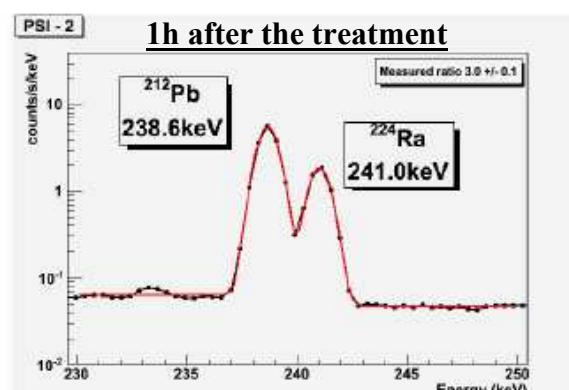
Equilibrium broken due  
to Rn gas emanation  
during the procedure



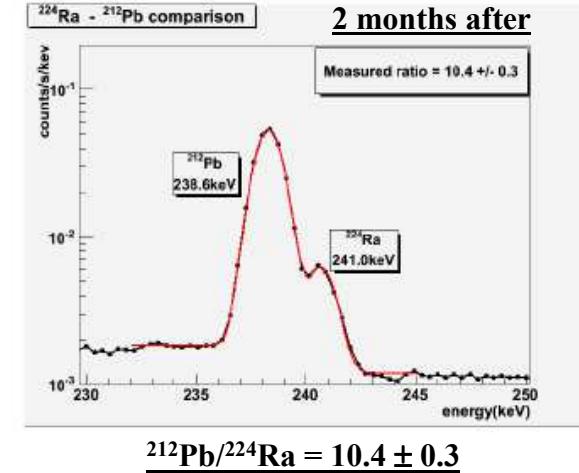
Relative peak height ratio:  $^{212}\text{Pb}/^{224}\text{Ra} \cong 10.6$



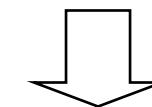
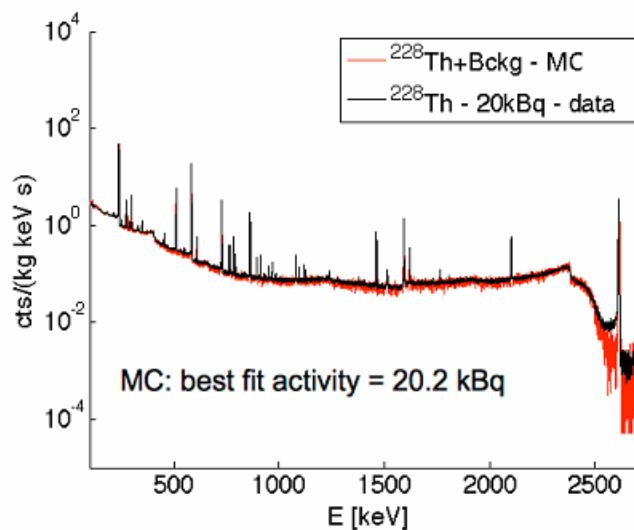
$$^{212}\text{Pb}/^{224}\text{Ra} = 10.7 \pm 0.2$$



$$^{212}\text{Pb}/^{224}\text{Ra} = 3.0 \pm 0.1$$



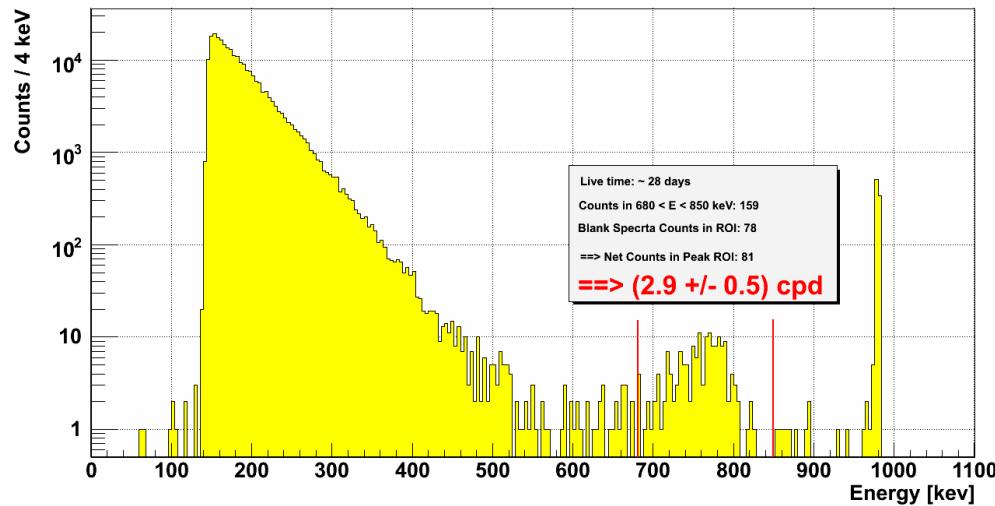
$$^{212}\text{Pb}/^{224}\text{Ra} = 10.4 \pm 0.3$$



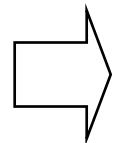
- Equilibrium restored in few weeks
- No measured activity loss

## RESULTS II

$^3\text{He}$  neutron counter @ LNGS (28d livetime)



$\phi: (0.017 +/- 0.003) \text{ n/s} @ 20\text{kBq}$



Good agreement with the predictions!

OK FOR PHASE II!

## **CONCLUSIONS**

- Strong interest in DM and  $0\nu\beta\beta$  research
- Claims by previous experiments
- XENON and GERDA under commissioning at Gran Sasso lab
- Upgrades already scheduled
- New capabilities for discovery
- Next?

*Thank you!*

# *BACKUP*

---

## Sensitivity of $0\nu\beta\beta$ decay experiments

Half life →

$$T_{1/2} \sim a \cdot \epsilon \cdot \sqrt{\frac{m \cdot t}{\Delta E \cdot B}} \cdot M_{nucl}$$

m → active target mass

B → background rate

a → enrichment of isotopes (<1)

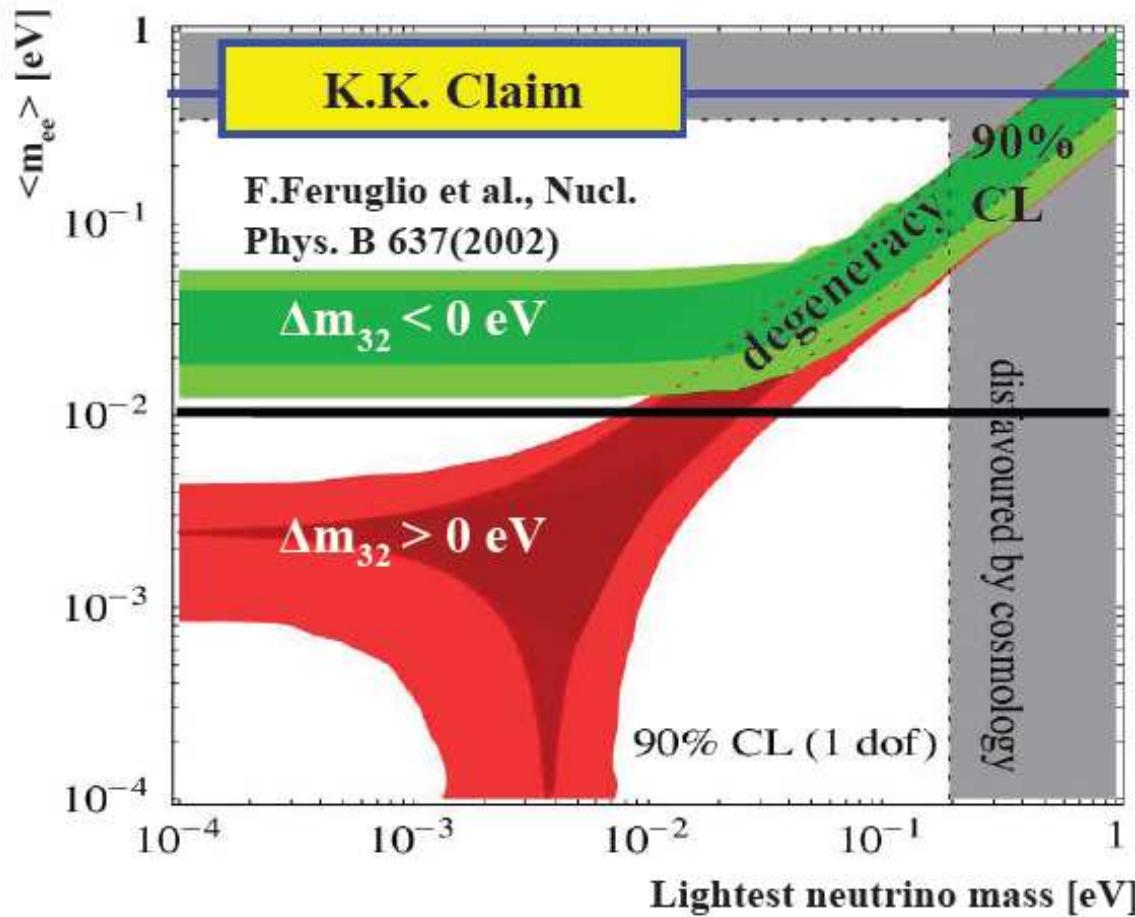
$\epsilon$  → signal detection efficiency (<1)

$\Delta E$  → energy resolution

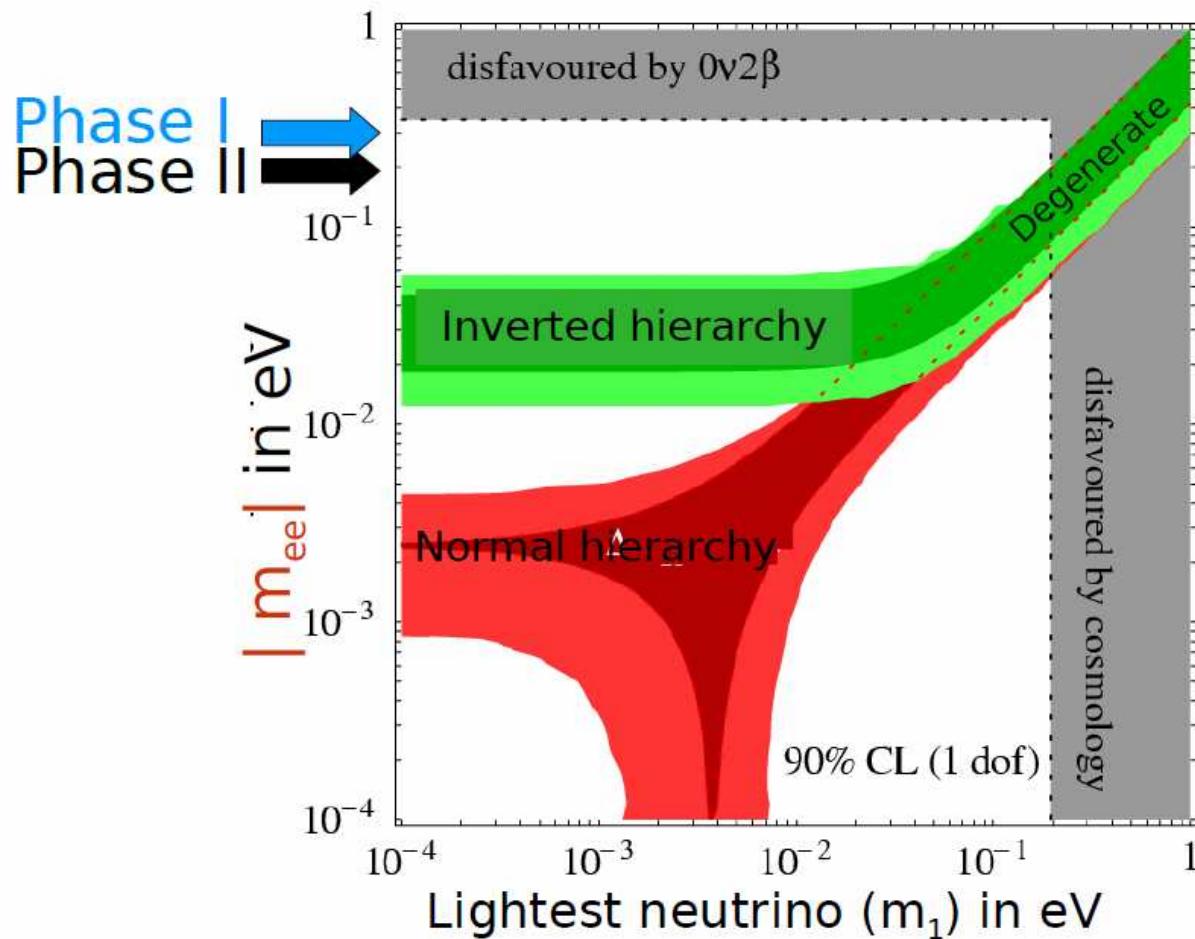
t → measuring time

M → nuclear matrix elements

In order to discriminate between normal and inverted hierarchy,  
we need an experiment with sensitivity down to  $\sim 10\text{mV}$  scale



F. Feruglio,  
A. Strumia,  
F. Vissani,  
NPB 637

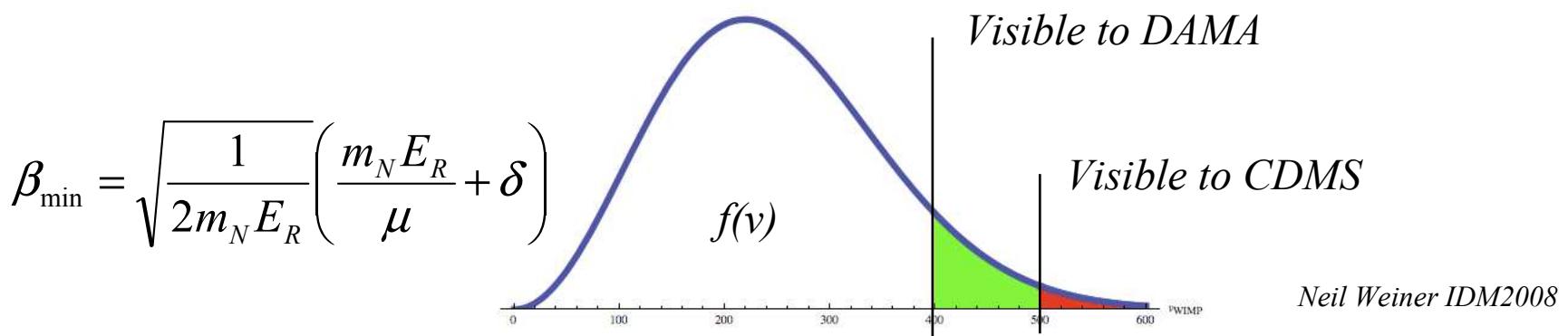


# INELASTIC DARK MATTER

- WIMP-nucleus scattering occurs through a transition to a WIMP excited state  $\chi^* + N \rightarrow \chi^* + N$
- elastic scattering  $\chi + N \rightarrow \chi + N$  highly suppressed
- only WIMP with sufficient kinetic energy to scatter into the heavier state will scatter off nuclei

Two states with a mass splitting around 100 keV  
(equal to the kinetic energy of the WIMPs in the halo)

$$\delta = m_{\chi^*} - m_\chi \sim \beta m_\chi \sim 100 \text{ keV}$$



Model is sensitive to the high velocity component of the halo,  
modulation is significantly enhanced

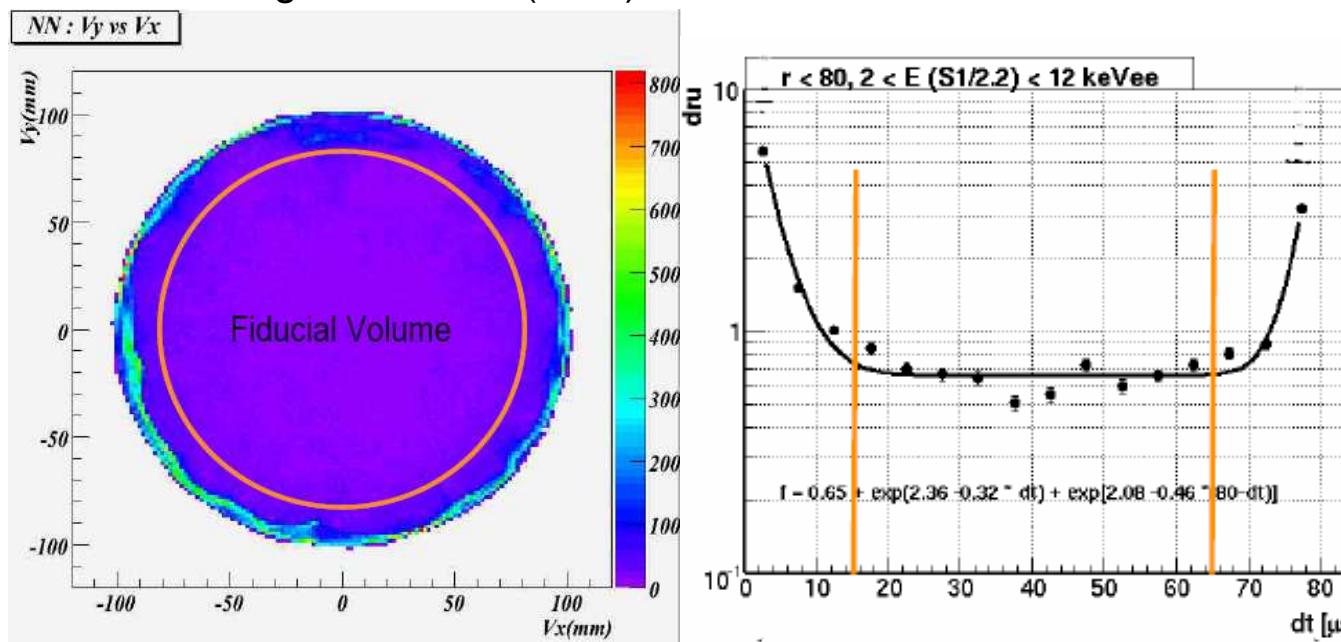
Eliminating low energy events, with signal peaking at higher energies  
( $\sim 35$  keV for I/Xe,  $\sim 70$  keV for Ge,  $\sim 25$  keV for W)

# XENON10 WIMP SEARCH RUN

- WIMP search from data accumulated between October,06 and February,07
- **Blind analysis** : data from WIMP search run in the box until cut definitions completed.  
Cuts defined on data from gamma and neutron calibration
- Two independent analyses (choose the one with NN technique and better analysis of the digitized signal waveform, different selection and cuts )
- Box open on April,07

## Three levels of cuts to select good events

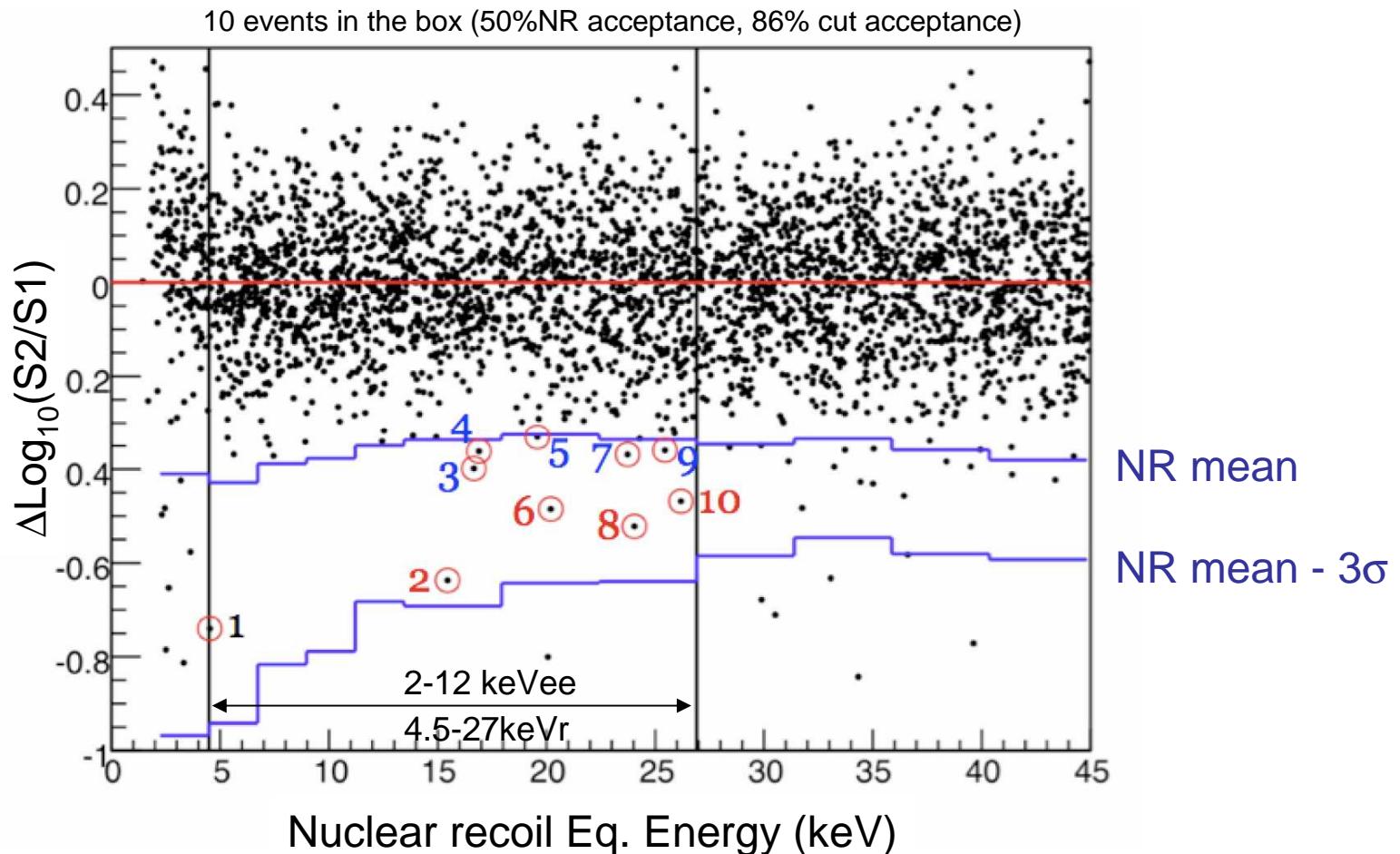
- Basic quality cuts (QC0) : reject saturation, no S1 or multiple S2 peaks, S2  $\chi^2$
- Fiducial volume cuts (QC1) :  $r < 80\text{mm}$  &&  $15\mu\text{s} < dt < 65\mu\text{s}$
- High level cuts (QC2) : to remove events with anomalous and unusual S1



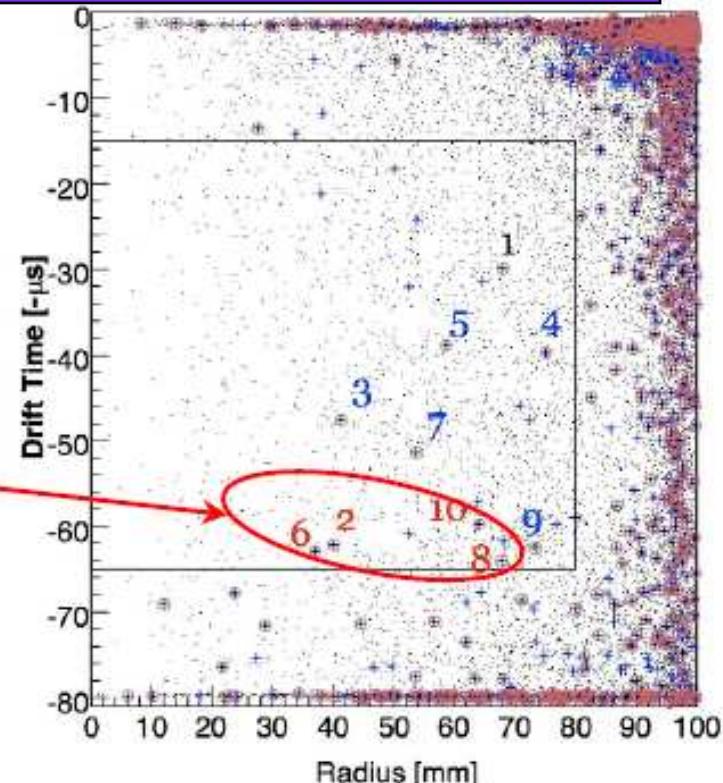
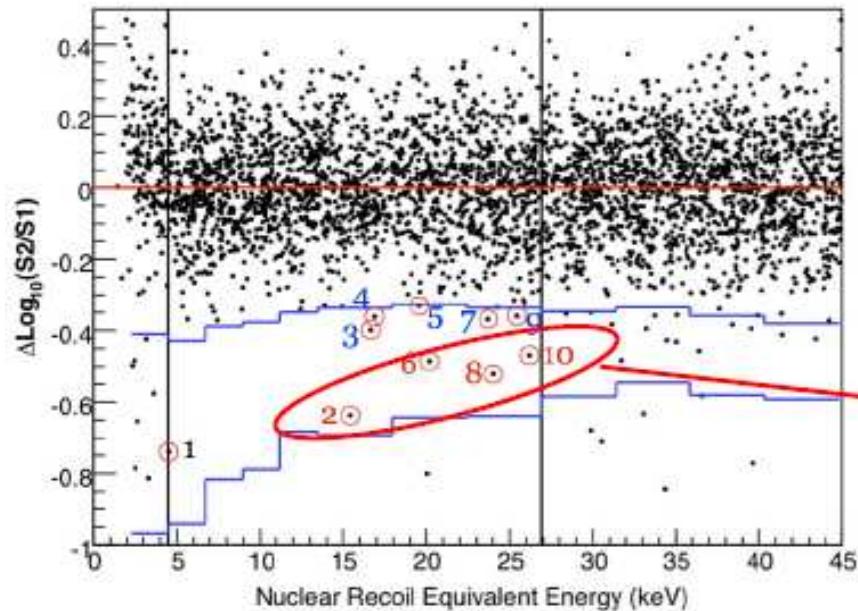
Overall background in the  
fiducial volume  
~0.6 event/(kg·day·keVee)

# WIMP SEARCH DATA

- WIMP acceptance window defined as ~50% acceptance of NR [mean,-3 $\sigma$ ] from gaussian fits
- ~1800 events in the energy box
- 10 events in the acceptance window after the primary analysis (QC0,QC1,QC2 cuts)
- 6.9 events expected from the  $\gamma$  calibration
- 5 events not consistent with the  $\gamma$  calibration



# ANOMALOUS EVENTS

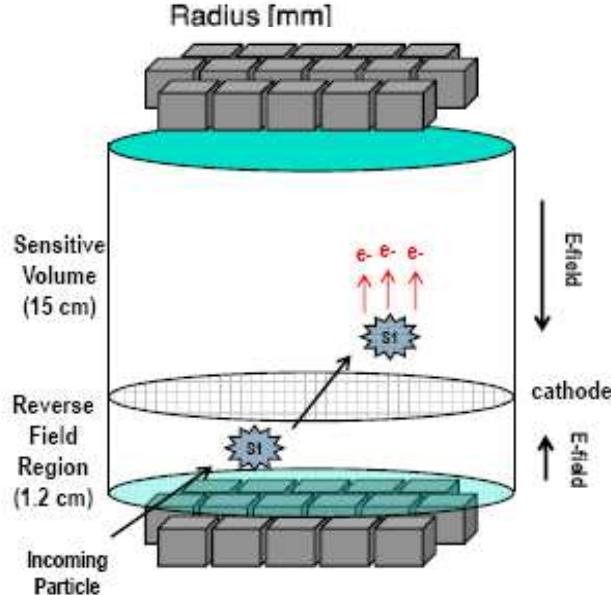


## Secondary analysis:

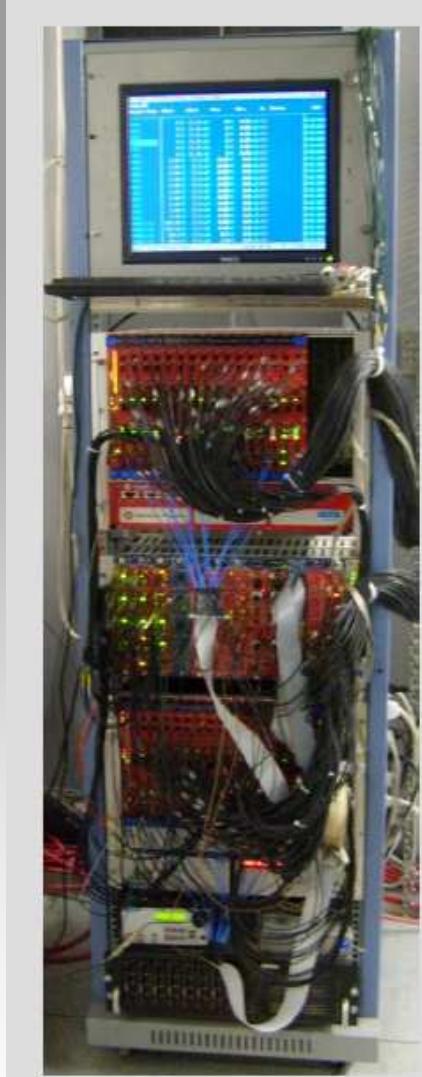
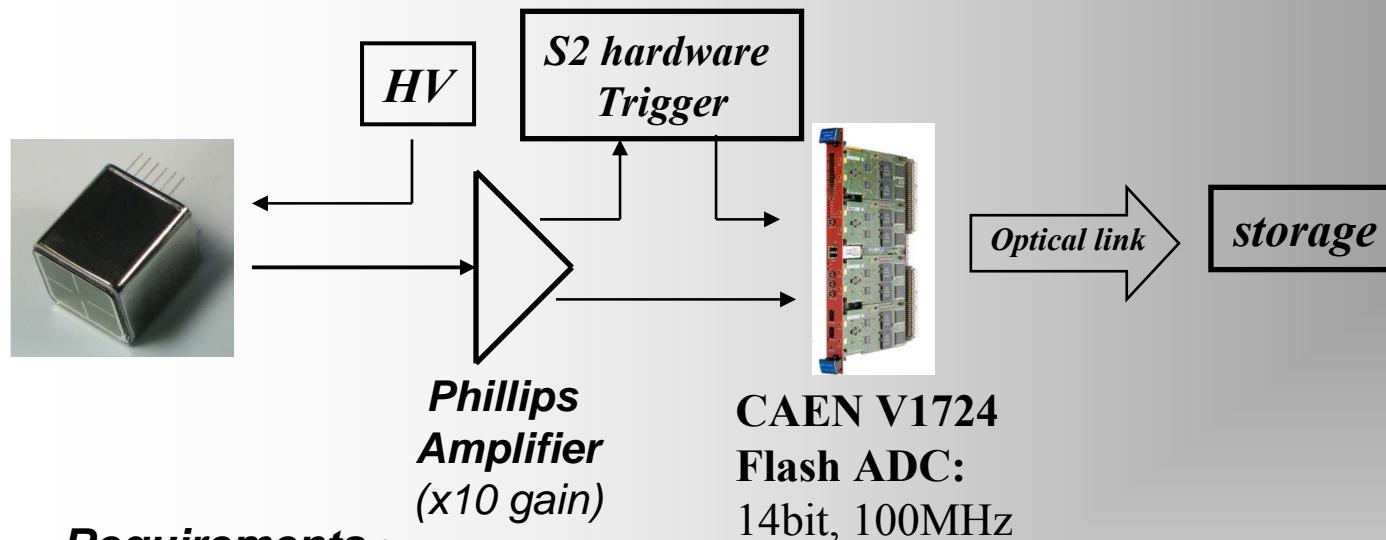
- 5 events are consistent with statistical leakage from electron recoil band (6.9 events expected)
- 4 of the 5 non-Gaussian events are removed by a more sophisticated gamma-x cut (~3 events expected from simulations)
- 1 event removed by signal quality cut (noise event)

## WIMP SIGNAL UNLIKELY

Detector upgraded in May 2007: Teflon blenders placed around bottom PMTs to reduce the rate of gamma-x events (~50 live days)



# DATA ACQUISITION



- *Circular buffer*
- *on board FPGA for Zero length suppression*

*Maximum acquisition rate ~60Hz*

# *PROJECTED SENSITIVITY*

