The XENON10 dark matter search

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Mass-energy inventory for the universe

- Fraction of Ω:

dark energy	≈ 0.73
dark matter	≈ 0.23
baryons	≈ 0.04 (≈ 0.004 in stars)
neutrinos:	≈ $0.001 < \Omega_\nu < 0.015$
total	1

- **W**eakly **I**nteracting **M**assive **P**articles
  - Generic prediction from freezeout
  - Generic prediction of supersymmetry.

Detecting galactic WIMP dark matter

Dark matter "Halo" surrounds all galaxies, including ours.

Density at Earth:

$$\rho \sim 300\ {m_{\text{proton}}}/{\text{liter}}$$

$$m_{wimp} \sim 100\ m_{proton}.$$

3 WIMPS/liter!

Typical orbital velocity:

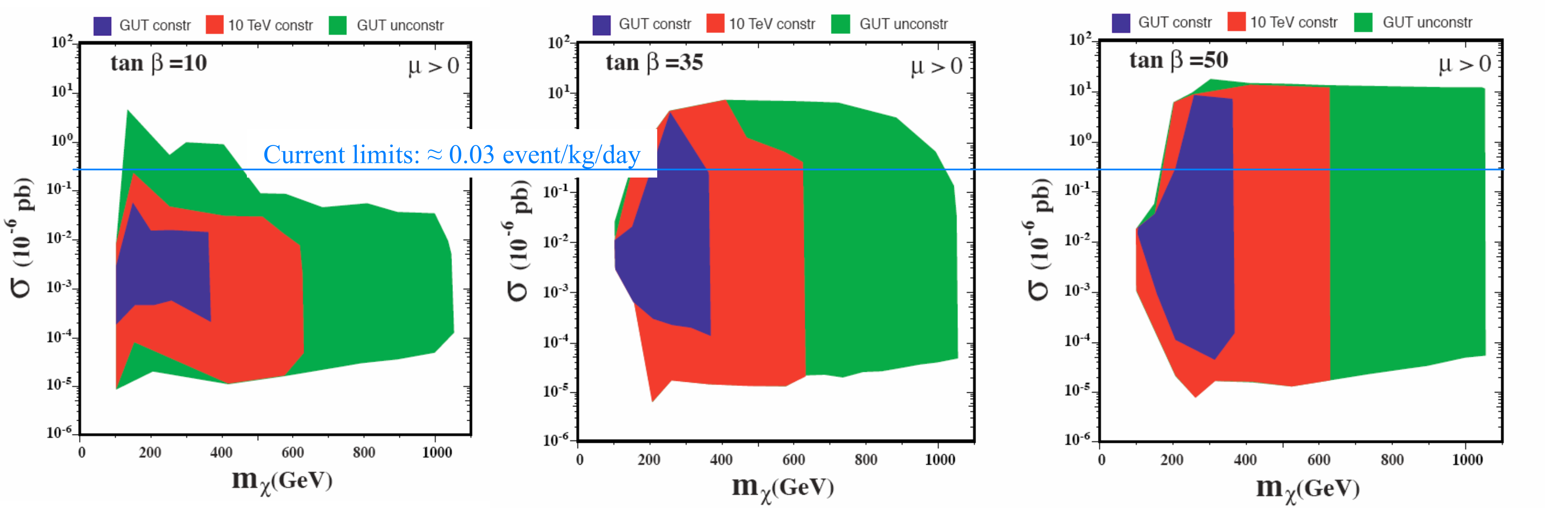
$$v \approx 230\ \text{km/s}$$

$\sim$ 1/1000 speed of light

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Rate: < 0.1 event/kg/day,
or much lower

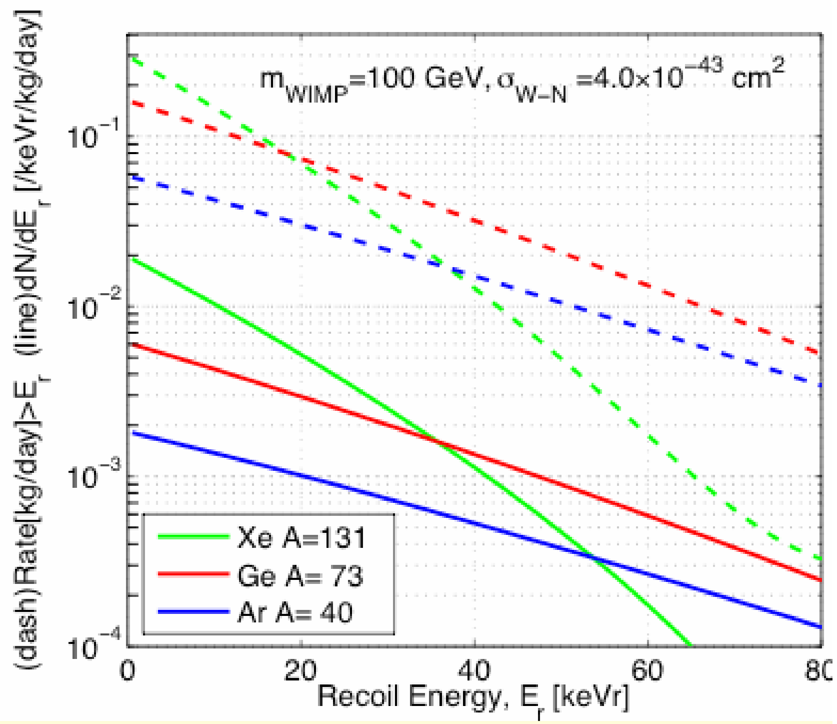
How big a detector?



Calculations in minimal supersymmetry framework (MSSM). Ellis, Olive, Santoso,Spanos, hep-ph/ 030875

- Motivation for very large detector clear
- "Generic" test of MSSM possible with 1-10 tons
  - Loopholes will still exist
- If signal seen, need larger mass to probe modulation.

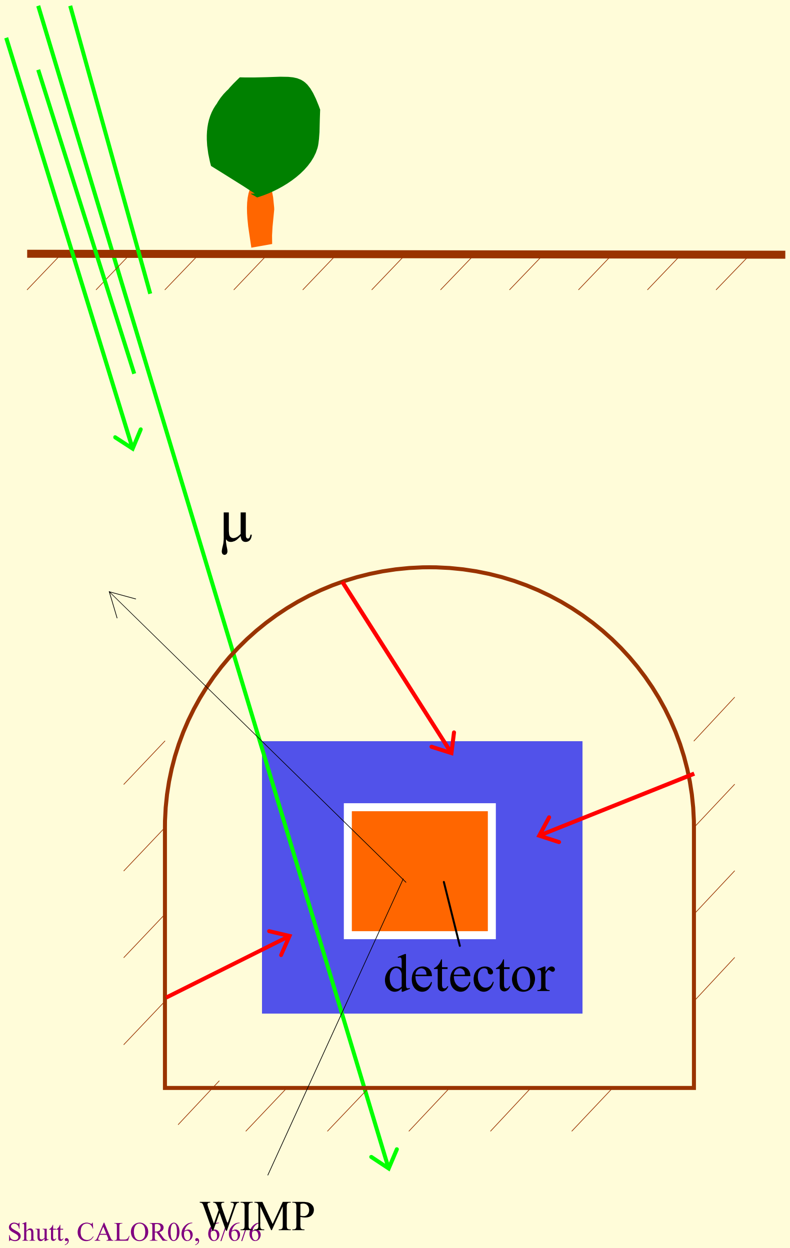
Promise of liquid Xenon.



- Good WIMP target.
- Readily purified (except ^{85}Kr)
- Self-shielding - high density, high Z.
- Can separate spin, no spin isotopes
  ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe, ^{134}Xe, ^{136}Xe
- ~ Low-background PMTs available
- Rich detection media
  - Scintillation
  - Ionization
  - Recombination discriminates between electron (backgrounds) and nuclear (WIMPs, neutrons) recoils

Scalable to large masses

Detecting rare events.



- Problem: radioactivity
  - Ambient: 100 events/kg/sec.
  - Pure materials in detector

- Shield against outside backgrounds

- Underground to avoid muons

Why Roman lead is special.

U, Th in rock: 2 ppm ≈ 10^7 decays/day/kg

Crude smelting removes U, Th from Pb.

^{210}Pb at bottom of U decay chain remains.

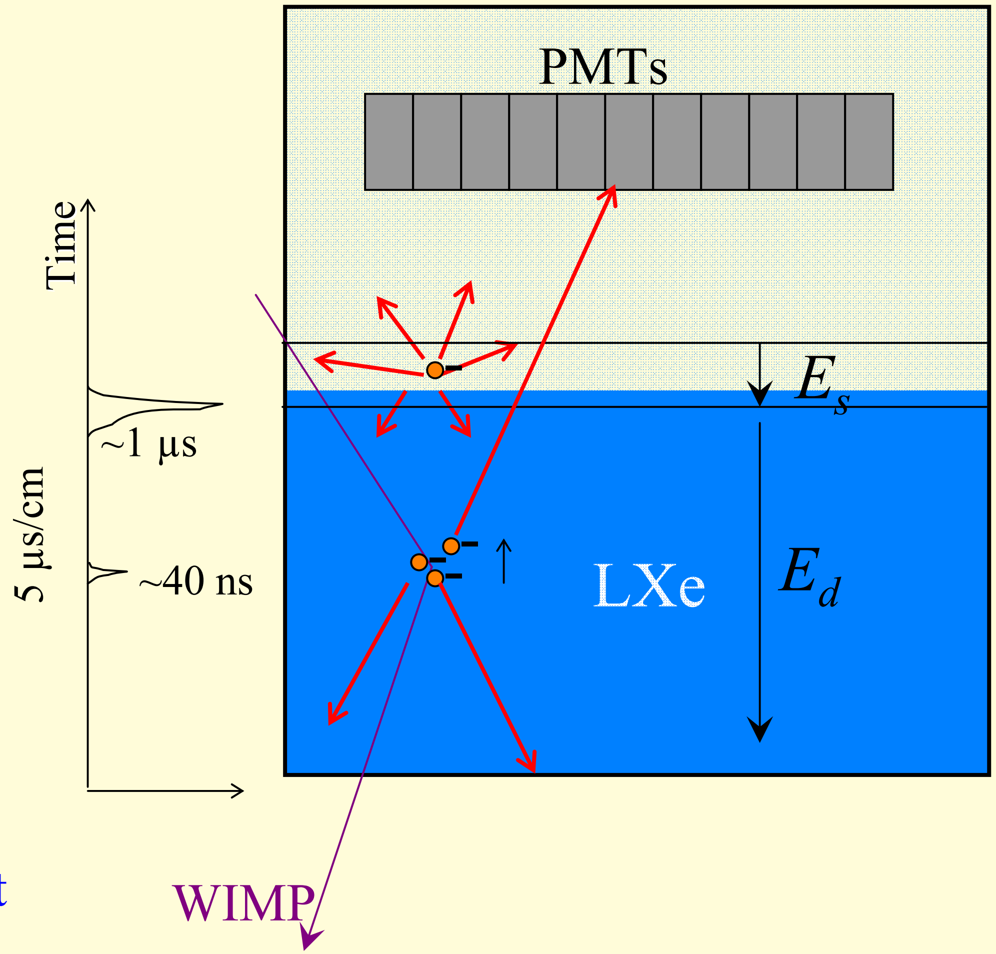
$T_{1/2}$= 22 years

XENON: Dual Phase, LXe TPC "Calorimeter"

- Very good 3D event location.
- Background discrimination based on recombination

XENON Overview

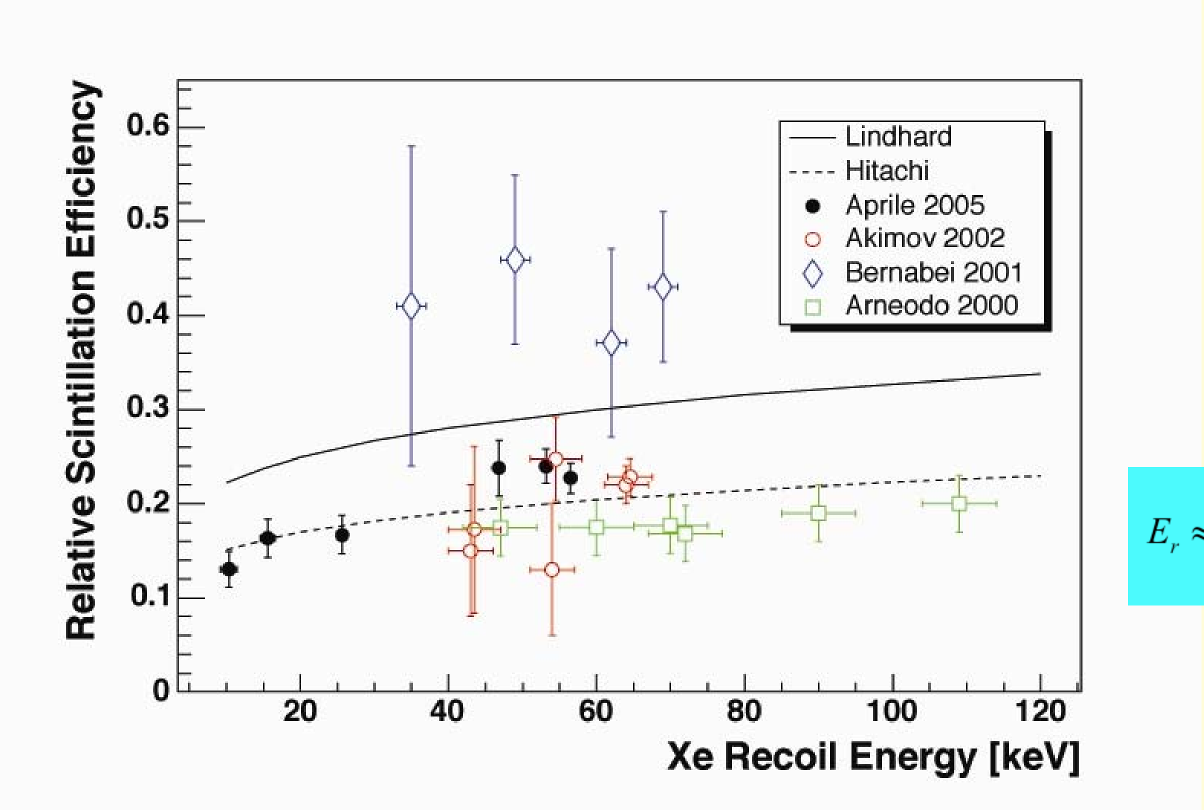
- Modular design: 1 ton in ten 100 kg modules.
- XENON10 Phase: 15 kg active target in Gran Sasso Lab as of March, 2006. Shield under construction. Physics runs start: June 2006.
- XENON100 Phase: design/construction in FY07 and FY08 ($2M construction). Commission and undeground start physics run with 2008.



A. Bolozdynya, NIMA 422 p314 (1999).

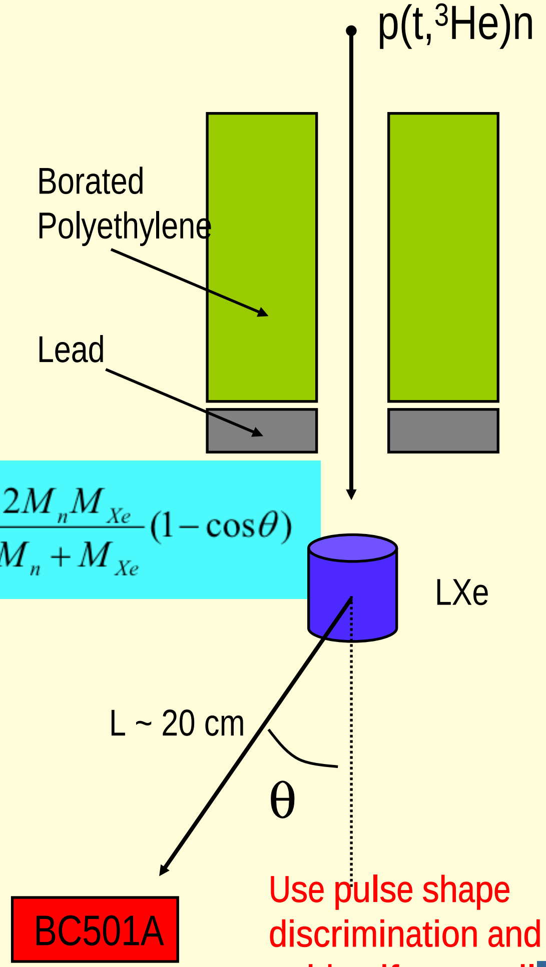
Scintillation Efficiency of Nuclear Recoils

Columbia and Yale



Aprile et al., Phys. Rev. D 72 (2005) 072006

Columbia RARAF
2.4 MeV neutrons

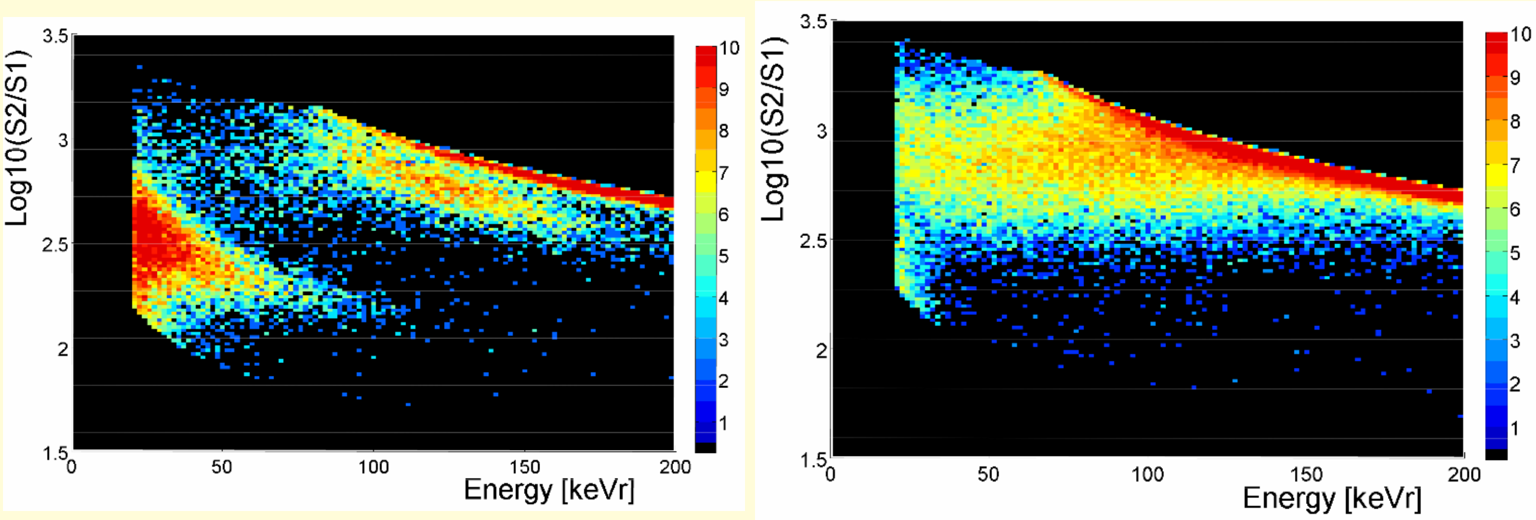


$$E_r \approx E_n \frac{2M_n M_{Xe}}{M_n + M_{Xe}}(1-\cos\theta)$$

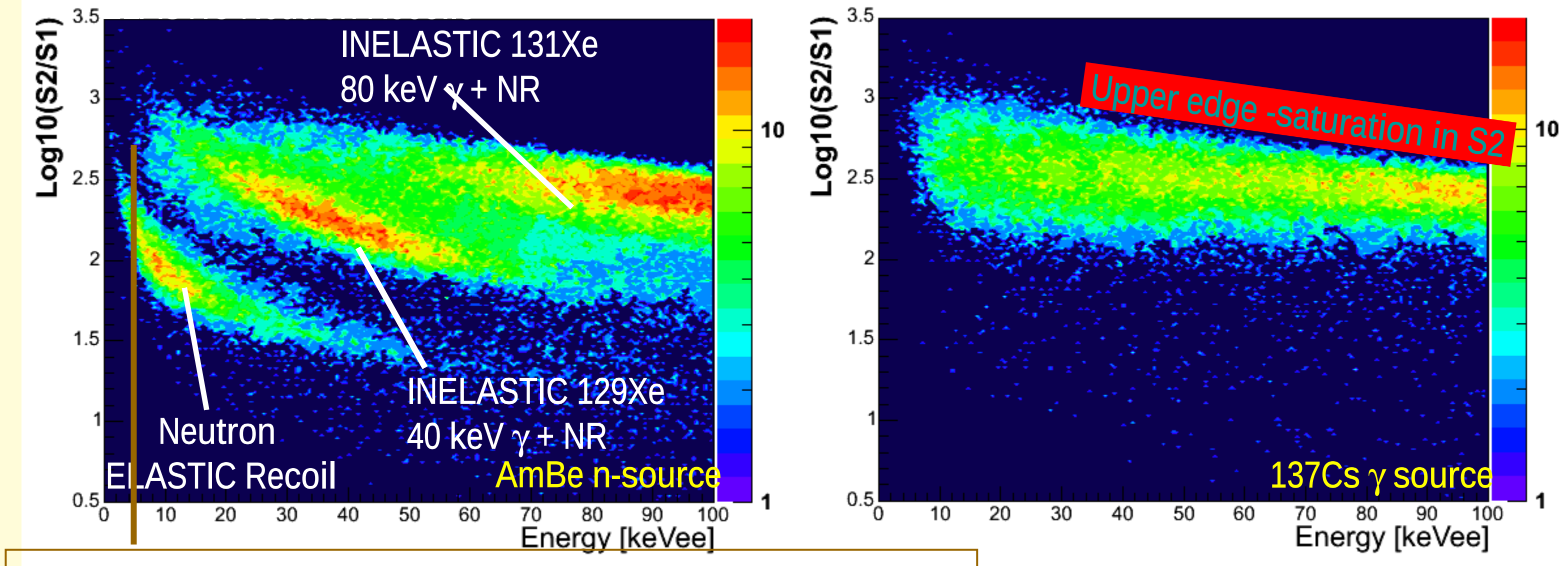
Use pulse shape discrimination and ToF to identify n-recoils

Nuclear and electron recoils in LXe

Case



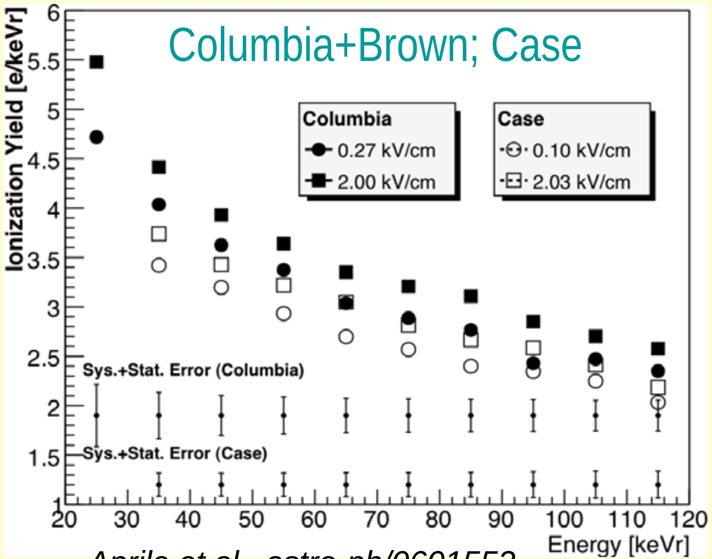
Columbia+Brown



5 keVee energy threshold = 10 keV nuclear recoil

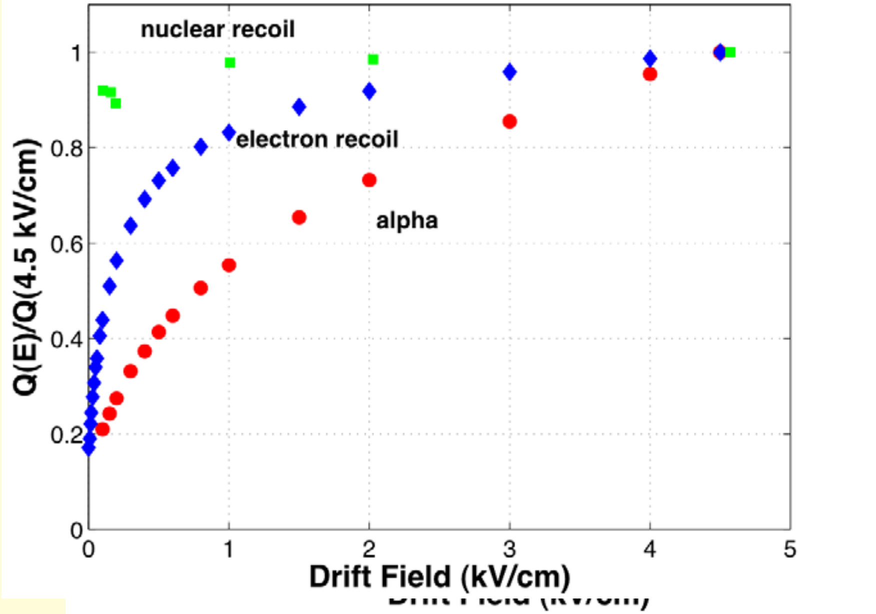
Charge and light yields

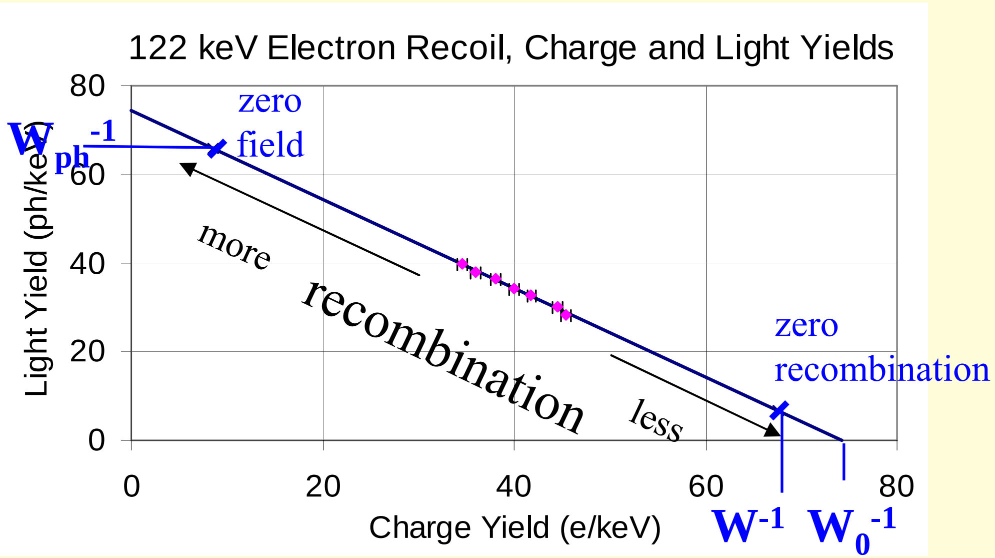
Charge yield - nuclear recoils

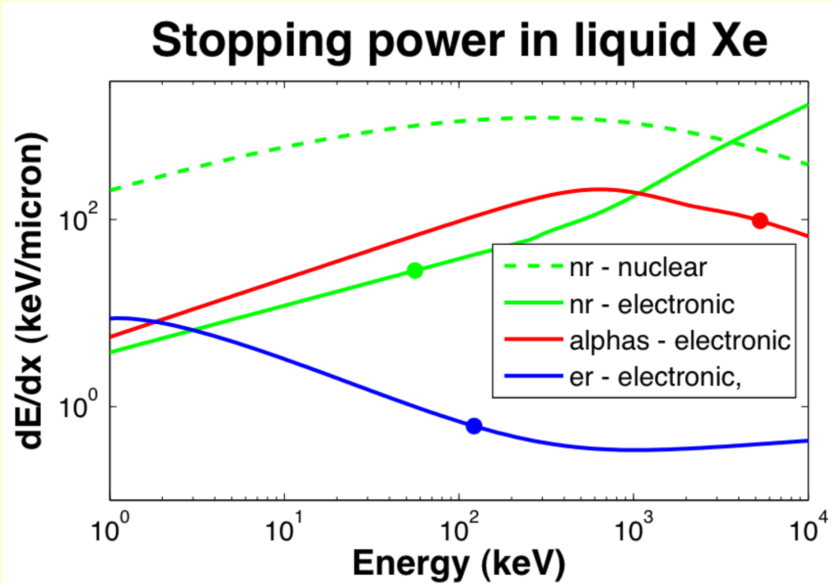


Aprile et al., astro-ph/0601552, submitted to PRL

Electrons escaping recombination - rescaled

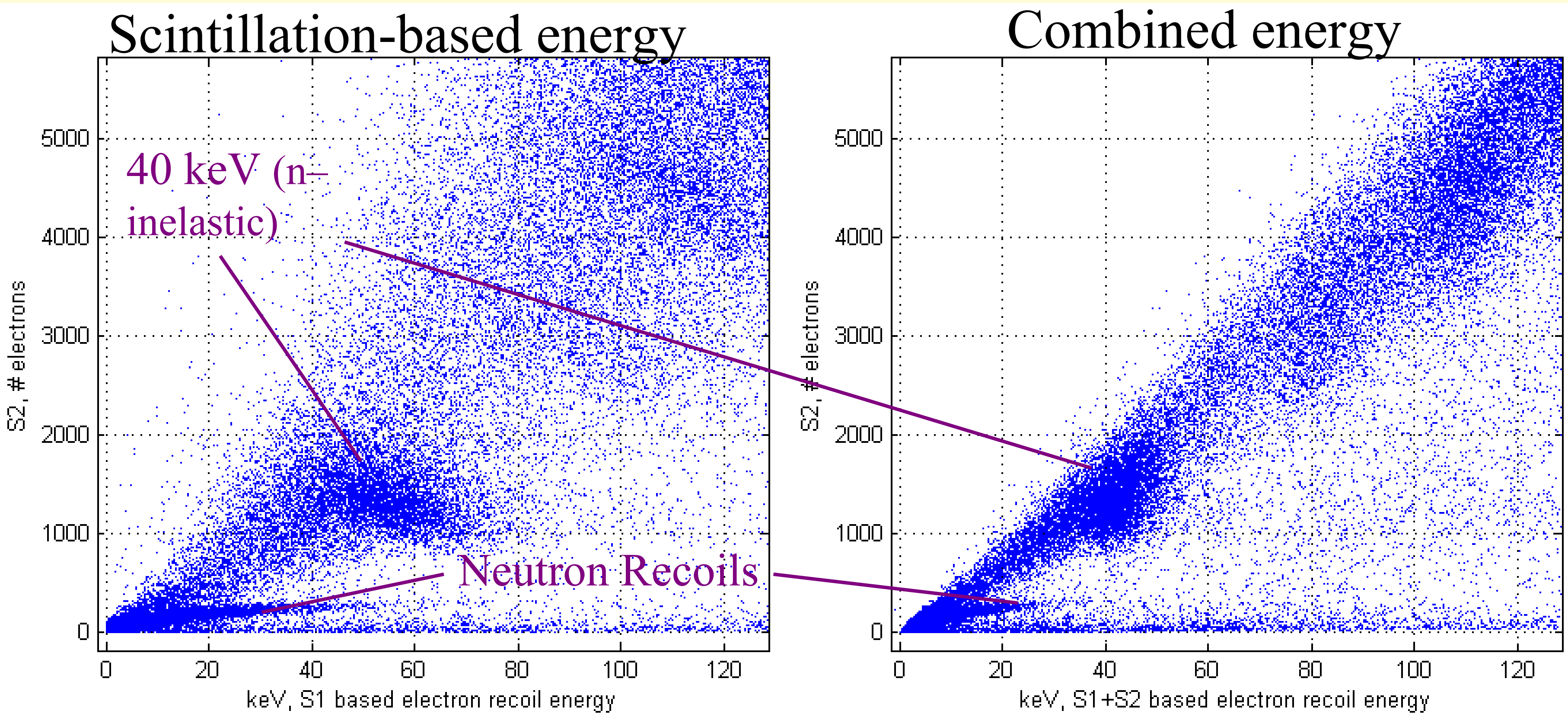






Recombination fluctuations

Case



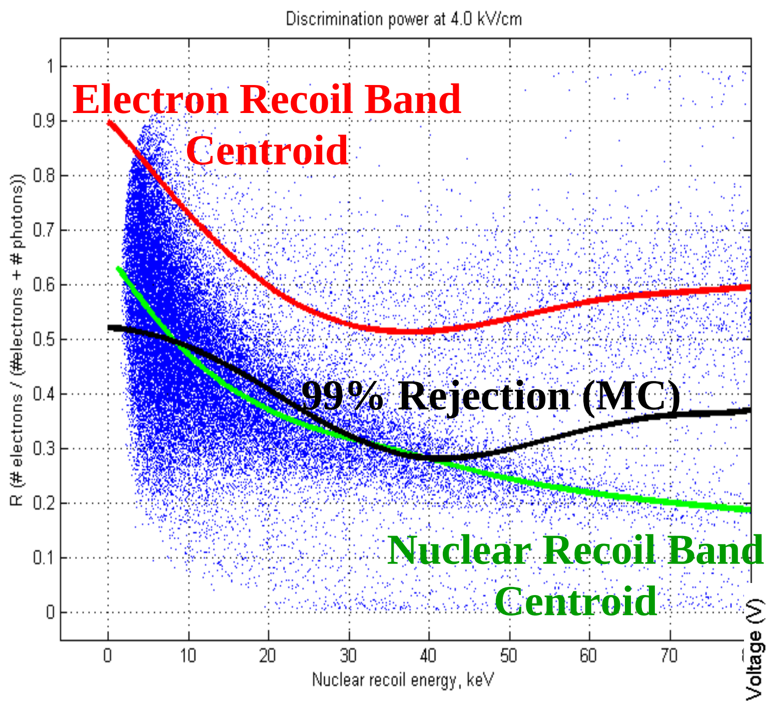
- Recombination independent energy: $E = W_0 \bullet (n_{e-} + n_\gamma)$
  - Improves energy resolution
  - Restores linearity.
- Recombination fluctuations fundamental issue for discrimination.
- New energy definition itself cannot improve discrimination

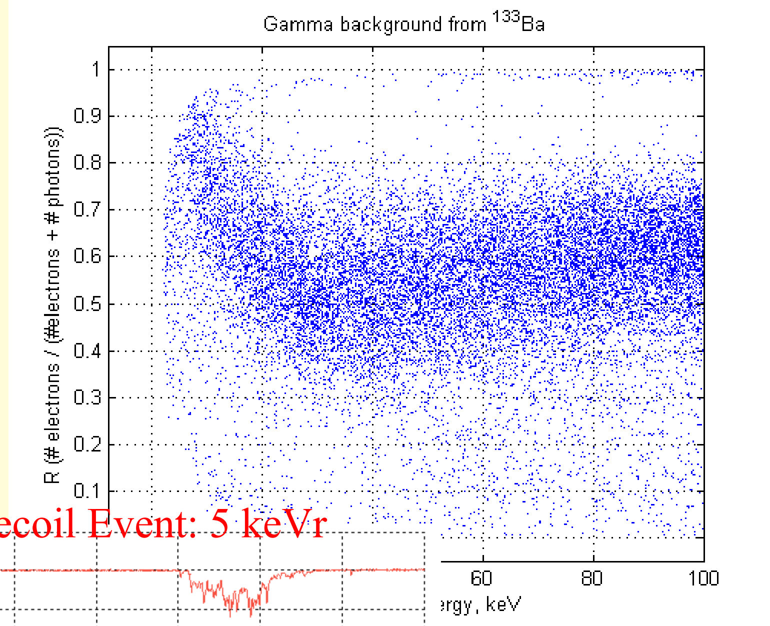
Discrimination at low energy

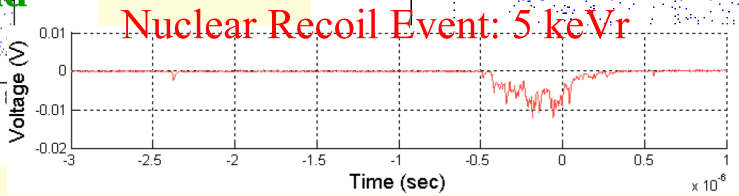
Nuclear recoil data

Case

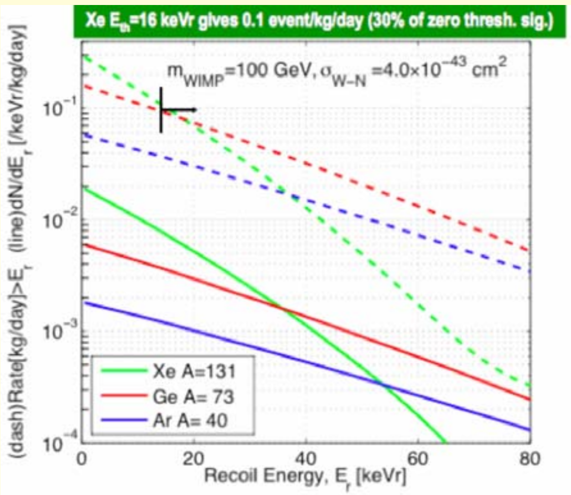
Electron recoil data



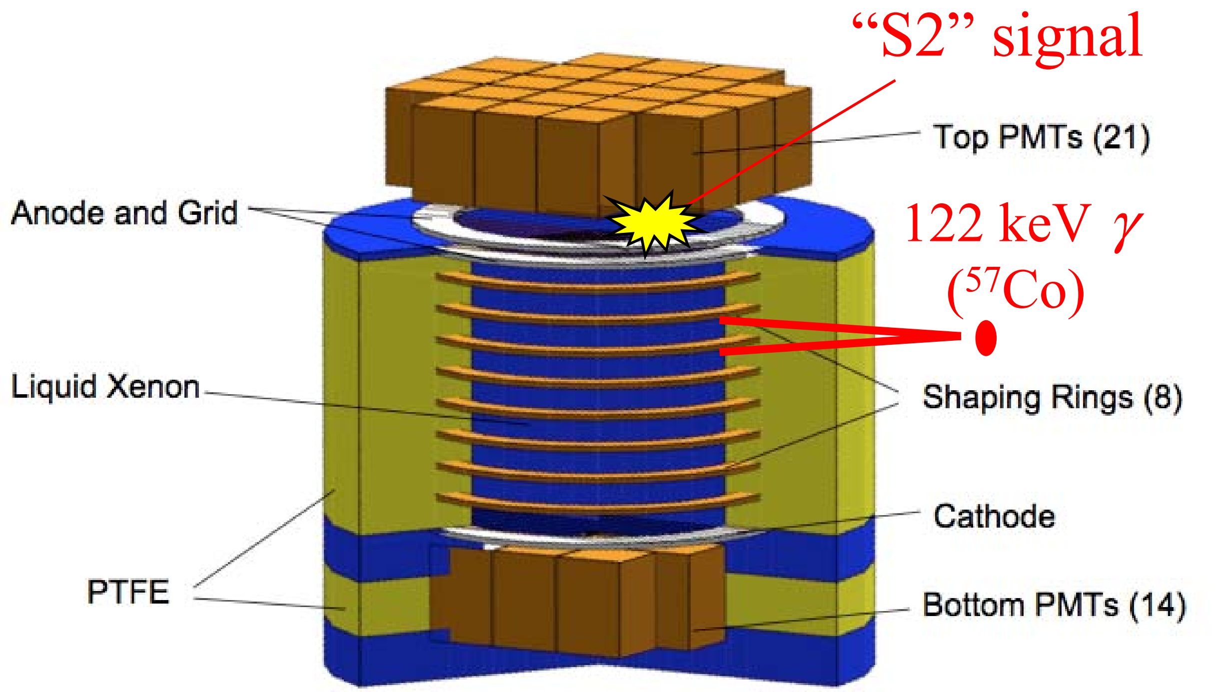




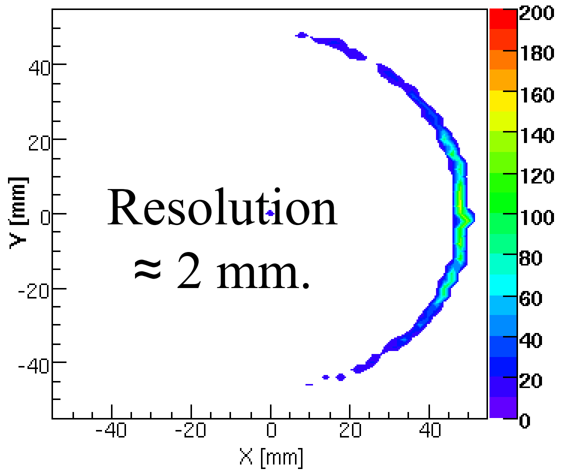
- Charge yield increase for *BOTH* nuclear recoils and electron recoils at low energy.
- E> 20 keVr: recombination fluctuations dominate.
- Monte Carlo:
  - >~99% discrimination at 10 keVr.
    This is value used in XENON10/100/1T proposals



XY Position Reconstruction in 3 kg prototype



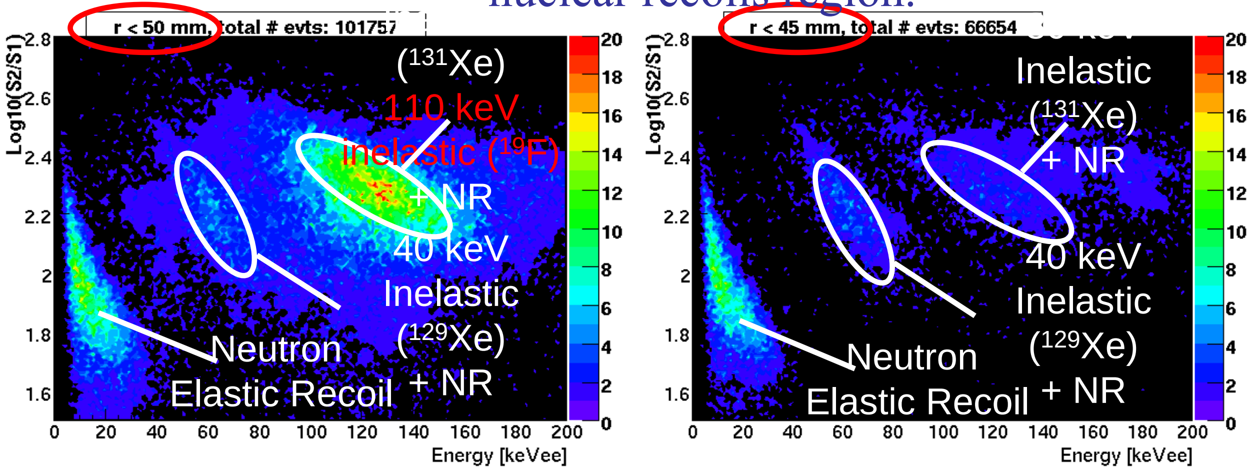
Reconstructed edge events at 122 keV



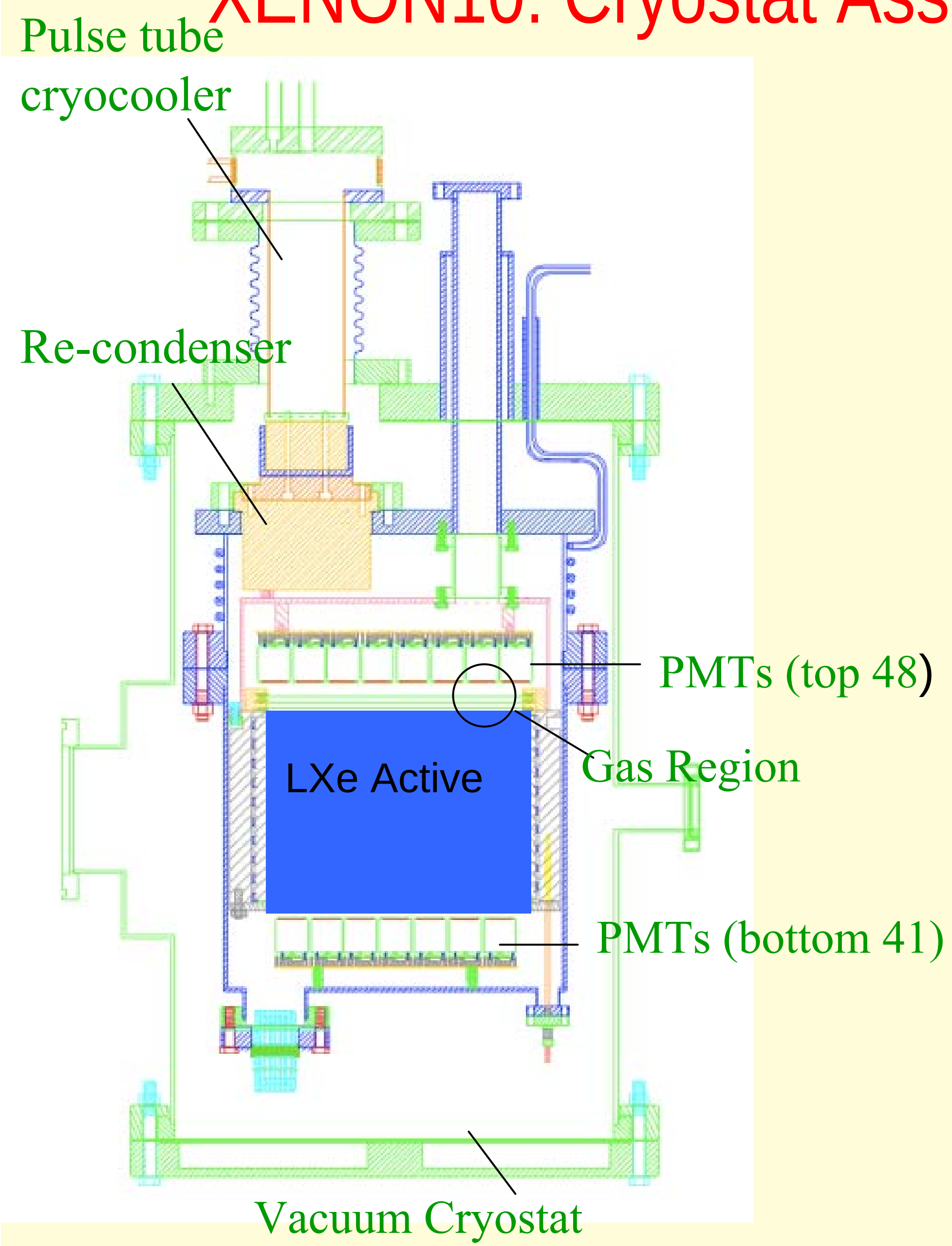
- Chisquare estimate from Monte Carlo - generated S2 map

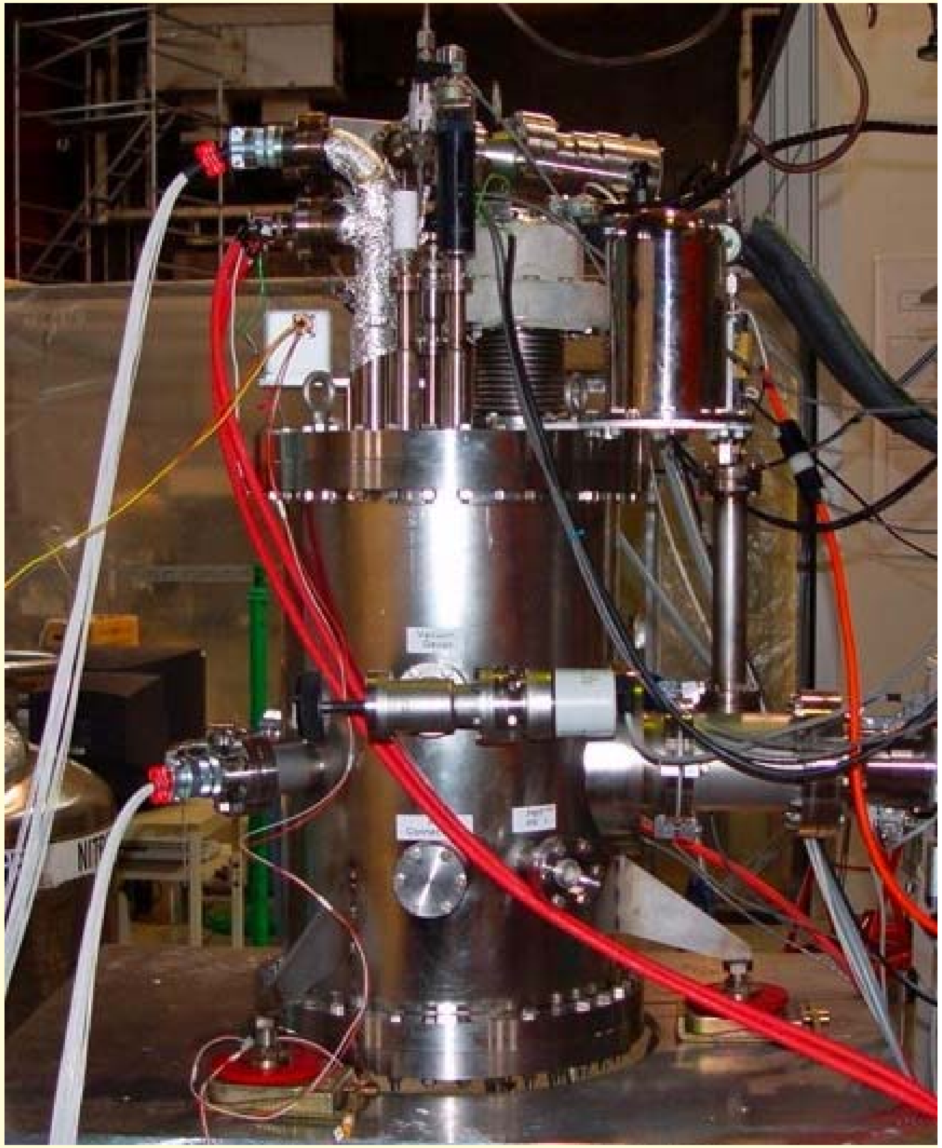
$$\chi^2(x,y) = \sum_{i=1}^{21} \frac{[S_i - s_i(x,y)]^2}{\sigma_i^2}$$

5 mm radial cut reduces gamma events in nuclear recoils region.



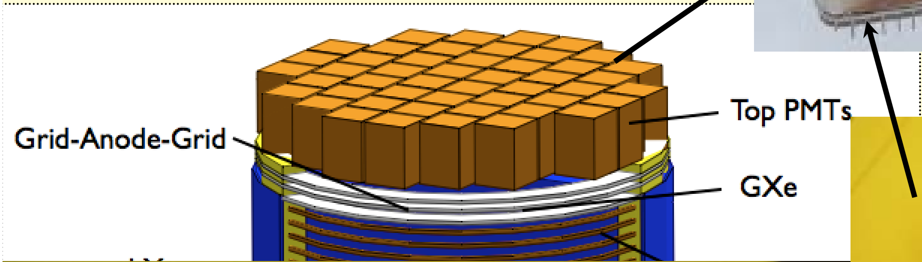
XENON10: Cryostat Assembly

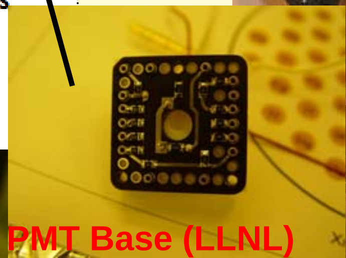


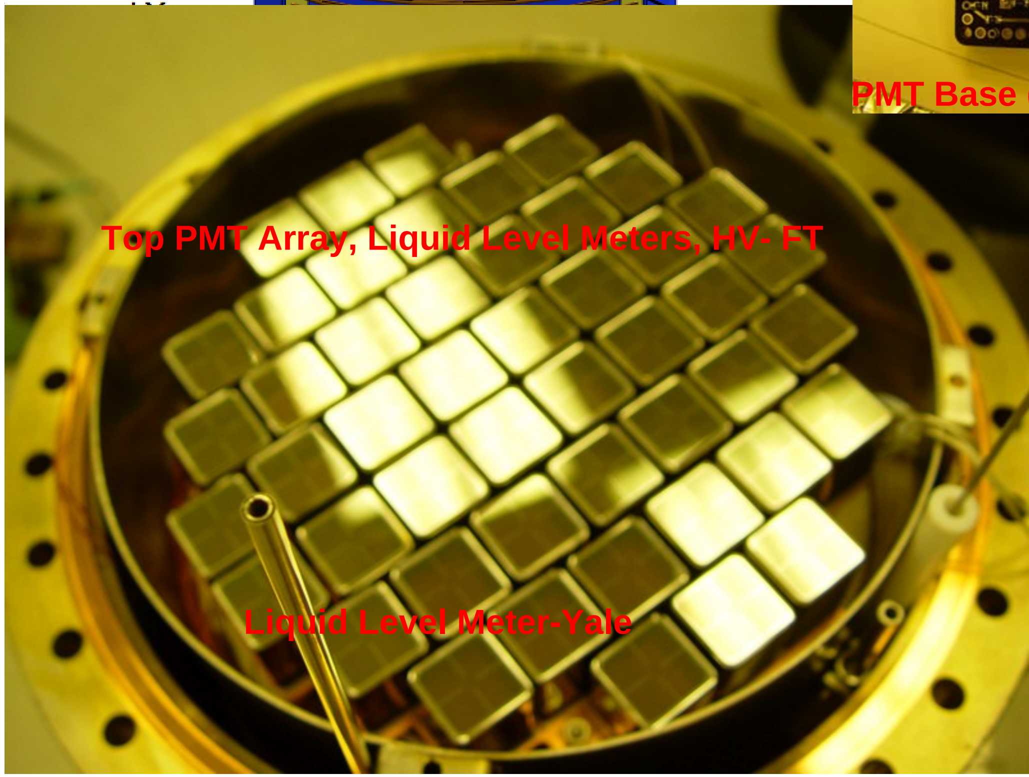


XENON10: Detector Assembly

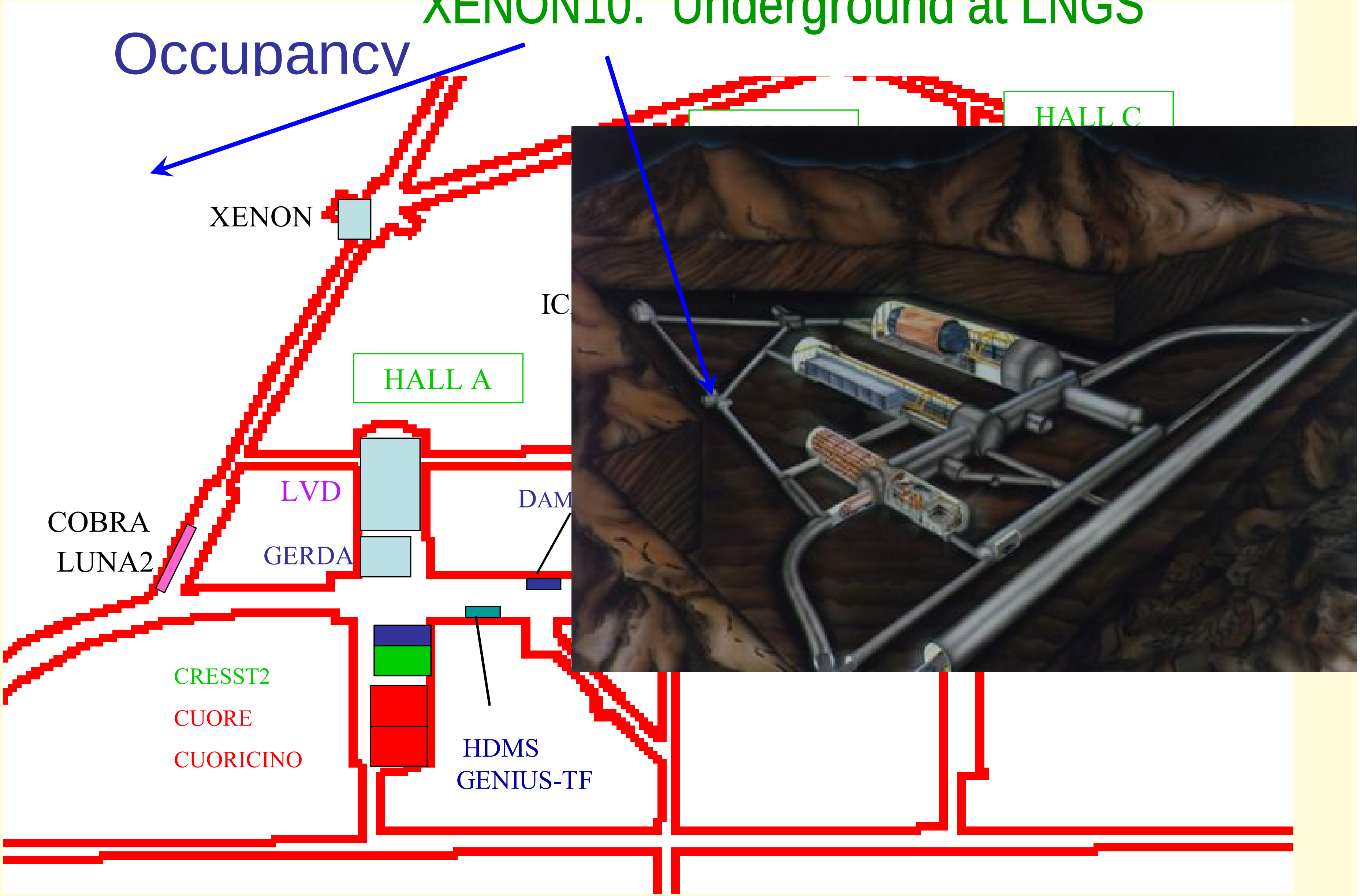
89 Hamamatsu R5900 (1” square)
20 cm diameter, 15 cm drift length
22 kg LXe total; 15 kg LXe active



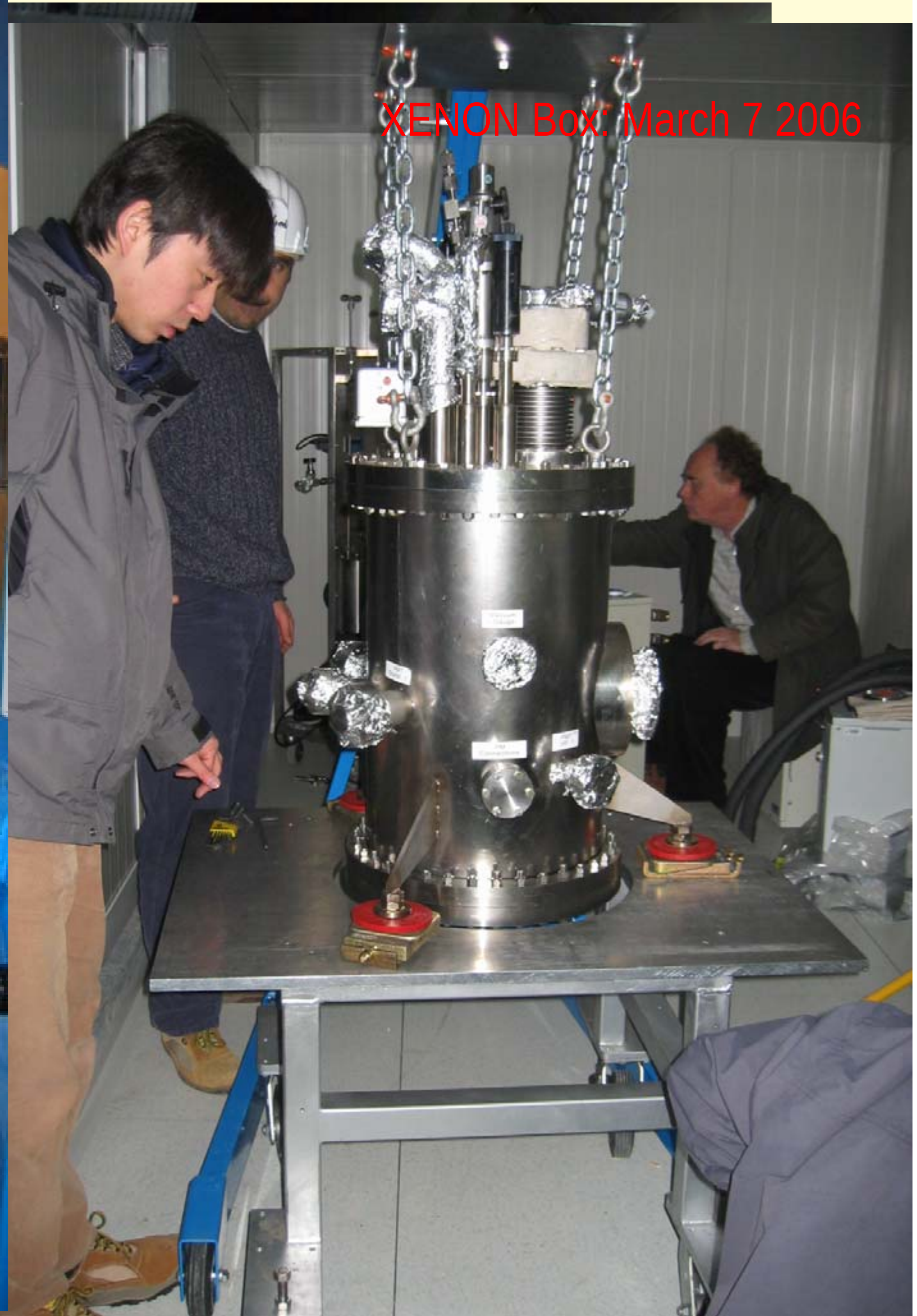




XENON10: Underground at LNGS



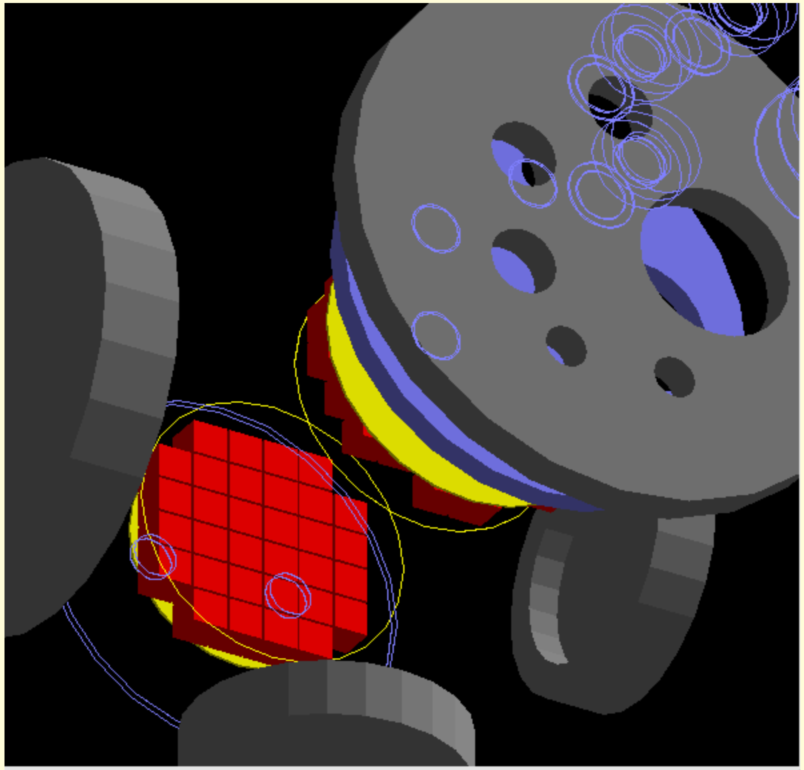

XENON Box: March 10, 2006


XENON Box: March 7 2006

Summary: XENON10 Backgrounds

Monte Carlo studies of Radioactivity (Background Events) from:

- Gamma / Electron
  - Gammas inside Pb Shield
    - PMT (K/U/Th/Co)
    - Vessel: Stainless Steel (Co)
    - Contributions from Other Components
  - Xe Intrinsic Backgrounds (incl. ^{85}Kr)
  - External Gammas - Pb Shield
  - Rn exclusion
  - Detector Performance/Design
    - Gamma Discrimination Requirements
    - Use of xyz cuts instead of LXe Outer Veto
- Neutron Backgrounds
  - Internal Sources: PMT (α,n)
  - External: Rock (α,n): Muons in Shield
  - Punch-through neutrons: Generated by muons in rock



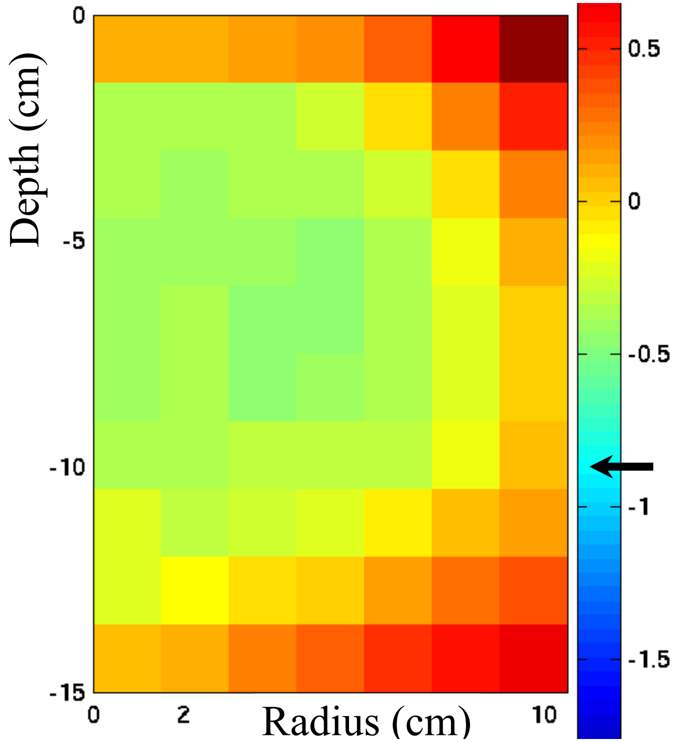
[Background Modeling U. FLORIDA / BROWN/COLUMBIA]

- NOTE: Active Muon Shield *Not* Required for XENON10 @ LNGS
  - Neutron flux from muon interaction in Pb shield << Target Level

XENON10 expected background

- Dominant background: Stainless Steel Cryostat & PMTs
  - Stainless Steel :100 mBq/kg 60Co
    - ~ 4x higher than originally assumed, **but faster assembly**
  - PMTs - 89 x 1x1" sq Hamamatsu 8520
    - 17.2/<3.5/12.7/<3.9 mBq/kg, U/Th/K/Co
    - Increased Bg from high number of PMTs / trade off with increased position info. = **Bg diagnostic**

Electron recoil background
5-25 keVee



Original
XENON10 Goal
<0.14 /keVee/kg/day

Current estimate:
2-3 x original goal

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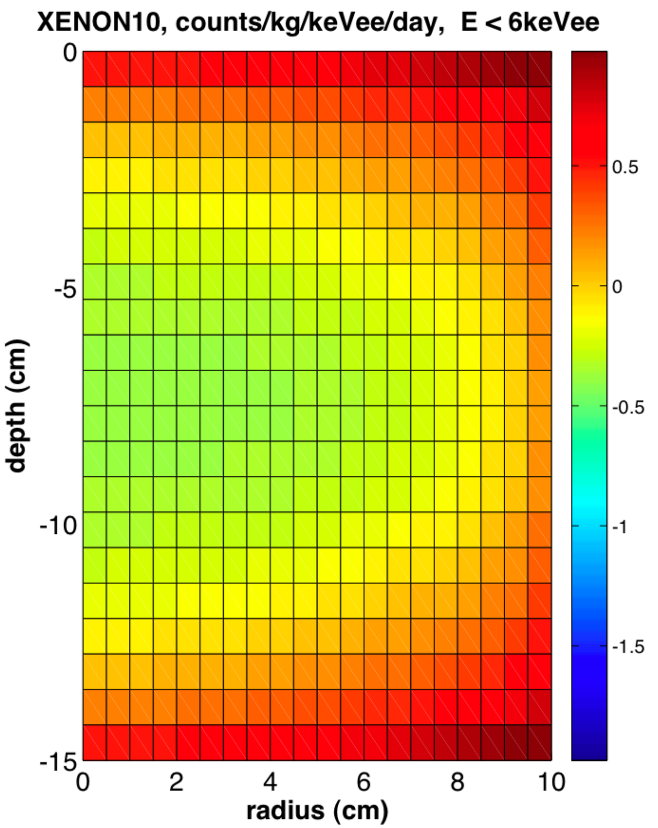

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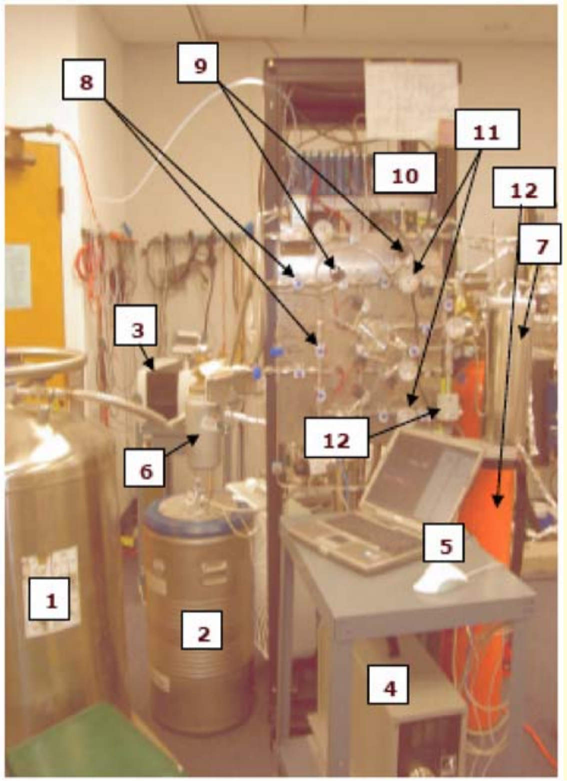
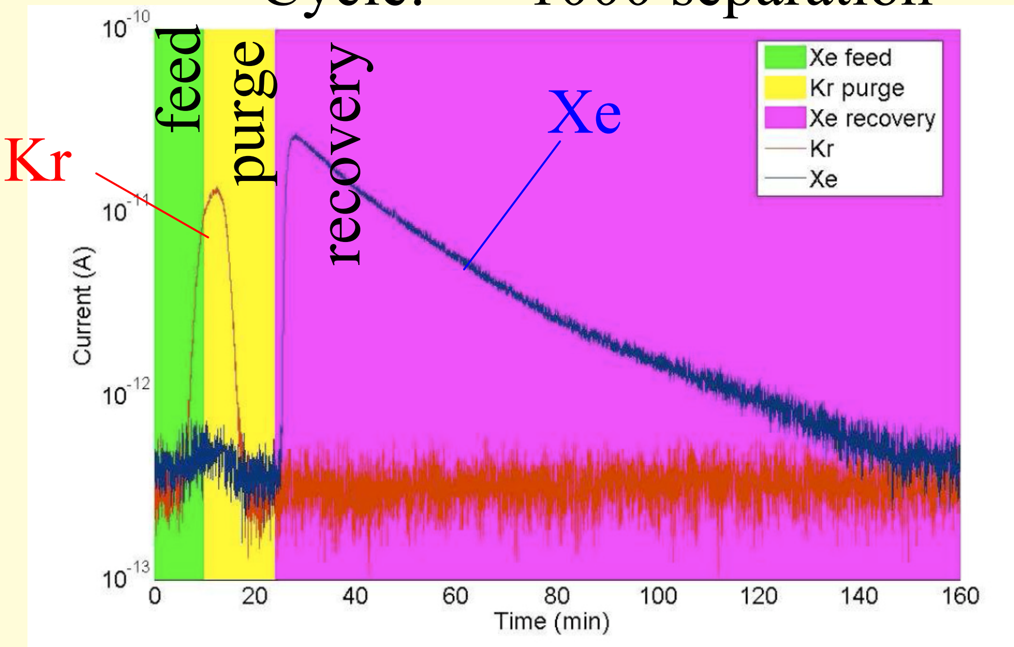
Kr removal

- ^{85}Kr - beta decay, 687 keV endpoint.
  - Goals for 10, 100, 1000 kg detectors: Kr/Xe < 1000, 100, 10 ppt.
  - Commercial Xe (SpectraGas, NJ): ~ 5 ppb (XMASS)
- Chromatographic separation on charcoal column

Cycle: > 1000 separation

10 Kg-charocoal column system at Case





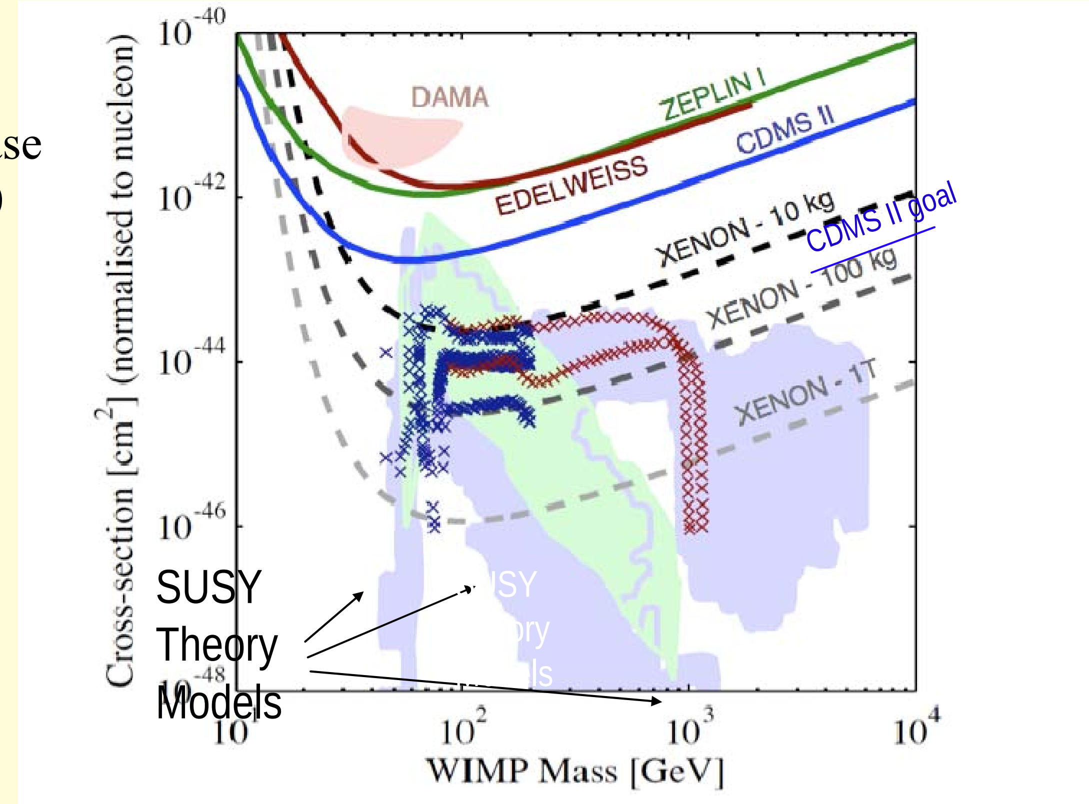
200 g/cycle, 2 kg/day

25 Kg purifed to < 10 ppt

XENON Goals

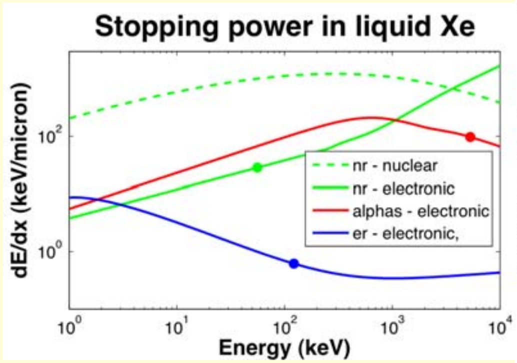
- XENON10 (2006-2007)
  - 10 kg target ~2 events/10kg/month
  - Equivalent to CDMSII Goal for mass >100 GeV (Current CDMS limit is 10 x above this level)
  - Establish performance of dual phase TPC, guide design of XENON100
- XENON100 (2007-2009)
  - 100 kg traget ~ 2 events/100 kg/month
- XENON 1T (2009-2012?):
  - 1 ton (10 x 100 kg? Larger? Modules)
  - 10^{-46} cm^2, or 1 event/ton/month

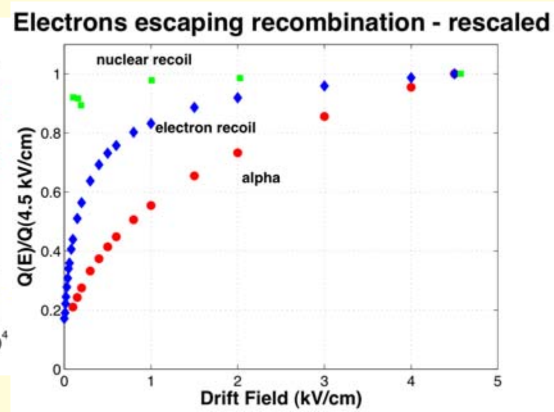
Dark Matter Data Plotter
http://dmtools.brown.edu



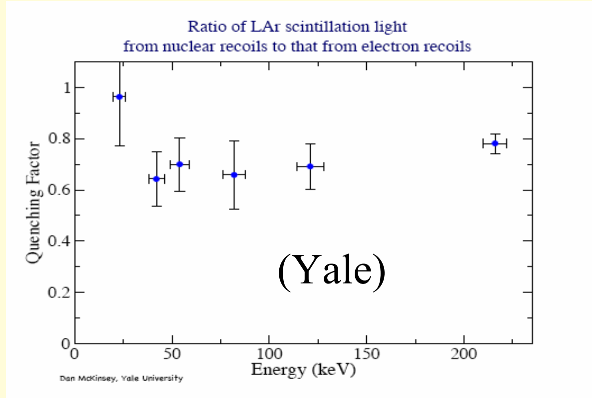
Some comments on Ar and Xe: atomic physics surprises

- Xe:
  - Drop in recombination for low energy nuclear recoils
  - Energy independence of nuclear recoil recombination.
  - Drop in recombination for very low energy electron recoils

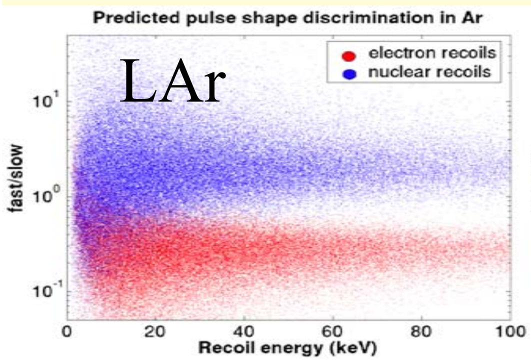


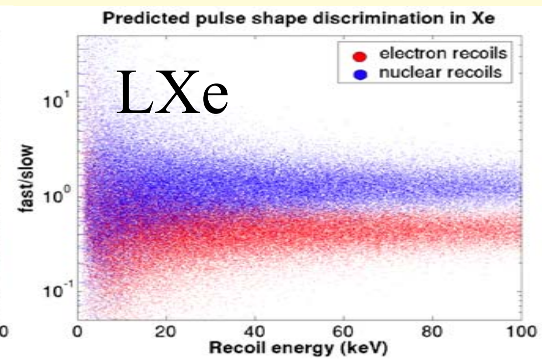


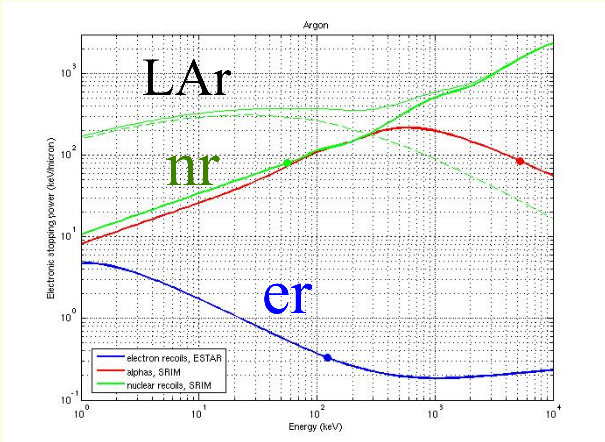
- Ar:
  - Huge pulse-shaped discrimination needed because of ^{39}Ar.
  - Very small apparent "Lindhard" factor.



- Xe scintillation discrimination: a cautionary tale







XENON10 Neutron Backgrounds

- Main Neutron Backgrounds
  - (alpha,N)/Fission Neutron from Rock
    - (alpha,N) Neutron Flux: 10^{-6} N/(sec· cm^2)
  - Muon Induced Neutrons from Pb Shielding
    - Neutron Yield in Pb: 4 x 10^{-3} N/(muon g cm^{-2})
    - Muon Flux at Gran Sasso: 1 muon / (hour m^2)
- Event rates for above types of Neutron sources are reduced below XENON10 goal by ~1/10x.
  - Low Energy Neutrons are currently moderated by 20cm internal poly. (XENON100 would require muon veto for Pb events + external poly)
- High Energy Neutrons from Muons in Rock (see table)
  - Depth necessary to reduce flux
  - LNGS achieves XENON10/100 goal
  - Traditional Poly shield is not efficient in moderating High Energy Muon-Induced Neutrons

Goal (Rates for Current Shield Design)	DM NR Signal Rate Xe @ 16 keVr	Soudan 2.0 kmwe	Gran Sasso 3.0 kmwe	Home-stake 4.3 kmwe
High Energy Neutron Relative Flux (from muons)		x1	X1/6	x1/30
XENON10 ($\sigma \sim 2\ 10^{-44}\ cm^2$)	400 μdru	x 20	x 120	x 600
XENON100 ($\sigma \sim 2\ 10^{-45}\ cm^2$)	40 μdru	x 2	x 12	x 60
XENON1T ($\sigma \sim 2\ 10^{-46}\ cm^2$)	4 μdru	x 0.2	x 1	x 6

TABLE: Integ. WIMP Signal (m_W=100 GeV) / HE Neutron BG evt
[~1/2–2x uncertainty in actual HE neutron BG]

DM Signal/HE Neutron BG needs to be >>10 to ensure WIMP differential signal spectrum can be observed in adequate recoil energy range (compared to flatter differential neutron bg spectrum)

1T Detector can use "thicker" shield (e.g. water/active) to reduce HE neutrons for even greater reach