Title: Direct Dark Matter Searches

Date: Jun 03, 2008 11:50 AM

URL: http://pirsa.org/08060038

Abstract: Astrophysical evidence indicates that the universe consists to about 25% of non-baryonic, cold Dark Matter, compared to merely ~4% of \'regular\' matter, composed of quarks and electrons. The existence of Dark Matter and Dark Energy is striking evidence for physics beyond the Standard Model, and understanding their nature ranks among the foremost questions in science today. If the bulk of matter in the universe consists of relic massive particles moving at non-relativistic speeds, we may be able to detect these particles in direct searches with low background experiments. This talk will focus on the search for weakly interacting massive particles (WIMPs), predicted in particular by theories invoking supersymmetry. The recoils of target nuclei resulting from elastically scattering WIMPs should be detectable in principle with sensitive detectors. I will review the current status of direct Dark Matter searches, and then elaborate on the XENON suite of experiments. The XENON Dark Matter program was established in 2002, and reached a major milestone with the installation of its first Dark Matter detector, XENON10, at the Gran Sasso underground laboratory in Italy. XENON10 reported the world-best limits on spin-independent WIMP-nucleon cross-sections last year. (CDMS-II has recently improved their limits even further.) Meanwhile, we are building the next generation detector XENON100 at the same location. The new detector will feature ten-fold greater fiducial mass and 100 times improved background. We anticipate first results by the end of the year. I will report on the status of XENON100 and its projected sensitivity, and conclude with an outlook on the prospects of the field.

Direct Dark Matter Searches
(A XENON Perspective)

Uwe Oberlack

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Rice University
http://xenon.physics.rice.edu

PASCOS '08
Perimeter Institute, June 3, 2008

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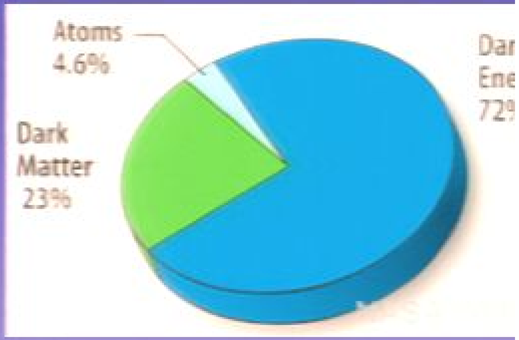
The Dark Universe



Transparent

The ~~Dark~~ Universe

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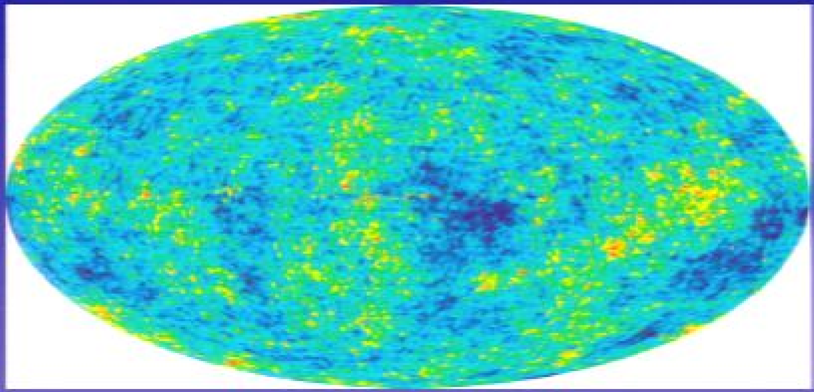
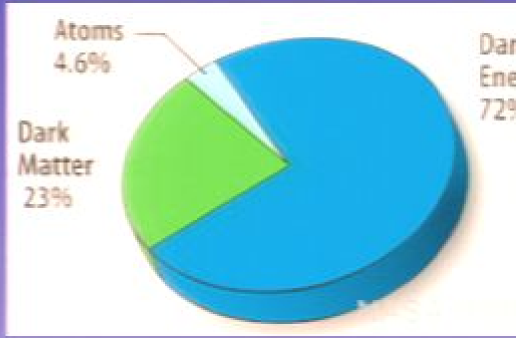
  - → Uniformity at age 380,000 yr.
  - → Geometry of the universe (with H_0 or other), etc.





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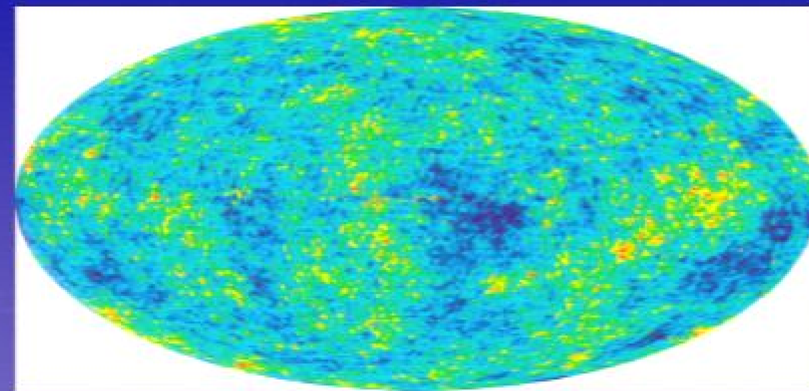
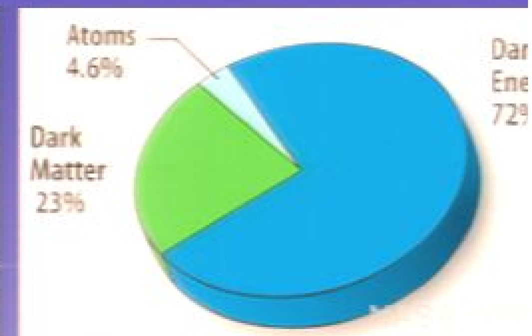
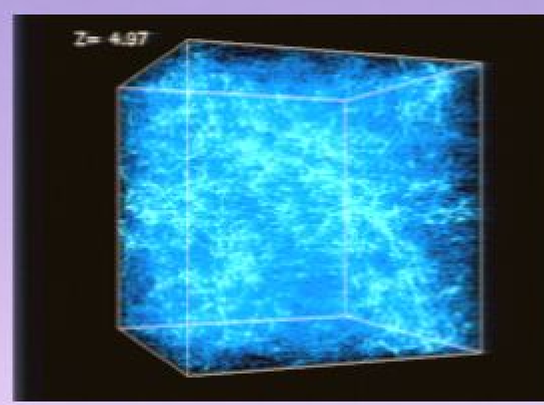
- Galaxy surveys (wide or deep) and Simulations of structure formation.
  - → Large scale structure.
  - → Early structure formation. First stars. Quasars and galaxies.







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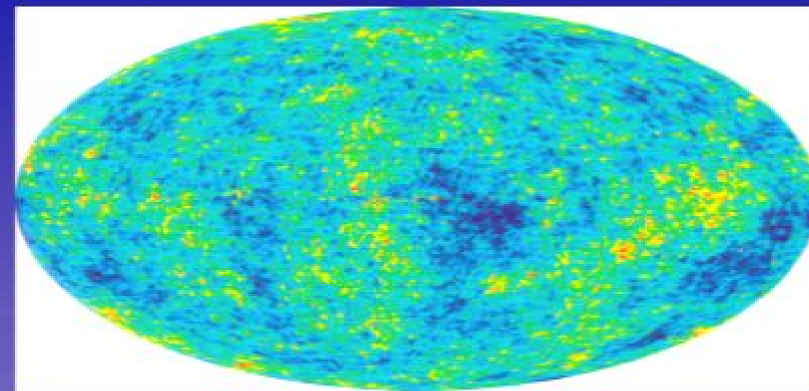

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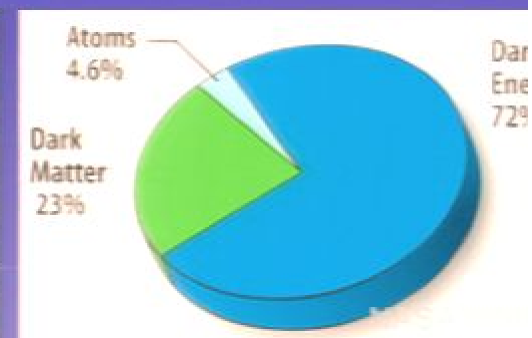
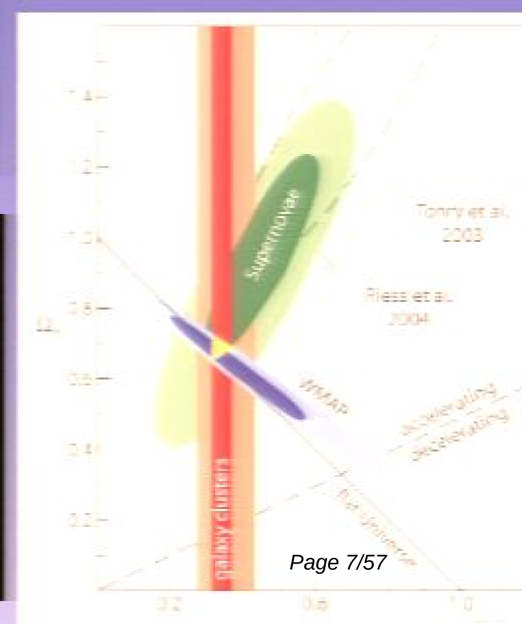
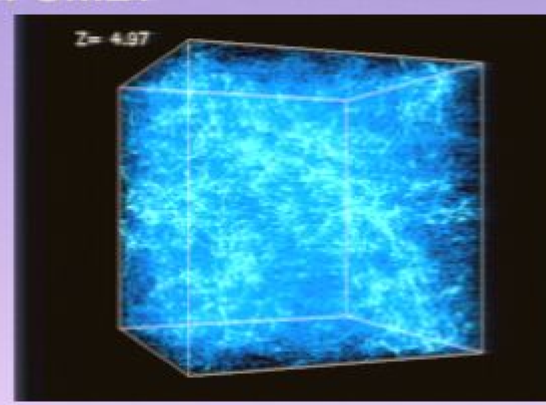
- Big Bang Nucleosynthesis and light element abundances observed in the early universe.
  - → Limit on baryon density, consistent with CMB.
- Galaxy clusters
- Baryon Acoustic Oscillations, etc.

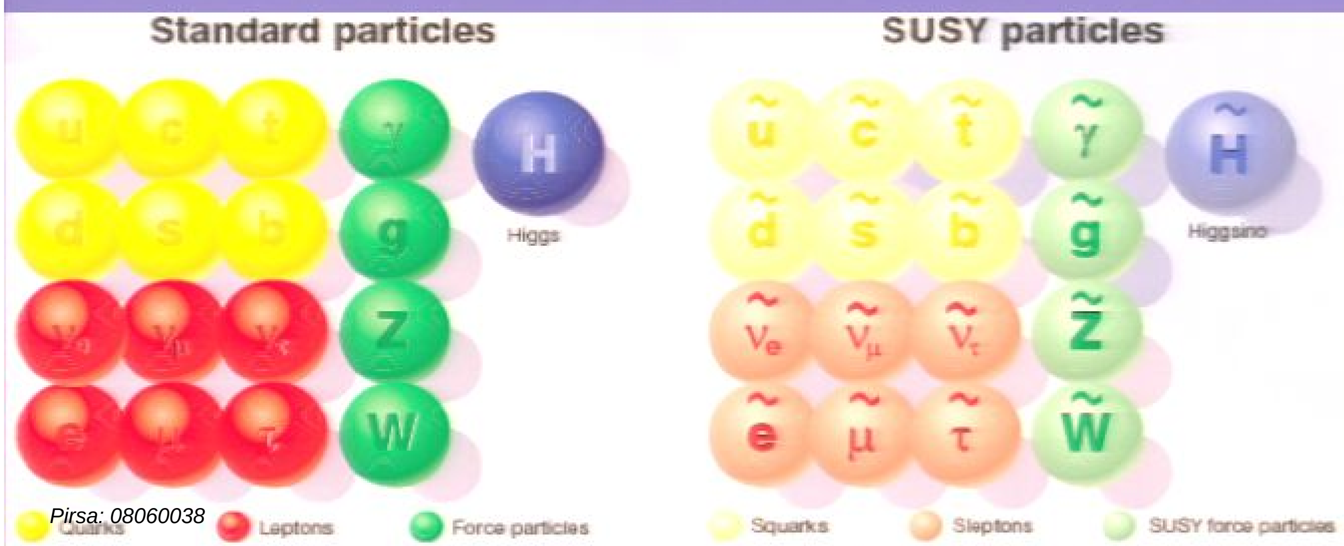


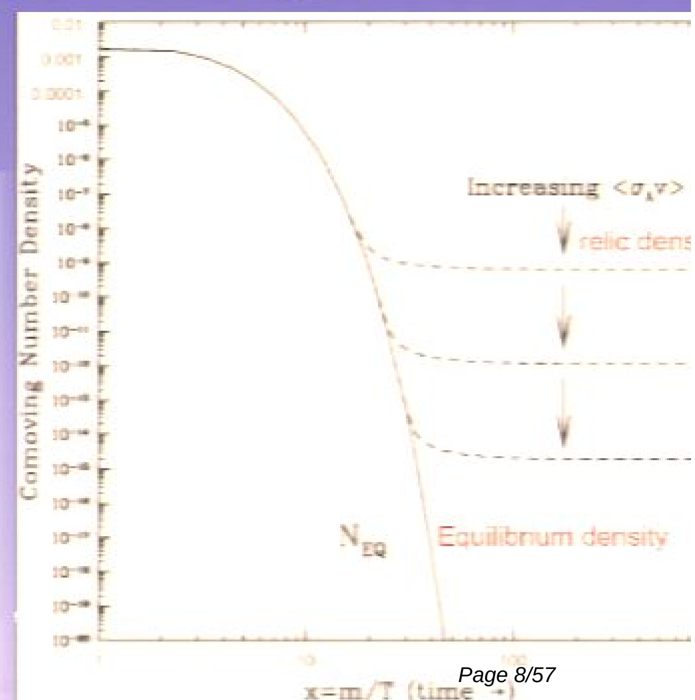




Dark Matter: A Relic of SUSY WIMPs?

- Dark Matter and Dark Energy: physics beyond the Standard Model.
- Postulate supersymmetry (SUSY) between fermions and bosons: each fermion (boson) in the SM has a bosonic (fermionic) SUSY counterpart.
  - → SUSY partners of particles: "sparticle" (squarks, selectrons, etc.).
  - → SUSY partners of gauge bosons: "gauginos". (wino, zino, etc.)
- SUSY was invented to solve problems in particle physics (hierarchy, GUT), ***not*** to explain DM. Yet, it provides a natural DM candidate if the lightest SUSY particle is stable. Mass eigenstate of LSP in R-parity conserving SUSY: neutralino χ. (Plus: gravitino, ...)



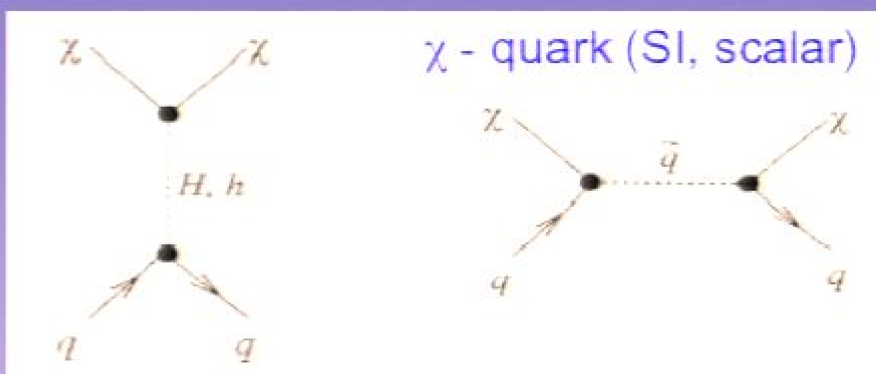


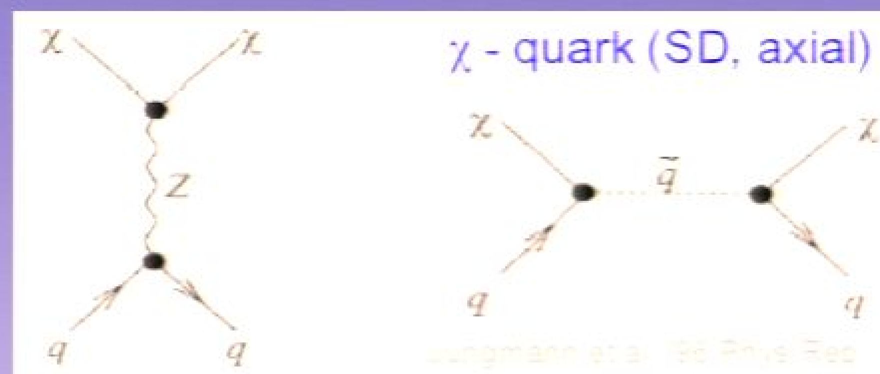
WIMP DM Direct Detection

- Elastic scattering of WIMP's χ off of nuclei A.
- Energy spectrum and rate depend on WIMP velocity v_χ and density ρ_χ distribution in DM halo.
  - → Local: $\rho_\chi \sim 0.3$ GeV/cm^3, $(\rho_\chi/m_\chi) \sim 1\text{-}10$ / liter
  - → $v_\chi \sim 230$ km/s
- For standard spherical halo:
  Featureless recoil spectrum with <E> ~ O(10 keV).
- **Scattering rate ~ N $(\rho_\chi/m_\chi) \langle v_\chi\, \sigma_{scat} \rangle$**
  - → N: number of target nuclei in the detector
  - → ρ_χ/m_χ: local number density of WIMPs
  - → σ_{scat} cross section per nucleus. <...>: velocity average
- Rate: $10^{-2} - 10^{-5}$ events / kg / day

WIMP DM Direct Detection Cross Sections

- Compute cross sections χ – quark and χ – gluon with various SUSY models. Large parameter space, constrained by accelerator and direct search experiments, and cosmology.
  - → spin-independent: coupling to mass of nucleus $\sim A^2$
  - → spin-dependent: coupling of spins of nucleus and neutralino $\sim(J+1)/J$ interaction with paired nucleons in the same energy state cancel => no A^2 enhancement

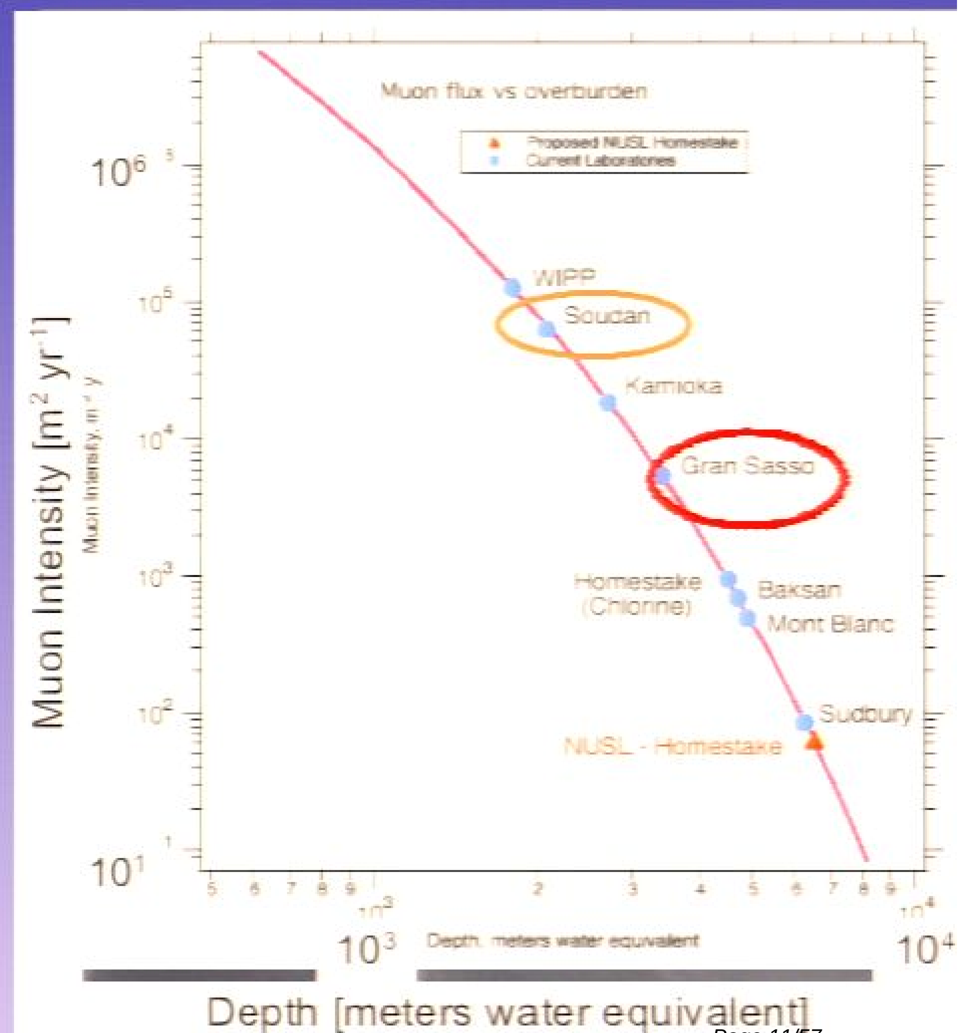




- Distribution of nucleons within nucleus: nuclear form factor.
  - → SI: Large nuclei gain $\sim A^2$ at small momentum transfer, but lose at higher momentum transfer due to coherence loss.

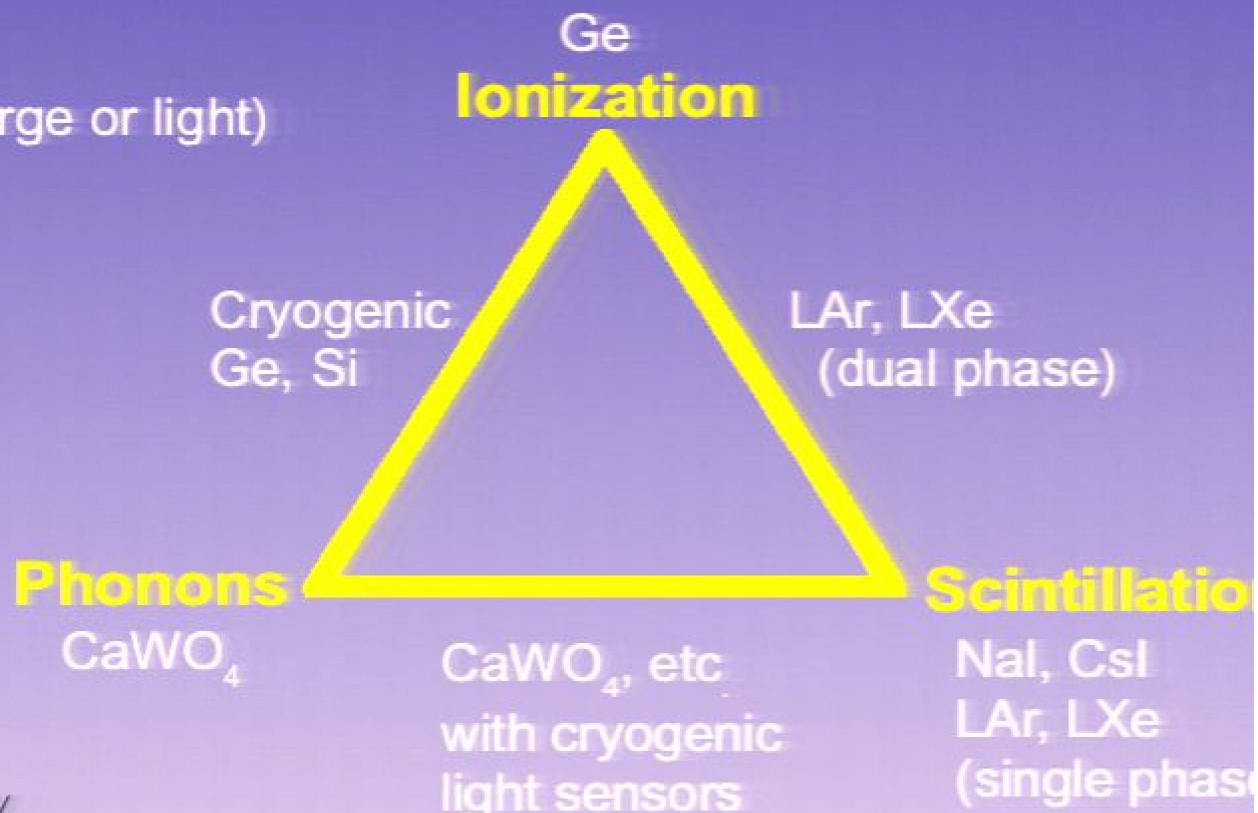
Backgrounds in Direct DM Search

- Cross-sections are *very* small: $<10^{-43}$ cm^2 or 10^{-7} pb (spin-independent)
- Without background, sensitivity ∝ (mass × exposure time)$^{-1}$
- With background subtraction ∝ $(M\ t)^{-1/2}$ until limited by systematics.
- Backgrounds:
  - → Gamma-rays & beta decays: ~100 events/kg/day
    - Need efficient β and γ background discrimination.
    - Shielding: low-activity lead, water, noble liquids (active), liquid N_2, ...
  - → Neutrons from (α, n) reactions in rock: ~ 1 event/kg/day (LNGS)
    - Neutron moderator (polyethylene, paraffin, ...)
  - → Neutrons from CR muons: depends on depth.



DM DETECTOR OVERVIEW

- Many detector concepts at various stages of fruition.
- Classify detectors by detection principle (physics channels).
- Some use more than one feature of a given physics channel (e.g. scintillation: amplitude and pulse shape).
- Single channel vs. two channels.
- Other approaches:
  - → Tracking gas detectors (charge or light)
  - → Bubble chambers



I will present only a focused view.
See talks at DM2008 conference for more details:
http://www.physics.ucla.edu/hep/dm08/

DM Detector Overview

Detector Type	Experiments	Strengths / Caveats	
Ionization	MAJORANA, GERDA	Search for $\beta\beta$-decay	
Crystal Scintillator	LIBRA/DAMA, NAIAD, KIMS	low threshold, large mass, poor background discrimination	
Cryogenic	CDMS, CRESST, EDELWEISS	good background discrim., smaller mass / high cost	
Liquid Noble Gas	Ar: ArDM, WARP, DEAP/CLEAN	large mass, good backgrnd discrim., position resol. (dual phase)	Ar: intrinsic background
	Xe: XENON, XMASS, ZEPLIN, LUX		Xe: self shielding, odd & even isotopes
Bubble Chamber	COUPP, PICASSO	large mass, good background discrim.	
Gas Detector	DRIFT, DM-TPC	directional information, good background discrim.	

Background Discrimination Techniques:

- none (low bgd)
- pulse shape
- charge/phonon
- light/phonon
- light/charge
- super-heated bubbles/drople
- ionization track
- plus: 3D positic

DAMA/LIBRA

(R. Bernabei et al. arXiv:0804.2738)

- Extended experiment from prior experiment DAMA/NaI (100 kg)
- 5x5 array of 9.7 kg NaI(Tl) crystals viewed by 2 PMTs each.
- PMTs with single photoelectron threshold, operating in coincidence.
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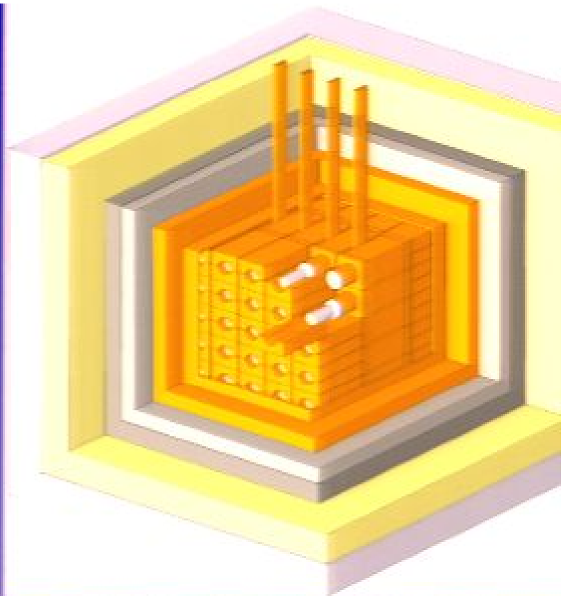
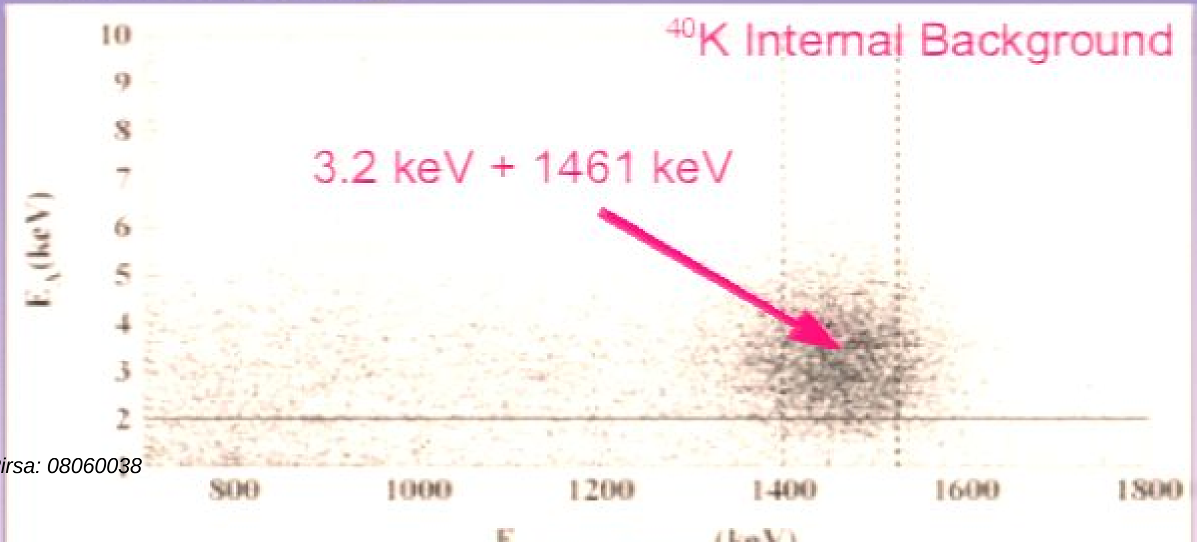
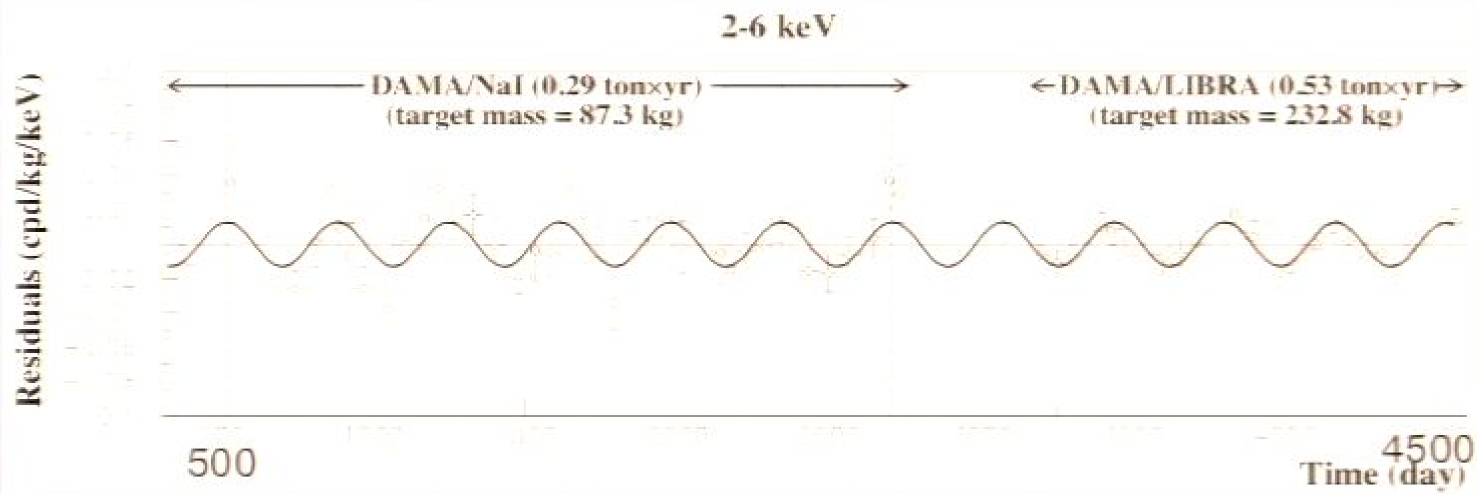




DAMA/LIBRA (NaI) Annual Modulation

(R. Bernabei et al. arXiv:0804.2741)



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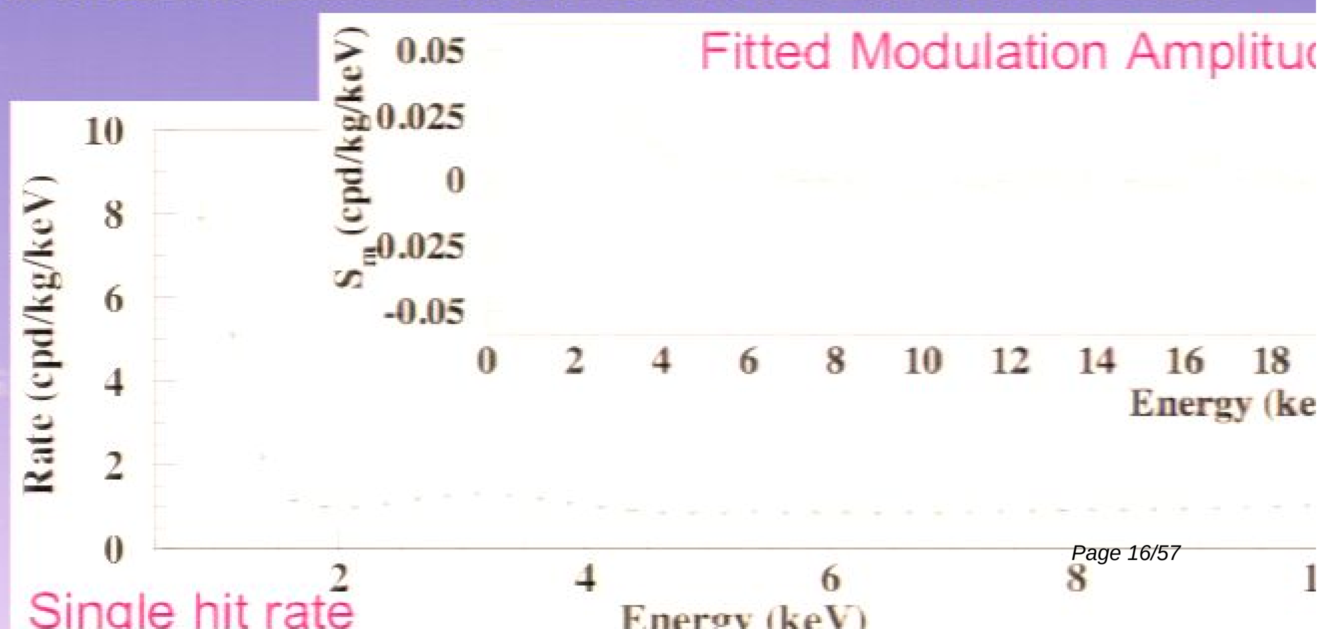
Drukier, Freese, Spergel PRD86
Freese et al. PRD88

$$v_{\oplus}(t) = v_{sun} + v_{orb} \cos\gamma \cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \simeq S_{0,k} + S_{m,k} \cos[\omega(t-t_0)]$$

- Annual modulation rate ~5% total interaction rate in standard DM distributions.
- DAMA/LIBRA modulation: ~0.02 cts/d/kg/keV (ee)
- i.e., ~0.4 cts/d/kg/keV total DM interaction rate
- i.e., XENON10 should have observed >50 events in standard scenarios.



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What shall we conclude?

- "Standard" scenarios put DAMA/LIBRA in conflict with several other experiments (XENON10, CDMS, COUPP, etc.).
- But aren't we talking "beyond standard" anyway? -- Well, maybe.
- Which options do we have?
  1. Nasty old physics (systematic effect).
     a) Background modulation effect.
     b) Response variations. (Thresholds, efficiencies, etc.)
  2. Fancy new physics. Maybe related to DM. Or to something else? If DM: inelastic scattering? 3 keV level splitting? Astrophysics? (DM streams), ...

How can we make progress?

- Study same energy regime (low threshold) with other large detectors for >1yr.
- Use position-sensitivity of liquid noble gas detectors to operate at much reduced background in inner fiducial volume.
- Look for signatures of seasonal vs. celestial effects (e.g., solar year vs siderial year, diurnal variations,...) in DAMA/LIBRA data.
- Exploit DAMA/LIBRA data further wrt hidden systematics (e.g.,all inner vs all outer detectors)
- Calibration of nuclear recoils of at least some of the detector crystals at low E.

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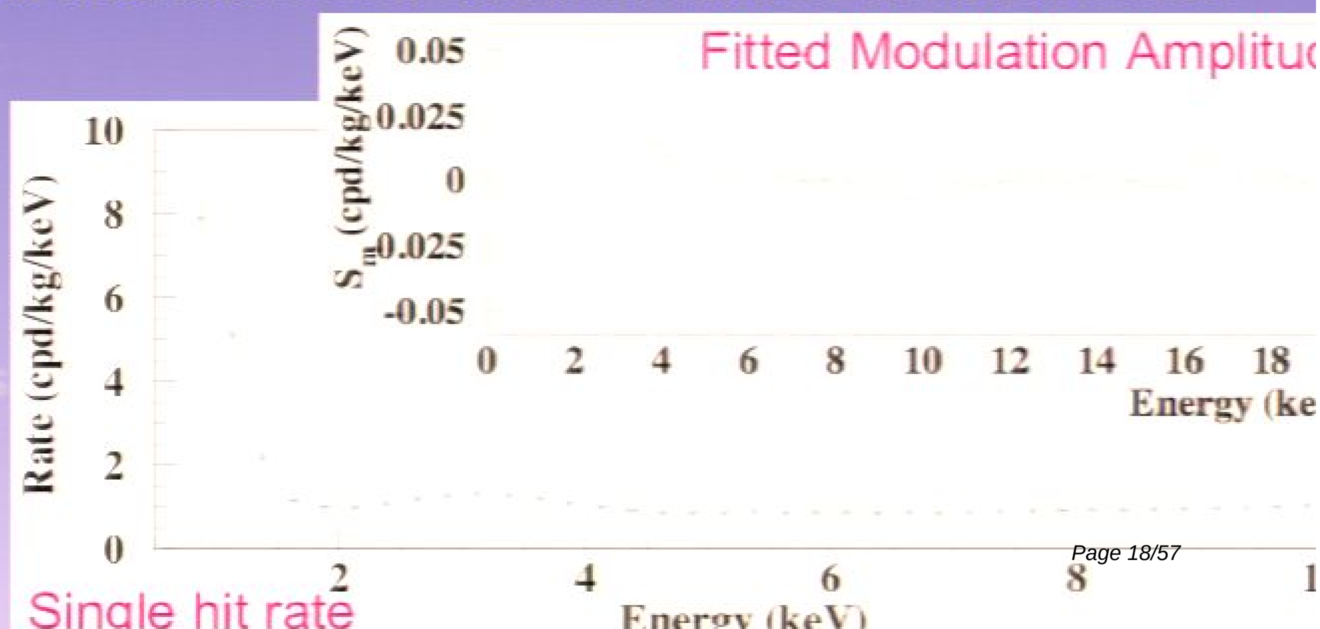

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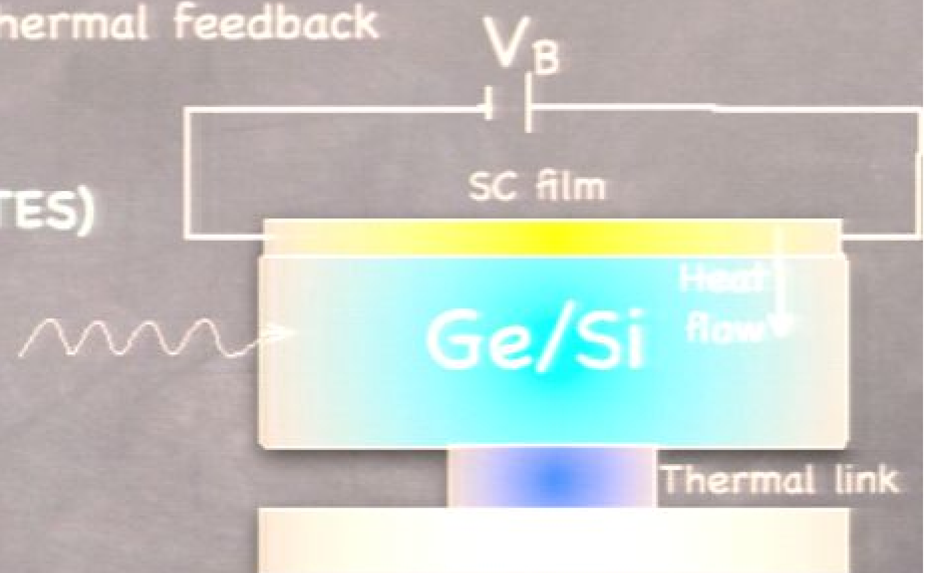
CDMS II: Ionization + Fast Phonons

Detect **fast phonons,** after a WIMP interacts in a Ge/Si absorber using transition edge sensors with electrothermal feedback

K.D.Irwin et al., Rev. Sci. Instr. 66 (1995)



$T_0 \ll T_C$; V_B is placed across the film (TES)

=> equilibrium: when ohmic heating

balanced by heat flow into the absorber

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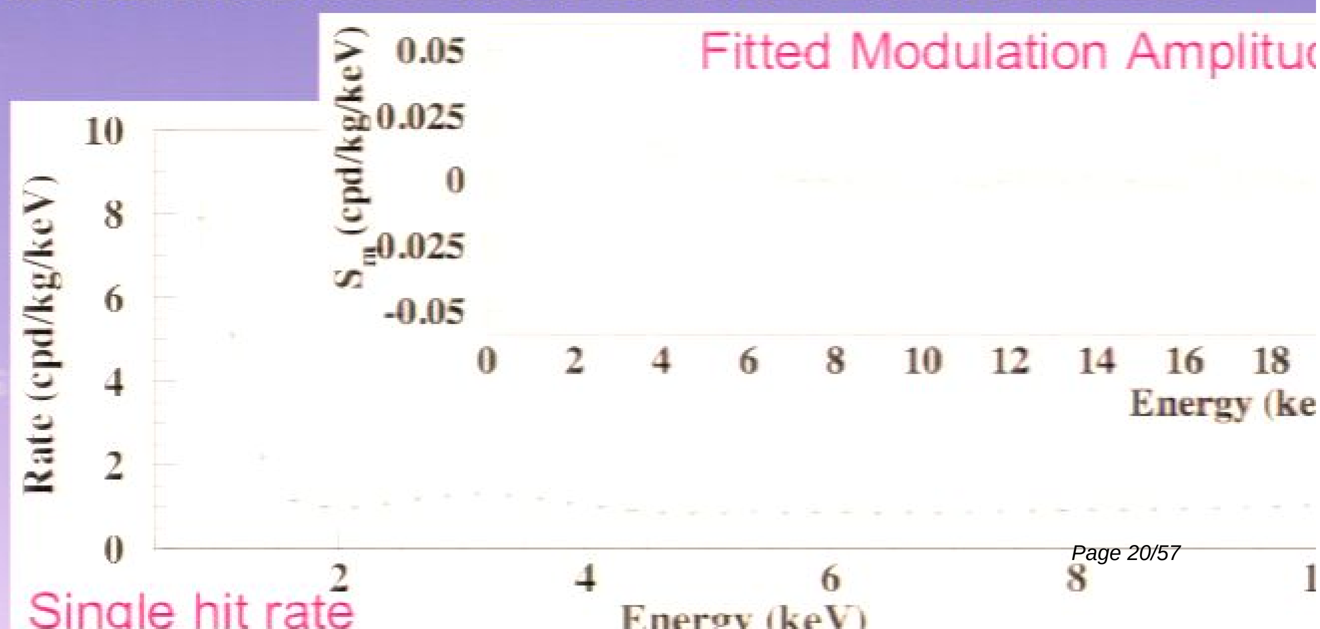

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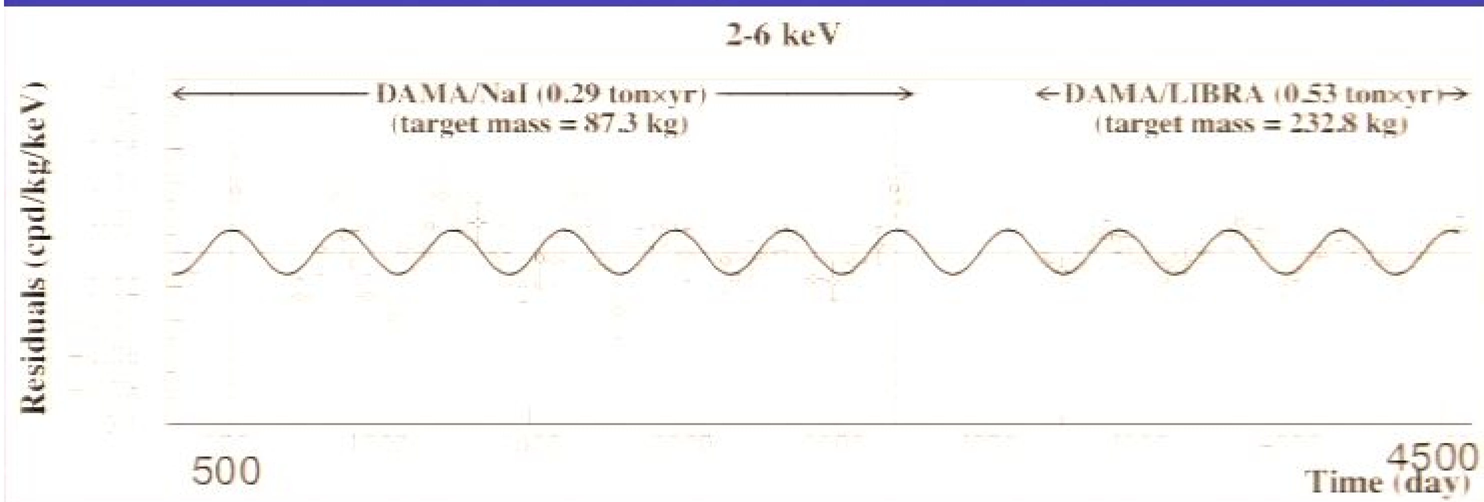

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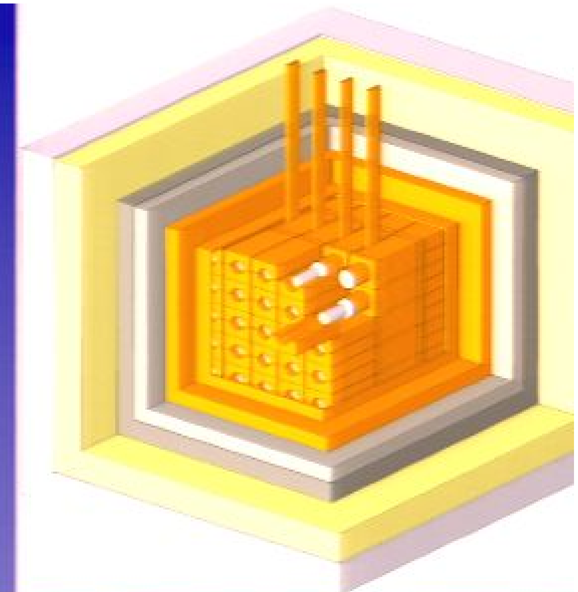

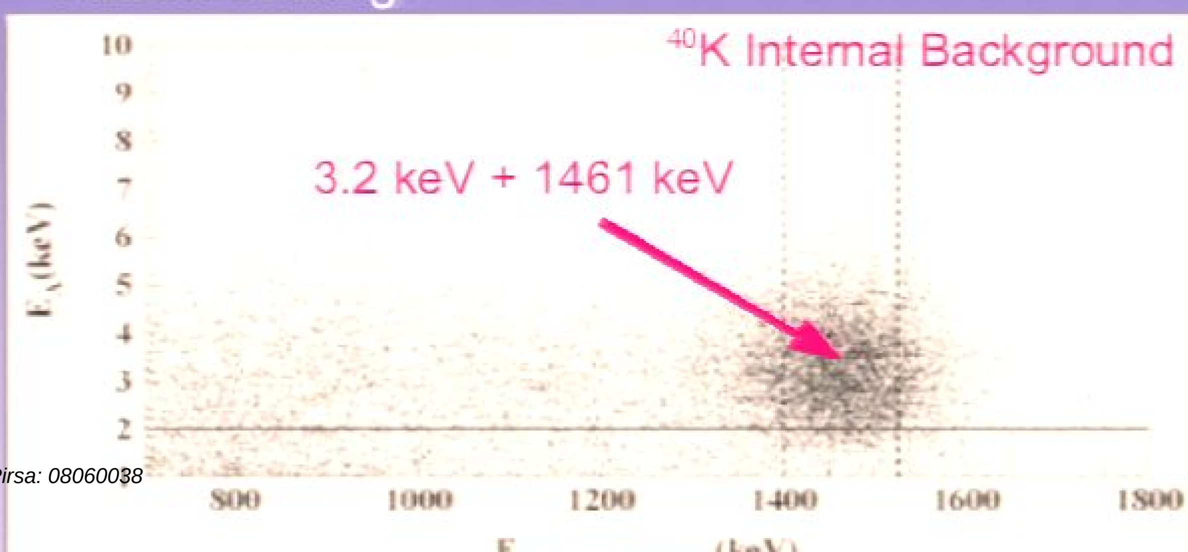

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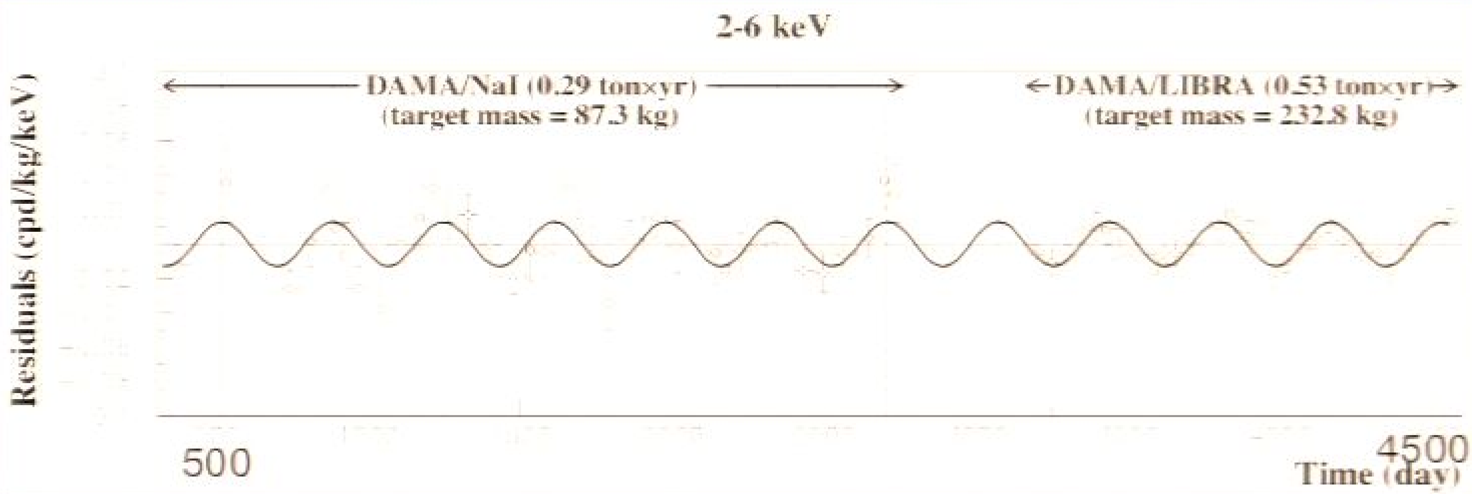

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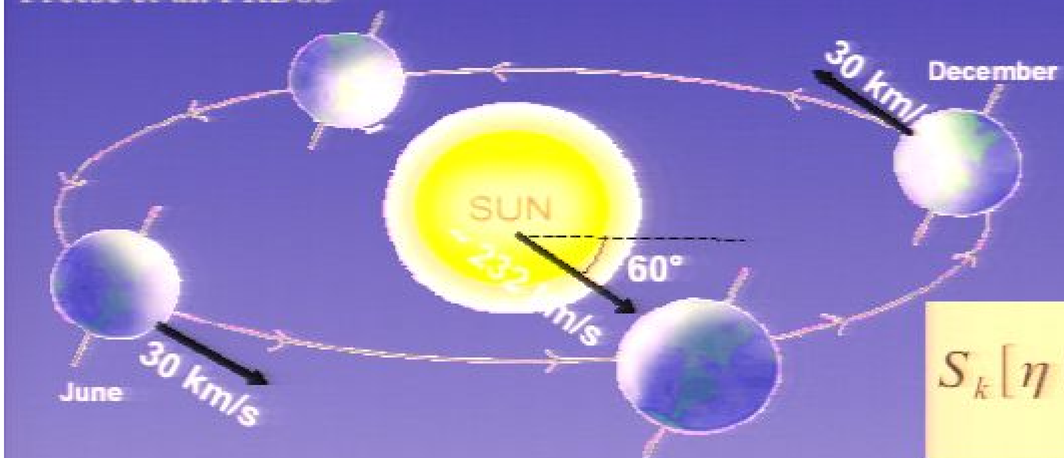
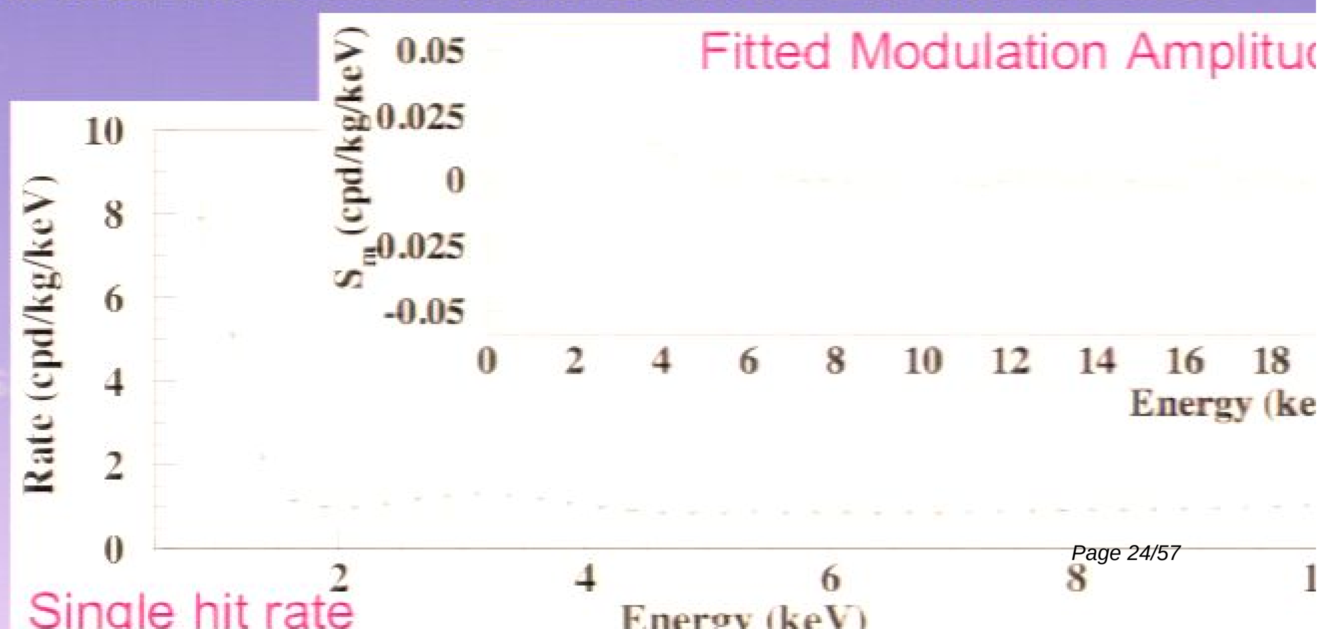


$$v_\oplus(t) = v_{sun} + v_{orb} \cos\gamma \cos[\omega(t-t_0)$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \simeq S_{0,k} + S_{m,k} \cos[\omega(t-t_0$$

- Annual modulation rate ~5% total interaction rate in standard DM distributions.
- DAMA/LIBRA modulation: ~0.02 cts/d/kg/keV (ee)
- i.e., ~0.4 cts/d/kg/keV total DM interaction rate
- i.e., XENON10 should have observed >50 events in standard scenarios.



Uwe Oberlack

What shall we conclude?

- "Standard" scenarios put DAMA/LIBRA in conflict with several other experiments (XENON10, CDMS, COUPP, etc.).
- But aren't we talking "beyond standard" anyway? -- Well, maybe.
- Which options do we have?
  1. Nasty old physics (systematic effect).
     a) Background modulation effect.
     b) Response variations. (Thresholds, efficiencies, etc.)
  2. Fancy new physics. Maybe related to DM. Or to something else? If DM: inelastic scattering? 3 keV level splitting? Astrophysics? (DM streams), ...

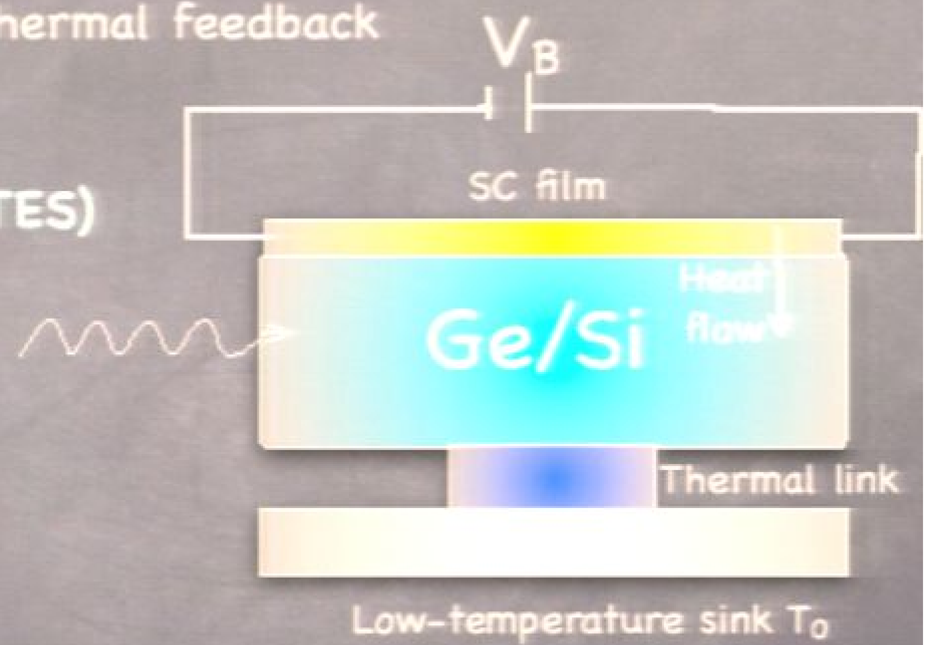
How can we make progress?

- Study same energy regime (low threshold) with other large detectors for >1yr.
- Use position-sensitivity of liquid noble gas detectors to operate at much reduced background in inner fiducial volume.
- Look for signatures of seasonal vs. celestial effects (e.g., solar year vs siderial year, diurnal variations,...) in DAMA/LIBRA data.
- Exploit DAMA/LIBRA data further wrt hidden systematics (e.g.,all inner vs all outer detectors)
- Calibration of nuclear recoils of at least some of the detector crystals at low E.

CDMS II: Ionization + Fast Phonons

Detect **fast phonons,** after a WIMP interacts in a Ge/Si absorber using transition edge sensors with electrothermal feedback

K.D.Irwin et al., Rev. Sci. Instr. 66 (1995)



$T_0 \ll T_C$; V_B is placed across the film (TES)

=> equilibrium: when ohmic heating

balanced by heat flow into the absorber

When an excitation reaches the TES

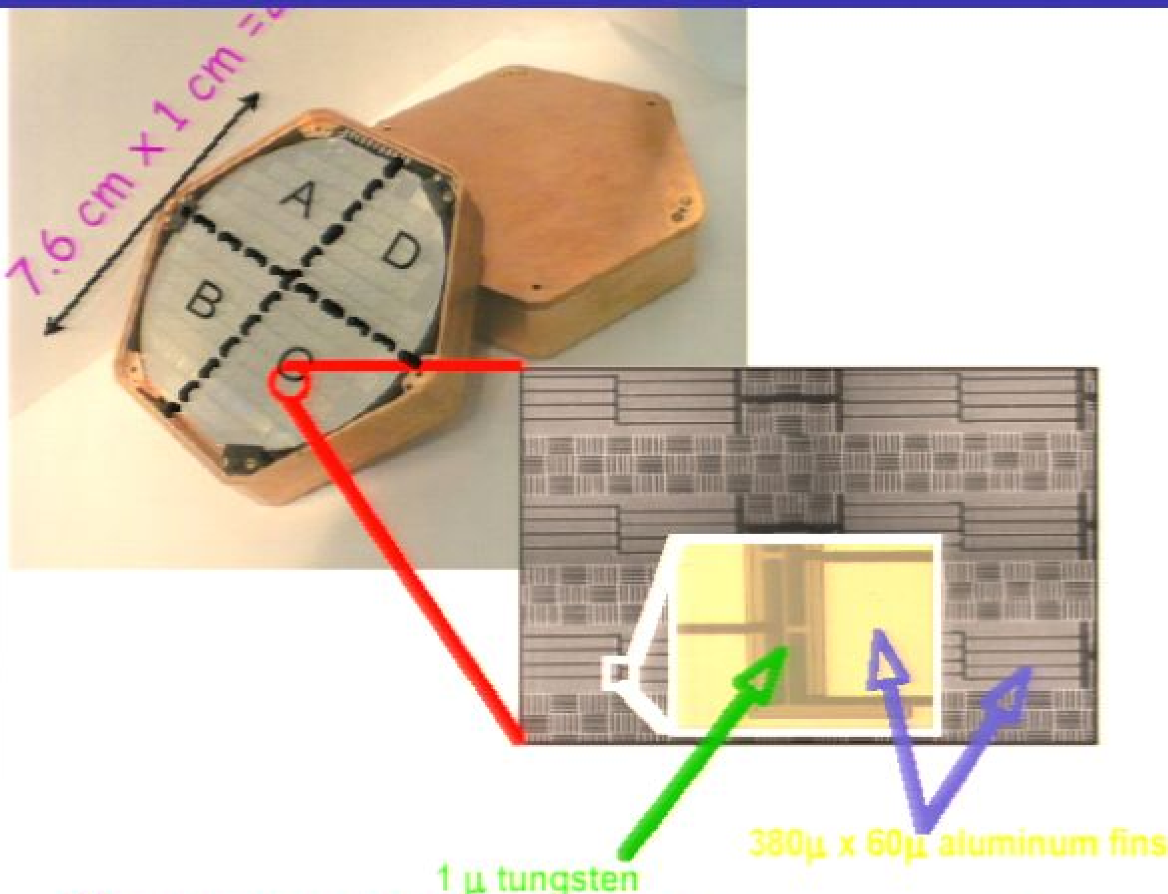
=> R ↗ => I ↘ by ΔI => P ↘

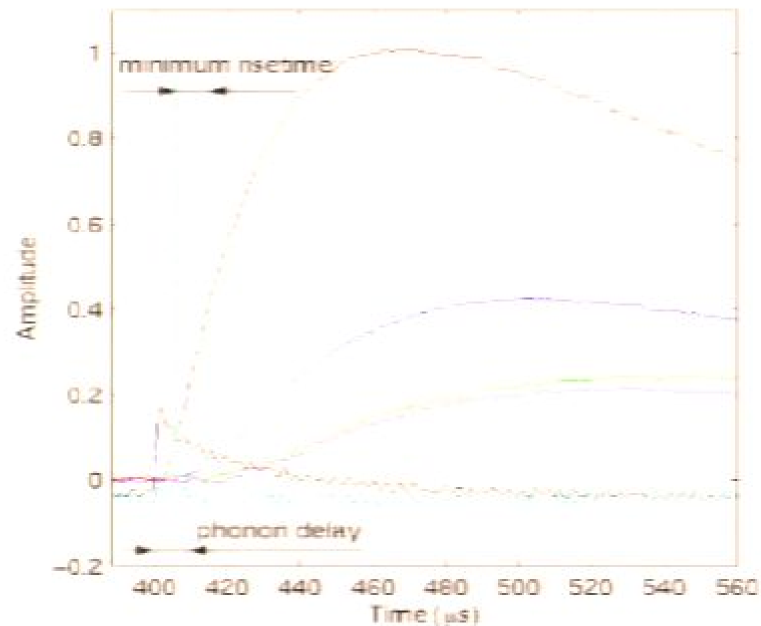
=> feedback signal = change in Joule power heating the film ($P=IV_B=V_B^2/R$)

The deposited energy:

$$E = -V_B \int \Delta I(t)\,\mathrm{d}t$$

CDMS II: Ionization + Phonons (Ge,Si)





Phonons+ionization large signal to noise (cf EDELWEISS, CRESST)

=> total energy, ionization yield: discrimination of nuclear recoils

Athermal => large amount of information

=> 3D position of the event

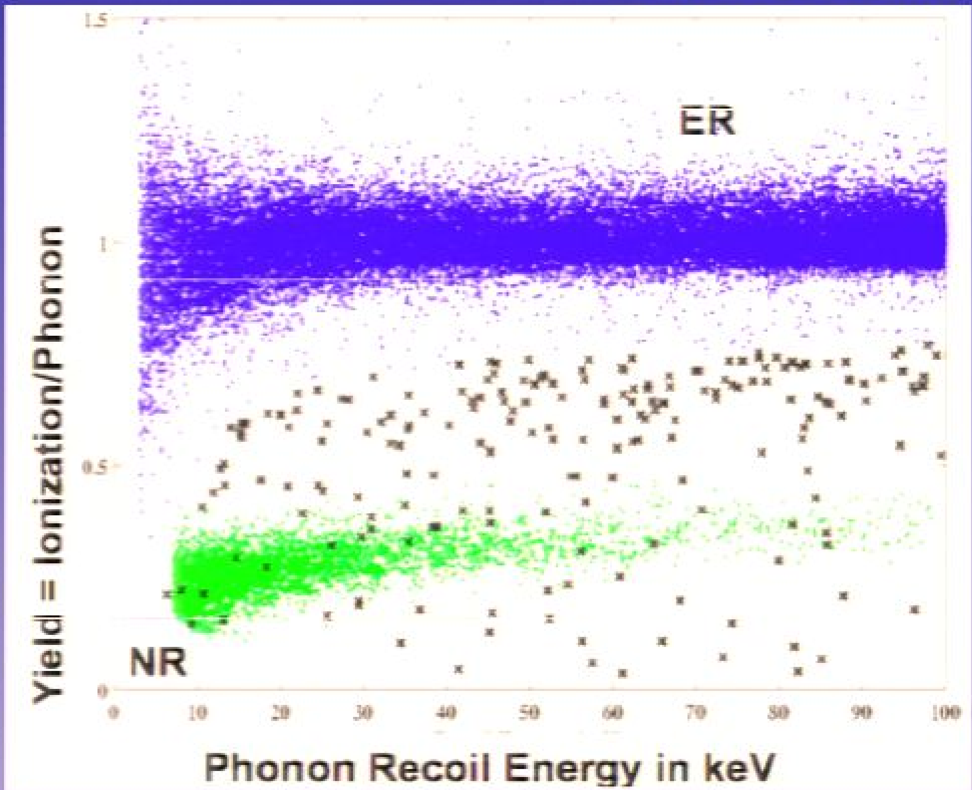
In particular, in spite of "folding", proximity to the surface

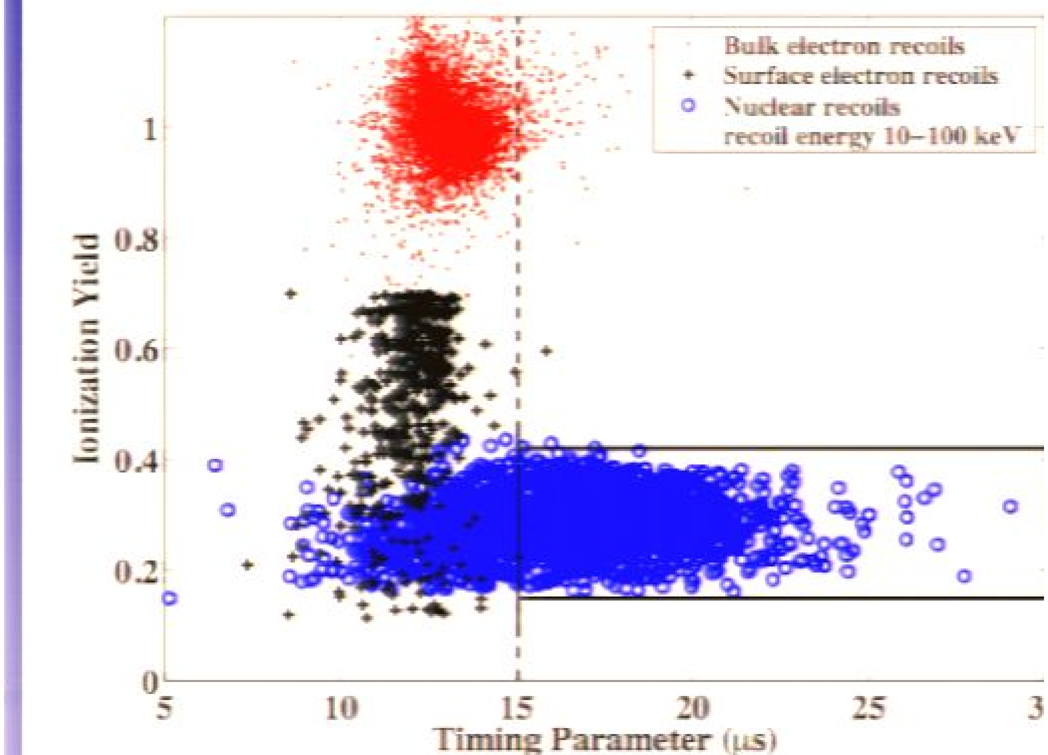
≠ surface electrons

B. Sadoulet

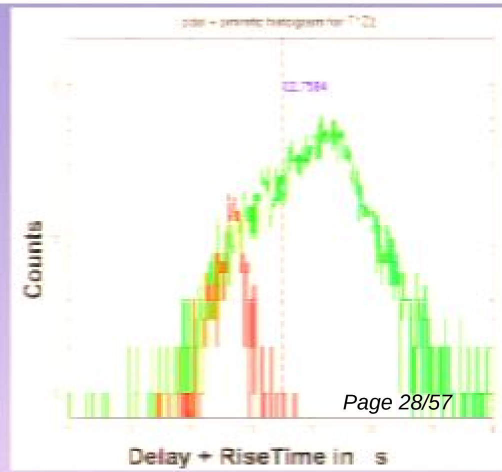
CDMS II Background Discrimination

arXiv:08020350, R. Mahapatra PPC2008



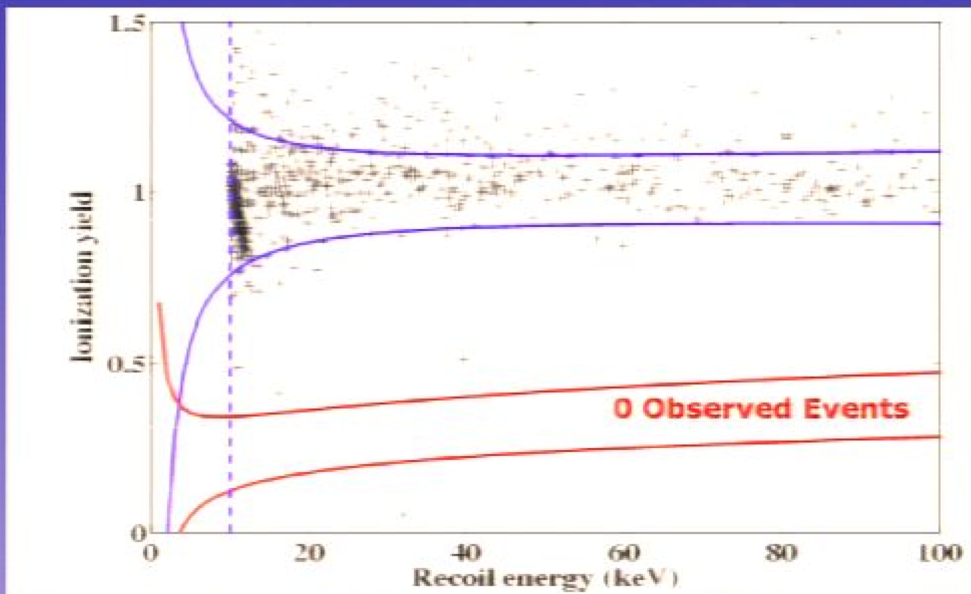


- 5 towers of detectors (previously 2)
- Fix cuts blind with calibration data.
- Choose cuts aiming at background level ~0.5 events, i.e., efficiency goes down with time.
- So far losses offset by analysis and detector improvements.

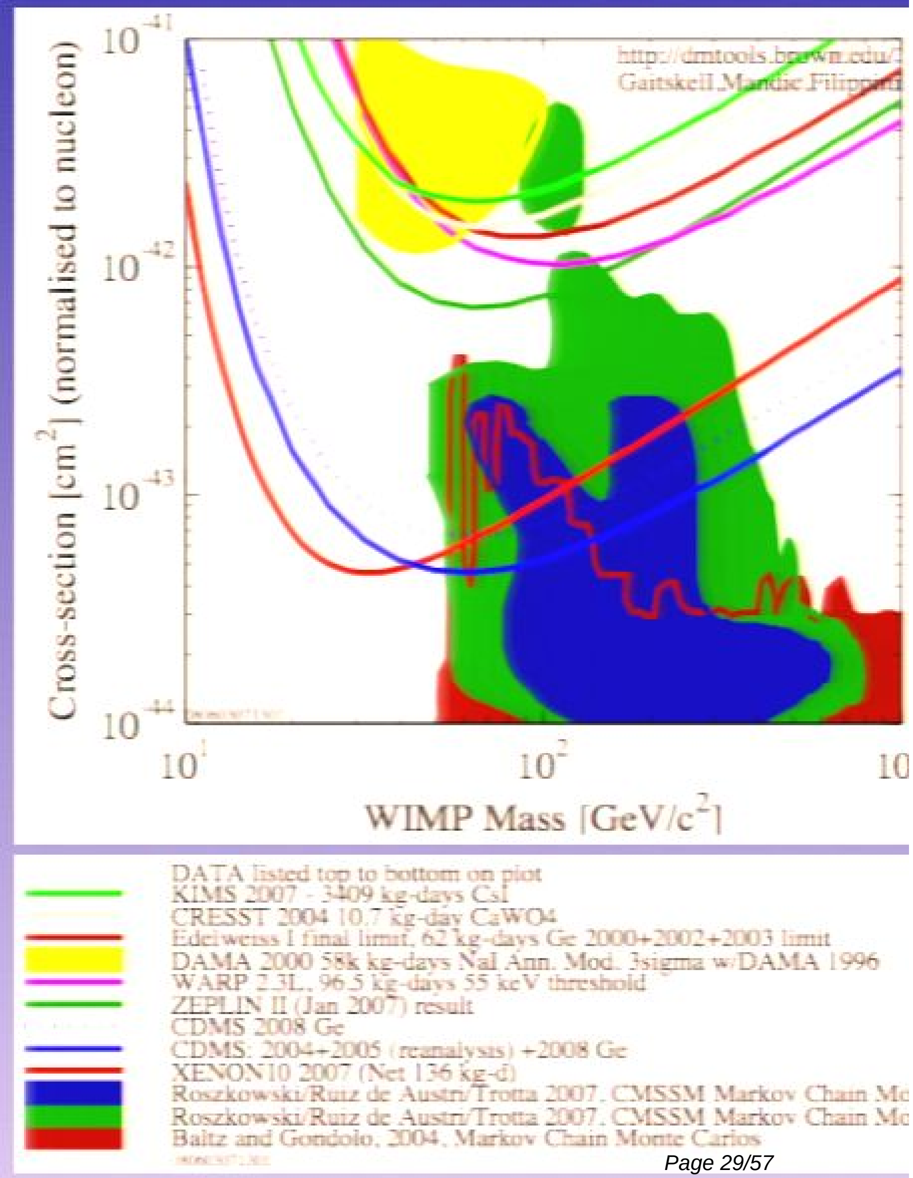


CDMS II – 2008 Result

arXiv:08020350



Expected Background: 0.6 ± 0.5 surface events and < 0.2 neutrons



- Exposure: 121.3 kg days
- Expect ~0.5 events gamma background
- Expect ~o.2 events neutron background.

The XENON Phased Program

Detector:

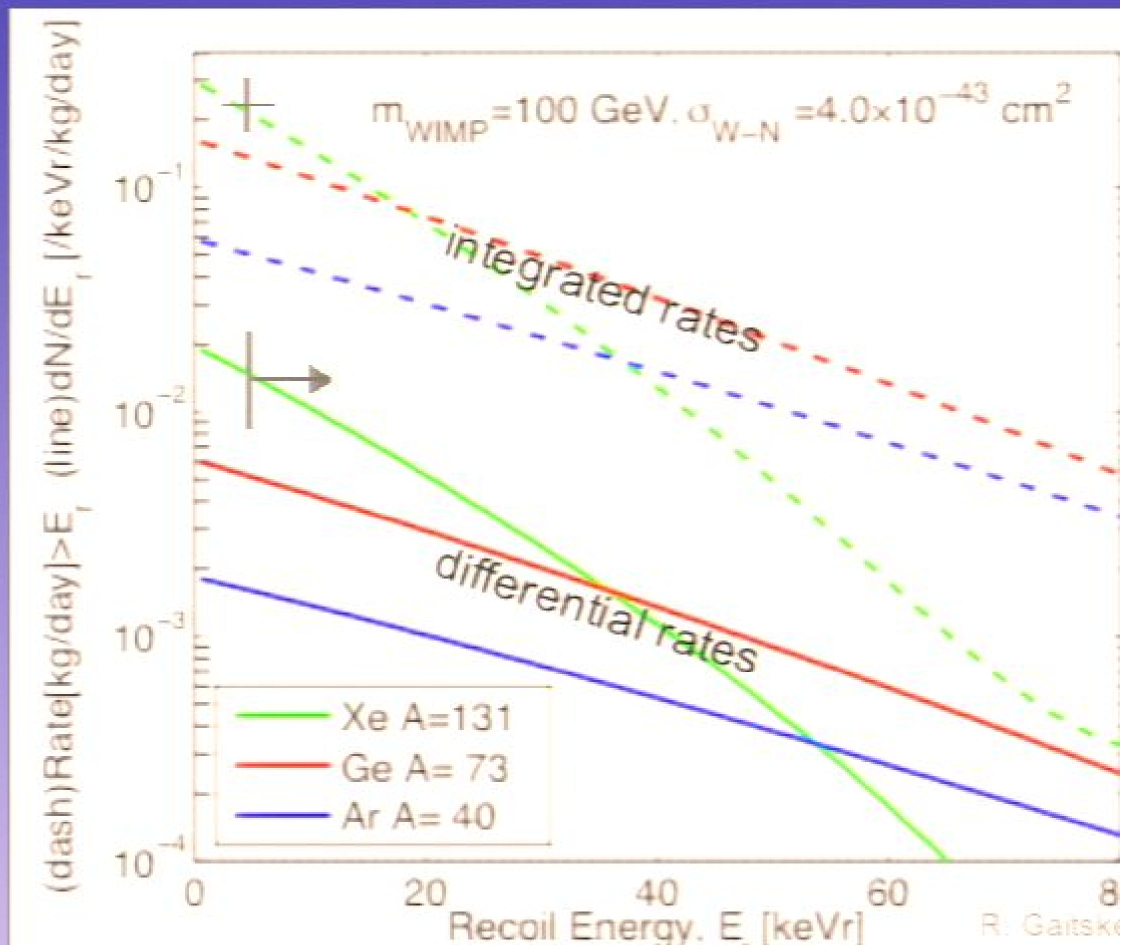
- Two-phase liquid/gas Xe TPC: 3D position sensitive, self-shielding.
- Target LXe: excellent for DM WIMPs scattering.
  → Sensitive to both axial and scalar coupling.
- Background discrimination: simultaneous charge & light detection (>99.5%)
- PMT readout with >3 pe/keV. Low energy threshold for nuclear recoils (~5 keV)

Phases:

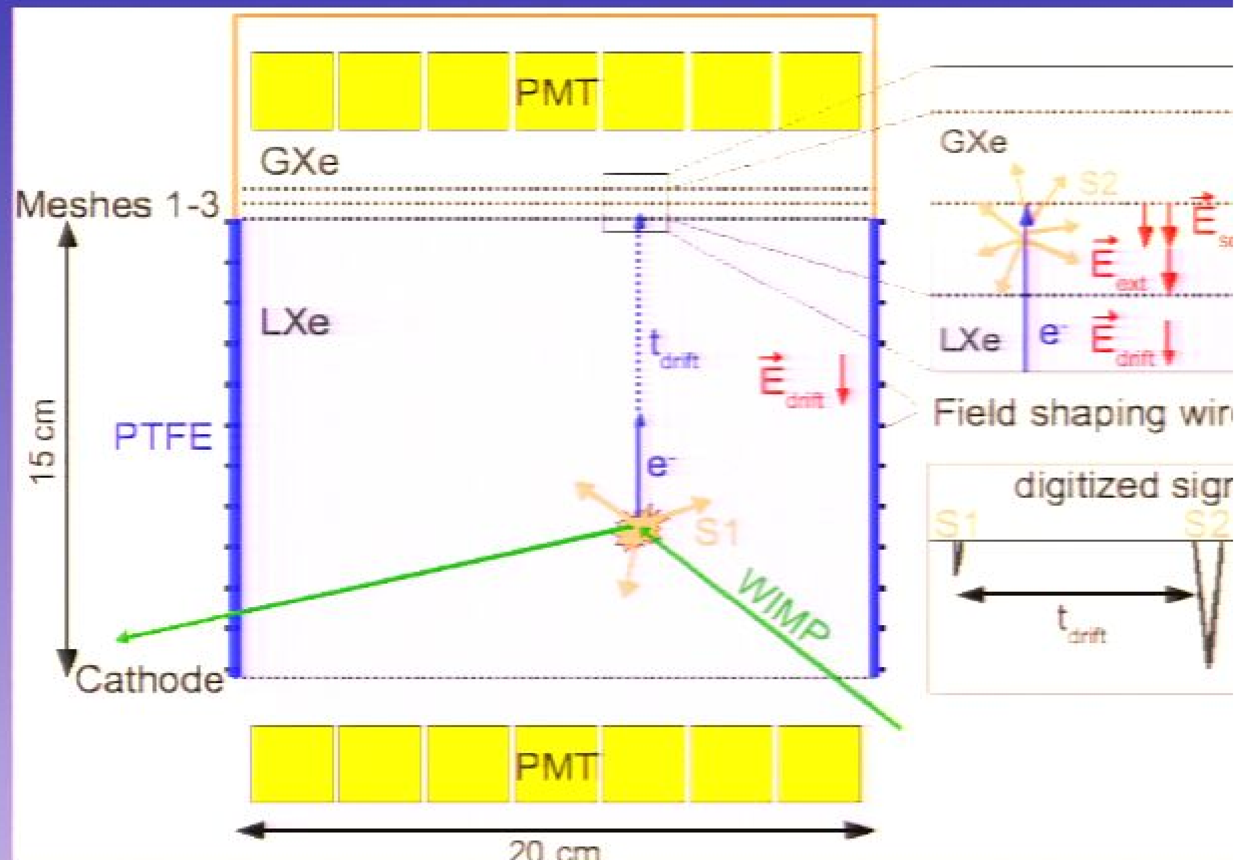
- **XENON10** first proof of concept in underground laboratory (LNGS).
  → Best sensitivity in 2007: σ_{SI}~10^{-43} cm^2 for 100 GeV WIMP
  → Decommissioned Oct. 2007.
- **XENON100** currently under commissioning at LNGS.
  → Physics run starts Summer 2008.
  → 70 kg target, shielded by 100 kg active LXe veto & passive Pb/PE/Cu shield. New engineering design & materials screening to minimize background.
  → Sensitivity: σ_{SI}~$2x10^{-45}$ cm^2 for 100 GeV WIMP after 3 months operation.
- **XENON1T** under study by larger collaboration in US & Europe.
  → Sensitivity (pre-DUSEL): σ_{SI}~10^{-47} cm^2 for 100 GeV WIMP after 1 yr.
- Pathway to a 10 ton LXe DM experiment at DUSEL.

Liquid Xenon for Dark Matter Search

- Large atomic number A~131 best for SI interactions ($\sigma \sim A^2$) if low threshold
- ~50% odd isotopes: very good for SD interactions
- No long-lived isotopes. Kr-85 reduction to ppt proven.
- High Z (54) and density:
  → compact & self-shielding
- Scalability to large mass for $\sigma \sim 10^{-47}$ cm^2 ~ 1evt/1ton/yr
  → cost
  → "easy" cryogenics (-100°C)
- Efficient scintillator
- Background discrimination
  → Ionization/Scintillation
  → 3D imaging of TPC

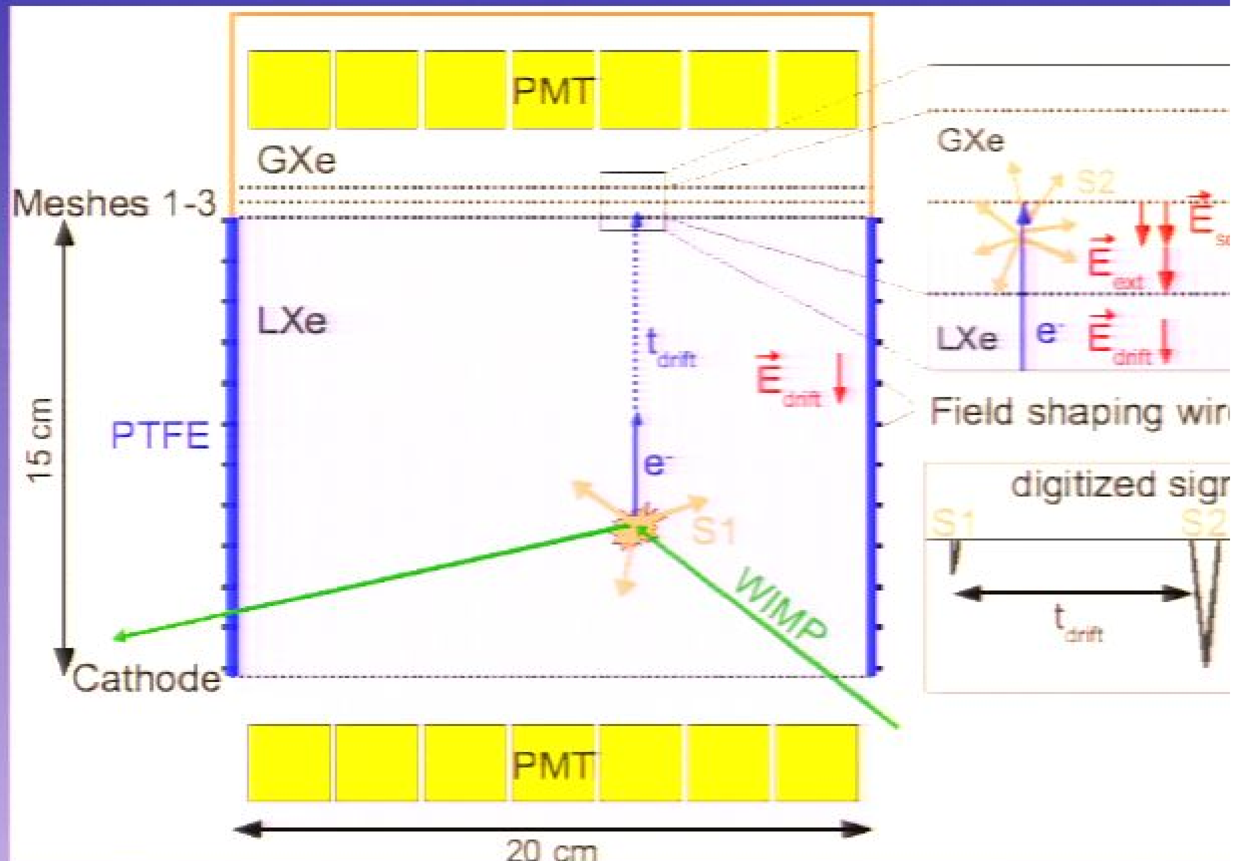


XENON – Principle of Operation



XENON – Principle of Operation

- Dual phase liquid/gas xenon TPC at ~ -94°C / 2 bar
- Wimp recoil on Xe nucleus in dense liquid (2.85 g/cm³) → Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs on top and bottom
- PTFE cylinder for reflectivity
- Charge drift towards liquid/gas interface at field of 0.73 kV/cm (XENON10)
- Charge extraction liquid/gas at high field (5 kV/cm) between meshes 1 (liquid) and 2 (gas)



XENON – Principle of Operation

- Dual phase liquid/gas xenon TPC at ~ -94°C / 2 bar
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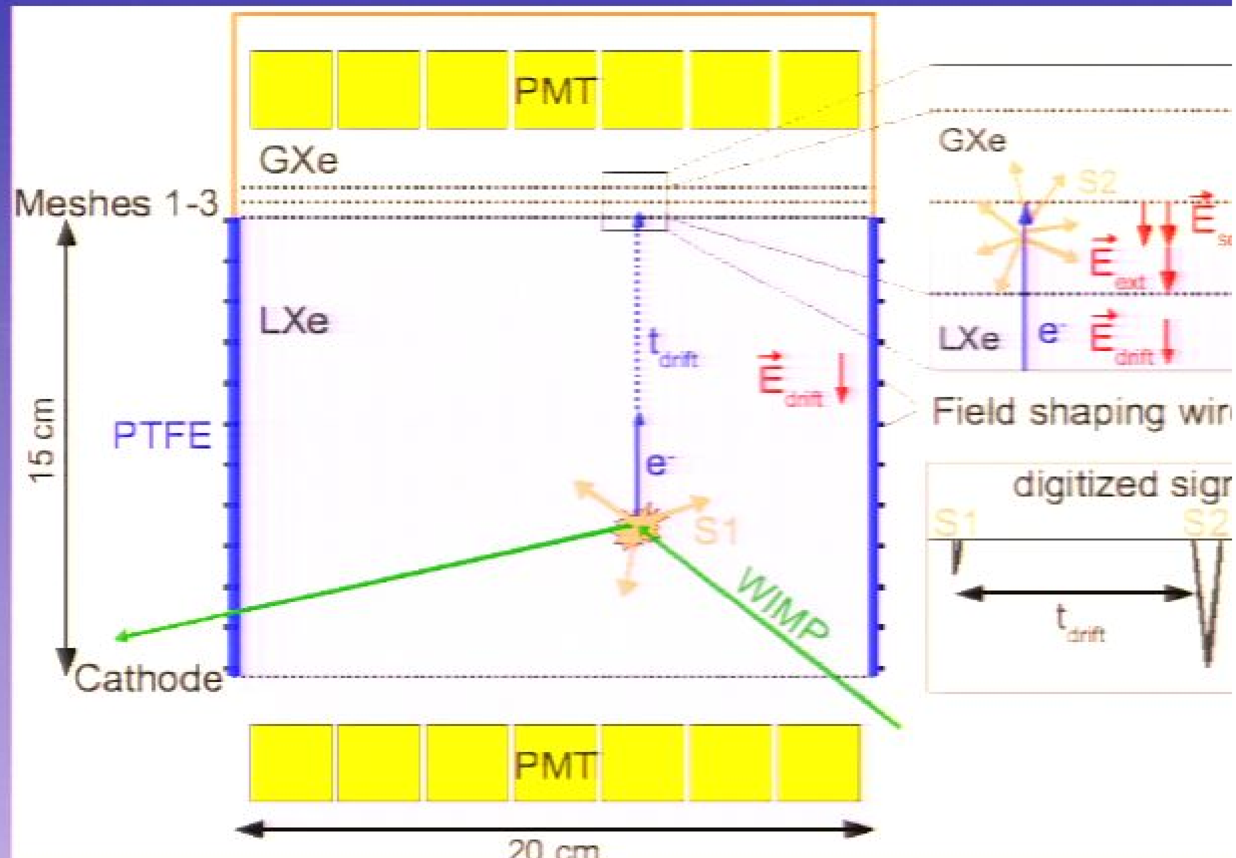
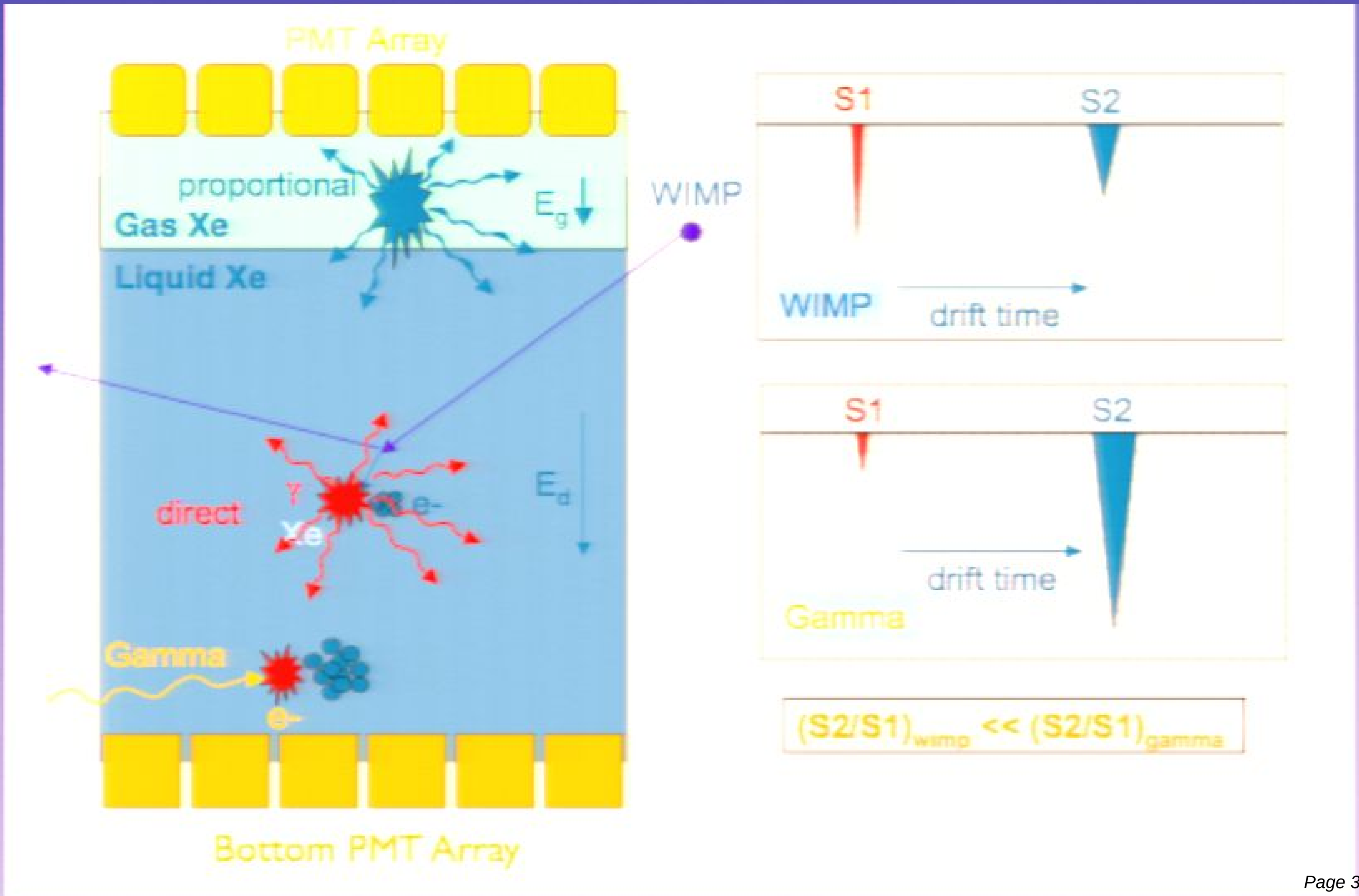
- Charge drift towards liquid/gas interface at field of 0.73 kV/cm (XENON10)
- Charge extraction liquid/gas at high field (5 kV/cm) between meshes 1 (liquid) and 2 (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (10 kV/cm)



- 3D position measurement:
  - → X/Y: from S2 signal, resolution few mm due to small PMT size (1”).
  - → Z: from electron drift time (~1 mm).

Background Discrimination based on Ionization/Scintillation Ratio in Dual Phase LXe/LAr TPC's



XENON10 Collaboration

(until Oct 2007)

Columbia University

Elena Aprile (spokesperson), Karl-Ludwig Giboni,
Maria Elena Monzani, Guillaume Plante*, Roberto Santorelli, Masaki Yamashita

Brown University

Richard Gaitskell, Simon Fiorucci, Peter Sorensen*, Luiz DeViveiros*

Case Western Reserve University

Tom Shutt, Eric Dahl*, John Kwong*, Alexander Bolozdynya

Lawrence Livermore National Laboratory

Adam Bernstein, Norm Madden, Celeste Winant

Rice University

Uwe Oberlack, Roman Gomez*, Yuan Mei*, Marc Schumann, Peter Shagin

Yale University

Daniel McKinsey, Louis Kastens*, Angel Manzur*, Kaixuan Ni

Coimbra University (Portugal)

Jose Matias Lopes, Luis Coelho, Luis Fernandes, Joaquin Santos

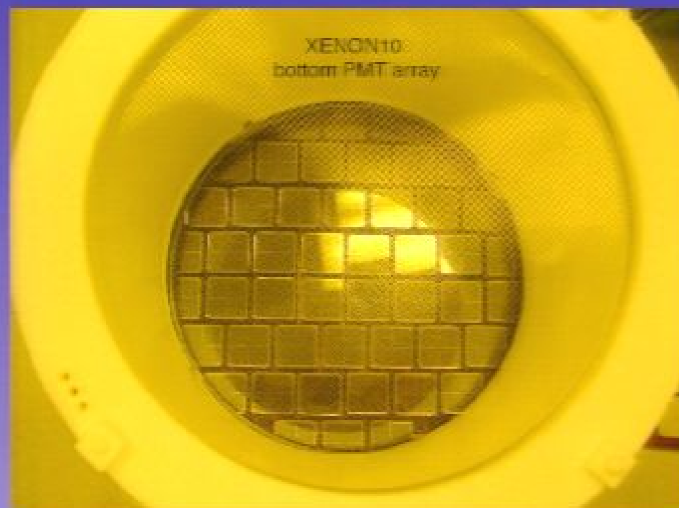
LNGS (Italy)

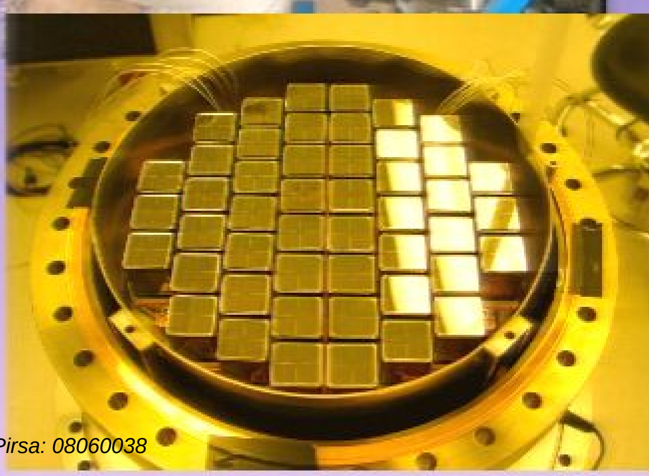
Francesco Arneodo, Serena Fattori

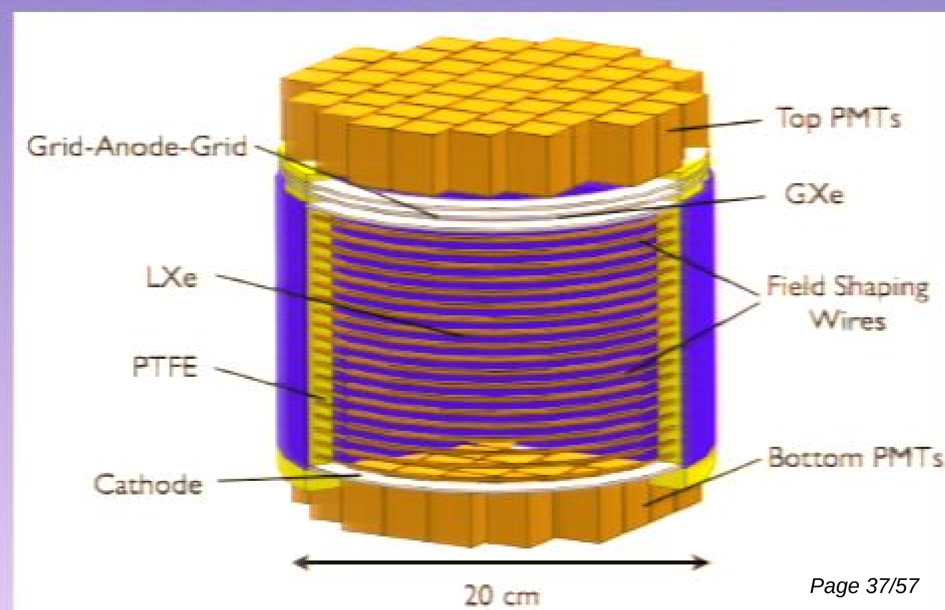
University of Zurich (Switzerland)

Laura Baudis, Jesse Angle*, Alfredo Ferella, A. Kish, Aaron Manalaysay*, S. Schulte

XENON10 Assembly at LNGS (2006)

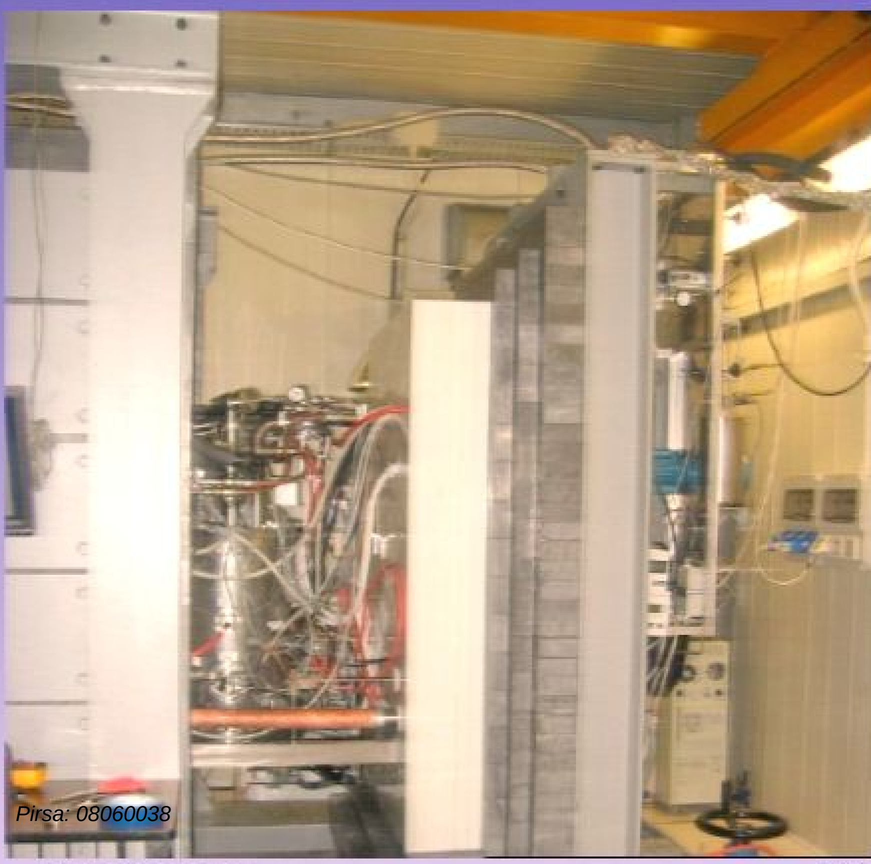


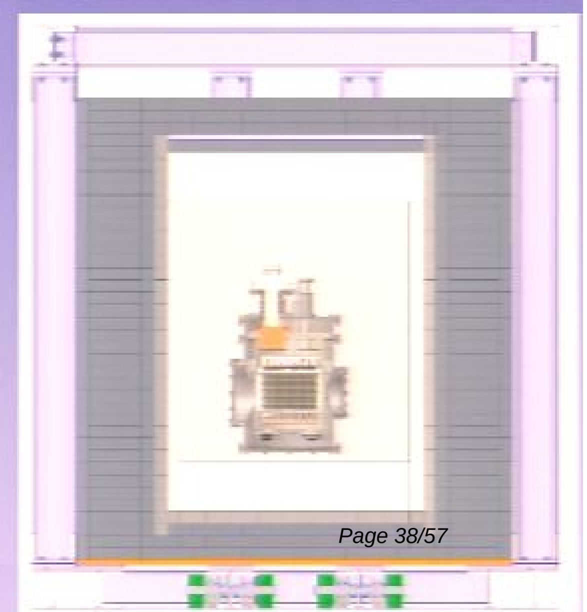




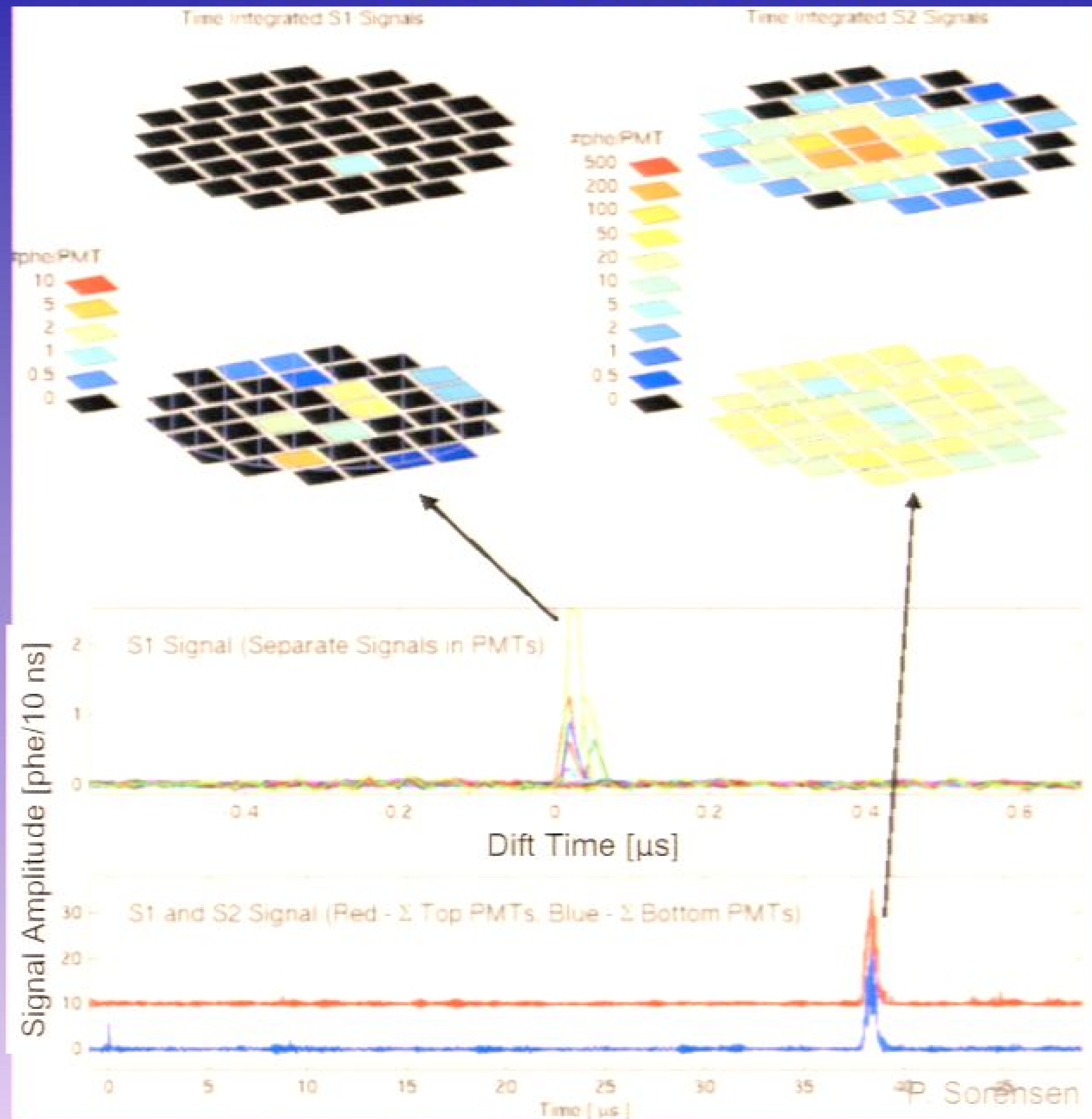
XENON10 Dark Matter Search at LNGS

- XENON10 operated at LNGS (Gran Sasso, Italy)
- Spring 2006: assembly
- August 2006: Operation inside shield
- Oct'06 – Feb'07: DM search, calibrations

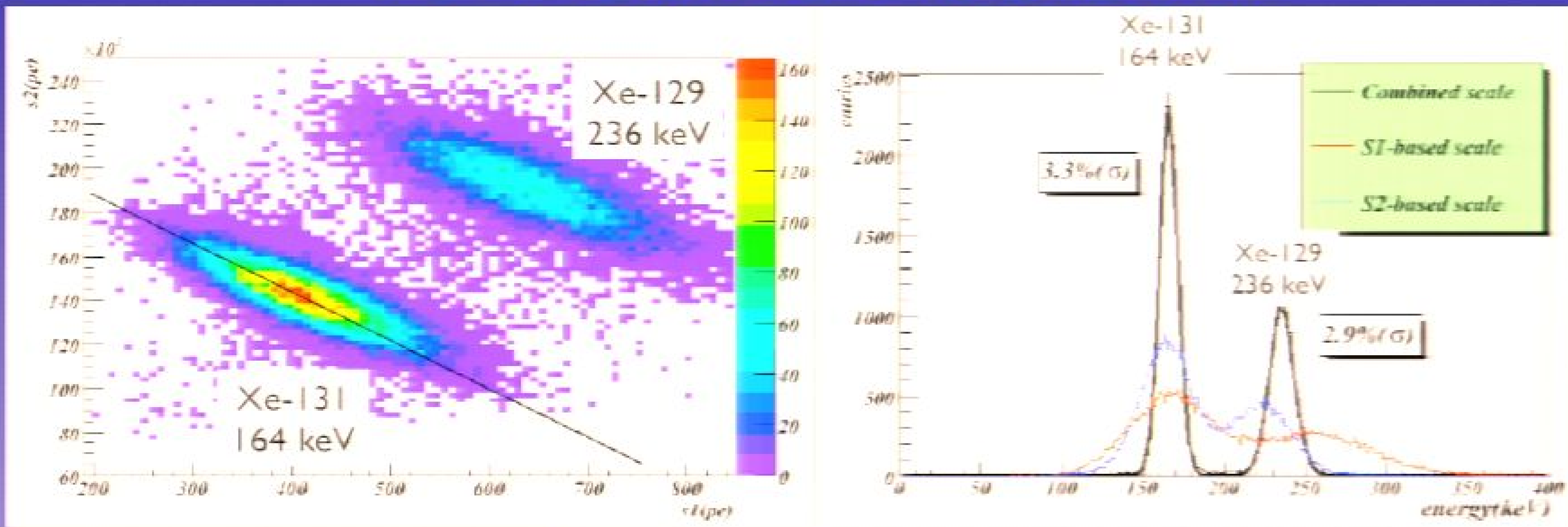




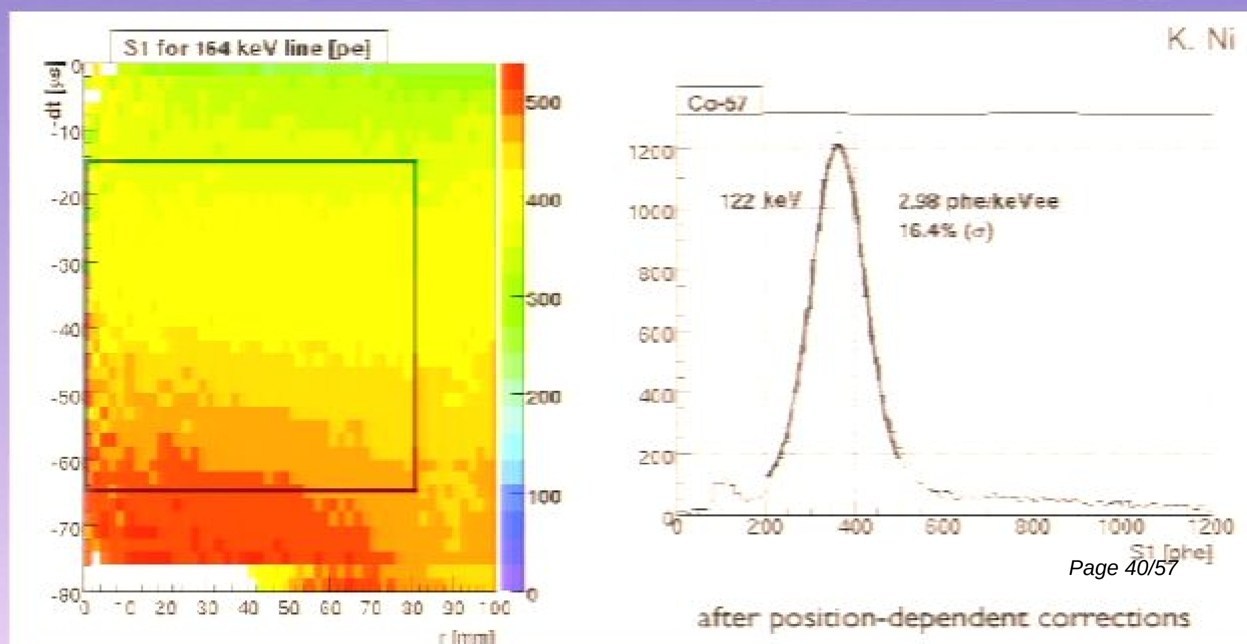
XENON10 Events



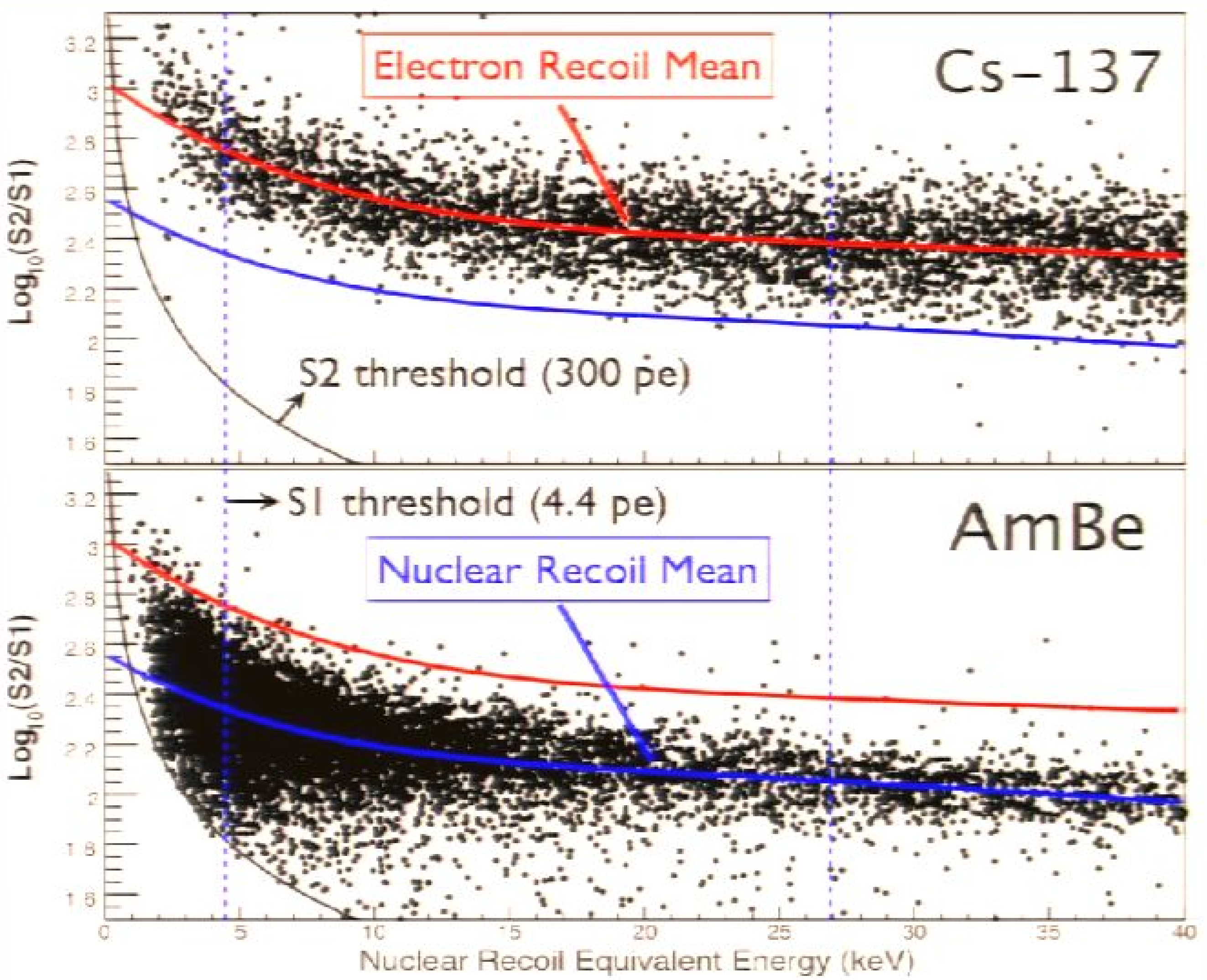
Xe Neutron Activation: 3D Gamma Calibration



- Uniform distribution of line source.
- Accurate position dependent corrections:
  - →in x/y/z for S1
  - →in x/y for S2



XENON10 Background Rejection: S2/S1



Gamma Calibration (ER band)

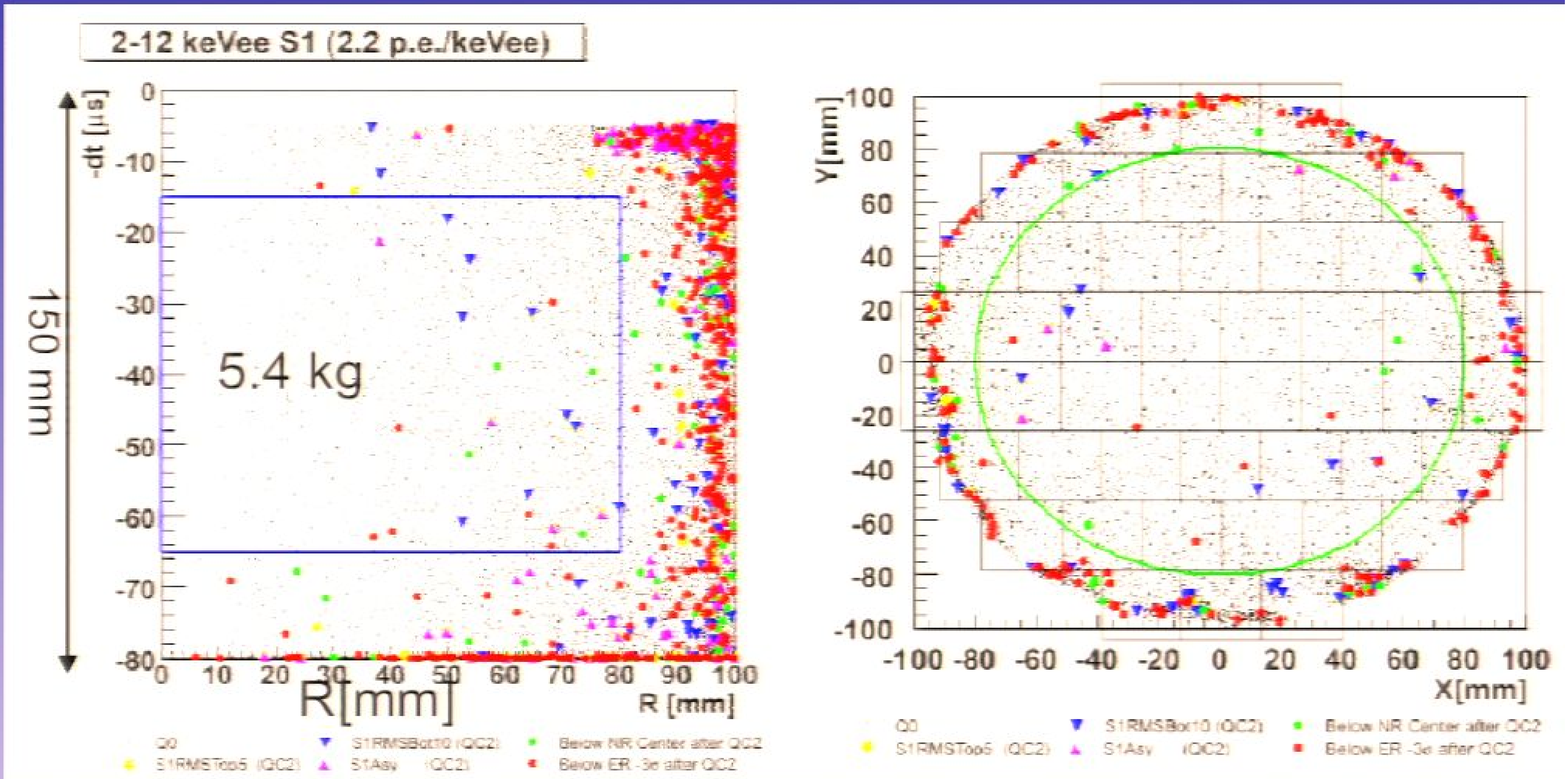
- Weekly
- Cs-137 source (1 kBq) in shield

Neutron Calibration (NR Band)

- Dec 1, 2006 (12 h)
- AmBe source (3.7 MBq) in shield
- Single interactions

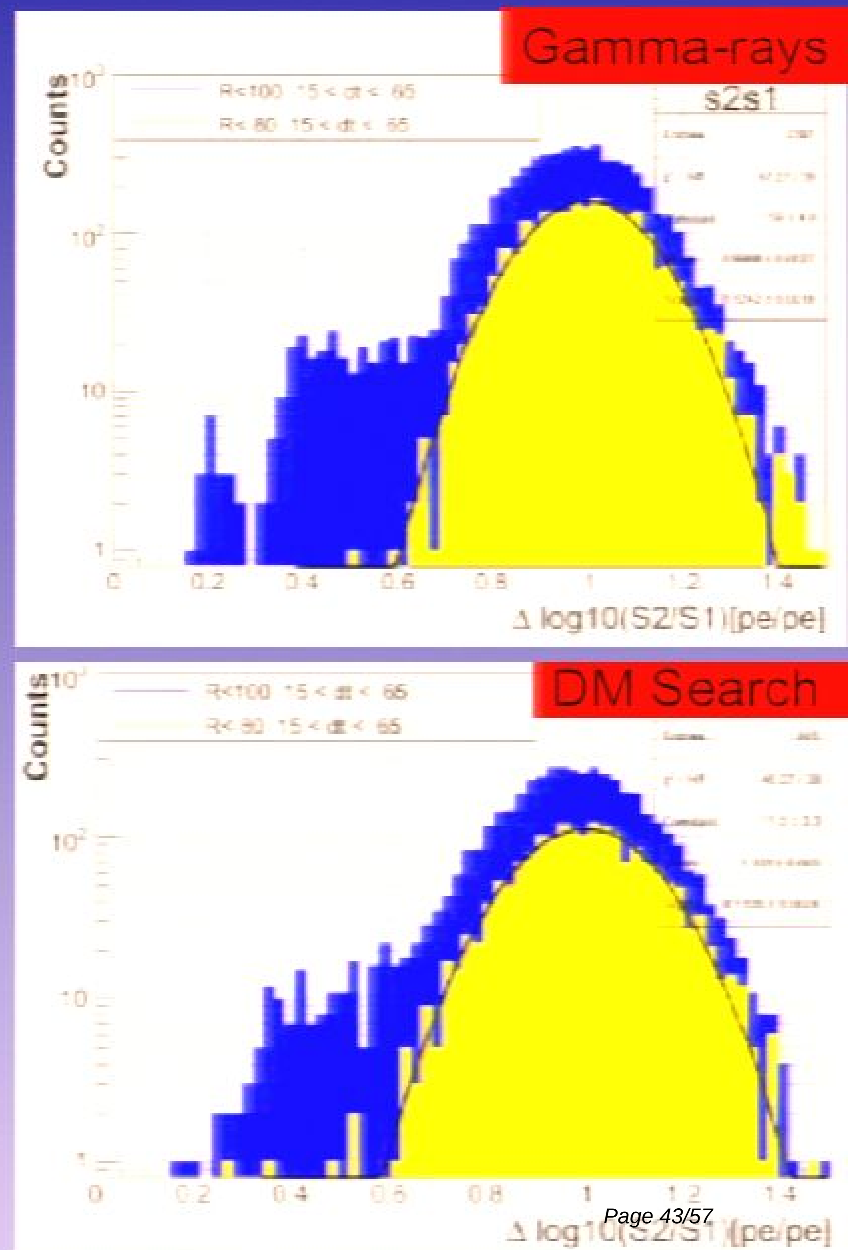
99.5% background rejection (99.9% at low E) at 50% acceptance.

XENON10 Background Rejection: Spatial



13 events inside fiducial volume removed by final quality cut.

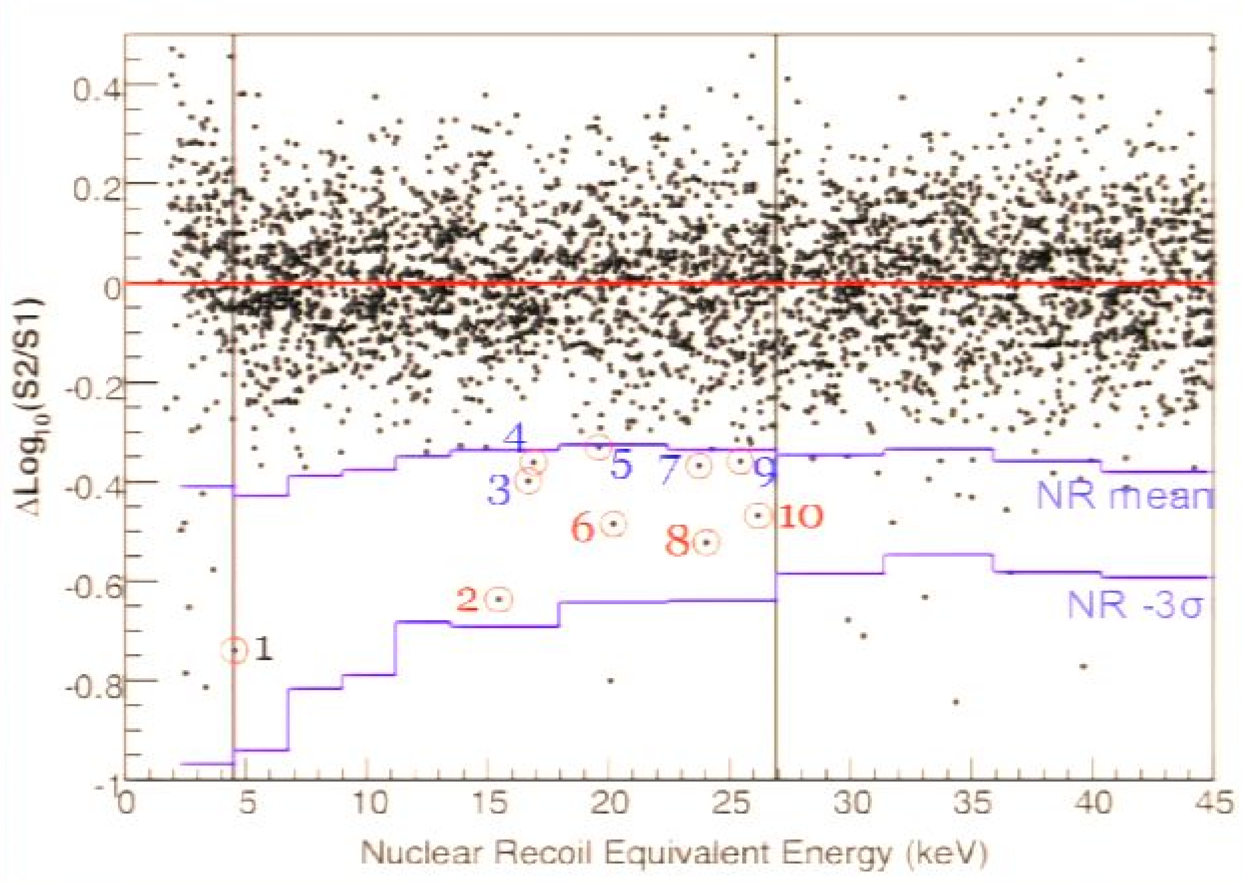
Elimination of Non-Gaussian Leakage



XENON10 WIMP Search with Blind Cuts

Oct 6, 2006 – Feb 14, 2007: 136 kg days exposure

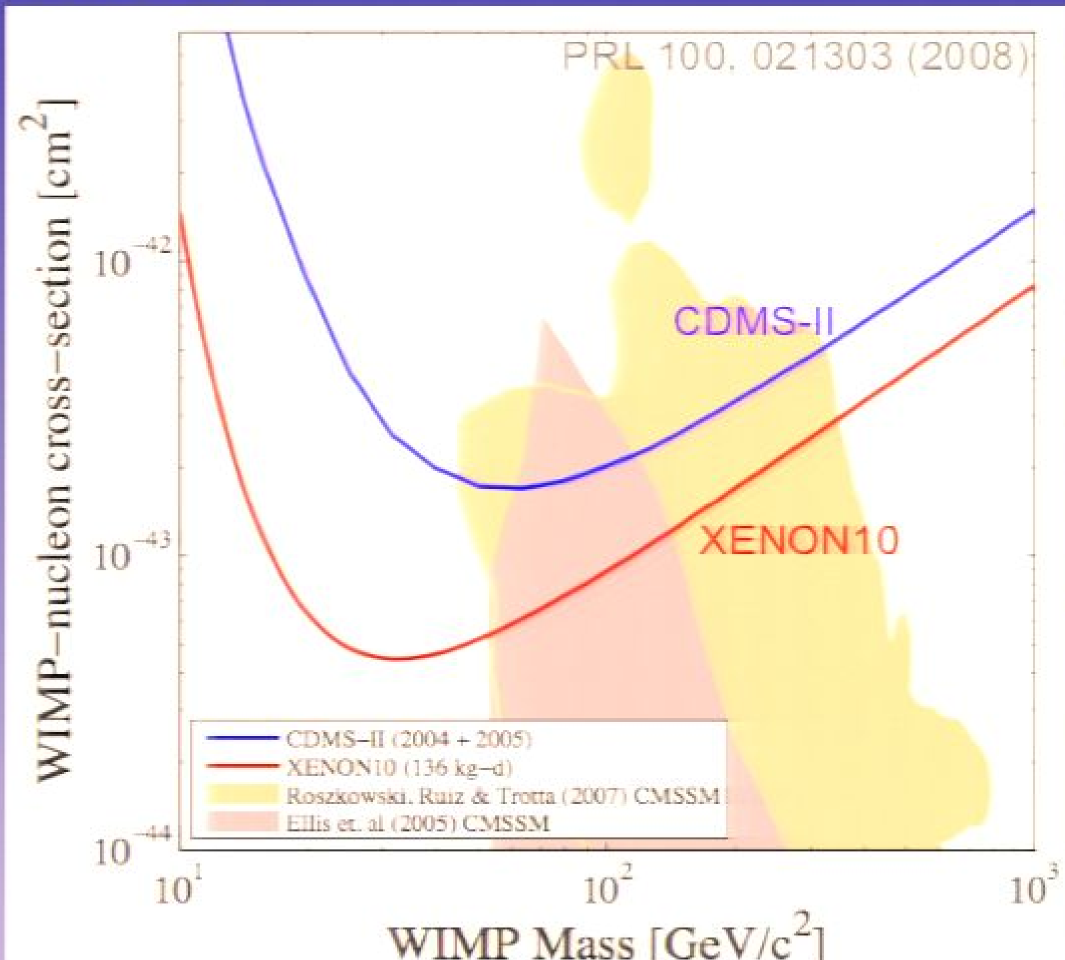
(58.6 live days × 5.4 kg × 0.86 cut efficiencies × 0.50 NR acceptance)



- WIMP search box defined by 50% NR acceptance region (blue lines) and E_r in 4.5-27 keV (black lines).
- Search box optimized with calibration data and additional 40 live days of unmasked data.
- 10 events in the box from "blind" data after cuts.
- Energy spectrum not as expected from WIMPs.
- ~7 events expected from gamma-ray leakage.
- NR energy scale based on 19% constant "quenching factor" at low energies.

XENON10 WIMP Search Result for Spin-Independent Interactions

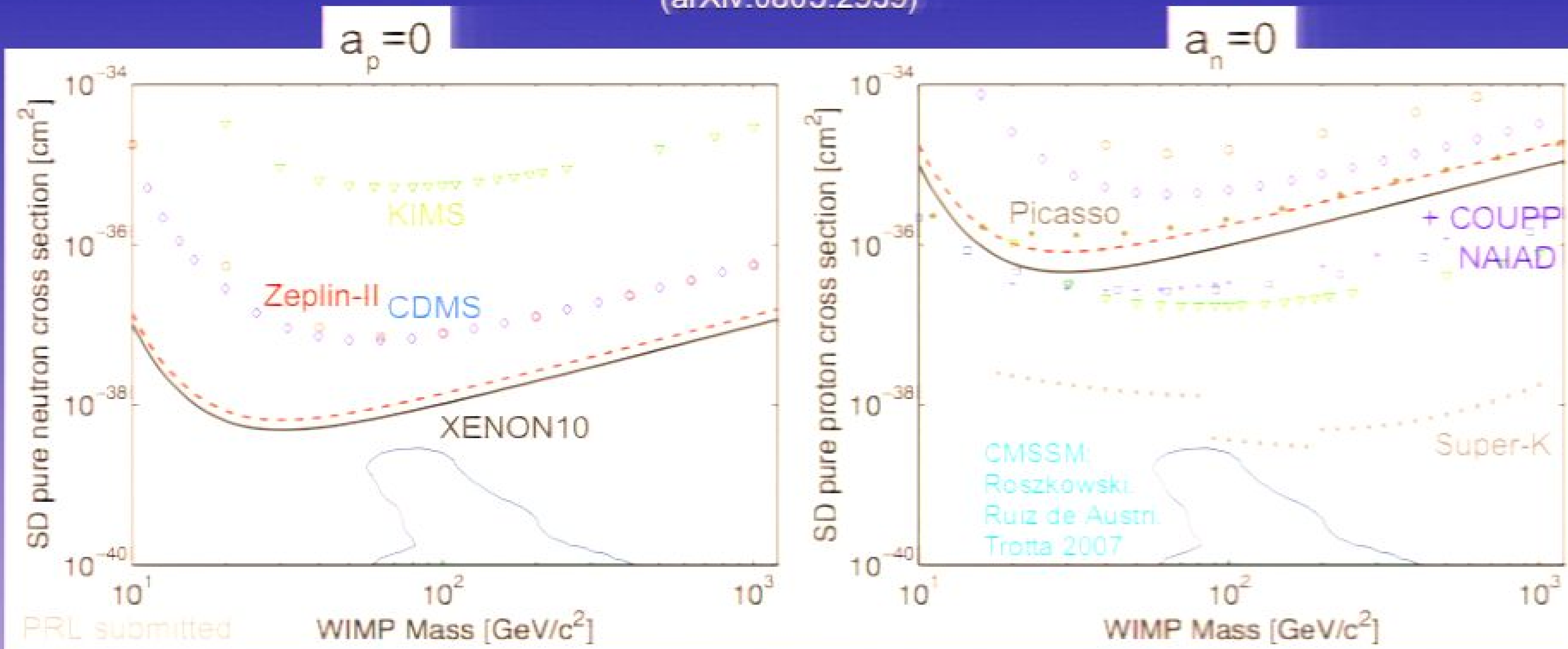
Status 2007



- 90% CL upper limit on WIMP-nucleon cross section derived with Maximal Gap Method [Yellin, PRD 66 (2002)]
- At 100 GeV/c^2 WIMP mass 8.8×10^{-44} cm^2 (no background subtraction)
- Uncertainty in scintillation efficiency: conservative < 1.0×10^{-43} cm^2

XENON10 Spin-Dependent Limits

(arXiv:0805.2939)



$$\frac{d\sigma}{d|\mathbf{q}|^2} = \frac{C_{spin}}{v^2} G_F^2 \frac{S(|\mathbf{q}|)}{S(0)}$$

S(|**q**|): Spin structure function at momentum transfer q

G_F: Fermi constant.

C_{spin}: spin enhancement factor

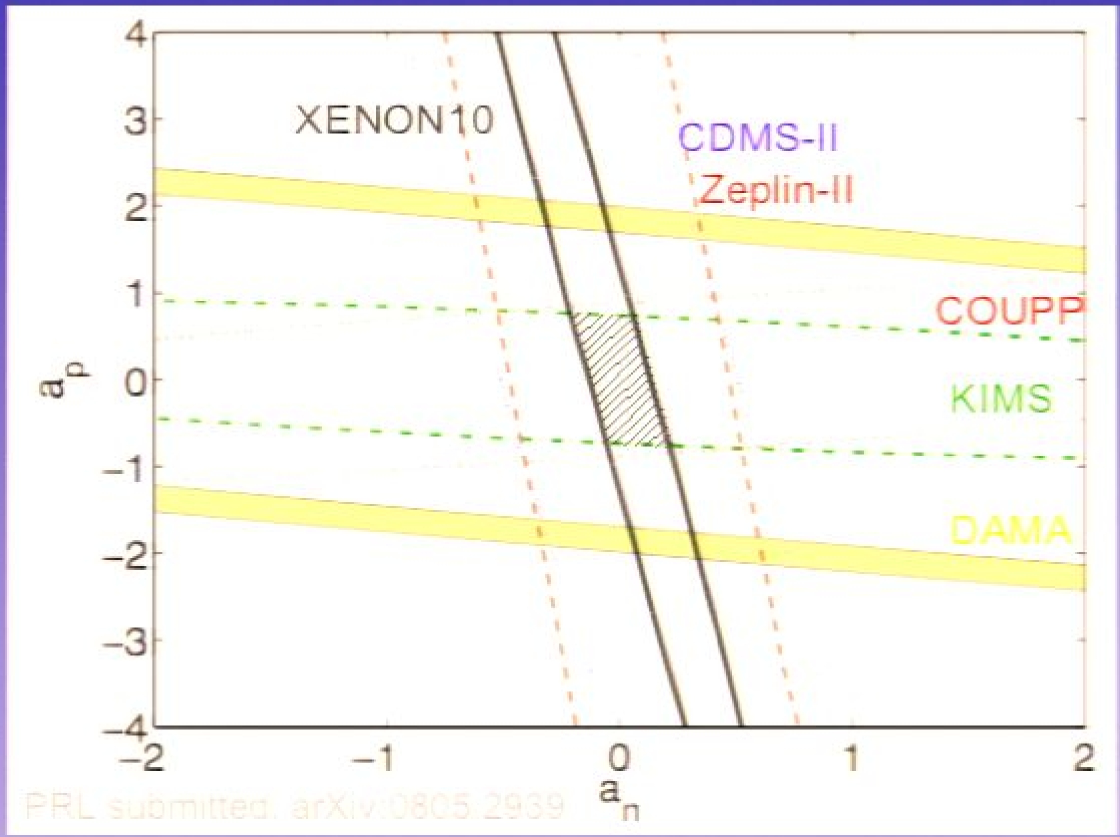
$$C_{spin} = \frac{8}{\pi}[a_p \langle S_p \rangle + a_n \langle S_n \rangle]^2 \frac{J+1}{J}$$

$\langle S_{p,n} \rangle$: expectation value of spin content of proton/neutron groups within nucleus.

J: total nuclear spin.

Pure neutron cross section: world best limit. At 30 GeV/c^2: $\sigma < 5\times10^{-39}$ cm^2

XENON10 Spin-Dependent Limits



- Plot for WIMP mass of 50 GeV/c^2
- Elliptical contours: expected events $N_{evt} = A\,a_p^{\,2} + B\,a_p\,a_n + C\,a_n^{\,2}$
- New regions excluded in a_p-a_n plane.

The Next Generation: XENON100 at LNGS

- Use of XENON10 shield + inner Cu layer
- Goal: 50-100 times lower background
- Material screening
- 10 times larger target mass:
  50 kg fiducial, 170 kg total LXe
- Active LXe Veto
- New PMTs with low activity and high QE
- Improved grids, electronics, ...
- Cryocooler/Feedthroughs outside shield
- DM search in 2008

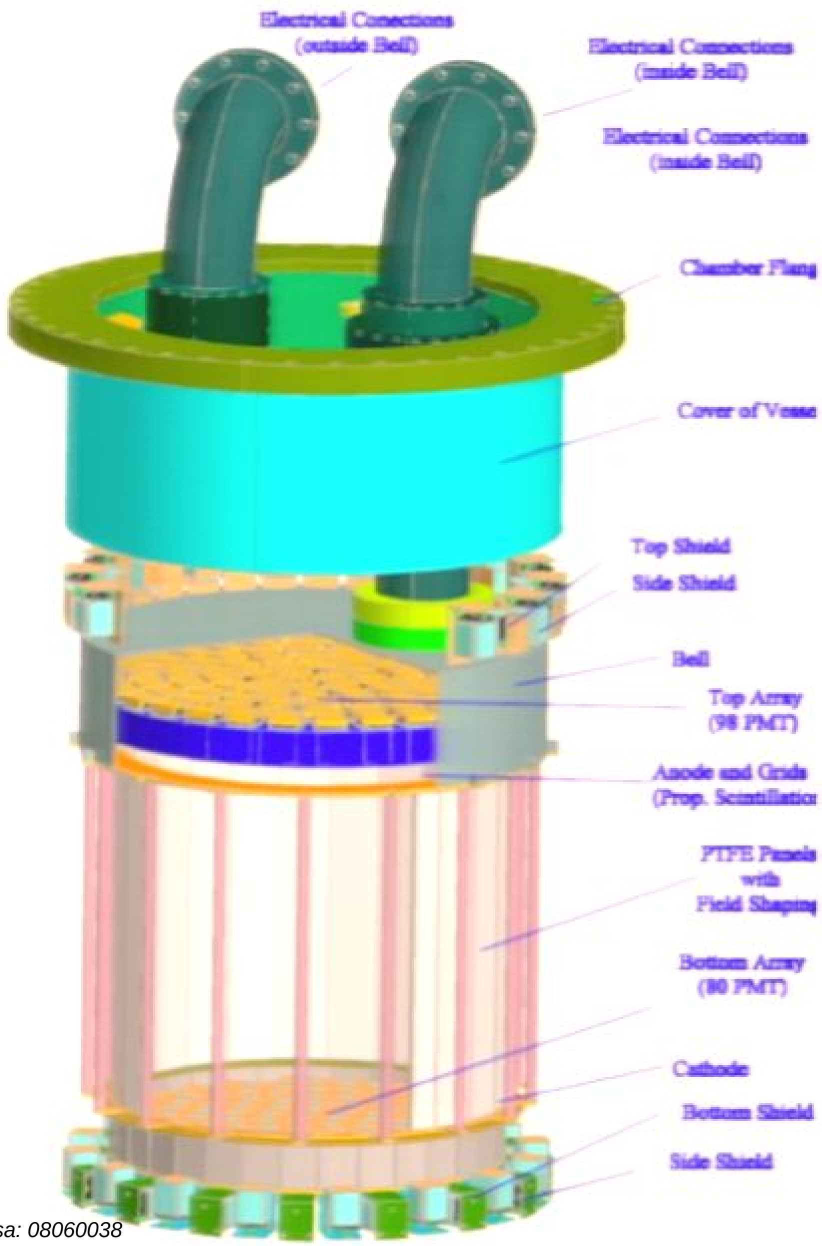
Status:
- Shield modification completed Jan 08
- Detector underground mounted in shield Feb 08
- LXe purification/circulation tested Mar'08
- Modifications May'08, starting filling.

The XENON100 / XENON1T Collaboration

Elena Aprile Columbia Univ.	Uwe Oberlack Rice University	Katsushi Arisaka UCLA	Laura Baudis Univ. of Zurich	Jose Matias Lopes Univ. of Coimbra	Francesco Arneo LNGS

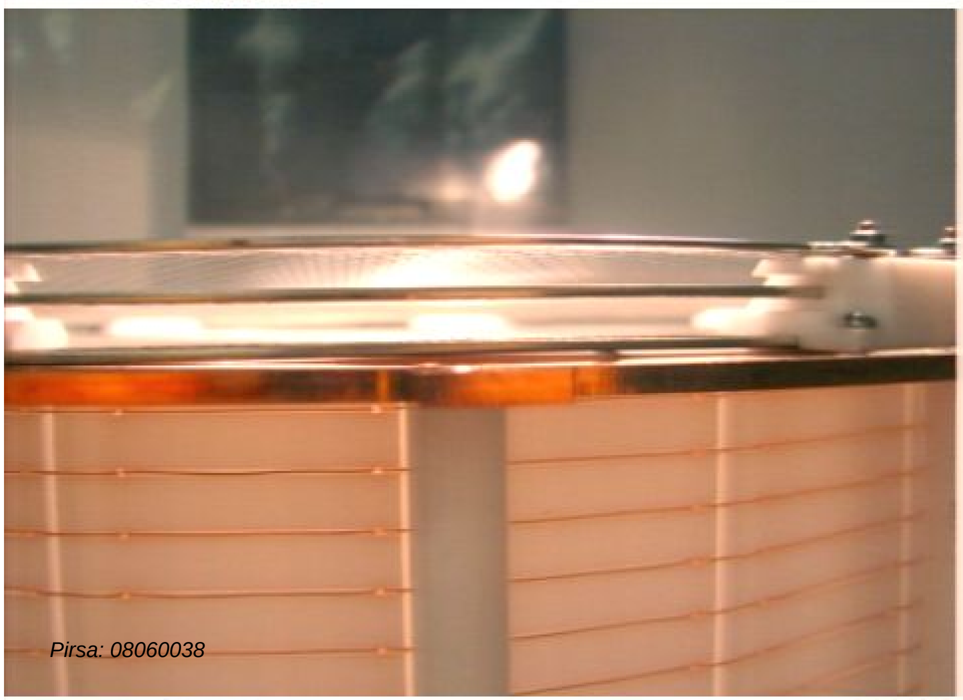
8 faculty - 3 research scientists - 7 postdocs- 12 Ph.D. students ~ 30

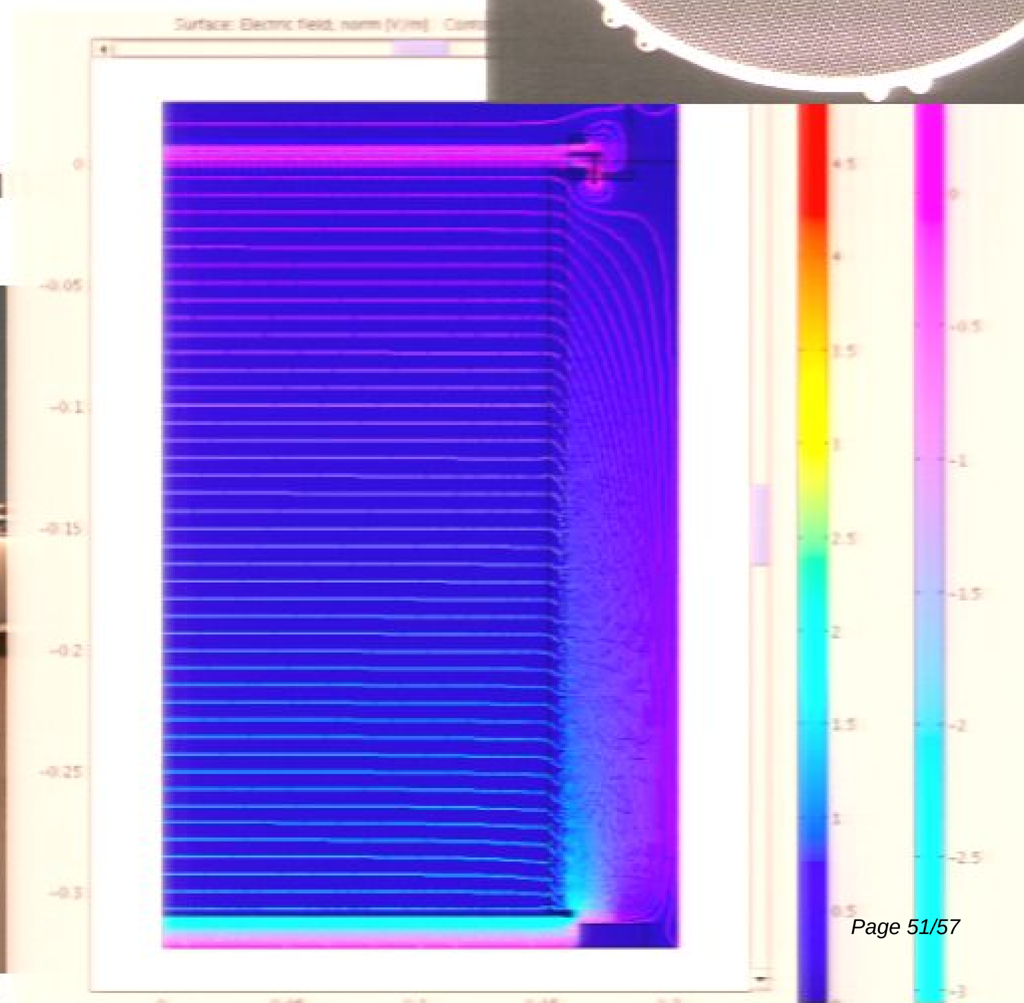
XENON100 TPC

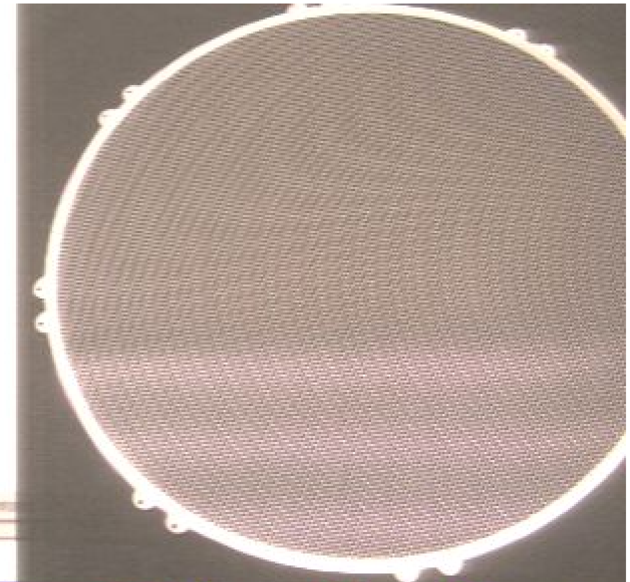


TPC Electric Field and Meshes

- Field cage optimized for uniformity with simulations: 40 double field shaping wires.
- 3 Mesh structure on top optimized
  - optical transparency
  - S2 energy broadening 4%
- Top mesh: ~5 mm pitch
- Anode, lower mesh: ~2.5 mm pitch
- Cathode

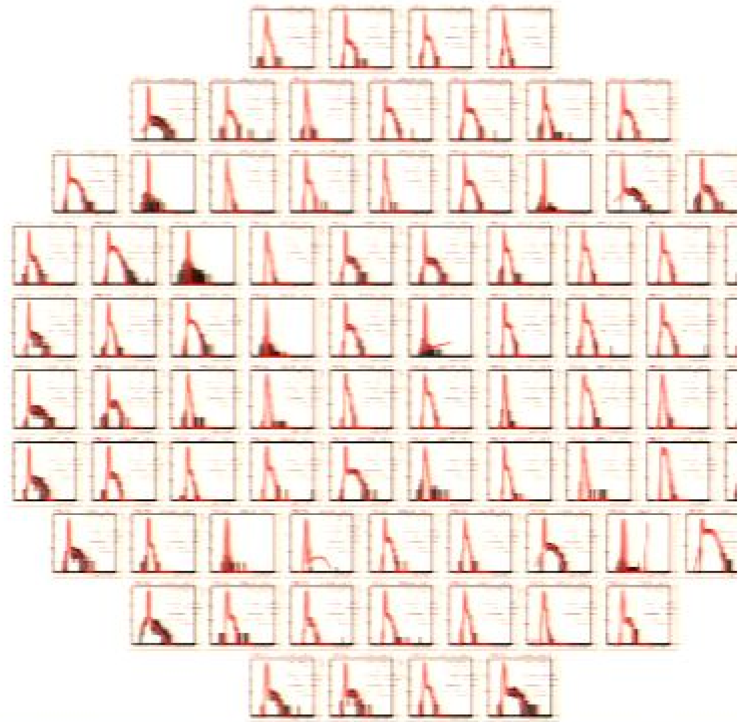


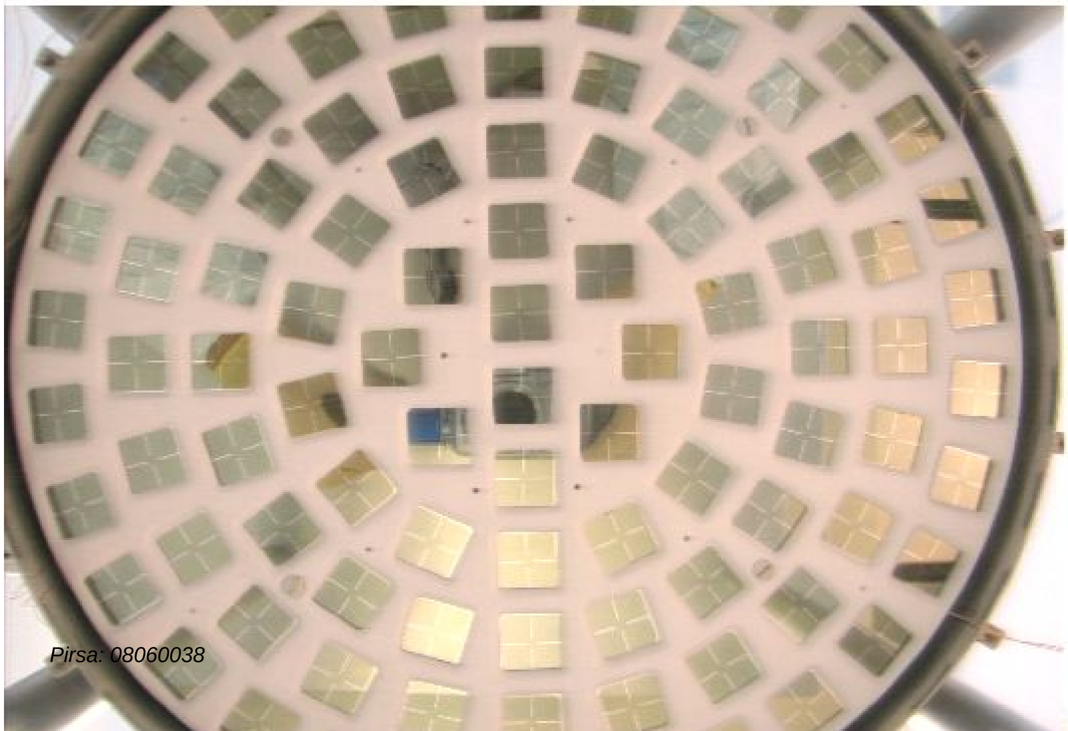




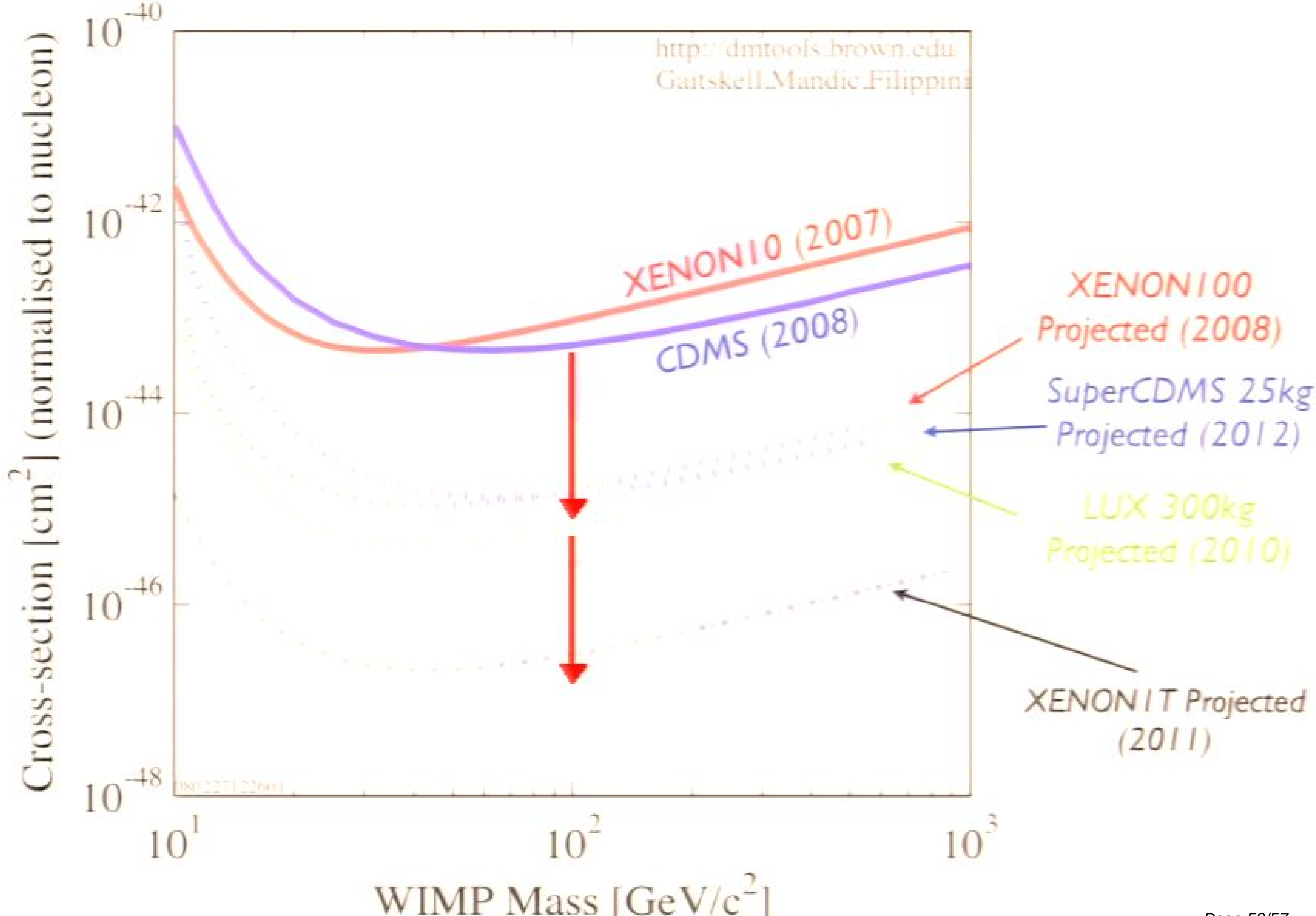
Status of XENON100 PMTs

- Photomultipliers: Hamamatsu R8520-06-Al
- 98 on top - 80 on bottom - 64 in active LXe shield
- QE~23% for top array; QE~33% for bottom array
- XENON10 PMTs for LXe shield
- Calibrated with external LED's & quartz fibers
- S1 source calibrations with gamma sources

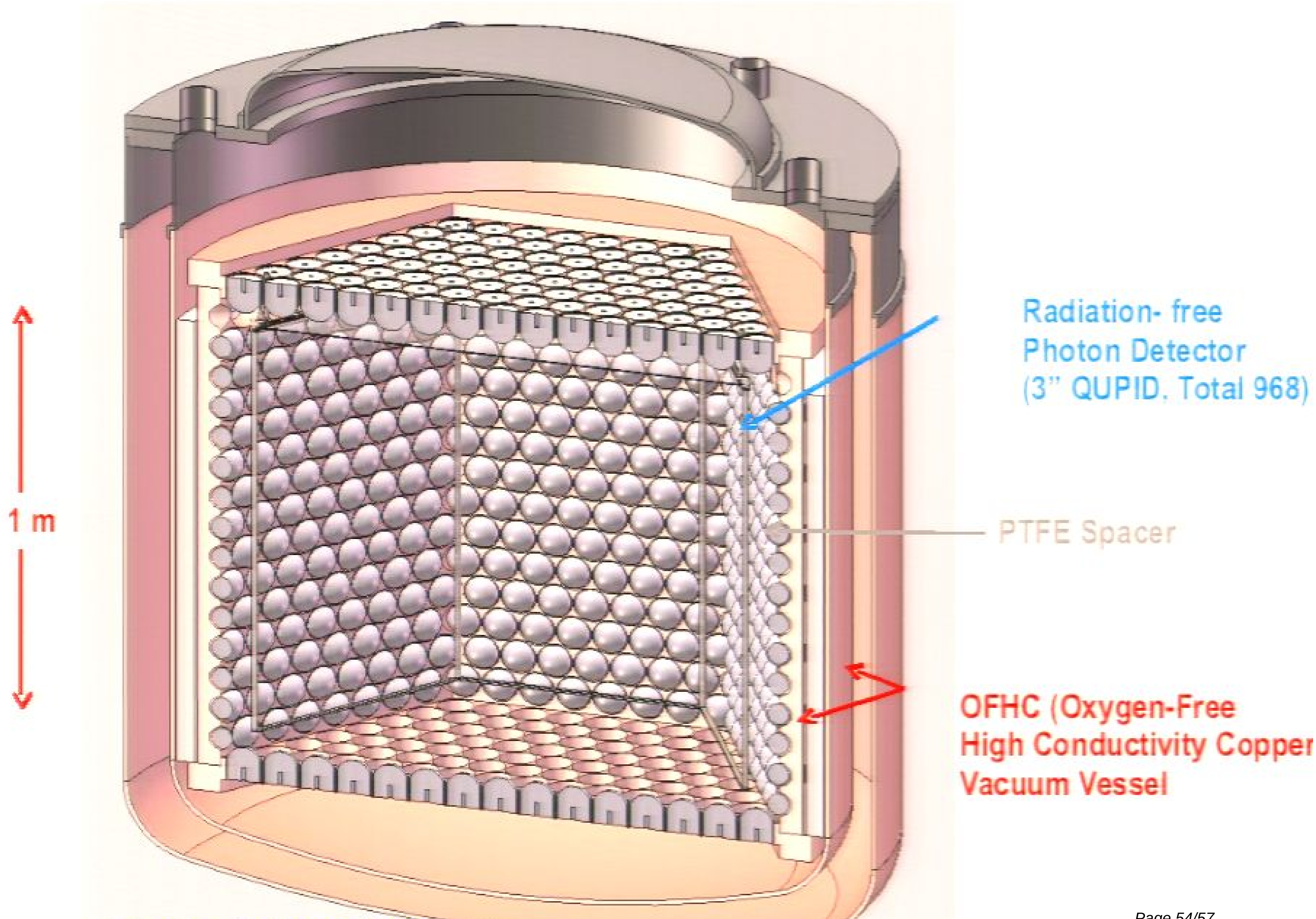




XENON Projected Sensitivities 2008-2012

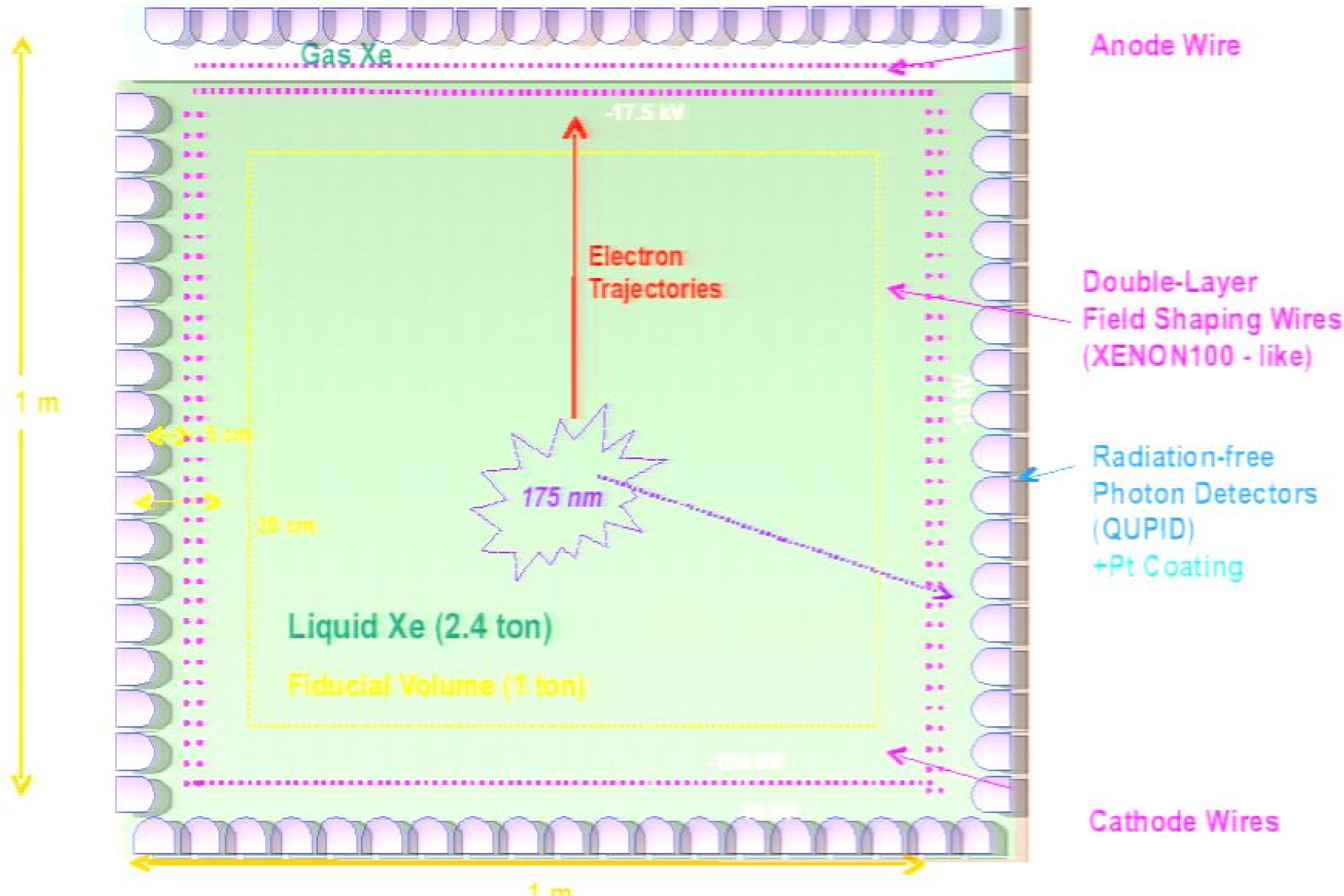


XENON1T: Mechanical Structure

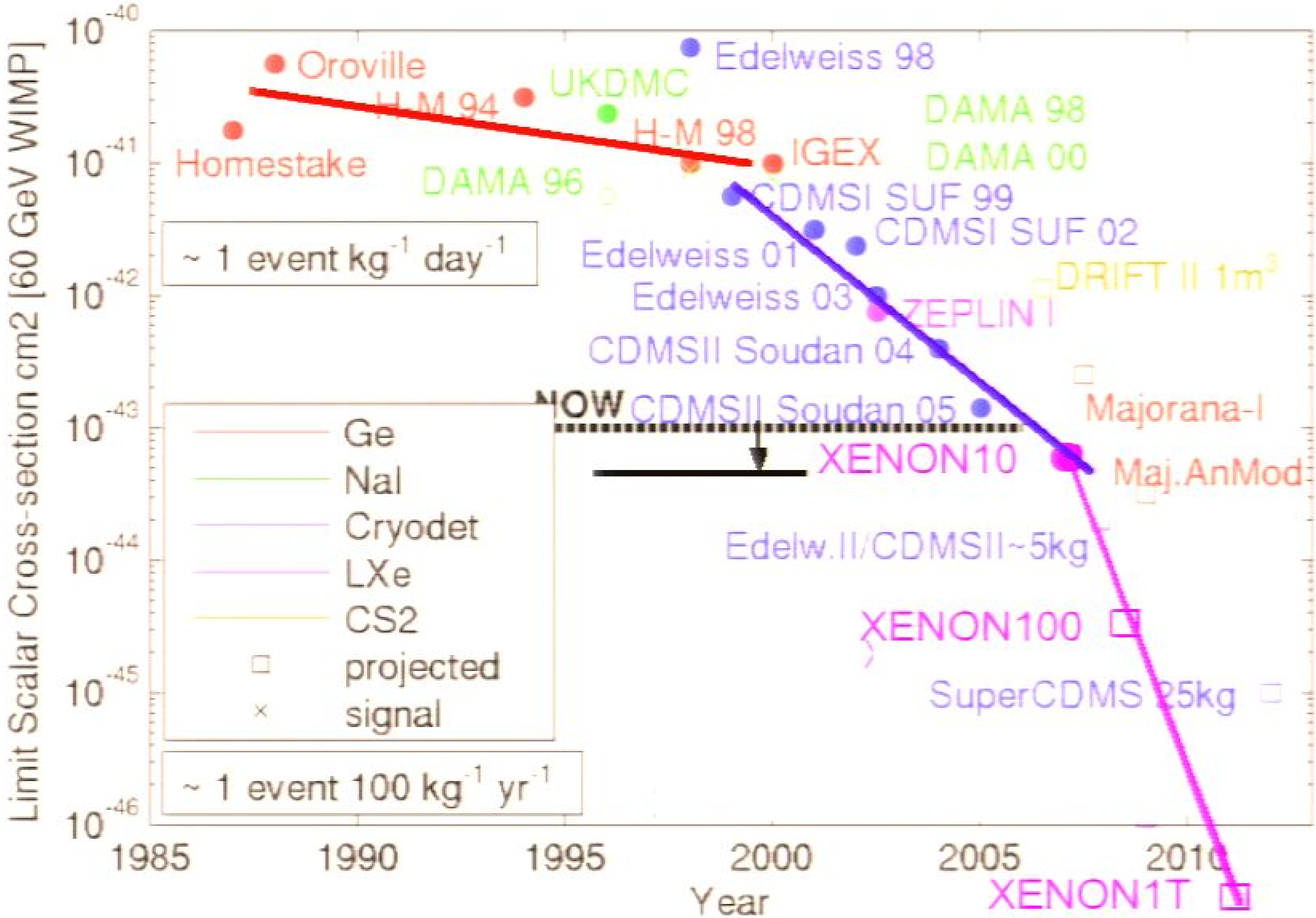


K. Arisaka, H. Wang UCLA

Conventional Double Phase TPC (Xe)



DM Direct Searches: Progress Over Time



Plot updated from DM Review: R. Gaitskell, Ann. Rev. Nucl. Part. Sci. 54 (2004) 315-359

Summary & Outlook

- Cryogenic Ge (CDMS) has been the driver over the last ~8 years. Will expand to 5 towers. Scalability?
- Various new detector technologies are maturing. Liquid noble gas concepts are making rapid progress (XENON, WARP, ...)
- XENON10 provided the best spin-independent DM limits in 2007. Currently neck and neck with CDMS.
- XENON10 has the best spin-dependent limits with unpaired neutrons.
- Next step XENON100 currently in progress (2008).
  - Expecting factor 50 improvement in sensitivity.
  - Very low background: operating in DM "detection mode".
- LUX: ~2× mass of XENON100, arriving later. Single & double phase LAr, ...
- Scalability of liquid noble detectors promises ton-scale detectors by ~2011, multi-ton for DUSEL (~2015?).
- Timeline for new DM direct search detectors is compatible with LHC (2008) and indirect searches by GLAST (launch ~~today~~ in 4 days ?)
- DAMA/LIBRA annual modulation: new physics or nasty old physics? DM? Large detector, huge exposure, but little information on events compared to recent concepts.
  Look for more signatures with current and upcoming experiments.
- *This is a very exciting period in WIMP DM search – stay tuned!*