A Known Unknown: Directly Detecting the Missing Mass of the Universe - The US Perspective

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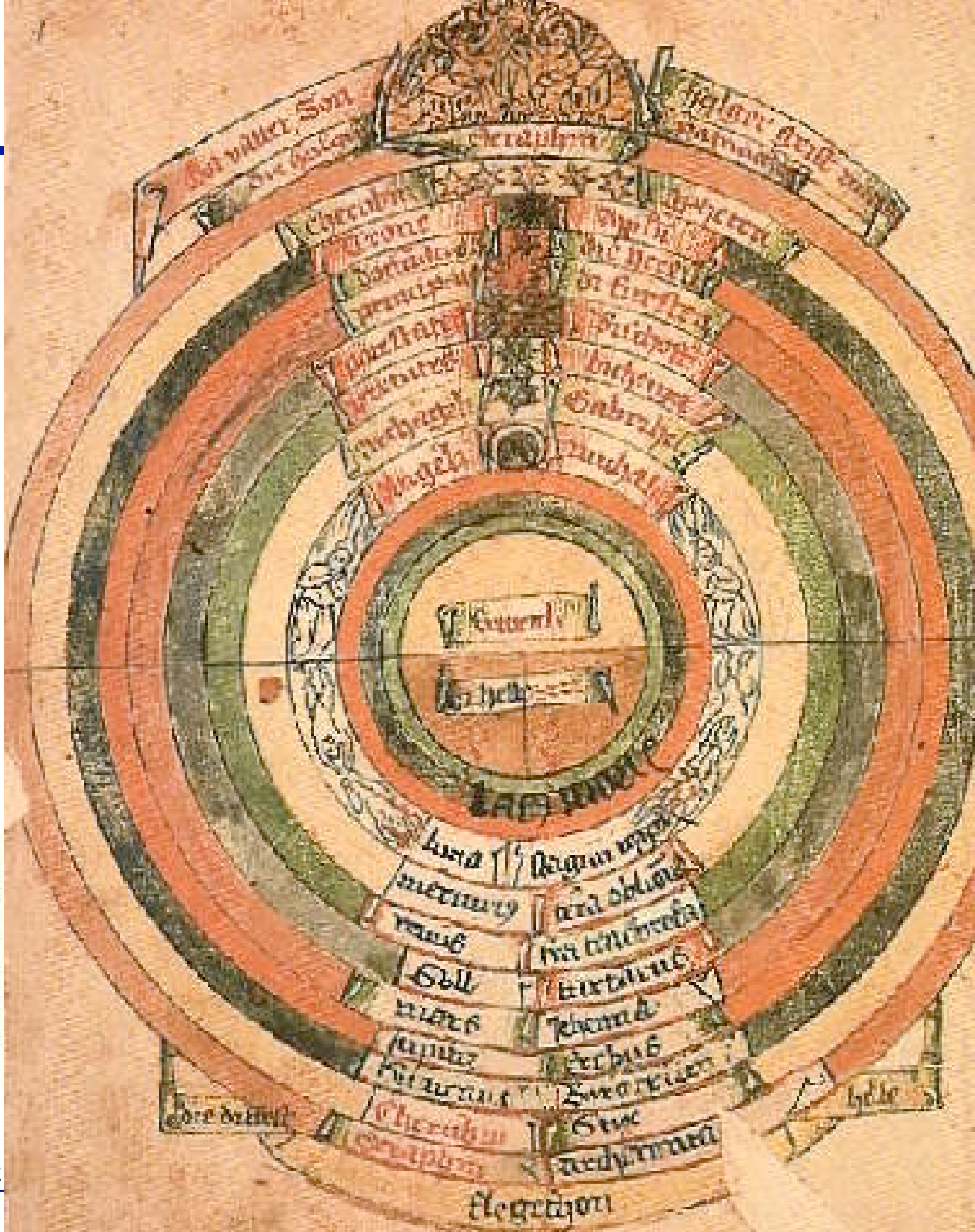
see information (and copy of talk) at
http://particleastro.brown.edu/

http://cdms.brown.edu/ http://xenon.brown.edu/

Medieval Universe



The geocentric pre-Copernican Universe in Christian Europe. At center, Earth is divided into Heaven (tan) and Hell (brown). The elements water (green), air (blue) and fire (red) surround the Earth. Moving outward, concentrically, are the spheres containing the seven planets, the Moon and the Sun, as well as the "Twelve Orders of the Blessed Spirits," the Cherubim and the Seraphim. German manuscript, c. 1450.

From Joel Primack, UC Santa Cruz

Confession

>95% of the Composition of the Universe is still unknown

Known Unknowns

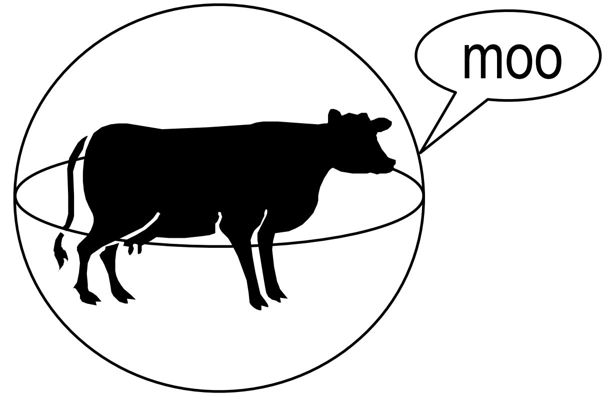
- "As we know,
  There are known knowns.
  There are things we know we know.
  We also know
  There are known unknowns.
  That is to say
  We know there are some things
  We do not know.
  But there are also unknown unknowns,
  The ones we don't know
  We don't know."
- -- Donald Rumsfeld, Secretary of Defense,
  February 12, 2002, Department of Defense news briefing

Introduction

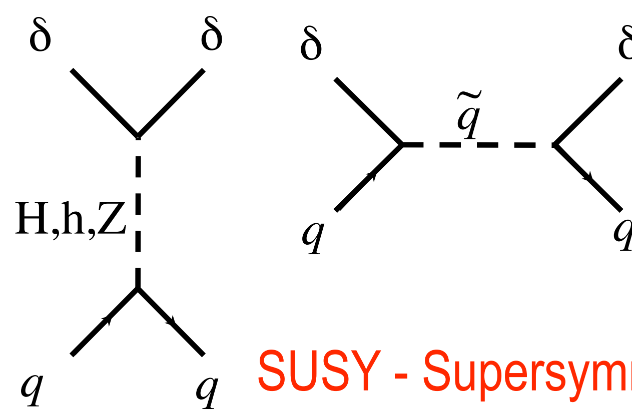
- --> 1990's For many a "known known" was that $\Omega_{Total} = 1$
  - This being matter dominated, $\Omega_m = 1$
- We have had to revise this view partially: $\Omega_{Total} = 1$, but $\Omega_m \sim 0.3$
  - Dark Matter now has to share the shadows with Dark Energy
  - Indeed it is convenient to split into 3 Dark Problems
    - Baryonic Dark Matter - Mostly known
    - Non-Baryonic Dark Matter - **Known Unknown**
    - Dark Energy - Only God knows, right now
- It has been a Problem in Cosmology that astrophysical assumptions often need to be made to interpret data/extra parameters
  - Now many independent/increasingly precise techniques are being used
  - This now enables disentanglement of "Gastrophysics"
- Ultimately new solutions will be related to Fundamental/Particle Physics
  - Non-baryonic dark matter - New Particles - SUSY, neutrinos, baryogenesis
  - Dark Energy - Gravity / Extra Dimensions

Direct Detection Astrophysics of WIMPs

- **Energy spectrum & rate depend on WIMP distribution in Dark Matter Halo**
  - **"Spherical-cow" assumptions: isothermal and spherical, Maxwell-Boltzmann velocity distribution**
  - **V_0= 230 km/s, v_{esc}= 650 km/s,**
  - **ρ = 0.3 GeV / cm^3**
- **Energy spectrum of recoils is featureless exponential with ⟨E⟩ ~ 50 keV**
- **Rate (based on σ_{nX} and ρ) is fewer than 1 event per kg material per week**



"Contains ten 60-GeV WIMPs on average. 20 billion WIMPs pass through each second."



SUSY - Supersymmetry

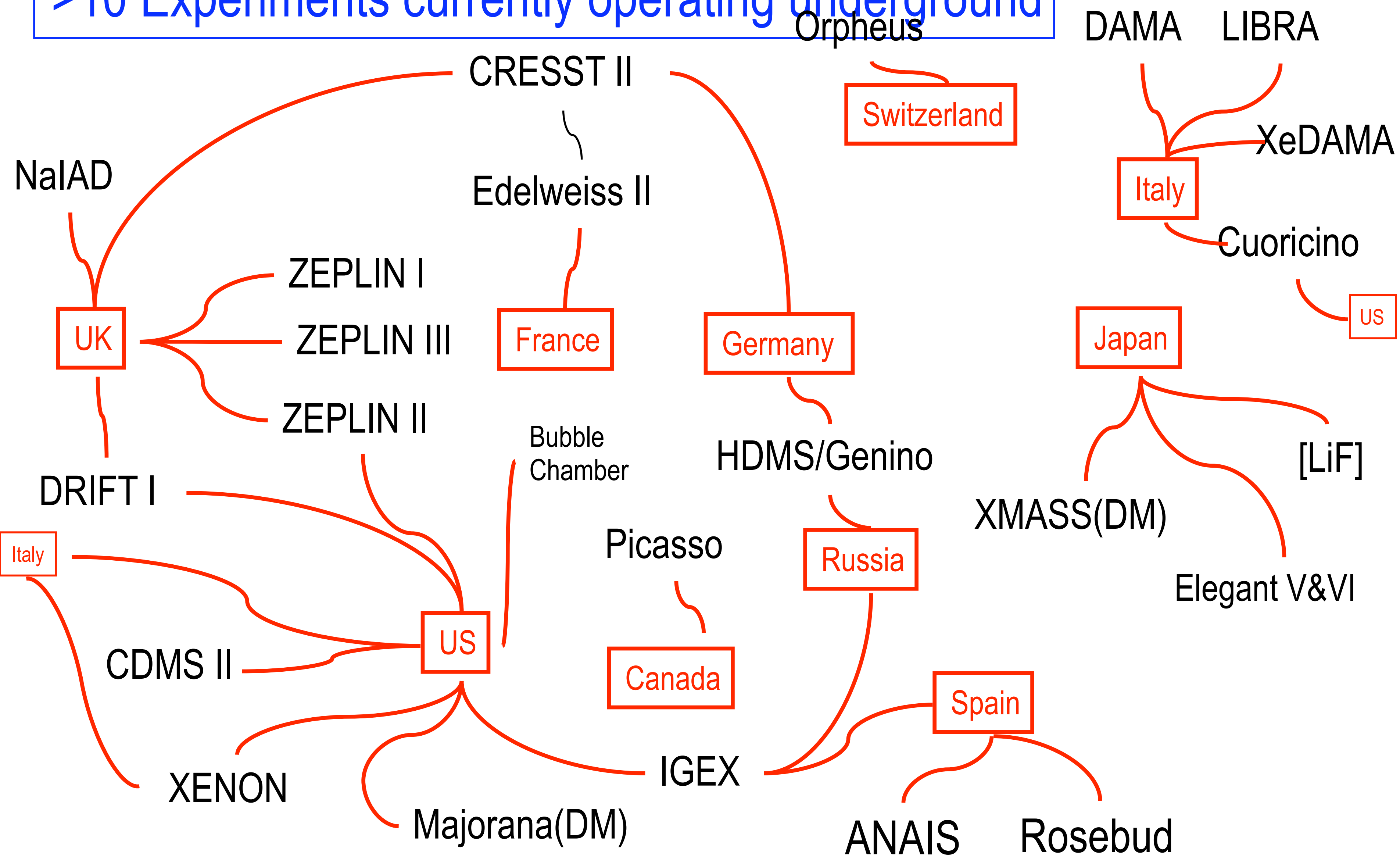
What Nature has to Offer

What we hope for!

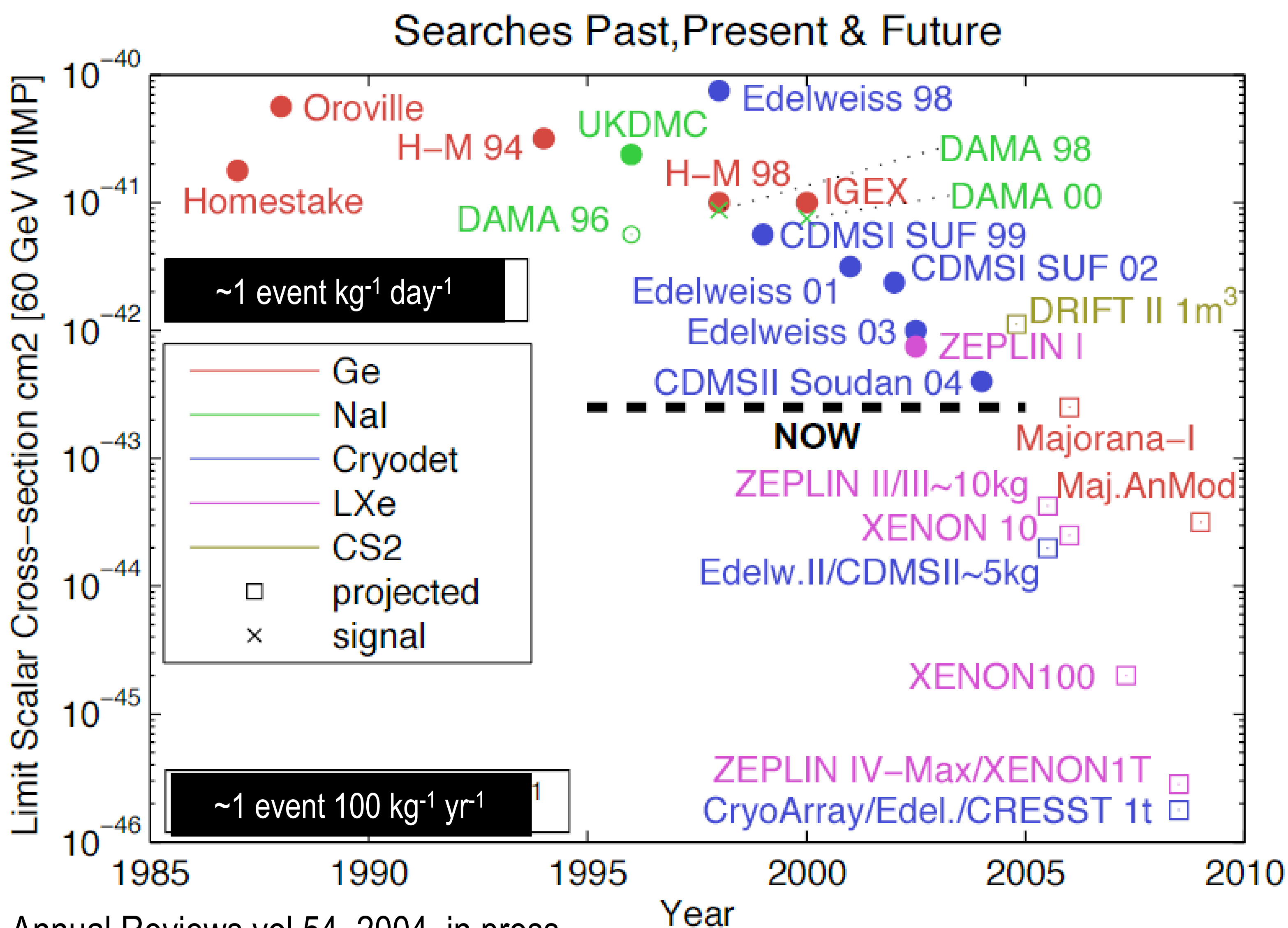
Dark Matter Experiments (Worldwide/affiliations)

(Running/Active Collaboration)

>10 Experiments currently operating underground

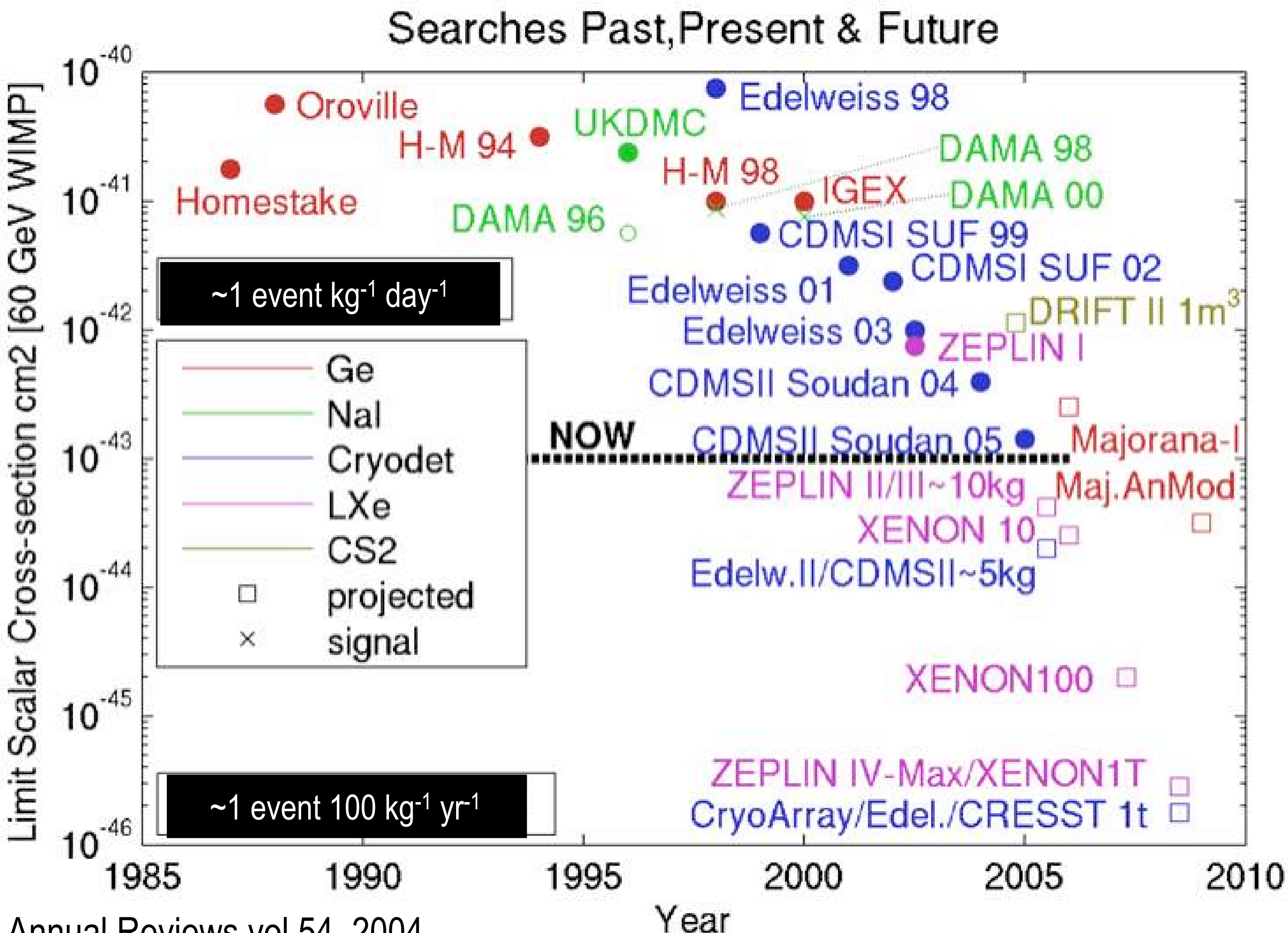


DM Direct Search Progress Over Time (->2004)



Gaitskell, Annual Reviews vol 54, 2004, in press

DM Direct Search Progress Over Time (2005)



Gaitskell, Annual Reviews vol 54, 2004

Current XENON Collaboration

Columbia University

Elena Aprile (PI), Karl-Ludwig Giboni, Sharmila Kamat+,
Pawel Majewski+, Kaixuan Ni*, Bhartendu Singh+ and Masaki Yamashita+

Brown University

Richard Gaitskell, Peter Sorensen*, Luiz De Viveiros*, Laurence Herrman+

University of Florida

Laura Baudis, David Day*

Lawrence Livermore National Laboratory

Adam Bernstein, Chris Hagmann and Celeste Winant+

Case Western Res. Univ. (group moved from Princeton)

Tom Shutt, John Kwong*, Eric Dahl*, Alex Bolozdinya+

Rice University

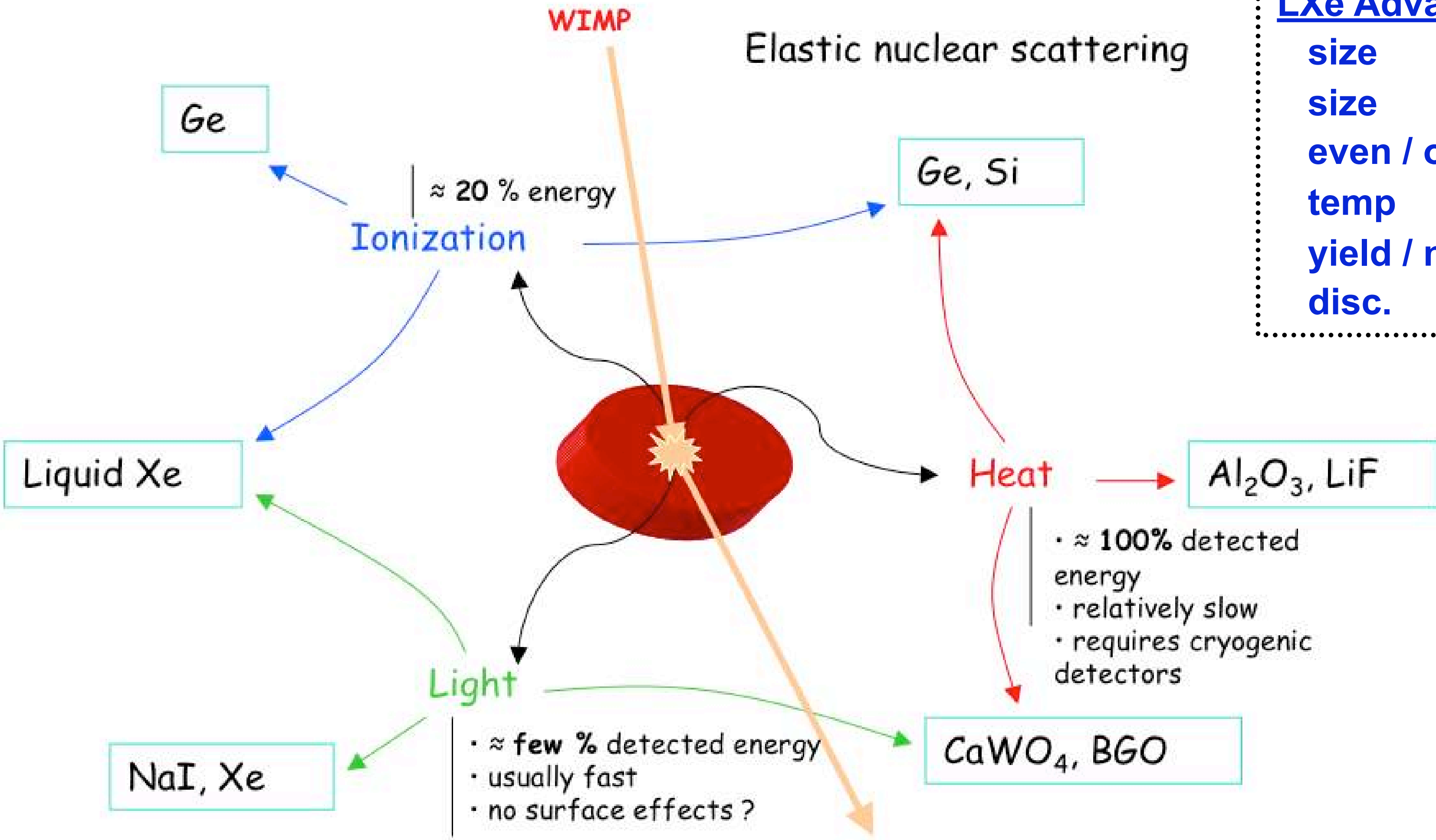
Uwe Oberlack ,Omar Vargas*

Yale University

Daniel McKinsey, Richard Hasty+, Angel Manzur*

+PostDoc/Engineer
***Grad**

Potential Signals from Interaction



LXe Advantages:
- size
- size
- even / odd
- temp
- yield / noise
- disc.

Figure from G. Chardin

XENON Event Discrimination: Electron or Nuclear Recoil?

Within the xenon target:

- **Neutrons, WIMPs => Slow nuclear recoils => strong columnar recombination**

=> Primary Scintillation (S1) preserved, but Ionization (S2) strongly suppressed

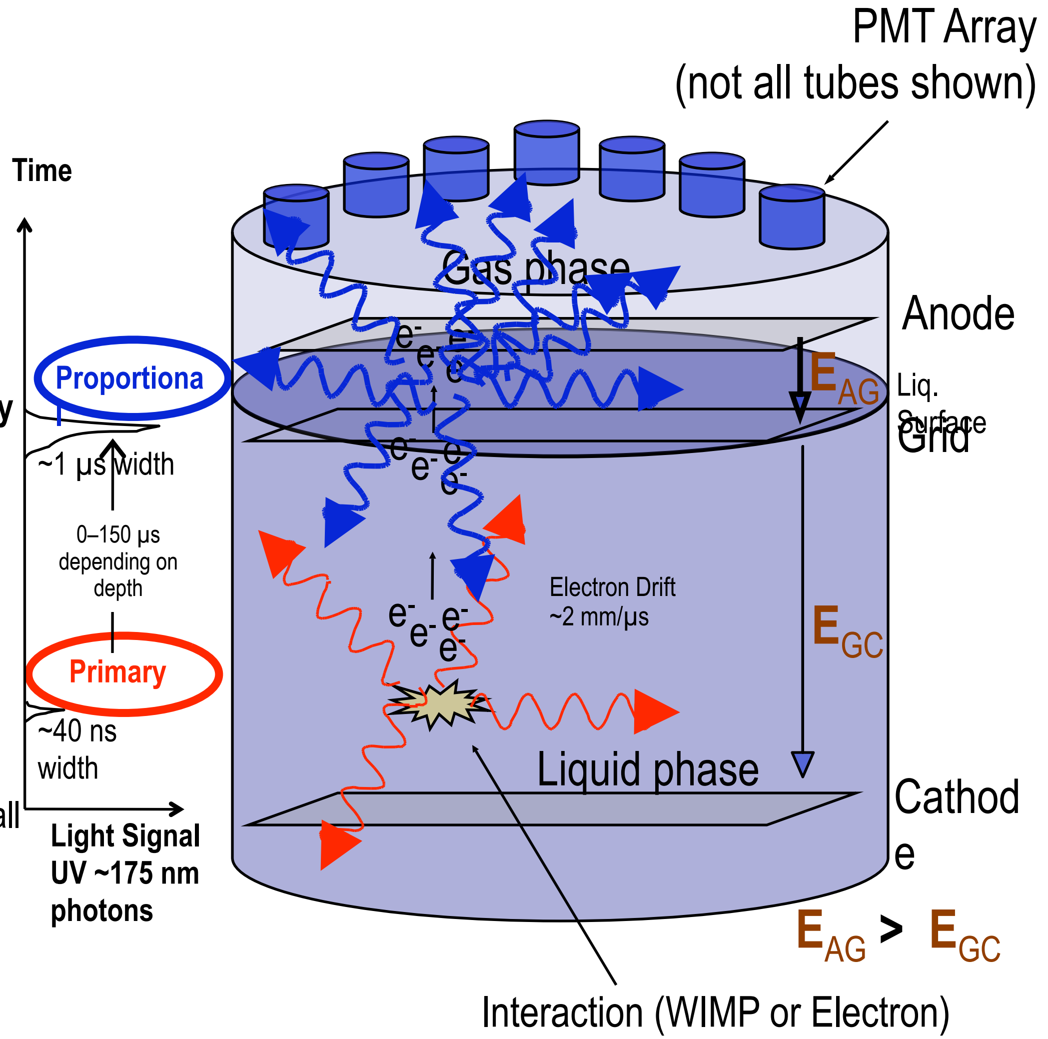
- **γ, e-, μ, (etc) => Fast electron recoils =>**

=> Weaker S1, Stronger S2

Ionization signal from nuclear recoil too small to be directly detected => extract charges from liquid to gas and detect much larger proportional scintillation signal => dual phase

Simultaneously detect (array of UV PMTs) primary (S1) and proportional (S2) light **=>**
Distinctly different S2 / S1 ratio for e / n recoils provide basis for event-by-event discrimination.

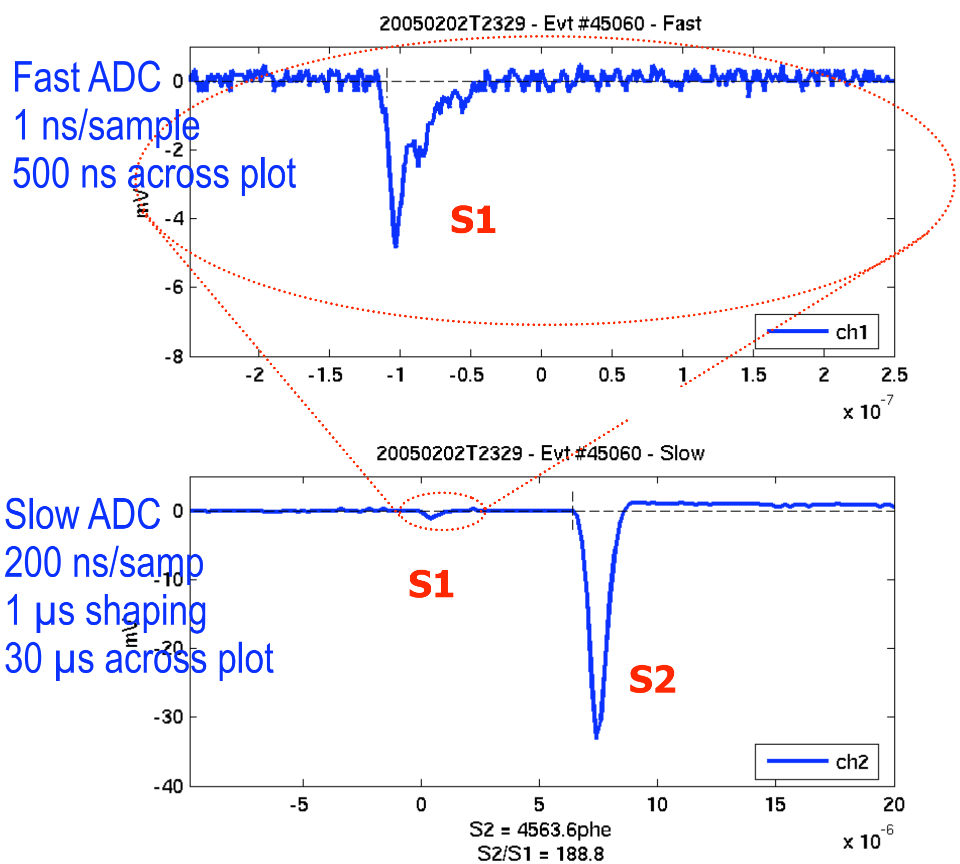
Challenge: ultra pure liquid and high drift field to preserve small electron signal **(~20 electrons)** ; efficient extraction into gas; efficient detection of small primary light signal **(~ 200 photons)** associated with **16 keVr**



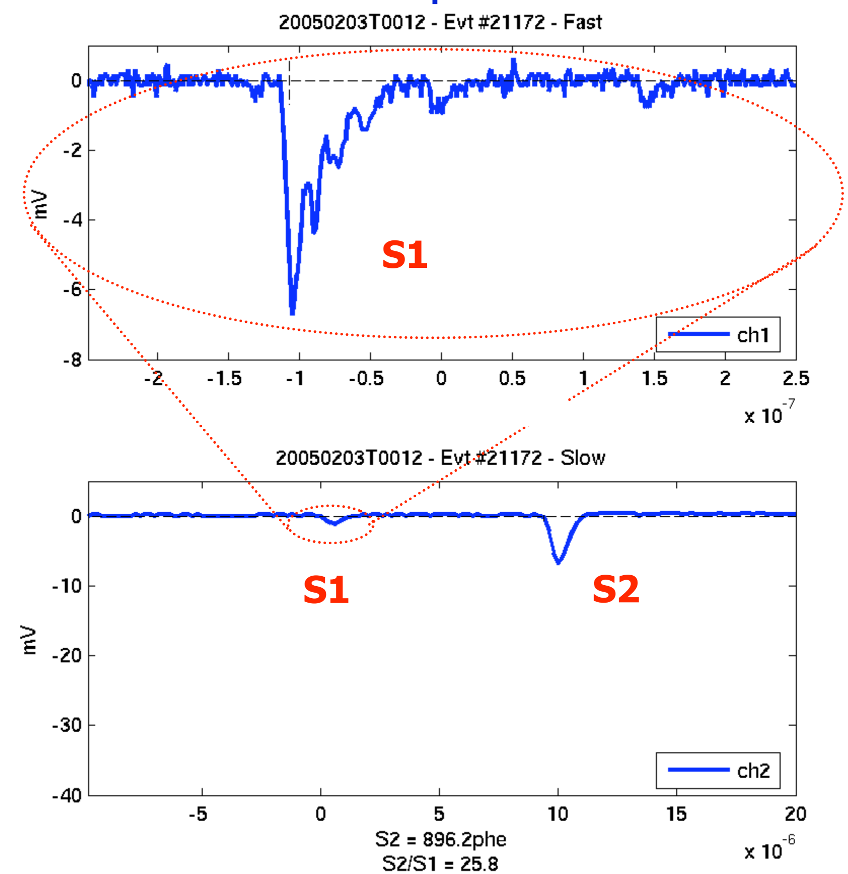
Sample Events from Xenon Detector (XeBaby)

- XeBaby two phase chamber response to neutrons (AmBe) and gammas (137Cs)
  - 2 PMTs (bottom one in liquid, top in gas) - example signals from Top shown below
  - E_C = 2.5kV/cm, E_A = 8.0 kV/cm
  - ~30 ns decay time of Xe excitation
  - Max Drift TIme ~7.5 μs for 15 mm (~1μs shaping on Slow Digitizer)

Gamma event
S1 2.2 phe/keVee



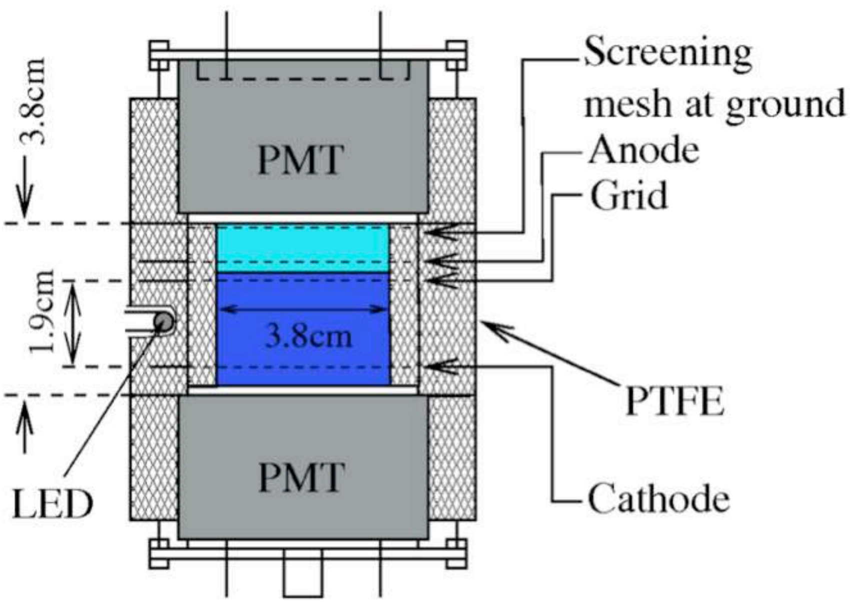
Nuclear Recoil event
S1 ~ 1 phe/keVr



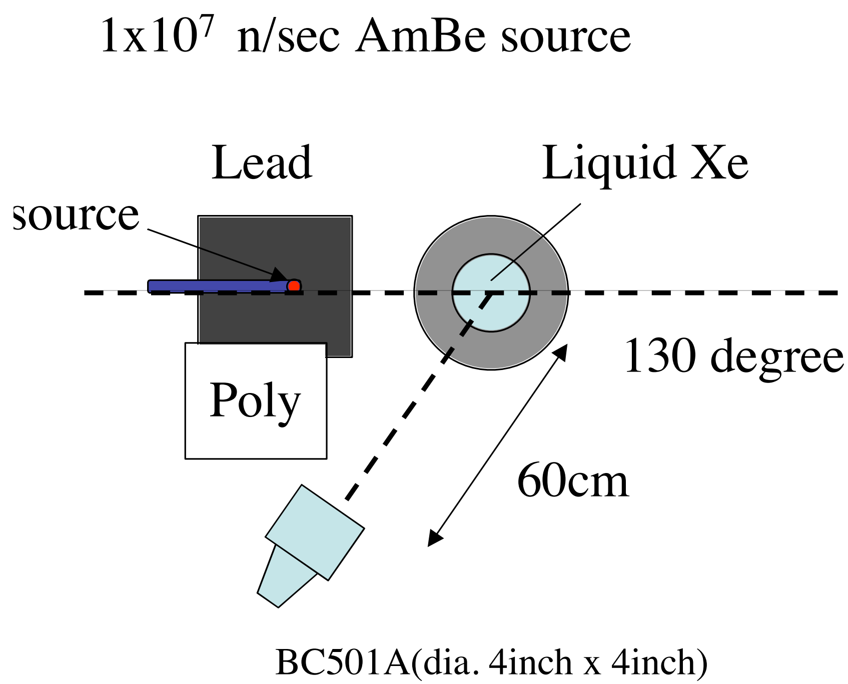
XeBaby Test Rig

- §Fiducial volume: ∅ = 4cm, h= 2cm (Xe ~100g)
- §2 PMTs (∅ = 5cm each)
- §Operated at Nevis Lab, Columbia University (Columbia/Brown Operation)

XeBaby Diagram

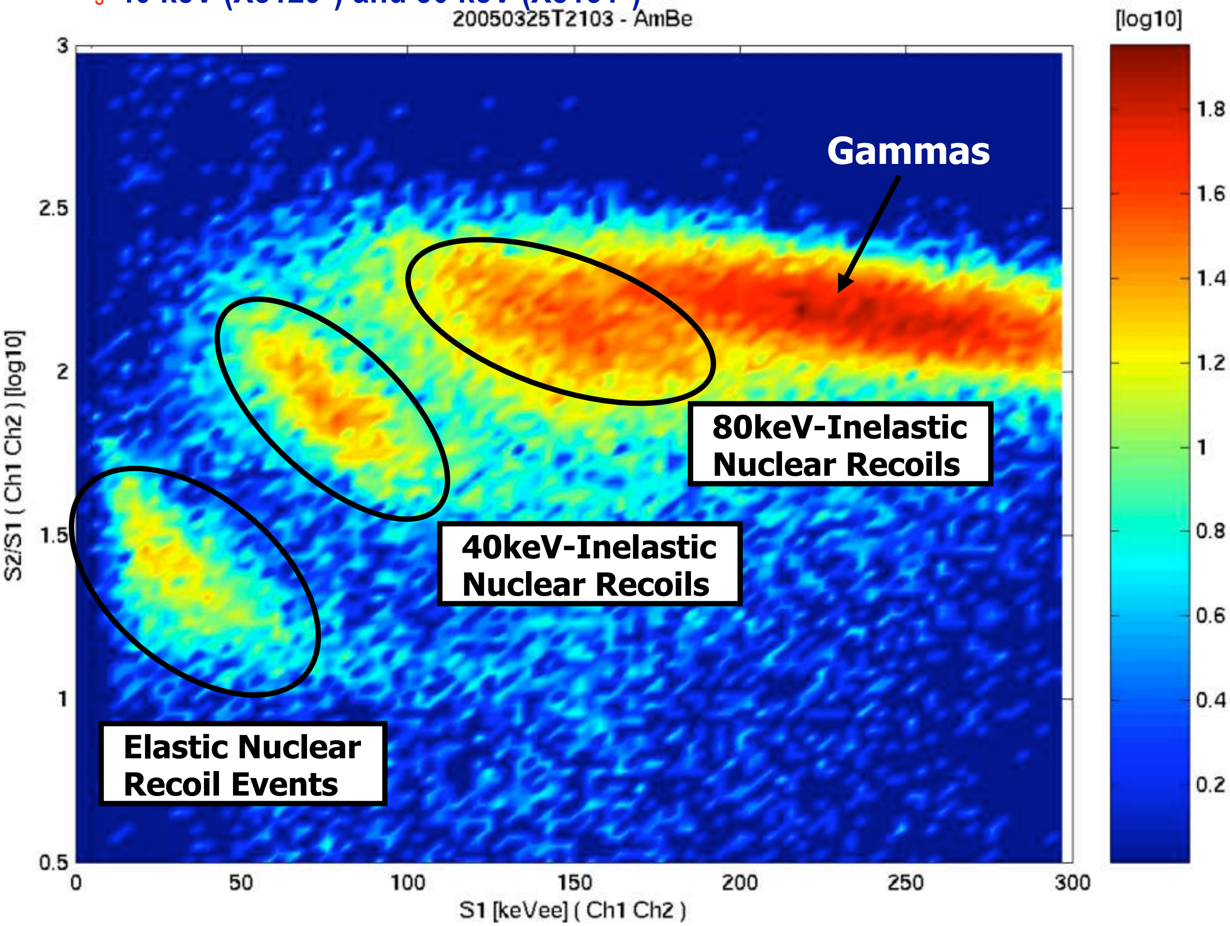


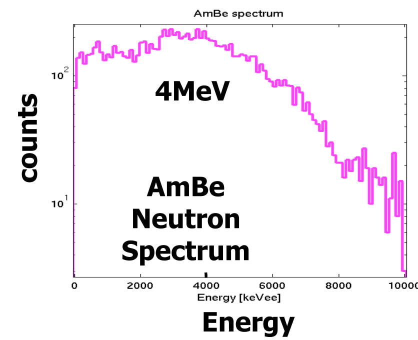
Source Position



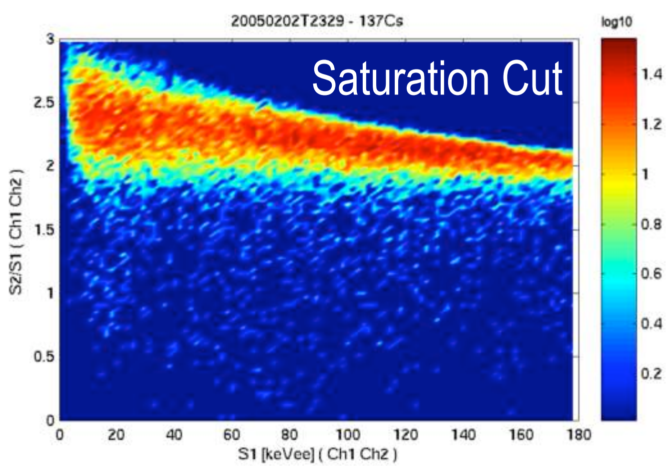
Event Discrimination (Using S2/S1 ratio)

- AmBe Source
  - Neutron spectrum peaked at 4MeV + 4.43MeV γ's (suppressed with 10cm Pb shield)
  - V_C = 4 kV/cm (max field probed), V_A = 3.5 kV/cm
- Inelastic Events:
  - 40 keV (Xe129*) and 80 keV (Xe131*)



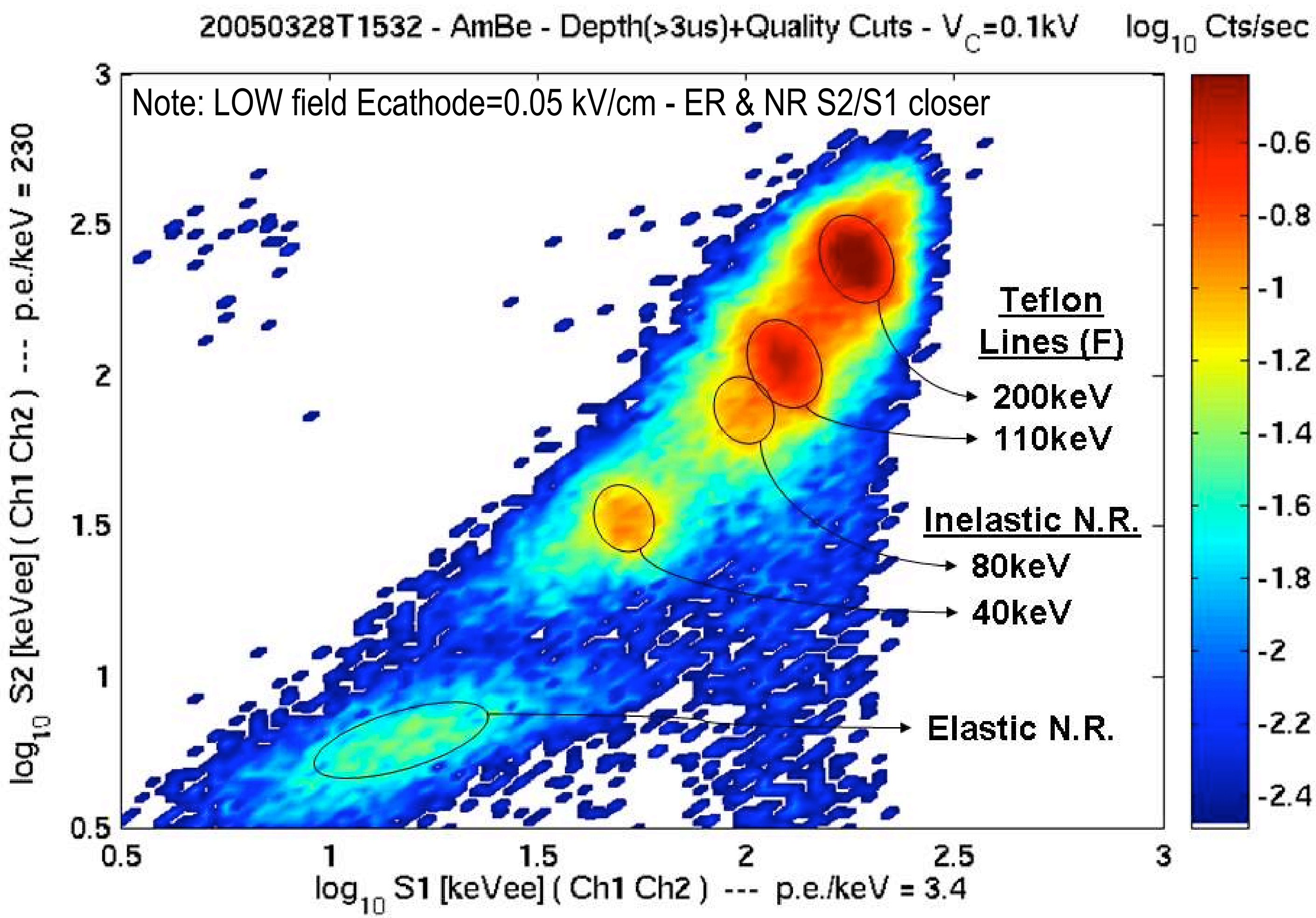


- 137Cs Source
  - V_C = 4 kV/cm, V_A = 4 kV/cm

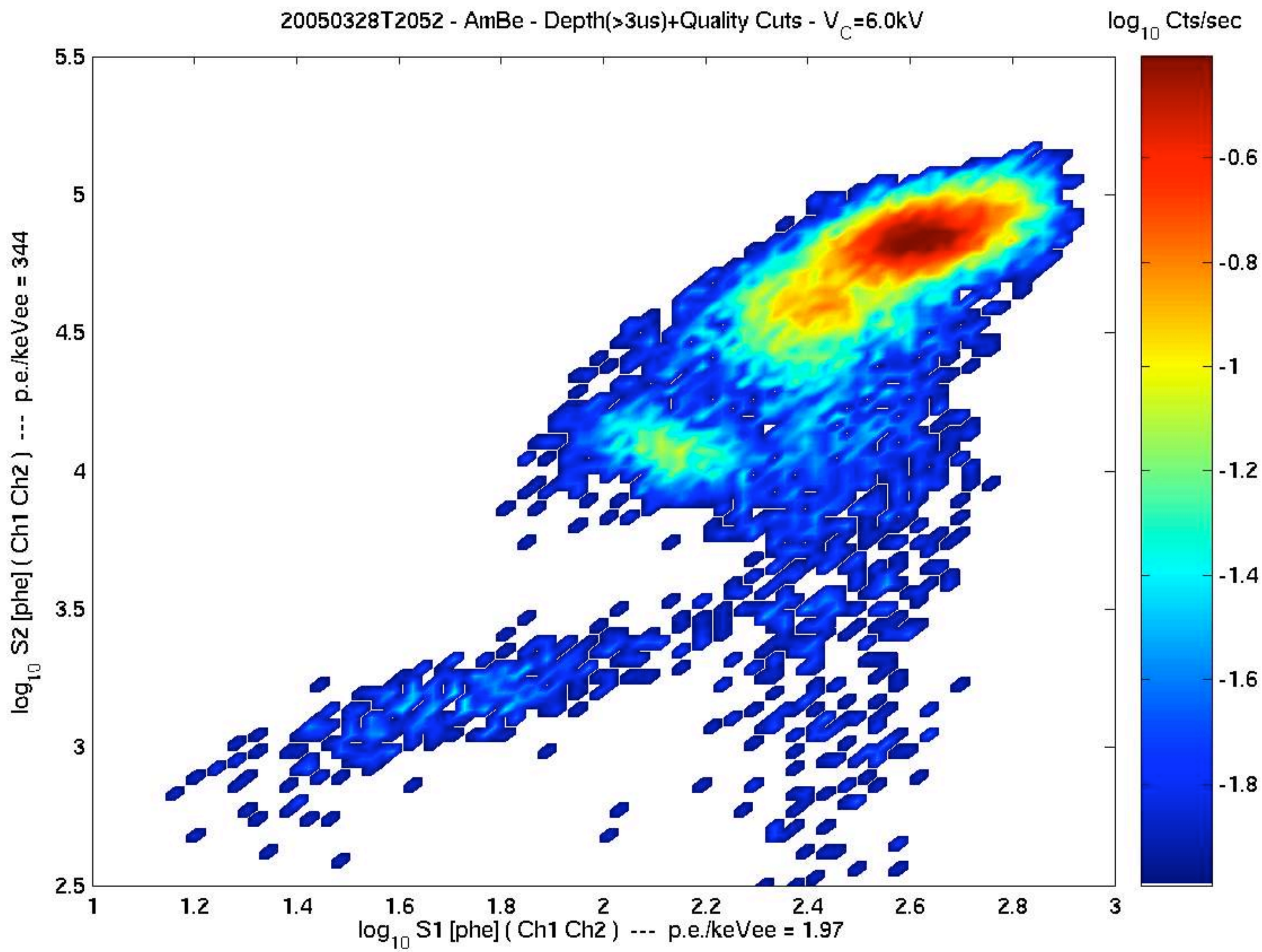


Features in Energy Spectrum

§ **Features in AmBe Spectrum:**
- § Elastic Nuclear Recoils in Xe
- § Inelastic Nuclear Recoils in Xe: 40keV (129Xe) and 80keV (131Xe)
- § Gammas from Inelastic Nuclear Recoils in Teflon (F): 110keV and 200keV



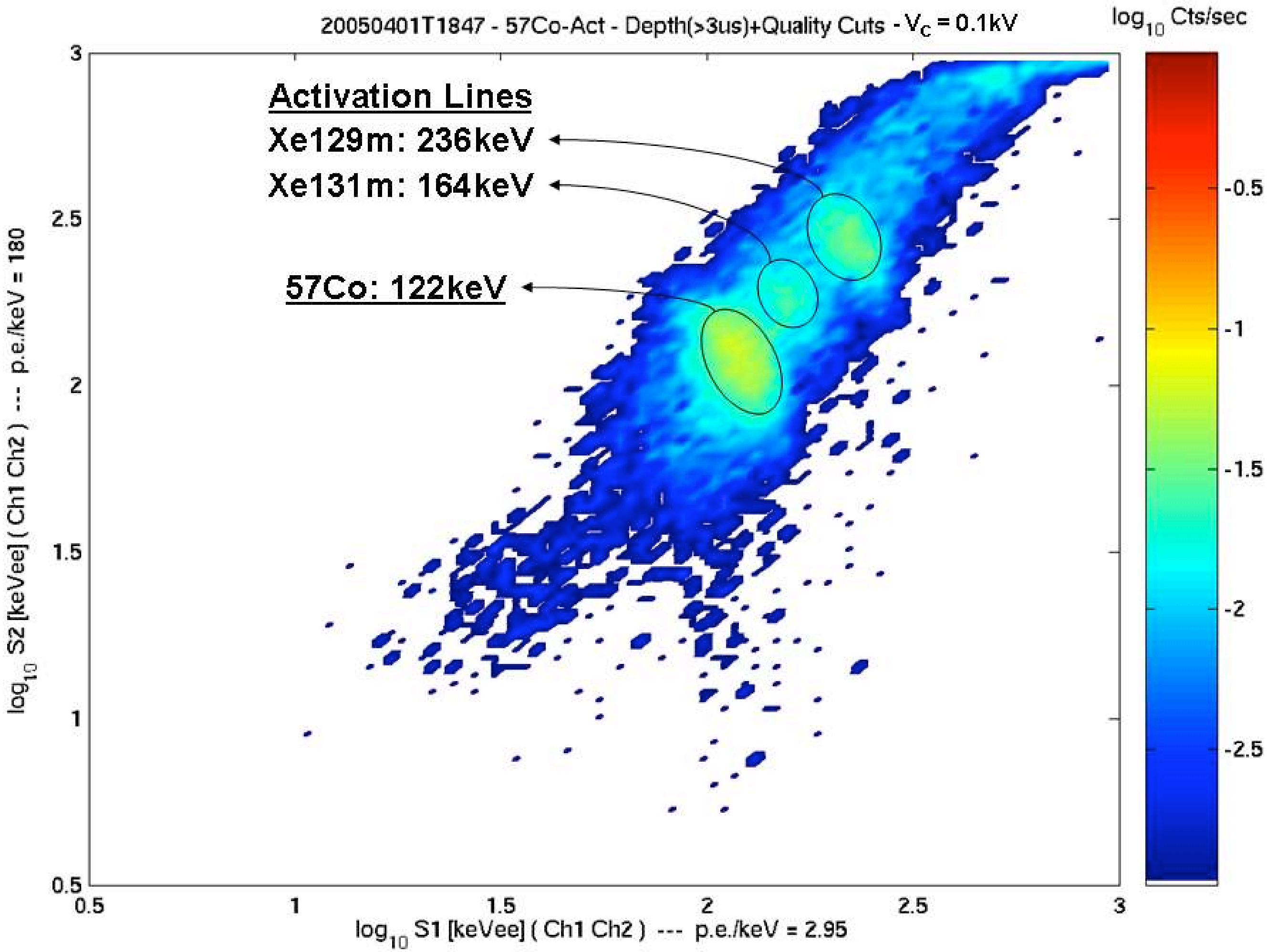
S2/S1 Dependence on E-Field for n/γ Recoils



Animation - log(S1) vs log(S2) as a function of applied drift field
0.05 kV/cm -> 4 kV/cm (1.5 cm drift)

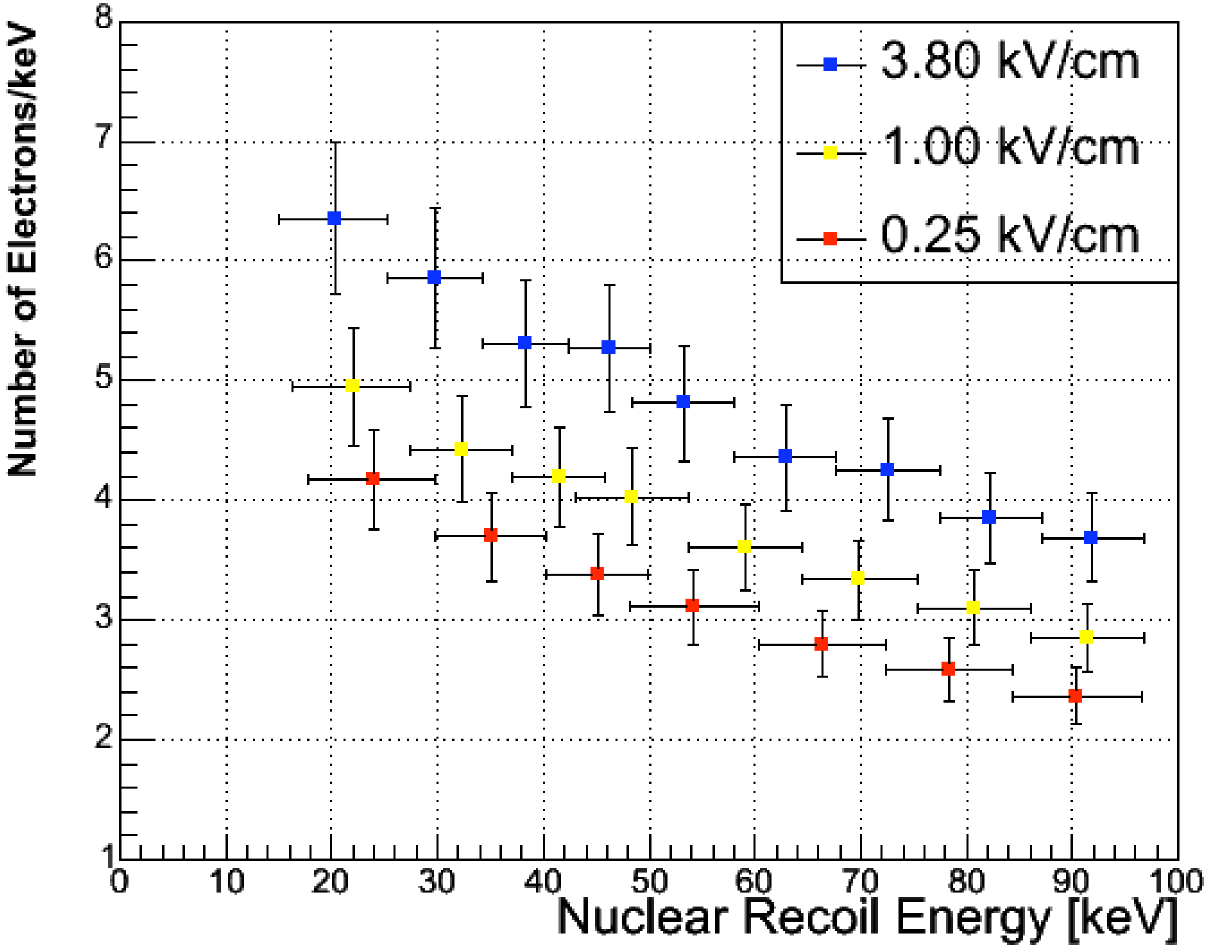
Features in Energy Spectrum

§ Calibration Spectrum
- § 57Co: 122keV
- § Xe Activation Lines: 164keV (Xe131m) and 236keV (Xe129m)
  - Xe in chamber has been activated due to intermittent exposure to AmBe neutron for the previous 10 days

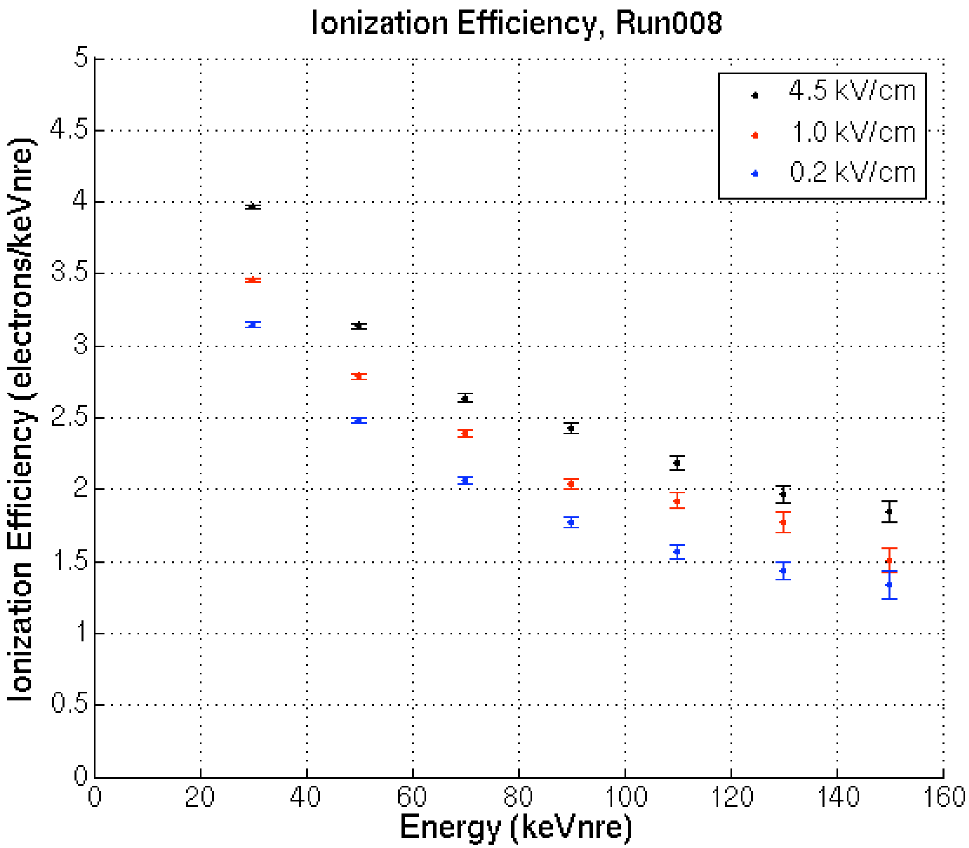


Ionization Yield of Xe Nuclear Recoils (Columbia/Brown)

• Number of electrons does not depend much on electric field.
• Ionization density along the track of a recoil ion appears to increase as the energy decreases, as expected from Bragg-like curve for LET in Xe

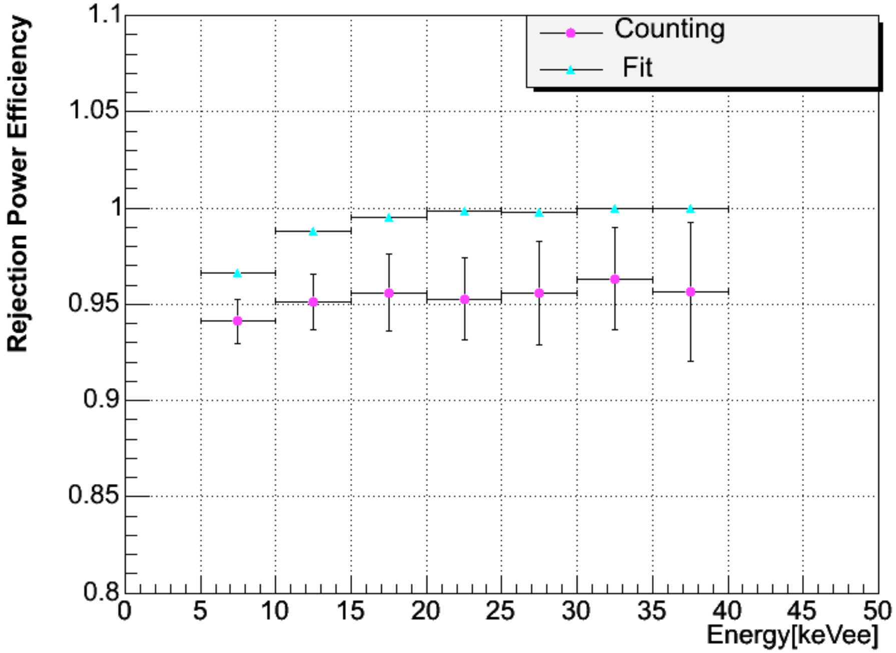


Nuclear Recoil Ionization Yield (CWRU)

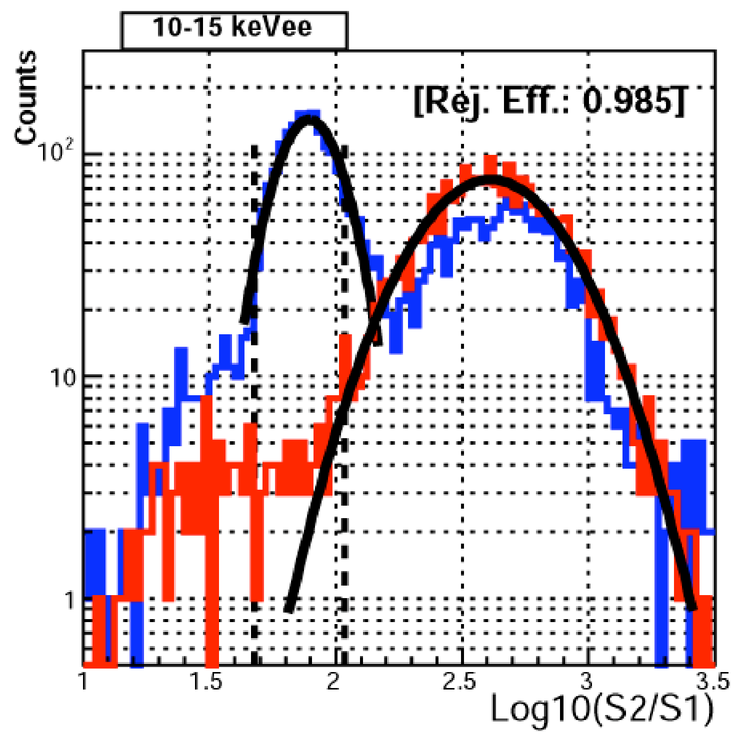


- Calibration with ^{210}Po alphas.
  - Cross check with 122 keV gammas (^{57}Co).
  - In progress
- Energy dependence presumably from E dependence of dE/dX.

Rejection Power by S2/S1



Rejection power
(80% acceptance window)
~95 % (with flat component)
>99% (by gaussian fit)

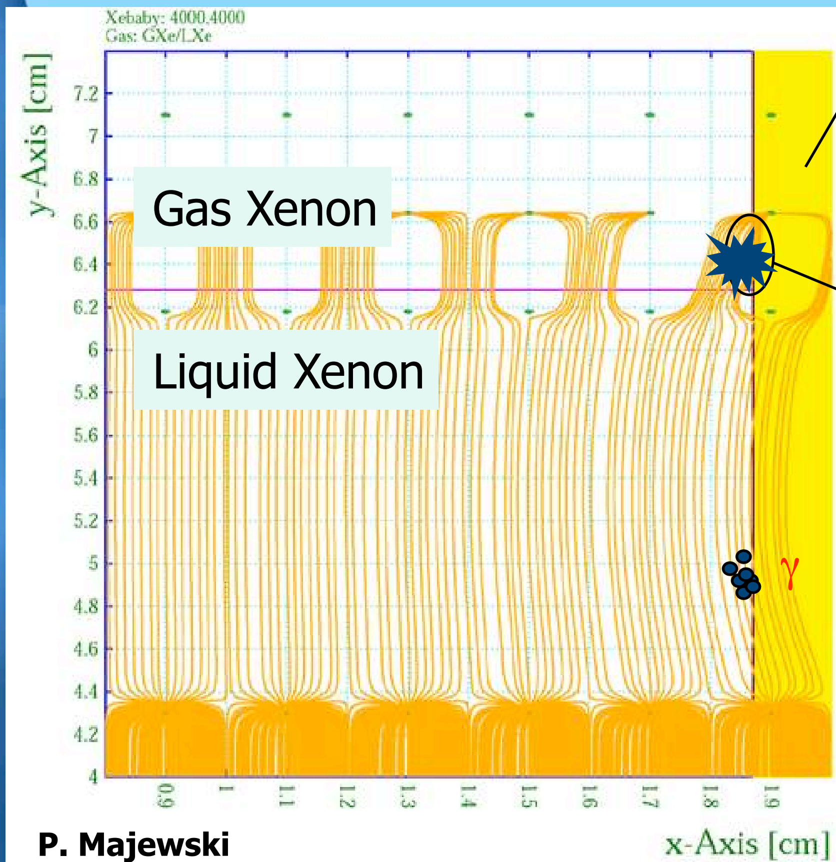


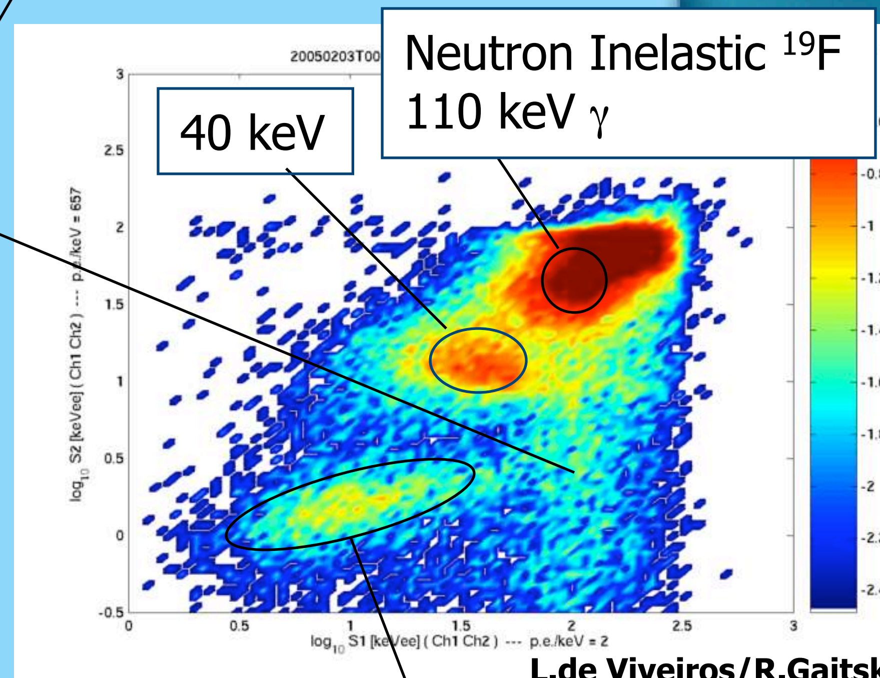
Flat component due to edge events
Non-uniform E-field;Charge trapped on PTFE

Improve with 3D detector

Field Non-uniformity and Edge Events

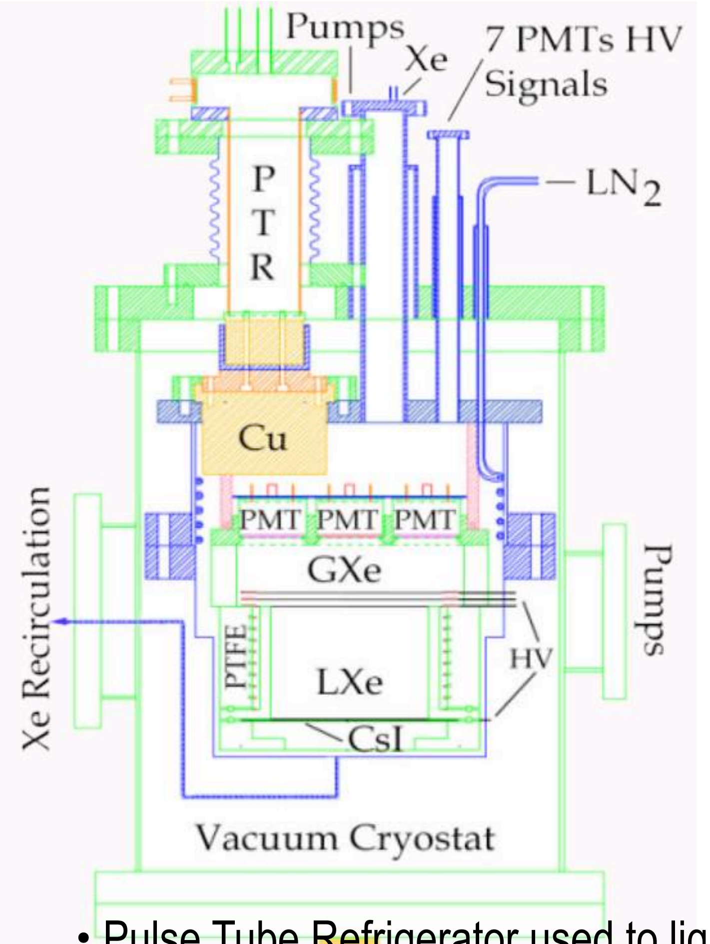
Teflon (PTFE)



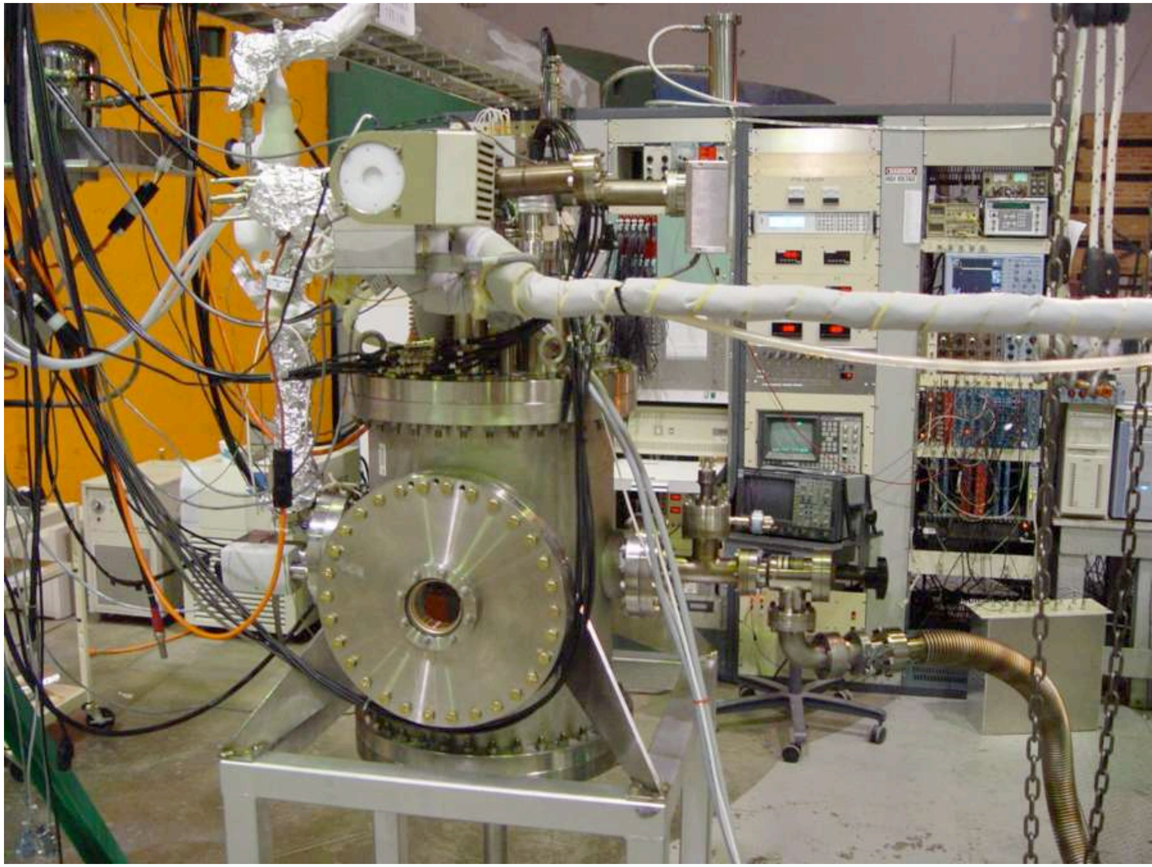


ELASTIC Nuclear Recoil

XENON R&D: Dual Phase 3D XeTPC Prototype



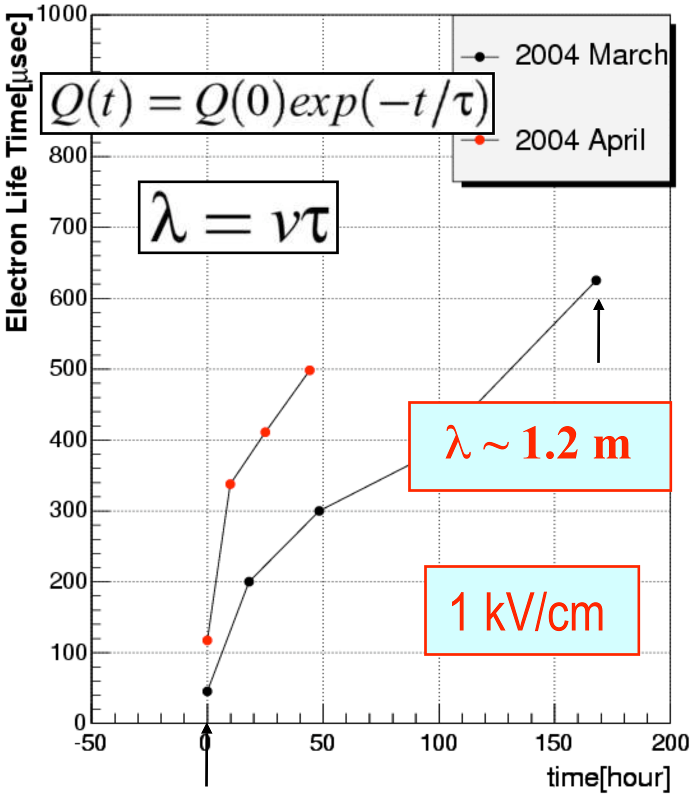
XENON Set-up at Columbia Nevis Lab

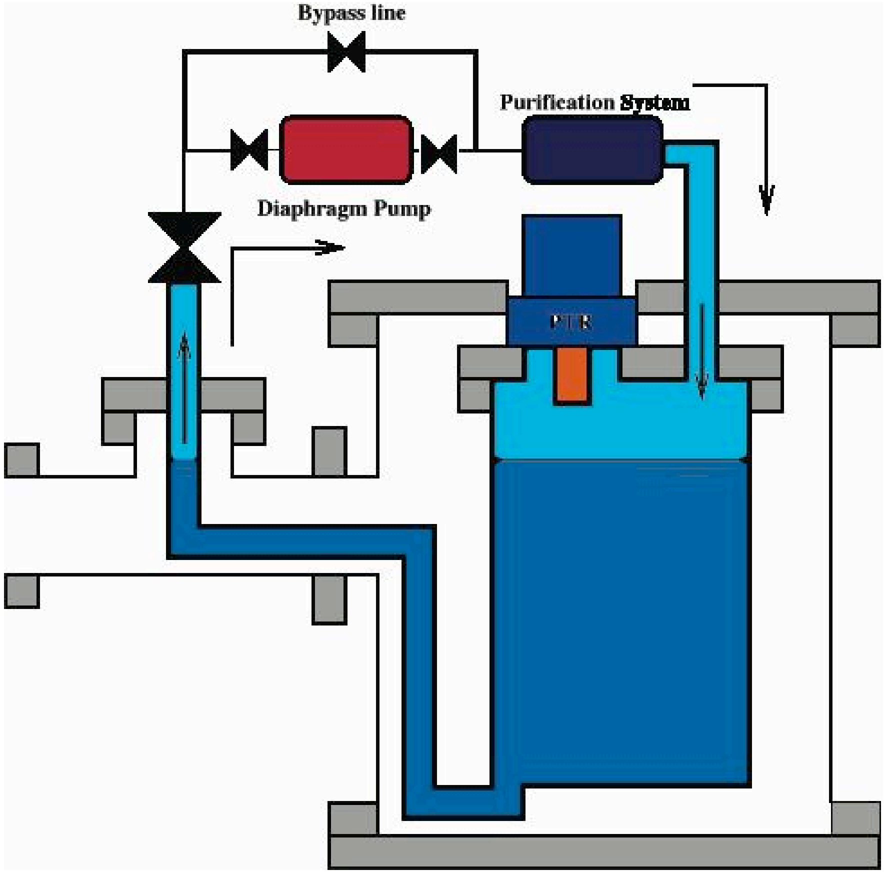


- Pulse Tube Refrigerator used to liquefy and maintain LXe at –95.1 ± 0.05 C
- Array of 7 PMTs (Hamamatsu R9288) directly coupled to the Xe active volume
- Fast and Slow digitizers for direct and proportional light waveforms
- Drift Field > 1kV/cm; Extraction Field > 10 kV/cm
- Calibration with gamma (Co-57), alpha (Po-210) and neutron (AmBe) sources.

R&D Milestone: > 1 m Electron Attenuation Length

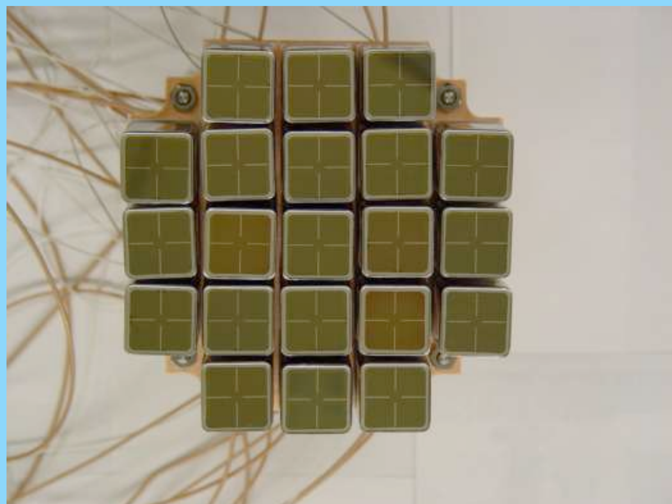
Continuous Circulation of Xe gas through high temperature metal getter to achieve high purity (<1ppb) of the liquid target a few days.

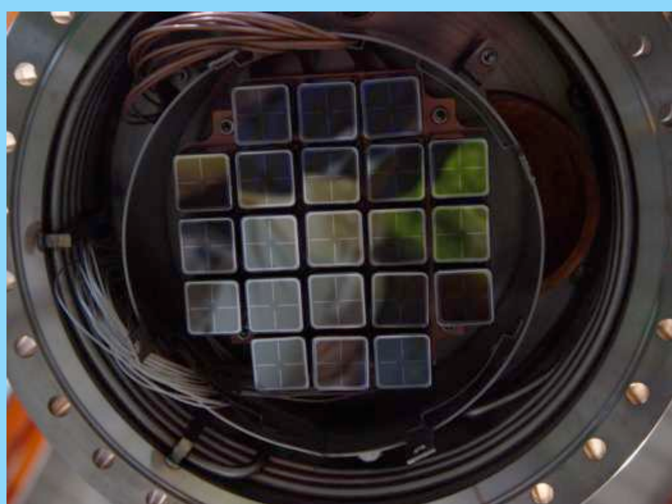




XENON_2005

21 PMTs Array Details (XENON3)





- Hamamatsu R8520
- Developed for operation in LXe
- Metal Channel, compact ((2.5 cm)^{2}x3.5cm))
- Square anode (good fill factor : 66.2%).
- Low background : ^{238}U / ^{232}Th = < 3 mBq total (Recent measurement)
- Quantum Efficiency : >20 % @178nm

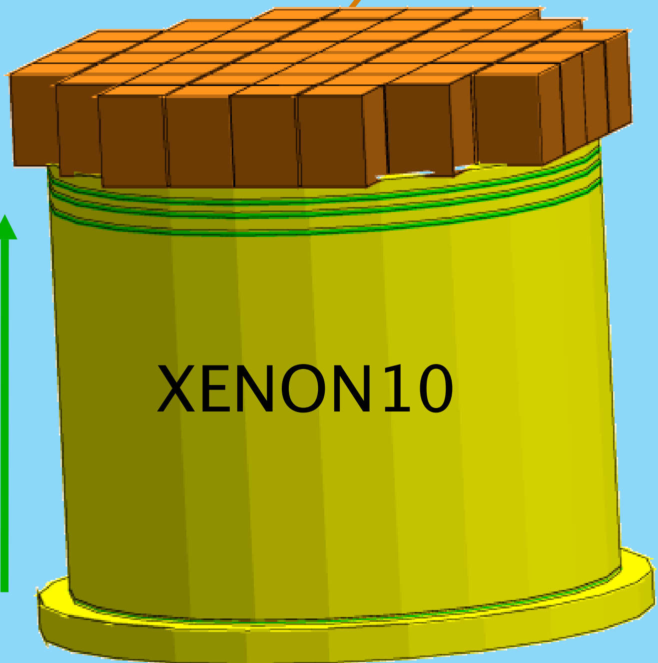
New Detector Construction / Testing Schedule

- Now Testing XENON Prototype @ Nevis for Underground Operation
- Moved from R9288 (ø 2”) to R8520 (sq 1”)to improve backgrounds from tubes (all stainless construction for housing) and also to maximize x-y position information
  - Tested operation of tubes in LXe at Brown
- XENON3 - currently running chamber with top PMTs only at Columbia
  - 21 Top PMTs + 14 Bottom PMTs, ø19 cm x 11 cm drift (9 kg gross/3 kg fid.)
    - Install bottom PMTs when next Hamamatsu batch comes in
    - Radioactivity of tubes is < than expected (<3 mBq/tube total U/Th/K)
- XENON10
  - Then increase # of tubes (in-line with Hamamatsu batch delivery schedule)
  - 46 Top PMTs + 32 Bottom PMTs, ø25 cm x 15 cm drift (21 kg gross/~10 kg fid.)
  - Actual fiducial will depend on how relaxed radial/z cuts can be
- Light collection modeling
  - Expect ~ 1 phe/keVee with 3 kV/cm applied (0.5 phe/keVr) for XENON3 and XENON8 (Simulation -> ~1/2 of light collection of XeBaby, latter matched MC

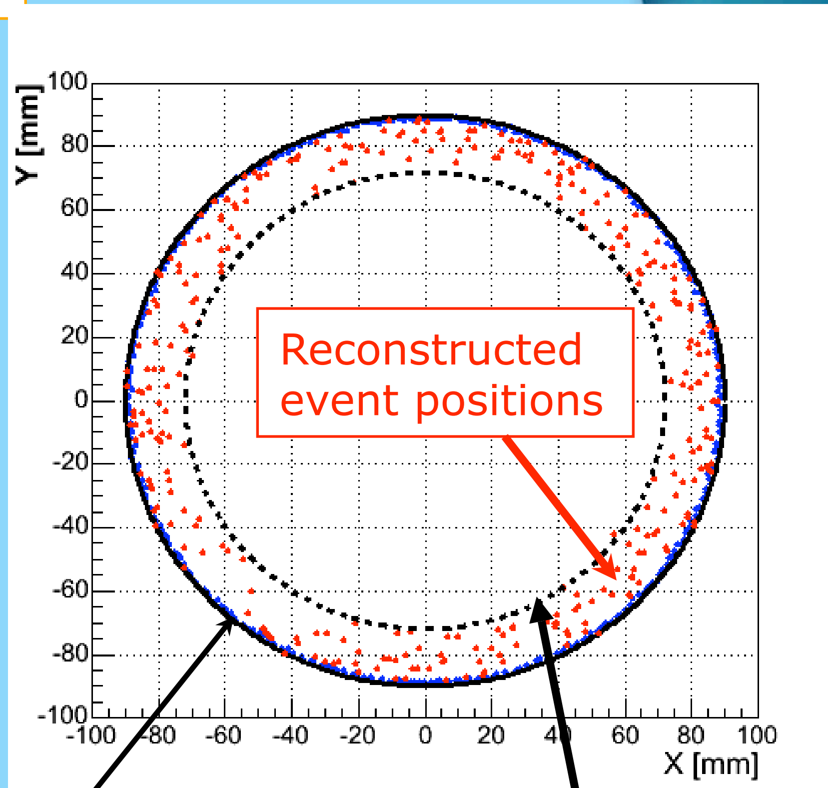
XENON10: A 3D Sensitive WIMP Detector

An array of R8520 PMTs allows X-Y position reconstruction

Z position determined from electron drift time



GEANT4 Simulation



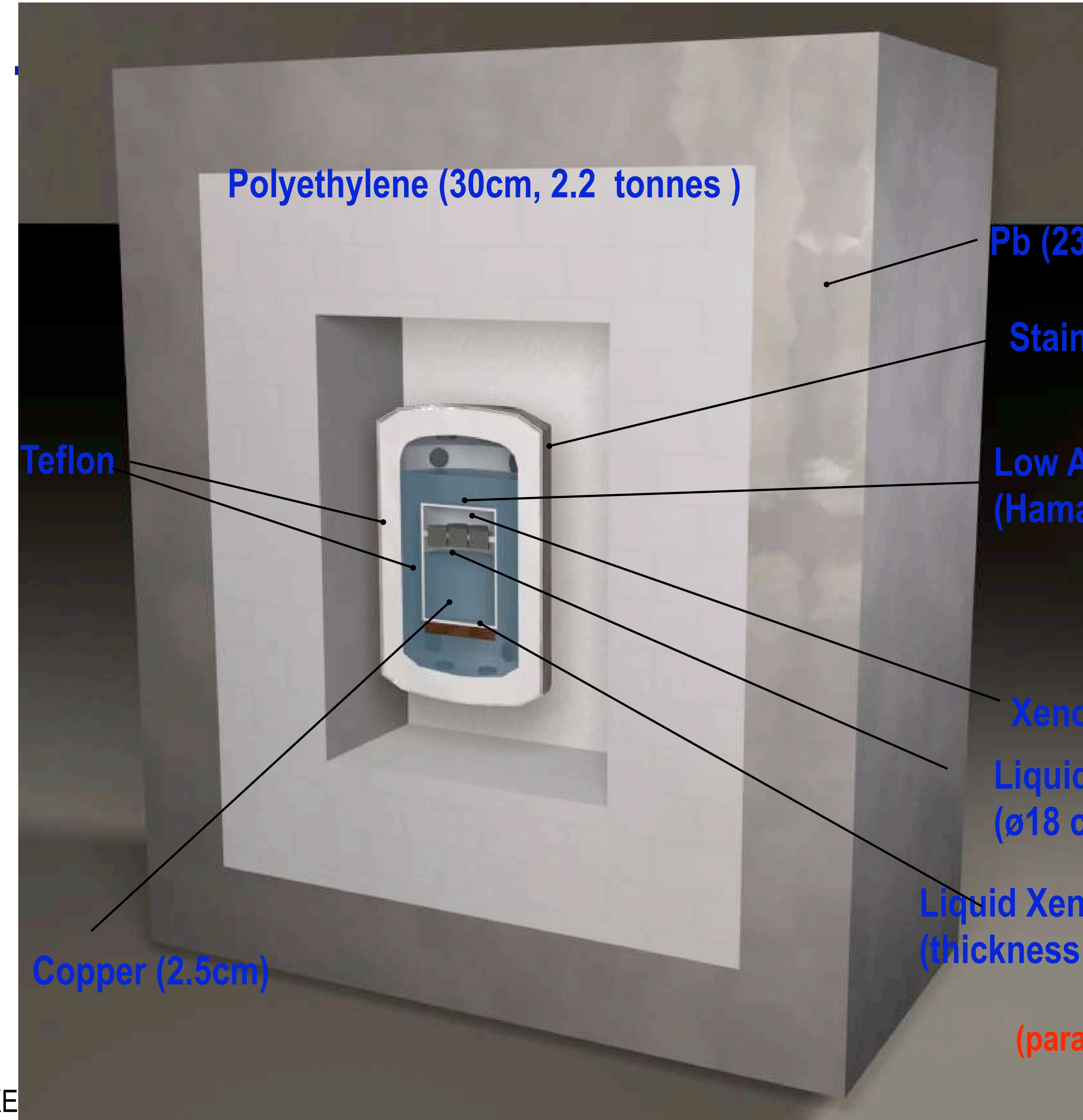
10keV Nuclear Recoil Events near the detector edge

Edge events can be rejected based on reconstructed positions

XENON R&D Milestones: Summary

+ PMTs operation in LXe	**Achieved**
+ > 1 meter λ_e in LXe	**Achieved**
+ CsI photocathode in LXe w/o Feedback	**Achieved**
+ Operating ~few kV/cm electric field	**Achieved**
+ Electron extraction to gas phase	**Achieved**
+ Efficient & Reliable Cryogenic System	**Achieved**
+ Electron/Alpha recoil discrimination	**Achieved**
+ Nuclear recoil Scintillation Efficiency (10-55 keVr)	**Achieved**
+ Nuclear recoil Ionization Efficiency	**Achieved**
+ Electron/Nuclear recoil discrimination	**Achieved**
+ Kr removal for XENON10	**In progress**
+ Electric Field / Light Collection Simulations	**Tools Developed_Done for XENON10**
+ Background Simulations	**Tools Developed_Done for XENON10**
+ Materials Screening for XENON10	**on-going (Soudan_SOLO Facility)**
+ Design of XENON10 System	**In Progress**
+ Low Activity PMTs and Alternatives Readouts	**on-going**

XENON10 Schematic of Detector and Shield Design

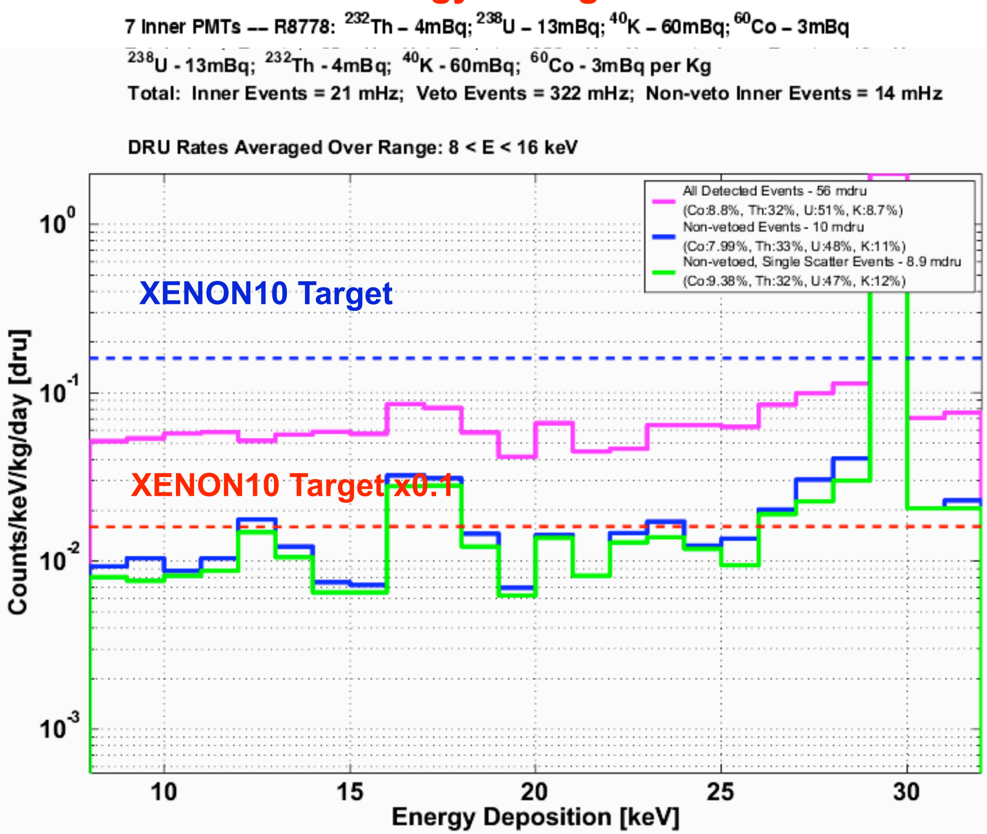


(parameters used in Monte Carlo)

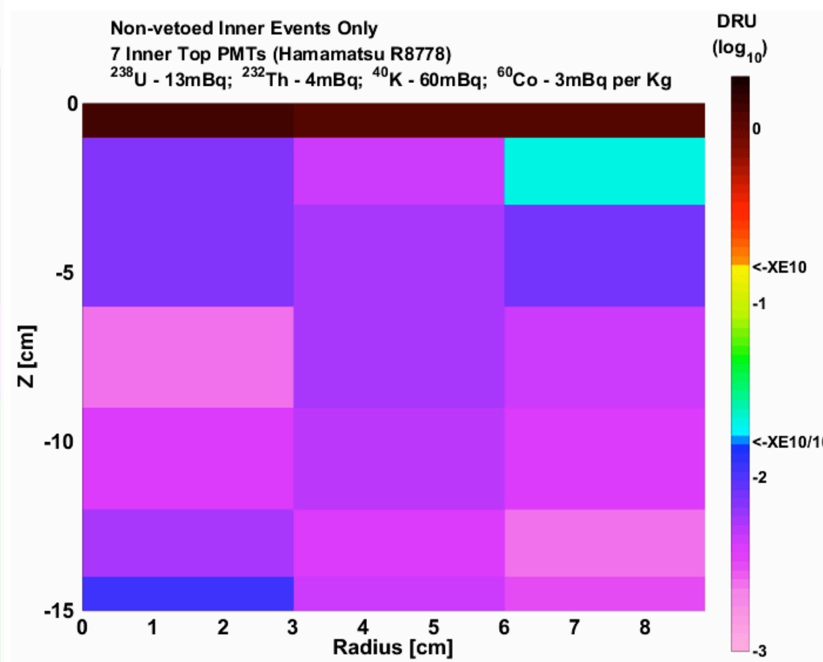
PMTs Gamma Background in XENON10

Gamma Background from PMTs (Hamamatsu R8520: **^{238}U / ^{232}Th / ^{40}K / ^{60}Co = 13 / 4 / 60 / 3 mBq**
is 4x below XENON10 target – can be further reduced to 40x with outer LXe Veto
and multi-site events cut - Recent batches of tubes counted and found to be <3 mBq total !

Inner Chamber Events (8 < E < 28 keV)
Energy Histogram



Inner Chamber Events (8 < E < 28 keV)
Spatial Distribution



XENON_2005

Summary of XENON10 Backgrounds

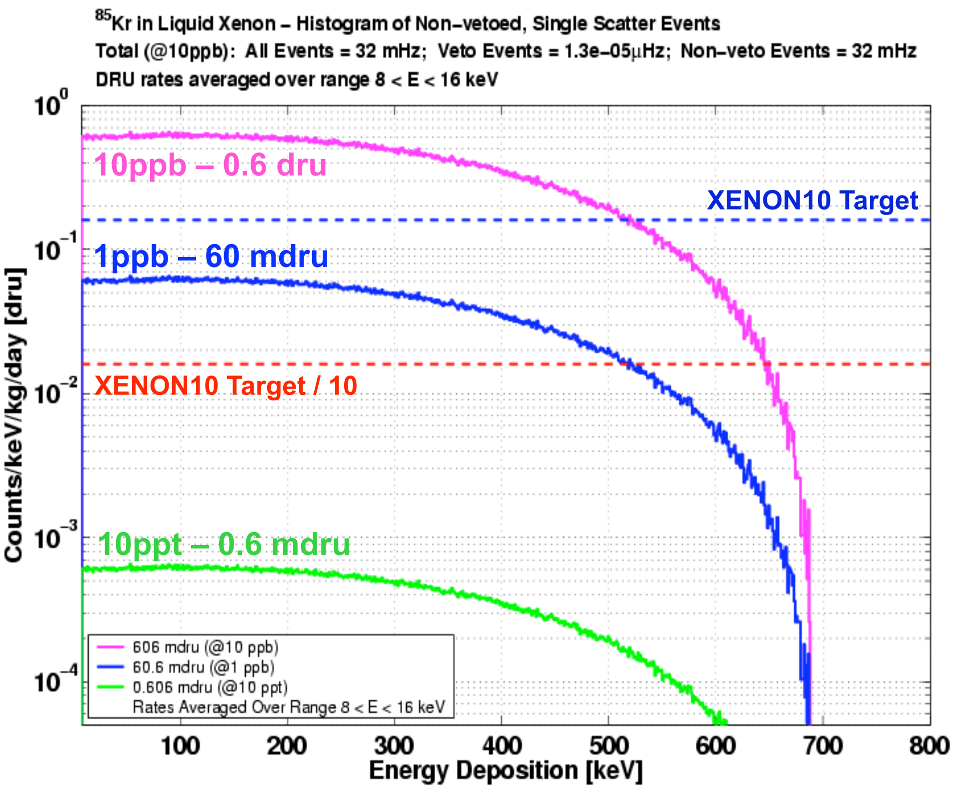
Current Monte Carlos have considered the following sources of backgrounds

- Gamma / Electron Recoil Backgrounds
  - External Gammas - Pb Shield
  - Gammas inside Pb Shield
    - PMT (K/U/Th/Co)
    - Vessel: Stainless Steel (Co)
    - Polyethylene Shield
    - Contributions from Other Components
  - Xe Intrinsic Backgrounds (incl. ^{85}Kr)
  - Rn gas exclusion from shield
- Neutron Backgrounds
  - Internal Sources: PMT (α,n)
  - External: Rock (α,n): Poly Shield
  - Punch-through neutrons: Generated by muons in rock
- No Muon Shield required fro XENON10
  - Neutrons arising from muon interaction in Pb/poly shield

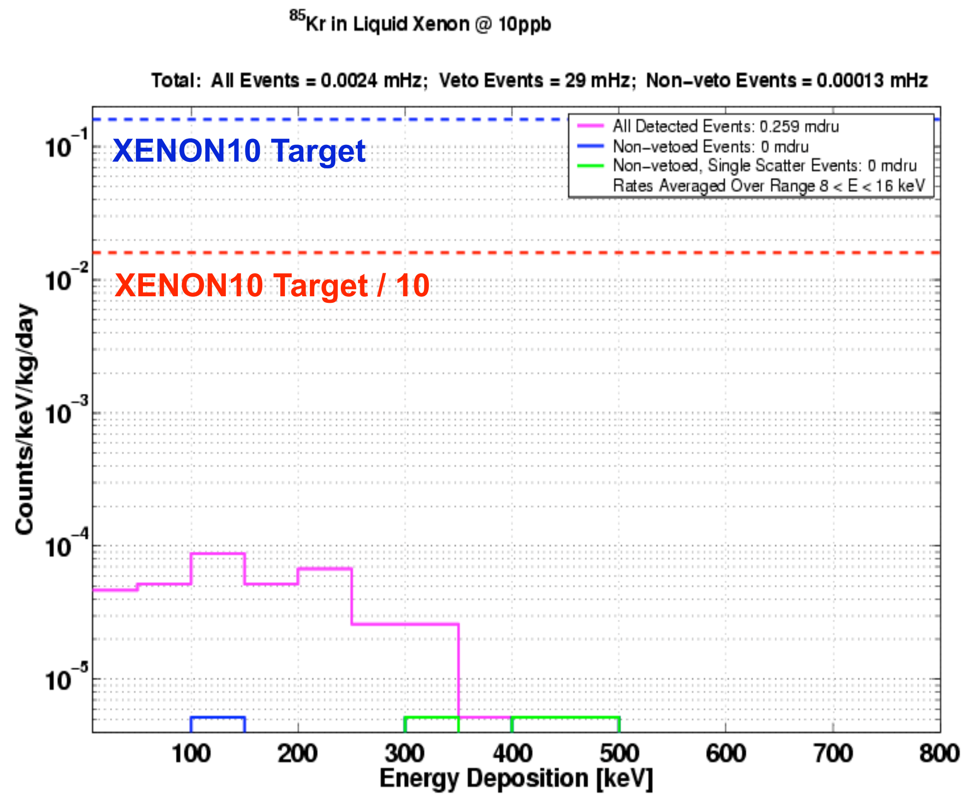
Liquid Xe Intrisic Background – ^{85}Kr

- ^{85}Kr contamination in Xenon – β decay (Q~687 keV)
  - Commercially Grade Purification Methods reach *10ppb* contamination
  - Required concentration to achieve XENON10 goal: < ~*1 ppb*
  - ^{85}Kr events in LXe Veto Region – minimal contribution to events in inner LXe

Anti-Coin., Single Scatter Inner Events due to ^{85}Kr Decays in Inner Chamber

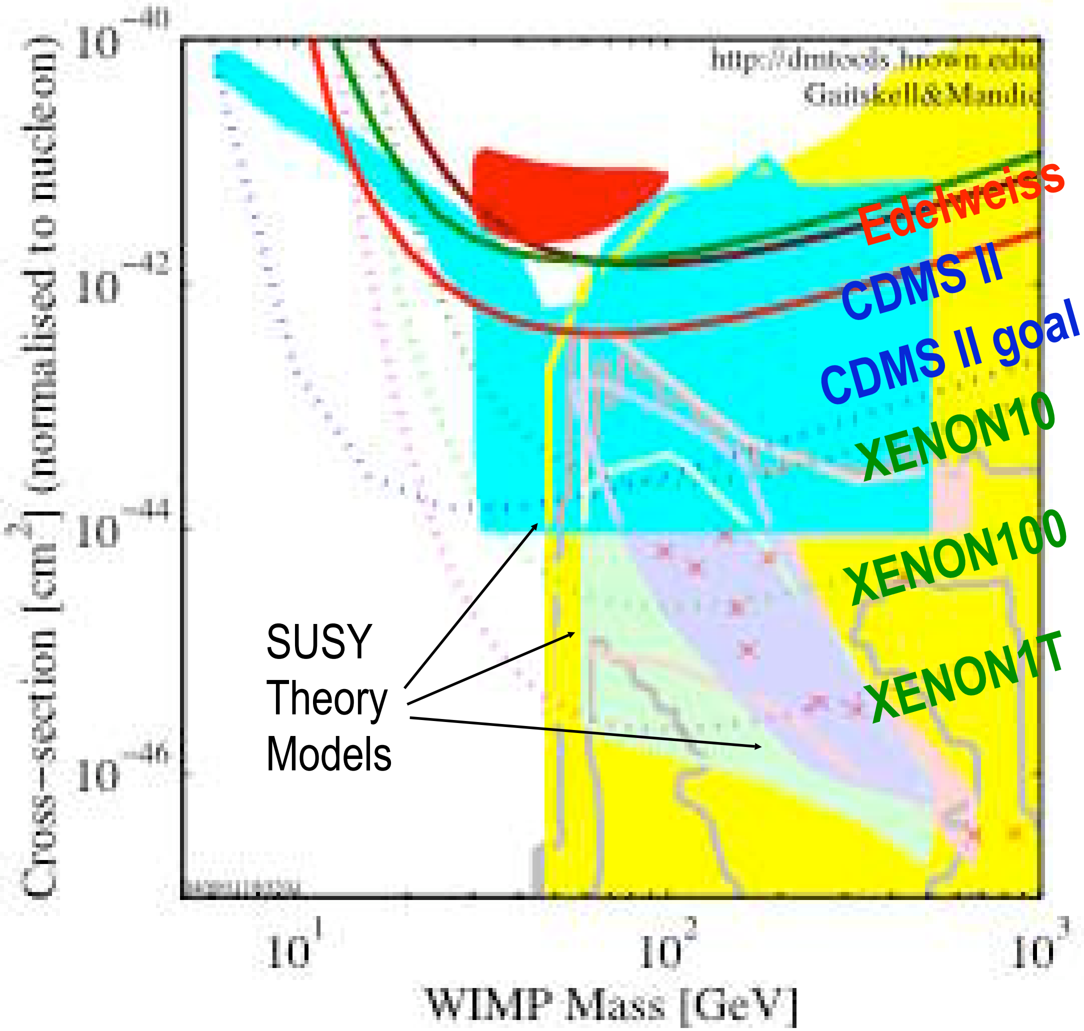


Events Detected in Inner Chamber due to ^{85}Kr Decays in Veto Region



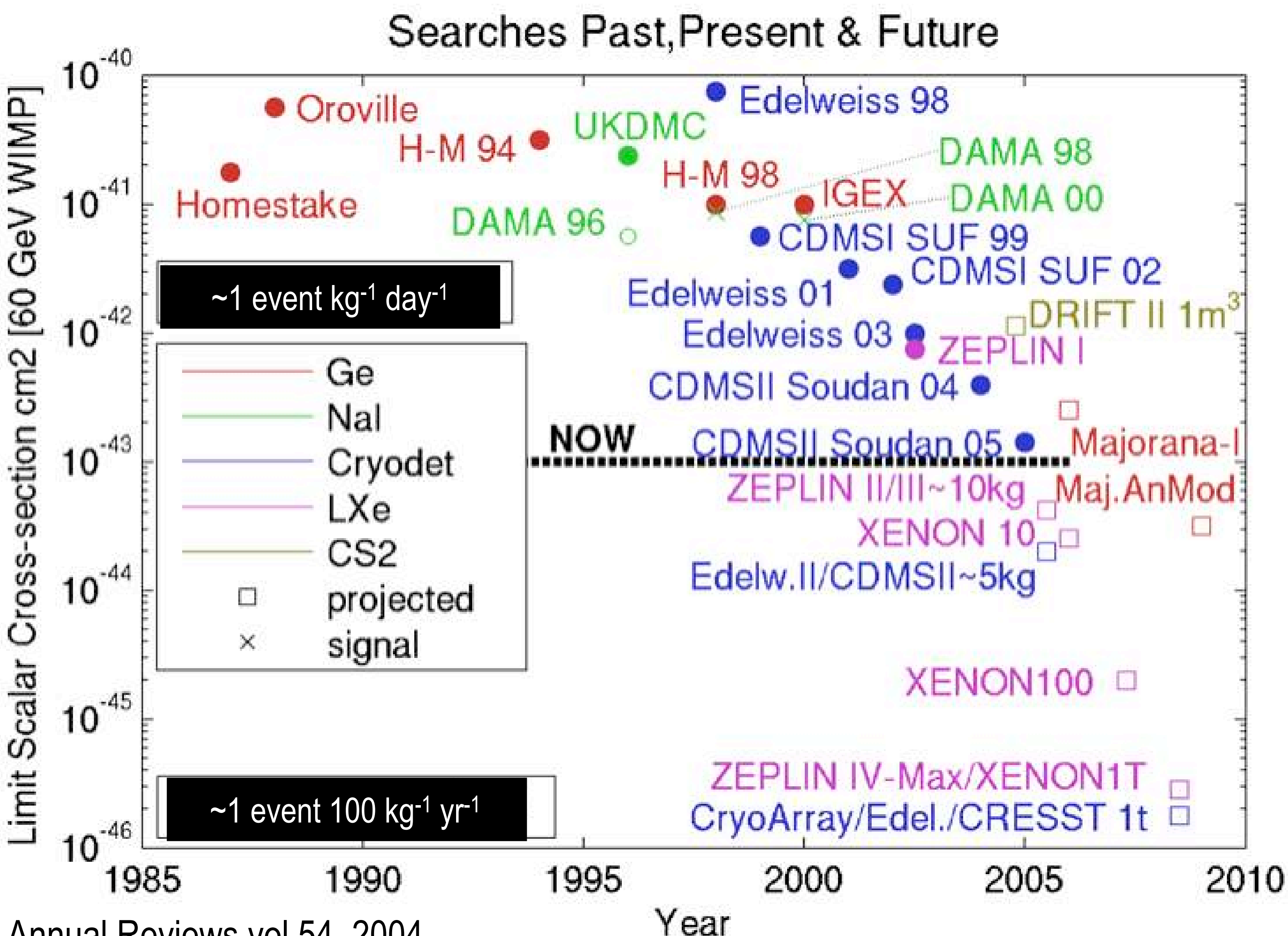
Dark Matter Goals

- Dark Matter Goals (labeled on figure)
  - XENON10 - Sensitivity curve corresponds to
    ~2 dm evts/10 kg/month
    - Equivalent CDMSII Goal for mass >100 GeV
      (Latest 2004 CDMSII result is x10 above this level)
    - With only 30 live-days x 10 kg fiducial - Zero events - would reach XENON10 sensitivity goal (90% CL), but we would like to do physics!
    - Important goal of XENON10 prototype underground is to establish clear performance of systems
  - XENON100 - Sensitivity curve corresponds to
    ~20 dm evts/100 kg/year
    - Background Simulations for XENON10 indicate it could reach b/g suppression necessary to reach this sensitivity limit (would require some modest upgrade), but with 10 kg target would only give ~2 dm evts/ 10kg/year - no physics.



Rick Gaitskell, Brown University

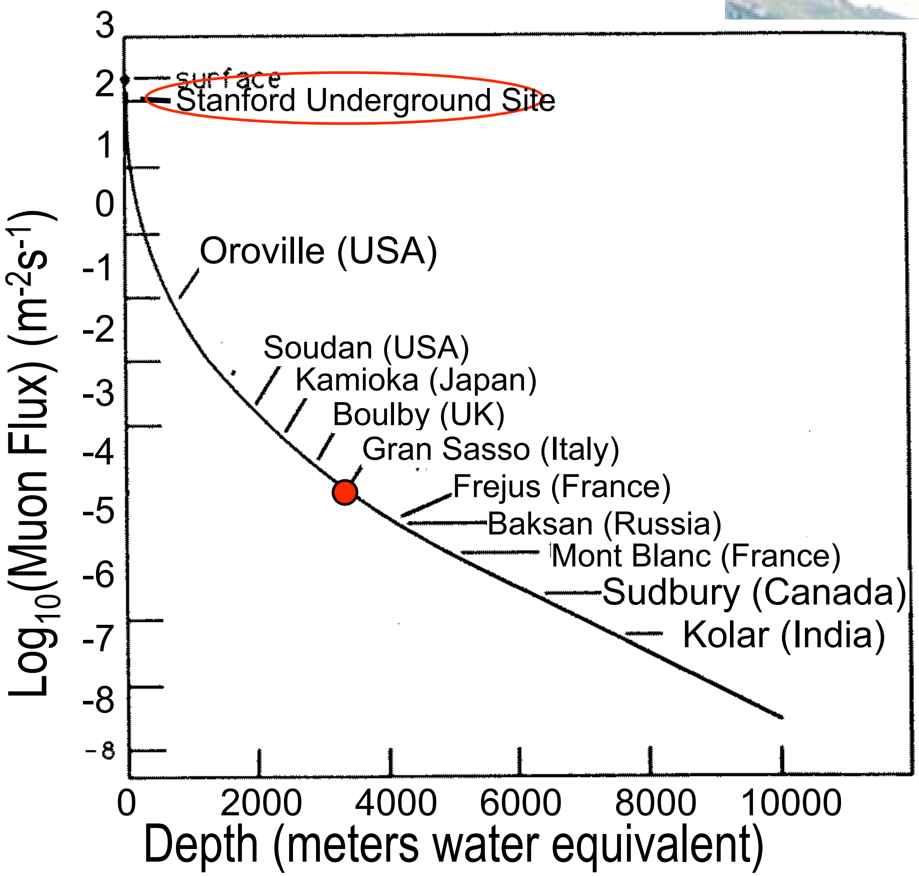
DM Direct Search Progress Over Time (2005)



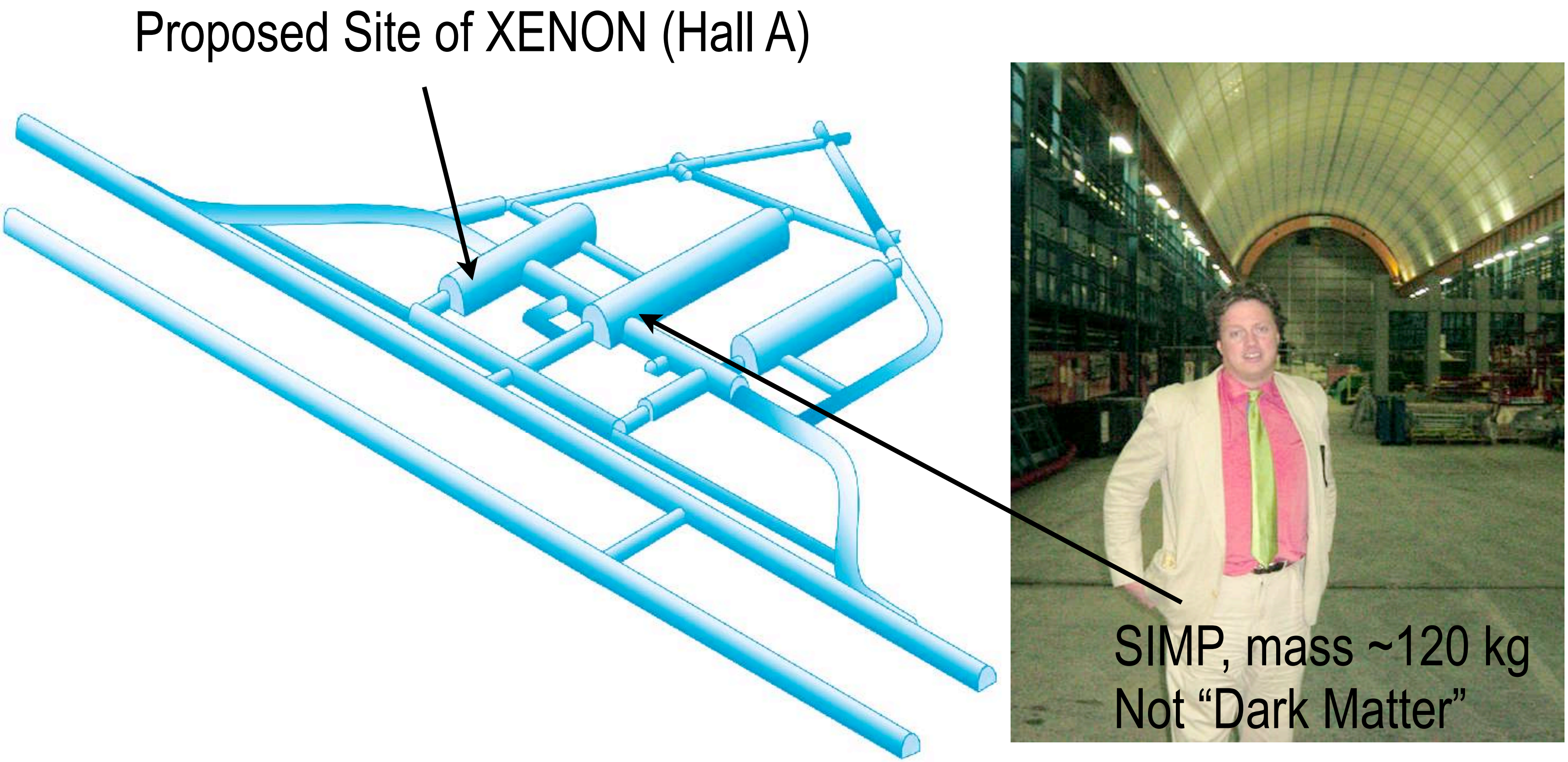
Gaitskell, Annual Reviews vol 54, 2004

XENON10 at LNGS: Gran Sasso National Laboratory

- Install Shield and Detector by end Fall 2005
- Stable Operation/Calibrations by Dec 2005
- Start physics run ~Jan 2006



XENON10 at LNGS: Gran Sasso National Laboratory



XENON Conclusions

- Demonstration Milestones - Acheived
  - Highlight: Electrons from Nuclear Recoils! over wide range of applied fields
- Starting infrastructure summer 2005, install detector Fall 2005
  - Funding from both NSF + DOE Now Established
- Goals
  - Physics: Target ~10 kg, ~5-10x better sensitivity than current CDMS limit, based on short run of a few months
  - Demonstrate operation in low bg environment
    - Clearly establish how well electron recoil rejection performs
    - Refine understanding of dominant contributions to bg
  - Establish dominant effects that limit sensitivity
    - Improvements for larger 100 kg system
- Design “Converging” following tests - Main Points
  - Top + Bottom PMTs (rather than CsI - successfully tested by is inherently unstable due to light feedback) to reduce operations risk
  - Drift ~15 cm @ 3kV/cm --> ~50 kV high voltage systems
    - Using 150 kV designs for feed throughs to test feasibility of larger det.
  - Conventional Shield Design Pb/Poly (no muon veto, will not limit detector at GS for first 10 & 100 kg instruments, given 30 cm poly)

Results from the Cryogenic Dark Matter Search

Review of results from first run
New, preliminary results from second run and beyond

Rick Gaitskell, Brown,
with big thanks to Richard Schnee,
CWRU

CDMS II Collaboration

Brown University
M.J. Attisha, **R.J. Gaitskell**, J-P. F. Thompson

Case Western Reserve University
D.S. Akerib, C. Bailey, P. Brusov, M.R. Dragowsky, D.D.Driscoll, D. Grant, R. Hennings-Yeomans, S.Kamat, T.A. Perera, R.W.Schnee, G.Wang

Fermi National Accelerator Laboratory
D.A. Bauer, M.B. Crisler, R. Dixon, D. Holmgren, E.Ramberg, J. Yoo

Lawrence Berkeley National Laboratory
R. McDonald, R.R. Ross, A. Smith

National Institute for Standards and Technology
K. Irwin

Santa Clara University
B.A. Young

Cryogenic
Dark
Matter
Search

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University of California, Berkeley
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University of California, Santa Barbara
R. Bunker, D.O. Caldwell, R. Ferril, R. Mahapatra, **H. Nelson**, J. Sander,

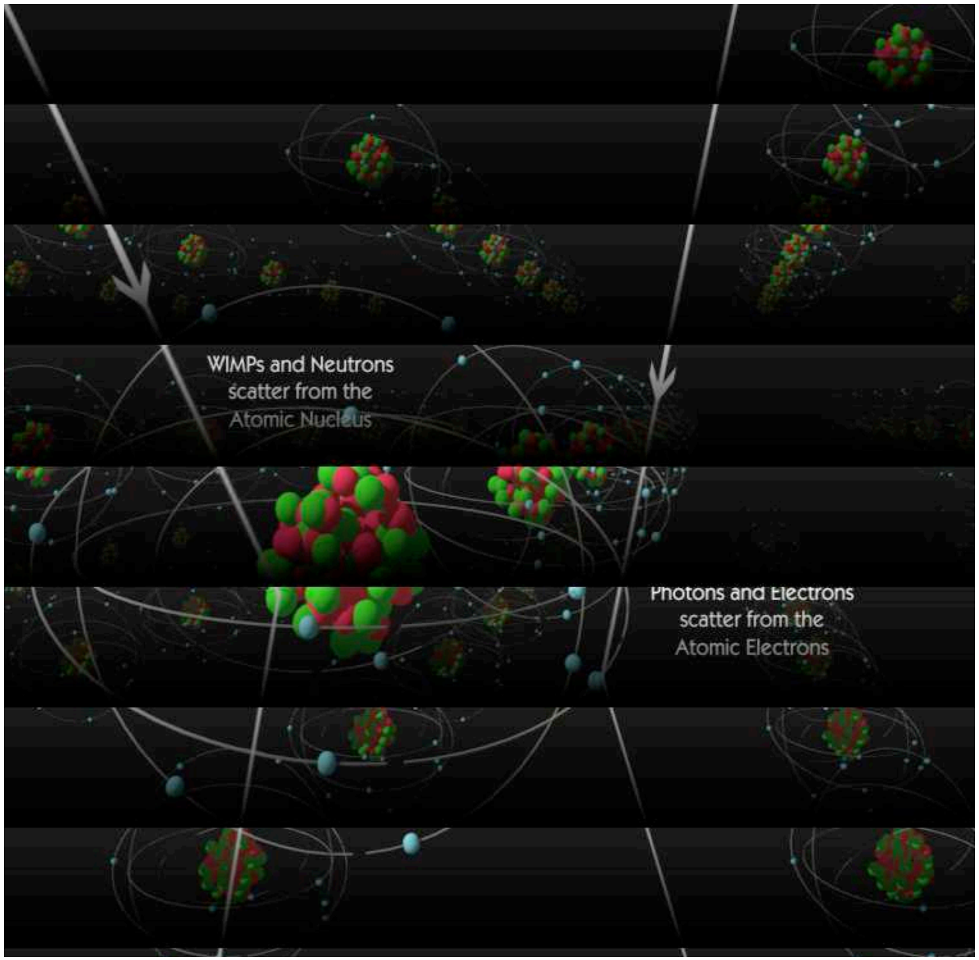
University of Colorado at Denver and Health Sciences Center
M. E. Huber

University of Florida
L. Baudis, S. Leclercq

University of Minnesota
P. Cushman, L. Duong, A. Reisetter

CDMS Collaboration (Mar. 2002)

Sources of Background



Detectors must effectively discriminate between

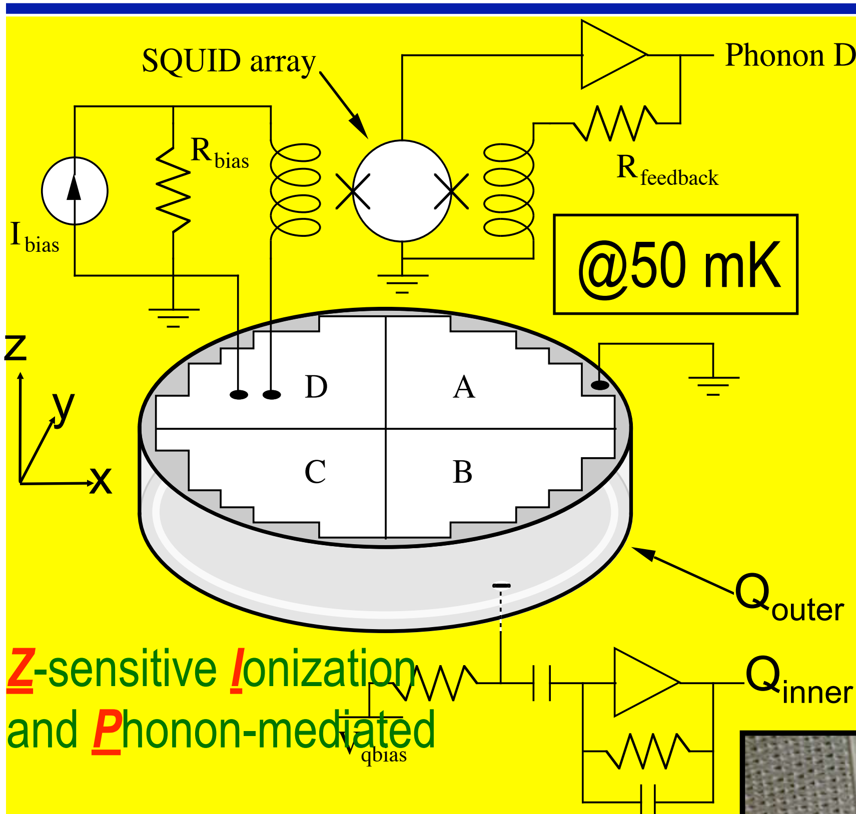
Nuclear Recoils (Neutrons, WIMPs)

Electron Recoils (gammas, betas)

Use Ge and Si based detectors with two-fold interaction signature:

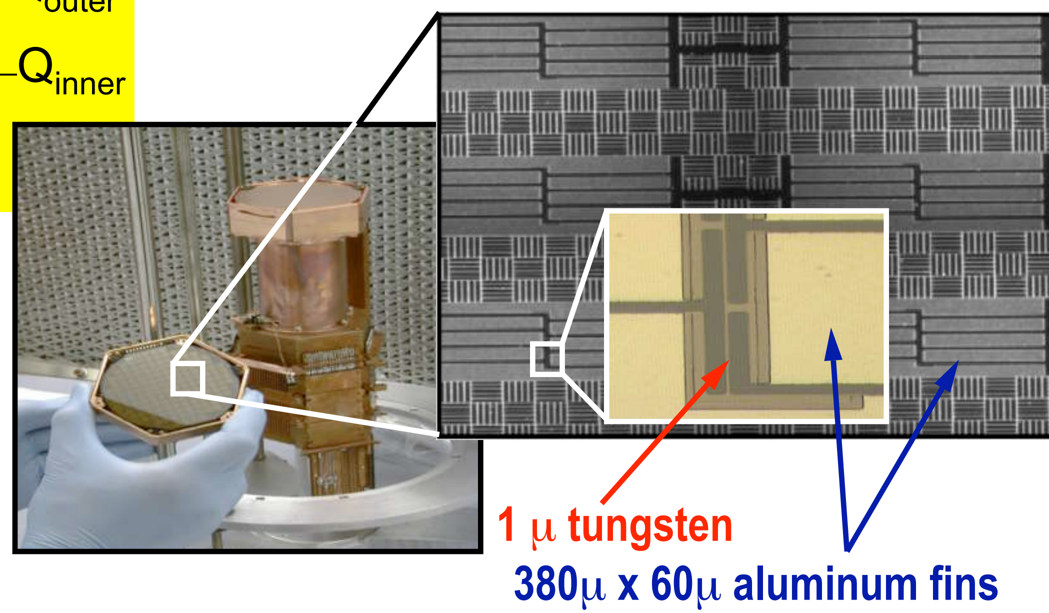
- Ionization signal
- Athermal phonon signal

Really Cool Detectors: ZIPs



- •250 g Ge or 100 g Si crystal
- •1 cm thick x 7.5 cm diameter
- •Photolithographic patterning
- •Collect athermal phonons:
  - XY position imaging
  - Surface (Z) event veto based on pulse shapes and timing

Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer edge



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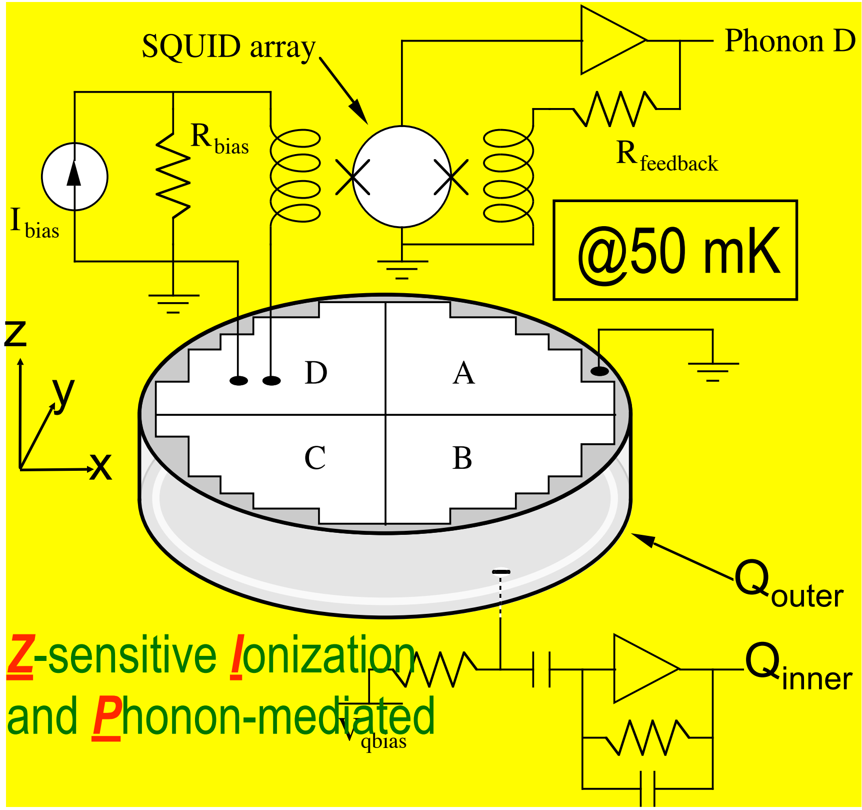

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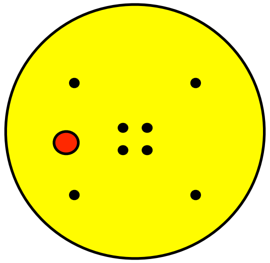
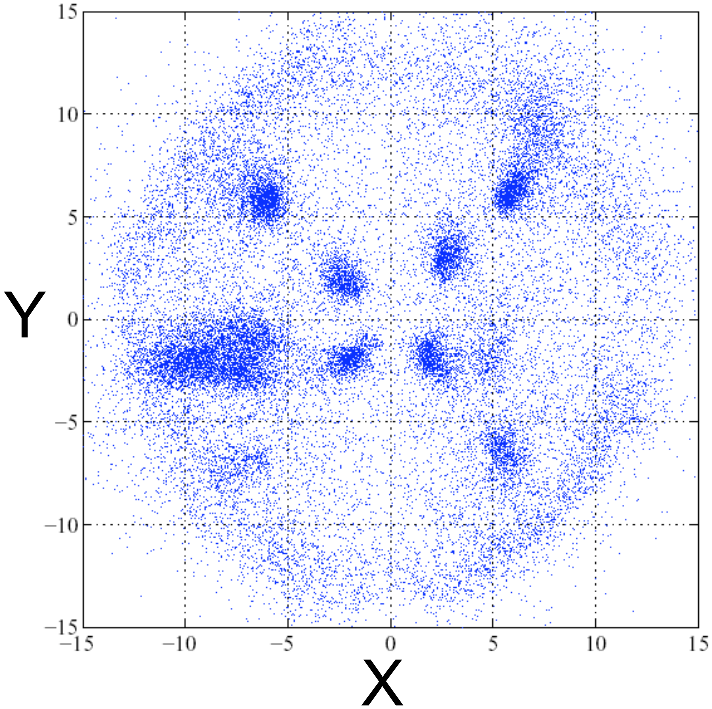
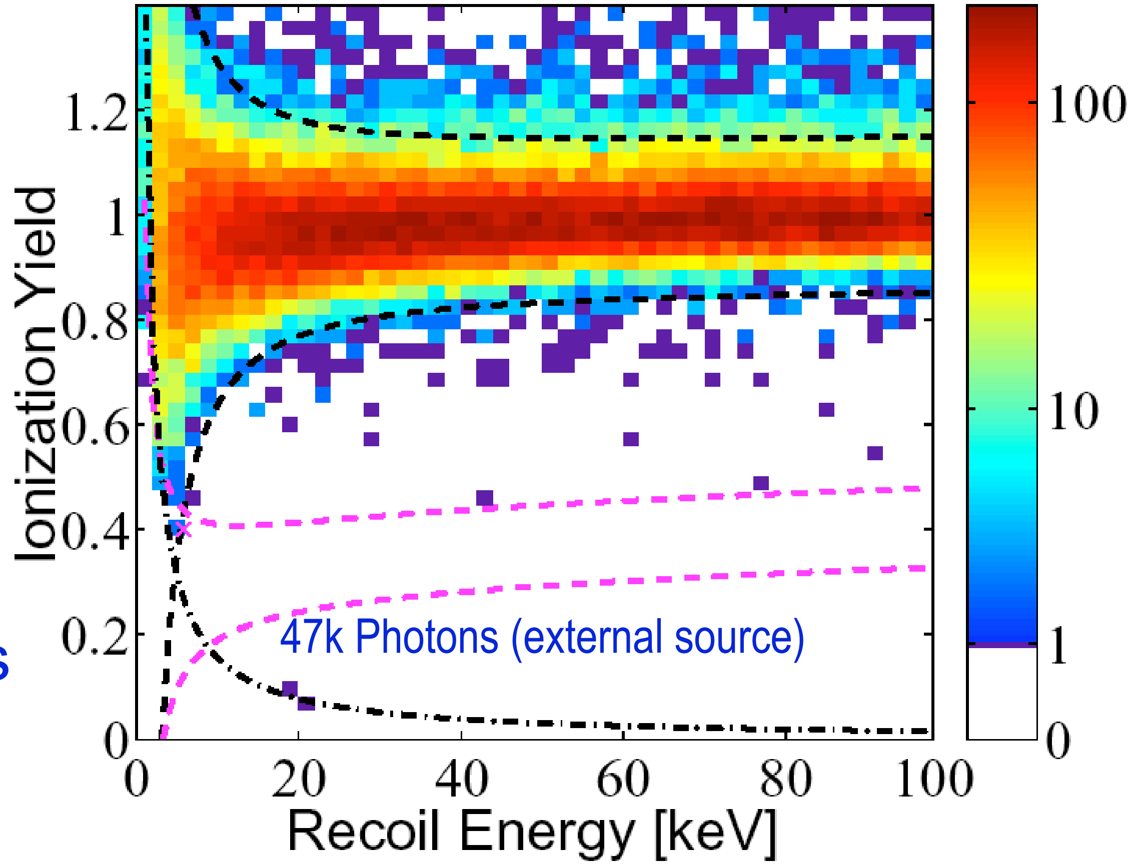




CDMS II Background Discrimination

- Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil
- Most background sources (photons, electrons, alphas) produce electron recoils



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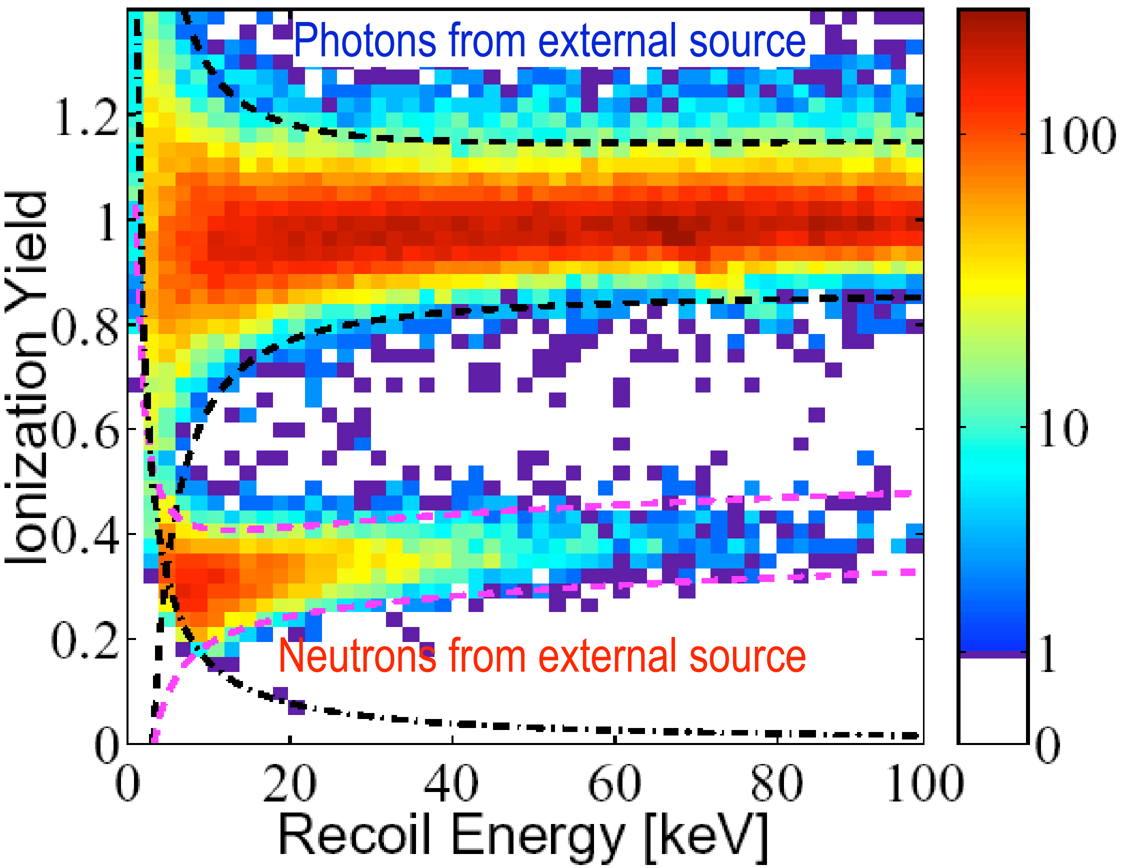

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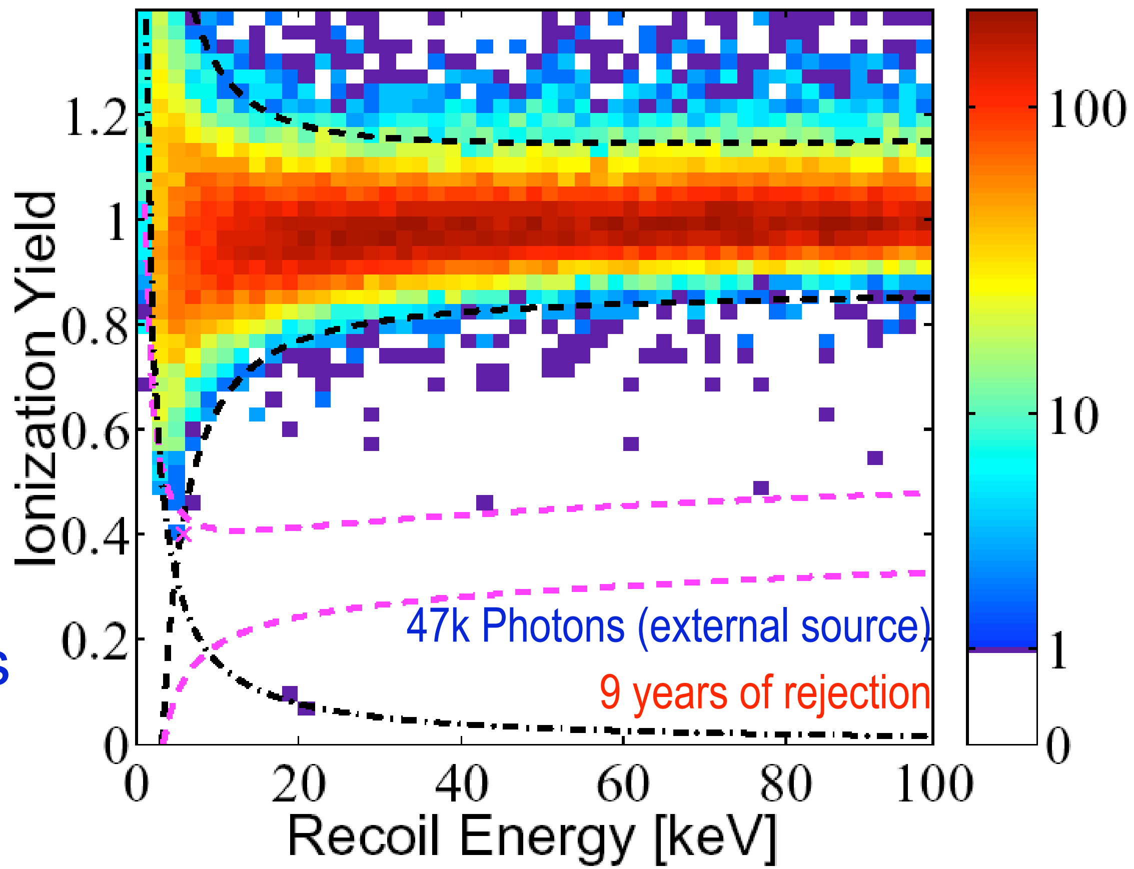

- Detectors provide near-perfect event-by-event discrimination against otherwise dominant bulk electron-recoil backgrounds

CDMS II Background Discrimination

•Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil

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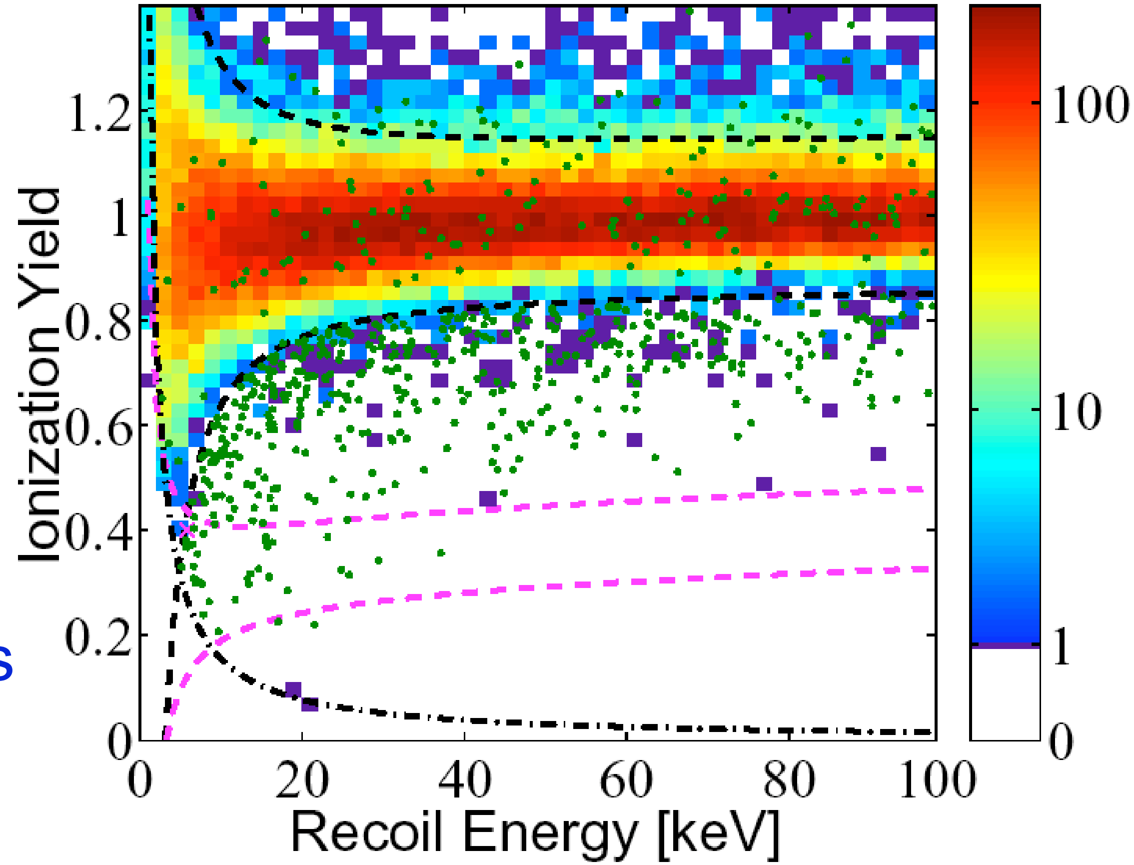
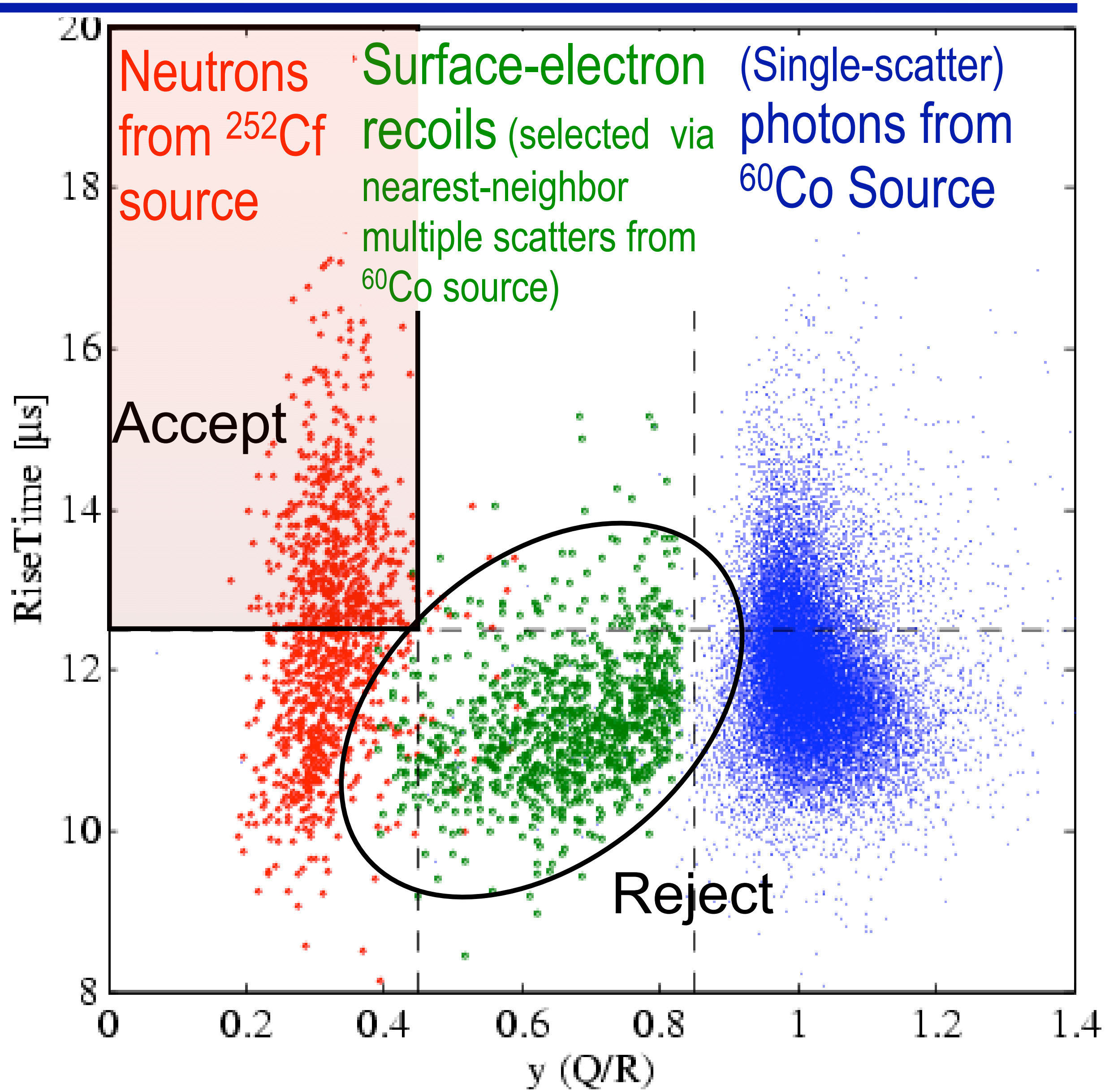


•Detectors provide near-perfect event-by-event discrimination against otherwise dominant bulk electron-recoil backgrounds

•Particles (electrons) that interact in surface “dead layer” of detector result in reduced ionization yield

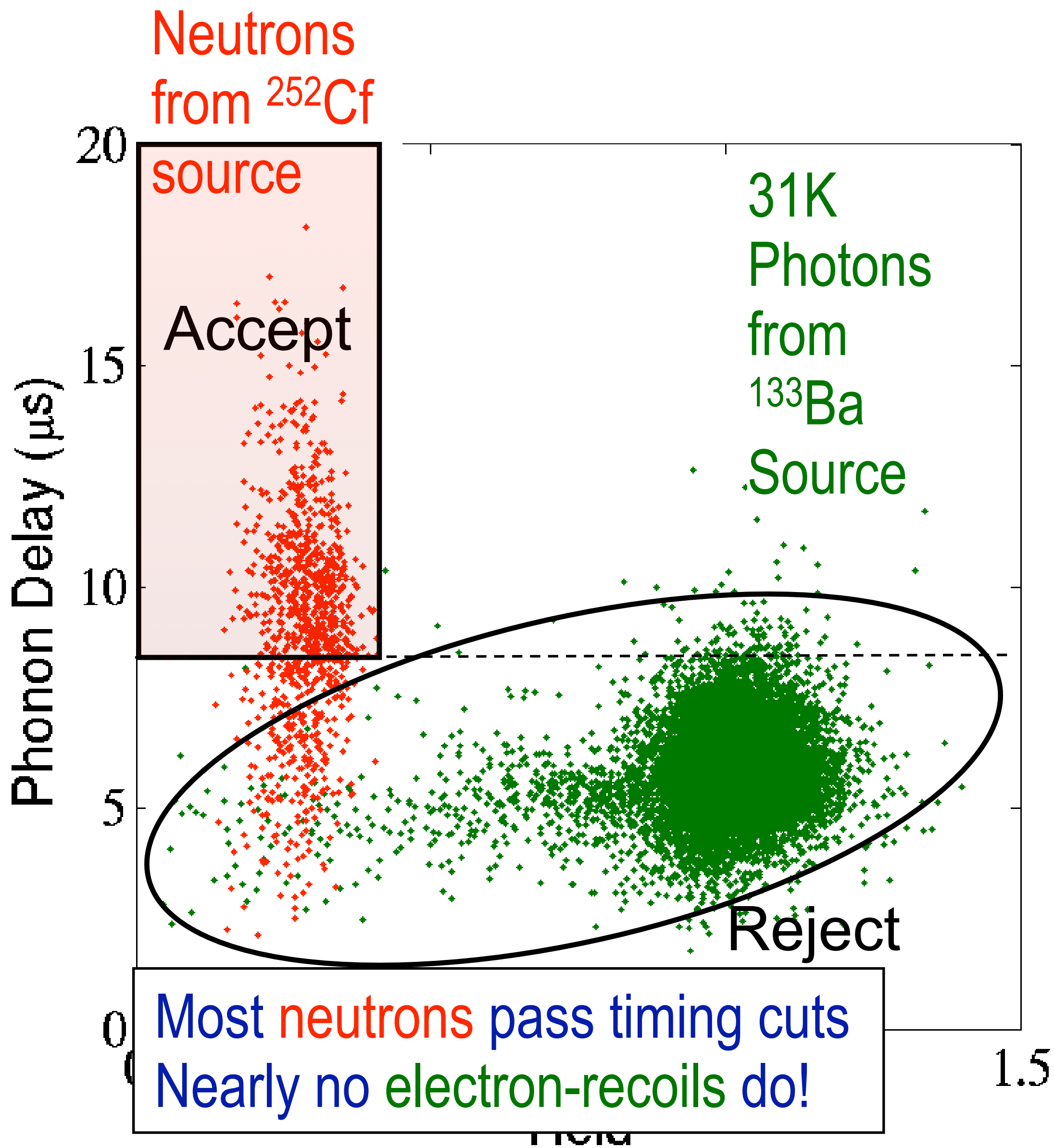
ZIP Z-Position Sensitivity Rejects Electrons

- Cut based on phonon-pulse risetime eliminates the otherwise troublesome background surface events
- >99% above 10 keV



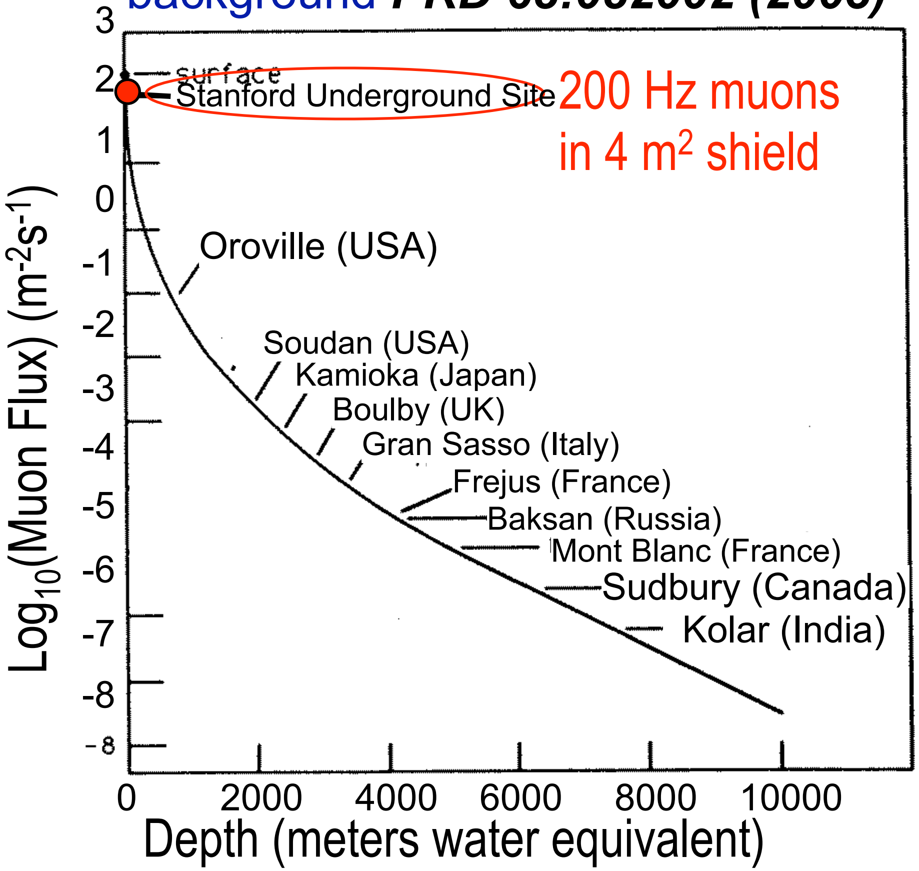
More ZIP Z-Position Sensitivity

- We are only beginning to take full advantage of the information from the athermal phonon sensors!
    - Improving modeling of phonon physics
    - Extracting better discrimination parameters (timing and energy partition)
- Towards a full event reconstruction, near-perfect rejection of surface events



CDMS II at Stanford and at Soudan

- 2001-2002 run at shallow site
  - 28 kg day exposure of 4x 250g Ge detectors (and 2x 100g Si detectors)
  - 20 nuclear-recoil candidates consistent with expected neutron background ***PRD 68:082002 (2003)***



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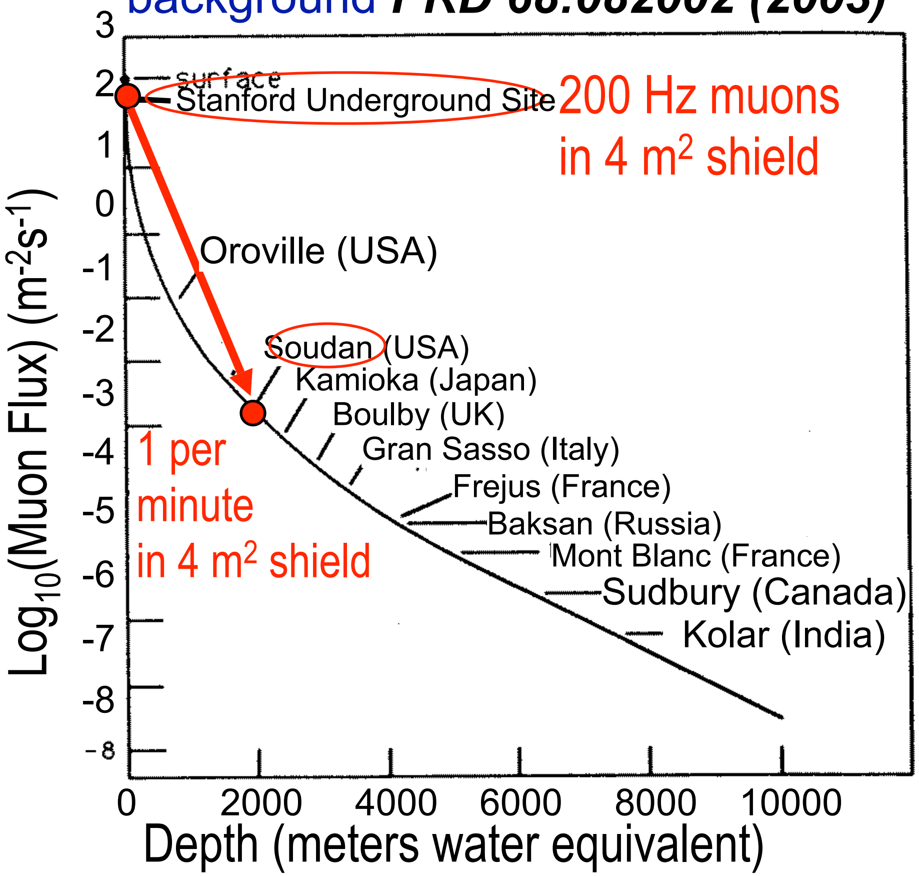
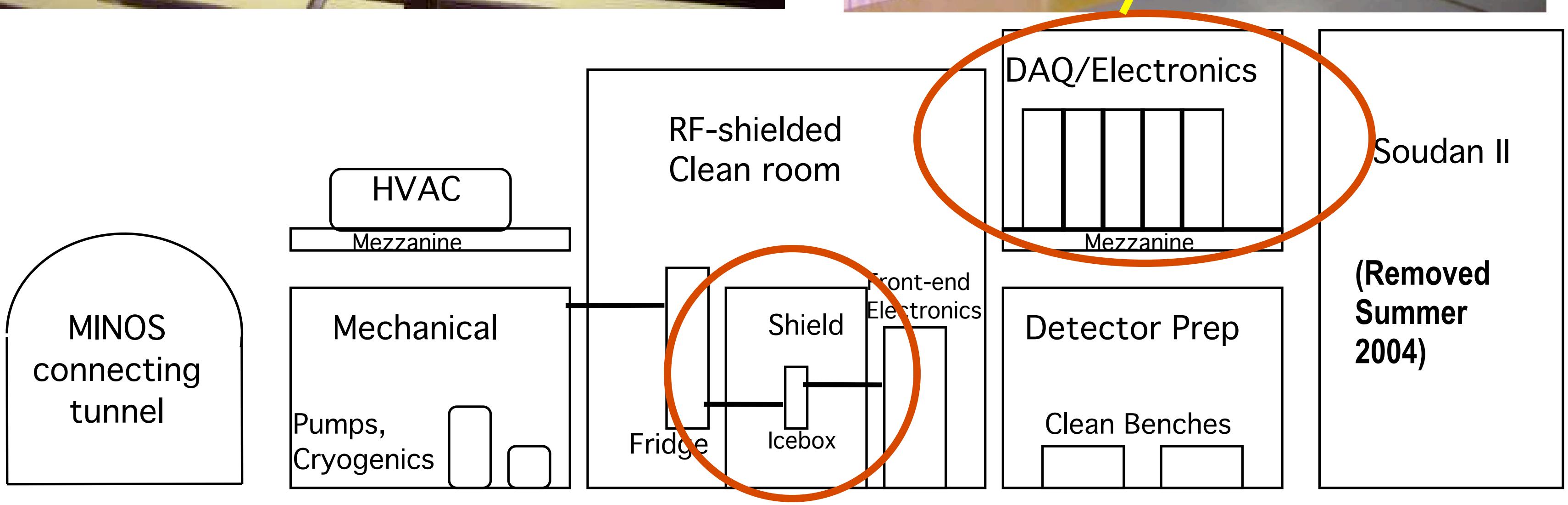


- 2003-2005 in Soudan Mine, Minn.
  - Depth 713 m (2090 mwe)
  - Reduce neutron background from ~1 / kg / day to ~1 / kg / year

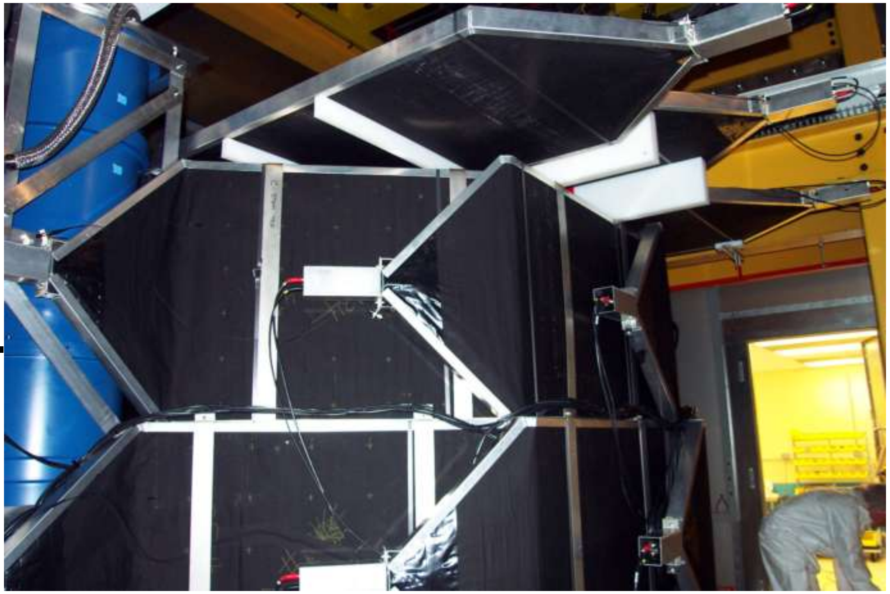
Rick Gaitskell

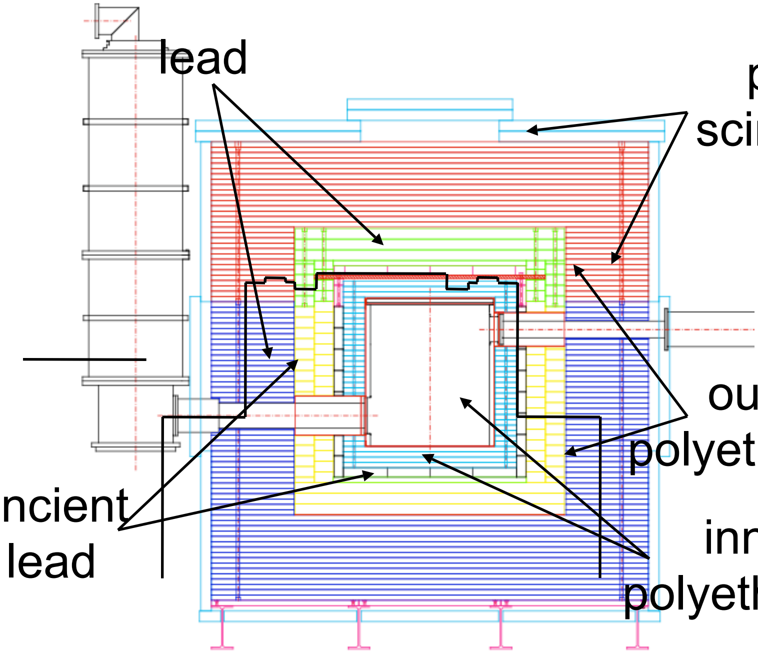
Experimental Setup in the Soudan Mine



Shielding from Backgrounds at Soudan

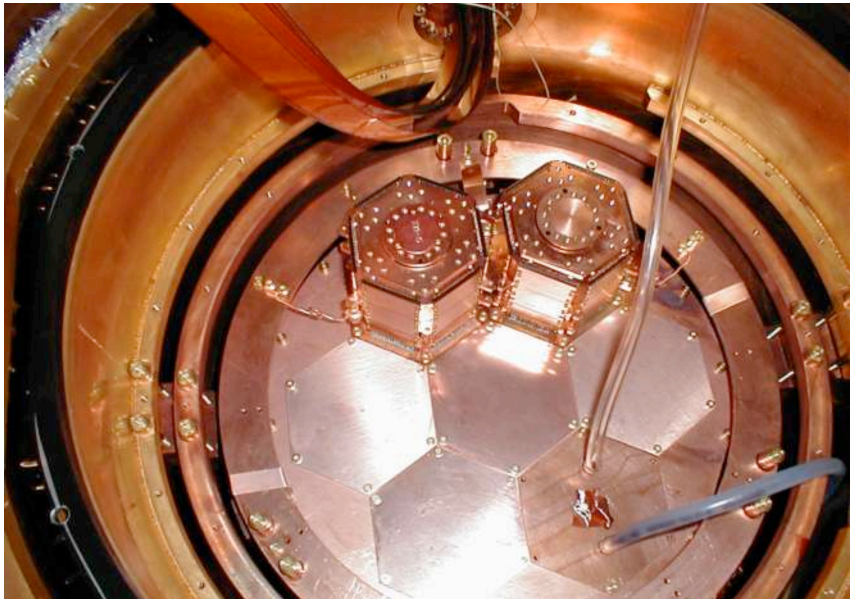
- Active scintillator veto, polyethylene and lead shielding, and radon purge reduce backgrounds from muons, neutrons and photons.

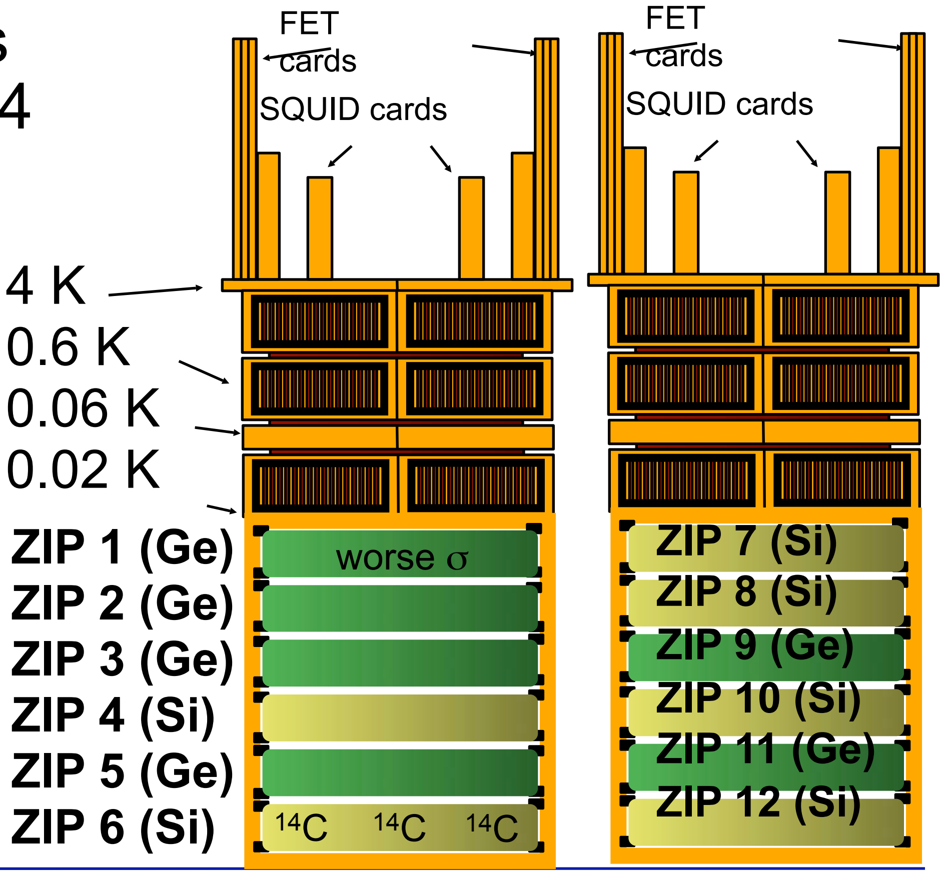




First Year of Running CDMS II at Soudan

- Installed two towers of 6 detectors each in 2003
- Ran "Tower 1" October 2003- January 2004
  - Same 4 Ge (1 kg) and 2 Si (0.2 kg) ZIPs run at Stanford
  - Results announced at last year's APS
- Ran 12 detectors in 2 towers from 25 March- 8 August 2004
  - New results today





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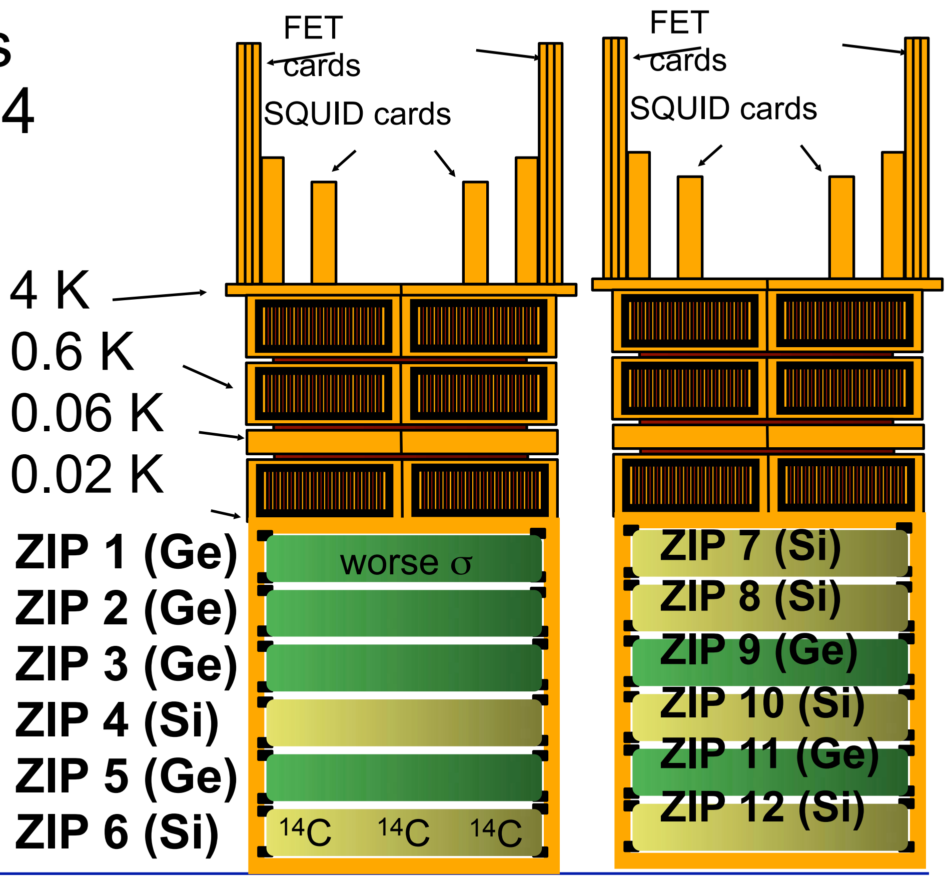
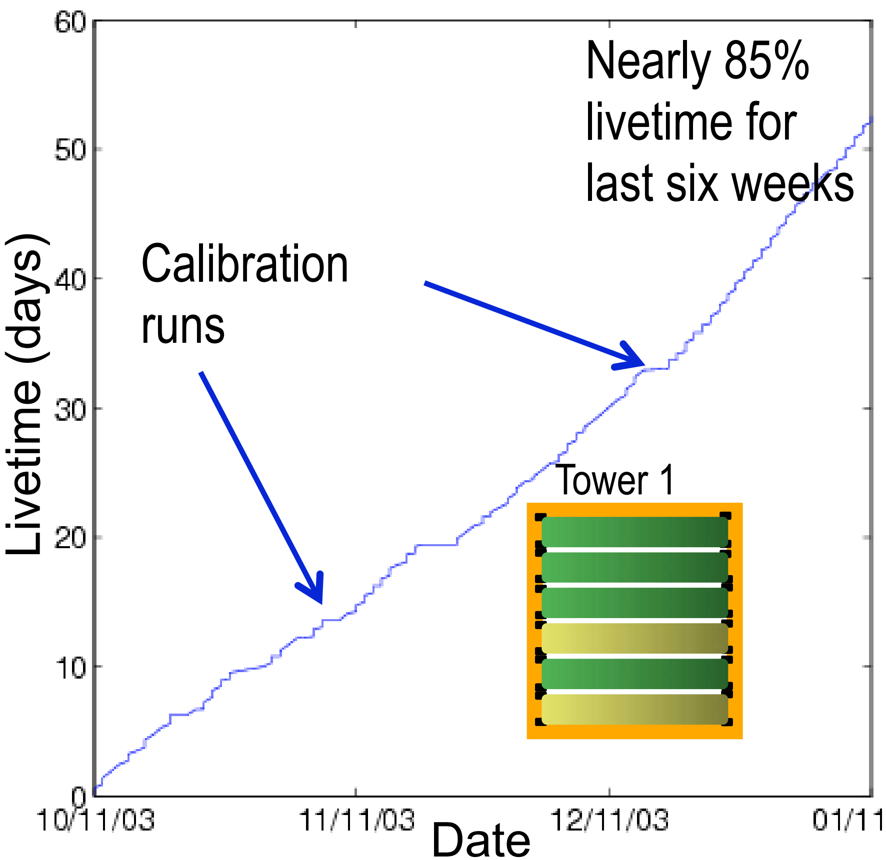
  - Results announced at last year's APS
- Ran 12 detectors in 2 towers from 25 March- 8 August 2004
  - New results today
  - Ge more sensitive to WIMPs since $\sigma_{n\chi} \propto A^2$
  - Si more sensitive to neutrons
  - Si sensitive to lower-mass WIMP
- I will discuss only results from the Ge detectors today

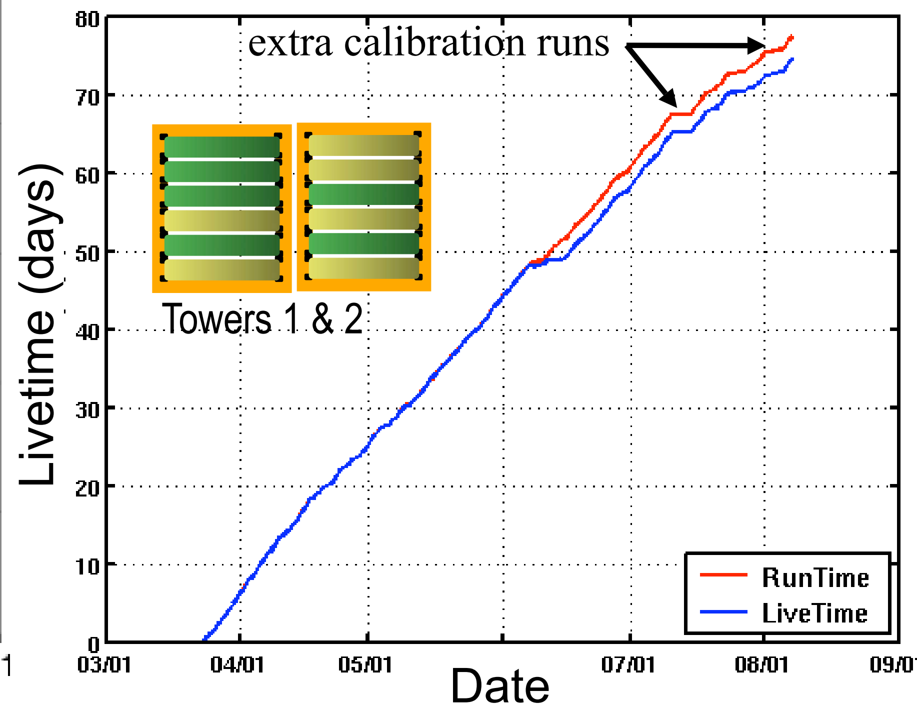


First Year of Running CDMS II at Soudan

- October 2003- January 2004 run of “Tower 1”
  - 62 “raw” livedays, 53 livedays after cutting times of poor noise, etc.



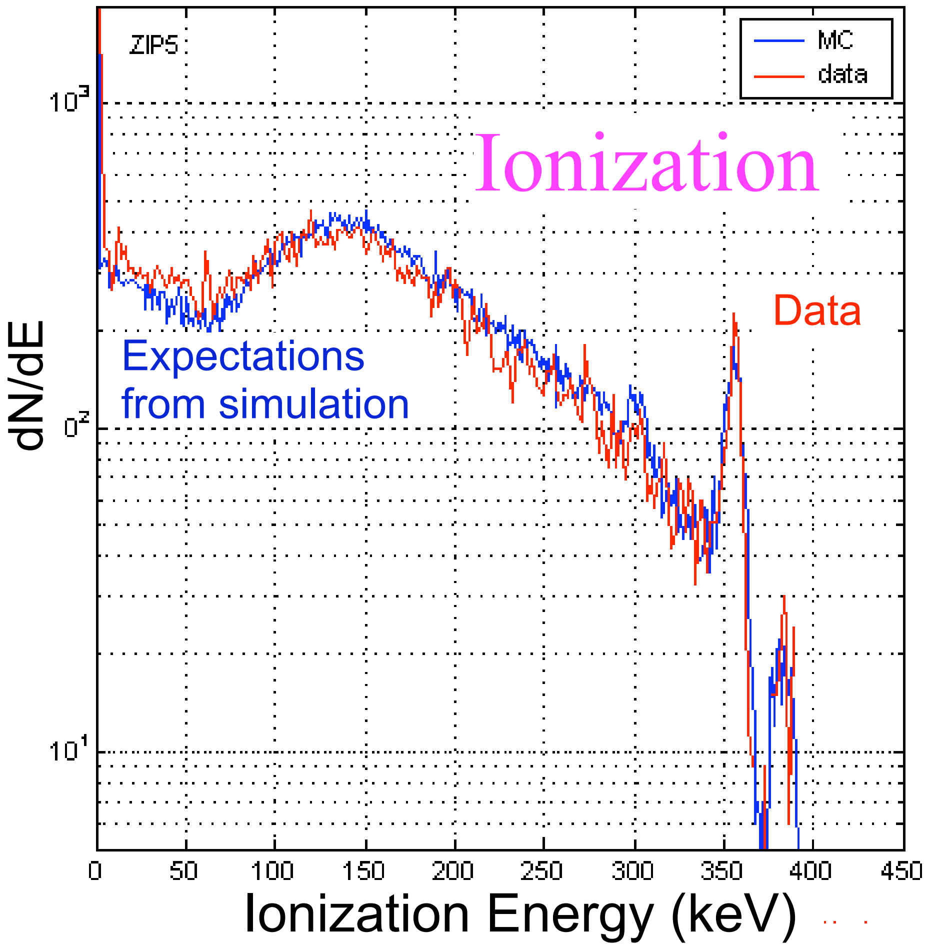
- March-August 2004 “The Two Towers”
  - 1.5 kg of Ge, 0.6 kg of Si
  - 76 “raw” livedays, 74 livedays
  - Nearly doubled exposure, expected sensitivity, and calibration data

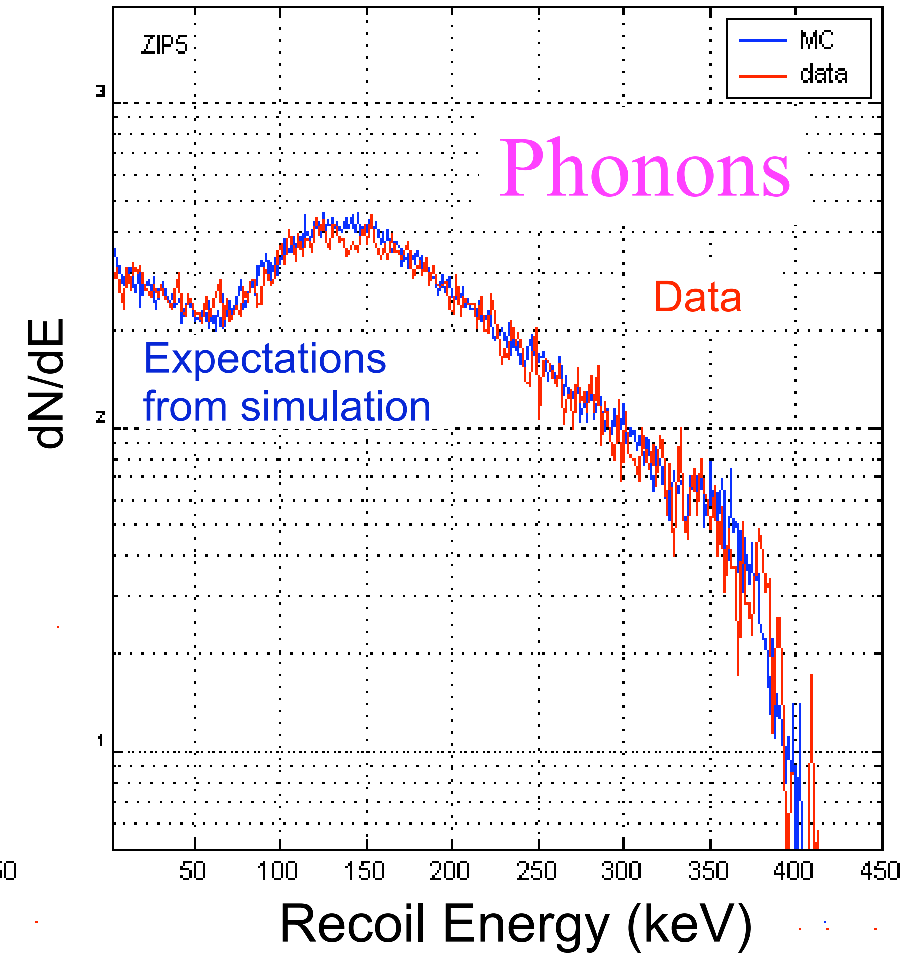


In Situ Photon Calibration with ^{133}Barium

- Calibrate position dependence of detector response

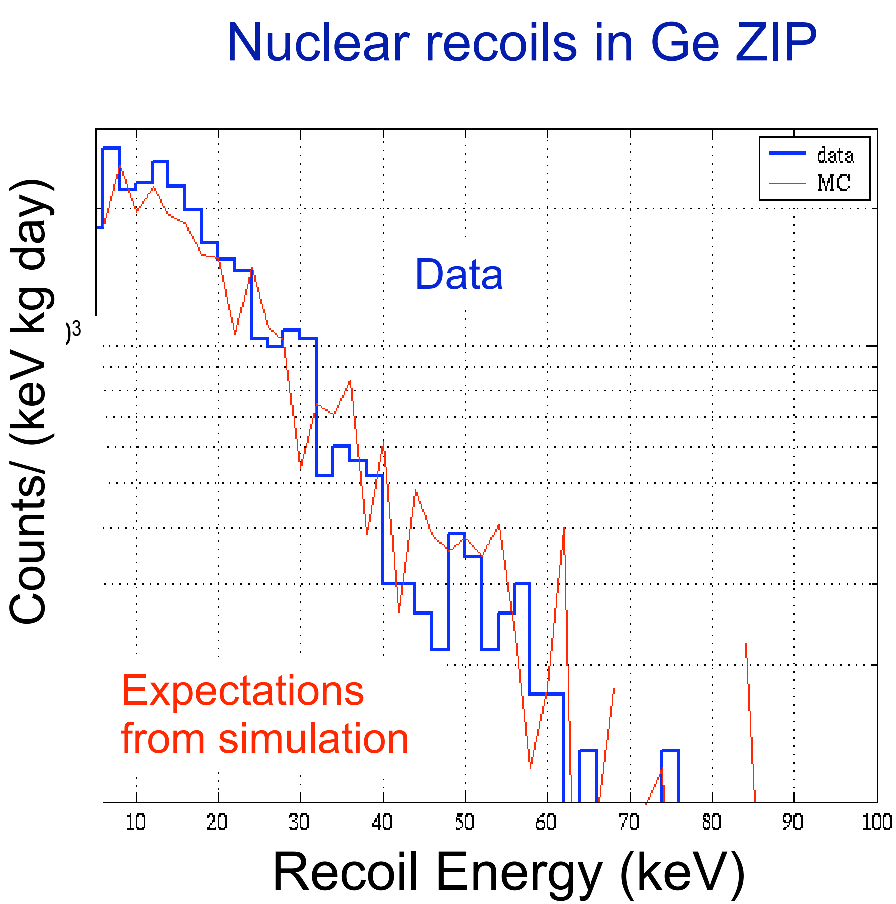
See R.W. Ogburn, session K9

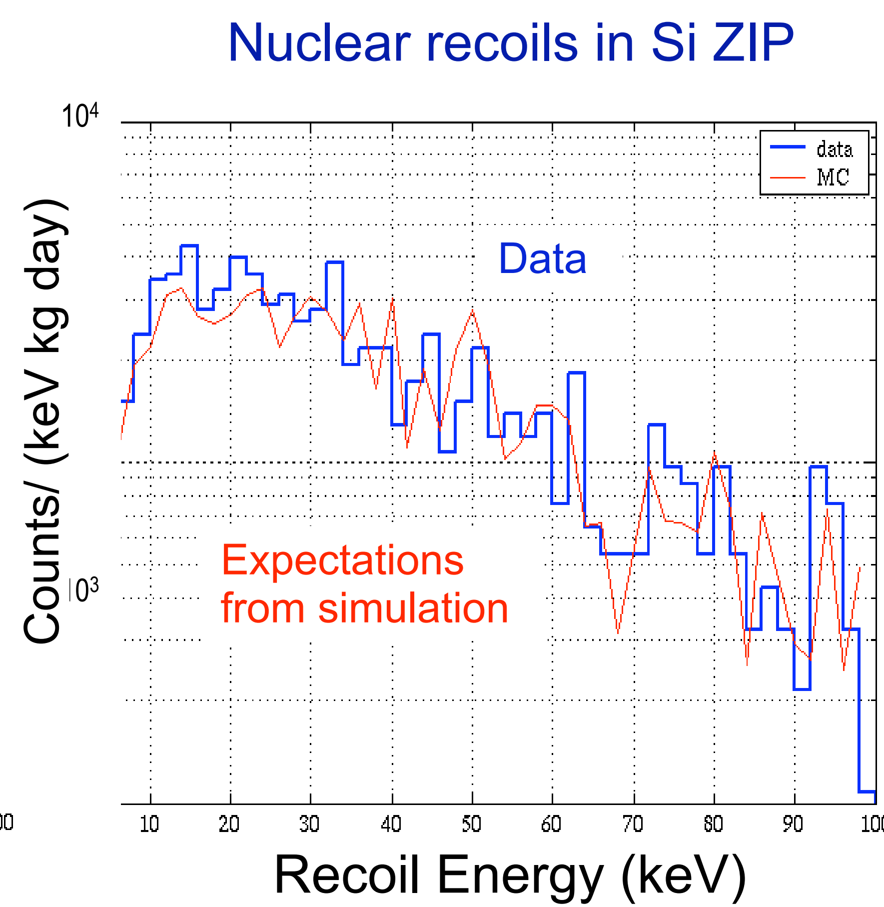




L. Baudis

In Situ Nuclear-recoil calibration with ^{252}Cf





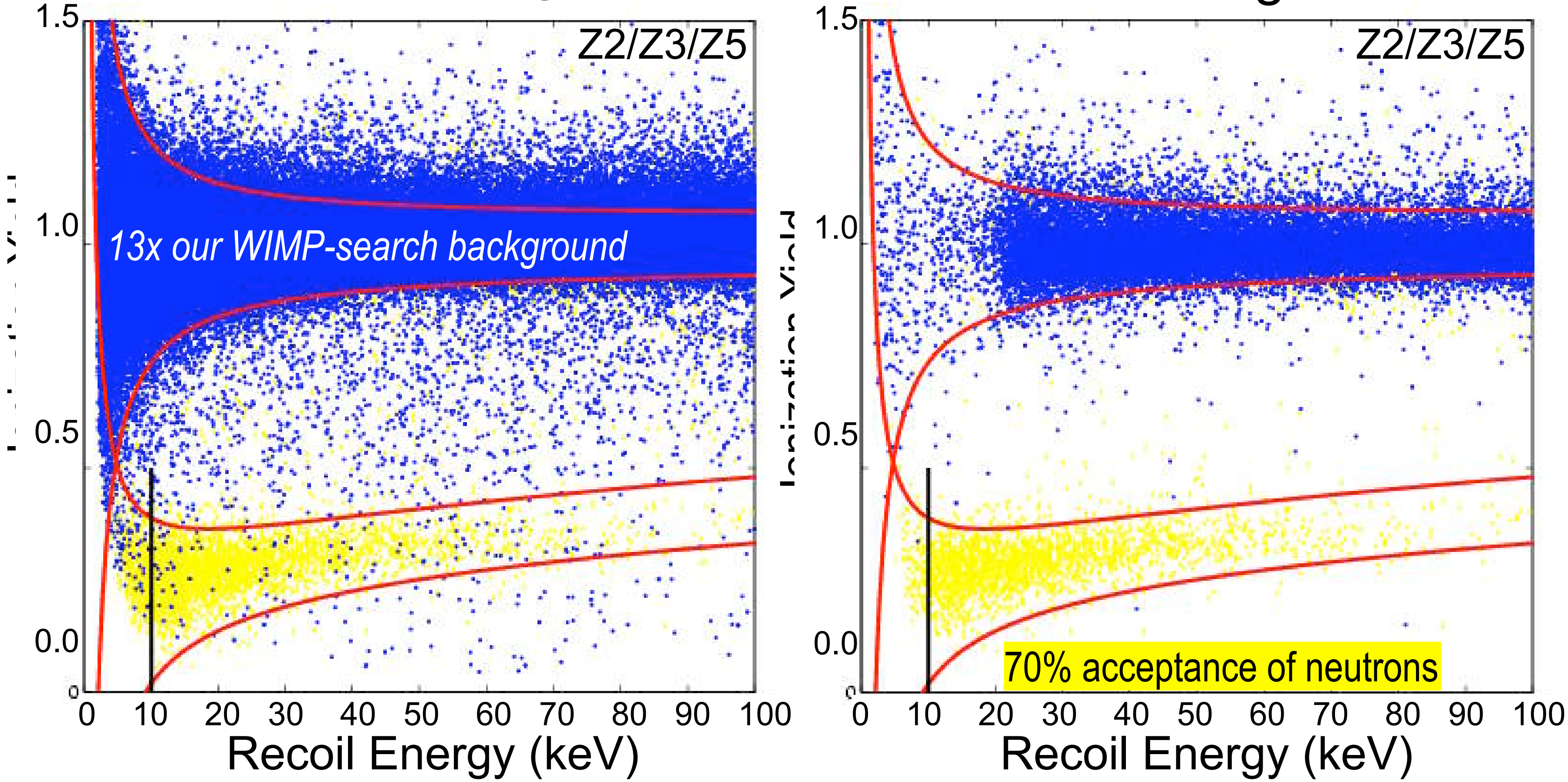
Excellent agreement between data and Monte Carlo
⇒Understand cut efficiencies

S. Kamat

In Situ Calibrations for Setting Cuts "Blind"

First run's calibration data, prior to timing cuts

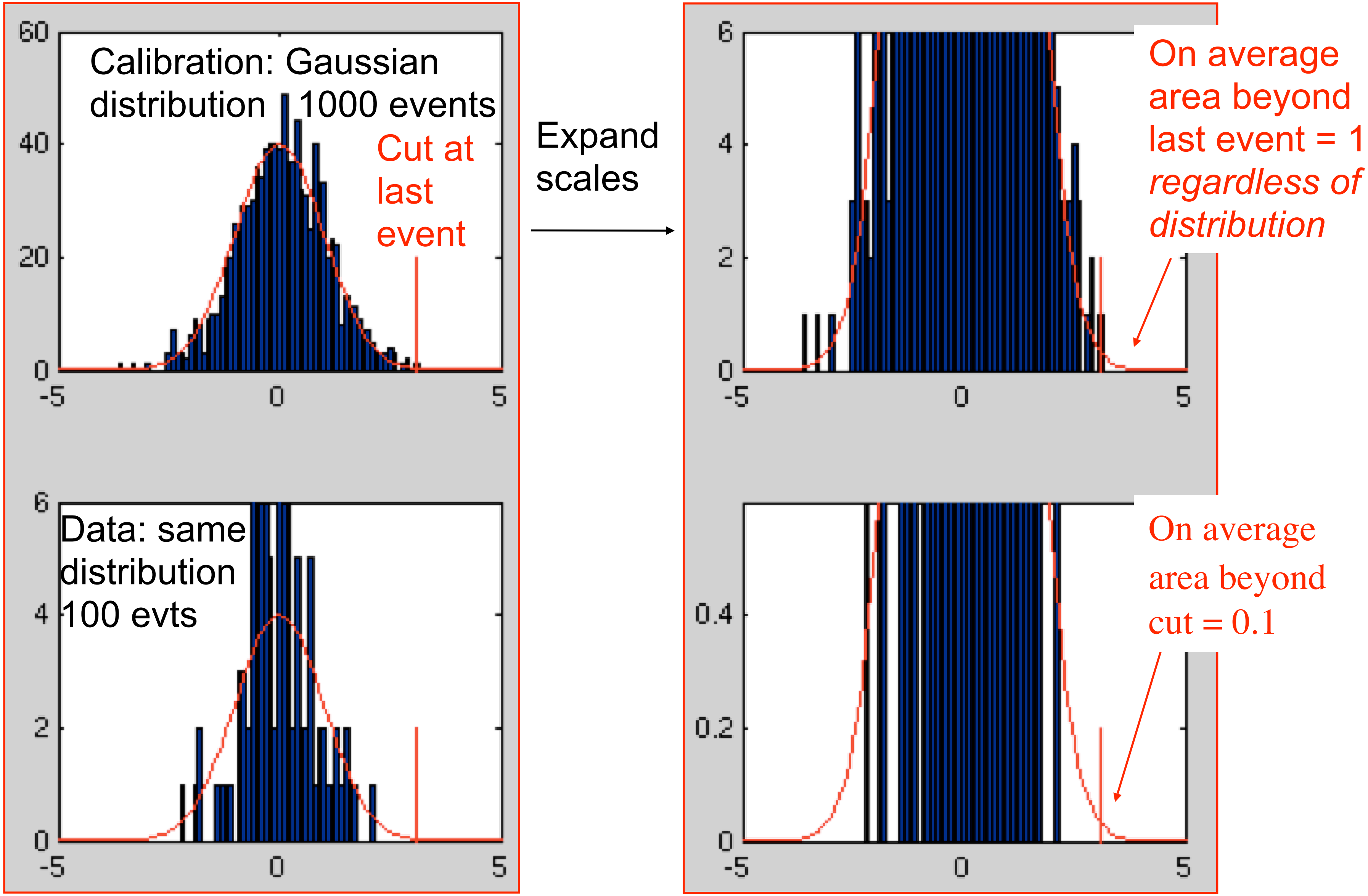
After timing cuts, set to reject all electron recoils in signal band



Blue points: electron recoils induced by a ^{133}Ba γ source

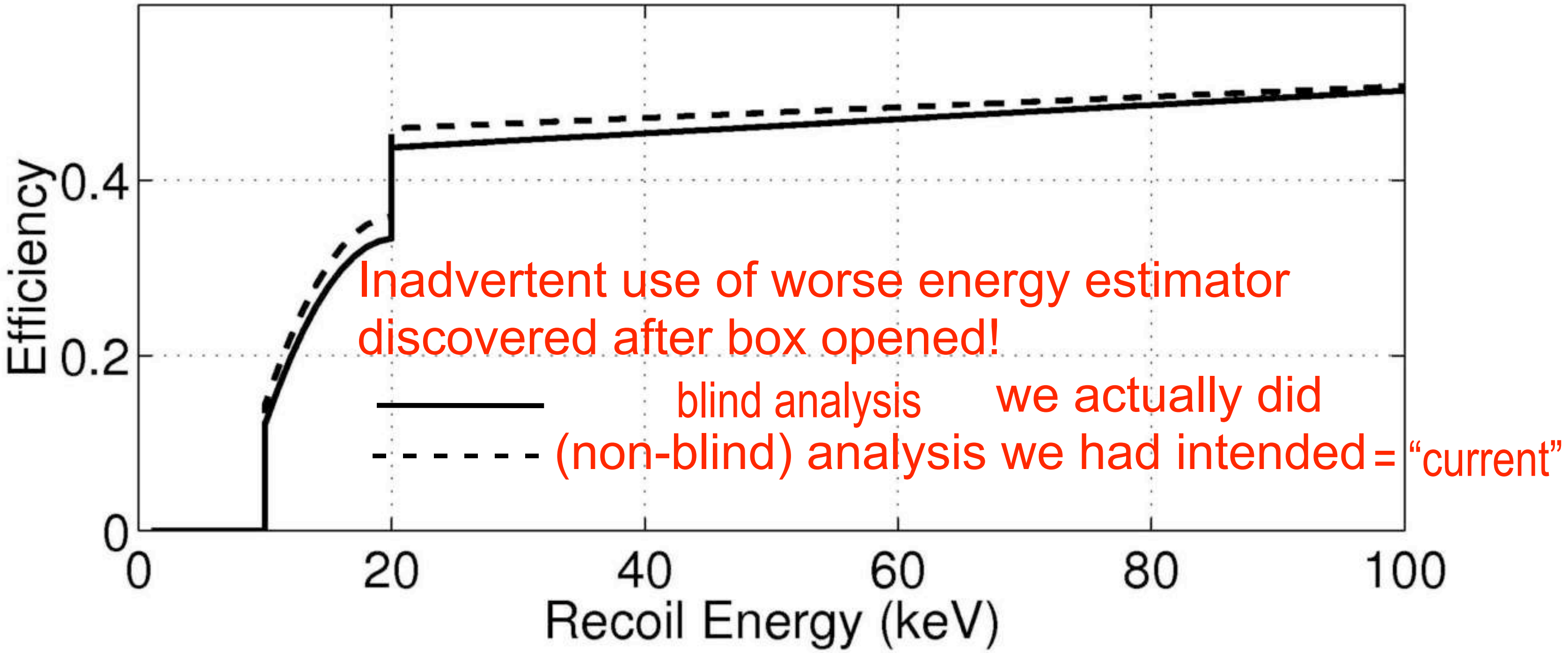
Yellow points: nuclear recoils induced by a ^{252}Cf neutron source

Setting cut with Calibration



Cuts and Efficiencies

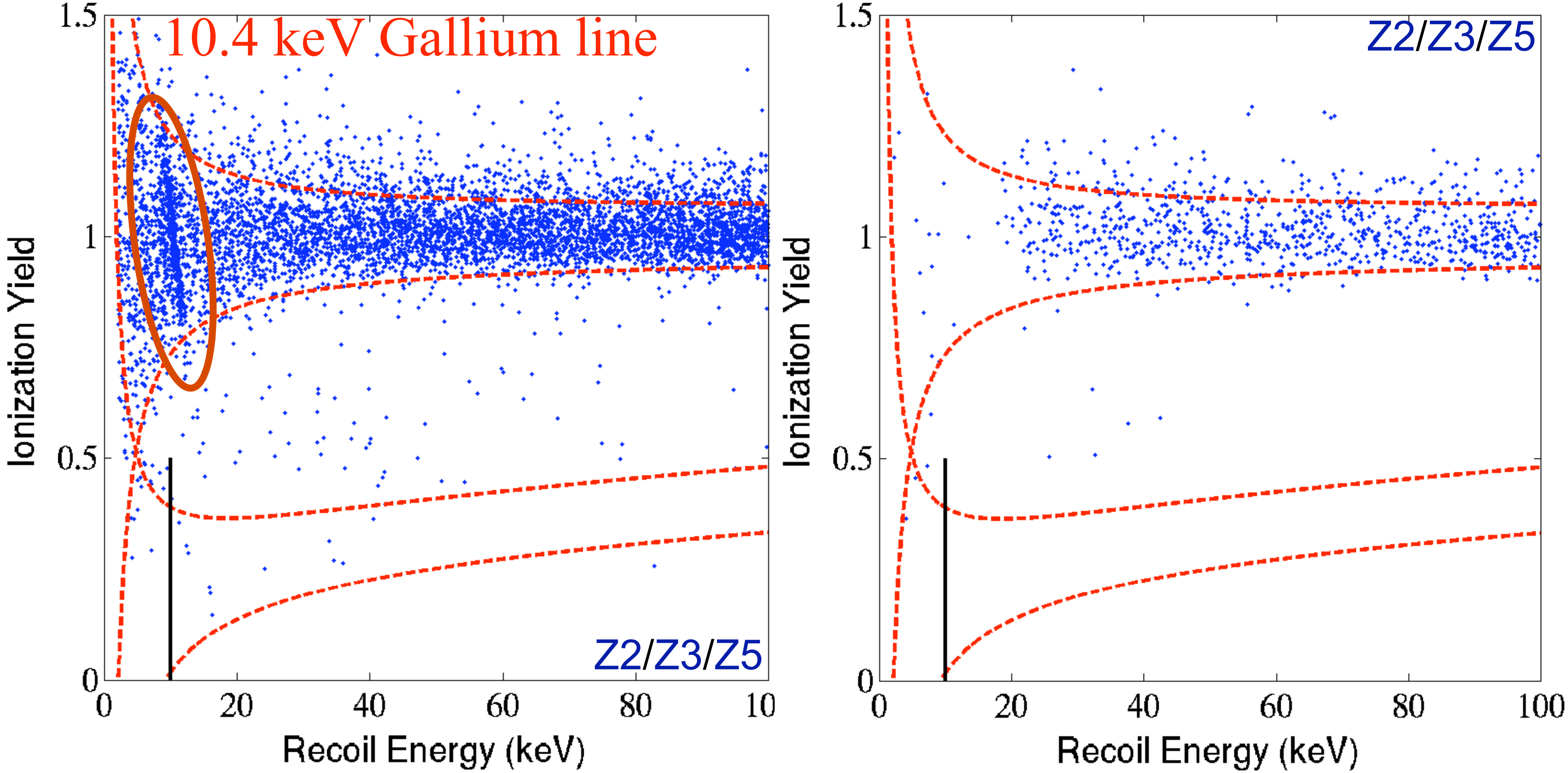
- Defined by calibration samples
- Blind analysis: data on low-yield events from WIMP-search run `in the box' until cut definitions completed
- Opened box on March 20th, 2004



WIMP-search data with blind cuts

Prior to timing cuts

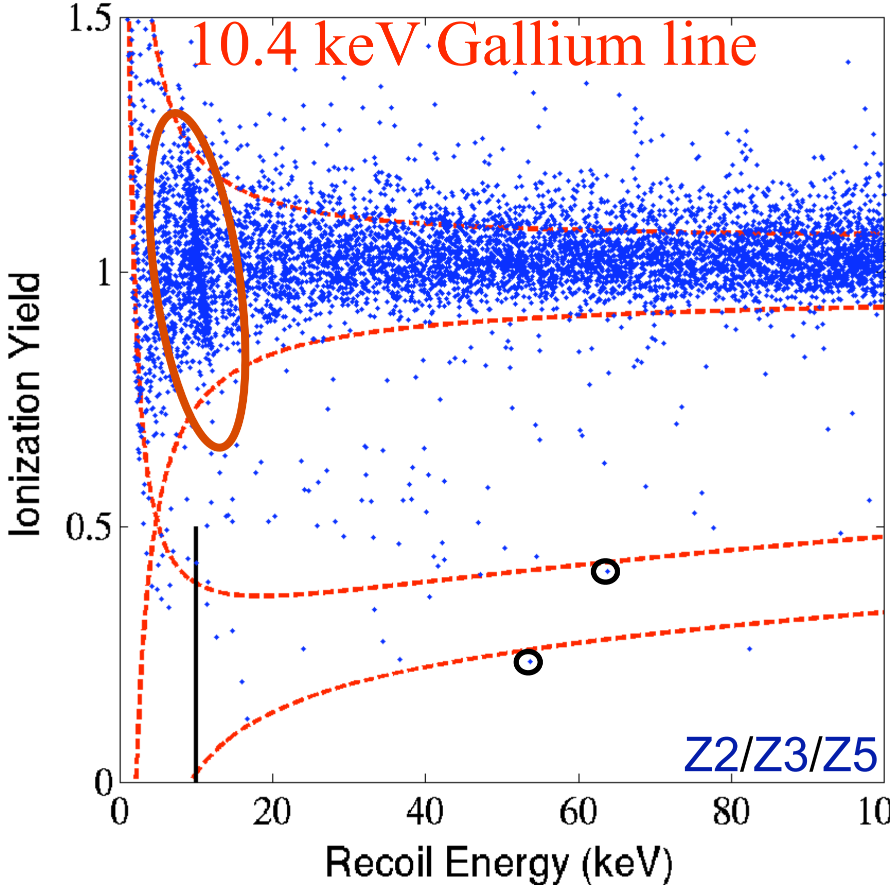
After timing cuts, which reject most electron recoils



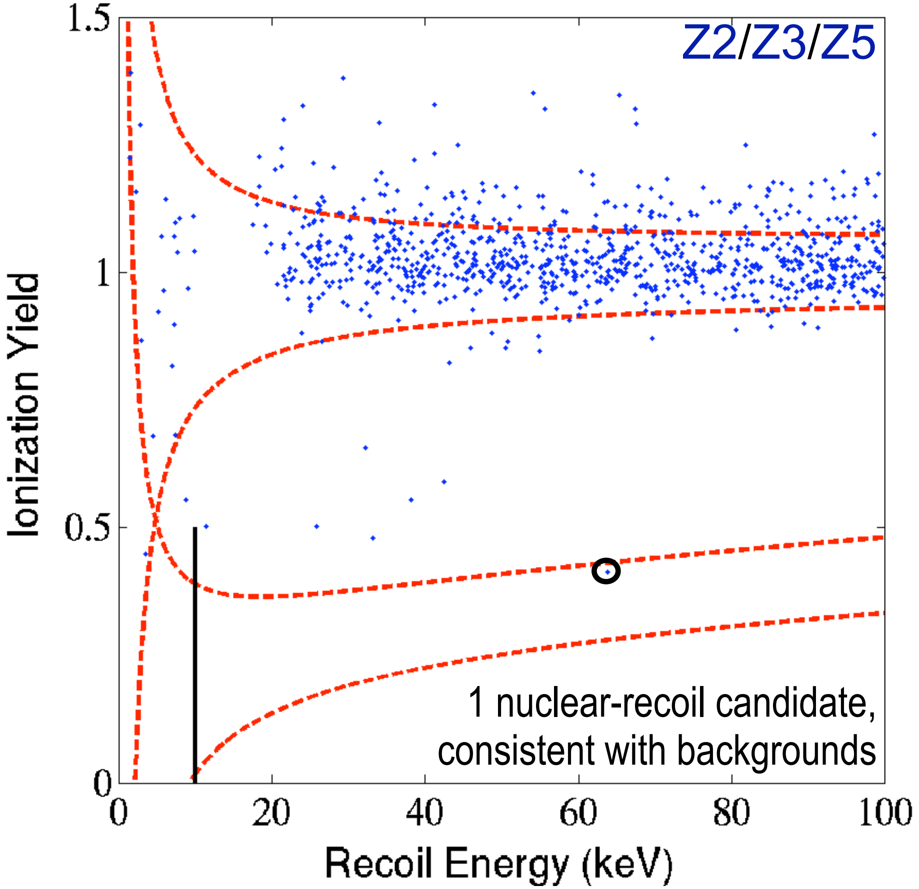
0.7 ± 0.35 misidentified electrons (w/Z1),
0.02 recoils from neutrons expected (w/ Z1)

WIMP-search data with final cuts

Prior to timing cuts



After timing cuts, which reject most electron recoils

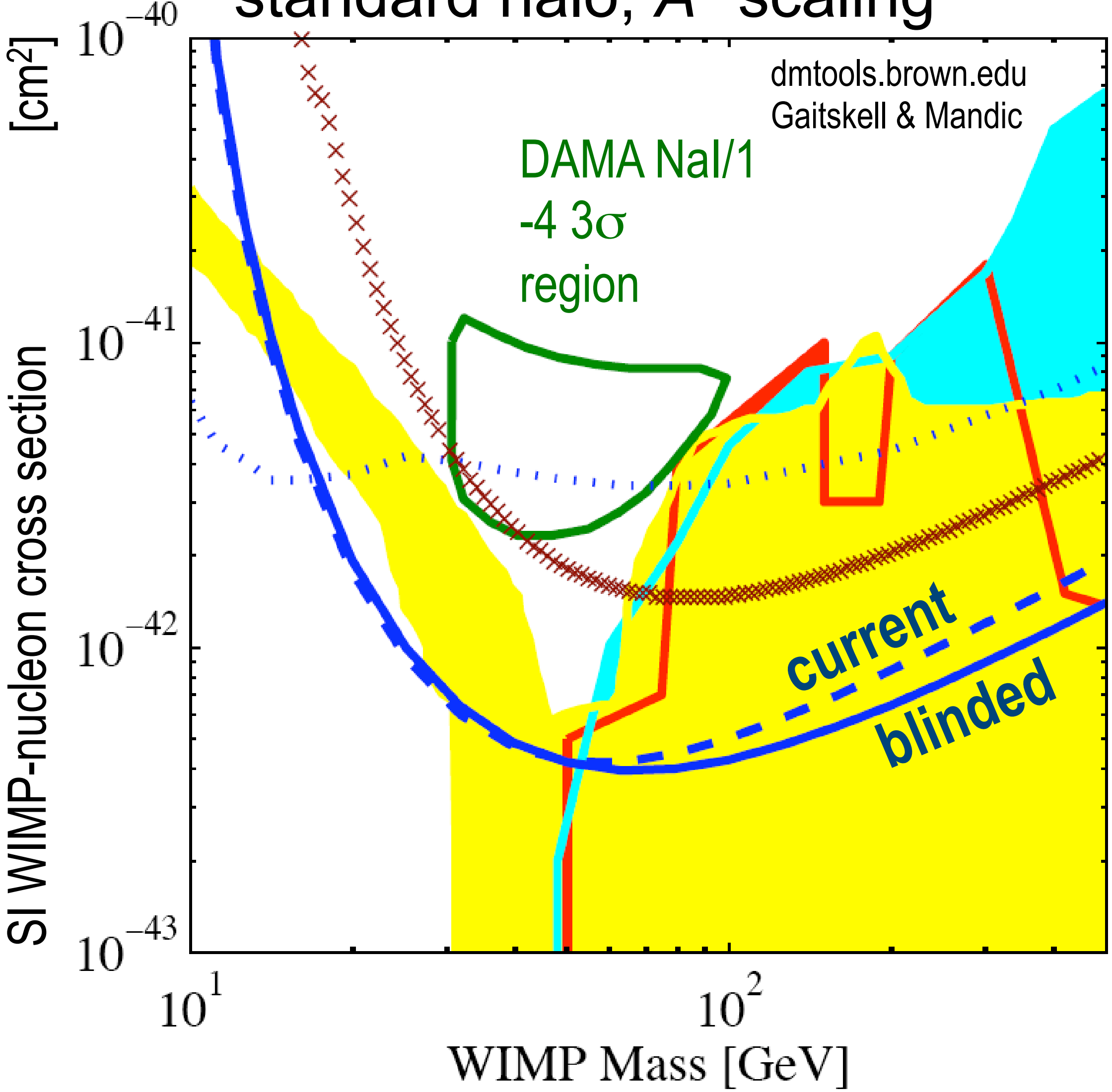


- Energy estimates improved
- Some new events pass cuts

0.7 ± 0.35 misidentified electrons (w/Z1),
0.02 recoils from neutrons expected (w/ Z1)

Resulting Experimental Upper Limits

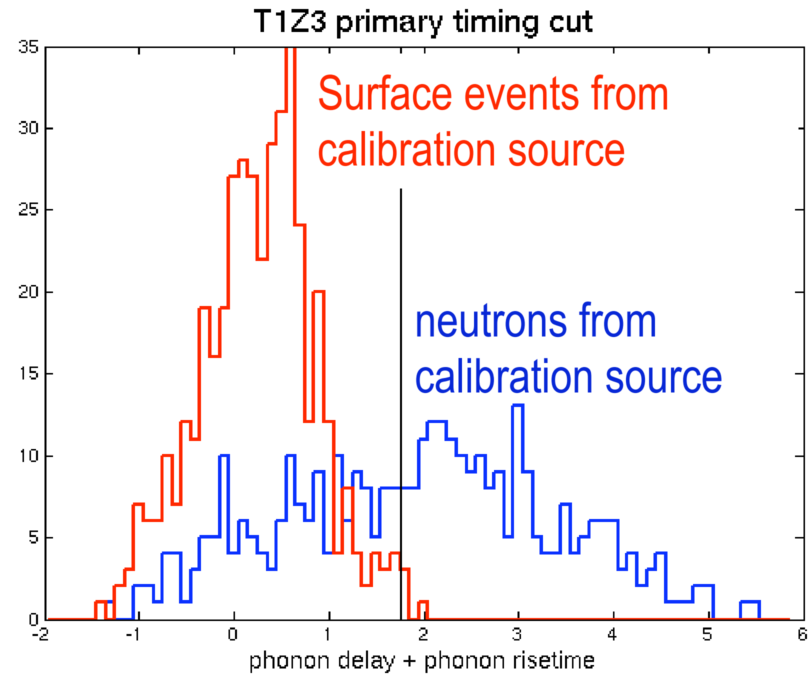
90% CL upper limits assuming standard halo, A^2 scaling

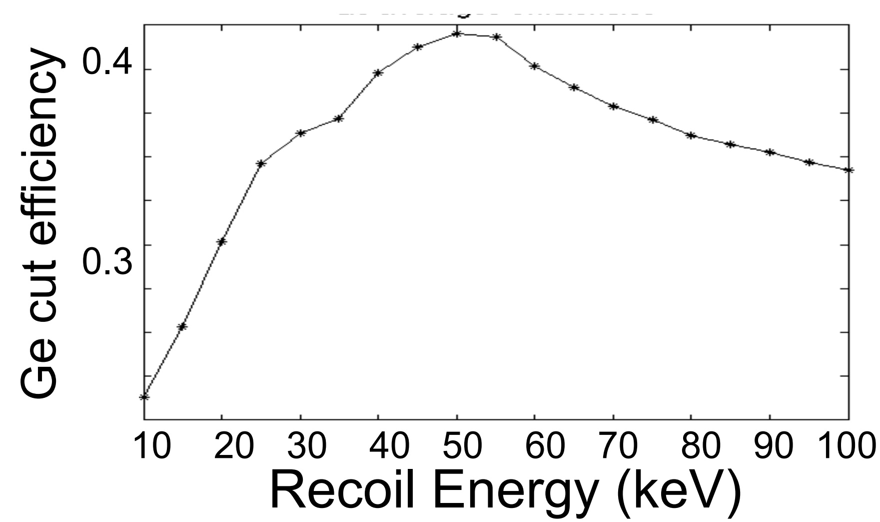


- Upper limits on the WIMP-nucleon cross section are 4×10^{-43} cm^2 for a WIMP with mass of 60 GeV/c^2
  - Factor of 4 below best previous limits (EDELWEISS xxx)
  - Factor of 8 below ••••CDMS-SUF ••••
- Incompatible with DAMA signal if "standard picture" but some alternatives
- Excludes large regions of SUSY parameter space under some frameworks
  - Bottino et al. 2004 in yellow
  - Kim et al. 2002 in cyan
  - Baltz & Gondolo 2003 in red

Analysis of 2nd Soudan Run of CDMS II

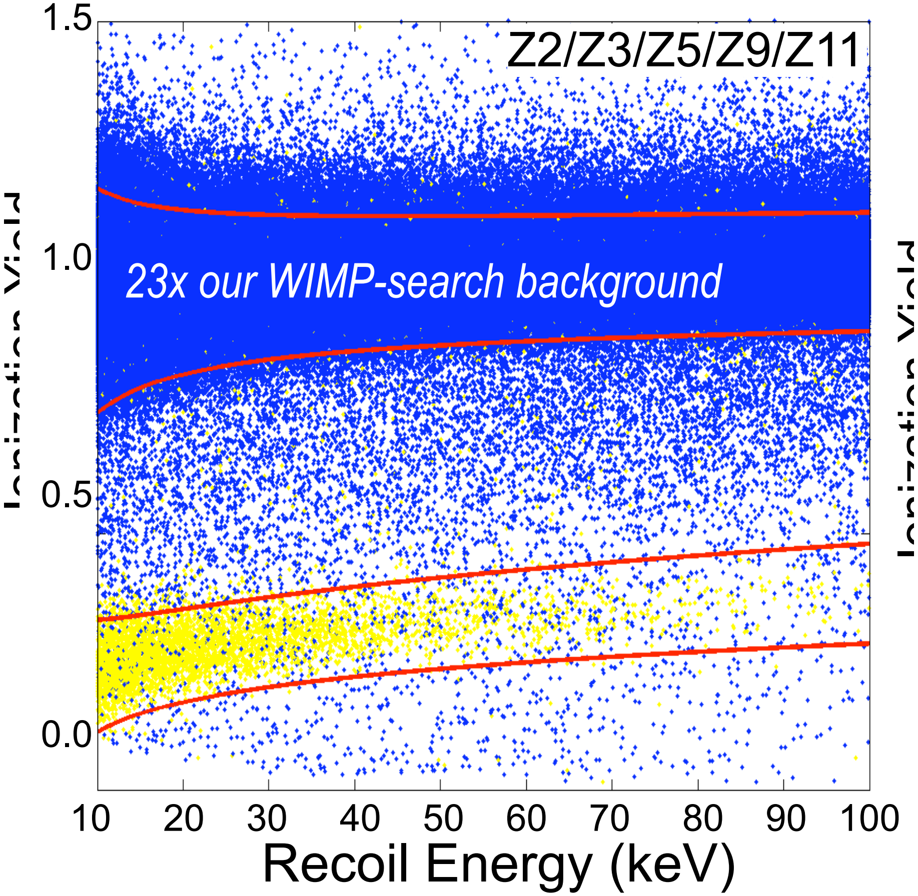
- Included 5 of 6 Ge and 4 of 6 Si detectors (others still blinded)
  - 1.25 kg of Ge, 0.4 kg of Si
  - 72 live-days WIMP-search data
- "Opened the box" on March 31, 2005
- Pre-designated "primary" analysis
  - Similar to timing cut used previously, but better rejection
- 4 "secondary" blind analyses with more sophisticated techniques, better rejection of backgrounds



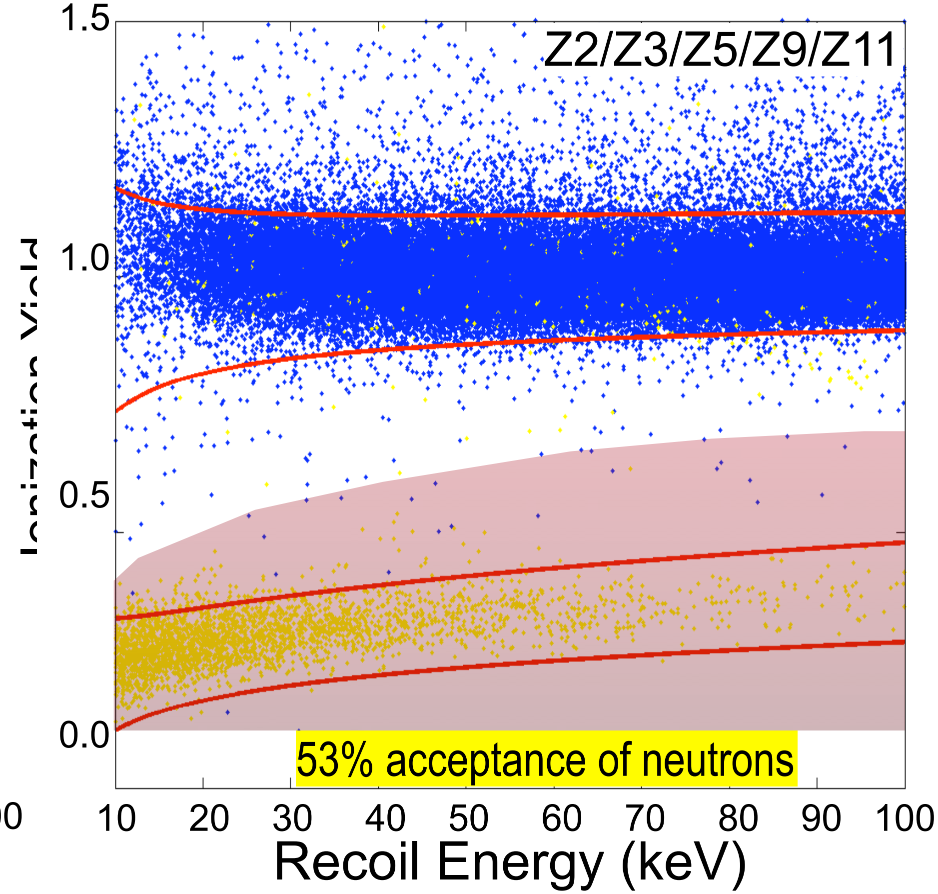


In Situ Calibrations for Setting Cuts "Blind"

Second run's calibration data, prior to timing cuts



After timing cuts, set to reject nearly all low-yield electron recoils

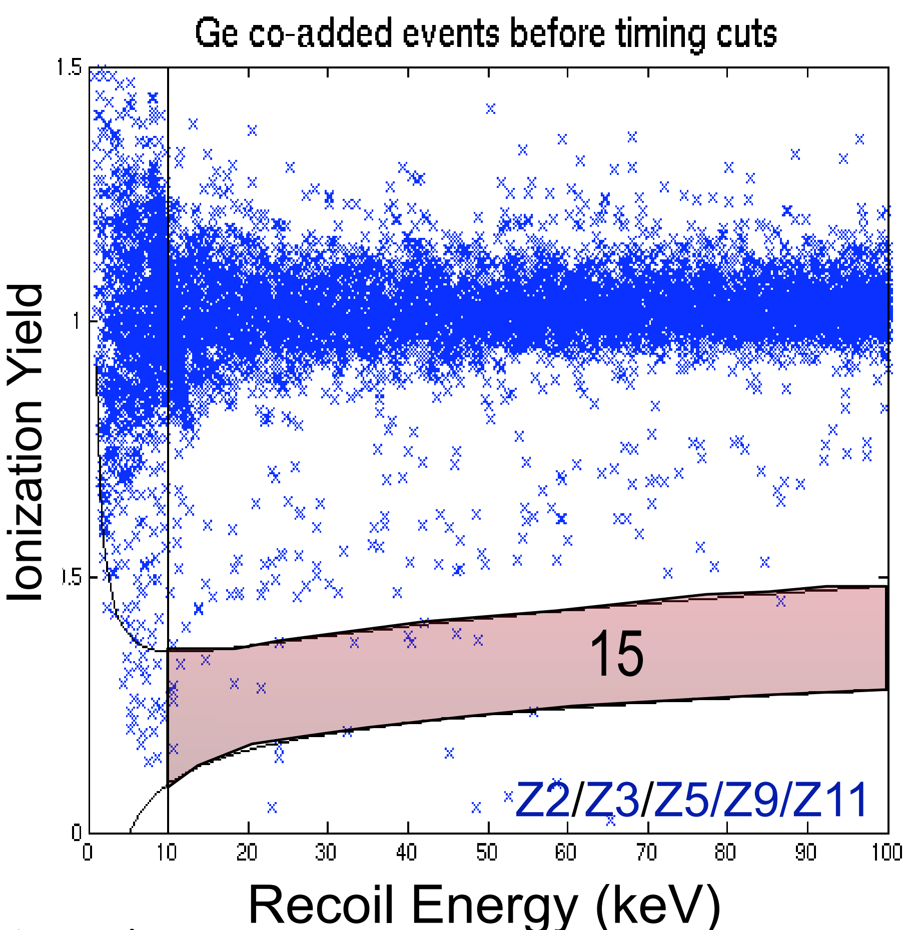


Blue points: electron recoils induced by a ^{133}Ba γ source

Yellow points: nuclear recoils induced by a ^{252}Cf neutron source

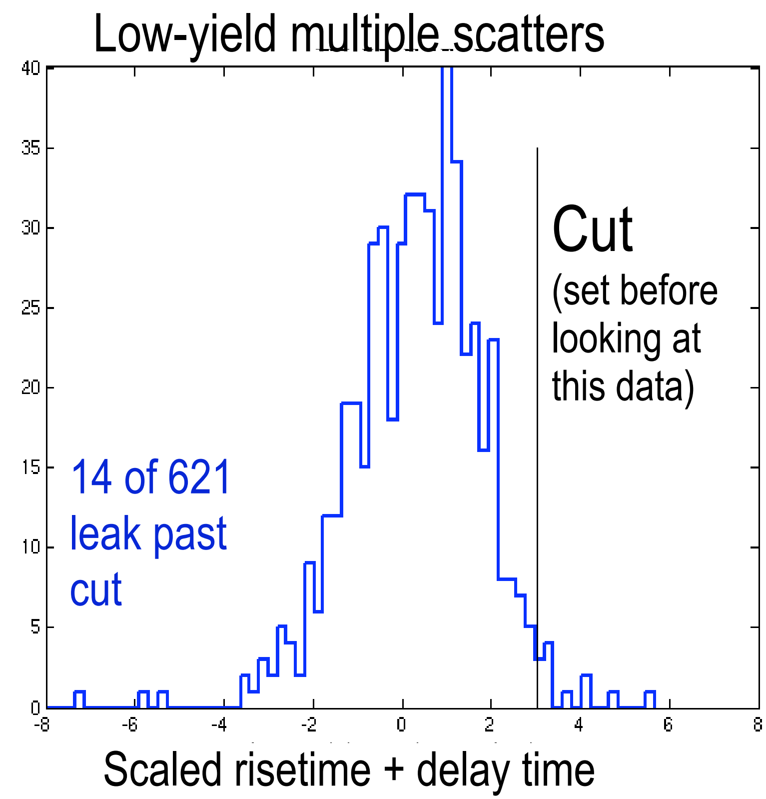
Estimating Expected Background

- Count number of events in signal region prior to timing cuts



A. Reisetter

- Multiply by leakage fraction of low-yield multiple scatters
  - Varies from 1% to 3% depending on detector and data sample



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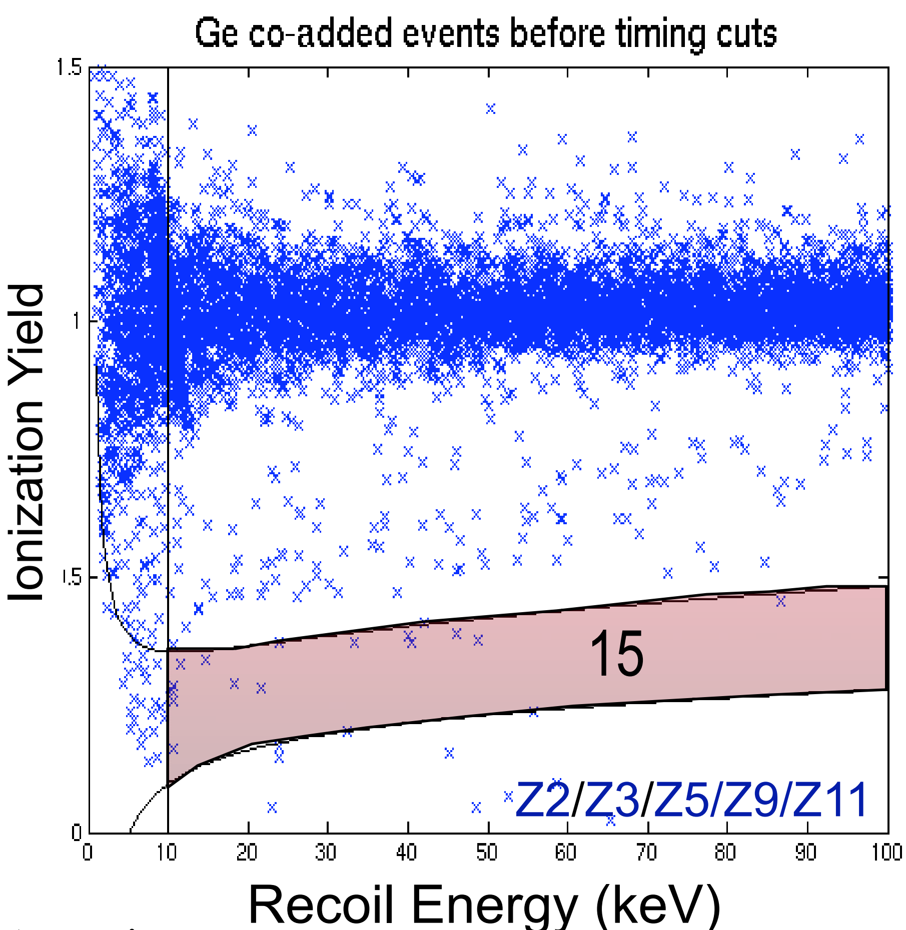


A. Reisetter

- Multiply by leakage fraction of low-yield multiple scatters
  - Varies from 1% to 3% depending on detector and data sample

PRELIMINARY ESTIMATE:

0.37 ± 0.20 (sys.) ± 0.15 (stat.)

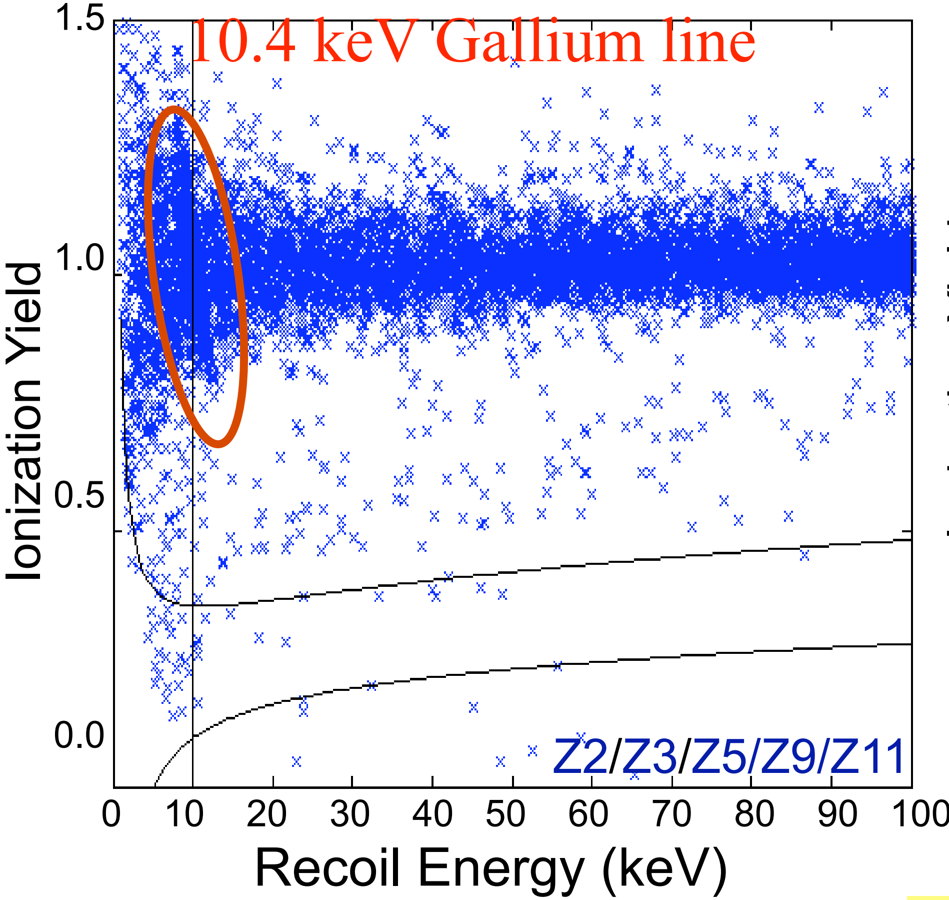
misidentified electron recoils

- Estimate and its errors are still under scrutiny
- leakage estimate would not influence an upper limit, but is crucial for present and future `discovery potential'

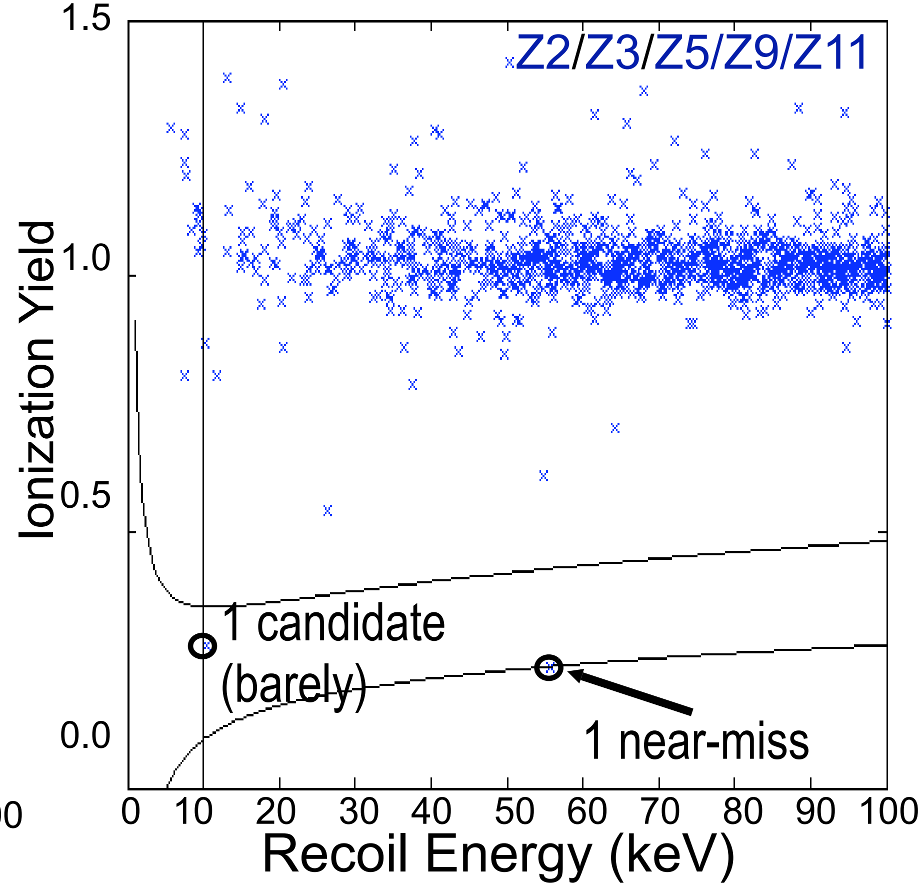
~0.05 recoils from neutrons expected after veto

WIMP-search data

Prior to timing cuts



After timing cuts, which reject most electron recoils



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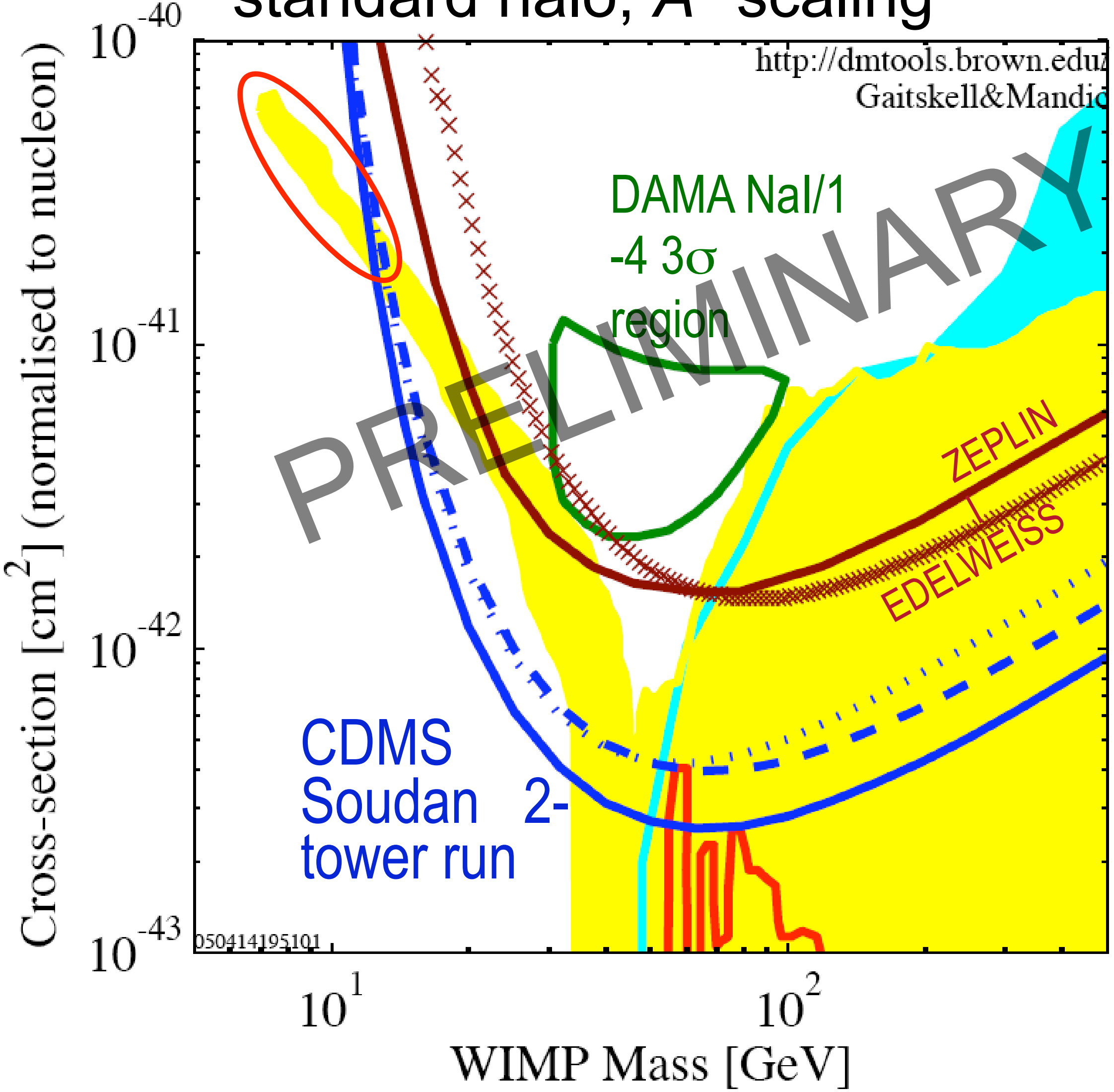
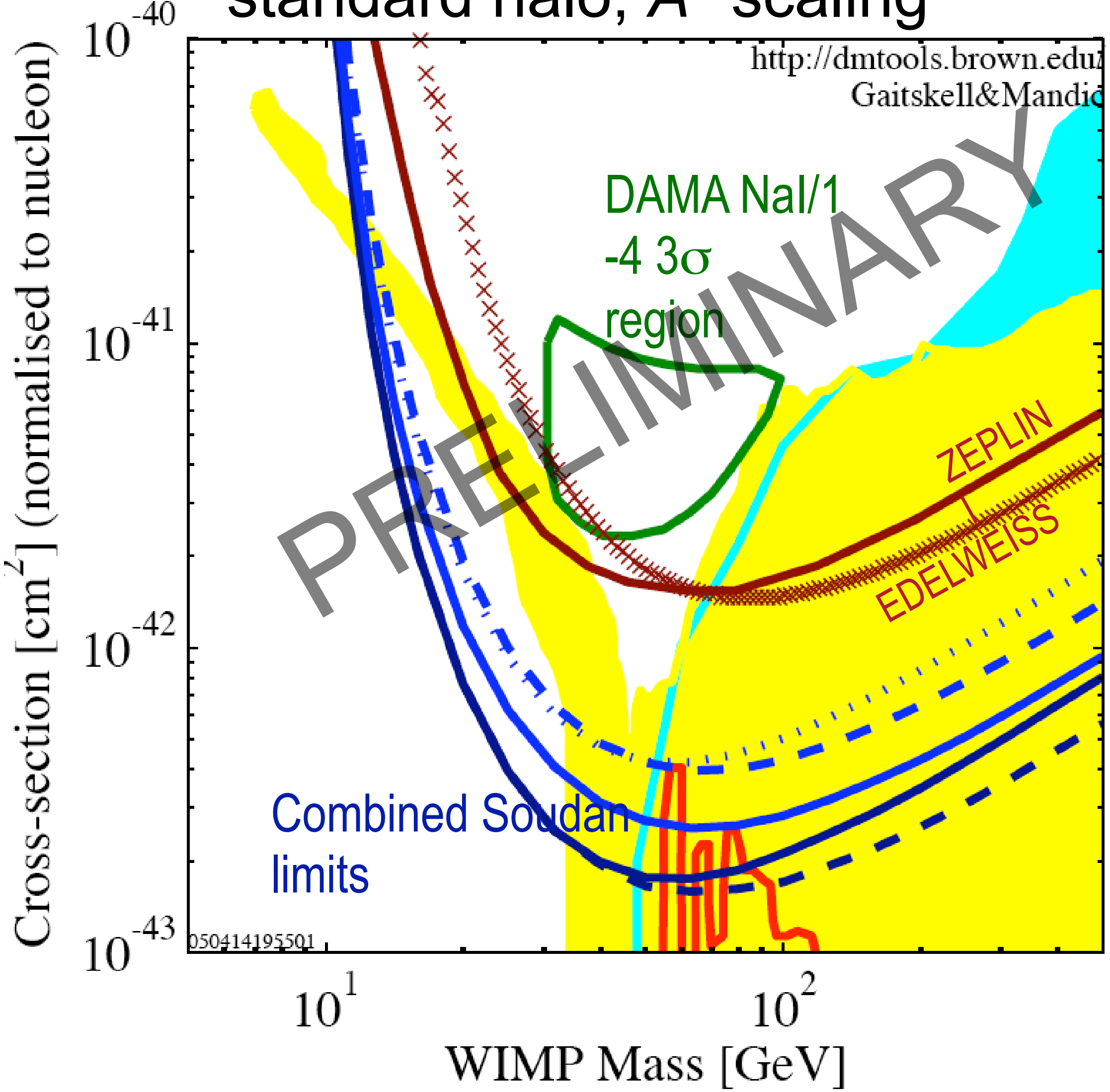
90% CL upper limits assuming standard halo, A^2 scaling



- Upper limits on the WIMP- nucleon cross section are 2.5×10^{-43} cm^2 for a WIMP with mass of 60 GeV/c^2
  - Factor of 1.5-2x below CDMS Soudan 1st run
    - - - blind - - -
    • • • current • • •
- Excludes large regions of SUSY parameter space under some frameworks
  - Bottino et al. 2004 in yellow
  - Kim et al. 2002 in cyan
  - Baltz & Gondolo 2004 mSUGRA in red
- What can CDMS say about low-mass region?

1st Year CDMS Soudan Combined Limits

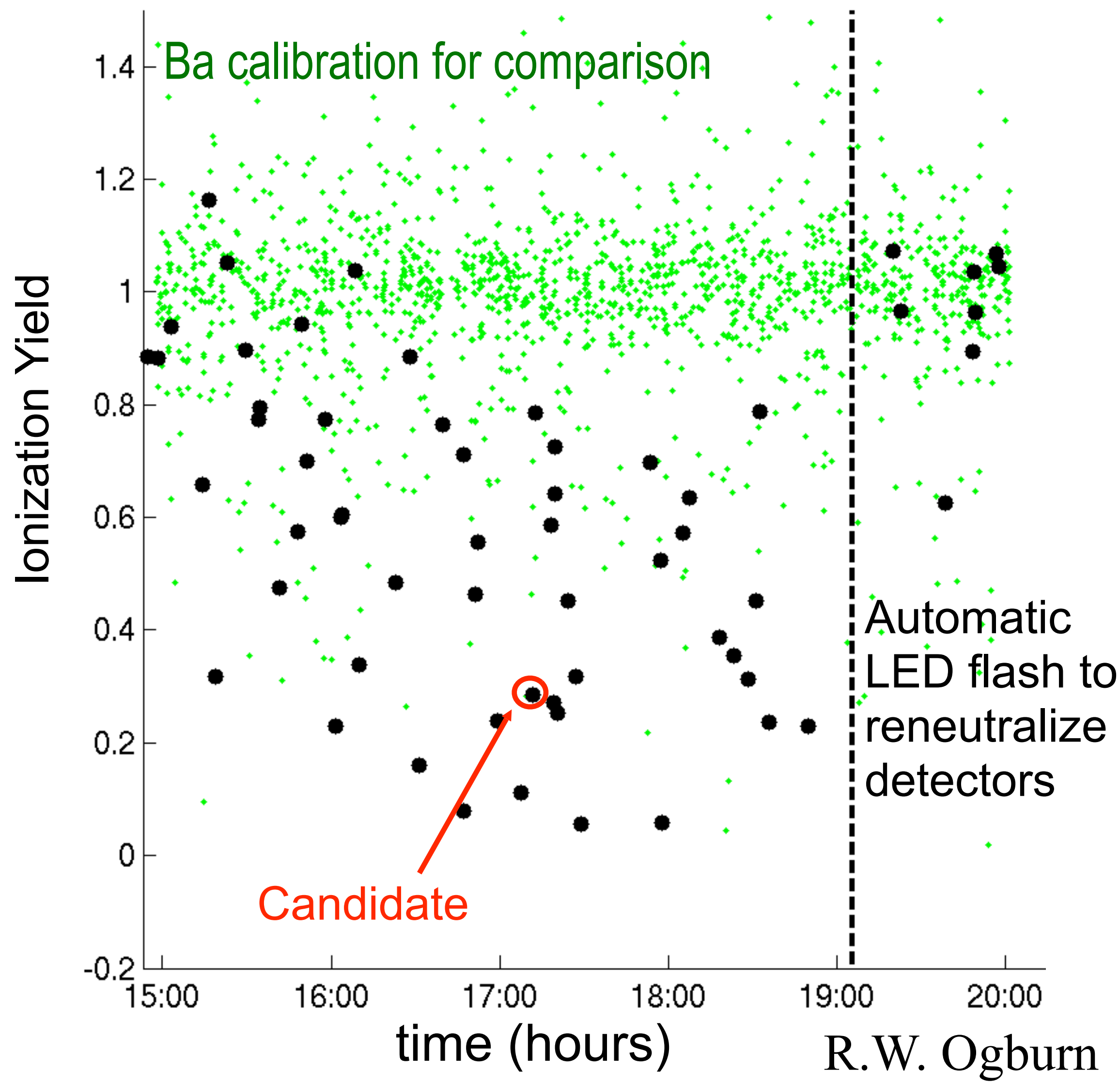
90% CL upper limits assuming standard halo, A^2 scaling



- Upper limits on the WIMP- nucleon cross section are 1.7×10^{-43} cm^2 for a WIMP with mass of 60 GeV/c^2
  - Factor of 2.3x below CDMS Soudan 1st run - - - blind - - - • • • current • • •
  - Factor 10 lower than any other experiment
- Excludes large regions of SUSY parameter space under some frameworks
  - Bottino et al. 2004 in yellow
  - Kim et al. 2002 in cyan
  - Baltz & Gondolo 2004 mSUGRA in red

Is the Candidate Event Just Background?

- Very likely so!
- Event occurred during run when its detector, Z11, suffered reduced ionization yield
  - Worst run for this detector
- In hindsight, our cuts on bad data periods for single detectors weren't strict enough
  - Some other detectors, without candidates, had similarly bad periods
- Will improve for next run

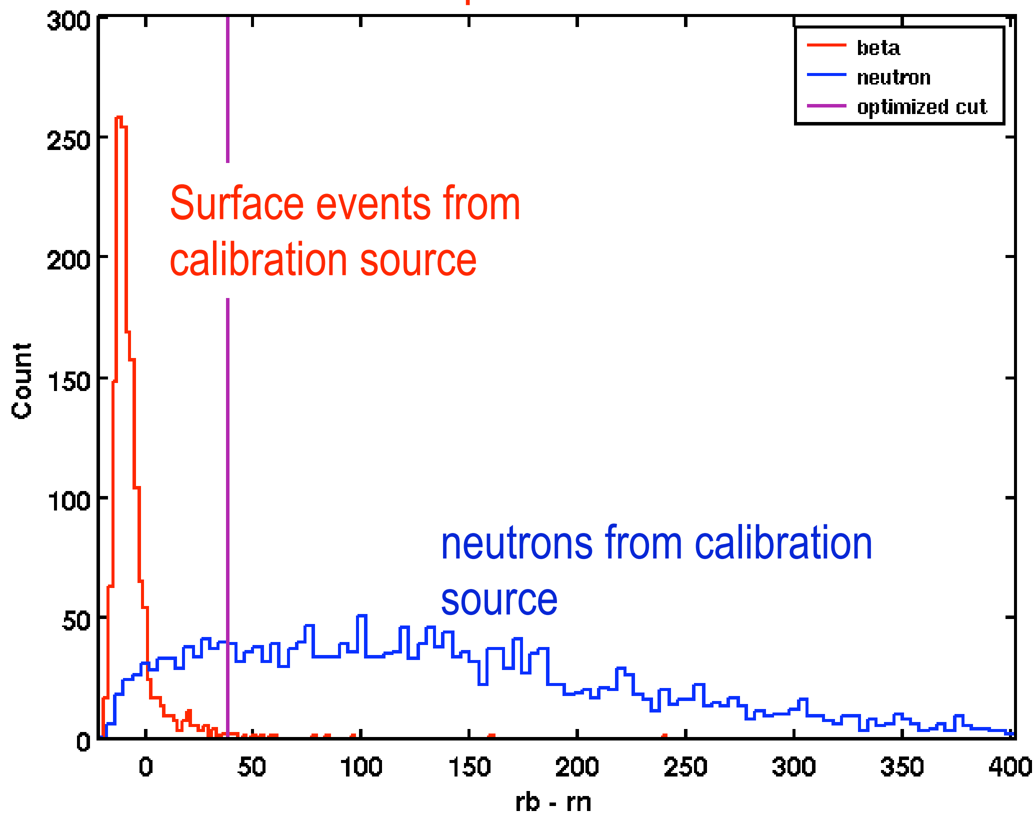


Will CDMS II be background-limited soon?

- No!
- More sophisticated analyses show better rejection of electron recoils

- Additional discrimination parameters
  - Ratio of energy in sensor with largest signal to energy in sensor with smallest signal
  - Still crude but improved reconstruction of event position
- Better combining of parameters
  - Form χ^2 including correlations amongst parameters
- Yet more improvements to come

One example of *several* leaked

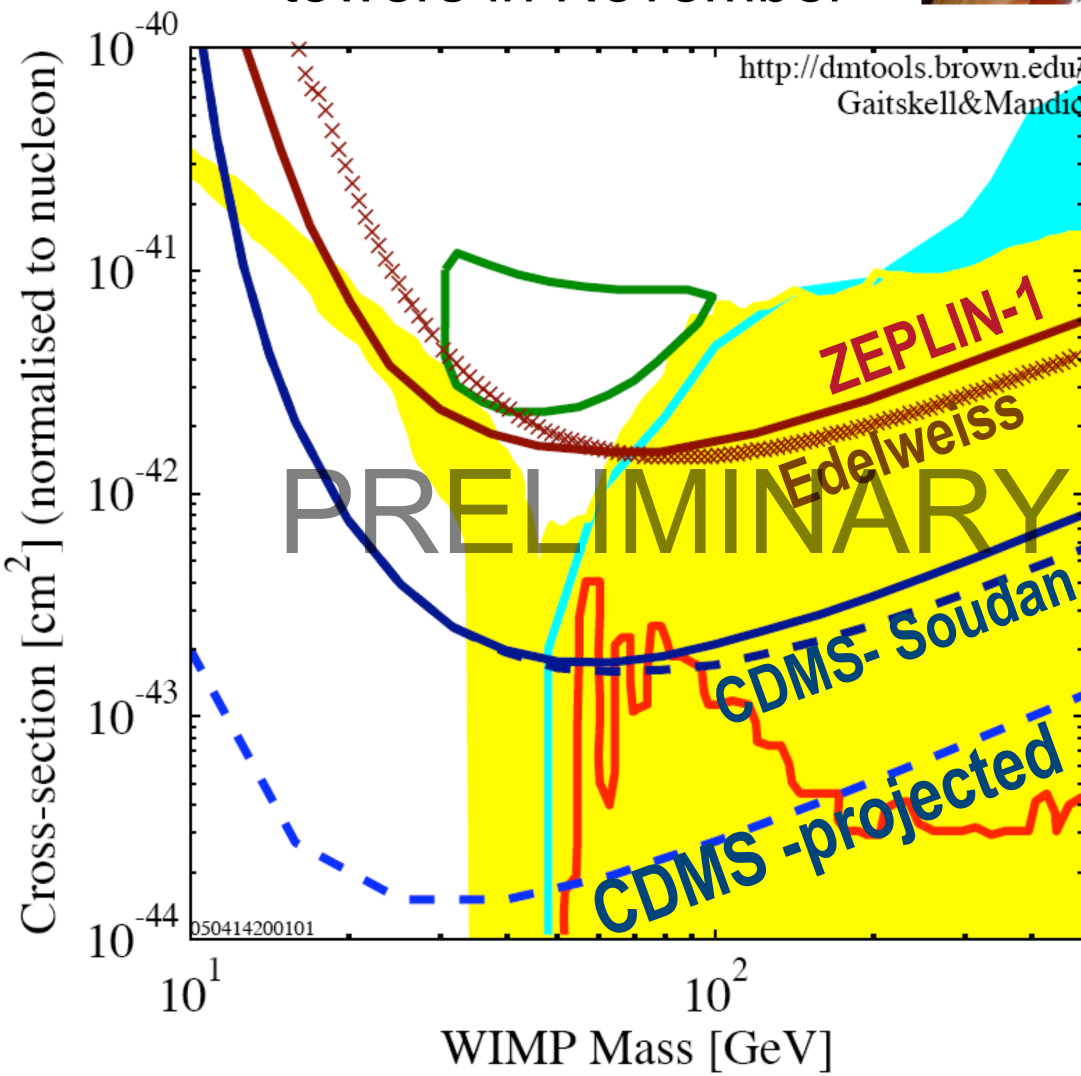


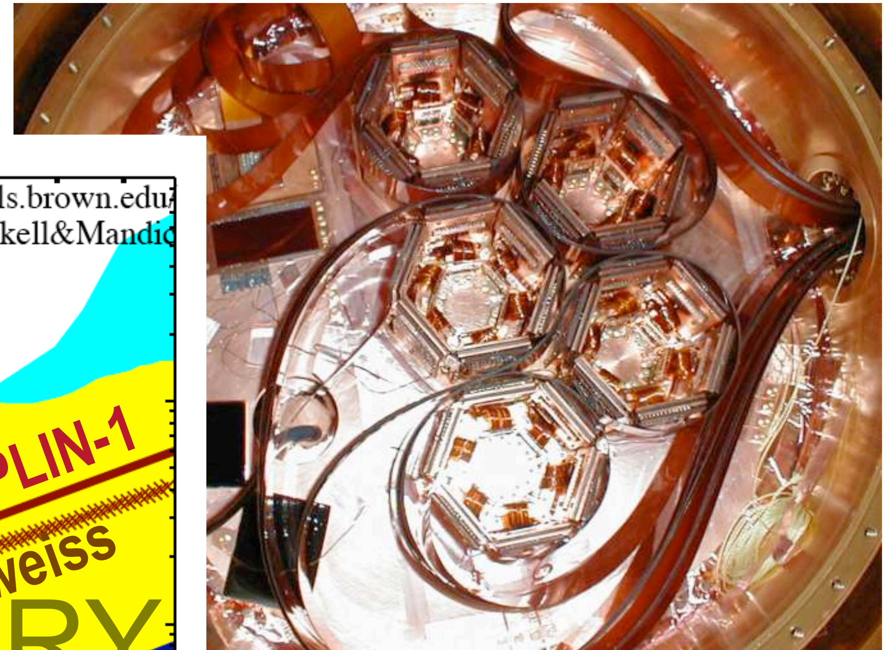
R. Mahapatra, J. Sander

- Can also greatly reduce leakage by slight tightening of cuts

Projected CDMS Sensitivity

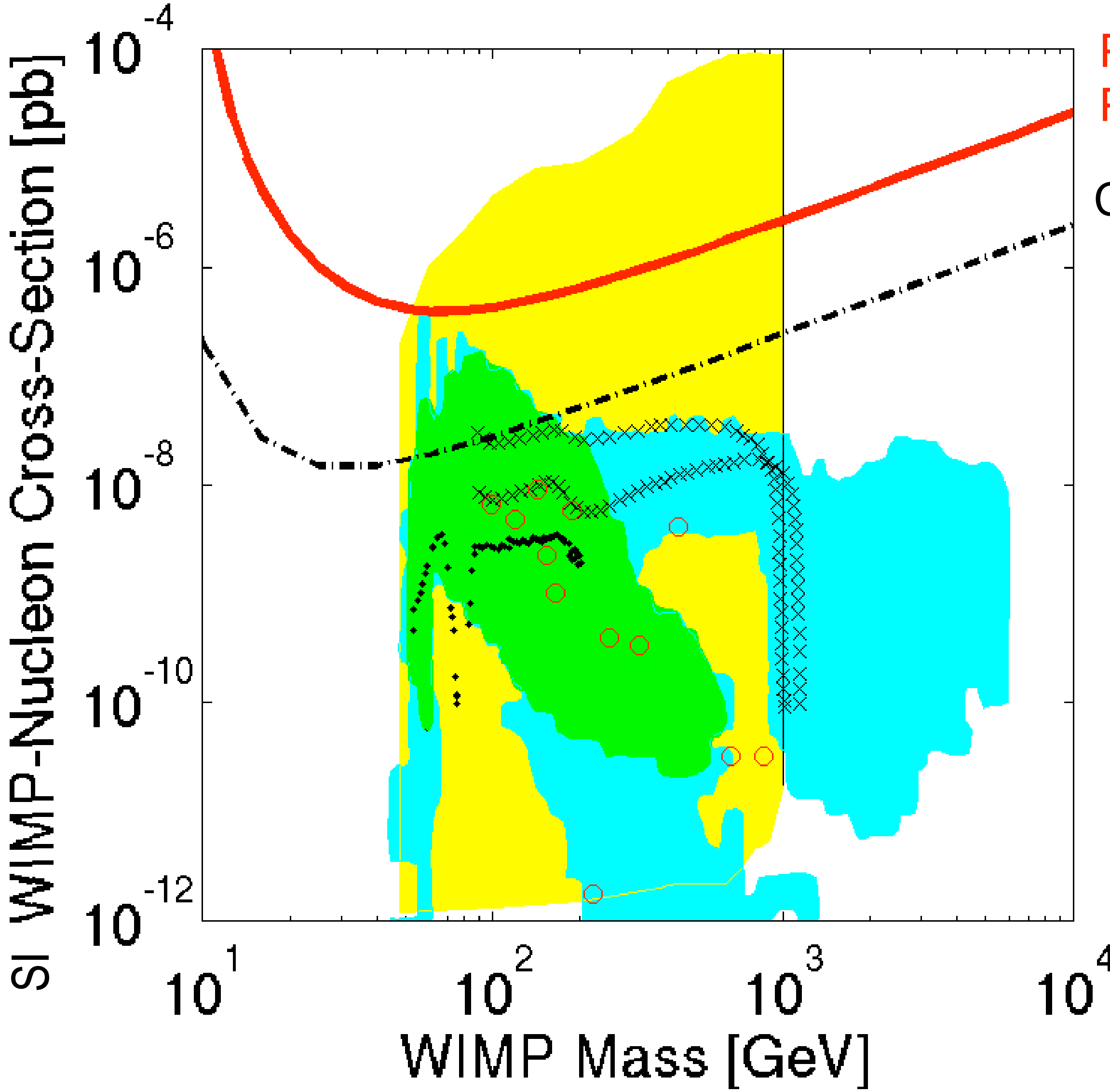
Installed 3 additional towers in November





- Additional improvements
  - Cryogenics, backgrounds, DAQ
  - Currently commissioning
- 30 detectors in 5 towers of 6
  - 4.75 kg of Ge, 1.1 kg of Si to run through 2006
  - Improve sensitivity x10

Supersymmetry Reach



Published CDMS II limit
PRL 93, 211301 (2004)

CDMS II goal (end 2005)

Kim et al. 2002 in yellow (MSSM scan)

Baltz & Gondolo 2004 in cyan (mSUGRA), in green ("" w/WMAP constraints)

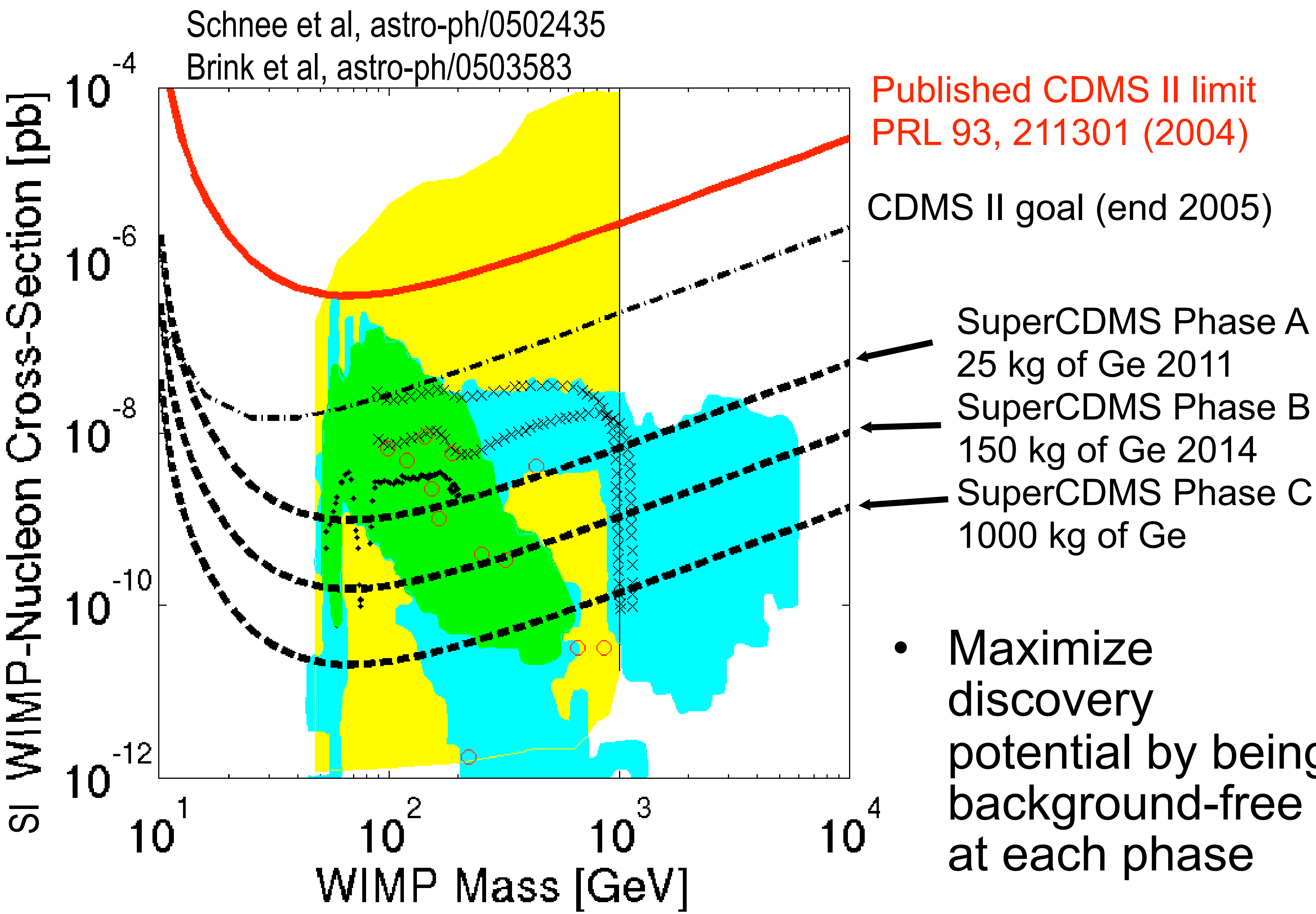
Battaglia et al. 2004 in red o (post-LEP benchmark points)

Guidice & Romanino 2004 x (split SUSY)

Pierce 2004 dots (split SUSY)

- Many model frameworks 10^{-8} - 10^{-10} pb (especially if g_{μ} -2 is due to SUSY)

SuperCDMS Reach



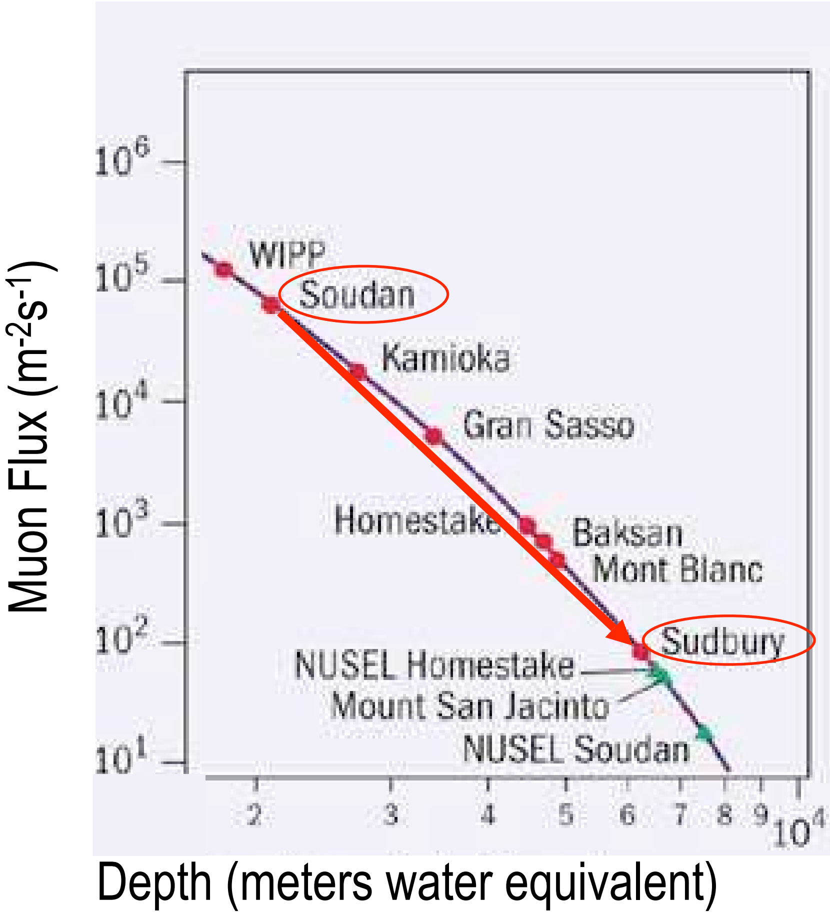
- Maximize discovery potential by being background-free at each phase

Maximizing Information for Discovery

- Background discrimination good enough for zero background with several handles on systematics

- Segmented detector (ton to be divided into ~ kg pieces)
  - Excellent sensitivity to multiple-scatters
- 3D position information within each detector
  - Z information relatively weak but ways to improve greatly
- Excellent energy resolution
- Low thresholds (small "quenching") allows us to require positive signal for both energy measurements
  - Immune to detector heating, microphonics, crackophonics, stray light, etc.
- Alas, no directional information
  - Zero background makes control of systematics for finding annual modulation much more tractable

Remove Muon-induced Neutron Background



- Move from Soudan to SNOLAB
  - Reduce muon flux by 500x
  - Reduce high-energy neutron flux by >100x -- problem gone
  - Worry about neutrons from residual radioactivity only

The EAC has reviewed your LOI and endorses it highly as a project appropriate for SNOLAB based upon its exceptional scientific merit, the technical accomplishments achieved to date by the CDMS collaboration, and the well defined program to proceed towards the [SuperCDMS] project.

Photon and Electron Backgrounds

	Photons	Electrons
Current raw rate (events/ exposure) [1000 kg, 500 days]	5×10^7	7×10^5
Published rejection	10^6:1	130:1
Rate after rejection	50	500
In hand	20	200
Improve analysis	5	50
Improve detectors	0.5	5
Reduce rates	0.5	0.5
SuperCDMS Goal	0.5	0.5

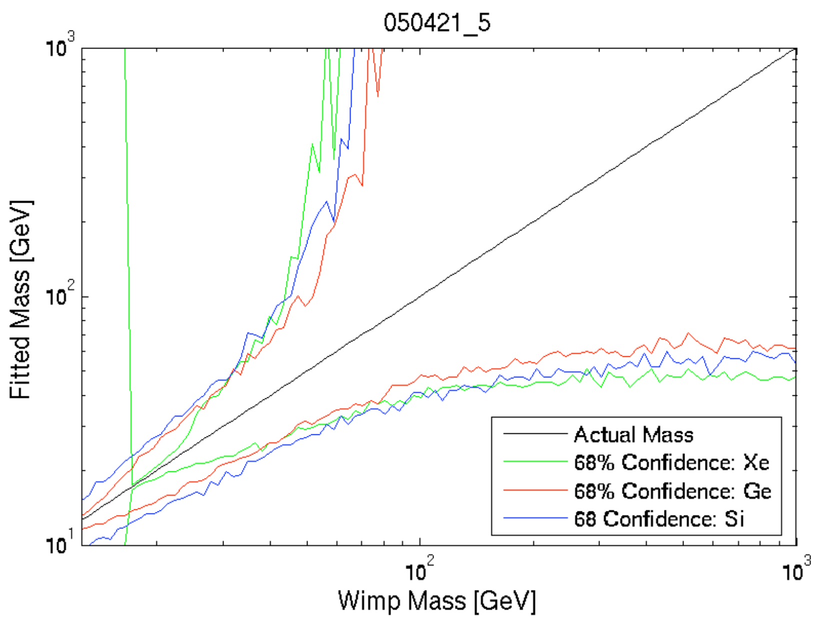
- Improve rejection
  - in hand: better phonon-timing cuts give ≥350:1 rejection
  - by further analysis improvements
  - via improving detectors
- Reduce raw rates via better shielding, cleanliness

Conclusions

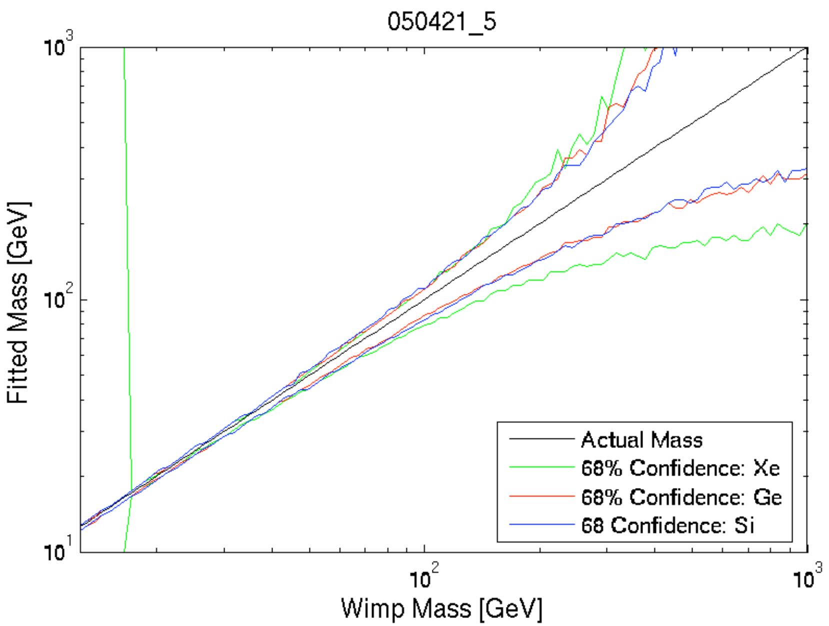
- CDMS II at Soudan (2003-2006)
  - Run of first tower of 6 detectors is fully analyzed
    - World's lowest limits by 4X increase in sensitivity
    - Incompatible with DAMA for scalar coherent interactions, standard halo
  - Analysis of run of towers 1 and 2 nearly done
    - Still no signs of WIMPs
    - Limits now 10x lower than any other experiment
    - Starting to probe mSUGRA region
    - Also world's strongest constraints on SD WIMP-neutron coupling, additional constraints from results of silicon detectors
  - Towers 1-5 to be run this year, through 2006
    - Tremendous additional reach: up to 10 times lower than current limits.
- SuperCDMS (2007-)
  - World's best discrimination can allow WIMP physics at $\sigma \sim 10^{-46}$ cm^2
    - Modest improvements needed, can be shared between improved discrimination and background reductions
    - Construction requires significant development but appears achievable

DM Mass From Direct Detection
Constant # of Events Above Threshold

10 events above threshold



1000 events above threshold



- Comparisons above assume same # of events in each experiment, (not constant cross section)
- At all masses, more events -> Better sensitivity to M_D

Undergraduate Senior Thesis, Brown