New results from the CDMSII final Run at Soudan Deep Underground Laboratory

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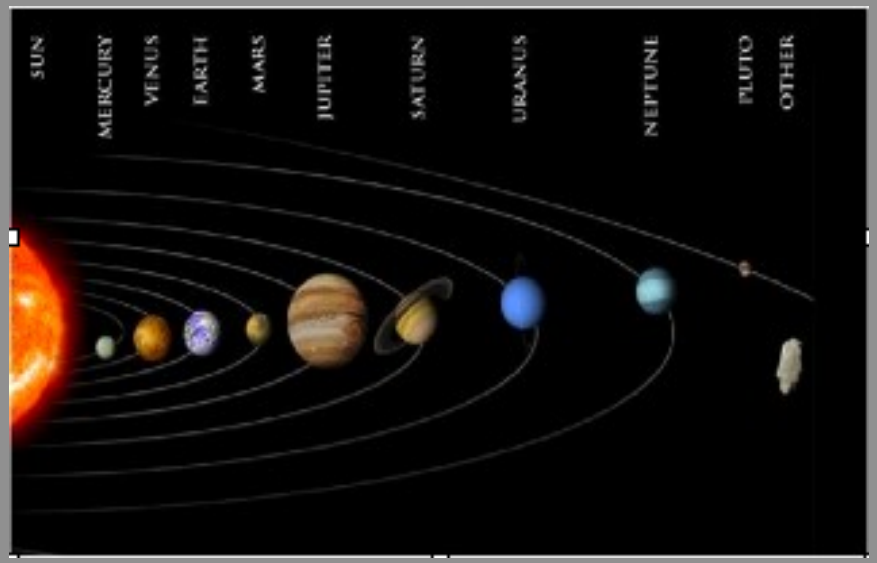
University of California, Berkeley

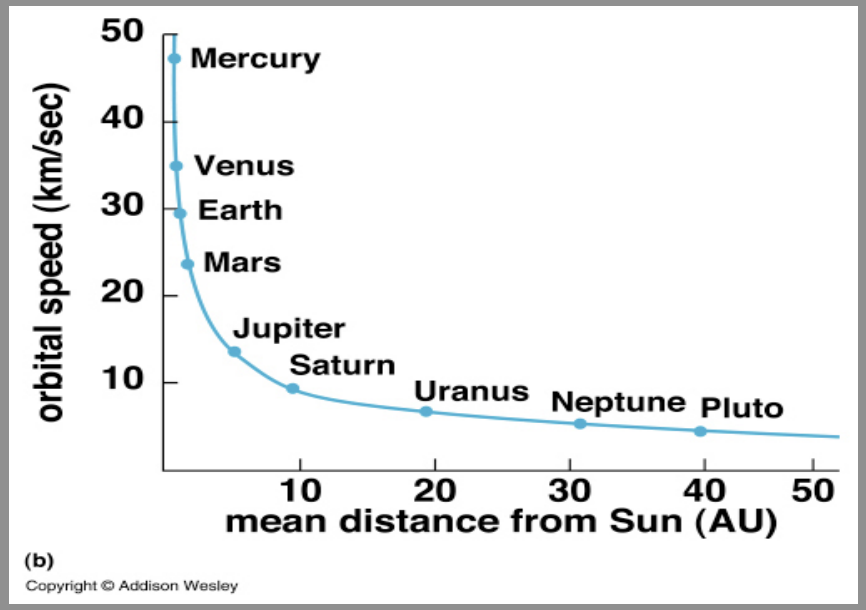
CDMS Collaboration

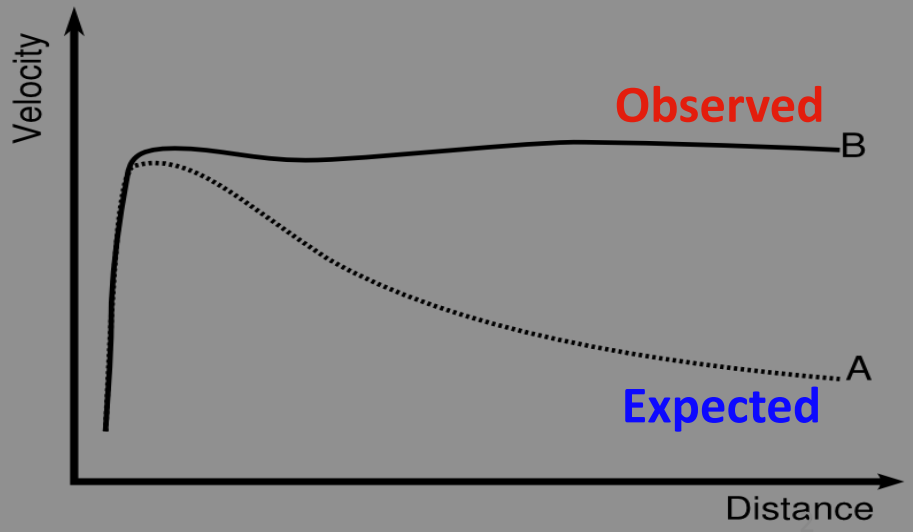
RPM, LBNL, July 2009

- Dark Matter and WIMPs
- CDMSII detection principle
- Results from the final run
- CDMS Future
- Conclusion

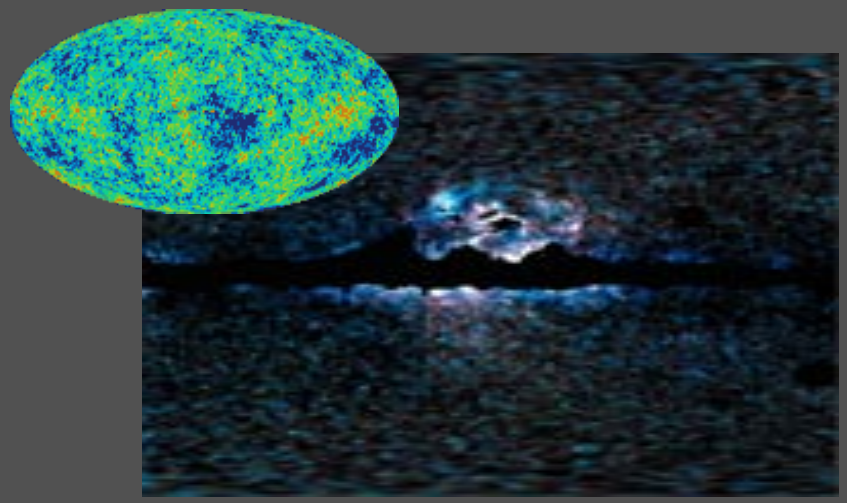
Dark Matter: Evidences

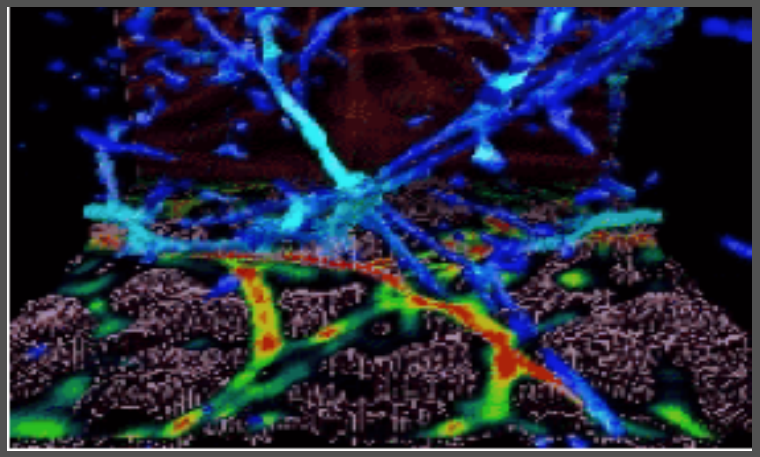


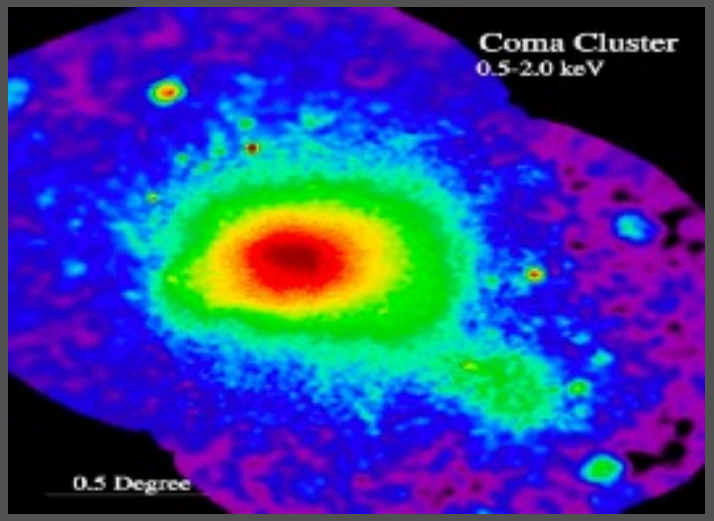




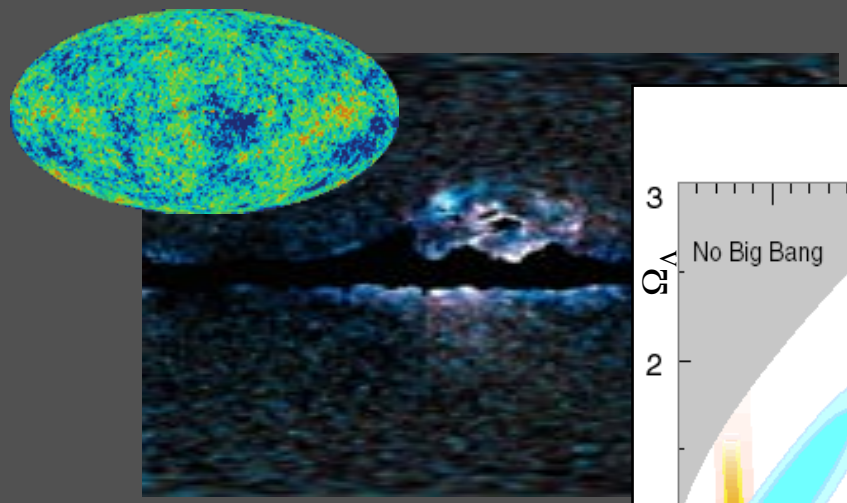
Dark Matter: Evidences

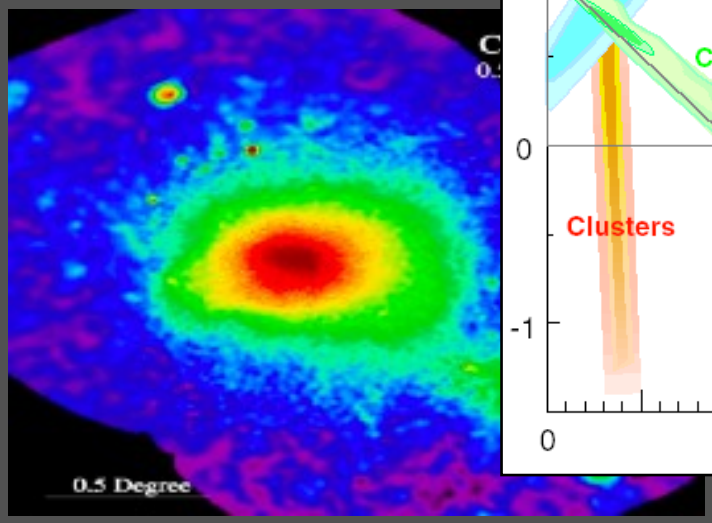


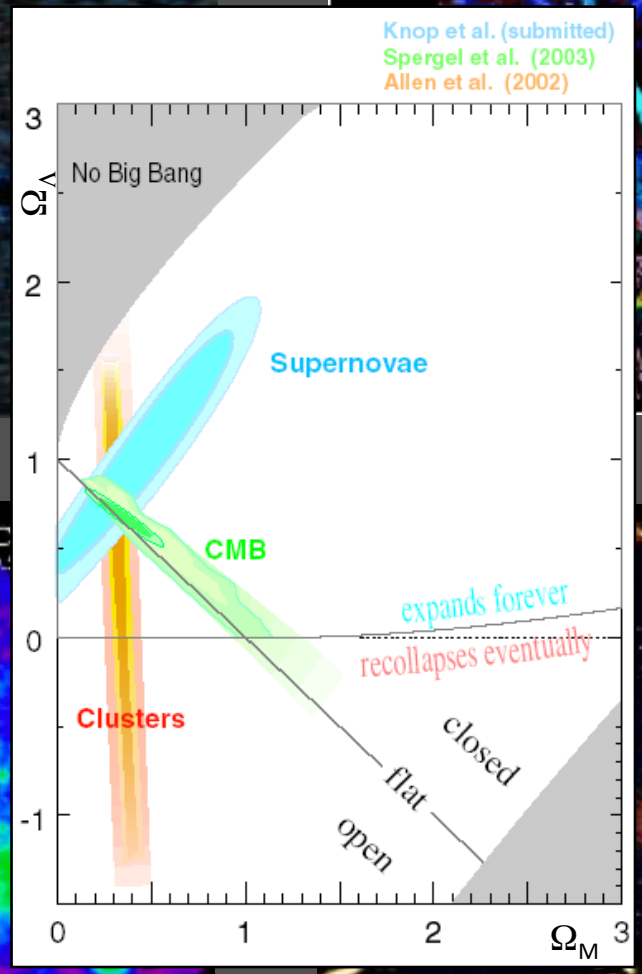


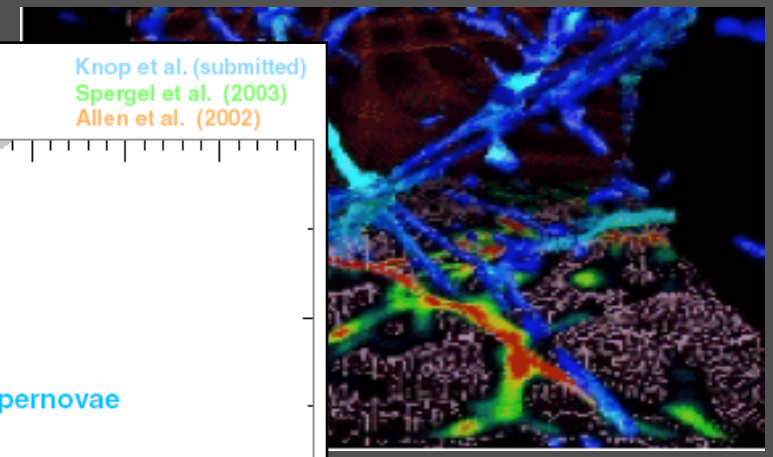


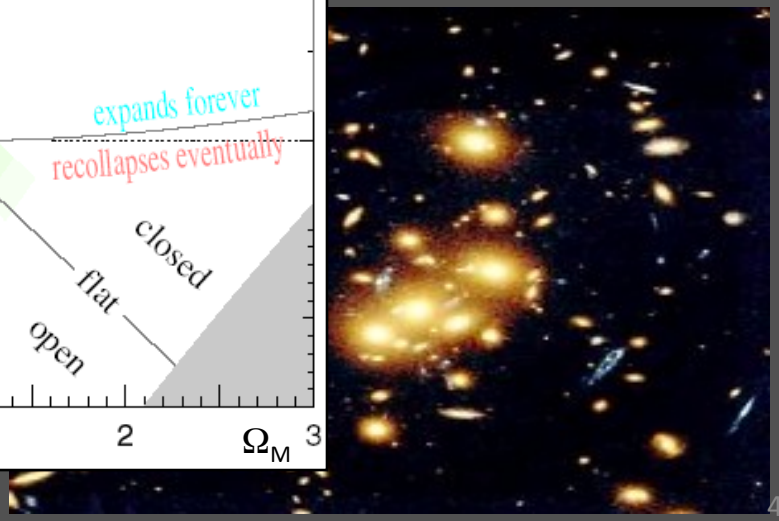
Dark Matter: Evidences





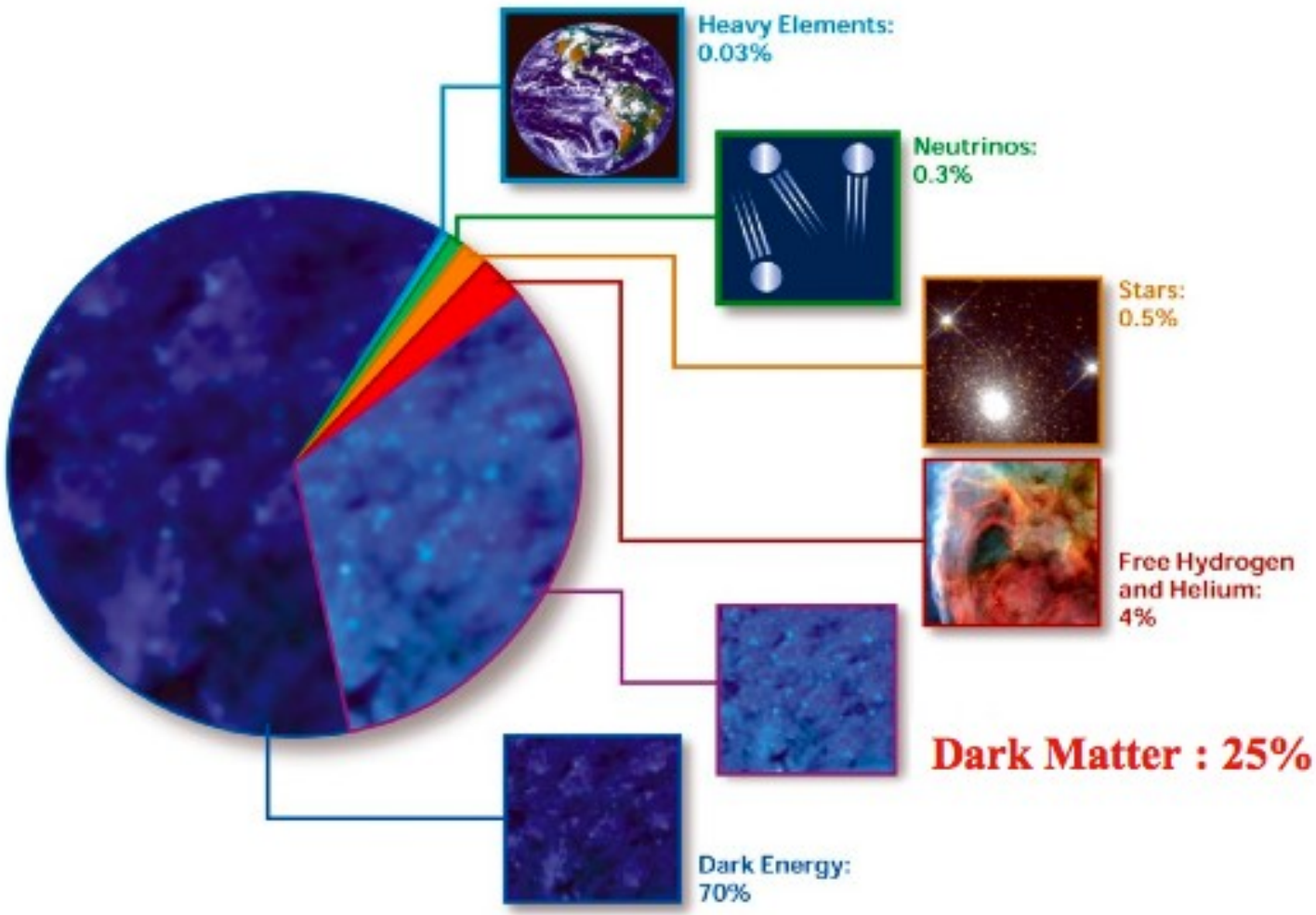




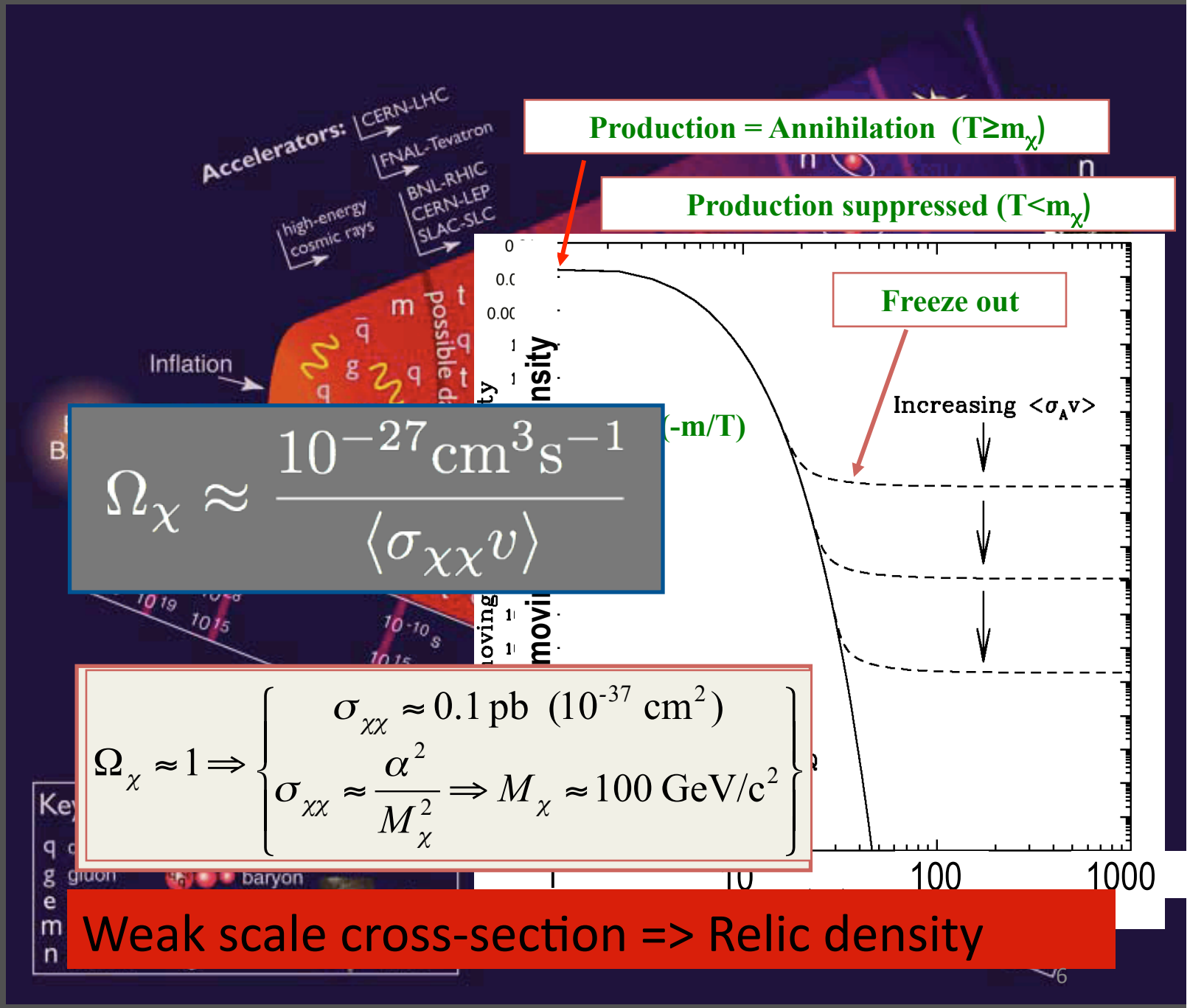


Confession:

95% of the content of the Universe is **unknown**



Weakly
Interacting
Massive
Particles



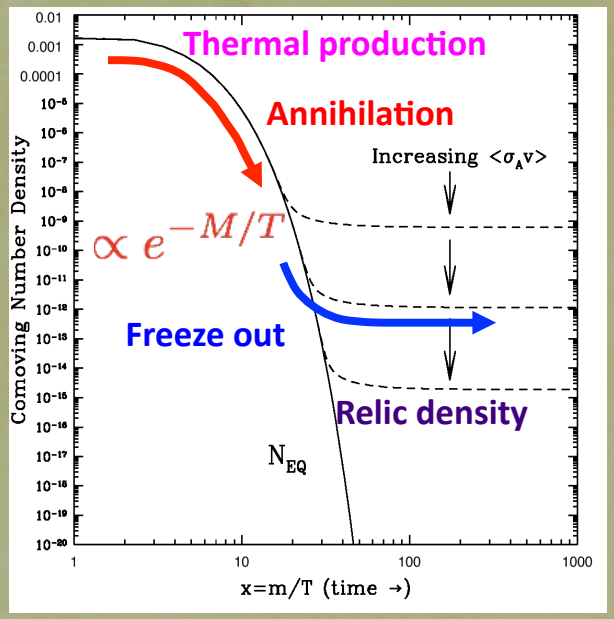
$$\Omega_\chi \approx \frac{10^{-27}\,\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma_{\chi\chi} v \rangle}$$

$$\Omega_\chi \approx 1 \Rightarrow \left\{ \begin{array}{c} \sigma_{\chi\chi} \approx 0.1\,\mathrm{pb}\ \ (10^{-37}\ \mathrm{cm}^2) \\ \sigma_{\chi\chi} \approx \dfrac{\alpha^2}{M_\chi^2} \Rightarrow M_\chi \approx 100\ \mathrm{GeV/c}^2 \end{array} \right\}$$

Weak scale cross-section => Relic density

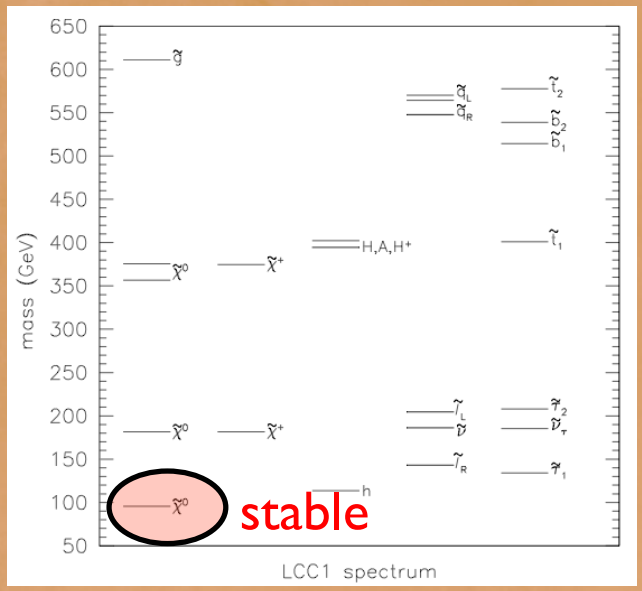
SUSY WIMPs

Cosmology



$$\Omega_\chi \approx \frac{10^{-27}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma_{\chi\chi} v \rangle}$$

Particle Physics



Baltz et al., PRD **74**, 103521 (2006)

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Strong theory motivation for **weakly interacting massive particles**

WIMPs in the Halo

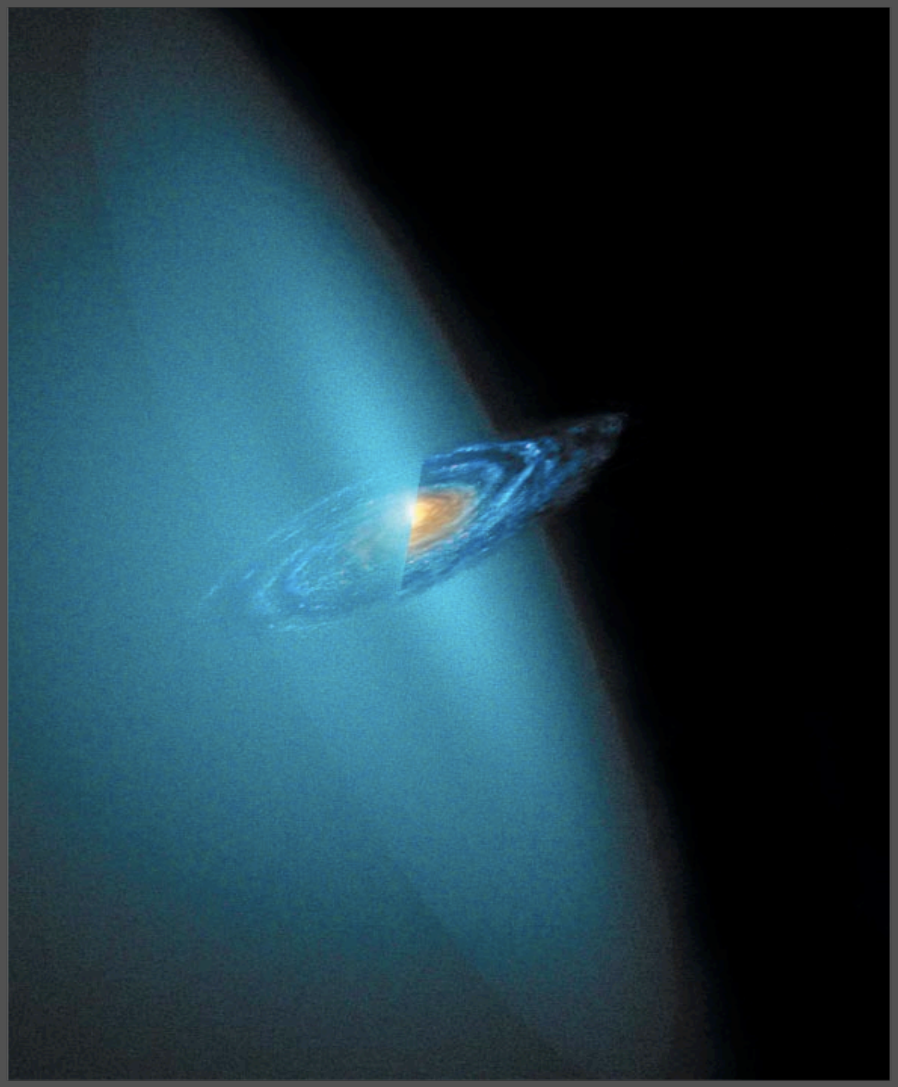
isothermal Maxwell-Boltzmann distribution:

Escape velocity=680 Km/s

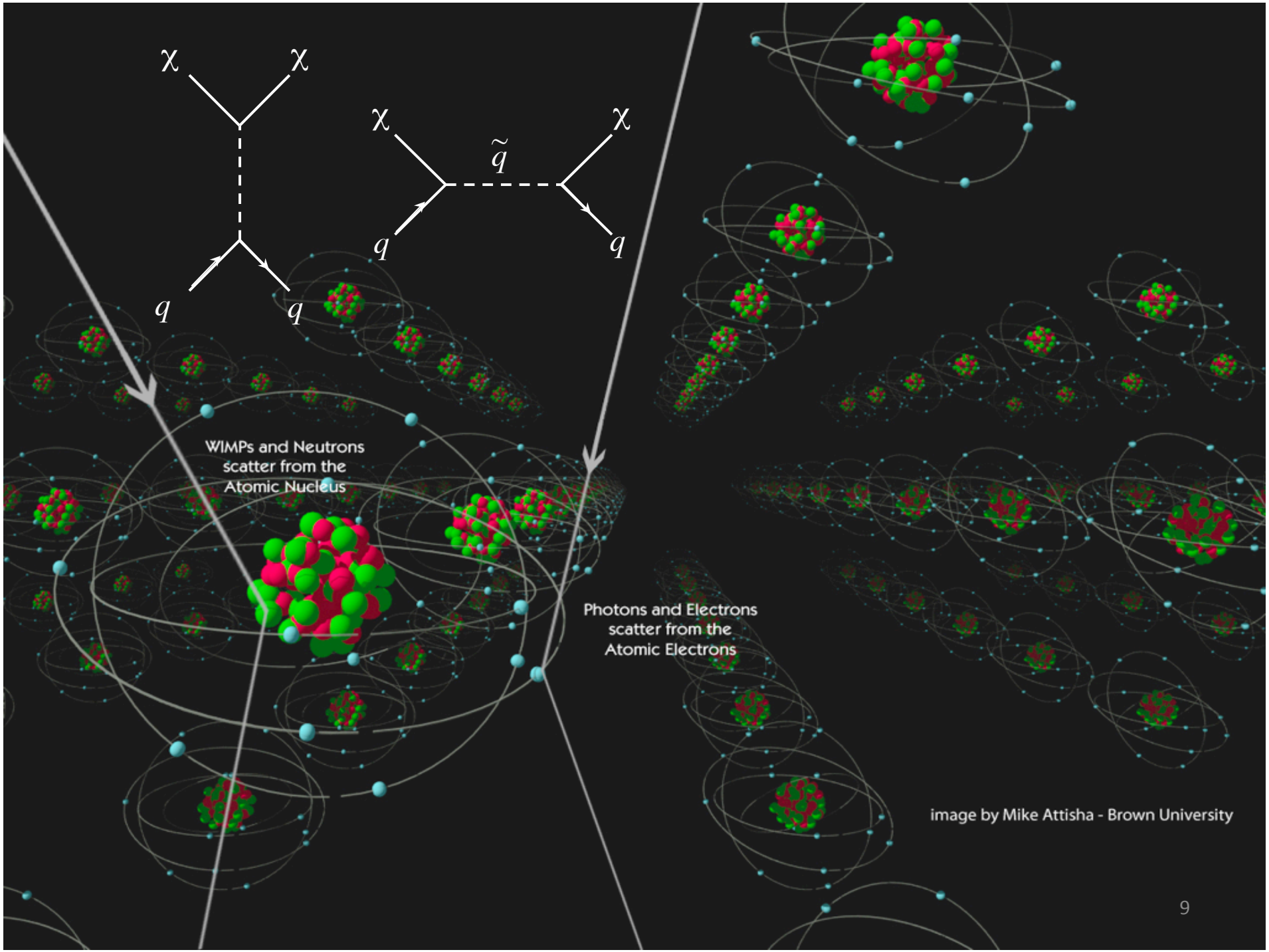
V_0 = 230 Km/s

ρ= 0.3 GeV/cm^3

Rate ~ N n_χ $\langle\sigma_\chi\rangle$



D. Cline, *Scientific American* 2003


χ
χ
q
q
χ
χ
$\tilde{q}$
q
q
WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons
image by Mike Attisha - Brown University

WIMPs in the Halo

isothermal Maxwell-Boltzmann distribution:

Escape velocity=680 Km/s

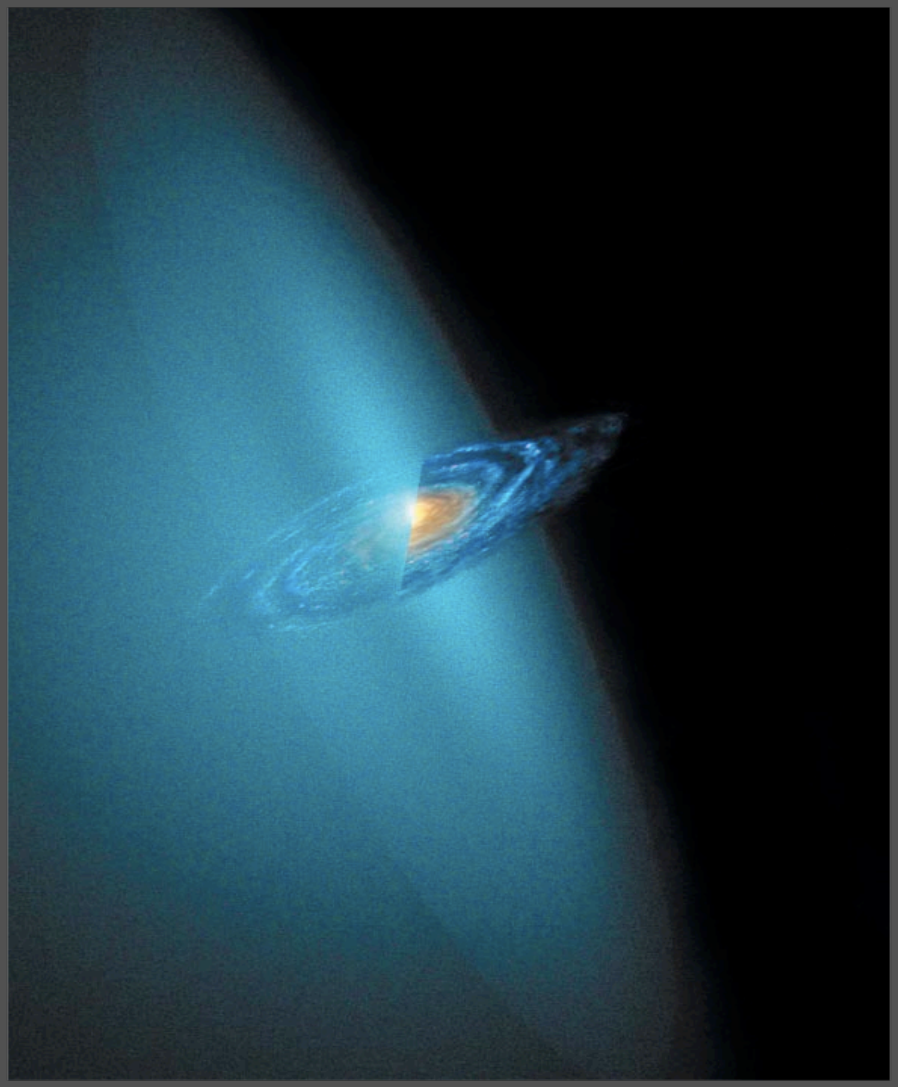
V_0 = 230 Km/s

ρ= 0.3 GeV/cm^3

Rate ~ N n_χ $<\sigma_\chi>$

Few 10s of keV recoil energy

Rate < 0.1 event/kg/day



D. Cline, *Scientific American* 2003

Direct detection challenges:

Backgrounds, Backgrounds and again Backgrounds

- Search sensitivity (low energy region <<100 keV)

  - ❑ **Current Exp Limit < 1 evt/kg/20 days, ~< 10^{-1} evt/kg/day**
  - ❑ **Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day**

- Activity of typical Human

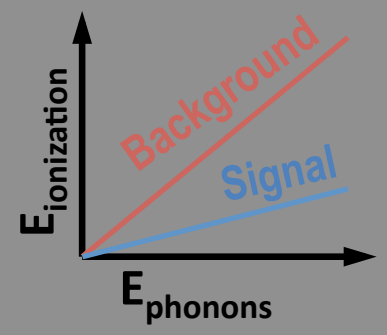
  - ❑ **~10 kBq (10^4 decays per second, 10^9 decays per day)**

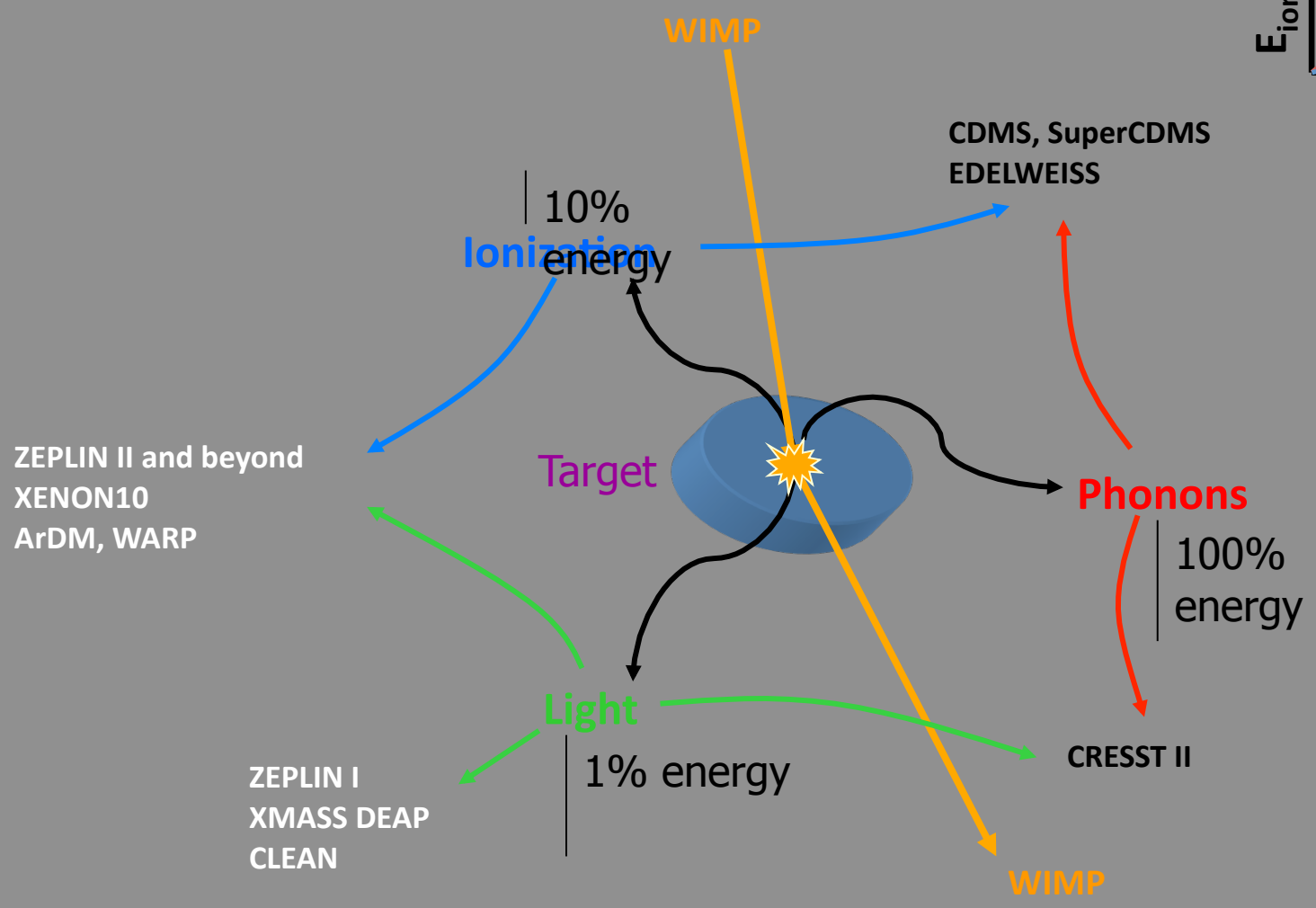
- Environmental Gamma Activity in unshielded detector

  - ❑ **10^7 evt/kg/day (all values integrated 0–100 keV)**
  - ❑ **This can be reduced to ~10^2 evt/kg/day using 25 cm of Pb**

An event-by-event discrimination based on Nuclear versus Electron recoil is therefore inevitable!

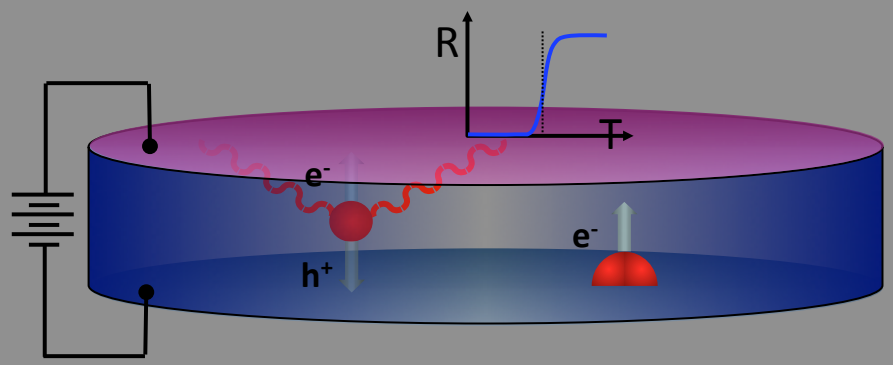
Event-by-event discrimination

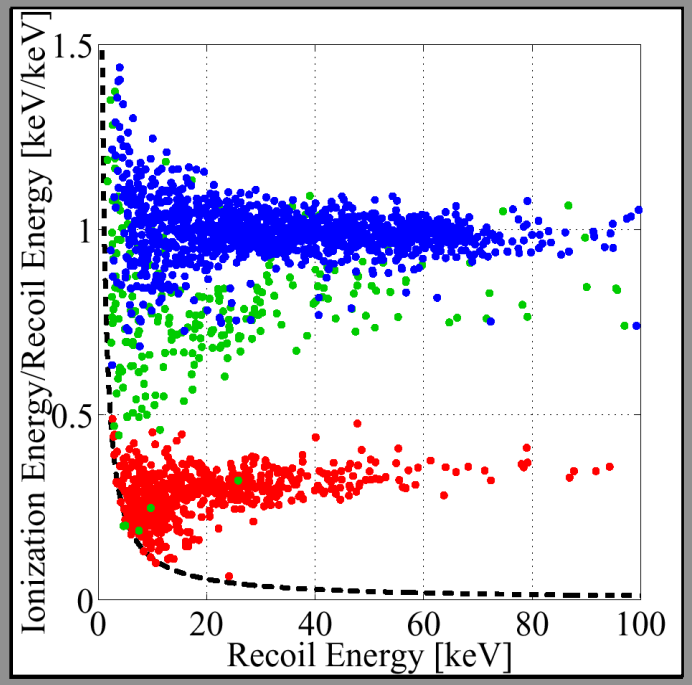




Detection Principle

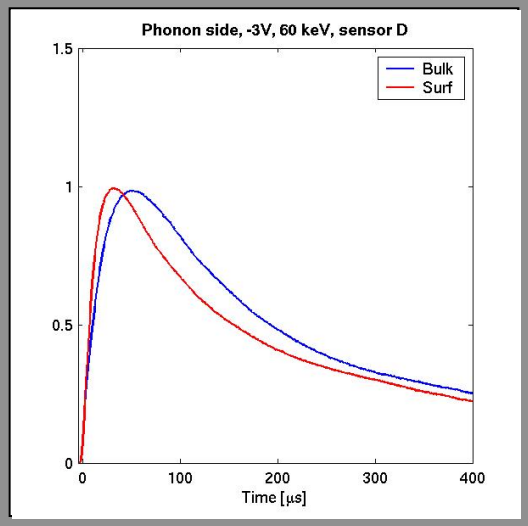
- Measure recoil energy via Lattice vibrations (phonons) in Ge or Si
- Measure the Ionization
- Ionizing power (Ionization yield:Y)
  - $Y_{electron\text{-}recoil} > Y_{nuclear\text{-}recoil}$
  - Event-by-event discrimination
- Near surface events
  - Electron recoil but poor charge collection
  - Near geometrical boundaries





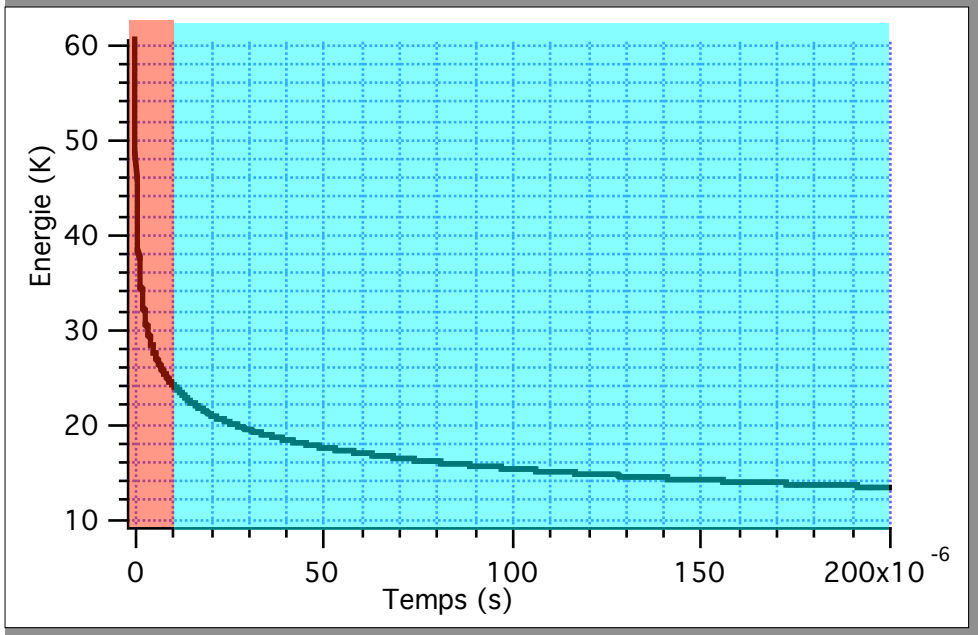
Evolution of phonons after particle interaction

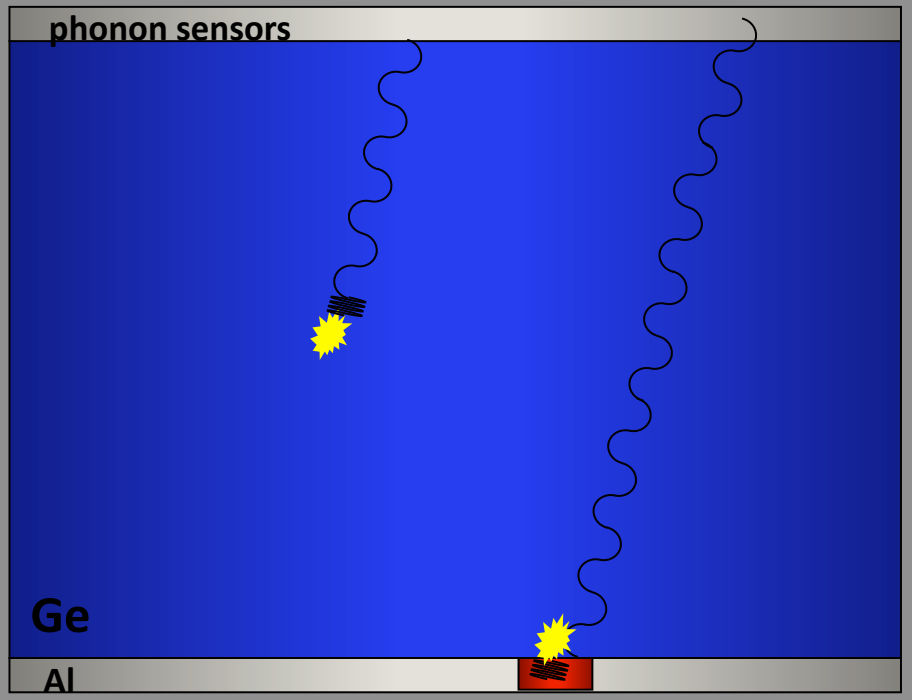
$$\frac{\partial n(E,r,t)}{\partial t} = D(E)\nabla^2 n(E,r,t) - \left\{ AE^5 n(E) - \int_E^{\infty} AE'^5 P(E',E) n(E') dE' \right\}$$



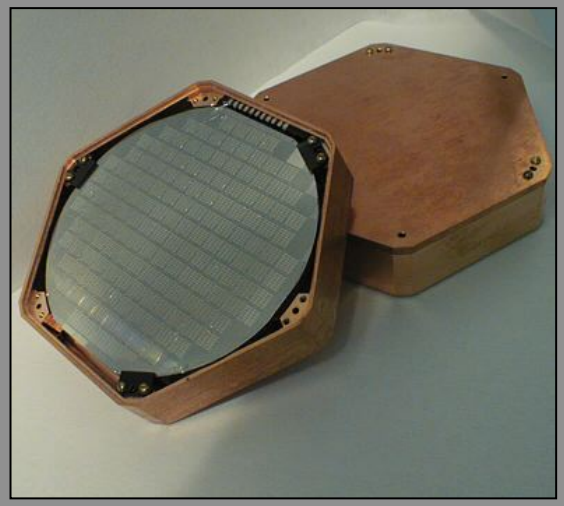
A) After ≈ 10 μs scattering rates very low: Ballistic Energy transport

B) For t< 10us phonons spectrum changes rapidly



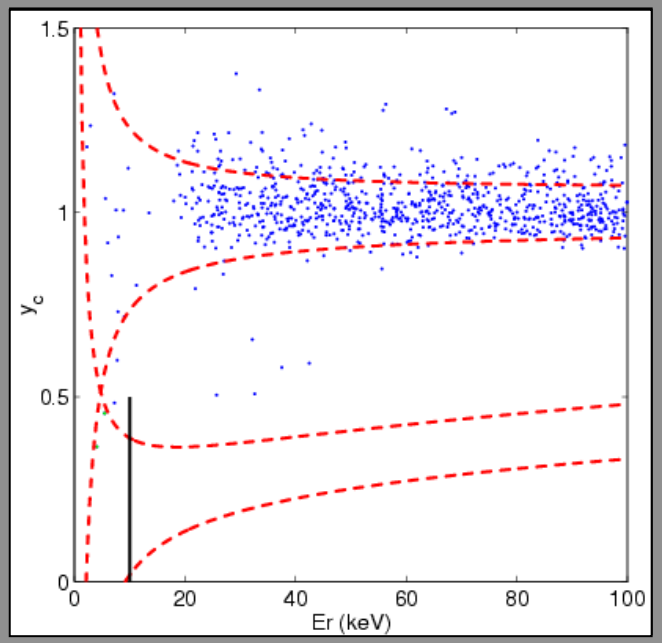


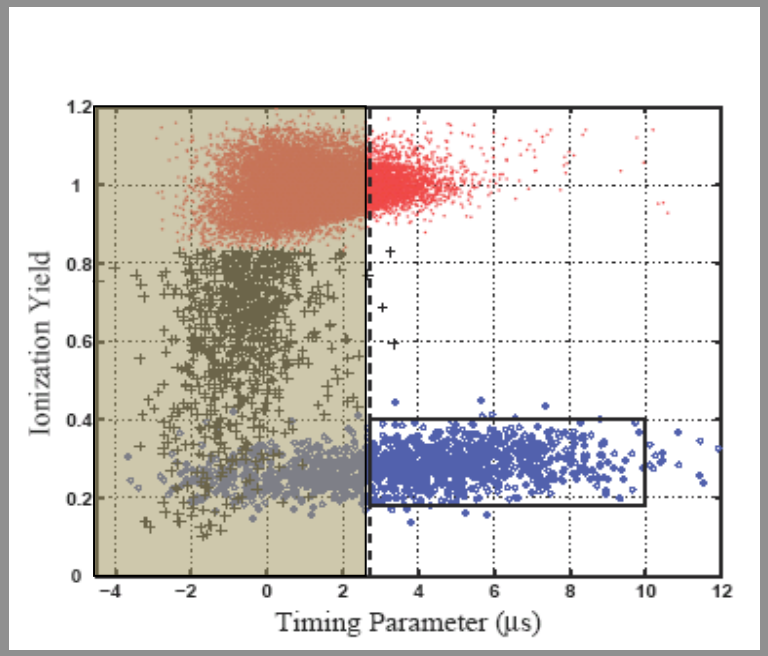
ZIPs , Timing Parameters and:
Identification of the near surface events



- Ge (0.25 kg), Si (0.1 kg)
  - Φ=7.5 cm, h=1 cm
- Athermal phonon-sensors covering one face:

  Quasi particle trapping (Al 40% surface coverage) Transition Edge Sensors (Fe implanted W Tc~80 mK).
- Catch phonons before equilibrium: Measure **Energy** AND find **position**





Reject <u>99.9998%</u> of **Gammas**, <u>99.8%</u> of **surface** events

Status before this analysis

1 kg Ge

52.6 kg.days
10/2003 to 01/2004

1.5 kg Ge

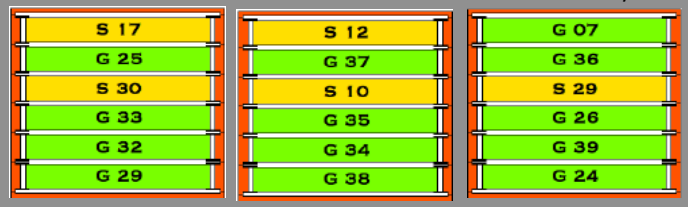
93.1 kg.days
03/2003 to 08/2004

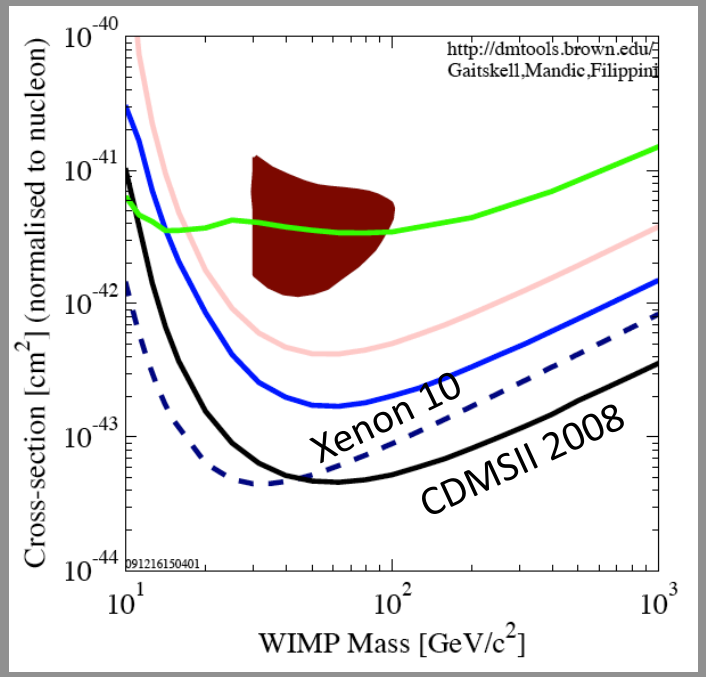
Important progress based on the previous runs:
Better timing rejection, Better phonon sensor tuning
Better background and background rejection

4.5 kg Ge

397 kg.days
10/2006 to 03/2007

1200kg.days
04/2006 to





Phys. Rev. Lett. **93, 211301 (2004)**
Phys. Rev. Lett. **96, 011302 (2006)**
Phys. Rev. Lett. **102, 011301 (2009)**

CDMS Collaboration

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S. Arrenberg, T. Bruch, L. Baudis, M. Tarka

** new collaborators or new institutions in SuperCDMS*

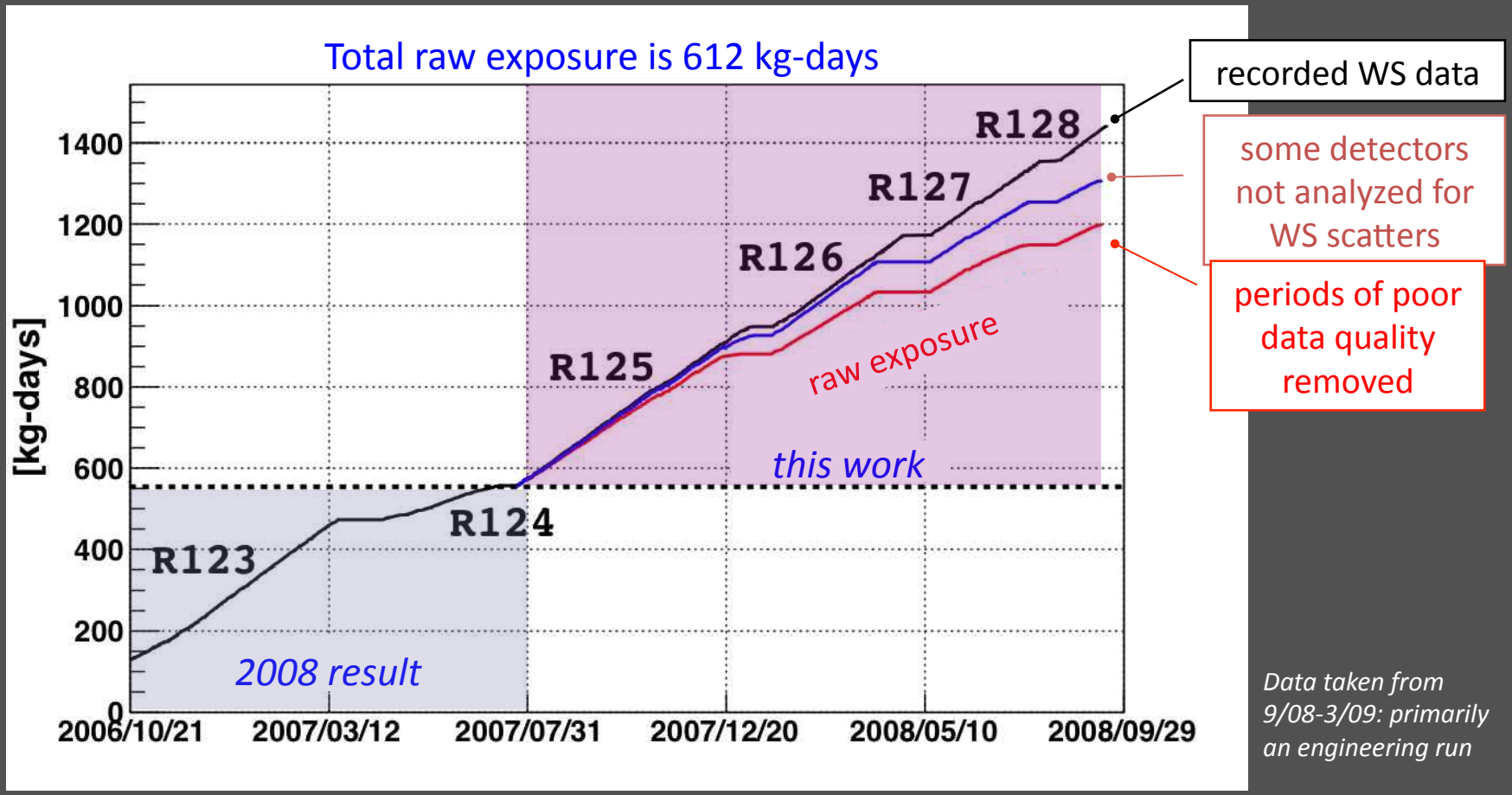
CDMSII run 125-128

(*This presentation*)

WIMP Search Exposure

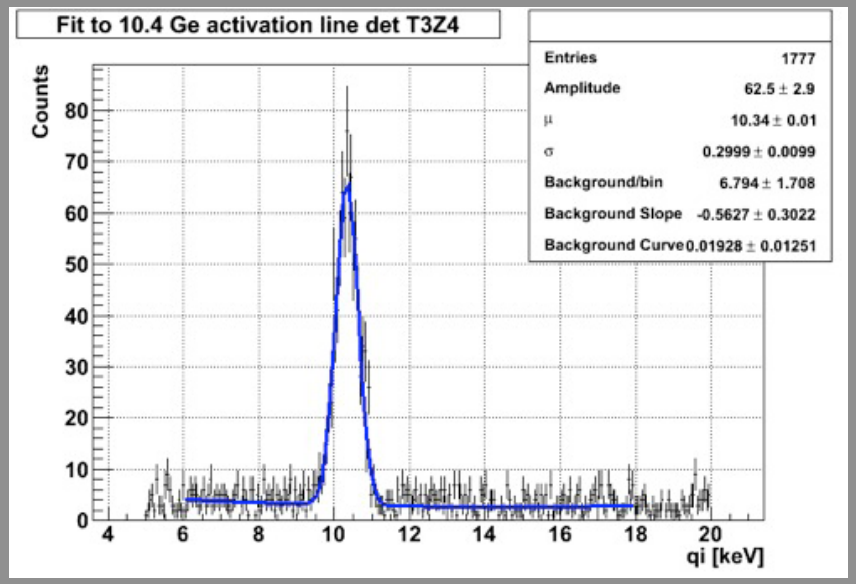
4 runs separated by partial warm-ups of cryostat

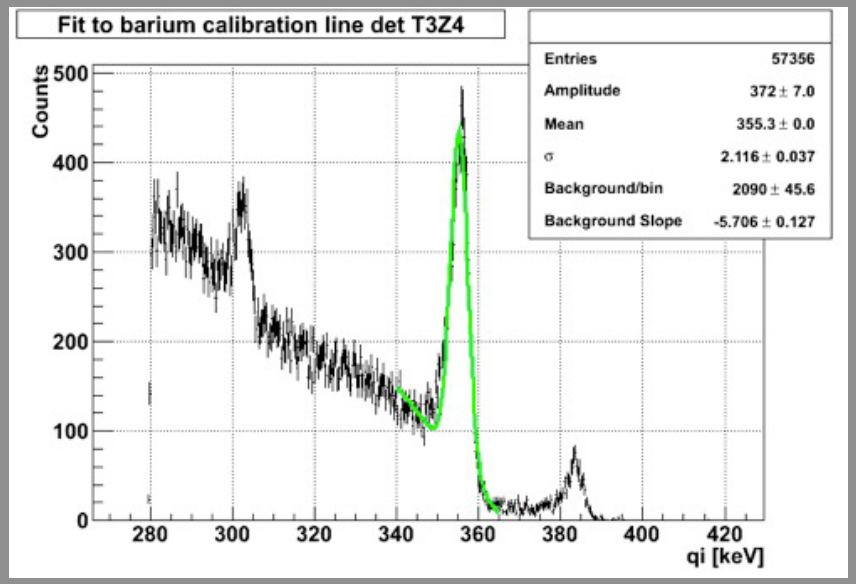
Dates of data taking: 7/2007 - 9/2008



Data taken from 9/08-3/09: primarily an engineering run

Calibration (1)





Two Sources:

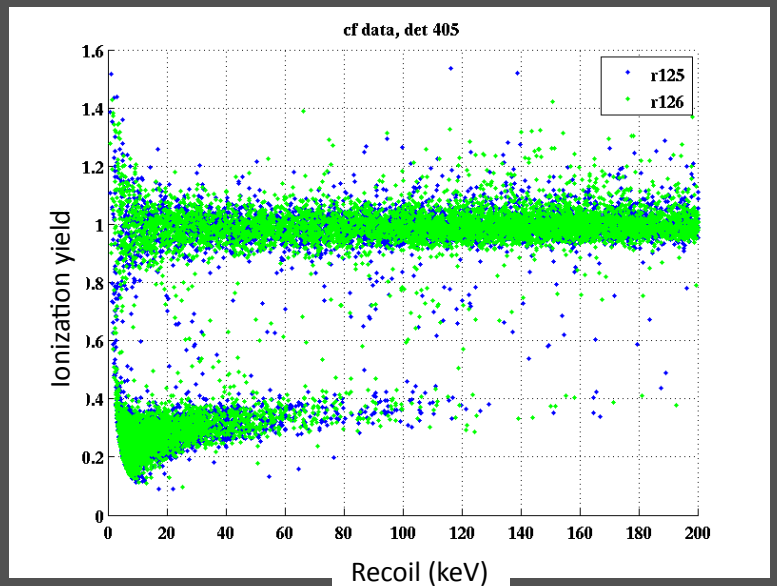
^{133}Ba: γ-lines at 303, 356 & 384 keV

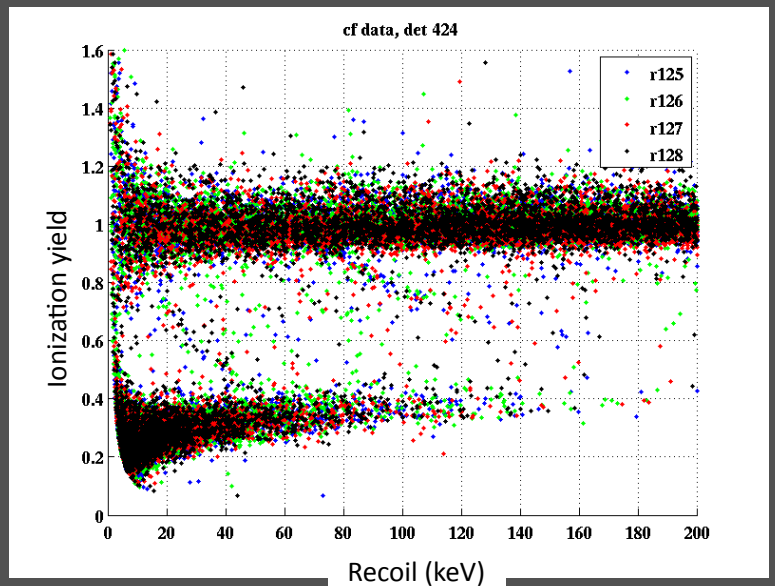
^{252}Cf: neutrons ~few MeV, neutron activation of Ge → 10.4 keV γ-line

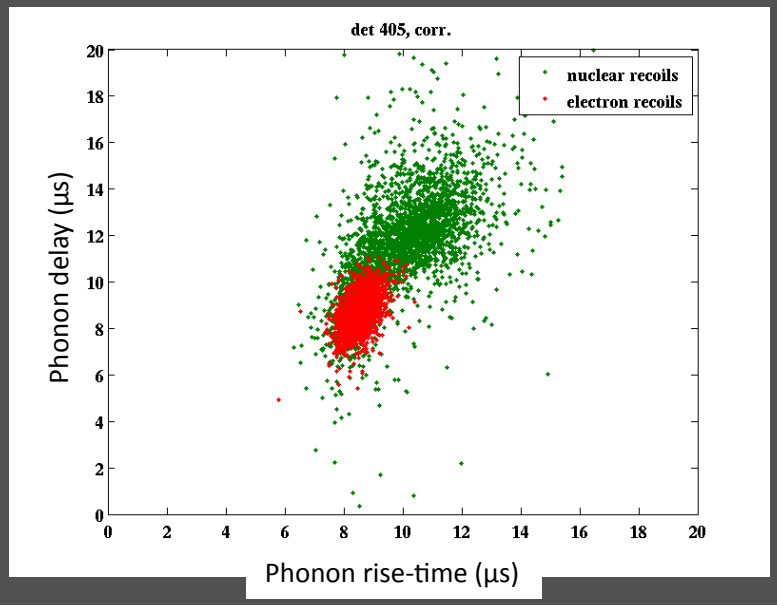
Many Uses:

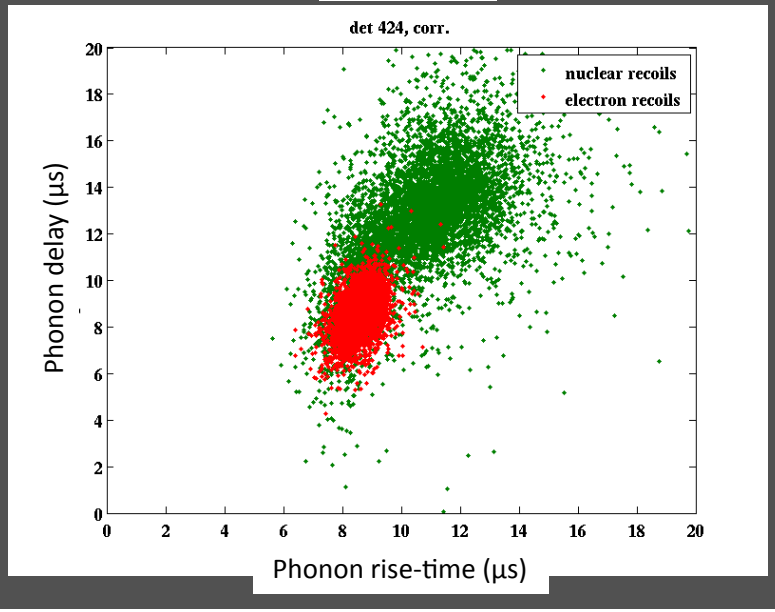
- In-situ measurement of energy scale
- resolution and linearity
- position correction
- measure selection efficiencies
- develop surface event rejection

Calibration (2)



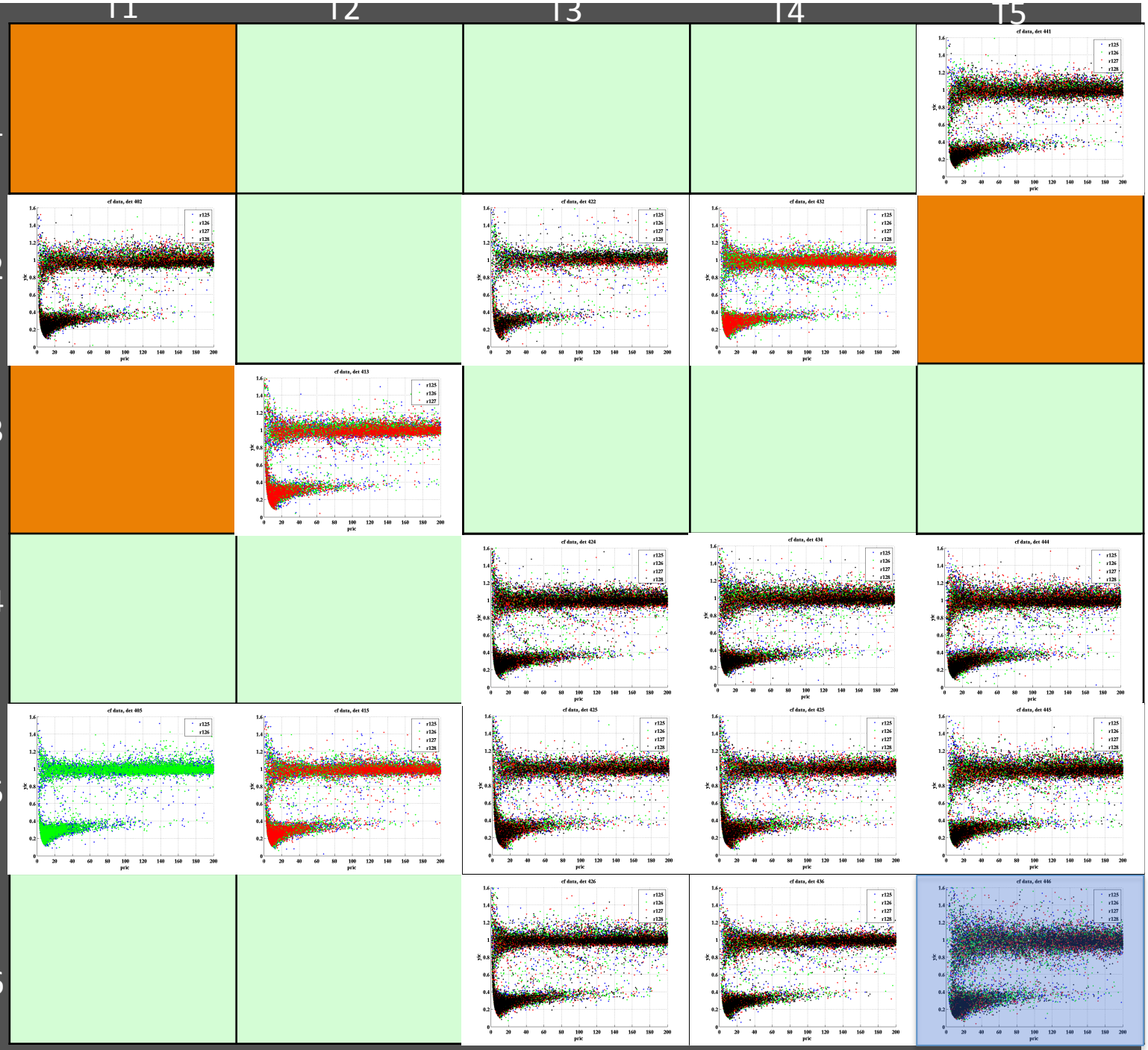






Silicon

Ge but Continuity failure



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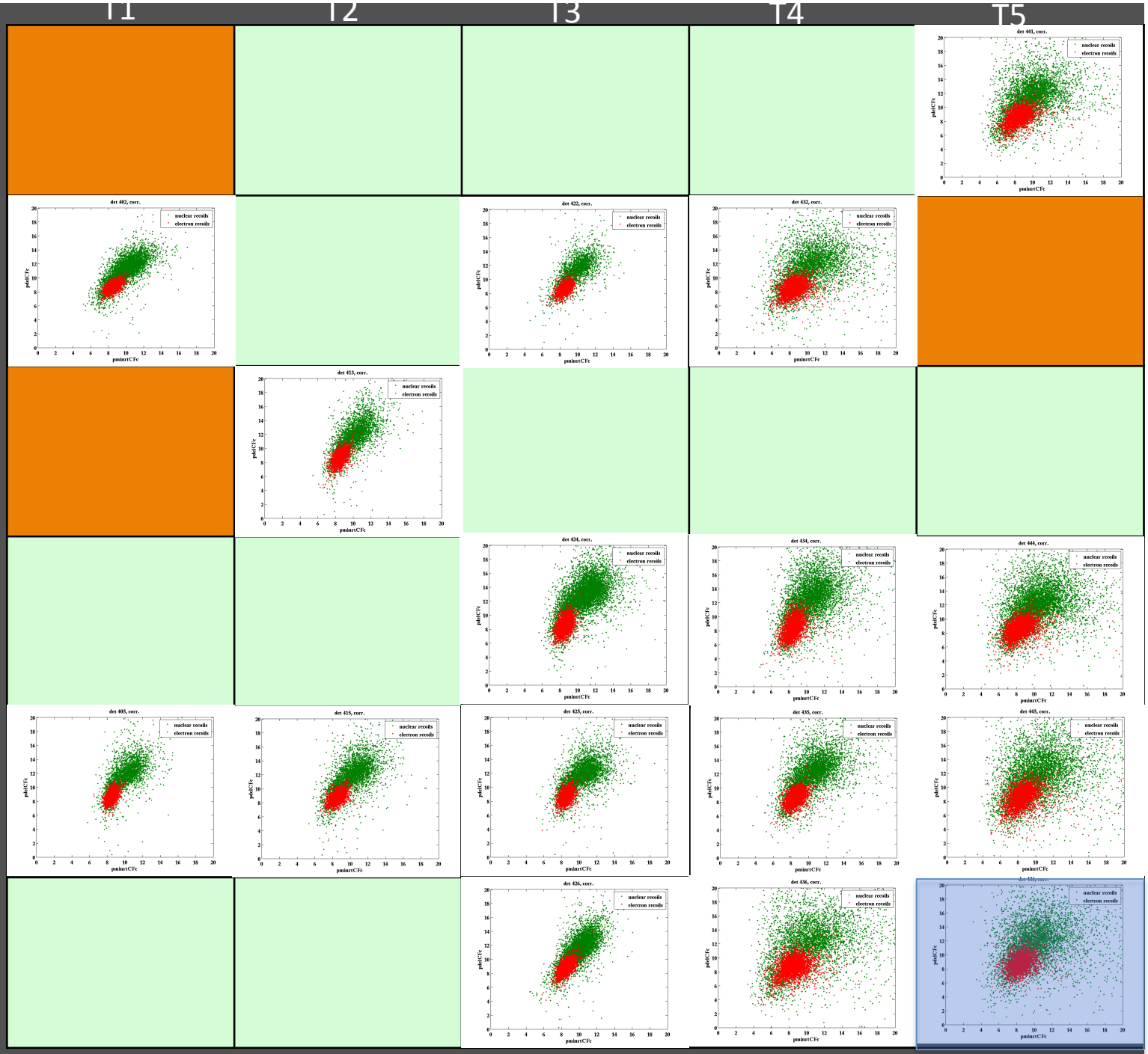


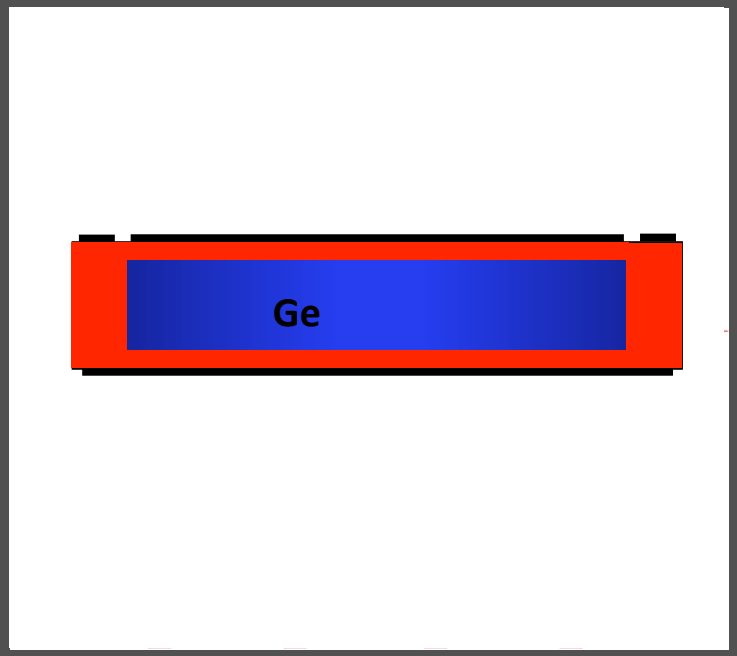
Analysis Steps

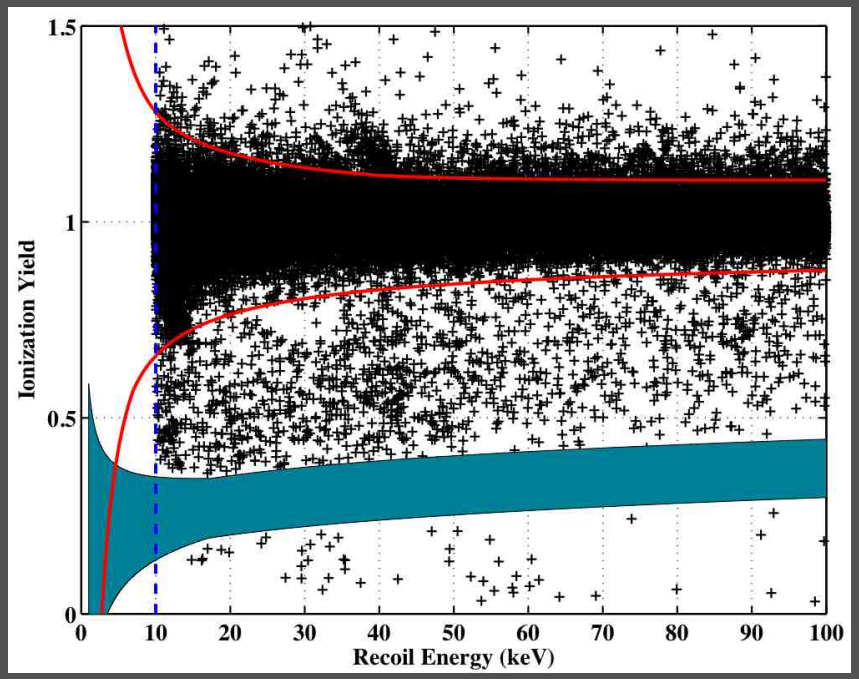
Blind analysis: NR singles veto anti-coincident masked (3σ)

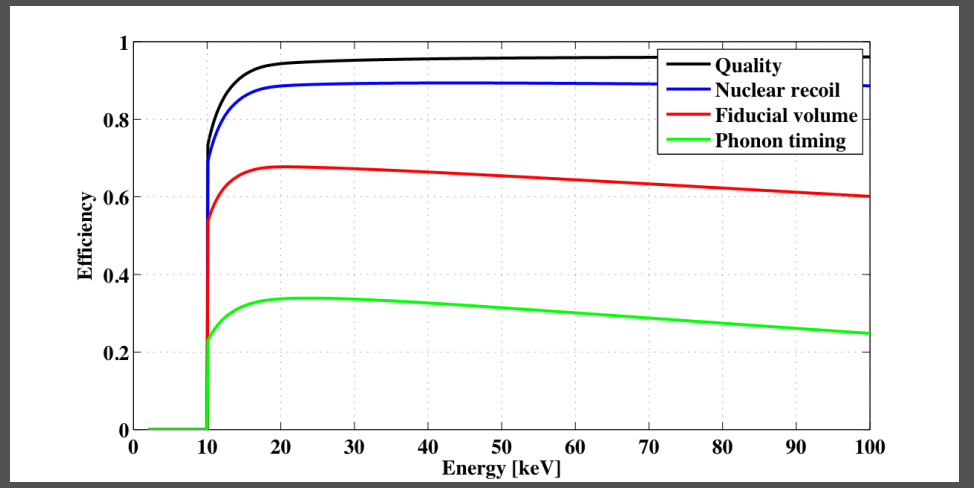
Data quality cuts

Physics cuts:

- Veto coincident
- Single scatter
- Q_{inner} (fiducial volume) cut
- Phonon timing



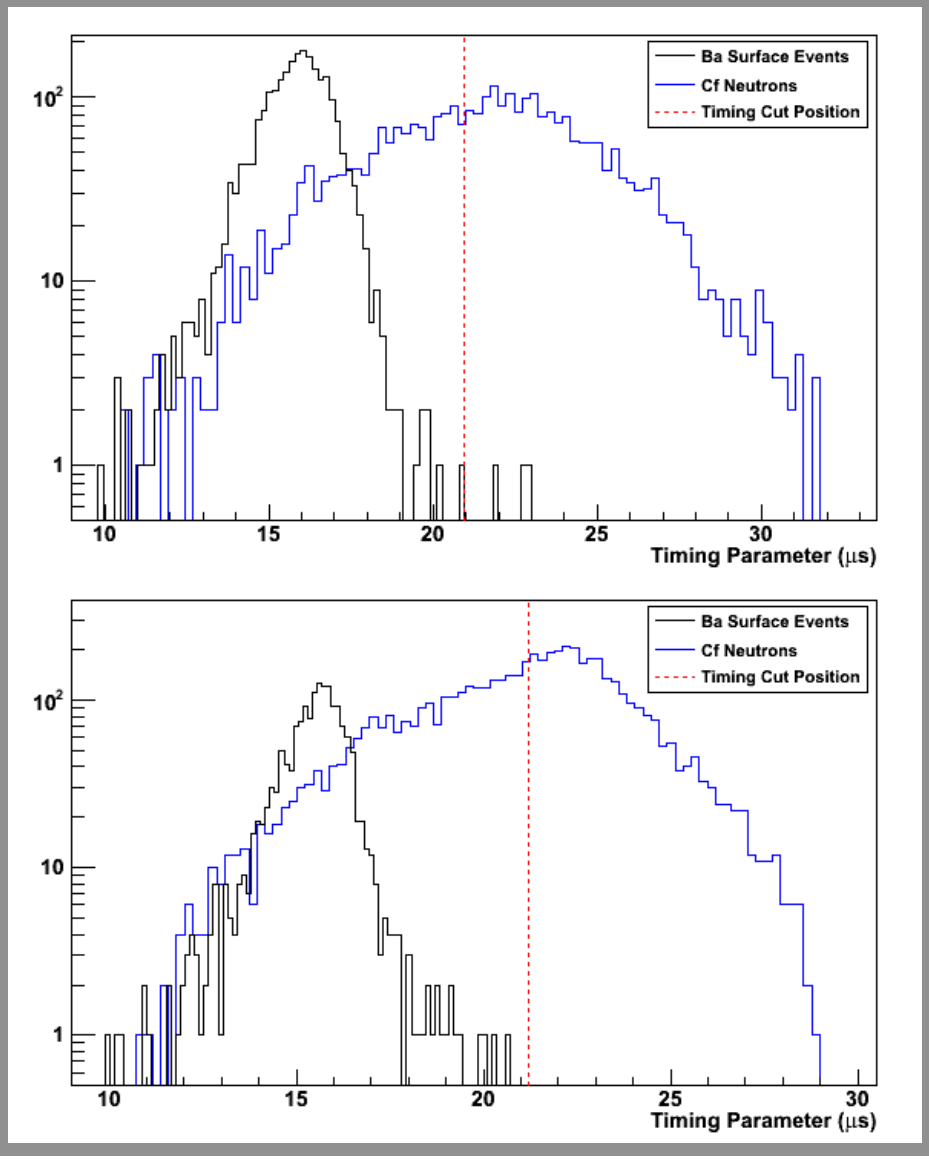




expected background

Surface Event Background

^{133}Ba provides surface events for tuning the surface event rejection cut.



We optimized for the best sensitivity while maintaining < 1 expected background.

Setting the cut on the tails of the distribution

Accounting for systematic differences between surface events in ^{133}Ba and WIMP-search datasets

Surface Event "Leakage"

$$\text{Expected surface leakage} = \frac{N^{\text{sideband}}_{\text{passing cut}}}{N^{\text{sideband}}_{\text{failing cut}}} * N^{\text{data}}_{\text{failing cut}}$$

3 independent sidebands for estimating the passing/failing ratio

SIDEBAND 1

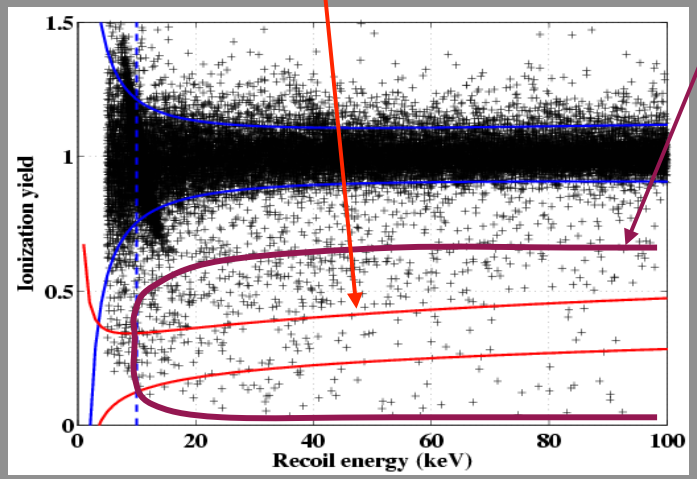
Use multiple-scatters in NR band

SIDEBAND 2

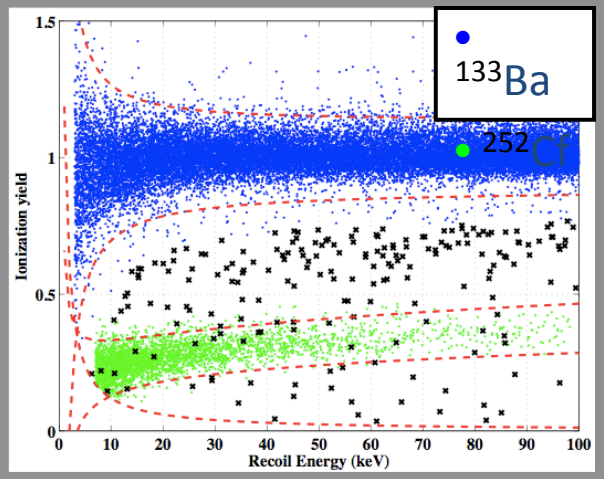
Use singles and multiples just outside NR band

SIDEBAND 3

Use singles and multiples from Ba calibration in wide region



Correct for systematic effects due to different distributions in energy and face



All 3 consistent, leakage (before unblinding) = 0.6 ± 0.1 (stat.)

Estimated Neutron Background

Cosmogenic Neutron Estimate:

$$\frac{N^{MC}_{\text{unvetoed, single NR}}}{N^{MC}_{\text{vetoed, single NR}}} * N^{data}_{\text{vetoed, single NR}} = 0.04^{+0.04}_{-0.03} \text{ (stat.) events}$$

From GEANT4 and FLUKA simulations

3 vetoed, single NR (in whole Soudan dataset)

Radiogenic Neutron Estimate:

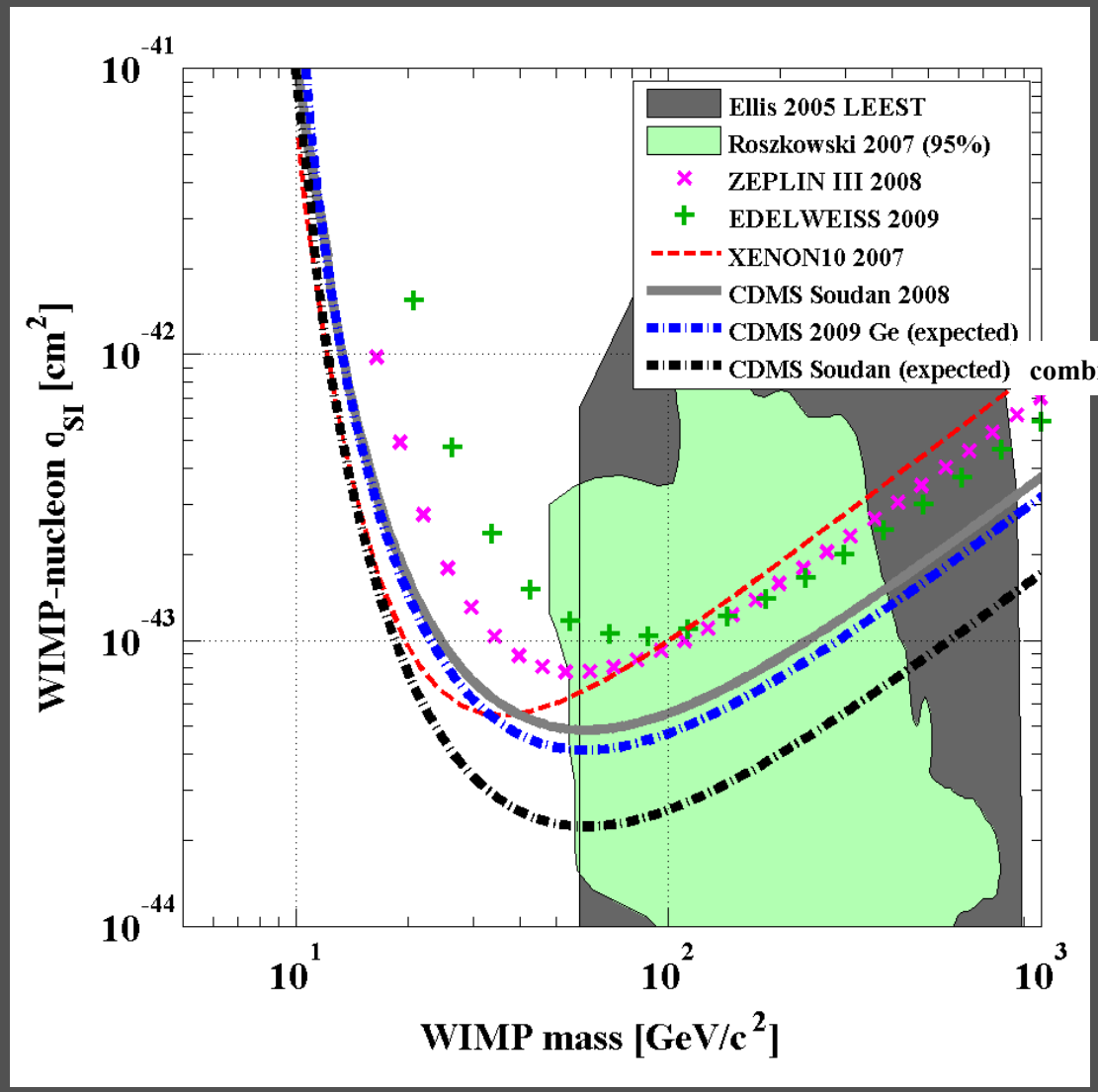
0.03 - 0.06 events

- fission in Pb shield
- (α,n) from Cu icebox

Detector contaimination measured with HP Ge detector

→ GEANT4 simulation of U/Th chains in detector materials

Expected Limit 90% C.L.



Total exposure after all cuts: 194.1 kg-days

Estimated Surface Events: 0.6 ± 0.1

Estimated Cosmogenic Neutrons: $0.04^{+0.04}_{-0.03}$

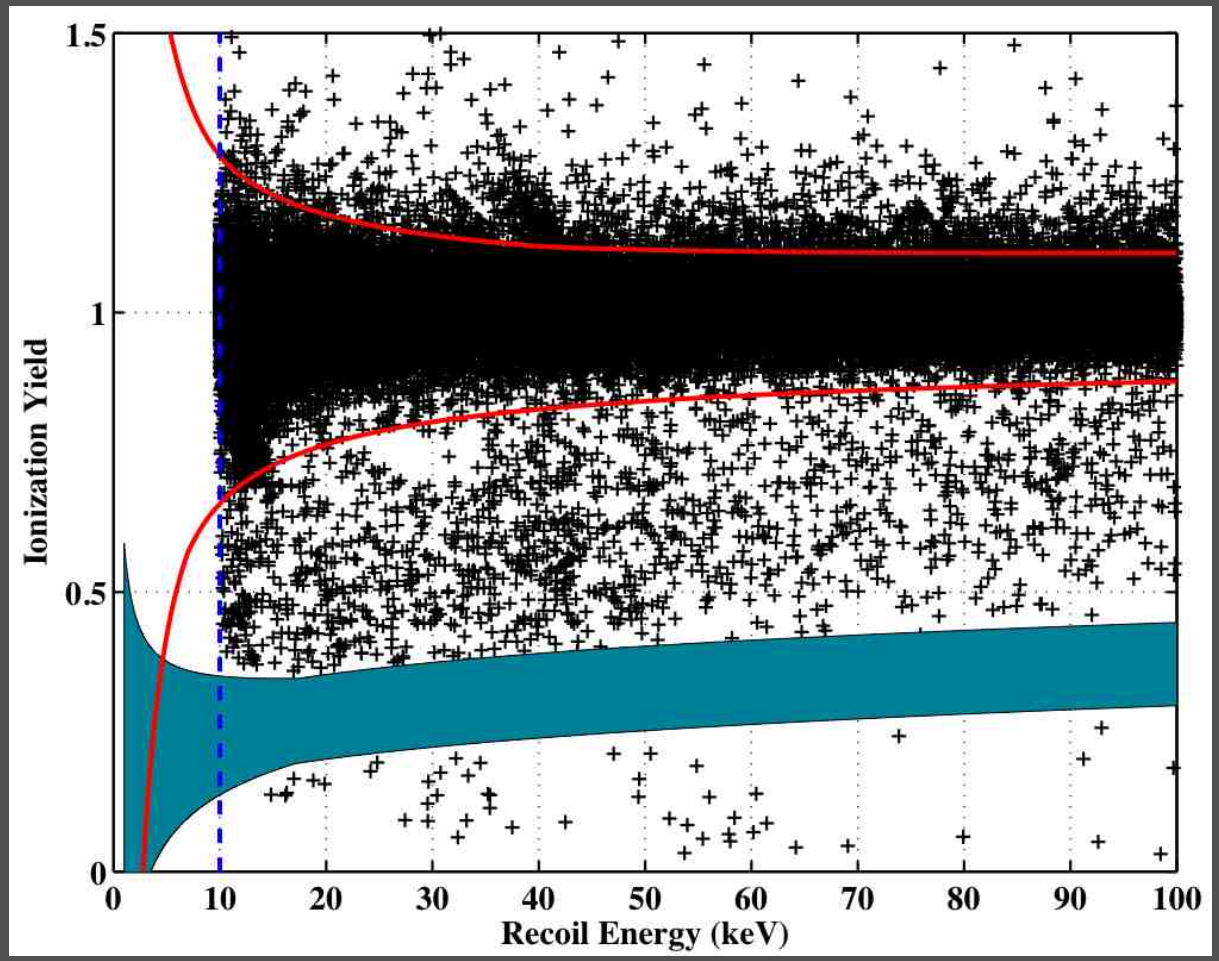
Estimated Radiogenic Neutrons: 0.03-0.06

results

Unblinding

We opened the box on Nov 5th 2009 for 14 Ge ZIP detectors

3σ region masked

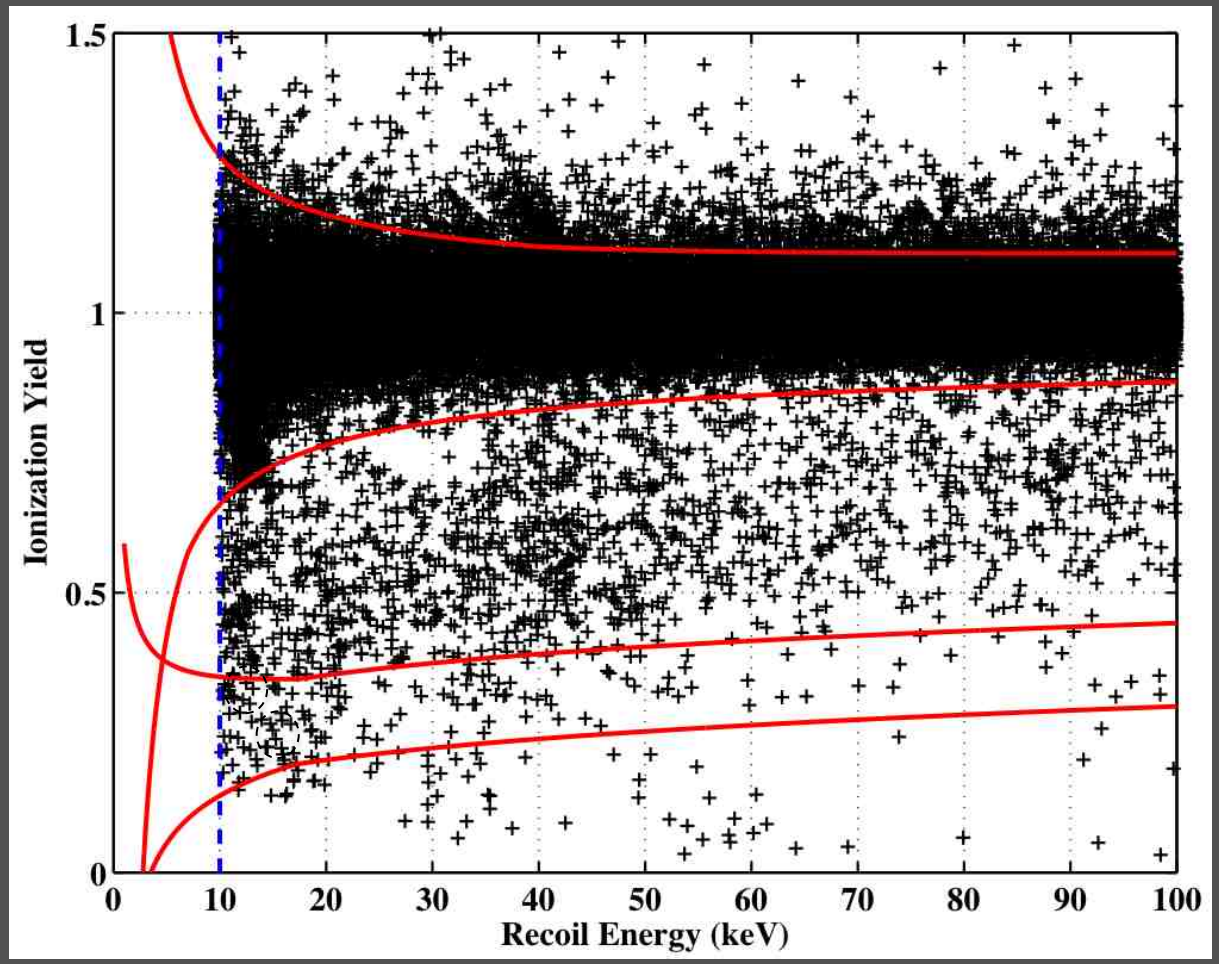


Unblinding

We opened the box on Nov 5th 2009 for 14 Ge ZIP detectors

3σ region masked

Lift mask saw 150 Singles failing timing cuts: ***Consistency deemed OK***



Unblinding

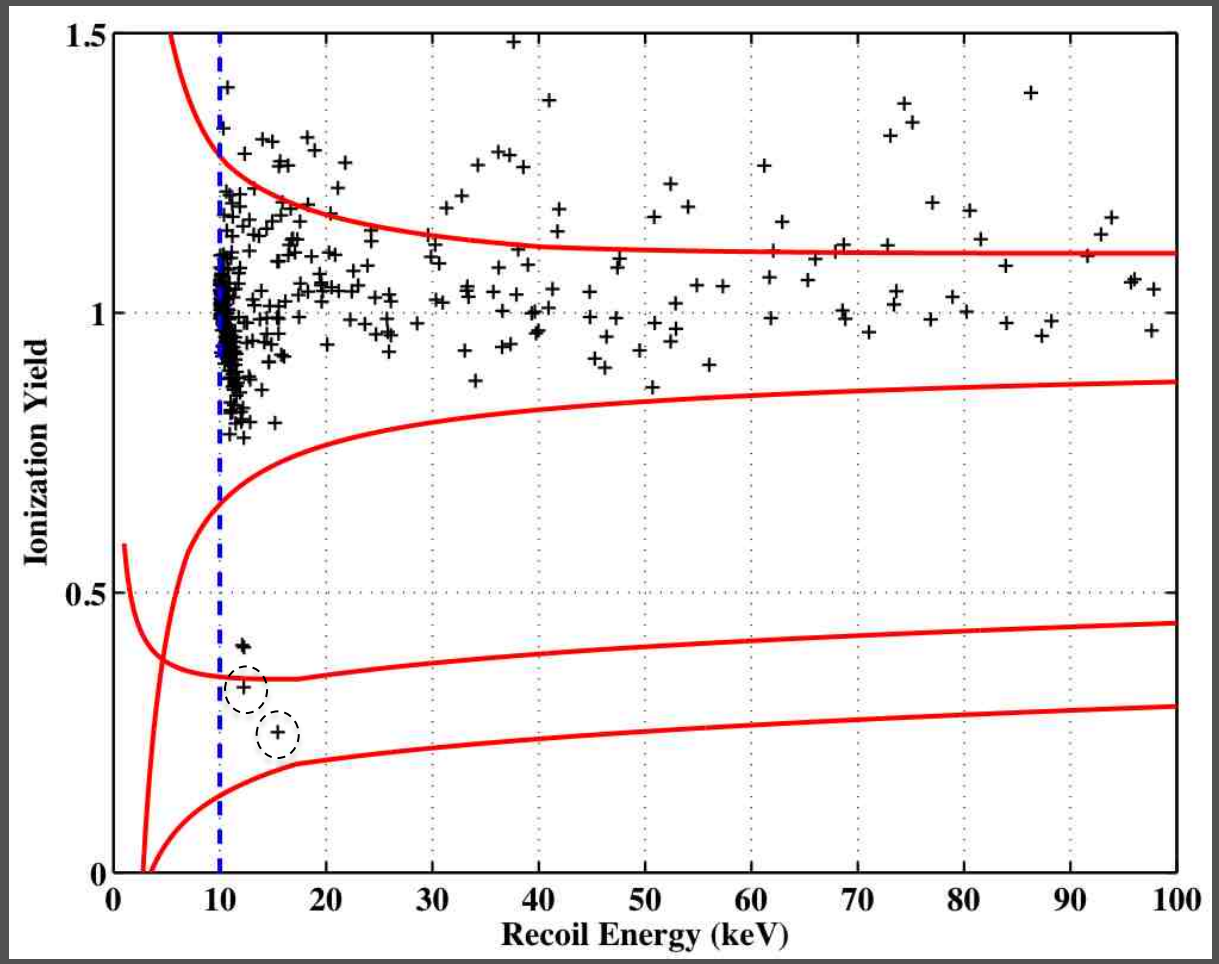
We opened the box on Nov 5th 2009 for 14 Ge ZIP detectors

3σ region masked

Lift mask saw 150 Singles failing timing cuts: ***Consistency deemed OK***

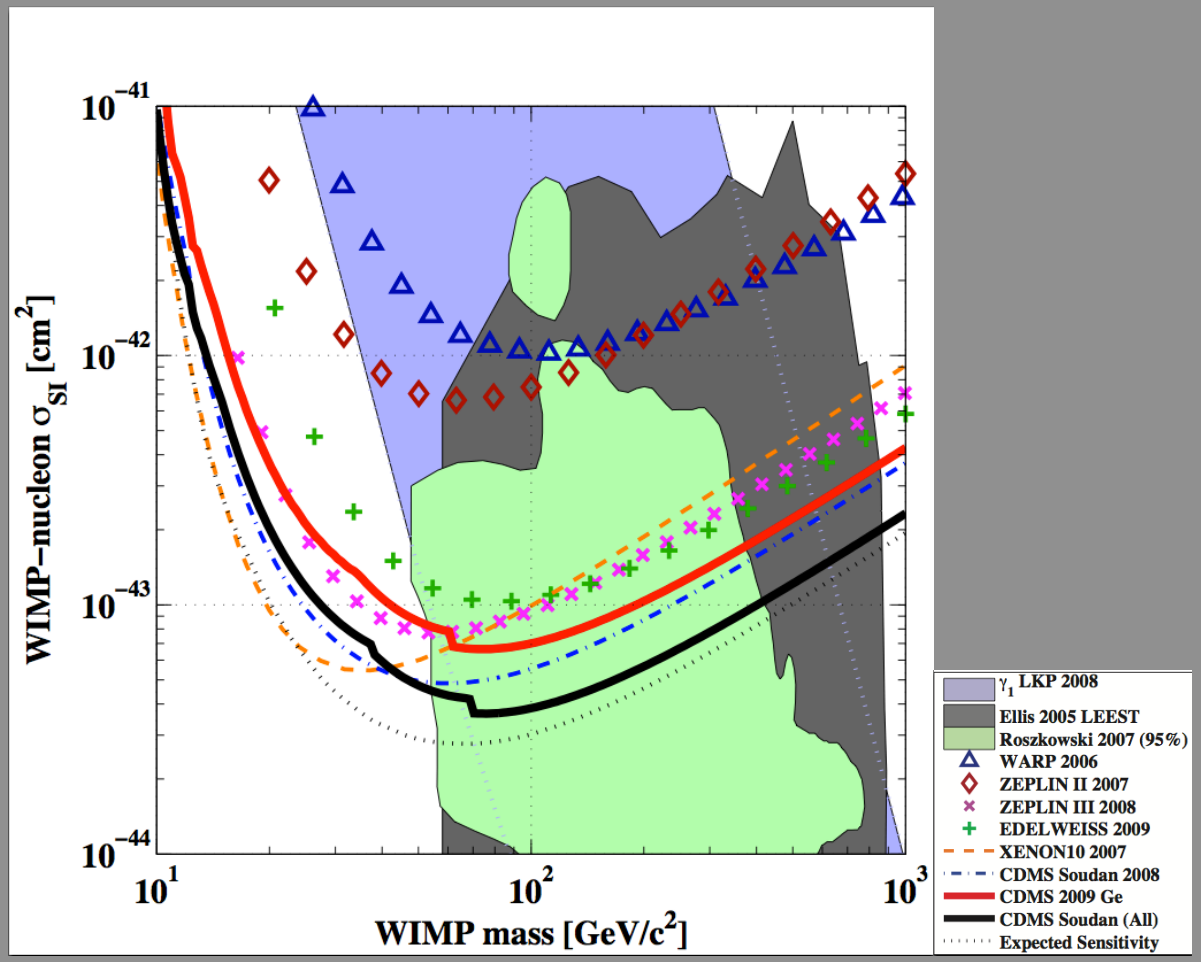
Apply timing cuts

2 events observed



arXiv:0912.3592v1 [astro-ph.CO] 18 Dec 2009

CDMS II Results

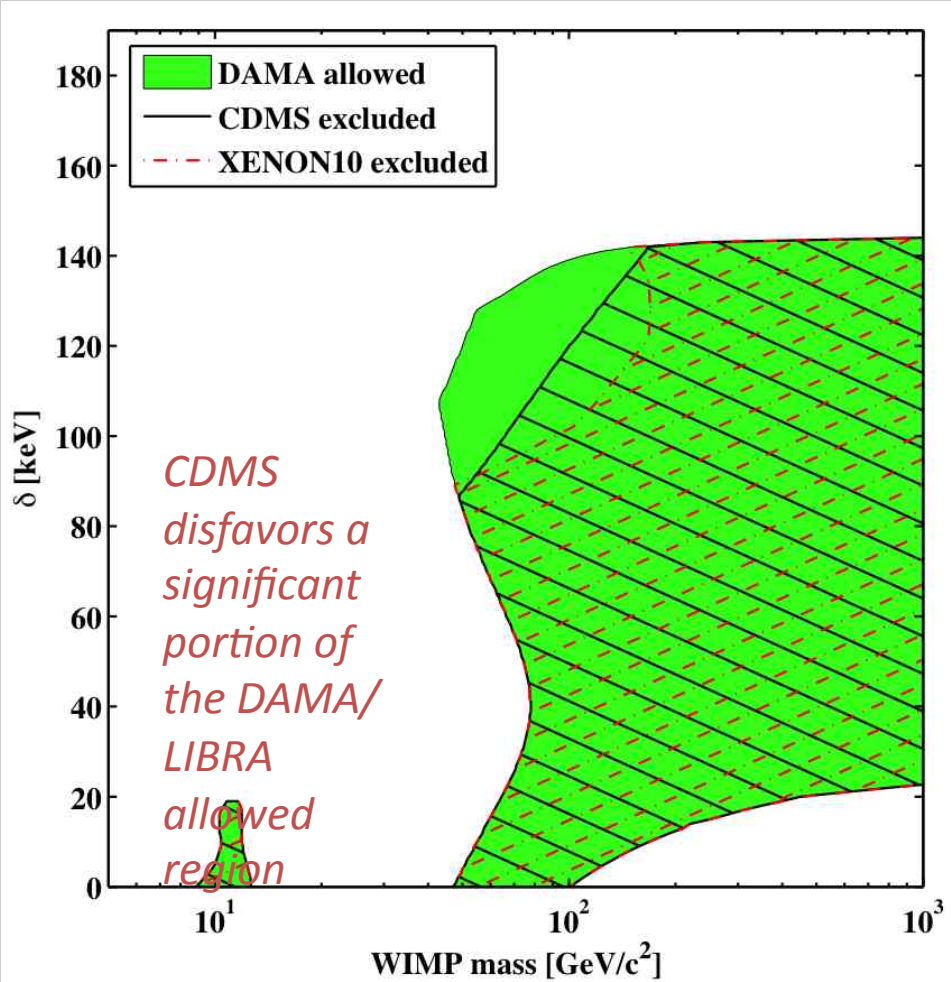


Upper limit at the 90% C.L. on the WIMP-nucleon cross section :

3.8×10^{-44} cm^2 for a WIMP of mass 70 GeV/c^2

arXiv:0912.3592v1 [astro-ph.CO] 18 Dec 2009

Inelastic Dark Matter



Has been invoked by Weiner et al. to explain DAMA/LIBRA data, among other things. [Phys. Rev. D 64, 043502 (2001)]

Scattering occurs via transition of WIMP to excited state (with mass splitting δ)

spectrum peaks at higher recoil energies

DAMA, allowed regions (at 90% C.L.) computed from χ^2 goodness-of-fit [JCAP 04 (2009) 010].

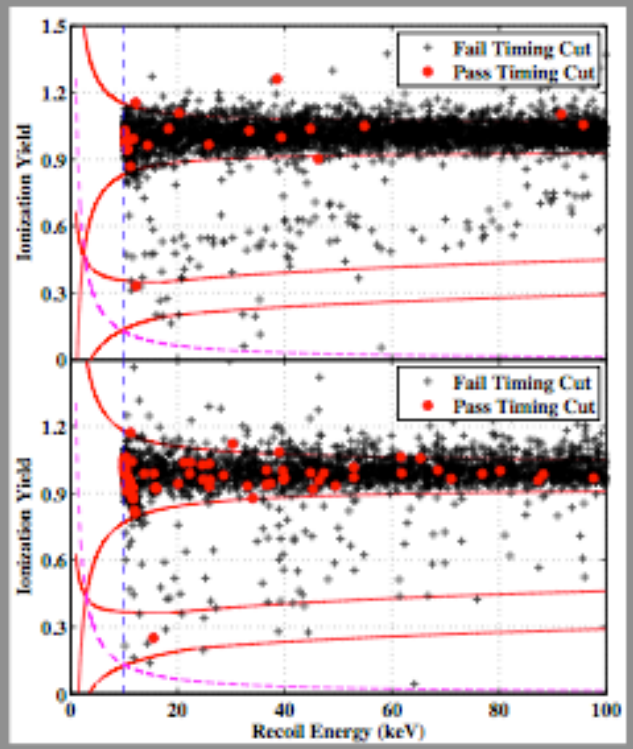
arXiv:0912.3592v1 [astro-ph.CO] 18 Dec 2009

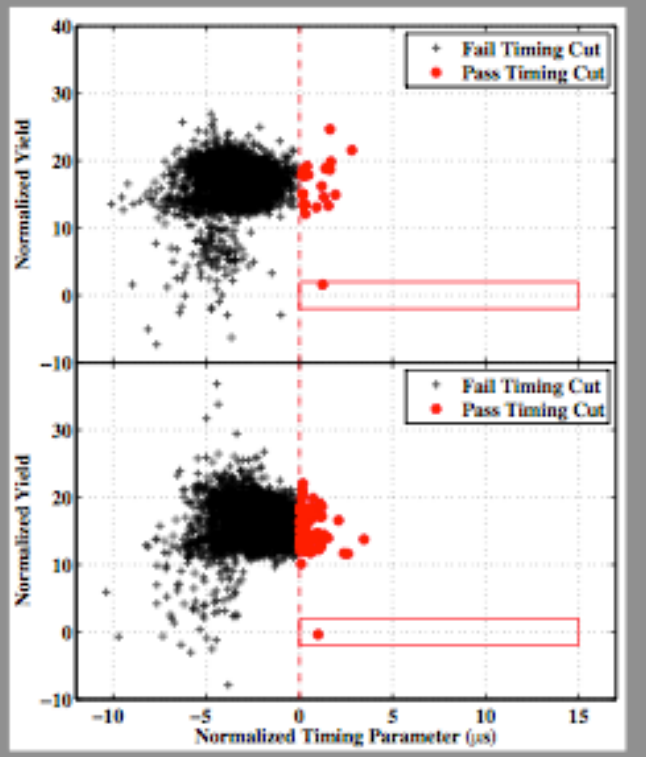
What about the 2 events?

Ionization Yield, Energy and Timing

Saturday Oct, 27th 2007

Sunday Aug, 5th 2007





Events in two different detectors in two different Towers at well separated times

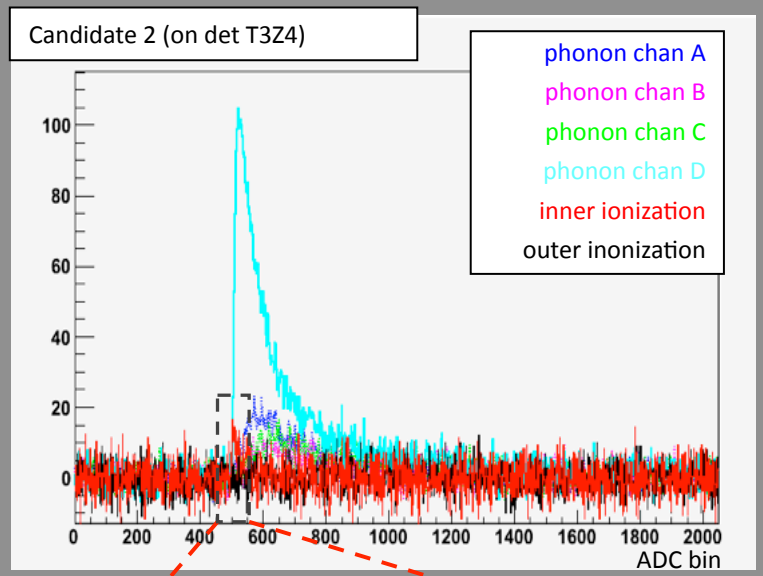
They occur in inner detectors: Better handle on backgrounds

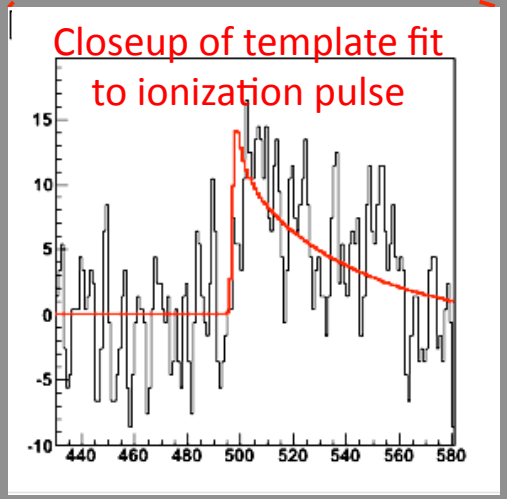
Anything wrong with the data quality we could have missed?

Data Quality Item	Result
muon veto performance	✓ *good*
neutralization	✓ *good*
KS tests	✓ *normal*
noise levels	✓ *typical*
pre-pulse baseline rms	✓ *typical*
background electron-recoil rate	✓ *typical*
surface event rate	✓ *typical*
radial position	✓ *well-contained*
single-scatter identification	✓ *good*
special running conditions	✓ *no*
operator recorded issues	✓ *no*

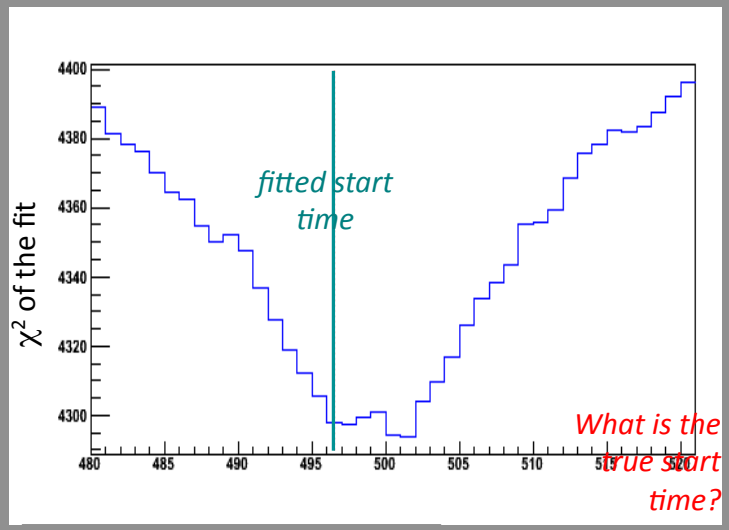
experimental performance was excellent at the time of both observed events

Reconstruction Checks (T3Z4 event)





ionization and phonon energies look good, phonon timing looks good…



This effect is strongly correlated with the ionization energy *(affects events with < 6 keV ionization energy)* and was mostly accounted for in the pre-unblinding leakage estimate.

•A refined calculation of the surface background taking into account this effect produced a post-unblinding leakage estimate of (pre unblinding: 0.6±0.1±0.2):

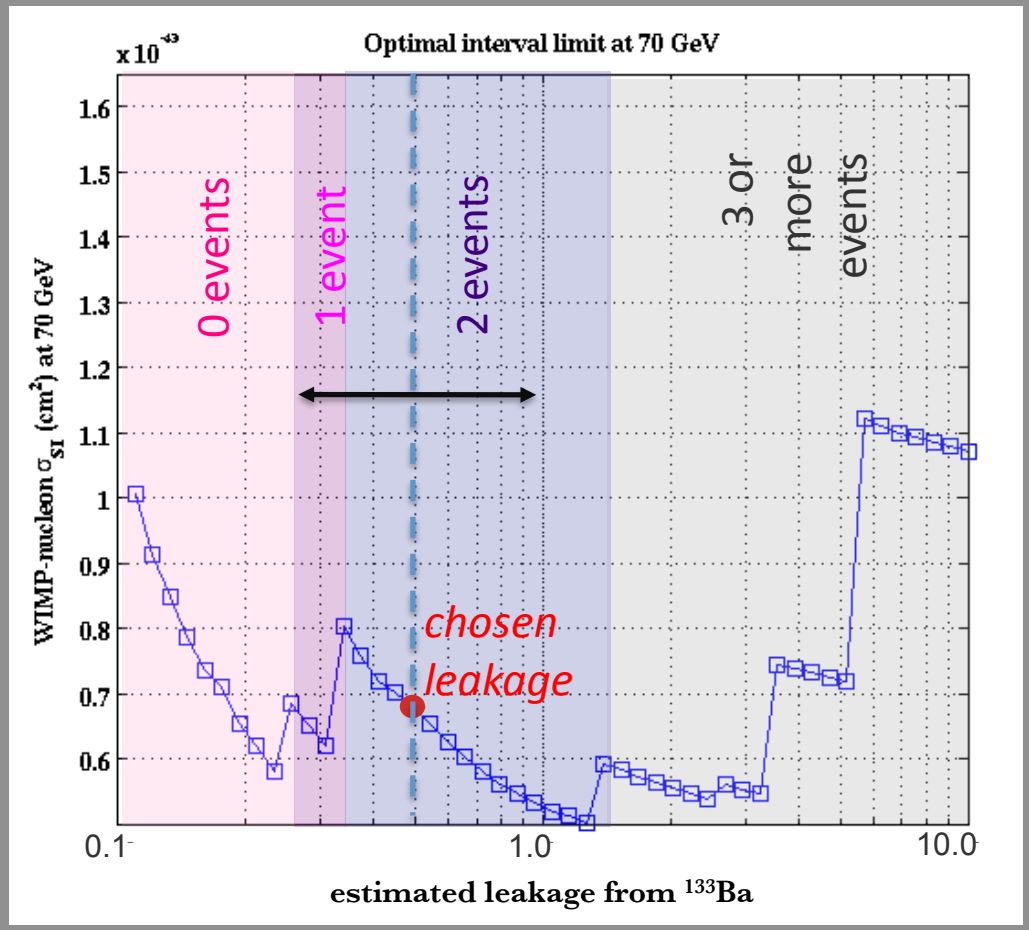
$$0.8 \pm 0.1(\text{stat.}) \pm 0.2(\text{syst.})$$

•In a blind analysis, events can not be rejected on individual basis but need to be considered as part of a distribution. Otherwise we are biasing ourselves to a lower upper limits.

•With an improved reconstruction algorithm, this pulse may fail the timing cut. However, the resulting narrower timing distribution will require resetting the cuts to have constant leakage. Other events may well be included.

•Based on this revised estimate the **probability of observing 2 or more events is 23% (includes neutron + surface event background).**

Cut Varying Study



Limit vs. chosen leakage is relatively flat !

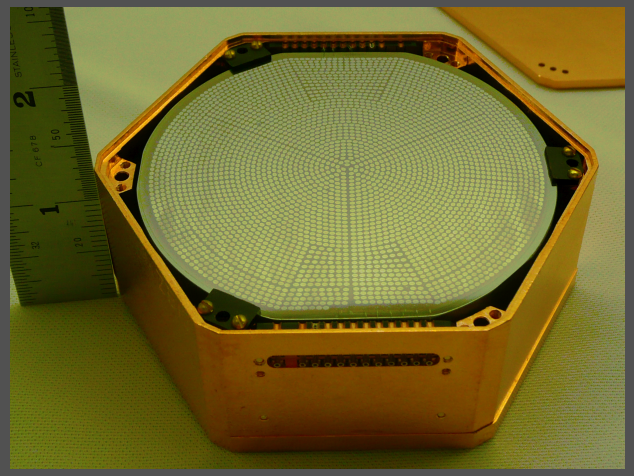
Tightening cut to ~1/2 the expected leakage, removes all events from the signal region and ~28% of exposure

Additional events appear in the signal region after loosening the cut to 1.7 x the expected leakage

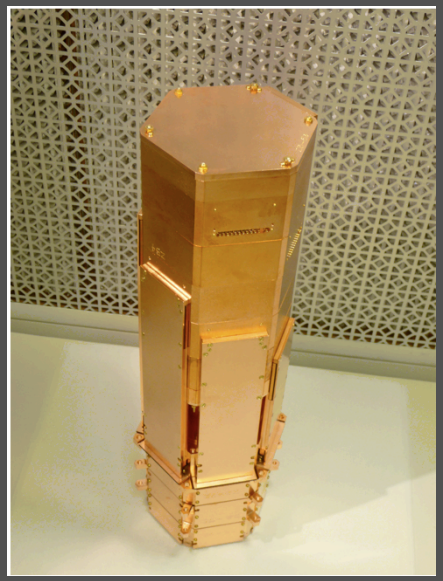
the future

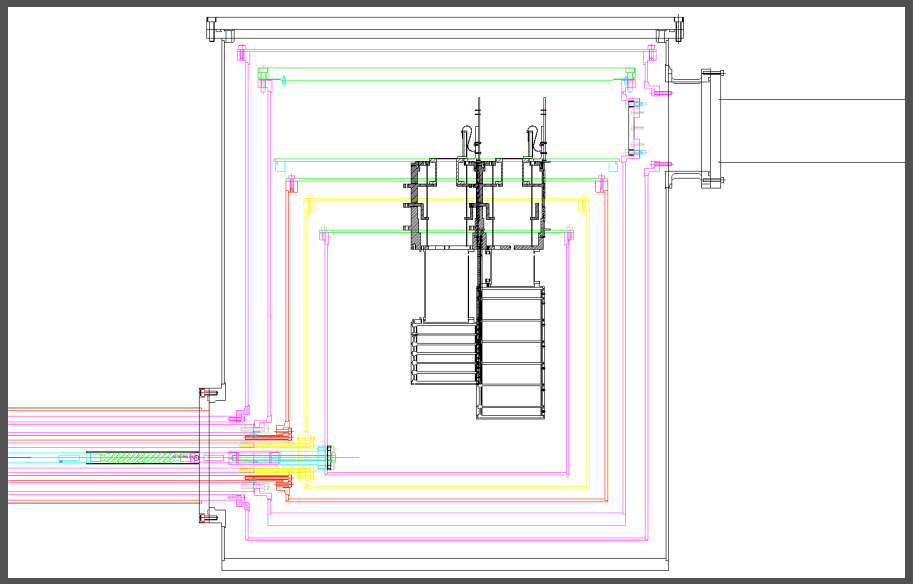
SuperCDMS Soudan 15kg

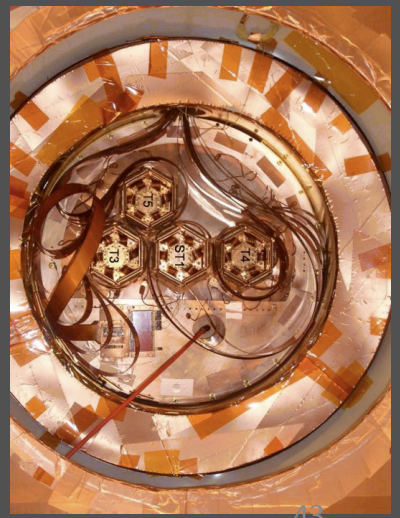
- New 1 inch thick detectors : 0.64 kg
  - improved phonon readout geometry
  - 2.5 × bulk/surface
  - Studied at the CDMS TF
- SuperTower: 5 × 1 inch detectors + 2 × 1 cm veto detectors



- SuperCDMS 5 ST: Approved
- ST1 installed at Soudan March 2009: Cold and running
- Summer 2010 install 4 more STs and run for 3 years: ~8000 kg-d
- Goal: $\sigma \sim 5\times10^{-45}$ cm^2





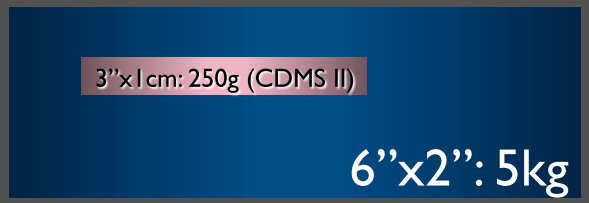


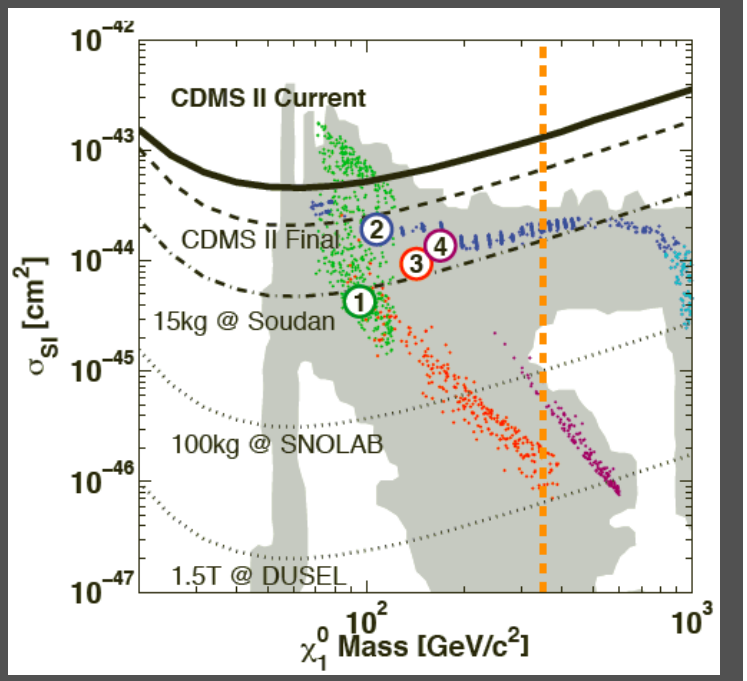
SuperCDMS future

CDMS SNOLAB 100 kg: 100 K kg-d

DUSEL: Germanium Observatory for DM (GEODM)
1500 kg: 1.5 M kg-d

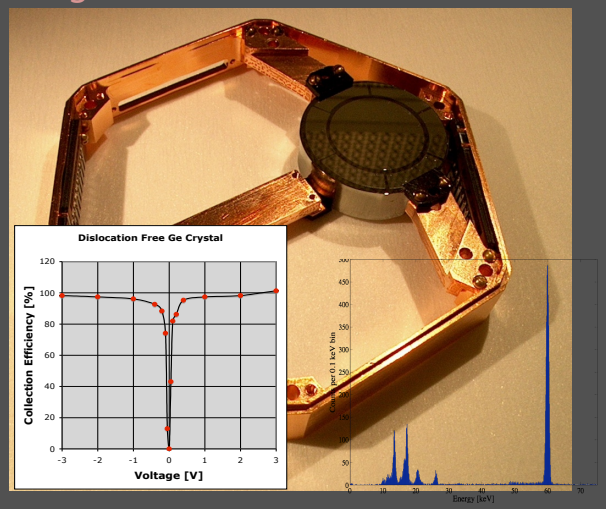
Rule of the game:
Larger exposure only if better discrimination/kg
Proportionally



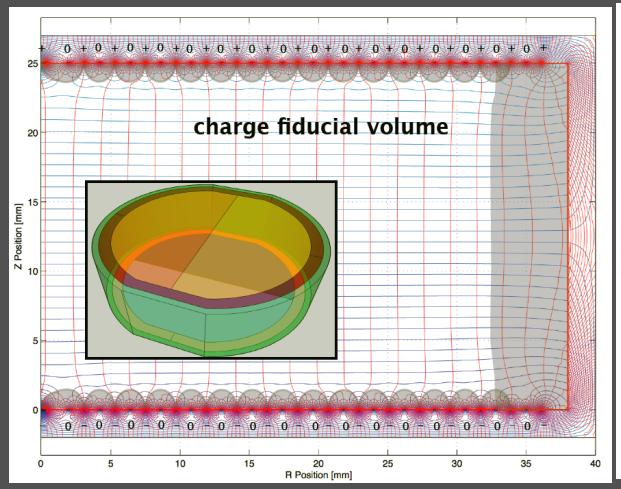


Large Ge substrate studies

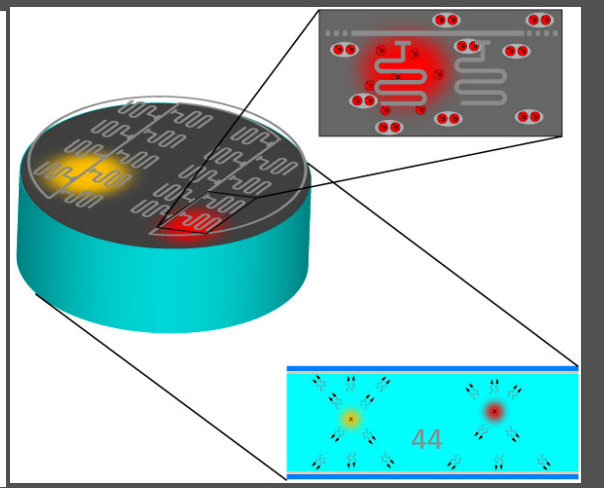
Strong LBNL involvement: E.E.Haller



New electrode geometry:
Inspired by P.Luke

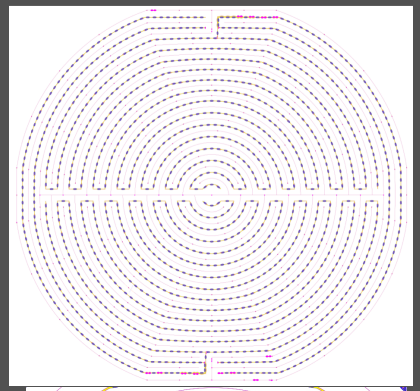


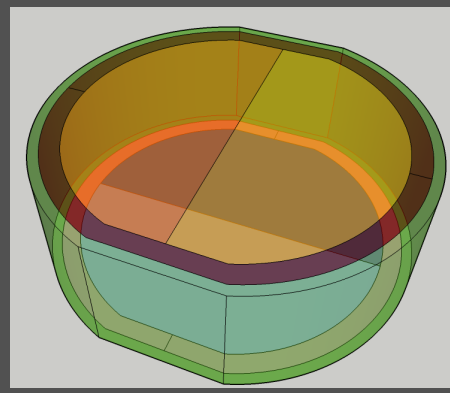
Kinetid Inductance Detectors
(KIDs)

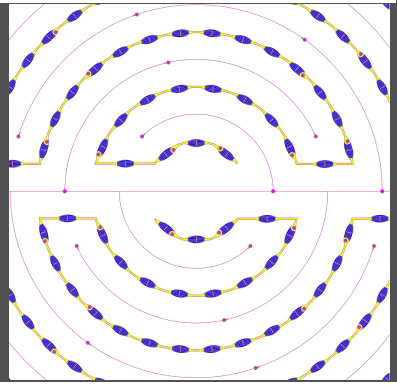


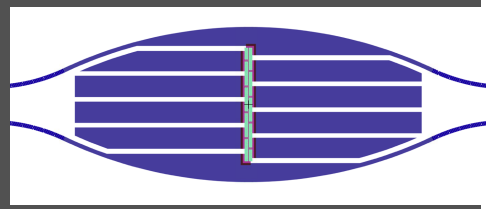
iZIP

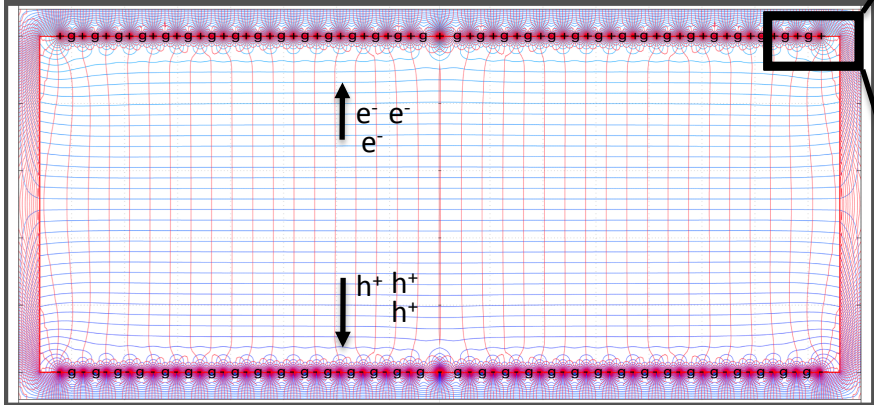
- Interleaved electrodes (1 mm pitch) on both sides
- Alternating +2 V & ground (phonon sensors) on one side -2Volts & ground on the other side.
- Transverse E field ~ 20 V/cm on the surface
- Near surface events: Ionization appears only on one side
- Bulk events: equal but opposite signal on both sides.
- Athermal Phonon sensors cover both sides: relative timing/amplitude to identify near surface events

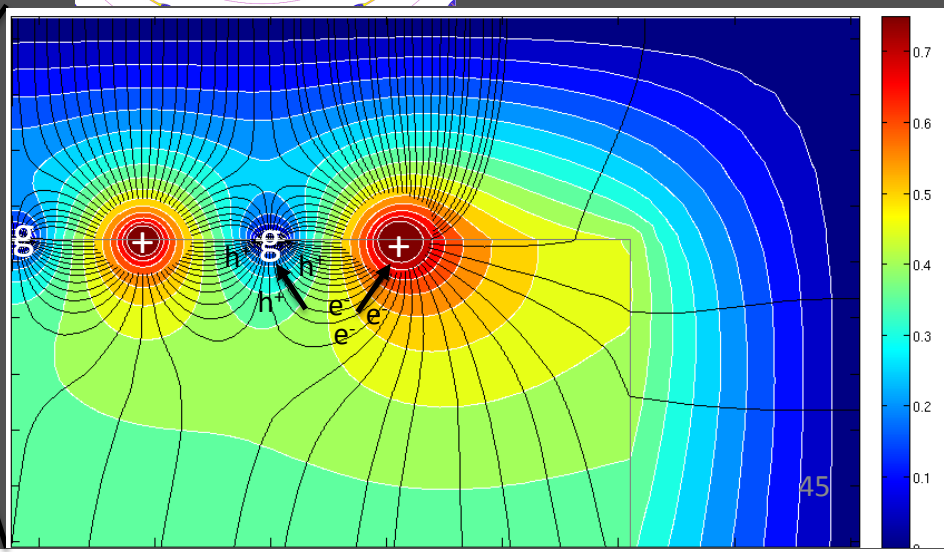








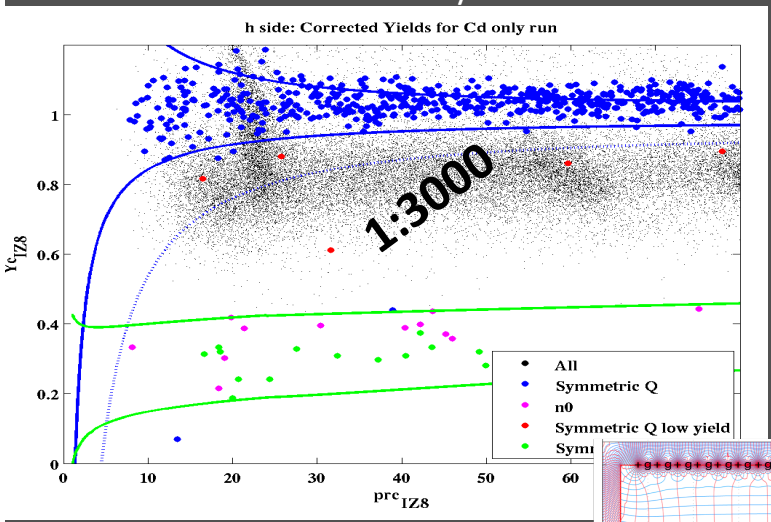




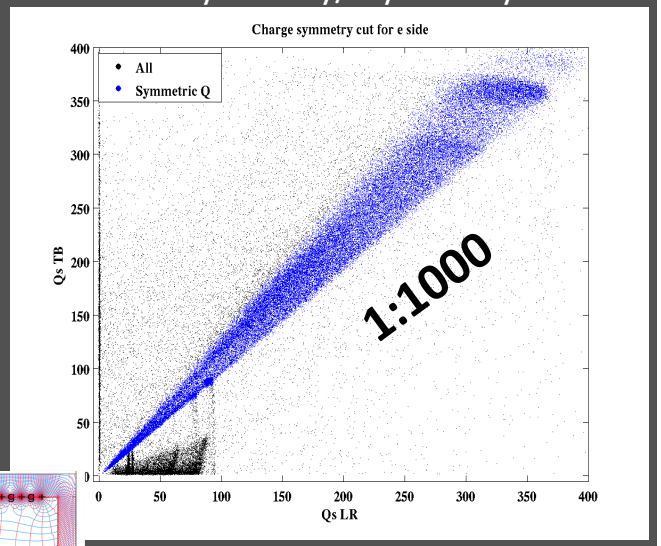
Prototyoe 1 inch iZIP:

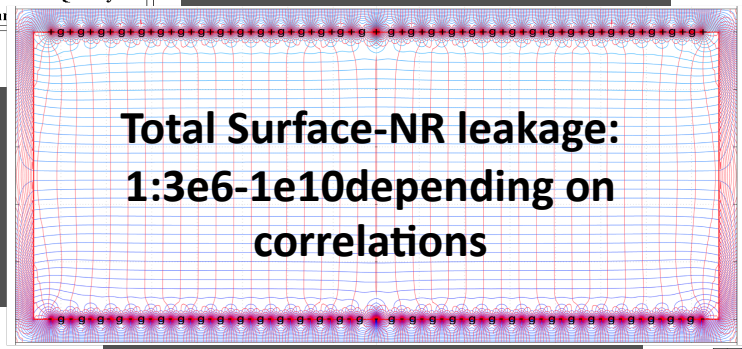
- Fabricated at Stanford
- Studied at UC-Berkeley with ^{109}Cd (Near surface electrons), ^{133}Ba (Bulk γ's) and ^{252}Cf (HE neutrons) Calibration sources

Better ionization yield performance for surface events: Before any cuts



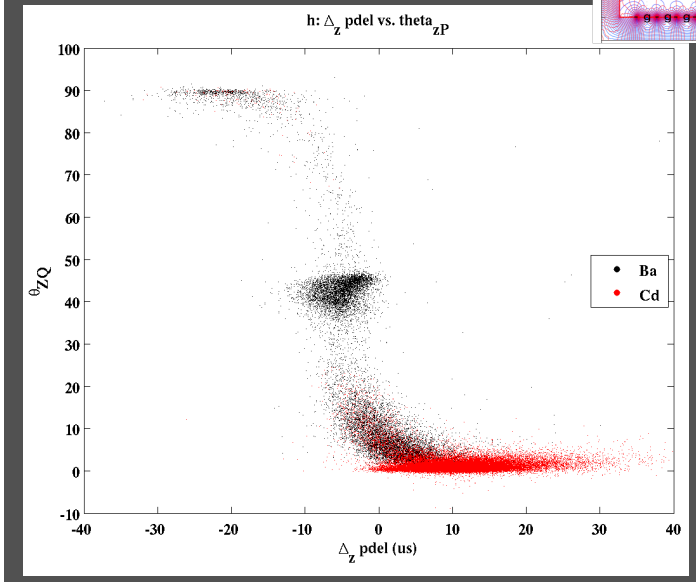
Ionization symmetry/asymmetry

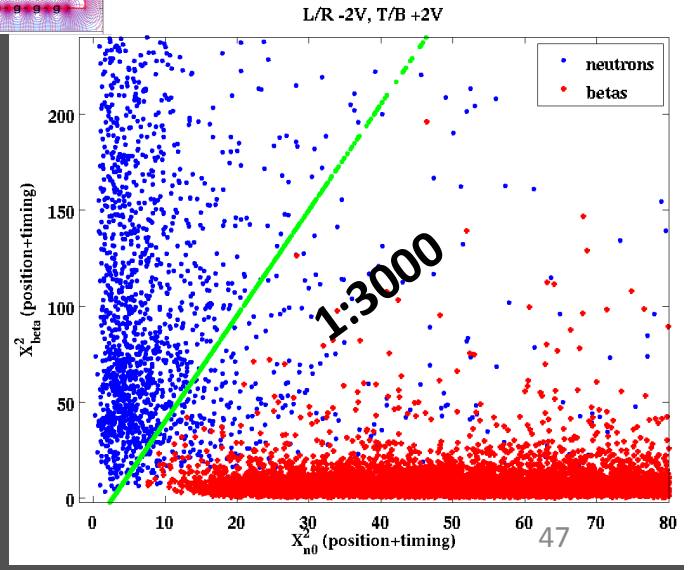




Total Surface-NR leakage: 1:3e6-1e10depending on correlations

Combining information in the athermal phonon on both sides into a χ^2 analysis





Conclusions

- We have reported 2 events from our blind analysis. Obtaining 2 or more event given our estimated background has a probability of 23%.

- As a result of this blind analysis we are reporting the world leading limit on SI WIMP-nucleon cross section $\sigma=3.8\times10^{-44}$ cm^{2}.

- Not a statistically significant to claim a signal (we would have needed ≈ 5 events).

- At this stage of the analysis we can not exclude that these events are WIMP signals..

- The detailed information provided by our detectors may allow us to sharpen our interpretation. Stay tuned!

- We are deploying 15kg in Soudan by summer 2010 and preparing for SuperCDMS SNOlab with 100 kg detectors. iZIP technology is very promising in terms of back ground rejection.

- Other experiments with low background and different systematics are needed to confirm an eventual signal: watch for XENON 100, LUX EDELWEISS

Thank you!

And to the Department Of Energy and the National Science Foundation
for the support