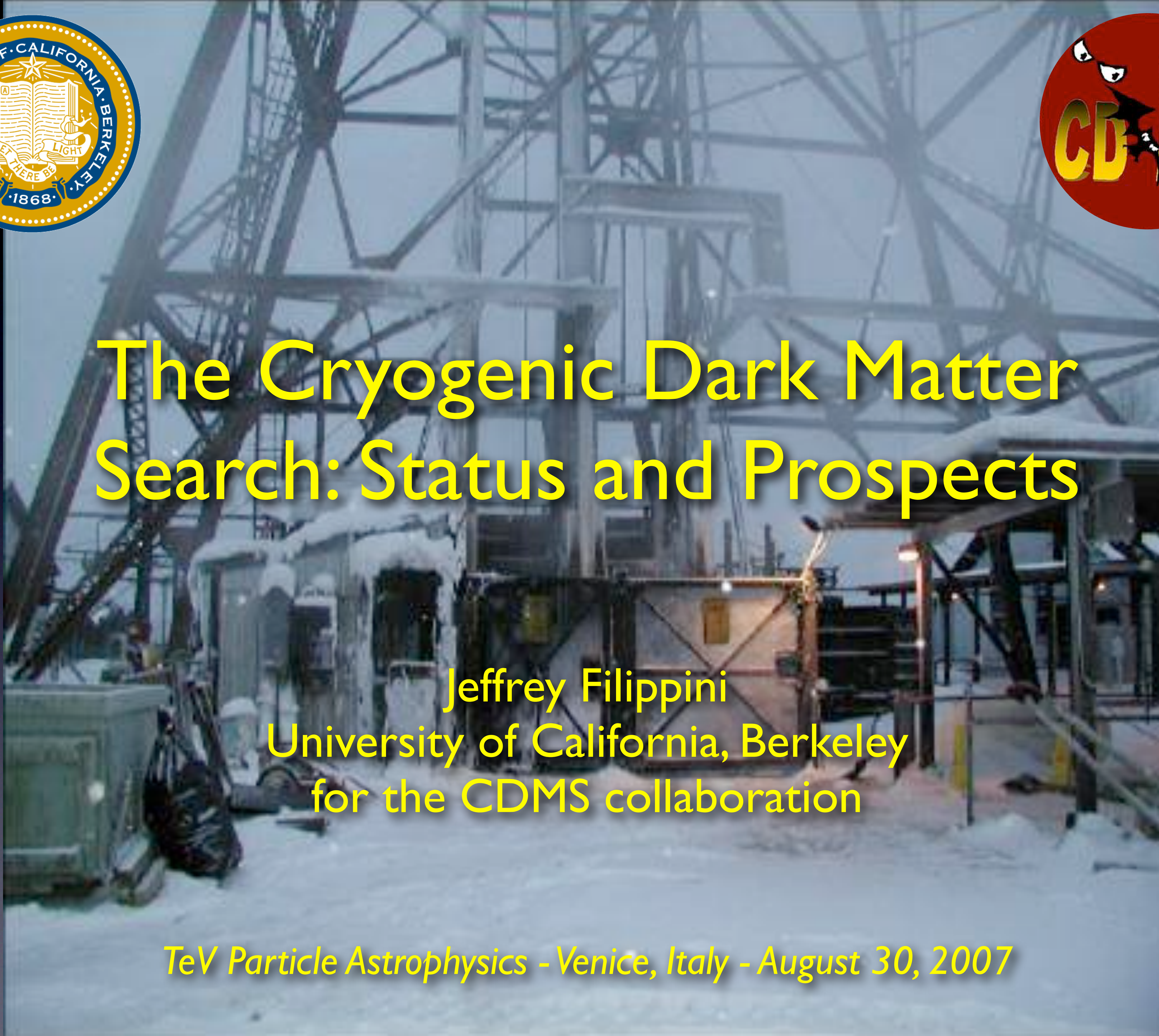


The Cryogenic Dark Matter Search: Status and Prospects

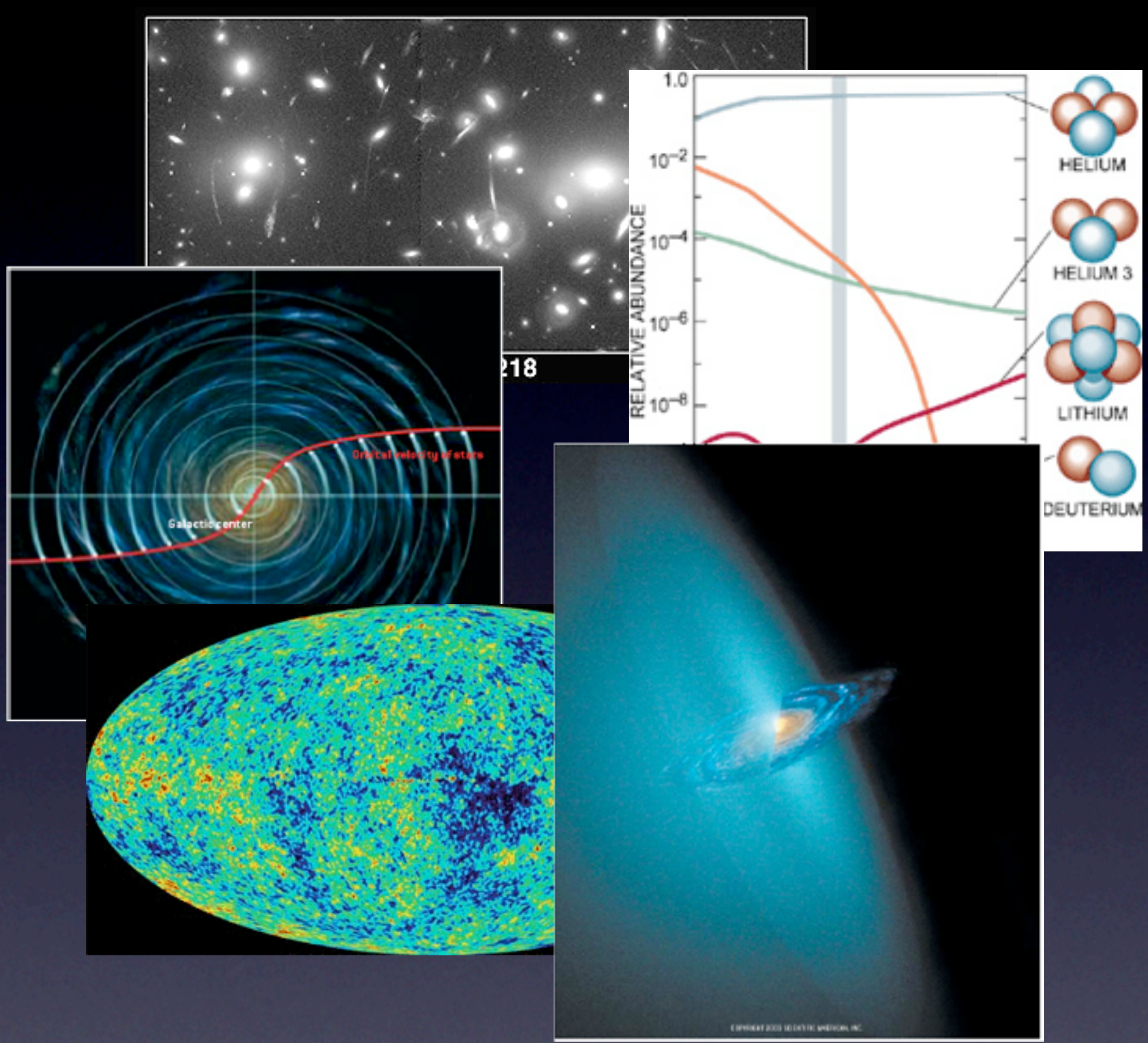
Jeffrey Filippini
University of California, Berkeley
for the CDMS collaboration

TeV Particle Astrophysics - Venice, Italy - August 30, 2007

Outline

- **Workings of the CDMS experiment**
- **Results of the 2-Tower run**
- **Status of the 5-Tower run**
- **The future: SuperCDMS**

Dark Matter and its Detection

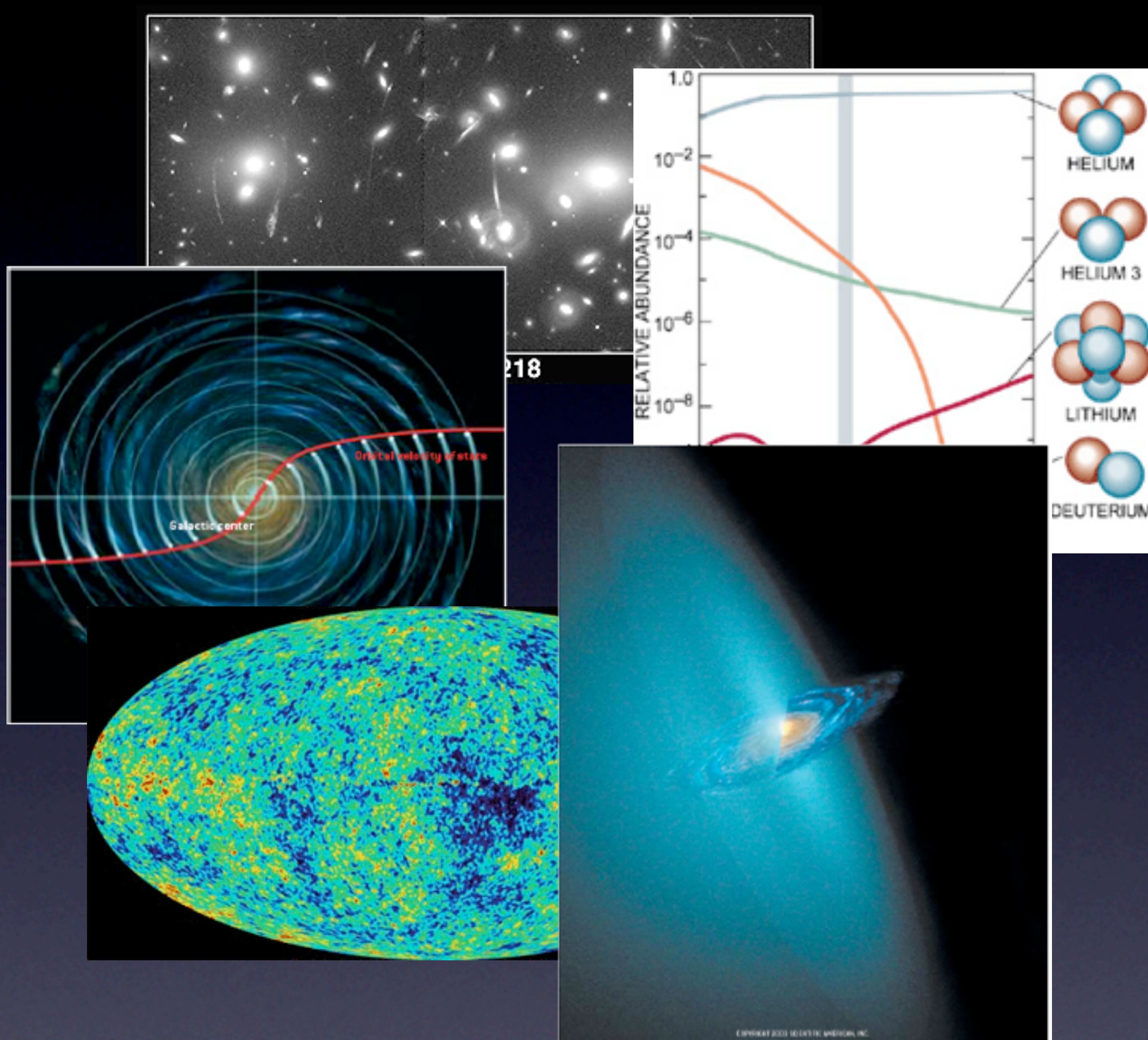


Dark matter is out there...

Strong theory motivation for **thermal WIMP**

- Stable, massive, neutral particle
- Relic density => σ_{XX} ~ 0.1 pb => M_X~100 GeV/c^2

Dark Matter and its Detection

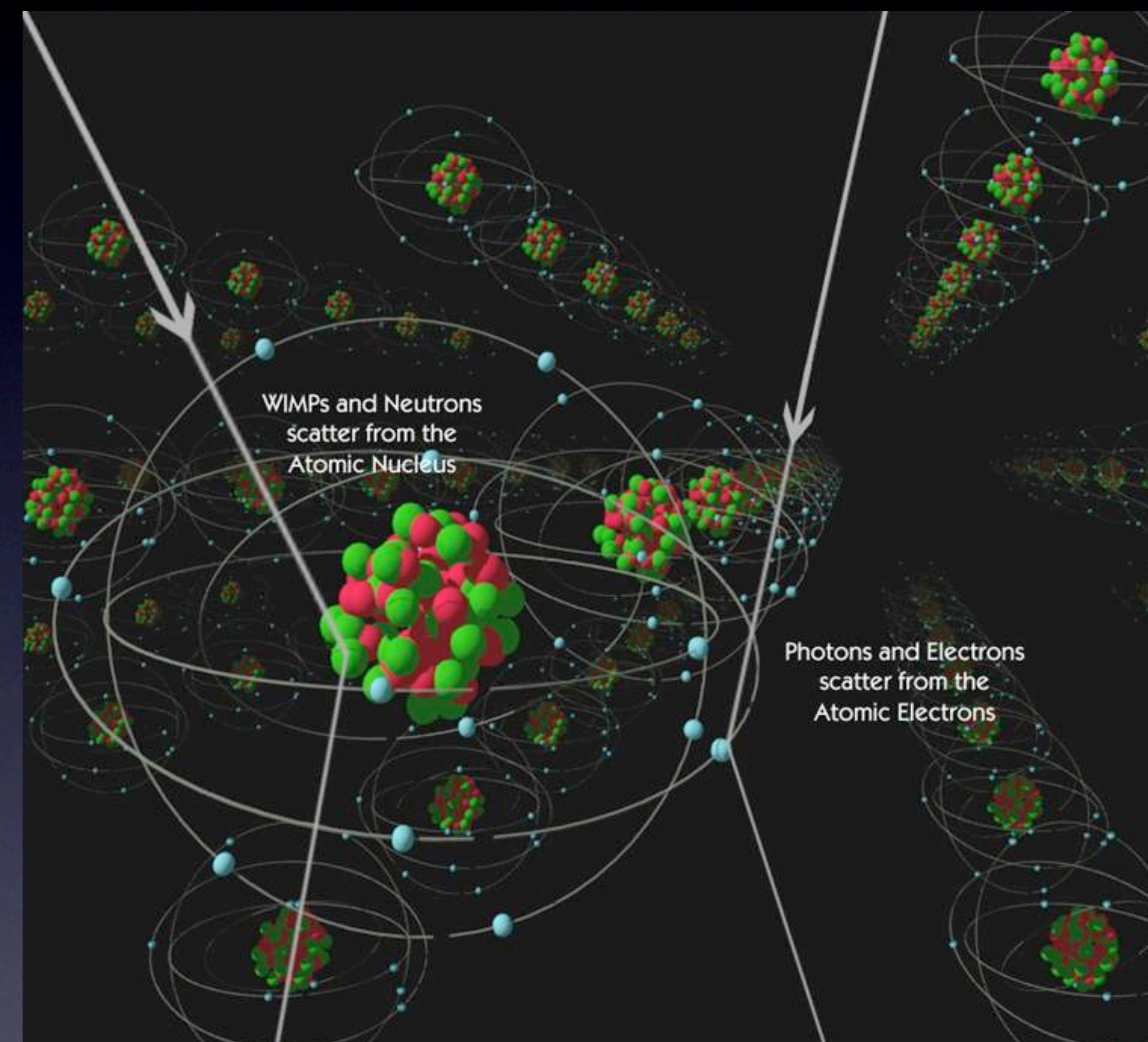


Dark matter is out there...

Strong theory motivation for **thermal WIMP**

- Stable, massive, neutral particle
- Relic density => σ_{XX} ~ 0.1 pb => M_X~100 GeV/c^2

... so it may interact on Earth!

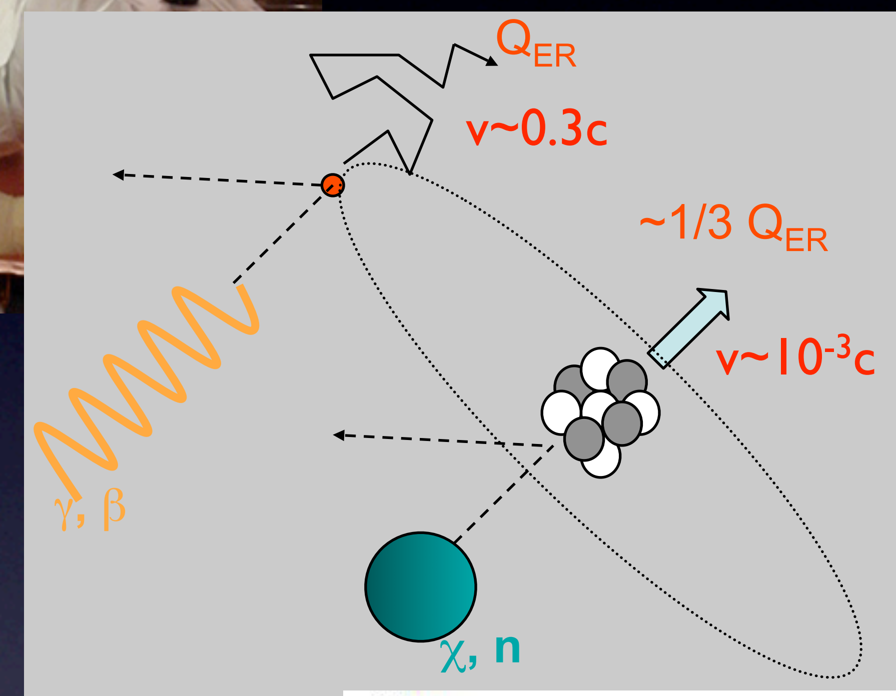


Crossing symmetry, $v_{galactic} \sim 10^{-3}c$, coherent enhancement (spin-independent scattering) => **~10 keV nuclear recoils, <<1/kg-day**

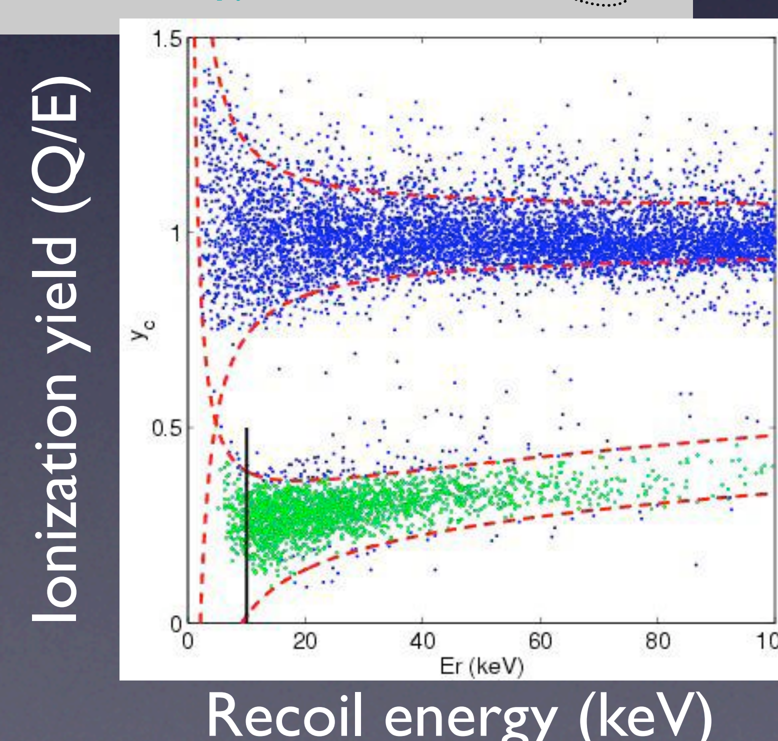
Direct Detection of WIMPs

Radioactive and cosmogenic backgrounds demand

- Background **reduction**
  - cleanliness
  - shielding
    - passive (depth, Pb, poly)
    - active (muon veto)



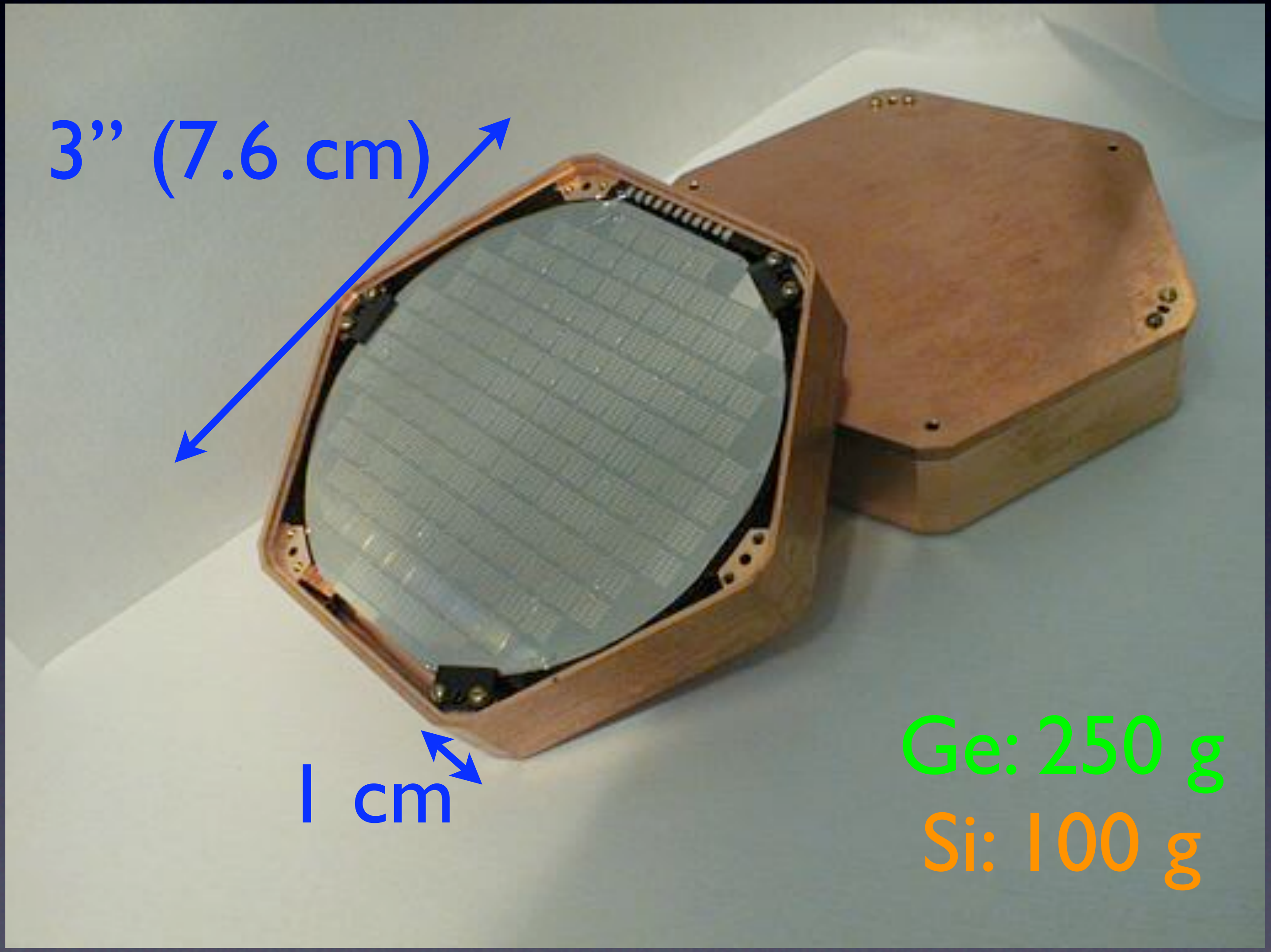
- Background **discrimination**
  - multiplicity
  - dE/dx



***CDMS in a nutshell**: Event by event discrimination of nuclear and electron recoils using ionization and (athermal) phonons with no background subtraction*

ZIP Detectors

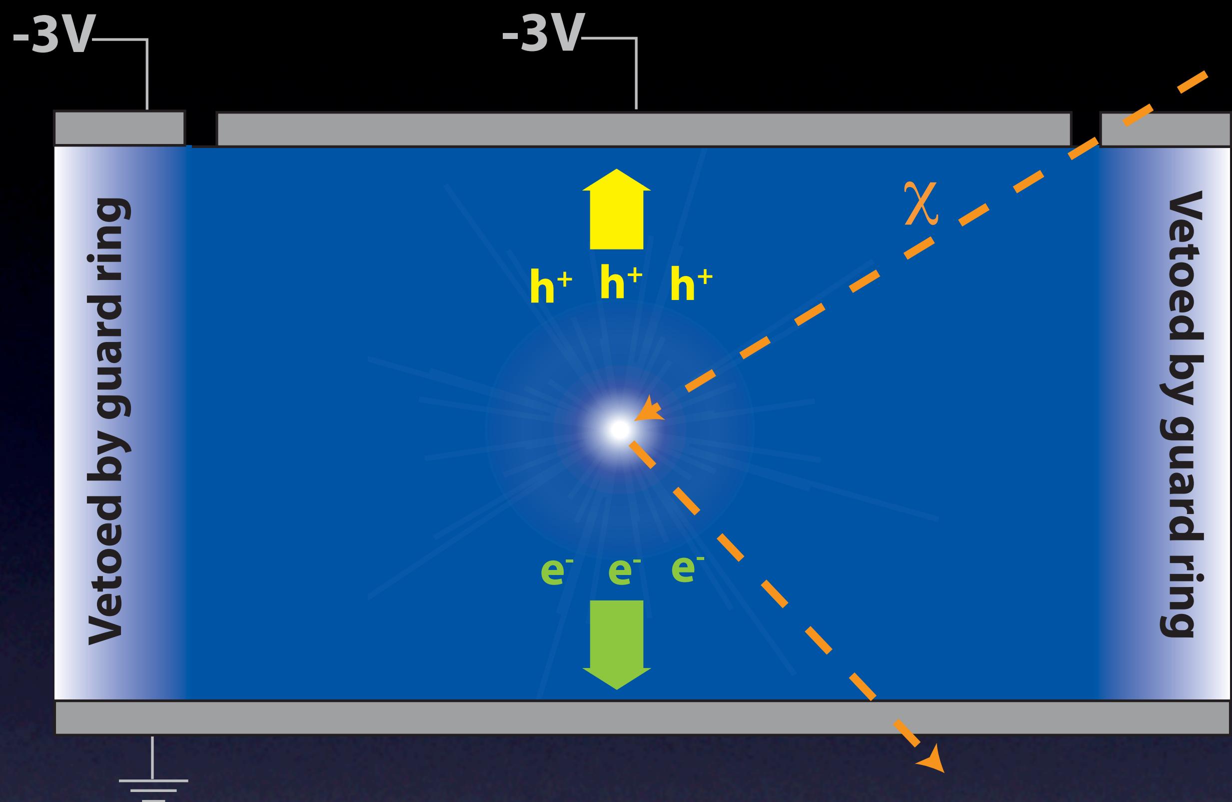
(Z-sensitive Ionization and Phonon)

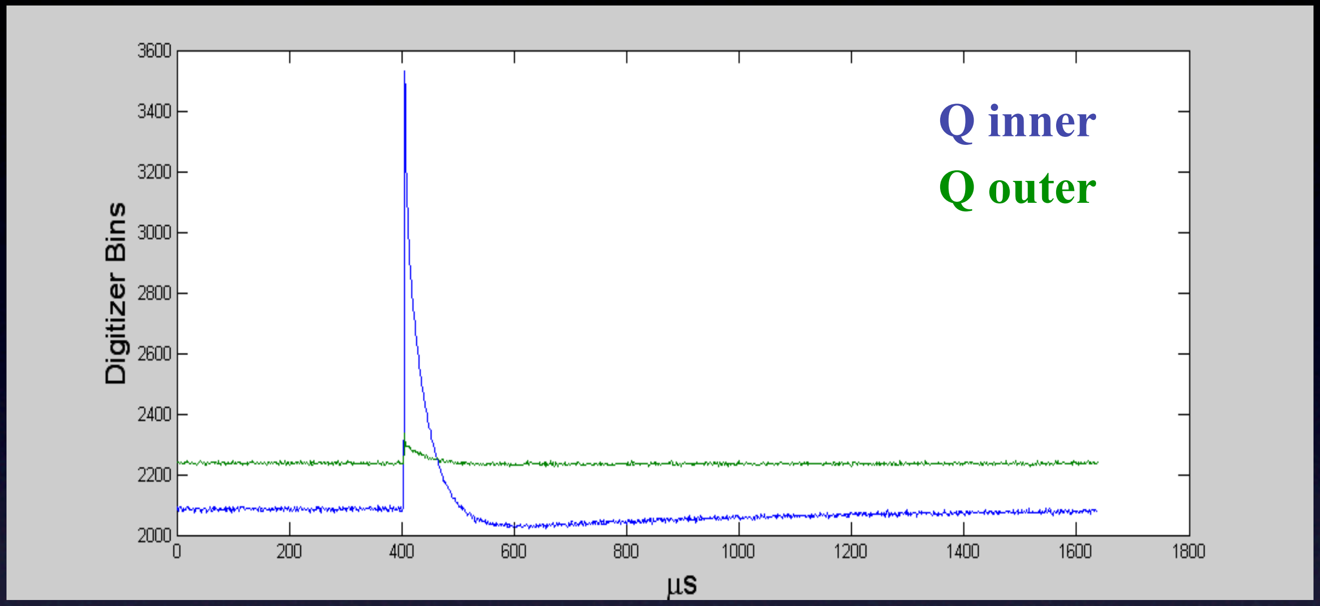


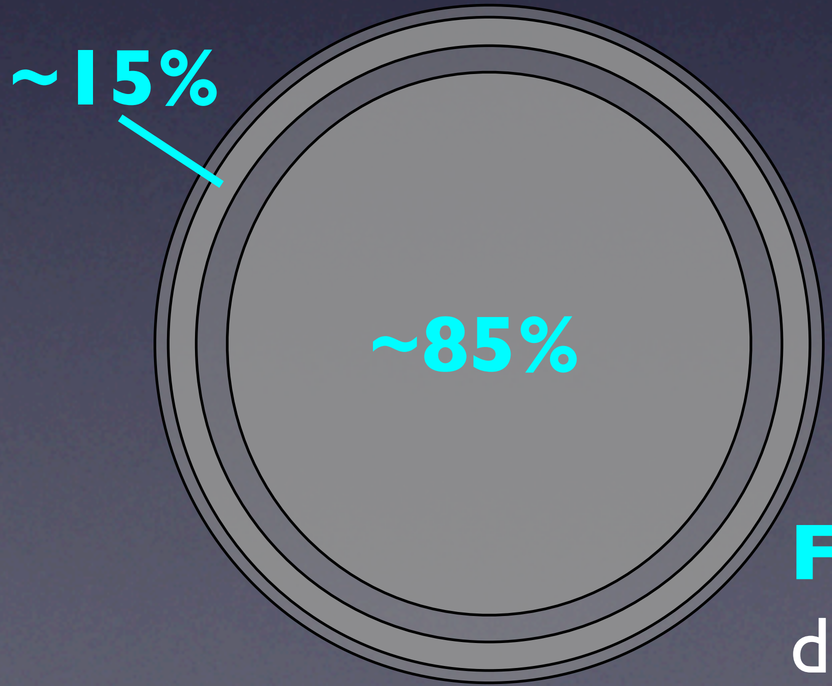
Phonon side: 4 quadrants of athermal phonon sensors => ***energy measurement***

Charge side: 2 concentric electrodes

ZIP Detectors: Ionization



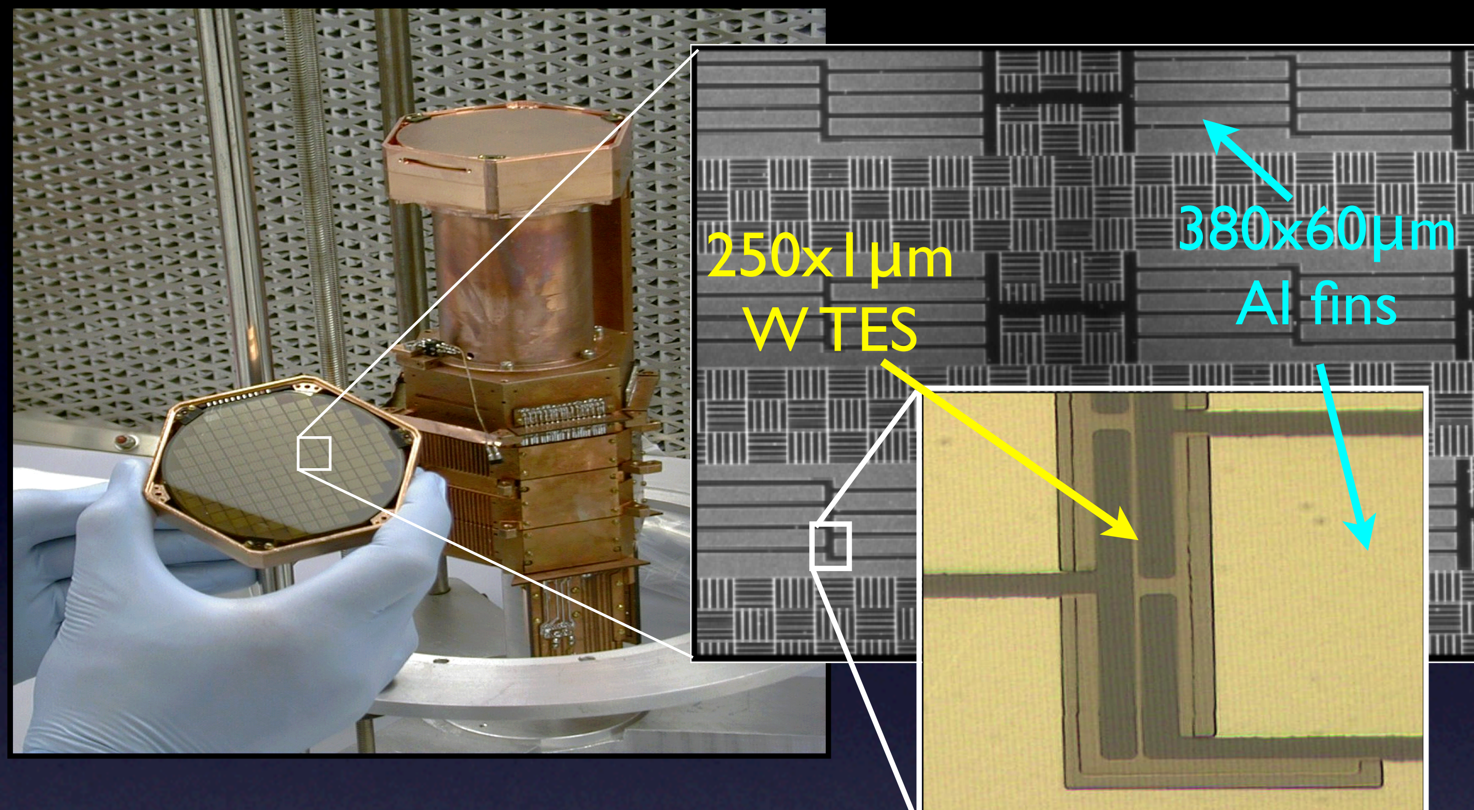


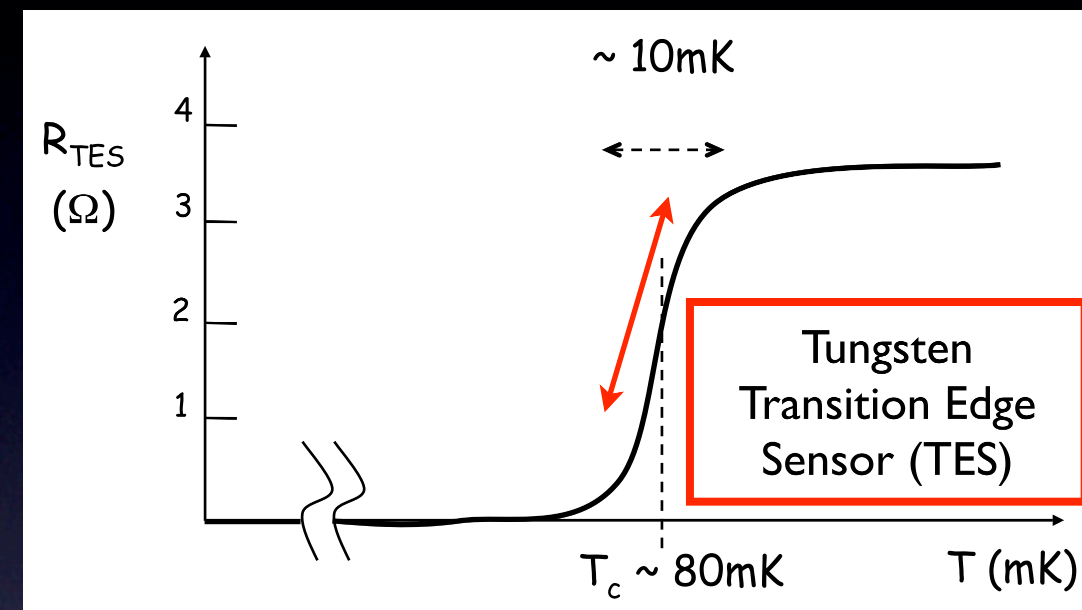


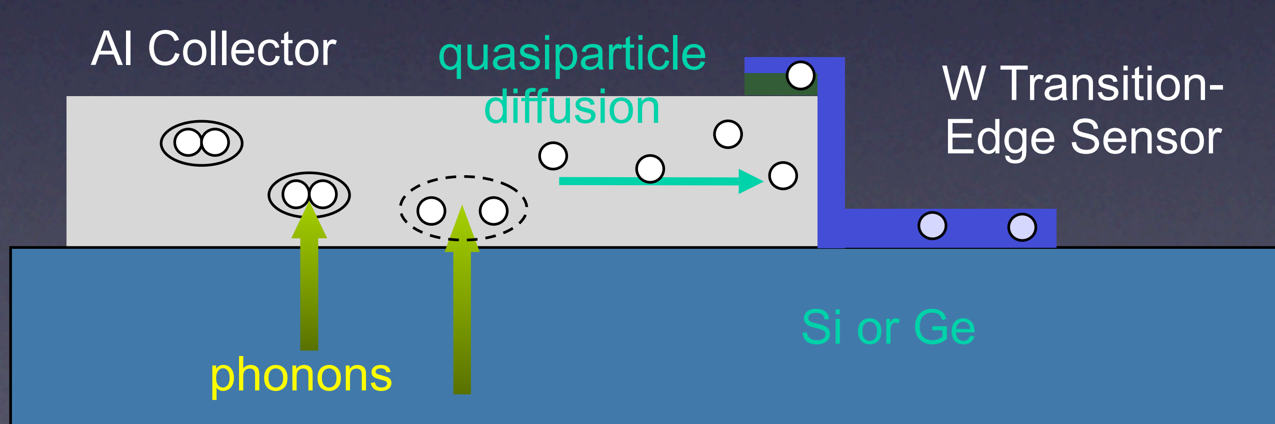
Zero-energy resolution **~250 eV**,
=> ~1% at high energies

Fiducial volume cut from
divided electrode ("**guard ring**")

ZIP Detectors: Phonons



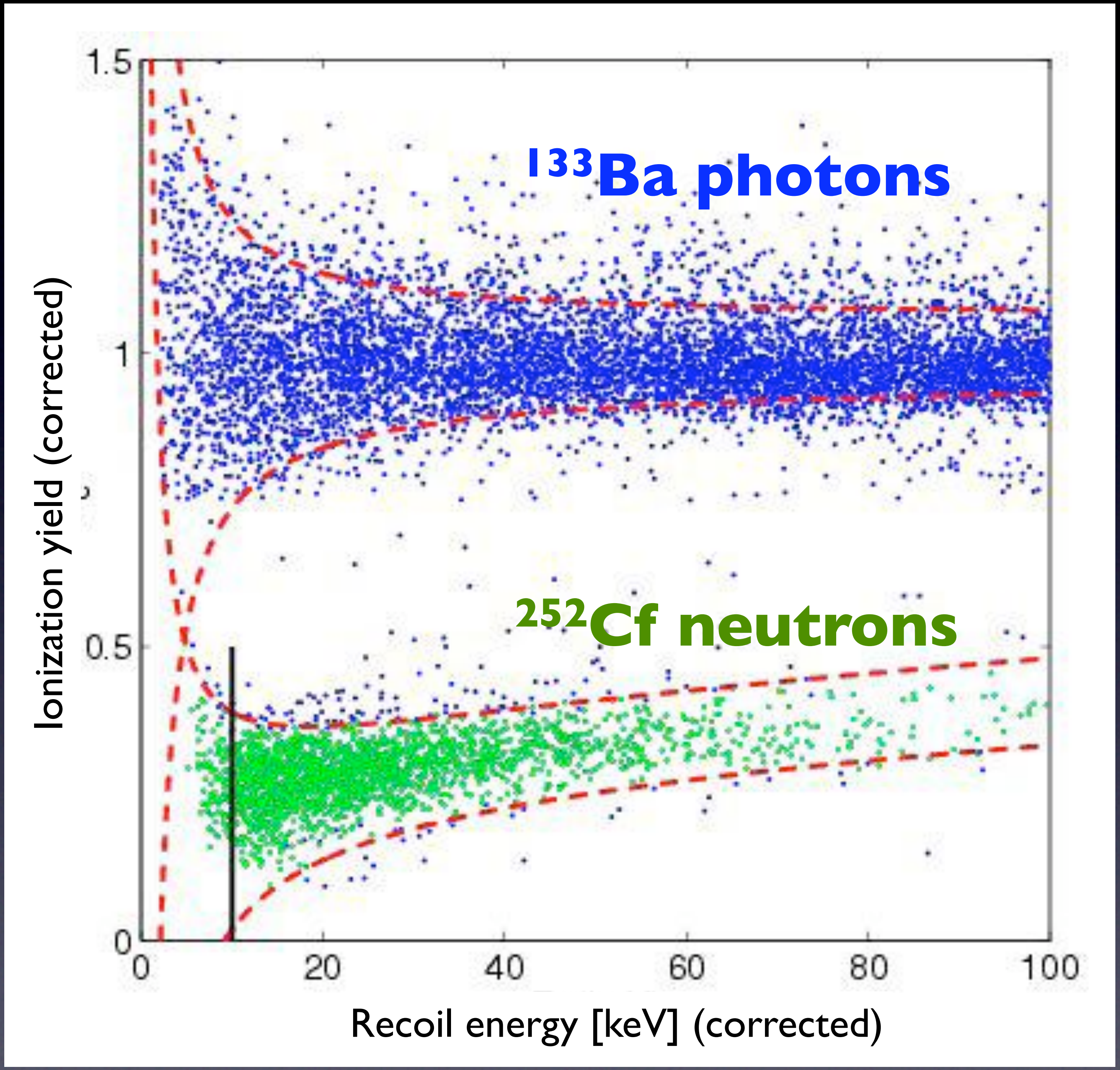




≈

- 4 readout channels, each 1036 W TESs in parallel
- Zero-energy resolution ~**100 eV** in each channel, total ~**5%** at higher energies (after position correction)

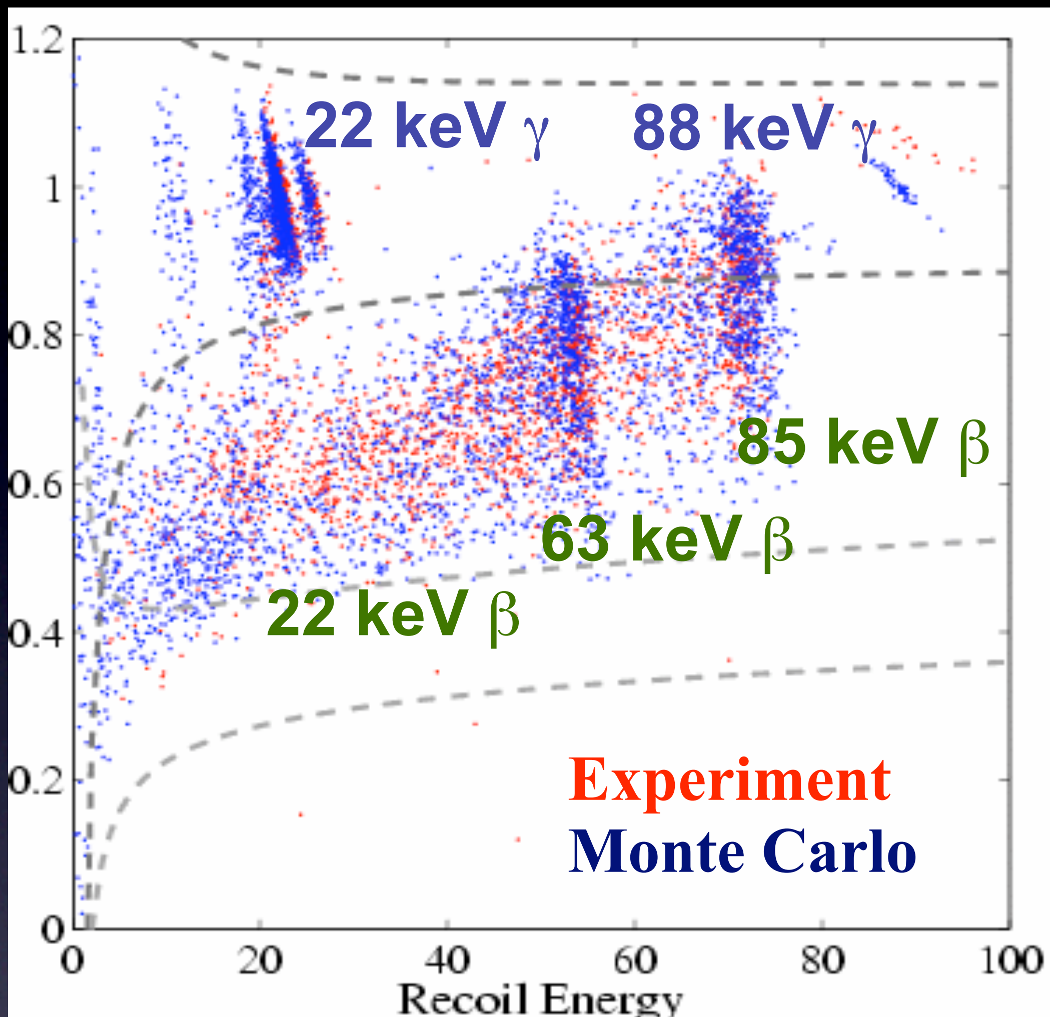
Yield Discrimination



Primary electron recoil rejection
>1,000,000:1

Good agreement with Lindhard theory

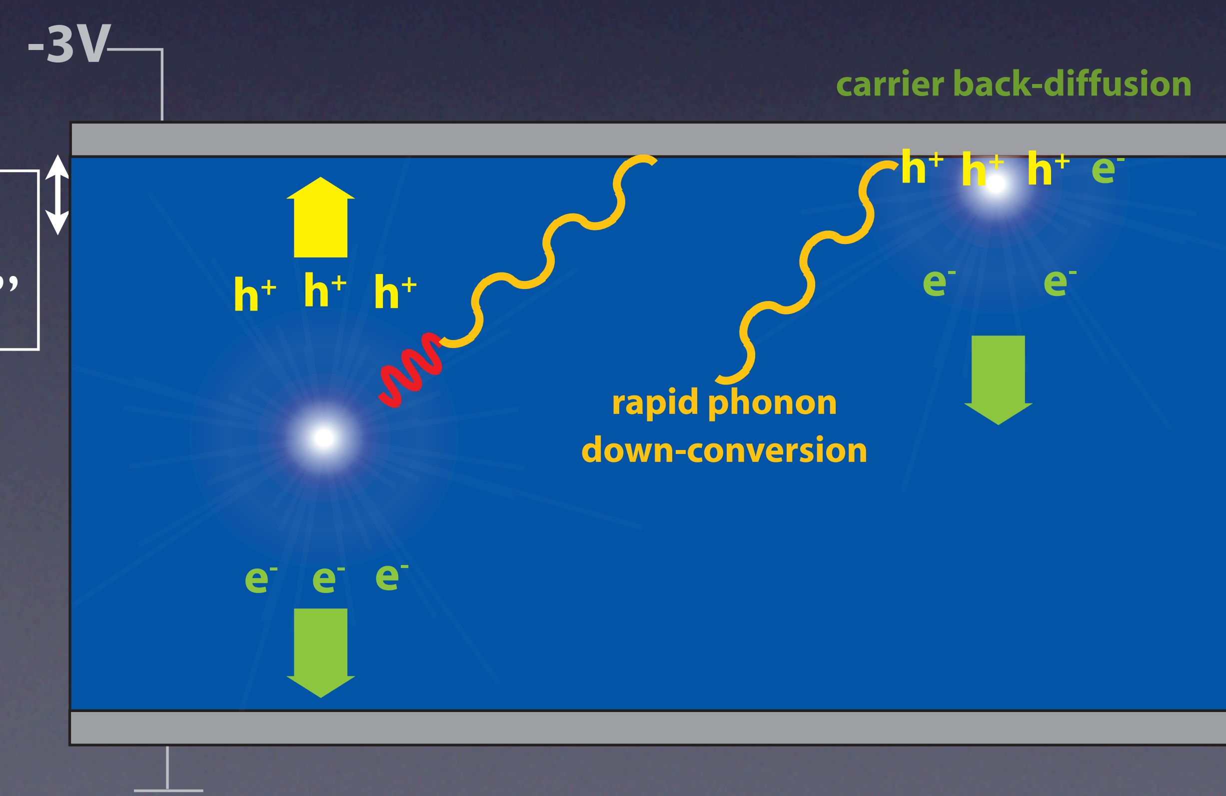
Near-Surface Events



Reduced charge yield from surface events (e.g. K-40, Rn chain) from carrier back-diffusion can mimic signal

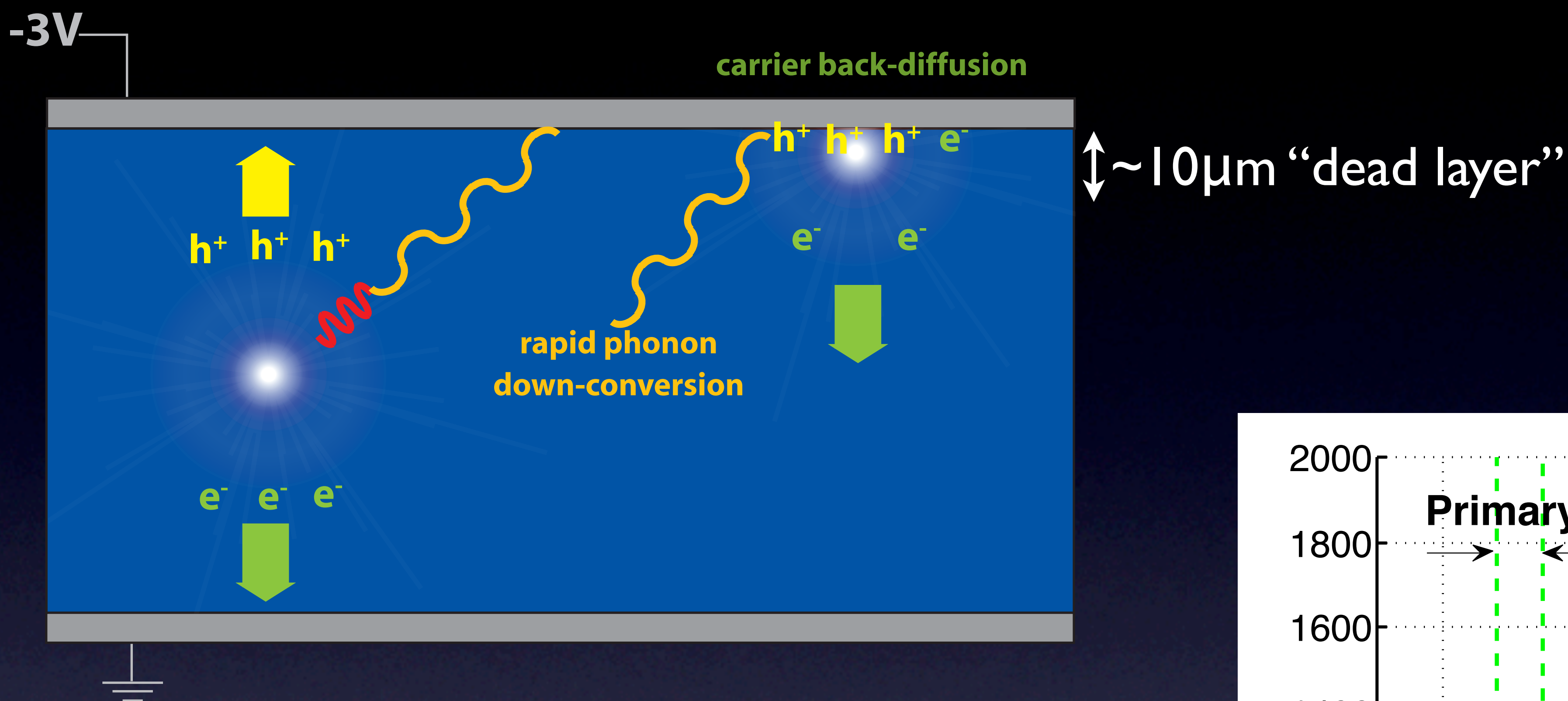
Greatly improved by αSi contact (Shutt et al.), still **dominant background** for CDMS

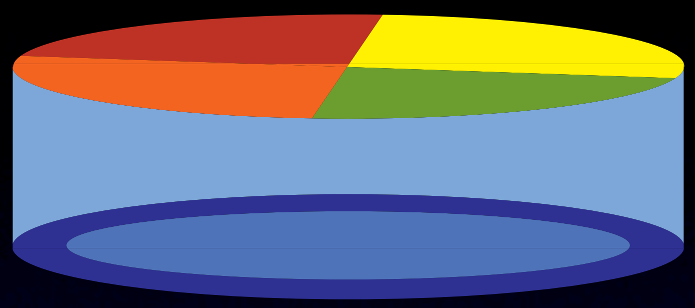
~10μm "dead layer"



Data from UC Berkeley calibration of ***T2Z5****, née* ***G31***
LTD10: NIM A ***520****, 171 (2004)*

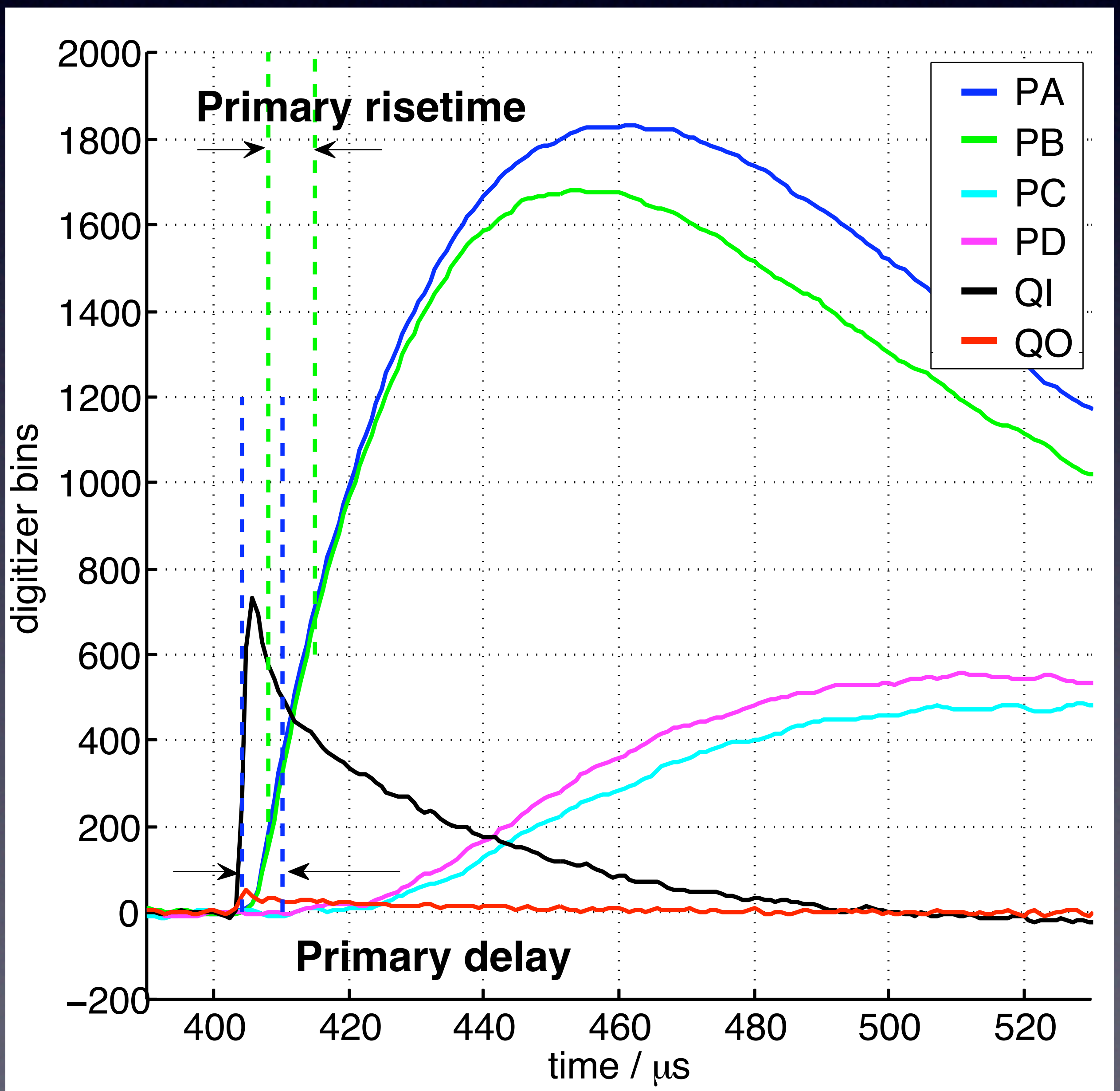
ZIP Detectors: Z-sensitivity





- Primary risetime
  (time from 10% - 40% in phonon amplitude for largest pulse)
- Primary delay
  (time from 20% charge amplitude to 20% phonon amplitude for largest pulse)

*Surface event rejection > **100:1***



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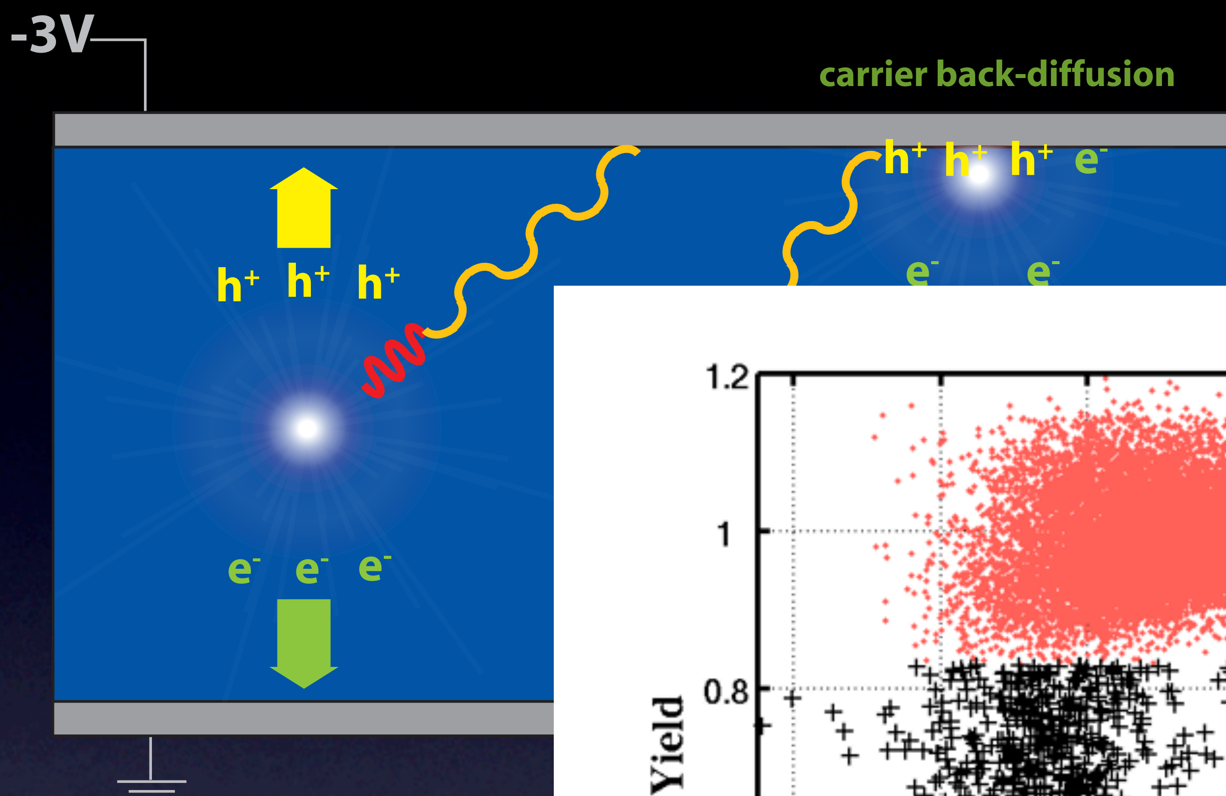

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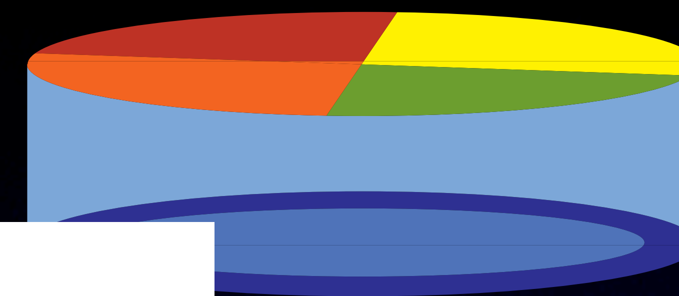
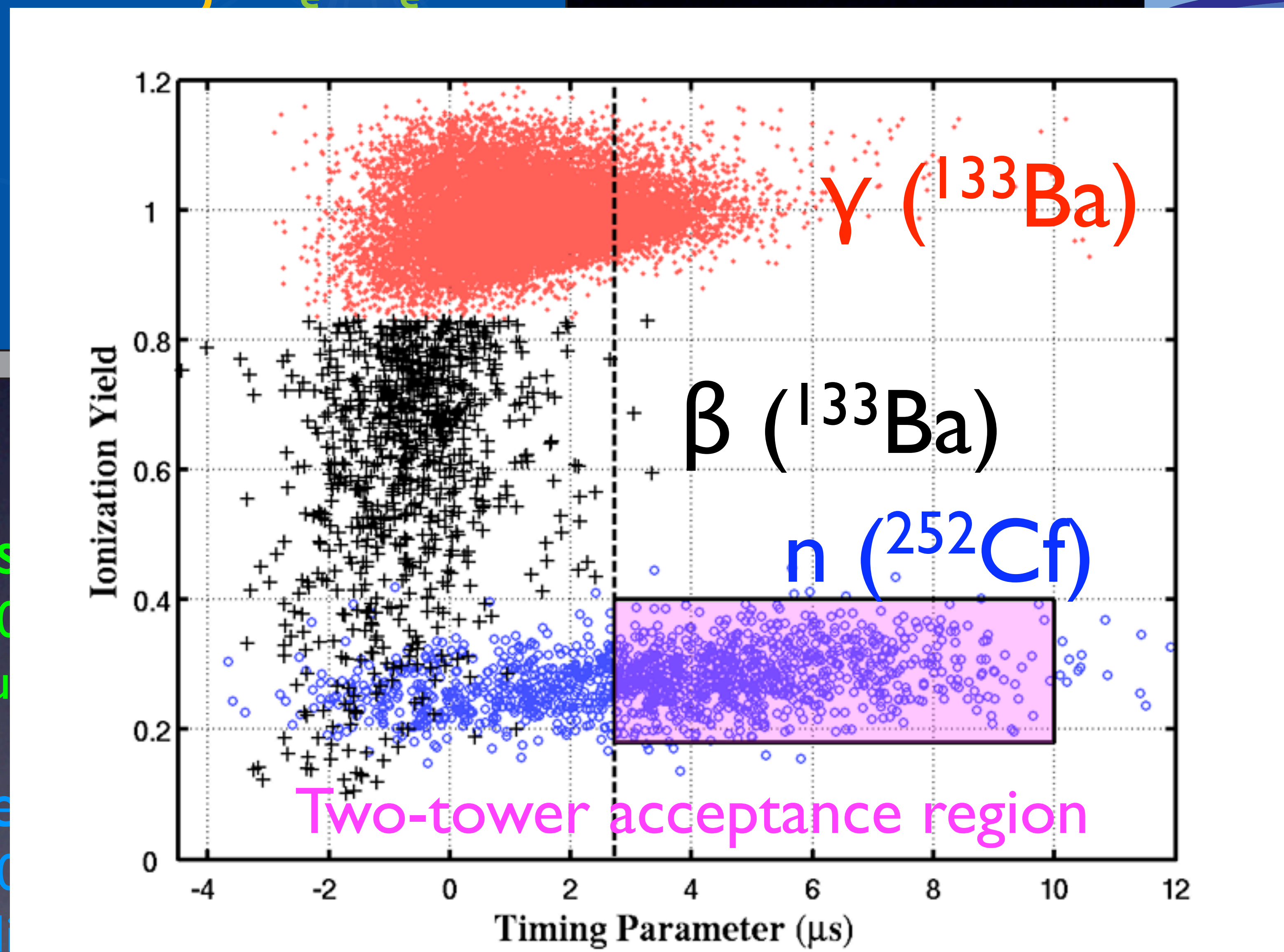
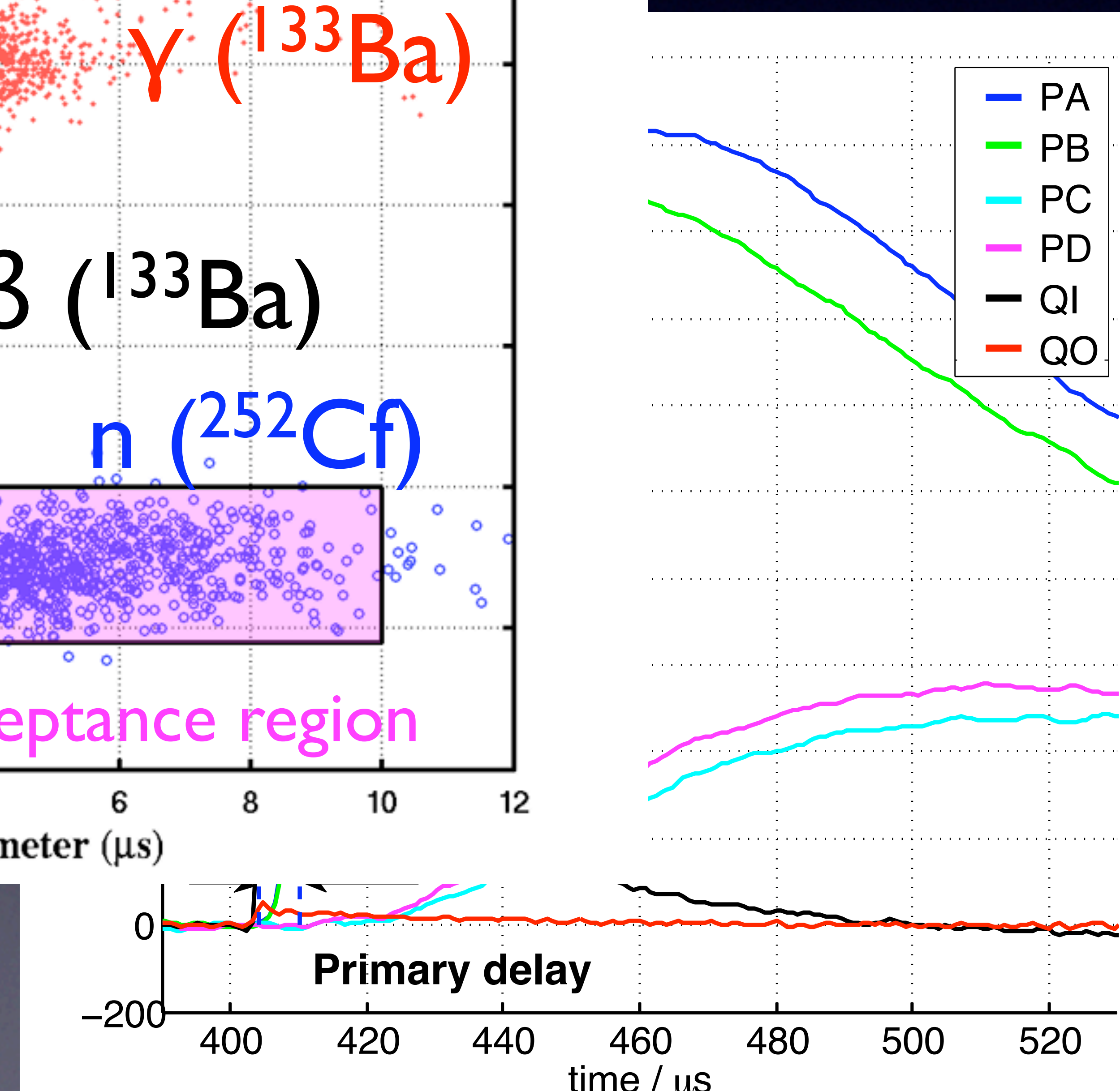




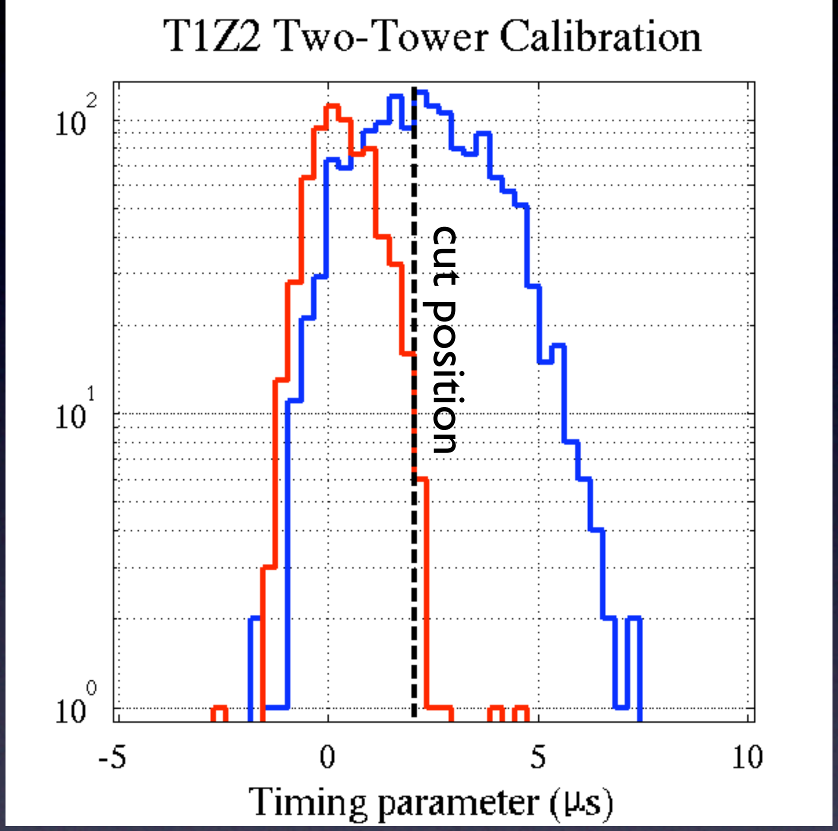


- Primary ris
  (time from 1
  for largest pu
- Primary de
  (time from 2
  phonon ampl

*Surface event rejection > **100:1***

Analysis Improvements

More exposure brings greater challenges: maintain signal acceptance with greater background rejection



“Standard” timing parameter (risetime+delay)

Surface events

Neutrons

(T1Z2, 2-T run)

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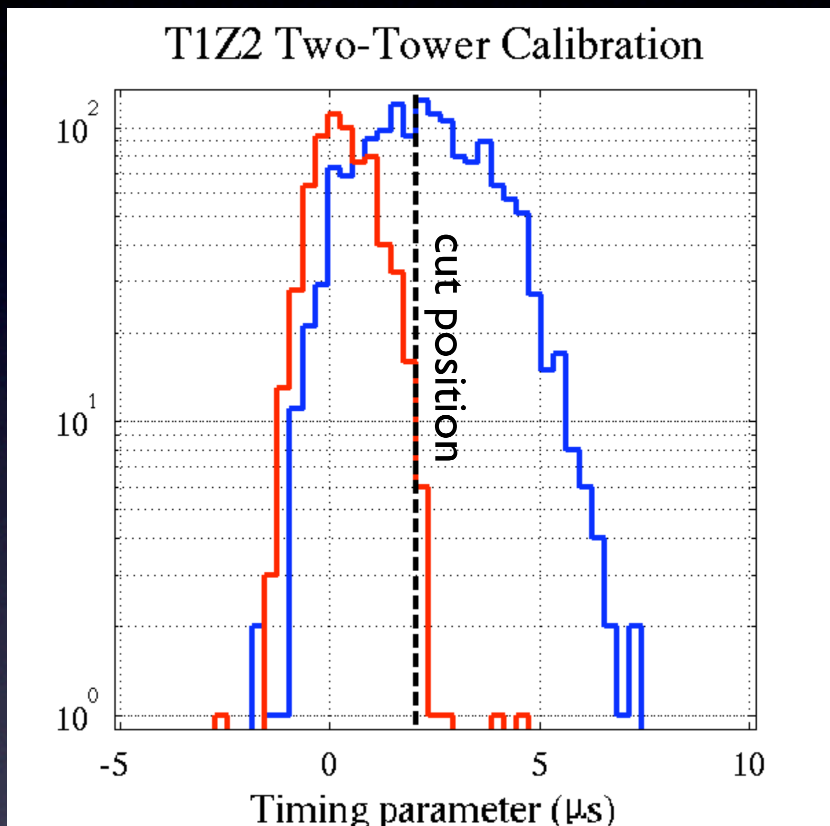

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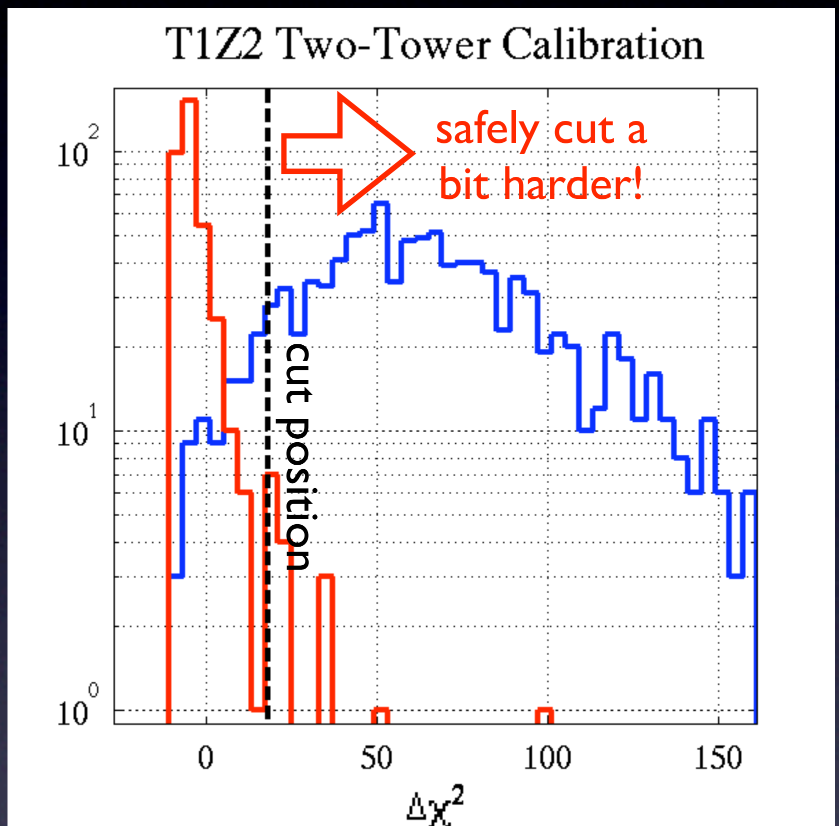


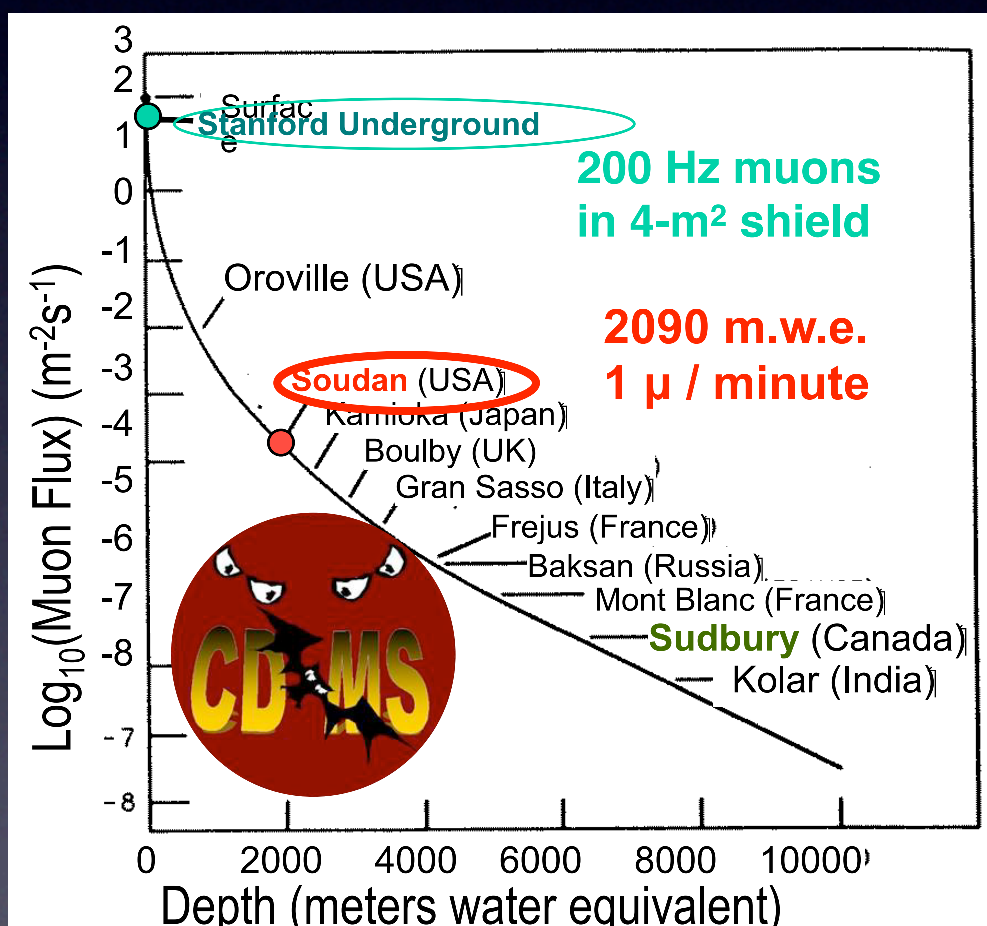
"Standard" timing parameter (risetime+delay)

Discrimination parameter from χ^2 tests using three shape parameters

More sophisticated analyses increase separation using vast information in our ZIP traces!

Further work on neural nets, position-tuned cuts, pulse fitting, ...

Soudan Underground Lab

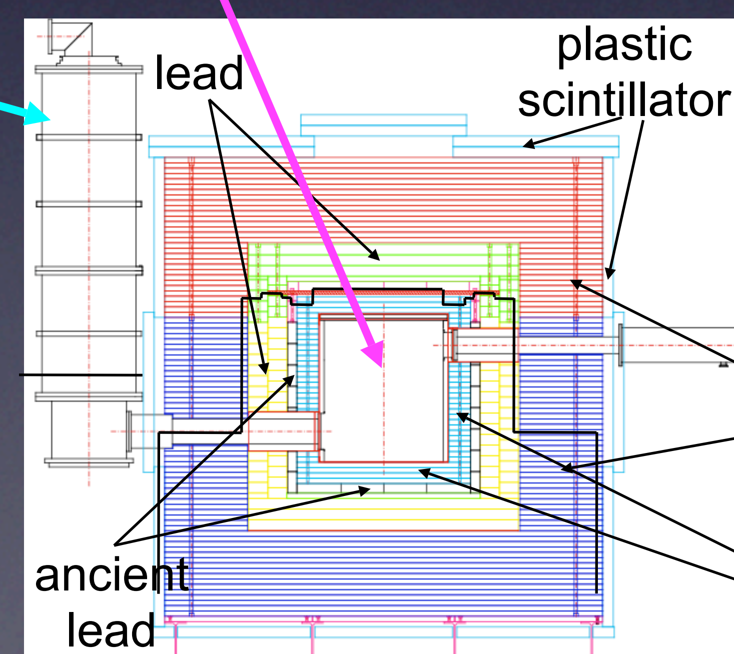


Oxford Instruments 400μW dilution refrigerator

detector cold volume (“icebox”)

vacuum-sealed electronic connector box (“E-box”)

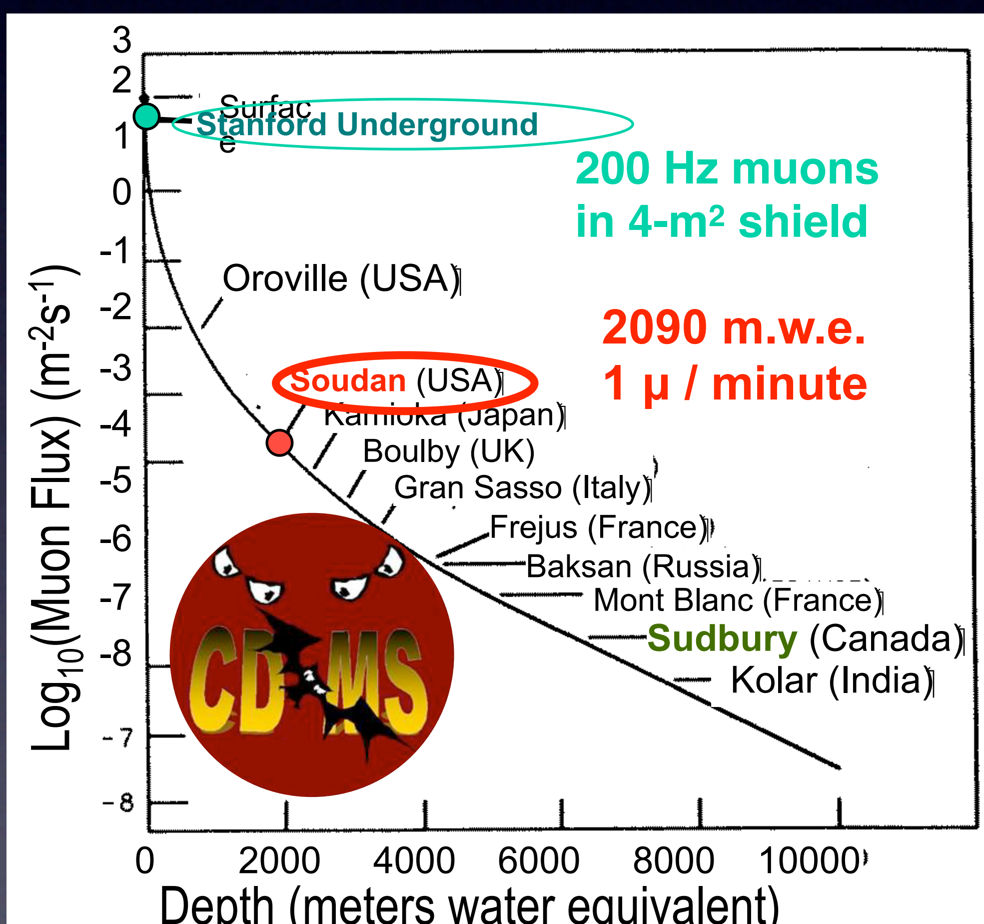
@40 mK!



outer polyethylene

inner polyethylene

Soudan Underground Lab



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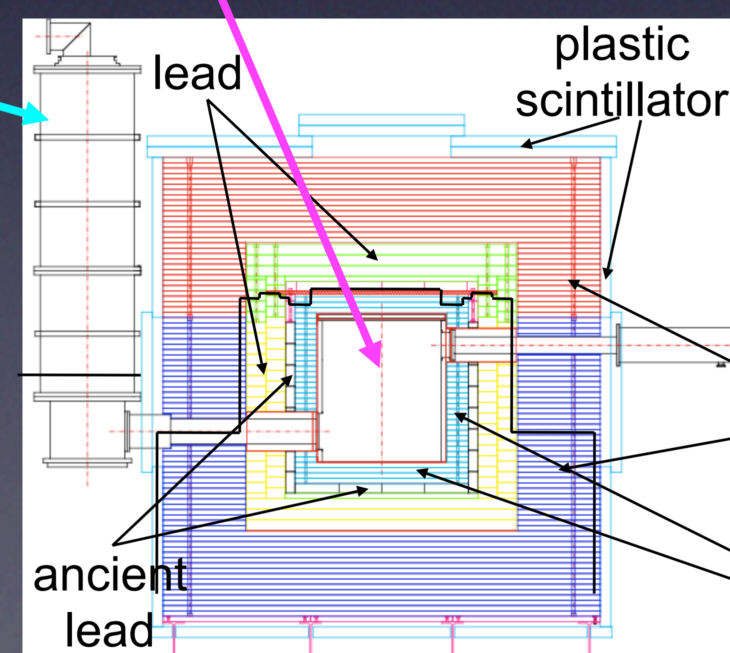


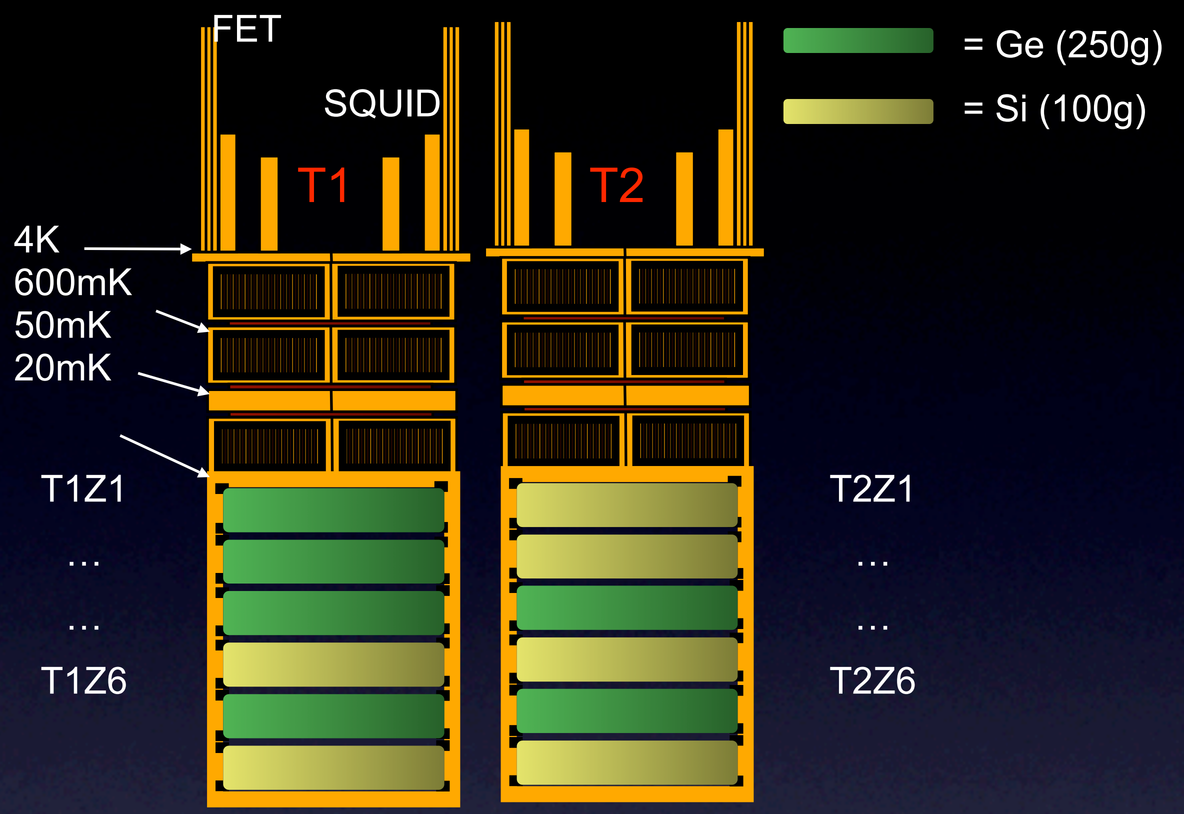
outer polyethylene

inner polyethylene

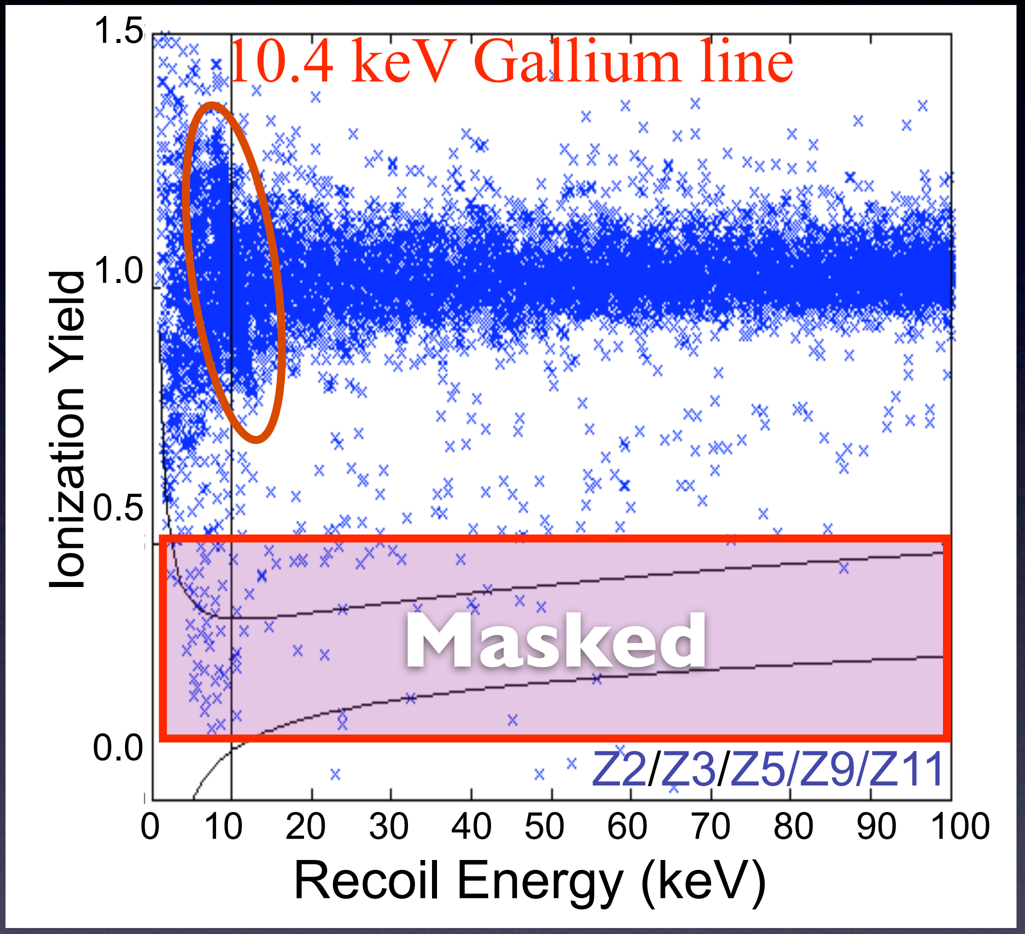
@40 mK!

~0.05 unvetoed neutrons per kg-y (Monte Carlo)

Two Tower Results (2005)



74.5 live days (2004)
1.25 kg Ge + 0.6 kg Si



Blind analysis: cuts set with WIMP-search NR band masked

- Data quality cuts
- Veto-anticoincidence cut
- Q_{inner} (fiducial volume) cut
- Ionization yield cut
- Phonon timing cut

0.4±0.2±0.2 Ge background expected

0.4±0.9±0.5 Si background expected

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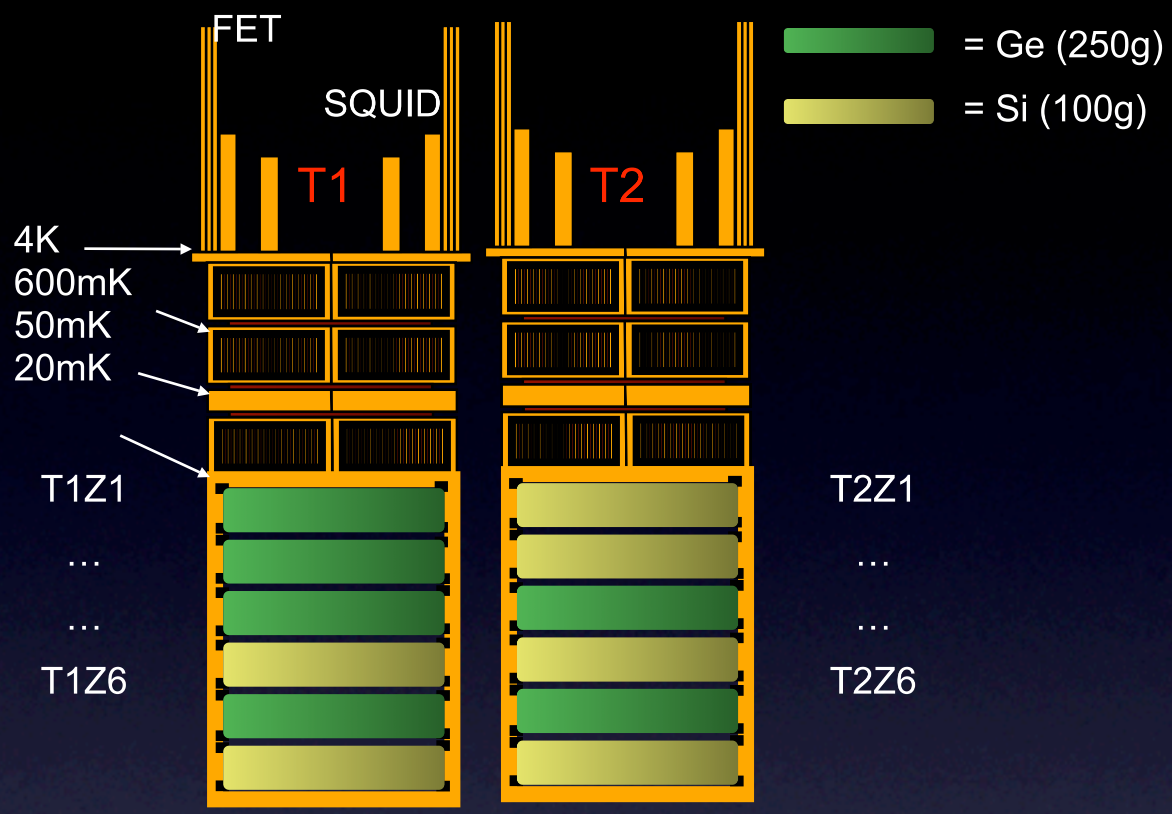

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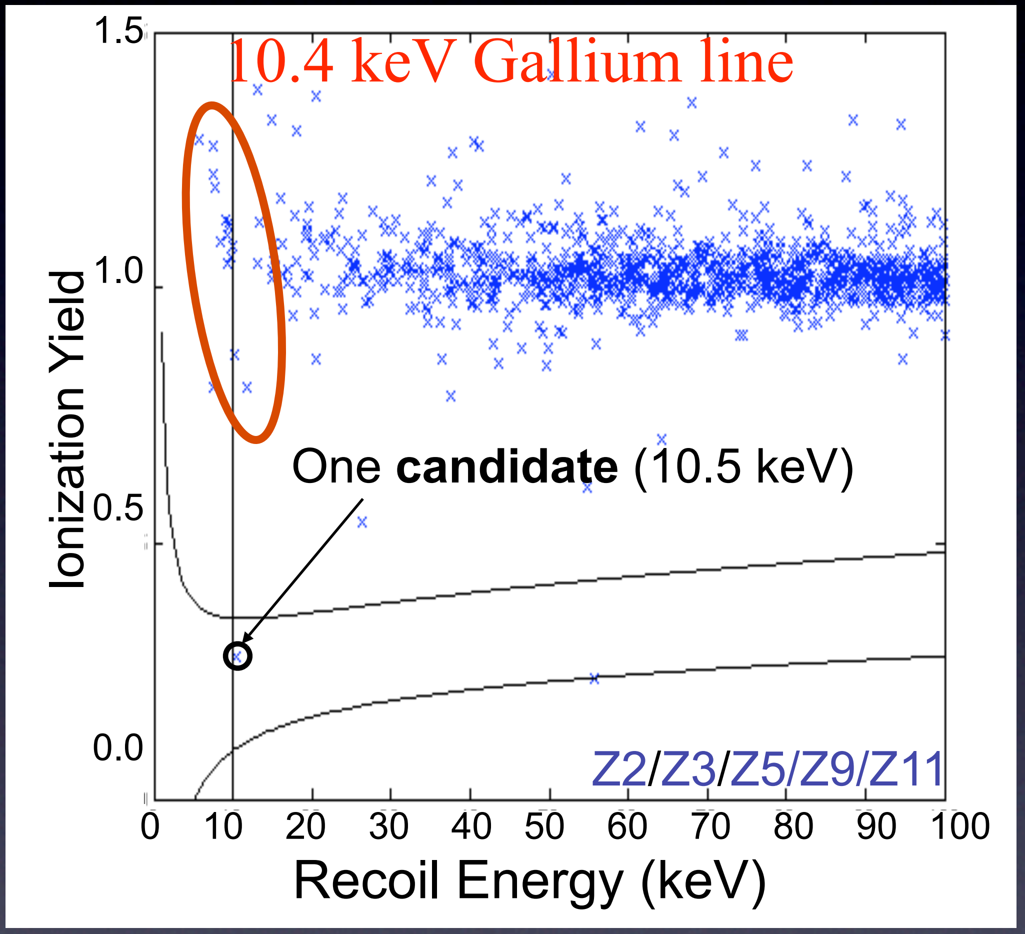

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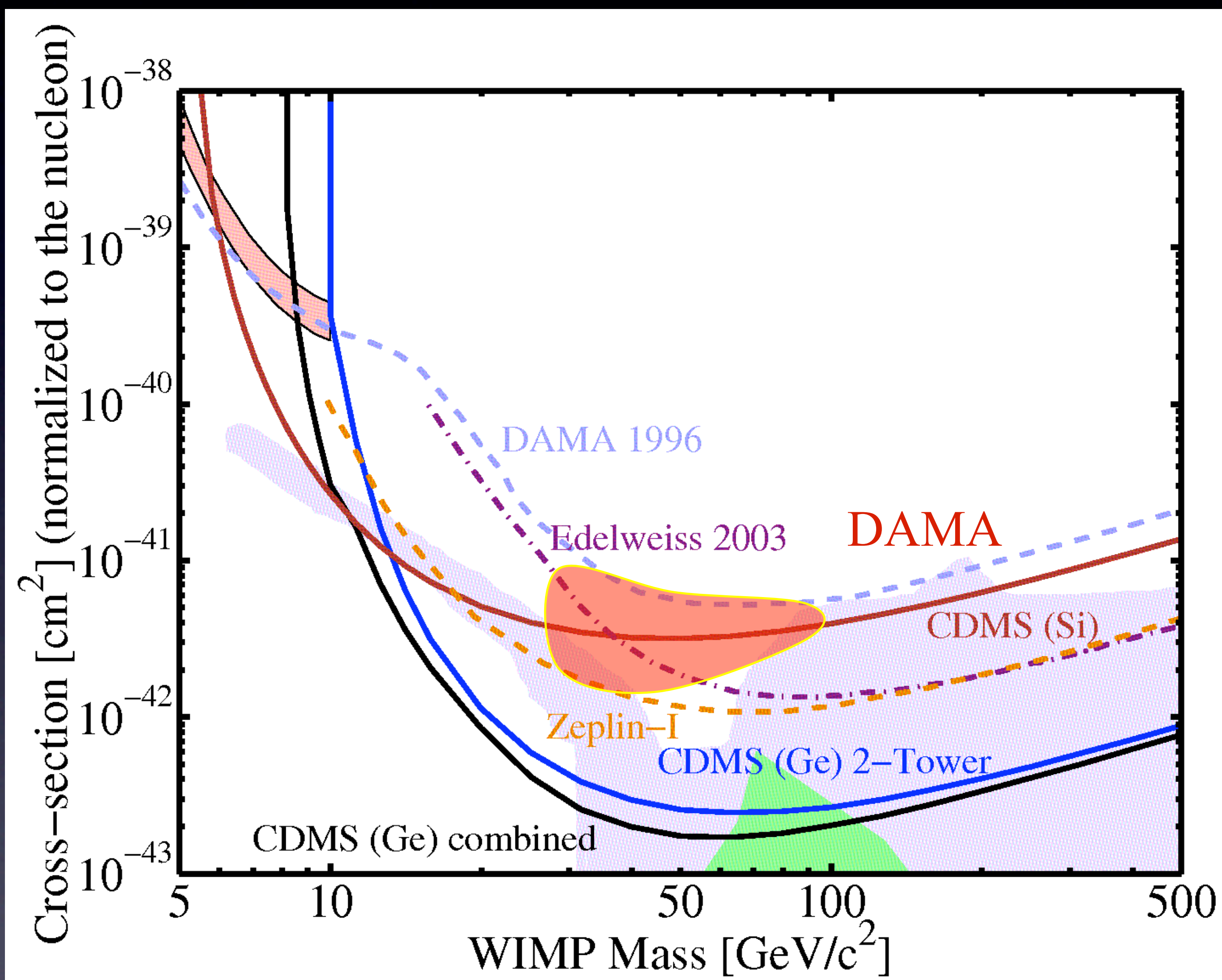
0.4±0.9±0.5 Si background expected

1 Ge event *(run with poor detector performance - oops!)*
0 Si events

Two Tower Limits

90% CL upper limits assuming standard halo, *spin-indenpent* coupling (A^2 scaling)



Upper limit of 1.7×10^{-43} cm^2 (=**170 zeptobarns!**) for a 60 GeV/c^2 WIMP

Phys. Rev. Lett. **96**, 011302 (2006) astro-ph/0509259

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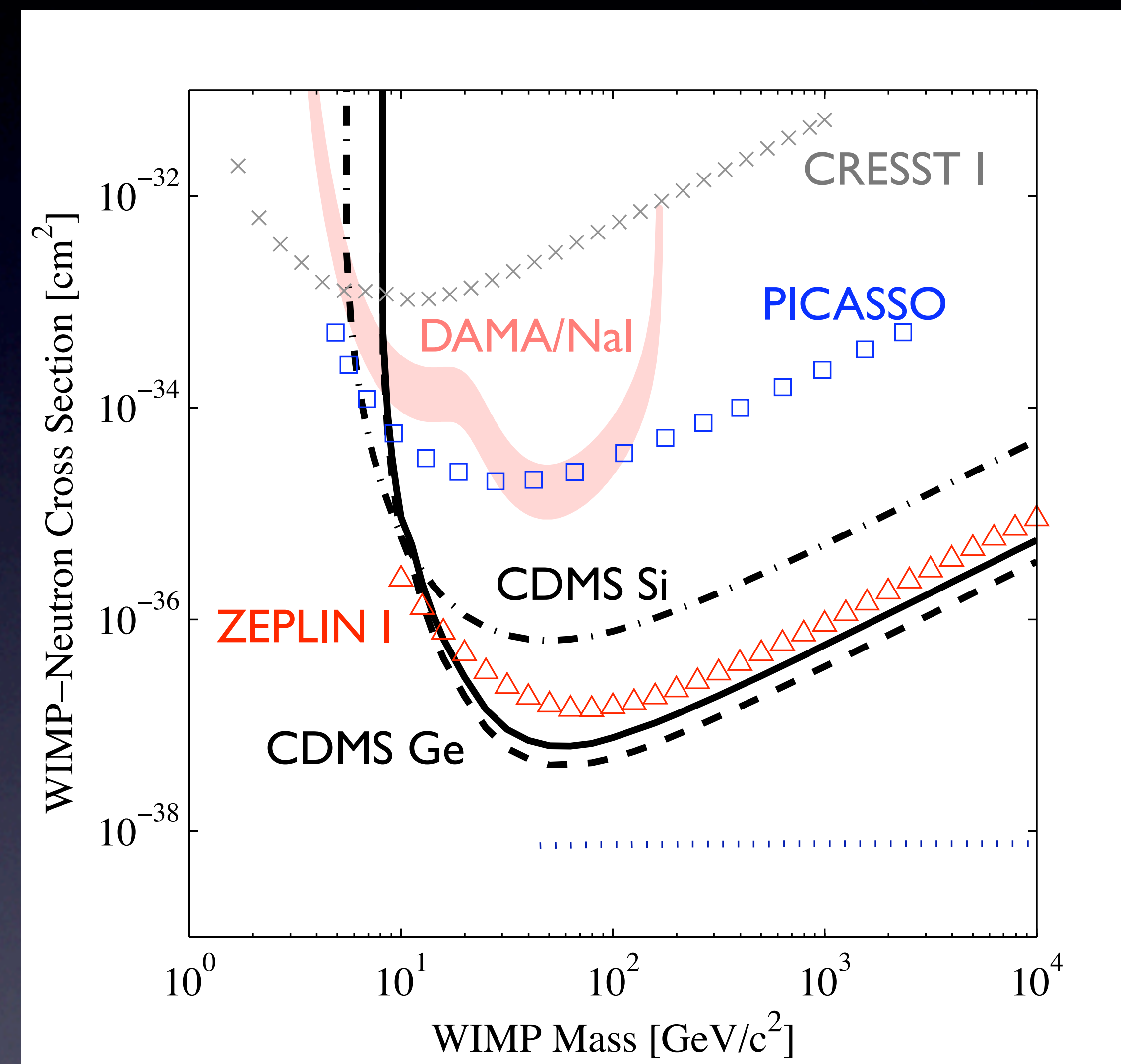

Phys. Rev. D **73**, 011102 (2006) astro-ph/0509269

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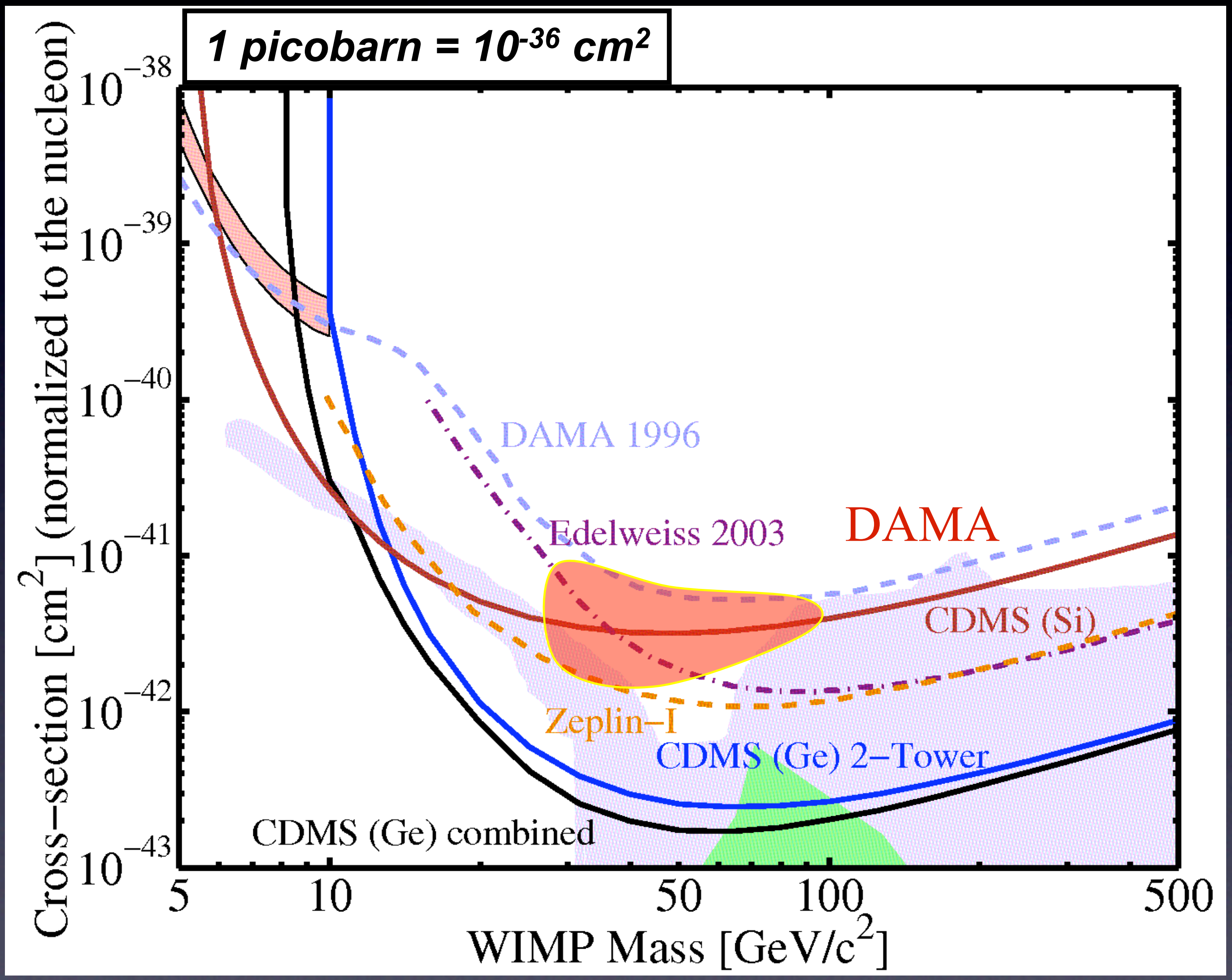

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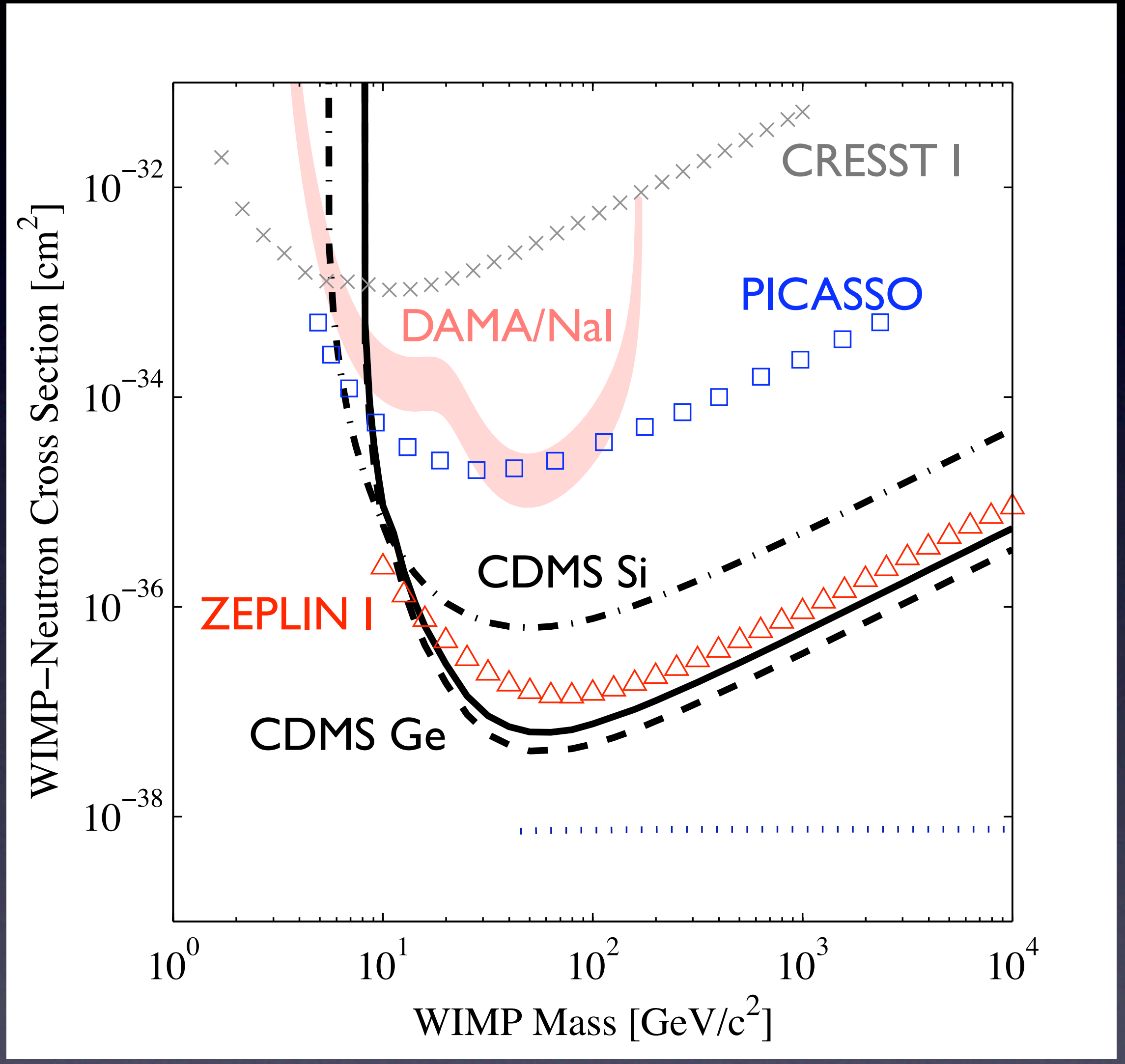

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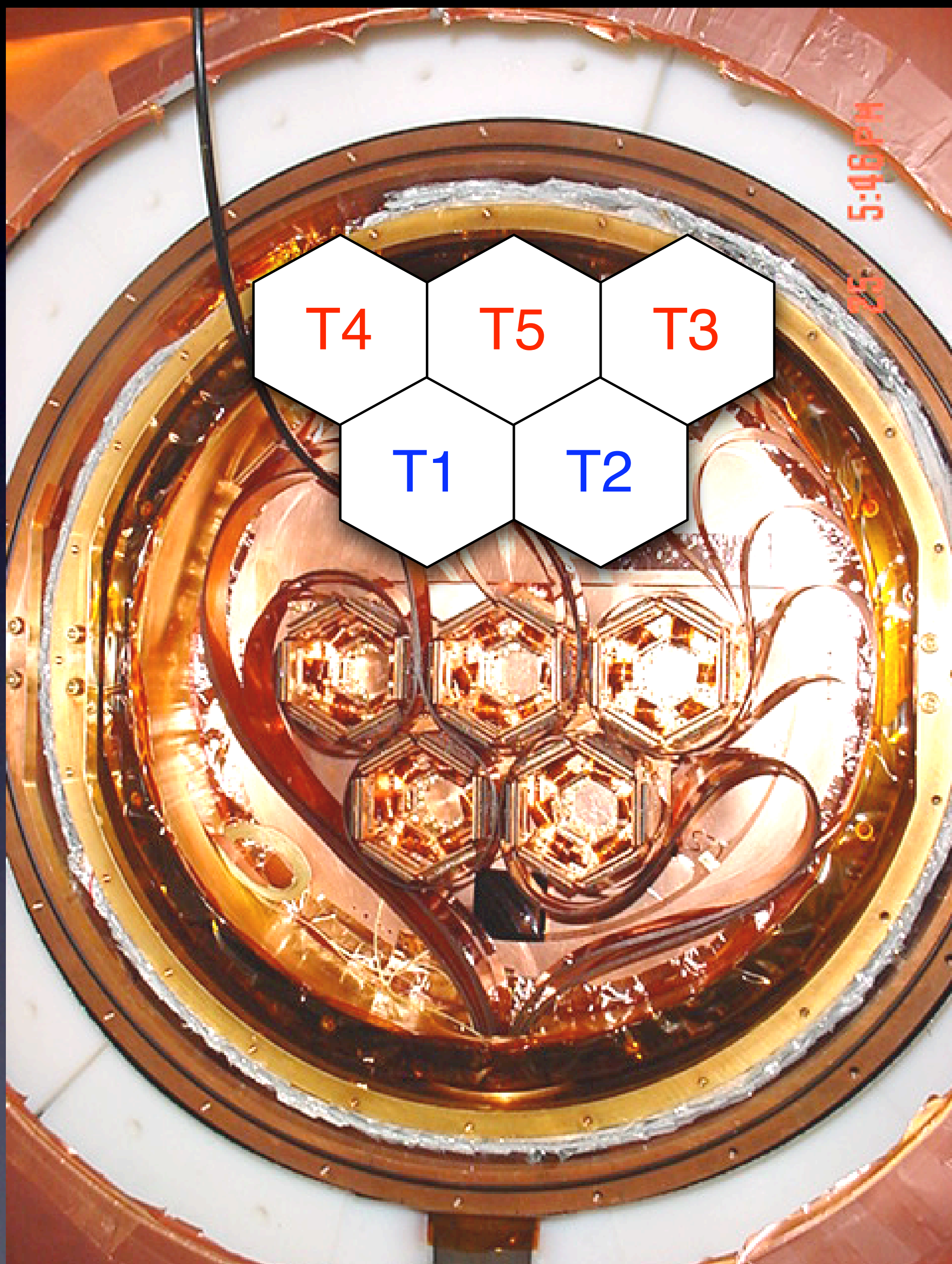
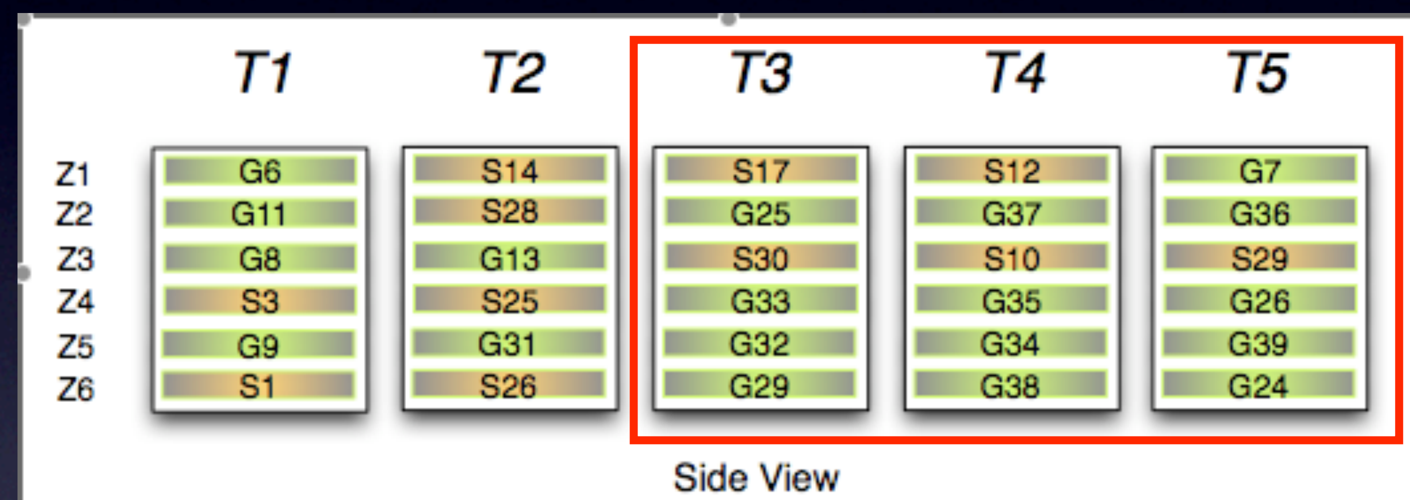
Five Tower Runs (2006-7)



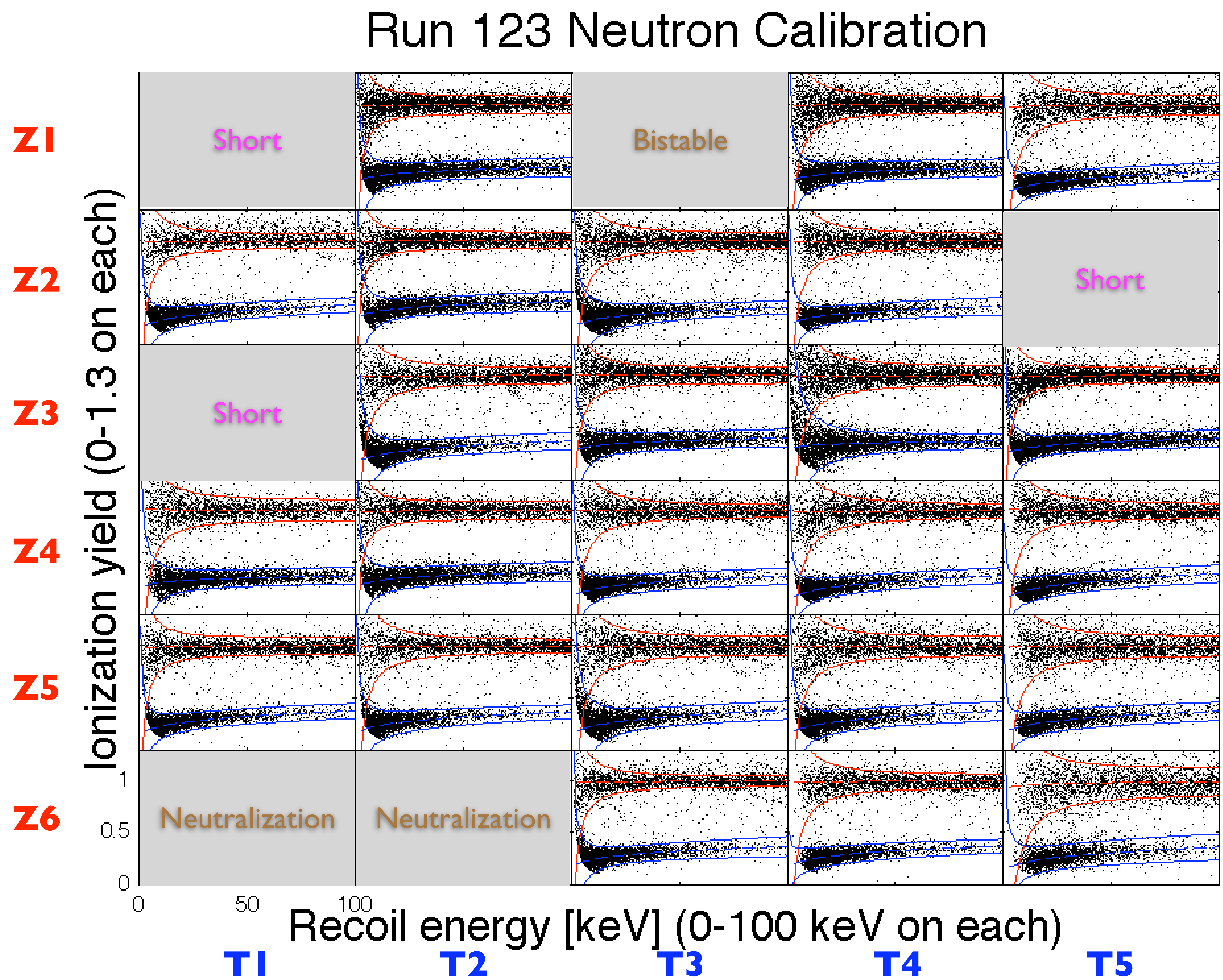
30 ZIPs (5 Towers) installed in Soudan icebox:
4.75 kg Ge, 1.1 kg Si



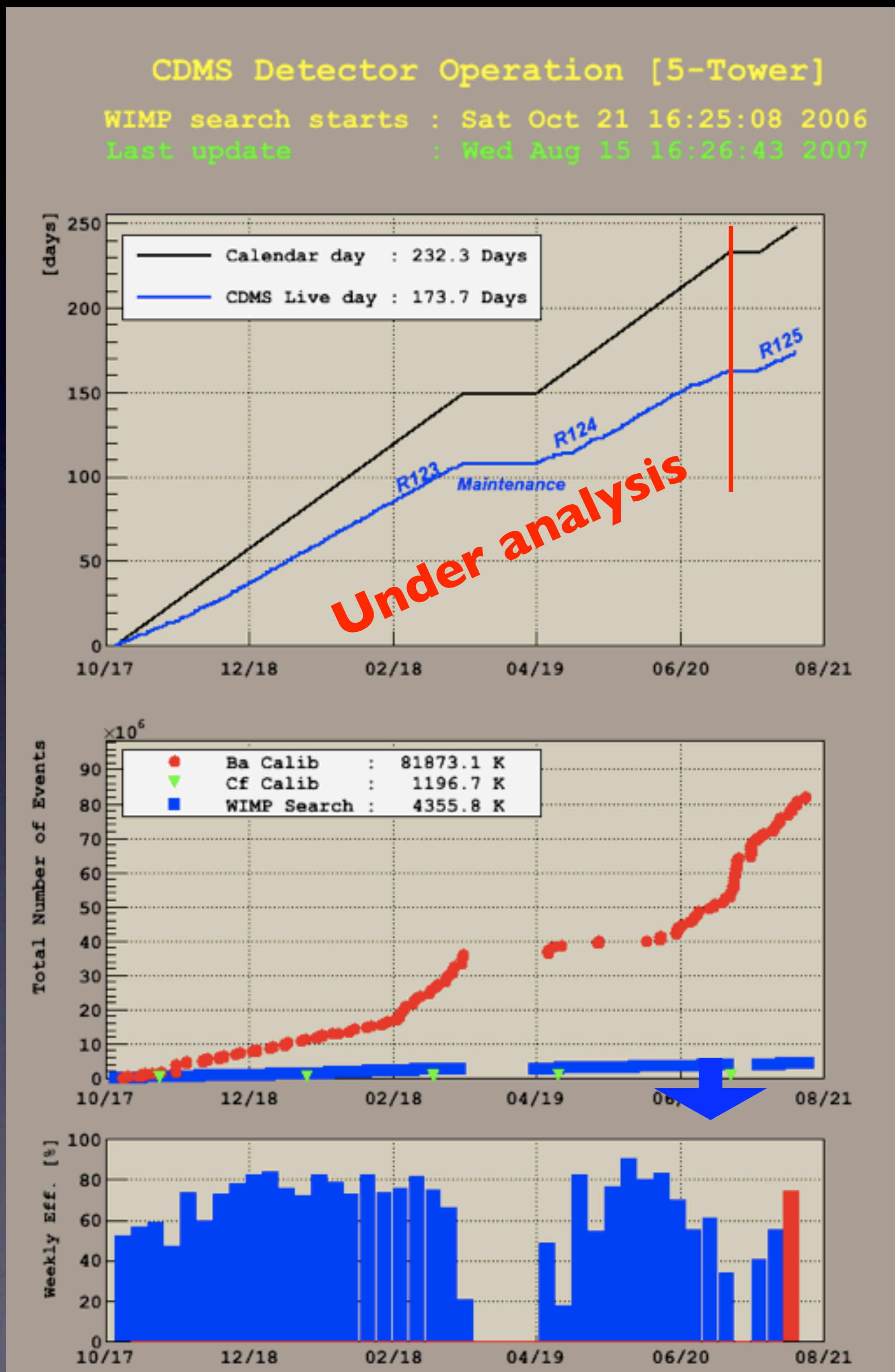
Significant improvements in new detectors:

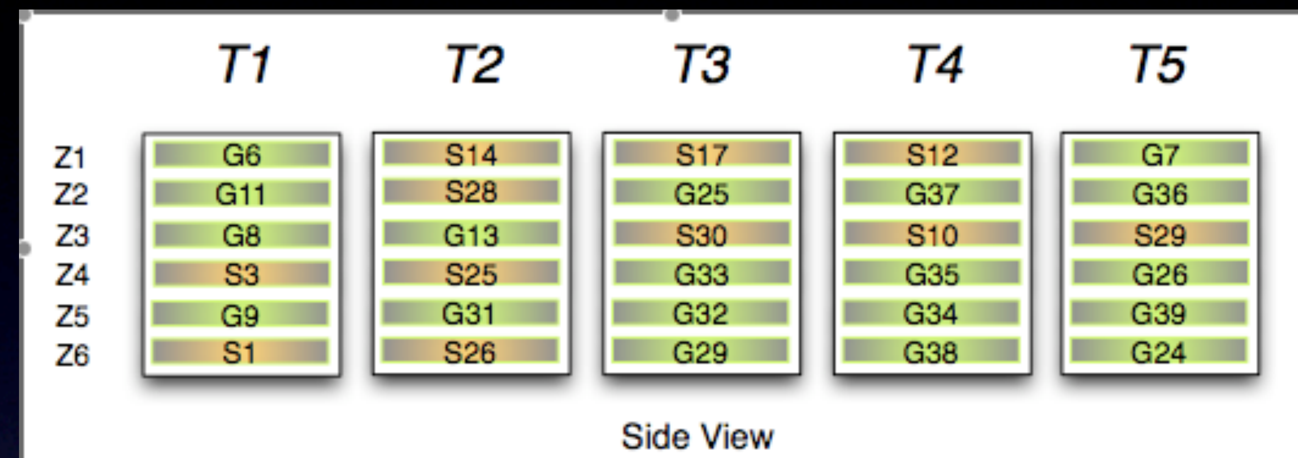
- Grounded outer grid eliminates low-yield events from **detector-detector crosstalk**
- Somewhat reduced **surface contamination** (vs. T2)

Five Tower Yield Bands



Five Tower Status





Three successful data runs so far:

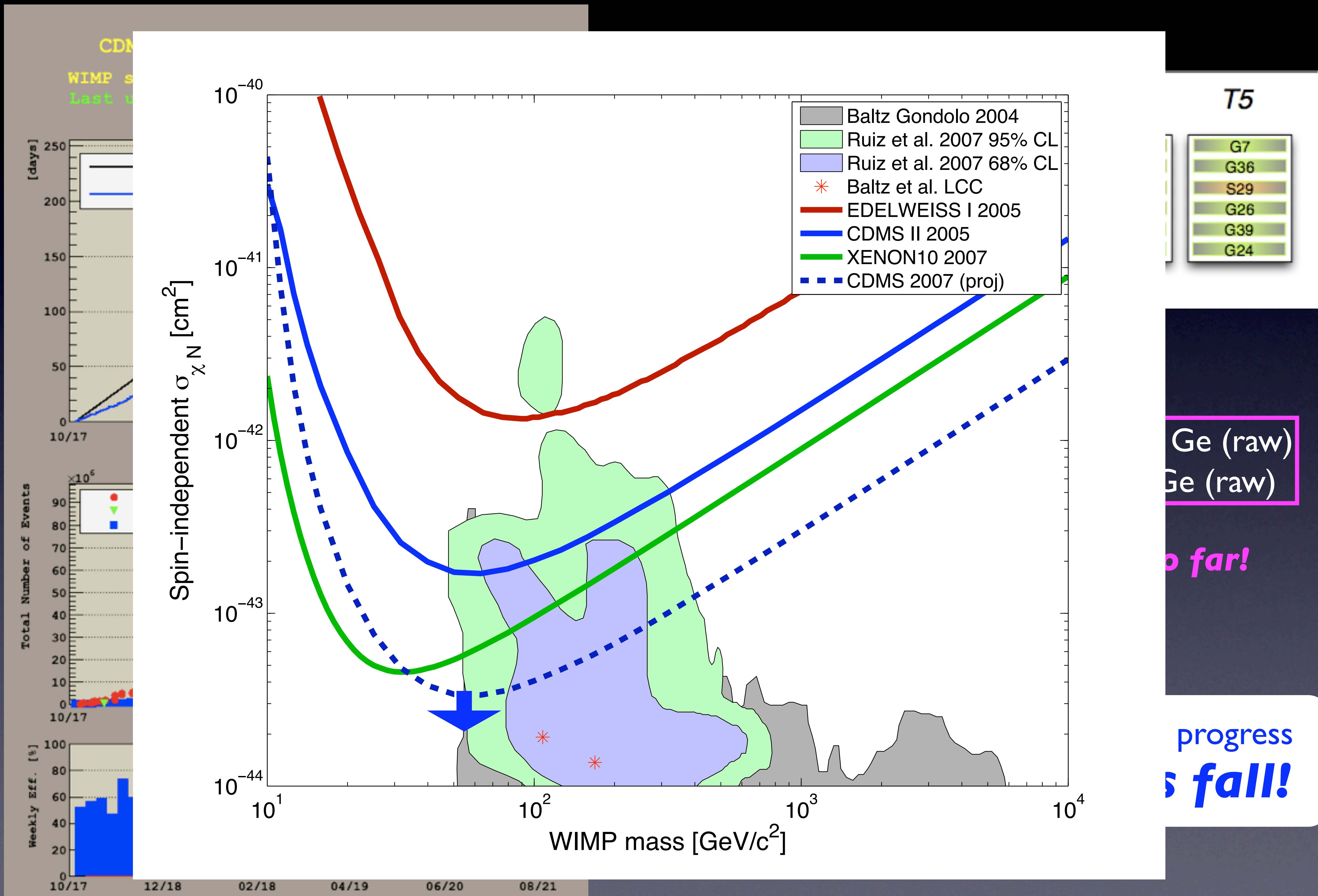
- Run 123 (10/21-3/21): **430 kg-d** Ge (raw)
- Run 124 (4/20-7/16): **224 kg-d** Ge (raw)
- Run 125 (7/21-date): **ongoing**

~7x the 2-Tower exposure so far!

Blind analysis of first two runs in progress

Results expected this fall!

Five Tower Status



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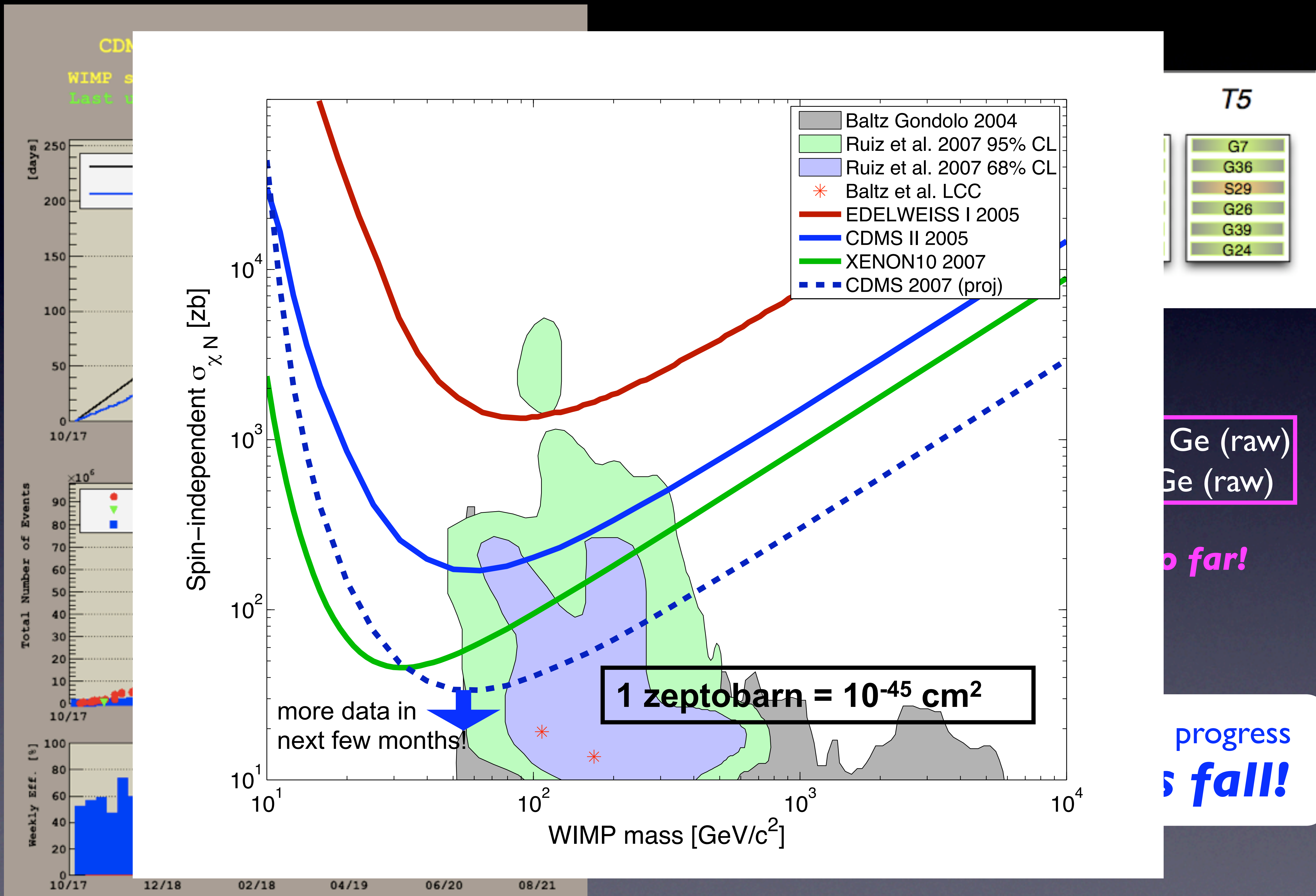
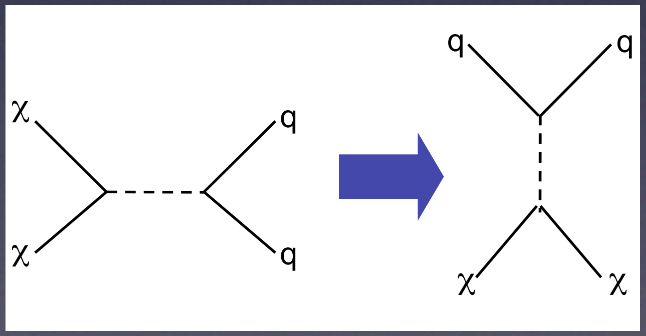


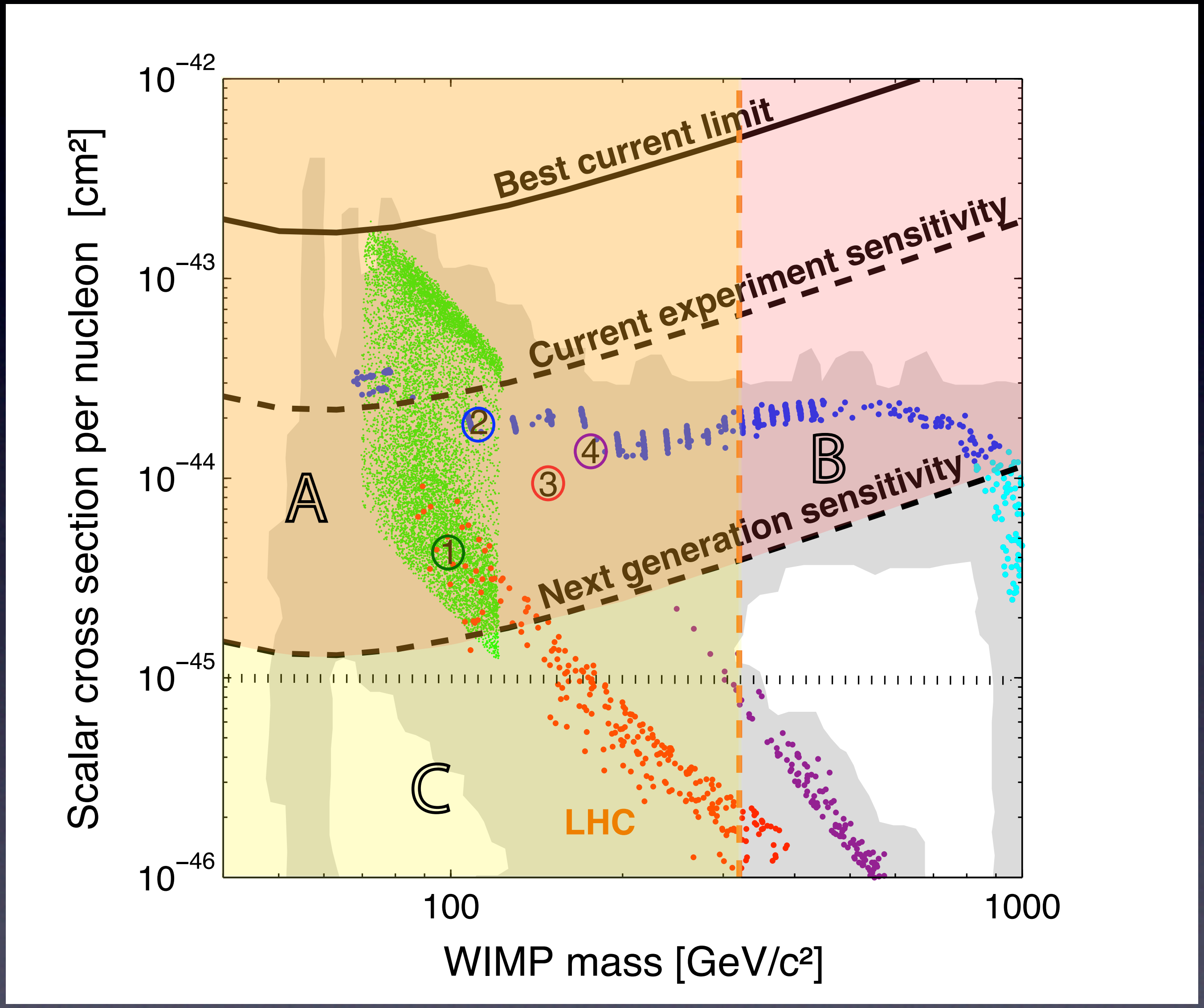
WIMPs at a Zeptobarn

Bulk region
- Natural weak scale from light SUSY
- G-2 favored, FCNC disfavored

Focus point
- Natural weak scale from RGE focusing
- Decoupled scalars => low FCNCs

Crossing symmetry!





B. Sadoulet, *Science* 315, p. 61 (2007)

Higgs funnel
- Broad resonance ($M_A \sim 2 M_\chi$) speeds annihilation

Coannihilation Tail
- Near-degeneracy between LSP and NLSP

"Spectral coincidences"

"Zeptobarn-class" direct detection has substantial discovery potential and complementarity with the LHC

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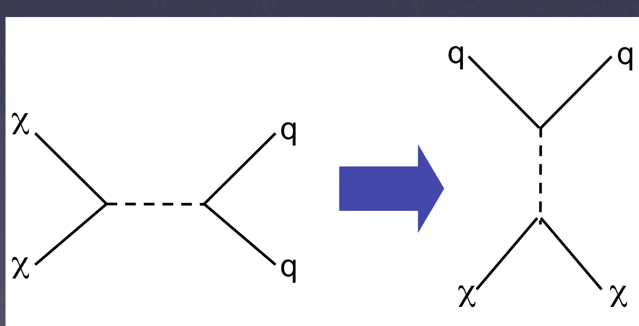

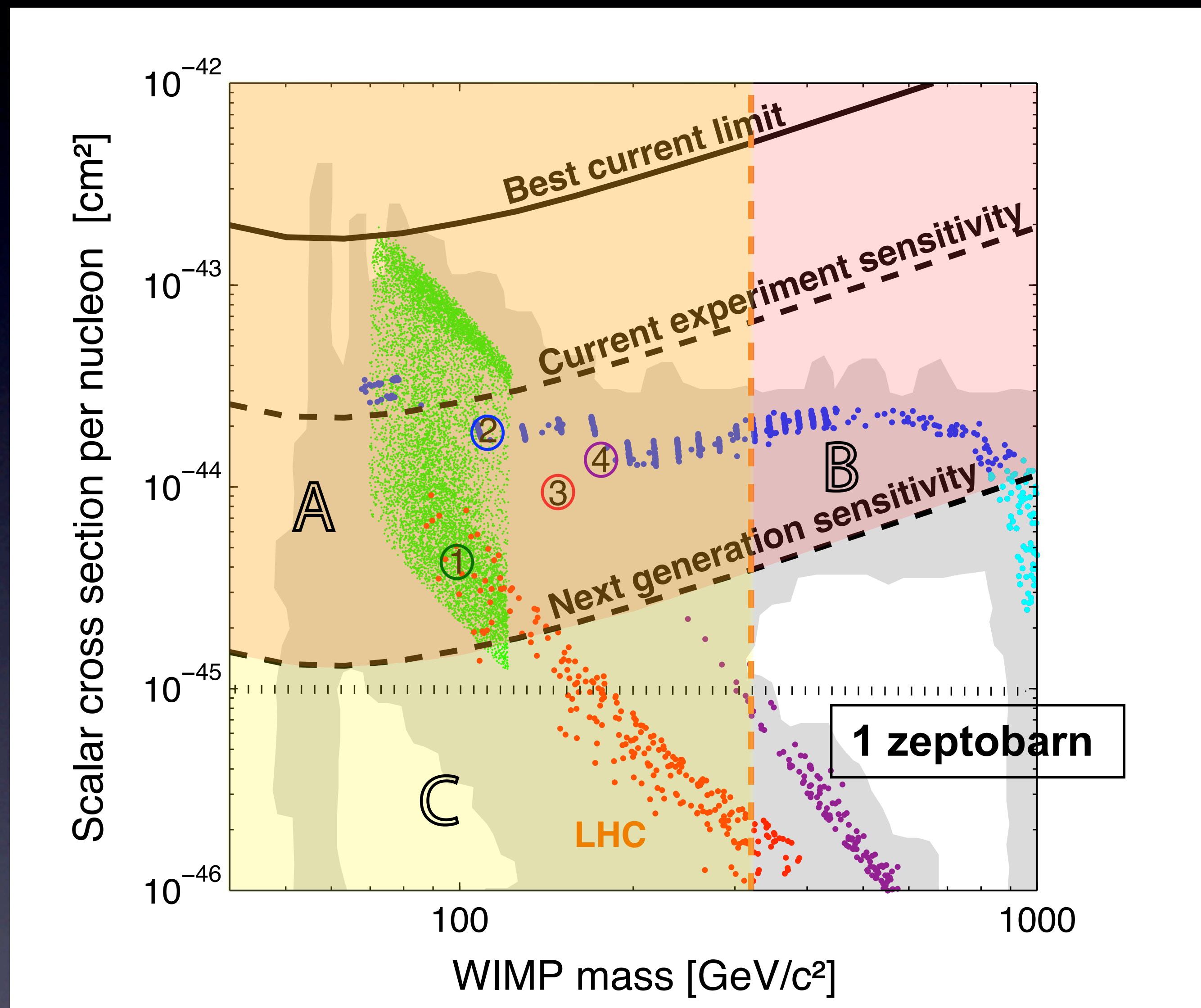

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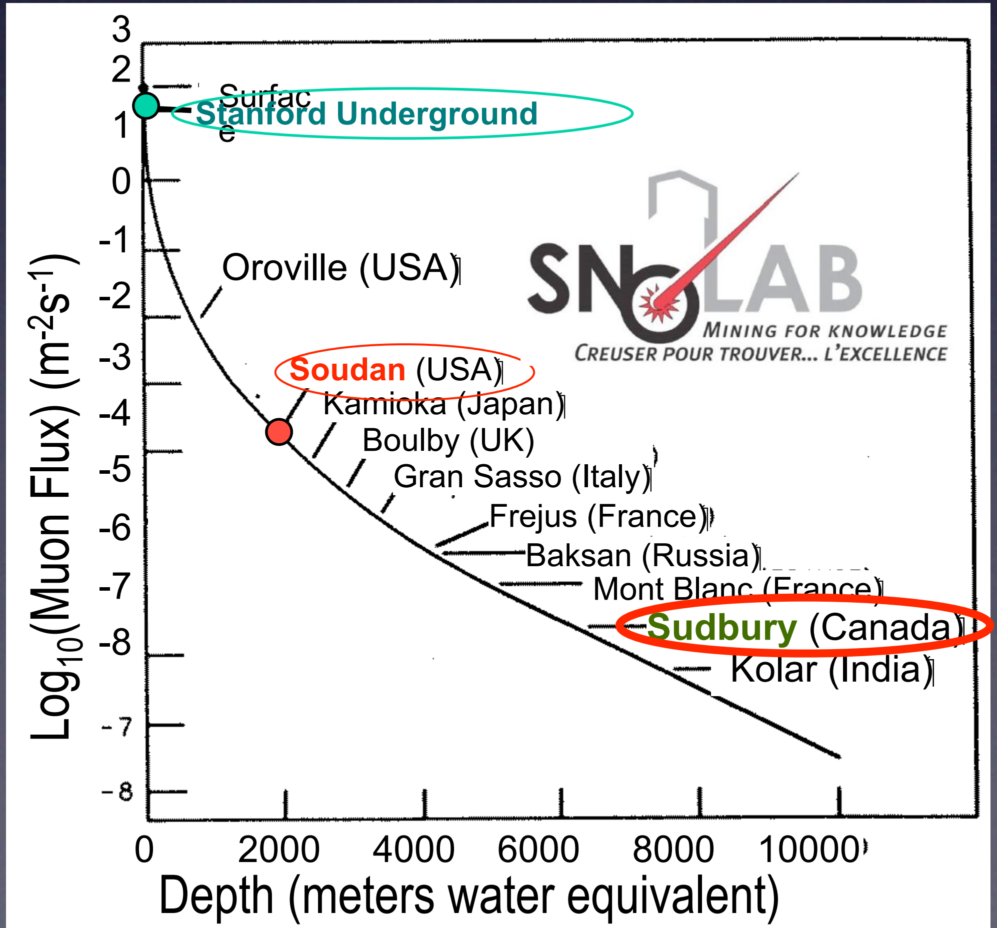
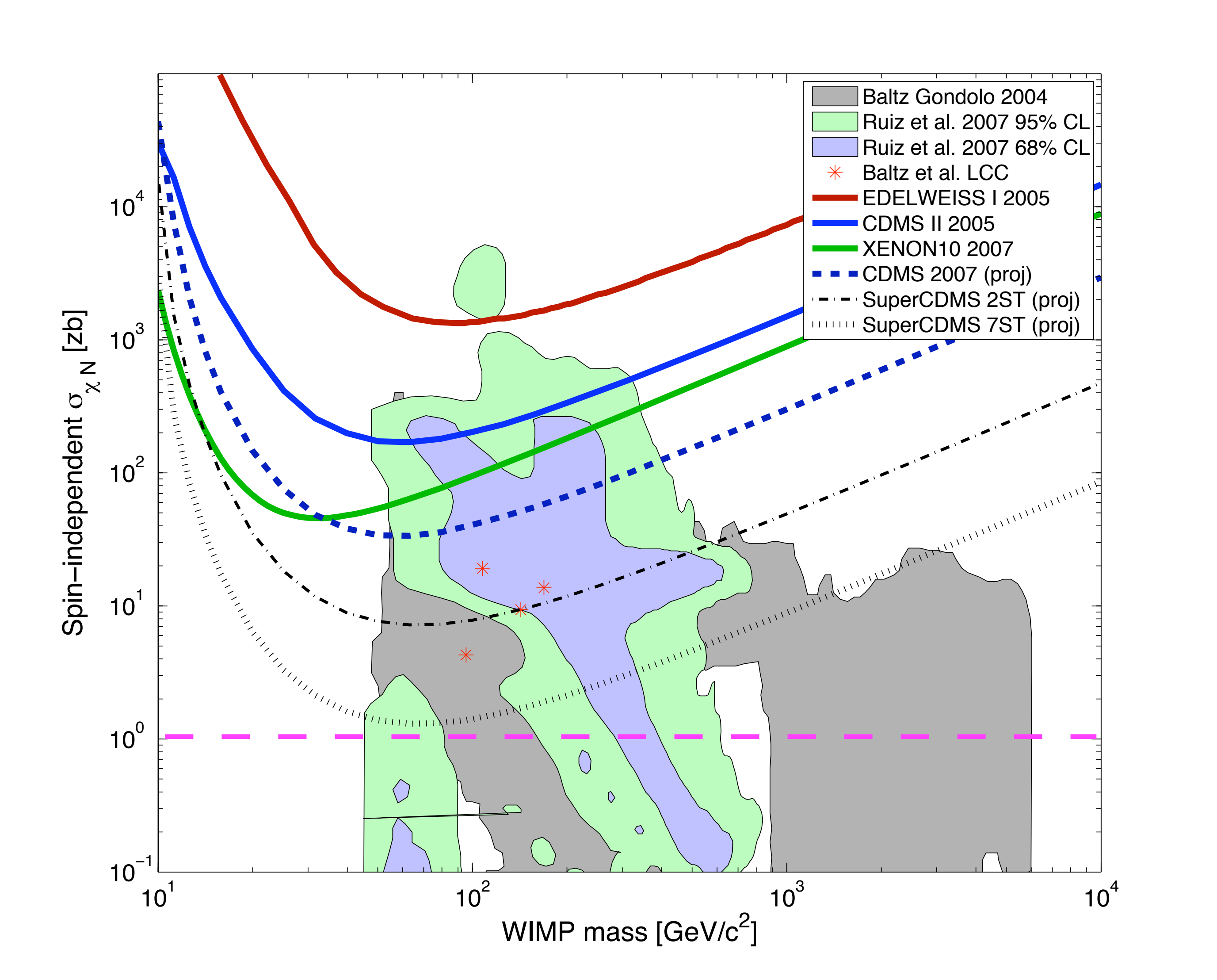
25kg and Beyond: SuperCDMS

(Formerly known as "**CryoArray**")

25 kg experiment to explore the zeptobarn scale, now funded by NSF/DOE to run first two SuperTowers at Soudan, then move to **SNOLAB**

- **7 SuperTowers** of thick Ge ZIPs
- Improved surface handling
- Improved analysis (some already in hand!)
- Improved detector performance





For references, see http://dmtools.berkeley.edu
(Gaitskell, Mandic, Filippini)

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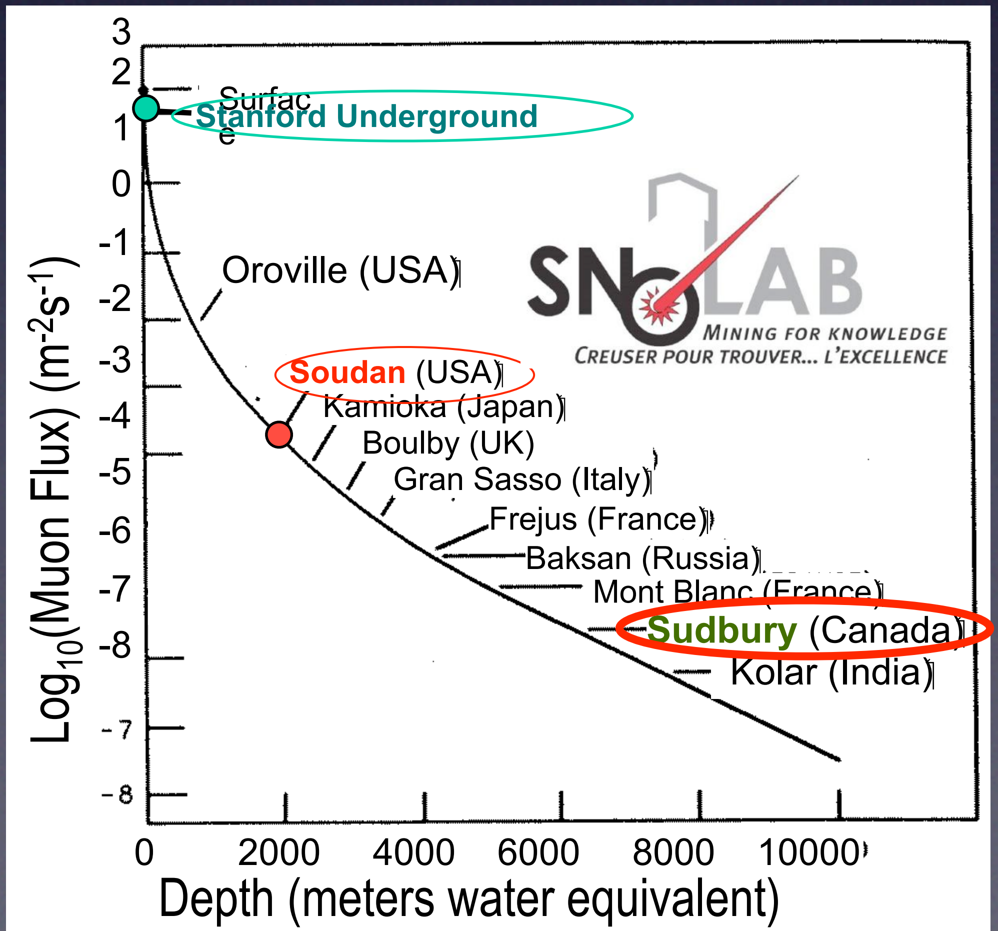

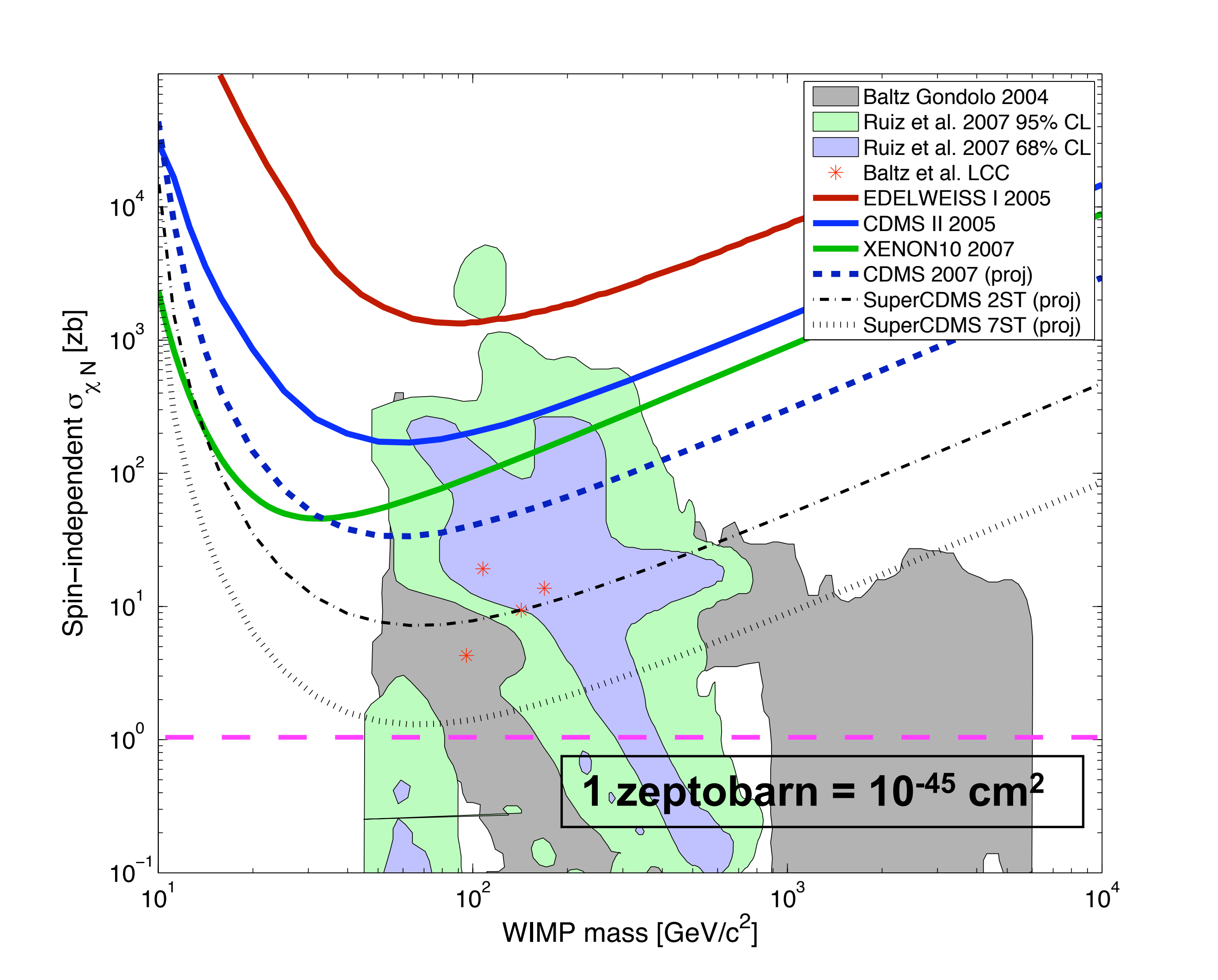

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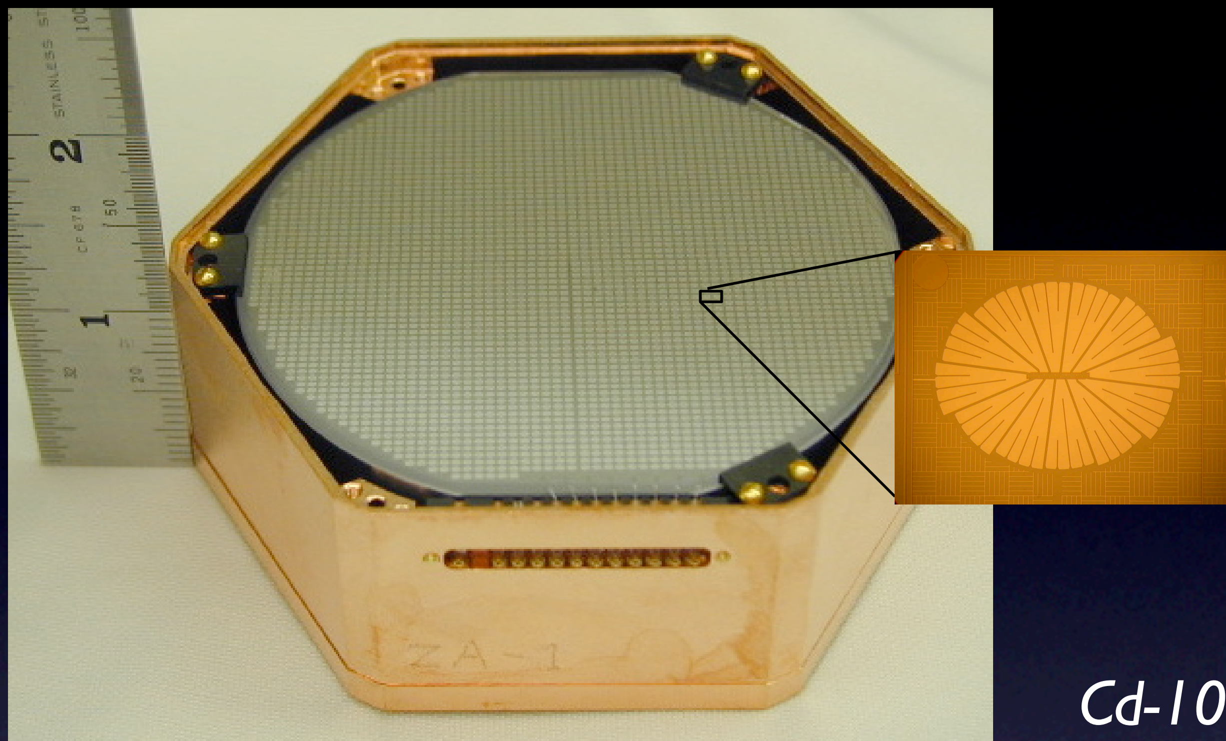
SuperCDMS ZIPs



- 2.5x detector mass (7.6 cm x **2.54 cm**)

=> *better volume/surface, faster manufacture*

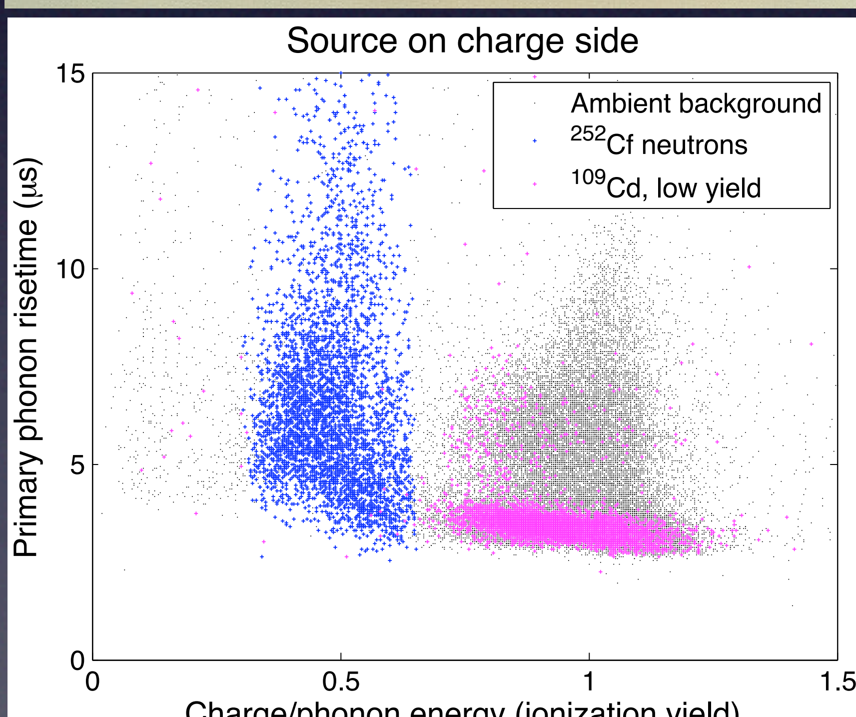
- Single mask lithography

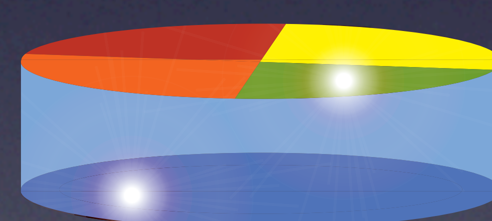
=> *reliable manufacture*

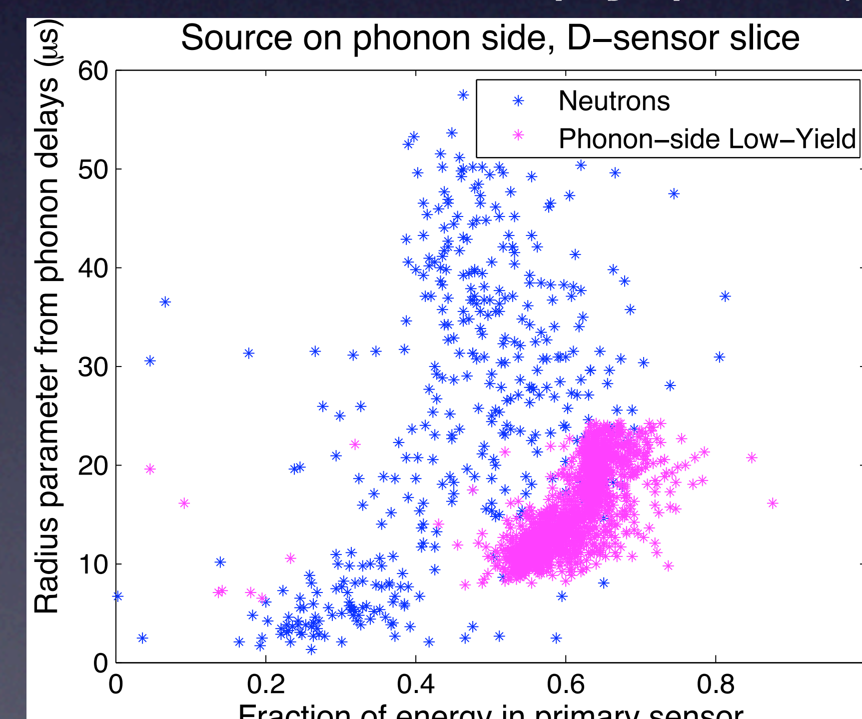
- Improved active Al coverage

=> *better "antennas"*

Cd-109 calibration of "G3D" at UC Berkeley (July 2007)



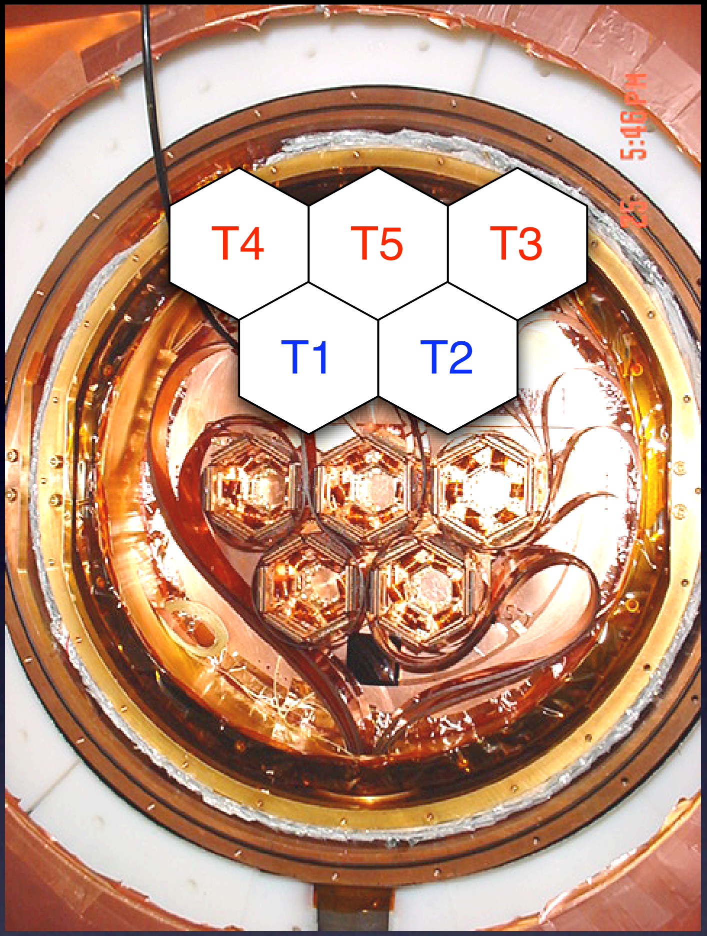


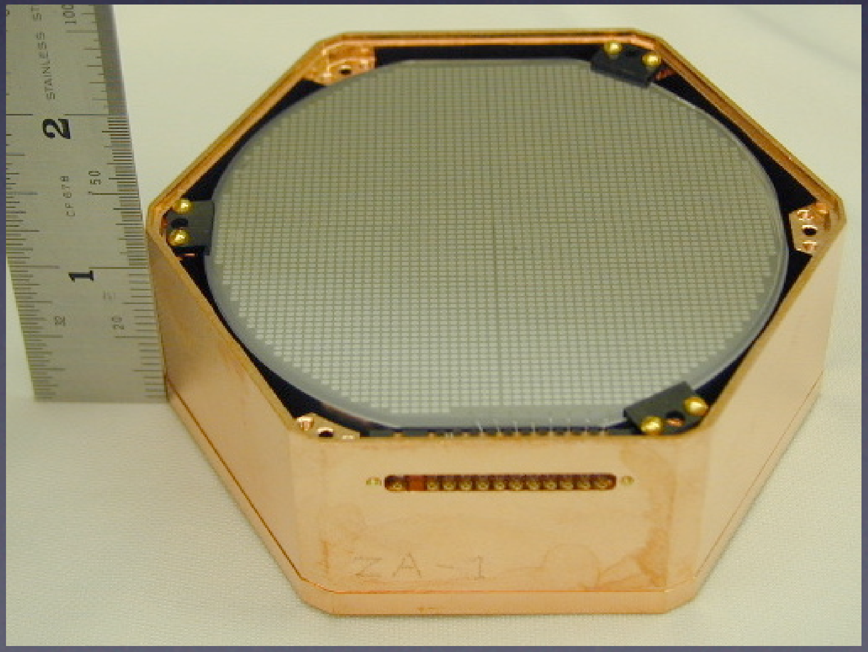


***Farther future:** ongoing work on new ZIP designs and kinetic inductance detectors (**KIDs**) for scalable athermal phonon detection (beyond 25 kg)*

Conclusions

- CDMS ZIP detectors have maintained zero background operation down to the 10^{-43} cm^2 (100 zeptobarn) level
- The 5-Tower run of CDMS II is well underway, pushing to 10^{-44} cm^2 (10 zeptobarn)
  => Results expected this fall!
- SuperCDMS has techniques in hand for next generation cryogenic detectors for the zeptobarn scale





The CDMS Collaboration

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Extra Slides

Background Budget

General

- Reject **multiple-scatters**
- Reject coincidence with **muon veto shield**

Photons (bulk electron recoils)

- Pb shielding
- Yield rejection > 10^5:1

Neutrons

- Polyethylene shielding
- Muon veto
- => 0.05/kg-y (Monte Carlo)
- => ~**0.1** in 1300 kg-d raw

"Betas" (surface electron recoils)

- Low-activity Cu, old air purge, clean handling
- Timing rejection ~ 100:1
- => Tune cuts for ~0.5 event leakage in given exposure

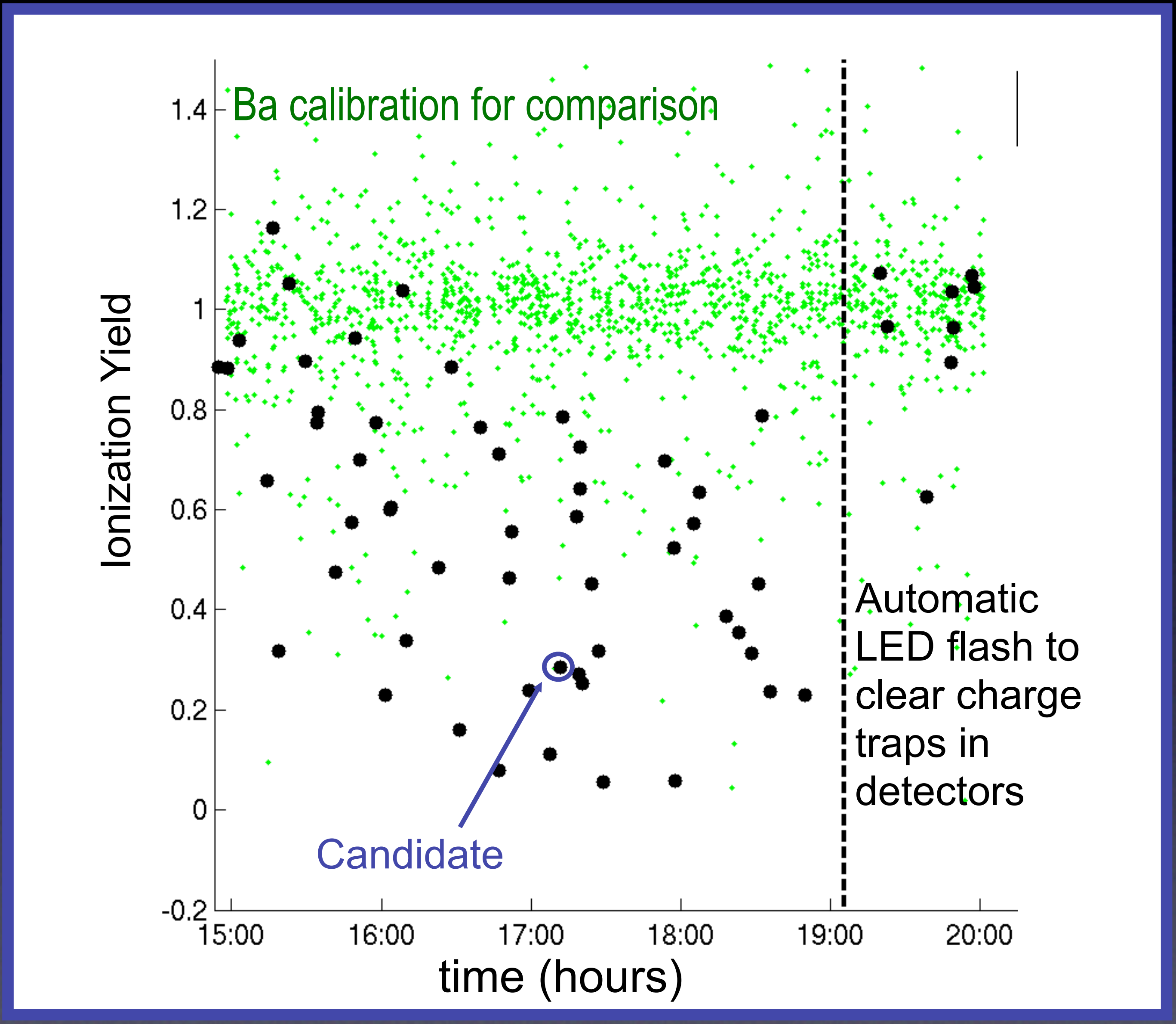
	1-Tower counts
All events	968,680
Not random trigger	940,619
Phonon thresholds	79,460
Single scatter	20.907
Data quality	19,027
Pile up	17,793
Muon veto	17,622
Ionization threshold	14,835
Fiducial volume	7,615
Nuclear recoil band	23
Phonon timing	**1**

Phys. Rev. D **72**, 052009 (2005) astro-ph/0507190

Two-Tower "Candidate"

Data selection failure, NOT a WIMP candidate

Two-Tower "Candidate"



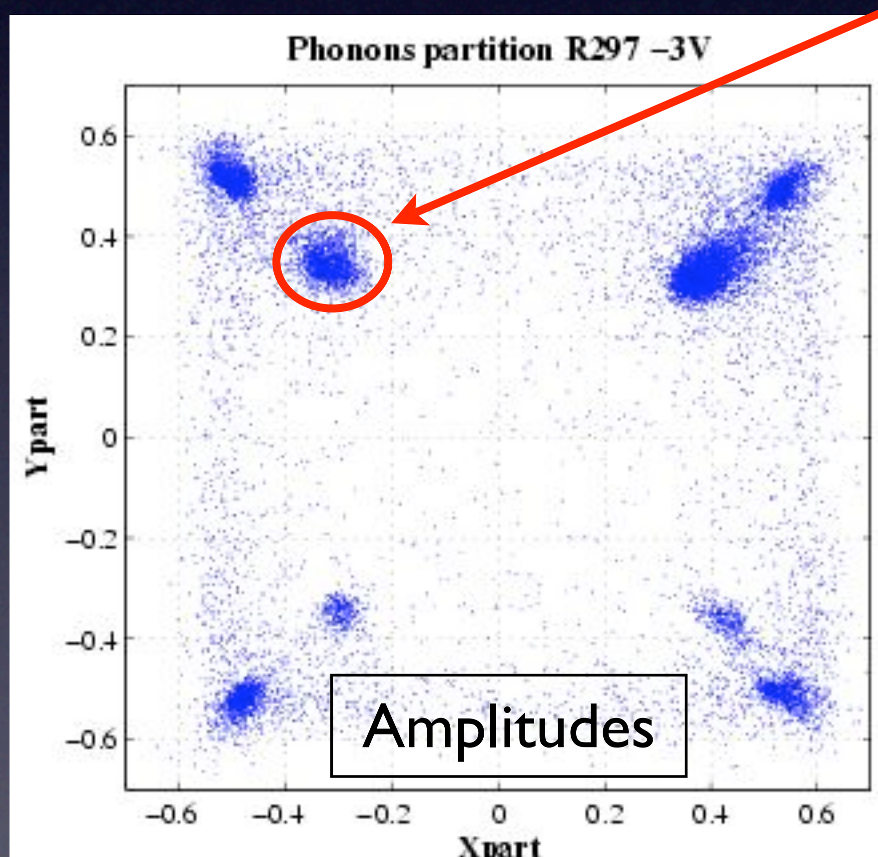
Data selection failure, NOT a WIMP candidate

Position Reconstruction

Crucial to correct for position dependencies of athermal phonon signals

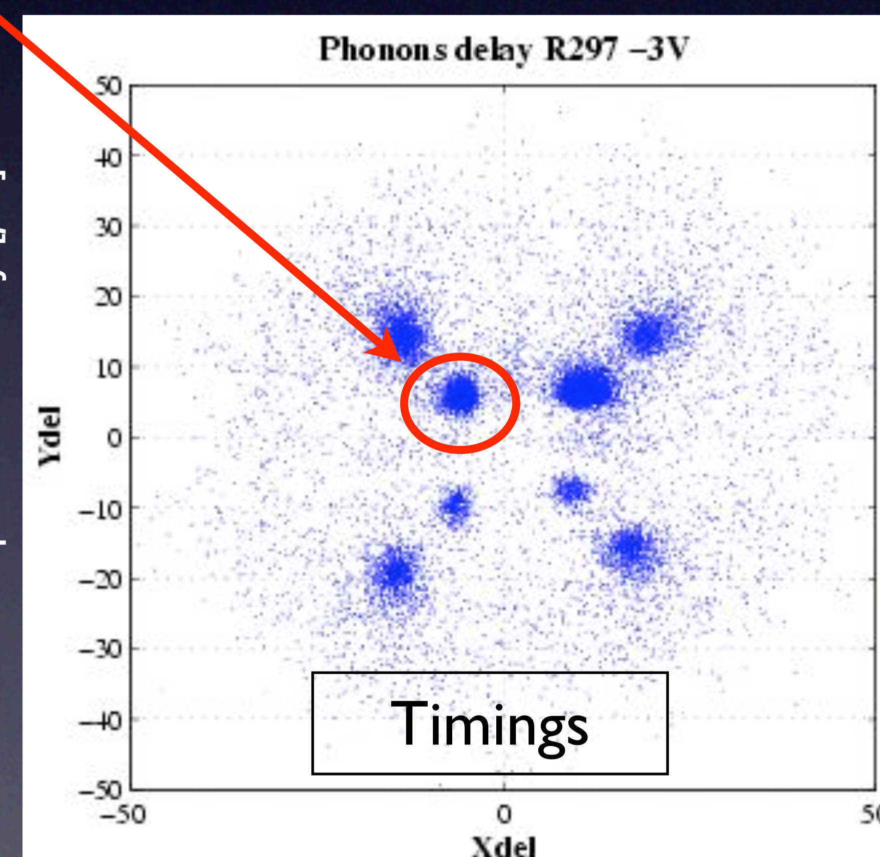
Collimated ^{109}Cd sources (β, 22 keV γ)

AC-BC phonon partition



CD-AB phonon partition

AC-BC phonon delay [μs]



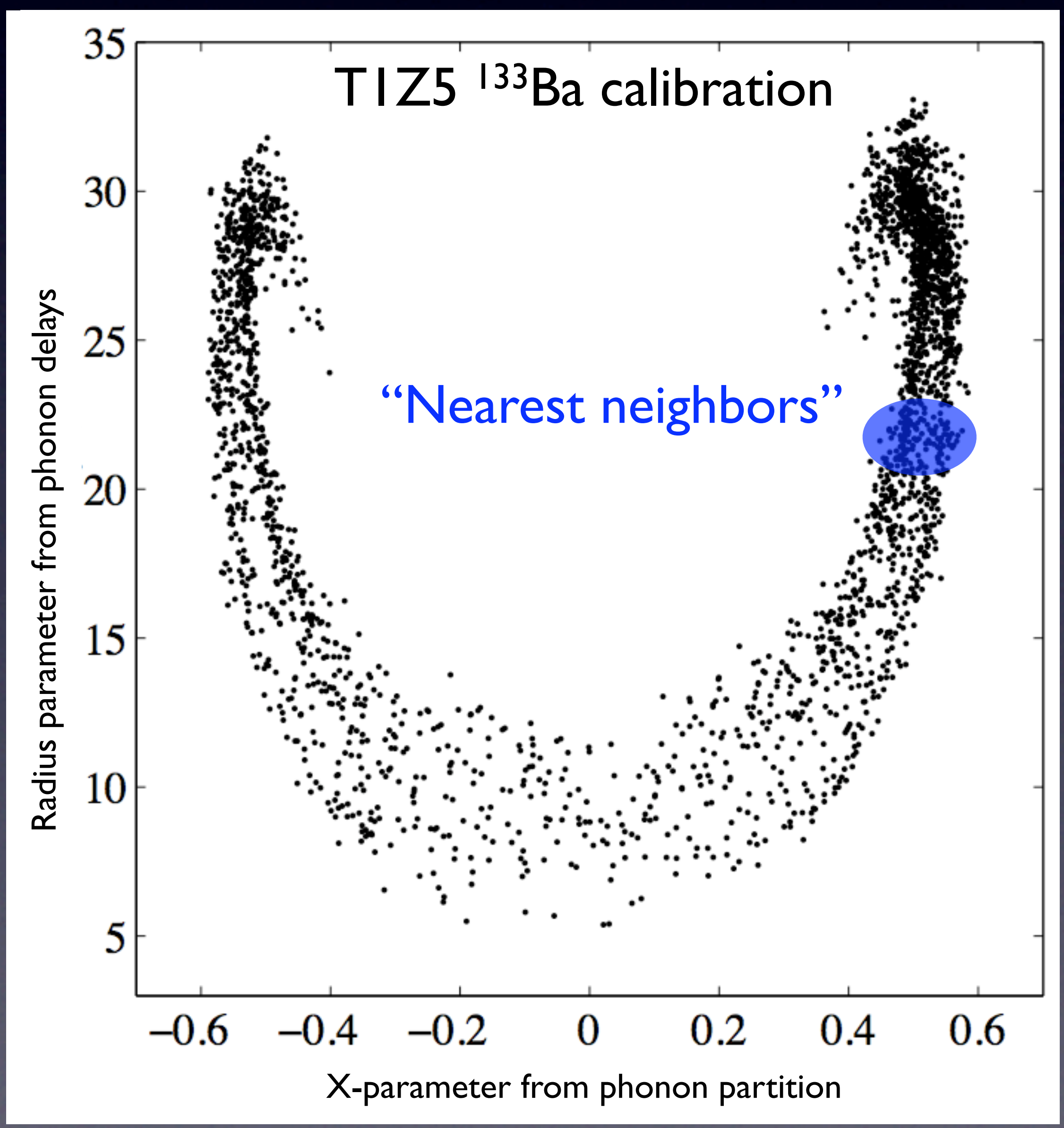
CD-AB phonon delay [μs]

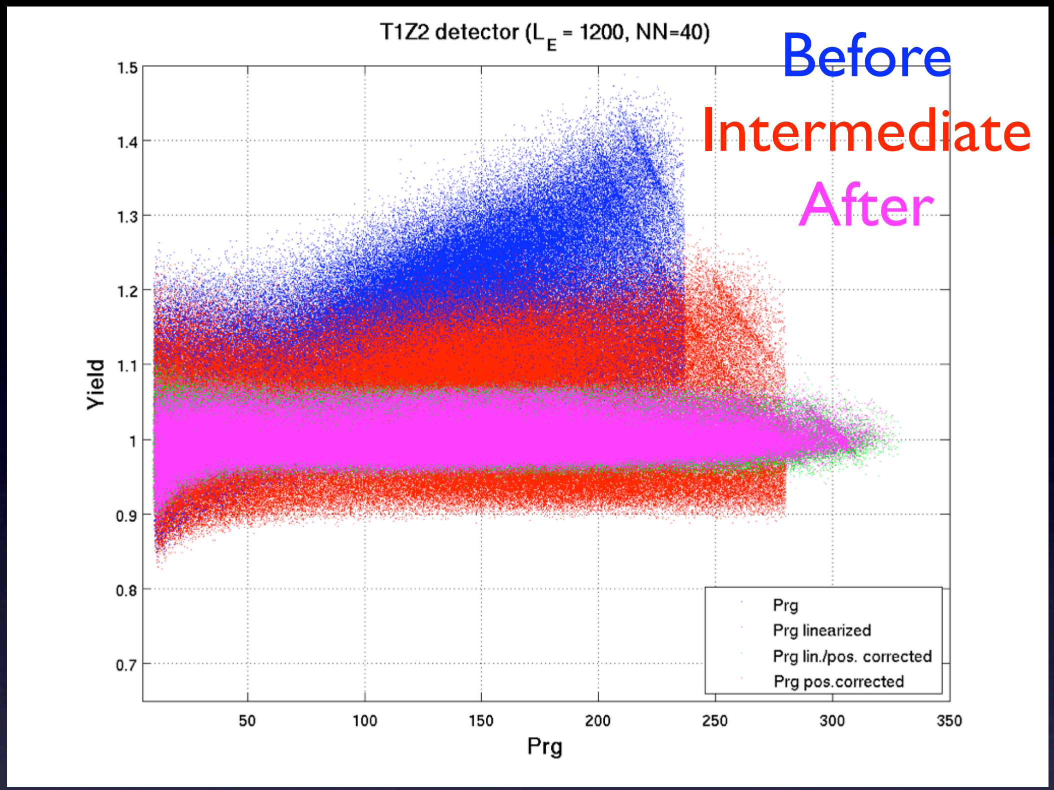
*Data from UC Berkeley calibration of **T2Z5**, née **G31***

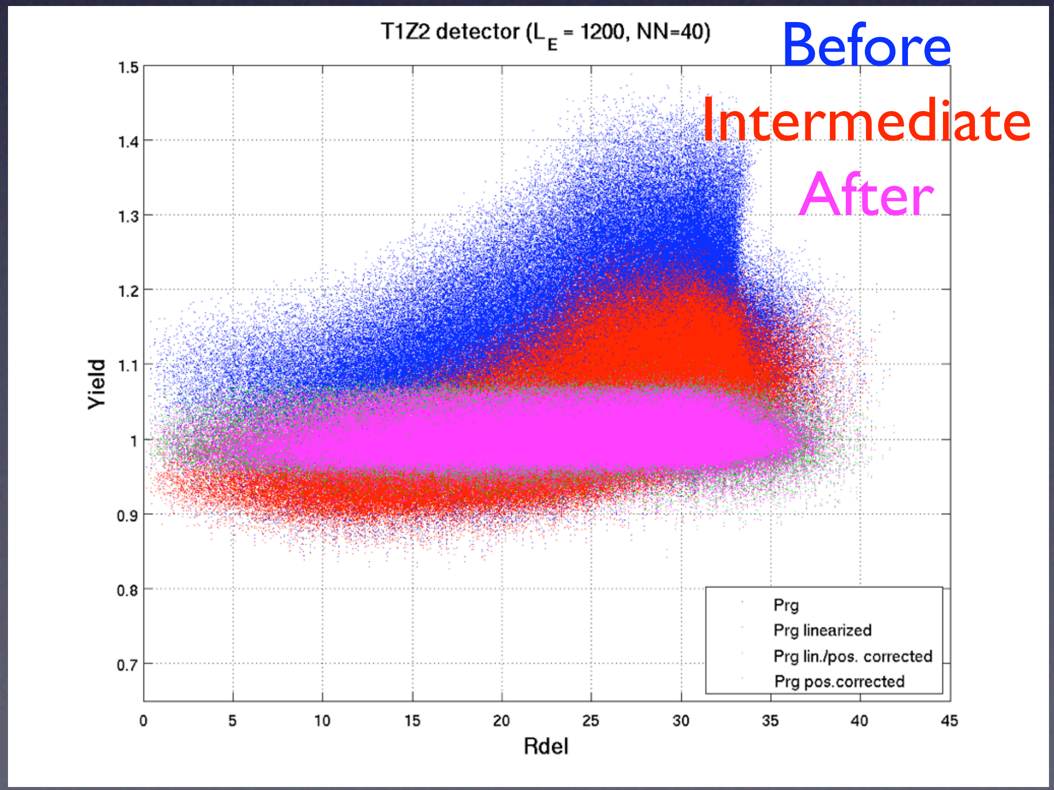
*LTD10: NIM A **520**, 171 (2004)*

Position Correction

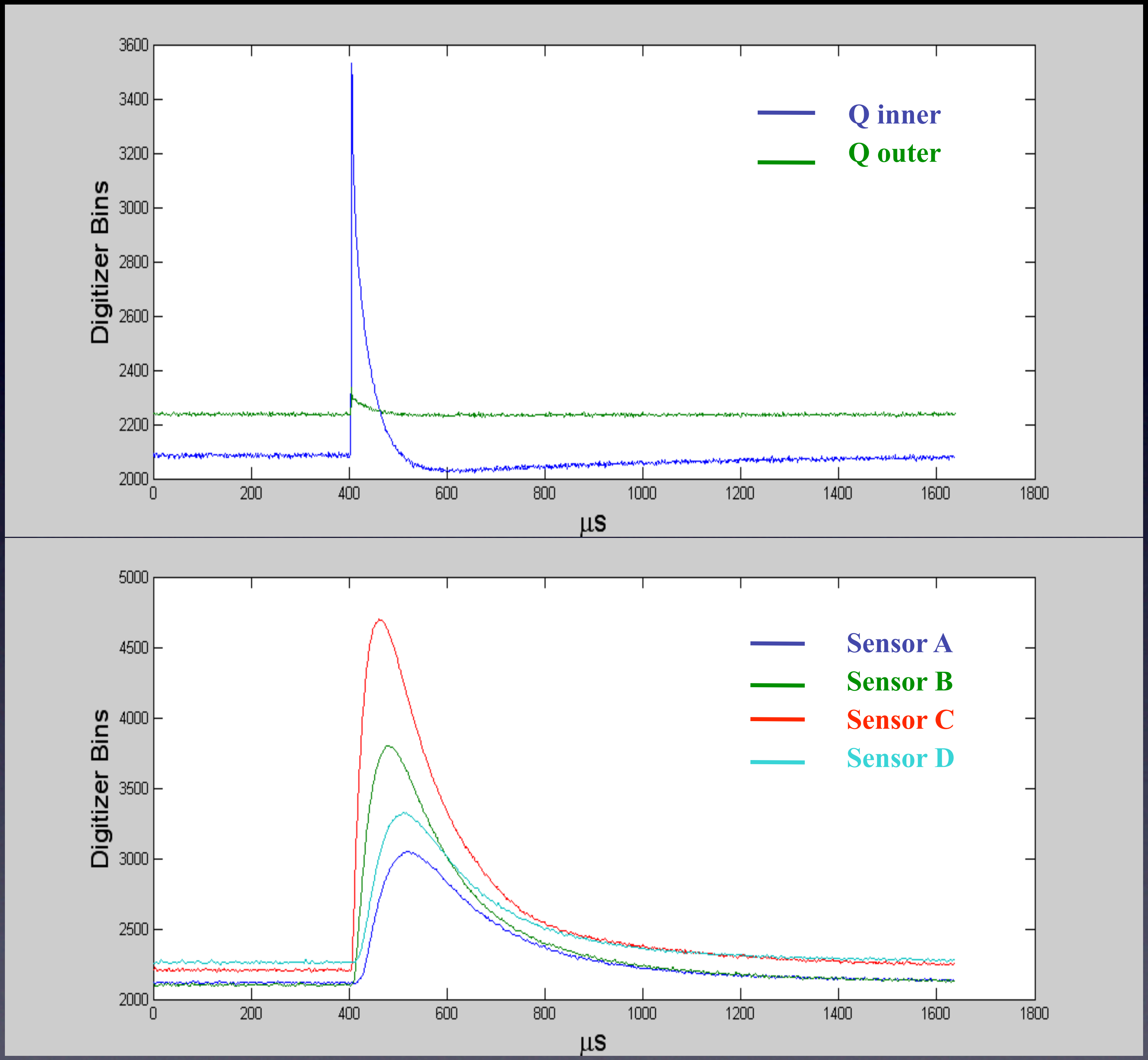
Correct events by comparisons to neighbors in phonon partition, phonon delay and energy







Event Reconstruction



Optimal Filter

- Amplitudes
  - **ionization yield**
  - fiducial volume
- Start time
  - phonon travel time

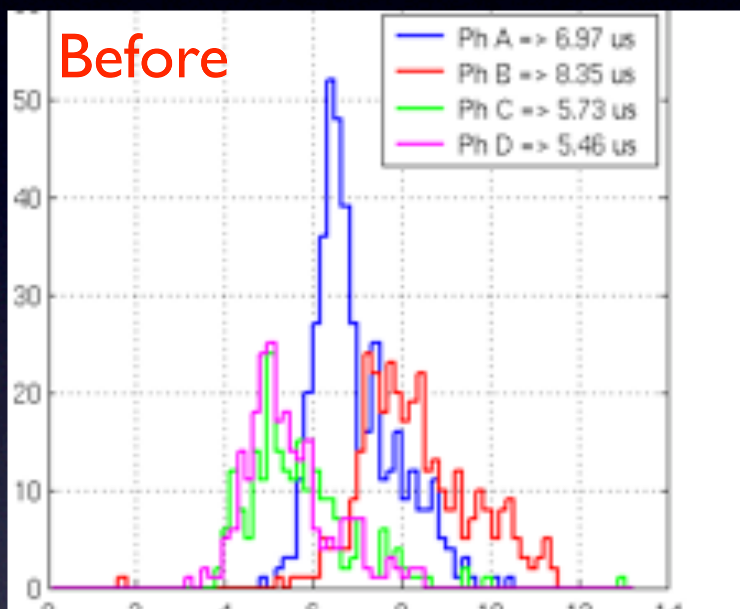
OF + walk

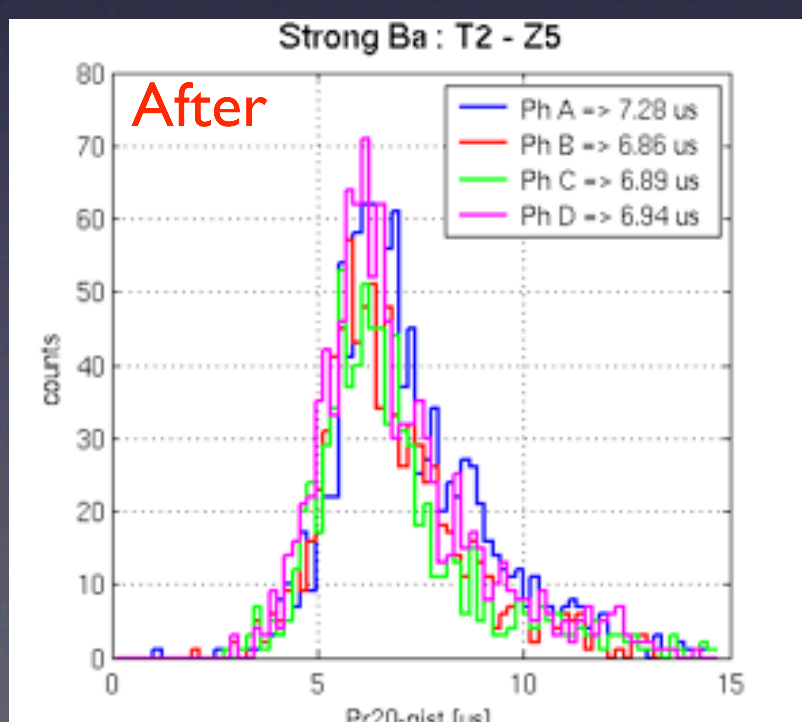
- Amplitudes
  - recoil energy (after Luke correction)
  - ionization yield
- **"Phonon timing"**
  - delays
  - risetimes
  - energy partition

2048 16-bit samples x 6 traces X 30 detectors + veto = **~1 MB/event**

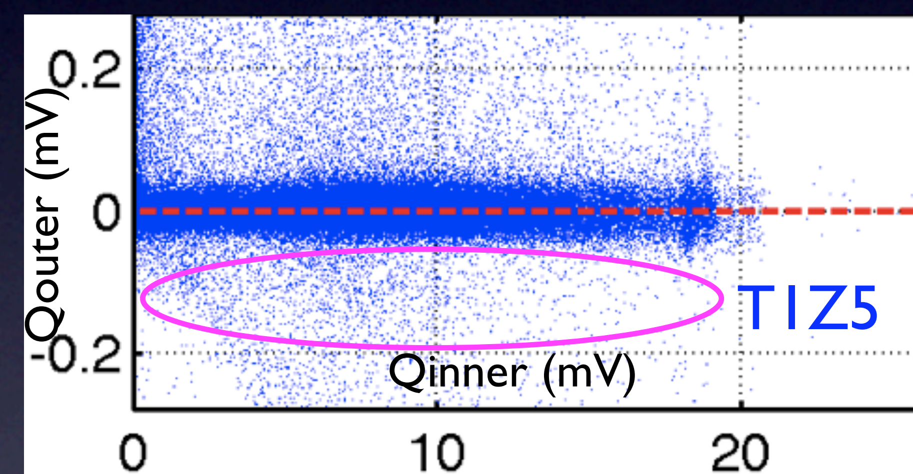
Better Mousetraps

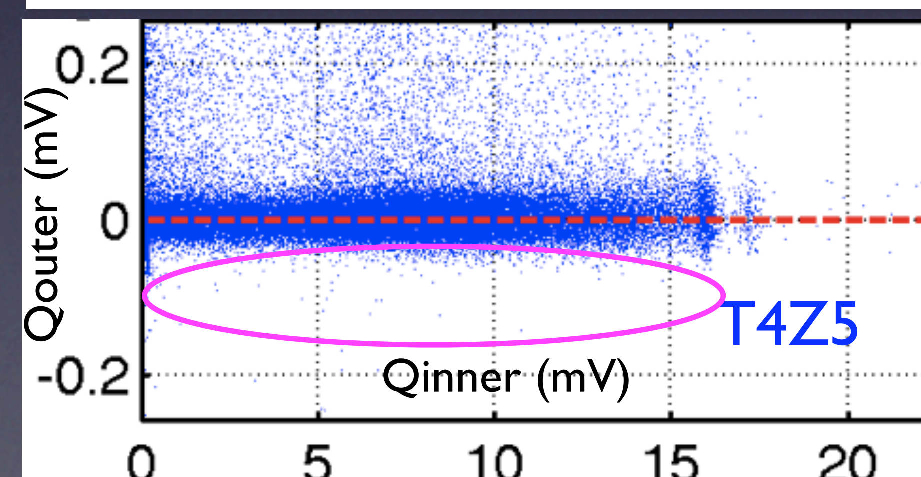
Improved TES tuning
on all detectors





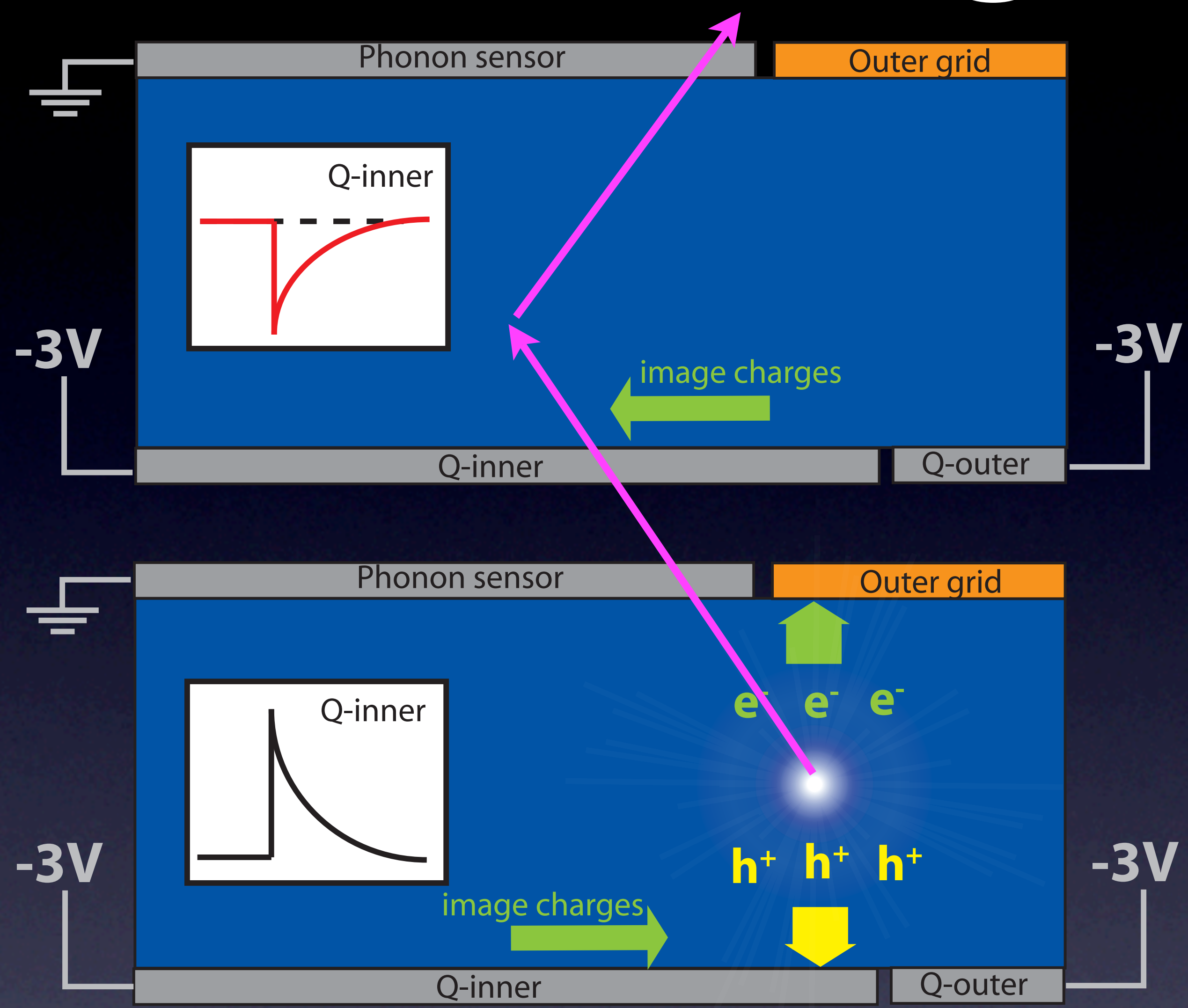
Grounded Q_{outer} grid on T3-5
=> fewer outliers

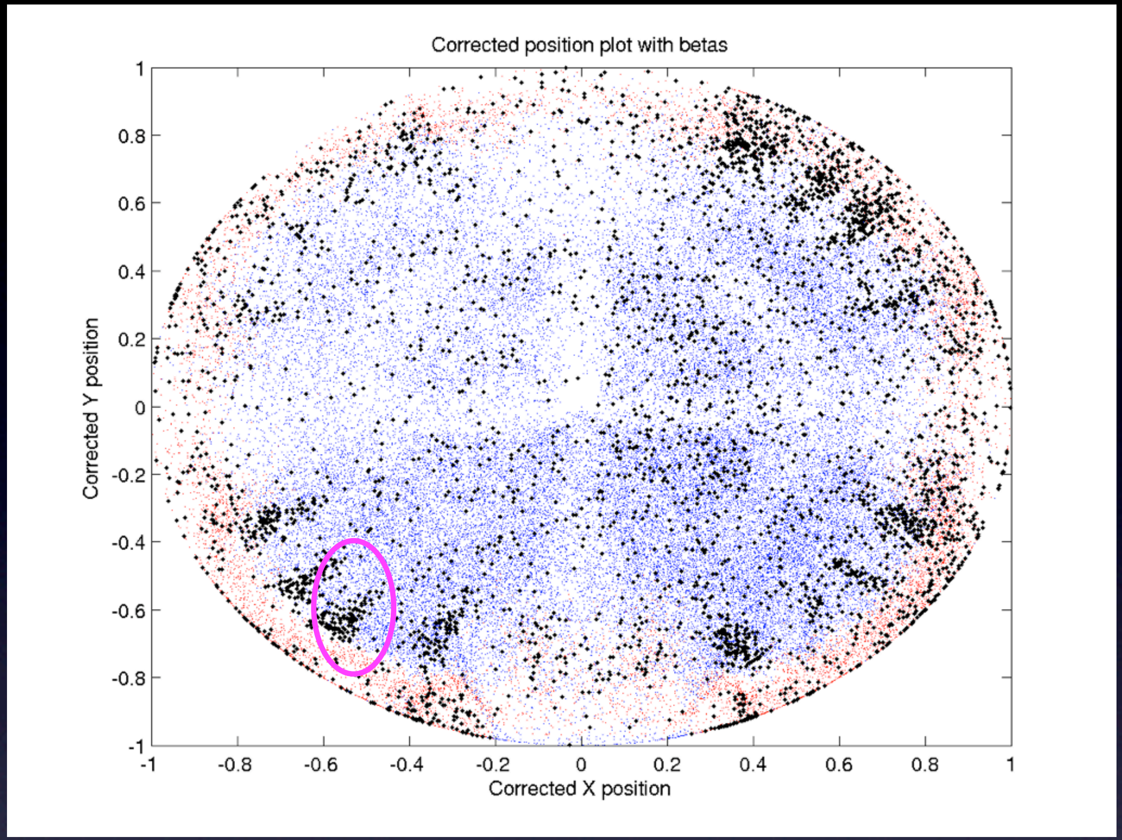


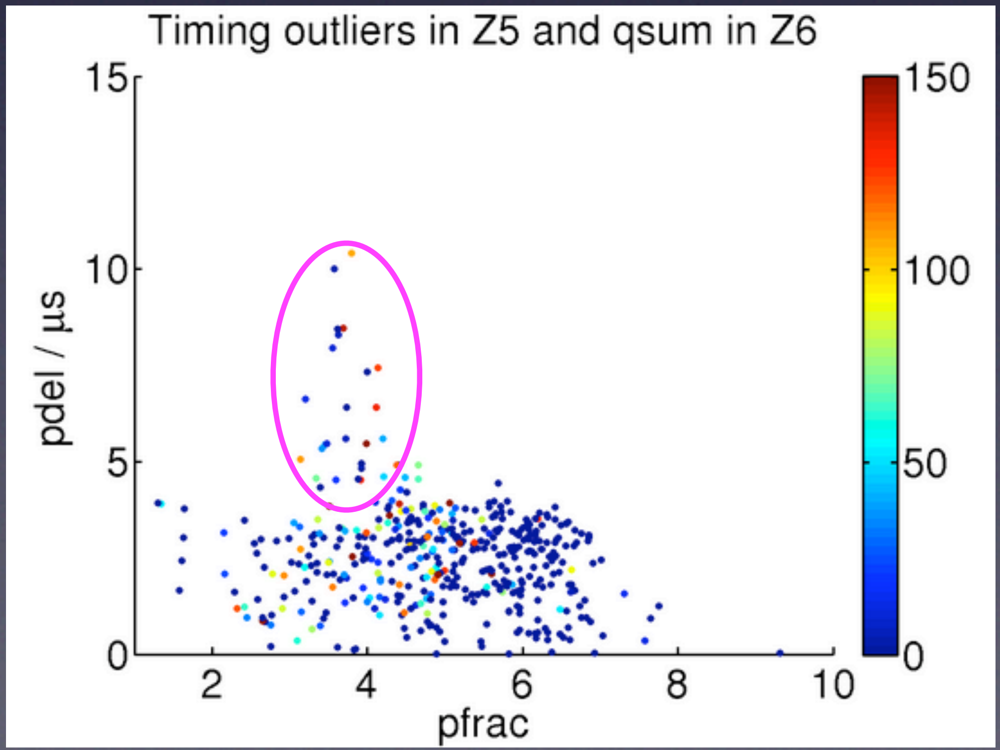


"Fuzz" tags presence of floating metal

Local charge pathologies







Slow, low-yield double-scatter events in Ba calibration: charge crosstalk via floating patches of phonon grid

Towers 1 and 2 only, specialized cut