Dark Matter Search Results from the Silicon Detectors of the Cryogenic Dark Matter Search Experiment

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On behalf of the SuperCDMS and CDMS Collaborations

Massachusetts Institute of Technology

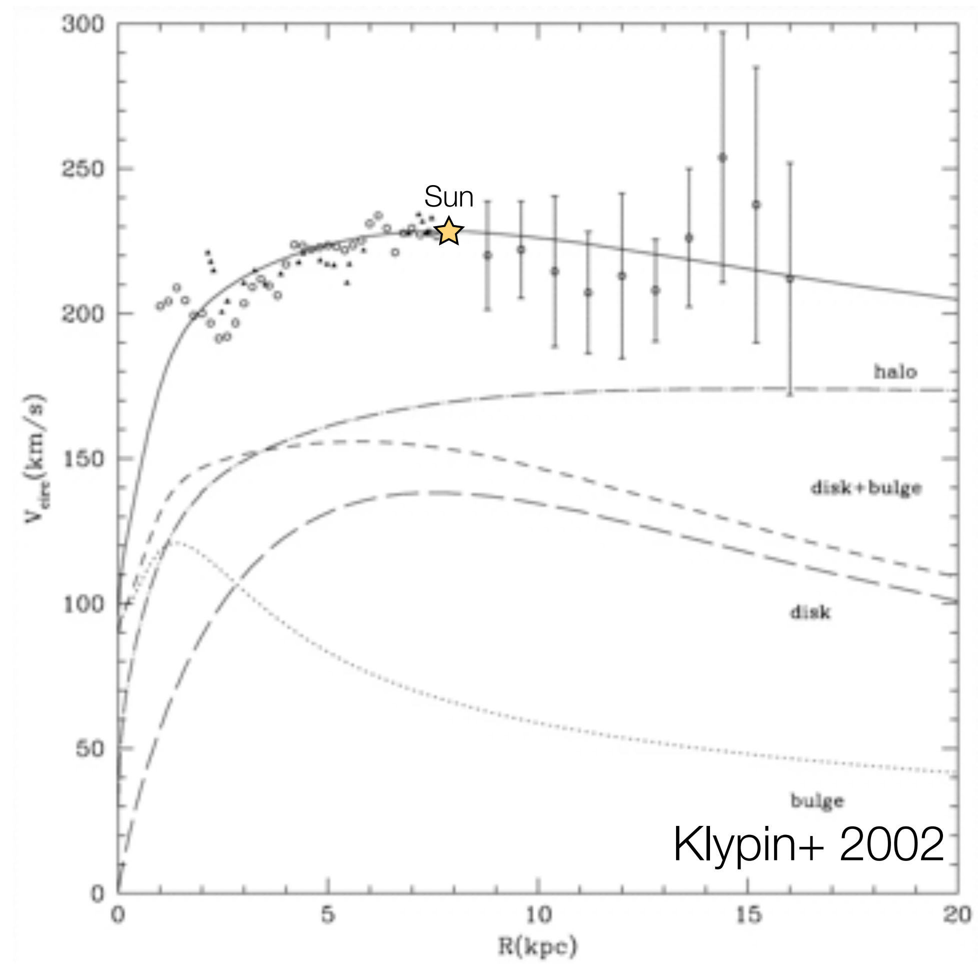
The SuperCDMS Collaboration

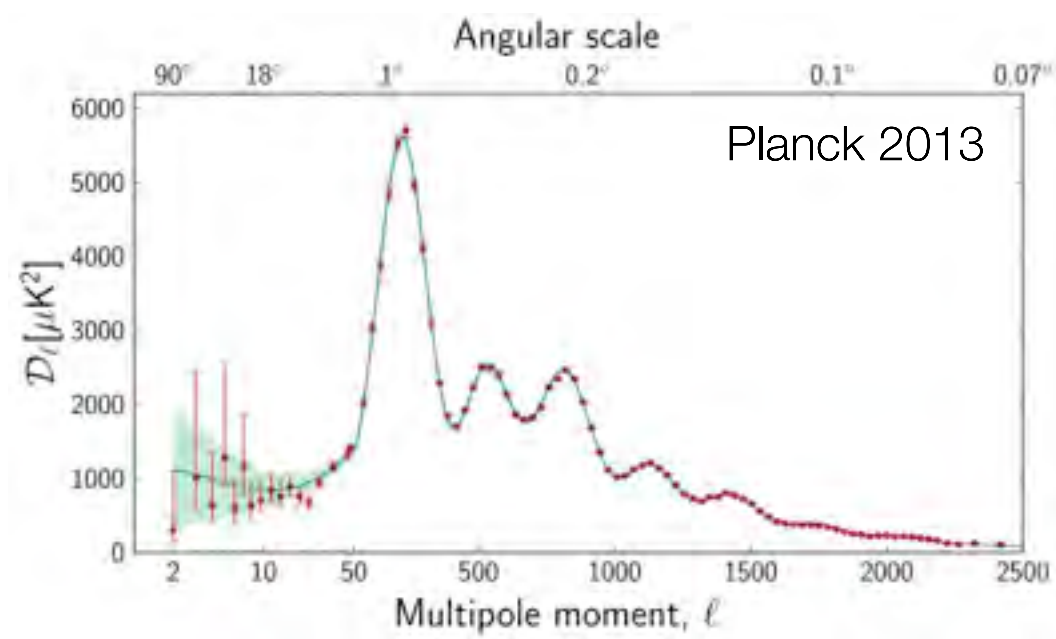
- California Institute of Technology
- Fermi National Accelerator Laboratory
- Massachusetts Institute of Technology
- Queen's University
- Santa Clara University
- SLAC / Kavli Institute for Particle Astrophysics and Cosmology
- Southern Methodist University
- Stanford University
- Syracuse University
- Texas A&M University
- Universidad Autónoma de Madrid
- University of British Columbia
- University of California, Berkeley
- Pacific Northwest National Laboratory
- University of Colorado, Denver
- University of Evansville
- University of Florida
- University of Minnesota

http://cdms.berkeley.edu

The Dark Matter Problem

- The Missing Mass Problem:
  - Dynamics of stars, galaxies, and clusters
  - Rotation curves, gas density, gravitational lensing
  - Large Scale Structure formation
- Wealth of evidence for a particle solution
  - MOND has problems with Bullet Cluster
  - Microlensing (MACHOs) mostly ruled out
- Non-baryonic
  - Height of acoustic peaks in the CMB (Ω_b, Ω_m)
  - Power spectrum of density fluctuations (Ω_m)
  - Primordial Nucleosynthesis (Ω_b)
- And STILL HERE!
  - Stable, neutral, non-relativistic
  - Interacts via gravity and (maybe) other mediator(s) with standard model particles

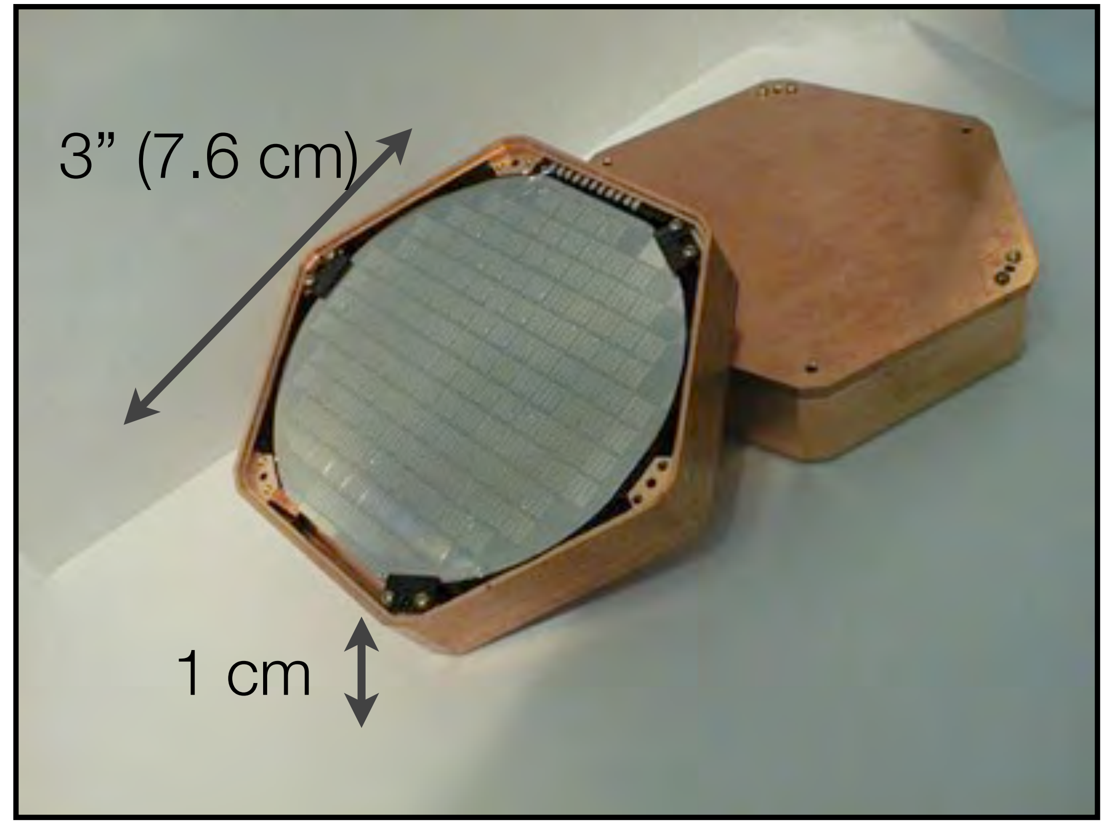




The CDMS-II Experiment

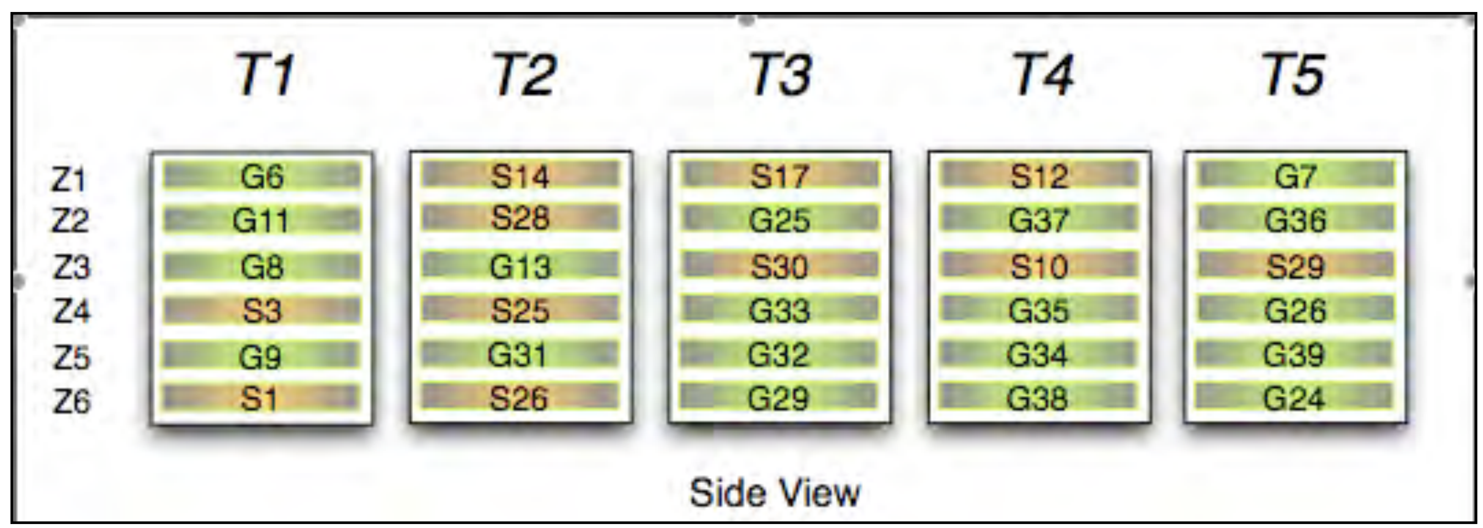
ZIP Detectors

- **Z**-sensitive **I**onization and **P**honon mediated
- 230 g Ge or 106 g Si crystals
  (1 cm thick, 7.5 cm diameter)
- Photolithographically patterned to collect athermal phonons and ionization signals
- Direct xy-position imaging
- Surface (z) event rejection from pulse shapes and timing
- 30 detectors stacked into
  5 towers of 6 detectors



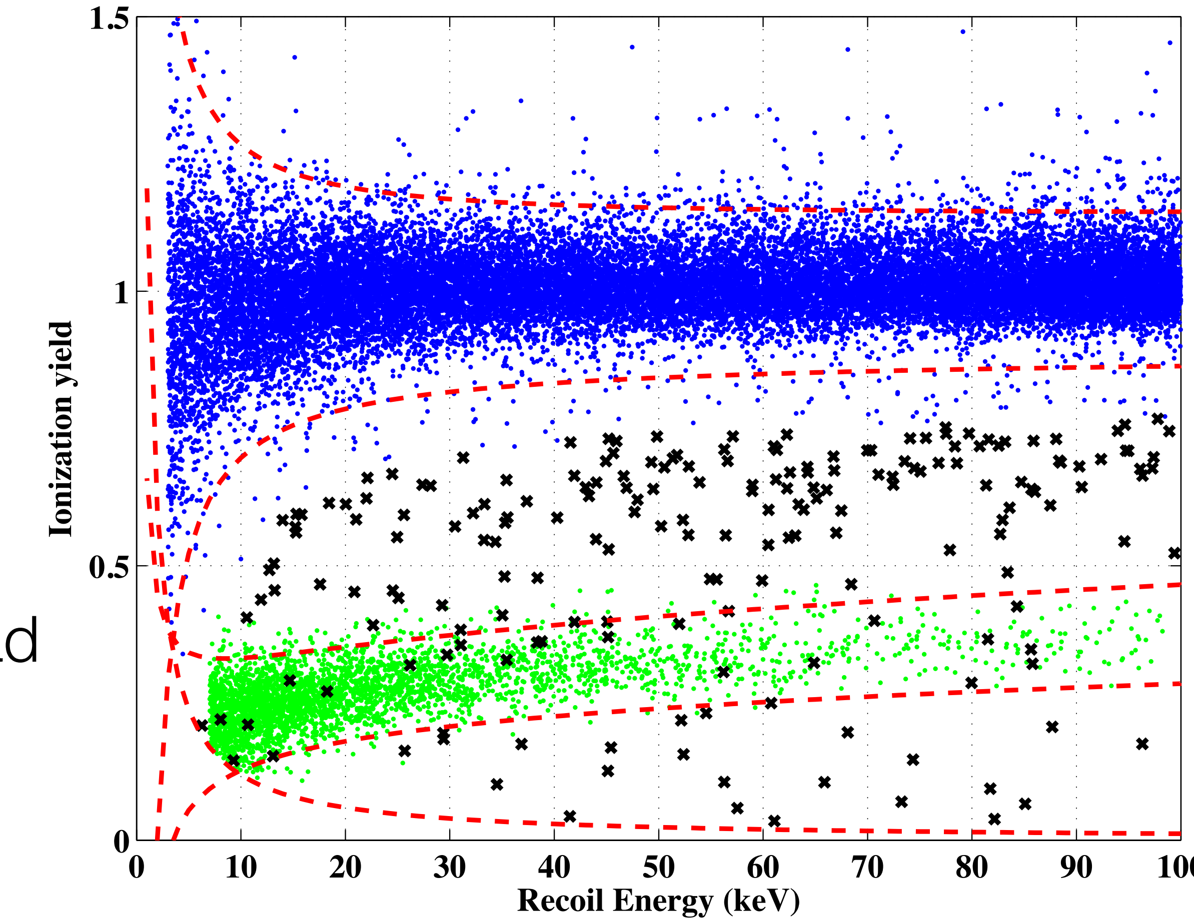
CDMS-II Exposure

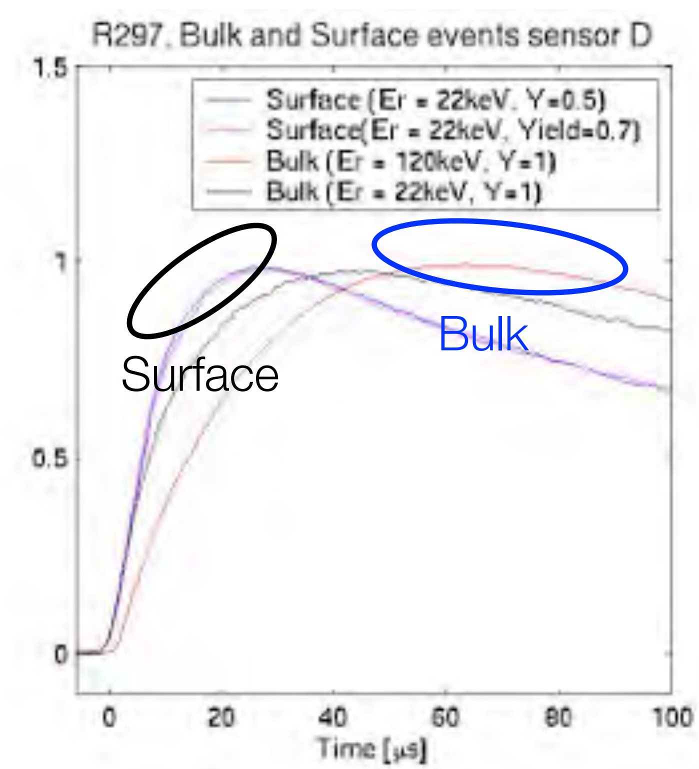
- Oct. 2003 - Aug. 2004
  - 42.7 kg-days in 4 Si detectors
- Oct. 2006 - July 2007
  - 55.9 kg-days in 6 Si detectors
- July 2007 - Sep. 2008
  - 140.23 kg-days in 8 Si detectors

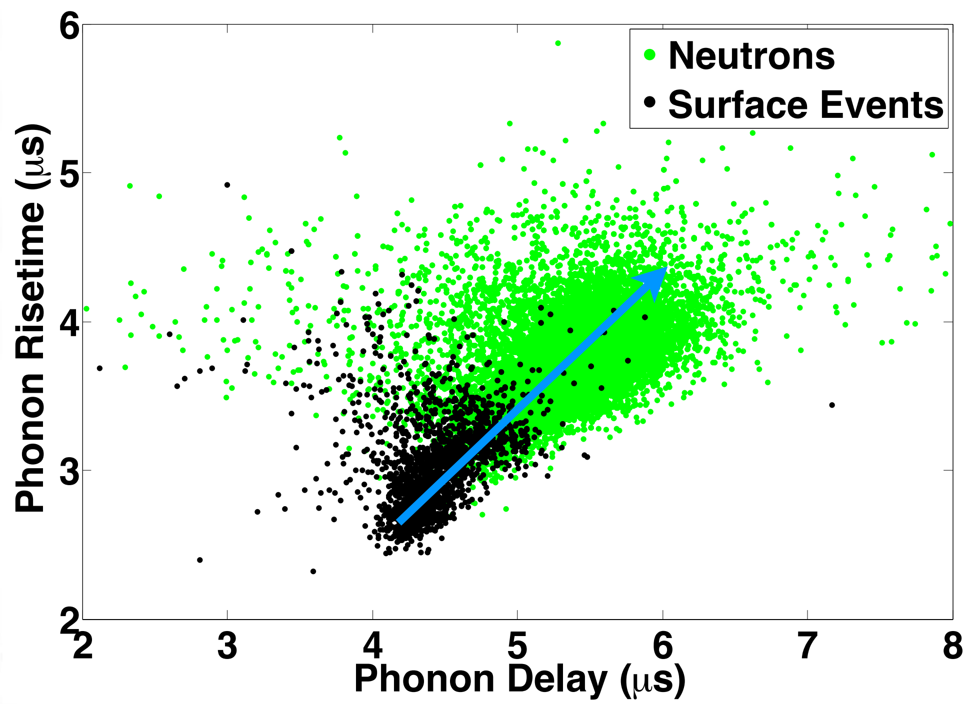


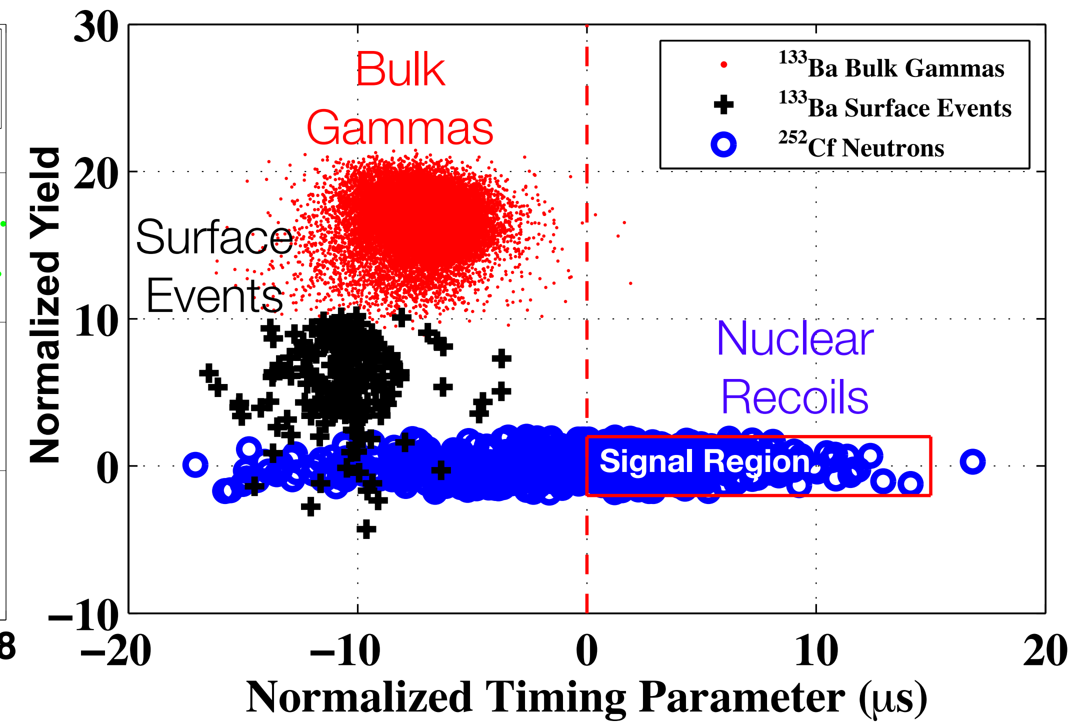
CDMS II Surface Background Rejection

- Most backgrounds (e, γ) produce electron recoils
- WIMPs and neutrons produce nuclear recoils.
- Ionization yield (ionization energy per unit recoil energy) strongly depends on recoil type.
- Particles that interact in the “surface dead layer” result in reduced ionization yield.
- These surface events can be rejected through a pulse shape rise time cut.



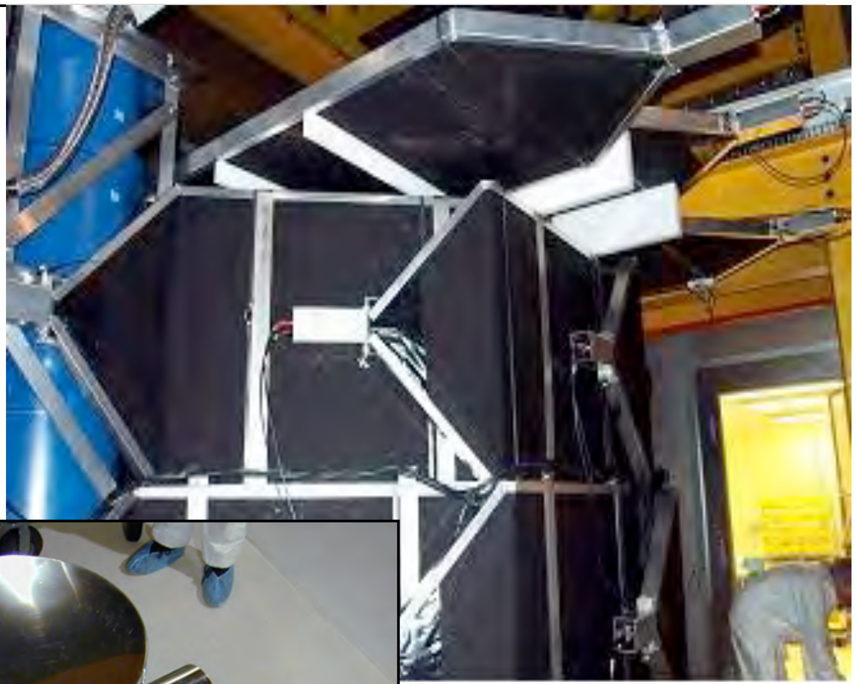


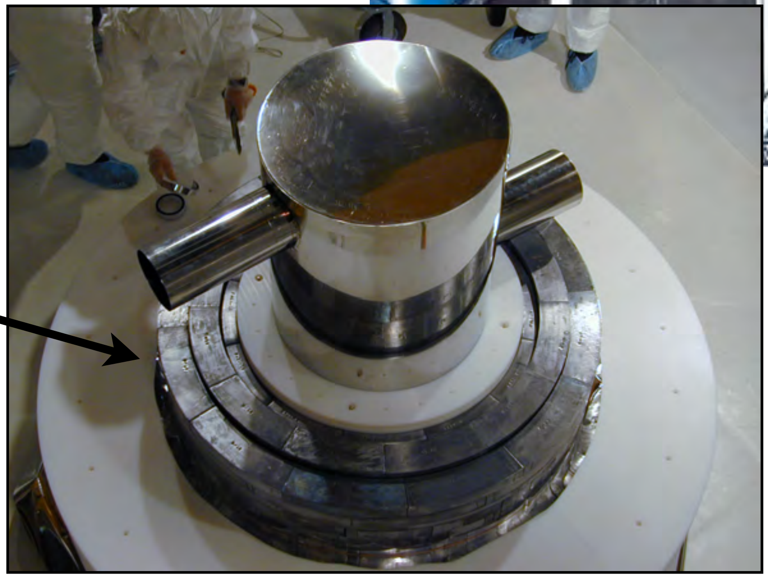


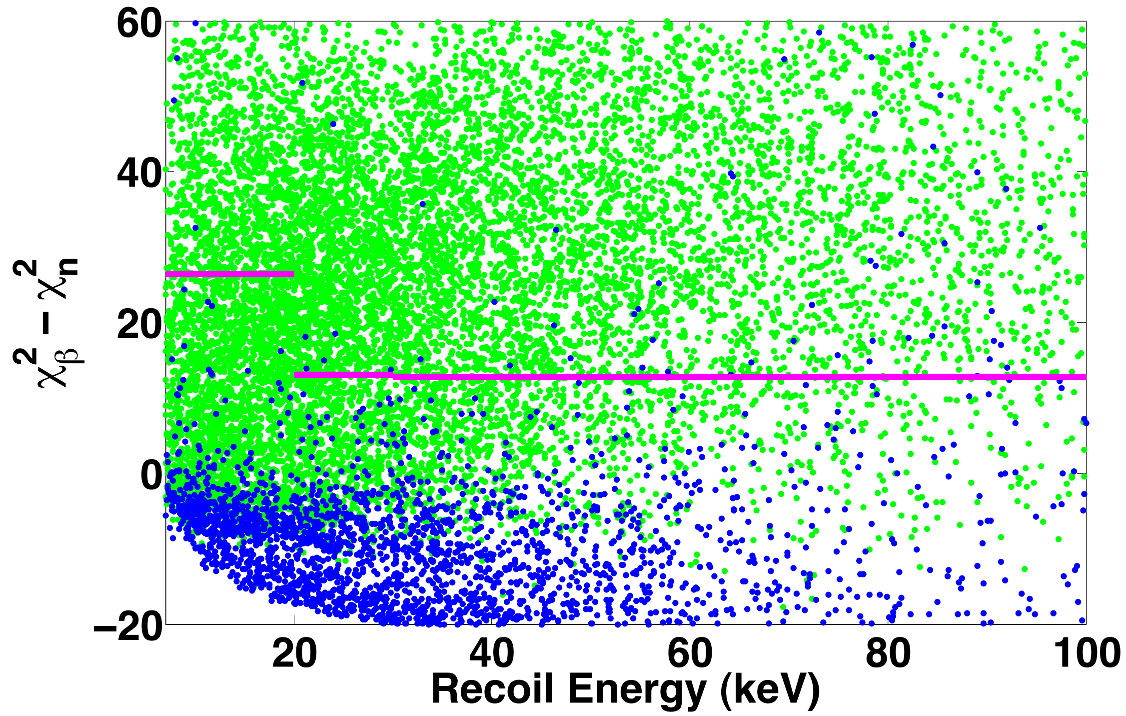


Background Estimate

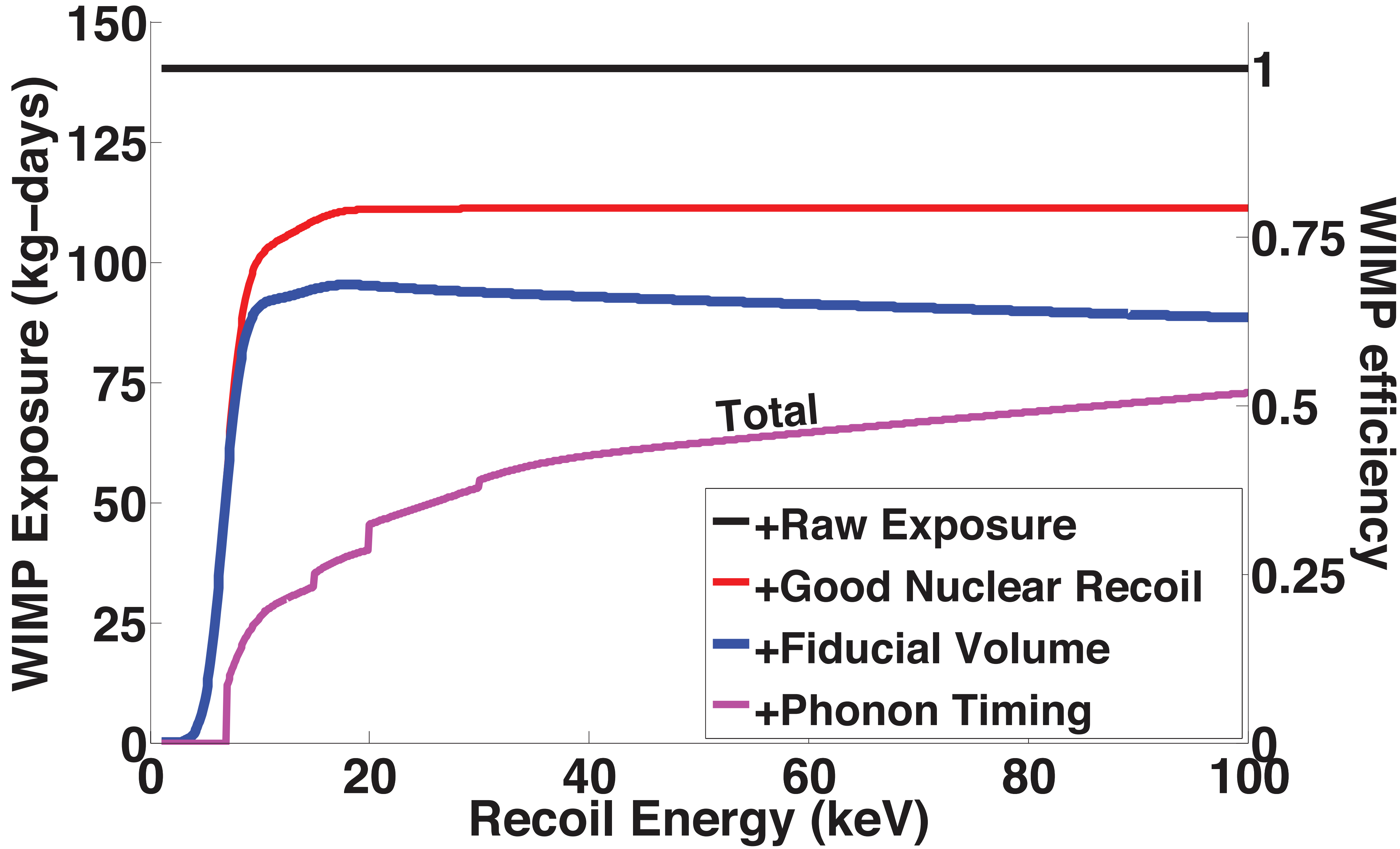
- **Neutrons**
  - Indistinguishable from WIMPs!
  - Cosmogenic: active veto
  - Radiogenic: passive shielding & materials screening
  - < 0.13 expected events
- **Surface events**
  - Discriminate using phonon timing
  - Optimize in 3 energy bins
    - 7-20, 20-30, 30-100 keV
  - 0.47 expected events estimated before unblinding.



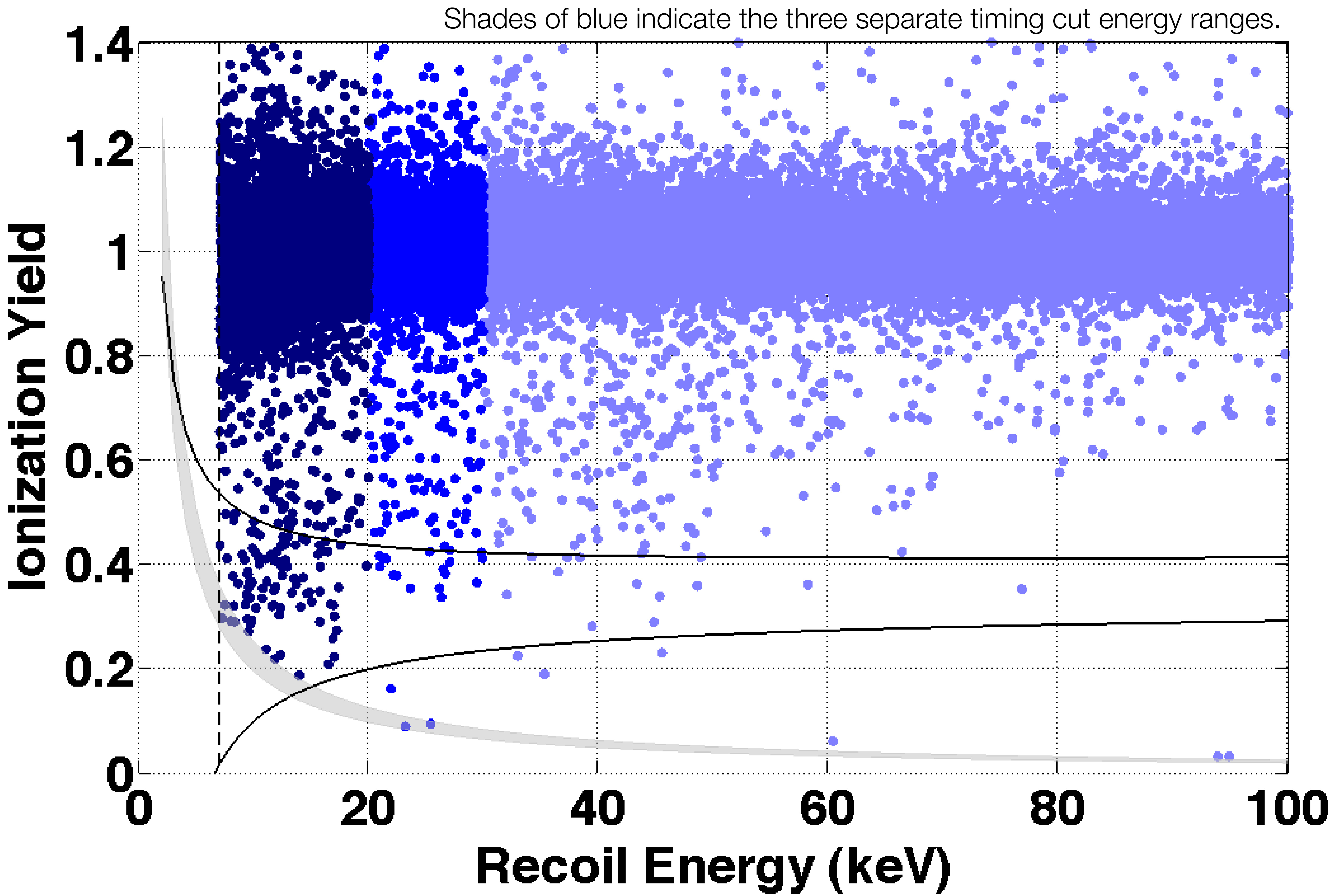




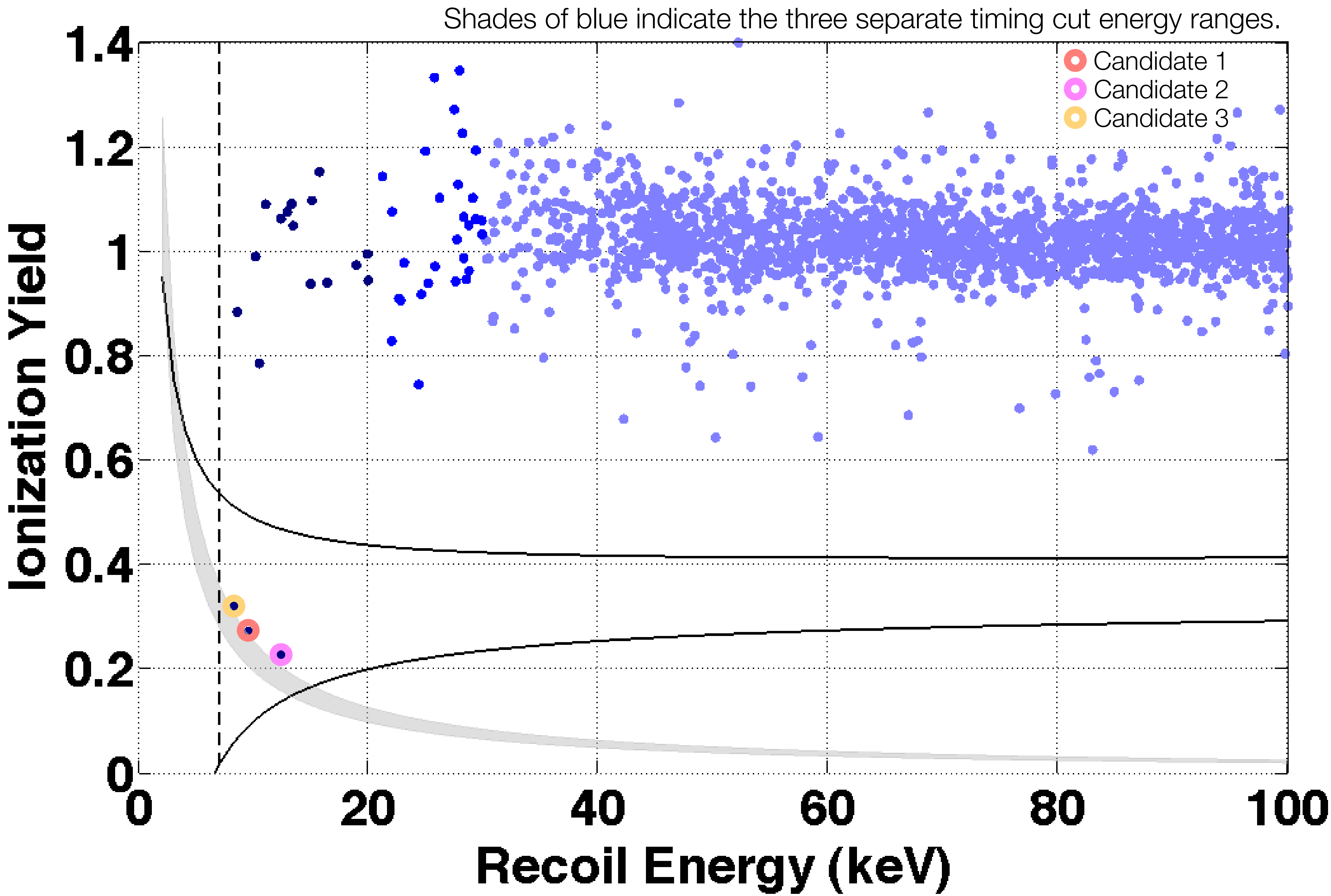
Exposure vs. Recoil Energy



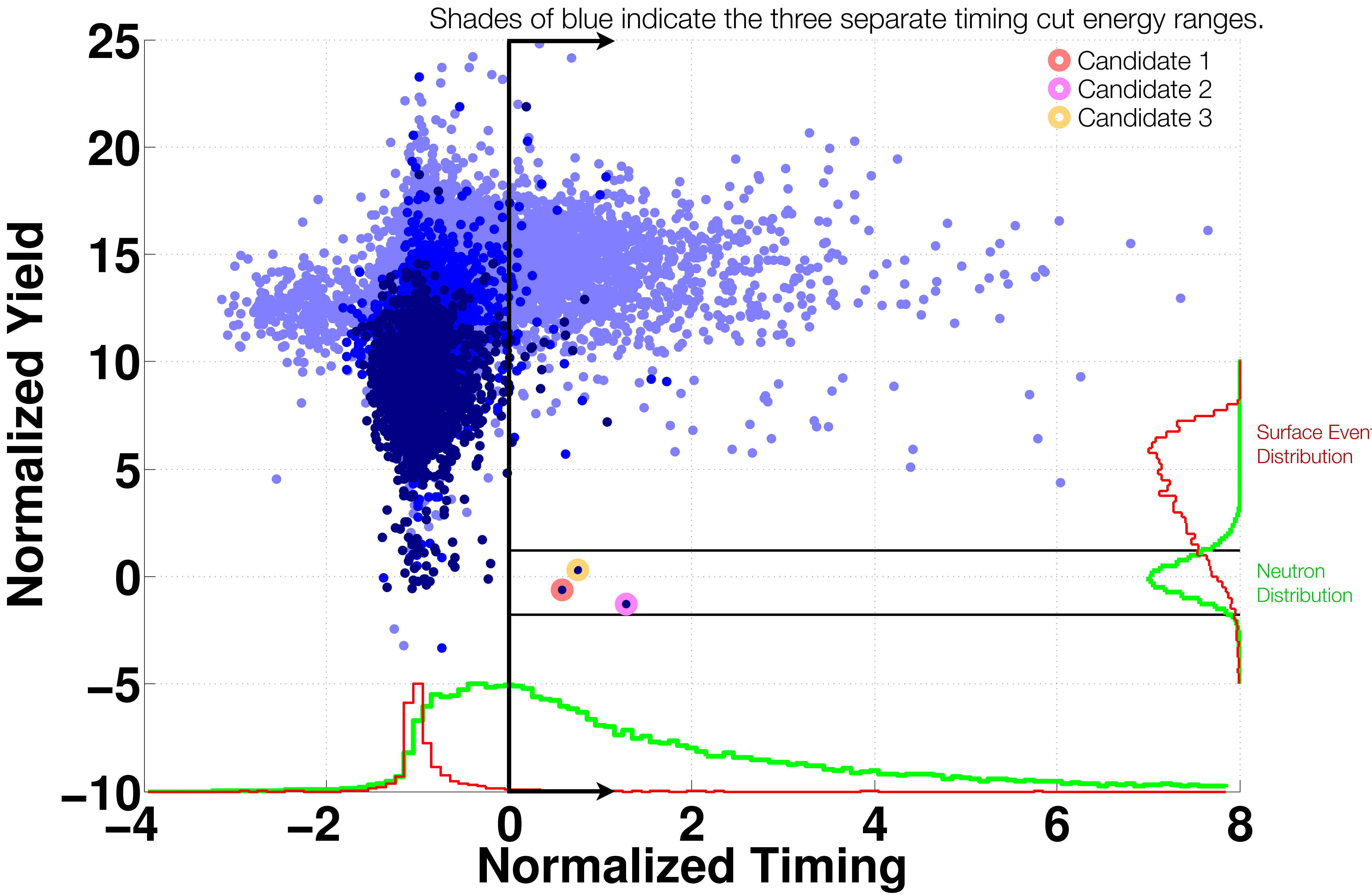
Unblinding Results - before timing cut



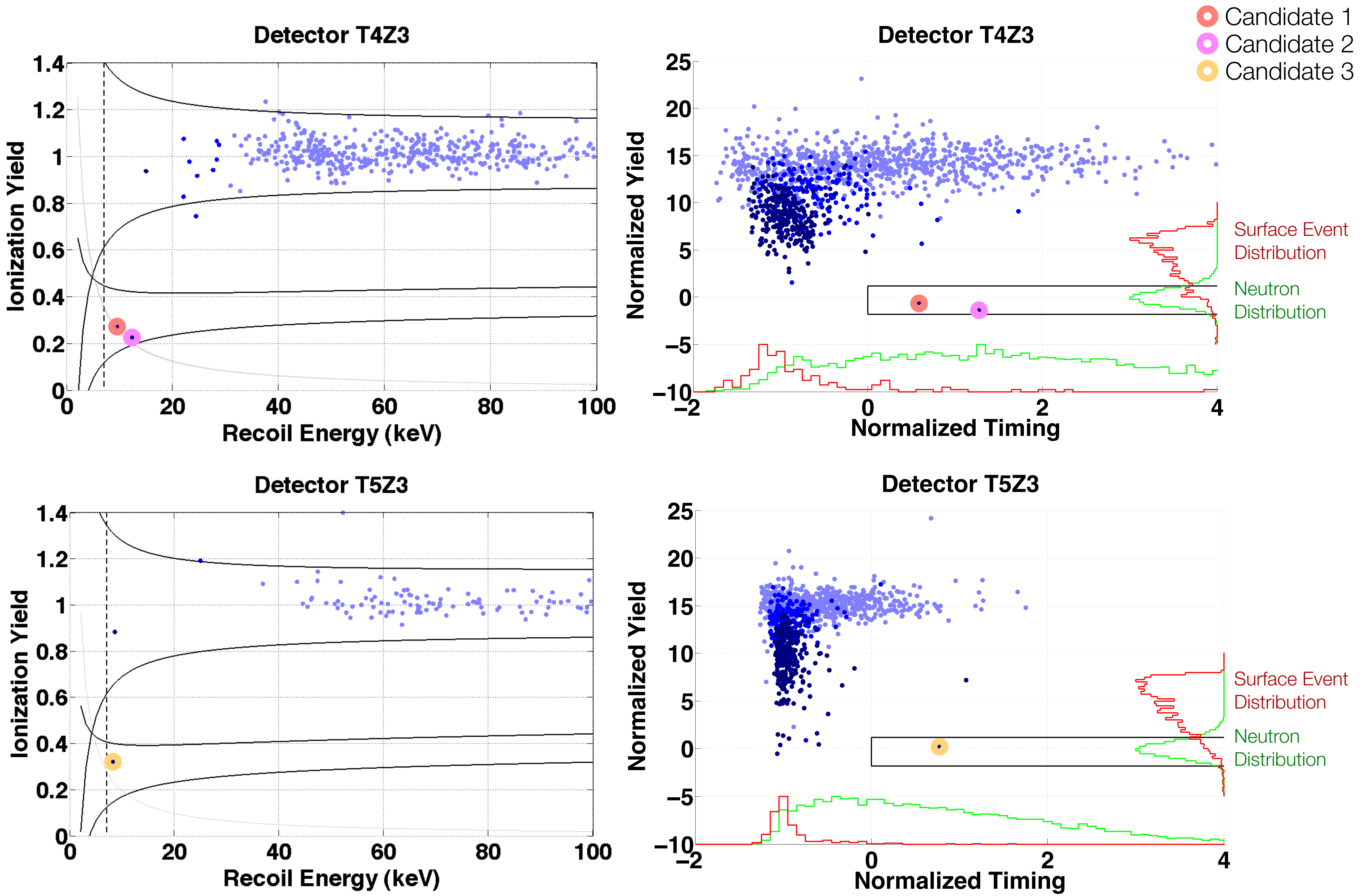
Unblinding Results - after timing cut



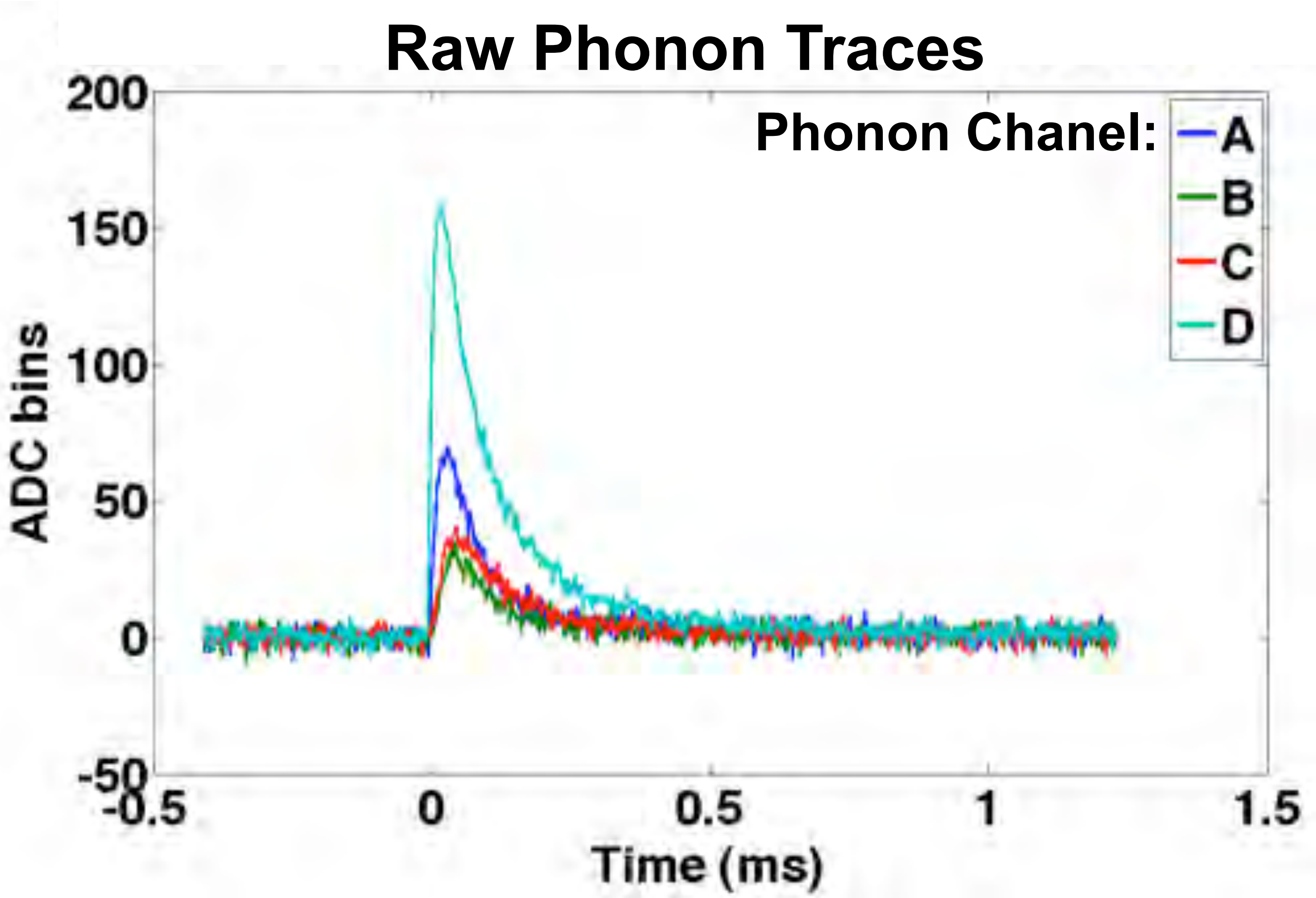
Unblinding Results - Yield vs Timing

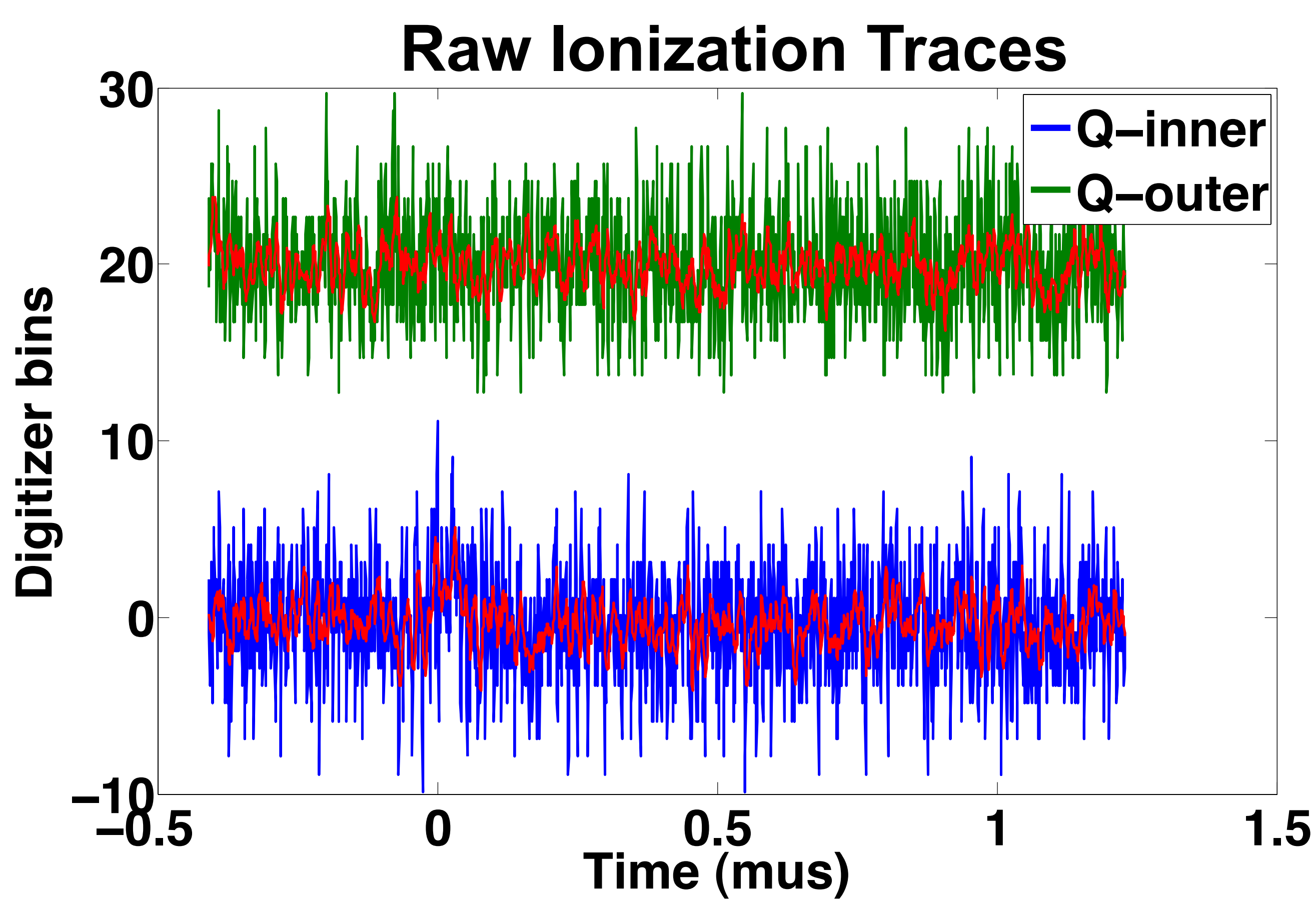


Three Events!



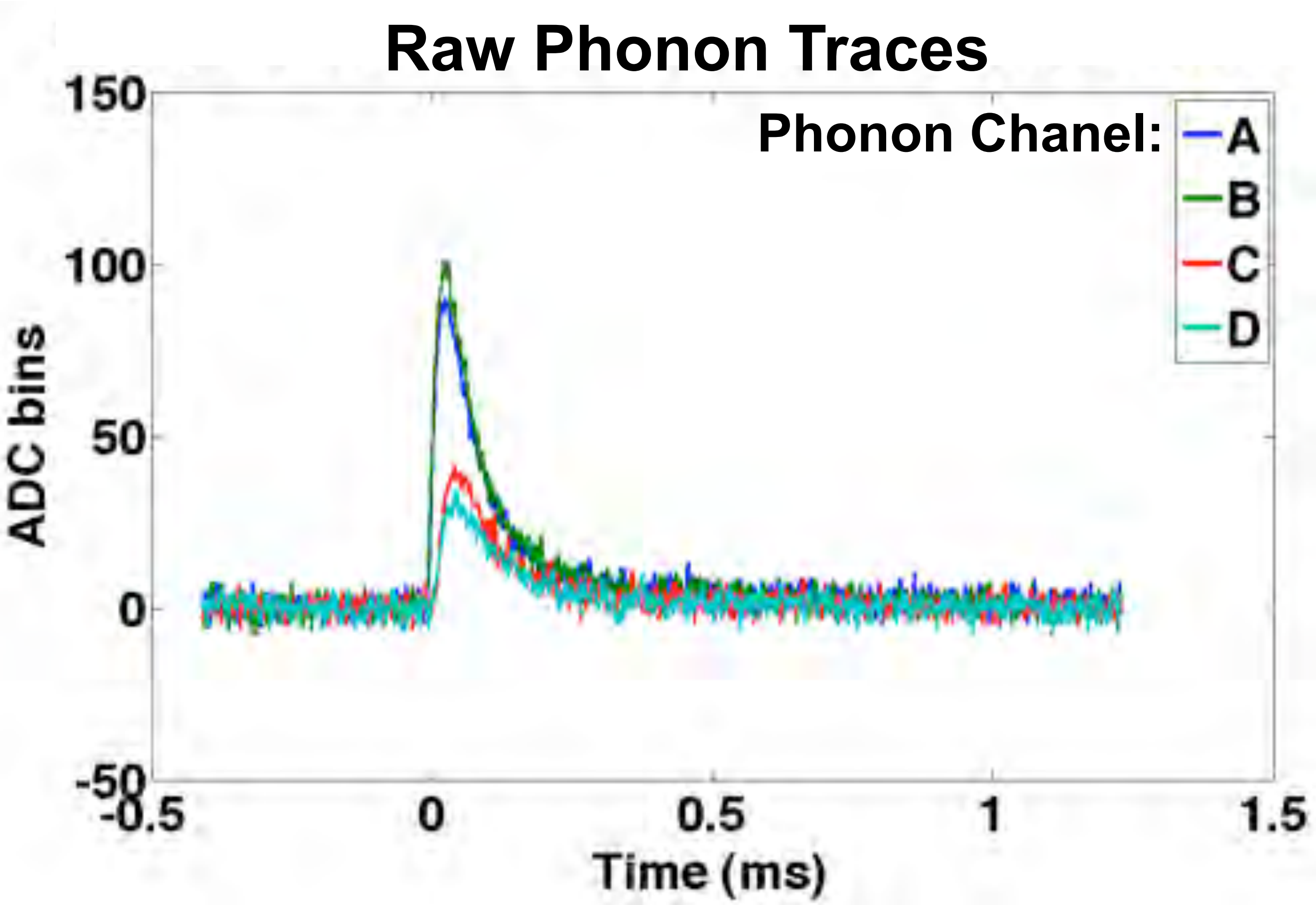
Candidate 1

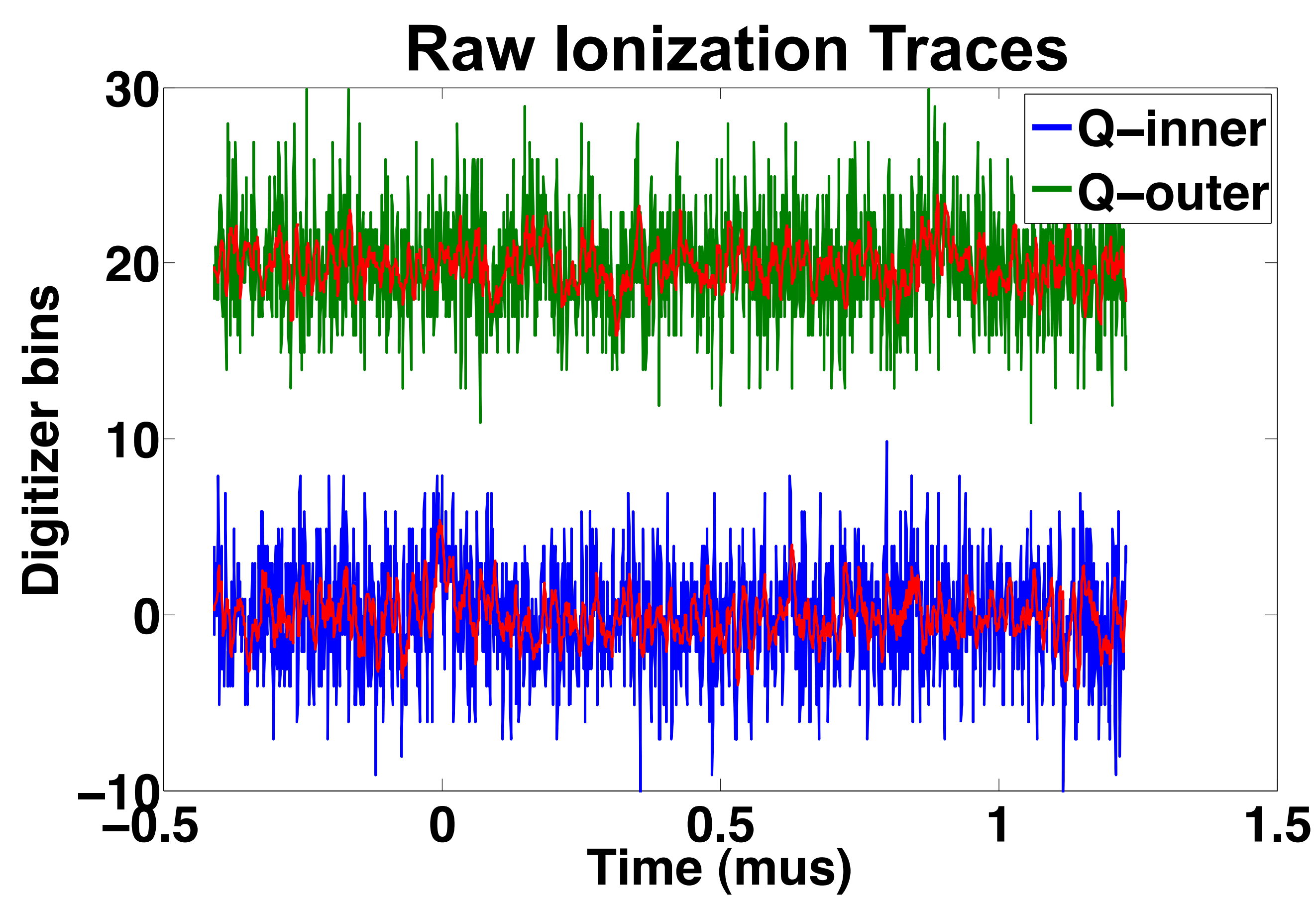




Detector	Recoil Energy	Yield	Charge Signal to Noise	Single Scatter Probability	Date
T4Z3	9.51 keV	0.27	4.87 σ	96.1%	July 1, 2008

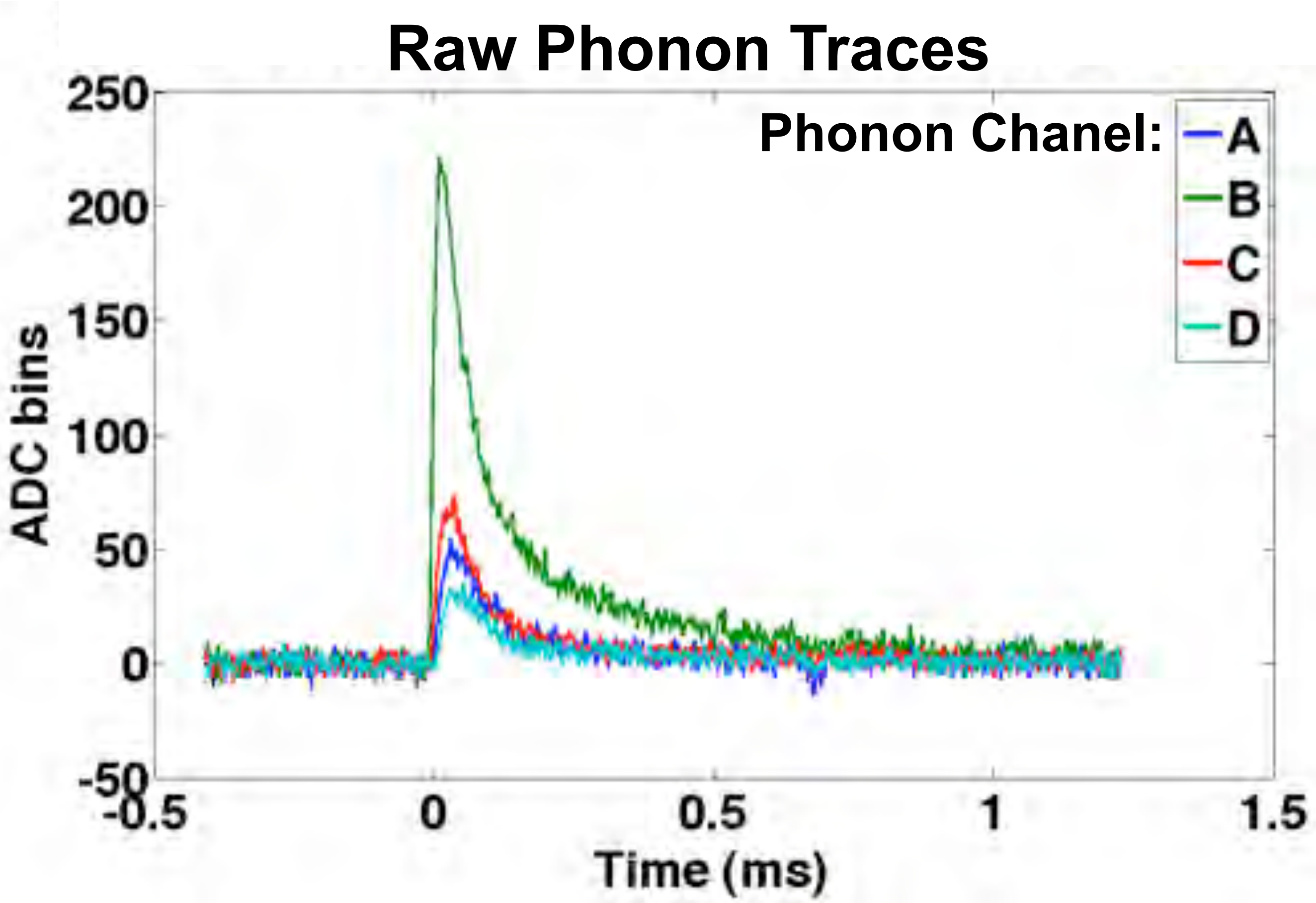
Candidate 2

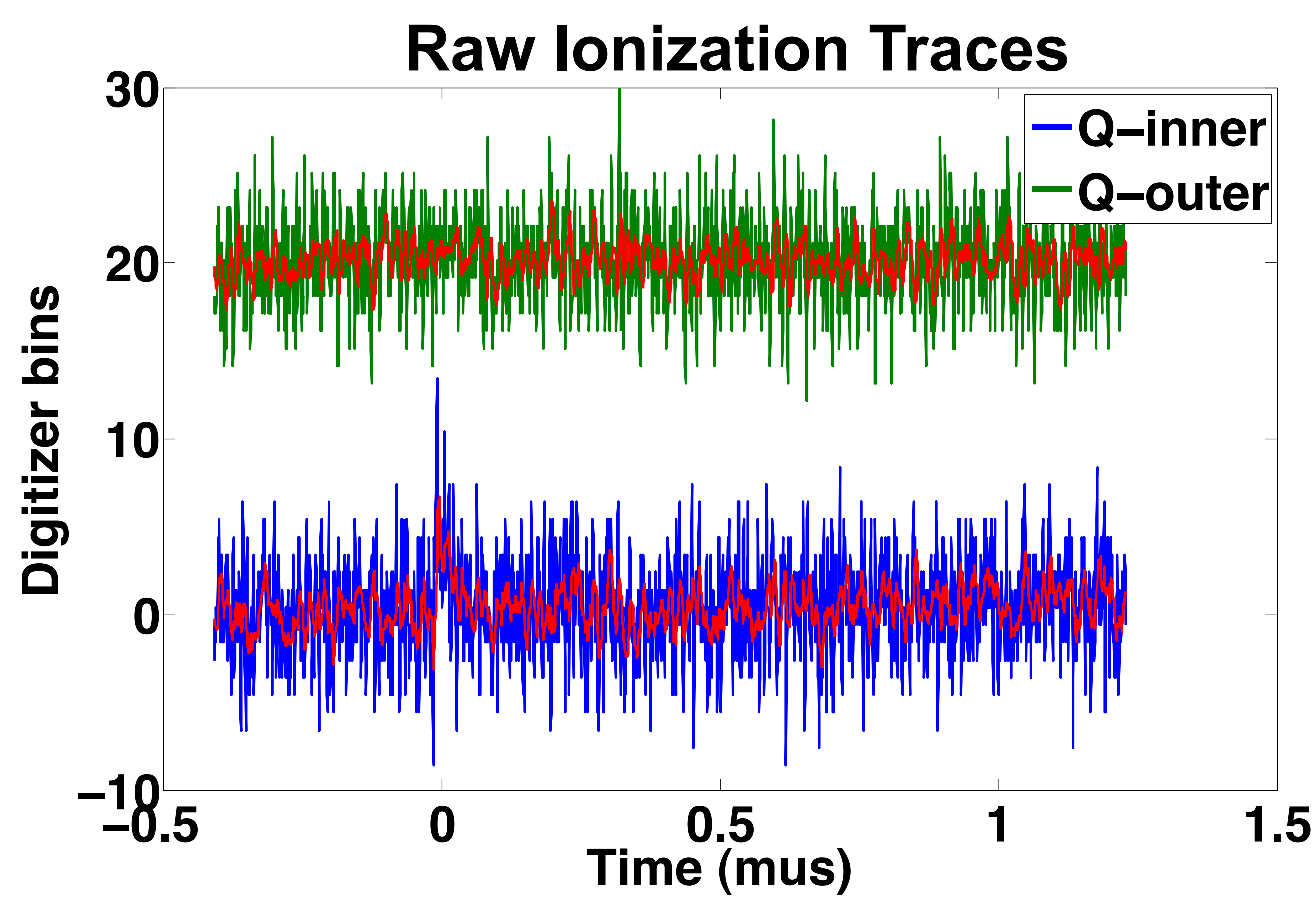




Detector	Recoil Energy	Yield	Charge Signal to Noise	Single Scatter Probability	Date
T4Z3	12.29 keV	0.23	5.11 σ	99.7%	Sep 6, 2008

Candidate 3





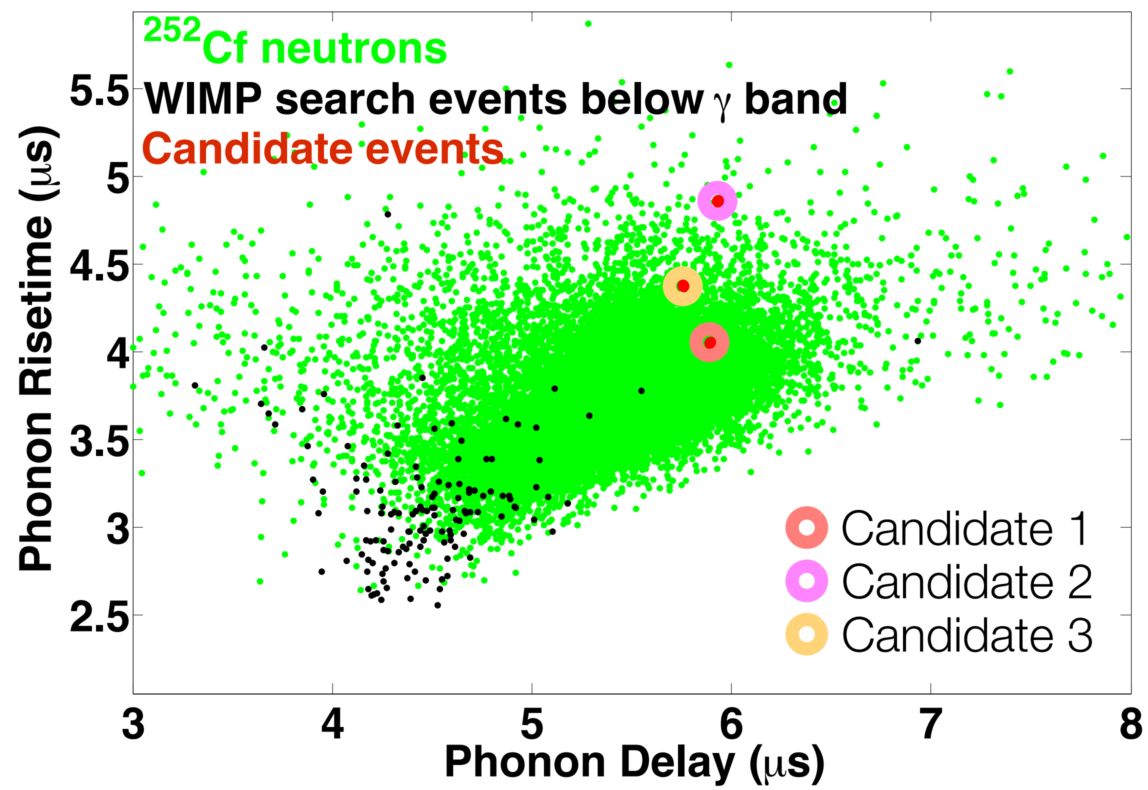
Detector	Recoil Energy	Yield	Charge Signal to Noise	Single Scatter Probability	Date
T5Z3	8.20 keV	0.32	6.66 σ	99.7%	March 14, 2008

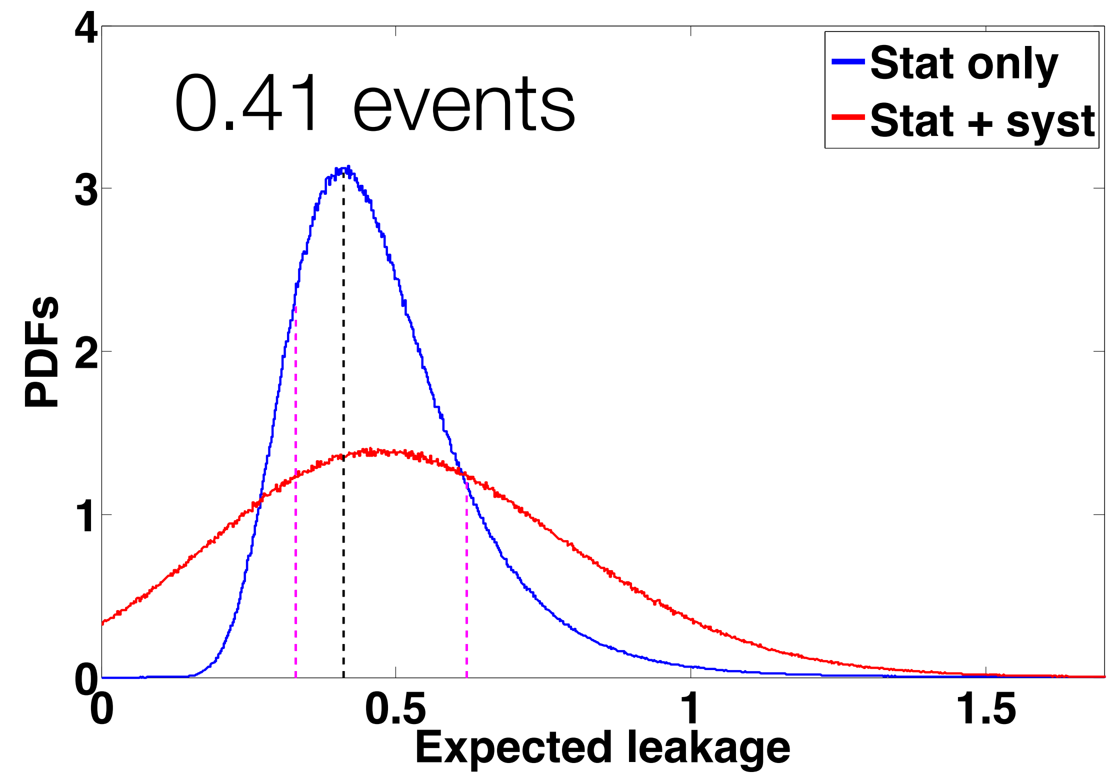
Post-Unblinding Checks

- After unblinding, the data quality was re-checked.
  - Events occurred during high-quality data series
  - Events were well-reconstructed
  - Checked energy in other detectors to verify events were single scatters
- Surface event background estimated from the tails of three different NR sideband distributions to be:

$$0.41^{+0.20}_{-0.08}(stat.)^{+0.28}_{-0.24}(syst.)$$

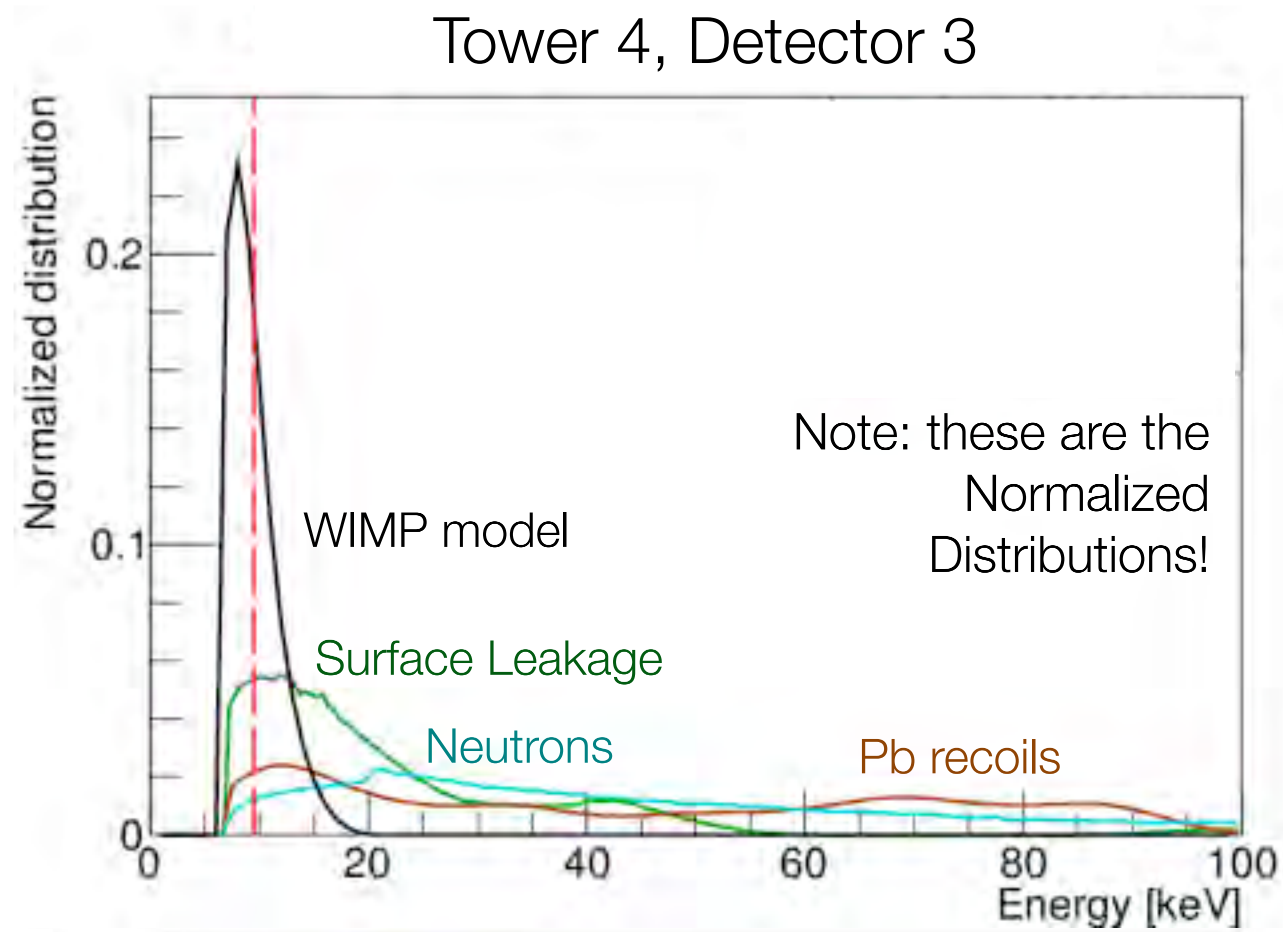
- Checked for the possibility of ^{206}Pb recoils from ^{210}Po decay, and limited this to be <0.08 events.

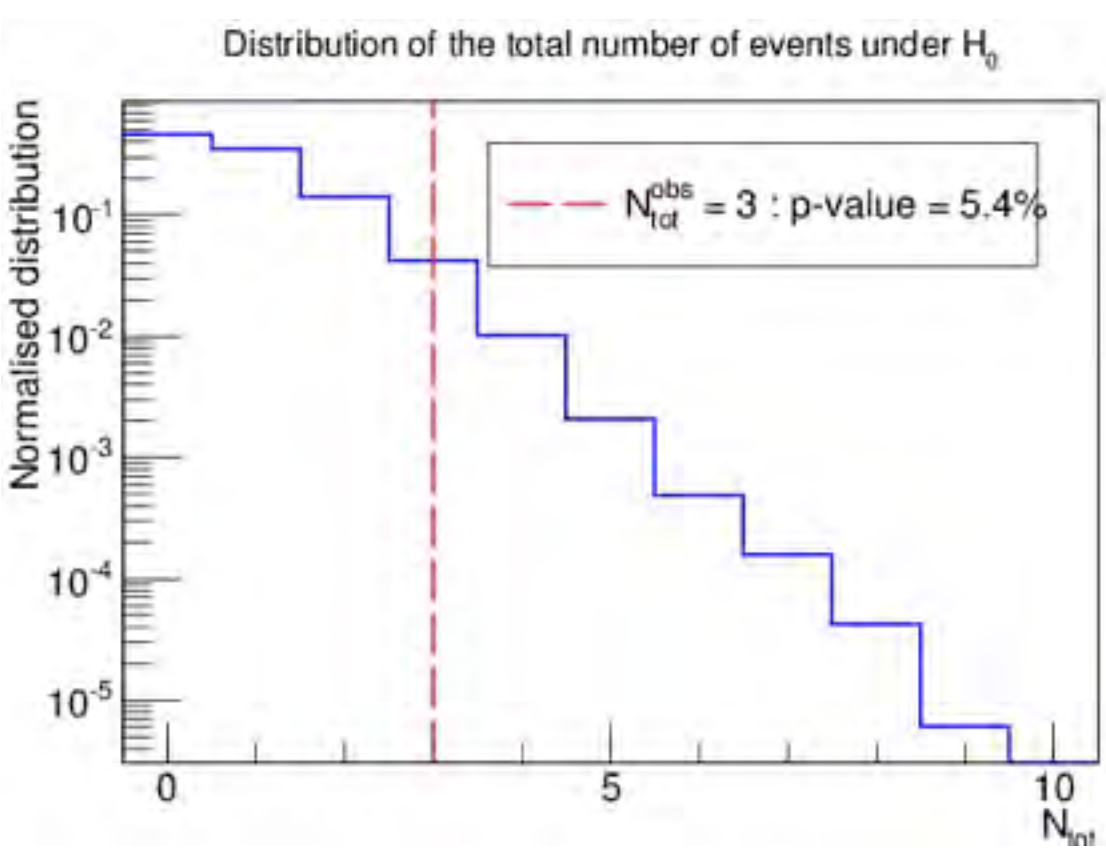


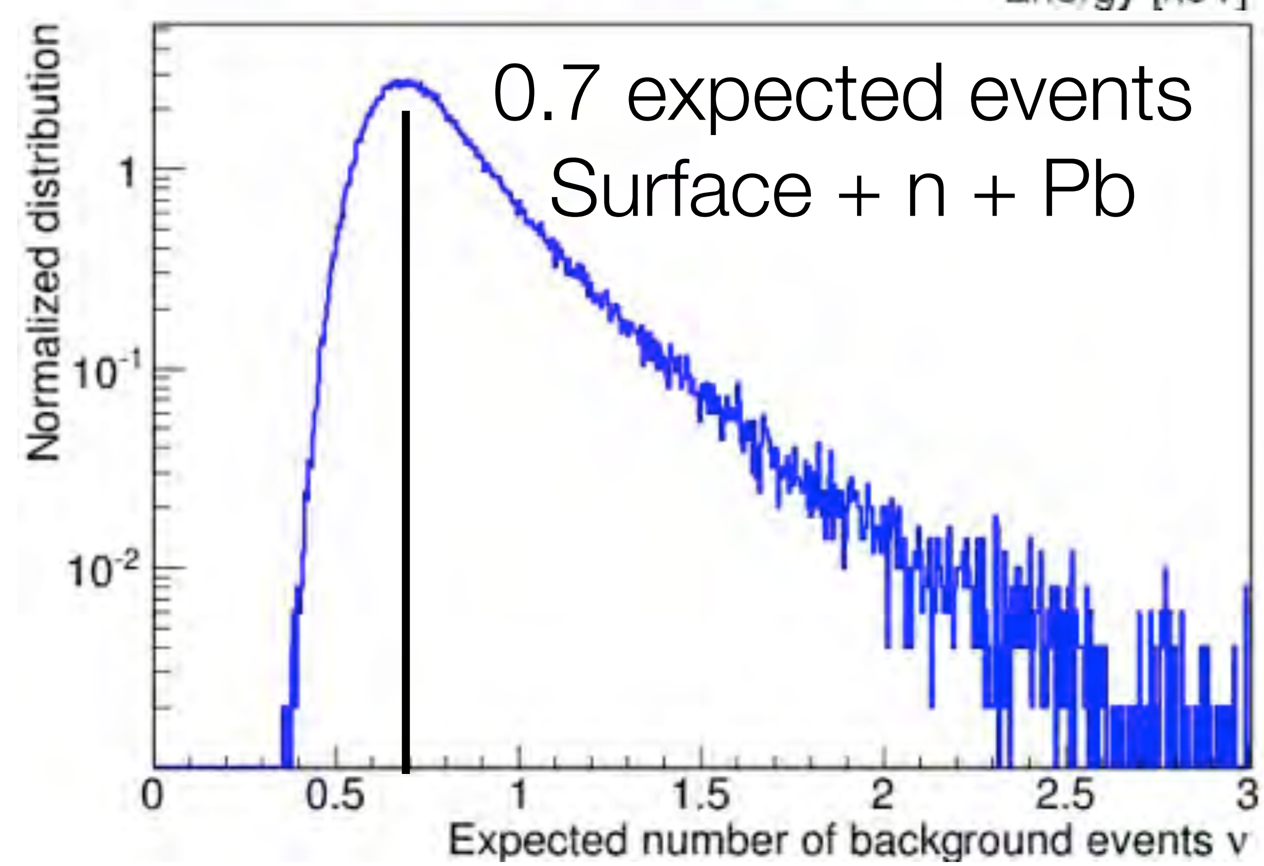


Profile Likelihood Analysis

- Incorporated data-driven background models into a WIMP+background likelihood analysis.
- Monte Carlo simulations of the background-only model indicate the probability of a statistical fluctuation producing three or more events anywhere in our signal region is 5.4%.





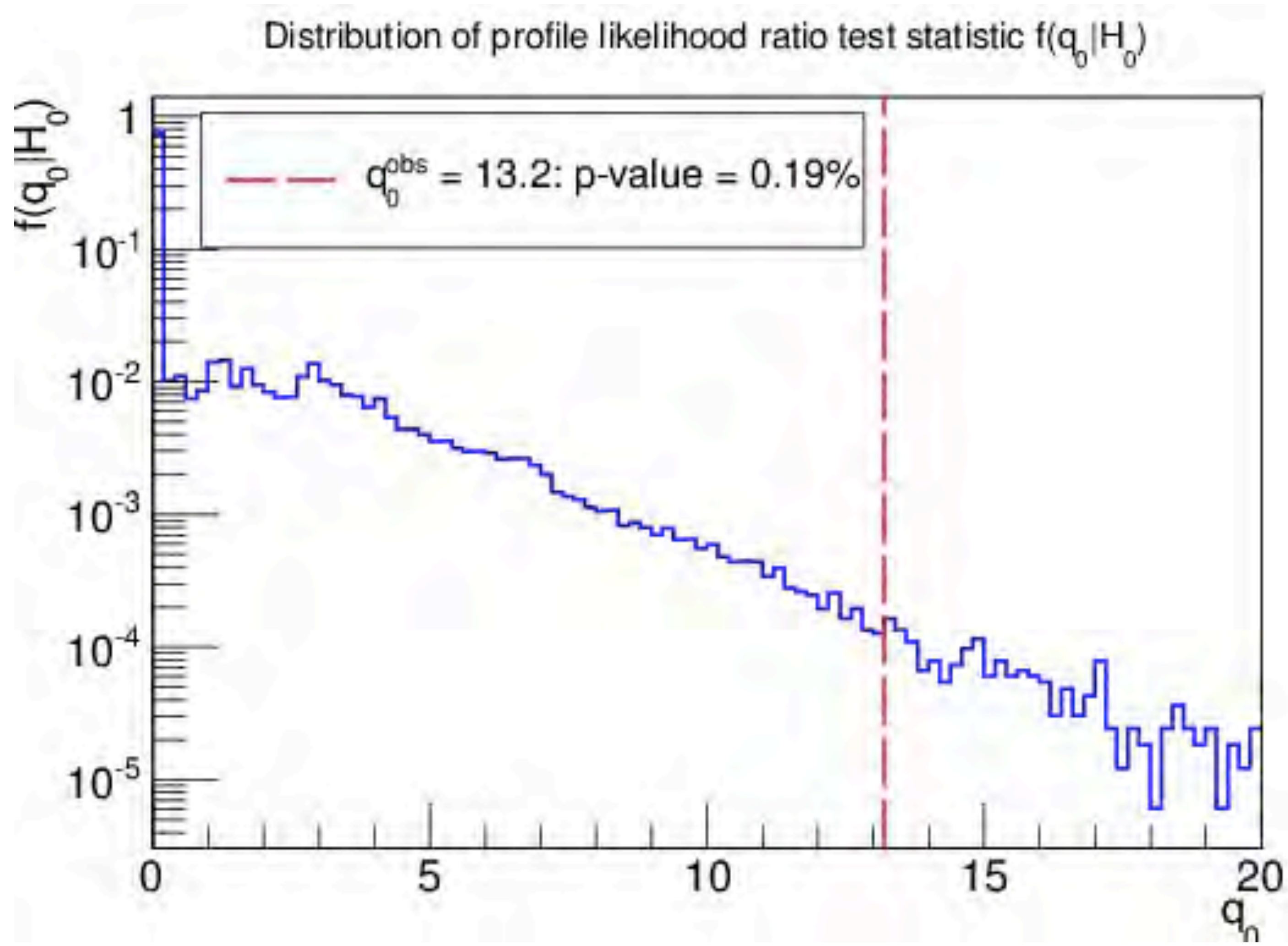


Profile Likelihood Analysis - cont.

Testing our known background estimate against a WIMP+background hypothesis

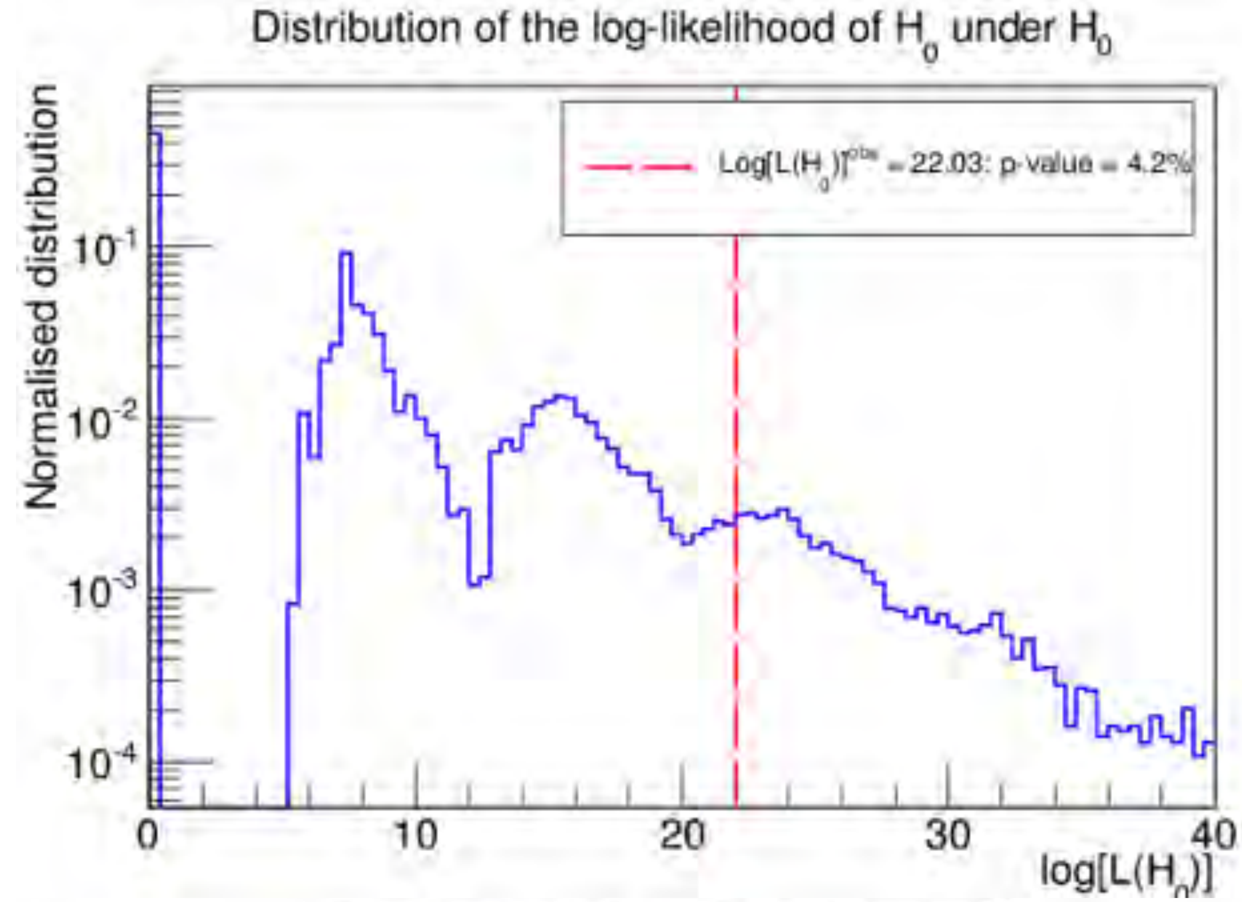
$$q_0 = -2\log\left\{\frac{\mathscr{L}(m_\chi, \sigma_{\chi-n} = 0, \hat{\hat{\vec{\nu}}})}{\mathscr{L}(\hat{m}_\chi, \hat{\sigma}_{\chi-n}, \hat{\vec{\nu}})}\right\} \equiv 2\log\left\{\frac{\mathscr{L}(H_1)}{\mathscr{L}(H_0)}\right\}$$

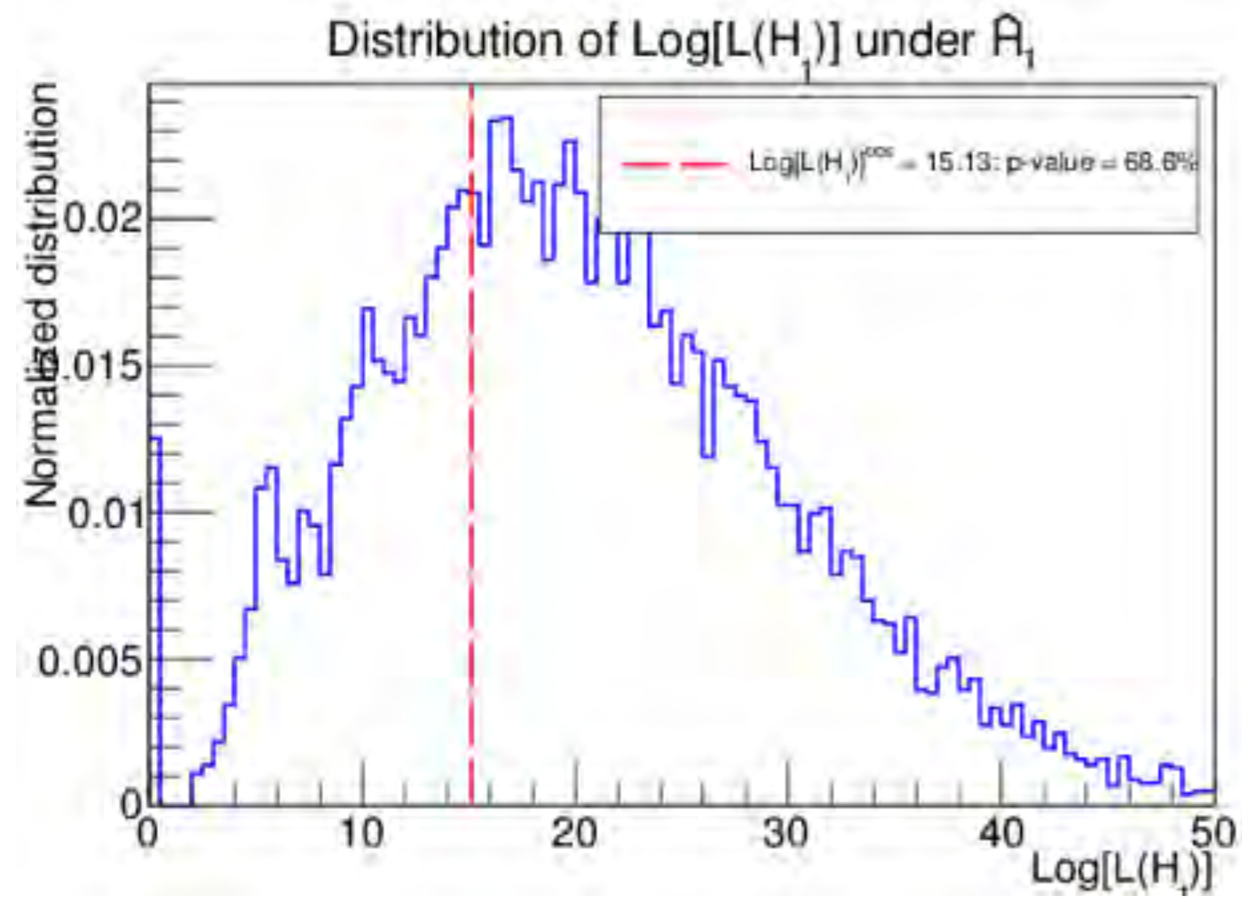
- A likelihood ratio test favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (p-value:0.19%, ~3σ).
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9×10^{-41} cm^2.



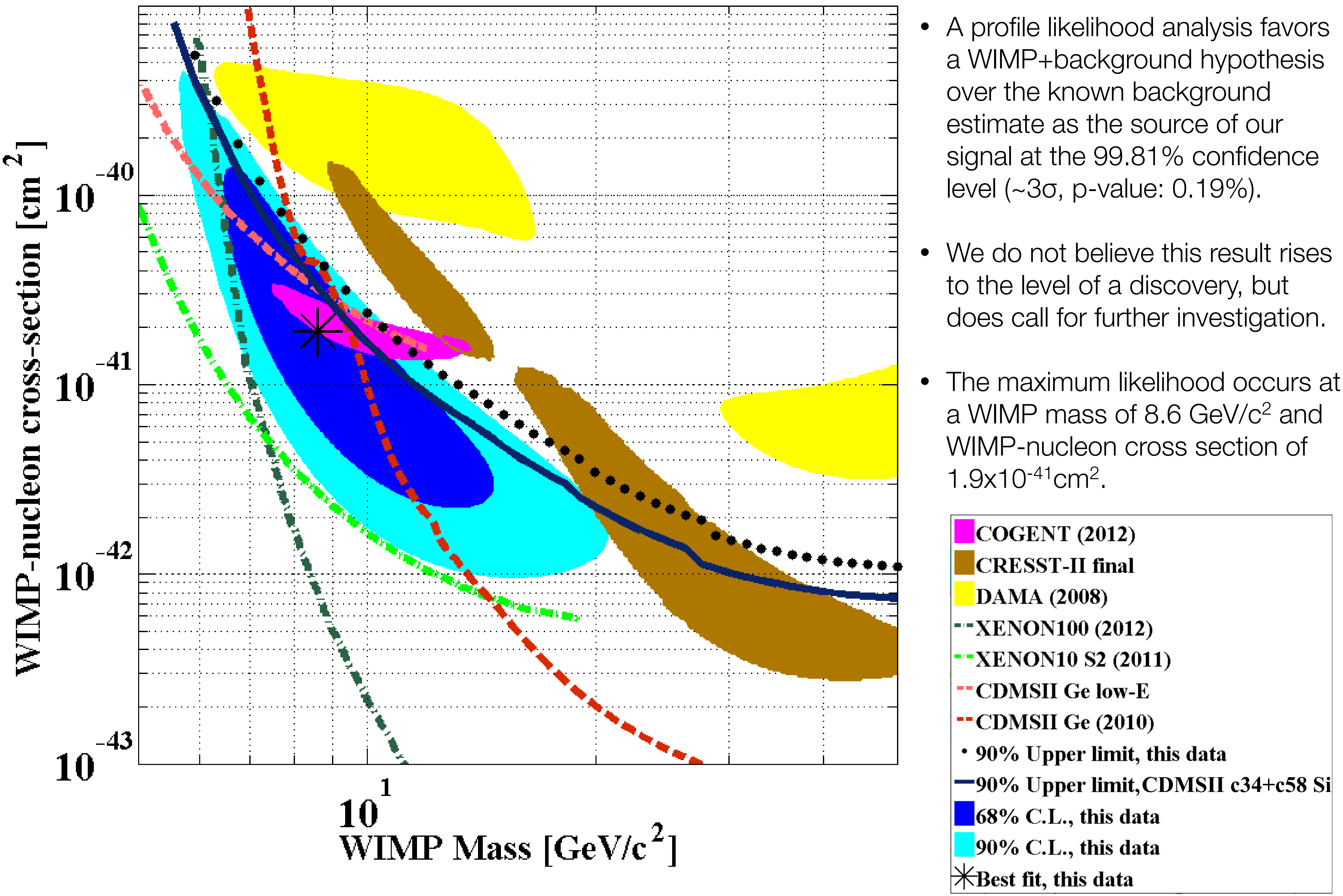
Profile Likelihood Goodness of Fit

- Its very important to check if the WIMP+background actually fits the data well.
- The goodness of fit of the known-background-only hypothesis is 4.2%
- The goodness of fit of the WIMP+background hypothesis is 68.6%



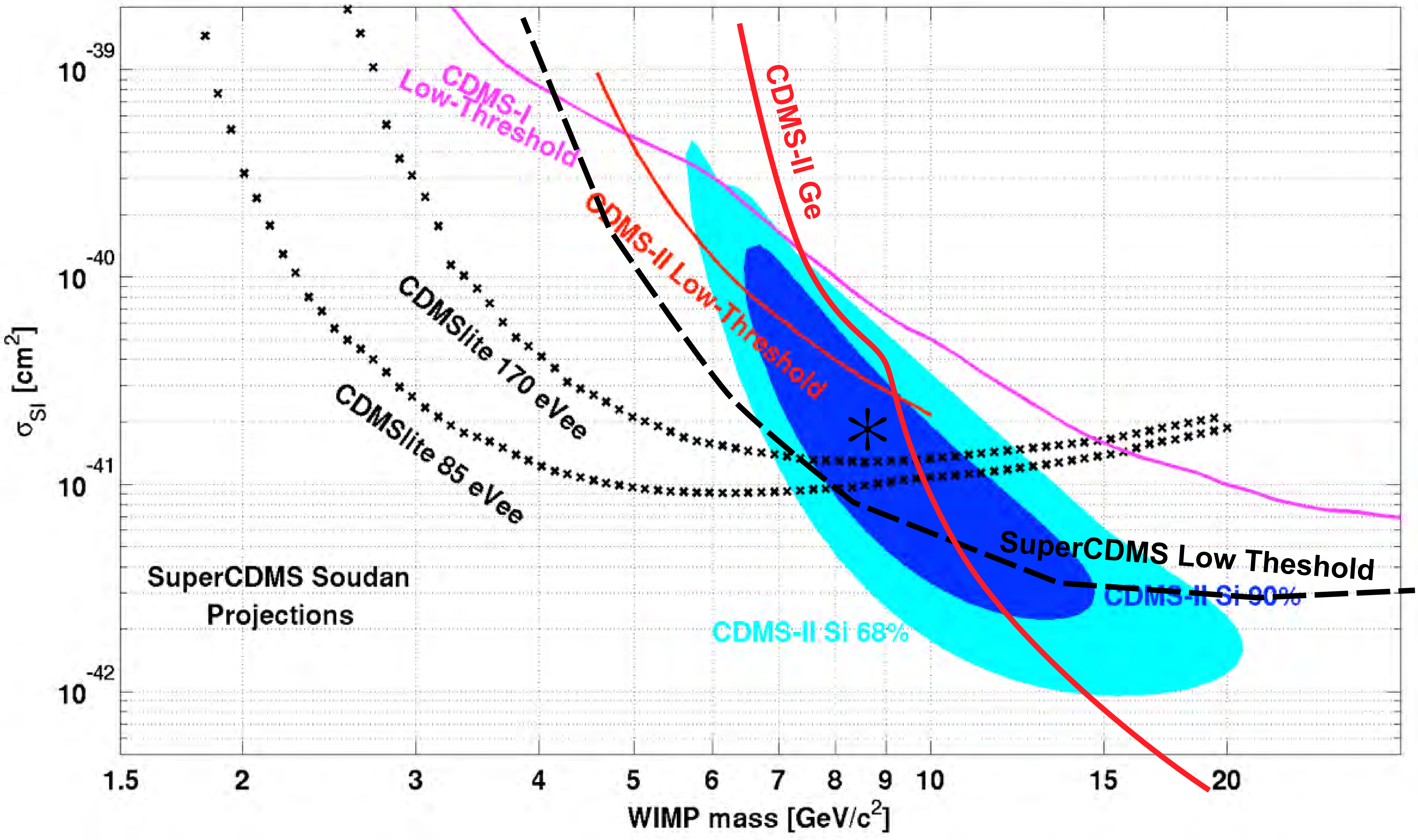


Profile Likelihood Confidence Intervals



- A profile likelihood analysis favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (~3σ, p-value: 0.19%).
- We do not believe this result rises to the level of a discovery, but does call for further investigation.
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9×10^{-41} cm^2.

Next Steps: SuperCDMS Soudan!



Conclusions

- Analysis of a 140.23 kg-day exposure of the CDMS-II Si detectors has been performed.
- Three events were seen in the signal region with a total expected background of <0.7 events.
- An optimal gap analysis sets a limit for the spin-independent WIMP-nucleon cross section of 2.4×10^{-41} cm^2 for a WIMP mass of 10 GeV/c^2.
- Monte Carlo simulations of the background-only model indicate that the probability of a statistical fluctuation producing three or more events anywhere in our signal region is 5.4%.
- A profile likelihood analysis favors a WIMP +background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (~3σ, p-value: 0.19%).
- We do not believe this result rises to the level of a discovery, but does call for further investigation.
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9×10^{-41} cm^2.