The First CDMS 5-Tower Results

Warm results from really cool detectors

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Fermilab

for the CDMS Collaboration

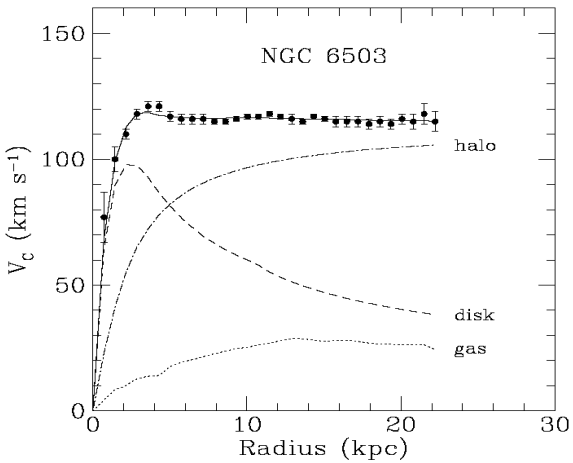
Wine and Cheese, 4th March 2008
Fermilab

Outline

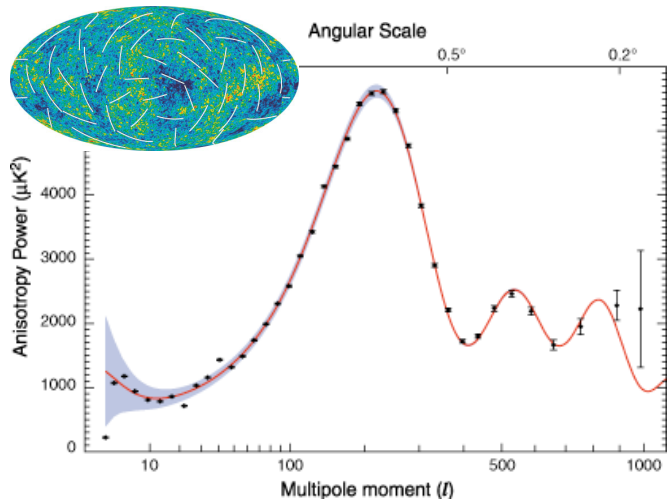
- Introduction
- Cryogenic Dark Matter Search
- New Results
- SuperCDMS
- Summary

Astrophysics Observations of Dark Matter

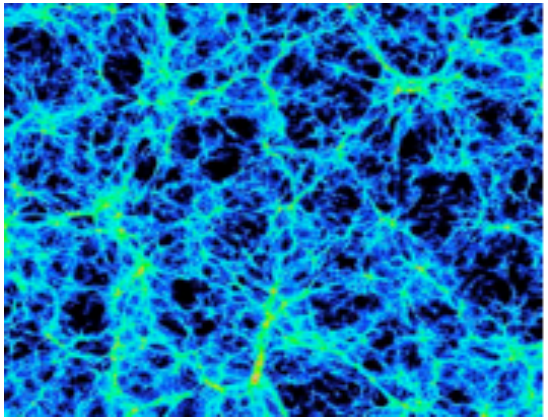
Rotation Curves of Galaxies



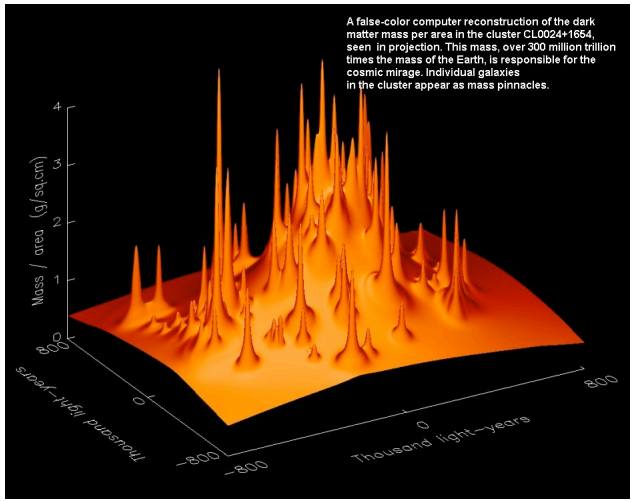
CMB



Large Scale Structure



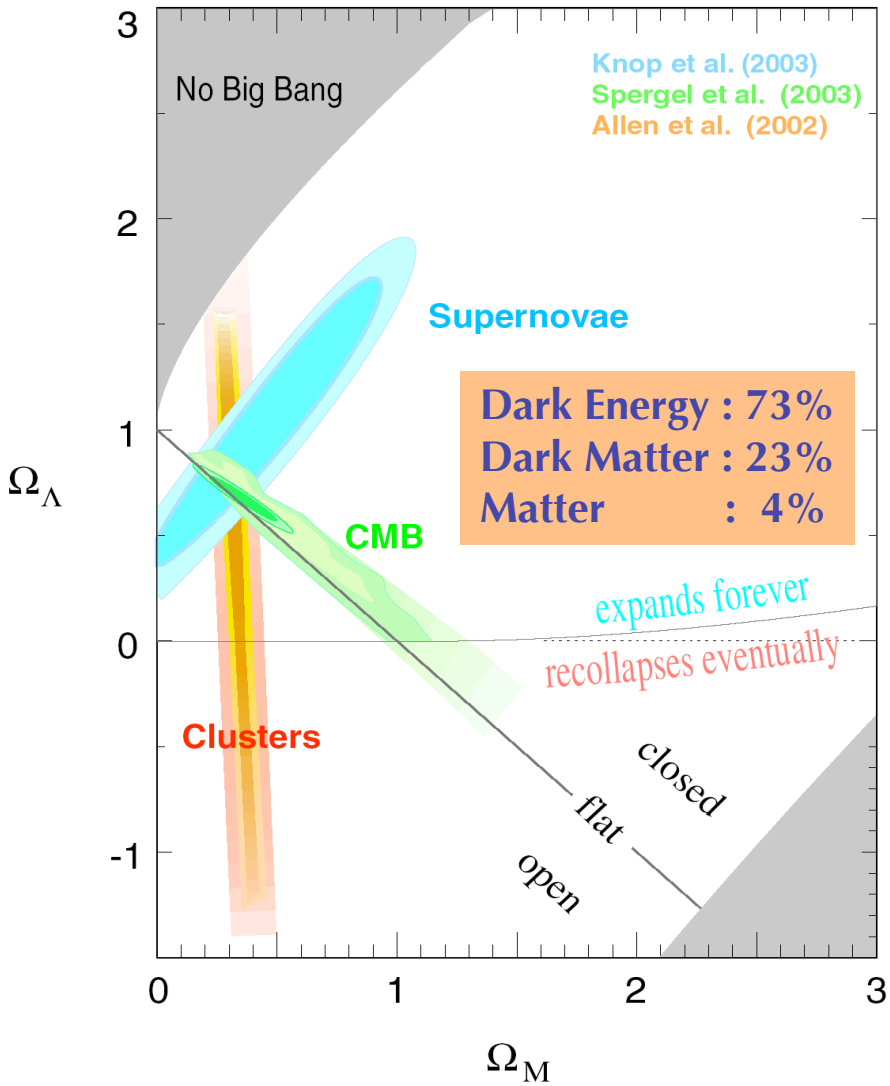
Galaxy Cluster



Dark Matter Ring

Bullet Cluster

The Universe is (mostly) Dark



- We know the Dark Matter is
  stable / non-baryonic / non-relativistic / interact gravitationally

- We don't know what it actually is
  mass / coupling / spin / composition / distribution in the Universe …

- Cosmology suggests to probe EW scale

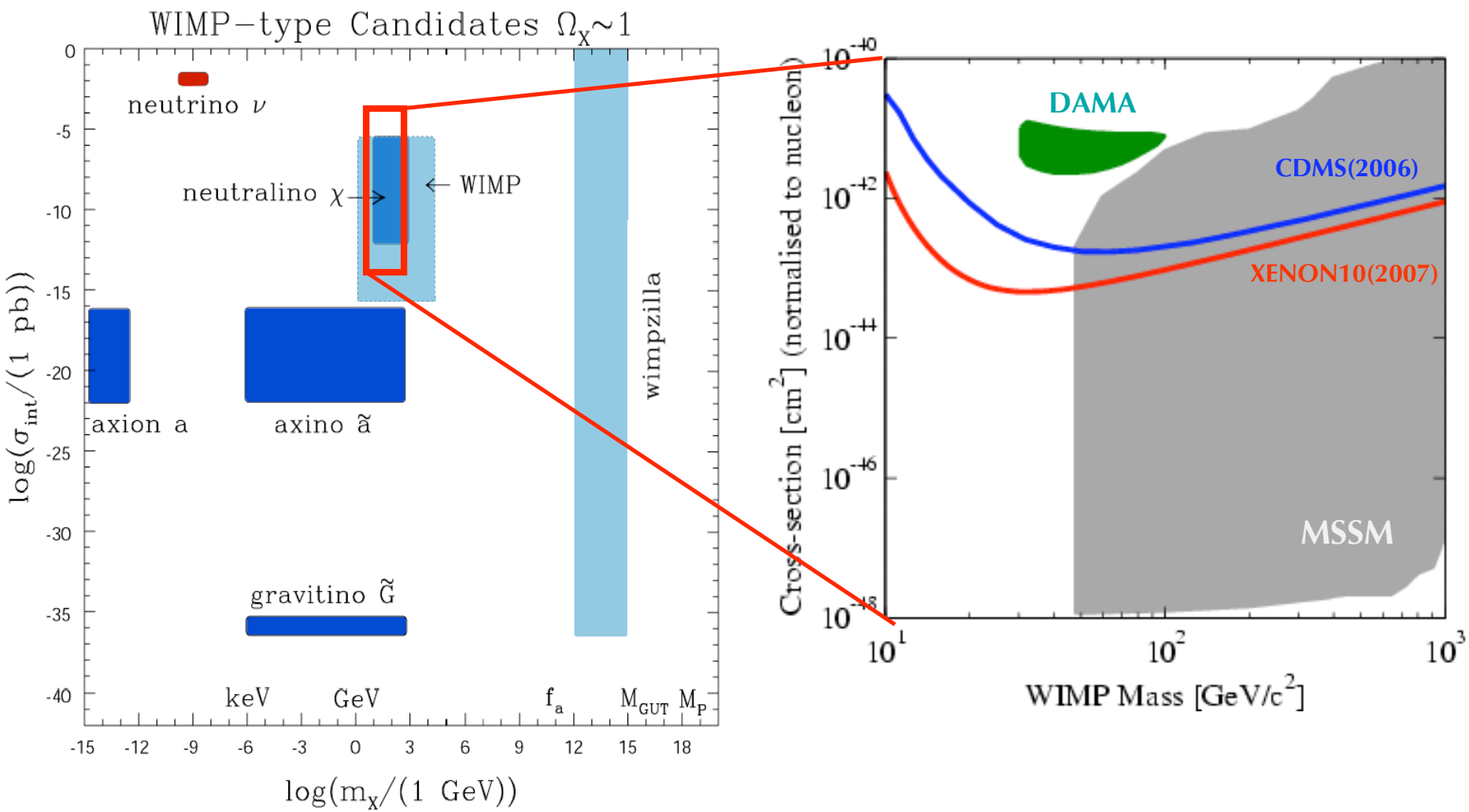
$$\Omega_{DM} \sim \langle \sigma_A v \rangle^{-1}$$

$$\sigma_A = \alpha^2 / M^2_{EW}$$

- SUSY model provides electroweak scale stable neutral particle : LSP

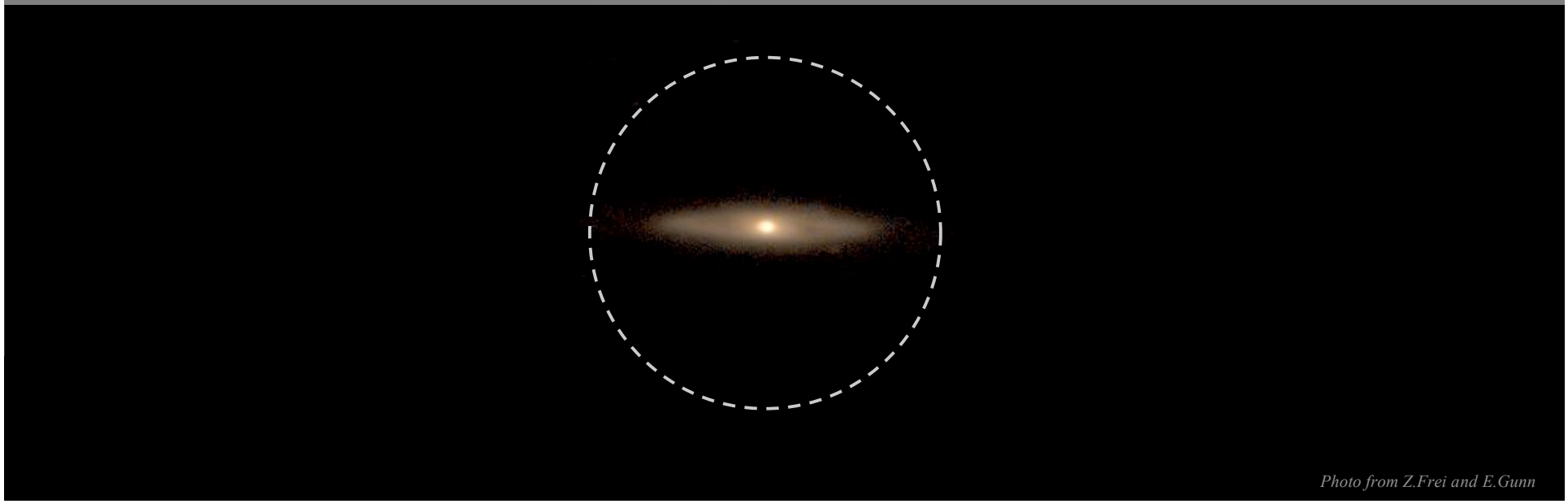
- However the Dark Matter is not necessarily a SUSY particle.

WIMPs



L. Roszkowski

WIMP Distribution in Our Galaxy



- **Spherical Halo Model :** $\rho \sim \rho_0 (r/r_s)^{-1}(1+r/r_s)^{-2}$
- **Energy spectrum & rate depend on WIMP distribution in Dark Matter Halo**

$$\frac{dR}{dE} \propto \sigma\rho \int_{v_{\min}}^{v_{esc}} \frac{f(v)}{v} dv$$

- **Assume isothermal Maxwell-Boltzmann velocity distribution**
- **Vo = 230 km/s (WIMP velocity against detector)**
- **Vesc = 650 km/s (escape velocity of WIMP from Galactic halo)**
- **Local density of WIMPs = 0.3 GeV/cm^3**
- **Energy spectrum of recoils is featureless exponential**

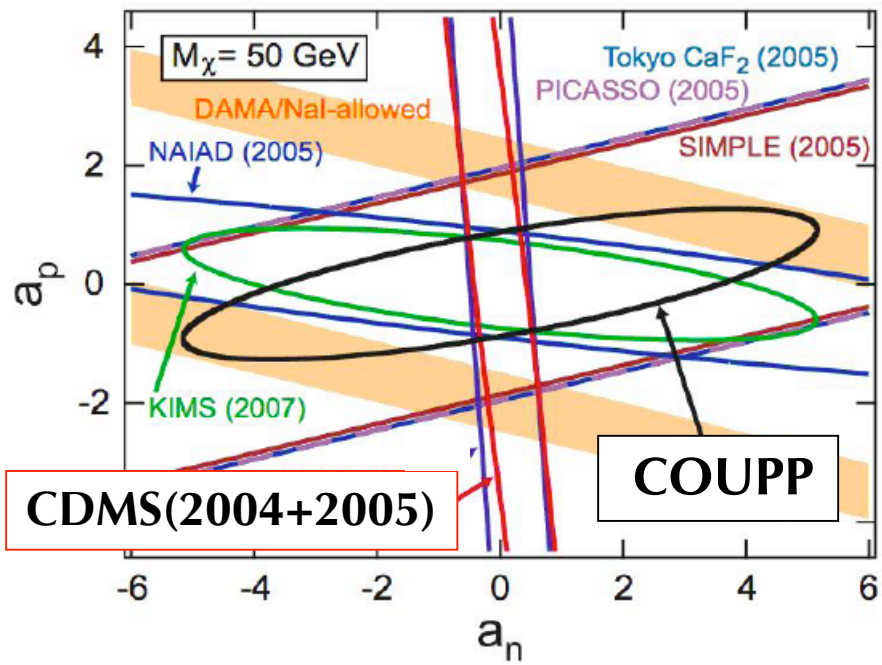
WIMP-nucleon Couplings

- **Spin Independent Coupling (Scalar)**

$$\frac{d\sigma_{\chi N}^{SI}}{dq^2} = \frac{1}{\pi \upsilon^2}[Zf_p + (A-Z)f_n]^2 F^2(q)$$

- **Spin Dependent Coupling (Axial)**

$$\frac{d\sigma_{\chi N}^{SD}}{dq^2} = \frac{8G_F^2}{(2J+1)\upsilon^2}[a_0^2 S_{00}(q) + a_0 a_1 S_{01}(q) + a_1^2(q) S_{11}(q)] \qquad a_p = \frac{1}{2}(a_0 + a_1),\ \ a_n = \frac{1}{2}(a_0 - a_1)$$



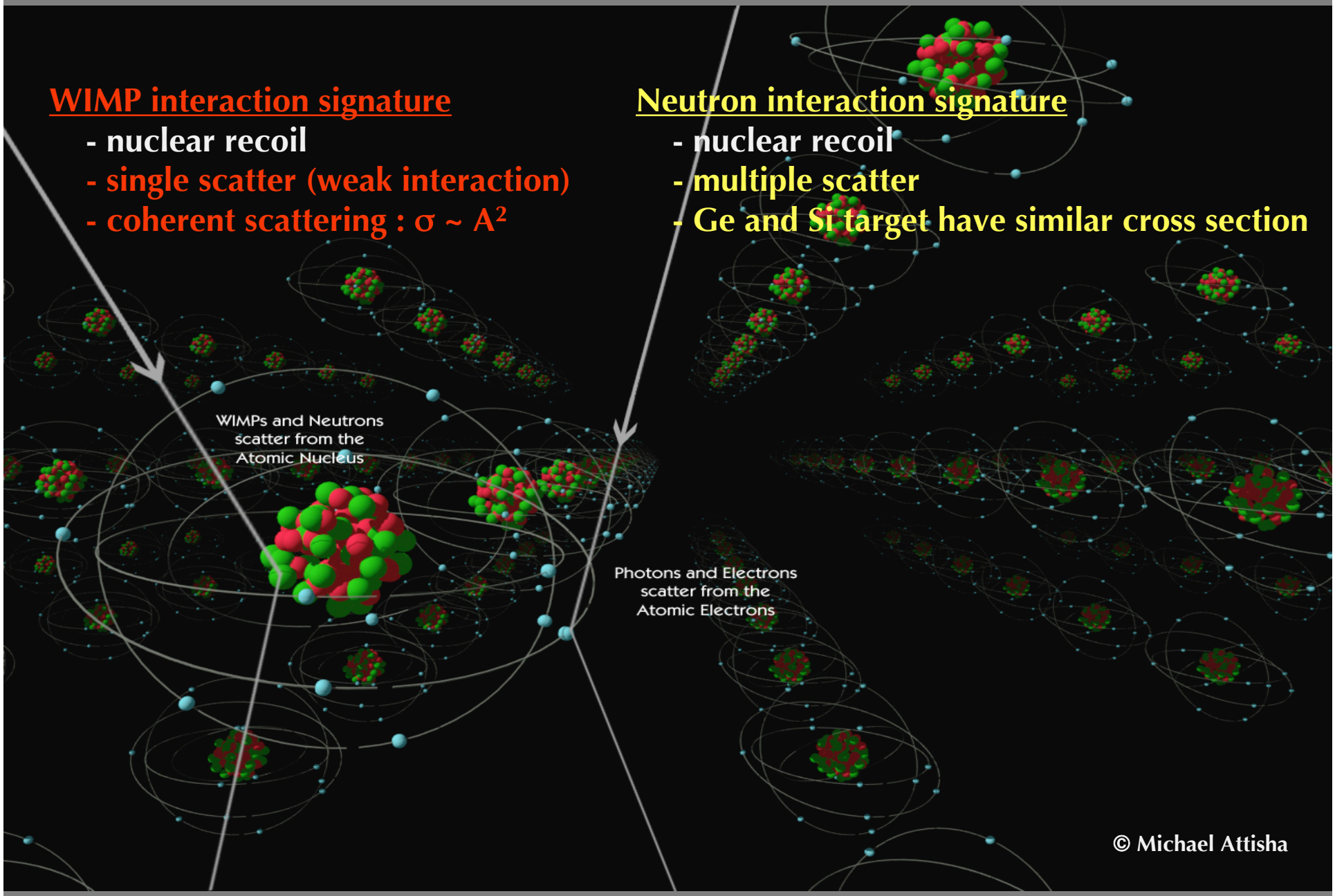
Direct Detection of WIMP

WIMP interaction signature

- nuclear recoil
- single scatter (weak interaction)
- coherent scattering : $\sigma \sim A^2$

Neutron interaction signature

- nuclear recoil
- multiple scatter
- Ge and Si target have similar cross section



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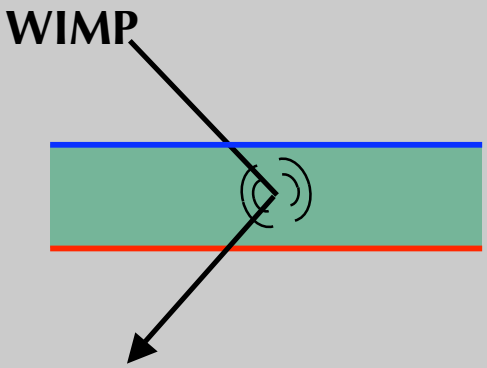
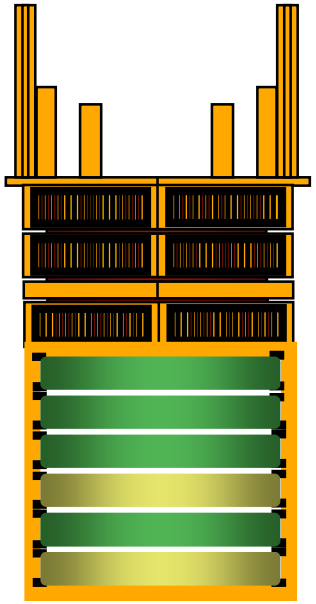
Cryogenic Dark Matter Search

WIMP Detection Strategy of CDMS



- Direct detection of WIMP signal
- Nucleus recoil by elastic scattering
- Read out phonons from recoil together with ionization signal



Weakly Interacting

WIMP mean free path in Ge ~ 10^{10}m

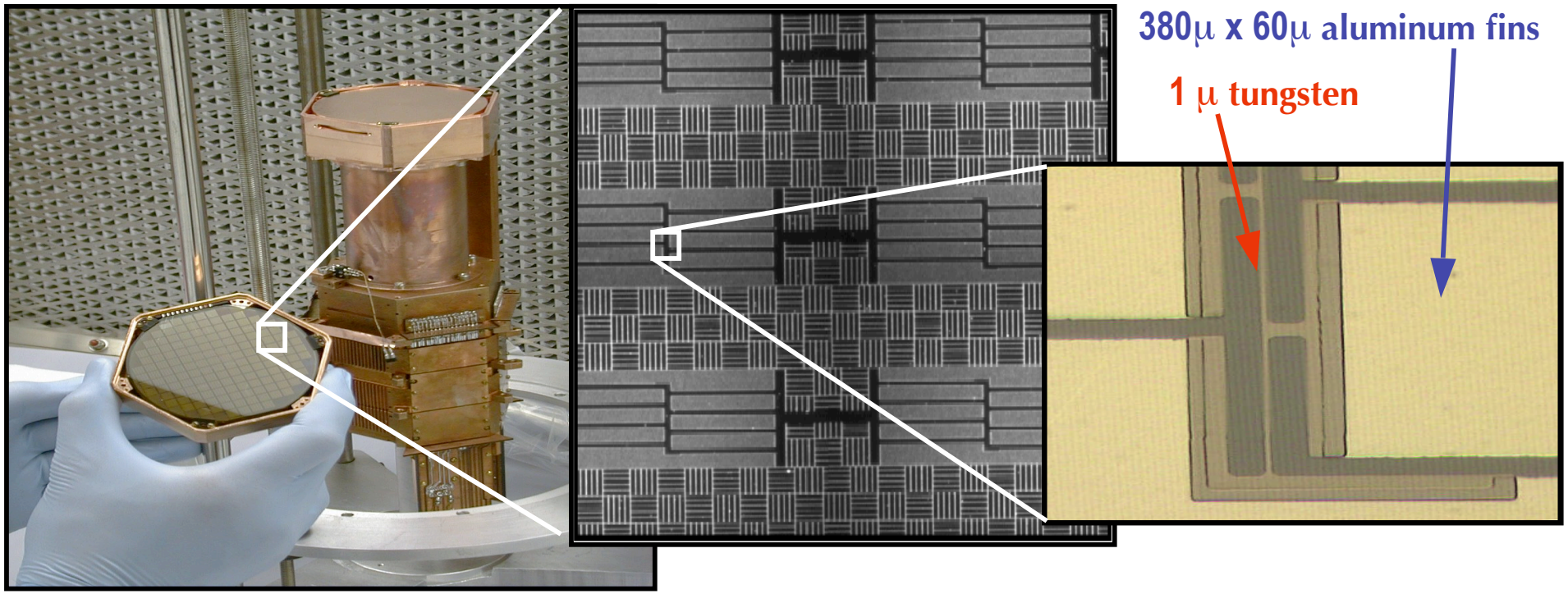
The event will single scatter

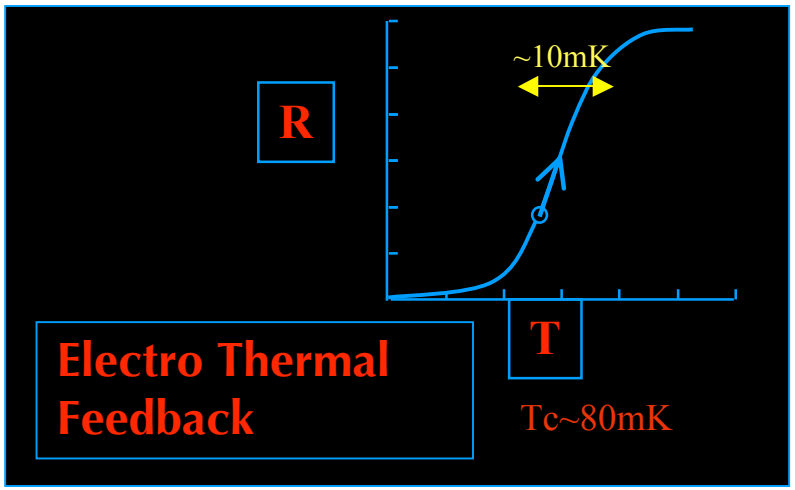
Interaction Rate $\propto A^2$

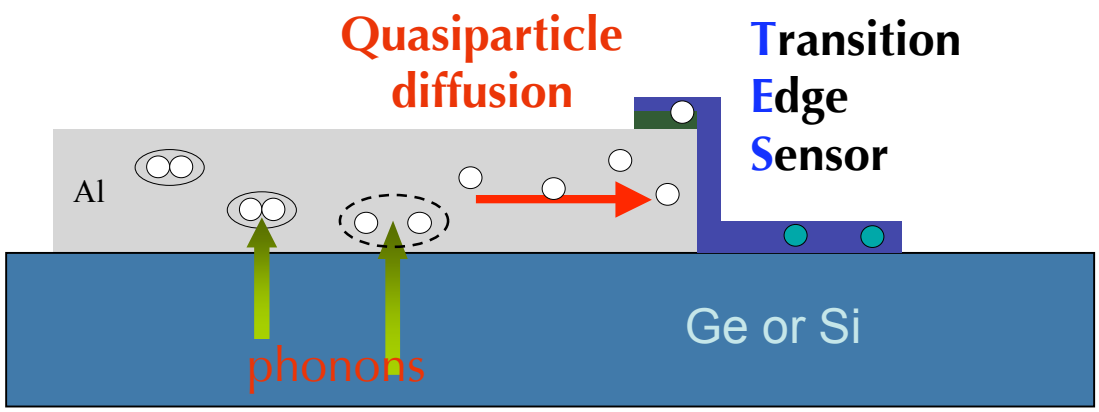
Use both Ge(73) and Si(28) targets

R(Ge/Si) = ~7

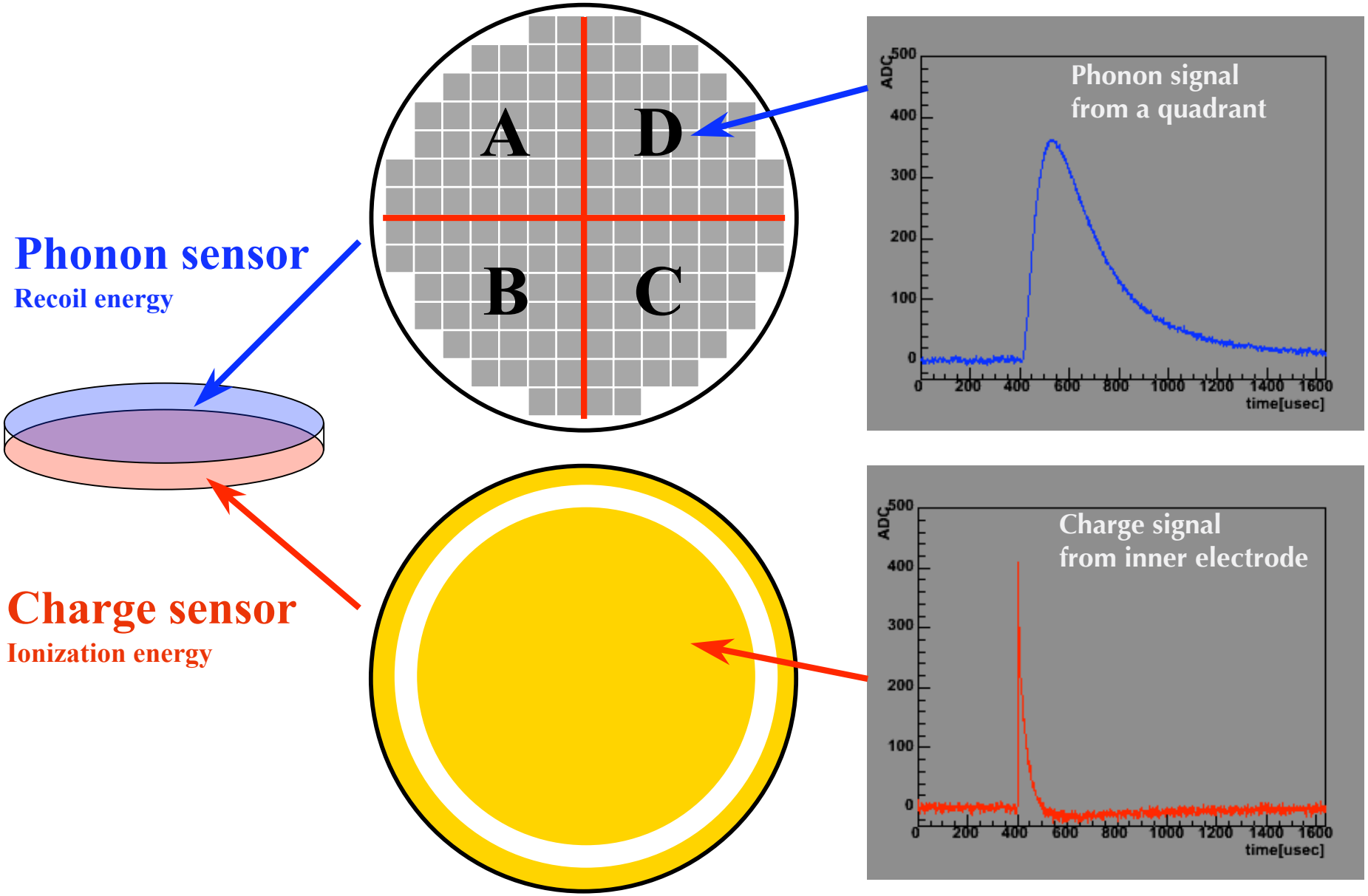
CDMS Detector





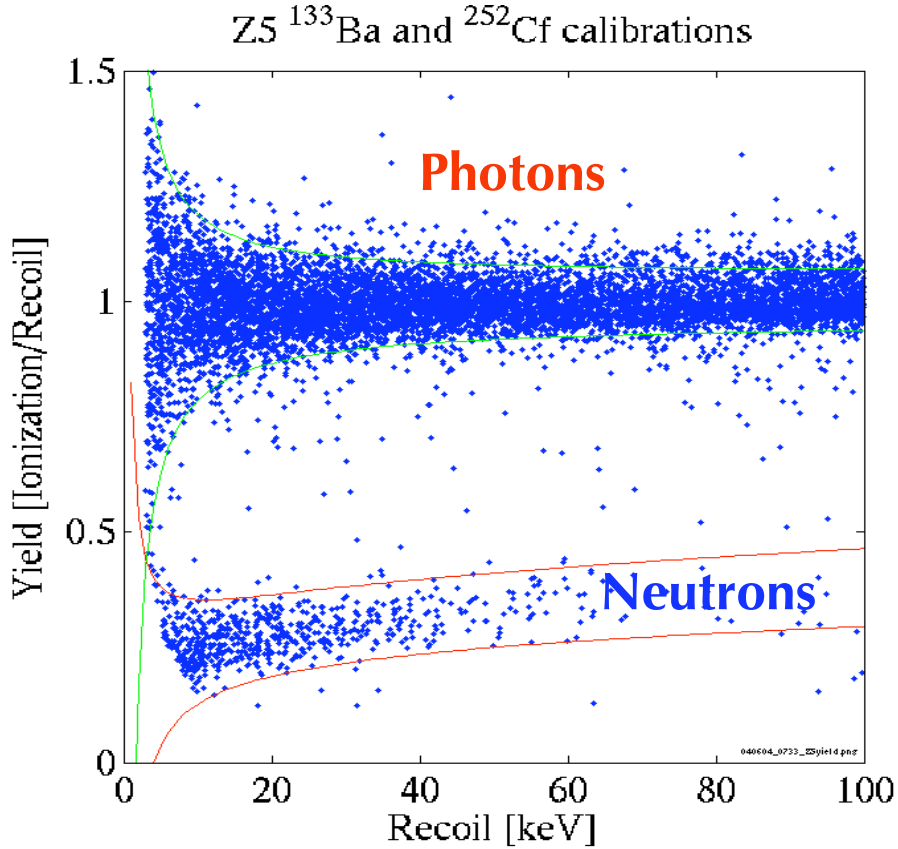


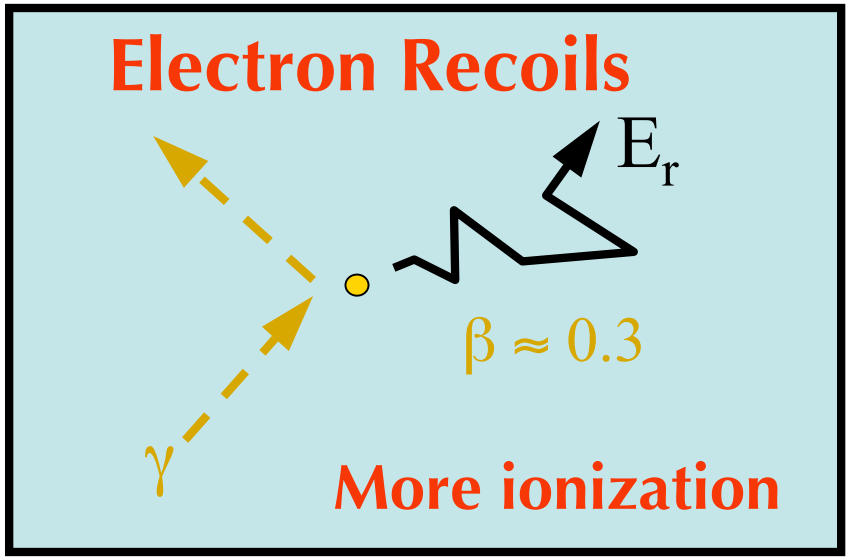
CDMS Detector Readout

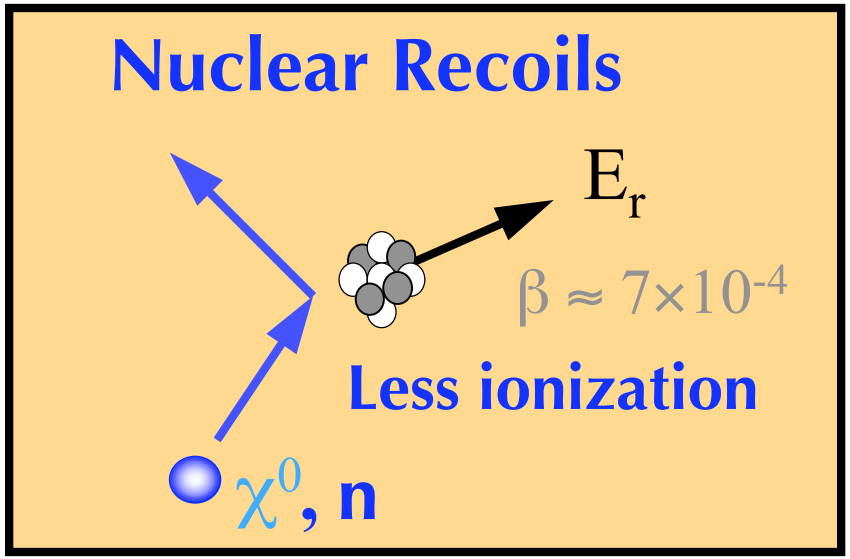


Gamma Background

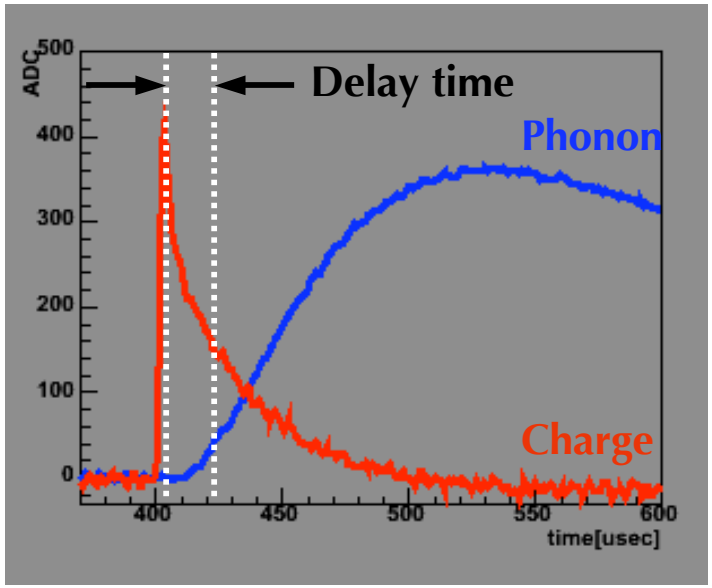
Yield = E(ionization) / E(recoil)

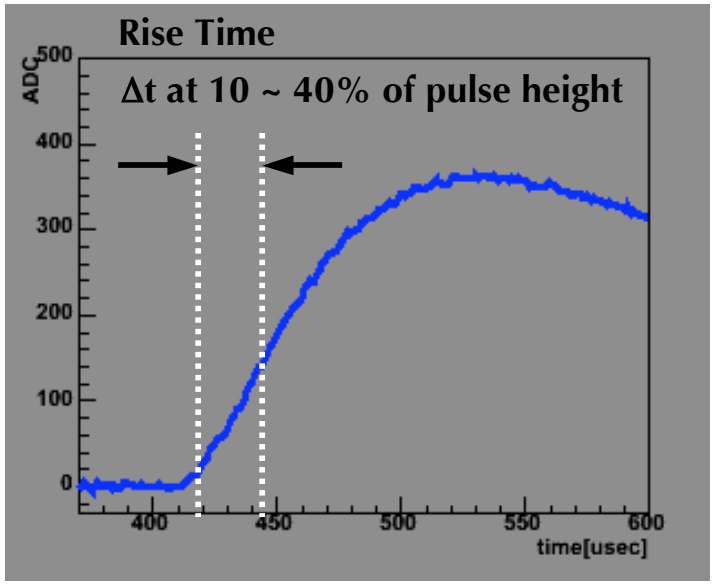


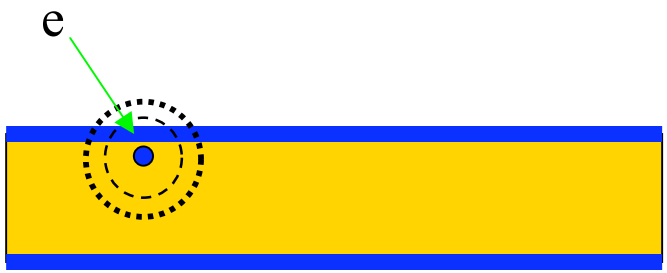


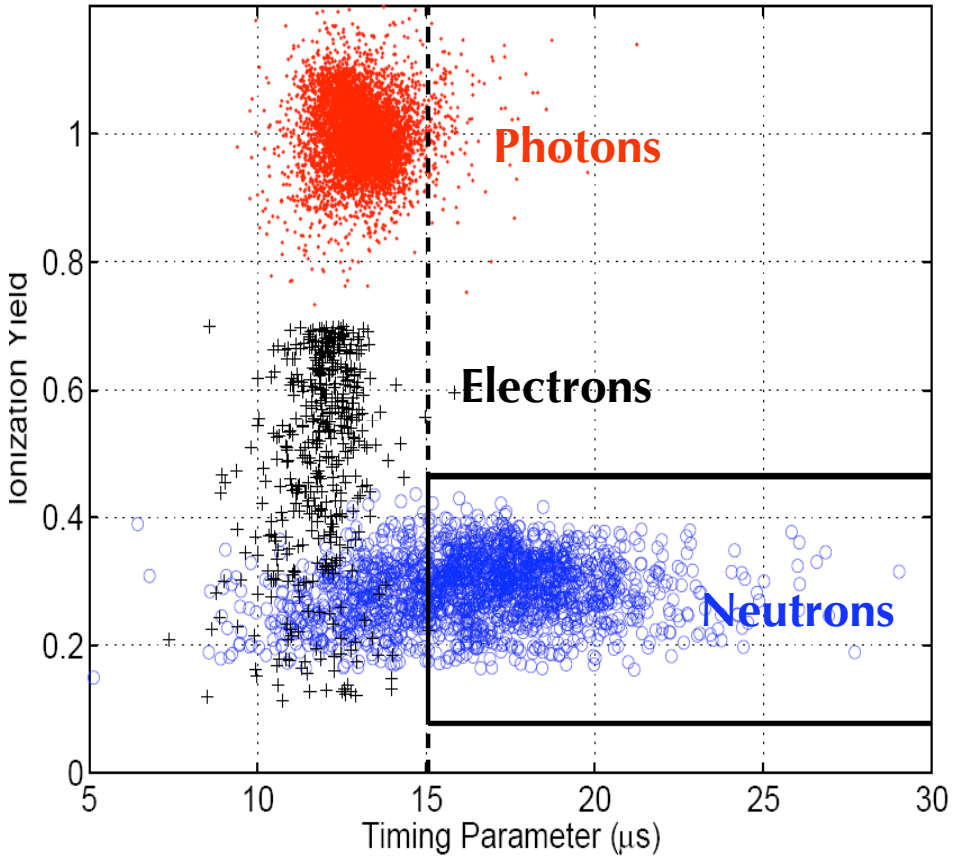


Electron Background









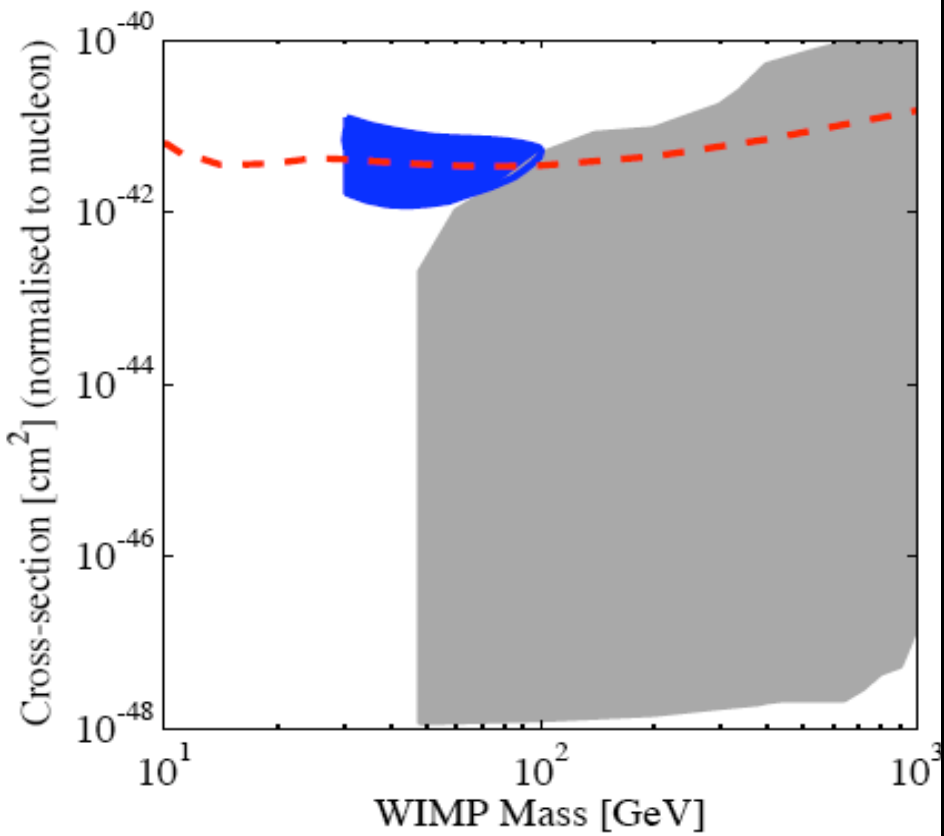
Neutron Background : Cosmogenic

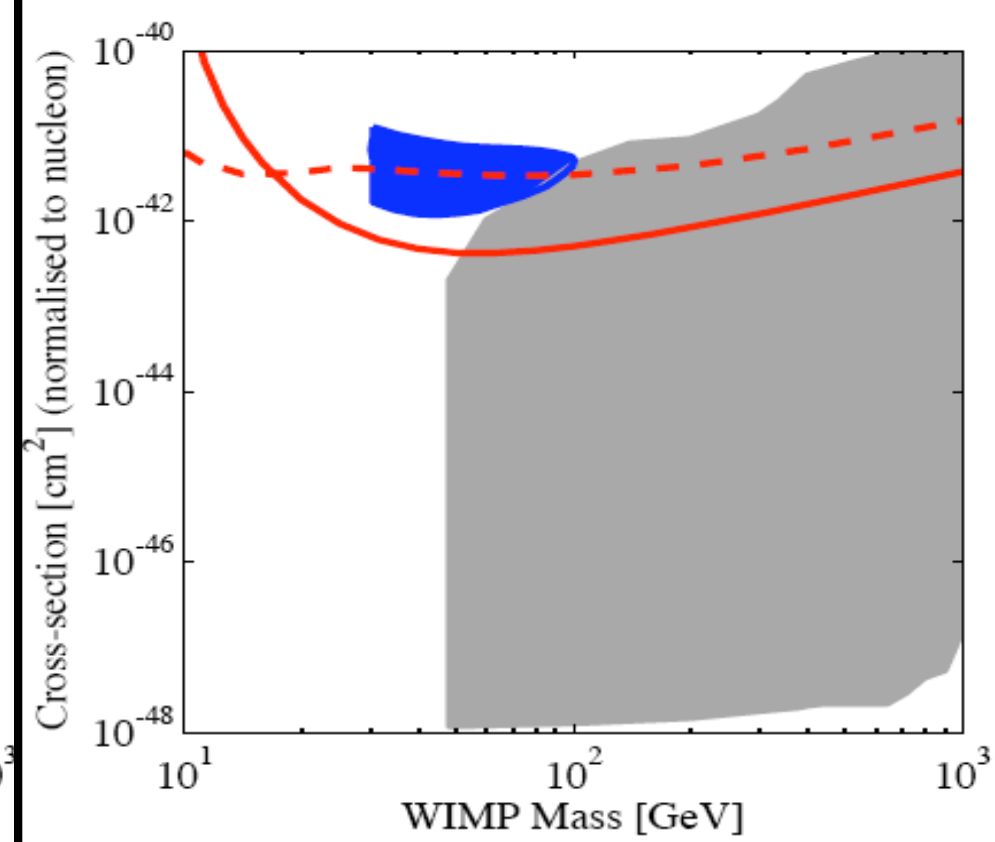
Stanford

- 2001-2002 operation
- 12m underground (50 μ/sec/m²)
- Single Tower (4Ge + 2Si detectors)
- 28 kg-days detector exposure
- 20 nuclear recoil events

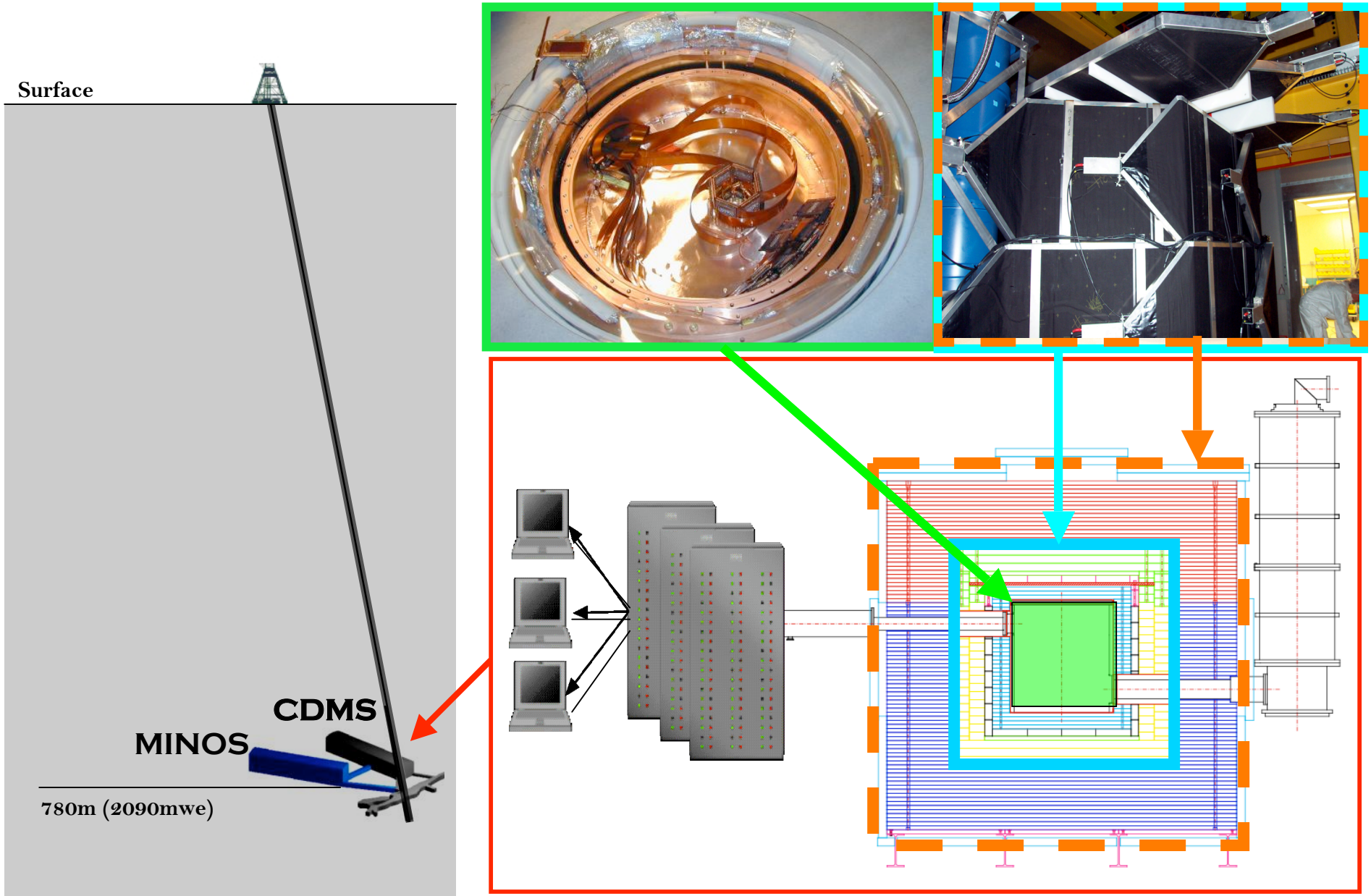
Soudan

- 2003 operation
- 780m underground (0.004 μ/sec/m²)
- Single Tower (4Ge + 2Si detectors)
- 19 kg-days detector exposure
- 1 nuclear recoil events



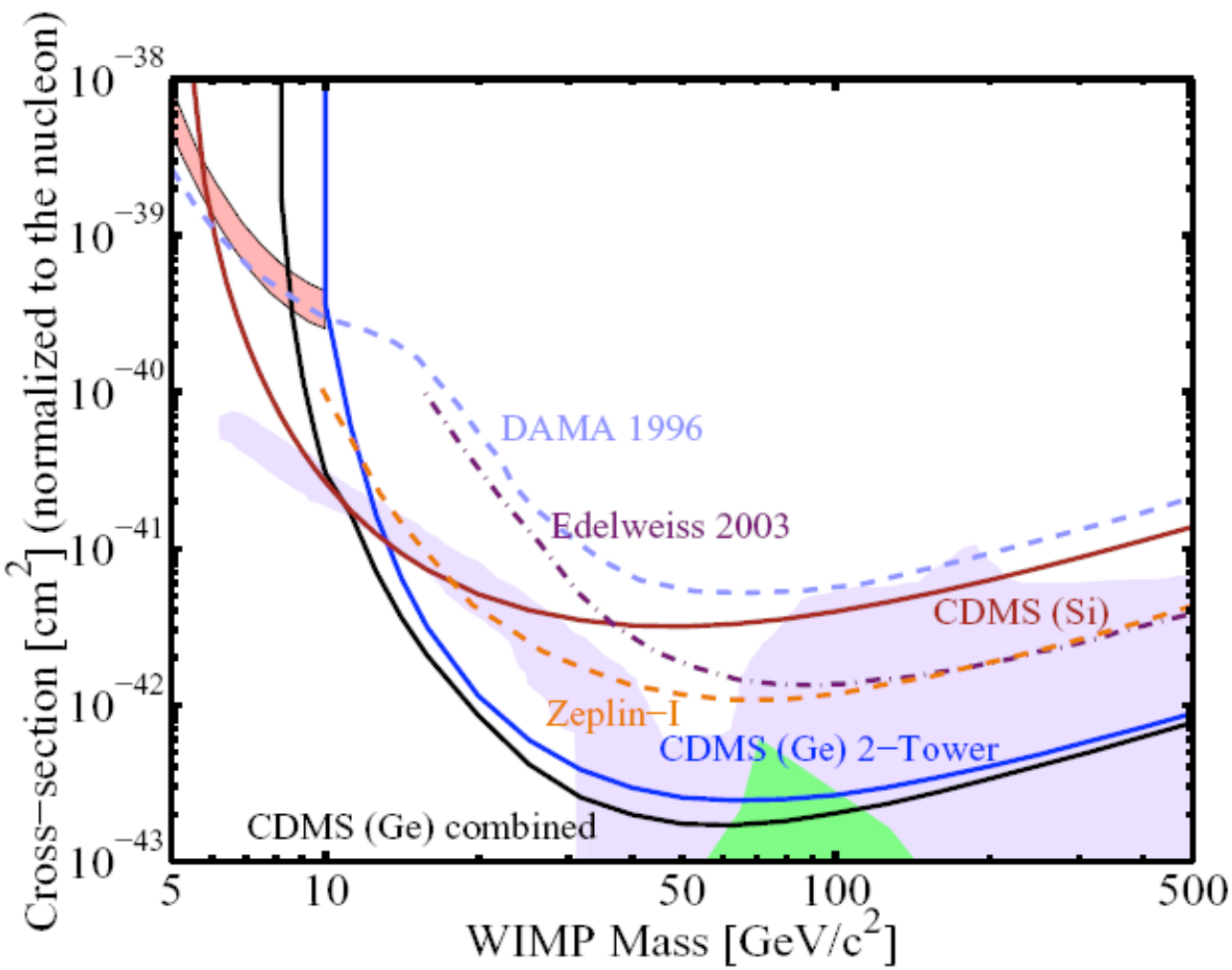


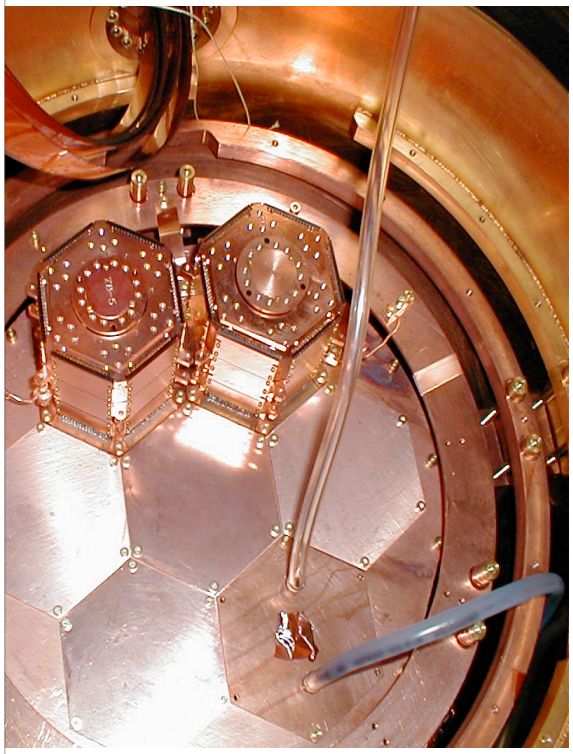
Experimental Setup in the Soudan Mine



Two Tower Results : 2006

- 34 kg-days Ge and 12 kg-days Si net exposure
- Zero background (0.6 electron BG expected for entire run)
- One event observed : consistent with the expected BG

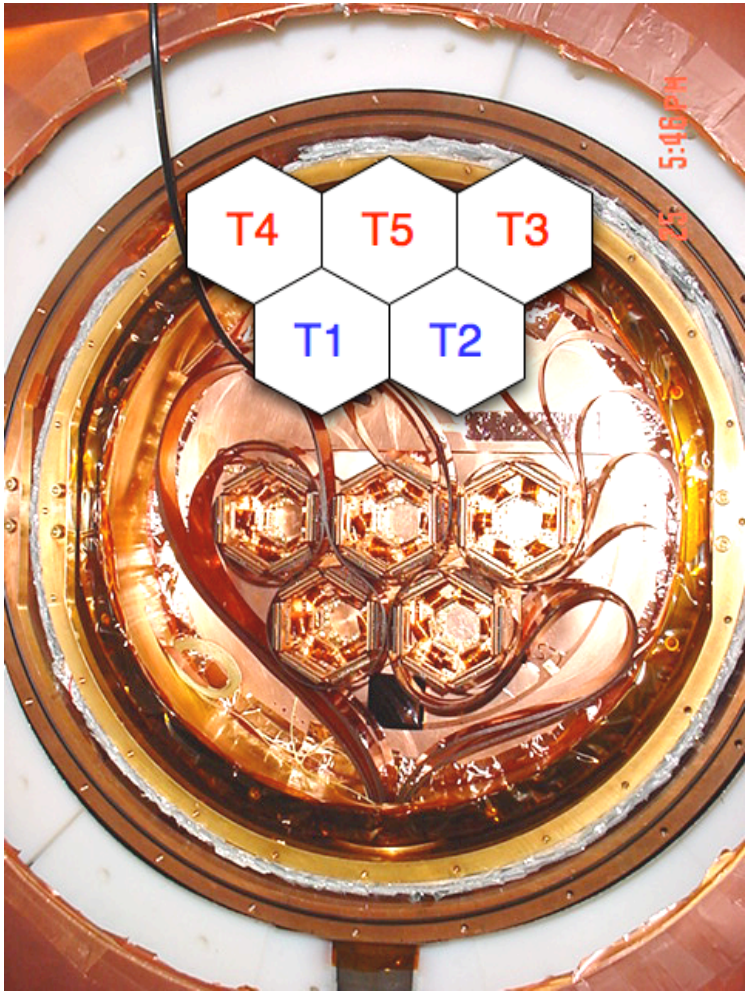




New Results

Five Tower Runs

30 ZIPs (2 Towers + 3 new)
4.75 kg Ge, 1.1 kg Si



Low Background Towers

Newer Towers have 2-3X lower backgrounds from Radon

Cryogenics

~6 months of stable base temperature

Cryocooler

Improved DAQ

10X Faster (100 Hz) calibration speed

GPS time record for NuMI event veto

Online & Offline data quality monitoring

New Analysis Pipeline

Huge calibration sample (4TB, 60M events)

Data processing at FermiGrid (Thanks!)

Detector Livetime (Ge)

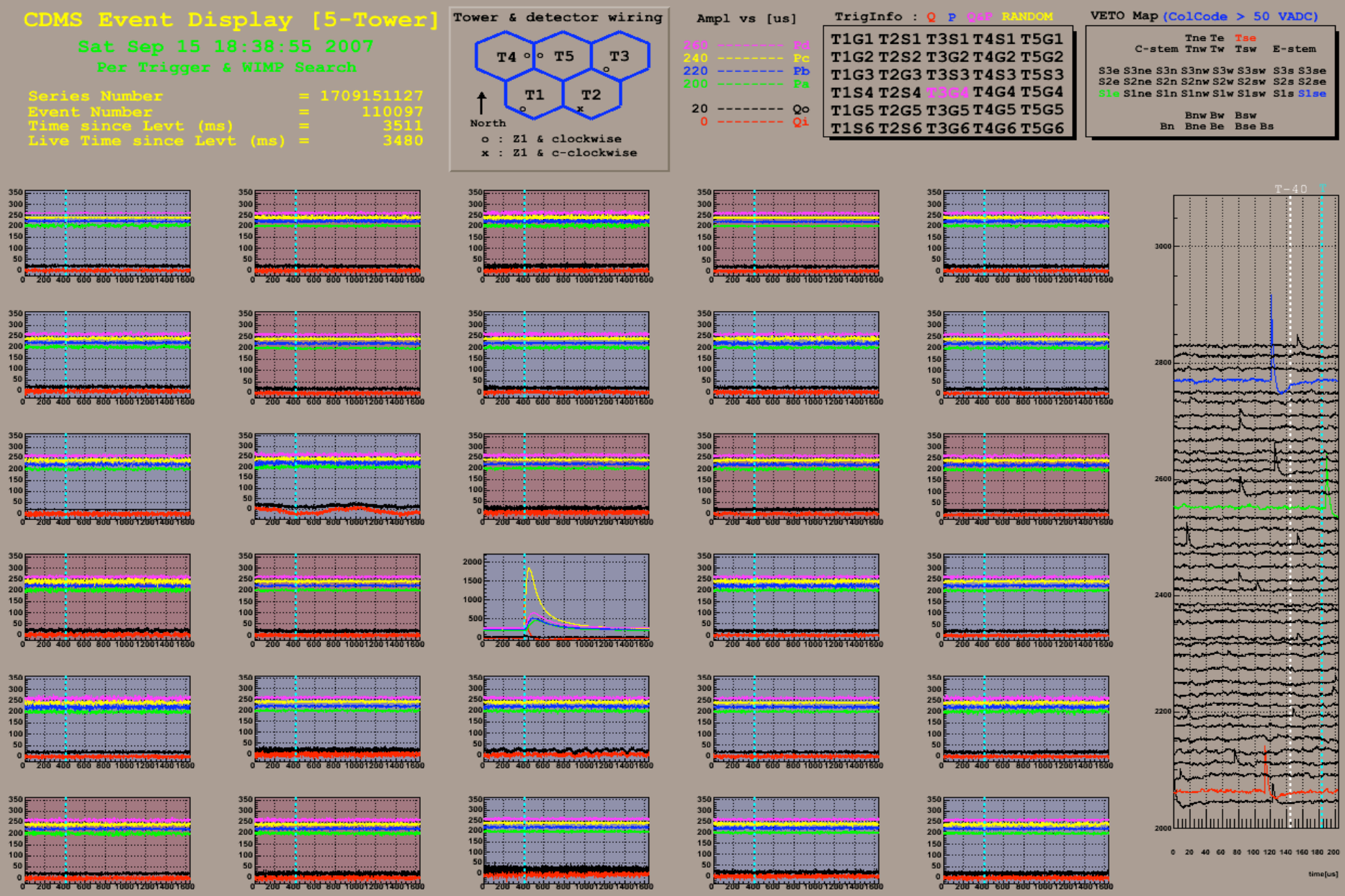
R123 (2006.10.21~2007.03.21) 430kg-d

R124 (2007.04.20~2007.07.16) 224kg-d

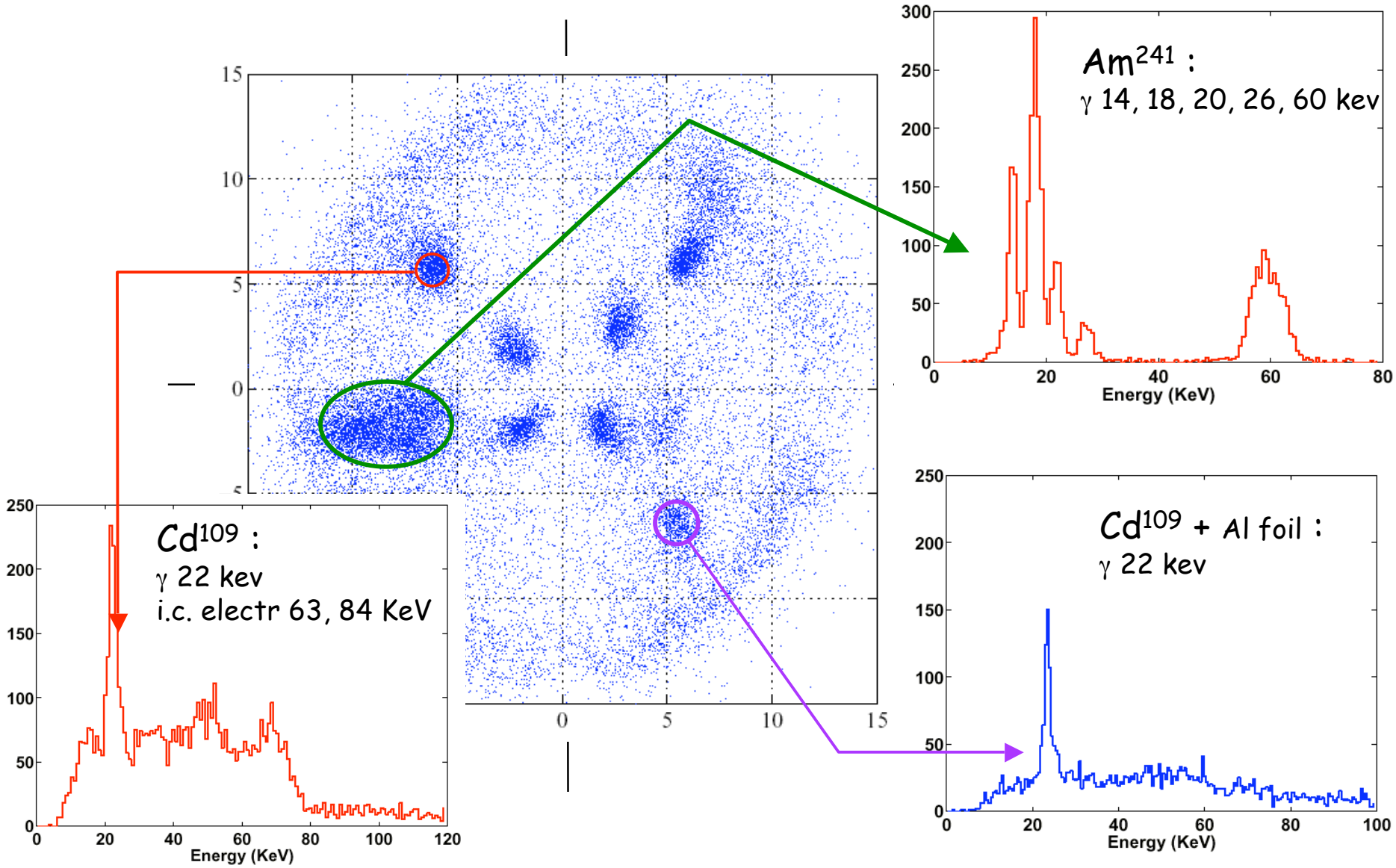
R125 (2007.07/21~2008.01.09) 465kg-d

R126 (2008.01.17~) running now

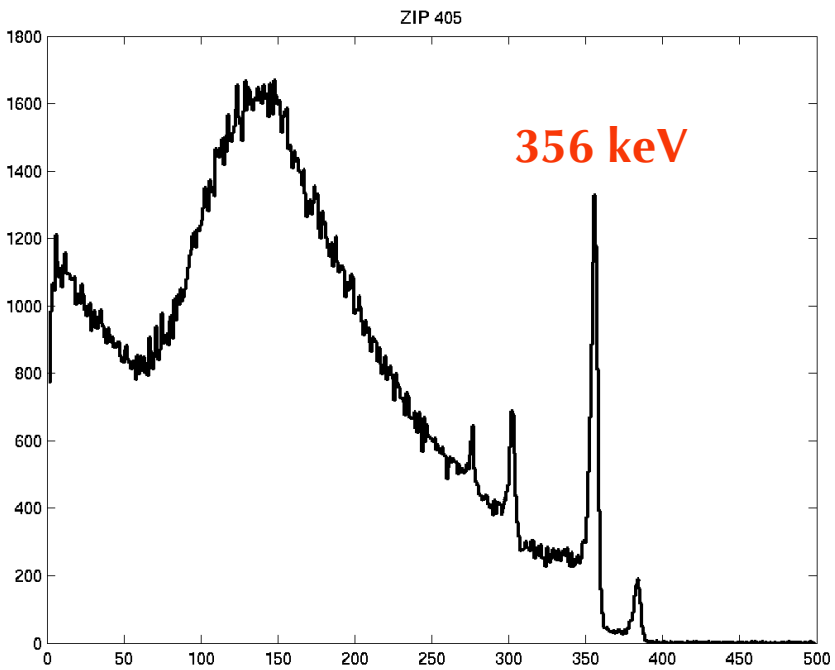
Real Time Event Monitor (WH6W)



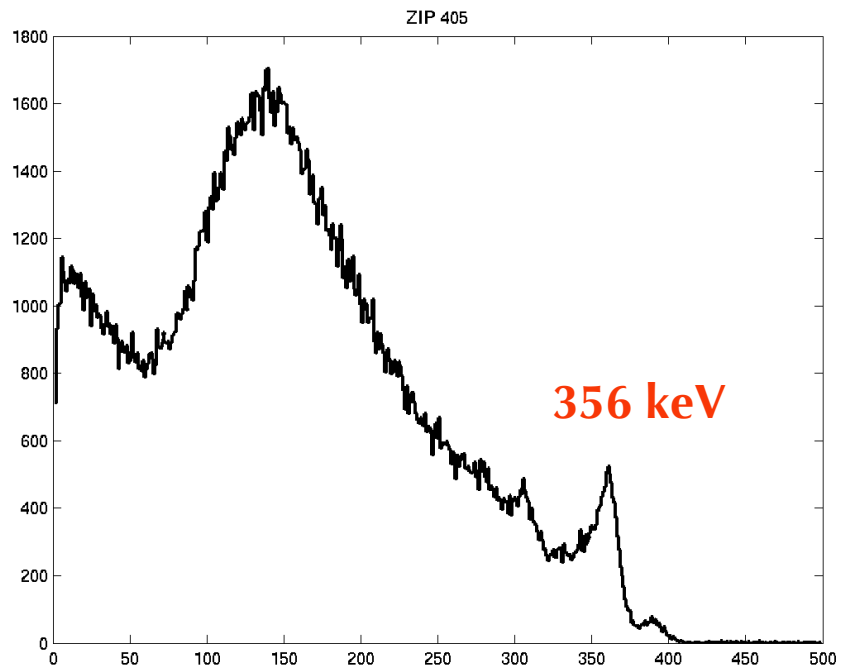
Position Resolution



Photon Calibration with ^{133}Ba



Ionization Energy [keV]

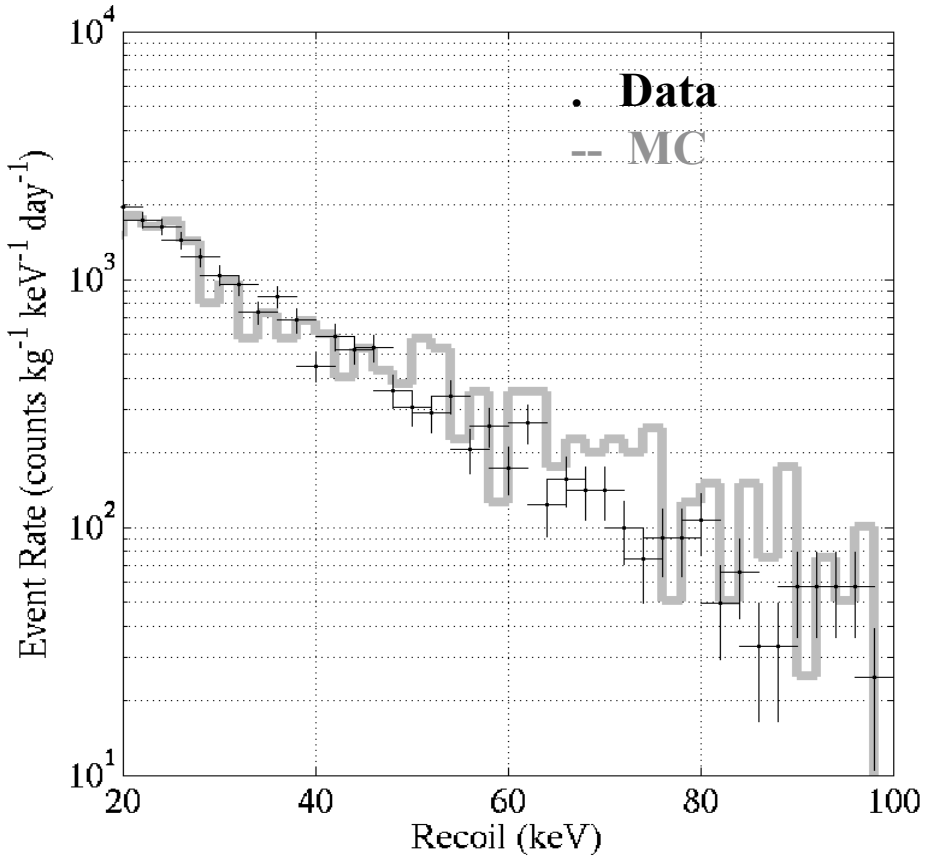


Phonon Energy [keV]

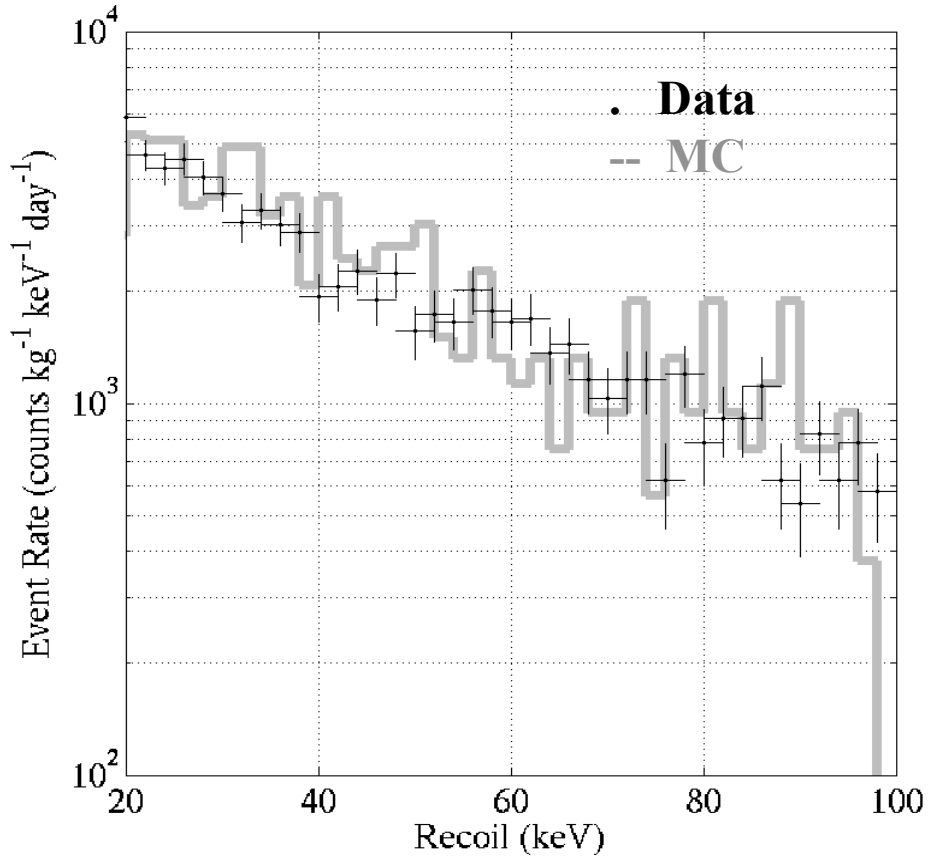
- Ba source (4 uCi), 60M events are collected during the period
- 100Hz detector read out performance
- Ba calibration gamma peak (356 keV) is used for absolute energy calibration

Neutron Calibration with ^{252}Cf

Nuclear recoils in Ge detector

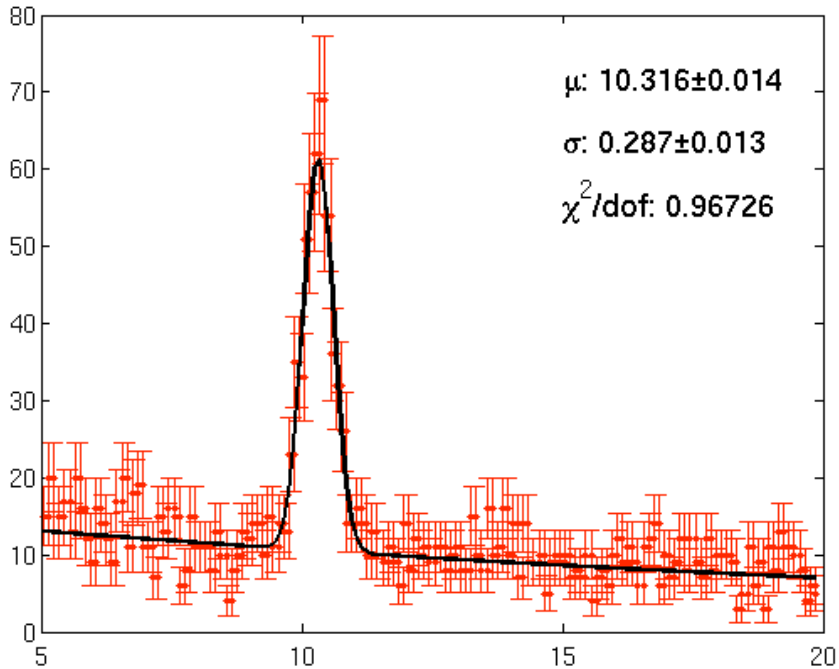


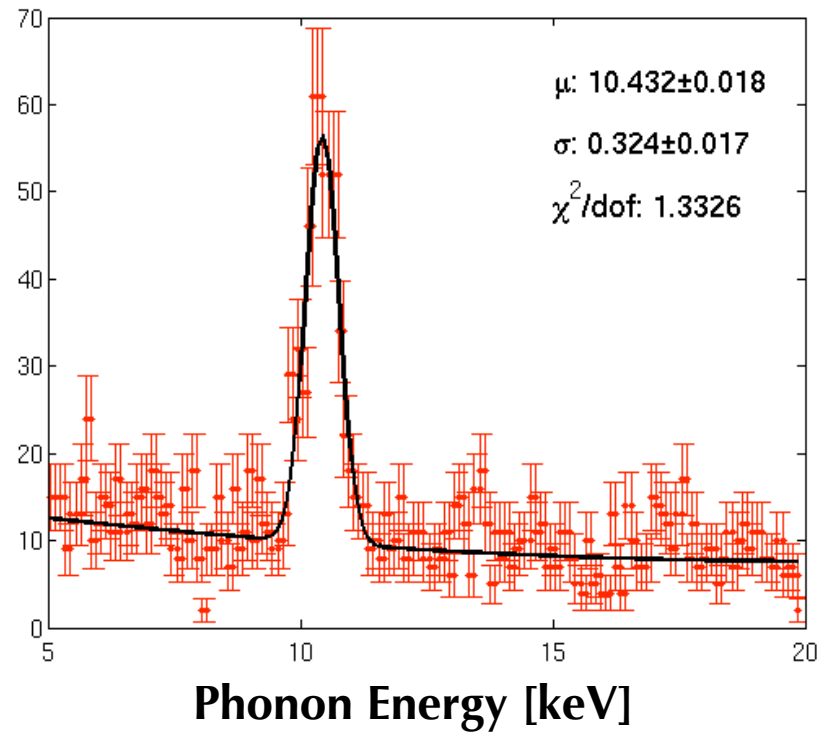
Nuclear recoils in Si detector



Excellent agreement between data and Monte Carlo
100K of neutron events are used to evaluate WIMP acceptance

10.4 keV Gamma



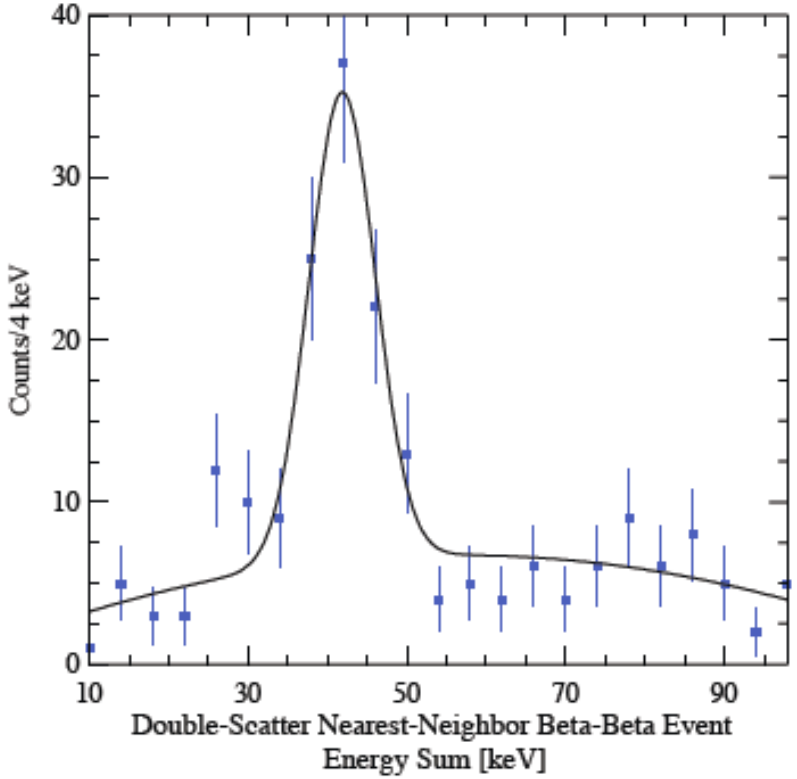


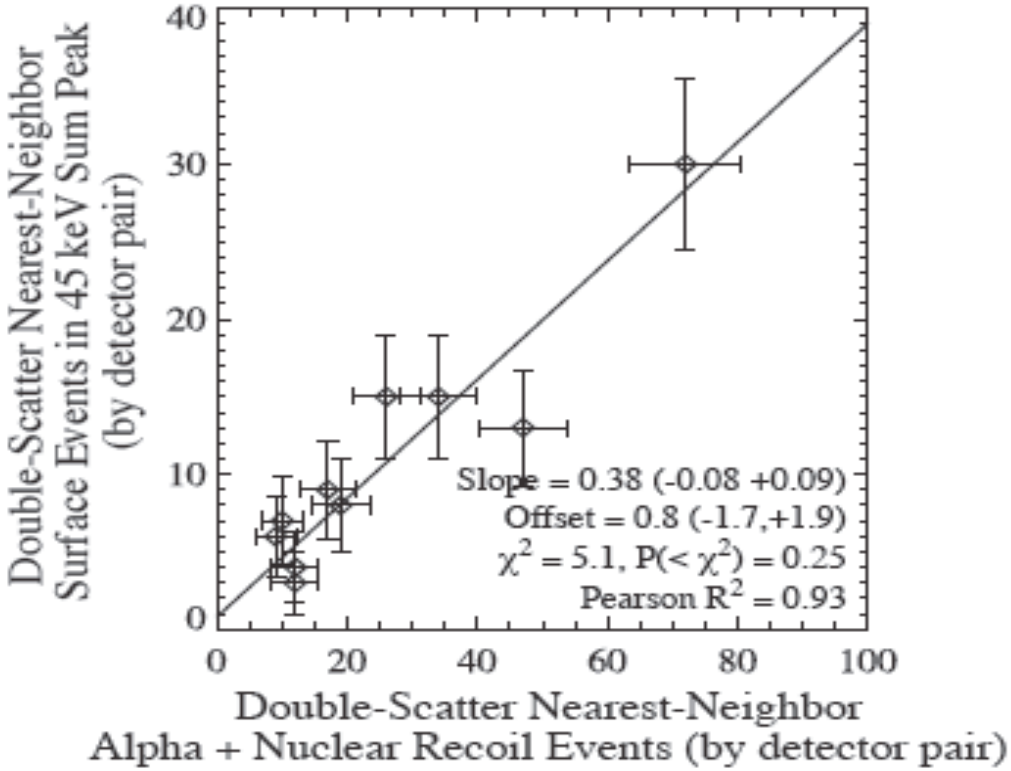
Neutron capture into ^{70}Ge during the Cf calibration
Excited ^{71}Ge emits gammas : 10.4 keV ($t_{1/2}$=11.4 days)

Very useful bulk gamma calibration source in the detector

Demonstrate ~ 5% of energy resolution in the region of interest : 10~100 [keV]

45.6 keV Beta and Alpha Rates





- ^{210}Pb decay ^{210}Bi* emits beta to be ^{210}Bi : combined energy 45.6 keV
- ^{210}Po decay ^{206}Pb emits 5.3MeV alpha counted on average ~0.4/detector/day

Betas and alphas show clear correlation : Later 3 towers have lower background

Data Processing and Analysis

- The data collected between : Oct. 2006 -- Jul. 2007 (R123 and R124)
- Data processing & reprocessing done at FermiGrid : Dec.2006 -- Oct.2007
- Huge efforts to confirm the data quality :

  15 Good Ge detectors are selected for WIMP search analysis

- 28M Ba calibration events are used for energy and position calibration

- WIMP signal region was determined using 0.6M neutron calibration data
- WIMP signal region masking done right after the data processing

  - Two separate WIMP search data sets were prepared

    : signal region masked data sets and unmasked data sets

  - Did not look at unmasked data sets until cuts frozen

Analysis Cuts

Data Reconstruction Quality

Charge pulse quality
Phonon pre-pulse baseline
Good phonon start time
Pick out negative phonon pulse amplitude
Bad detector region

Data Quality

Electric glitch select out
Cryocooler noise pickup
Detector cross-talks
Unusual detector bias events
Trigger burst period
High charge noise

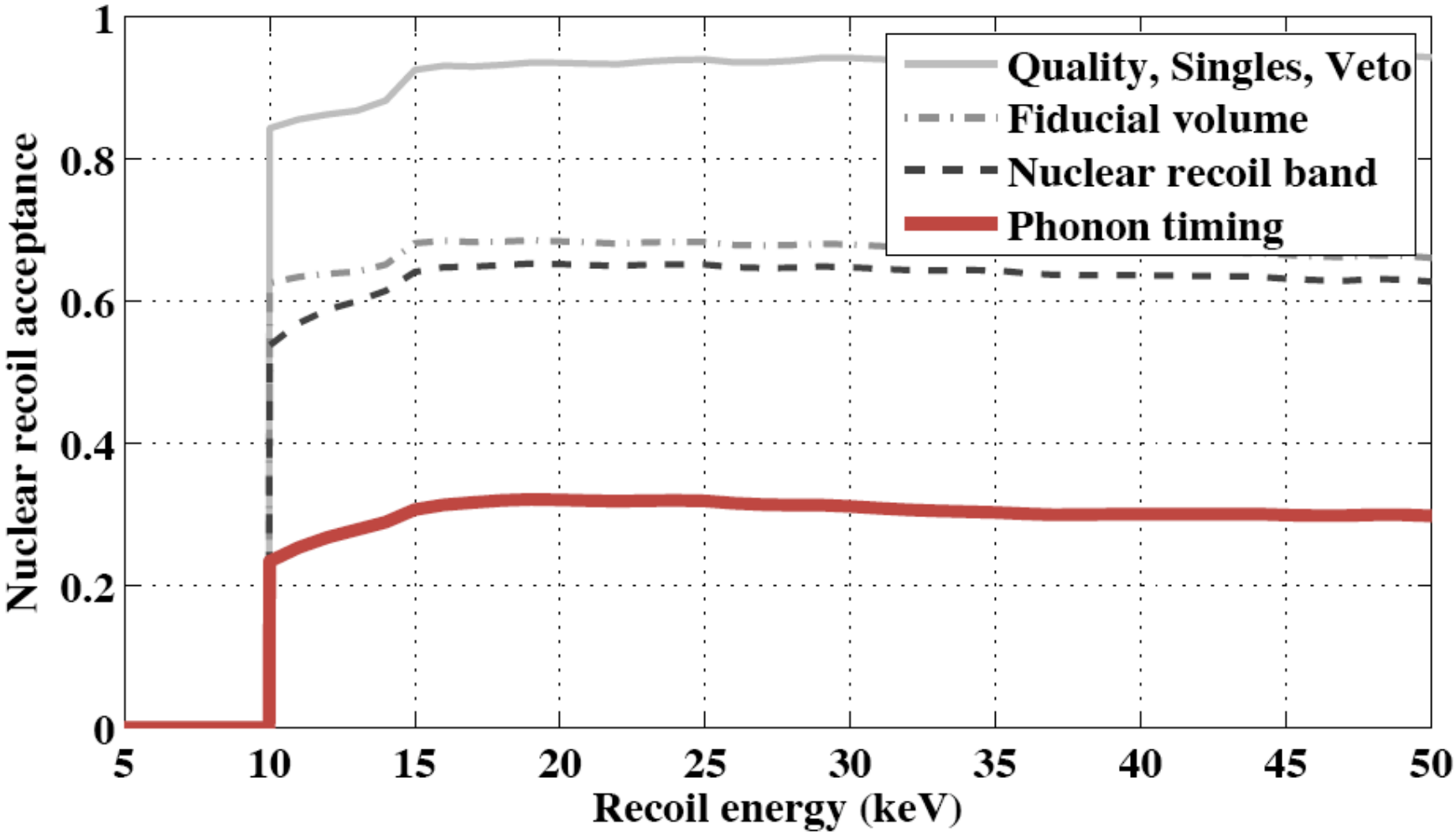
Event Selection

Charge energy threshold
Fiducial volume cut (~30%)
Nuclear Recoil Band Selection
Surface Beta Rejection (~30%)

Vetos

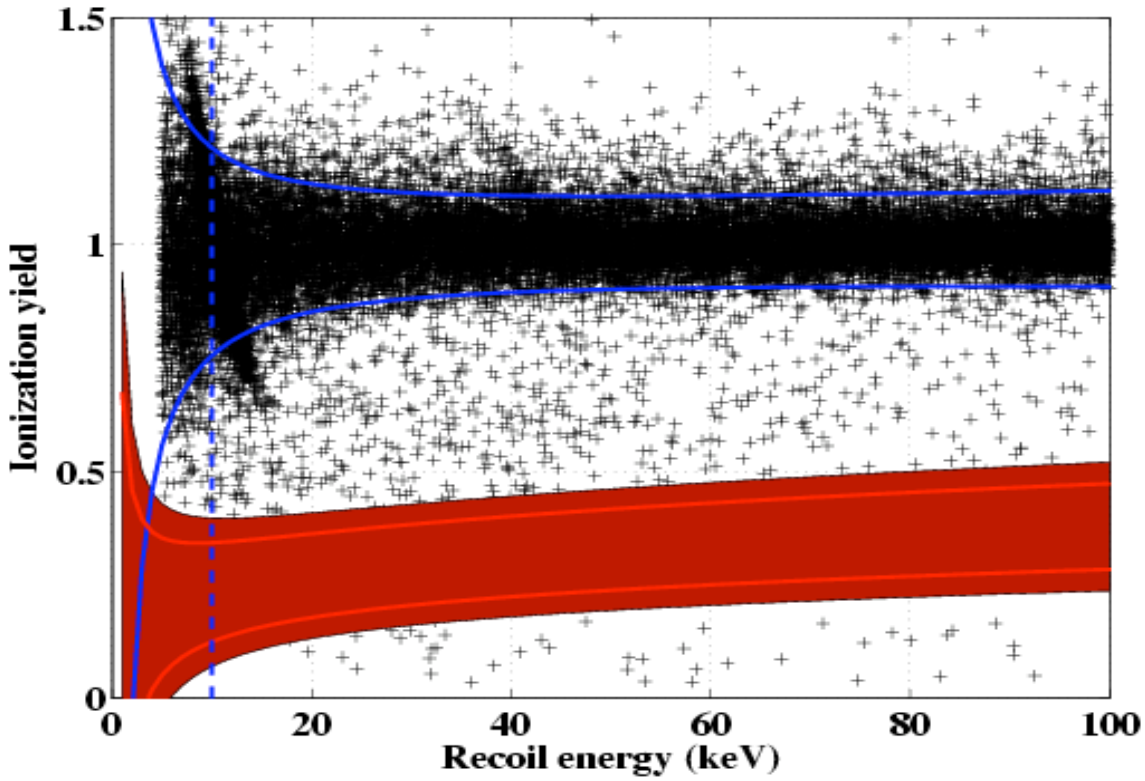
No significant veto hits before the trigger time
No NuMI beam coincident events : GPS time record

Cuts Efficiencies



All cuts set and frozen

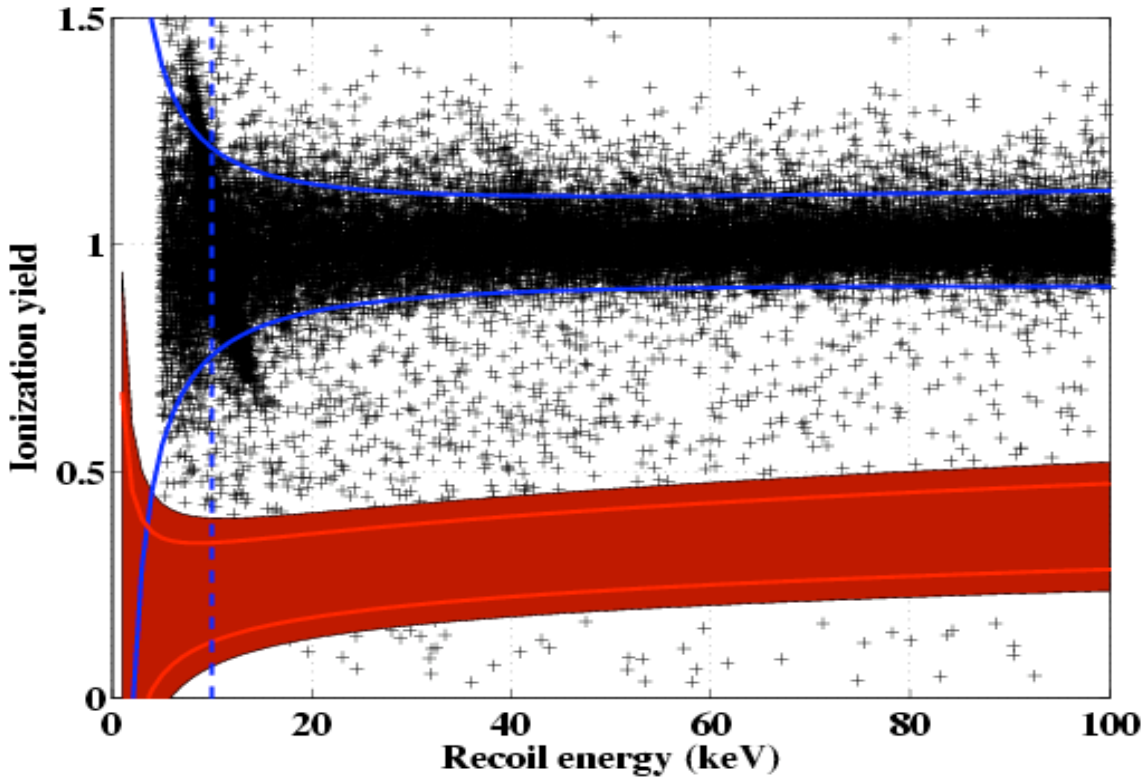
Blind Analysis



Blinding signal region

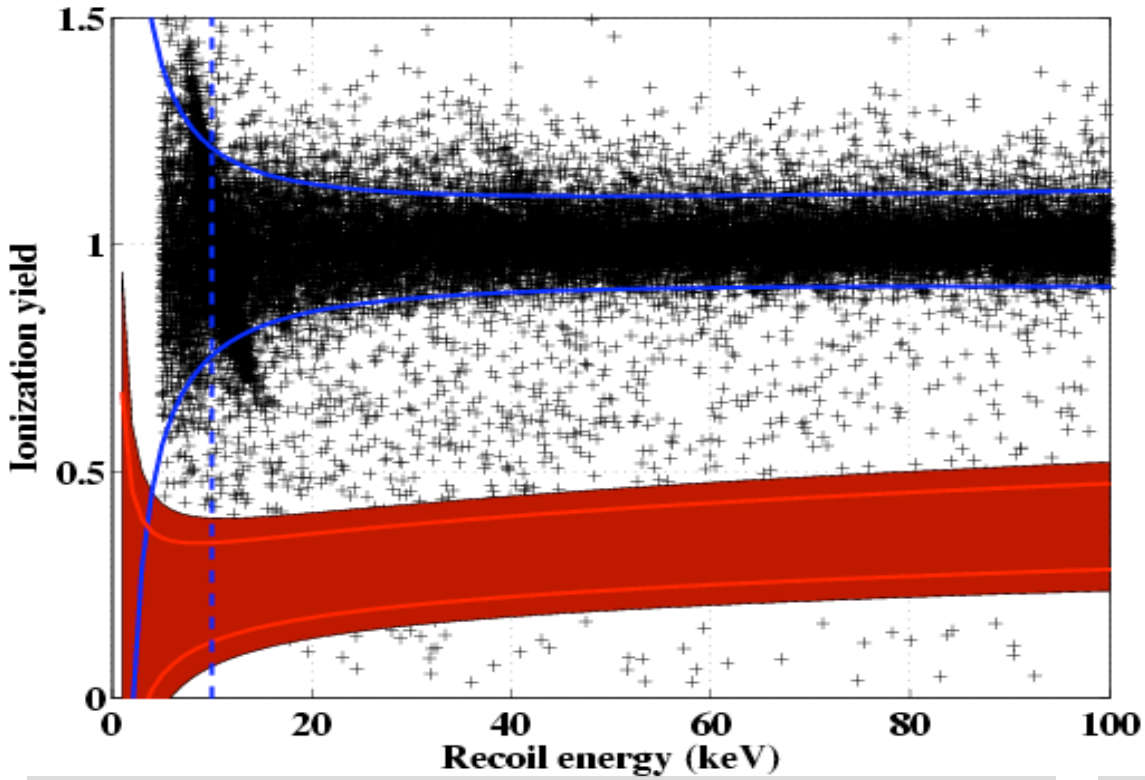
- Within fiducial volume : No signal in outer electrode
- In the nuclear recoil band
- Not a surface event : phonon timing parameter cut
- Single scatter

Gamma Background



Gammas :
> 10^6 rejection power

Neutron Background



Expected
Total neutron BG
< 0.2 event

Cosmogenic neutron background

8 vetoed nuclear recoil multiples observed
No vetoed single scatter event observed

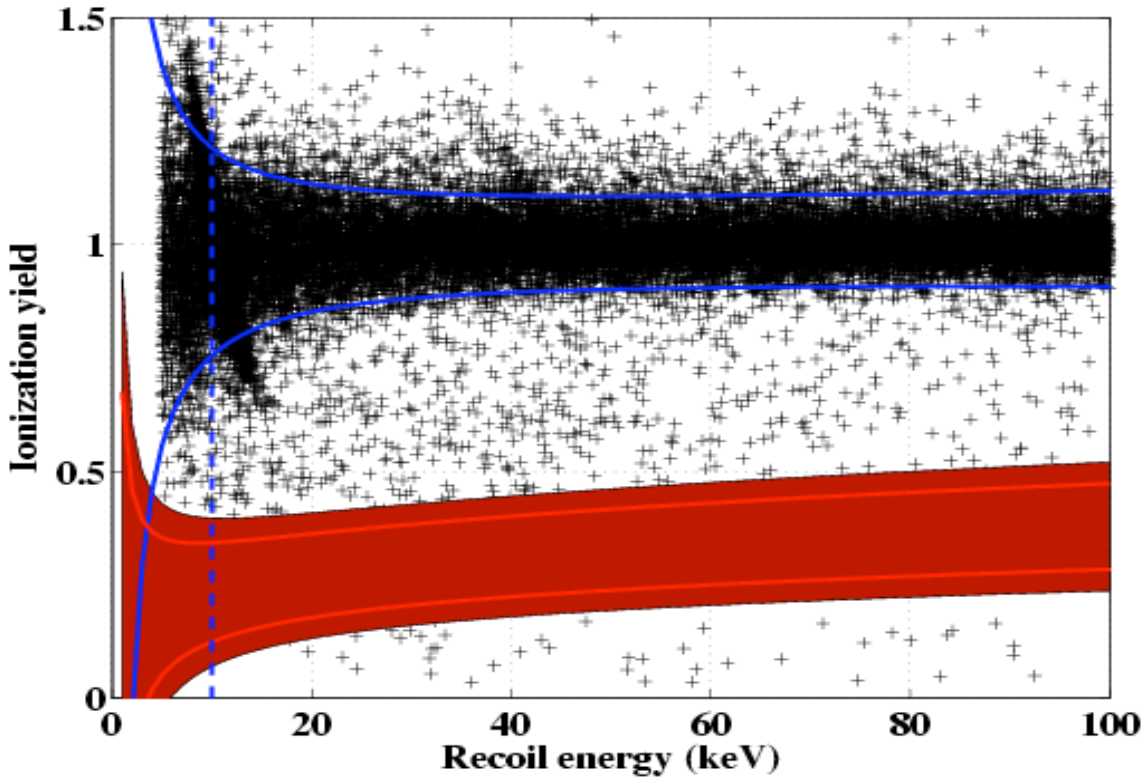
MC prediction

single/multiple ratio
vetoed/unvetoed ratio
Expect < 0.1 unvetoed neutron background

Neutrons from Radioisotope

< 0.1
from fission and (α,n)

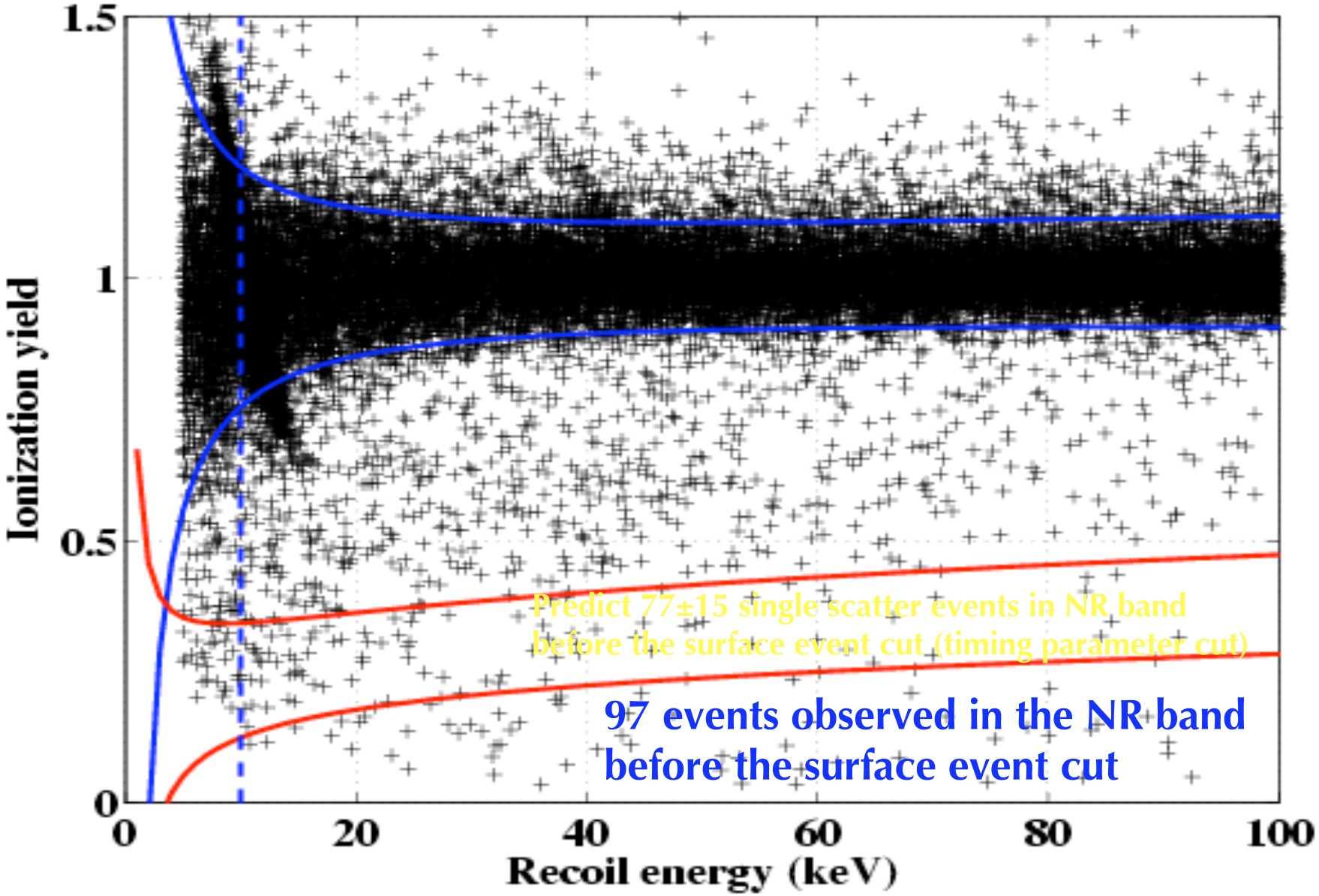
Electron Background



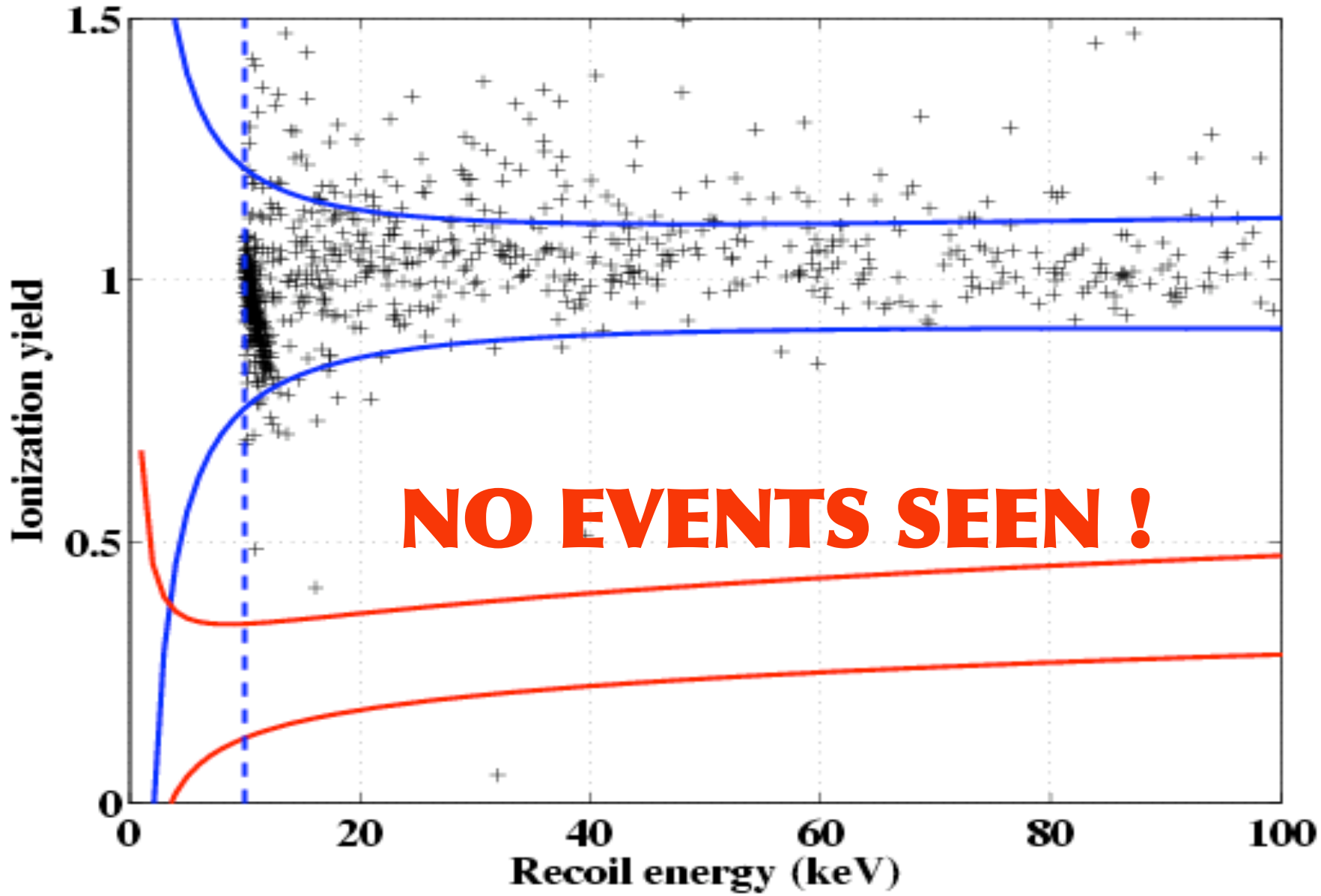
Expected Electron BG = 0.6 ± 0.5 events

- 300:1 Rejection is chosen on calibration Data
- 200:1 Rejection in WIMP side bands
- The difference dominated by differences in phonon/charge side rejection and beta energy spectrum in calibration
- Uncertainty on the electron background is conservative

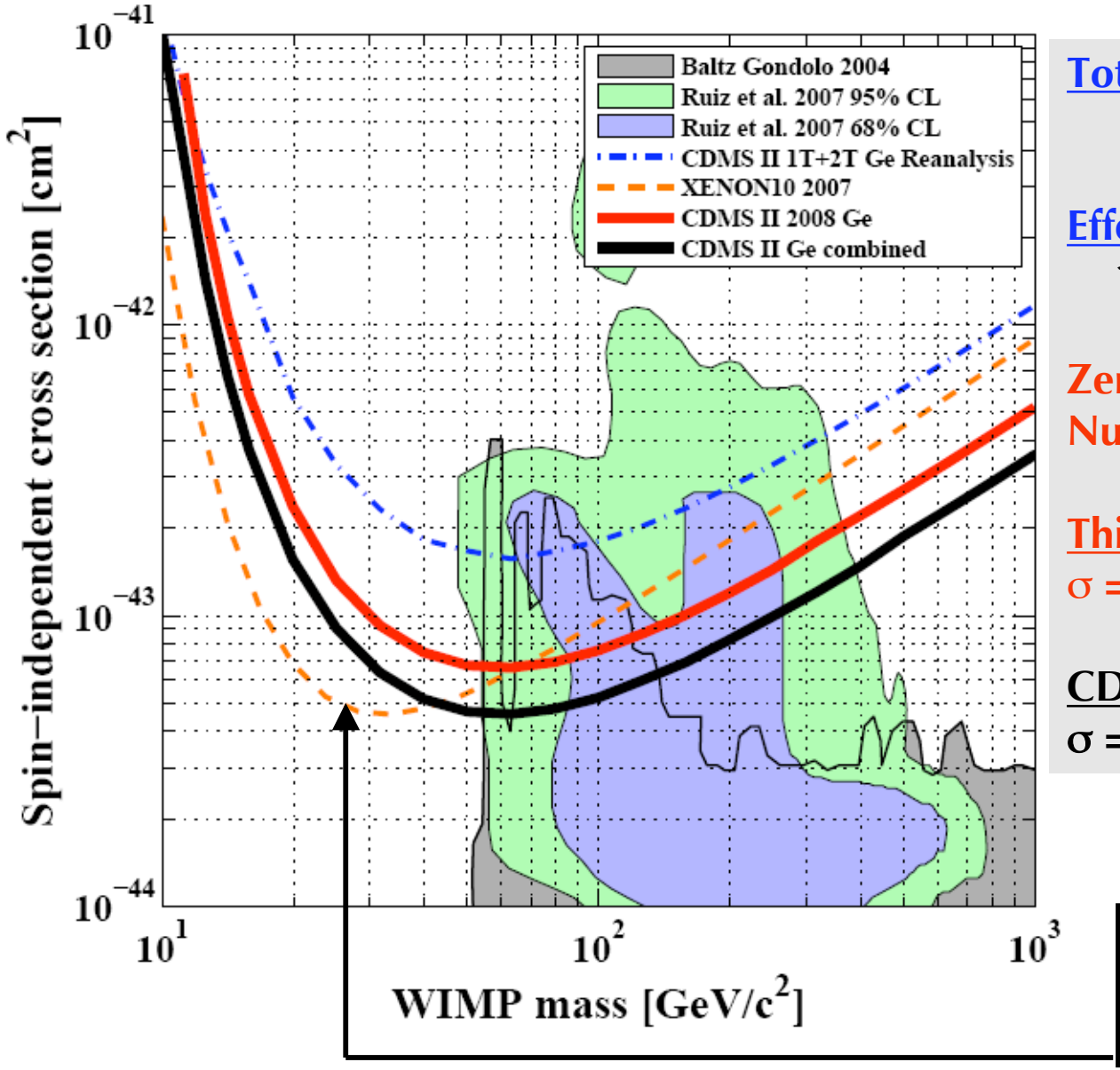
Ready to Open the Box



Final Cut


1.5
1
0.5
0
Ionization yield
0
20
40
60
80
100
Recoil energy (keV)
NO EVENTS SEEN !

Interpretation : Spin Independent Limit



Total Livetime (15 Ge detector)

397.8 kg-day

Effective Exposure (after cuts)

121.3 kg-day

Zero-Background !
Null-Observation !

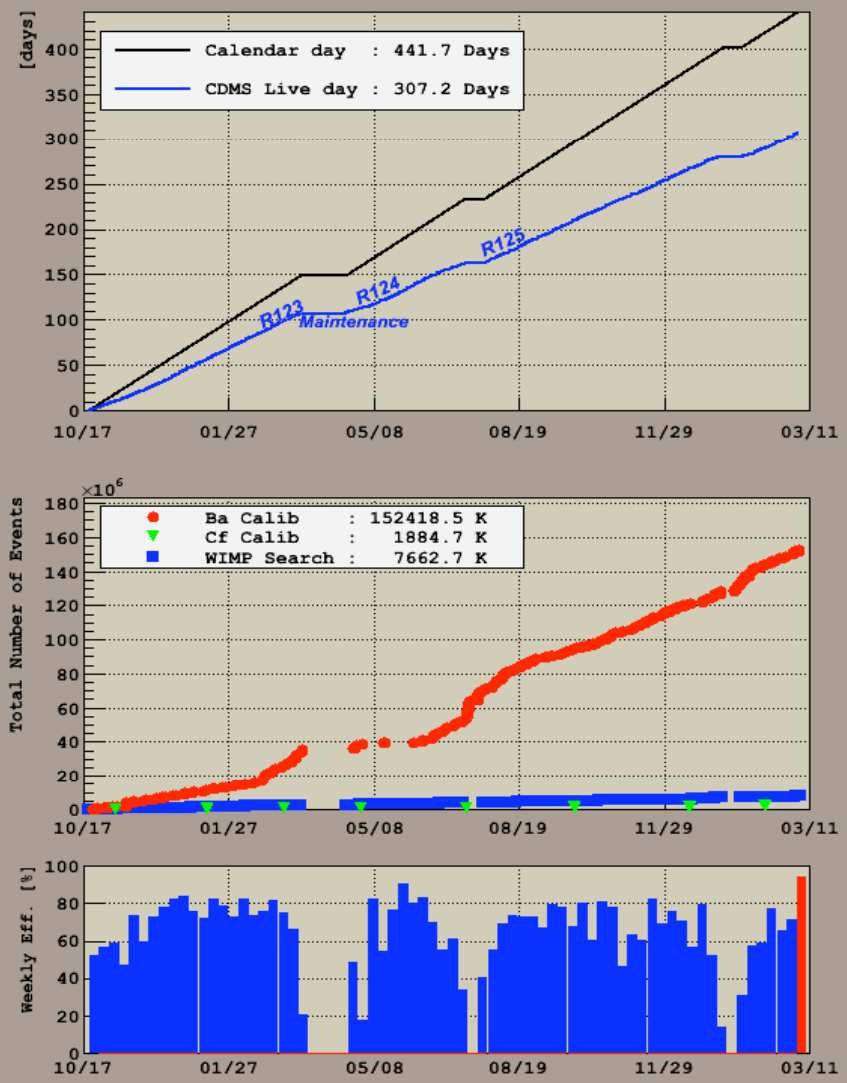
This Results (@60GeV)
$\sigma = 6.6 \times 10^{-44} cm^2$ (90%CL)

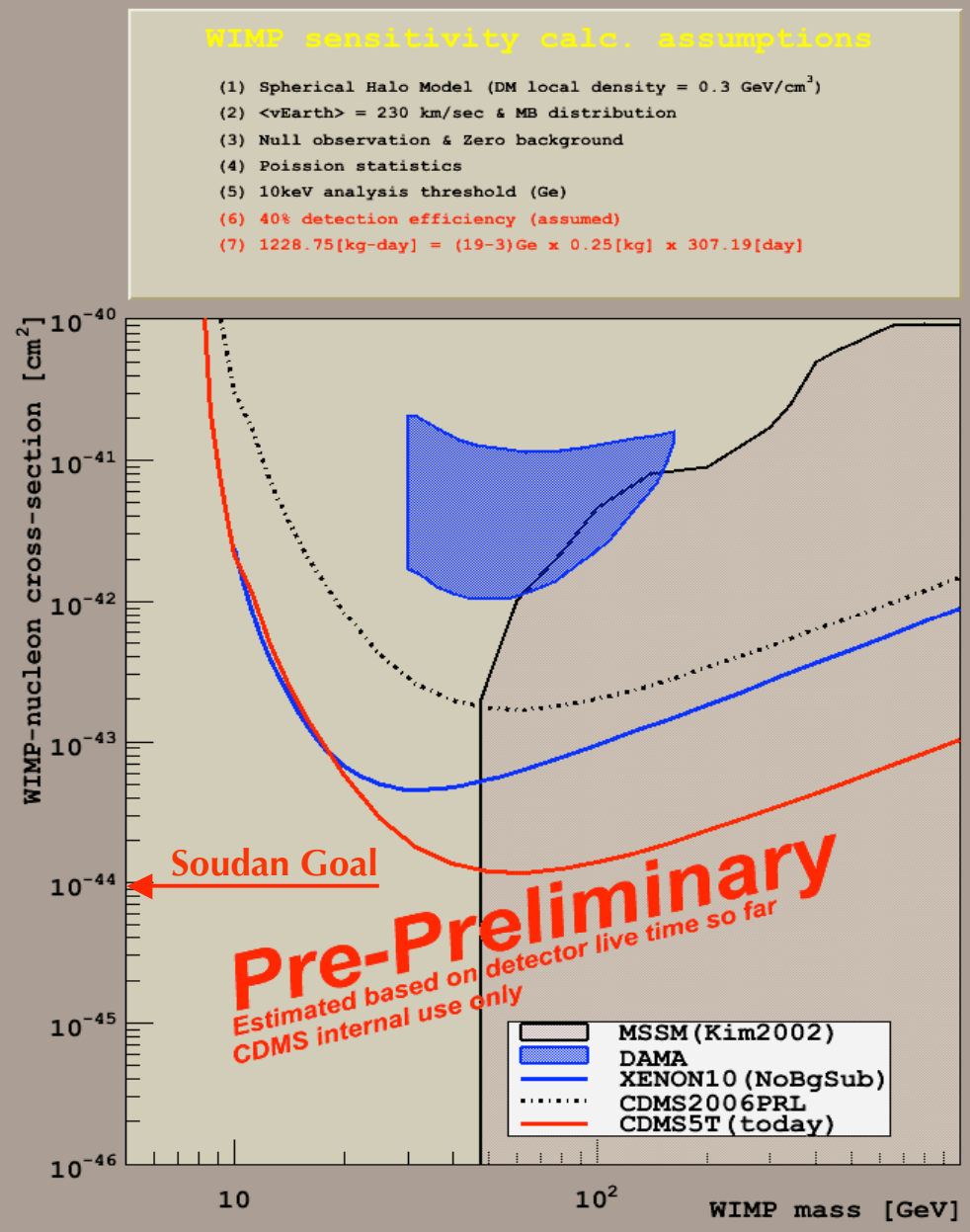
CDMS Combined (@60GeV)
$\sigma = 4.6 \times 10^{-44} cm^2$ (90%CL)

XENON10
Seen 10 events in signal band
with 7 expected BG

What's Next ?

Next Analysis Pipeline (WH6W)



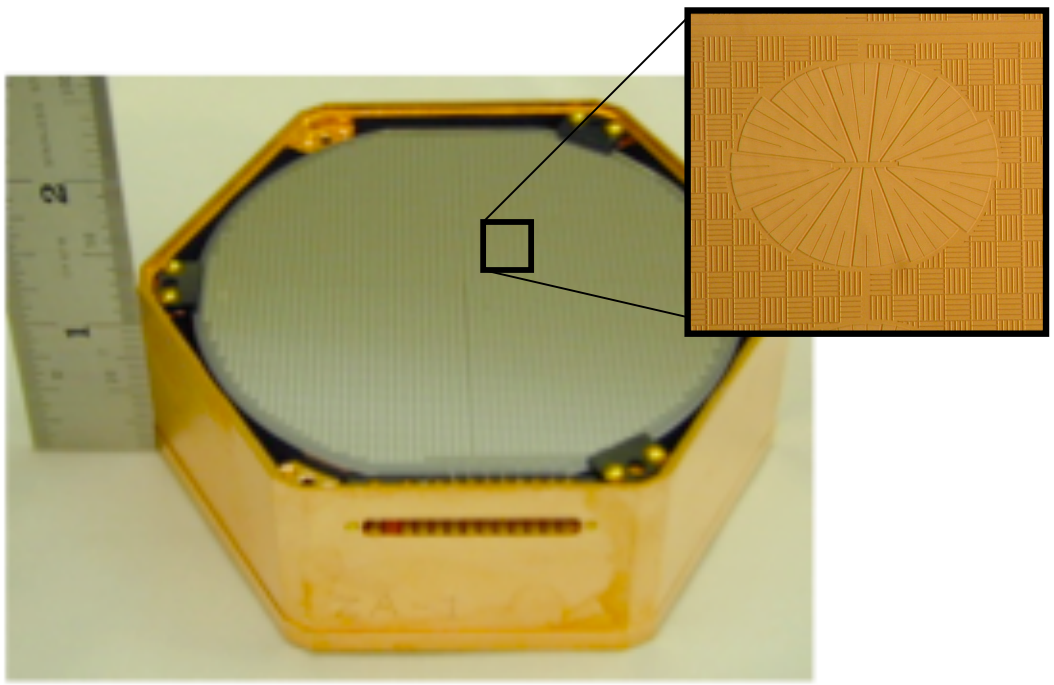


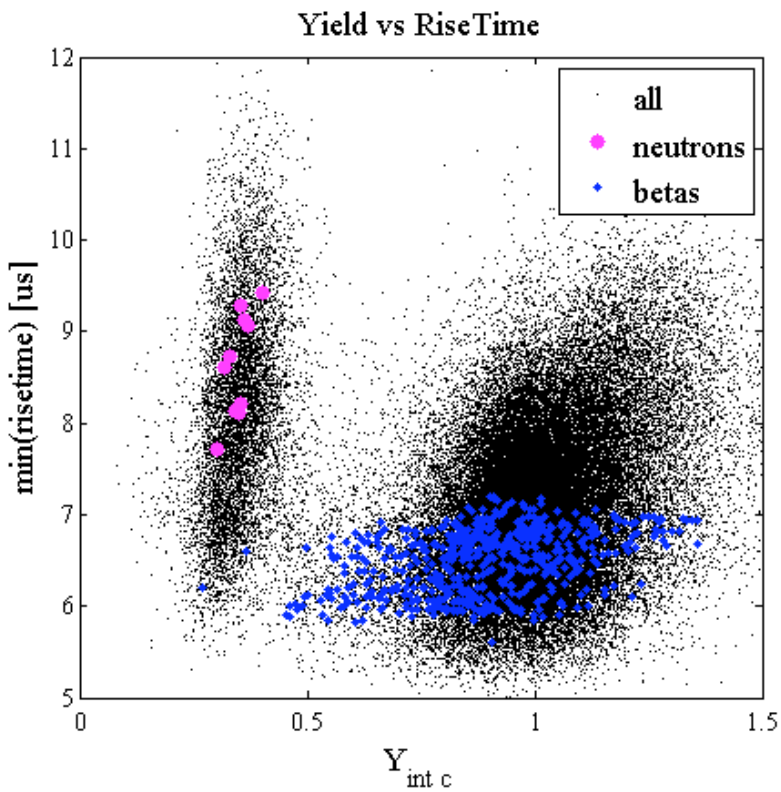
SuperCDMS

SuperCDMS @ Soudan (2009)

- 2 Super Tower + 3 Normal Tower @Soudan (2009)
  Super Detector (7 cm diameter x 1 inch thick : 600 g)

- Improved background rejection and reduction
  - Increase phonon collection area
  - H-a-Si electrodes to discriminate surface event better
  - Advanced analysis method
  - Better control of radioactive backgrounds

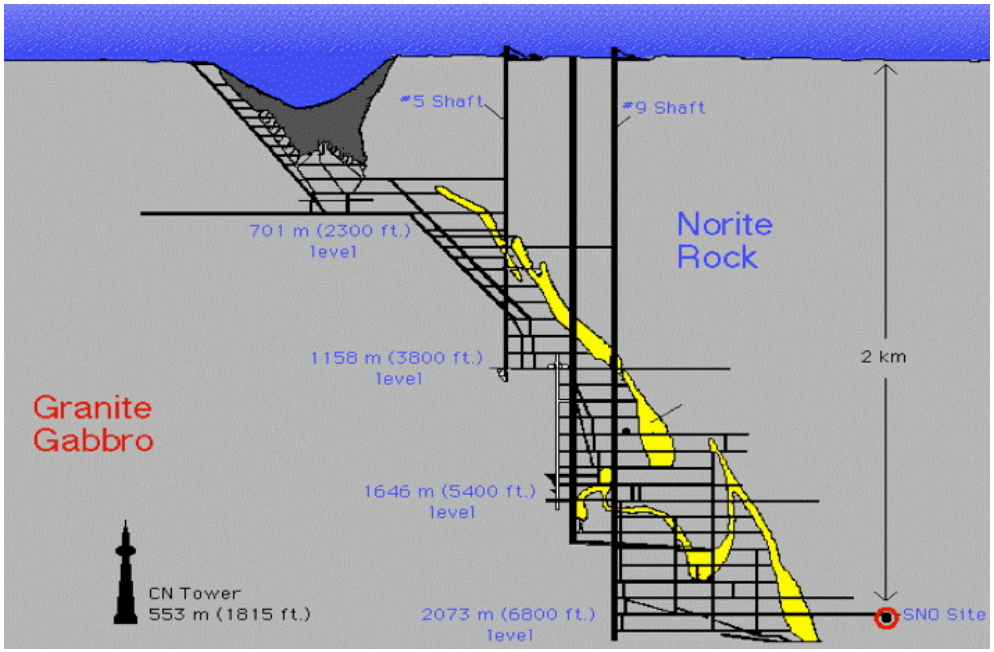


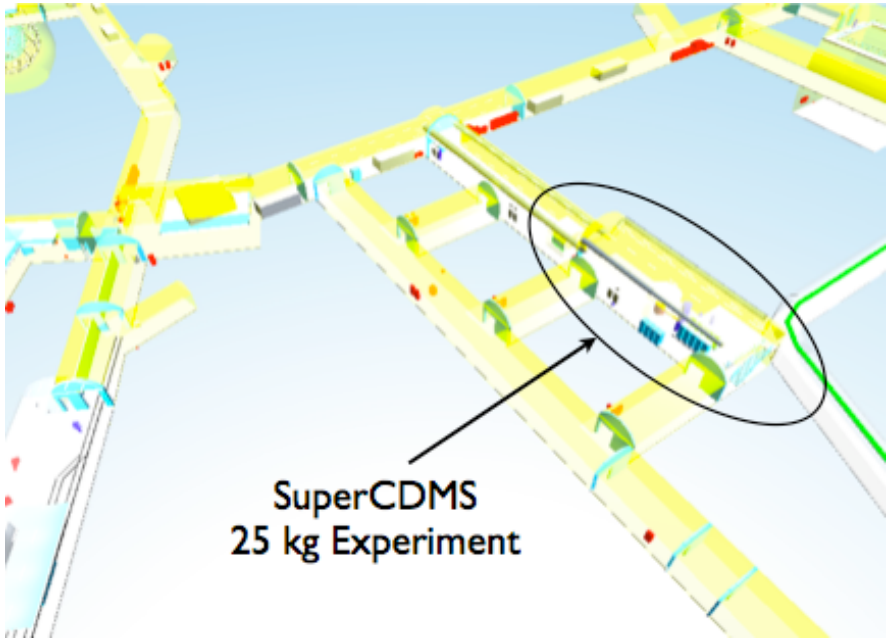


SuperCDMS @ SNOLab (2012)

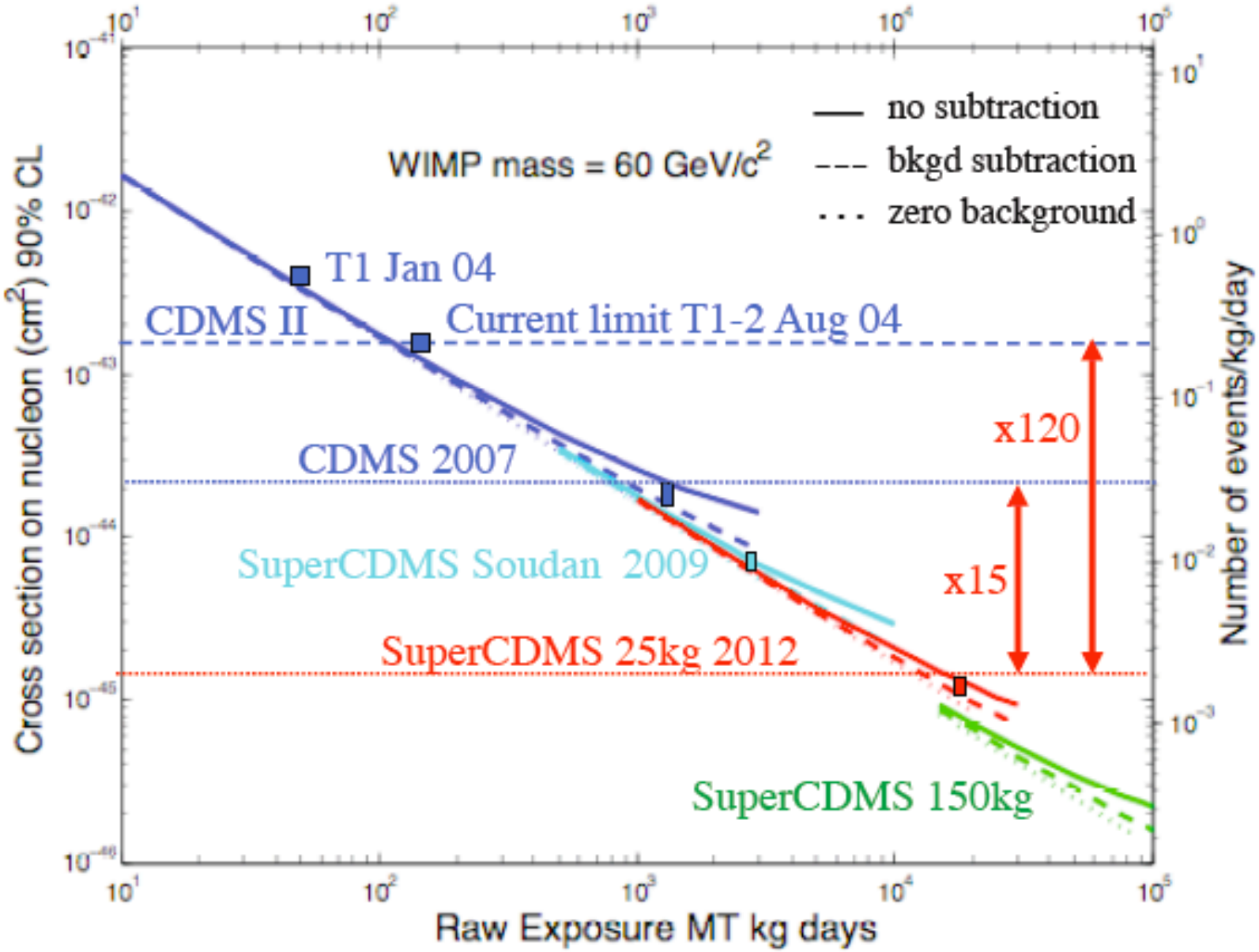
Proposed 25-kg experiment based on updated 42 x 600-g Ge ZIPs

- **Factor 120 beyond current limits**
- **15x beyond CDMS-II goal**
- **Approved for space at SNOLAB**



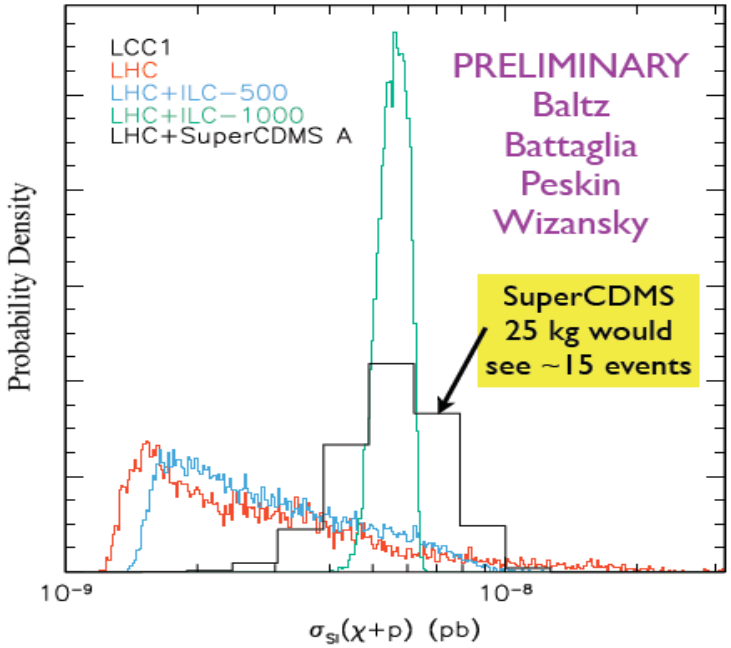


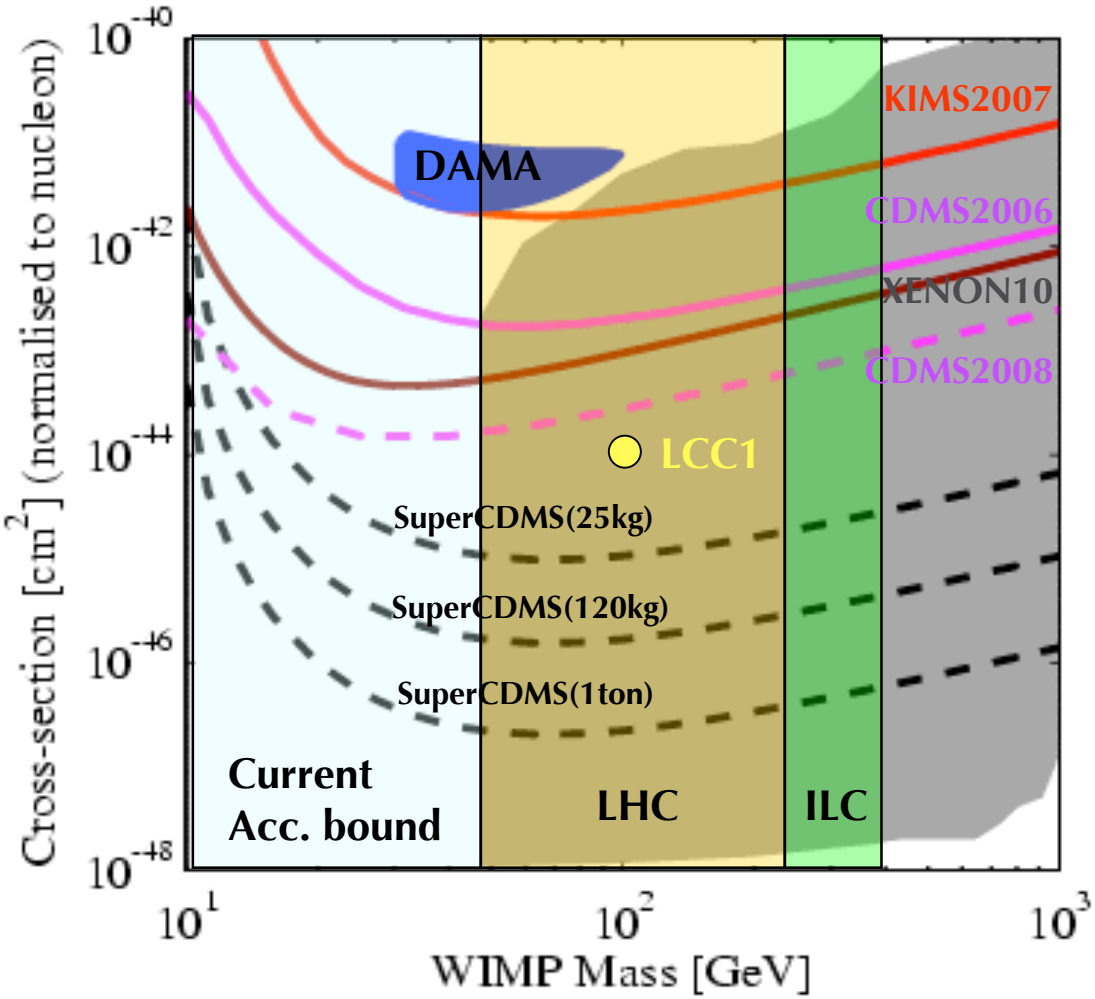
Zero Background



WIMPs in Colliders

Improved constraints on cross-section by combining collider measurements





Suppose LSPs are observed at LHC/ILC :

Those particles may not be a dark matter
and we don't know they are stable in cosmological time scale

Suppose Dark Matter observed at direct detection experiments :

The particle is not necessarily a SUSY or a Kaluza-Klein elements
The dark matter don't even need to have a weak force interaction

➔ **We strongly need both Colliders and Direct detection**

Summary

- <u>Bad News</u>
  There are no WIMPs above : $\sigma(SI) = 4.6\ (6.6) \times 10^{-44} cm^2$ (90%CL)
  Factor 3 more sensitive than our previous results

- <u>Good News</u>
  We still have zero background experiment
  It is the only direct detection experiment with less than 1 background

- Preprint ready to view : arxiv:0802.3530

- Open box for Si detectors is coming soon

No voice from WIMPs yet !

Dark Matter Music from CDMS

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