Dark Matter Search: Experiments

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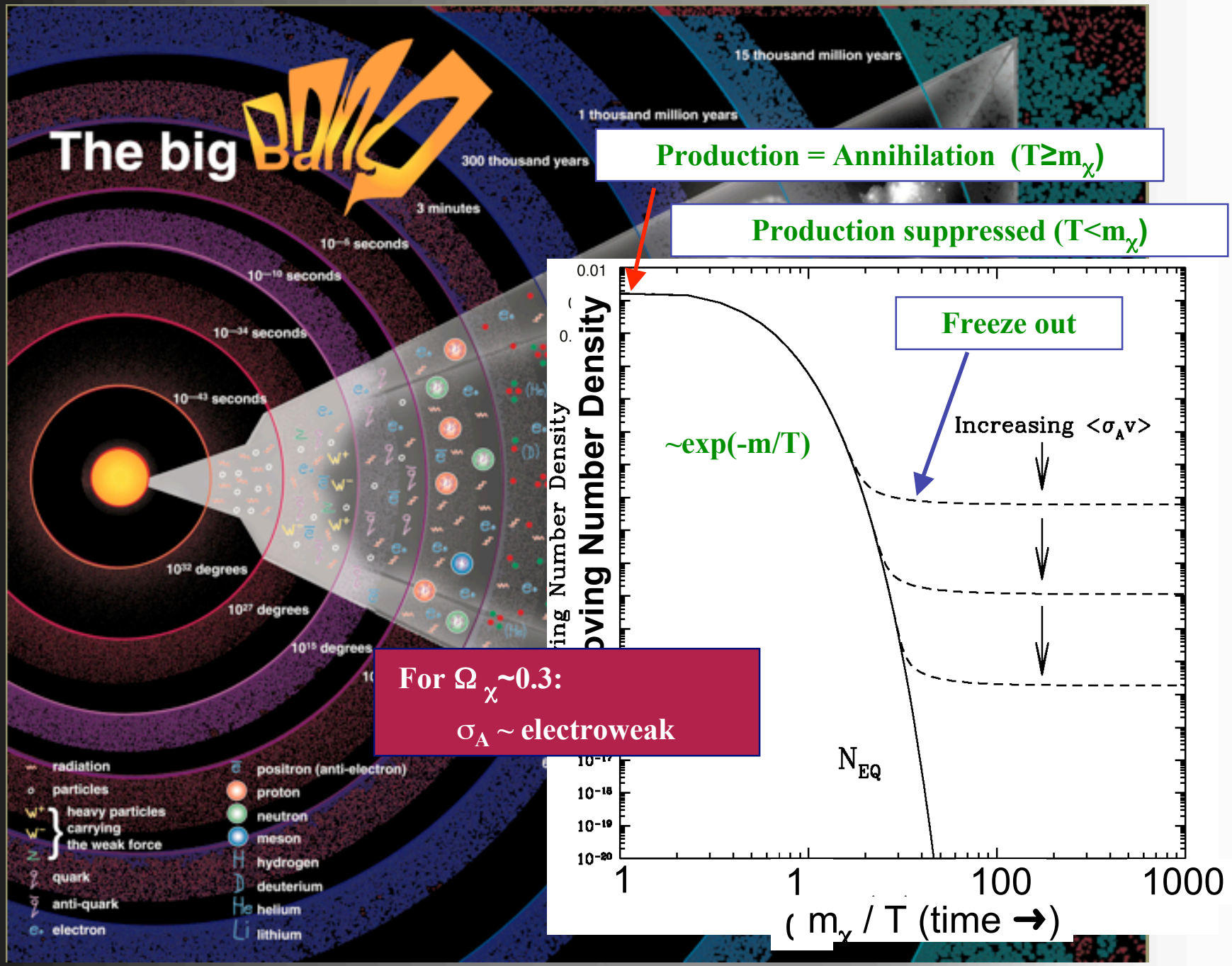
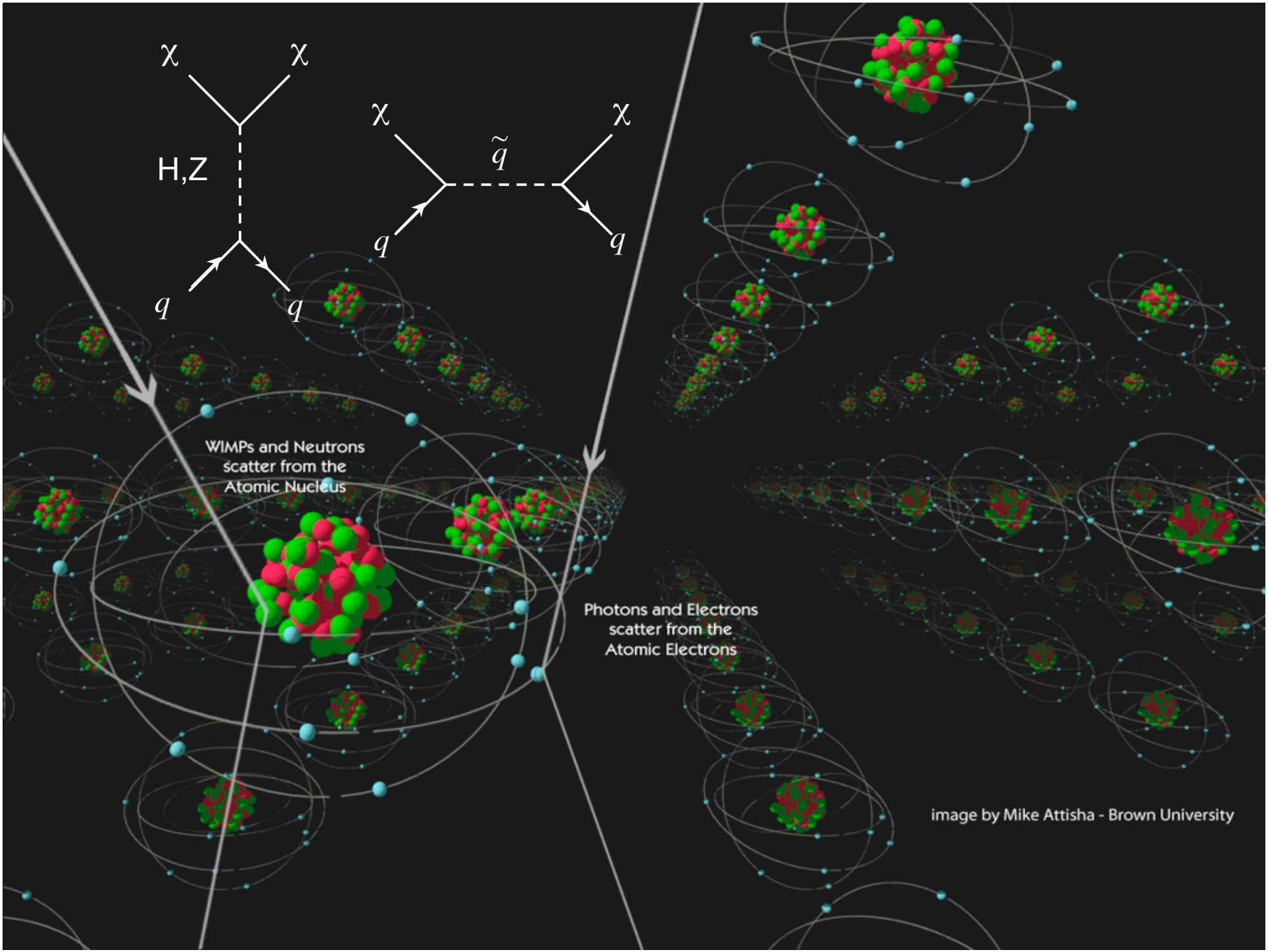
L'Observatoire de Paris, August 2007

- WIMPs: direct detection
- Experimental challenges
- Current experiments
- Future
- Conclusion

WIMP


The big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
10^{-6} seconds
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
10^{32} degrees
10^{27} degrees
10^{15} degrees
radiation
particles
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium
Production = Annihilation (T≥m_χ)
Production suppressed (T<m_χ)
Freeze out
Increasing <σ_Av>
~exp(-m/T)
N_{EQ}
0.01
10^{-18}
10^{-19}
10^{-20}
1
100
1000
(m_χ / T (time →)
For Ω_χ~0.3:
σ_A ~ electroweak


χ
χ
H,Z
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

Interaction rate (I)

$$\sigma_0 = \left(\frac{m_r}{m_{r-p}}\right)^2 A^2 \sigma_{\chi-p}$$

$$F^2(Q) = \left[\frac{3 j_1(qR_1)}{qR_1}\right]^2 \exp\left(-(qs)^2\right)$$

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{\sqrt{\pi} v_0 m_\chi m_r^2} F^2(Q) T(Q)$$

$$m_r = \frac{m_\chi m_N}{m_\chi + m_N}$$

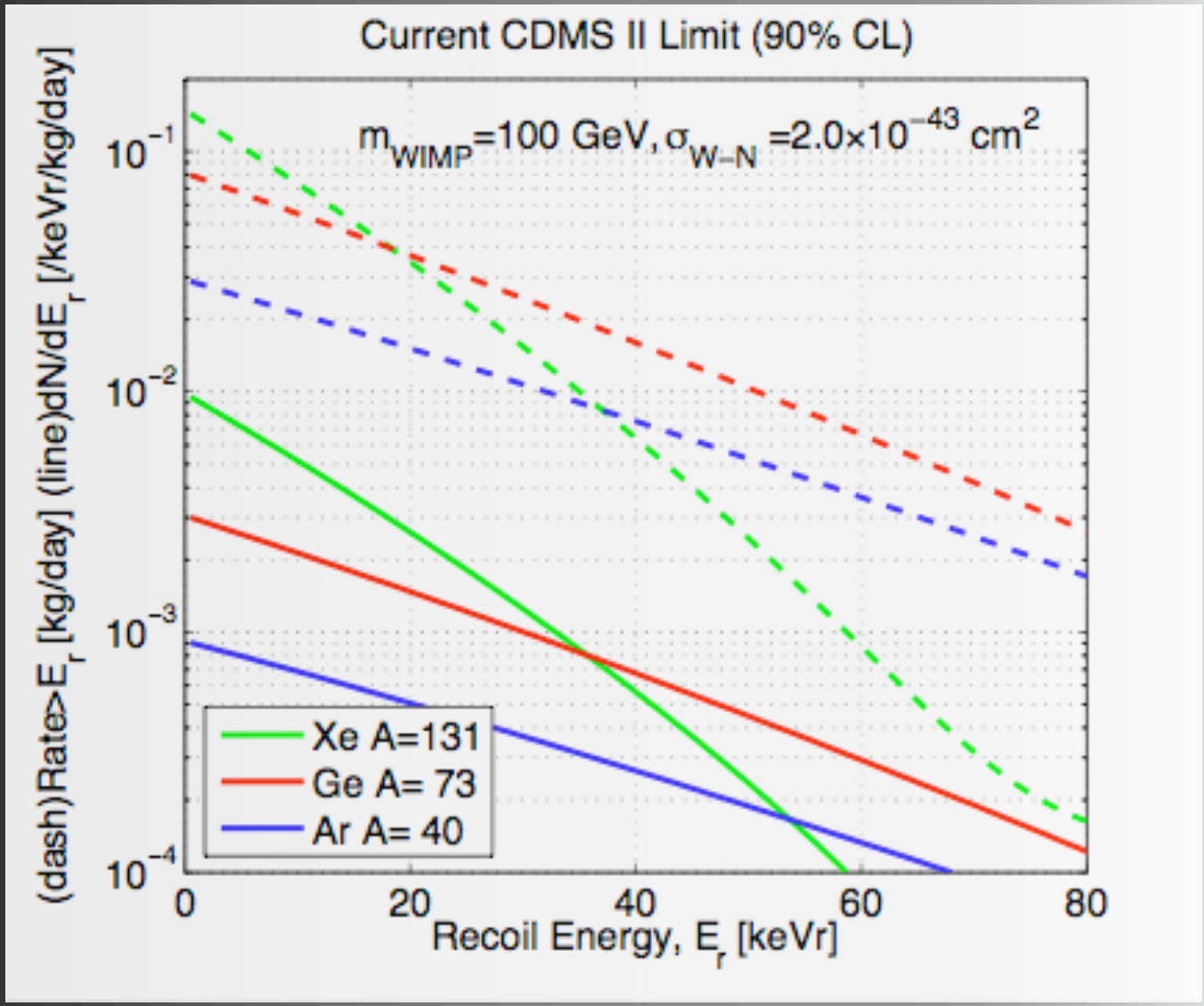
$$m_{r-p} = \frac{m_\chi m_p}{m_\chi + m_p}$$

$$T(Q) = \exp\left(-v_{min}^2 / v_0^2\right)$$

$$v_{min} = \sqrt{\frac{E_R m_N}{2 m_r^2}}$$

$$v_0 \approx 220\,\mathrm{km/s}$$

Interaction rate (II)

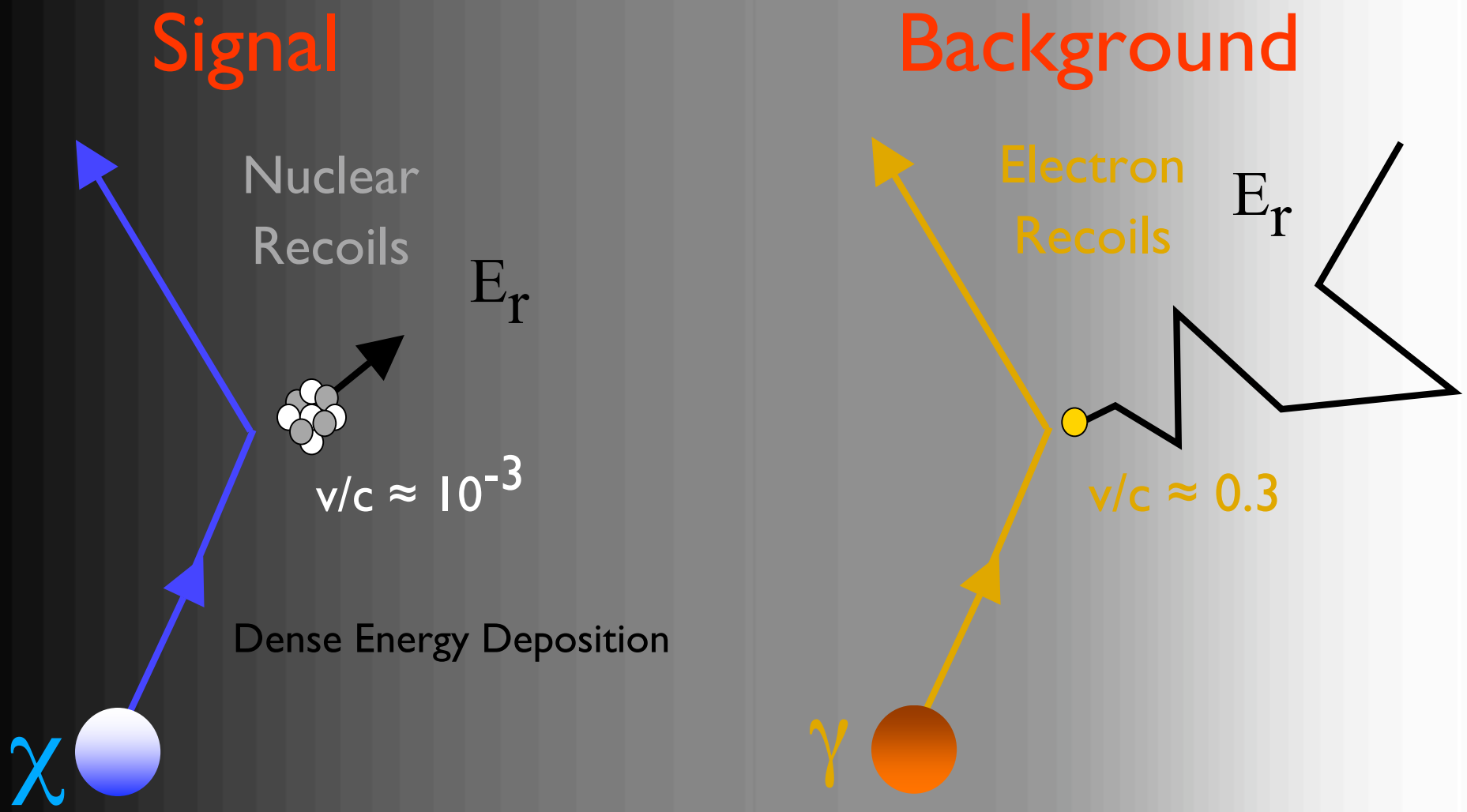


Background rates

- Search sensitivity (low energy region <<100 keV)
  - ❑ Current Exp Limit ~< 10^{-2} evt/kg/day
  - ❑ Goal < 1 evt/tonne/year, ~< 10^{-3} to 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 easily reduced to ~10^2 evt/kg/day using 25 cm of Pb

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

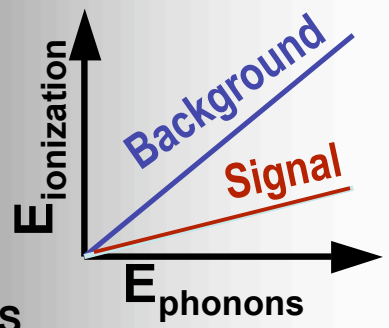
Event-by-Event discrimination (I)

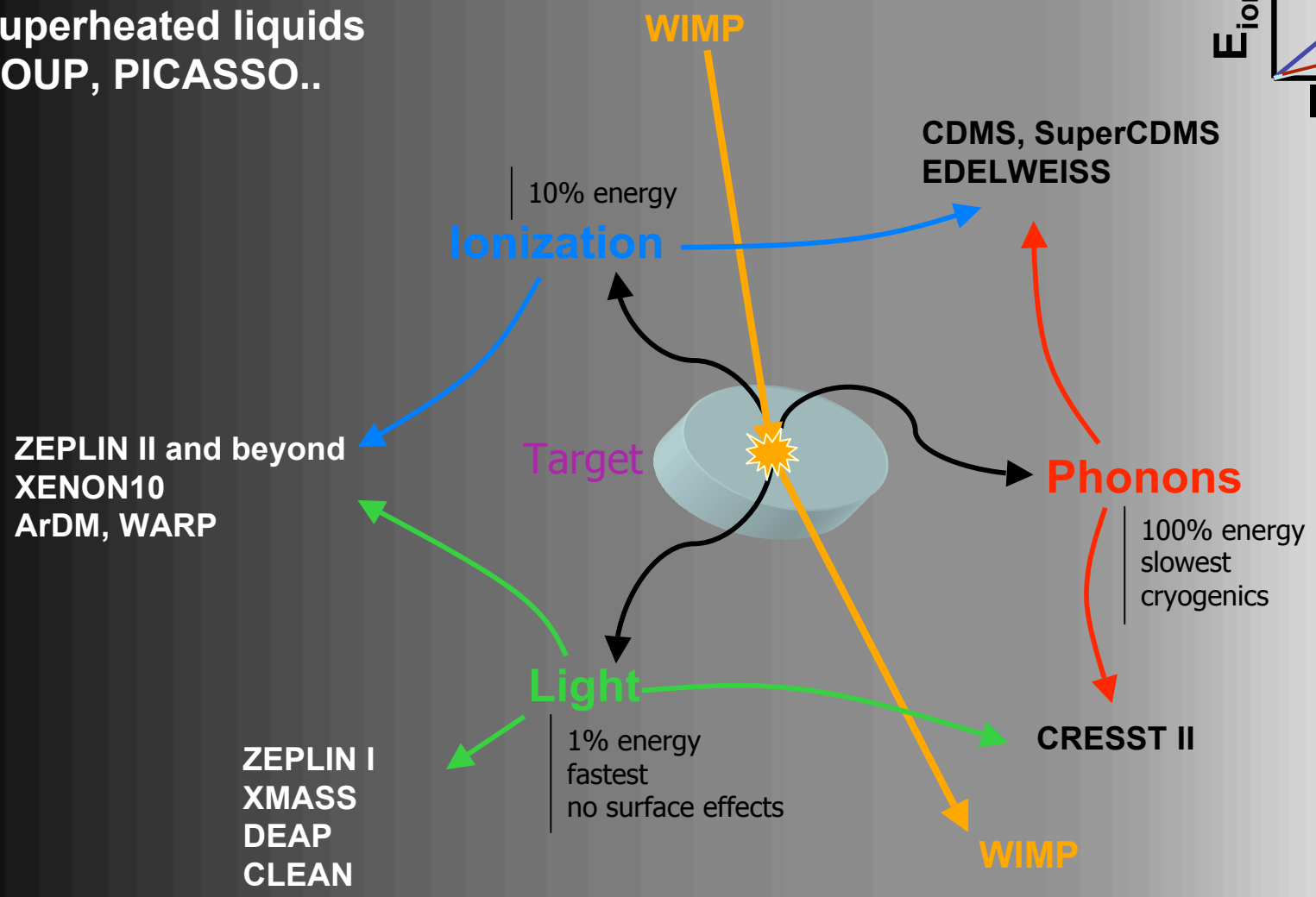


Density/Sparsity: Basis of Discrimination

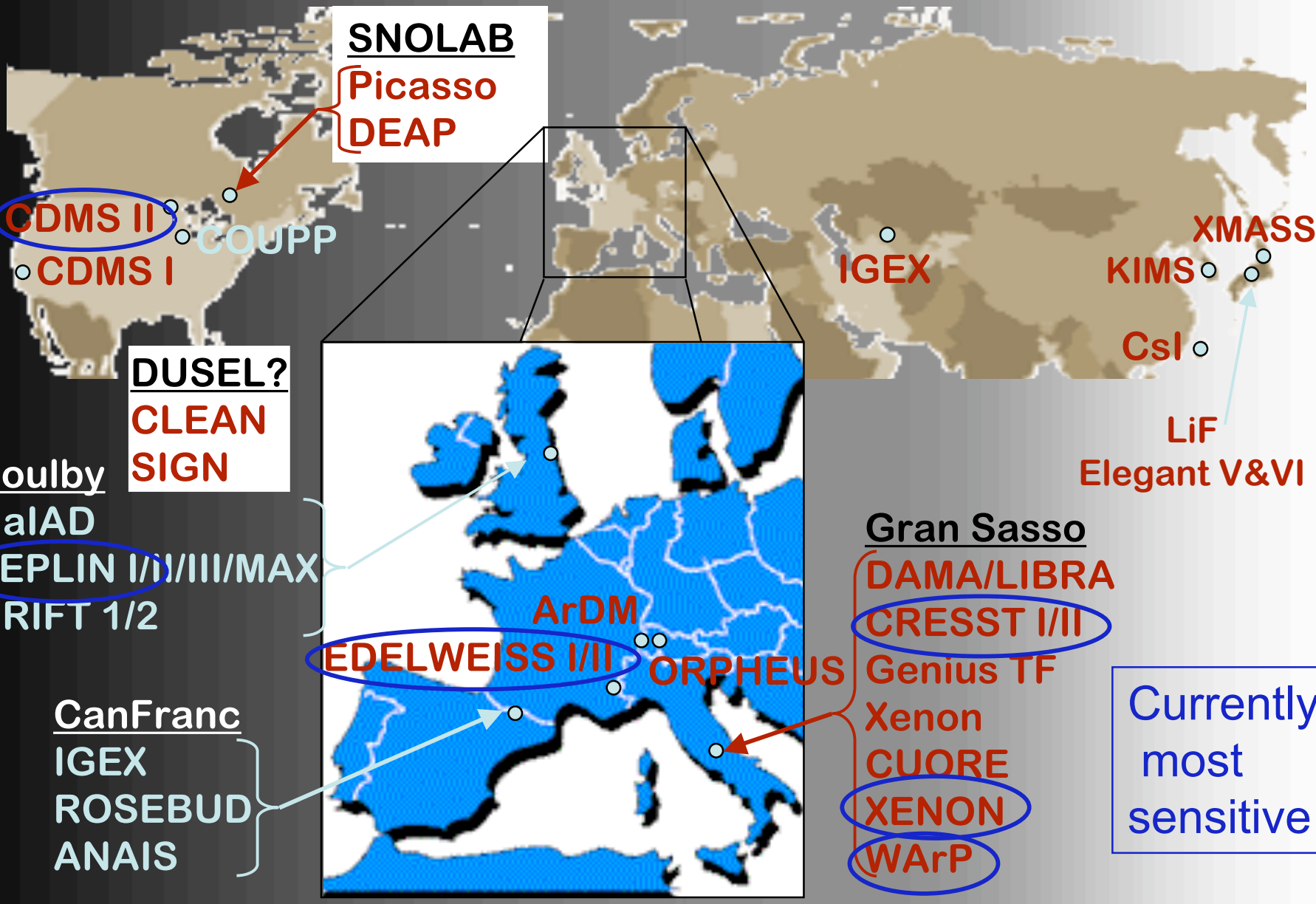
Event-by-Event discrimination (II)

Also threshold experiment:
Superheated liquids
COUP, PICASSO..



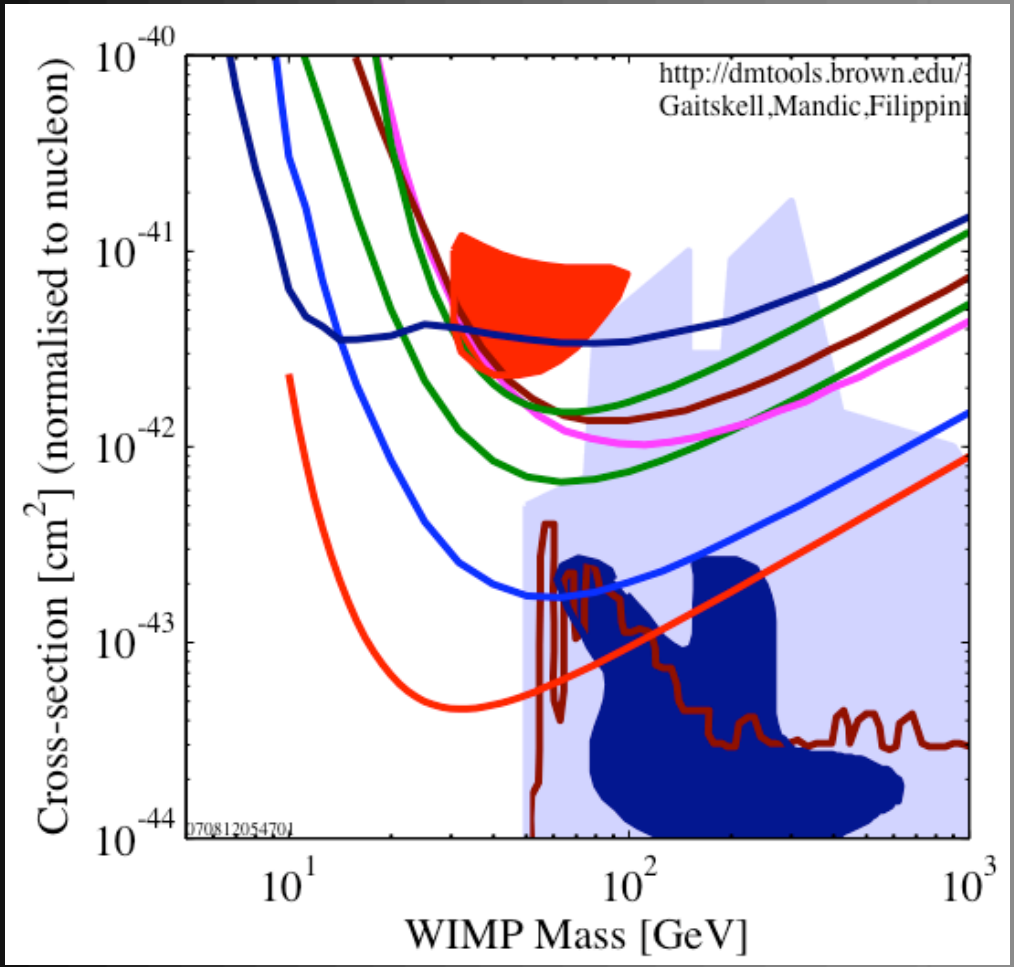


WIMP-detection Experiments Worldwide



Current status: No WIMPs

Sensitivity race



CDMS II SUF 2000

CRESST 2004 10.7 kg-day CaWO4

Edelweiss I final limit, 62 kg-days
Ge 2000+2002+2003 limit

WARP 2.3L, 96.5 kg-days
55 keV threshold

ZEPLIN II (Jan 2007) result

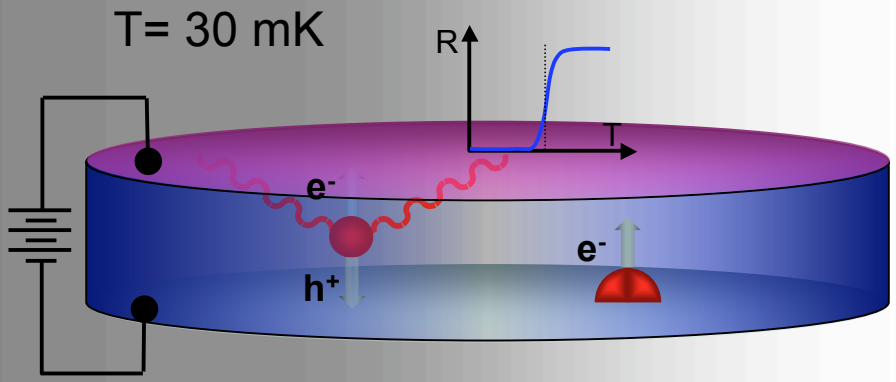
CDMS (Soudan) 2004 + 2005 Ge
(7 keV threshold)

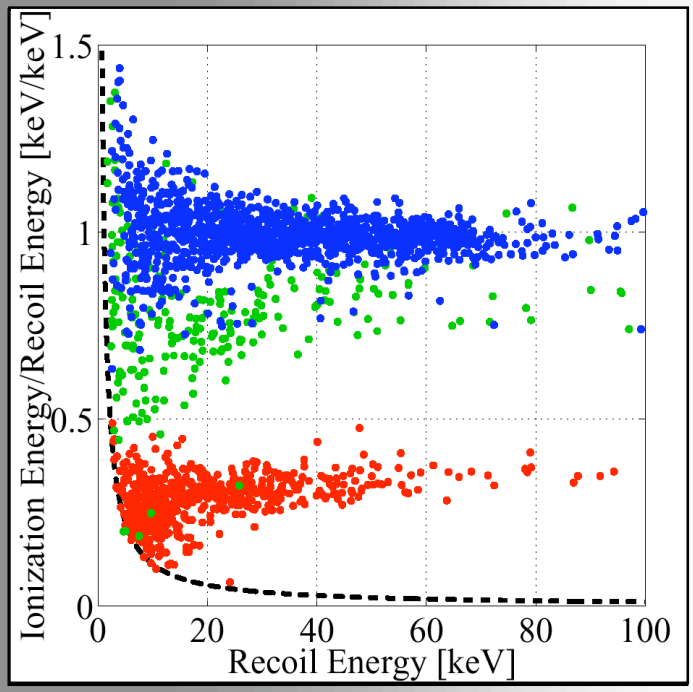
XENON10 2007 (Net 136 kg-d)

CDMS: 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

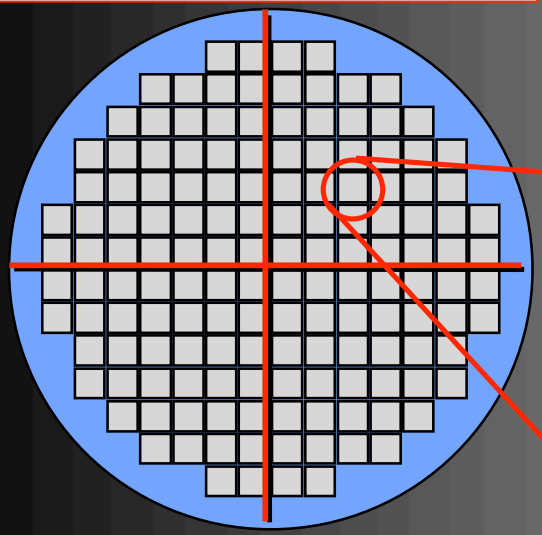
- CDMS solution:
- Catch and measure the phonons before they reach thermal equilibrium (athermal phonons)
- Reconstruct the position of the events in addition to energy



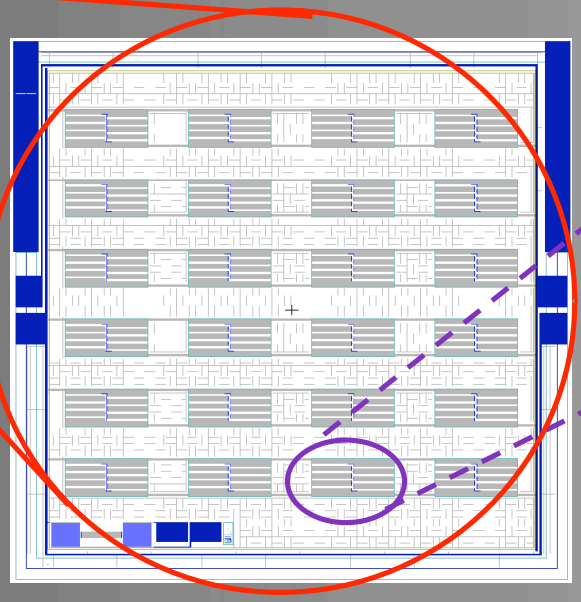


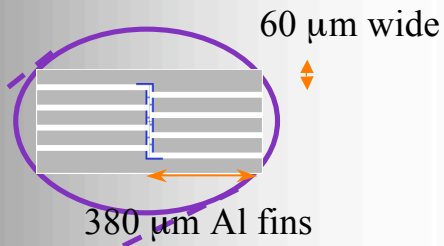
Z-sensitive Ionization Phonon detectors: ZIPs

Detectors
- 250 g Ge or 100 g Si crystal
- 1 cm thick x 7.5 cm diameter



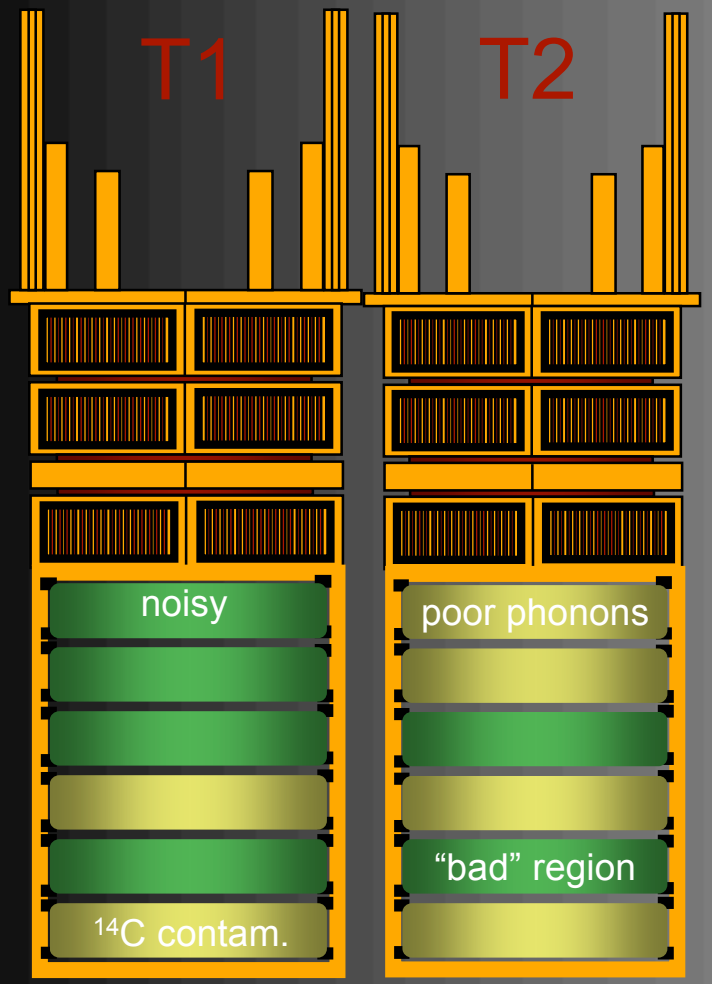
Phonon Sensors
- Photolithographic patterning
- 4 quadrants
- 37 cells per quadrant
- 6x4 array of 250μm x 1μm W TES per cell
- Each W sensor "fed" by 8 Al fins

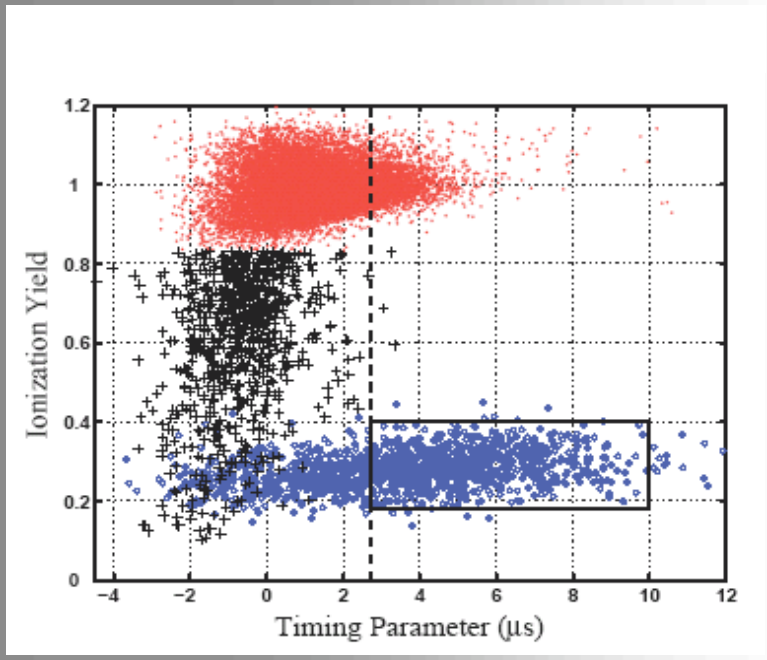


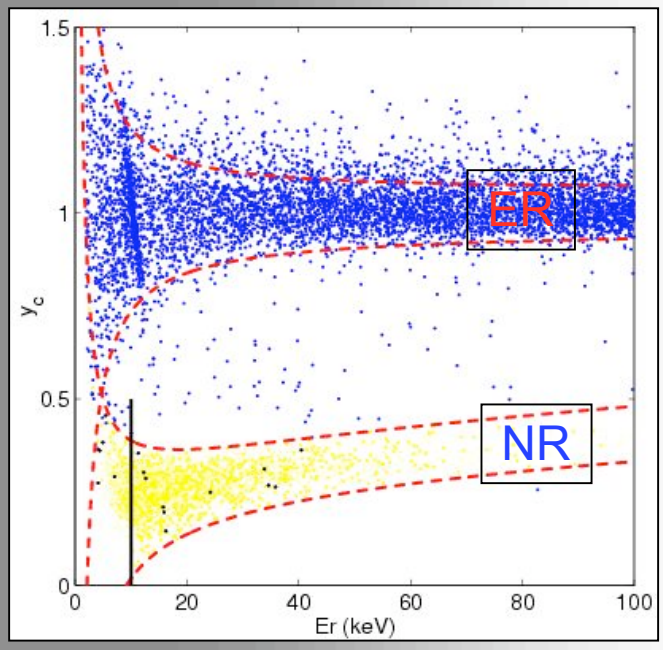


Ionization Sensors
- 2 electrodes (+ ground)
- Allow rejection of events near outer edge

CDMSII results



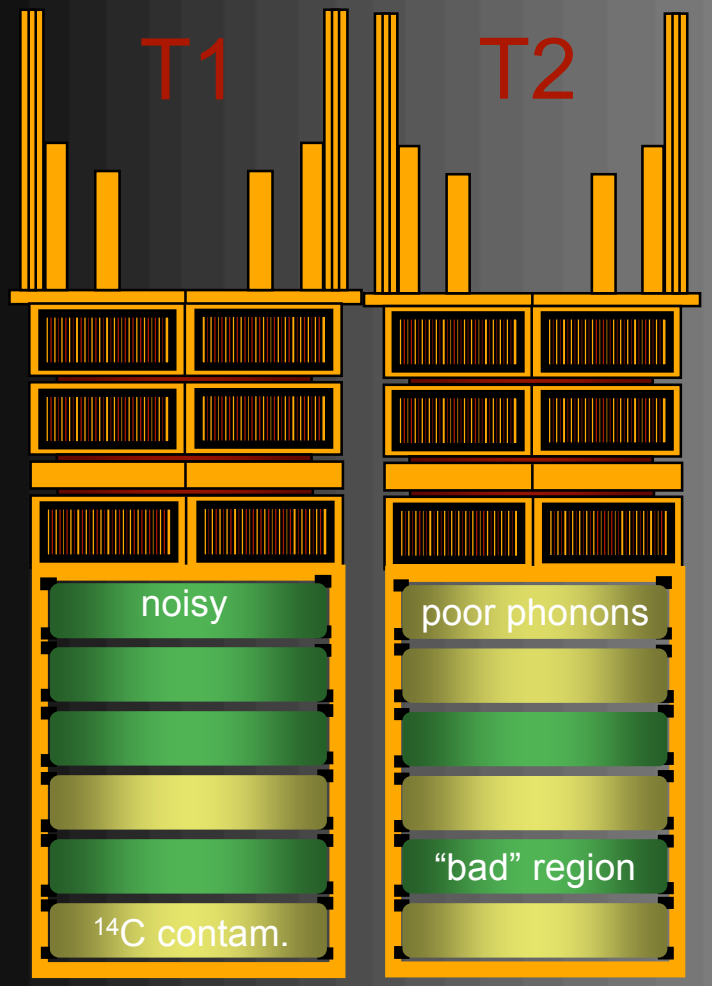


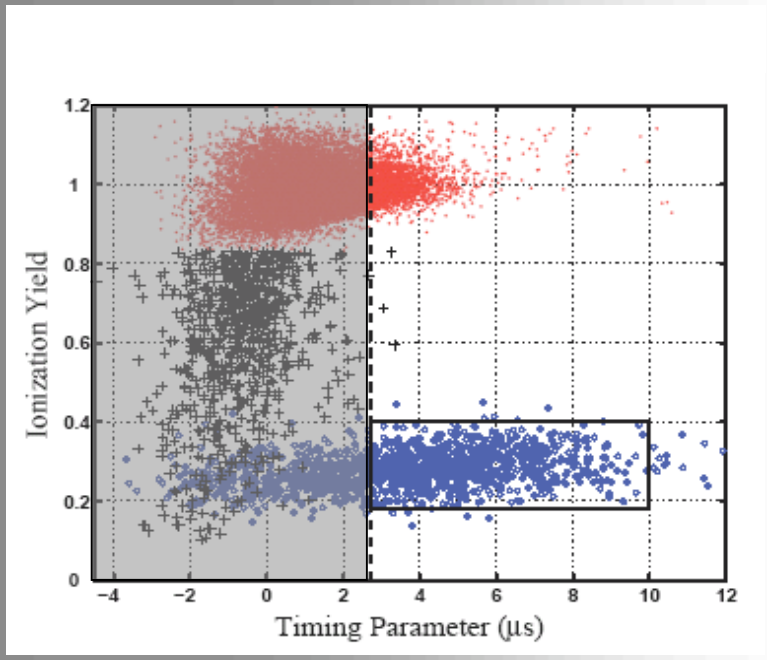


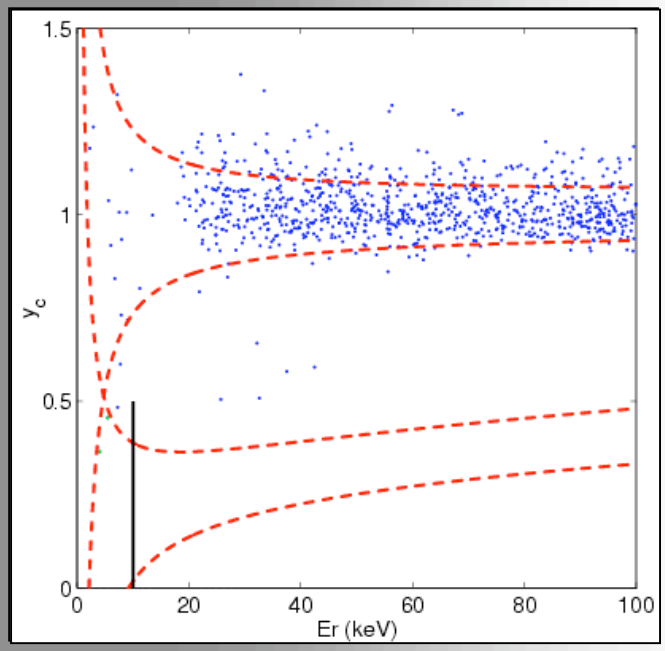
- Reject 99.9998% of **Gammas**
- Reject 99.8% of **surface events**

Phys. Rev. Lett. 96, 011302 (2006)

CDMSII results







- Reject 99.9998% of **Gammas**
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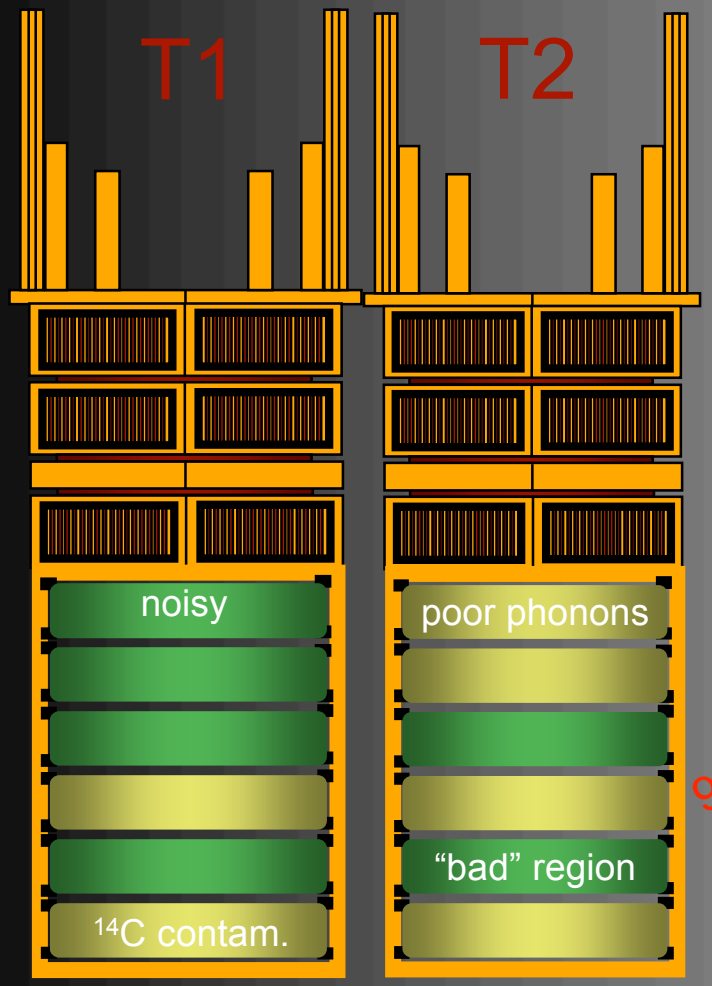
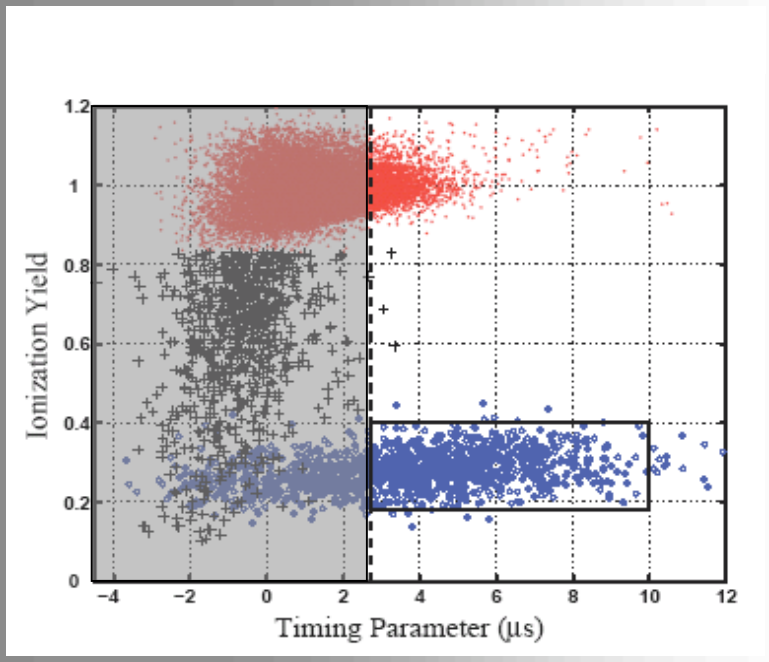
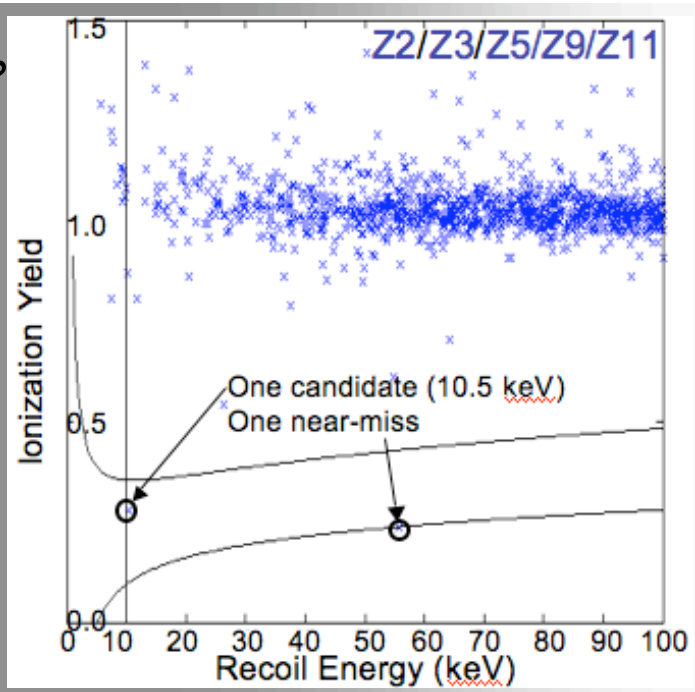
CDMSII results



96.8 (31.0) kg-days



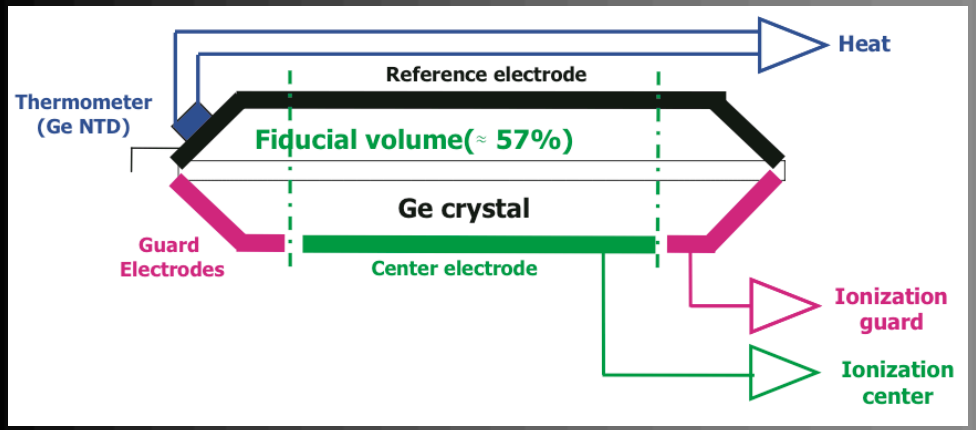


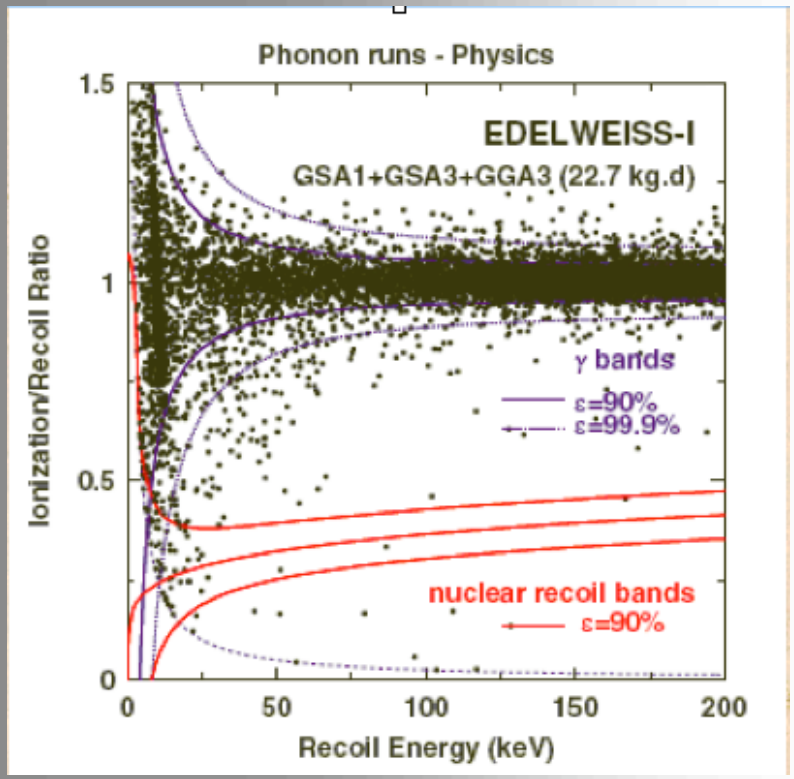
0.4±0.2±0.2 Ge background expected -> ***1 seen***
0.4±0.9±0.5 Si background expected -> ***0 seen***

- Reject 99.9998% of **Gammas**
- Reject 99.8% of **surface events**

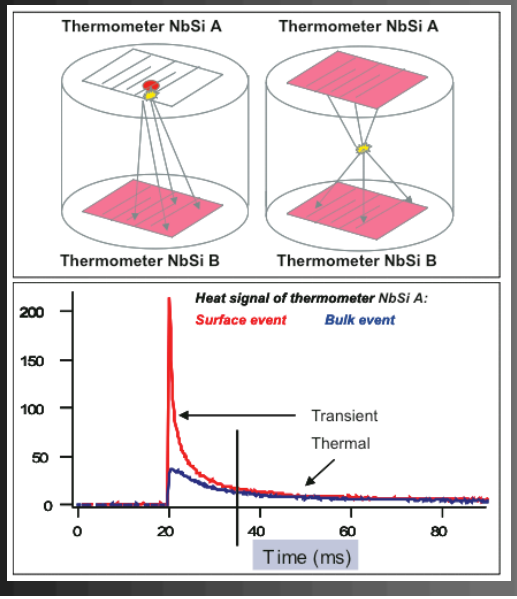
Phys. Rev. Lett. 96, 011302 (2006)

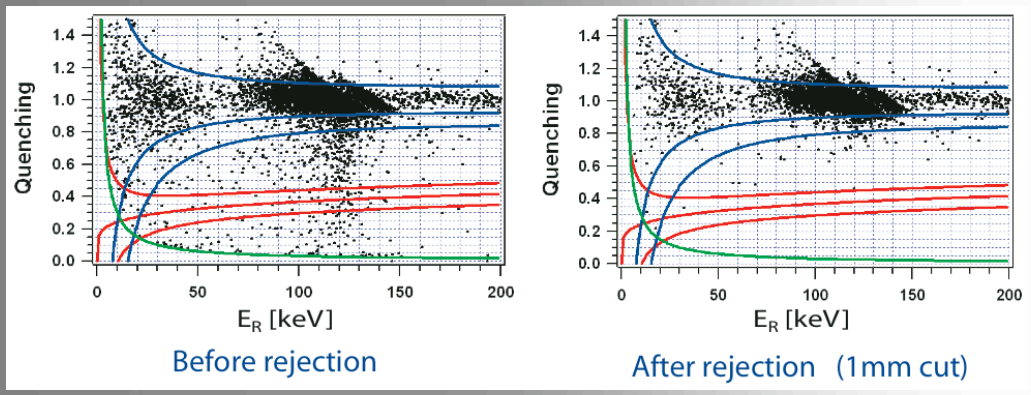
Edelweiss status/ progress





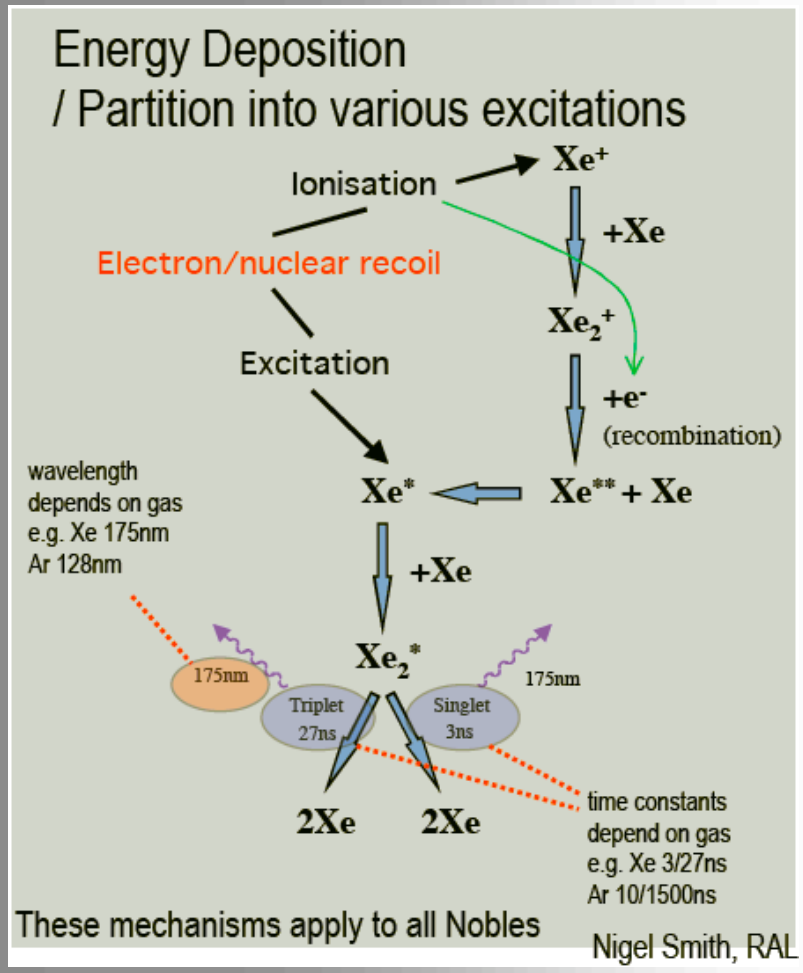
- Limited by near surface events: ^{210}Pb
- Design new detectors with surface event rejection ability
- Thin film NbSi athermal phonon sensors
- New ionization scheme





Noble gas principle (I)

	Single phase (Liquid only) PSD	Double phase (Liquid + Gas) PSD/Ionization
Xenon	ZEPLIN I XMASS	ZEPLIN II+III, XENON, XMASS-DM, LUX
Argon	DEAP, CLEAN	WARP, ArDM
Neon	CLEAN	



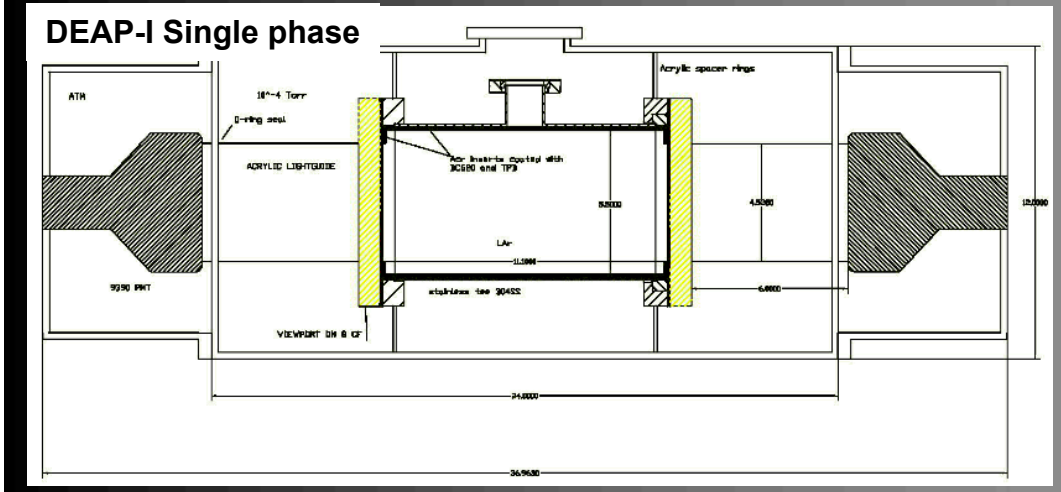
Single phase: Scintilation only
Singlet/Triplet ratio 10:1 N-recoil:E-recoil
⇒Rise time discrimination

Double phase: separate Ion^{+}/e^{-}
A part of the initial scintillation suppressed

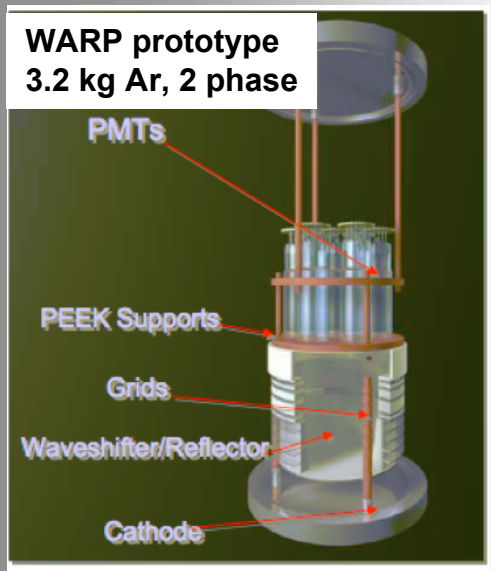
Energy estimate AND discrimination parameter depend on the Recoil type and ENERGY

Noble gas principle (II)

DEAP-I Single phase

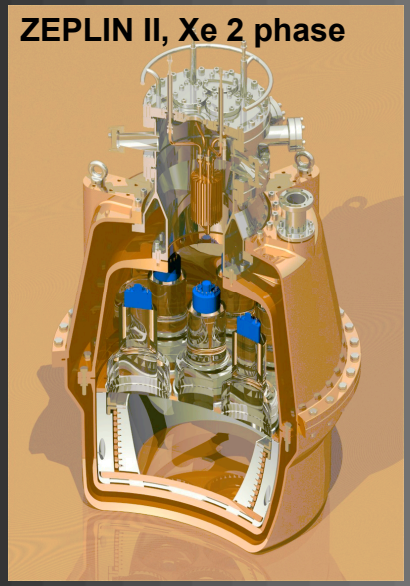


WARP prototype
3.2 kg Ar, 2 phase

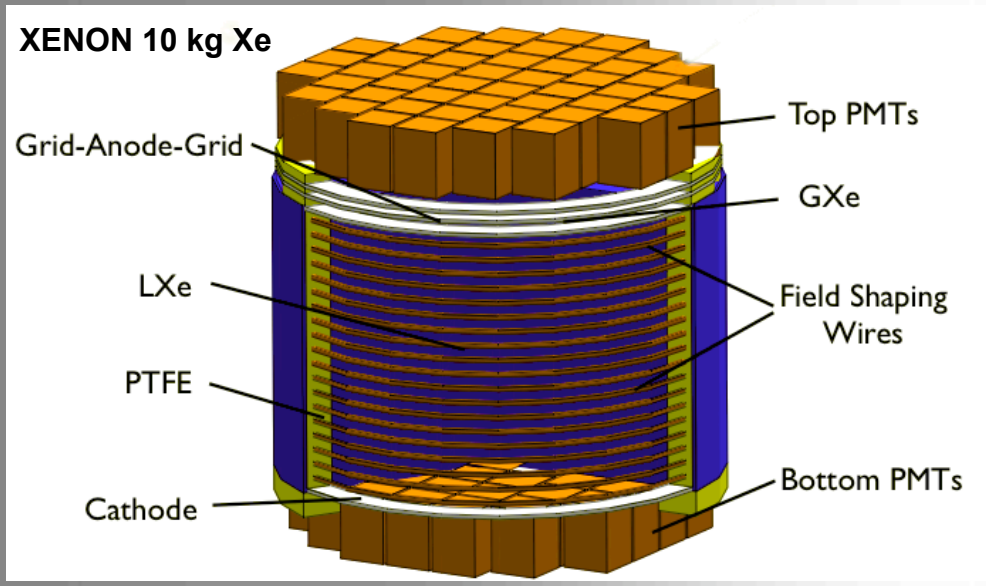


Schematic view of the 2.3 liters chamber

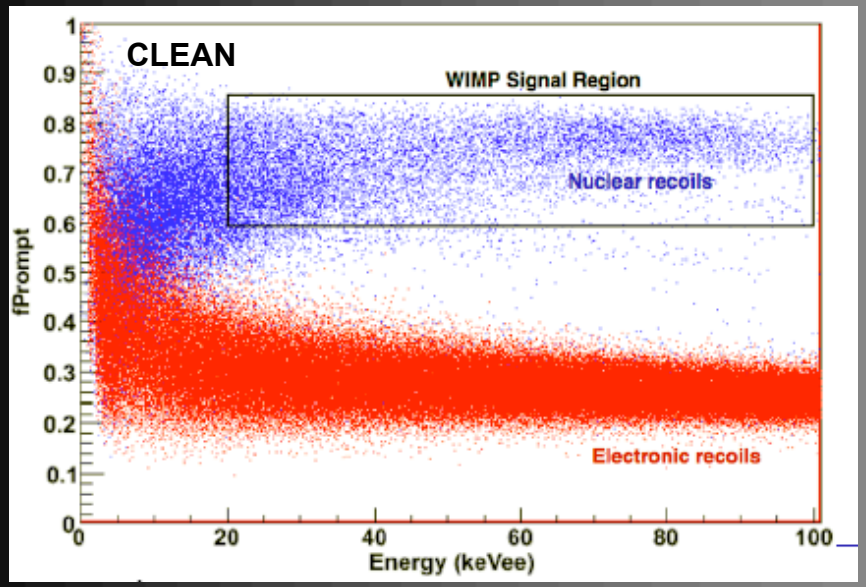
ZEPLIN II, Xe 2 phase

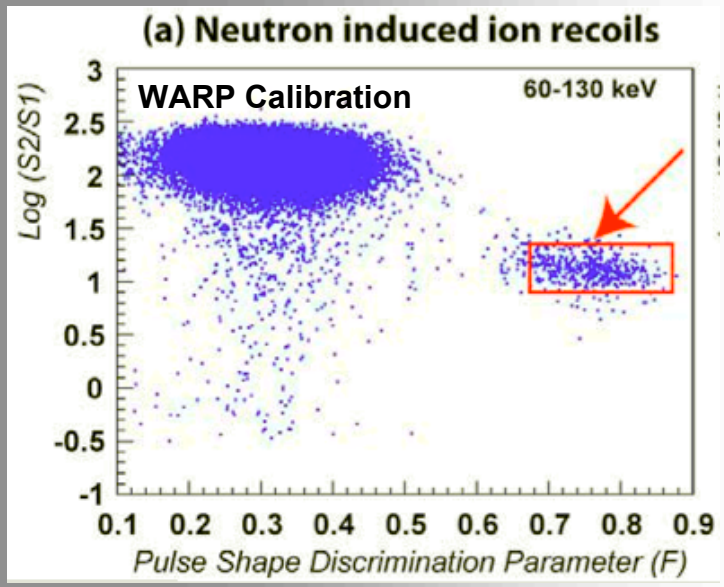


XENON 10 kg Xe

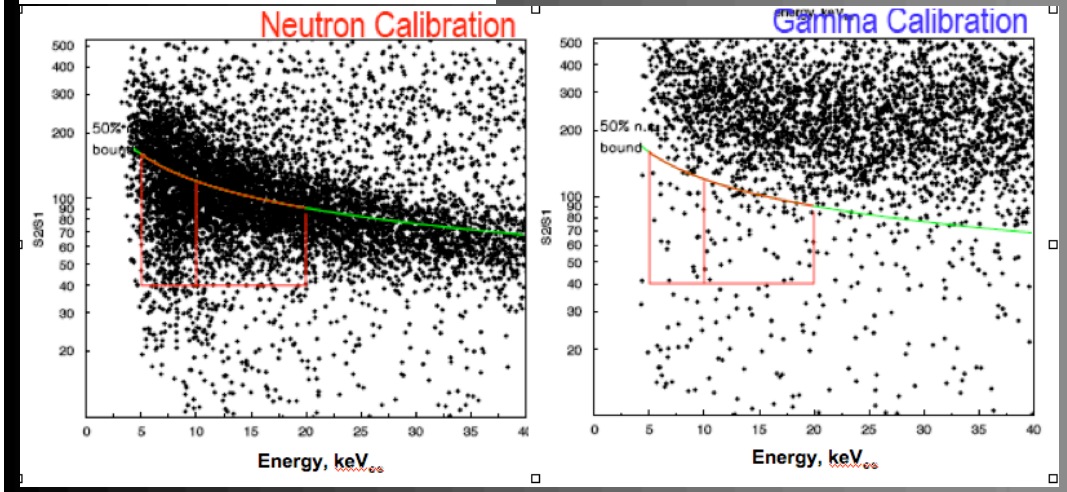


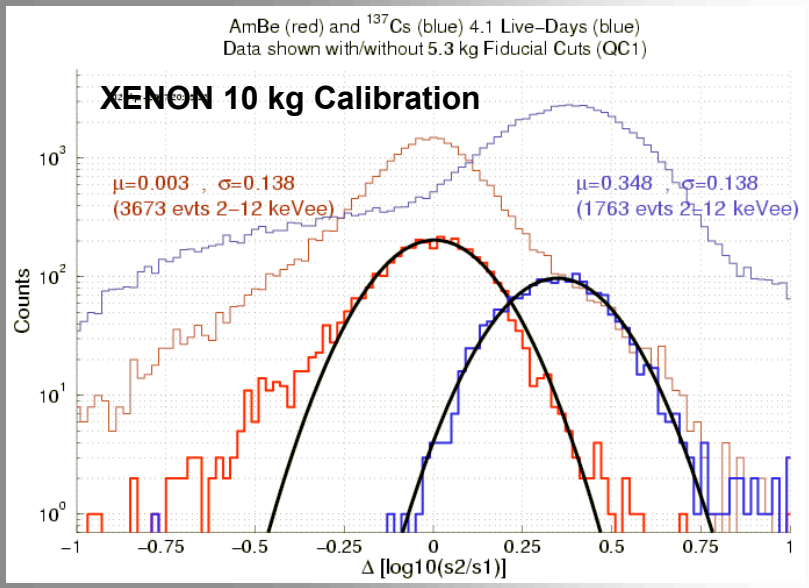
Noble gas principle (II)



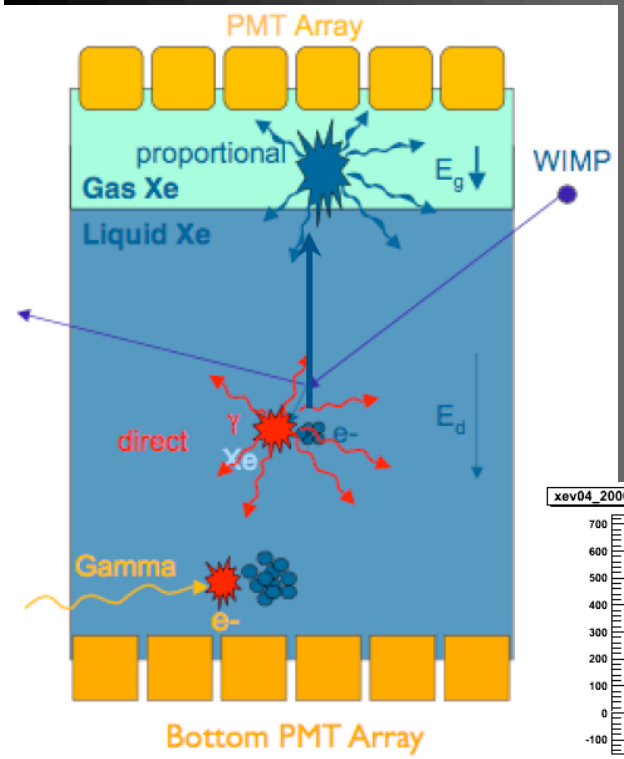


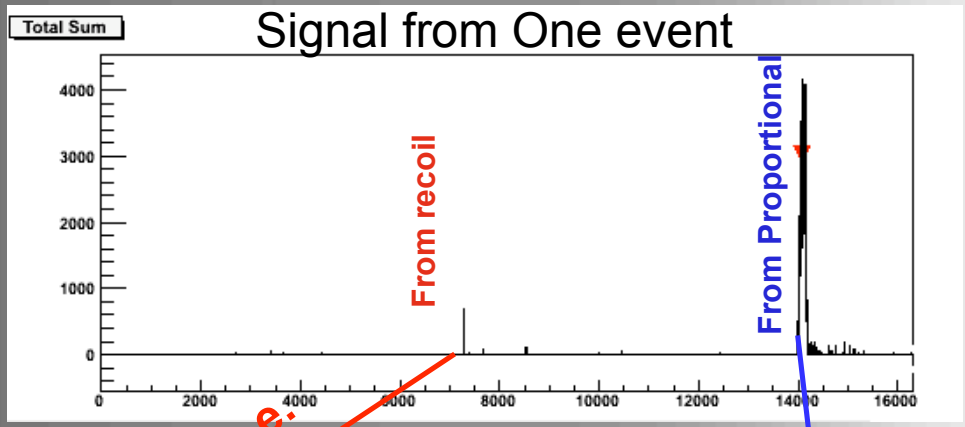
ZEPLIN II Calibration





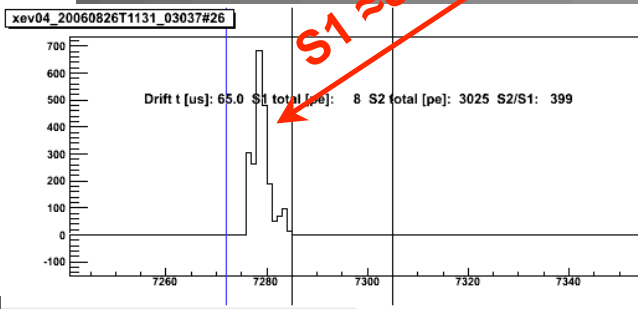
XENON detector

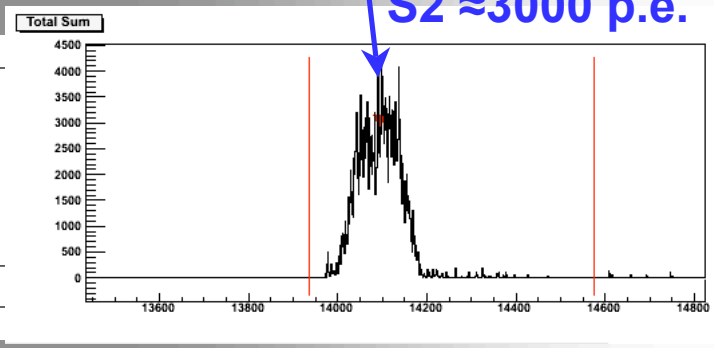




S1 ≈8 p.e.

S2 ≈3000 p.e.





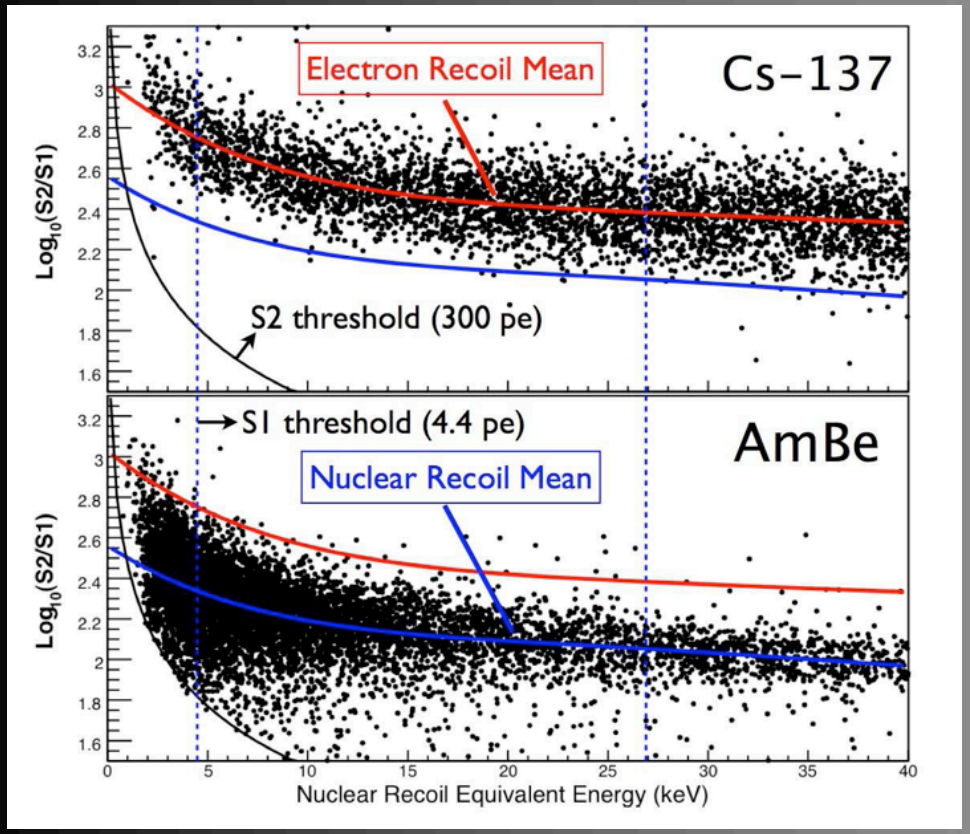
Liquid Xenon: Scintillation + ionization

two photon pulses => depth

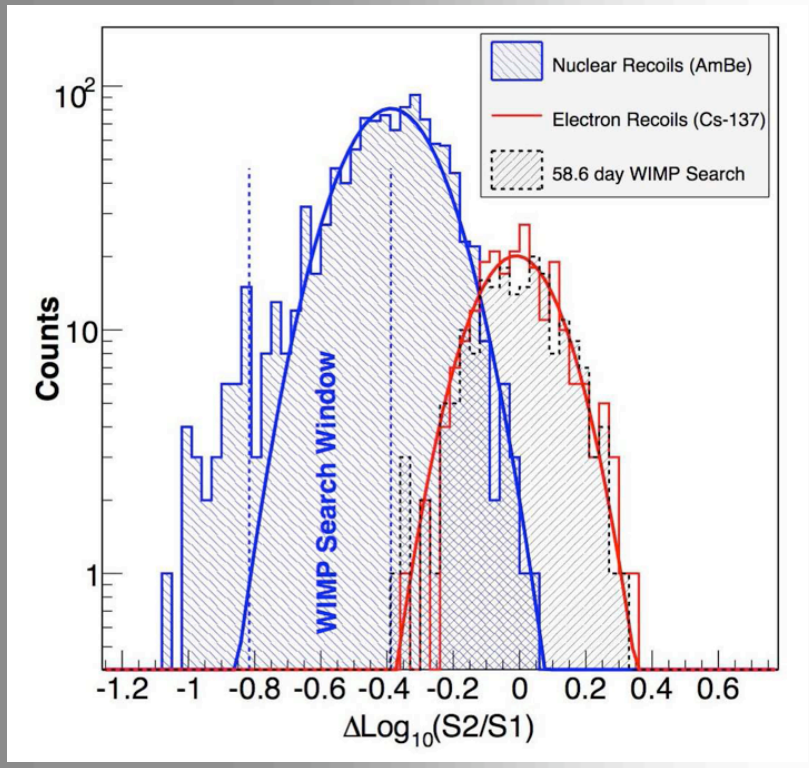
Breakthrough: extraction of electrons from liquid

importance of having photon detector at the bottom +
high spatial resolution ≠ ZEPLIN II

Xenon 10 Calibration, Rejection

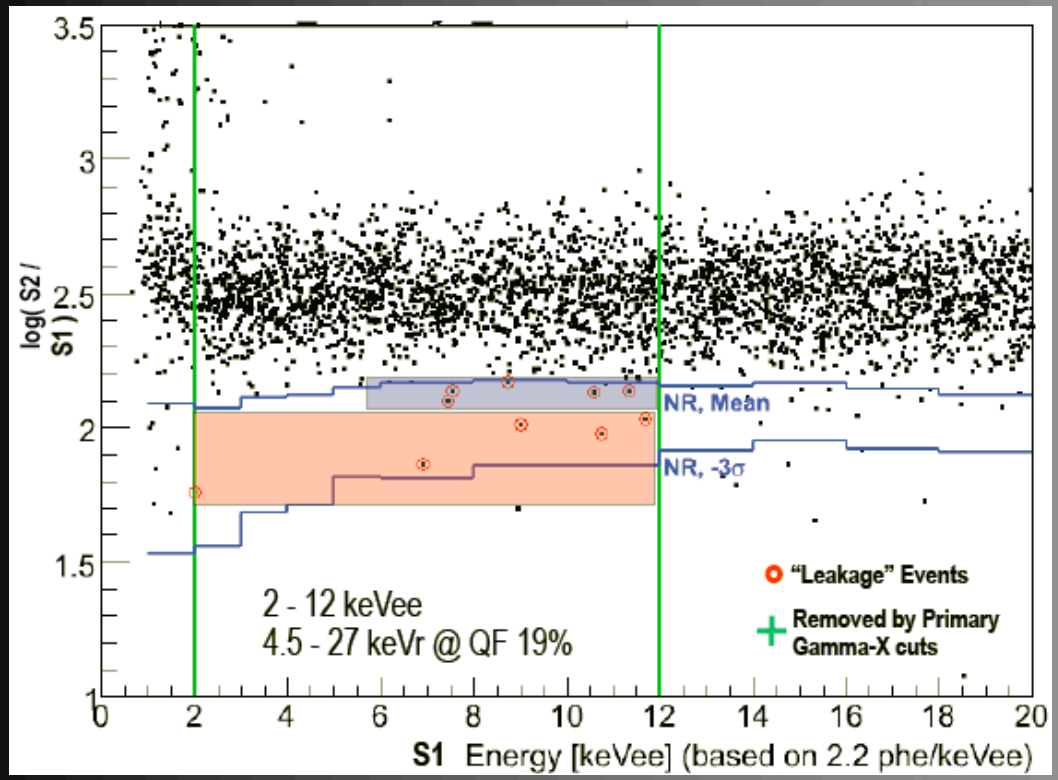


6.7- 9.0 keV nuclear recoil equivalent energy

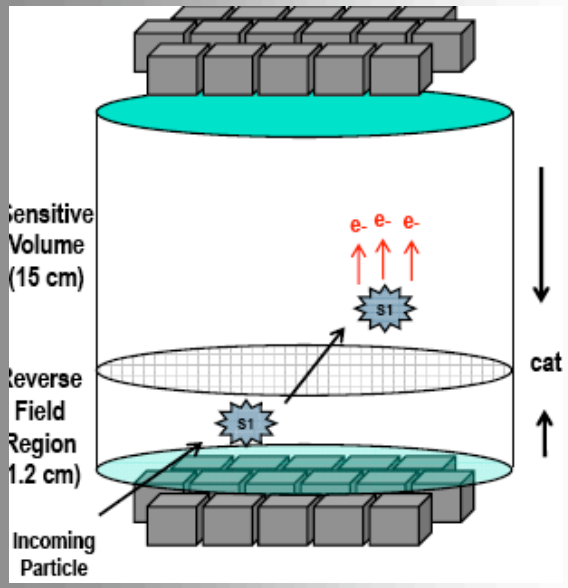


Astro-ph/0706.0039

XENON 10 WIMP search result

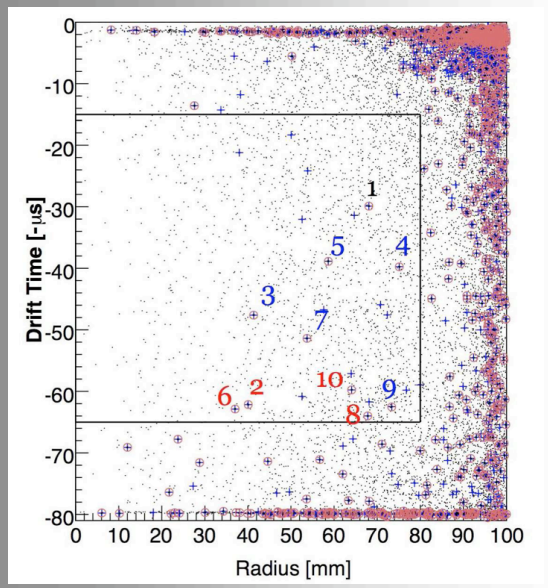


Example of an event with depressed S2



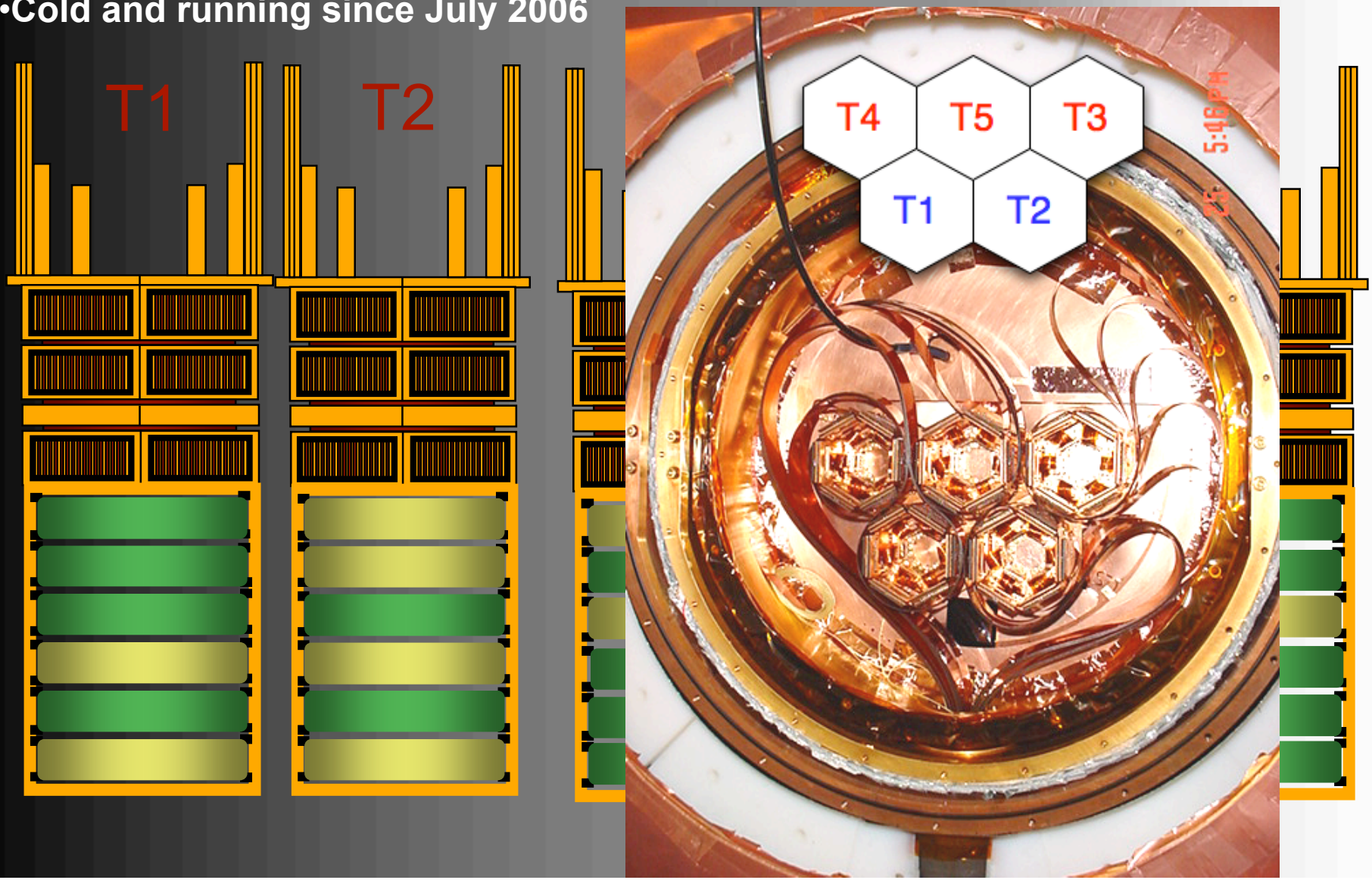
- 53 Live day, 22 kg Xe
- 4.5 - 27 keV recoil
- After fiducial and 50% NR acceptance 23 pass

•13 removed cutting out with the blind gamma-X cut +
•5 consistent with distribution tail another 5
•The remaining ones are not likely to be WIMPs candidate



Exciting year 2007 to end

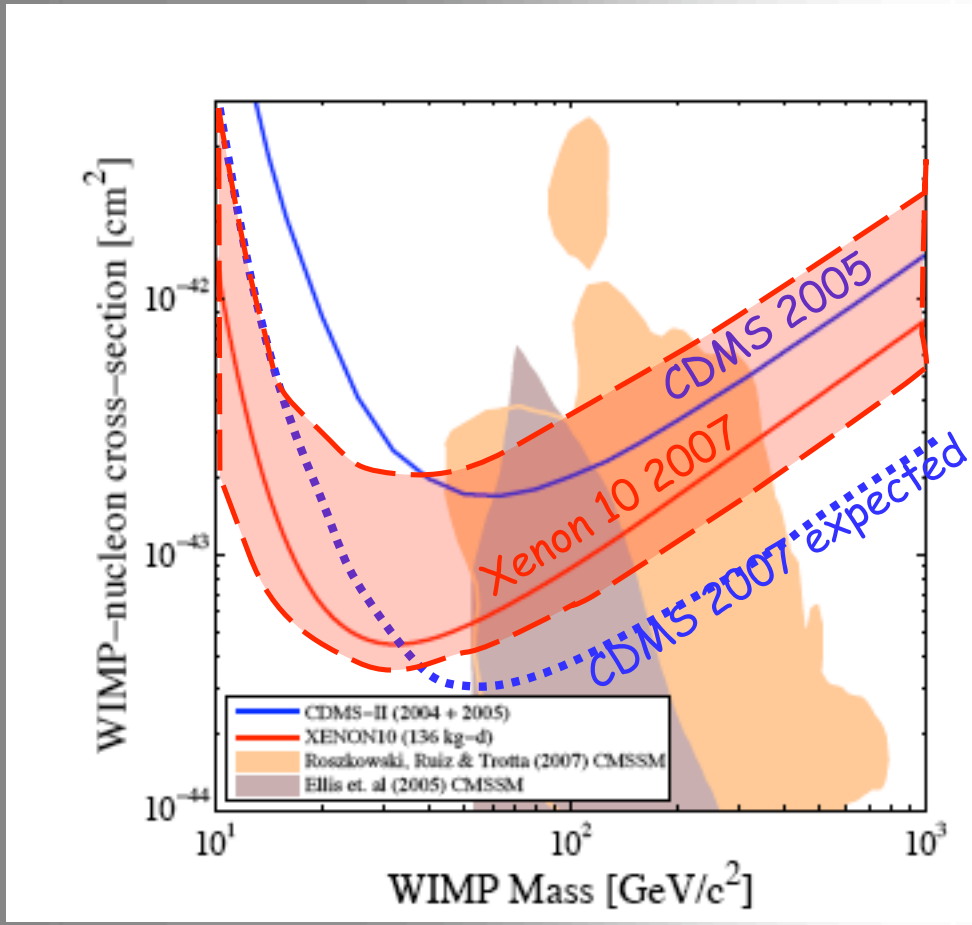
- **CDMS: Increased Ge mass from 1.5 to 4.5 kg**
- **Cold and running since July 2006**



Exciting Year 2007 to end

- CDMS II new run with 5 towers
  - 650 kg.days accumulated
  - Analysis to be finalized by this fall
  - Will remain background free
  - Expected sensitivity 3×10^{-44} cm^2
  - Another year of running to reach the goal: 1500 kg.days $\sigma_{\text{WIMP-Nucleon}} \sim 1\times10^{-44}$ cm^2

- Xenon 10
  - Clear demonstration of technology
  - Still some doubts about low threshold
  - Detector used where no calibration?
  - New calibration this summer



Exciting immediate future (I)

CDMS: run till ≈ next summer ≈1500kg days

sensitivity $<10^{-44}$ cm^2/nucleon

stay background free: - new towers 3 lower back grounds

- better discrimination tools

Edelweiss-> 10^{-43} cm

21 x 330g Ge detectors with NTD

+ 7 400g Nb Si (athermal phonons)

first commissioning run April -May 07 encouraging

no event > 30keV for eight NTD detectors (19 kg day) (cf 3 in Edell)

first underground test of two 200g Nb Si

CRESST II-> 10^{-43} cm

Major upgrade 66 SQUIDs for 33 detectors + neutron shield

Three detectors running since 4/07.

Will report≈ 60kg days at TAUP

XENON10 : Corrections installation of larger vessel, results 2008

Liquid Argon: an additional handle: rise time,

WARP: Scintillation, Ionization and rise time: 39Ar

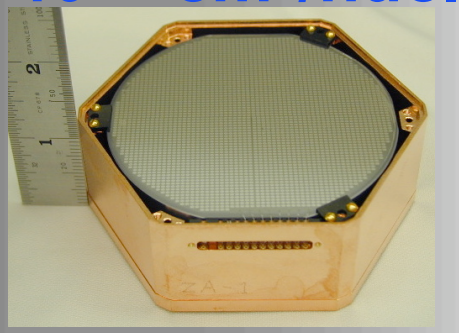
Toward 10^{-45} cm^2 (conclusion)

At least 3 technologies able to go to 10^{-45} cm^2/nucleon

Phonon mediated detectors

SuperCDMS 25kg 1" detectors

first phase approved

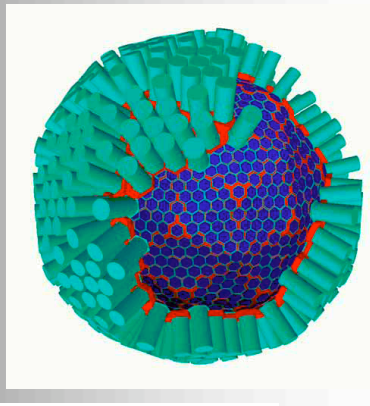


2-phase Xenon (LUX 300 kg)

number of photo-electrons + reduction of reduced ionization regions

• 2 phase Argon scintillation+ionization+pulse shape

but: Ar 39



Can we do something simpler?

Borexino/Kamland like geometry

• single-phase Xenon (XMASS 800 kg)

use self shielding of Xe

approved

• single phase Argon scintillation +pulse shape

(MiniClean/DEAP) but Ar 39