The Search for WIMPs in the Galactic Halo: the Quest to Detect the Dark Matter

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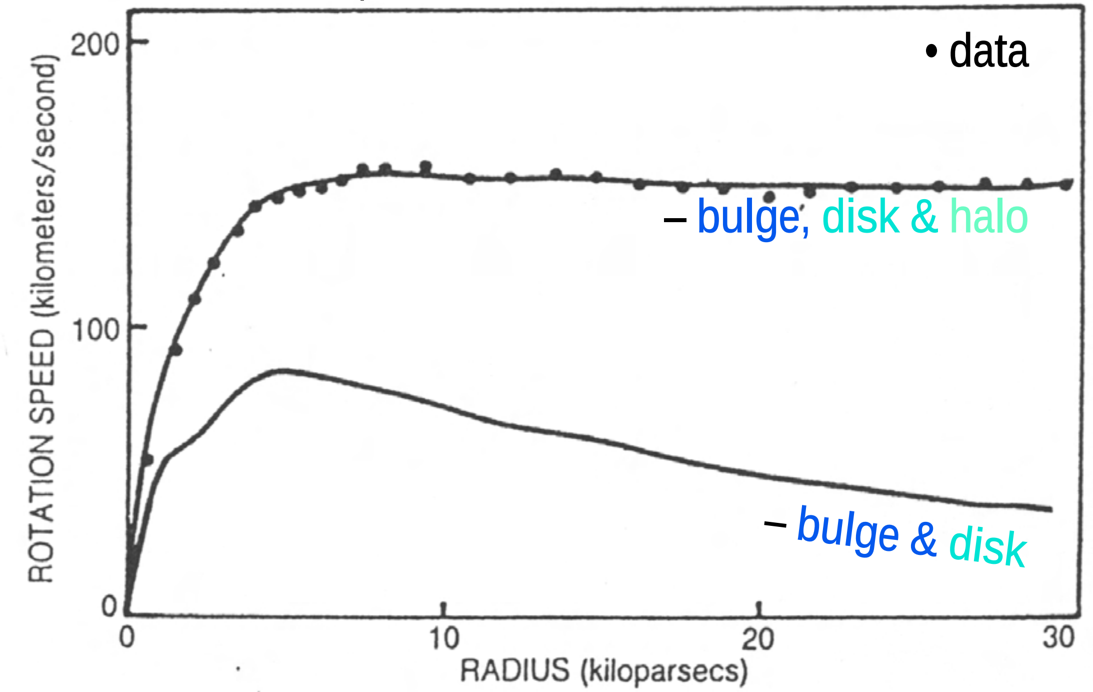
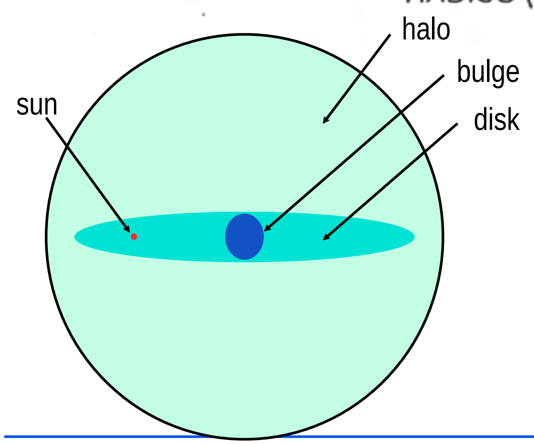
What's missing in the Universe?

– do we understand gravity and the origin of structure and galaxies?
– new form of matter? -origin of the fundamental forces?
– can we find it? -these questions are settled by experiment/observation

Dynamical Evidence: Galactic Halos

Galaxies – 10-100 kpc

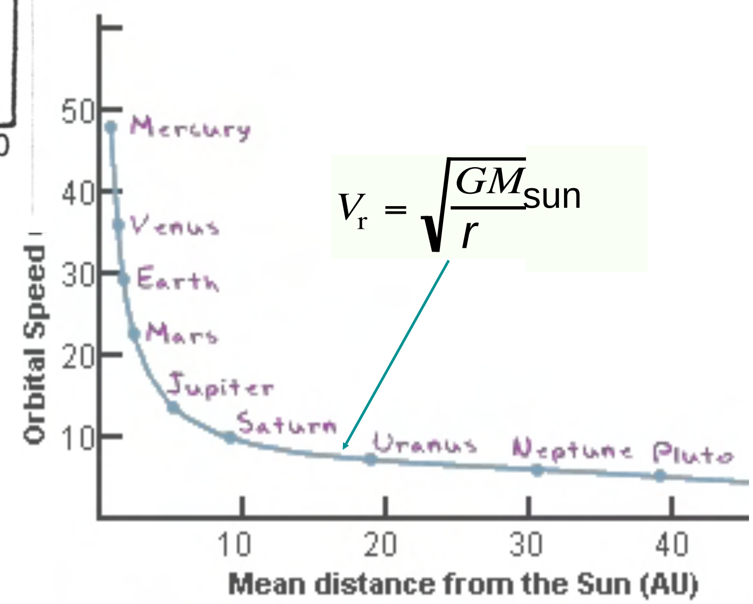




$$F_{\text{centripetal}} = F_{\text{gravity}}$$

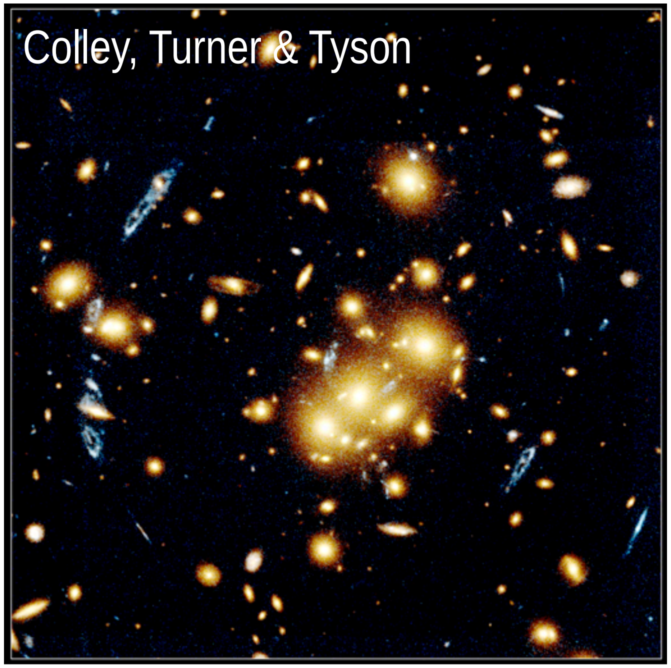
$$\frac{mV_r^2}{r} = \frac{GmM_{\text{total}}(r)}{r^2}$$

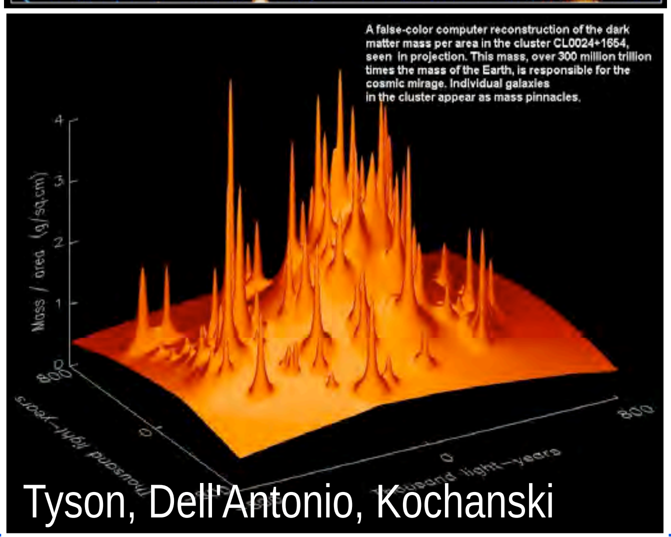
$$V_r = \sqrt{\frac{GM_{\text{total}}(r)}{r}}$$



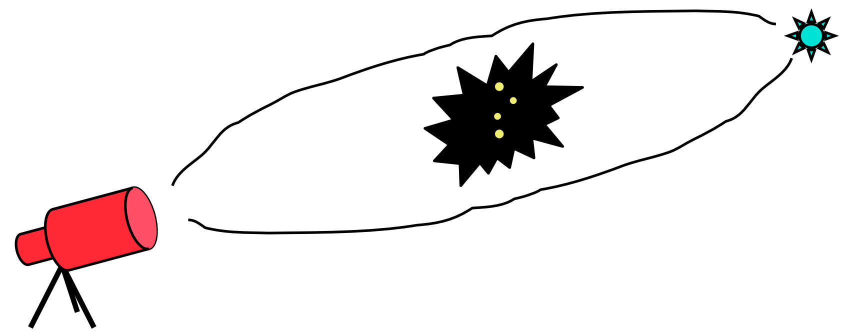
$$V_r = \sqrt{\frac{GM_{\text{sun}}}{r}}$$

Dynamical Evidence: Galaxy cluster lensing





Clusters – 1-10 Mpc



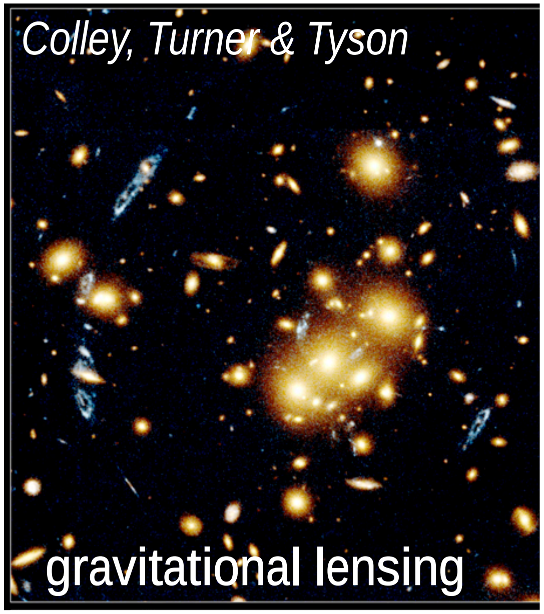
Infer total mass density:

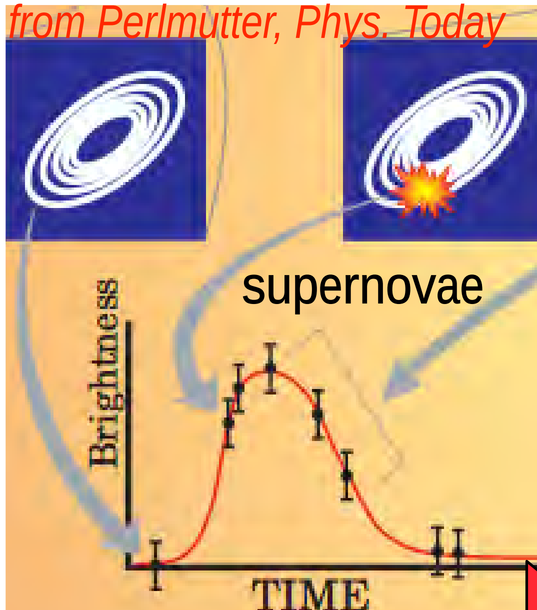
→ $\Omega_m = \rho/\rho_{crit} = 0.30 \pm 0.03$

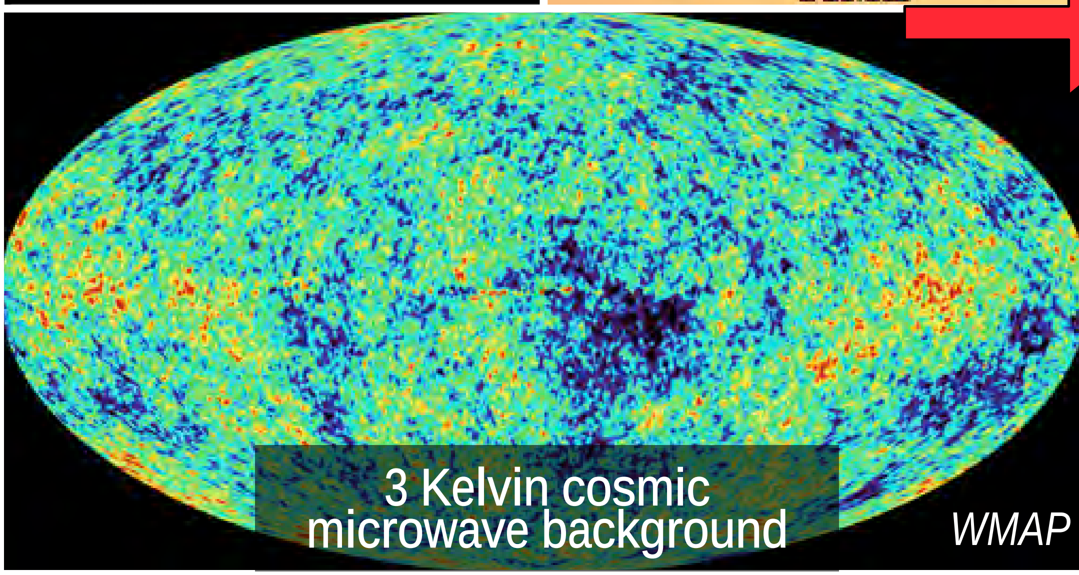
→ dark matter dominates

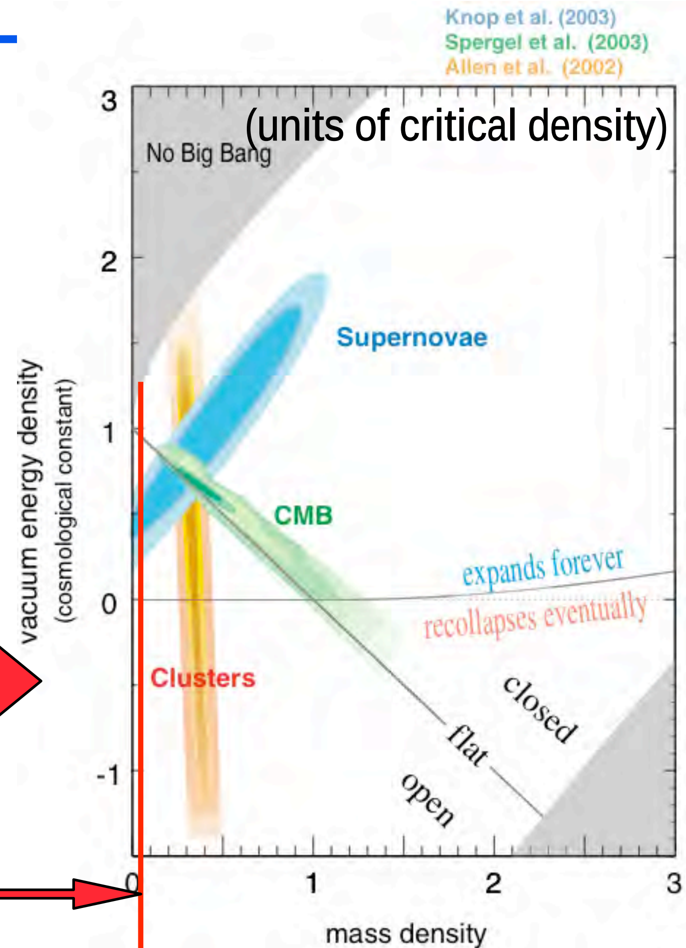
$\rho_{dark} > 30\ \rho_{luminous}$

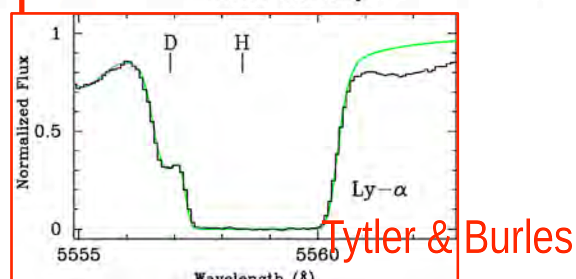
Standard Cosmology









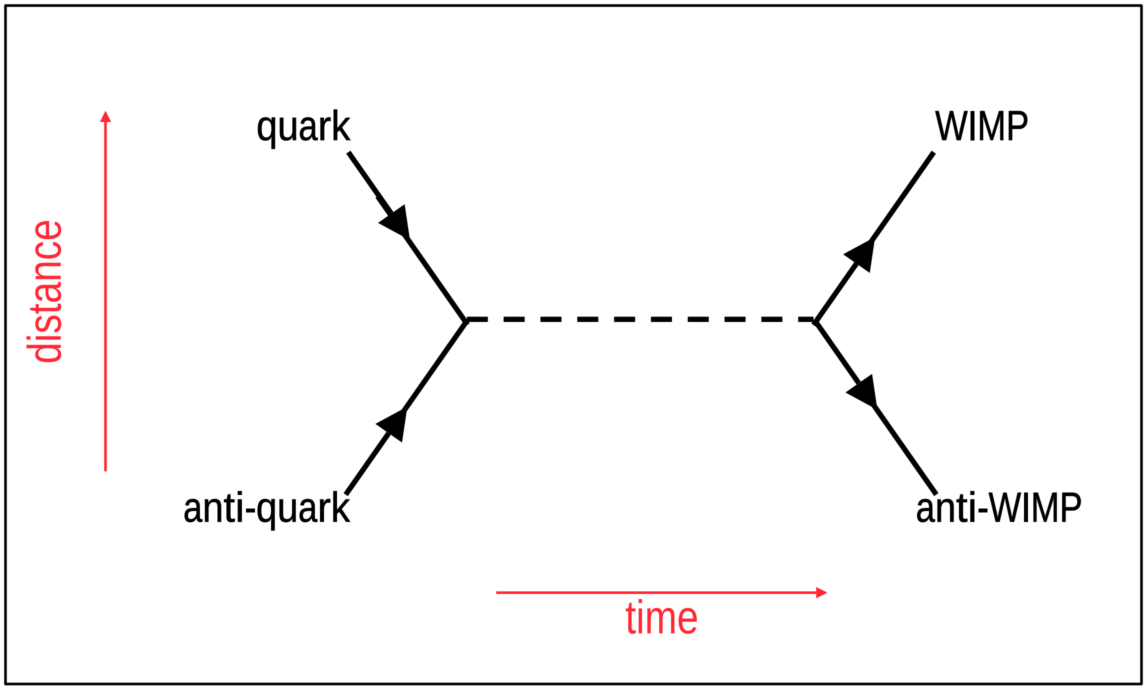


What is it? Extraordinary stuff!

- Early Universe as Particle Factory
  - Not enough protons and neutrons produced in the Big Bang

Convert energy to mass

$E=mc^2$

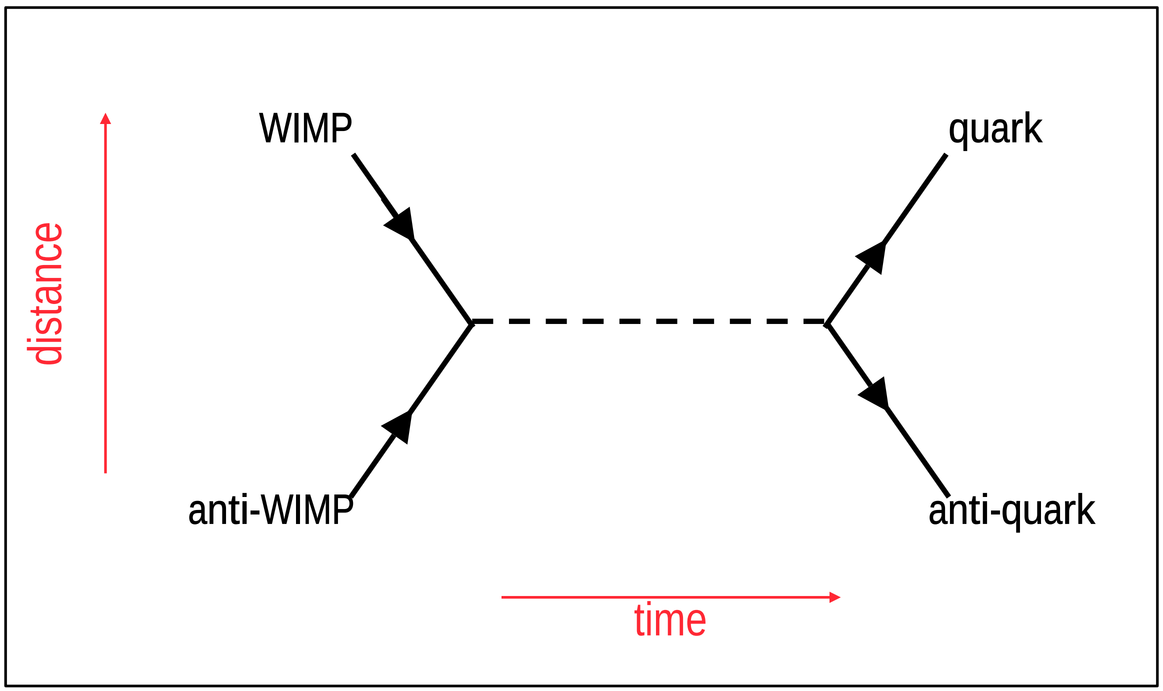


- *A new type of particle:* WIMPs = weakly interacting massive particles

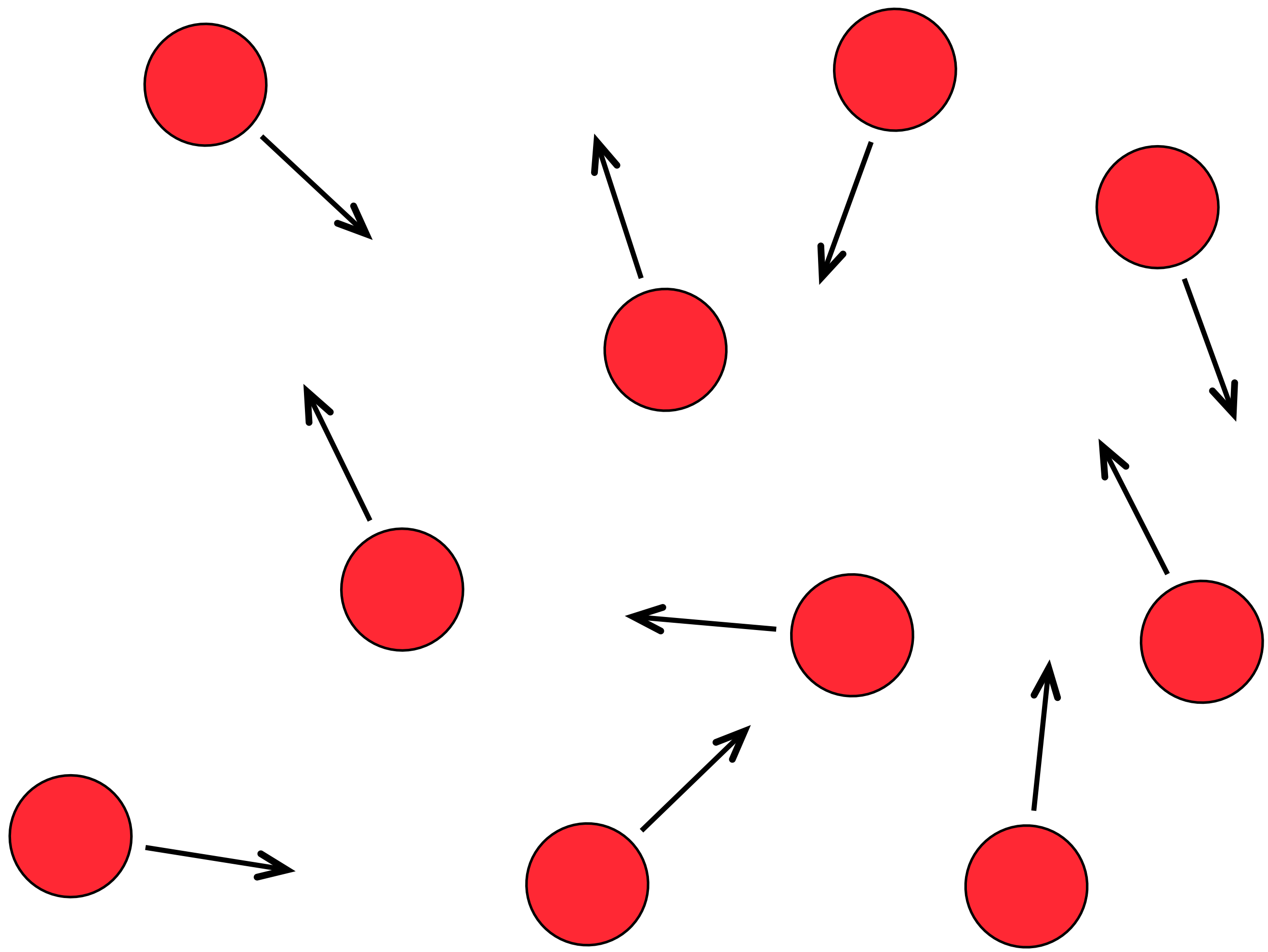
Massive: source of gravity Weakly-interacting: not star forming

Still around?

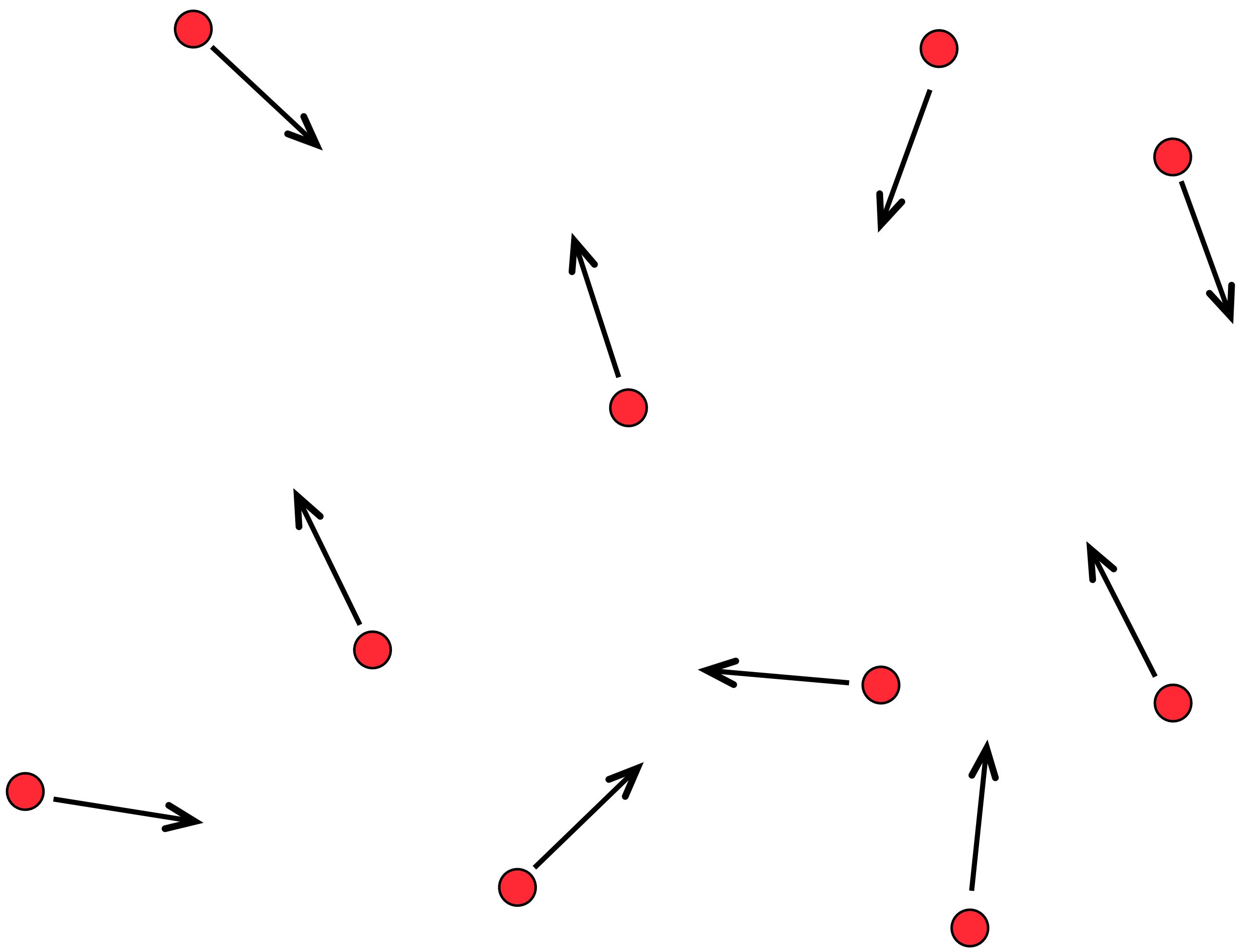
Expanding Universe and Weak Interactions



cross section → annihilation rate

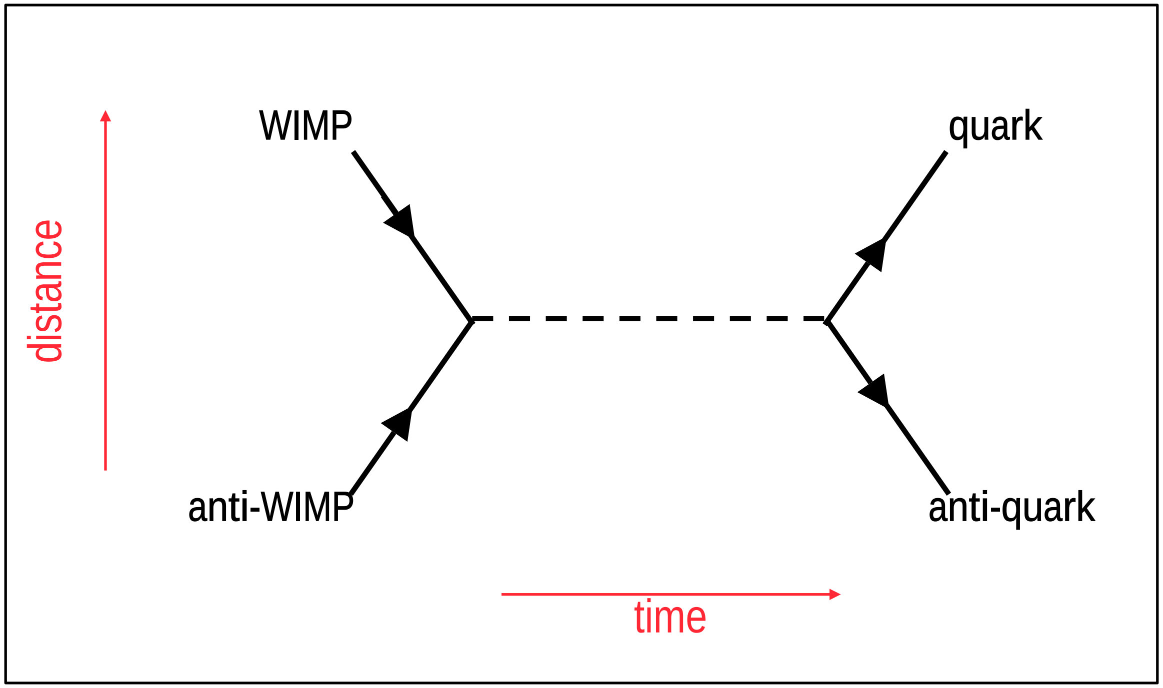


cross section → annihilation rate



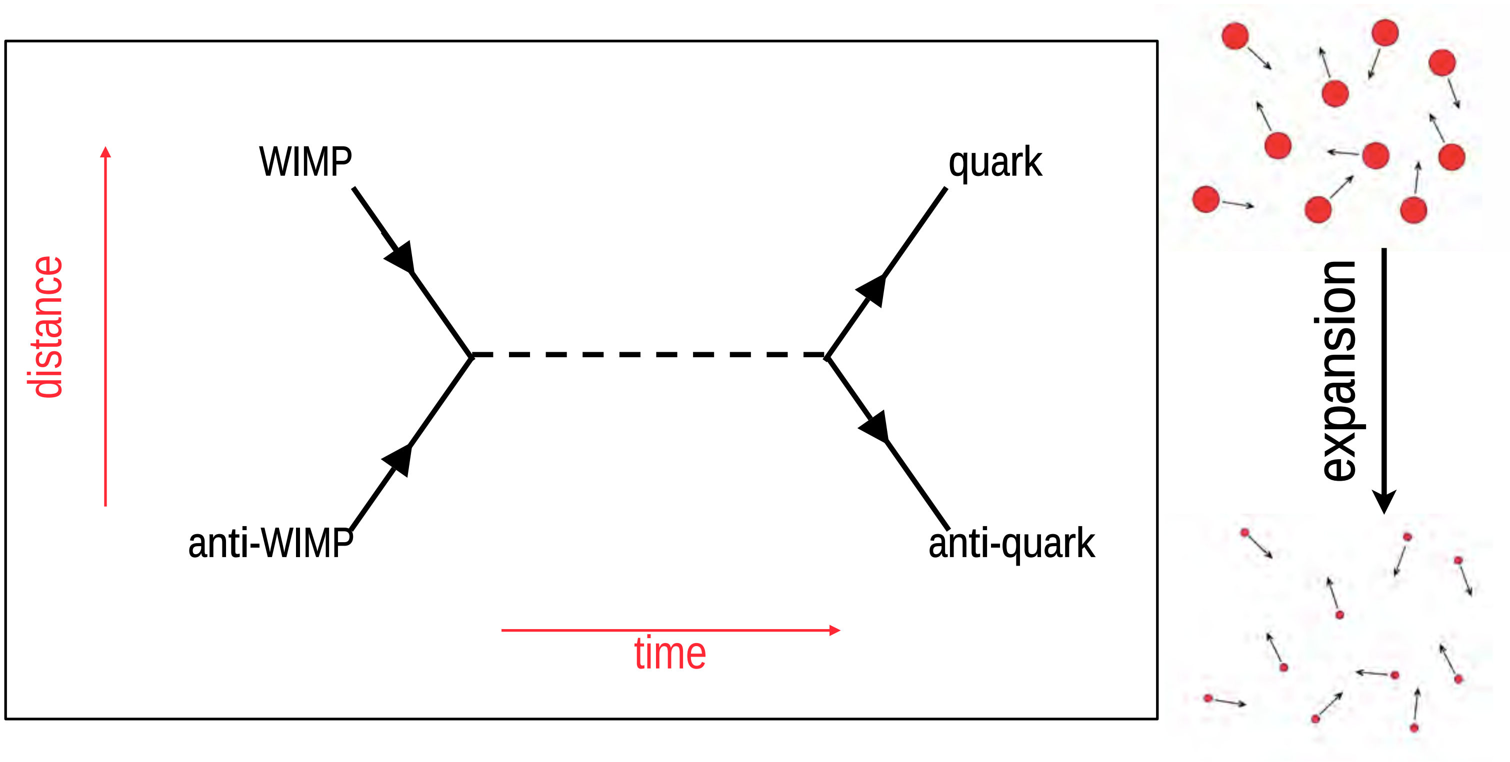
Still around?

Expanding Universe and Weak Interactions – annihilations stop if cross sections are small enough



Still around?

Expanding Universe and Weak Interactions – annihilations stop if cross sections are small enough



Weakly Interacting Massive Particles

- WIMP pairs $\chi\,\bar{\chi}$ produced in dynamic equilibrium
- Annihilation *stops* when number density falls too low

$$H > \Gamma_A \sim n_\chi \langle \sigma_A v \rangle$$

→ annihilation rate slower than Hubble expansion ("freeze out")

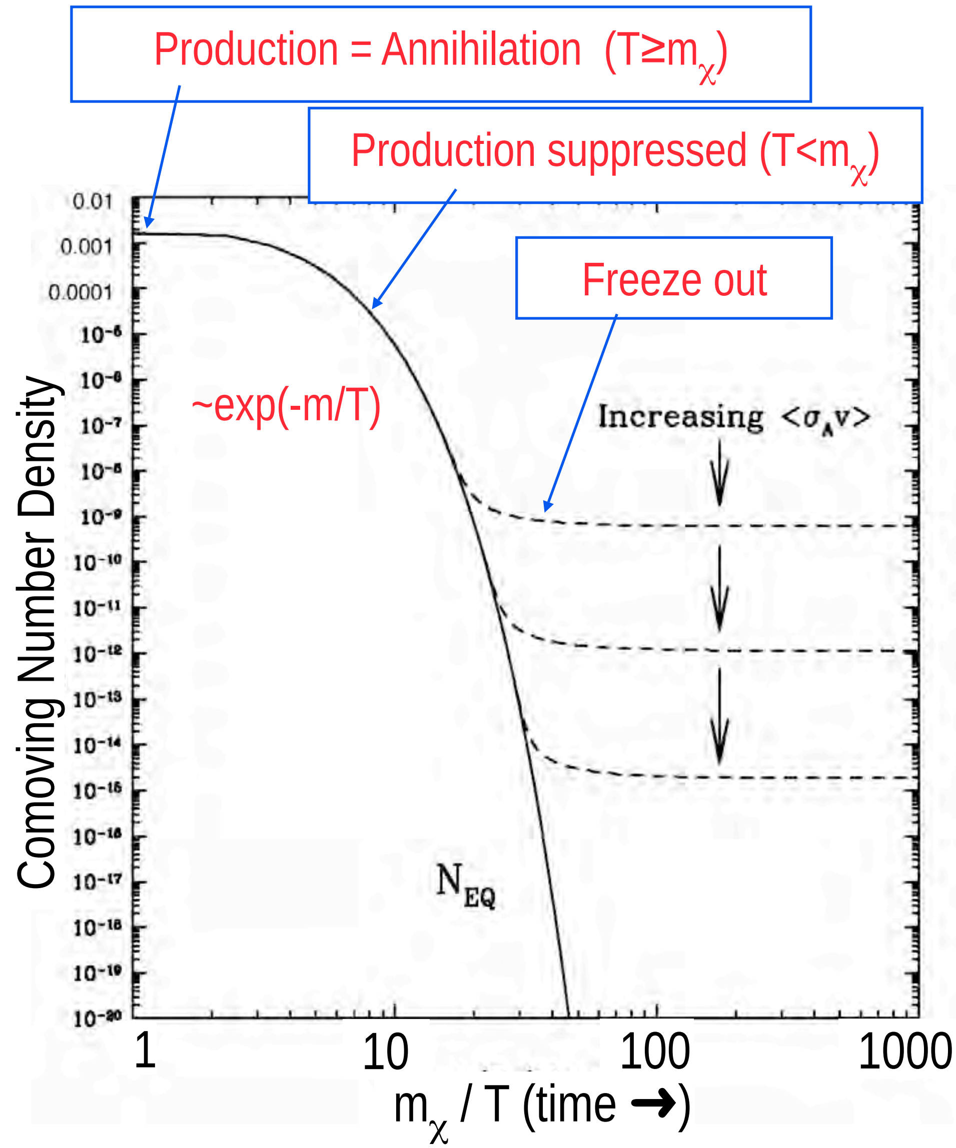
→ mean free time > age

- For $\Omega_\chi \approx 1$
  - M ~ 10-1000 GeV
  - σ_A ~ electroweak

SUSY/LSP

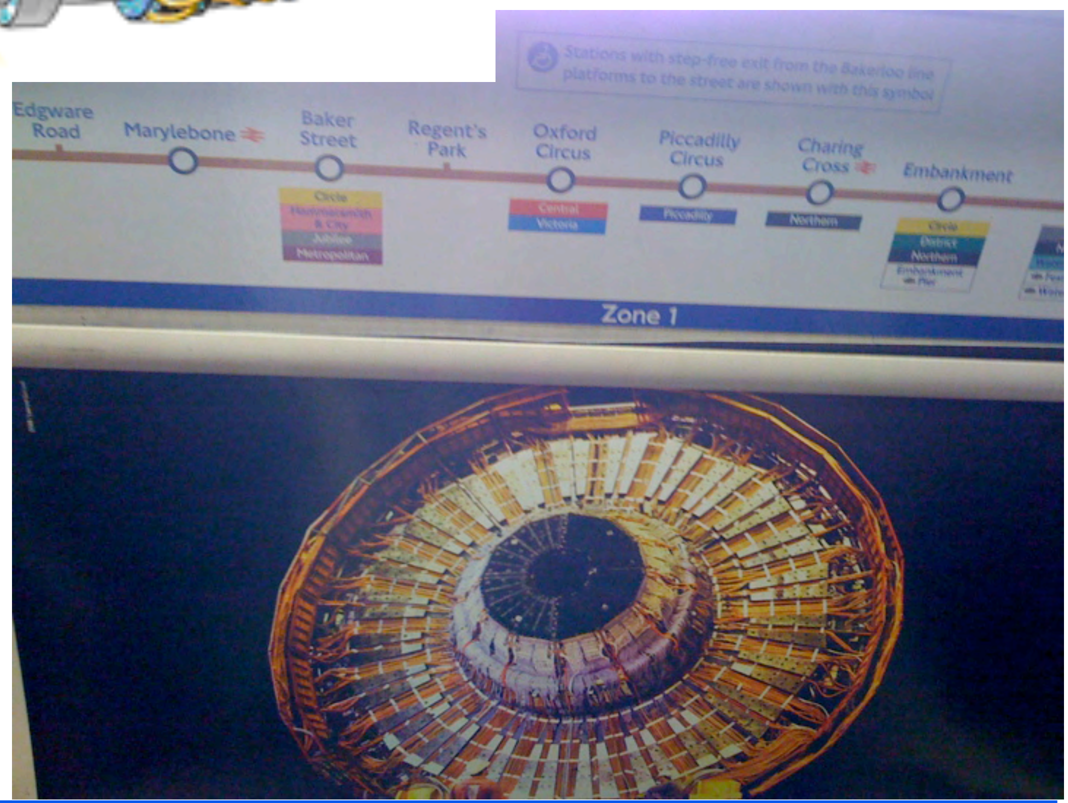
- T_{FO} ~ m/20
  - Non-relativistic

'Cold'

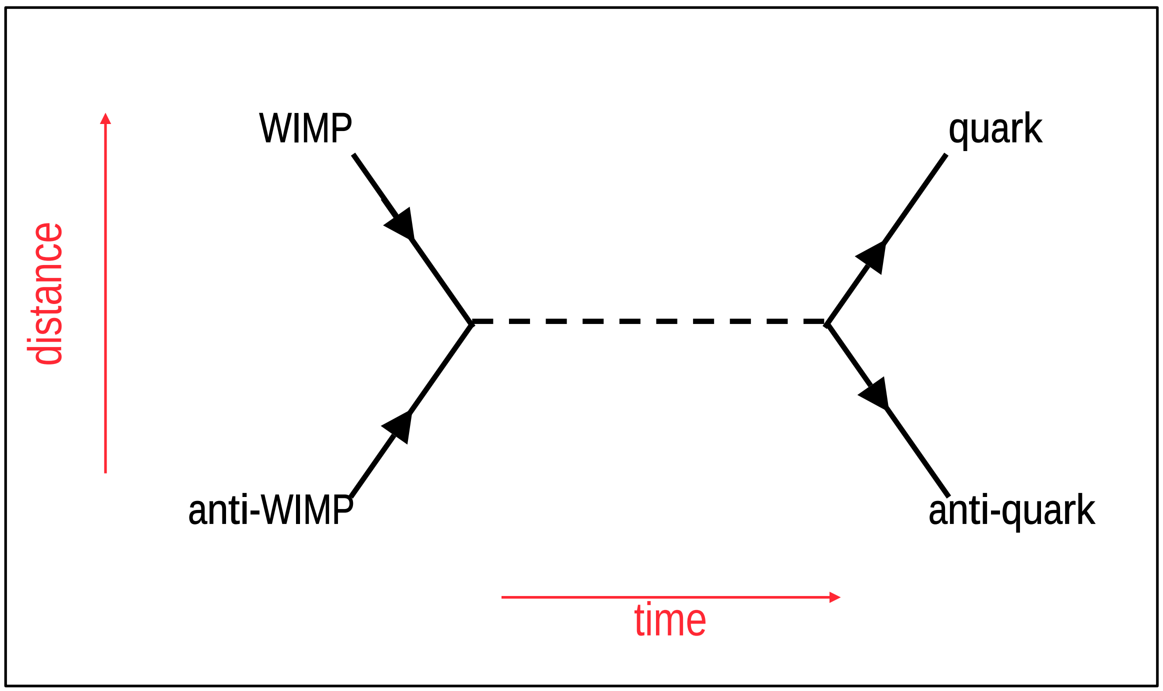


The LHC: make DM in the Laboratory

The Large
Hadron Collider,
CERN/Geneva



Annihilation ↔ Scattering



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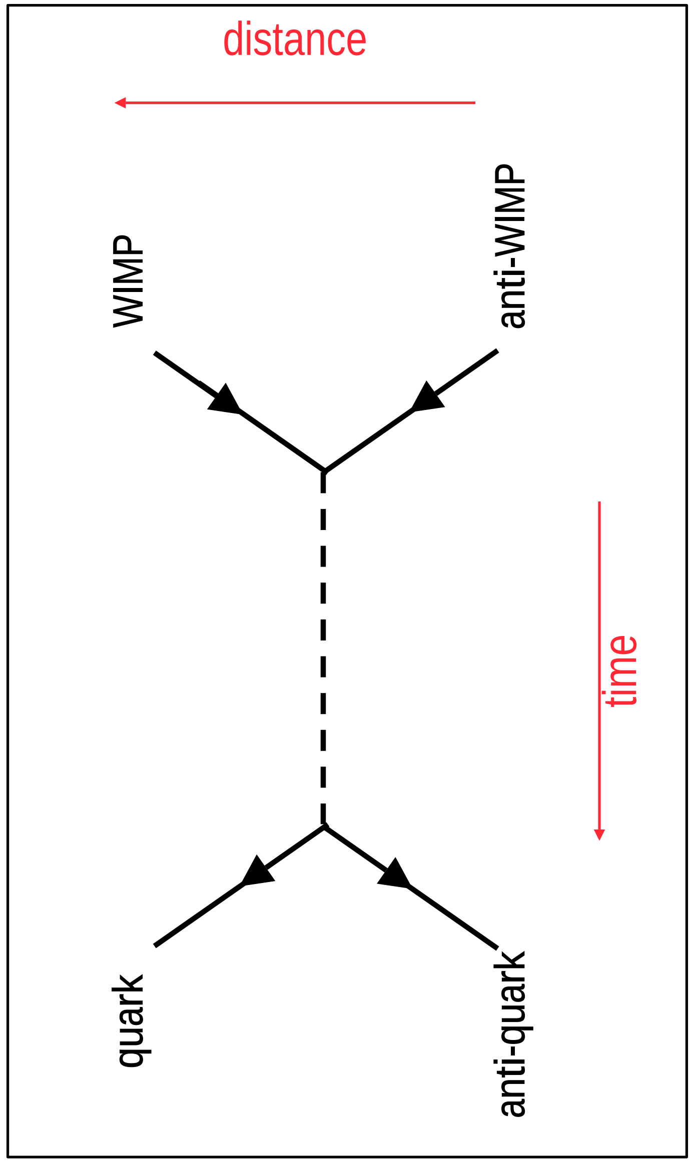
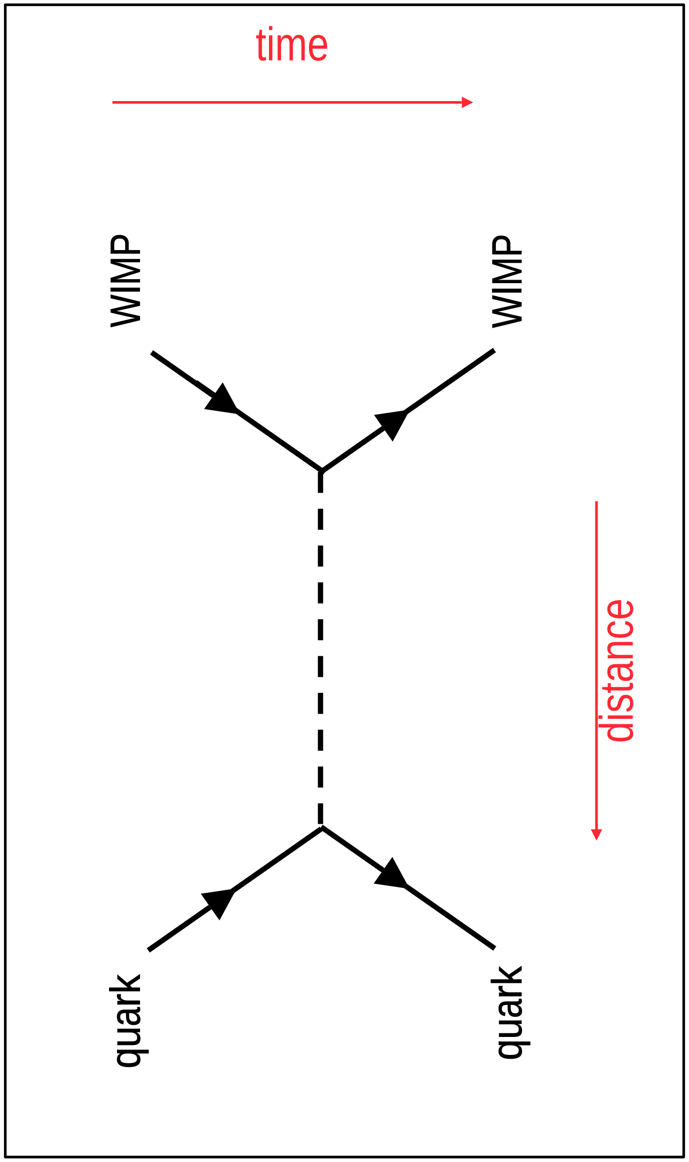
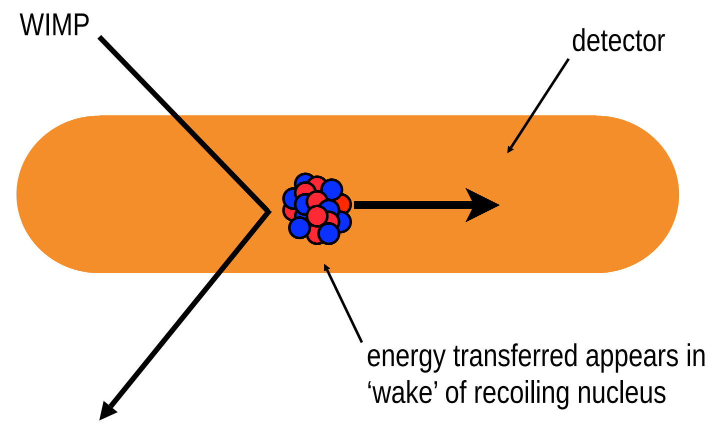


Annihilation ↔ Scattering

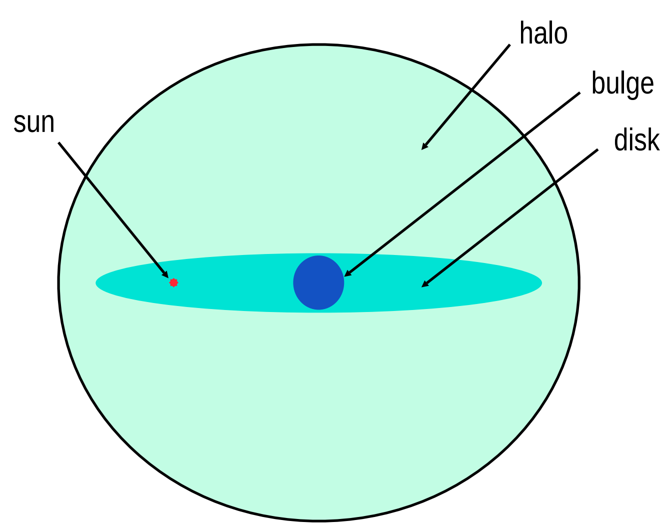


Testing the hypothesis: WIMPs in the Galactic Halo?

WIMPs – the source of Mass in the Rotation Curves?



WIMP-Nucleus Scattering



The Milky Way

Assumption: Scatter from a Nucleus in a Terrestrial Particle Detector

Big Problem: weakly interacting. Expect less than one-a-day in a kilogram detector with E~10keV

How do we make measurements?

In physics, we measure voltages…

Particle Detection

It's simple – detected particle ionizes the gas, collect the charge…

Or detected particle produces a flash of light, which is converted to 'photoelectrons'…

Or detected particle interacts with a nucleus, which ionizes the gas, which…

Or…

Background Radioactivity

It's in the air: a practical demonstration

Before…

It's in the air: a practical demonstration

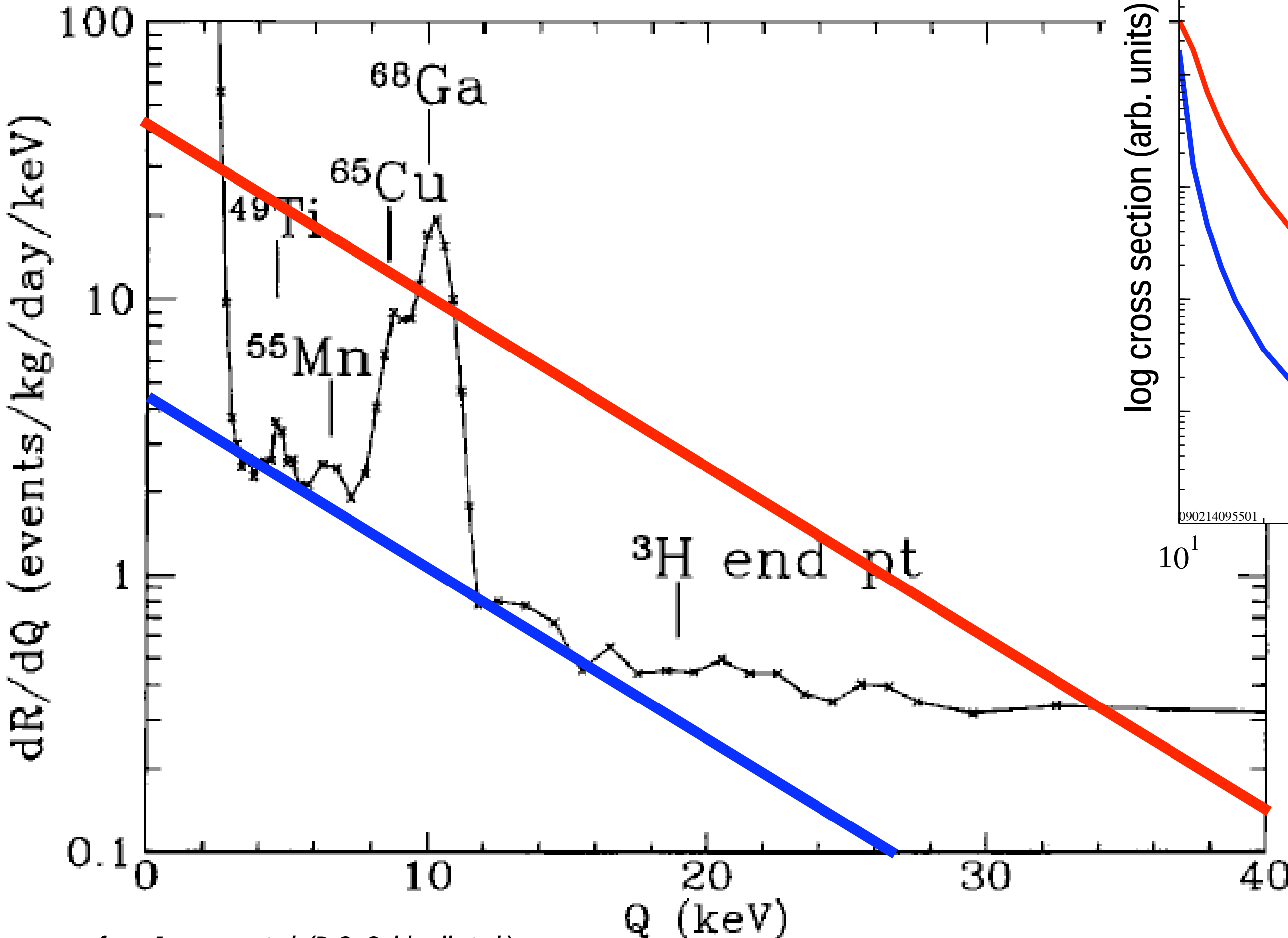
During…

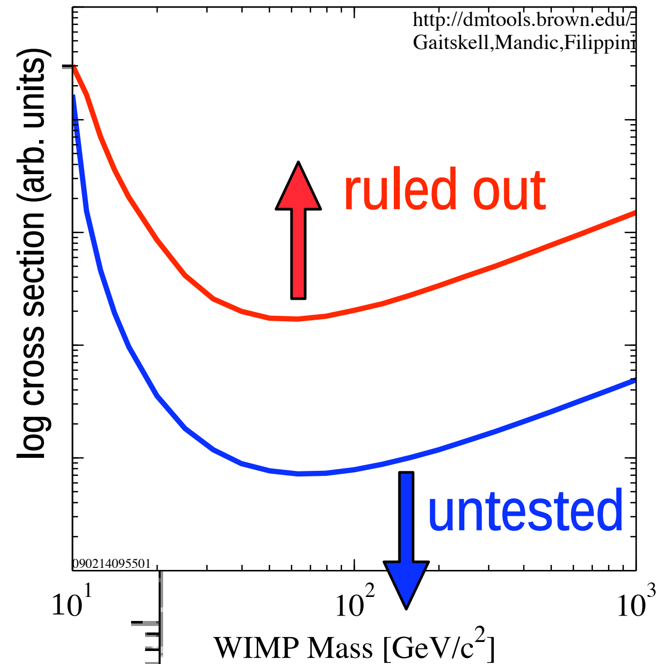
It's in the air: a practical demonstration

After…

WIMP search - c.1988

- Germanium ionization detector (UCSB/UCB/LBL)



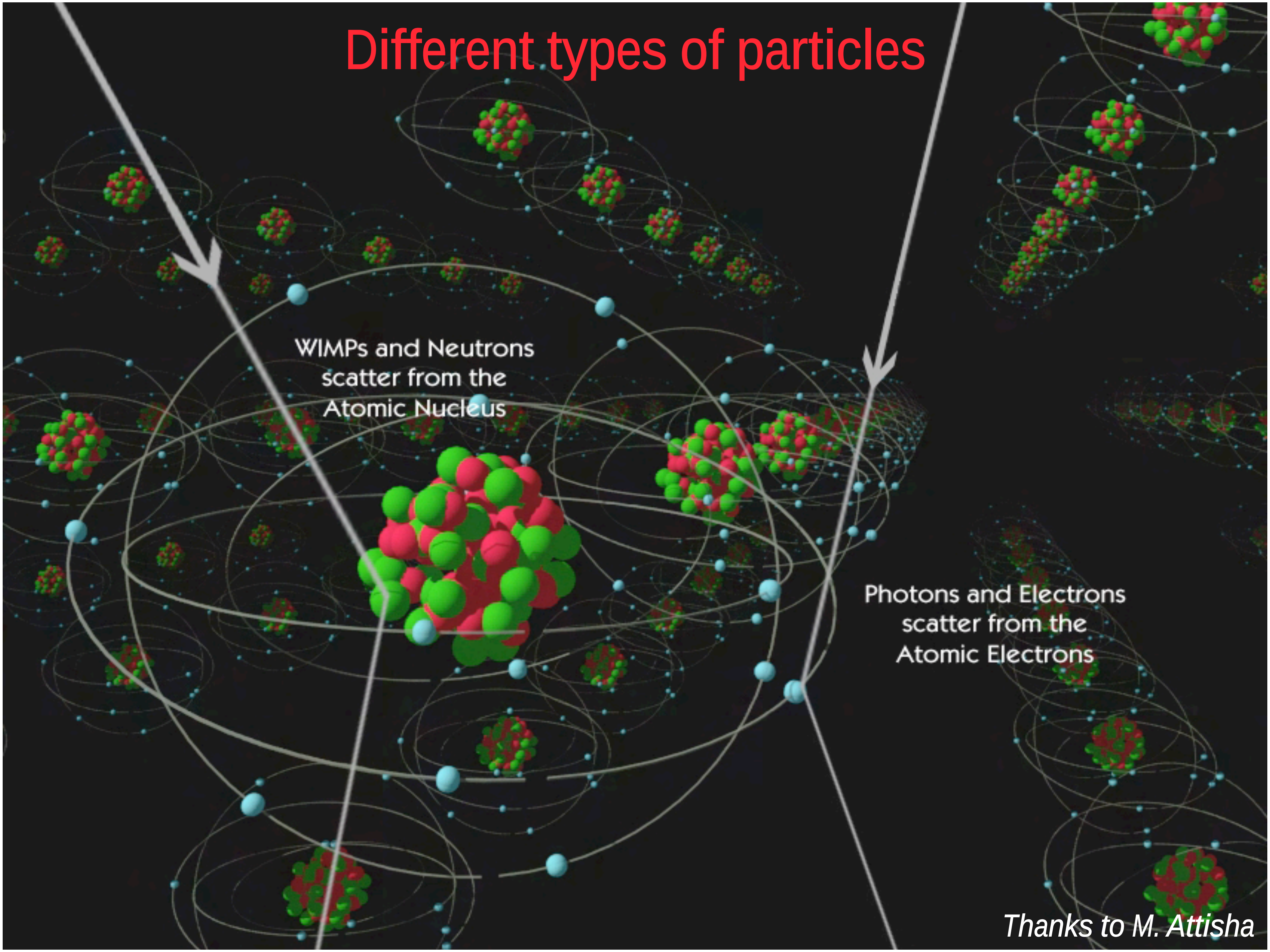


from Jungman et al. (D.O. Caldwell et al.)

What nature has to offer

What you hope for!

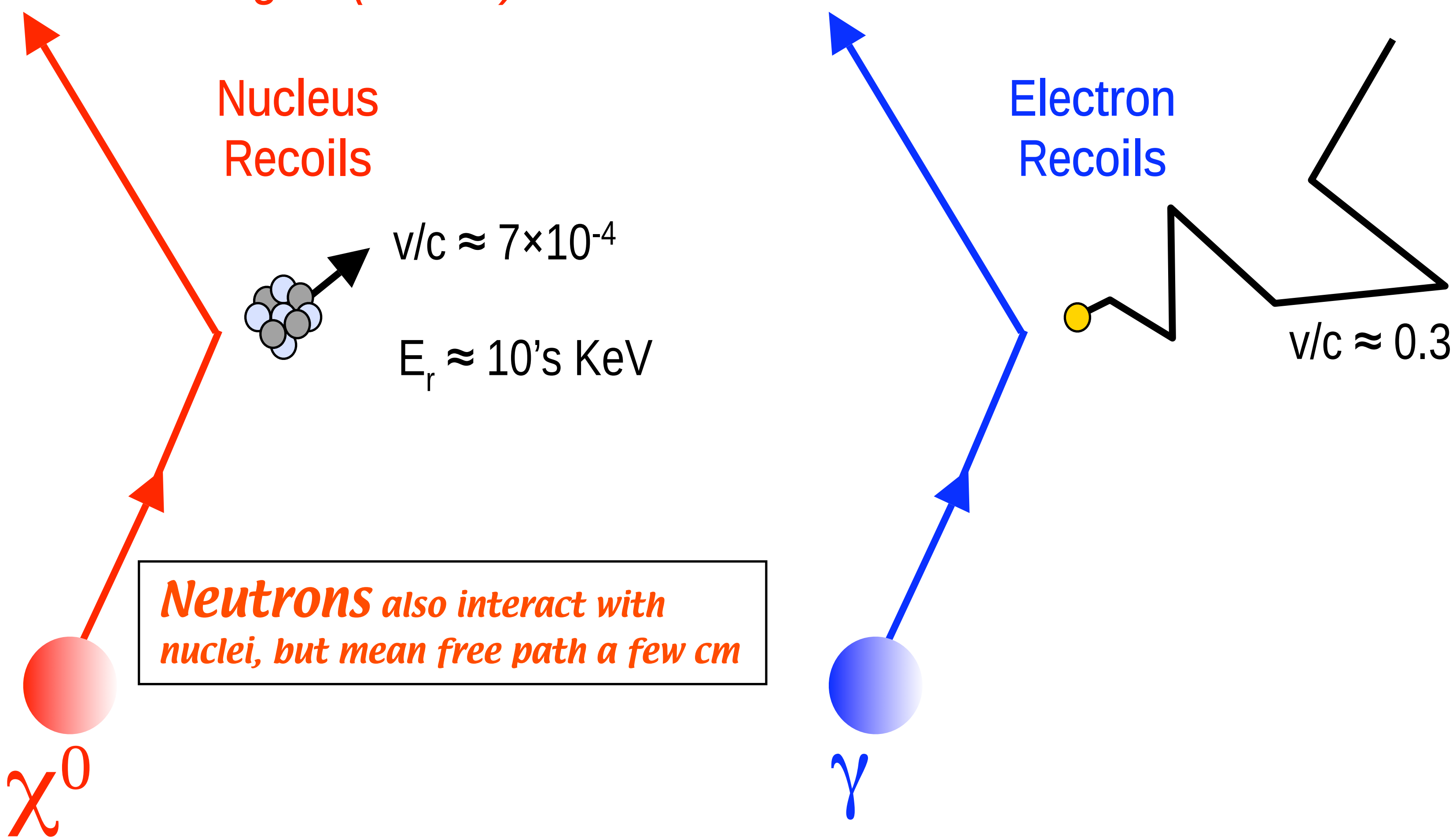
Different types of particles



Thanks to M. Attisha

The Signal and Backgrounds

Signal (WIMPs) *Background (gammas/betas)*

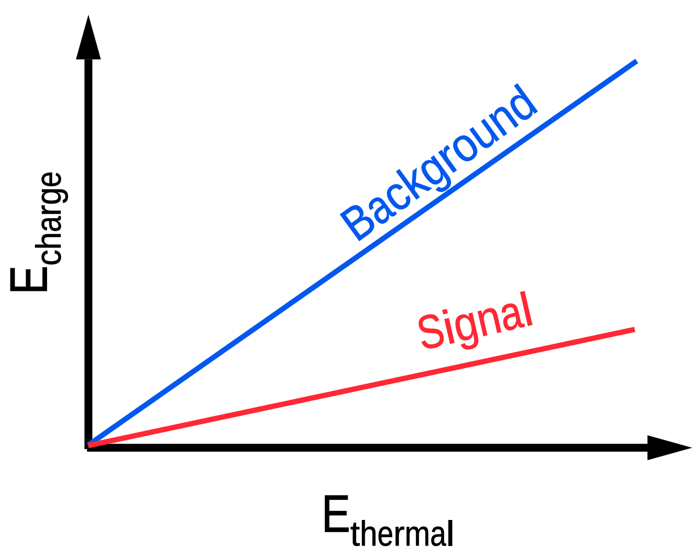


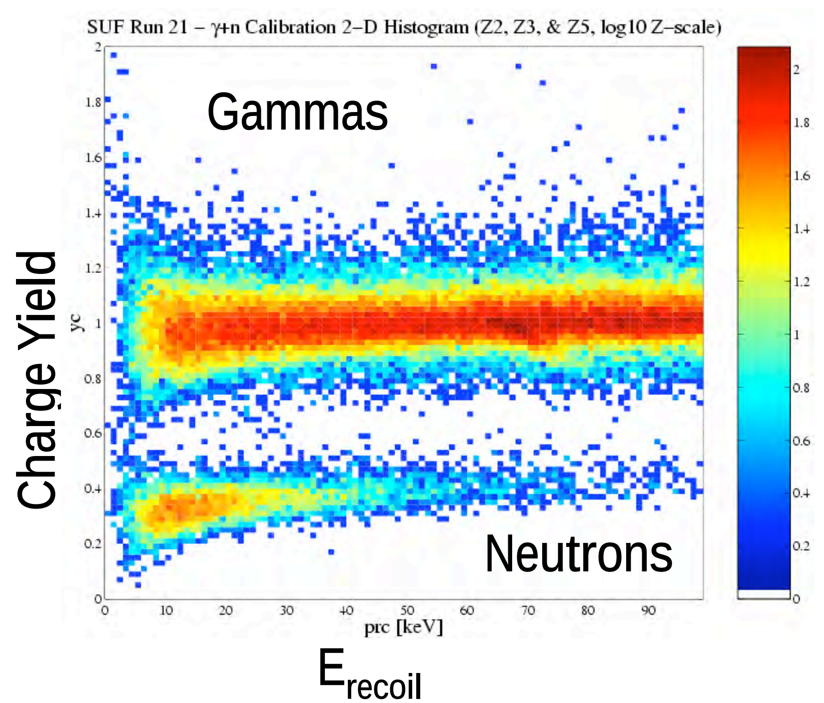
***Neutrons** also interact with nuclei, but mean free path a few cm*

Recoil Discrimination Demonstrated

WIMPs 'look' different – recoil discrimination

- Photons and electrons scatter from electrons
- WIMPs (and neutrons) scatter from nuclei





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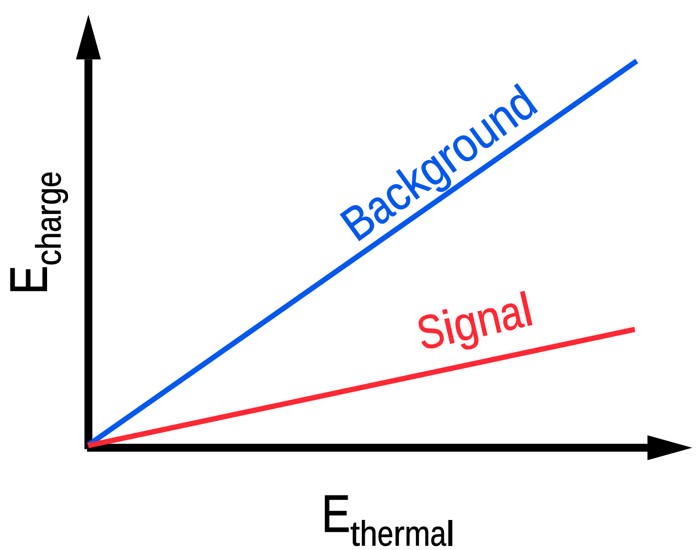
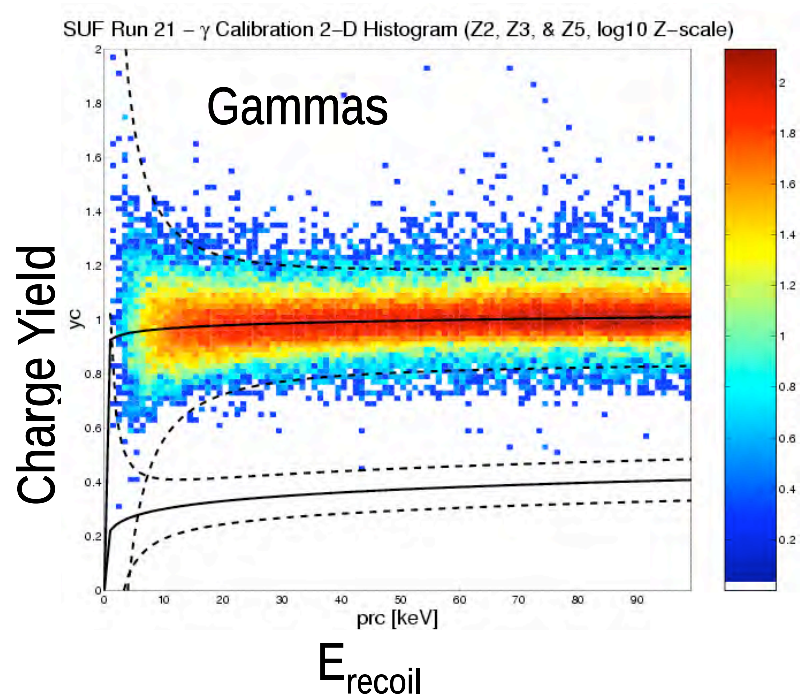
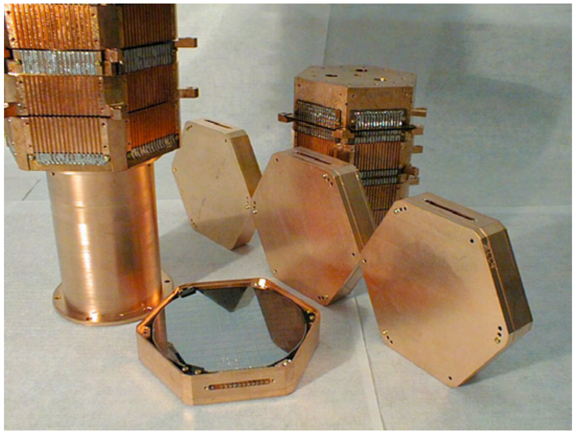


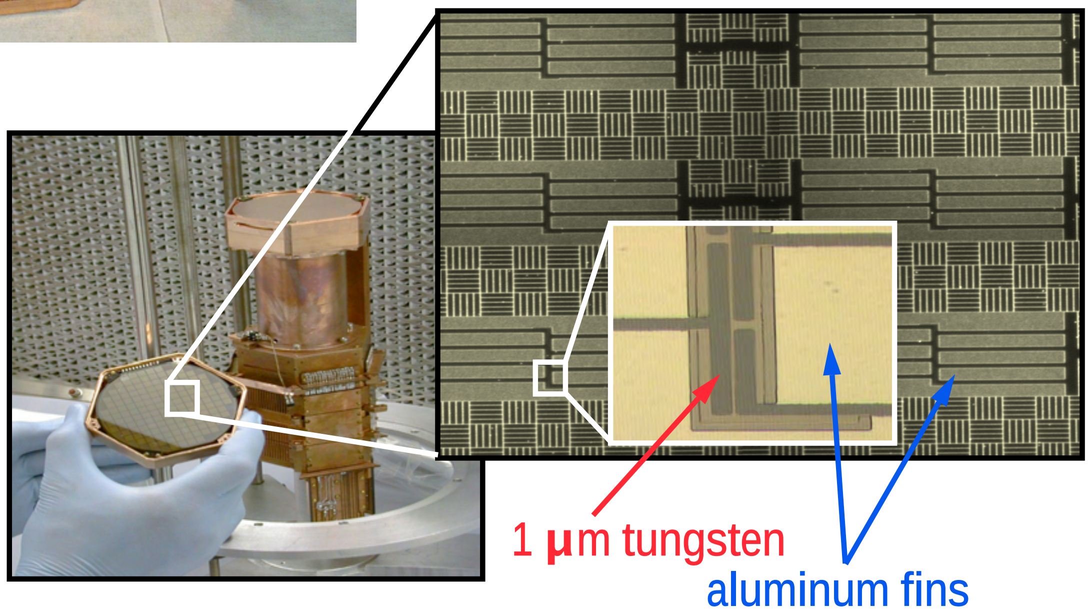
50,000 gamma calibration events



‘Cryogenic’ detectors



- Heat sensitive detectors sensitive to *individual particle interactions.*
- Operated near absolute zero (“cryogenic”)
- Cryogenic Dark Matter Search (CDMS)

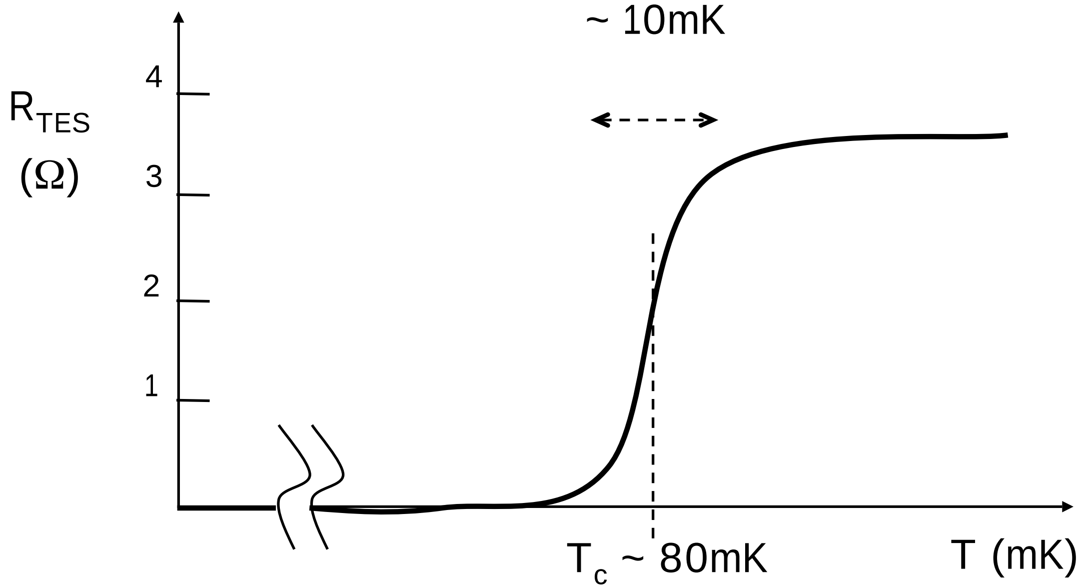


- The detectors are cooled in dilution refrigerators to ~20mK

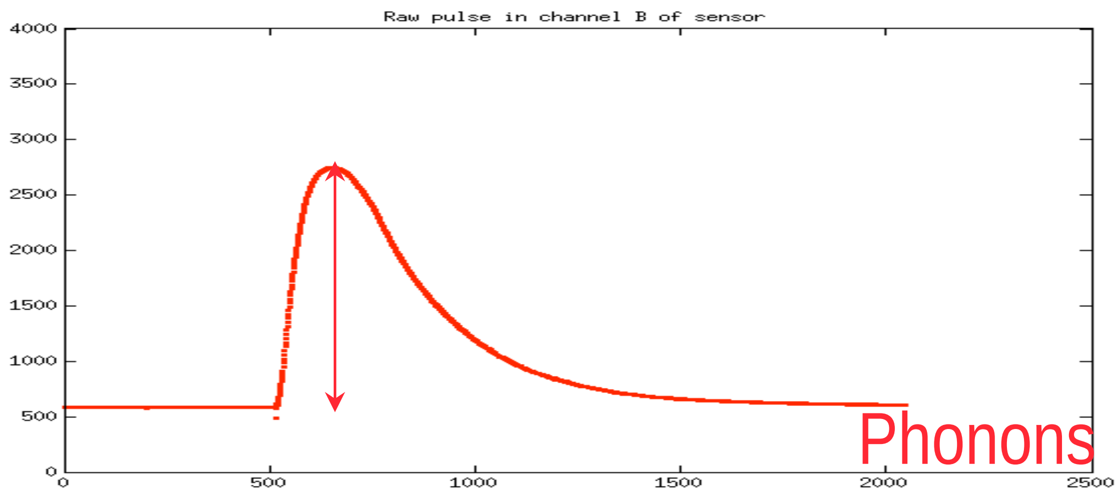
Superconducting Films: Ultrasensitive Thermometers

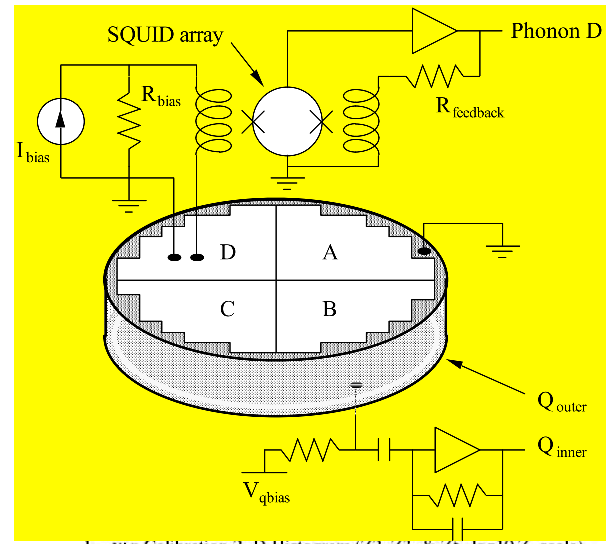
Superconducting films that detect minute amounts of heat

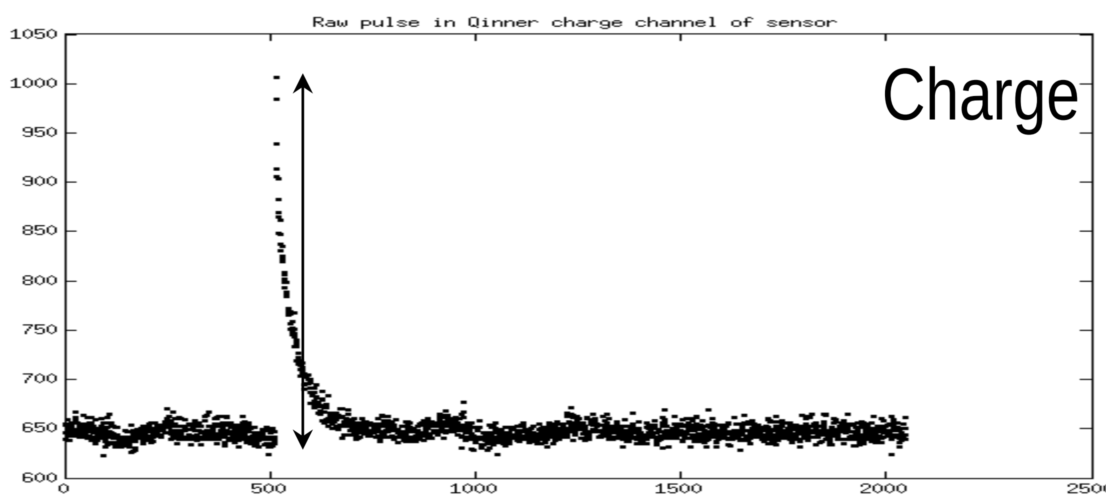
Transition Edge Sensor sensitive to fast athermal phonons

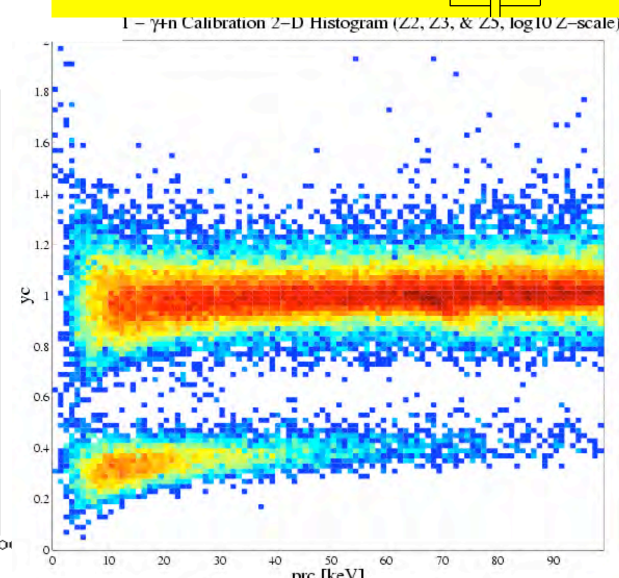


The Voltages We Measure





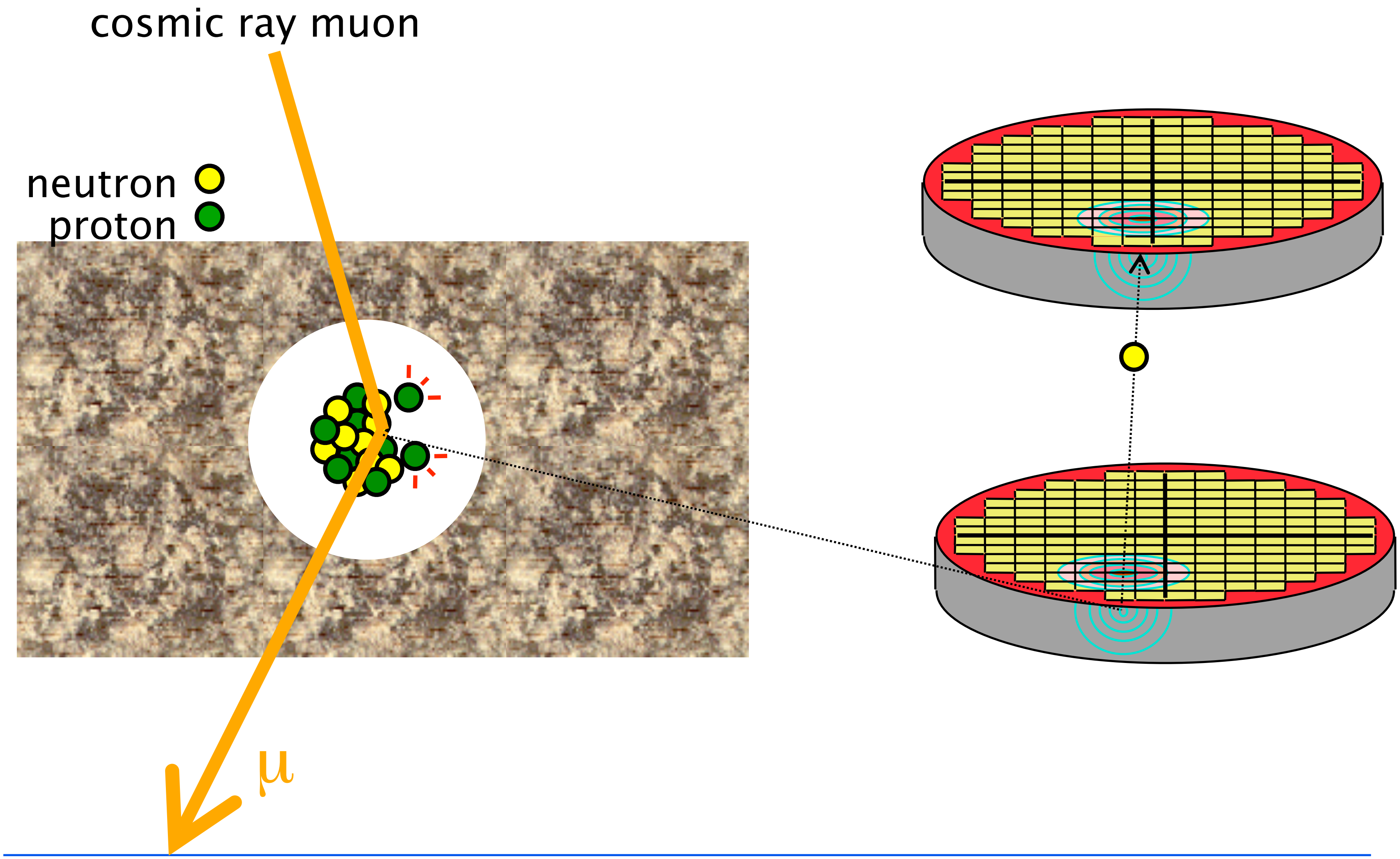




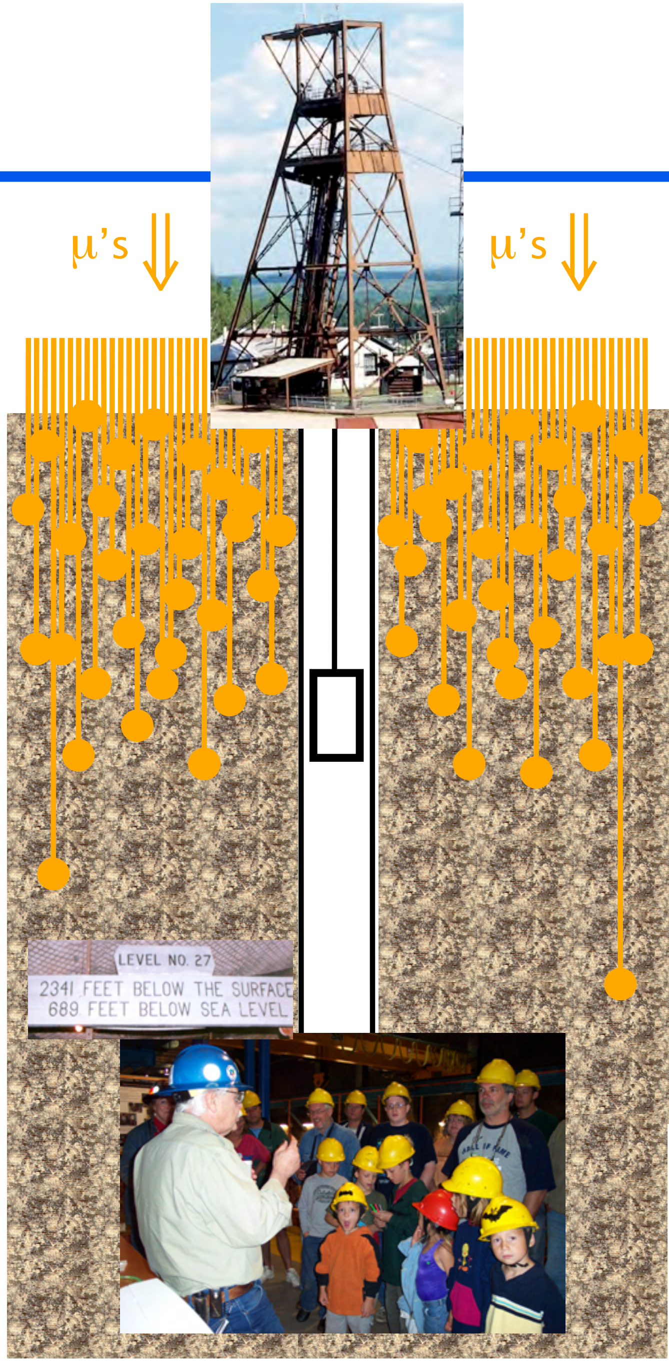
Charge/Phonons

Phonons – Charge = Recoil energy

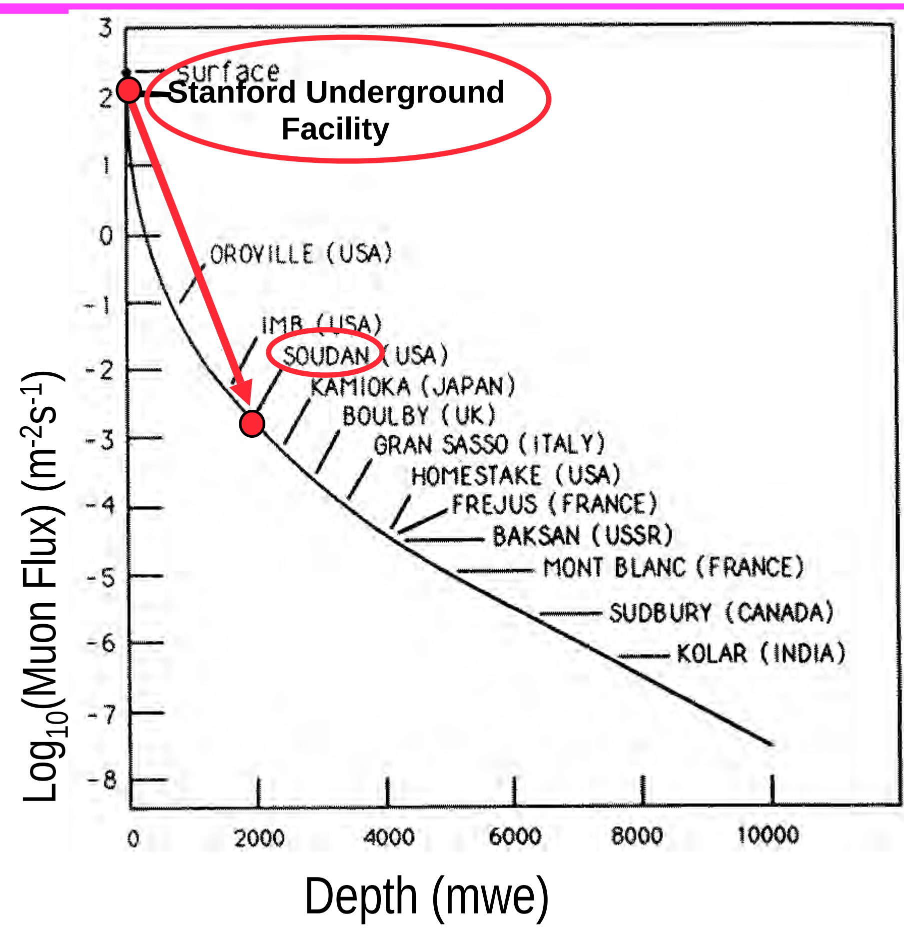
Neutrons: a WIMP-like background



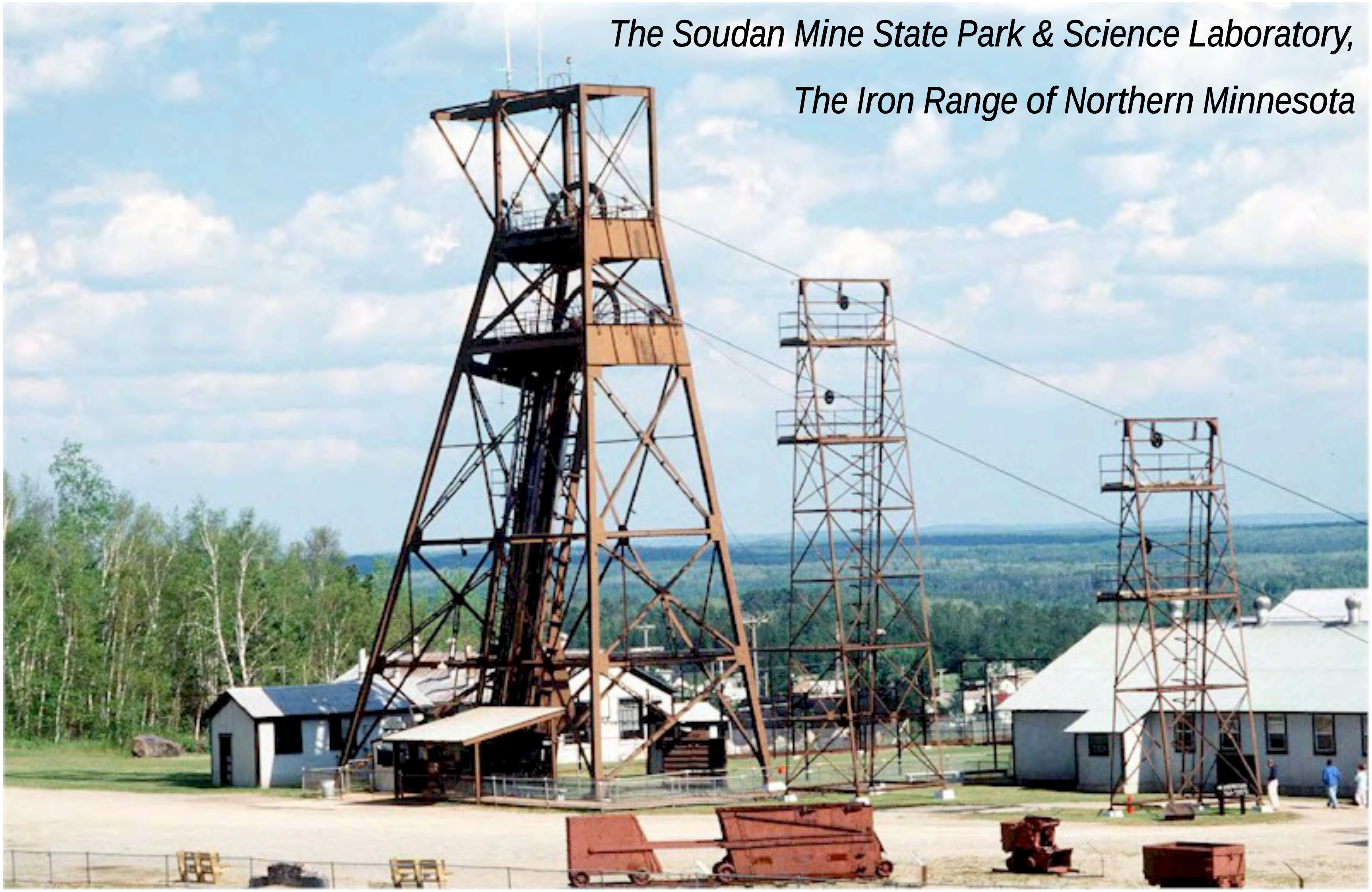
Got neutrons? Go deep



Most muons slow down and stop in the rock



Underground science: 2030' deep

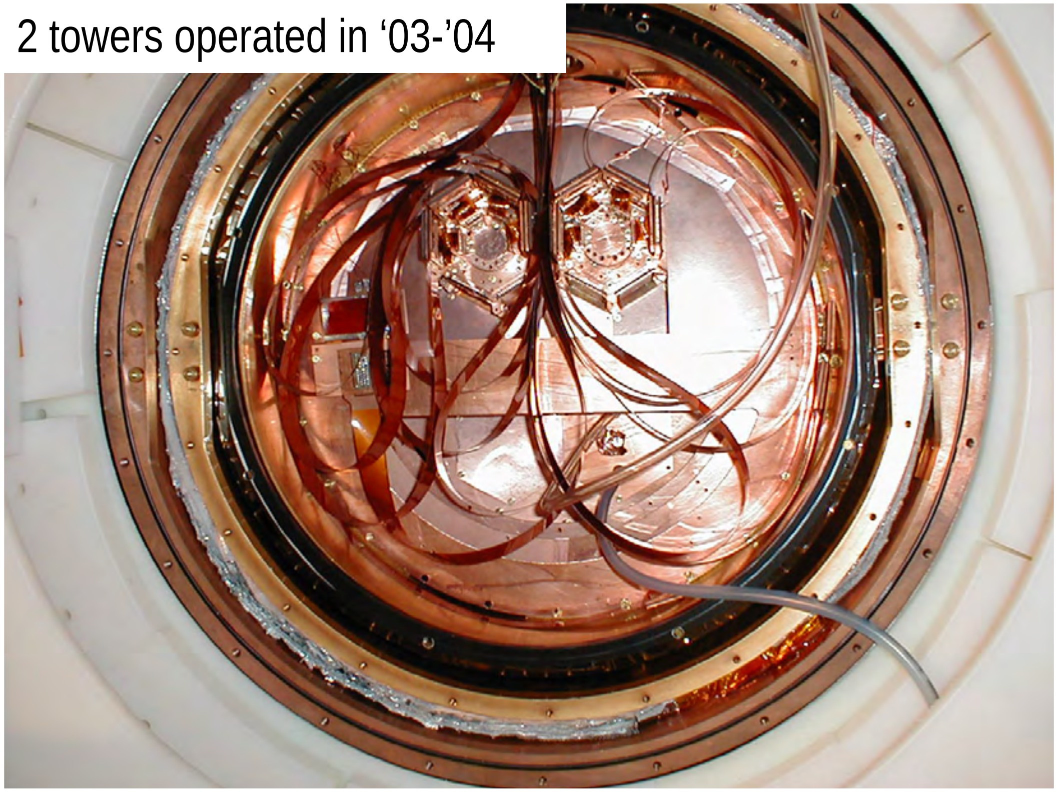


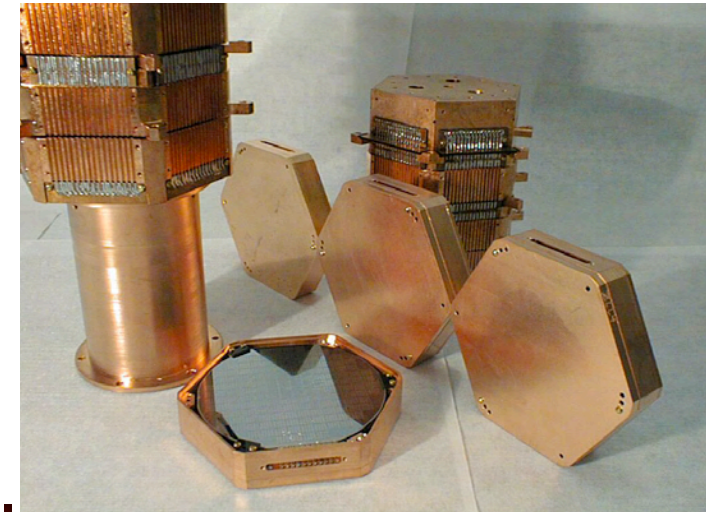
The CDMS II Apparatus

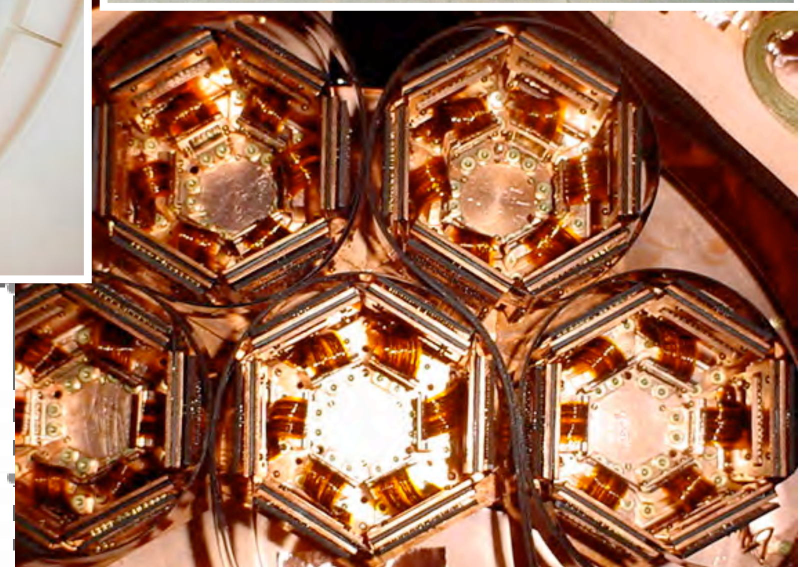
- The Soudan Mine refrigerator includes a low-radioactivity 'clean room' shielded environment
- Science data commenced October 2003
- 2000 mwe depth
  - ~10^5 reduction in muon flux
  - ~400x reduction in fast neutrons
- *New in 2008: first results from first full apparatus*

Detector Towers in Soudan

2 towers operated in '03-'04





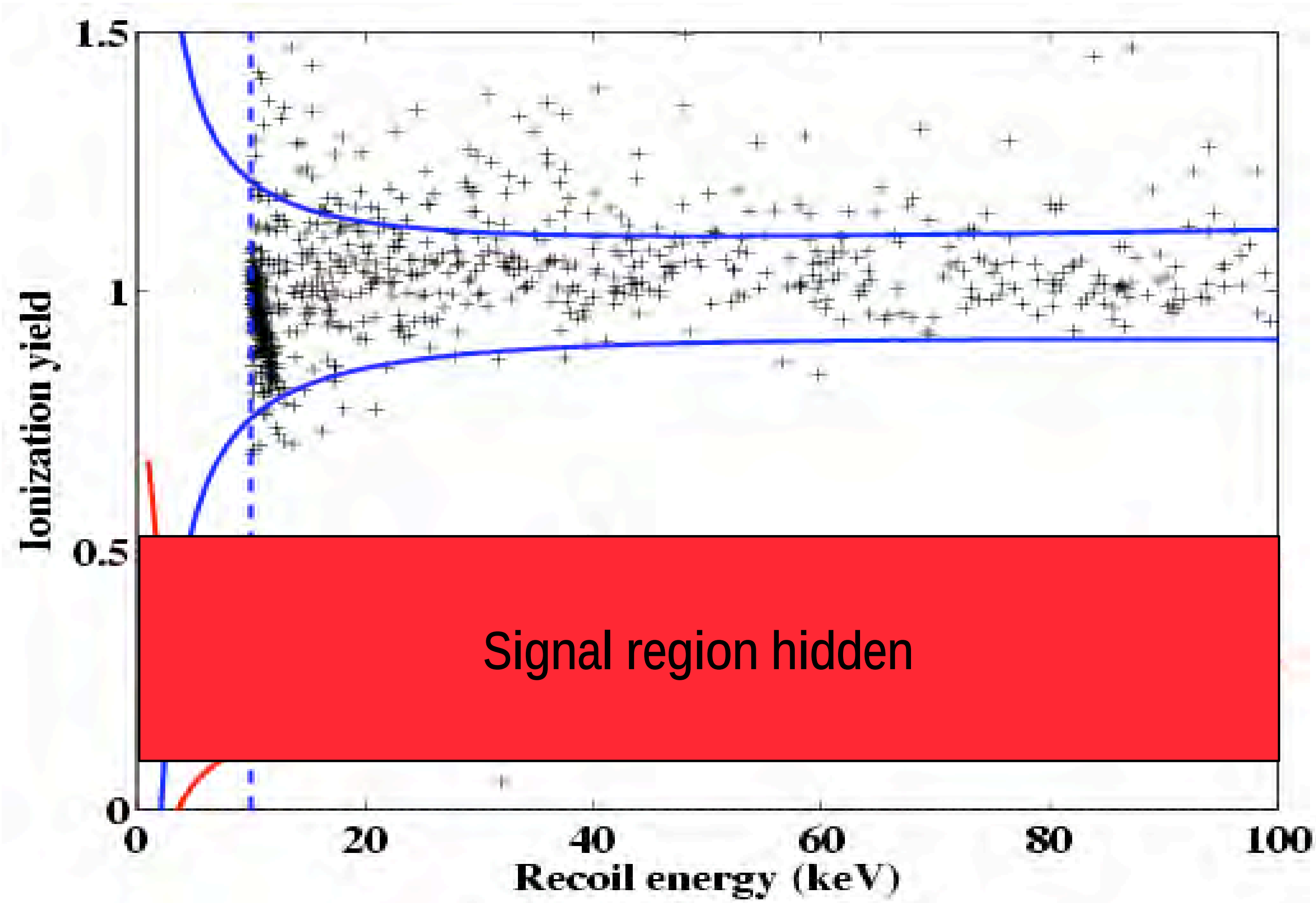


Full 5 towers operating since Oct 2006

	T1	T2	T3	T4	T5
Z1	G6	S14	S17	S12	G7
Z2	G11	S28	G25	G37	G36
Z3	G8	G13	S30	S10	S29
Z4	S3	S25	G33	G35	G26
Z5	G9	G31	G32	G34	G39
Z6	S1	S26	G29	G38	G24

4.75 kg Ge, 1.1 kg Si

WIMP Search Data: blind analysis



Predict Background: 0.6 ± 0.5 surface events and < 0.2 neutrons

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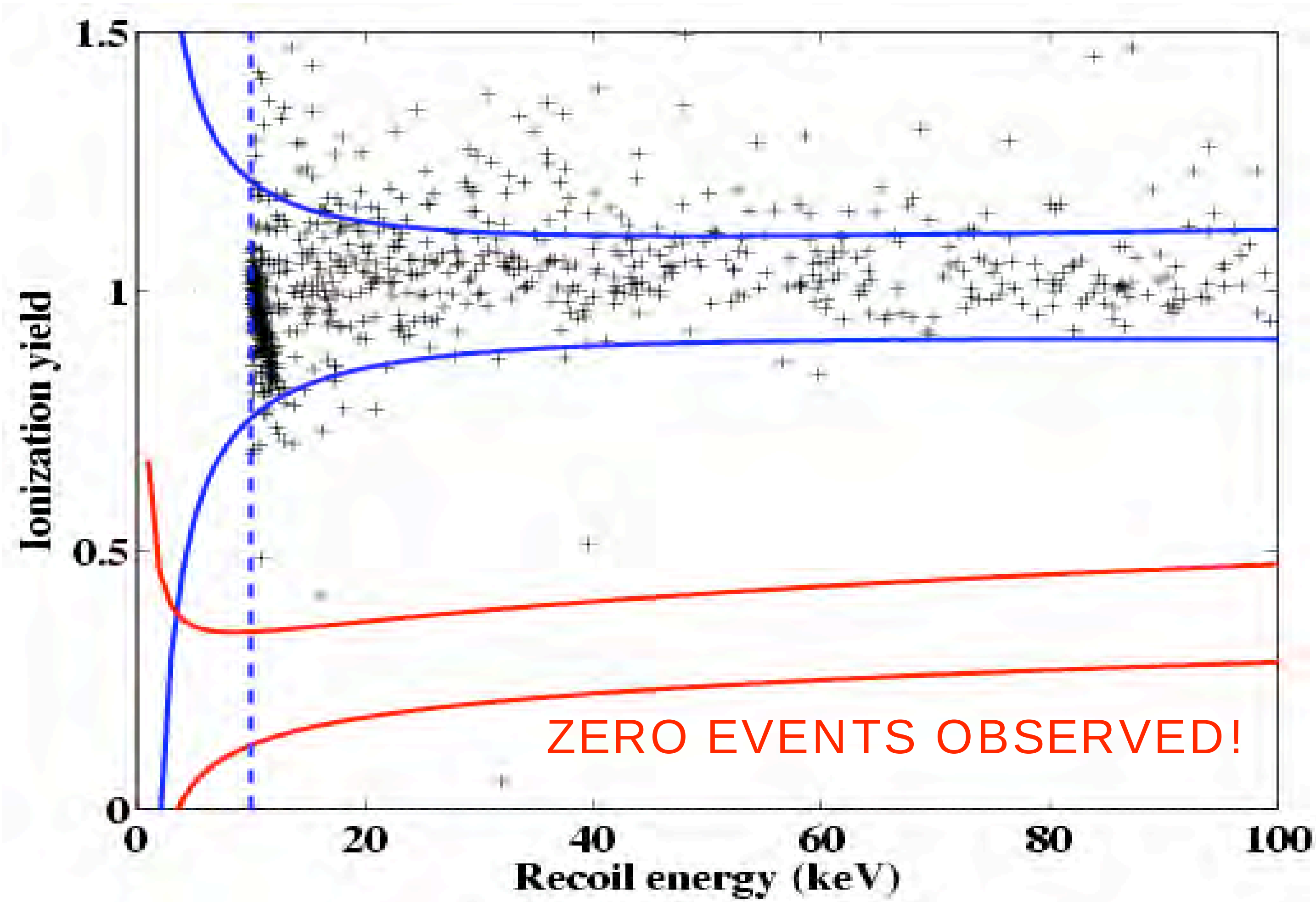

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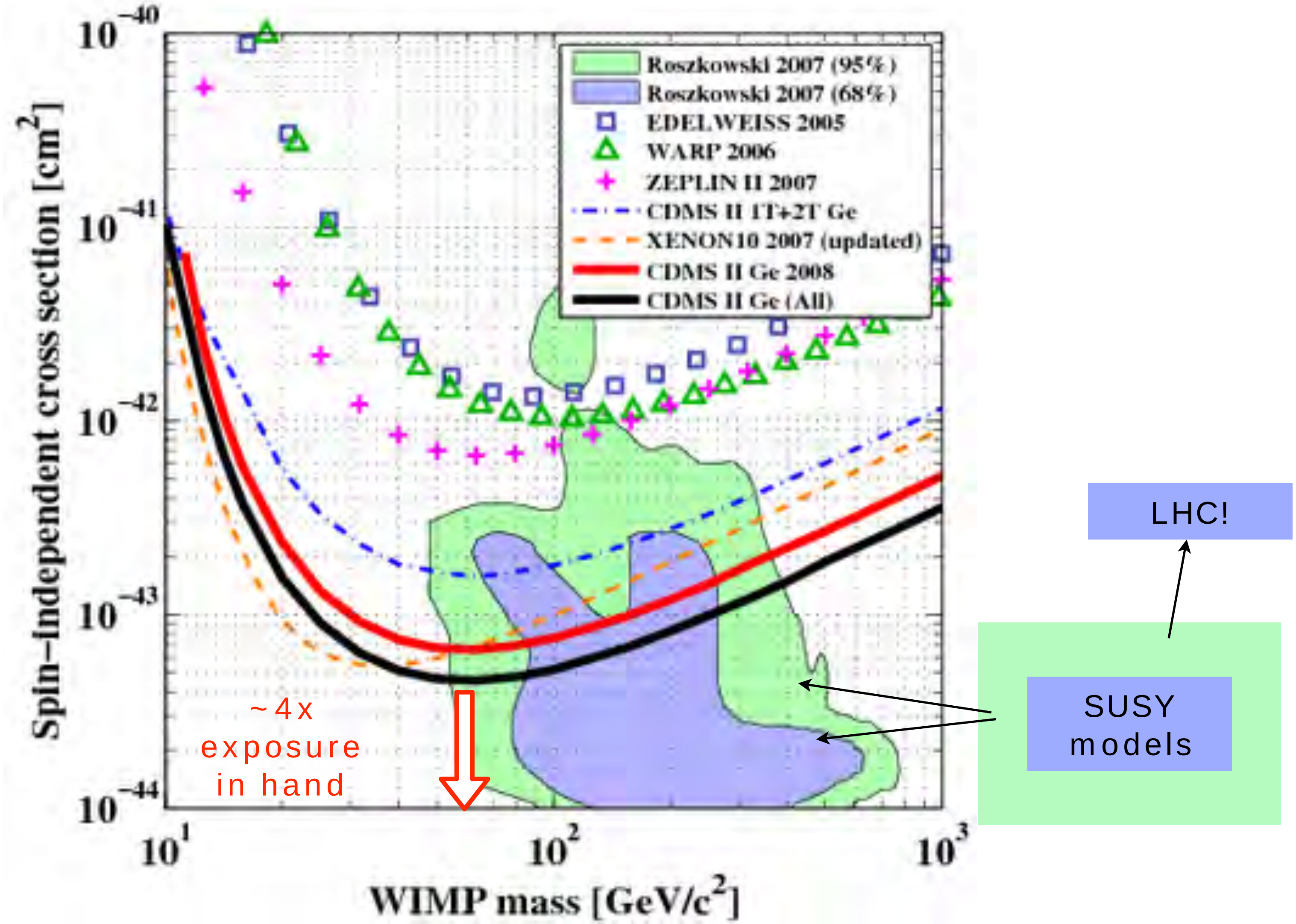
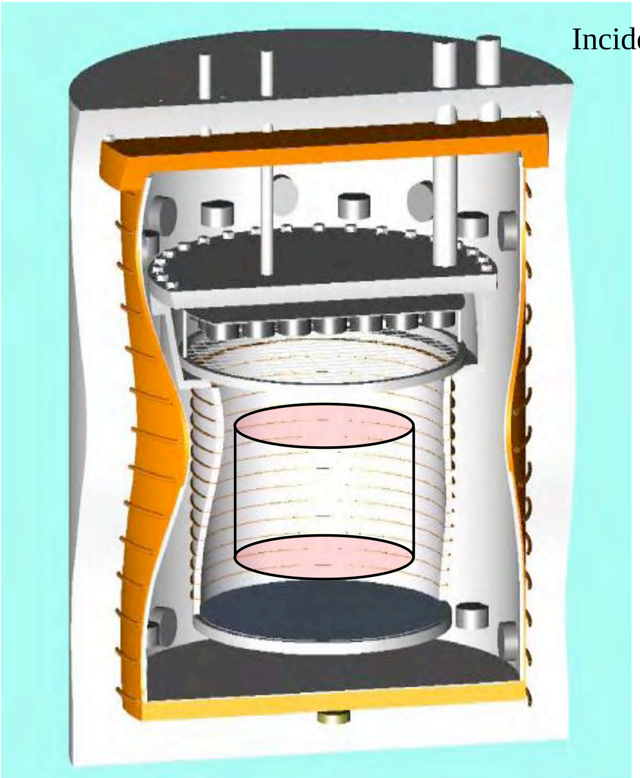
New upper limit on WIMP cross section

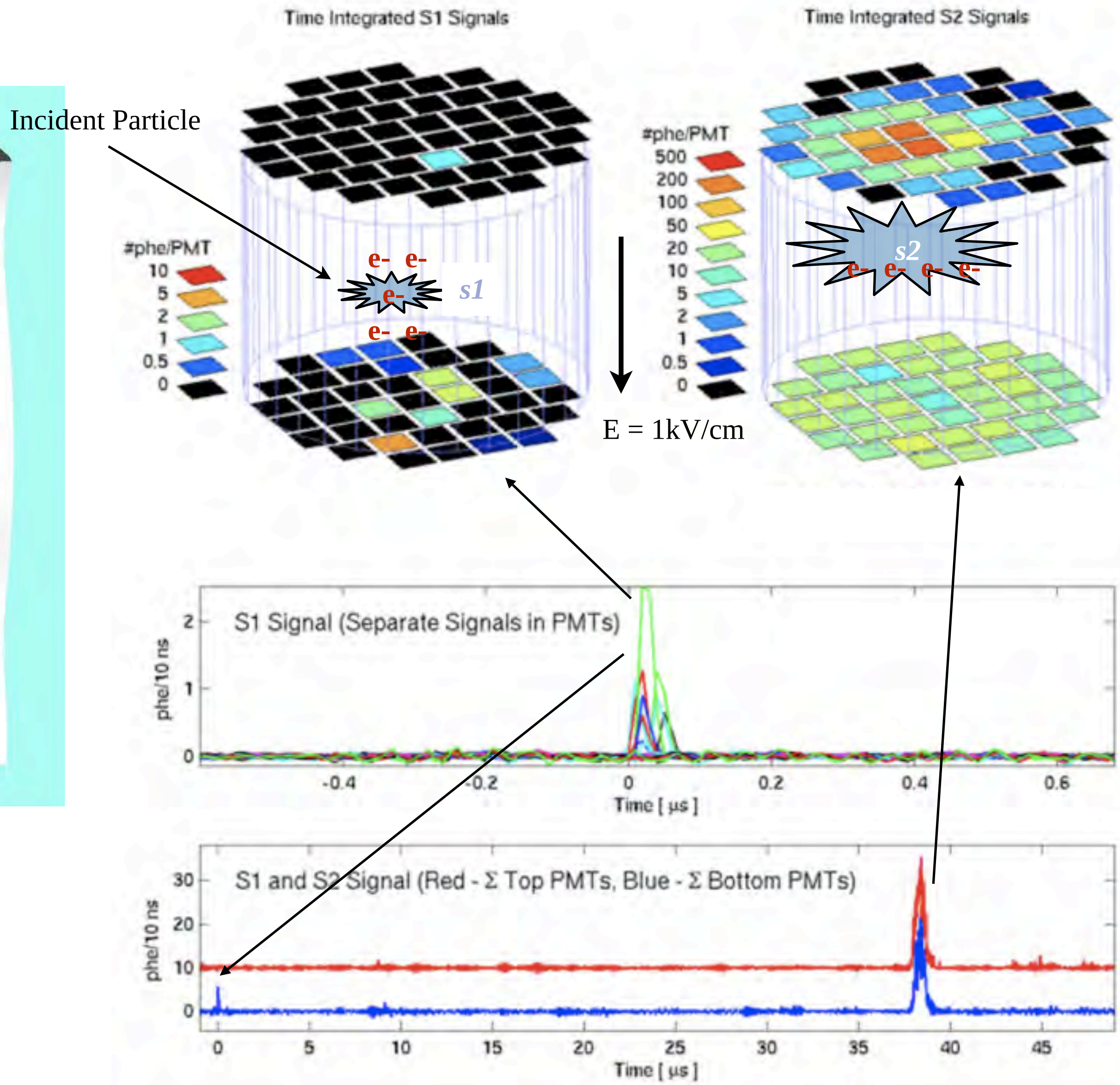


121 kg-day exposure   200 kg-d combined

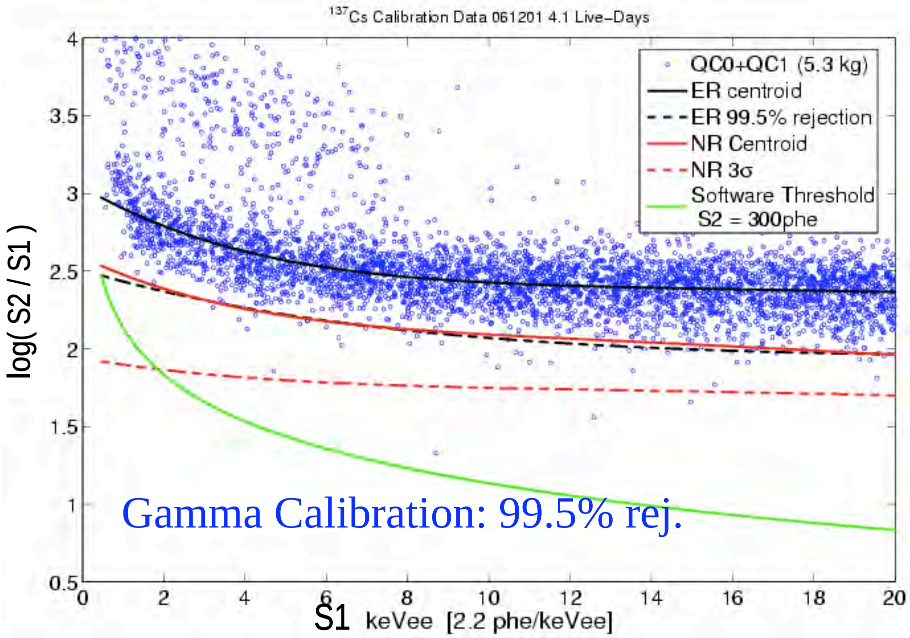
2-Phase Liquid Xenon: scintillation + ionization

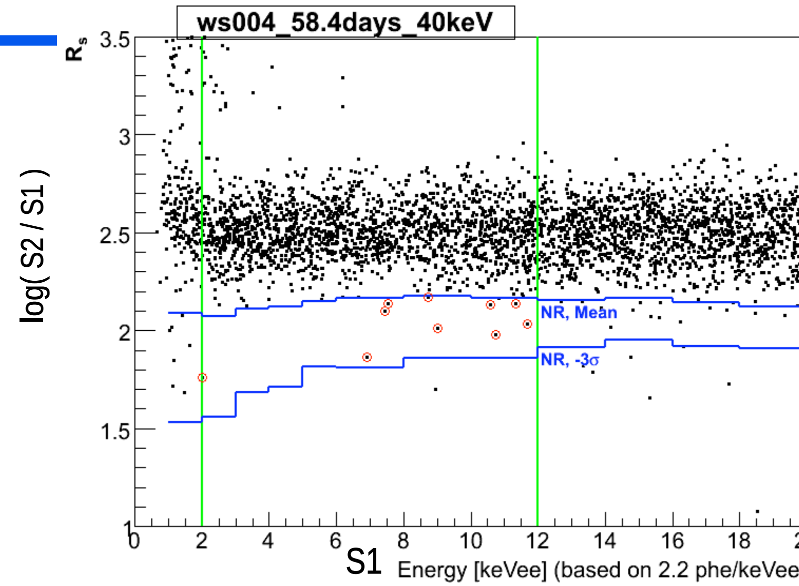
XENON-10 detector

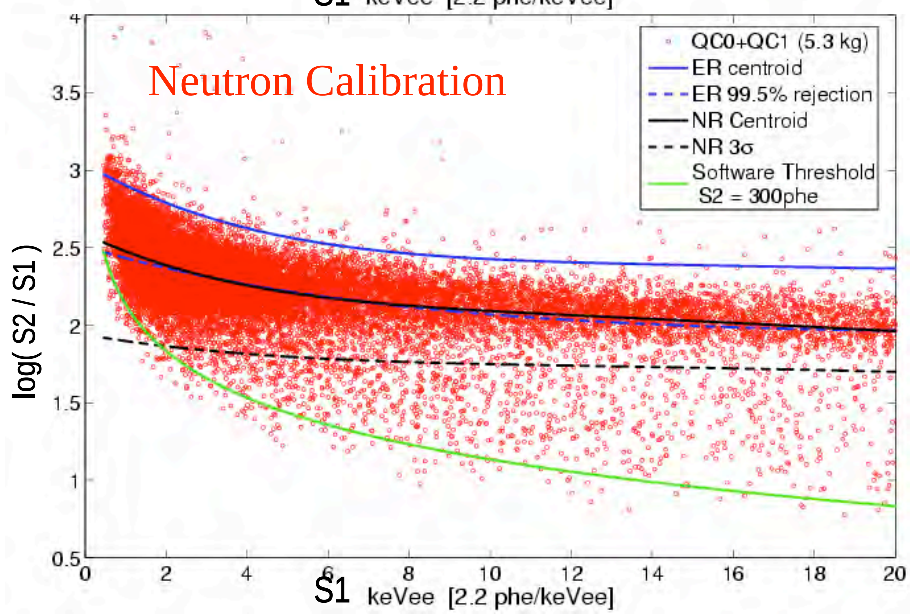


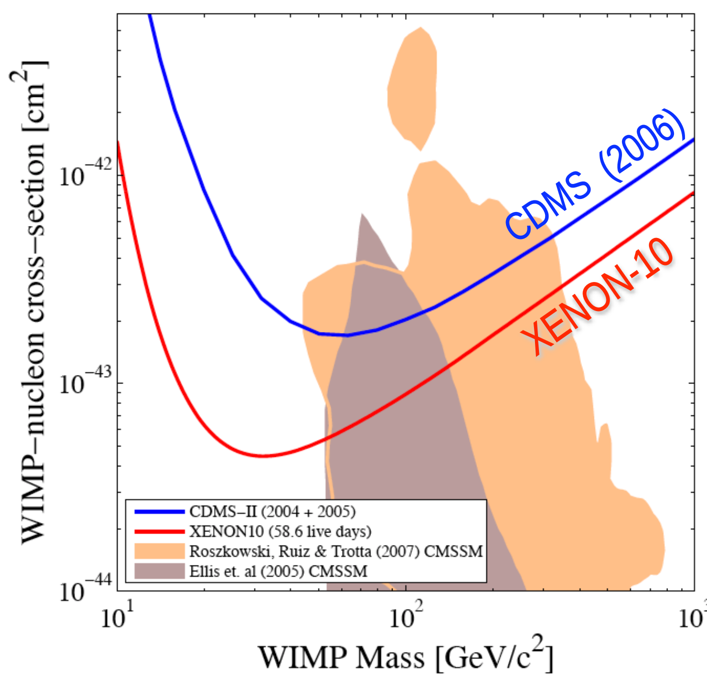


XENON-10 calibrations & results





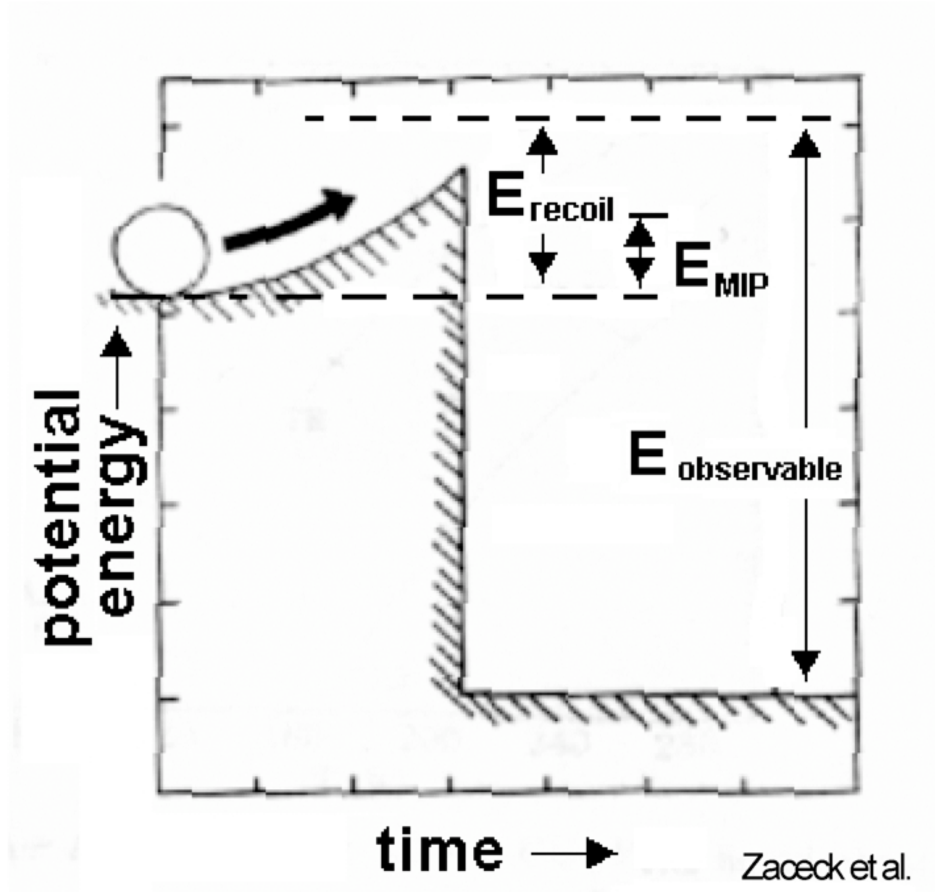




J. Angle et al., PRL 100, 021303 (2008) (arXiv:0706.0039)

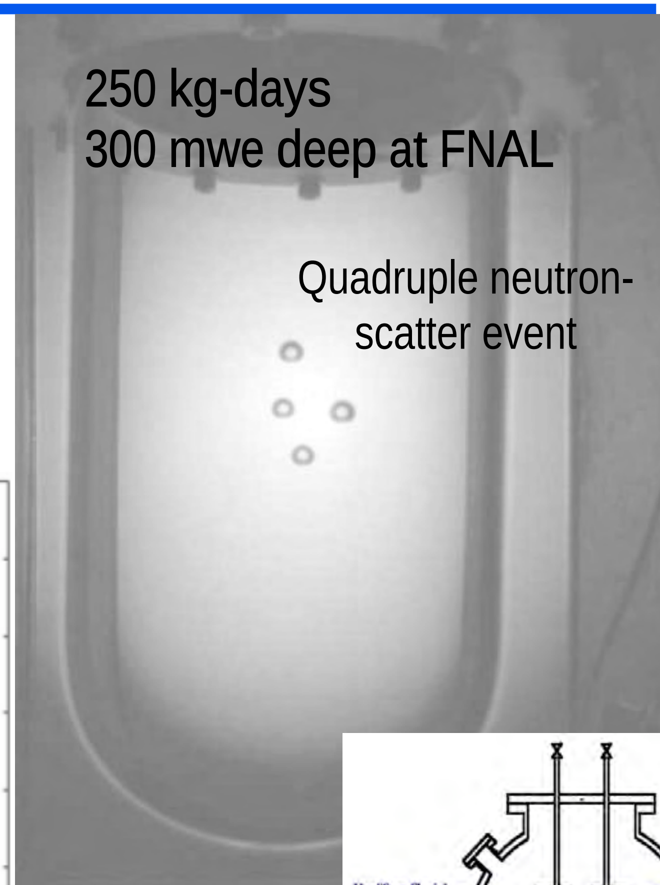
Superheated liquids: immune to EM backgrounds

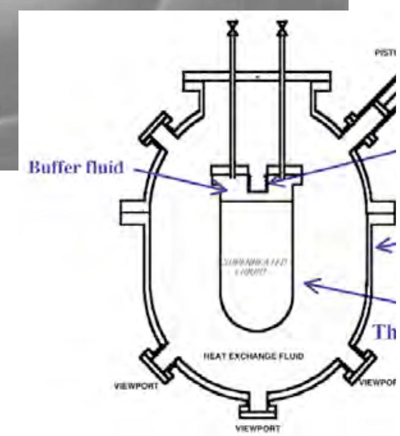
- Principle: Superheated liquid
  - Requires nucleation energy to overcome surface tension and form bubble
  - Tune thermodynamic parameters
    - Insensitive to min. ionizing and low-energy electron recoils
    - Sensitive to higher-energy-density nuclear recoils
  - Threshold detector - release of stored energy enhances observability

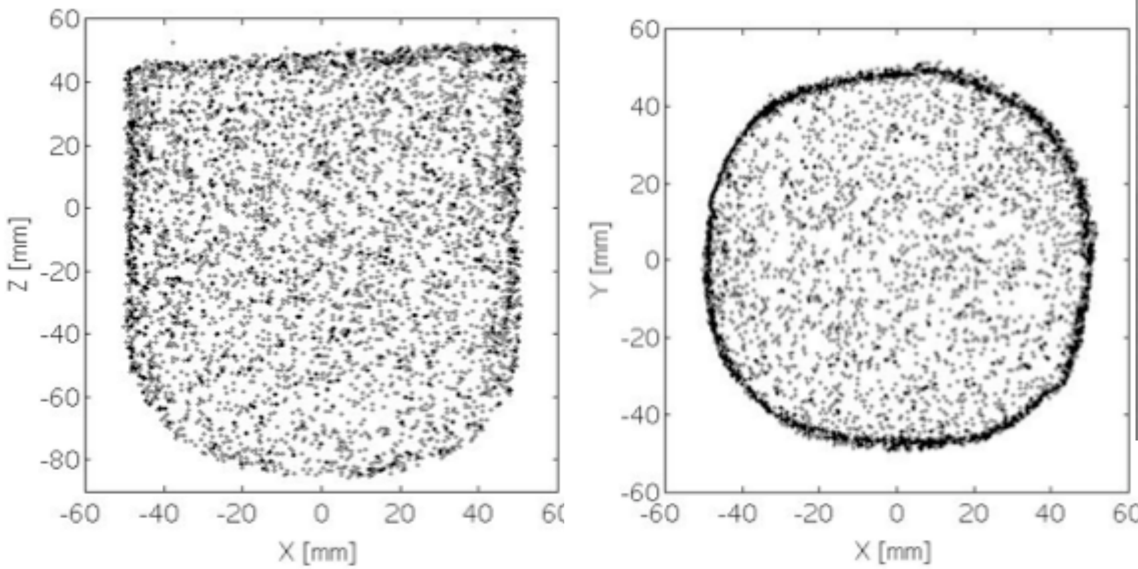


COUPP: Bubble Chamber Revival

- 2-kg CF_3I Bubble Chamber – U. of Chicago, U. of Indiana/South Bend, and Fermilab
- Two principal challenges:
  - passivate nucleation from vessel walls
    ⇒ trigger rate ~ laboratory neutron background ✔
  - internal alphas ~ 85% dead time ~ 200 events/day ✔

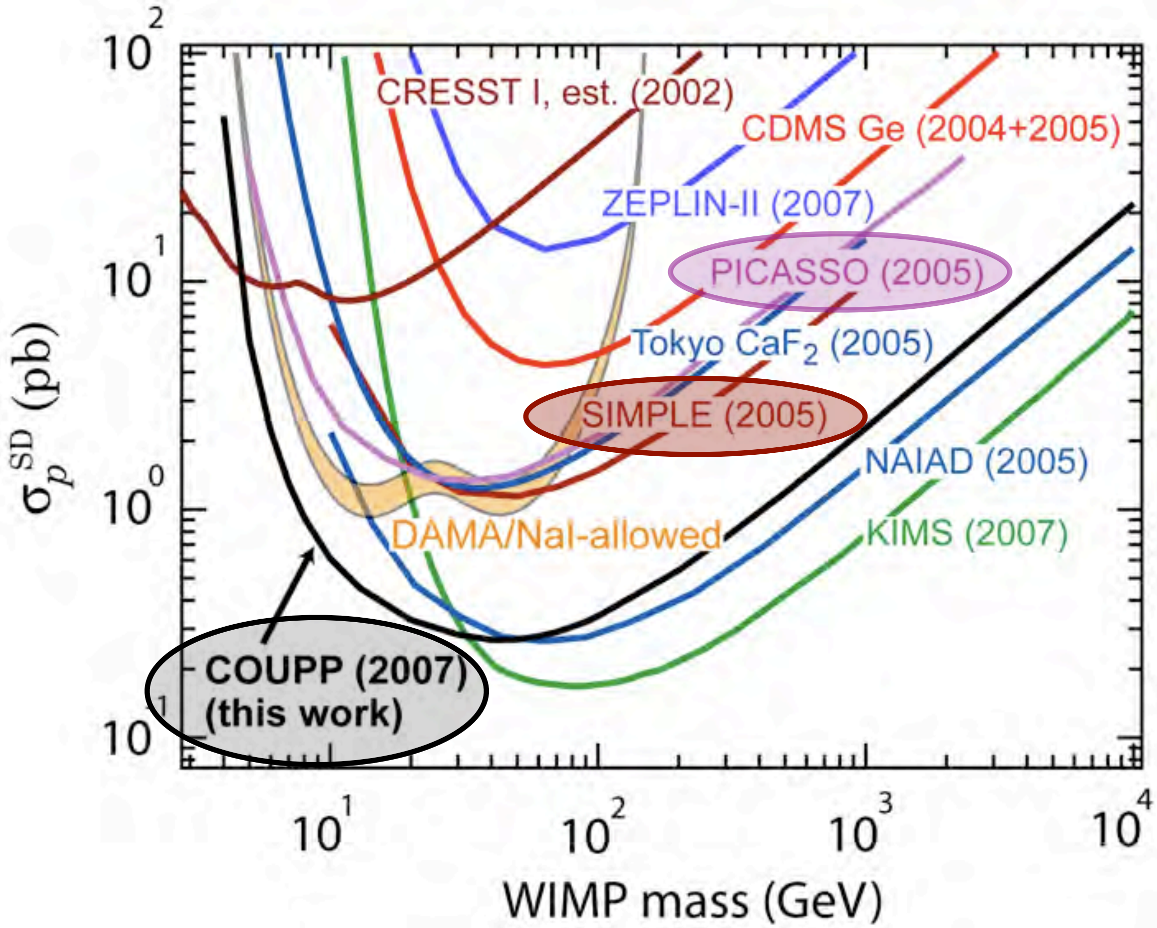






reject wall events
residual bulk events from radon progeny

Superheated Detectors: Spin Dependent limits

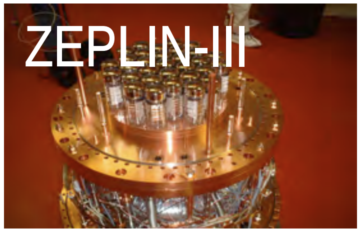


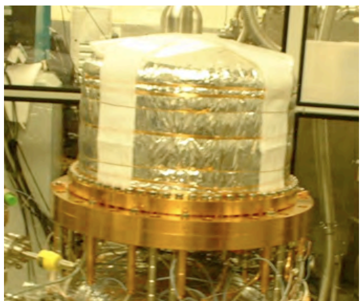
coupling to proton

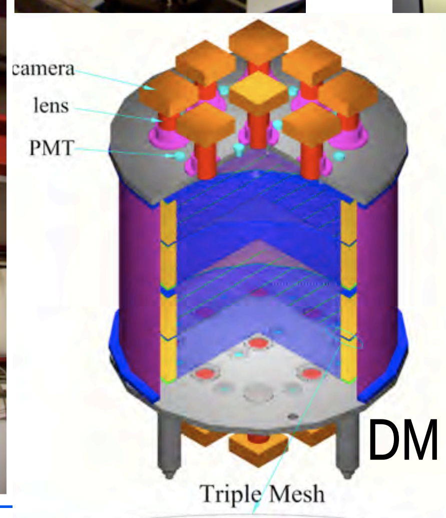
*from Science **319**, 15 Feb 2008*

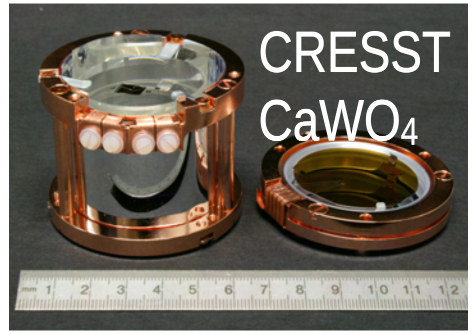
When spin independent coupling suppressed, rate dominated by axial coupling to unpaired nucleon

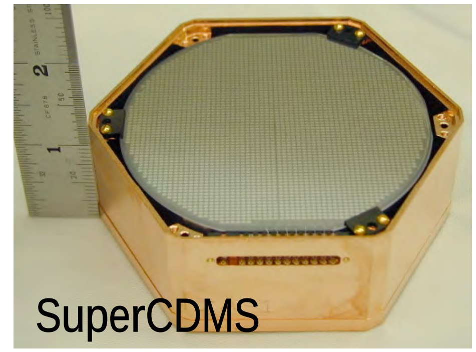
Active / International Field: representative sample







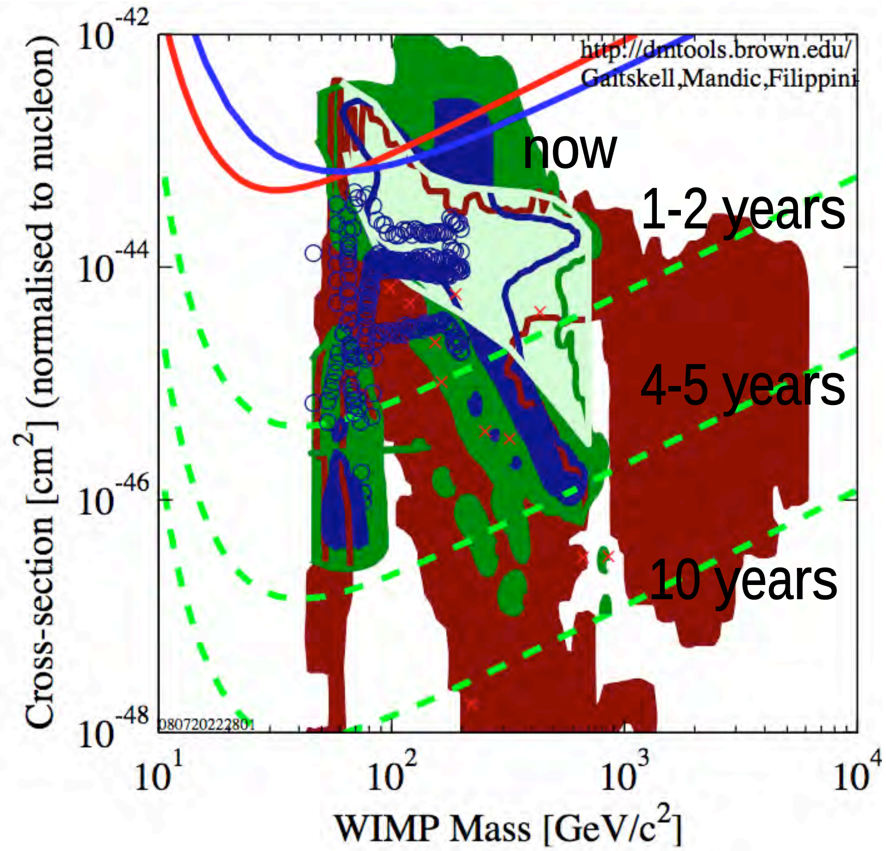




Summary

- Dark matter remains a fundamental mystery -- do we understand gravity?
  - Possible solution lies in new fundamental particle physics
    - Establishing a concordant model requires laboratory and astrophysical meas.

      particle mass, lifetime, relic density, halo
- Advances in sensitivity
  - New generation of detectors
  - Technology ready for major scale-up
  - Proposed new national lab - DUSEL
  - Next 5-10 years looks very exciting!



Acknowledgments

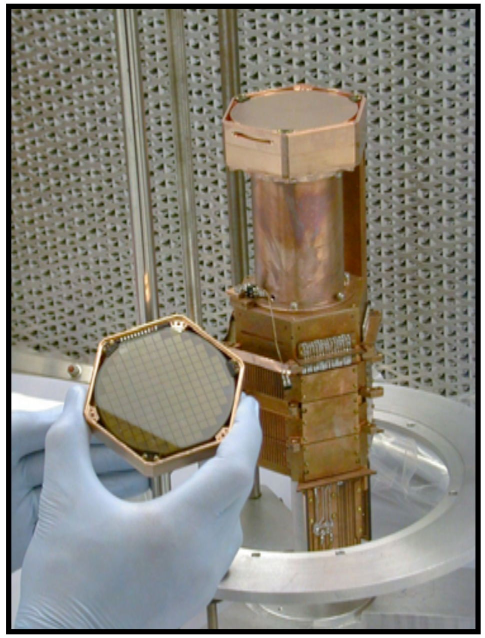
CDMS Collaboration

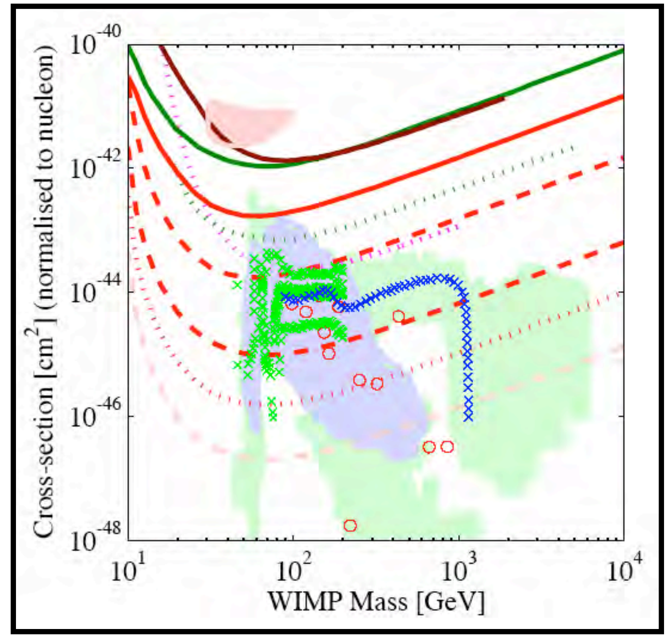
Caltech, Case Western Reserve U., Fermilab, Zurich, U of Florida, MIT, Queen's U., Santa Clara U., Stanford U., Syracuse U., UC Berkeley, UC Santa Barbara, CU Denver, U. of Minnesota

LUX Collaboration

Brown U., Case Western Reserve U., LBNL, LLNL, U. of Maryland, UC Davis, U. of Rochester, U. of South Dakota, Texas A&M U., Yale U.

Thank you…




Cross-section [cm^2] (normalised to nucleon)
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
10^1
10^2
10^3
10^4
WIMP Mass [GeV]