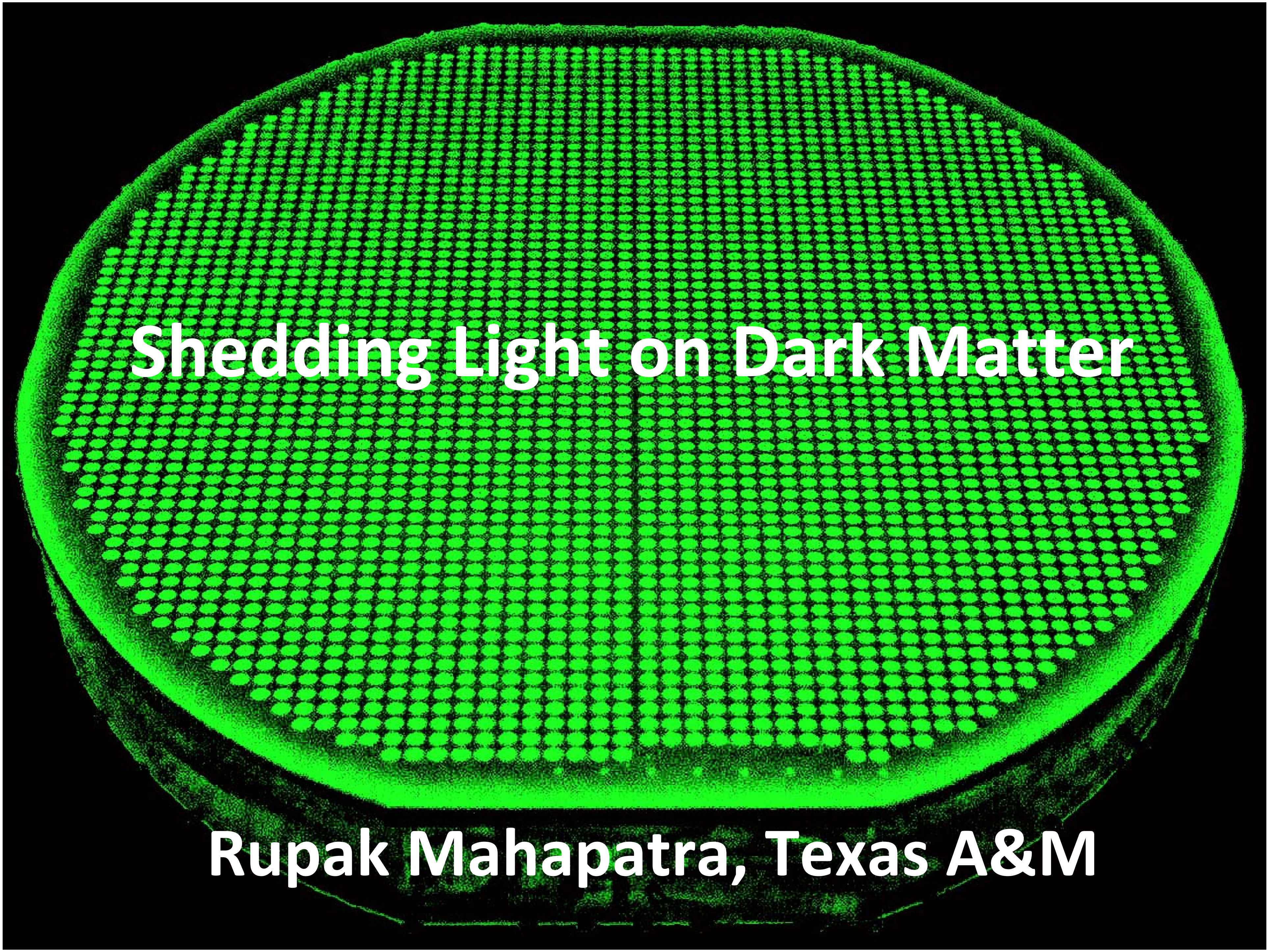
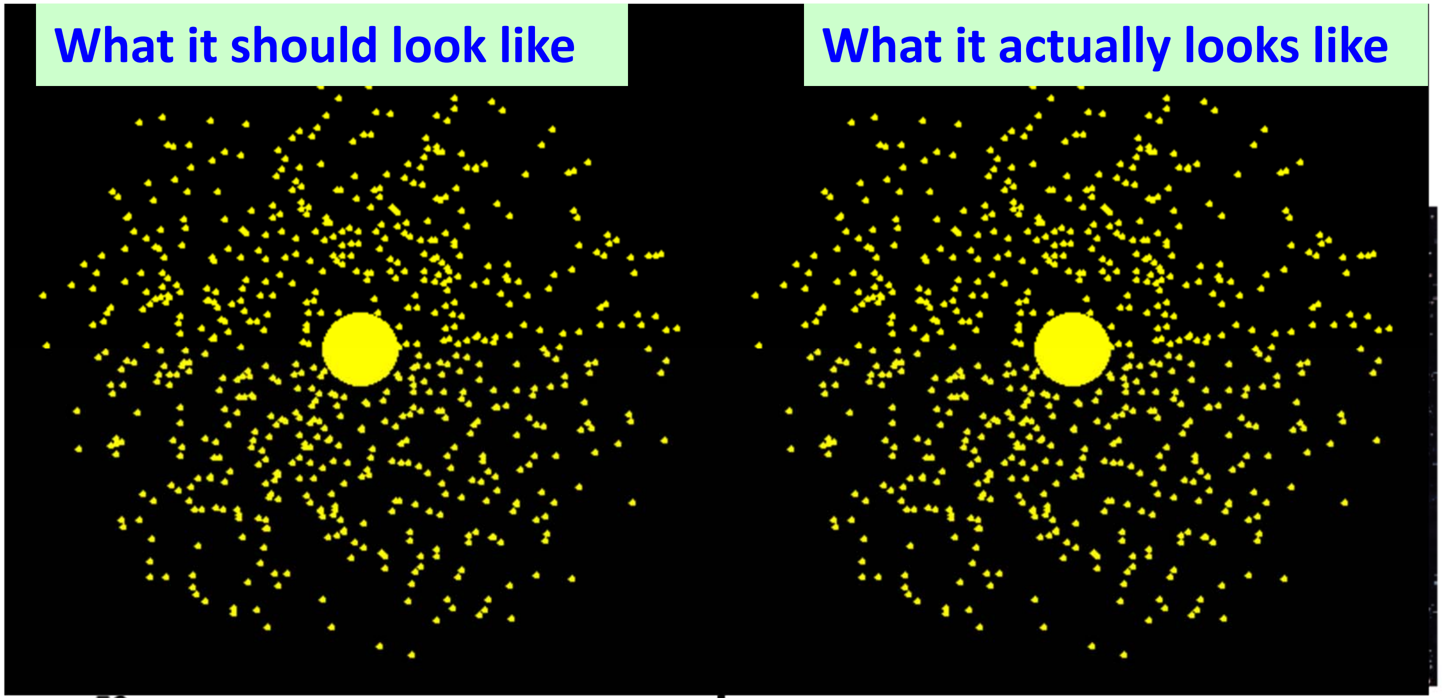
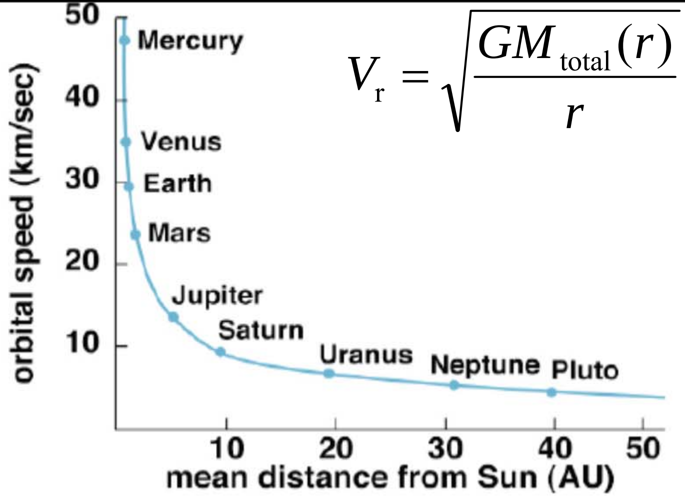


Shedding Light on Dark Matter

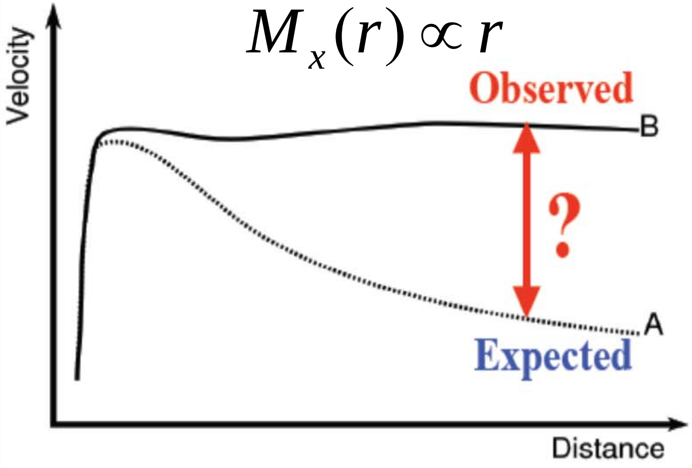
Rupak Mahapatra, Texas A&M

Dark Matter: Something Invisible?





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



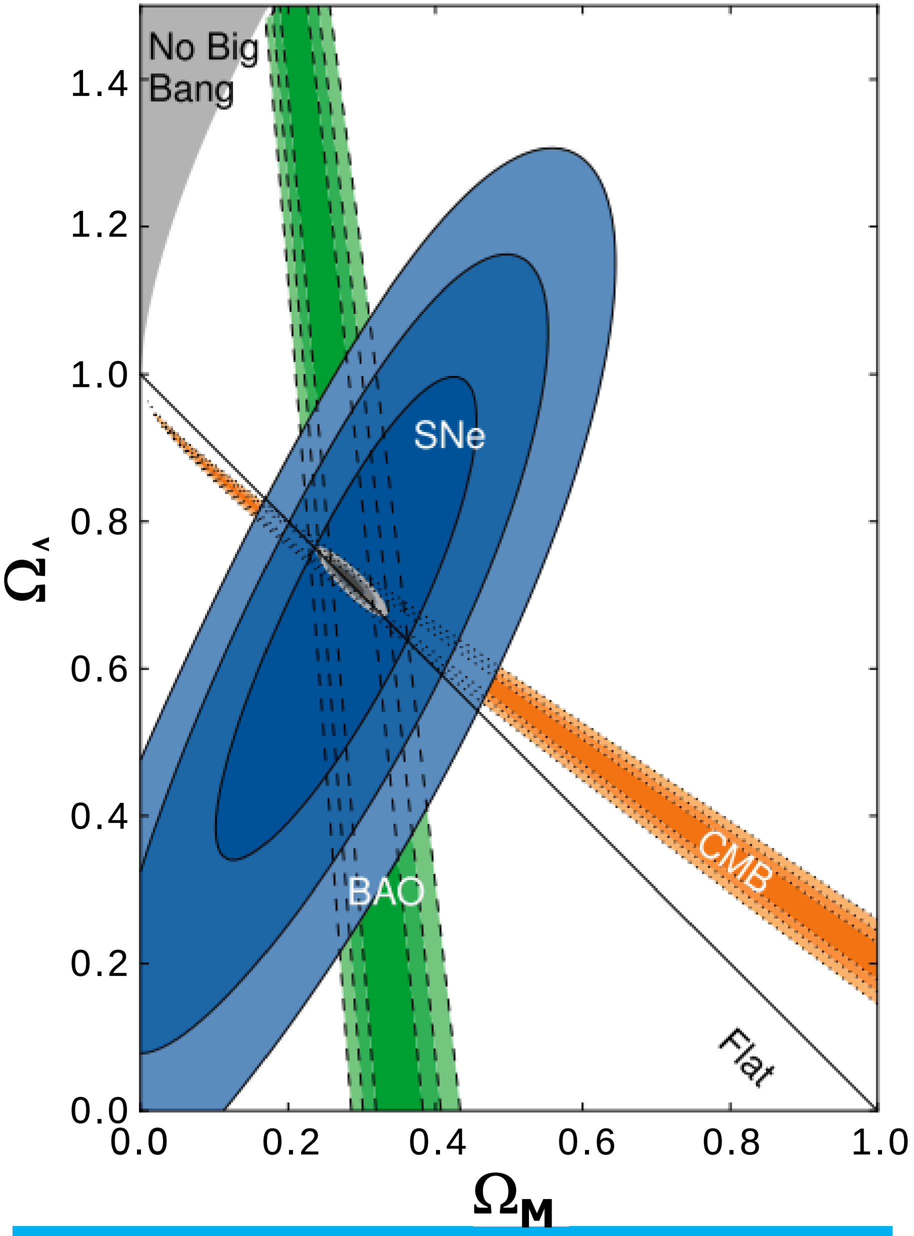
$$M_x(r) \propto r$$

Fritz Zwicky 1898--1974

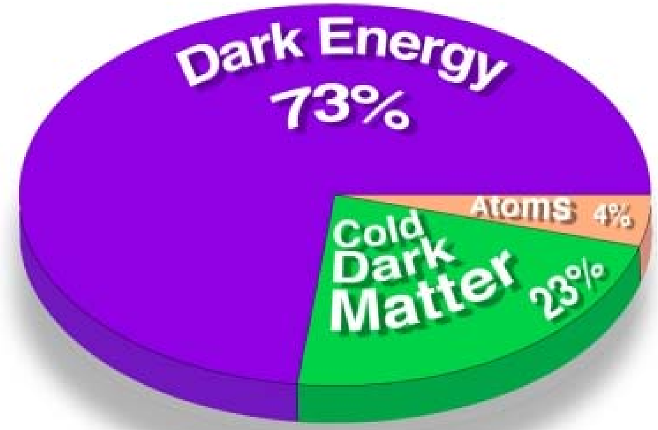
Vera Rubin

Dark-matter postulated 80 years ago by Zwicky from high rotational speed of stars and confirmed

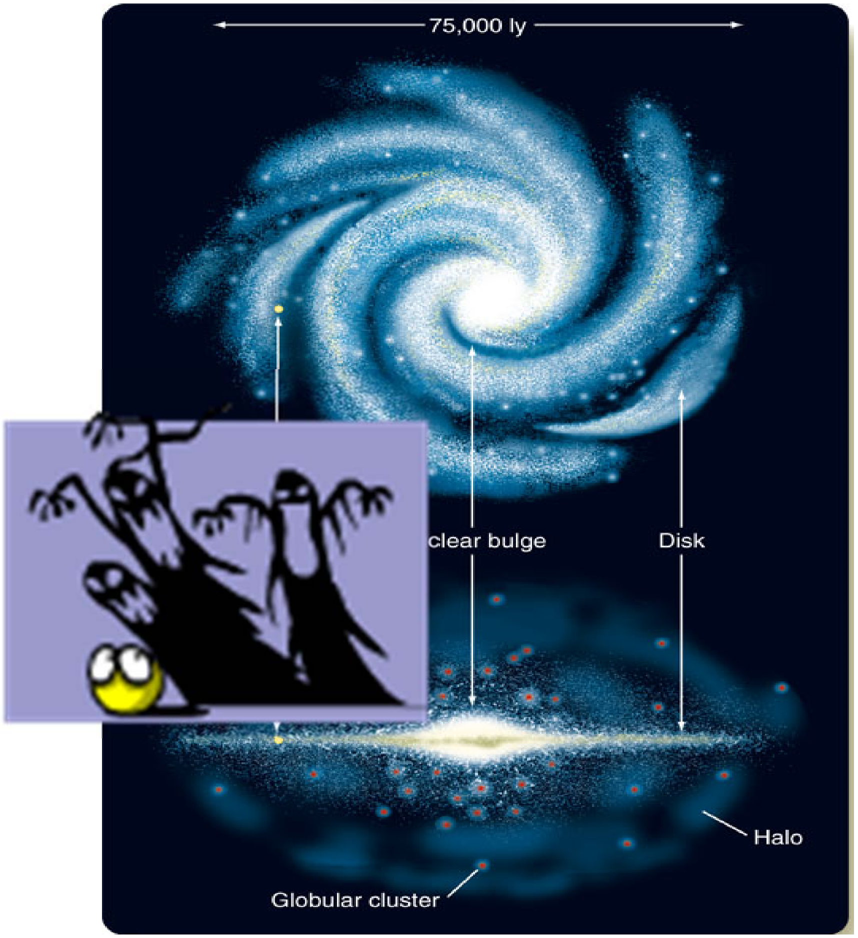
Universe: Mostly Unidentified



Accelerating Flat Universe



Planck: 68% DE, 27% DM

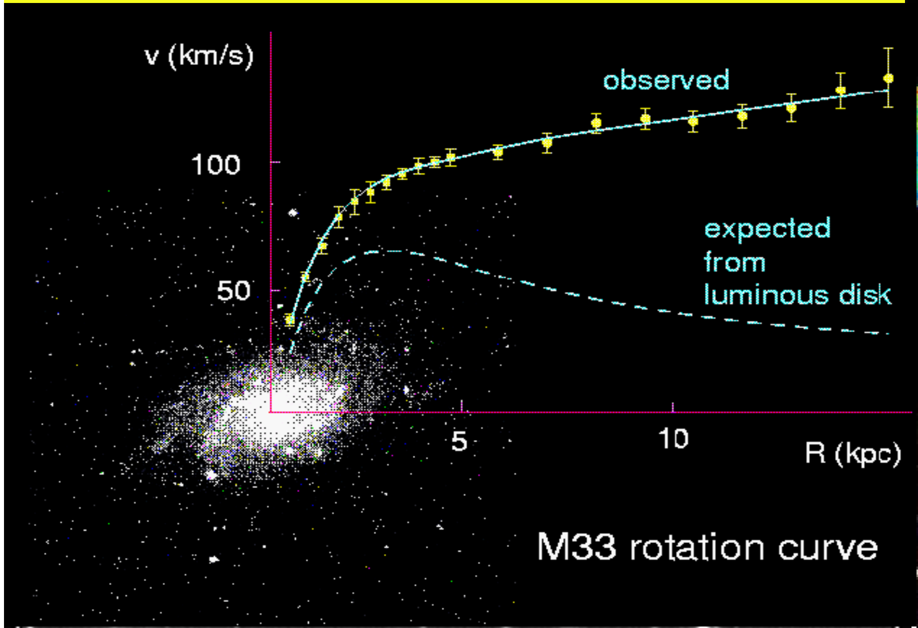


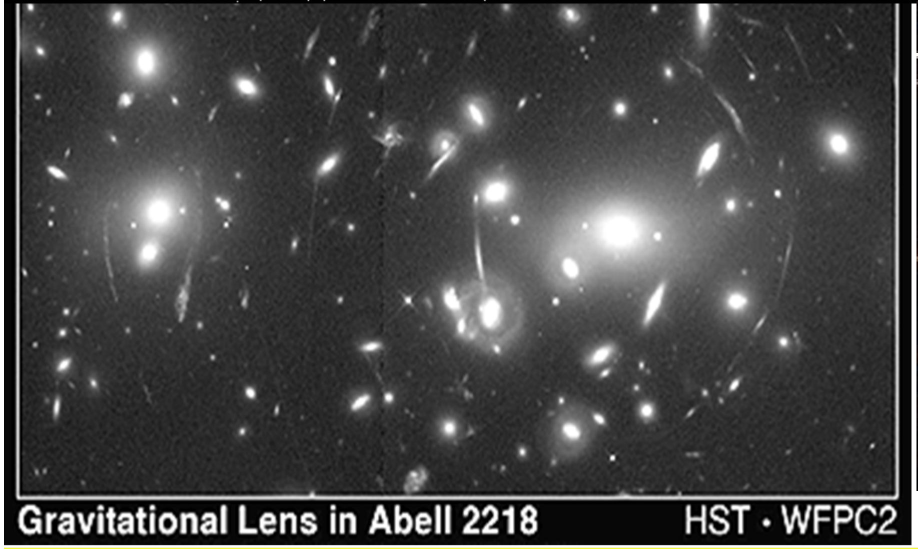
Two Galaxies Collide: Dark and Ordinary Matter Separated

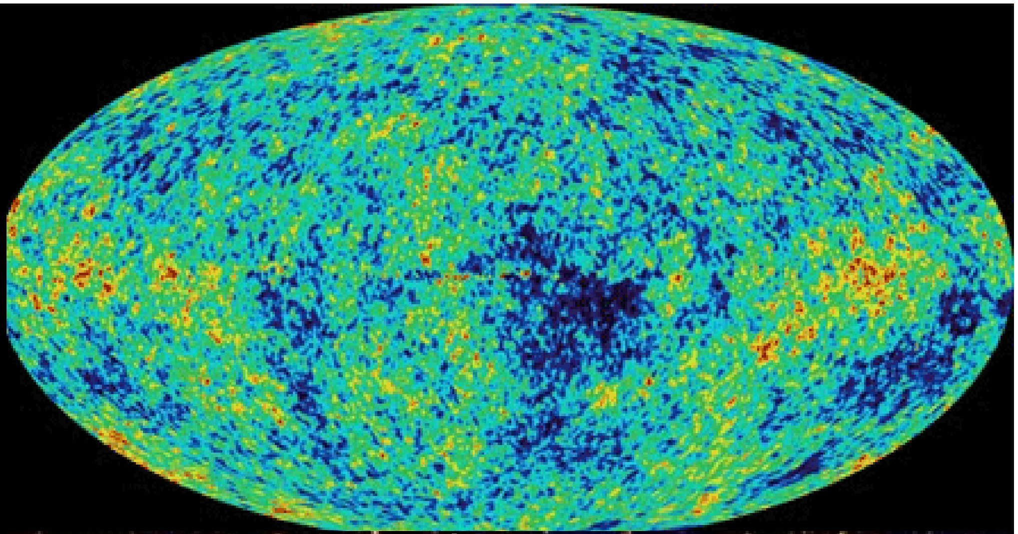
- **Two galaxies pass right through each other, each having ordinary and dark matter**
- **Dark Matter (shown in blue) has very little interaction, and continues to move through**

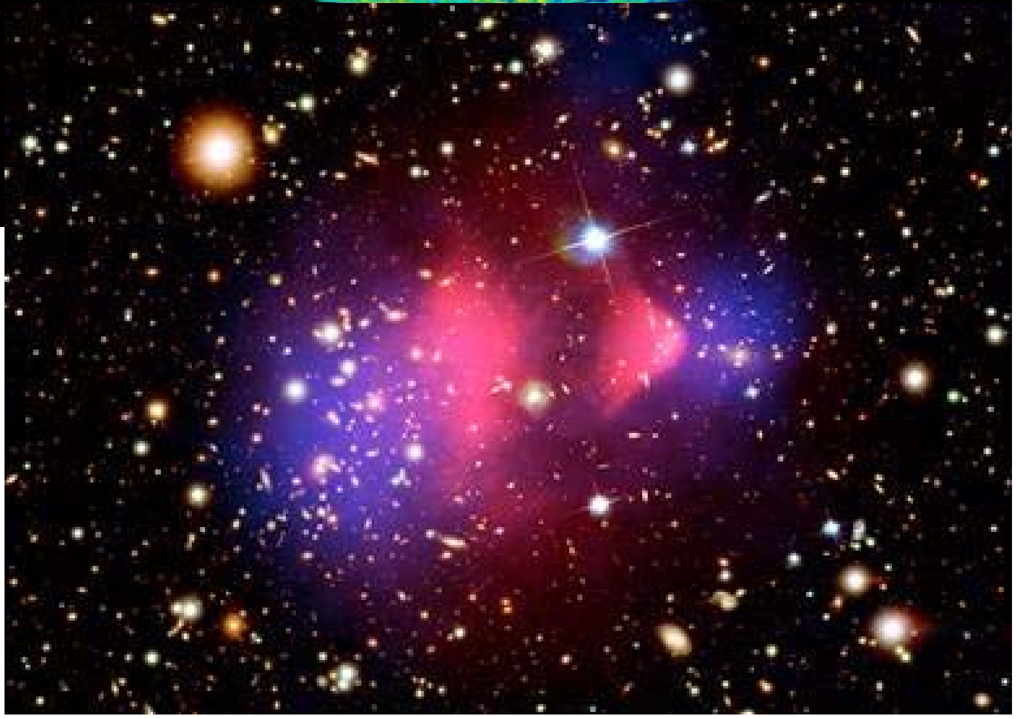
Clowe, D.,*et al*., Ast. J. Lett. 648, L109, (2006)

Dark Matter exists …



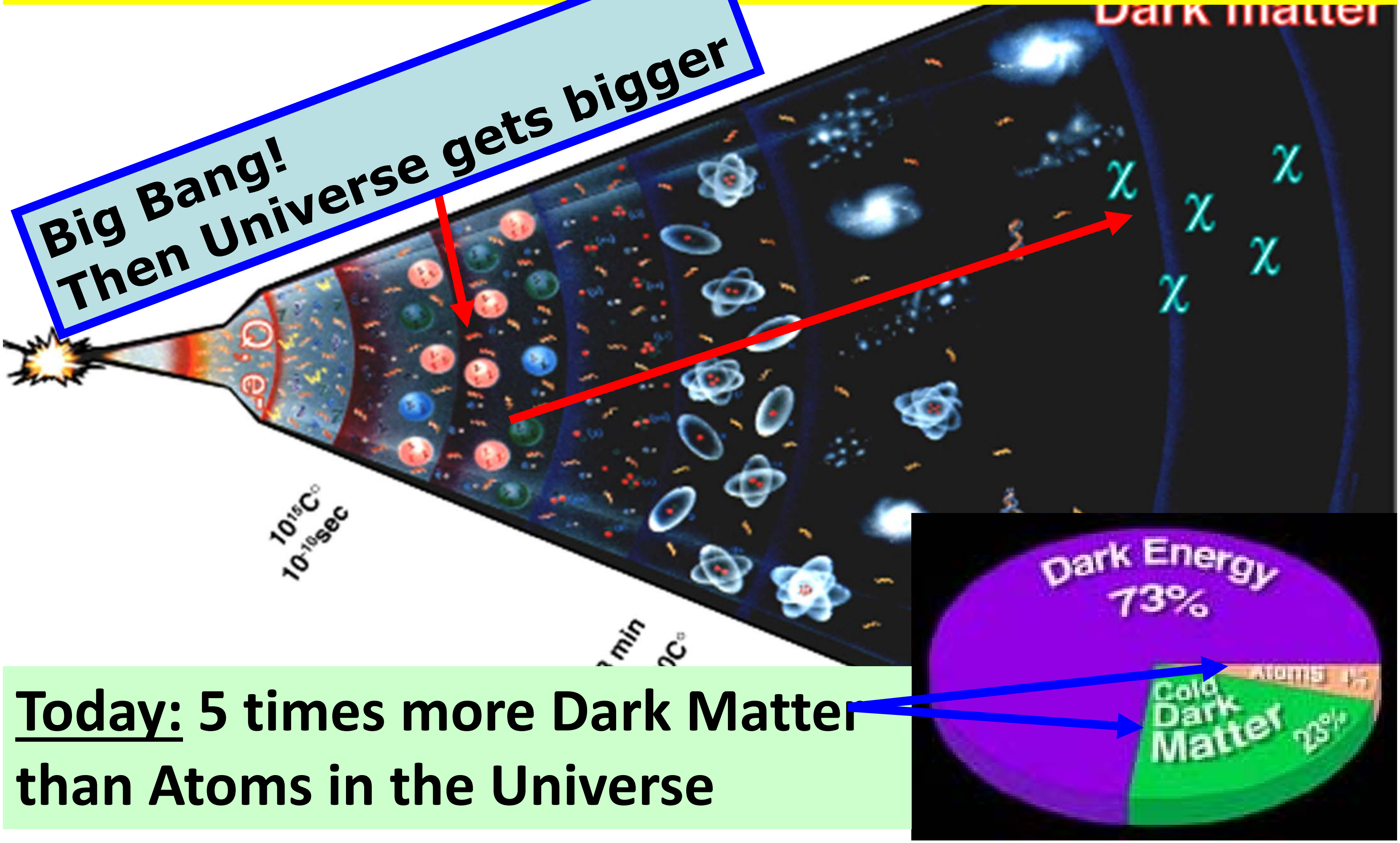






What is it made of? Can we detect it?

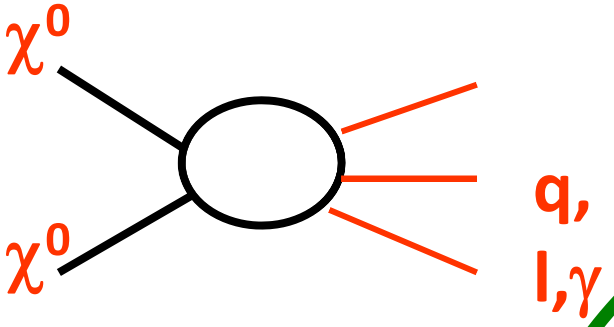
Guess: Dark Matter in the Universe is made up of LOTS of **particles** that we haven't discovered yet! Got created in the Early Universe like everything else and are still here today!



Big Bang!
Then Universe gets bigger

Today: 5 times more Dark Matter than Atoms in the Universe

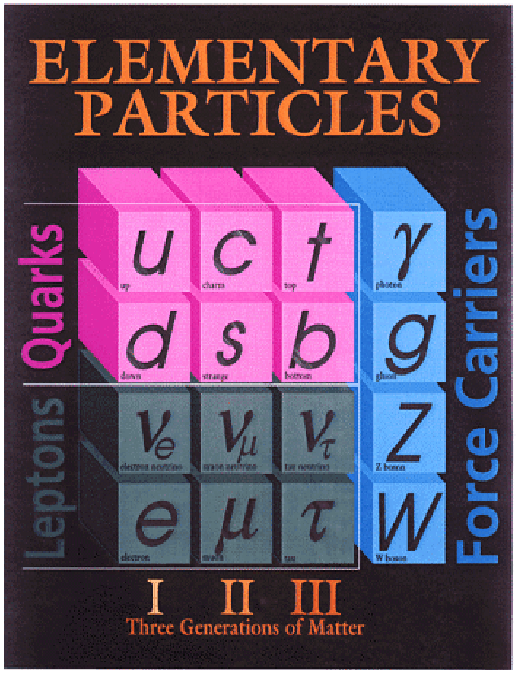
Coincidence or Clue?

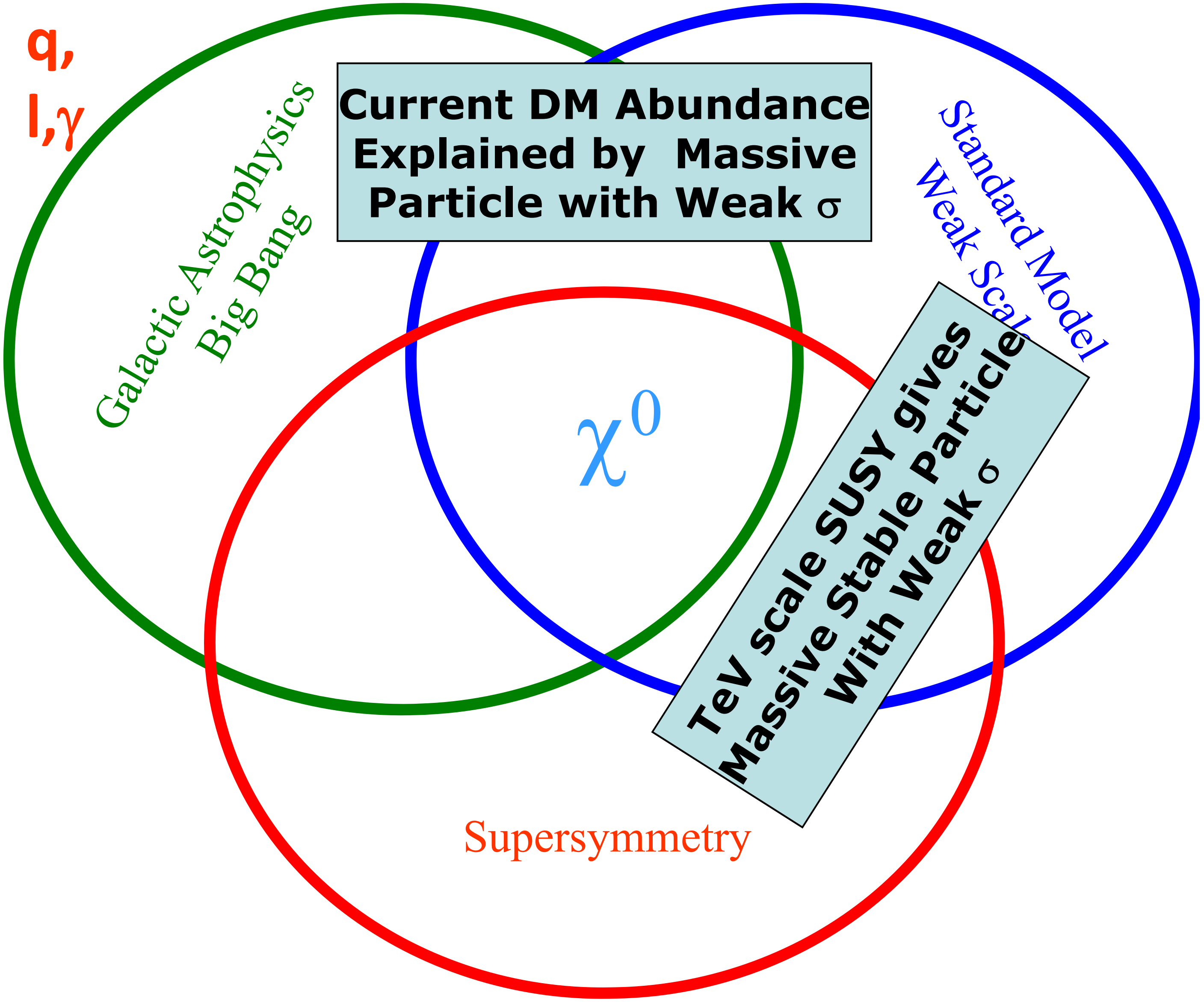


σ_{ann} ~ weak

gives Ω_χ = ¼

No known SM particle fits!





Galactic Astrophysics
Big Bang

Current DM Abundance Explained by Massive Particle with Weak σ

Standard Model
Weak Scal

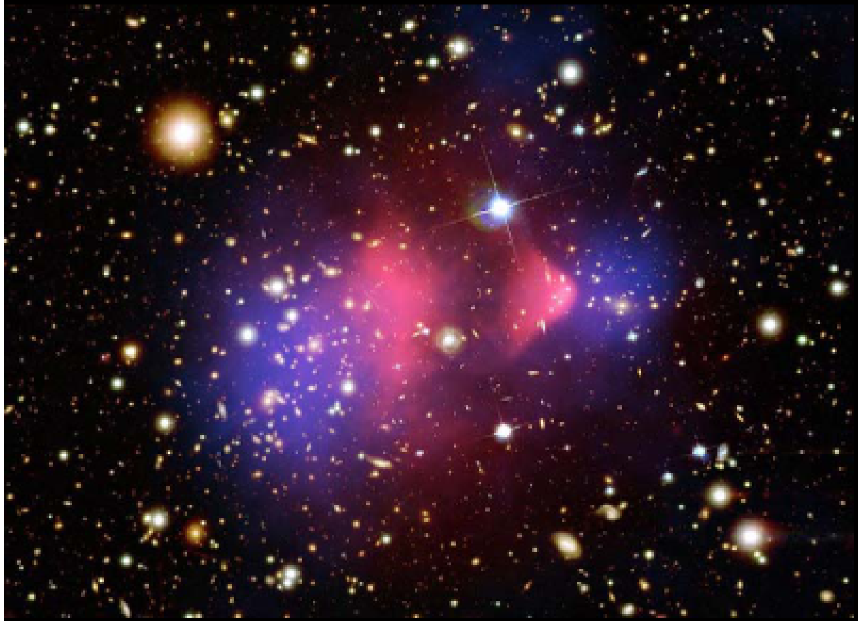
χ^0

TeV scale SUSY gives Massive Stable Particle With Weak σ

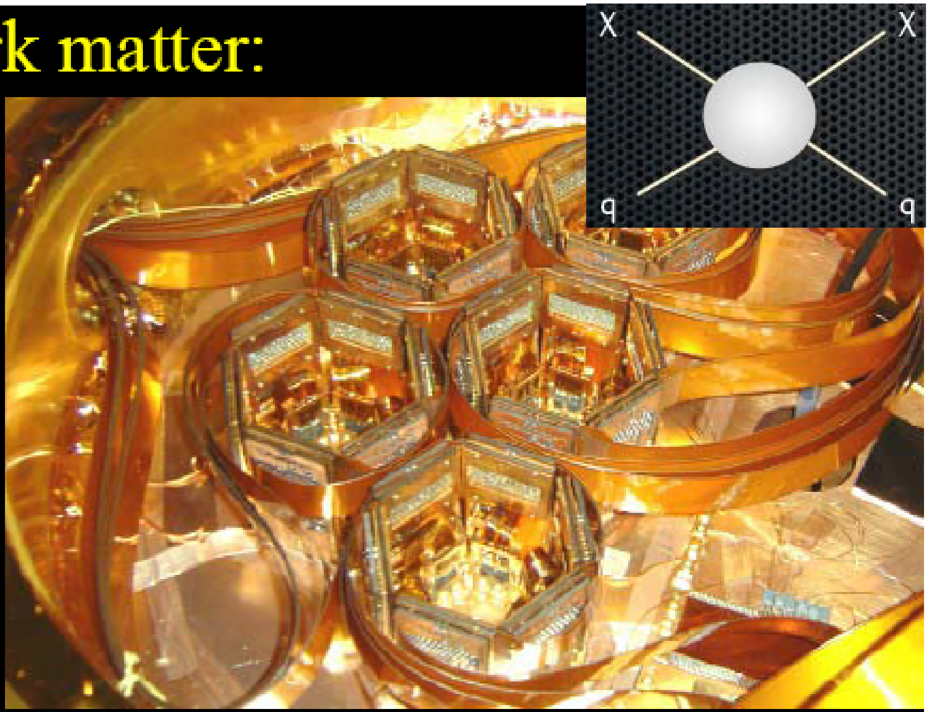
Supersymmetry

Weakly Interacting Massive Particle (WIMP)

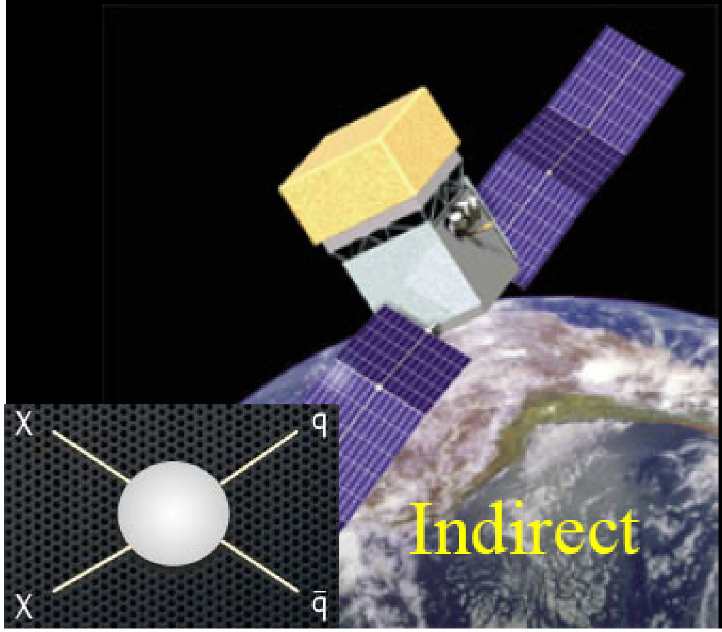
Four roads to dark matter:



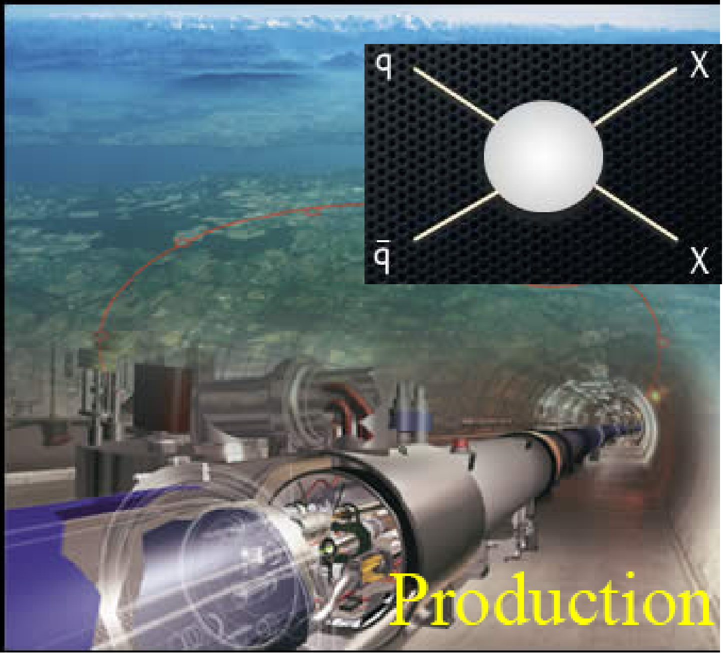
Gravitational



Direct



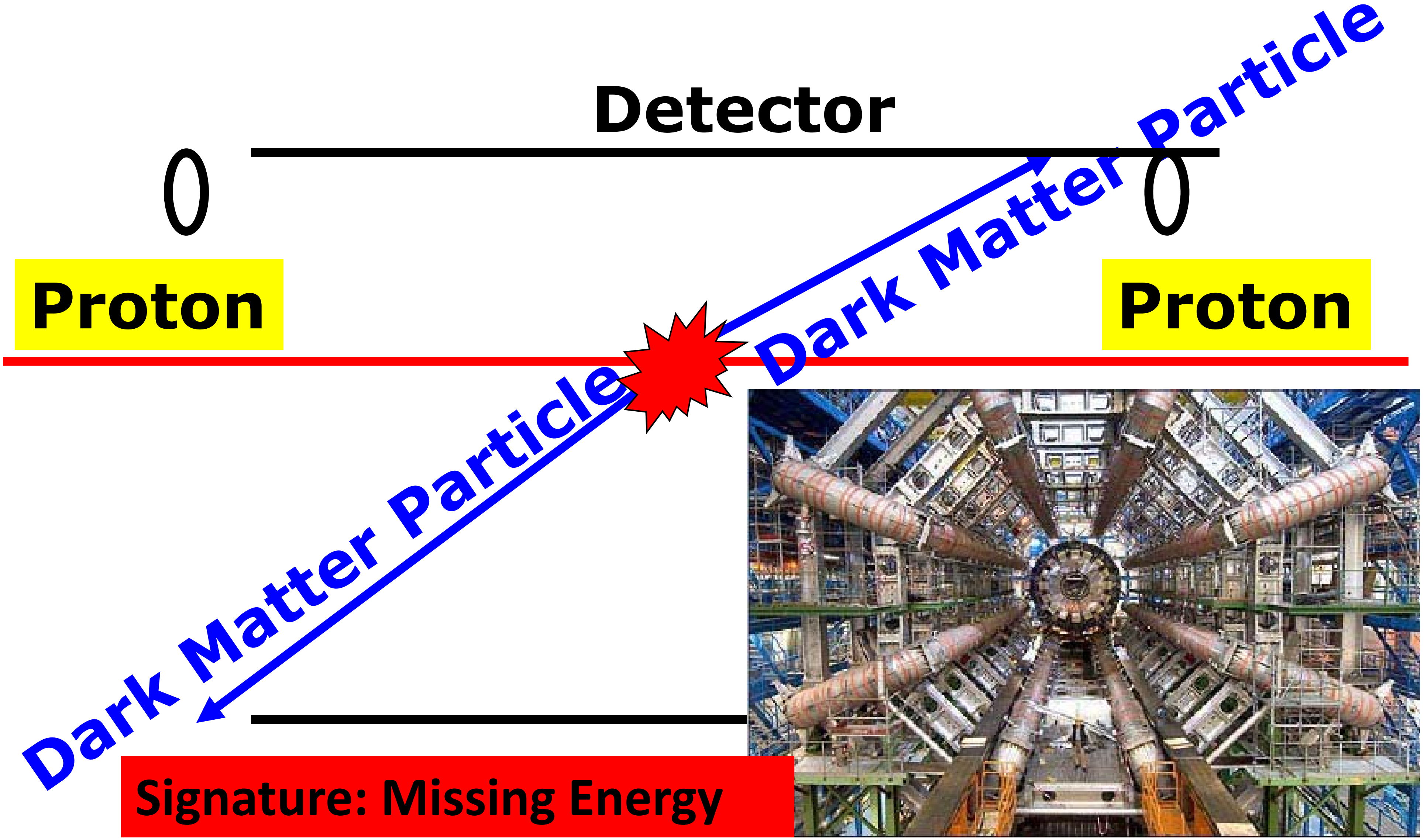
Indirect



Production

Direct Production at Accelerators

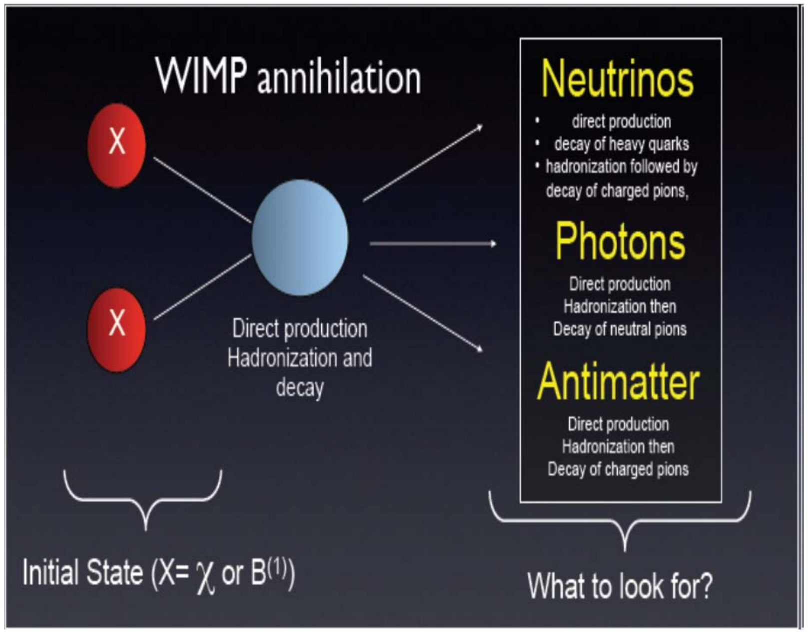
LHC = High Energy Collisions = Big Bang

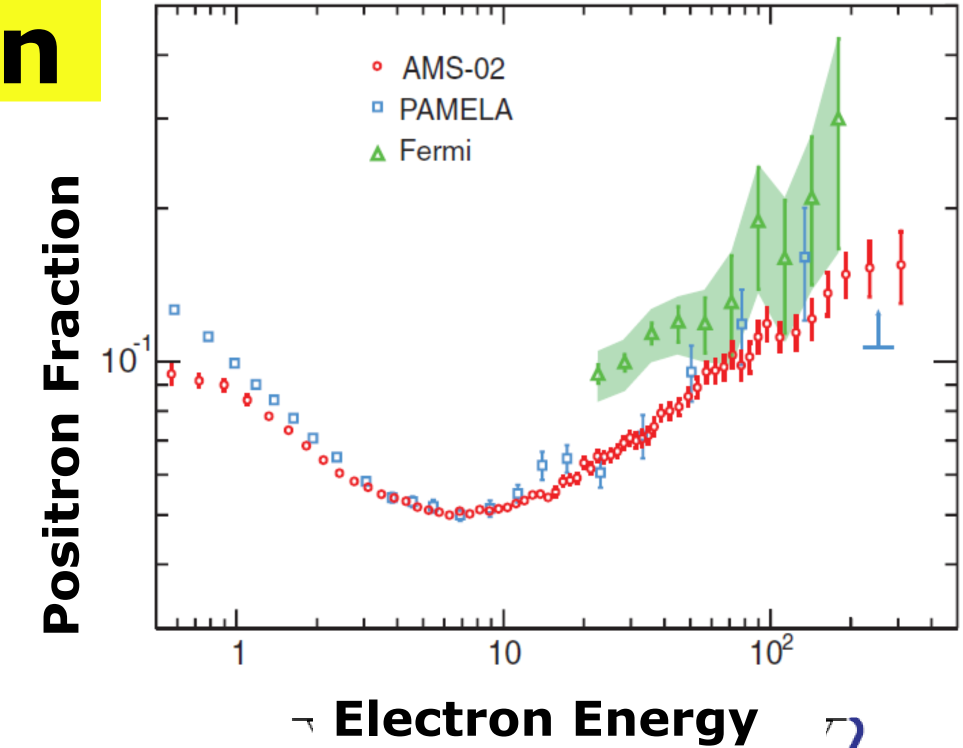


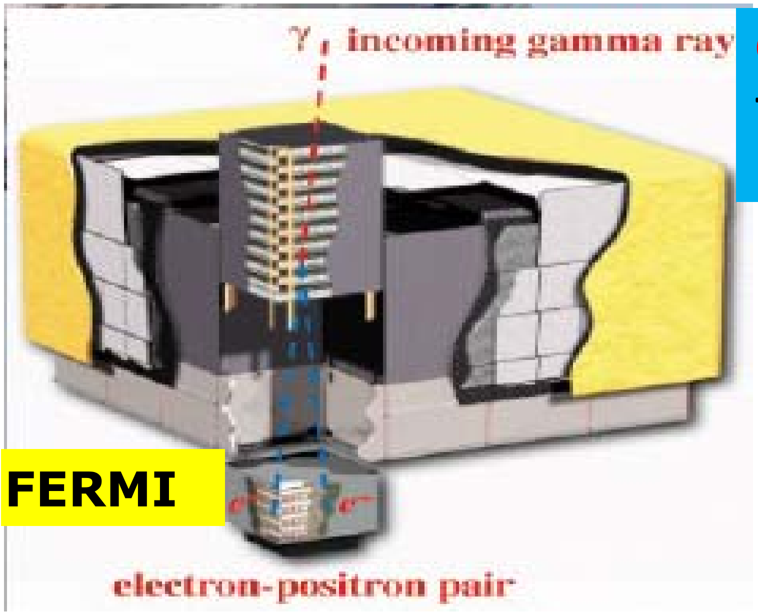
Signature: Missing Energy

Indirect Detection

Goal: Dark Matter Annihilation products

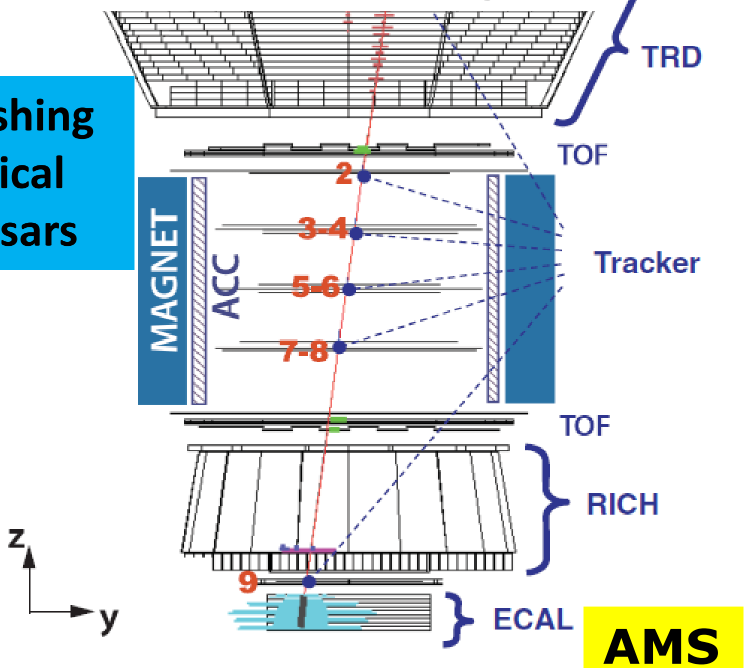






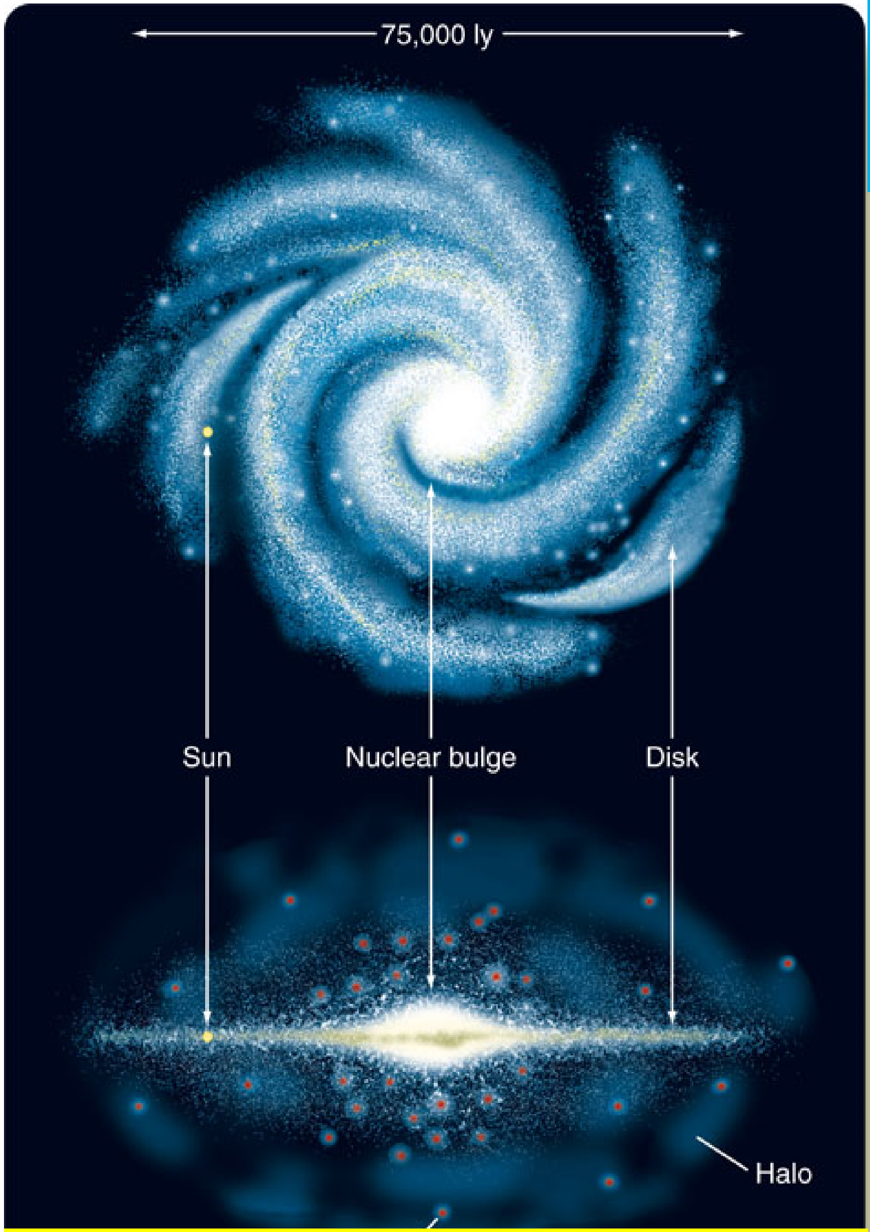
FERMI

Challenges: Distinguishing from other astrophysical processes such as pulsars



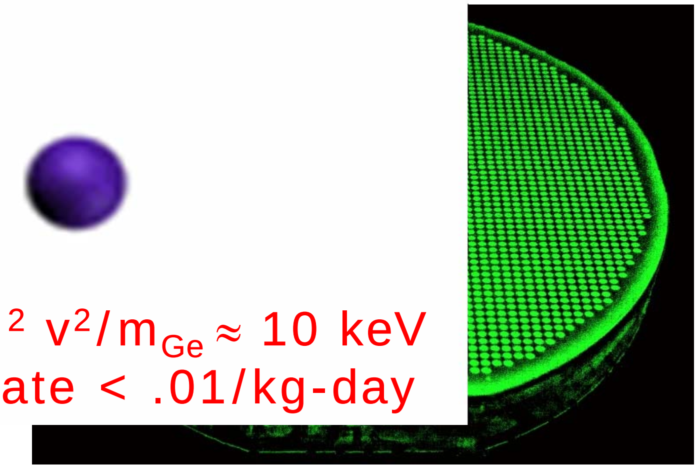
AMS

Direct Detection: Can we observe WIMPs?



Out there and may interact on Earth!

Goal: Detect WIMP recoil on terrestial detector, as we move through halo

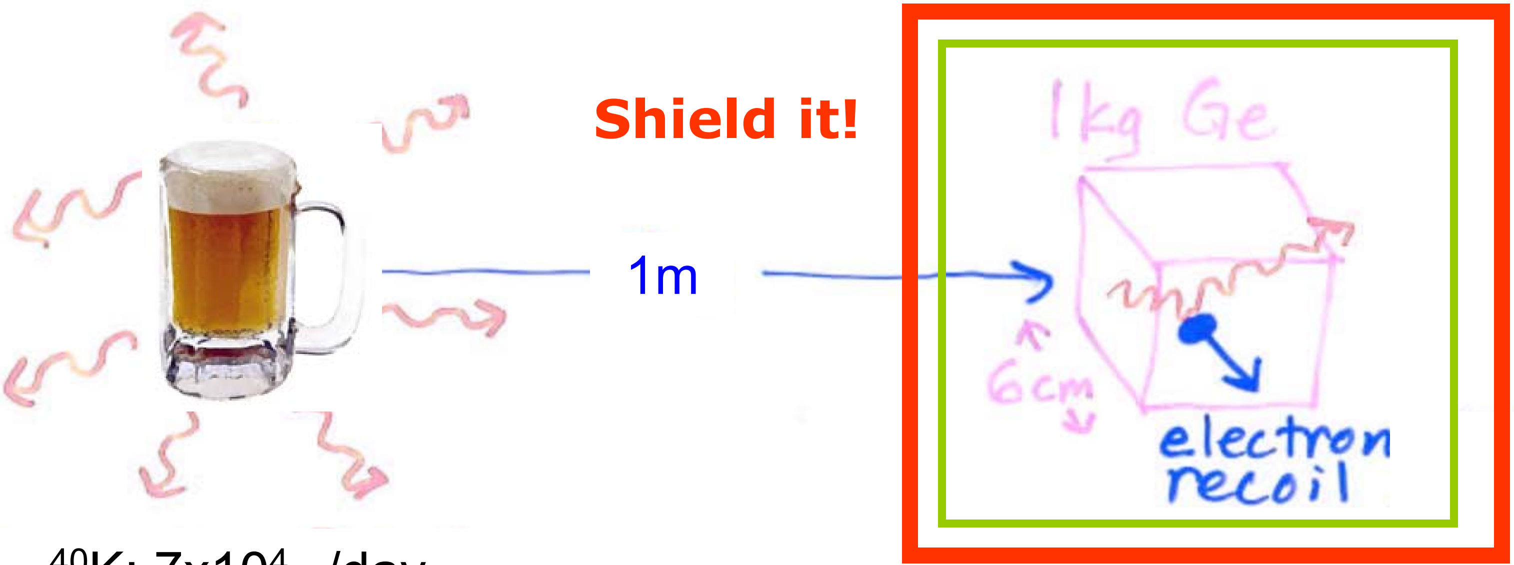


$E_R \approx m^2 v^2 / m_{Ge} \approx 10$ keV
But, rate < .01/kg-day

ρ ~ 1/3 GeV/cm^3

NUTRITIONAL WARNING: may contain few 100-GeV WIMPs. 10 billion WIMPs may pass through each sec

Billion X Higher Radioactive Background



Shield it!

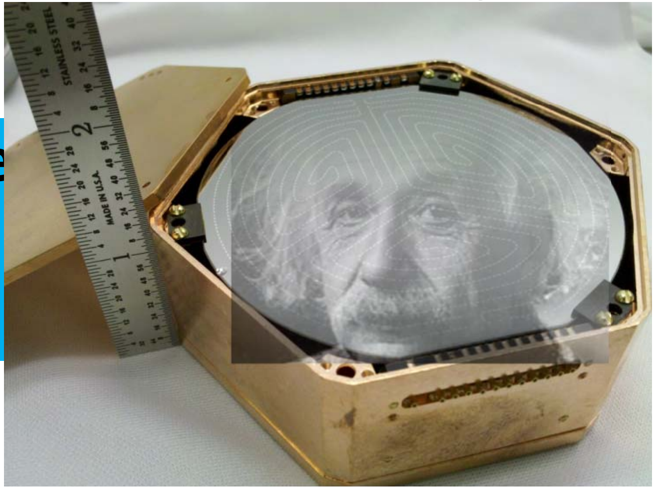
^{40}K: 7x10^4 γ/day

(E≃1.5 MeV)

Rate about 20 / (kg-day) !

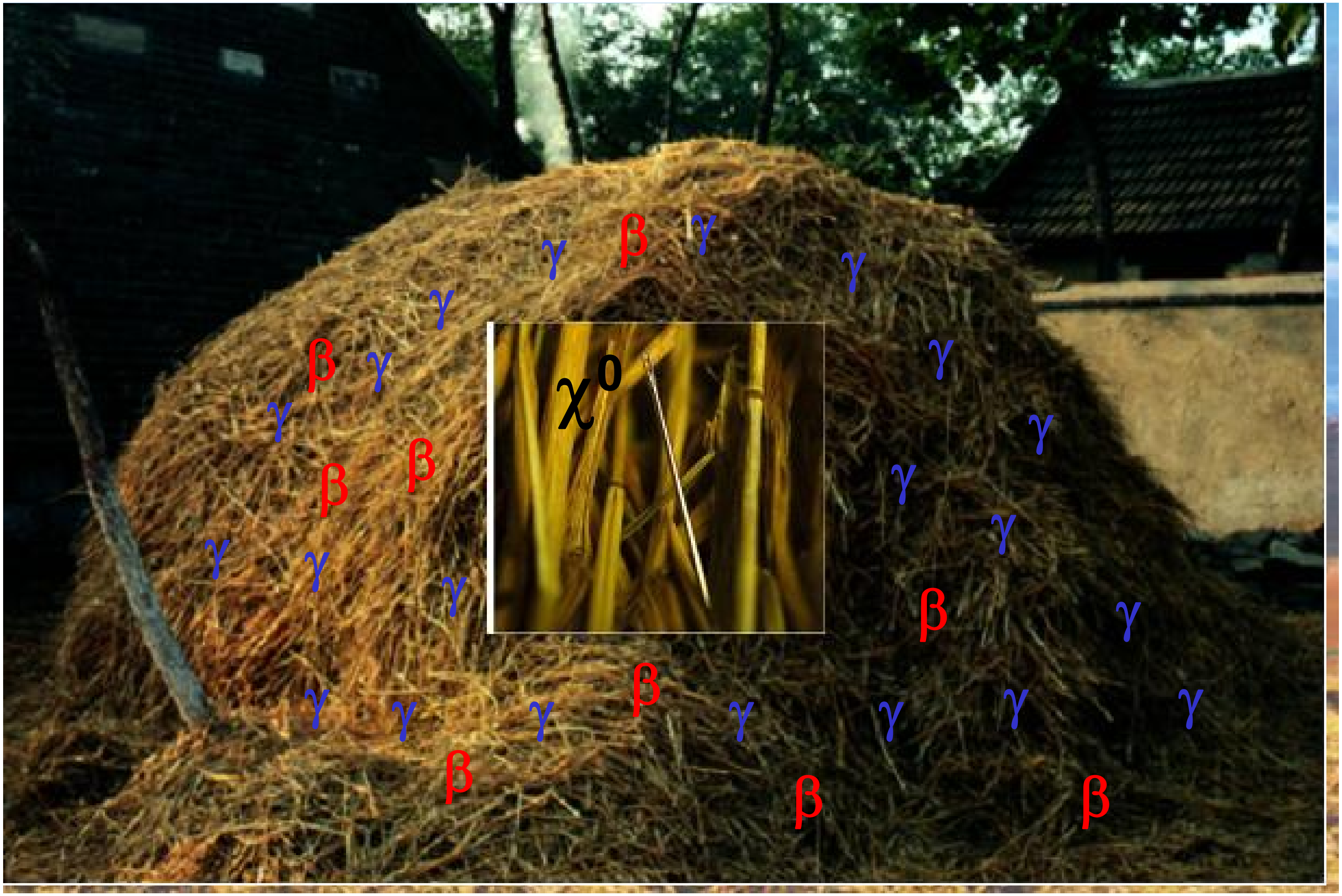
Strategies: shield Cosmogenic and Radioactive backgrounds, and reject remaining background through detector technology

Smart detectors



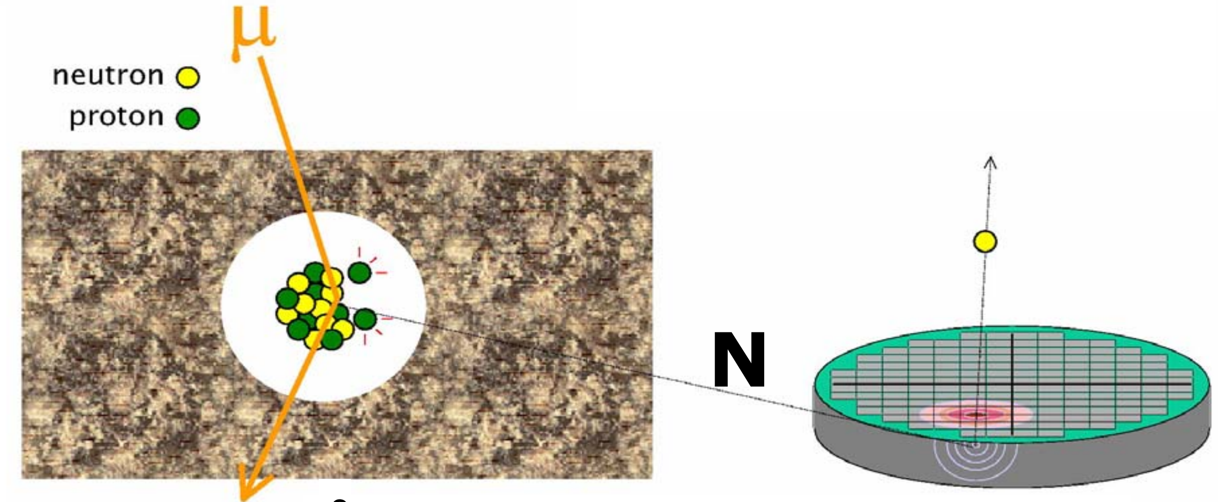
What Nature has to Offer

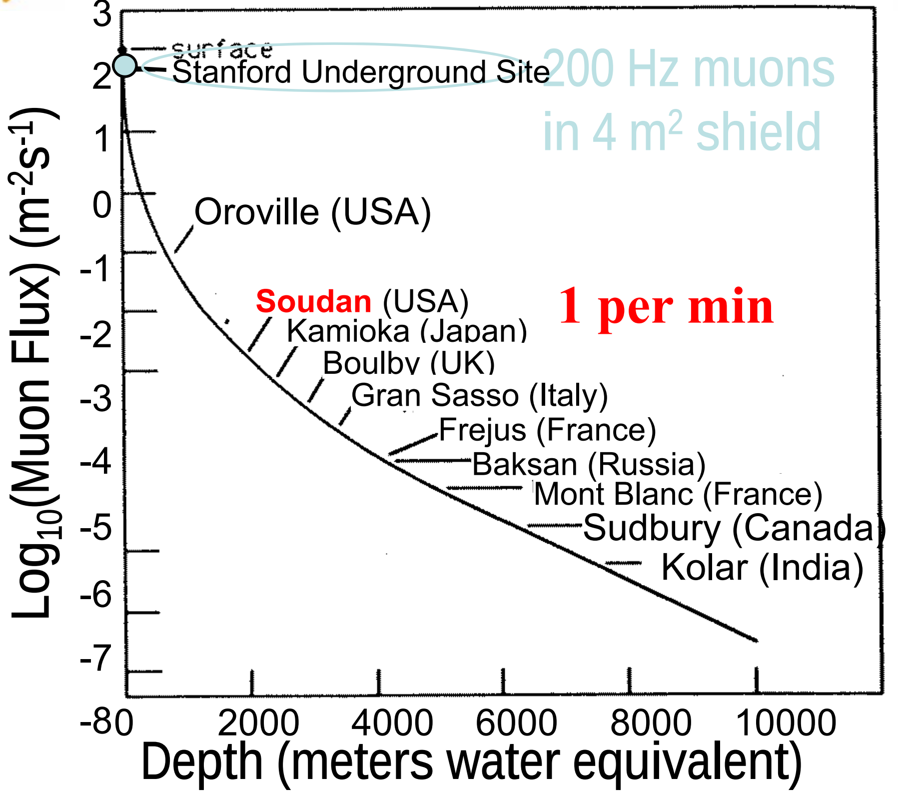
What Our Detectors Need to do!

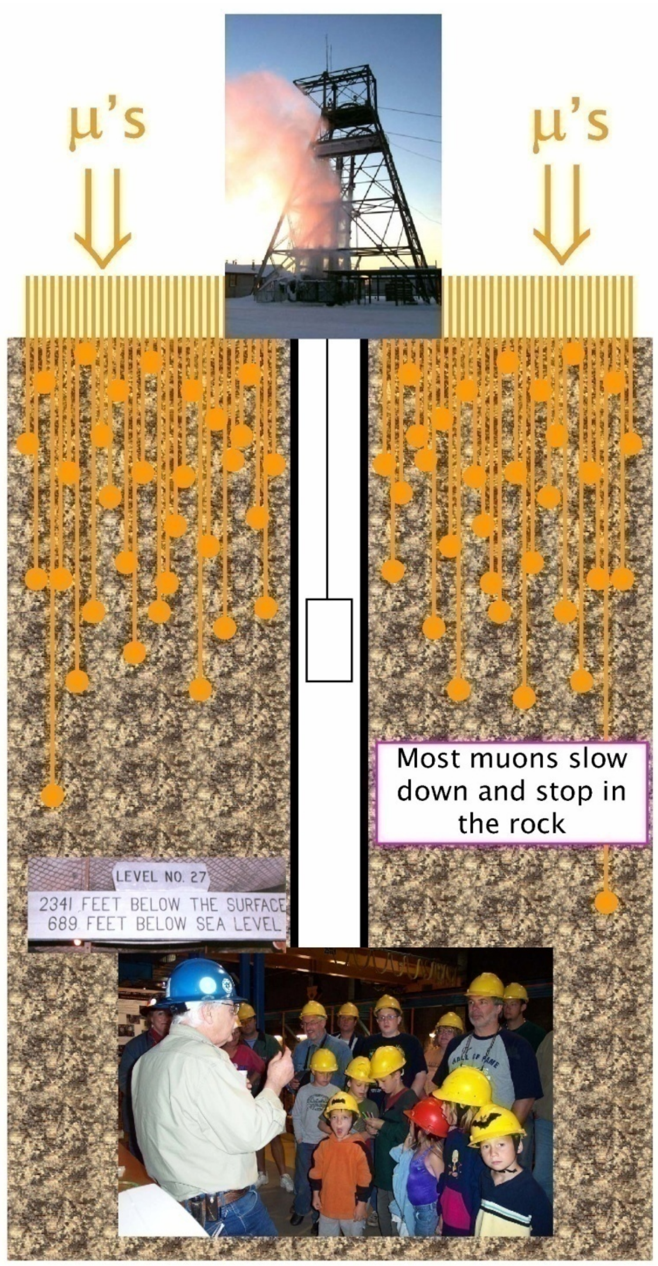


Reduce and Reject background with Shielding and Sophisticated Detectors

Reducing Cosmogenic Background







Reducing Cosmo and Radiogenic Background (CDMS)

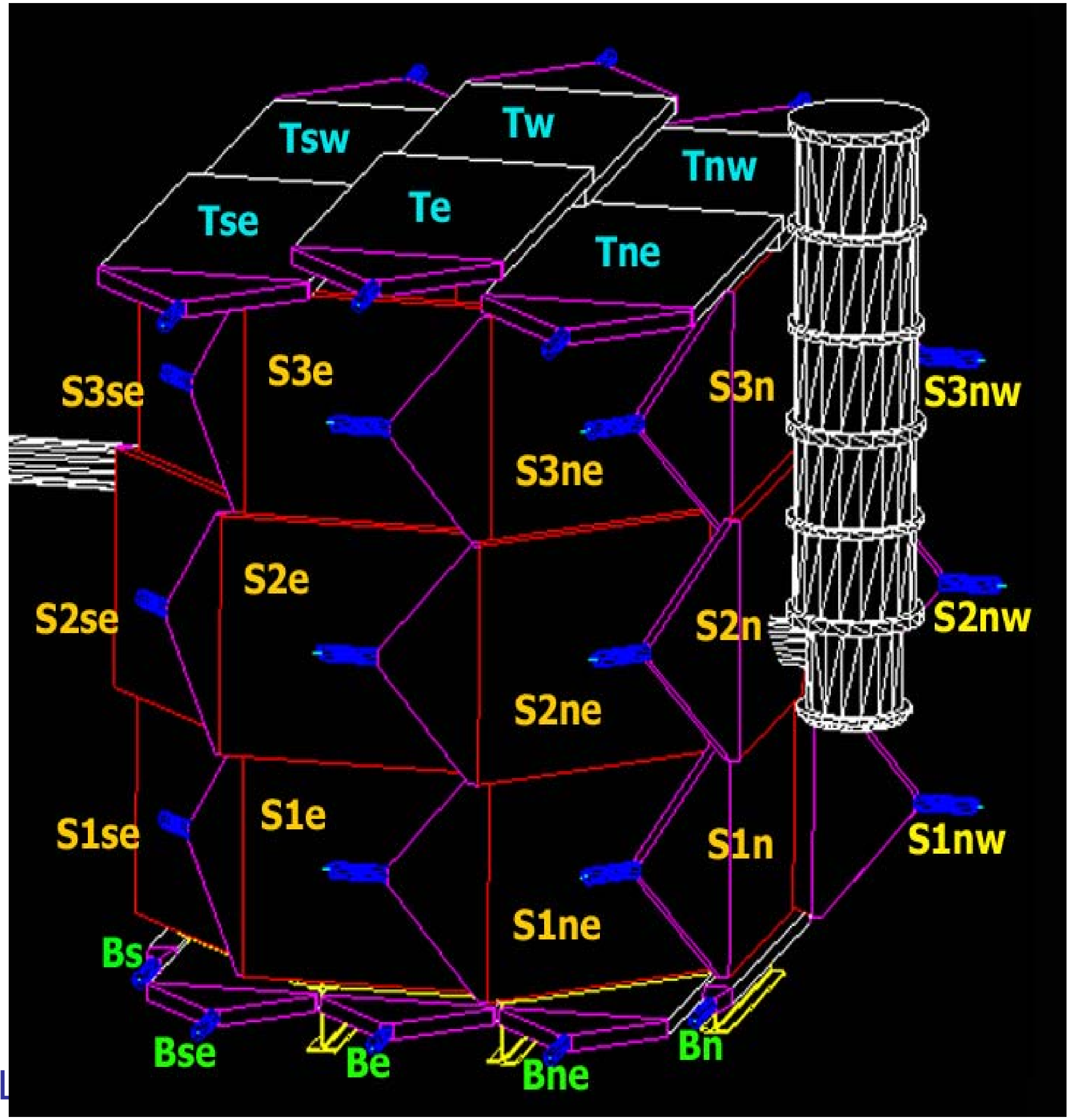
Typical structure for most experiments

Surround detectors with active muon veto

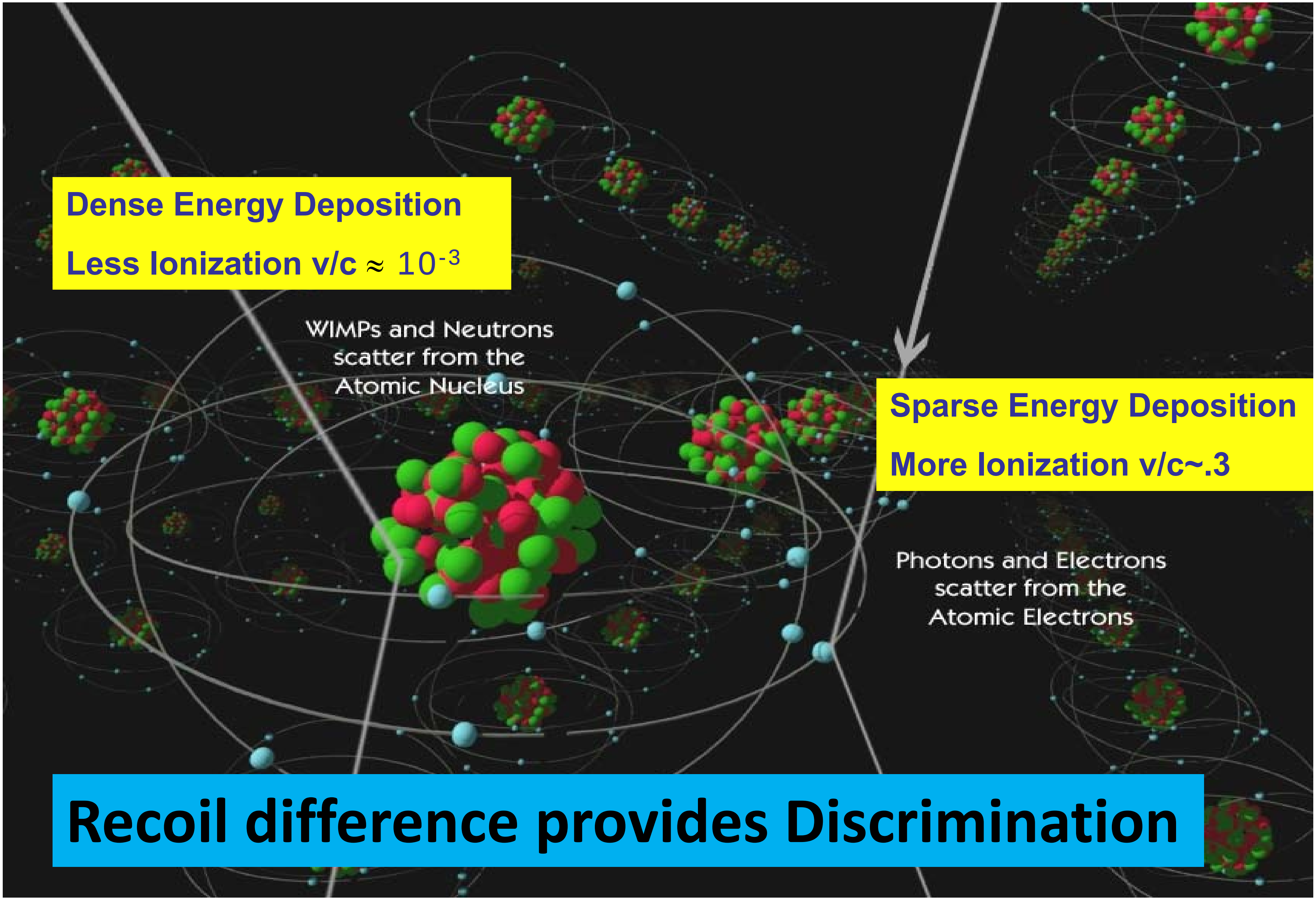
Use passive shielding to reduce γ/Neutrons

- Lead and Copper for photon
- Polyethylene for low-energy neutron

Neutron background negligible in Soudan, for recent runs



Radiogenic Background – Higher Ionization Energy



Dense Energy Deposition

Less Ionization v/c ≈ 10^{-3}

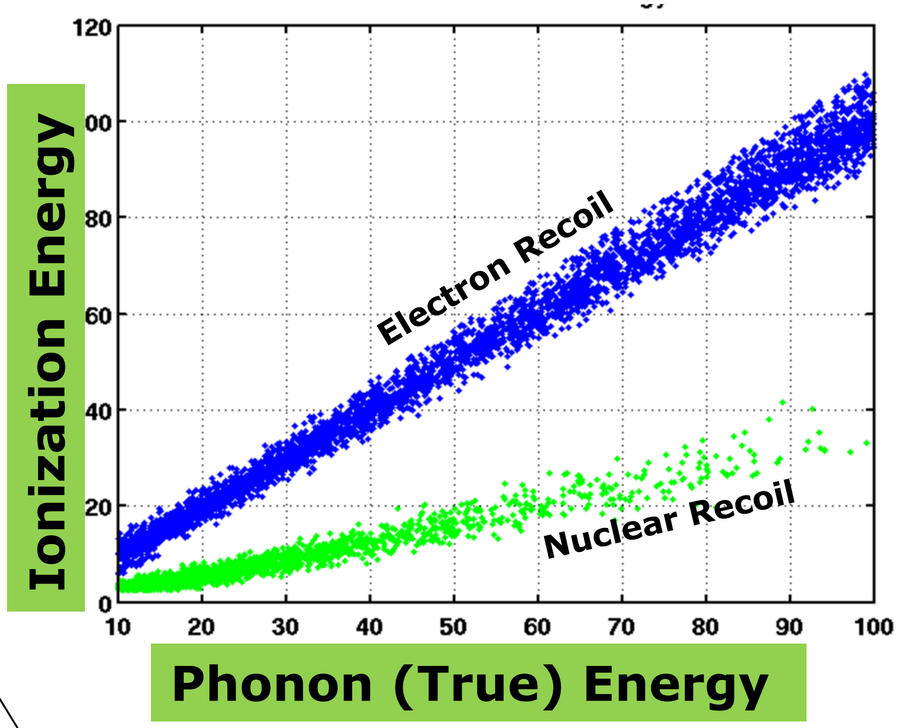
Sparse Energy Deposition

More Ionization v/c~.3

Recoil difference provides Discrimination

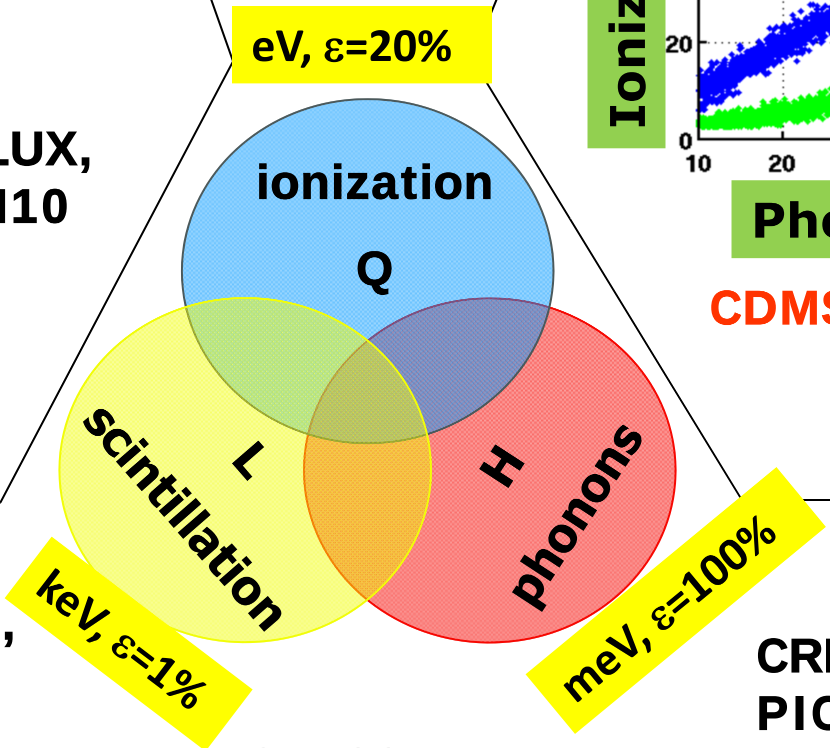
Detection and Discrimination Methods

IGEX,
DRIFTI, II



CDMS, EDELWEISS

ZEPLIN II, III, LUX,
XMASS, XENON10



NAIAD, ZEPLIN I,
DAMA

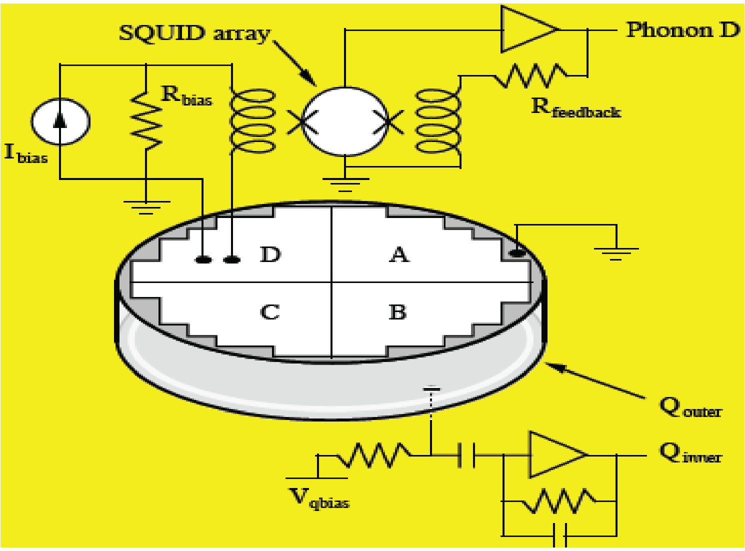
CRESST II,
ROSEBUD

CRESST,
PICASSO,
COUPP

At 1 keV – Million phonon quanta vs 0 light quanta. Huge statistics.

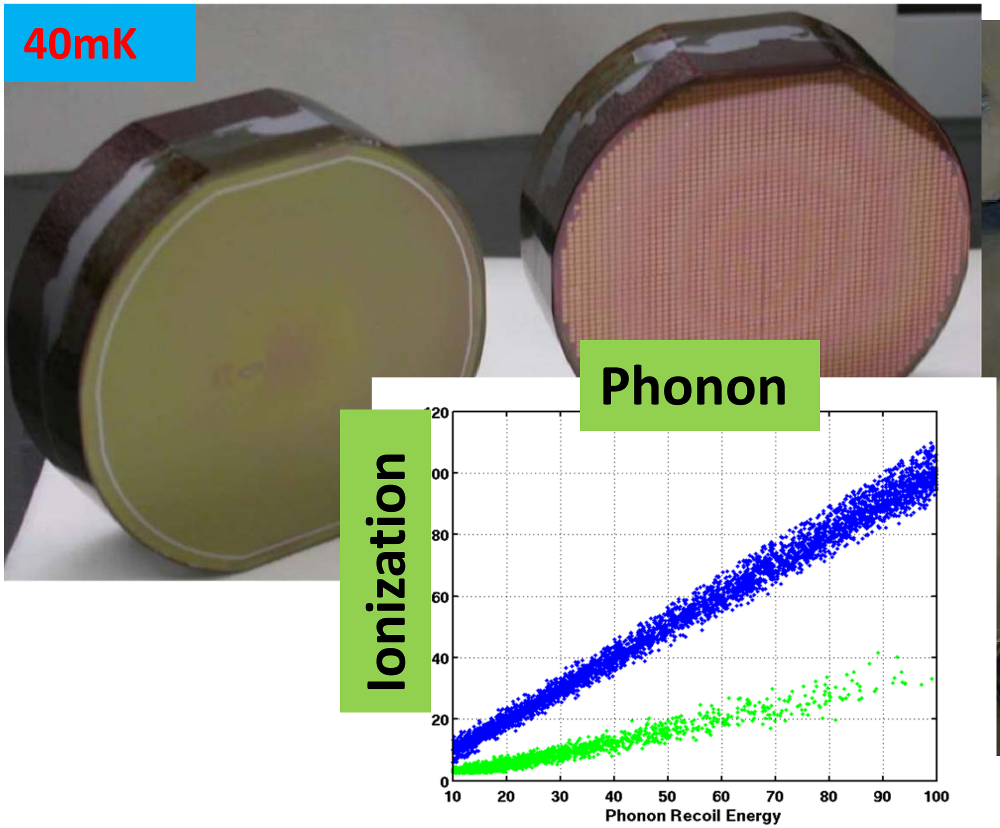
CDMS Collaboration

- Caltech
- Fermi National Accelerator Laboratory
- Univ. of Madrid
- Massachusetts Institute of Technology
- NIST
- Queen’s University
- Santa Clara University
- Southern Methodist University
- SLAC/KIPAC
- Stanford University
- Syracuse University
- Texas A&M University
- University of California, Berkeley
- UC Santa Barbara
- University of Colorado Denver
- University of Florida
- University of Minnesota
- University of Zurich



CDMS: The Big Picture

Cryogenically cooled Ge/Si detectors with photo lithographically patterned Transition Edge Sensors for good energy and position resolution



X-Y-Z Position from Phonon Pulse Timing

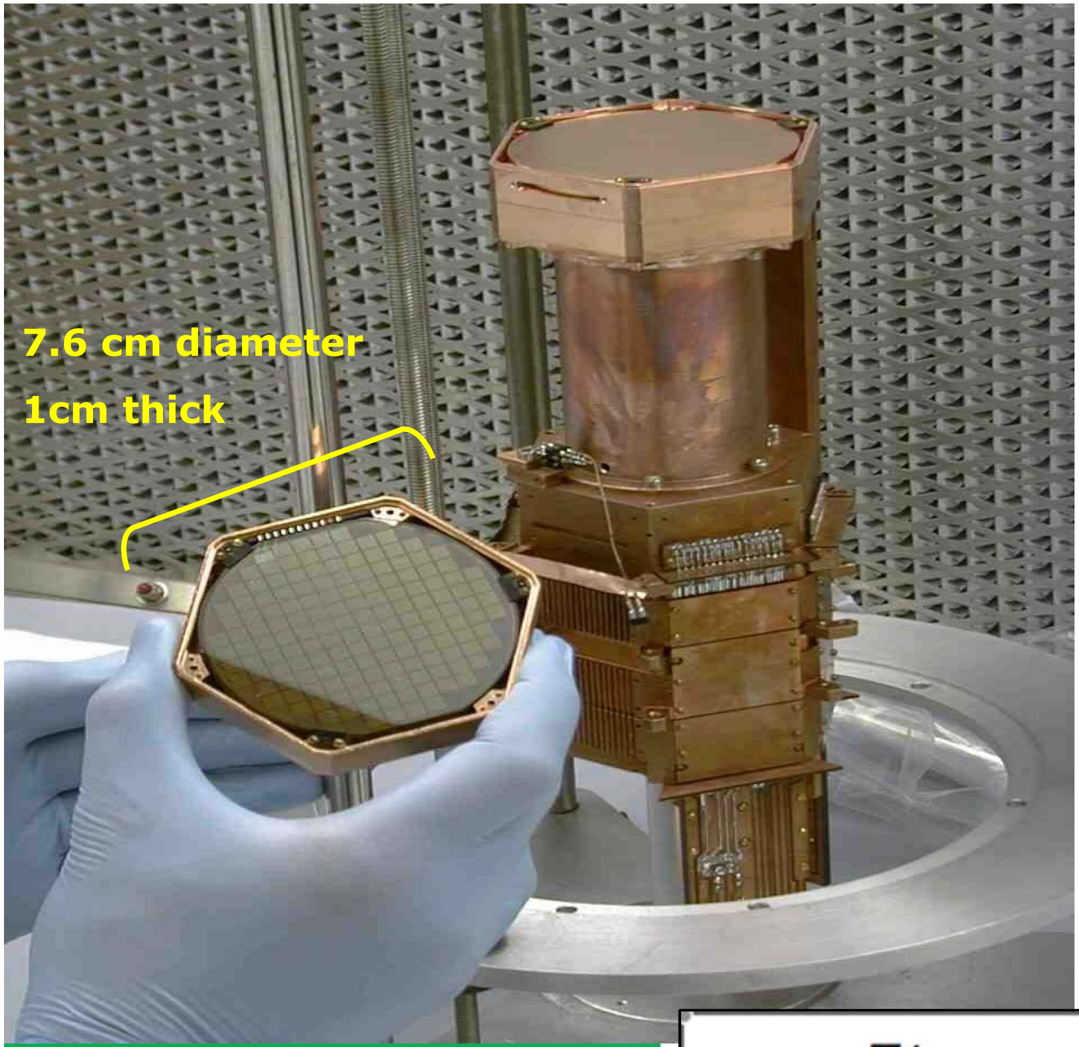
- **Passive Shielding (Pb, poly, *depth*)**
- **Active Shielding (muon veto shield)**

CDMSII ZIP

(Z-sensitive Ionization and Phonon)

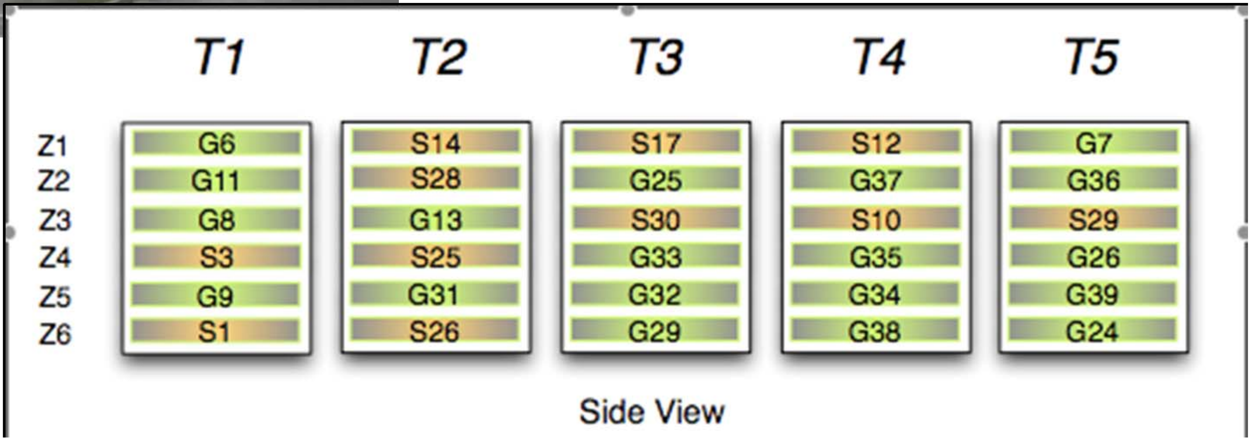
Phonon side: 4 quadrants of athermal phonon sensors
Energy & Position (Timing)

Charge side: 2 concentric electrodes (Inner & Outer)
Energy (& Veto)



Ge: 0.25 kg, Si 0.1 kg
3"dia x1cm thick

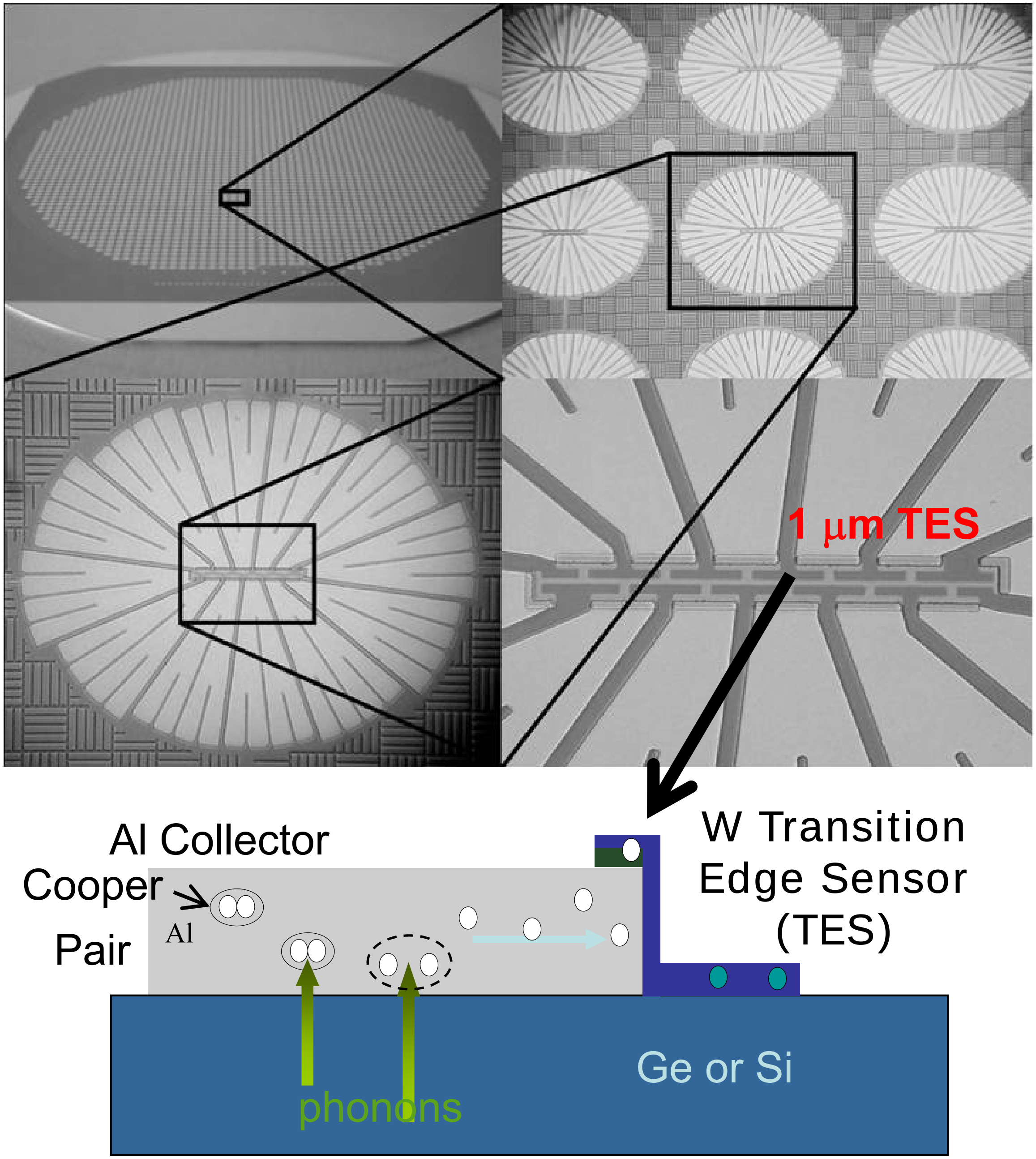
Operated at **~40 mK** for phonon signal-to-noise



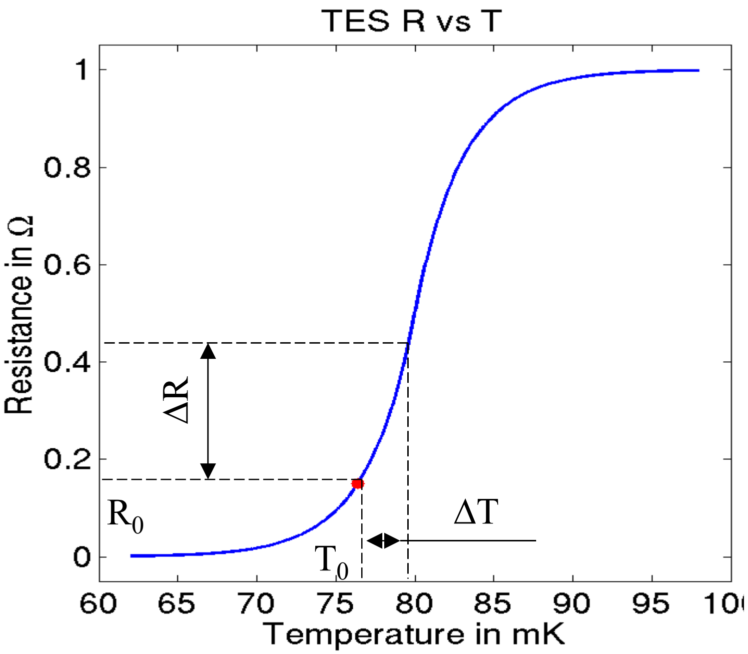
	T1	T2	T3	T4	T5
Z1	G6	S14	S17	S12	G7
Z2	G11	S28	G25	G37	G36
Z3	G8	G13	S30	S10	S29
Z4	S3	S25	G33	G35	G26
Z5	G9	G31	G32	G34	G39
Z6	S1	S26	G29	G38	G24

Side View

Phonon Sensors

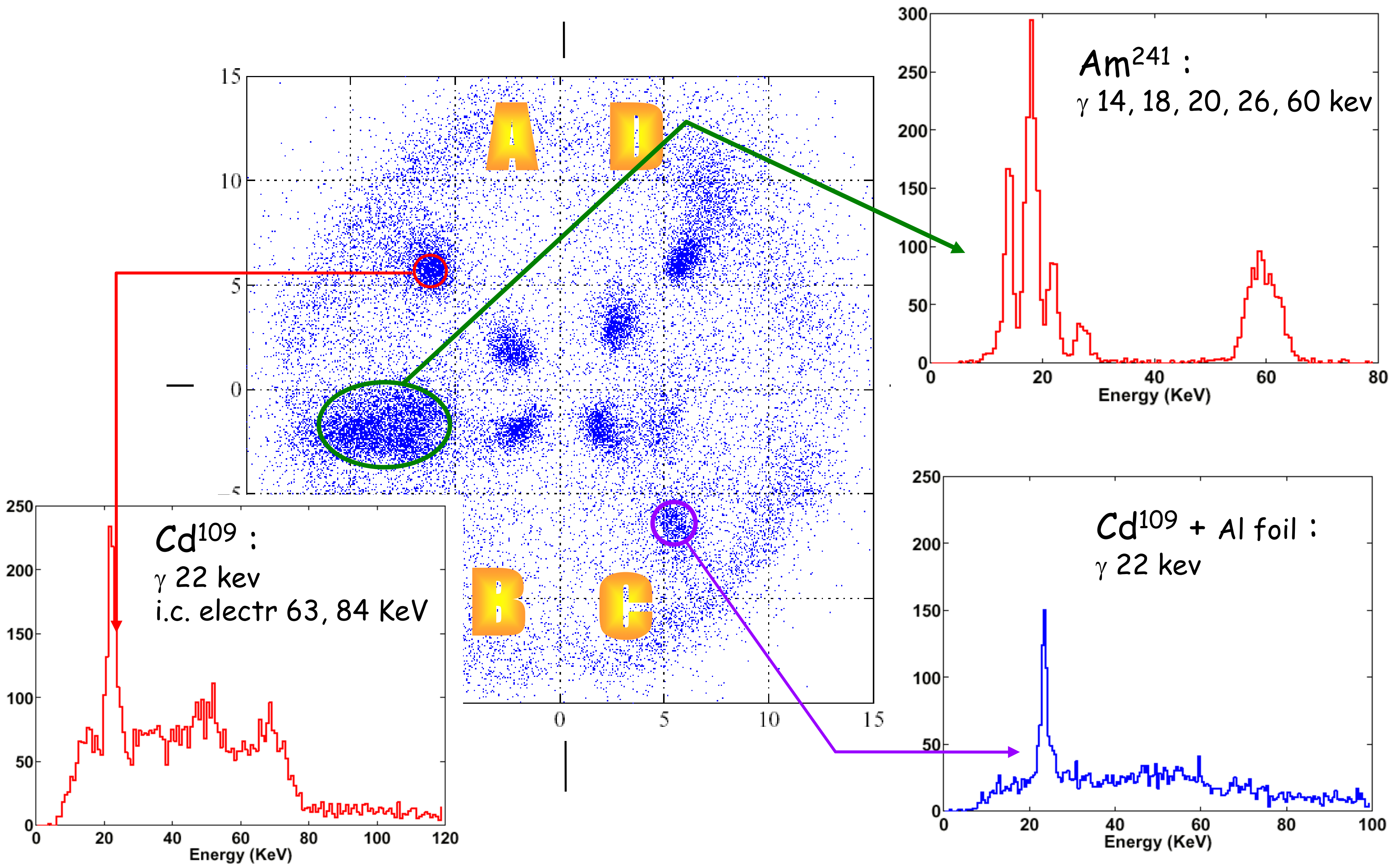


Phonons are collected by Al fins, creating quasi particles that are then trapped by the W TES



Sensors held in equilibrium between Normal and Super Conducting. Highly sensitive to small energy deposit. Fast signal. SQUID Readout

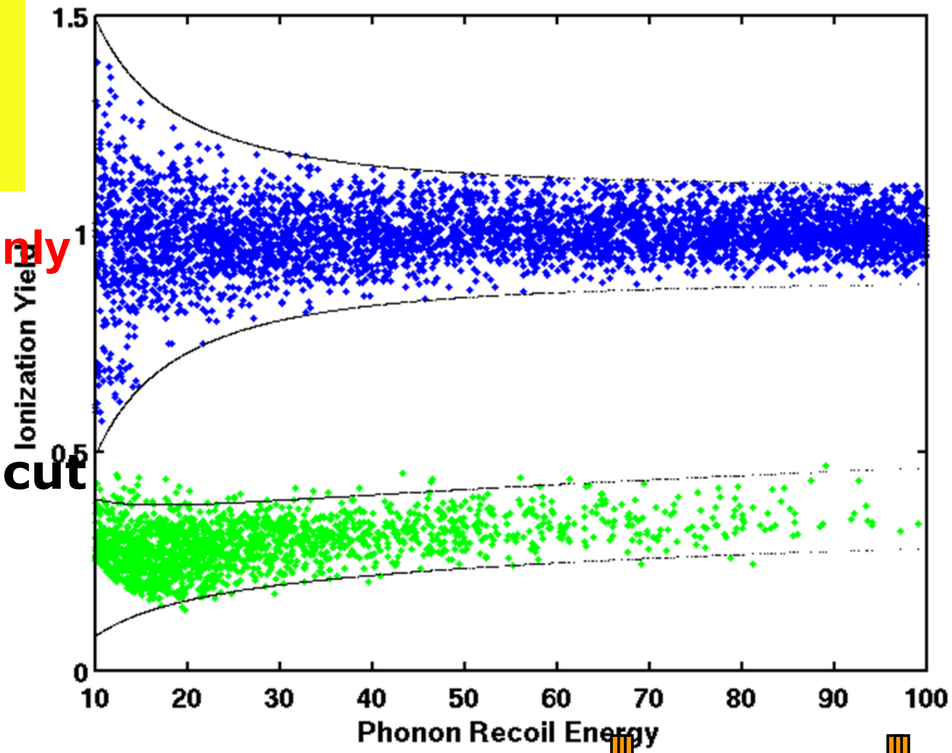
Excellent Energy, Position Resolution

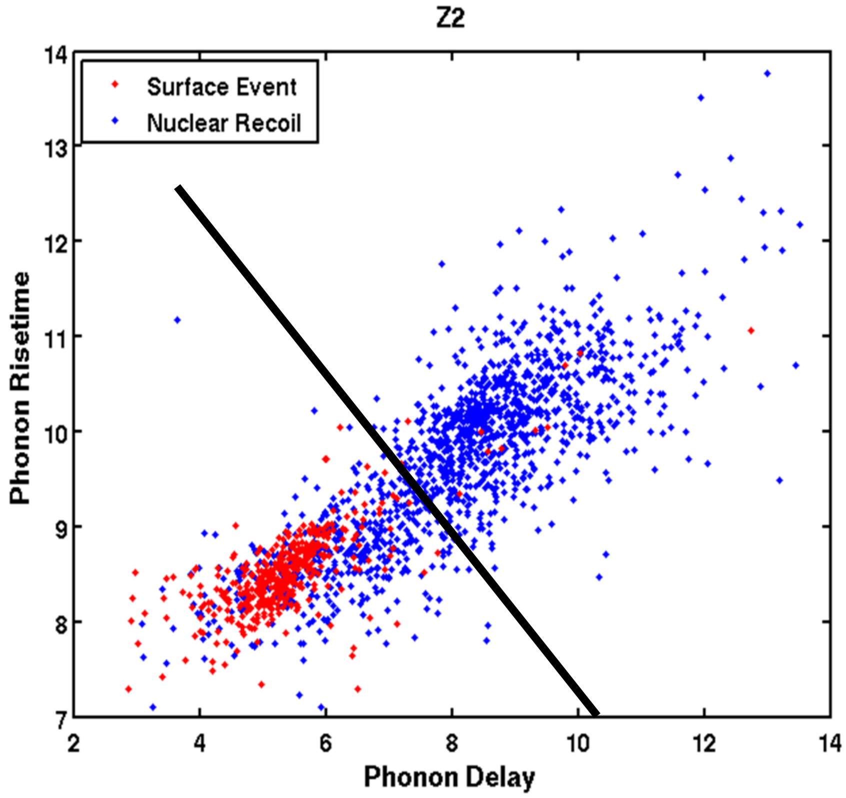


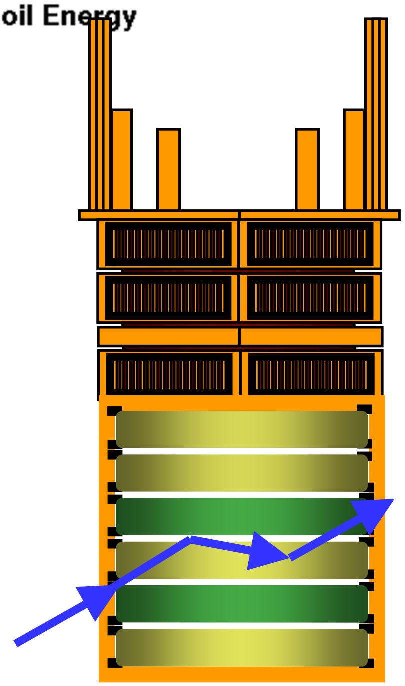
WIMP Candidate: Blind Analysis

All cuts set blind, using calibration data only

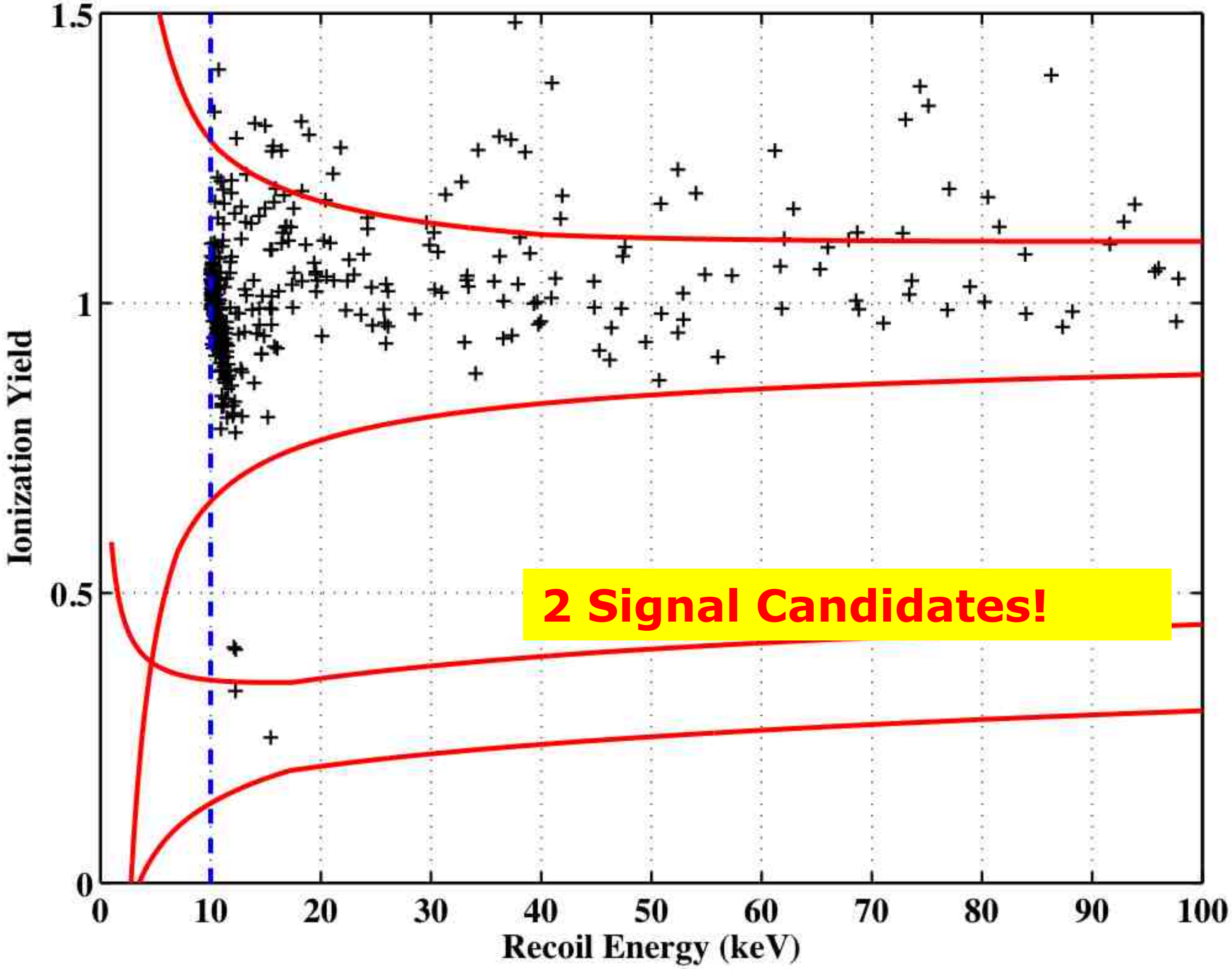
- In good Fiducial Volume
- In the Nuclear Recoil Band
- Not surface event: phonon timing cut
- Not a Multiple Scatter







CDMSII (4kg) Ge Final Result (2010)



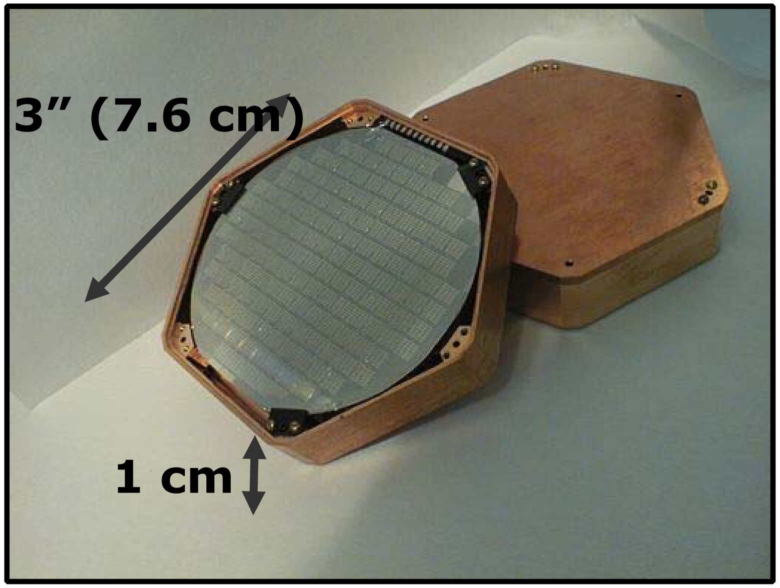
2 Signal Candidates!

Science 327 (2010)

20% chance of fluctuation from 0.8 ± 0.2 background

The CDMS-II Si Data

Ge: 0.25 kg, Si 0.1 kg
3”dia x1cm thick

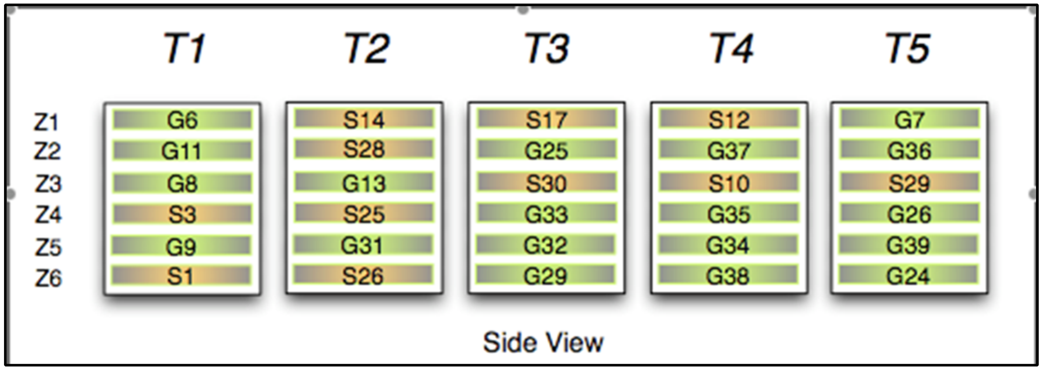


CDMS-II Exposure

- **Oct. 2003 - Aug. 2004**
- **42.7 kg-days in 4 Si detectors**

- **Oct. 2006 - July 2007**
- **55.9 kg-days in 6 Si detectors**
- http://xxx.lanl.gov/abs/1304.3706

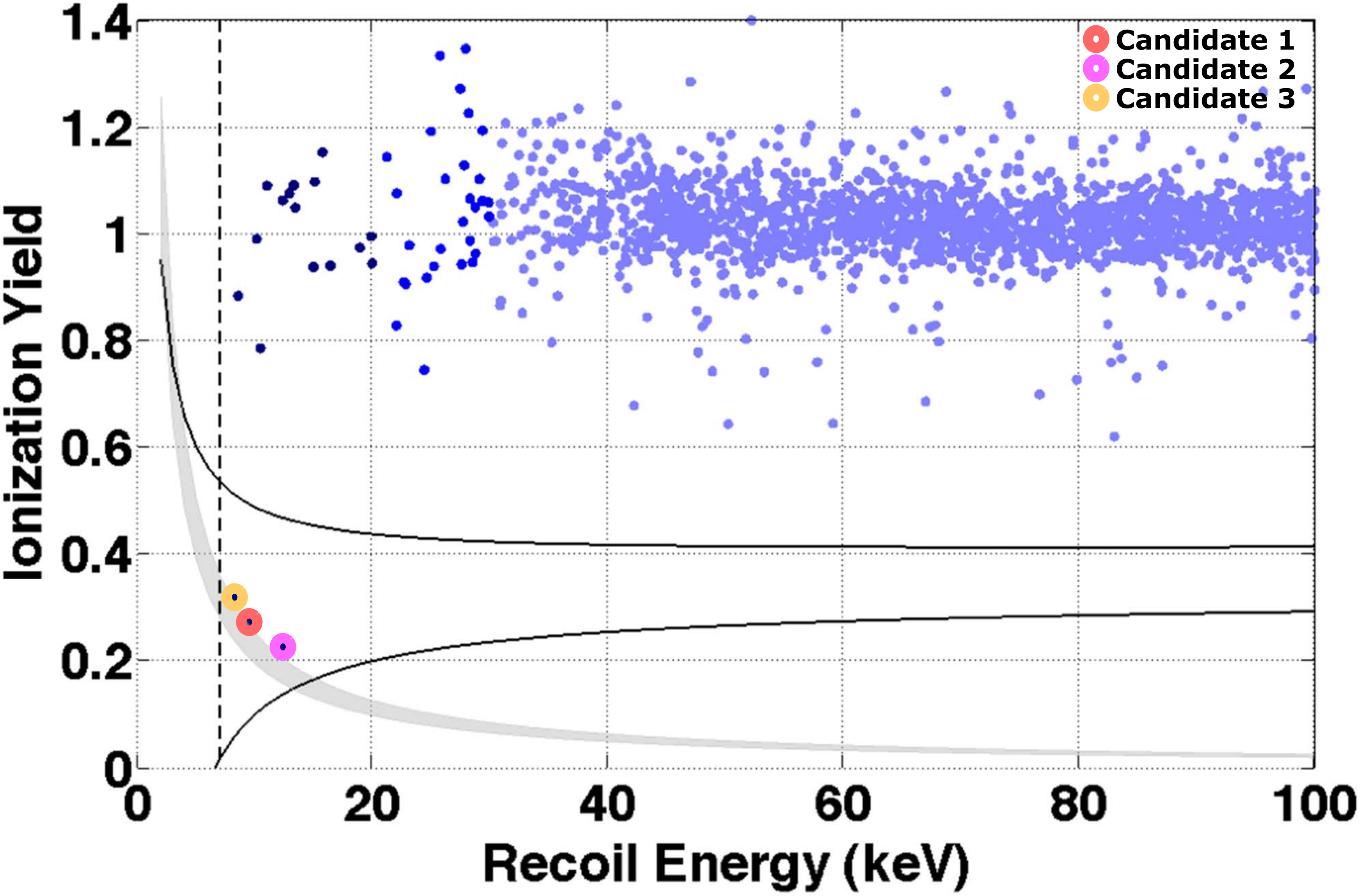
- **July 2007 - Sep. 2008**
- **140.23 kg-days in 8 Si detectors**



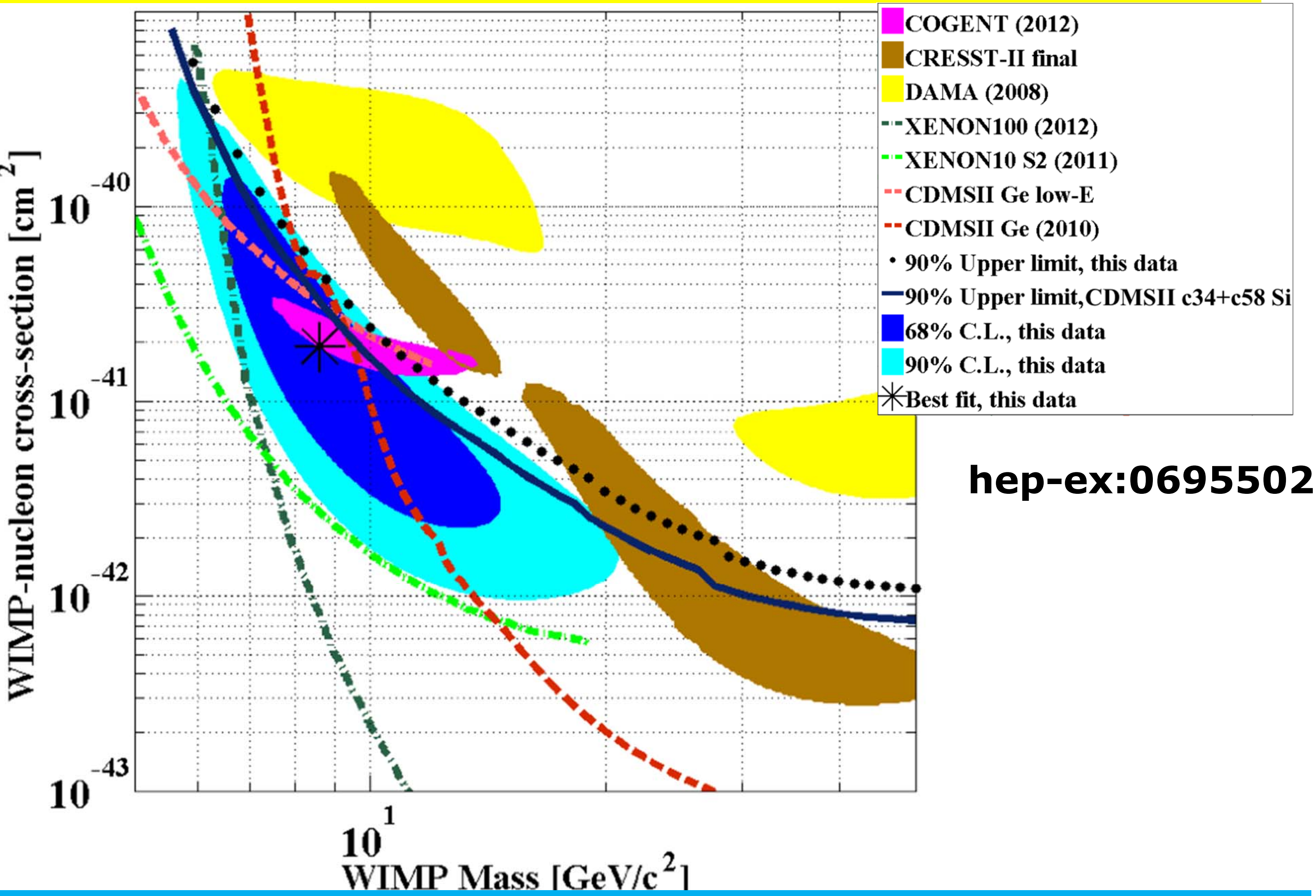
	T1	T2	T3	T4	T5
Z1	G6	S14	S17	S12	G7
Z2	G11	S28	G25	G37	G36
Z3	G8	G13	S30	S10	S29
Z4	S3	S25	G33	G35	G26
Z5	G9	G31	G32	G34	G39
Z6	S1	S26	G29	G38	G24

Side View

Unblinding Results - after timing cut



Confidence Intervals and Results



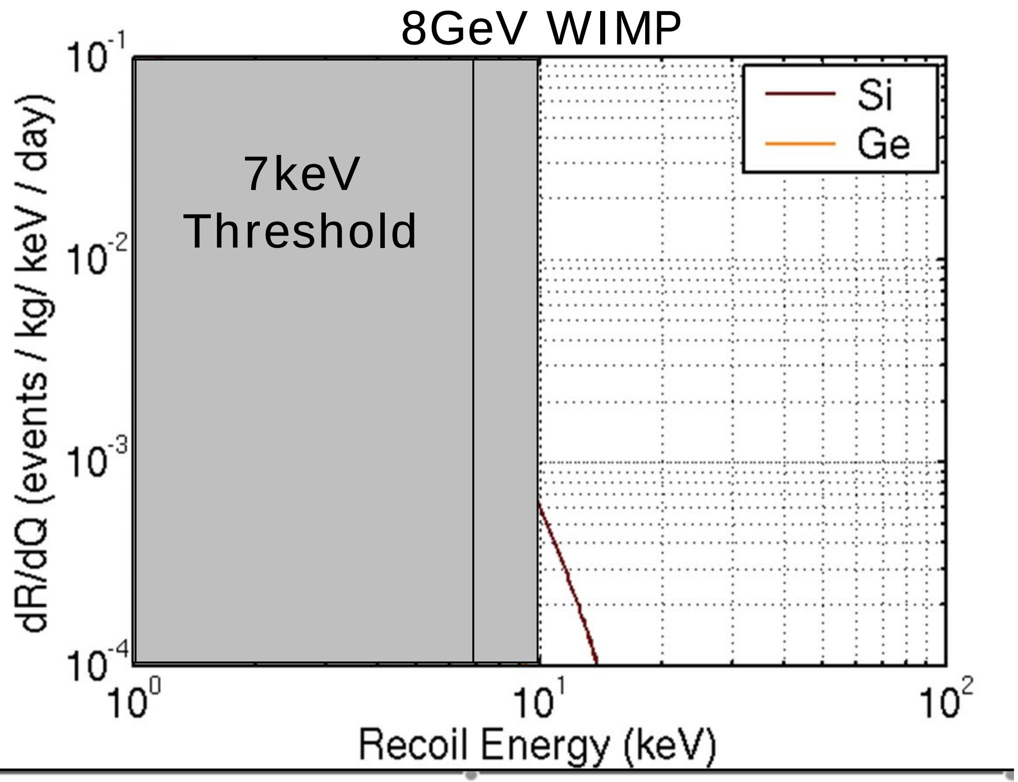
hep-ex:0695502

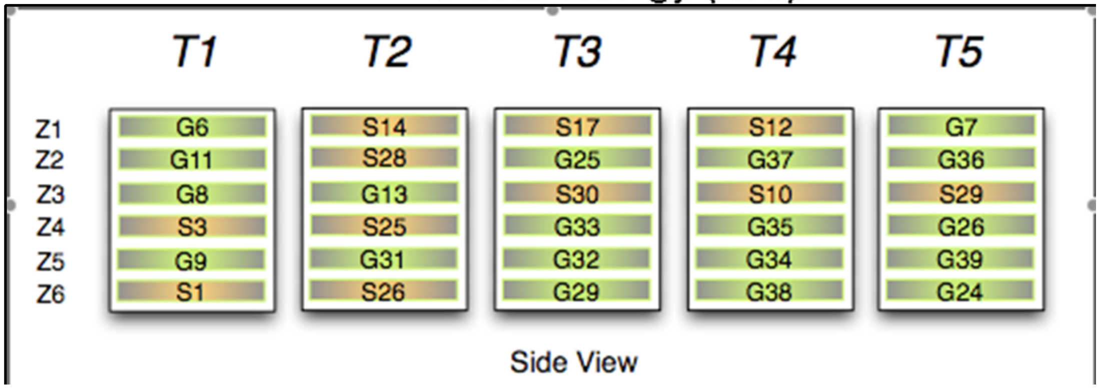
3.1 σ (99.8% sure) is NOT a discovery! Certainly needs to be explored by other experiments. Maximum likelihood occurs at a WIMP mass of 8.6GeV/c^2 and cross section of $1.9\text{x}10^{-41}$$\text{cm}^2$

WIMP Searches Using Si Detectors

Si Detectors good for low mass WIMP search (kinematics)

- **8 Si Crystals (0.1 kg each)**
- **Two sets of data obtained**
  - **2006-2007 with 55.9 kg-day**
  - http://xxx.lanl.gov/abs/1304.3706
  - **2007-2008 with 140.2 kg-day**
  - http://xxx.lanl.gov/abs/1304.3706





	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

Side View

DM, Baryons: Coincidence

Matter Abundance

$$\Omega = \frac{\rho}{\rho_c}, \rho = mn$$

m: mass; n: number density

$$\frac{\Omega_b}{\Omega_{DM}} = \frac{m_b n_b}{m_{DM} n_{DM}}$$

Coincidence Problem:

$$\frac{\Omega_b}{\Omega_{DM}} \sim \frac{1}{6}$$

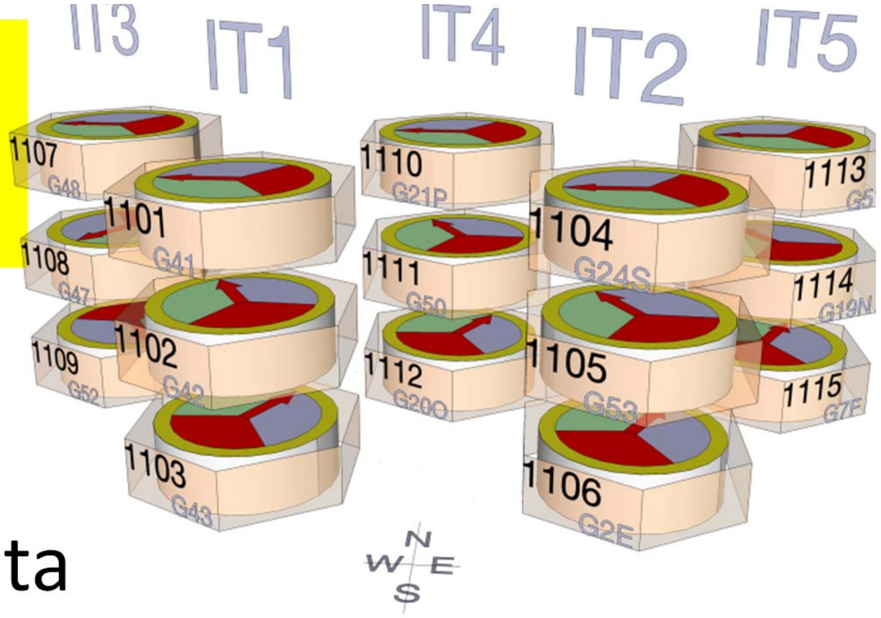
$$\frac{m_b}{m_{DM}} \sim \frac{1}{8}$$ **[CDMS]** ➡ $$n_b \sim n_{DM}$$

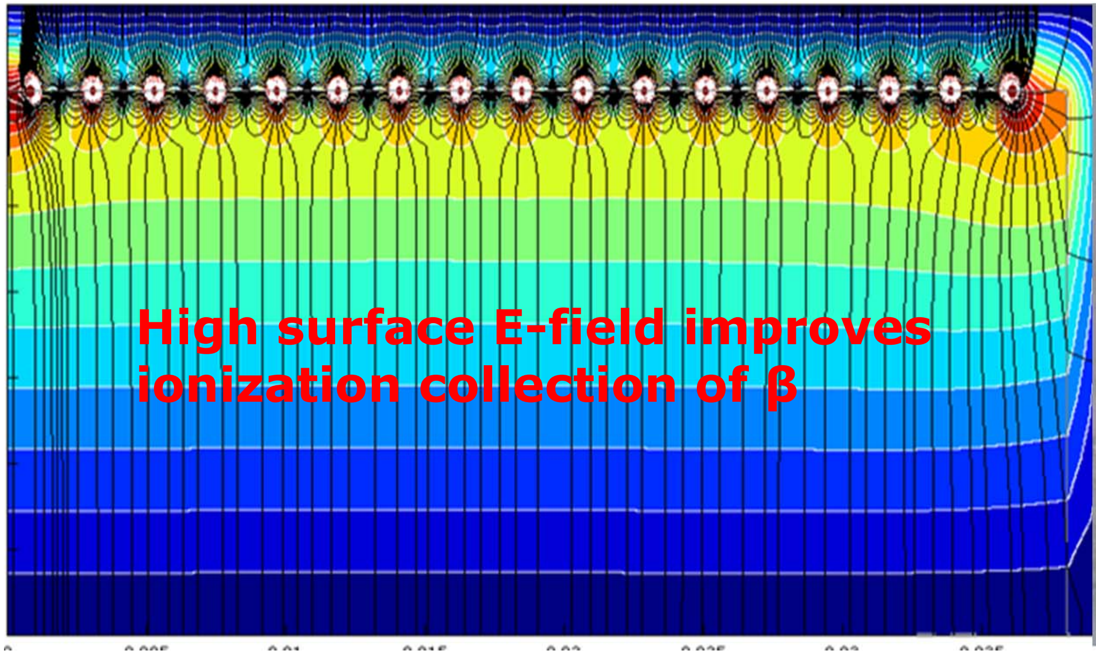
Soln: **Both DM abundance and Baryon asymmetry are produced from the same source→Cladogenesis**

Allahverdi, Dutta, Sinha: Phys.Rev. D83 (2011) 083502

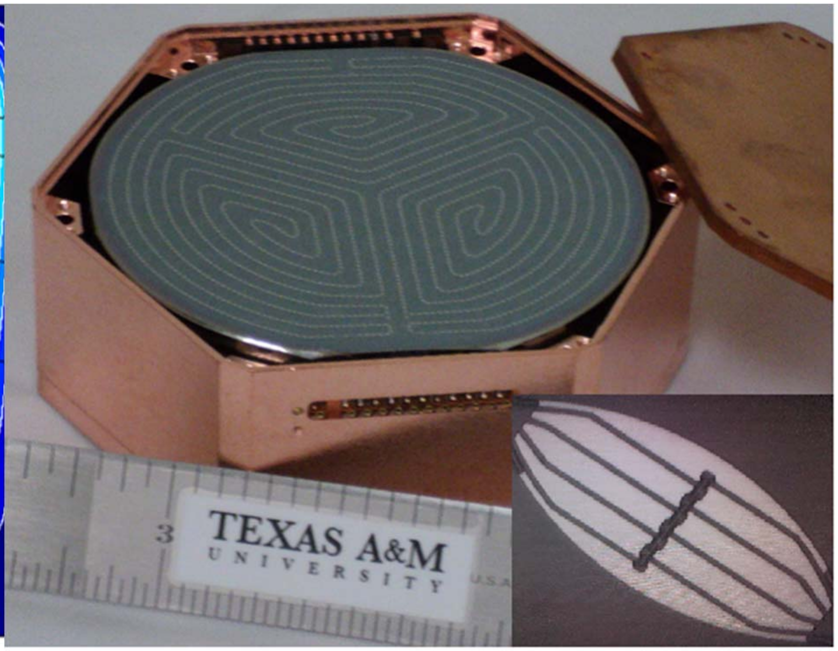
SuperCDMS Soudan Results by end Jan!

- iZIP designed to reject all surface event background
- 10 kg total mass, 2 years data
- Sensitivity ~ Xenon 100

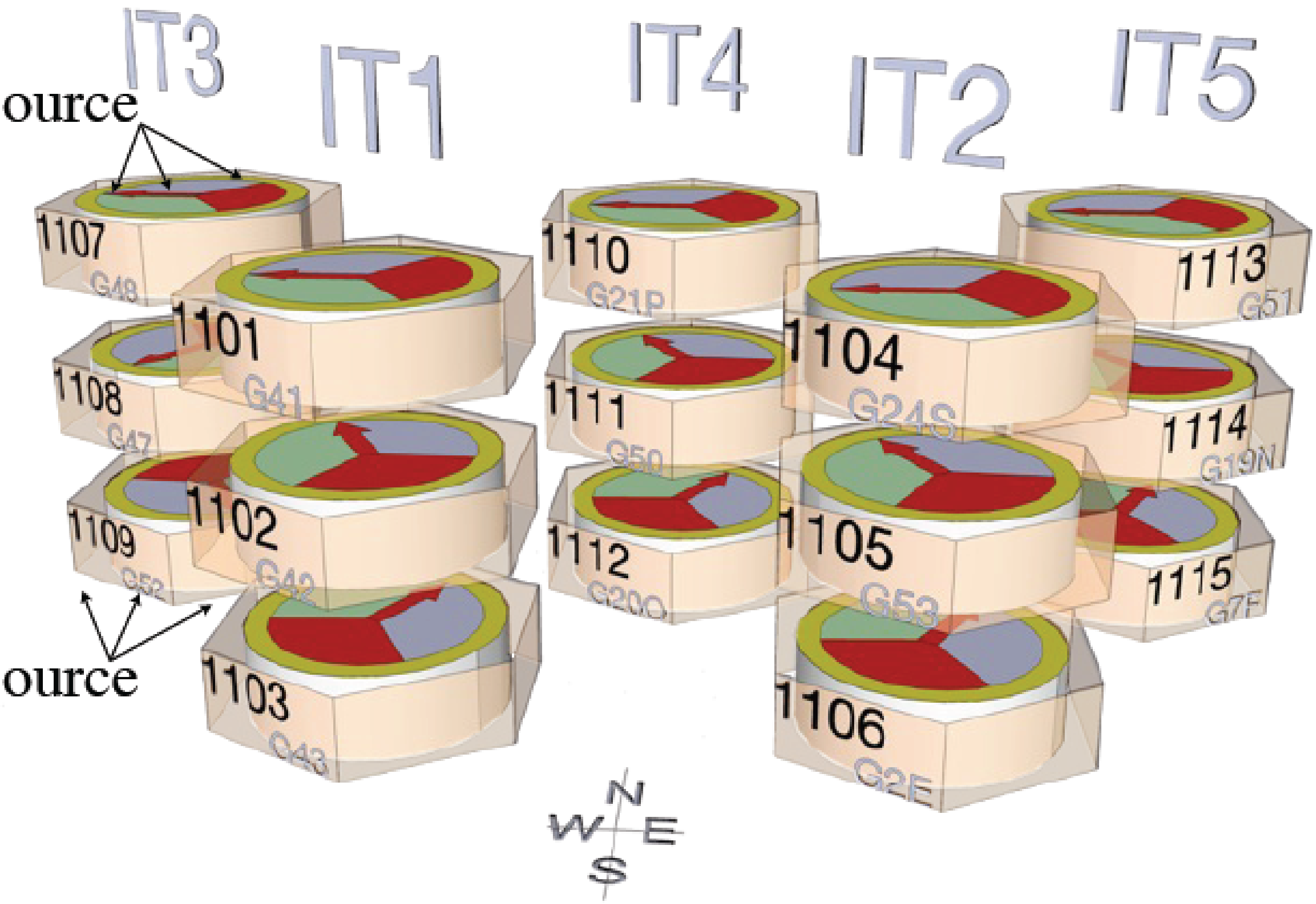




High surface E-field improves ionization collection of β



Configuration for up to 3 yr run to Mar 2015

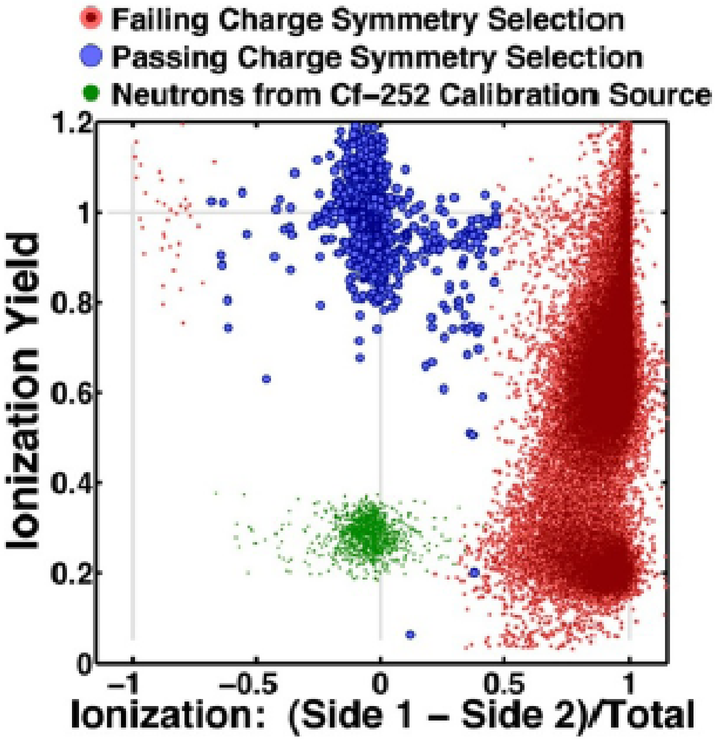


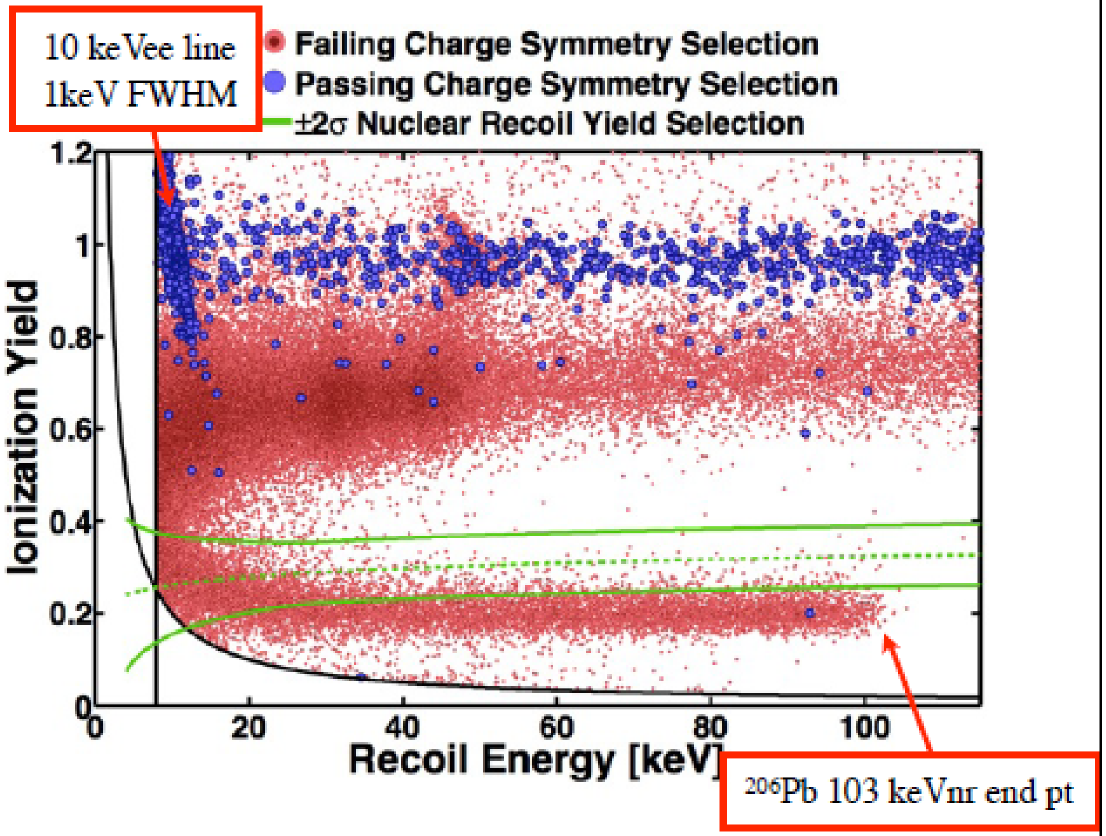
^{210}Pb source

^{210}Pb source

^{210}Pb Source Data from SuperCDMS Soudan

- Two detectors with one ^{210}Pb decay every min operated for 20 live days corresponds to more than total ^{210}Pb events for SuperCDMS Soudan and even for future 200 kg SuperCDMS SNOLAB

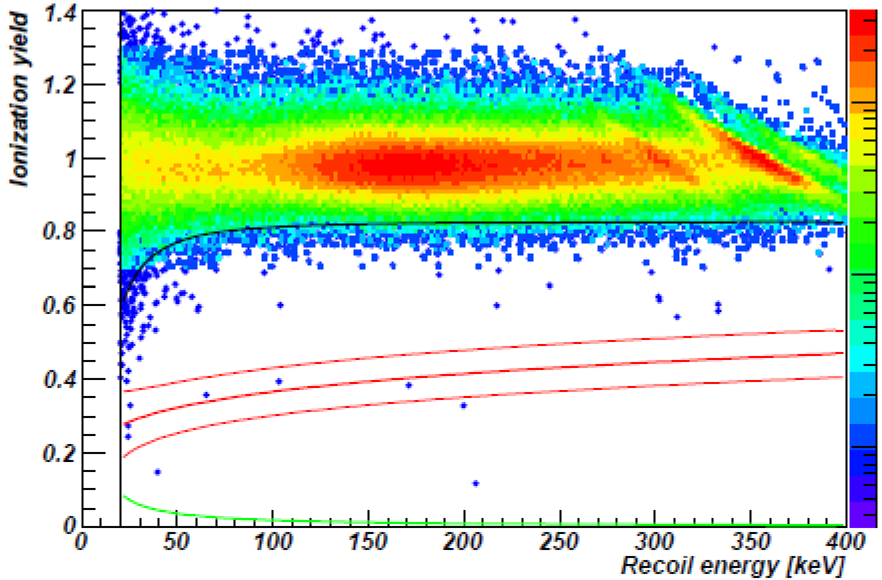


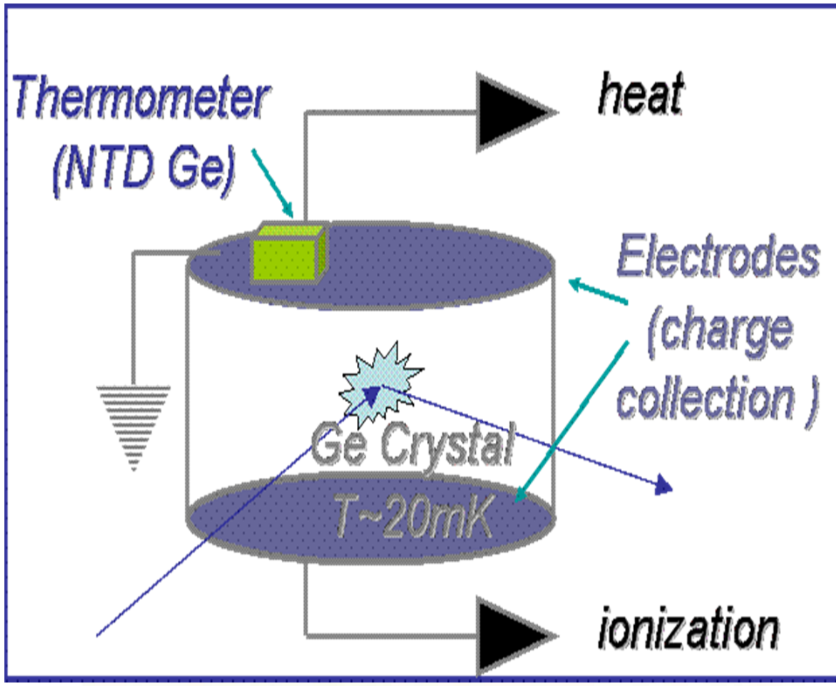


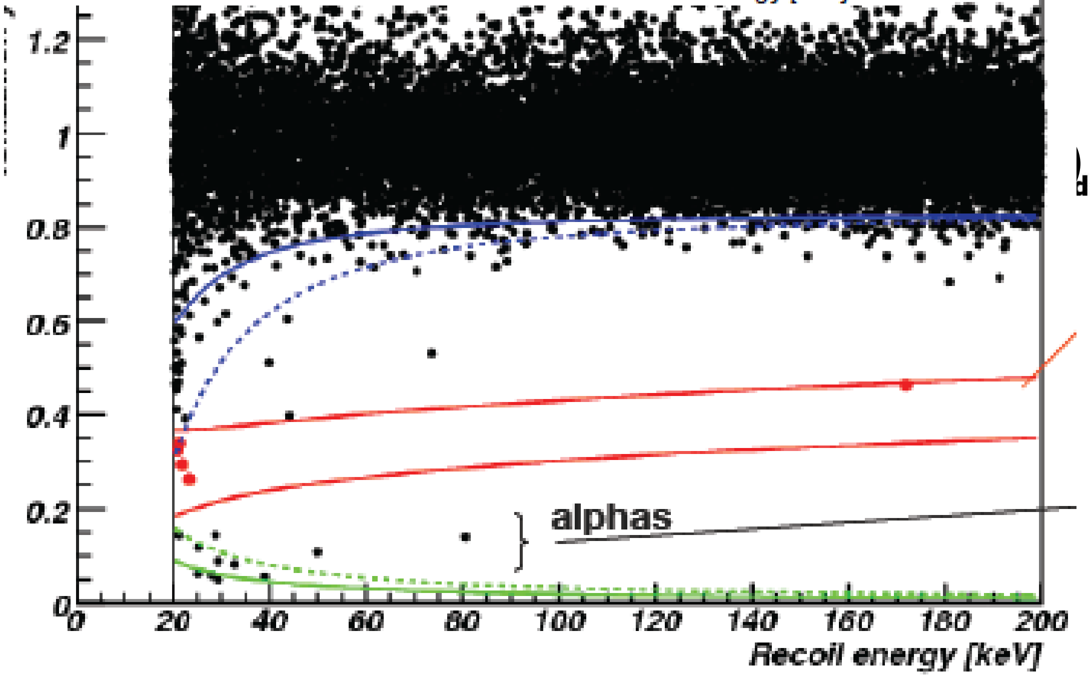
10 keVee line
1keV FWHM

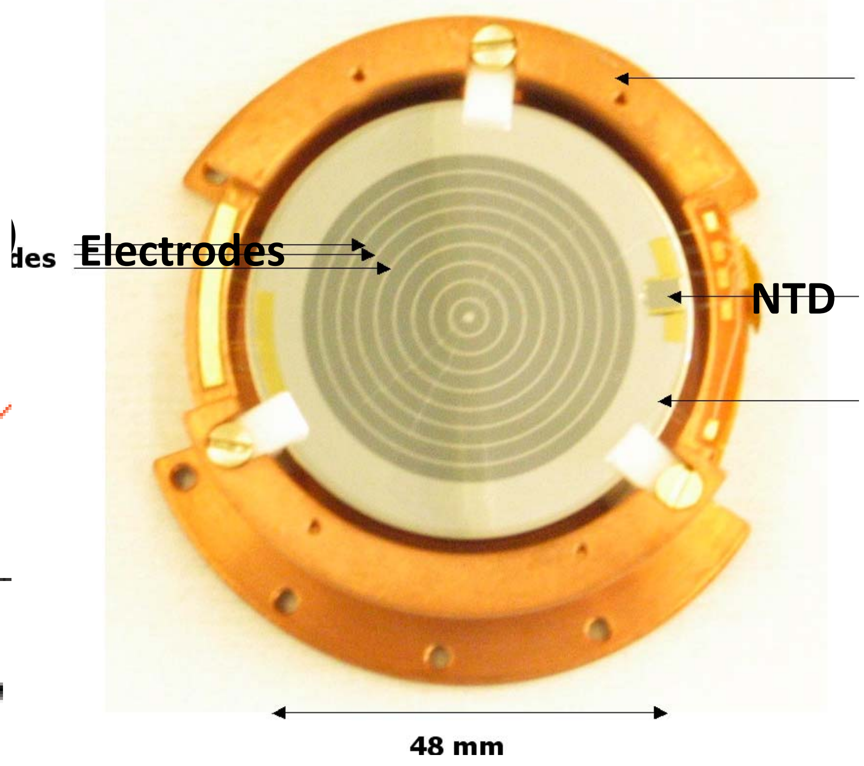
^{206}Pb 103 keVnr end pt

EDELWEISS: Ge with Thermal Phonons



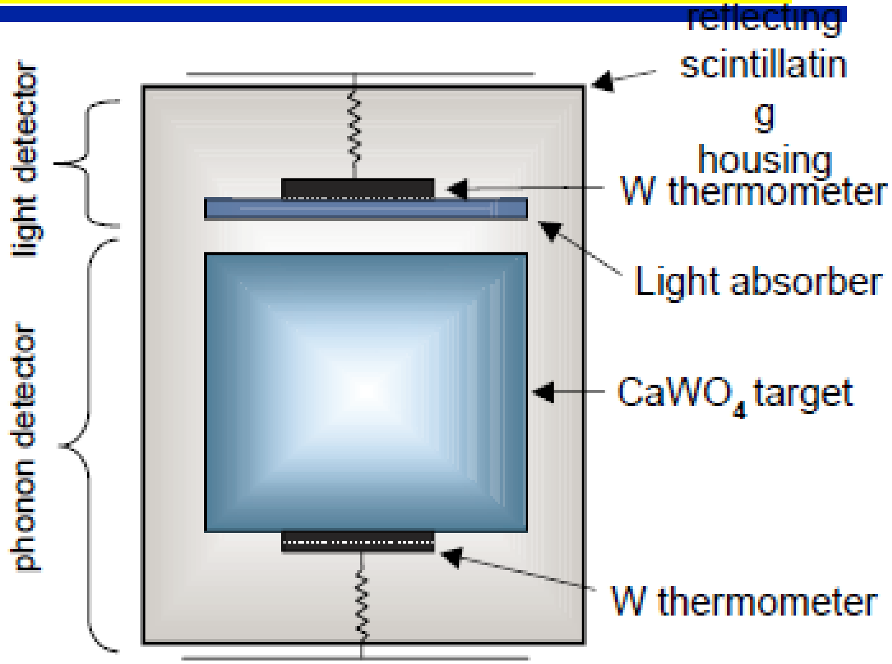






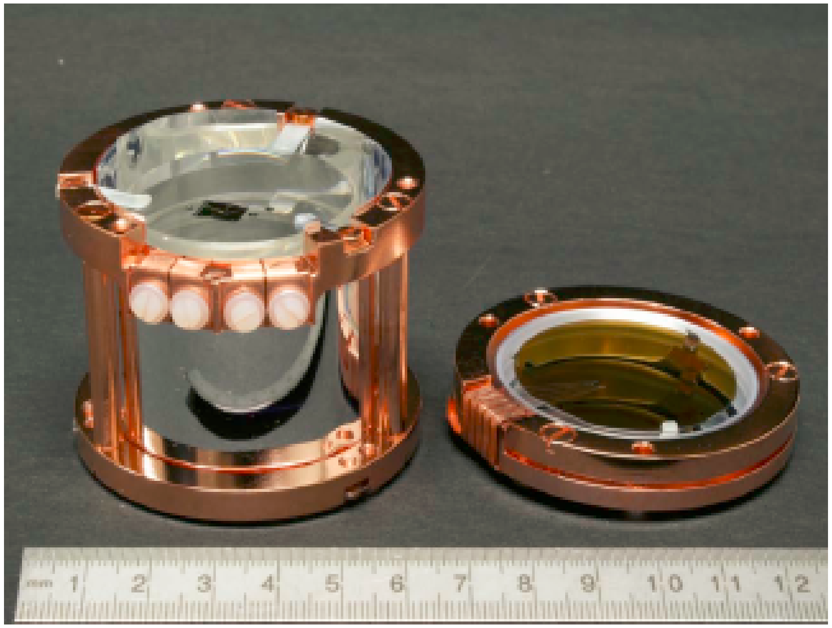
CRESST Cryogenic Detectors

- ☐ Target crystals operated as ***cryogenic calorimeters*** (~10mK)
  - energy deposition in the crystal:
    - → mainly phonons
      - temperature rise detected with W-thermometers
      - measurement of deposited energy (sub keV resolution at low energy)
    - → small fraction into scintillation light
- ☐ Separate ***cryogenic light detector*** to detect the light signal



Detector module:

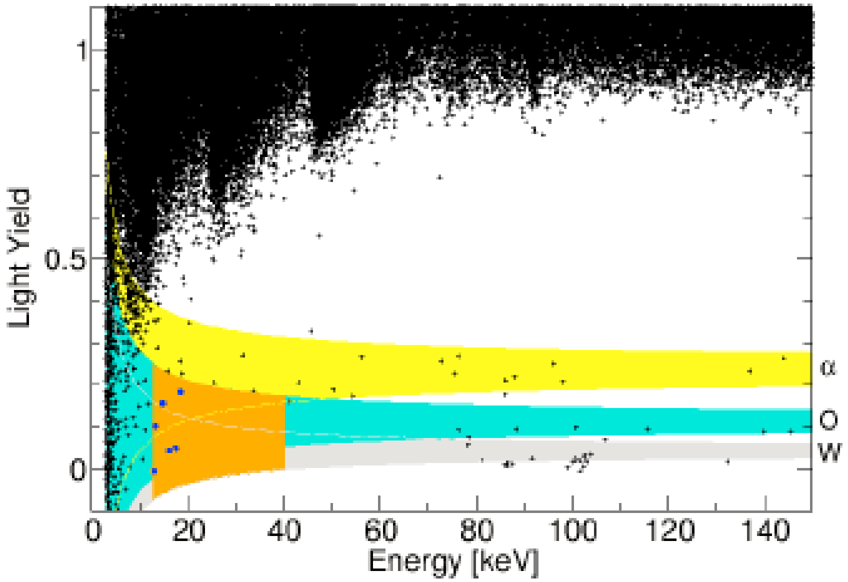
- Simultaneous measurement of:
  - →***deposited energy E in the crystal*** (independent of the type of particle)
  - →***scintillation light L*** (characteristic of the type of particle)



F. Petricca

Observed Events

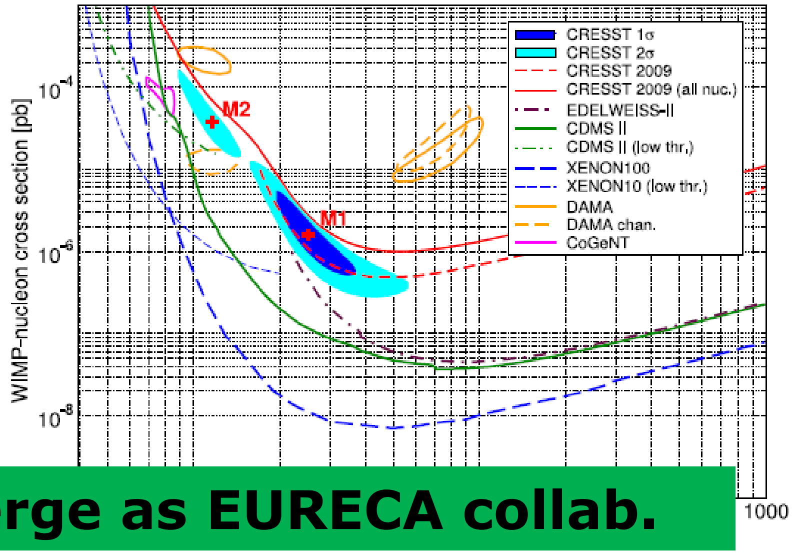
- highly populated *e*/γ band
- low-energy α-events
  - α-contamination in the clamps holding the crystals
- ^{206}Pb nuclei from ^{210}Po α-decays
  - ^{206}Pb recoils (103keV) from ^{210}Po α-decays at the surface of the clamps
- events in the O, Ca and W bands



Acceptance region: O, Ca and W bands

- E_{max} : 40 keV (no significant WIMP signal
- E_{min} : *e*/γ leakage in the acceptance regi

67 accepted events (730 kg d

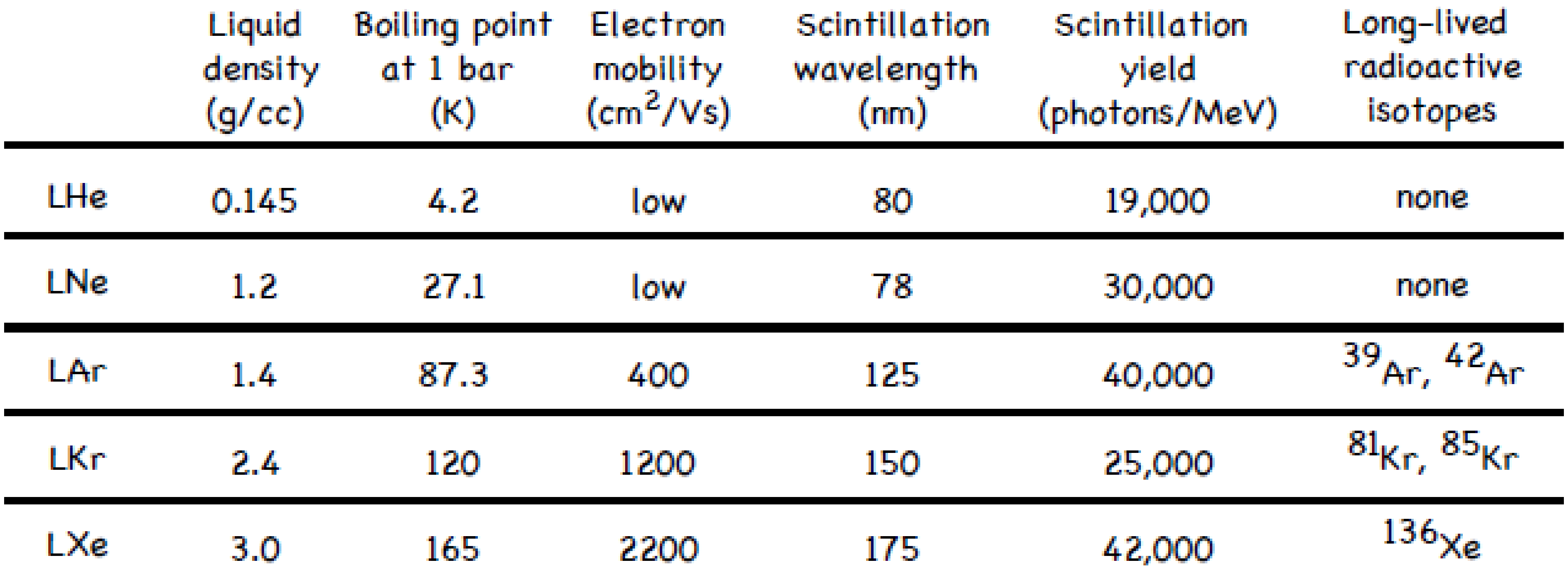


EDELWEISS & CRESST ($CaWO_4$) merge as EURECA collab.

Noble Liquid Scintillation Detectors

Take Your Pick!

Essentially most noble gases can be used for detectors and such prototypes have been demonstrated to work!

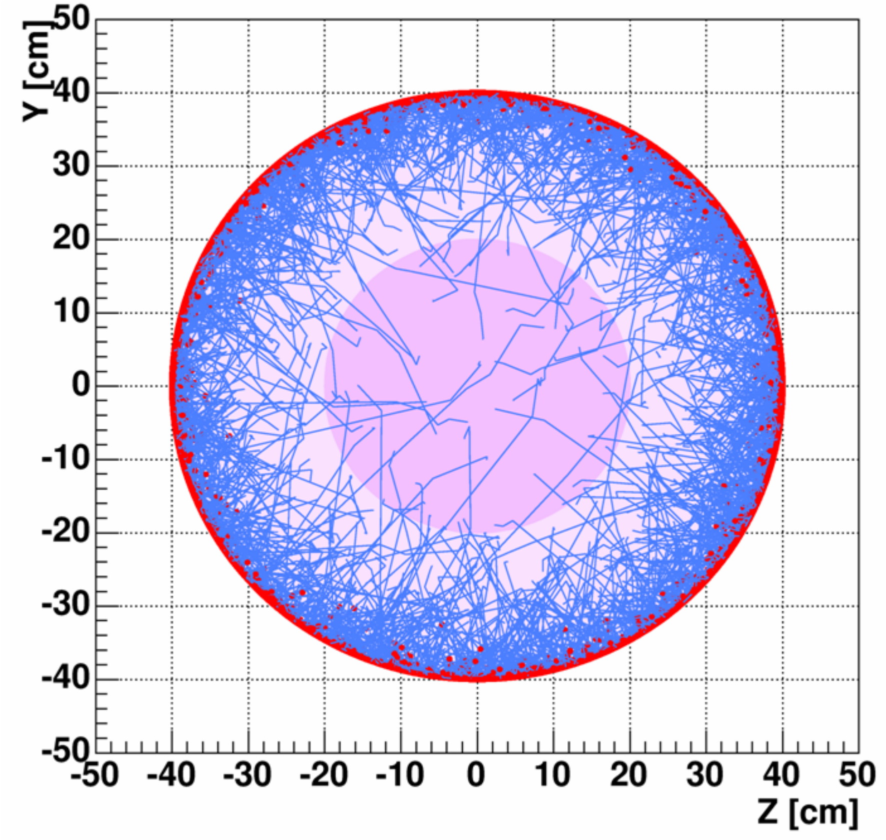


	Liquid density (g/cc)	Boiling point at 1 bar (K)	Electron mobility (cm^2/Vs)	Scintillation wavelength (nm)	Scintillation yield (photons/MeV)	Long-lived radioactive isotopes
LHe	0.145	4.2	low	80	19,000	none
LNe	1.2	27.1	low	78	30,000	none
LAr	1.4	87.3	400	125	40,000	^{39}Ar, ^{42}Ar
LKr	2.4	120	1200	150	25,000	^{81}Kr, ^{85}Kr
LXe	3.0	165	2200	175	42,000	^{136}Xe

Background rejection for WIMP discovery demonstrated for Xe, and Ar

Single Phase Noble Liquid (Xe/Ar)

Self Shielding, Easier cryogenics (160K) and no-self absorption of scintillation light



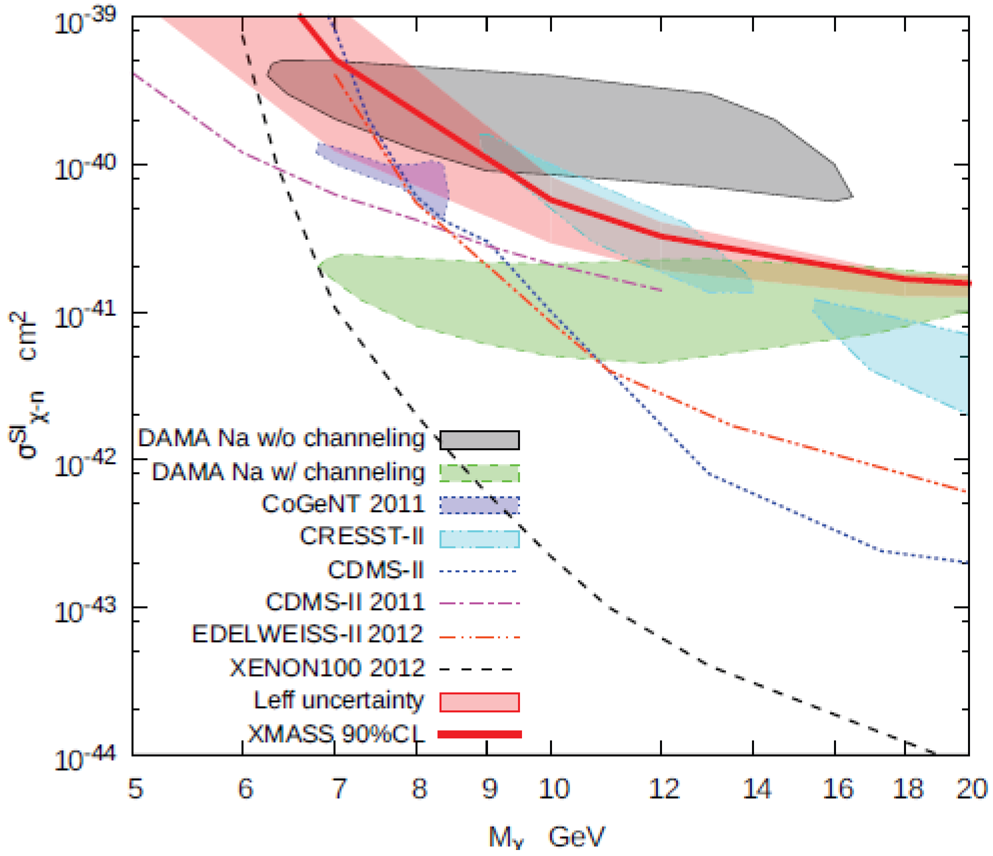
XMASS Single Phase

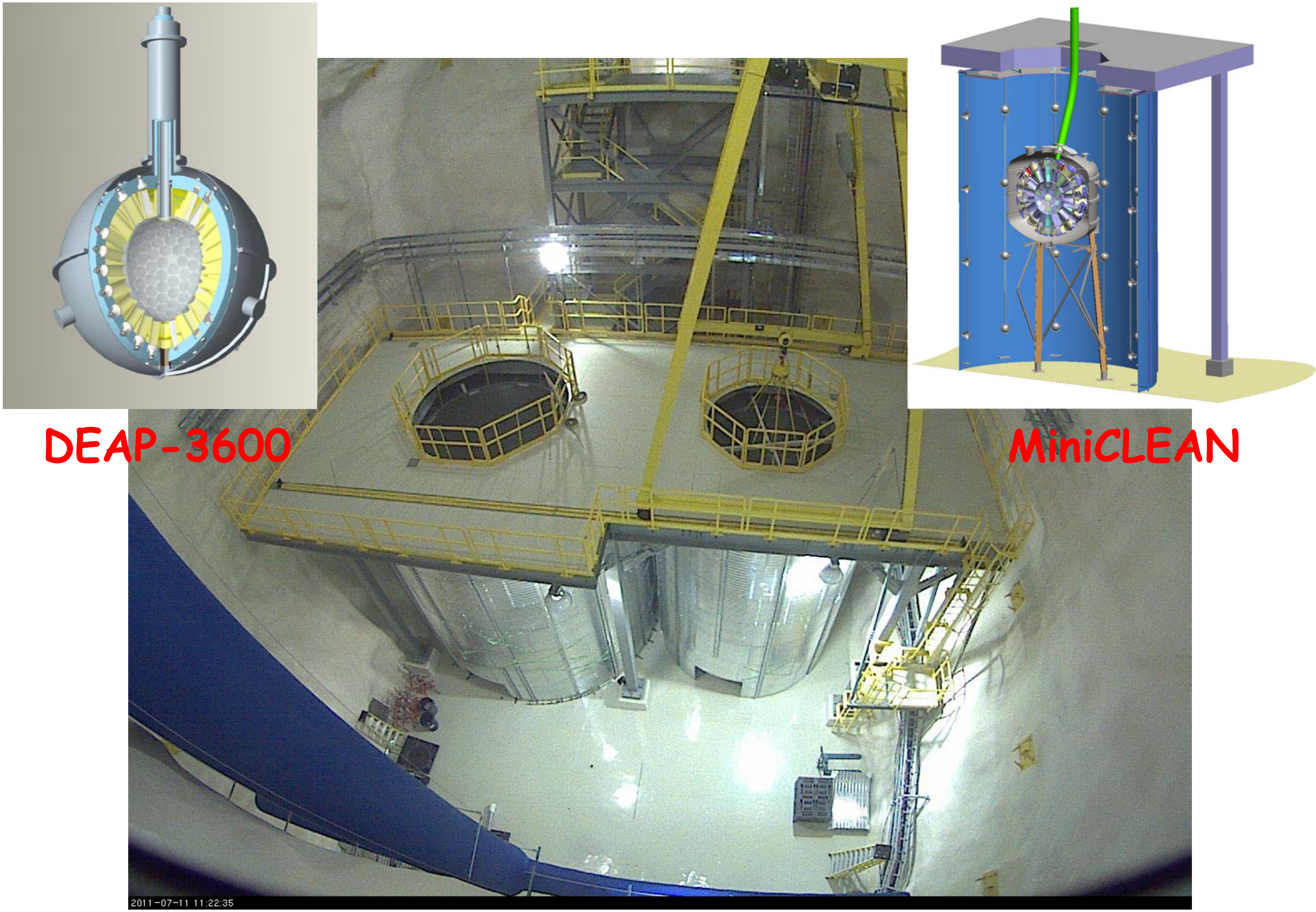
Pros: Simpler design and best possible light yield

Cons: No ER/NR discrimination

XMASS Single Phase Xenon Detector @ Kamioka

- 800kg Xe, 100kg fiducial
- 14.7 pe/keV – can have low E_{th}
- ~25keV NR threshold
- Taking Data Now





DEAP-3600

MiniCLEAN

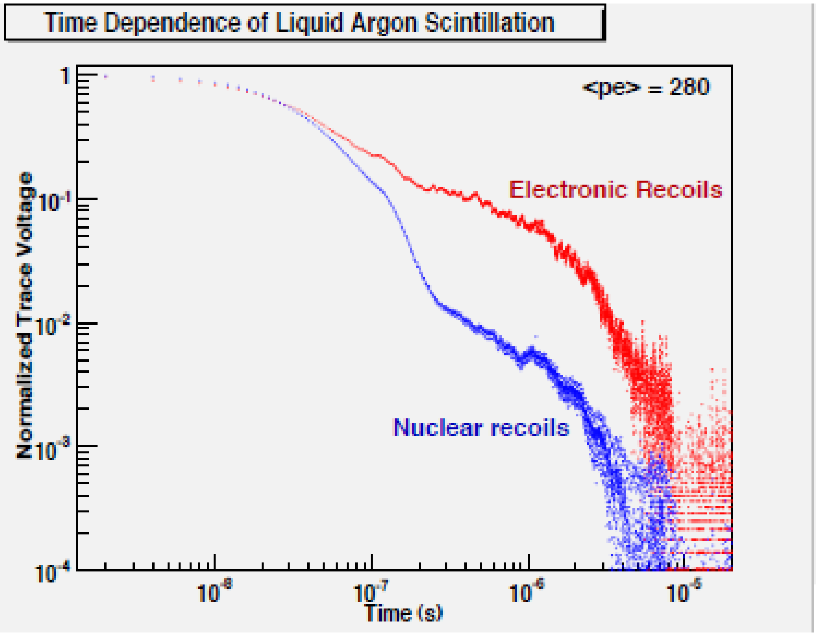
DEAP Liquid Argon@SNOLab

- **7kg (DEAP1) -> 3600 kg, 1000 kg Fid**

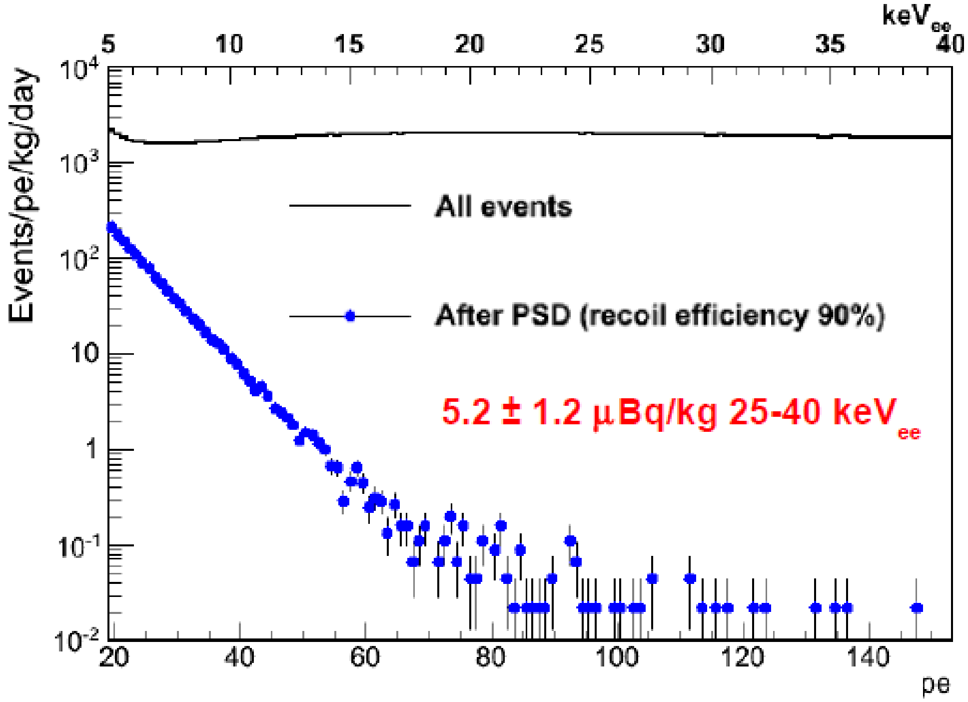
- **To run 2014 – 2019**

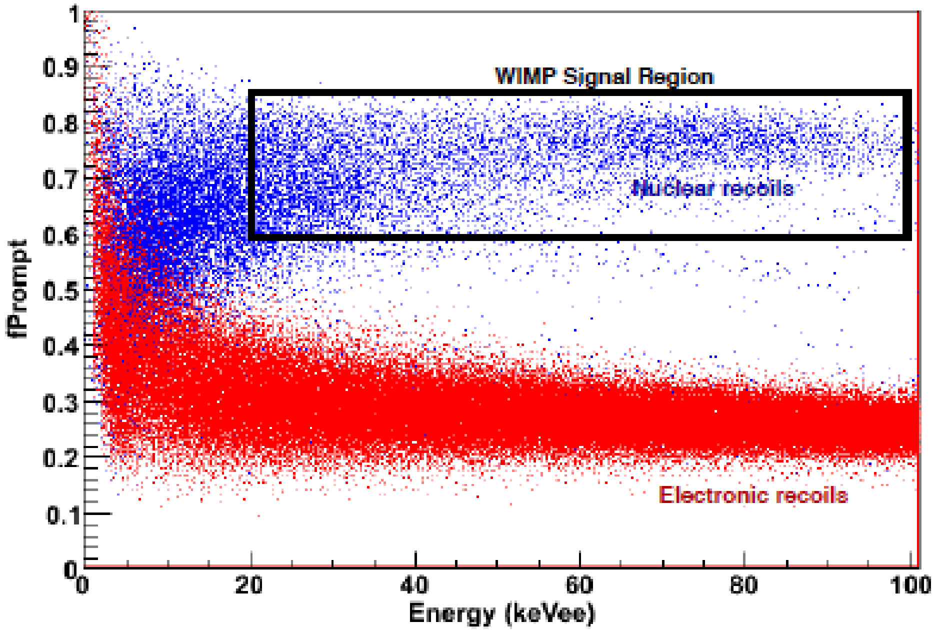
- **Background mainly from 39Ar**
    - **Will utilize PSD Discrimination**

- **Radon surface contamination is a worry**



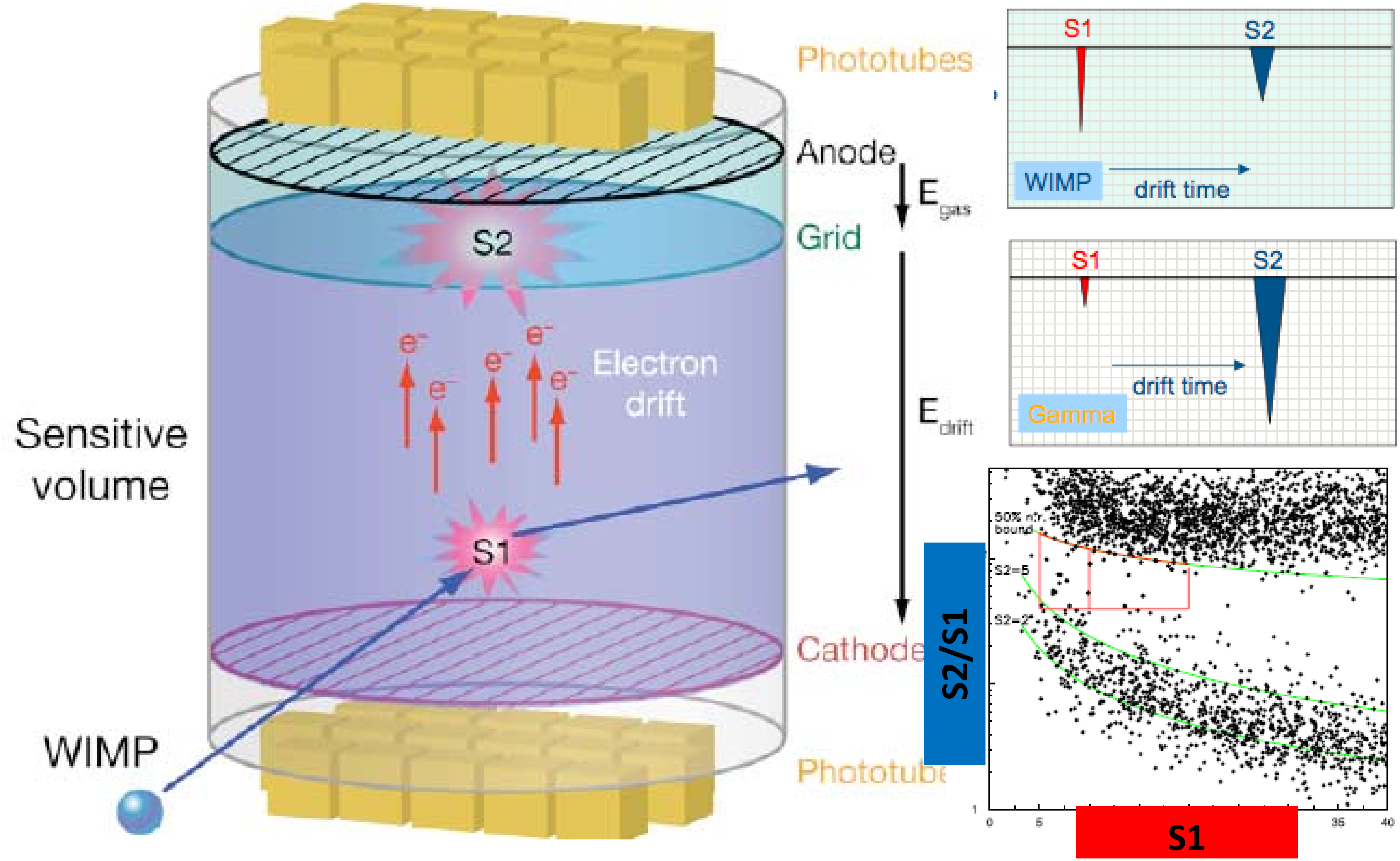
$$F_{prompt} = \frac{\text{PromptPE}\ (150ns)}{\text{TotalPE}\ (9\mu s)}$$





Dual Phase Noble Liquid (Xenon/Ar)

- **Prompt scintillation (S1) from recoil. Delayed S2 from drifted ionization**
- **Nuclear recoil has reduced ionization ⇒ Lower S2 than Electron recoil**



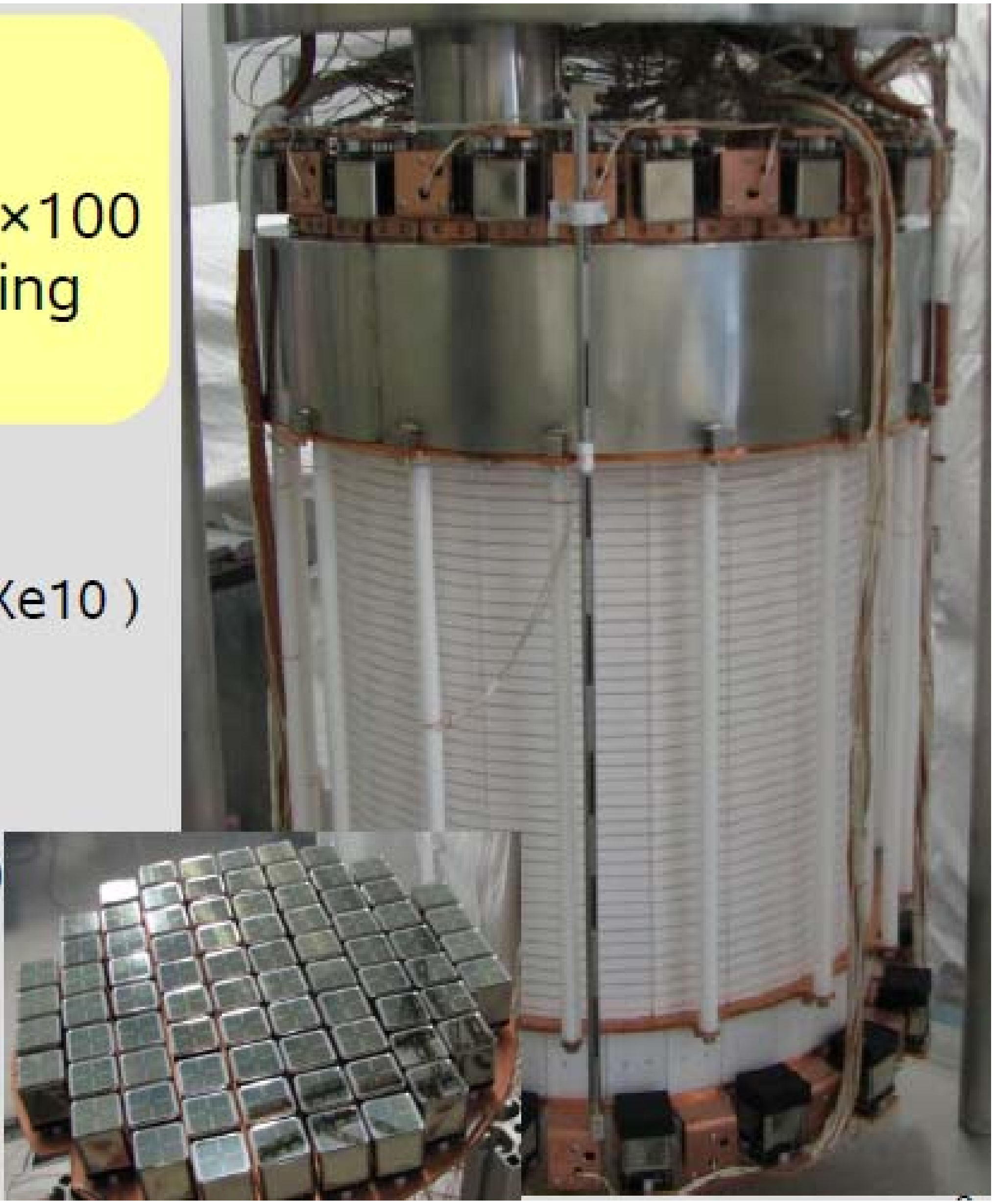
XENON100

Goal (compared to XENON10):
- increase target ×10
- reduce gamma background ×100

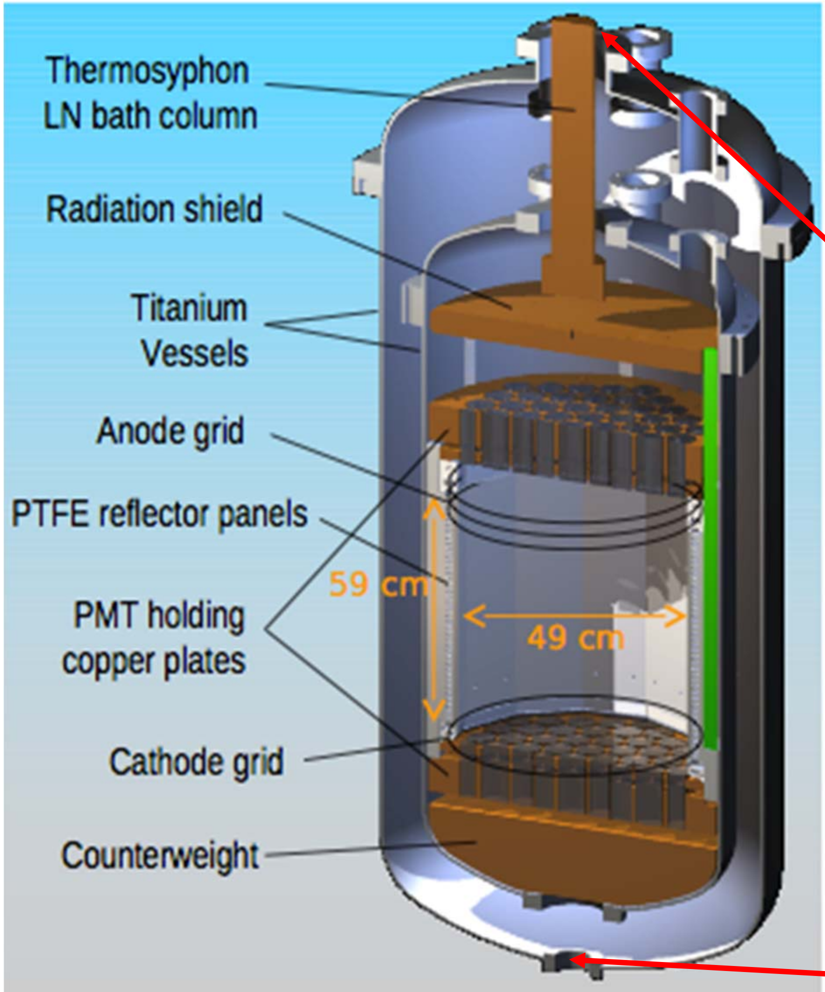
→ material selection & screening
→ detector design

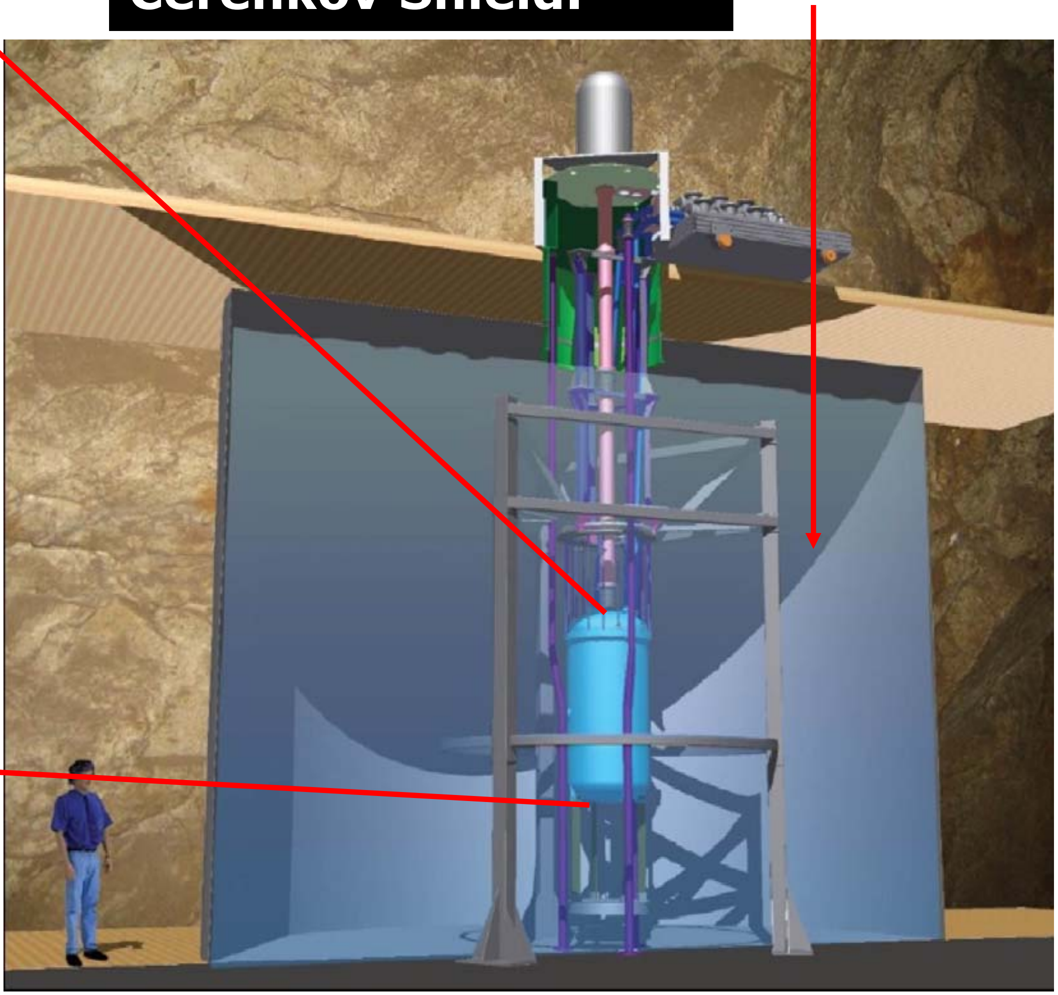
Quick Facts:
- 161 kg LXe TPC (mass: 10 × Xe10)
- 62 kg in target volume
- active LXe veto (≥4 cm)
- 242 PMTs (Hamamatsu R8520)
- improved Xe10 shield
  (Pb, Poly, Cu, H_2O, N_2 purge)

~30 kg Fiducial Mass



The LUX detector

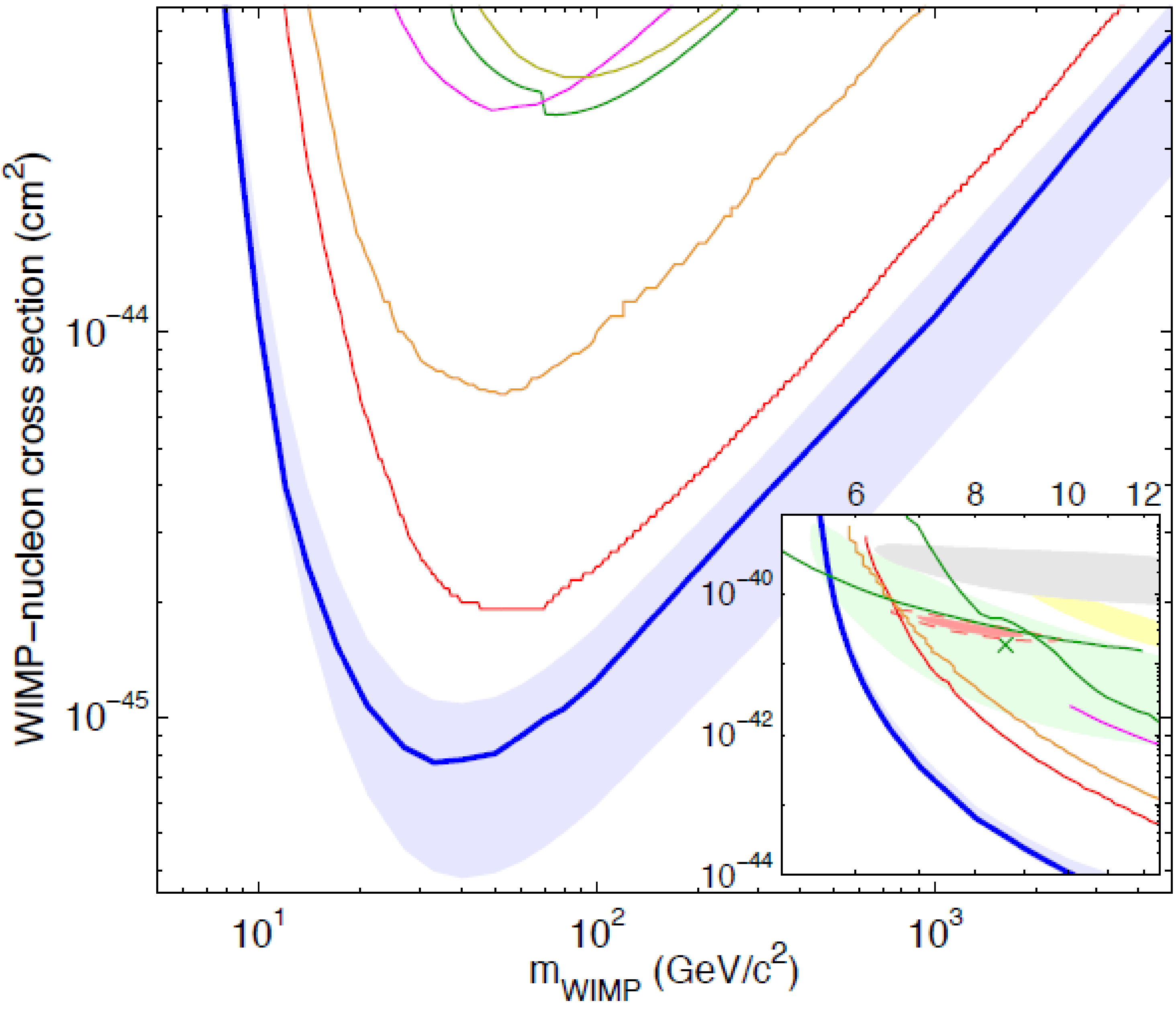




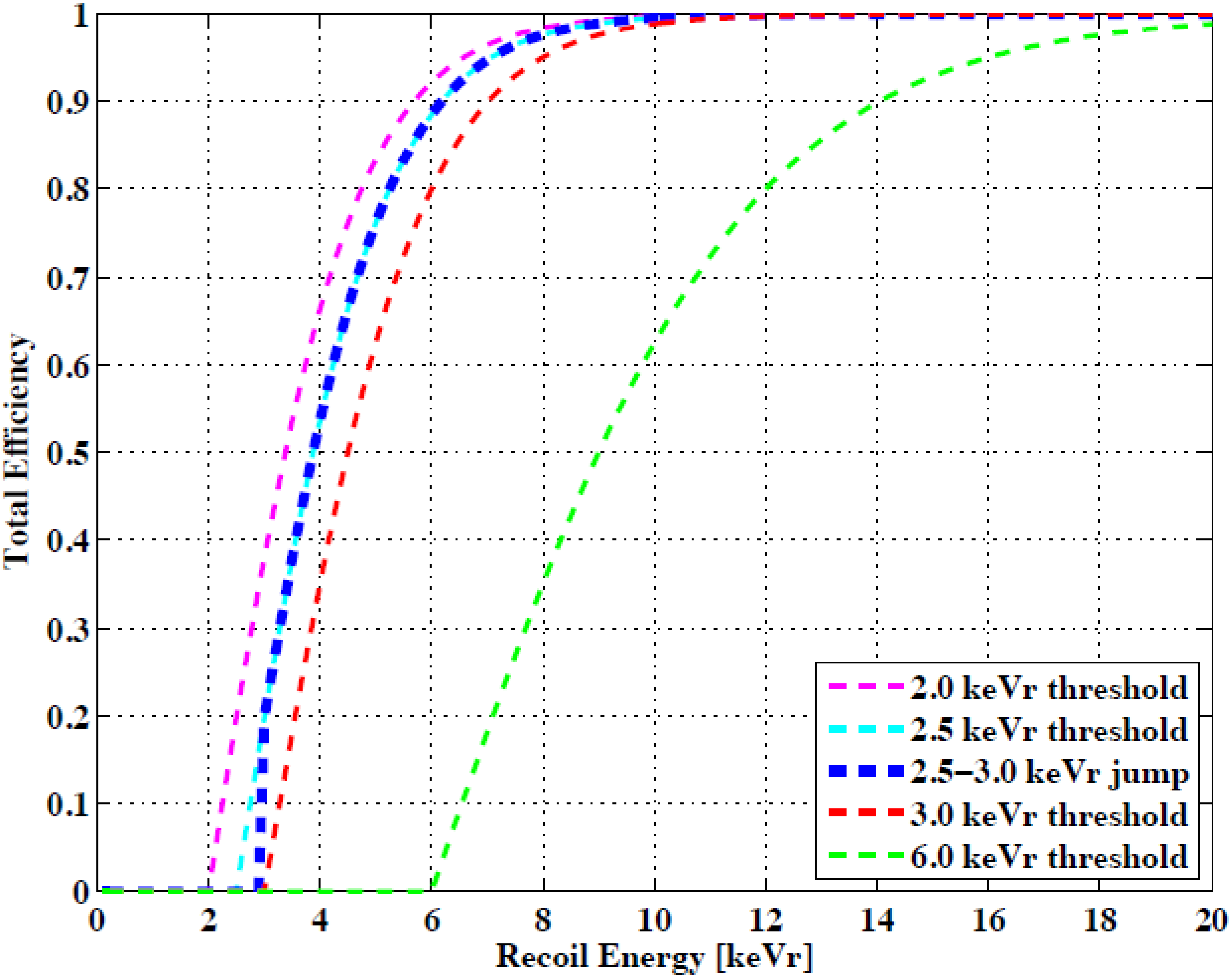
~ 7m diameter Water Cerenkov Shield.

- 350 kg of Lxe
- 122 photomultiplier tubes (top plus bottom)

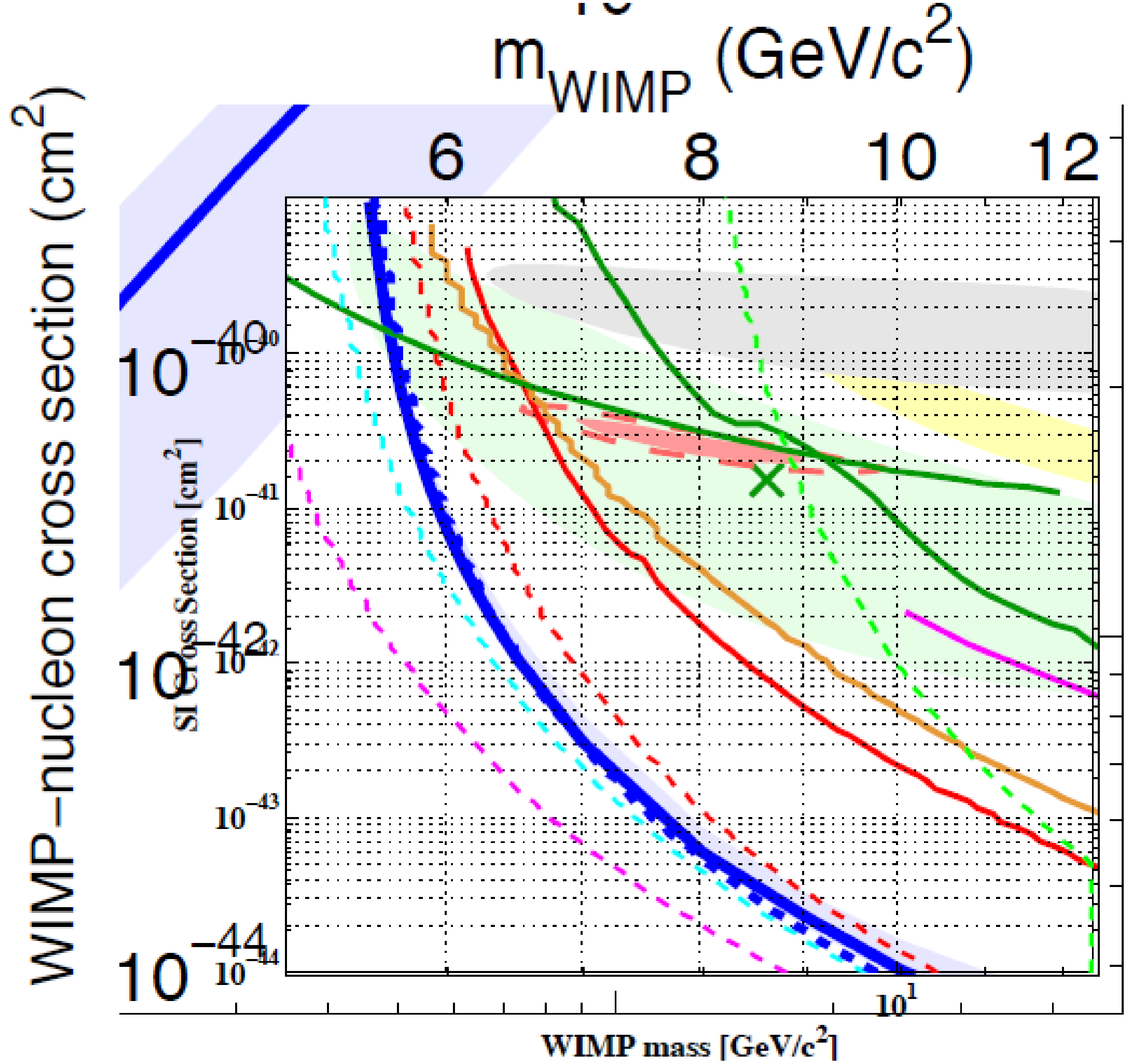
New LUX Results with lower limits



Xe Sensitivity to Threshold



New LUX Results - low mass WIMPs



Xenon Calibration of Energy Scales

Global fit of all L_{eff} data

Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Aprile 2009
Sorensen 2009
Manzur 2010

Energy of nuclear recoil (NR)

measured signal in p.e.

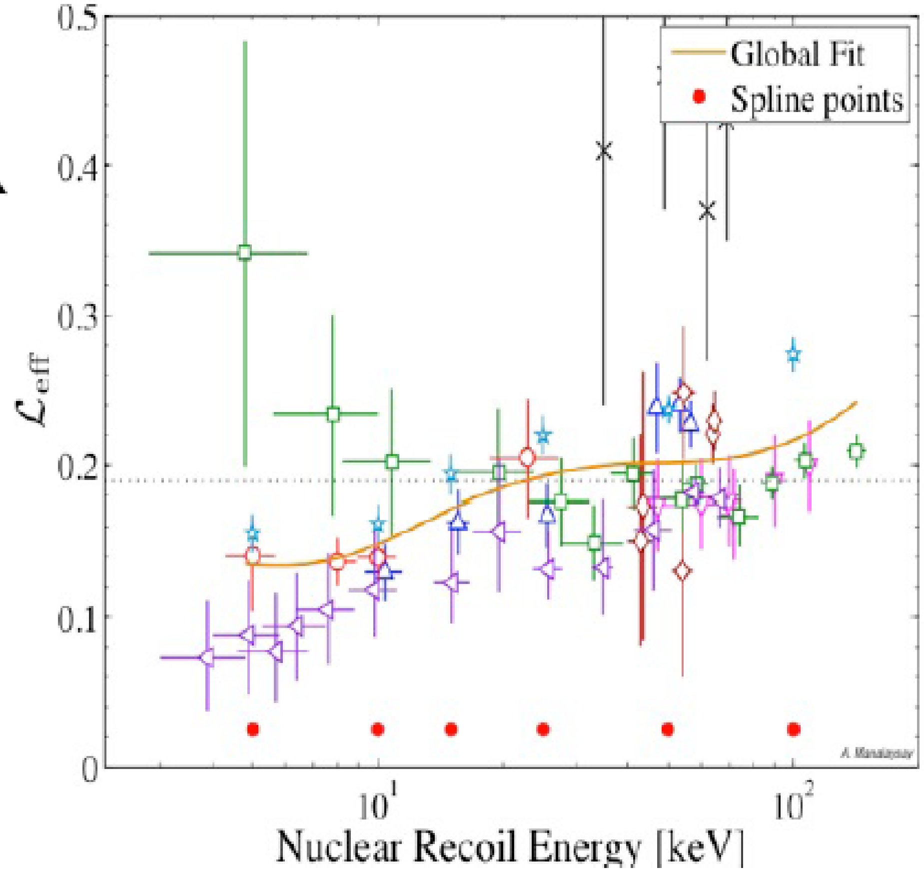
quenching of scintillation yield for 122 keV γ due to drift field

$$E_{nr} = \frac{S1}{L_y L_{eff}} \times \frac{S_e}{S_r}$$

light yield for 122 keV in p.e./keV

scintillation efficiency of NR relative to 122 keV γ at zero field

quenching of scintillation yield for NR due to drift field



Significant uncertainty in energy scale at low energy

No Discovery yet. What Next?

$$R = N \phi \sigma$$

Signal/Background Improvement:
Lower Background, More and Better Detectors at Cheaper Costs!

Germanium Technology Evolution

Sensitivity ∝ Mass. Background ∝ Surface . Detector Cost ∝ # of Dets

CDMS, Soudan (4kg)

3”x 1 cm 0.25kg
2 Yrs, 16 dets=1700kg-d

SuperCDMS, Soudan (15kg)

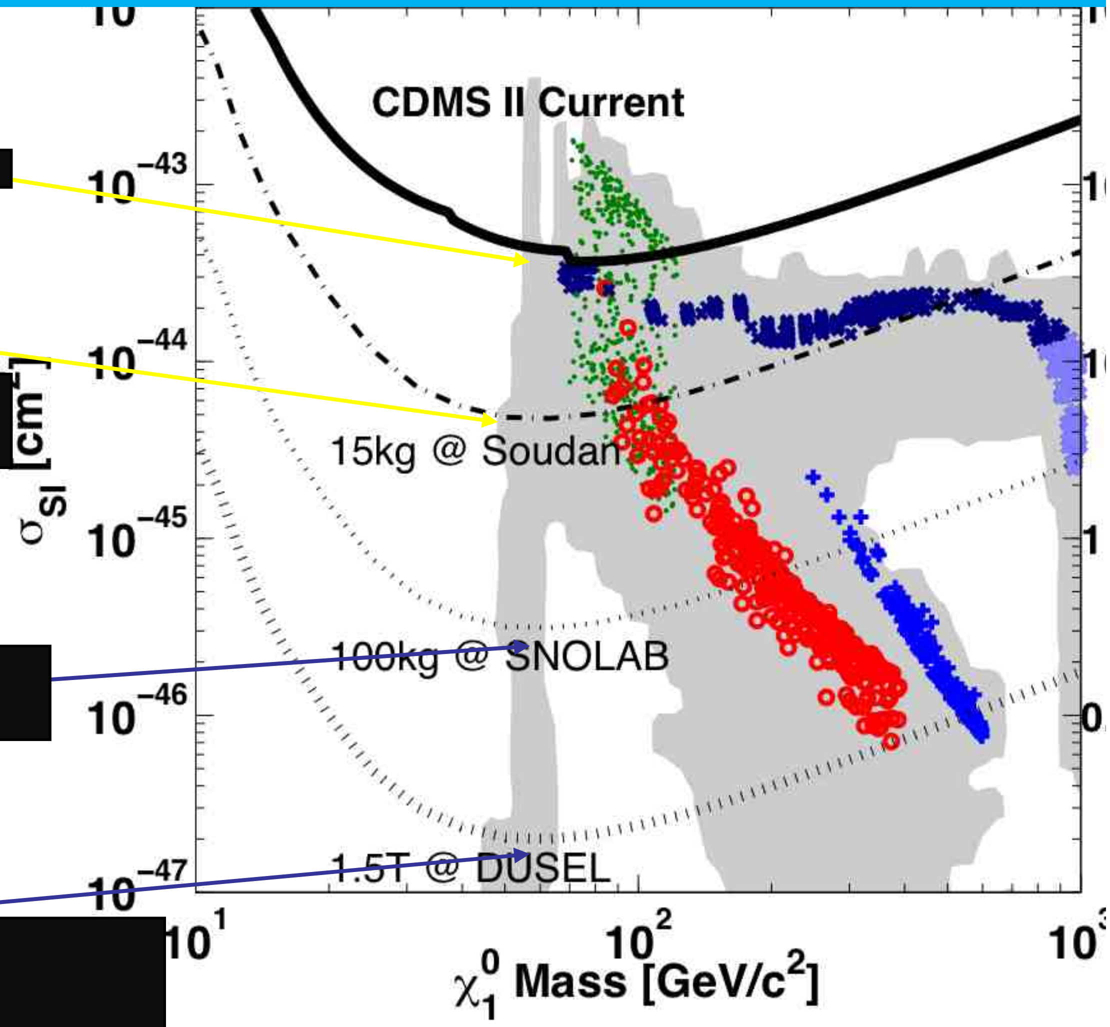
3”x 1” iZIP 0.64kg
2 Yrs, 25dets=8000kg-d

SuperCDMS, SNOLab (200kg)

4”x 1.33” iZIP 1.5kg
2 Yrs, 70dets=200000kg-d

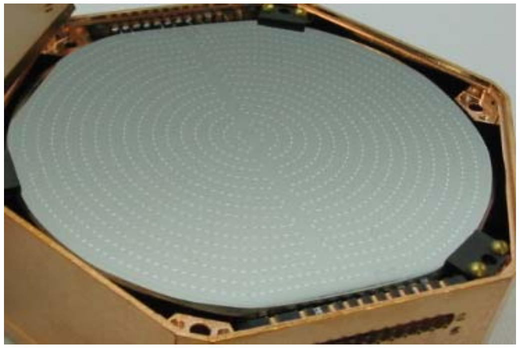
GEODM, DUSEL? (1500kg)

6”x 2” iZIP 5kg
2 Yrs, 300dets=1.5M kg-d

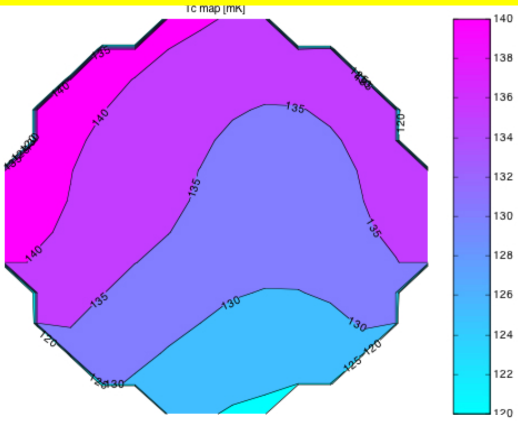


COST scaled from now ($350K/kg): $525 M!

CDMS Detector $350k/kg: Why so expensive?

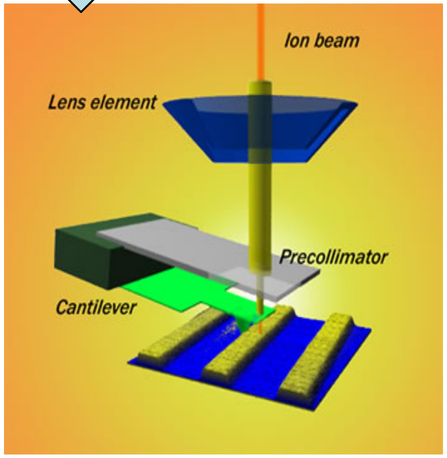


Fabricate, 2 weeks

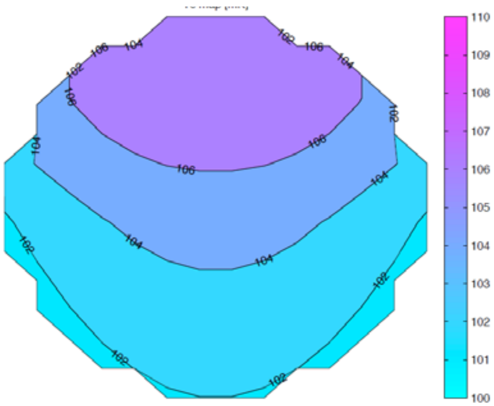


Measure Tc, 2 weeks

Yield: 20% detectors are Science quality!



Ion Implant Tc Fix, 2 weeks



Measure Tc again, 2 weeks

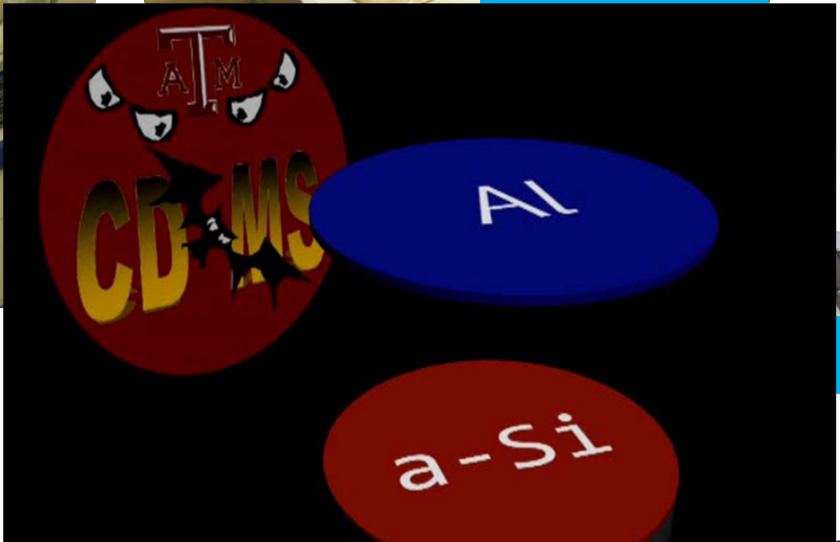
Stanford Nanofab – Common use facility, contamination, lack of tight quality control

Labs - $3M in funds and $2M in donated instruments

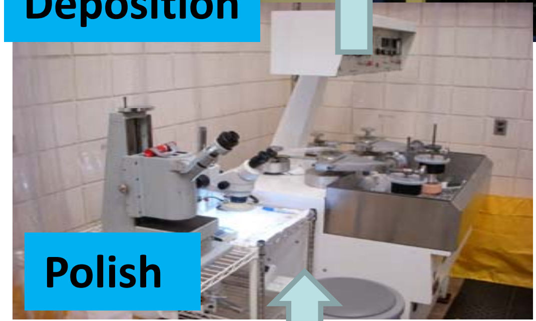
Instruments Donated by: Maxim Integrated Products
DOE (Career) and NSF (DUSEL) and TAMU Startup funds

Photolithographically Patterned Ge Detector

Multi-step process repeatable for high quality detectors

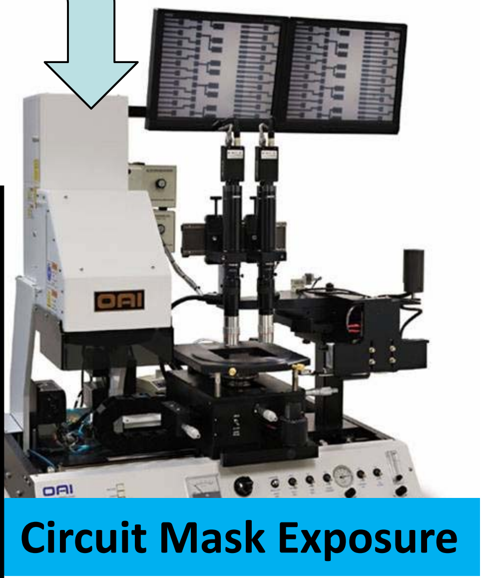



XRD


Polish


Deposition


Photo Coat

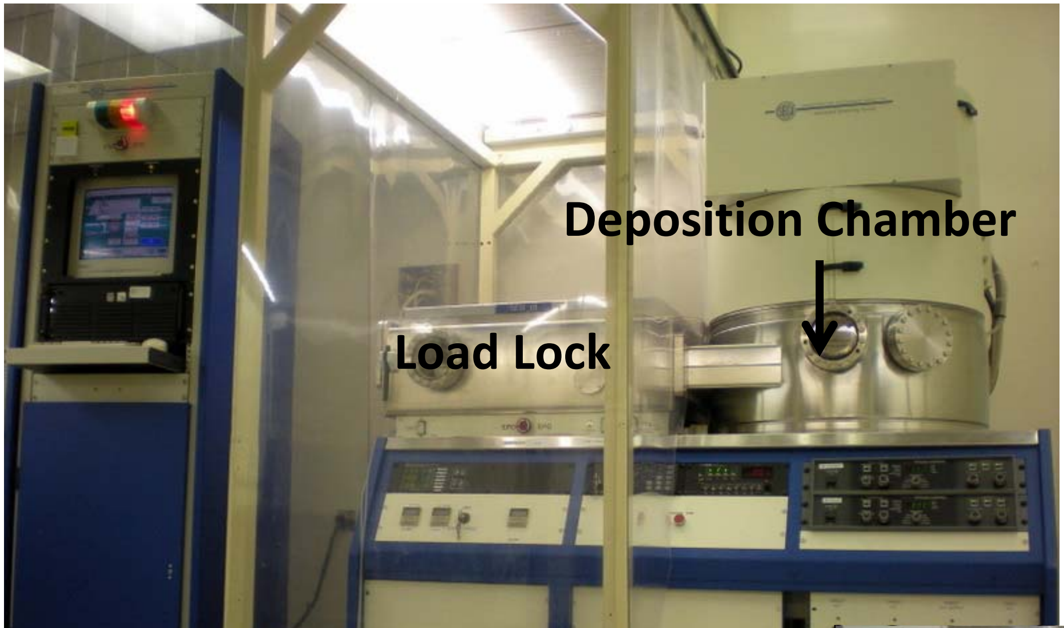


Circuit Mask Exposure


Chemical Etch


Inspect and Package

Better and Faster Fabrication through Industrial Equipments



Industrial Thin Film Deposition System

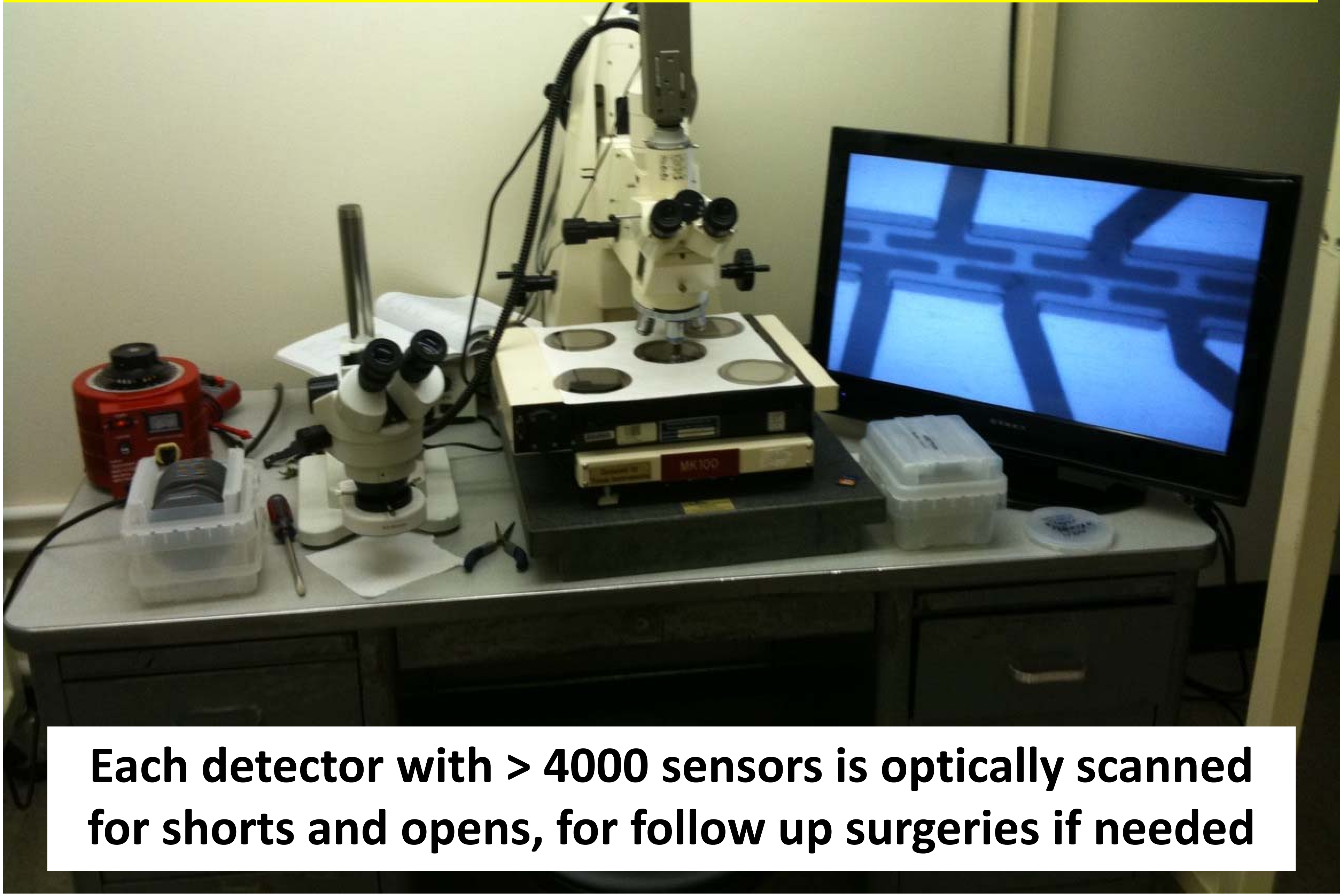
Have fabricated multiple detectors from bare crystal in less than 24 hours!

Takes 2 weeks at Stanford

Photolithography

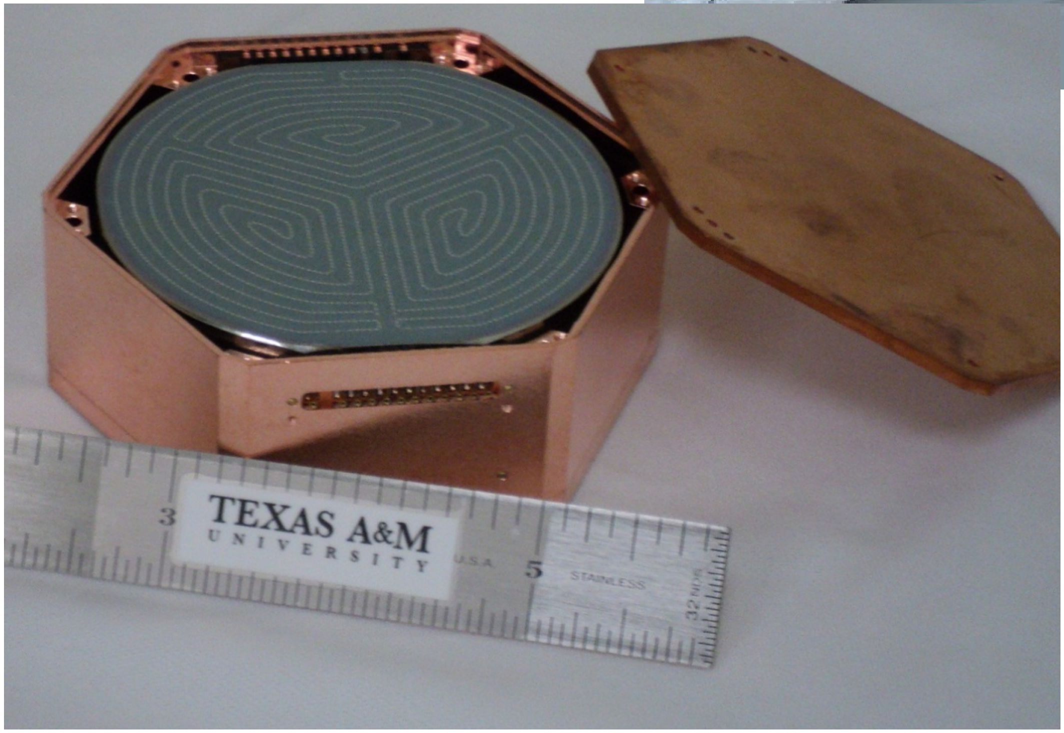
Expose UV through mask

Optical Inspection Station for Defects



Each detector with > 4000 sensors is optically scanned for shorts and opens, for follow up surgeries if needed

Detector Mounting



Entire surface must have full circuit integrity…unlike semiconductor devices, where wafer is a repeating structure of independent circuits and bad areas can be rejected

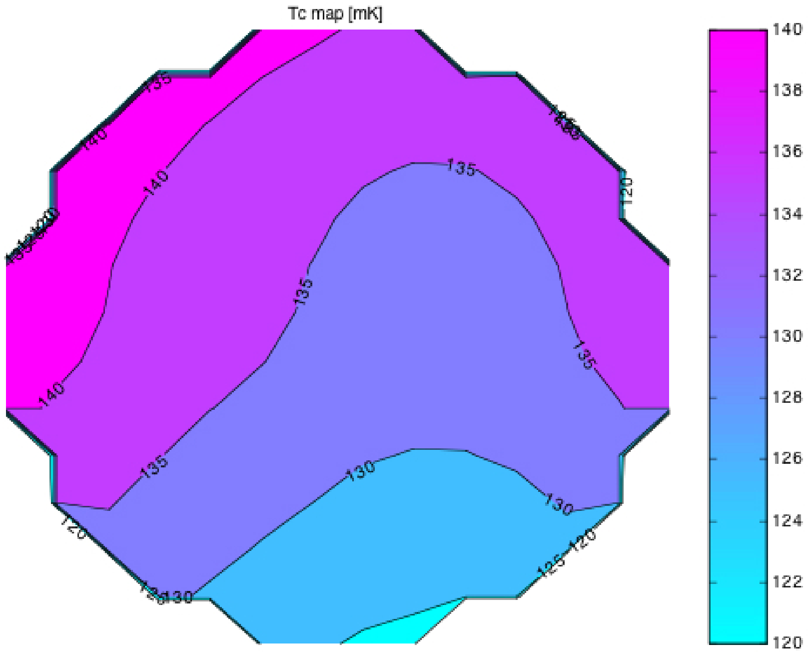
Verification Of Film Quality

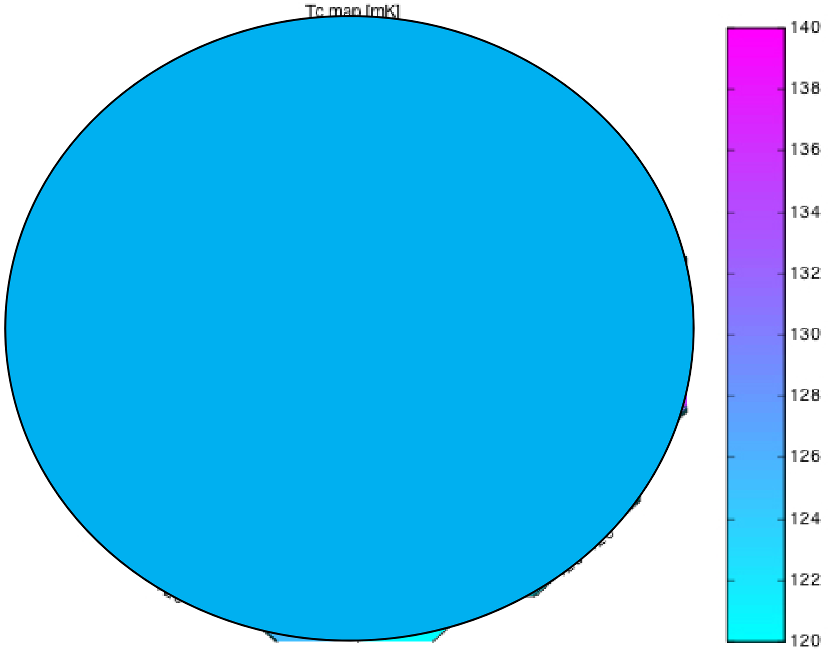
- Residual Resistance ratio of Aluminum film – guides signal collection efficiency
- SEM (Scanning electron microscope) – verifies deposited film thickness
- XPS, AFM, EDS, Profilometer

He Dewar

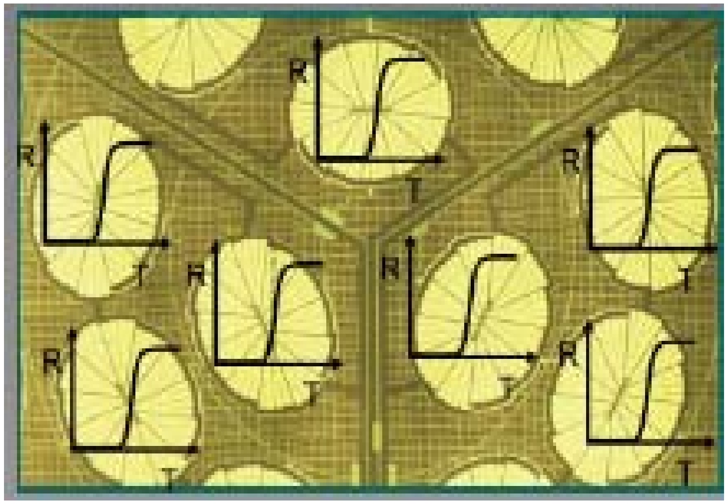
RRR probe

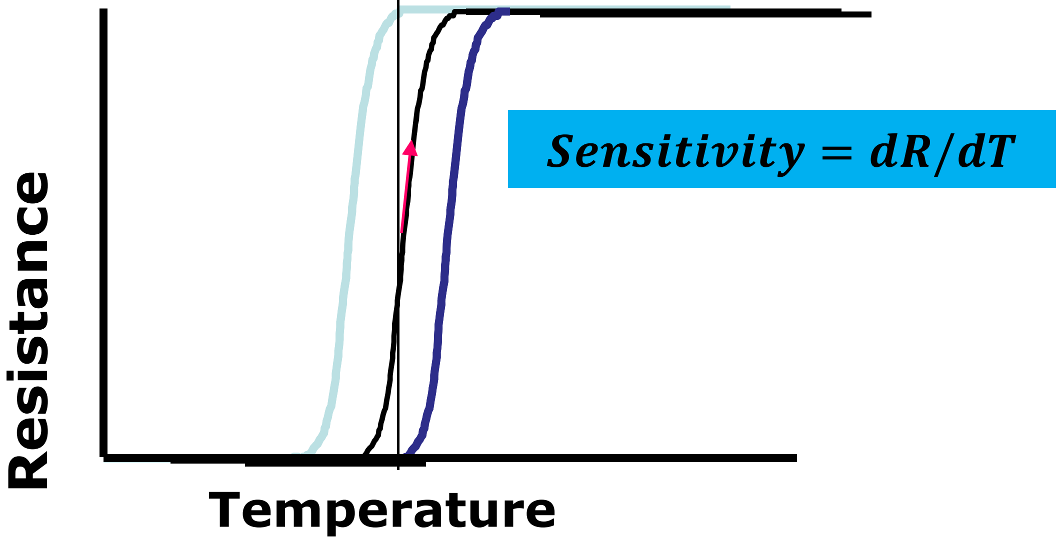
Completely Uniform Tc Across Entire Wafer





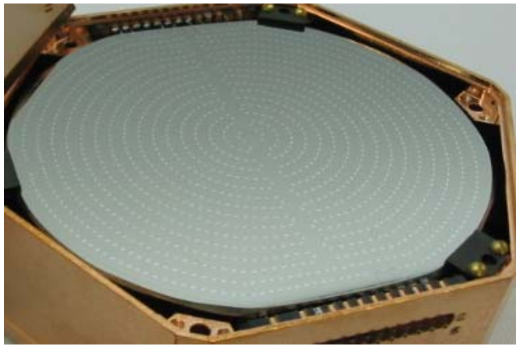
T_c variation across the detector surface: 20 mK down to 1 mK!



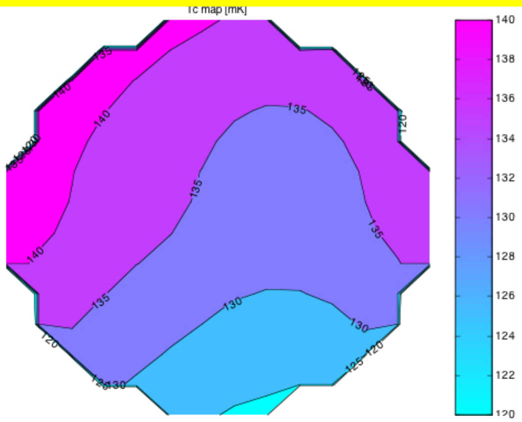


$Sensitivity = dR/dT$

CDMS Detector $350k/kg: Why so expensive?

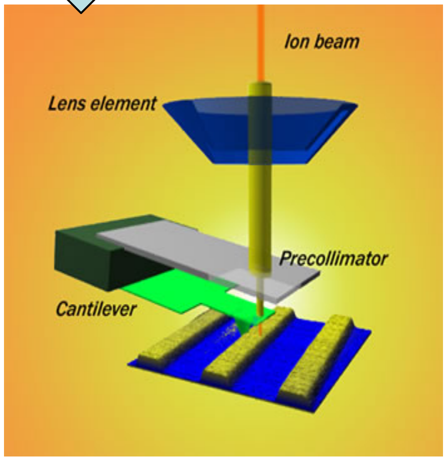


Fabricate, 2 weeks

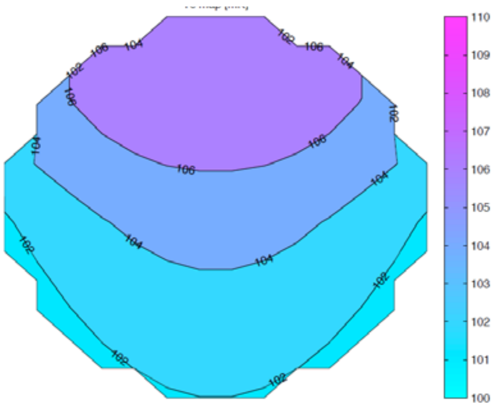


Measure Tc, 2 weeks

Yield: 20% detectors are Science quality!



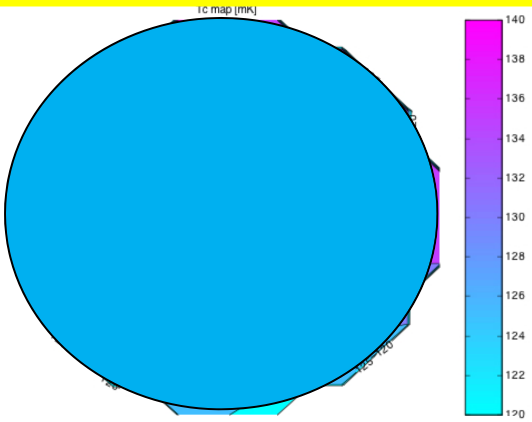
Ion Implant Tc Fix, 2 weeks



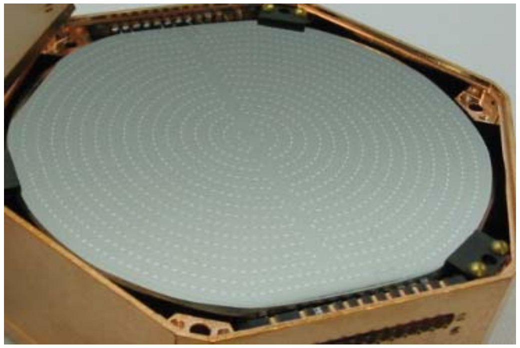
Measure Tc again, 2 weeks

Reduce cost by improving reliability & repeatability using state of the art fabrication

Cost brought down from $350k/kg to $25K/kg!



Measure Tc, 1 week

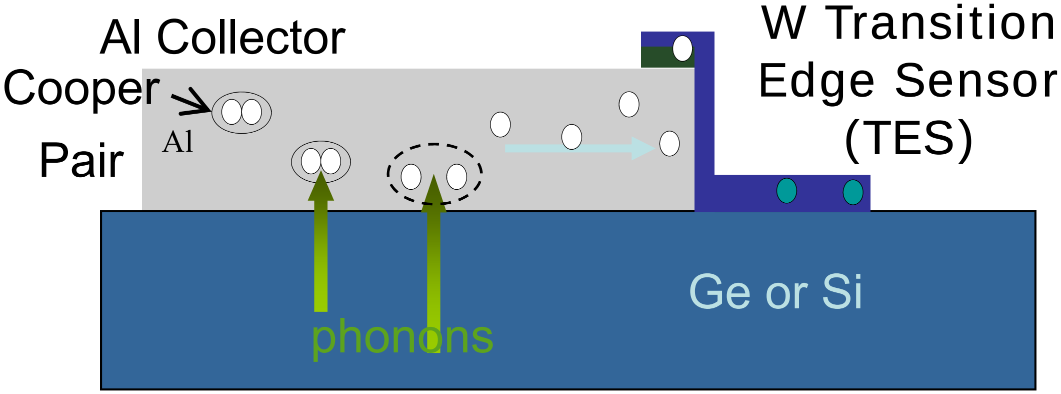


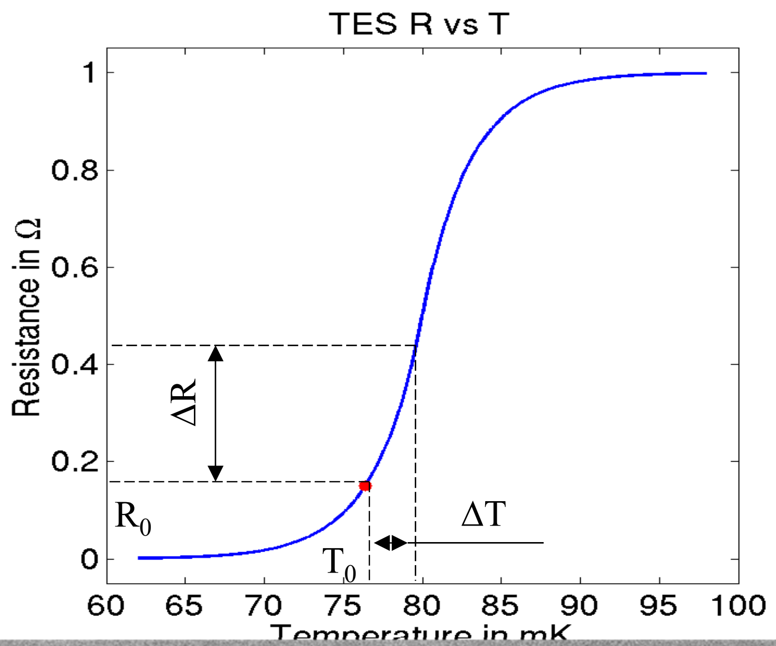
Fabricate, 2 days

TAMU Yield: > 90%

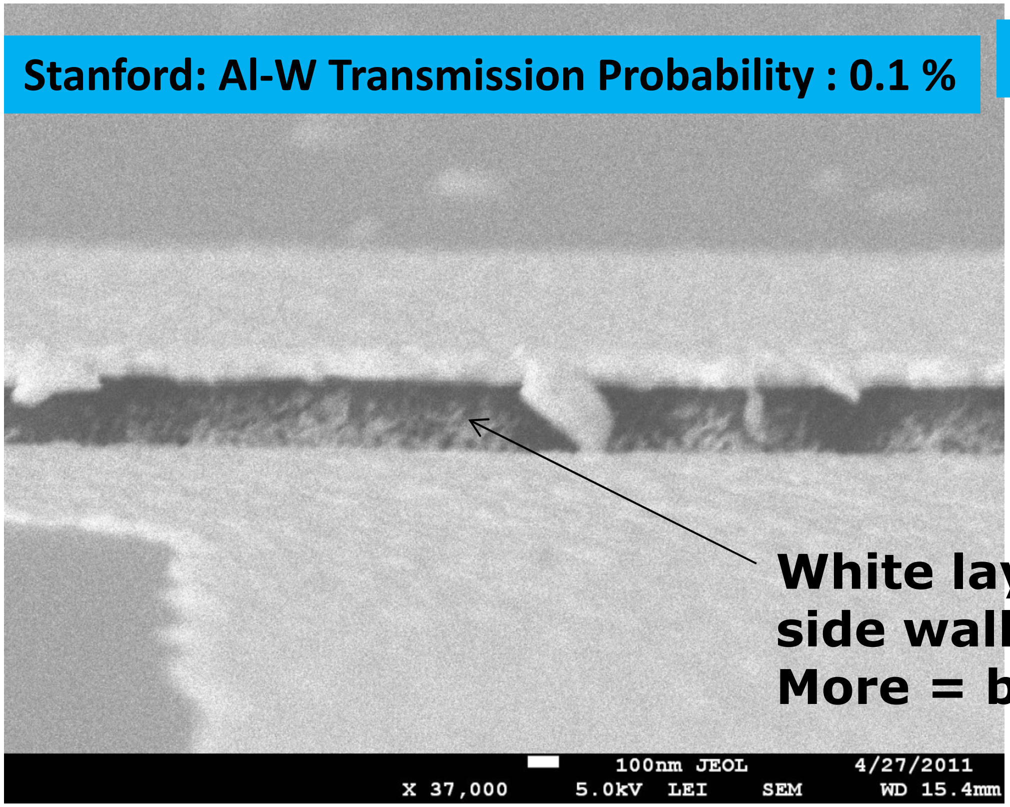
Reduce cost by improving reliability & repeatability using state of the art fabrication

Superior Sensors – Ultra Low Phonon Threshold

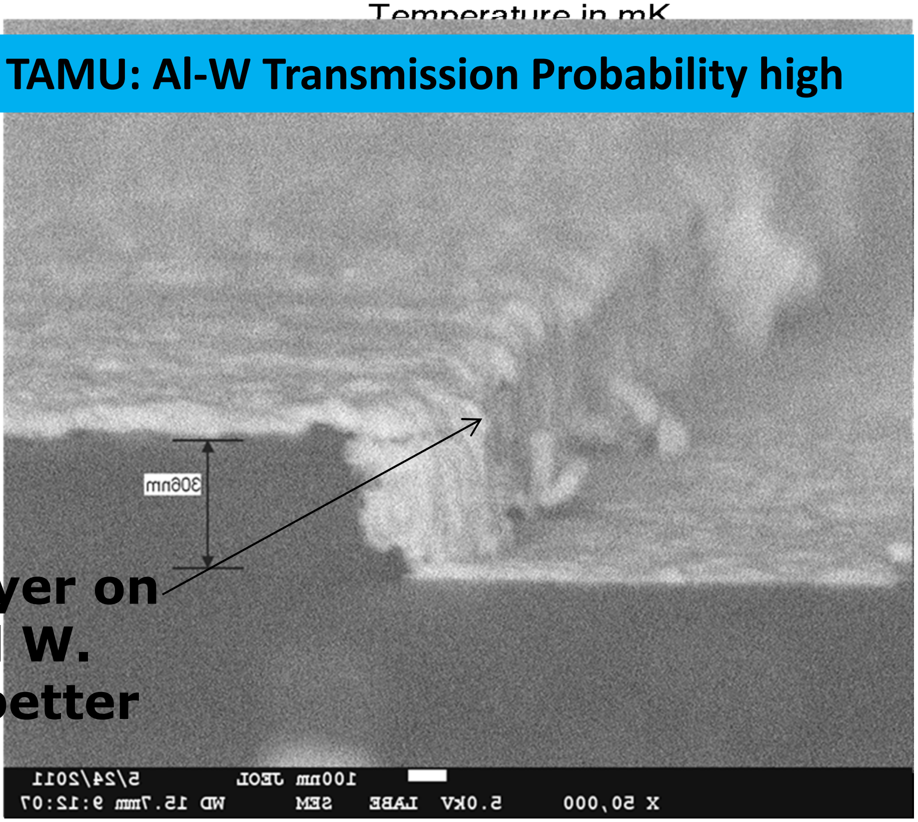




Stanford: Al-W Transmission Probability : 0.1 %



TAMU: Al-W Transmission Probability high



White layer on side wall W. More = better

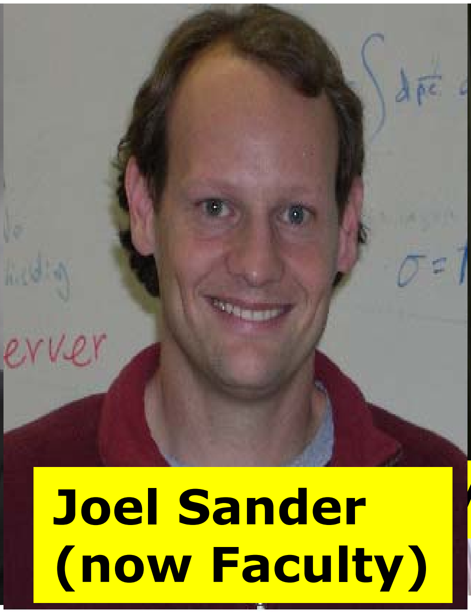
From Raw Ge crystal to Fully Fabricated Detector at TAMU

- Entire process flow performed at TAMU
- Crystal axis orientation through X-ray Diffraction
- Polishing to within ± μm flatness across 100mm
- Detector fabrication in dedicated fab facility
- Detector imaging (Scanning Electron Microscopy) and Optical inspection for defects
- Wire-bonded, packaged and tested for payload

TAMU Group

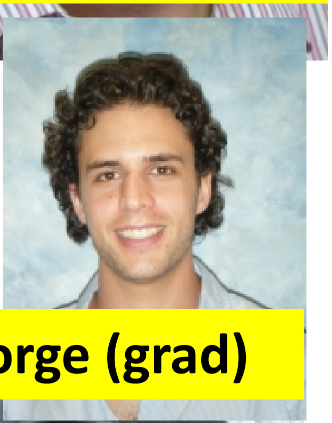

Mahapatra


Rusty Harris


Joel Sander (now Faculty)


Mark Platt (Engg)


Dave Toback


Jorge (grad)

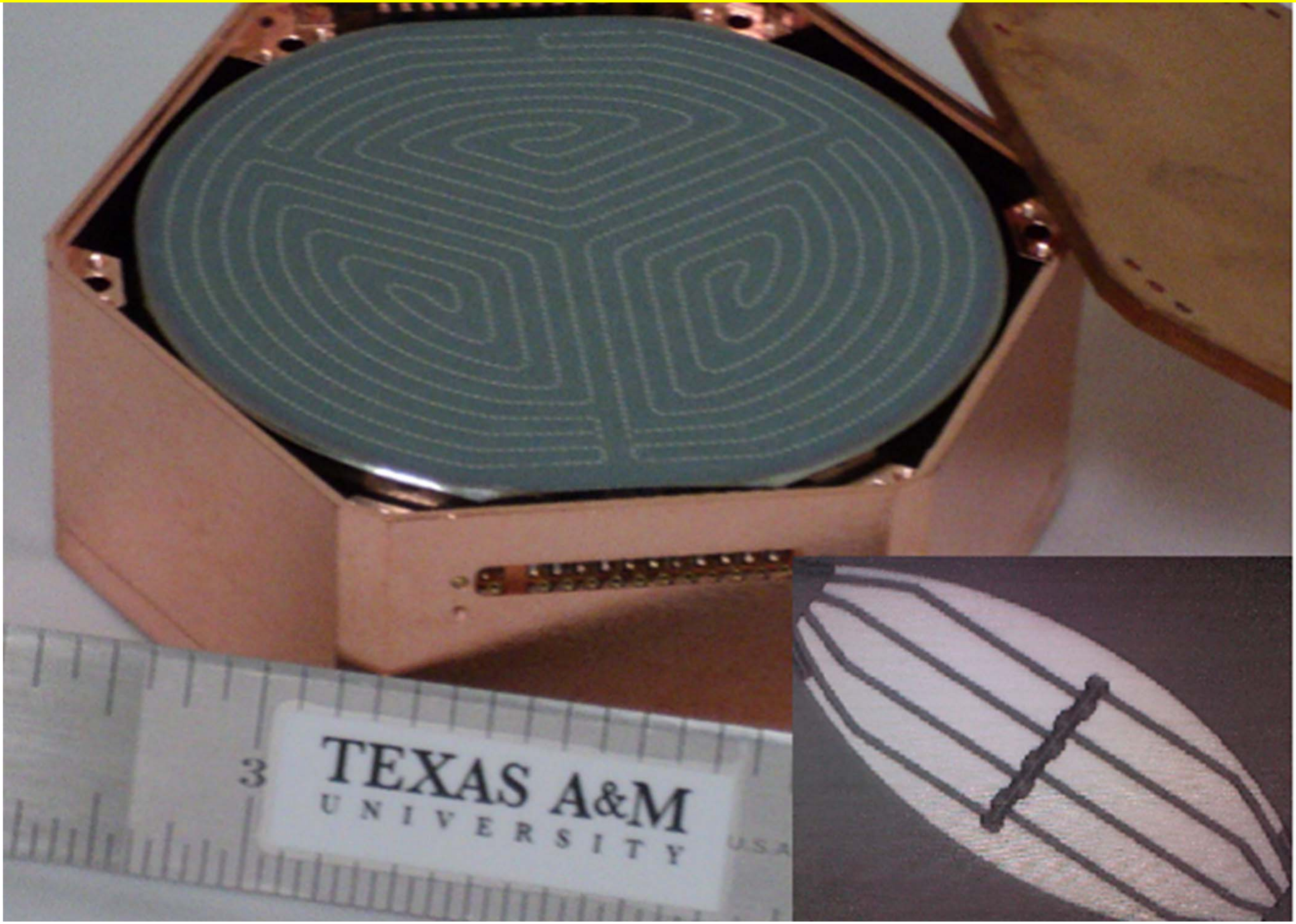

Kunj(just finished)


Sriteja (grad)


Andrew (grad)


James (technician)

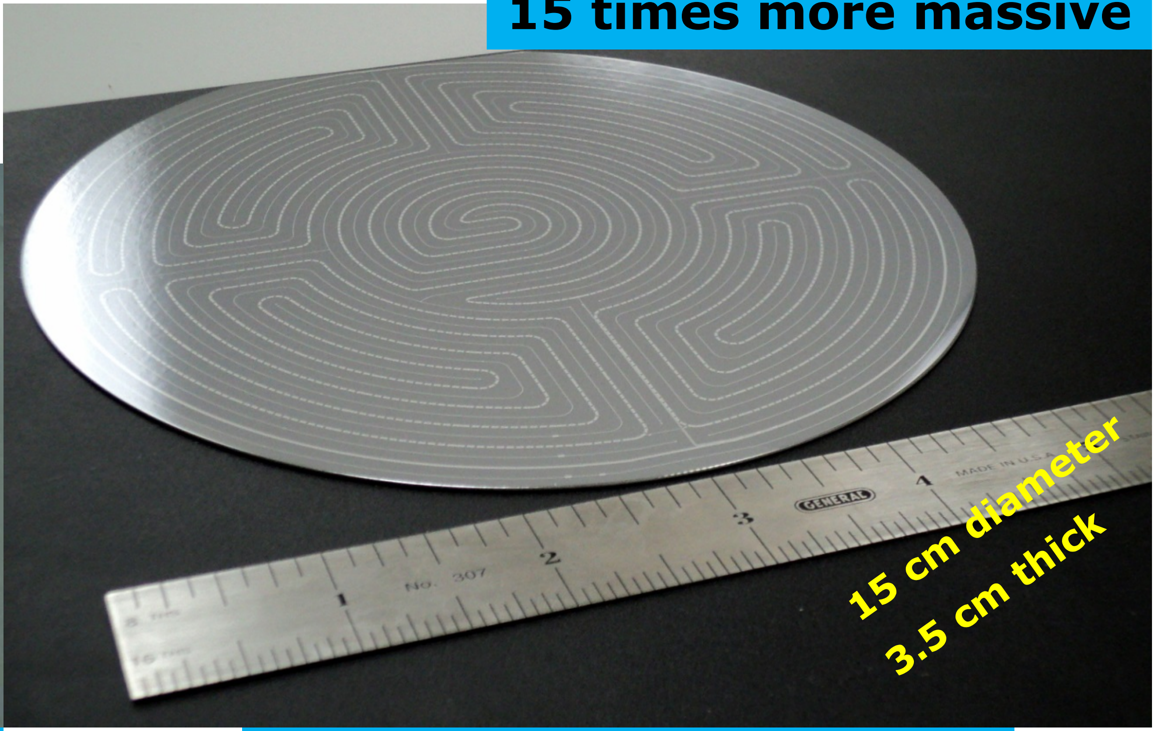
iZIP Detector Fabricated at Texas A&M



World’s First 6” Cryogenic Detector

TAMU has industrial fabrication equipment, capable of making the leap from 3” to 6”

15 times more massive



Fiducial Efficiency ~ 35%

Fiducial Efficiency ~ 75%

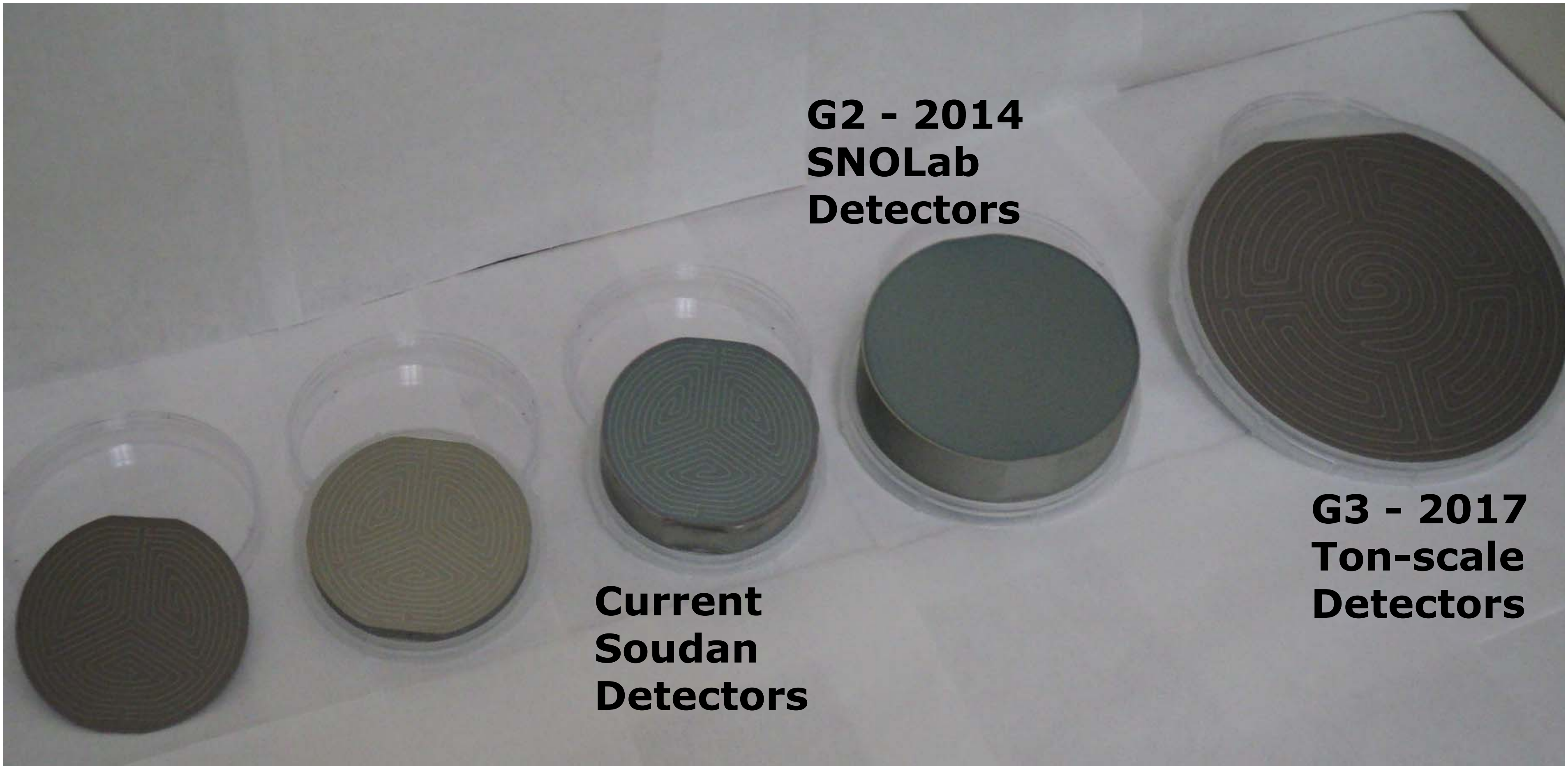
This TAMU 6” detector has ~30x higher sensitivity than CDMSII Si!

Having one of these detectors could result in 5-σ discovery!

Cost of project scales with number of detectors, not mass

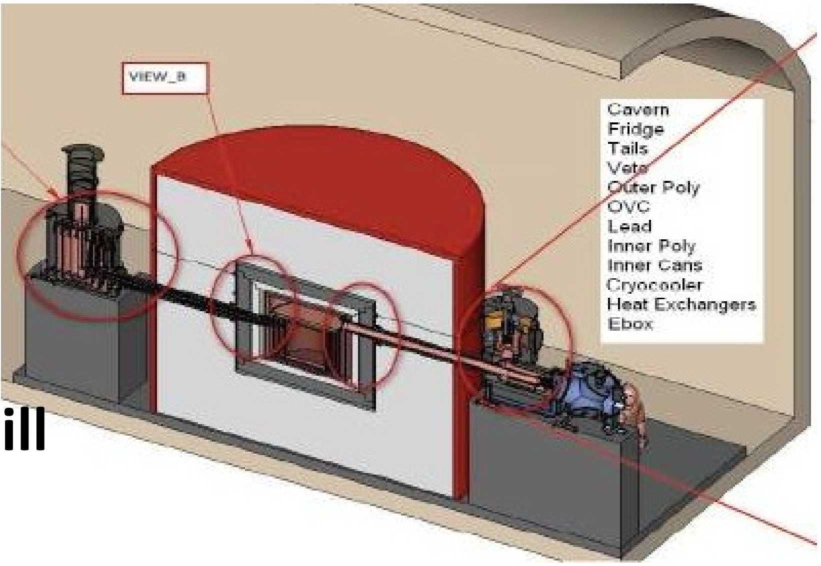
From 3” to 6”

Cost of project scales with number of detectors, not mass

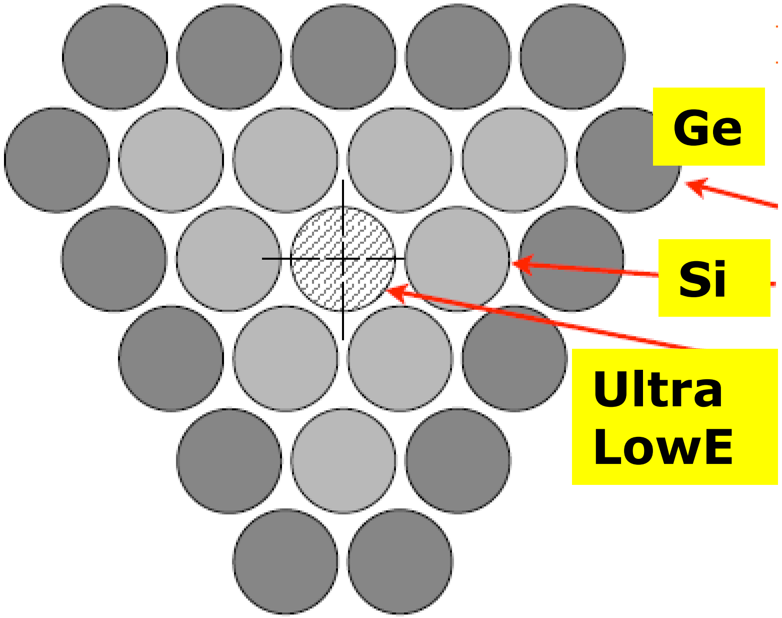


G2 SuperCDMS 200kg SNOLab $30M (DOE $20M, NSF $10M)

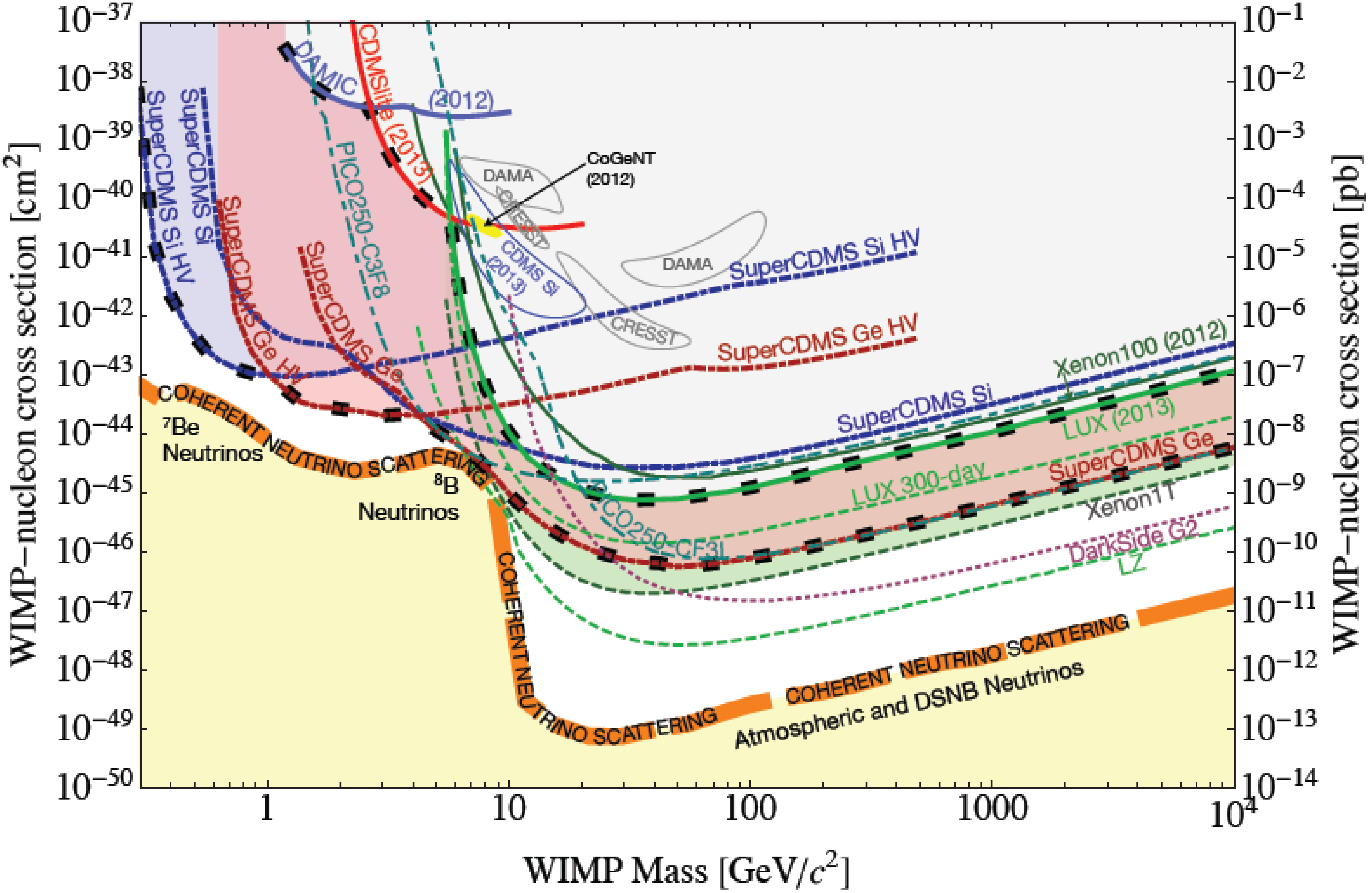
- Cryostat and facility built for 400kg
- Initial payload 200kg. Further funding will allow us to push to full 400 kg
- With high fiducial efficiency (~90% compared ~30% for Xenon), SuperCDMS SNOLab will have competitive sensitivity to Xenon 1T and better than LUX
- Both Ge and Si detectors to be used, to b sensitive to high and low mass WIMP
- All Si detectors to be made at Texas A&M



SuperCDMS, SNOLab

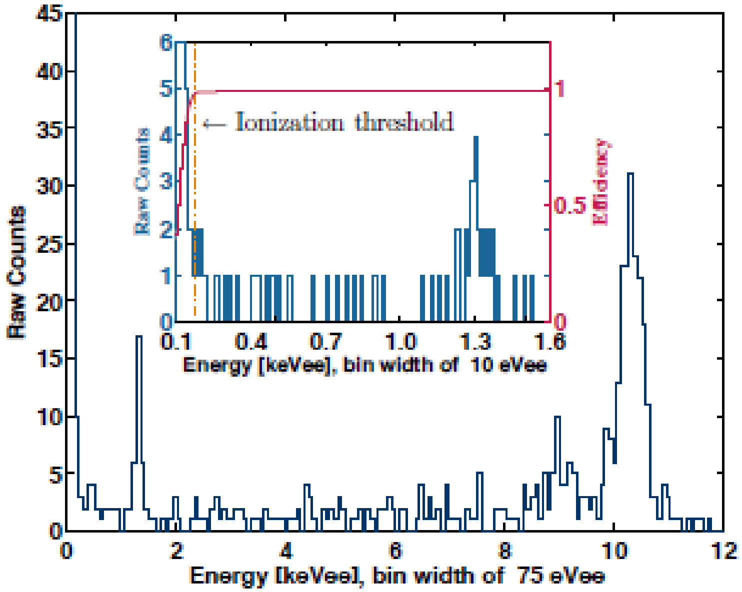


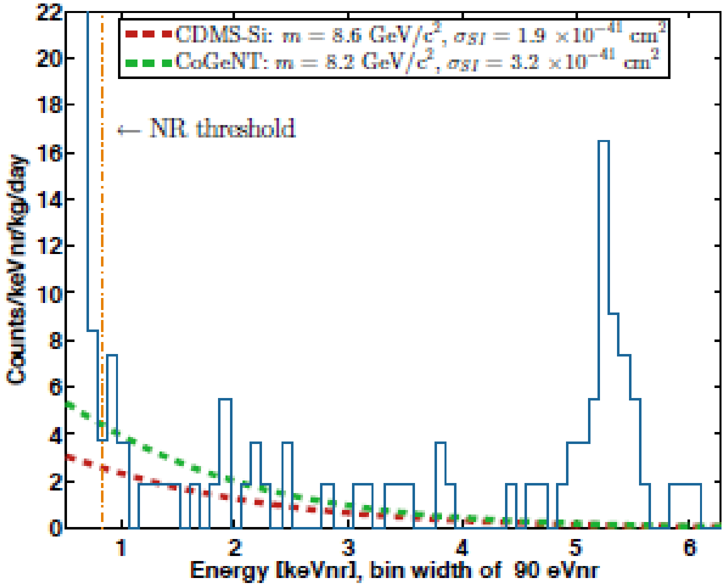
SuperCDMS SNOLAB: Four Experiments

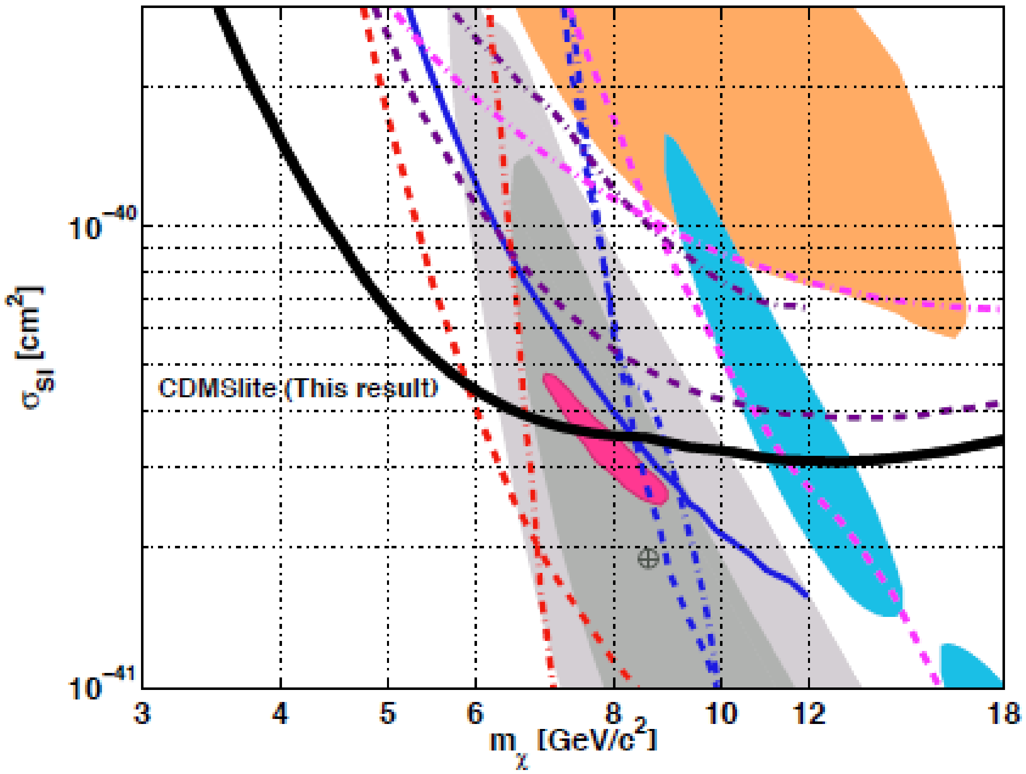


New Ge CDMSlite Result

- arXiv: 1309.3259v1
- systematics from Lindhardt very small for 8 GeV/c^2







Better and Cheaper Detectors with High Yield

CDMS, Soudan (4kg)

3"x 1 cm 0.25kg
2 Yrs, 16 dets=1700kg-d

SuperCDMS, Soudan (15kg)

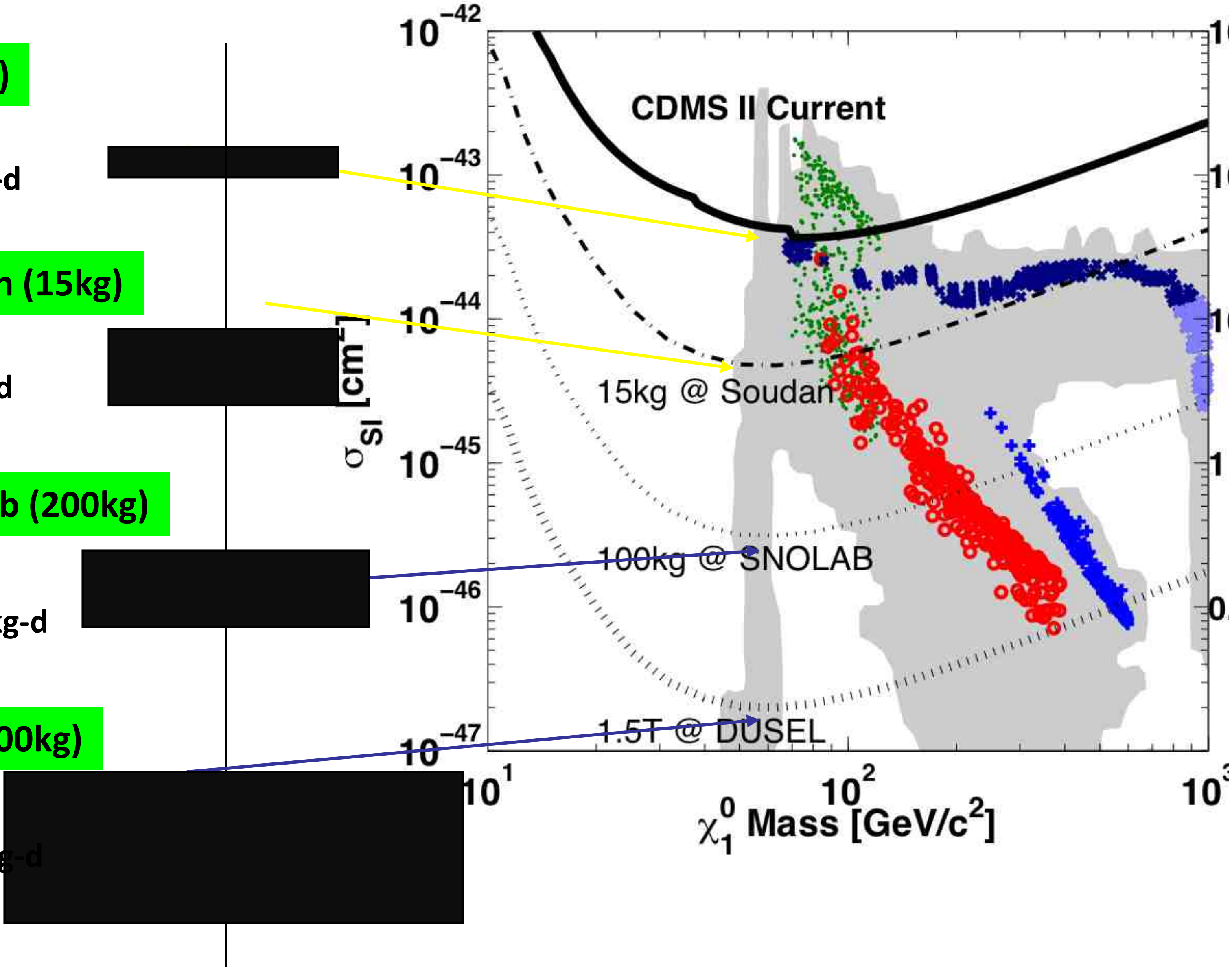
3"x 1" iZIP 0.64kg
2 Yrs, 25dets=8000kg-d

SuperCDMS, SNOLab (200kg)

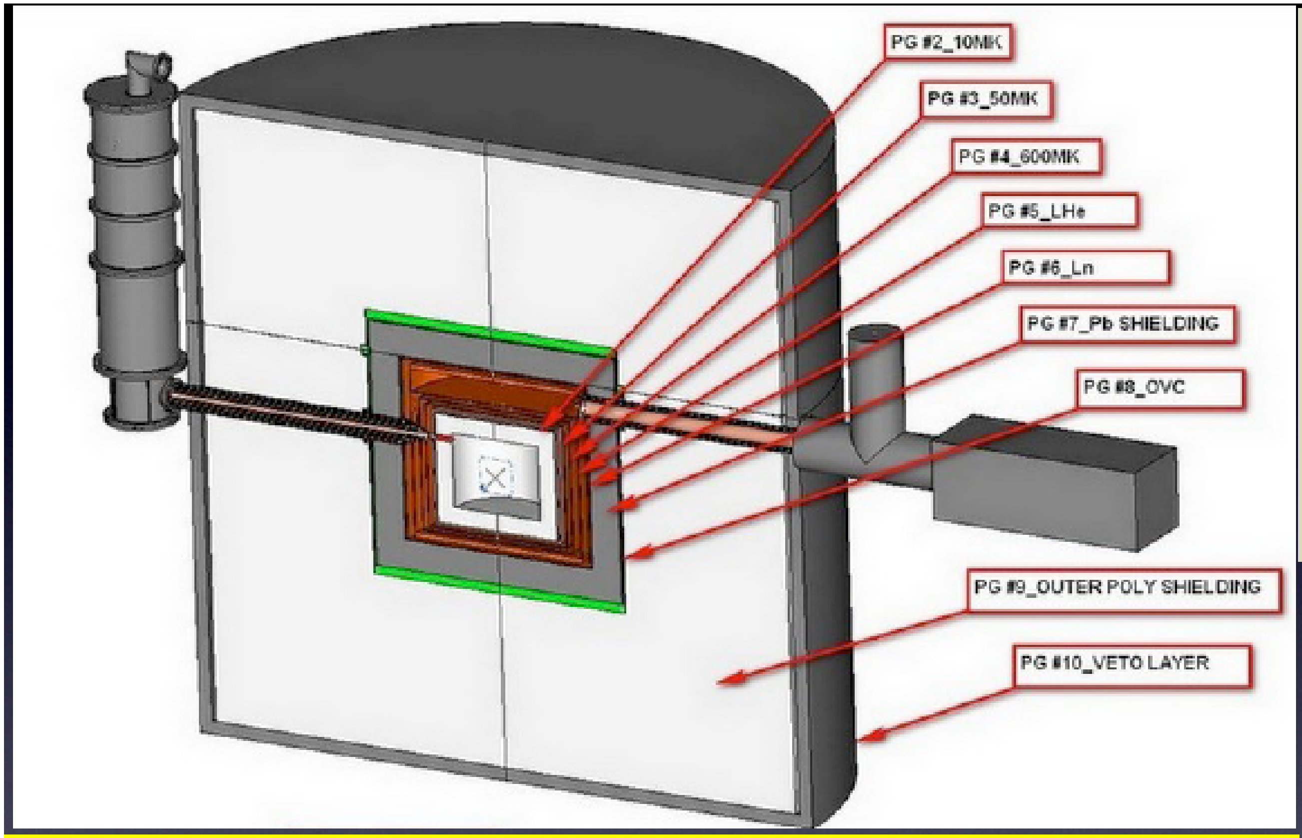
4"x 1.33" iZIP 1.5kg
2 Yrs, 70dets=100000kg-d

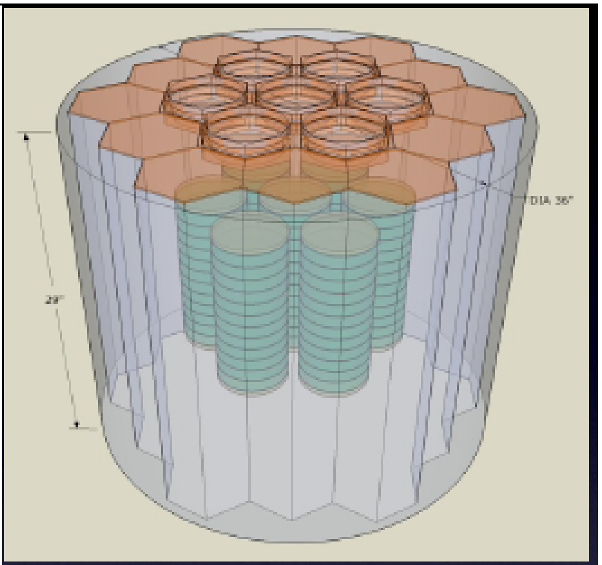
GEODM, DUSEL (1500kg)

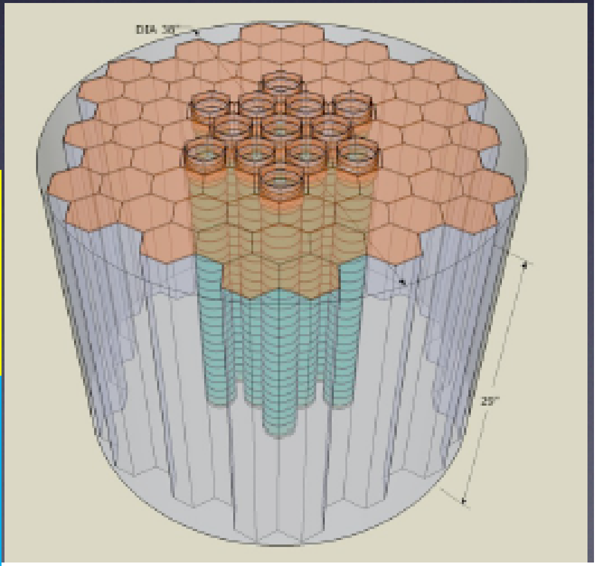
6"x 2" iZIP 5kg
2 Yrs, 300dets=1.5M kg-d



G3 (10^{-47}cm^2) ton-scale in USA?



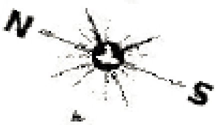


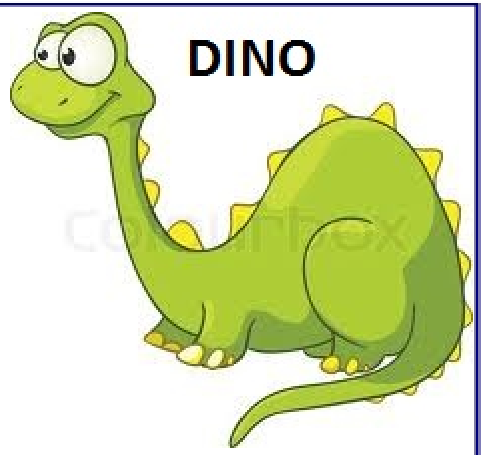


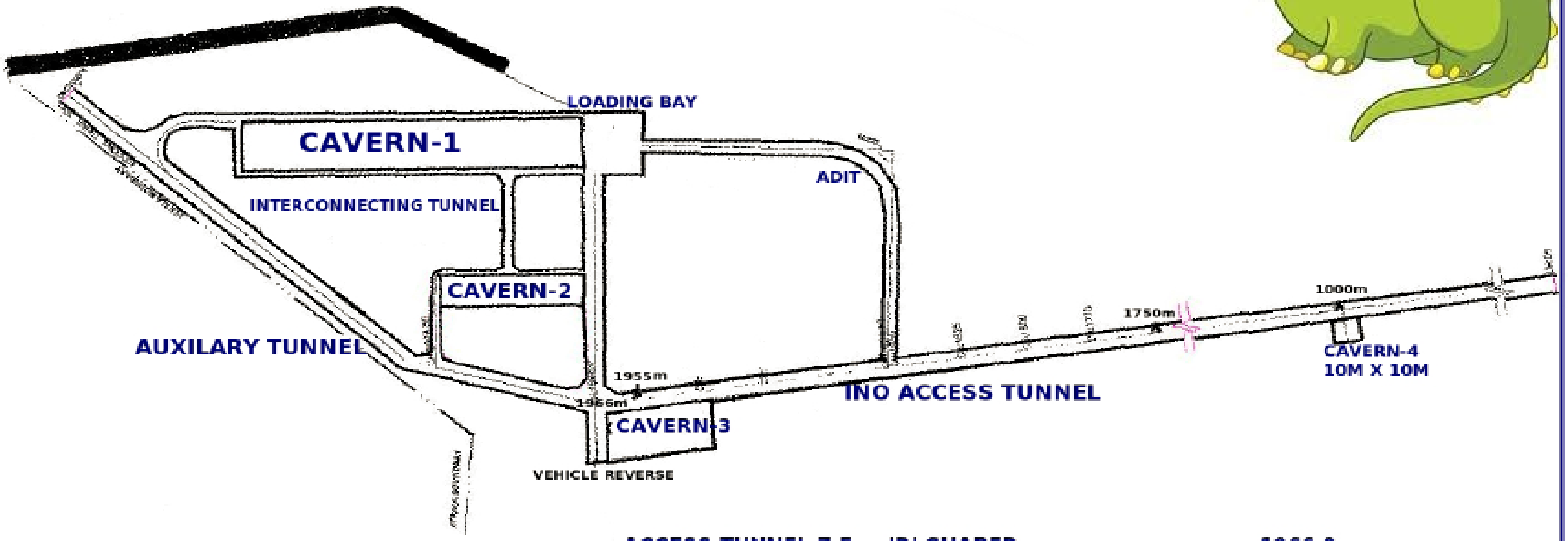
Projected cost ~ \$60M (1.5 Ton), compared to ~\$30M (200 kg)

Detector quality/repeatability at TAMU makes it feasible, but no site yet!

Dark-matter@INO (DINO) Ton-scale 2018







ACCESS TUNNEL 7.5m, 'D' SHAPED :1966.0m
ADDITIONALLY DRIVEN INT. TUNNEL 5.5m 'D' SHAPED: 175.4m
AUXILARY TUNNEL 7.5m 'D' SHAPED : 224.6m
INTERCONNECTING TUNNEL 3.5m 'D' SHAPED : 72.5m
ADDITIONAL TUNNEL 7.5m 'D' SHAPED (future expn) : 50.0m

CAVERN -1 : 132m x 26M x 32.5m
CAVERN -2 : 55m x 12.5m x 8.6m
CAVE
CAVE

Pottipuram in Bodi West hills

INO Lab Depth 1.3km

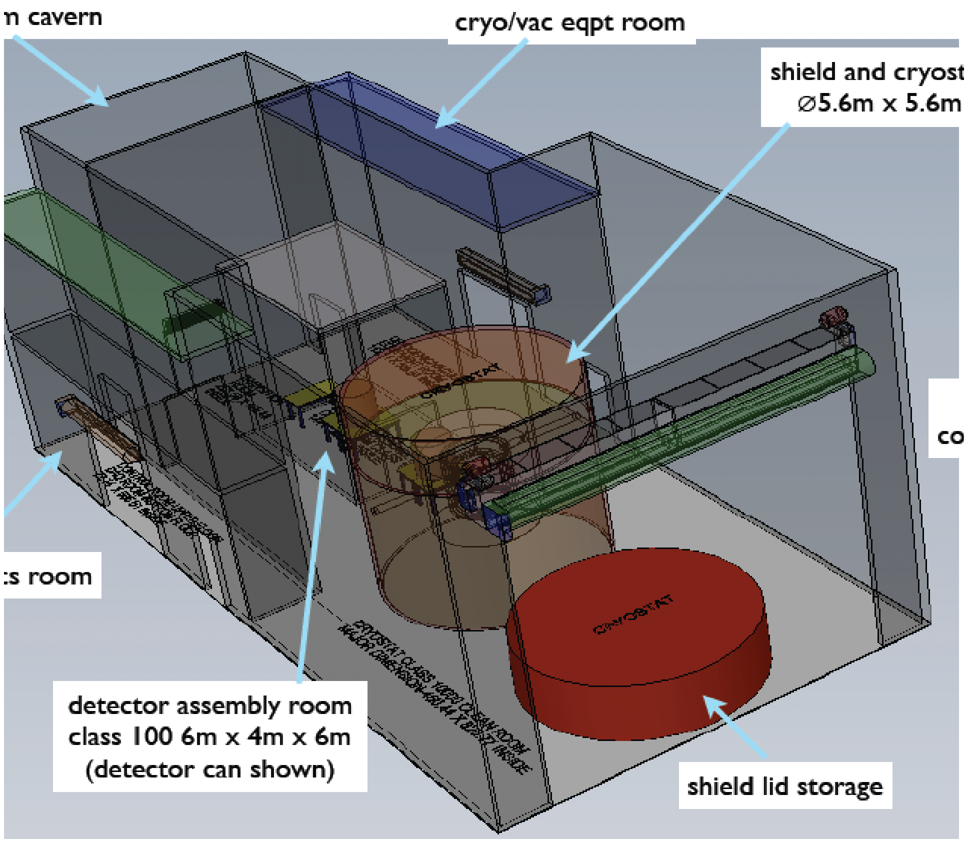
Ton-scale Dark-matter@INO 2018

- Ton-scale Ge/Si @ INOLab
- Major technical enterprise to involve collaborators from India and USA.

- No uncommitted large underground space to host ton-scale experiments

- Large available funding in India and deep desire and commitment to establish world leading experiment

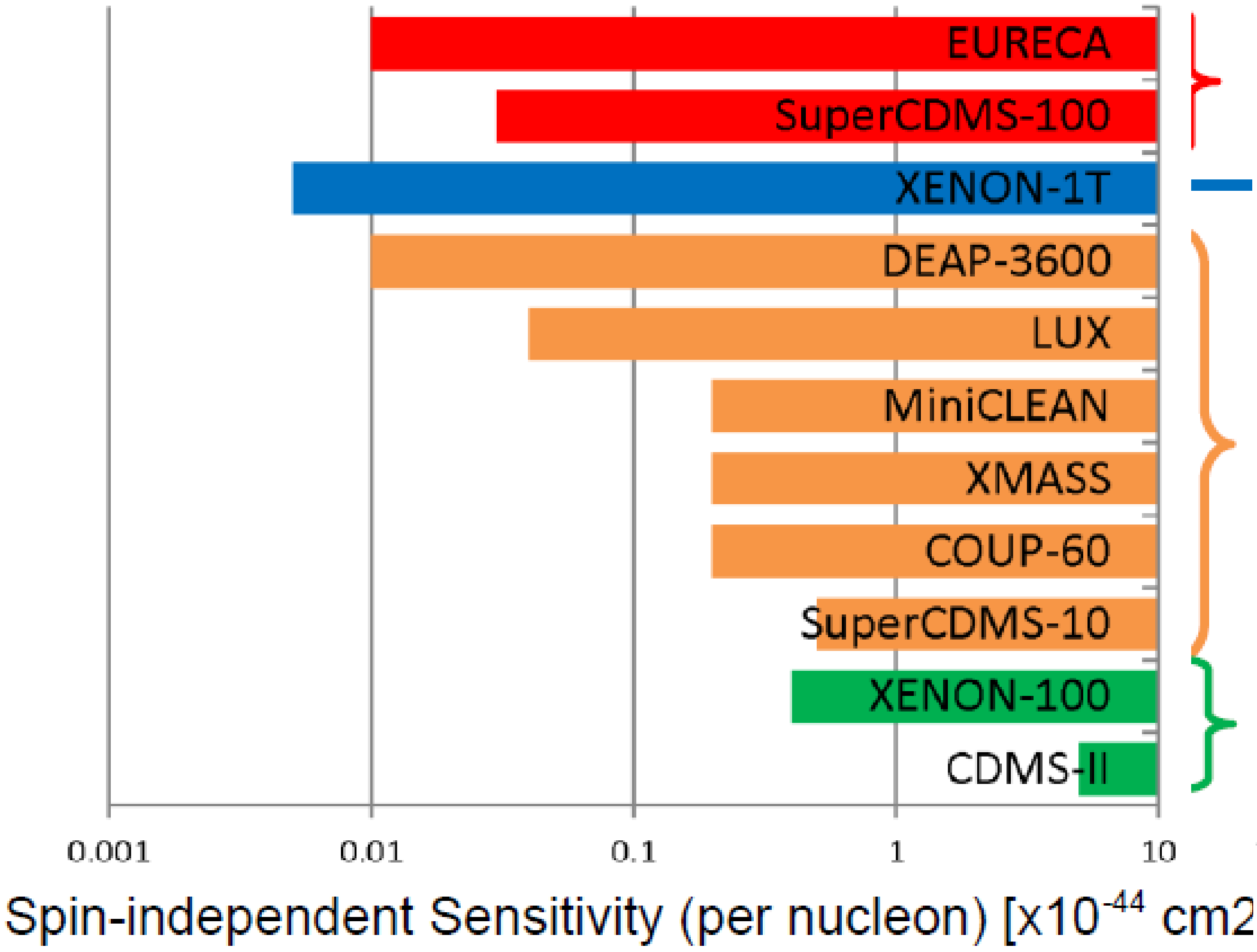
Possible Layout of DINO Project



mini-DINO – Si Prototype Project by 2015

- Demonstrate such a project possible in India
- A 10-30 kg demonstrator project using Si detectors
- Focus on right combination of simplicity and science case, so as to get an experiment going in India and train manpower for much larger experiment
- UCIL Jadugara mines near Jamshedpur with available cavern at 550 m level. Deep enough to reduce Cosmic
- Excellent opportunities for students and postdocs

Best Sensitivity when Target mass matches WIMP Mass

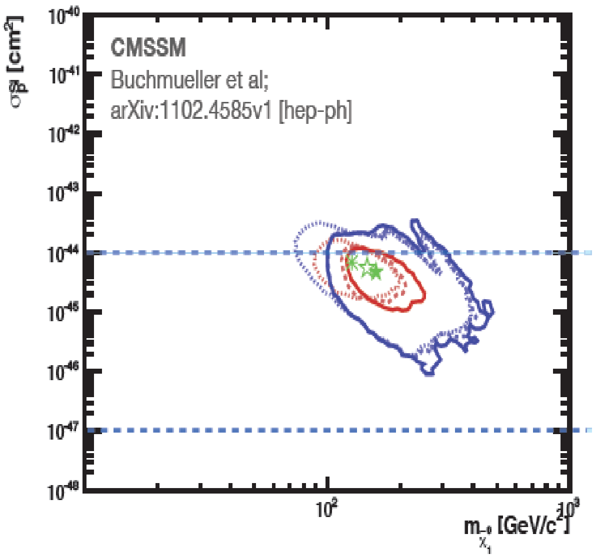


Proposed/
Future Development

Being Designed

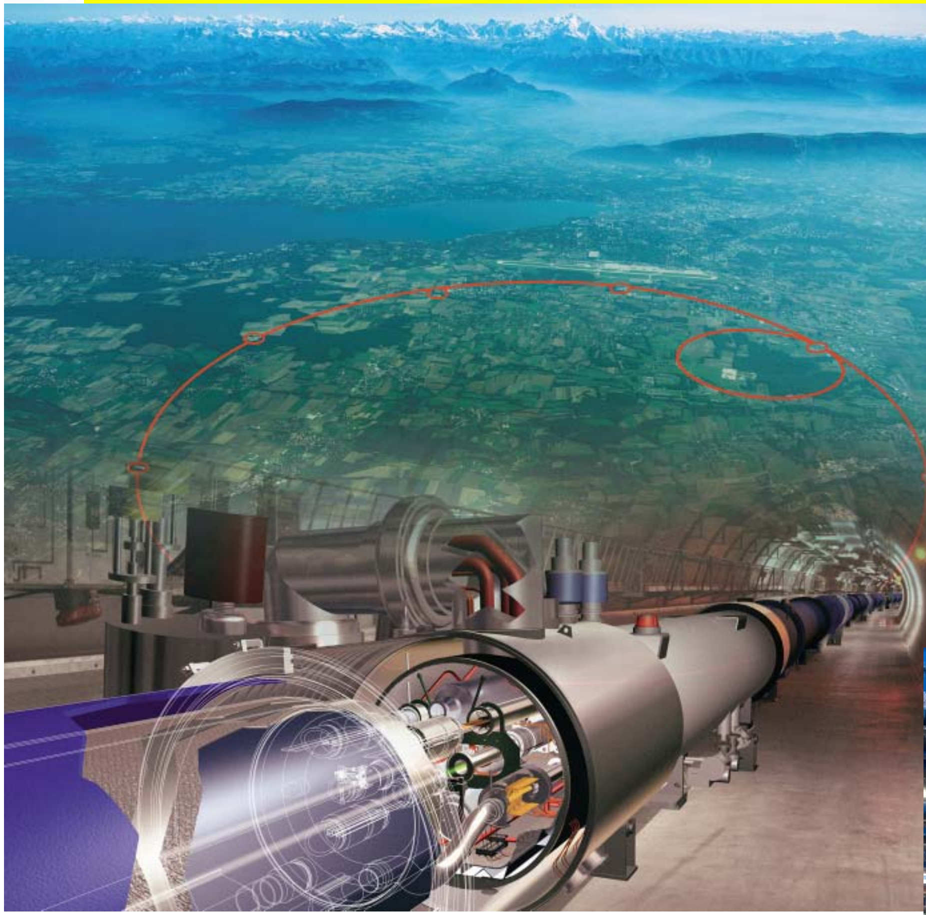
Under
Construction
or
Operating

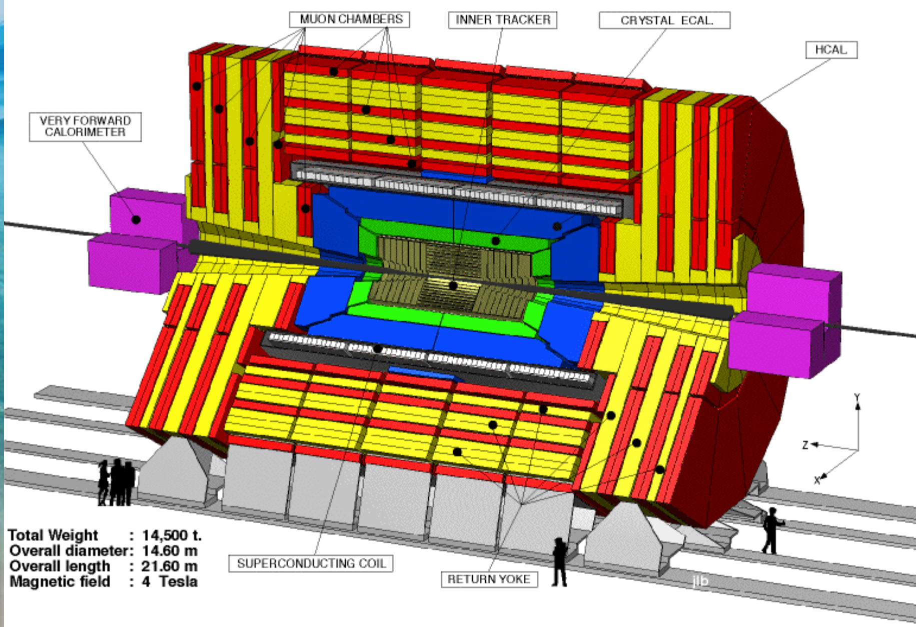
Current Results

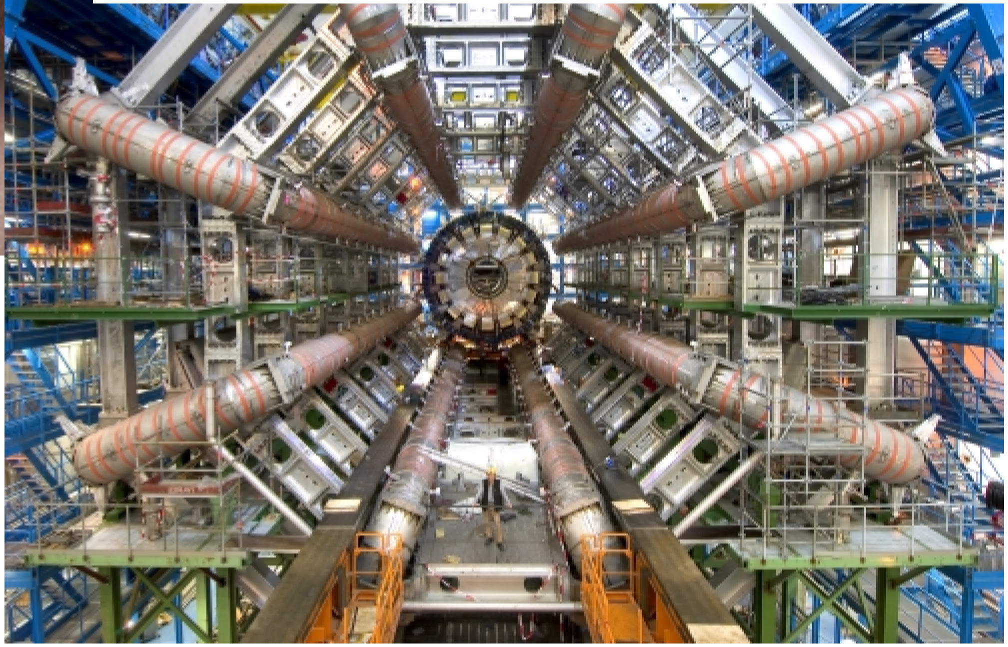


State of the Field

LHC: The WIMP Maker



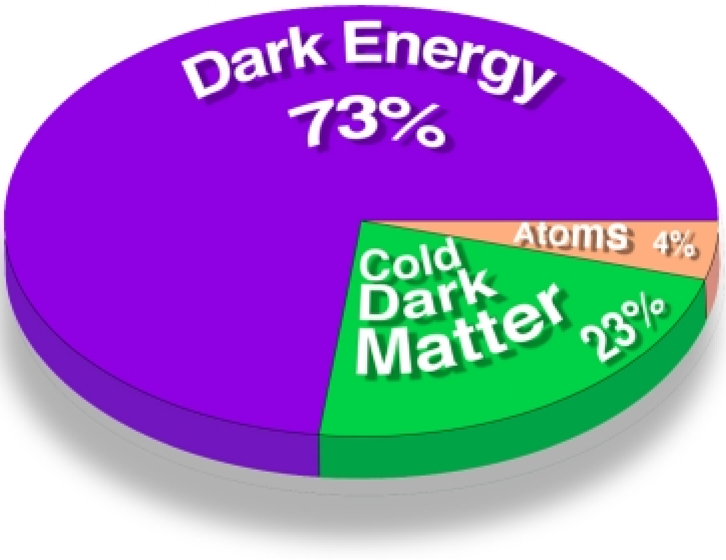




Will LHC discover SUSY before Direct Detection?

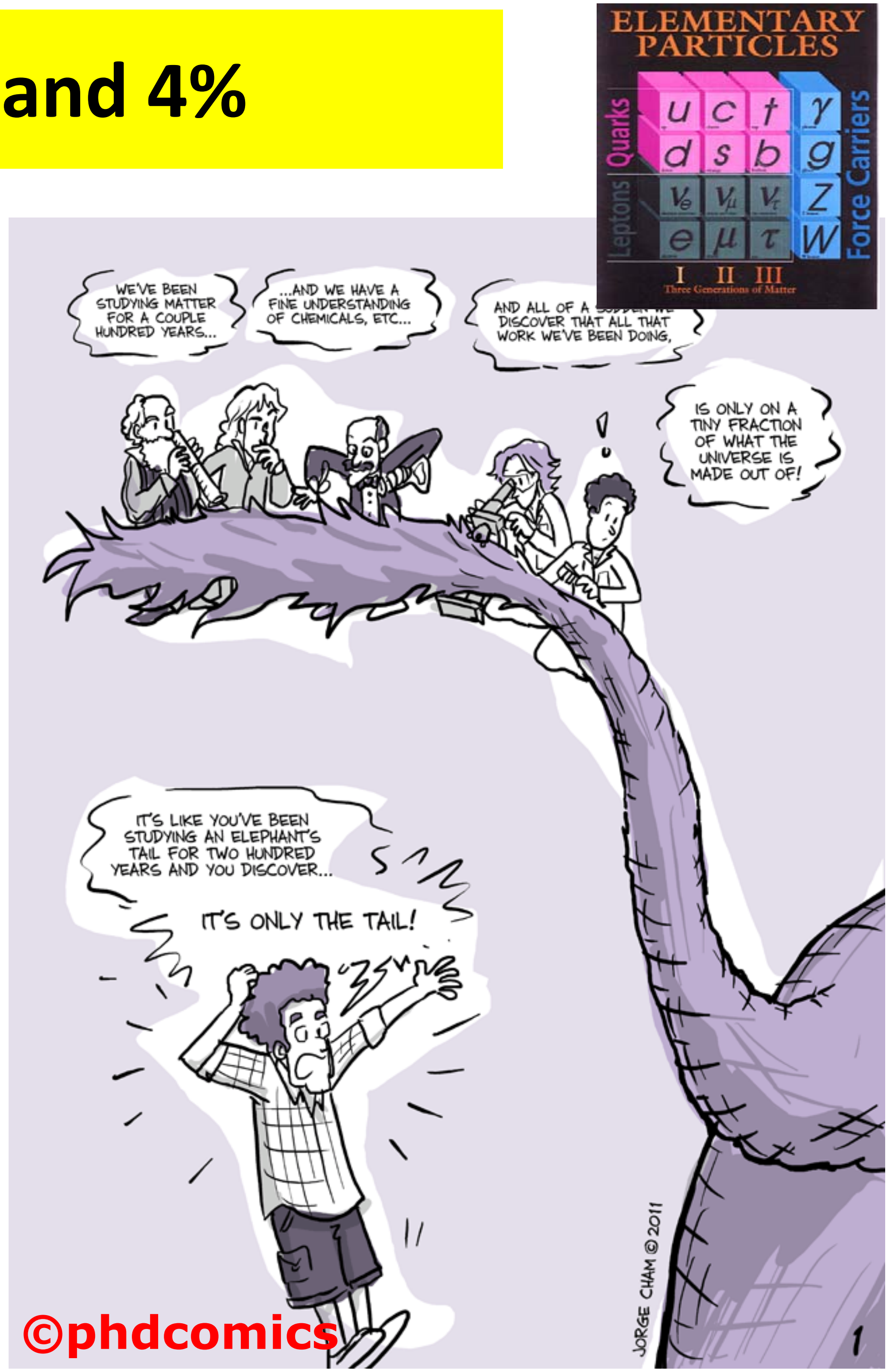
100 years to understand 4%

How long to understand 23%?



Source: Robert Kirshner
Source: NASA/WMAP Science Team

Gravity √	**Electromagentic X**
Weak ?	**Strong X**



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Conclusions

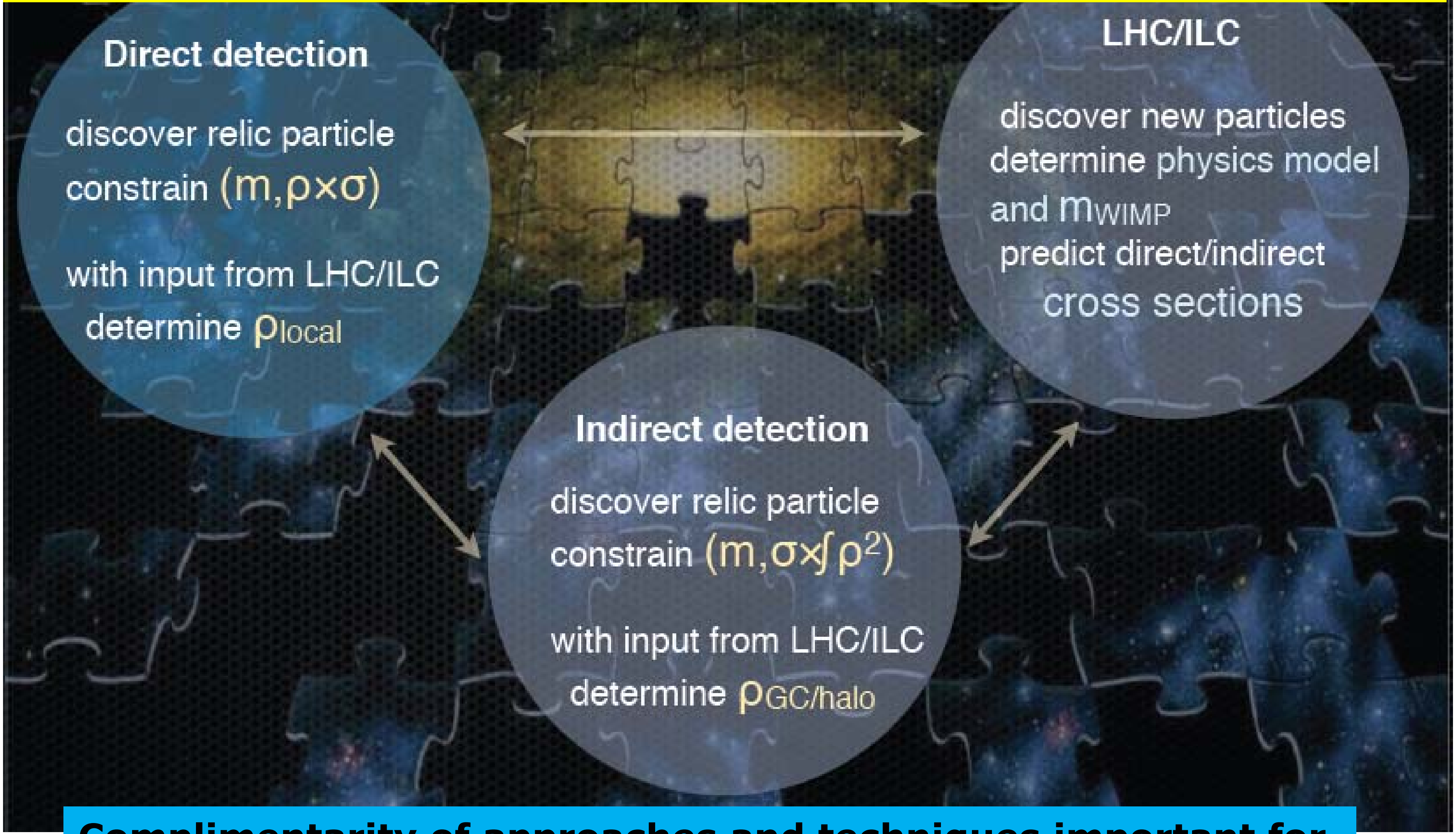
- Many technologies for G2 (~200-300 kg 10^{-46}cm^2) ~ 2013-2014
  - SuperCDMS, Xenon-1T, LUX 350, DEAP, EURECA
  - Not all have the same level of background rejection
  - First SuperCDMS, Soudan results by end of month!

- G3 (~2020) Prospects bleak in US, due to DUSEL failure. SNOLab doesn't have enough space for G3 expts. Major ton-scale in Europe and China being proposed. Also, possible ton-scale in India

- Excellent opportunities available in mini-DINO experiment starting now. Must succeed to push for ton-scale DINO in India, as major international venture with best possible technology and funding.

- When will we detect Dark Matter? "The two most powerful warriors are patience and time" – Leo Tolstoy

To Understand the Biggest, You have to Understand the Smallest



Direct detection

discover relic particle
constrain $(m, \rho\times\sigma)$

with input from LHC/ILC
determine ρ_{local}

LHC/ILC

discover new particles
determine physics model
and m_{WIMP}
predict direct/indirect
cross sections

Indirect detection

discover relic particle
constrain $(m, \sigma\times\int\rho^2)$

with input from LHC/ILC
determine $\rho_{GC/halo}$

Complimentarity of approaches and techniques important for understanding our Universe and solve the mysterious puzzle