Direct Dark Matter Searches Overview

Harry Nelson

UCSB/LUX

Silver (25 y) Jubilee of DDMS…

Insanity is doing the same thing over and over again and expecting different results… Rita Mae Brown

(my apologies, most slides stolen!)

Historical Analogs…

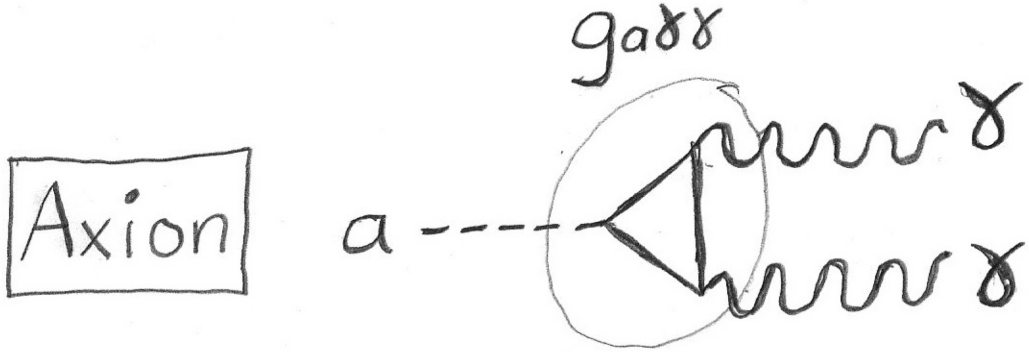
- Rutherford & Chadwick between 1920-1932 conducted many unsuccessful experiments to discover the neutron
  - Joliot-Curie clue
  - Technique is now used in WIMP searches

- 110 years of neutrino physics
  - Beta decay in 1900 or so
  - … (Parity violation! R.T. Cox et al., PNAS 14, 544 (1928)) …
  - 2020… complete mixing/mass matrix?
  - Majorana Mass?

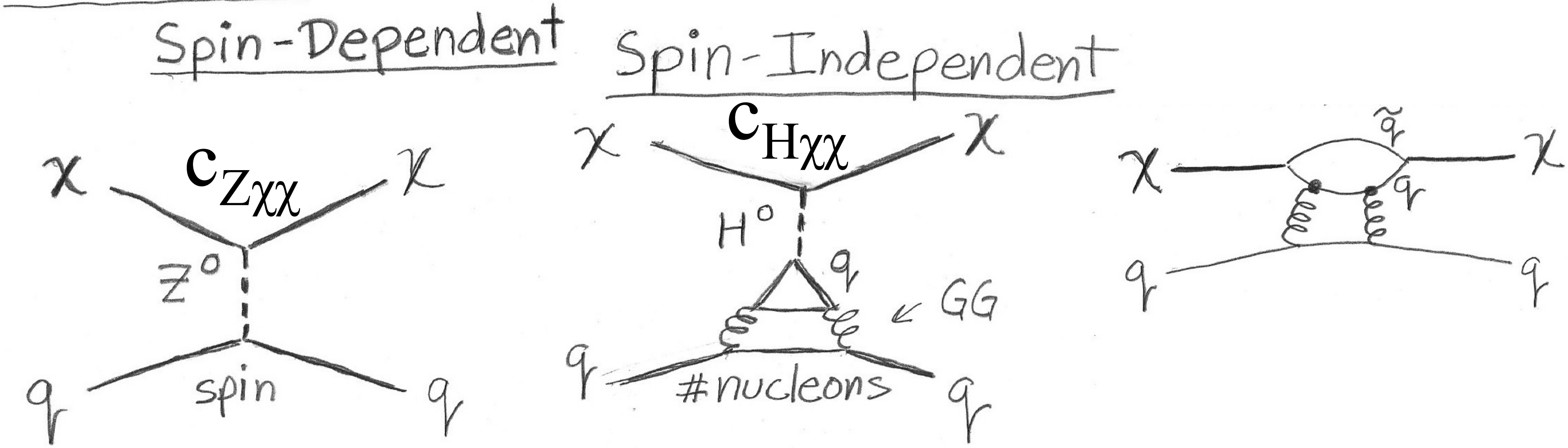
How does Dark Matter interact with us?

- Gravitationally... astrophysics utilizes…
- Not via conventional electromagnetic or strong couplings (dark, no peculiar terrestrial nuclei with an extra particle bound)…. however, axions!
  - Gluon field doesn't violate CP, weak interaction does
- Could be via `conventional' weak interaction… focus of most terrestrial experiments…
  - WIMP miracle… thermal equilibrium in Big Bang
  - SUSY favors a stable lightest superpartner

Generic Feynman Diagrams



WIMP χ $\sigma_{nucleon}$



The Old Way (1987 Ahlen et al)

Volume 195, number 4 PHYSICS LETTERS B 17 September 1987

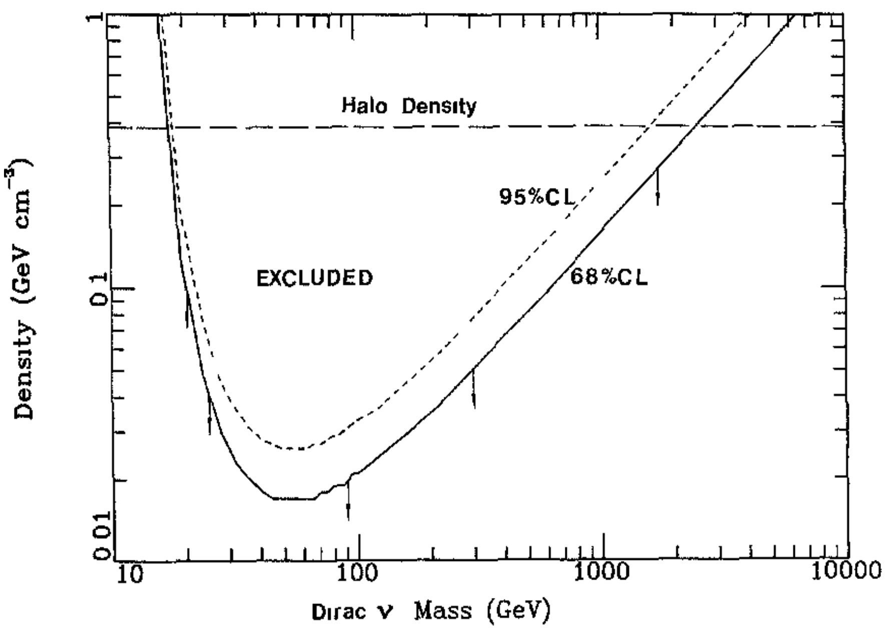


Fig. 3. The maximum halo density of heavy standard Dirac neutrinos (as an example of particles with weak spin-independent interactions) is shown, consistent with the observed count rate, as a function of their mass. The solid line shows the 68% confidence level and the dashed line shows the 95% confidence level.

cosmogenic radioactive contamination. In this way the background has been reduced by about a factor

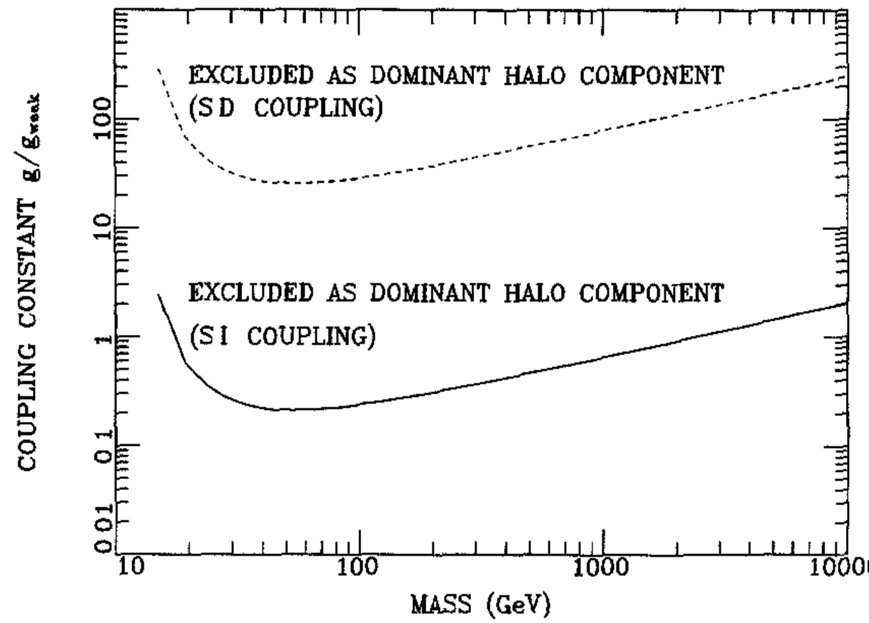
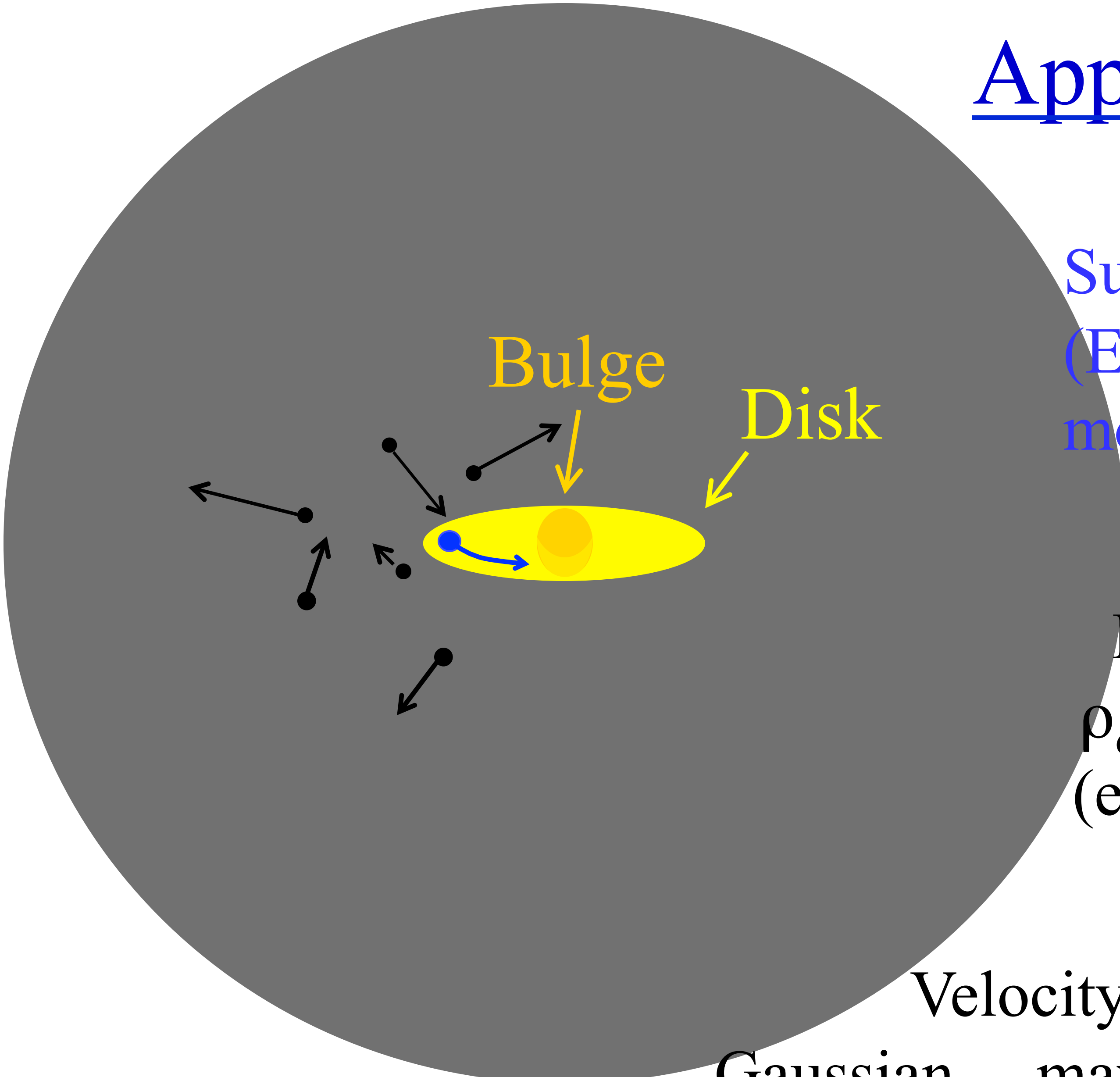


Fig. 4. The regions in mass–cross section space excluded at the 68% confidence level are shown. The halo cannot be composed of particles that interact with nuclei through spin-independent interactions whose coupling constant (normalized to the coupling of massive Dirac neutrinos to baryons) lies above the solid line. Nor can the halo be composed of particles that interact with nuclei through spin-dependent interactions whose coupling constant (normalized as above) lies above the dashed line.

Apparent `beam'



Sun: $v/c = \beta \cong 0.7 \cdot 10^{-3}$
(Earth's motion modulates)

Particles in `halo':
$\rho_{dark} \cong 0.3$ GeV/cm^3
(extrinsic systematic)

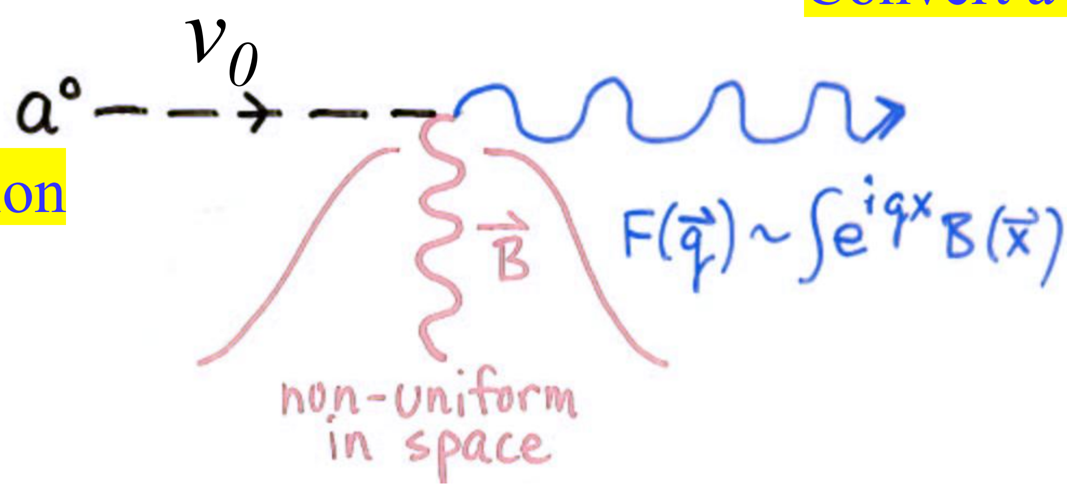
Velocity Dispersion?
Gaussian… maybe axions have less

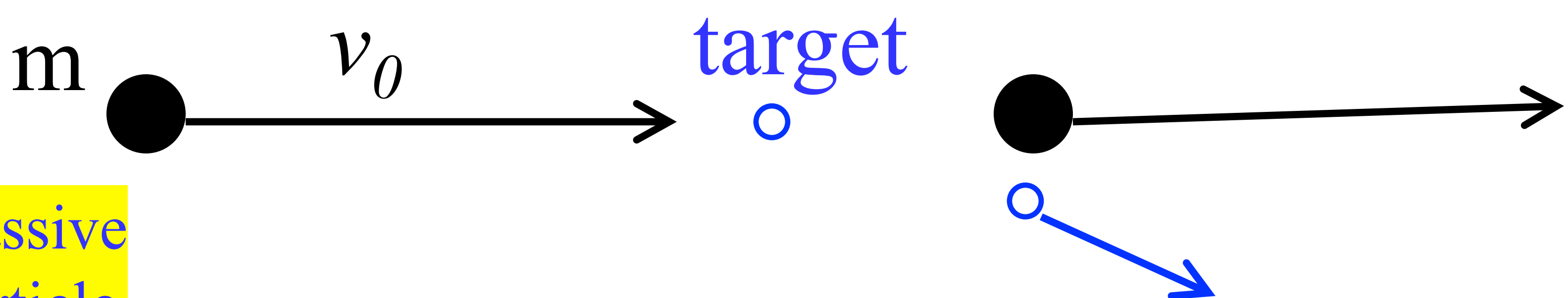
Direct Detection

- Momentum Transfer

Convert a to photon – detect it

axion

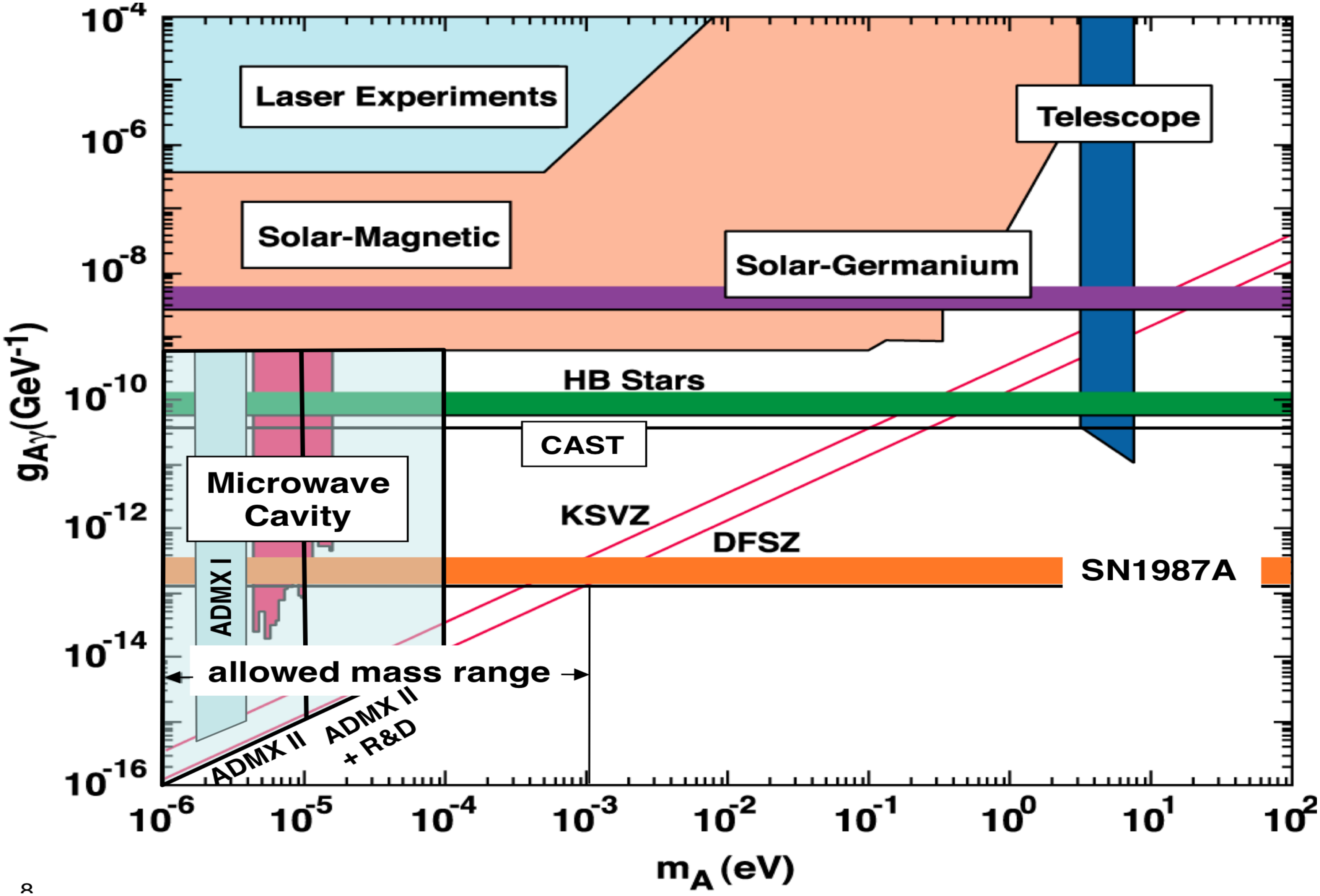




Massive Particle

Cause target recoil – detect it – (nuclei) 10's of keV

Axion Parameter Space…



Key ADMX Innovation… AC SQUID Amp

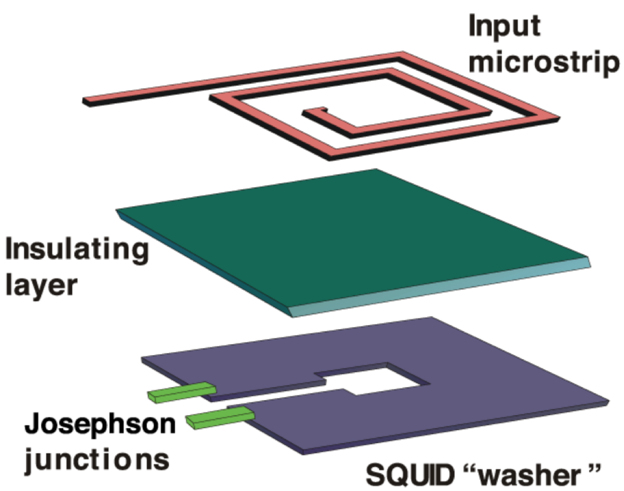
APPLIED PHYSICS LETTERS VOLUME 78, NUMBER 7 12 FEBRUARY 2001

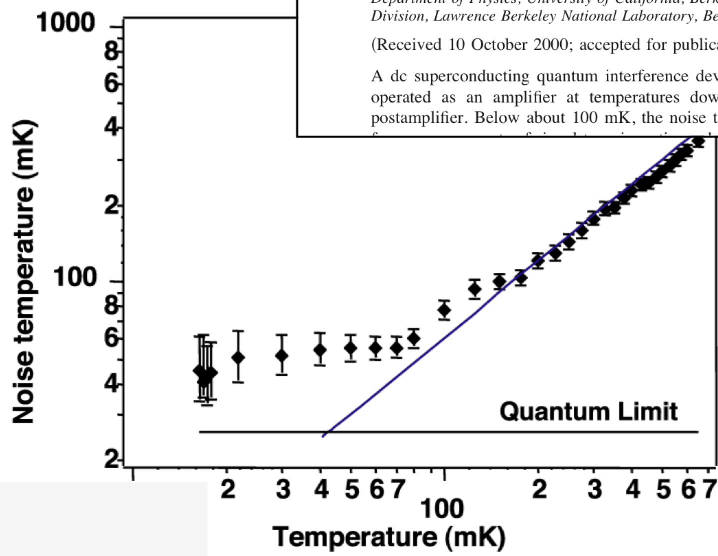
Superconducting quantum interference device as a near-quantum-limited amplifier at 0.5 GHz

Michael Mück, J. B. Kycia, and John Clarke
Department of Physics, University of California, Berkeley, California 94720 and Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720

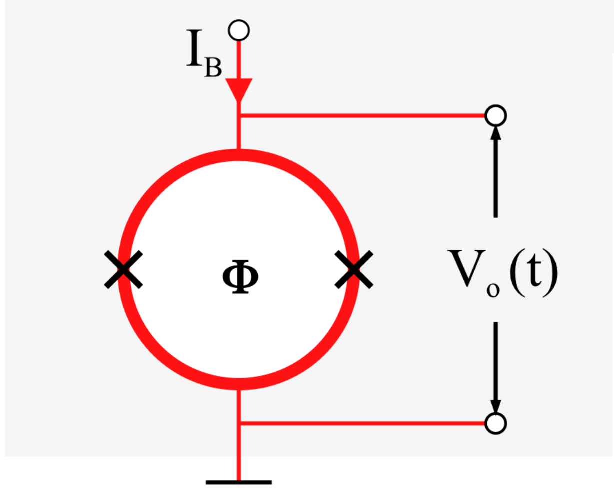
(Received 10 October 2000; accepted for publication 14 December 2000)

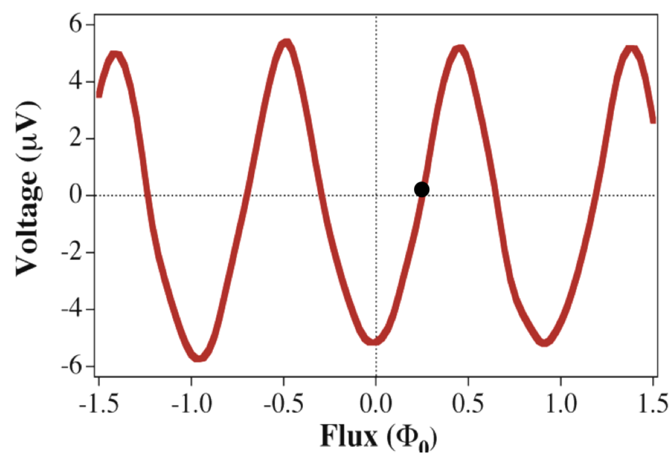
A dc superconducting quantum interference device (SQUID) with a resonant microstrip input is operated as an amplifier at temperatures down to 20 mK. A second SQUID is used as a postamplifier. Below about 100 mK, the noise temperature is 52±20 mK at 538 MHz, estimated





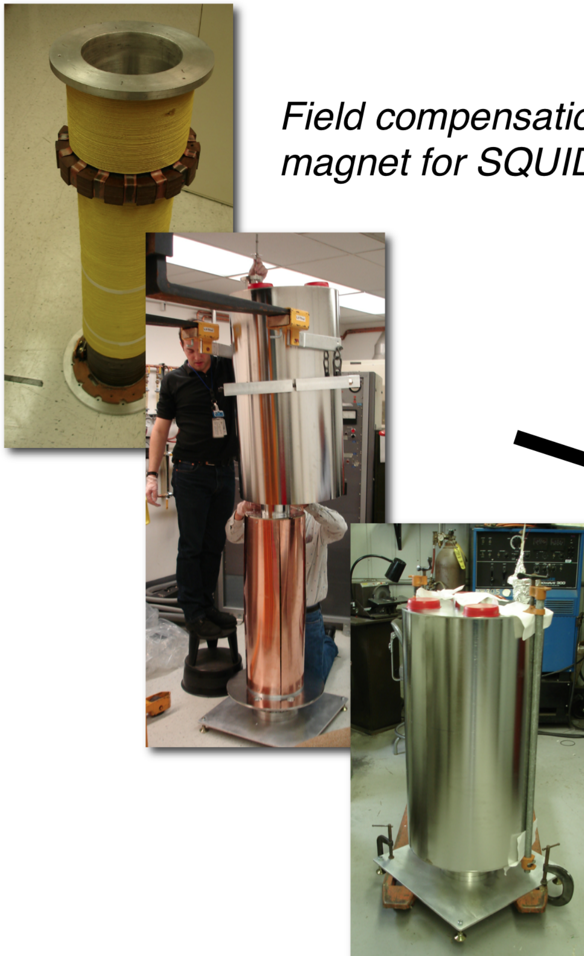
- GHz SQUIDs have been measured with T_N ~50 mK
- Near quantum–limited noise
- This provides an enormous increase in ADMX sensitivity



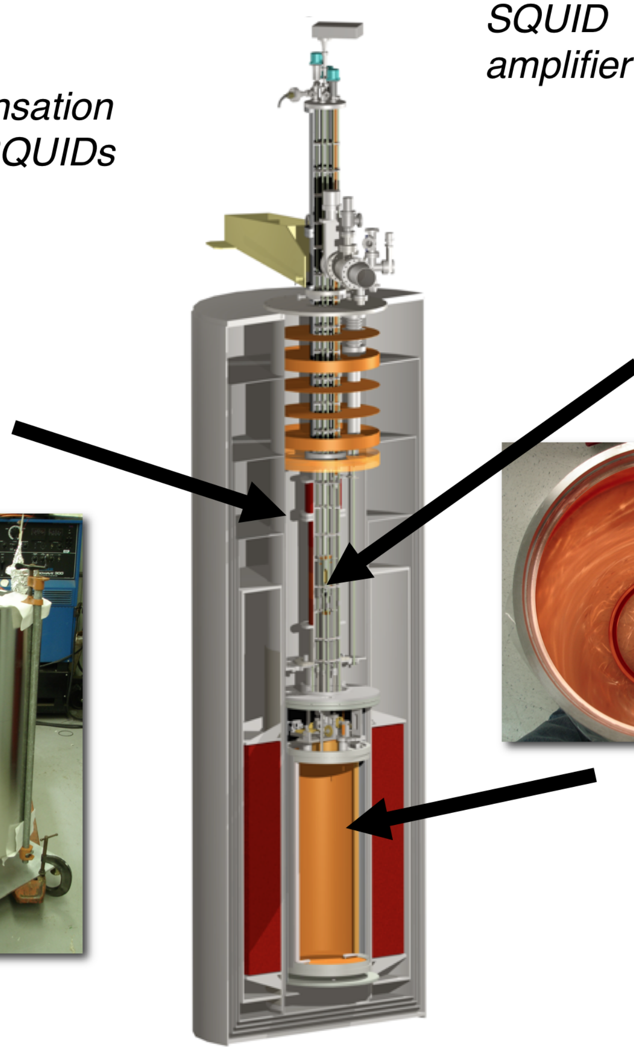


The ADMX Experiment

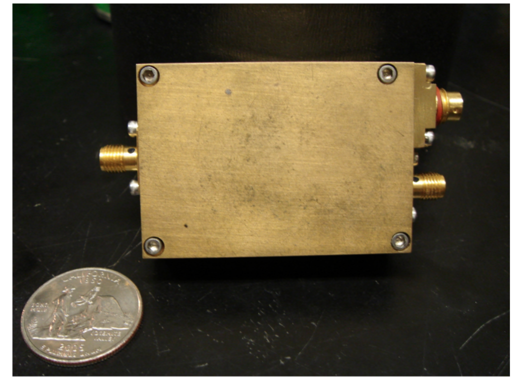
ADMX SQUID-based detector



Field compensation magnet for SQUIDs



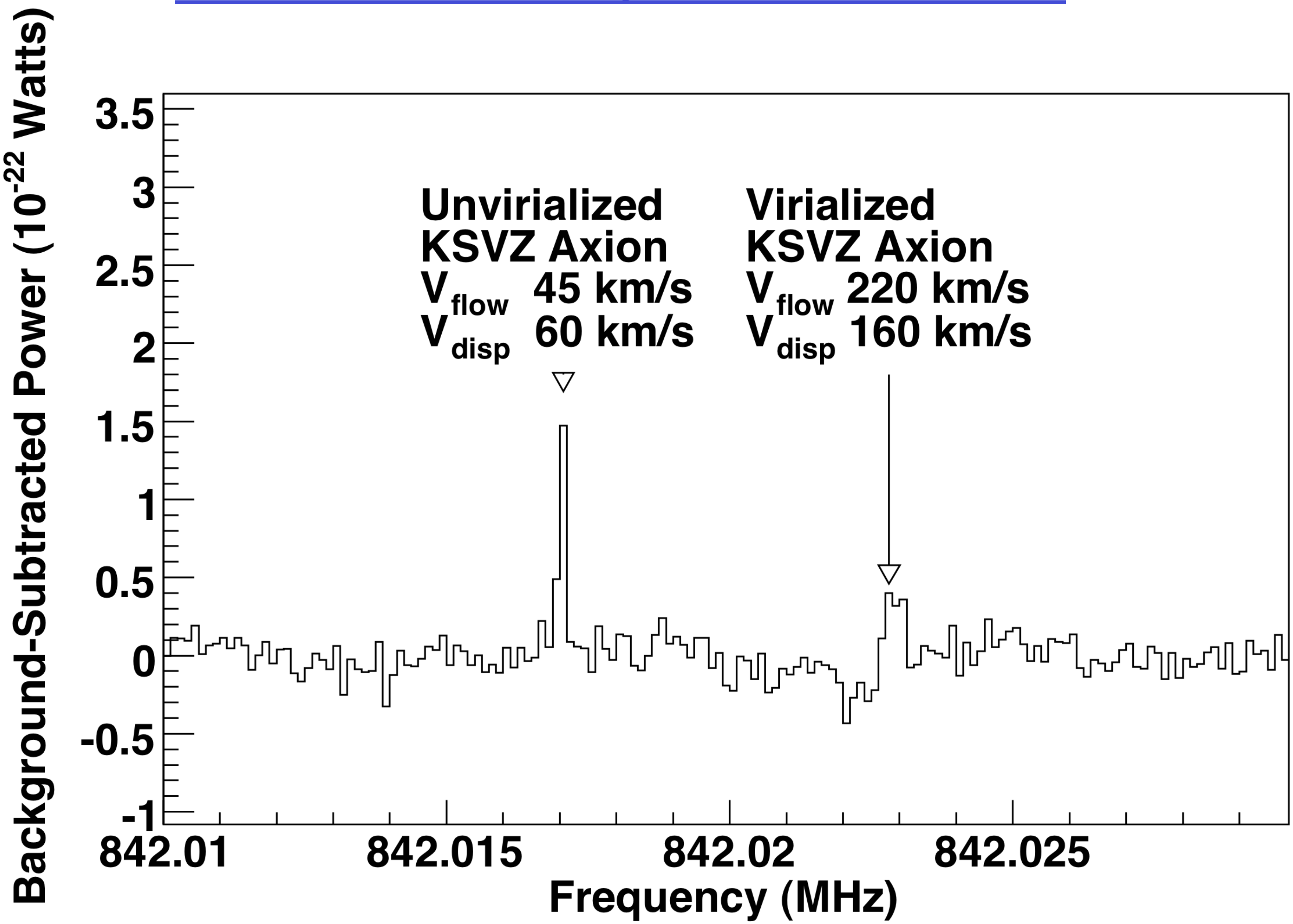
SQUID amplifier



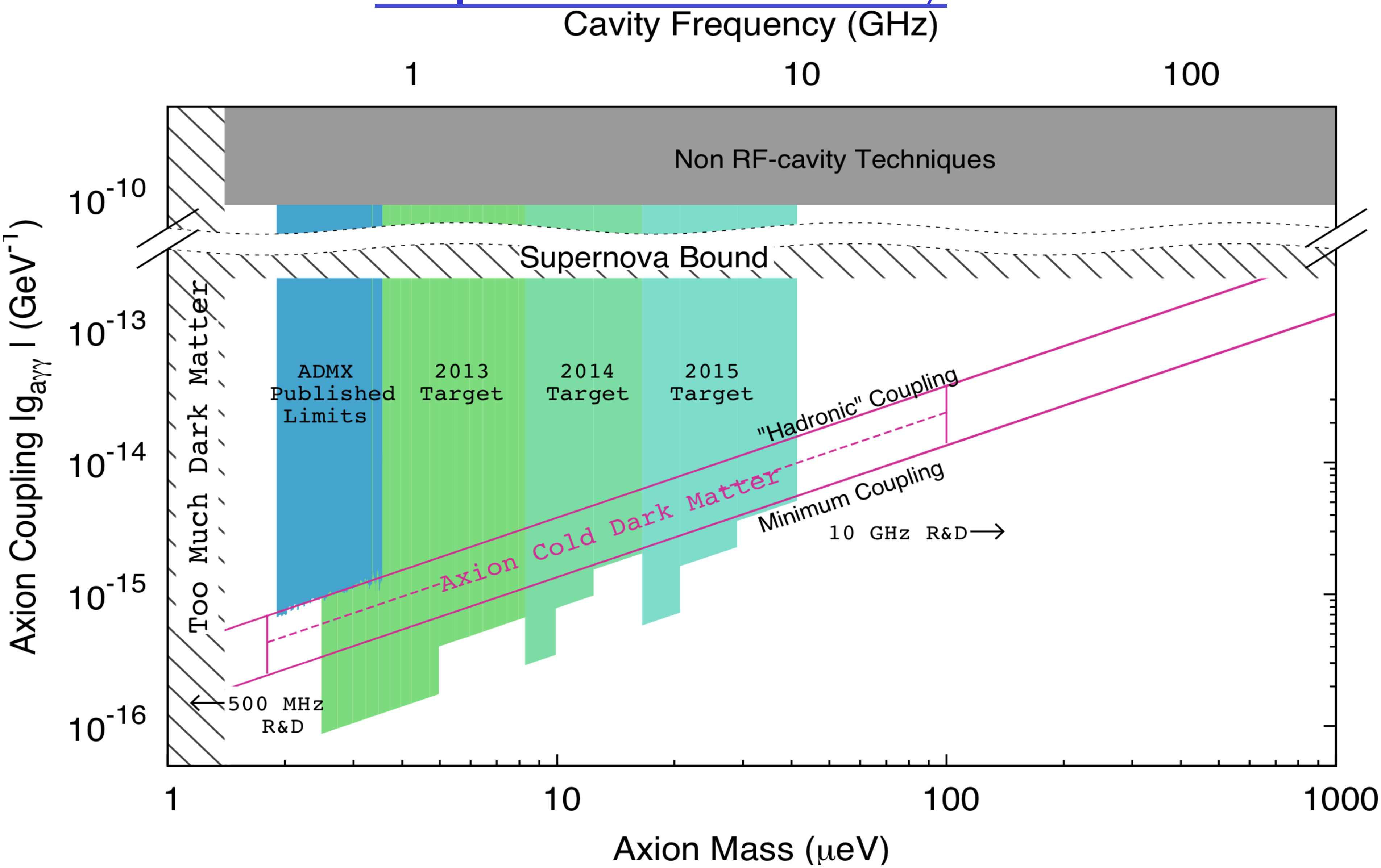
All new experiment package

IDM23jul12 LJR 18

Axion Lineshapes in ADMIX



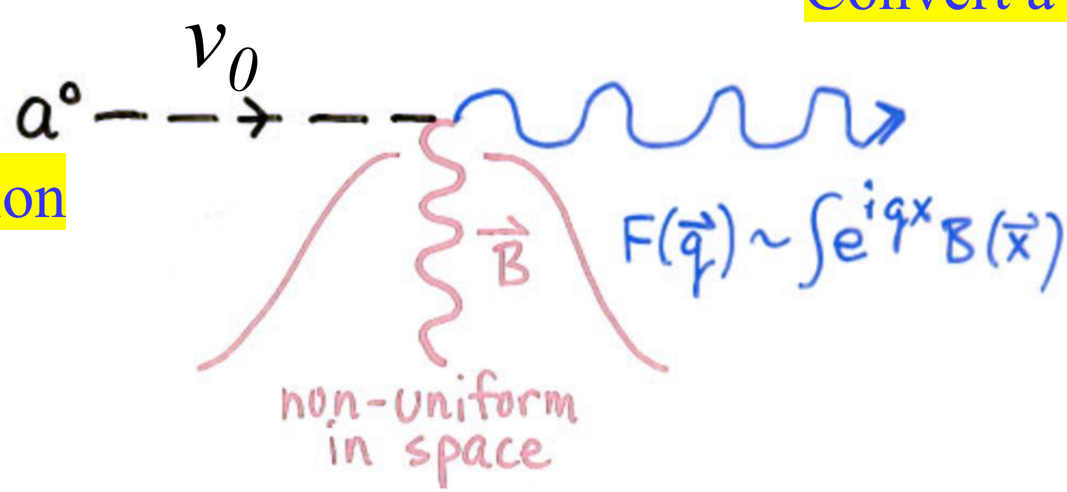
Expected Sensitivity



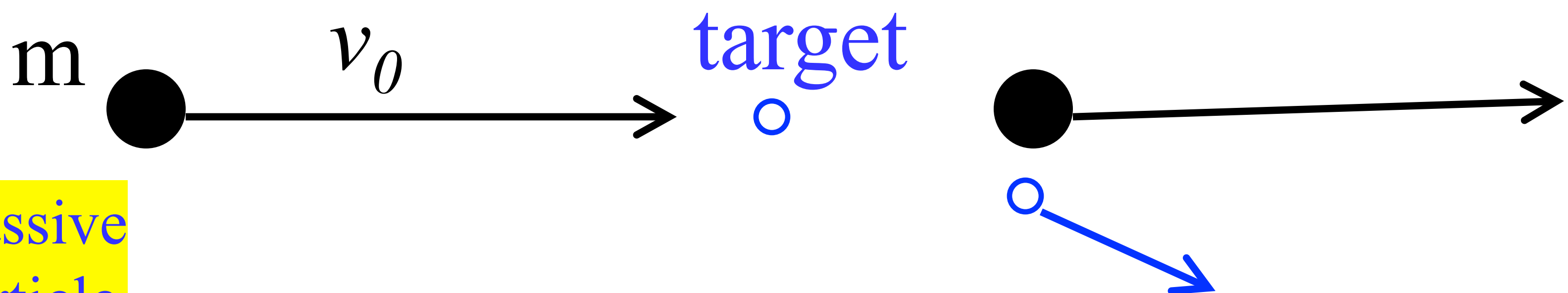
Direct Detection

- Momentum Transfer

Convert a to photon – detect it



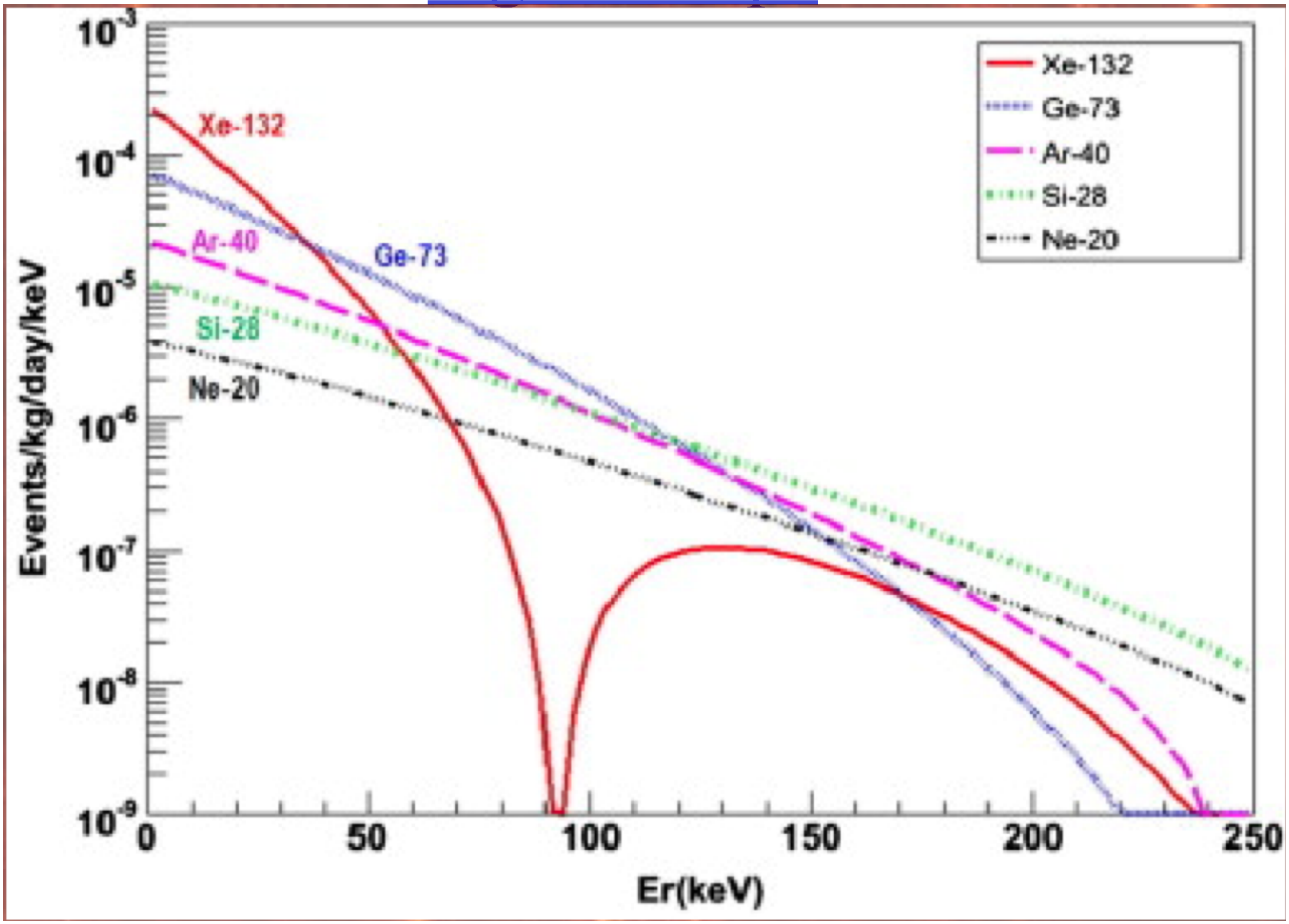
axion



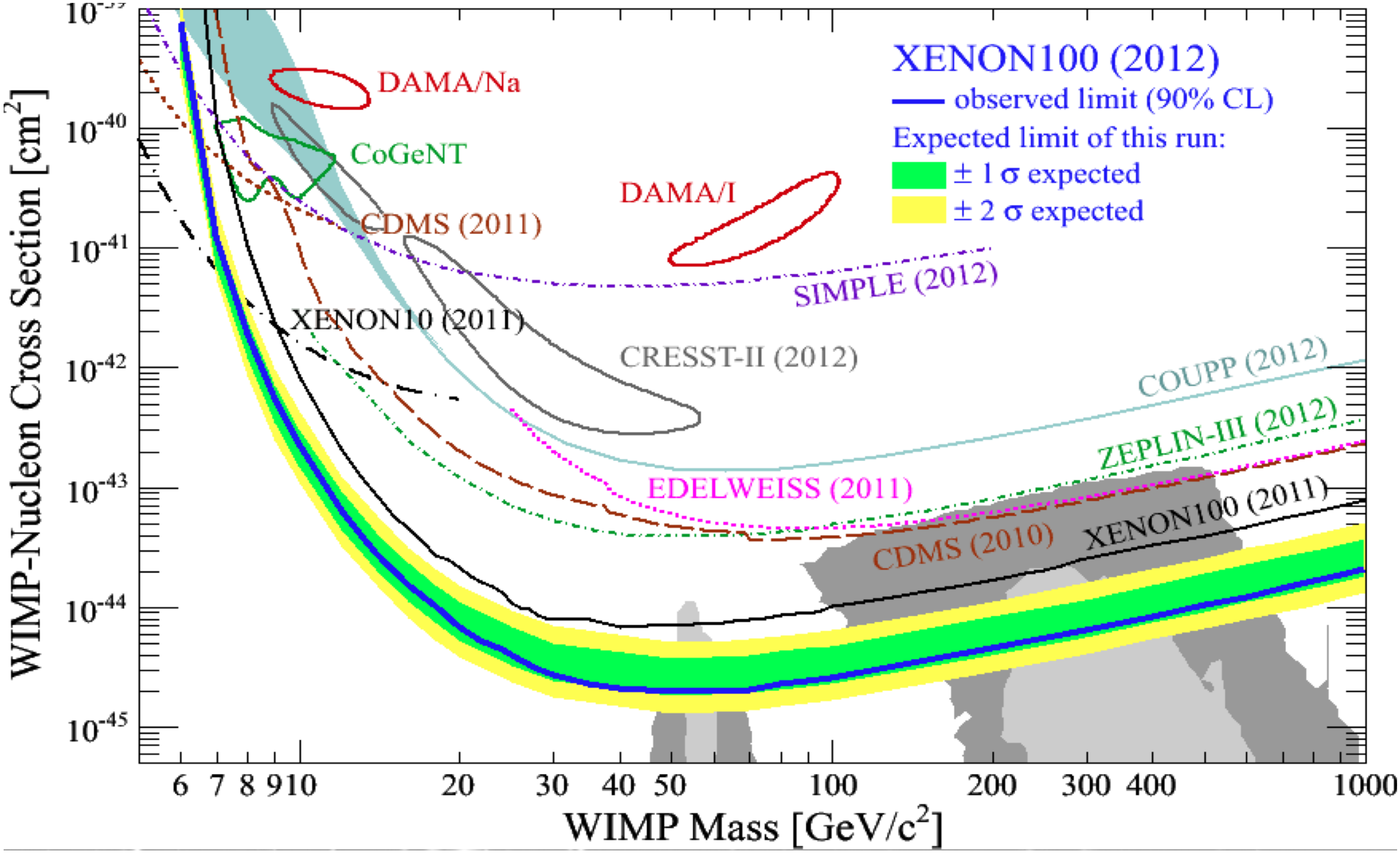
Massive
Particle

Cause target recoil – detect it – (nuclei) 10's of keV

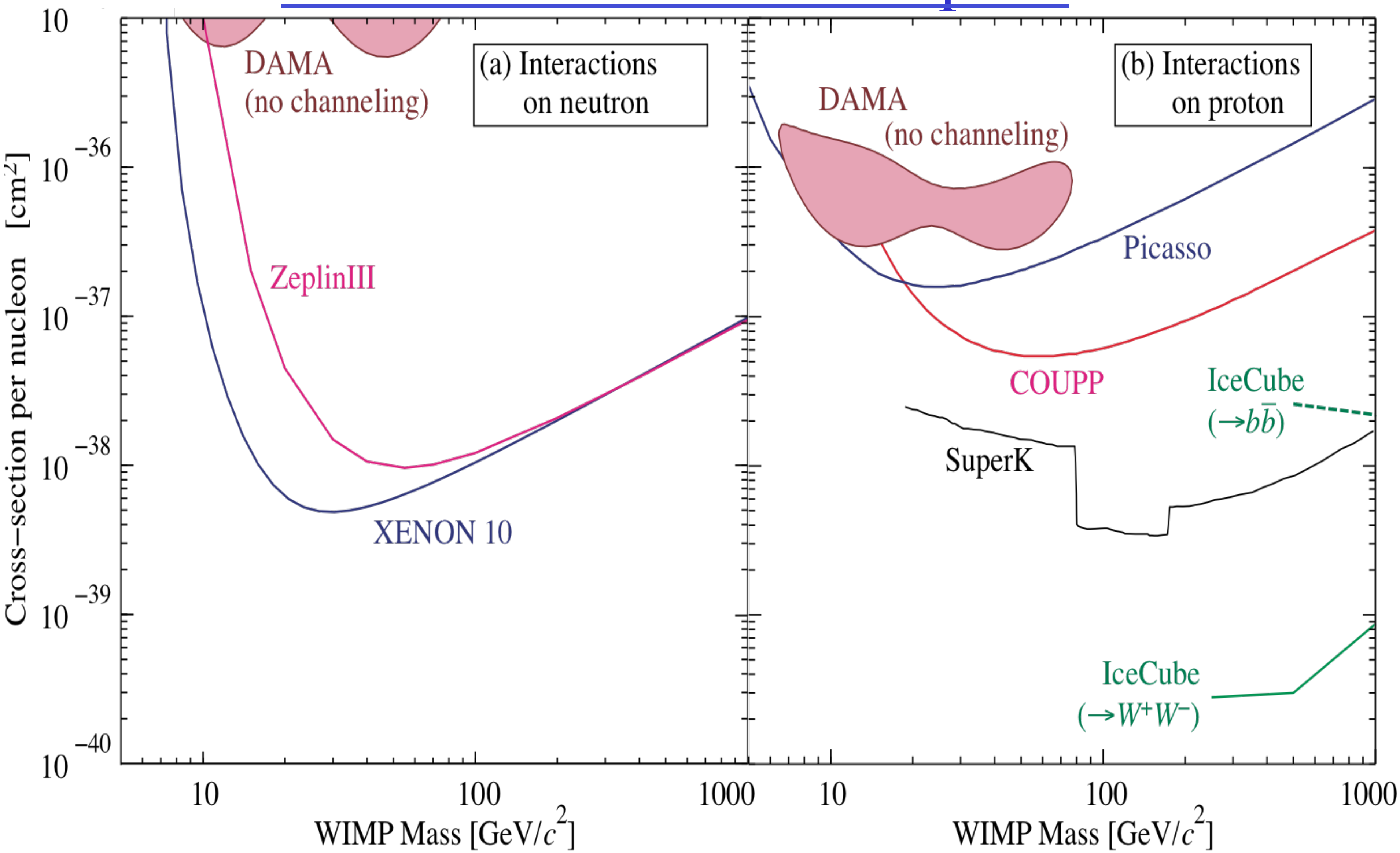
Signal Shape



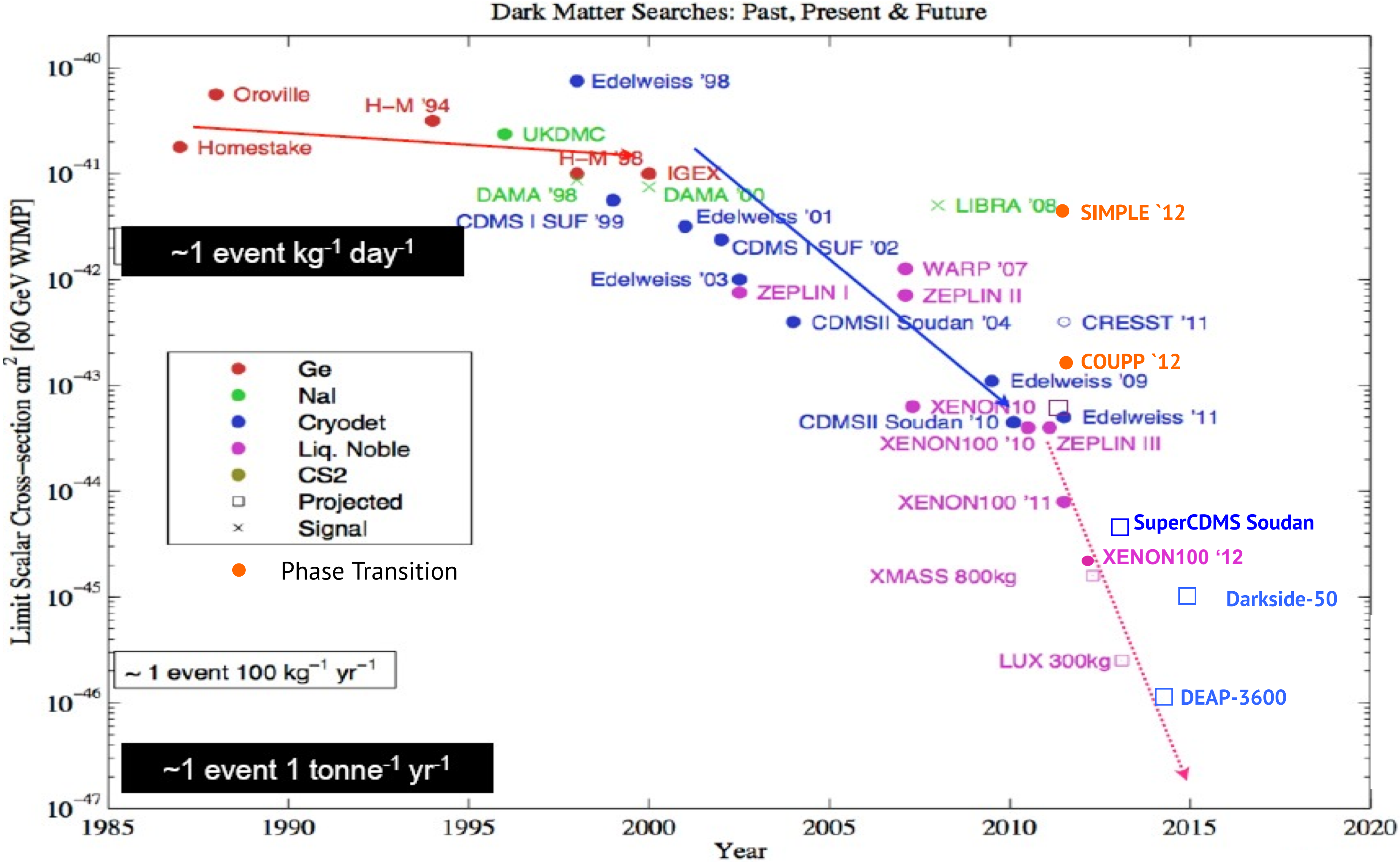
WIMP SI Parameter Space "race to the bottom"



WIMP SD Parameter Space



Historical Trend ("Livingston Plot")



10's-1000's of KeV from γ are easy to detect…

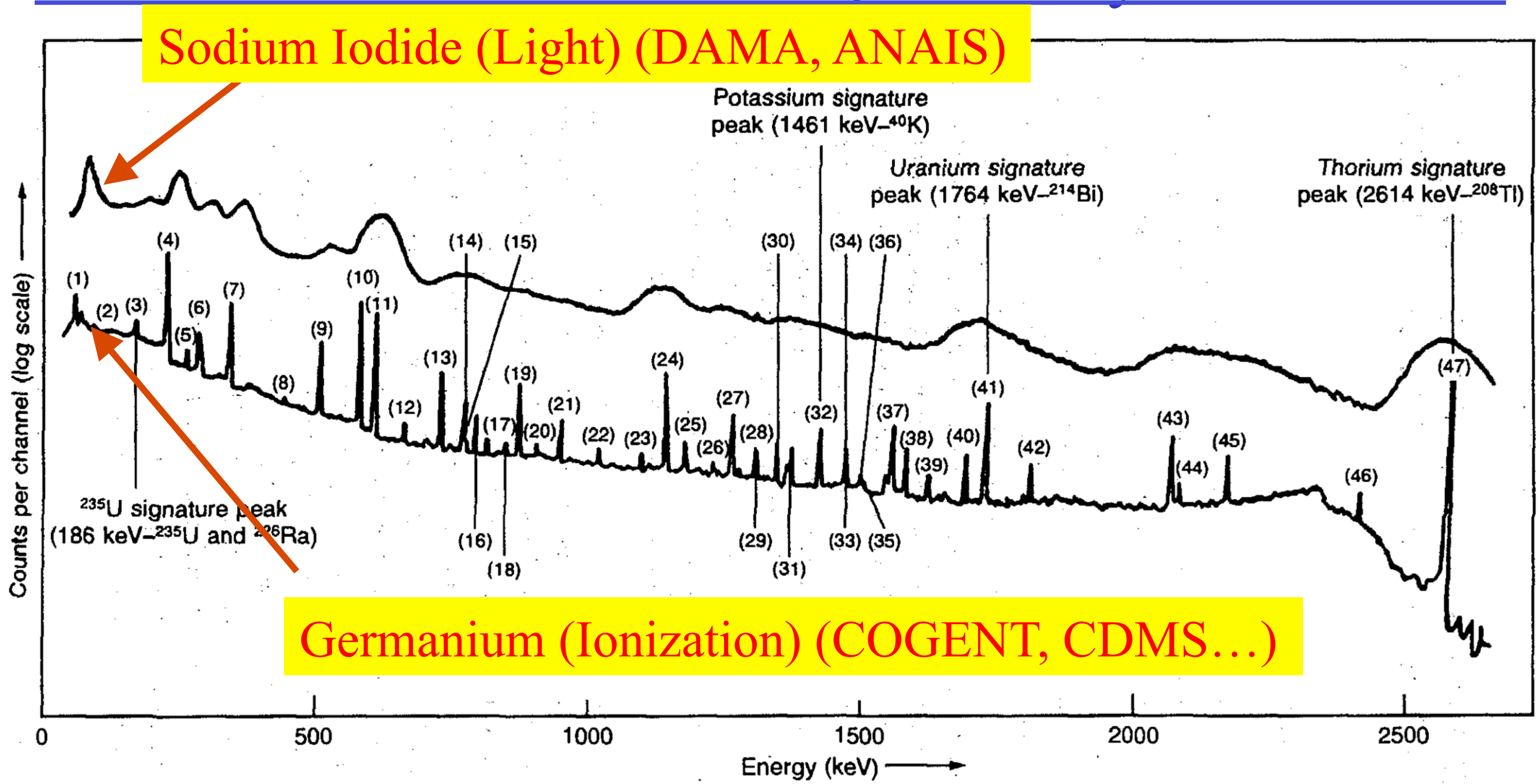
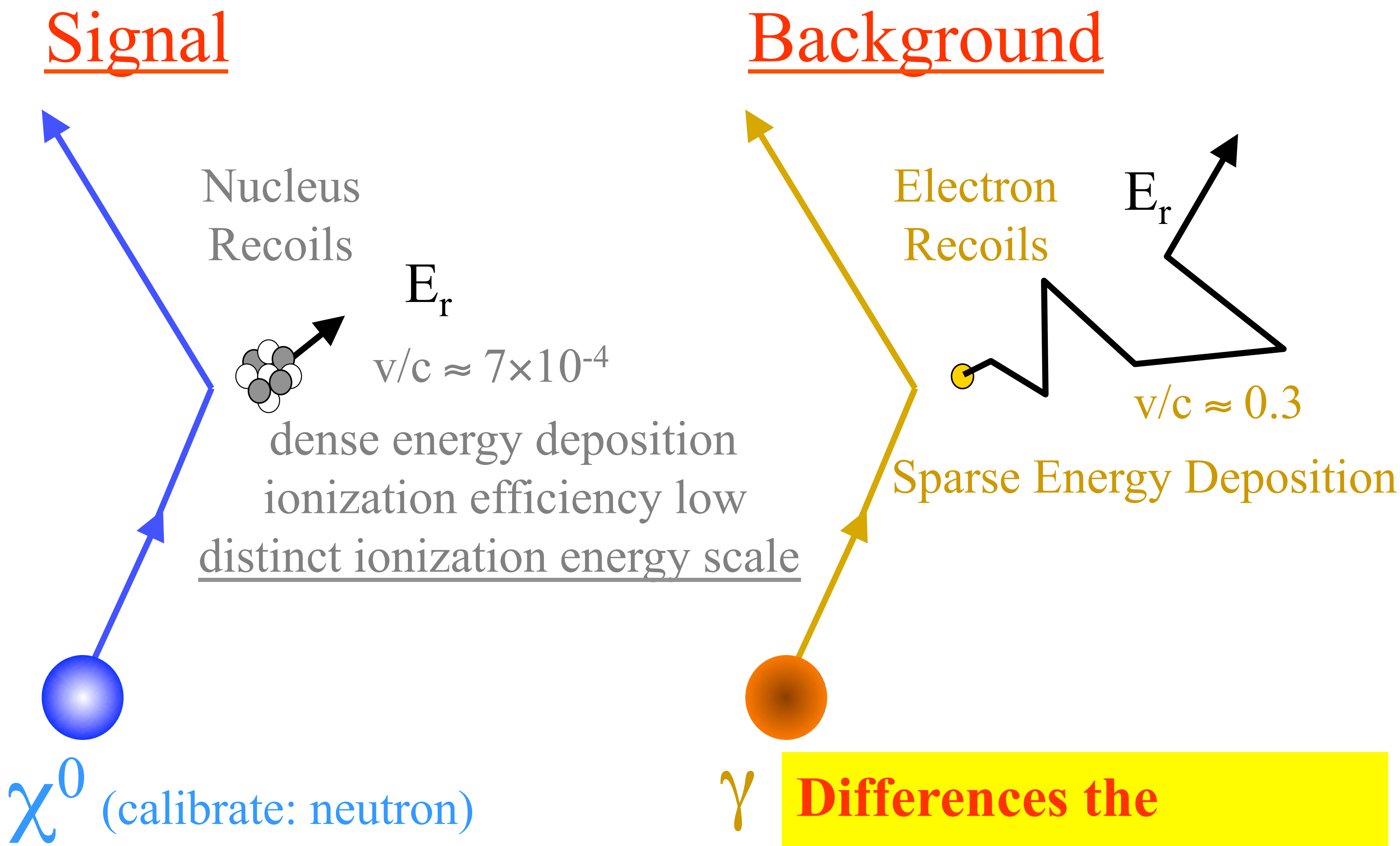


FIG. II–1. Comparison of NaI(Tl) and Ge(Li) detector resolution (refer to Table II–I for peak identification).

Second measurement to distinguish nuclear recoils

Direct Detection: Signal and Main Background

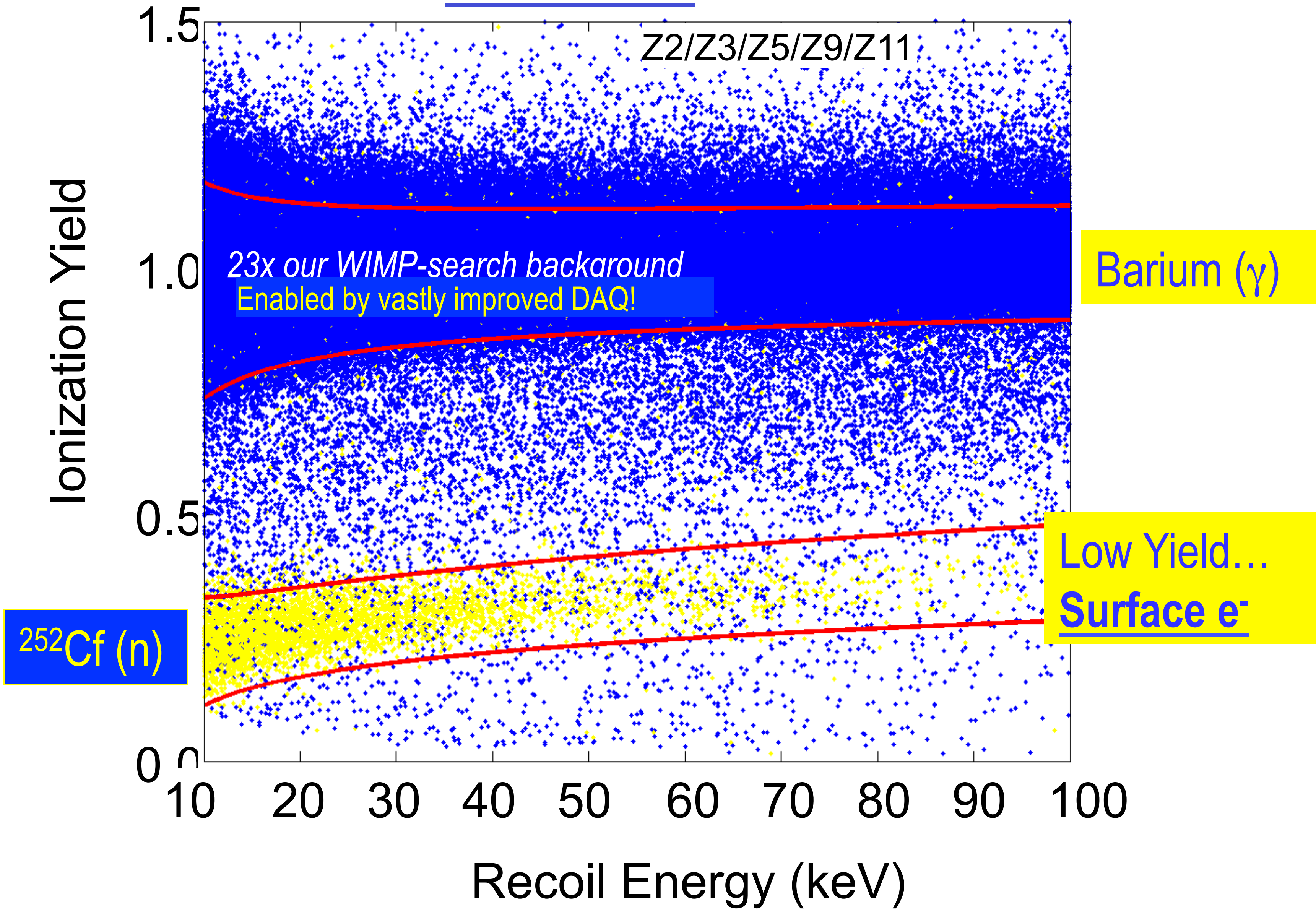


Differences the Basis of Particle ID

Who Does What

- One instrumental signal; look for annual modulation, do pulse shape analysis, or shield.
  - Solids: DAMA/LIBRA, ANAIS (NaI, 100's kg); KIMS (CsI, 100 kg) (light)
  - Liq: XMASS (Xe, 800kg), DEAP-3600 (Ar, 1000kg)
- Double Signal (much discussion of E scales)
  - CDMS/Edelweiss – phonons + ionization – Ge/Si
  - Liquid/Gas – Xenon-100/LUX (Xe, 350kg); Darkside (Ar, 50kg) – light + ionization
- Phase Change – COUPP, SIMPLE
  - Only nuclear recoils grow bubbles

CDMS-II


Z2/Z3/Z5/Z9/Z11
23x our WIMP-search background
Enabled by vastly improved DAQ!
Barium (γ)
Low Yield…
Surface e-
252Cf (n)
Ionization Yield
1.5
1.0
0.5
0.0
10
20
30
40
50
60
70
80
90
100
Recoil Energy (keV)

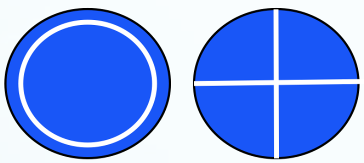
SuperCDMS Detector Improvements

An Evolving Detector

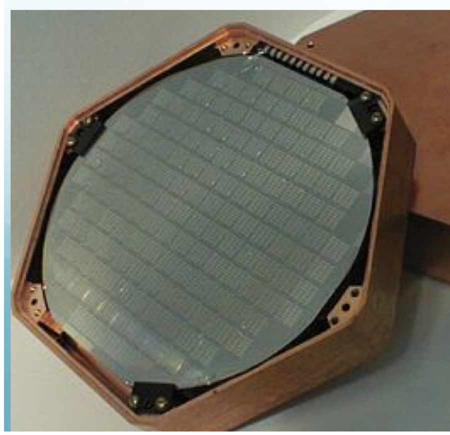
CDMS II

Single-sided
1 cm thick
3"diameter
250 g Ge

2 charge + 4 phonon



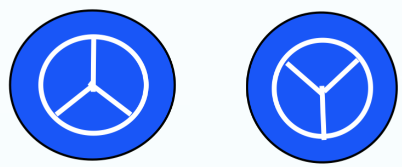
5 towers of 6 det each



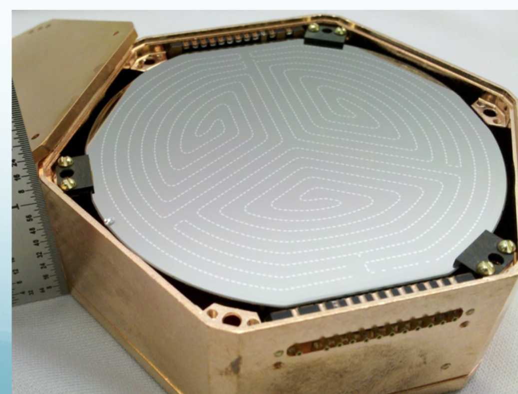
SuperCDMS Soudan

Double-sided
2.5 cm thick
3"diameter
620 g Ge

2 charge + 2 charge
4 phonon + 4 phonon



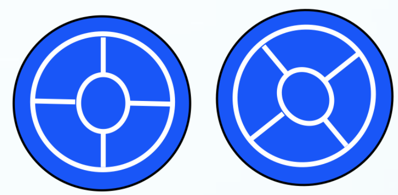
5 towers of 3 det each



SuperCDMS SNOLAB

Double-sided
3.3 cm thick
4"diameter
1.38 kg Ge

2 charge + 2 charge
6 phonon + 6 phonon

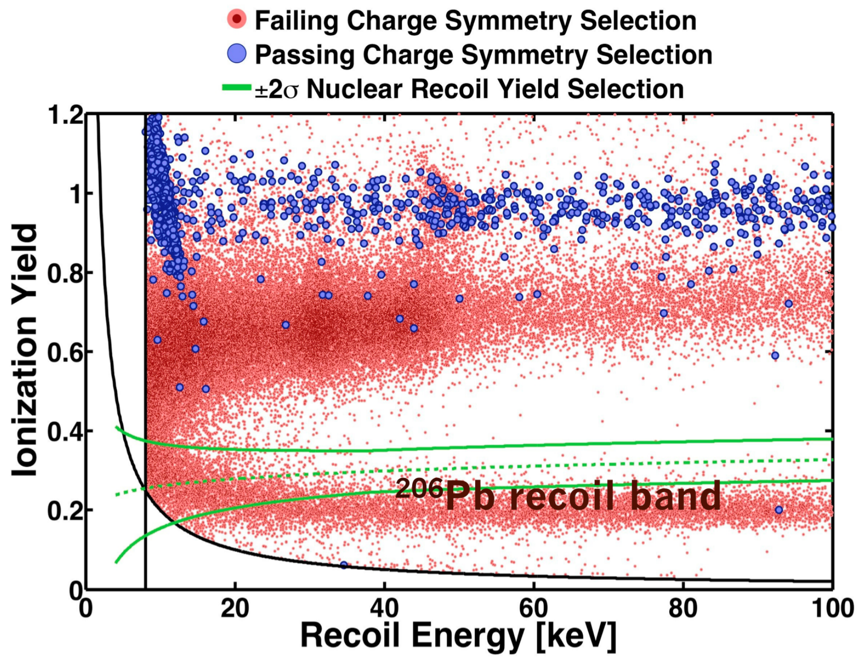


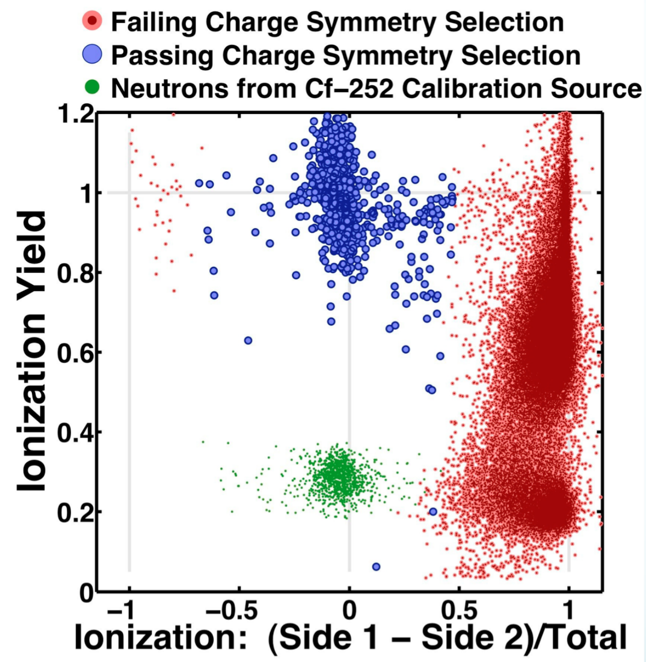
24 towers of 6 det each

SuperCDMS Surface Rejection

SuperCDMS Soudan Data: Surface Event Rejection

^{210}Pb → $^{210}Bi^{*}/Bi$ → ^{210}Po which then alpha decays to ^{206}Pb

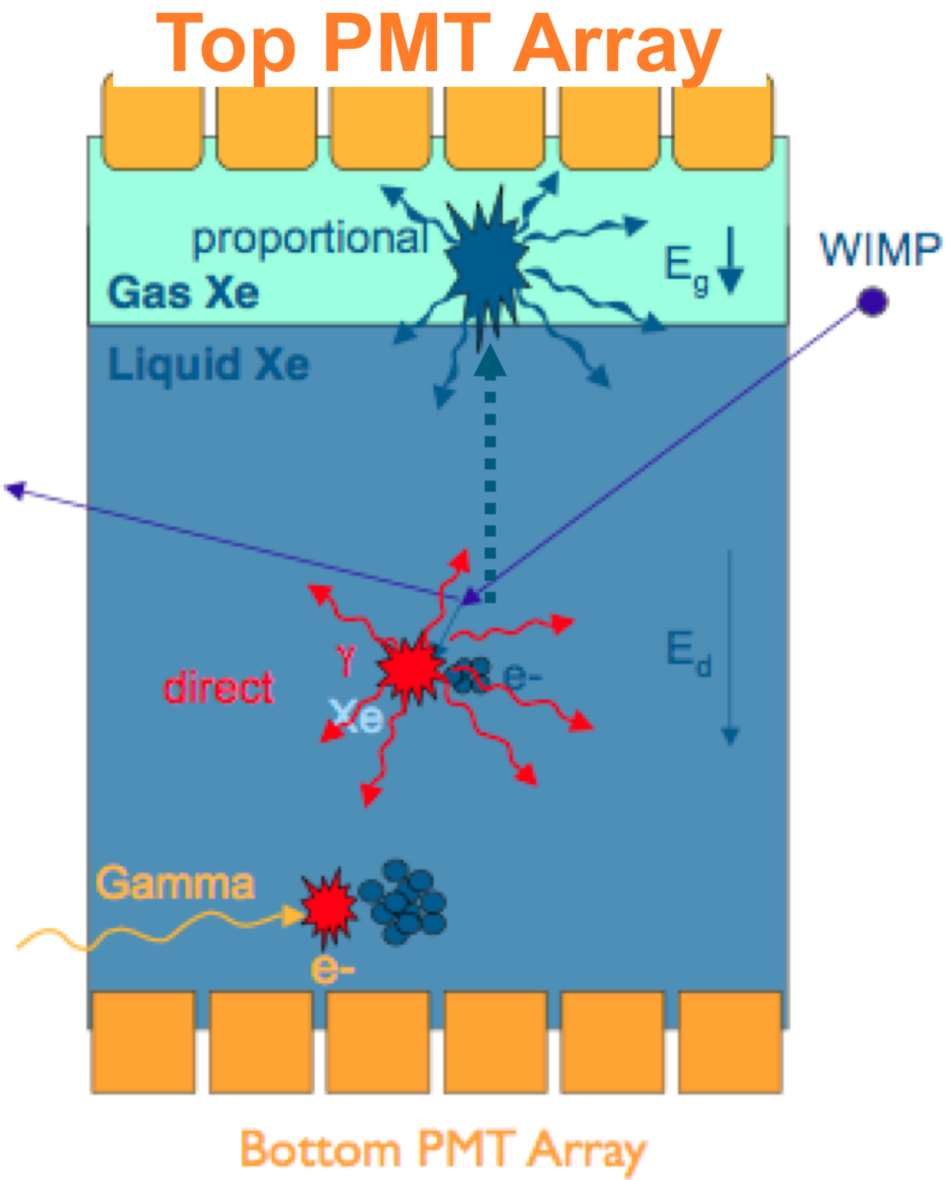


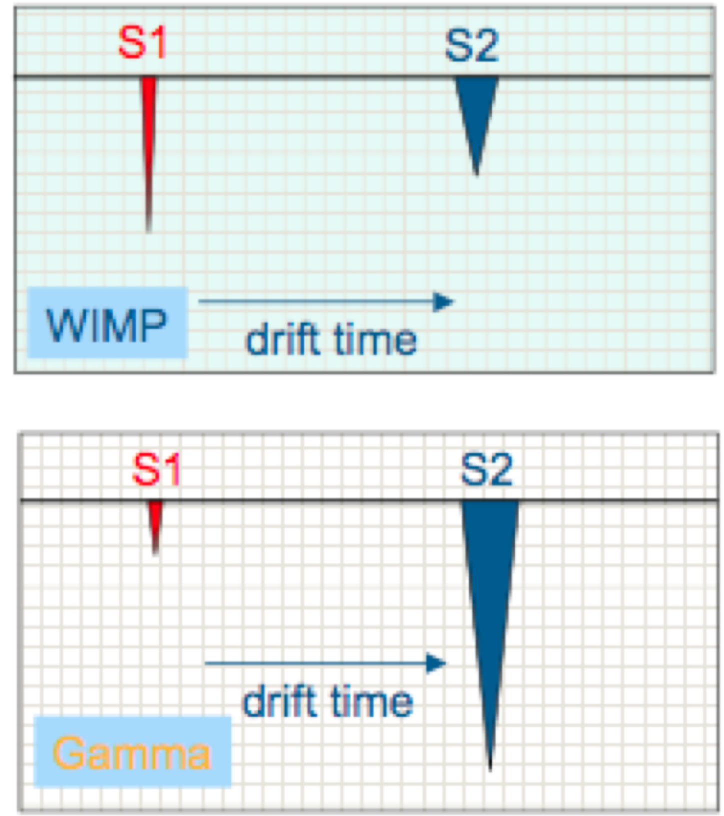


Demonstrated Rejection (Soudan, 900 live hours with ^{210}Pb source)
<2.9 x 10^{-5} @ 63% WIMP fiducial cut

Demonstrated Rejection (surface test facility with ^{109}Cd source)
<2.9 x 10^{-5} @ 74% WIMP fiducial cut

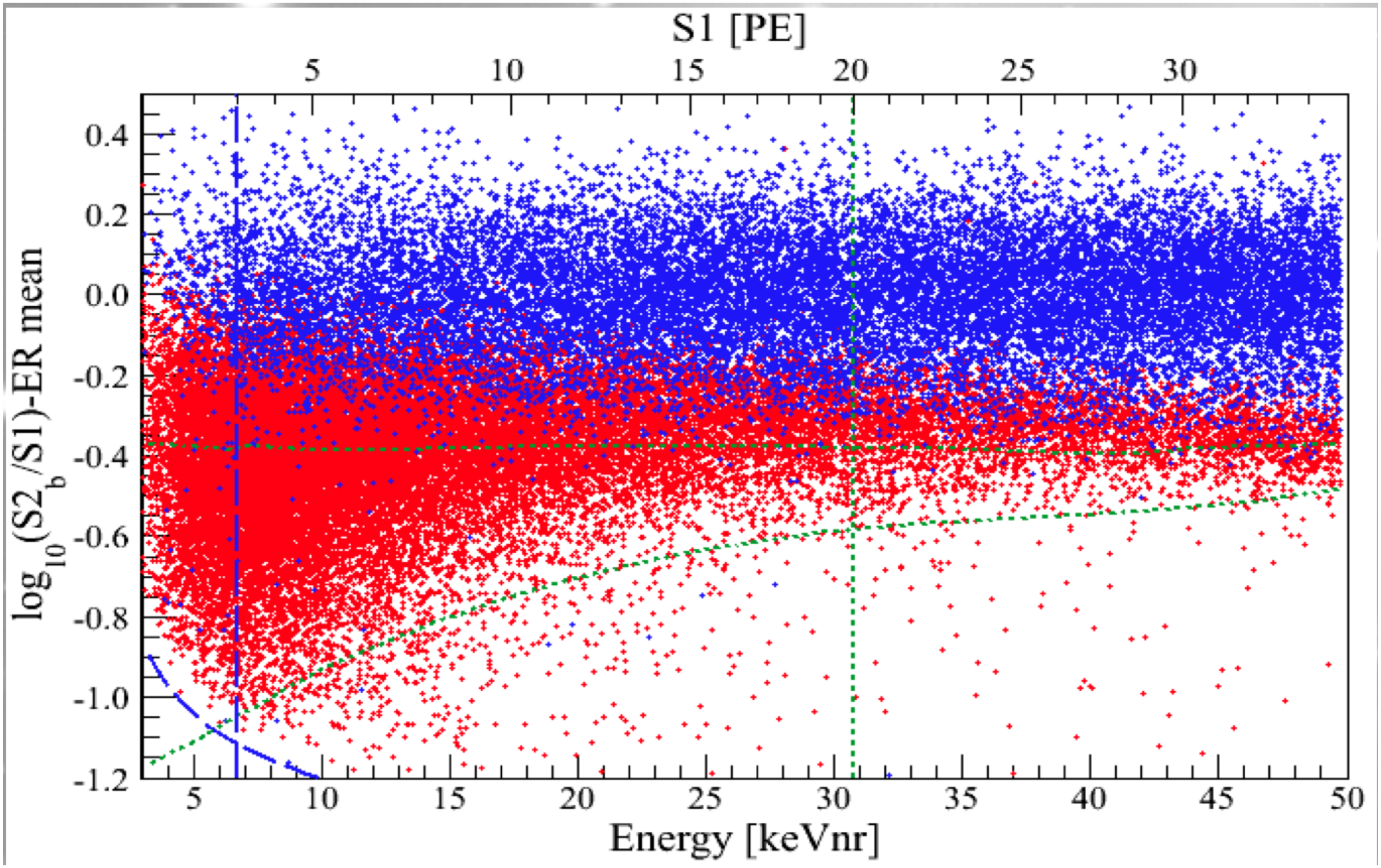
2-Phase Nobel Liquid



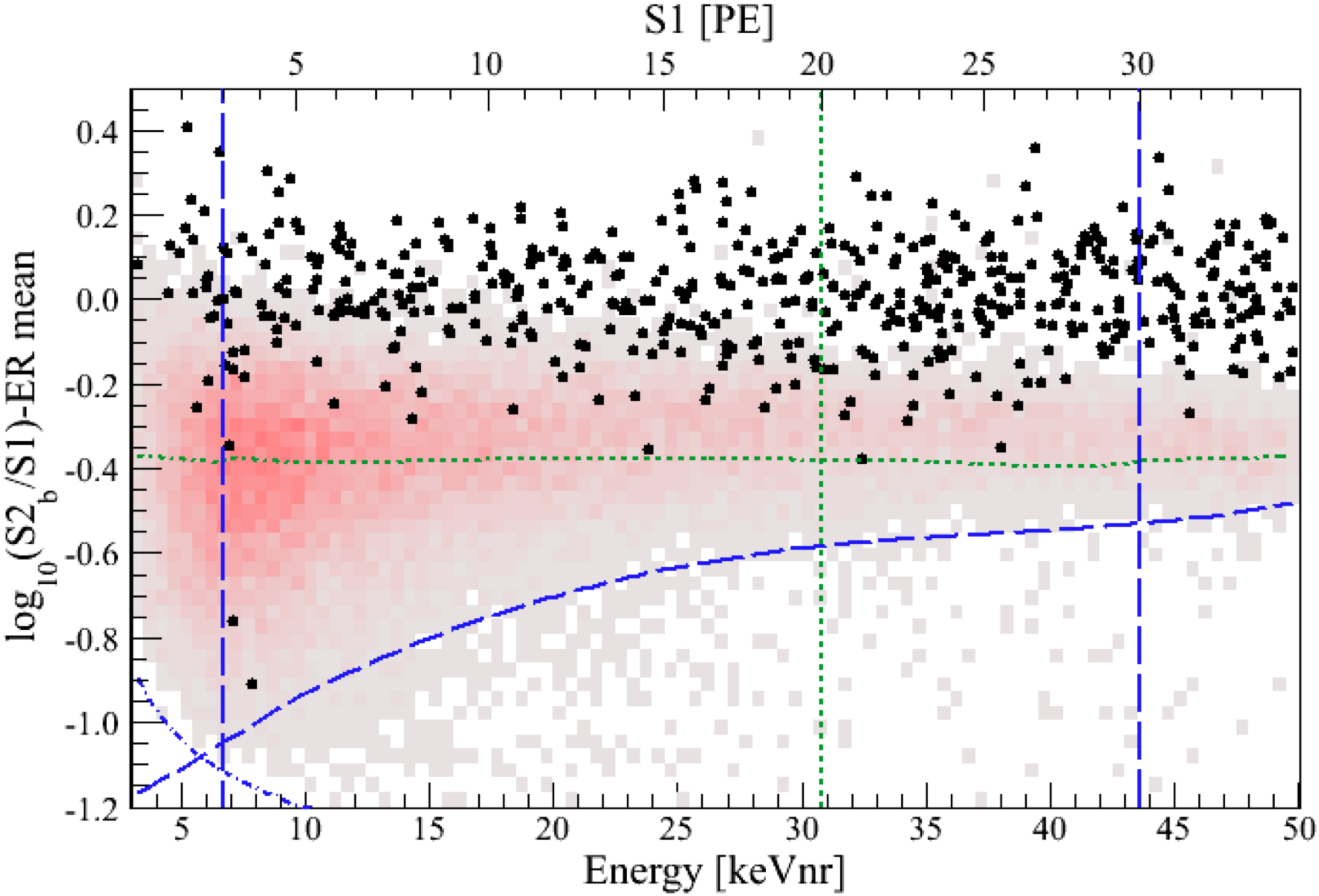


$(S2/S1)_{wimp} << (S2/S1)_{gamma}$

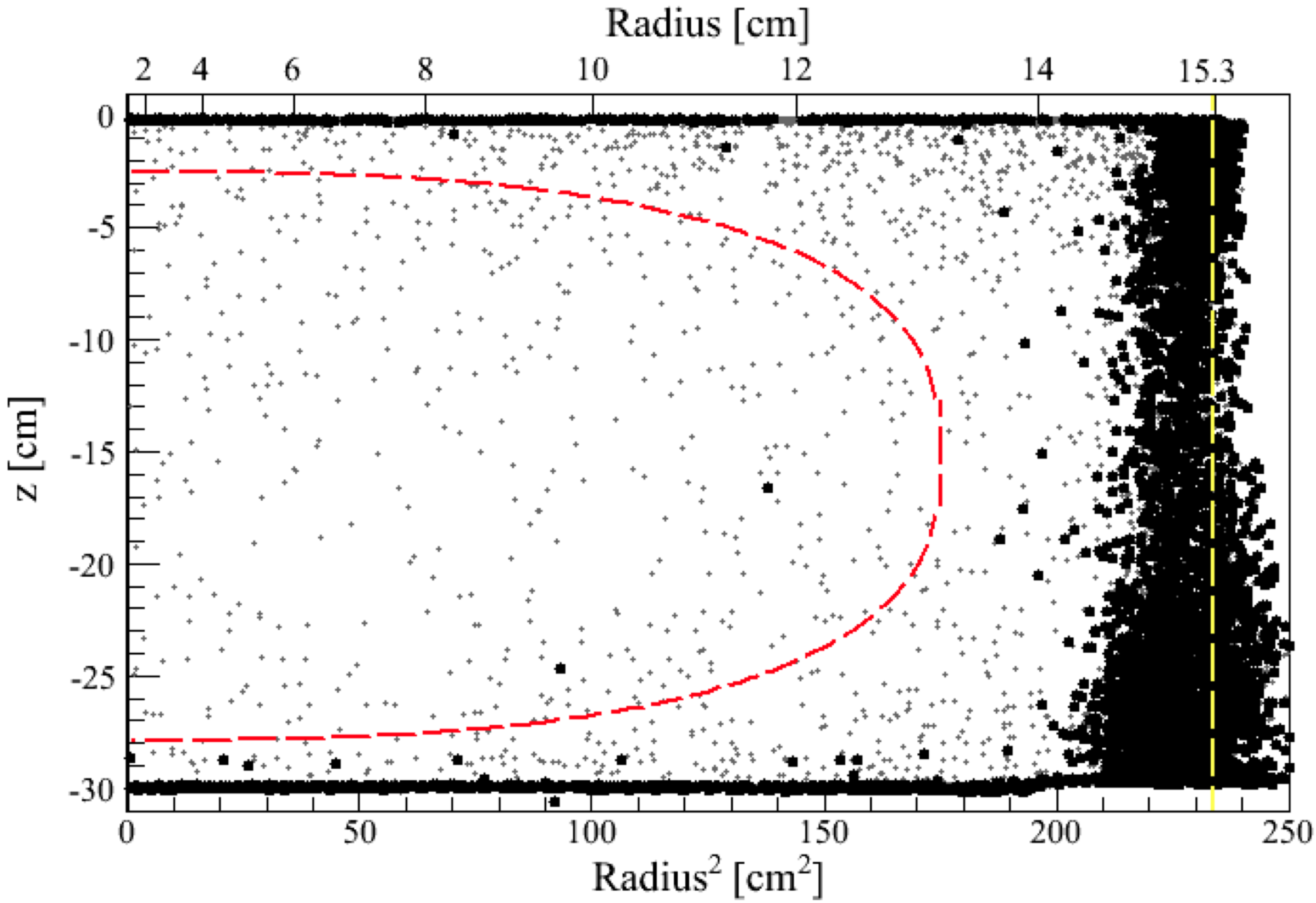
Separation… less impressive than CDMS



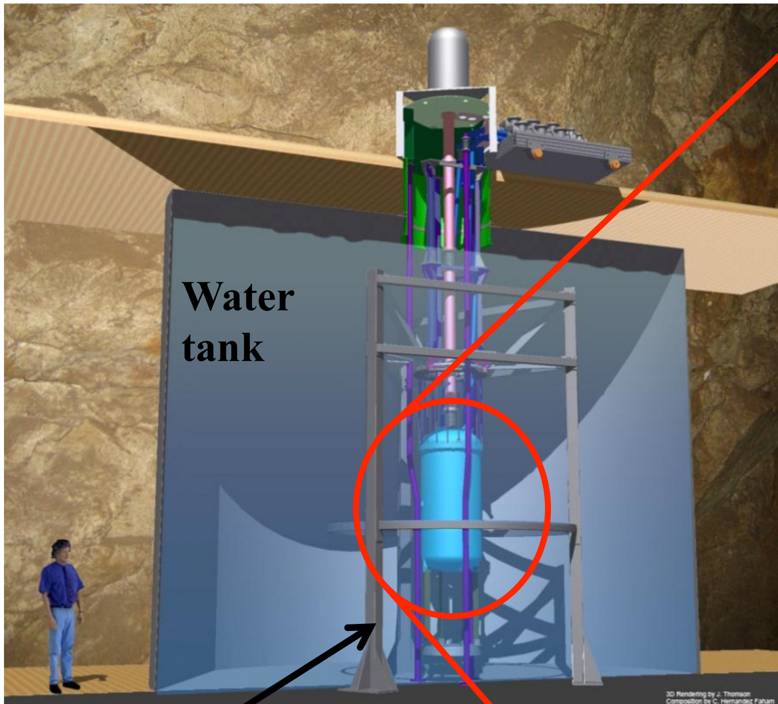
Xenon-100 Search Region

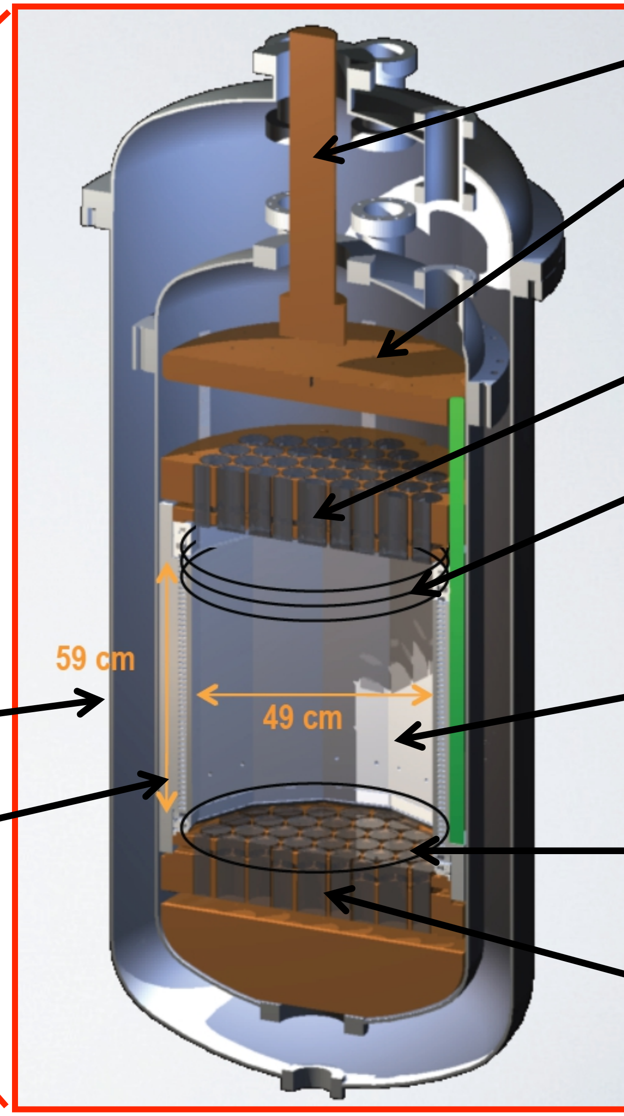


Xenon-100 Fiducial (LUX 1.7X linear dim)



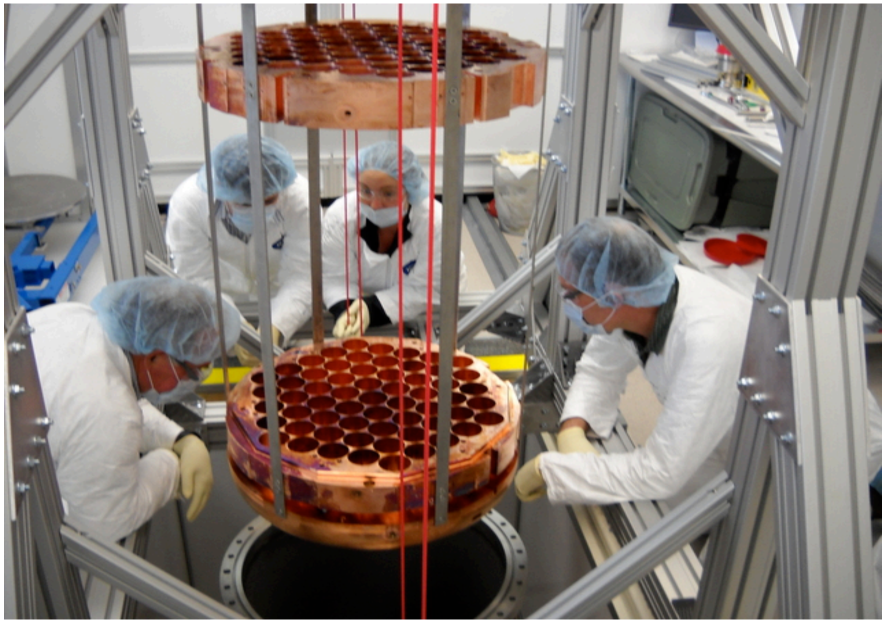
The LUX Experiment (Sanford Lab/SD)

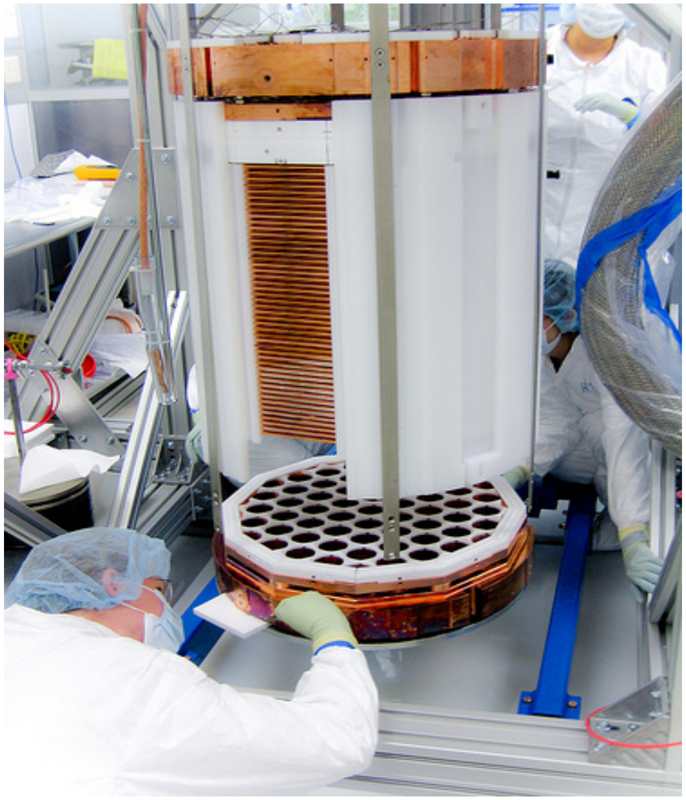


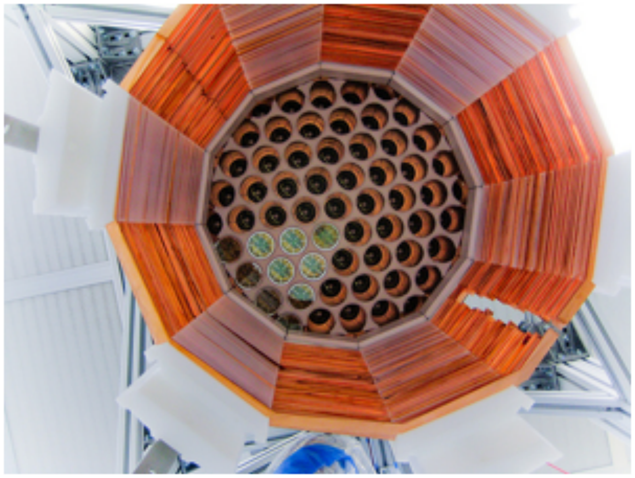


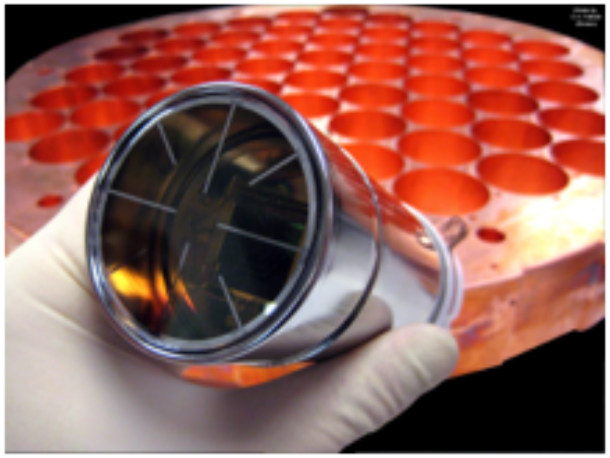
- **370 kg xenon**
  - **300 kg active region**
  - **100 kg fiducial**
- **122 PMTs 2" round**
- **Low-background Ti cryostat**

LUX being built









LUX Is Installed

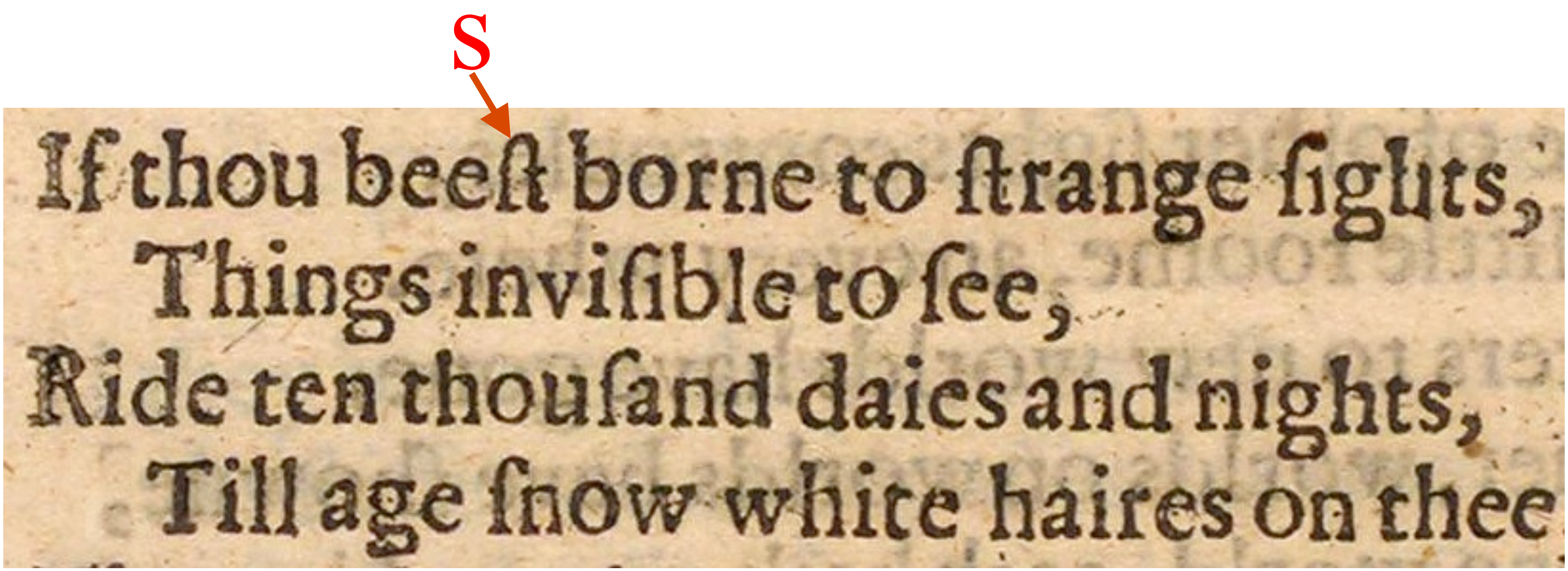
LUX Is Underwater

LUX Details

- Helped commission a new laboratory
- Circulate/purify Xenon at 300 kg/day
  - Xenon-100 about 40kg/day
- Xenon heat from condensation used to drive evaporation (heat exchanger)
- 0.8 kV/cm drift field
- Water Tank
- Surface Operation; underground gas run, ^{83m}Kr
- Cooldown started yesterday!
- Checkout / short open run / long blinded run

10,000 days gives us until September 20, 2014

John Donne circa 1600…



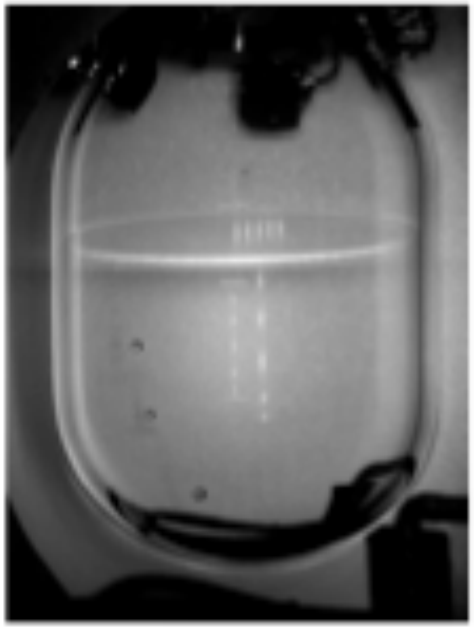
If thou beeſt borne to ſtrange ſights,
Things inviſible to ſee,
Ride ten thouſand daies and nights,
Till age ſnow white haires on thee


DENNIS the MENACE
"LOTS OF THINGS ARE INVISIBLE, BUT WE DON'T KNOW HOW MANY BECAUSE WE CAN'T SEE THEM."

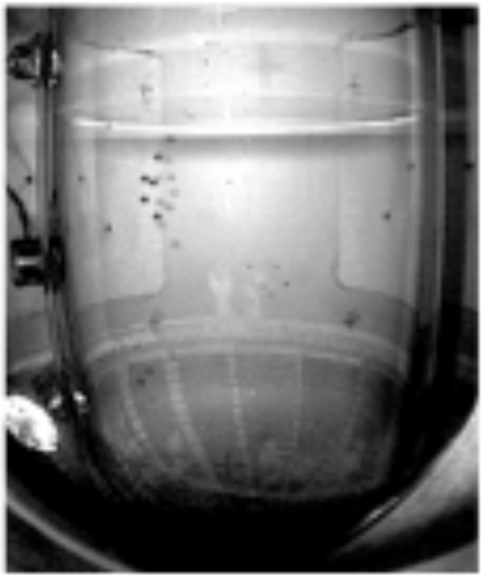
THANKS!

The COUPP program

- COUPP-4: A 2-liter chamber - shallow site in 2009, at SNOLAB since September, 2010
- COUPP-60: A 30-liter chamber commissioning at Fermilab, goal is to move to SNOLAB within a year



COUPP-4

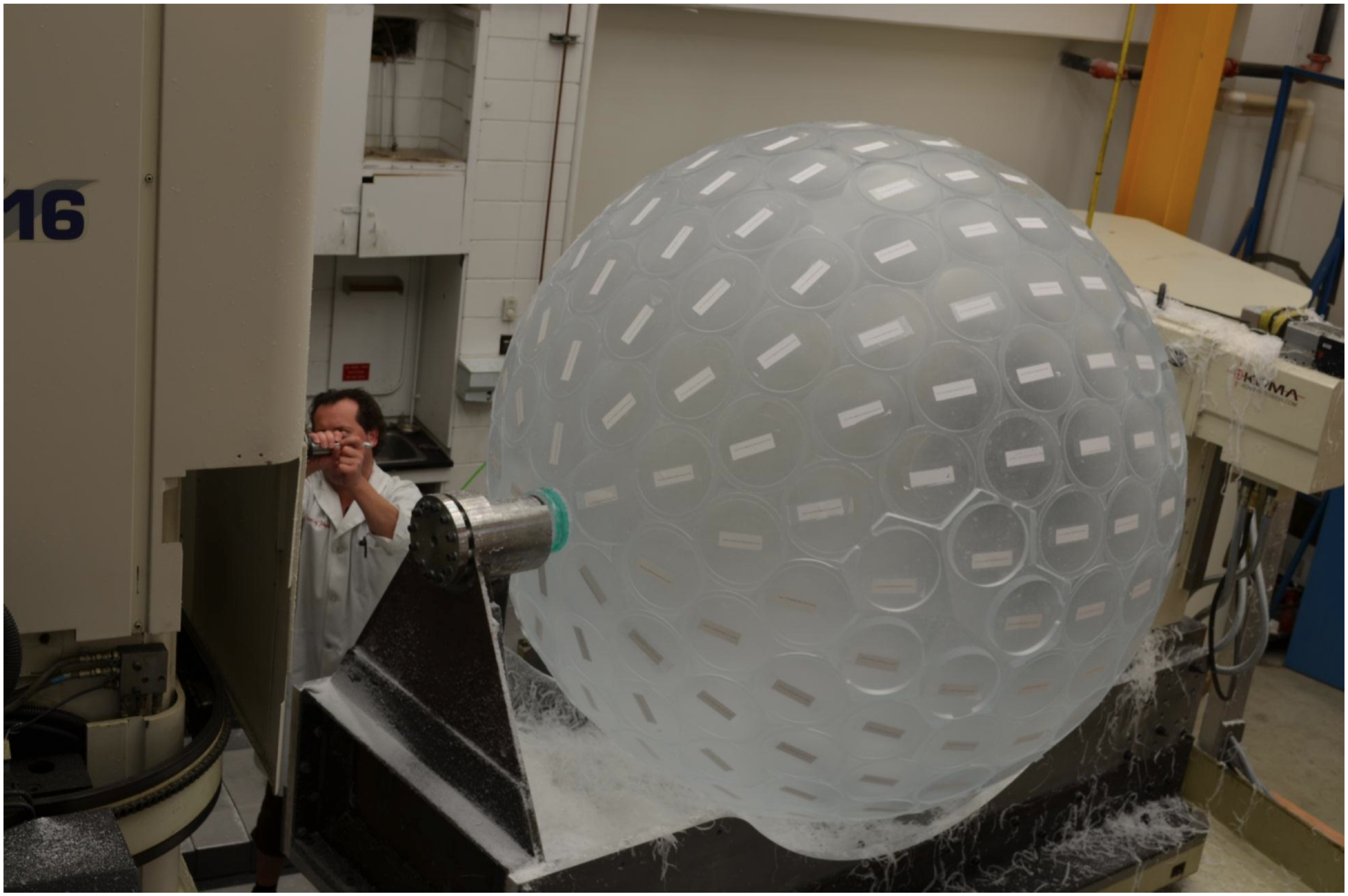


COUPP-60

U. Chicago / Indiana U South Bend / Fermilab / SNOLAB / Virginia Tech

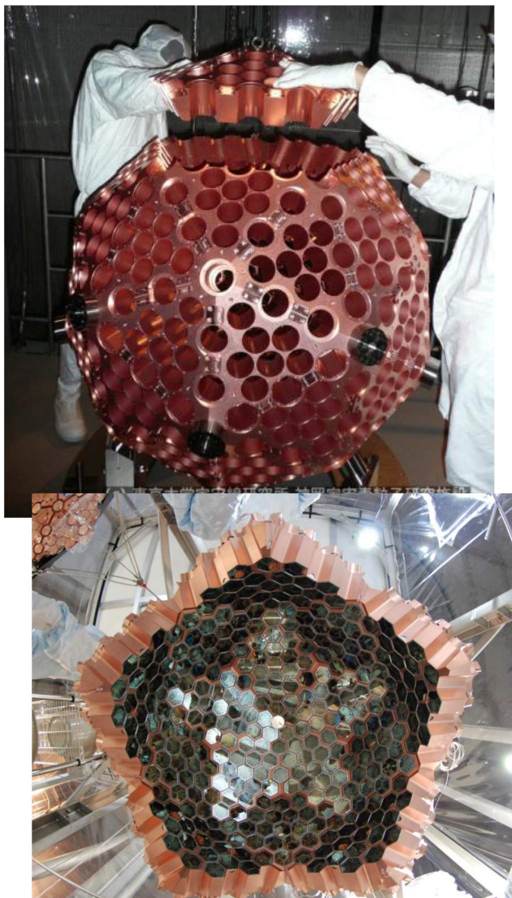
DEAP 3600

DEAP Acrylic Vessel with Light Guide "Stubs" July 2012

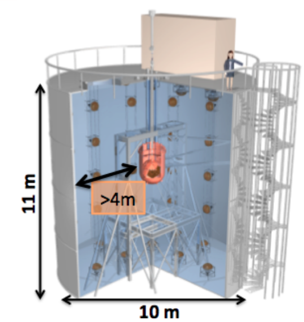


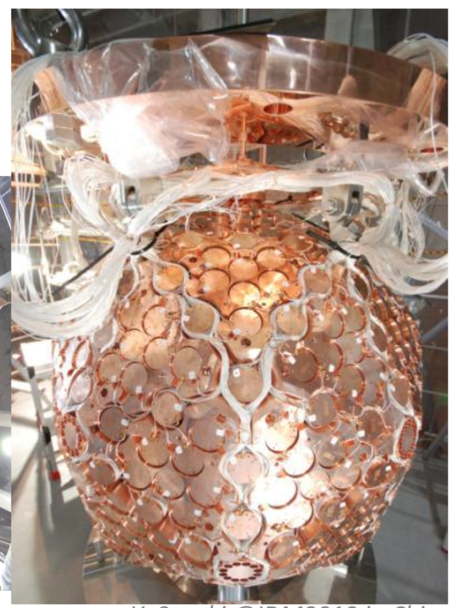
XMASS

Detector Construction

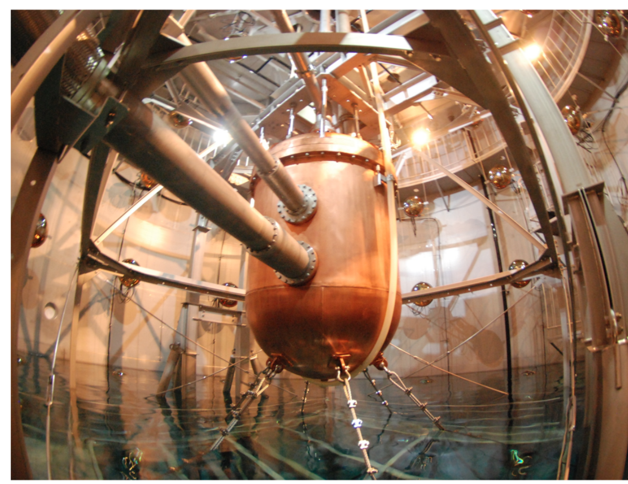


- 2009.11: PMT holder and PMT installation





- 2010.09: Construction Completed



12/07/25 Y. Suzuki @IDM2012 in Chicago 4

DarkSide-50