Dark matter:
direct searches with underground detectors

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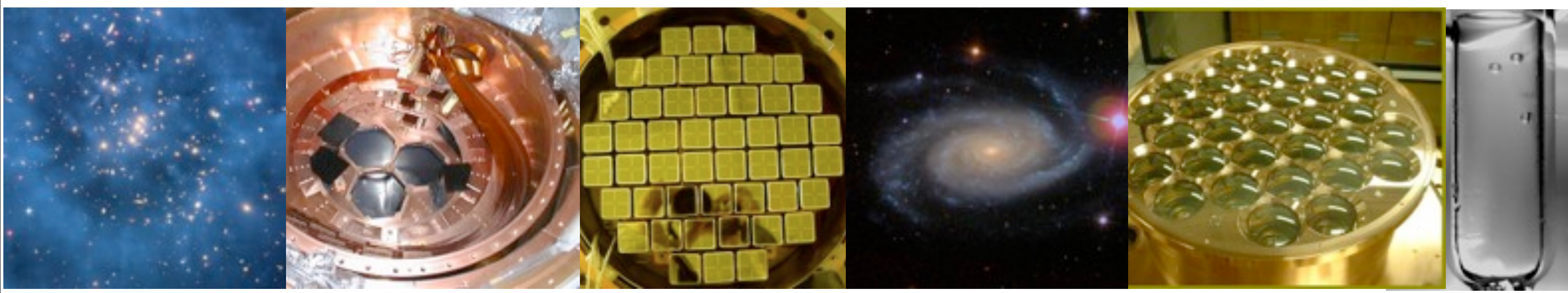
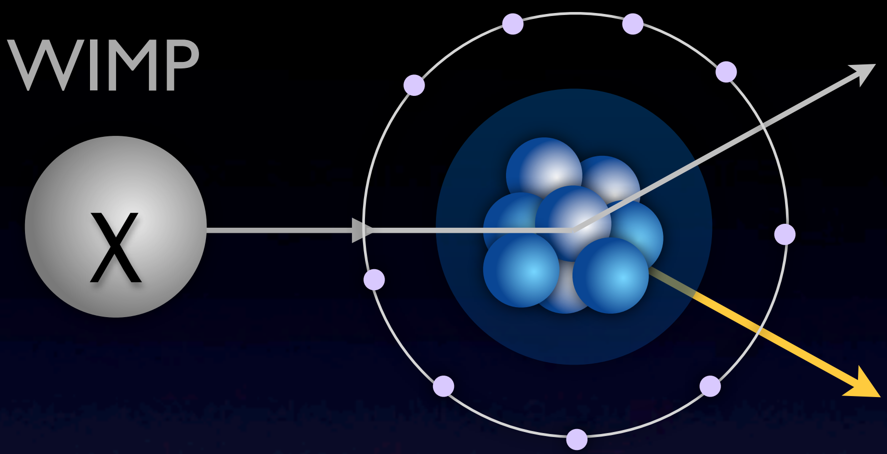
July 1, 2013



WIMP direct detection



χN → χN
elastic scattering off nuclei

M. Goodman, E. Witten, PRD 1985

$$E_0 = \frac{1}{2} m_\chi c^2 \beta^2$$

$$r = \frac{4 m_\chi m_N}{(m_\chi + m_N)^2}$$

$$E_R = E_0 r \frac{(1 - \cos\theta)}{2}$$

$\beta \approx 10^{-3}$

$m_\chi \approx 100$ GeV

Nucleus recoil energy < 100 keV

Spin Independent:
χ scatters coherently off of the entire nucleus A: $\sigma \sim A^2$

Spin Dependent:
only unpaired nucleons contribute to scattering amplitude: $\sigma \sim J(J+1)$

Expected Scattering Cross Sections

- A general WIMP candidate: fermion (Dirac or Majorana), boson or scalar particle
- The most general, Lorentz invariant Lagrangian has 4 types of interactions (S, P, V, A)
- In the extreme NR limit relevant for galactic WIMPs ($v_{WIMP} \sim 10^{-3}c$), the interactions leading to WIMP-nuclei elastic scattering are classified as:

➡ **scalar interactions** (WIMPs couples to nuclear mass; from the scalar and vector part of L)

$$\sigma_{SI} = \frac{m_N^2}{4\pi(m_\chi + m_N)^2}\left[Zf_p + (A-Z)f_n\right]^2$$

$f_{p,n}$ = effective couplings to p, n

➡ **spin-spin interactions** (WIMPs couples to nuclear spin J_N, from the axial part of L)

$$\sigma_{SD} = \frac{32}{\pi}G_F^2\frac{m_\chi^2 m_N^2}{(m_\chi + m_N)^2}\frac{J_N+1}{J_N}\left(a_p\langle S_p\rangle + a_n\langle S_n\rangle\right)^2$$

$\langle S_{p,n}\rangle$ = expectation values of the spin content of the p, n in the target nucleus

$a_{p,n}$ = effective couplings to p, n

large hadronic uncertainties in the cross section
J. Ellis, K.A. Olive, C. Savage, arXiv:0801.3656v2

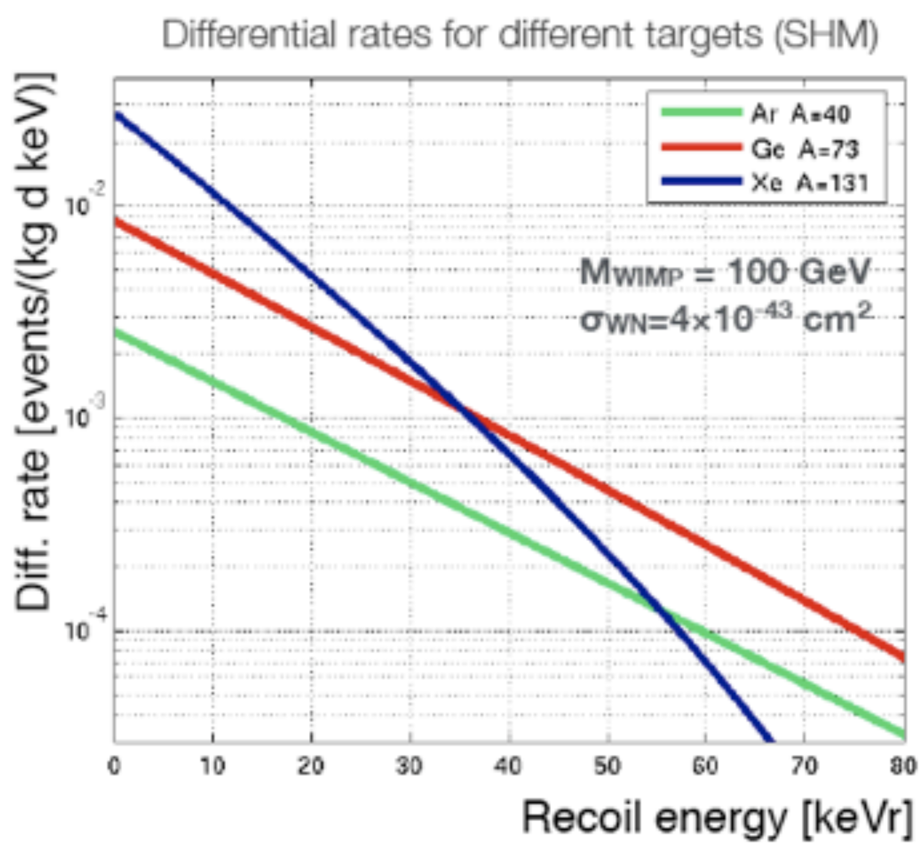
Expected Interaction Rates

- Integrate over WIMP velocity distribution; in general assumed to be a simple 1D Maxwellian (good approximation for isothermal halo with ideal WIMP gas):

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{2 m_\chi \mu^2} F^2(E_R) \int_{v > \sqrt{m_N E_R / 2\mu^2}}^{v_{max}} \frac{f(\vec{v},t)}{v} d^3 v$$

$$f(\vec{v},t) \propto \exp\left\{ \frac{-(\vec{v}+\vec{v}_E(t))^2}{2\sigma^2} \right\}$$

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

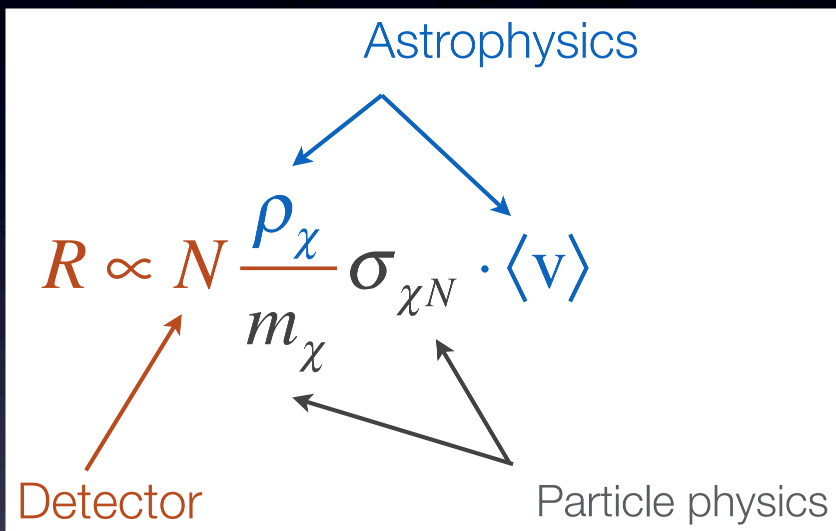


- with WIMP-nucleon cross sections $< 10^{-7}$ pb, the expected rates are

< 1 event/100kg/day

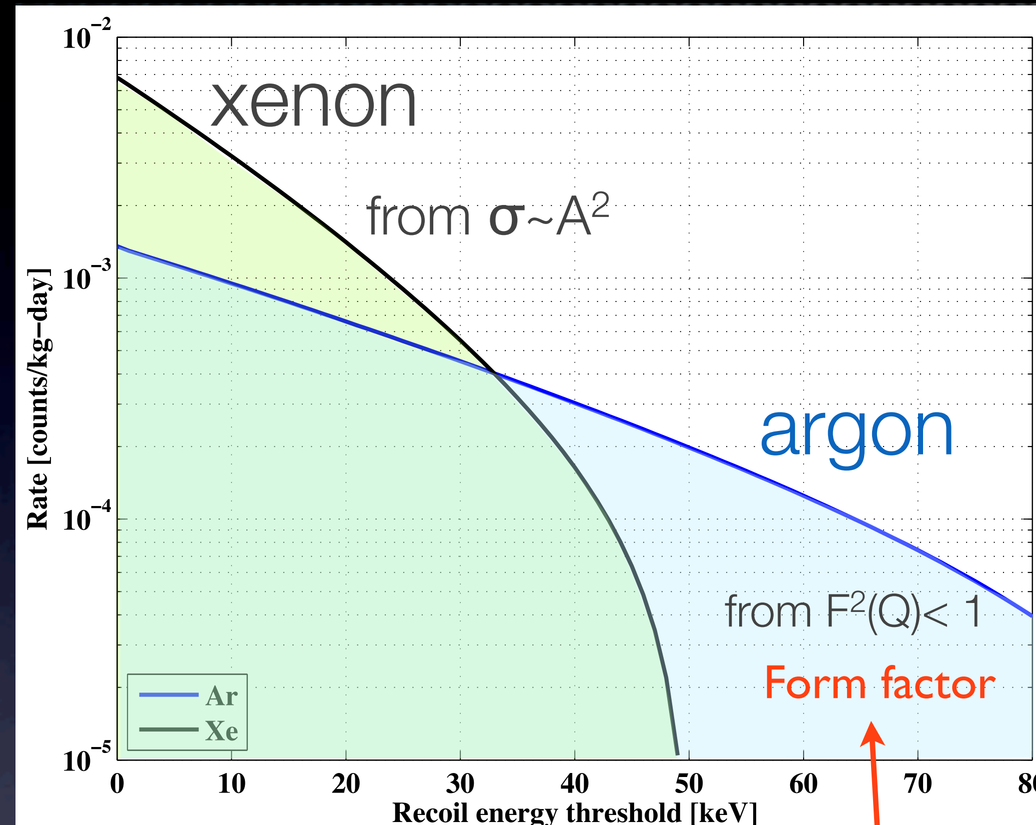
Measurement

Expected rate



Sun's velocity around the galaxy
$\langle v \rangle \approx 230$ km/s
WIMP energy density
$\rho_\chi \approx 0.3$ GeV/cm^3

Integral rate (as a function of E_R) <1 ev/kg/yr

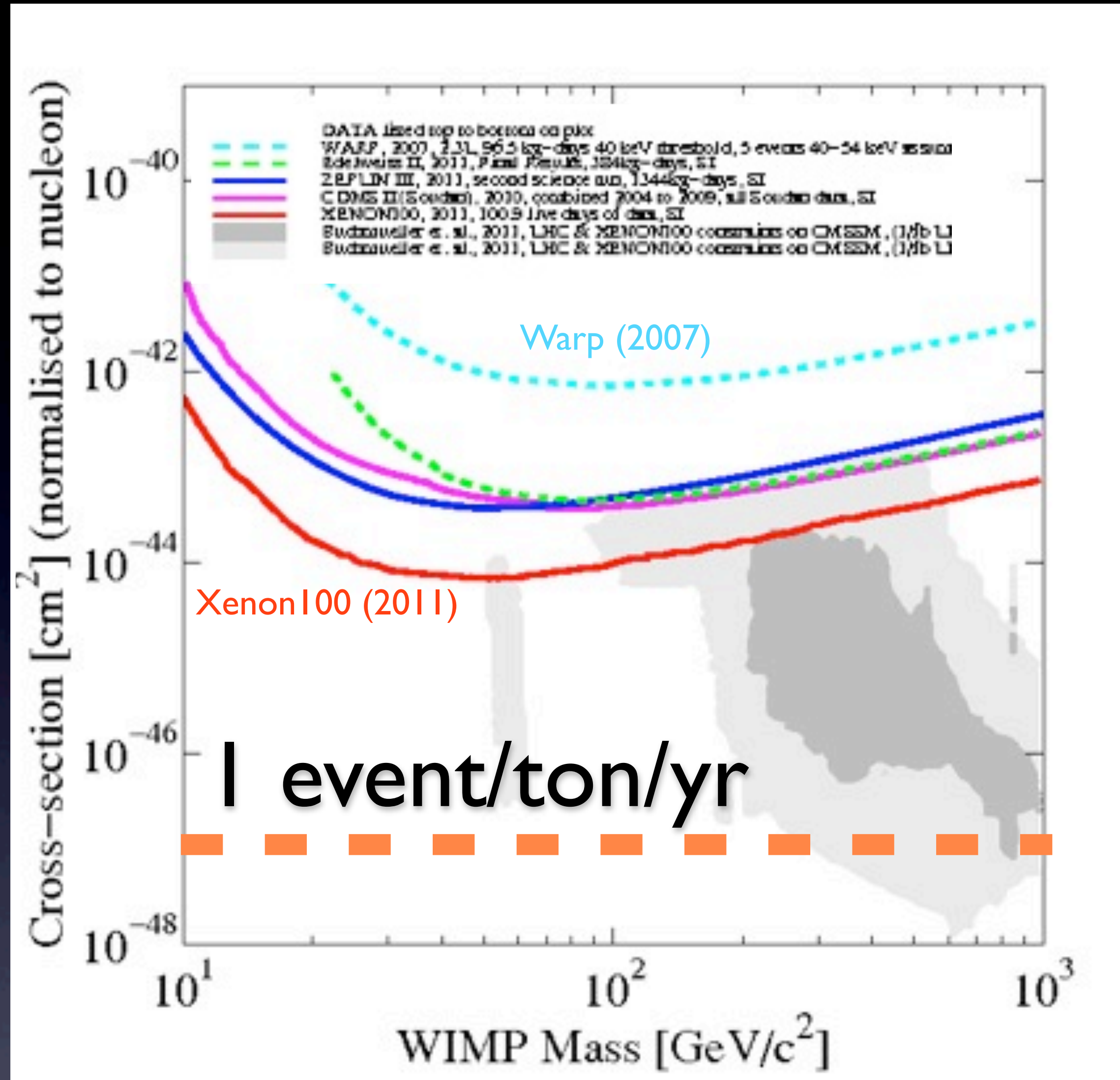


$$\left.\frac{dR}{dE_R}\right|_{Ideal} = \frac{R_0}{E_0 r}\exp\left(-\frac{E_R}{E_0 r}\right)$$

$$\left.\frac{dR}{dE_R}\right|_{True} = \left.\frac{dR}{dE_R}\right|_{Ideal} \times \left[S(E_R)F^2(q^2)I\right]$$

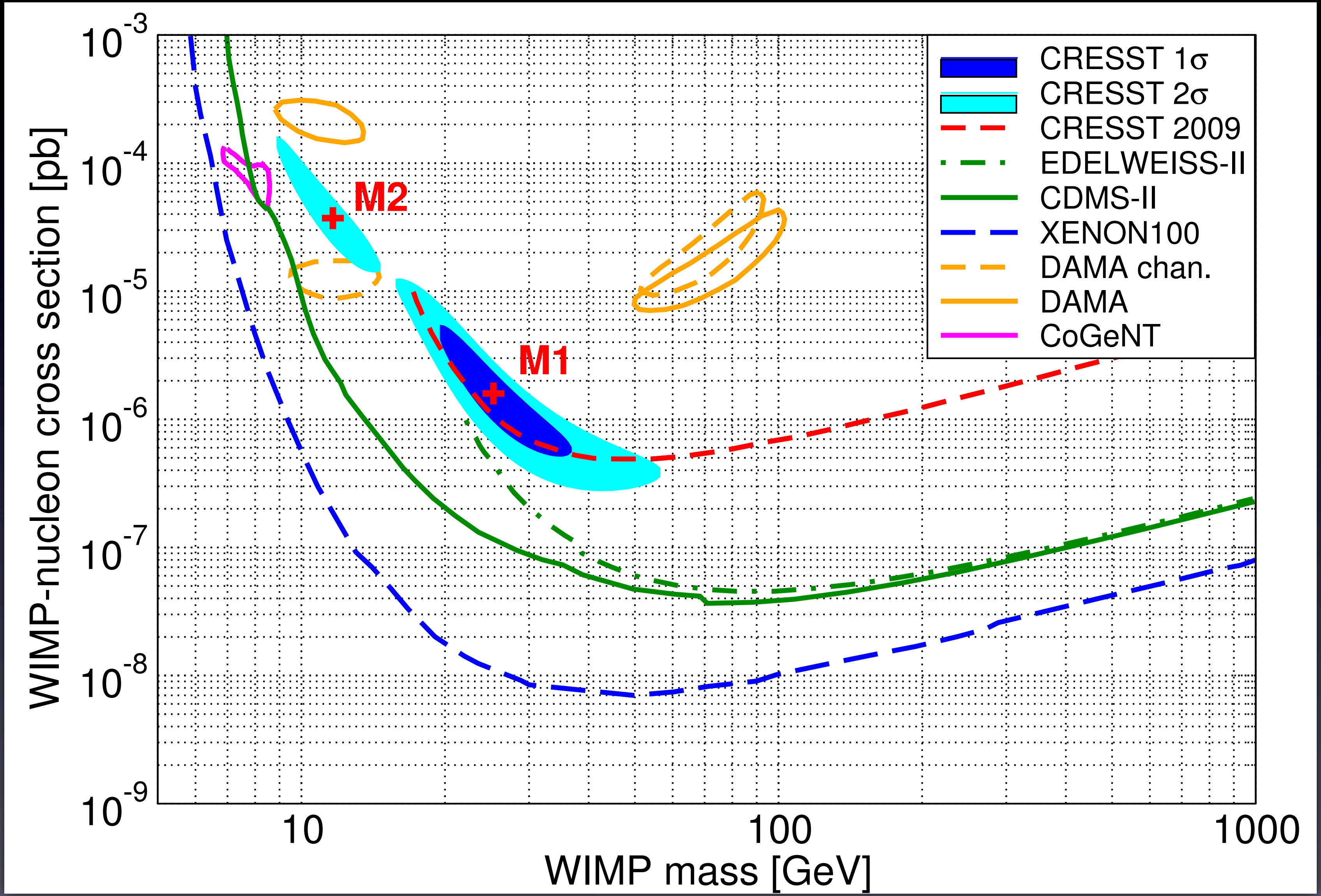
$\sigma_p (cm^2)$

The interesting region for σ_p, m_χ



Current experimental limits

A low mass signal?



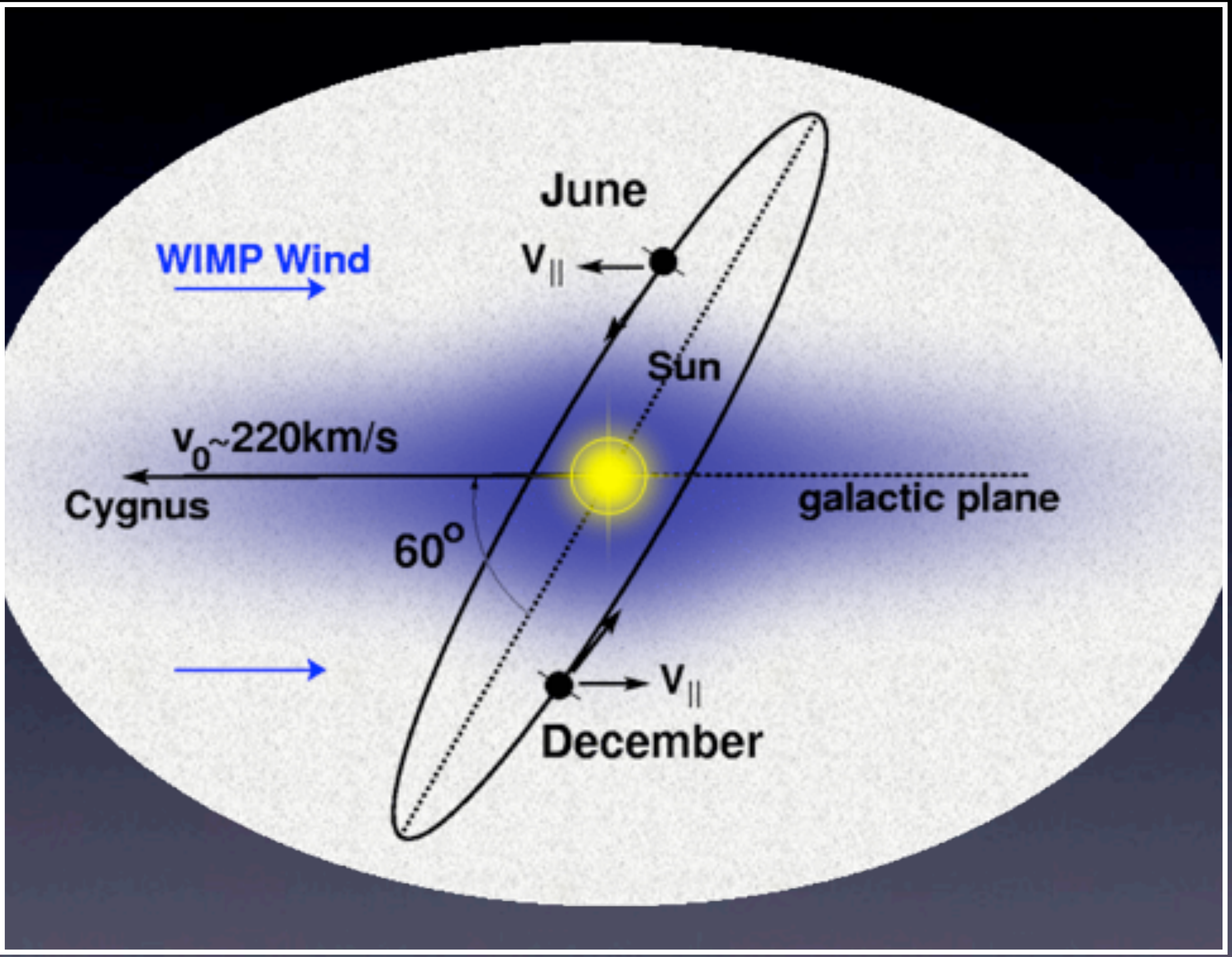
2011 CRESST-II (Angloher et al. 1109.0702, Eur. Phys. J. C (2012) 72:1971)

Local dark matter

Galaxy embedded in a dark matter "halo"

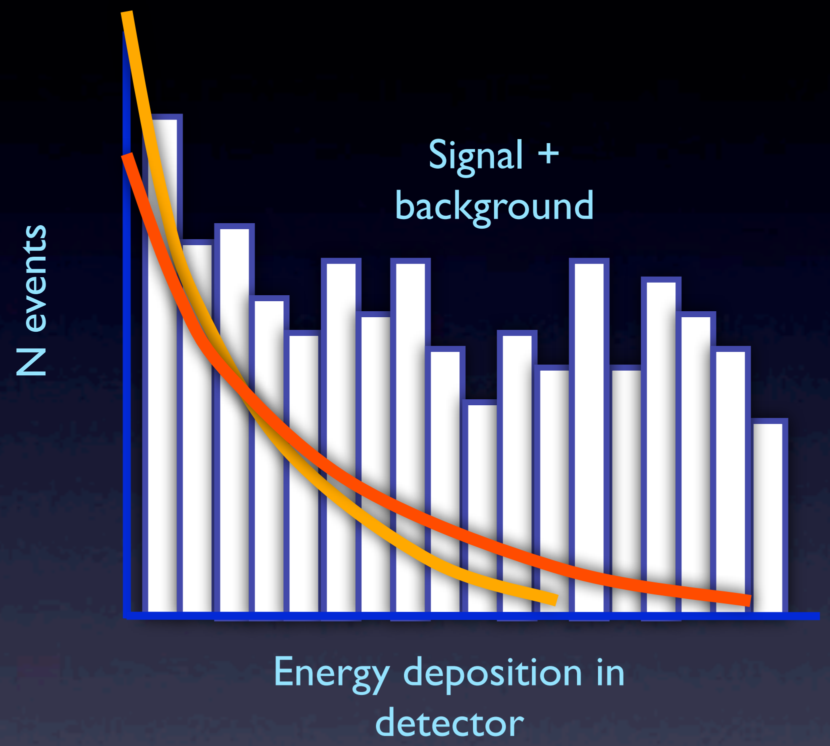
Local density ≈ 0.3 GeV/cm^3

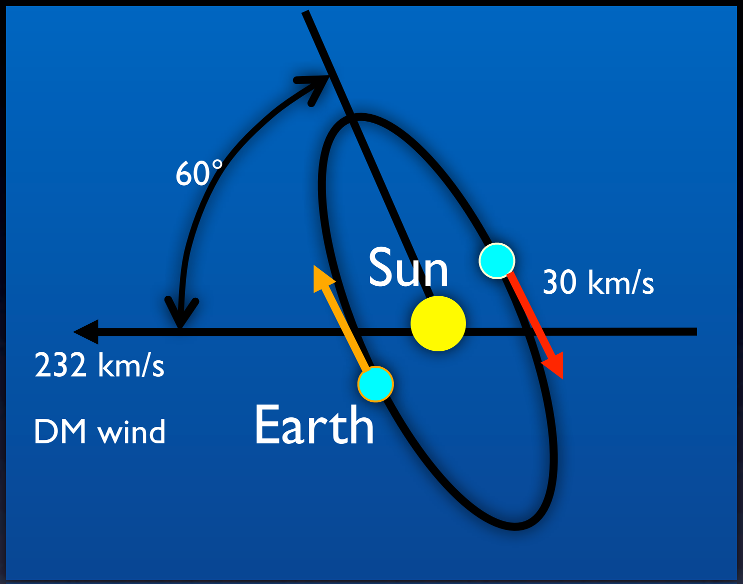
Motion of the sun around the galaxy induces a WIMP "wind"



Rotation of the earth about the sun produces a seasonal modulation in the velocity of the wind

Annual flux modulation





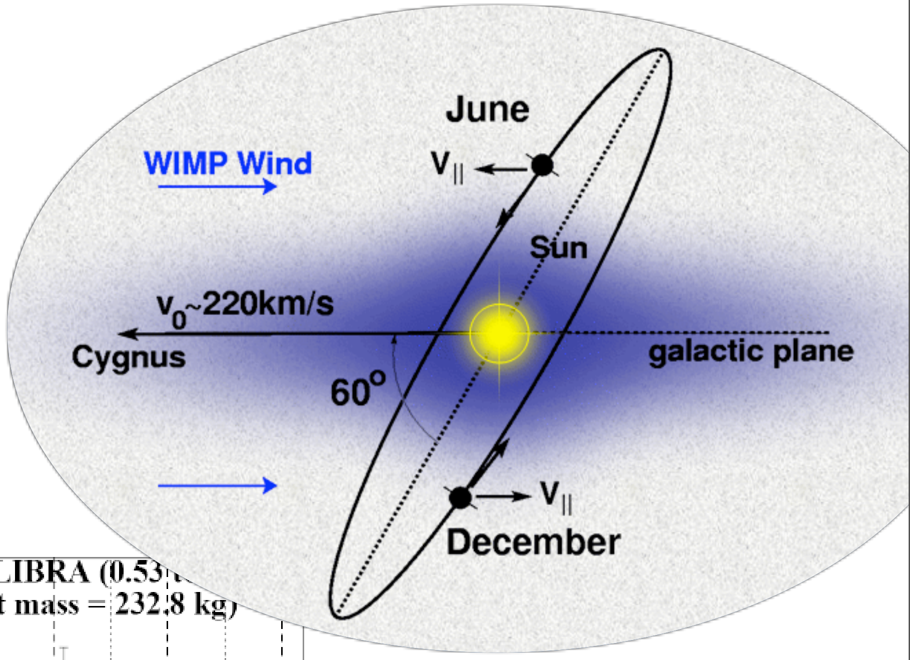
Expected variation of WIMP count rate ± 3%

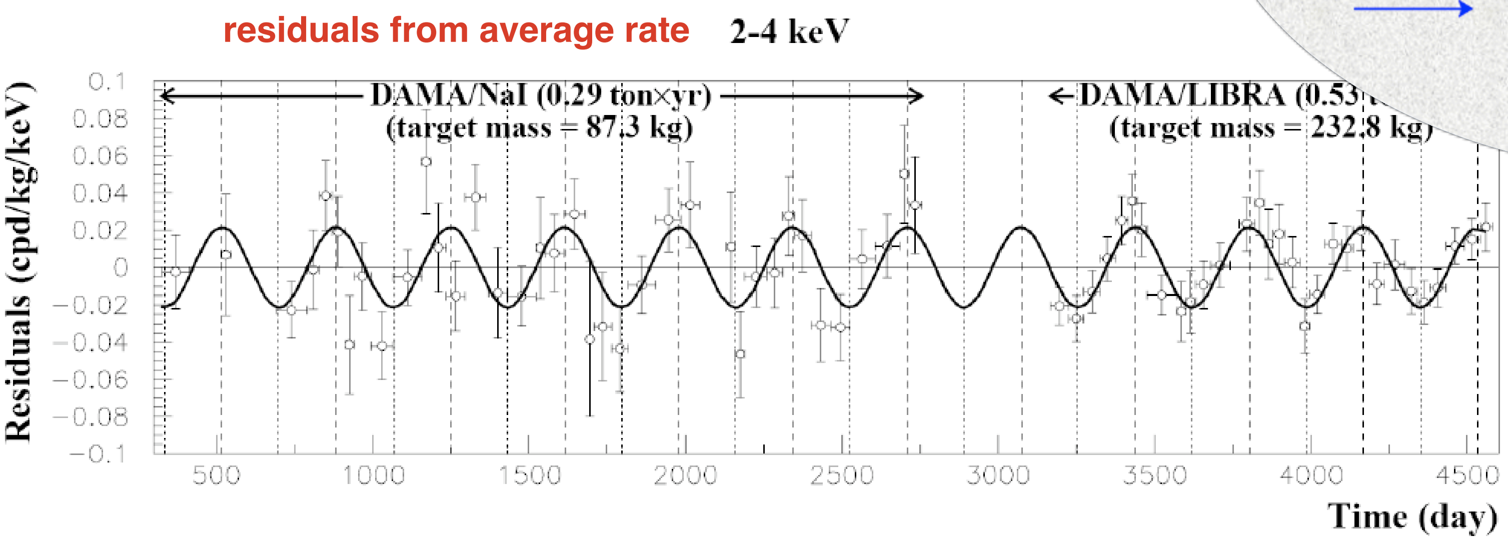
D. Akimov

2010 DAMA/LIBRA (Bernabei et al. 1002.1028)

25 NaI (Tl) crystals of 9.5 kg each, operated at Gran Sasso Underground Lab

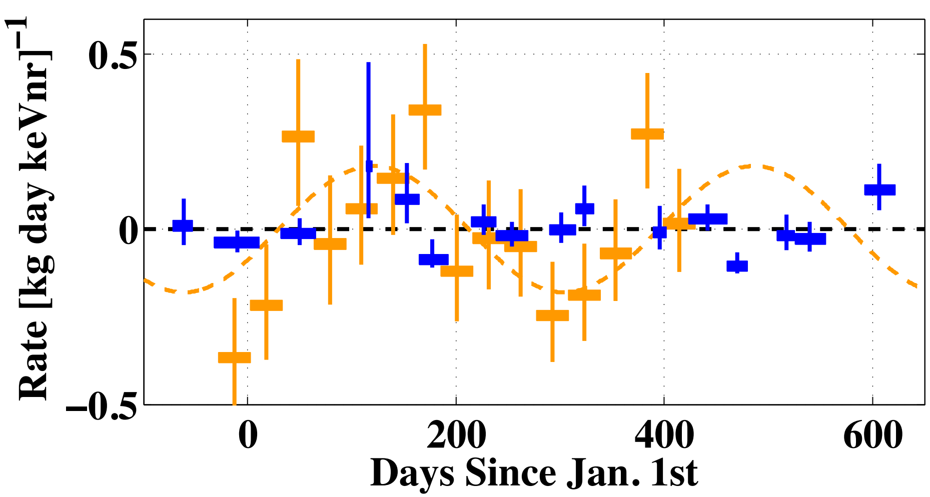
6y in LIBRA (13 years total), 1.17 ton × year, 8.9 σ modulation signal





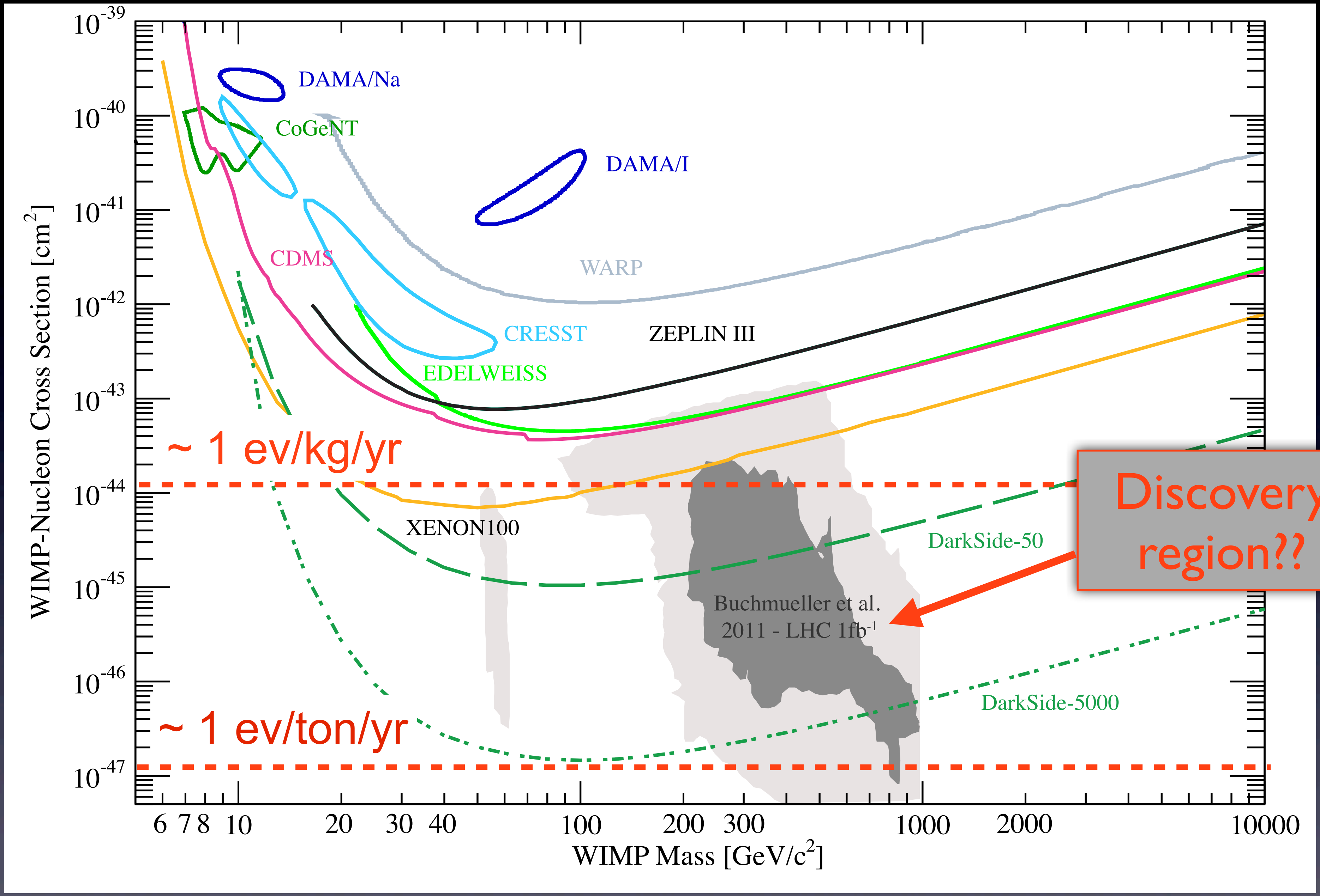
2012 CDMS vs COGENT

(Ahmed et al. 1203.1309)

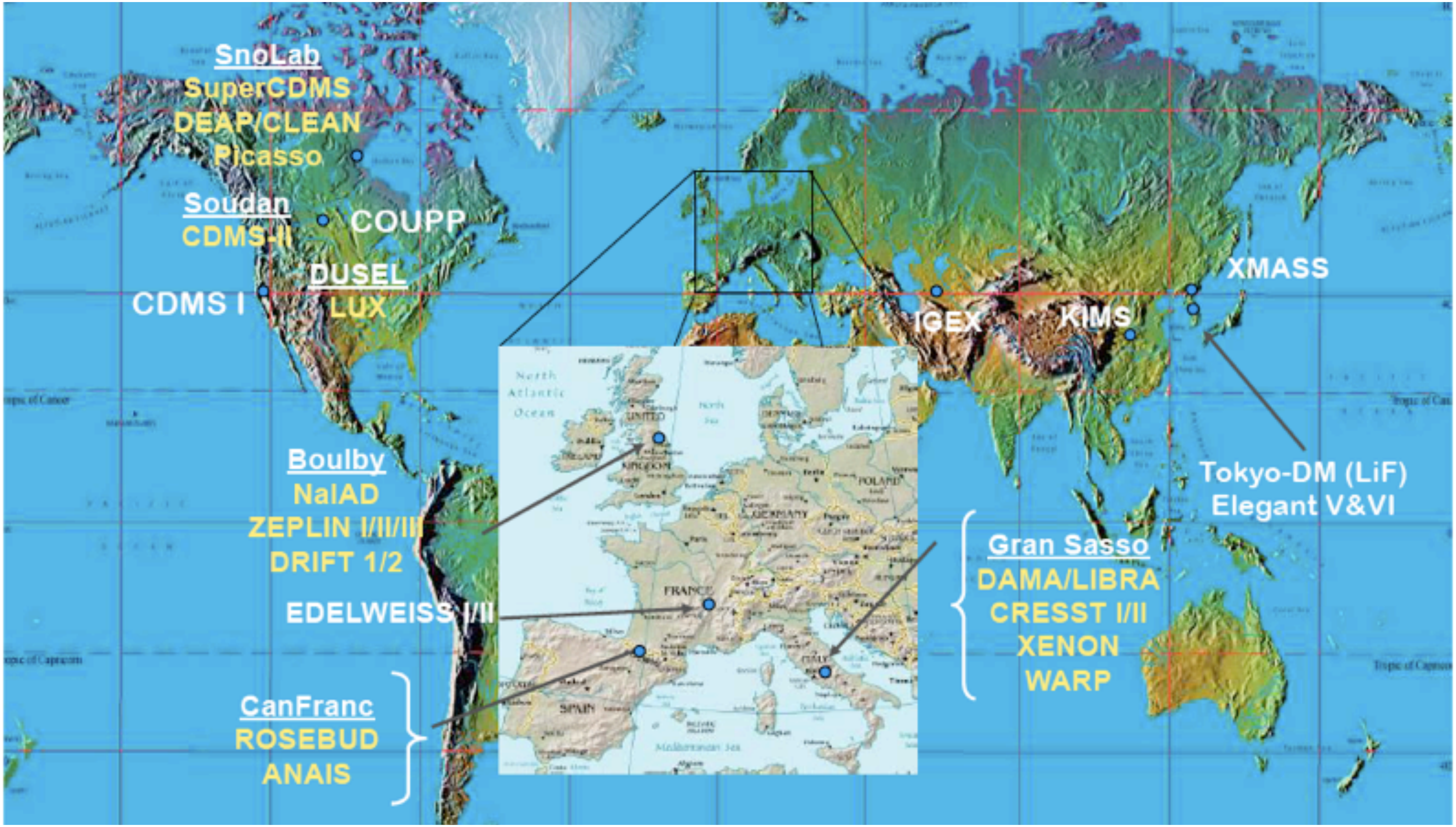


P-type Point Contact (PPC) HPGe Detector, 440g/ detector operated in Soudan Underground Lab, 15 months of data

~2.8σ modulation in the low energy range (0.5~3.0 keV)

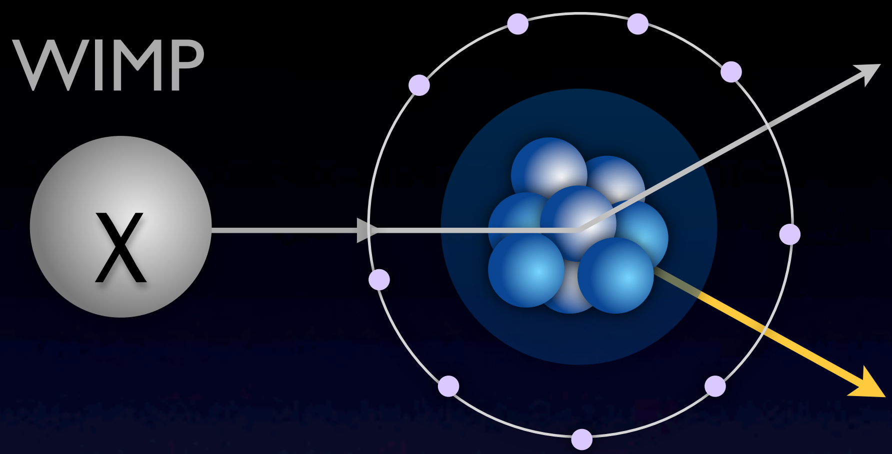


The current status



La ricerca mondiale delle WIMP

WIMP direct detection



$\chi N \rightarrow \chi N$

elastic scattering off nuclei

M. Goodman, E. Witten, PRD 1985

$\beta \approx 10^{-3}$

$m_\chi \approx 100$ GeV

Low energy nuclear recoils (< 100 keV)

Low rate (~1 event/ton/yr for $\sigma = 10^{-47}$ cm^2)

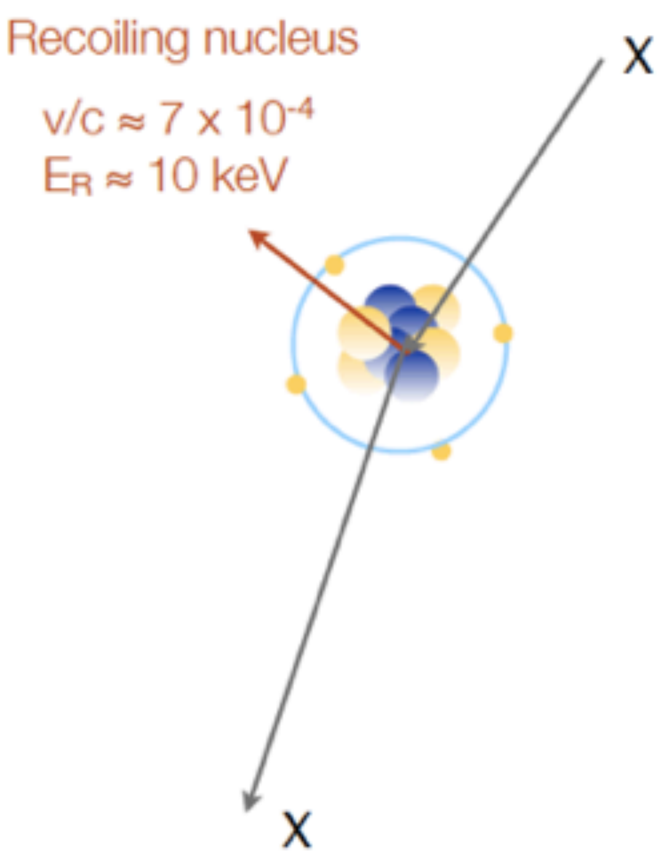
→ Ideal WIMP Detector

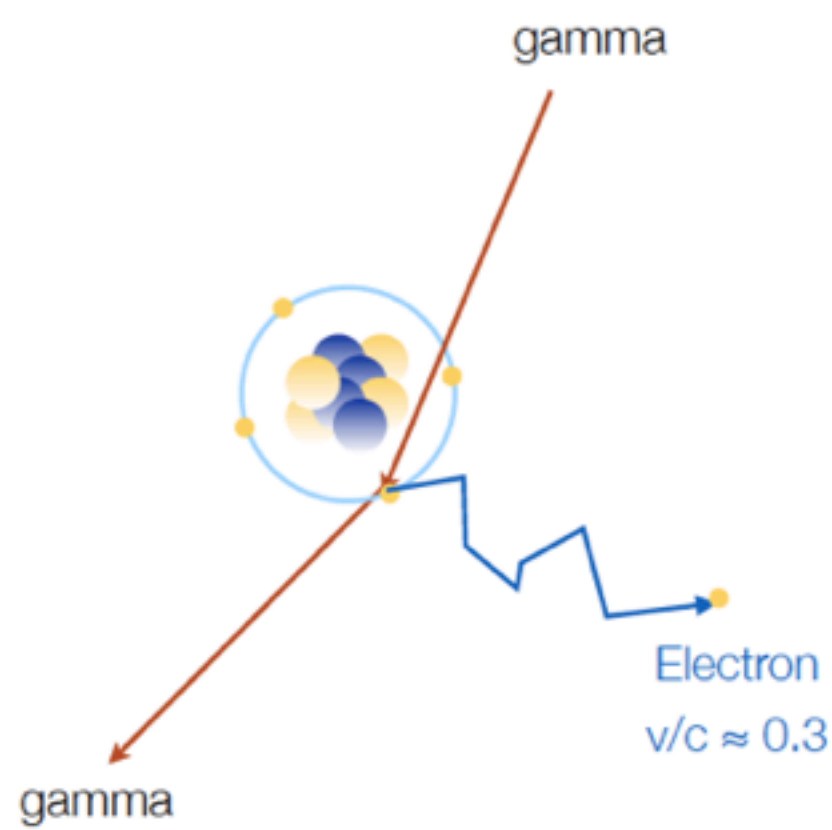
- Large mass, long exposure
- Low threshold
- Low radioactive bg
- Good bg discrimination

Detection of WIMPs: Signal and Backgrounds

Signal (WIMPs)

Background (gamma-, beta-radiation)





L. Baudis, Dark matter lectures (2012)

Quenching Factor and Discrimination

- WIMPs (and neutrons) scatter off nuclei
- Most background noise sources (gammas, electrons) scatter off electrons
- Detectors have a different response to nuclear recoils than to electron recoils
- **Quenching factor (QF)** = describes the difference in the amount of visible energy in a detector for these two classes of events
  - ➡ keVee = measured signal from an electron recoil
  - ➡ keVr = measured signal from a nuclear recoil

- **For nuclear recoil events:**

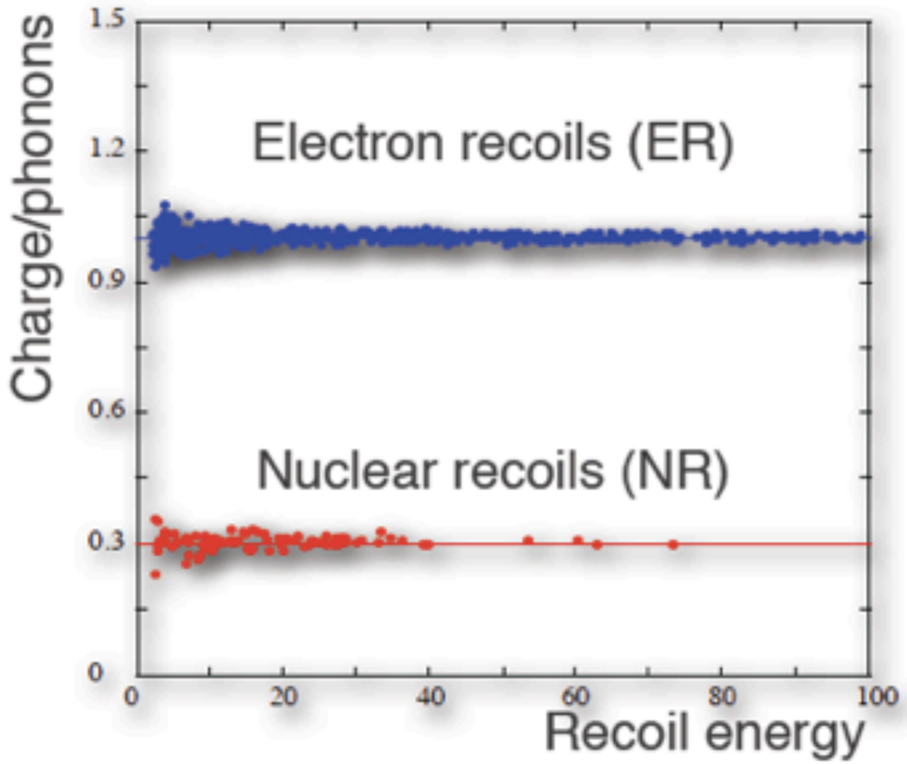
$$E_{visible}(keVee) = QF \times E_{recoil}(keVr)$$

- The two energy scales are calibrated with gamma (^{57}Co, ^{133}Ba, ^{137}Cs, ^{60}Co, etc) and neutron (AmBe, ^{252}Cf, n-generator, etc) sources

Quenching Factor and Discrimination

- The quenching factor allows to distinguish between electron and nuclear recoils if two simultaneous detection mechanisms are used

- Example:
  - ➡ charge and phonons in Ge
  - ➡ $E_{visible} \sim 1/3\ E_{recoil}$ for nuclear recoils
  - ➡ QF ~ 30% in Ge



- ER = background
- NR = WIMPs (or neutron backgrounds)

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Backgrounds in Dark Matter Detectors

- Radioactivity of surroundings
- Radioactivity of detector and shield materials
- Cosmic rays and secondary reactions

- Remember: activity of a source $A = \frac{dN}{dt} = -\lambda N$
- **Do you know?**

N = number of radioactive nuclei
λ = decay constant, $T_{1/2} = \ln 2/\lambda = \ln 2\ \tau$
[A] = Bq = 1 decay/s (1Ci = 3.7×10^{10} decays/s = A [1g pure ^{226}Ra])

1. how much radioactivity (in Bq) is in your body? where from?

1. 4000 Bq from ^{14}C, 4000 Bq from ^{40}K (e^- + 400 1.4 MeV γ + 8000 ν_e)

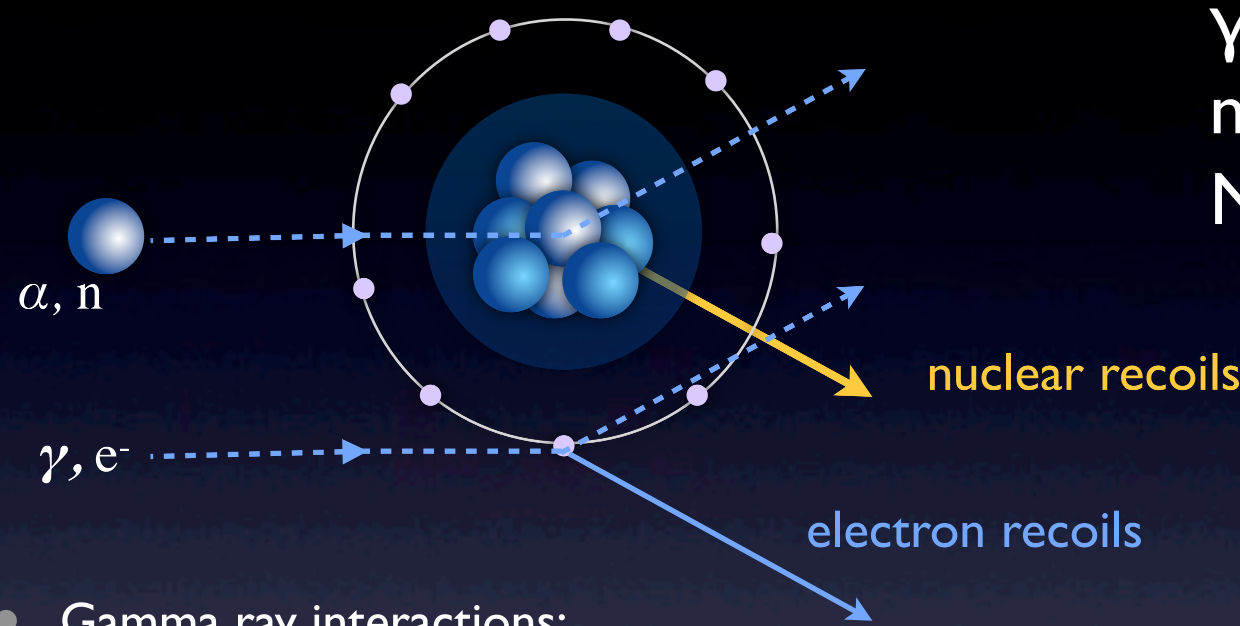
2. how many radon atoms escape per 1 m^2 of ground, per s?

2. 7000 atoms/m^2 s

3. how many plutonium atoms you find in 1 kg of soil?

3. 10 millions (transmutation of ^{238}U by fast CR neutrons), soil: 1 - 3 mg U per kg

Background



from natural radioactivity:

γ e- → γ e-

nN → nN

N → N' + α, e-

- Gamma ray interactions:

  mis-identified electrons mimic nuclear recoil signals

- Neutrons:

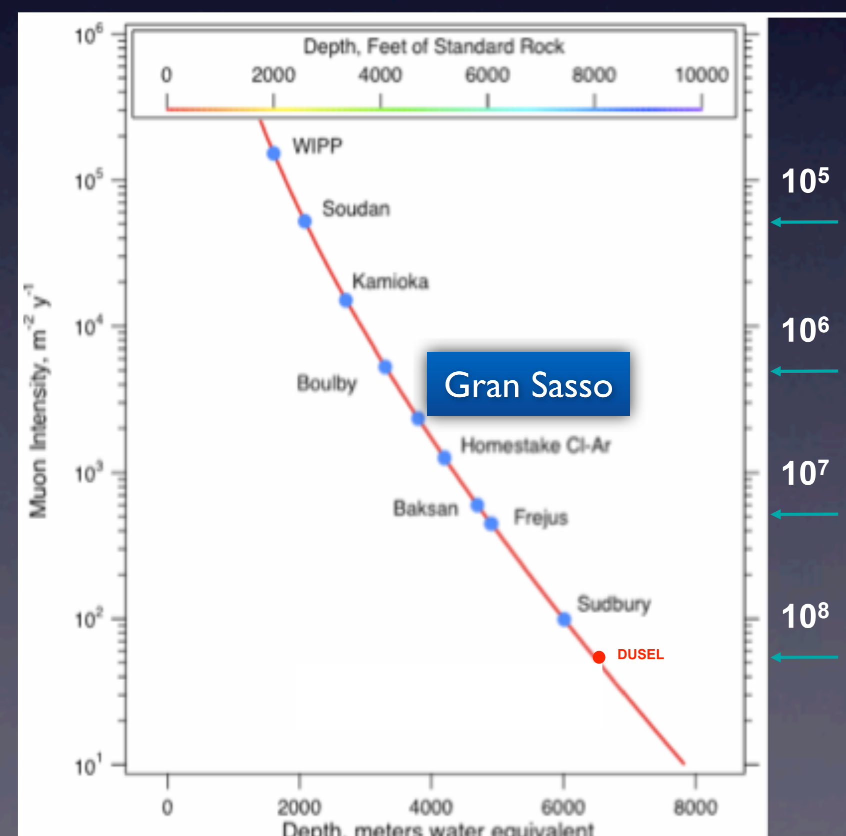
  (α,n), U, Th fission, cosmogenic spallation →

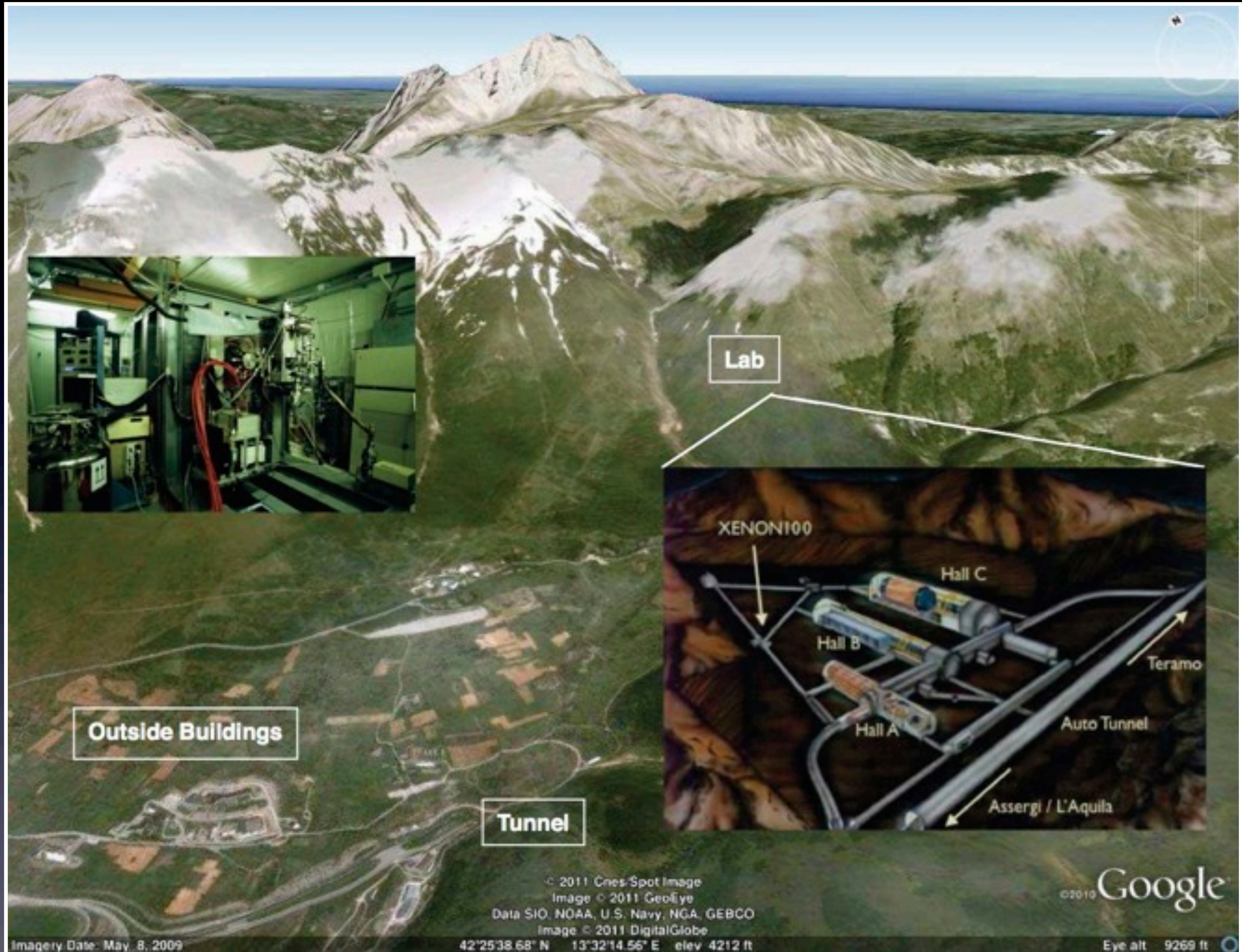
- Contamination:

  ^{238}U and ^{232}Th decays, recoiling progeny mimic nuclear recoils

Underground labs

reduction of muon flux by:





I Laboratori Nazionali del Gran Sasso

Detector strategies

Aggressively reduce the absolute background	Background reduction by pulse shape analysis and/or self-shielding	Background rejection based on simultaneous detection of two signals	Other detector strategies
State of the art: (primary goal is $0\nu\beta\beta$ decay): Past experiments: Heidelberg-Moscow HDMS IGEX Current and near-future projects: GERDA MAJORANA	Large mass, simple detectors: NaI (DAMA, LIBRA, ANAIS, NAIAD) CsI (KIMS) Large liquid noble gas detectors: XMASS, CLEAN, DEAP	**Charge/phonon** (CDMS, EDELWEISS, SuperCDMS, EURECA) **Light/phonon** (CRESST, ROSEBUD, EURECA) **Charge/light** (XENON, ZEPLIN, LUX, ArDM, WARP, DARWIN)	Large bubble chambers - insensitive to electromagnetic background (COUPP, PICASSO, SIMPLE) Low-pressure gas detectors, sensitive to the direction of the nuclear recoil (DRIFT, DMTPC, NEWAGE)

In addition:

→ reject multiple scattered events and events close to detector boundaries

→ look for an annual and a diurnal modulation in the event rate

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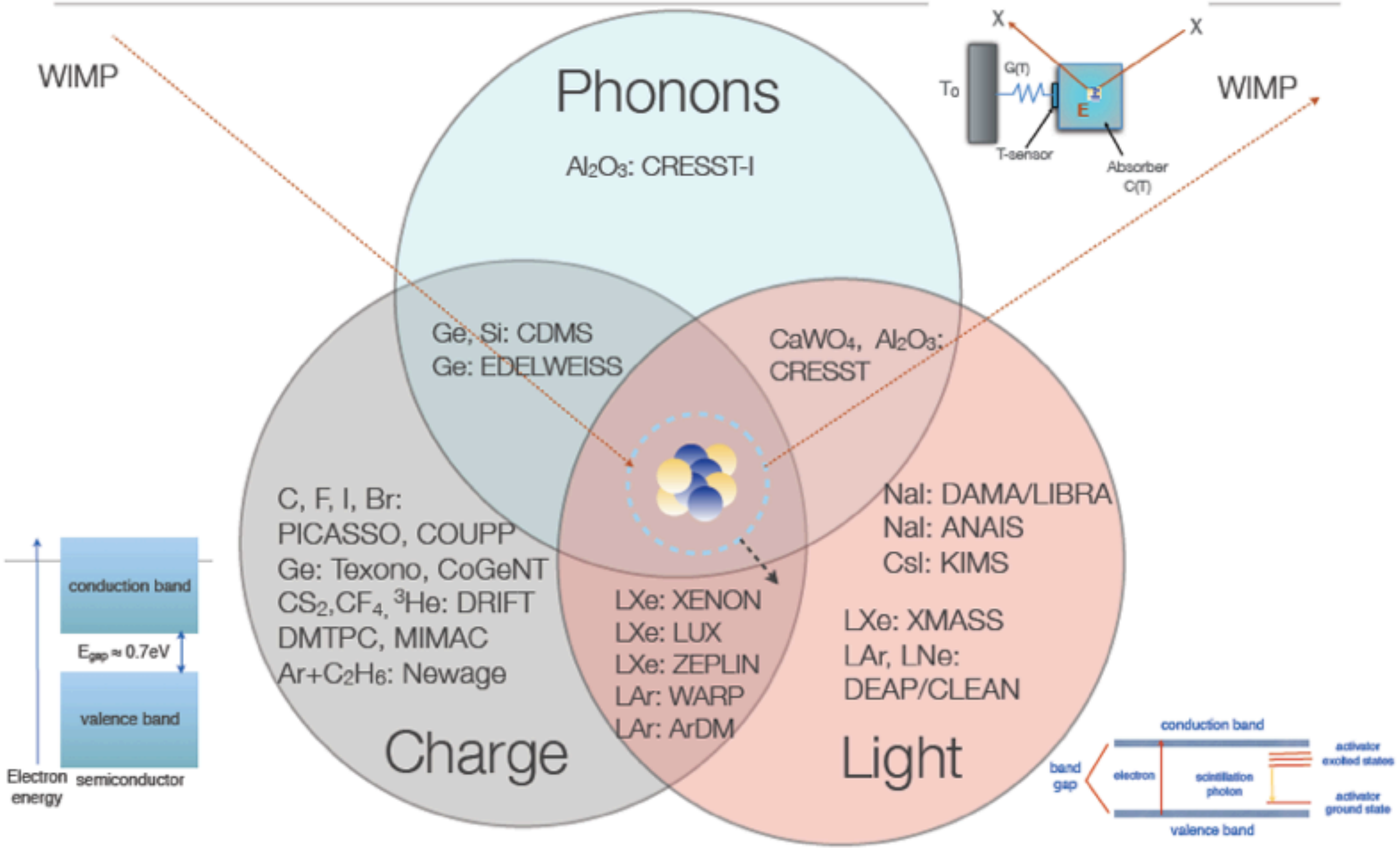
Direct Detection Techniques



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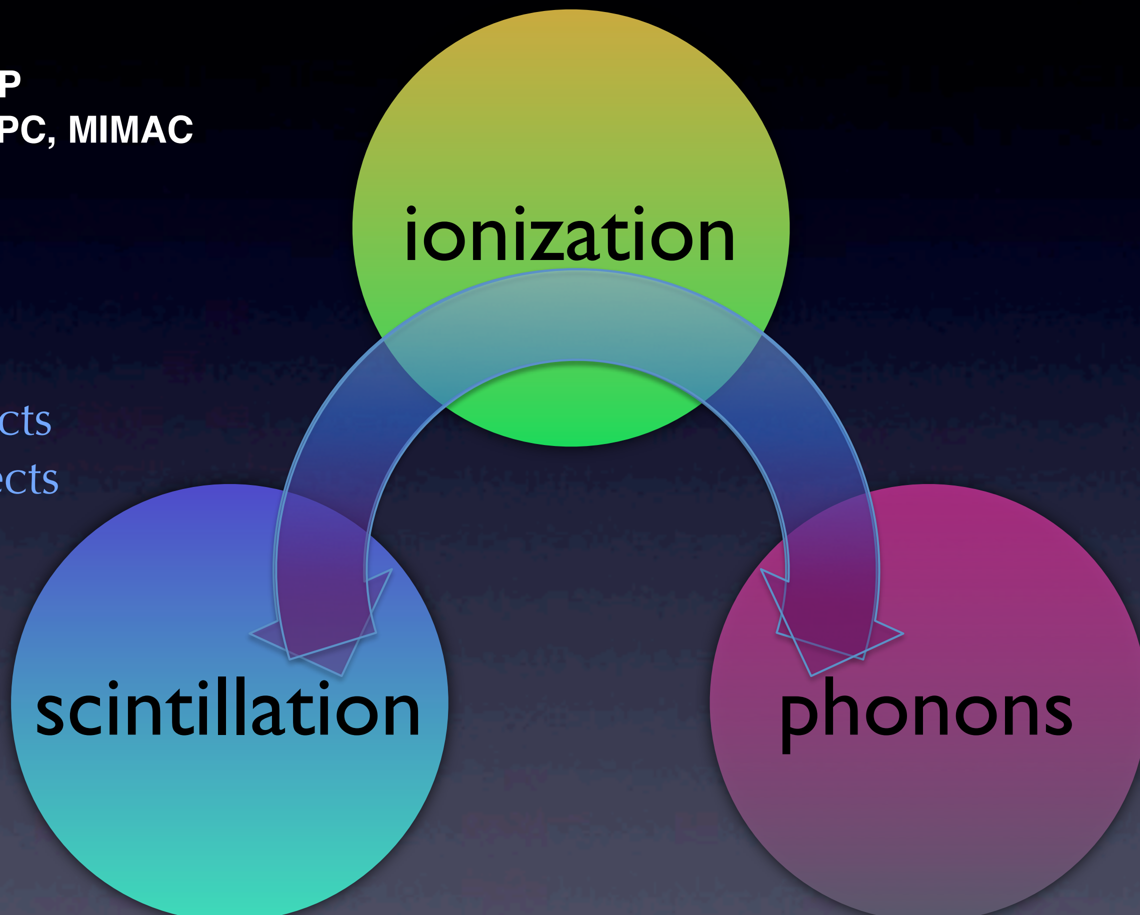
Single channel techniques

Charge
Ge: **COGENT, TEXONO**
C,F,I,Br: **PICASSO, COUPP**
CS_2,CF_4,^3He: **DRIFT, DMTPC, MIMAC**

Improve surface effects
Improve volume effects
Improve scaleability



Improve resolution
Improve threshold
Improve noise
Decrease T

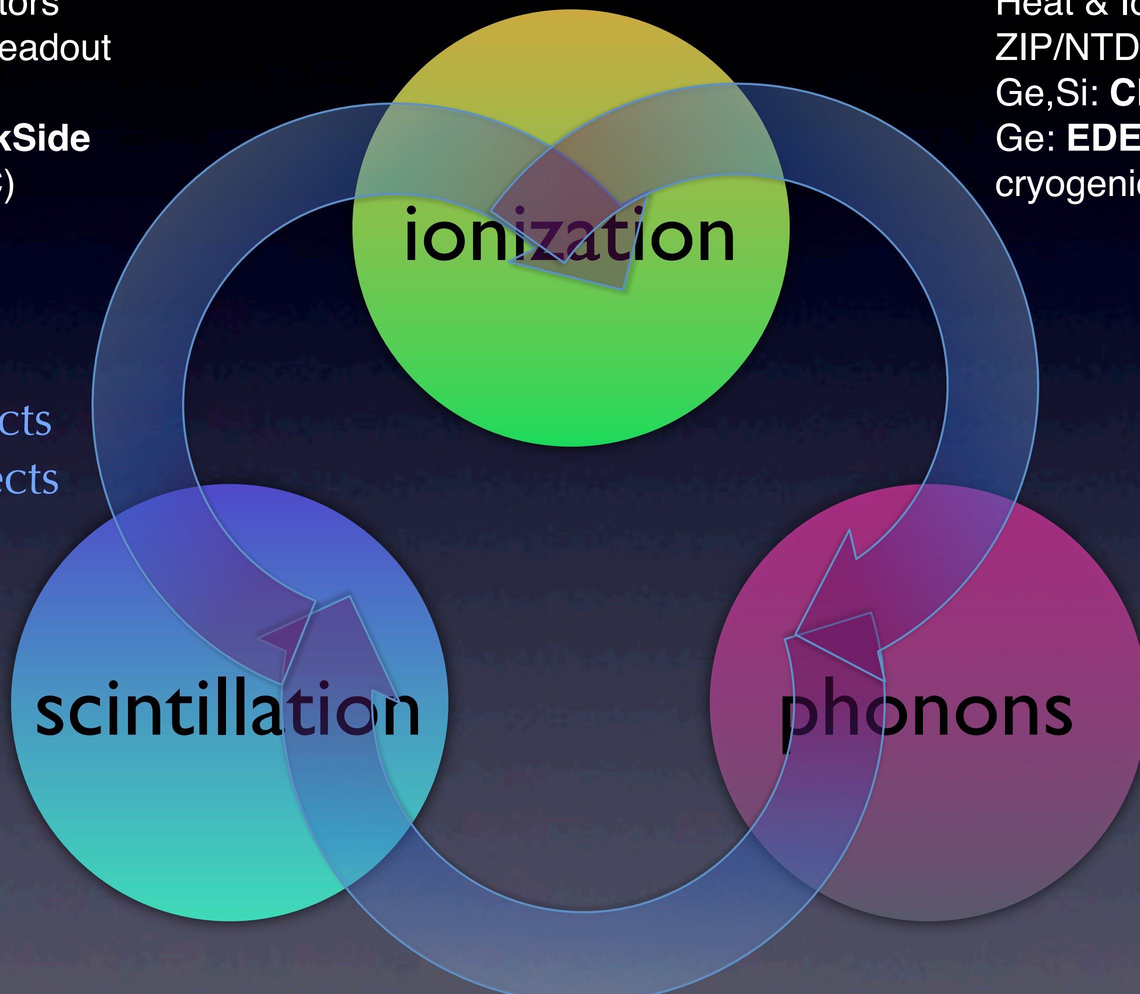
Light
NaI: **DAMA/LIBRA**
CsI: **KIMS**
LXe: **XMASS**,
LAr, LNe: **CLEAN/DEAP**

Heat
Al_2O_3: **CRESST-I**

Double channel techniques

Light & Ionisation Detectors
PMTs for both channel readout
LXe: **ZEPLIN, XENON**,
LAr: **WARP, ArDM, DarkSide**
mildly cryogenic (-100 C)

Heat & Ionisation Bolometers
ZIP/NTD for Q & H channels
Ge,Si: **CDMS**
Ge: **EDELWEISS**
cryogenic (<50 mK)



Improve surface effects
Improve volume effects
Improve scaleability

Improve resolution
Improve threshold
Improve noise
Decrease T

Light & Heat Bolometers
TES/NTD for L & H channels
$CaWO_4$, Al_2O_3: **CRESST**
even more cryogenic (~10 mK)

Path to Discovery

- current experiments: O(100 kg) detector mass

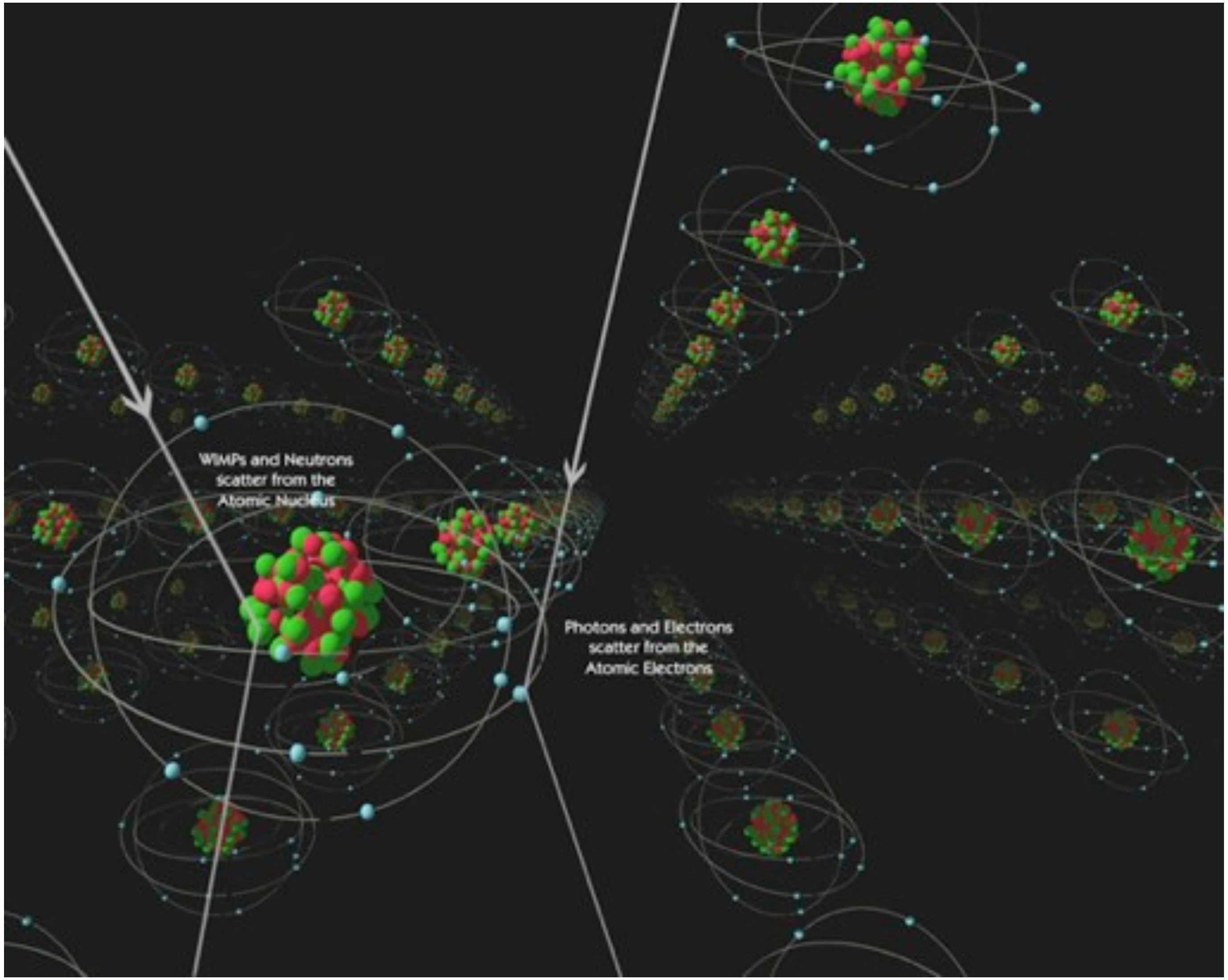
  zero background paradigm → any excess of events is candidate signal

- future goal: multi-ton experiments to measure dark matter properties with 100-1000 events

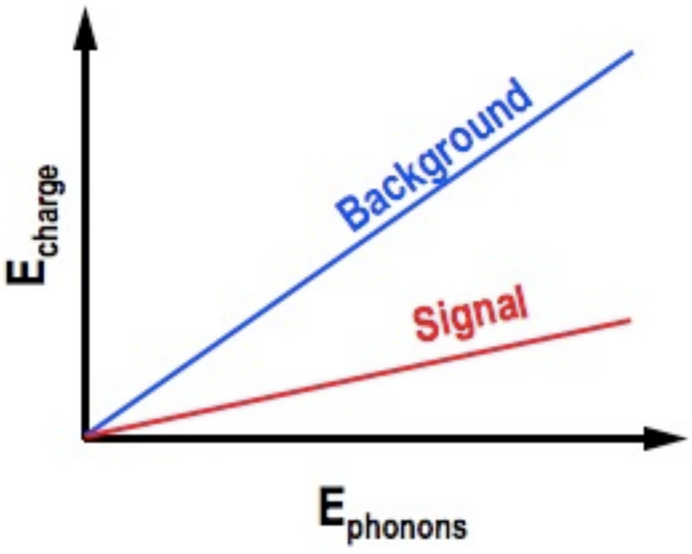
  paradigm shift → search for signal above measured background, in a low background observatory

➡ need multiple targets and techniques to verify signals

Hybrid techniques: nuclear recoil discrimination



- WIMPs and neutrons scatter off nuclei
- Photons and electrons scatter off electrons

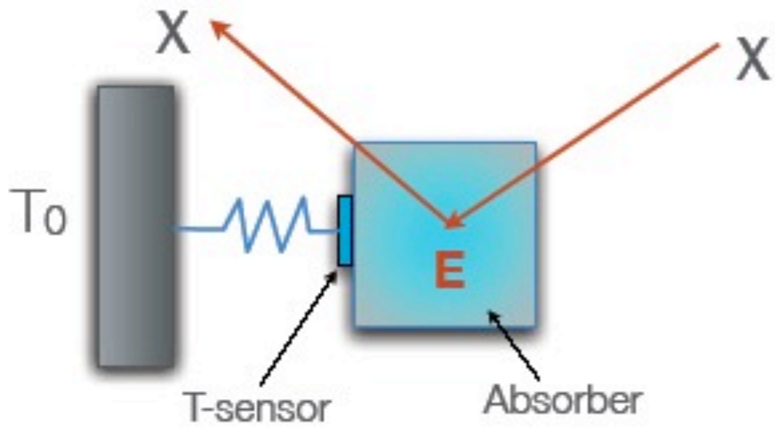


M.Attisha

NTD= Neutron Transmutation Doped (thermal phonons) crystals
TES= Transition Edge Sensors (athermal phonons)
SPT= Superconducting Phase Transition thermometers

Bolometers

- **Principle:** a deposited energy E produces a temperature rise ΔT

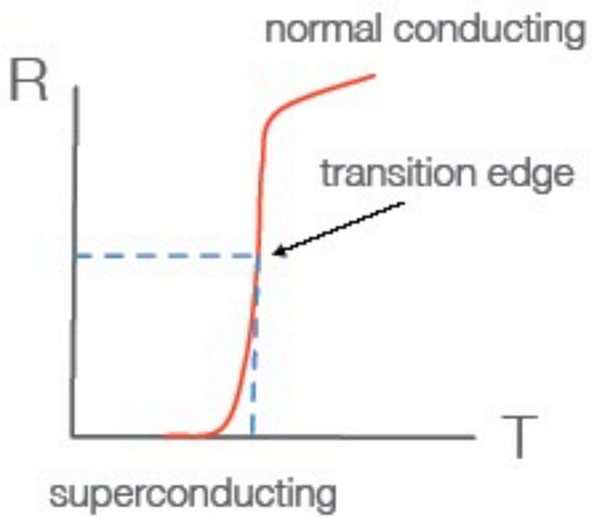


$$\Delta T \propto \frac{E}{C(T)}$$

$$T \ll T_c \Rightarrow C(T) \propto T^3$$

=> the lower T, the larger ΔT per unit of absorbed energy

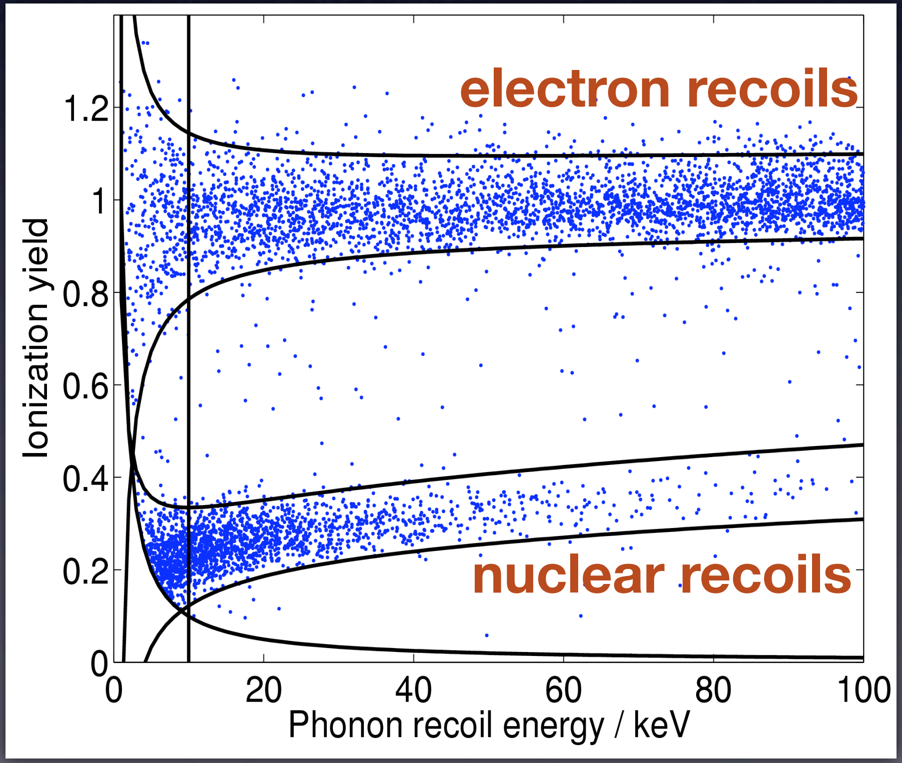
- **T-sensors:**
  - **superconductor thermistors**
    (highly doped superconductor): NTD Ge → EDELWEISS
  - **superconduction transition sensors**
    (thin films of SC biased near middle of normal/SC transition):
    TES→CDMS, SPT→CRESST



Phonons: discriminating backgrounds

- Advantages: high sensitivity to nuclear recoils (measure the full energy in the phonon channel); good energy resolution, low energy threshold (keV to sub-keV)
- Ratio of light/phonon or charge/phonon:
  - nuclear versus electronic recoils discrimination
    → separation of S and B

Ratio of charge (or light) to phonon

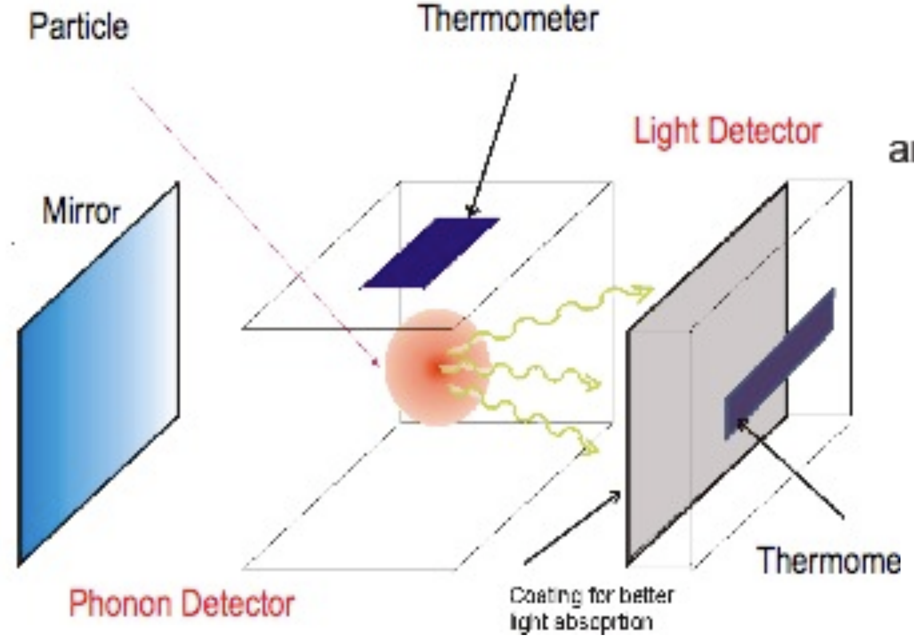


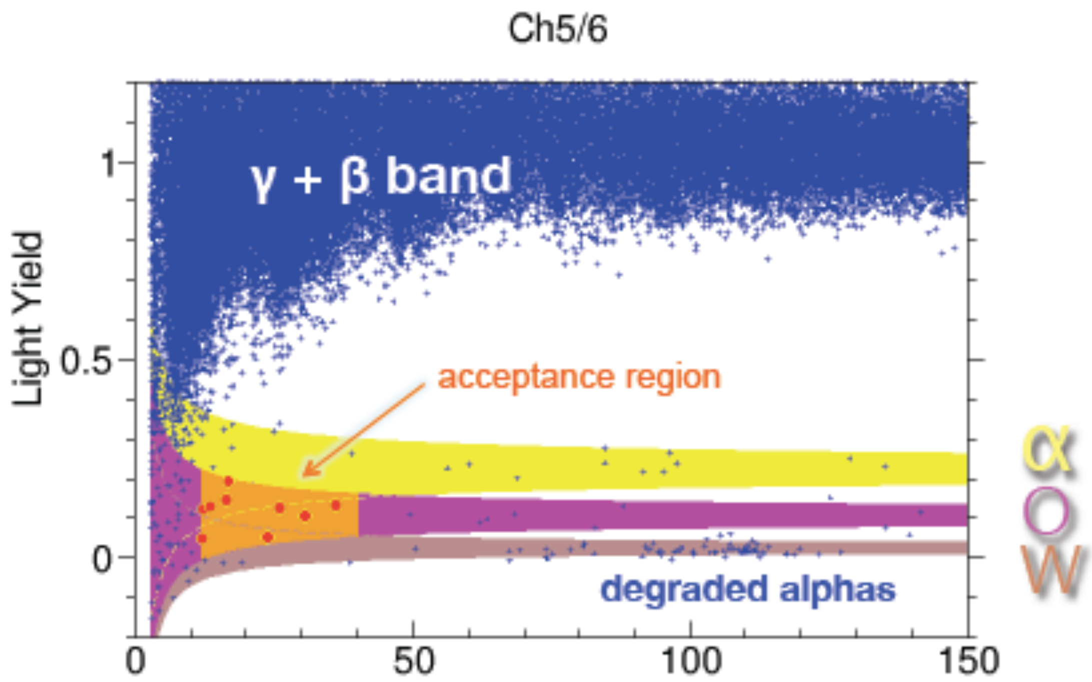
Background region

Expected signal region

CRESST at LNGS: light and phonons

- Phonons and scintillation in $CaWO_4$ targets at ~ 10 mK
- Phonon detector: W-SPT (Superconducting Phase Transition) thermometers (Tc at 15 mK)
- Light detector: Si wafer read out by W-SPT(E_{thr} → few optical γ, ~ 20eV)
- No dead layer effects





arXiv:1109.0702

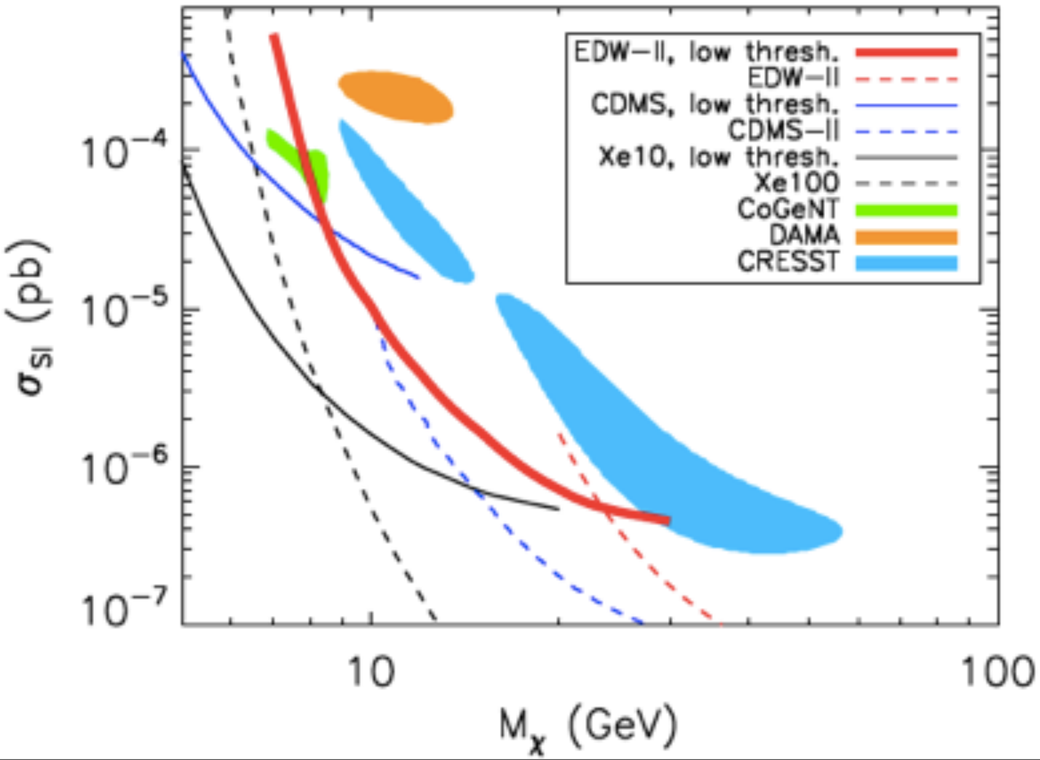
- Nuclear recoils have much smaller light yield than electron recoils
- Photon and electron interactions can be be distinguished from nuclear recoils (WIMPs, neutrons)

67 events observed (730 kg-day)
~ 37 expected from backgrounds
room for a signal?
focus on reducing backgrounds

EDELWEISS at LSM: charge and phonons

- EDELWEISS-I: Ge NTD heat and ionization detectors (3 x 320 g at 17 mK)
  - Data taking 2000-2003
  - Backgrounds from neutrons, alpha and surface electron recoils
- EDELWEISS-II: 10 kg (30 modules) of NTD and NbSi Ge detectors in new cryostat, new charge electrodes
  - 113 kg d low threshold analysis E < 20 keV)

arXiv:1207.1815v2 [astro-ph.CO]



CDMS

Superconducting films that detect minute amounts of heat

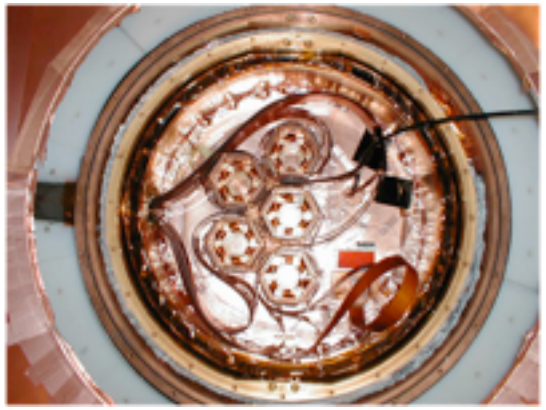
Transition Edge Sensor sensitive to fast athermal phonons

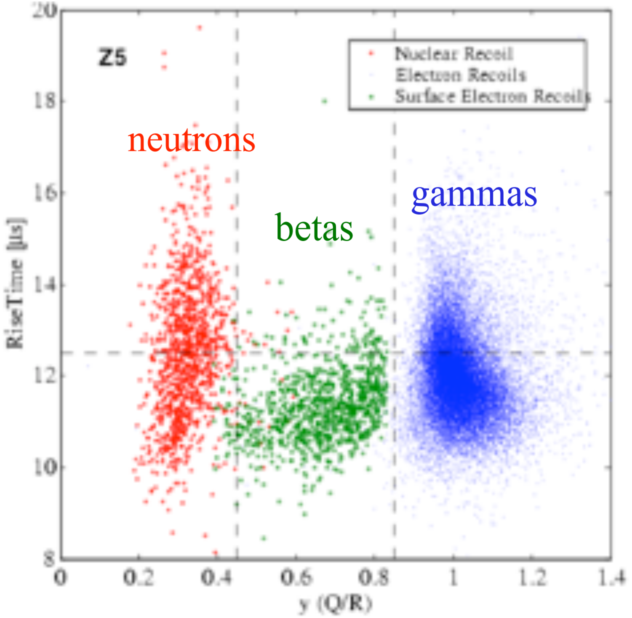
ZIP: Z-dependent ionization and phonon detectors

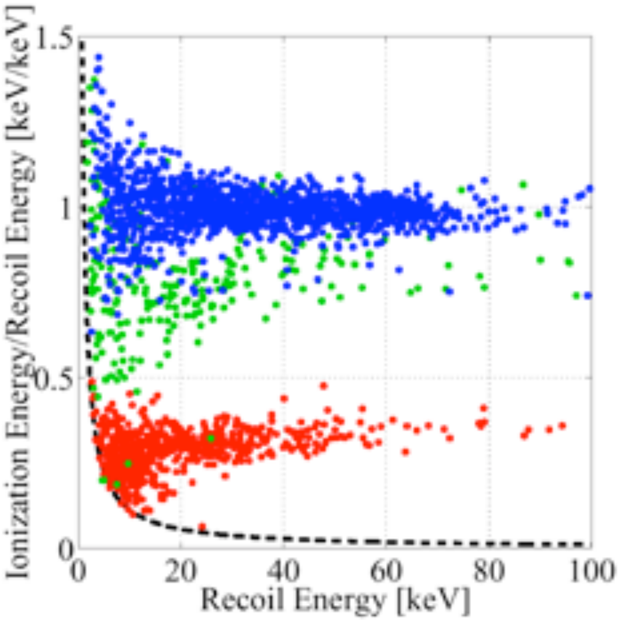
- Charge/phonon AND phonon timing different for nuclear and electron recoils; event by event discrimination!
- Measured background rejection still improving!

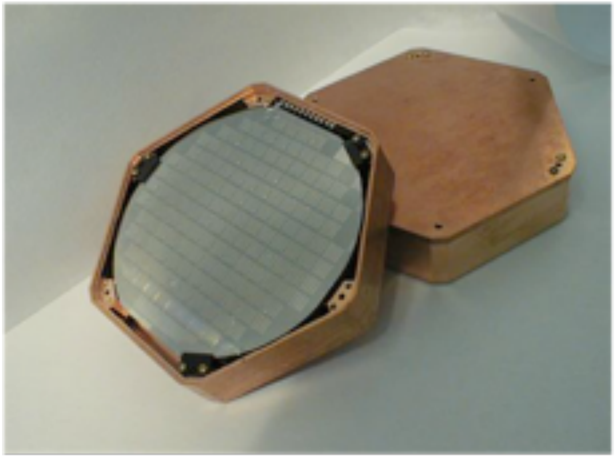
  99.9998% for γ's, 99.79% for β's
- Clean nuclear recoil selection with ~ 50% efficiency

  Can tune between signal efficiency and background rejection







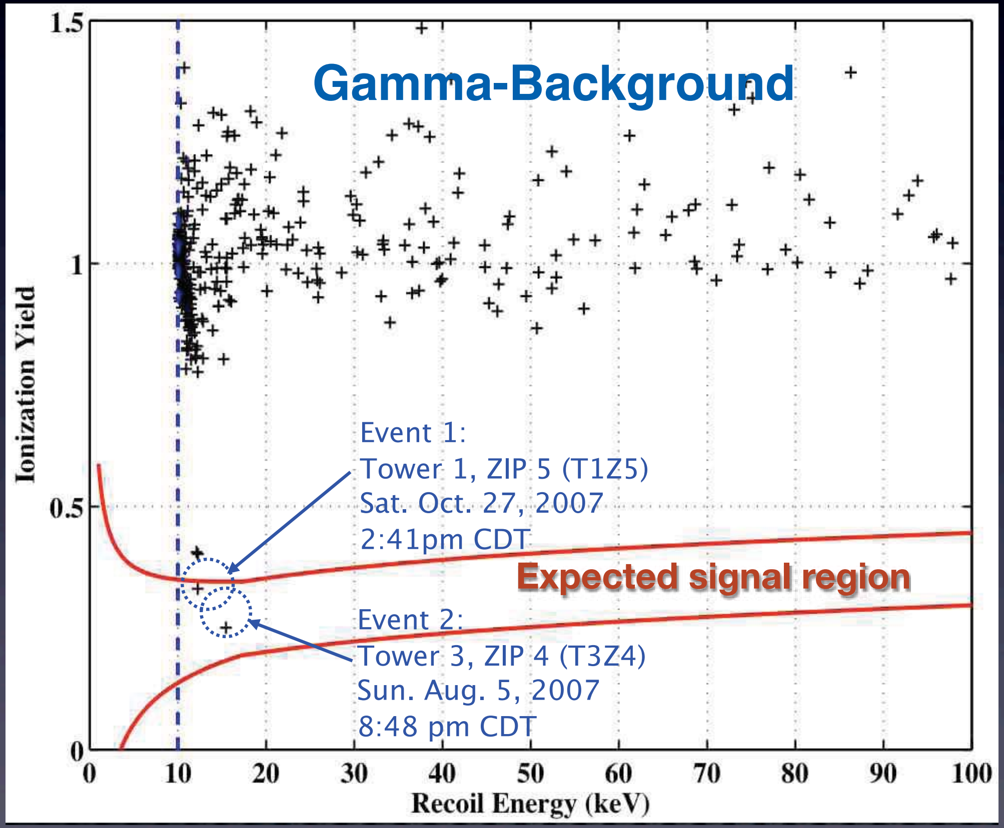


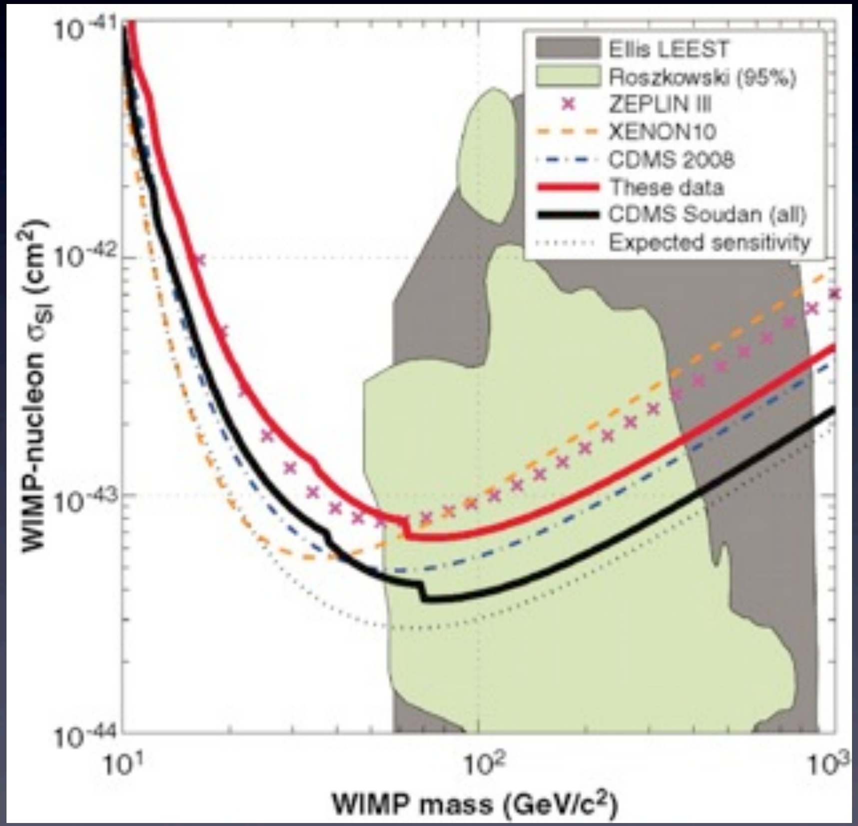
CDMS: a negative result?

30 Ge/Si detectors operated at 40 mK in a low-background shield at the Soudan mine in northern Minnesota

Final WIMP search runs (Ge detectors) - 612 kg-d: 2 events passing all cuts

Science, 1186112 (2010)





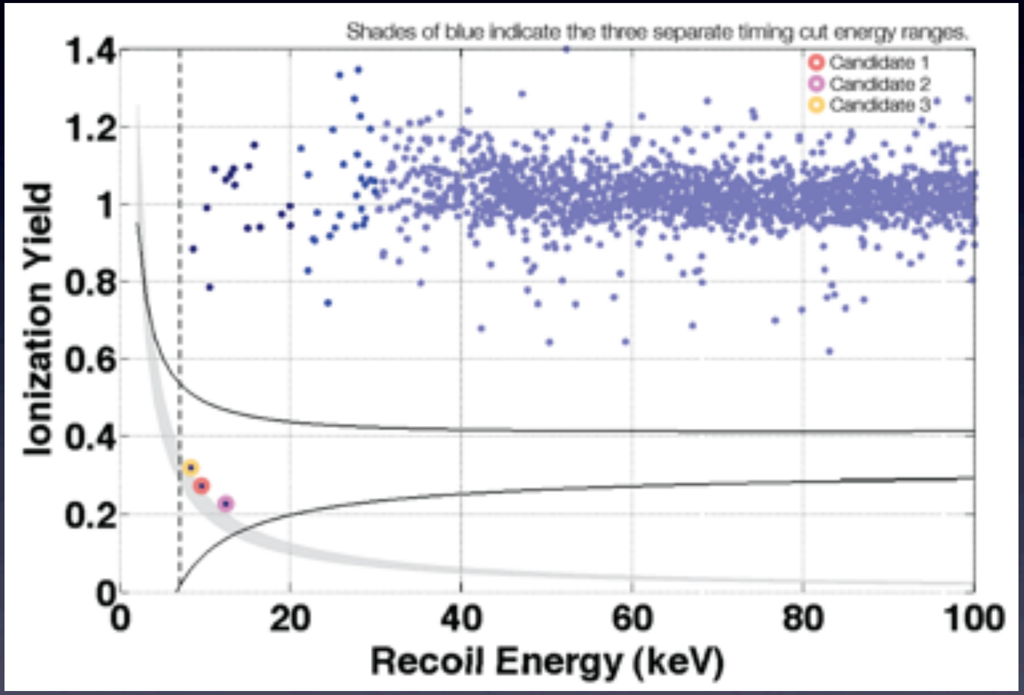
- Expected background: 0.8 ± 0.1 (stat) ± 0.2 (syst) events
- Probability to observe two or more events is 23%

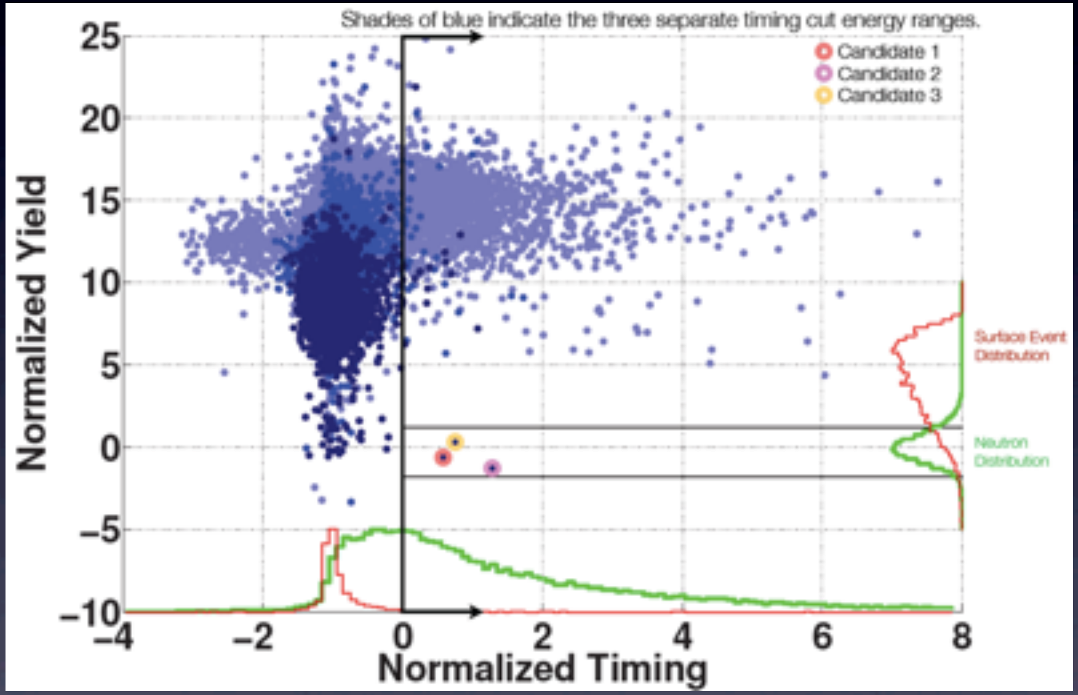
CDMS: latest results

Analysis of a 140.23 kg-day exposure of the CDMS-II Si detectors

Enectali Figueroa-Feliciano / U.Mich. Light Dark Matter 2013

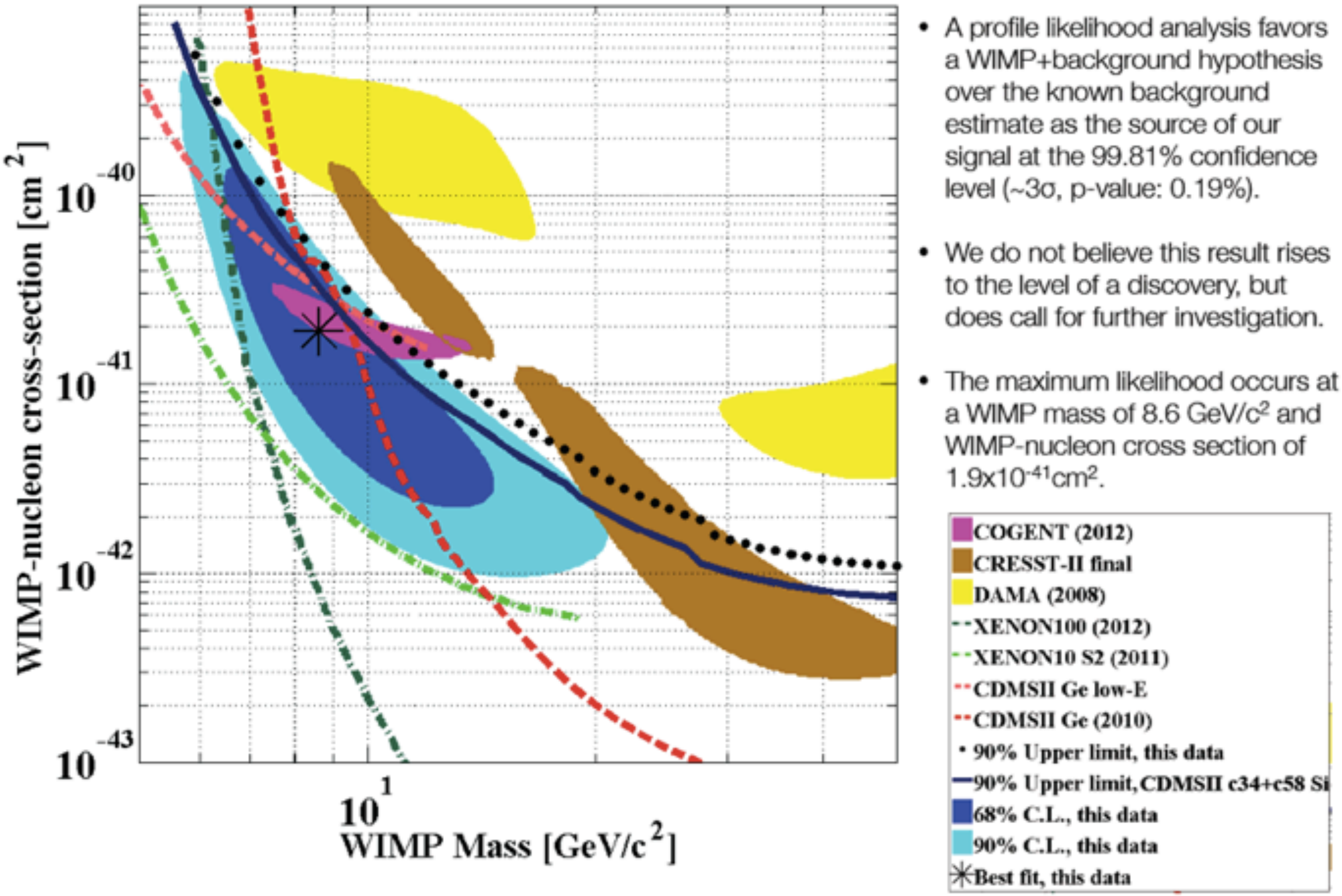
arXiv, 1304.4279v2 [hep-ex]





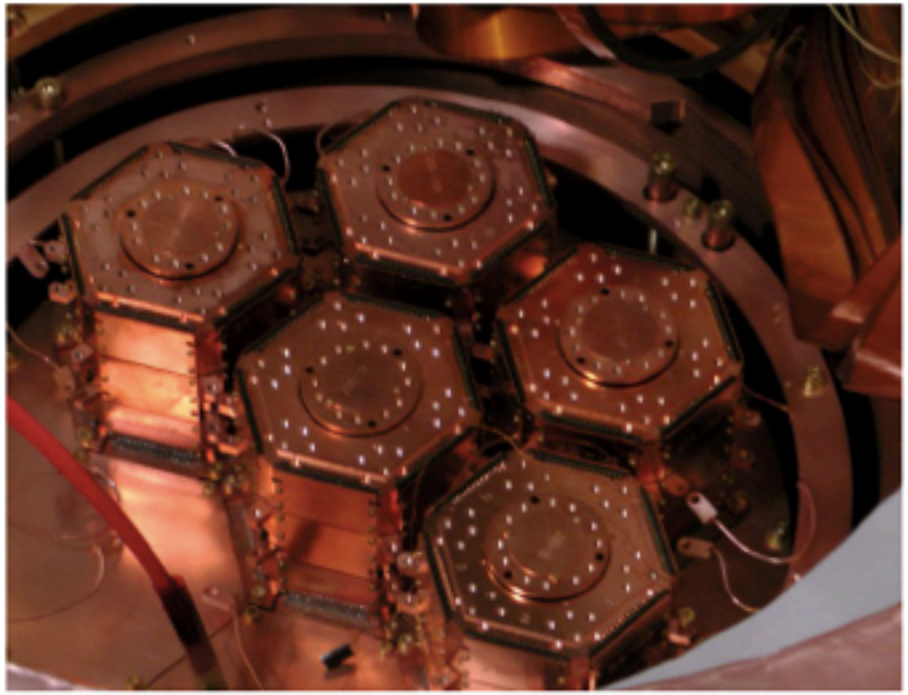
- Three events were seen in the signal region with a total expected background of <0.7 events
- A profile likelihood analysis favors a WIMP +background hypothesis over the known background estimate as the source of signal at the 99.81% confidence level (~3σ)

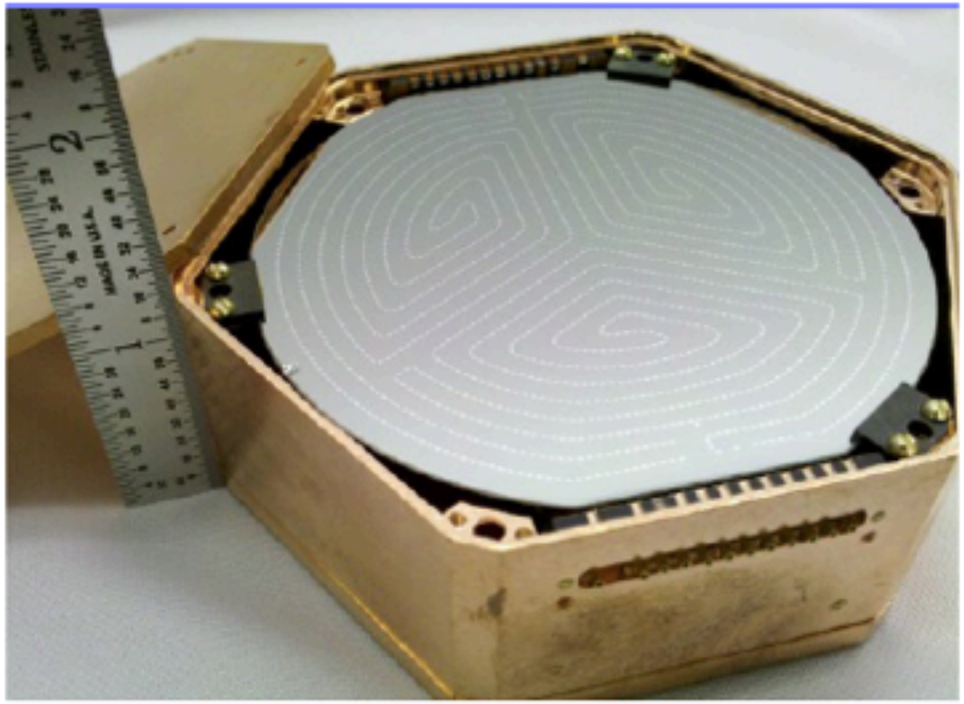
CDMS profile likelihood analysis



- A profile likelihood analysis favors a WIMP+background hypothesis over the known background estimate as the source of our signal at the 99.81% confidence level (~3σ, p-value: 0.19%).
- We do not believe this result rises to the level of a discovery, but does call for further investigation.
- The maximum likelihood occurs at a WIMP mass of 8.6 GeV/c^2 and WIMP-nucleon cross section of 1.9x10^{-41}cm^2.

Current step: the SuperCDMS experiment





CDMS II data-taking ended March 2009

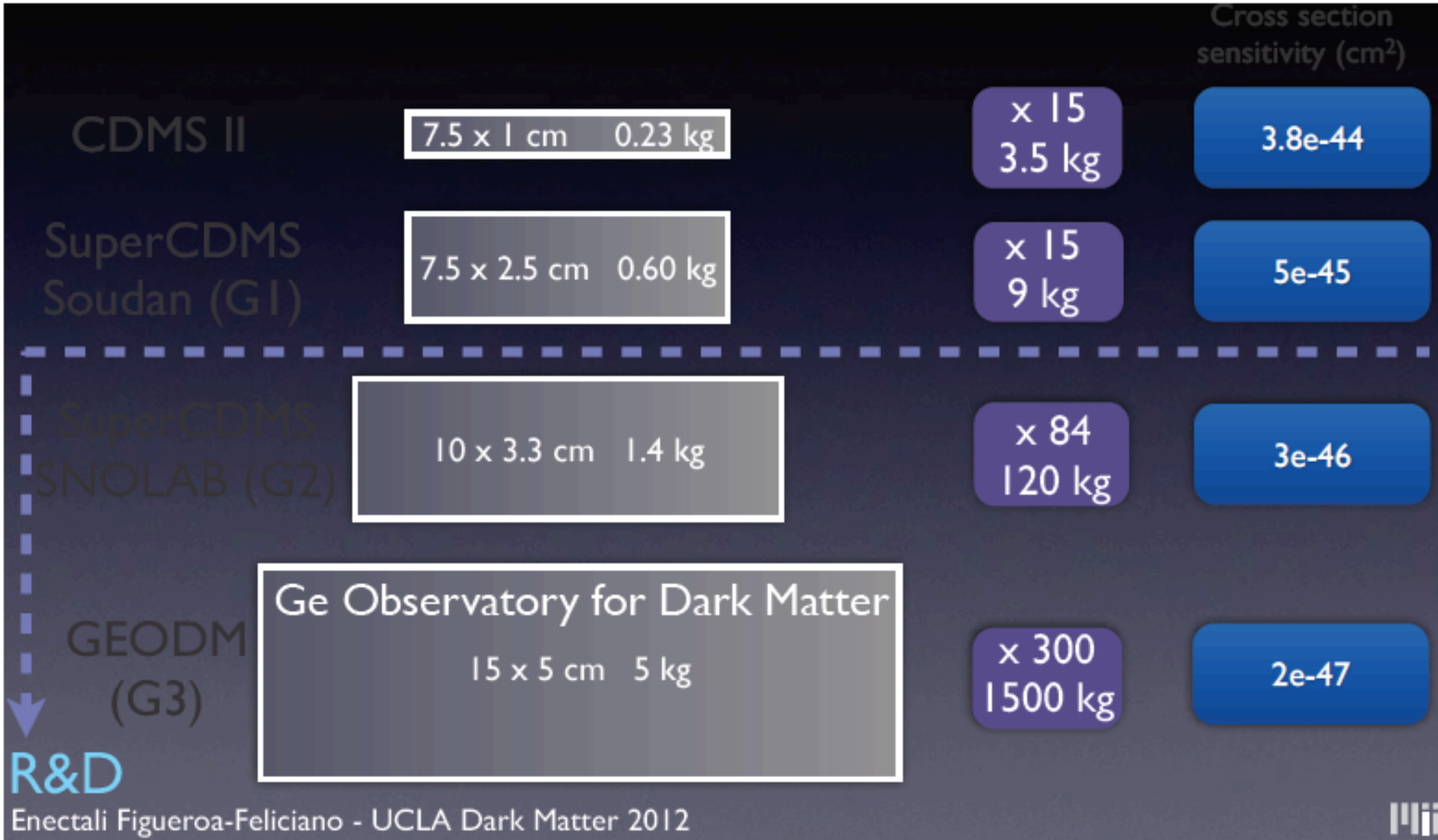
Five super-towers installed at Soudan, each with 3 new, iZIP detectors, of 650 g

Total mass is 9 kg (~ 6kg fiducial mass)

The detectors are cold, the science run should start soon; expected to run for 2 years

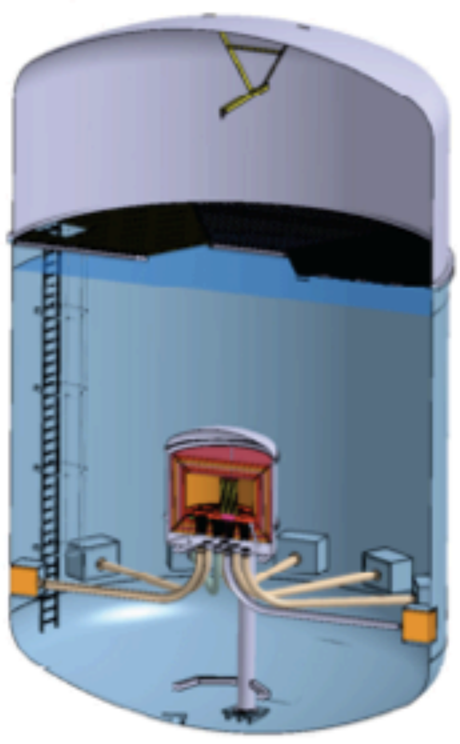
Expected sensitivity: between 5 - 8 x 10^{-45} cm^2

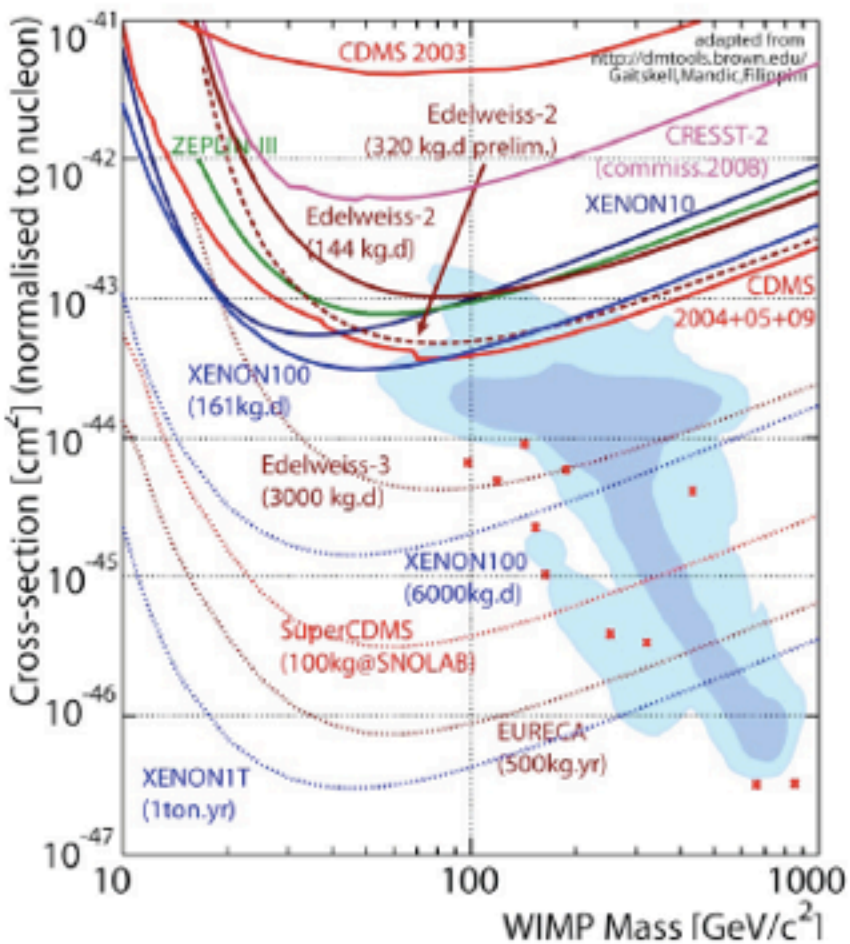
The SuperCDMS program: future



Future in Europe: EURECA

- Joint effort for 100 kg-1 t cryogenic mK experiment in Europe (CRESST, EDELWEISS, ROSEBUD and other groups)
- Multi-target approach: Ge, $CaWO_4$, Al_2O_3, other?
- Design study (2009 - 2012) approved by ASPERA first common call in Europe
- Technical design report to be submitted in 2012



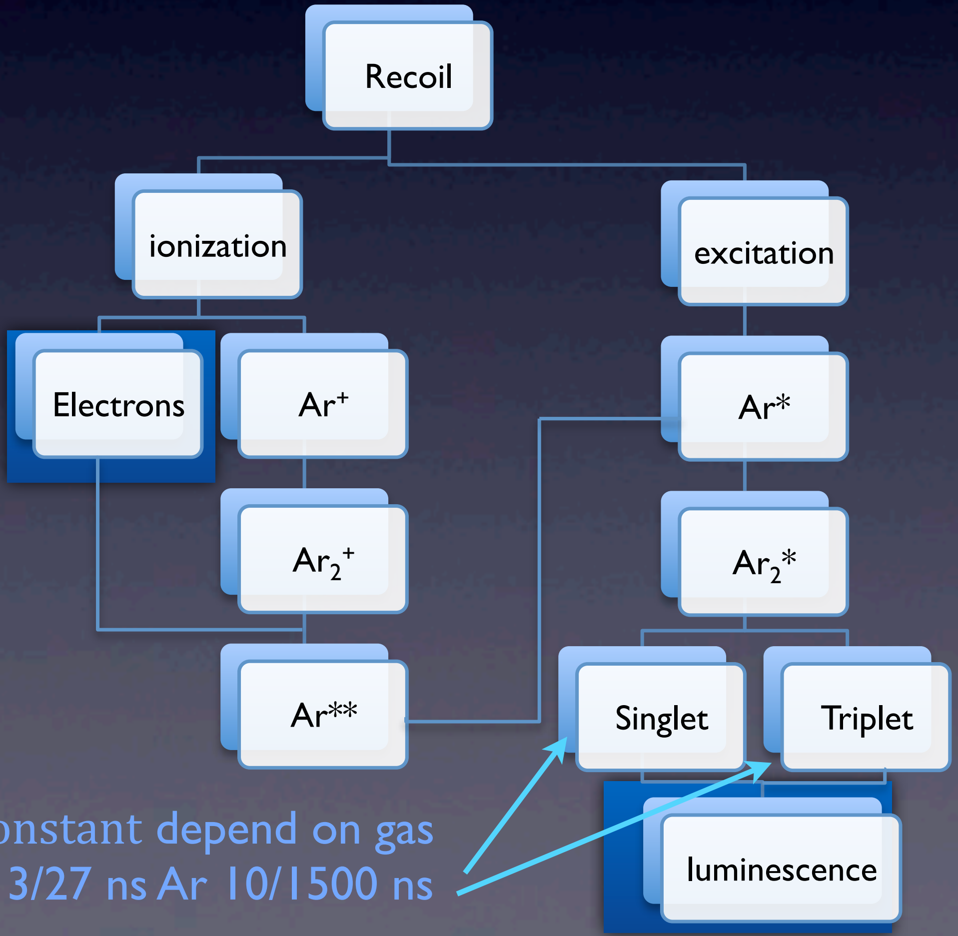


Light: the noble liquids strategy

- Large mass detectors → scalability
- Multiple targets available: Xe, Ar
- Bright scintillators: Light Yield ~ 40 γ/keV → low threshold

Two detection channels:
ionization charge
scintillation light

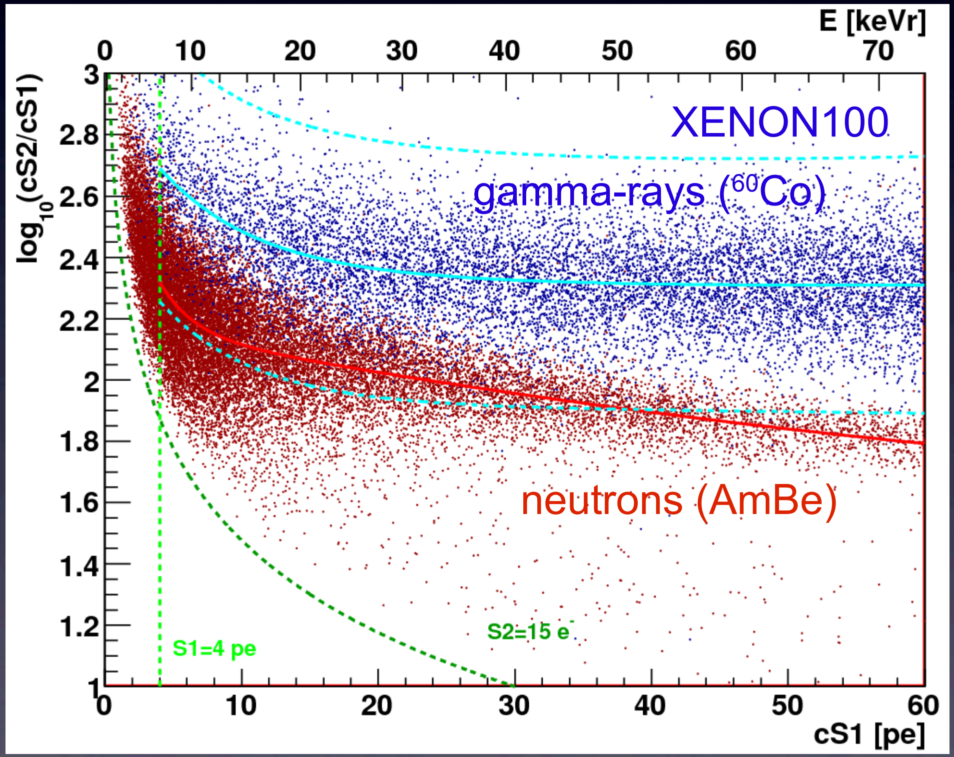
different dE/dx from nuclear and electron recoils
→ background discrimination



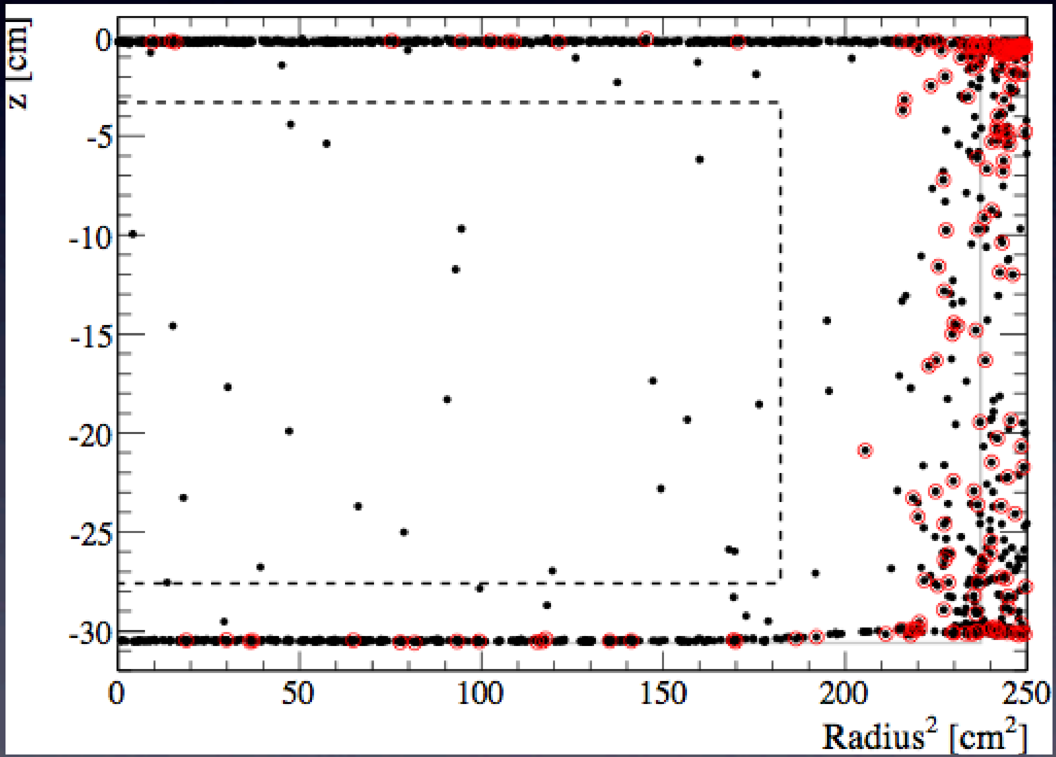
time constant depend on gas
e.g. Xe 3/27 ns Ar 10/1500 ns

Ionization and scintillation

Ratio of charge to light



3D Position Resolution: fiducial cut, singles/multiples



XENON100 ~99.5% rejection @ 50% acceptance

A low background technique

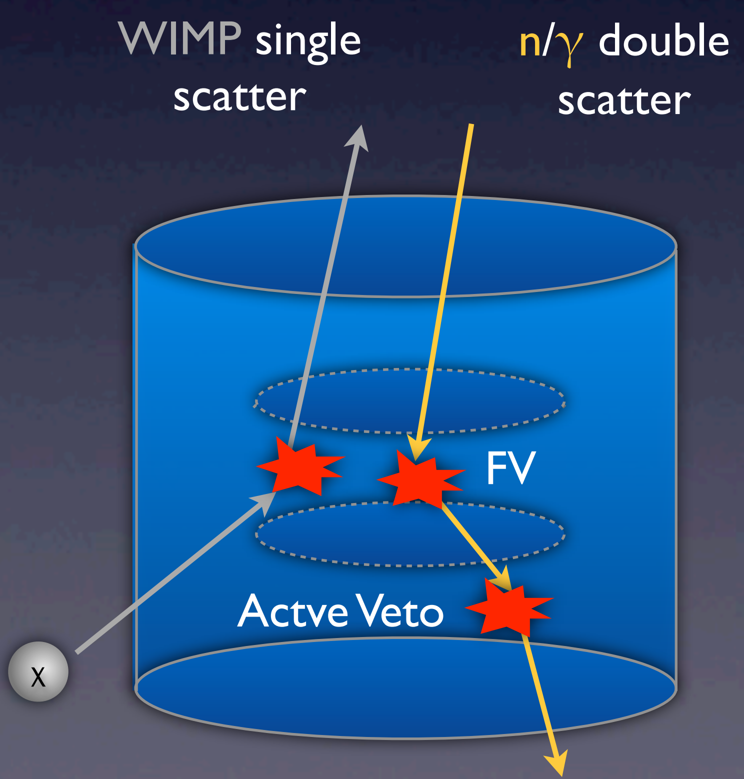
Intrinsic contaminations

LXe – U/Th $<10^{-13}$, technogenic ^{85}Kr (beta) removed ($<10^{-13}$) by distillation or chromatography
LAr – cosmogenic ^{39}Ar (beta) depleted ($<10^{-2}$) Ar from underground reservoirs

Use low-radioactive materials ONLY !

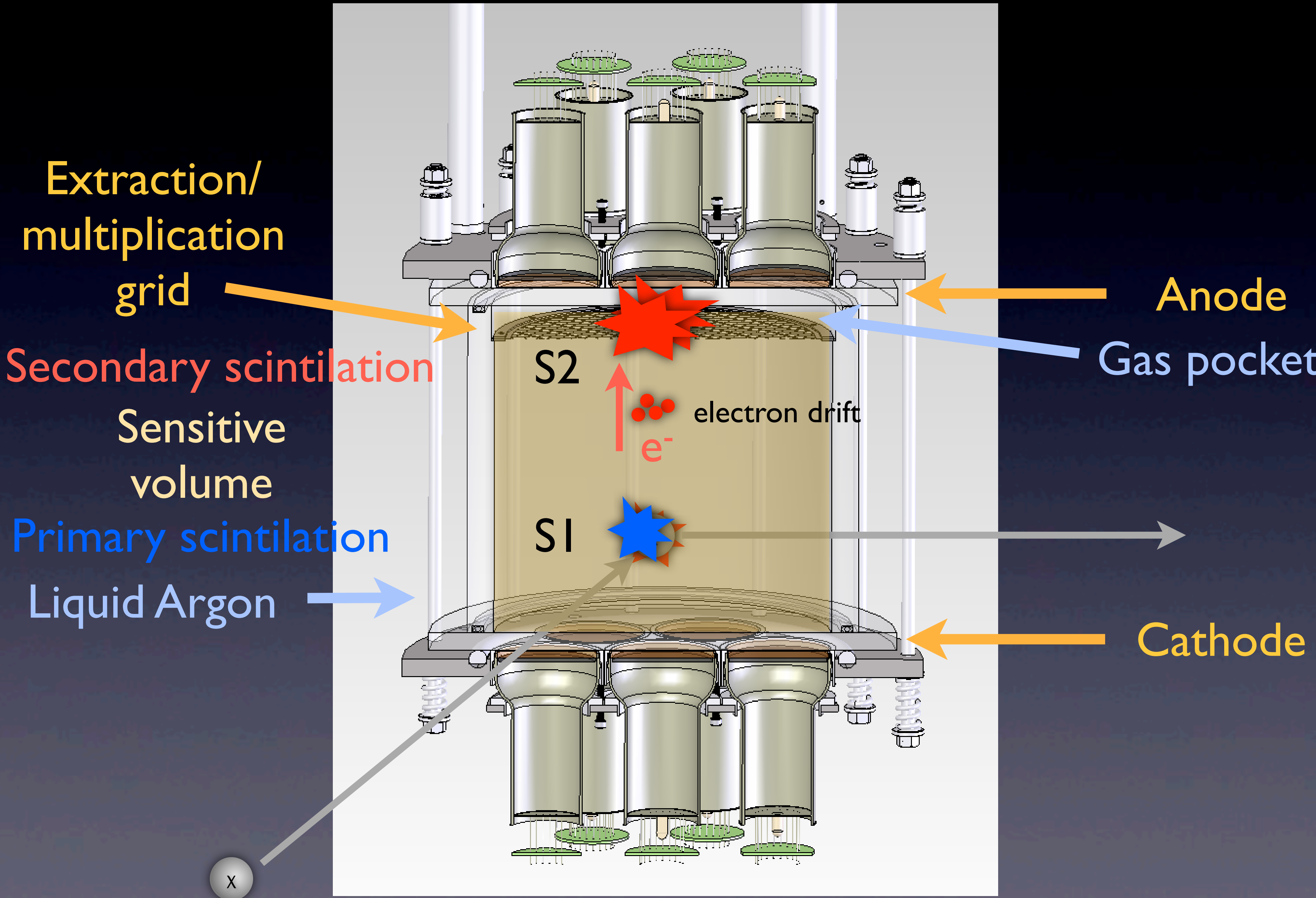
Teflon – U $<10^{-8}$, Th $<10^{-9}$, K$<10^{-6}$
Copper – U$<10^{-11}$, Th$<10^{-11}$, K$<10^{-9}$
Titanium – U $<10^{-9}$, Th $<10^{-9}$, K$<10^{-6}$

Rn – should be removed from the vicinity of setup

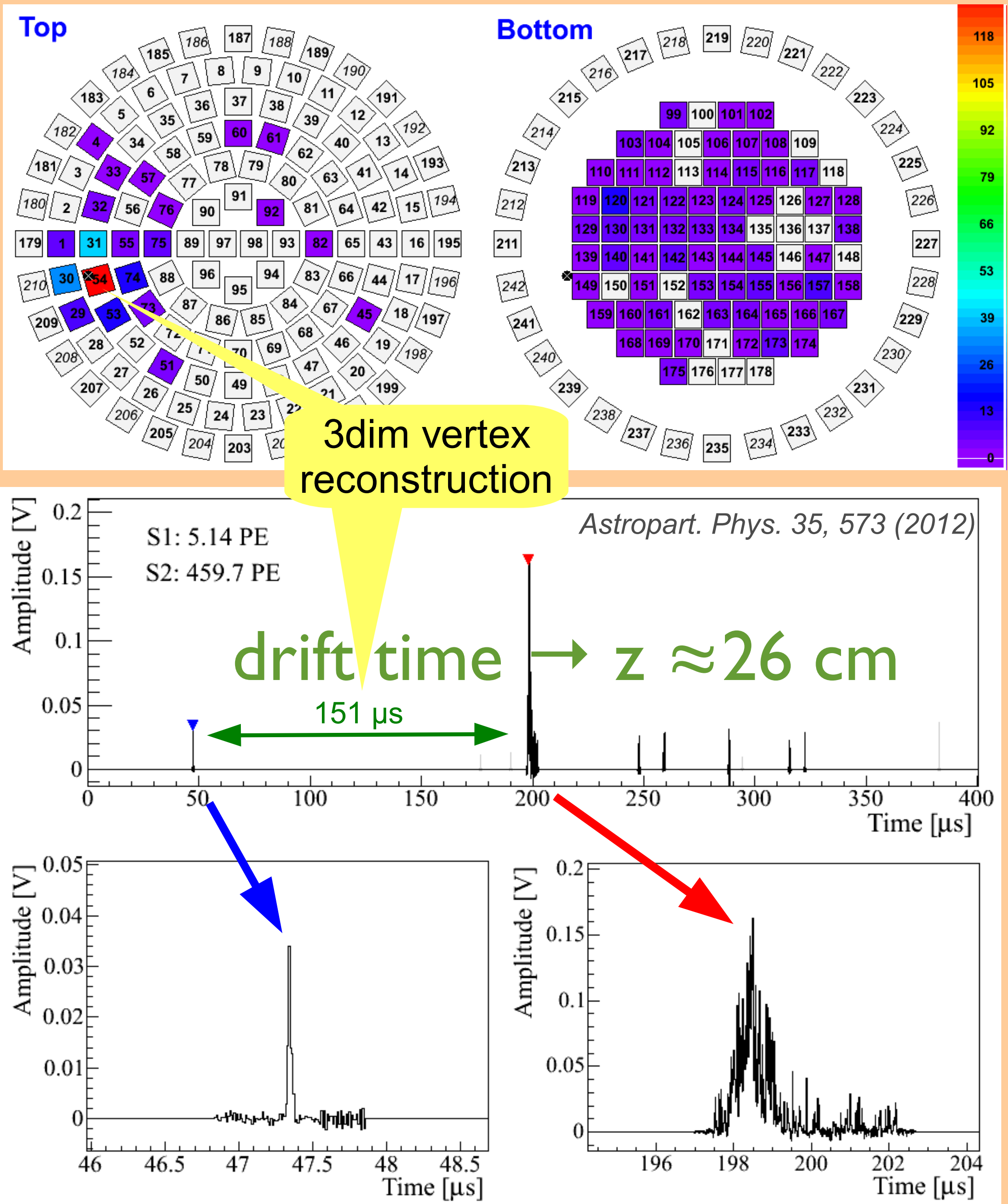


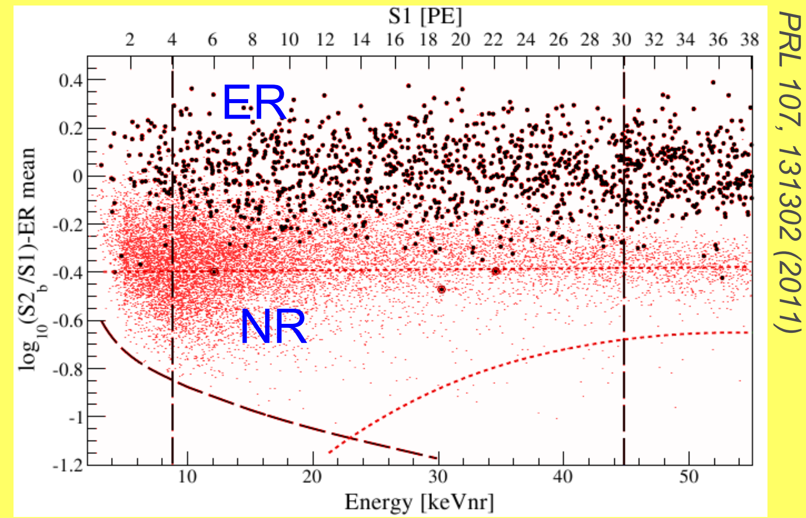
In-situ measurement of backgrounds:
Active veto shield
→ identification of neutron recoils

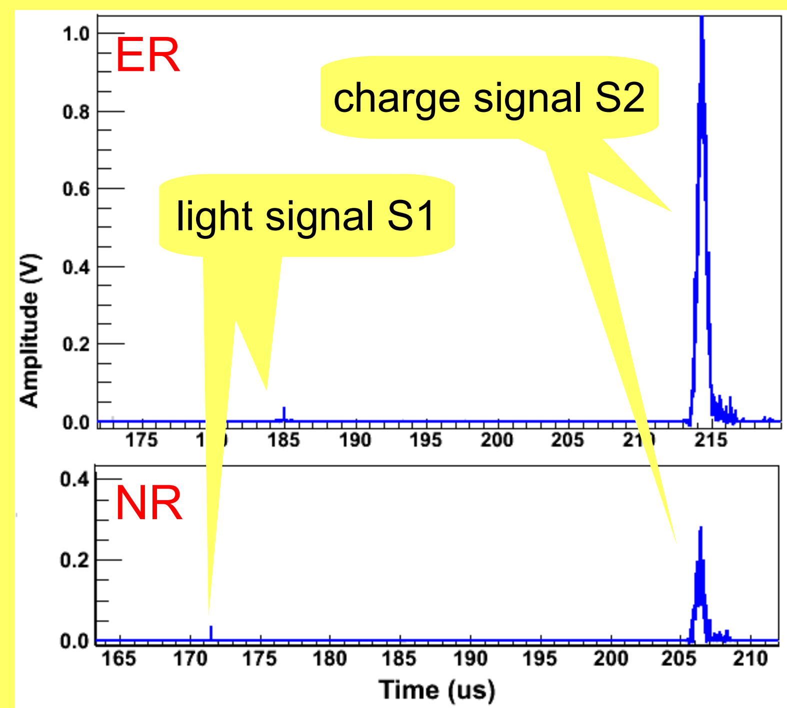
Noble liquid TPC principle



Dual phase TPC: signals

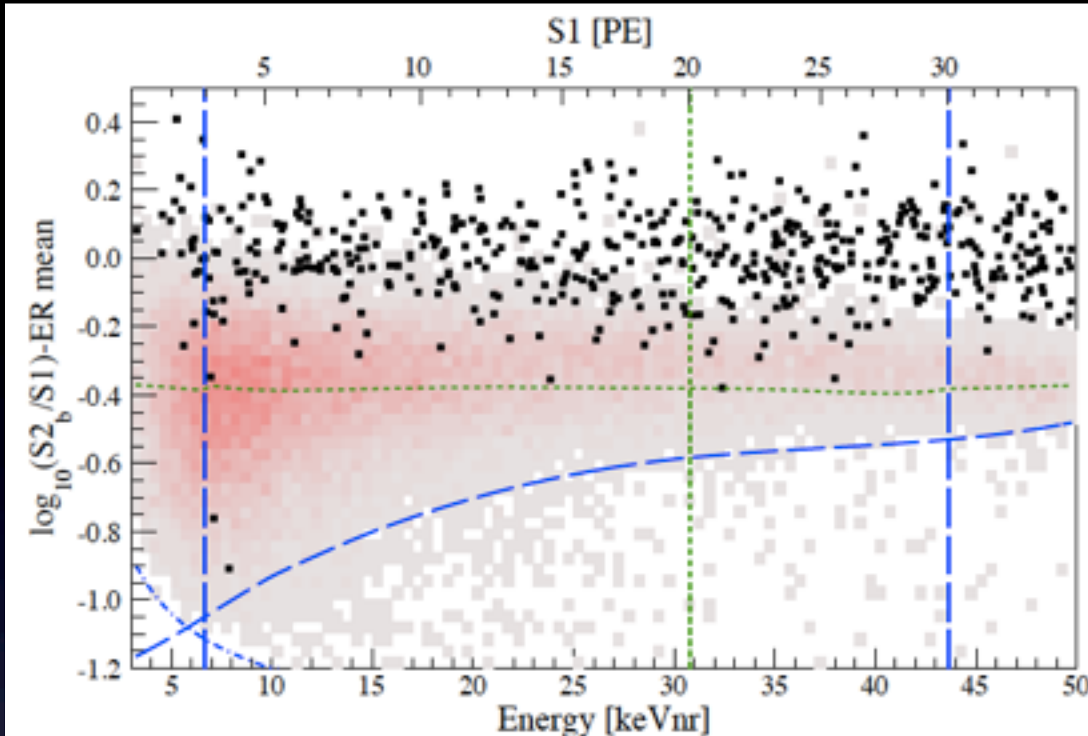


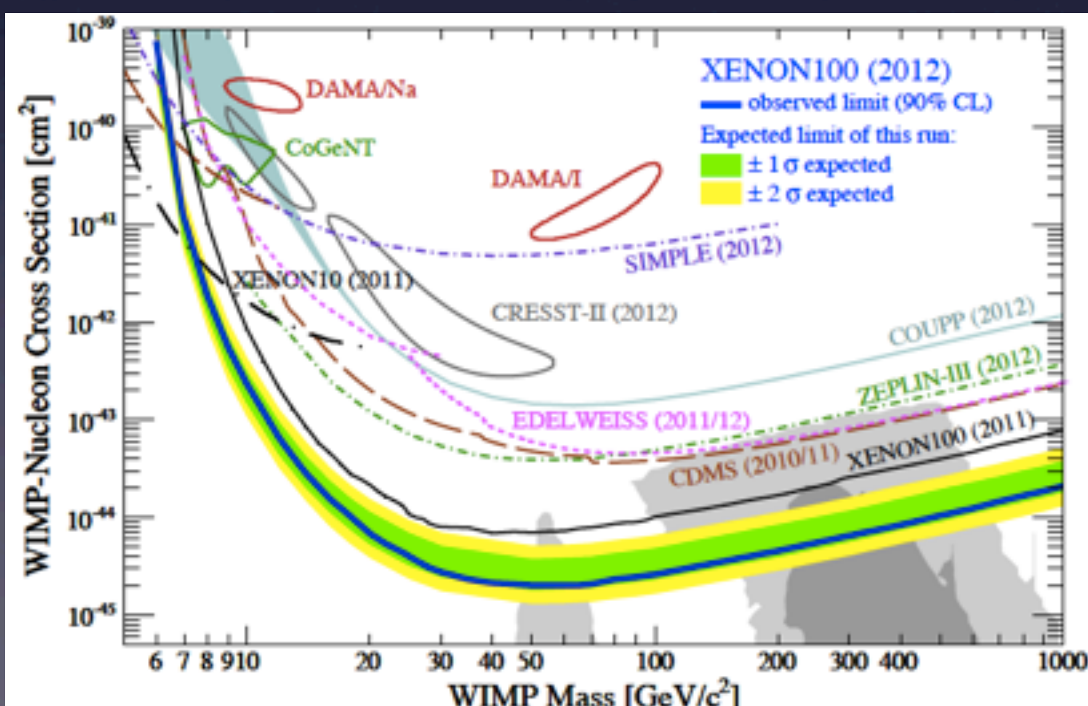




Xenon100

- 62 kg LXe target
- 99 kg active LXe veto
- Dual phase TPC 30 cm drift
- 242 PMTs
- running @ LNGS (IT)

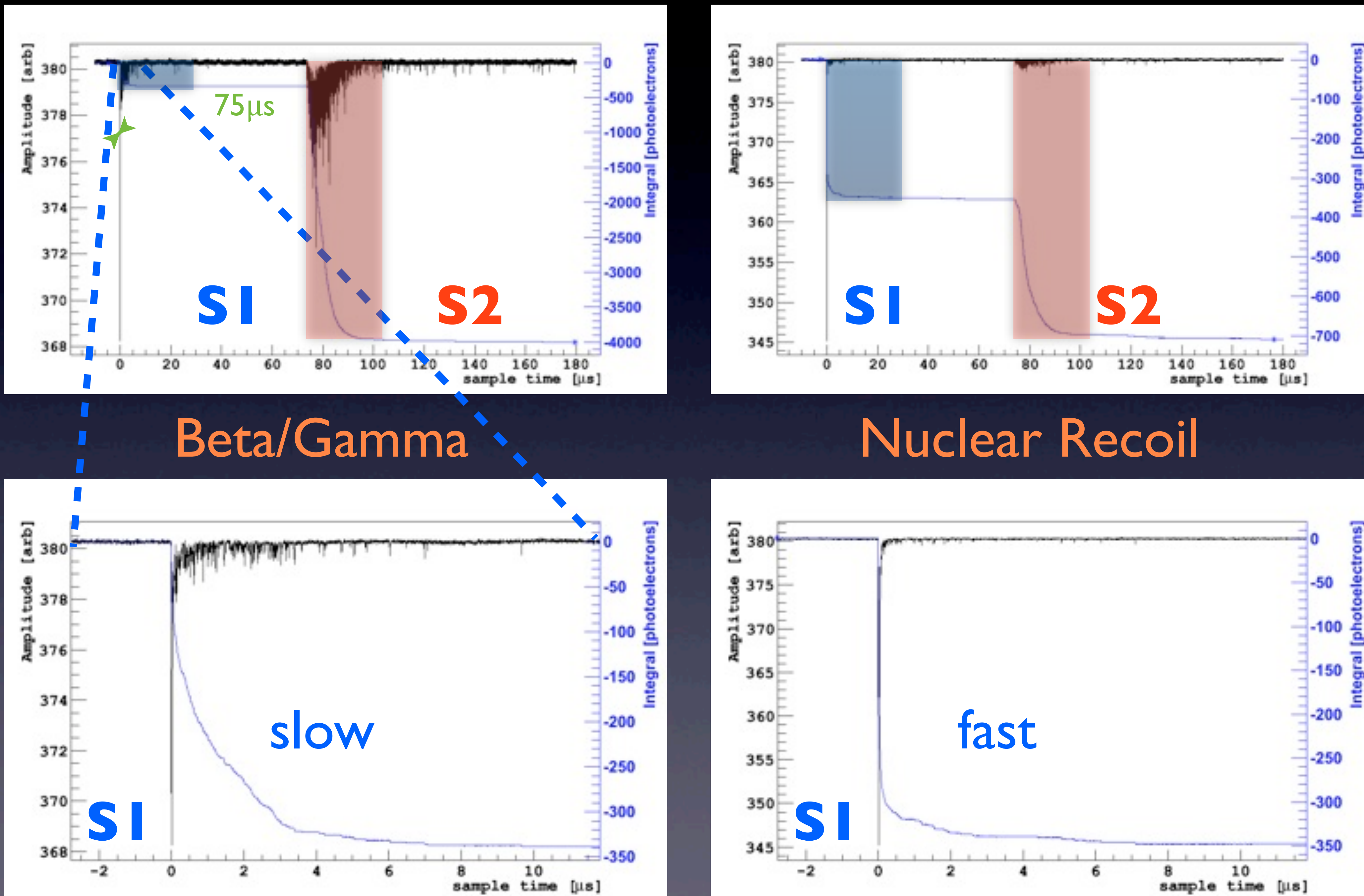




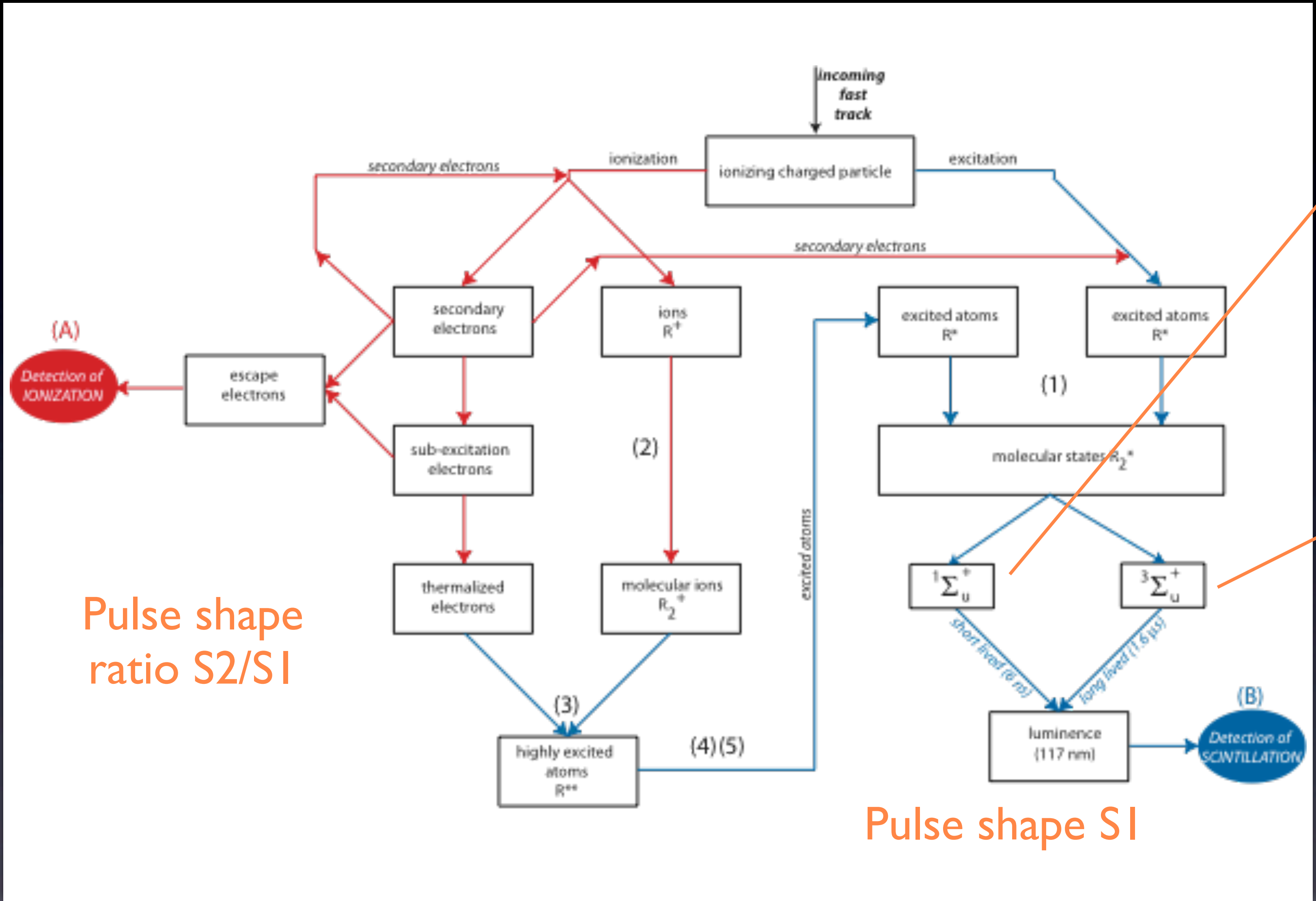
Last science run: PRL 109, 181301 (2012)
224.6 live days x 34 kg exposure

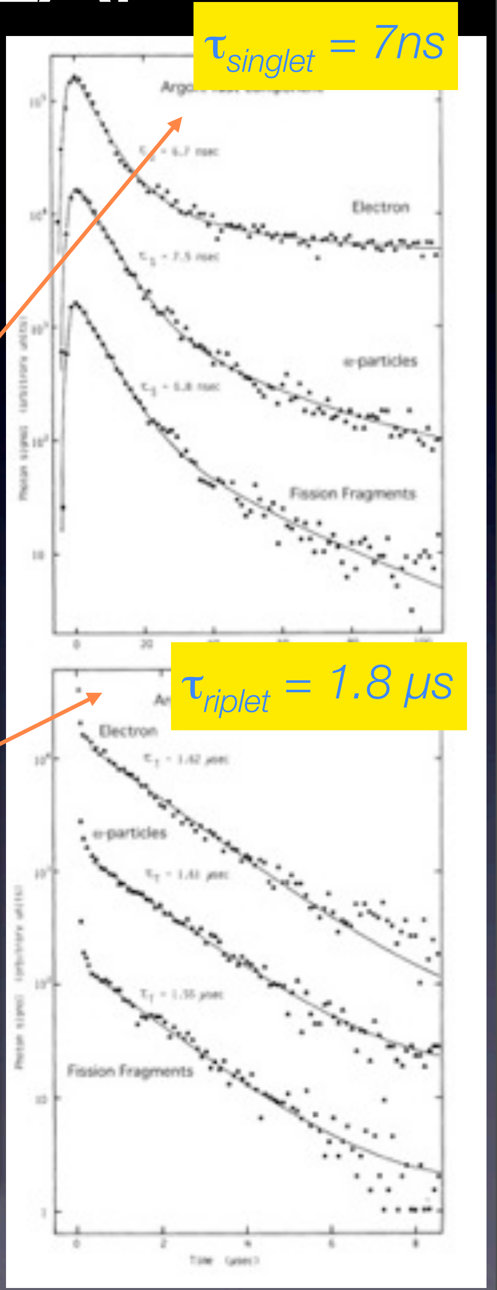
two candidate events observed in the nuclear recoil energy range of 6.6-30.5 keVnr → fully compatible with background → best WIMP limit over large mass range

Argon: Pulse Shape Discrimination



Scintillation and ionization in LAr





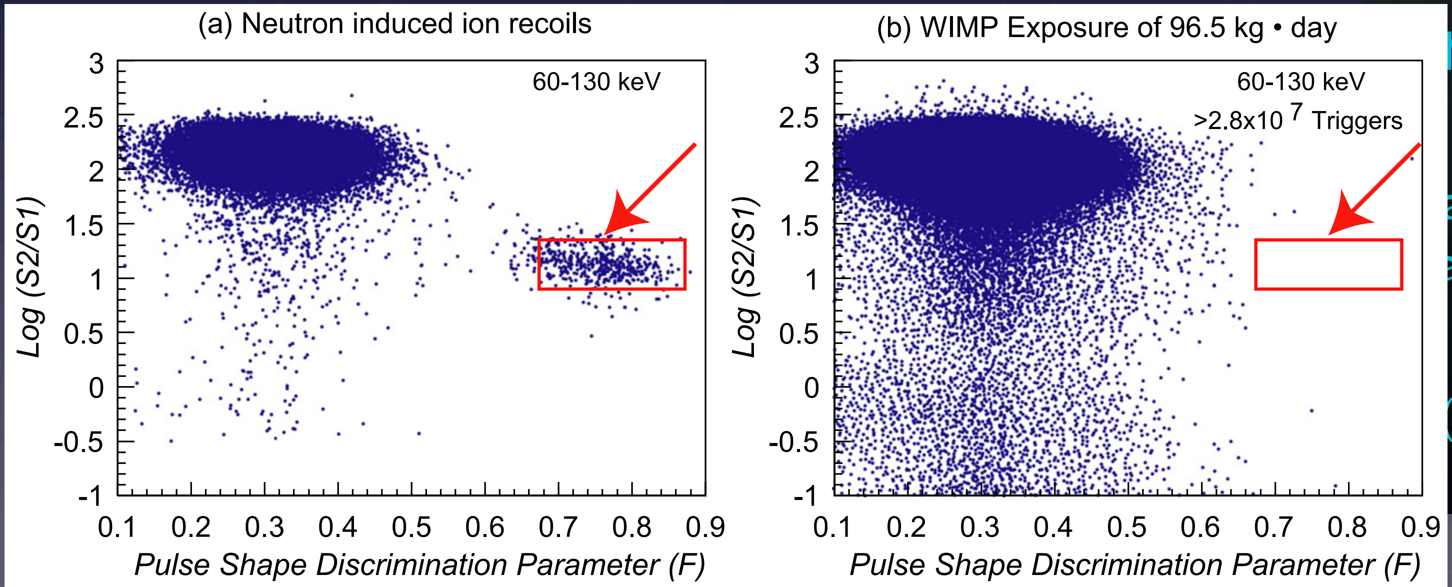
In LAr:

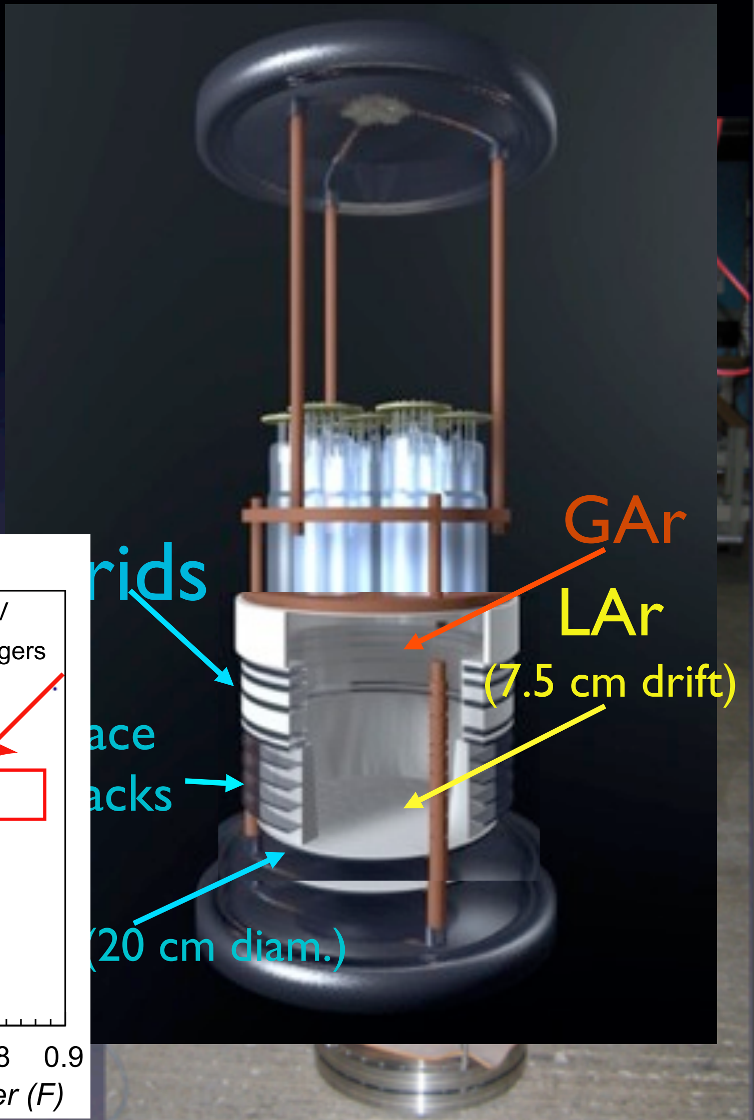
I_s/I_t = 0.3 (e), 1.3 (α), 3.0 (ff)

PSD

a seminal work: WARP 3.2 kg

- Operational since 2005 at LNGS
- First LAr detector to publish DM search results (3 months WIMP search)
- Testing ground for larger scale detectors





P. Benetti et al., Astrop. Phys. 28 (2008) 6

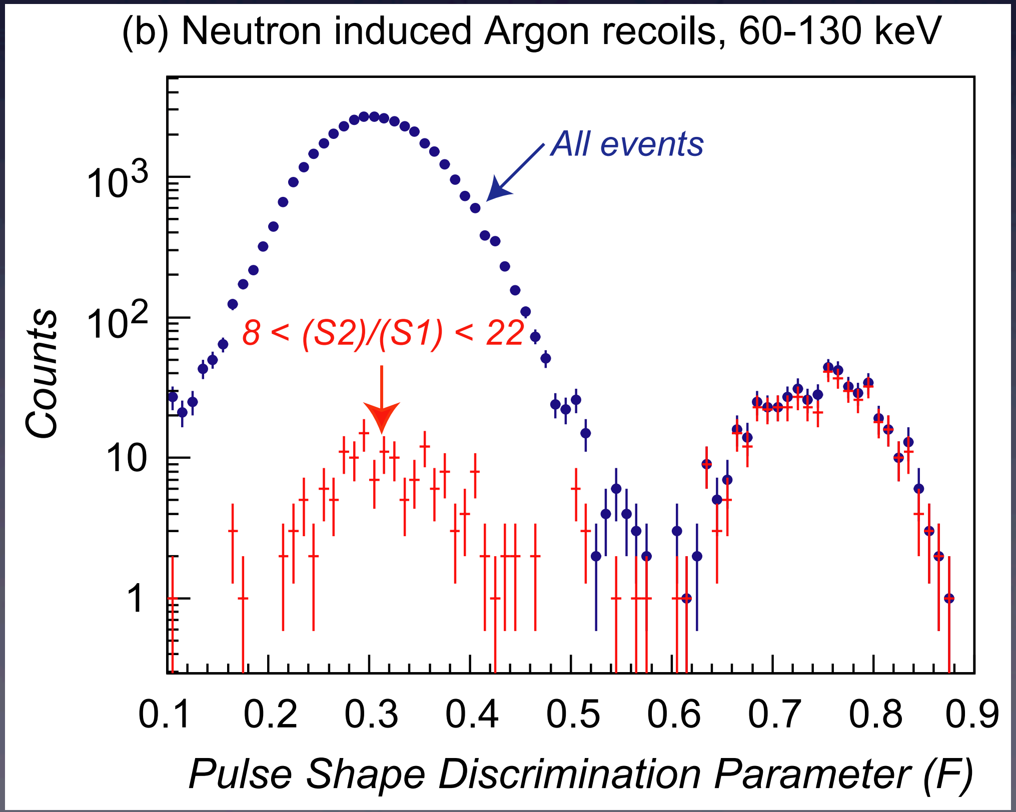
WIMP search results from WARP 3.2 kg

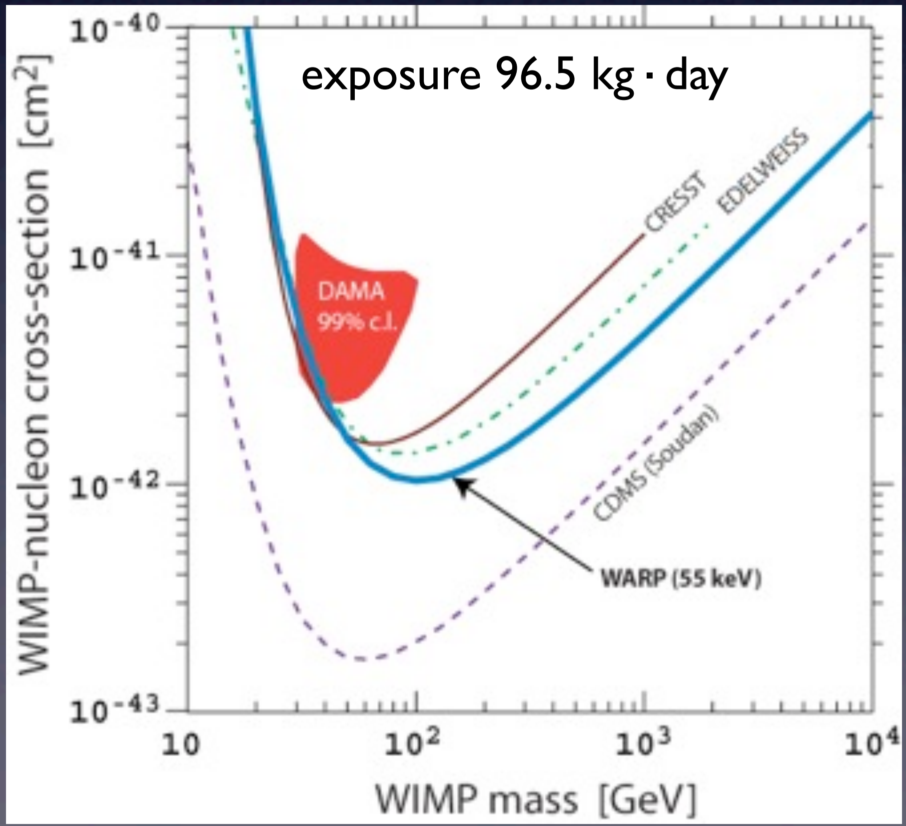
- Very good test of the detection principle
- Excellent results from study of discrimination power between nuclear and electron recoils:

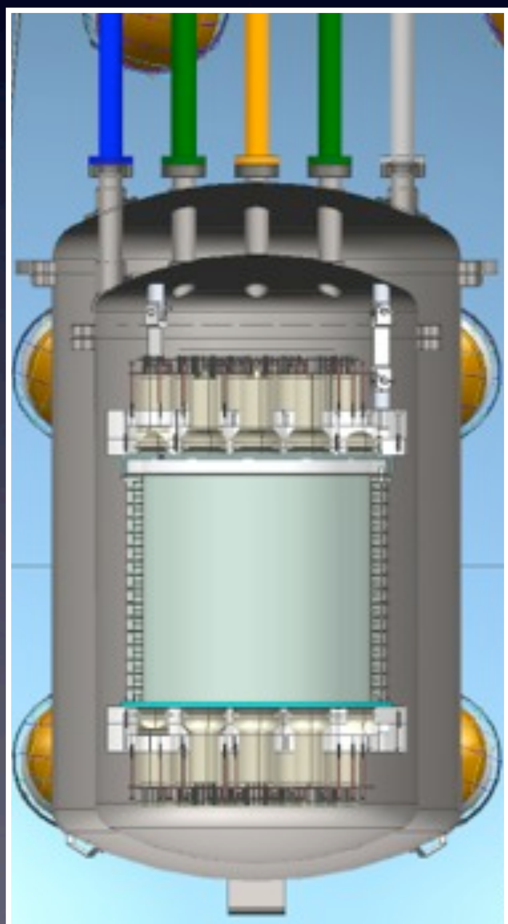
10^{-8} pulse shape discrimination

5×10^{-3} ionization/scintillation

P. Benetti et al., Astrop. Phys. 28 (2008) 6

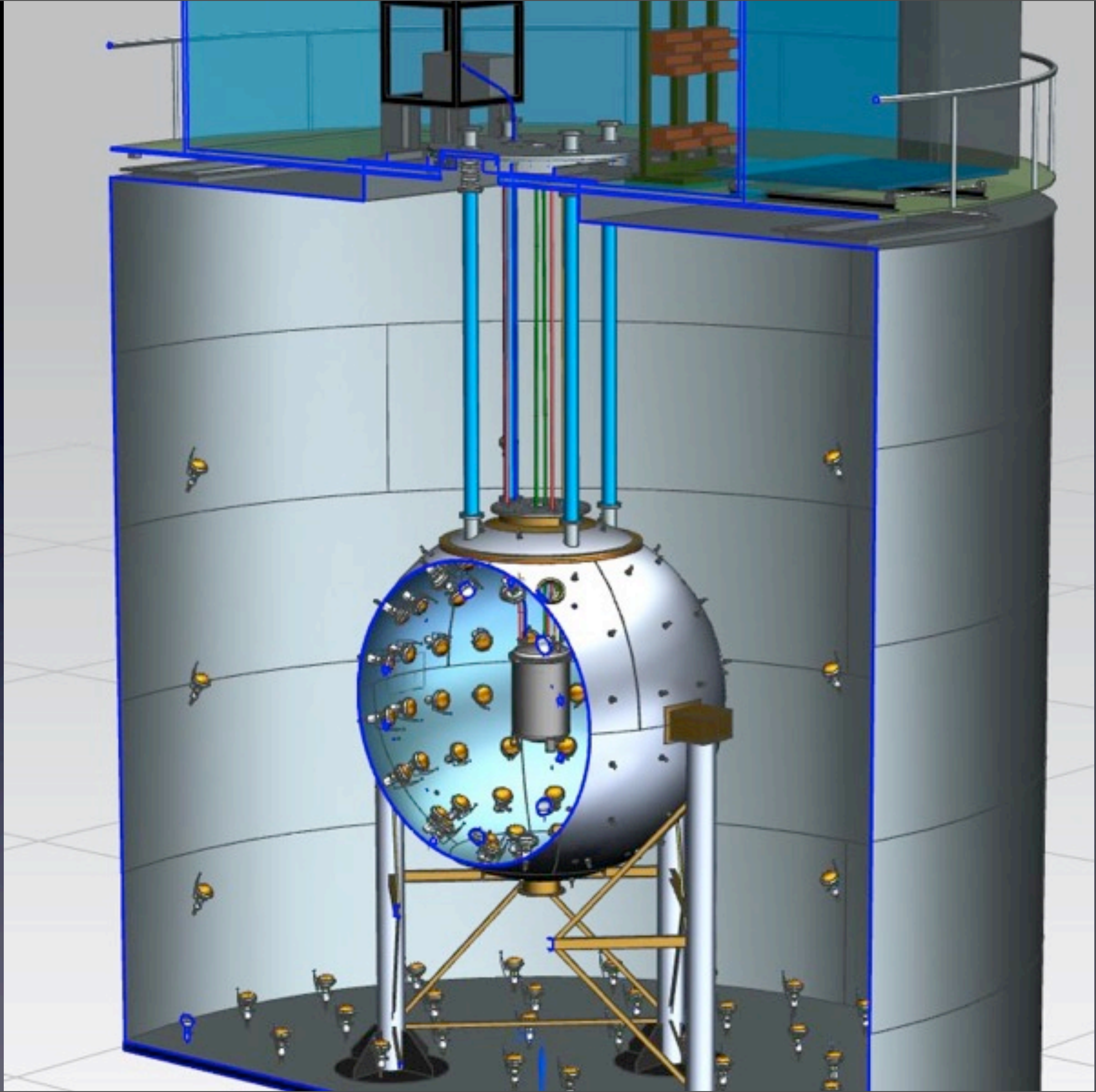






- New technologies for large background-free exposure
  - depleted argon
  - liquid-scintillator based neutron veto
  - ultra-low bkgd PMTs
- DarkSide-50 sensitivity 10^{-45} cm^2
  - Demonstrate potential of the technology for multi ton-year **background-free** sensitivity
- DarkSide-5k sensitivity 10^{-47} cm^2

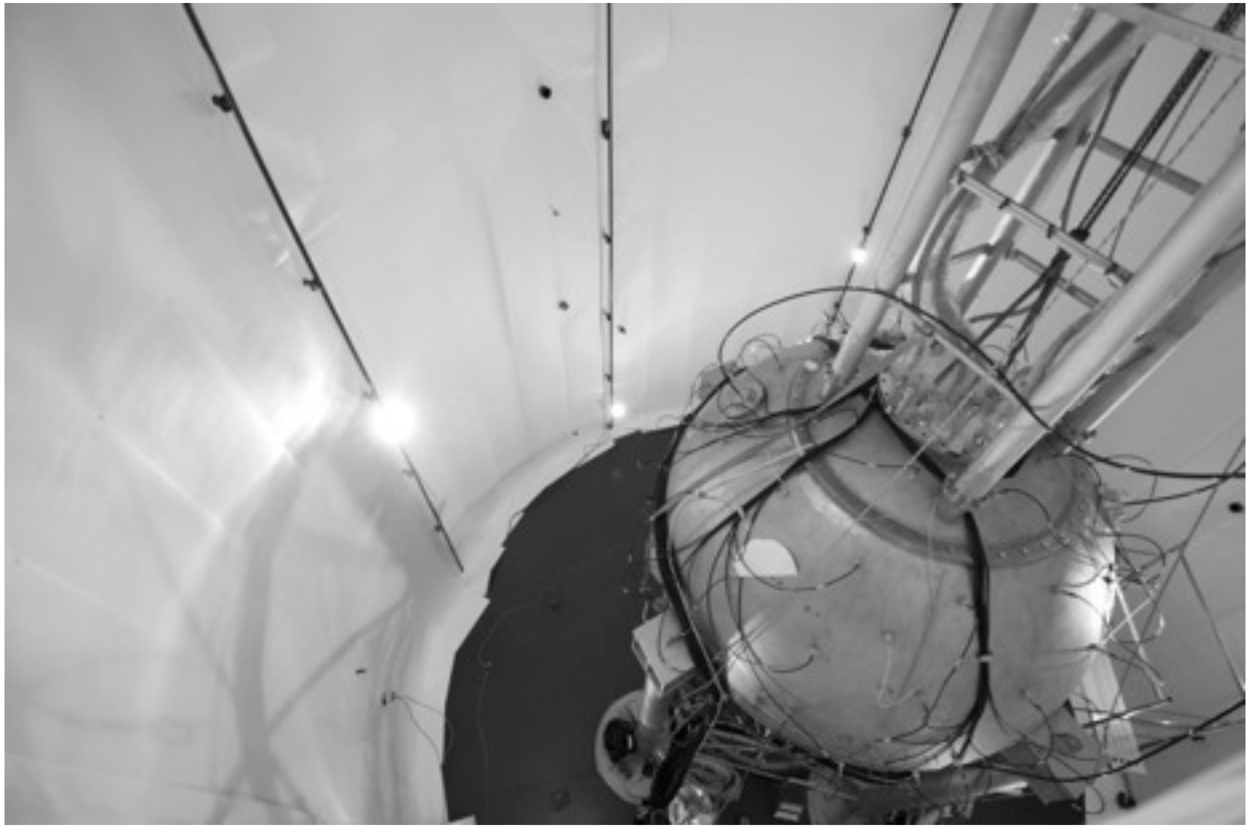
Artist Rendition of DarkSide-50, its 30-ton Neutron Veto, and its 1,000 ton muon veto (CTF)

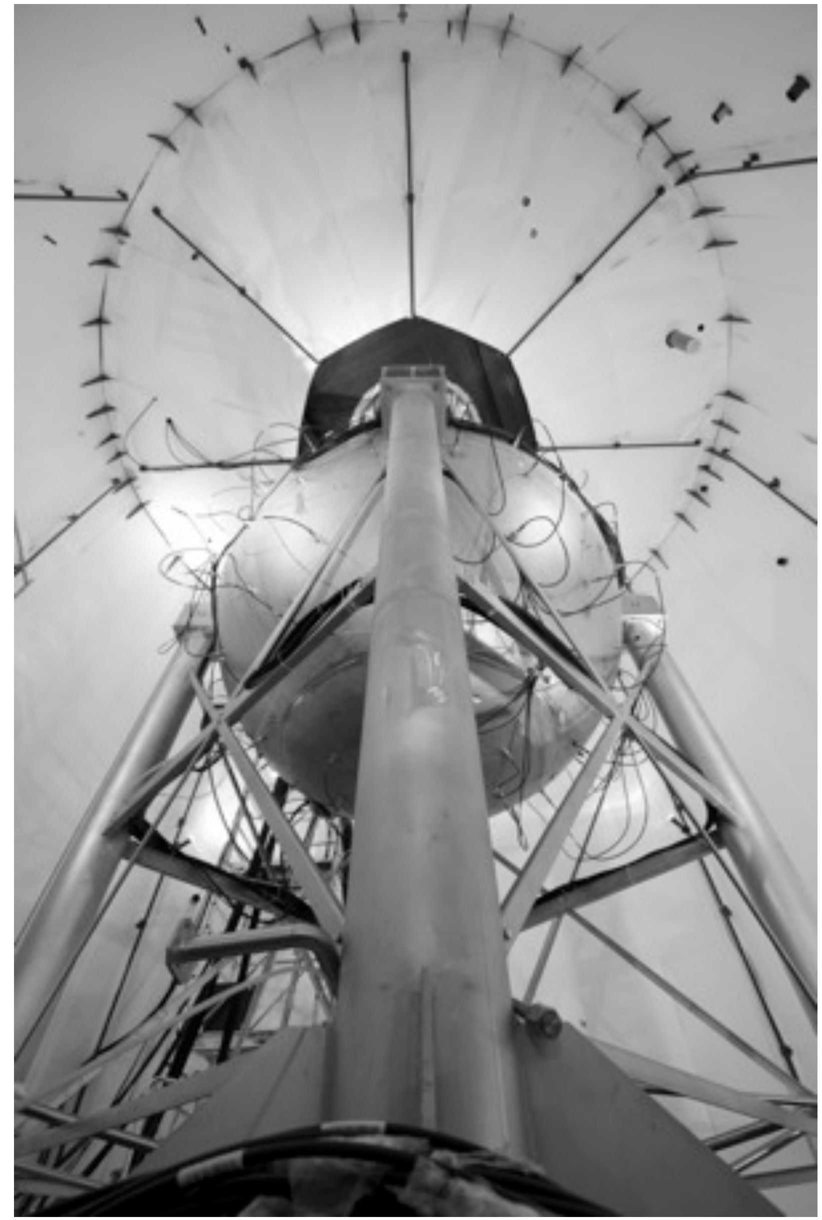


DarkSide-50 Status

- Construction/Assembly near completion
  - ➡ TPC: assembly completed (first deployment configuration)
  - ➡ LSV: assembly completed
  - ➡ WT: assembly partially completed (PMTs still missing)
- Commissioning started end of May 2013
  - ➡ TPC: first test run with atmospheric argon ongoing
  - ➡ LSV: PMTs and electronic tested
- Physics run Fall 2013
- Towards G2 detector: 1,000 tons water Cerenkov muon veto and 30 tons liquid scintillator neutron veto built to house 5-ton DarkSide-G2 dark matter search

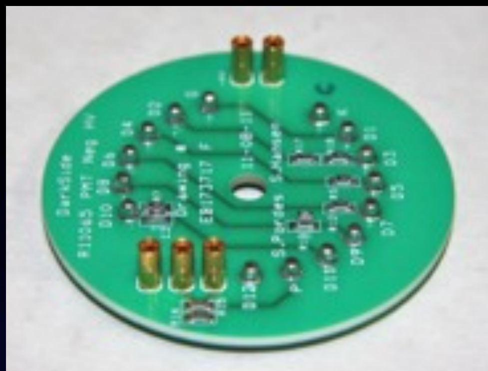
Cryostat containing the Time Projection Chamber hanging inside the neutron veto. The neutron veto sphere will be filled with boron-loaded liquid scintillator.

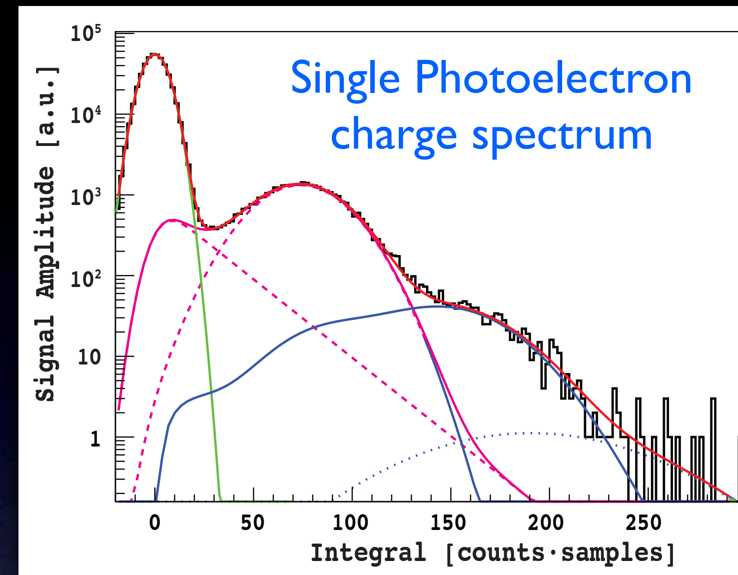




Neutron Veto sphere inside the Water tank.

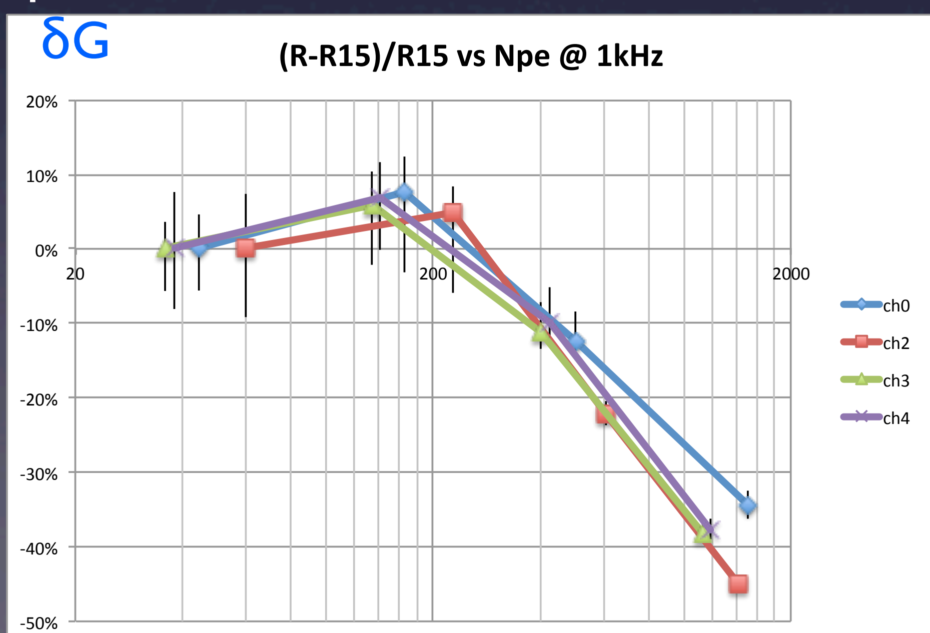
@Napoli: tests of DS-50 cryogenic PMTs

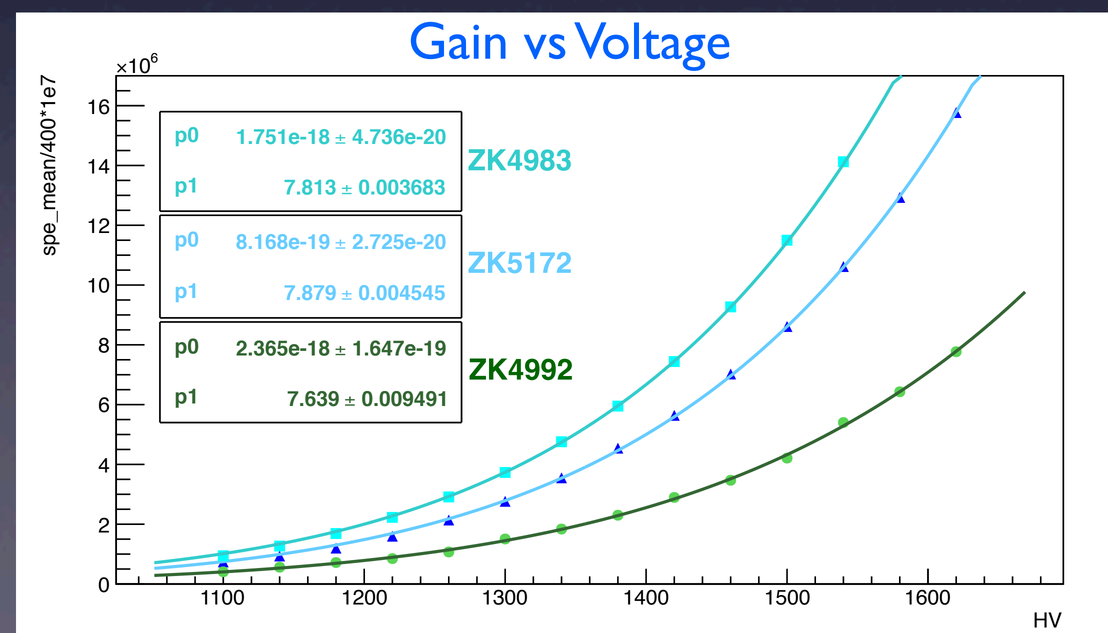




Optimization of the voltage divider
Pulse linearity measurements

Characterization at LN temperature

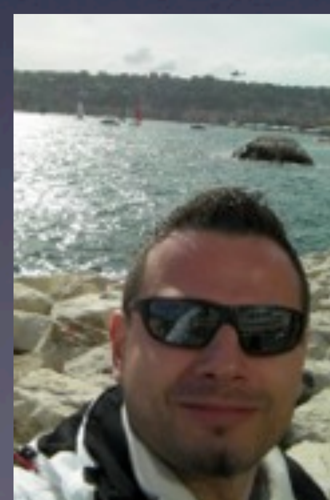




former
Naples
fellows

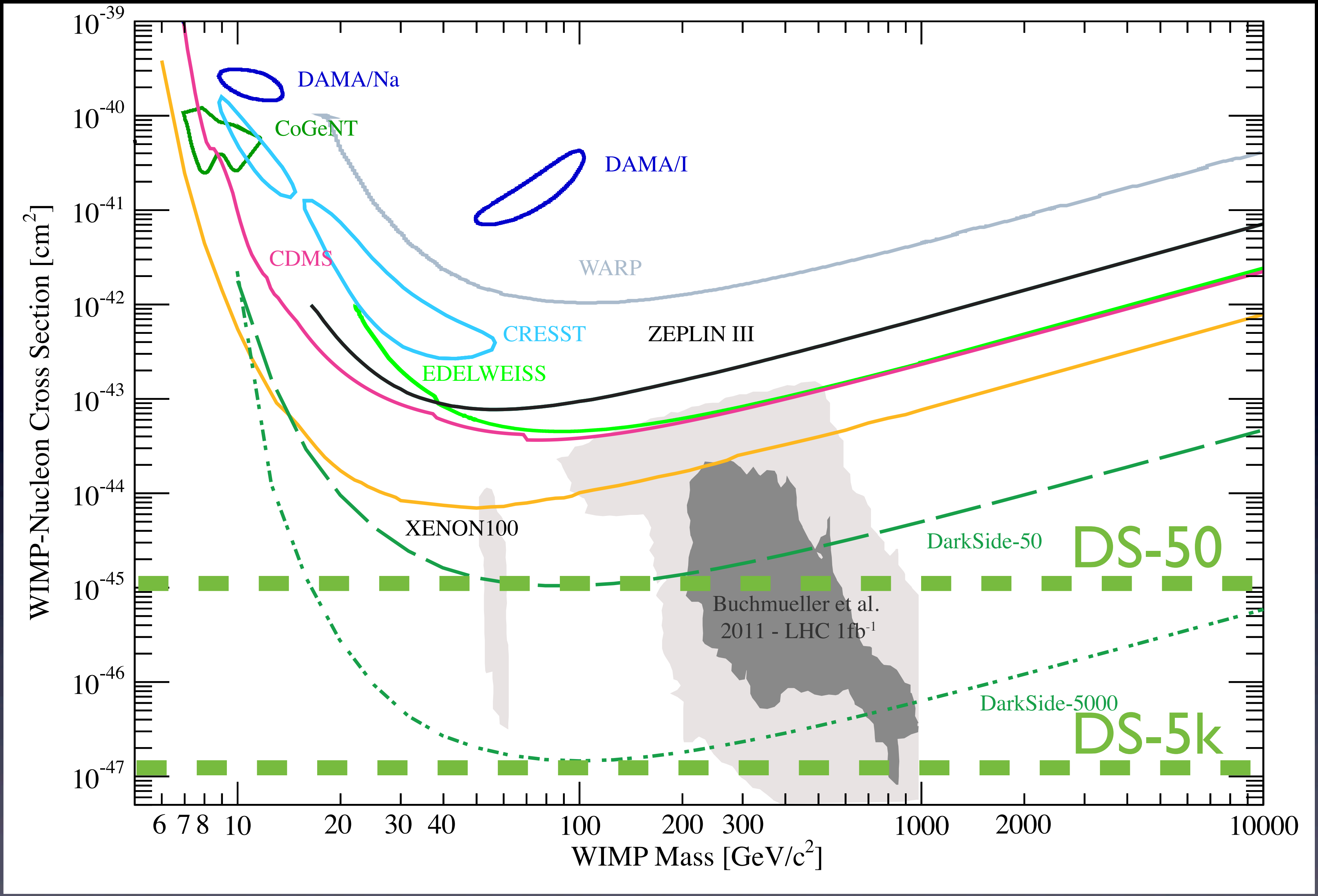
Naples
fellow

Princeton
PhD



Naples
Princeton
fellow !

Cocco



Darkside projected sensitivity

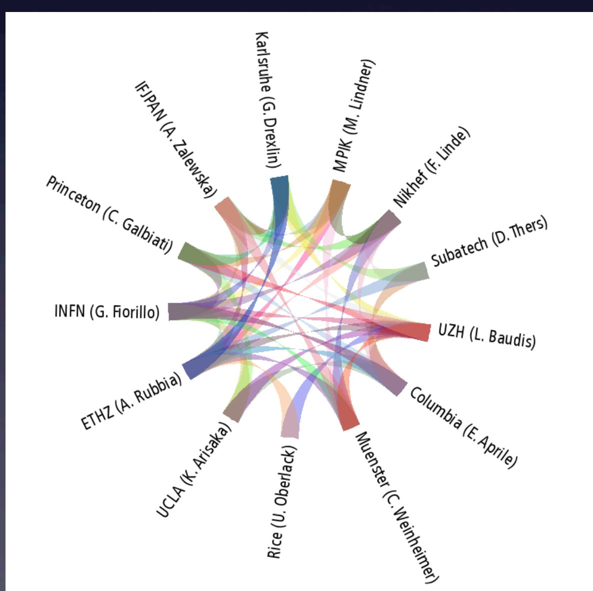
DARWIN

dark matter search with noble liquids

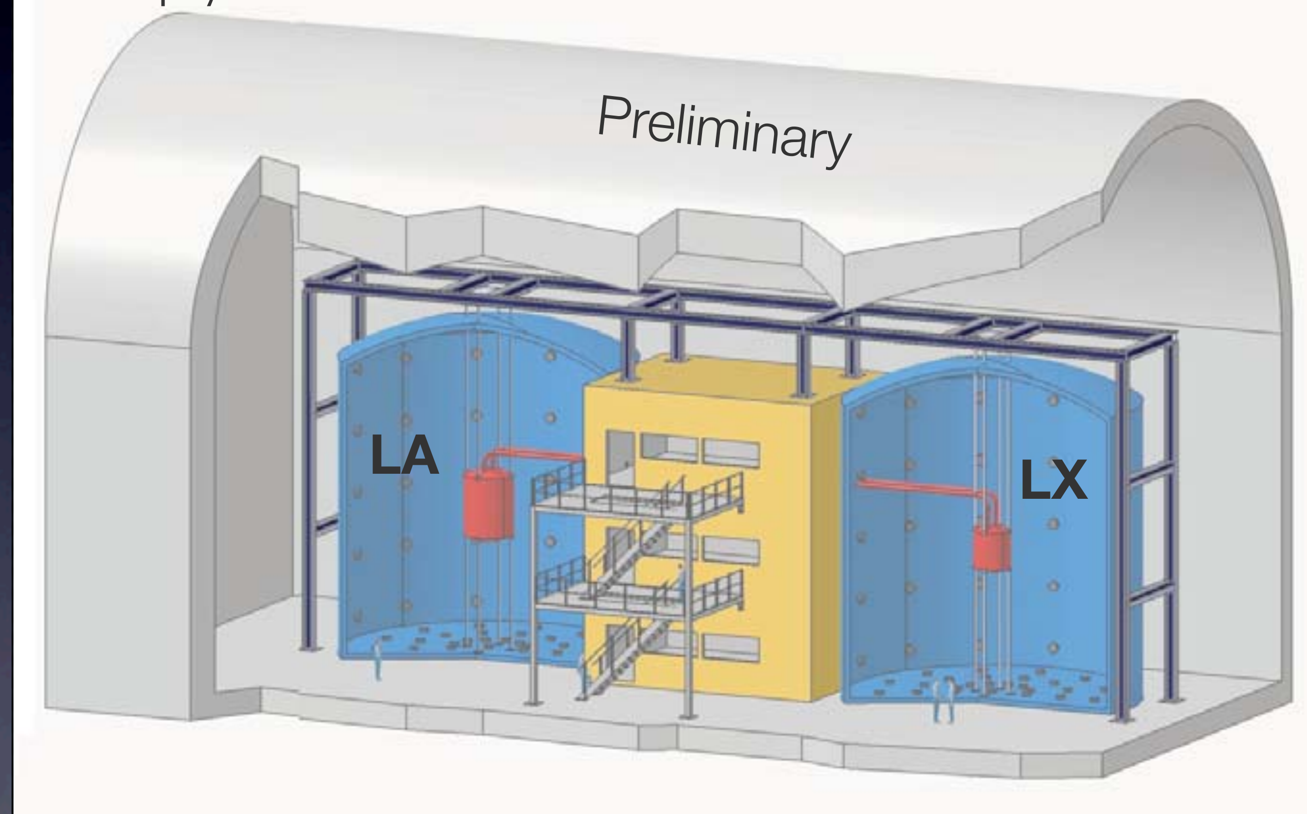
ASPERA

R&D and design study for a multi-ton scale LXe/LAr facility in Europe

funded by FP7-ASPERA in 2010

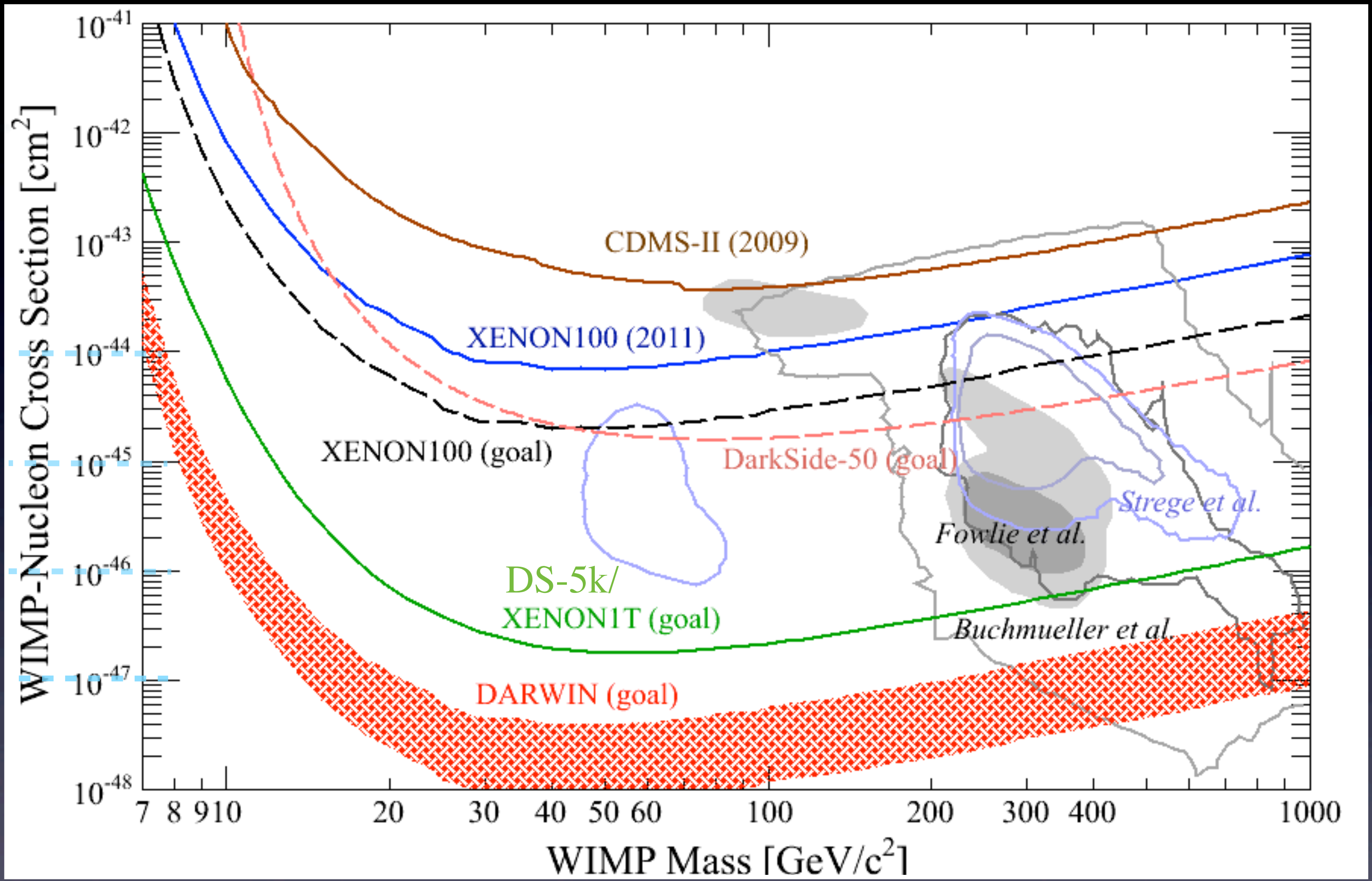


darwin.physik.uzh.ch arXiv:1012.4764v1



A total of 25 groups from ArDM, DarkSide, WARP, XENON
Europe: UZH, INFN, ETHZ, Subatech, Mainz, MPIK, Münster, Nikhef, KIT, TU Dresden,
Israel: WIS, USA: Columbia, Princeton, UCLA, Arizona SU

DARWIN

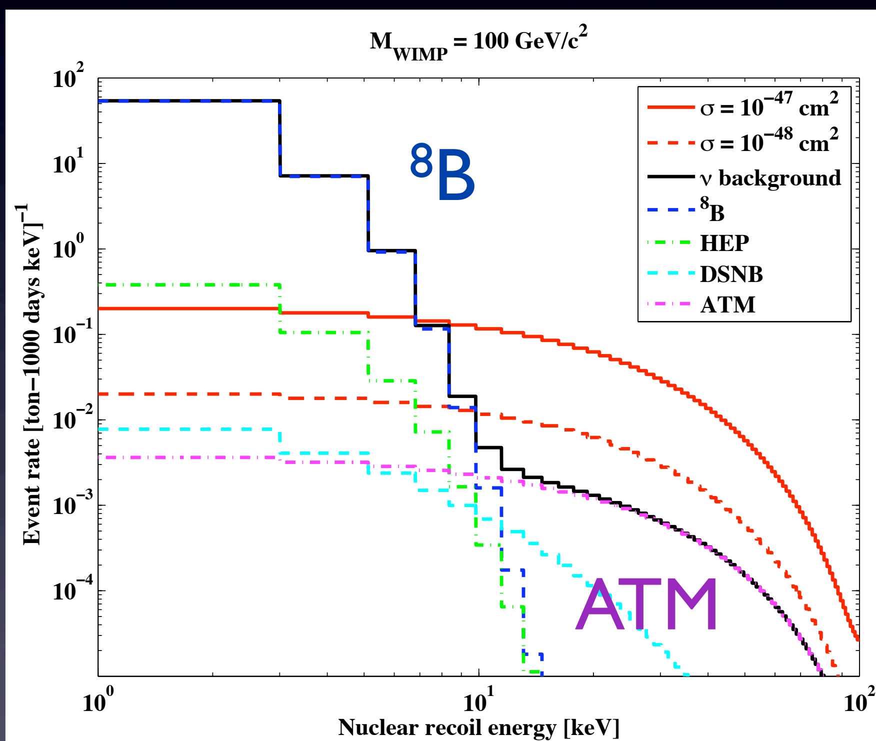


“ultimate” sensitivity

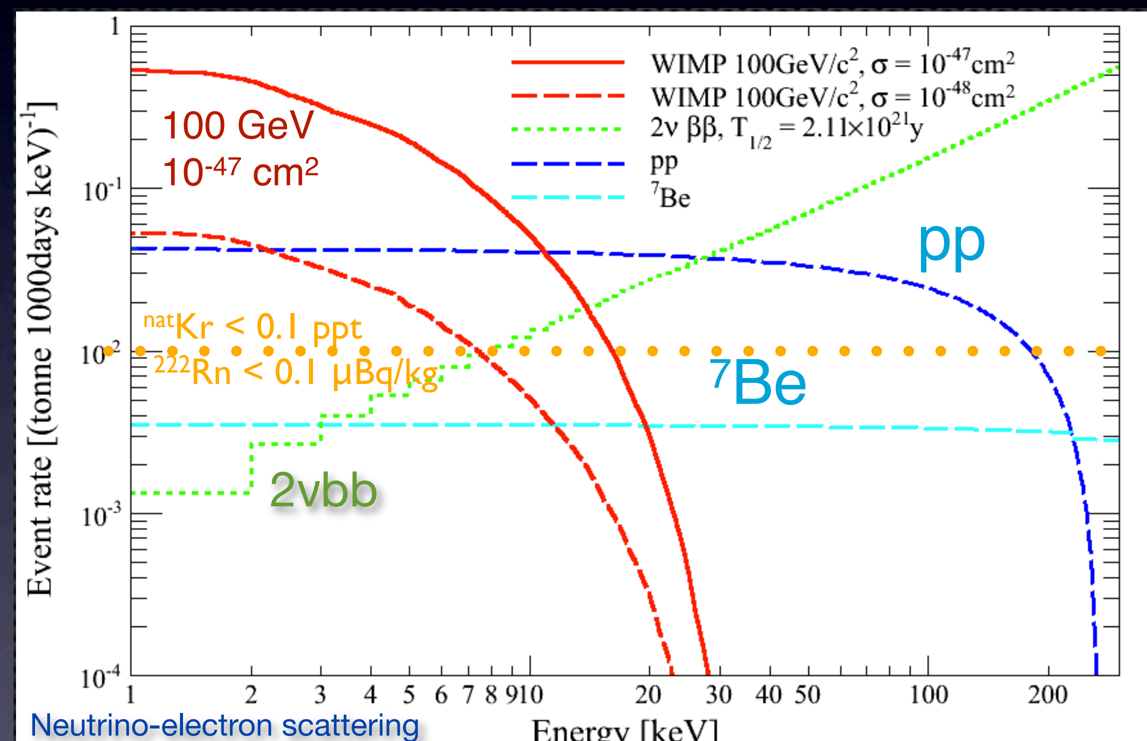
neutrino background or further physics reach?

DARWIN

Neutrino-nucleus scattering



Neutrino-electron scattering



Neutrino spectra: L. Strigari, New J. Phys. 11 (2009)

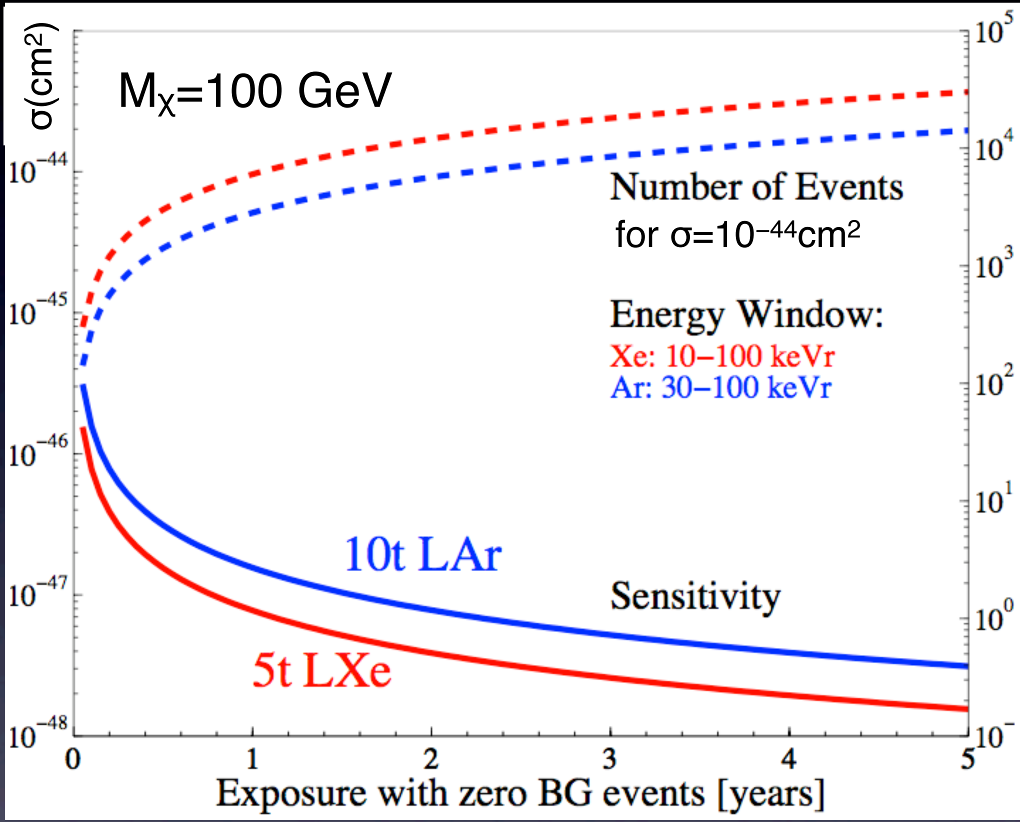
2νββ: EXO measurement of ^{136}Xe $T_{1/2}$

Assumptions: 50% NR acceptance, 99.5% ER discrimination, 80% flat cut acceptance

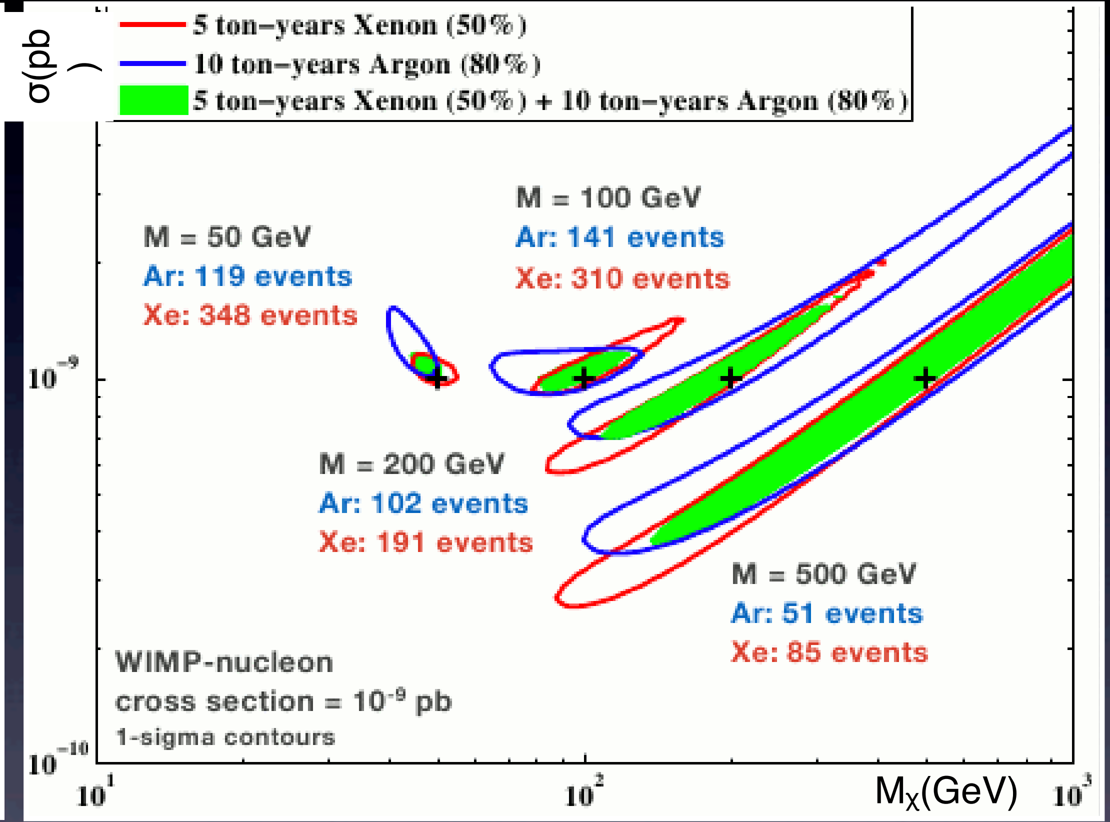
Contribution of 2νββ background can be reduced by using depleted xenon

DARWIN

hundreds of events observed
σ=10^{-44} cm^2



WIMP mass measurement for
σ=10^{-45} cm^2 and two targets



A WIMP observatory

Scientific Roadmaps 2015-2020

"Looking beyond the scale of one ton, we strongly recommend that DARWIN, a program aiming to extend the target mass of noble liquids to several tons, is pursued and supported."

"The construction and operation of the DARWIN multi-ton Dark Matter search facility should receive an appropriate Swiss contribution."

DOE/NSF HEPAP

US Particle Physics: Scientific Opportunities

A Strategic Plan for the Next Ten Years

"The panel further recommends joint NSF and DOE support for direct dark matter search experiments."

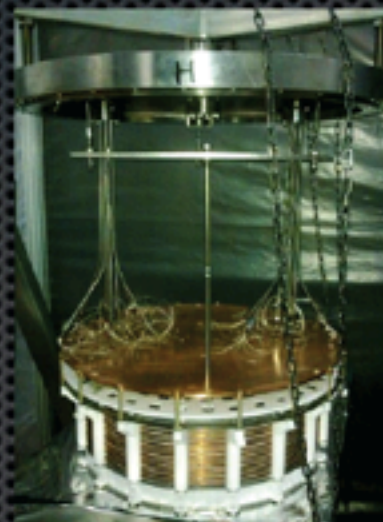
Liquid xenon and liquid argon TPCs

XENON100 at LNGS:

in conventional shield 161 kg LXe (~50 kg fiducial), dual-phase, 242 PMTs
taking science data

LUX at SURF:

in water Cherenkov shield
350 kg LXe (100 kg fiducial), dual-phase, 122 PMTs, physics run to start in early 2013

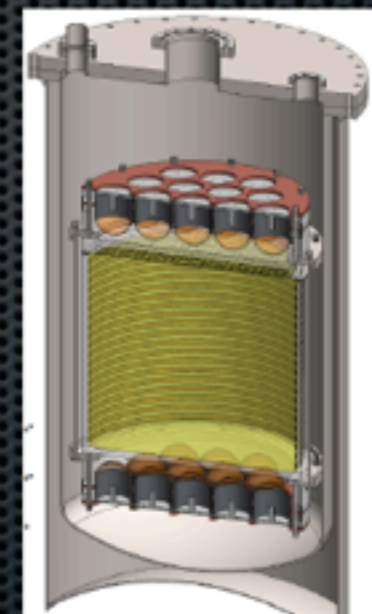


PandaX in conventional shield at CJPL:

stage I: 123 kg LXe (25 kg fiducial), dual-phase, 180 PMTs starts in early 2013

ArDM at Canfranc:

850 kg LAr TPC
2 arrays of PMTs
in commissioning at Canfranc Laboratory

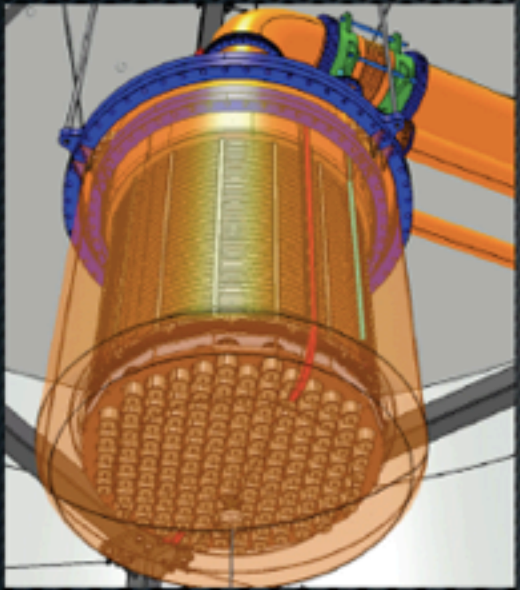


DarkSide at LNGS

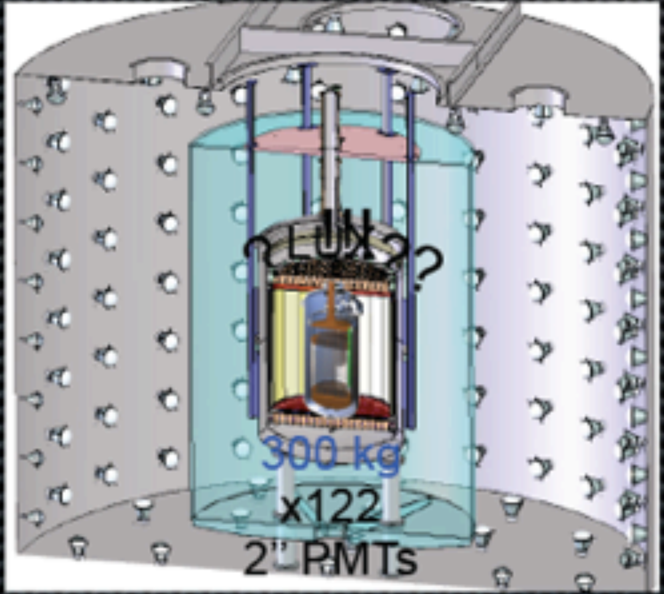
50 kg LAr (depleted in 39Ar) TPC in CTF at LNGS
under construction
to run 2013 - 2014

Liquid xenon and liquid argon detectors

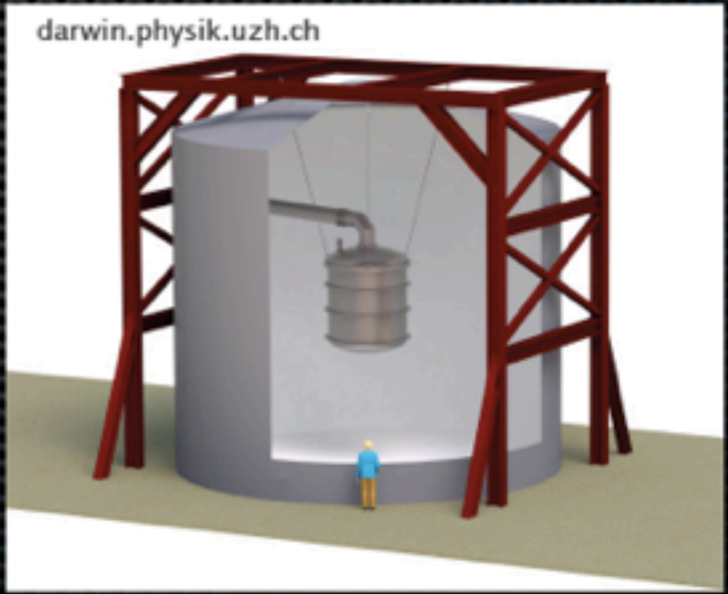
- Under construction: XENON1T at LNGS, 3 t LXe in total
- Future and R&D: XMASS (5 t LXe), LZ (7 t LXe), DARWIN (20 t LXe/LAr)



XENON1T TPC



LZ (LUX + ZEPLIN) 7t LXe



DARWIN 20 t LXe/LAr

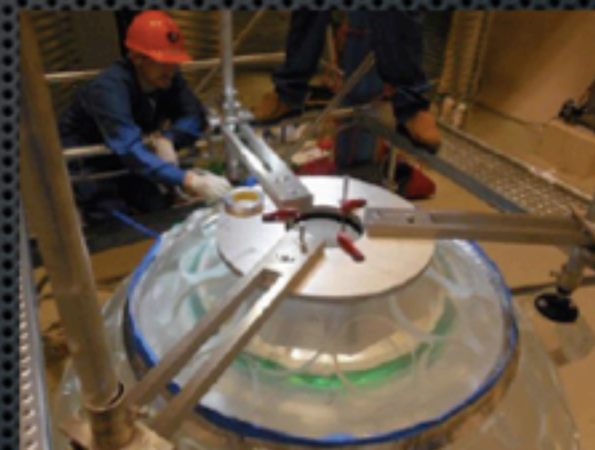
Laura Baudis, University of Zurich, VCI2013, Vienna

Single-phase detectors (light only)

- XMASS at Kamioka (LXe), DEAP/CLEAN at SNOLab (LAr)
- Challenge: ultra-low absolute background

XMASS at Kamioka:
in water Cherenkov shield at Kamioka
835 kg LXe (100 kg fiducial), single-phase, 642 PMTs
soon to take science data

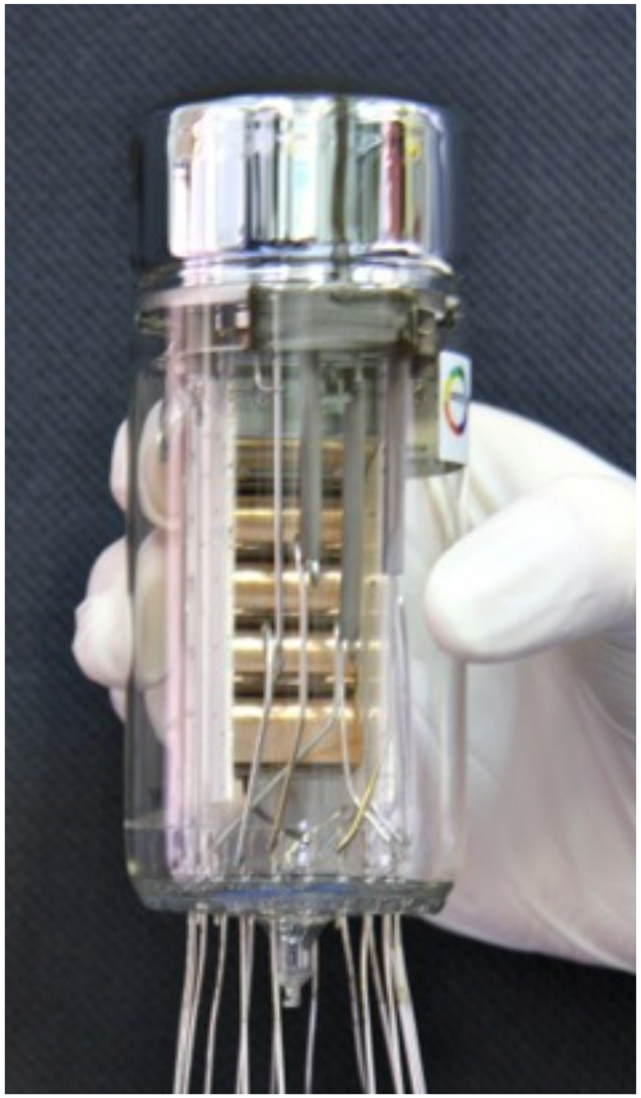
MiniCLEAN at SNOLab:
500 kg LAr (150 kg fiducial)
single-phase open volume
under construction
to run in summer 2013

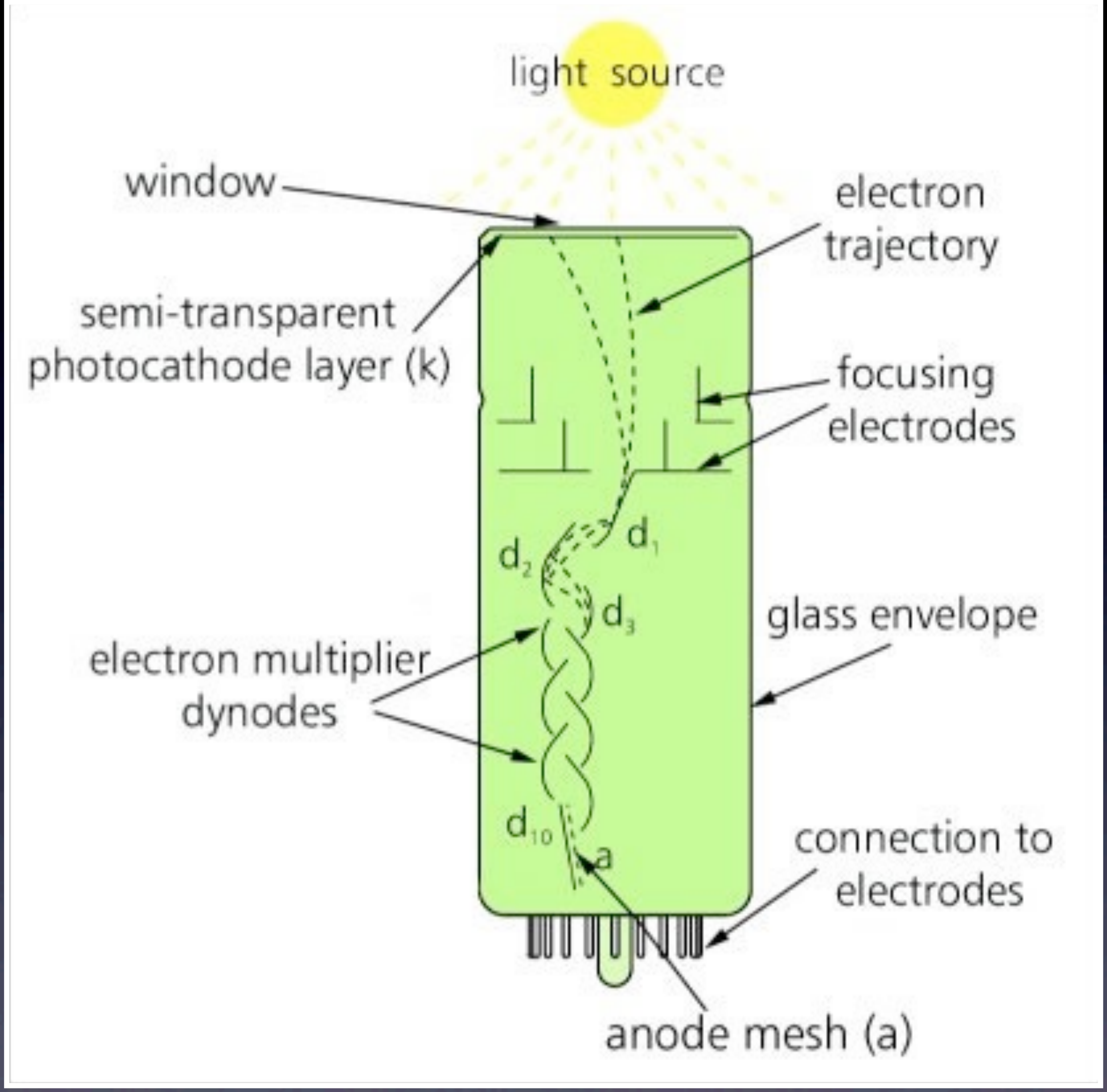


DEAP-3600 at SNOLab:
3600 kg LAr (1t fiducial)
single-phase detector
under construction
to run in 2014

Light on WIMPs

Light collection: PMT Principle



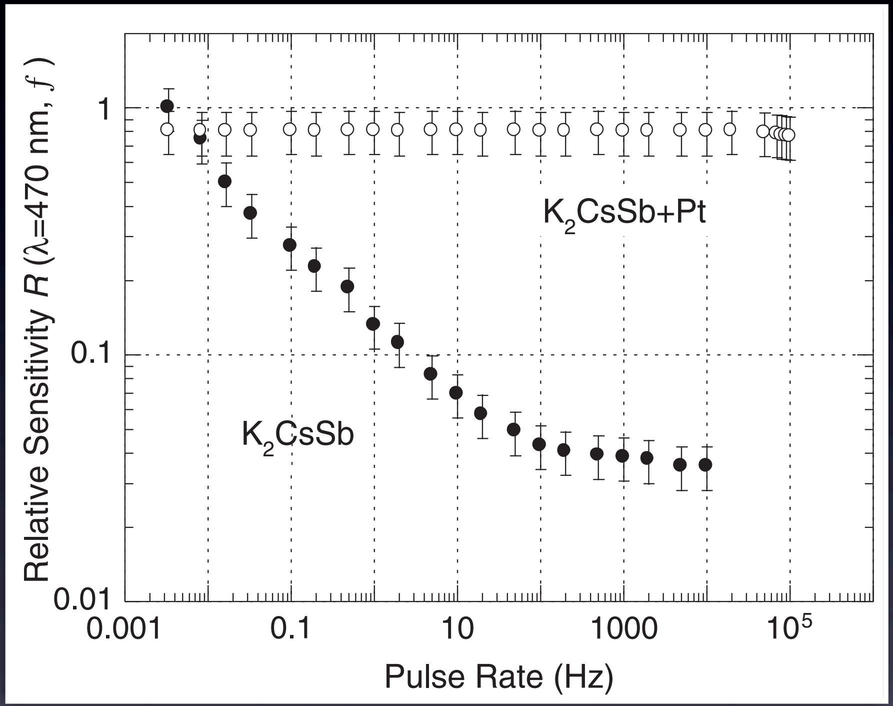


The light signal is converted into a charge signal and amplified: $G \sim 10^6$

Even a single photon can be detected in this way: $Ne = QE \cdot CE \cdot G \cdot N_\gamma$

An ICARUS spin-off: Photocathode sensitivity at LN temperature

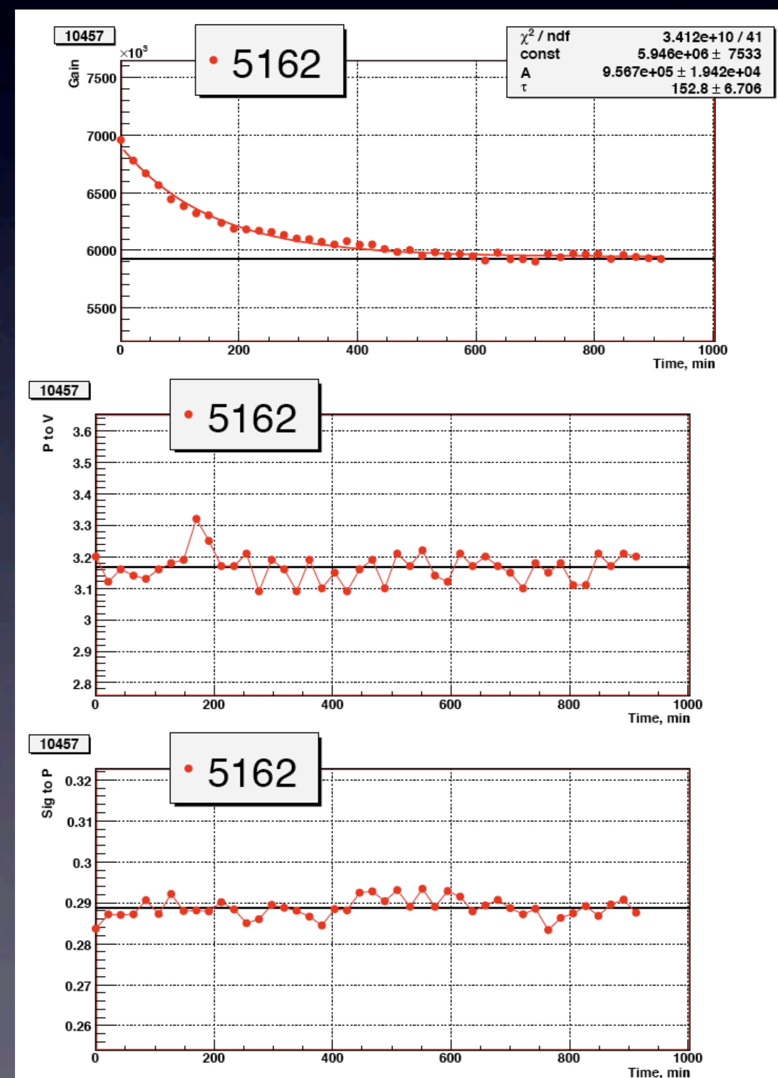
A. Ankowski et al. NIMA 556 (2006) 146



- Increase of photocathode resistivity at low temperature → non-linear response
- The drawbacks due to the photocathode resistivity can be avoided at manufacture by the use of conductive underlayers

Napoli PMT test facility

More than 400 PMTs characterized at cryogenic temperature for the WARP programme



gain stabilization

peak to valley ratio

single pe resolution

Warp R&D on photomultipliers

QE~19%

QE~33%

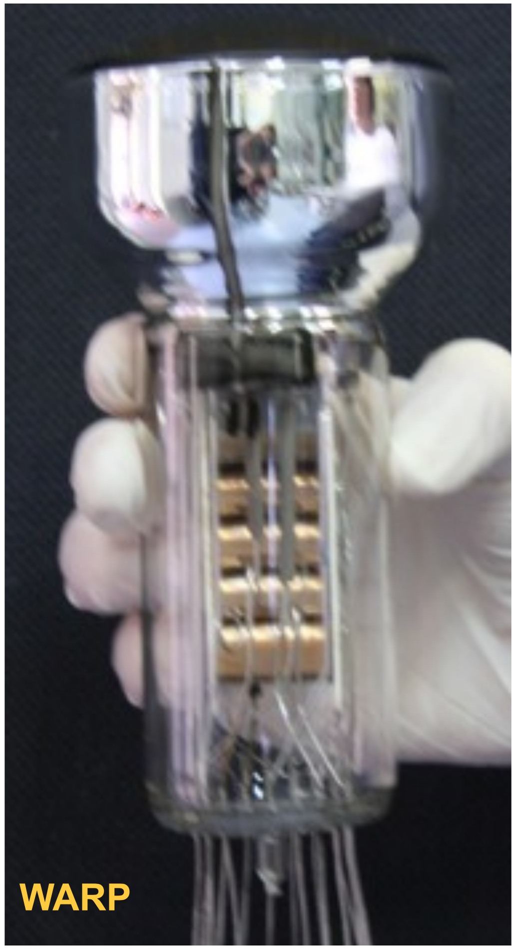
Metal underlayer to increase conductivity of photocathode at LAr temperature

New LT-Bialkali photocathode

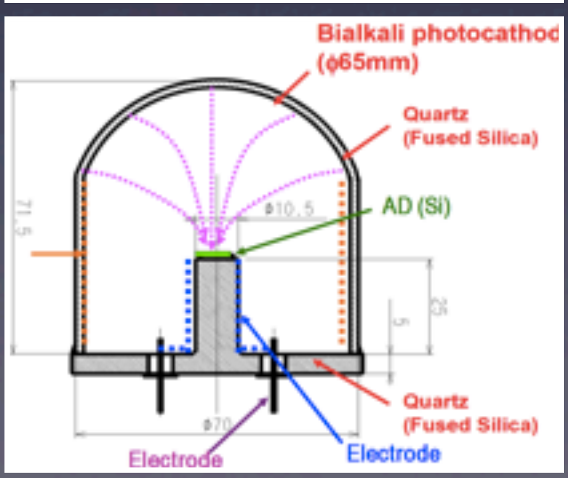
Special development: low-radioactive photodetectors

100 mBq → 10 mBq → <1 mBq

by ETL:

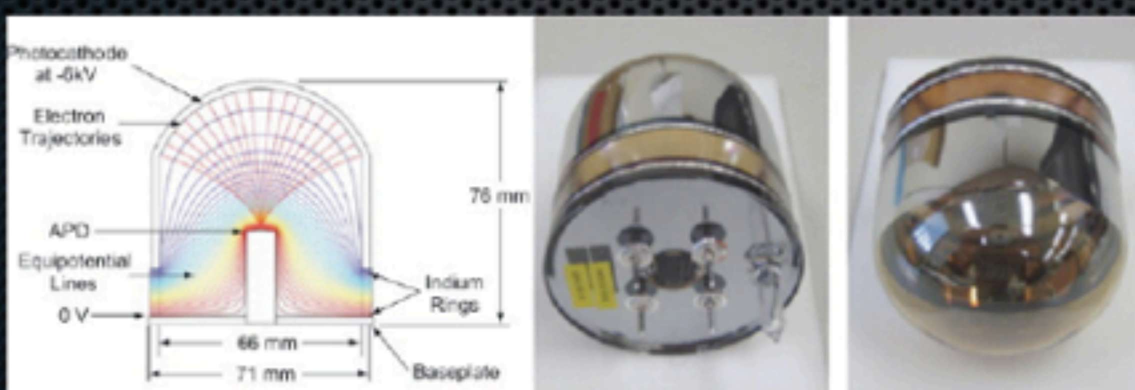


by Hamamatsu:

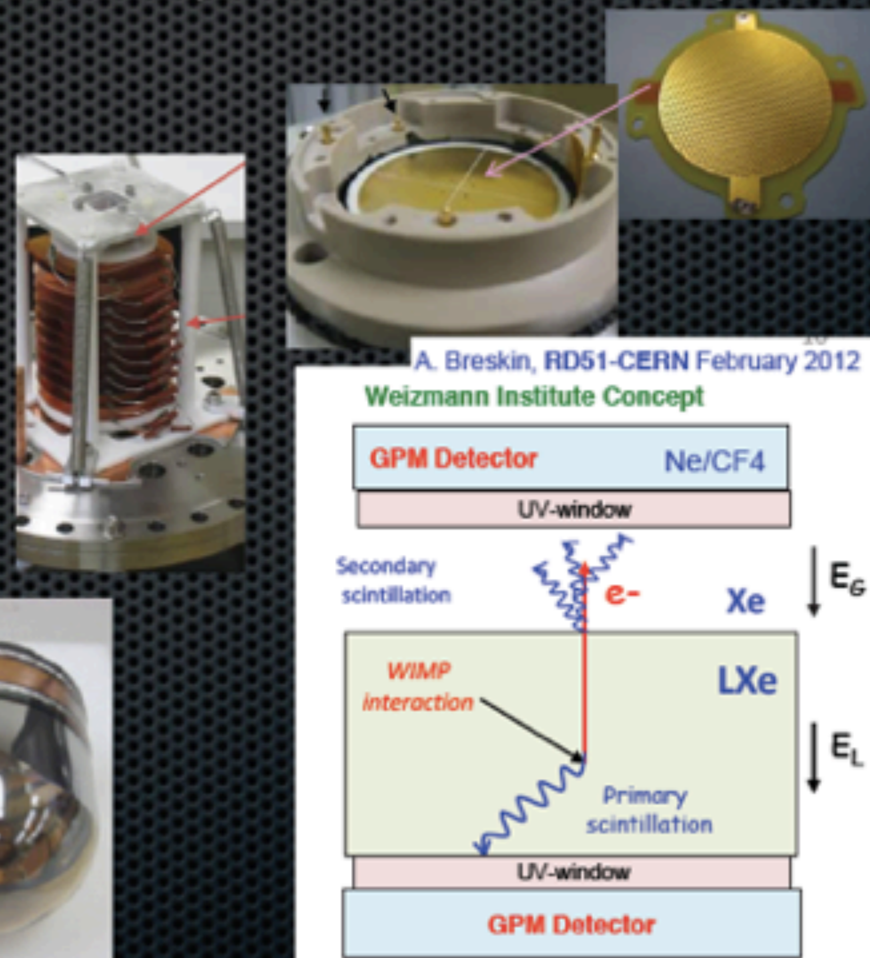


Photodetectors in noble liquids

- New ideas: gas photomultipliers (GPMs)
- hybrid photodetectors (QUPID), LAAPDs (so far in EXO - LXe)



QUPID for LXe/LAr detectors

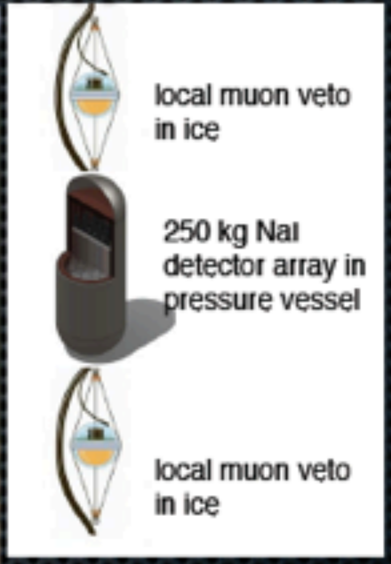


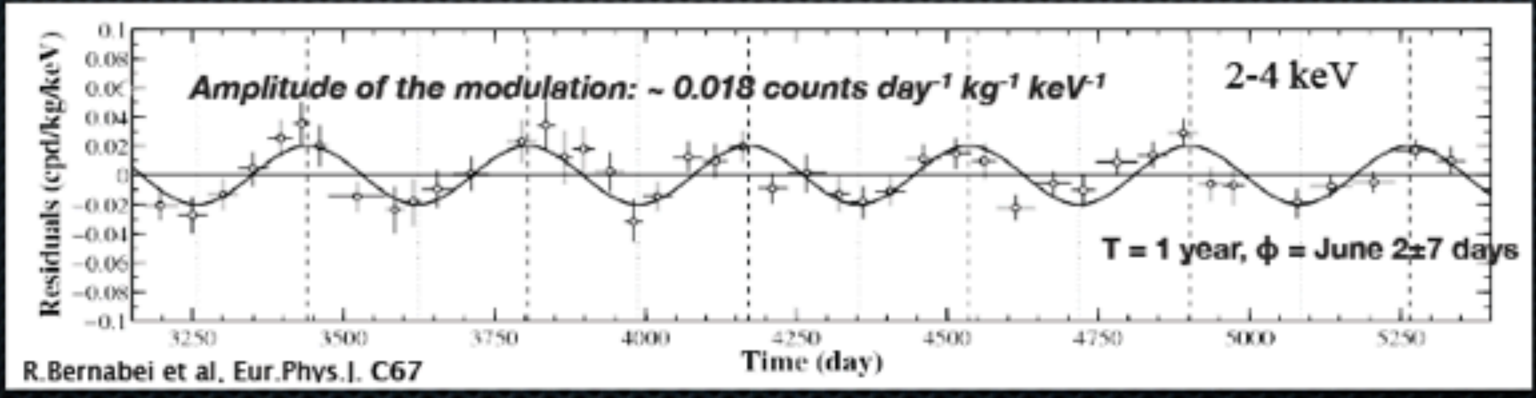
GPM LXe/LAr detectors

Room temperature scintillators

- NaI: DAMA/LIBRA, ANAIS; CsI: KIMS
- New idea: DM-Ice -> 17 kg NaI deployed as feasibility study at the South Pole (look for annual modulation in the southern hemisphere, 2.4 km deep in ice)
- Goal: build a 250-500 kg NaI detector array, closely packed inside a pressure vessel; use IceCube as a veto

DM-Ice





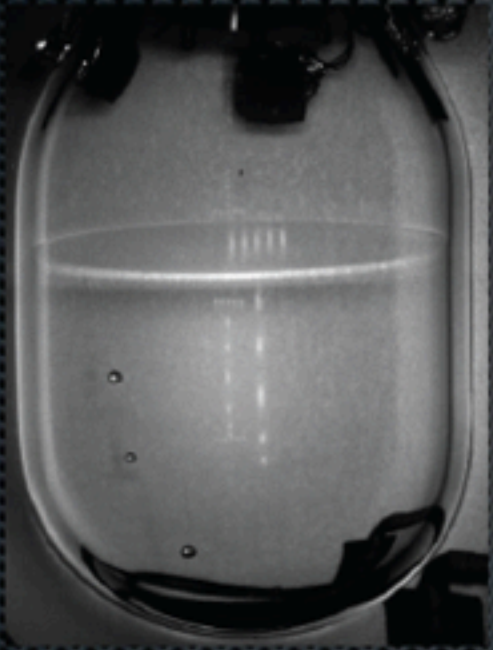
Bubble chambers

- Detect single bubbles induced by high dE/dx nuclear recoils in heavy liquid bubble chambers (with acoustic, visual or motion detectors)
- Large rejection factor for MIPs (10^{10}), scalable to large masses, high spatial granularity
- Existing detectors: COUPP, PICASSO, SIMPLE
- Future: COUPP-500 -> ton-scale detector

Example:

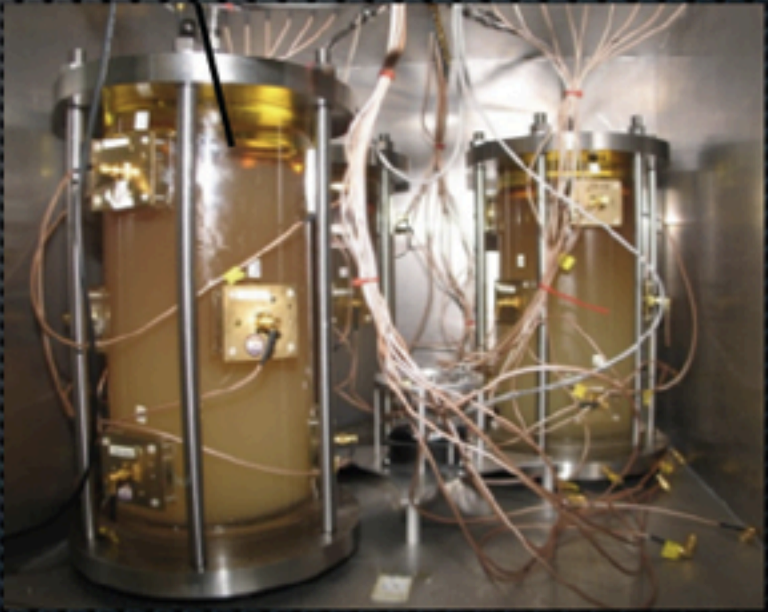
n-induced event (multiple scatter)

WIMP: single scatter



COUPP 4 kg CF_3I detector at SNOLAB

COUPP 60 kg CF_3I detector installed at SNOLAB; physics run in March 2013

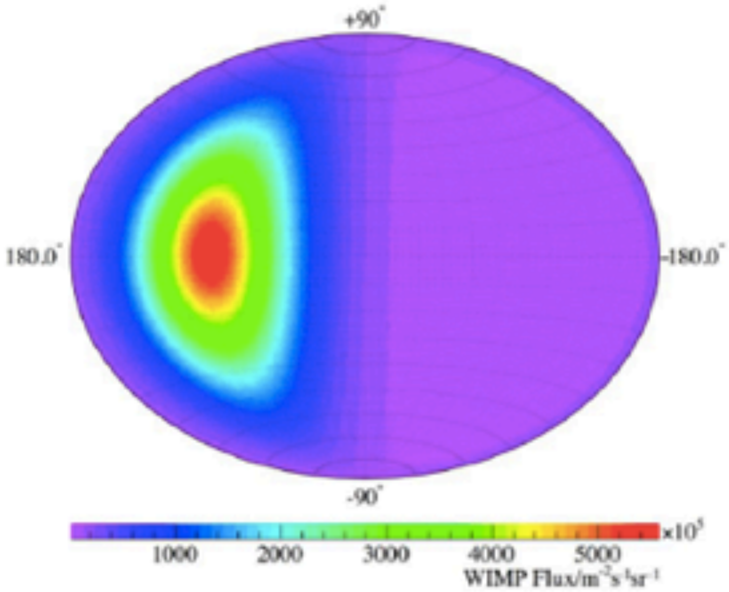


PICASSO at SNOLAB

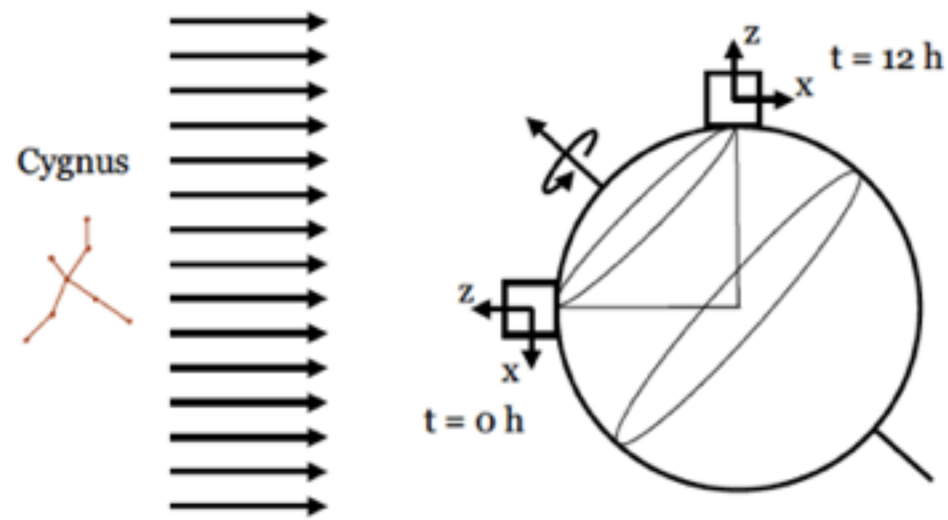
Recoil range << 1 μm in a liquid - very high dE/dx

Directional dependance of the signal

- The Earth's motion with respected to the Galactic rest frame produces a direction dependance of the recoil spectrum
- The peak WIMP flux comes from the direction of the solar motion, which points towards the constellation Cygnus
- Assuming a smooth WIMP distribution, the recoil rate is then peaked in the opposite direction
- In the laboratory frame, this direction varies over the course of a sidereal day due to the Earth's rotation
- This effect can provide a robust signature for a Galactic origin of a WIMP signal



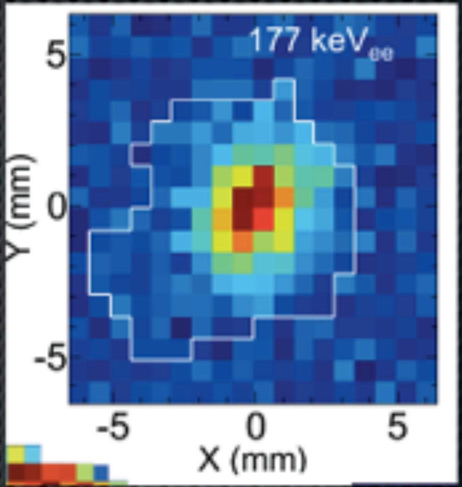
Projection of the WIMP flux in Galactic coordinates

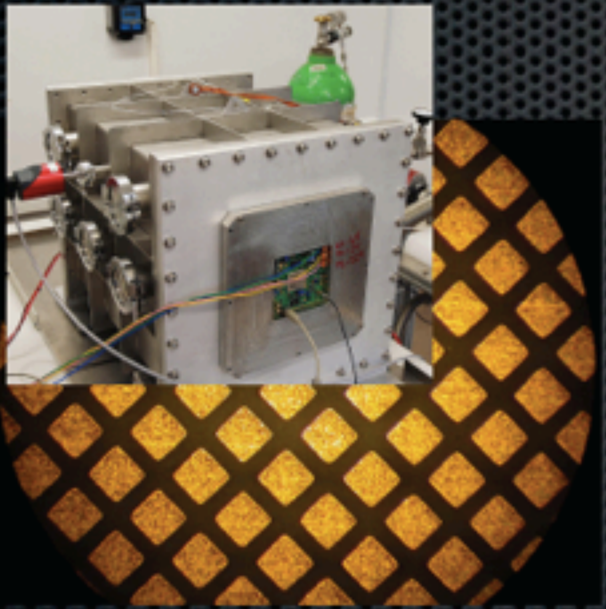


Directional detectors

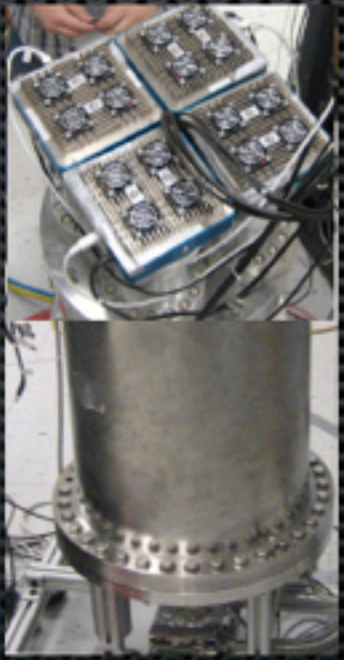
- R&D on low-pressure gas detectors to measure the recoil direction, correlated to the galactic motion towards Cygnus
- MicroTPCs: MIMAC (CF_4, CHF_3, H gas), NEWAGE (CF_4 gas)
- TPC: DRIFT (negative ion, CS_2), DM-TPC (CF_4 gas)
- New ideas: see talk by D. Nygren

DM-TPC
n-calibration





MIMAC 100x100 mm^2
5l chamber at Modane



18l DM-TPC at MIT
CCD readout

NEWAGE, Kamioka

DRIFT, Boulby Mine

References

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