Dark Matter Status Review

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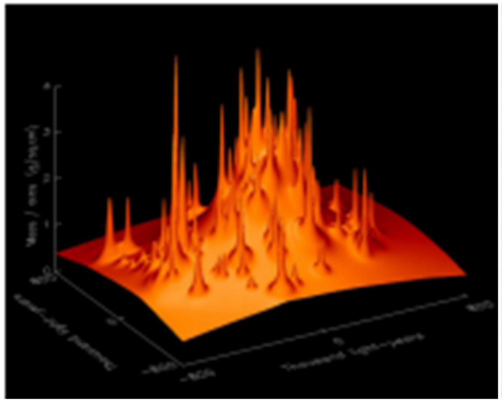
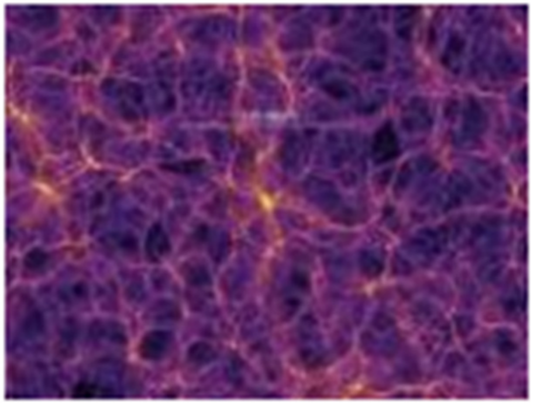
Outline

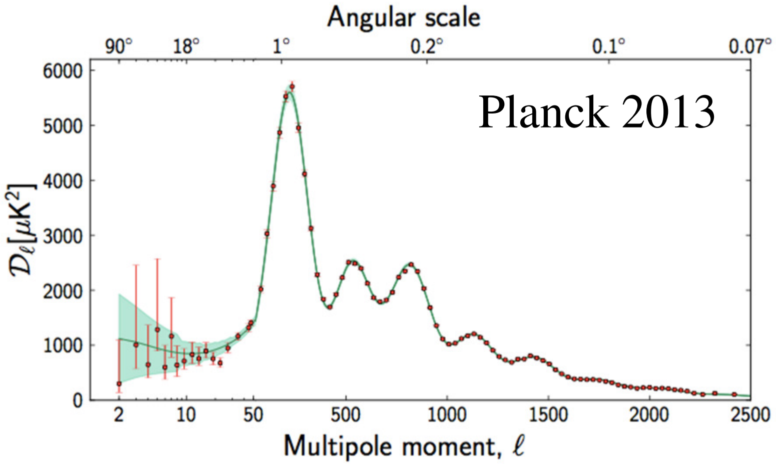
- Introduction
- The Dark Matter problem
- Direct Detection of DM
- Current experimental results
- Prospects

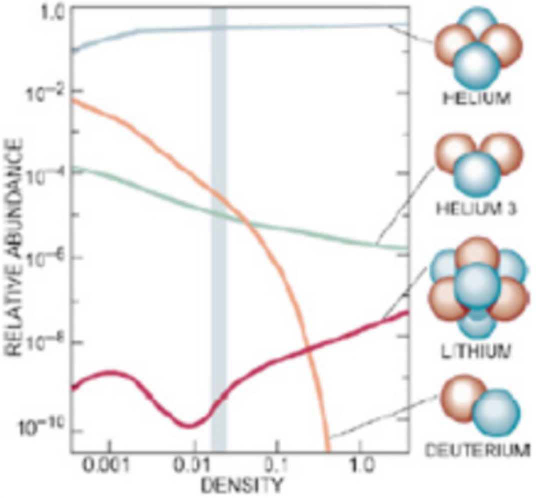
The Dark Matter problem

- The ΛCDM model has been successful explaining CMB, large scale structure etc..
- It fits all the observations with only 6 parameters
- A Cold Dark Matter model is necessary for the formation of structure and galaxies in the universe

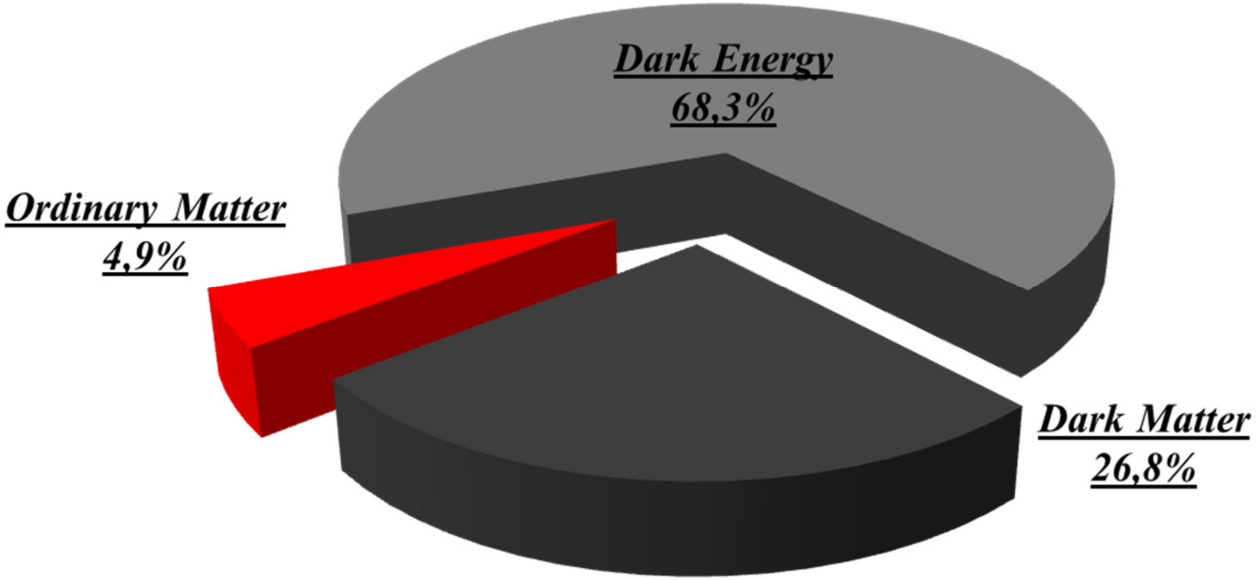






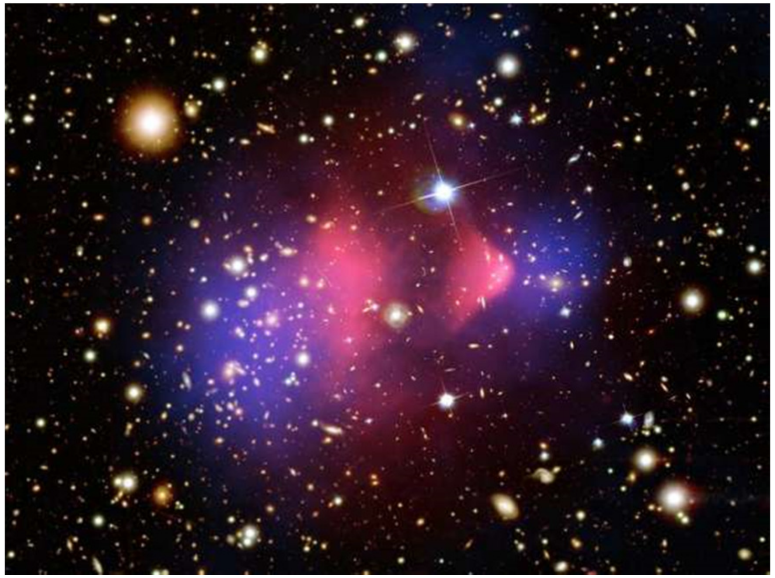


The Dark Matter problem

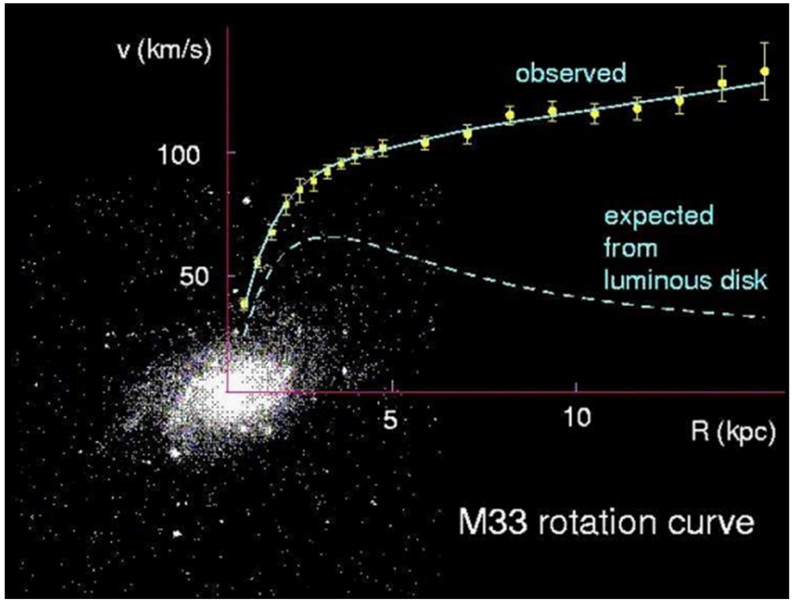


- Invisible dark matter makes up most of the universe – but we can only detect it from its gravitational effects
- The nature of dark matter is one of the most fundamental problems in modern physics and cosmology

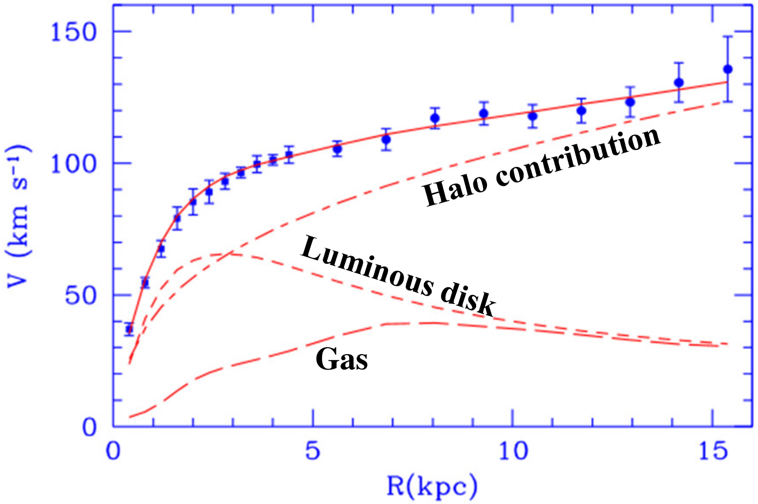
More evidences



(1E 0657-558) Bullet Cluster
Dark matter (blue)
Luminous matter (red)



Stars at high radius are faster than expected



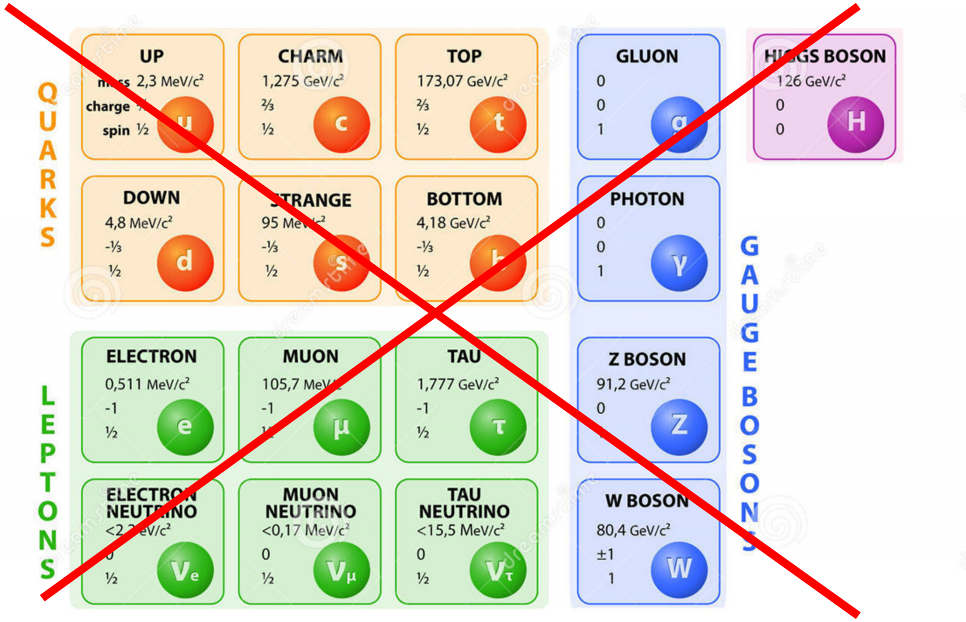
E *Corbelli*, P *Salucci*. MNRAS *311*, *441*-447, 2000

What is Dark Matter made of?

MOND has problems with weak lensing and CMB
MACHOs mostly ruled out

Constraints from astrophysics and searches for new particles:

- No color charge
- No electric charge
- Non-relativistic
- No strong self-interaction
- Stable, or very long-lived

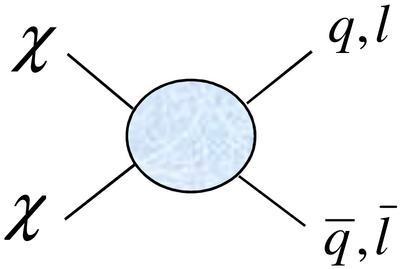


Not a particle in the Standard Model of particle physics!!!!

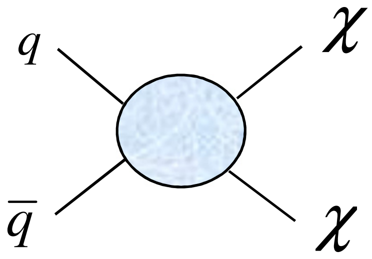
Which way?


Dark Matter
Dark Matter
Dark Matter
Dark Matter
Dark Matter
Dark Matter

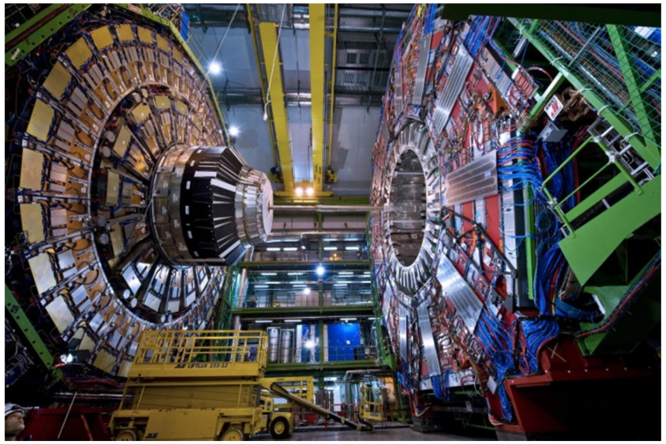
Detection

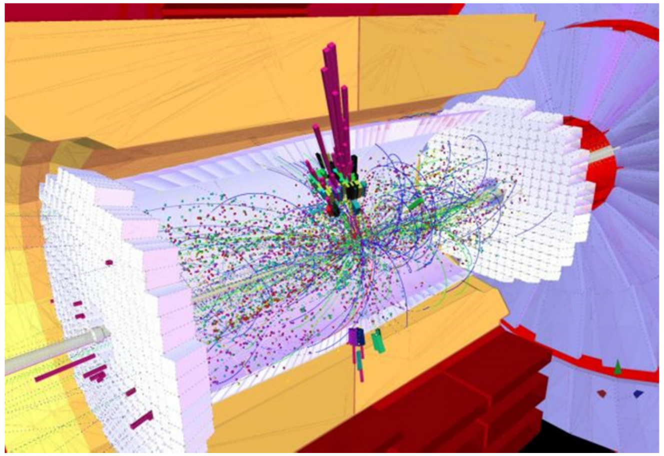


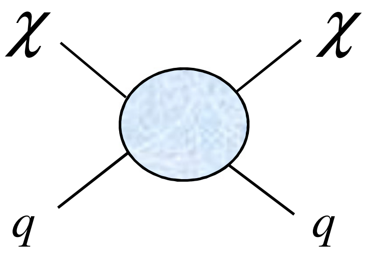
Above ground



Collider

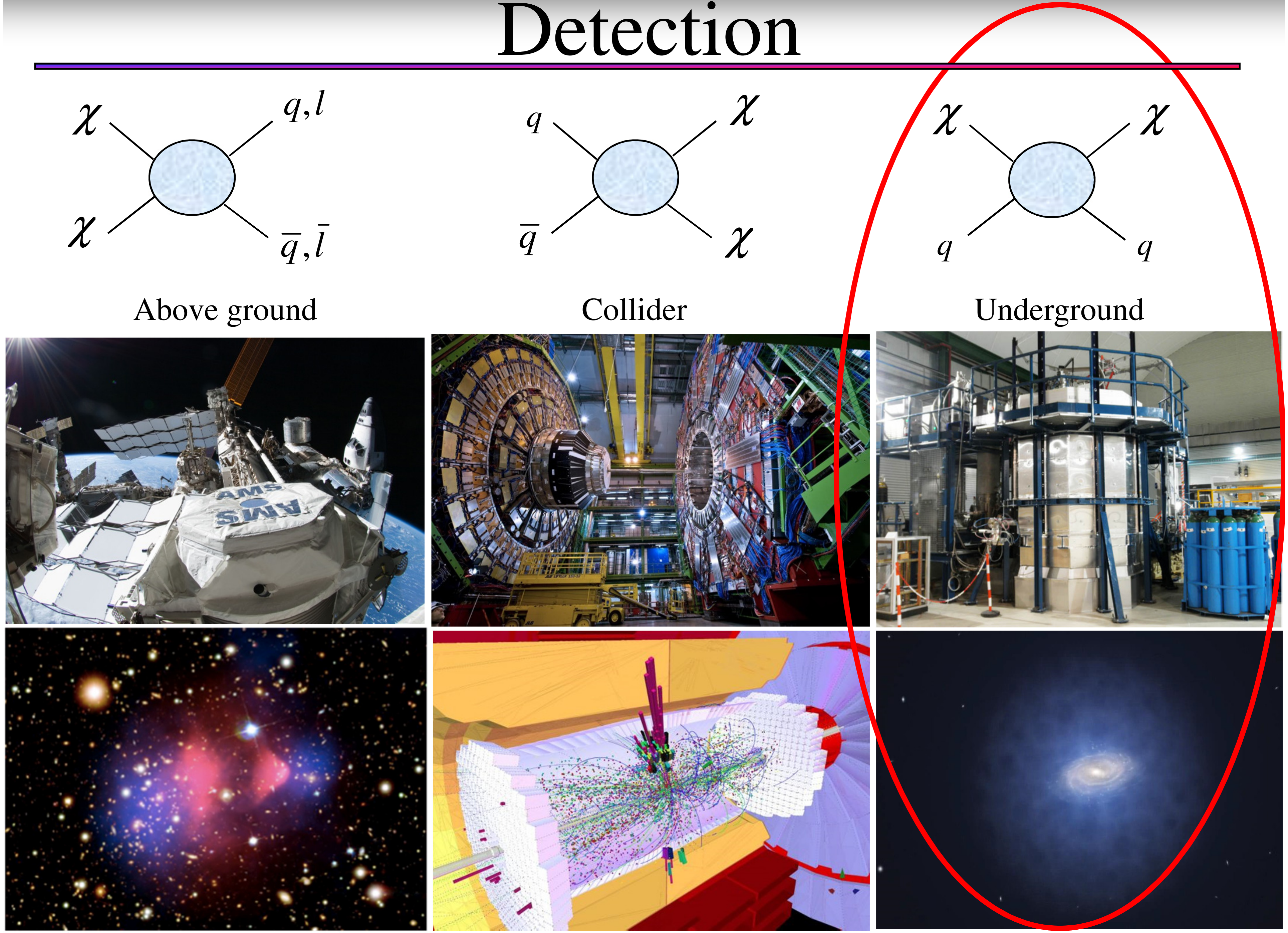






Underground

Detection


χ
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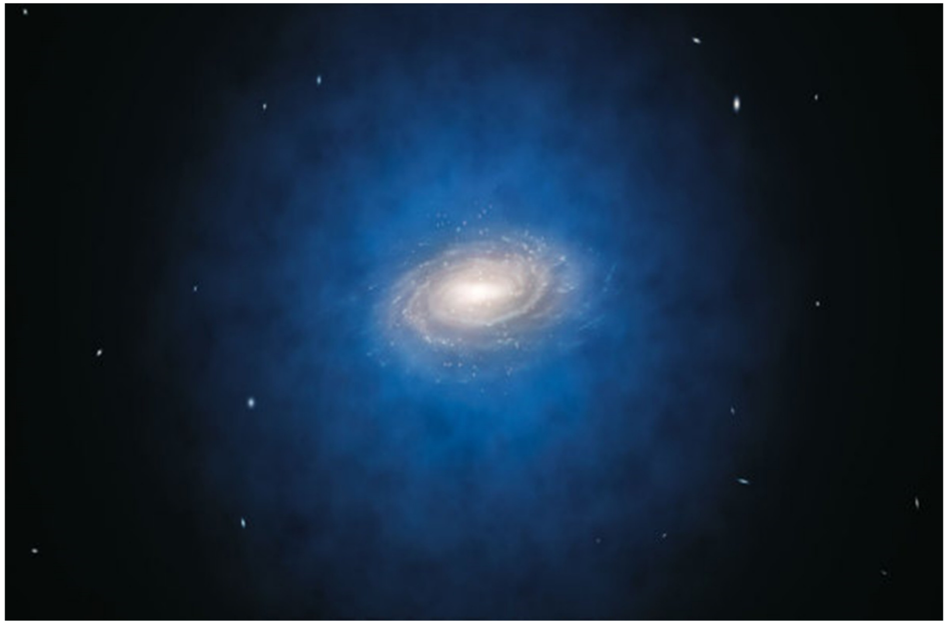
Above ground
Collider
Underground
AMS

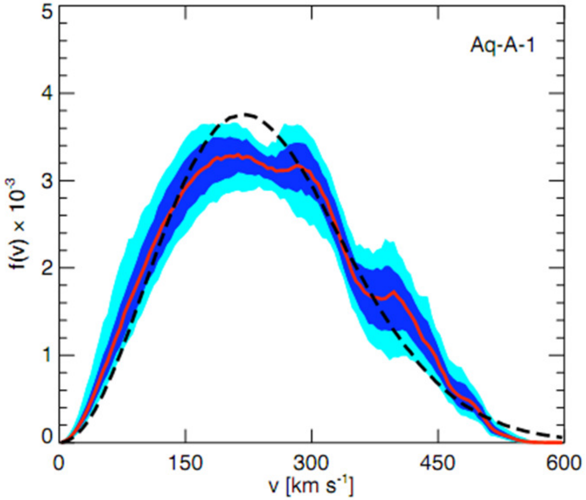
The Galactic DM Halo



- Dark Matter distributed in a spherical halo around the Milky Way
- Isothermal Maxwell-Boltzmann velocity distribution 220 km/s and V_{esc}=544 km/s
- V_e~245 km/s WIMP velocity relative to Earth
- Local density = 0.3 GeV/cm^3

J.Bovy S.Tremaine APJ 756 2012

($1e^5$ cm^{-2}s^{-1} for M_W=100 GeV/c^2)



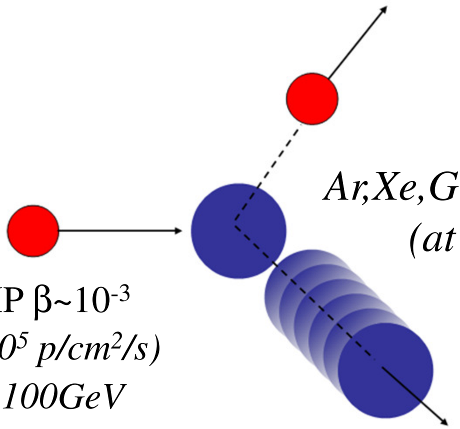
Vogelsberger, et al., MNRAS 395, 797, 2009

Dark Matter direct detection

GOAL: Detection of the WIMP collisions with atomic nuclei

***W**eakly*
***I**nteractive*
***M**assive*
***P**article*

- stable
- slow
- relic from the Bing Bang
- with the "right" mass and abundance



Ar,Xe,Ge…Nuclei
(at rest)

WIMP $\beta \sim 10^{-3}$
(Flux ~10^5 p/cm^2/s)
$M_W \sim 100GeV$

E_{recoil}

Scattering non relativistic :
coupling spin-dependent / spin-independent

Possible scalar (coupling to the mass of the nucleus) and spin-spin interactions (coupling to the nuclear spin)

$$R_0 = \frac{2}{\sqrt{\pi}} \frac{N_0}{A} \frac{\rho_W}{m_W} \sigma_N v_0 \qquad \sigma_N = \frac{\mu^2{}_N}{\mu^2{}_n} A^2 \sigma_n$$

N_0 = Avogadro number
A= atomic mass
m_W = WIMP mass
ρ_0 = local WIMP density *($\rho_0 \sim 0.3GeV/cm^3 \rightarrow 3000$ wimp/m^3 , $m_W = 100GeV$)*
σ = WIMP-nucleus and WIMP-nucleon scattering cross section ($\leq 10^7$pb)

The Galactic DM Halo

Recoil energy $$E_R = \frac{\left|\vec{q}^{\,2}\right|}{2m_N} = \frac{m_r{}^2 V^2}{m_N}(1-\cos\theta) \le 1 \div 10 keV$$

J.D. Lewin, P.F. Smith, Astropart. Phys. 6 (1996),87

$|\vec{q}| = 2\mu^2 V^2 (1-\cos\theta)$ *momentum transfer*

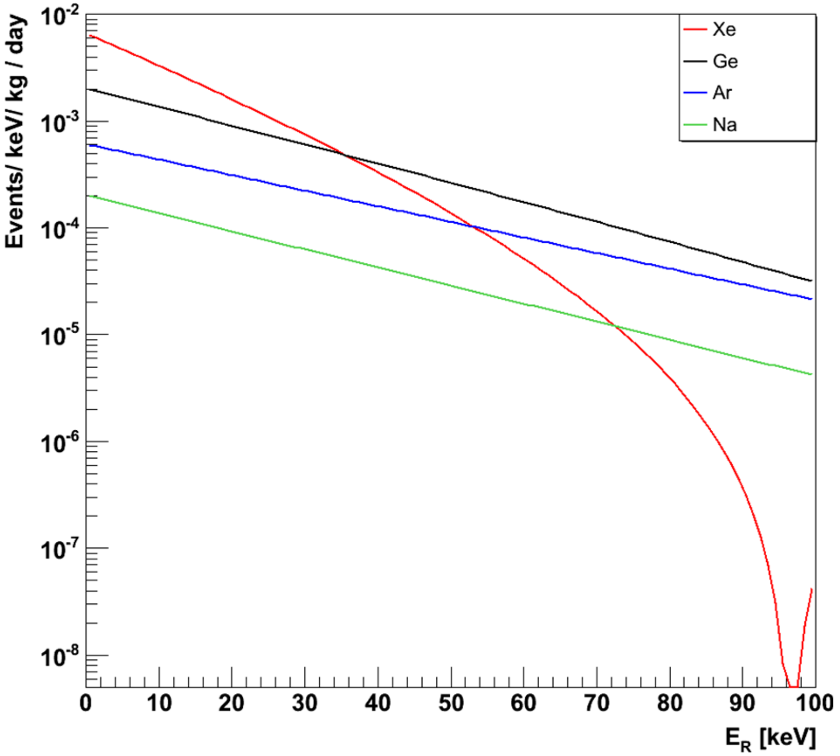
$r = 4 m_W m_N / (m_W + m_N)^2$ *Kinematic factor*

$m_r = m_W m_N / m_W + m_N$ *reduced mass*

$E_0 = \frac{1}{2} m_W v_0^2$ *Most probable energy*

Differential Recoil Energy spectrum

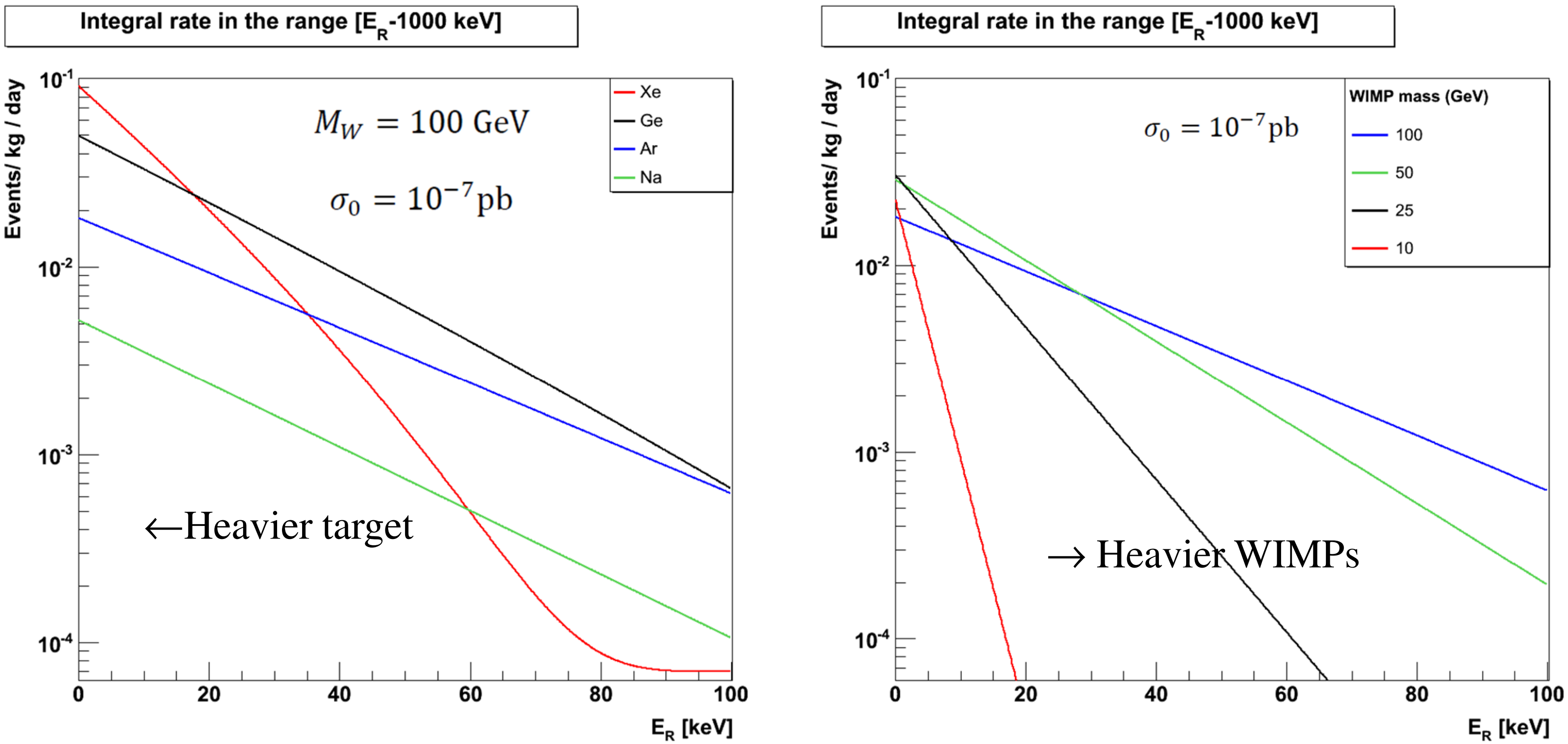
$$\frac{dR}{dE_R} = \frac{R_0}{E_0 r} e^{-\frac{E_R}{E_0 r}} F^2(q)$$



Other Corrections:

- Earth annual modulation
- Finite Galactic escape velocity
- Finite Energy range

Integral rates for different M_W and targets

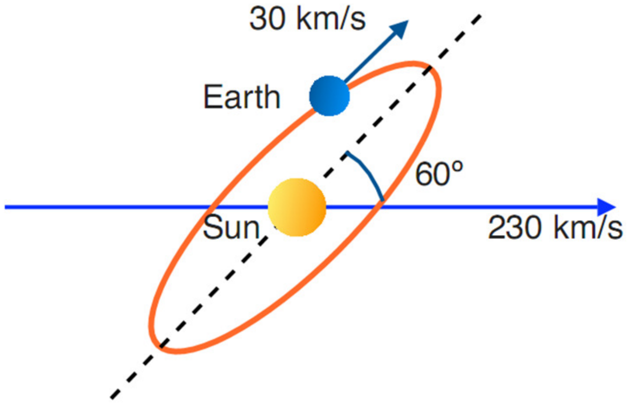


- Heavy target and lower threshold favored but only at low WIMP mass

Experimental signature

- *Nuclear recoils ~ 10s keV*
- *Featureless recoil spectrum (no bump)*
- *Single scatters   (uniform throughout the detector volume)*

Motion of the Earth
respect to the halo:



- Rate variation (June – December ~2-10%)
- Direction asymmetry (Daily rotation)

Annual modulation (~7%)→ Additional signature

$$v_E(t)\ [km/s] = v_S + 15\cos\theta = 232 + 15\cos\left(2\pi\frac{t-152.5}{365.25}\right)$$

Direct Detection - backgrounds

- α : *higher energy depositions*
- μ : *underground + veto*
- γ,β : *ER → shielding + discrimination*
- *n : NR → shielding + multiple interactions*

Extremely low background technique required and good discrimination NR-ER

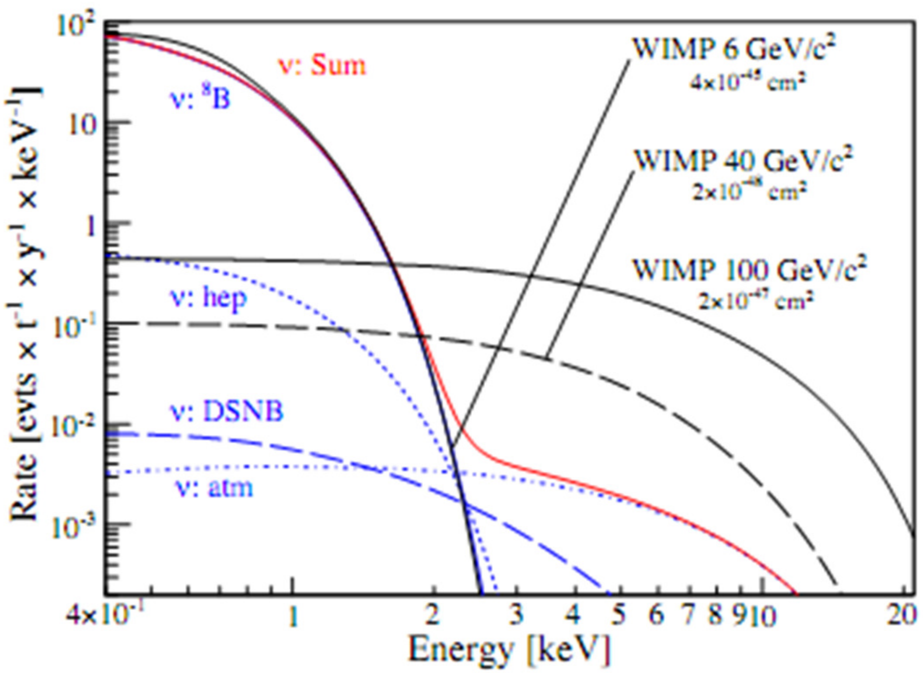
→ Underground experiments

Cosmic rays and activation of the detector materials (^{39}Ar, ^{22}N)

Natural (^{238}U, ^{238}Th, ^{40}K)

Anthropogenic (^{85}Kr)

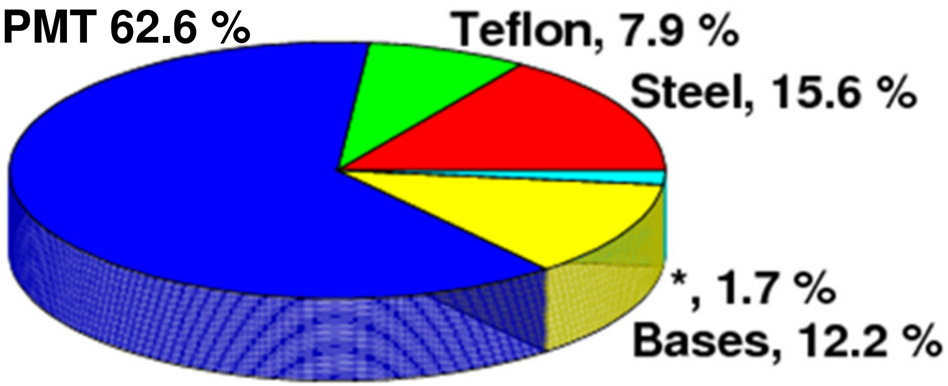
Ultimately: solar, atmospheric and SN ν



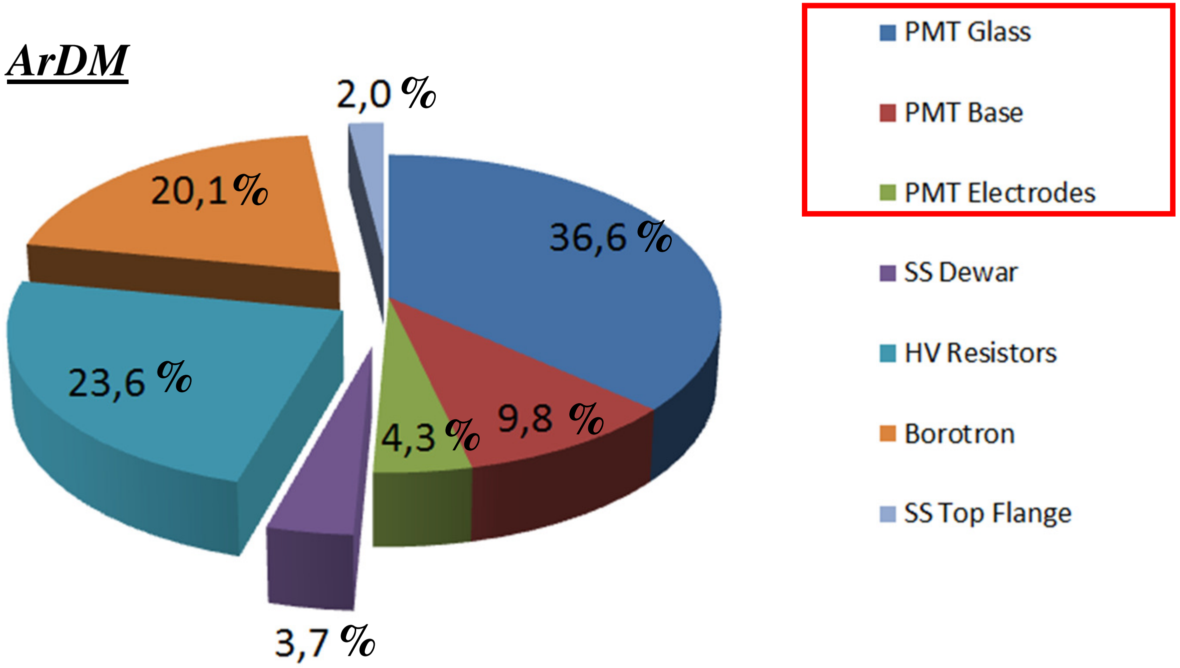
L.Baudis et al., JCAP01 (2014) 044

Background budget

XENON100



ArDM

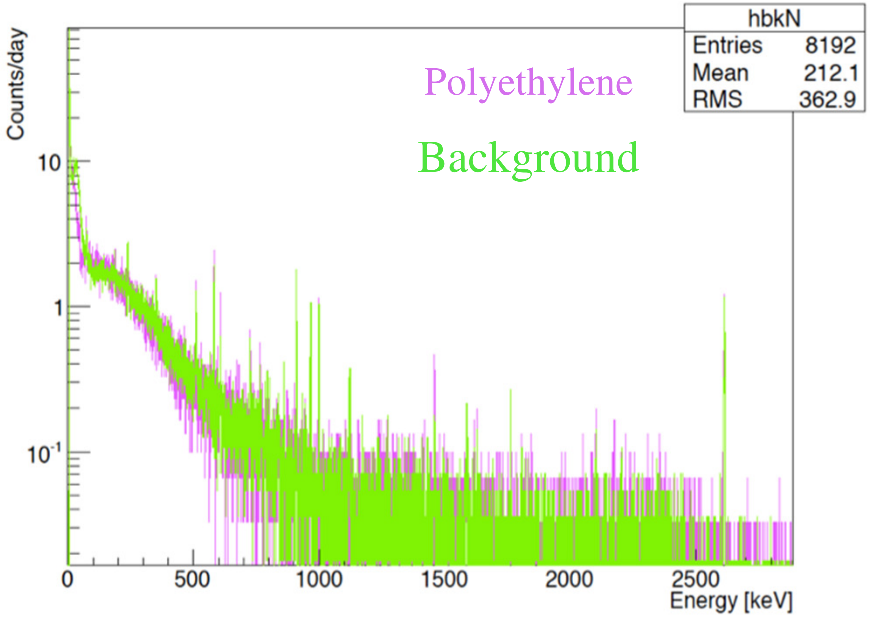


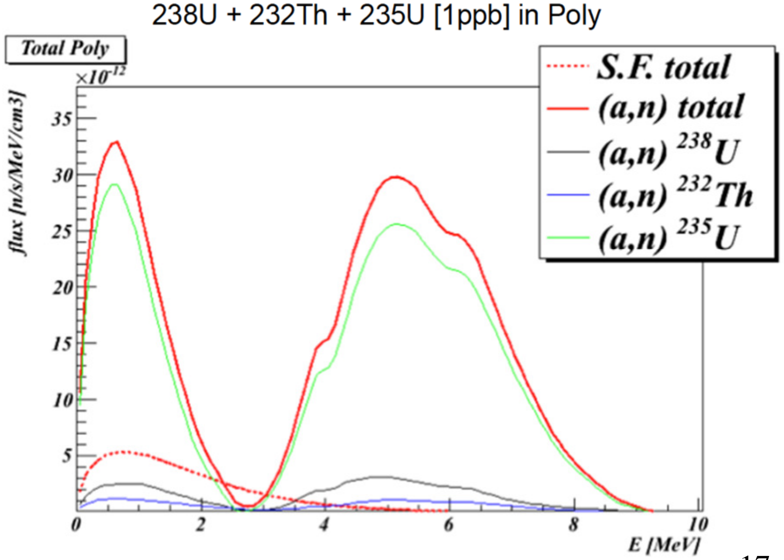
Background typically dominated by the PMTs (glass)

Radiopurity: material screening

- ArDM measurement campaign with **HPGe detector** @LSC.
- Screened samples:
  - **PMT**: glass, electrodes, base, holder components (SS, PE).
  - **HV resistors** for field cage.
  - **Polyethylene** for neutron shield.
  - **Perlite**

- Evaluating the neutron flux inside the detector (irreducible background)





The dream of the experimentalist

- Large Exposure (Mass × Time) : 100s ton × year
- Low Energy Threshold : ~10 keV
- Event topology
- Low Background Rate : <0.1 evt in the exposure
- Discrimination between Signal and Backgrounds

  : > 99.9%

-

Underground Experiments

F: SNOLab
DEAPCLEAN
Picasso
COUPP
DAMIC

G: Soudan
SuperCDMS
CoGeNT

E: Homestake
LUX-LZ

C: Boulby
Drift

D: Canfranc
ArDM
Rosebud
ANAIS

A: GranSasso:
XENON
CRESST
DAMA/LIBRA
DarkSide

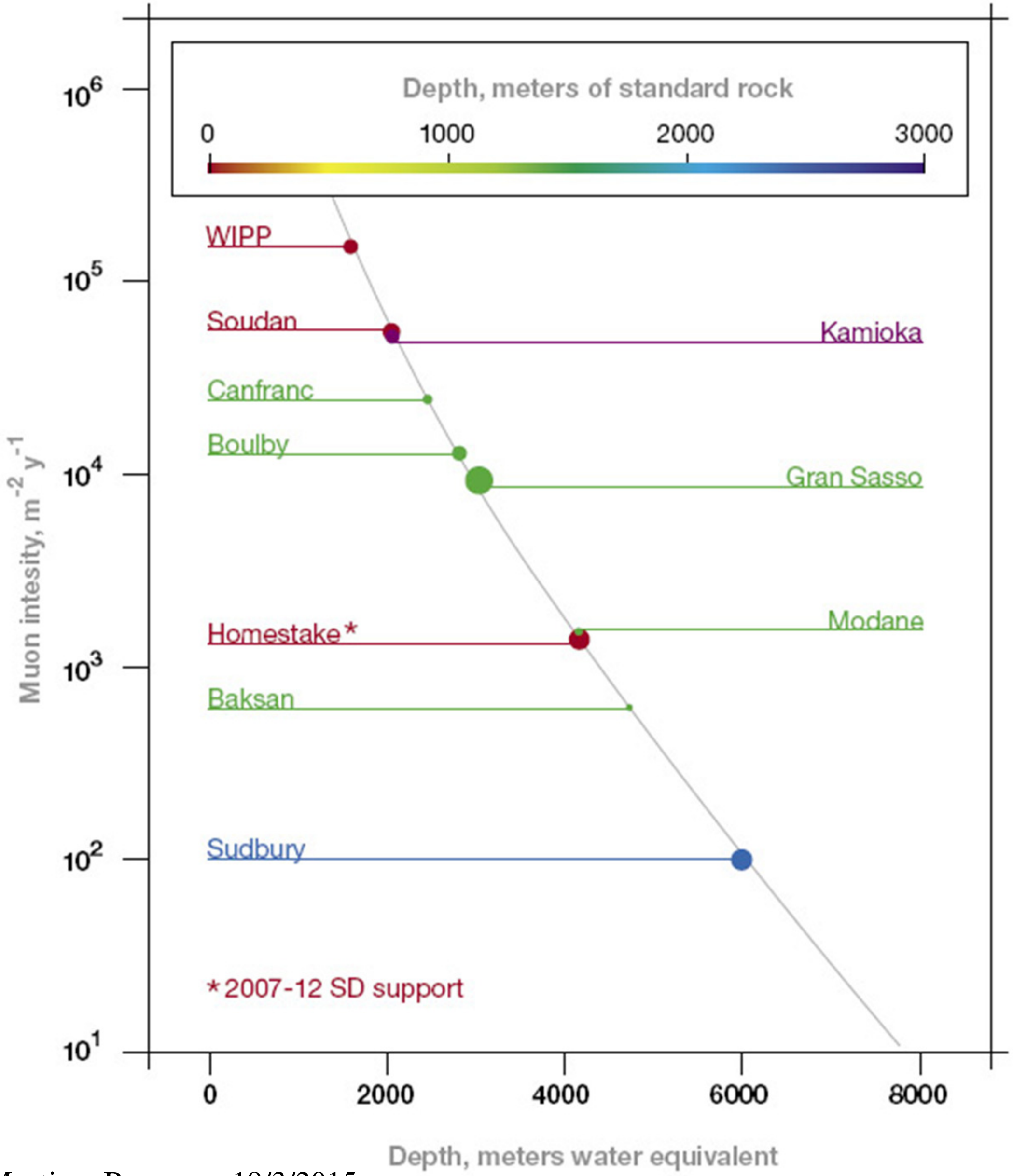
B: Modane
EDELWEISS
MIMAC

I: YangYang
KIMS

H: Kamioka
XMASS
Newage

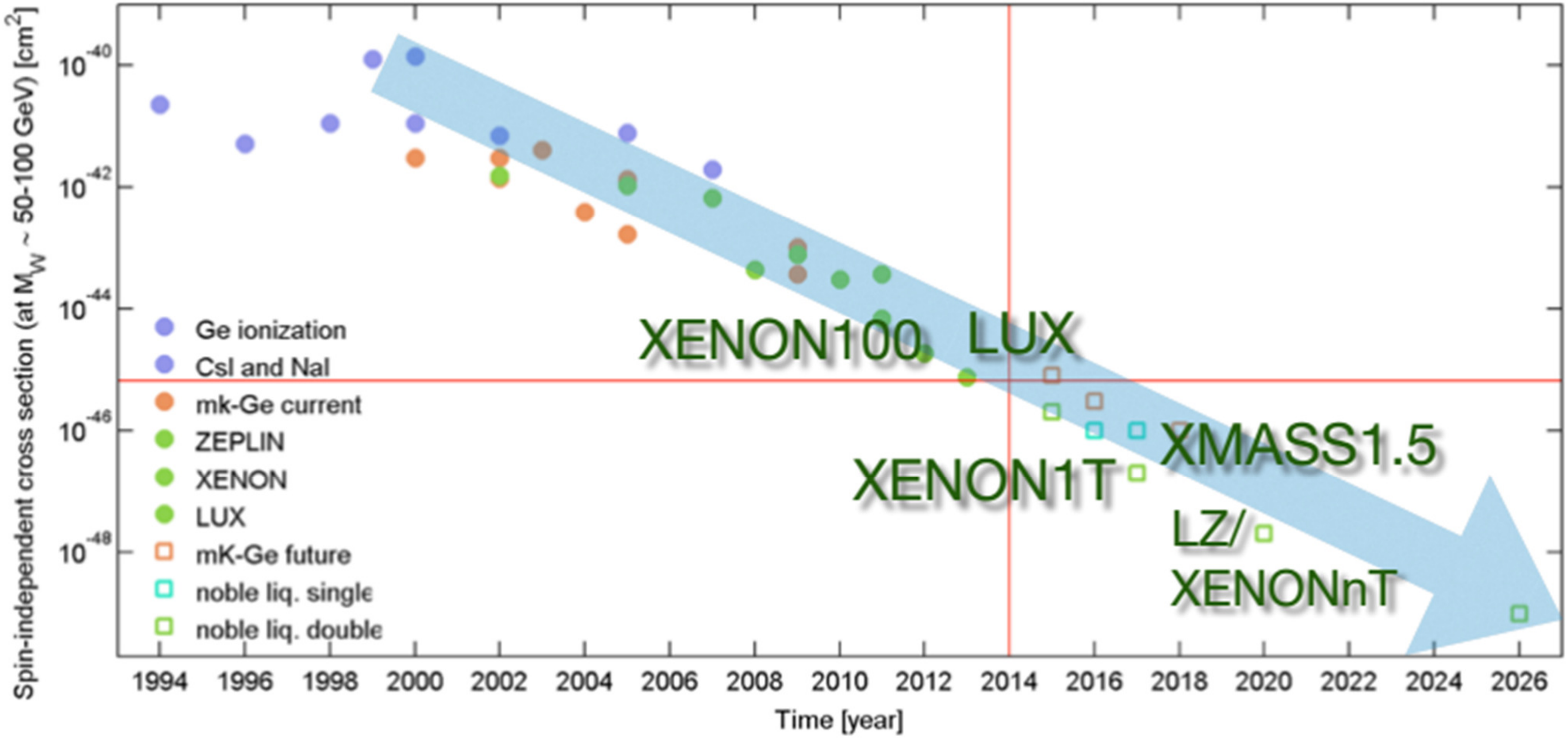
J: Jinping
Panda-X
CDEX

Underground Laboratories



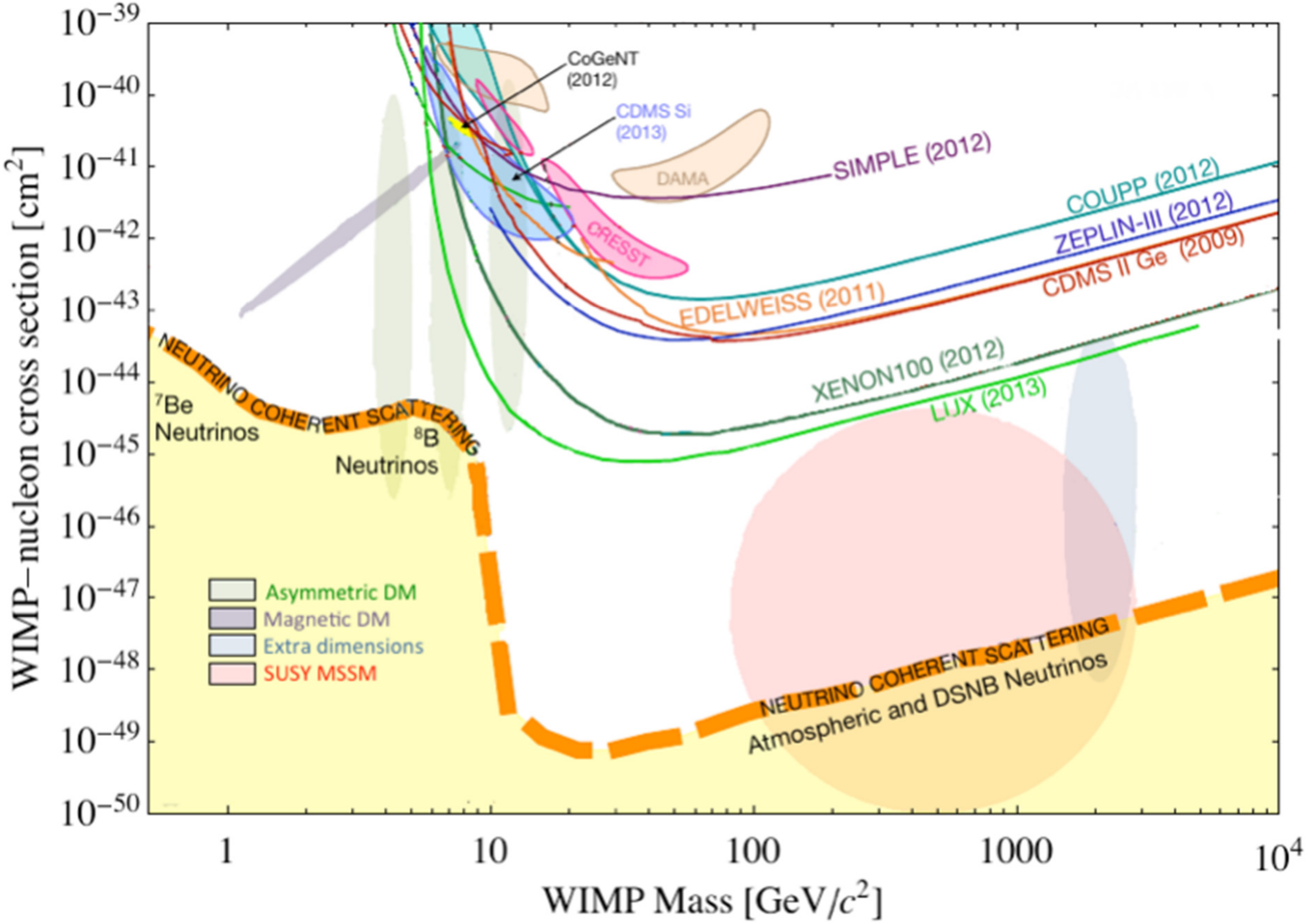
DM experiments sensitivity

L.Baudis Physics of the Dark Universe, 2014

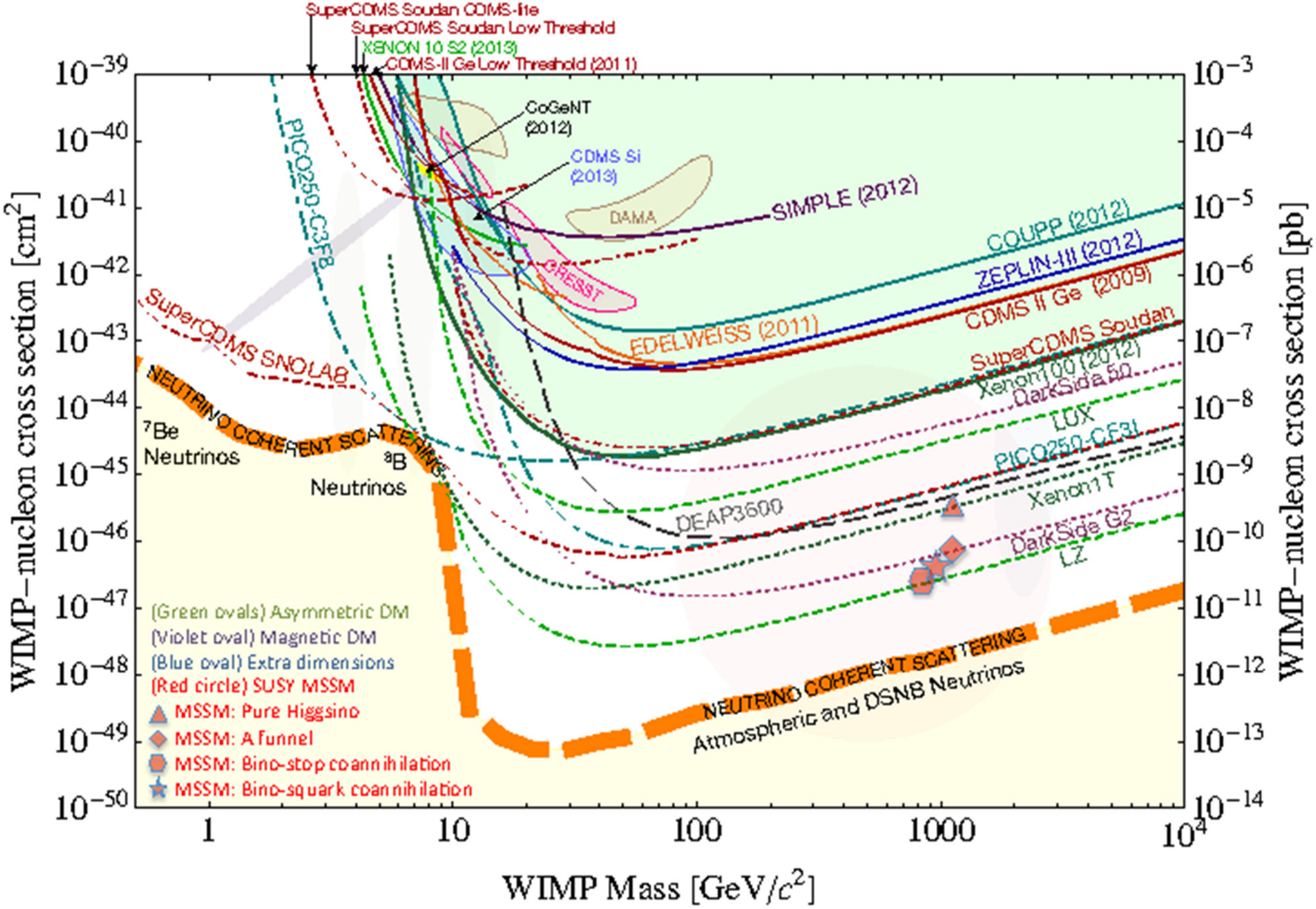


About an order of magnitude increase in every ~2 years

Current scenario



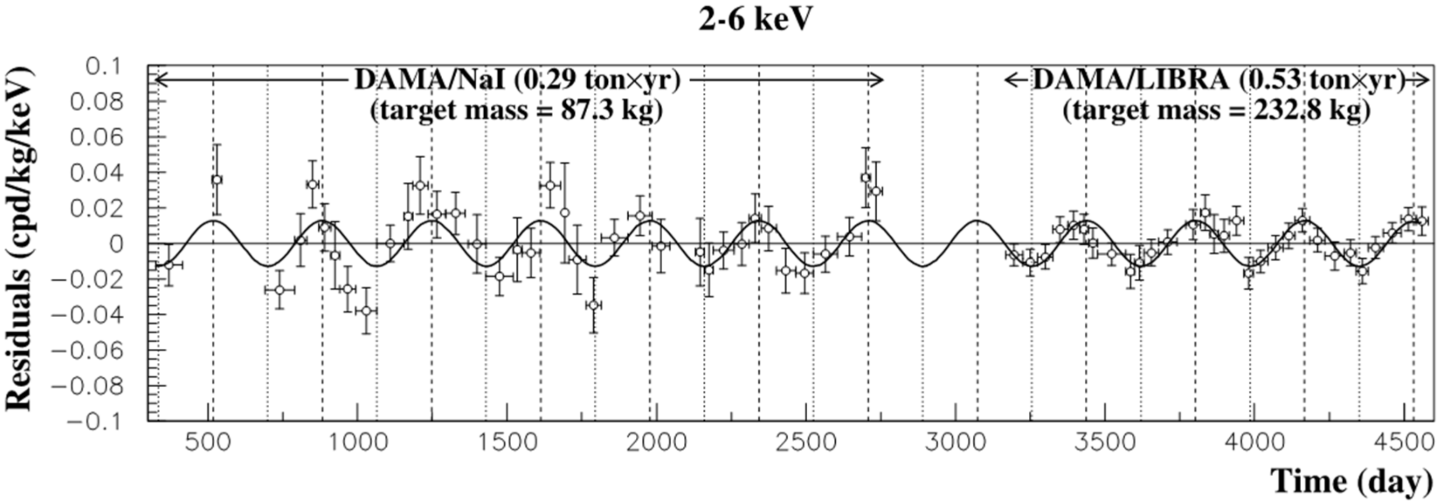
Current/Future scenario



Annual modulation → DAMA/LIBRA

DAMA/NaI :~100 kg NaI(Tl)
0.29 ton/y over 7 annual cycles
DAMA/LIBRA: ~250 kg NaI(Tl) – 25 crystals
0.53 ton/y over 4 annual cycles

Total exposure : 0.82 ton y
Modulation in the range 2-6 keV



$R(t)=A\cos\omega(t-t_0)$
$T=\omega/2\pi=1y$
$t_0=152.5d$

- Correct phase and period
- Modulation only in the low energy bin
- No modulation in the multi-hit events

A=(0.0215±0.0026) cpd/kg/keV (8.3σ CL)
Eur.Phys.J.C.(2008)56:333-355

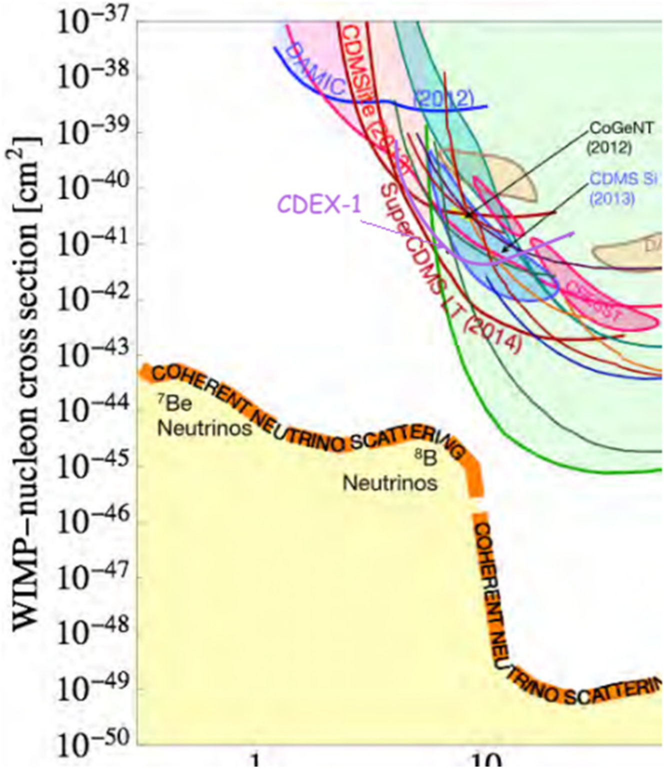
Eur. Phys. J. C 73 (2013) 2648. 2013
Total Exposure: 1.33 ton y (9.3 CL)

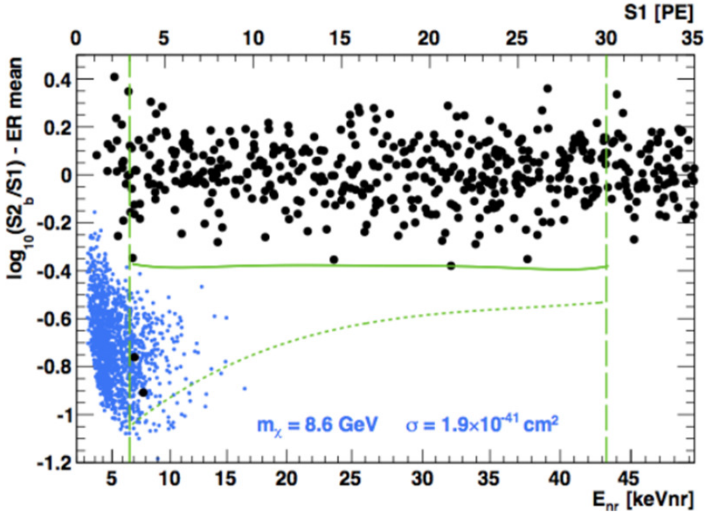
Low Mass Region

- Interest triggered by DAMA/LIBRA with the summer / winter modulation: solid evidence but wide suspicion that is an instrumental effect.
- (Close to the detector threshold, however no convincing explanation so far!)

- Additional evidences during the last years from CoGeNT, CRESST, CDMS-Si: excess of events above the expected background

- Light DM interpretation disfavored by many other experiments: XENON100, LUX, SuperCDMS





Assuming:

M_W=8.6 GeV and σ=1.9 × 10^{-41} cm^2

→ 220 events expected

ANAIS

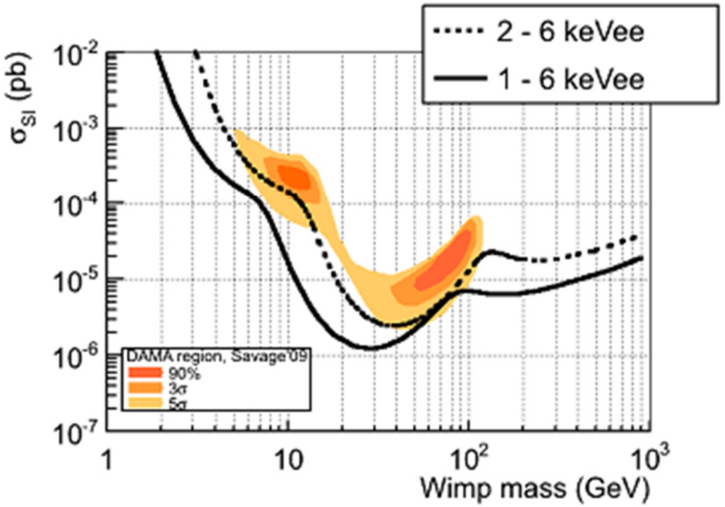
Annual modulation studies: Data taking @ LSC from Dec 2012

Detectors: 2NaI(Tl) cylindrical modules, 12.5 kg each (Alpha Spectra - USA)
Shield: 10cm roman lead 20 cm low activity lead
Active veto scintillators
Radon free box
1 keV_{ee} threshold achievable

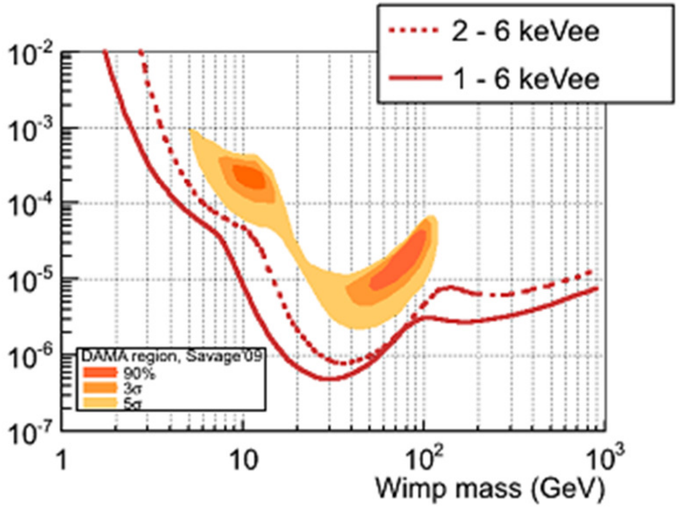
Goals: Crystal radiopurity (40K)

NEW 12,5 kg **ULTRAPURE NaI(TI) DECTECTOR at LSC since March 2015**

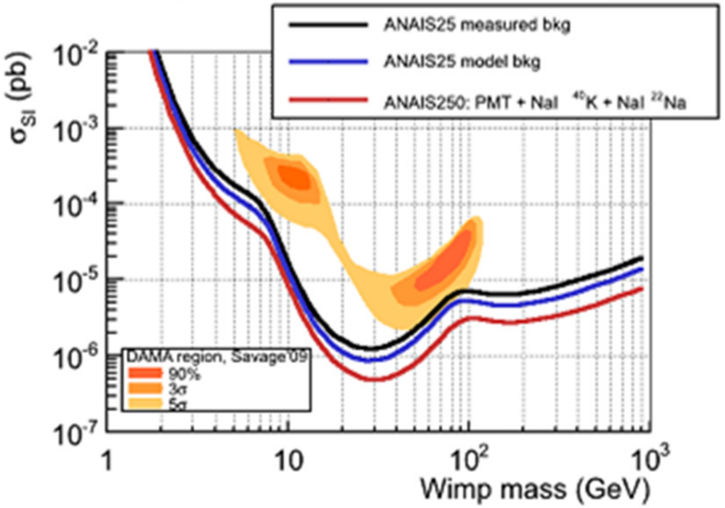
Bkg: pessimistic approach (ANAIS25)
Exposure: 250 kg x 5 y



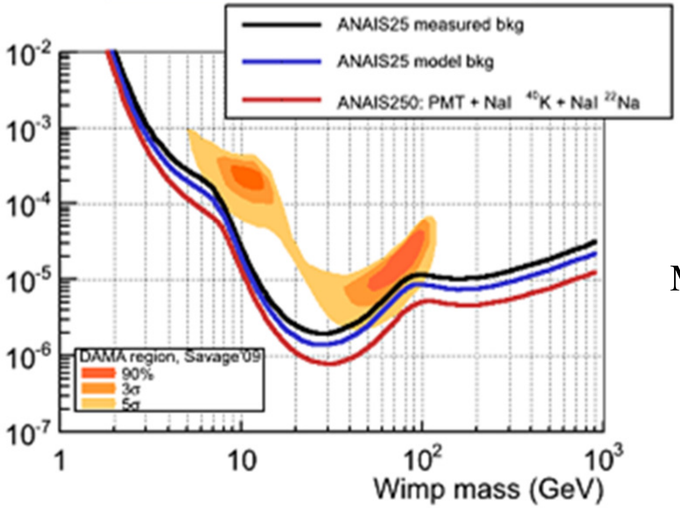
Bkg: ANAIS250 model
Exposure: 250 kg x 5 y



Exposure: **250 kg x 5 y**



Exposure: **100 kg x 5 y**

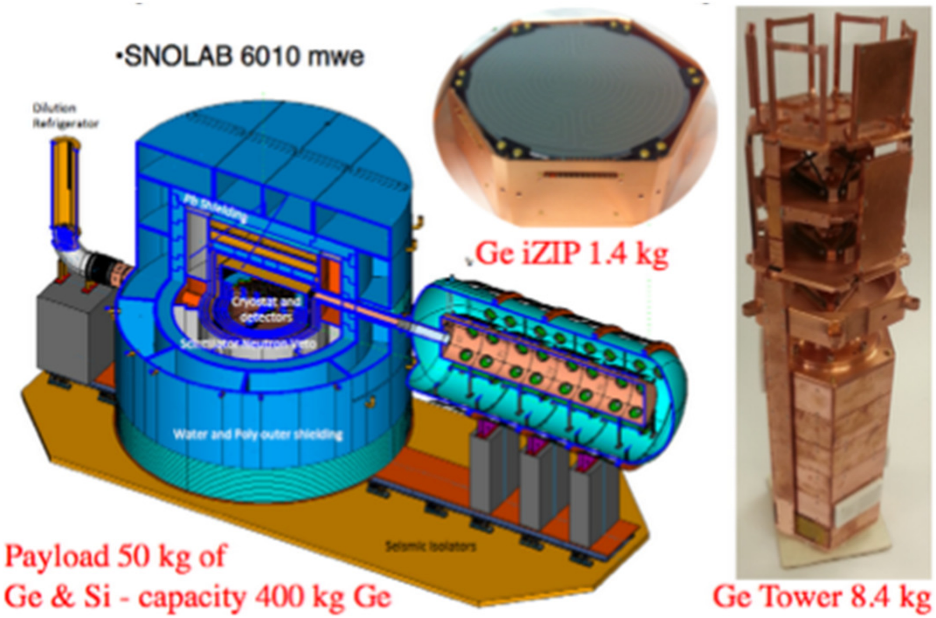


M. Martinez 11th
MultiDark meeting
Nov,2014

Cryogenic experiments at T~mK

SuperCDMS:
low temperature Ce/Si detectors at SNOLab. Rejection through ionization and phonos.
Focus on low mass WIMPs.

- 6 towers (≈50 kg) Ge with NR discrimination through ionization + phonons
- 1 tower (3Ge+3Si from CDMS). No discrimination. Background limited after 1y
- Start data taking 2018. Ultimate goal 8×10^{-47} (SI)



- Potential future increase with multi-target approach (EURECA). Cryostat able to host up to 400 kg

Noble liquids technology for particle physics

- *low energy threshold*

  (high scintillation/ionization yield)

- *large mass*

  (available in large quantity/affordable)

- *ultra low background*

  (radiopure and clean)

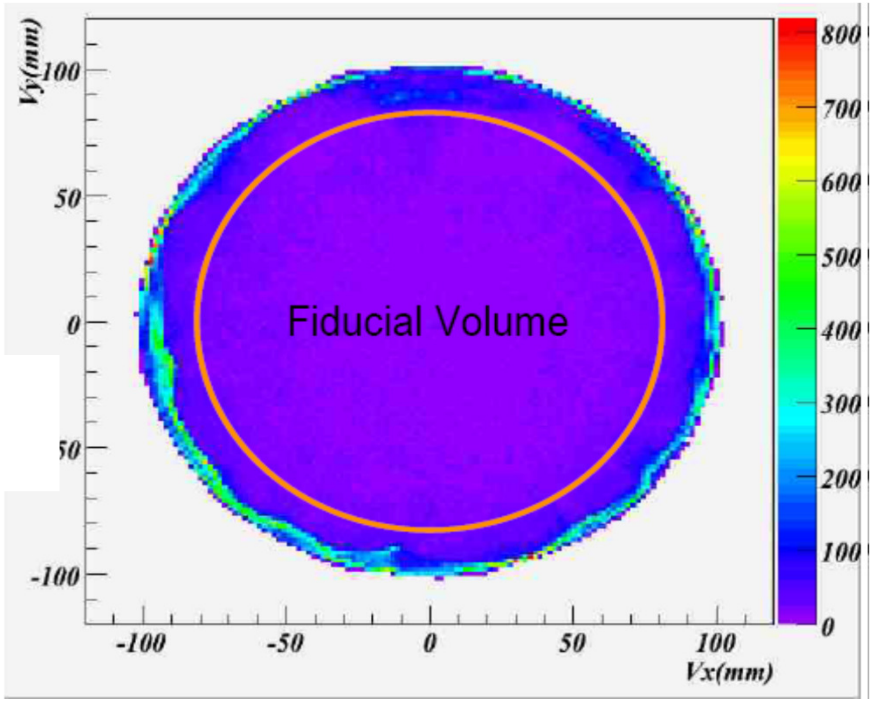
- *background rejection*

  (pid through pulse shape, light/charge, dE/dx)

Element	*Z(A)*	*Boiling point (Tb) @1bar [k]*	*Liquid density @Tb [g/cm³]*	*Energy loss dE/dx (MeV/cm)*	*Radiation length X_0(cm)*	*Collision length λ(cm)*	*Ionization [e^-/keV]*	*Scintillation [γ/keV]*	*Cost*
Ne	10(20)	27.1	1.21	1.4	24	80	46	7	
Ar	***18(40)***	***87.3***	***1.40***	***2.1***	***14***	***80***	***42***	***40***	
Kr	36(84)	119.8	2.41	3.0	4.9	29	49	25	
Xe	***54(131)***	***165.0***	***3.06***	***3.8***	***2.8***	***34***	***64***	***46***	

Noble liquids technology for particle physics

- High atomic number and density good for compact and flexible detector geometry. Good stopping power (i.e. self shielding active volume)
- "Easy" cryogenics
- High scintillation yield with fast response (yield ~80% of NaI)
- High ionization yield and small Fano factor for good ΔE/E
- Available in large quantity and "easy" to purify with a variety of methods (~2k$/kg for Xe).

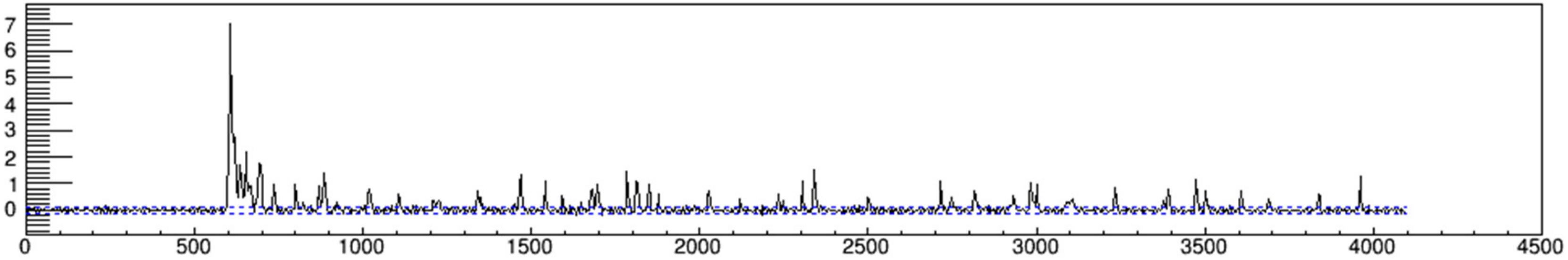


Overall bkg in the fiducial volume ~0.6 dru

Ar scintillation

- LAr is an Excellent scintillator: $W_\gamma = 19.5$ eV → ~ 5000 photons/mm/m.i.p.
- Singlet ($\tau \sim 6$ns) and triplet ($\tau \sim 2$ μs) excimers giving a spectrum peaked at 128 nm
- Transparent to its own scintillation light: 9.7 eV not enough to cause secondary scintillation/ionization.
- Light propagation governed only by Rayleigh scattering (purity dependent).

Pulse height [p.e.]

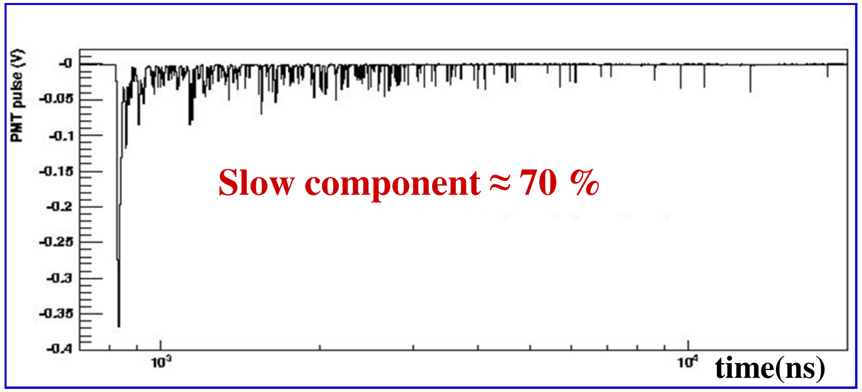


Time [ns]

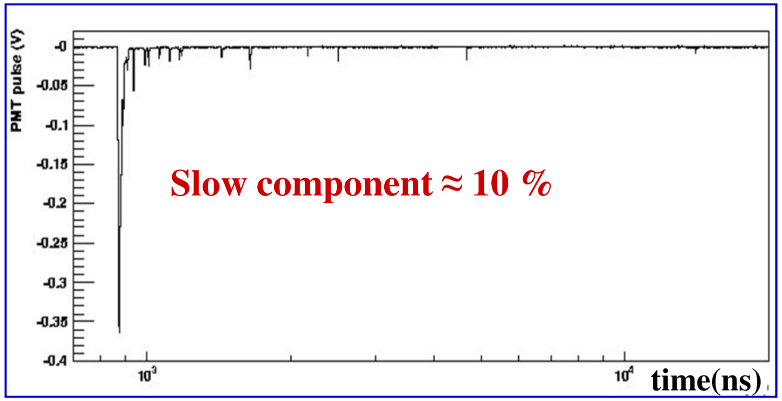
Event discrimination technique in Ar

- *Noble liquids detectors effective* particularly at higher WIMP masses
  Preferred option because of event selection / background rejection

El. recoil like event



N.recoil like event



Pulse shape discrimination of primary scintillation: very large difference in decay times between fast (≈ 7 ns) and slow (~2 μs) components of the emitted VUV light.

Systematic uncertainty

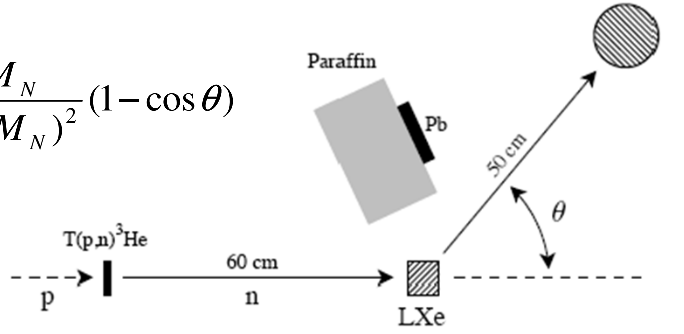
Nuclear recoil energy calibration

$$E_{nr} = \frac{S_1}{L_y L_{eff}} \times \frac{S_e}{S_r}$$

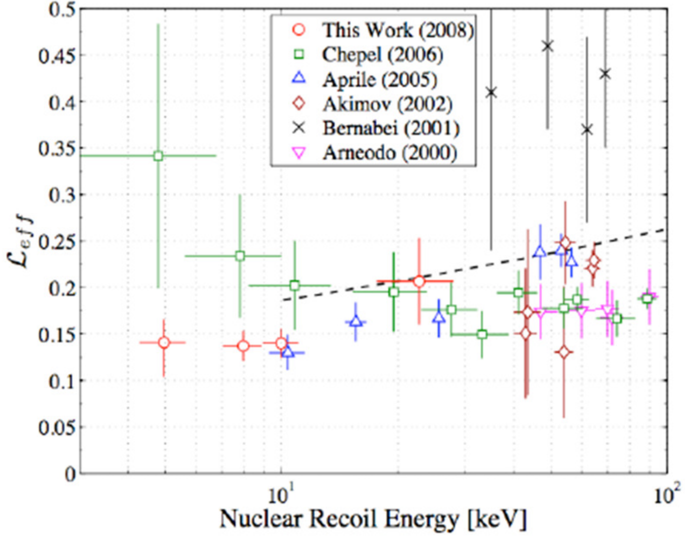
S_1= signal in pe
L_y=light yield @122 keV (pe/keV)
L_{eff}=NR scintillation efficiency rel. to 122keV (0 field)
S_e=quenching of scintillation yield @ 122keV due to the field
S_r= “ “ for NR

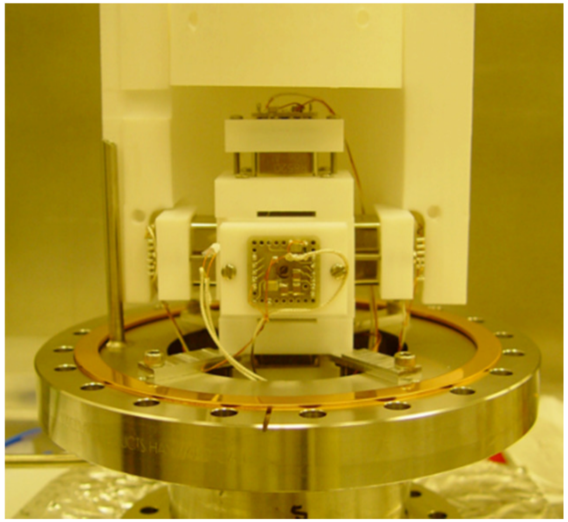
Single-phase LXe scintillation detector
(>95% light coll efficiency – 25pe/keV)
→ Neutron scattering experiment

$$E_{nr} \cong E_n \frac{m_n M_N}{(m_n + M_N)^2}(1 - \cos\theta)$$



- Results consistent with previous data for E>10keV
- Average value E<10keV : L_{eff}=0.14
  (discrepancy with other data but consistent with the best fit on Xe10 neutron calib.)





Phys.Rev.C 79-045807

LAr vs LXe

LXe:

- ✓ *Density*
- ✓ *~50% odd isotopes (^{129}Xe, ^{131}Xe) for spin dependent interactions*
- ✓ *No long-lived radioactive isotopes*

- ✗ *Price*
- ✗ *ER discrimination*

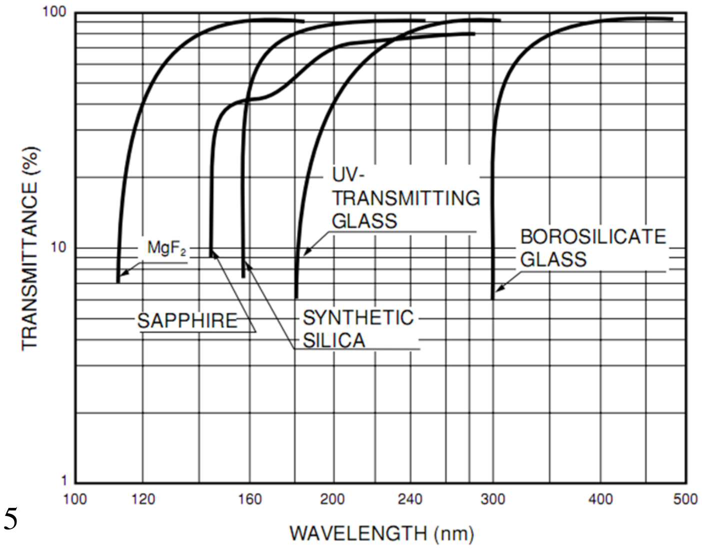
LAr:

- ✓ *Available in large quantity*
- ✓ *ER background discrimination*

- ✗ *Radioactive isotopes*
  ^{39}Ar → 1.01 Bq/kg
  (NIM-A 574 (2007) 83–88)

Additionally: Scintillation wavelength

λ_{LXe}~*175 nm*
λ_{LAr}~*128 nm*
(λ_{LNe}~77.5nm)



LXe : No need for wavelength shifter!

Hamamatsu:
" Photomultipliers tubes "
3rd edition

RA contamination in ^{nat}Ar

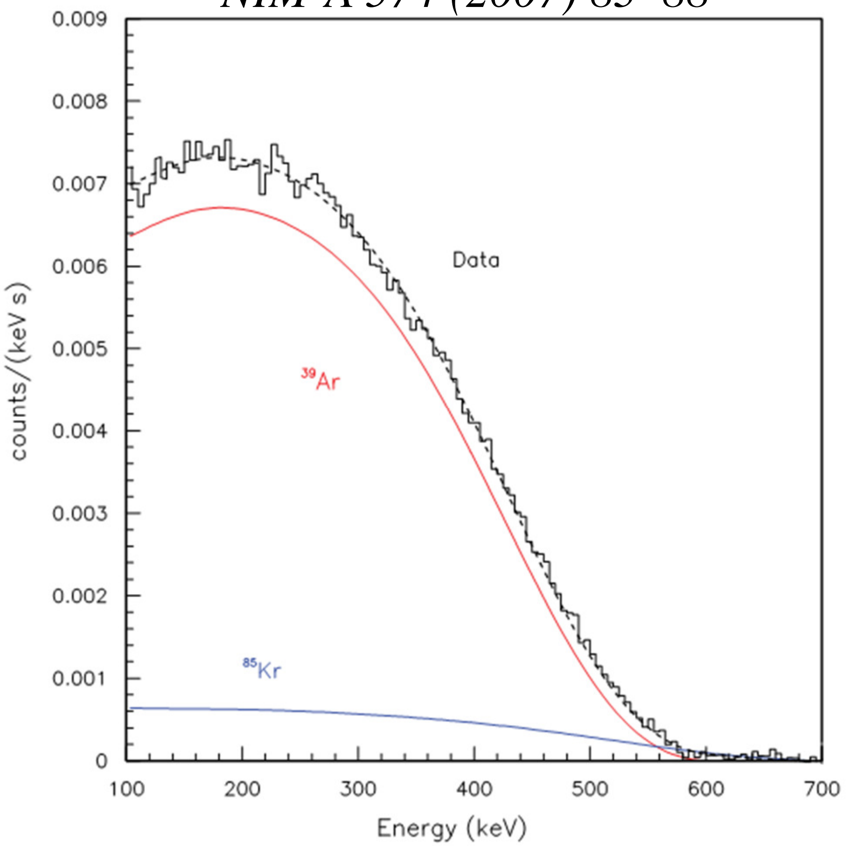
- ^{39}Ar and ^{85}Kr "Activity in the atmosphere ~10mBq/m^3

Isotope	Half-life (y)	β end-point (keV)	β mean energy (keV)
^{39}Ar	269	565	220
^{85}Kr	10.8	687	251

^{39}Ar : (1.41±0.11) Bq/l ~ 1.0 Bq/kg

^{85}Kr : (0.16±0.13) Bq/l ~ 0.1 Bq/kg

NIM-A 574 (2007) 83–88



Underground Experiments

F: SNOLab
DEAP/CLEAN
Picasso
COUPP
DAMIC

G: Soudan
SuperCDMS
CoGeNT

E: Homestake
LUX-LZ

C: Boulby
Drift

D: Canfranc
ArDM
Rosebud
ANAIS

A: GranSasso:
XENON
CRESST
DAMA/LIBRA
DarkSide

B: Modane
EDELWEISS
MIMAC

I: YangYang
KIMS

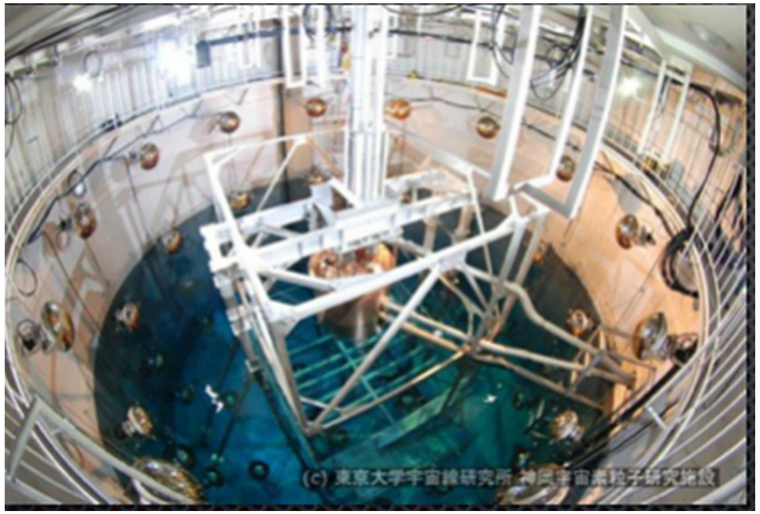
H: Kamioka
XMASS
Newage

J: Jinping
Panda-X
CDEX

XMASS at Kamioka

850 kg (~100 kg fiducial?) single phase LXe detector

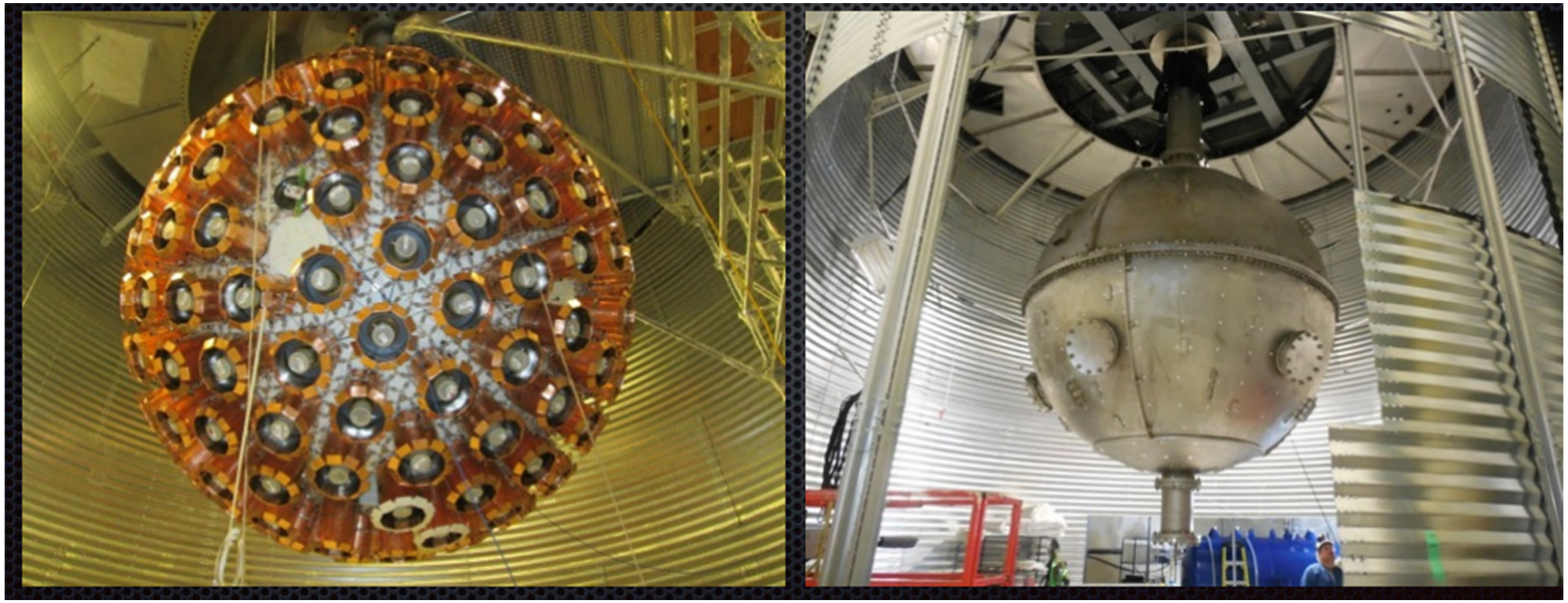
- LXe in copper vessel, water tank
- 62% active surface (632 high QE, HEX PMTs: 13 PE/keV)
- 1 yr of data after refurbishment to reduce surface background
- Expected results by summer



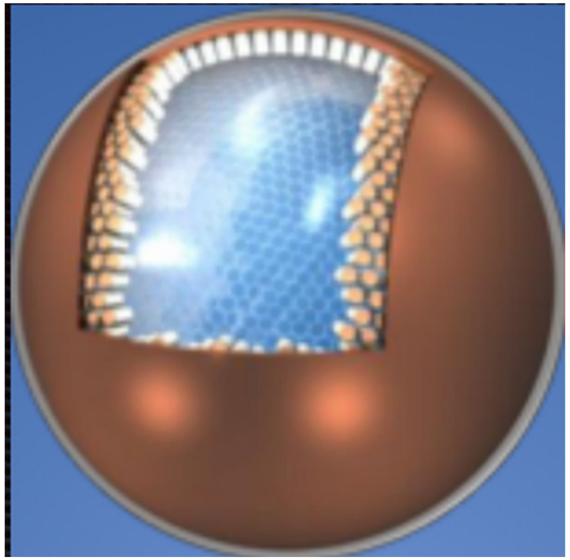
DEAP3600 at SNOLab

3.6 ton (1 ton fiducial?) LAr single phase

- Acrylic vessel, water tank
- 255 8” high QE, round PMTs
- Steel containment sphere immersed in 8m water tank
- Commissioning 2014. Physics 2015
- Goal ~10^{-46} cm^2 (SI) for M_w ~100 GeV after 3 y

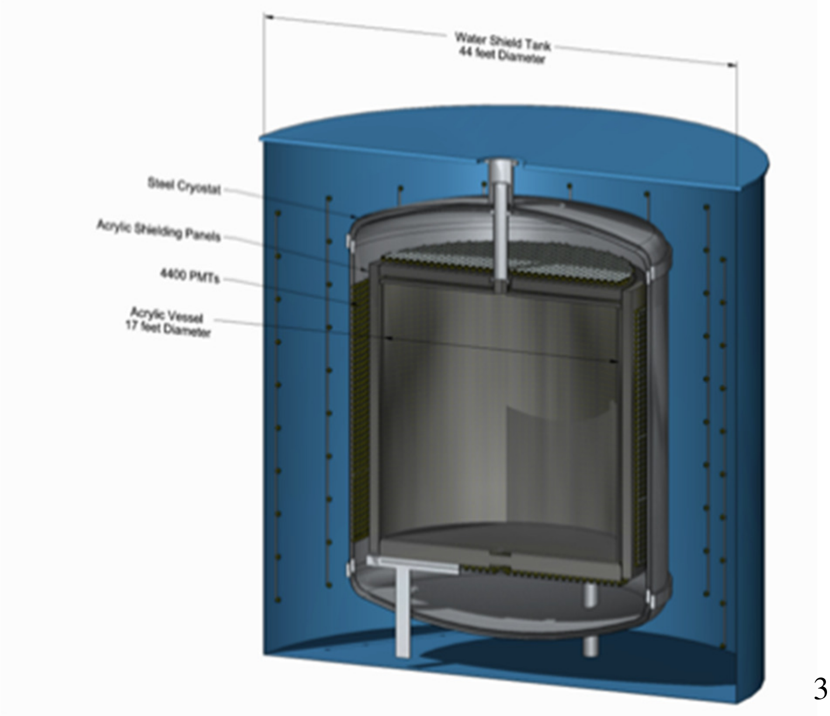


Outlook for the single phase



XMASS1.5 : 5 ton total mass (~3 ton fiducial)

- New PMTs to achieve 10^{-5} eve/keV/kg/day
- Projected Sensitivity: $\sigma_{SI} = 10^{-47}$ cm^2 @50 GeV
- Status: start in ~2017 ?
- XMASSII ➔ 24 ton total mass (~10 ton fiducial)



DEAP - 50T ➔ 150 ton (~50ton fiducial)

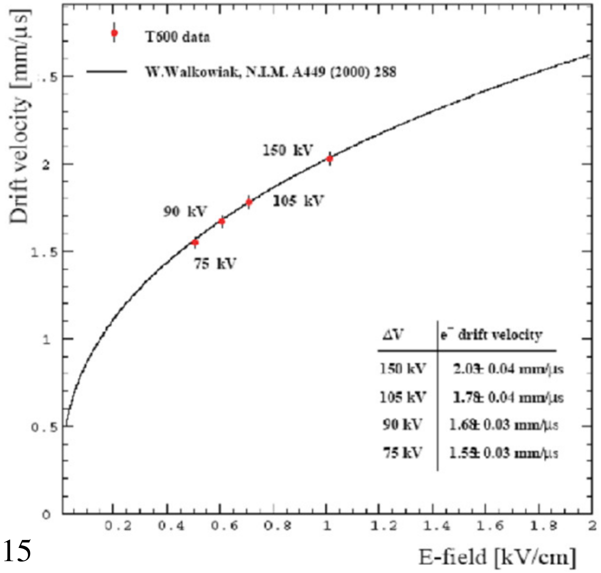
- Proposal only
- Depleted Ar in acrylic vessel
- New 4400 PMTs (development)
- Projected Sensitivity $\sigma_{SI} \sim 10^{-48}$ cm^2

Ar ionization charge

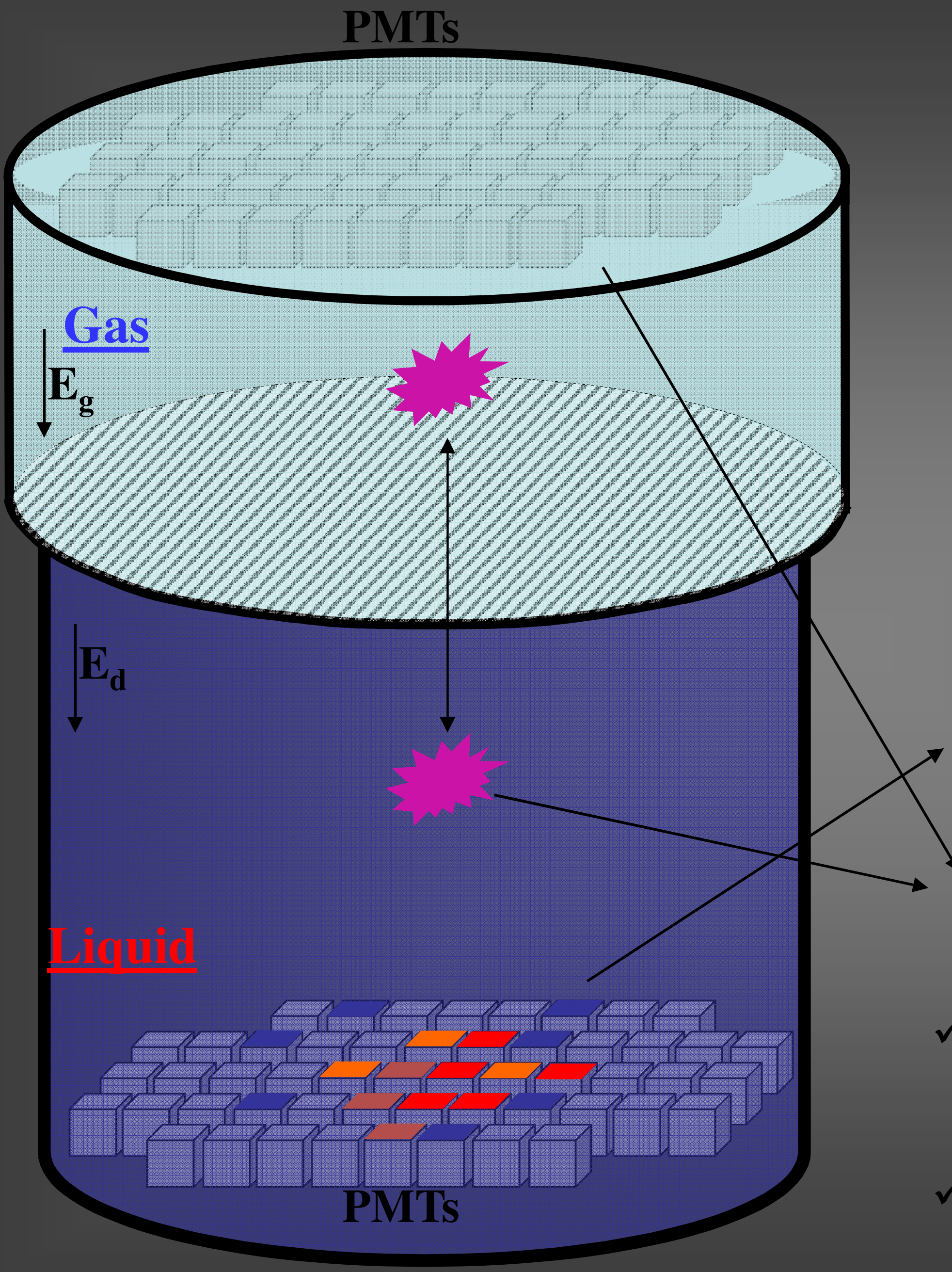
- LAr ionization: W_e~23.6 eV → low detection thresholds
- Possible electron/ion recombination suppressed by E_{drift} (absent for mip's at $E_{drift} \geq$ 10KV/cm)
- Drift velocity parameterized and measured in LAr-TPC's:
  $V_{drift}(E,T)$ ~2 mm/μs @ E_{drift}=1 KV/cm $\Delta V_{drift}/ \Delta T\ V_{drift}$ ~ -1.7%/K
- Oxygen (nitrogen) impurities capture free electrons: τ_e [μs] ~300/ρ [ppb]
  → **crucial issue for LAr**

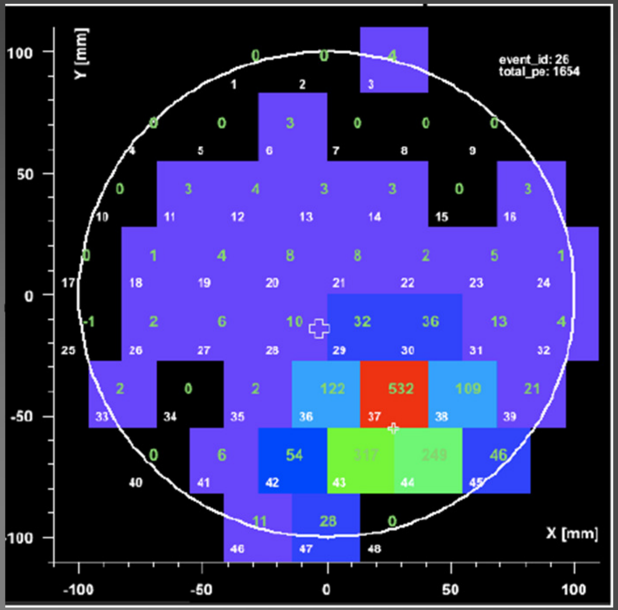
τ→electron lifetime
ρ→O_2 concentration

- Diffusion effects are small for E_{drift} ~1 kV/cm:
  transverse ~ mm's longitudinal « uncertainty on V_{drift}



ΔV	e^- drift velocity
150 kV	2.03 ± 0.04 mm/μs
105 kV	1.78 ± 0.04 mm/μs
90 kV	1.68 ± 0.03 mm/μs
75 kV	1.55 ± 0.03 mm/μs





Primary scintillation S1 in liquid

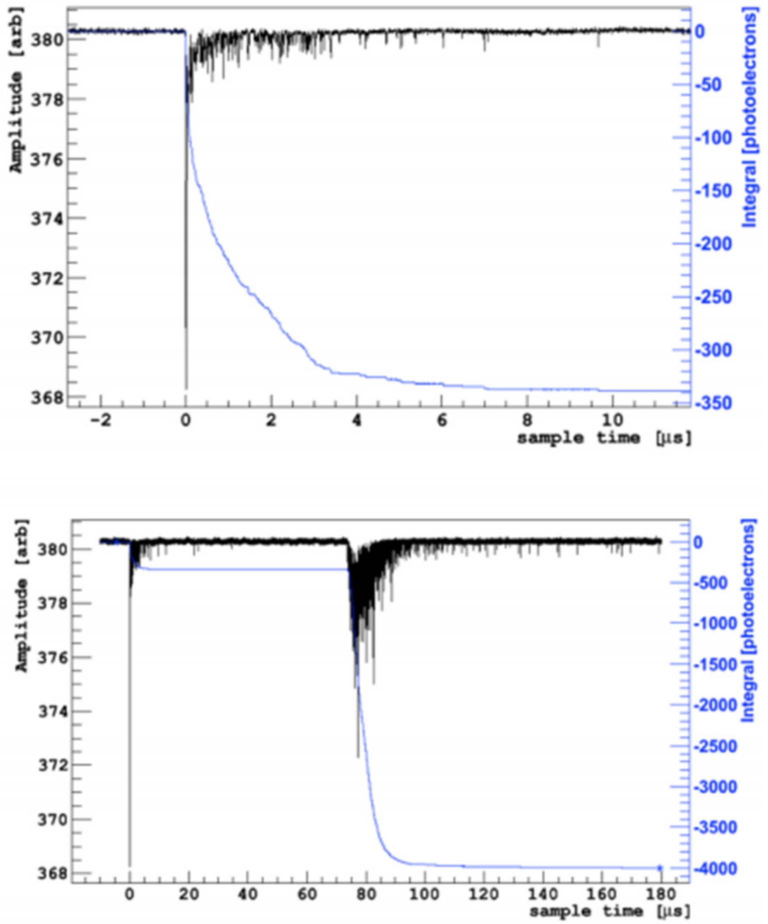
Secondary scintillation S2

Ionization charge

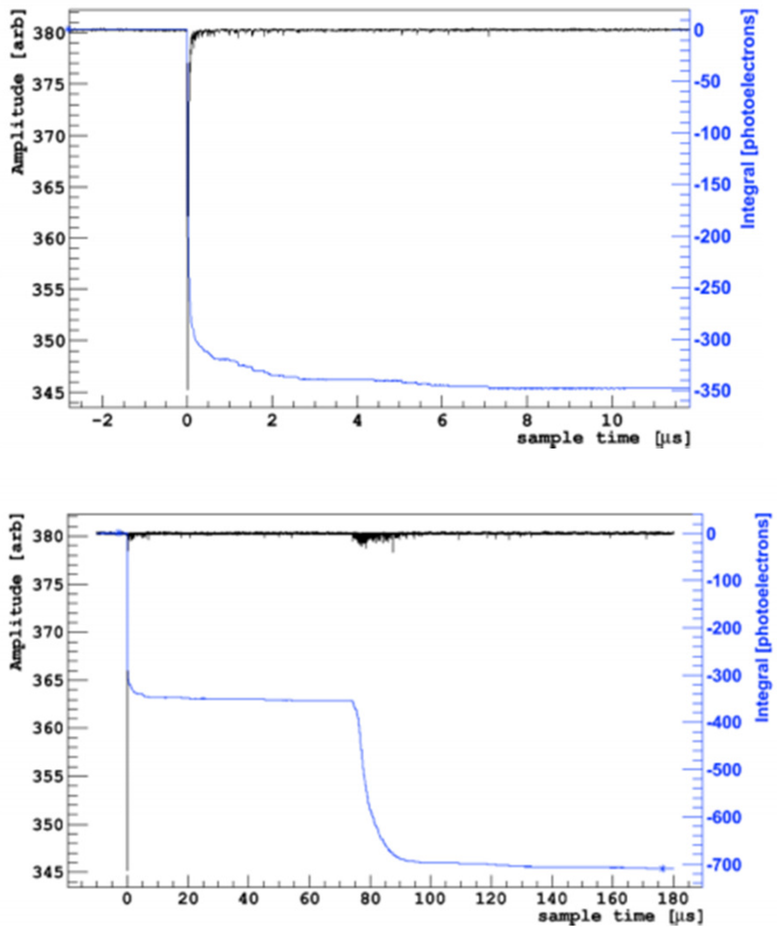
- ✓ **xy position reconstructed through the S2 light pattern on the top array (σ_{xy}~ 1 mm)**
- ✓ **Z position reconstructed through the Drift time (σ_z~ 0.3 mm)**

Event discrimination technique in Ar

El. recoil like event



N.recoil like event



$$\left.\frac{S_2}{S_1}\right|_{ER} > \left.\frac{S_2}{S_1}\right|_{NR}$$

Due to an enhancement of the recombination process

Two phases Ar and Xe TPCs currently in operation

XENON100

LNGS
161kg
~50 kg fiducial
242” PMTs

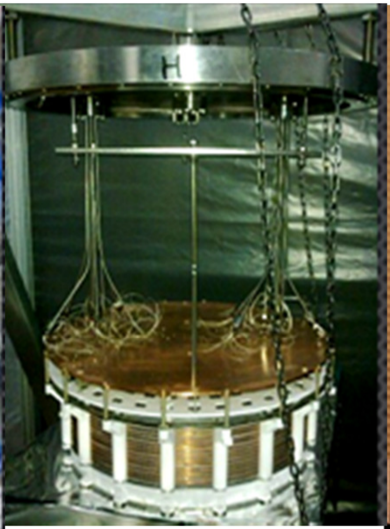
New DM data
still blinded
Modulation
studies

LUX

Homestake
370 kg LXe
100 kg fiducial
122 2” PMTs

Physics run and
first results in
2013
2015 new data
(300d blinded)

Panda-X



CJPL
125 kg LXe
37 kg fiducial
143 1” PMTs
37 3” PMTs

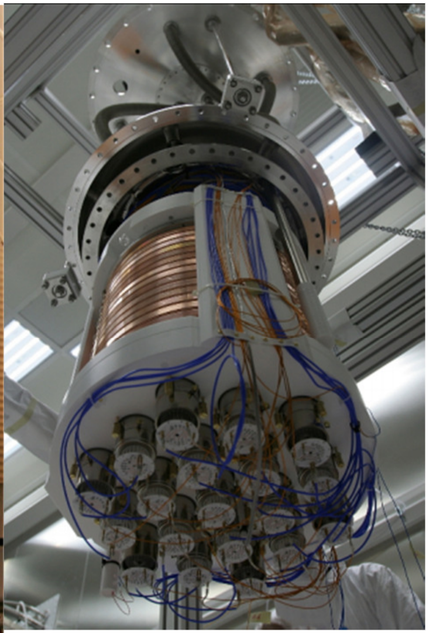
First results in
Aug 2014
80 days DM data
still blinded

ArDM

Canfranc:
850 kg LAr
~500 kg fiducial
28 8” PMTs

Filled in Feb 15.
First
science run in
2015?

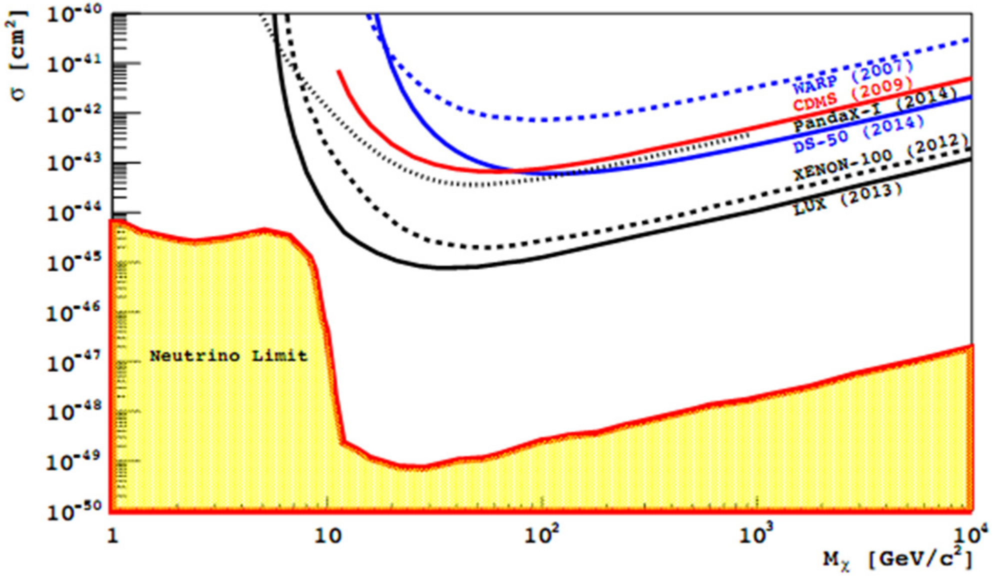
DarkSide50

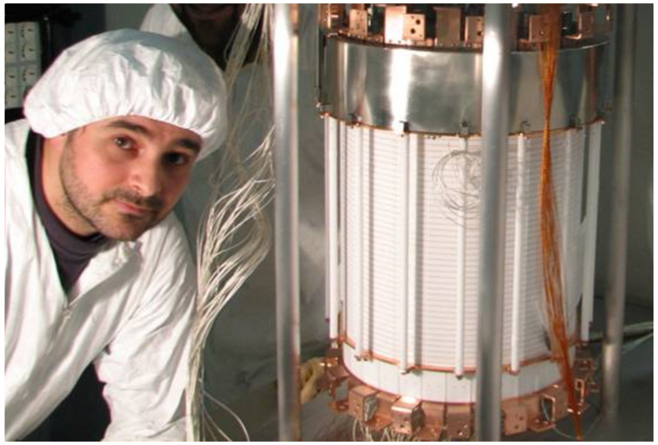


LNGS
50 kg LAr
33 kg fiducial
38 3-inch PMTs

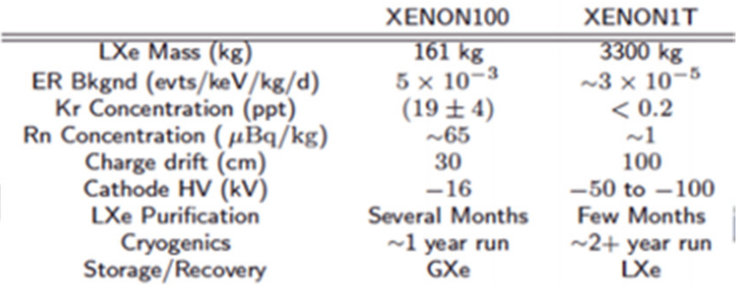
2014 First result
2015 First run
depleted Ar

XENON100 / XENON1T

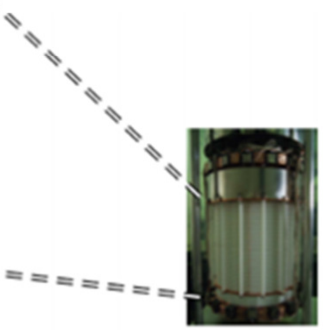




XENON100
still taking data during
Release 2015?
Testing calibration sources



	XENON100	XENON1T
LXe Mass (kg)	161 kg	3300 kg
ER Bkgnd (evts/keV/kg/d)	5×10^{-3}	$\sim 3 \times 10^{-5}$
Kr Concentration (ppt)	(19 ± 4)	< 0.2
Rn Concentration (μBq/kg)	~65	~1
Charge drift (cm)	30	100
Cathode HV (kV)	−16	−50 to −100
LXe Purification	Several Months	Few Months
Cryogenics	~1 year run	~2+ year run
Storage/Recovery	GXe	LXe

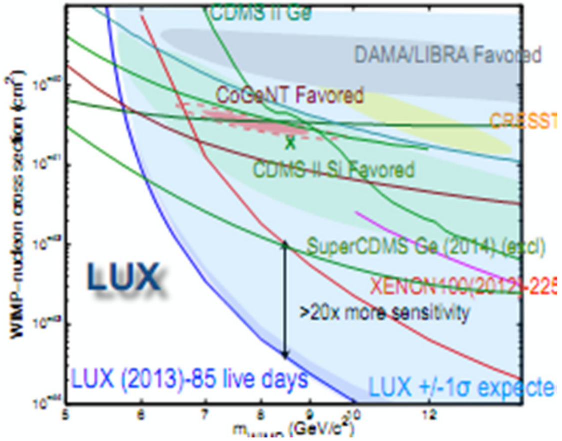


XENON1T
Extensive material selection
248 × 3” PMTs (R11410-21)
Average QE (178nm) 34%

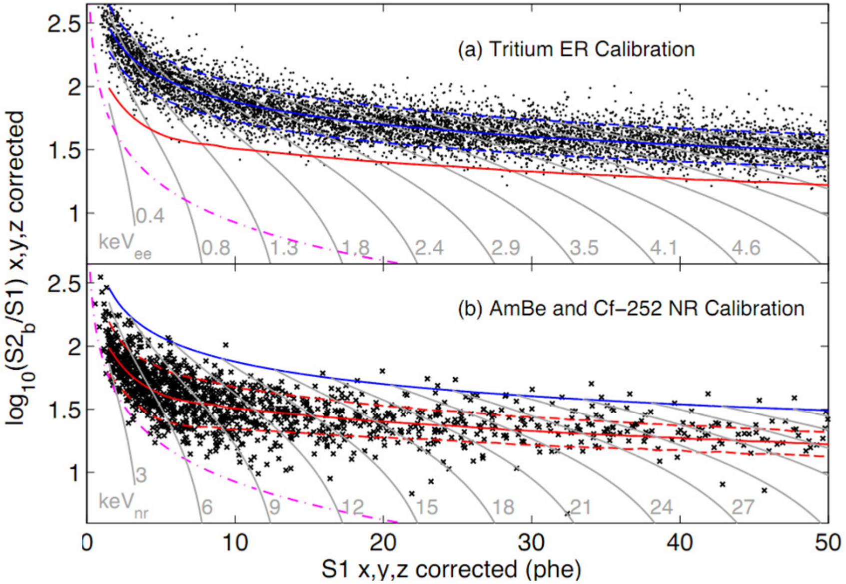
Under construction (Design completed)
Install June 2015?

- 10 m high – 9 m diameter Water tank
- 84 high QE 8” Hamamatsu R5912 PMTs
- μ-induced background < 0.01 evt/yr
- Trigger efficiency >99.5% for neutrons with μ in water tank , ~78% with μ outside

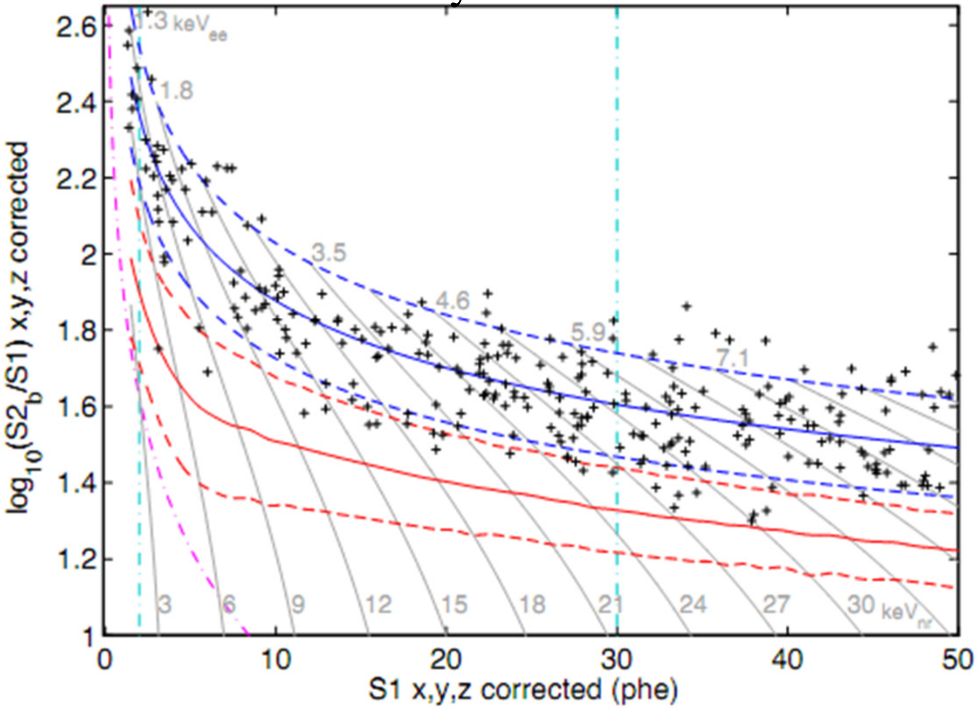
LUX



Homestake
370 kg LXe
100 kg fiducial
122 2” PMTs



PhysRevLett.112.091303



Measured ER background 3.6±0.3 mdru

(1 dru = 1 count / [keVee × kg × day])

- 2-30 pe (S1) ROI
- 160 events observed
- 0.64 events expected from ER leakage below the NR mean
- 1 event observed in the box

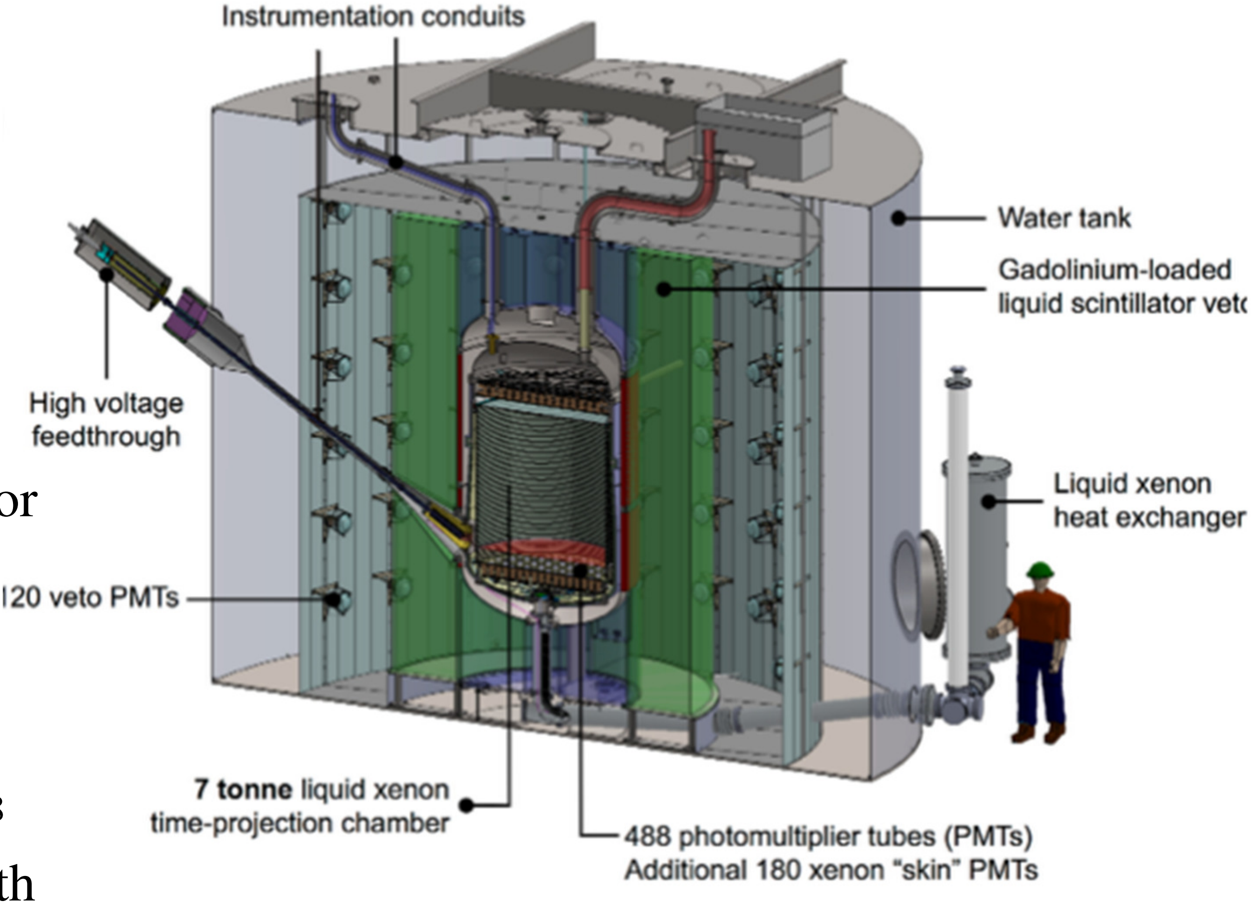
LZ: LUX+ZEPLIN

At Homestake . Approved in mid-2014 as DOE-only supported project. (Total cost ~55M$)

Detector:
- Dual-phase TPC with
- 7t LXe viewed
- 488 3-inch PMTs

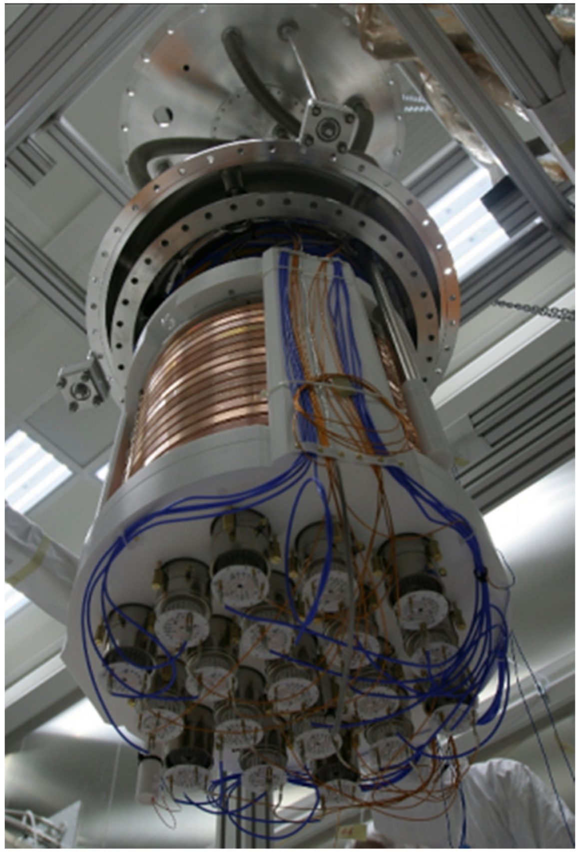
Shield:
- Gd-loaded liquid scintillator
- LUX water shield

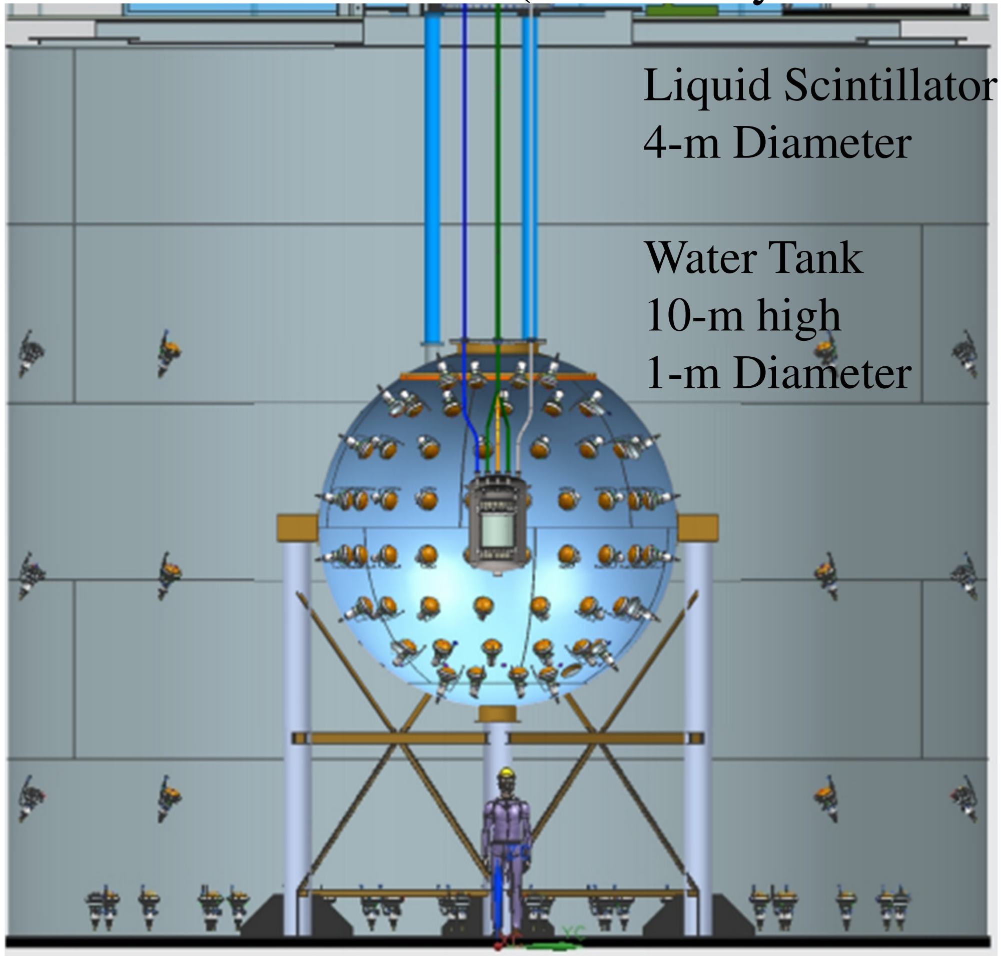
- Status: start in 2018?
- Projected Sensitivity: 10^{-48} cm^2 for 50 GeV WIMP with 1000 live days



DarkSide

- DS50: results published in October 2014 (1.422 kg×day, no background)
- Depleted (UG) Argon run in 2015
- G2 phase O(5 ton) within the existing active veto
- G3 phase planned O(100 ton) to reach the neutrino floor (~400 ton×yr with no background)



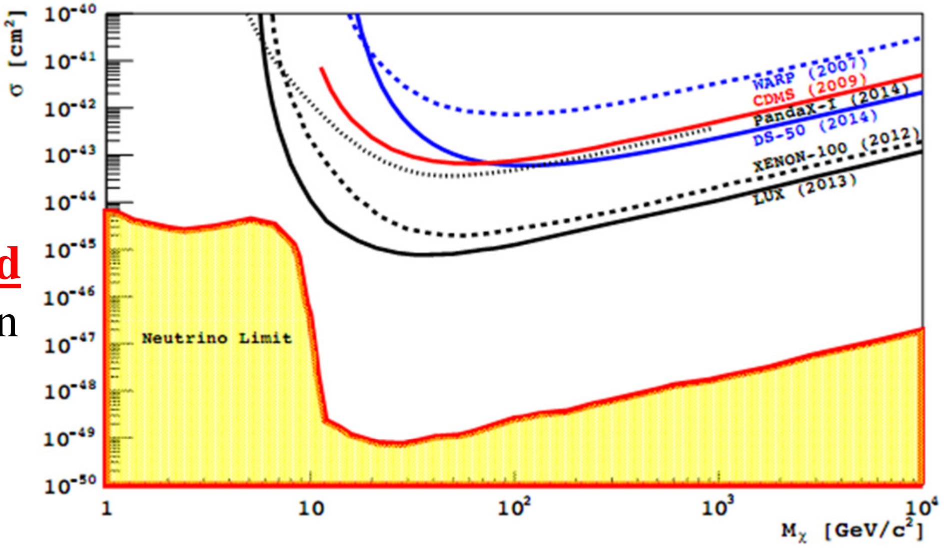


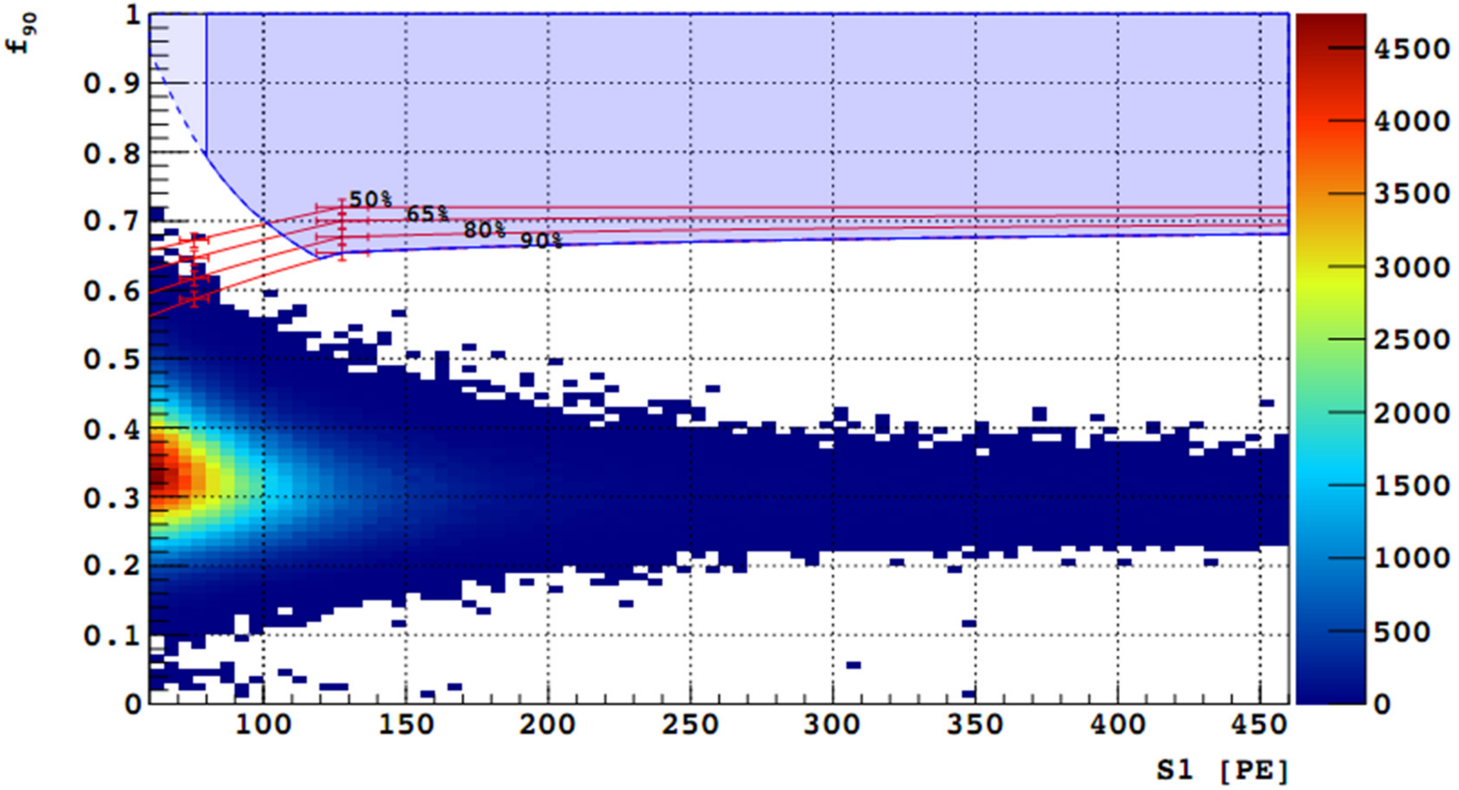
First results from Atm-Ar, 1422 kg d

6.1×10^{-44} cm^2 at a M_W~100 GeV

<u>**Rejection factor ~10^7 at 36 keVr threshold**</u>

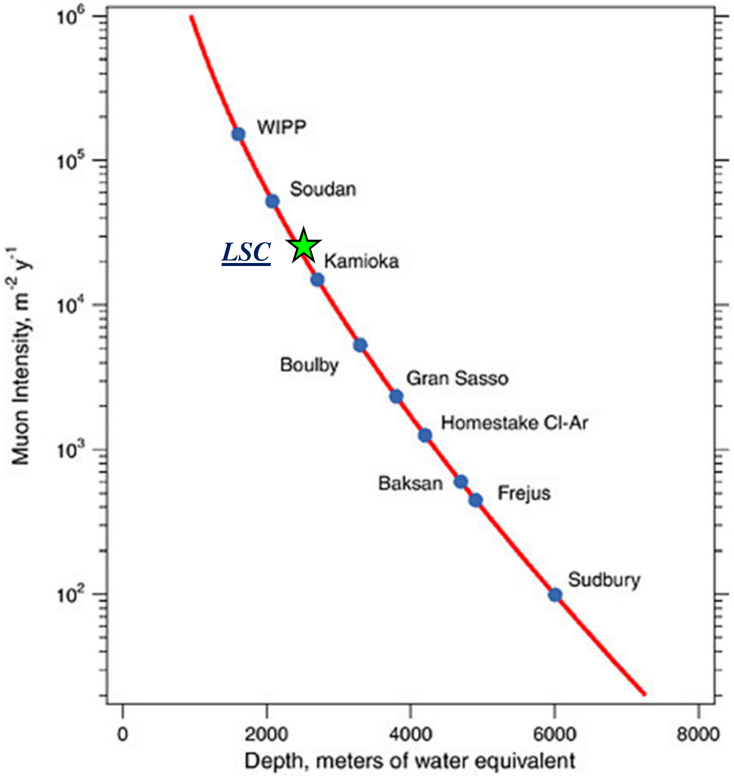
Results interpreted as a zero background run in 0.6 ton × yr with Ug-Ar





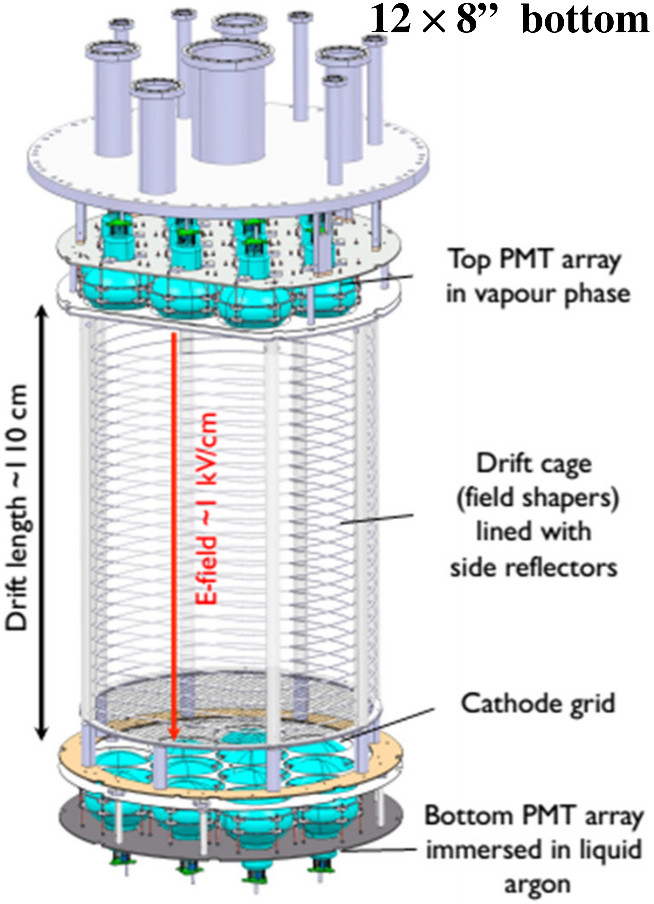
LSC – Canfranc Underground Laboratory

- Lab. space ≈ 4000 m^3 (main hall).
- Gamma flux ≈ $2x10^{-2}$ $\gamma/cm^2/s$.
- ≈ 2450 mwe
- Neutron flux ≈ 10^{-6} $n/cm^2/s$ (CUNA).
- Radon ≈ 50-100 Bq/m^3.
- Temperature, pressure and humidity monitored.



ArDM-1t in a nutshell

- ~2000 kg Ar mass double-phase (~850 kg in the target, > 500 kg fiducial)
- Cylindrical volume 80 cm diameter, ~120 cm max drift
- ~1 kV/cm drift field
- Cryogenic low radioactivity PMT (Hamamatsu R5912)
  - 12 × 8” top (first phase)
  - 12 × 8” bottom



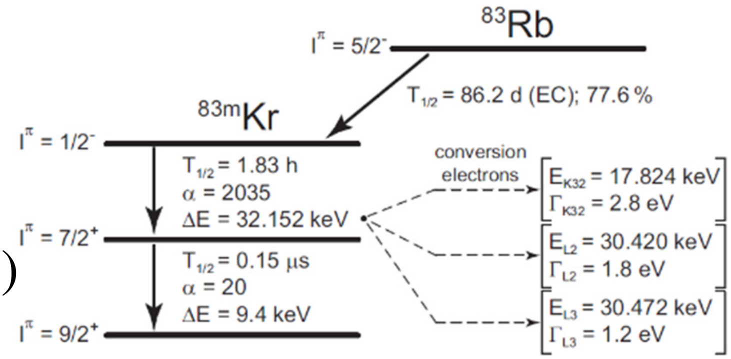
ArDM Phases of the project

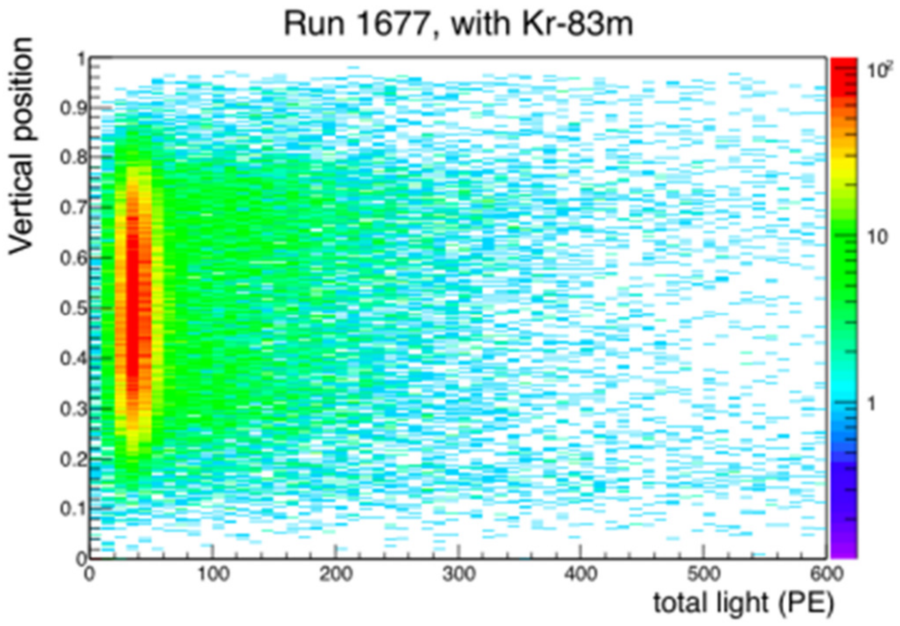
- **Surface** operation :
  - Building the ArDM prototype ✓
  - Commissioning the detector cryogenics, purification, HV, electronics, light readout and software ✓
- **Underground** operation I:
  - Construction and installation of the passive neutron shielding ✓
  - Installation of ArDM and its infrastructures ✓
  - Warm gas argon runs and test of the light readout system ✓
  - ^{83m}Kr source calibration → ✓
  - Material screening → **Ongoing**
  - Neutron flux measurements → **Ongoing**
- **Underground** operation II :
  - First Liquid argon run (commission HV, purification, cryogenics, …). → **Ongoing**
  - Physics runs (→2015?)

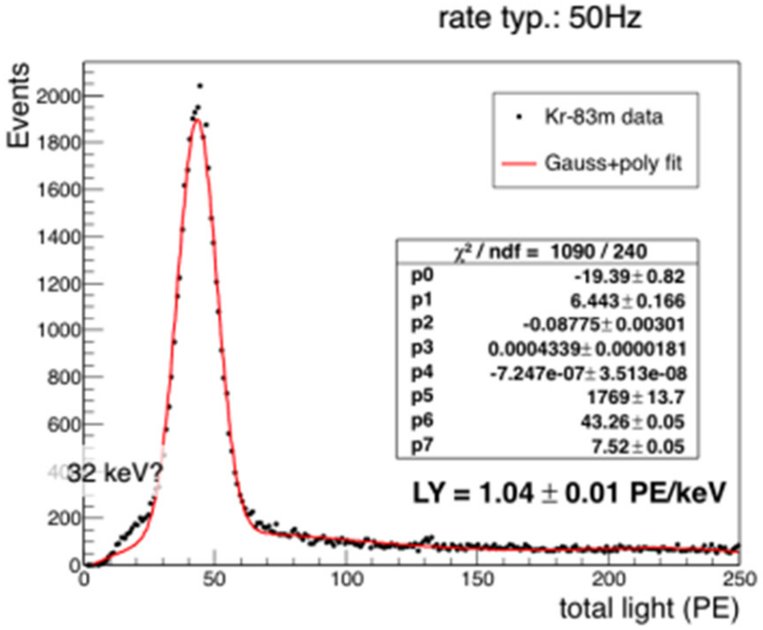
ArDM: First 1-ton scale double-phase TPC in operation!!

Detector Calibration

- 83Kr data: Verified LY and energy threshold
- Peak width well described by photons statistics (10% intrinsic resolution)
- Uniform light collection (vertical distribution)
- Expected threshold for DM search ~30keV$_r$



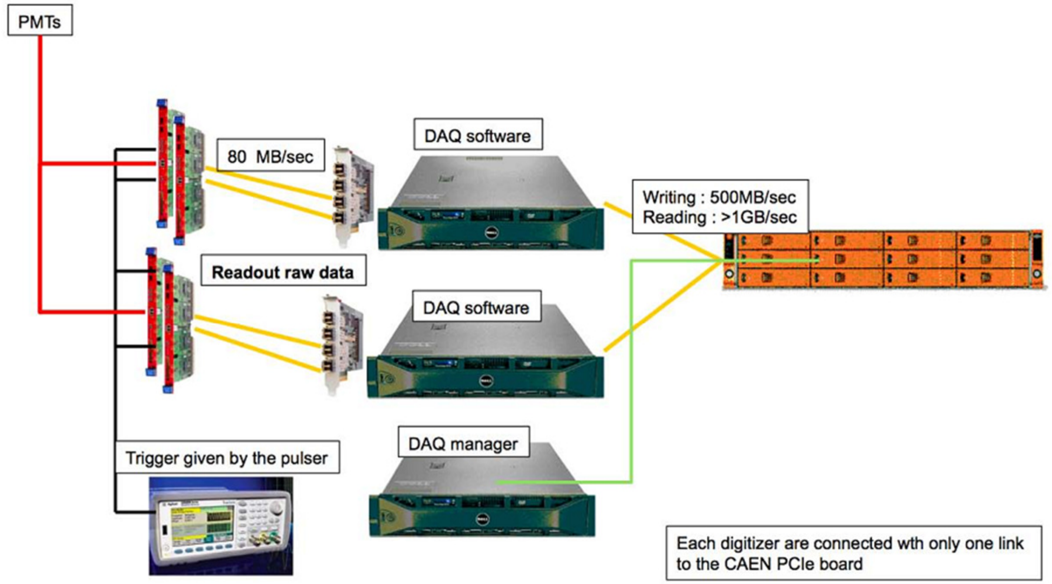




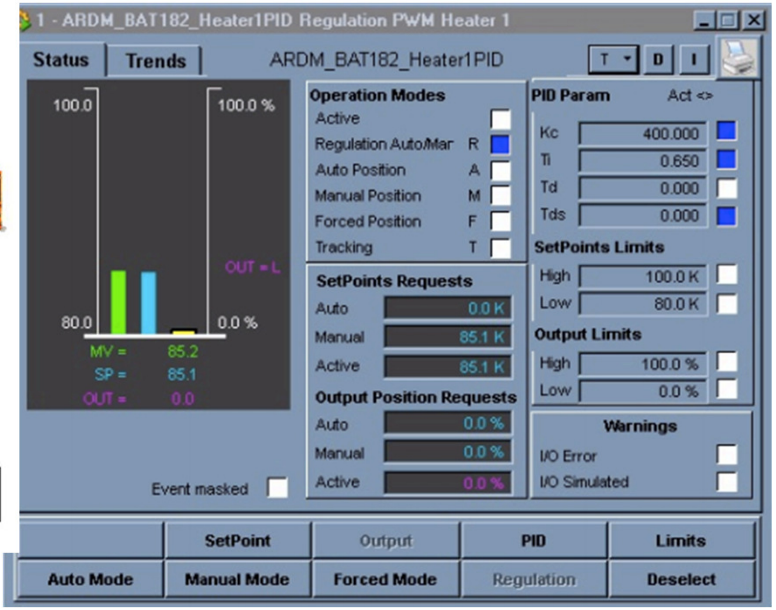
Threshold for DM search of ~30 keV$_{NR}$ within reach
(trigger on fast component of NR = 75% of signal)

Slow control, trigger and DAQ

- Control of the cryocoolers and cryogenic system fully integrated in the existing PLC
- Reduced manpower requirements during the data taking
- 4x ADC V1720, 8ch, 12bit, 2Vpp, 250MS/s.
- handling up to 2.2 kHz trigger rate (289 MB/s – 8 µs digitalization)



Each digitizer are connected wth only one link to the CAEN PCIe board



MV = 85.2
SP = 85.1
OUT = 0.0

Event masked ☐

Operation Modes
Active ☐
Regulation Auto/Mar R ■
Auto Position A ☐
Manual Position M ☐
Forced Position F ☐
Tracking T ☐

SetPoints Requests
Auto 0.0 K
Manual 85.1 K
Active 85.1 K

Output Position Requests
Auto 0.0 %
Manual 0.0 %
Active 0.0 %

PID Param
Kc 400.000 ■
Ti 0.650 ■
Td 0.000 ☐
Tds 0.000 ■

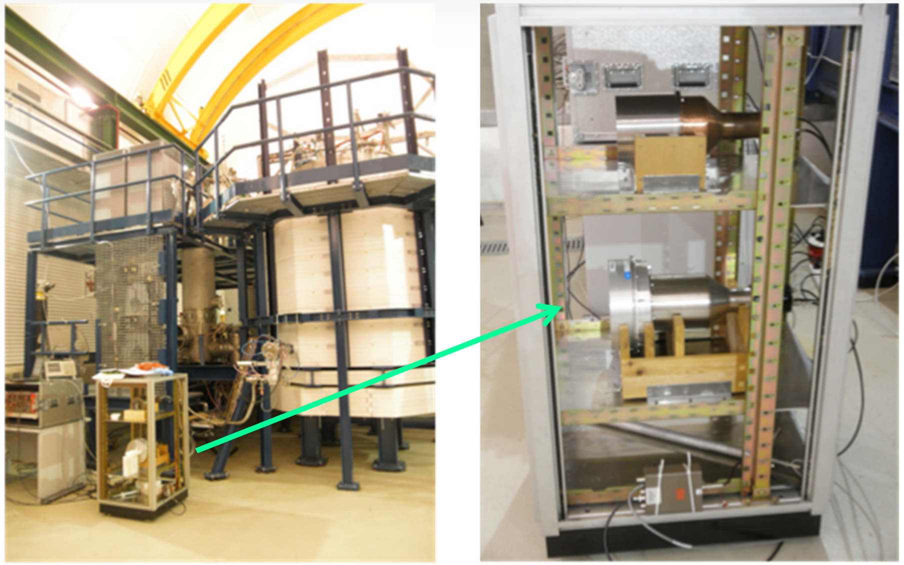
SetPoints Limits
High 100.0 K ☐
Low 80.0 K ☐

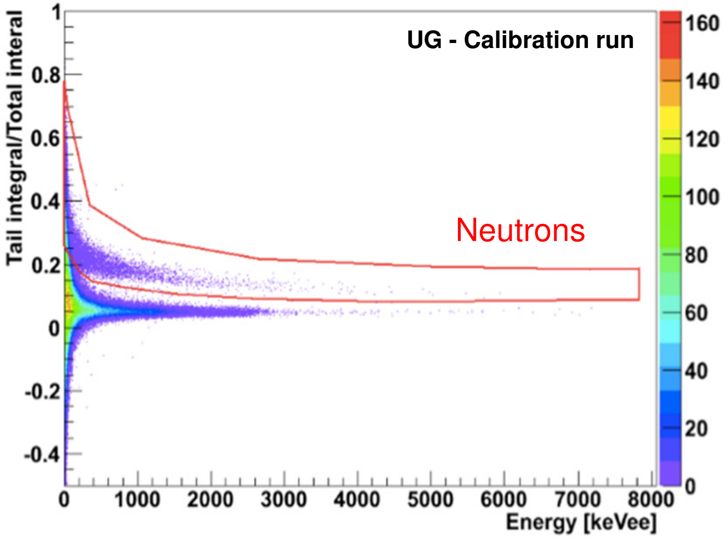
Output Limits
High 100.0 % ☐
Low 0.0 % ☐

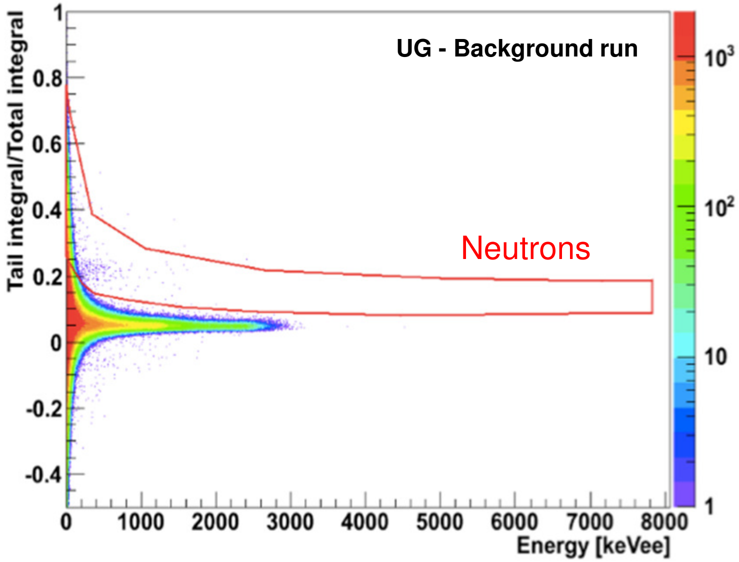
Warnings
I/O Error ☐
I/O Simulated ☐

Environmental neutron flux measurement

- Detector in operations @ LSC since November 2013.
  - Two BC501A **liquid scintillators** → fast neutron spectroscopy.
  - ^{3}He **proportional counter** → thermal neutron background.
- **Periodical calibrations** with gamma sources and a neutron source
- **Data taking** of **several months** is foreseen in collaboration with the ***Nuclear Innovation Unit from CIEMAT*** and **CUNA**.

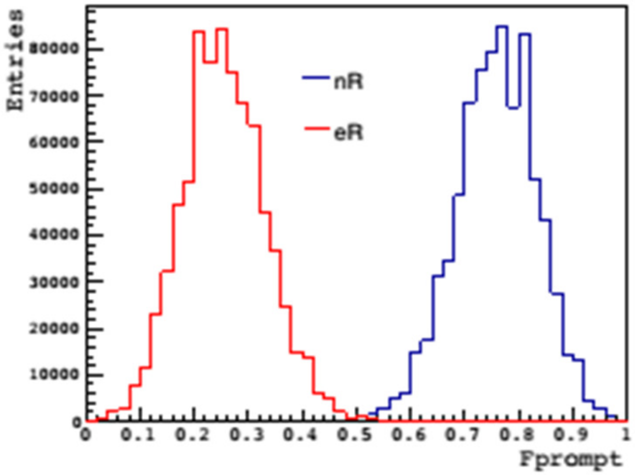




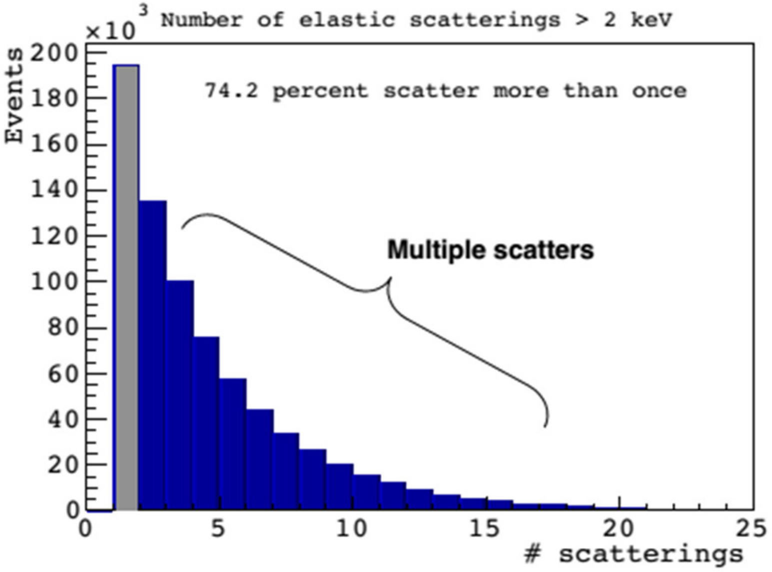


Plans

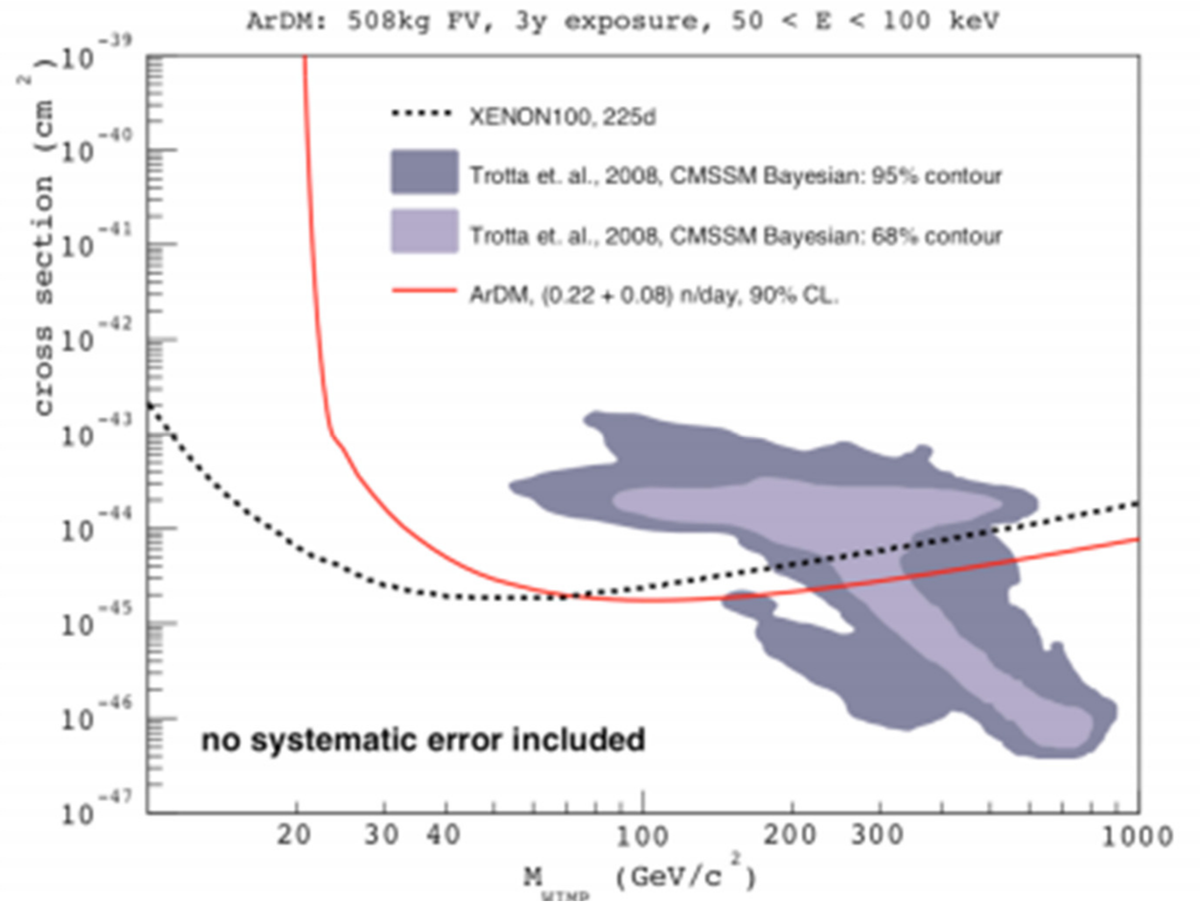
- Commission the detector in liquid
- Assess the LAr purity
- Explore the light yield for the full target
- Measure the ^{39}Ar background
- Measure the rejection power for electron background
- Measurements of the neutron background from multiple scattering



Simulation based on photon statistics



Expected sensitivity



50 < E < 100 keV

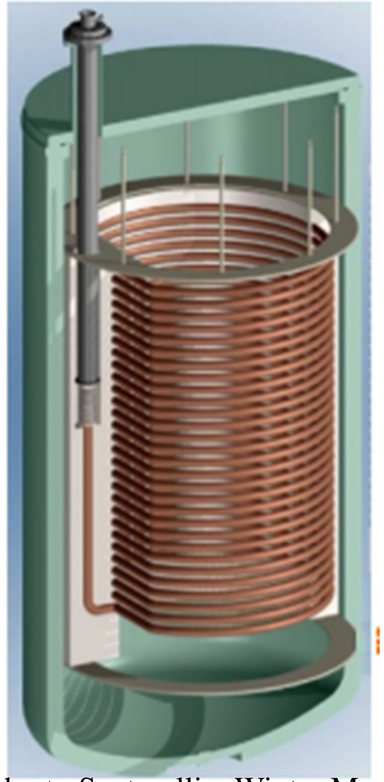
Projected sensitivity with (2.2±0.08) n/d
From MC and screening results

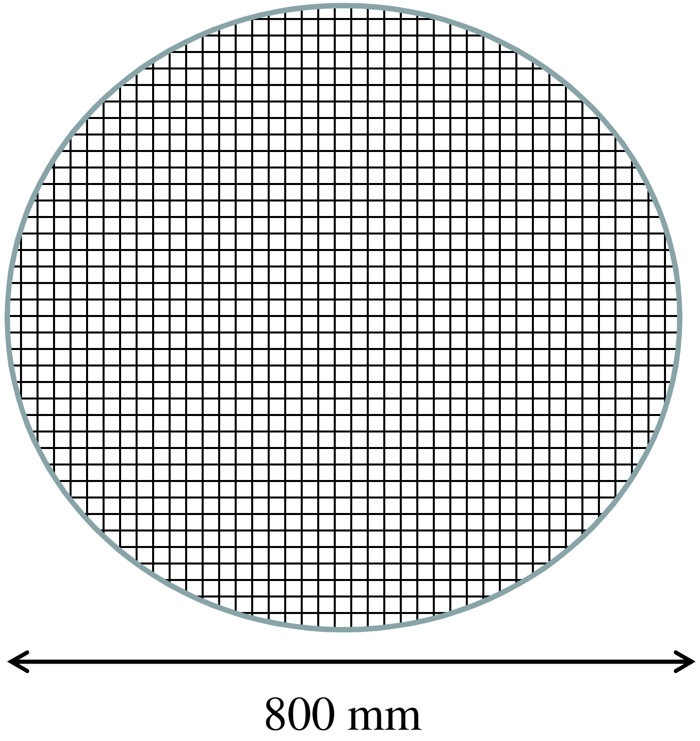
Upgrades

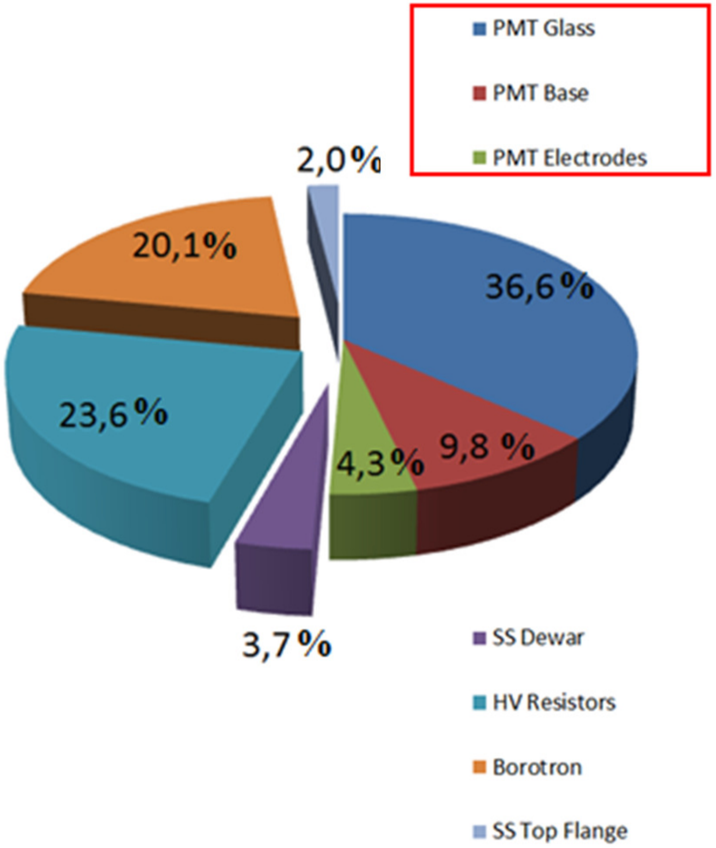
- New field cage (Fully manufactured, stored at LSC)
- New reflectors
- Upgrade of the light readout with SiPMTs

  2000 SiPMTs (7×7 mm^2 - SENSEL) necessary for the same light readout

- Ar recovery system



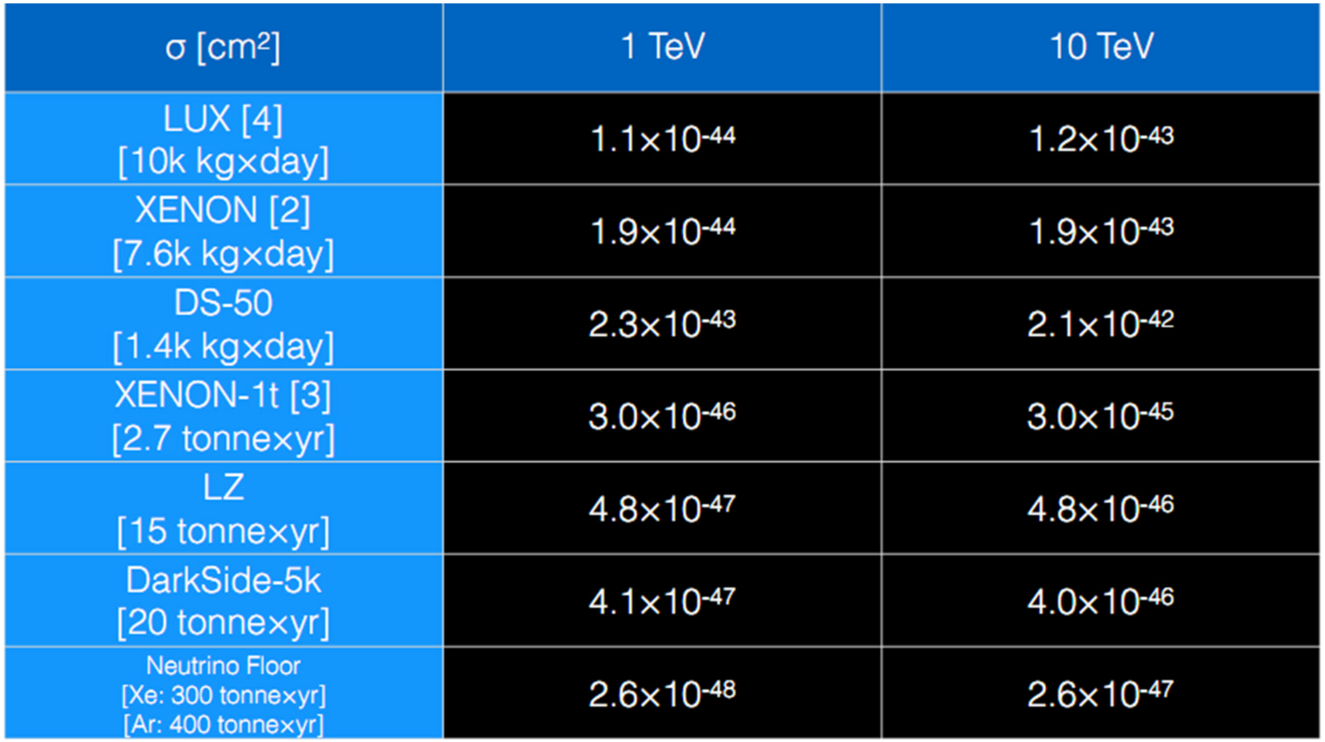




Argon over Xenon?

What is required to explore dark matter to the "Neutrino Floor" well above 100 GeV?

("Neutrino Floor": dark matter sensitivity level where neutrino-induced coherent scattering by atmospheric neutrinos provide one count in given exposure)



σ [cm^2]	1 TeV	10 TeV
LUX [4] [10k kg×day]	1.1×10^{-44}	1.2×10^{-43}
XENON [2] [7.6k kg×day]	1.9×10^{-44}	1.9×10^{-43}
DS-50 [1.4k kg×day]	2.3×10^{-43}	2.1×10^{-42}
XENON-1t [3] [2.7 tonne×yr]	3.0×10^{-46}	3.0×10^{-45}
LZ [15 tonne×yr]	4.8×10^{-47}	4.8×10^{-46}
DarkSide-5k [20 tonne×yr]	4.1×10^{-47}	4.0×10^{-46}
Neutrino Floor [Xe: 300 tonne×yr] [Ar: 400 tonne×yr]	2.6×10^{-48}	2.6×10^{-47}

Argon over Xenon?

Complete exploration requires a background-free exposure of
300 tonnes×yr for xenon
400 tonnes×yr for underground argon

Can an Argon experiment be background free at that exposure?
YES thanks to pulse shape discrimination!!!

Can an Argon experiment be background free at that exposure?
VERY tough job! Background need to be reduced to <30 μdru
(1 dru = 1 count / [keVee × kg × day])

XENON100 [2012]: 2 leakage events over 400 in ROI
LUX [2014]: 1 leakage events over 160 in ROI

Cooperation between DarkSide and ArDM

- Cooperation on depleted argon for ArDM at LSC
- Cooperation for a 5k detector at LNGS
- Cooperation on technology (SiPM)
- Joint letter of intent for 100 tonnes detector

Conclusions

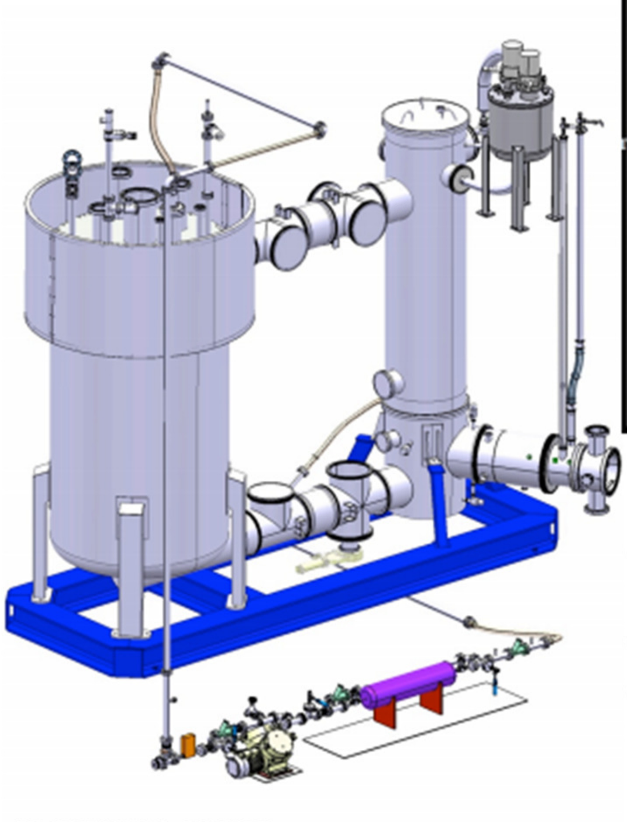
- Direct detection experiments have excluded WIMP-nucleon cross sections down to 10^{-8} pb
- Tension in the low WIMP mass, but some claims rejected
- Double-phase liquid noble TPCs best prospective for the 100 GeV ÷ 1 TeV WIMP mass region
- Program of strong cooperation between DarkSide and ArDM
- G3 Argon detector proposed to reach the “neutrino floor”
- Exciting times for dark matter…

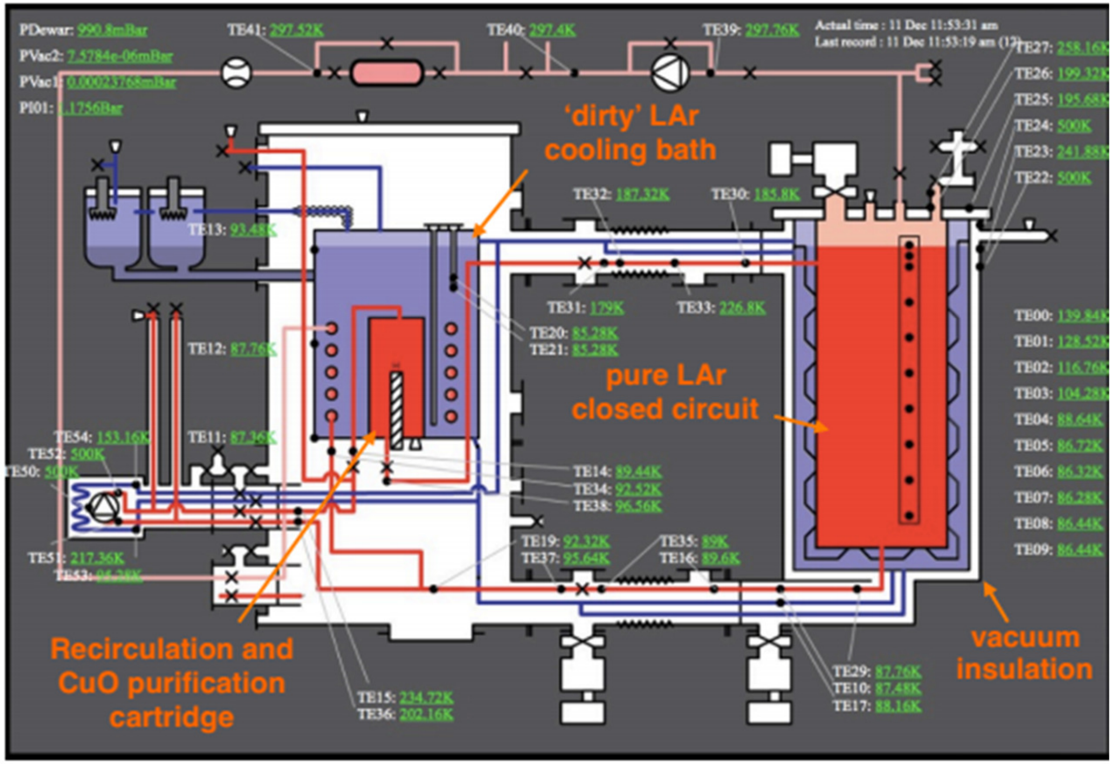
Backup

Cryogenic design

Bath design in a modular design

- **"clean" and "dirty" LAr volumes**
- **no direct heat load to the clean LAr**
- **bubble free ?**





'dirty' LAr cooling bath

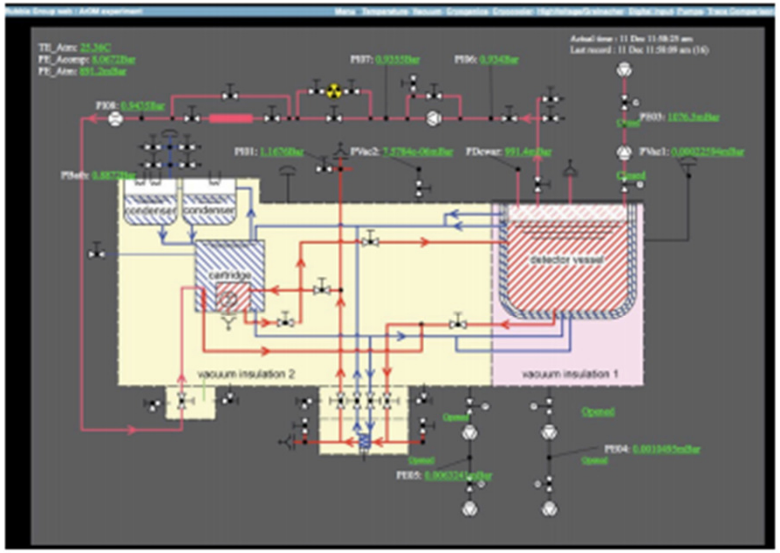
pure LAr closed circuit

Recirculation and CuO purification cartridge

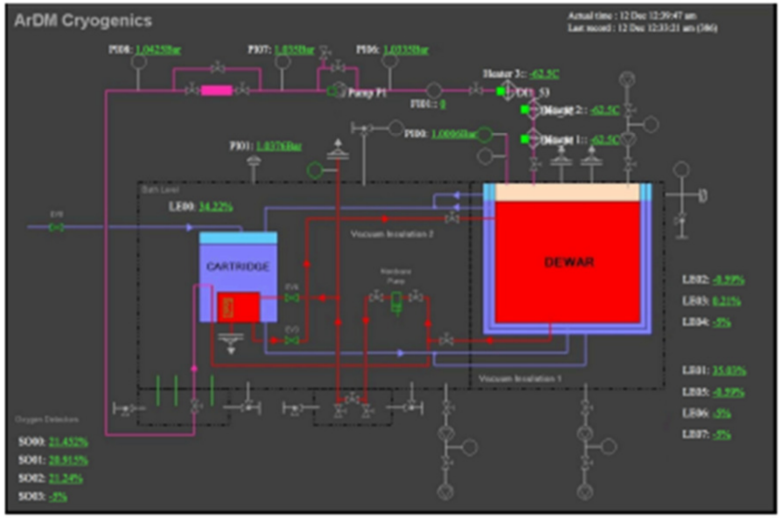
vacuum insulation

- **3 x 300W Gifford-McMahon cryocoolers (Cryomech AL300)**
- **Heat influx from the env. ~350 W**
- **Third cryocooler for redundancy**

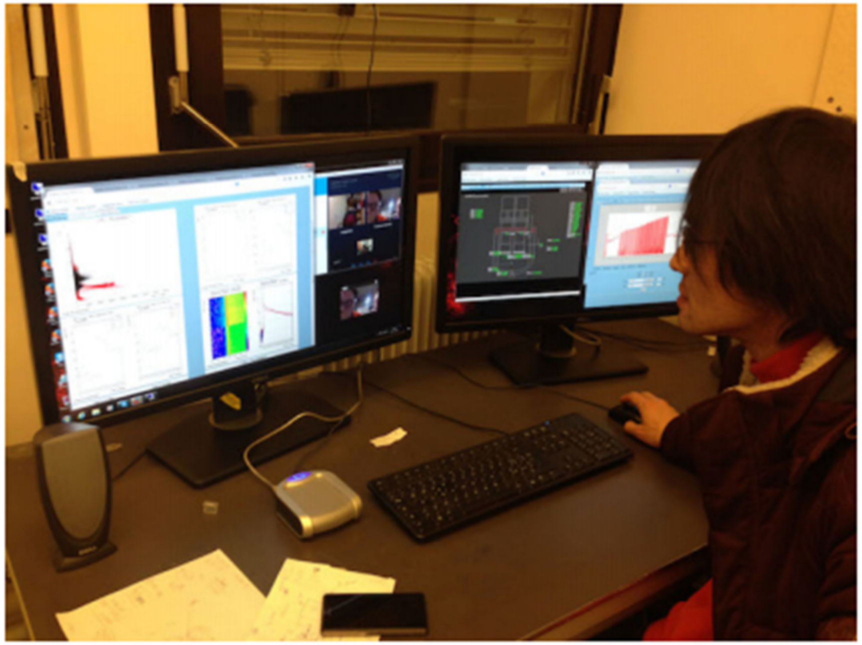
Experiment - fully remotely controlled



Webinterface



ArDM Control Center CERN



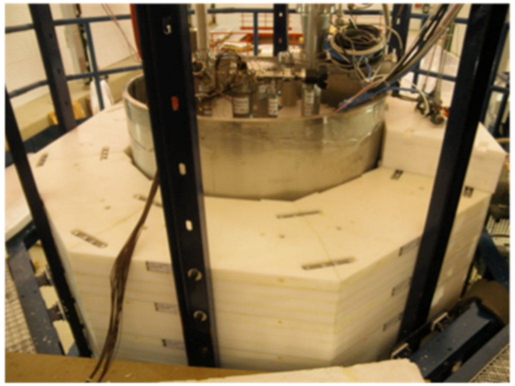
Audio visual contact with shifters at LSC

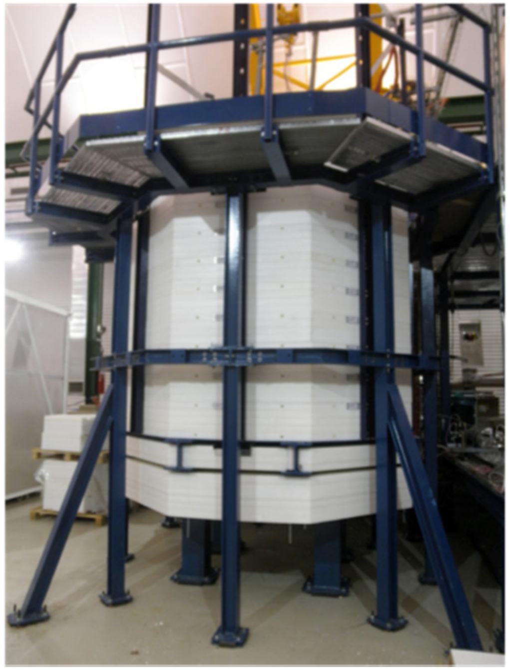
Neutron shield

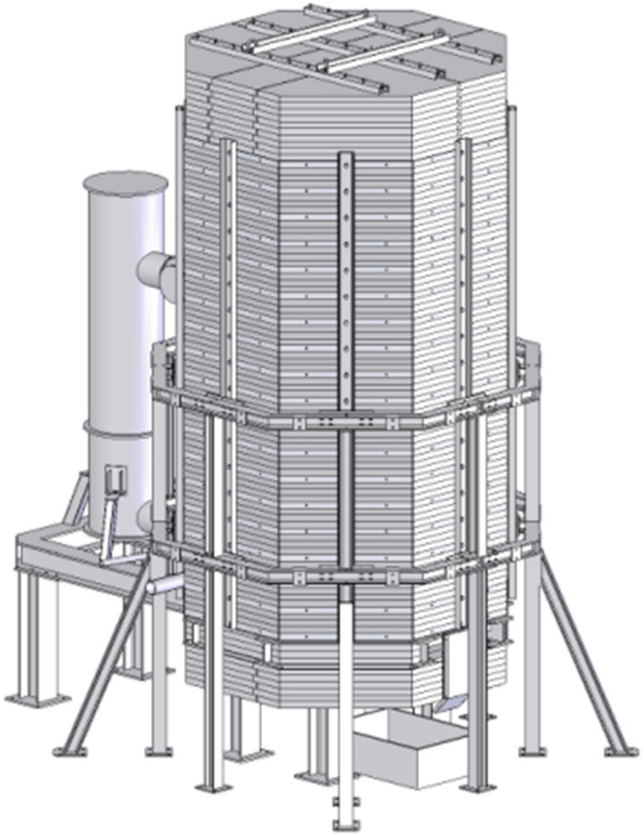
- **Polyethylene neutron shield**
  - 50 cm thick
  - 17 ton total (12 + 2×2.5)
  - ~10^5 reduction of the neutron flux of neutron (<1 MeV)
  - Installed: bottom + side
  - Top part: pending.

Safety (fire protection)

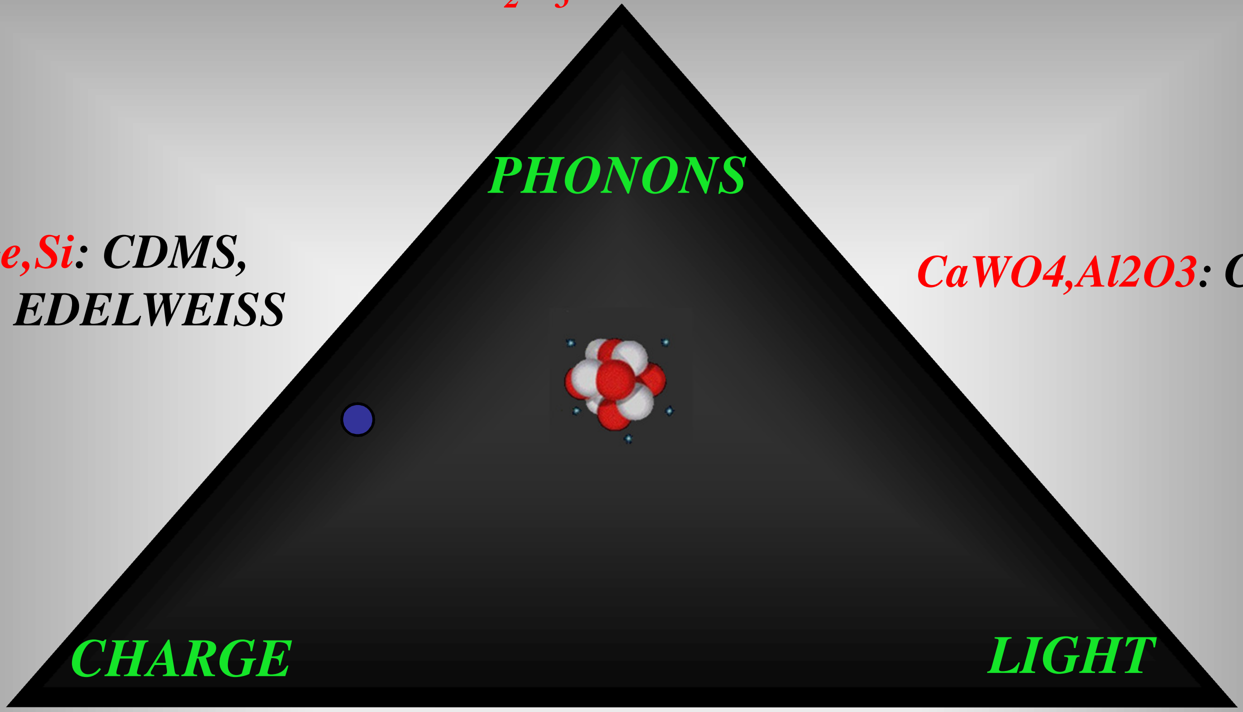
- Fire-retardant paint.
- Insulating layer +ext. aluminum sheet.







Experiments



Al_2O_3:CRESST-I

PHONONS

Ge,Si: CDMS,
Ge: EDELWEISS

CaWO4,Al2O3: CRESST

CHARGE

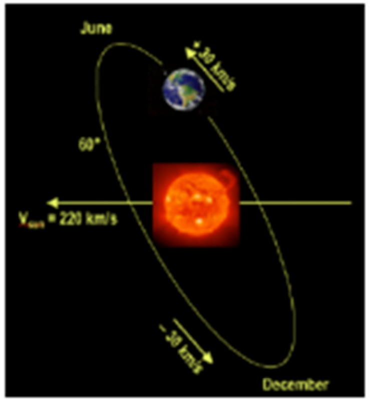
LIGHT

C,F,I,Br: PICASSO, COUPP
Ge: Texono, CoGeNT
CS_2,CF_4,^3He: DRIFT,MIMAC
Ar+C_2H_6: Newag

LAr: ArDM
LAr: WARP
LXe: XENON
LXe: LUX
LXe: ZEPLIN

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

Corrections



- Form factor

$$\sigma(qr_n) = \sigma_0 F^2(qr_n) \qquad F(qr_n) = 3\frac{j_1(qr_n)}{qr_n}e^{-(qs)^2/2}$$

- Earth velocity: annual modulation

$$v_E(t)\ [km/s] = v_S + 15\cos\theta = 232 + 15\cos\left(2\pi\frac{t-152.5}{365.25}\right)$$

- Finite galactic escape velocity

$$v_{esc} = 600\ \mathrm{km\ s^{-1}}$$

- Finite energy range

$$\frac{dR(v_E, v_{esc})}{dE_R} = \frac{k_0}{k_1}\frac{R_0}{E_0 r}\left[\frac{\sqrt{\pi}}{4}\frac{v_0}{v_E}\left[\mathrm{erf}\left(\frac{v_{min}+v_E}{v_0}\right) - \mathrm{erf}\left(\frac{v_{min}-v_E}{v_0}\right)\right] - e^{-v_{esc}^2/v_0^2}\right]$$

$$\frac{k_0}{k_1} = \left[\mathrm{erf}\left(\frac{v_{esc}}{v_0}\right) - \frac{2}{\sqrt{\pi}}\frac{v_{esc}}{v_0}e^{-\frac{v_{esc}^2}{v_0^2}}\right]^{-1}$$

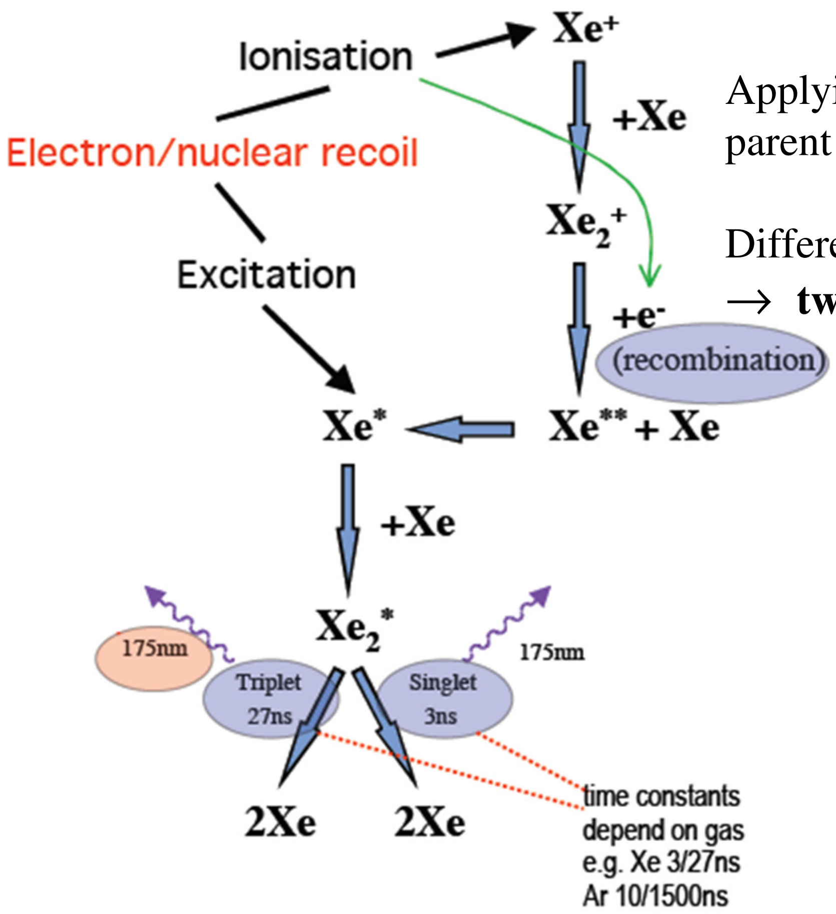
$$v_{min} = \sqrt{E_R/E_0 r}\,v_0$$

$$\mathrm{erf}\left(\frac{v_{esc}}{v_0}\right) = \frac{2}{\sqrt{\pi}}\int_0^{v_{esc}/v_0} e^{-t^2}dt$$

The double phase EL-TPC

Wimps (or neutrons) → Slow nuclear recoils

γ,e^- etc → Fast electron recoils



Applying a drift field fewer and fewer electrons recombine with the parent ions : **recombination light suppressed**.

Different track structures of recoiling electron and nuclei

→ **two different amount of quenching**

Different ionization/scintillation ratio for electron and nuclear recoil

→ Event by Event discrimination

Ionization signal from nuclear recoil too small to be directly detected

DUAL PHASE DETECTOR

Ultra pure liquid necessary to preserve small electron signal (~10 el)