Direct dark matter search using liquid noble gases

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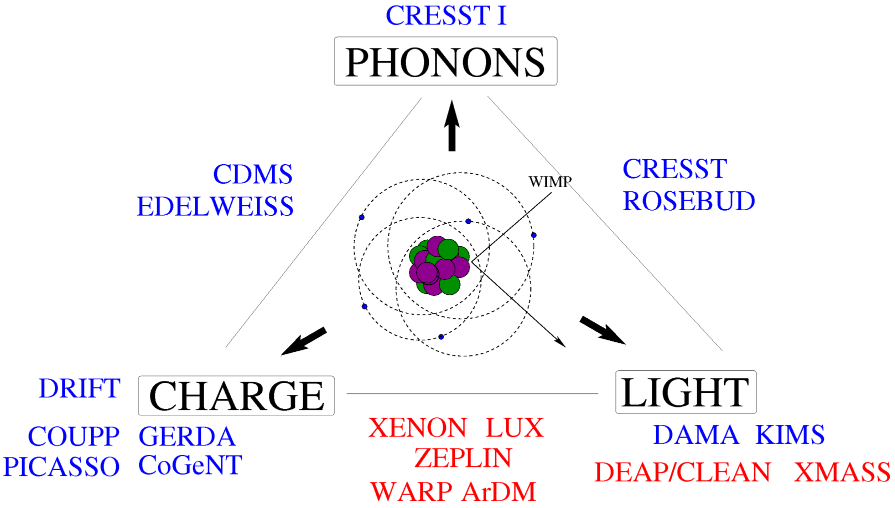
Texas Symposium 2010,
Heidelberg, 09.11.2010

Direct detection experiments

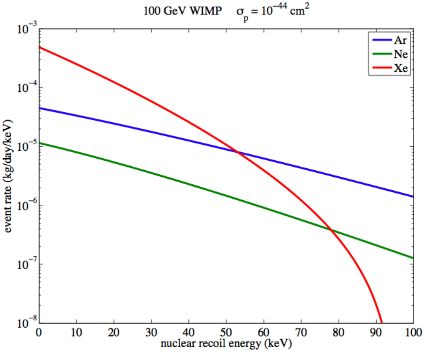


Advantages of liquid noble gases for DM searches

- Large masses and homegeneous targets (LNe, LAr & LXe)
- Very high scintillation yield ($\sim$ 40 000 photons/MeV)
- Transparent to their own scintillation light
- 3D position reconstruction
  - Light pattern in the PMTs for single phase (cms)
  - Few mms resolution in TPC mode
- High ionization yield (W_{LXe} = 15.6 eV and W_{LAr} = 23.6 eV)
- Particle discrimination
  - Pulse shape discrimination
  - Charge to light ratio

Comparison between noble gases

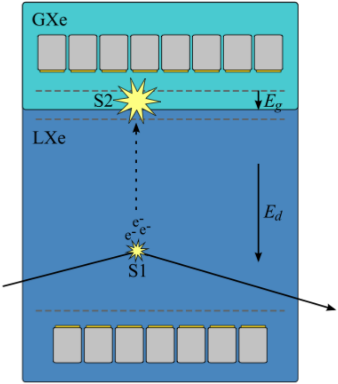
	LNe	LAr	LXe
Z (A)	10 (20)	18 (40)	54 (131)
Density [g/cm^3]	1.2	1.4	3.0
Scintillation λ	78 nm	125 nm	178 nm
BP [K] at 1 atm	27	87	165
Ionization [e$^-$/keV]	46	42	64
Scintillation [γ/keV]	7	40	46



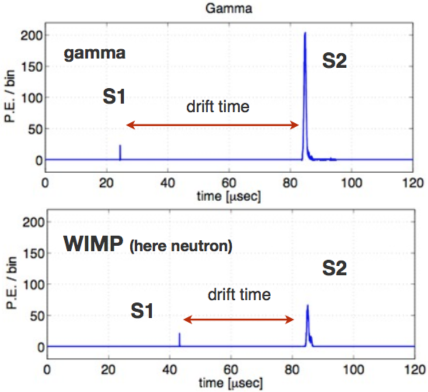
Radioactive isotopes:

- Argon: ^{39}Ar (565 keV endpoint, 1 Bq/kg), ^{42}Ar
- Xenon: ^{136}Xe $\beta\beta$ candidate *not yet measured!*
- ^{85}Kr in argon or xenon $\rightarrow$ removal using distillation

Two phase noble gas TPC



- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)



Electron recombination is stronger for nuclear recoils

$\longrightarrow$ Electron- / nuclear recoil discrimination

Calibration of noble gas detectors

Electron recoil calibration

- Energy calibration and electron recoil band characterization
- Introducing sources inside
  - Easier in single phase detectors (field distorsion)
  - Light blocking issue
- Calibration sources outside $\rightarrow$ self-shielding issue for low energies

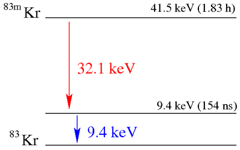
Nuclear recoil calibration

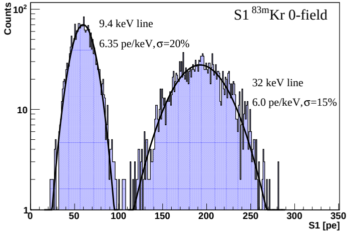
- No monoenergetic neutron lines for calibration

$\longrightarrow$ Dedicated neutron scattering experiments

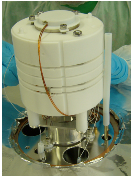
Low energy calibration

- ^{83m}Kr calibration source:
  - EC decay-product of ^{83}Rb
  - Lines at 9.4 and 32.1 keV
  - Uniform distribution



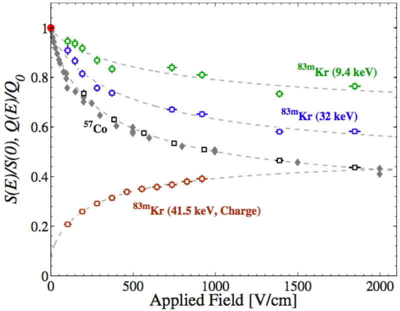


Liquid xenon



- Target mass: $\sim$ 0.1 kg LXe
- Volume: 3 cm drift length and 3.5 cm diameter
- Two R9869 PMTs
- 6 pe/keV in double phase

$\rightarrow$ at University of Zürich



A. Manalasay *et al.*, Rev. Sci. Instr. **81**, 073303 (2010), 0908.0616

Calibration of the nuclear recoil energy scale

- Nuclear recoil energy (E_{nr}):

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

$S1$: measured signal in p.e.

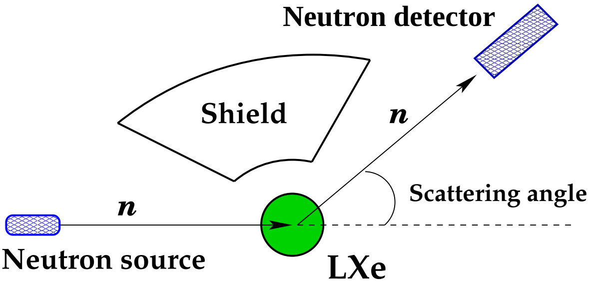
L_y: LY for 122 keV γ in p.e./keV

S_e/S_r: quenching for 122 keV γ/NR due to drift field

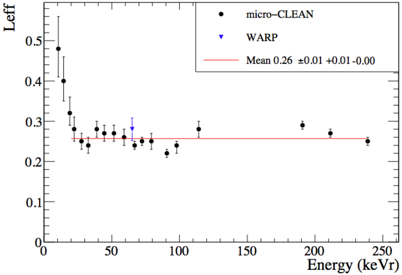
- Relative scintillation efficiency of NR to 122 keV γ at 0-field

$$L_{eff} = q_{nucl} \times q_{el} \times q_{esc}$$

  - q_{nucl}: Linhard quenching
  - q_{el}: Electronic quenching
  - q_{esc}: Escape e^-'s at 0-field



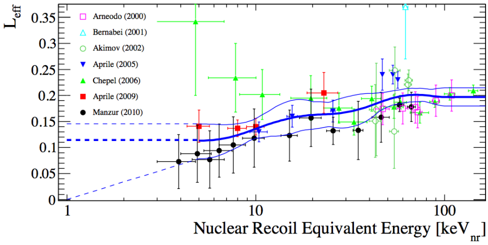
Measuring the nuclear recoil scale



Liquid argon

Figure from D. Gastler *et al.*, arXiv:1004.0373

Two existing measurements

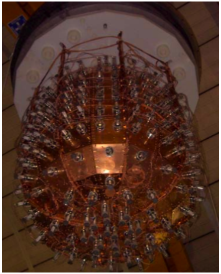


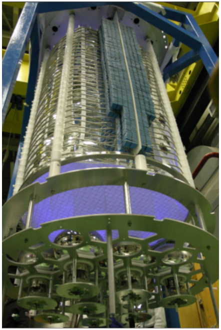
Liquid xenon

Discrepancies in the low energy for the xenon experiments

→ Currently: plans to do such measurements at lower recoil energies and understand the systematics

see A. Manalaysay, arXiv:1007.3746





WARP140: 140 kg

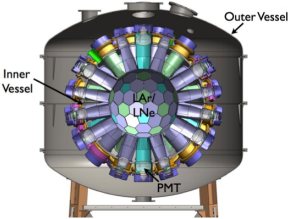
- First results with a 23 l prototype
- 60 cm drift length and 50 cm ∅
- Commissioning at Gran Sasso
- Detector filled in March 2010
- PMT upgrade to lower the threshold

ArDM: 850 kg

- 120 cm drift length and 26 cm ∅
- Charge read-out on top: LEMs
- First cool down completed
- Commissioning the protopype at CERN
- Underground @ Canfranc in 2011

LUX - **L**arge **U**nderground **X**enon detector

- $\sim$ 100 kg LXe in double phase
- Status: commissioning above ground
- waiting for the Homestake mine



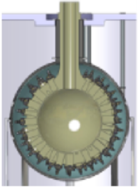
CLEAN - **C**ryogenic **L**ow **E**nergy **A**strophysics with **N**oble gases

- MiniCLEAN: 150 kg fv single phase detector with LAr/LNe
- In commissioning phase

DEAP - **D**ark matter **E**xperiment with **A**rgon and **P**ulse shape discrimination

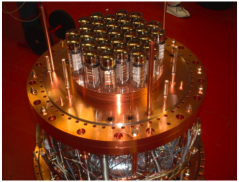
- 3 600 kg LAr in single phase (depleted)
- Status: in construction

$\longrightarrow$ DEAP/CLEAN in Snolab



DEAP-3600

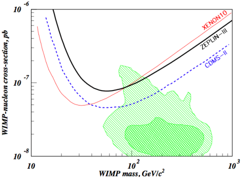
LXe experiments: Zeplin III & XMASS



- **Zeplin III**: 12 kg active mass @ Boulby (UK)
- $\sim$ 30 cm $\varnothing$ and 3.6 cm drift

UPGRADE in 2010

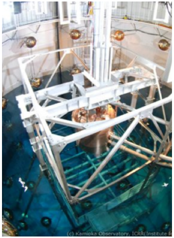
$\longrightarrow$ Detector currently running and acquiring dark matter data



$\longrightarrow$ **XMASS**: Search for DM

+ Solar ν's + 0ν $\beta\beta$ of ^{136}Xe in Japan

- 800 kg of LXe (single phase)
- Self-shielding concept
- Plans for DM run within 2010



September 2010

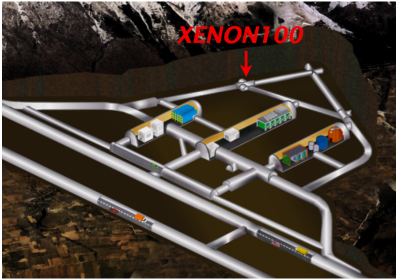
XENON experiment

- Laboratori Nazionali del Gran Sasso (Italy)
- $\sim 3\,500$ m.w.e. shielding

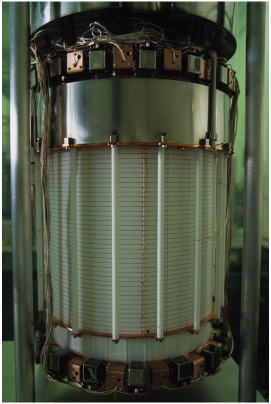
- XENON10: 15 kg active volume
  - Finished: No evidence for DM

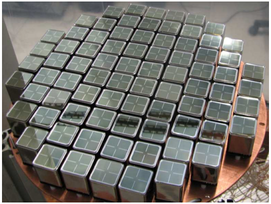
J. Angle *et al.*, Phys. Rev. Lett. 100, 021303 (2008)
J. Angle *et al.*, Phys. Rev. Lett. 101, 091301 (2008)
J. Angle *et al.*, Phys. Rev. D80, 115005 (2009)

- XENON100: 62 kg active volume
  - Currently running

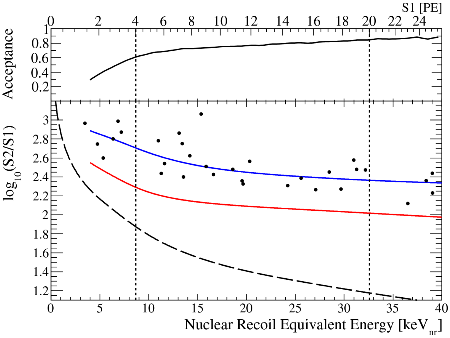


XENON100



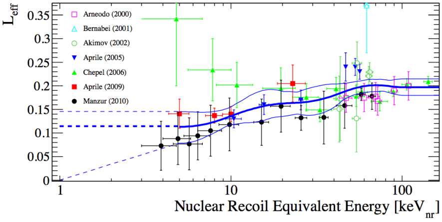


- 30 cm drift length and 30 cm ∅
- 161 kg total (30-50 kg fiducial volume)
- 100x lower background than XENON10

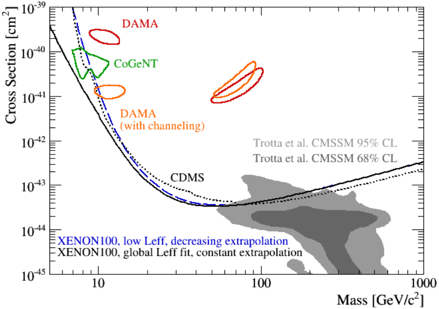


→ 'Background free': in the 11.17 days of data after discrimination

Limit from non-blinded data analysis



- **Spin independent limit**: for standard halo parameters



E. Aprile *et al.* (XENON100 Collaboration), Phys. Rev. Lett. 105, 131302 (2010)

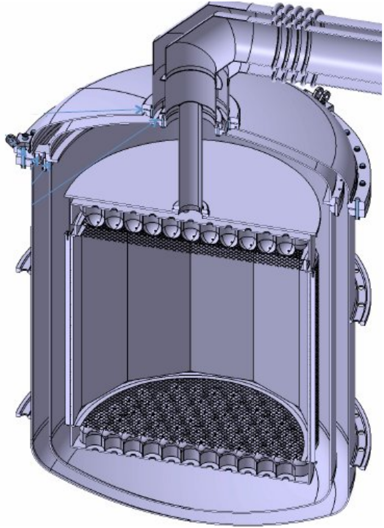
- **Excellent sensitivity**: even for few days of data

→ Sensitivity to low WIMP masses depends on L_{eff}

- Much more data recorded in blind mode

\+ analysis in the high nuclear-recoil energy region

Future: XENON1t



- 1.0 ton fiducial mass
  ($\sim$2.4 ton LXe in total)
- Drift length: $\sim$90 cm
- 100x background reduction
- Muon veto
- Copper/titanium cryostat
- QUPIDs for photo-detection

$\rightarrow$ New collaborators

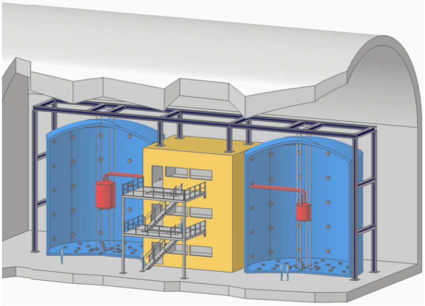
$\rightarrow$ Currently working on MC simulations and design

- Location under discussion: Gran Sasso/Modane

DARWIN and MAX future projects

dark matter wimp search in noble liquids
DARWIN

- R&D and DS for a noble liquid facility in Europe

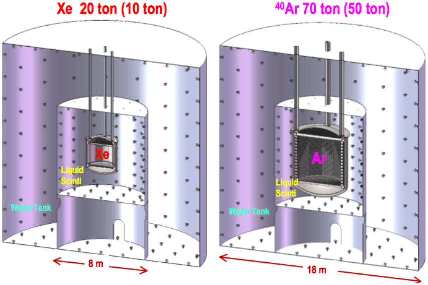


http://darwin.physik.uzh.ch/

MAX
Multi-ton Argon Xenon

@ DUSEL

- US R&D activities for multi-ton argon and xenon detectors



Summary

- DM search with noble liquids has progressed rapidly in the last years $\rightarrow$ No discovery so far!
  $\rightarrow$ Best limit by XENON100 at 3.4×10^{-44} cm^2 (SI) for 55 GeV/c^2 WIMP mass
- Big effort to increase the mass and reduce the backgrounds
  - $\rightarrow$ Material screening and selection
  - $\rightarrow$ Fiducialization: Position reconstruction best in TPCs
- Current experiments in the order of 10 – 100 kg LAr/LXe
  - $\rightarrow$ Plans for ton-scale experiments (some already under construction)