Dark Matter
(and direct searches for it)

School for Astroparticle Physics 2018
Obertrubach-Bärnfels

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# Content

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Direct WIMP Detection: Experiments

- **Crystals (NaI, Ge)**
- **Cryogenic Detectors**
- **Liquid Noble Gases**

- **SuperCDMS**
- **EDELWEISS**

- **XENON, LUX, LZ**
- **ArDM, Panda-X**
- **ZEPLIN, Darkside**

- **DEAP**
- **DAMA**
- **XMASS, COSINE, Sabre**

- **Tracking:**
  - **DRIFT, DMTPC**
  - **MIMAC, NEWAGE**

- **Superheated Liquids:**
  - **COUPP, PICO**
  - **PICASSO**
  - **SIMPLE**
Experimental Progress

Careful! Results since 2014 not included...
3 Crystals, Cryogenic, Directional Detectors

• Crystal Detectors
  → mainly anorganic NaI, CsI scintillators
  → also Ge
  → DAMA/Libra, COSINE, Sabre, CoGeNT

• Cryogenic Detectors
  → cooled down to mK measure lattice vibrations
  → two signals (phonons+charge, phonons+light) for signal/background discrimination
  → SuperCDMS, EDELWEISS, CRESST

• Directional Detectors
  → measure direction of nuclear recoils
  → this requires non-dense targets → very low target mass
  → DRIFT, DMTPC, NEWAGE, MIMAC
Annual Modulation

→ recoil spectrum gets harder and softer during the year
→ search for annually modulating signal (3% effect)
→ does not require many physical assumptions
Annual Modulation: DAMA/Libra

- PMTs coupled to NaI(Tl) Scintillators @ LNGS → extremely clean background necessary
- looks for annual modulation (~3% effect)
- large mass and exposure: 1.17 ton years
- DAMA finds annual modulation @ 8.9σ C.L.
- BUT: no ER/NR discrimination!


Interpretation as Dark Matter interaction is in conflict with numerous other experiments
New: DAMA/Libra-Phase 2

- PMTs coupled to NaI(Tl) Scintillators @ LNGS → extremely clean background necessary
- looks for annual modulation (~3% effect)
- large mass and exposure: >2 ton years

- DAMA finds annual modulation @ 8.9σ C.L.
- BUT: no ER/NR discrimination!

Interpretation of new DAMA results as DM interaction is in conflict with old DAMA result!

Different shape!

no modulation above 6 keV
Solid state detector

Semiconductor = band gap between valence and conduction band is small
Silicon = 1.12 eV, Germanium = 0.66 eV
CoGeNT
Low Energy Spectra

NaI: DAMA/LIBRA

Ge: CoGeNT
SuperCDMS

- 600 g iZIP detectors, 1" thick → larger prototypes (10cm x 3.8 cm under study)
- was at Soudan → now moved to SNOLAB
Cryogenic Detectors: Discrimination
SuperCDMS: Surface Event Rejection
WIMP Signatures: Directionality

- The Earth’s motion with respect 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

→ daily modulation!

BUT: detector must be able to detect direction of recoils;
up to now this only works in very „non-dense“ detectors.
Fig. 17: (a) UNM optical CCD test TCP - with particle tracking event images as follows with skewness head-tail analysis inset, (b) example high energy 178 keV F recoil showing clear head-tail, (c) very low energy F recoil event of 10 keV$_{ee}$ (23 keV$_{rec}$) still shows asymmetry skewness, (d) similar energy electron recoil (9.7 keV$_{ee}$) shows clearly different dE/dx morphology with segmentation of track (see text for refs).
DRIFT-II @ Boulby (GB)
4 Cryogenic Liquids

- The liquefied (→ cryogenic) noble liquids Xe and Ar are excellent scintillators and ionizers
  - single phase: measure as much as light as possible
    DEAP-3600, CLEAN, XMASS
  - dual phase TPCs: measure light and charge
    XENON1T, LUX, Panda-X, DarkSide → XENONnT, LZ

- The detectors have position sensitivity
  - fiducialization
  - multiple scatter rejection

- Background reduction
  - charge/light ratio and scintillation pulse shape (Ar)

- A path towards massive future detectors
  - ton-scale experiment already taking science data
Light-Charge anti-Correlation

LXe examples

Astropart. Phys 35, 573 (2011)

PRB 76, 014115 (2007)
Single Phase Detector

Figures from XMASS

very low background

very high light yield

proper vertex reconstruction needs huge number of photons
XMASS

- single phase LXe detector
- 800kg total, 100kg fiducial mass
- 60% of surface covered with 642 hexagonal PMTs
- very high LY
- located in Kamioka (JP)

→ will not continue beyond 2018
most of XMASS collaboration joined XENON project
Charge/Light Ratio

**Charge/Light ratio depends on** $dE/dx \rightarrow$ **discrimination**

ZEPLIN-III
~99.99% rejection @ 50% acceptance

XENON100
~99.5% rejection @ 50% acceptance

E=3.90 kV/cm

PRD 80, 052010 (2009)

E=0.53 kV/cm

PRL 105, 131302 (2010)
Direct Detection: Current Status

spin-independent WIMP-nucleon couplings

best results from cryogenic liquids
Water Cerenkov Shield
- 9.6m diameter, 10m height
- external γ, neutrons irrelevant
- muon induced NRs irrelevant
→ dominating background of XENON1T will be intrinsic
M. Schumann (Freiburg) – Exploring the Dark Universe

XENON1T @ www.gransassovideogame.it
XENON1T

Low-background stainless steel cryostats

dual-phase LXe TPC
- total mass ~3.2 t
- active mass ~2.0 t
- fiducial mass: ~1 t

TPC made from OFH Cu and PTFE

248 photomultipliers
- Hamamatsu R11410-21
- low background
- high QE (36% @ 178nm)
- extensive testing in cryogenic environments

JINST 8, P04026 (2013)
XENON1T → XENONnT

**XENON1T**
- 2t active LXe target
- taking data

**XENONnT**
- 5.9t active target
- science run in 2019
The WIMP Landscape today

- DAMA/I
- DAMIC
- DMAD
- DAMA/Na
- CRESST-II
- PICO-60 CF31
- PICO-60 C3F8
- DarkSide-50
- SuperCDMS
- XENON100
- LUX
- PandaX-II
- XENON1T
- XENONnT/LZ (proj)
- v-floor (Billard, 2014)

**Present**

- "neutrino floor"
- "v-floor"
Interactions from coherent neutrino-nucleus scattering (CNNS) will dominate → ultimate background for direct detection
Exciting times ahead of us

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