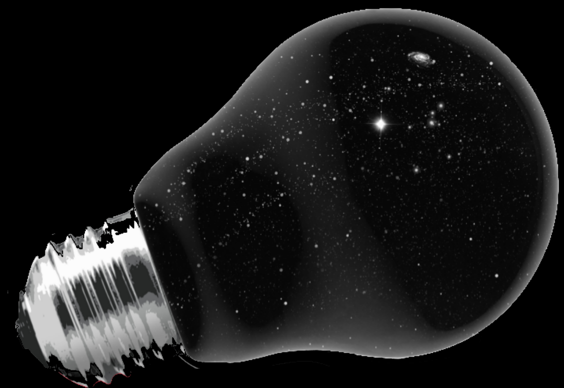
Theorie LHC France Workshop

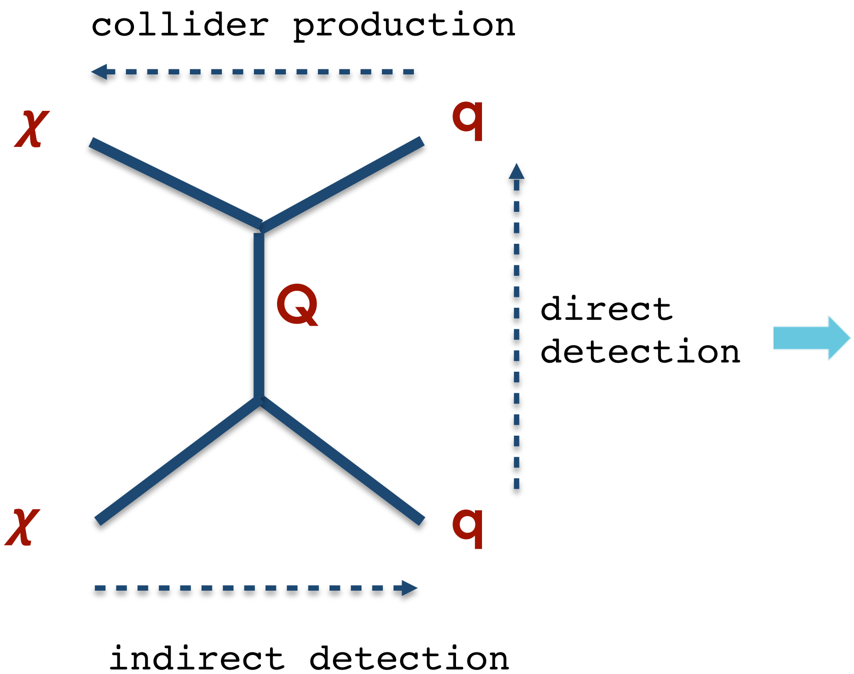


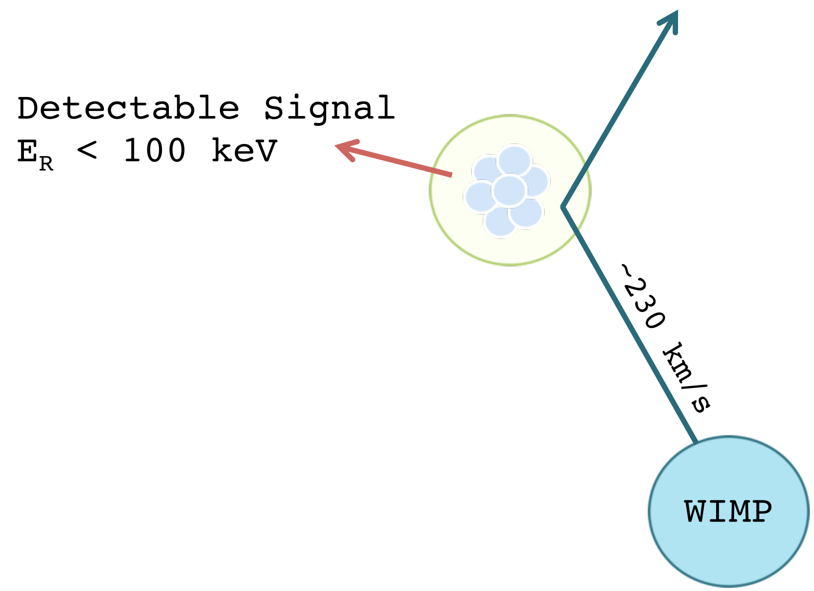
Status of dark matter direct search

Davide Franco
APC

9th November 2016

WIMP Direct Search

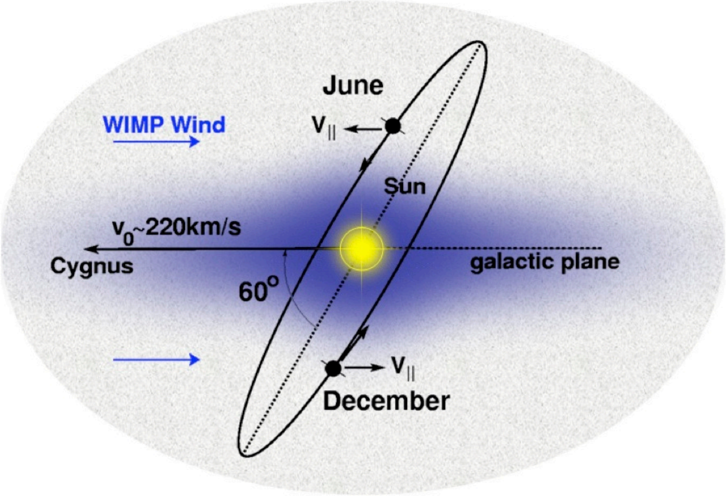




Annual Modulation

Earth rotation around the Sun => **largest speed** of the dark matter particles in the Milky Way halo relative to the Earth around **June 2nd** and **smallest in December**

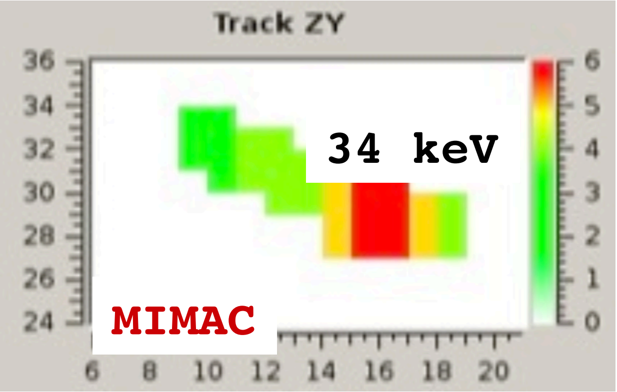
Expected seasonal variation at **2-10%** level



Directionality

The recoil rate, in the Galactic rest frame, is **highly anisotropic**: the rate in the **forward direction** is roughly an order of magnitude larger than that in the backward direction

10 WIMP events could be **enough to reject isotropy** (Green & Morgan, Phys. Rev. D81 061301, 2010)



Observables: Rate and Spectrum

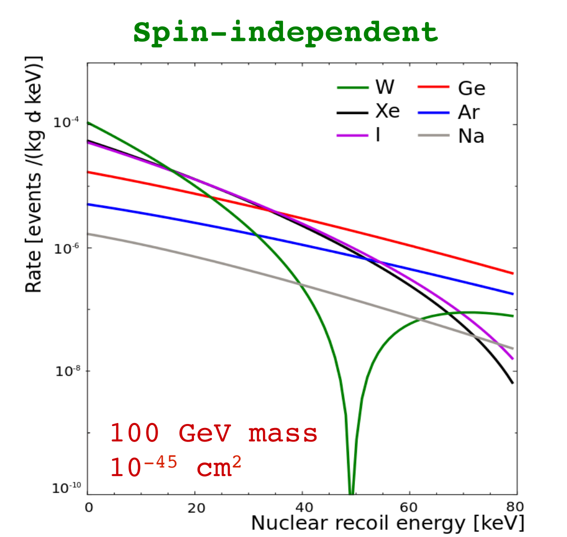
Event rate proportional to:
- Number of target nuclei
- Local WIMP density
- Elastic cross section

$$R \propto N \frac{\rho_\chi}{m_\chi} \sigma_{\chi N} \cdot \langle v \rangle$$

For instance:
- liquid argon target
- 100 GeV WIMP mass
- $\sigma = 10^{-47}$ cm^2

=> 1 event/ton/year

In case of positive observation, measurements with **multiple targets** are needed

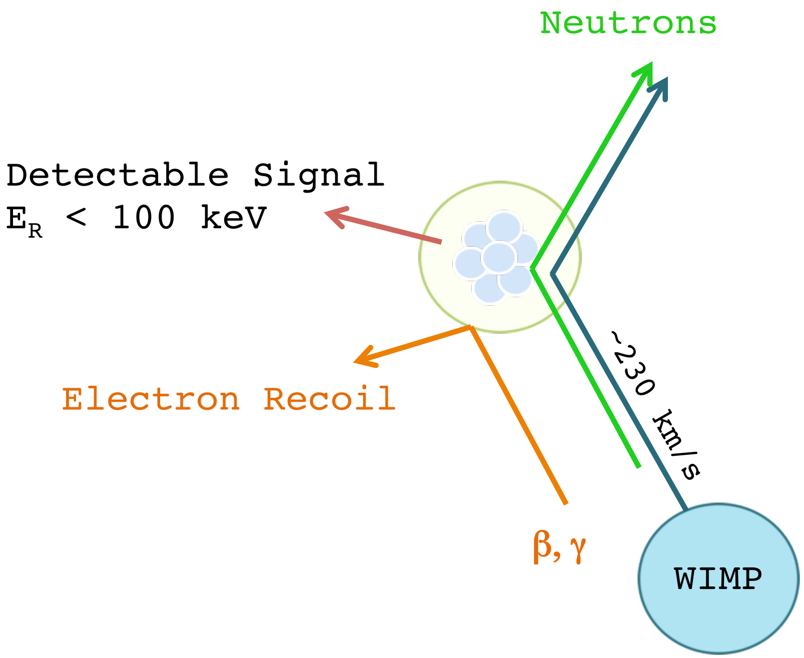


Backgrounds and Detector Requirements

Cosmic rays and cosmogenic isotopes

Natural (^{238}U, ^{232}Th, ^{235}U, ^{222}Rn,…) and anthropogenic (^{85}Kr, ^{137}Cs,…) **radioactivity**

Neutrinos (solar, atmospheric, diffuse supernovae)

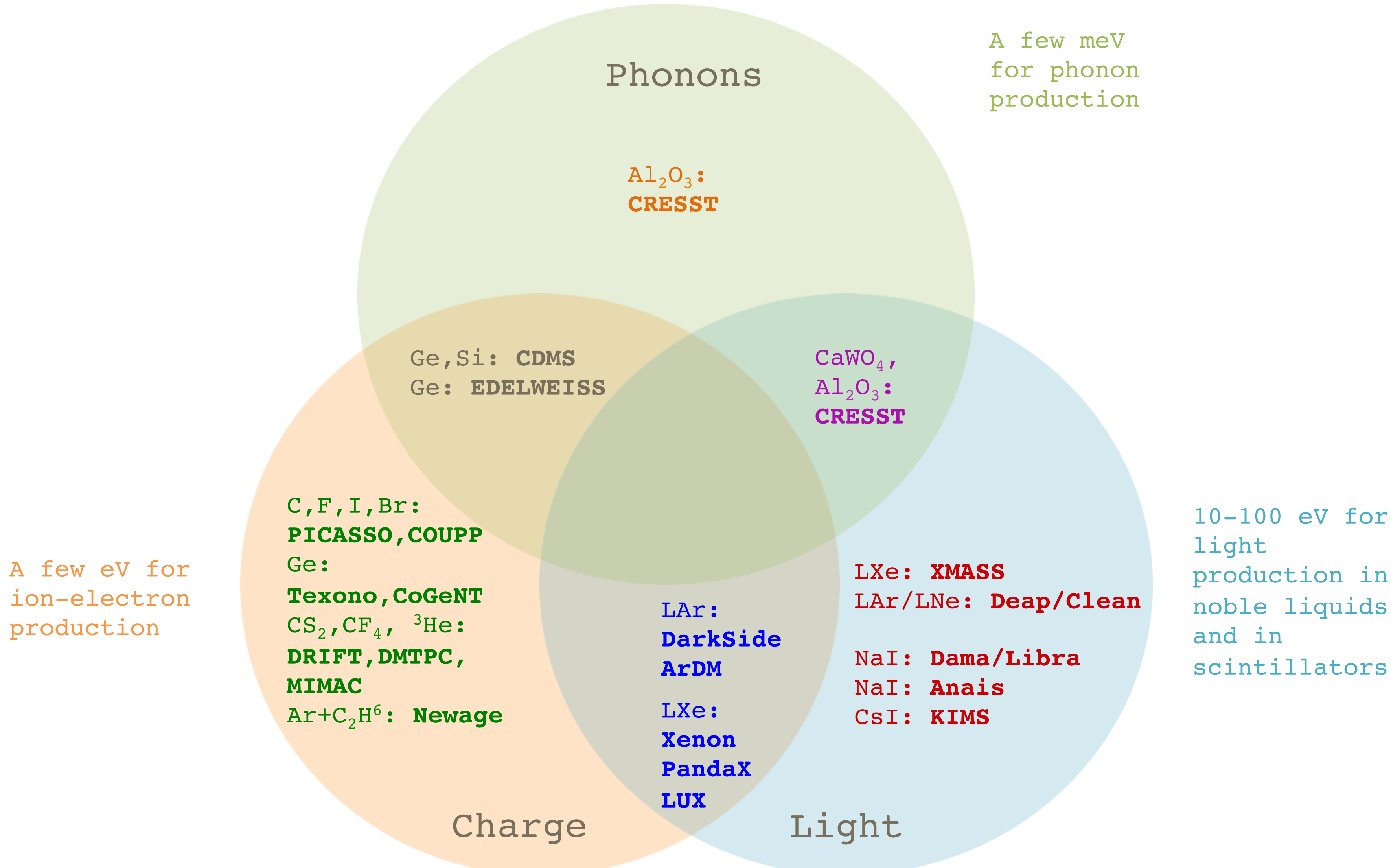


WIMP detector requirement:
- Large mass
- Low energy threshold
- Ultra-low background
- Signal/background discrimination

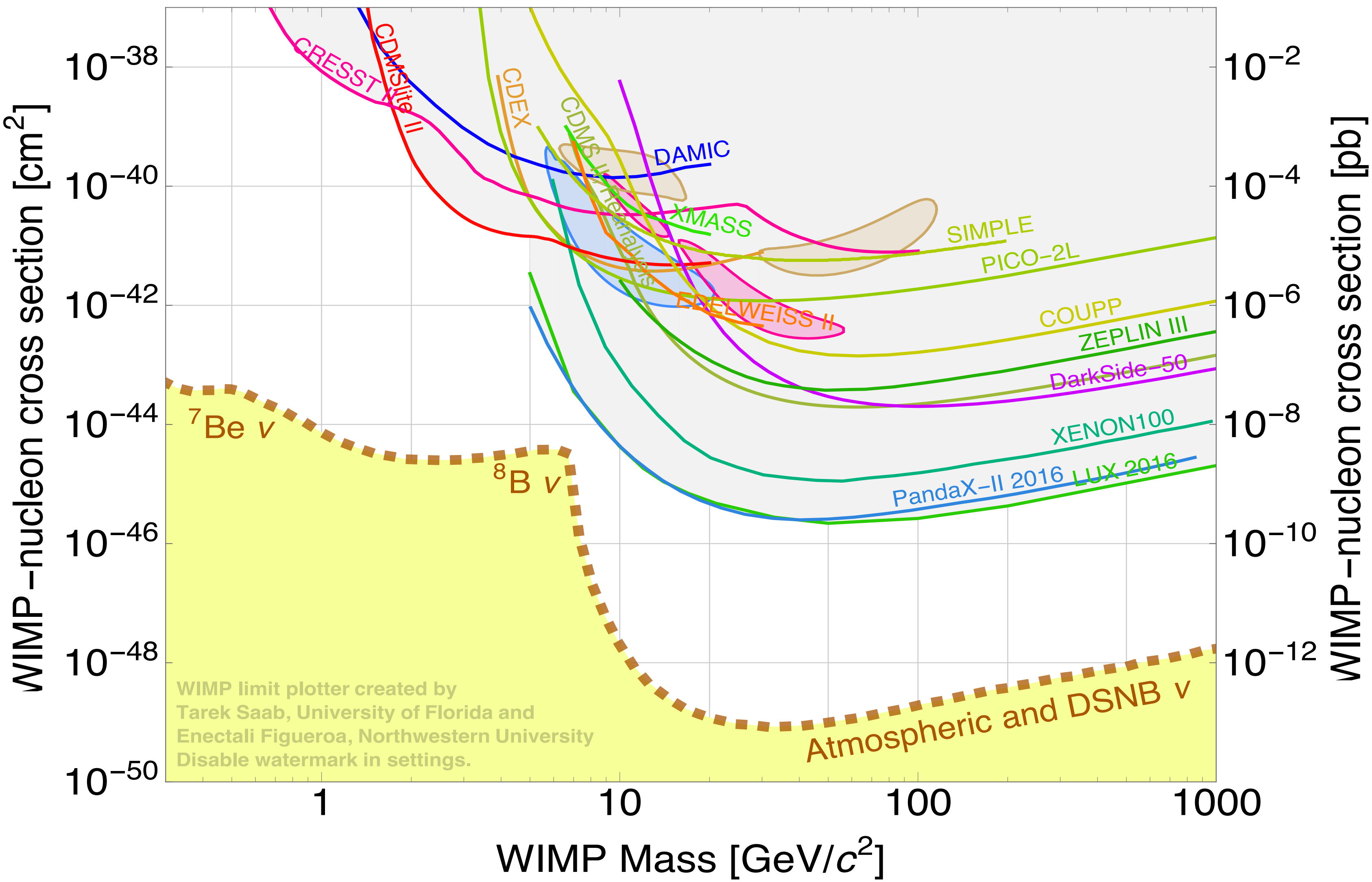
Either **background free** or perfectly constrained background

Or **clear signature** (annual modulation, directionality)

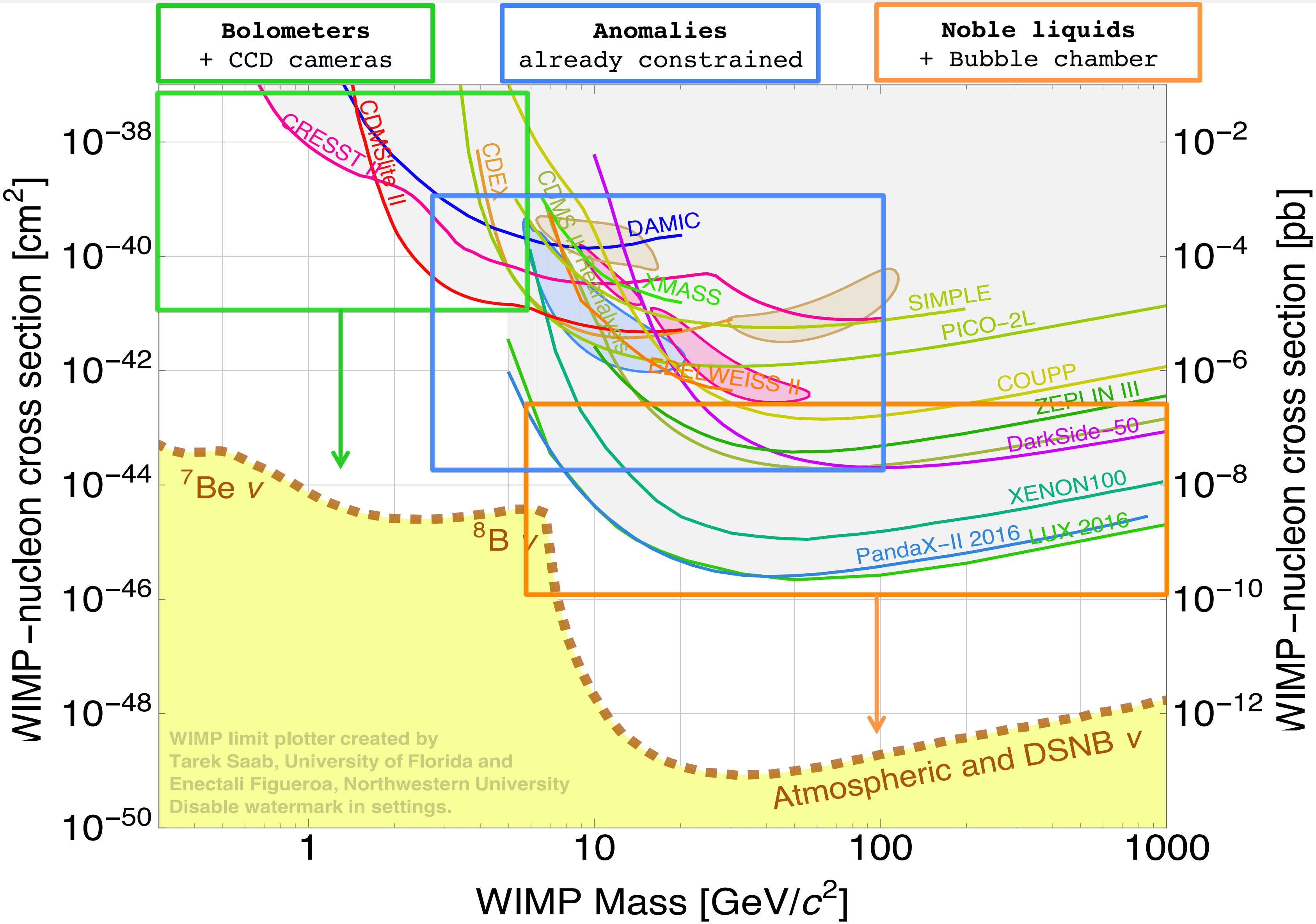
Direct Detection Techniques



Search Status



Search Status

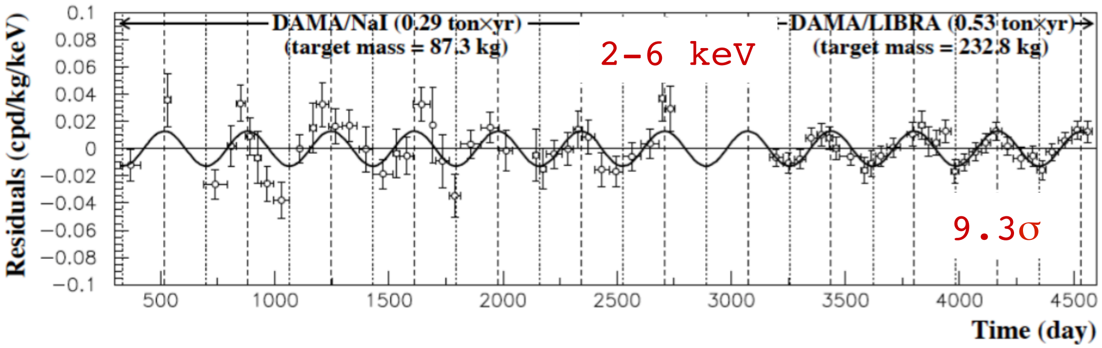


Characteristics

- Operating at room temperature
- High density (3-5 g/cm^3): **large stopping power**
- High light yield: **low thresholds** ~O(keV)
- **Limited crystal size** (several cm^3): several detectors for large masses
- **Limited background rejection** (only multiple crystal cut)

DAMA/Libra

Annual modulations with high radio-purity NaI crystals
Exposure: 1.33 ton/year
Phase: compatible with June 2nd within 2σ
Evidence at more than 9σ

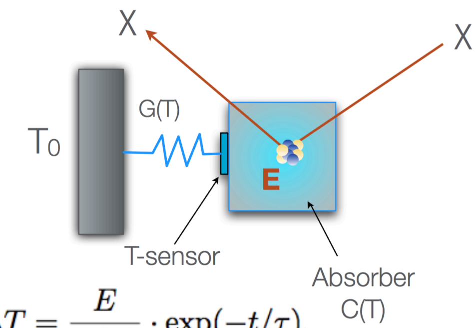


Several experiments in the next years with same techniques (NaI, CsI) will probe the modulation signal: **DM-Ice, Anais, KIMs, SABRE**

Cryogenic Bolometers

Characteristics

- Operating at **mK temperature**
- Excellent **energy resolution**
- Very low thresholds **>0.2 keV**
- **Limited crystal sizes** (100 g – 1.4 Kg)
- **Good discrimination with phonon vs light/charge**

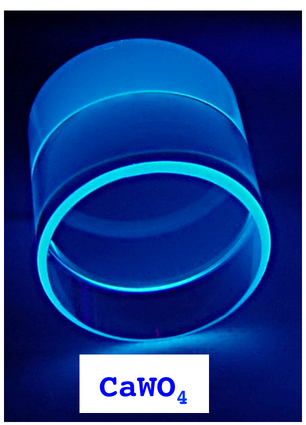


$$\Delta T = \frac{E}{C(T)} \cdot \exp(-t/\tau),$$

$$\tau = C(T)/G(T)$$

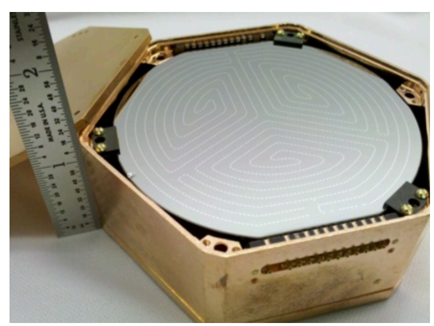
just focus on the most recent results

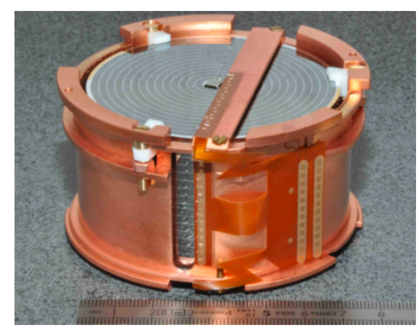
Phonon vs **Light**



CRESST-II

Phonon vs **Charge**

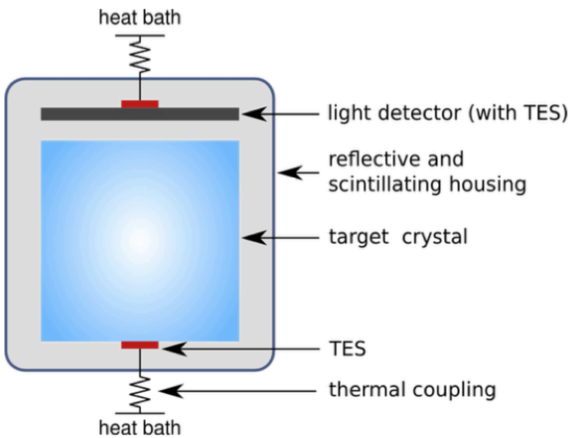




SuperCDMS: Ge, Si

EDELWEISS-III: Ge

Phonon vs Light: CRESST

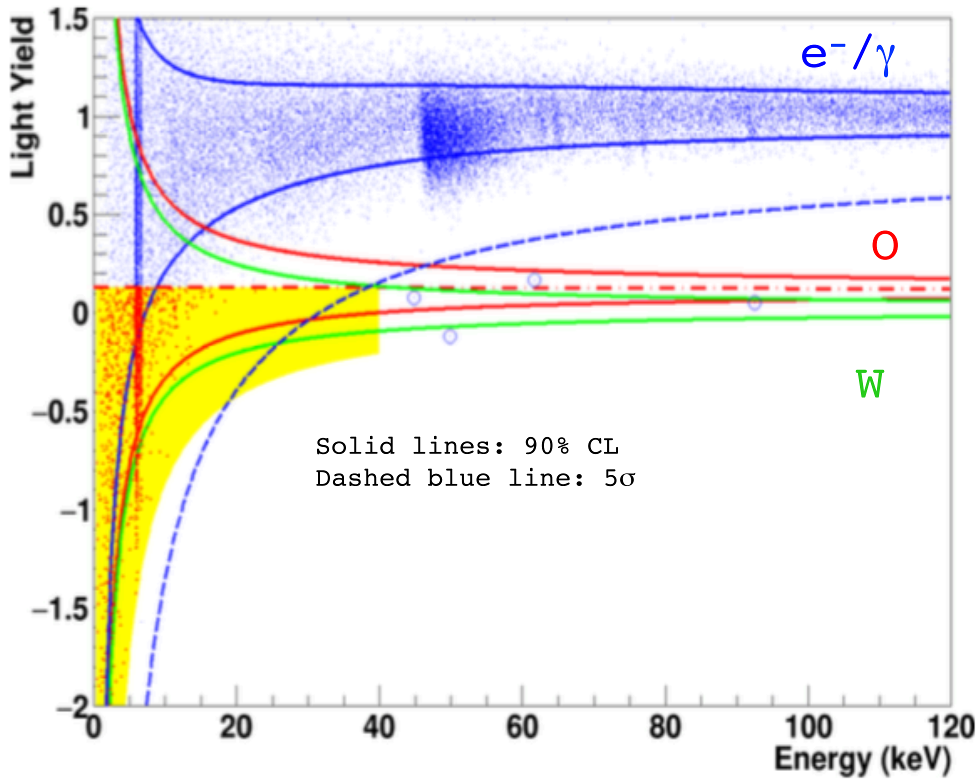


CRESST II Phase 2
arXiv:1509.01515
Exposure: 52 kg day
Threshold: **0.3 keV**
Background level: 8.5 /(keV kg day)

249 g $CaWO_4$ crystals operating at ~10 mK at LNGS
Several passive shieldings + active muon veto

Deposited energy converted mainly in phonons -> **Reconstructed energy**

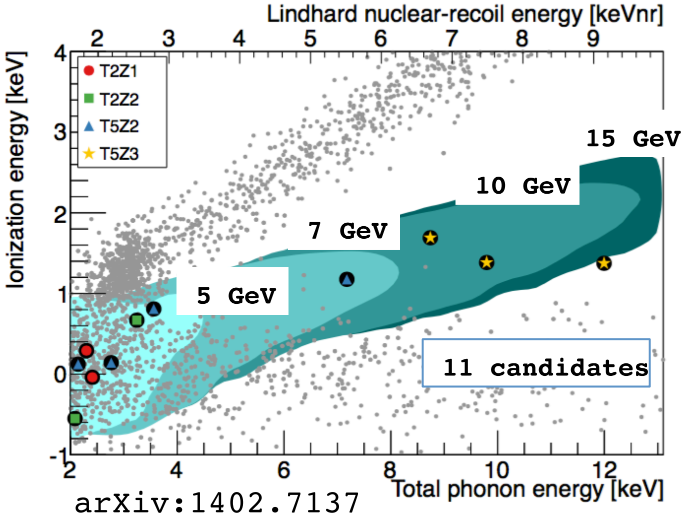
Small fraction into scintillation light -> **Particle discrimination**



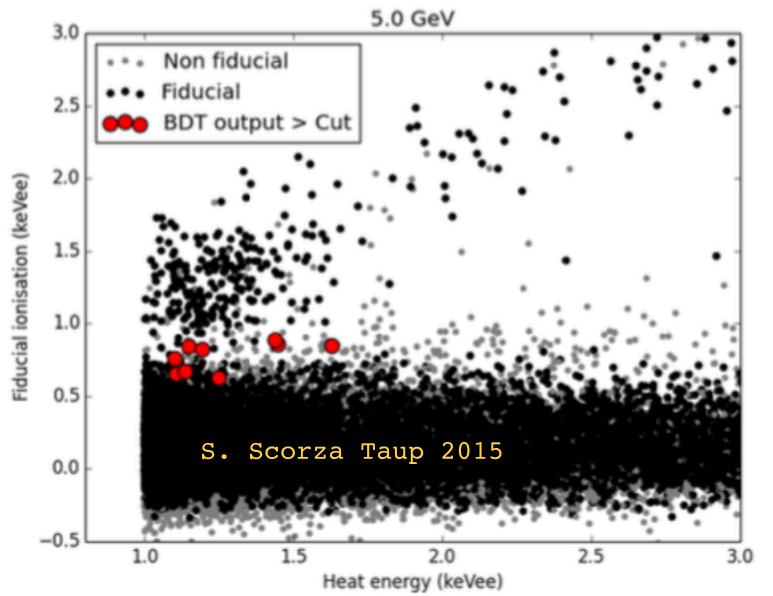
Phonon vs Charge: SuperCDMS and Edelweiss

SuperCDMS at SOUDAN
- 15x0.6 kg iZIP Ge at 50 mK
- Exposure: **577 kg day**
- Energy RoI: **1.6 – 10 keV_{nr}**
- Efficient surface background rejection

EDELWEISS at LSM
- 8x0.8 kg HP Ge at 18 mK
- Exposure: **582 kg day**
- Energy RoI: **1 – 15 keV_{ee}**
- Surface background rejection with Boosted Decision Tree



arXiv:1402.7137



+ CDMSLite at SOUDAN (arXiv:1509.02448)
- 0.6 kg iZIP Ge detector at 50 mK
- High bias potential (~70 V): **Neganov-Luke** effect Energy Threshold: **56 eV**
- **No ER/NR discrimination**
- Background level: **~1 count/keV/kg/day**

Example at 5 GeV WIMP mass:
9 events in 4 detectors at $1keV_{ee}$

Future Bolometric Detectors

SuperCDMS at SNOLab

Next Phase

1. Ge iZIP – 36 detectors, 50 kg
2. Si iZIP – 6 detectors, 4.1 kg
3. Ge HV – 4 detectors, 5.6 kg
4. Si HV – 2 detectors, 1.4 kg

Then (>2018-2019) SuperCDMS + EURECA

EURECA: Edelweiss + CRESST

EDELWEISS-III at LSM

Low mass roadmap: LV + HV (Neganov-Luke effect)

1 ton day < 2018-19

CRESST-III at LNGS

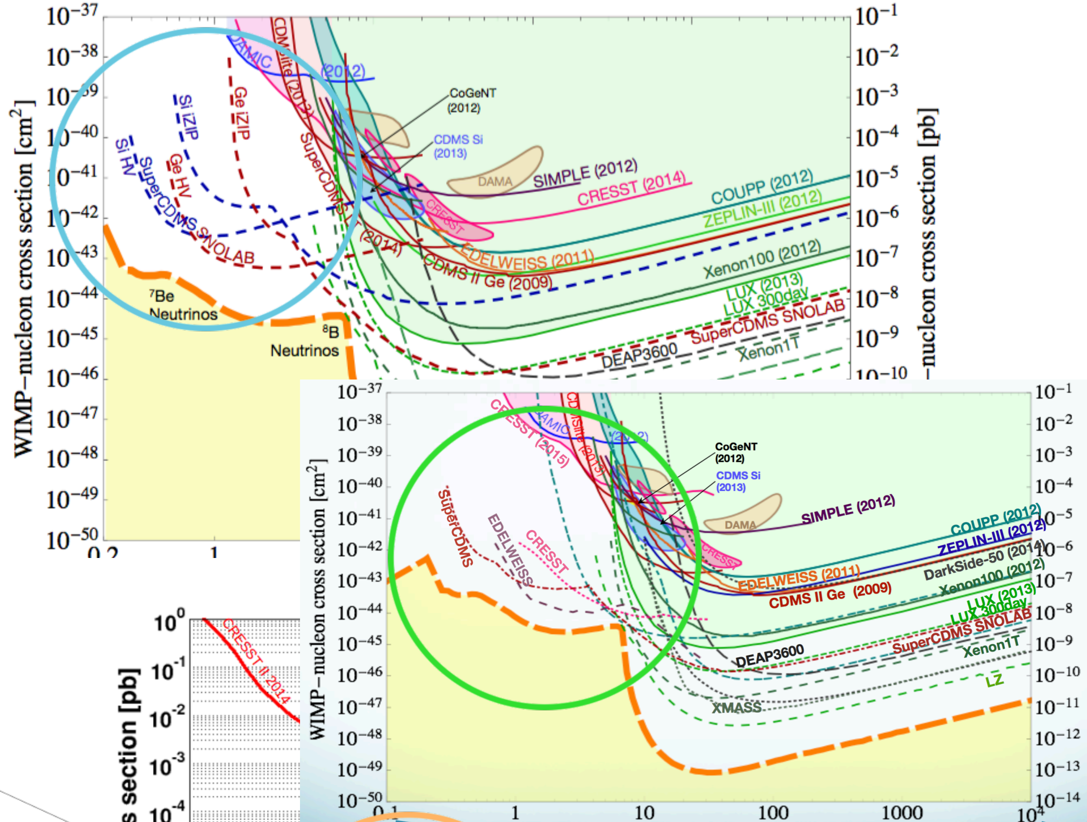
Phase 2: 100x25g

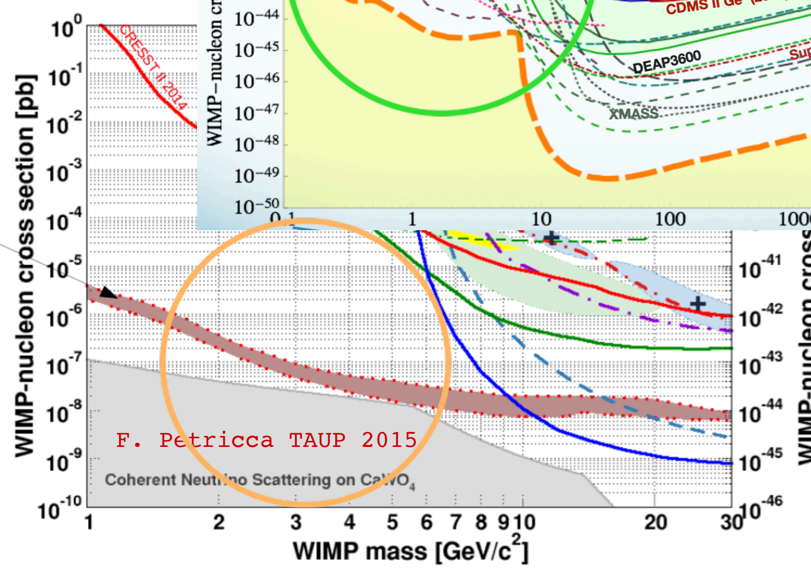
Background level ~3 /(keV kg day)

Threshold: **0.1 keV**

Phase 2

- 1000 kg-days
  2 years of running with 100 small modules
- factor 100 reduction in background

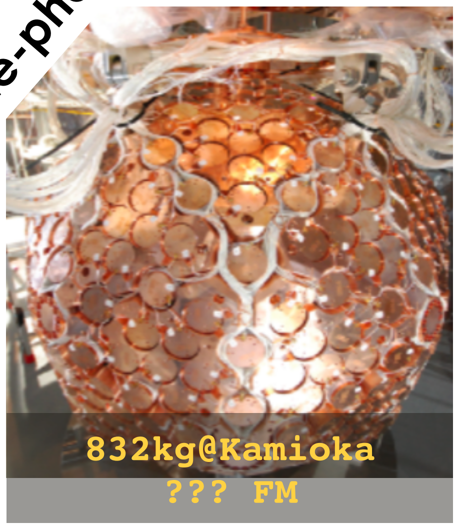




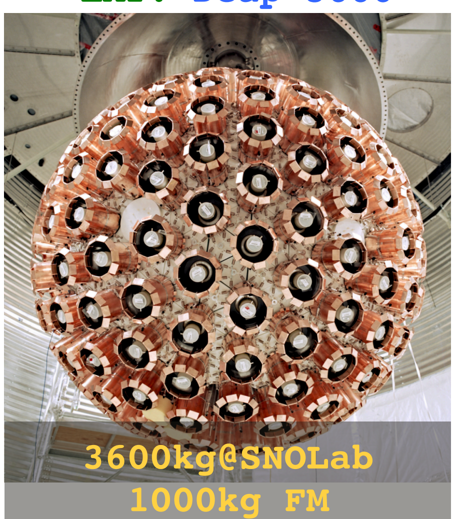
Noble Liquid Experiments

Single-phase

LXe: XMASS



LAr: Deap-3600

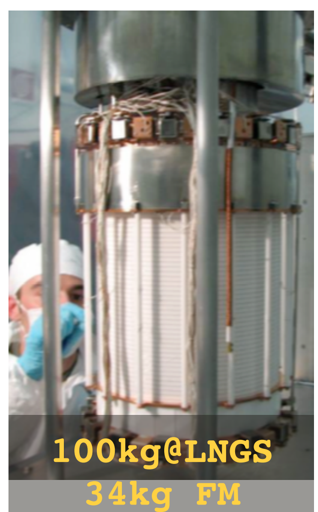


Dual-phase

LXe: LUX

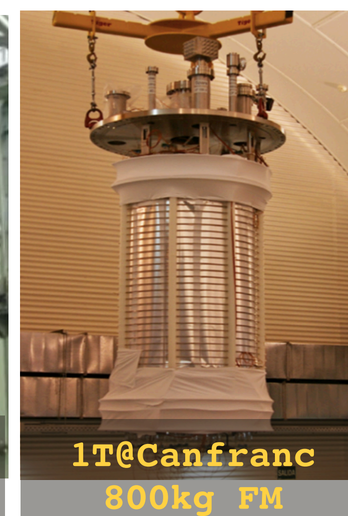
LAr: DarkSide

LXe: Xenon100/1T



LXe: PandaX-II

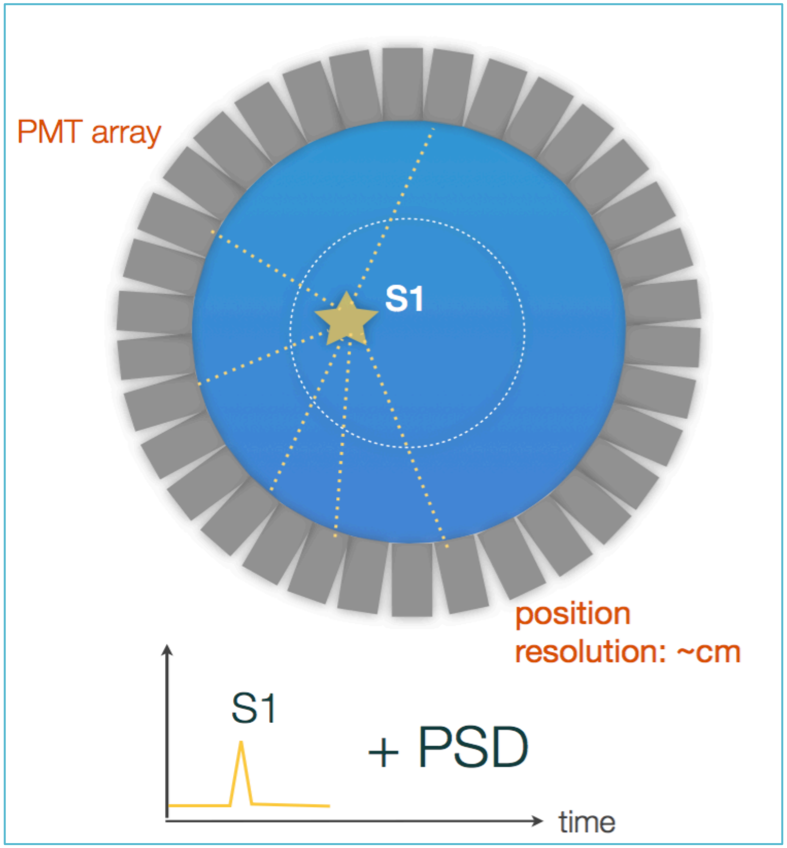
LAr: ArDM



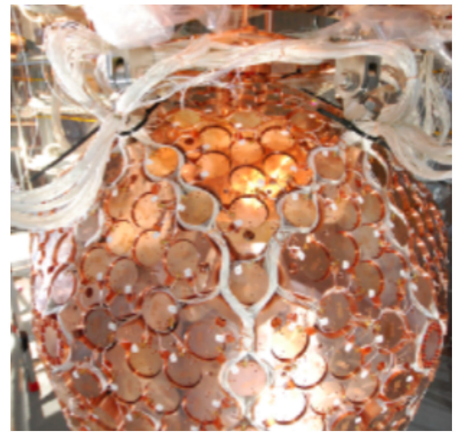
Noble Liquids: Xenon vs Argon

	LAr	LXe
WIMP SI cross section	**Limited to large masses ($M\chi$ > 10 GeV)**	**Sensitive also to low masses**
WIMP SD cross section	**Not accessible**	**Accessible**
Radio-purity	^{39}Ar contamination (fixed: see next slides)	**Intrinsically pure**
Density	1.4 g/cm^3	**3.1 g/cm^3**
Temperature	**87.2 K** (close to nitrogen)	166.4 K
S1 Pulse Shape Discrimination	**Yes (singlet ~7 ns; triplet ~1600 ns)**	Very limited (singlet: ~2 ns; triplet: ~27 ns)
Cost and availability	**Generically cheap** (~$/kg) + **extra costs** for underground extraction **Abundant**	**Expensive** (~kDollar/kg) **Limited** world production

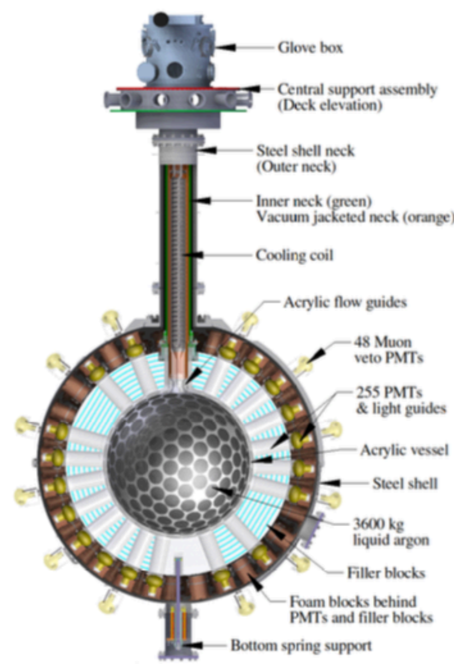
Single-Phase Noble Liquids



from L. Baudis@Solvey-Francqui Workshop 2015



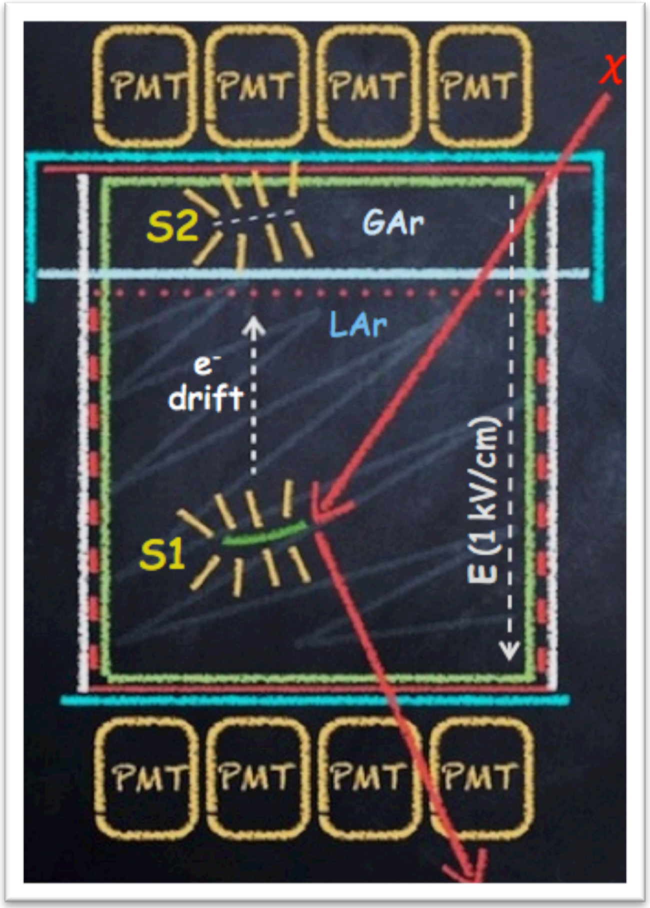
XMASS at Kamioka
- **832 kg of LXe**
- Data taking ~1 year
- 642 2'' PMTs (62% optical coverage)
- **Light Yield: 14.7 pe/keV**
- Looking for annual modulation



Deap-3600 at SNOLab
- **3600 kg of LAr**
- 255 PMTs
- Light Yield: ~8 pe/keV
- **Exceptional PSD**
- Ready for beginning 2016

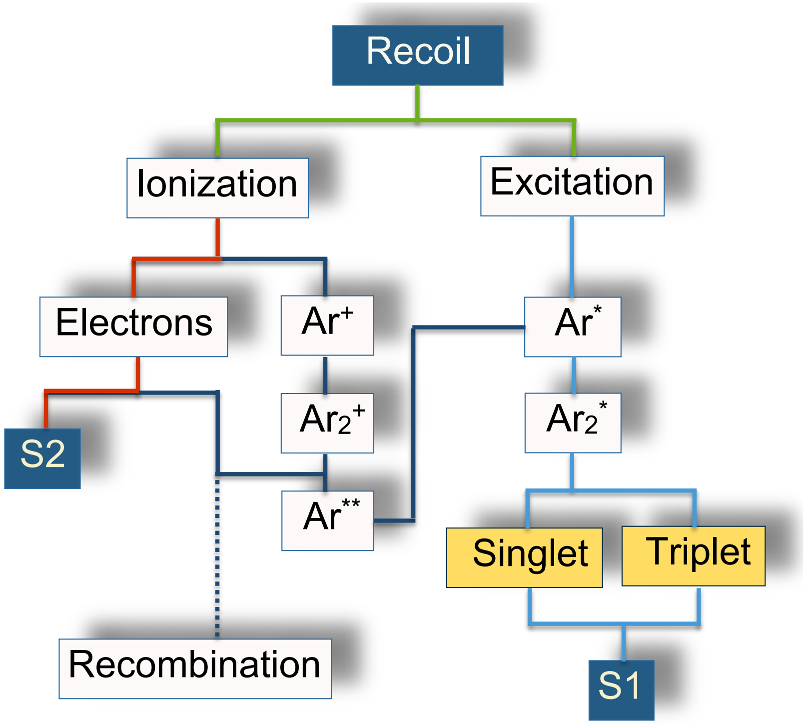
x-y projection

z from the drift time

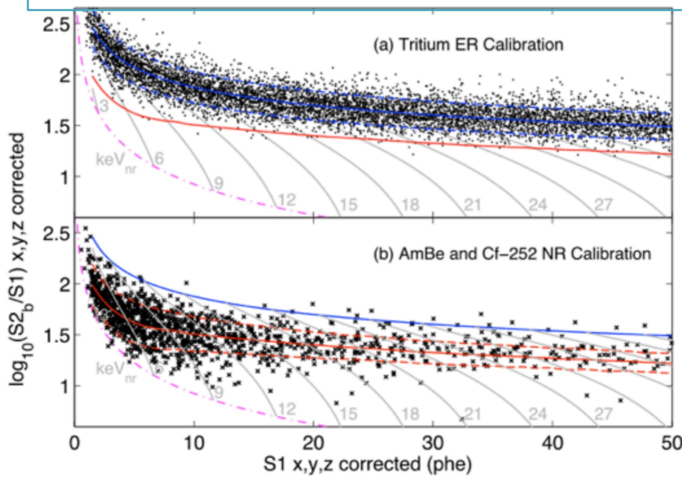


Particle discrimination through:

- Accurate 3D **position** identification
- **Multiple**-scattering rejection
- **S2/S1** ratio
- S1 **PSD** (if available)



ER and NR calibration

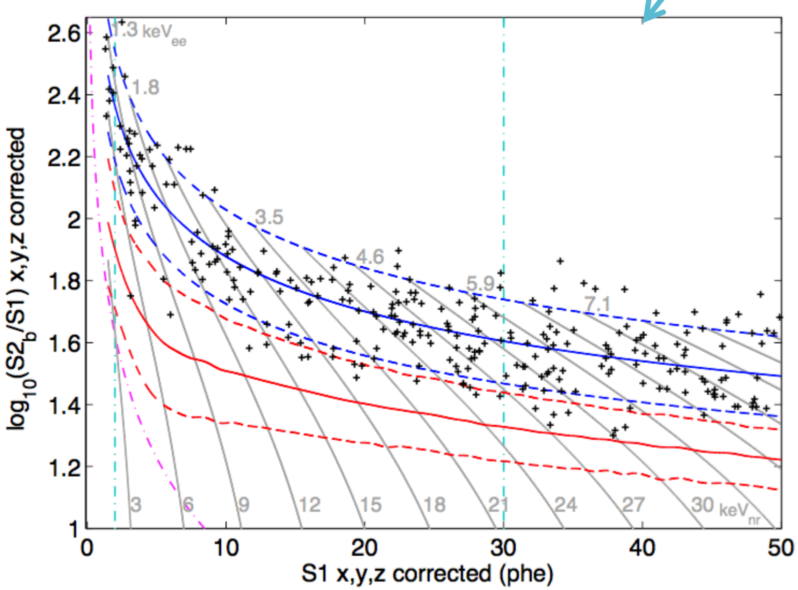


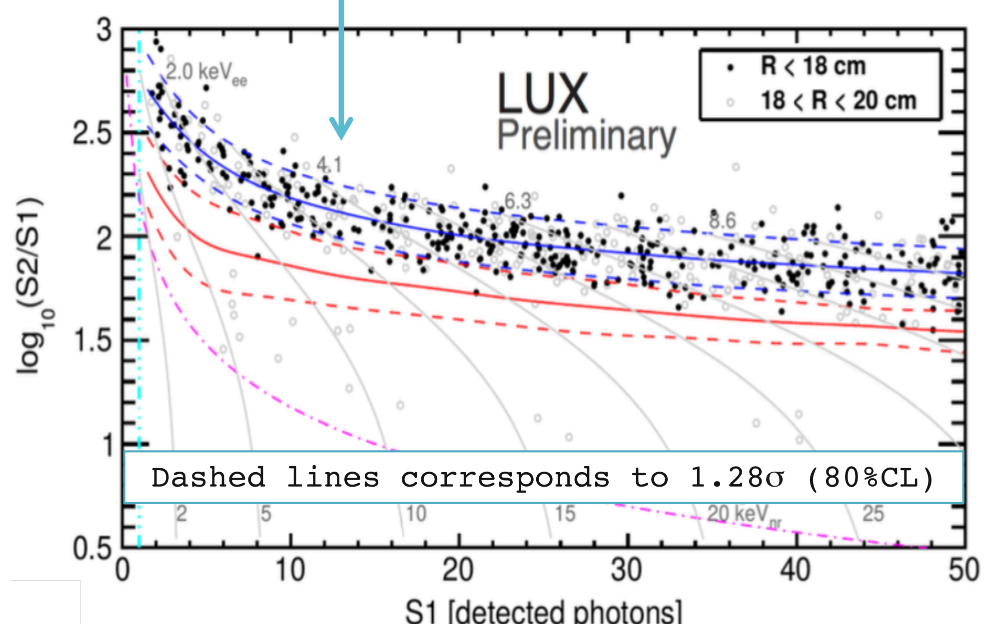
Data Analysis

Exposure: ~10,000 kg day

Background: 1.9 count/day without radial cut (compatible with expectations)

New analysis with larger exposure (+12%) and larger fiducial mass (+23%)



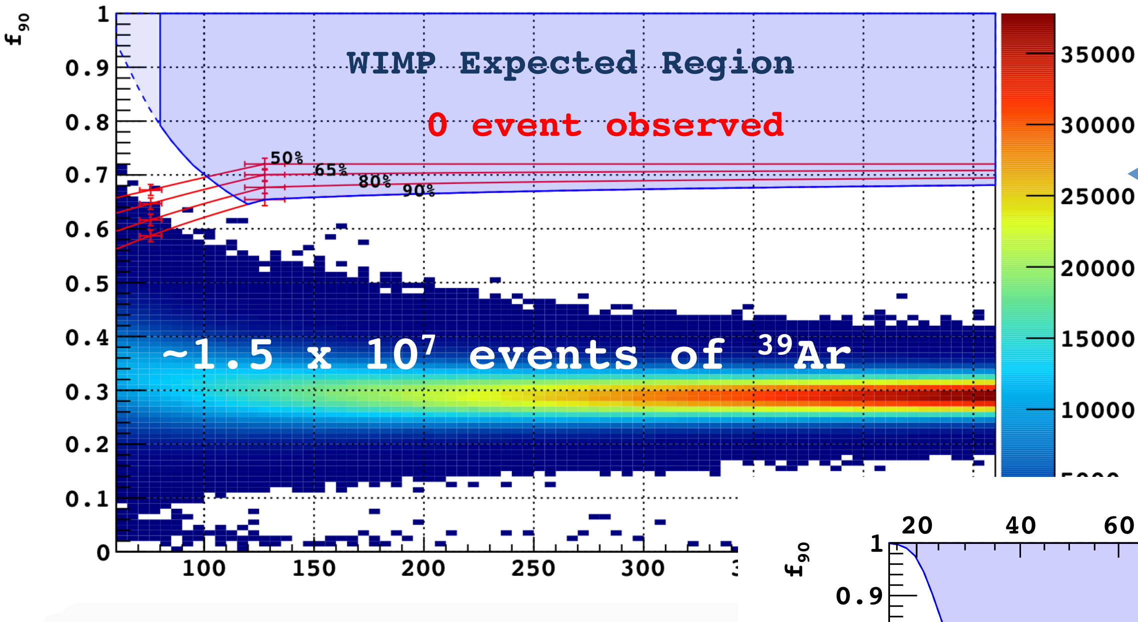


Dashed lines corresponds to 1.28σ (80%CL)

Phys. Rev. Lett. 112, 091303 (2014)

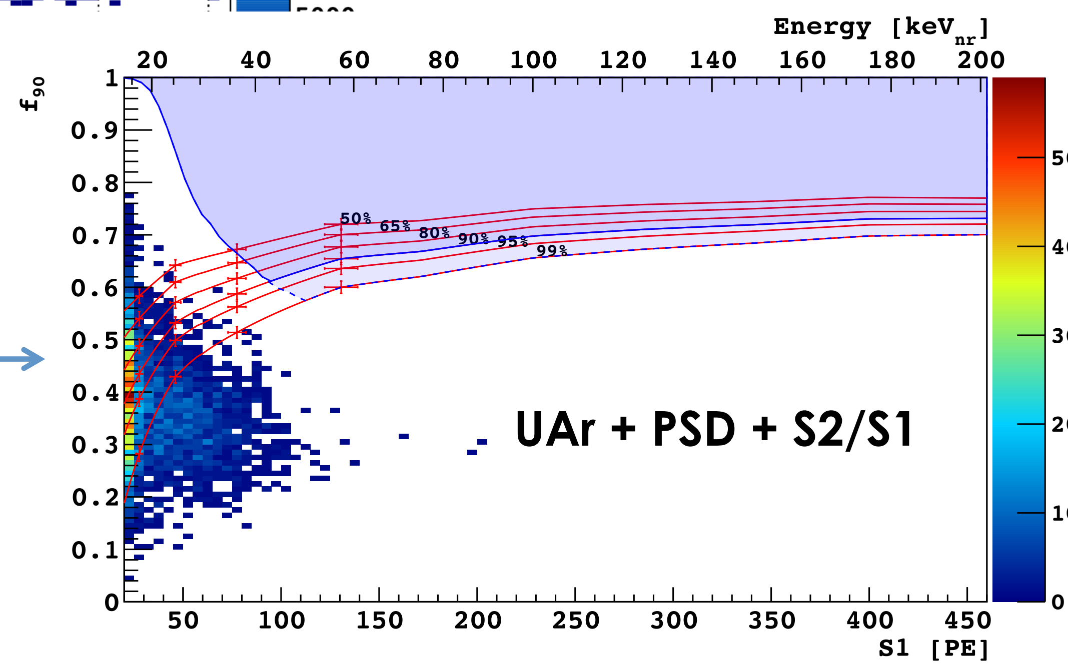
DarkSide-50: the AAr and UAR Runs

ER/NR Particle discrimination based on the S1 light pulse



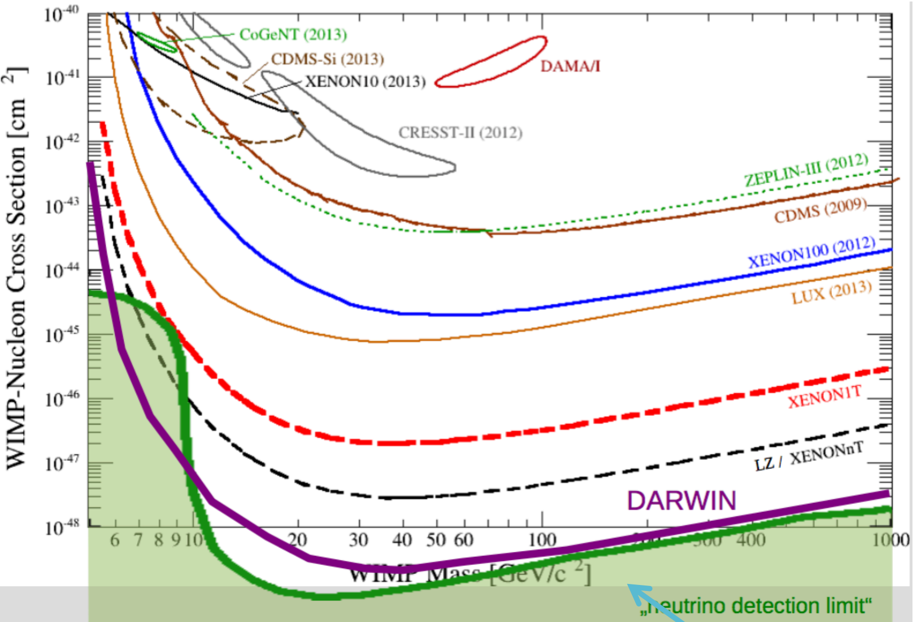
Atmospheric argon

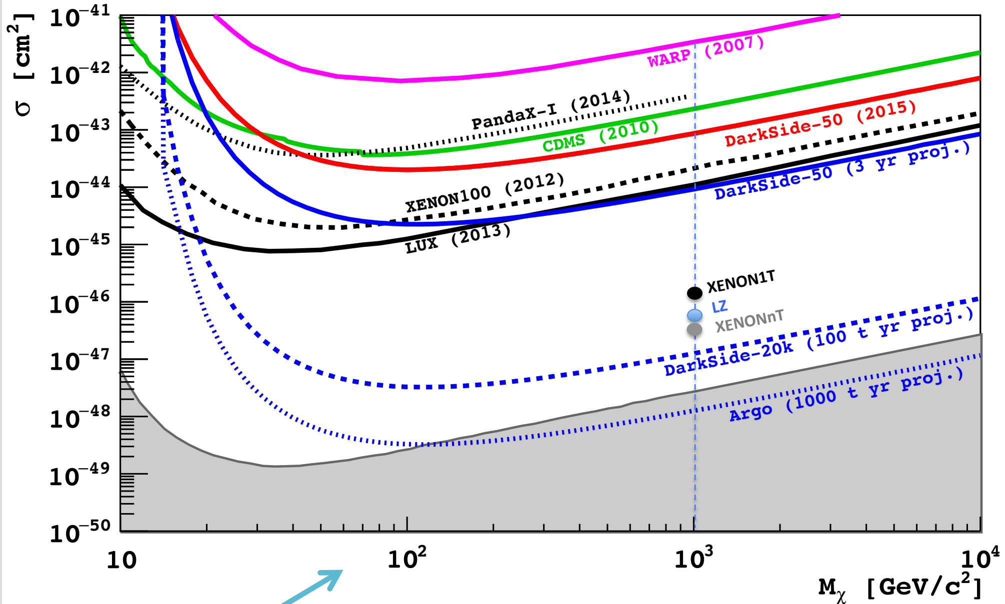
Underground argon depleted in ^{39}Ar



Phys. Lett. B 743 (2015) 456.

Future of Noble Liquids





Note:

Sensitivity projections depend on exposure and on the **background-free** assumption

Conclusions

Next generation will reach **10^{-47} cm^{2}** at 100 GeV

Third generation will approach the "**neutrino floor**"

Background free experiments are challenging but possible thanks to several discrimination techniques (PSD, S2/S1, Light/Phonon, Charge/Phonon, Multiple scatter cut, fiducial volume cut)

Many (almost) **new interesting technologies** non mentioned here: MIMAC, DAMIC, PICO, COUPP, etc

In case of a positive result, **multiple targets** are mandatory

Clear signature (**annual modulation/directionality**) highly desired: under study some ideas for directionality also with noble liquids