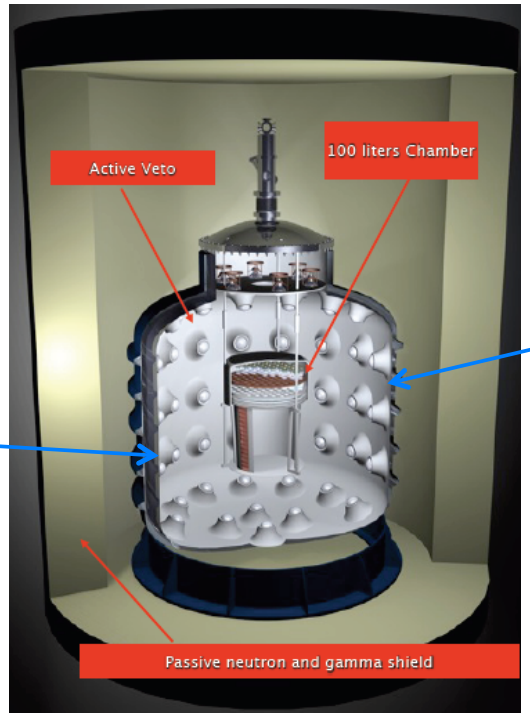
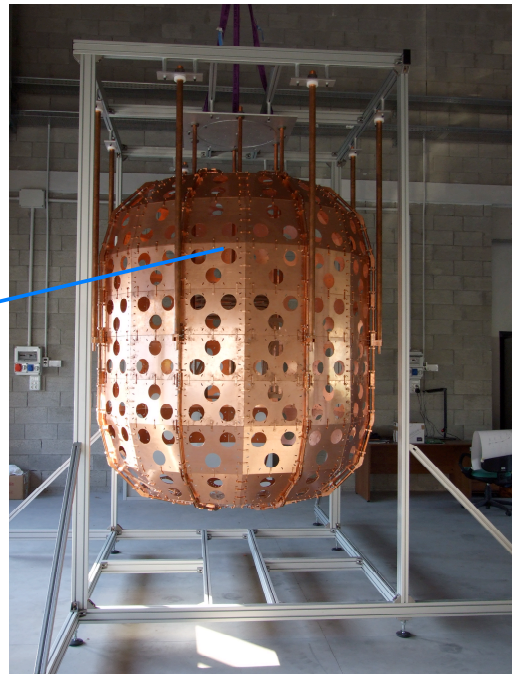
The WArP Experiment @ LNGS

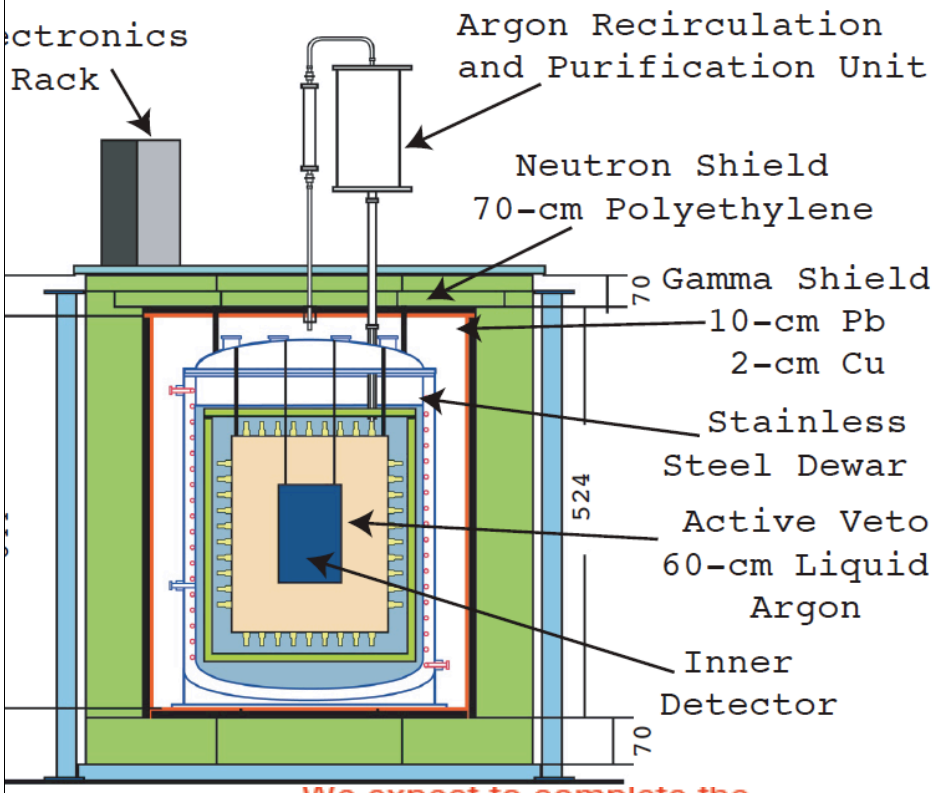
- The WArP detector is under commissioning at LNGS
- 140 kg active target, with active LAr shield (9 tons and 300 PMTs)
- 3D Event localization and definition of fiducial volume for surface background rejection
- Cryostat designed to allocate a possible 1400 kg detector
- Ar gas with low level of radioactive ^{39}Ar from US u.g. reservoir promising for multi-ton expt
- Main Cryostat

after positioning in Hall-B (Jul.'07) inside sustaining structure

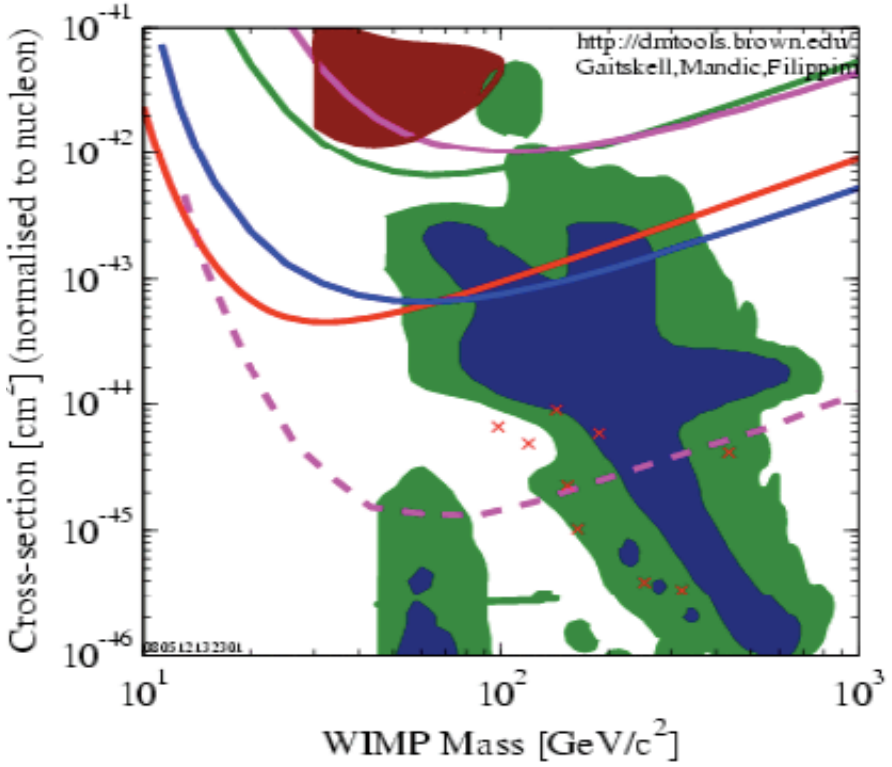




WArP 140 kg status



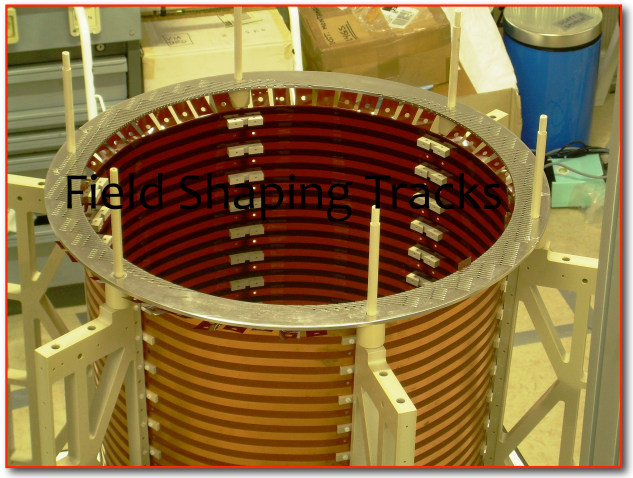
- We expect to complete the detector assembly and commissioning and to be able to run with the complete detector within the end of the year.

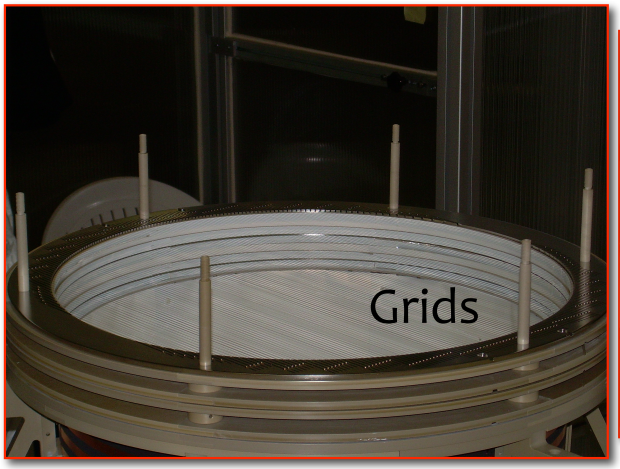


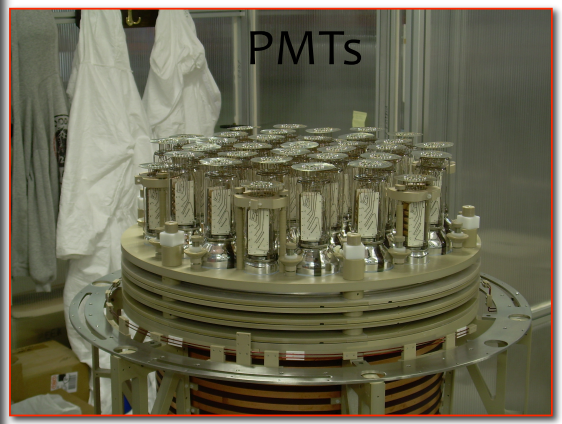
DATA listed top to bottom on plot
DAMA 2000 58k kg-days NaI Ann. Mod. 3sigma w/DAMA 1996
WARP 2.3L, 96.5 kg-days 55 keV threshold
ZEPLIN II (Jan 2007) result
CDMS 2008 Ge
XENON10 2007 (Net 136 kg-d)
WARP 140kg (proj)
Roszkowski/Ruiz de Austri/Trotta 2007, CMSSM Markov Chain Monte Carlos (
Roszkowski/Ruiz de Austri/Trotta 2007, CMSSM Markov Chain Monte Carlos (
Ellis et. al Theory region post-LEP benchmark points

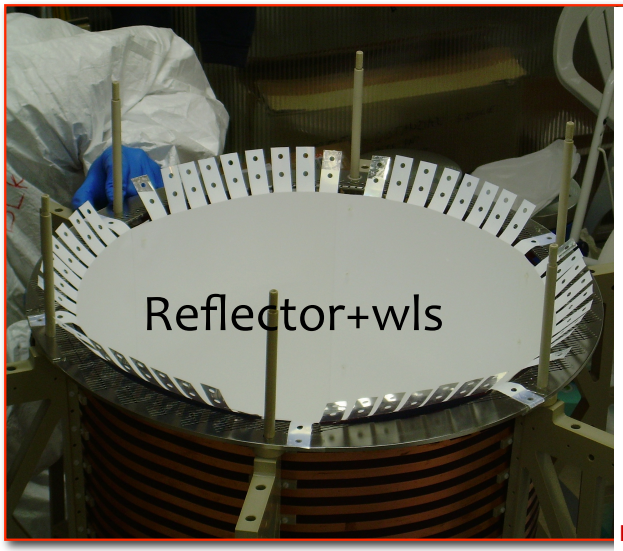

WARP Update
December 2008

WArP Inner Detector Components

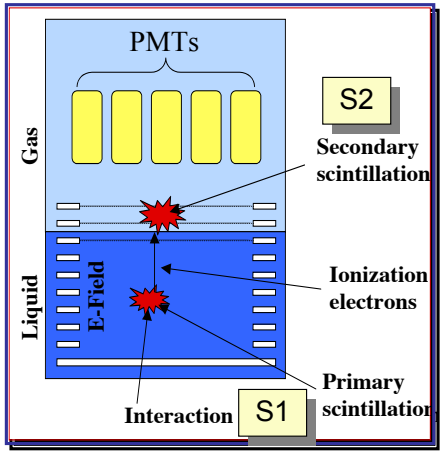






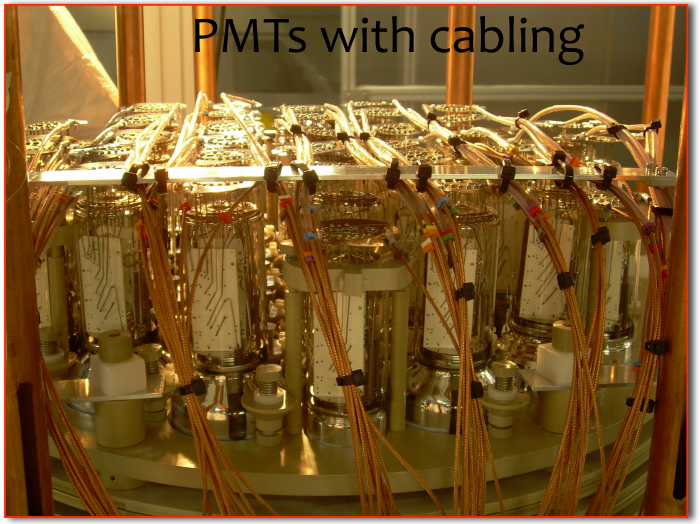


Two-Phase Argon Drift Chamber



Recoil-like event
Slow component ≈ 10 %

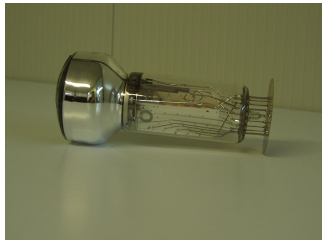
γ-like event
Slow component ≈ 70 %



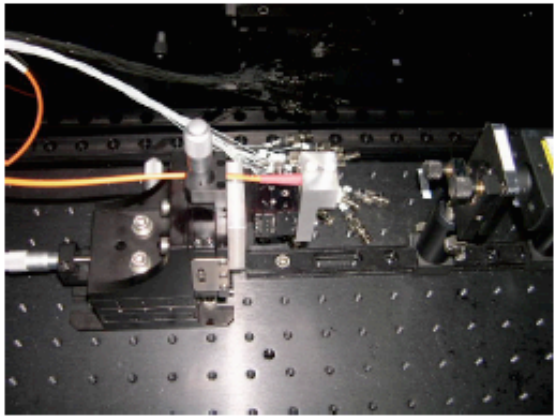
WARP Photomultipliers

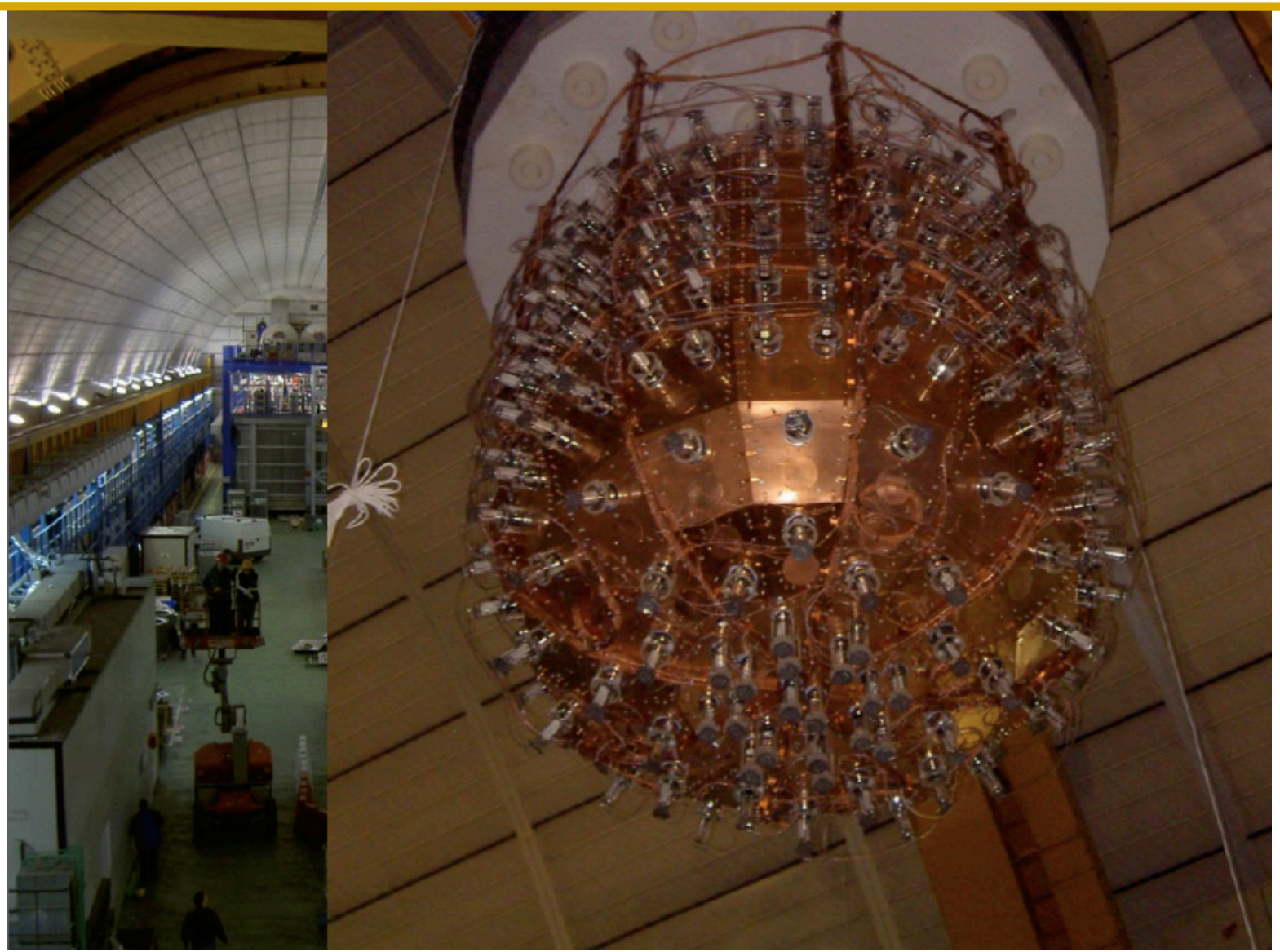
WIMP ARGON PROGRAMME

- 3" and 2" Bialkali Photomultipliers developed in co-operation with **Electron Tubes EMI** to work at **LAr temperature (ETL D750UKFLA, D757UKFLA)**
- **7% coverage** in the active veto
- **10% coverage** in the inner detector
- Low activity (0.2 Bq/PMT) and high QE (19% on average)

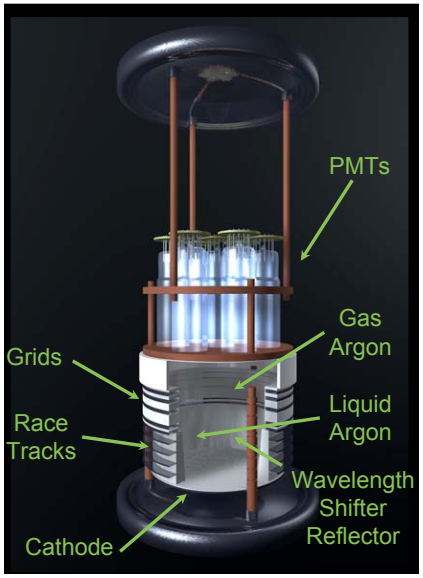


More than 400 PMTs verified to work at cryogenic temperature (77 K) in Napoli INFN laboratories and delivered to LNGS

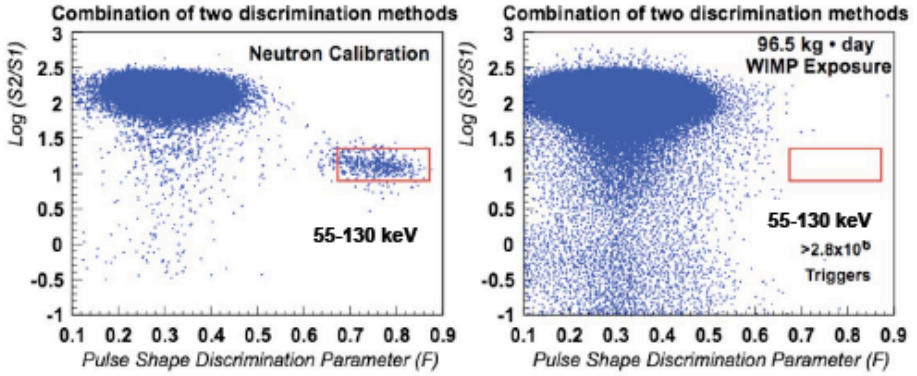




WARP 3.2 kg detector: summary of results

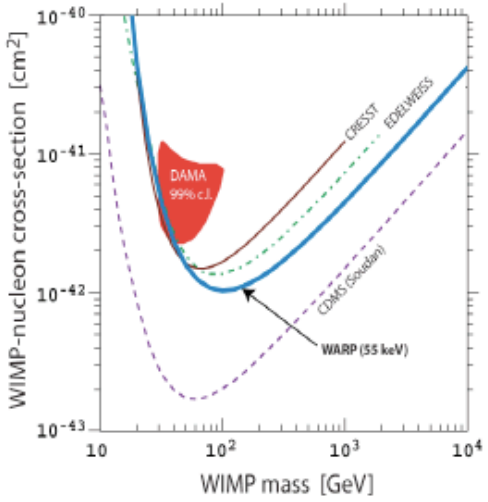


Live-time = 52.8 days (≈ **96.5 kg • day**)
Total triggers ≈ 2.8 x 10^7
Trigger threshold ≈ 3.5 keV_{rec}
Threshold for data selection = 20 keV_{rec}
Threshold for WIMP analysis = **40 keV_{rec}**



Selected events in the n-induced single-recoils window during the WIMP search run:
5 events above 40 keV, 0 events above 55 keV ⇒
≈ 0.1 events / day (**0.05 events / (kg • day)**)
The main beta background comes from the intrinsic ^{39}Ar.

Excellent results from study of discrimination power between nuclear recoils and γ-betas:
10^{-8} pulse shape discrimination,
$5x10^{-3}$ ionization/scintillation

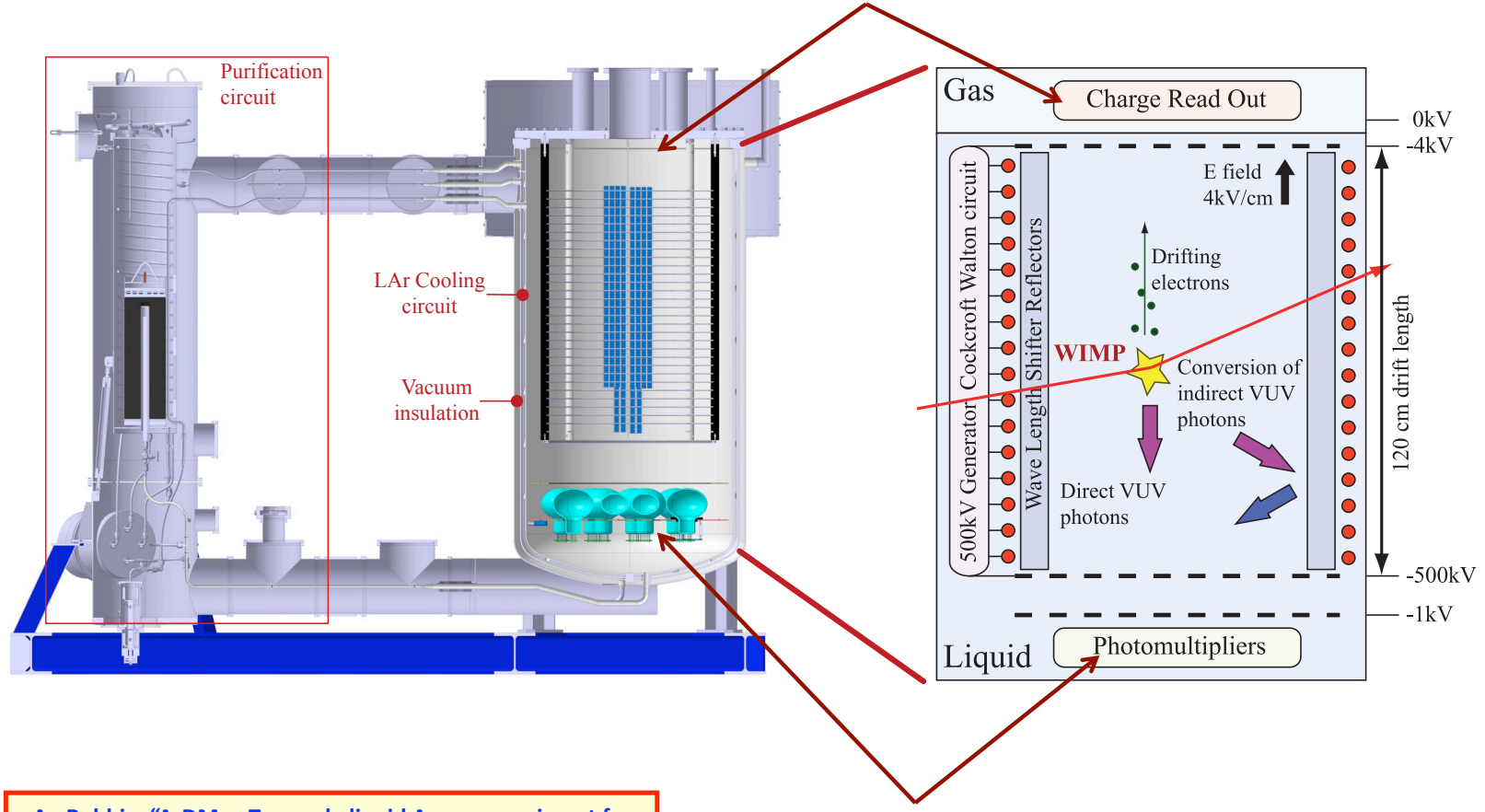


P. Benetti et al., Astrop. Phys. 28 (2008) 6.

The ArDM Experiment @ LSC

General Layout of the Experiment

Double stage LEM System



A. Rubbia, "ArDM: a Ton-scale liquid Argon experiment for direct detection of dark matter in the universe", J. Phys. Conf. Ser. 39 (2006) 129

14 Cryogenic PMTs to detect the scintillation light

The ArDM main parameters

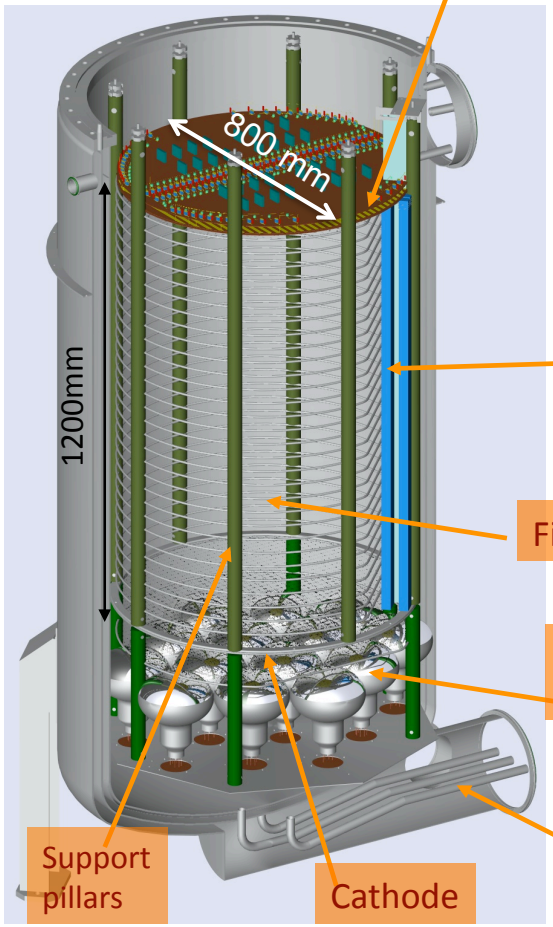
Detector	
Max. drift length	120 cm
Target mass	850 kg
Readout method	Independent readout of charge & light
Drift field	1÷4 kV/cm
Charge readout	
Charge gain	500÷10^3 per e^-
Light readout	
Global light collection efficiency	1÷2%

Background rejection is based on:

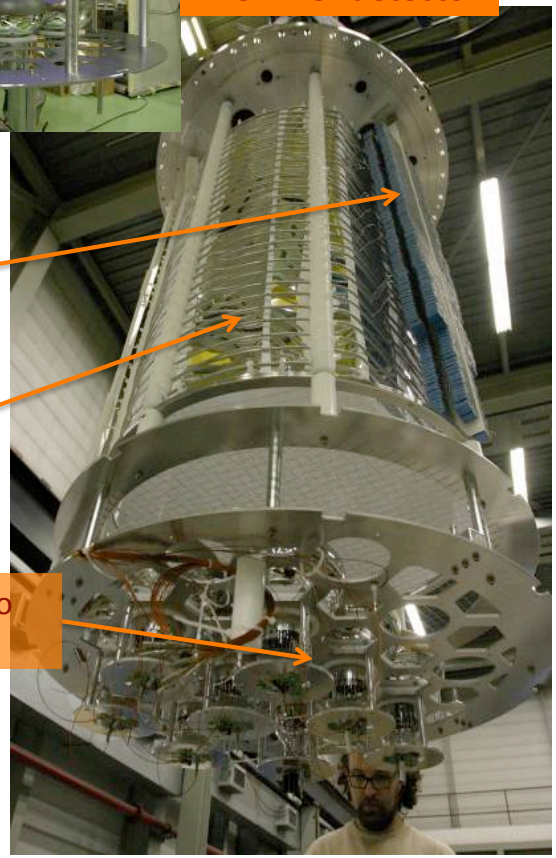
1. Light pulse shape discrimination. Different light structure for WIMP-like (nuclear recoil) events and e/γ-like events.
2. Different Light/Charge rations for WIMP and e/γ-like events

P.Otyugova (UniZH)

The ArDM design and assembly



The inner detector



HV system

Field shapers

14 PMTs below the cathode to detect the scintillation light.

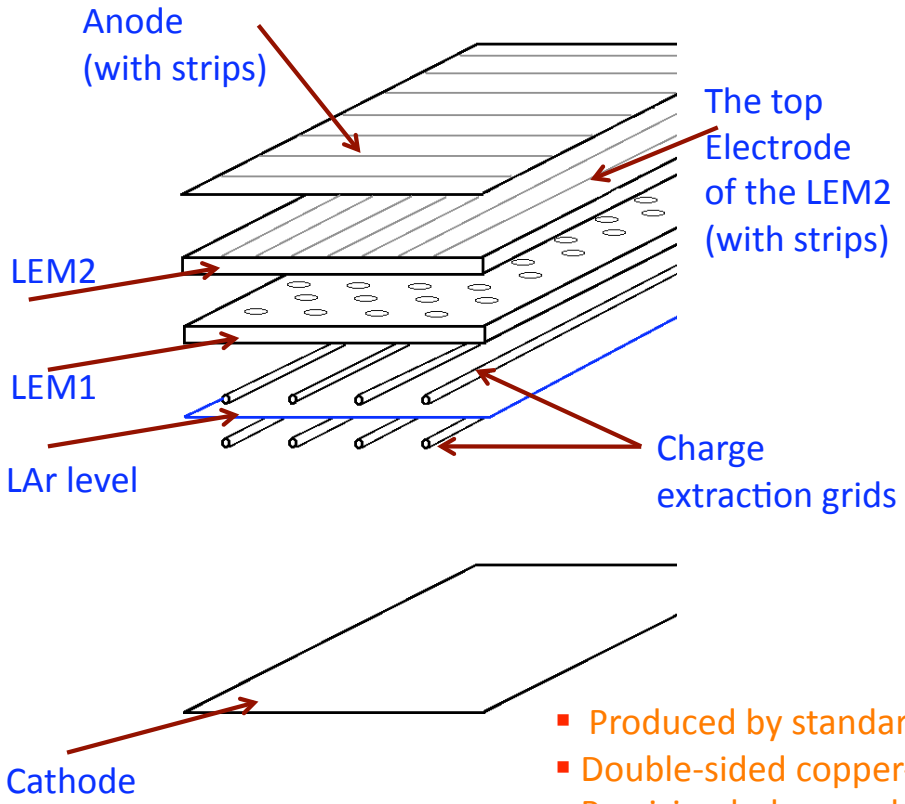
Input/output of the recirculation system

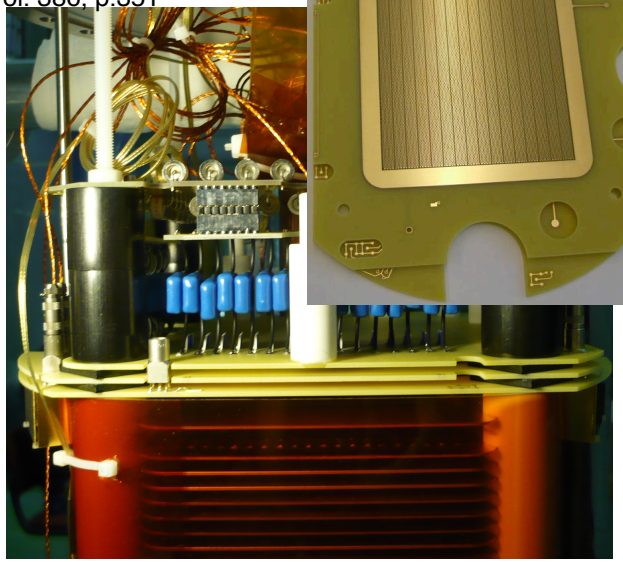
P.Otyugova (UniZH)

Charge Read-Out System: Large Electron Multiplier (LEM)

LEM is a thick macroscopic GEM Ref. F.Sauli, NIM A, 1997, vol. 386, p.351

LAr LEM-TPC principal





10 x 10 cm^2 prototype chamber
Two planes 16 strips, 6 mm width

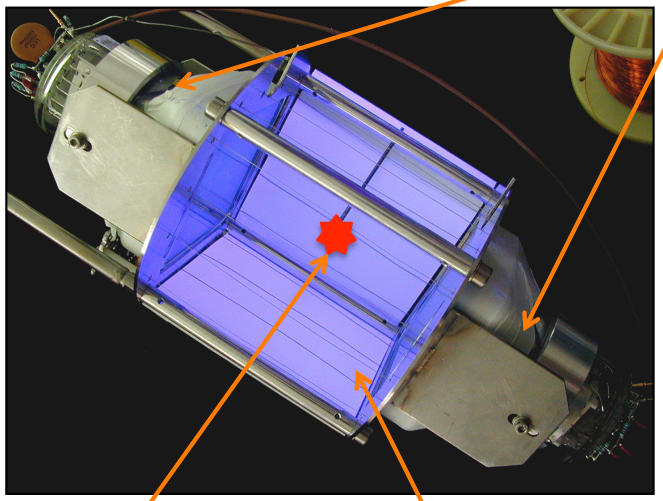
F.Resnati
Proceeding for IEEE-NSS 2008

- Produced by standard PCB technique
- Double-sided copper-clad (18 µm layer) FR4 plates
- Precision holes made by drilling
- Gold deposition on Cu (<~ 1 µm layer) to avoid oxidization

P.Otyugova (UniZH)

Dual- PMT cell for the pulse-shape events separation

2 Cryogenic PMTs.

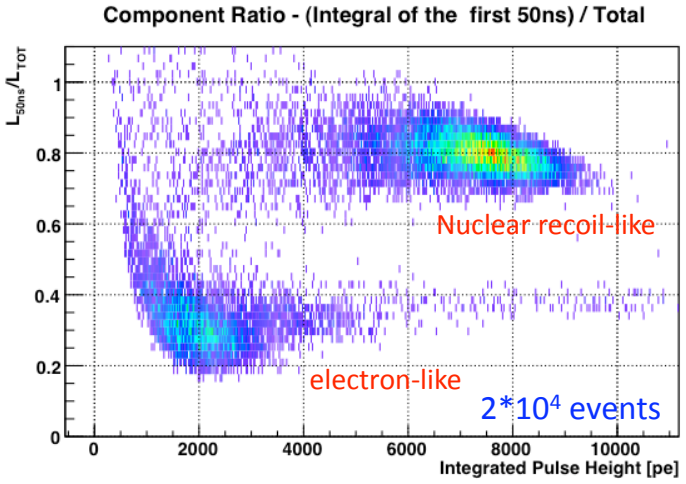


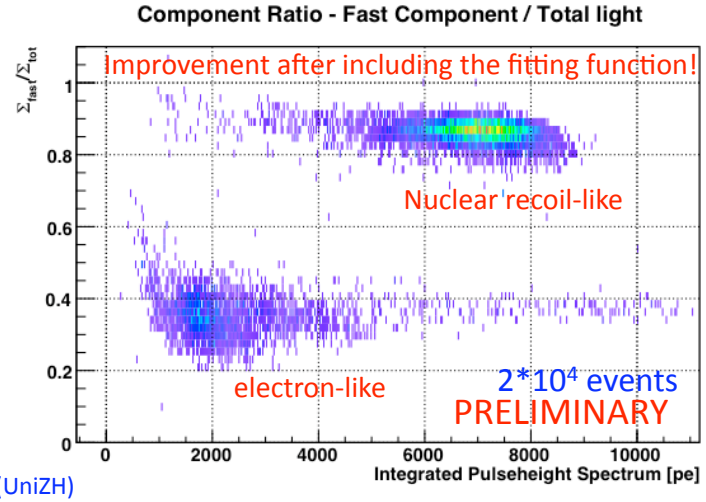
Pb^{210} source
50 Bq.

TPB coated reflectors.

Inner volume: 6 l of LAr

Radioactive source: ^{210}Pb,
α 5.3 MeV, β 1.16 MeV
α and β events are clearly separated.





P.Otyugova (UniZH)

Preliminary Light Yield Prediction

	Gaseous Argon	Liquid Argon
6lt.Test Cell (only 1 PMT)	~800phe/5.3MeV α ~0.150phe/keVne (measured)	~4500phe/5.3MeV α ~0.8phe/keVne (measured)
1ton ArDM	~550phe/4.4MeVα ~0.125phe/keVne (measured)	~3000phe/4.4MeV α ~0.7phe/keVne (expected)

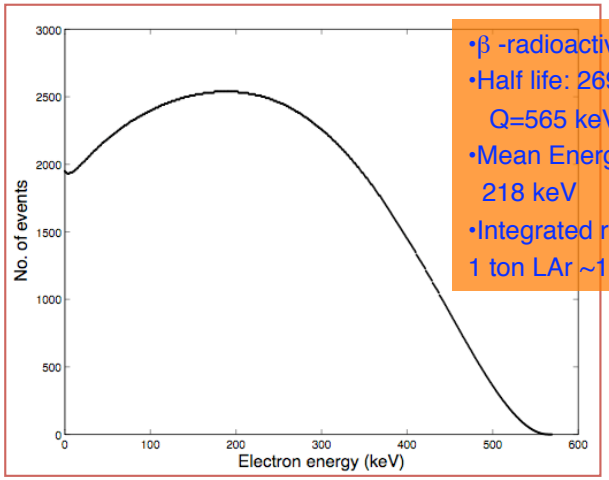
A quenching factor (~0.3) has to be taken in account for hadrons, because of high ionization density

Electrons and gamma events have almost no quenching, so the light yield will be 3.3 times higher, i.e. we should reach a light yield of 2phe/keVee (electron equivalent)

The expected light yield fulfills the ArDM requirements!

Ar^{39} and neutrons backgrounds

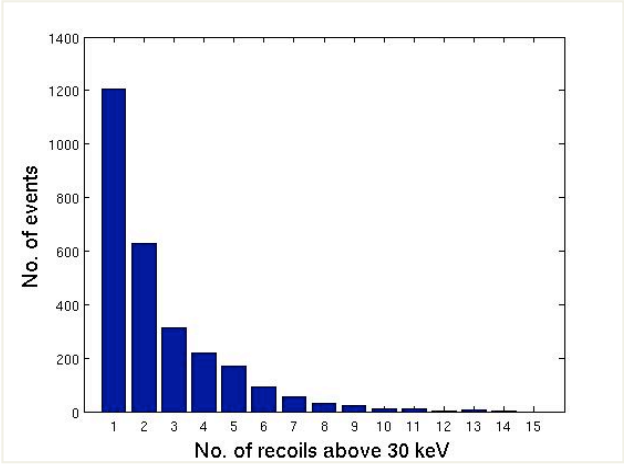
Natural argon from liquefaction of air contains small fractions of ^{39}Ar radioactive isotope.

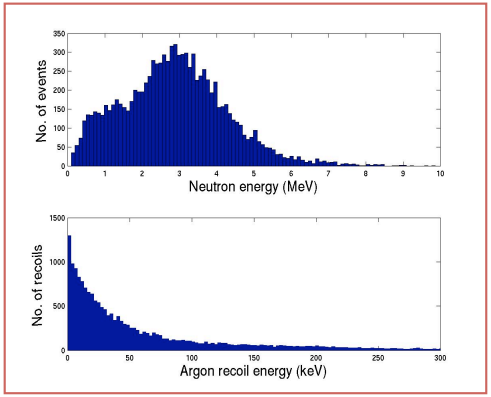


- β -radioactive isotope
- Half life: 269 years
  Q=565 keV
- Mean Energy:
  218 keV
- Integrated rate in
  1 ton LAr ~1kHz

Component	n per year	WIMP-like recoils per year
Container	~ 400	~ 30
LEM (std. mat.)	~ 10000	~ 900
LEM (low bg. mat.)	< 20	< 2
14 PMTs (std. mat.)	~ 12000	~ 1000
14 PMTs (low bg. mat.)	~ 600	~ 50

About 55% of the interacting neutrons scatter more than once at the threshold of 30keV.
Less than 10% of the emitted neutrons produce WIMP-like events single recoils, energy ∈ [30,100] keV).
The WIMP cross-section is very low, and it will scatter at most once.



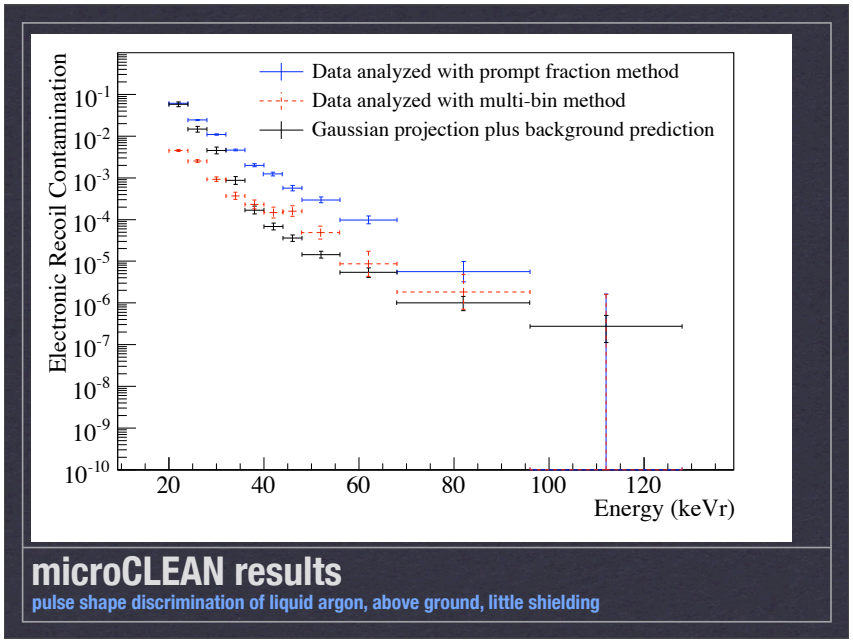


We need:
Rejection power of 10^8
OR
use of ^{39}Ar-depleted argon

P.Otyugova (UniZH)

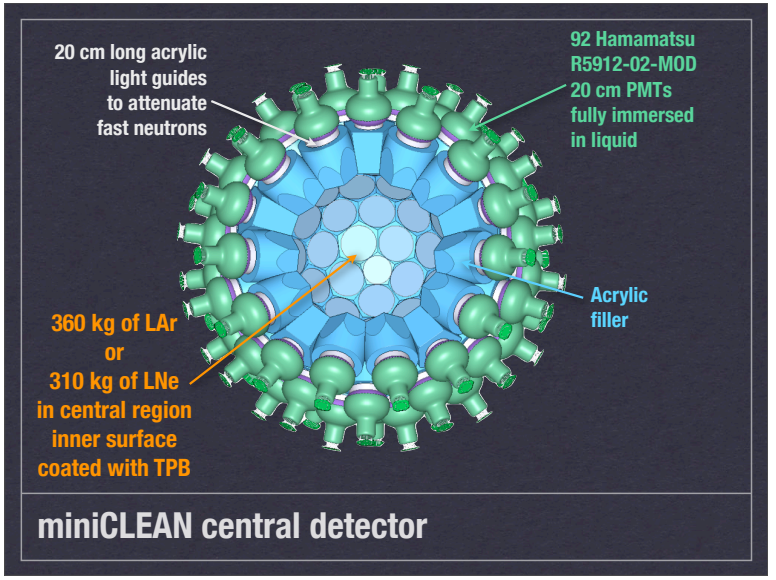
DEAP & CLEAN: Single Phase LAr Detectors

- ton scale DEAP/CLEAN planned for SNOLAB
- proposed first phase: 100 kg mini-CLEAN with WIMP search goal of ~ 5 x 10^{-45} cm^2 or ~10 events/yr
- To reject gamma background from PMTs and Ar-39 a discrimination better than 10^{-8} for ER> 50keVr is required
- Current data from small (~7 kg) DEAP-1 and micro-CLEAN detectors above ground demonstrate a discrimination of 10^{-5} limited by neutron back in lab

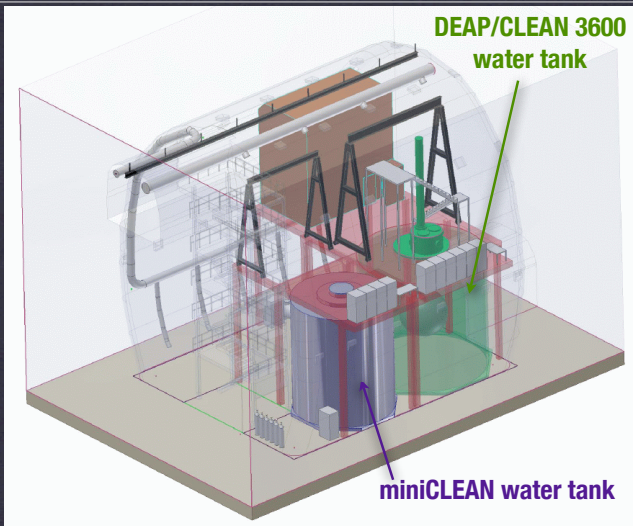


microCLEAN results

pulse shape discrimination of liquid argon, above ground, little shielding

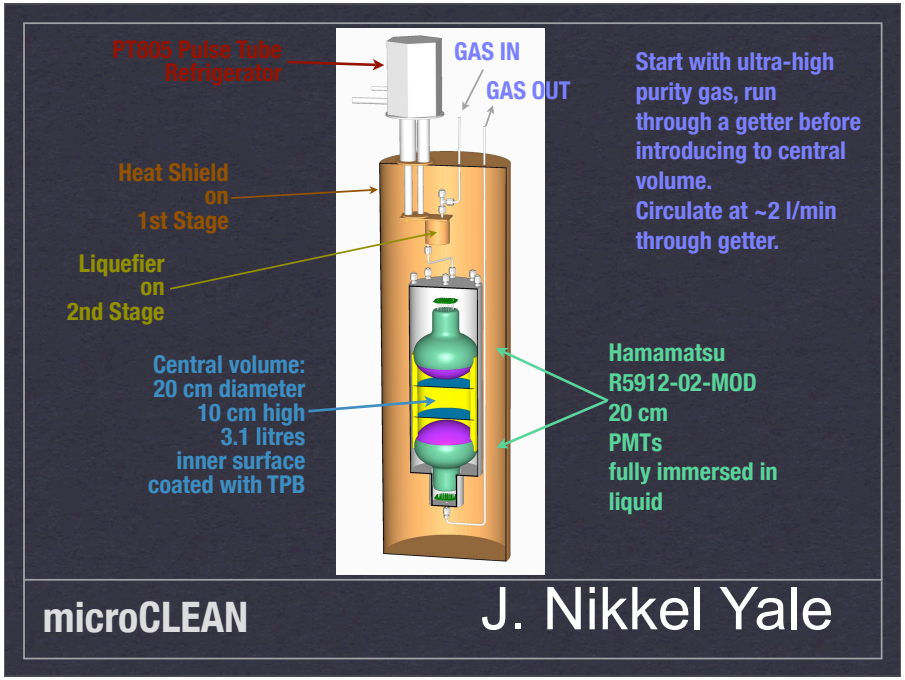


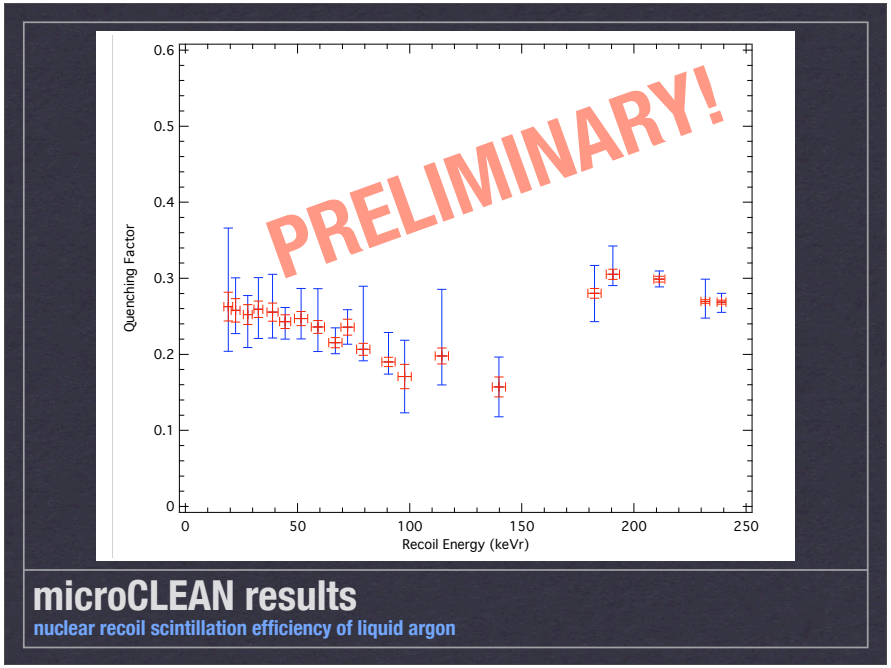
miniCLEAN central detector

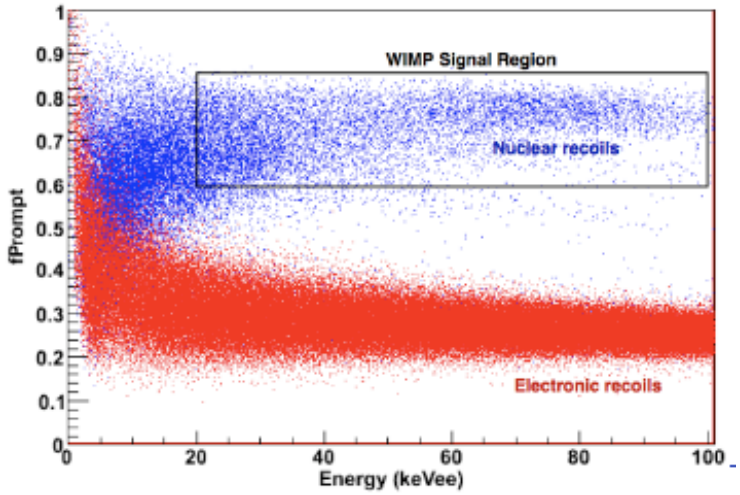


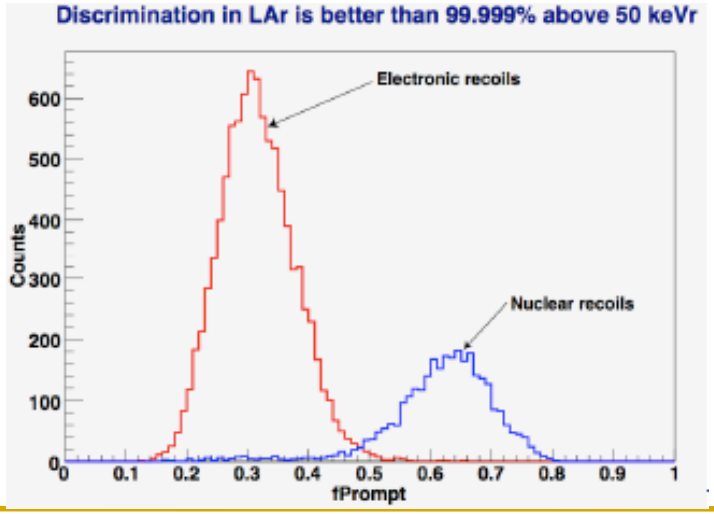
SNOLAB Cube Hall

Micro-CLEAN: PSD and QF



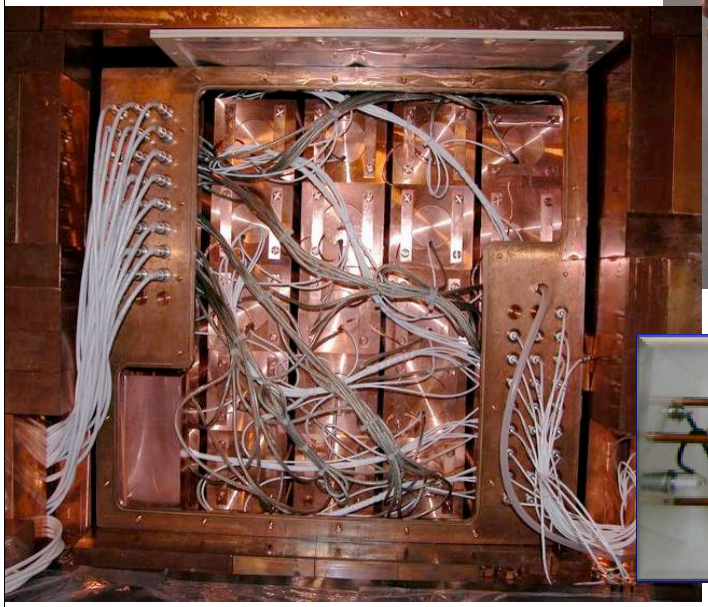


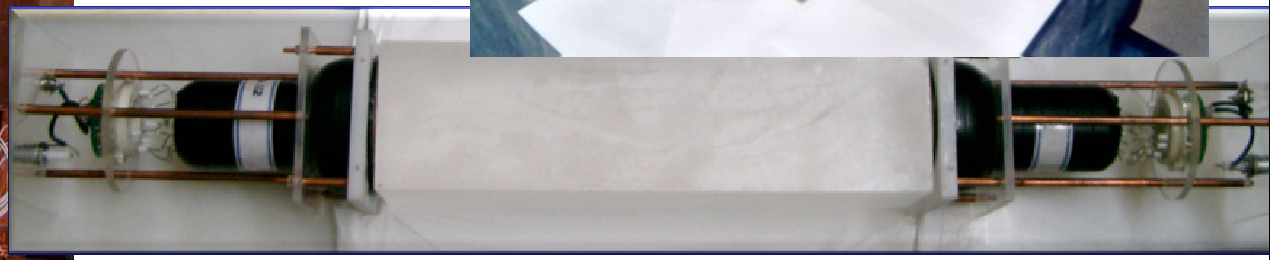




Room Temperature Scintillation Experiments

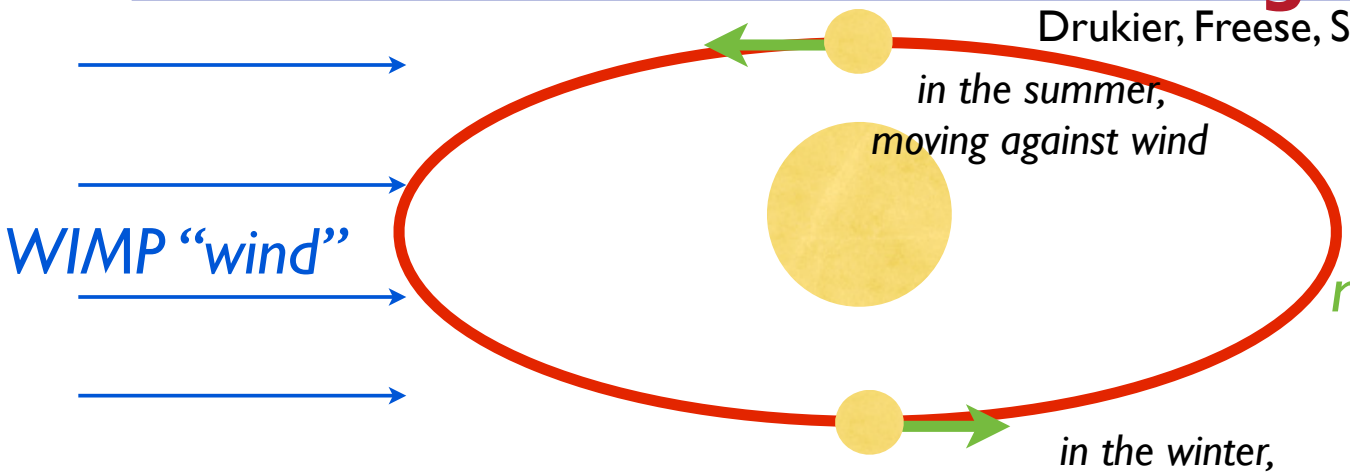
- Inorganic alkali halide crystals (NaI (Tl), CsI (Tl) : high density, high light output
- can be produced with high purity in large mass at affordable cost (annual modulation study)
- Sensitive to both SD and SI WIMP interactions
- PSD (better for CsI) but no discrimination between electron and nuclear recoils on an event-by-event basis
- Experiments: DAMA-LIBRA/Italy, KIMS/Korea, ANAIS/Spain (plan for 100kg NaI expt at Canfranc)



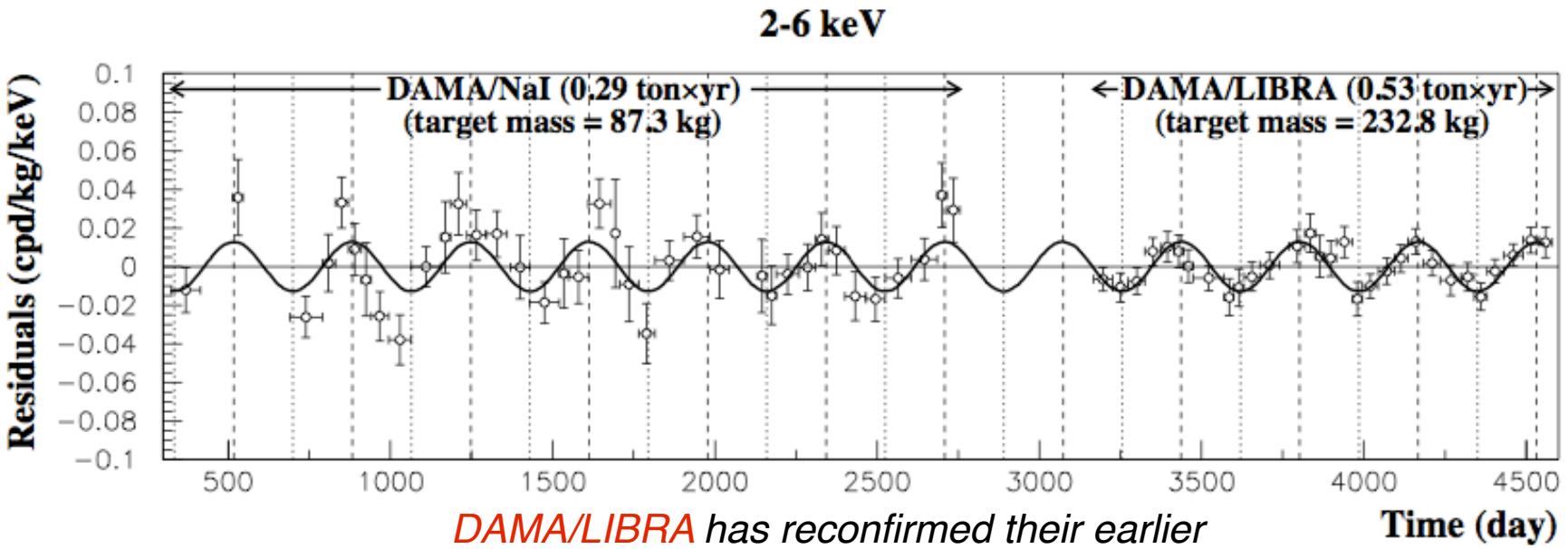


Designed to search for Annual Modulation of WIMP Signal

Drukier, Freese, Spergel PRD33,3495,1986

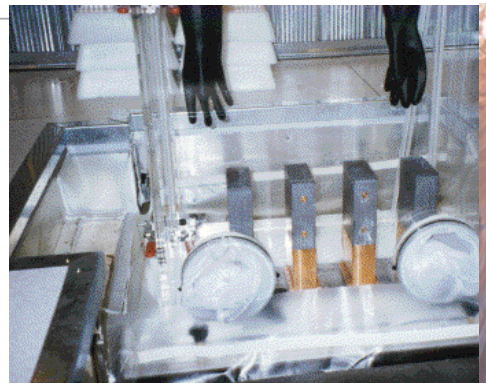


expect an annual modulation in signal!

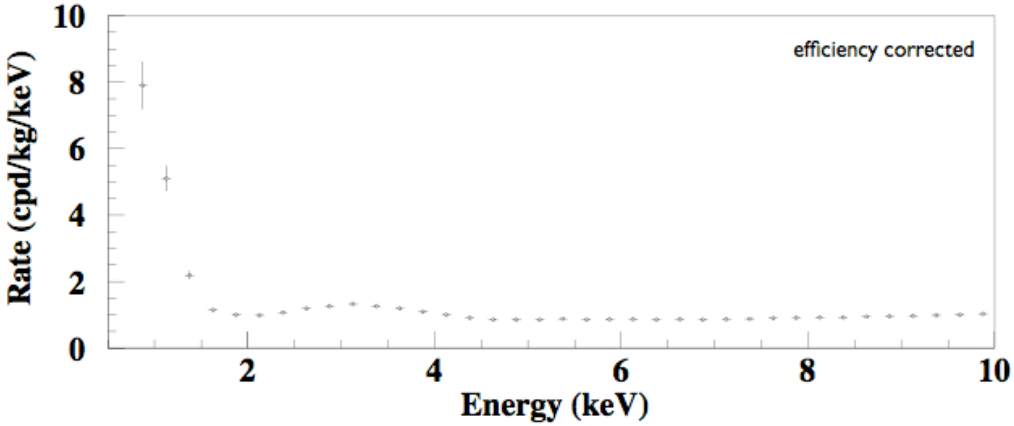


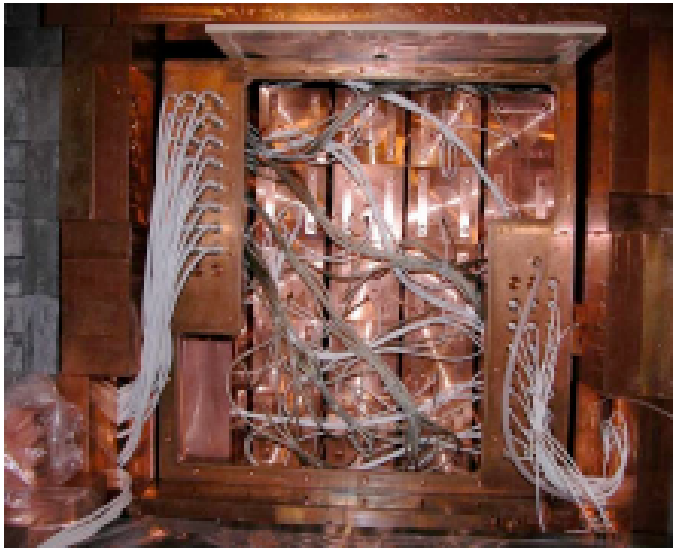
DAMA/LIBRA has reconfirmed their earlier observation of annual modulation signal [arXiv:0804.2741]

DAMA/LIBRA @ LNGS



- **DAMA: 9 x 9.7 NaI (Tl) crystals**
- BG level: 1-2 events/kg/d/keV
- $E_{threshold} \approx 2keV_{ee} \approx 25\ keV_r$
- **Data period:** 7 annual cycles, until July 2002; 0.29 ton x yr
- **LIBRA: 25 x 9.7 NaI (Tl) crystals in 5 x 5 matrix**
- **Data period:** 4 annual cycles, 0.53 ton x year



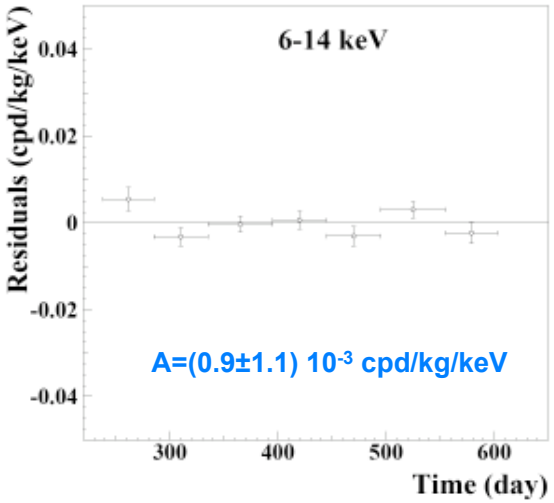


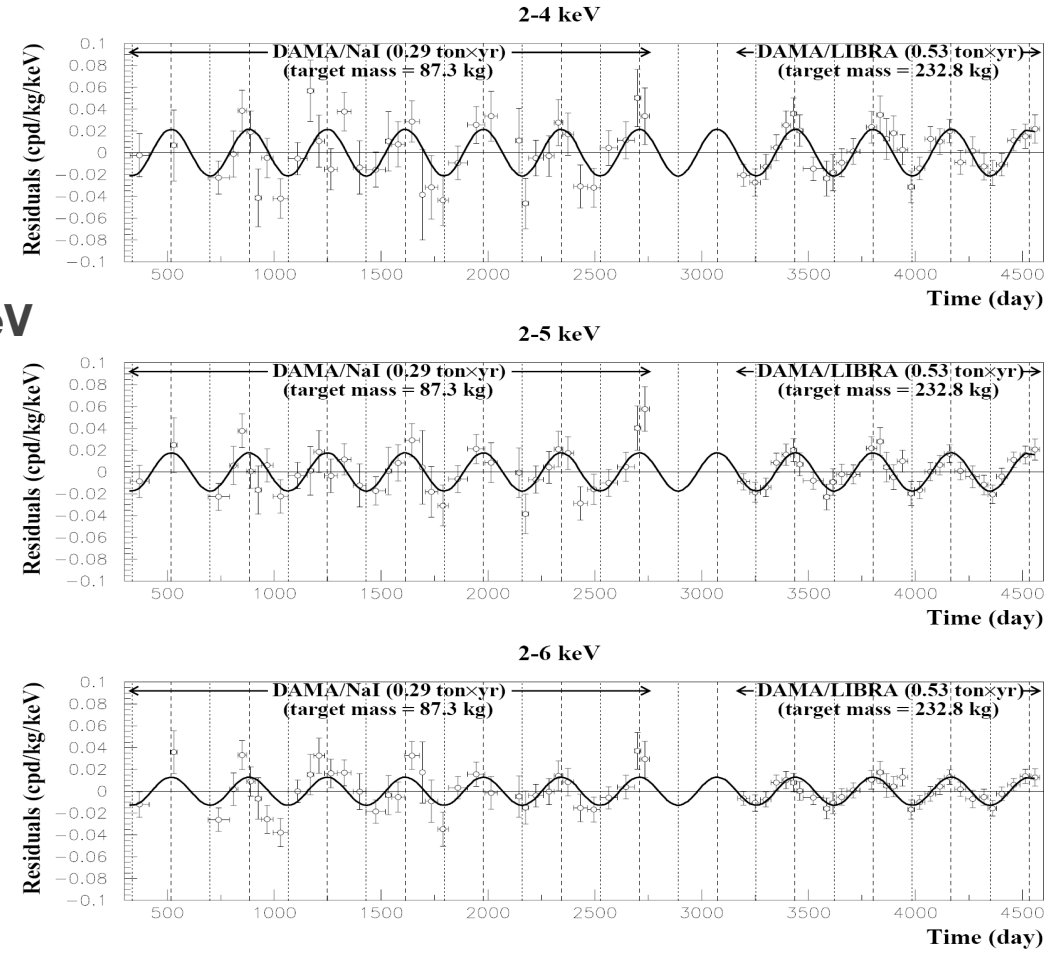
DAMA/LIBRA Results: A Strong Modulation Signal

- Total exposure: 0.82 ton x year
- **Modulation amplitude:**
- A cos [ω(t-t_0)]

  t_0 = 152.5 d, T = 1 year
- **A = (0.0215 ± 0.0026) cpd/kg/keV**

  (at 8.3 σ CL)
- No modulation above 6 keV





arXiv:0804.2738
arXiv:0804.2741

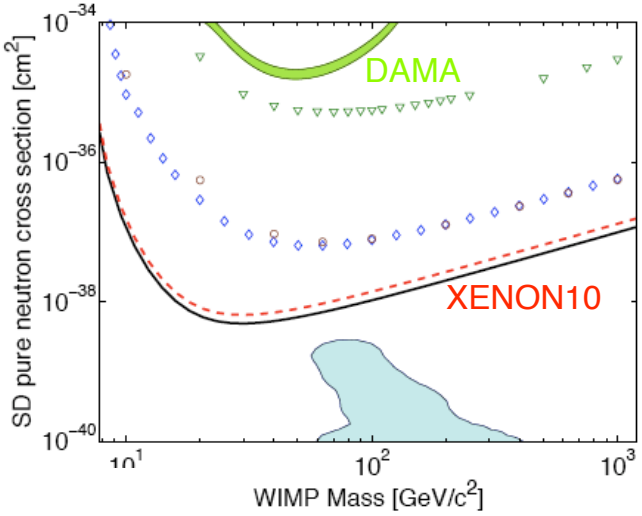
Modulation result inconsistent with WIMP Recoils

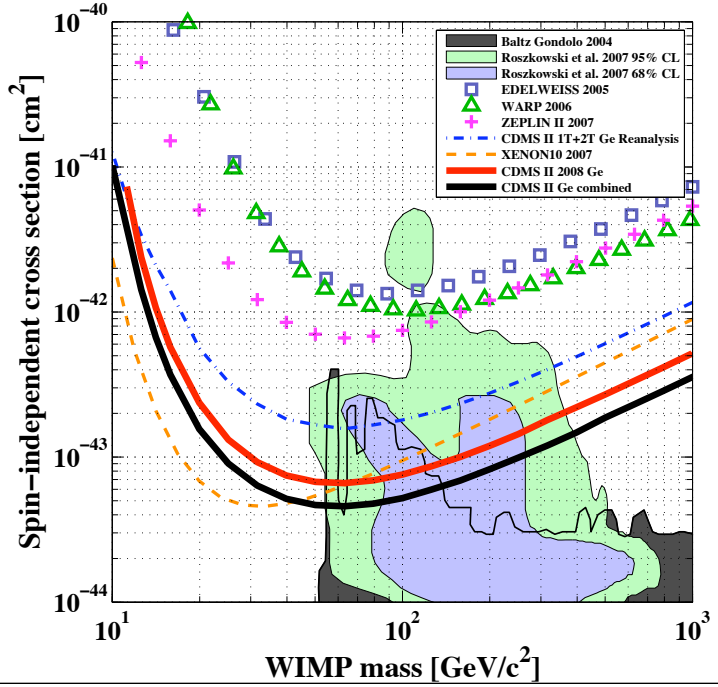
WIMP recoils excluded by other experiments for both SD and SI

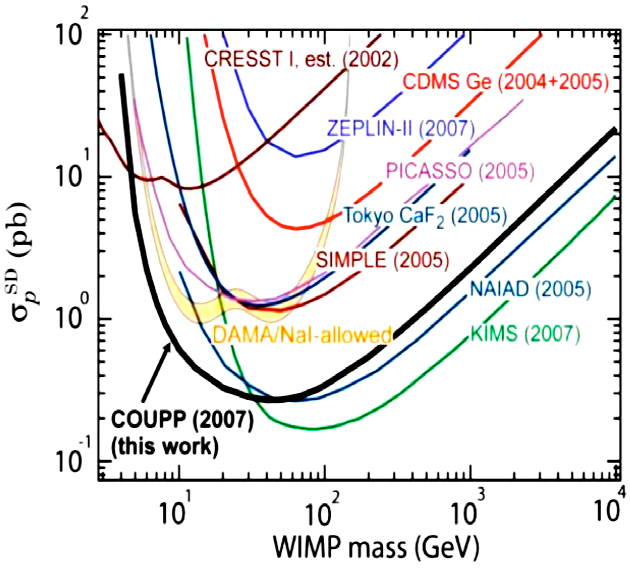
For a $m_W = 50$ GeV, $\sigma_{SI} = 2\text{x}10^{-6}$ pb, the predicted rates are:

XENON10: 136 kg day, 4.5-27 keVr => 162 events

CDMS R123/124: 397.8 kg day in Ge, 10-100 keVr => 62 events







Light Mass WIMPs also recently excluded!

- **a 475 g Ge with a threshold of 0.33 keV ! WIMPs with mass <10 GeV ruled out**
- **see Collar et al.** http://arxiv.org/abs/0807.0879

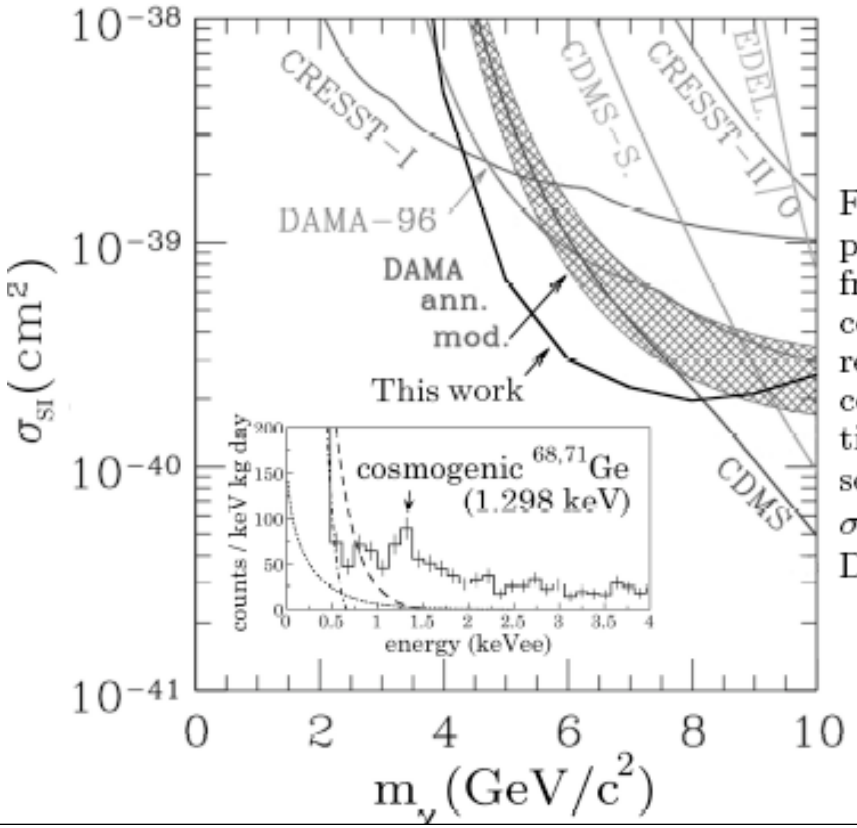


FIG. 2: Parameter space region (cross-hatched) able to explain the DAMA modulation via spin-independent couplings from an isothermal light-WIMP halo [5]. Lines delimit the coupling (σ_{SI}) vs. WIMP mass (m_χ) regions excluded by relevant experiments [5]. All regions are defined at the 90% confidence level. Inset: PPC spectrum used for the extraction of present limits. Lines display the signals expected from some reference WIMP candidates (dotted: m_χ= 8 GeV/c^2, σ_{SI} = 10^{-4}pb. Dashed: m_χ= 6 GeV/c^2, σ_{SI} = 0.002 pb. Dash-dotted: m_χ= 4 GeV/c^2, σ_{SI} = 10^{-2}pb).

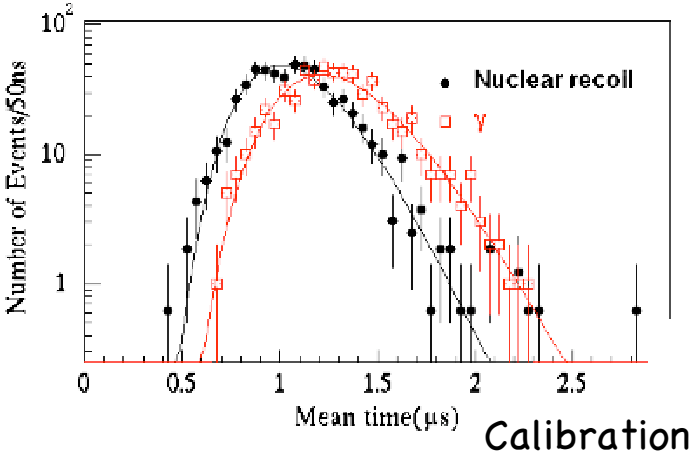
KIMS @ Yang Yang Lab

CsI(Tl) crystals at the YangYang Underground Lab in Korea (2000 mw

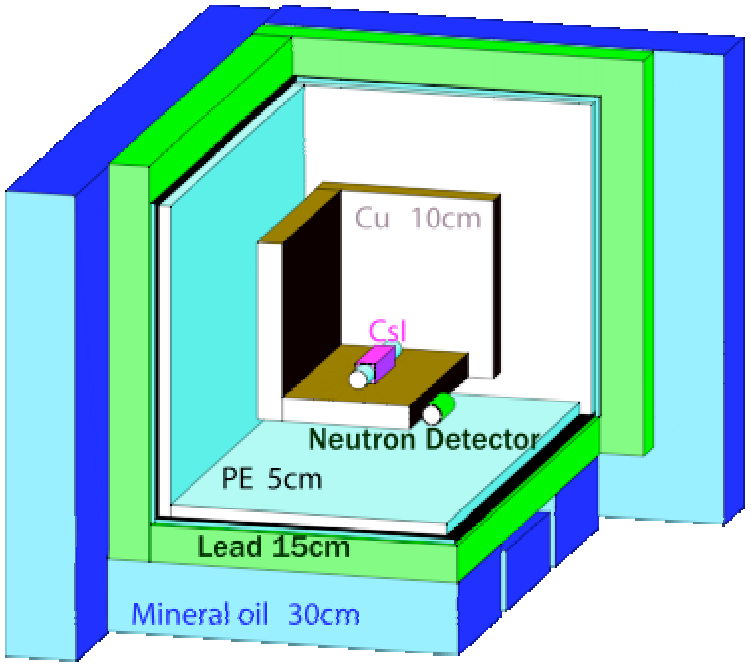
light yield: 5×10^4 photons/MeV

QF: 8-15% between 10-100 keV_e

	CsI(Tl)	NaI(Tl)
Density(g/cm3)	4.53	3.67
Decay Time(ns)	~1050	~230
Peak emission(nm)	550	415
Hygroscopicity	slight	strong



Calibration data



KIMs Crystals

12 crystal array

Name♪	Weight (kg)♪	Data♪ (kg days)♪
S0406♪	6.7 ♪	237♪
S0501A♪	8.7 ♪	1147♪
S0501B♪	8.7 ♪	1030♪
B0510A♪	8.7 ♪	616♪
B0510B♪	8.7 ♪	616♪

published PLB(2006) Pilot run

published PRL(2007)

Engineering run

Total crystals
8.7 kg x 12 = 104.4 kg
started data taking

background level
2~4 cpd/keV/kg (preliminary)

3" PMT (9269QA) quartz window, RbCs PC (green enhanced) ; 5 pe/keV

- **CsI(Tl) Crystal 8x8x30 cm^3 (8.7 kg)**

Sensitive to both SD and SI WIMP interactions
Ge, Xe not sensitive to SD proton coupling
complementary to CDMS, XENON10
direct check of DAMA signal by I-127 recoil

Easy to get large mass at an affordable cost
annual modulation study

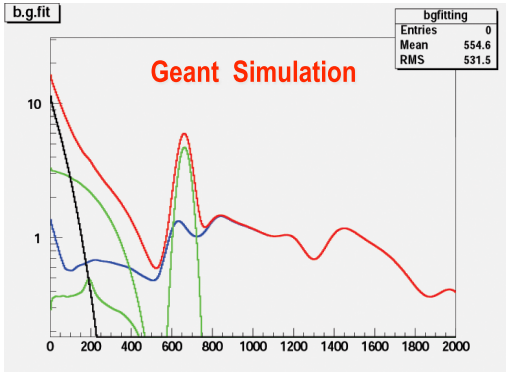
High light yield ~60,000/MeV

Pulse shape discrimination
better gamma rejection than NaI(Tl)

Easy fabrication and handling

Internal background

Radioisotopes in the crystal



^{137}**Cs** : 10 mBq/kg,
0.35 cpd/mBq/kg @ 10 keV

^{134}**Cs** : 20 mBq/kg
0.07 cpd/mBq
0.005 cpd/mBq

^{87}**Rb** : 10 ppb
1.07 cpd/ppb

Cs-137 reduction – use ultra pure water in powder production; ~1.7 mBq/kg

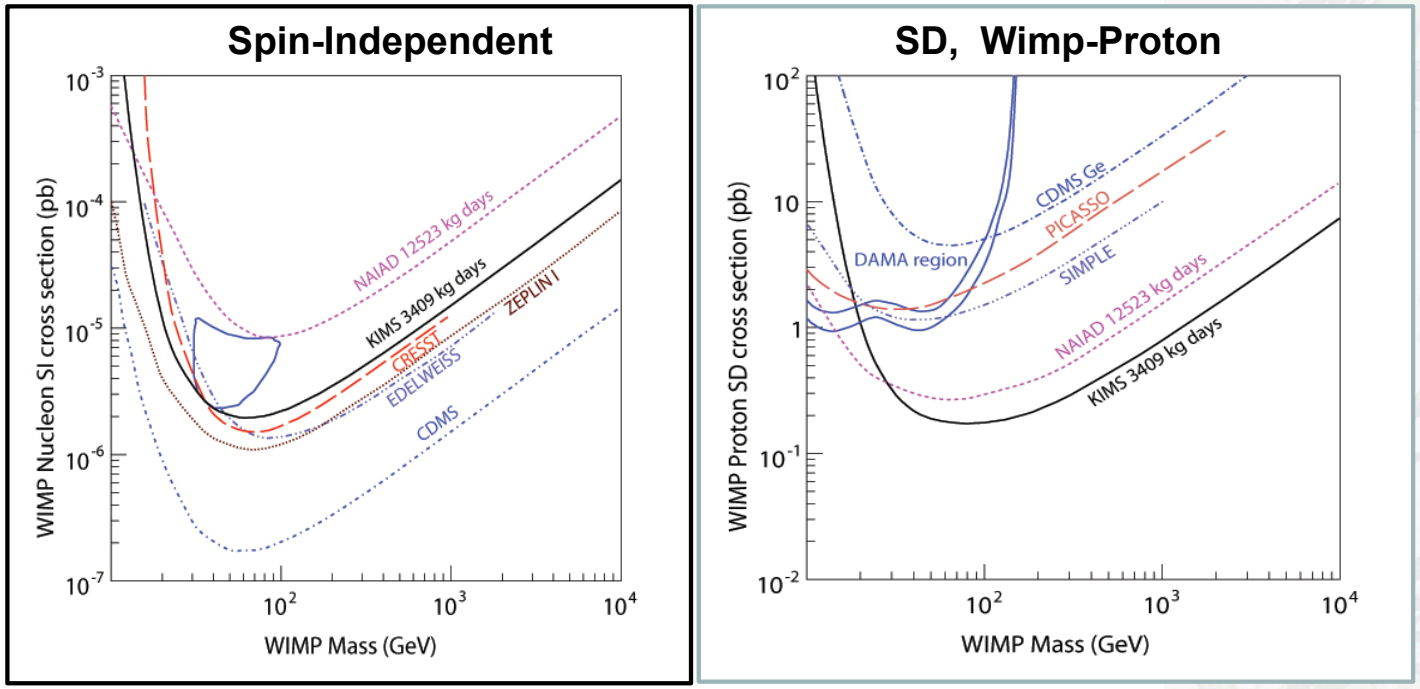
Rb reduction - recrystalization method ; < 1ppb

Latest crystals are from ~2 cpd level powder

KIMS Results

Direct comparison with DAMA (same nucleus) for SI coupling
Published data (3049 kg days) rule out DAMA signal region for both SD and SI interactions for WIMPs > 20GeV
Most stringent limit on SD interactions for pure proton coupling

Cross-section upper limits



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ρ_D=0.3 GeV/c^2/cm^3
v_0=220km/s, v_{esc}=650km/s
Systematic uncertainty ~15%

Nuclear recoil of ^{127}I of DAMA signal region