Dark Matter Searches

New Opportunities at CERN

May 11-13, 2009

European Rare Event Calorimeter Array (EURECA)

The Argon Dark Matter Search (ArDM)

The XENON Dark Matter Detection Experiment

Dark Matter Search with Bubble Chambers

The GERDA Neutrinoless Double Beta Decay Experiment

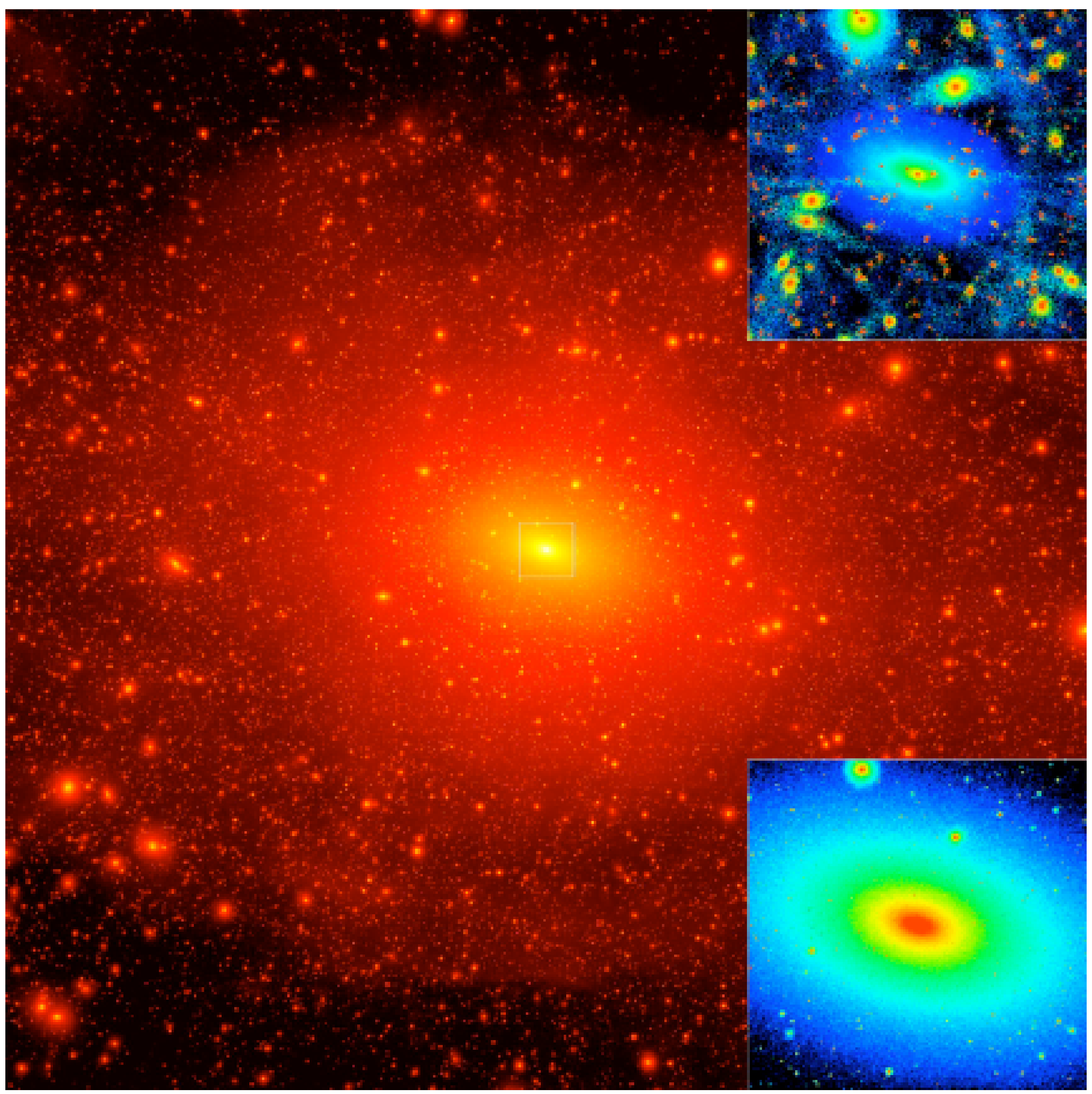
Laura Baudis

University of Zurich

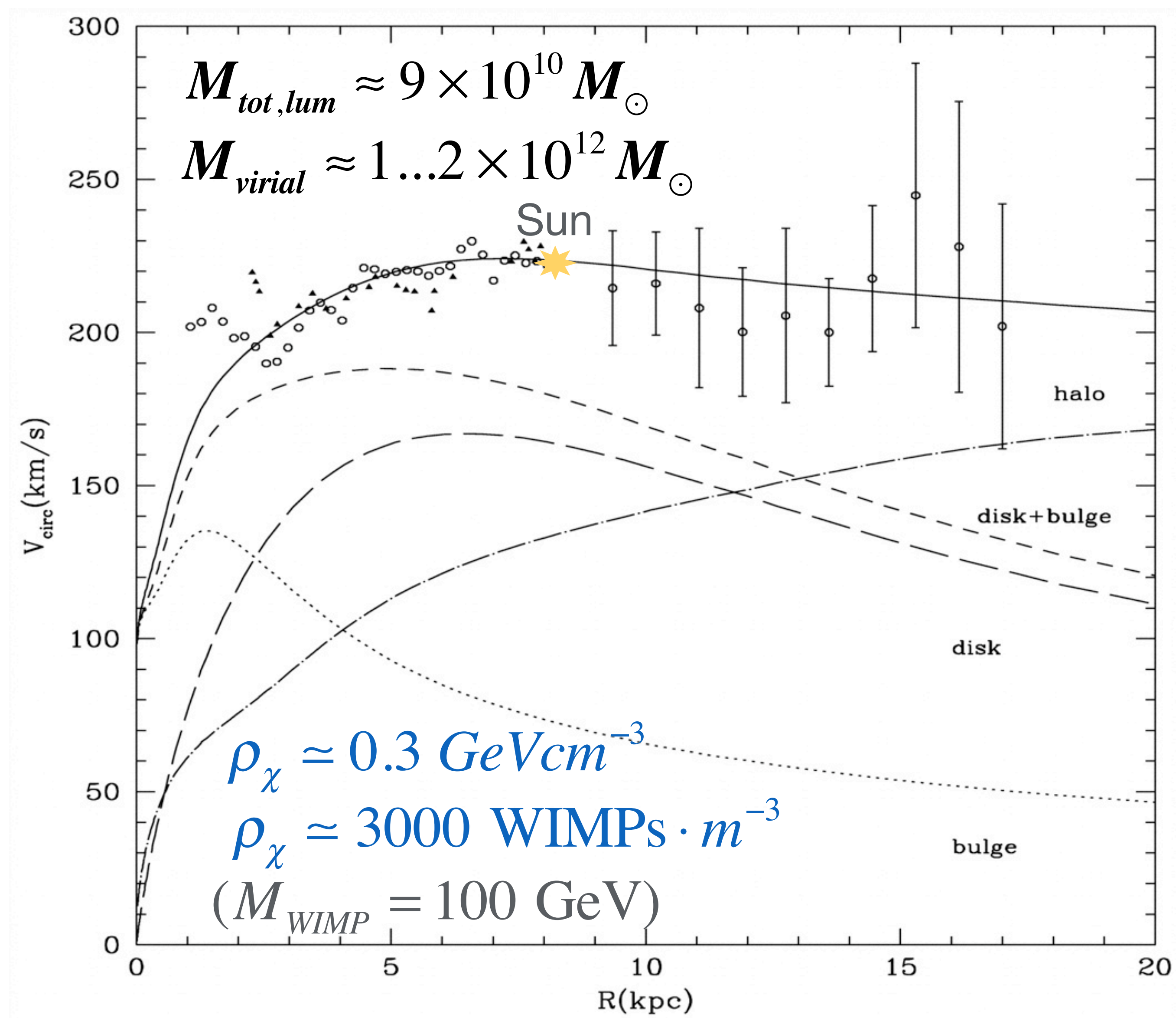
for above collaborations

Goal of Direct Detection Experiments

- **Detect new, yet undiscovered particles, which may be responsible for the dark matter in our galaxy.** Example: WIMPs = heavy (few GeV - few TeV), color and electrically neutral; in thermal equilibrium with the rest of the particles in the early universe, freeze out when $M_W >> T_F$



(J. Diemand et all, Nature 454, 2008, 735-738)

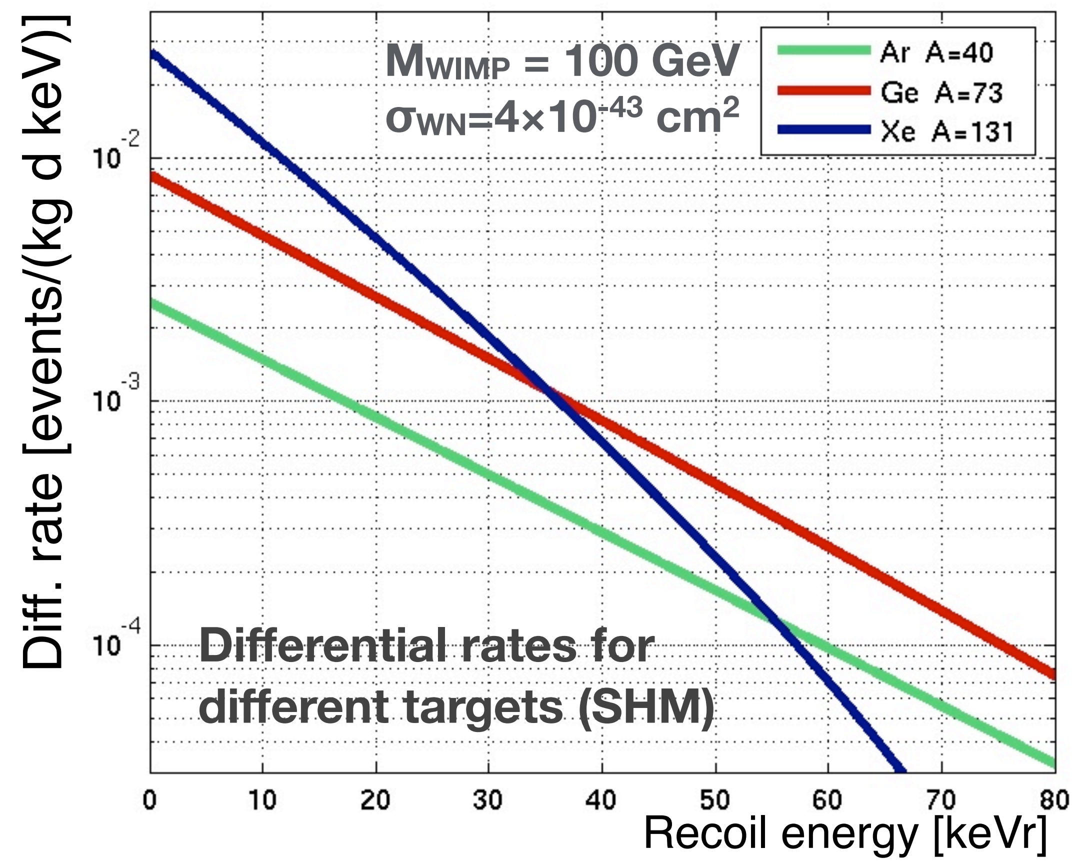


(Klypin, Zhao & Somerville 2002)

Strategy for WIMP Direct Detection

- **Elastic collisions with atomic nuclei**
- Rates depend on: **[m_χ, σ]**, **[f(v), ρ_0]**, **[N, E_{th}]** ...

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{2 m_\chi \mu^2} F^2(E_R) \int_{v > \sqrt{m_N E_R / 2\mu^2}}^{v_{max}} \frac{f(\vec{v},t)}{v} d^3 v$$

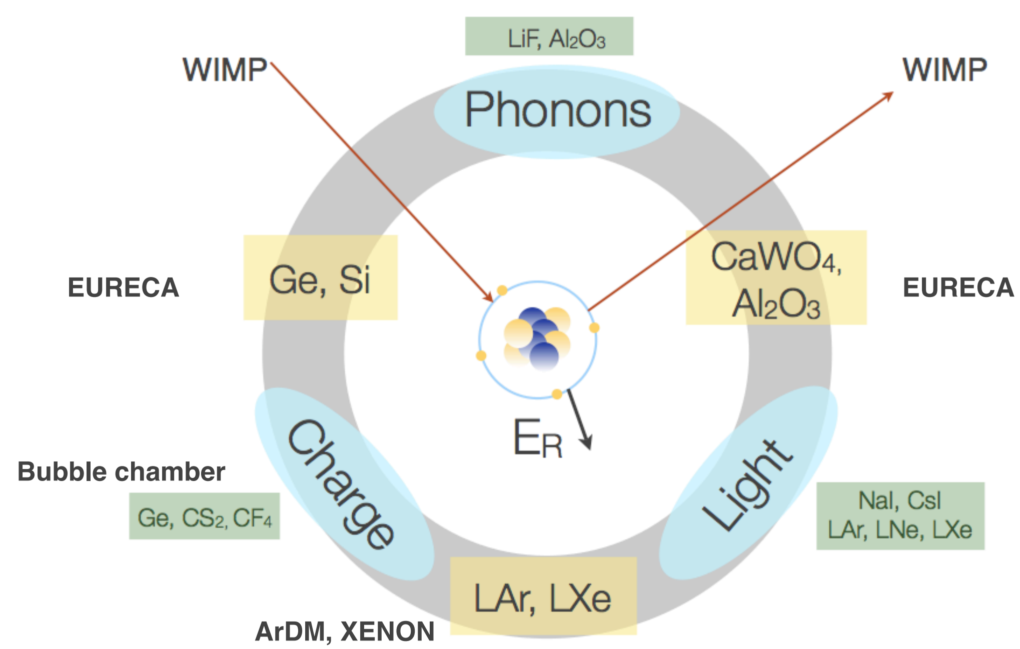


- With WIMP-nucleon cross sections < 10^{-7} pb, the expected rates are

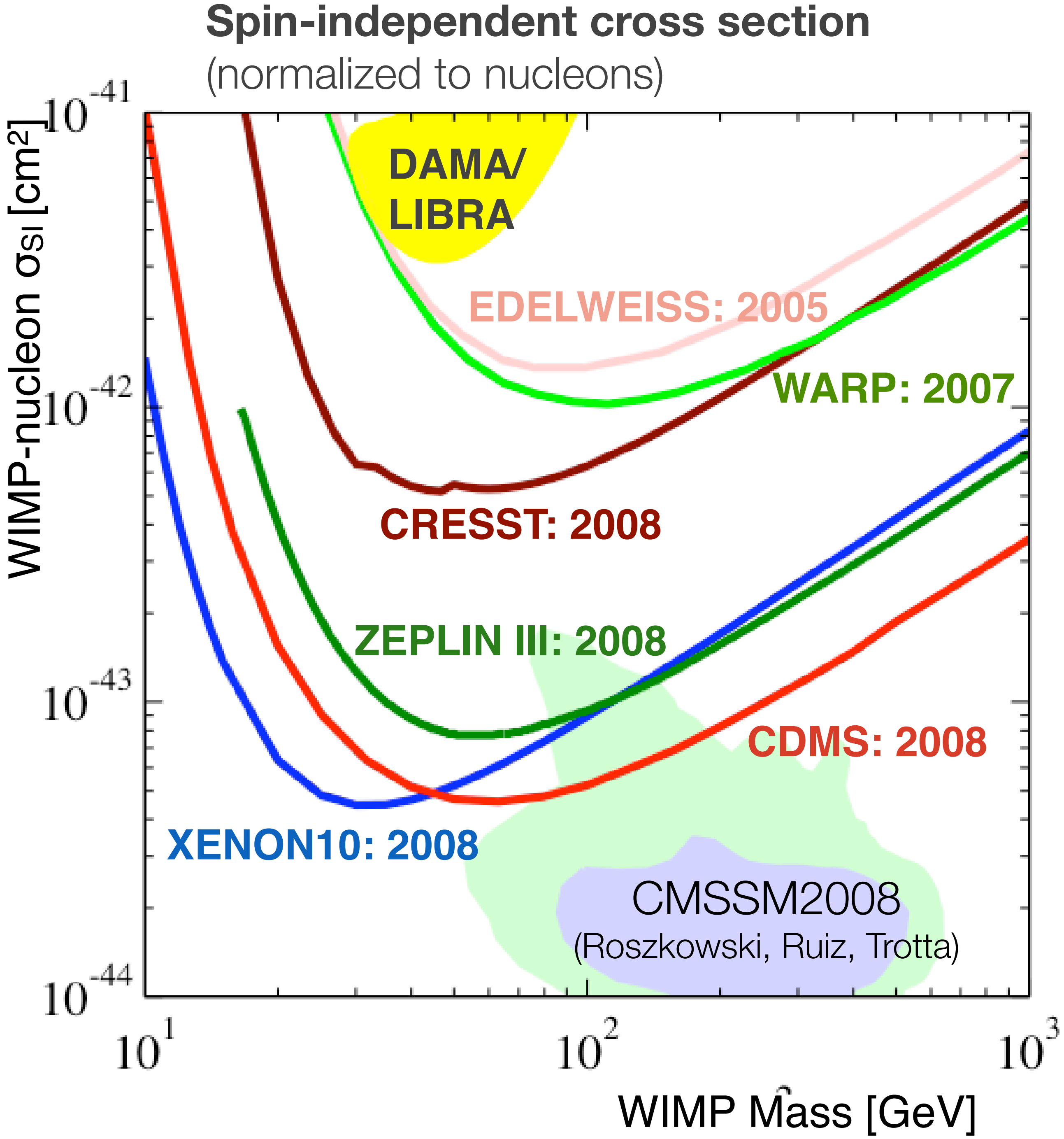
< 1 event/100kg/day

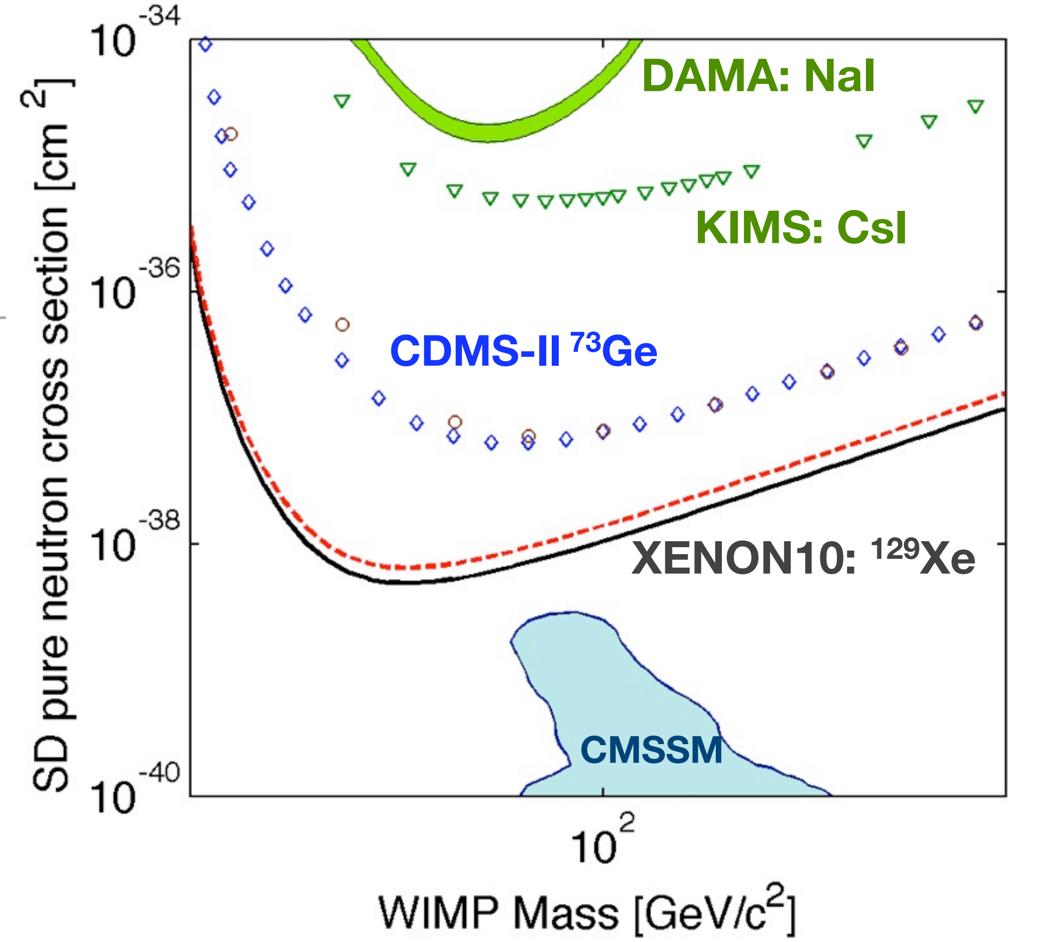
- **Energy of recoiling nuclei**

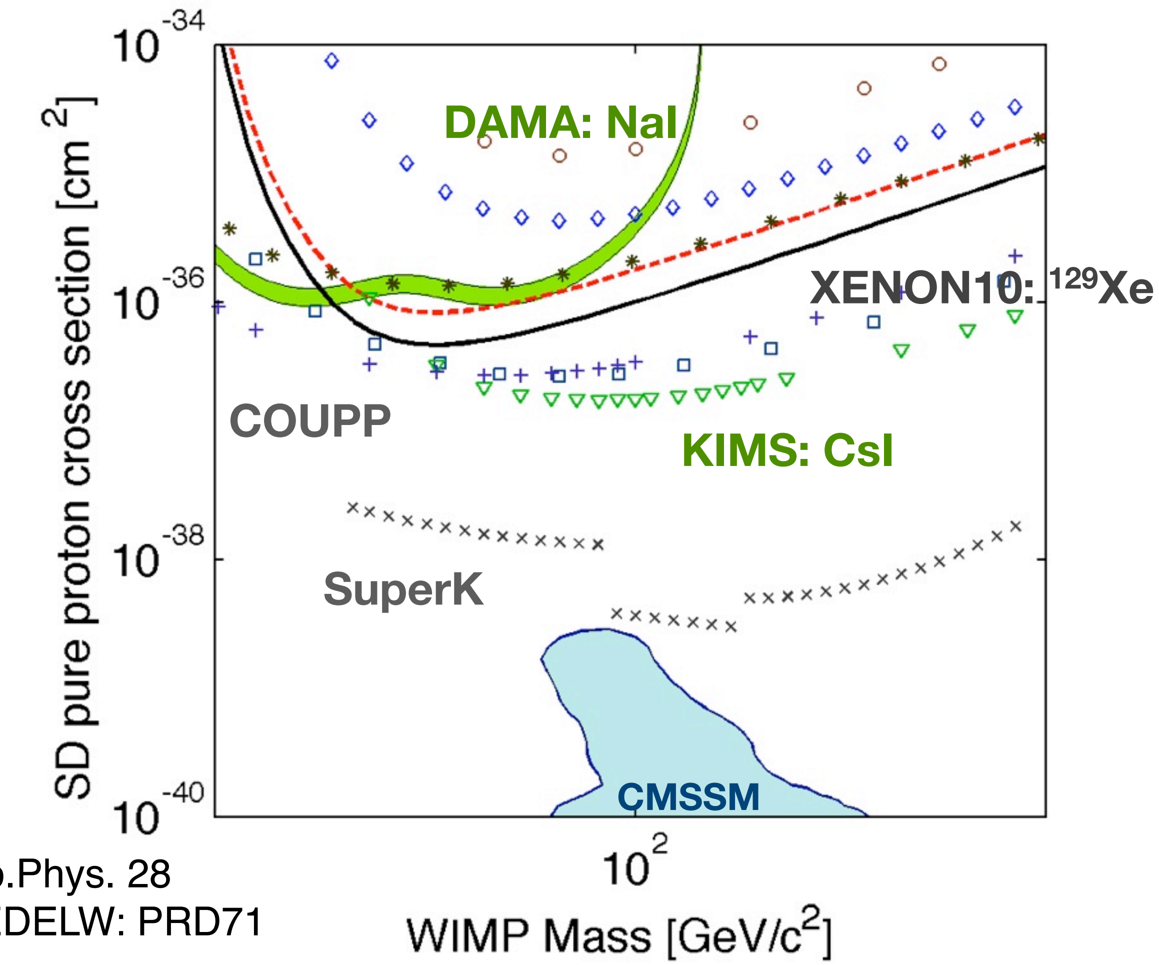
$$E_R = \frac{|\vec{q}|^2}{2 m_N} = \frac{\mu^2 v^2}{m_N}(1 - \cos\theta) \le 50\ keV$$



Status of Direct Detection Field (May 2009)







Spin-dependent cross sections

XENON10: PRL100, PRL101; ZEPLIN-III: arXiv:0901.3448, WARP: Astrop.Phys. 28
CDMS-II: PRL 102, DAMA/LIBRA: EPJ C 56, CRESST: Astrop.Phys. 31, EDELW: PRD71

Abstract by Hans Kraus, Oxford

EURECA

European Rare Event Calorimeter Array

A European coordinated effort to build a ton-scale cryogenic dark matter experiment

Joint effort of ~110 physicists from EDELWEISS, CRESST, ROSEBUD, CERN + others

Part of ILIAS / ASPERA / ApPEC strategy (roadmap)

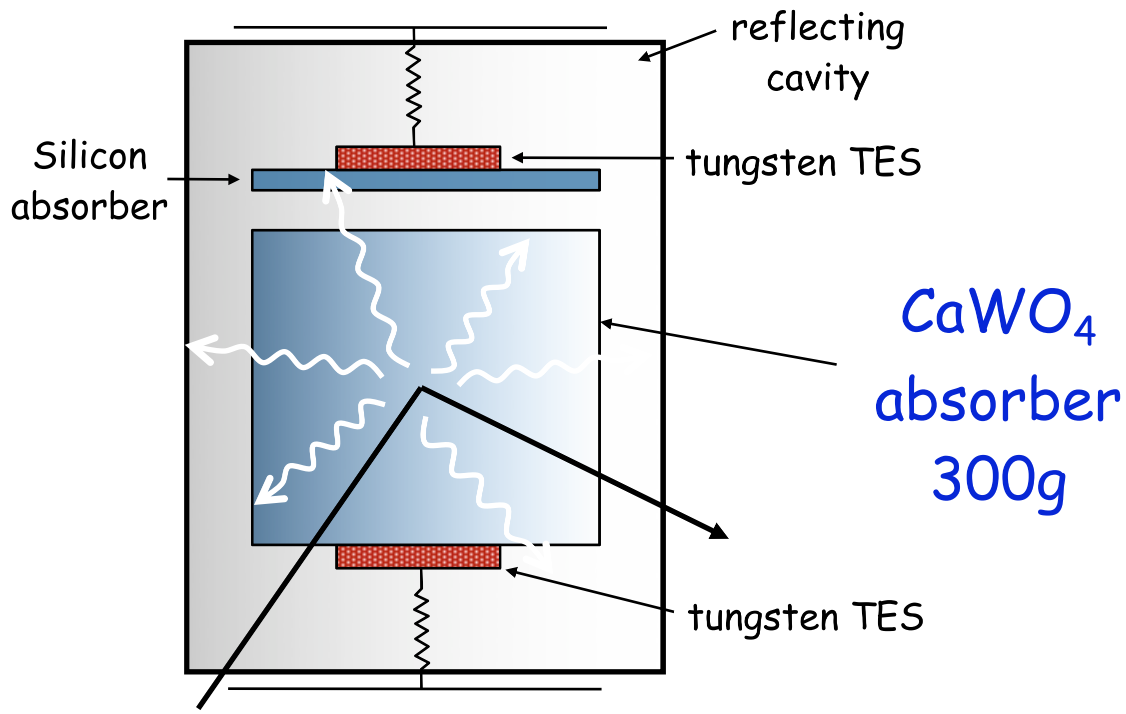
- Cryogenic detectors are modular and inherently scalable
- Multi-element target for WIMP identification (Ge and solid state scintillators)

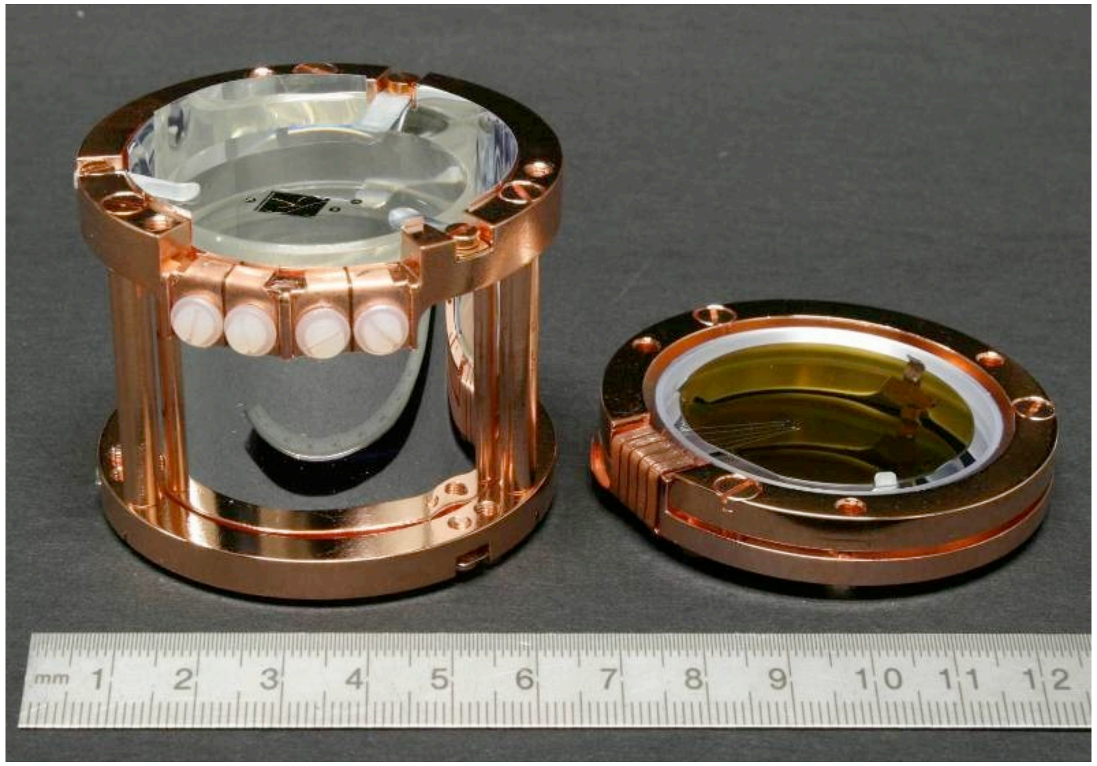
Current topics:

- design study, technology down selection
- major effort in background control and detector fabrication

Preferred site: 60 000 m^3 extension of present Laboratoire Souterrain de Modane

CRESST Detectors

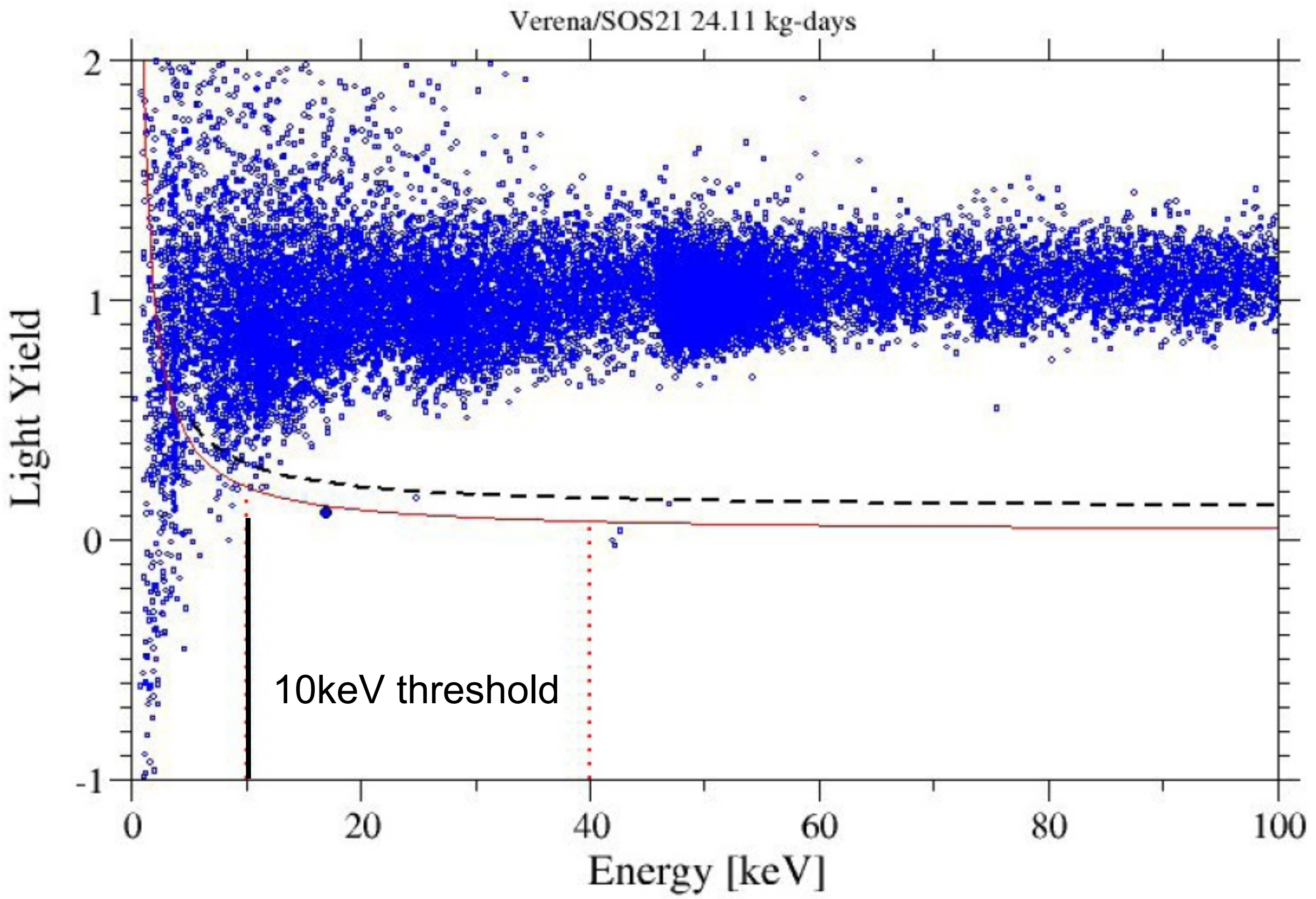




Phonon – Scintillation

Energy scale:
Excellent resolution

Particle Identification:
Background discrimination



Range of Scintillator Targets

18 Detector Modules installed

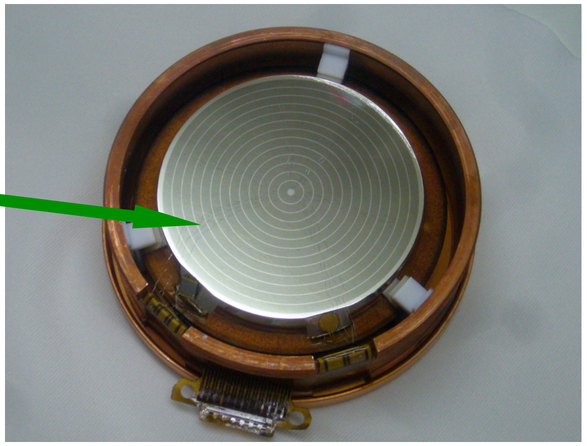
Edelweiss (InterDigitised) Detectors

Phonon – Ionization

Energy scale: Excellent resolution

Particle Identification: Background discrimination

From plain to concentric alternate V electrodes



12 new detectors (400 g Ge) running with **InterDigitized electrodes:**

Removes "surface events" by avoiding incomplete charge collection

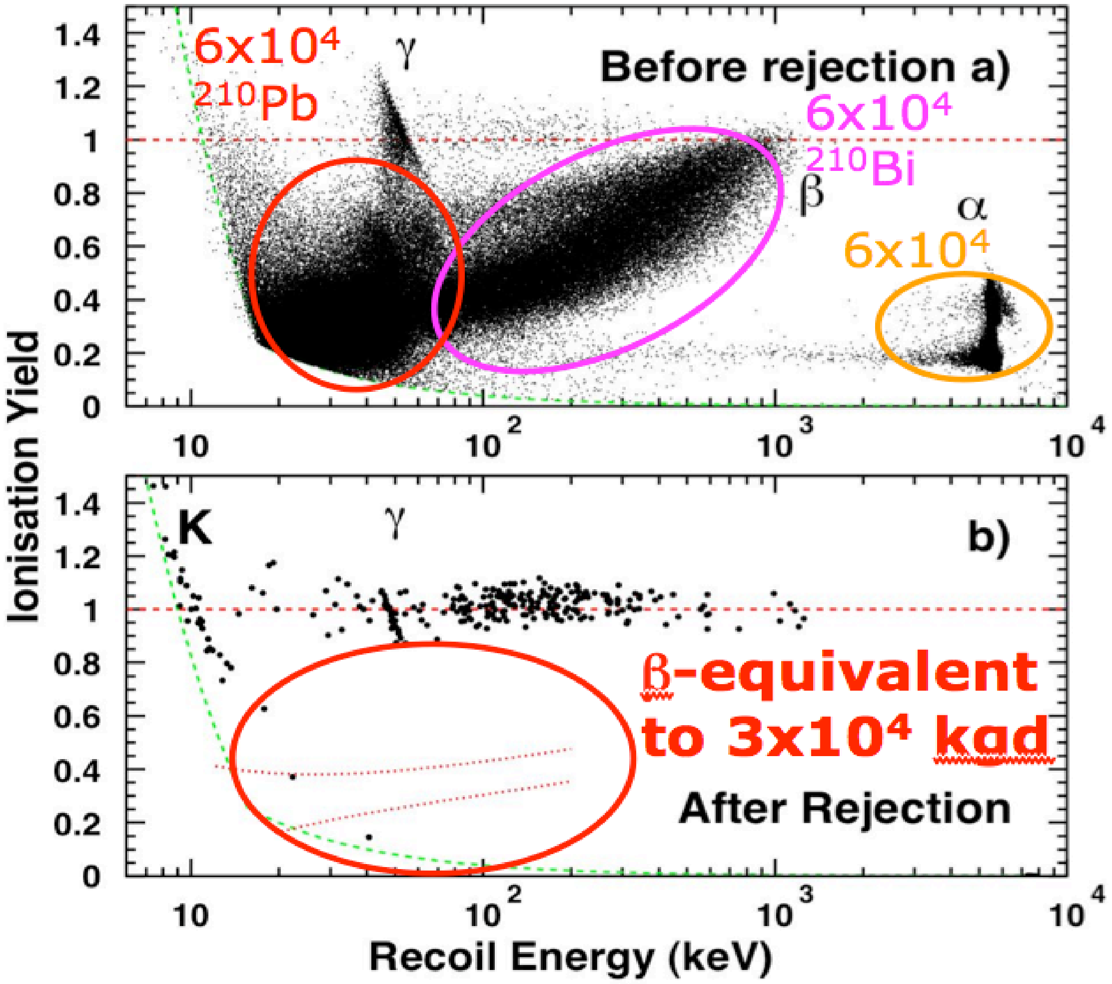
→ clean nuclear recoil band

→ one surface event expected in $3x10^4$ kg days

→ equivalent to 10^{-45} cm^2 sensitivity + decrease of surface (^{210}Pb) background

Meets EURECA goal

(see recent preprint: arXiv:0905.0753v1)



EURECA Aims

EURECA = "European Rare Event Calorimeter Array"

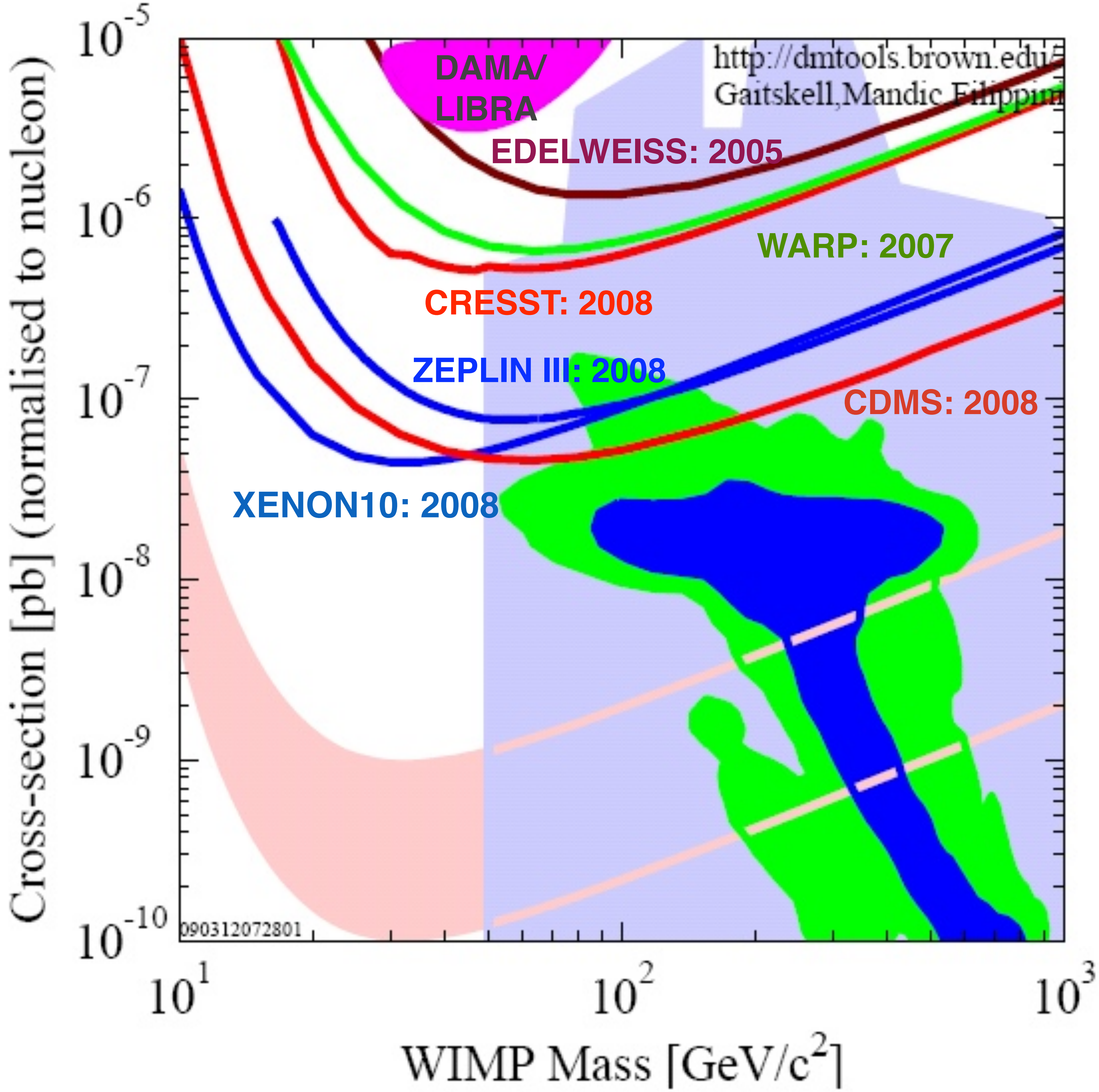
CRESST / EDELWEISS
~5×10^{-7} pb (spring 2009)

~1 evt/kg/day

~3 evt/kg/yr

EURECA aim

~30 evt/ton/year



EUREKA in LSM

Timeline:

2009/10: Design Study → TDR; currently preparing bid for ASPERA design study call

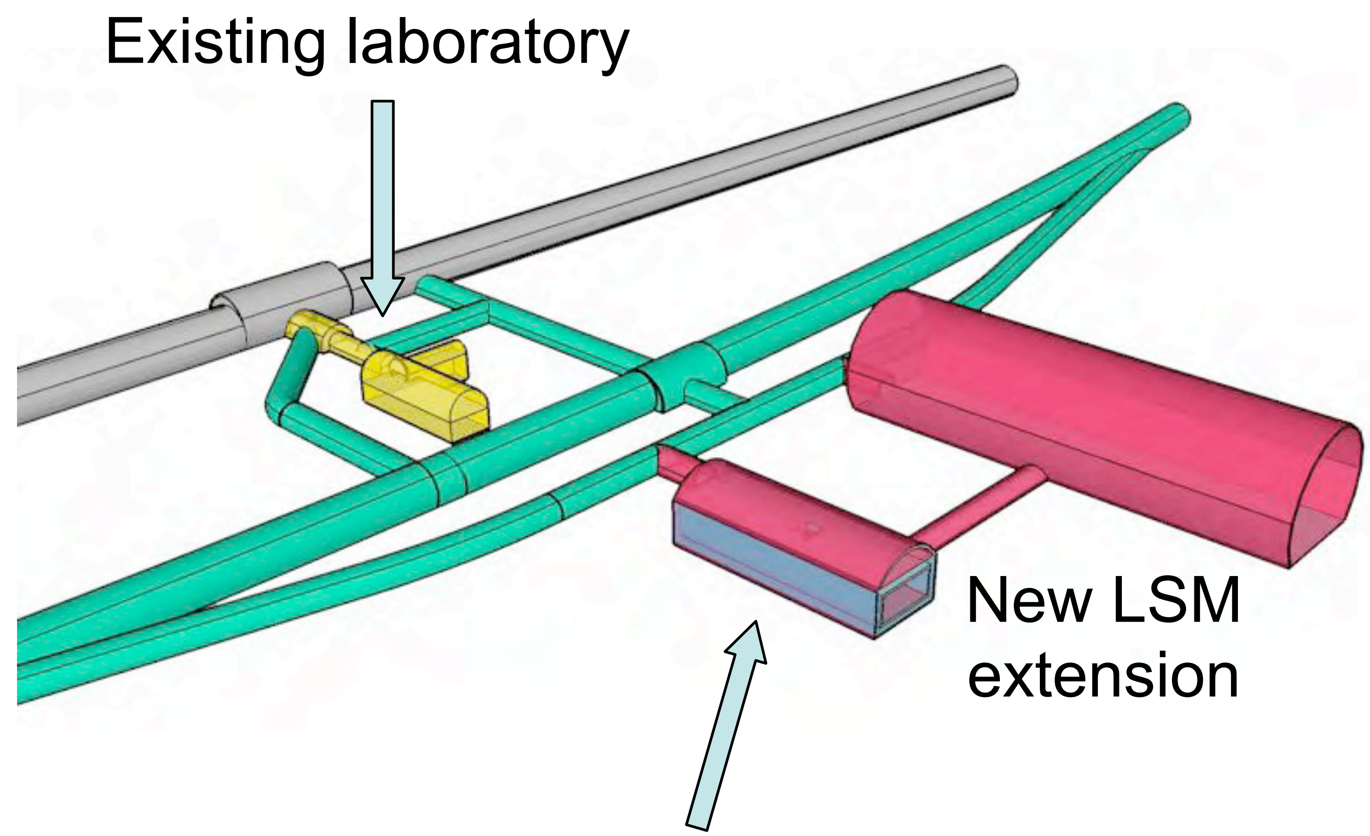
2011/12: Digging out of LSM extension begins. In parallel, begin construction of EURECA components away from LSM

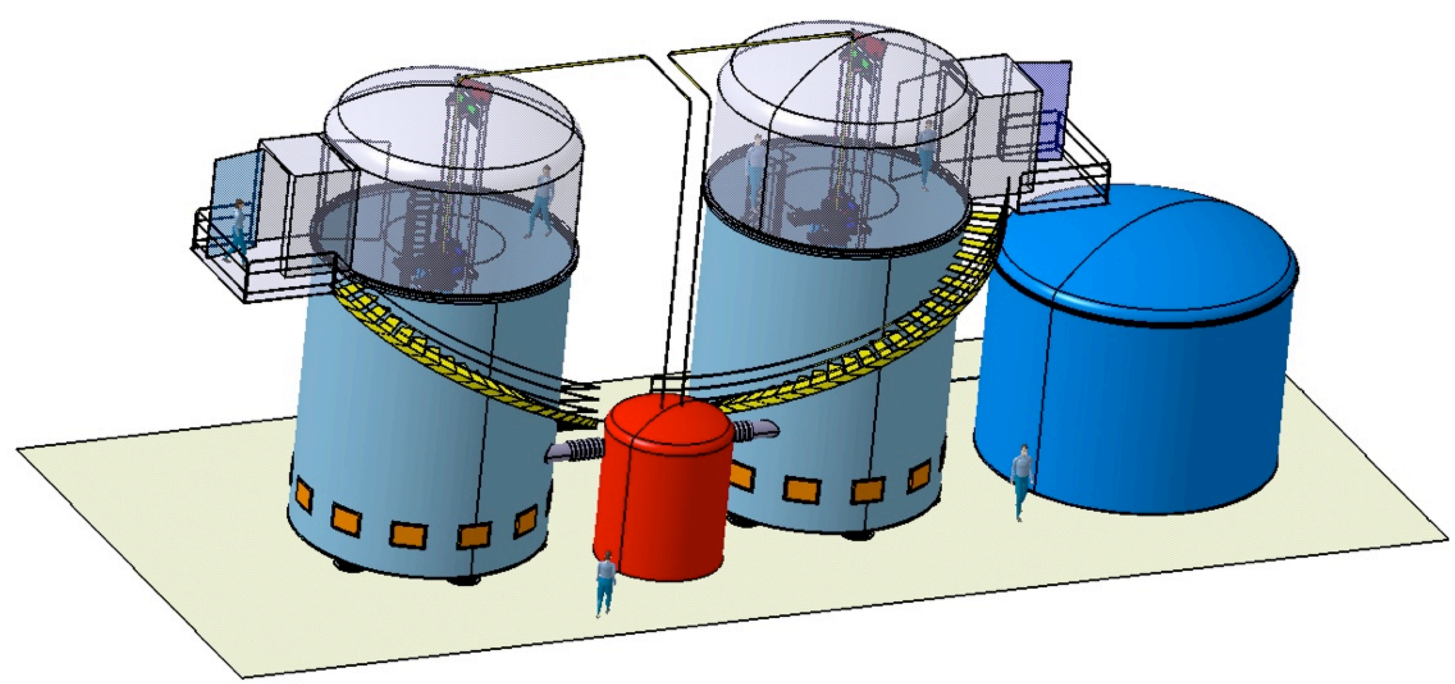
Aim for ~100 kg stage (10^{-45} cm^2).

2014: LSM extension ready to receive EURECA.

2015: Begin data taking and in parallel improve and upgrade.

2018: One tonne target installed.





Possible EURECA Facility Layout

EURECA CERN Involvement

Expertise of Technology and Engineering Departments:

Design studies for large-scale shielding

Planning, manufacturing of cryogenic infrastructure

R&D of radio-pure cryogenic scintillator

Support Facilities:

Use of CERN finance office / administration of funds

Meeting facilities

Common procurement

Physics Studies:

Coherent approach with LHC and direct DM searches

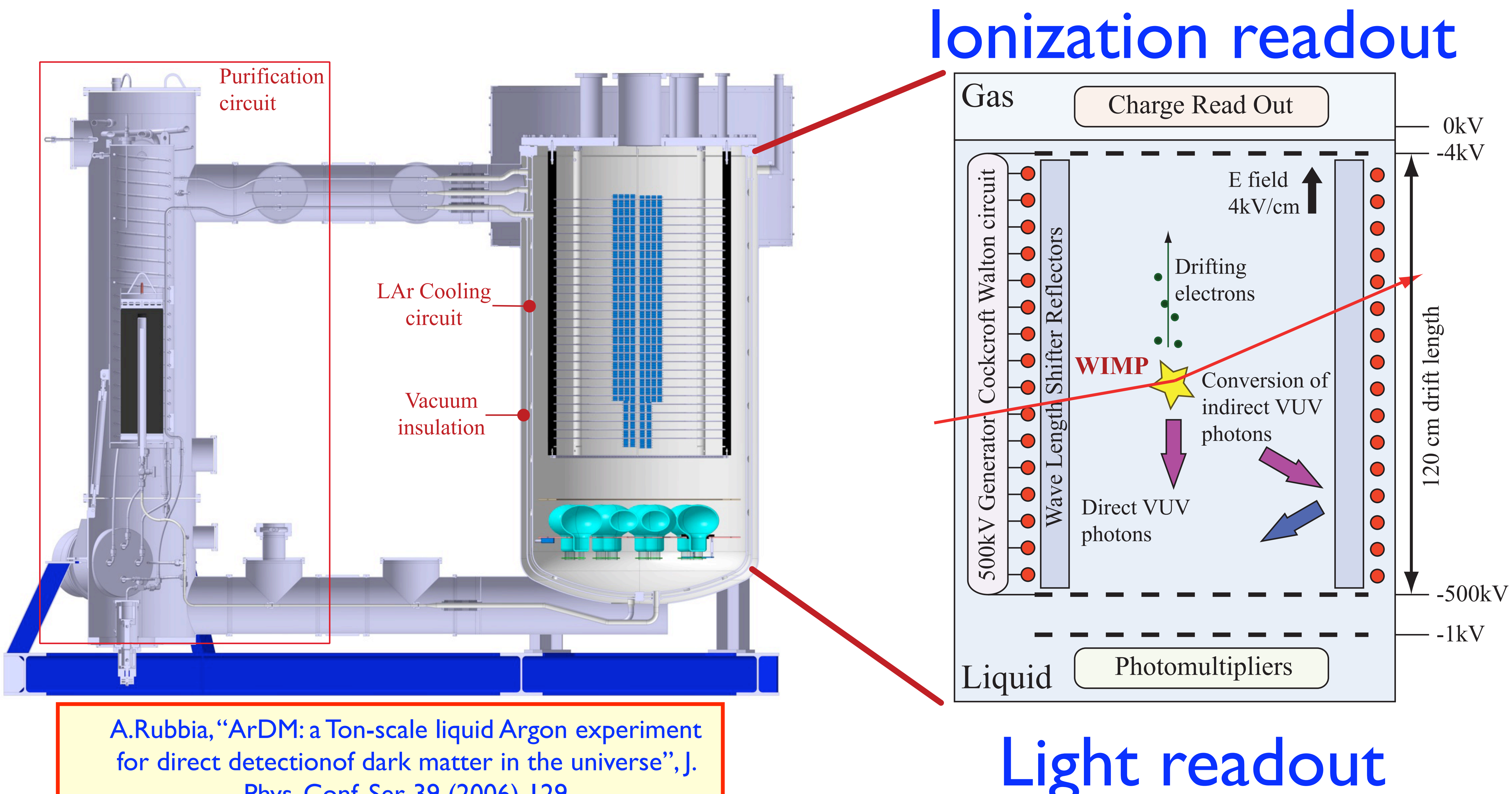
Closer collaboration with Theory Division on interpretation of experimental data in the context of SUSY models and LHC results

The ArDM-1ton experiment at CERN

ETHZ - UniZ - Granada - CIEMAT - Warzsawa - Sheffield

Abstract by Andre Rubbia, ETHZ

- Dual-phase LAr LEM-TPC to search for nuclear recoils induced by WIMPs
- ≈850 kg target, viewed by 14 8” PMT + finely segmented LEM charge readout
- Goal: 30 keVr threshold, ≈ 1 WIMP event/ton/day at $\sigma_{SI} \approx 10^{-44}$ cm^2
- Status: surface operation at CERN to characterize detector
- Underground deployment foreseen after successful tests on surface (2010?)



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

Double phase LAr LEM-TPC

A novel kind of double phase LAr TPC based on a Large Electron Multiplier (LEM) (arXiv:0811.3384)

Successfully demonstrated on small scale prototypes

Anode (with strips)

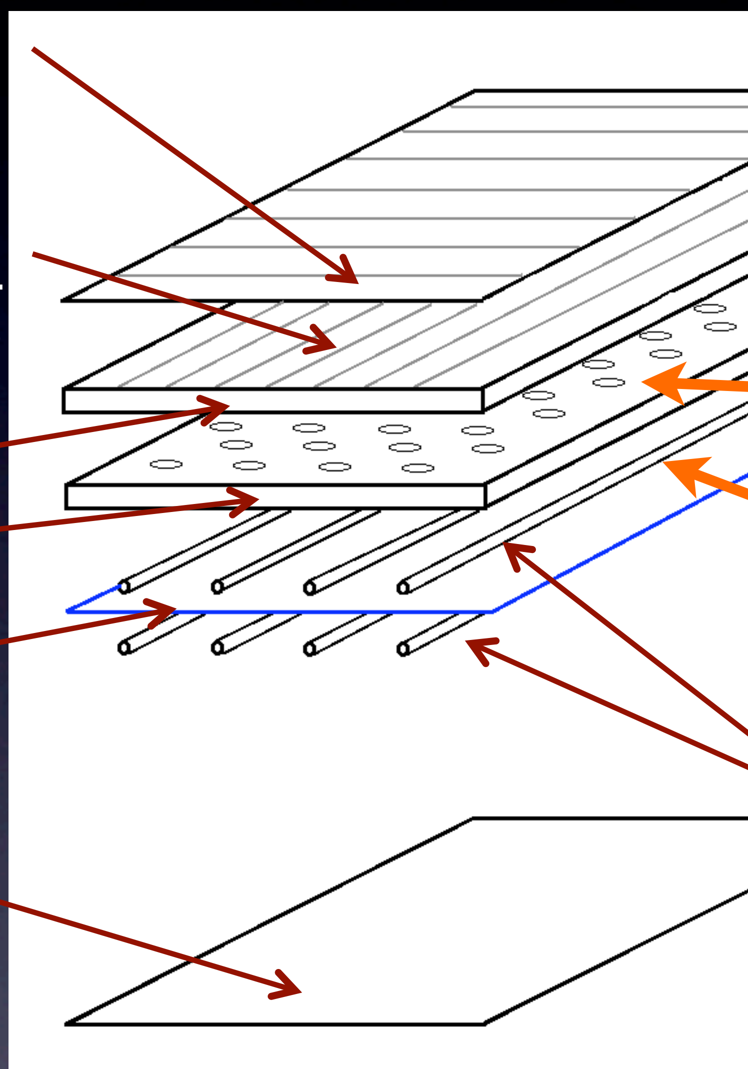
The top Electrode of the LEM2 (with strips)

LEM2

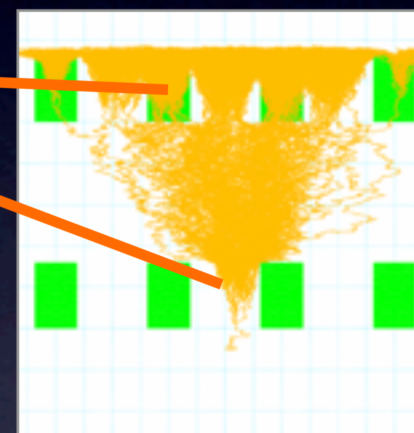
LEM1

LAr level

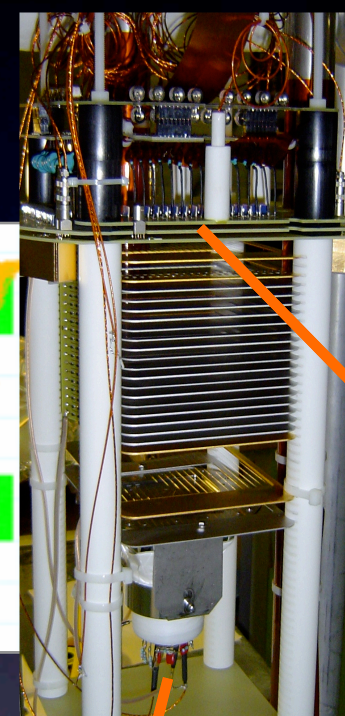
Cathode



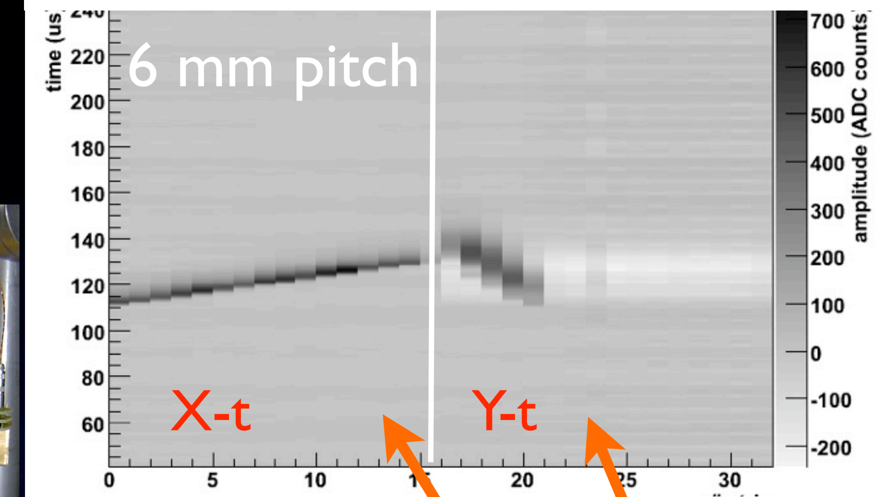
LEM concept based on pionieering successes of GEM technology

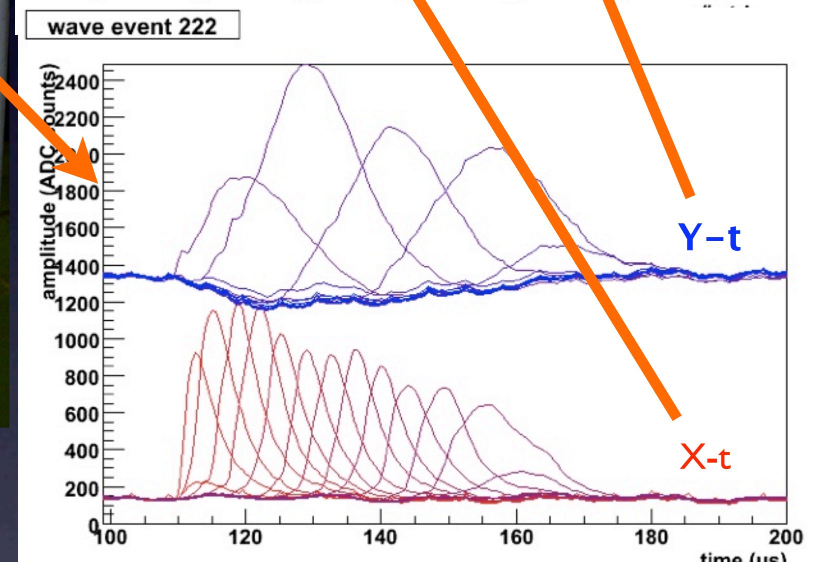


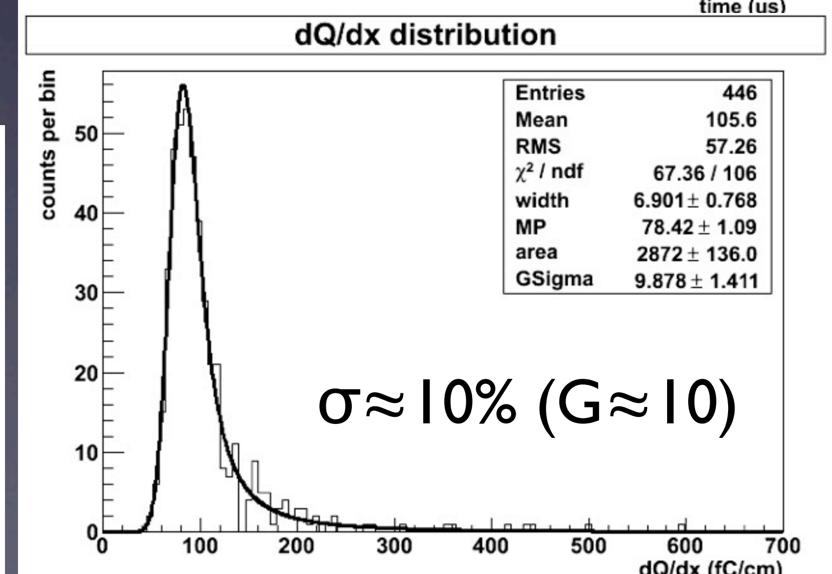
Charge extraction grids



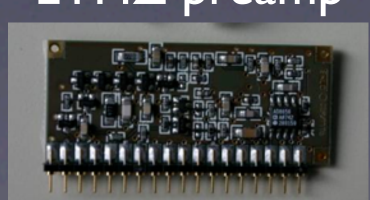
Cosmic tracks in 3 lt prototype:

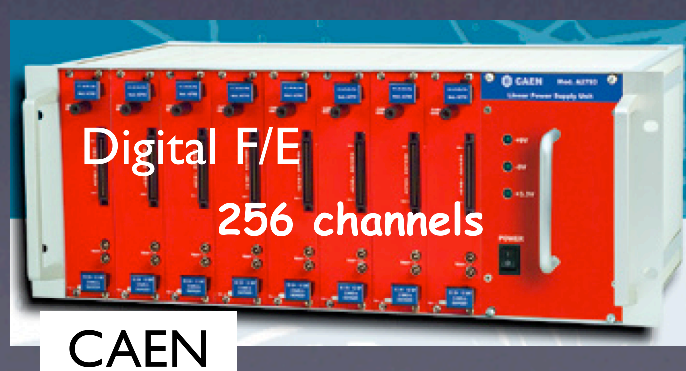


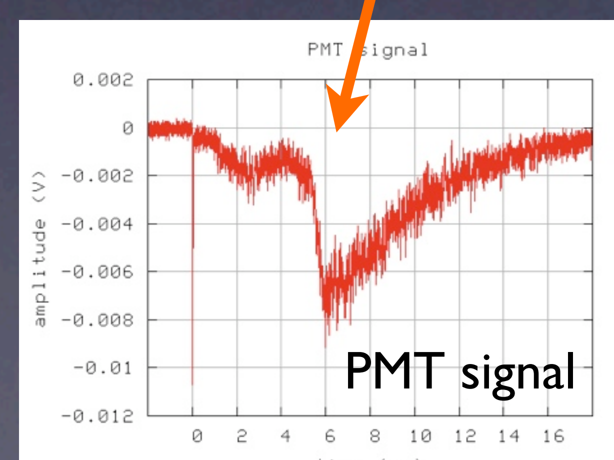




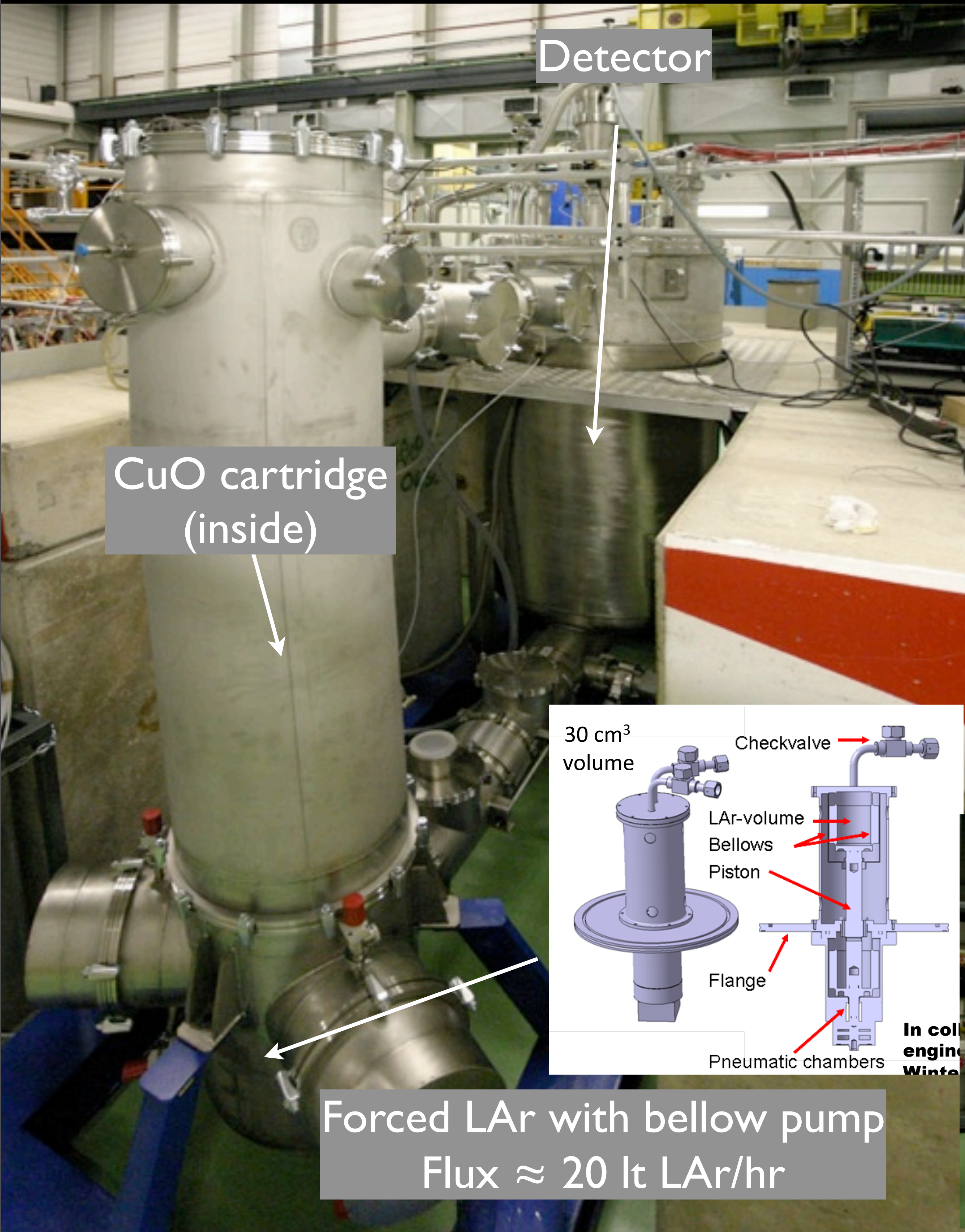
ETHZ preamp

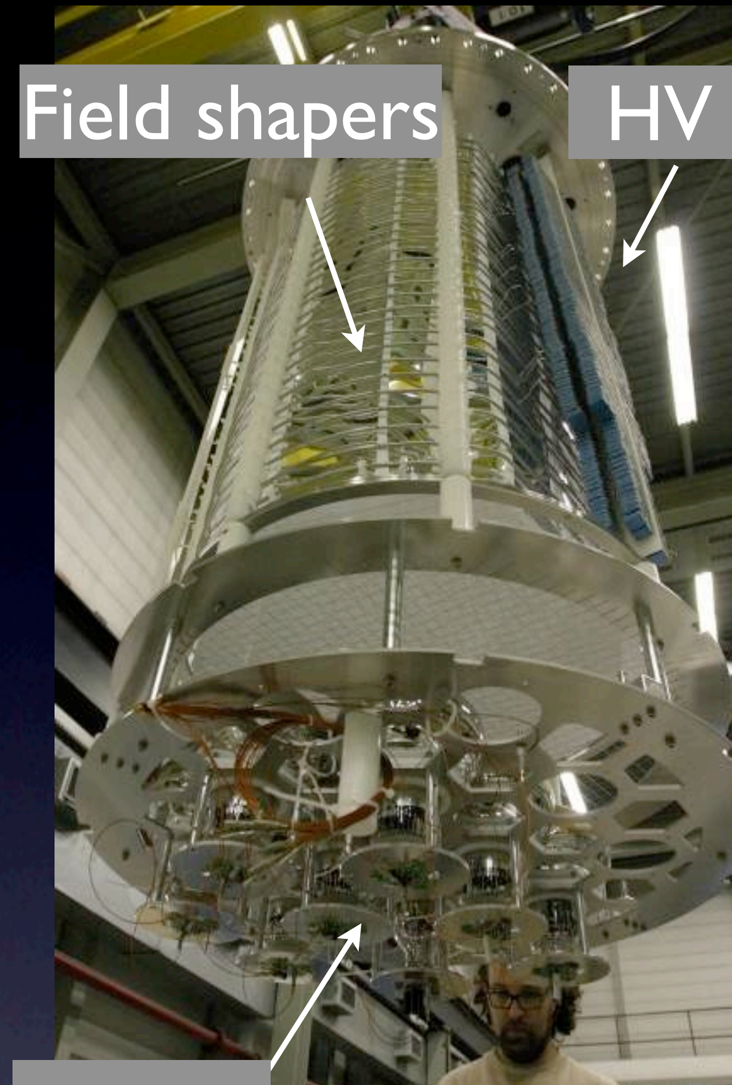


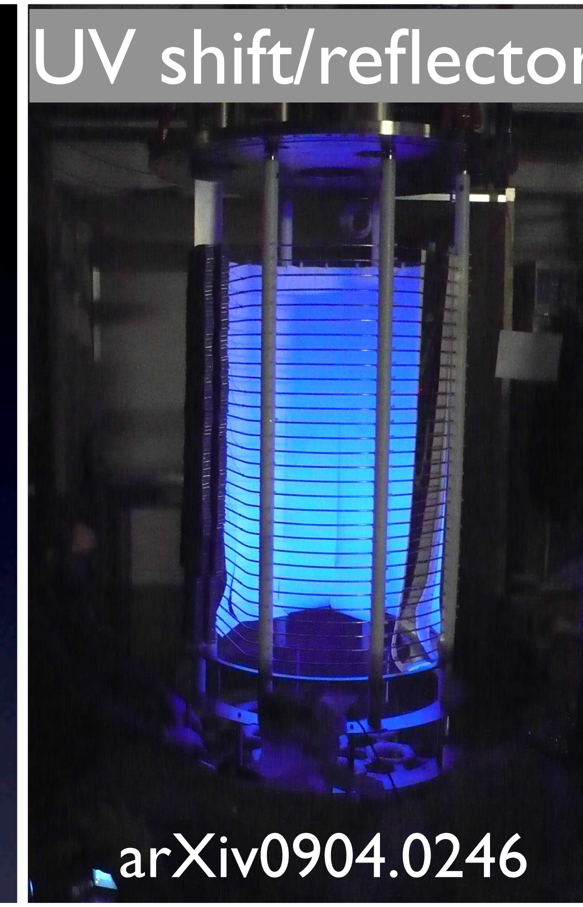


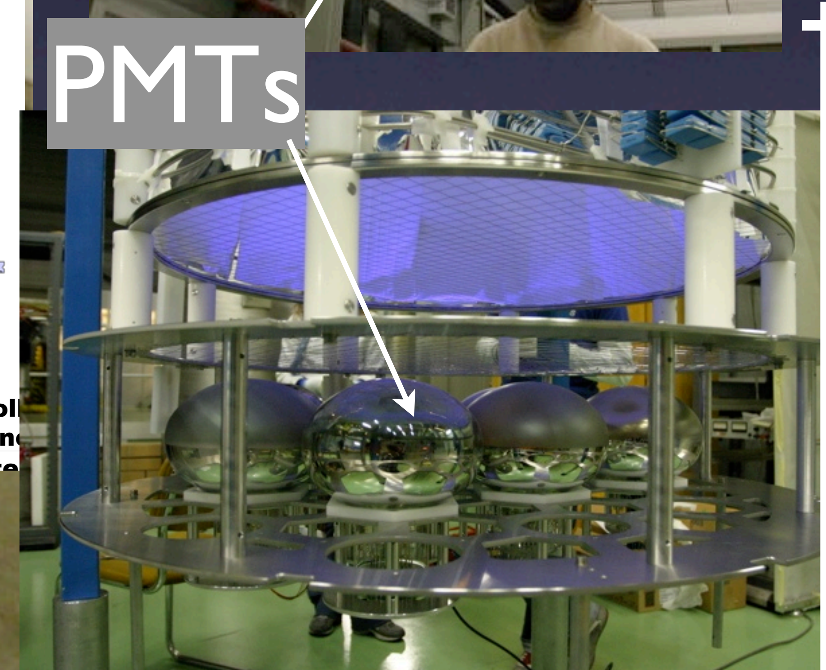


ArDM-1ton assembly & operation at CERN

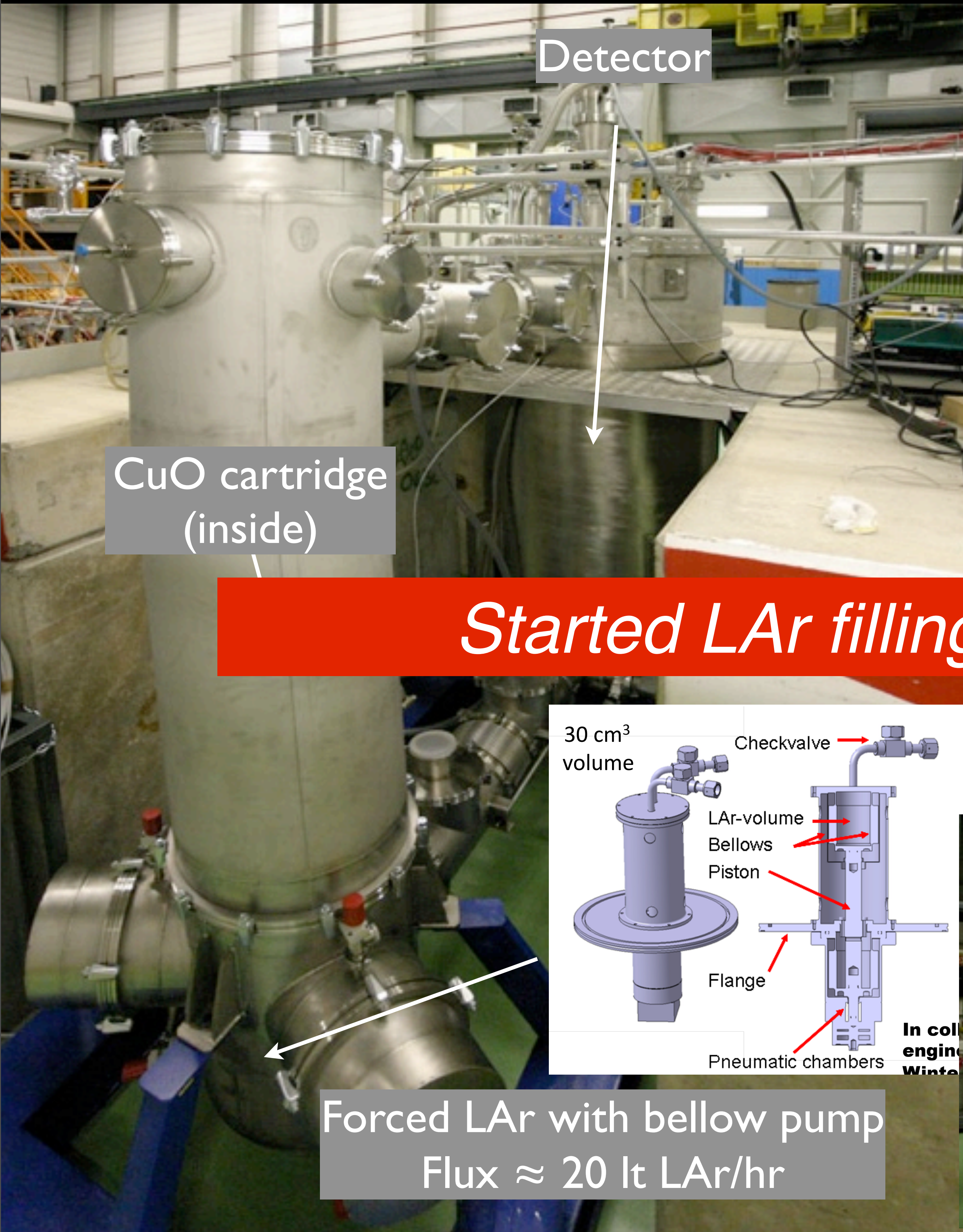


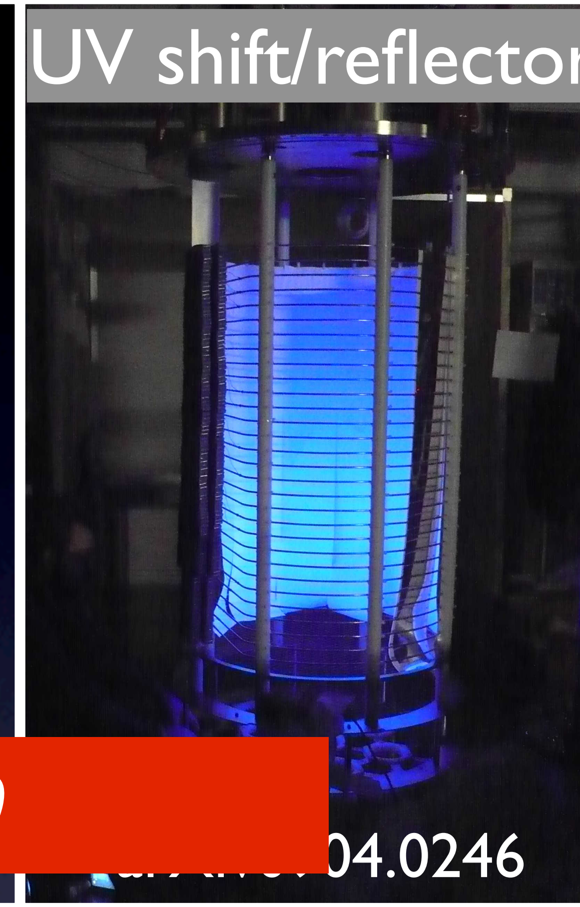




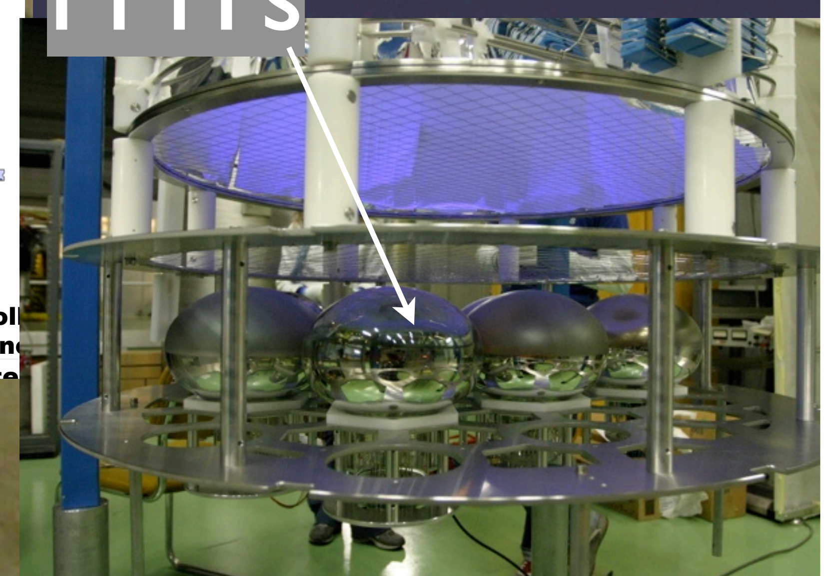


ArDM-1ton assembly & operation at CERN

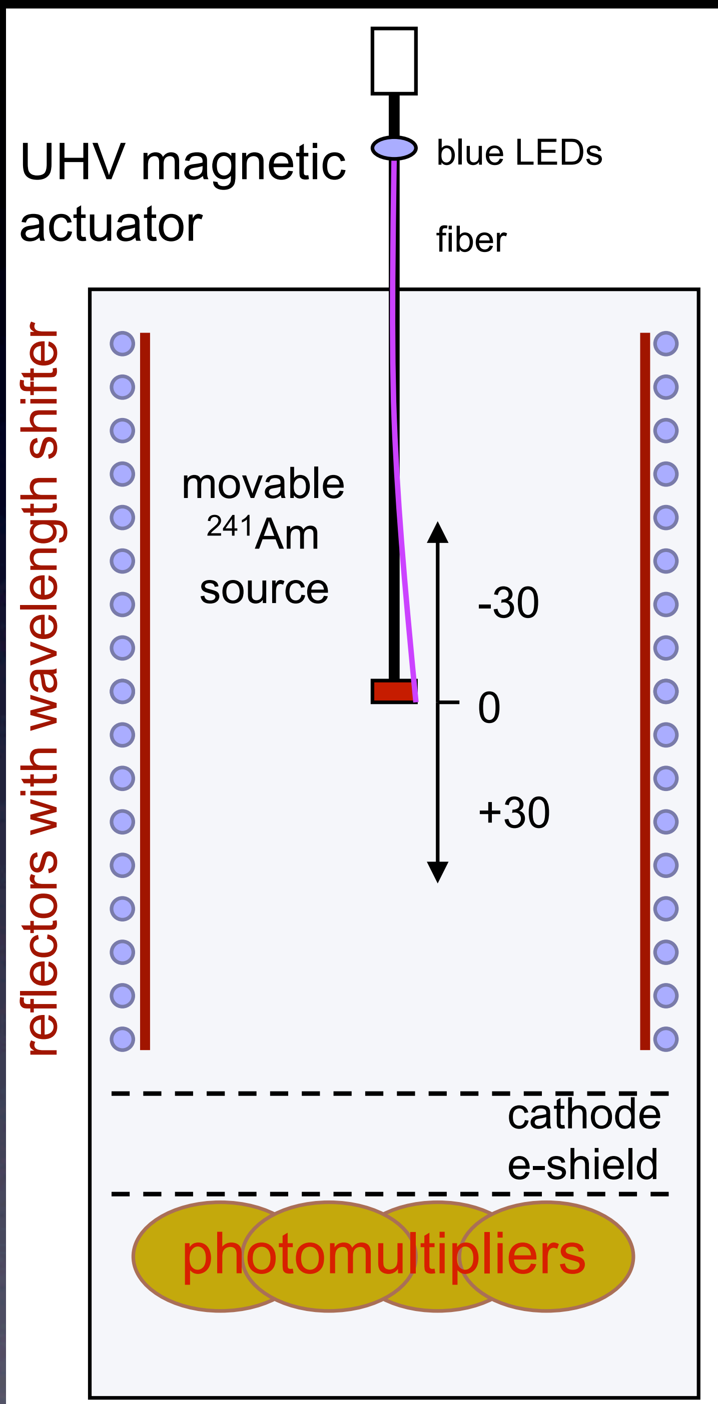




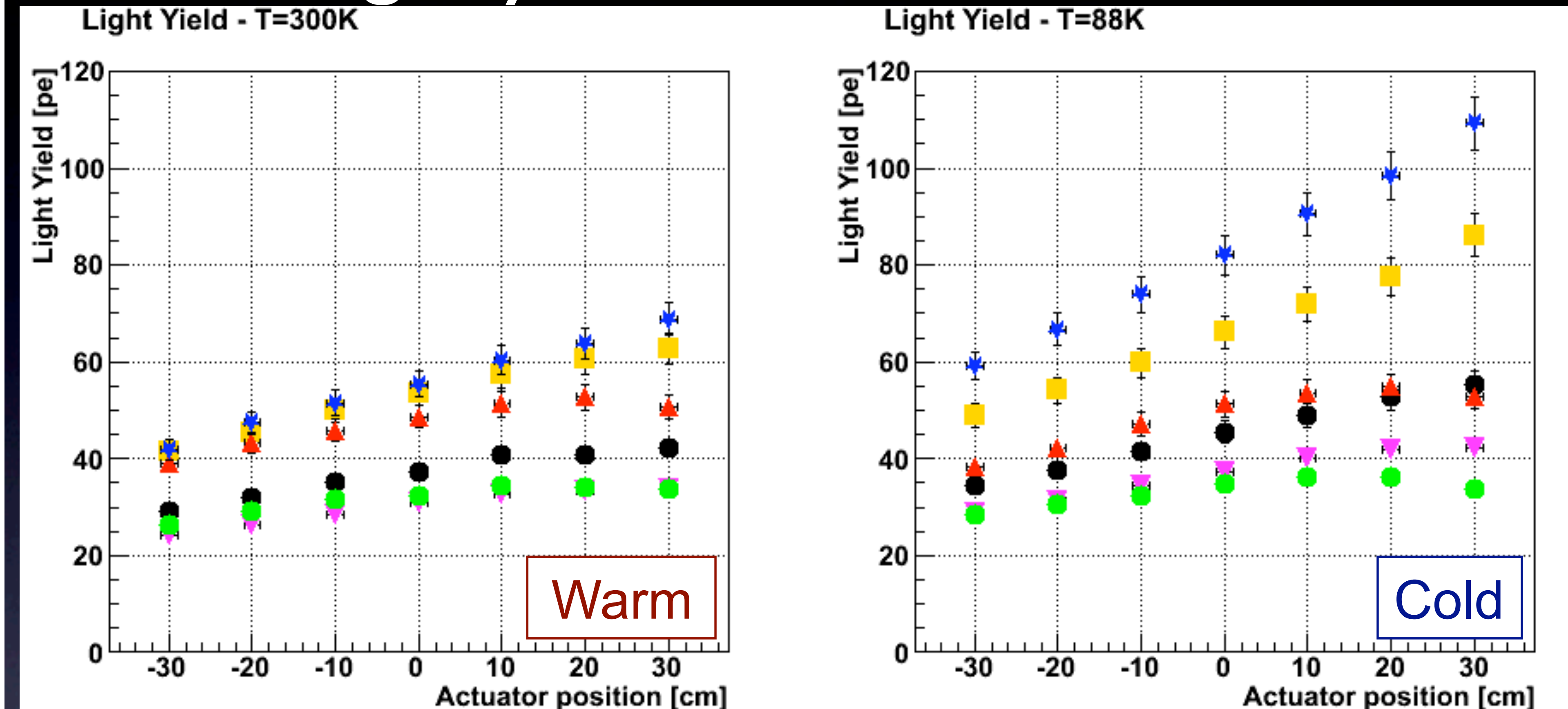
Started LAr filling on May 1st 2009



Preliminary light Yield in ArDM



Light yield from α source



- GAr P=1.1bar
- T=300K
- τ_2~2.8μs
- LY values extrapolated to max known purity τ_2=3.2μs

1) ZD0051 - Evap - Side
2) ZD0045 - TPB/PRL - Center
3) ZD0038 - Clean - Center
4) ZD0046 - TPB/PRL - Side
5) ZD0050 - Evap - Center
6) ZD0049 - Clean - Side

- GAr P=1.1bar
- T=88K
- τ_2~3.7μs
- Value are not extrapolated

Very good cold GAr purity ($\tau_{triplet}$≈3.5-3.7μs)

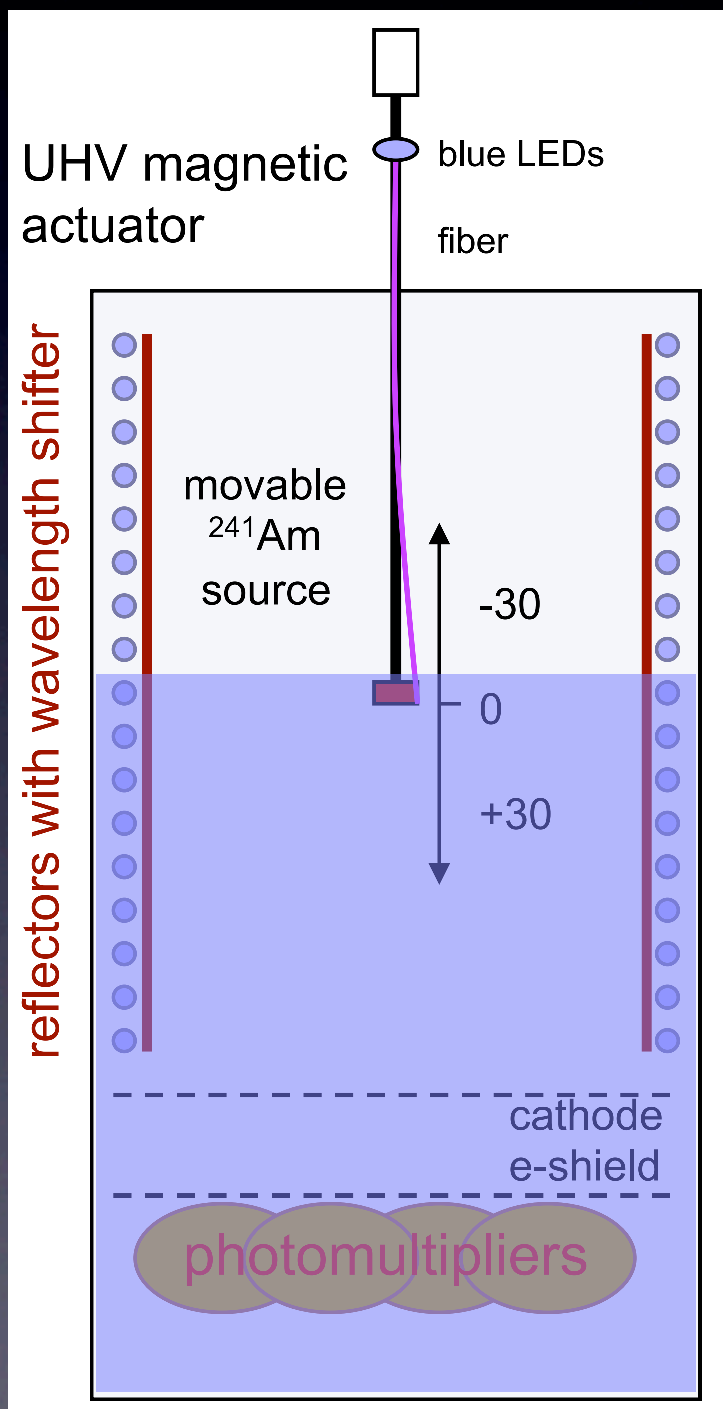
Confirms effect of liquid phase trapping impurities

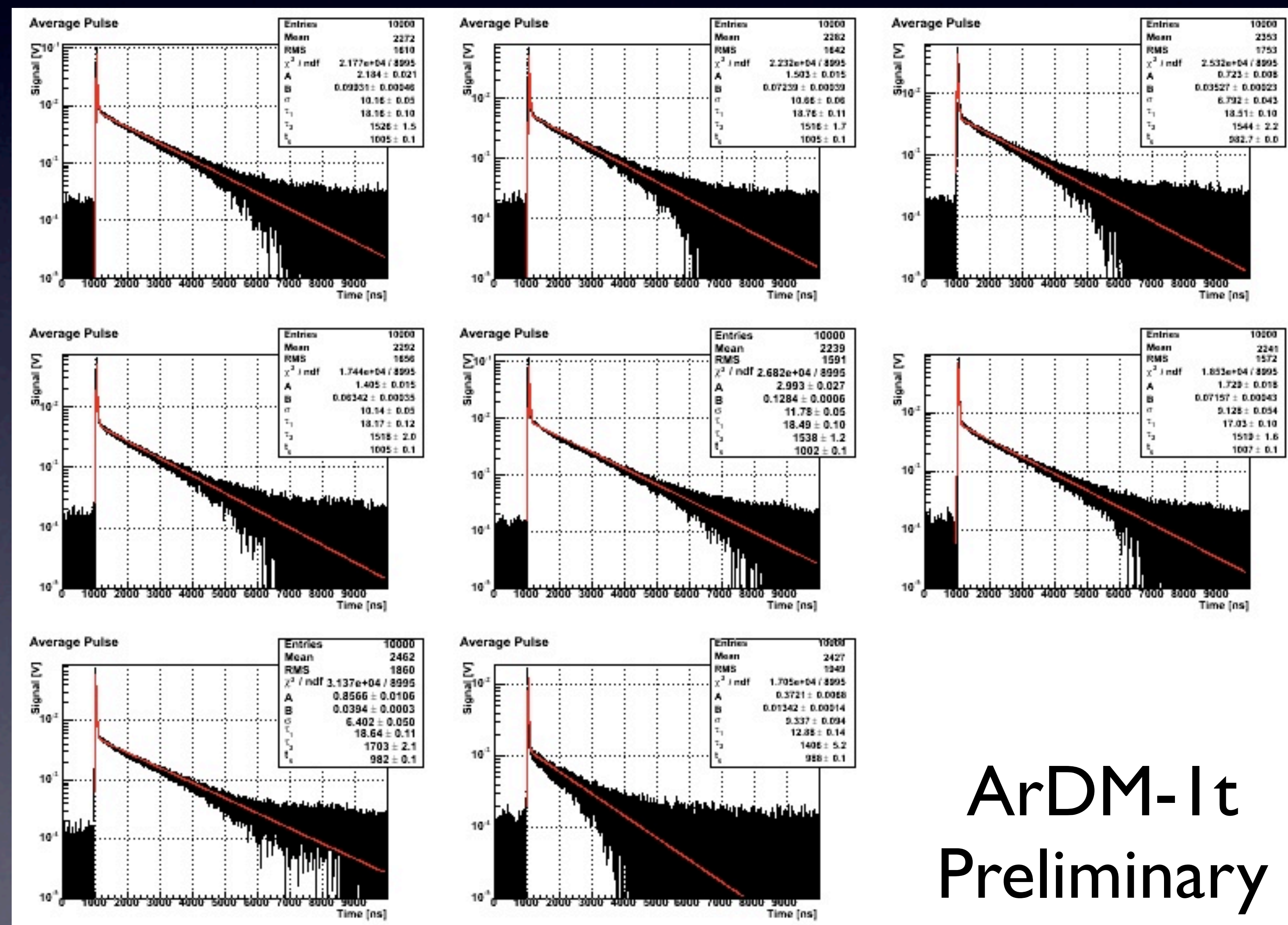
Light measurement in liquid phase

Status: May 8th 2009 - ***completed vessel filling !***

α source submersed with liquid

$\tau_{triplet} \approx 3.5\mu s(GAr) \rightarrow 1.5\mu s(LAr)$





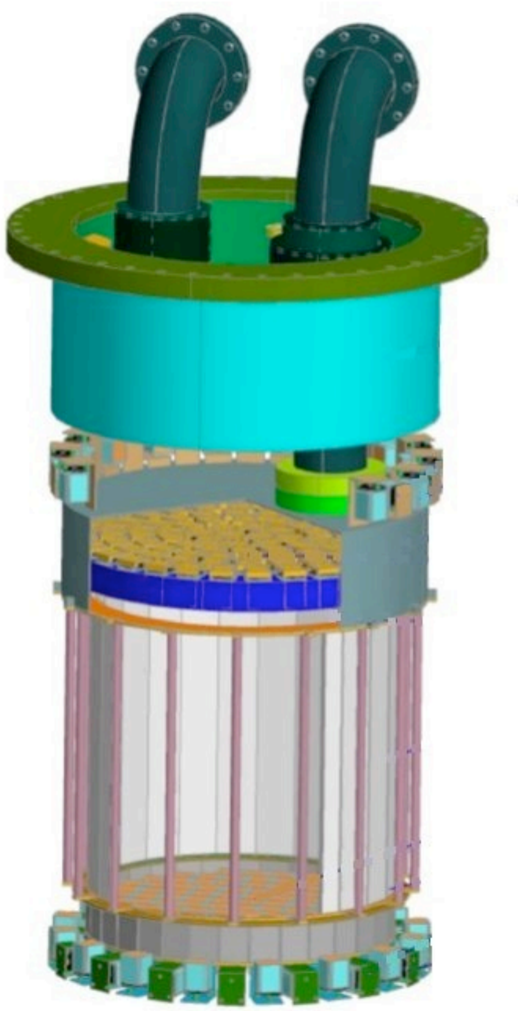
ArDM-1t
Preliminary

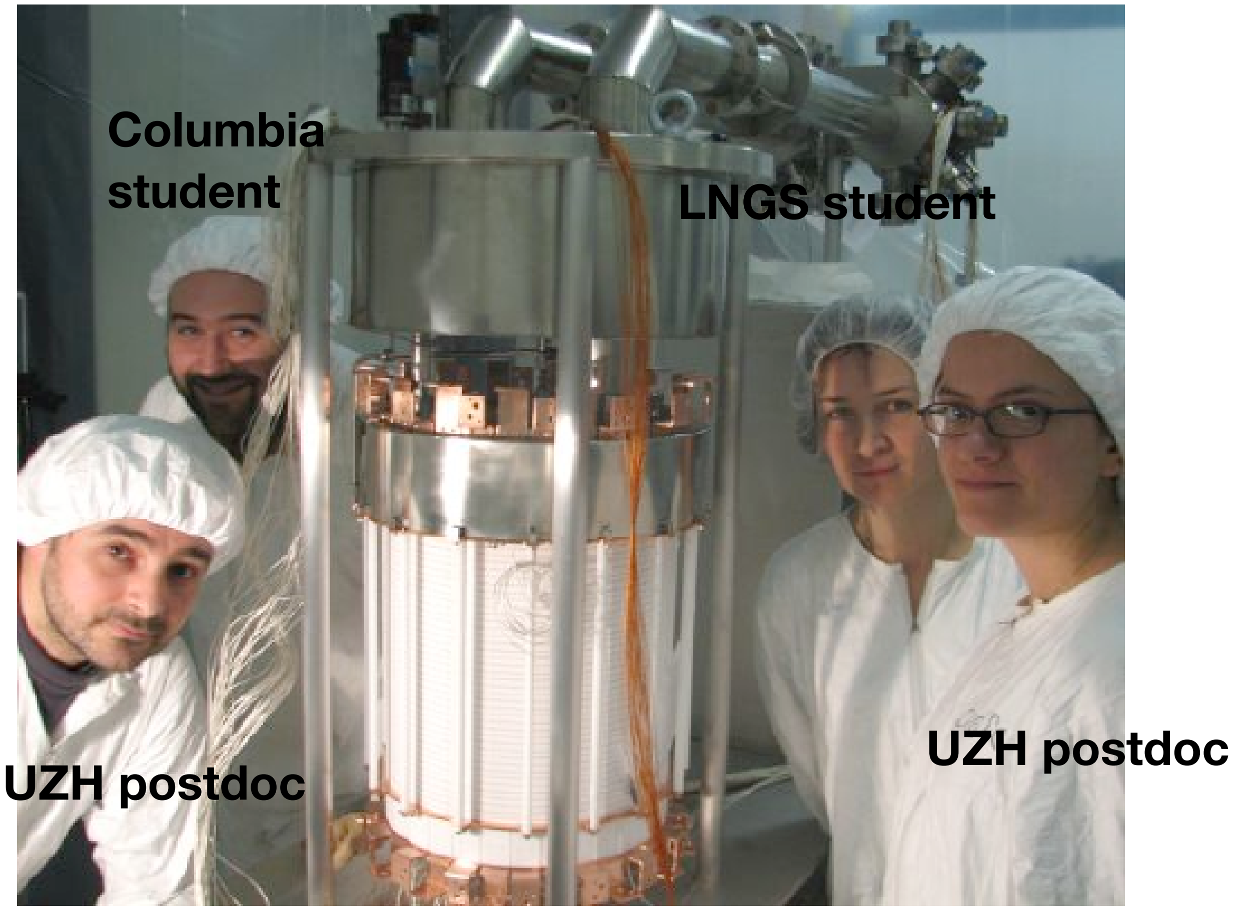
The XENON100 Experiment at LNGS

Columbia, Coimbra, LNGS, Münster, Rice, Subatech, UCLA, Waseda, Zürich

- **Dual-phase, Xe-TPC to search for WIMPs by their collision with Xe-nuclei**
- 170 kg (100 kg in active veto) LXe, viewed by 242 low-BG PMTs, 30 cm ⌀, 30 cm drift
- Goal: mass x 10, background x 1/100 with respect to XENON10
- Status: under commissioning at LNGS, expected to start science run in 2009
- **Expectation: test WIMP-nucleon cross sections of 2×10^{-45} cm^2 after 6000 kg days**

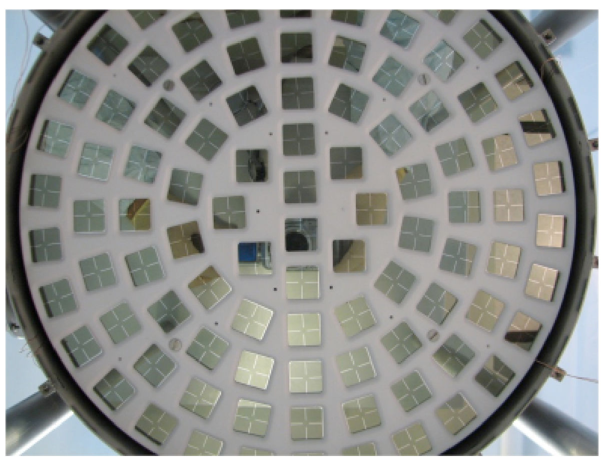
Abstract by Laura Baudis, UZH

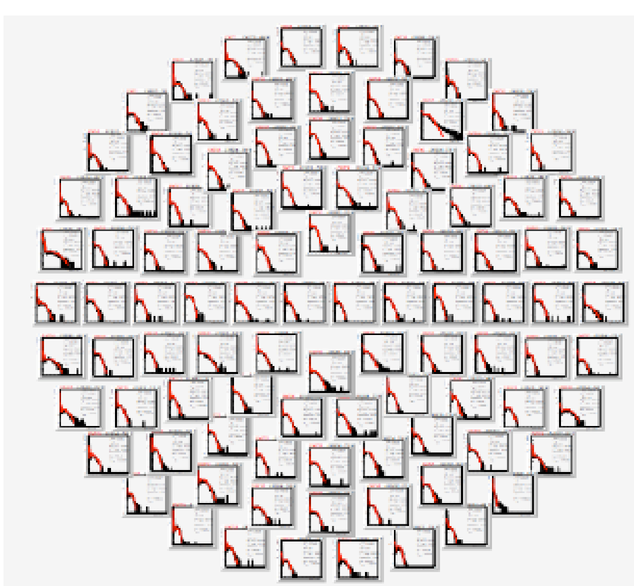


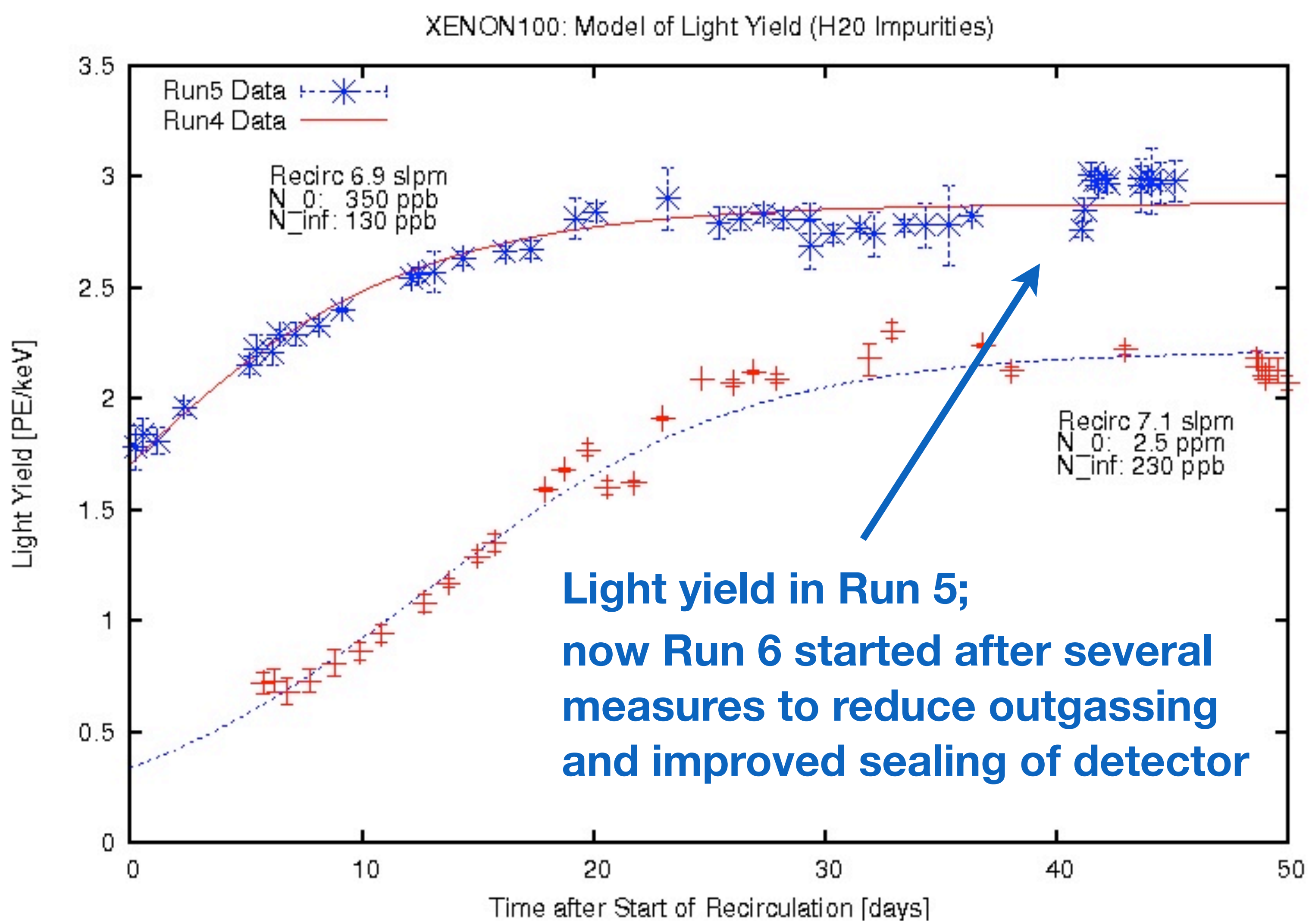


Status of XENON100

- Several calibration runs with LEDs and external sources
- Short background runs (**BG at the level predicted by Monte Carlo simulations**, based on $^{238}U/^{228}Th/^{40}K/^{60}Co/^{137}Cs$ data from screening of all XENON100 materials and shields)
- **Currently improving light yield; achieved so far ~ 2.7 p.e./keV; prediction is ~ 3.5 p.e./keV**
- **Neutron calibration, then WIMP search run starting in the fall of 2009**

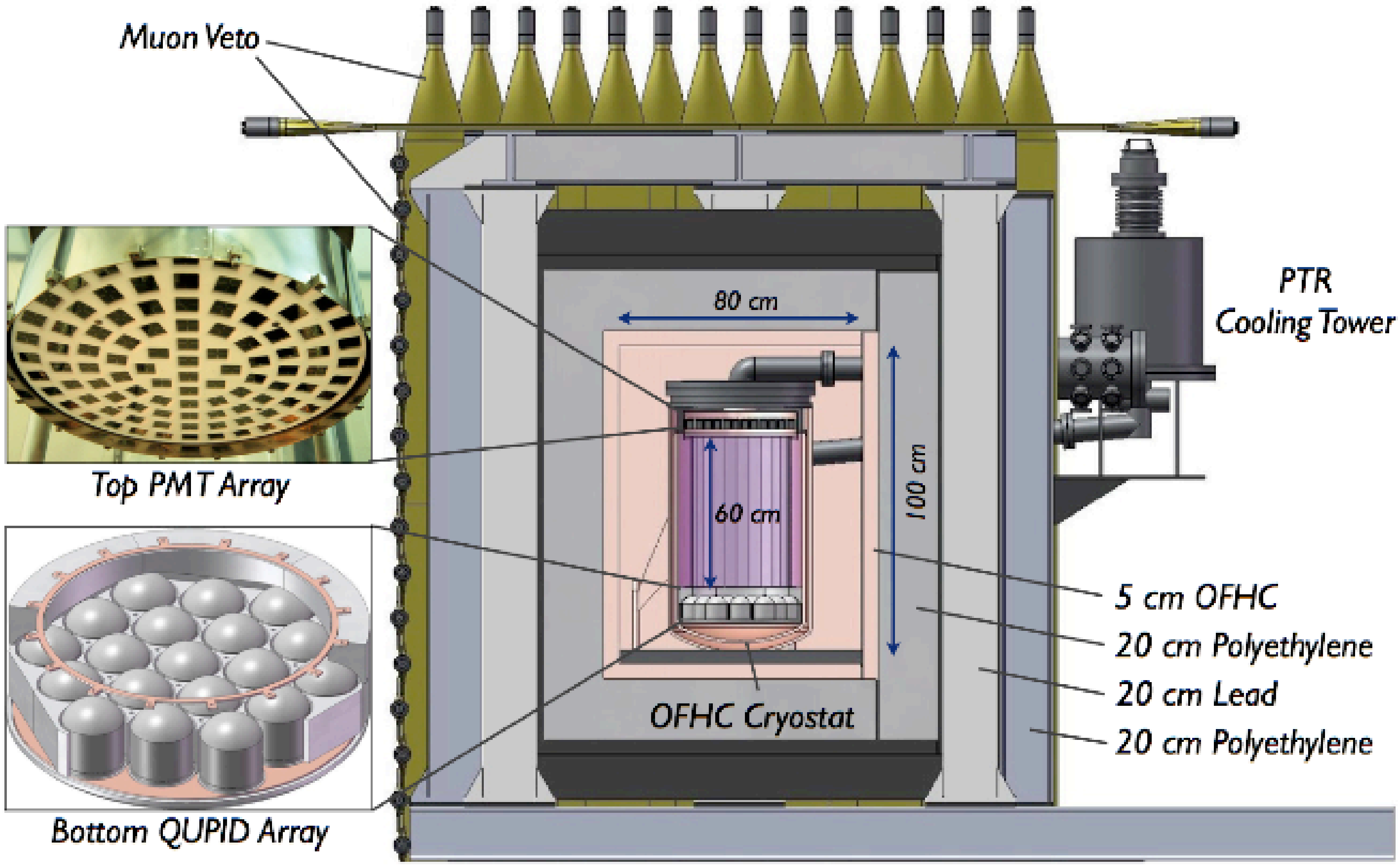


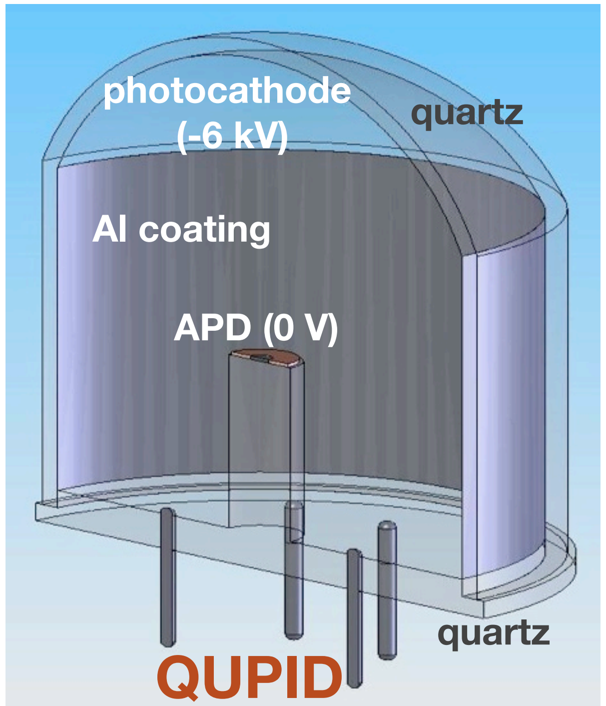




Next step: The Xenon100 Upgrade

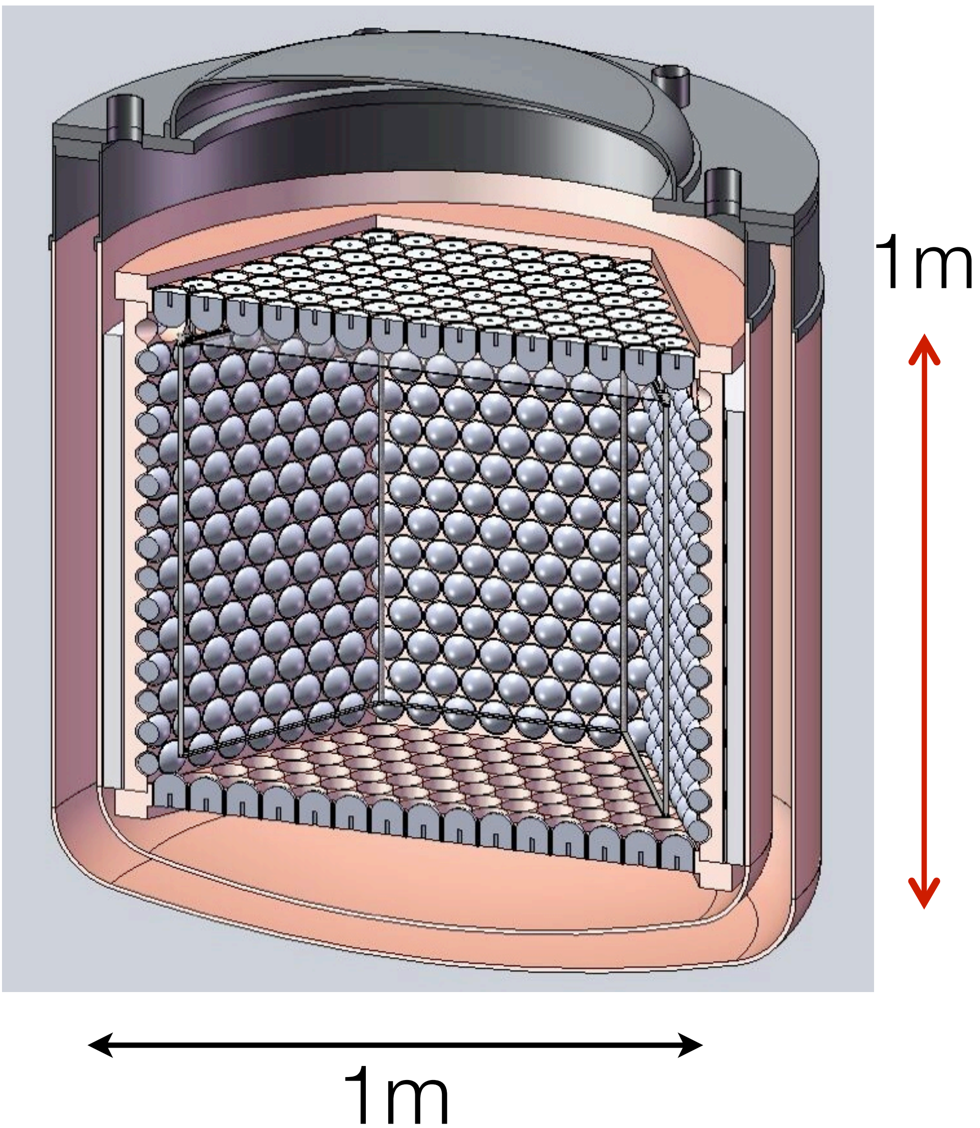
- **100 kg fiducial mass (total of 260 kg LXe), background 5×10^{-4} events/(kg day keV)**
- New photon detectors, QUPIDs; ultra-low BG Cu cryostat, new shield, including muon veto
- Larger collaboration: Europe, US, Japan, China
- **Construction 2010; WIMP search 2011-2012; goal: 2×10^{-46} cm^2**
- **NSF funding approved; SNF proposal submitted in March 09**





Next-to-Next Step: XENON1t

- Studies in progress for 3 ton (1 ton fiducial) LXe-TPC; 4π QUPID coverage
- **Possible locations: LNGS or ULISSE extension of the Modane Laboratory**
- **Construction: 2012; WIMP search: 2013-2015; goal ~ 2×10^{-47} cm^2 after 1t x year**



- Possible CERN Involvements:

- cryogenic and liquid xenon purification system?
- the HV system?
- the electronics/DAQ system?
- ultra-low background Cu cryostat and/or shield?
- use p/n/μ beams to study production rate of radioisotopes in LXe

Proposal for R&D and design study for ton-scale LAr/LXe detector in response to ASPERA call is being prepared by European 'noble liquid community' (Germany, France, Italy, Poland, Switzerland)

Dark matter search with bubble chambers

Abstract by Antonino Pullia

- **Superheated liquid** -> detects single bubbles induced by high dE/dx nuclear recoils; **advantage:** large masses due to mechanical simplicity of detectors, low costs, SD, SI (I, Br, F, C) couplings, high spatial granularity, 'rejection' of ERs 10^{10} at $10keV_r$; **challenge:** reduce alpha background
- **Two important news:**
  - ➡ indefinitely long stability in moderately superheated bubble chambers can now be reached (J. Bolte, NIM A577, 569 (2007))
  - ➡ different degrees of the superheated state correspond to different sensitivity for different particles (now better demonstrated than 40 years ago)
- Three different techniques for dark matter searches: continuously sensitive **bubble chambers**, the **Geyser detector**, superheated droplets detectors
- **EXAMPLE: the COUPP experiment (Univ. of Chicago, FNAL)**

n-induced event (multiple scatter)

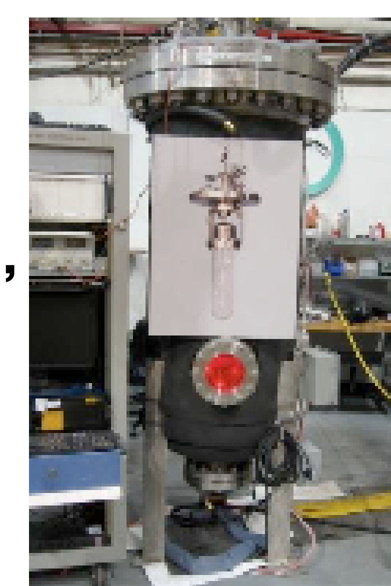
WIMP: single scatter

2 kg detector at 300 mwe in 2006: α BG from walls ^{222}Rn decays -> ^{210}Pb plate-out + ^{222}Rn emanation

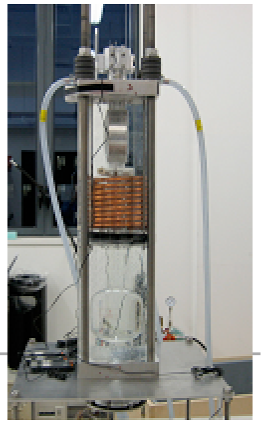
run with 2 kg in 2007/2008 (reduced backgrounds)

best SD limit for M_{WIMP} ≤ 30 GeV (pure p-couplings), Science 319 (2008)

60 kg module under construction at FNAL with the goal of reaching 3 x 10^{-8}pb



The GEYSER detector



- **Principle of operation** (B. Hahn and H.W. Reist-Berna, 1973, P. Negri et al., Milano-Bicocca 2009)
  - ➡ A liquid is brought into a metastable state and kept at a temperature T_2 = 30 C by a thermal bath
  - ➡ The vapor above the liquid is kept at $T_1 = 20C < T_2$, by water cooling of glass bottle neck
  - ➡ The equilibrium vapor pressure above the surface is p_1 and the entire system is under p_1 (the equilibrium pressure for the liquid should be $p_2 > p_1$)
  - ➡ **When energy is released locally (nuclear recoil), a bubble is created, becomes supercritical and grows to a large size, pushing the liquid into the bottle neck**
  - ➡ The pressure increases and when it reaches its equilibrium value at T_2, the liquid returns into the main volume and the hot vapor in the neck re-condenses
  - ➡ The metastable state is automatically recovered in a time scale ≈ few seconds
- **This project (Milano-Bicocca, INFN, CERN, Torino, Berne) has the following phases:**
  - ➡ **construction of small scale prototypes** (Geyser and bubble chamber), with traditional liquids (Propane, Freon etc); investigation of scintillating properties of these liquids (CF_4 scintillates at 150-500 nm, with 1500 photons/MeV); Xe, Ar work as bubble chambers and scintillate
  - ➡ **choice of technique** with best performance
  - ➡ **design of a larger scale detector** (1 m^3)
  - ➡ the construction of a Geyser is in progress

Goals and comparison with COUPP

- **A new technique (Geyser or Bubble chamber) with scintillating properties is investigated**
- **Advantage of Geyser:** the dead time is strongly reduced
- **Advantage of Bubble Chamber:** larger final masses could be reached (1-2 tons)
- **Advantage of scintillation:** discrimination against alpha background
  - ➡ Reduction of neutron background by underground operation and active n-shield (Gd, or Cd doped)
  - ➡ Use ultra low-radioactivity materials
  - ➡ Construct and operate a Geyser
  - ➡ Study mechanical design for Larger Bubble Chamber (≈ 1 m^3)

- **Requests to CERN**
  - ➡ Support for use of scintillation liquid
  - ➡ Collaboration with experts in the bubble chamber construction
  - ➡ Very small part of laboratory for possible tests at CERN

The GERDA Experiment

Belgium, Germany, Italy, Poland, Russia, Switzerland

Abstract by Laura Baudis, UZH

- **Goal: detect the neutrinoless double beta decay in enriched ^{76}Ge detectors**
- Operate detectors in LAr (cooling medium and shield against external backgrounds, 63 m^3)
- **Phase I: 18 kg (of existing) ^{76}Ge detectors; exposure: 30 kg years**
- Sensitivity reach:

$$T_{1/2}^{0\nu} > 3.0 \times 10^{25}\ yr$$

$$\langle m_{\nu e} \rangle < 0.27 eV$$

- **Phase II: 40 kg enriched ^{76}Ge detectors**
- Sensitivity reach after **150 kg years:**

$$T_{1/2}^{0\nu} > 15 \times 10^{25}\ yr$$

$$\langle m_{\nu e} \rangle < 0.11 eV$$

detector array

GERDA LAr cryostat

Status of GERDA (April 2009)

- Double walled, stainless steel LAr cryostat, water tank, superstructure, electrical system and clean room installed at LNGS
- Phase-I detectors have been tested in the GERDA Detector Lab at LNGS
- Lock and gas handling system, as well as muon veto under installation
- **Detector commissioning planned for fall 2009**
- **Concomitantly: R&D effort for phase II detectors (18-fold segmented, n-type and/or BEGe p-type)**

water tank and super structure

Possible CERN involvement in GERDA phase-II (and III ?):

➡ R&D and production of 76-Ge detectors?

➡ use p/n/μ beams to study production rate of radioisotopes in Ge and LAr

END