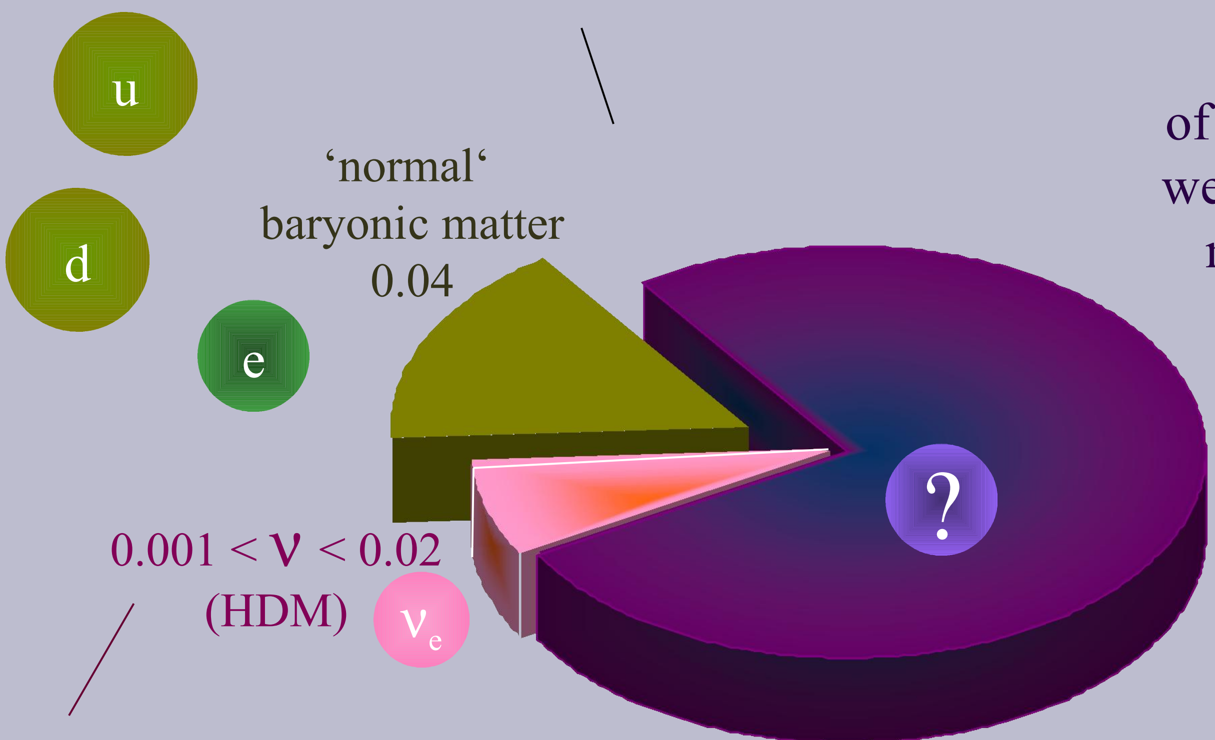
Dark Matter

Cryogenic Detectors
Direct Dark Matter Search

Matter in the Universe - Composition

$$\Omega_{mat} = 0.27 \pm 0.04$$



'normal' baryonic matter
0.04

$0.001 < \nu < 0.02$
(HDM)

from ν–oscillations
=> $\Sigma m_\nu > 0.05$eV

cold Dark Matter (CDM)
0.23

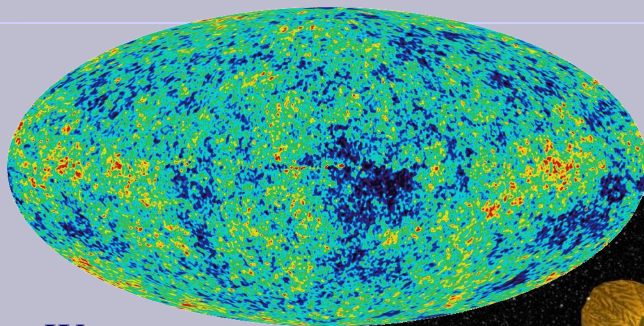
'ν too light' =>
most of the
Dark Matter
is cold

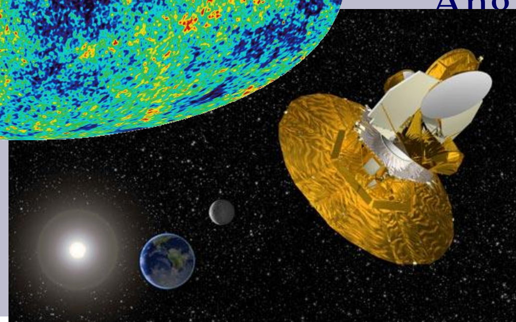
of so far unknown
weakly interacting,
massive particles
WIMPs
(50GeV~1000GeV
Neutralino?)

⇒

physics beyond
standard model
supersymmetry?

Cosmic Microwave Background – Matter-Density Ω_{matter}





Wilkinson
Microwave
Anisotropy
Probe

Anisotropy:

Angular scale => geometry, Ω_{tot}

...sities => gravitational pote...
matter densities

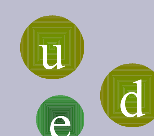
- gravitation Ω_{matter}
- coupling to radiation Ω_{baryon}

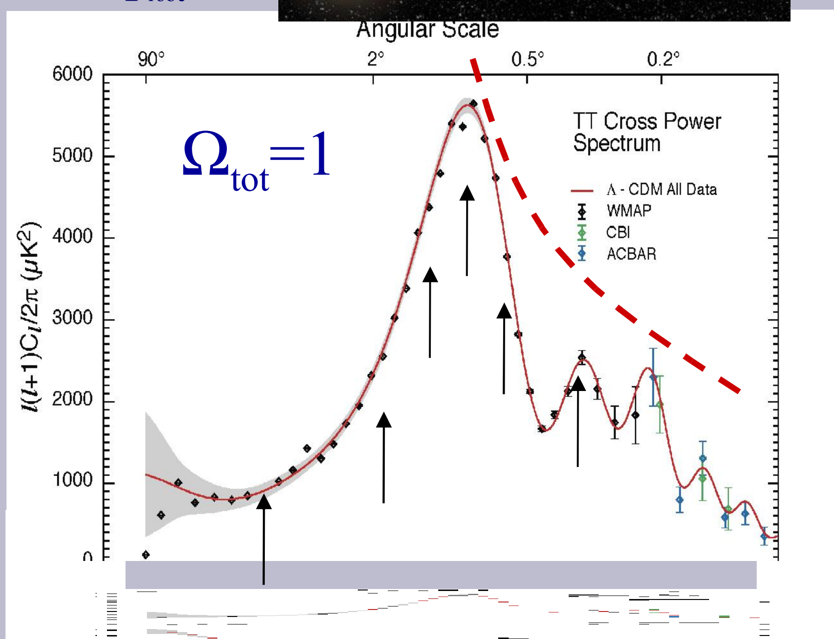
$\Omega_{matter} = 0.27$

=> Ω_{matter} ▯ Ω_{lum} =0.01

mostly Dark Matter

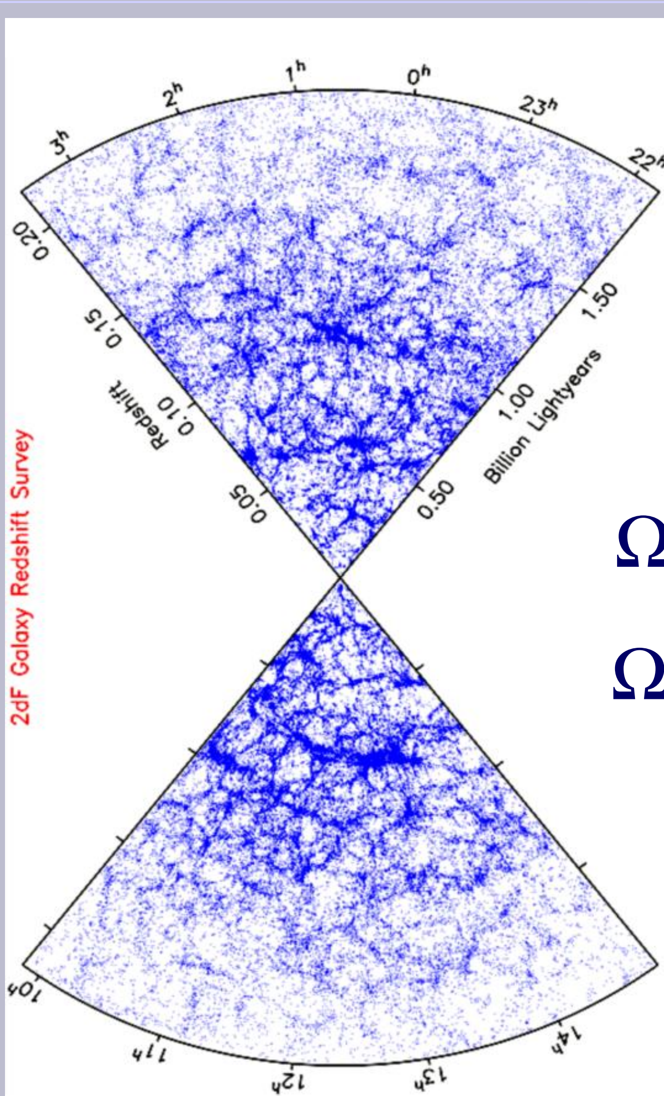
$\Omega_{baryon} = 0.044$

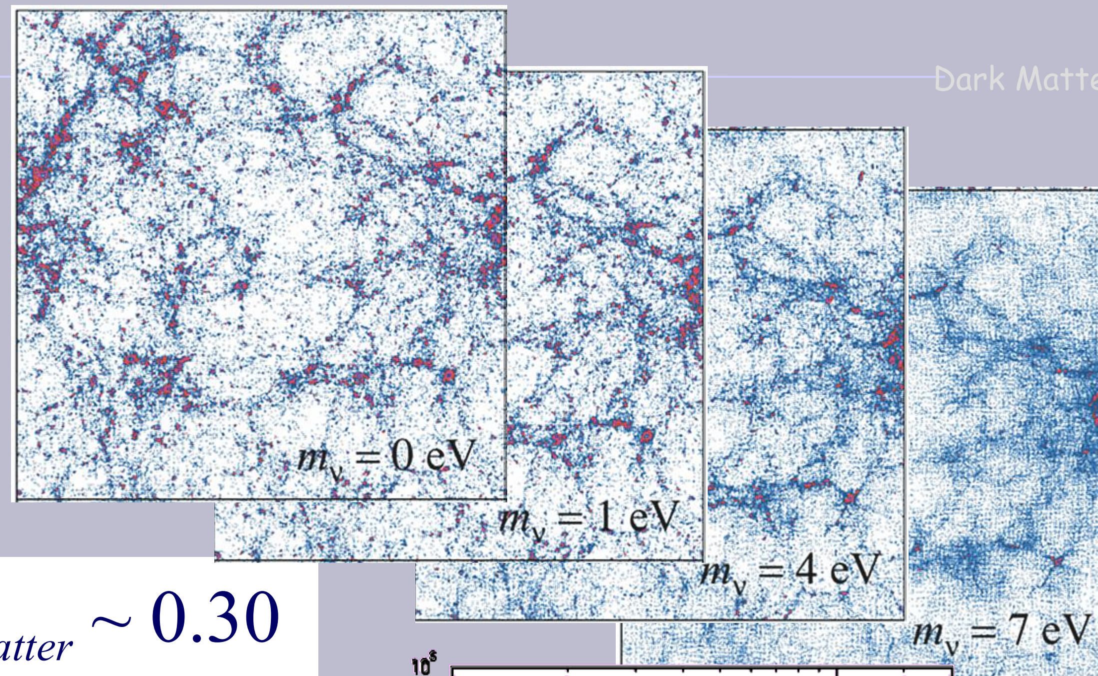




=> $\Omega_{matter} >> \Omega_{baryon}$

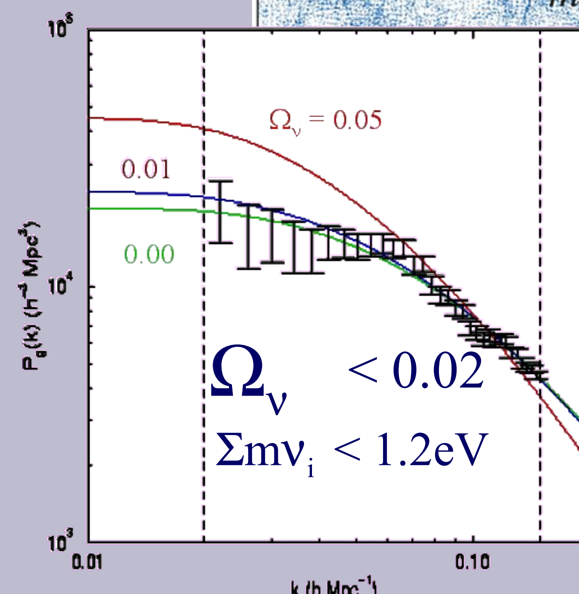
Structure in the Universe and Neutrinos





$\Omega_{matter} \sim 0.30$

$\Omega_\nu \quad < 0.02$



Matter in the Universe - Composition

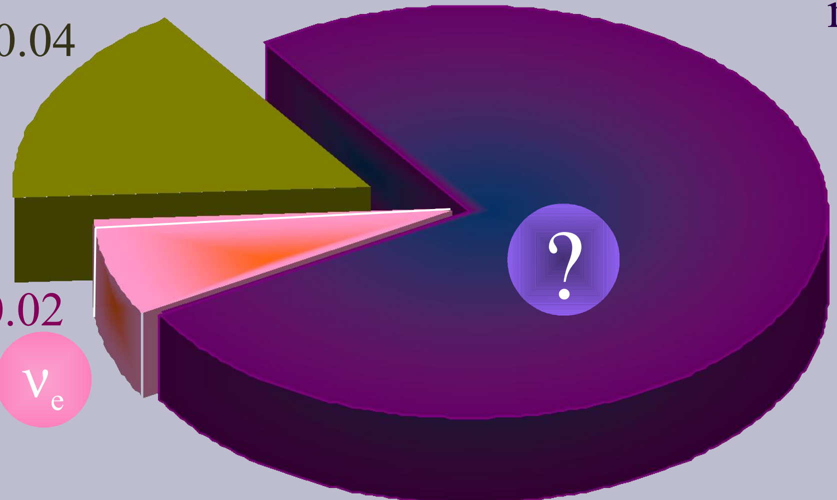
$\Omega_{mat} = 0.27 \pm 0.04$

u

d

e

'normal' baryonic matter 0.04



0.001 < ν < 0.02 (HDM) ν_e

from ν–oscillations => $\Sigma m_\nu > 0.05$eV

cold Dark Matter (CDM) 0.23

'ν too light' => most of the Dark Matter is cold

of so far unknown weakly interacting, massive particles *WIMPs* *(50GeV~1000GeV Neutralino?)*

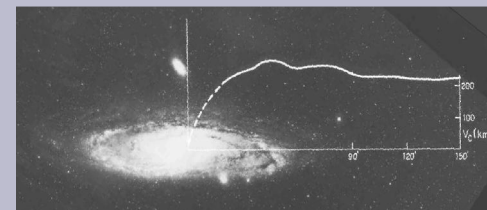
⇒

physics beyond standard model supersymmetry?

WIMP - Direct Detection

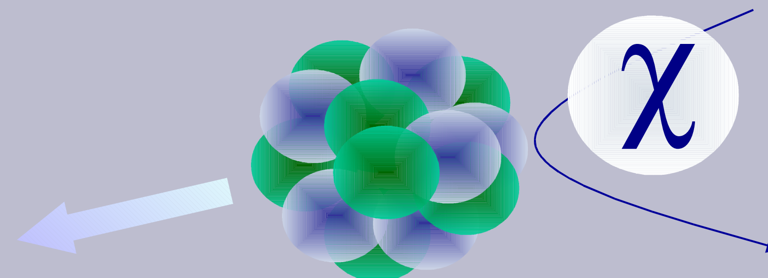
W**eakly **I**nteracting **M**assive **P**articles = **WIMPs

elastic scattering on nuclei



- nuclear recoils: reduced efficiency of charge or light production

  - mass *50 GeV - ~ 1000 TeV*
  - relative speed *270 km/s*

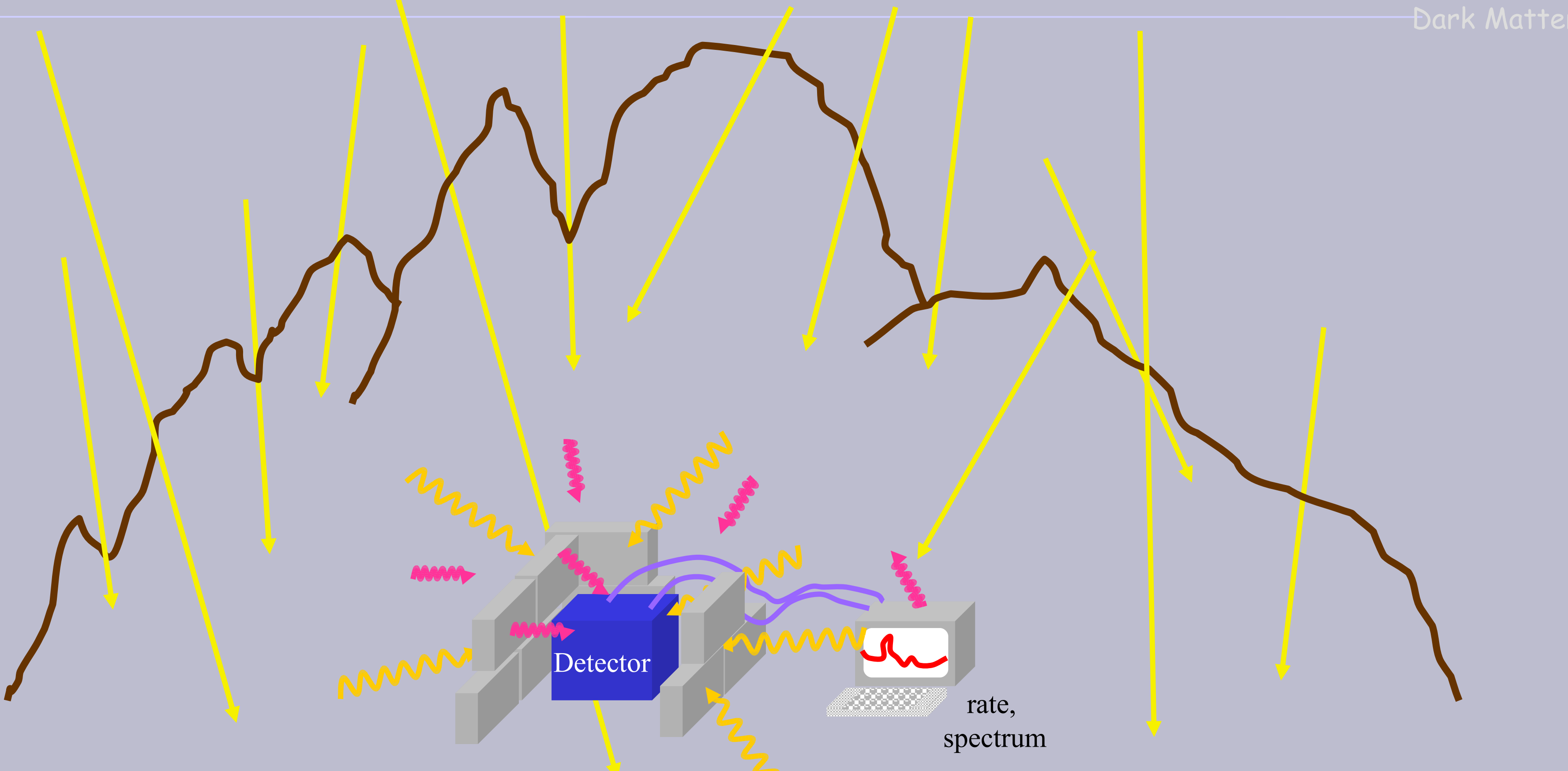


⇒ only a few keV of energy

- cross section $\sigma_\chi < 10^{-36} cm^2$
- local WIMP-density $\rho_\chi = 0.3\ GeV / cm^3$ - *corresp. 3 WIMPs(100GeV) / liter*
  - *75000 /s /cm²*

⇒ very very rare scattering events (< 1 / week / kg)

WIMP Direct Detection - Signal and Background



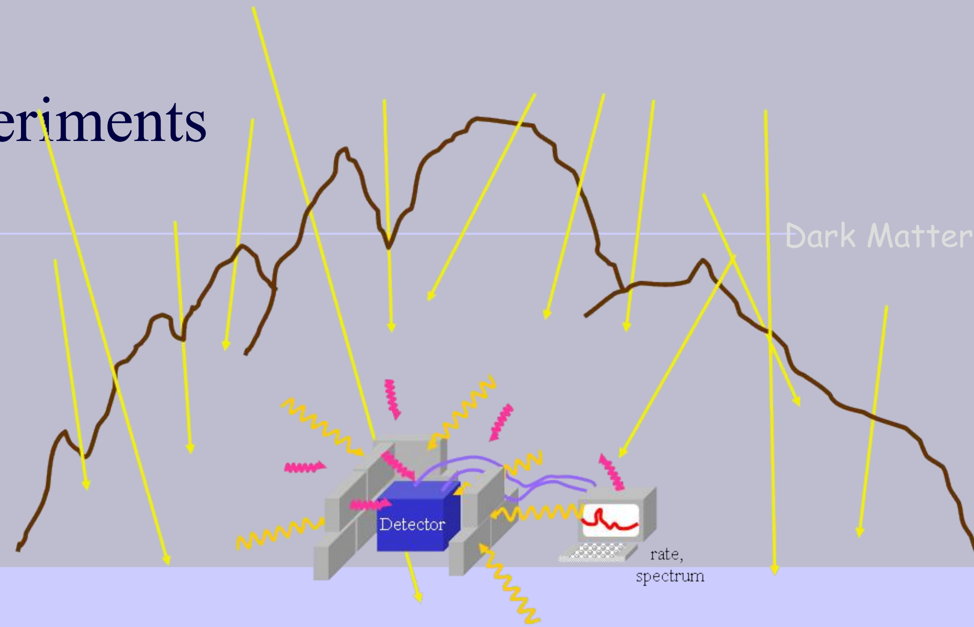
required sensitivity	~ 1 event / kg / week	(future experiments even 100 x less)
radioactivity: > 1Hz/kg	~ 10^6 events /kg /week	=> ‘clean‘ shielding: (old) Pb, Cu
muons ~ 0.1Hz/kg:	~ 10^5 events /kg /week,	=> needs ~ 1.5 km Rock
		=> Underground-Laboratory

WIMP Direct Detection - Underground Laboratory

shielding
from
cosmic rays

Soudan Mine USA

WIMP Direct Detection - Experiments



Conventional Detectors:

DAMA-LIBRA	*NaI-Scintillation*
ββ Experiments	*Ge-Ionisation*
….	

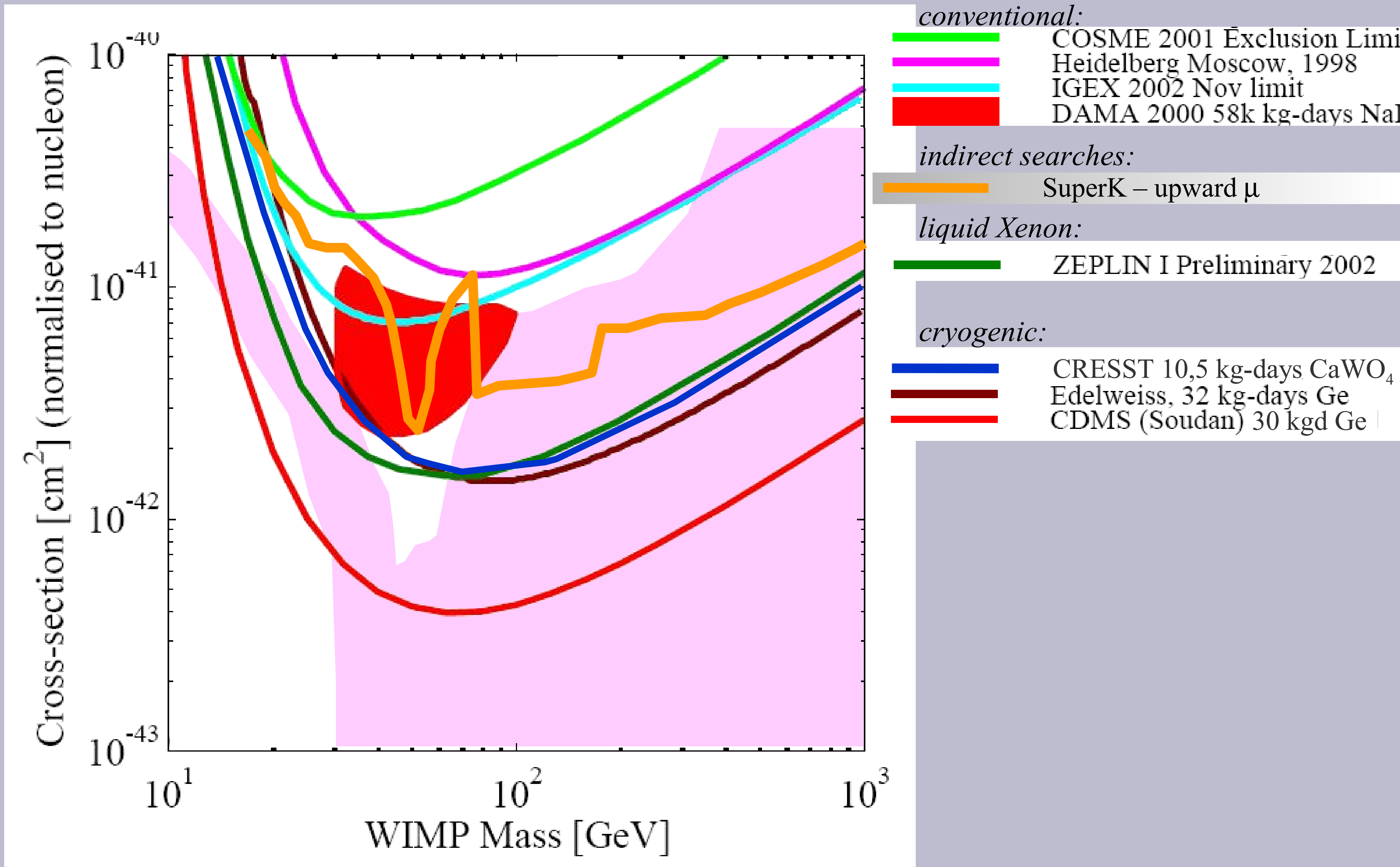
Cryogenic Detectors:

CDMS	*Ge-Ionisation-Phonons*	USA	Soudan Mine
EDELWEISS	*Ge-Ionisation-Phonons*	France, Germany	Fréjus-Tunnel
CRESST	*CaWO4-Scintillation-Phonons*	Germany, UK, Italy	Gran Sasso
…			

Liquid NobleGas Detectors:

ZEPLIN	*Xe-Scint., Scint.-Ionisation*	UK	Boulby Mine
XENON	*Xe-Scintillation-Ionisation*	US, Italy, Germany, Portugal	Gran Sasso
WARP	*Ar-Scintillation-Ionisation*	Italy, US, Poland	Gran Sasso
ArDM	*Ar-Scintillation-Ionisation*	Switzerland, Spain, UK, Poland	CERN, Canfranc?

Sensitivity WIMP Dark Matter Searches

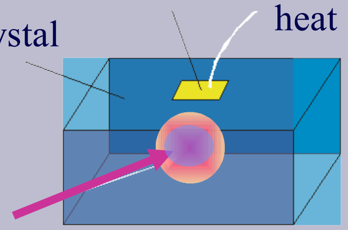


WIMP Direct Detection - Low Temperature – Calorimeter

particle absorption
=>
phonons (~heat)

phonon-absorption
in thermometer
=> temperature rise

low temperatures (~20mK)
=> high sensitivity, small C

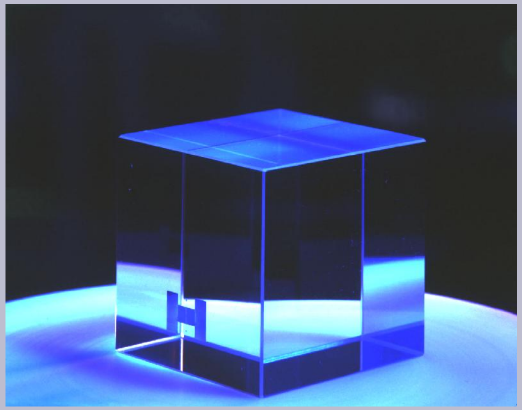


$$\Delta T \propto E/C$$

high sensitivity to nuclear recoils
no quenching

low
energy threshold

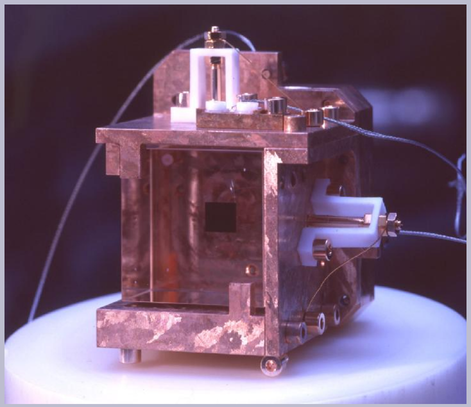
wide choice of
absorber materials



thermometer types:

superconducting phase
transition thermometers (SPT)

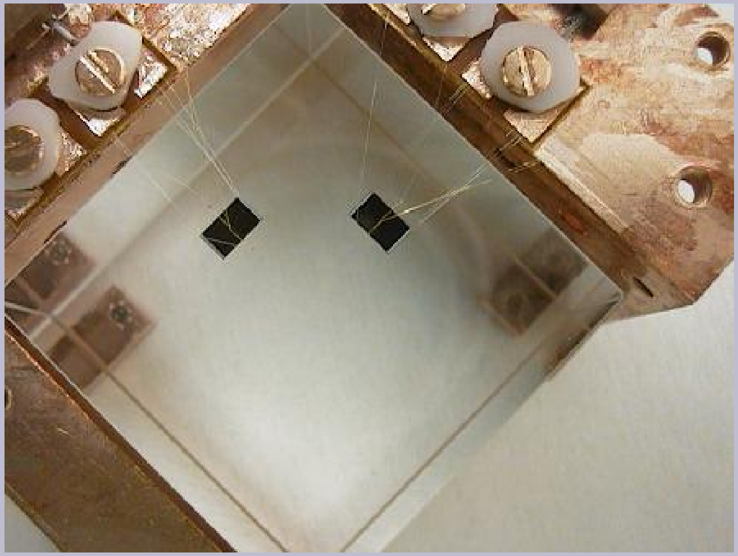
NTD - Ge thermistors
(highly doped semiconductors)



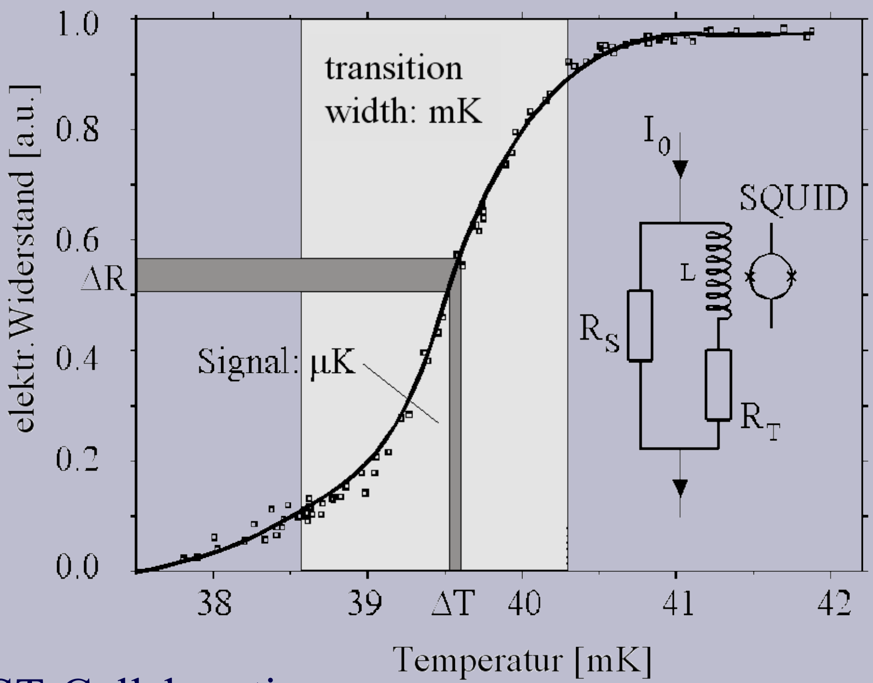
Superconducting Phase Transition Thermometer

superconducting phase
transition thermometer
Tungsten Tc 15mK

heat capacity– Sapphire 250gr
2 MeV / mK @ 25mK
130 GeV / mK @ 1K



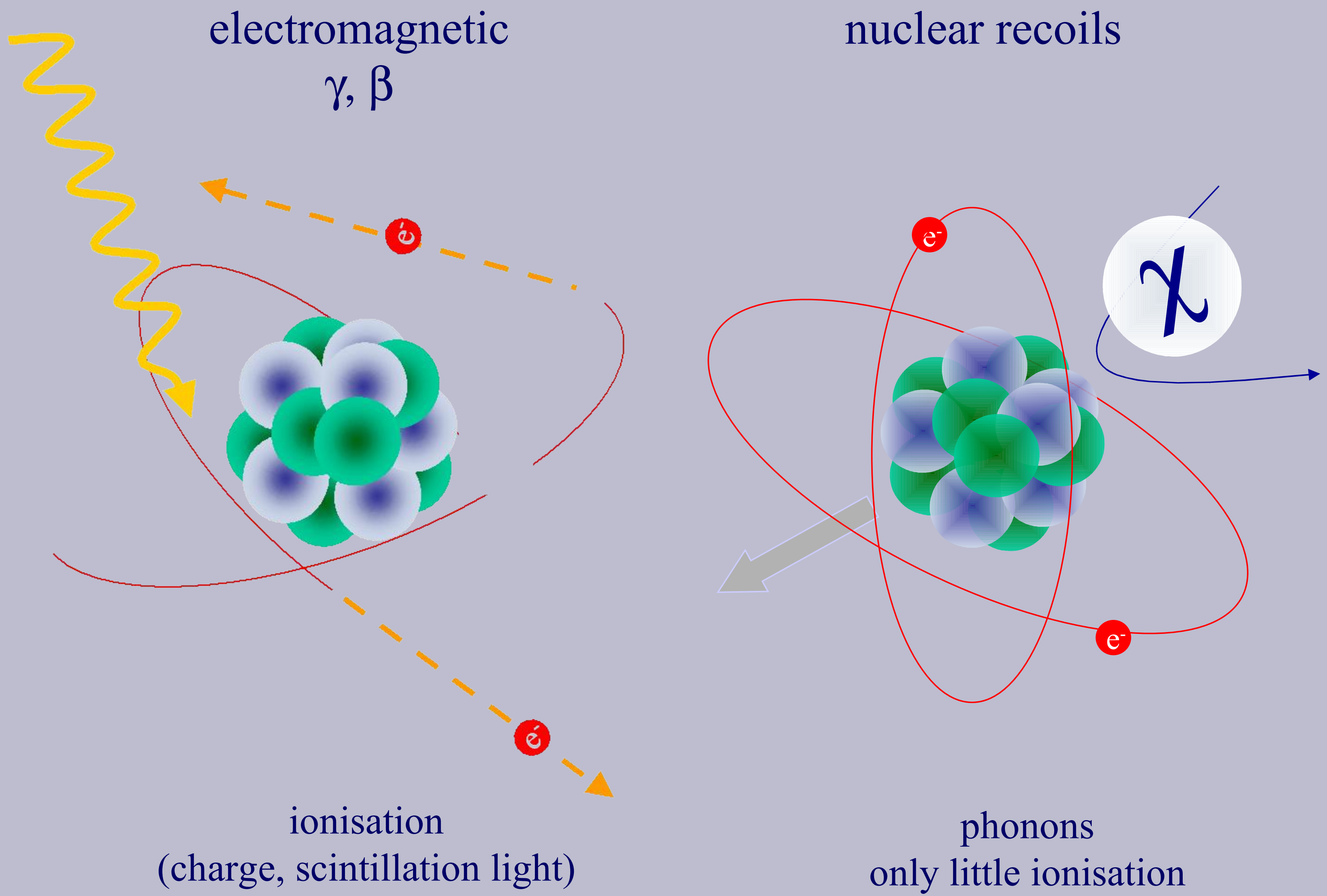
Sapphire- or $CaWO_4$ -absorber
250gr, 4cm x 4cm x 4cm



CRESST-Collaboration

Cryogenic Rare Event Search with Superconducting Thermometers

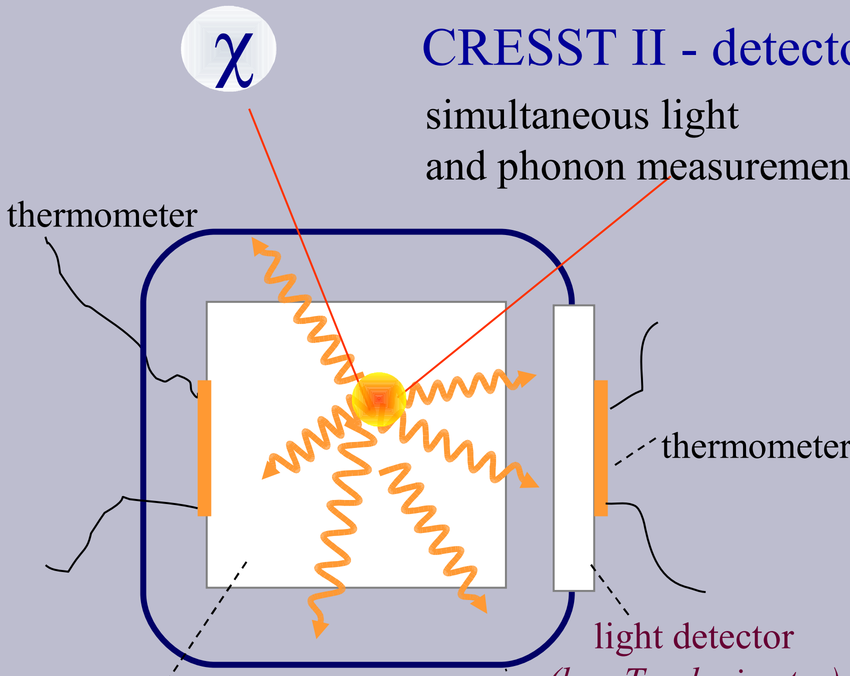
Max-Planck-Institut München, TU München
Universität Tübingen, Oxford University, Gran Sasso Lab

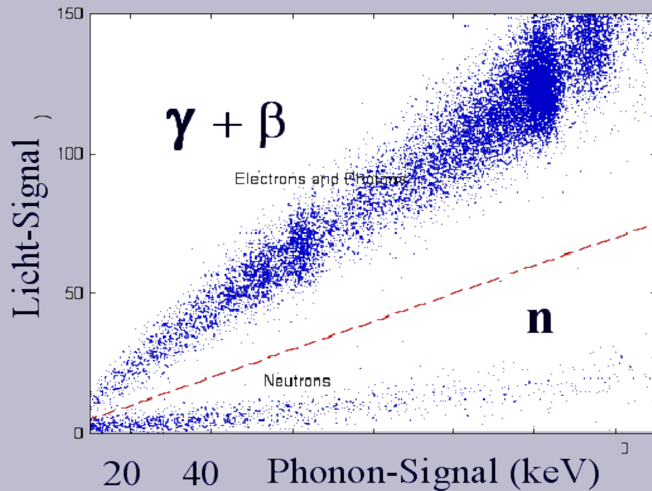

electromagnetic
γ, β
nuclear recoils
χ
ionisation
(charge, scintillation light)
phonons
only little ionisation

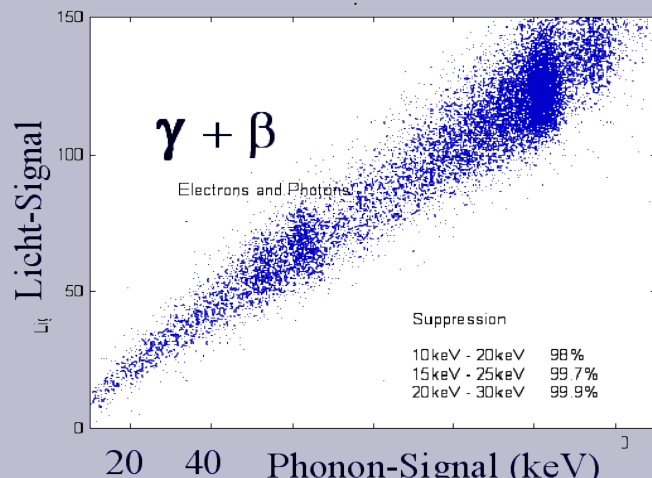
Phonon + Charge / Light Measurement => recognize Background

CRESST II - detectors

simultaneous light
and phonon measurement







EDELWEISS-France and Karlsruhe
CDMS - US

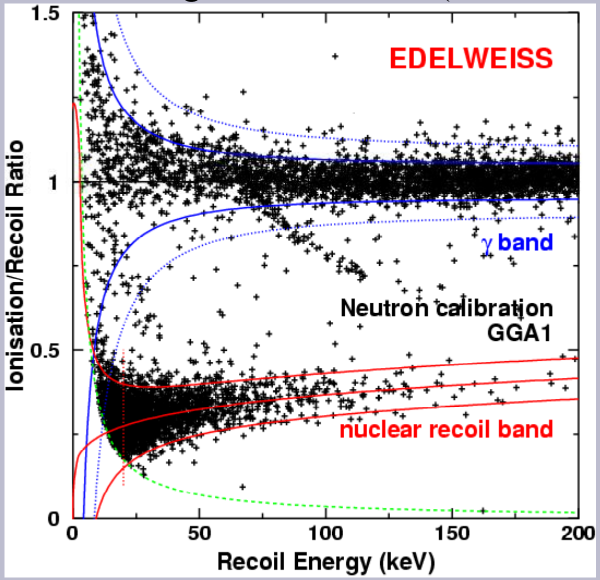
simultaneous charge and phonons
(semiconductors Ge, Si)

WIMP Direct Detection – Event by Event Discrimination

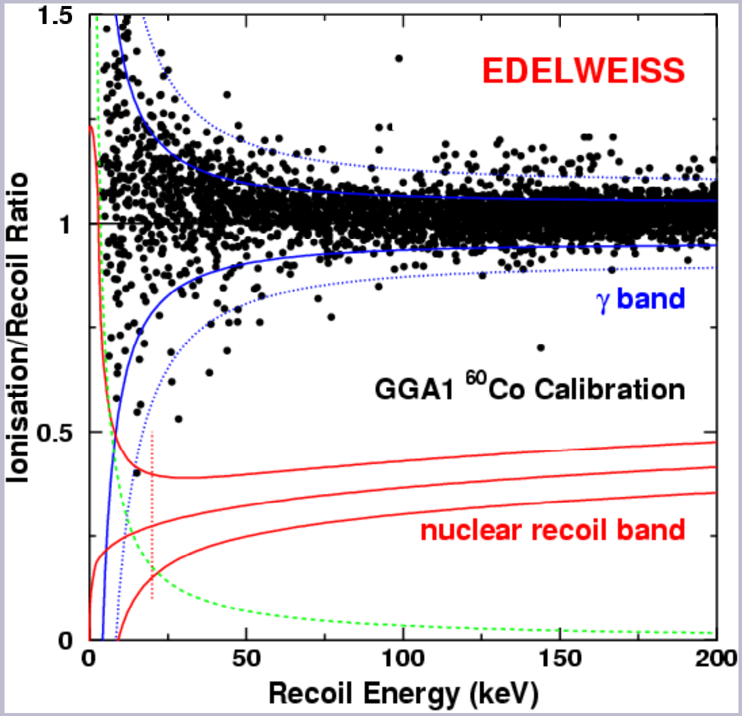
EDELWEISS (France) und CDMS (USA) Dark Matter Projects

Ioniosation-Phonon
320g Ge-Detector

Testmessung mit Neutronen (=> Kernrückstöße)



'Low Background Data'



EDELWEISS - Cryogenic Ge-Detectors – Heat / Charge

IAP Paris
IPN Lyon
CRTBT Grenoble
CSNSM Orsay
DAPNIA Saclay
DRECAM Saclay
LSM Modane
Forschungszentrum Karlsruhe
Universität Karlsruhe
JINR Dubna

3 x 320g detectors, 1 liter experimental volume, cryostat made with low radioactivity materials in the Fréjus Underground Laboratory

External shield: 30cm paraffin, 20cm lead and 10cm copper

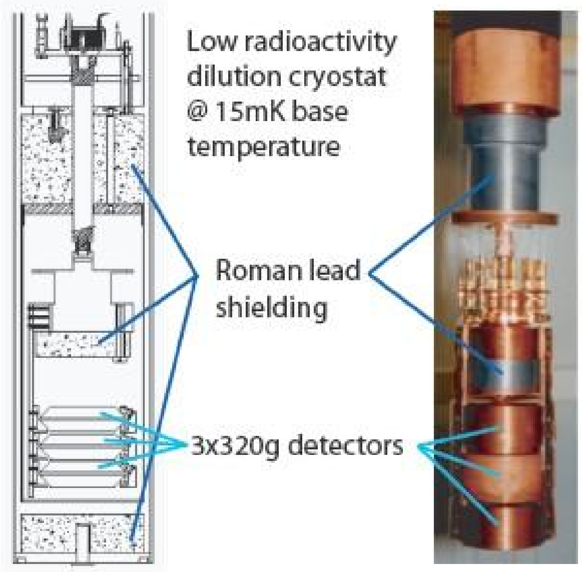
1st data taking: 4.5 kg d
Fall 2000 (GeAl5), GeAl6, (Ge8)

2nd data taking: 8.6kg d
Spring 2002 GGA1, (GeAl9), (GeAl10)

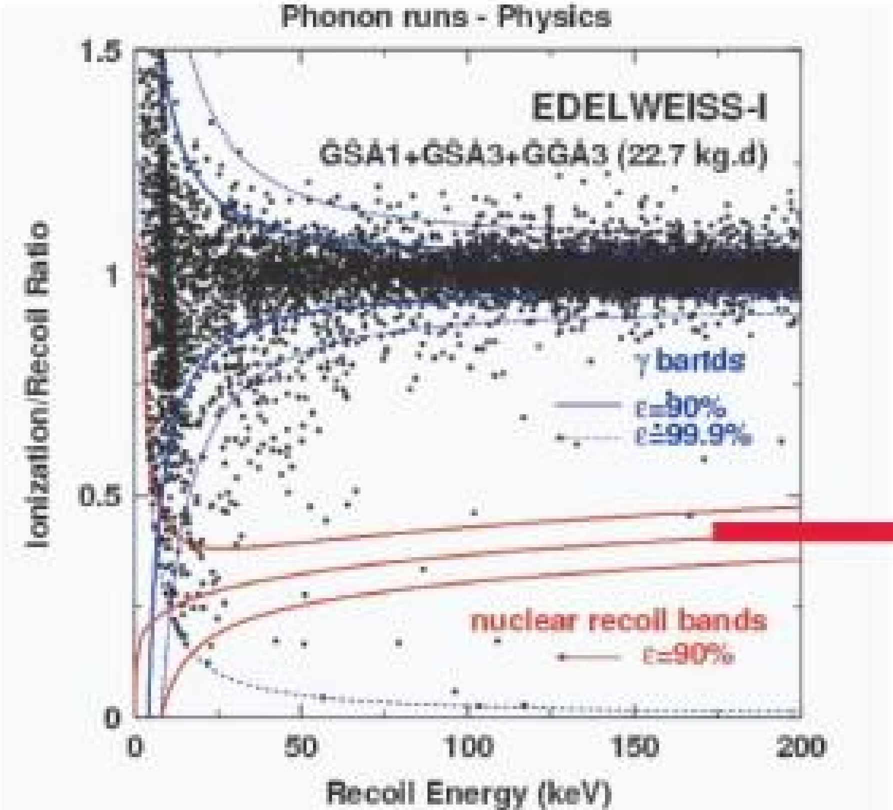
3rd data taking: 19kg d
Oct-Mar 2002 GGA3, GSA1, GSA3

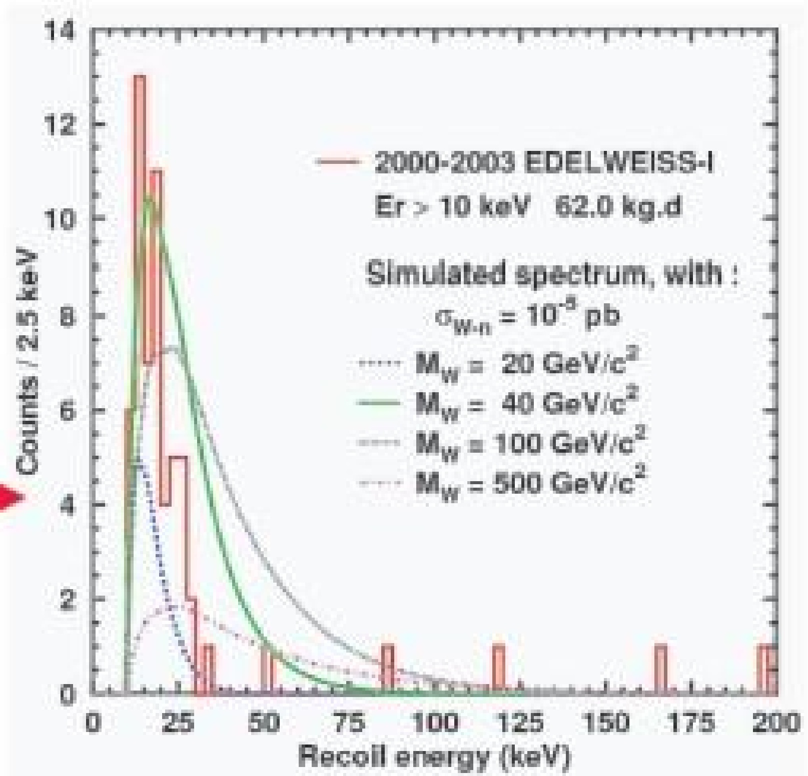
4th data taking: 30kg d
Apr-Nov 2003 GGA3 GSA1 GSA3

Total exposure: 62kg d

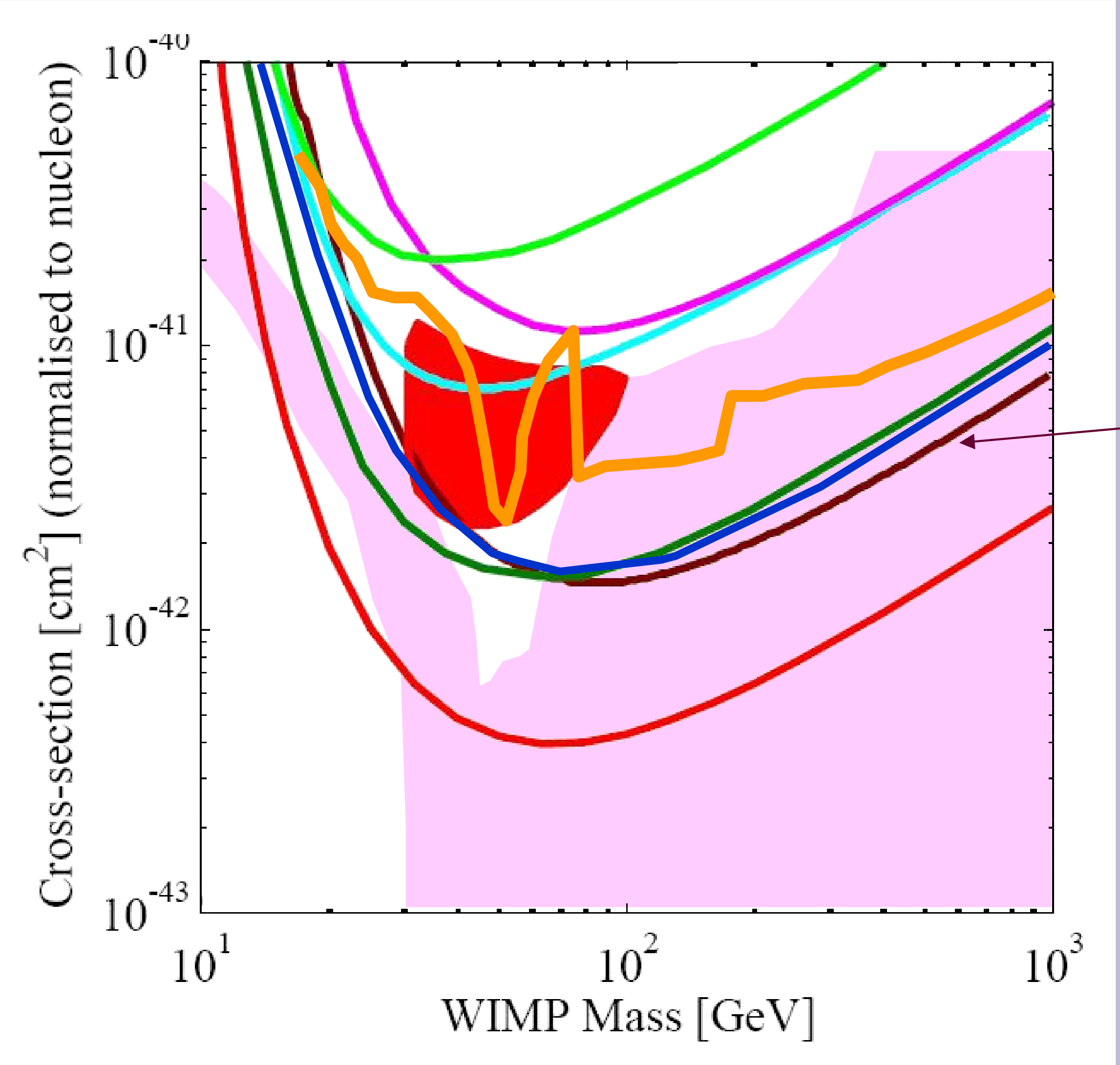


EDELWEISS at Frejus tunnel - Results 2003





EDELWEISS - Results 2003 – *60kg d*



EDELWEISS 2002

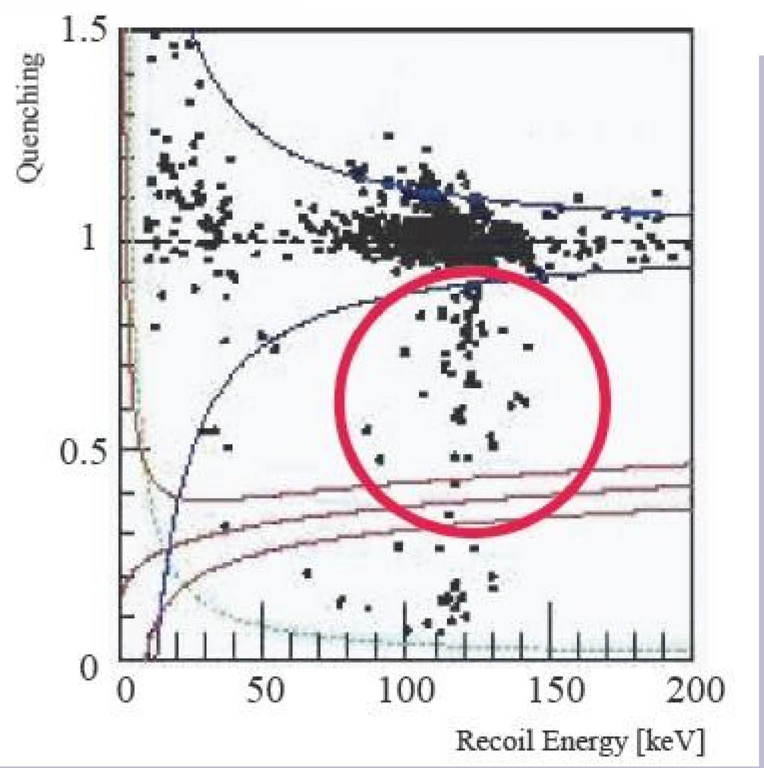
upgrade – done

just started 7kg run

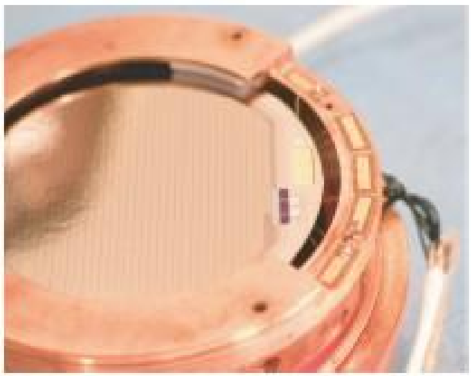
Heat / Charge - *reduced charge collection from surface*

Main limitation to the sensitivity: due to trapping and recombination, surface events are misscollected and can mimic nuclear recoils

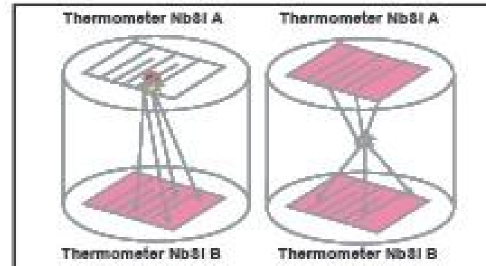
Most of the EDELWEISS R&D is concentrated on this problem

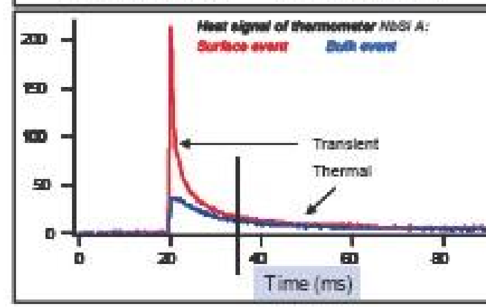


Identification of near surface events using athermal phonon measurement with NbSi thin film thermometers



- Heat and ionization Ge detectors
- Each signal consists of thermal + athermal component
- For surface event close to A, athermal higher in NbSi A
- Thermal signals proportional to the energy deposit

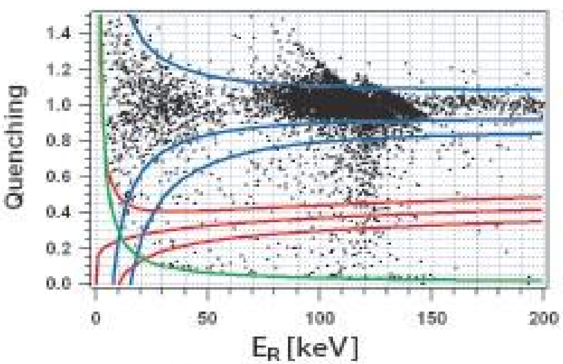




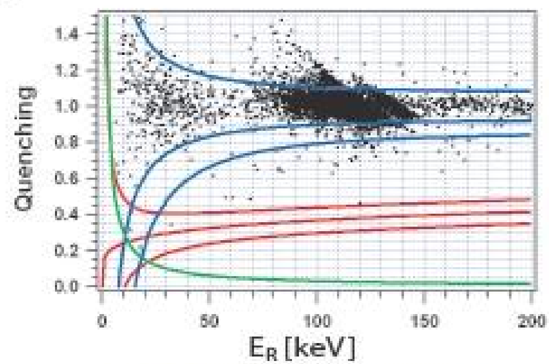
Tests with 200g prototype in EDELWEISS-I

Improvement of the rejection by a factor of 20

Fiducial volume reduction of 10 %

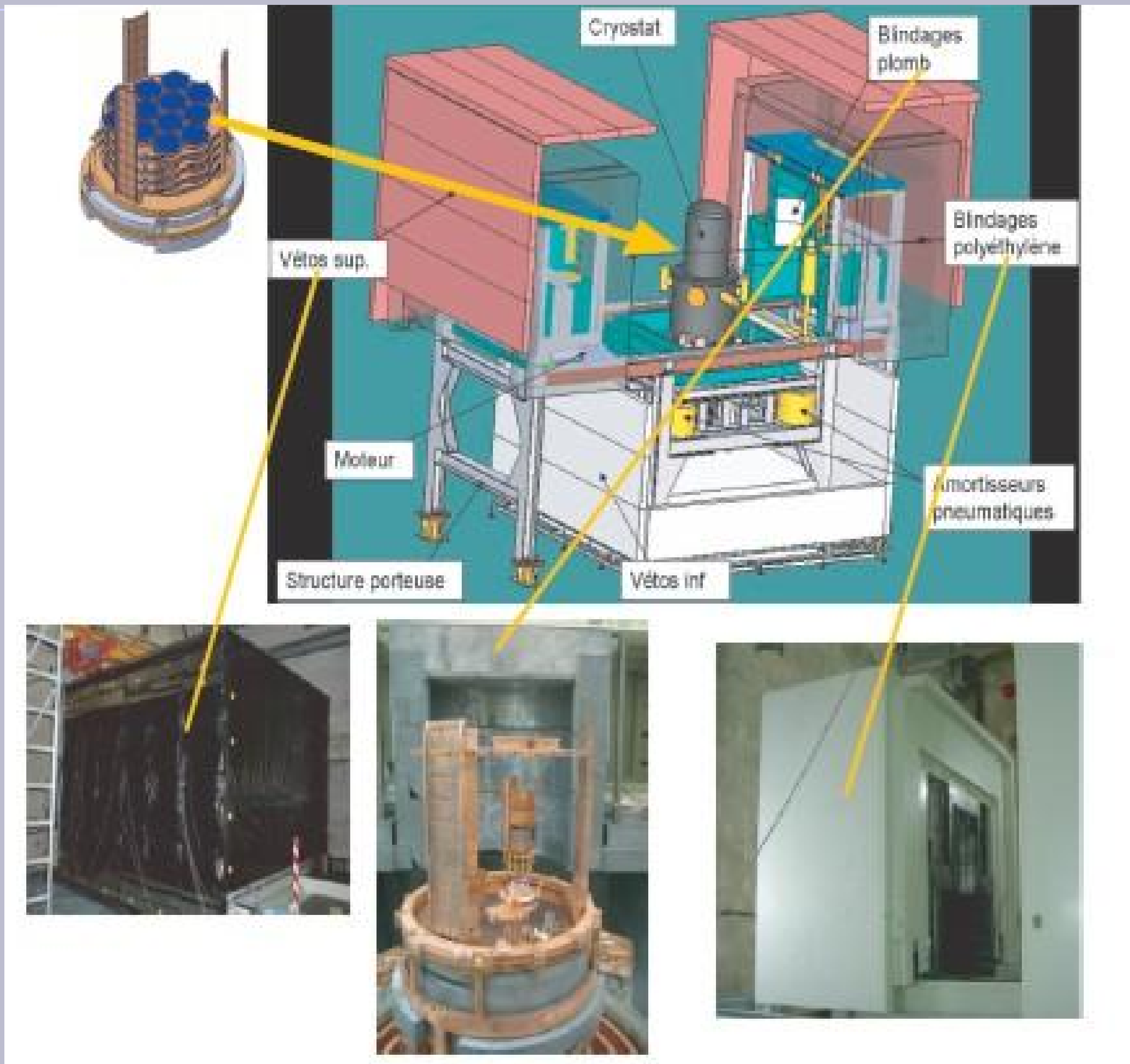


Before rejection



After rejection (1mm cut)

EDELWEISS Upgrade – Start 2007



able to run up to
100 detectors
~30kg

started in 2007
with 30 detectors

=> expect new results

CDMS at Soudan Mine

Brown University

Case Western Reserve University

University of Colorado at Denver

Fermi National Accelerator Laboratory

Lawrence Berkeley National Laboratory

Santa Clara University

Stanford University

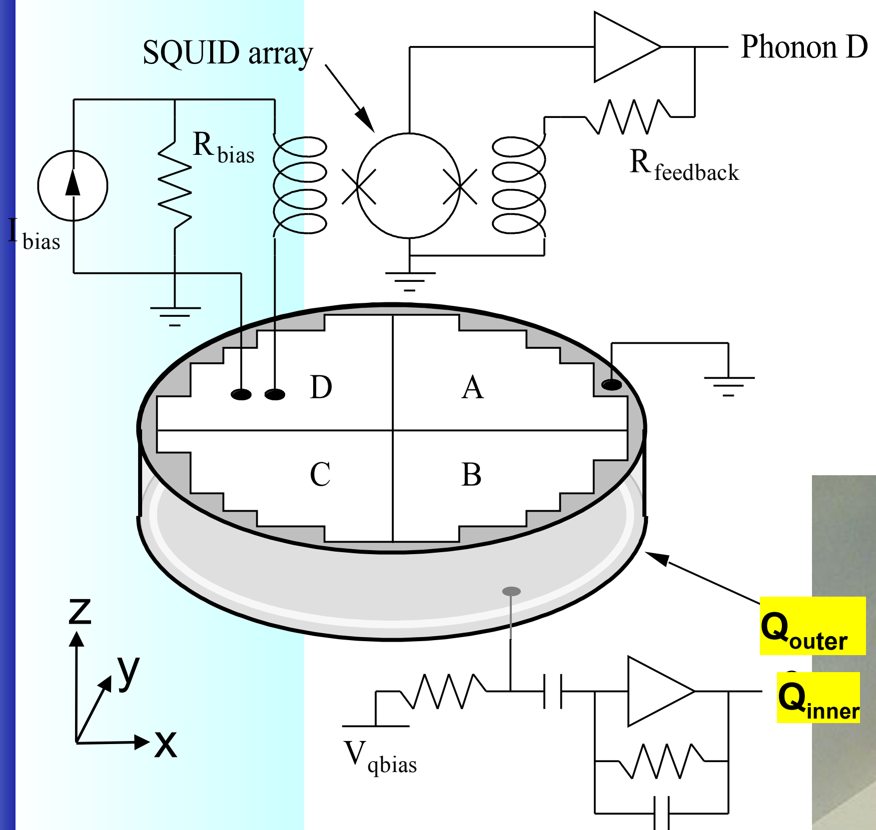
University of California, Berkeley

University of California, Santa Barbara

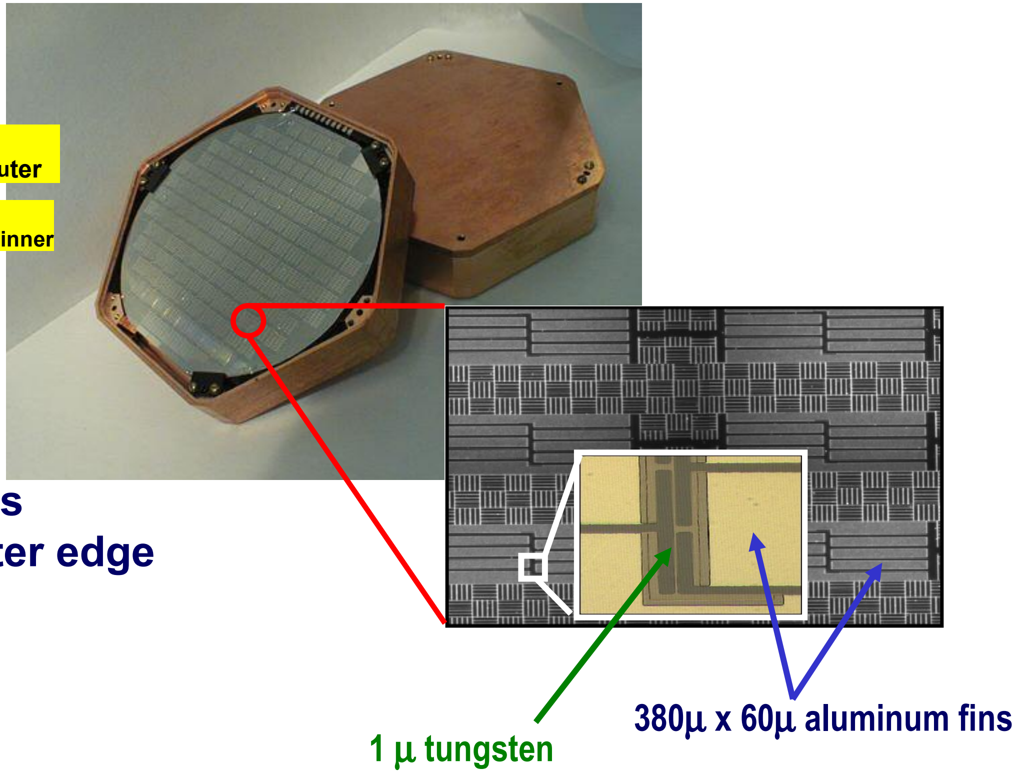
University of Florida

University of Minnesota

CDMS *Charge & Phonon Detectors*



- 250 g Ge or 100 g Si crystal
- 1 cm thick x 7.5 cm diameter
- Photolithographic patterning
- Phonon sensors:
  - 4 quadrants with each 888 sensors (TES) operated in parallel
  - TES: 1-µm-thick strip of W connected to 8 superconducting Al collection fins

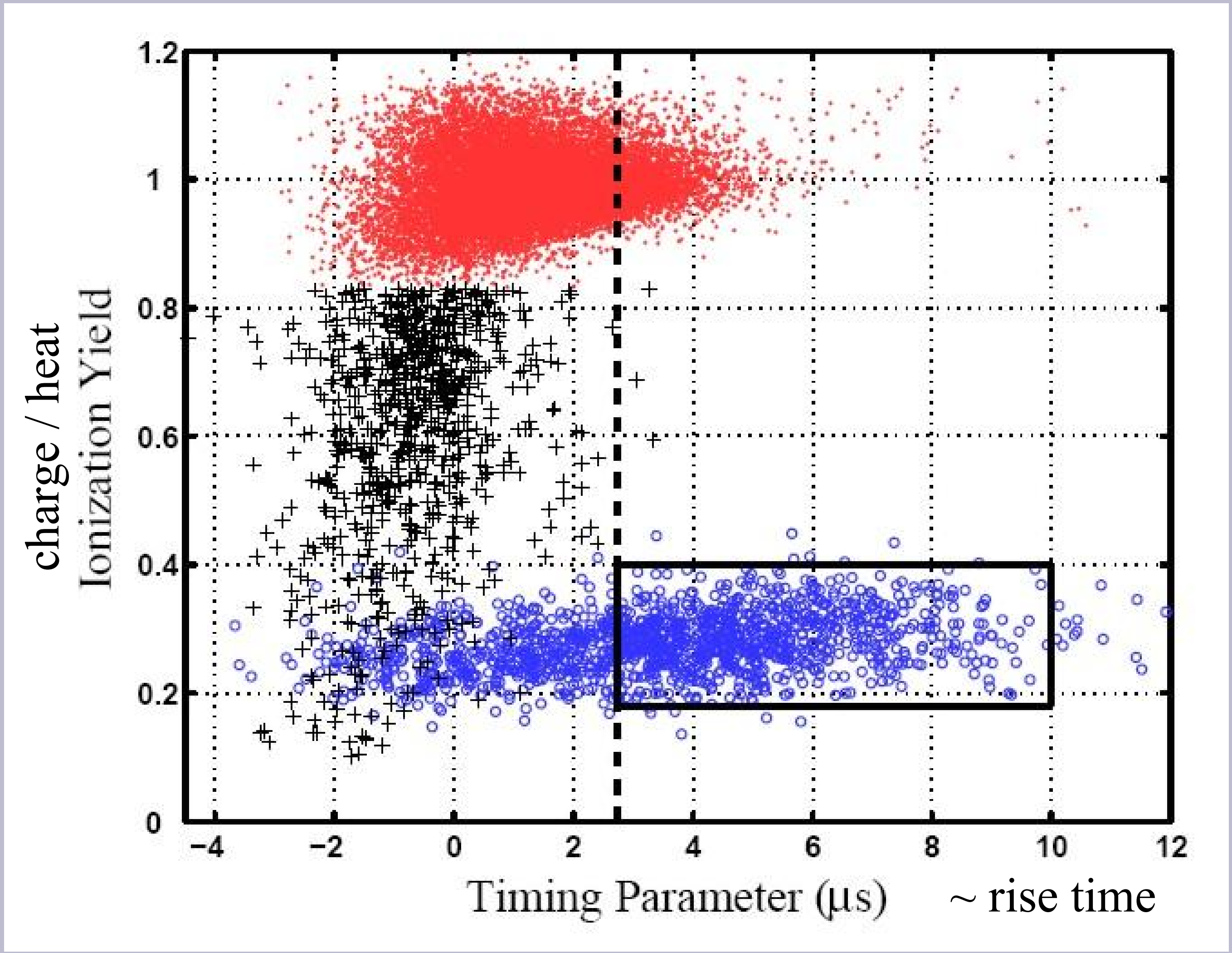


- Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer edge

2 charge electrodes:

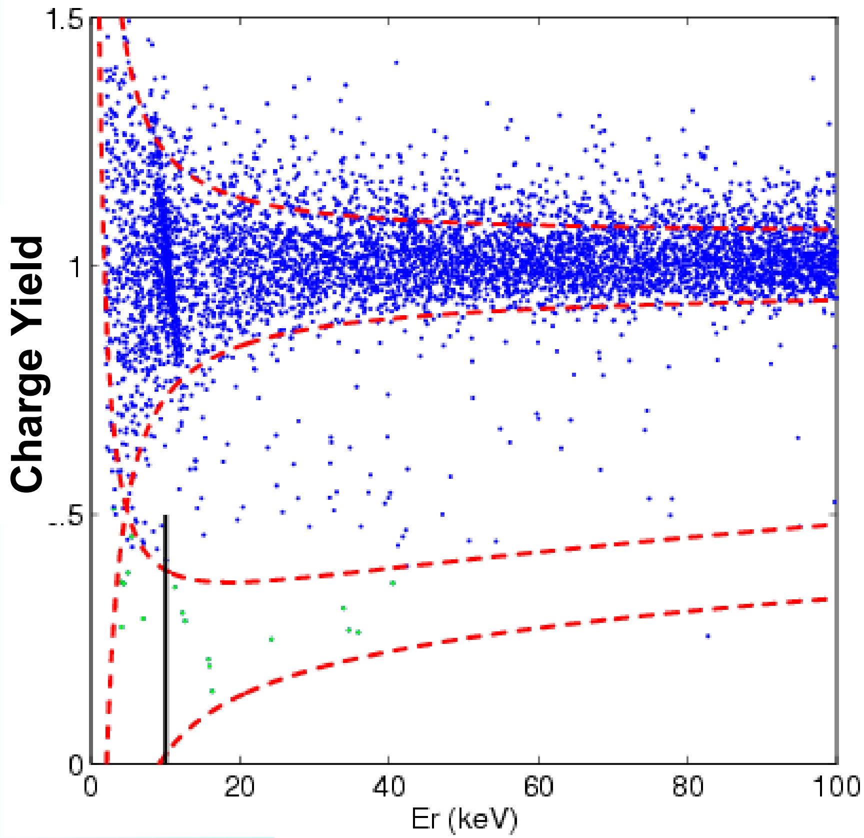
- "Inner" fiducial electrode
- "Outer" guard ring

CDMS Timing Cut – remove near surface events

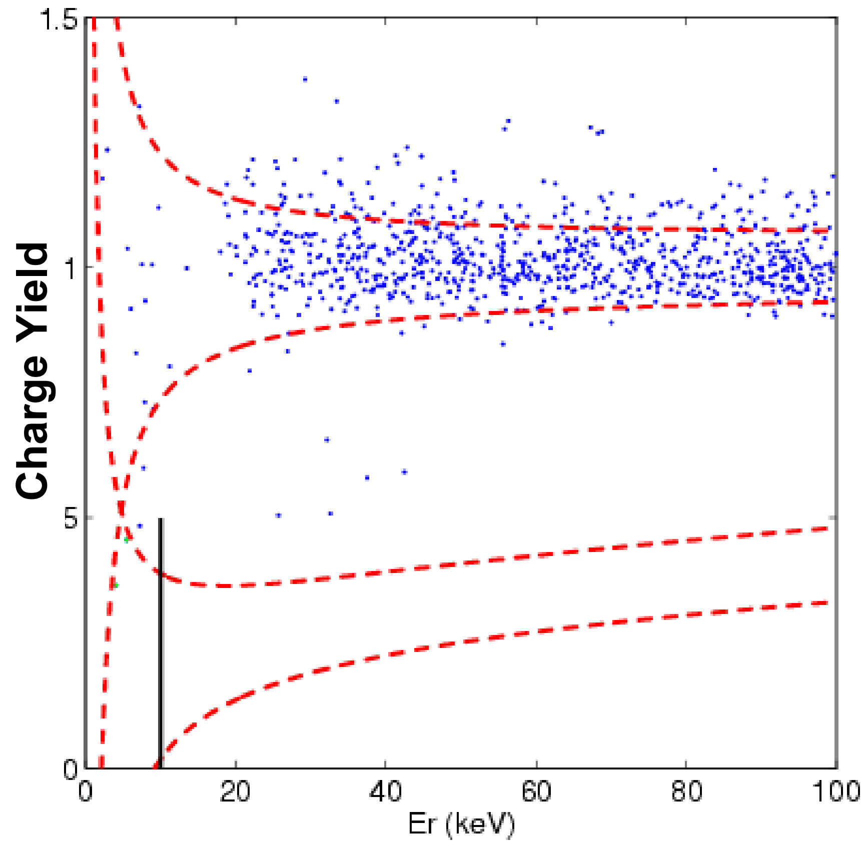


CDMS data 2004/2005

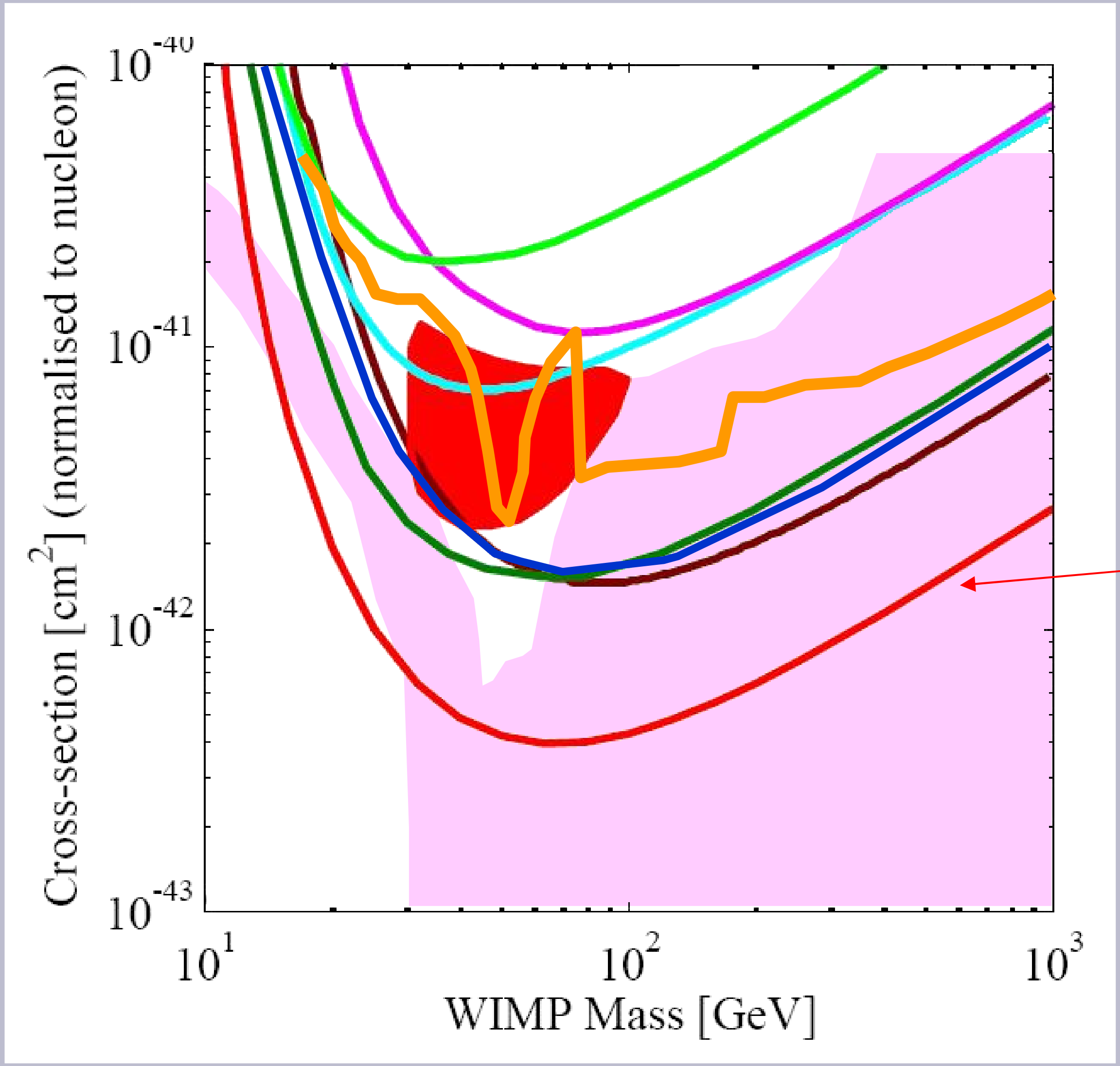
Prior to timing cuts



After timing cuts



CDMS - Results 2005 - *50 kg d*

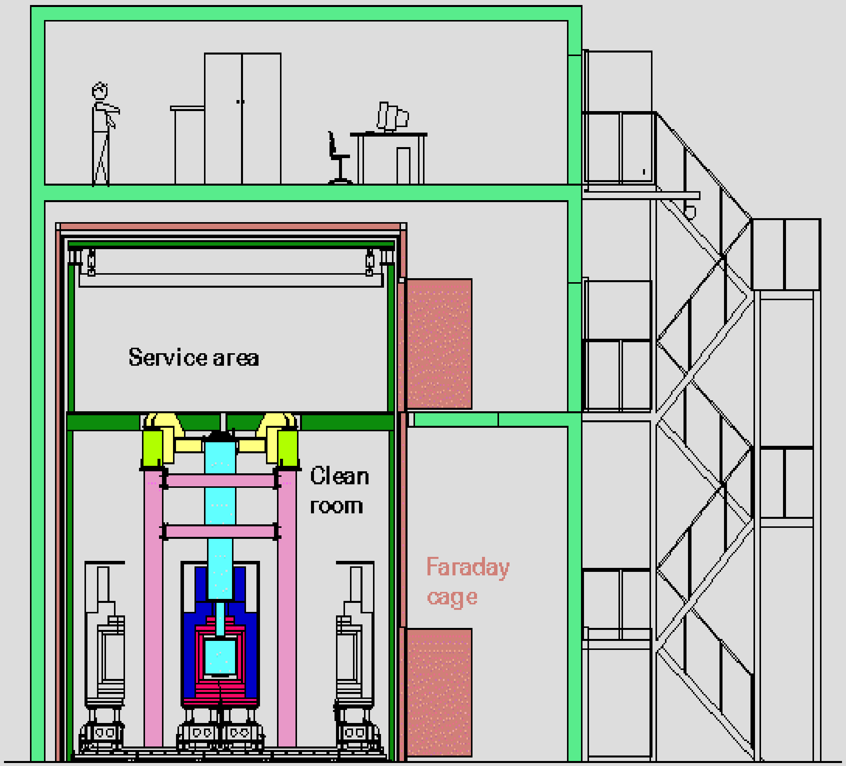


CDMS 2005

continues to run
with ~ 5kg detectors

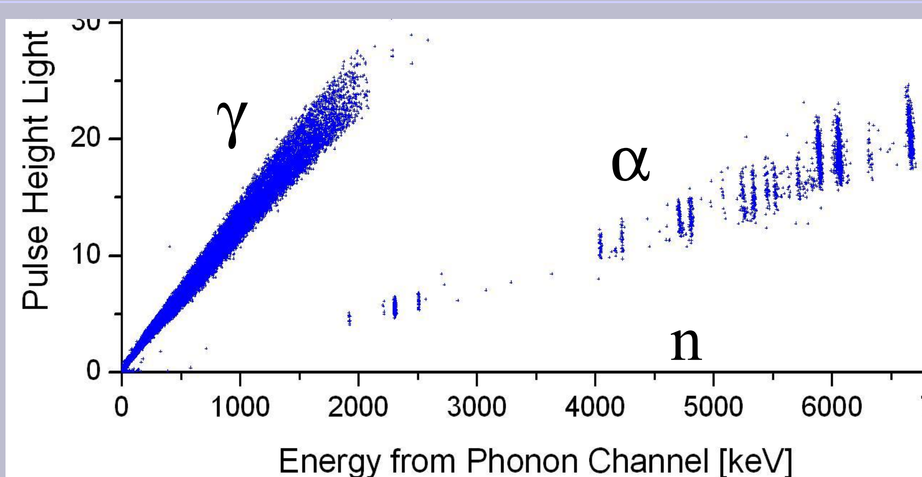
=> expect more data

CRESST at Gran Sasso Underground Laboratory

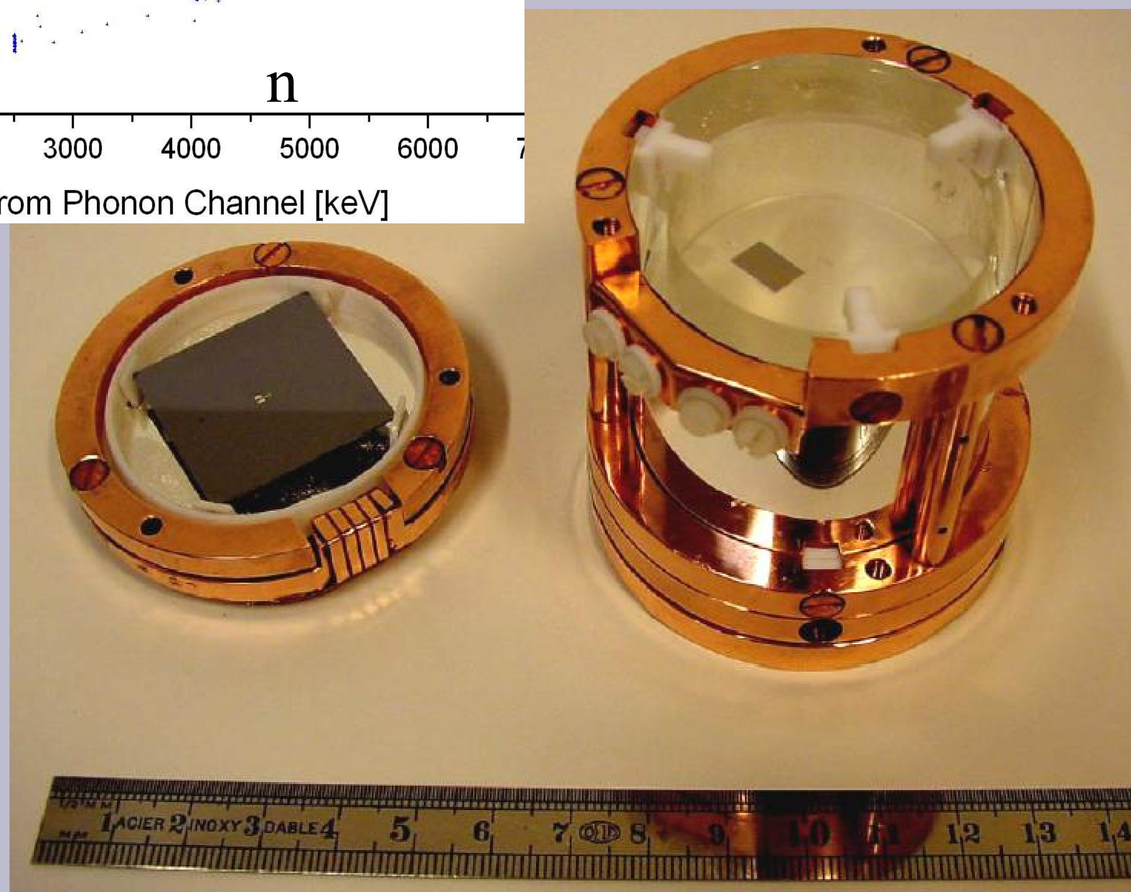


Max-Planck-Institut München
TU München
Universität Tübingen
Oxford University
Gran Sasso Lab

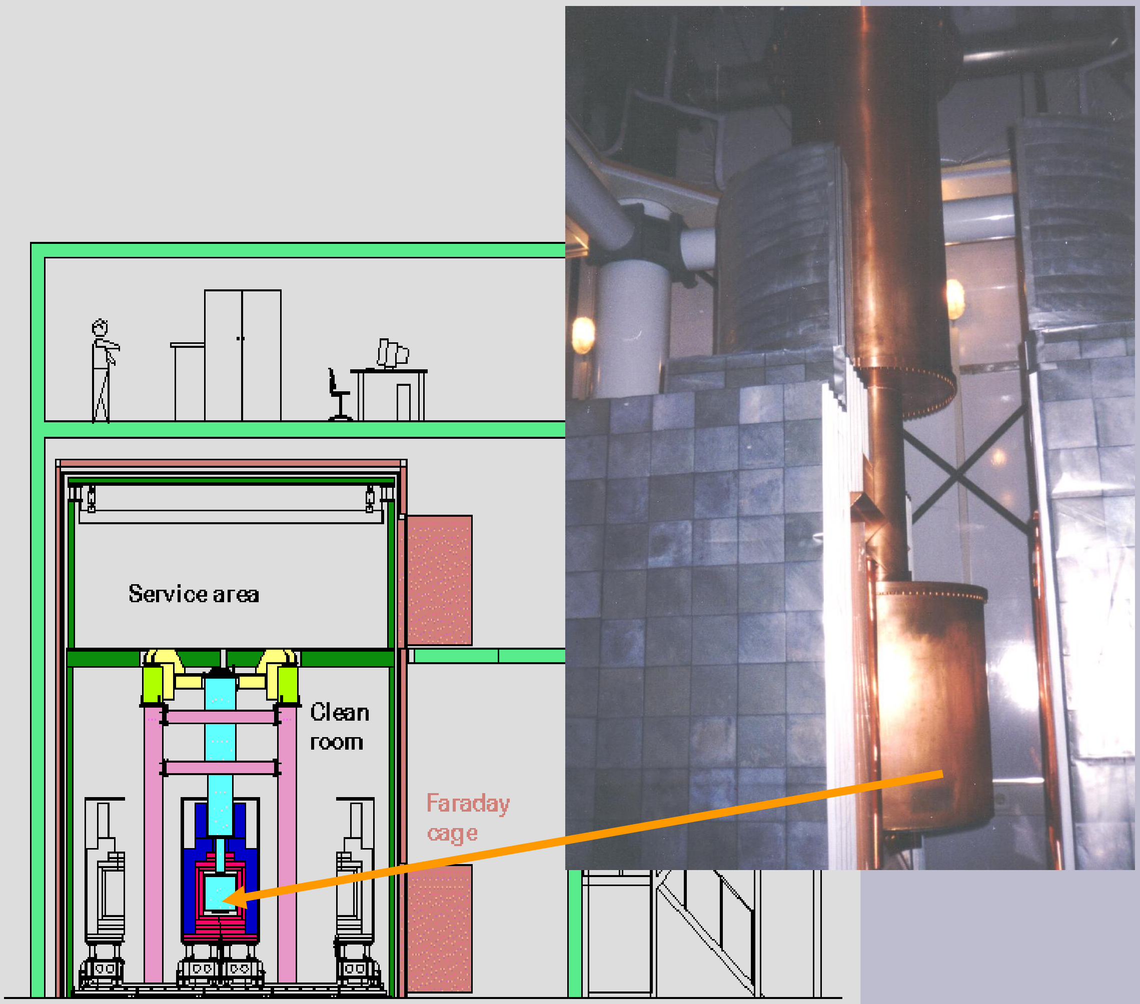
CRESST light - heat - particle identification



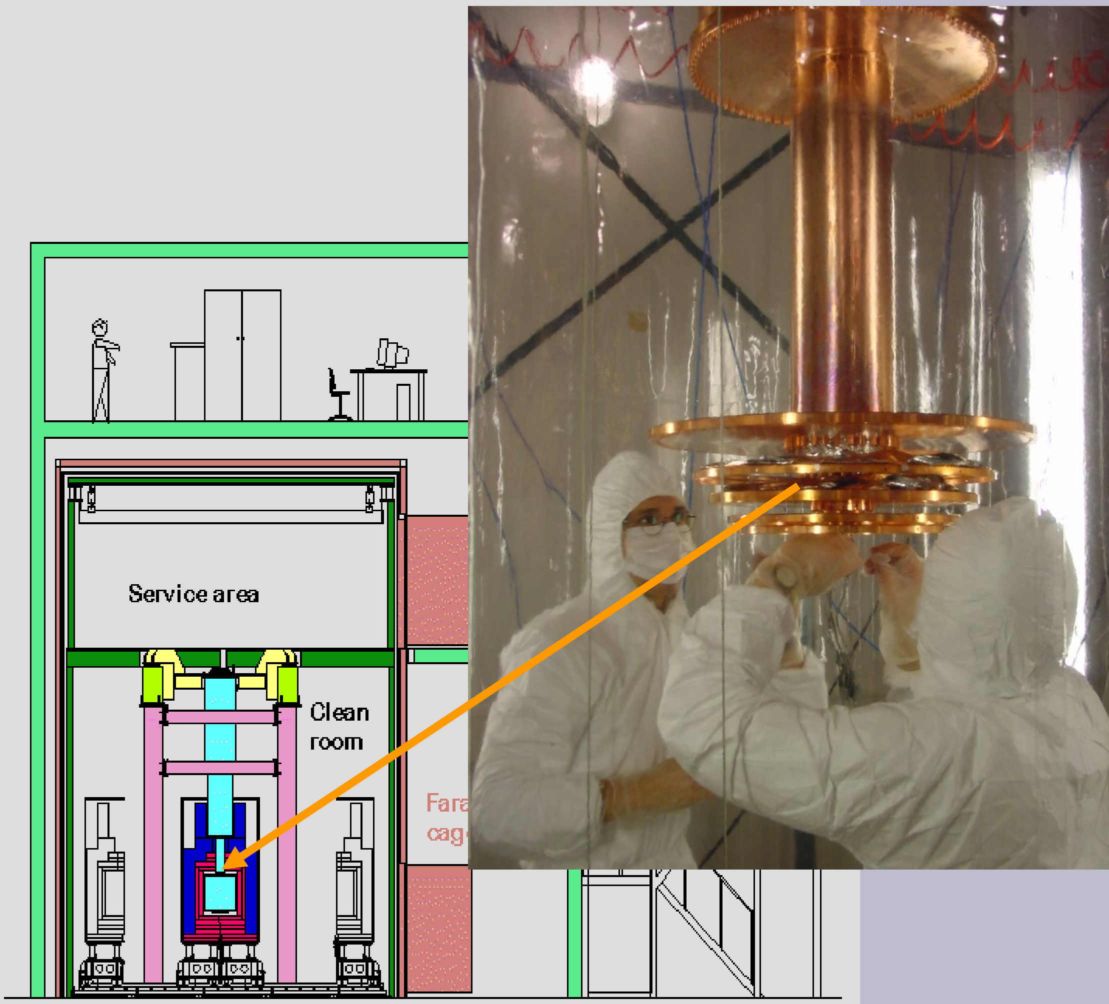
$CaWO_4$



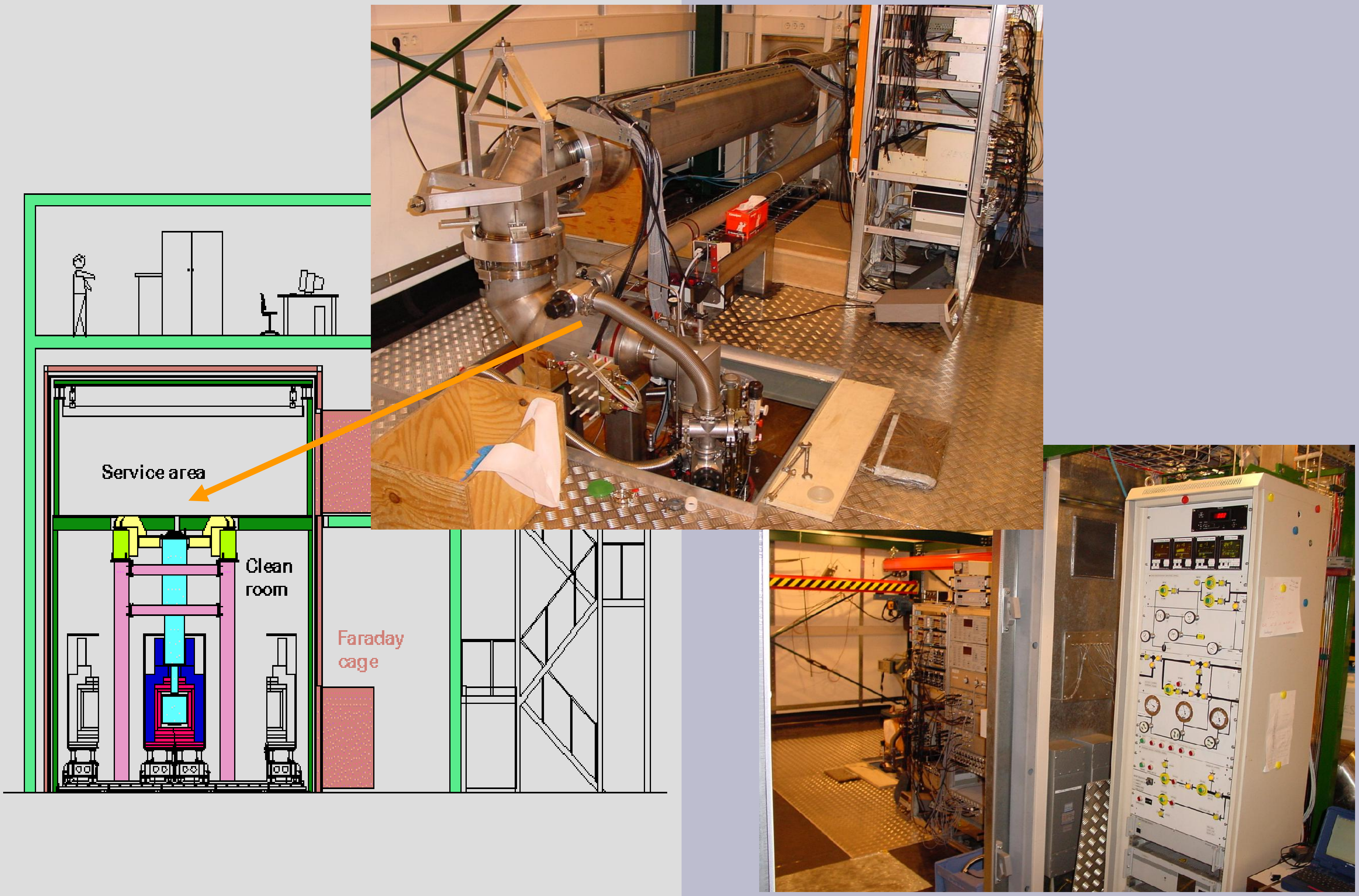
CRESST at Gran Sasso Underground Laboratory



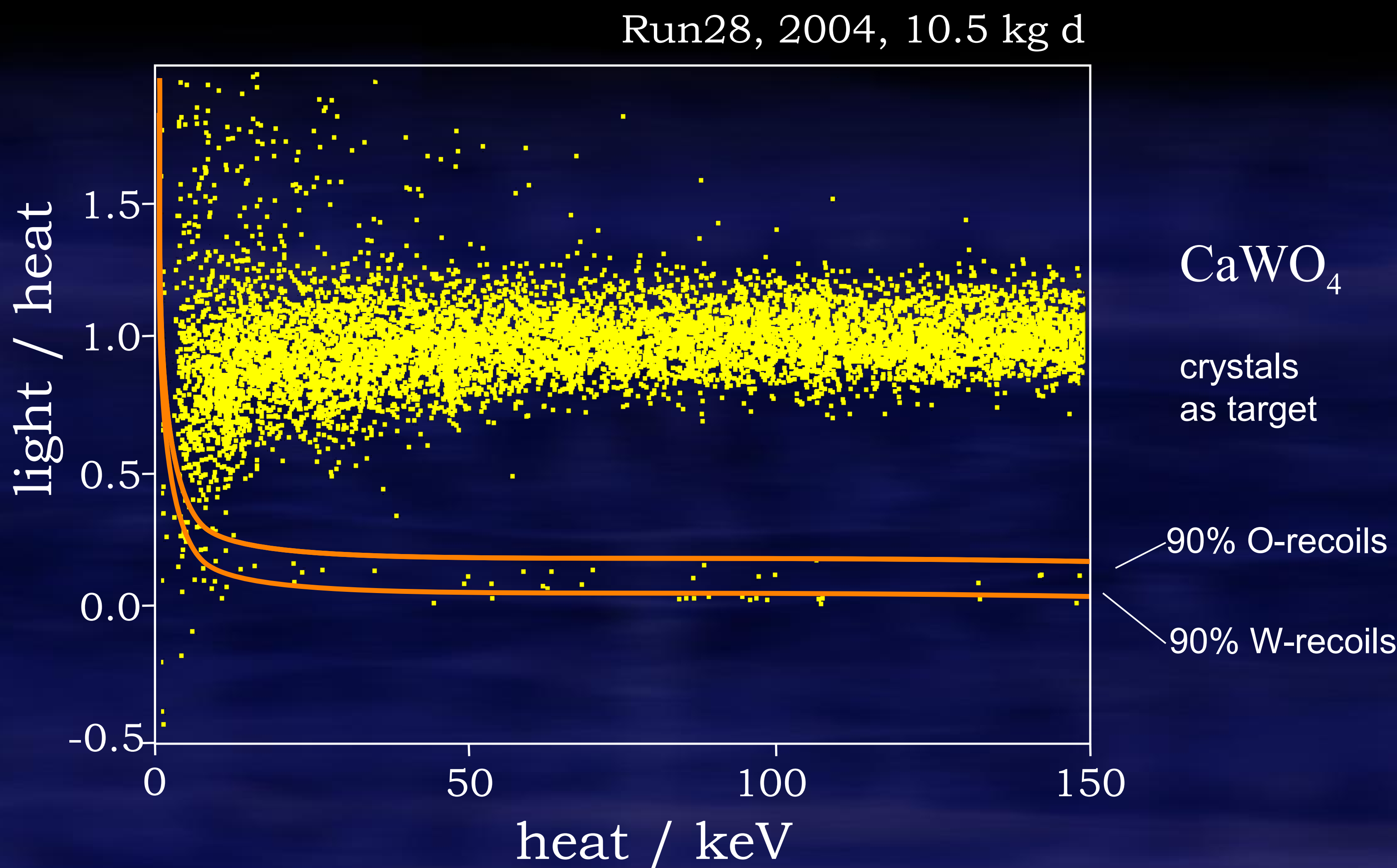
CRESST at Gran Sasso Underground Laboratory



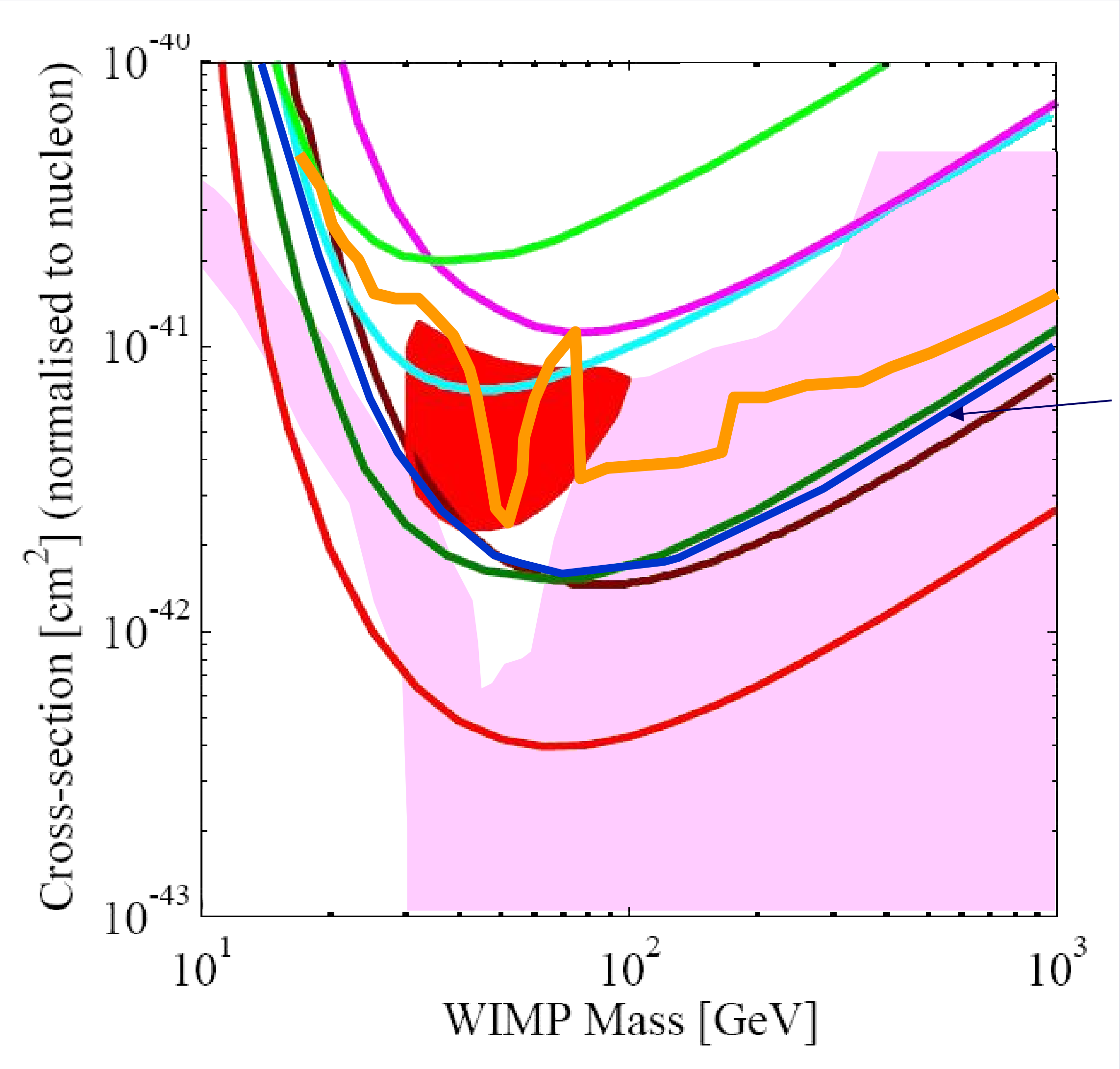
CRESST at Gran Sasso Underground Laboratory



CRESST 2004 no neutron shield



Sensitivity WIMP Dark Matter Searches



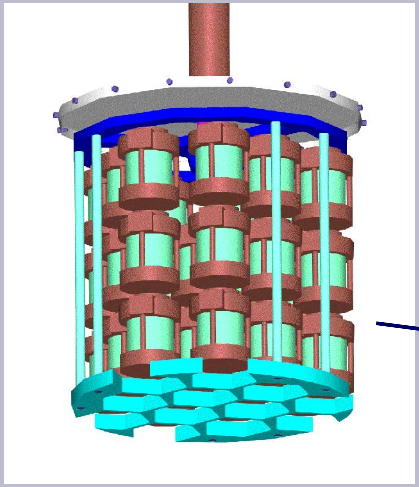
CRESST 2004

now started
to run
in upgraded
and shielded
set up

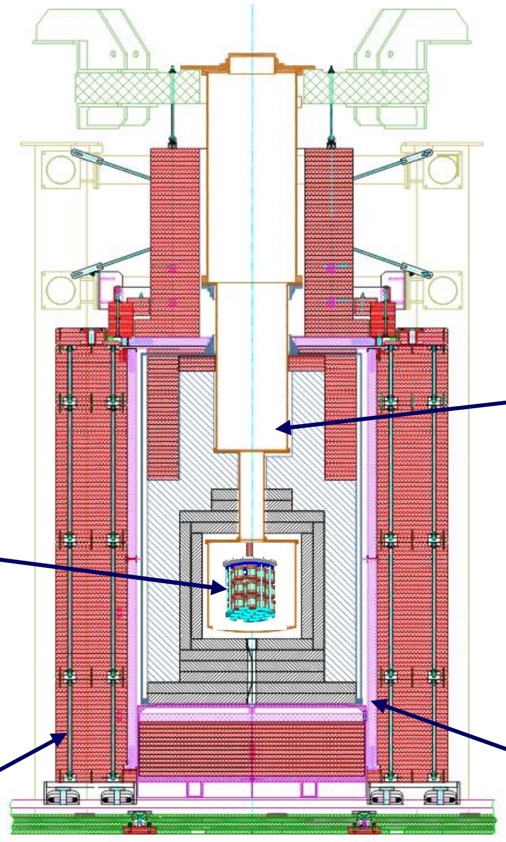
expect more data

CRESST upgrade – more channels – neutron shield

2007: start to install 10kg of target mass (33 modules)



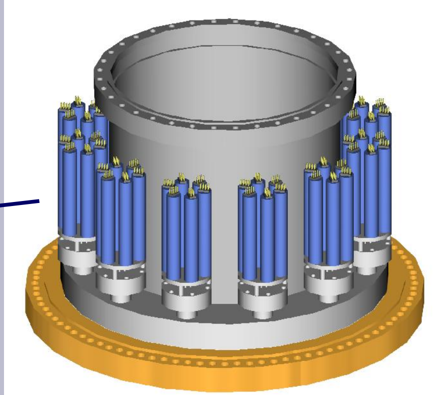
Shielded cryostat



PE neutron moderator

Plastic scintill. μ-veto

2004/05: upgrade to 66 channel SQUID array

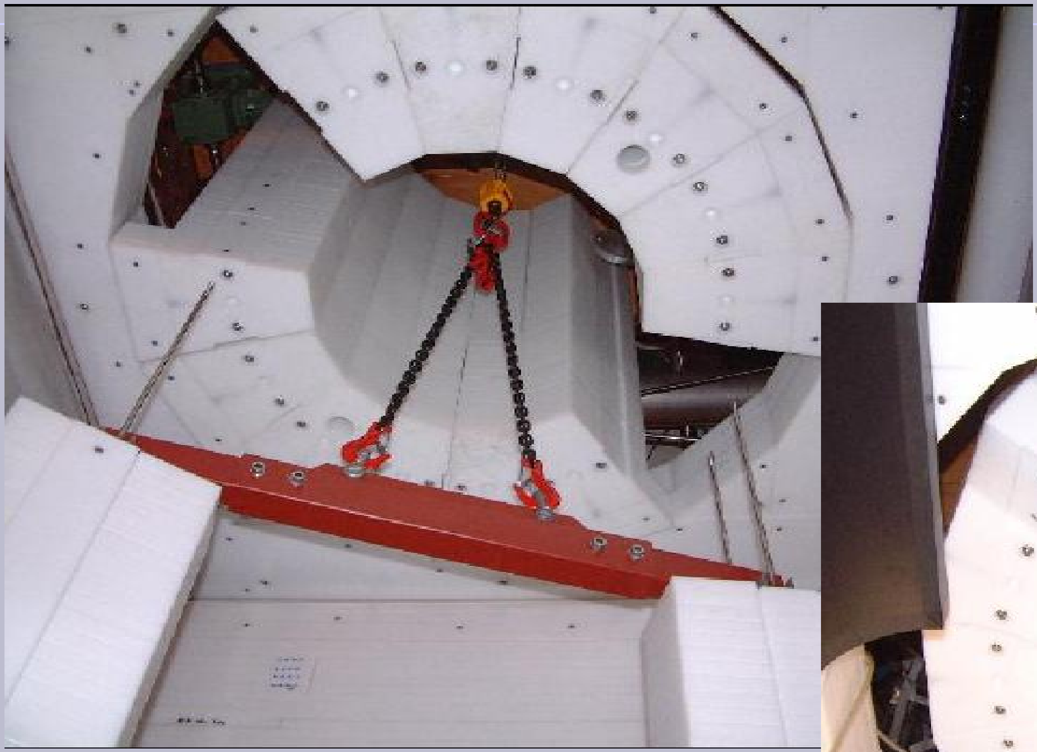


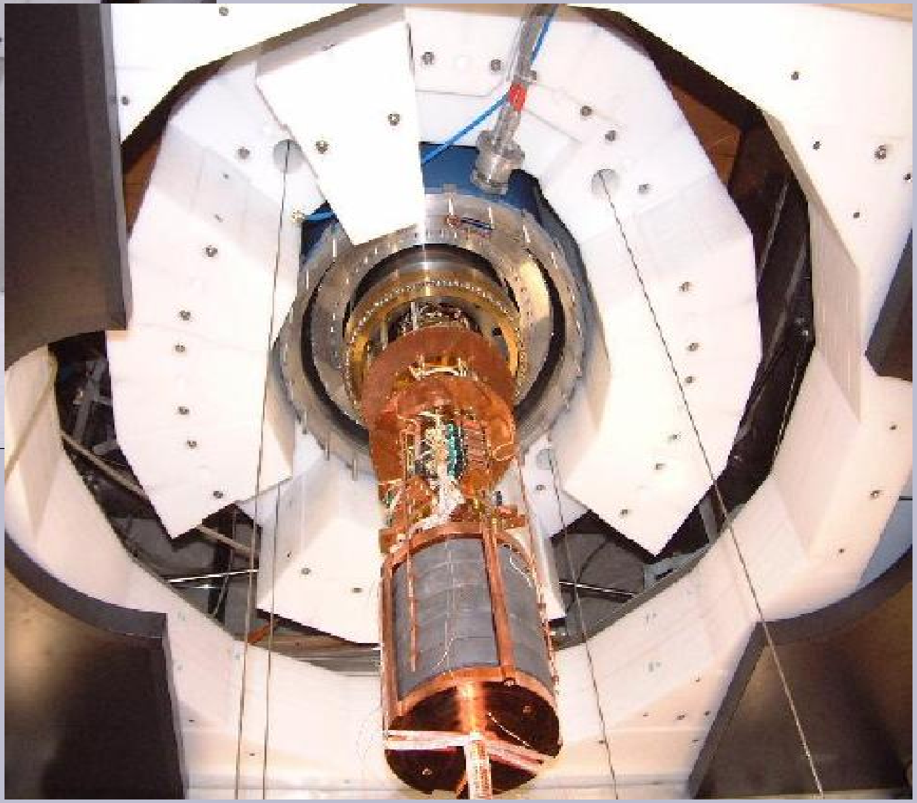
66 SQUIDs on He-flange

2004: installation of PE neutron moderator shield

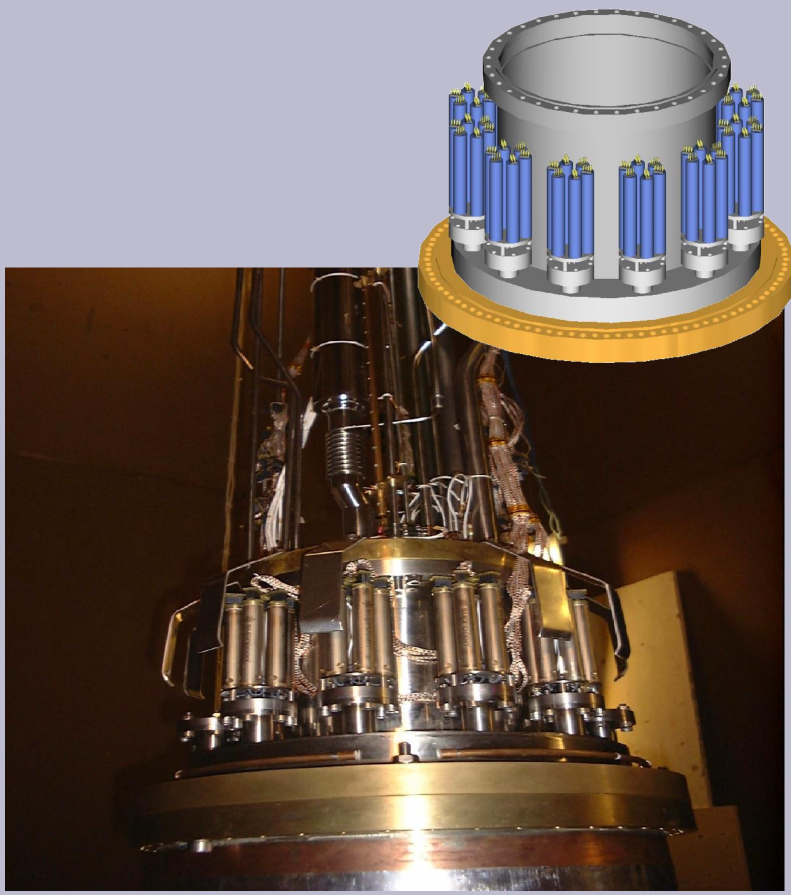
2005/06: add muon veto (against muon induced neutrons in the Pb/Cu shield)

CRESST – neutron shield

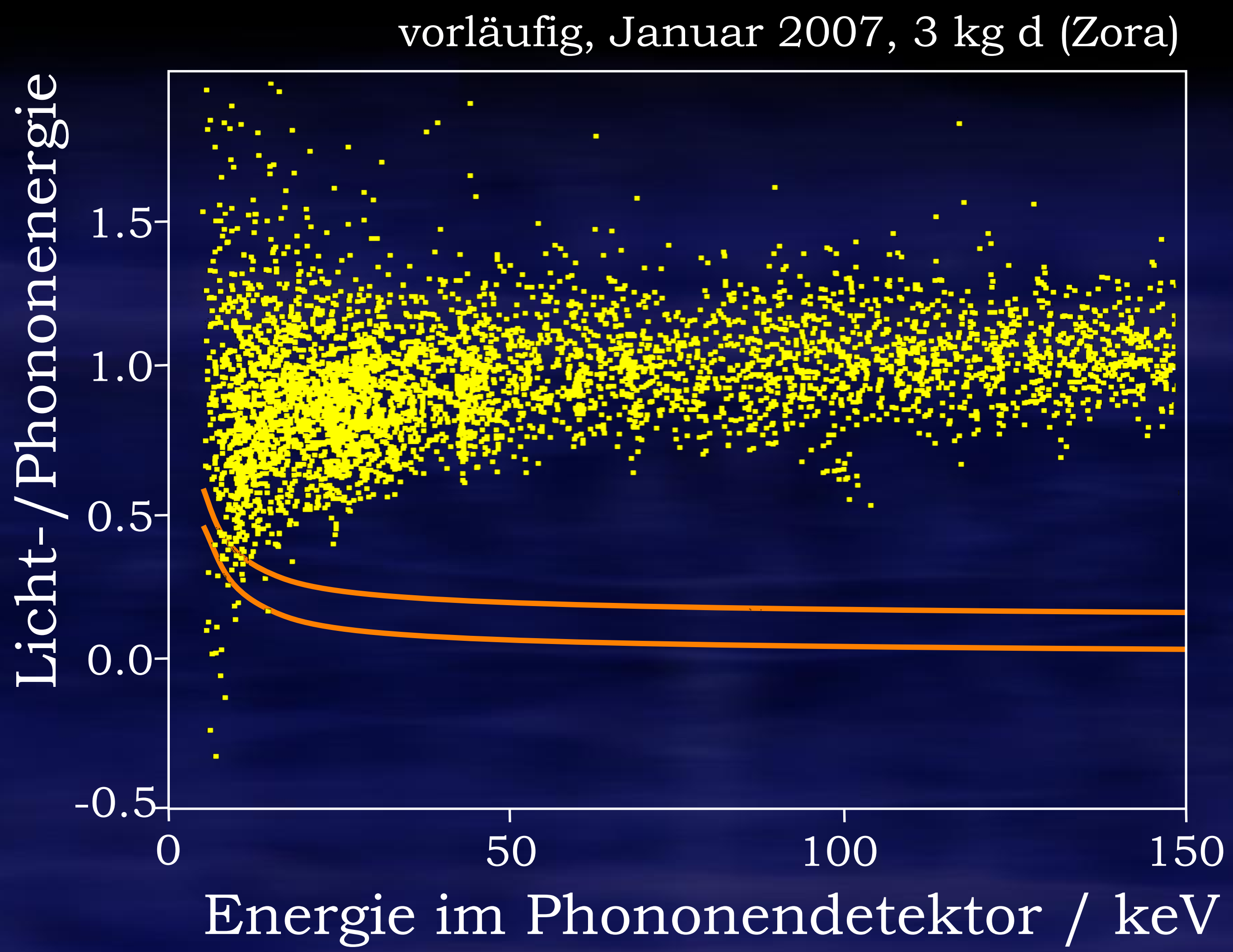




CRESST – SQUID system and detectors



CRESST *2007 preliminary (only 3kg d)*



with neutron shield and alpha recoil rejection

Future

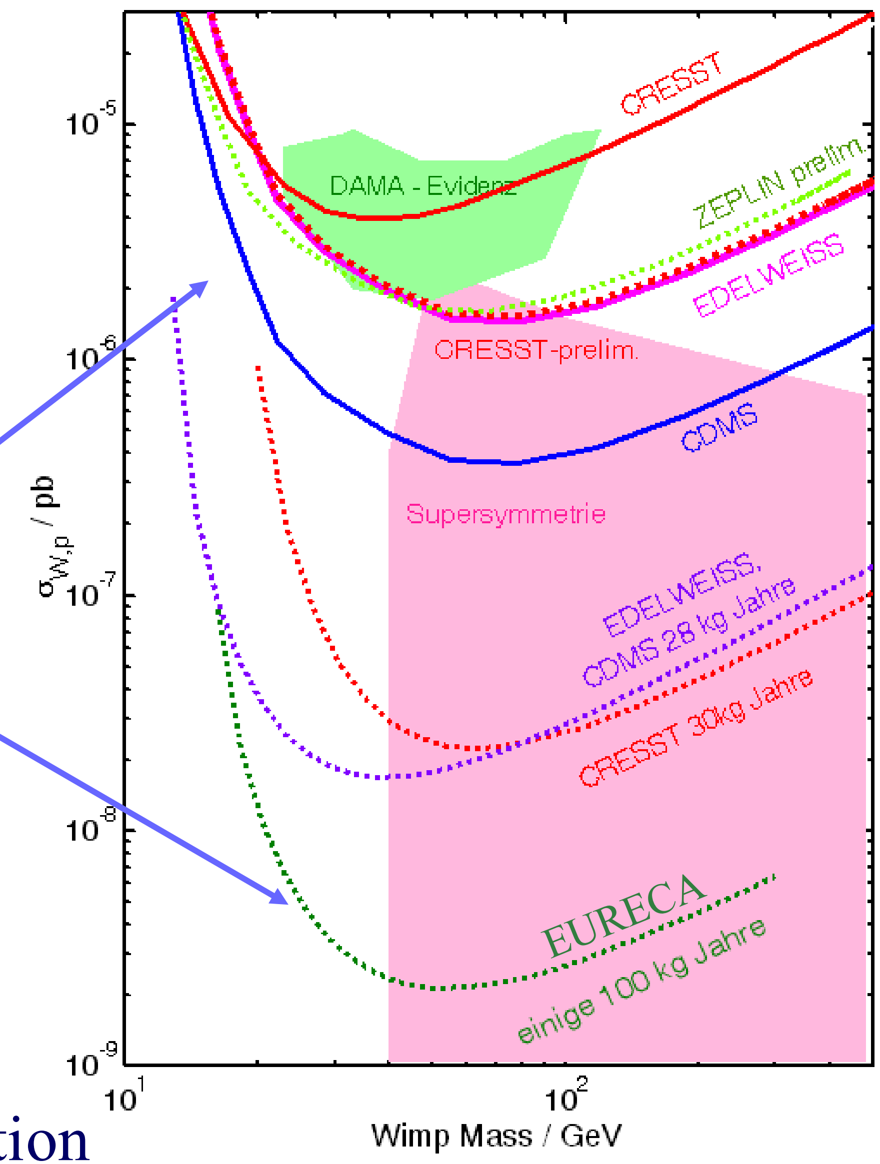
so far : ~ 1kg targets
in preparation: ~ 10kg targets

=> expect new results soon

long term:

increase sensitivity
1/week/kg
to
a few/year/100kg

- very very good background control
- some 100kg of cryogenic detectors



=> EURECA Collaboration