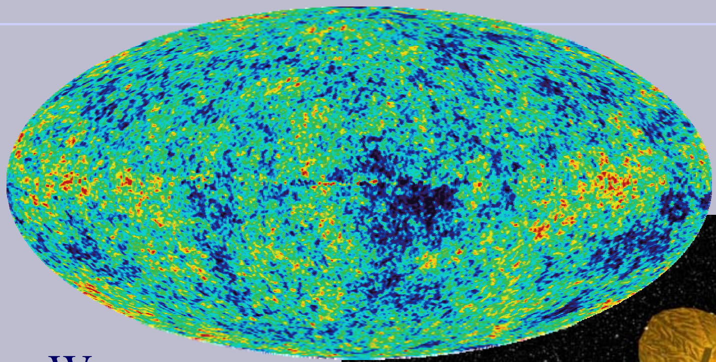
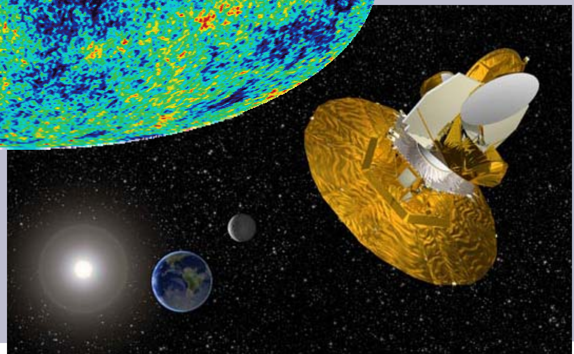
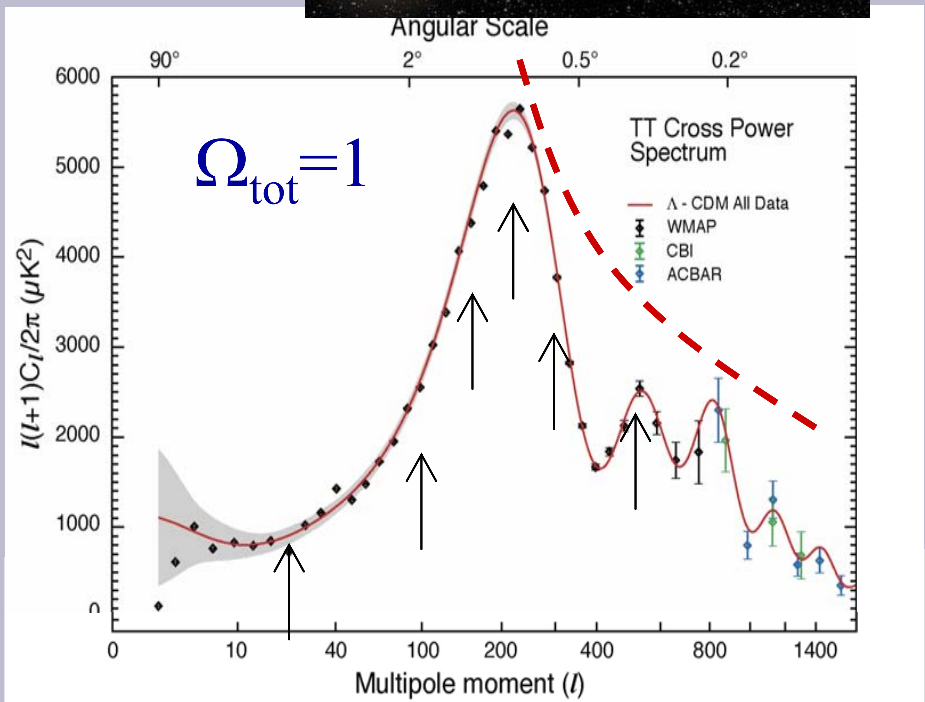

Cryogenic Detectors
Direct Dark Matter Search
Dark Matter
Cryogenic Detectors
CRESST Project

Cosmic Microwave Background – Matter-Density Ω_{matter}





Wilkinson
Microwave
Anisotropy
Probe



Anisotropy:

Angular scale => geometry, Ω_{tot}

Intensities => gravitational potentials, matter densities

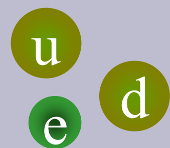
- gravitation Ω_{matter}
- coupling to radiation Ω_{baryon}

$$\Omega_{matter} = 0.27$$

=> Ω_{matter} φ $\Omega_{lum} = 0.01$

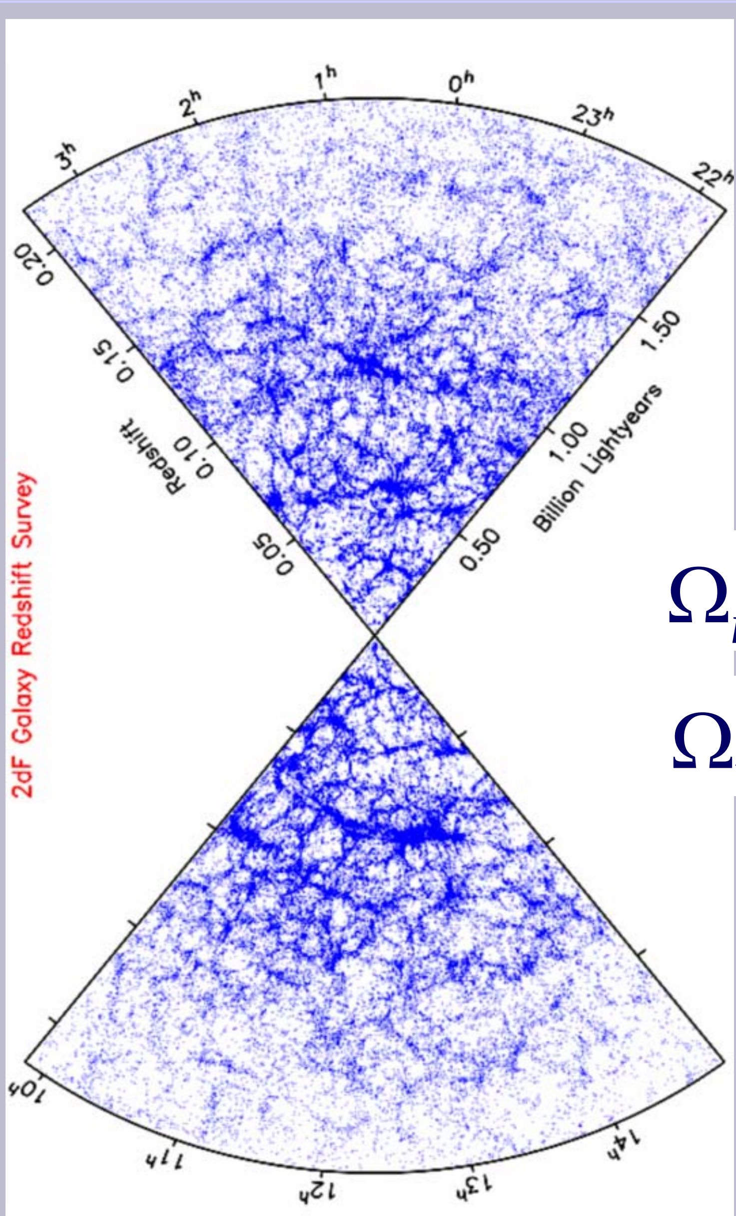
mostly Dark Matter

$$\Omega_{baryon} = 0.044$$



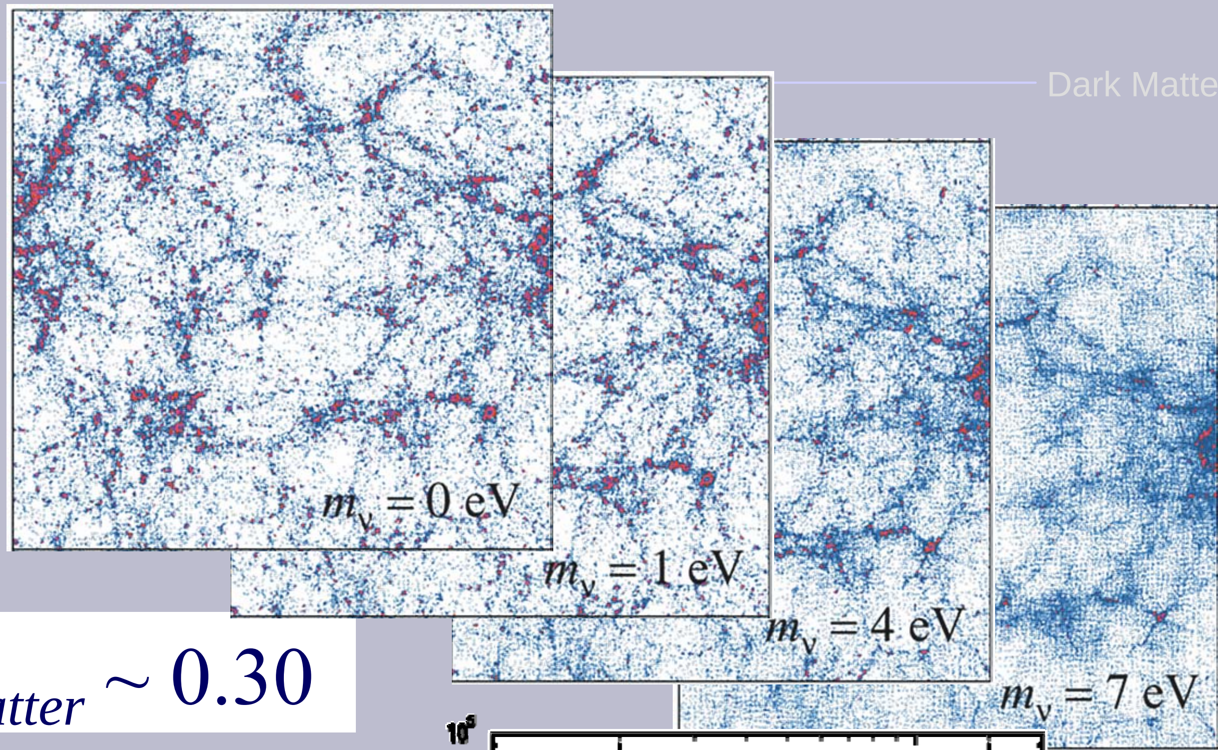
$$\Rightarrow \Omega_{matter} >> \Omega_{baryon}$$

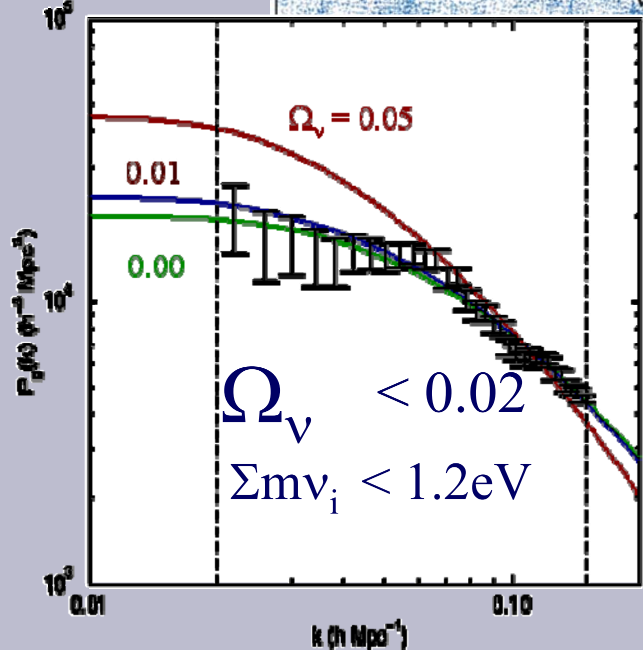
Structure in the Universe and Neutrinos



$\Omega_{matter} \sim 0.30$

$\Omega_\nu < 0.02$





$\Omega_\nu < 0.02$

$\Sigma m\nu_i < 1.2$eV

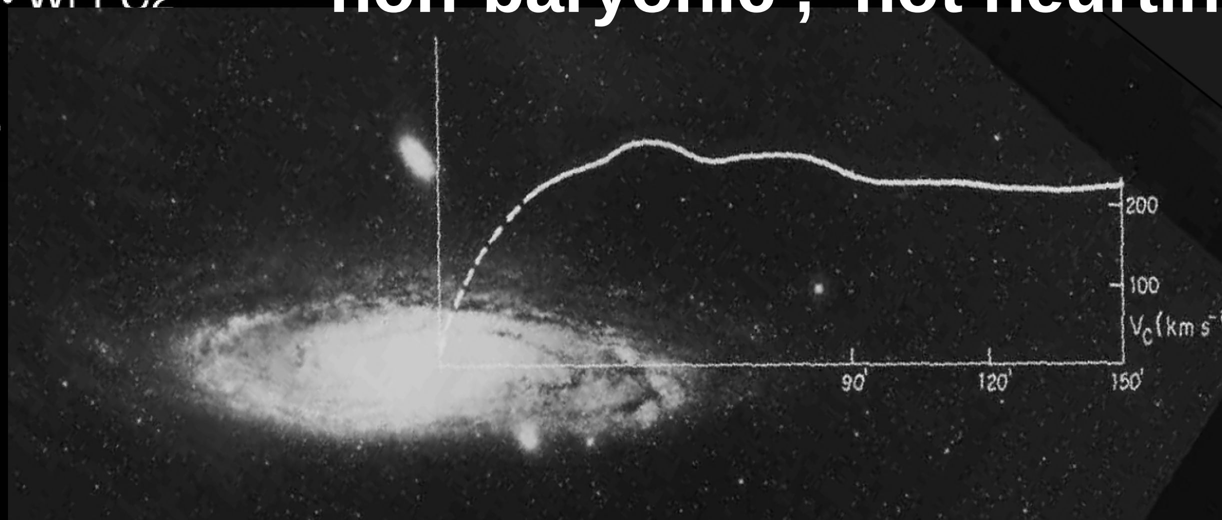
Gravitational Lens HST • WFPC2
Galaxy Cluster 0024+1654
PRC96-10 · ST ScI OPO · April 24, 1996
W.N. Colley (Princeton University), E. Turner (Princeton University), J.A. Tyson (AT&T Bell Labs) and NASA

Cosmic Microwave Background
Nucleosynthesis
Large Scale Structure
Gravitational Lensing
Hot Gas kinetic Energy
Cluster Velocity Dispersion
Galaxy Rotation Curves

$$\Omega_{matter} > \Omega_{lum} \Rightarrow \text{dark}$$

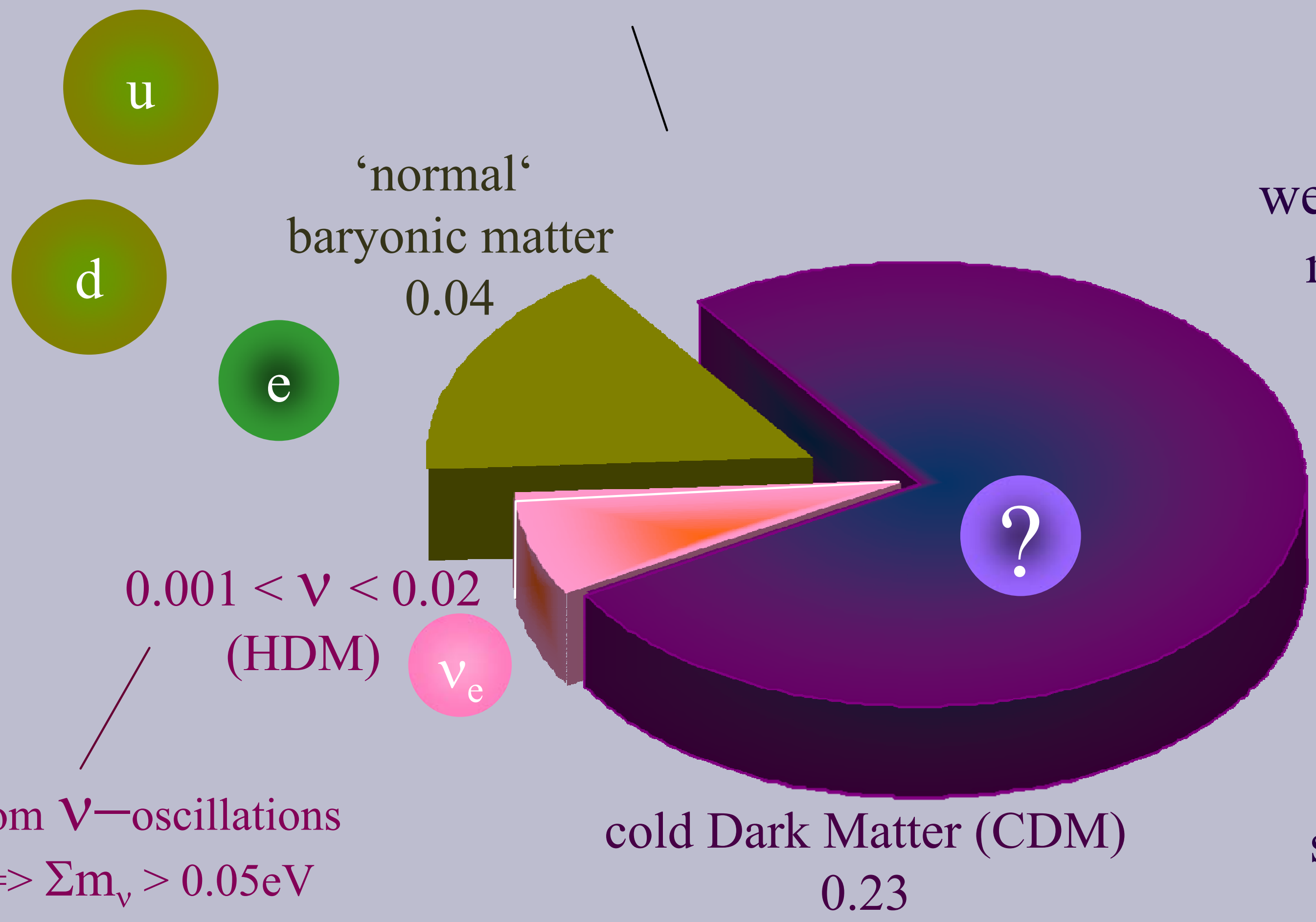
$$\Omega_{matter} > \Omega_{baryons} \Rightarrow \text{exotic}$$

non-baryonic , not neurtinos



Matter in the Universe - Composition

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



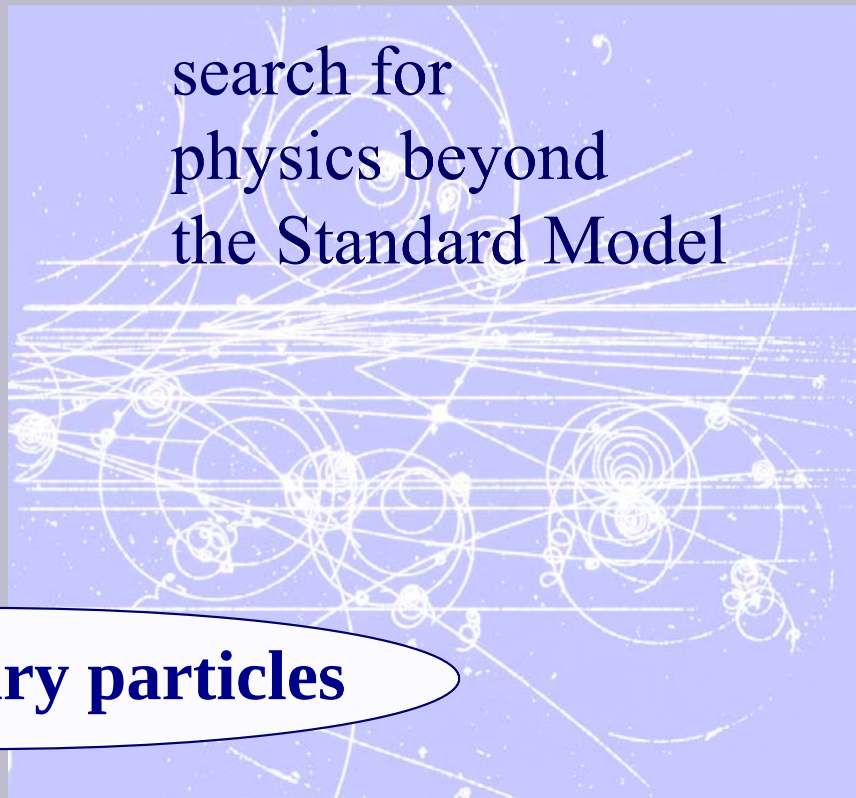
from ν–oscillations
=> $\Sigma m_\nu > 0.05$eV

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

Axions,
weakly interacting,
massive particles
WIMPs
(50GeV~1000GeV
Neutralino?)

$\Rightarrow$

physics beyond
standard model
supersymmetry?



new elementary particles

AXIONs ??? Supersymmetry ??? ….

Beyond the Standard Model

SUSY,
unification of
fundamental interactions
why flavour-symmetry,
CPT & Lorentz inv.
extra dimensions

Cosmology

Dark Matter and Dark Energy
structure formation
nucleosynthesis
leptogenesis, baryon-asymmetry
supernovae
UHE cosmic rays

Experiments

high energy

high precision

Neutrino Physics

neutrino-oscillations
finite neutrino mass => SM ?

absolute mass scale ?
Majorana- or Dirac?
right handed neutrinos ?
CP violation ?

search for:

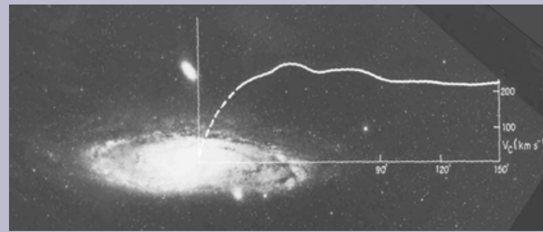
- neutrino less double beta decay
- Dark Matter particles

rare effects
=>
very good knowledge on background

How to detect WIMP – Dark Matter

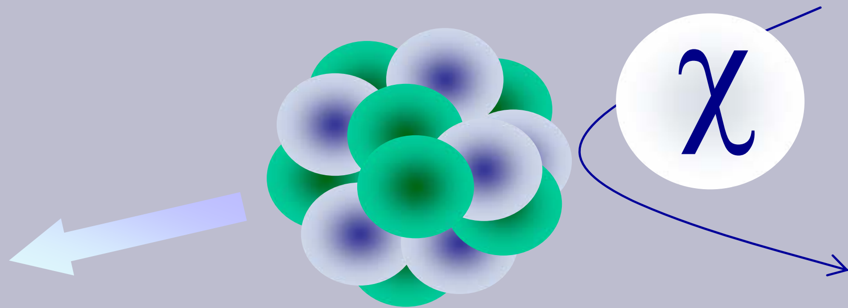
***W**eakly **I**nteracting **M**assive **P**articles = WIMPs*

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 /cm^2*

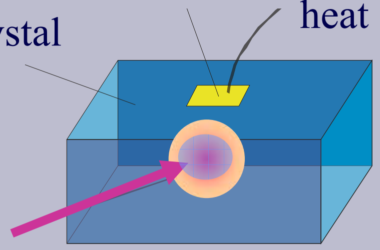
⇒ very very rare scattering events (< 1 / week / kg)

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

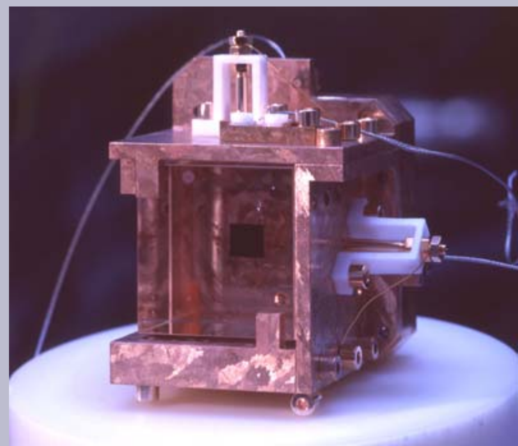
low
energy threshold

wide choice of
absorber materials

thermometer types:

superconducting phase
transition thermometers (SPT)

NTD - Ge thermistors
(highly doped semiconductors)

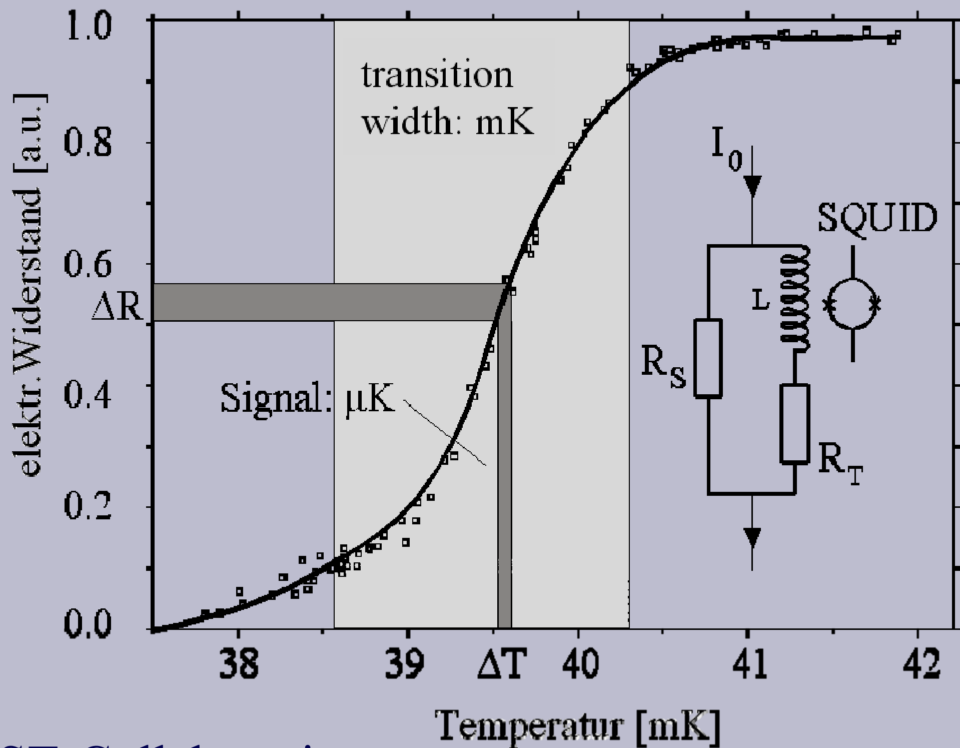


Superconducting Phase Transition Thermometer

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

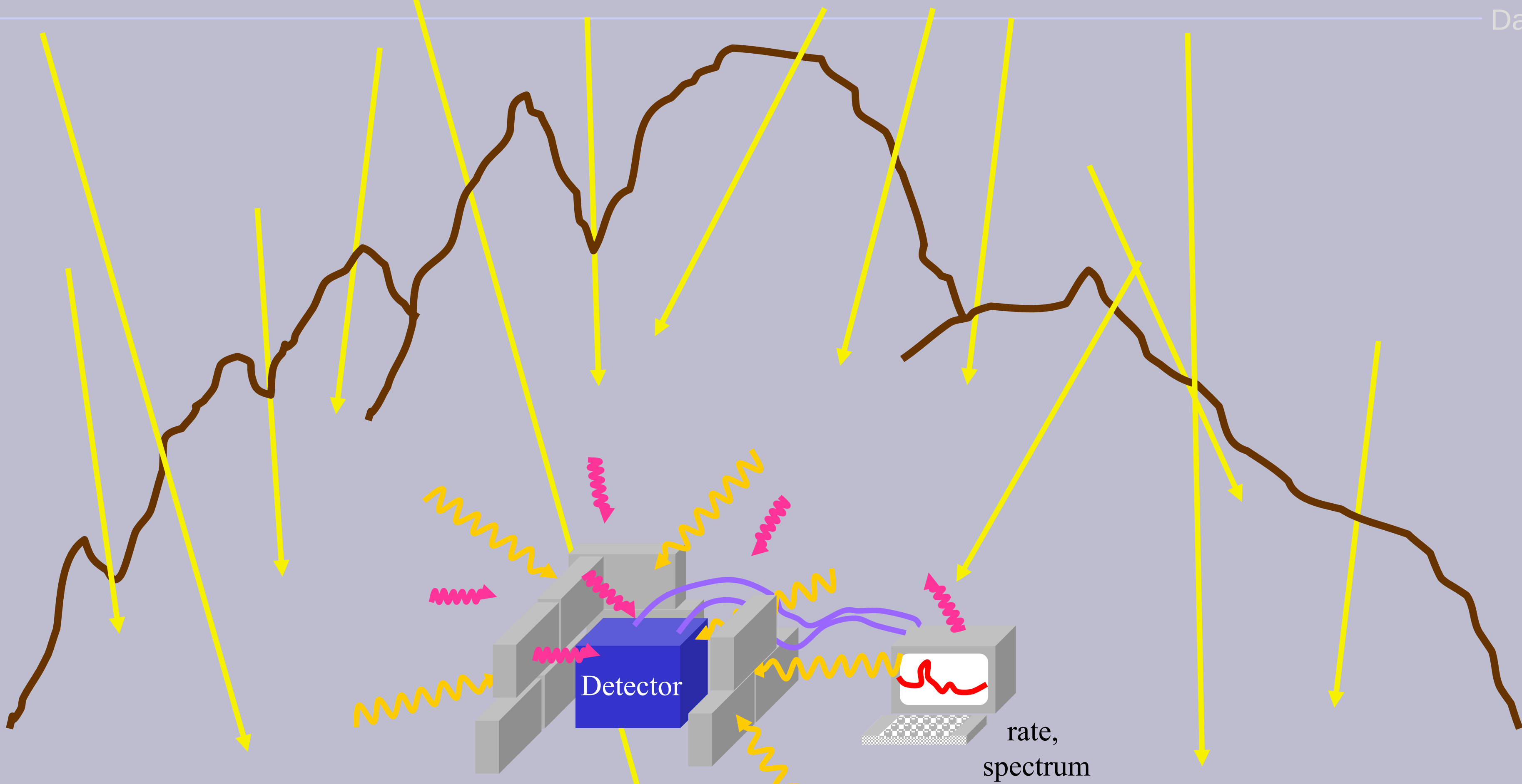


CRESST-Collaboration

Cryogenic Rare Event Search with Superconducting Thermometers

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

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

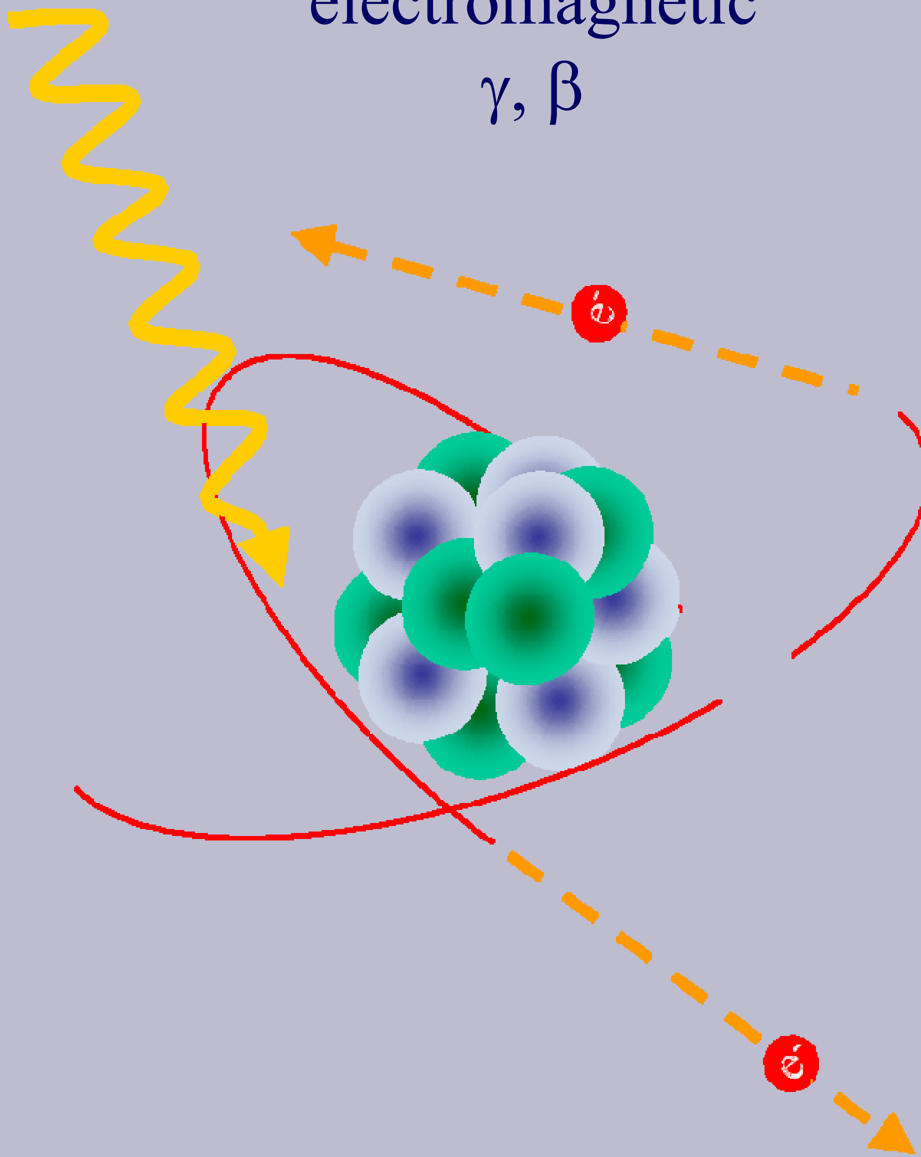
WIMP Direct Detection - Underground Laboratory

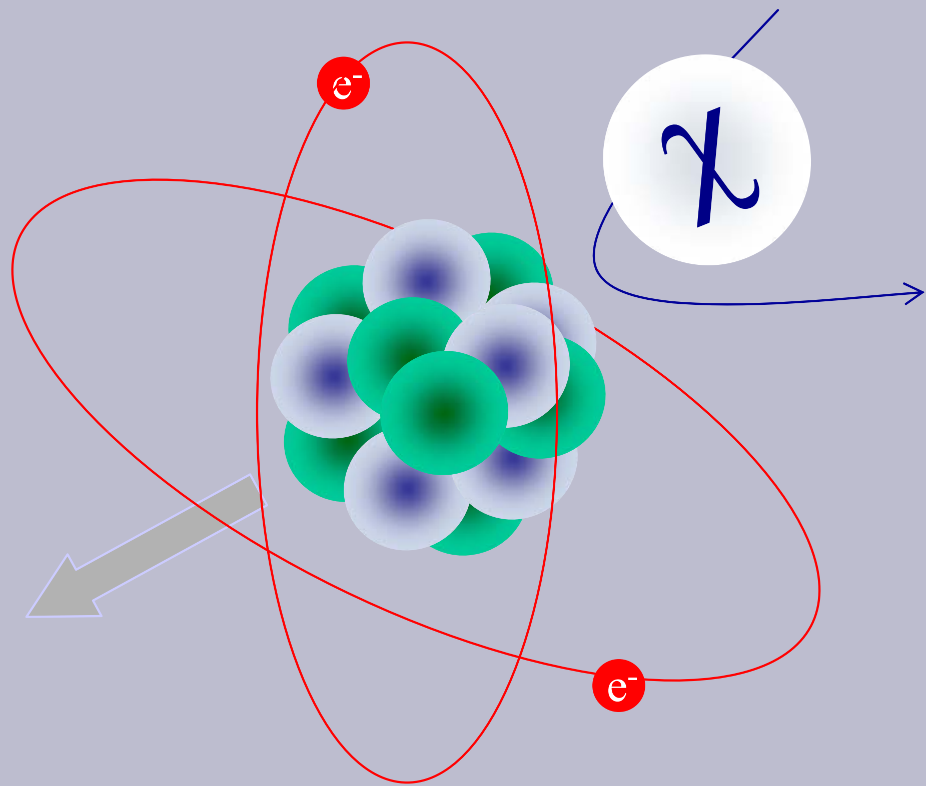
shielding
from
cosmic rays

Soudan Mine USA

electromagnetic
γ, β

nuclear recoils





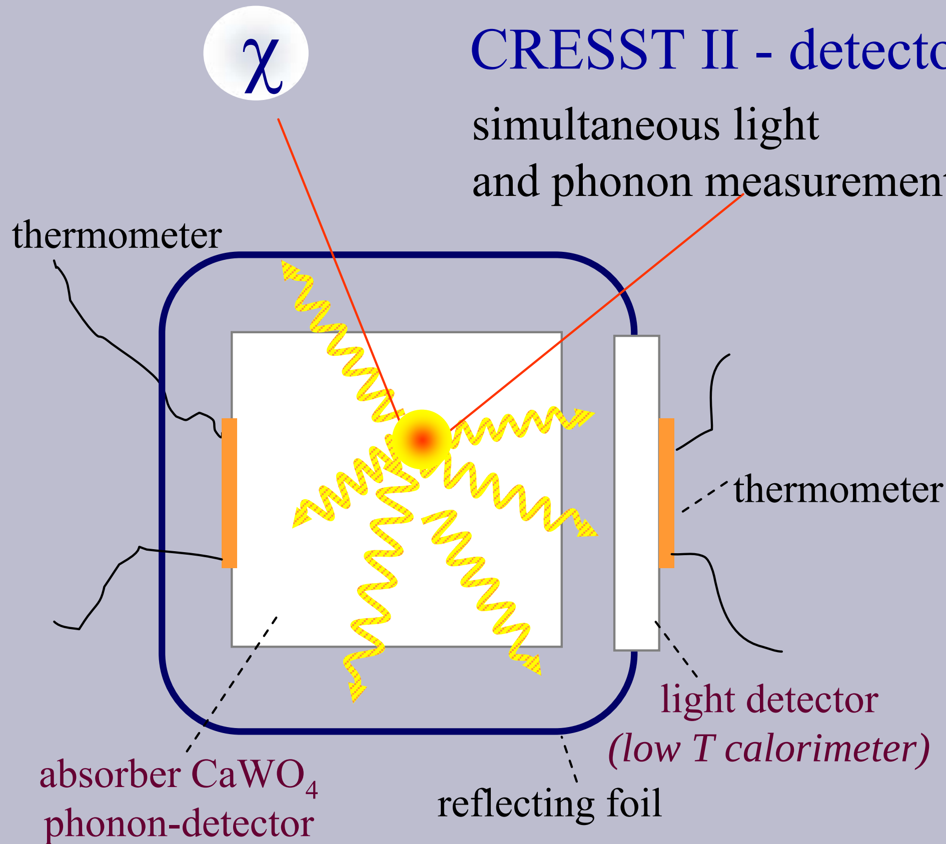
ionisation
(charge, scintillation light)

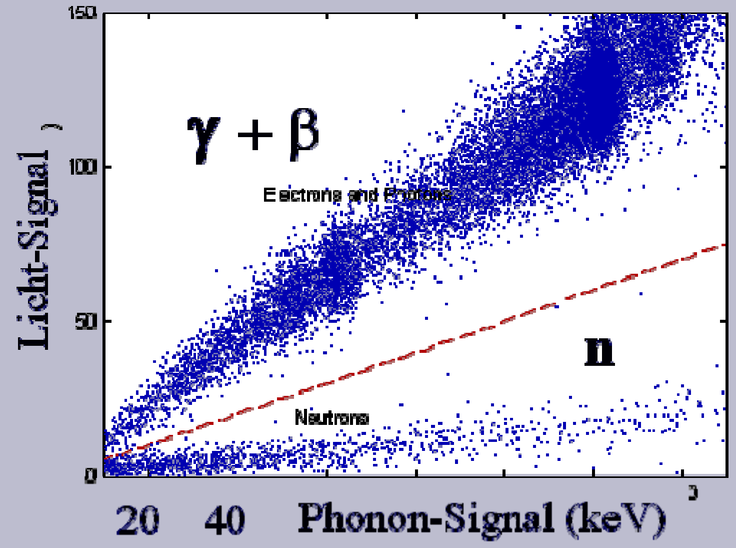
phonons
only little ionisation

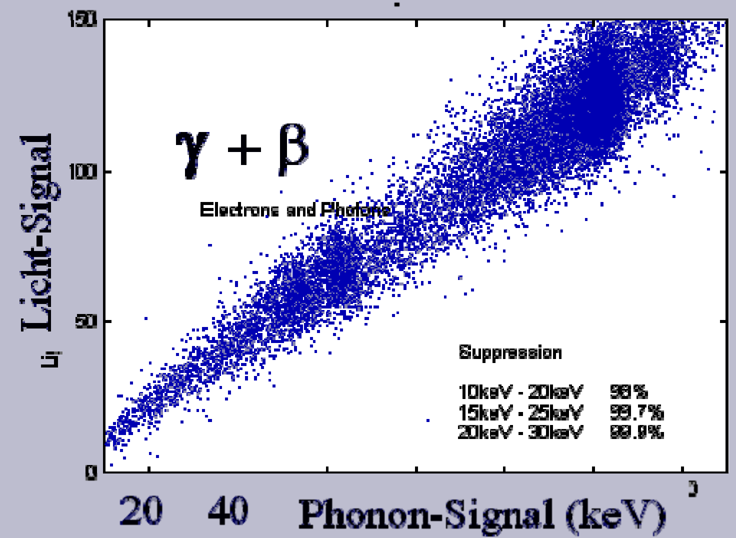
Phonon + Charge / Light Measurement => recognize Background

CRESST II - detectors

simultaneous light
and phonon measurement

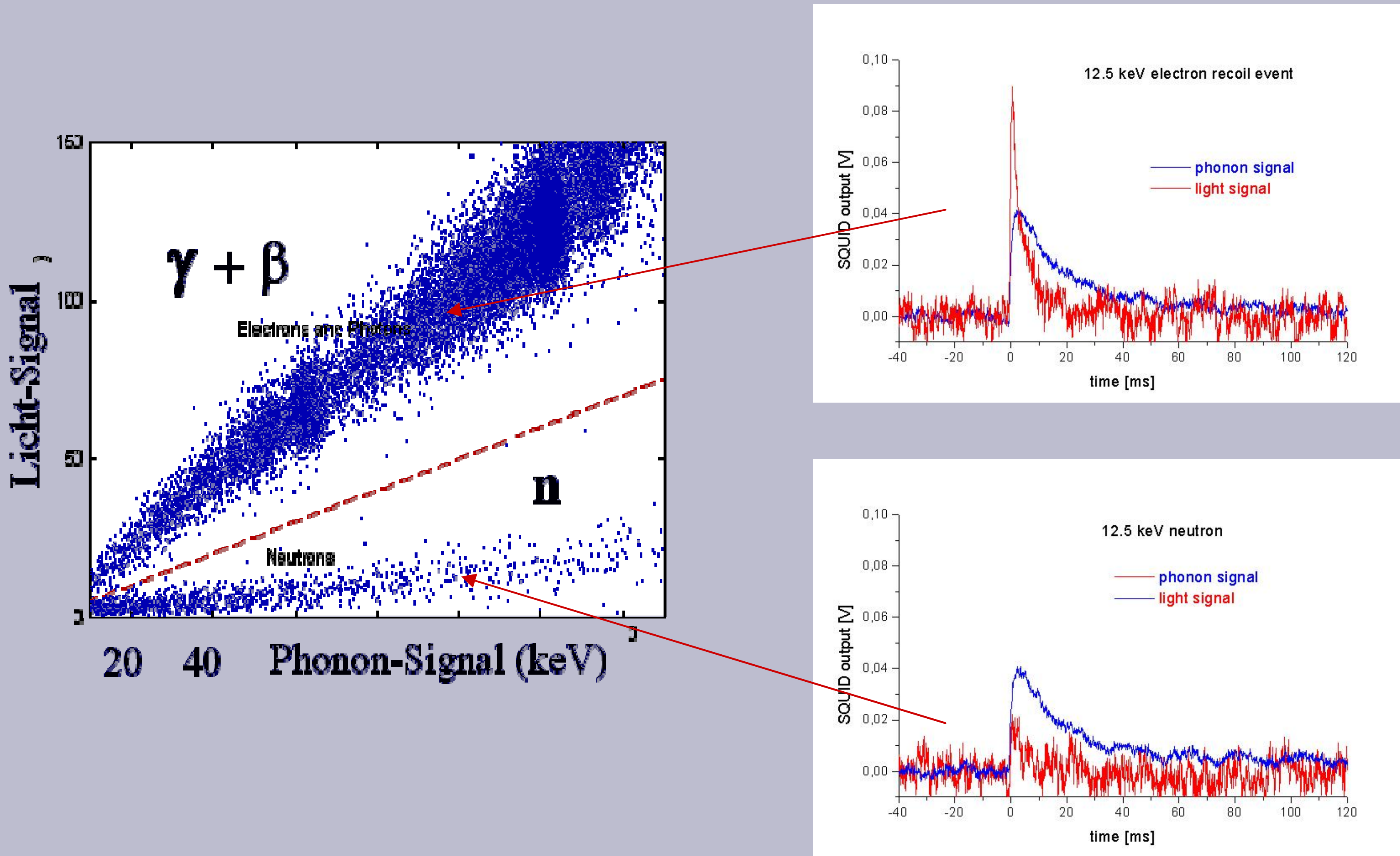




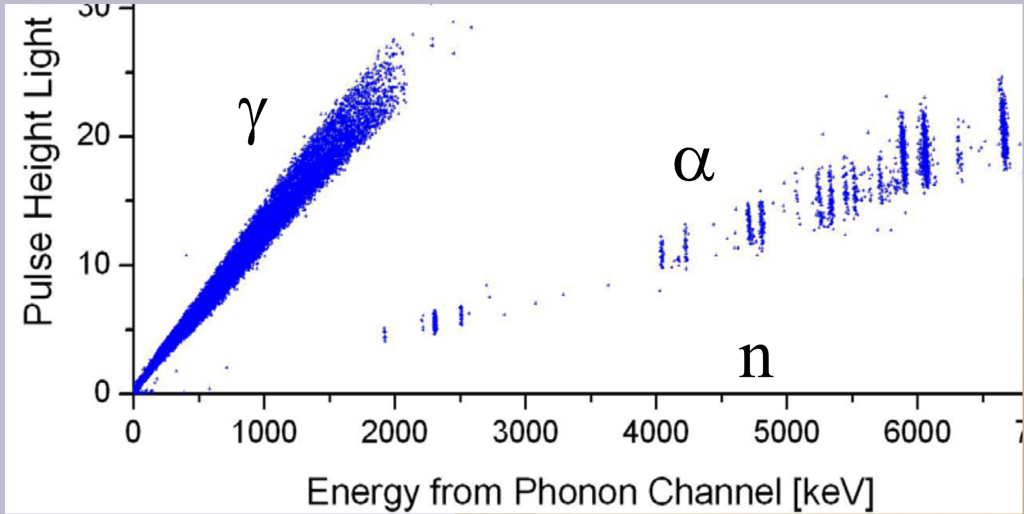


CRESST – Cryogenic Rare
Event Search with Superconducting
Thermometers

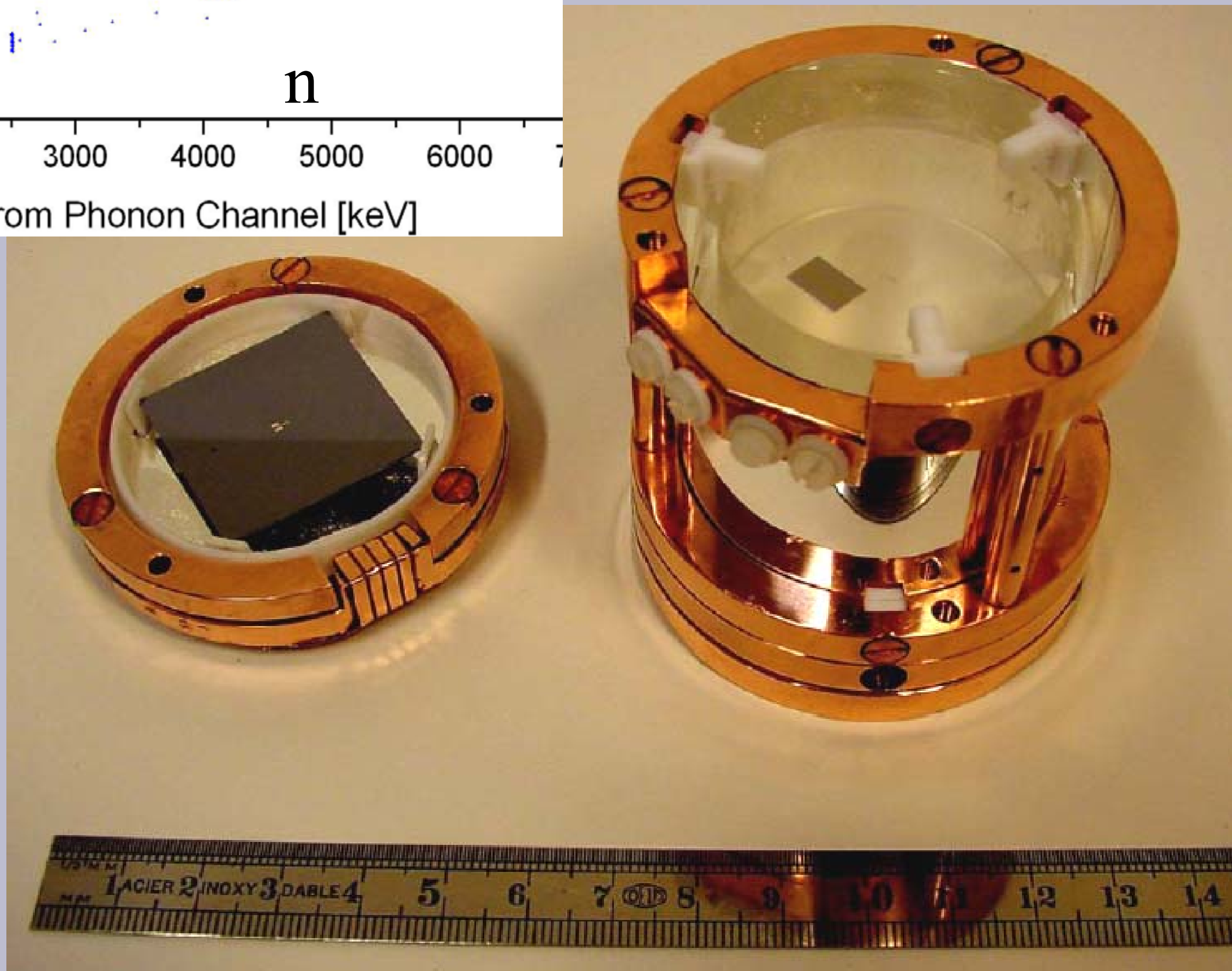
CRESST Light Phonon Detectors



CRESST Light Phonon Detectors - Particle Identification



$CaWO_4$

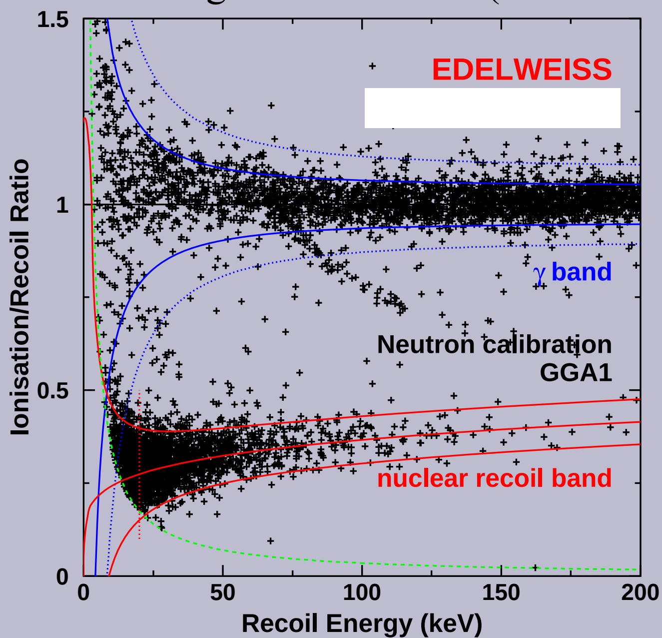


WIMP Direct Detection – Event by Event Discrimination

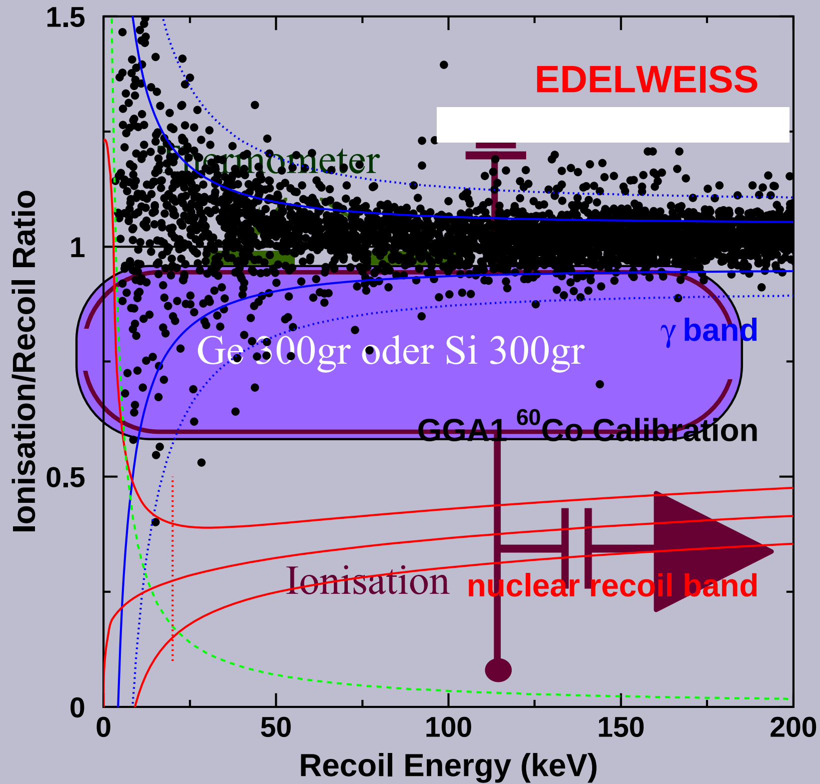
EDELWEISS (France) und CDMS (USA) Dark Matter Projects

Ioniosation-Phonon
320g Ge-Detector

Testmessung mit Neutronen (=> Kernrückstöße)



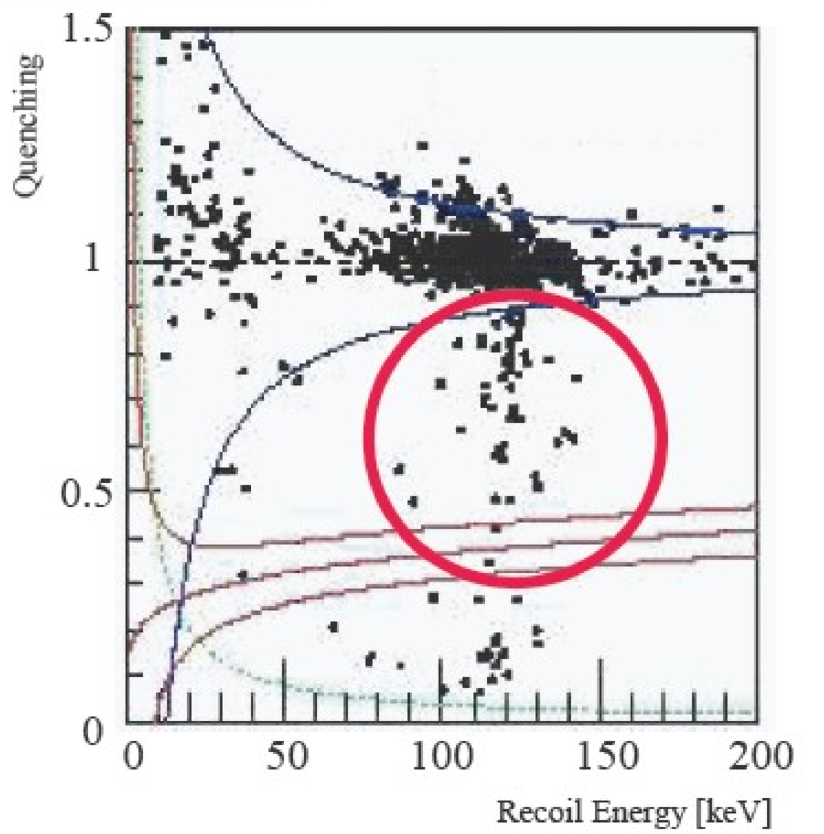
'Low Background Data'



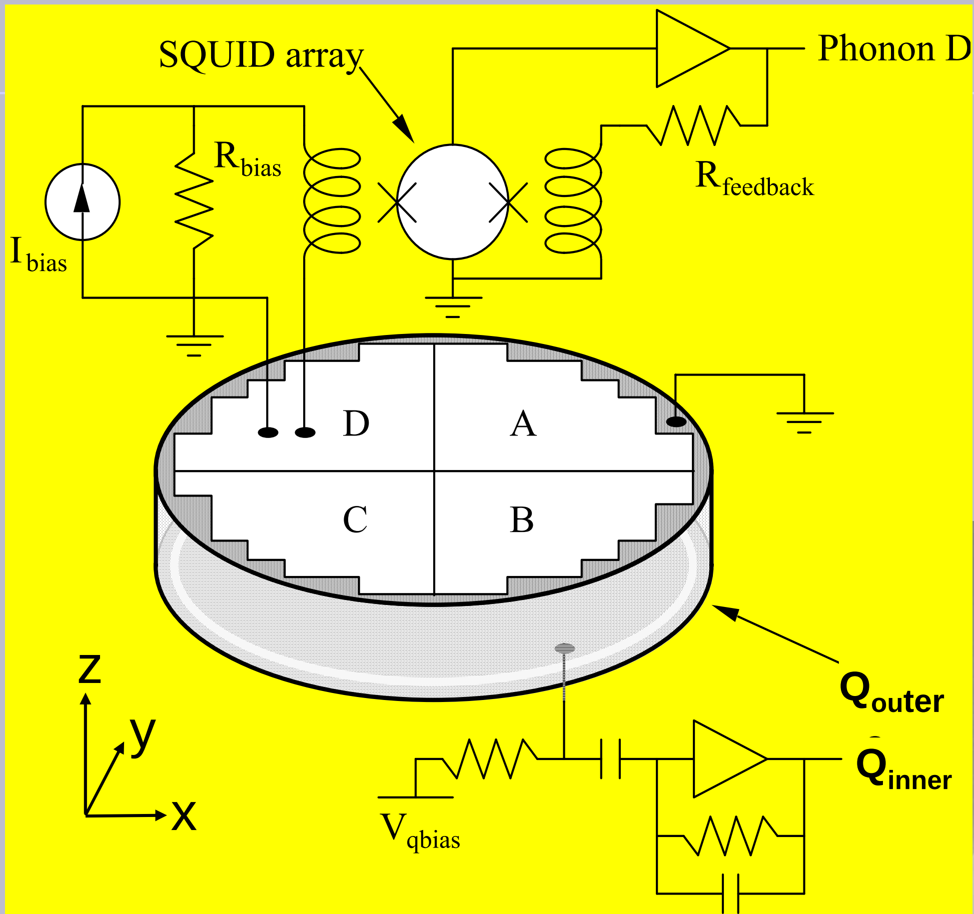
Heat / Charge - *reduced charge collection from surface*

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

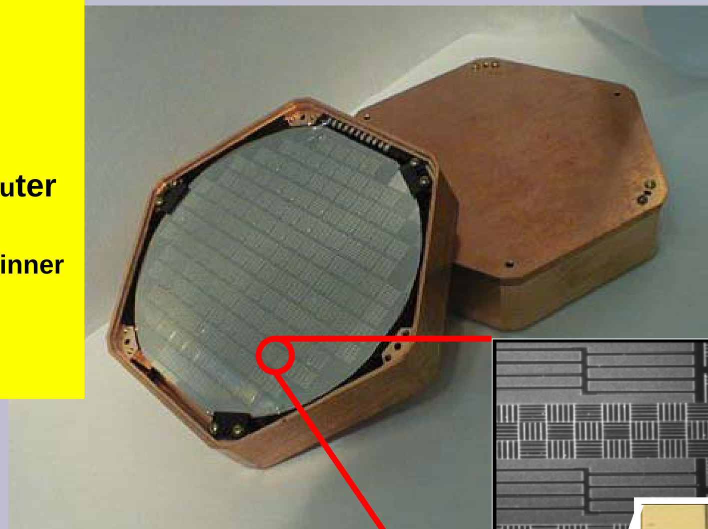
Most of the EDELWEISS R&D is concentrated on this problem

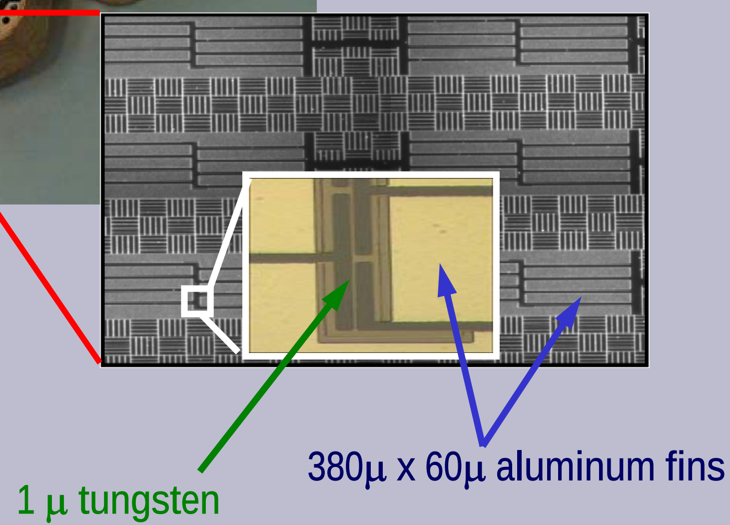


CDMS *Charge & Phonon Detectors*



- 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

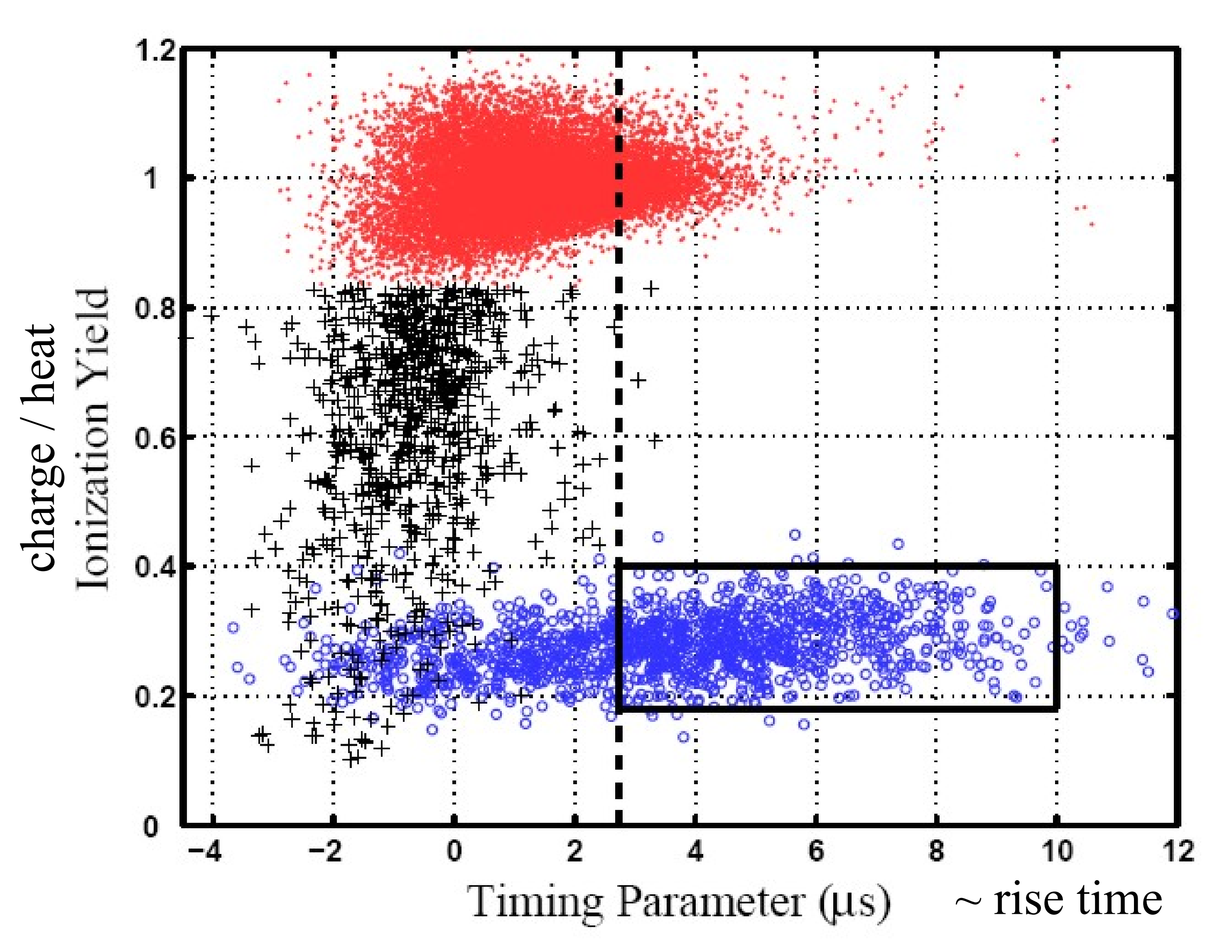




- Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer edge

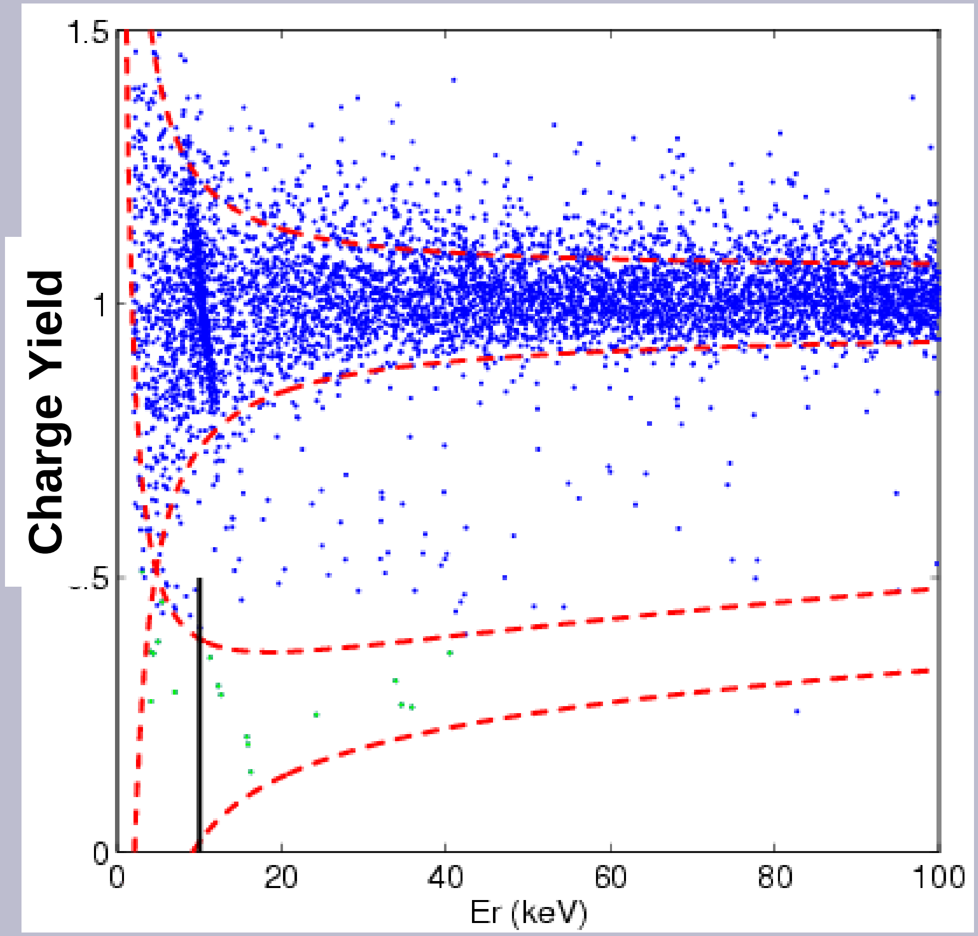
  2 charge electrodes:
  - "Inner" fiducial electrode
  - "Outer" guard ring

CDMS Timing Cut – remove near surface events

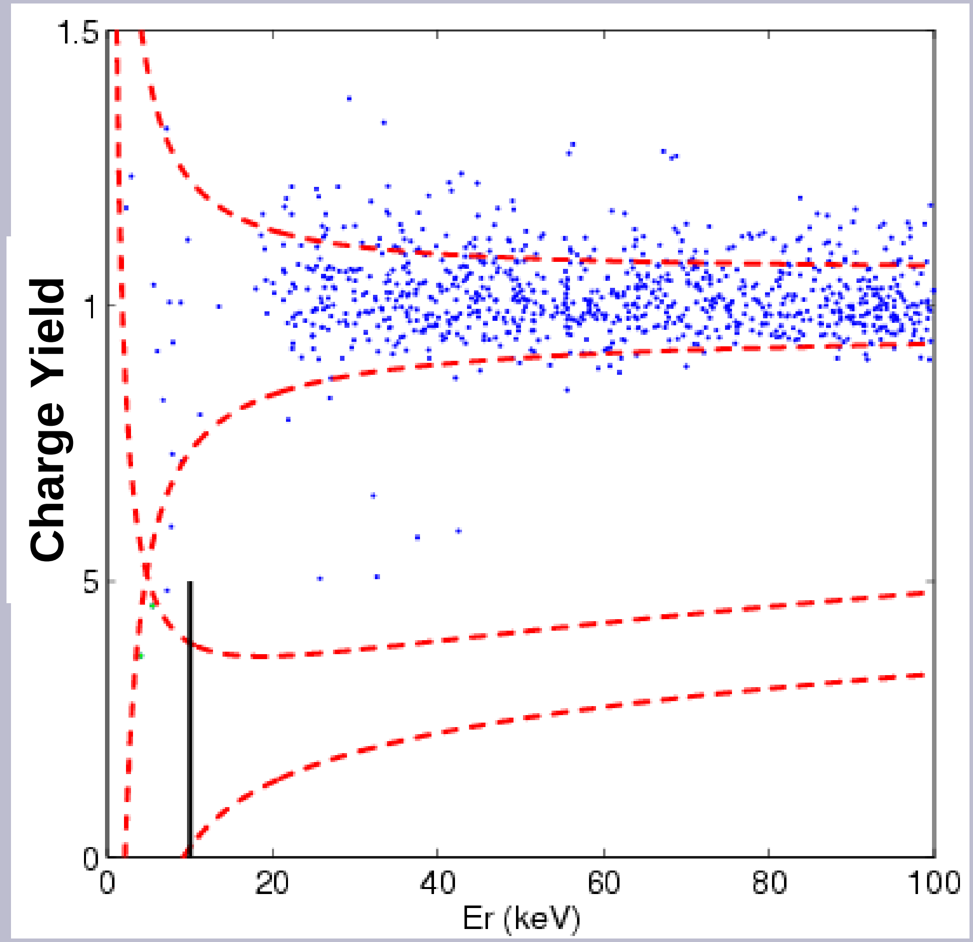


CDMS data 2004/2005

Prior to timing cuts

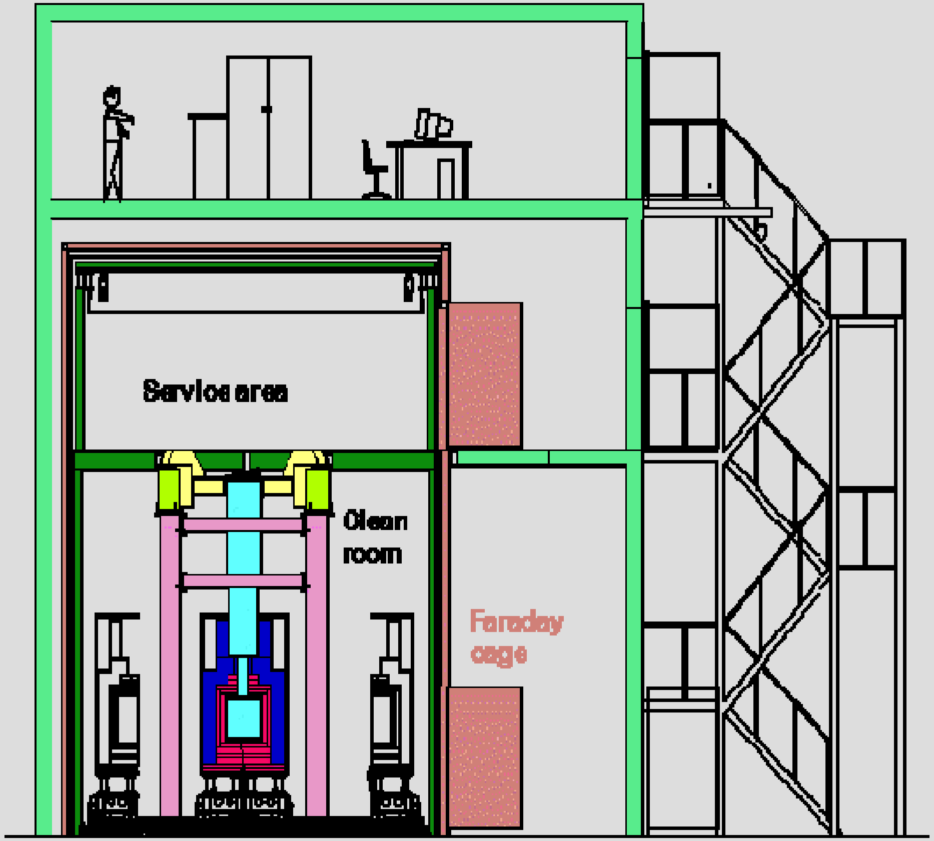


After timing cuts

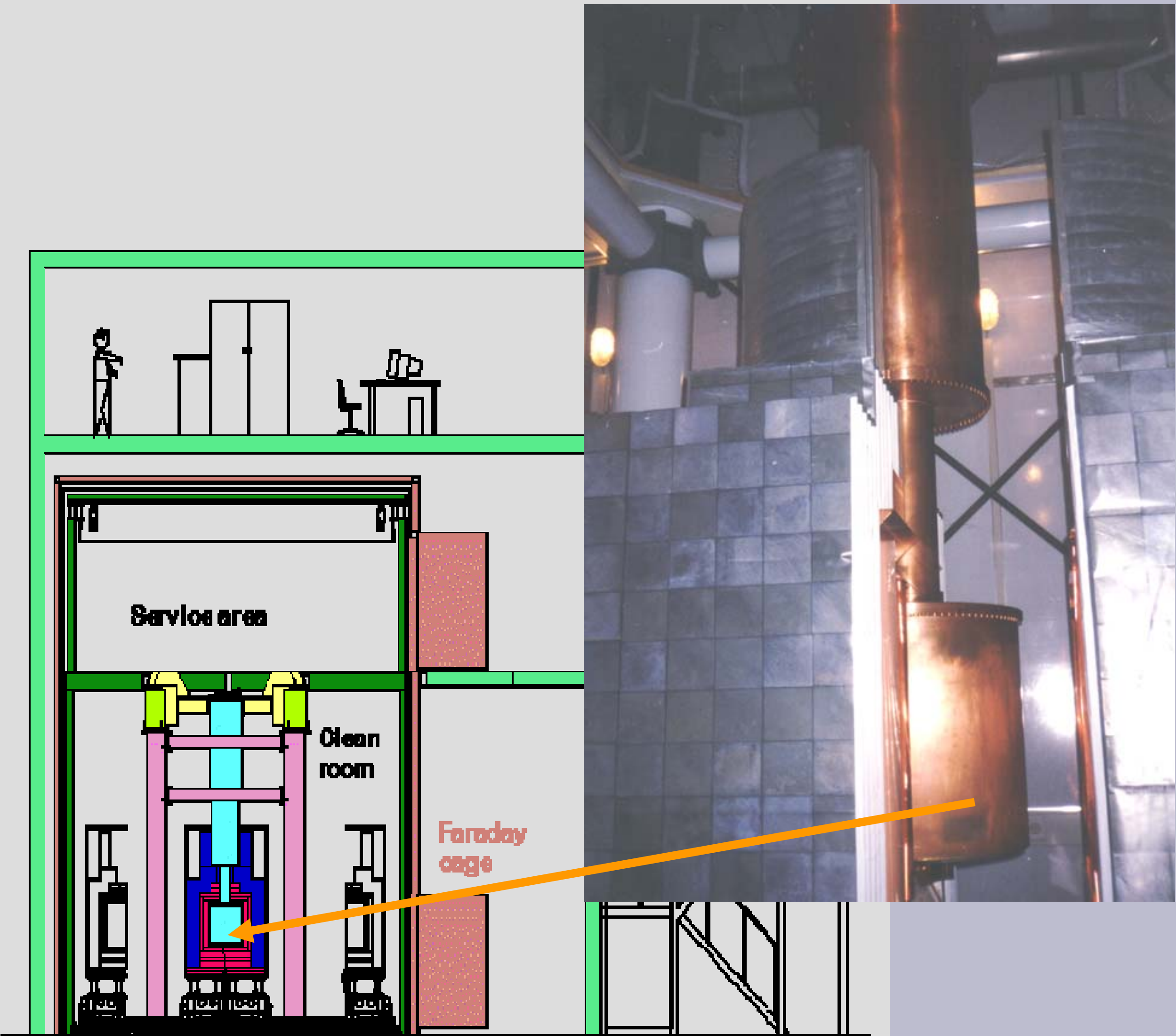


CRESST at Gran Sasso Underground Laboratory

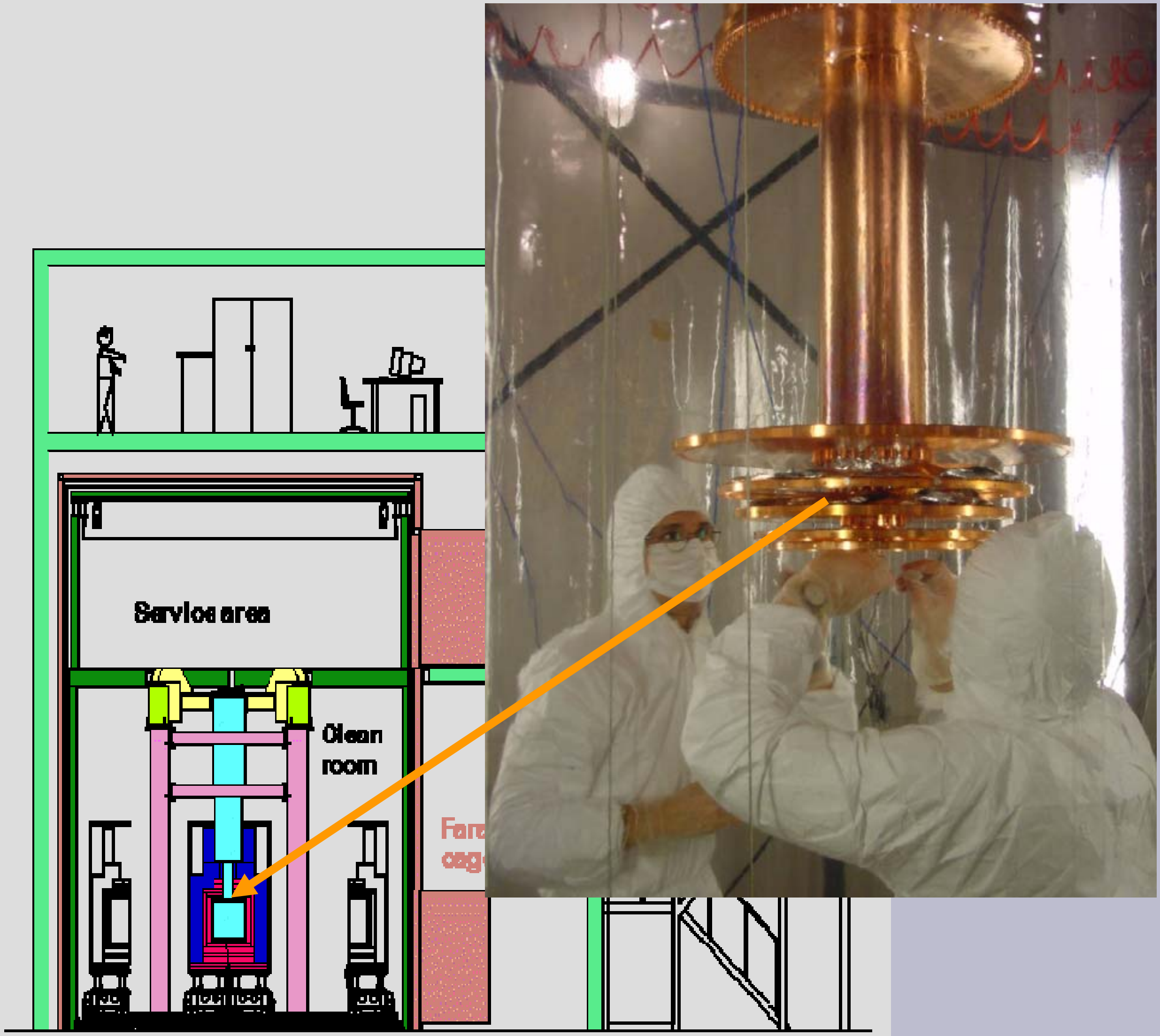
Max-Planck-Institut München
TU München
Universität Tübingen
Oxford University
Gran Sasso Lab



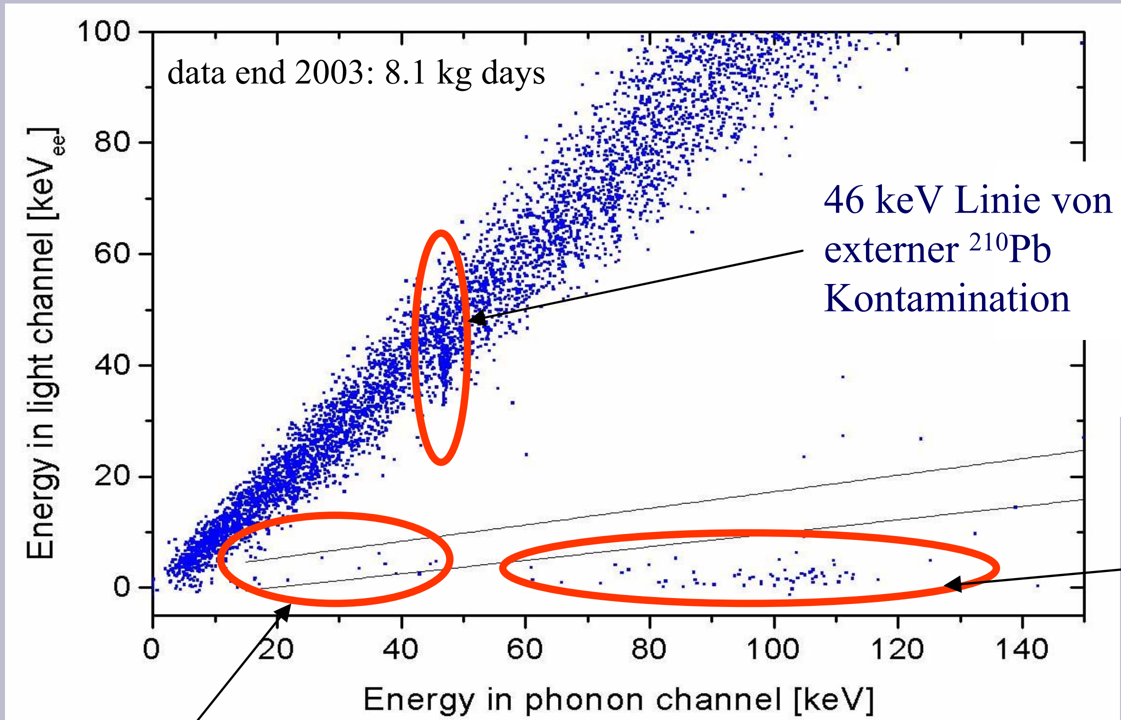
CRESST at Gran Sasso Underground Laboratory

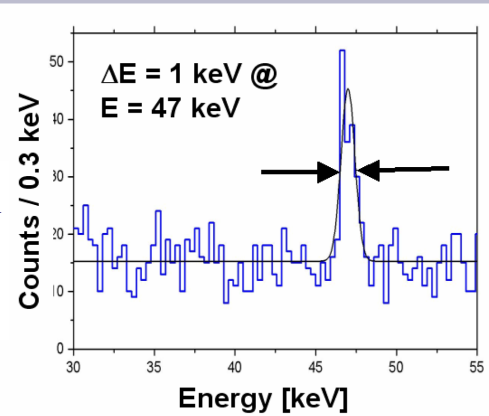


CRESST at Gran Sasso Underground Laboratory



Nuclear Recoils - Examples





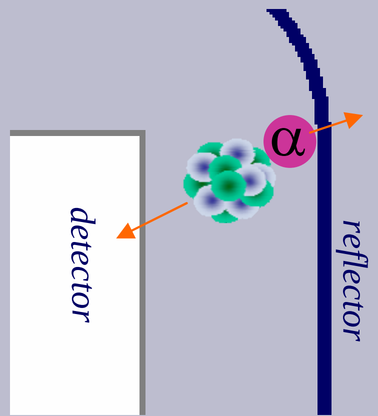
no Beta-Tail => external

recoiling nuclei from α-decays below region of O-recoils
($CaWO_4$, O-recoils dominatte calibration with AmBe-source)

countrate as expected from external neutrons (1 count/kg/day)

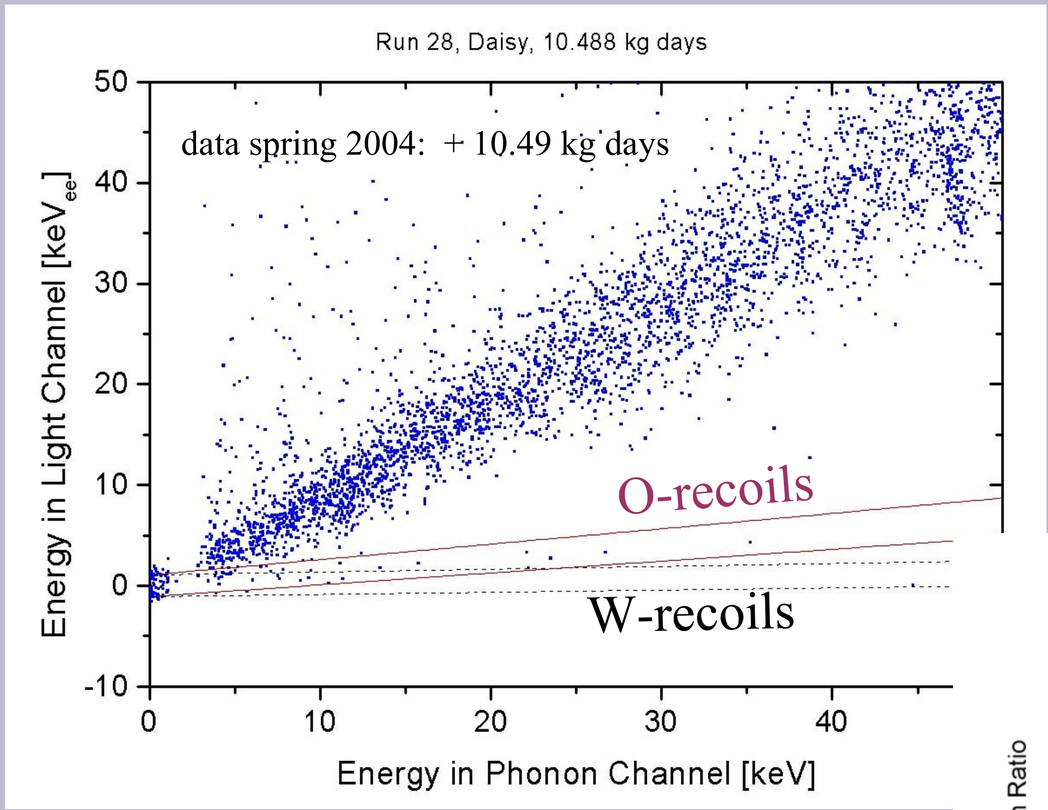
CRESST I   at that time
no neutron shield
only γ: Pb/Cu shield

⇒ meanwhile PE moderator shield and muon-veto



⇒ larger quenching for heavy nucleii ?

CRESST: Results with Phonon-Light Detectors - 2004

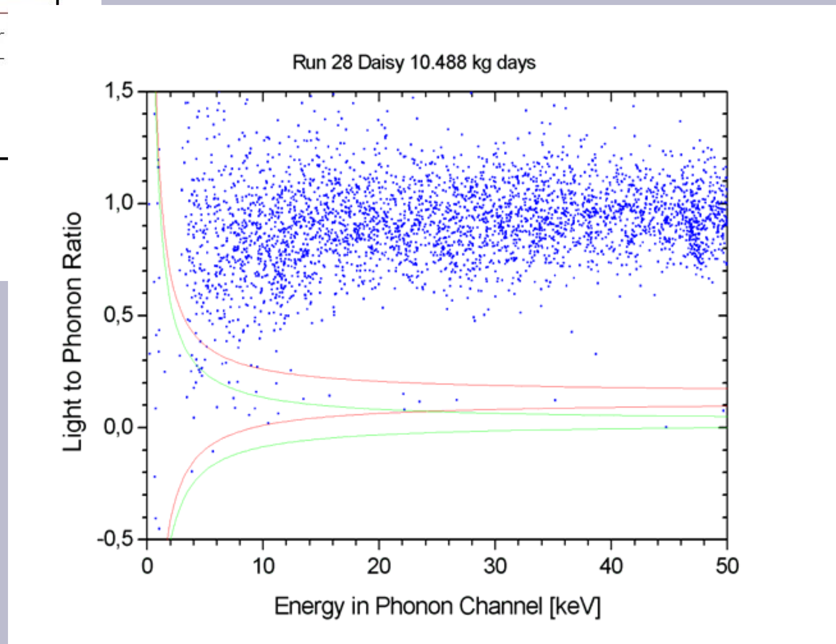


different quenching
factors for O- and W-recoils

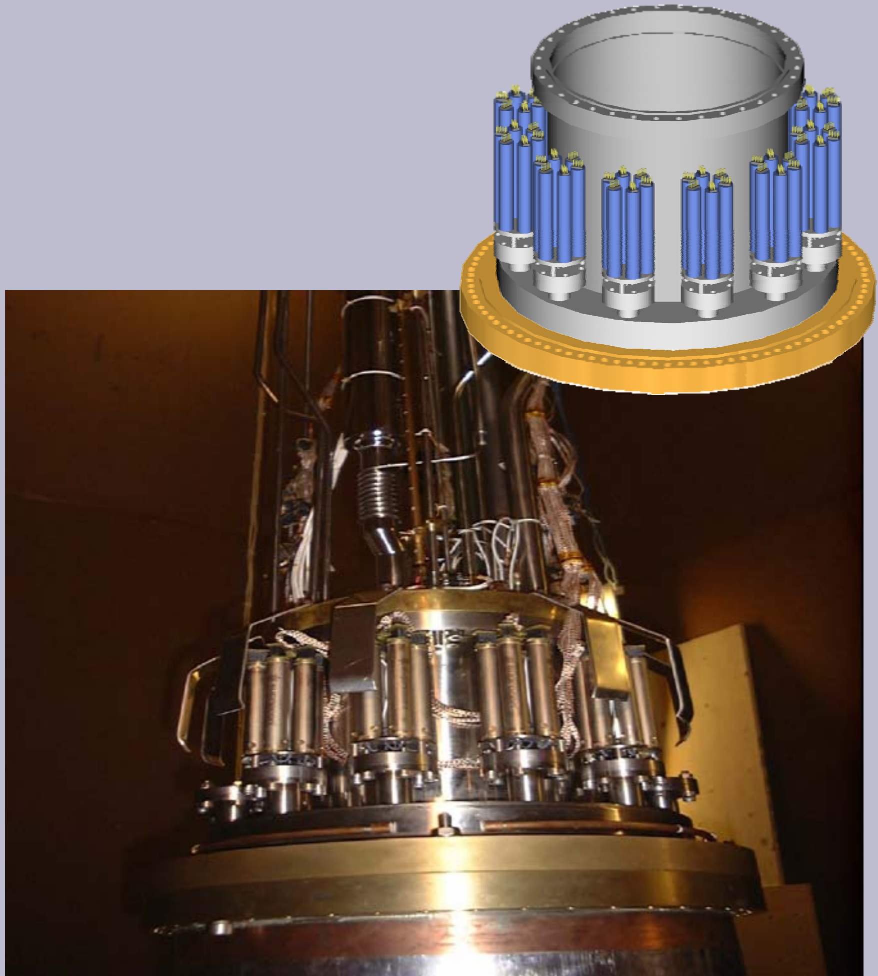
=> distinguish neutrons (O-recoils)
from WIMPs (W-recoils ~A^2) ?

data taken without neutron shield
=> neutron rate as expected from
radioactivity in rock

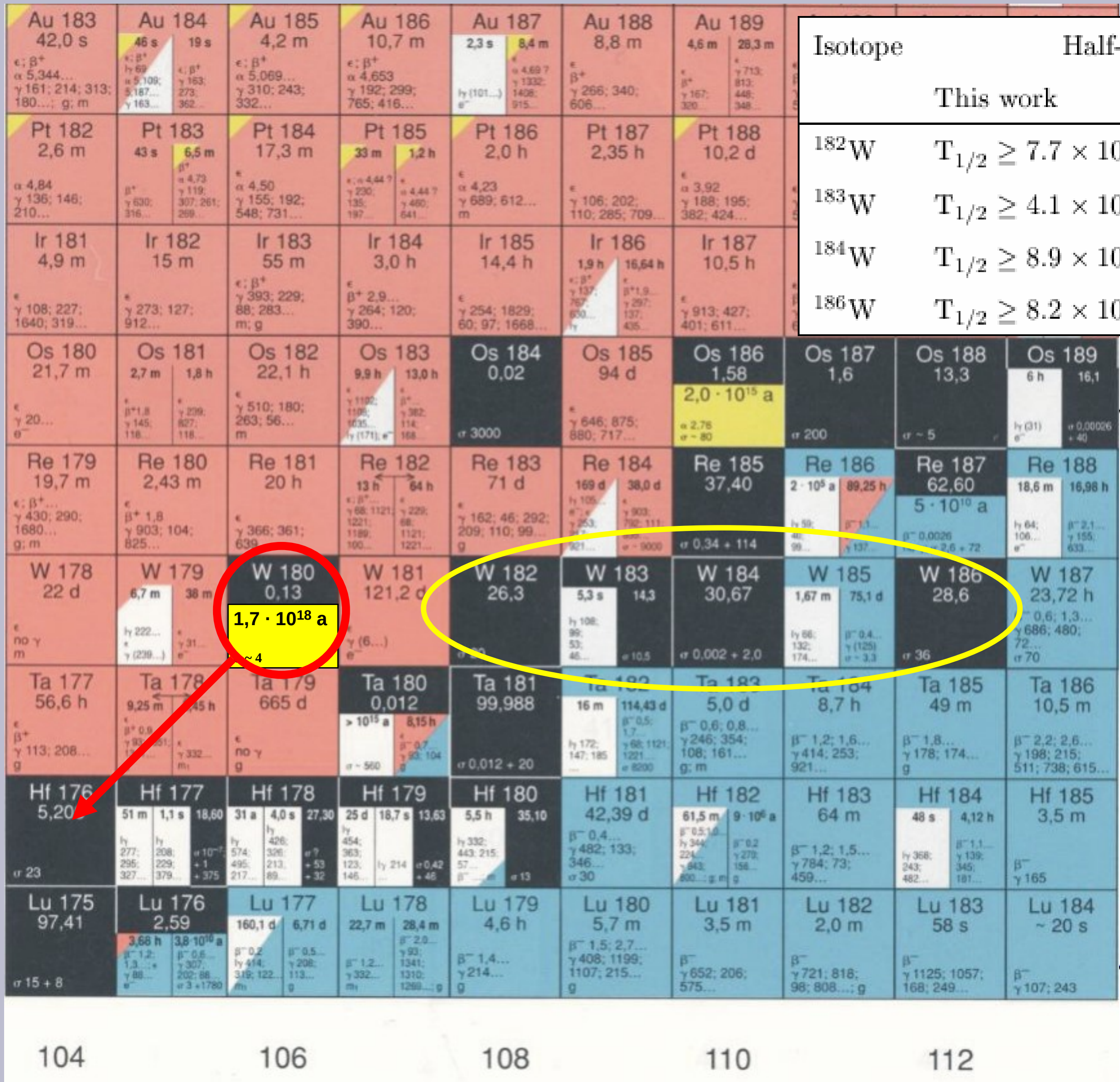
now: 40cm polyethylene around set-up



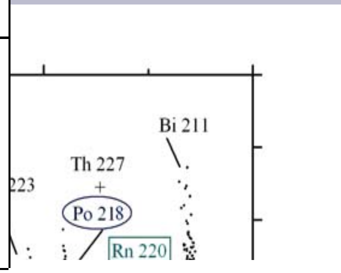
CRESST – 66 channel SQUID system and detectors



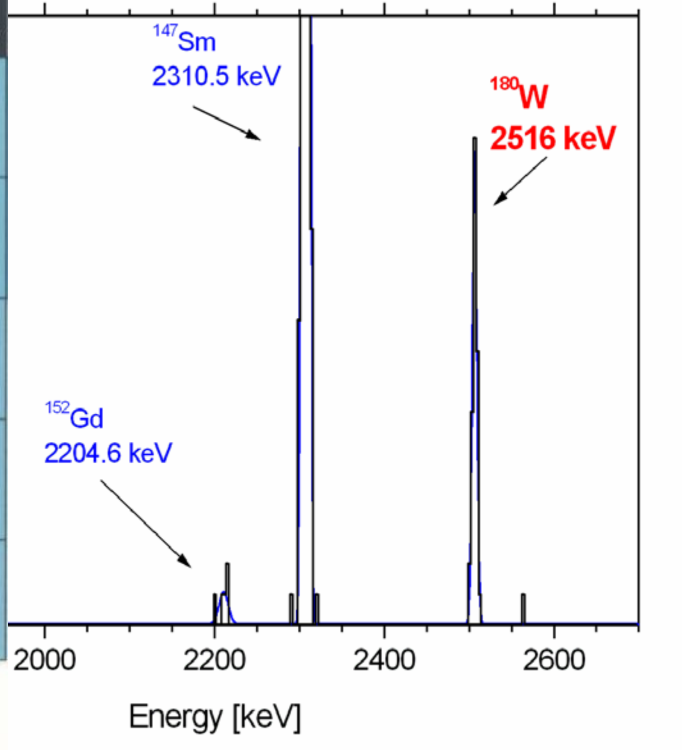
$CaWO_4$ - α Nachweis



Isotope	Half-life time [y]	
	This work	Previous [4]
^{182}W	$T_{1/2} \geq 7.7 \times 10^{21}$	$T_{1/2} \geq 1.7 \times 10^{20}$
^{183}W	$T_{1/2} \geq 4.1 \times 10^{21}$	$T_{1/2} \geq 0.8 \times 10^{20}$
^{184}W	$T_{1/2} \geq 8.9 \times 10^{21}$	$T_{1/2} \geq 1.8 \times 10^{20}$
^{186}W	$T_{1/2} \geq 8.2 \times 10^{21}$	$T_{1/2} \geq 1.7 \times 10^{20}$

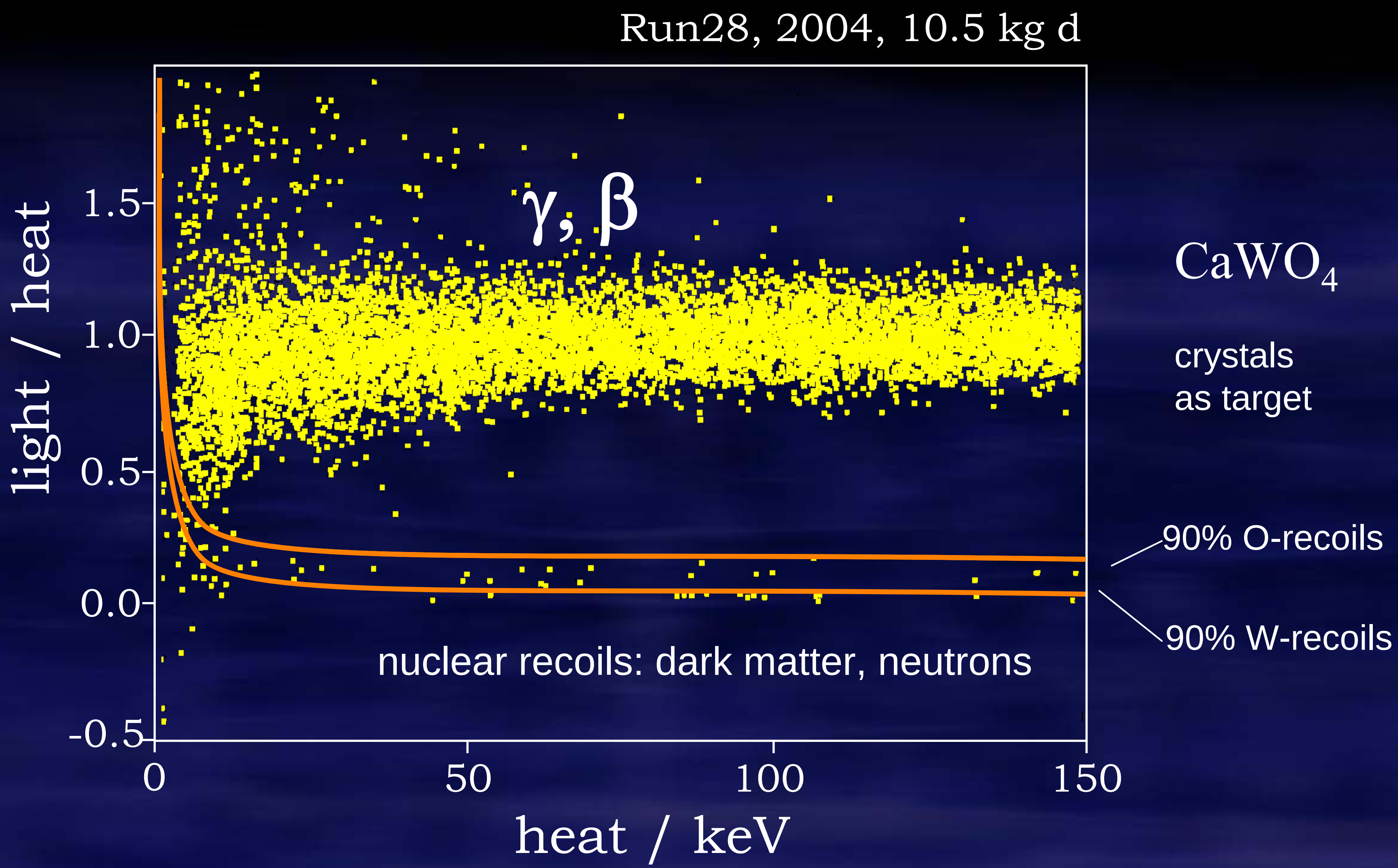


$$t_{1/2}(^{180}W) = (1.7 \pm 0.2)\, 10^{18}\ y$$



Phys.Rev.C 70 (2004) 064606-1 und nucl-ex/0408006

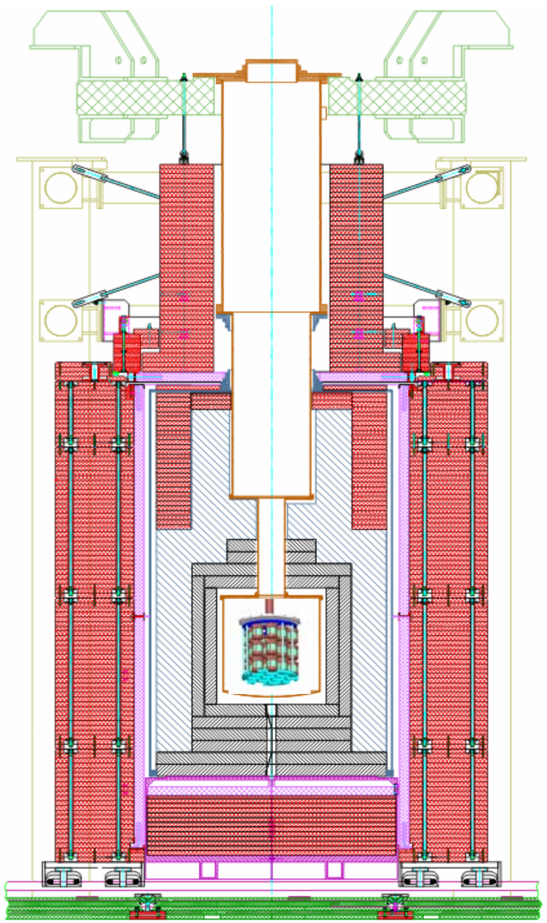
CRESST 2004 no neutron shield



$CaWO_4$

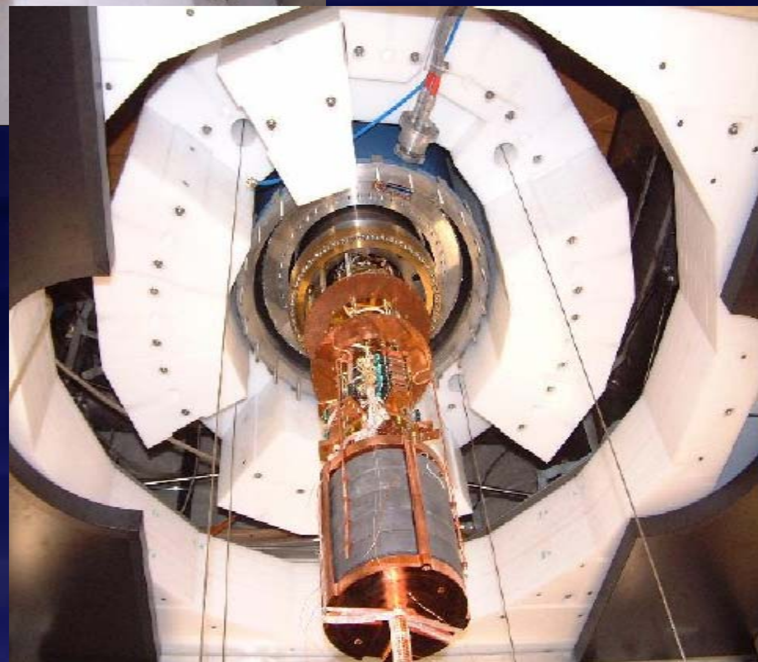
crystals
as target

CRESST – neutron shield

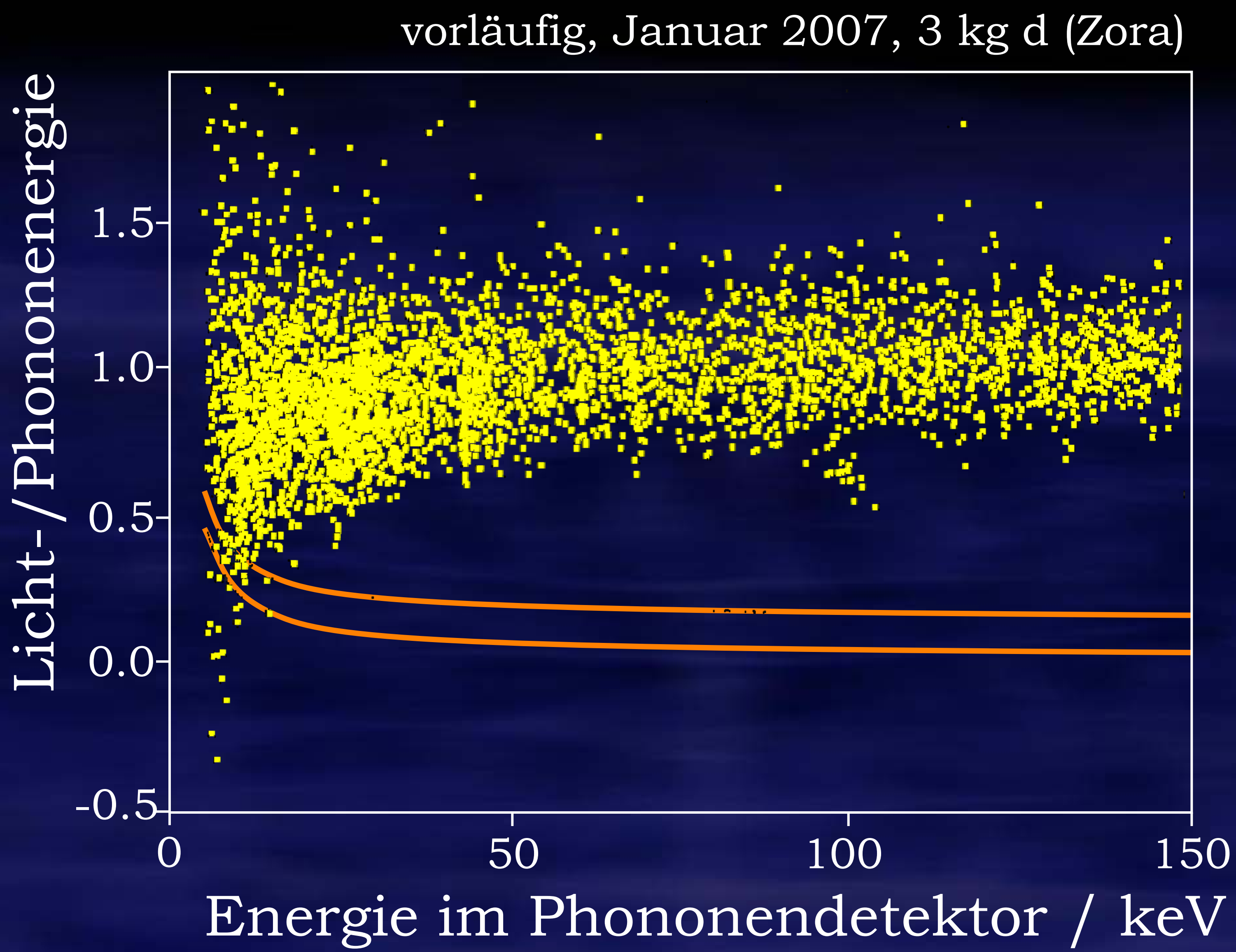


PE neutron moderator

Plastic scintill. μ-veto



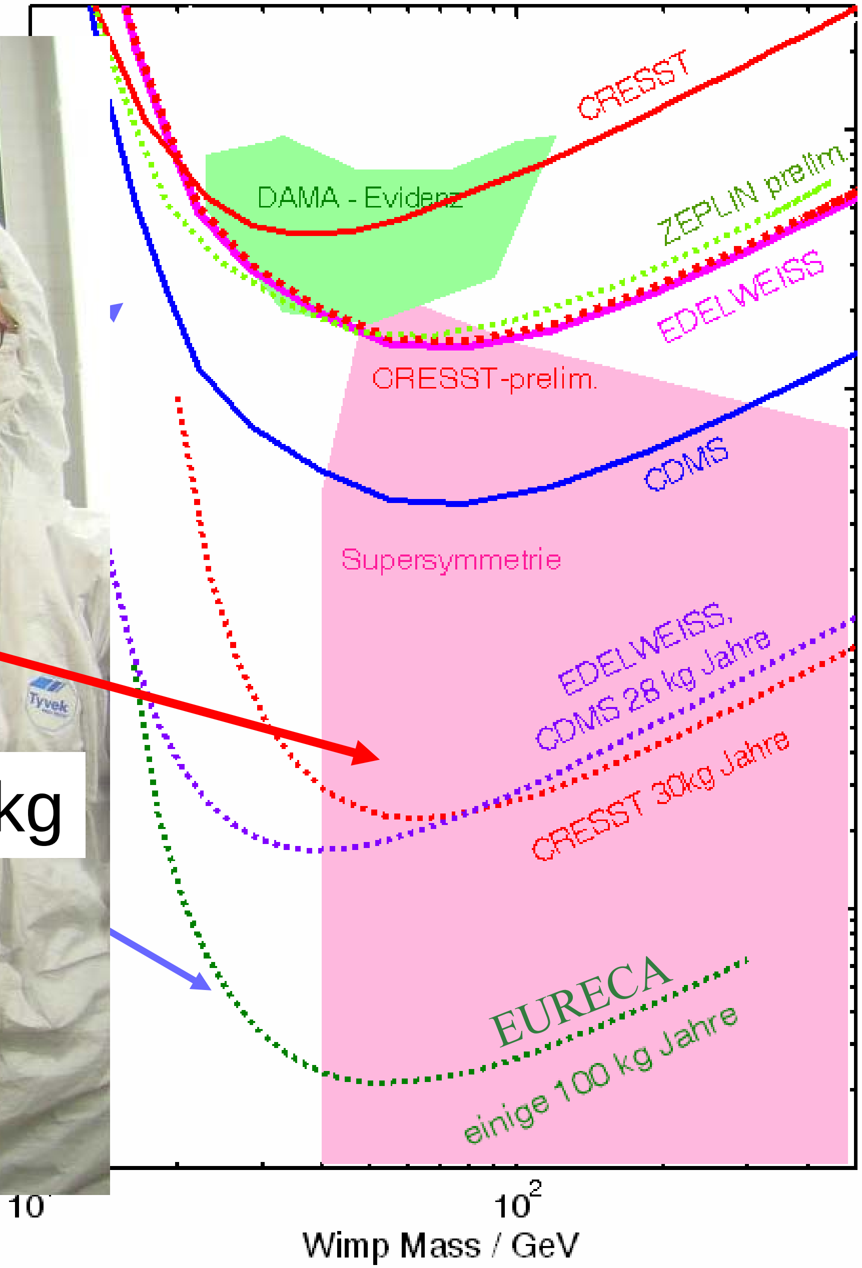
CRESST *2007* *preliminary (only 3kg d)*



with neutron shield and alpha recoil rejection

Future

go from <1kg towards 10kg



=> EURECA Collaboration

European Underground Rare Event Calorimeter Array

Search and Find Dark Matter Particles

- Based on CRESST and EDELWEISS expertise, with additional groups joining.
- Target materials: Ge, $CaWO_4$, etc (A dependence)
- Mass: above 100 kg towards 1 ton
- Timescale: after CRESST-II and EDELWEISS-II
- R&D: demonstrate CRESST / EDELWEISS
- Collaboration started March 2005 and has formed since then

CRESST + EDELWEISS + new groups

United Kingdom

- Oxford (H Kraus, coordinator)

Germany

- MPI für Physik, Munich
- Technische Universität München
- Universität Tübingen
- Universität Karlsruhe
- Forschungszentrum Karlsruhe

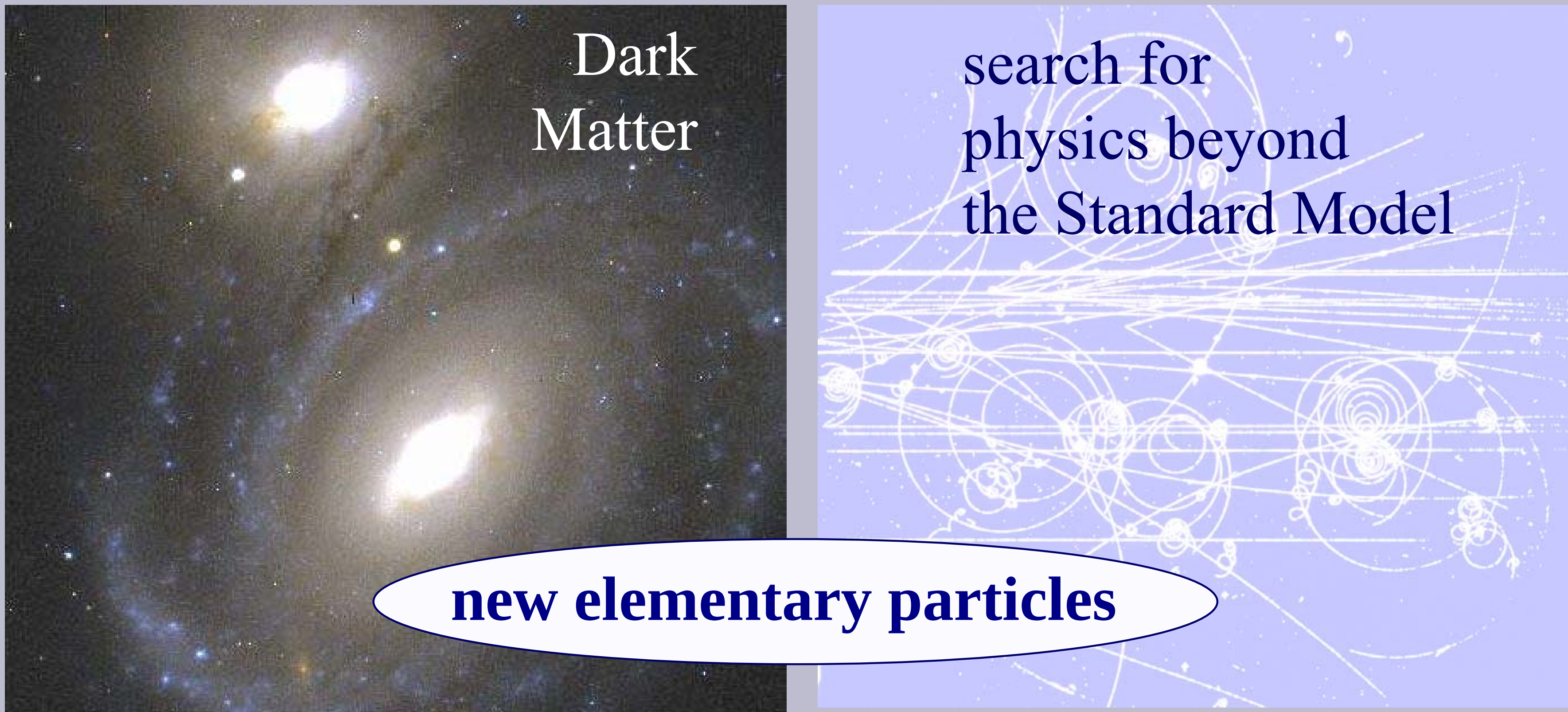
Russia

- DLNP Dubna

France

- CEA/DAPNIA Saclay
- CEA/DRECAM Saclay
- CNRS/CRTBT Grenoble
- CNRS/CSNSM Orsay
- CNRS/IPNL Lyon
- CNRS/IAP Paris

CERN


Dark
Matter
search for
physics beyond
the Standard Model
new elementary particles