

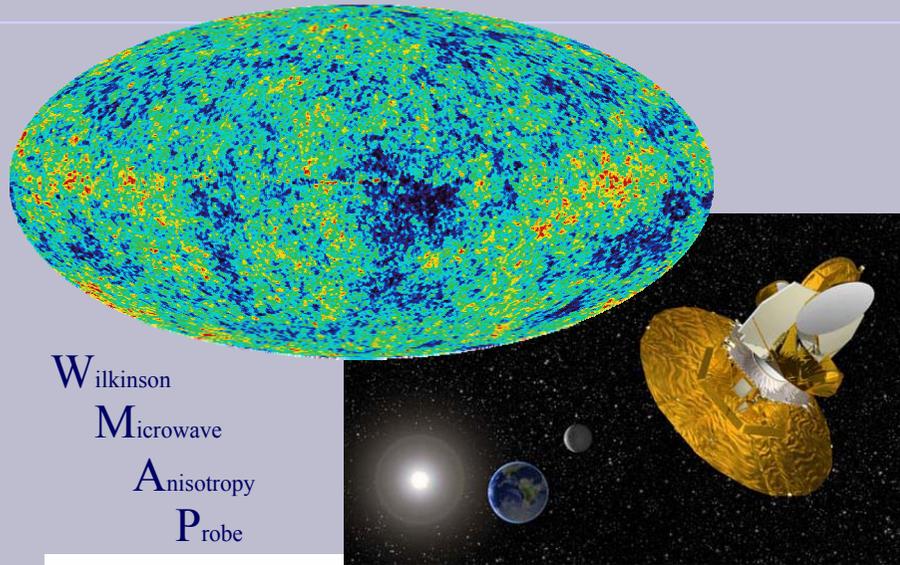
# Cryogenic Detectors Direct Dark Matter Search

Dark Matter  
Cryogenic Detectors  
CRESST Project

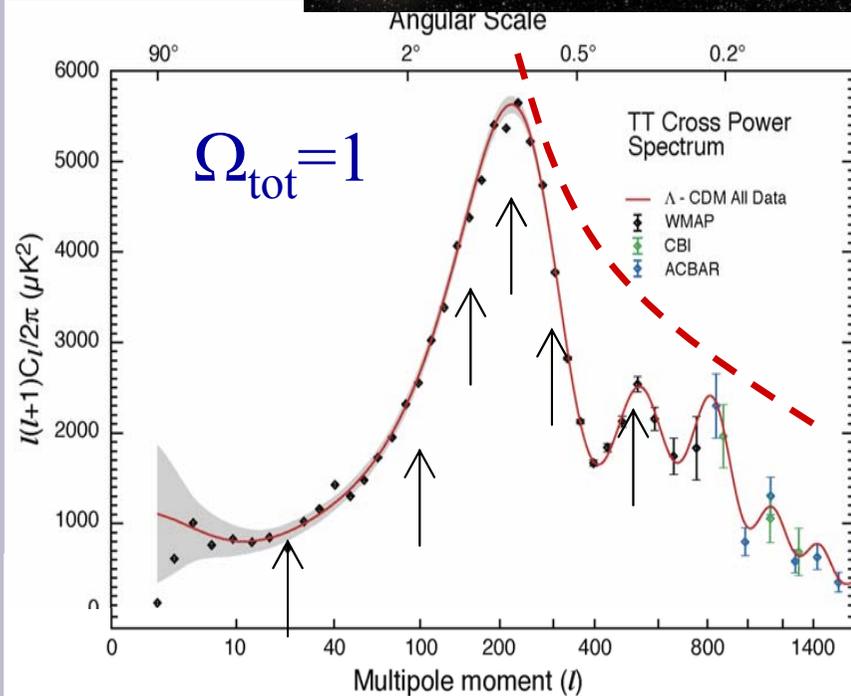


# Cosmic Microwave Background – Matter-Density $\Omega_{matter}$

Dark Matter



Wilkinson  
Microwave  
Anisotropy  
Probe



Anisotropy:

Angular scale  $\Rightarrow$  geometry,  $\Omega_{tot}$

Intensities  $\Rightarrow$  gravitational potentials,  
matter densities

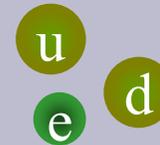
- gravitation  $\Omega_{matter}$
- coupling to radiation  $\Omega_{baryon}$

$$\Omega_{matter} = 0.27$$

$$\Rightarrow \Omega_{matter} \phi \Omega_{lum} = 0.01$$

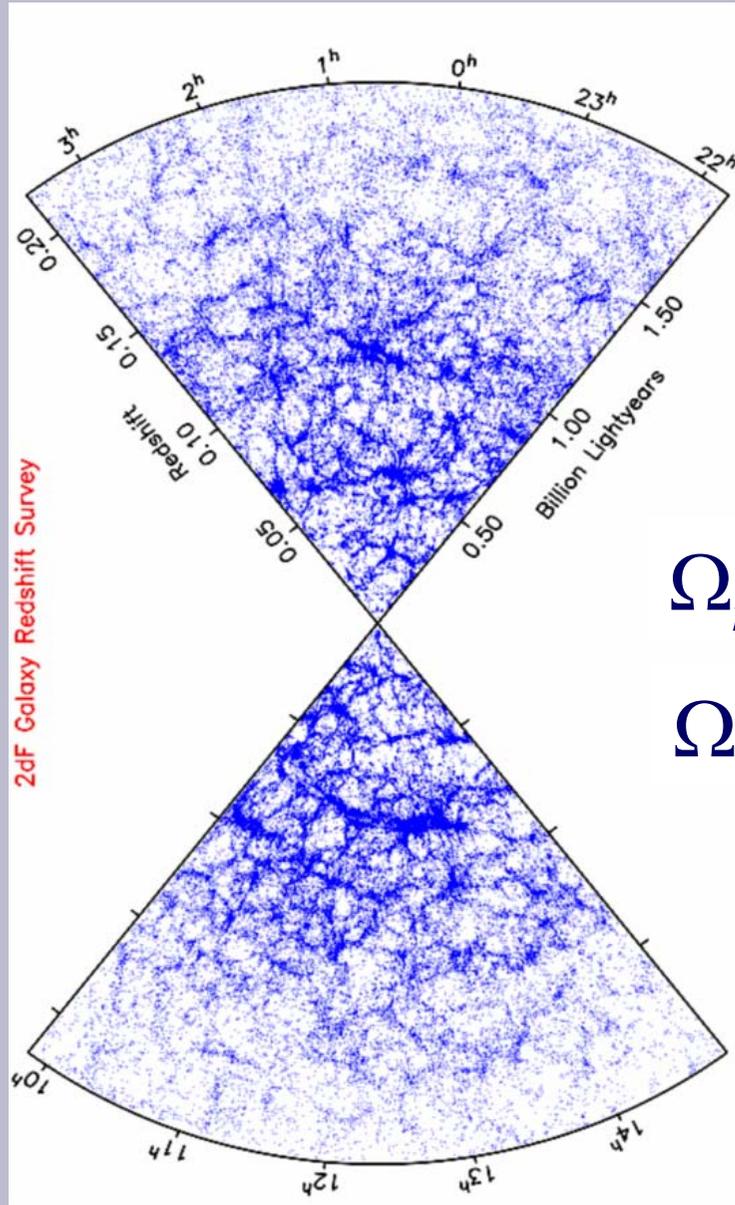
mostly Dark Matter

$$\Omega_{baryon} = 0.044$$



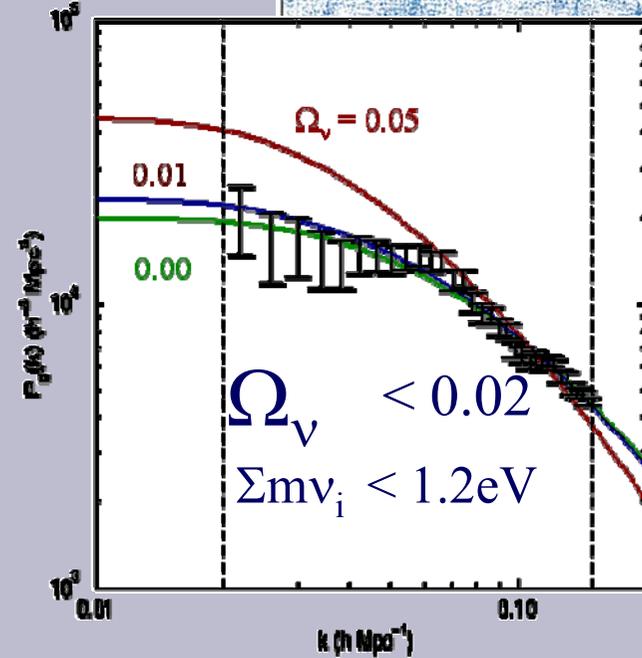
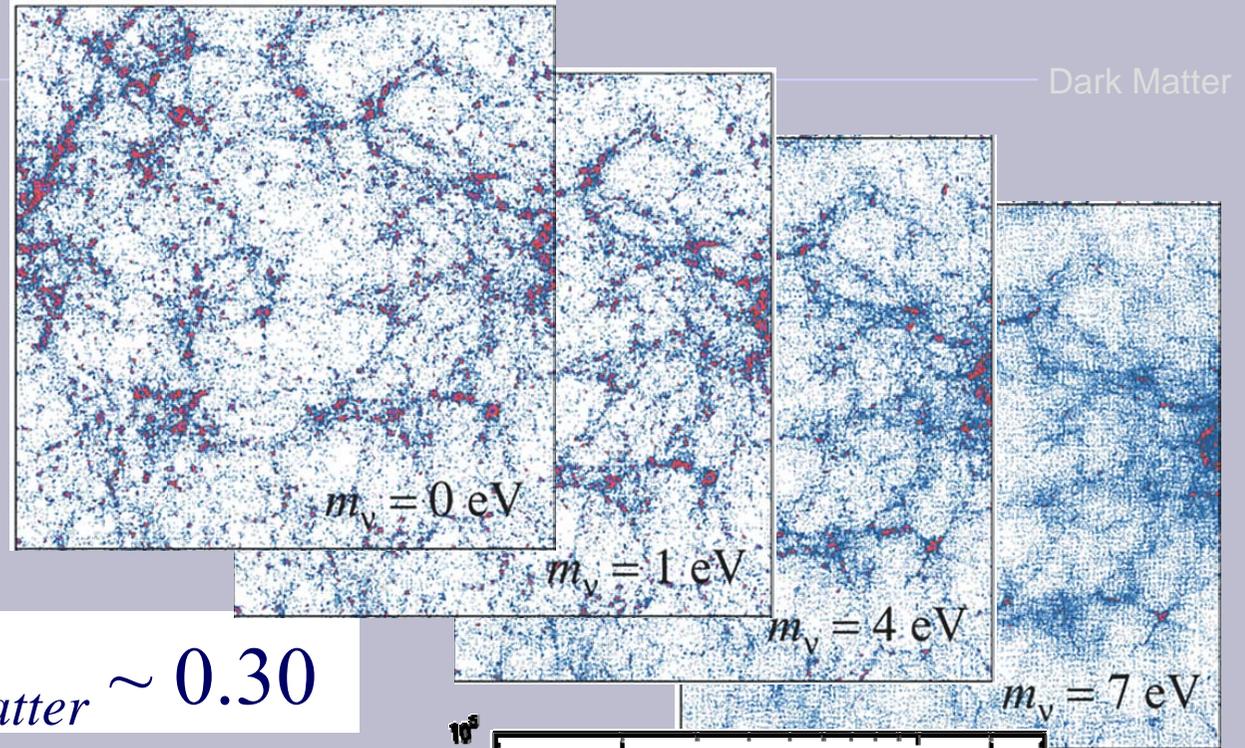
$$\Rightarrow \Omega_{matter} \gg \Omega_{baryon}$$

# Structure in the Universe and Neutrinos



$$\Omega_{matter} \sim 0.30$$

$$\Omega_{\nu} < 0.02$$



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 neutrinos**

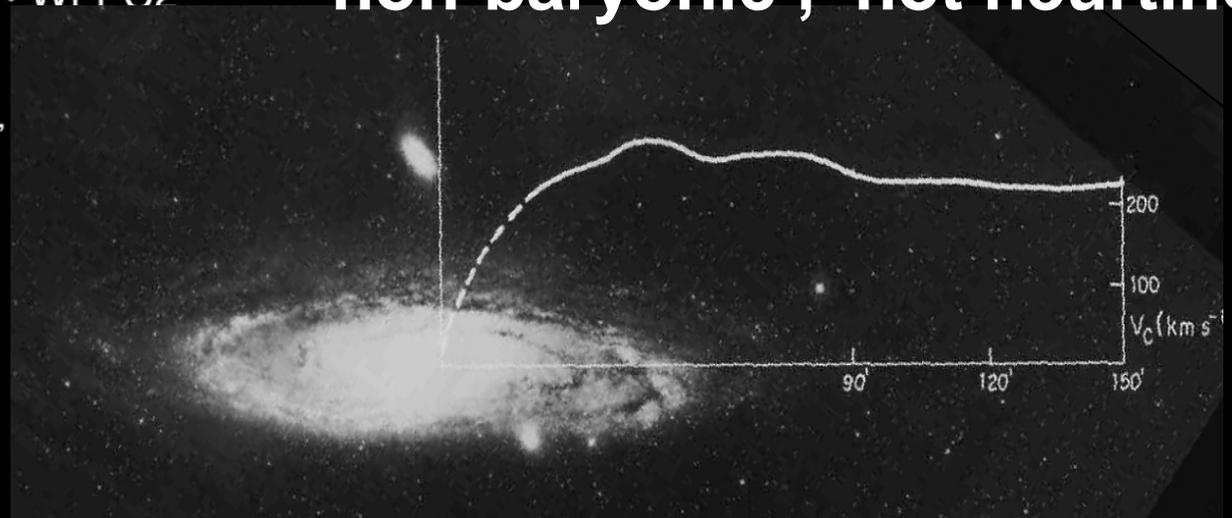


**Gravitational Lens**  
**Galaxy Cluster 0024+1654**

HST · WFPC2

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

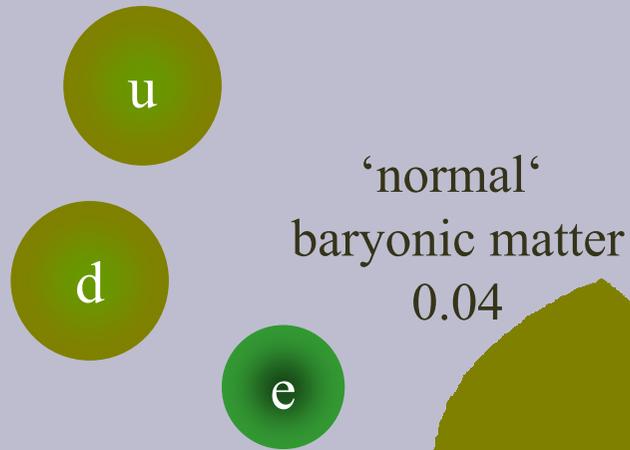


# Matter in the Universe - Composition

Dark Matter

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

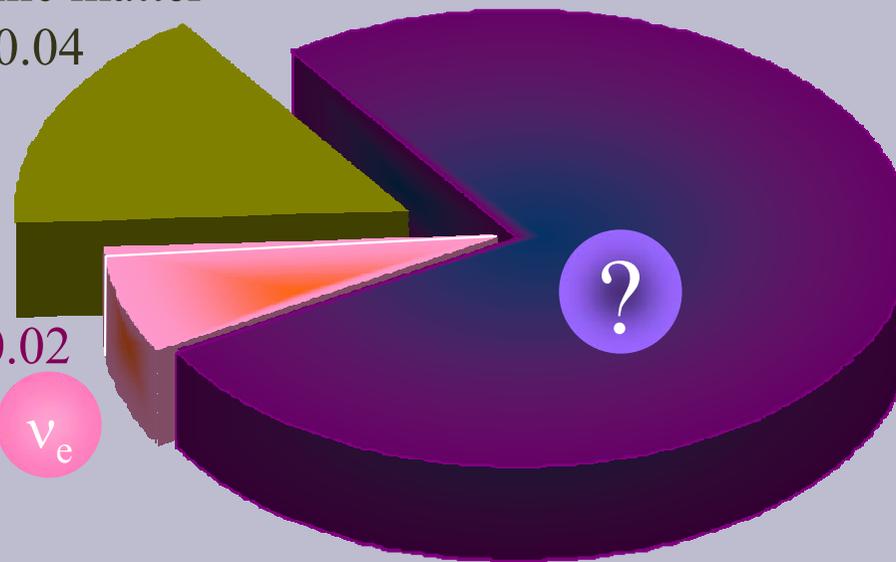
‘ $\nu$  too light’  $\Rightarrow$   
most of the  
Dark Matter  
is cold



$0.001 < \nu < 0.02$   
(HDM)



from  $\nu$ -oscillations  
 $\Rightarrow \Sigma m_\nu > 0.05\text{eV}$

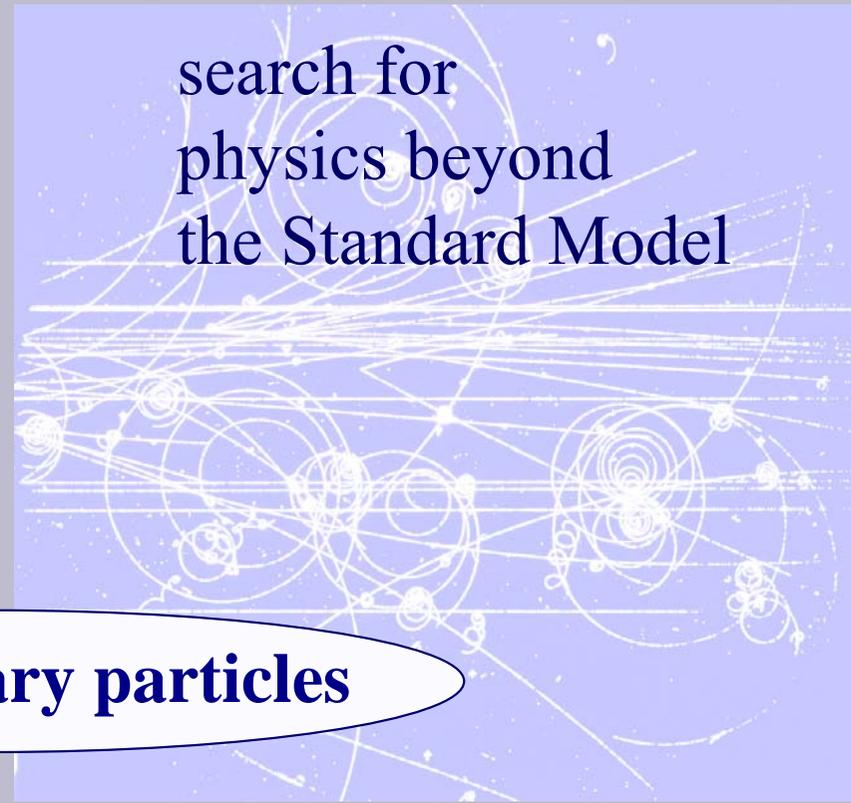


cold Dark Matter (CDM)  
0.23

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

$\Rightarrow$

physics beyond  
standard model  
supersymmetry?



**new elementary particles**

*AXIONs ??? Supersymmetry ??? ....*

## Cosmology

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

## Beyond the Standard Model

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

Dark Matter

## 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

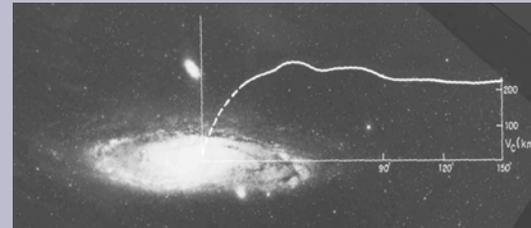
**rare effects**  
**=>**  
**very good knowledge**  
**on background**

# How to detect WIMP – Dark Matter

Weakly Interacting Massive Particles = **WIMPs**

Dark Matter

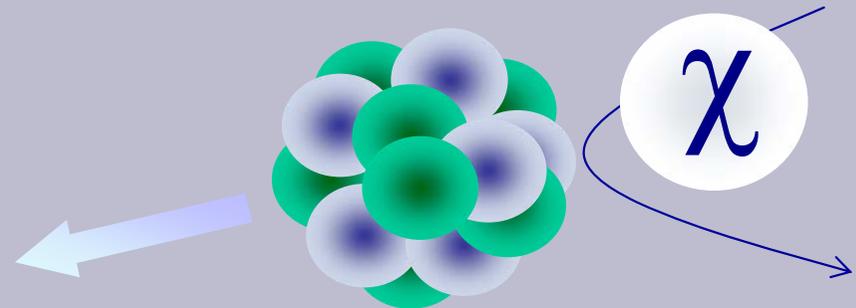
elastic scattering on nuclei



- **nuclear recoils:** reduced efficiency of charge or light production

- mass  $50 \text{ GeV} - \sim 1000 \text{ TeV}$
- relative speed  $270 \text{ km/s}$

⇒ only a few keV of energy



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

⇒ very very rare scattering events ( $< 1 / \text{week} / \text{kg}$ )

# WIMP Direct Detection - Low Temperature – Calorimeter

particle absorption

=>

phonons (~heat)

phonon-absorption  
in thermometer

=> **temperature rise**

**low temperatures (~20mK)**

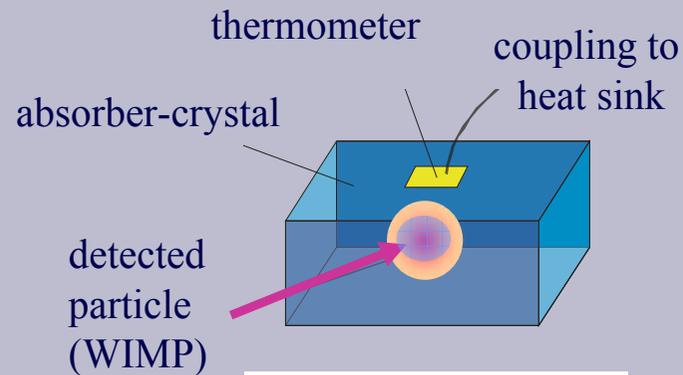
=> high sensitivity, small C

high sensitivity to nuclear recoils

no quenching

low  
energy threshold

wide choice of  
absorber materials



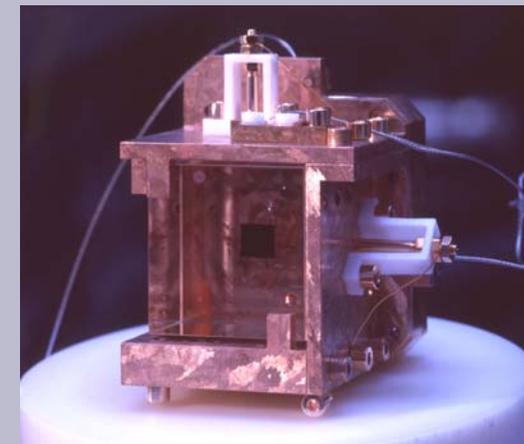
$$\Delta T \propto E/C$$



thermometer types:

superconducting phase  
transition thermometers (SPT)

NTD - Ge thermistors  
(highly doped semiconductors)



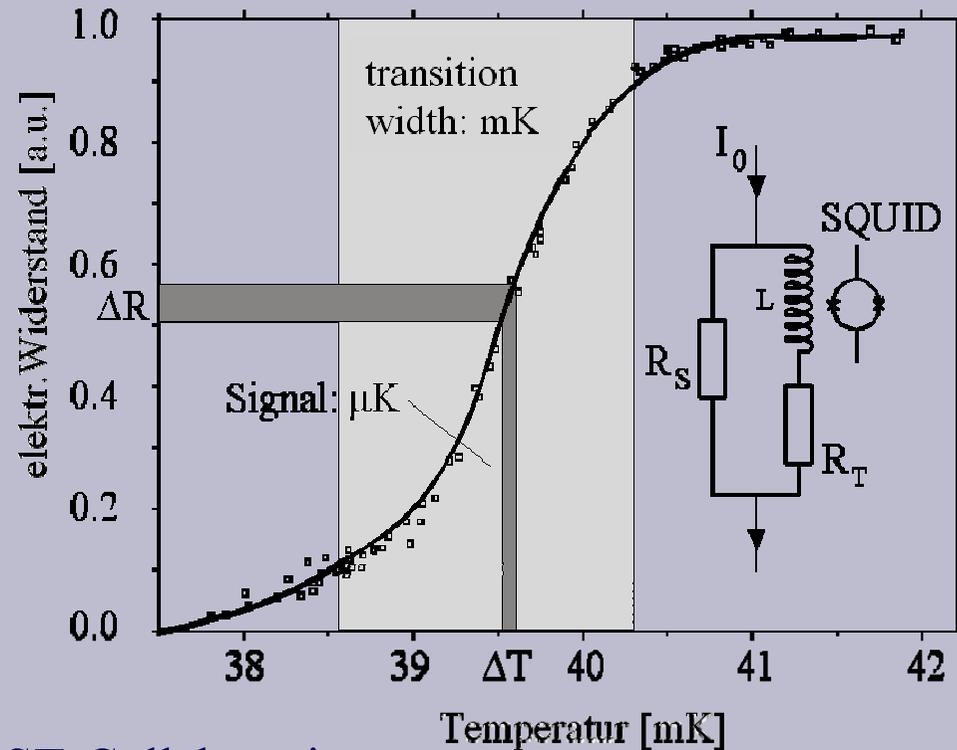
# Superconducting Phase Transition Thermometer

superconducting phase  
transition thermometer  
Tungsten Tc 15mK

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



Sapphire- or  $\text{CaWO}_4$ -absorber  
250gr, 4cm x 4cm x 4cm



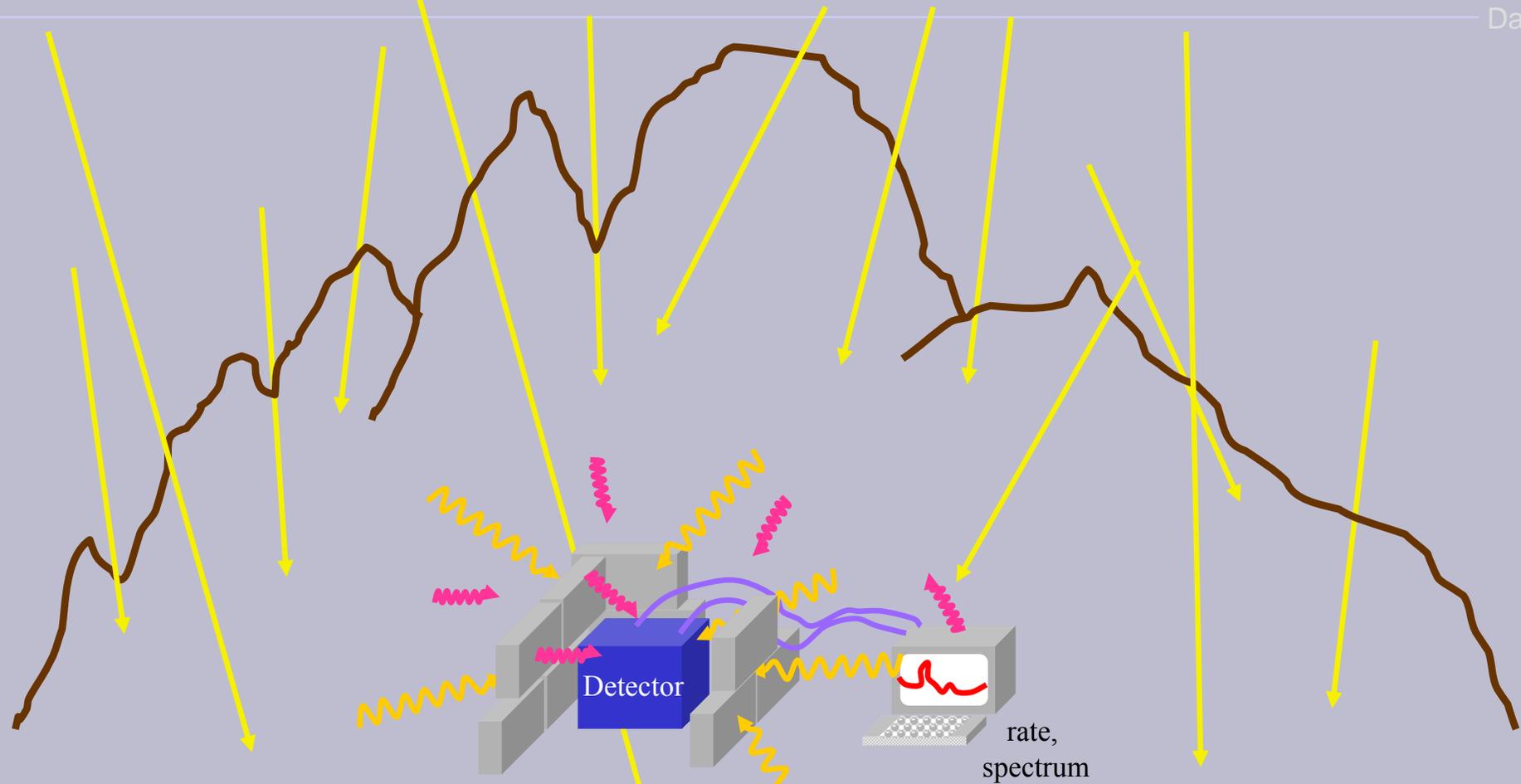
CRESST-Collaboration

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

Dark Matter



required sensitivity

$\sim 1 \text{ event / kg / week}$

(future experiments even 100 x less)

radioactivity:  $> 1 \text{ Hz/kg}$

$\sim 10^6 \text{ events /kg /week}$

$\Rightarrow$  'clean' shielding: (old) Pb, Cu

muons  $\sim 0.1 \text{ Hz/kg}$ :

$\sim 10^5 \text{ events /kg /week,}$

$\Rightarrow$  needs  $\sim 1.5 \text{ km Rock}$

$\Rightarrow$  Underground-Laboratory

# WIMP Direct Detection - Underground Laboratory

Dark Matter



shielding  
from  
cosmic rays

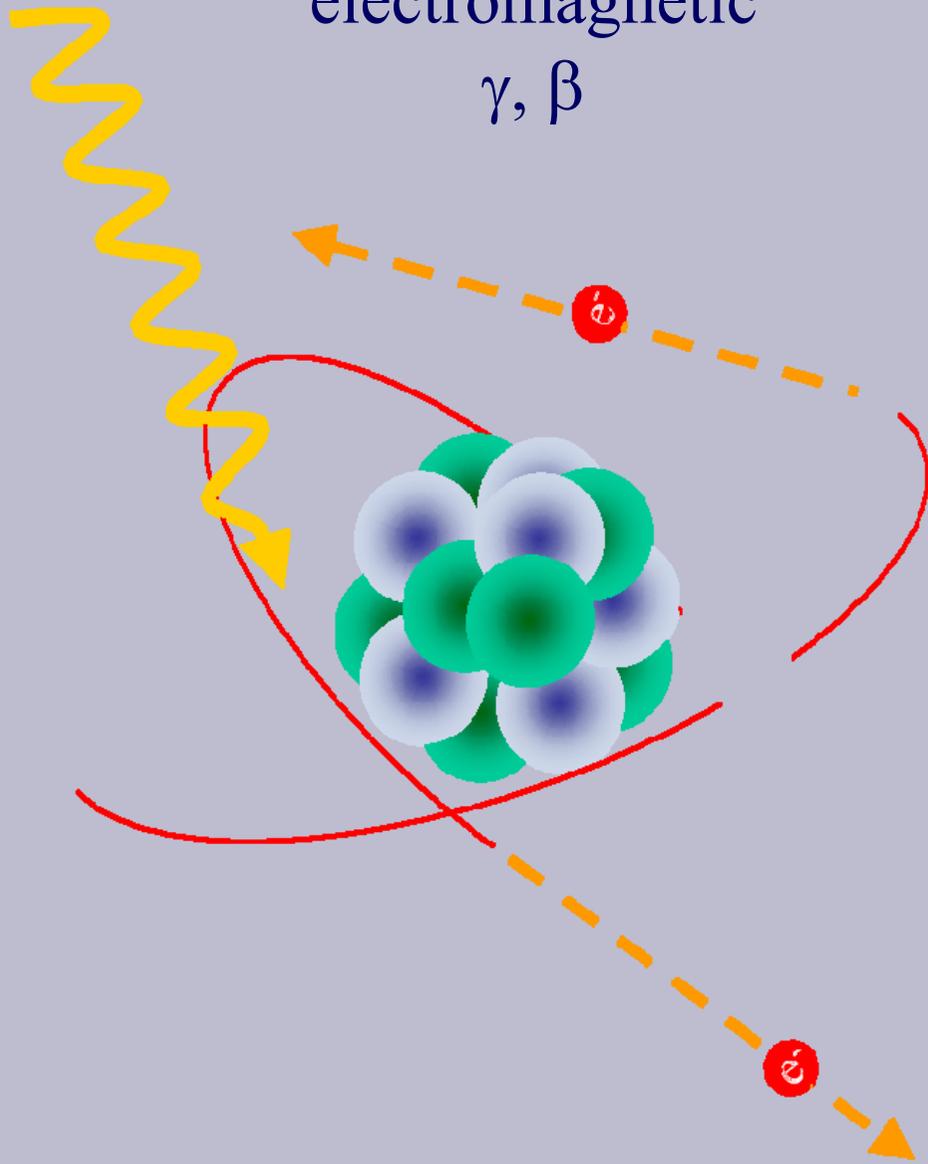


Soudan Mine USA



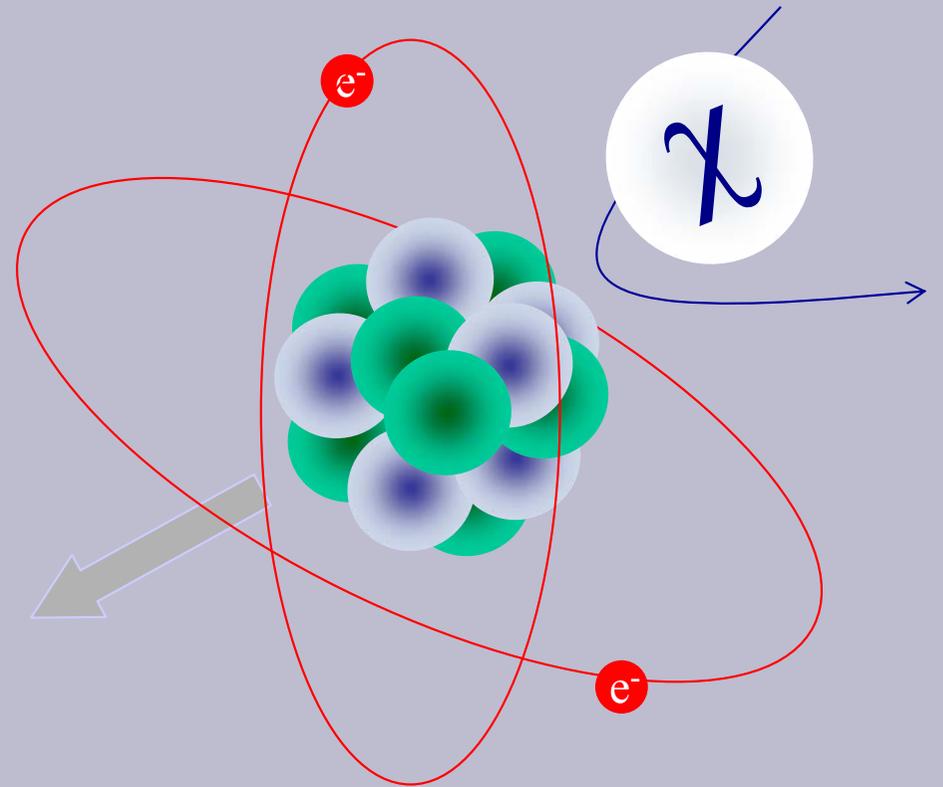
electromagnetic

$\gamma, \beta$



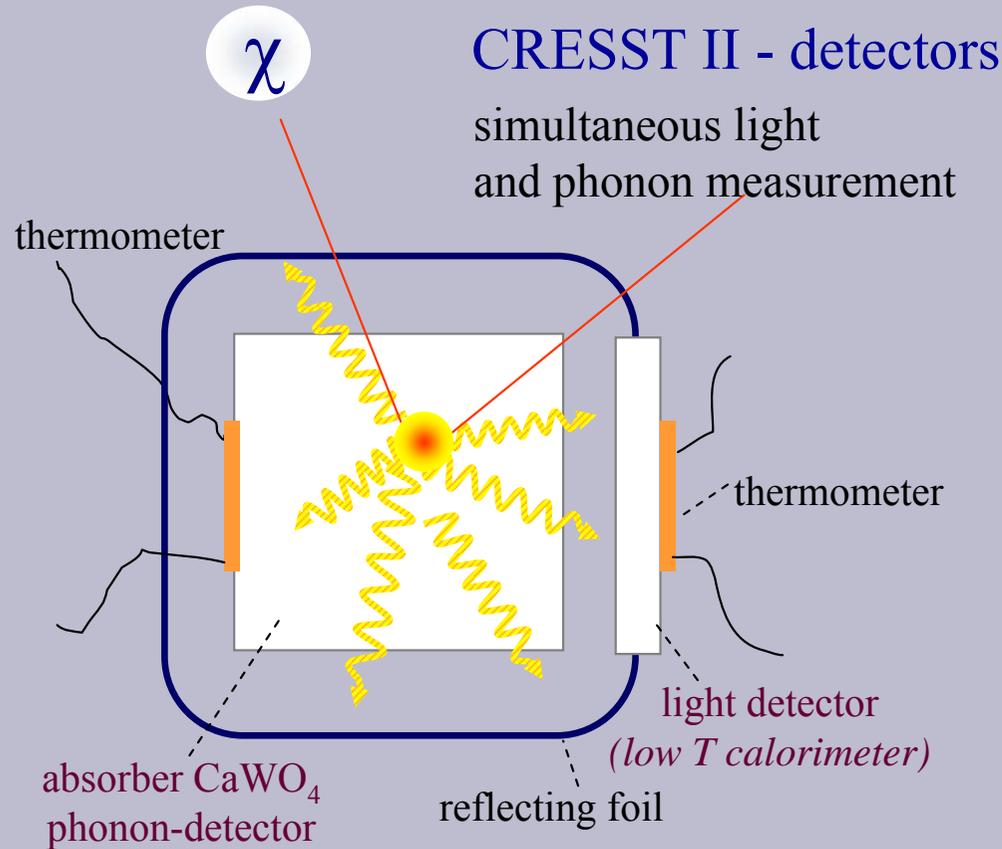
ionisation  
(charge, scintillation light)

nuclear recoils

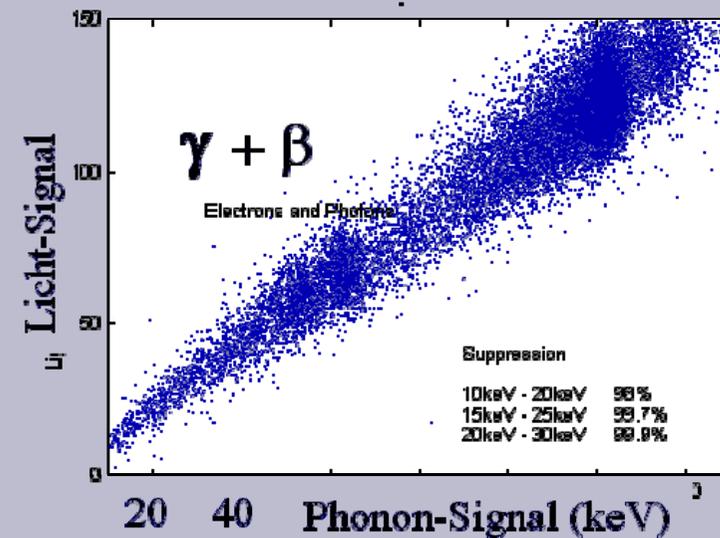
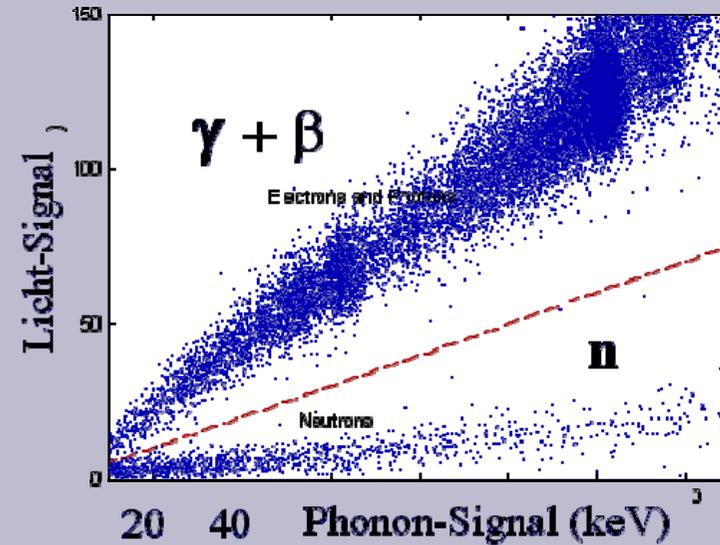


phonons  
only little ionisation

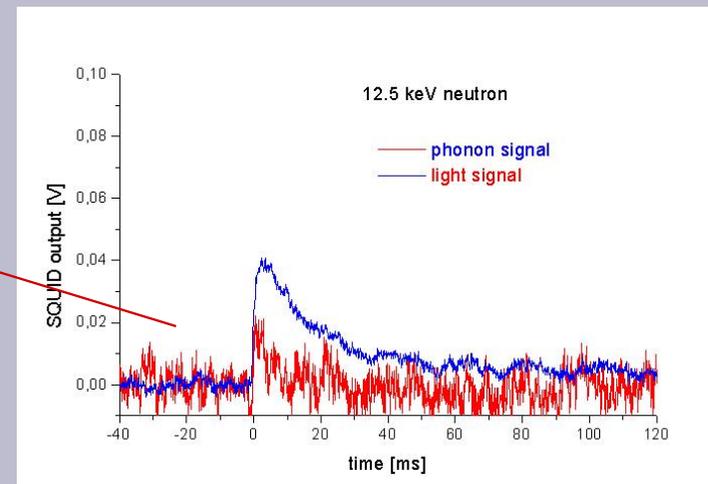
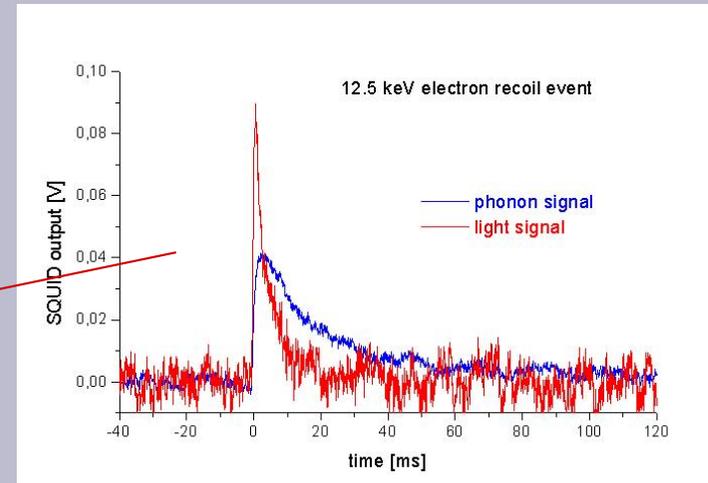
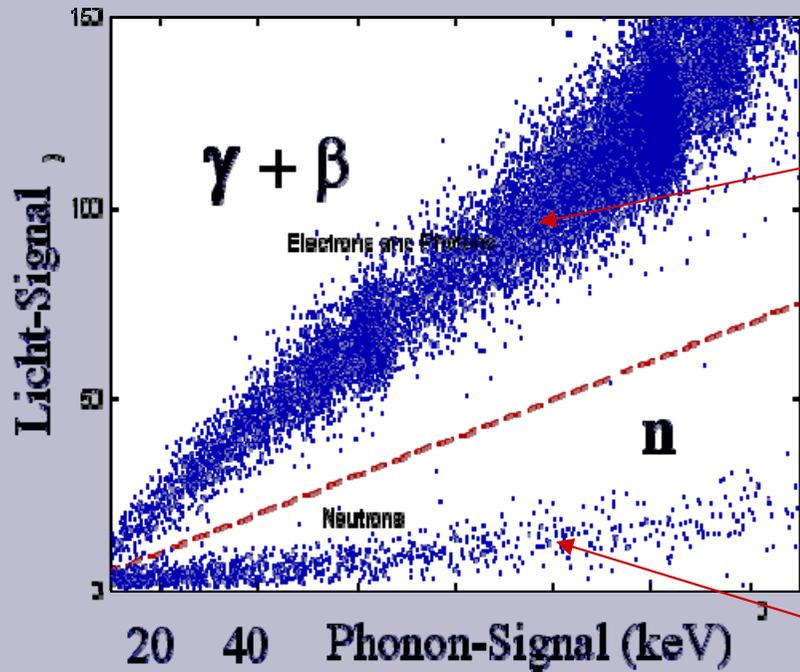
# Phonon + Charge / Light Measurement => recognize Background



CRESST – Cryogenic Rare  
Event Search with Superconducting  
Thermometers

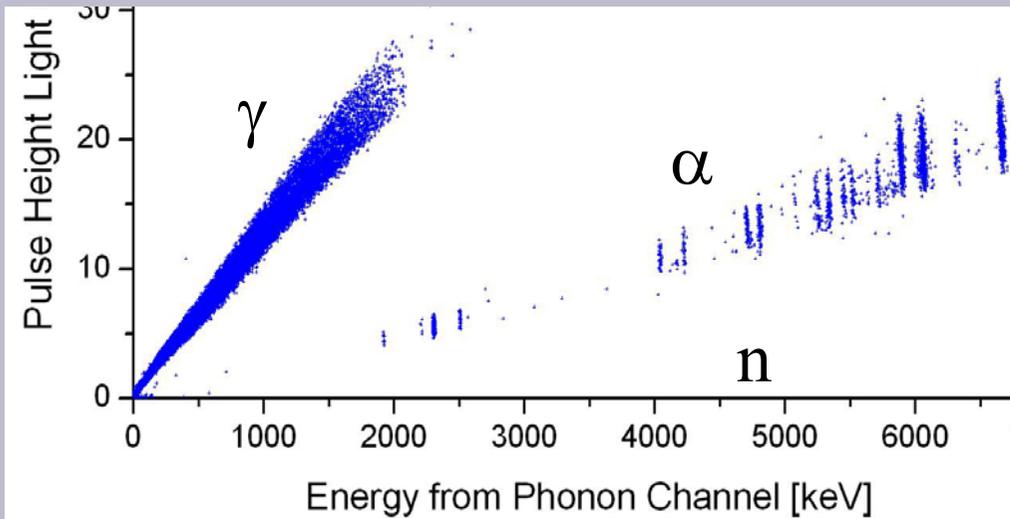


# CRESST Light Phonon Detectors

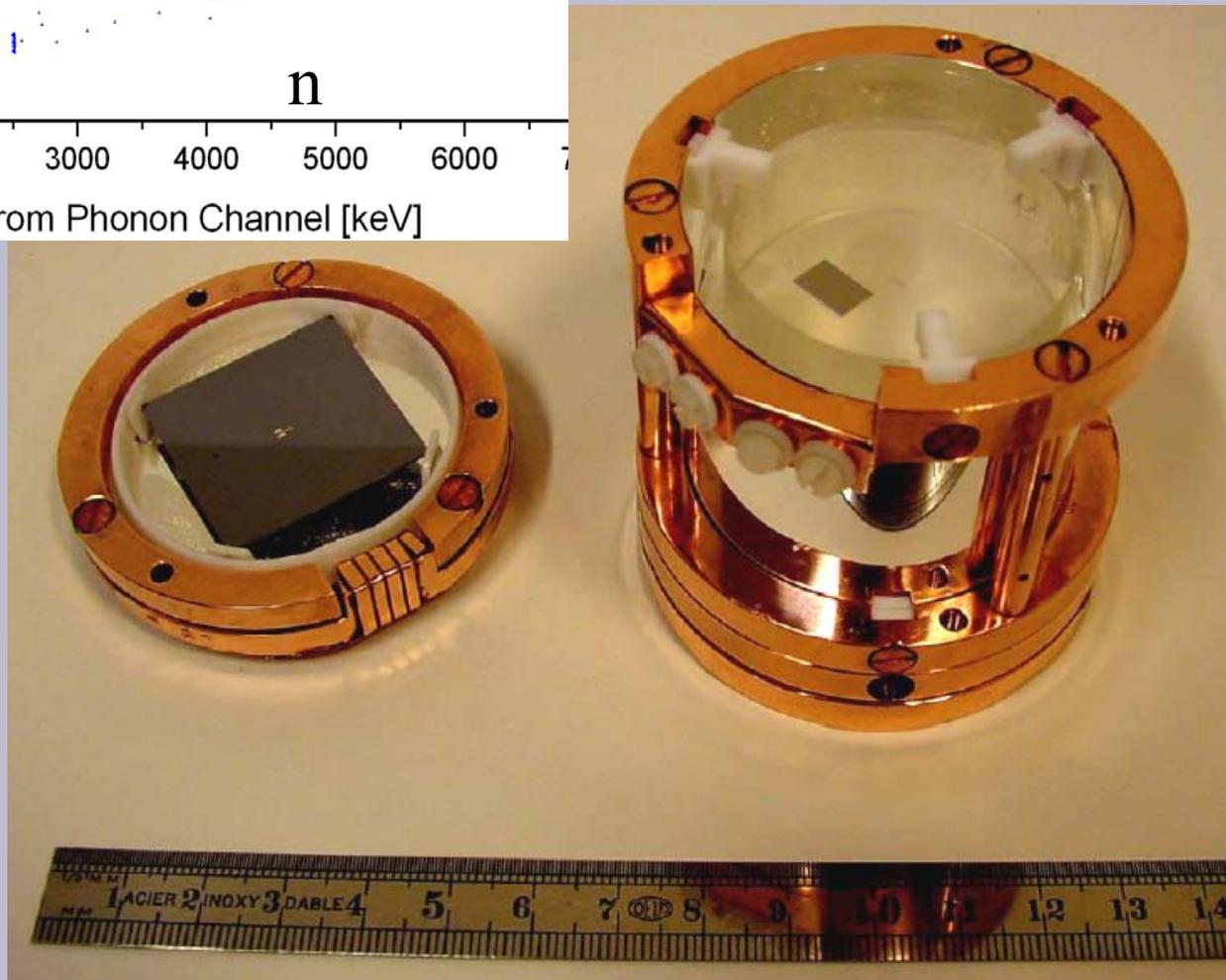


# CRESST Light Phonon Detectors - Particle Identification

Dark Matter



$\text{CaWO}_4$



# WIMP Direct Detection – Event by Event Discrimination

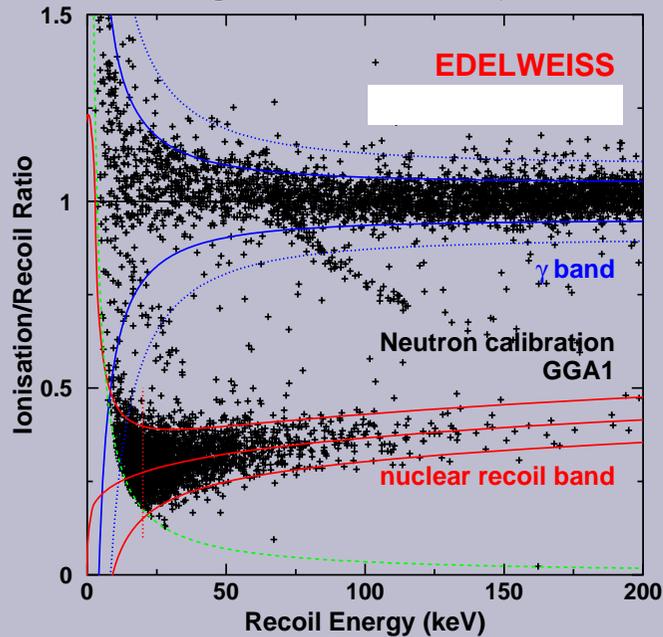
## *EDELWEISS (France) und CDMS (USA) Dark Matter Projects*

Dark Matter

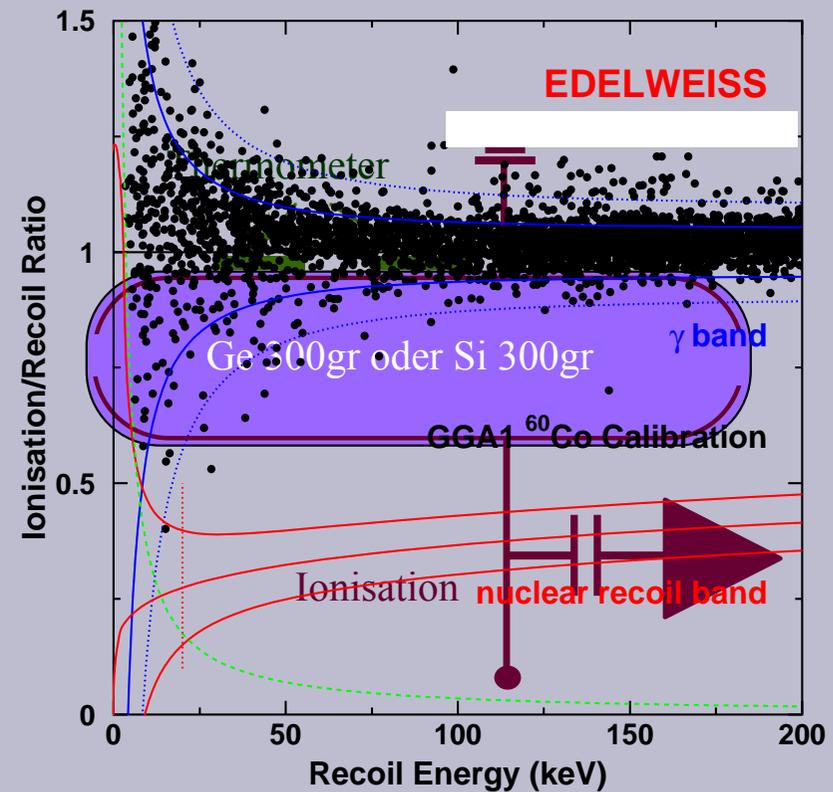


Ionisation-Phonon  
320g Ge-Detector

Testmessung mit Neutronen (=> Kernrückstöße)



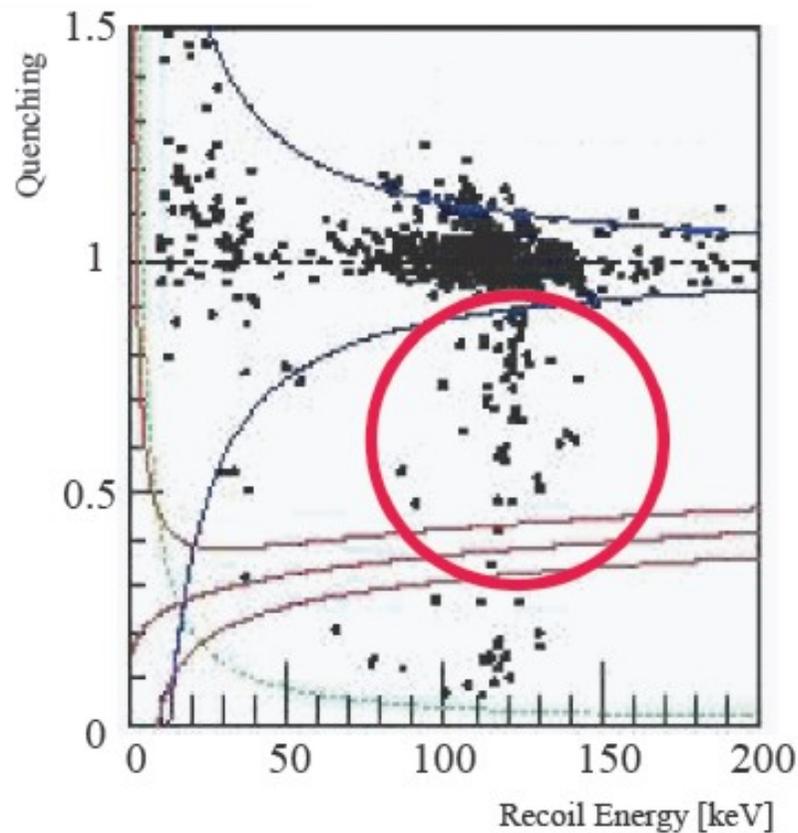
‘Low Background Data’

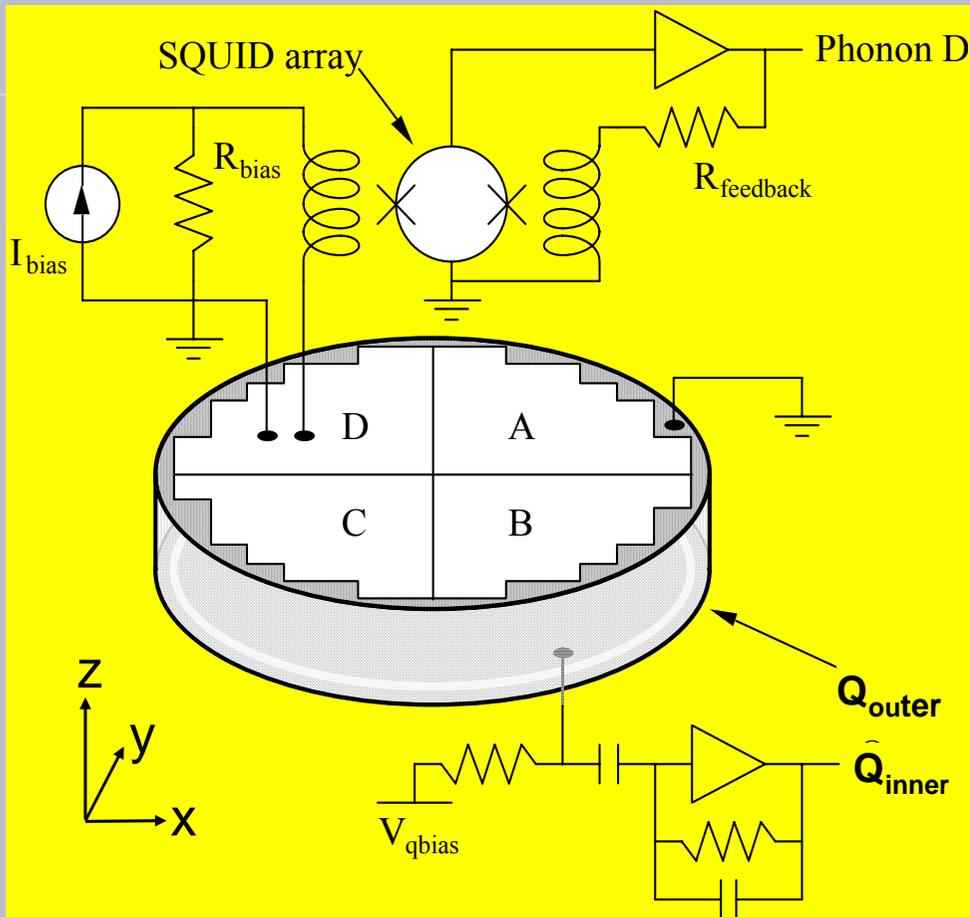


# Heat / Charge - *reduced charge collection from surface*

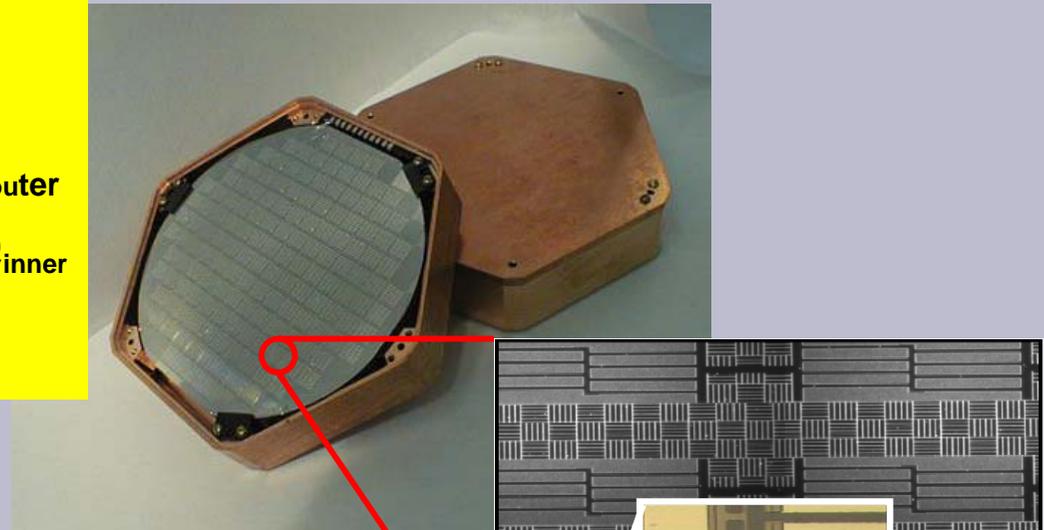
Main limitation to the sensitivity: due to trapping and recombination, surface events are miscollected and can mimic nuclear recoils

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





- 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- $\mu$ m-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

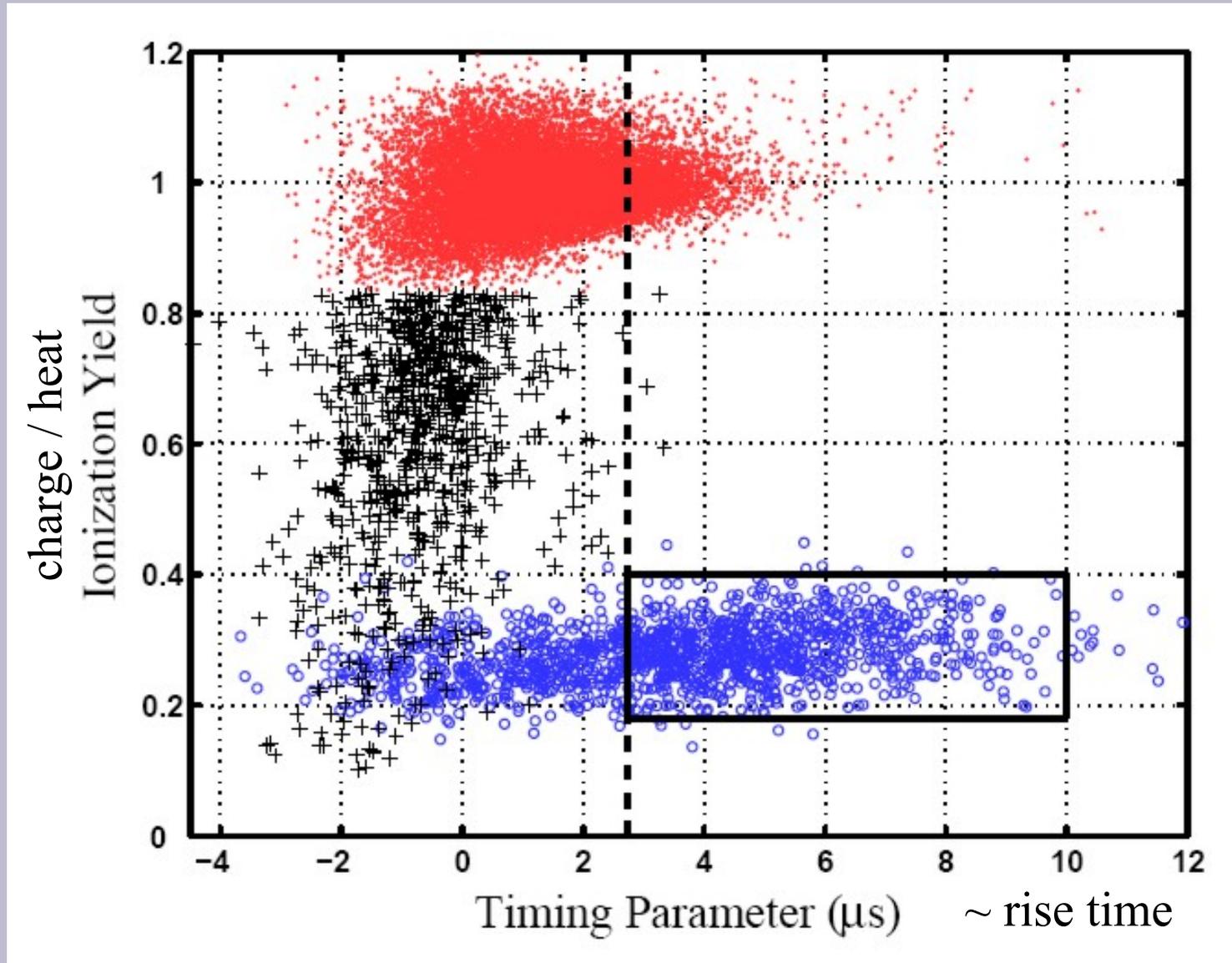
**2 charge electrodes:**

- “Inner” fiducial electrode
- “Outer” guard ring

1  $\mu$  tungsten

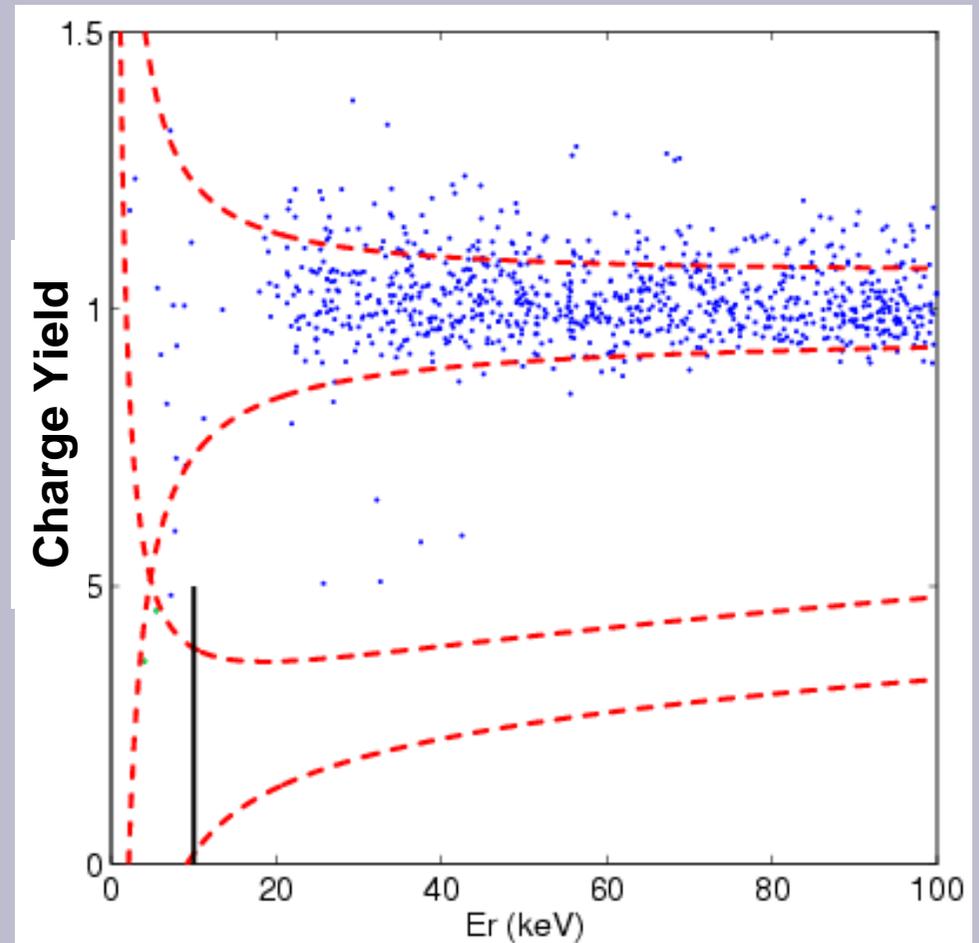
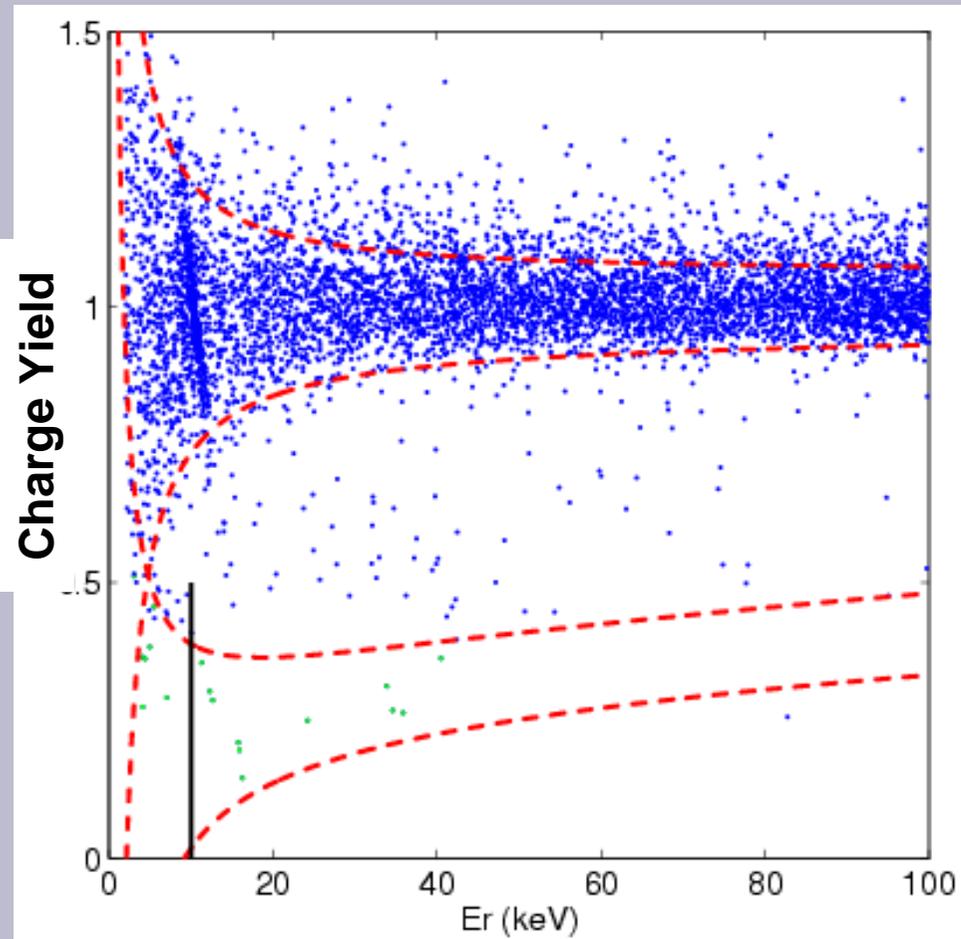
380 $\mu$  x 60 $\mu$  aluminum fins

# CDMS Timing Cut – remove near surface events



Prior to timing cuts

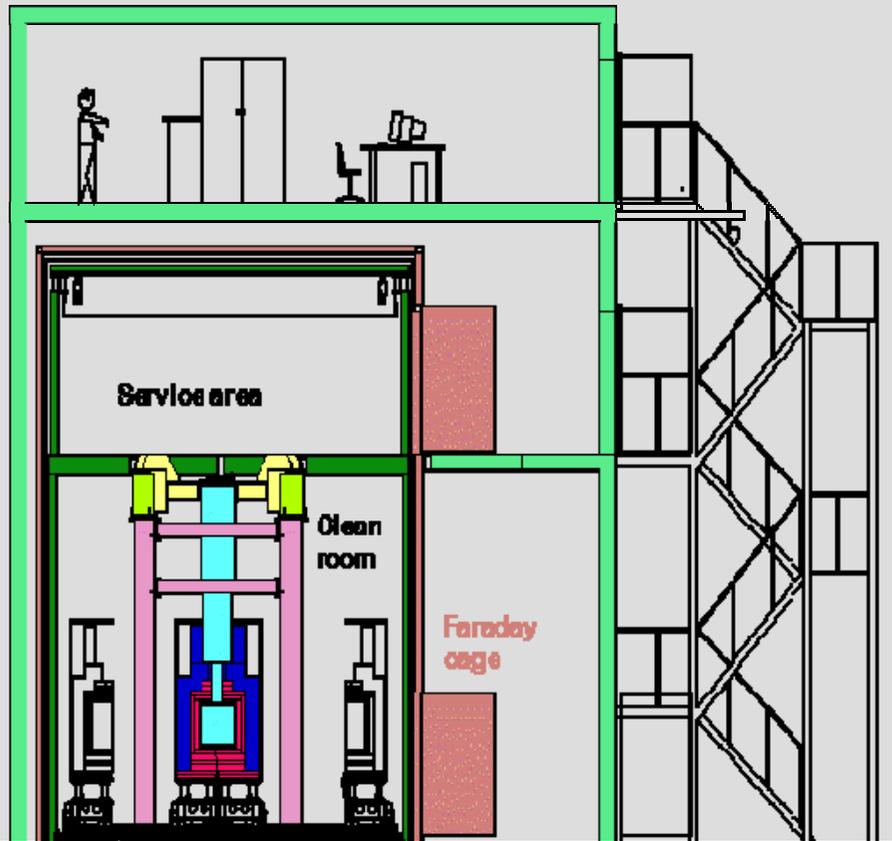
After timing cuts



# CRESST at Gran Sasso Underground Laboratory

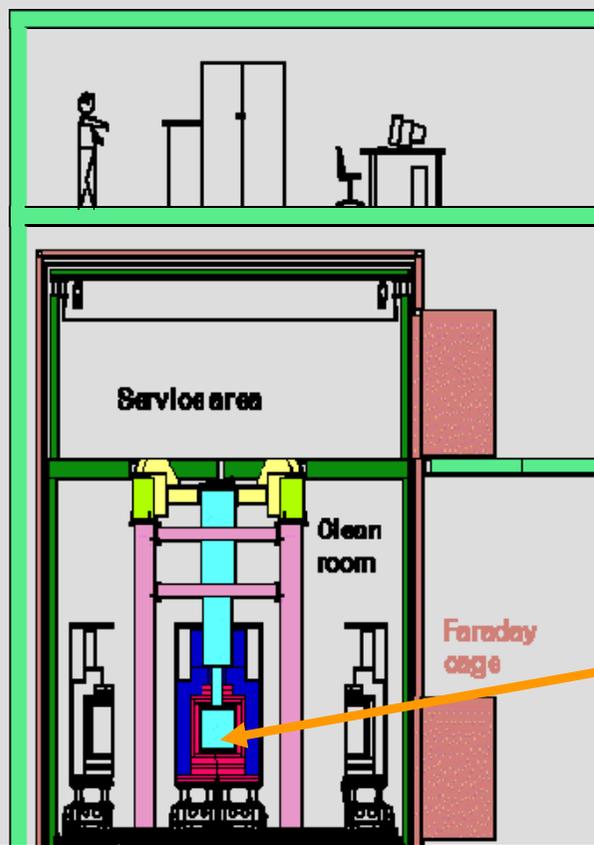
Dark Matter

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



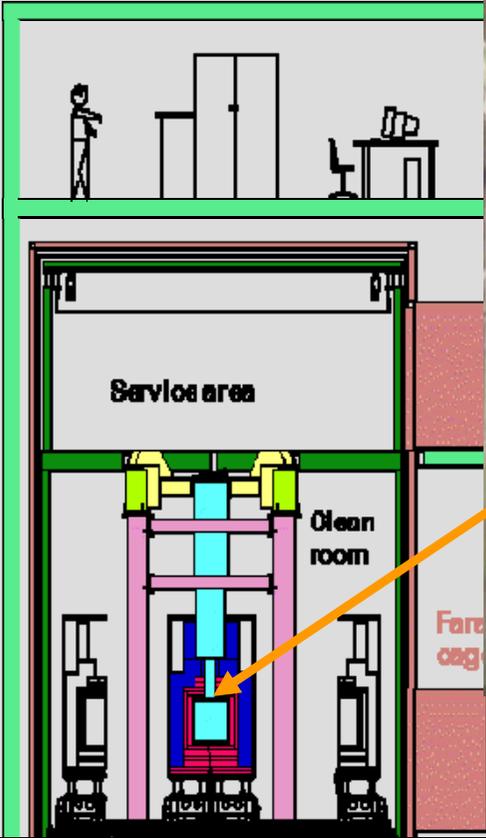
# CRESST at Gran Sasso Underground Laboratory

Dark Matter

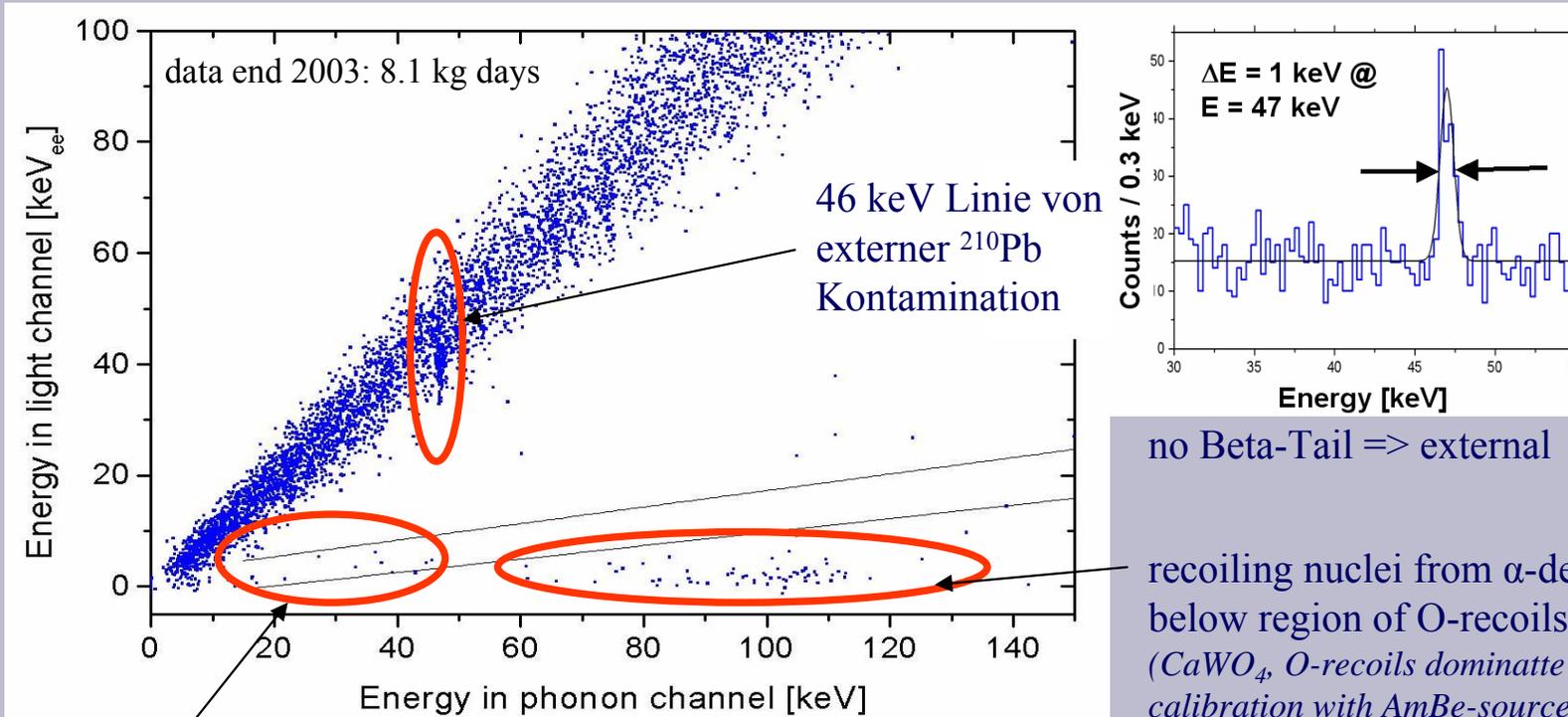


# CRESST at Gran Sasso Underground Laboratory

Dark Matter



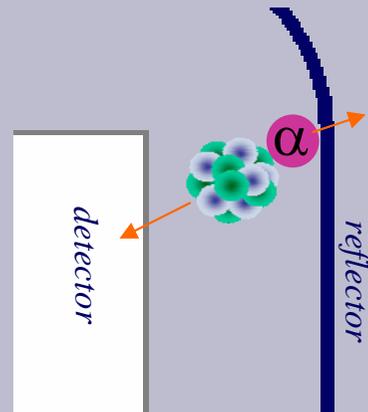
# Nuclear Recoils - Examples



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

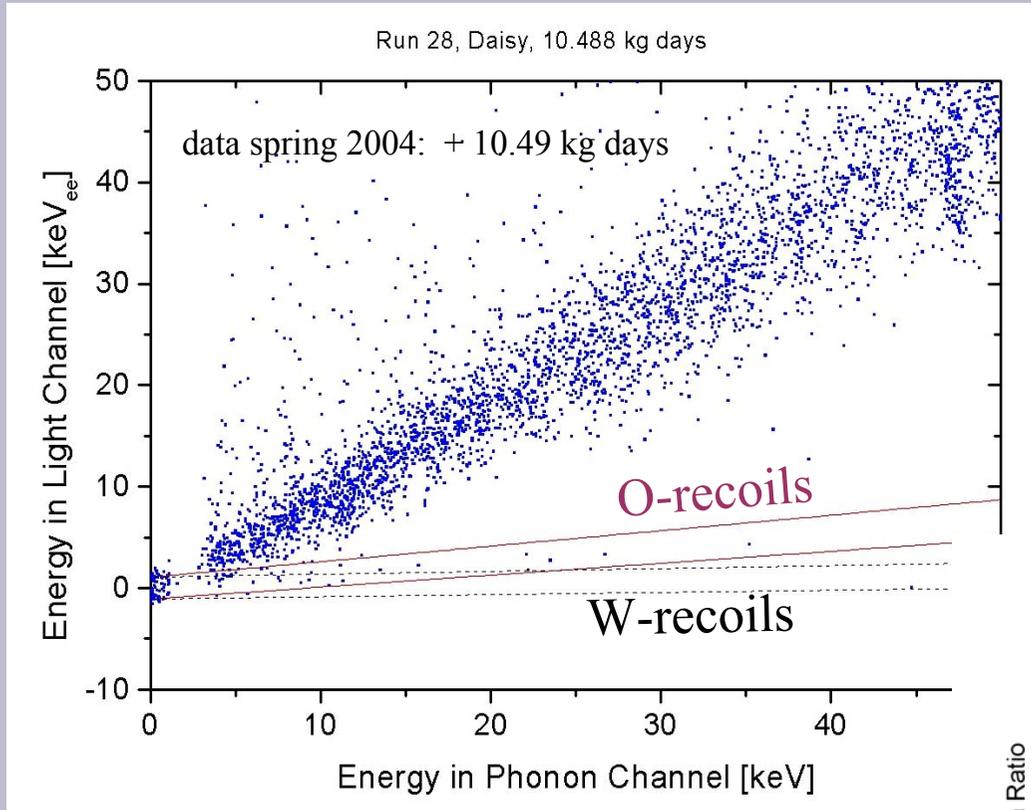
CRESST I at that time  
no neutron shield  
only  $\gamma$ : Pb/Cu shield

=> meanwhile PE moderator shield and muon-veto



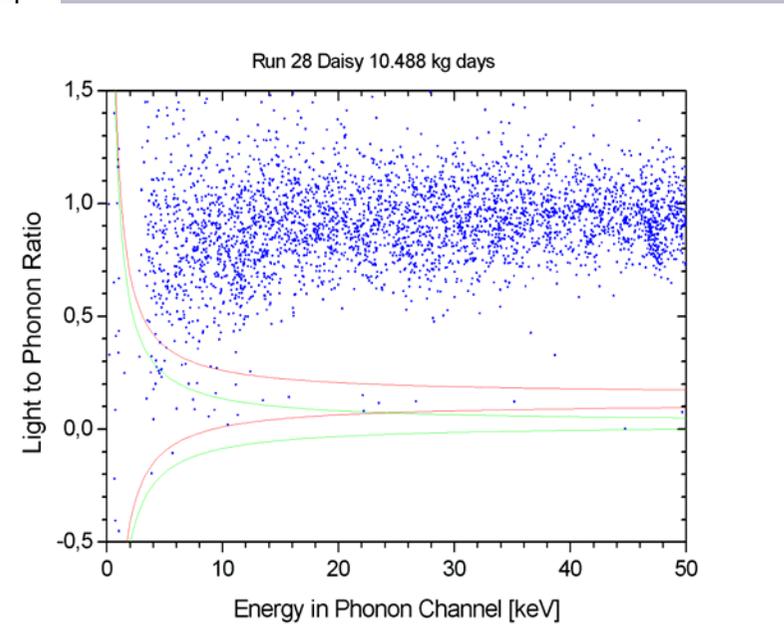
=> larger quenching for heavy nuclei?

# CRESST: Results with Phonon-Light Detectors - 2004



different quenching factors for O- and W-recoils

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

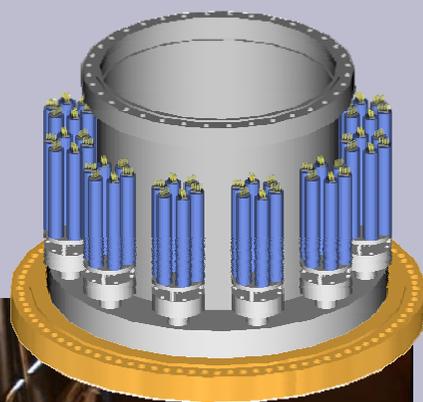


data taken without neutron shield  
=> neutron rate as expected from radioactivity in rock

now: 40cm polyethylene around set-up

# CRESST – 66 channel SQUID system and detectors

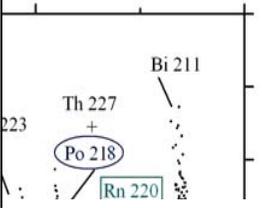
Dark Matter



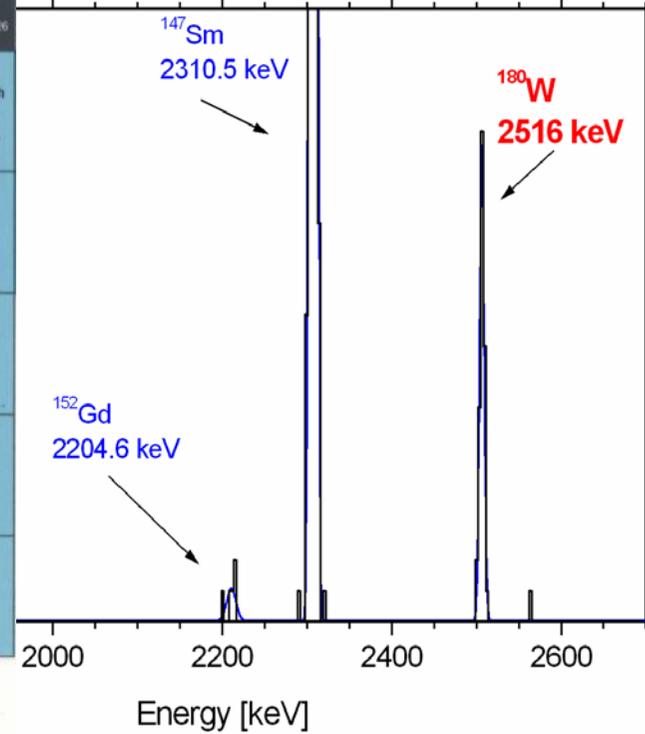
# CaWO<sub>4</sub> - α Nachweis

<b>Au 183</b> 42,0 s ε; β <sup>+</sup> α 5,344... γ 161; 214; 313; 180...; g; m	<b>Au 184</b> 46 s 19 s ε; β <sup>+</sup> α 5,108; γ 167; 213; 183...; g; m	<b>Au 185</b> 4,2 m ε; β <sup>+</sup> α 5,069... γ 310; 243; 332...; g; m	<b>Au 186</b> 10,7 m ε; β <sup>+</sup> α 4,653 γ 192; 299; 765; 416...; g; m	<b>Au 187</b> 2,3 s 8,4 m ε; β <sup>+</sup> α 4,697 γ 132; 149; hγ(101...); e <sup>-</sup>	<b>Au 188</b> 8,8 m ε; β <sup>+</sup> α 4,653 γ 256; 340; 606...; g; m	<b>Au 189</b> 4,6 m 28,3 m ε; β <sup>+</sup> α 4,653 γ 713; 813; 167; 446; 330; 348...; g; m			
<b>Pt 182</b> 2,6 m α 4,84 γ 136; 146; 210...; g; m	<b>Pt 183</b> 43 s 6,5 m β <sup>+</sup> α 4,47 γ 119; β <sup>+</sup> 630; 307; 261; 316...; g; m	<b>Pt 184</b> 17,3 m ε; β <sup>+</sup> α 4,50 γ 155; 192; 548; 731...; g; m	<b>Pt 185</b> 33 m 1,2 h ε; β <sup>+</sup> α 4,447 γ 230; 135; 440; 197...; g; m	<b>Pt 186</b> 2,0 h ε; β <sup>+</sup> α 4,23 γ 689; 612...; g; m	<b>Pt 187</b> 2,35 h ε; β <sup>+</sup> α 3,92 γ 106; 202; 110; 285; 709...; g; m	<b>Pt 188</b> 10,2 d ε; β <sup>+</sup> α 3,92 γ 188; 195; 382; 424...; g; m			
<b>Ir 181</b> 4,9 m ε; β <sup>+</sup> γ 108; 227; 1640; 319...; g; m	<b>Ir 182</b> 15 m ε; β <sup>+</sup> γ 273; 127; 912...; g; m	<b>Ir 183</b> 55 m ε; β <sup>+</sup> γ 393; 229; 88; 283...; m; g	<b>Ir 184</b> 3,0 h ε; β <sup>+</sup> α 2,9... γ 264; 120; 390...; g; m	<b>Ir 185</b> 14,4 h ε; β <sup>+</sup> α 2,9... γ 254; 1829; 60; 97; 1668...; g; m	<b>Ir 186</b> 1,9 h 16,64 h ε; β <sup>+</sup> α 2,9... γ 79; 60...; g; m	<b>Ir 187</b> 10,5 h ε; β <sup>+</sup> α 2,9... γ 913; 427; 401; 611...; g; m			
<b>Os 180</b> 21,7 m ε; β <sup>+</sup> γ 20...; g; m	<b>Os 181</b> 2,7 m 1,8 h ε; β <sup>+</sup> α 1,8 γ 145; 827; 118...; g; m	<b>Os 182</b> 22,1 h ε; β <sup>+</sup> α 1,8 γ 510; 180; 263; 56...; m	<b>Os 183</b> 9,9 h 13,0 h ε; β <sup>+</sup> α 1,8 γ 102; 119; 103; 114; hγ(171); e <sup>-</sup>	<b>Os 184</b> 0,02 α 3000	<b>Os 185</b> 94 d ε; β <sup>+</sup> α 2,78 γ 646; 875; 880; 717...; g; m	<b>Os 186</b> 1,58 2,0 · 10 <sup>15</sup> a α 80	<b>Os 187</b> 1,6 α 200	<b>Os 188</b> 13,3 α 5	<b>Os 189</b> 6 h 16,1 hγ(91) α 0,00026 + 40
<b>Re 179</b> 19,7 m ε; β <sup>+</sup> γ 430; 290; 1680...; g; m	<b>Re 180</b> 2,43 m ε; β <sup>+</sup> α 1,8 γ 903; 104; 825...; g; m	<b>Re 181</b> 20 h ε; β <sup>+</sup> α 1,8 γ 366; 361; 639...; g; m	<b>Re 182</b> 13 h 64 h ε; β <sup>+</sup> α 1,8 γ 68; 1121; 1221; 68; 1189; 1121; 106...; g; m	<b>Re 183</b> 71 d ε; β <sup>+</sup> α 1,8 γ 162; 46; 292; 209; 110; 99...; g; m	<b>Re 184</b> 38,0 d ε; β <sup>+</sup> α 1,8 γ 105; 253; 790; 111...; g; m	<b>Re 185</b> 37,40 ε; β <sup>+</sup> α 1,8 γ 97...; g; m	<b>Re 186</b> 89,25 h 2 · 10 <sup>5</sup> a ε; β <sup>+</sup> α 1,8 γ 50; 137...; g; m	<b>Re 187</b> 62,60 5 · 10 <sup>10</sup> a ε; β <sup>+</sup> α 1,8 hγ 64; 106...; 72...; g; m	<b>Re 188</b> 18,6 m 16,98 h ε; β <sup>+</sup> α 1,8 hγ 64; 106...; 72...; g; m
<b>W 178</b> 22 d ε; β <sup>+</sup> no γ m	<b>W 179</b> 6,7 m 38 m hγ 222...; γ(239...); e <sup>-</sup>	<b>W 180</b> 0,13 1,7 · 10 <sup>18</sup> a ε; β <sup>+</sup> α 1,8 γ(239...); e <sup>-</sup>	<b>W 181</b> 121,2 d ε; β <sup>+</sup> α 1,8 γ(6...); e <sup>-</sup>	<b>W 182</b> 26,3 ε; β <sup>+</sup> α 1,8 γ(6...); e <sup>-</sup>	<b>W 183</b> 5,3 s 14,3 ε; β <sup>+</sup> α 1,8 hγ 108; 99; 46...; g; m	<b>W 184</b> 30,67 ε; β <sup>+</sup> α 1,8 γ 0,002 + 2,0	<b>W 185</b> 1,67 m 75,1 d ε; β <sup>+</sup> α 1,8 hγ 66; 132; 174...; g; m	<b>W 186</b> 28,6 ε; β <sup>+</sup> α 1,8 hγ 66; 132; 174...; g; m	<b>W 187</b> 23,72 h ε; β <sup>+</sup> α 1,8 hγ 66; 132; 174...; g; m
<b>Ta 177</b> 56,6 h ε; β <sup>+</sup> γ 113; 208...; g; m	<b>Ta 178</b> 9,25 m 1,45 h ε; β <sup>+</sup> α 1,8 γ 93; 311; γ 332...; g; m	<b>Ta 179</b> 665 d ε; β <sup>+</sup> α 1,8 no γ g	<b>Ta 180</b> 0,012 ε; β <sup>+</sup> α 1,8 no γ g	<b>Ta 181</b> 99,988 ε; β <sup>+</sup> α 1,8 no γ g	<b>Ta 182</b> 16 m 114,43 d ε; β <sup>+</sup> α 1,8 hγ 172; 147; 185...; g; m	<b>Ta 183</b> 5,0 d ε; β <sup>+</sup> α 1,8 hγ 172; 147; 185...; g; m	<b>Ta 184</b> 8,7 h ε; β <sup>+</sup> α 1,8 hγ 172; 147; 185...; g; m	<b>Ta 185</b> 49 m ε; β <sup>+</sup> α 1,8 hγ 172; 147; 185...; g; m	<b>Ta 186</b> 10,5 m ε; β <sup>+</sup> α 1,8 hγ 172; 147; 185...; g; m
<b>Hf 176</b> 5,20 α 23	<b>Hf 177</b> 51 m 1,1 s 18,60 ε; β <sup>+</sup> α 1,8 hγ 277; 206; 229; 327...; g; m	<b>Hf 178</b> 31 a 4,0 s 27,30 ε; β <sup>+</sup> α 1,8 hγ 426; 574; 326; 496; 213; 375...; g; m	<b>Hf 179</b> 25 d 10,7 s 13,63 ε; β <sup>+</sup> α 1,8 hγ 454; 443; 215...; g; m	<b>Hf 180</b> 5,5 h 35,10 ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Hf 181</b> 42,39 d ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Hf 182</b> 64 m ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Hf 183</b> 64 m ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Hf 184</b> 4,12 h ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Hf 185</b> 3,5 m ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m
<b>Lu 175</b> 97,41 α 15 + 8	<b>Lu 176</b> 2,59 ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 177</b> 160,1 d 6,71 d ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 178</b> 22,7 m 28,4 m ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 179</b> 4,6 h ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 180</b> 5,7 m ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 181</b> 3,5 m ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 182</b> 2,0 m ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 183</b> 58 s ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m	<b>Lu 184</b> ~ 20 s ε; β <sup>+</sup> α 1,8 hγ 332; 443; 215...; g; m

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

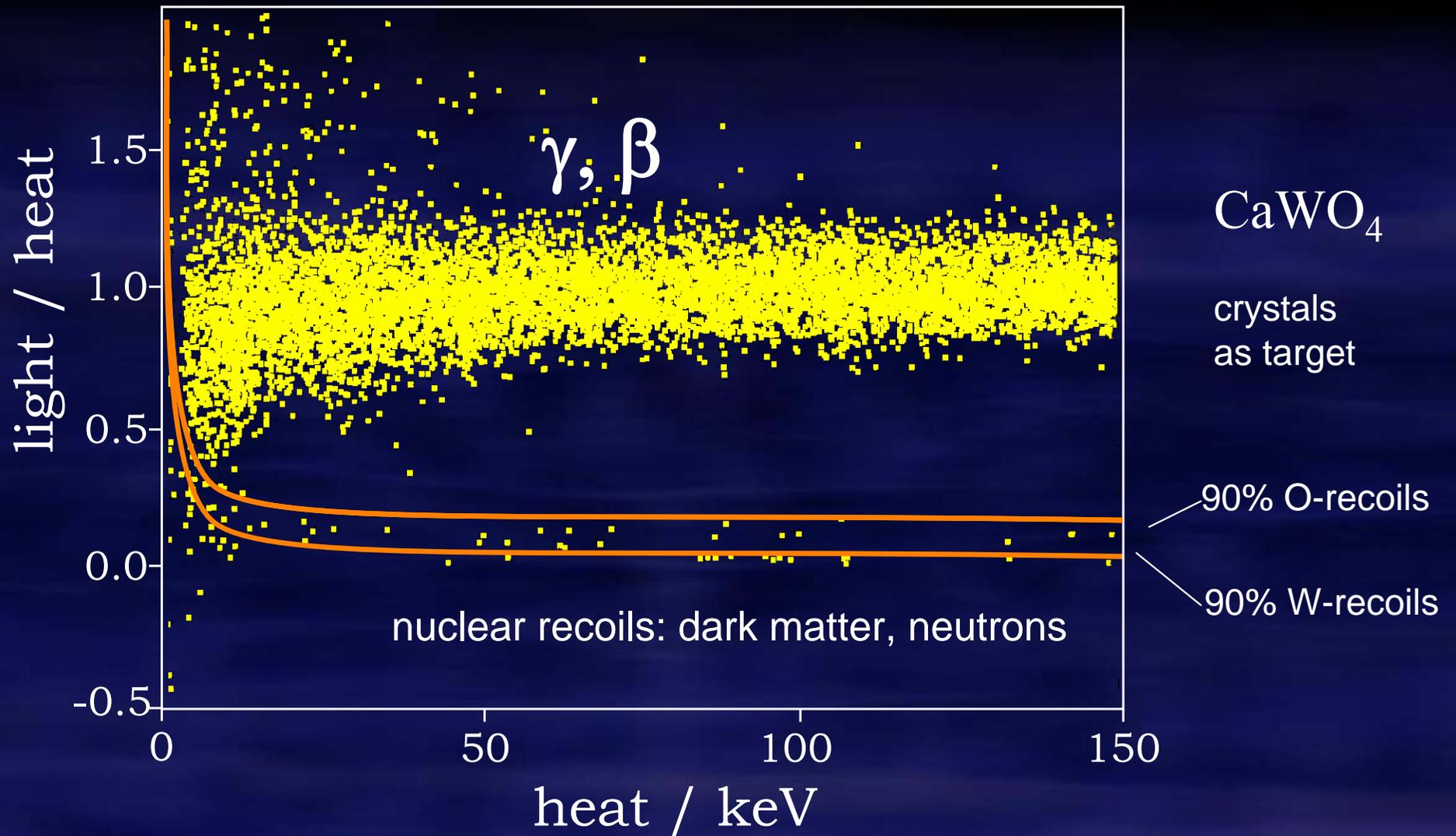


$$t_{1/2}({}^{180}\text{W}) = (1.7 \pm 0.2) 10^{18} \text{ y}$$

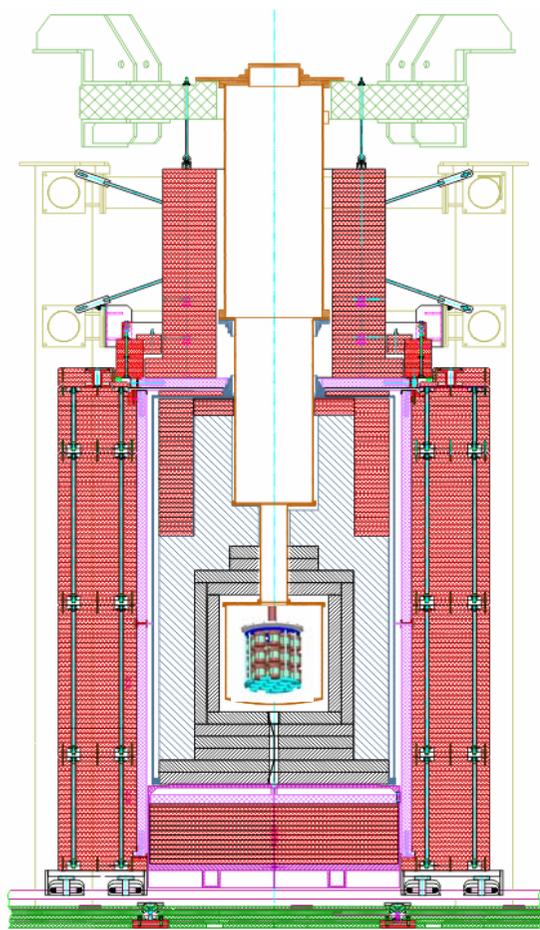


# CRESST 2004 no neutron shield

Run28, 2004, 10.5 kg d

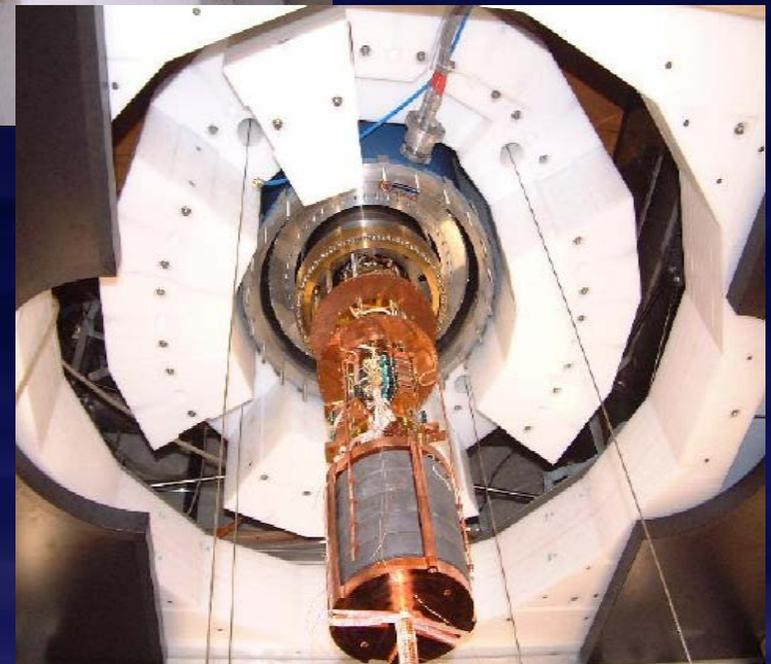


# CRESST – neutron shield



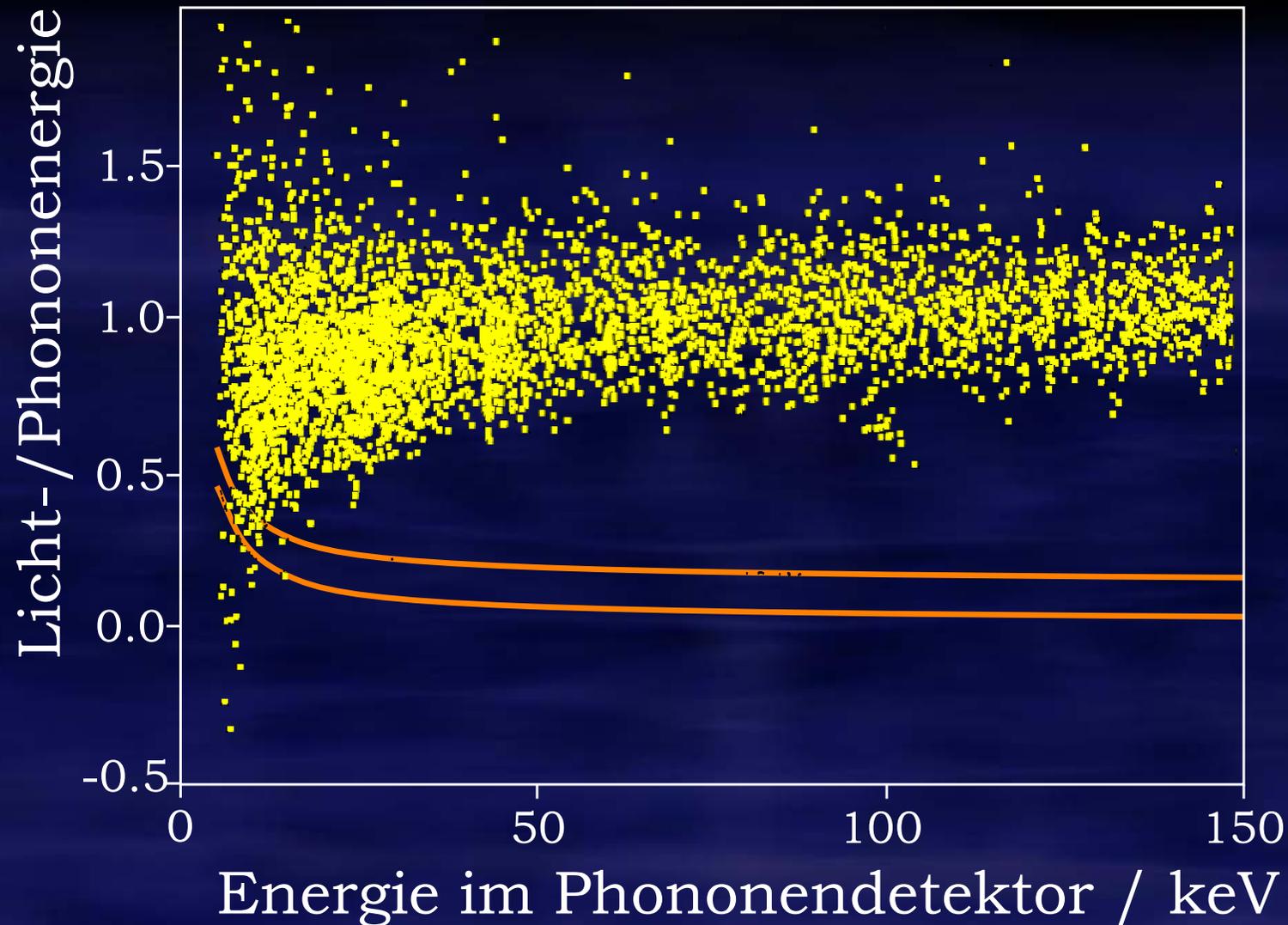
PE neutron moderator

Plastic scintill.  $\mu$ -veto



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

vorläufig, Januar 2007, 3 kg d (Zora)



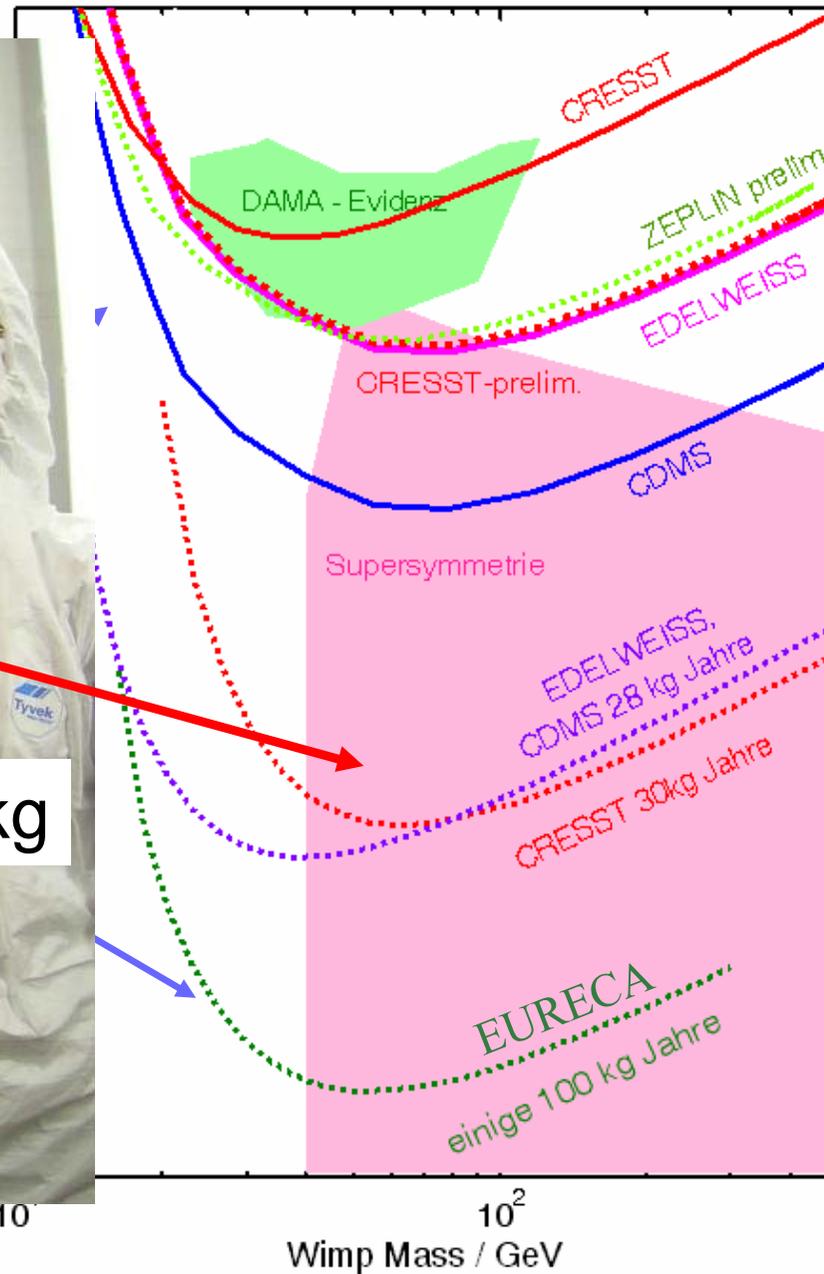
with neutron  
shield  
and  
alpha recoil  
rejection

# Future



go from <1kg towards 10kg

=> EURECA Collaboration



Dark Matter

## Search and Find Dark Matter Particles

- Based on CRESST and EDELWEISS expertise, with additional groups joining.
- Target materials: Ge, CaWO<sub>4</sub>, 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

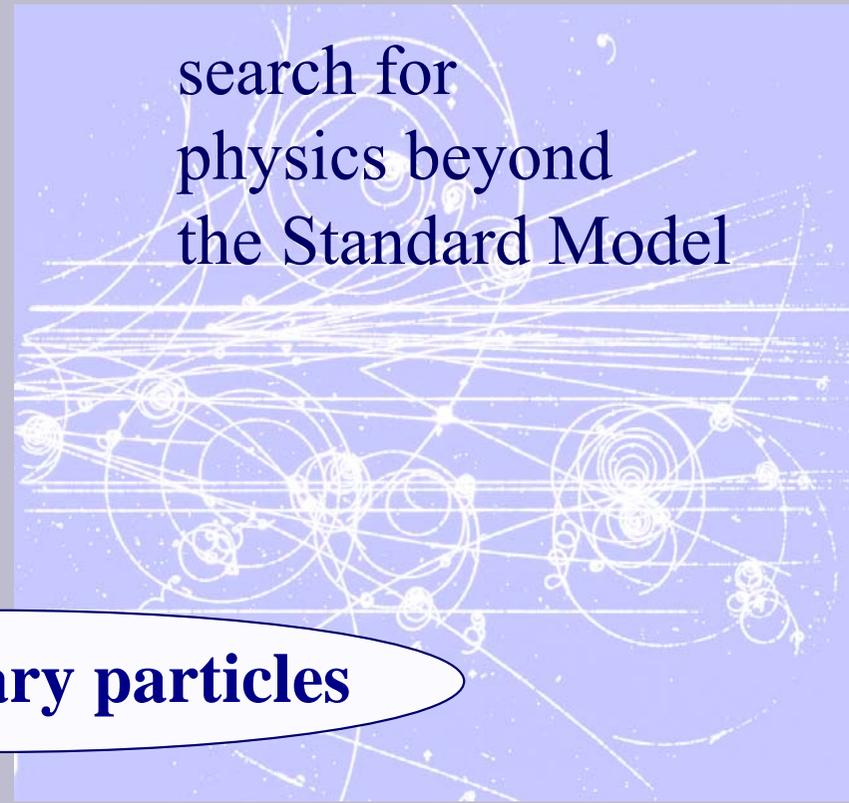
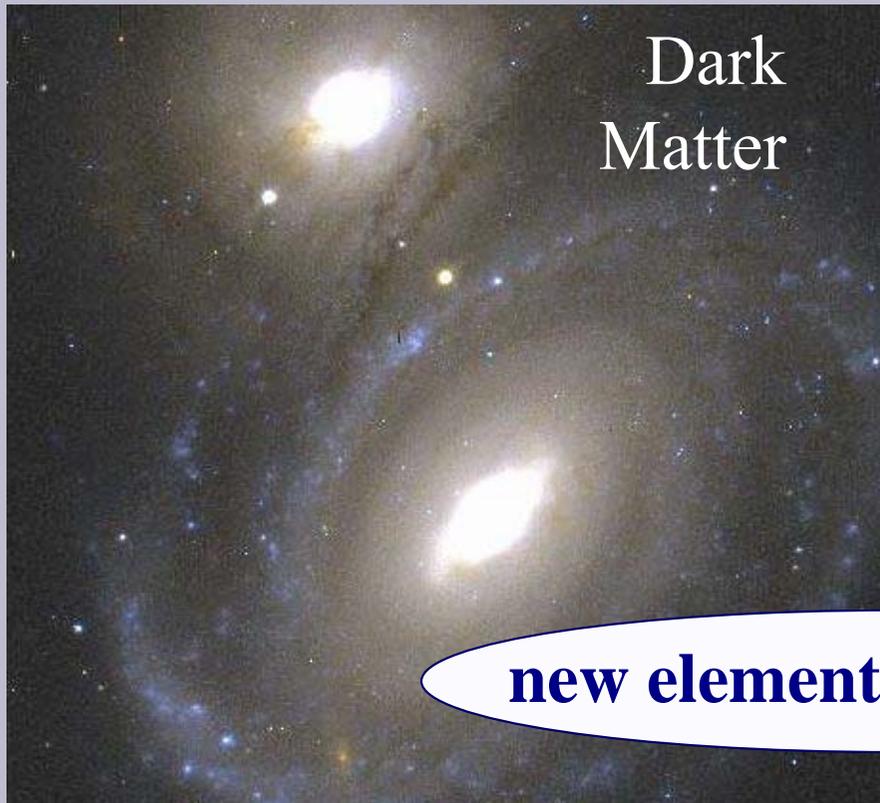
CNRS/CRTBT Grenoble

CNRS/CSNSM Orsay

CNRS/IPNL Lyon

CNRS/IAP Paris

## CERN



**new elementary particles**