Dark Matter Search Experiments

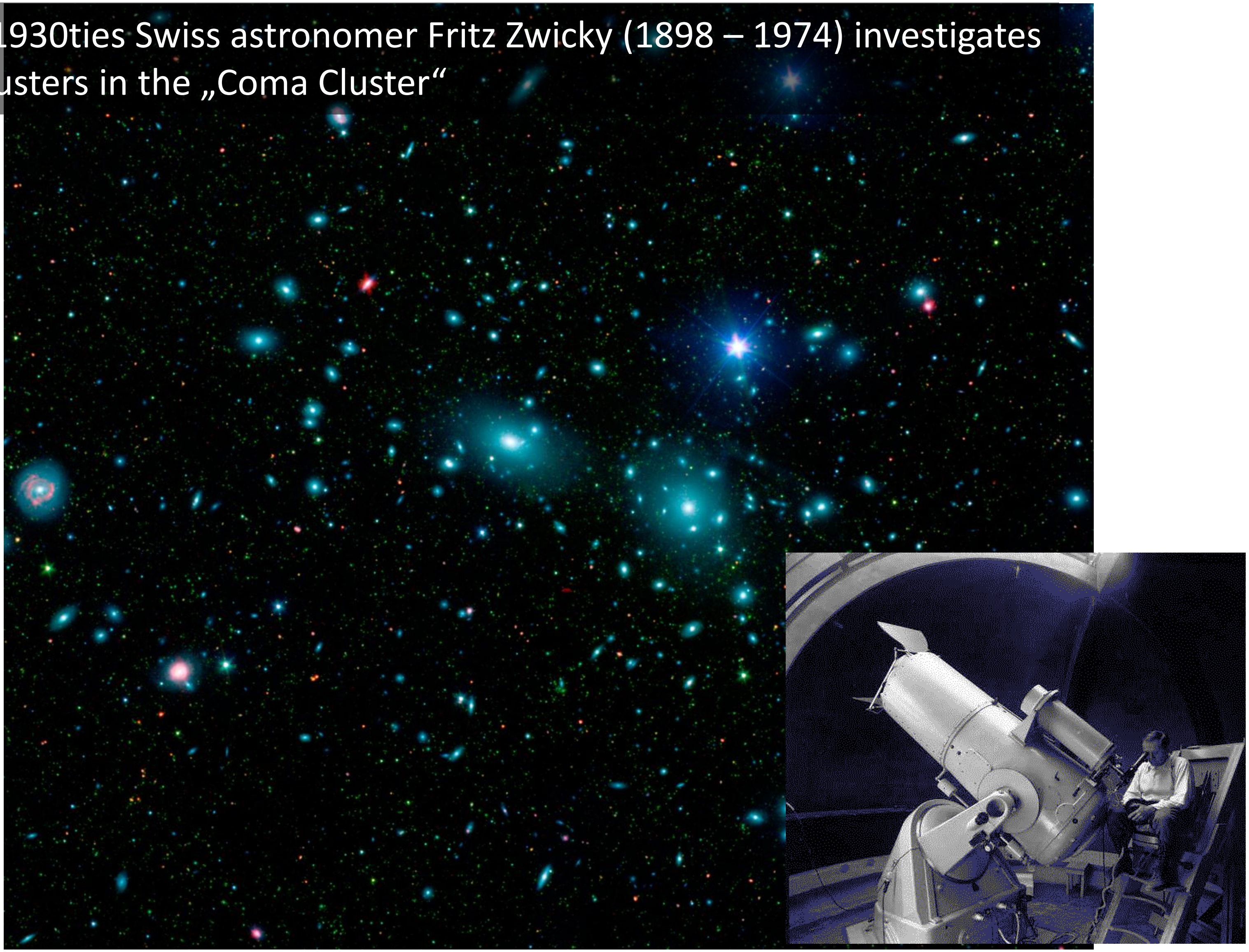
Bruno Pontecorvo School 2012,
Alushta, Crimea

Outline

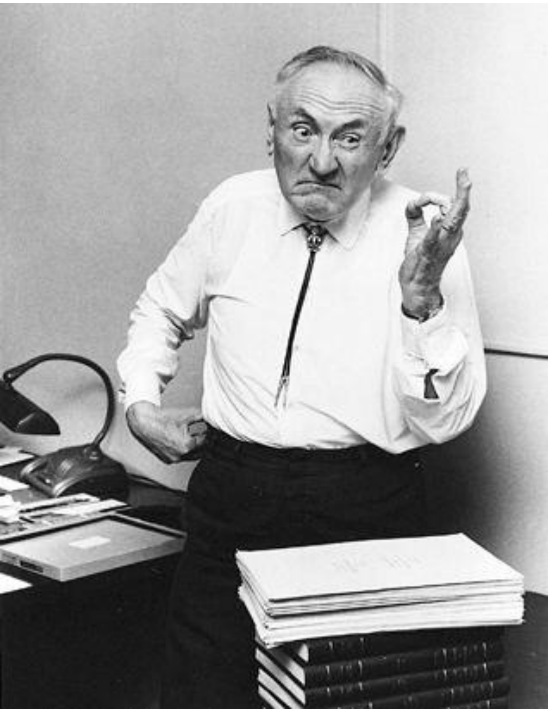
- Motivation for Dark Matter Search
- Candidates for Dark Matter
- Detection Approaches
- Direct Dark Matter Search
- Conclusions

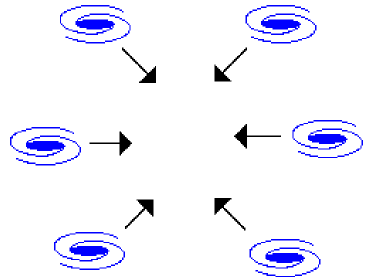
First Hints for Dark Matter

- In the 1930ties Swiss astronomer Fritz Zwicky (1898 – 1974) investigates galaxy clusters in the „Coma Cluster“

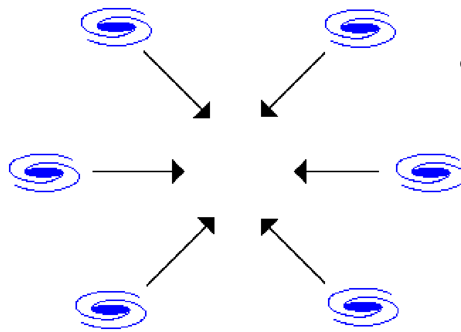


Dynamics of Galaxies



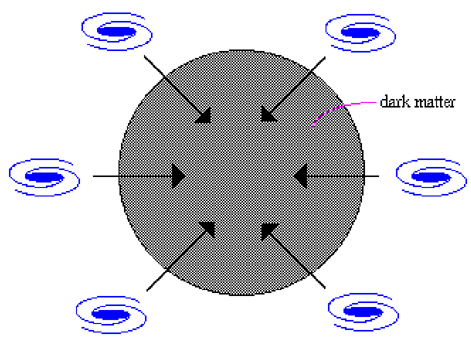


- Observation: **rotation speed of single galaxies too high**



- Luminous matter alone cannot account for the anomaly

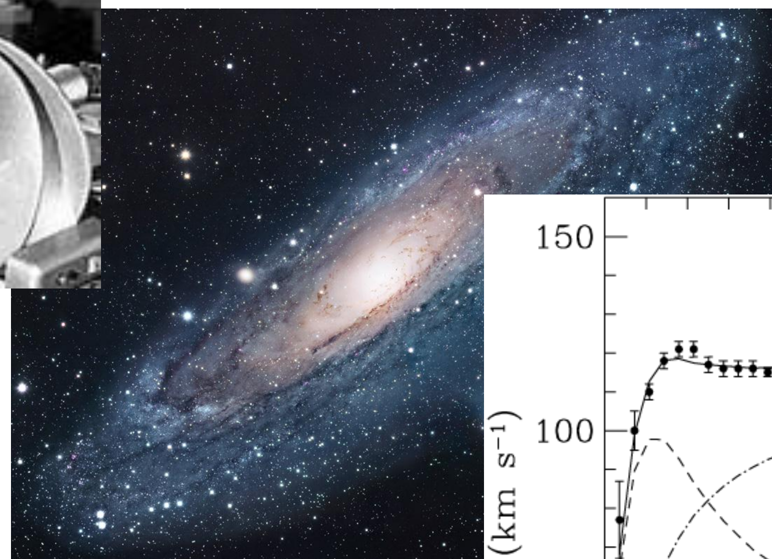
- Fritz Zwicky postulates in 1933 the existence of Dark Matter

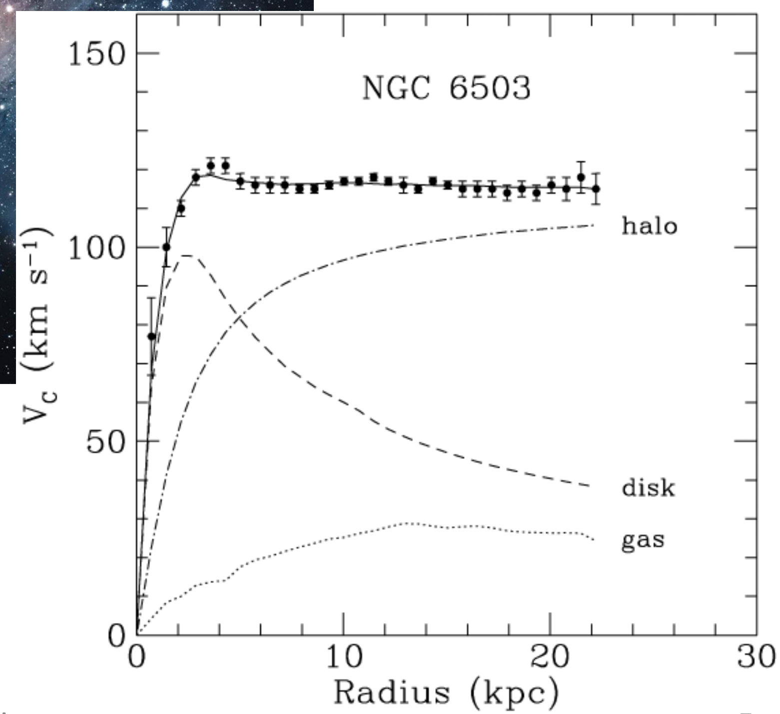


- In 1937 (!) Zwicky predicts that gravitational lensing will be used in the future to investigate DM

Rotation Curves of Single Galaxies

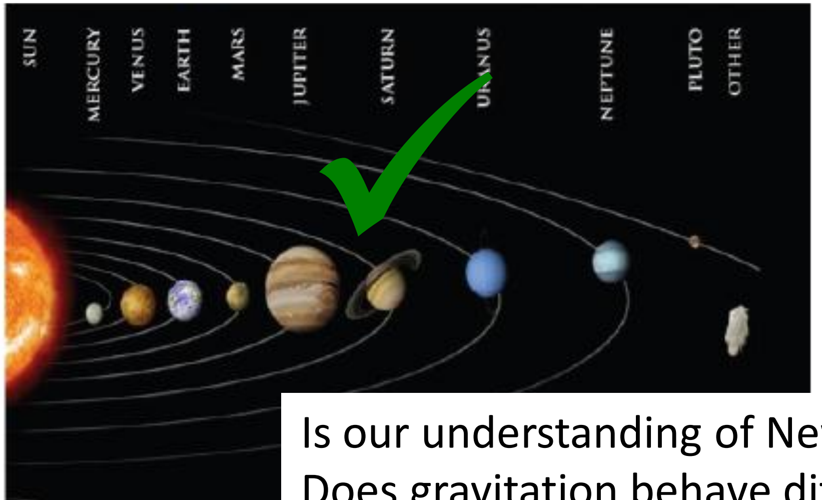
- Analogous finding by Vera Cooper-Rubin as Fritz Zwicky: rotation speed too high in the outer parts of the galaxy
- Gravitational potential of luminous matter alone not sufficient to explain effect





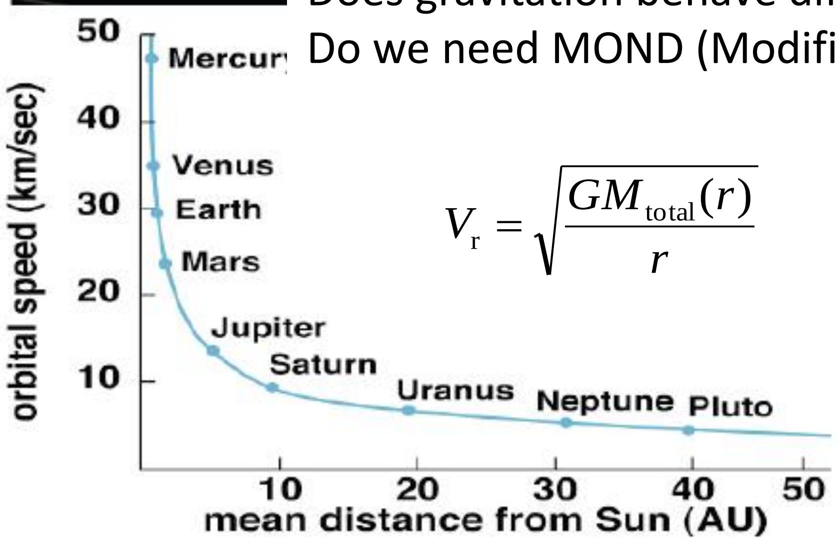
Gravitation on Different Scales

Solar system



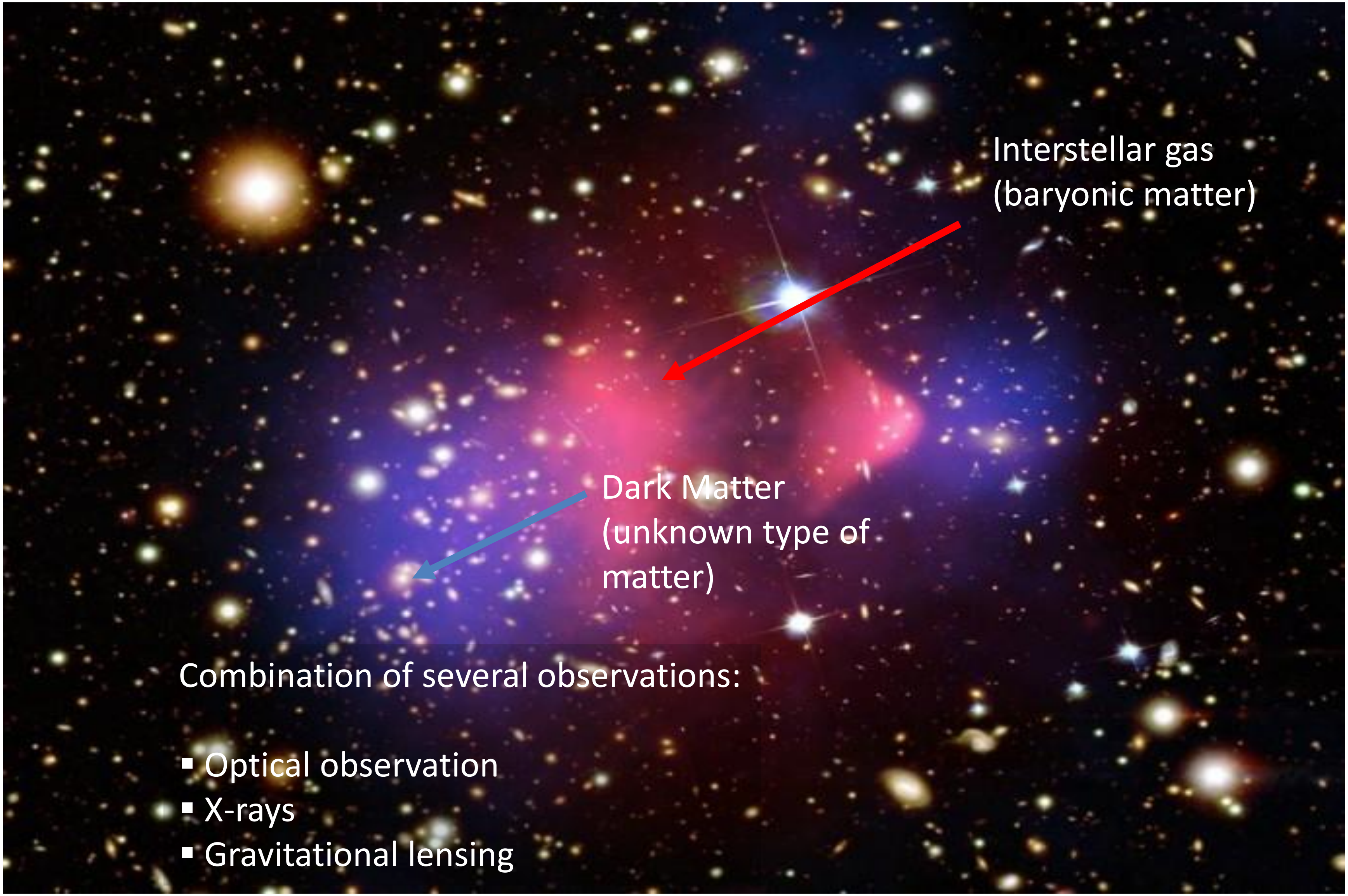
Single galaxy

Is our understanding of Newtonian gravitation wrong?
Does gravitation behave differently on various scales?
Do we need MOND (Modified Newtonian Dynamics)?



$$V_r = \sqrt{\frac{GM_{total}(r)}{r}}$$

DM Dynamics: The „Bullet“ Cluster

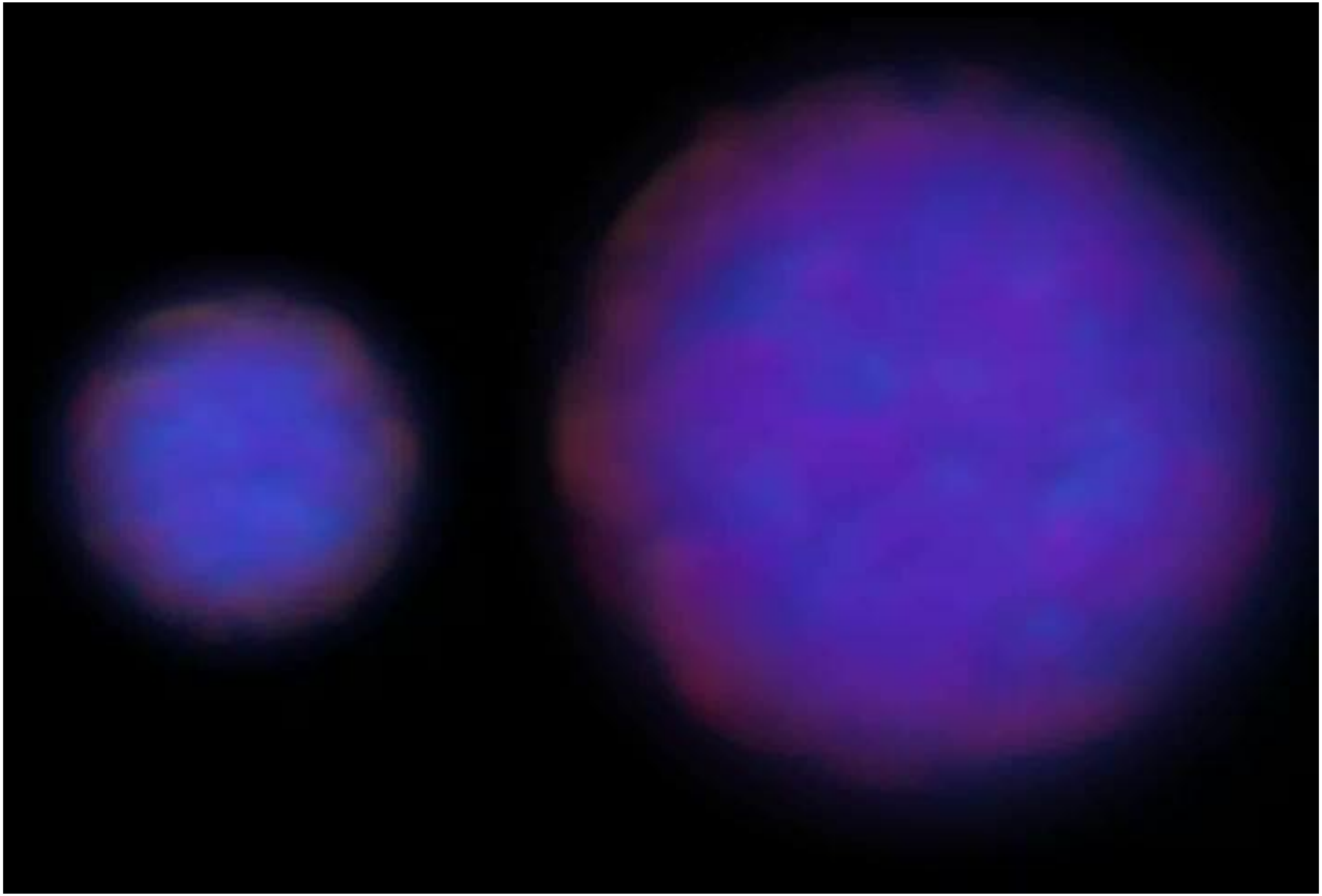


Combination of several observations:

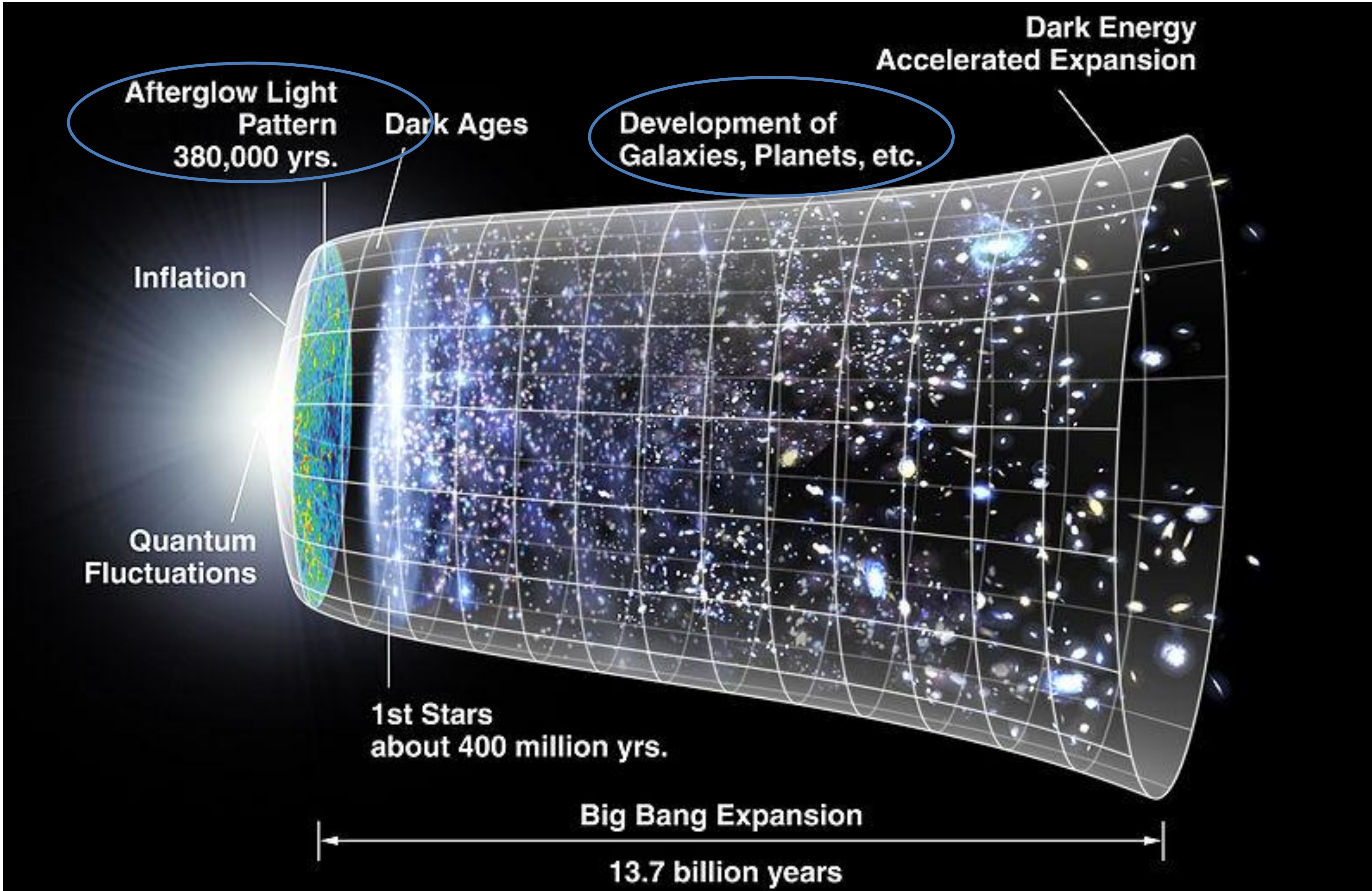
- Optical observation
- X-rays
- Gravitational lensing

-> Up to now strongest indication for the existence of Dark Matter!!

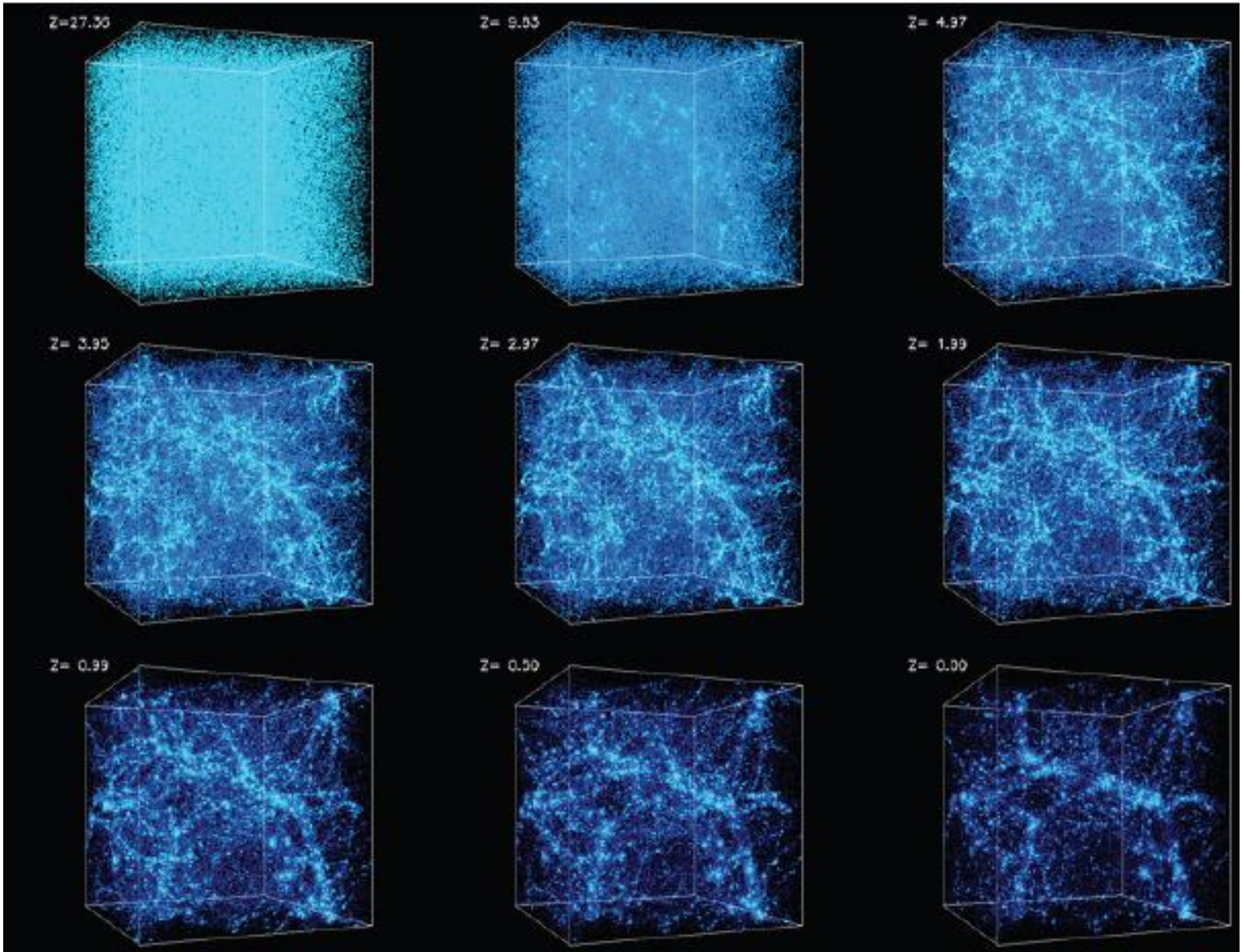
Animation of „Bullet“ Cluster Collision



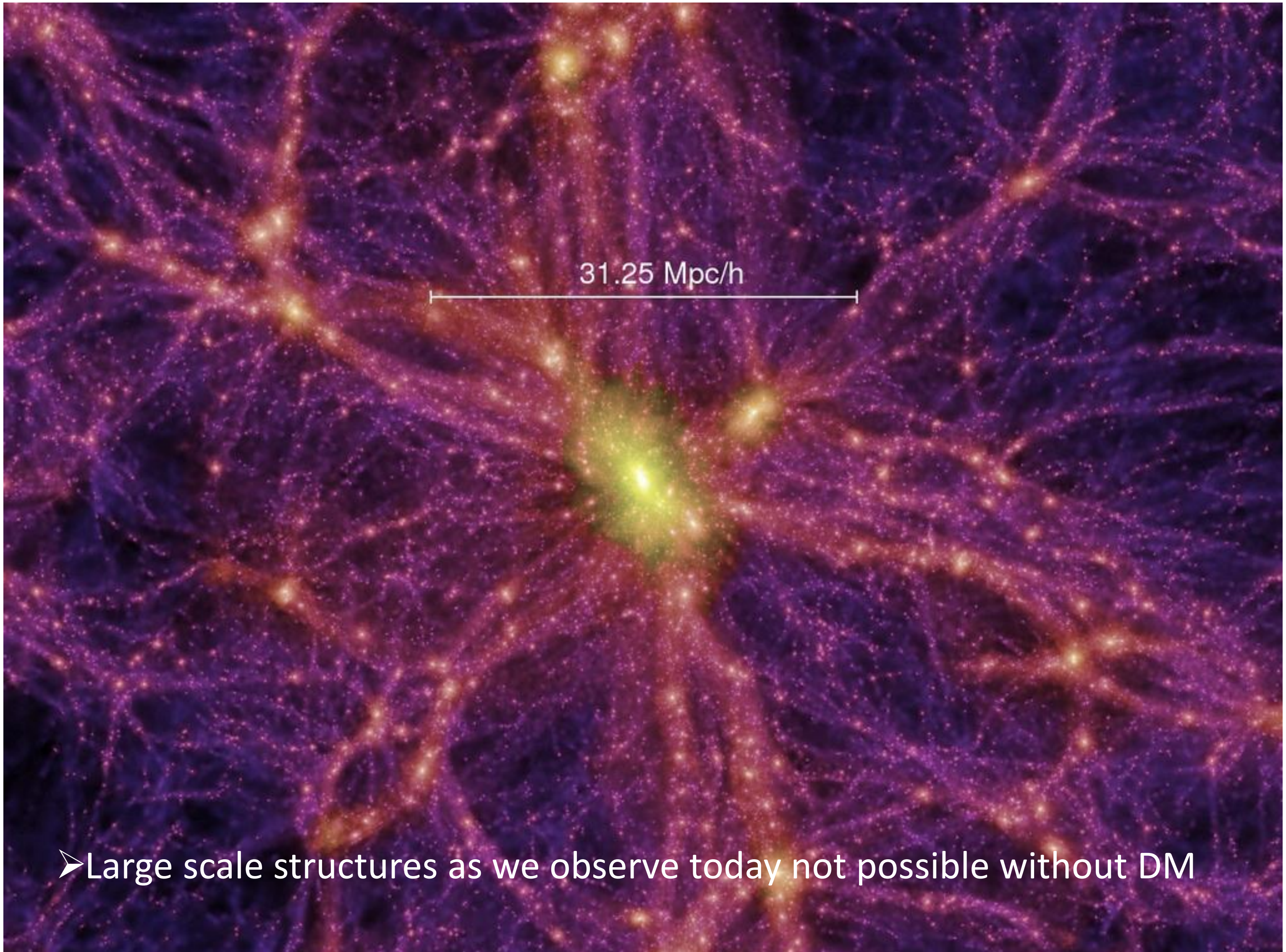
What About Large Scales ?



Large-Scale Structure Formation

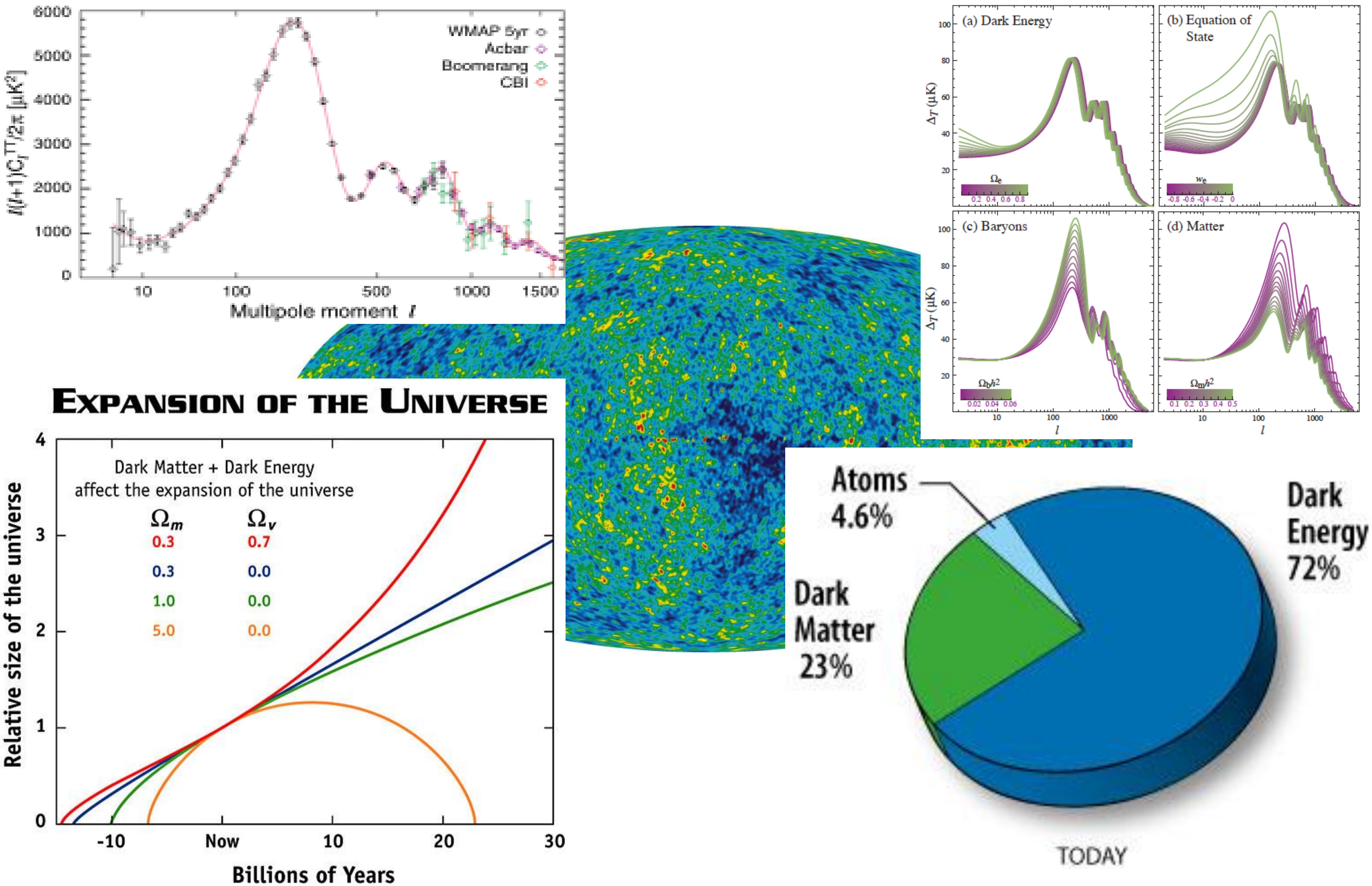


Millenium Simulation

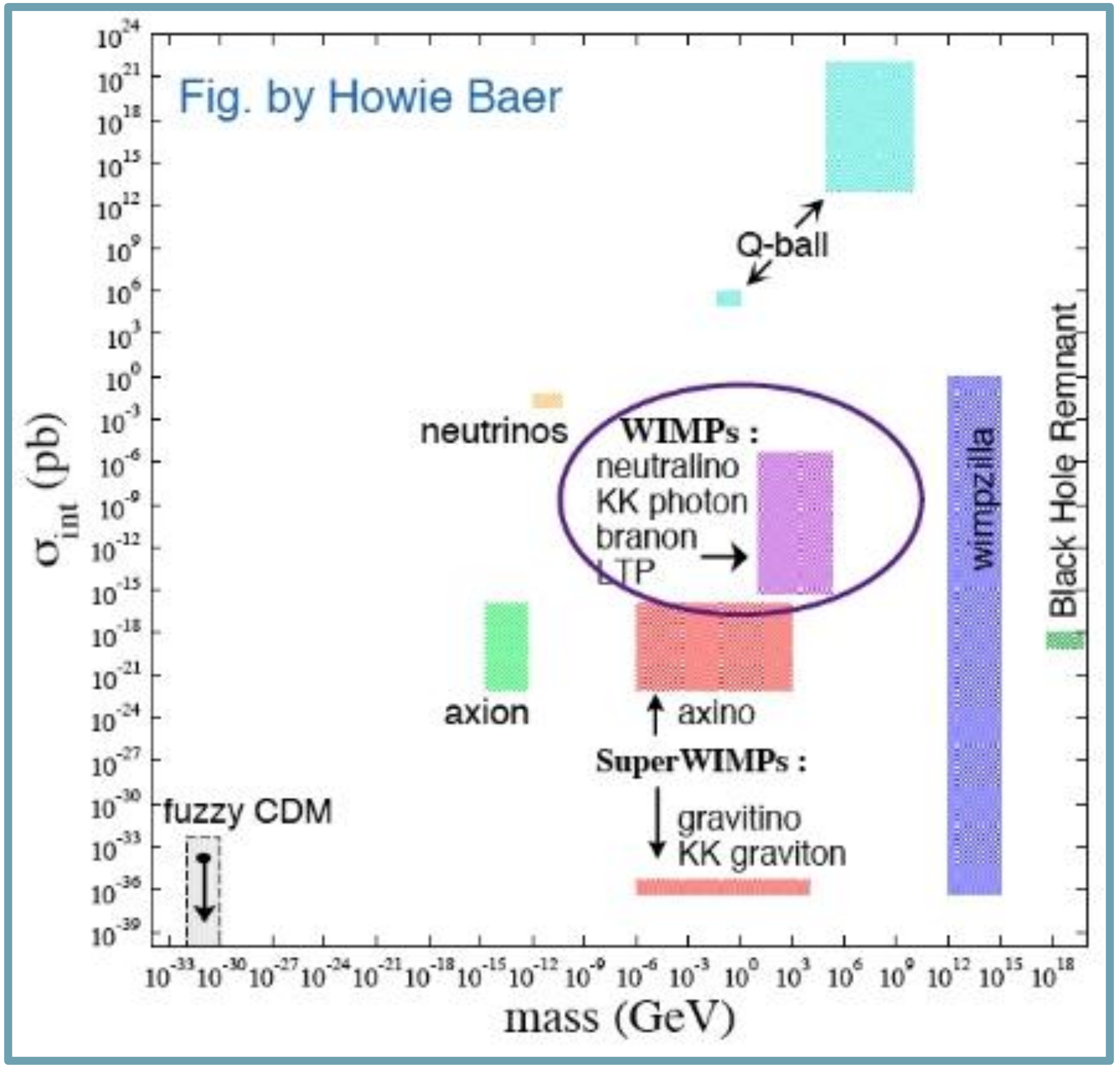


- Large scale structures as we observe today not possible without DM

Information from the Cosmic Microwave Background



Dark Matter Particle Candidates



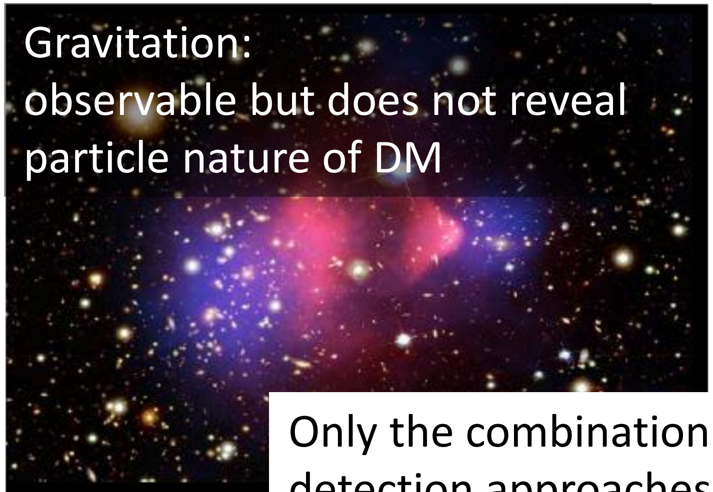
The universe could plausibly consist of particles ranging from 10^{-6} eV axions to 10^{15} GeV WIMPzillas

➢**WIMP (Weakly Interacting Massive Particle)** is focused on by various detection experiments

- WIMP could be the lightest supersymmetric particle (LSP) -> must be stable on cosmological timescales (R-parity conservation)

- The lightest neutralino, is a very attractive and thoroughly studied candidate for Dark Matter

Dark Matter Detection Approaches

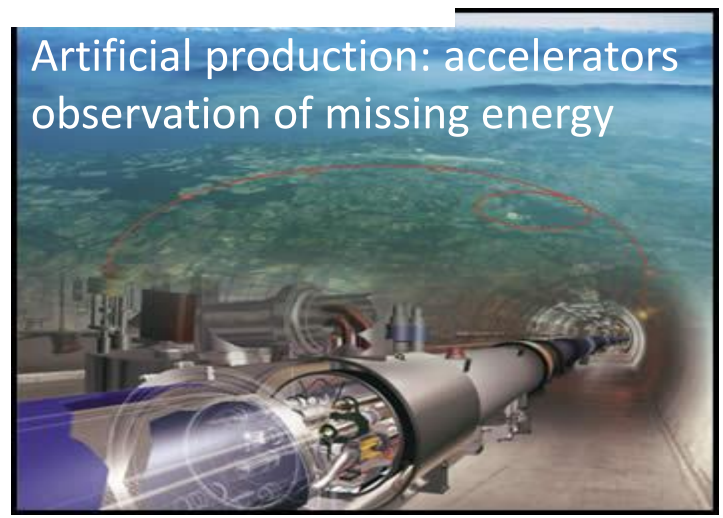


Gravitation:
observable but does not reveal particle nature of DM

Direct Search:
subject of this lecture

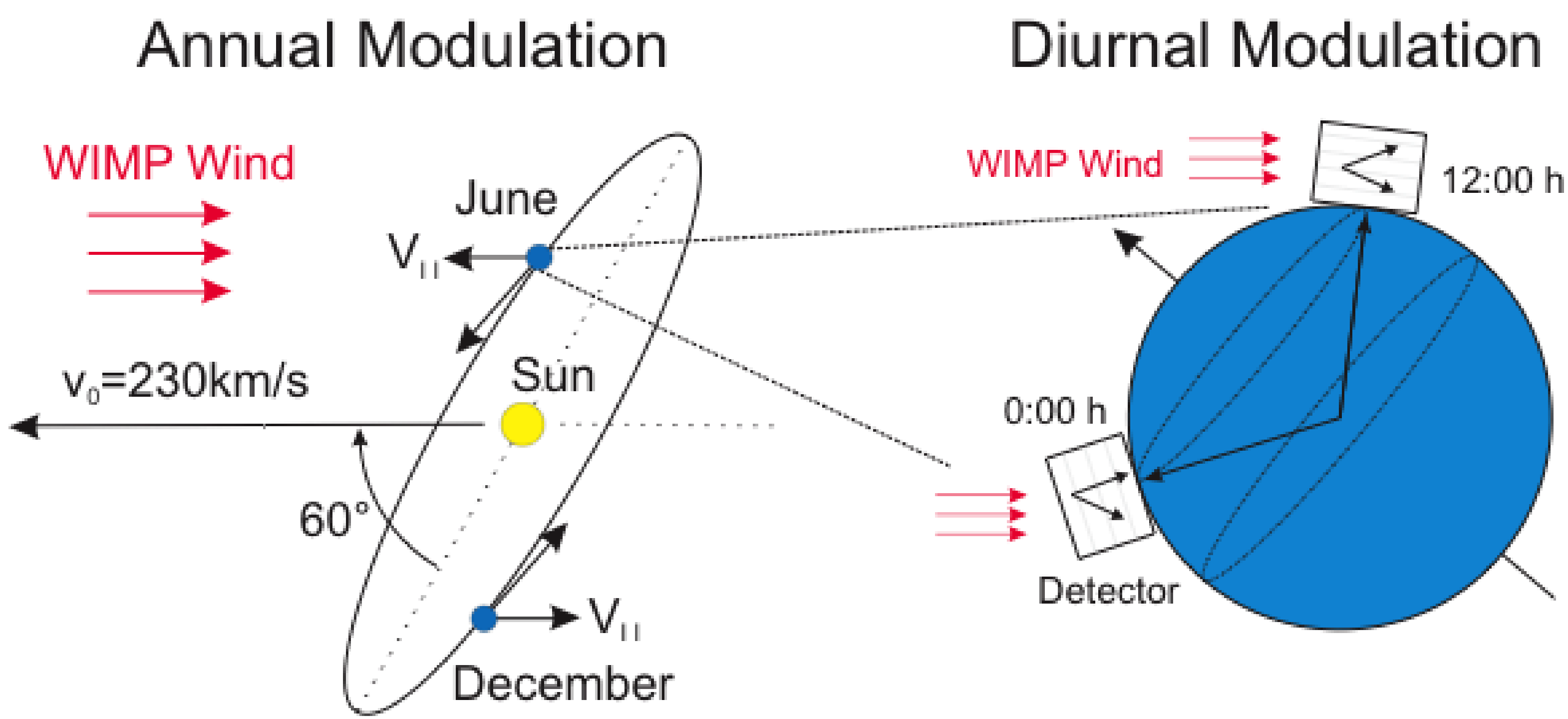
Only the combination of the different detection approaches is likely to solve the mystery of dark matter

Indirect search:
observation of annihilation products of DM particles



Artificial production: accelerators
observation of missing energy

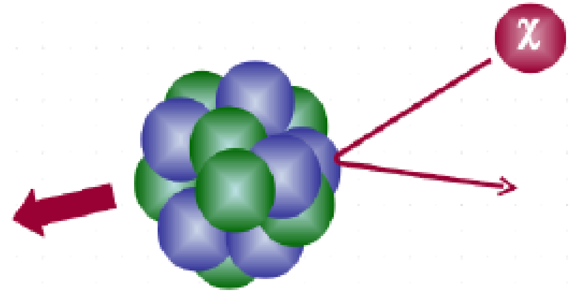
Possible „Smoking Gun“ Signatures of Dark Matter



- Coherent interaction with baryonic matter: **~A^2** (A = atomic mass number)
- Information provided by high-energy accelerators (e.g., LHC at CERN)

Detection Approach

Goal: Detect **WIMP (Weakly Ineracting Massive Particle)** by measuring nuclear recoil of a few keV in an earth based target material



- WIMP density at the Earth: 0.3 GeV/c²/cm³
- Wide range of WIMP masses: 10 – 1000 GeV/c²
- Expected signature: nuclear recoil (of a few keV)
- Expected scattering behaviour: coherent, i.e. ~ A^2
- Single scatters distributed uniformly in target volume
- Extremely rare interaction rate with baryonic matter (< 0.01 evts/kg/d)

$$\frac{\partial R}{\partial E_R} \propto N F^2(\vec{q}) \frac{\rho_D}{M_D} \sigma_\chi e^{-\frac{E_R}{E_0}}$$

R measured rate in detector
M_D mass of WIMP
N number of target nuclei
E_R recoil energy of target nucleus
σ_χ WIMP nucleus cross section
F^2 nuclear Form factor

→ suppress natural radioactivity and cosmic radiation:

- Deep underground facilities
- Additional shielding with selected materials
- Detectors with very low energy threshold and excellent background discrimination capability

Backgrounds

• Intrinsic radioactivity in materials surrounding the detector (U, Th, K, Co, etc.)
-> source of gammas and neutrons
-> careful material screening and selection

• Intrinsic radioactivity in target material itself (U, Th, Rn,...)
-> special handling and purification techniques

• Radioactivity from the surrounding environment
radioactivity of environment materials (γ and neutrons from (α,n)
and μ-reactions)
-> shielding (Pb, Cu, PE, H_2O, ...)

• Cosmic ray muons
-> penetrate deep underground

• Fast neutrons induced by unvetoed muon-showers in the surroundings

• Neutrinos (solar, atmospheric, ...)
-> relevant for future ultra-low threshold detectors

Direct Detection Experiments

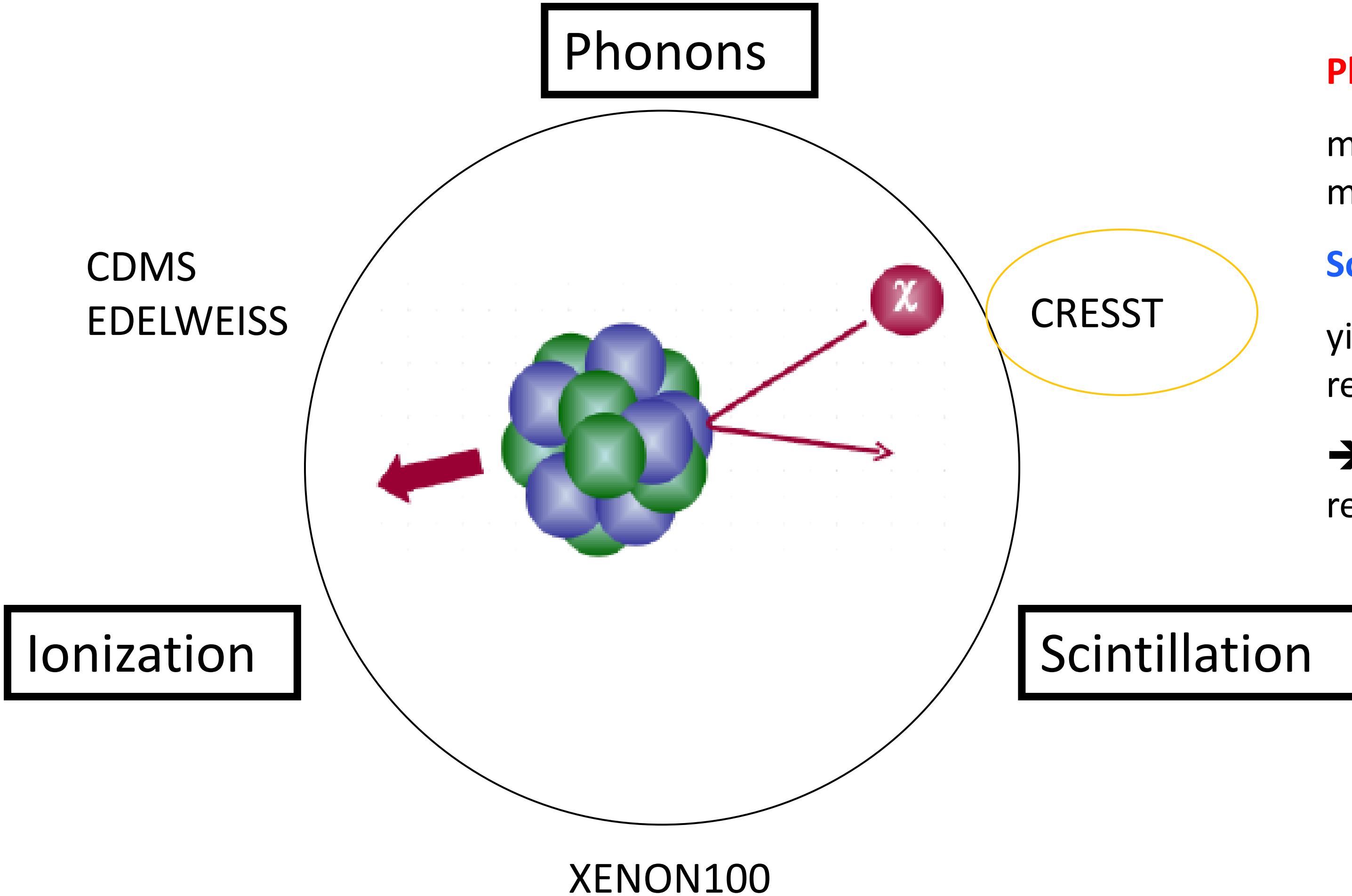
Experiment	Technology	β,γ rejection	Comments
CDMS Edelweiss CRESST, Rosebud	Cryo Ge/Si Cryo Ge Cryo $CaWO_4$	ionization/phonon ionization/thermal scintillation/thermal	surface β's, timing helps surface β's, NbSi helps low light for WIMP on W
Zeplin, XENON, WArP, ArDM,	LXe 2-phase LAr 2-phase	charge/scintillation charge/scintillation	low light, PMT radioactivity purification (^{39}Ar,^{42}Ar,^{85}Kr)
XMASS CLEAN	LXe LAr/LNe	scint,self-shielding, scint,pulse shape disc.	No E-field, good scaling also solar ν, no E-field
CoGeNT Majorana, Gerda Genius, GEDEON Cuoricino	p-point HPGe HPGe counting HPGe counting Cryo TeO_2	low threshold energy resolution extreme purity stat. subtraction	CNNS/DM primarily ββ-decay large mass, ann mod.
DAMA,LIBRA, ANAIS	NaI scint.	pulse shape disc. extreme purity	large mass, ann mod. also ββ-decay
Picasso, COUPP	bubble chambers	nucleation thresh	large mass, alpha bkgd
DRIFT	drift chmbr (gas)	track length	directionality/low density

Background suppression by using information from **2 channels**

Background suppression by using information from **1 channel**

Nucl. Inst. Meth. A 579 (2007) 437

Recoil Detection & Background Identification



Phonons

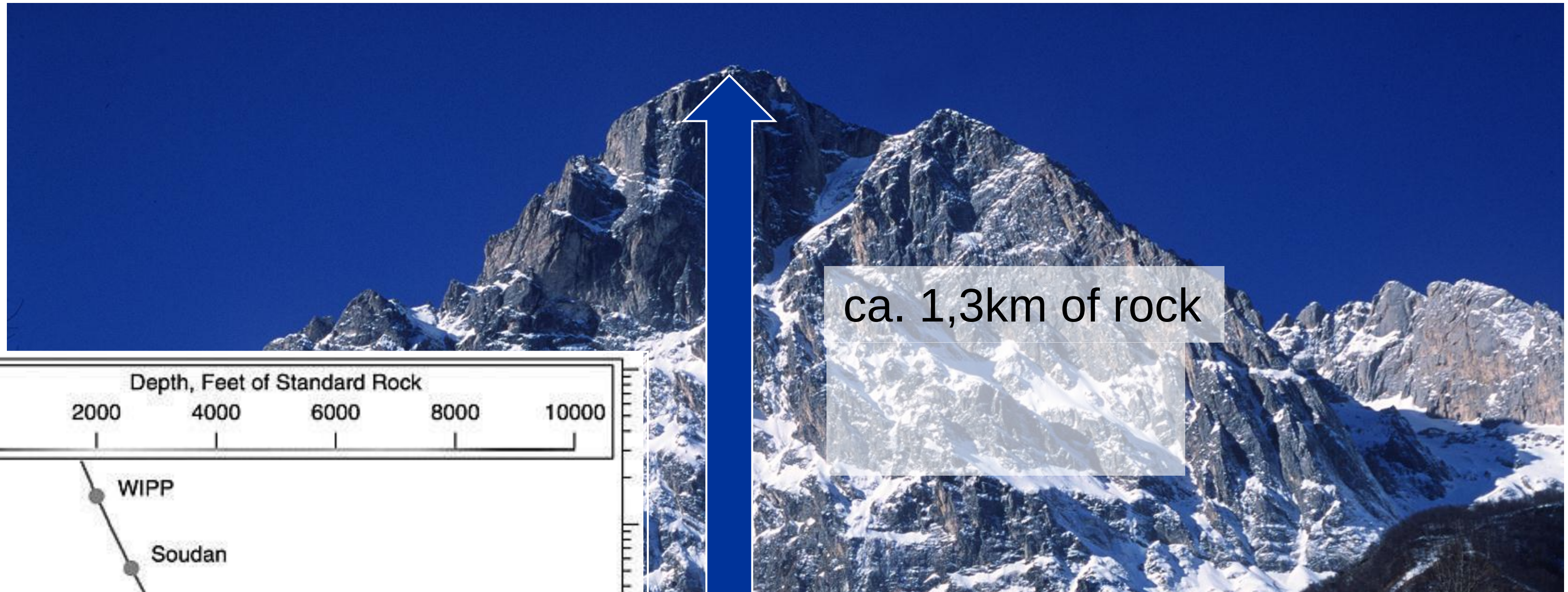
most precise total energy measurement

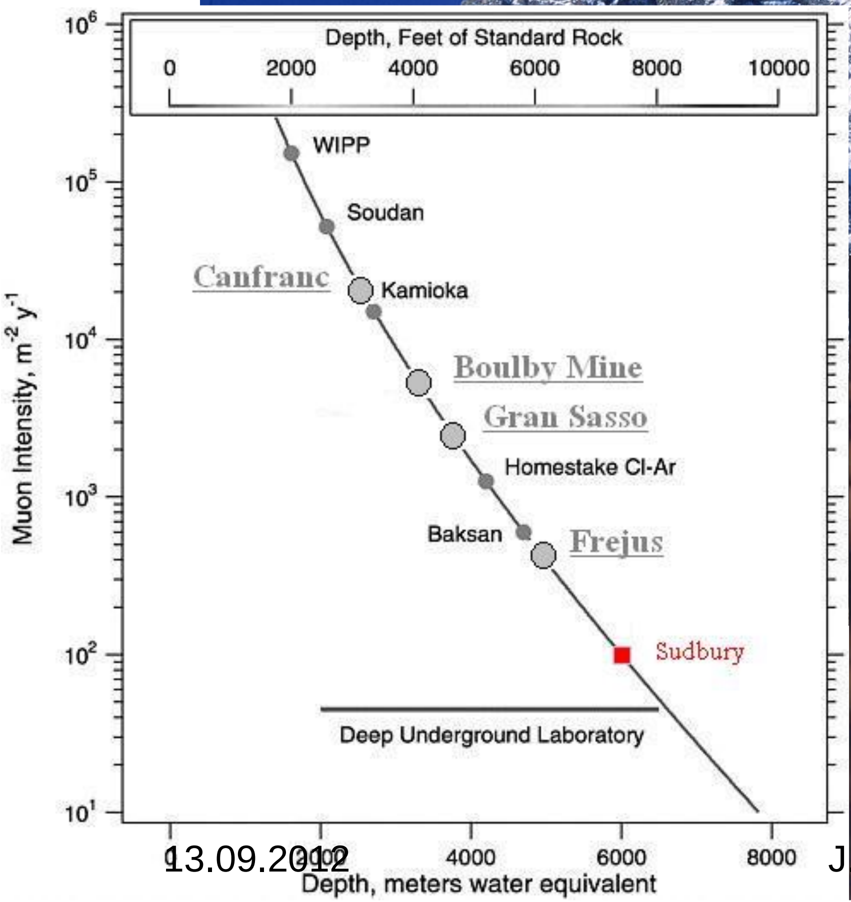
Scintillation:

yield depends on recoiling particle

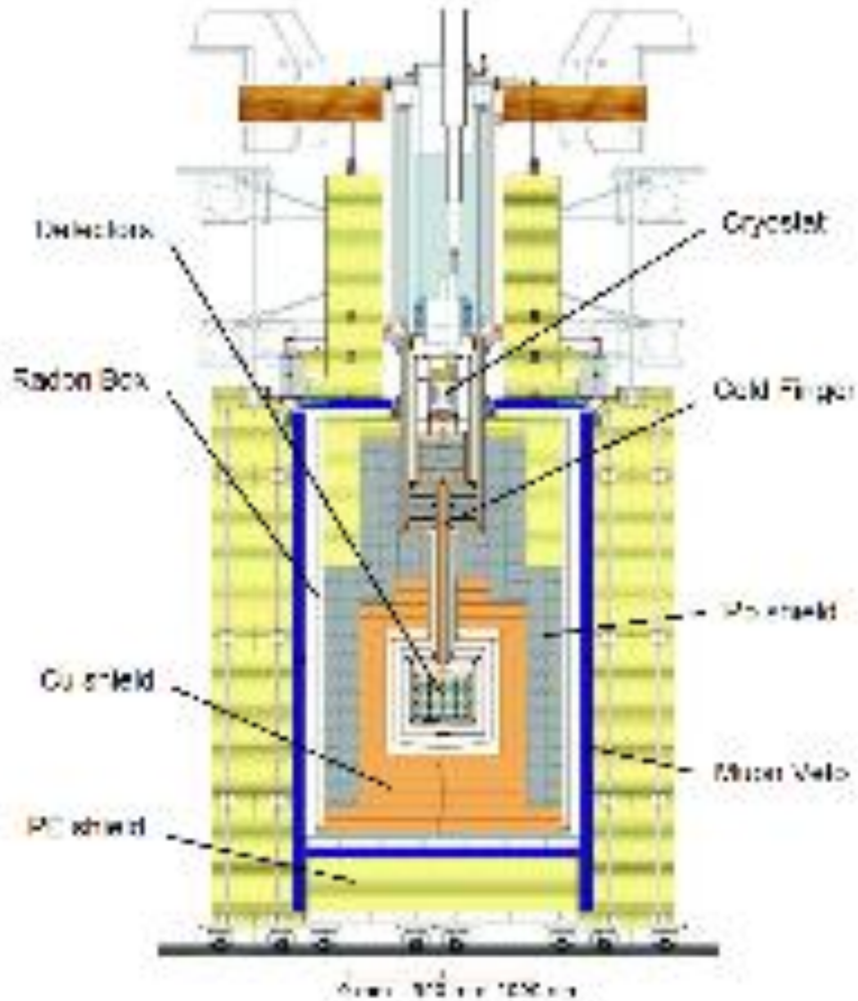
➔ Nuclear / electron recoil discrimination

Underground Laboratories



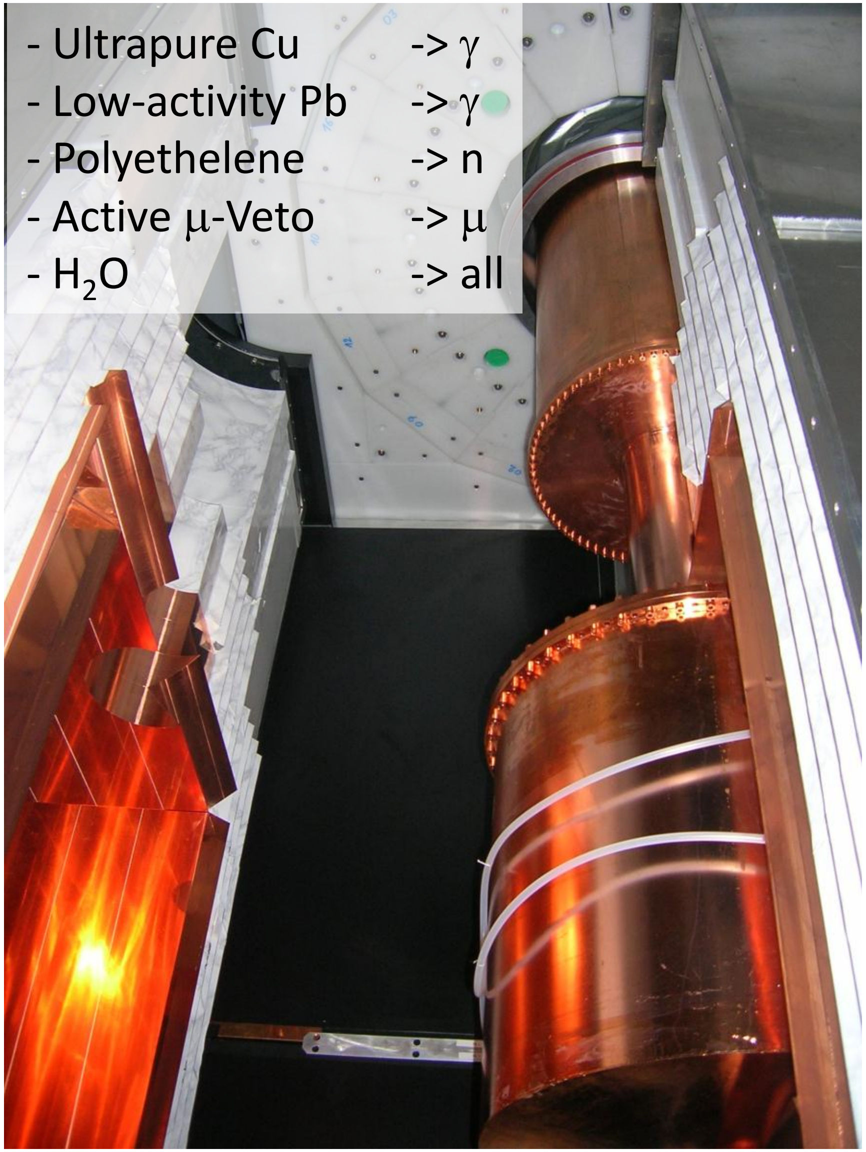


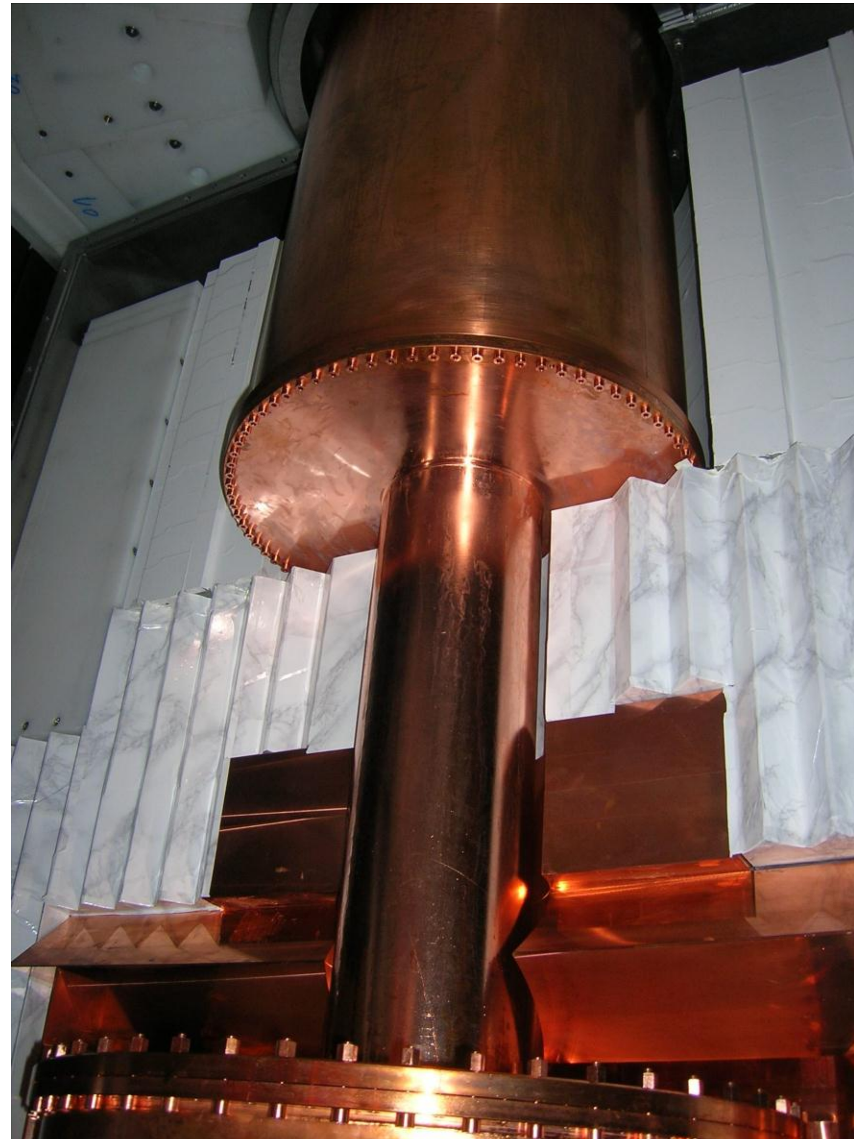
CRESST (Cryogenic Rare Event Search with Superconducting Thermometers)



Typical Shielding Materials

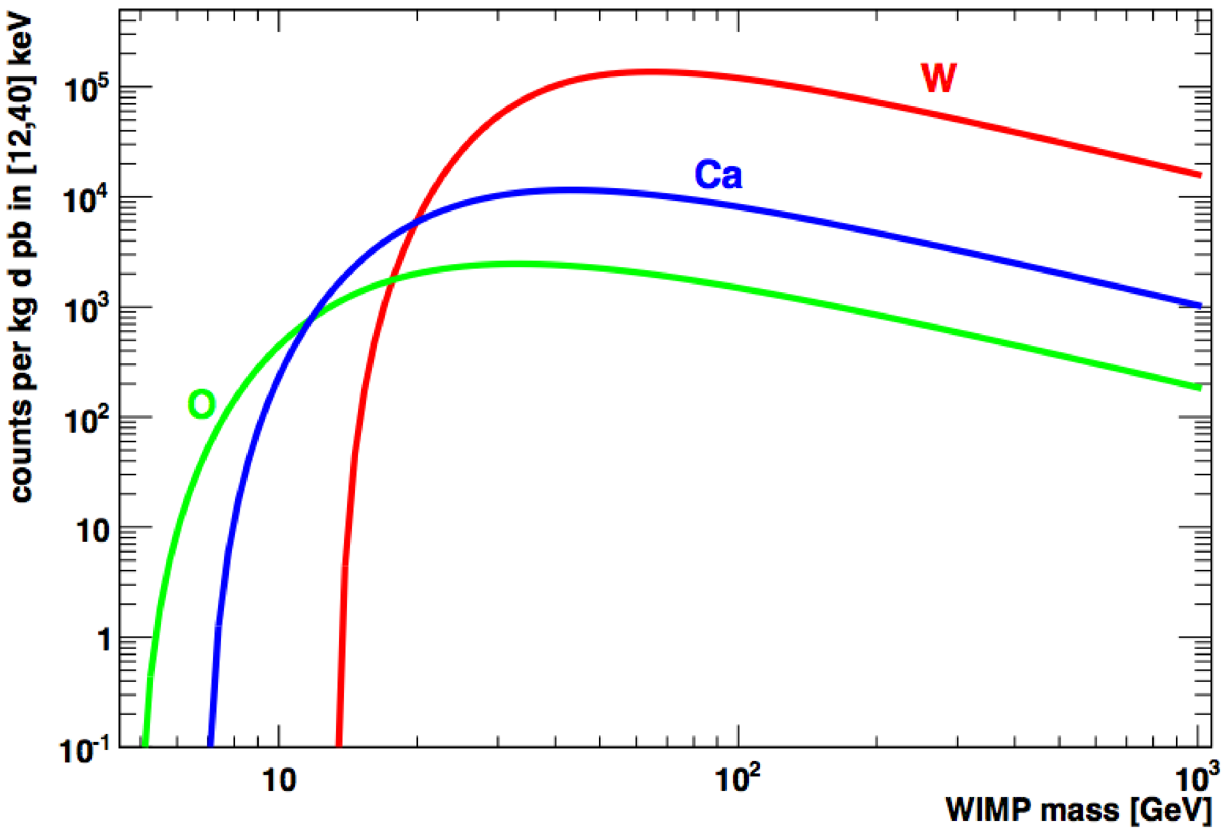
- Ultrapure Cu -> γ
- Low-activity Pb -> γ
- Polyethelene -> n
- Active μ-Veto -> μ
- H_2O -> all





$CaWO_4$ as WIMP-Target

$CaWO_4$ Multi-Material WIMP Target



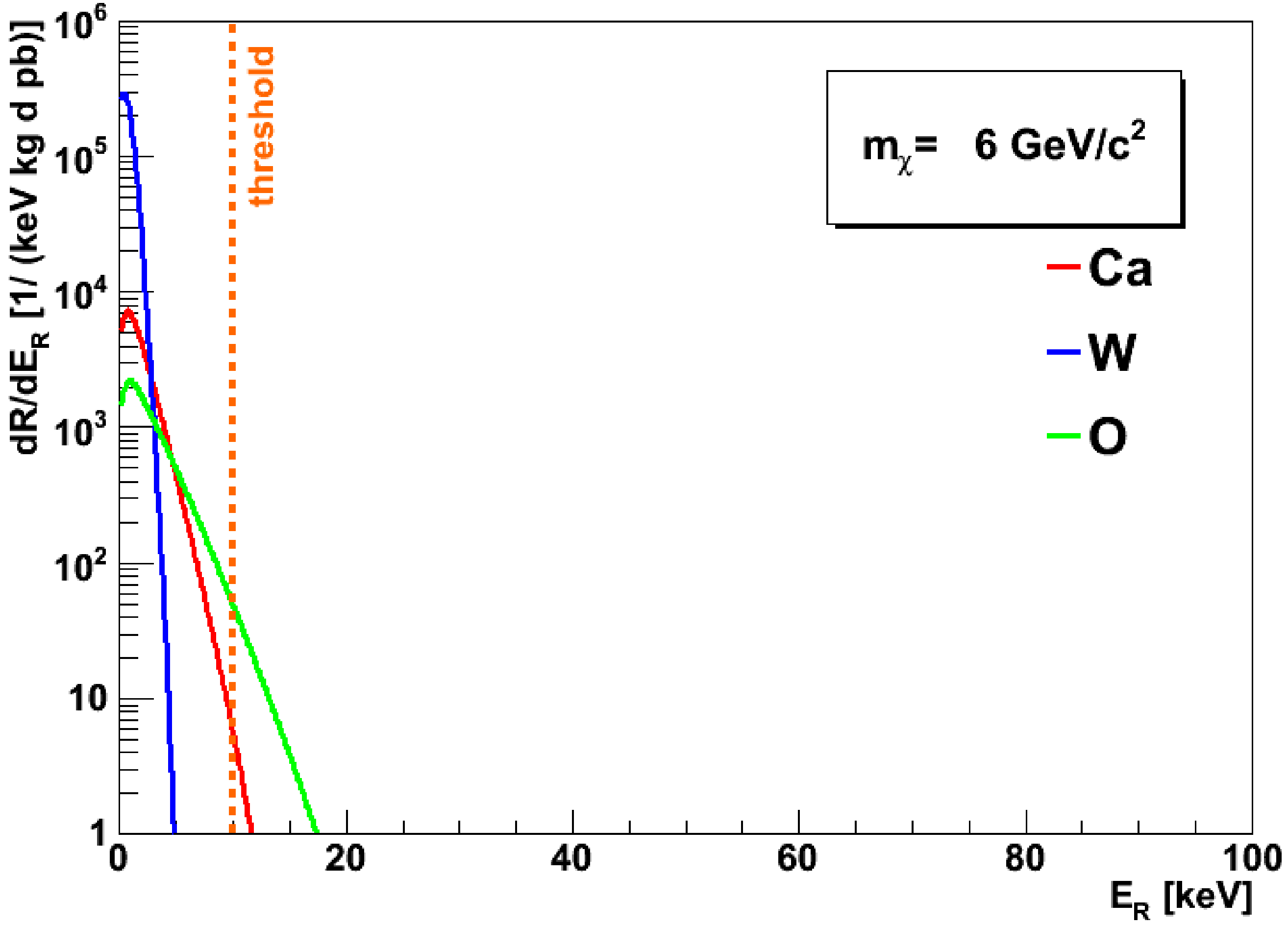
$$\Gamma = \frac{M_{Target}}{m_N} \frac{\varrho_\chi}{m_\chi} < v > \sigma_\chi A^2$$

low WIMP masses ≤20GeV: only O, Ca recoils above detection threshold

high WIMP masses ≥30GeV: dominated by W recoils

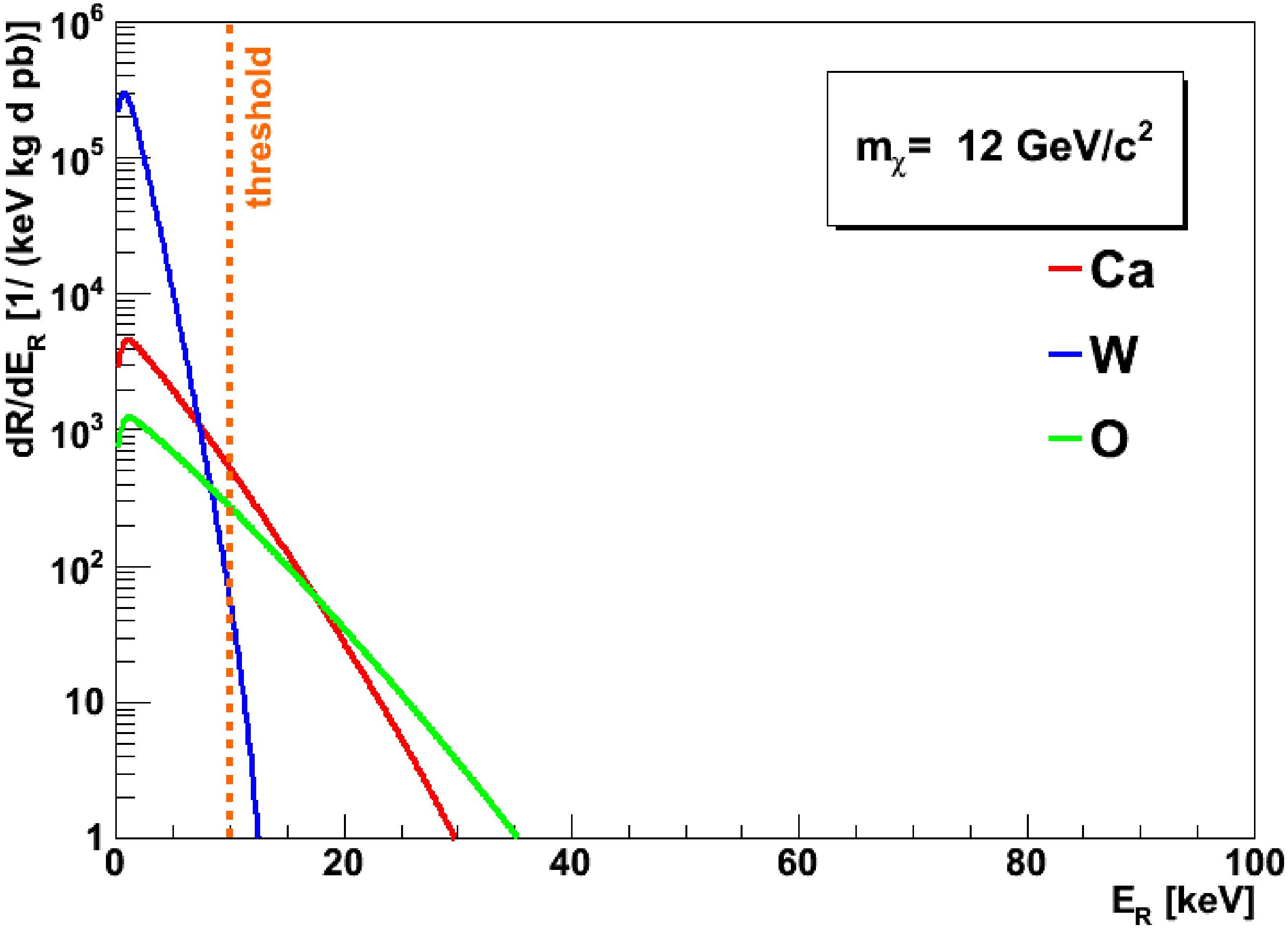
neutron background mainly O recoils above detection threshold

Composition of Recoil Spectrum



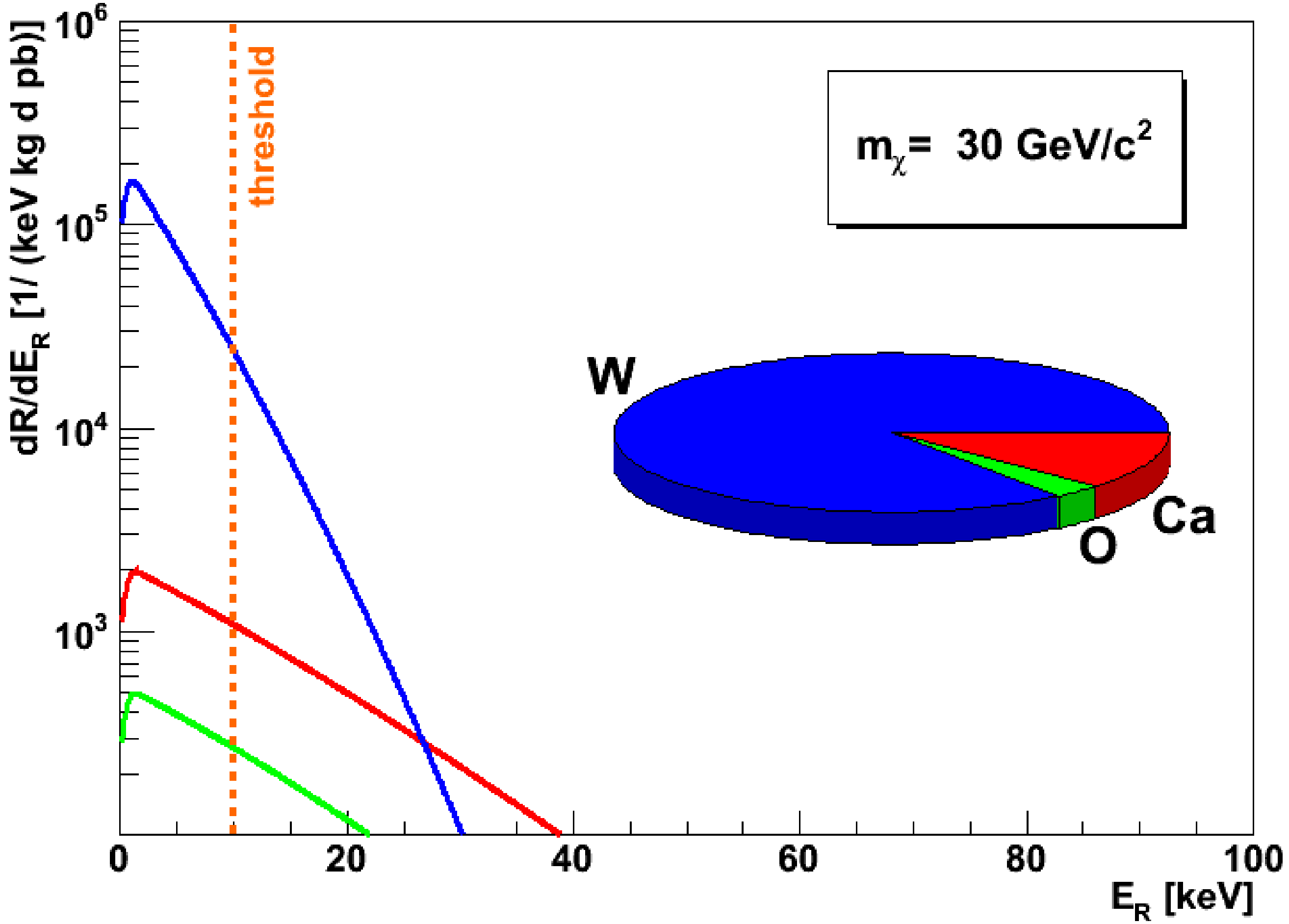
Light-mass WIMP (6GeV): only O recoils above threshold

Composition of Recoil Spectrum



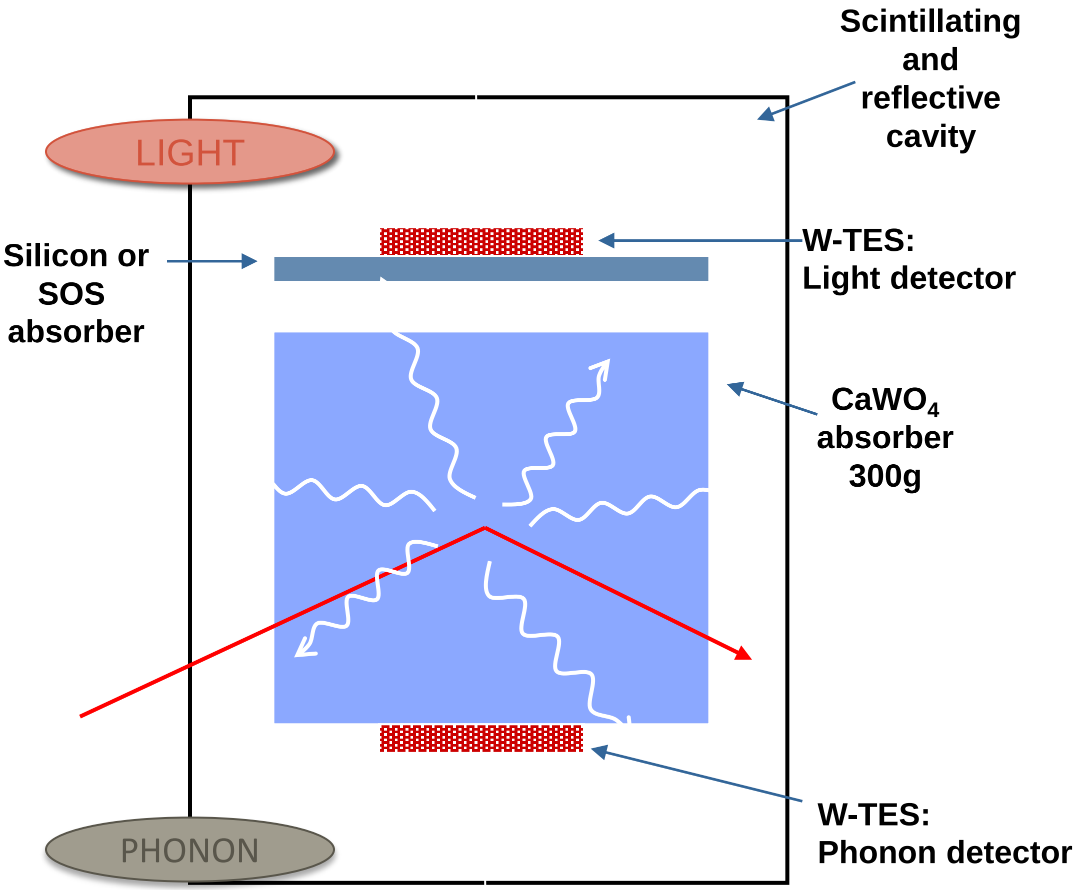
Light-mass WIMP (12 GeV): contribution of O and Ca, W just above threshold

Composition of Recoil Spectrum

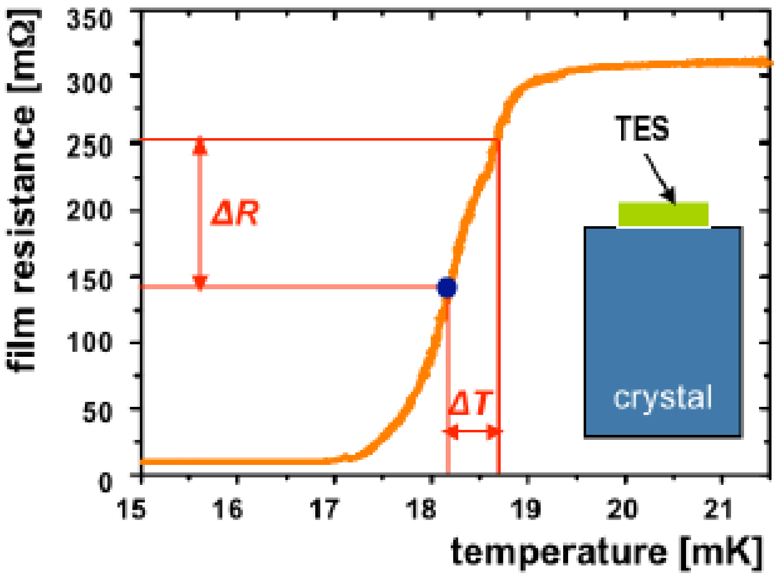


For higher WIMP masses (>30GeV): tungsten dominates recoil spectrum

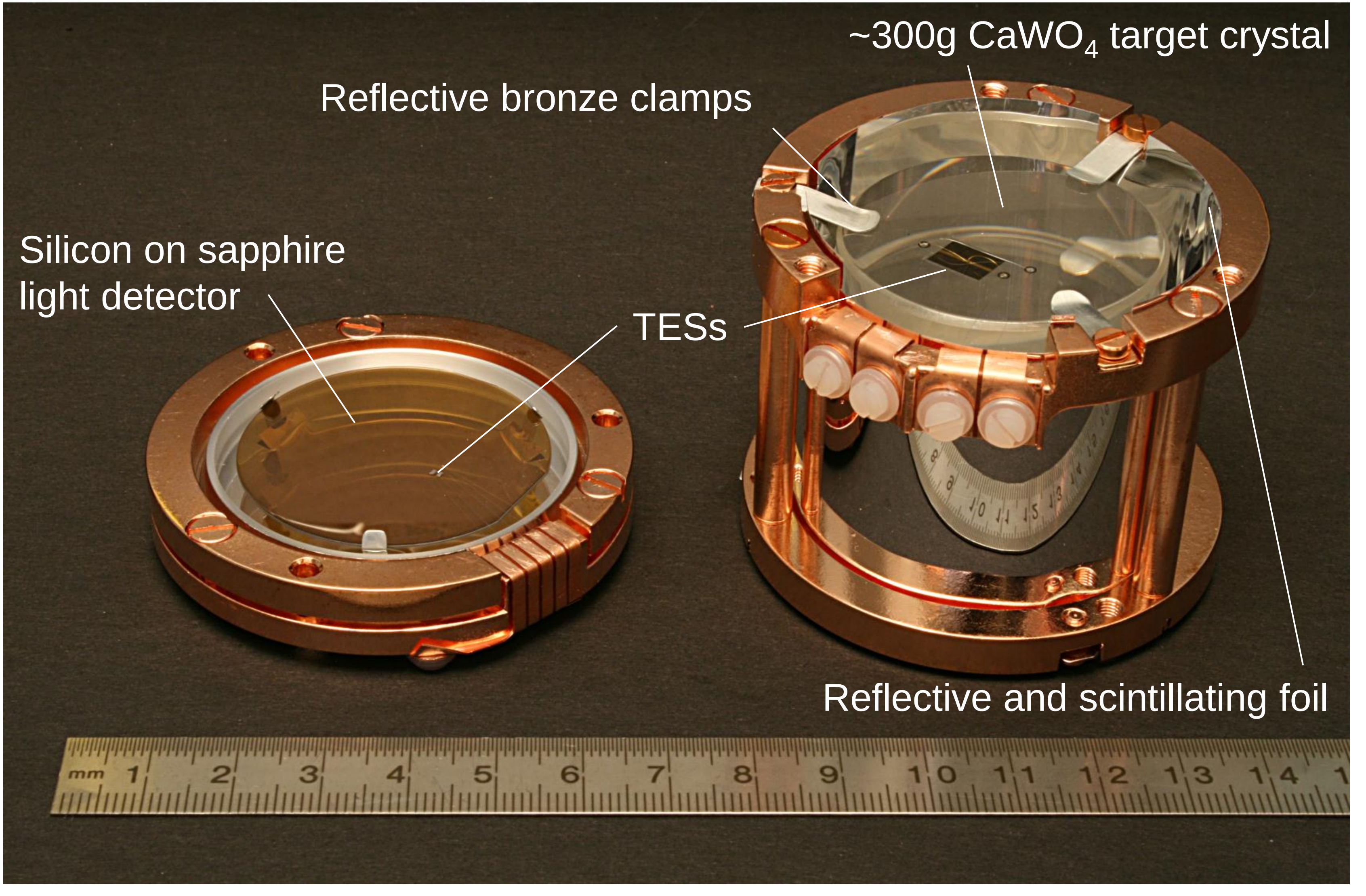
CRESST II Detector Modules



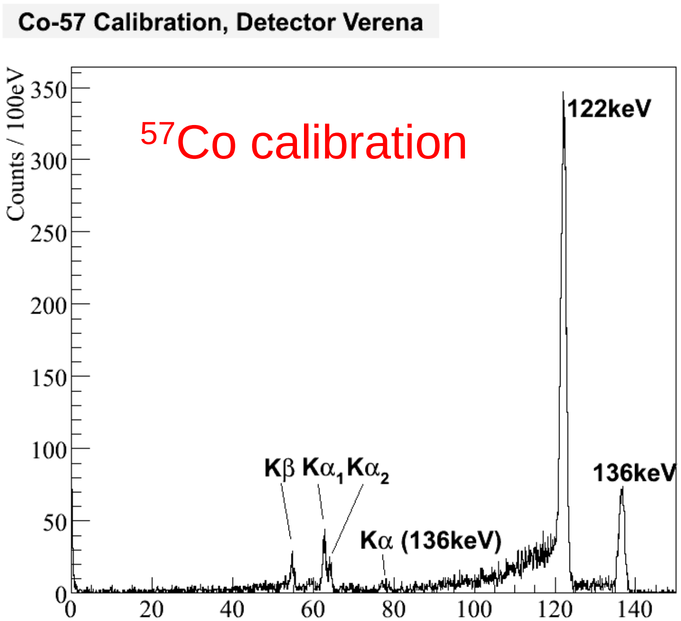
Transition Edge Sensor (TES)

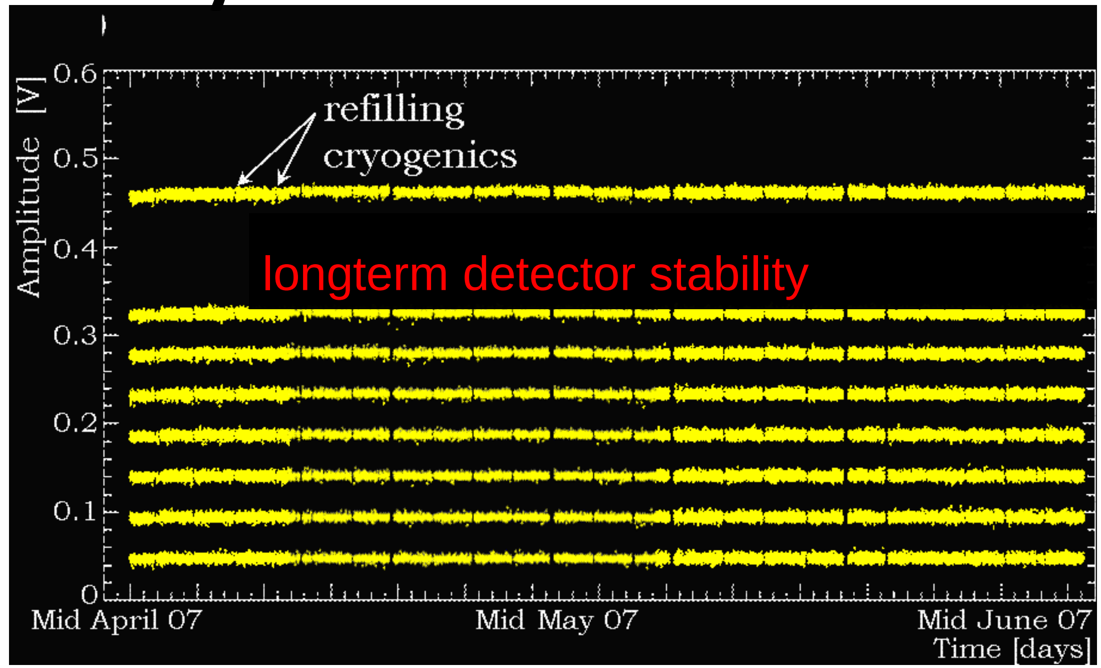


CRESST II Detector Modules

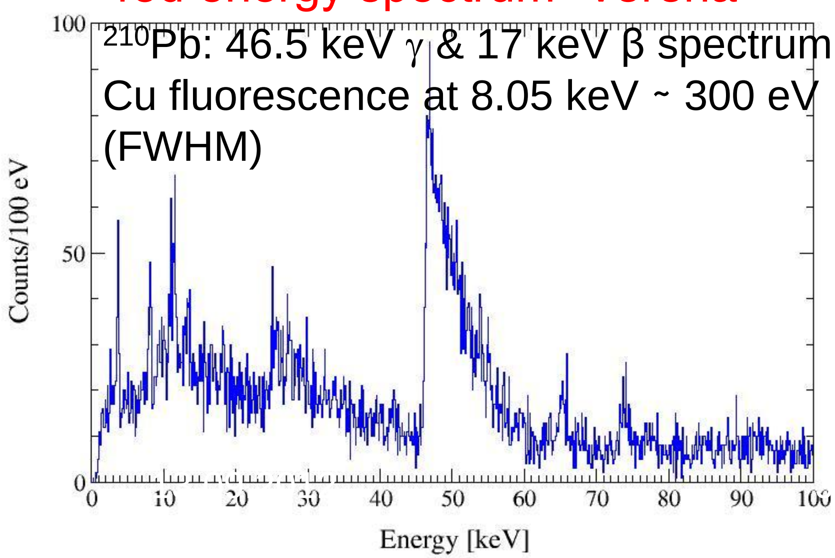


Detector Stability & Performance





48d energy spectrum “Verena”

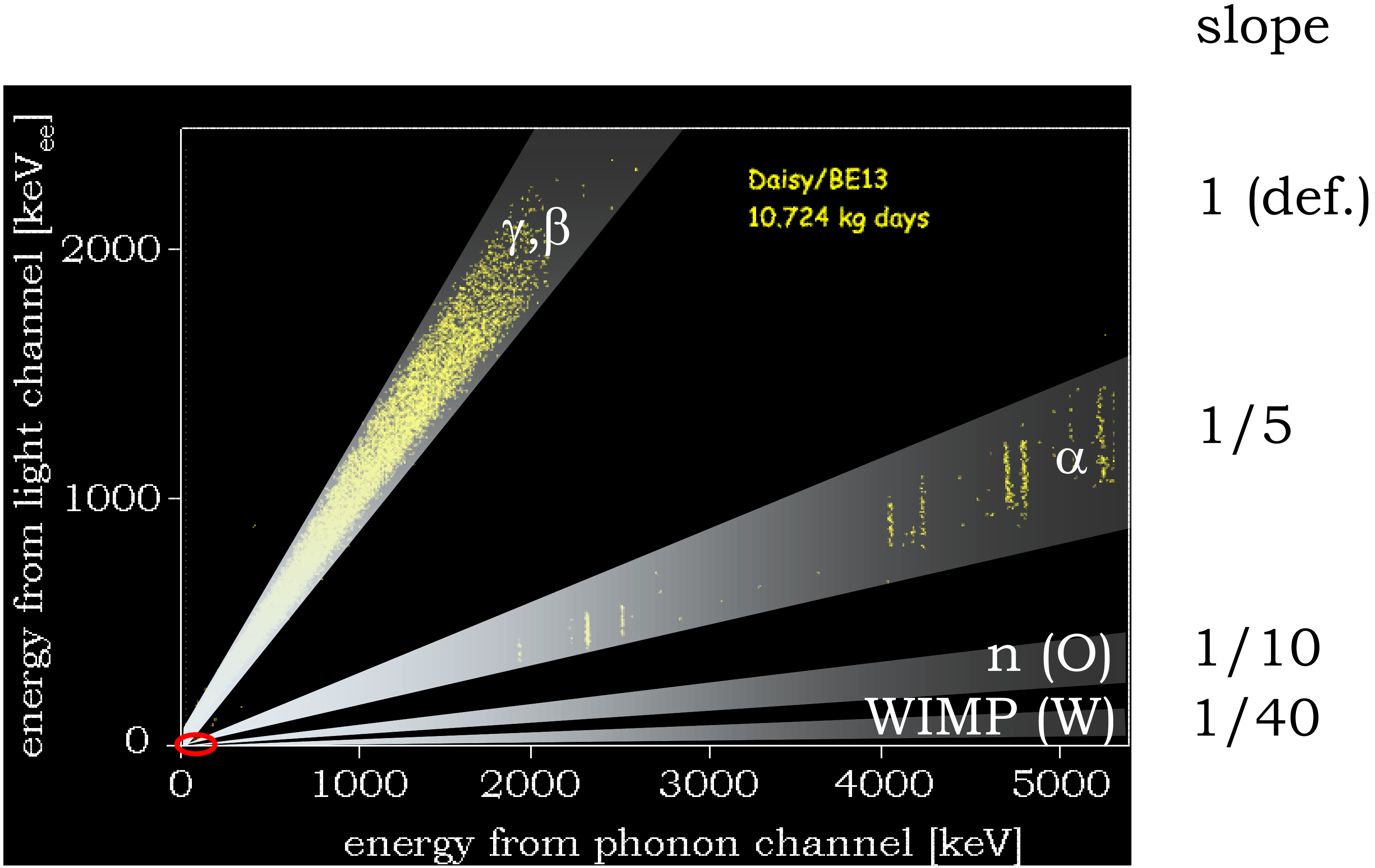


^{210}Pb: 46.5 keV γ & 17 keV β spectrum
Cu fluorescence at 8.05 keV ~ 300 eV (FWHM)

Agreement of energies with known values (background) confirm the excellent accuracy of the heater pulse calibration method.

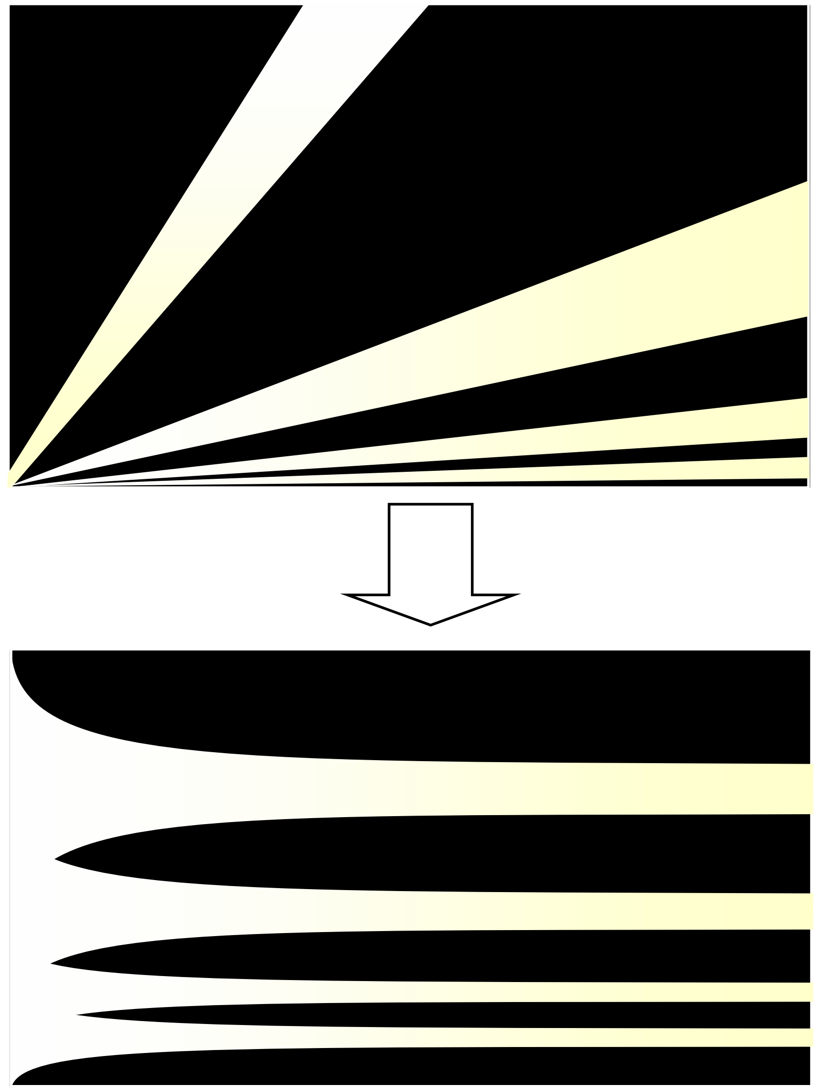
Rafael F. Lang et al.
„Electron and Gamma Background in CRESST Detectors“
http://arxiv.org/abs/0905.4282

Unique Discrimination Capability



Event-by-event discrimination !

Data Plots



Light versus phonon-energy

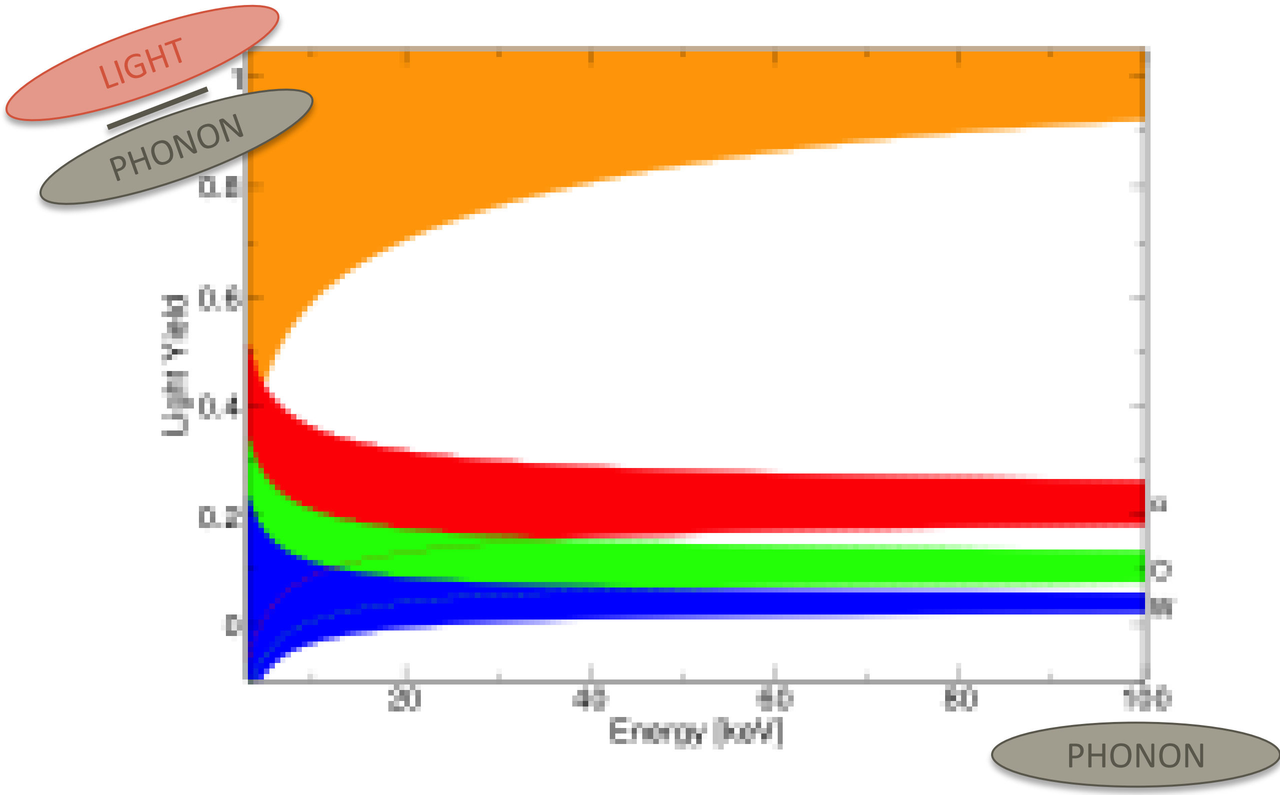
Light yield (light to phonon ratio) versus phonon-energy

Identification of Event Type

- **Characteristic light yield (LY) for each type of event:**

e-recoil:	**1**	**(by def.)**
α:	**~ 0.22**	
O-recoil:	**~0.10**	
Ca-recoil:	**~0.06**	
W-recoil:	**~0.04**	

(„Quenching factors“)

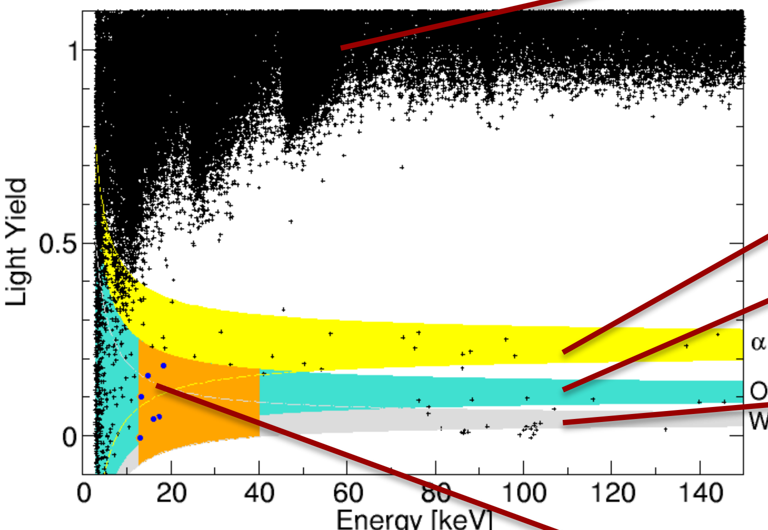


- **Excellent discrimination between dominant radioactive background (electron recoils induced by γ and β) and nuclear recoils**
- **To some extent identification of recoiling nucleus possible (depends on achievable separation of Ca, W and O nuclear recoil bands)**
- **Possibility to probe different WIMP mass scenarios in same target (unique feature of CRESST)**

Results of Run32 (2009-2011)

Eur. Phys. J. C (2012) 72:1971
DOI 10.1140/epjc/s10052-012-1971-8

Data of one single 300g detector module in Run32:



Electron recoils: excellent discrimination of from e/γ–band and nuclear band

α–events: from surfaces

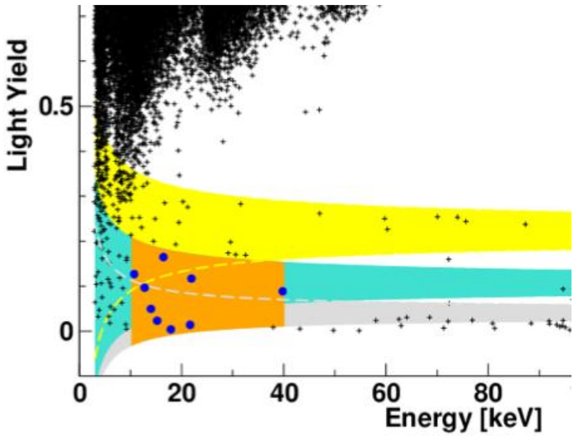
O-band: neutrons or „light"-WIMPs

W-band: expect „heavy"-WIMP interaction -> band is contaminated by recoiling ^{206}Pb nuclei from ^{210}Po α-decays (clamps), 103keV downwards

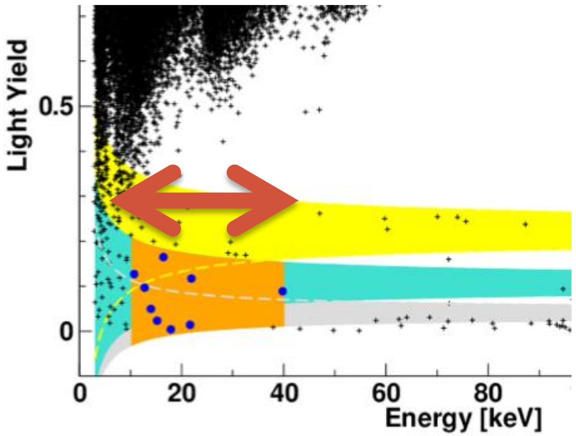
67 events at low energy observed in O, Ca and W-bands in all detector modules (~730kg d)

Acceptance region:
includes O, Ca and W recoil bands

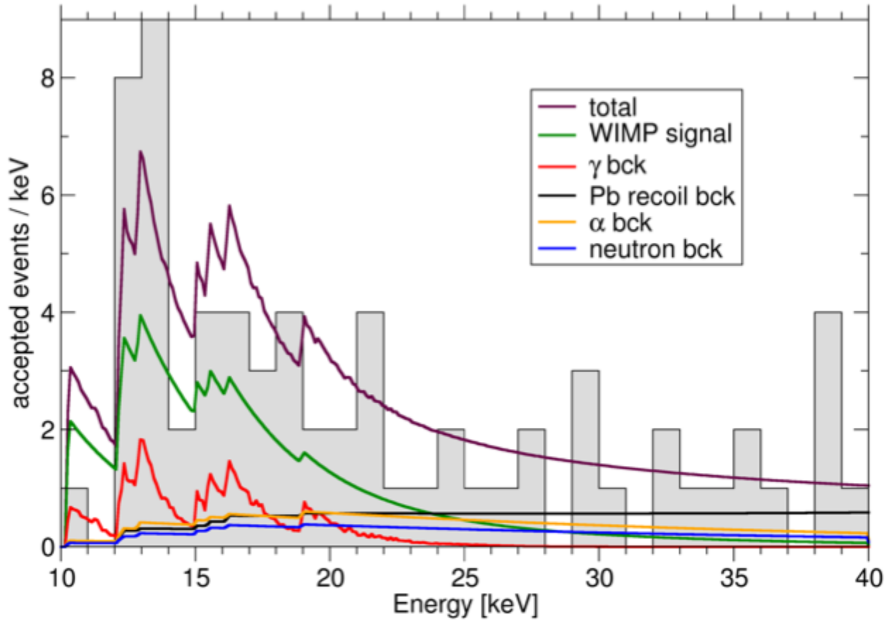
Spectral Distribution of Observed Events



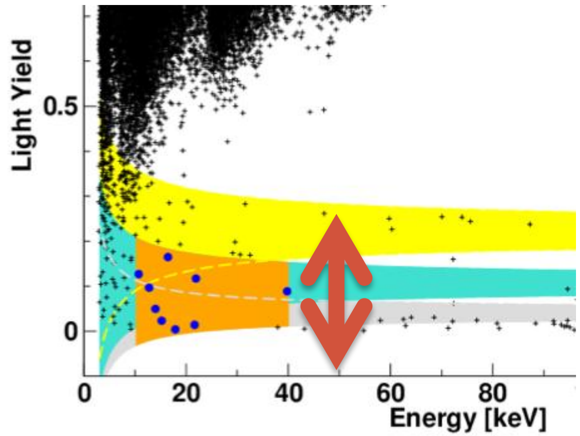
Spectral Distribution of Observed Events



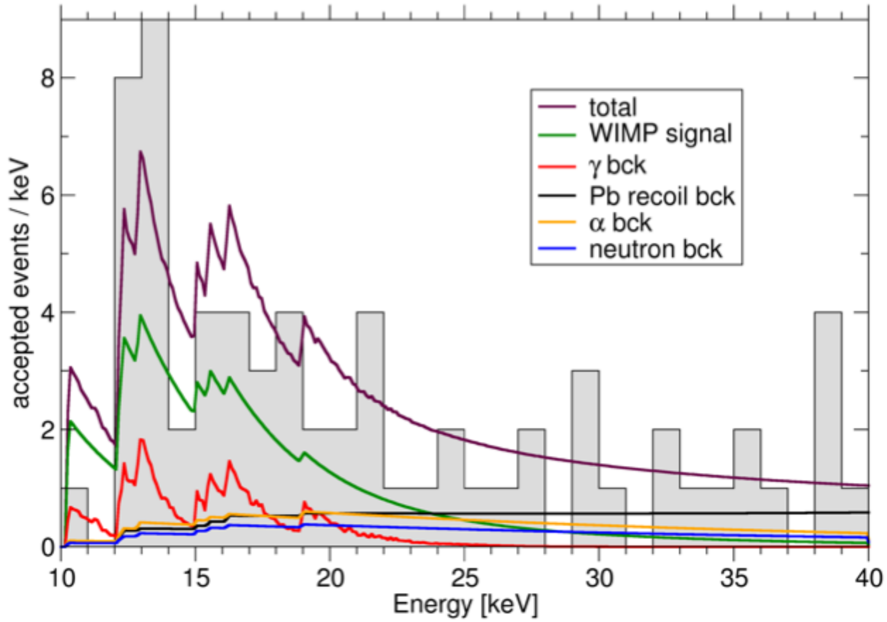
Energy spectrum



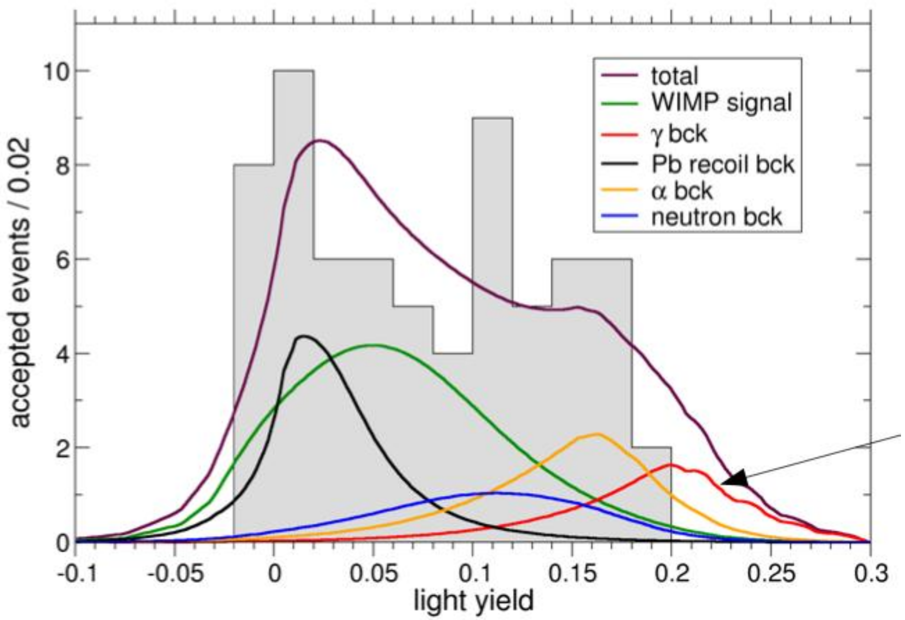
Spectral Distribution of Observed Events



Energy spectrum

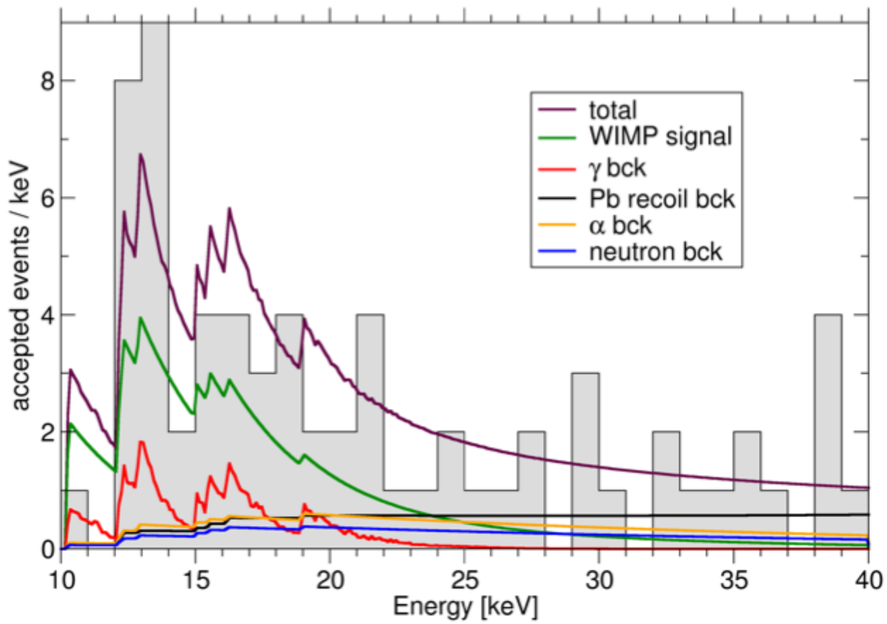


Light yield distribution

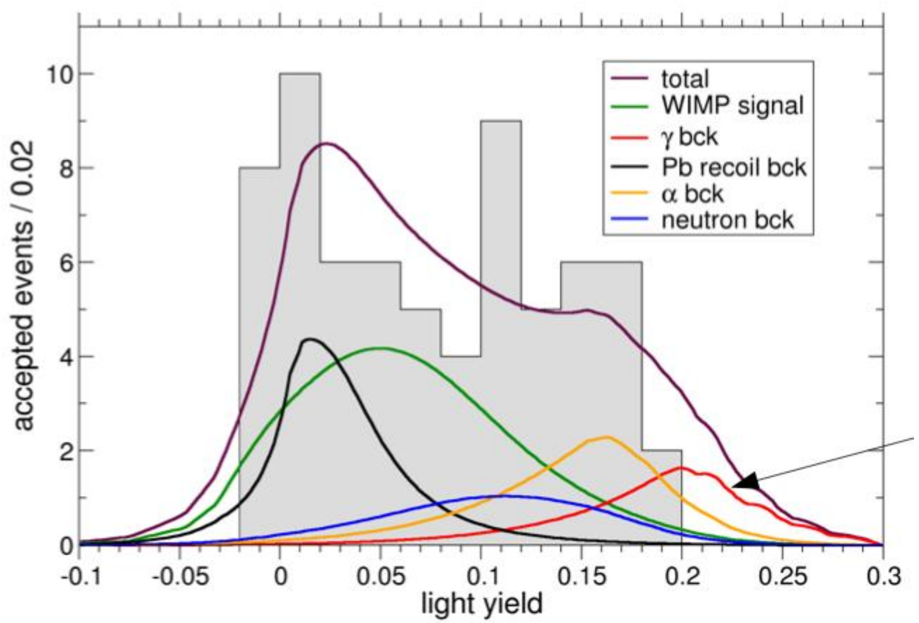


Spectral Distribution of Observed Events

Energy spectrum

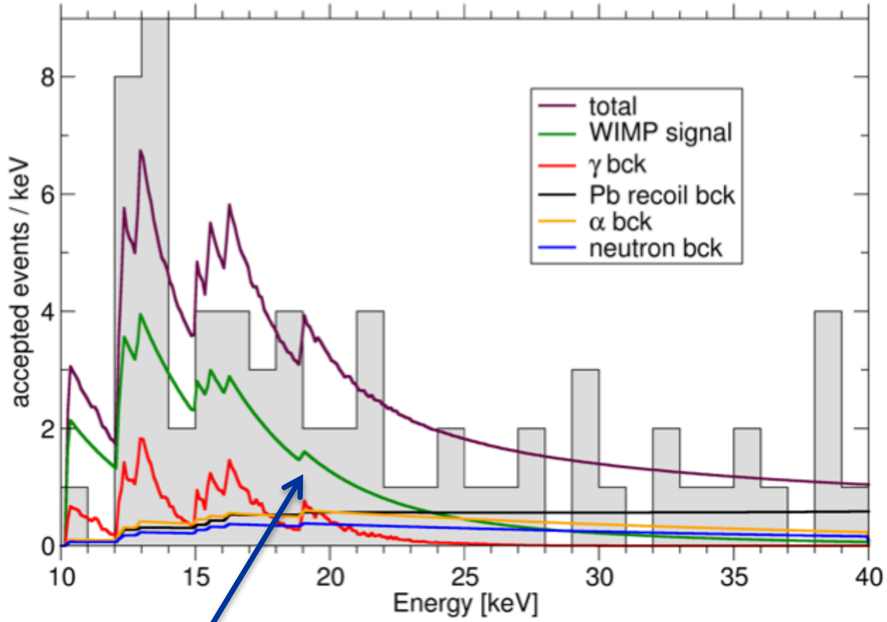


Light yield distribution

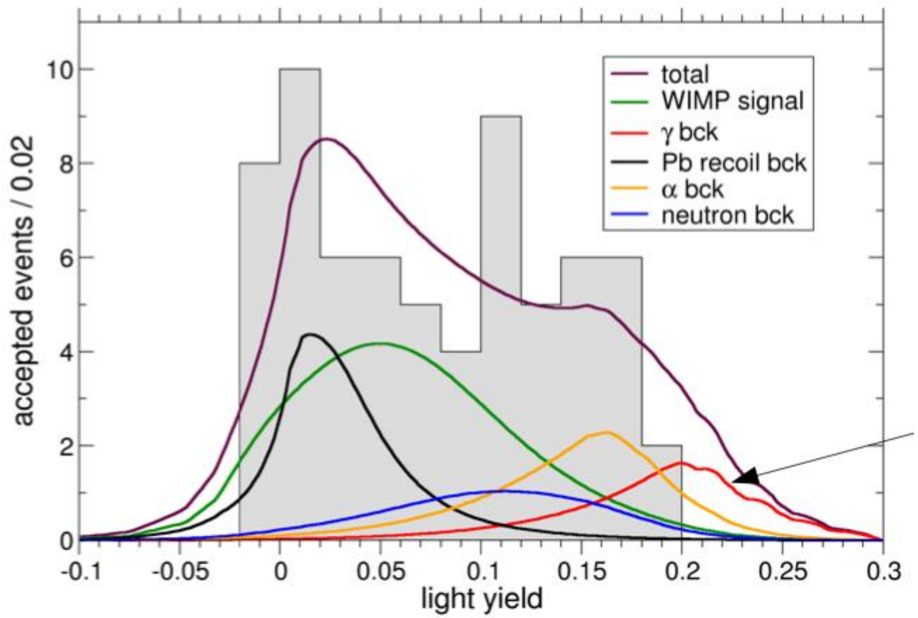


Spectral Distribution of Observed Events

Energy spectrum



Light yield distribution

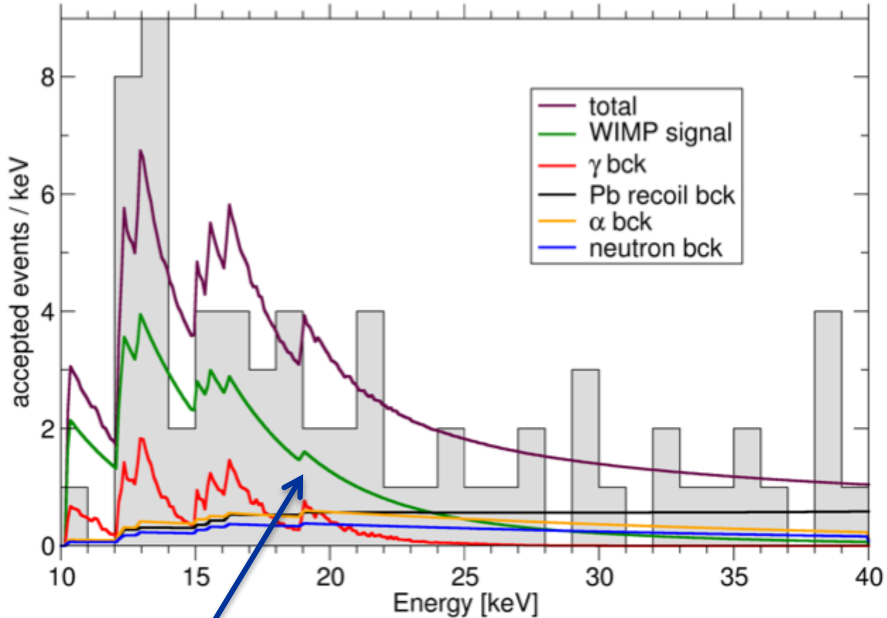


WIMP-signal spectrum is exponential
like:
gamma background
unlike:
^{206}Pb, neutron alpha background

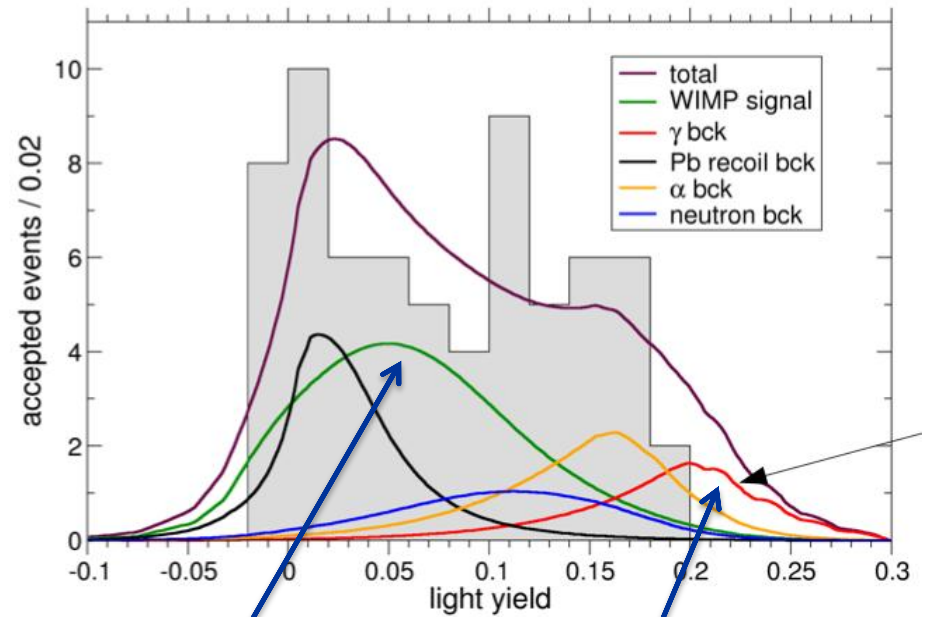
Is the signal due to gamma leakage?

Spectral Distribution of Observed Events

Energy spectrum



Light yield distribution



WIMP-signal spectrum is exponential

like:

gamma background

unlike:

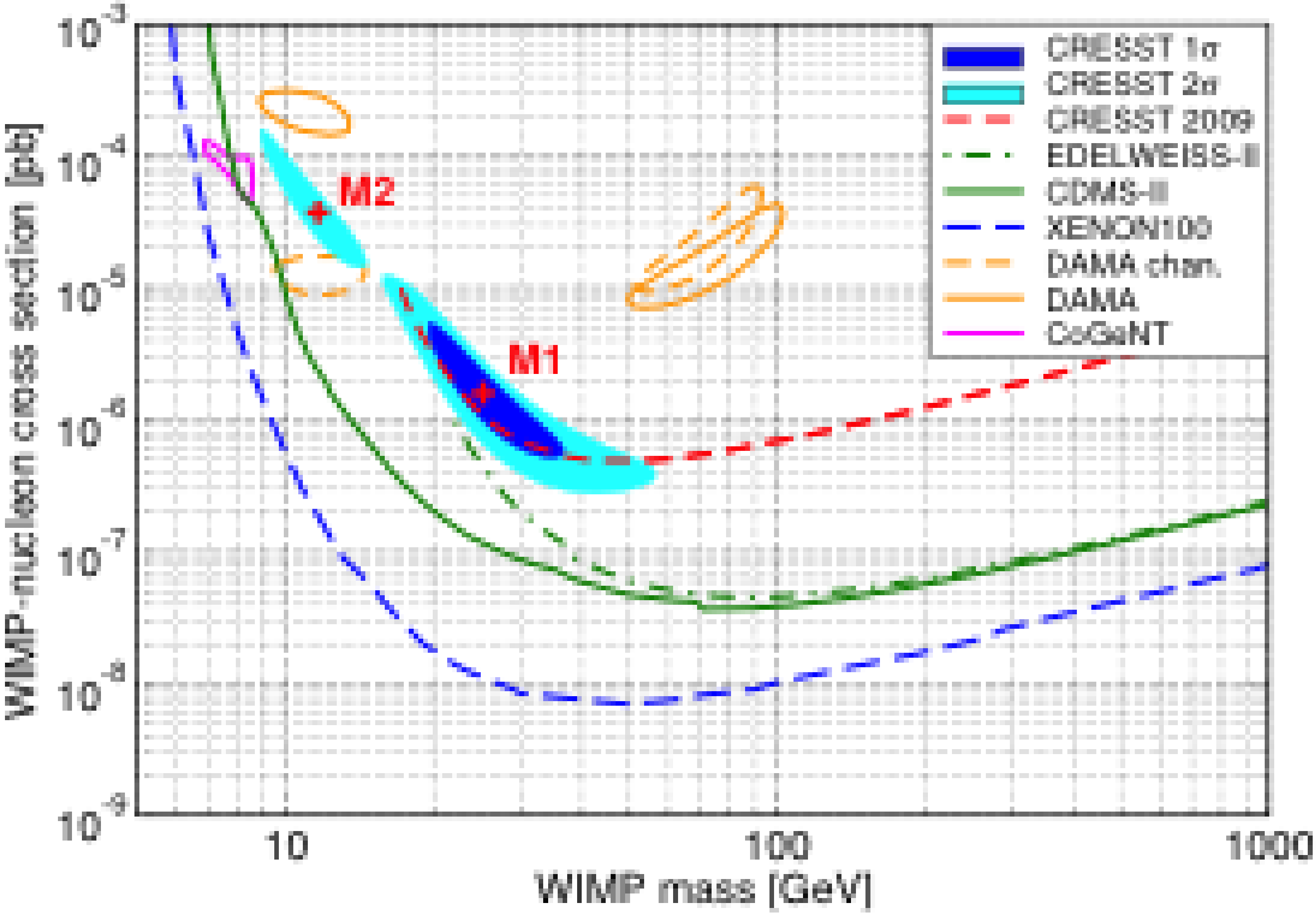
^{206}Pb, neutron ,alpha background

Is the signal due to gamma leakage?

Unlikely!

WIMP-signal and gamma leakage differ significantly in the light yield distribution!

WIMP Parameter Space

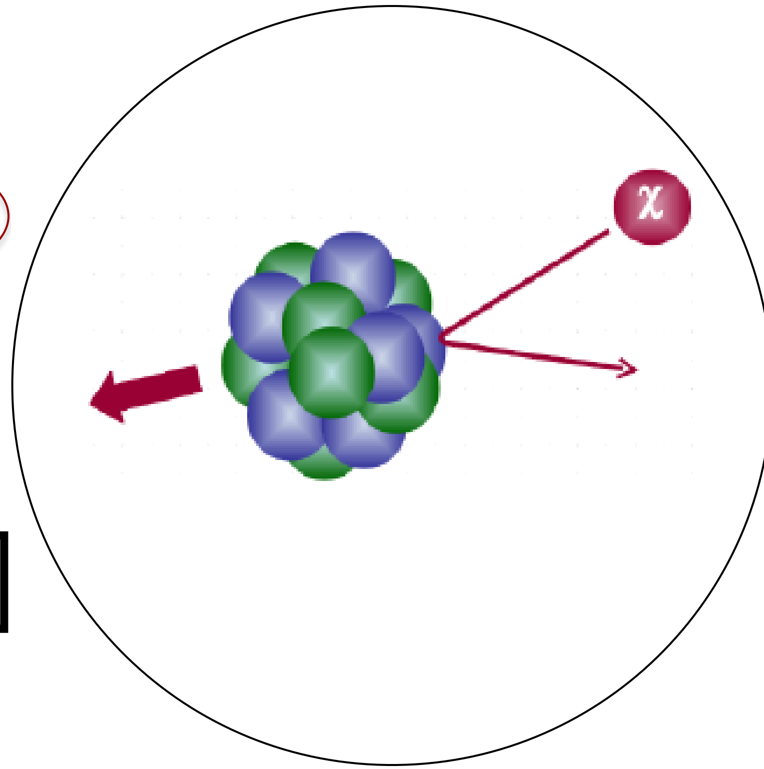


Recoil Detection & Background Identification

Phonons

Germanium Bolometers

CDMS
EDELWEISS



CRESST

Ionization

Scintillation

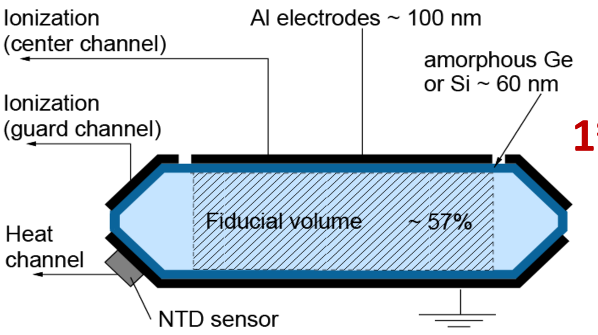
XENON100

EDELWEISS-II Detector Technology

Germanium bolometers

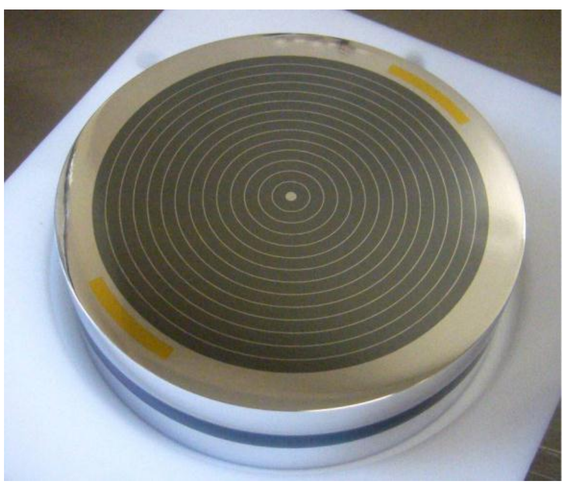
- **Heat measurement (NTD sensor)**
  - **→ $E_{recoil} \approx E_h$ (after NL correct.)**
- **Ionization measurement @ few V/cm**

- discrimination between ER and NR
  Q = ionization/recoil energy
  Q(NR) ~ 1/3 Q(ER)



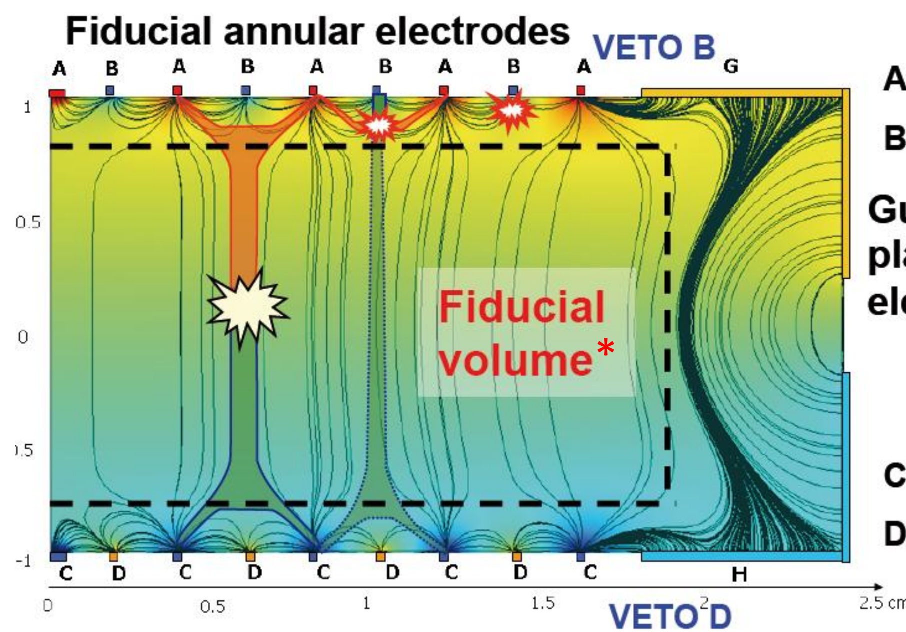
1st generation GeNTD 320g all planar electrodes

2nd generation ID400



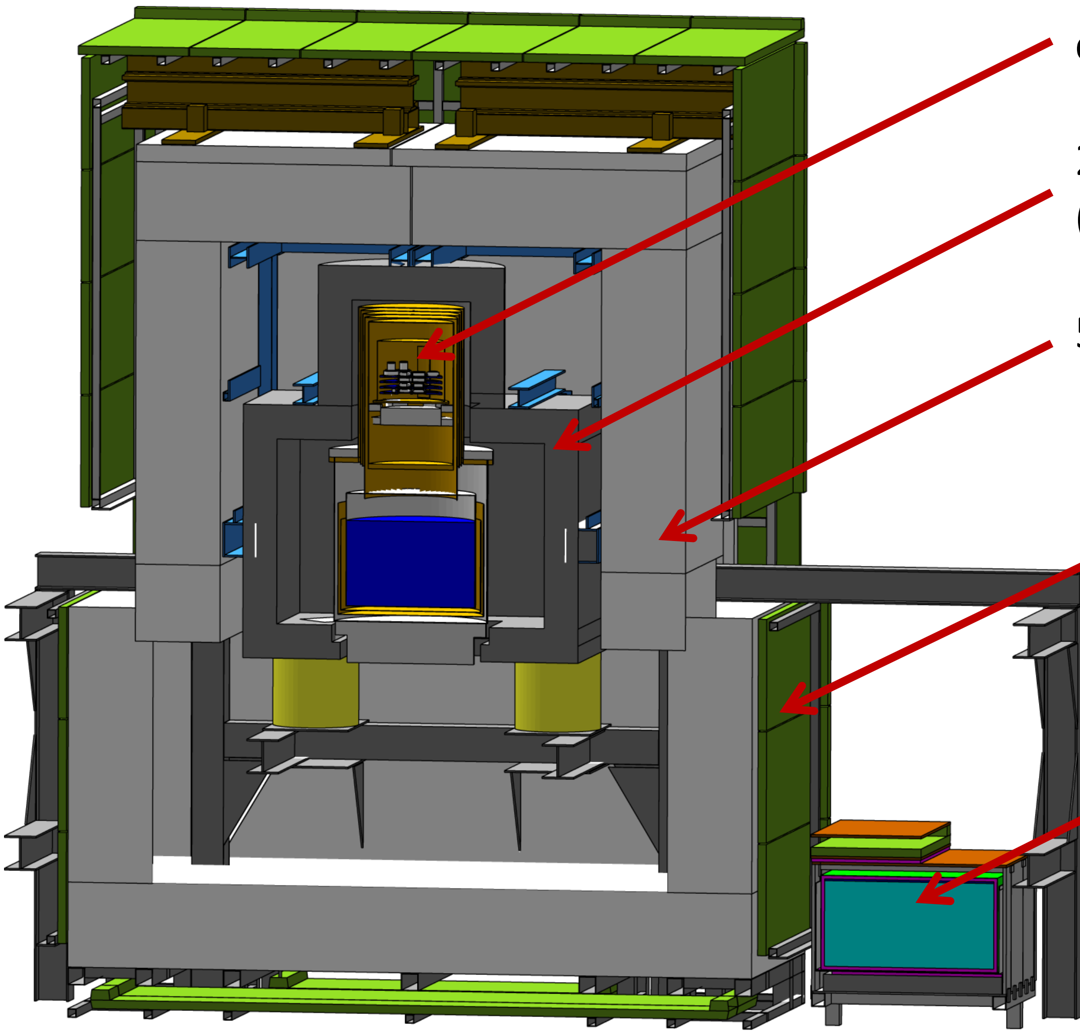
ID400g

(Courtesy K. Eitel, KIT)



*measured via cosmogenic γ lines

EDELWEISS-II Experimental Setup



cryogenic bolometer array

20 cm Pb shield
(innermost 2 cm ancient Pb)

50 cm polyethylene

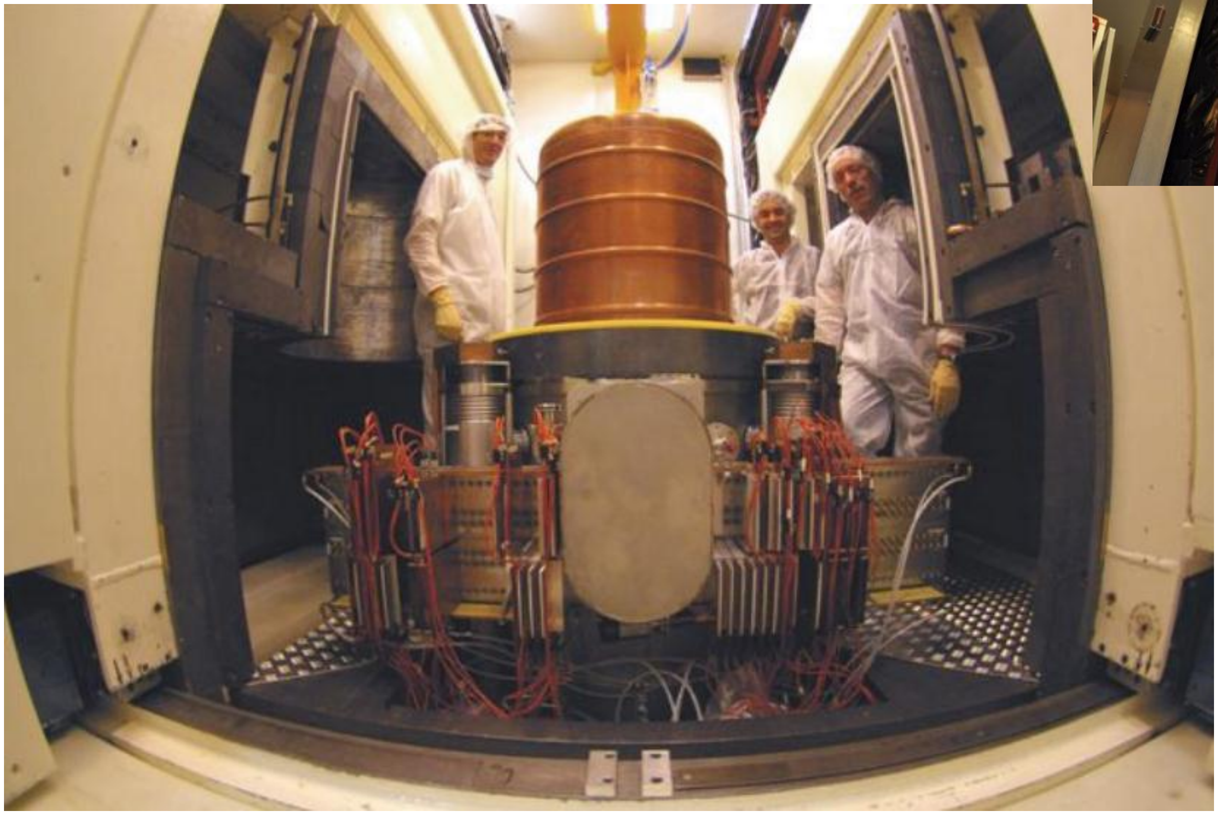
100 m^2 μ veto
(48 plastic scint. modules)

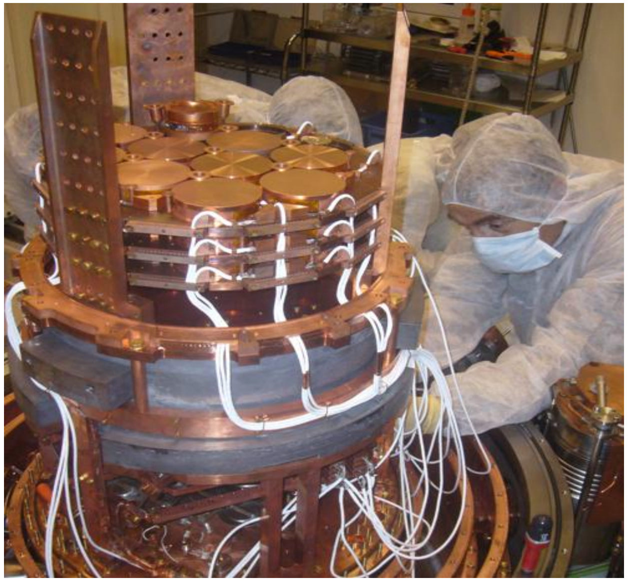
1ton Gd-loaded liquid scint.
for μ-induced Gd(n,γ)

not shown:
Rn detector (~ mBq/m^3)
^{3}He n detector (~10^{-9} $n_{therm}/cm^2/s$)

(Courtesy K. Eitel, KIT)

EDELWEISS-II Experimental Setup

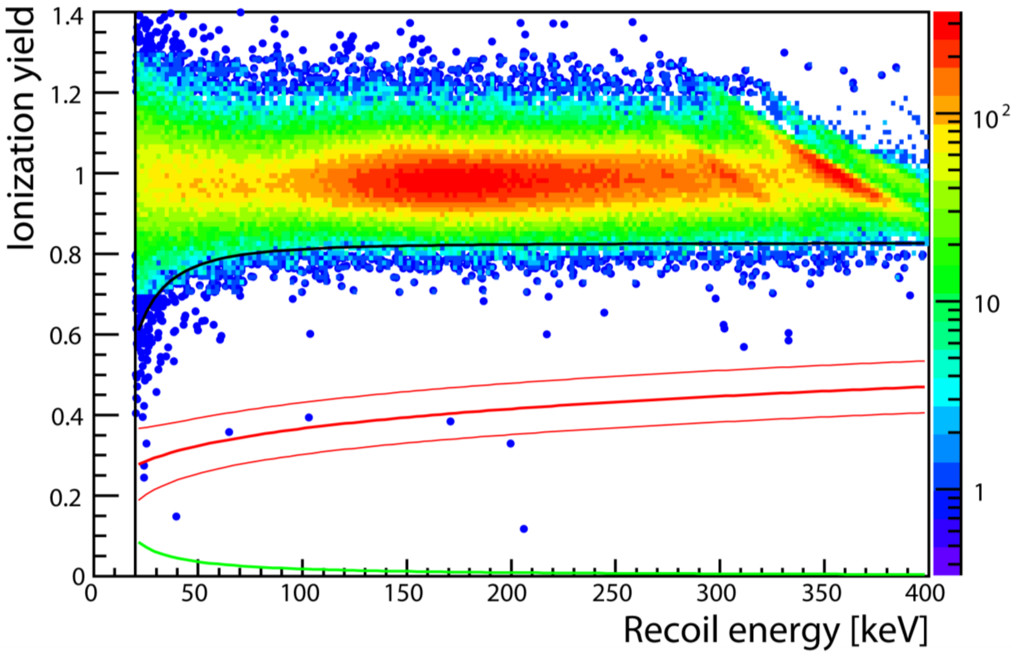




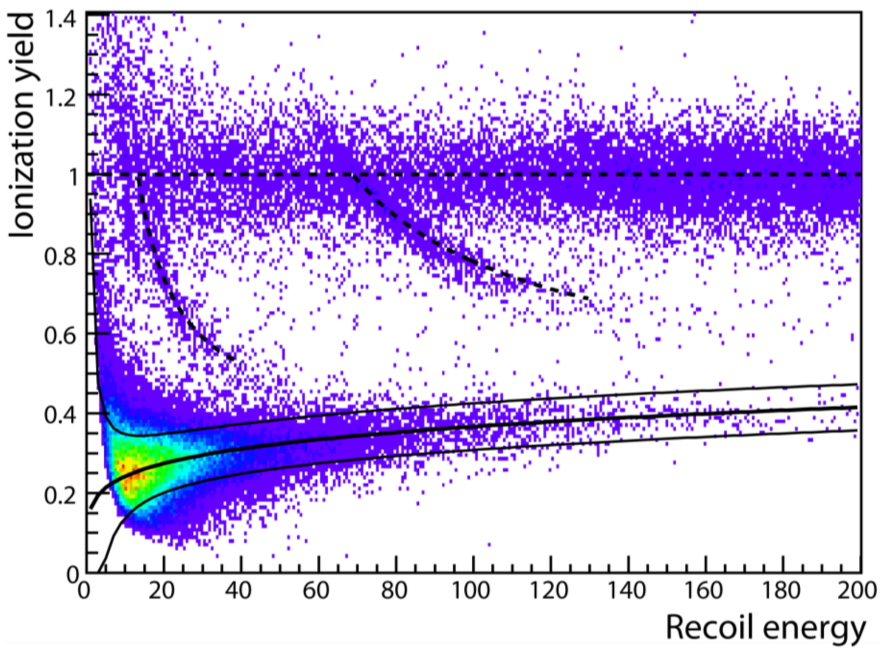
(Courtesy K. Eitel, KIT)

Calibration with γ/n-Sources

γ calibrations with ^{133}Ba



n calibrations with AmBe



more than 350.000 γ´s
γ suppression factor 3x10^{-5}
1 ”NR” for every 30k γ´s (20-200keV)

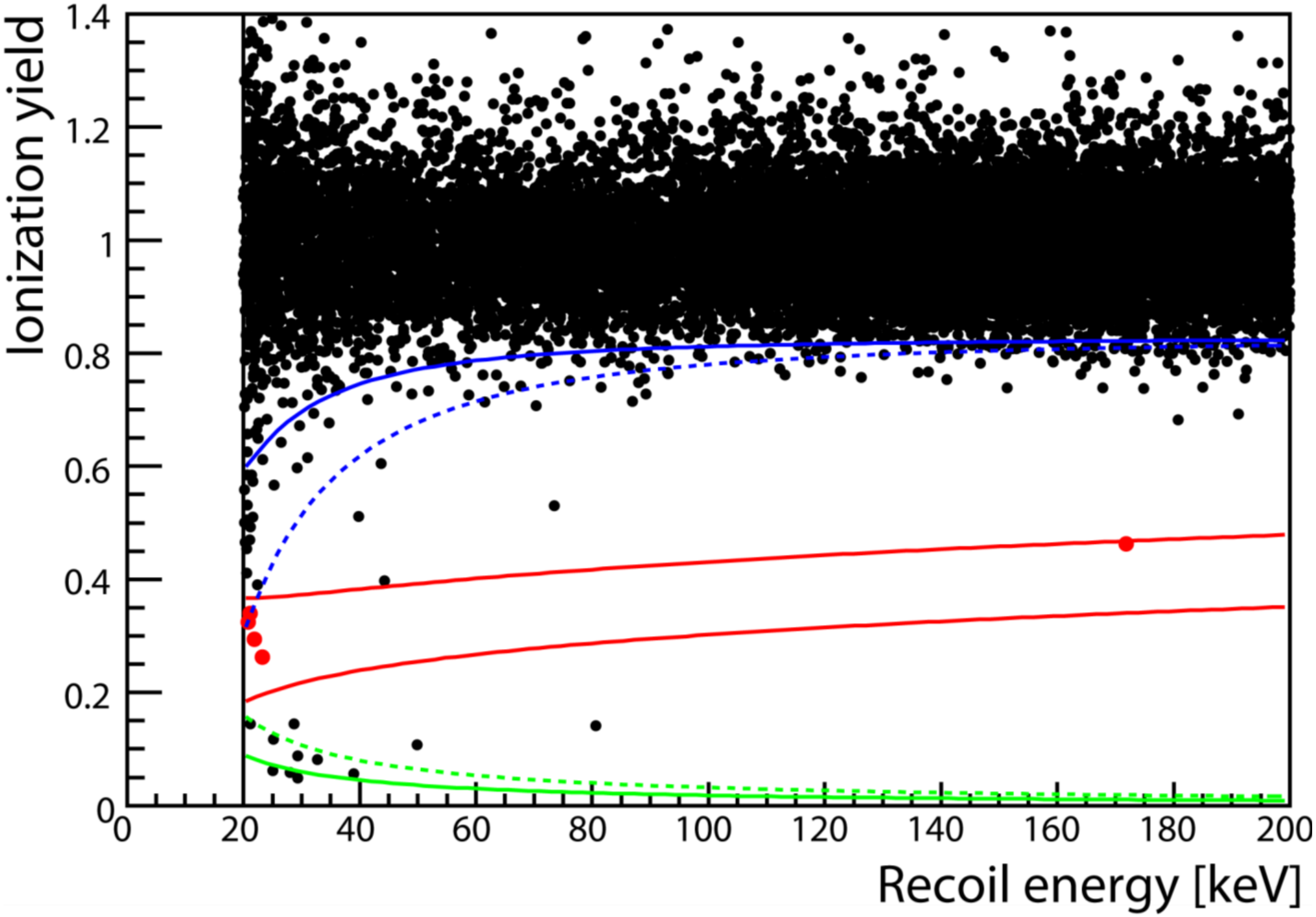
90% CL signal region
$Q = 0.16\ E_r^{0.18}$ from <10 to 200keV
(detection efficiency below 20keV)

P. Di Stefano et al., ApP14 (2001) 329
O. Martineau et al., NIMA 530 (2004) 426
A. Broniatowski et al., PLB 681 (2009) 305

(Courtesy K. Eitel, KIT)

EDW-II final result (2008+2009+2010)

(PLB702,5 (2011) 329)



total exposure
of 427kg.d
→384kg.d
in 90% NR band
(WIMP RoI)
fiducial mass 1.6kg

5 events observed
(4 with E<22.5keV;
1 with E=172keV)

3 evts bg expected
20<E<100 keV

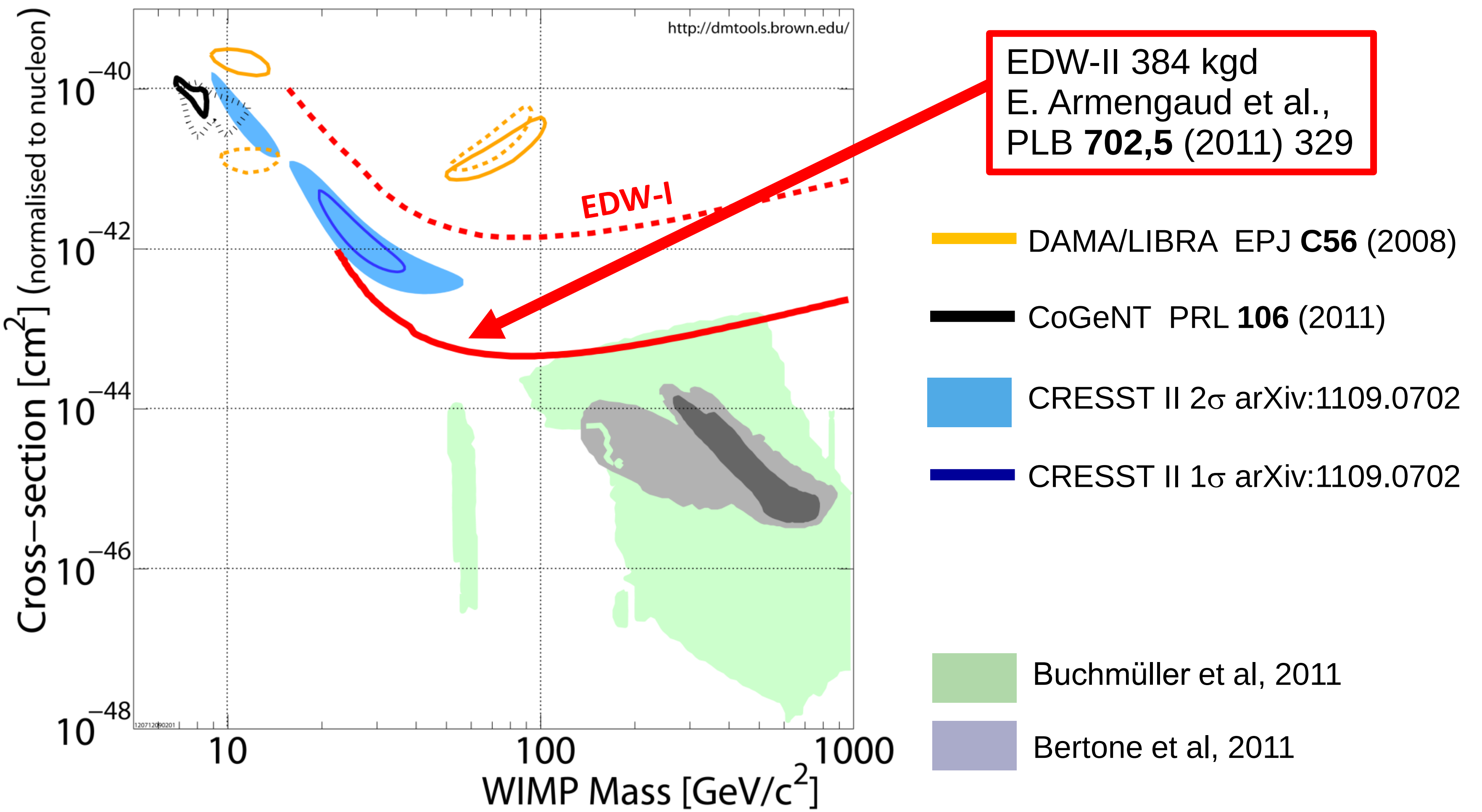
→no indication for a WIMP signal

standard halo → σ_{SI} < 4.4 x 10^{-8} pb at 90%C.L. for M_{WIMP} = 85 GeV/c^2

(Courtesy K. Eitel, KIT)

EDW-II results in σ_χ vs. m_χ

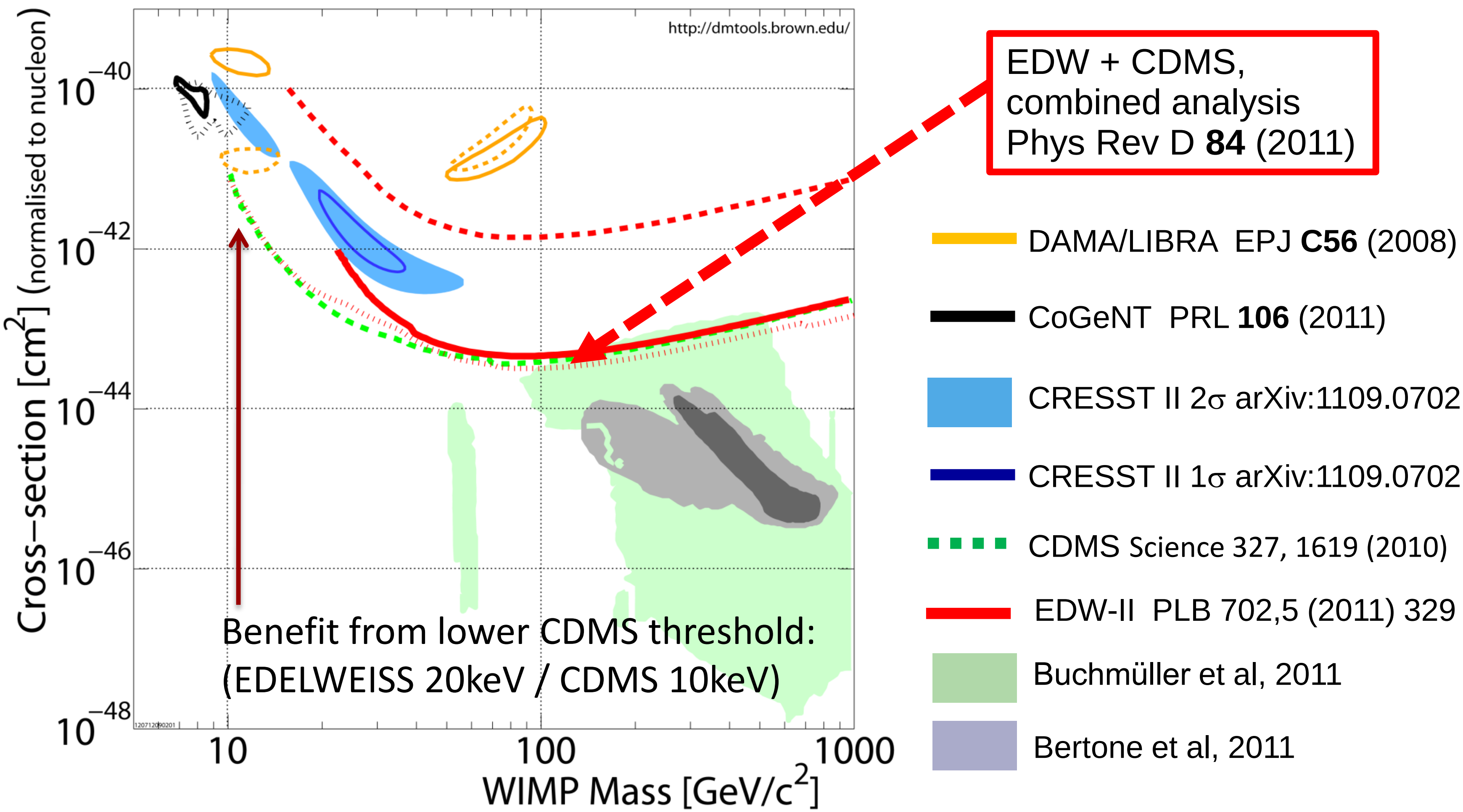
EDW (384kgd; [20-200keV], 5evts → $\sigma_{SI} < 4.4 \times 10^{-8}$ pb; $M_{WIMP} = 85$ GeV/c^2)
EDW-I → EDW-II **x20 improvement**



(Courtesy K. Eitel, KIT)

EDW-II & CDMS comb. in σ_χ vs. m_χ

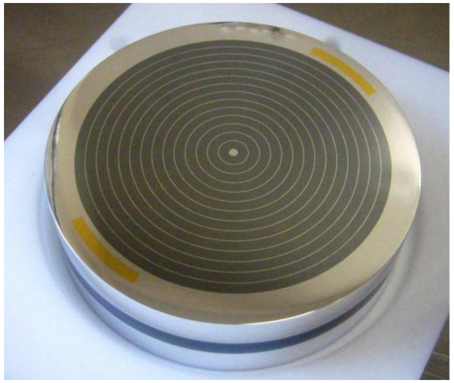
EDW (384kgd; [20-200keV], 5evts → σ_{SI} < 4.4 x 10^{-8} pb; M_{WIMP} = 85 GeV/c^2)
CDMS (~379kgd; [~10-100keV], 4 evts; σ_{SI} <3.8 x 10^{-8} pb; M_{WIMP} = 70 GeV/c^2)



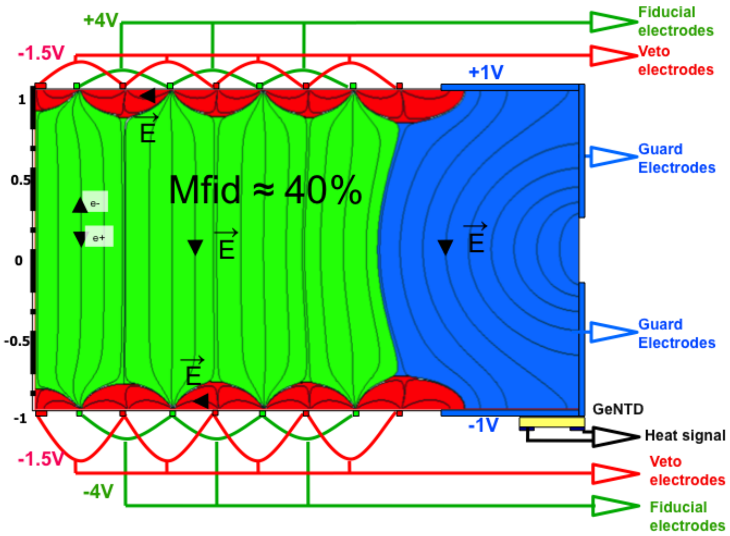
(Courtesy K. Eitel, KIT)

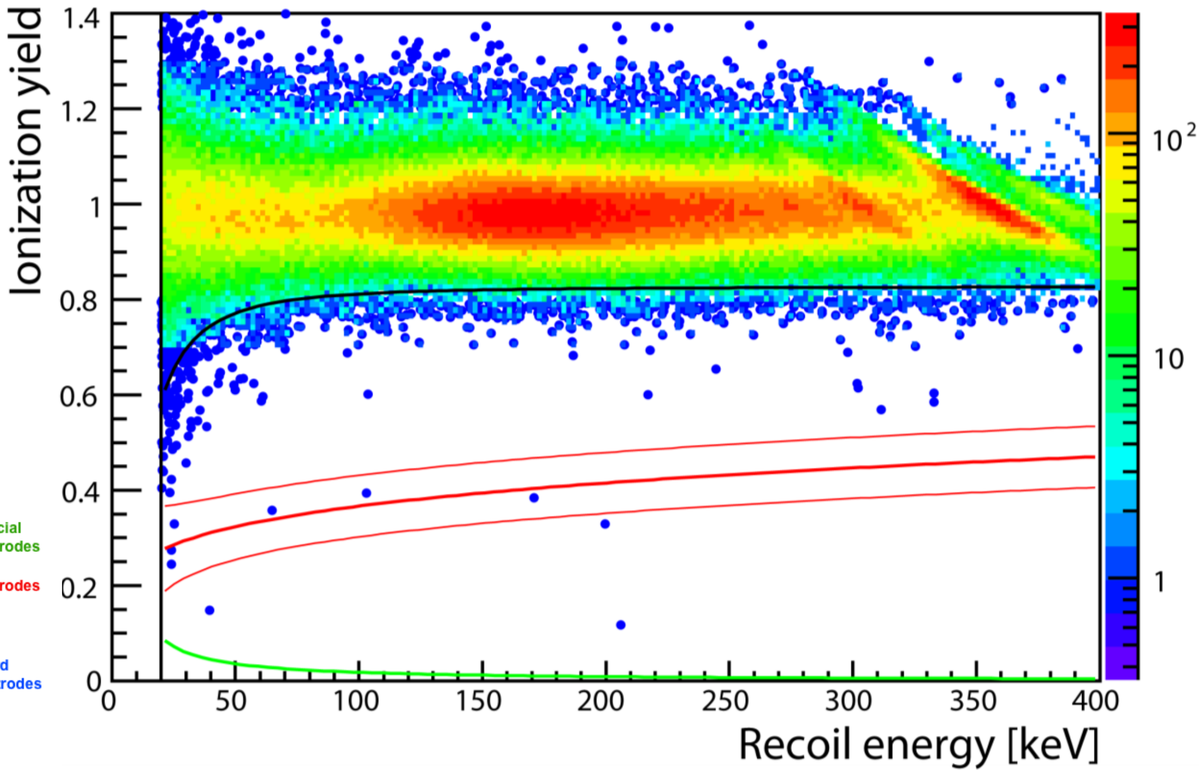
EDW-III: next generation of detectors

2. generation ID detectors with lateral planar electrodes



400g cylindrical ID detector



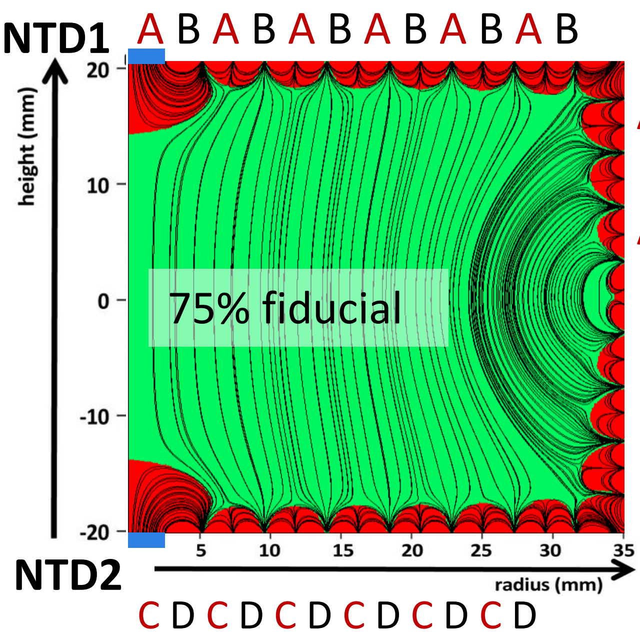


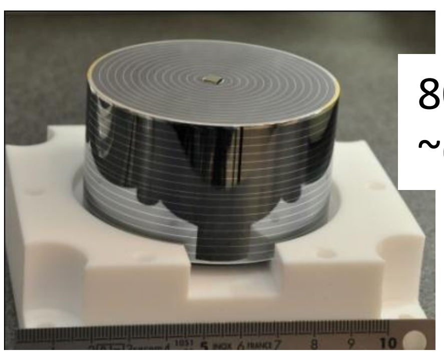
6 “NR evts” in 350.000 gamma calib evts

(Courtesy K. Eitel, KIT)

EDW-III: next generation of detectors

3. generation: FID detectors with rings on all surfaces

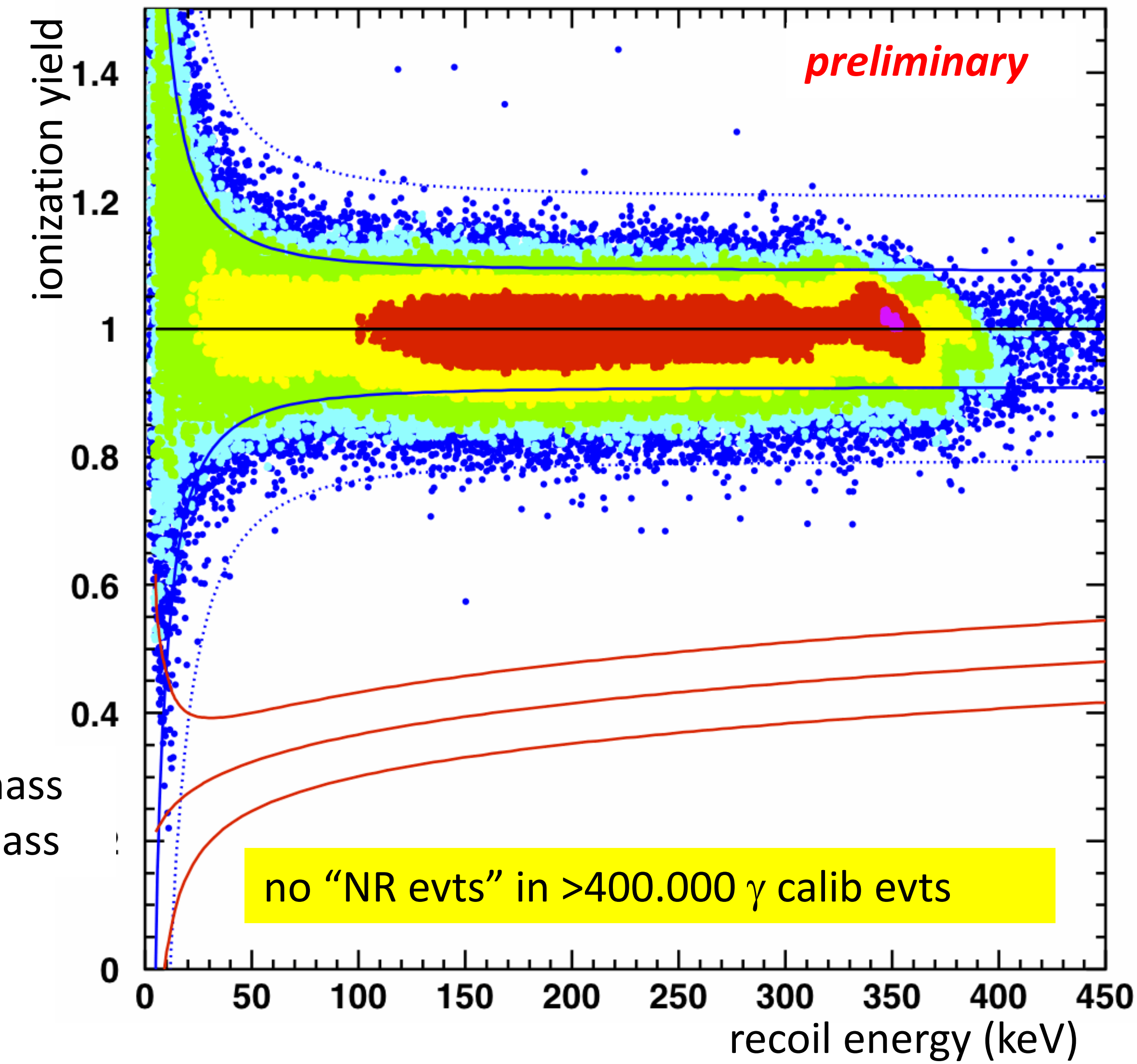




800g total mass
~600g fid. mass

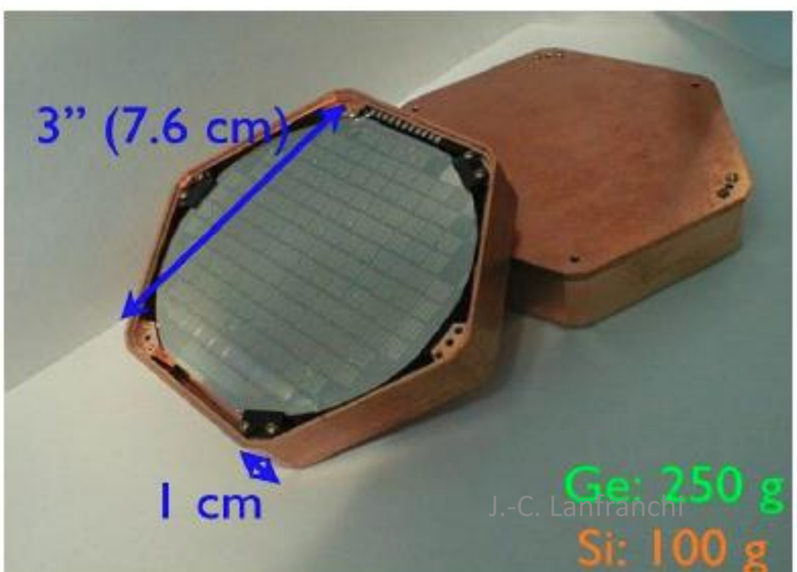
(Courtesy K. Eitel, KIT)

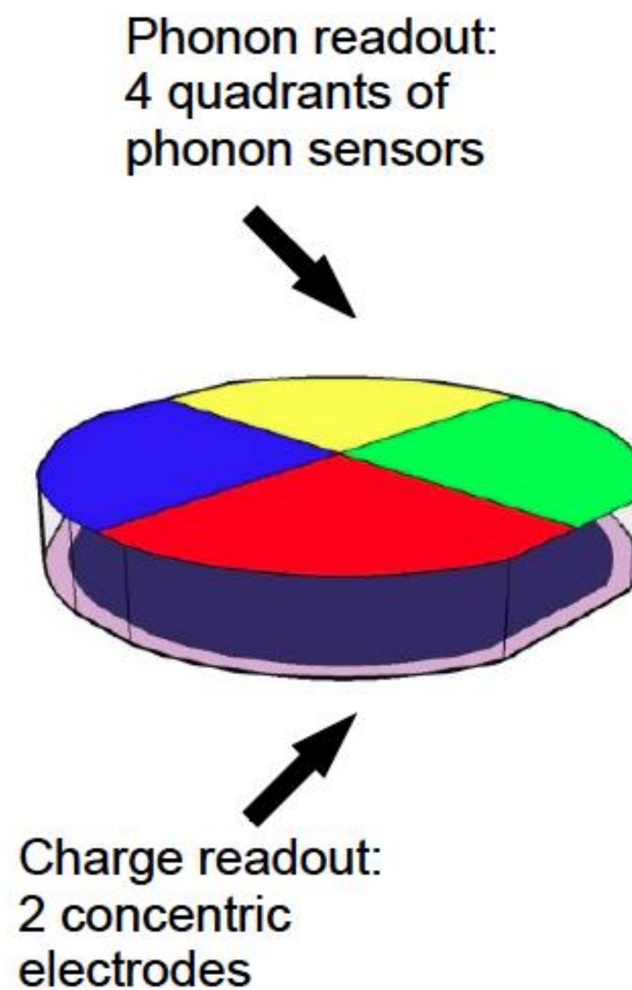
γ-calibration with ^{133}Ba (411663γ´s)



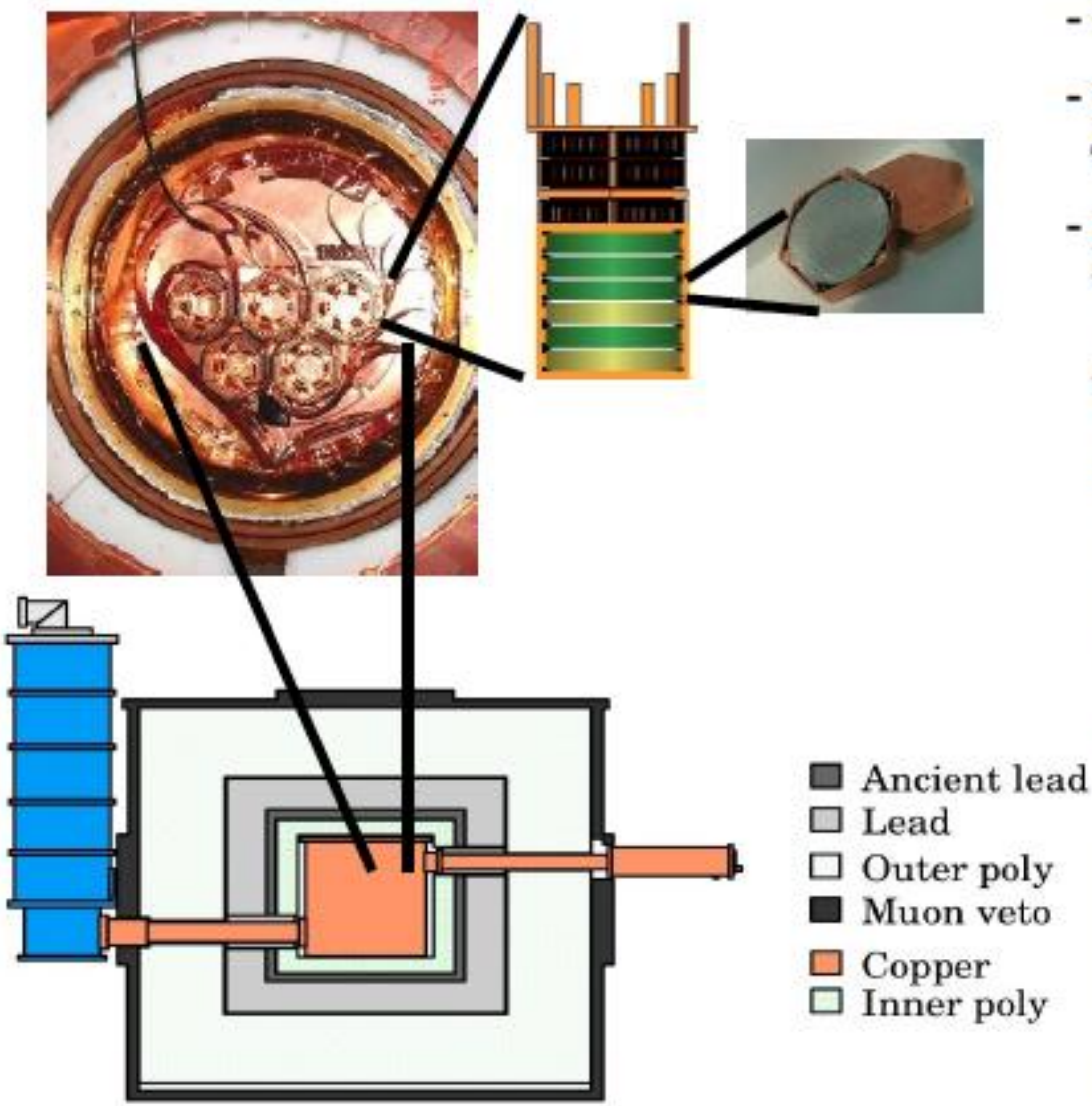
CDMS – Cold Dark Matter Search

- 19 Ge and 11 Si semiconductor detectors
- operated at cryogenic temperatures (~40 mK)
- 2 signals from interaction (ionization and phonon) ⟶ event by event discrimination between electron recoils and nuclear recoils
- z-sensitive readout
- xy-position imaging



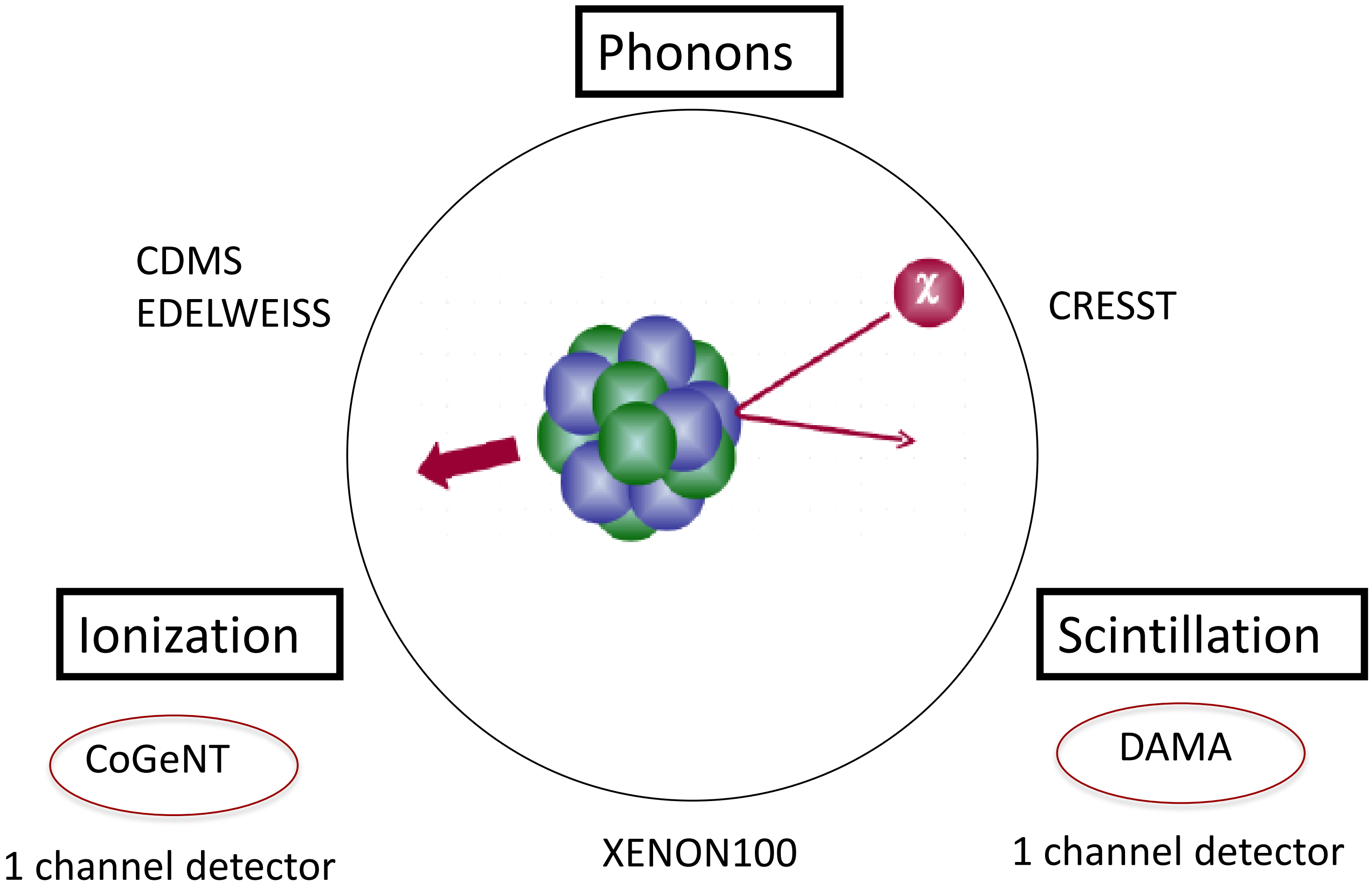


CDMS Setup and Shielding



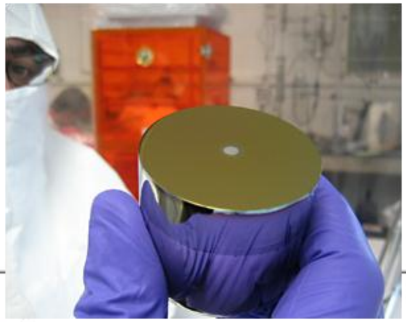
- 5 towers with 6 detectors each
- active veto against high energetic muons
- passive shielding:
  - lead against gammas from radioactive impurities
  - polyethylene to moderate neutrons from fission decays and from (α,n) interactions resulting from U/Th decays

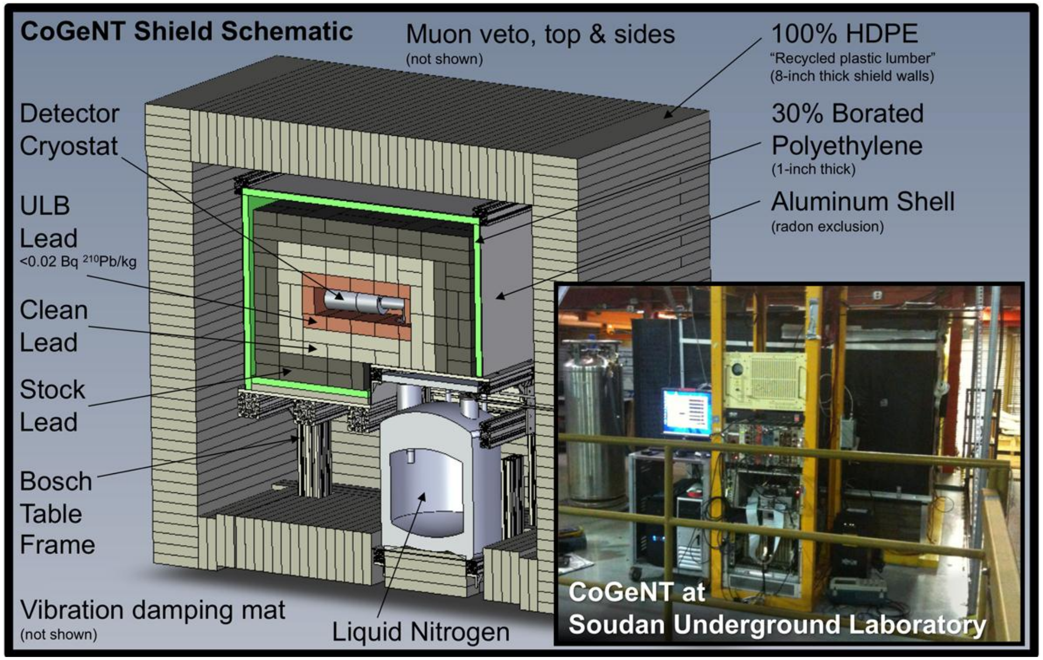
Recoil Detection & Background Identification

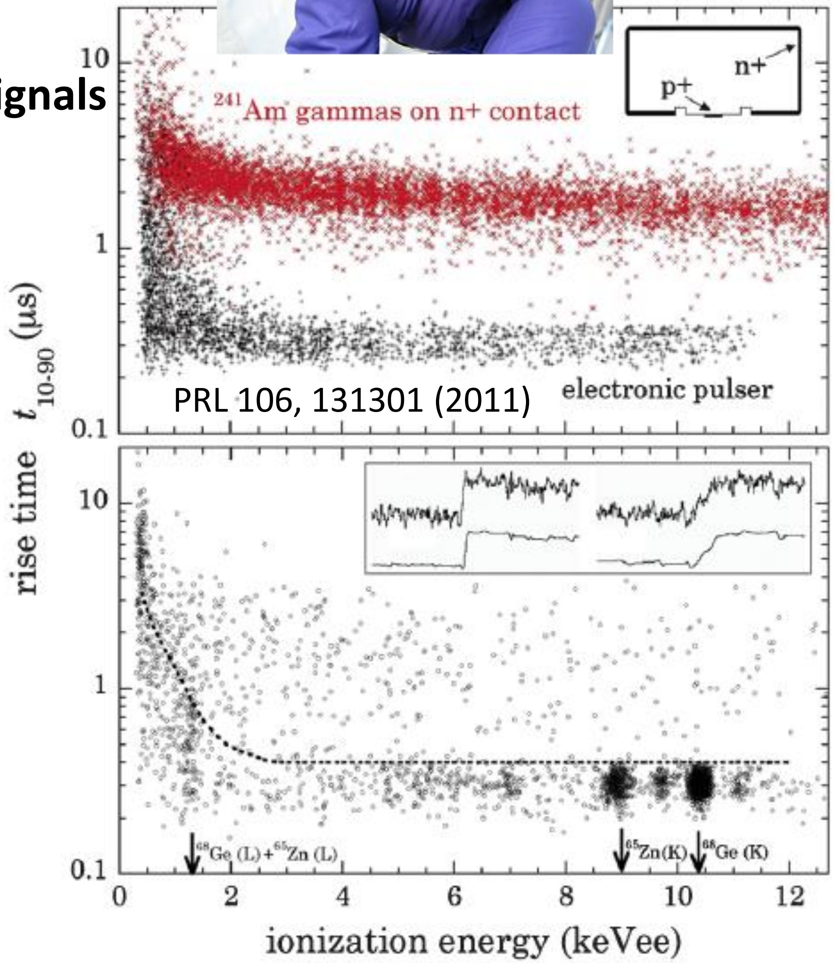


CoGeNT- Coherent Germanium Neutrino Technology

- 440g high-purity germanium crystal (p-type point contact)
- Measurement of nuclear recoils via ionization channel only
- Location: Soudan Underground Laboratory (SUL)
- Very low energy threshold: ~0.5keV
- Sensitivity to low-mass WIMPs (>5GeV/c^2)
- Surface events can be rejected by risetime of the signals

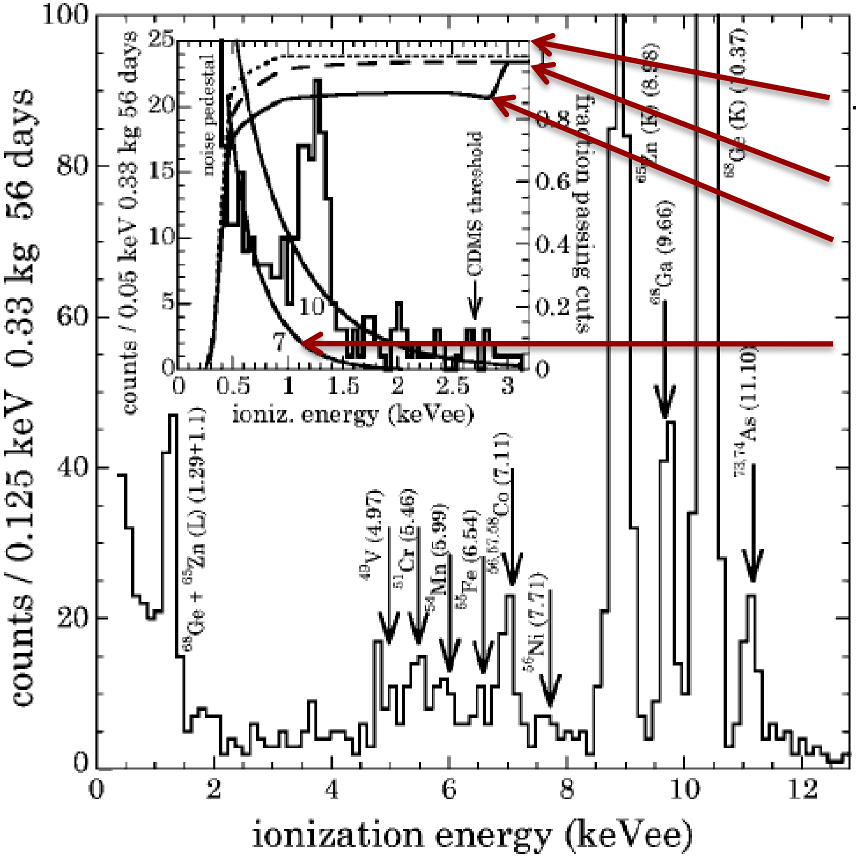






CoGeNT Results

Low-energy spectrum after all cuts:



Expanded threshold region with ^{65}Zn and ^{68}Ge L-shell EC

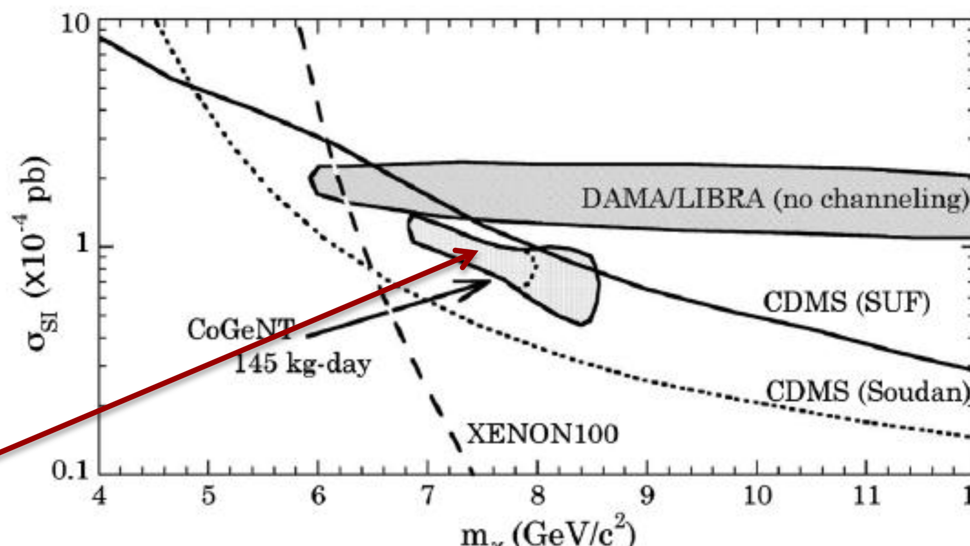
Trigger efficiency

Microphonic cuts

Rise time cuts (high-stati. by electr. pulser calibration)

Fits for a 7 GeV/c^2 and 10 GeV/c^2 WIMP, $\sigma_{SI} = 10^{-4}$pb

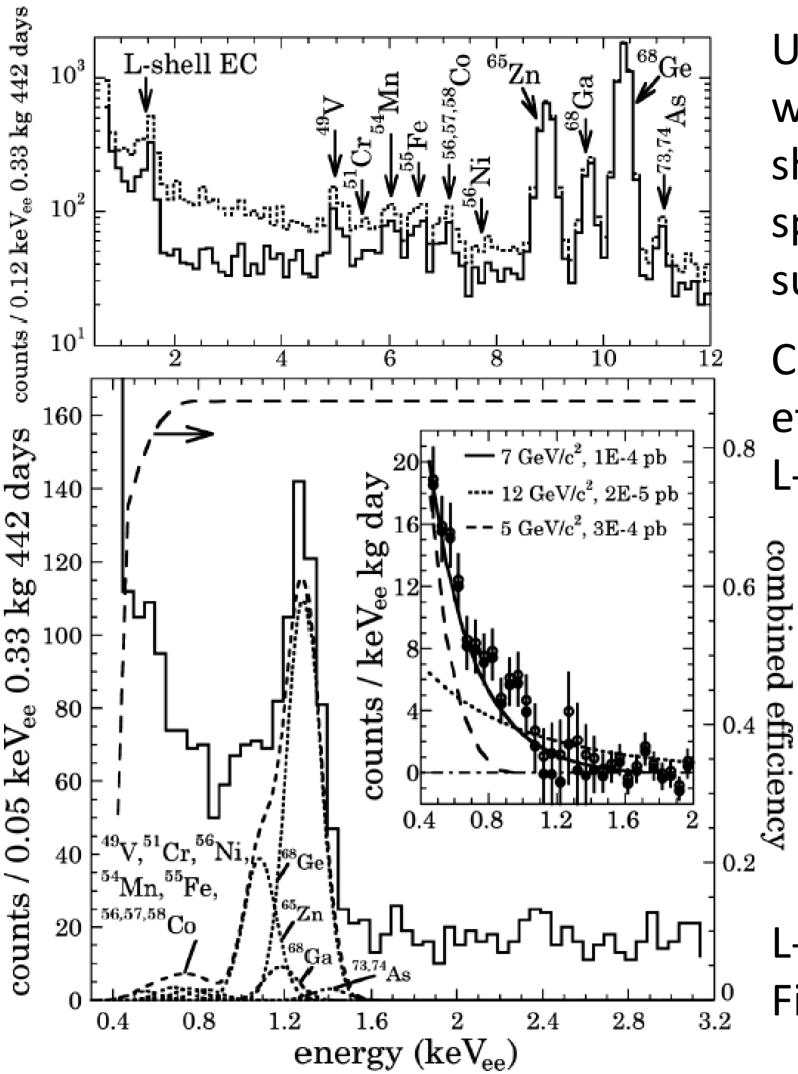
PRL 106, 131301 (2011)



WIMP parameter space favoured by the experiment

PRL 106, 141301 (2011)

CoGeNT – Search for Annual Modulation



PRL 106, 141301 (2011)

Uncorrected spectrum with all expected K-shell ECs (cosmogenic) spectrum prior to surface event rejection

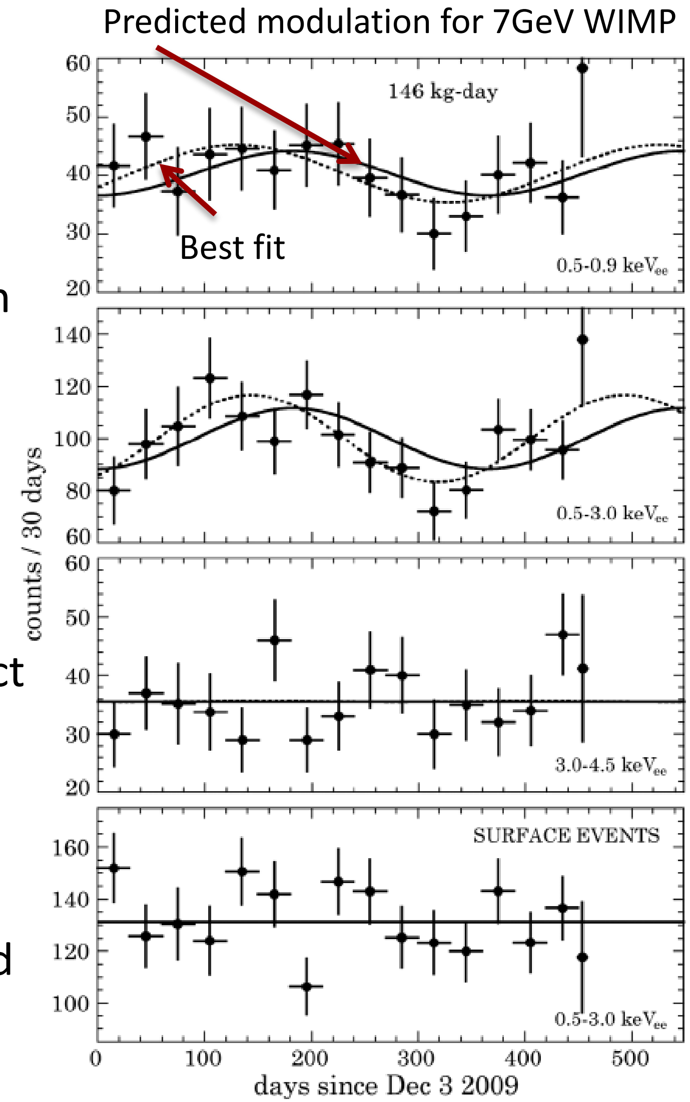
Comb. threshold efficiency

L-shell contributions

Significance of effect 2.8σ

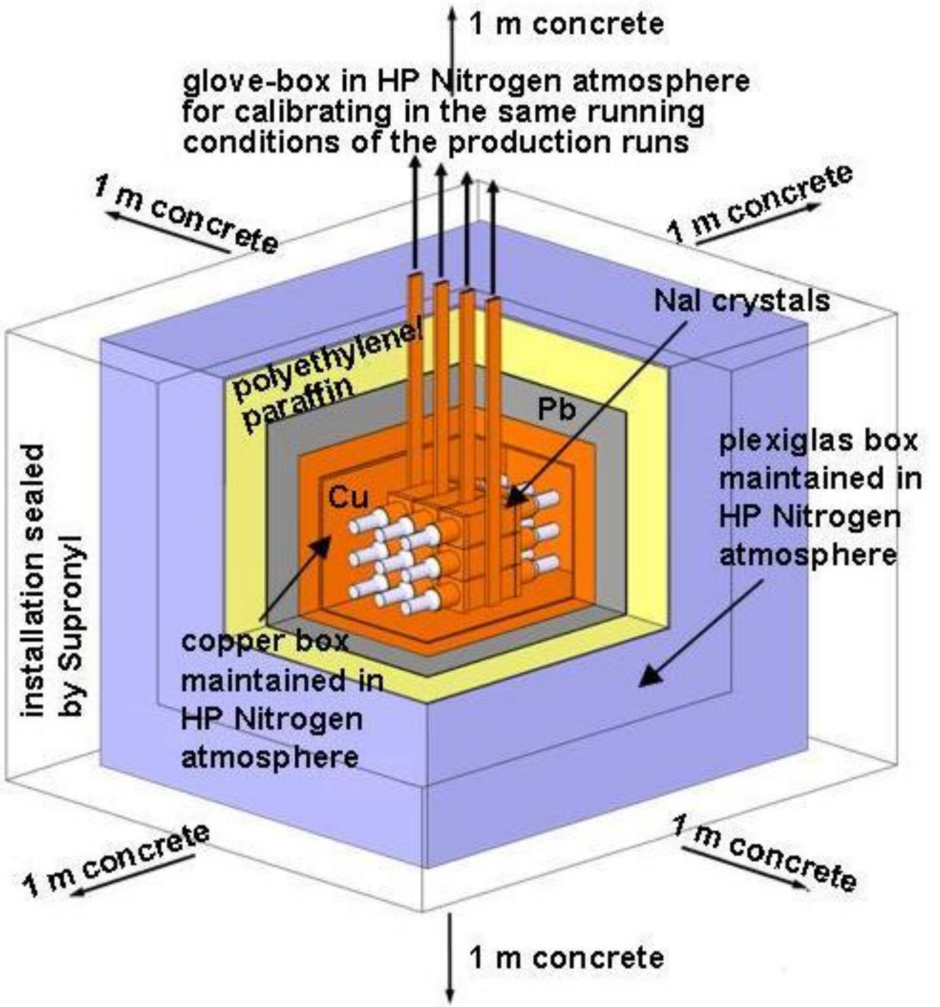
L-shell events removed

Fits for 3 WIMP types



PRL 106, 141301 (2011)

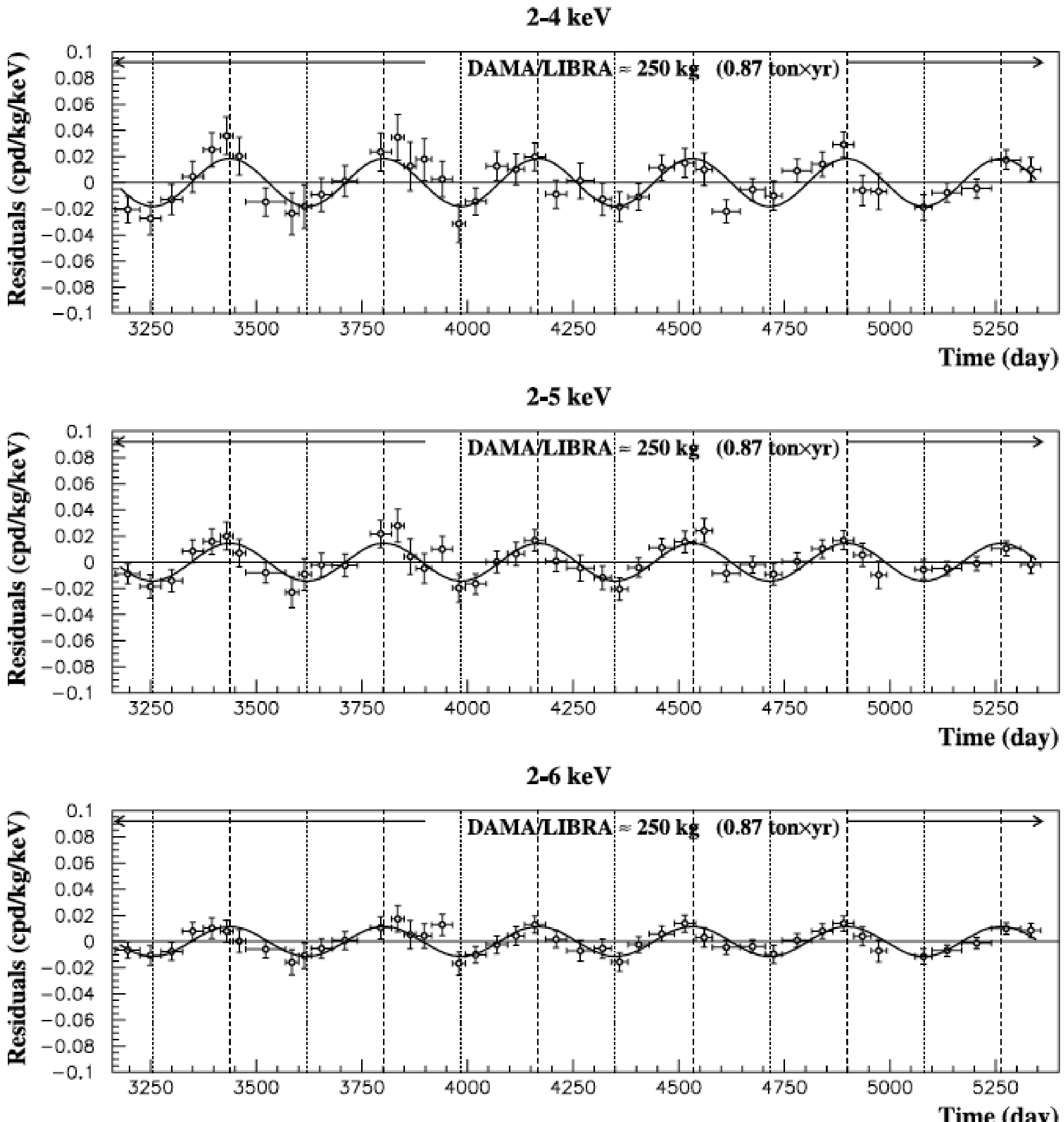
DAMA



Simplified schema of ~ 100 kg NaI(Tl) set-up

Location: Gran Sasso, Italy
Pure scintillation detector using NaJ(Tl)
Large target mass: ~250kg
Goal: measure DM induced modulation of signal over the year: max on June 2nd
Smallest December 2nd
Under standard halo assumptions:
<7% effect

DAMA – Annual Modulation



EUR. Phys. J. C (2010) 67: 39-49

Cumulative exposure of DAMA/NaJ and DAMA/LIBRA: **1.17 ton years**

In total: **13 annual cycles**

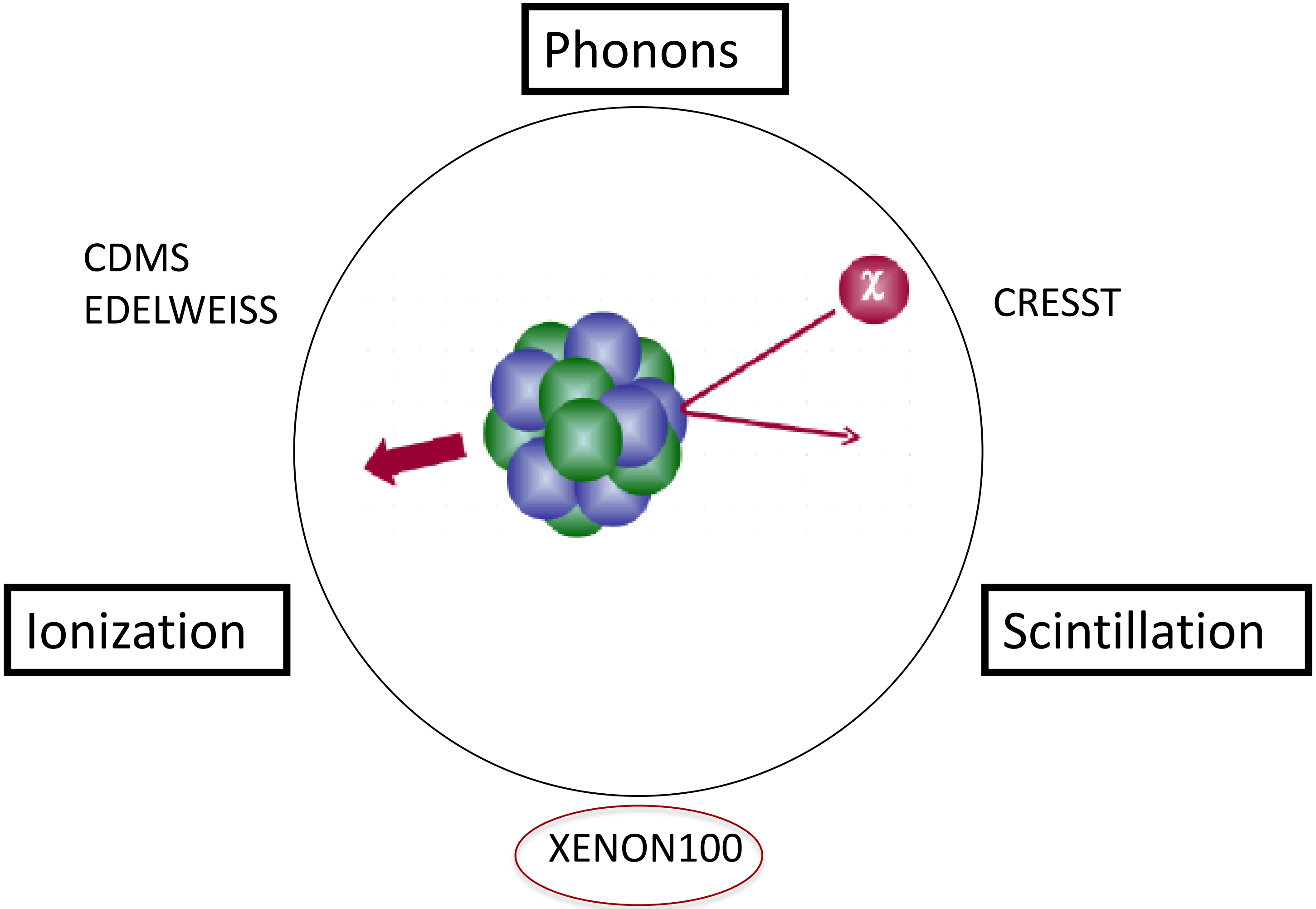
Modulation only present at low energies: **2-6keV**

Only single hits exhibit modulation

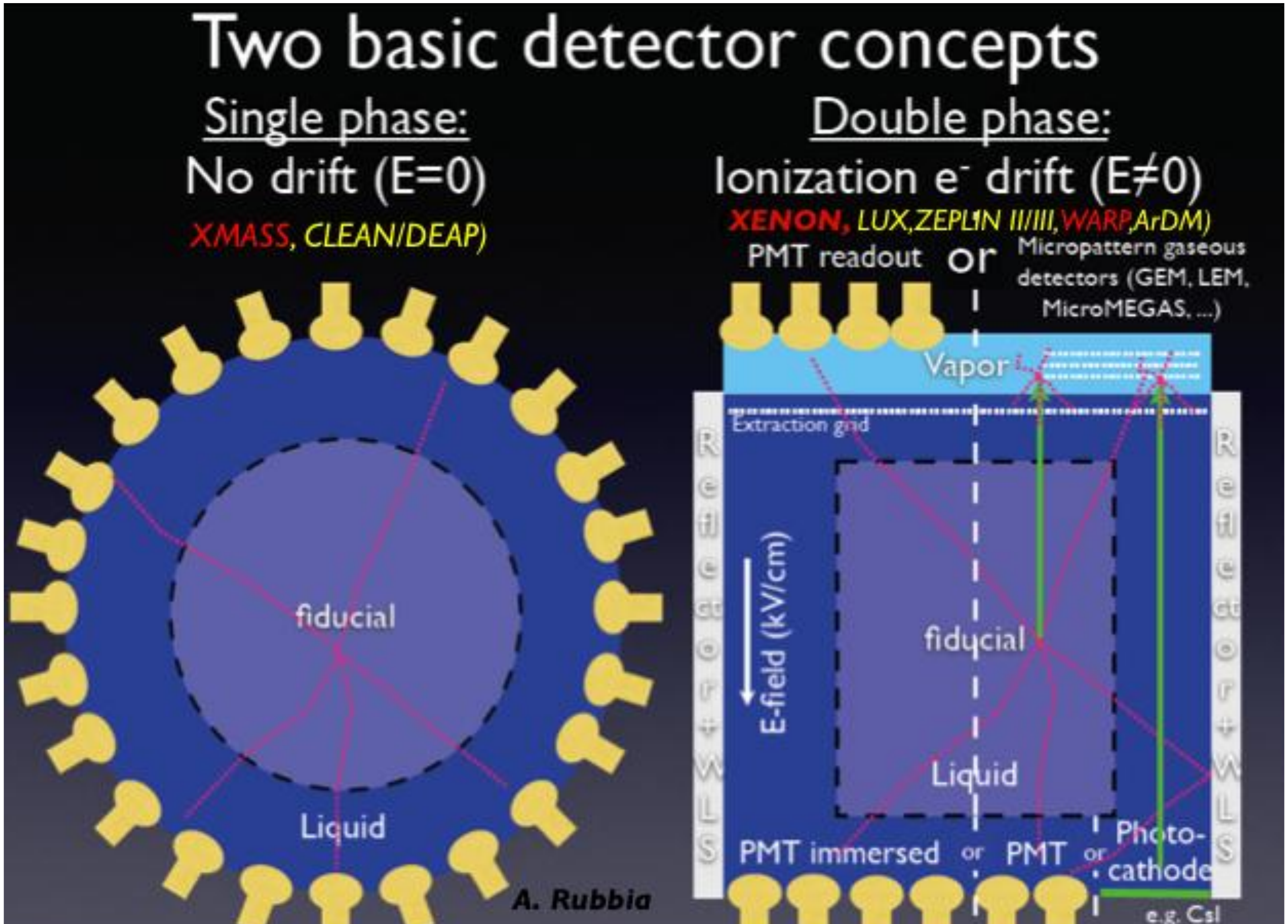
Phase of modulation within error margins agrees well with predictions:
- measured: **147+/-7 days**
- expected: **156.5 days**

DM annual modulation signature: confidence level **8.9σ**

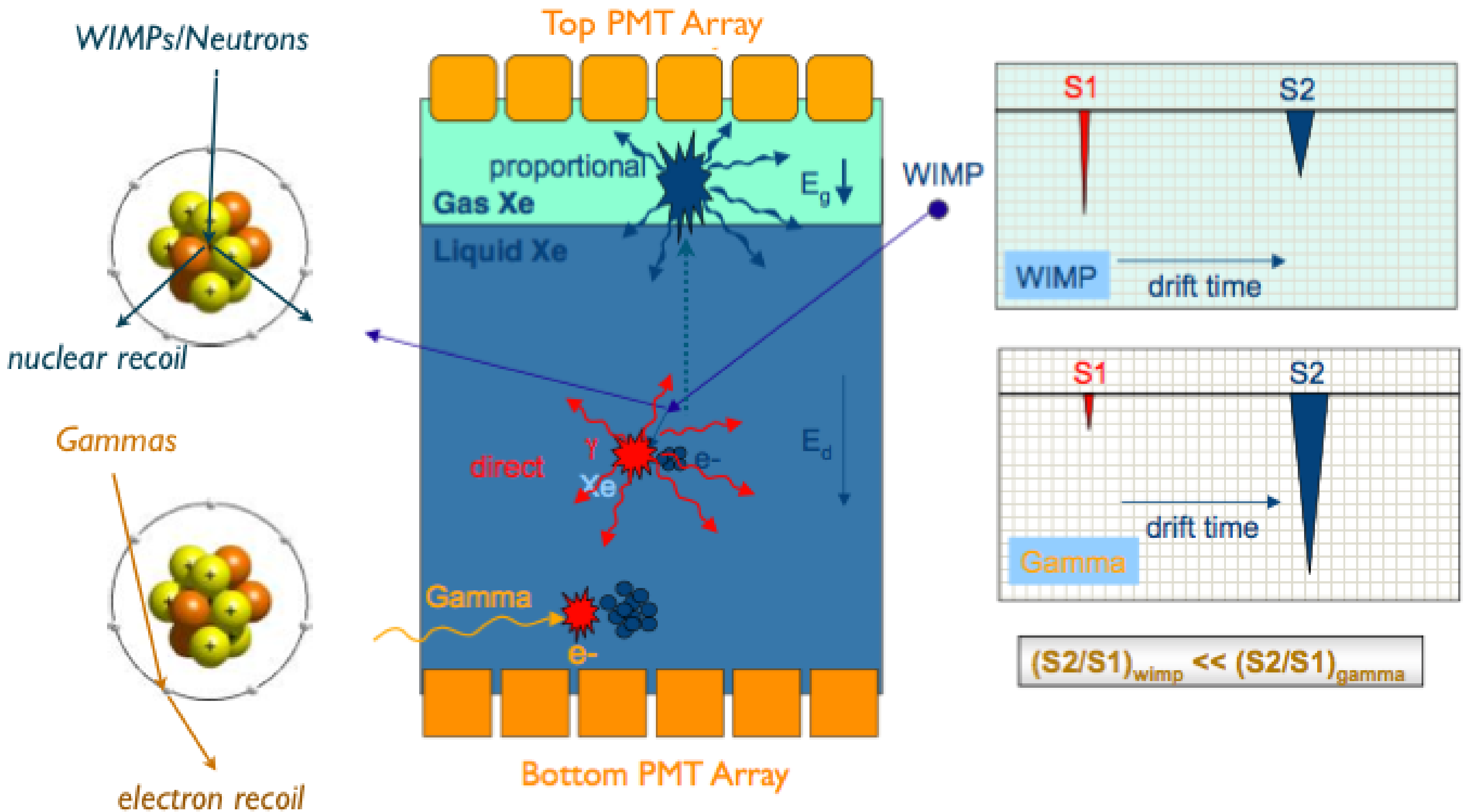
Recoil Detection & Background Identification



Liquid Noble Gas Detectors



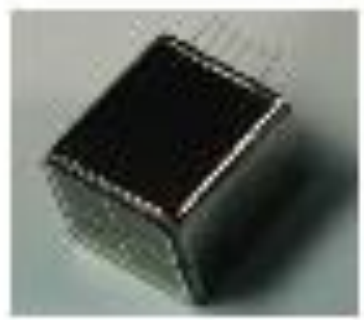
XENON Detector



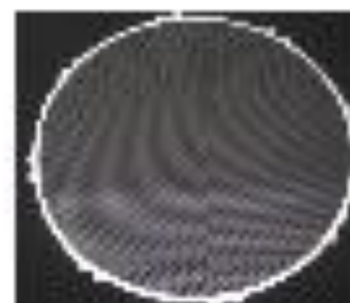
- Single electron and single photon measurement sensitivity
- > 99.5% ER rejection via Ionization/Scintillation ratio (S2/S1)
- 3D event-by-event imaging with millimeter spatial resolution

XENON100 Detector

- 30 cm drift length and 30 cm ⌀
- 161 kg total (30-50 kg fiducial volume)
- ~ 100x less background than XENON10
- Material screening and selection
- 242 low activity 1" PMTs (R8520)
- Cooling (PTR) outside the shield
- Active liquid xenon veto

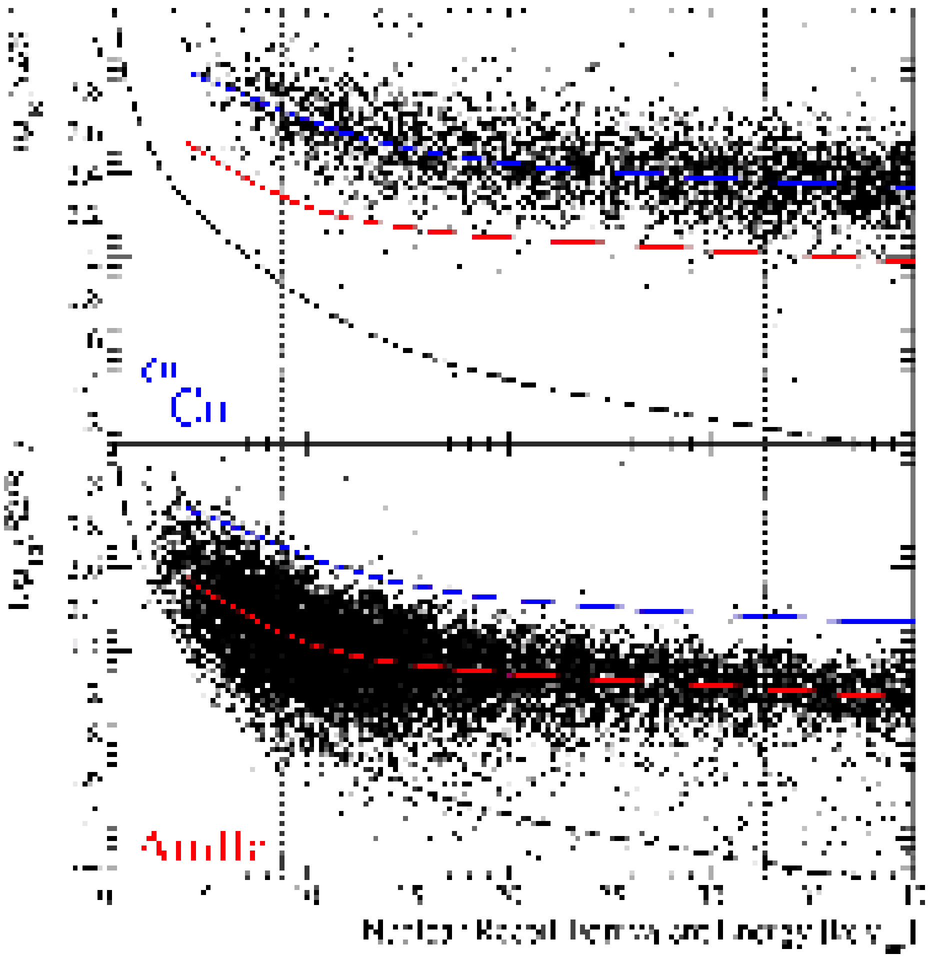


1 inch PMTs



30 cm ⌀ meshes

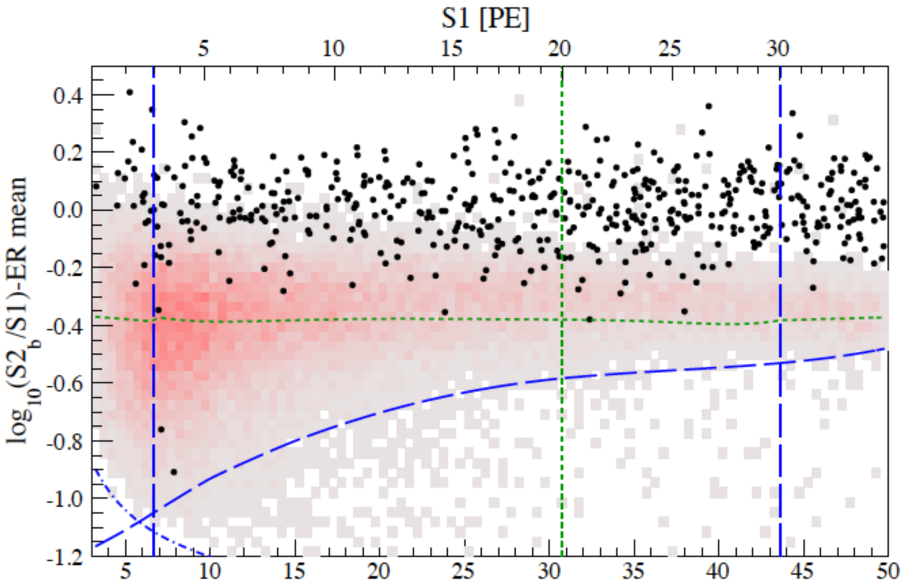
Event Discrimination



- Electronic recoil band: defined with ^{60}Co source
- Nuclear recoil band: defined with AmBe neutron source

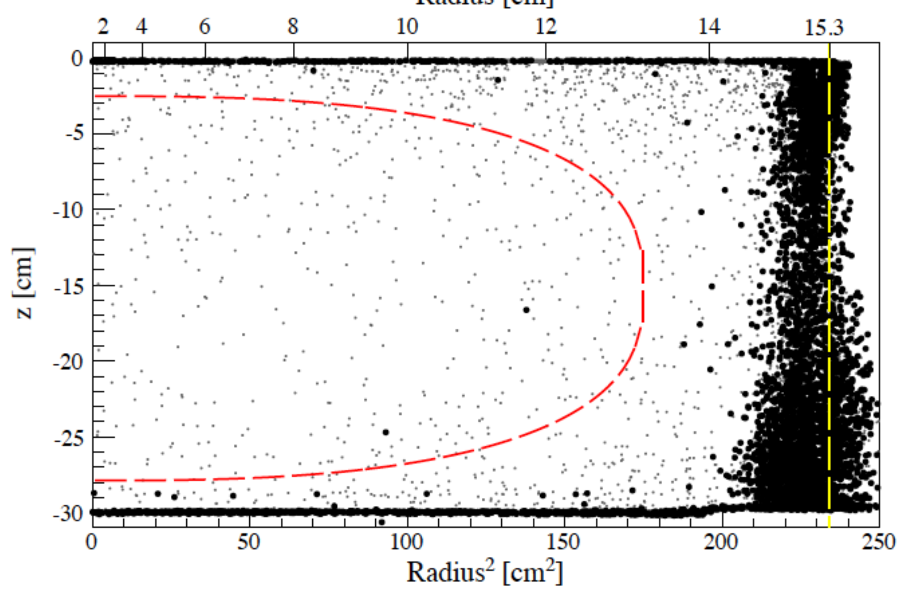
- Discrimination better than 99% @ 50% nuclear recoil acceptance

XENON100



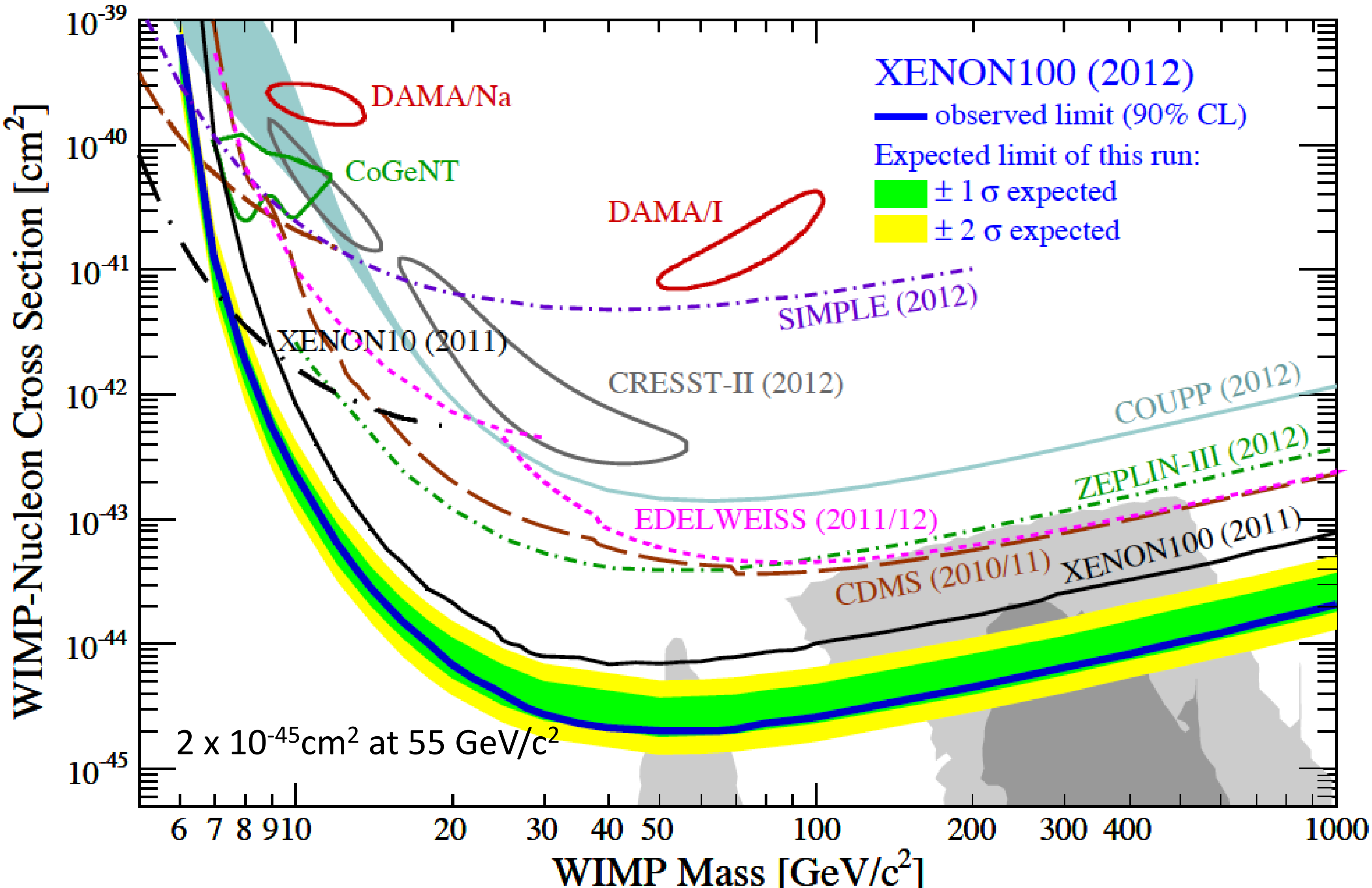
arXiv:1207.5988v1

- Total exposure: 224.6d x 34kg
- 2 events detected (after all cuts) in region of interest for WIMP search
- Expected background: 1.0 +/- 0.2 events
- 2 events still compatible with background



- spatial reconstruction of the 2 events
-> events contained in fiducial volume of the detector

XENON100



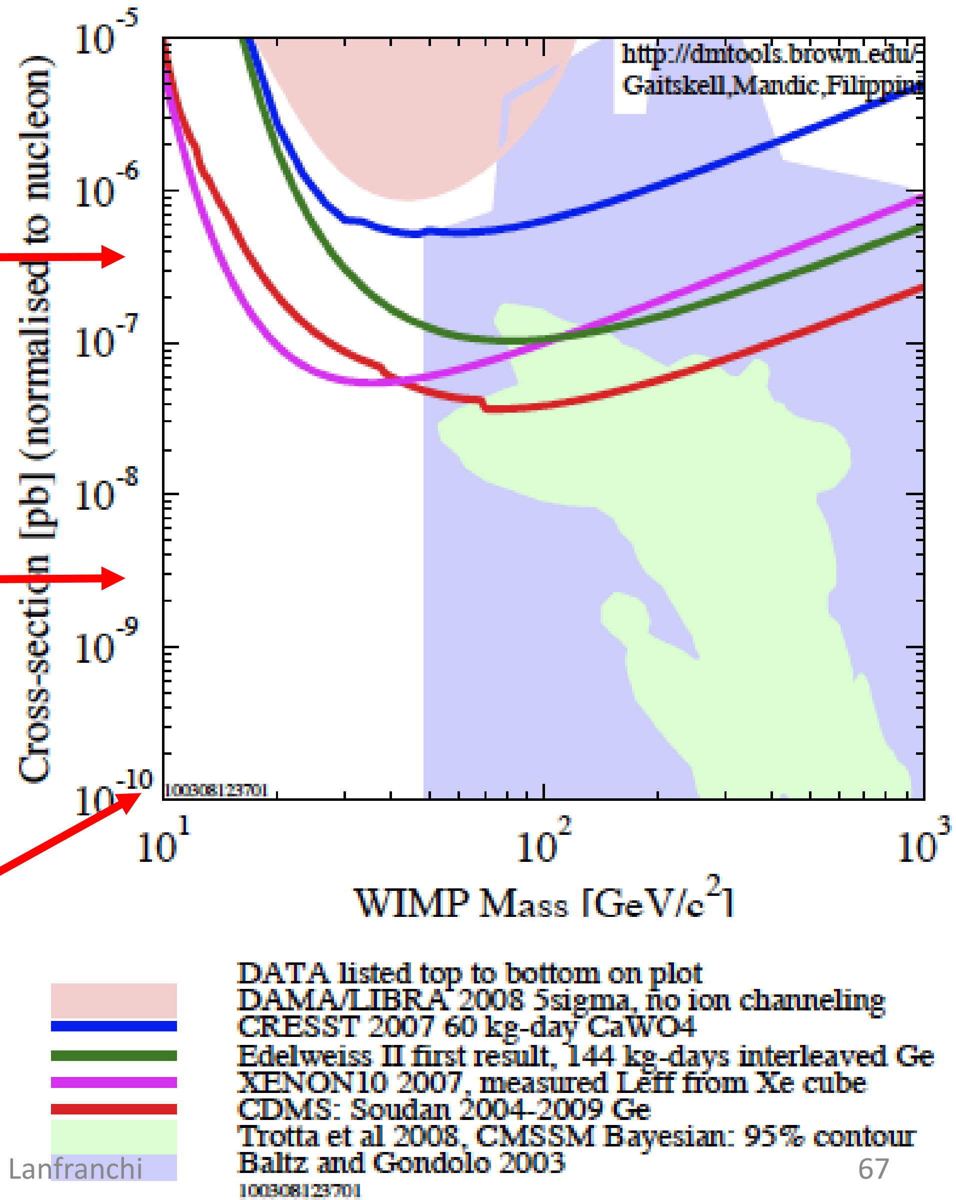
arXiv:1207.5988v1

Future Ton-Scale Dark Matter Detectors

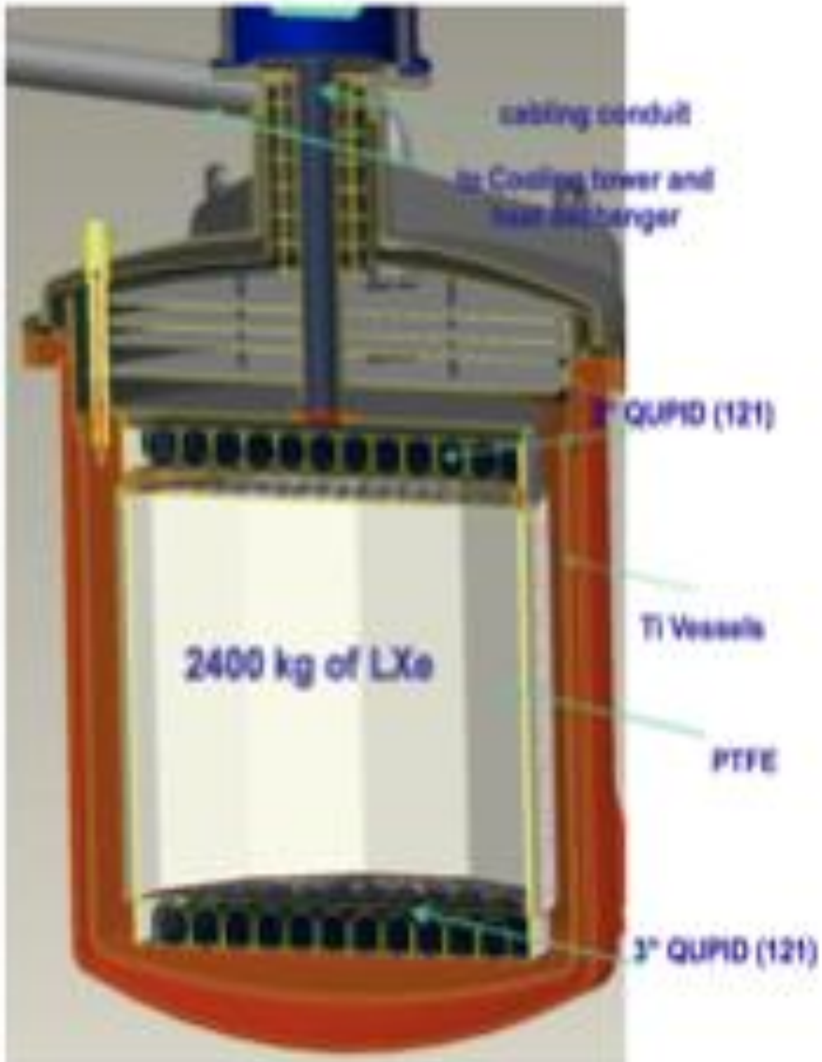
~1 event/kg/day
Reached

~3 events/kg/year
Present phase II experiments

~30 events/ton/year
Next generation requires further x100 improvement!



Future XENON Detector



- 1.2 ton fiducial mass (total of 2.4 ton LXe)
- Drift length = ~ 90 cm
- 100x background reduction
- Muon veto
- Copper/titanium cryostat
- New photo-detectors: QUPIDs

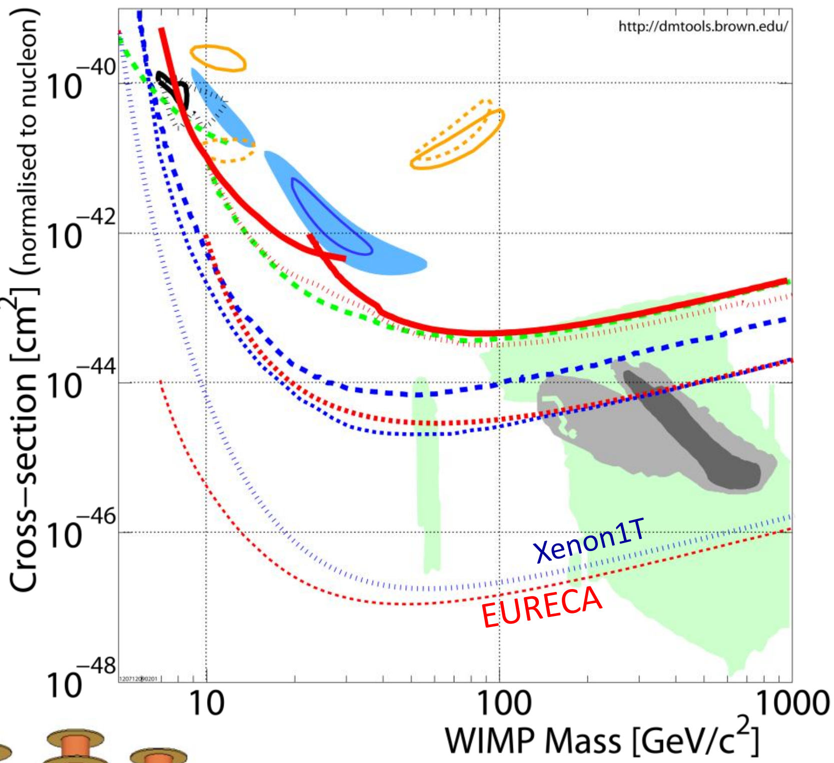
→ New collaborators

→ Currently working on MC simulations and design + secure remaining funding

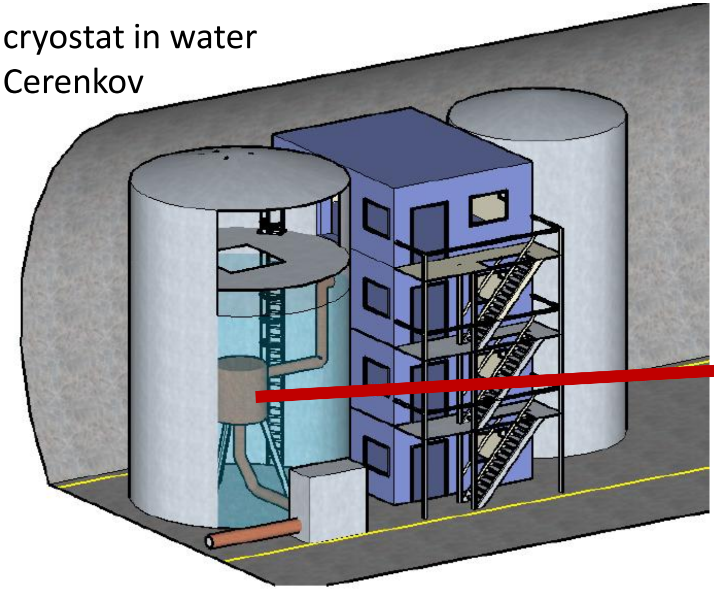
- Timeline: 2010 - 2015

EURECA (European Underground Rare Event Calorimeter Array)

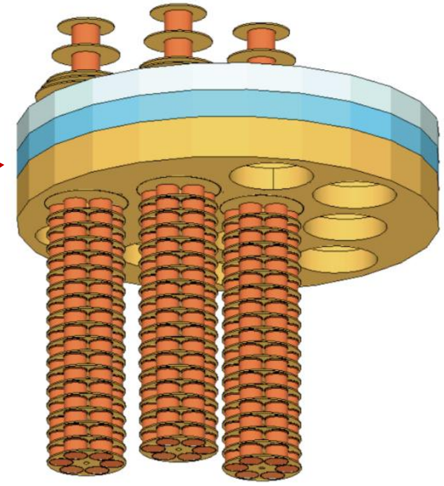
- EURECA goal: 10^{-10} - 10^{-11} pb, 150kg → 1000kg, multi-target, bgd ~ 10^{-3} evts/(kg.y)
- EDW, CRESST, ROSEBUD, + others…
- coordinated cooperation with SuperCDMS
- CDR in summer 2012
- facility type (DM, $0\nu\beta\beta$,...)
- part of European ASPERA roadmap



cryostat in water Cerenkov



detector towers multi-target det´s

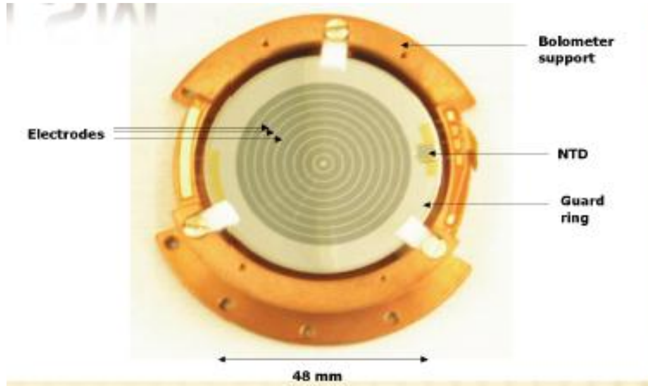


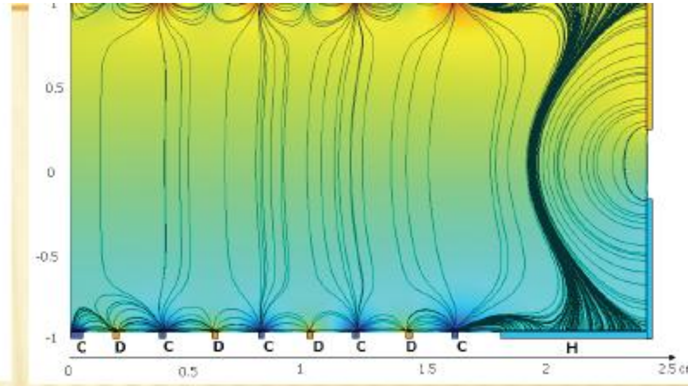
(Courtesy K. Eitel, KIT)

EURECA Combining Detection Techniques

Phonon - Charge (EDELWEISS)

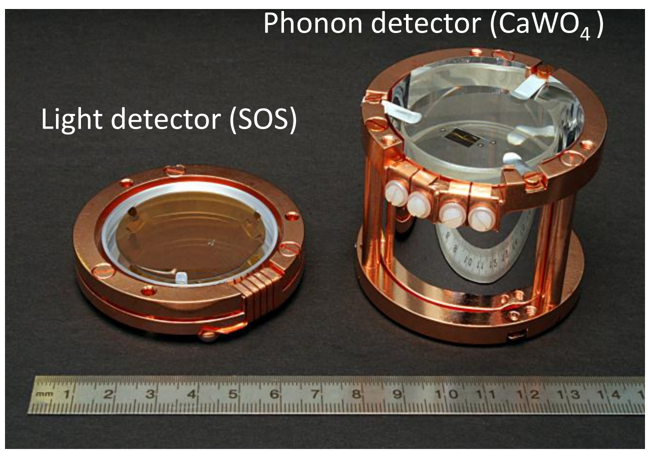
Ge detectors with surface event rejection (interdigit)

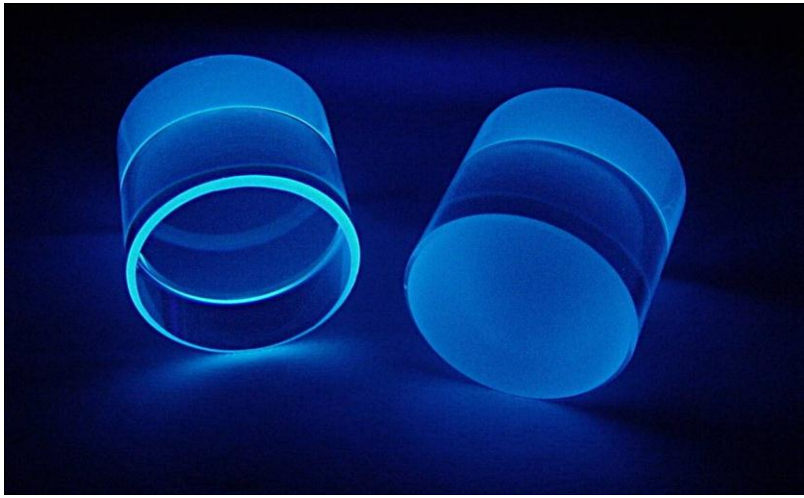




Phonon - Scintillation (CRESST, ROSEBUD)

Event by event discrimination in scintillating $CaWO_4$ detectors





Phonon-scintillation technique allows flexibility in choice of target materials: $ZnWO_4$, $CaMoO_4$, BGO, Al_2O_3, NaI ...

Ultimate Background - Neutrinos

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1984

Principles and applications of a neutral-current detector for neutrino physics and astronomy

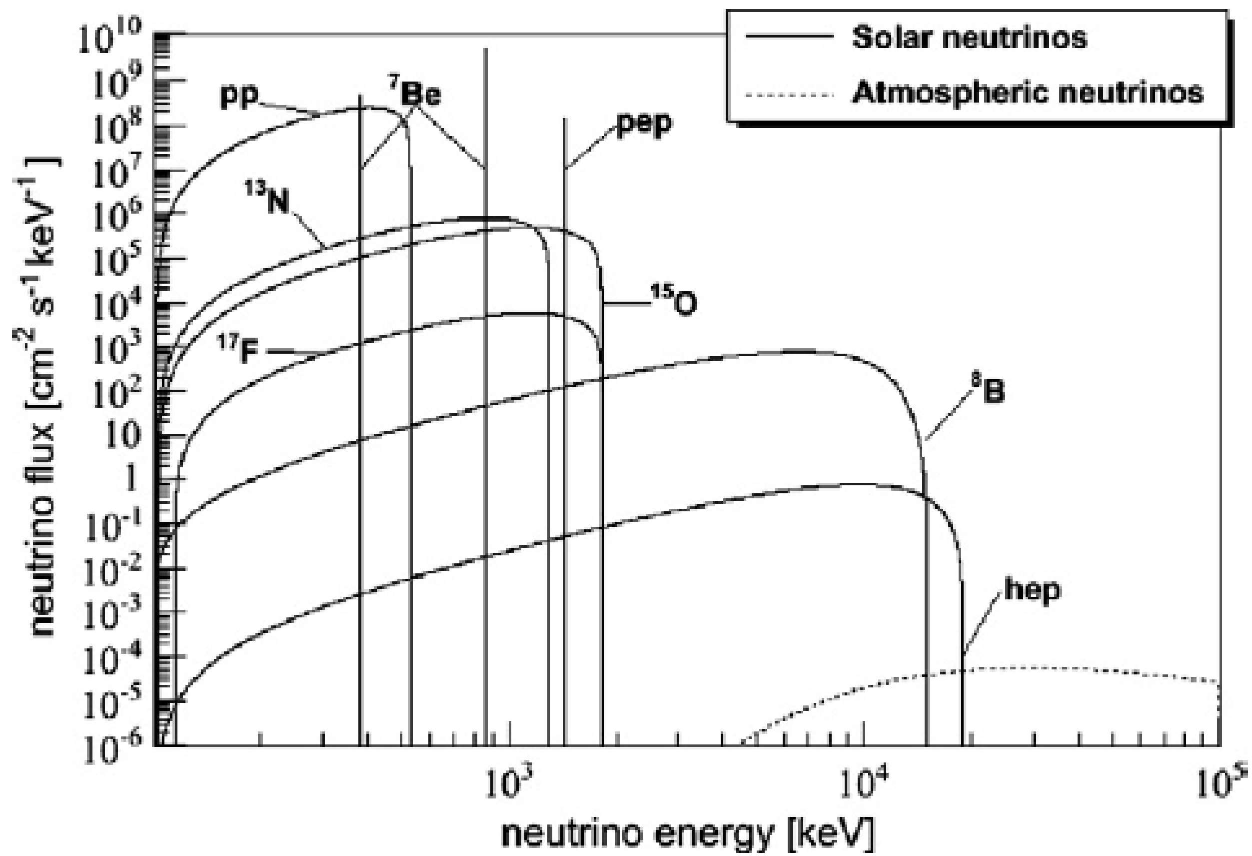
A. Drukier and L. Stodolsky
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany
(Received 21 November 1983)

We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small ($10-10^3$ eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit determination of the neutrino energy spectrum and should be insensitive to neutrino oscillations since it detects all neutrino types. Various applications and tests are discussed, including spallation sources, reactors, supernovas, and solar and terrestrial neutrinos. A preliminary estimate of the most difficult backgrounds is attempted.

- For future DM searches Coherent Neutrino Nucleus Scattering (CNNS) may constitute a limiting background for future direct Dark Matter searches
- CNNS is a neutral current process sensitive to all neutrino flavours
- cross section is enhanced by N^2

$$\sigma_{tot} \approx \frac{G_F^2}{4\pi} N^2 E_\nu^2 |f(q)|^2 = 4.2 \times 10^{-45} N^2 \left(\frac{E_\nu}{1\,\mathrm{MeV}}\right)^2 |f(q)|^2\ \mathrm{cm}^2$$

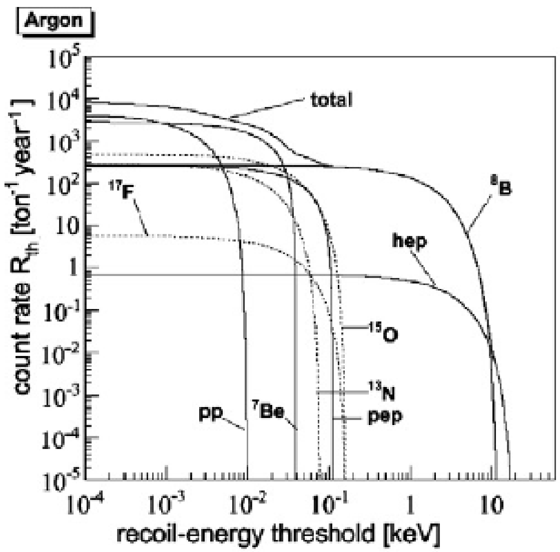
Neutrino Spectrum

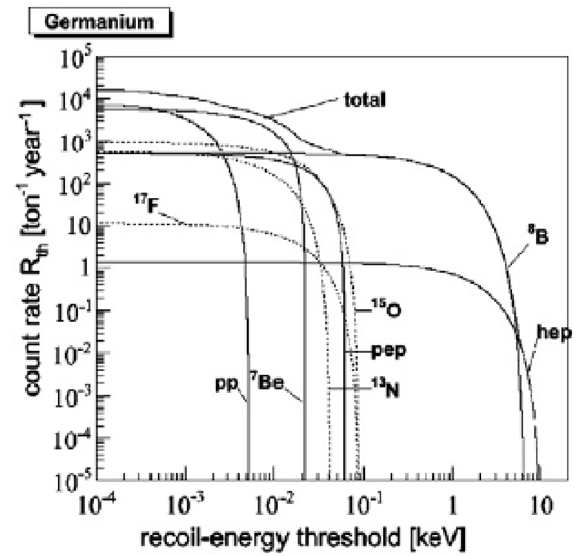


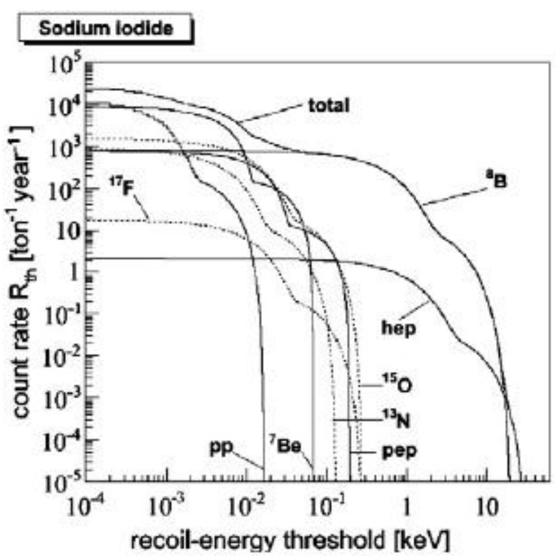
Solar Neutrino Count Rates for Various DM Targets

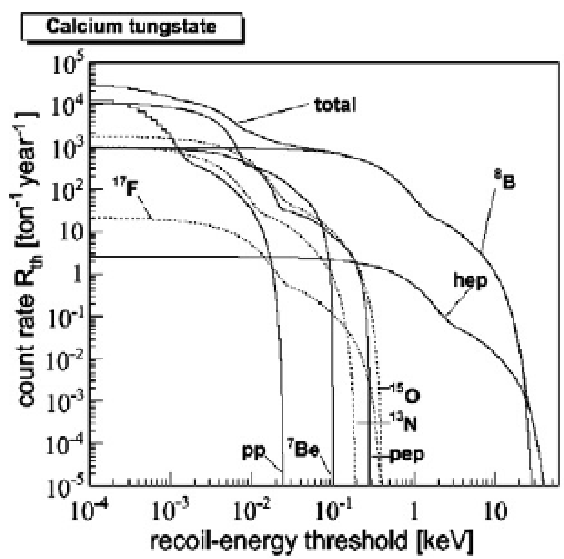
Astroparticle Physics 34 (2010) 90–96

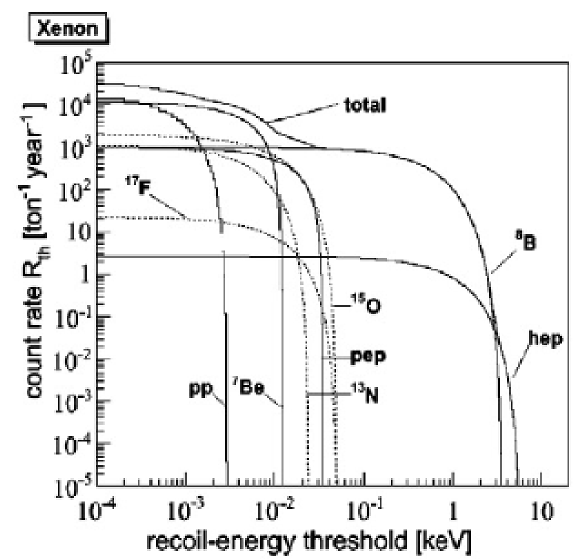
- Neutrino „background“ depends on achievable energy threshold in the various experiments











Ultimate Backgrounds

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Nuclear recoil count rates from solar neutrino scattering per ton-year for various target materials and different energy thresholds. The count rates for the different nuclei of calcium tungstate are given separately.

Material	0 keV	1 keV	2 keV	3 keV	5 keV	10 keV
Ar	8.0×10^3	1.3×10^2	6.5×10^1	3.2×10^1	6.2	1.5×10^{-2}
Ge	1.6×10^4	1.4×10^2	3.6×10^1	7.2	7.9×10^{-2}	2.5×10^{-8}
NaI	2.4×10^4	9.6×10^1	1.4×10^1	6.3	2.7	2.4×10^{-1}
Xe	3.0×10^4	9.5×10^1	4.7	6.2×10^{-2}	9.0×10^{-5}	-
$ZnWO_4$	2.7×10^4	6.6×10^1	1.8×10^1	9.7	4.4	1.0
$CaWO_4$	2.8×10^4	5.8×10^1	1.8×10^1	1.2×10^1	5.4	1.1
O	5.8×10^2	1.4×10^1	1.1×10^1	8.1	4.6	1.1
Ca	9.0×10^2	1.4×10^1	7.2	3.5	6.9×10^{-1}	1.7×10^{-3}
W	2.6×10^4	2.9×10^1	1.4×10^{-1}	2.3×10^{-3}	-	-

Atmospheric and Solar Neutrino Count Rates

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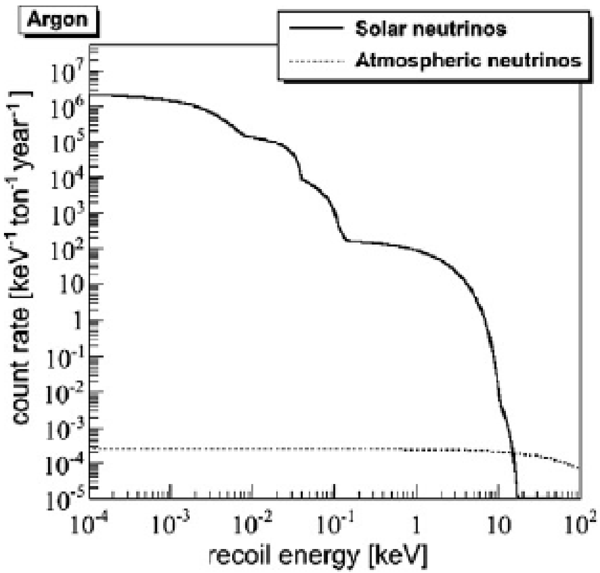
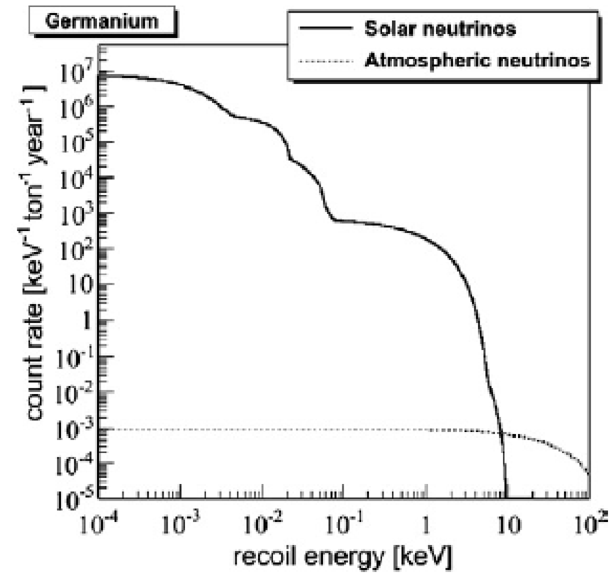
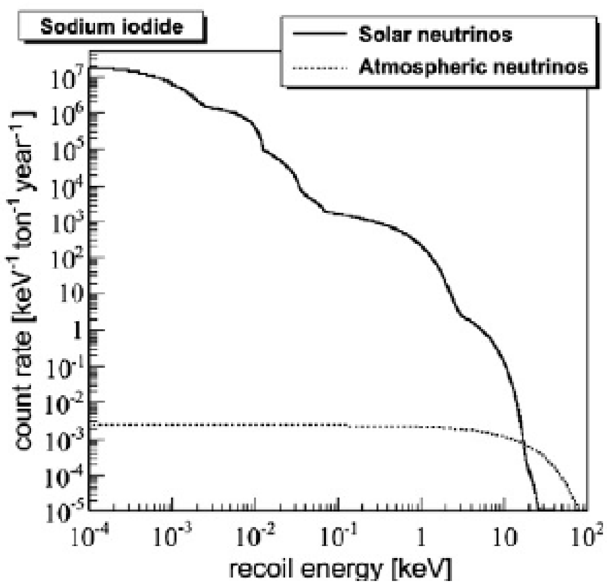
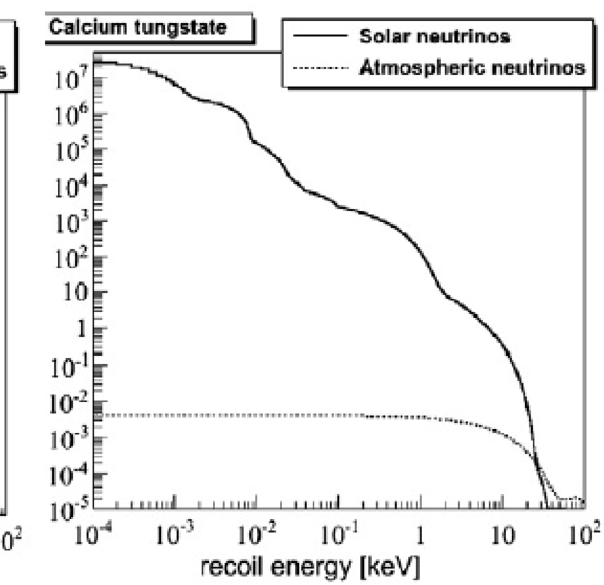
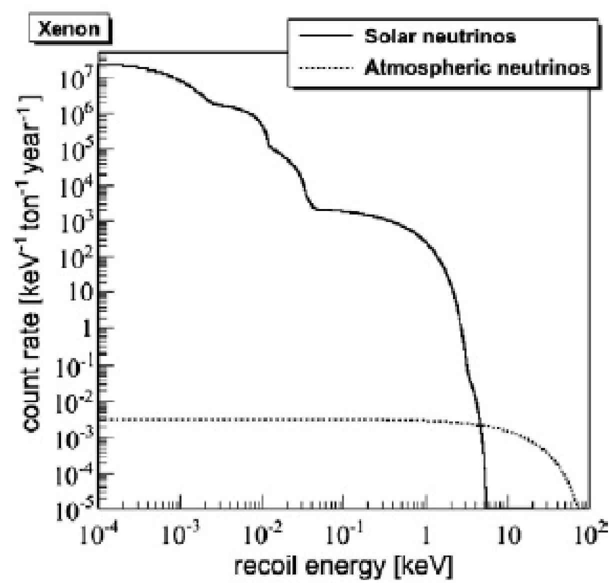
For DM search sensitivities better than 10^{-12}pb atmospheric neutrinos become an ultimate background even with carefully chosen energy thresholds!











Conclusions

- Great progress has been made in the past few years in the field of direct Dark Matter detection
- Tension between different experiments exists at present
- Ongoing searches will produce new results in the near future and new detector concepts on the ton-scale are underway aimed at clarifying the present situation
- Complementary information from indirect searches and accelerator experiments are required to draw a consistent picture in the end
- The understanding of Dark Matter is a great challenge for the next generation of scientists working in this field ...

➢ YOU?