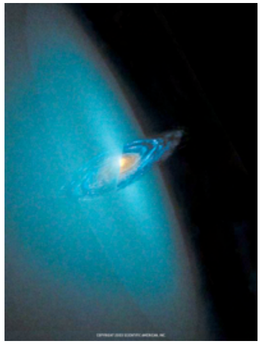


Direct Dark Matter Searches and the EDELWEISS-II experiment

- The method
- *Some* present experiments

Liquid Scintillating

Solid Cryogenic

Skip directionnal and modulation expts

- Prospects

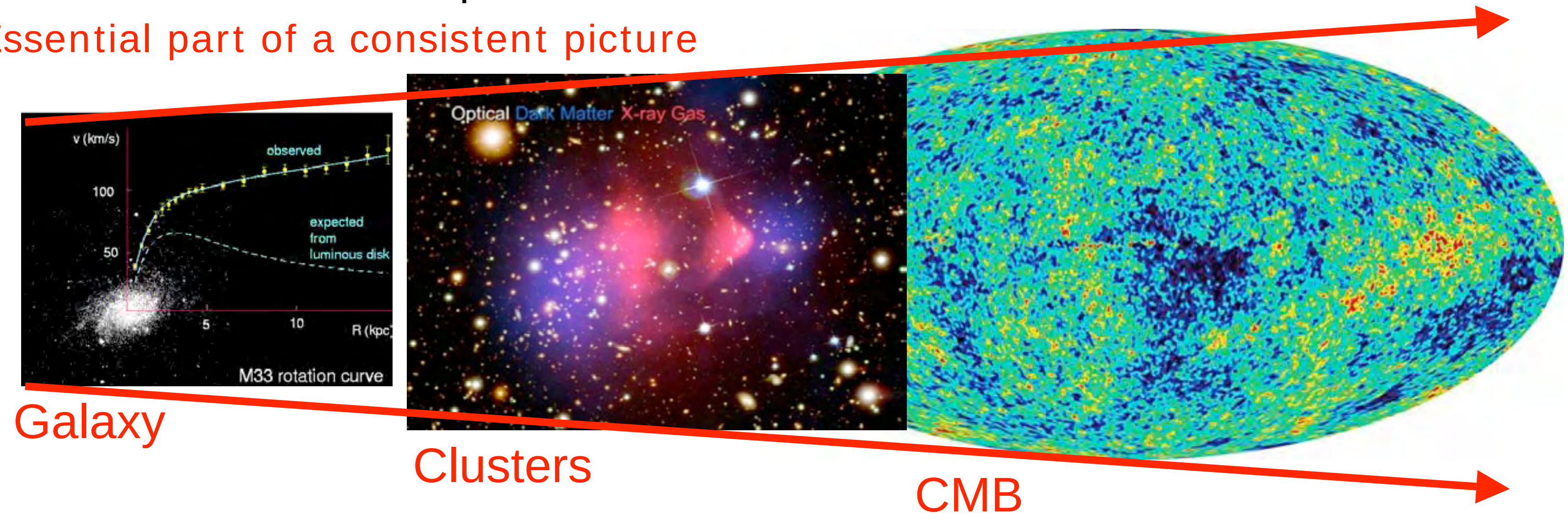
J. Gascon

UCB Lyon 1, CNRS/IN2P3/IPNL

Dark Matter at all scalesin our Universe

- Cold Dark Matter present at all scales in the Universe…

Essential part of a consistent picture

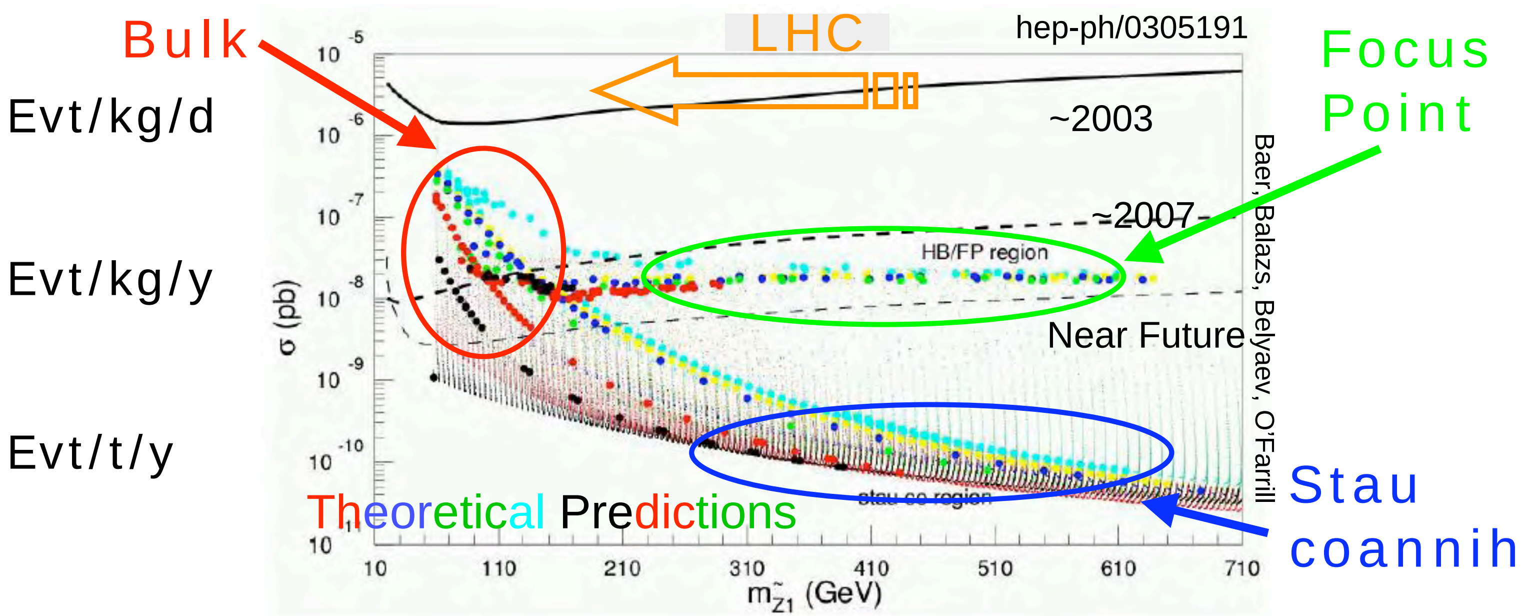


- … and soon, maybe also in collider experiments (LHC)
  - Natural candidates arise from New Physics scenarii, such as SUSY

- Direct Searches: linking the two worlds
  - The Dark Matter in our Galaxy is indeed Weakly Interacting Particles
  - The new particles found in colliders are indeed in our halo

Supersymmetry naturally "predicts" WIMP DM

- Neutralino LSP can (easily) reproduce cosmological WIMP density
- Annihilation $\sigma \rightarrow$ WIMP density (Ω_{DM})
- Scattering σ on proton $\rightarrow$ prediction for direct detection
- 10^{-8} pb is an extremely significant goal for direct detection: Test of cosmologicaly + SUSY motivated "Focus Point" region

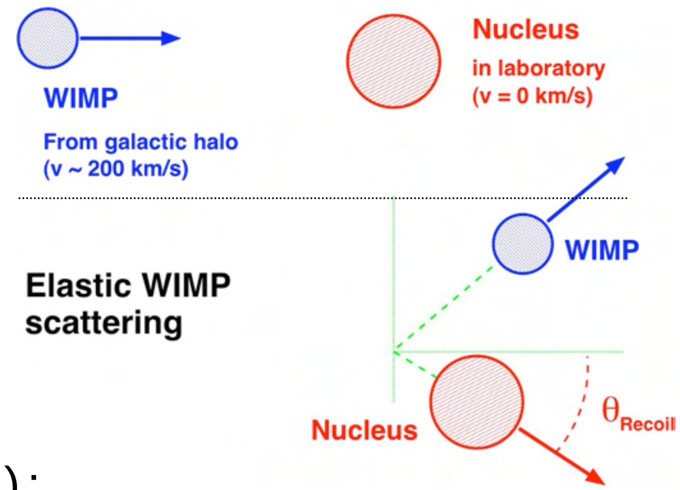


- 10^{-9} to 10^{-10} pb even more interesting (but significantly more challenging, experimentaly)

Direct searches for WIMPs

- If WIMPs forming our Galactic halo is ~100 GeV:
  - >1000 WIMPs/m^3 in this room
  - v~200 km/s (typical): WIMP-nucleus collisions produce 10-50 keV nuclear recoils

$$E_{recoil} = E_{WIMP} \frac{4 M_{nucleus} M_{WIMP}}{(M_{nucleus} + M_{WIMP})^2} \cos^2 \theta_{recoil}$$



- If WIMP ~ SUSY neutralino (σ prediction):
  - as many as 1 WIMP-nucleus collision / kg / month (or as few as 1 / ton / year)
- Direct search: detect these energy deposits
- Main challenge: background from natural radioactivity (people = 10^{10} decay/kg/year)

Prediction uncertainties

- WIMP mass, scattering σ on nucleon: *Free parameters*
  - Limits set in the $\sigma_{SCATTERING}$ vs M_{WIMP} plane
- Scaling of σ from scattering on quarks to scattering on nucleus
  - Strangeness content of nucleon; nuclear form factors
  - *In most SUSY models, on A>20 nuclei, coherent Spin-Independent scattering dominates (rate/kg/d scales as A^3)*
- WIMP density (astrophysics: 0.2 to 0.4 GeV/cm^3)
- WIMP velocity: halo distribution
  - Central cusp? clumps? triaxial? caustics? tidal flows? Comoving?
  - *Direct search mostly sensitive to average v^2* (if not too clumpy)
- Use simple "Lewin and Smith" prescriptions [Astropart. Phys. **6**, 87 (1996).] for above parameters to compare experiments
  - But use caution when comparing expts with theoretical predictions

Comparing signals in direct searches

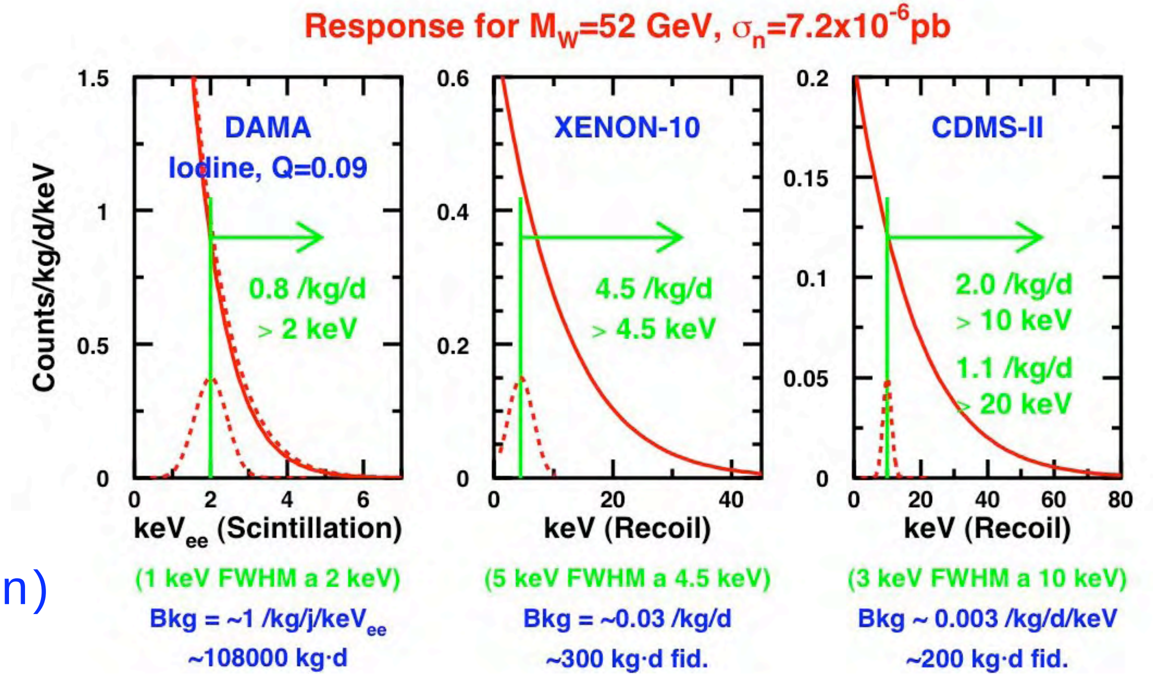
- Comparison well-defined within Lewin&Smith prescriptions
- Exponential-like spectrum in all detectors (except modulation)
- Low A or decrease from nuclear form factor can be compensated with low threshold or mass (or price)

What matters more:

- Background level

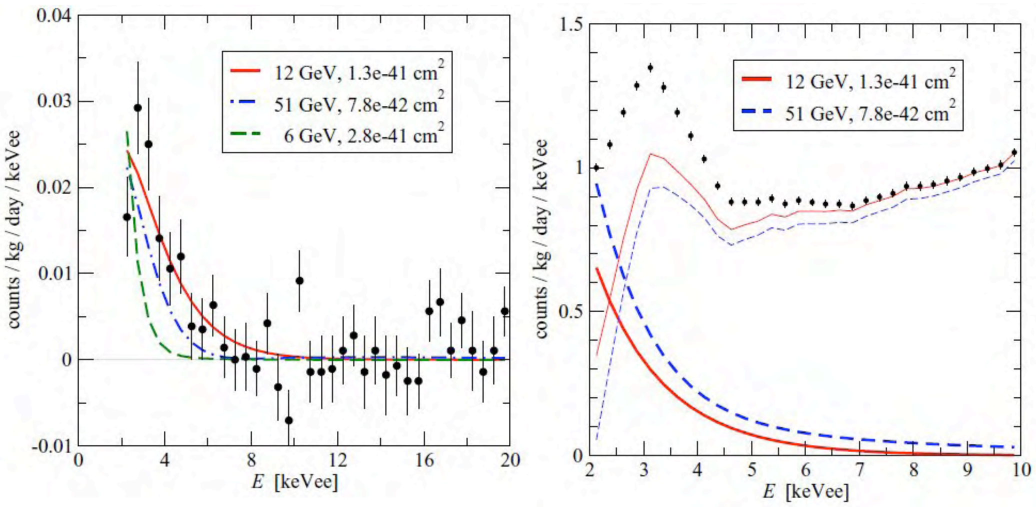
  radiopurity, shielding
- Threshold level
- Background shape

  (often poorly known)
- Resolution



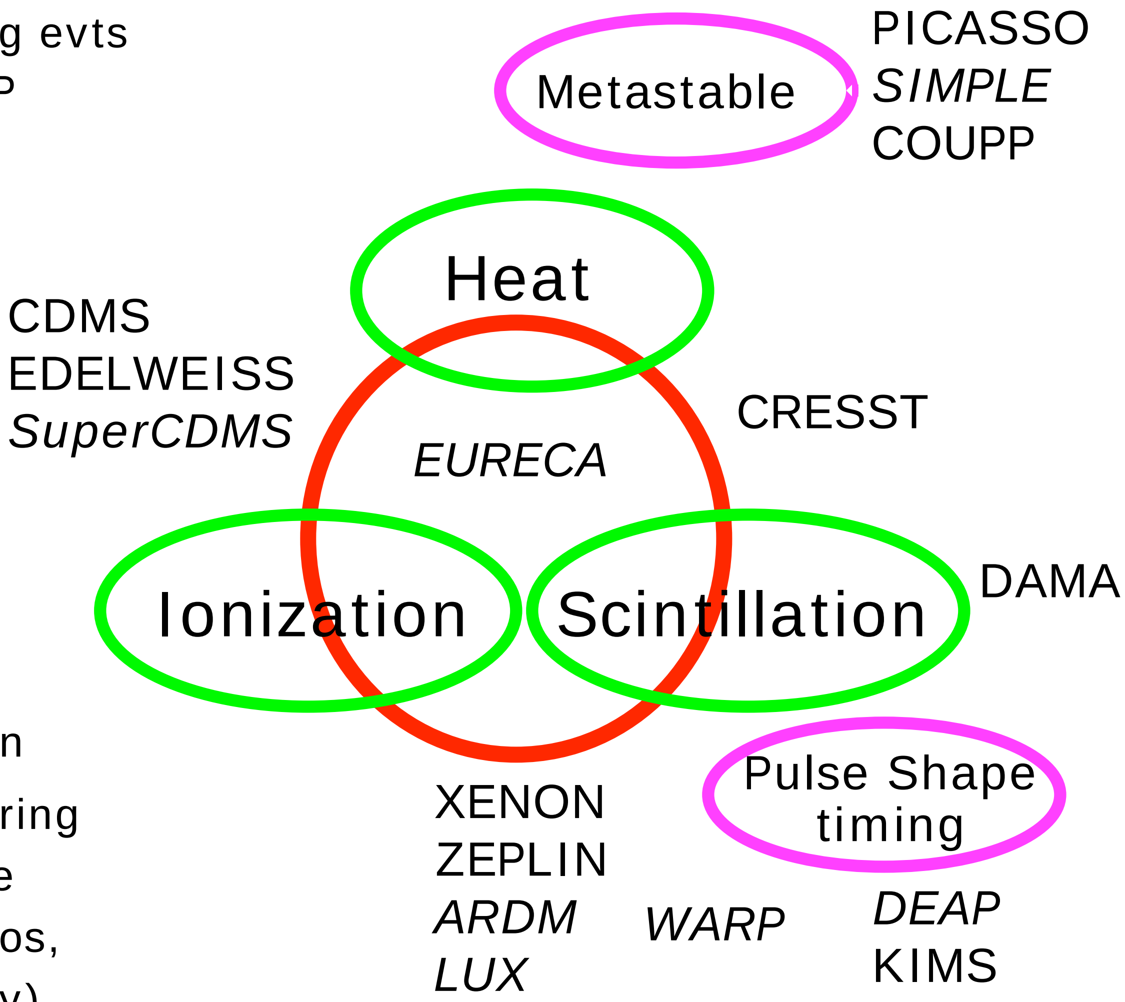
Background philosophy

- Difference with LEP/Tevatron/LHC physics: large uncertainties on backgrounds and on detector imperfection effects
  - Probing never-encountered before background levels
  - Very high rejections → detailed understanding of tails of distributions
- Strategy: as soon a background is “sufficiently” understood, it pays more to redesign and rebuild the detector to get rid of it
  - In collider physics, one would accumulate more background to get a better model and a better subtraction
- Nevertheless, we should bear in mind this often-asked question in collider physics: “What is your bkg model?”
  - Example: residual bkgs in expts in this review, see later
  - Example: DAMA non-modulating spectrum (see DAMA’s talk, or M. Fairbairn, hep-ph:0808.0704v2)



Searches techniques & bkg rejection

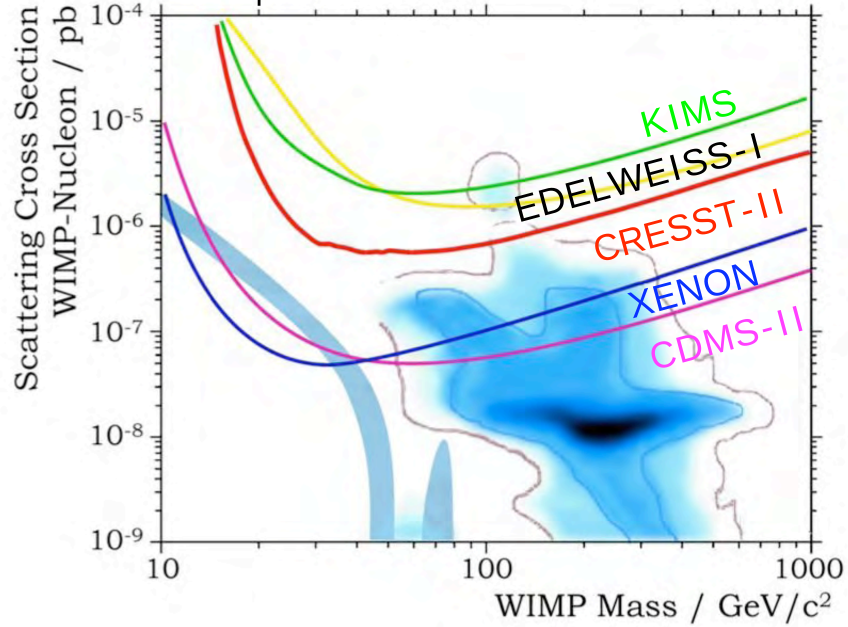
- Active rejection: most bkg evts are e^- recoils (γ, β); WIMP signal = nuclear recoil
- Large dE/dx, short track length (~10 nm in solid, directionnality difficult)
- Solid matrix directly excited: lower ionization and scintillation yields: combine 2 signals
- Pulse shape discrimination
- Beware of neutron scattering background (polyethylene shields, cosmic muon vetos, self-shielding / granularity)



Present limits

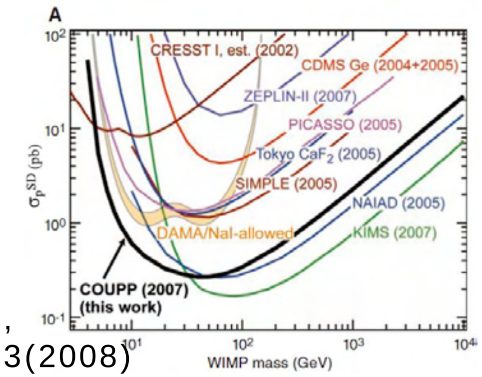
- Best present Spin-Independent limits:
  - CDMS-II (Ge cryo)
  - XENON (2-phase Xe)

astro-ph/08054705



- Other techniques compete for alternate models:
  - M<8 GeV, SI: CoGeNT
  - Spin-Dependent, pure-p: COUPP (M<30 GeV), KIMS (M>30 GeV) PRL99 091301 (2007)

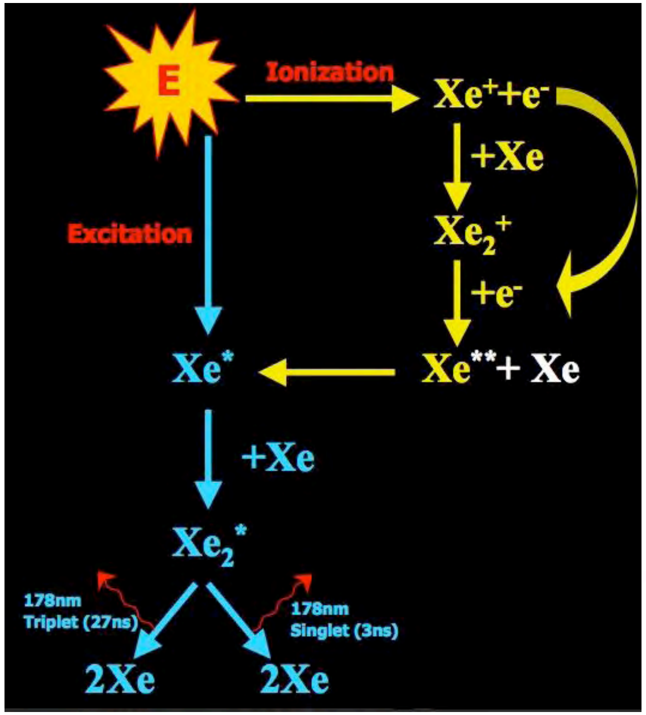
C.E.Aalseth,
arXiv: 0807.0879v4

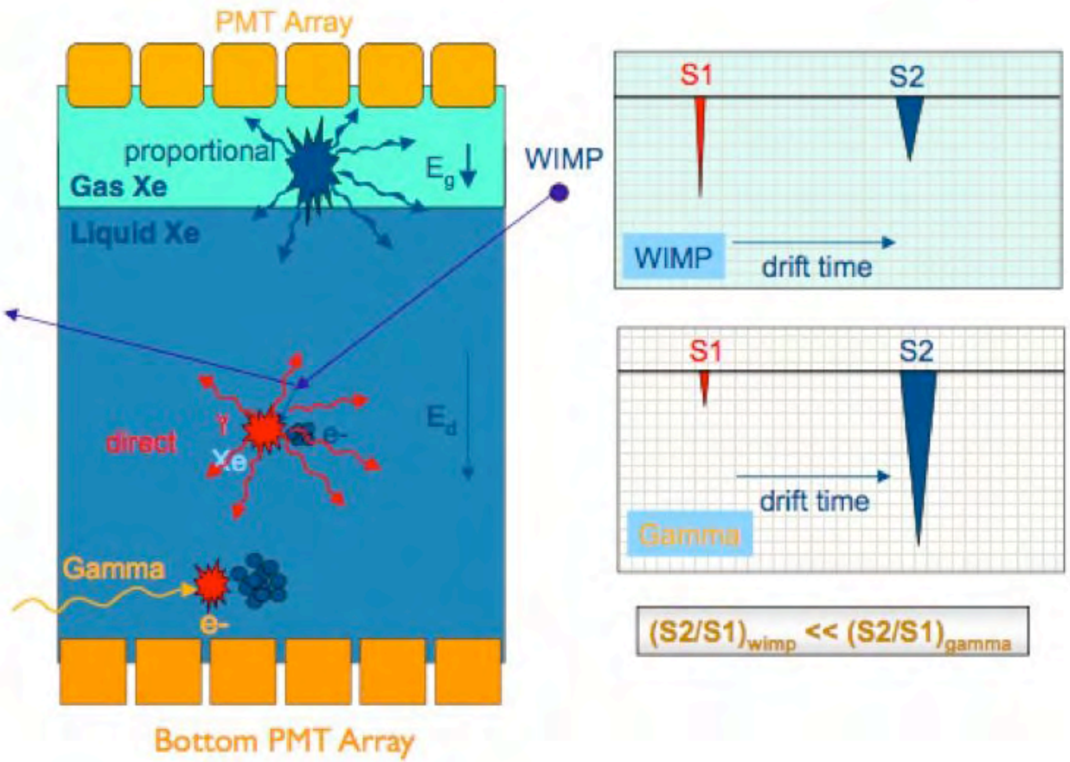


E.Behnke, et al.,
Science 319, 933(2008)

Two-Phase Xenon detectors

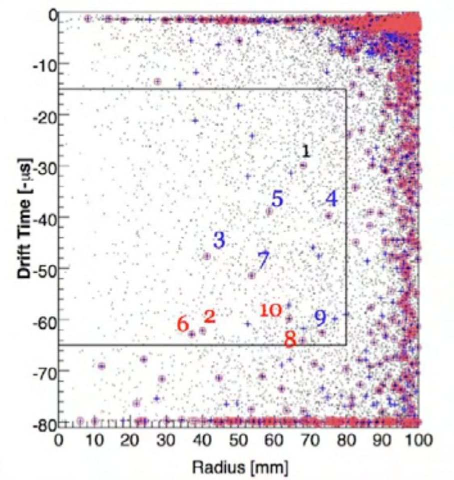
- Different scintillation (S1) and ionisation (S2) yields for nuclear and electronic recoils
- PMT array for (x,y), drift time for z : fiducial volume



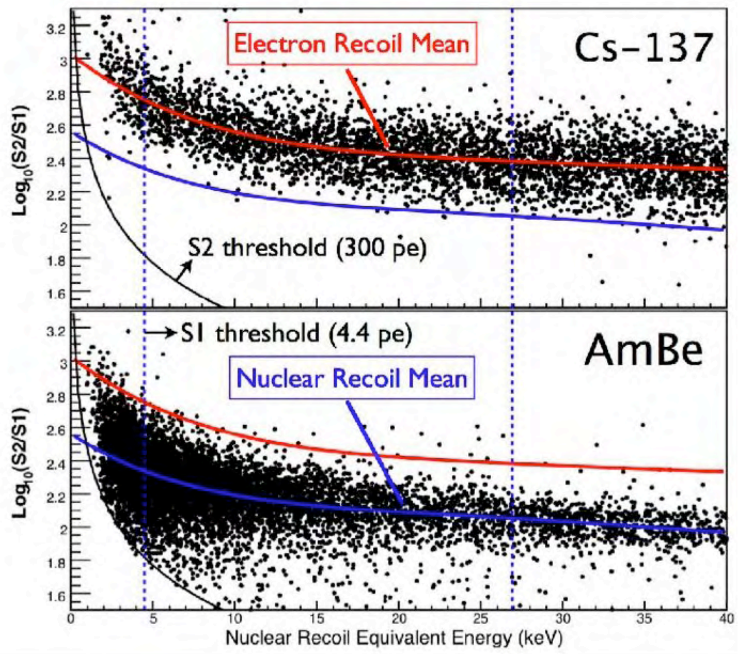


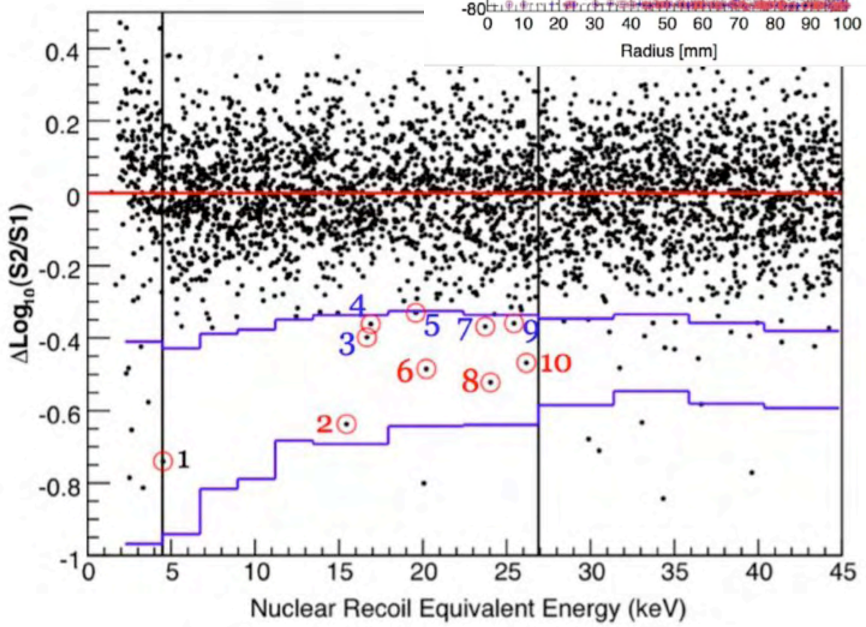
Xenon-10

- Large mass of Xe (10 kg) + purification
- Located at Gran Sasso
- 59 days x 5.4 kg fiducial
- ~ 10 evts (Compton?)



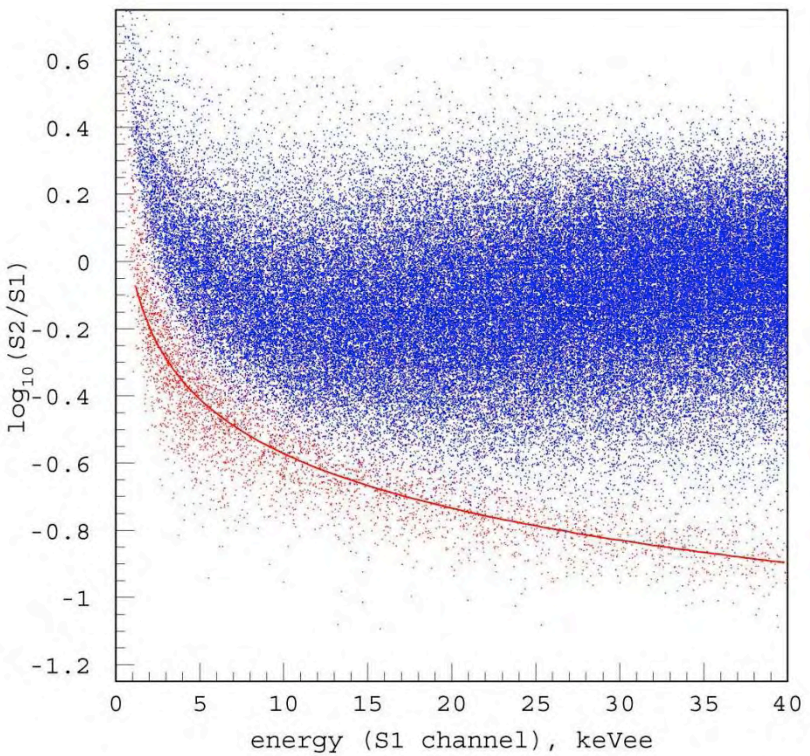
*J.Angle et al., PRL **100**, 021303(2008)*



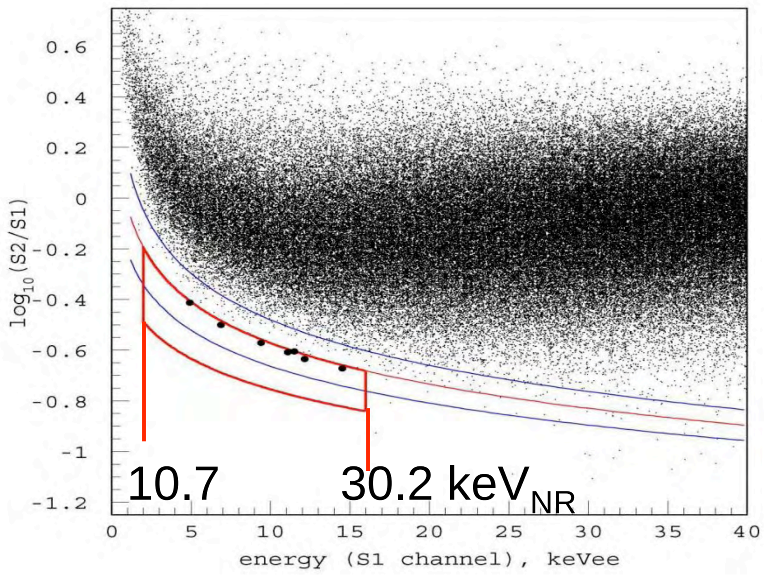


- ZEPLIN-III: two-phase Xe (Boulby mine)

V.N.Lebedenko, et al., arXiv: 0812.1150v1



127 kgd result

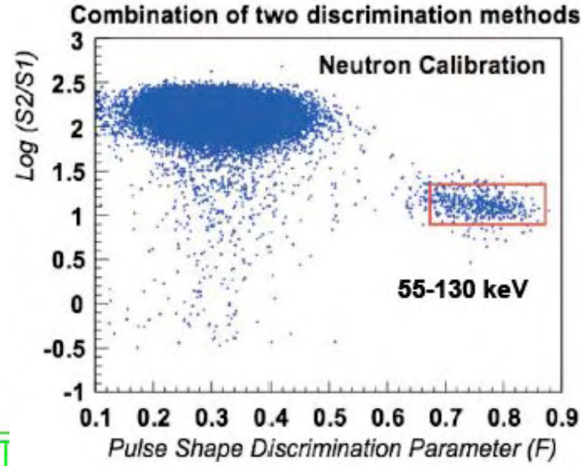


Xenon-100

- Evolution: larger, better design for "zero"-bkg (<~1 evt) goal
- (10 →) 170 kg LXe, (5 →) ~50 kg fiducial
- (89 →) 242 low-activity PMTs, (15 →) 30 cm drift

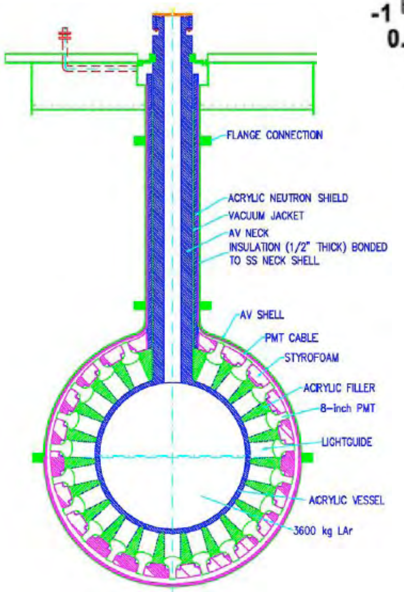
Liquid Argon

- Lower mass than Xe, but very efficient *pulse shape discrimination* (5ns vs 1μs)
- However, radioactive ^{39}Ar ~10^5kg/d



WARP

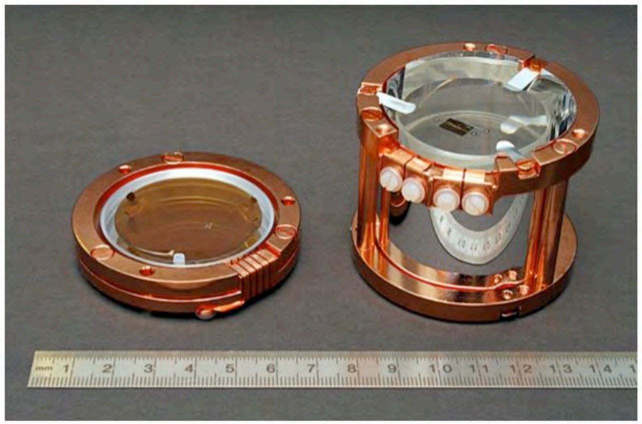
- WArP: 140 kg detector
- ArDM: 2 phase, goal = 1t
- DEAP/CLEAN: $6x10^{-8}$ PSD rejection with 7 kg prototype, 3.6 t goal

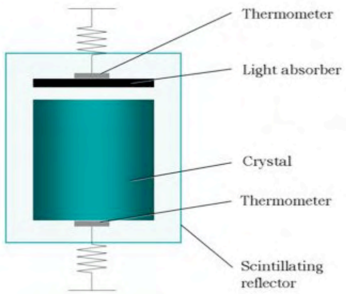


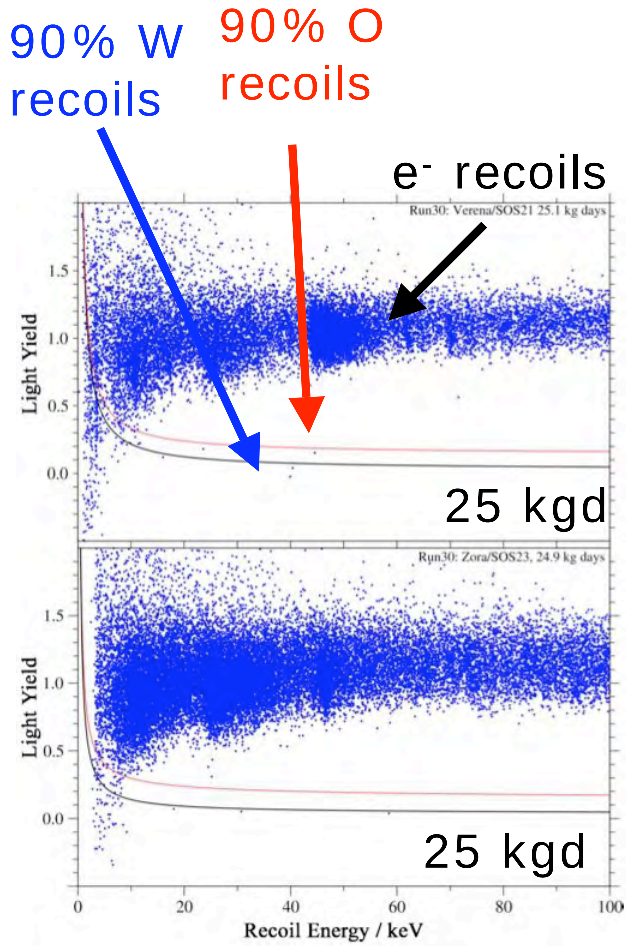
DEAP/CLEAN

CRESST: Scintillation vs heat

- 17 x 300 g modules installed in Gran Sasso
- W films: Superconducting Transition Edge temperature sensors + SQUID read-out
- Absorber: $CaWO_4$ cristal (Wimps = W recoils, neutrons = O, Ca recoils)



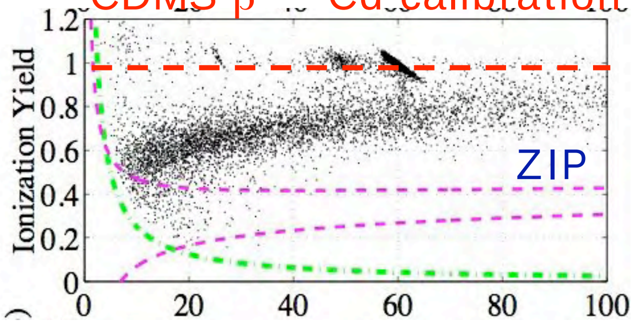




Cryogenic Germanium detectors

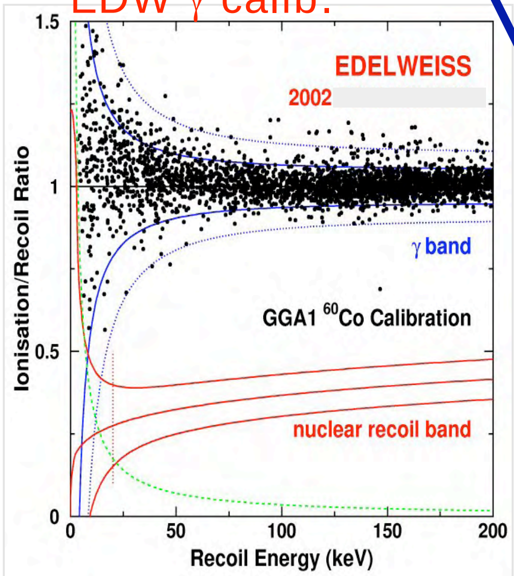
- Ge: Very pure material
- True calorimetric measurement of recoil energy using very-low temperature sensors
- Potential limitation: *deficient charge collection (mostly surface β's)*

CDMS β ^{109}Cd calibration

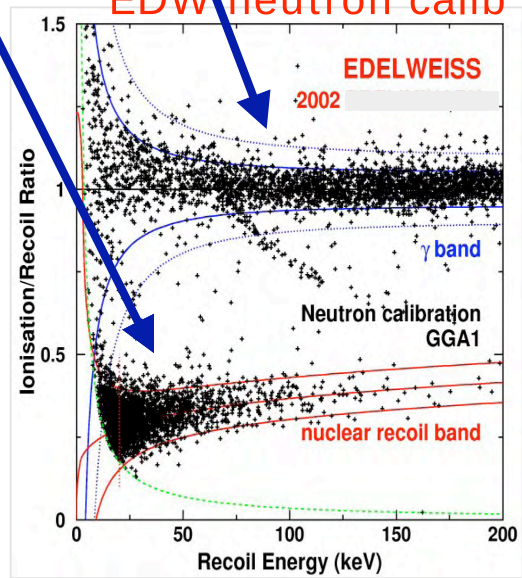


- Different ionization yields for nuclear recoils (WIMP or neutron scattering) and e^- recoils (β,γ)
  - discrimination of dominant background

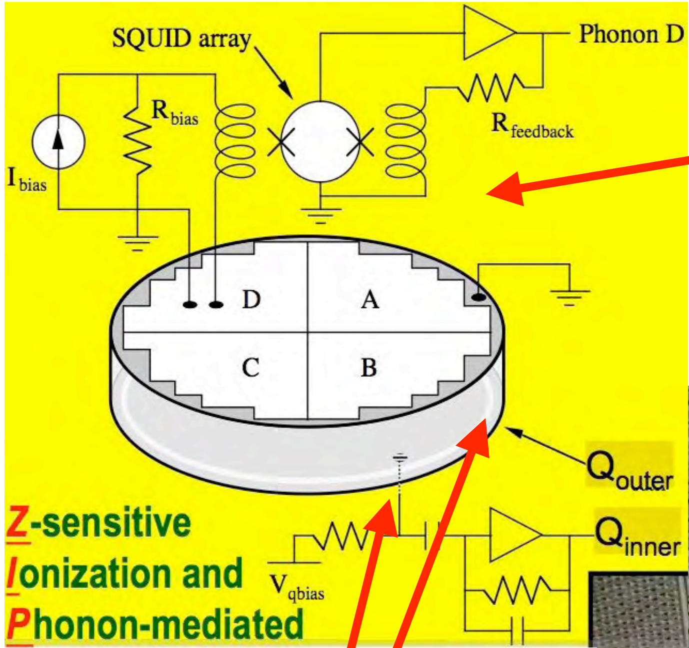
EDW γ calib.



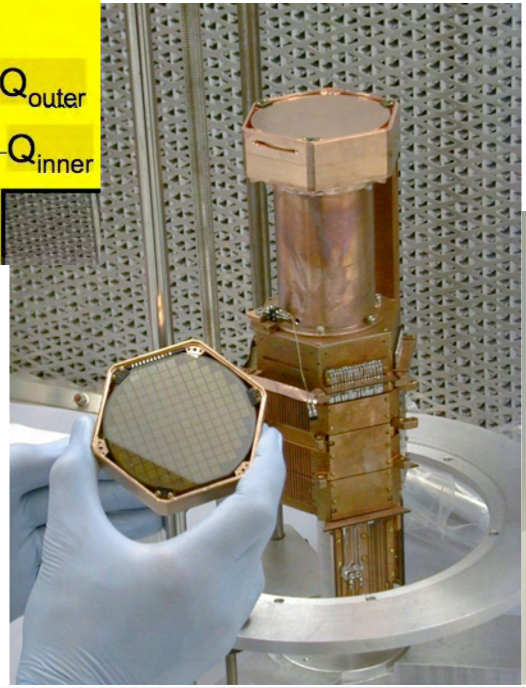
EDW neutron calib

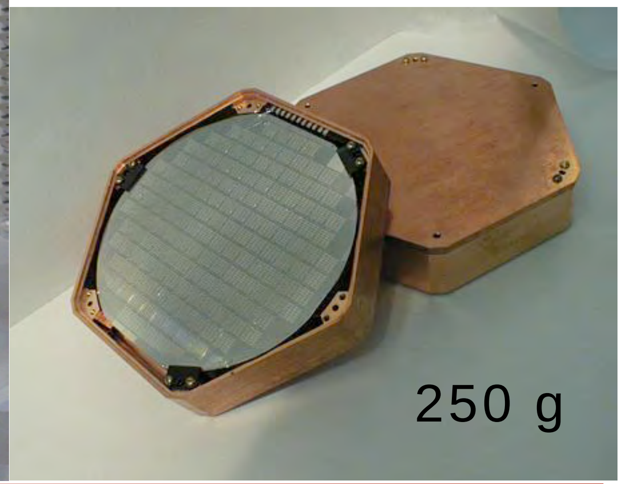


CDMS Ge detectors



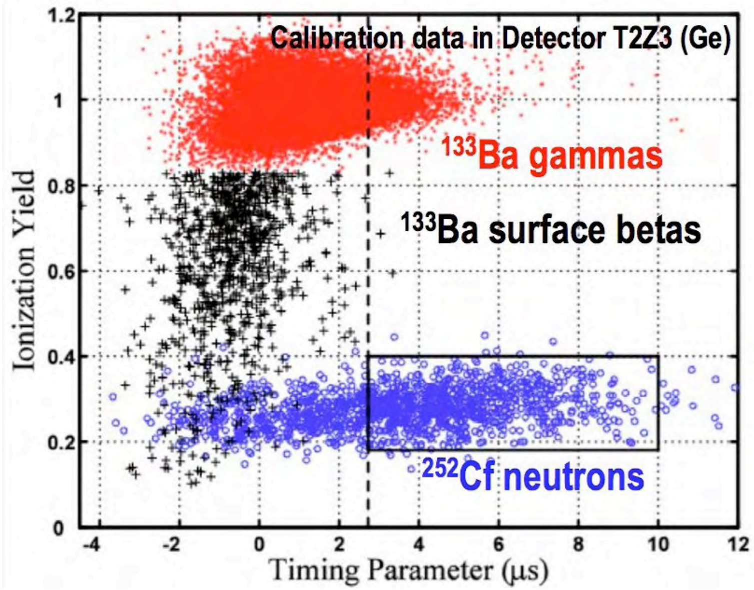
- Athermal phonon measurement with 4 quadrants of ~1000 transition-edge W sensors
  - Phonon risetime and delay wrt ionization: detects proximity from surface ("Z")
- Charge measurements: centre and guard ring

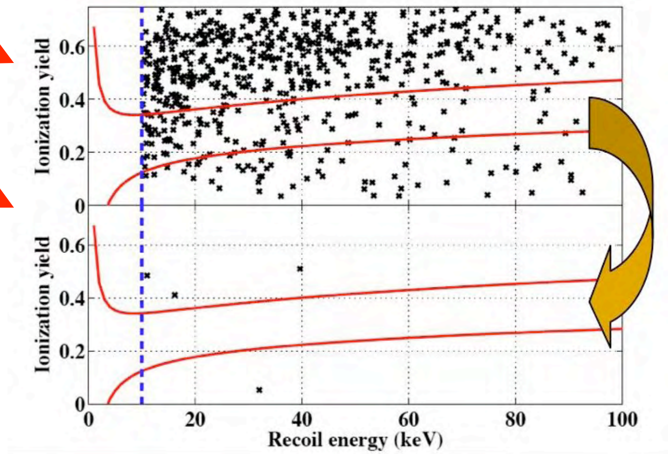




CDMS data

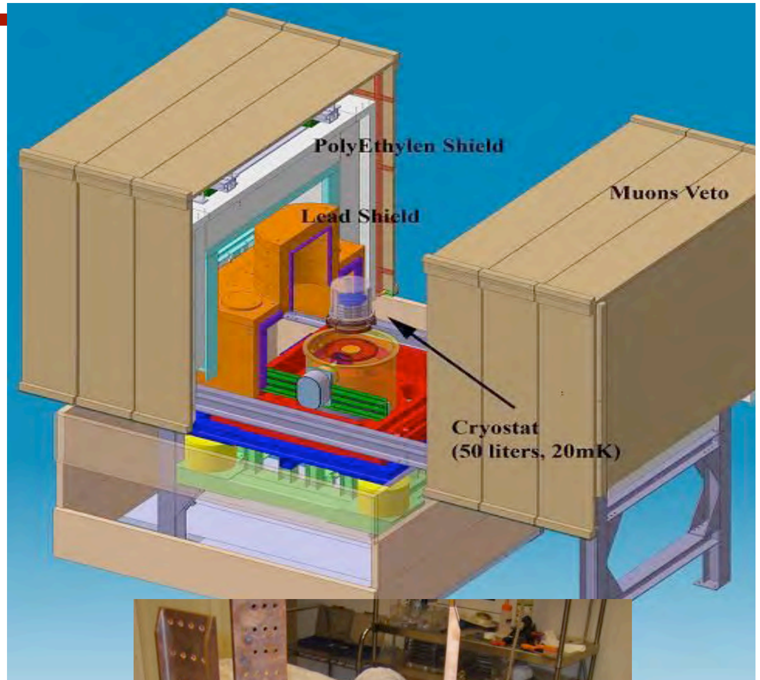
- Surface e^- rejected via ionization yield + phonon timing cuts
  - Phonon risetime + delay wrt ionisation
  - Single film can veto both surfaces
- 2008: 1000 kg.d raw data with 15x250g Ge, 650 kg.d analyzed; 121 kg.d after quality, fiducial, acceptance cuts.
- 97 evts in nuclear recoil band before timing cut, 0 evts after
  - Expected 0.6 +- 0.3 from surf. e^- leakage
- Best limit M_W>50 GeV
- Data taking going on, cuts improved to reduce expected bkg
- Preparing for a 25 kg stage (superCDMS); then ton-scale





EDELWEISS-II Goals

- ... improve on EDELWEISS-I (2002)
- Goal: 10^{-8}pb, <0.003 evts/kg/d
- 5 kg Ge, can host up to 40 kg
- Installed at LSM in Frejus Tunnel (Deeper site than CDMS)
- Neutron shield designed for $<10^{-8}$pb
  - U/Th in rock: 50cm polyethylene, solid angle
  - μ in Pb shield/ in rock: μ veto
- Strict control of backgrounds
  - Material selection / Cleaning procedure / Environment
- Surface events rejection
  - Develop new detectors (ID)

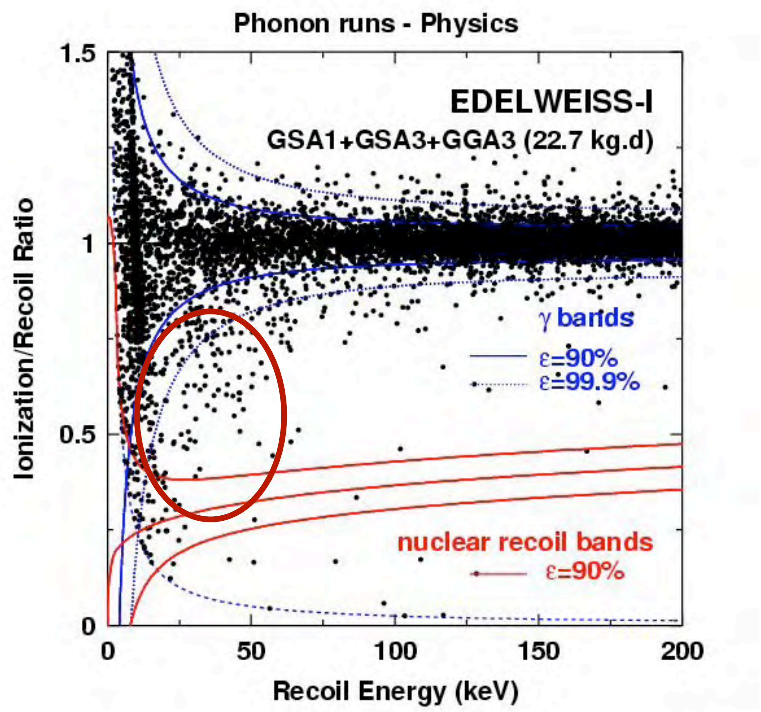


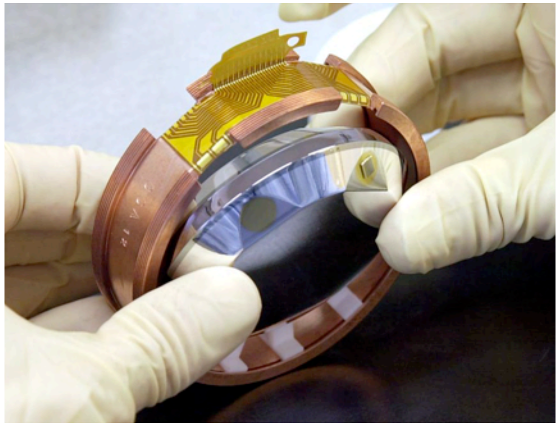
EDELWEISS detectors

- EDELWEISS-I

  Simple design:

  - 1 NTD heat sensor
  - 1 centre electrode
  - 1 guard ring
  - Limitation: surface events





Not sufficient to reach 10^{-8}pb

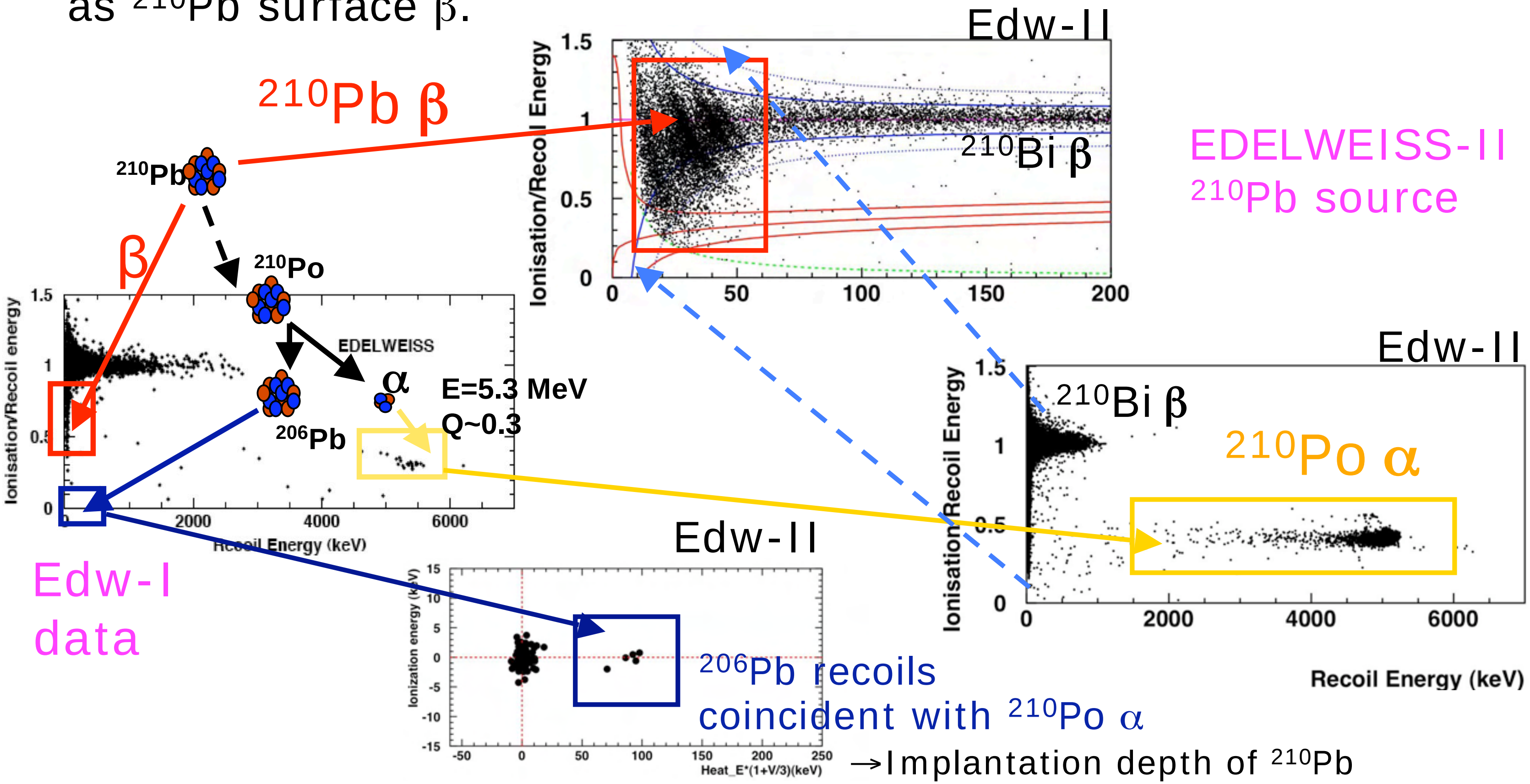
Need ~2500 kgd at 15 keV threshold

Need ~10^4 rejection for gammas

Need to reject expected ~5000 β from ^{210}Pb

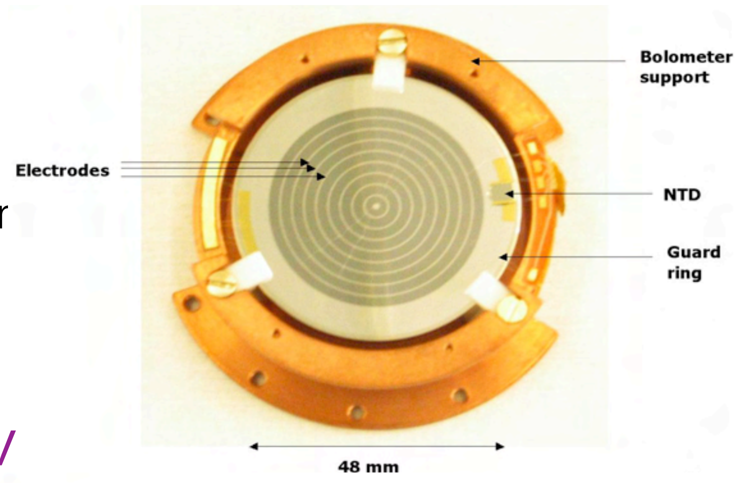
EDELWEISS-II ^{210}Pb source calibration

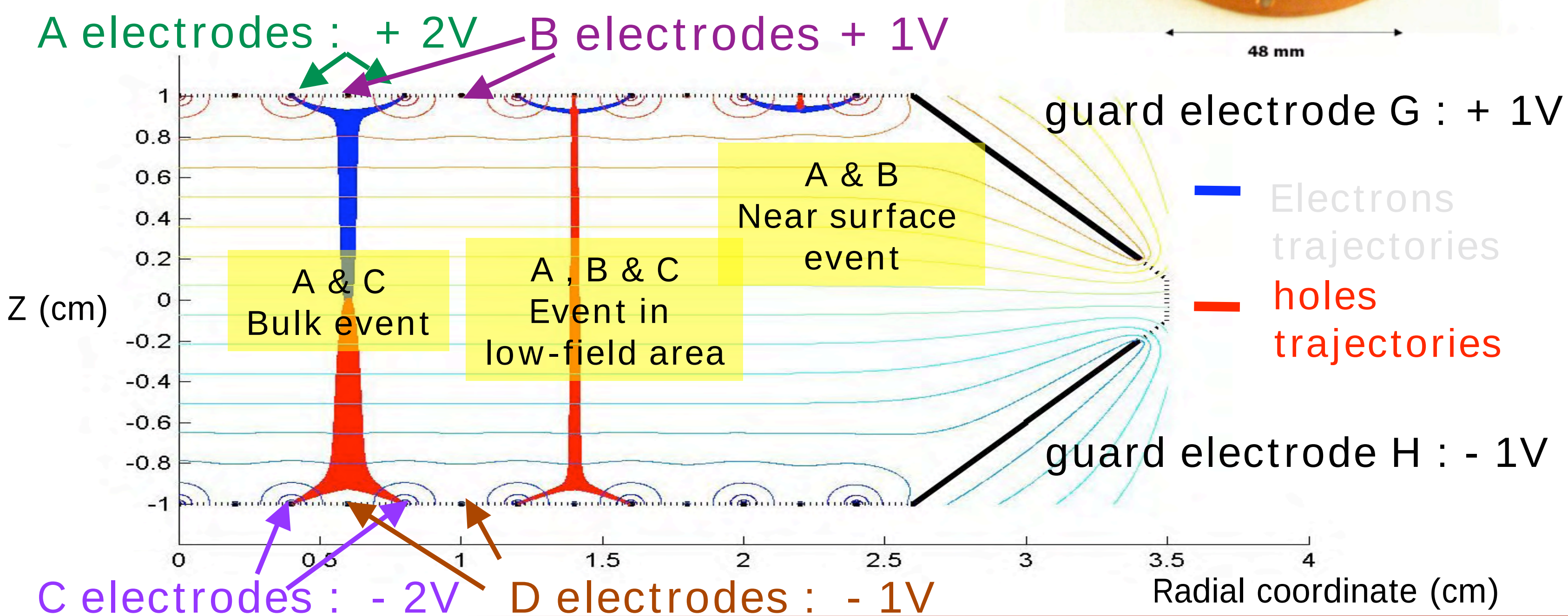
- Response of detectors to this important background
- Detailed in-situ spectroscopy confirms interpretation of main bkg as ^{210}Pb surface β.



EDELWEISS: InterDigit Detectors

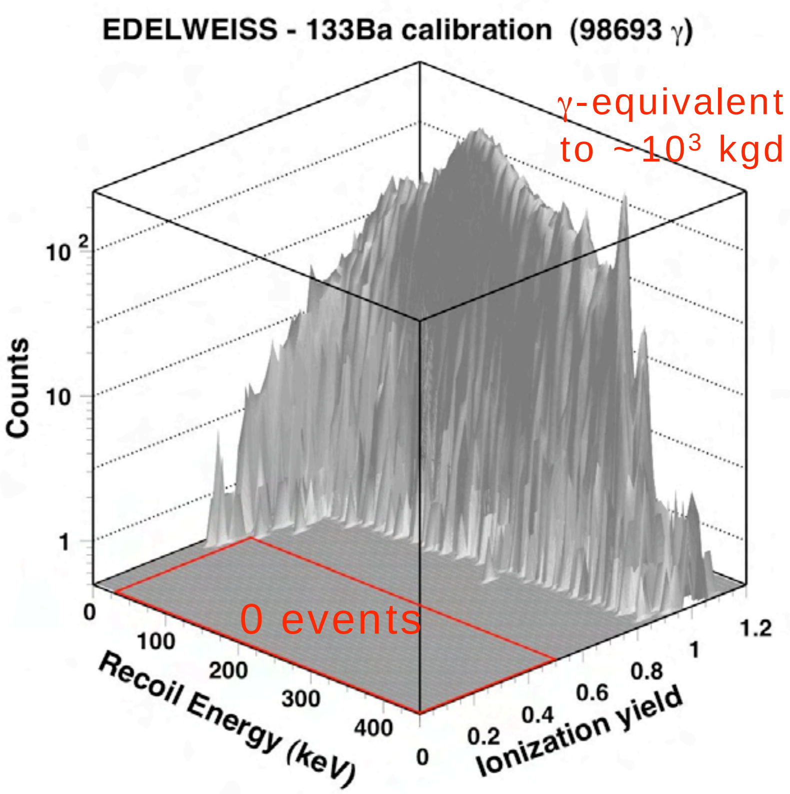
- GeNTD heat sensor
- E-field modified near surface with interleaved electrodes
- B + D signals = vetos against surface ever
- 1x200g and 3x400g tested in 2008
- 10x400 g in operation in 2009



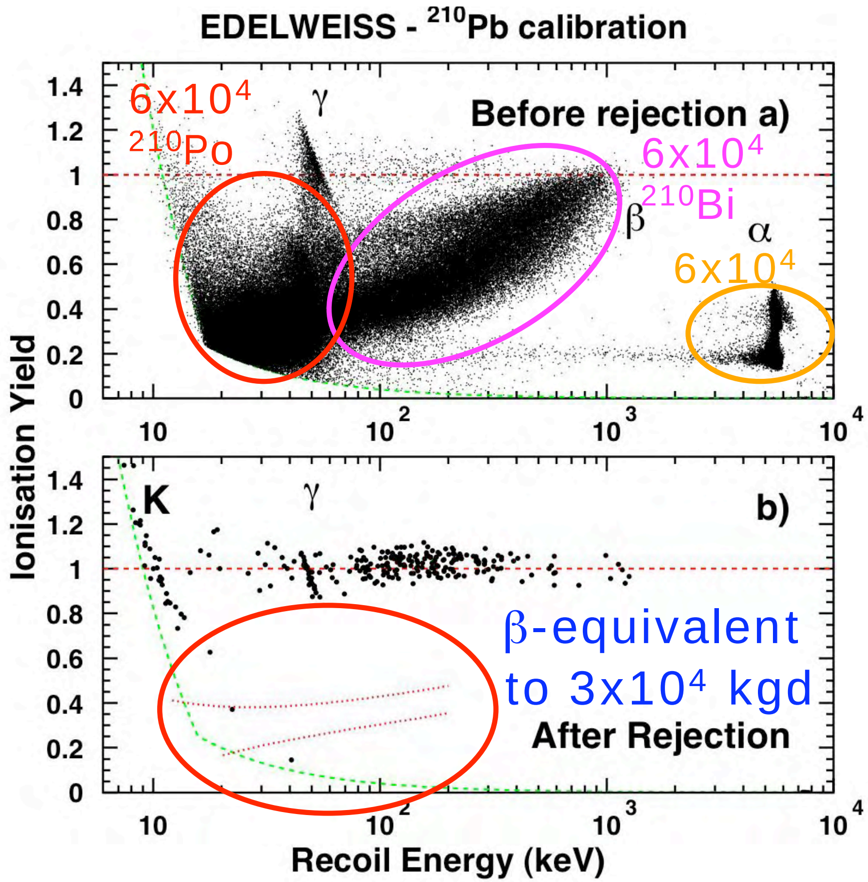


ID detector rejection

- Gamma rejection of 400g
  - ~1 month calibrations

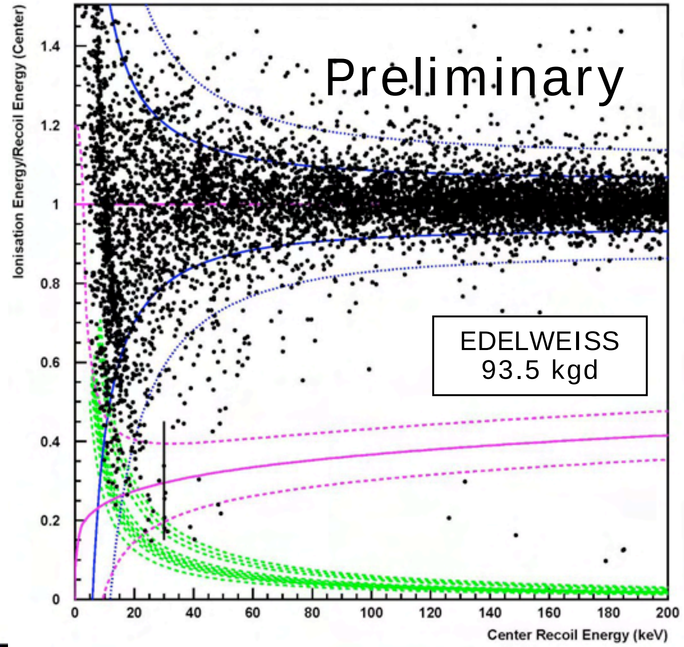


- ^{210}Pb β rejection of 200g

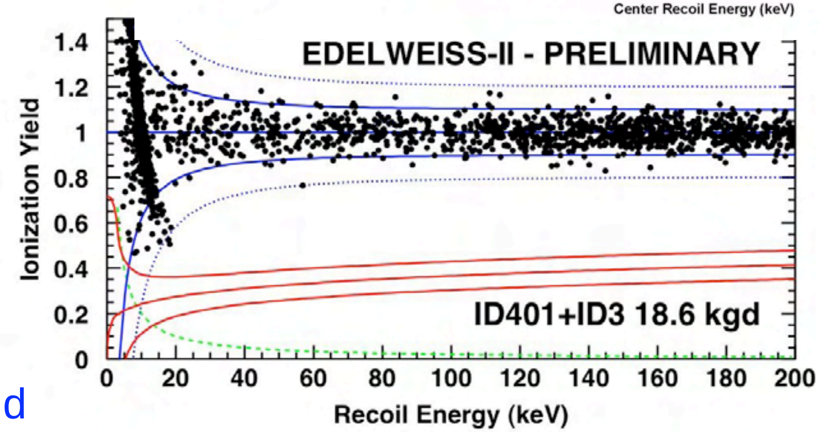


New physics run with GeNTD

- 23 detectors installed
- Understandig bkgs in new environment
- 11 detectors with <30 keV thresholds: NEW GeNTD 08 DATA: 93.6 kgd / 4 mo.
  - Threshold chosen before start of run (Expected β bkg based on EDW-I results)
- 3 events in nuclear recoil band
- *Bkg reduced wrt EDELWEISS-I, but not sufficient to reach 10^{-8} pb: need ID*

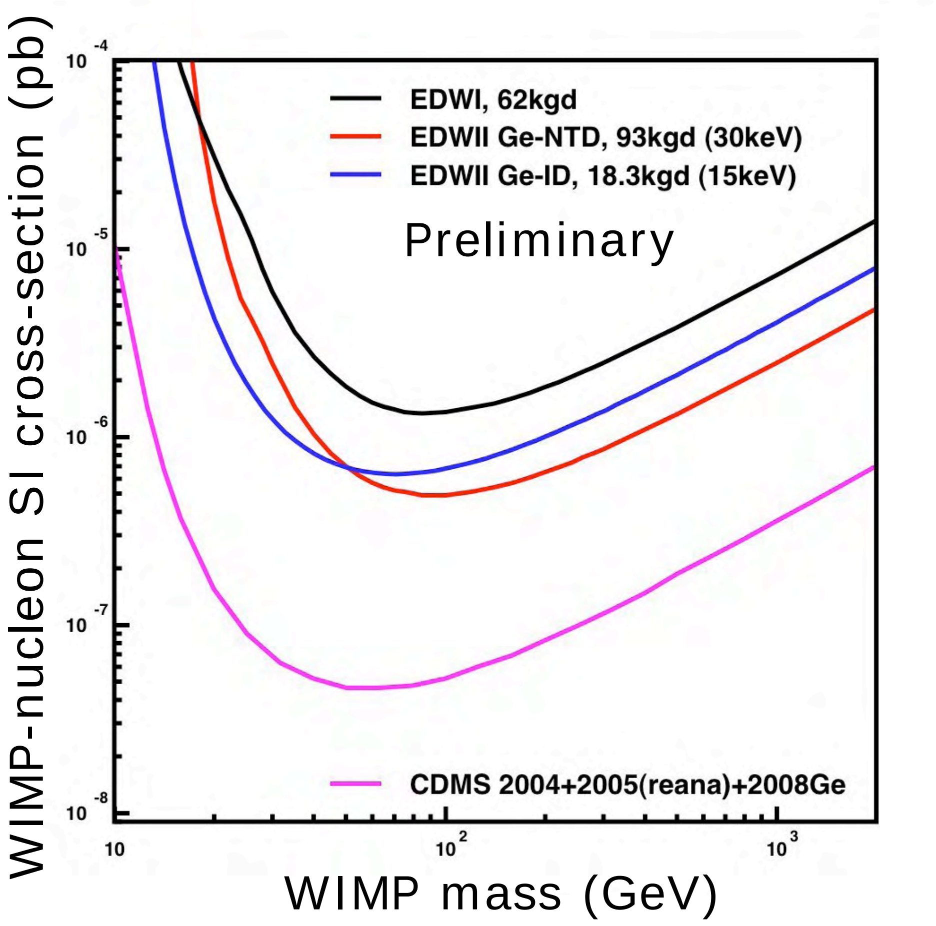


- NEW ID 08 DATA: 2 x 400g
  - 86 live days / 4 mo.
- 18.3 kgd with <15 keV threshold
- 50% efficiency at 10 keV
- No evts in *(or around)* nucl. recoil band



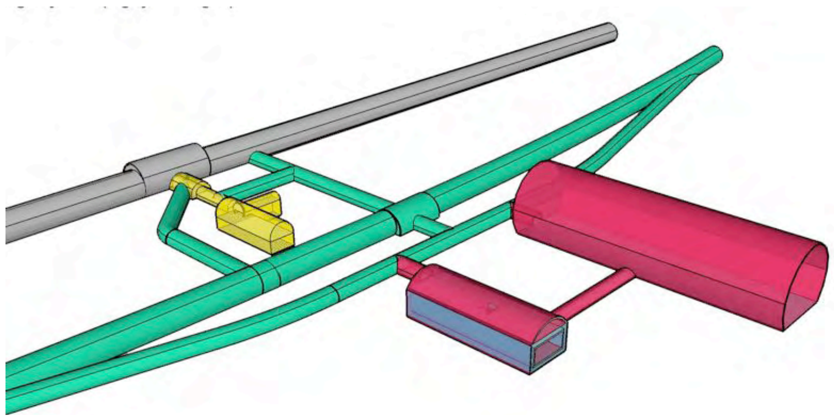
Limits with GeNTD and ID detectors

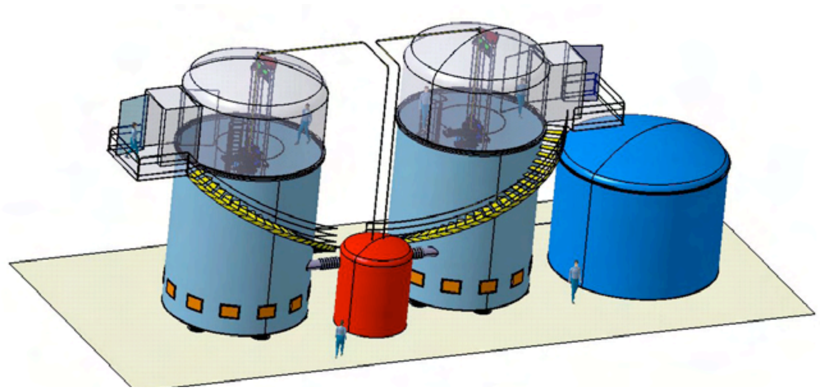
- 93.5 kgd GeNTD
  - 11 detectors x 4 months
  - 30 keV threshold
  - 3 evts in nuclear recoil band
- 18.6 kgd ID
  - 2 detectors x 4 months
  - 15 keV threshold
  - No nuclear recoils
  - No evts outside γ band
- Jan. 2009: 10 ID detectors
  - x 20 improvement in 8 months: 4×10^{-8} pb
  - More detectors build in 2009, w increased fiducial volume



Future: EURECA

- EURECA: beyond 10^{-9} pb, major efforts in background control and detector development
- Joint effort from teams from EDELWEISS, CRESST, ROSEBUD, CERN, +others...
- >>100 kg cryogenic experiment, multi-target
- Part of ILIAS/ASPERA European Roadmap
- Prefered site: 60 000 m^2 extension of present LSM (4 μ /m^2/d), to be dig in 2011-2012





Conclusions

- Serious competition between present leaders
  - Two-phase Xe offers large mass (but sees background)
  - Cryo Ge has better resolution and rejection (but can it scale up quickly and cheaply?)
- CDMS, EDELWEISS aiming at 2×10^{-8}pb within year + gradual increase; Xe/Ar projects to go to larger masses
- Questions for 1-ton being addressed
  - Xe/Ar: bkg/limitations of larger-size detector?
  - Ge/Cryo: price per unit? Optimal detector size?
  - All: Undiscovered problems arising with 25-100 kg stages?
- Other techniques to complete the palette of targets & investigated physics models