First results of the EDELWEISS-II Direct Dark Matter search experiment.

- Dark Matter enigma
- EDELWEISS-II experiment
- Ge-NTD Data analysis and interpretation
  - *Radioactive background understanding*
  - *WIMP search*
- New ID-detectors
  - *First results*
- Perspectives

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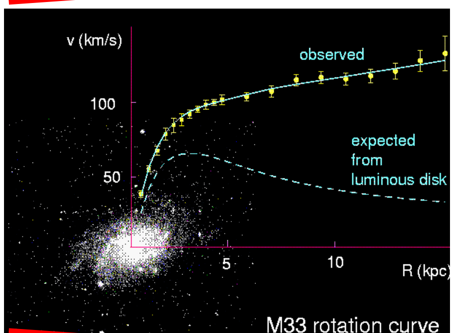
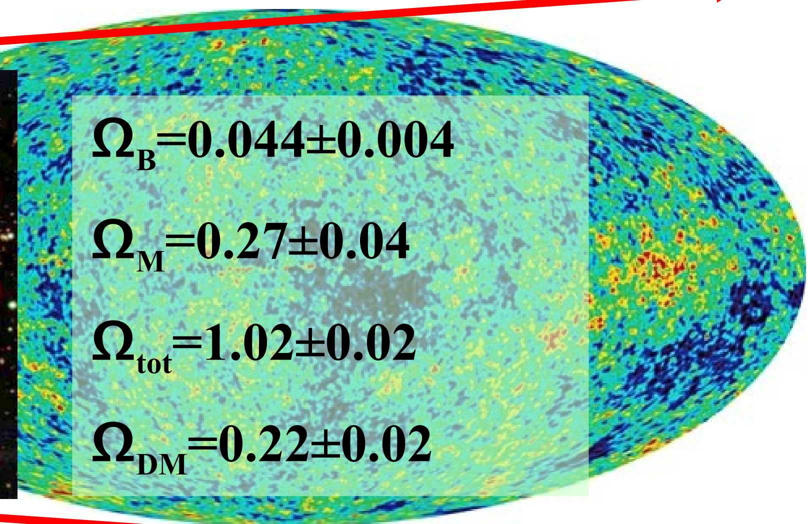
DM search motivations

CDM present at all scales in the Universe…



Galaxy

Clusters



$\Omega_B=0.044\pm0.004$

$\Omega_M=0.27\pm0.04$

$\Omega_{tot}=1.02\pm0.02$

$\Omega_{DM}=0.22\pm0.02$

Cosmology

DM searches justified : direct (DM elastic scattering off target nuclei) and indirect (DM annihilation signal in galactic halo)

→ not enough to identify DM nature

… and soon, maybe also at LHC (natural candidates arise from New Physics scenarii, such as SUSY)

→ no direct cosmological test (relic abundance or stability)

WIMP dark matter (particles)

WEAKLY INTERACTING MASSIVE PARTICLE

- ✓ Neutral and weakly interactions:

  neither strong nor electromagnetic

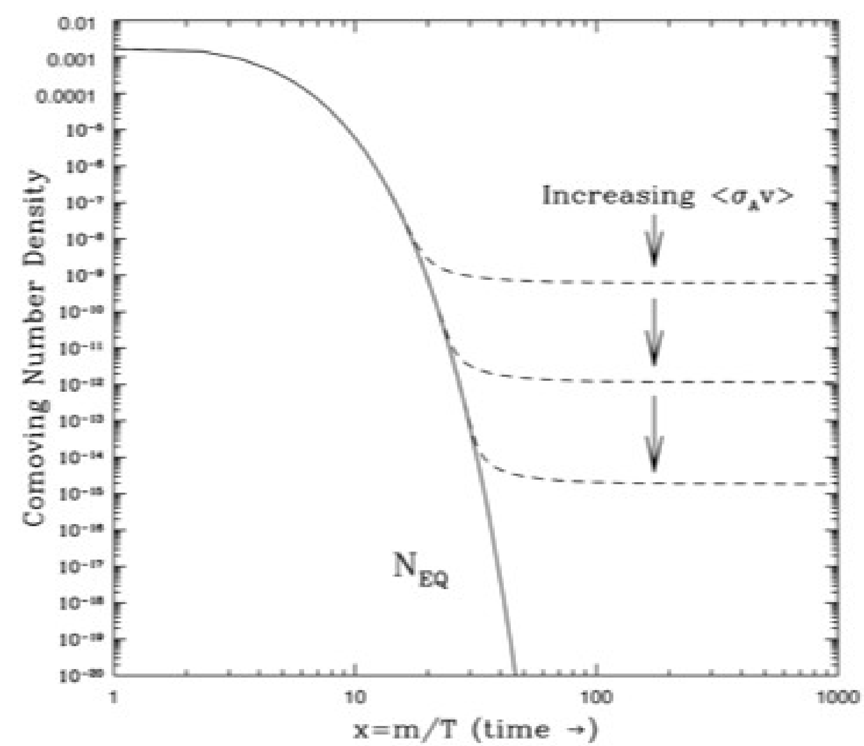
  → DM does not collapse to the center of the galaxy

- ✓ Cold enough (non-relativistic) at decoupling era

- ✓ Stable at cosmological scale

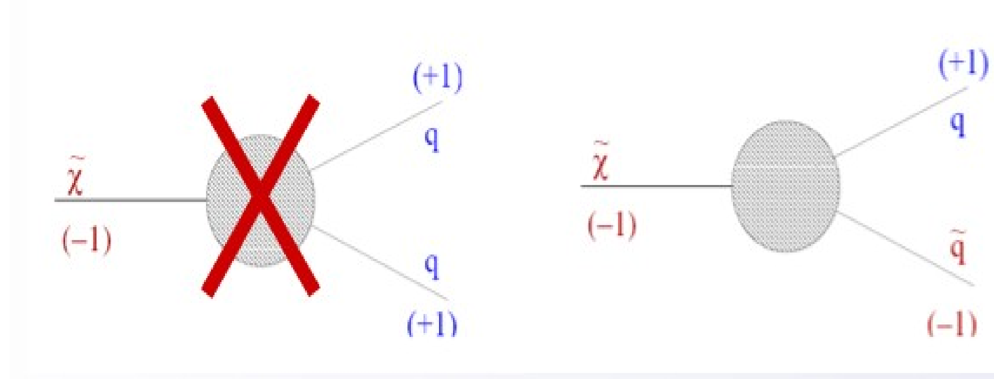
- ✓ Relic present today

  → explanation of Ω_m

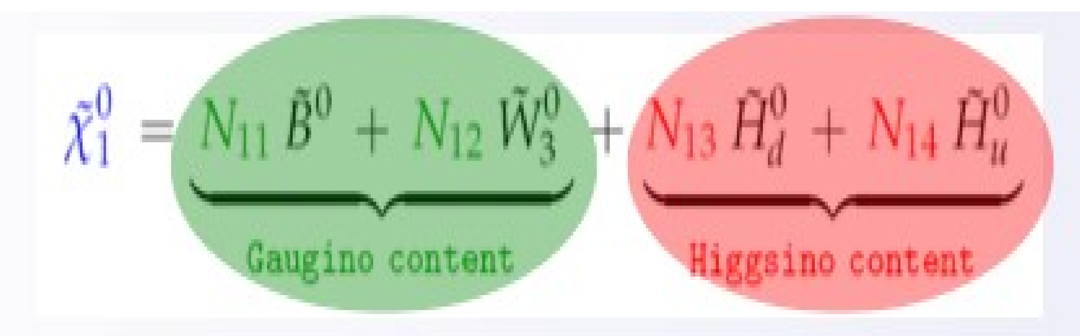


SUSY naturally "predicts" WIMP DM

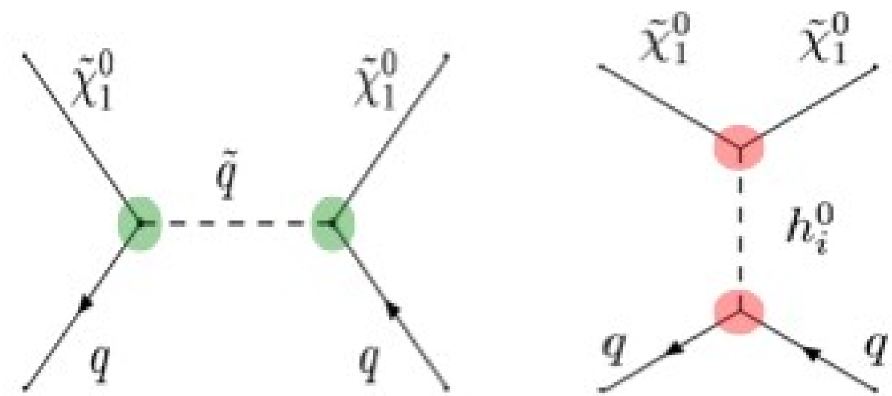
R-parity conserved → LSP stable
(particle : R=+1; sparticle : R=-1)



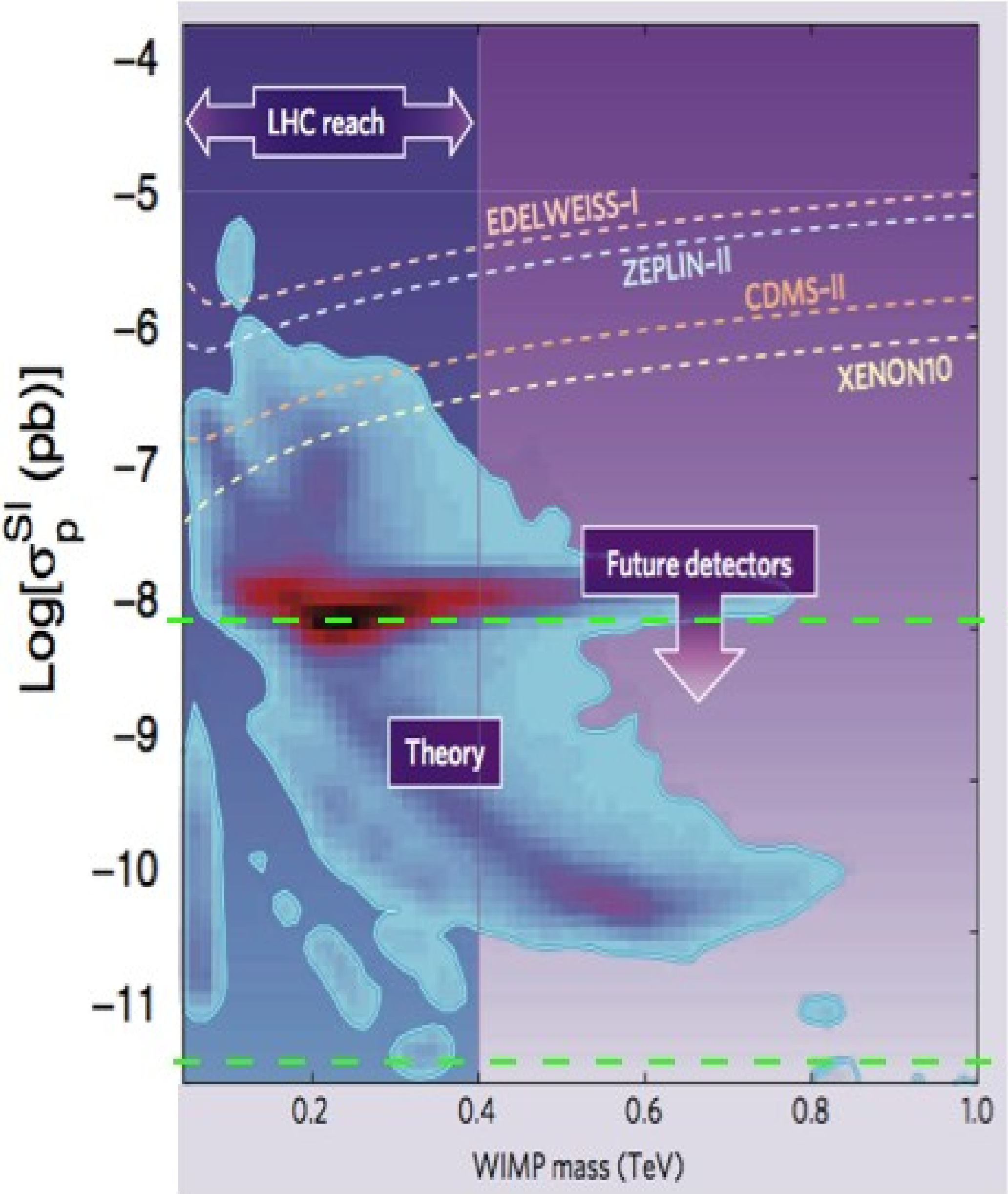
NEUTRALINO



Spin-Independent Diagrams



Interaction cross section: 10^{-11} - 10^{-5} pb
Mass: 40 GeV/c² - 1 TeV/c²



L.Baudis ENTApP DARK MATTER 2009

Theory example: CMSSM (Roszkowski, Ruiz, Trotta)
see also: Balz, Baer, Bednyakov, Bottino, Cirelli, Chattopadhyay, Ellis, Fornengo, Giudice, Gondolo, Massiero, Olive, Profumo, Santoso, Spanos, Strumia, Tata,...+ many others

1 event/kg/yr

sensitivity of existing experiments:
CDMS-II, XENON100, ArDM, COUPP, CRESST-II, EDELWEISS-II, ZEPLIN-III,...

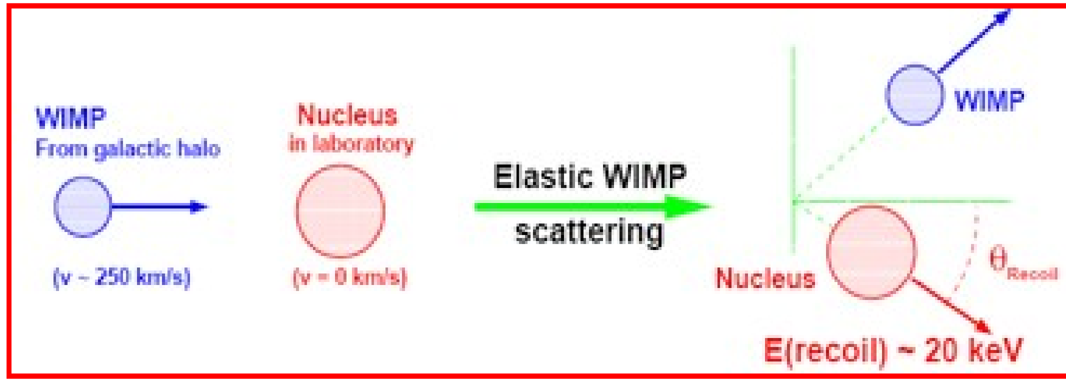
1 event/t/yr

sensitivity of near-future projects
SuperCDMS1t, WARP1t, ArDM
XENON1t, EURECA, XMASS, ...

10^{-8} pb: direct dark matter searches "focus point"
→ Cosmological test + SUSY

Direct search for WIMPs

Detection of the energy deposited due to **elastic scattering** off target nuclei



Interaction rate:

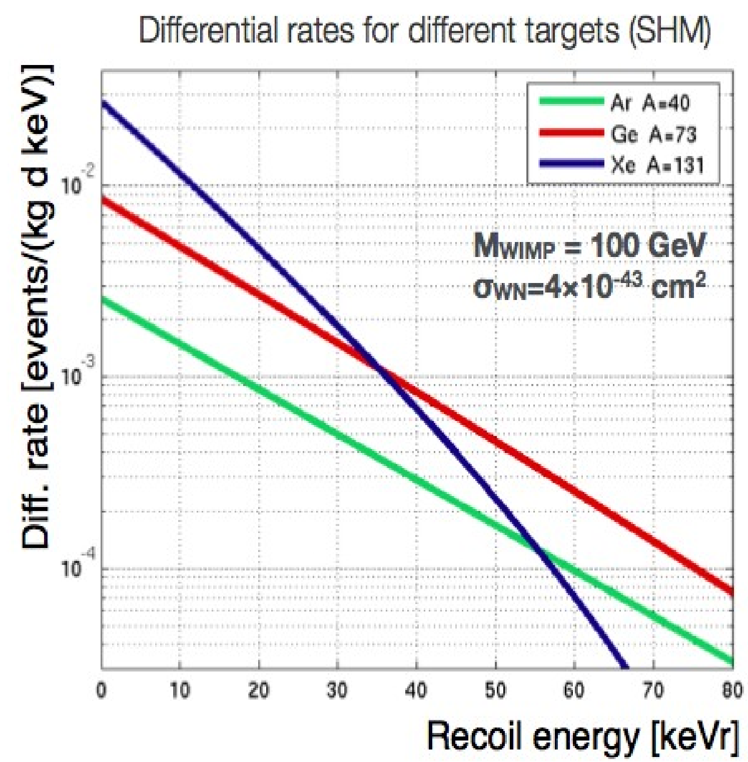
$$R \propto N \frac{\rho_W}{m_W} \sigma_{W-N} \cdot \langle v \rangle$$

Astrophysics

Particle physics

- Integrate over WIMP velocity (assumed to be 1D Maxwellian→ good approximation for isothermal halo)
- for a WIMP-nucleon cross section < 10^{-7}pb

< 1 event/100kg/day



Experimental constraints

WIMP ~ Neutralino SUSY

(prediction : elastic σ)

→ ~ 1 collision WIMP-n/kg/month

(up to 1 evt / ton / y)

Masse WIMP ~ 100 GeV

(prediction : recoil energy deposit)

→ < 50 keV nuclear recoil

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

Main Challenges

- **Low energy threshold**
- **Large detector mass**
- **Low background**

  Radio – purity

  Active/passive shielding

  Deep underground sites

Searches techniques & bkg rejection

BACKGROUND REJECTION:

- Dominant background: electron recoil

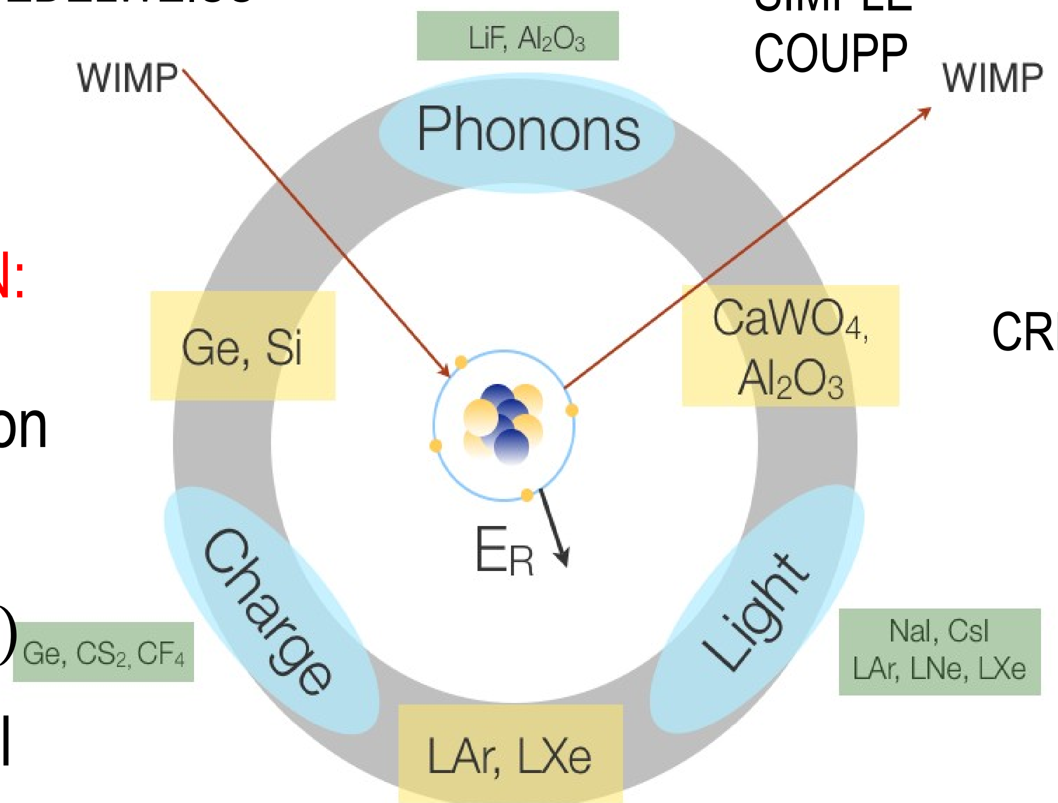
  (→ γ, α and β particles)

- WIMP signal = nuclear recoil

- Beware of neutron scattering background (polyethylene shields and cosmic muon vetos)

CDMS
EDELWEISS

PICASSO
SIMPLE
COUPP



CRESST

DAMA

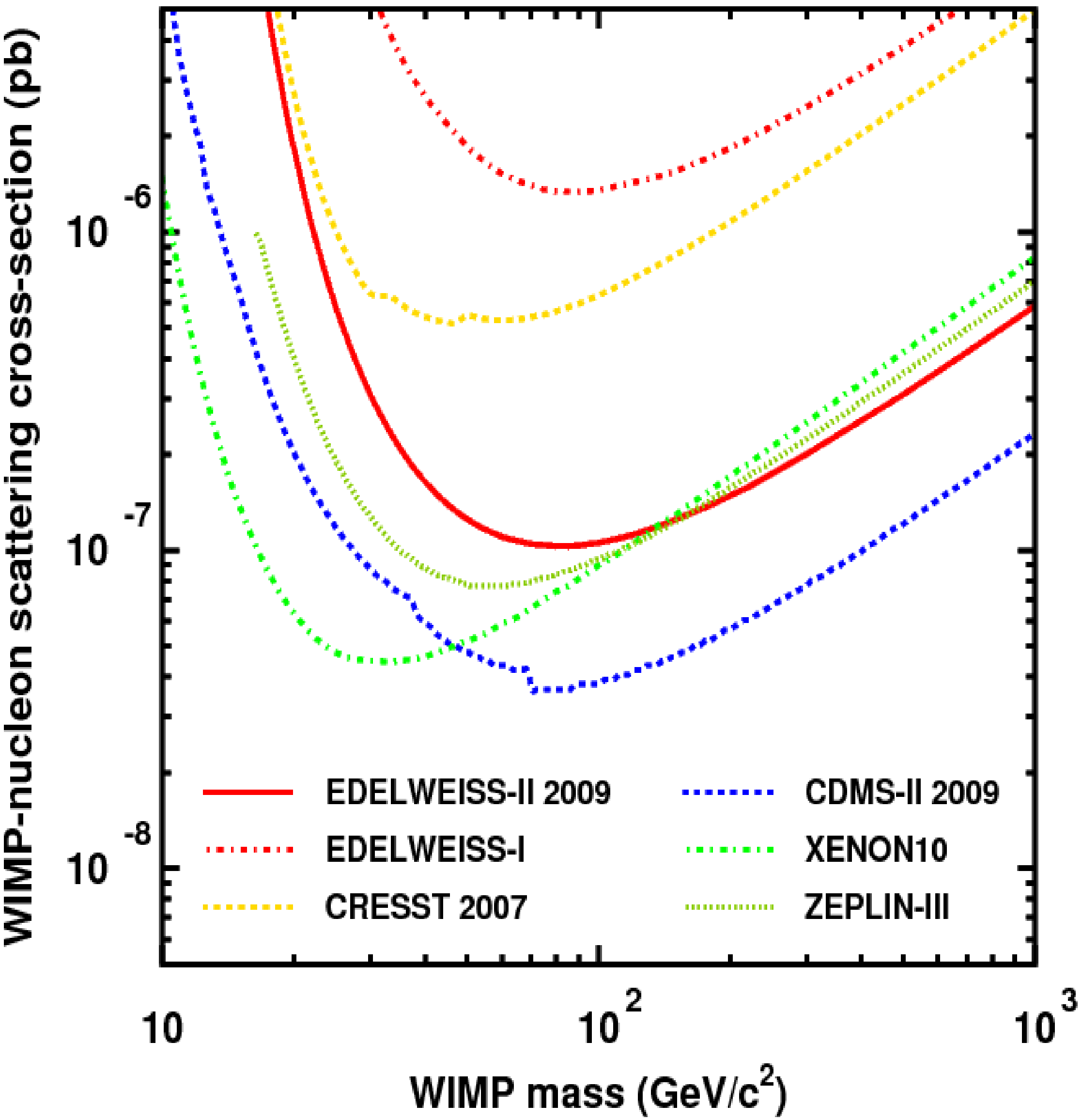
XENON
ZEPLIN
ARDM
LUX

DEAP
KIMS

Present limits

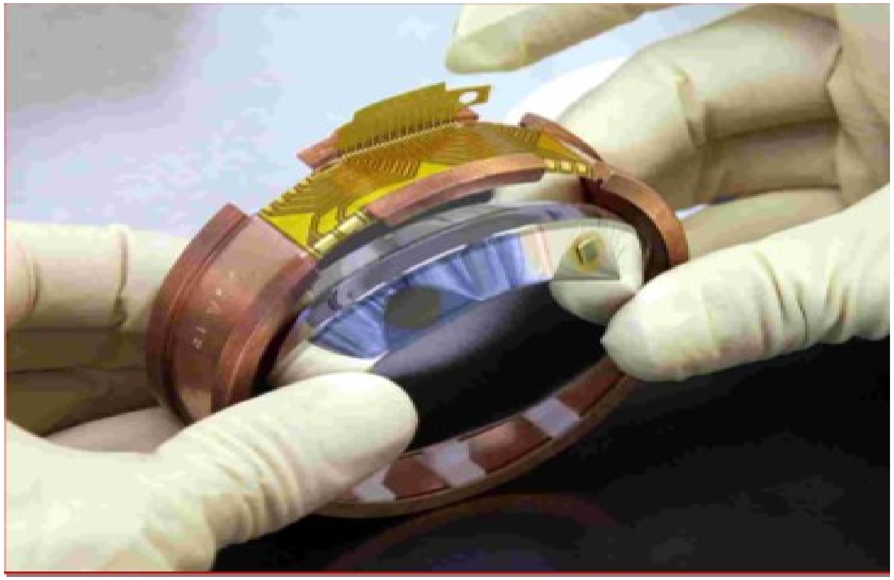
Best present Spin-Independent limits:

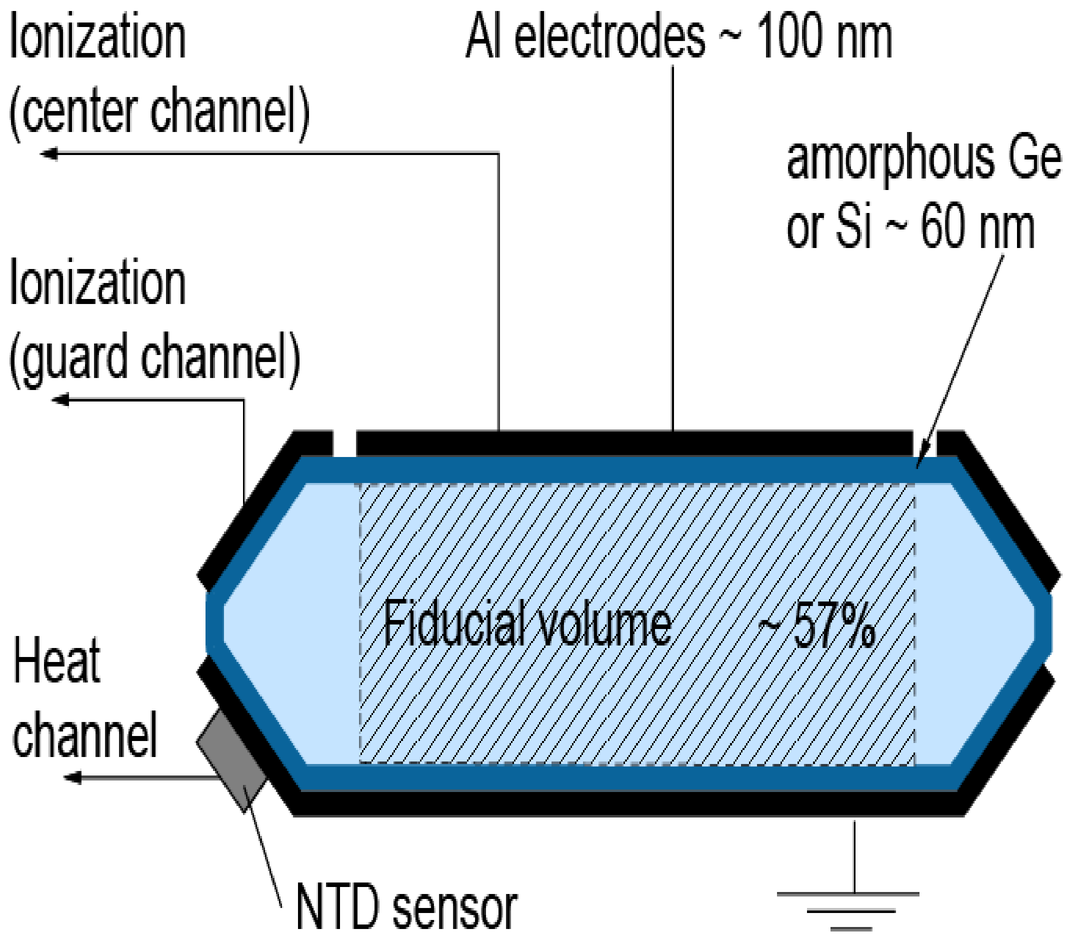
- CDMS-II (Ge cryo)
- XENON (2-phase Xe)



L'expérience EDELWEISS

``Ge-NTD´´ EDELWEISS detector type





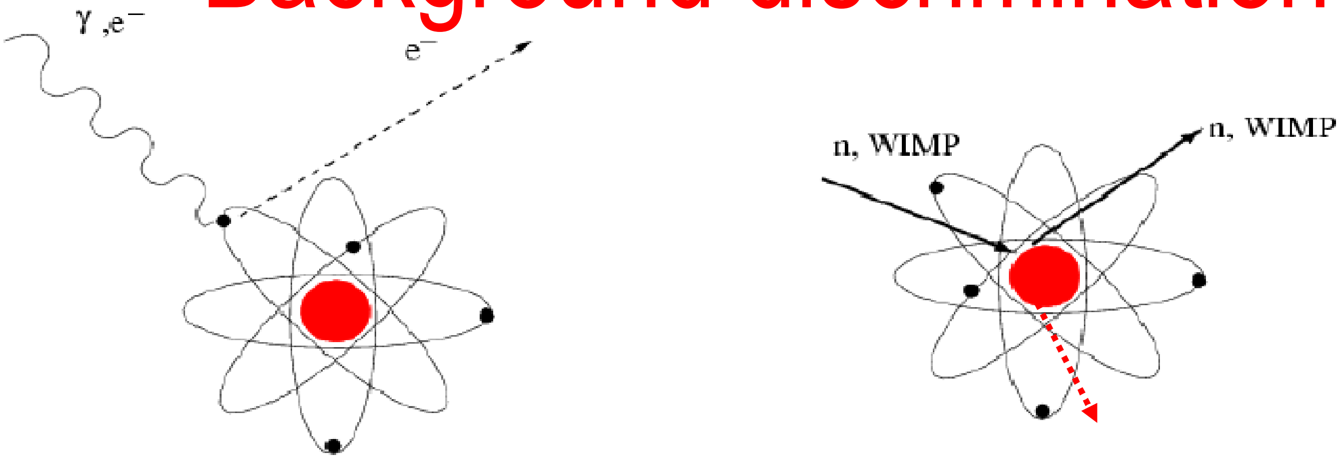
Simultaneous measurements:

Ionization @ few V/cm with Al electrodes

Heat @ 20 mK with **NTD** sensor

$$E_R = \left(1 + \frac{V}{\epsilon_\gamma}\right) E_C - \frac{V}{\epsilon_\gamma} E_I$$

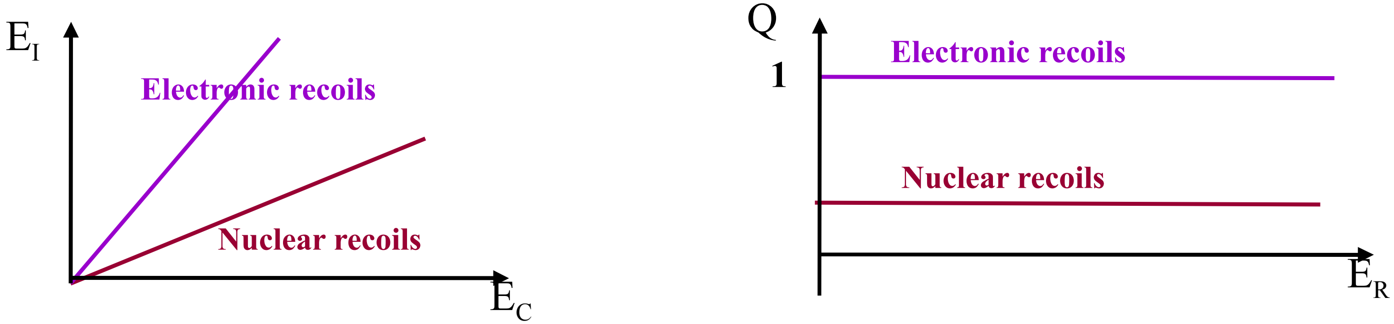
Background discrimination



Recul électronique

Recul nucléaire

- Pairs (e^-/h) due to nuclear recoils = 1/3 pairs (e^-/h) due to electronic recoils
- Difference ⇔ quenching factor $Q_n = \varepsilon_\gamma/\varepsilon_n$ (ε_γ ~ 3 eV, ε_n ~ 10 eV (Ge))



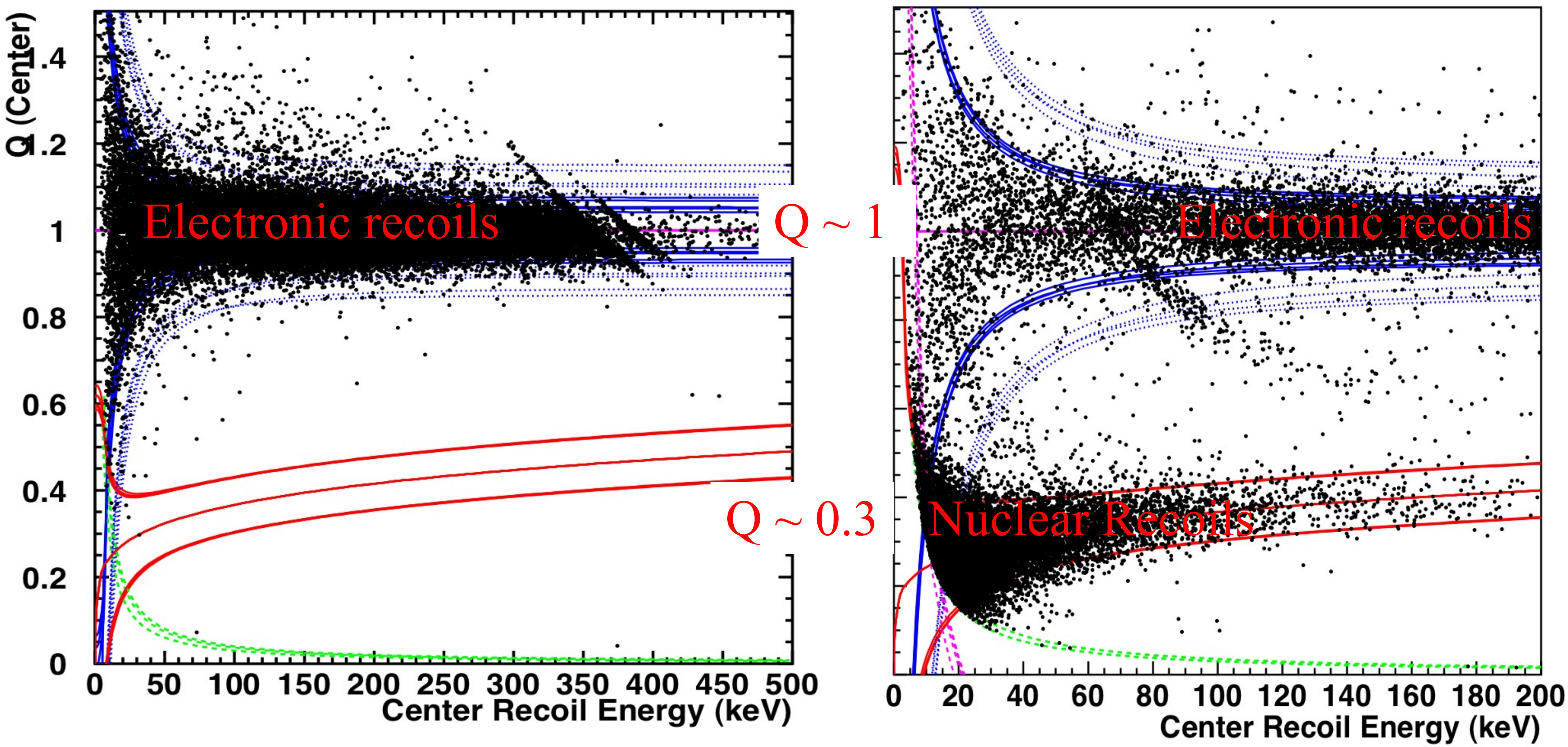
- Simultaneous measurement of ionization and heat ⇒ $Q=E_I/E_R$ parameter

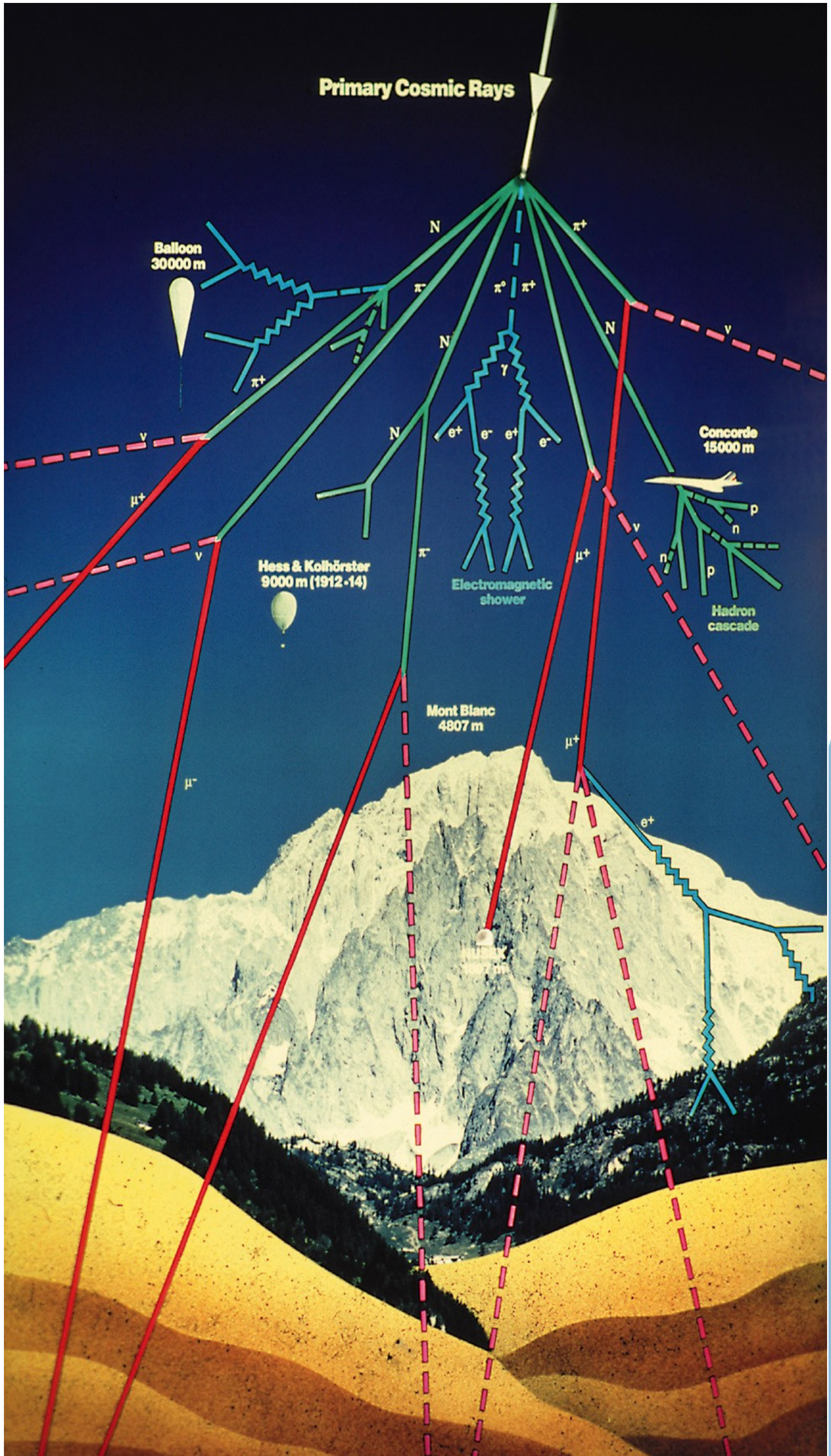
Event by event background rejection

Discrimination example

^{133}Ba, γ source

^{241}AmBe, n/γ source





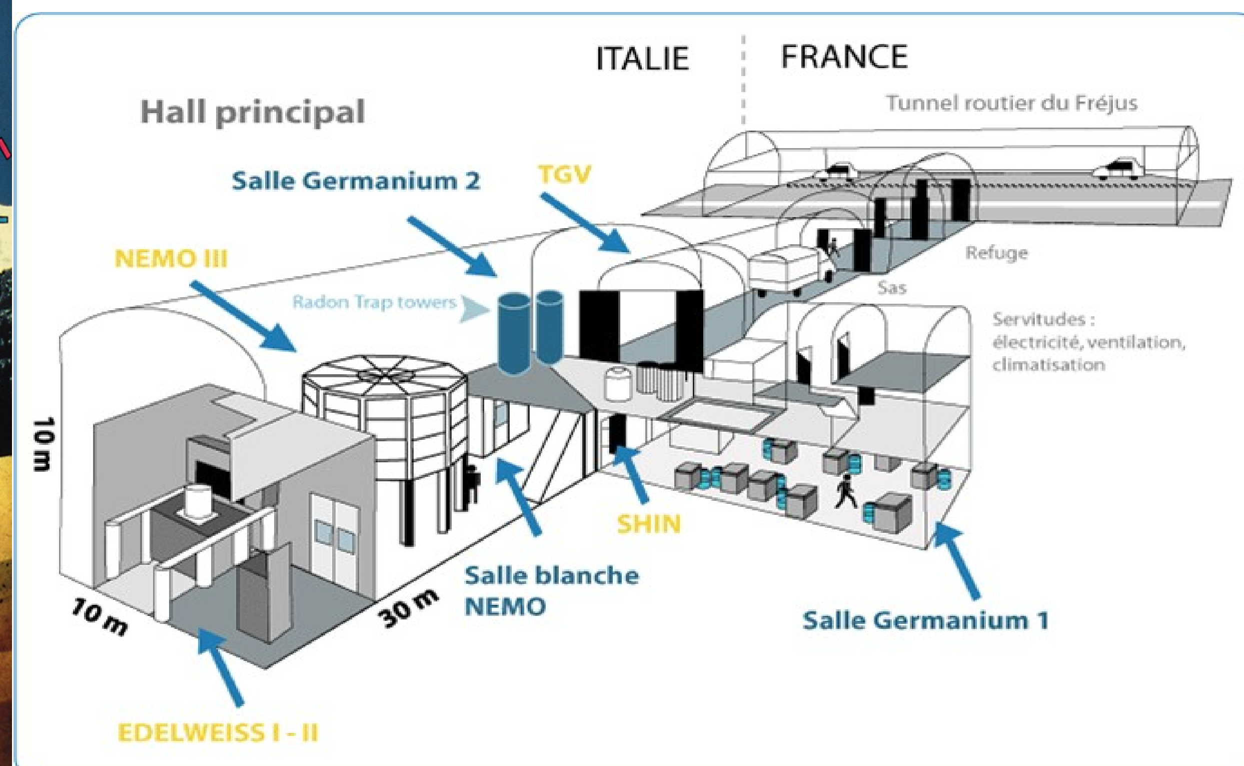
EDELWEISS-II @ LSM

(Installation 2006
commissioning 2007)

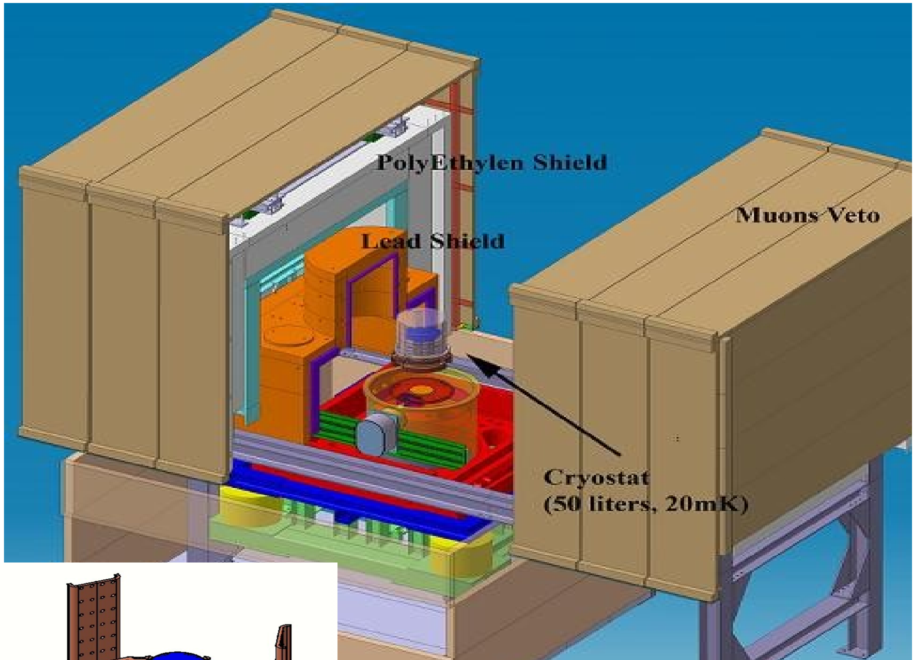
@ LSM (underneath ~1700 m of rock) :

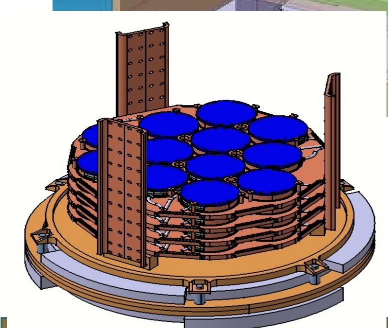
- Neutron flux ~ 1400/m²/d
- μ flux ~ 4/m²/d

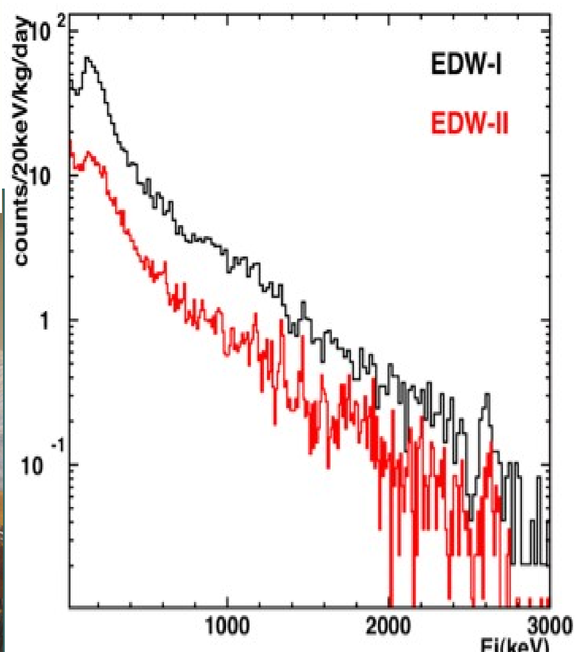
→ Cosmic rays reduction of ~ 10^6 factor



Setup EDELWEISS-II





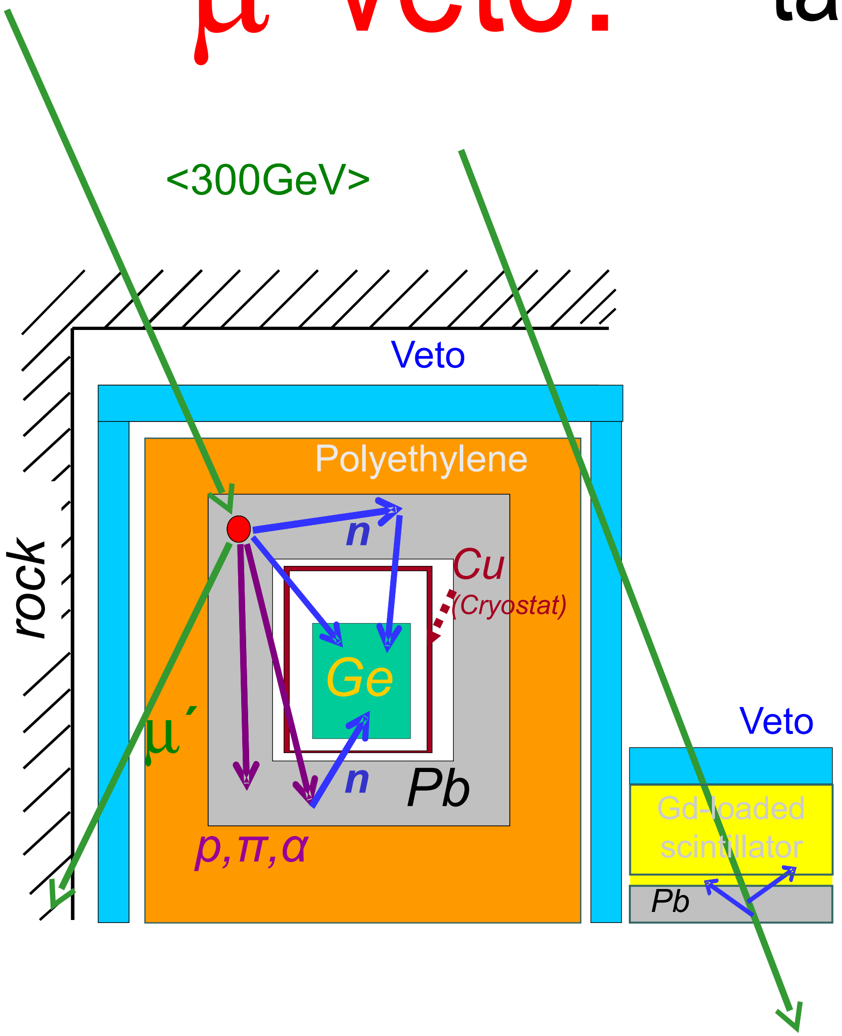


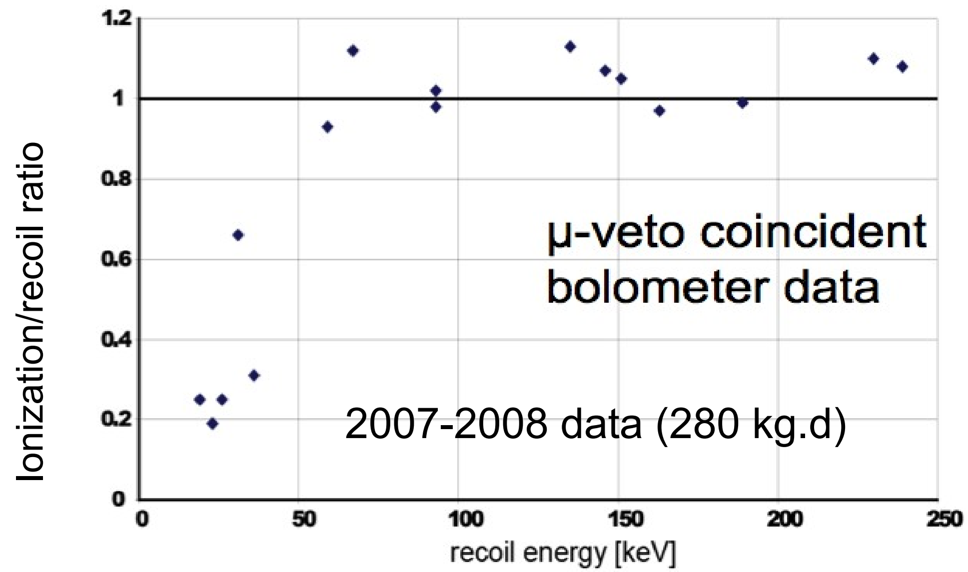
- Goal: **EDW-I × 100**

  10^{-8}pb, <0.002 evts/kg/d
- 5 kg Ge, can host up to 40 kg
- Simple/reliable detectors
- Alternative surface events rejection based on charge signal
- Strict control of material selection/ Cleaning procedure/ Environment
- Gamma shield (20cm Pb)

  ⇒ background reduced by ~ 3 wrt EDW1
- Neutron shield designed for <10^{-8}pb
- 50cm polyethylene
- Active muon veto (>98% coverage)

μ-veto: tags interaction due to muons





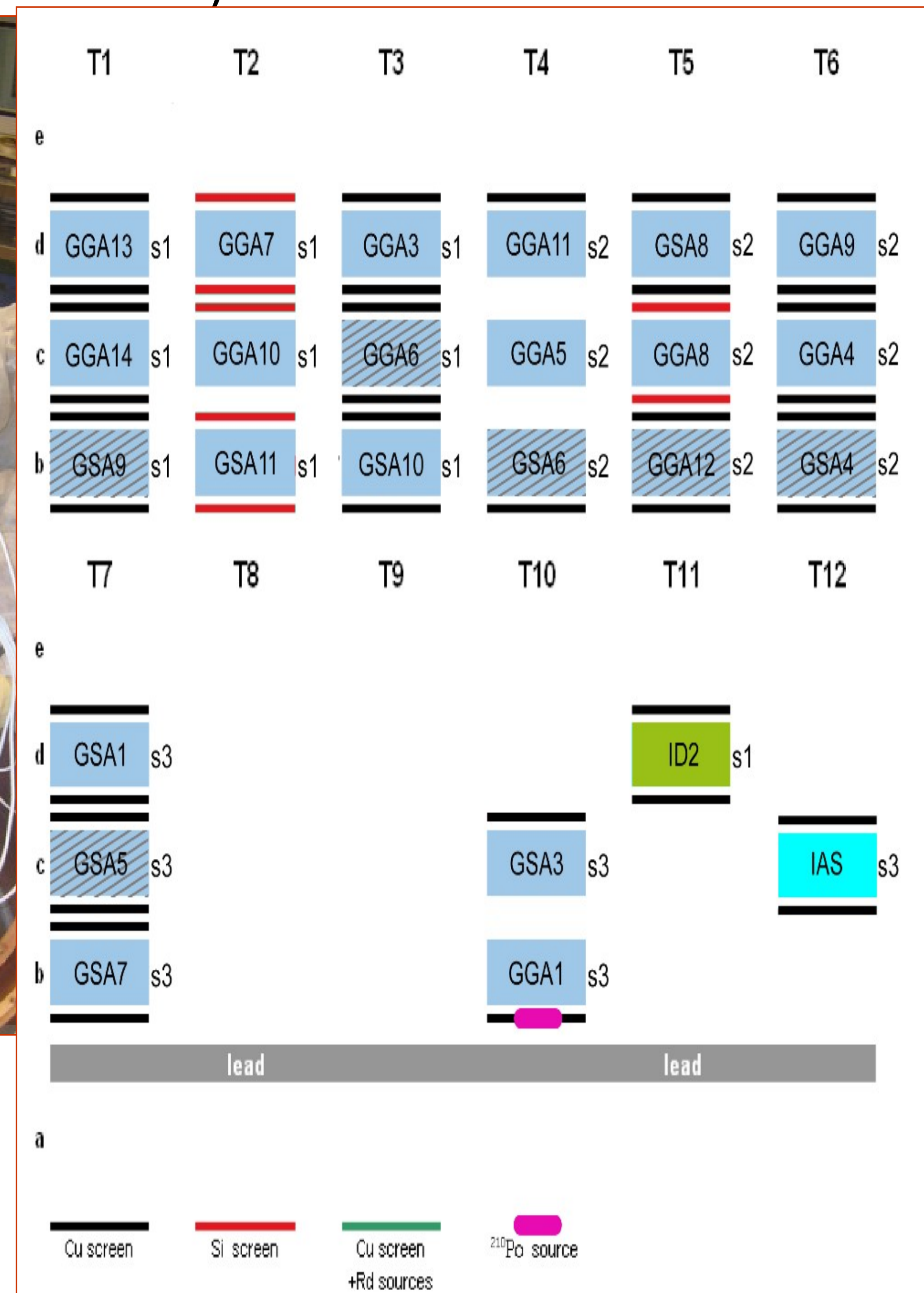
- GEANT4 expectation:
  - ~0.03 evt/kg/d
  - ~0.004 neutron/kg/d above 20 keV recoil
- Measurement:
  - 280 kg.d in 2007-2008 +160 kg.d in 2009
  - ~0.04 evt/kg/d
  - 0.011+-0.005 nucl.rec./kg/d above 20 keV

In addition: several neutron flux measurements carried out near the experiment

First Physics run: Run 8

23 detector installed (11/2007 → 3/2008)

17 x 320g NTD
2 x 200g NbSi
1 x 400g NbSi
1 x 50g 73Ge NTD
1 x 200g ID
1 x 50g Al2O3 IAS



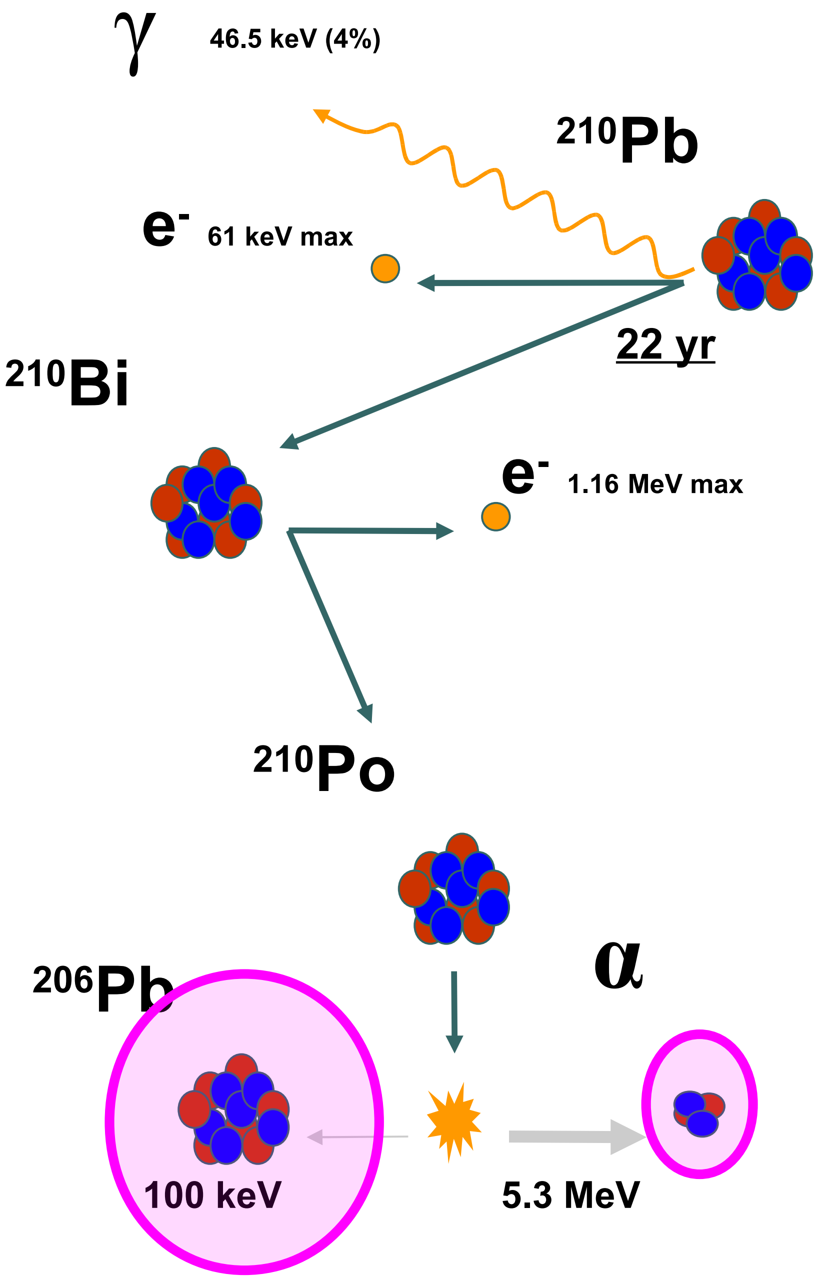
Ge-NTD study:

- ➔ Background understanding
- ➔ WIMP signal?

Background interpretation

- Gamma
- Alpha-Beta

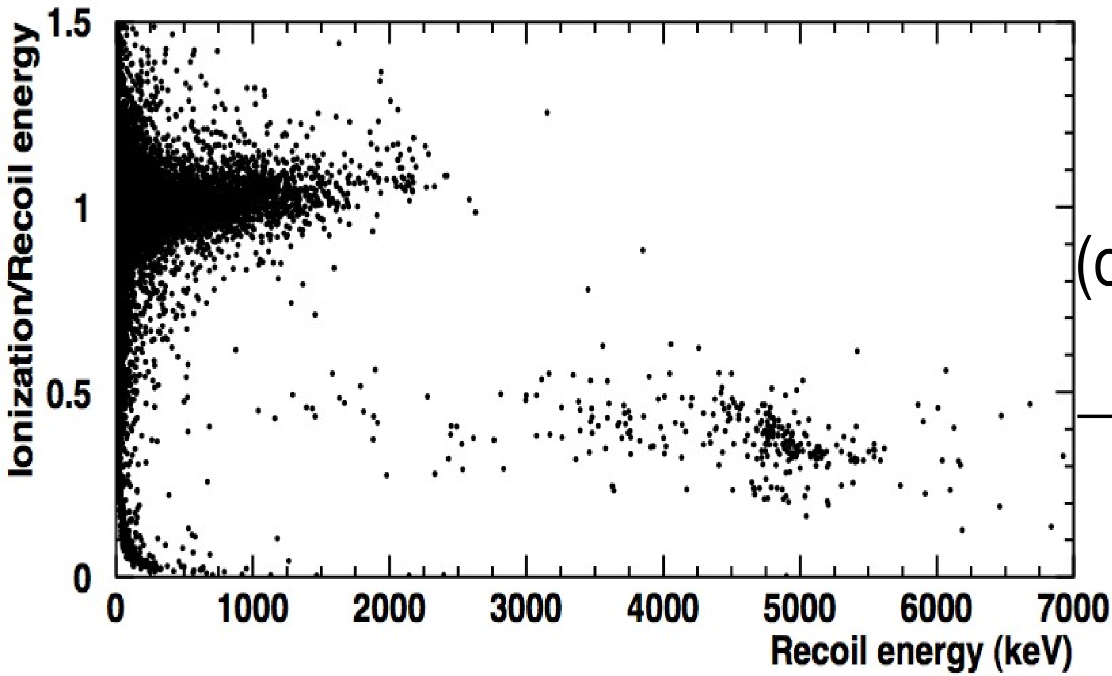
α & β background



Four populations to confirm ^{210}Pb contamination scenario

- Alpha @ 5.3MeV
- High energy beta (Bi) ->1.1MeV
- Low energy beta (Po)
- Pb nuclear recoils ionization less

Particule	Energie	Cu	Ge	Pb
Gamma	10 keV	9 μm	170 μm	18 μm
	100 keV	6 mm	8 mm	400 μm
	1 MeV	40 mm	80 mm	30 mm
Electron	10 keV	200 nm	350 nm	
	100 keV	11 μm	20 μm	
	1 MeV	340 μm	700 μm	
Alpha	5.3 MeV	11 μm	19 μm	15 μm
Polonium	100 keV	40 nm	68 nm	



Alpha background reduction of a factor 2 in comparison to EDW-I

Rate: 2.0±0.1 alpha/kg.d

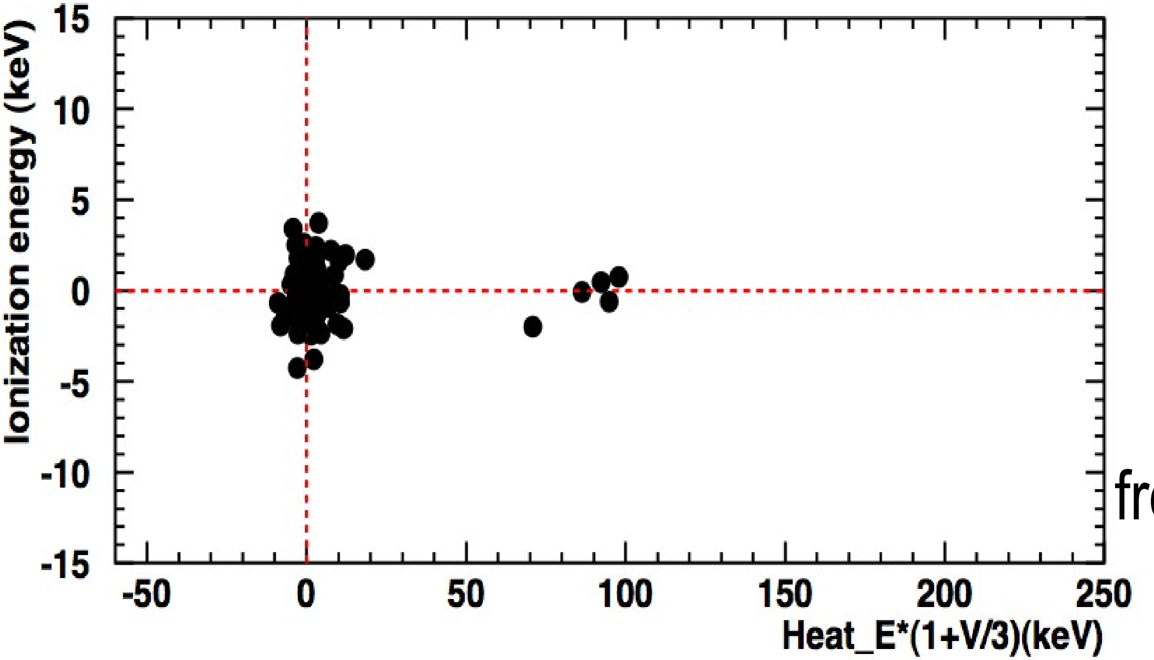
(observations : alpha rates as a function of surfaces (Cu/Si/Ge) are consistent → direct evidence of Ge contamination: coincidences study)

GGA11 et GGA5

Coincidences study

α rate: 3.2±0.4 alpha/kg.d

Pb recoil rate: 0.19±0.09 evt/kg.d



Pb recoils rate small compared to alpha rate (6% only).

Likely explanations : alphas come from Cu surfaces or ^{210}Pb implantation depth not well understood.

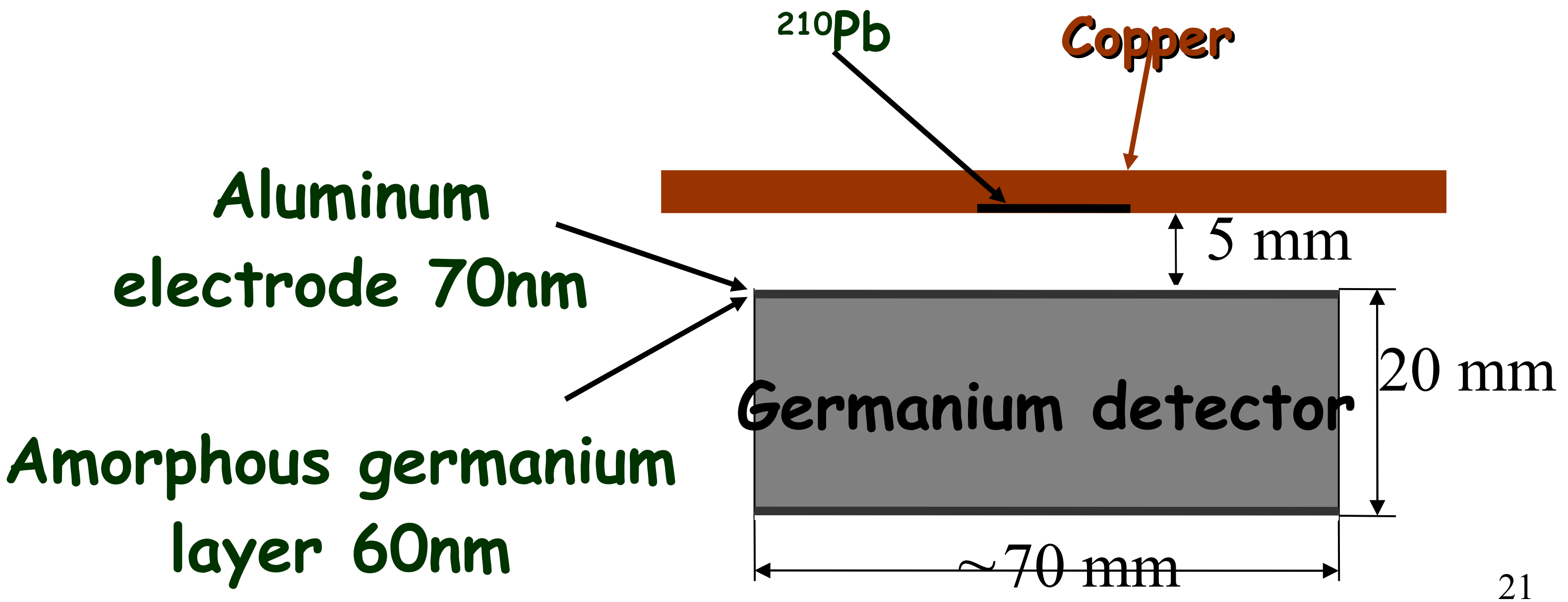
Confirmation : Ge polluted by Pb

GGA1: ^{210}Pb source

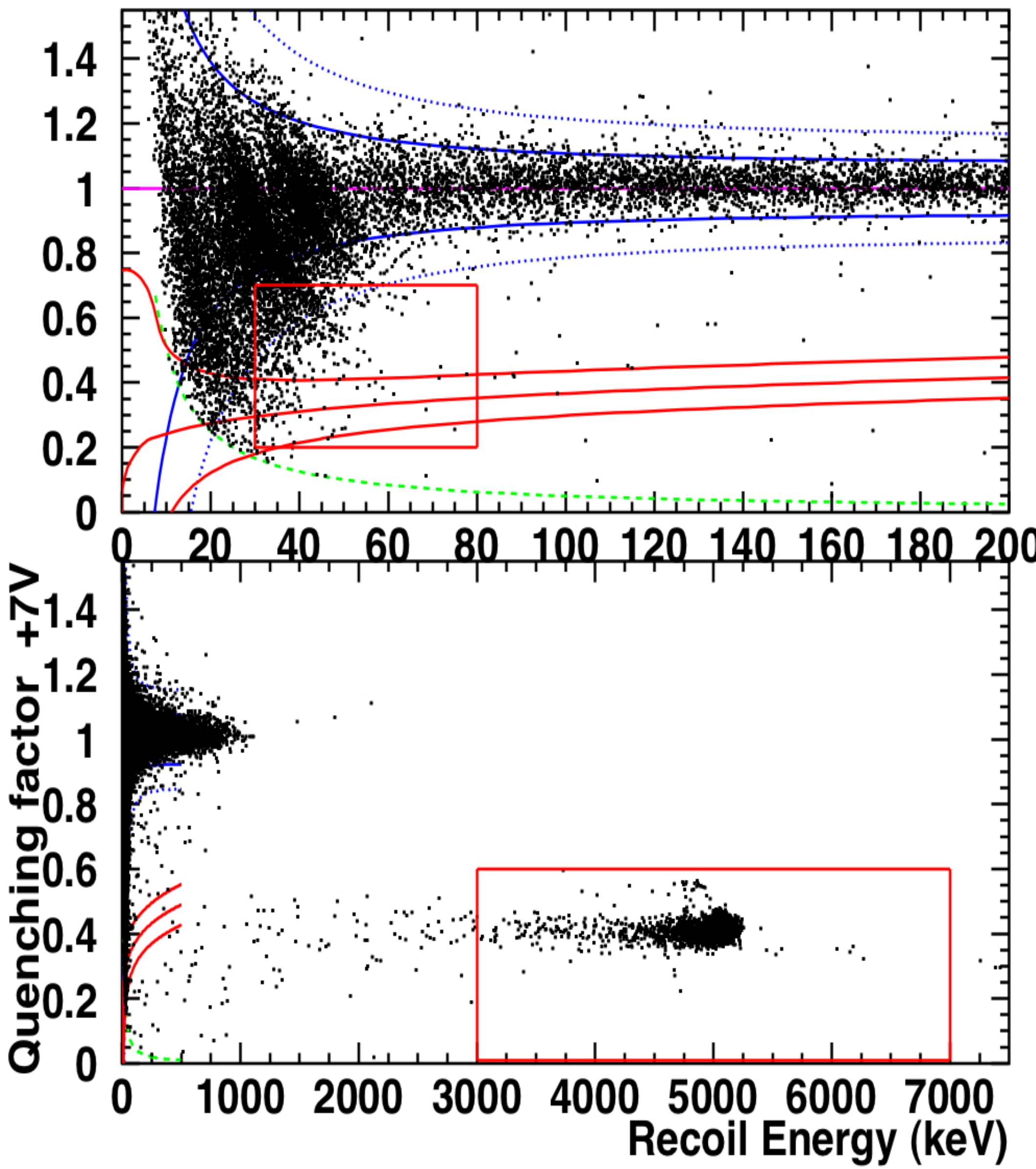
Problem : alpha population present, but we don't know how betas due to this contamination leak down to the nuclear recoil band.

Solution idea: Ge-NTD detector equipped with a ^{210}Pb source

→ Low energy beta calibration



GGA1 study

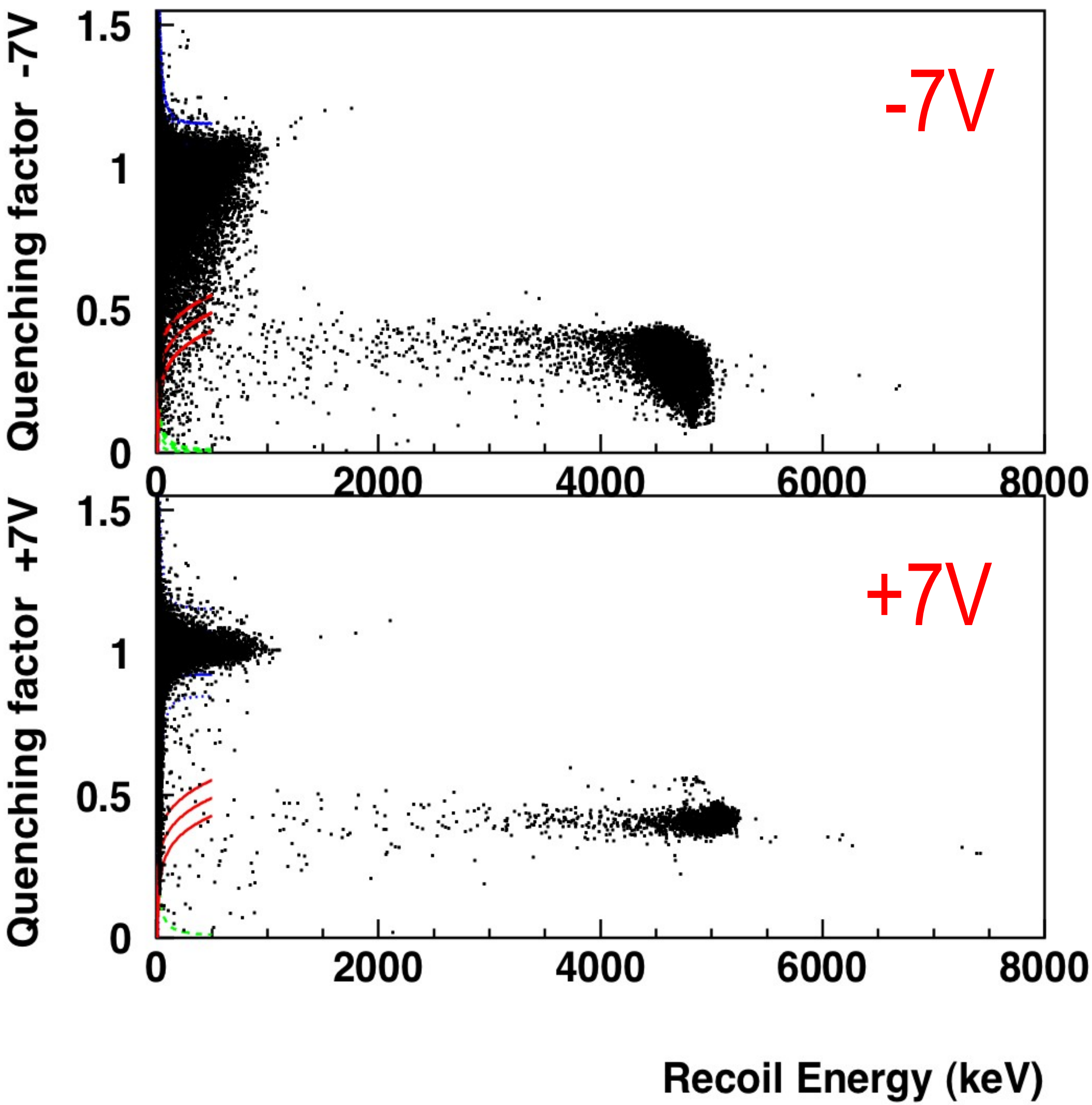


IDEA :

Starting from GGA1 calibration data analysis (= measurement of nbeta/nalpha ratio) in order to predict number of beta leaking into the nuclear recoil band (NRB) in the physics run

(knowing measured alpha rate: 2.0±0.1 alpha/kg.j
and
under the hypothesis:
α rate~ β rate
→ chain at the equilibrium)

GGA1: ^{210}Pb source Alpha



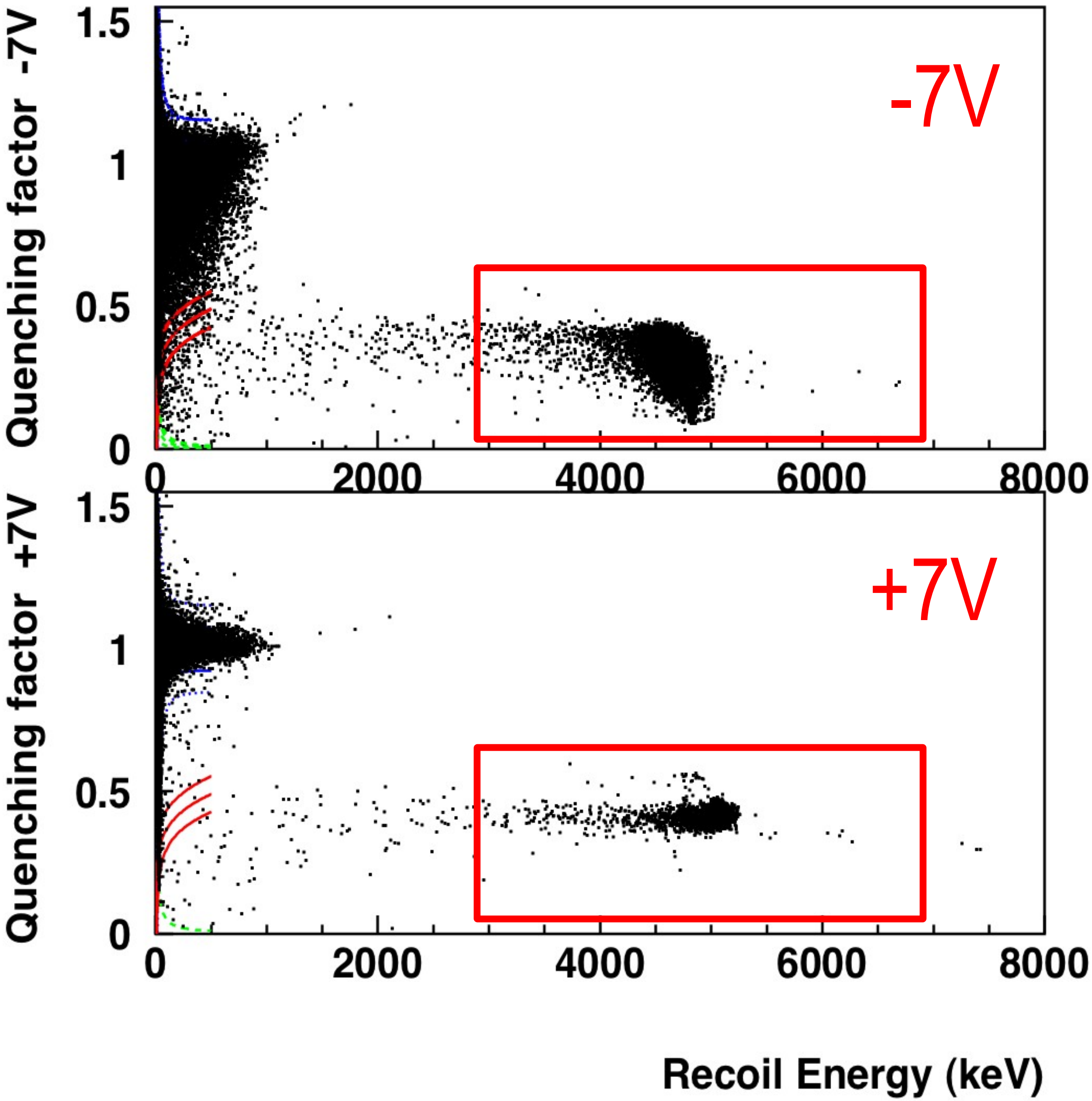
Different α way of life

-7V : alpha quenching factor degradation as a function of time

+7V : alpha quenching factor not degraded in time

Trapping e^-/h on surface

GGA1: ^{210}Pb source Alpha



Different α way of life

-7V : alpha quenching factor degradation as a function of time

+7V : alpha quenching factor not degraded in time

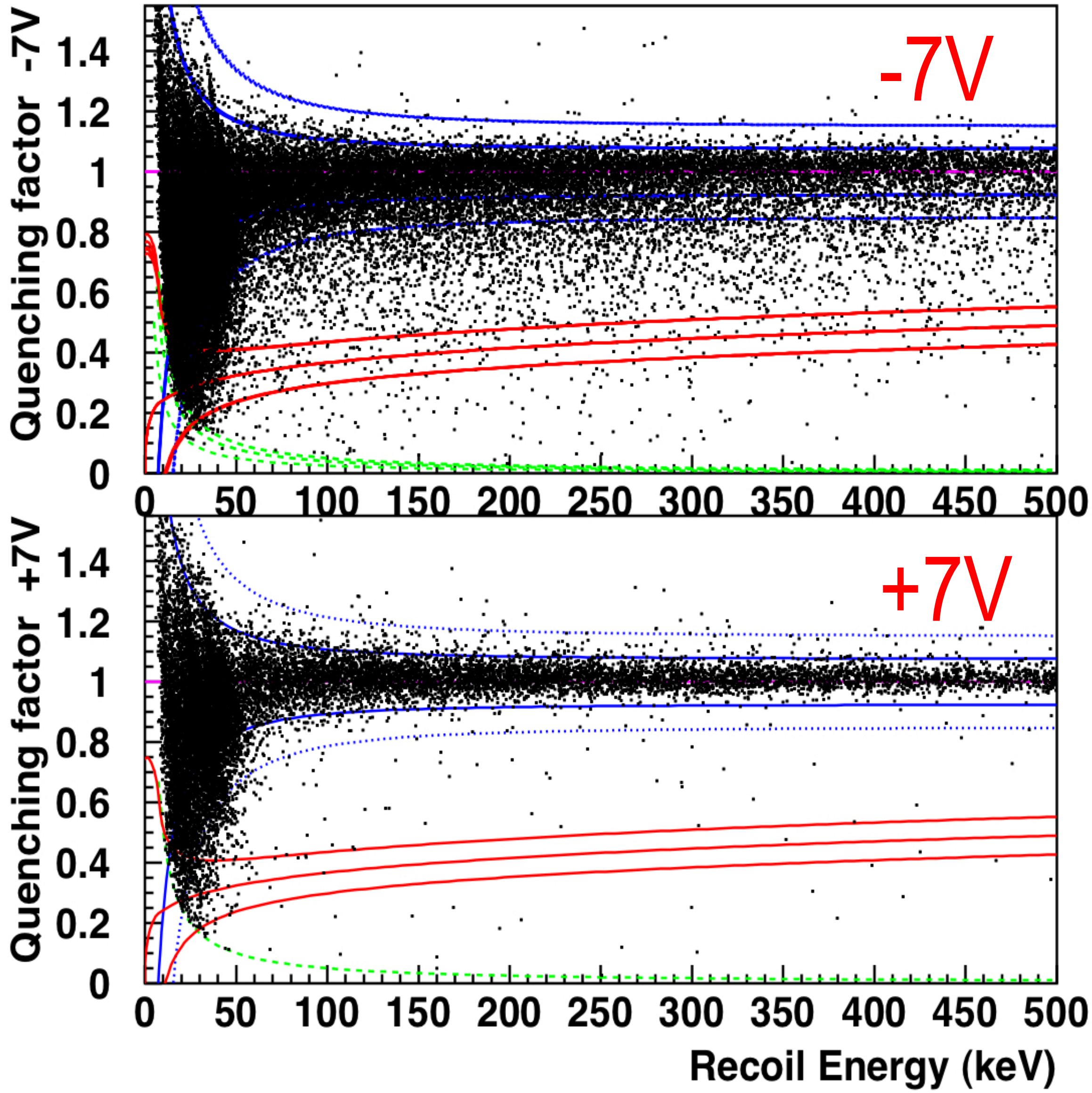
Alpha Box :

$3 < E_R(\mathrm{MeV}) < 7$

and

$0.01 < Q < 0.6$

GGA1: ^{210}Pb source Beta

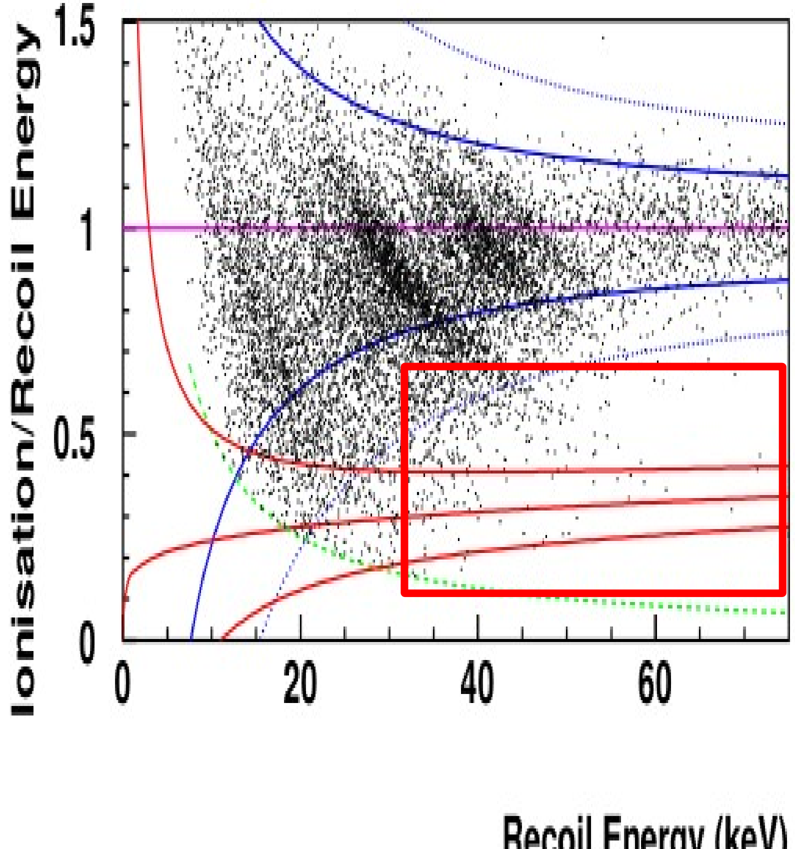


Beta Box:

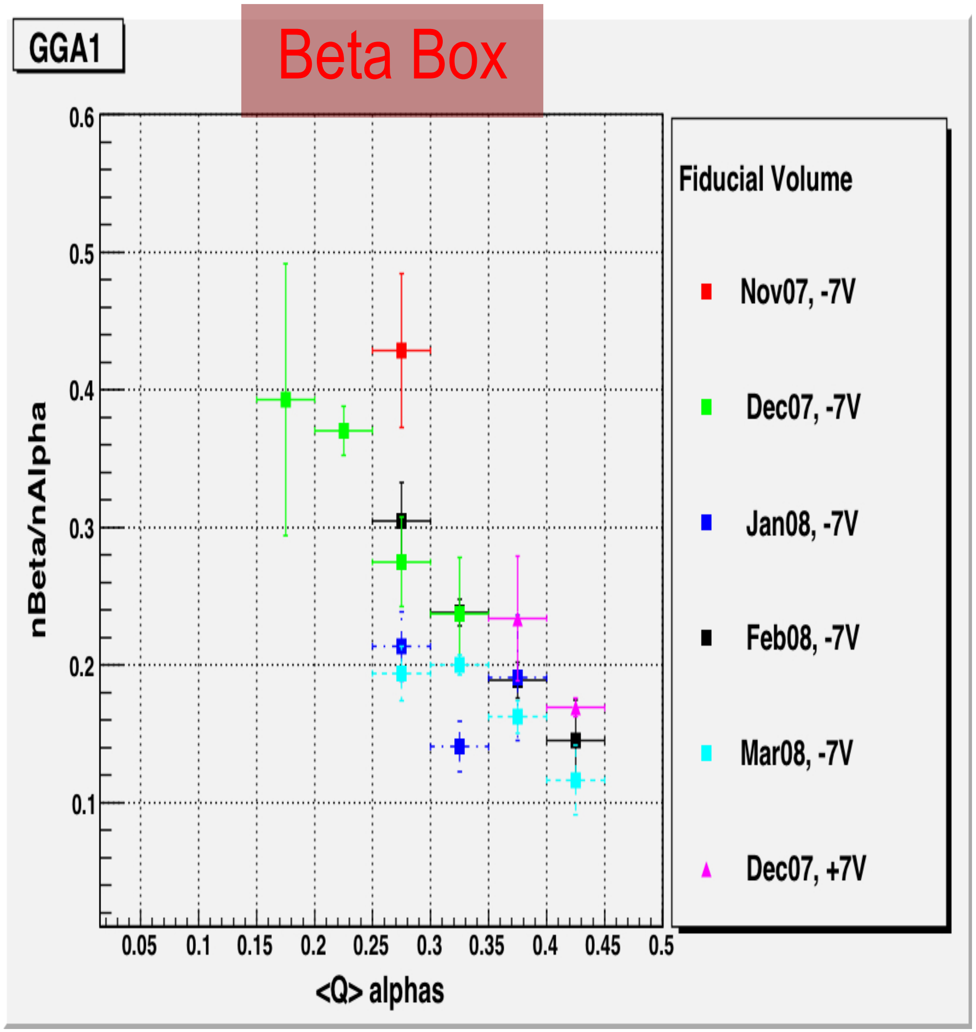
30 < E_R(keV)< 80

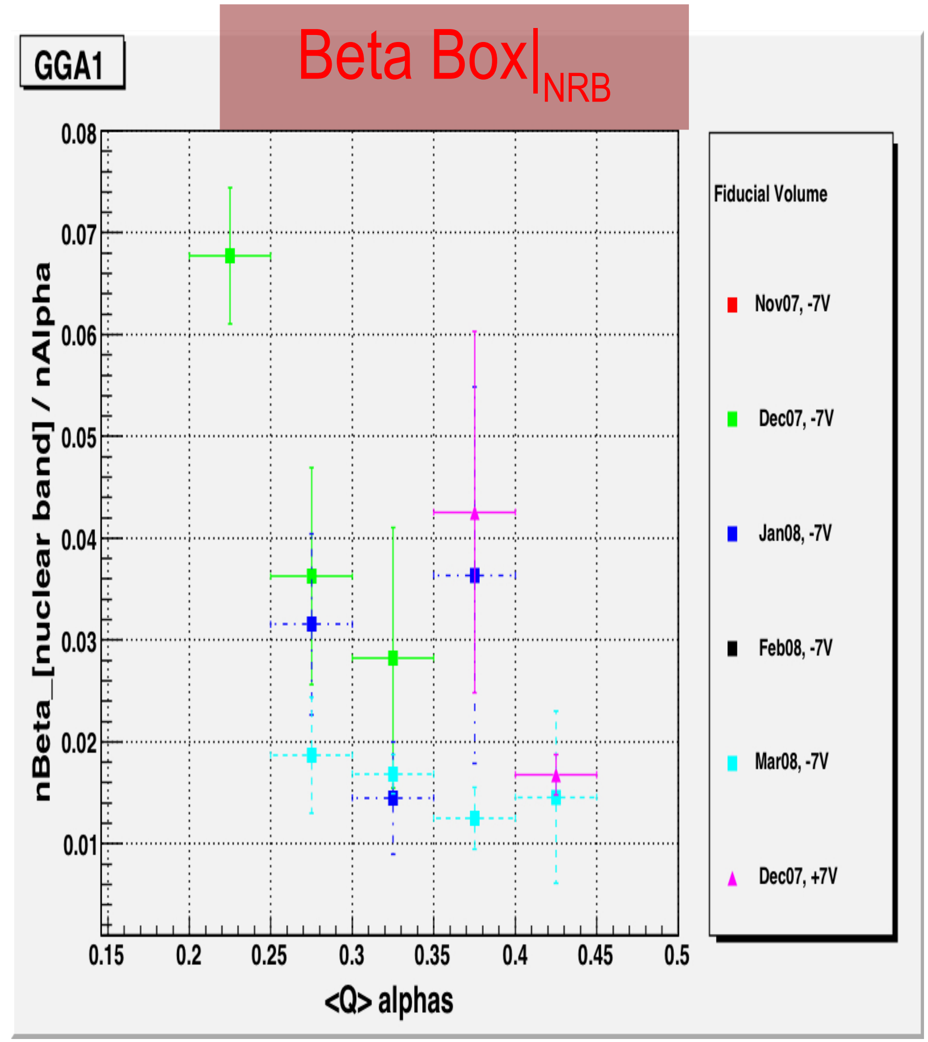
and

0.2 < Q < 0.7



GGA1 study
nbeta/nalpha predictions





<Q>alpha(PR) → nβ/nα= 0.20±0.05 **<Q>alpha(PR) → nβ/nα= 0.024±0.009**

GGA1predictiosn on
low background physics run

	GGA1 β/α predictions	Rate counts/kgd: β Predicted	Rate counts/kgd: β Observed
Beta box	0.20±0.05	0.40±0.10	0.60±0.08
Beta box in NRB	0.024±0.009	0.048±0.018	0.03±0.02

Pb calibration

Physics Run

Alpha rate (PR) :
2.0±0.1 alpha/kg.j

Beta box NRB: after a fiducial exposure of ~100kg.d prediction gives: 5±2 events (3 observed events)

→ compatibility in NRB of events registered in physics run and events due to ^{210}Pb contamination.

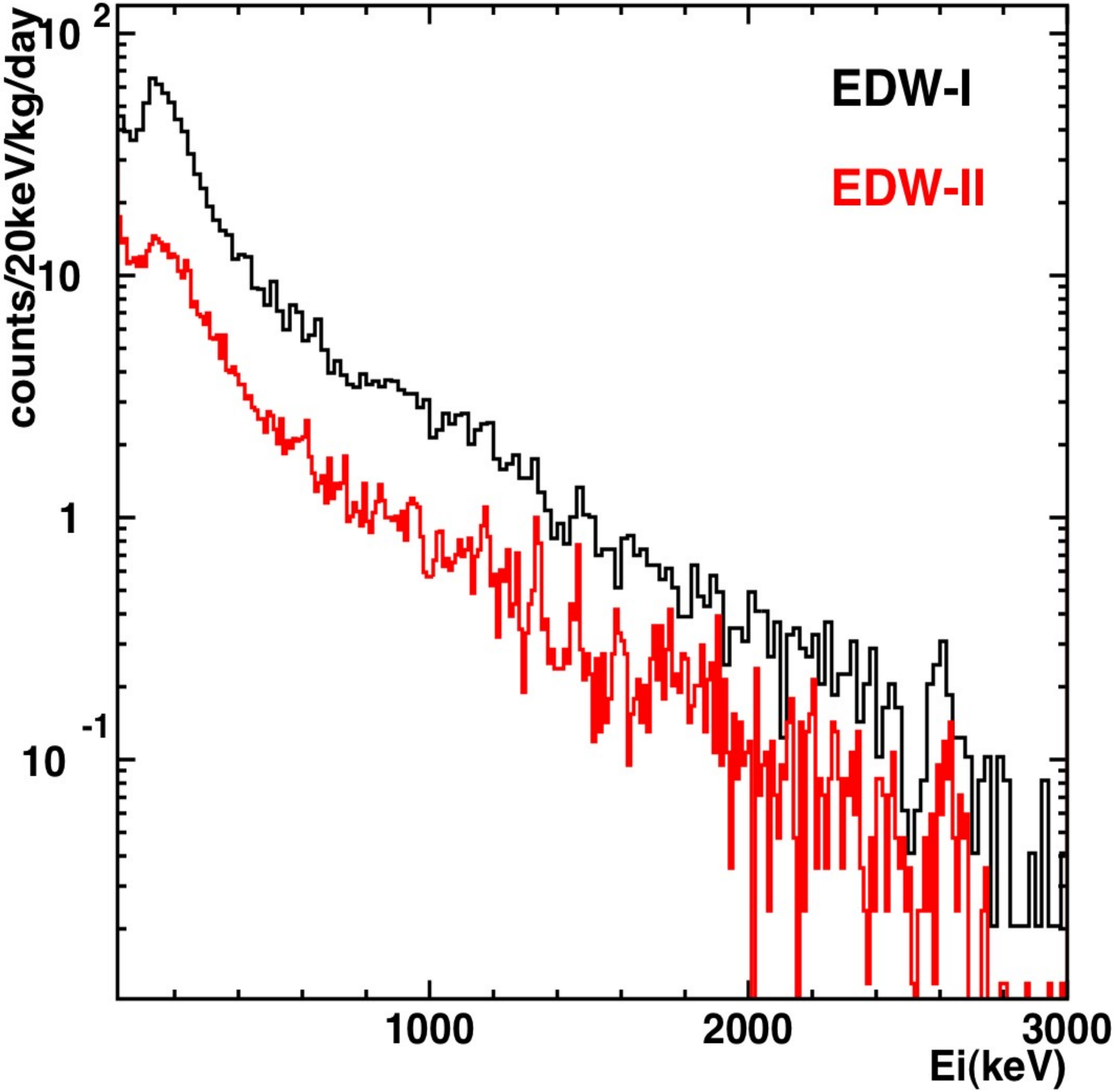
Beta box: data/prediction agreement @1.5σ.

→ *Systematic effect*: $Q(E_R)$ distribution might not be gaussian as far away from Q=1

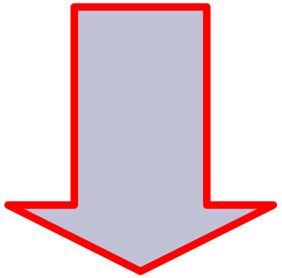
α & β background Conclusion

- Alpha population reduced by about a factor 2 compared to EDELWEISS-I;
- ^{210}Pb contamination confirmed by study of GGA1 equipped with a ^{210}Pb source;
- Low energy predicted betas rate in agreement with observed one BUT this is not precise enough for a background subtraction due to large uncertainties (charge collection profile and Pb implantation profile).

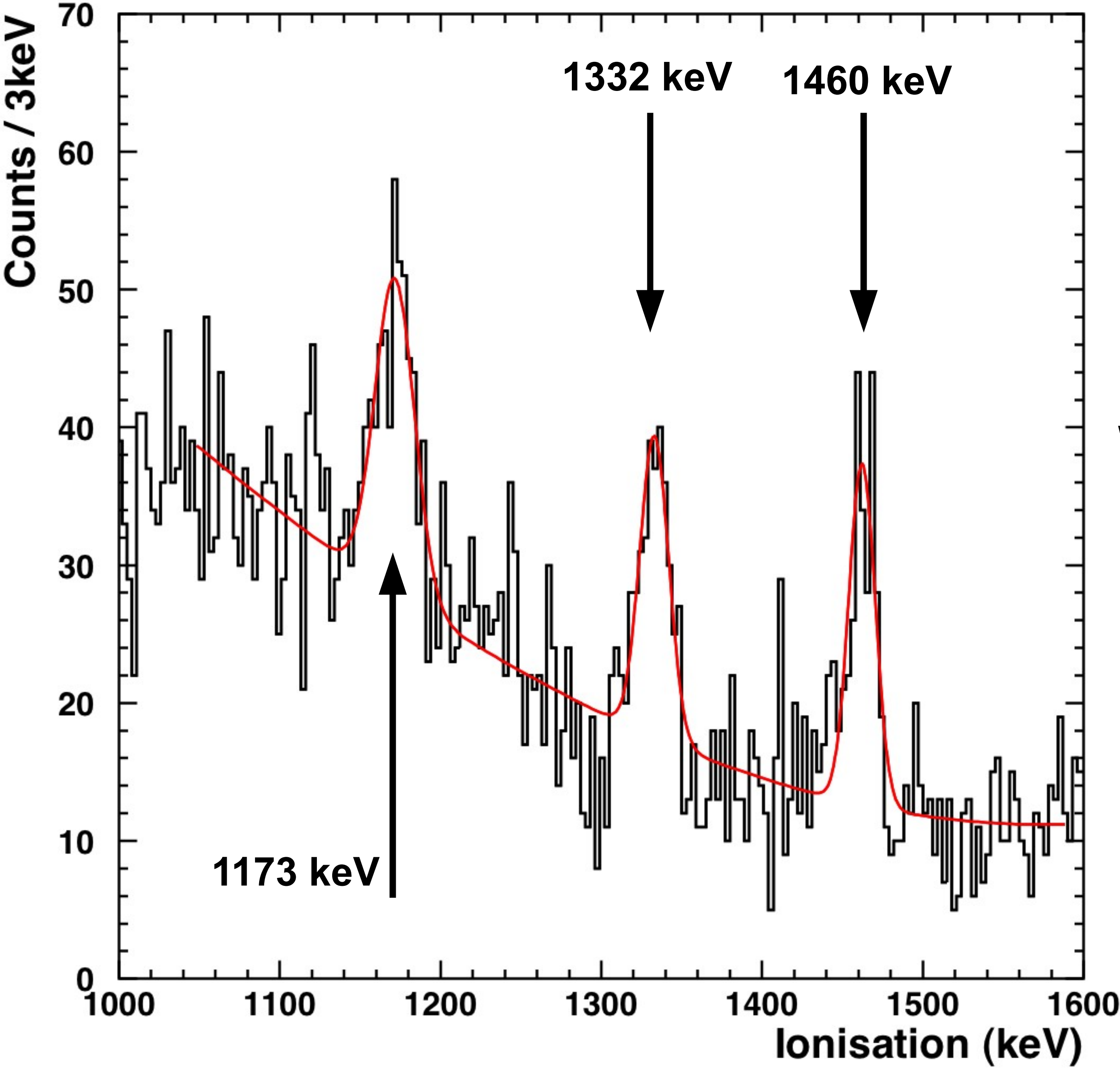
γ background



Rate :
200 ± 3 gamma/kg.d

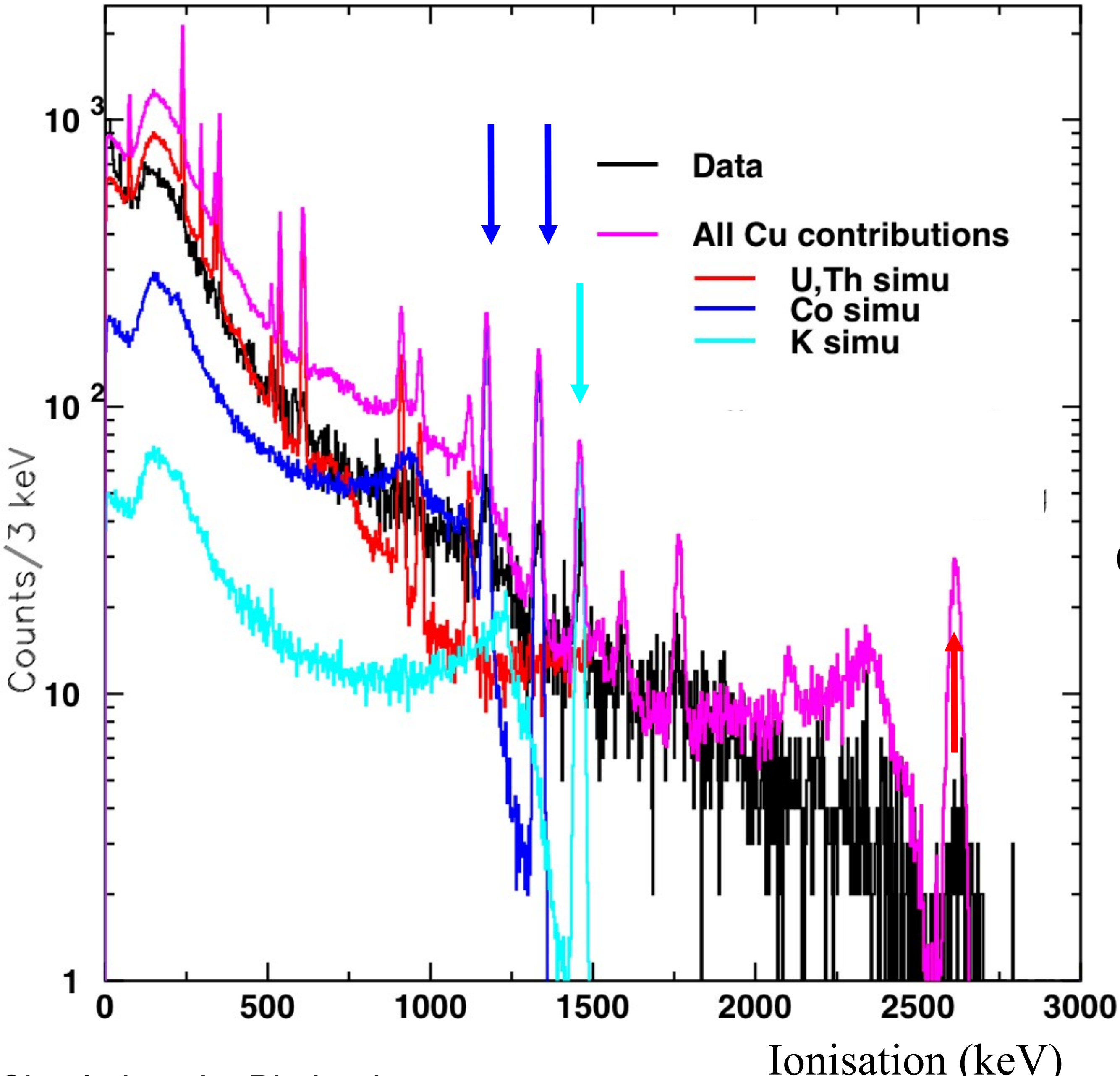


Reduction of a factor
~3 wrt EDW-I



Gamma ray peaks → probe of nearby contaminat

- Peak FWHMs compatible with theoretical expectation → verification of 356 keV calibration
- Correct peaks position → Linearity of ionization
- Rate is tower-level independent

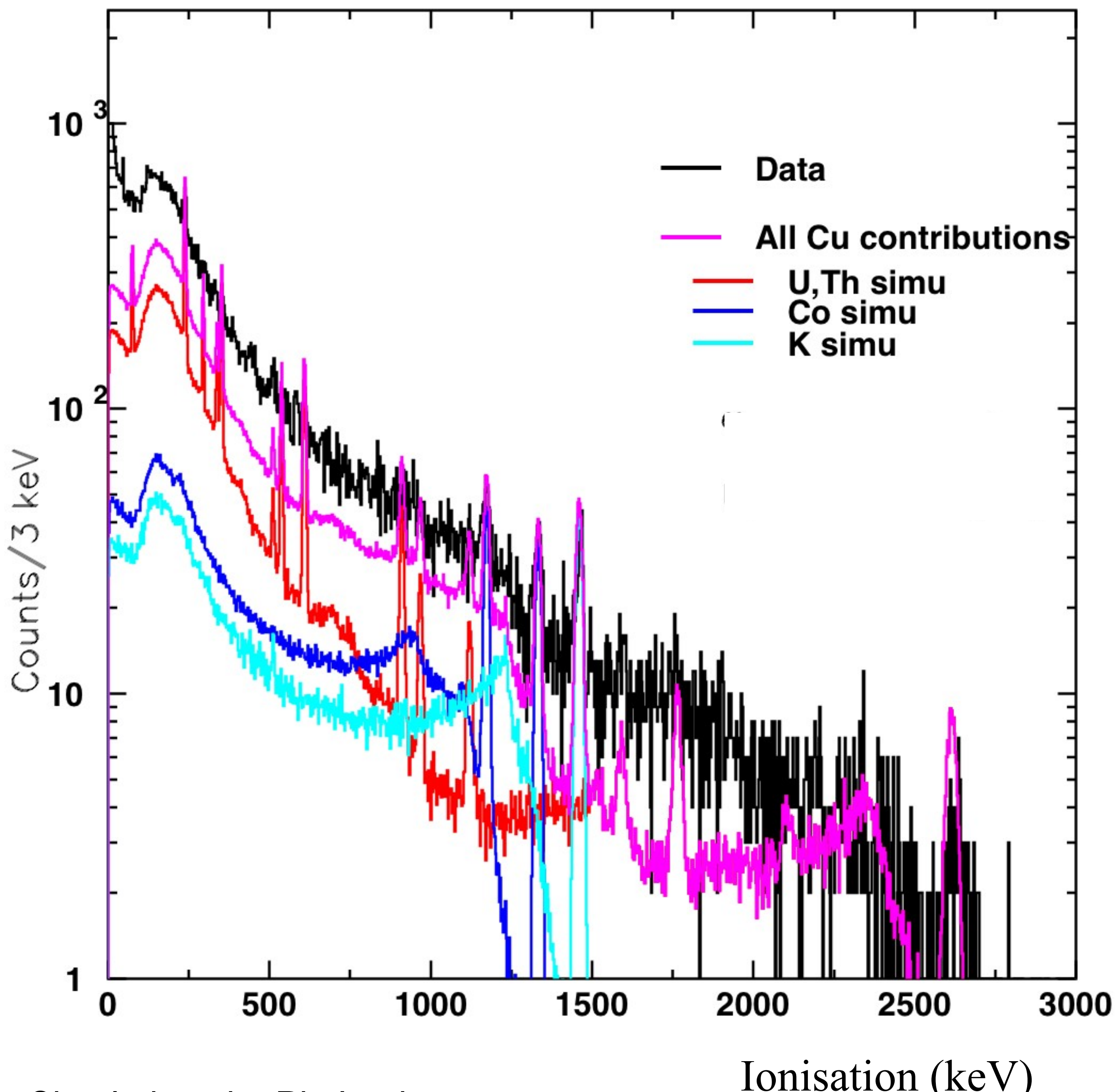


Simulations by Pia Loaiza

Ionization energy spectrum
Total volume (310kgd)

Data compared to Monte Carlo simulations of possible U/Th (2614 keV), ^{40}K (1460 keV) and ^{60}Co (1173 and 1332 keV) contaminations in the copper of detector holders, cryostat structure and thermal shields.

HPGe upper limits:
U/Th < 1.2 mBq / kg
^{60}Co < 1.0 mBq / kg
^{40}K < 4.0 mBq / kg



Simulations by Pia Loaiza

Data compared to Monte Carlo simulations of possible contaminations:
U/Th ^{60}Co et ^{40}K.

Simulations are normalized in experimental peak counting rate.

Obtained max values:
U/Th = 0.4 mBq / kg
^{60}Co = 0.2 mBq / kg
^{40}K = 2.8 mBq / kg
→ better than HPGe by a factor ~2-5

¡ Near-detector Cu is clean !

Gamma background Conclusion

→ Global and uniform reduction of background of about a factor 2 compared to EDELWEISS-I

→ Simulations of closest materials (Cu) show contaminations ~ 2-5 better than the HPGe measured one → next-to detectors copper is clean.

→ To do: simulations of far-away contaminant (Pb)

WIMP search

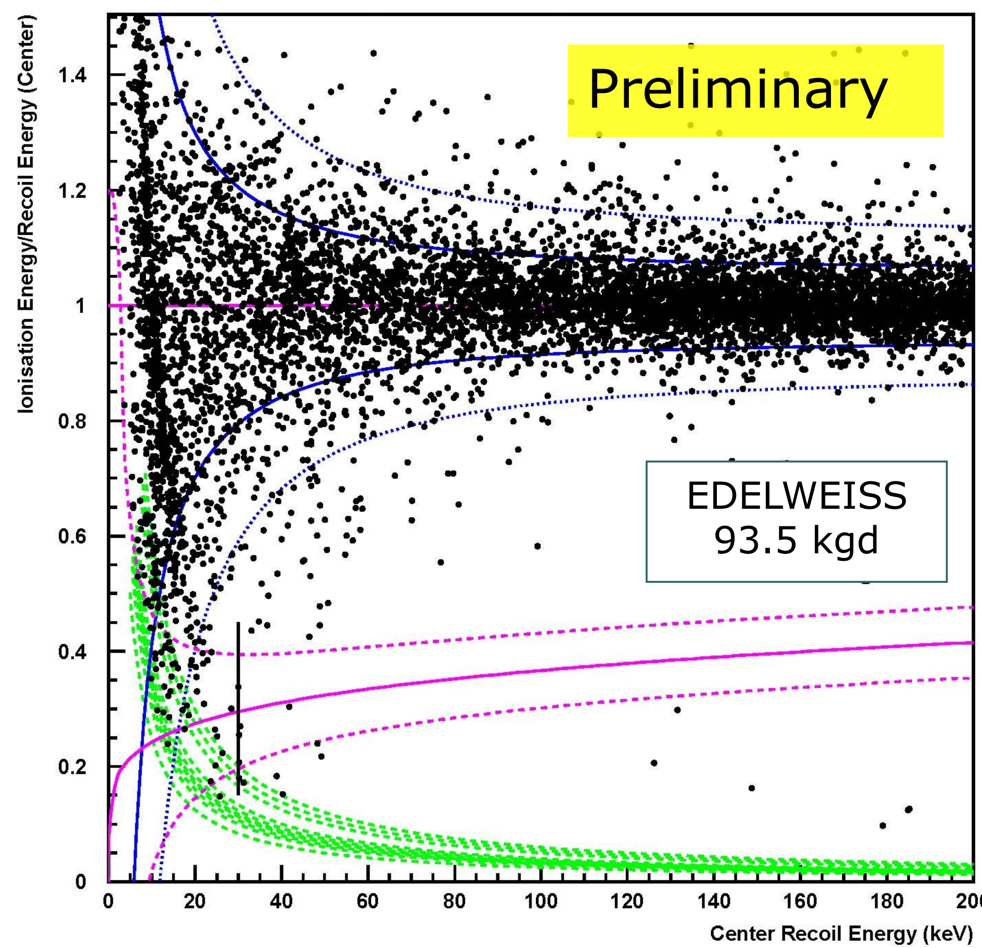
Goal: point out a WIMP signal

Need: data stability

Physics run: "Ge-NTD"

- 11 detectors with <30 keV threshold (fixed threshold chosen *a priori* due to EDW-I results ⟶ expected β bkg)
- 93.5 kg.day
- 3 events observed in nuclear recoil band

  ⟶ 31, 31 and 42 keV
- Evidence for events with deficient charge collection from ^{210}Pb



Question:

How to reach 10^{-8} pb ?

NEED

- ~2500 kgd at 15 keV threshold
- ~10^4 rejection for **gammas**
- to reject expected ~5000 **β** from ^{210}Pb

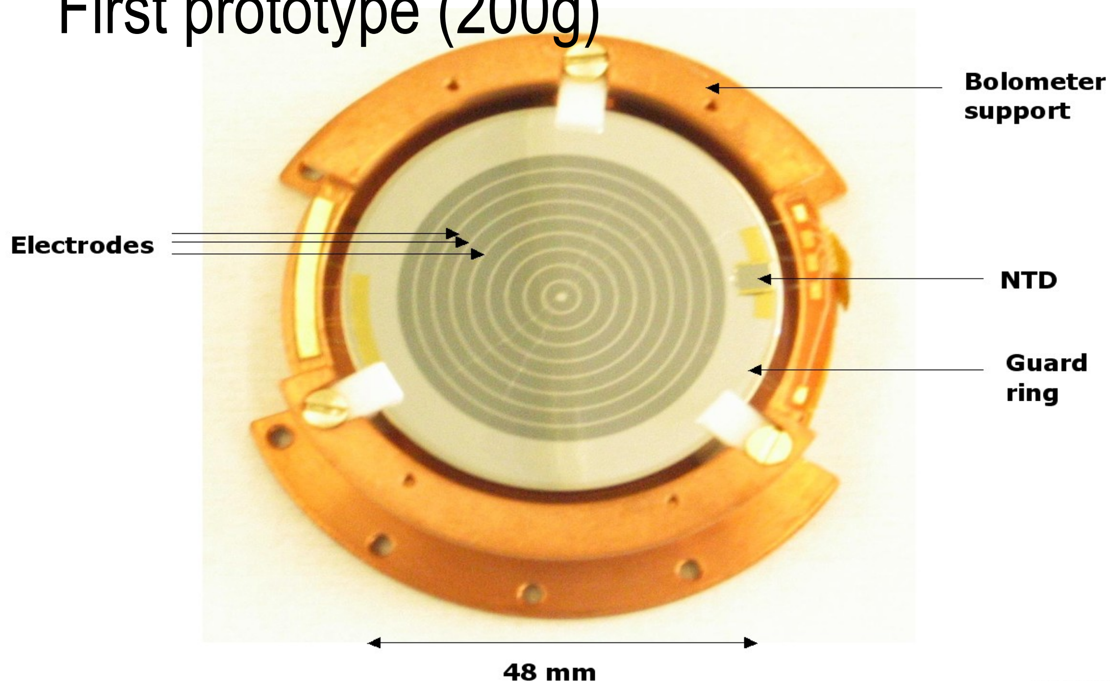
IDea:

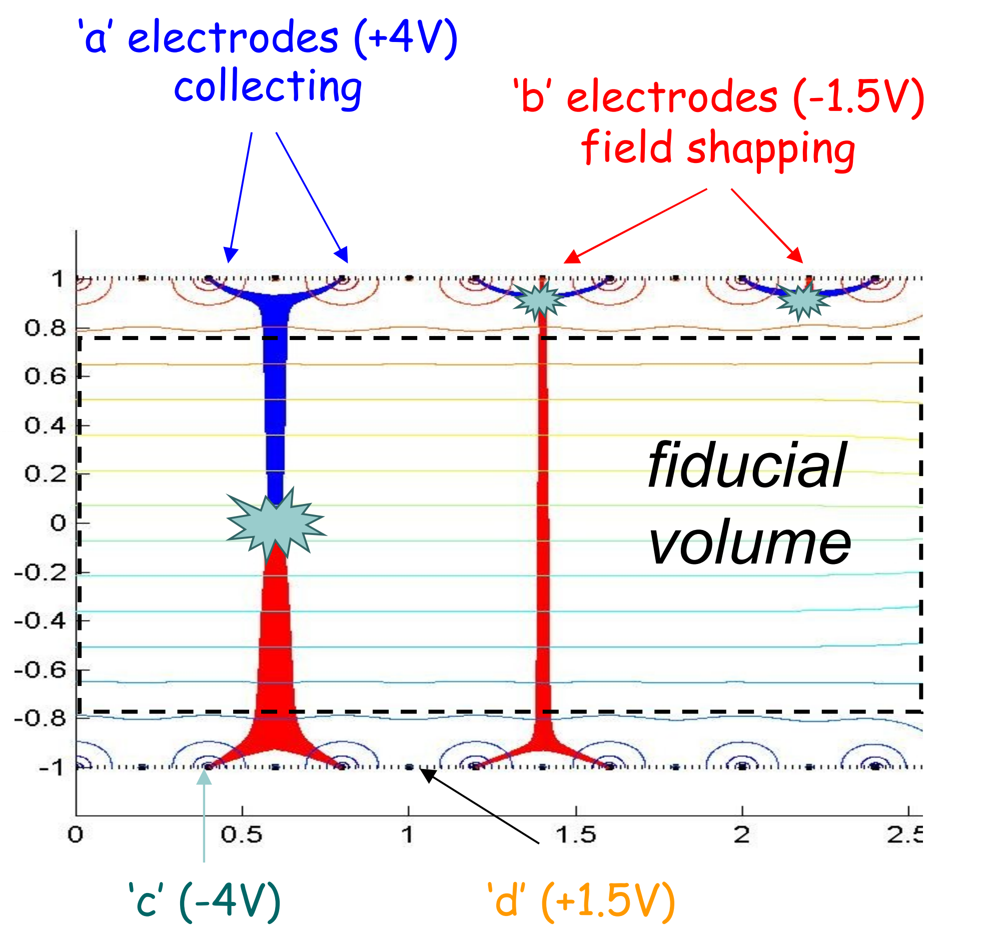
Use detectors with surface event rejection using interleaved electrode design (ID)

InterDigit detectors

- EDW-I NTD heat sensor
- E-field modified near surface
  with interleaved electrodes
- 'b'+'d' signals -> vetos % surface

First prototype (200g)



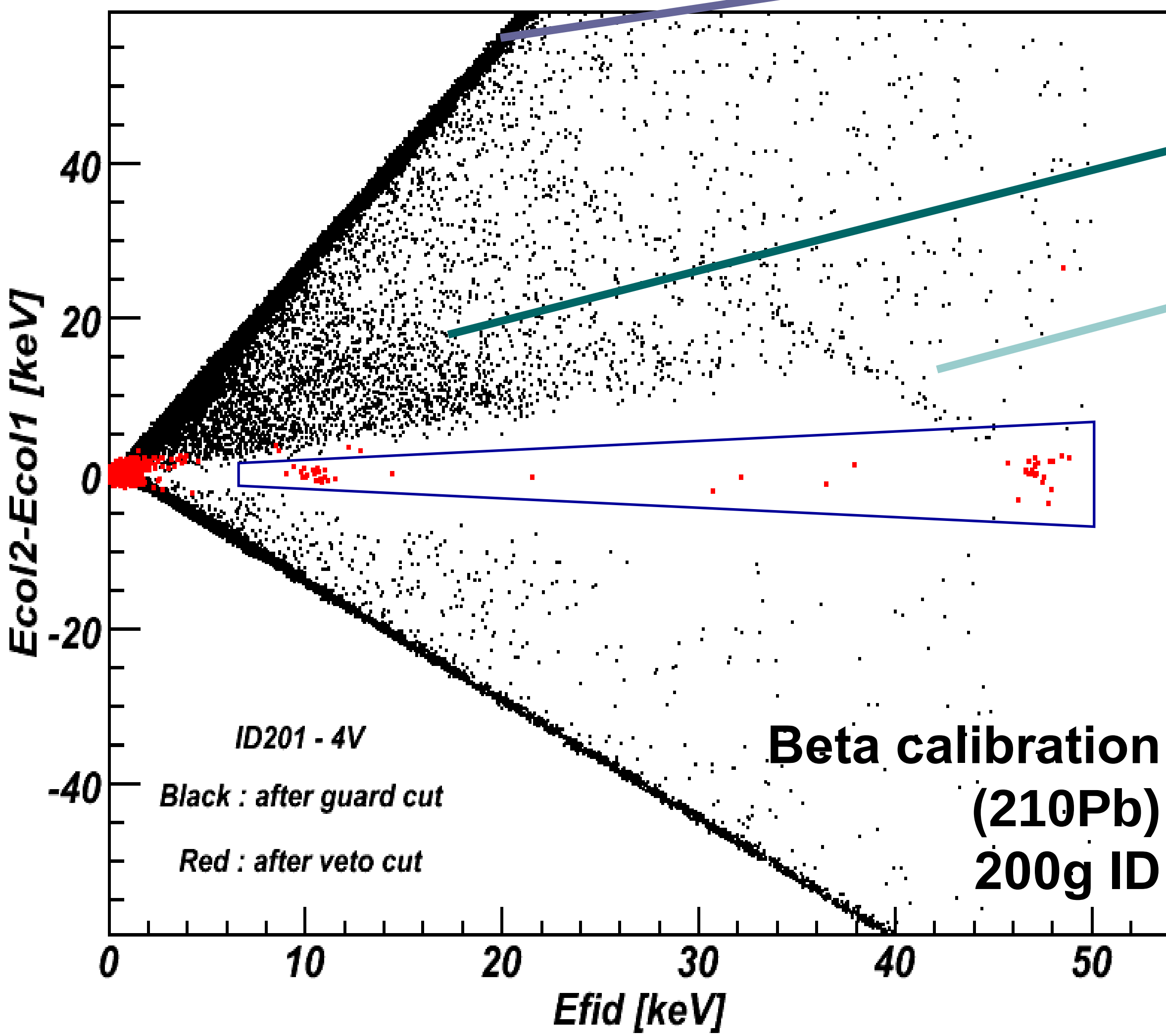


First detector built 2007

1x200g + 3x400g tested in2008

10x400g running since beginning 2009

Surface event discrimination



E1 = energy of top collecting electrode
E2 = bottom collecting electrode

"single side"
surface events (E1=0)

"3 electrodes" events
near-surface events (low field)

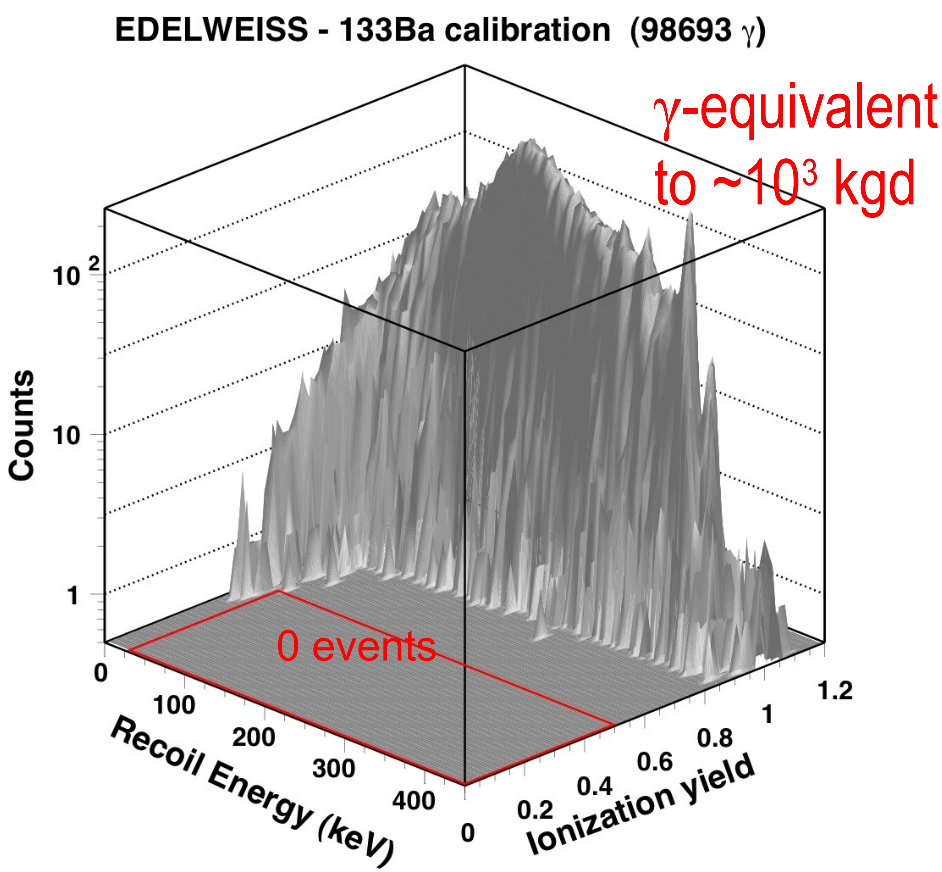
46 keV ray line (0.5mm depth)

Fiducial volume
« ***Veto + guard*** » cut (red points) +
« ***E2 = E1***» criterium (blue box) :
strong redundancy !

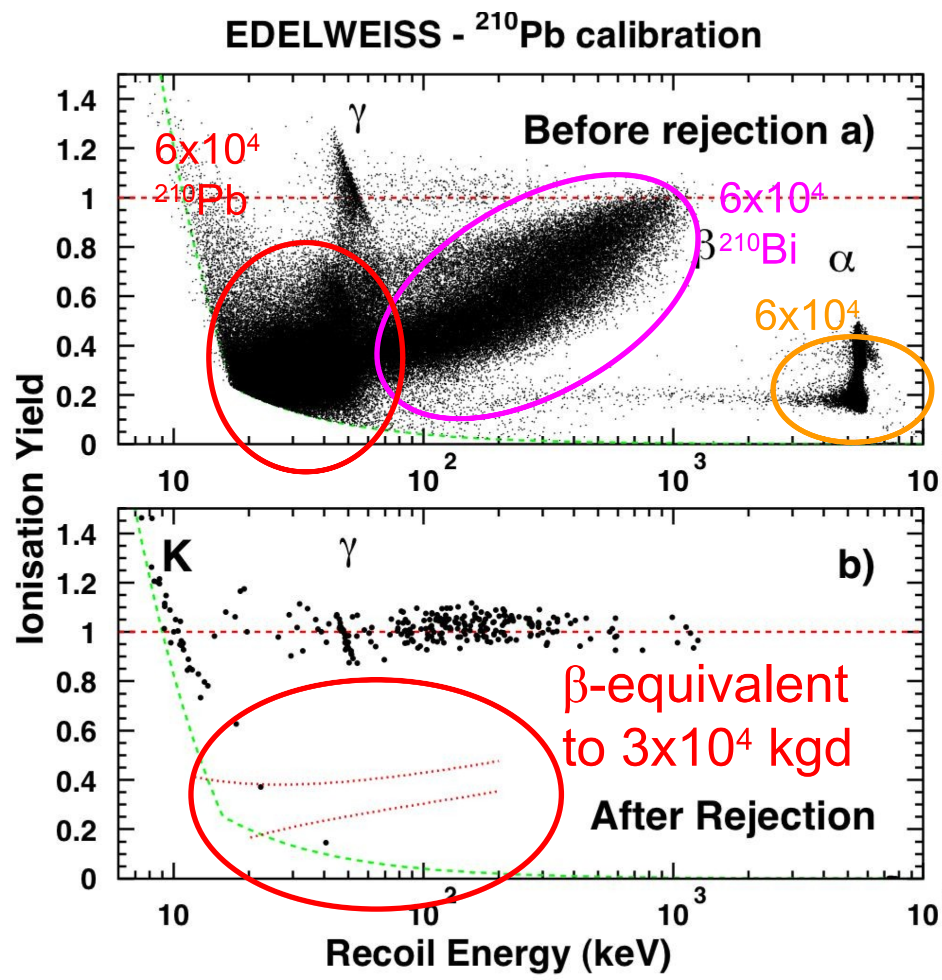
Surface and volume events are completely separated !
Overall rejection $1/10^5$

ID detector rejection

- Gamma rejection of 400g
  - ~1 month calibrations



- Beta rejection of 200g

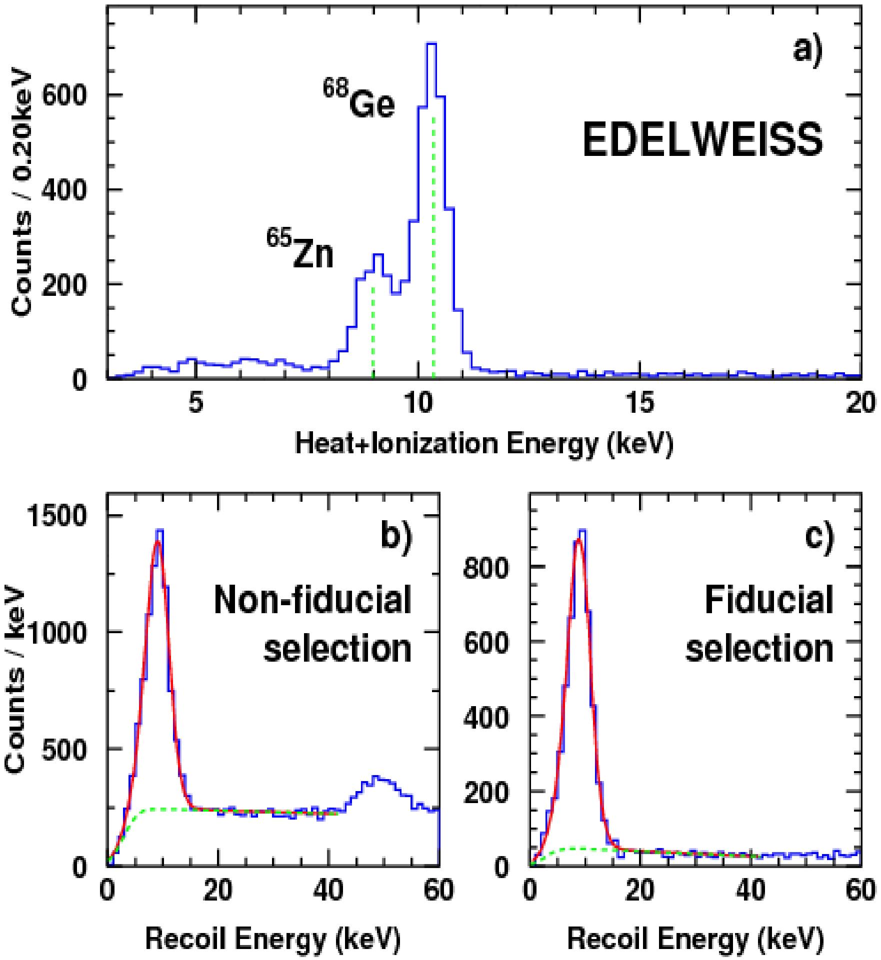


Fiducial volume measurement

- Cuts based on ionization signals only (FidIon1=FidIon2, all other electrodes consistentt with noise)
- Measurement with cosmogenic lines:
  - ^{68}Ge and ^{65}Zn isotope lines at 9.0 and 10.4 keV
  - Homogeneously distributed in the volume of the cristal
  - Real-condition measurement of fiducial cuts efficiencies at low energy in WIMP search conditions (baselines, voltages…)
- Fiducial volume = 166g ± 6

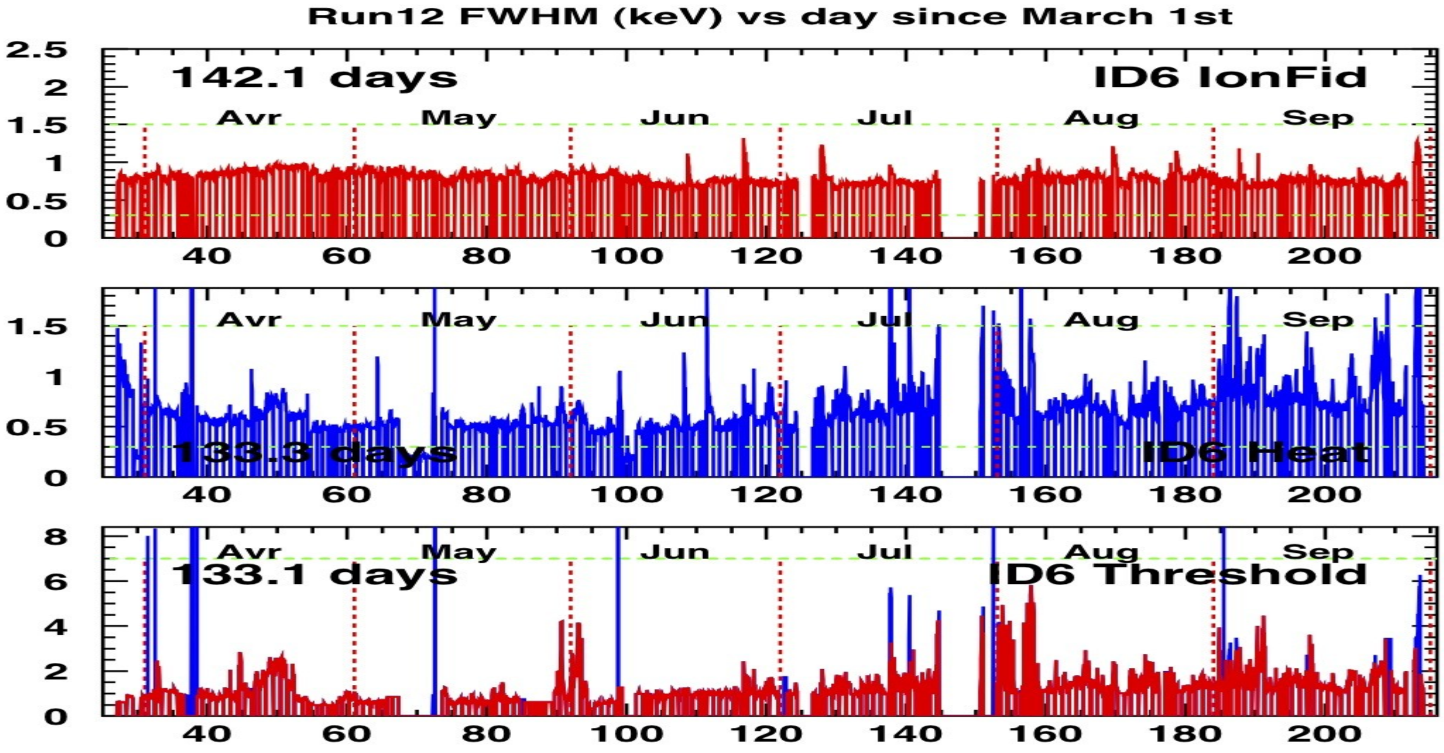
  => 160g, conservative value

  consistent with estimations based on neutron calibration data



First WIMP search with ID detectors

- 10 ID (400 g units, 160g fiducial) tested/built/installed/run in 2008-2009
- First assessment of technology in real physics run: 144 kgd / ~6 months
  - Reliability: 9/10 detector used for physics
  - >50% physics running efficiency (wrt to 186 days x 1.6 kg_fiducial)
  - *Average resolutions*: σ ~ 400 eV ionization, 500 eV heat



Data analysis of first 6 months

- Two independent processing pipelines

  WIMP search threshold fixed a priori

  Erecoil > 20 keV

  20 keV recoil far from efficiency thresholds (full efficiency achieved with ~3 keV ionization and ~7 keV heat thresholds):

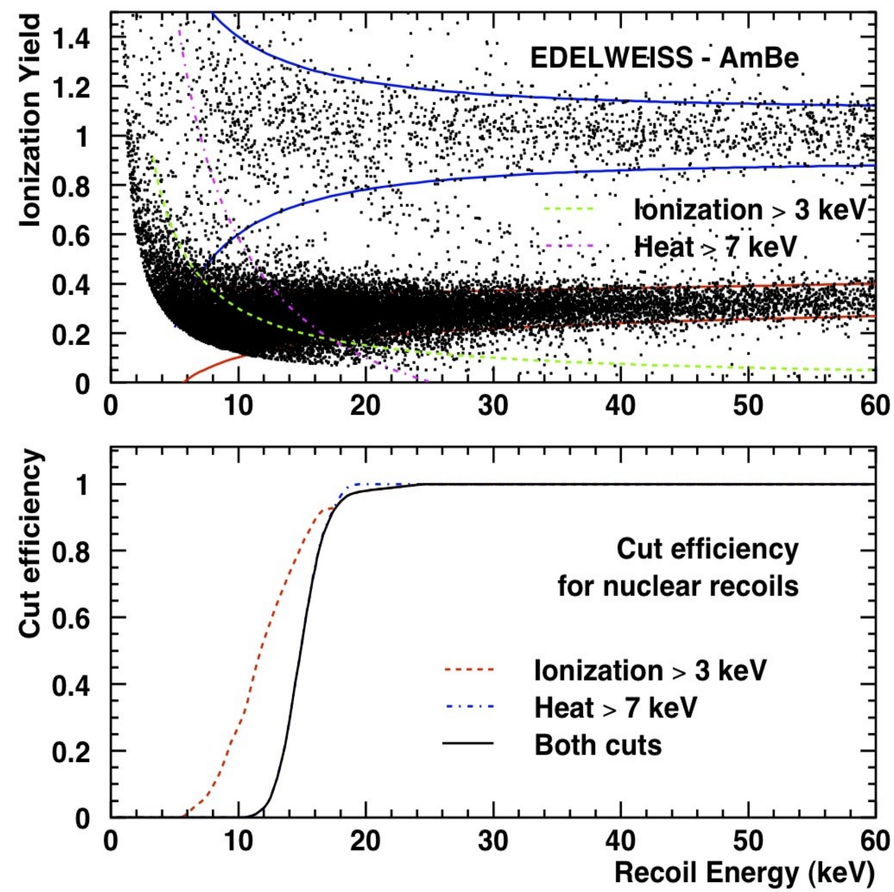
  robust results independent of analysis details

- Period selection based on baseline noises

  → **80% efficiency**
- Pulse reconstruction quality (chi2)

  → 97%
- **Fiducial cuts** based on ionization signals (160g)
- ε = 90% **nuclear recoil, gamma rejection** 99.99%
- Bolo-bolo & bolo-veto coincidence rejection (ε >99%)

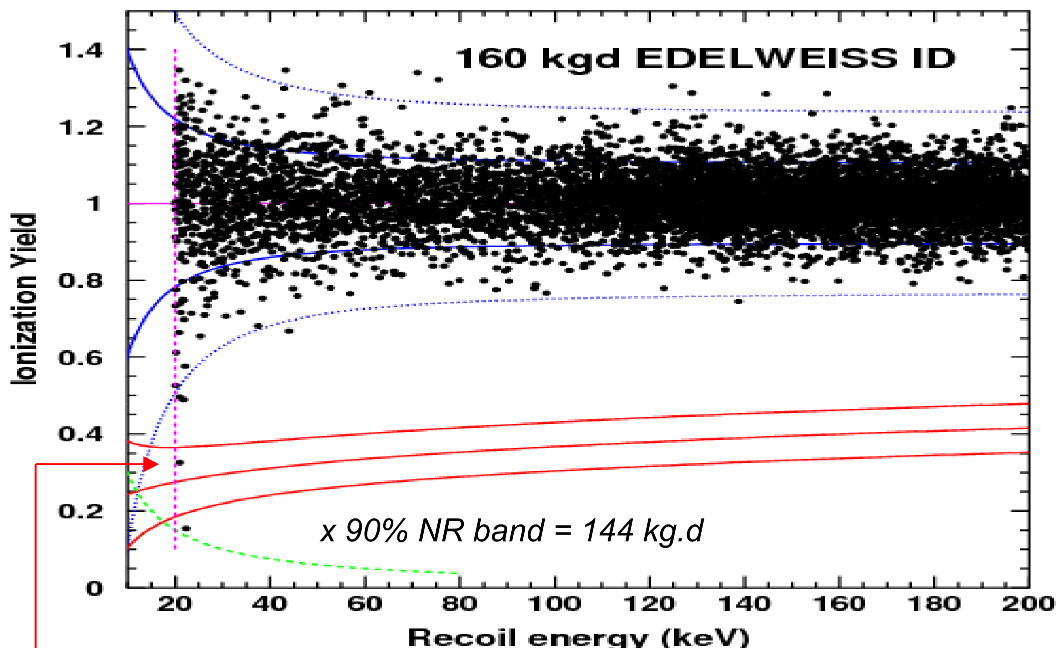
All detectors – neutron calibration



Agreement between the results the two analyses

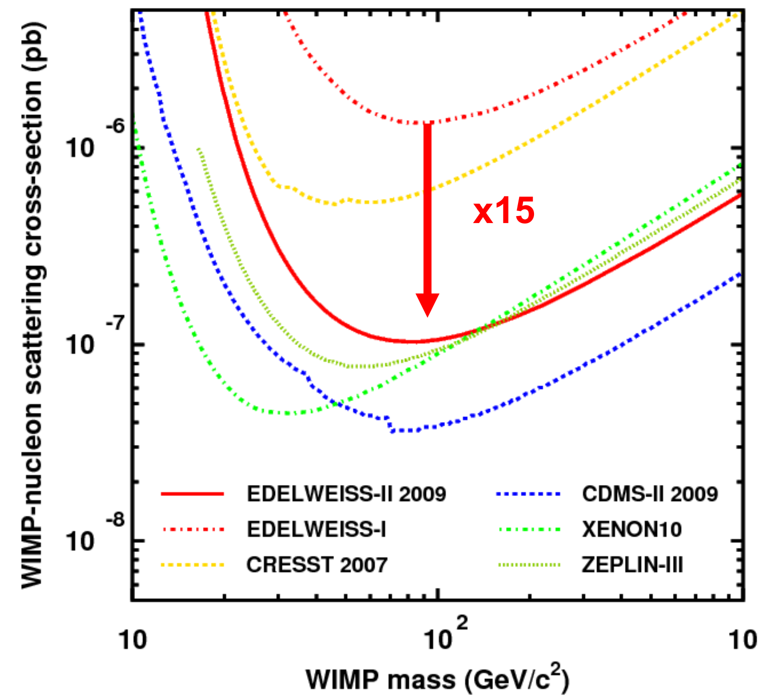
EDELWEISS-II: First Results

Background reduced wrt EDELWEISS-I by a factor 50



« WIMP candidate »
Er = 21 keV

arXiv:0912.0805s



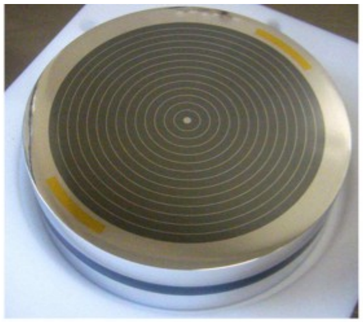
End of January:
~ x1.75 exposure,
Run continues
until spring

Background estimation from previous calibrations/simulations:

- gamma < 0.01 evt (99.99% rejection)
- beta ~ 0.06 evt (from ID201 calibration+obs. surf. evts)
- neutrons from ^{238}U in lead < 0.1 evt
- neutrons from $^{238}U+(\alpha,n)$ in rock ~ 0.03 evt
- neutrons from muons < 0.04 evt

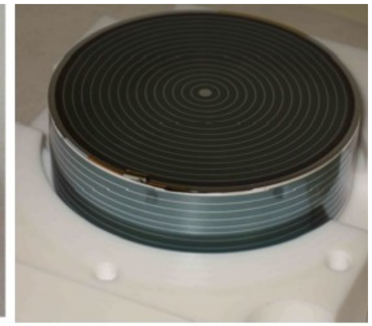
} < 0.23 evt

Increasing the fiducial volume



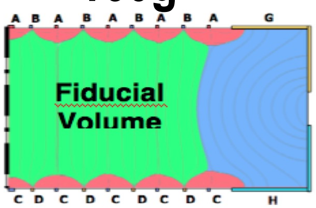
ID401 to 405:
Φ 70mm, H 20mm, 410g

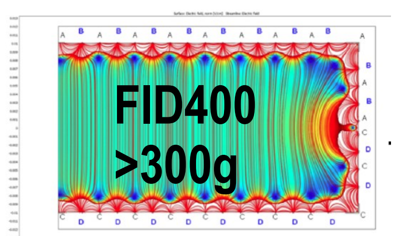
ID2 to ID5:
Φ 70mm, H 20mm, 410g

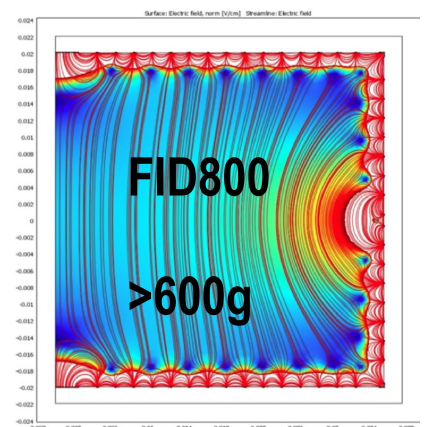


FID401 and FID402:
Φ 70mm, H 20mm, 410g

ID400
160g

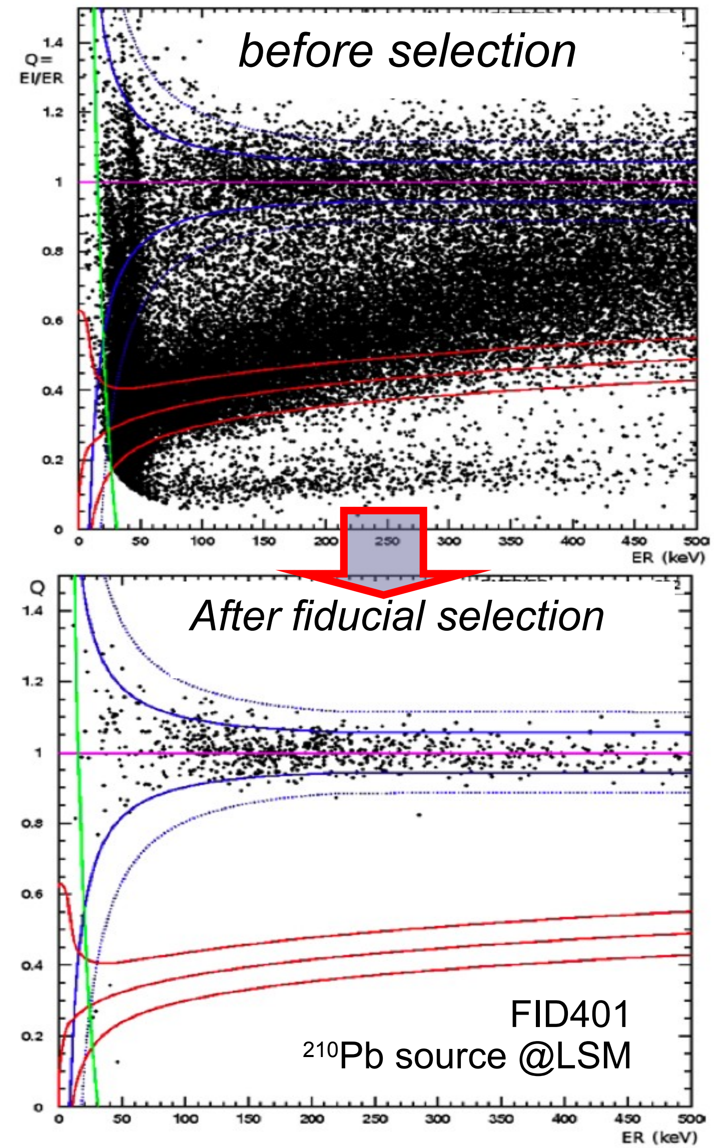






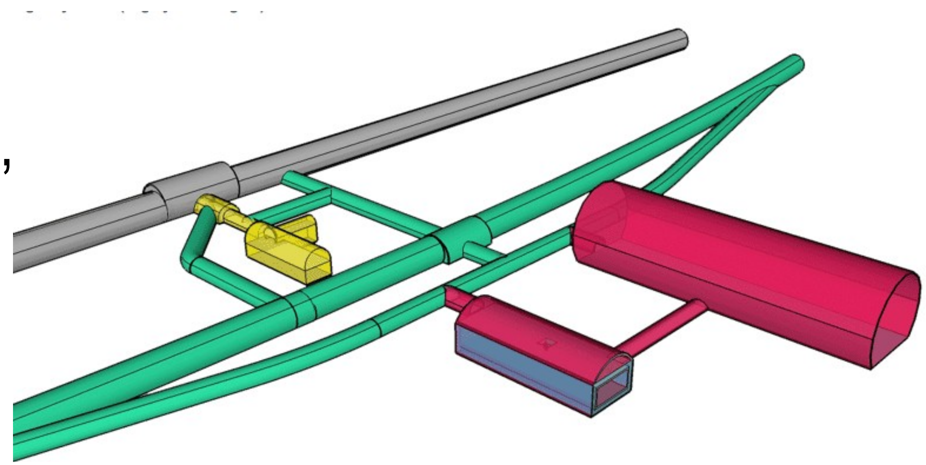
Doubling/Quadrupling the fiducial mass:
ID400 => FID400 => FID800

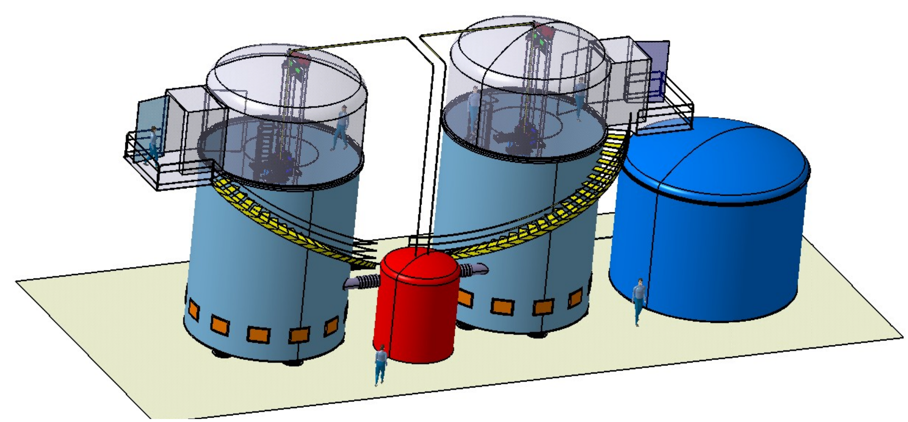
FID beta rejection @ LSM :
4/68000 for E>25keV



Future: EURECA

- EURECA: beyond 10^{-9} pb, major efforts in background control and detector development
- Joint effort from teams from EDELWEISS, CRESST, ROSEBUD + others…
- >>100 kg cryogenic experiment, multi-target
- Part of ILIAS/ASPERA European Roadmap
- Preferred site: 60 000 m^3 extension of present LSM, to be dug in 2011-2012





Conclusions/Outlook

- Significant reduction in α, β and γ backgrounds relative to EDELWEISS-I
- New generation ID detectors
  - Robust detectors with redundancy and very high beta rejection
  - First 160kg.d => WIMP limit @ 10^{-7}pb, 1 evt observed
  - X2 exposure in Spring (+lower thresholds & improved bkg estimations)

- Prototype of ID detectors with larger fiducial volumes currently tested (FIDs 400g+800g) with goals:
  - 2011 = 1000 kg.d
  - 2012 = 3000 kg.d
- Long term: EURECA (European Underground Rare Event Calorimeter Array): beyond 10^{-9} pb, major efforts in background control and detector development

Thank you