Dark matter searches in Europe
Recent results, prospects, future projects

Gilles Gerbier- CEA Saclay/IRFU

ASPERA UGL workshop
Zaragoza june 30th 2011

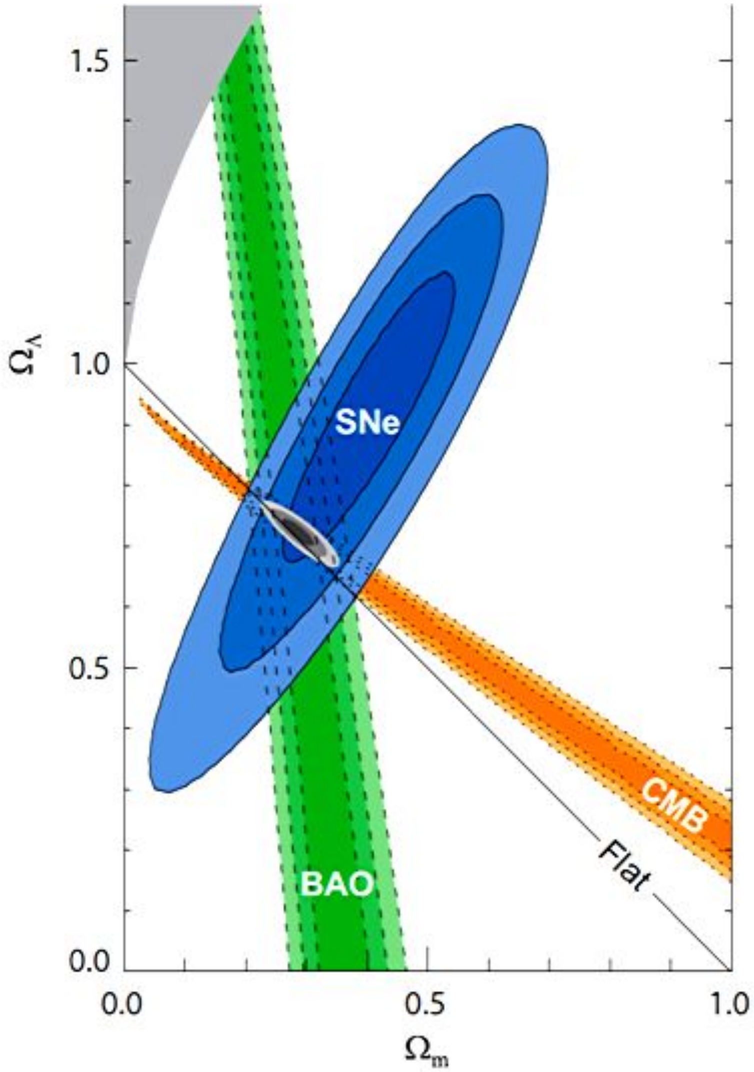
NB

- Xenon @ Gran Sasso not covered here, being “US led” project, covered by C Galbiati

Outline

- Introduction
- Overview
- Status and prospects of currently running experiments
  - **DAMA** & low mass WIMP
  - **CRESST**, ZeplinIII, **Simple**, **Edelweiss**, **Edelweiss-CDMS**
- Other detectors
  - **DRIFT**, MiMac, Cygnus
  - ArDM, (Warp)
- Future large scale -1 t, multi t- projects
  - EURECA
  - Darwin, Cygnus

Which dark matter for ΛCDM ?



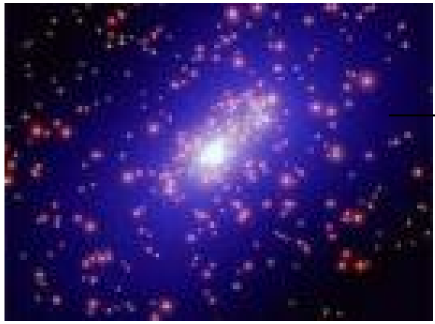
- New field(s) of « gravitationnal » nature = modified gravity (MOND etc)
  - justified by obs. galactic dynamics + Λ + …
  - no convincing theory yet

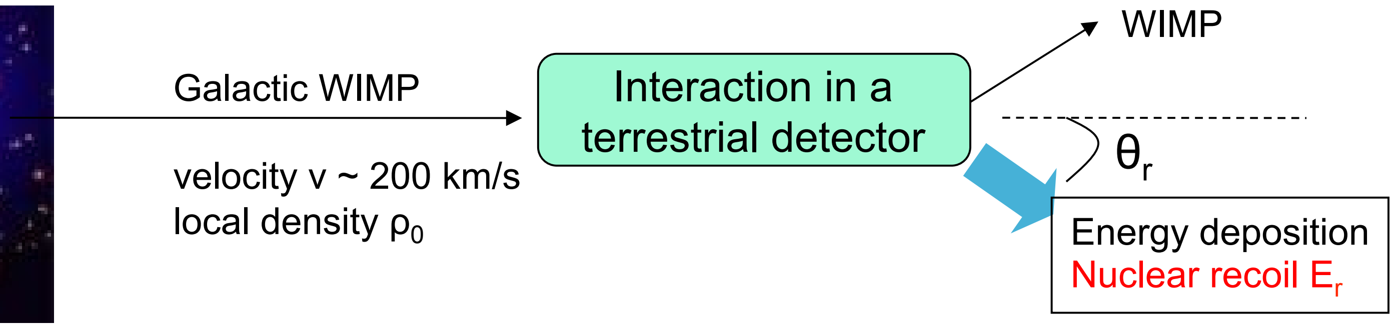
- New « particle-like » field(s), many possibilities among which:

- « SuperWIMPs » eg. gravitino, axino (SUSY)
- Supermassive relics (M_{Pl})
- Axions : Peccei-Quinn axions (QCD) or ALPs

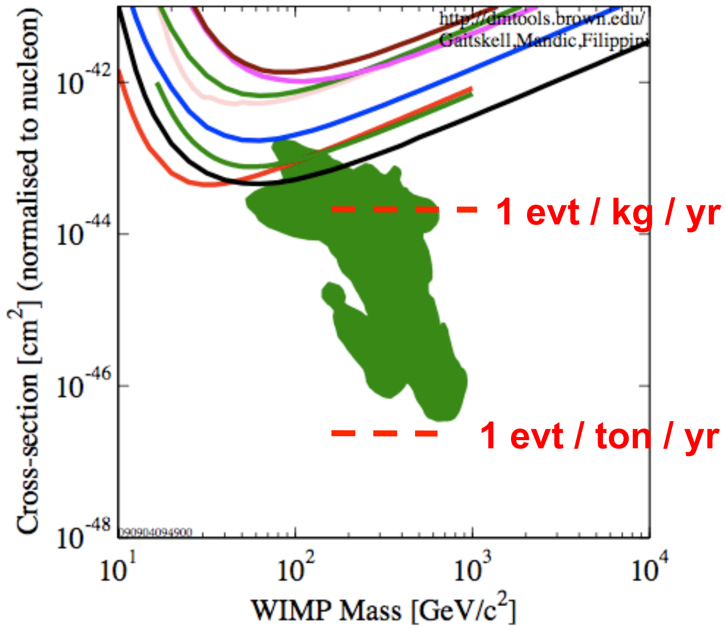
- The « WIMP miracle » : *thermal relic hypothesis* :
  $\Omega_{DM}\sim 0.3 \Rightarrow \langle\sigma_{ann}v\rangle \sim 3\times10^{-26}$ cm^3/s weak interactions, M~100 GeV (Weakly Interacting Massive Particles)
  - neutralino [SUSY models]
  - LKP [UED models]
  - …

Principle of WIMP direct detection





- Relevant parameters:
- **mass m_χ ~ 10 GeV to 10 TeV** for usual extensions of the Standard Model
- **WIMP-nucleon cross-section σ**, weakly contrained but of the order of EW scale



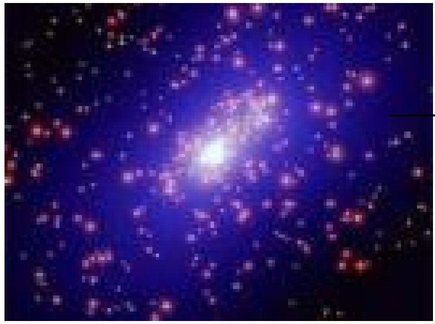
- Non-relativistic diffusion:

$$E_r = \left(\frac{m_\chi}{2} v^2\right) \times \frac{4 m_N m_\chi}{\left(m_N + m_\chi\right)^2} \times \cos^2 \vartheta_r \sim 1 - 100 \text{ keV}$$

- Interaction rate:

$$R \sim \frac{\rho_0 \sigma v}{m_\chi m_N} \sim 0.04 \left(\frac{100}{A}\right) \left(\frac{100\,GeV}{m_\chi}\right) \left(\frac{\sigma_0}{10^{-8}\,pb}\right) \left(\frac{\rho_0}{0.3\,GeV\,cm^{-3}}\right) \left(\frac{v_0}{230\,km\,s^{-1}}\right) kg^{-1} day^{-1}$$

Principle of WIMP direct detection



Galactic WIMP

velocity v ~ 200 km/s
local density ρ_0

Interaction in a terrestrial detector

WIMP

θ_r

Energy deposition
Nuclear recoil E_r

• Relev
- mass
extens
- WIMI
contrai

• Non-r

$E_r = \Big(\frac{m}{\ }$

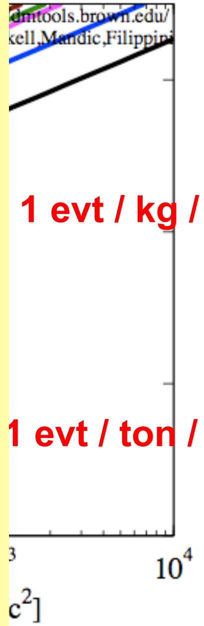
• Inter

$R \sim \frac{\ 0}{m\ \ m}$

• **Low-threshold detectors**
• **Ultra-low-background detectors :**

- « Passive » bckgd reduction (shields, radiopurity, external vetos..)
- « Active » bckgd reduction (discrimination of electron recoils, multiple scatters..)

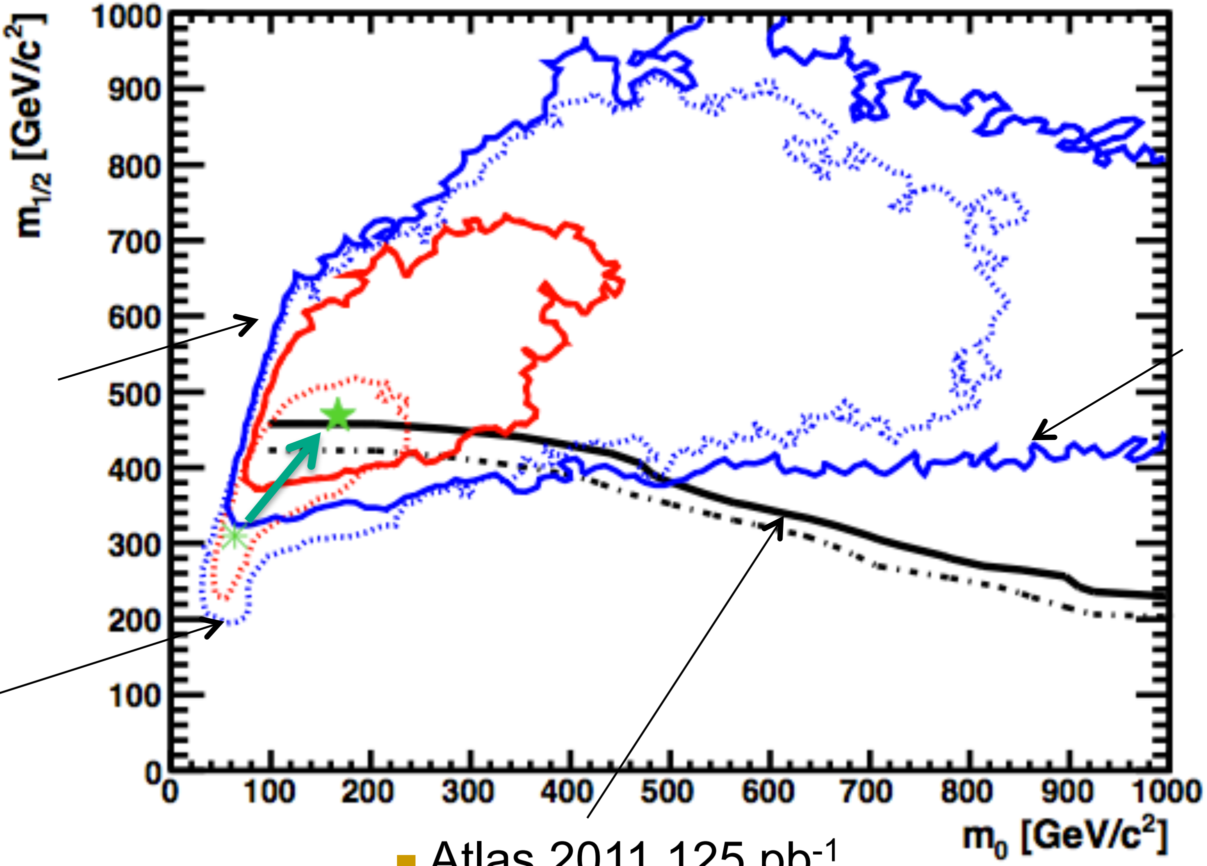
• **We consider only the « spin-independent » channel here → single WIMP-nucleon cross-section ∀ target**



LHC constraints on CMSSM $m_{1/2}$ vs m_0

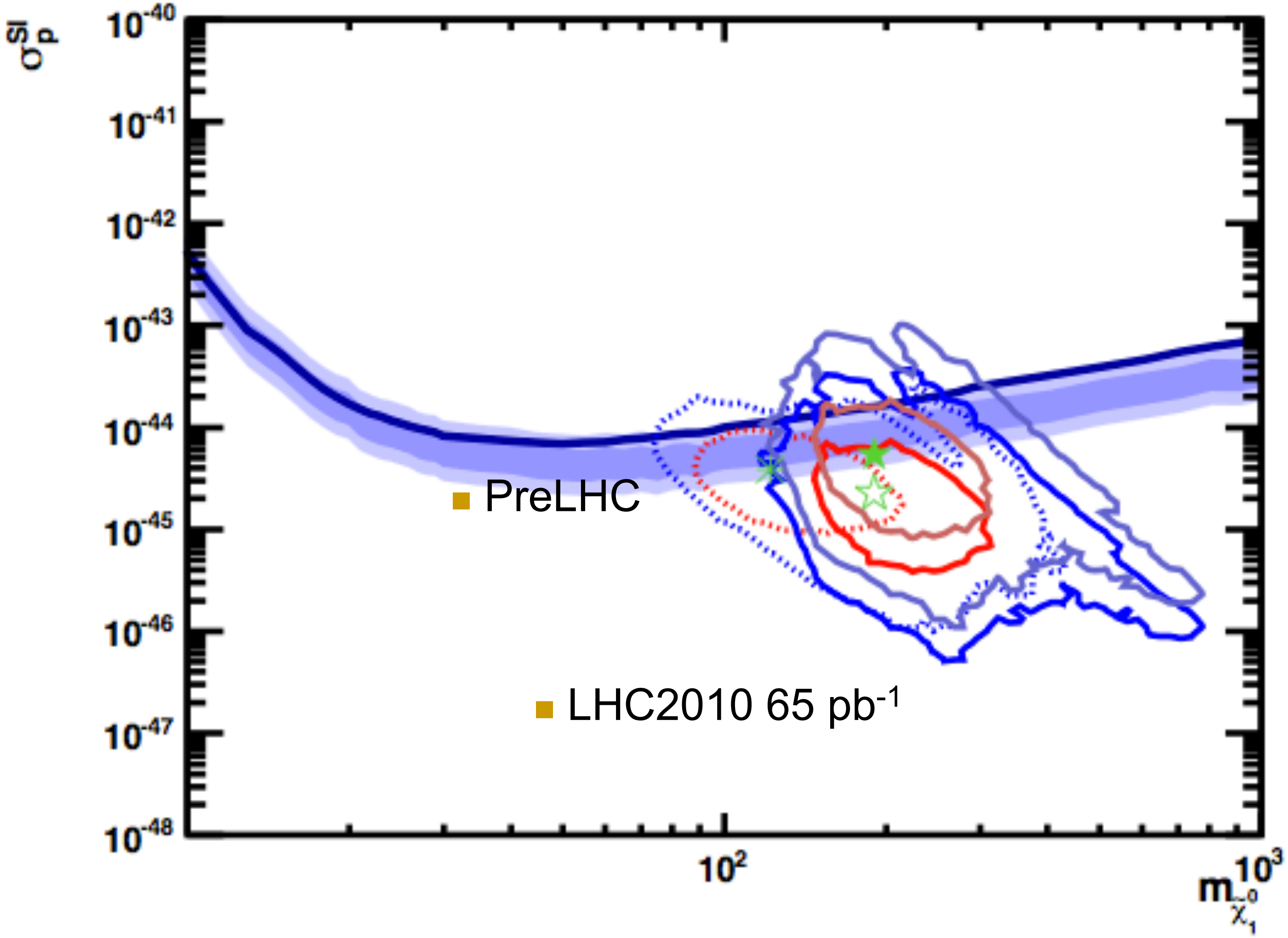
Ellis arXiv:1106.2923v1

- Xenon 100 + LHC2010 65 pb^{-1}



- PreLHC
- Atlas 2011 125 pb^{-1}

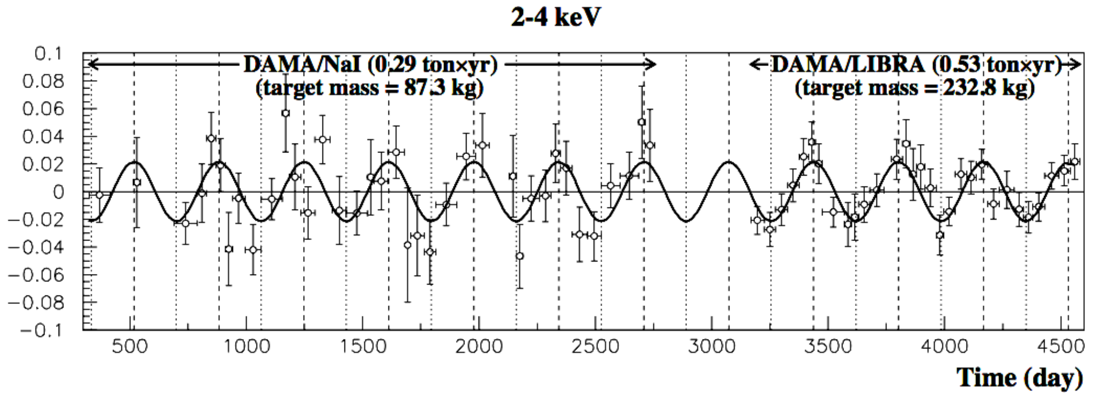
CMSSM models in σ vs M_{wimp}

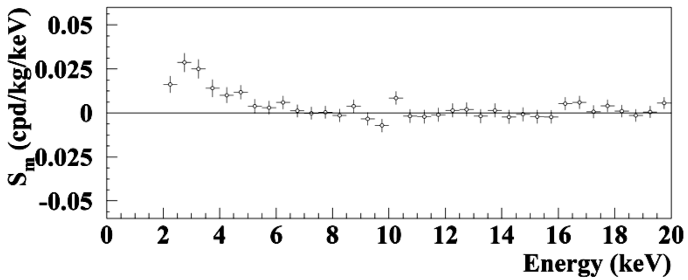


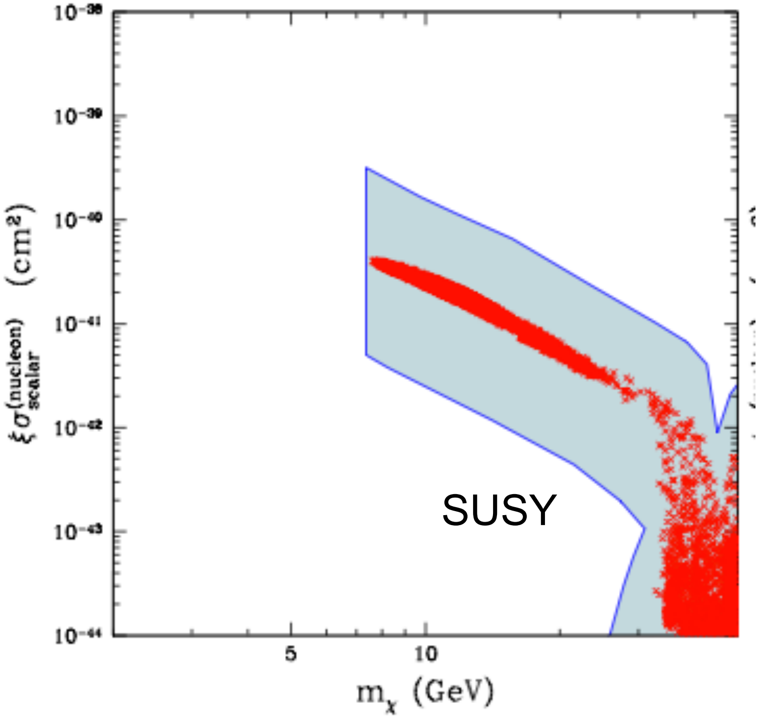
DAMA, 250 kg NaI(Tl) @ Gran Sasso

- Last paper : arXiv:1106.4667v1 "Observations of annual modulation in direct detection of relic particles and light neutralinos"

models and by taking into account the impact of various experimental uncertainties. It is shown that the DAMA and the CoGeNT regions agree well between each other and are well fitted by a supersymmetric model with light neutralinos which satisfies all available experimental constraints, including the most recent results from CMS and ATLAS at the CERN Large Hadron Collider.







DAMA

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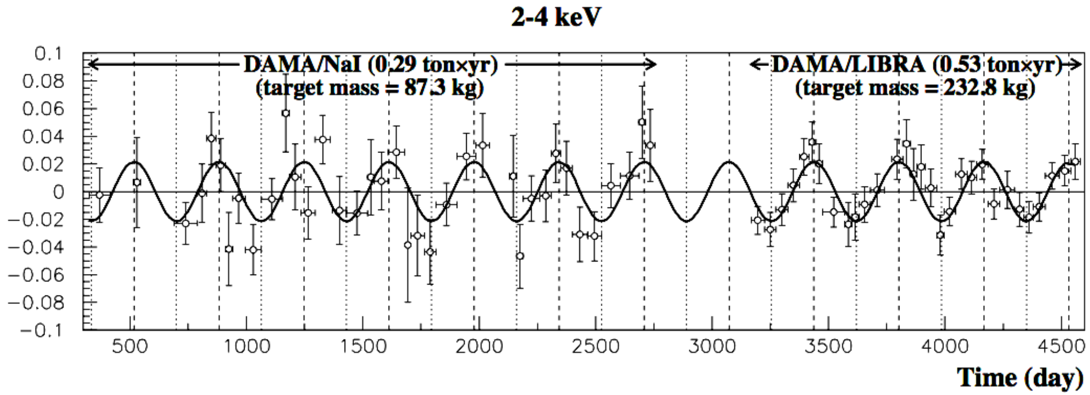
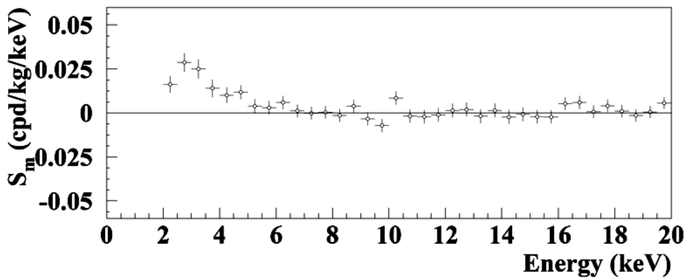
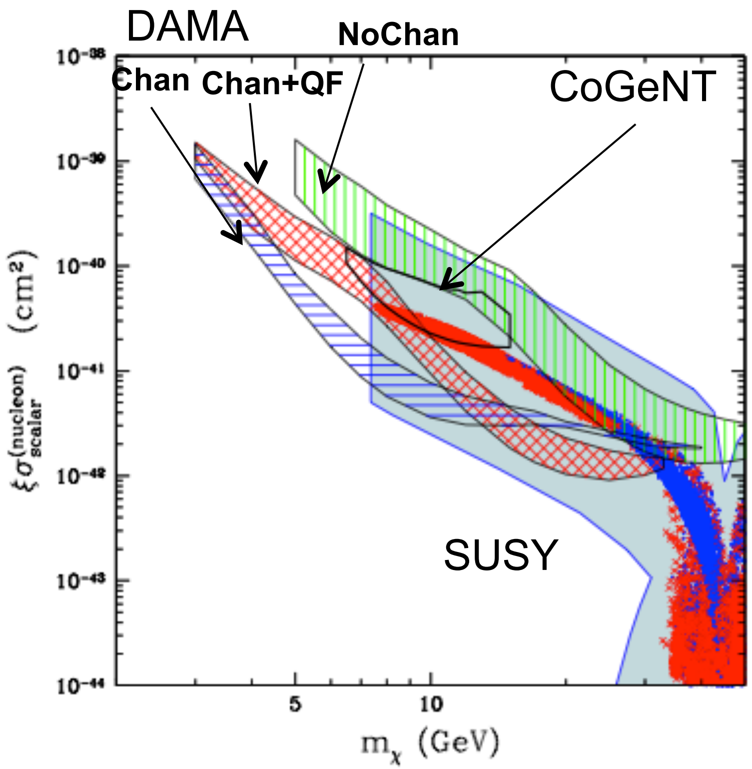






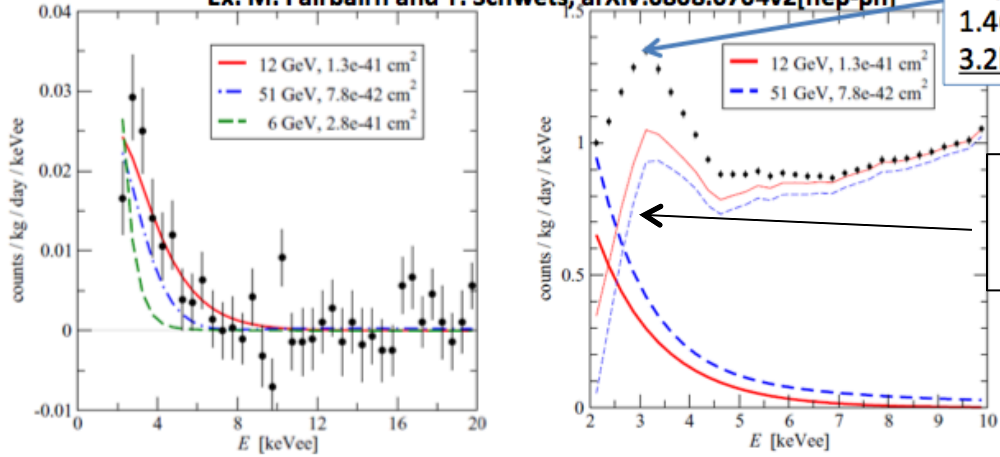
But if Na recoils, unanswered question : “unnatural” background shape

arXiv:0808.0704v2

S_0 (E)

It is not simple: ‘inversion problem’ -- depends on dark matter model, DM mass, halo model, velocity spread, local density, interaction **and so on, but**

Ex. M. Fairbairn and T. Schwets, arXiv:0808.0704v2[hep-ph]



^{40}K
EC(10%): de-excit. γ
1.46MeV (escape)
3.2keV Auger

Unphysical background shape

- In most of the case, S_0(E) monotonically goes down as energy increase, then backgrounds sharply goes down below 3~4 keV.

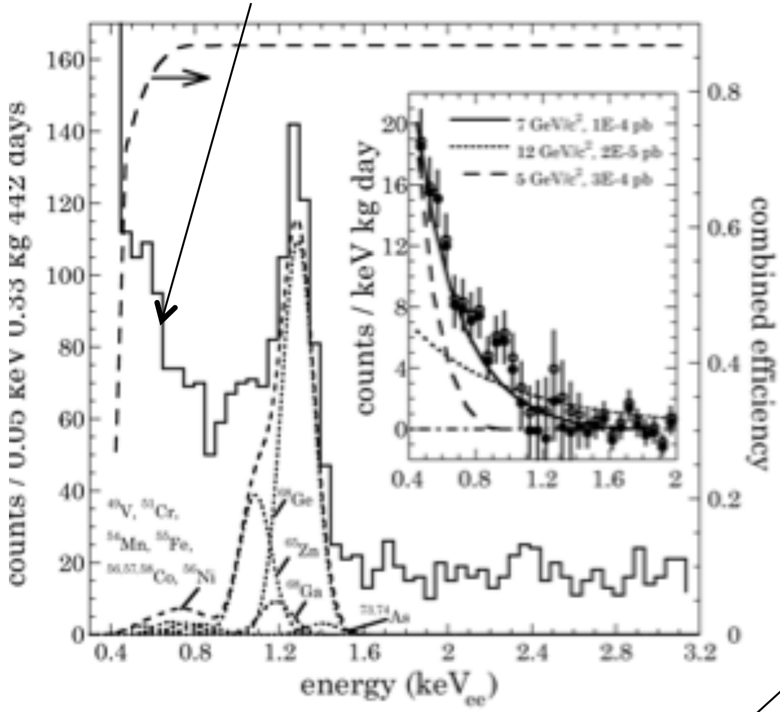
➔ **This is unnatural !. This must be explained.**

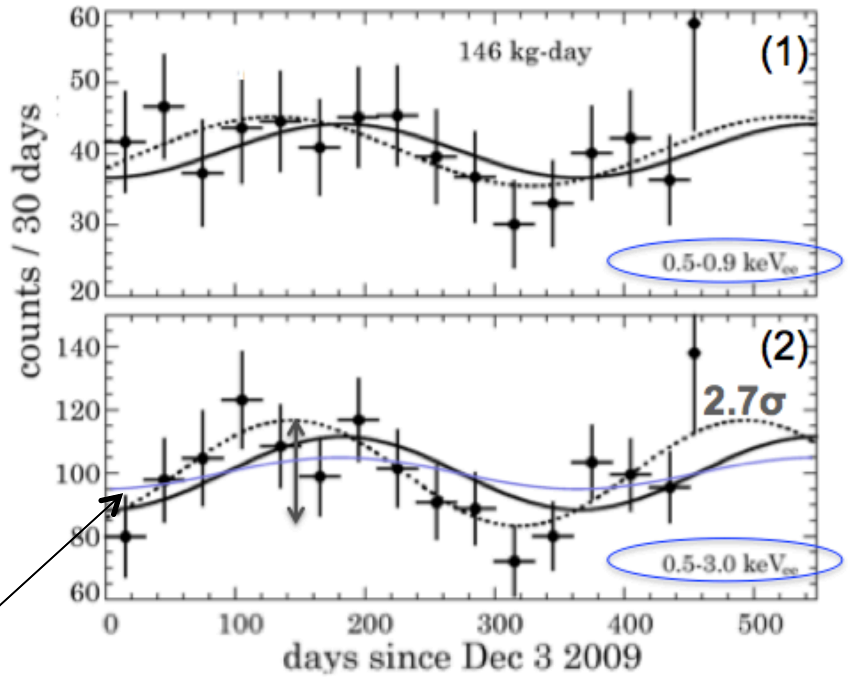
Compatibility with CoGeNT ?

arXiv:1106.0650v1

- 1) Within constraint of spectrum, not much to play with M $_{wimp}$ with

WIMP is here





- 2) Error in the 7 GeV WIMP prediction in 0.5-3 keV bin, blue curve ok
- No compatibility of observed modulation with WIMP (Schwetz @ PPC2011)
- Compatibility with DAMA requires QF_{Na} excluded by data

CRESST

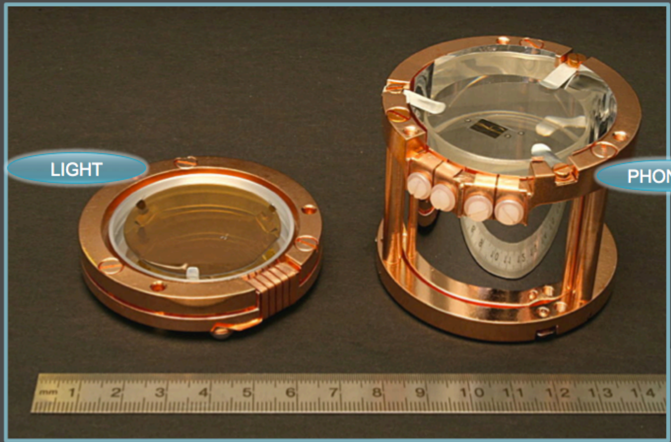
THE CRESST EXPERIMENT

R. Strauss,
TU Munich,
on behalf of the CRESST collaboration.

Patras Workshop,
30.06.2011

CRESST Detector Module

- Light detector: Silicon-on-Sapphire (threshold ~20eV)
- Phonon detector: 300g $CaWO_4$ crystal (threshold ~500eV)



Run 32 – An Overview

- **Runtime:** June 2009 till April 2011
- **Net exposure** (after cuts): >700kg-days
- 10 detector modules running
- Various neutron calibration campaigns
- All results preliminary. Final analysis @TAUP2011

F. Petricca

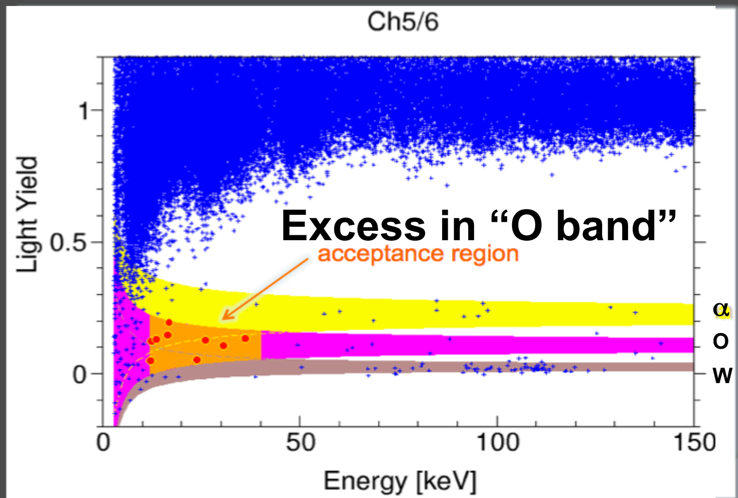
2011 MUNICH TAUP

➤ First extensive physics run of CRESST II

But:

- **Additional backgrounds !!!**

Run 32 – Additional Backgrounds



One typical detector module

Quantitative Background Analysis

preliminary

Likelihood analysis including:
- all backgrounds
- calibration measurements
- multiplicities
- possible WIMP signal

Backgrounds in preliminary dataset (~50 events):

α events	16 %
neutron events	30 %
e-/γ events	15 %

room for signal: 39 %

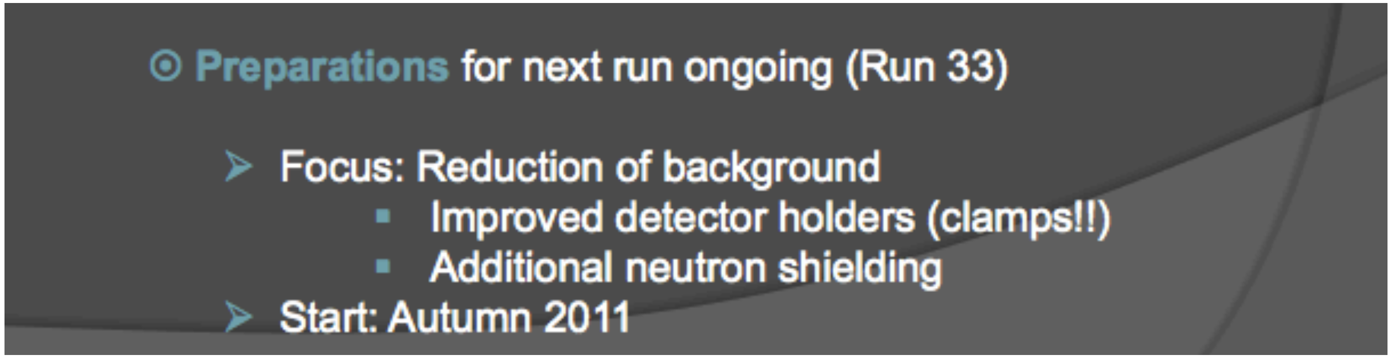
Possible solution for a WIMP signal:

$\sigma_\chi \sim 10^{-5}$ pb

$m_\chi \sim 13$ GeV

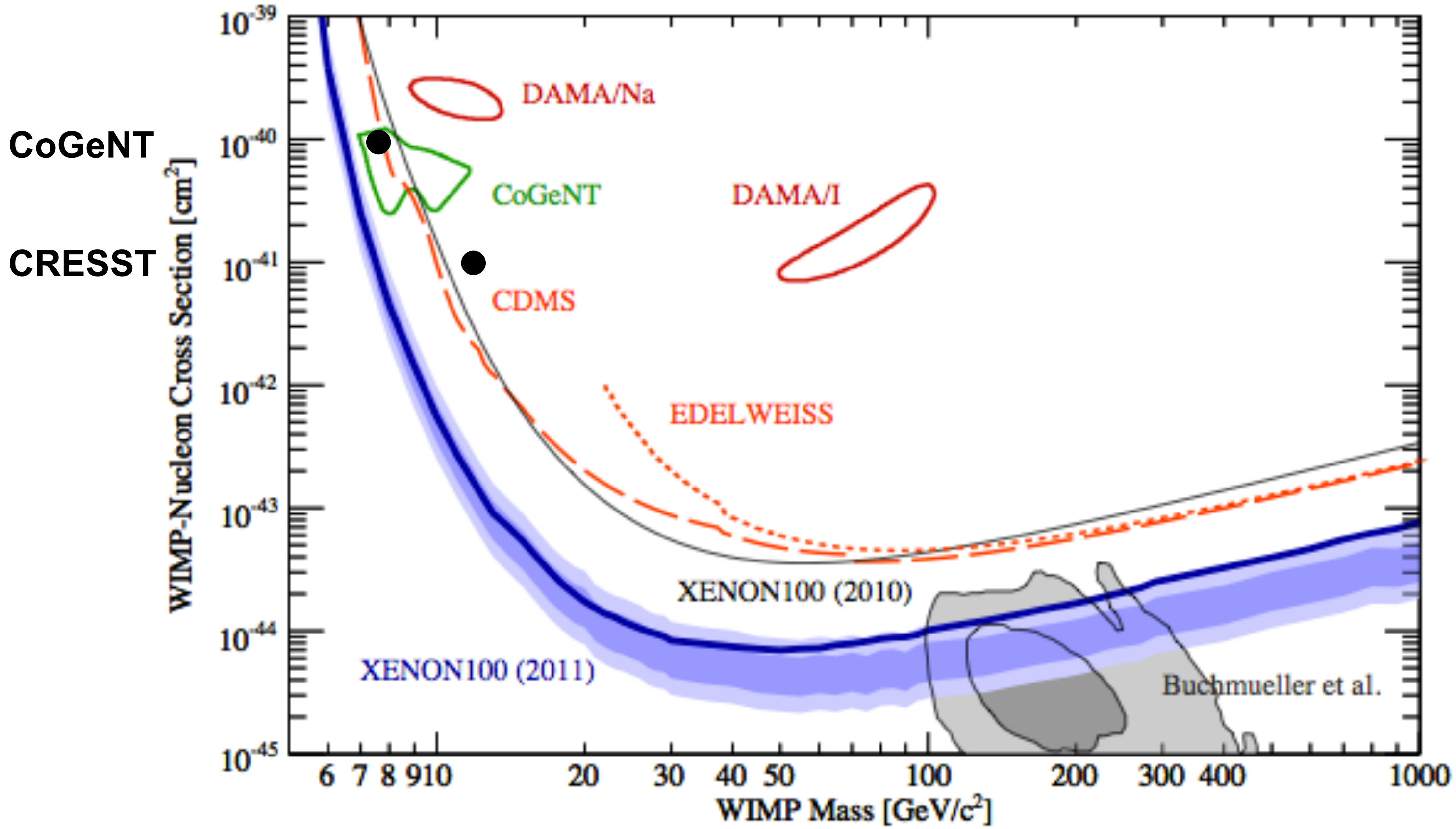
Final analysis @ 2011 MUNICH TAUP

CRESST : prospects

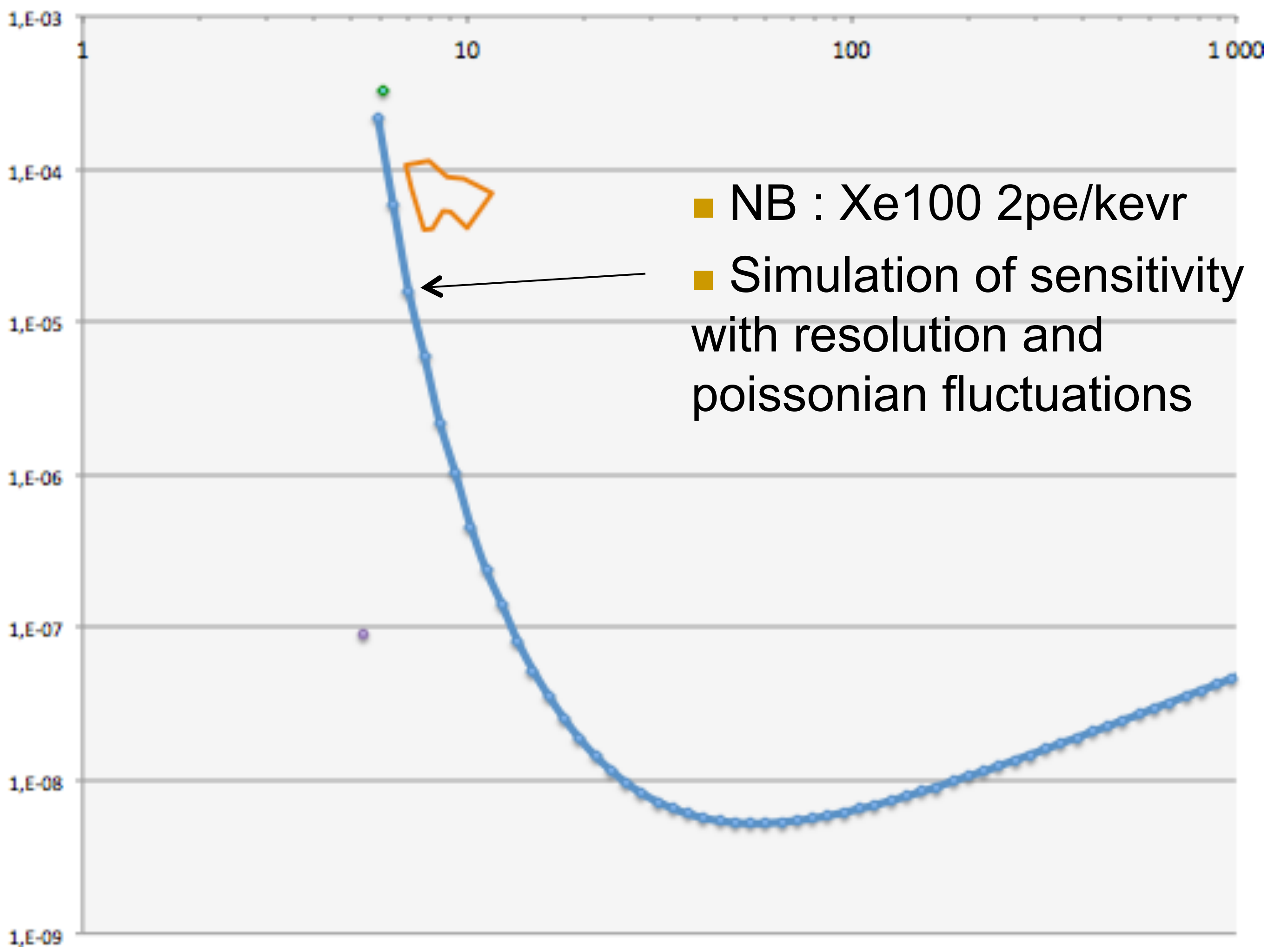


- CRESST III : 20 kg of $CaWO_4$ in upgraded cryostat, not funded

Updated picture : june 2011



About Xenon100 sensitivity at M<10 GeV

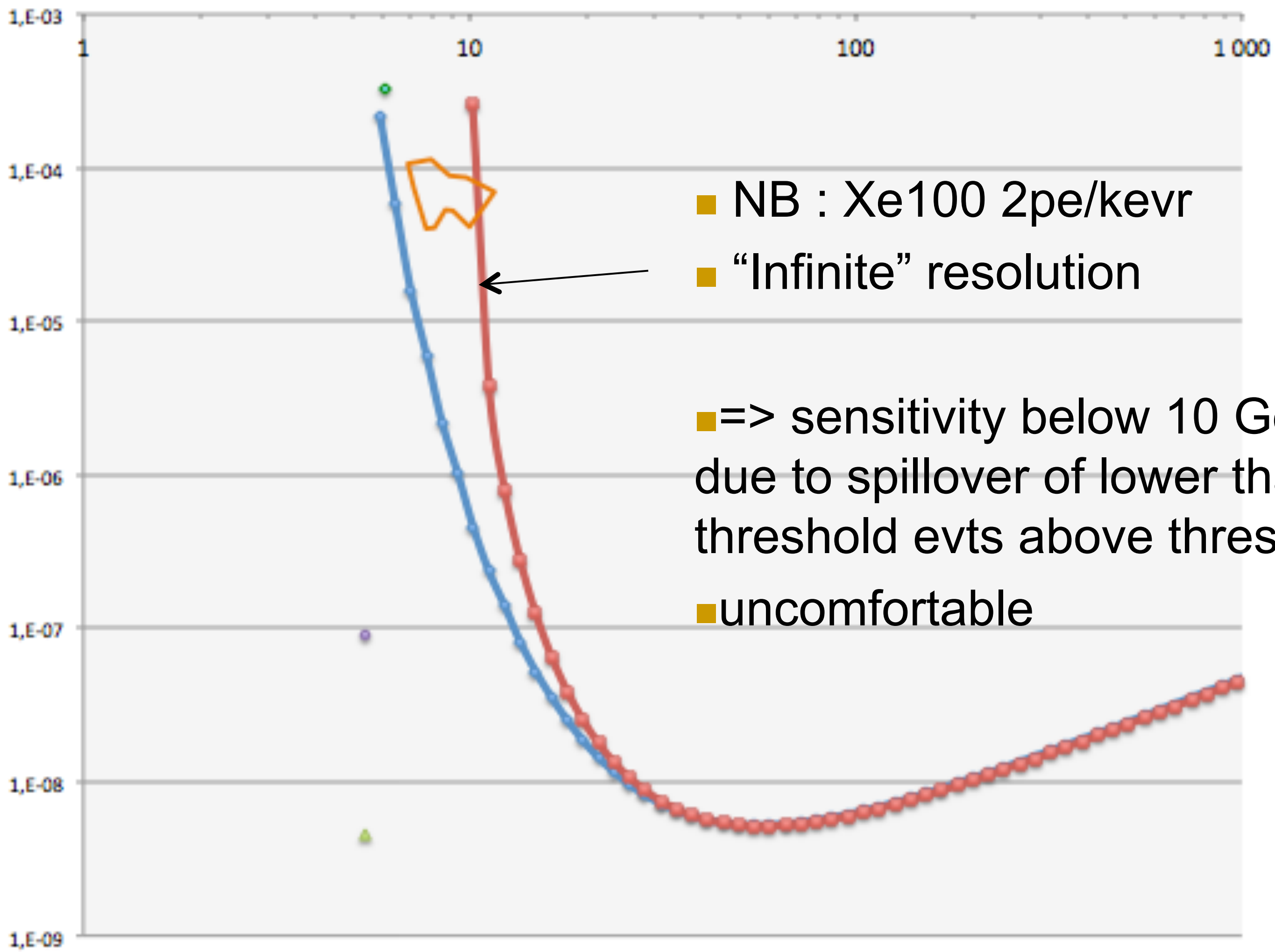


- NB : Xe100 2pe/kevr
- Simulation of sensitivity with resolution and poissonian fluctuations

- Low mass sensitivity

About Xenon100 sensitivity at M<10 GeV

1)



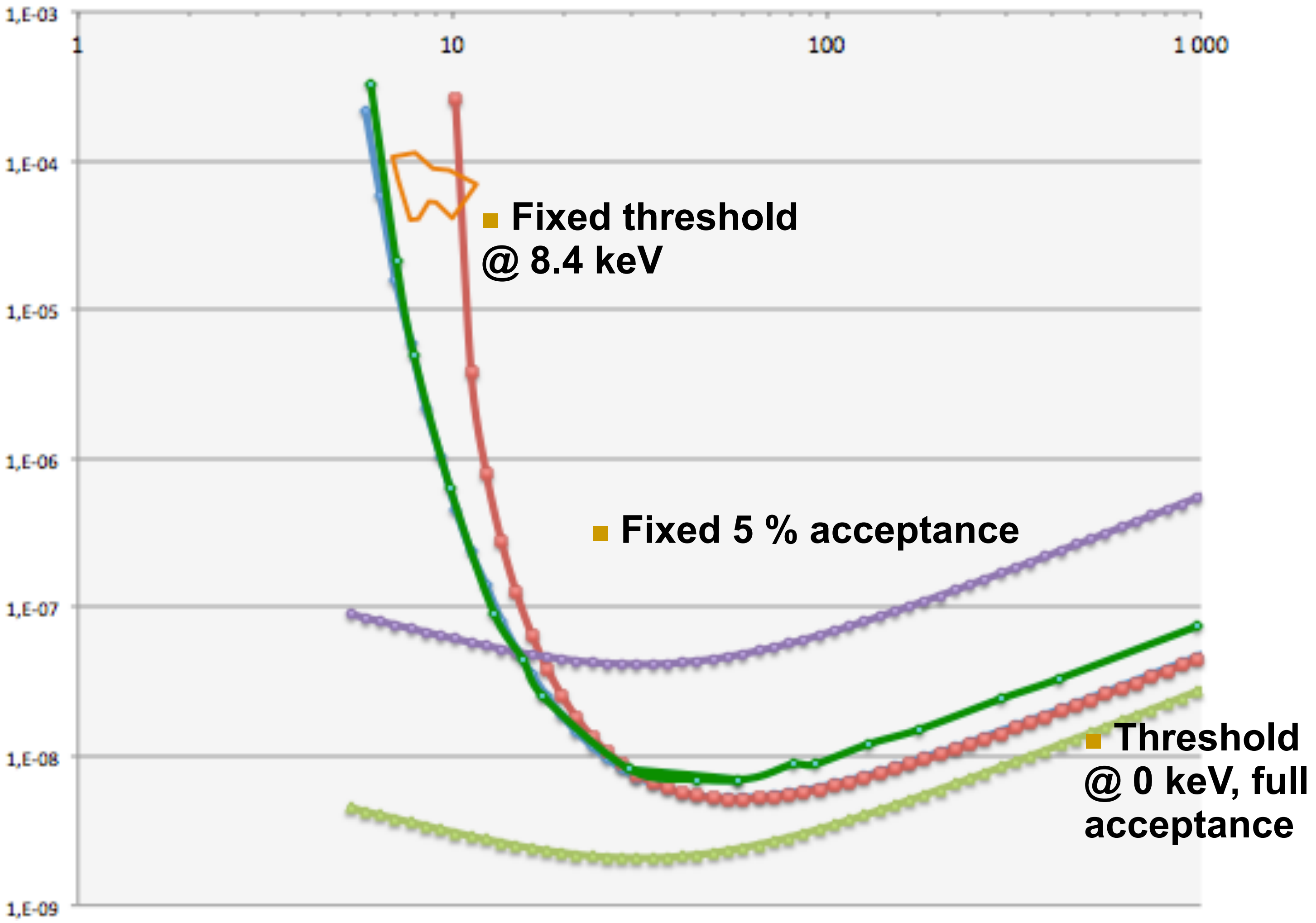
- NB : Xe100 2pe/kevr
- "Infinite" resolution

- => sensitivity below 10 GeV due to spillover of lower than threshold evts above threshold
- uncomfortable

- At low mass, Xenon sensitive to E<Ethresh

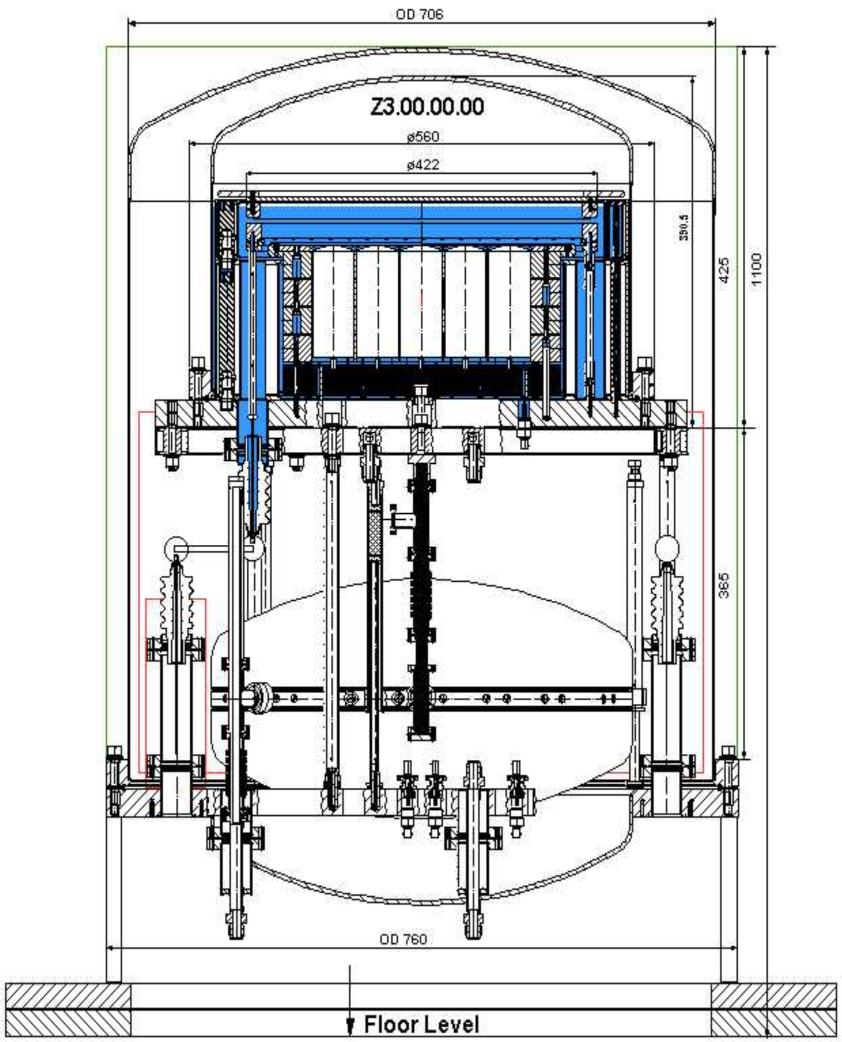
About Xenon100 sensitivity at M<10 GeV

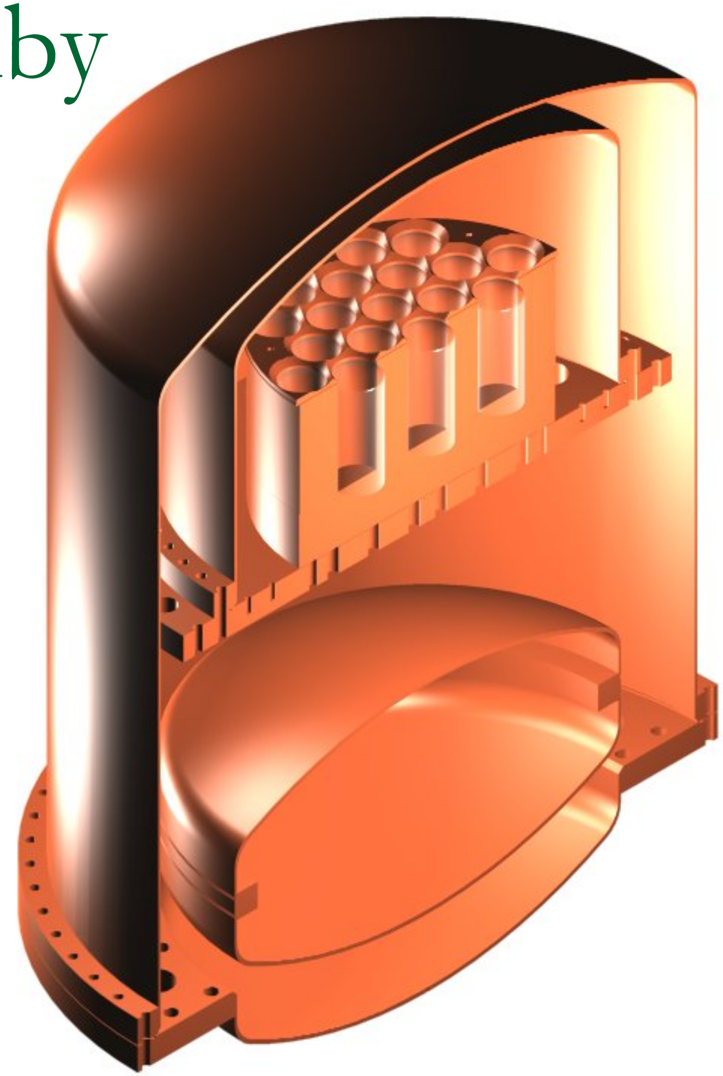
2)



- At low mass, Xenon sensitive to the tail of E distribution

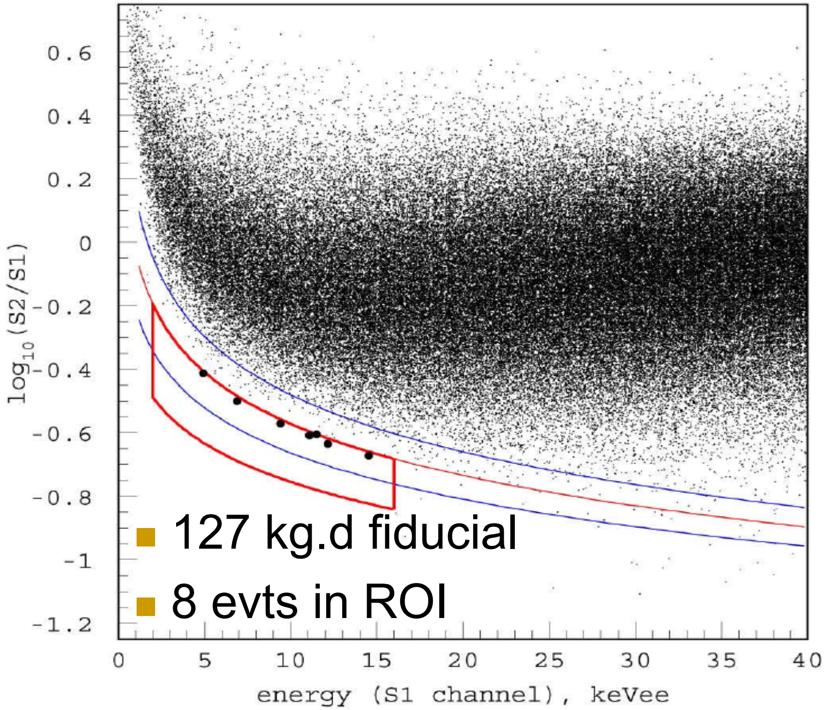
ZEPLIN III @ Boulby



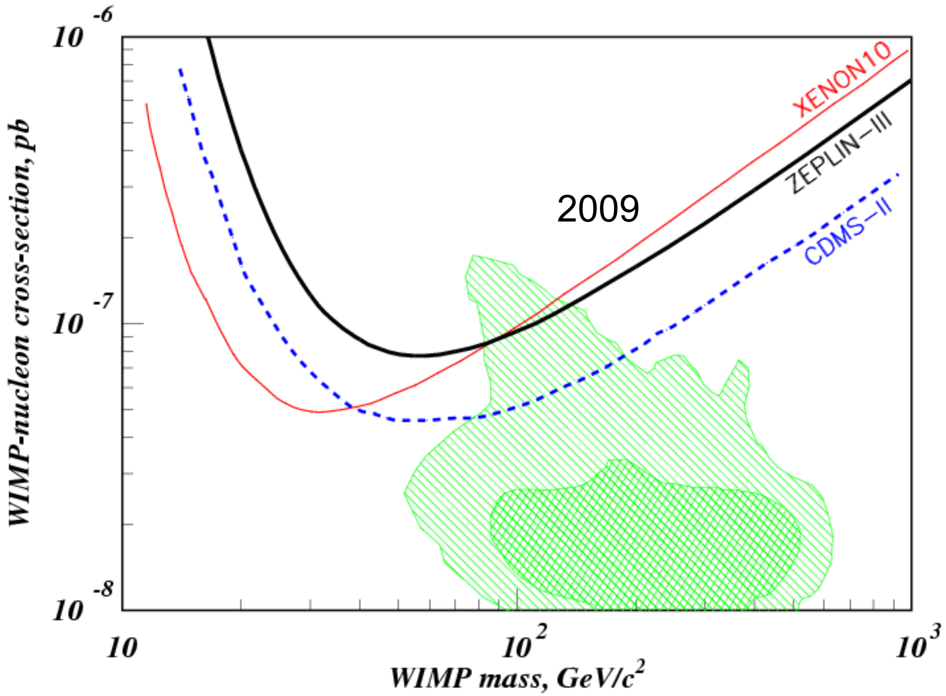


- Xe Two phases
- 8 kg fid mass, small 3.5 cm drift length

ZeplinIII phys runs : 1 published, 1 on going

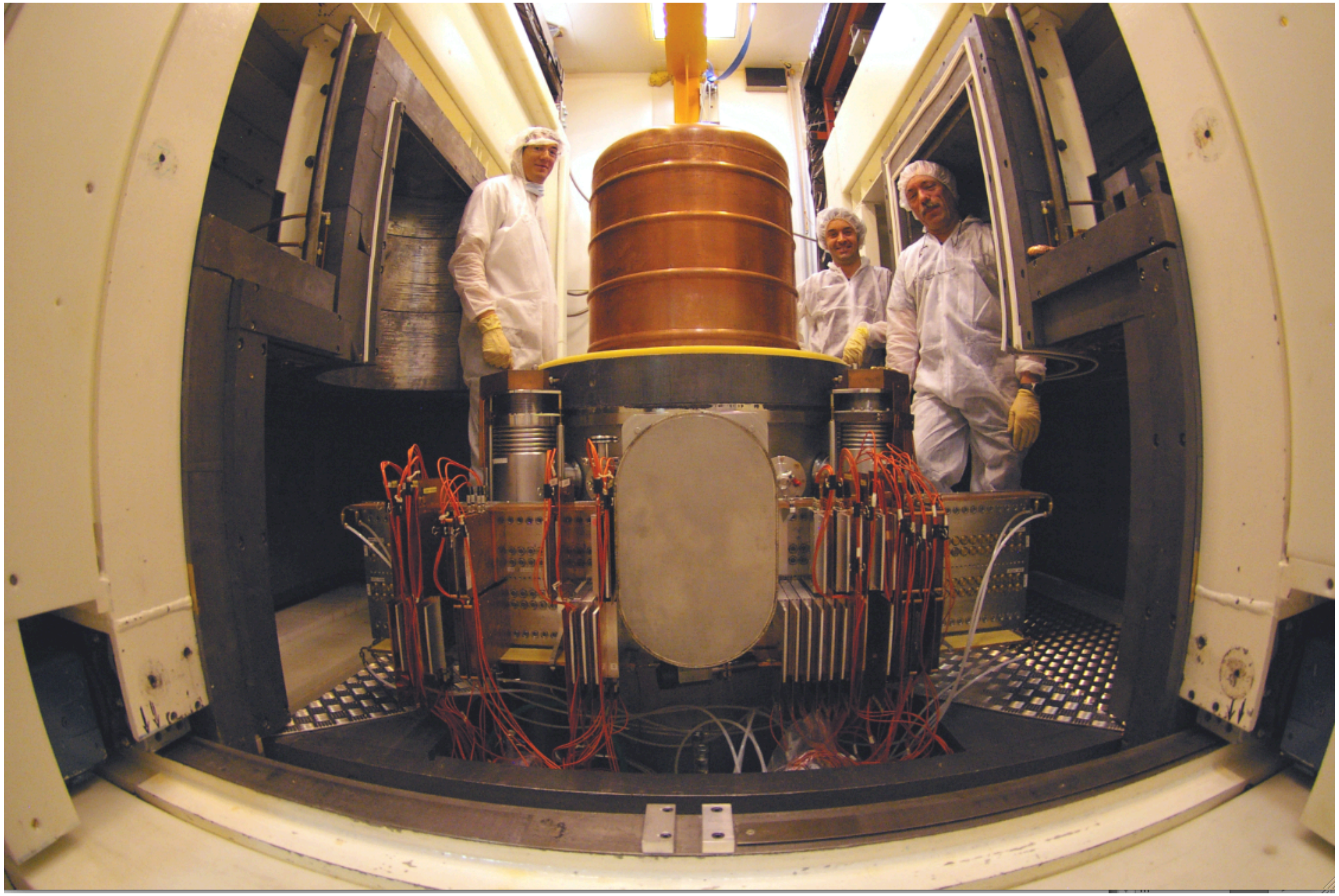


- 127 kg.d fiducial
- 8 evts in ROI

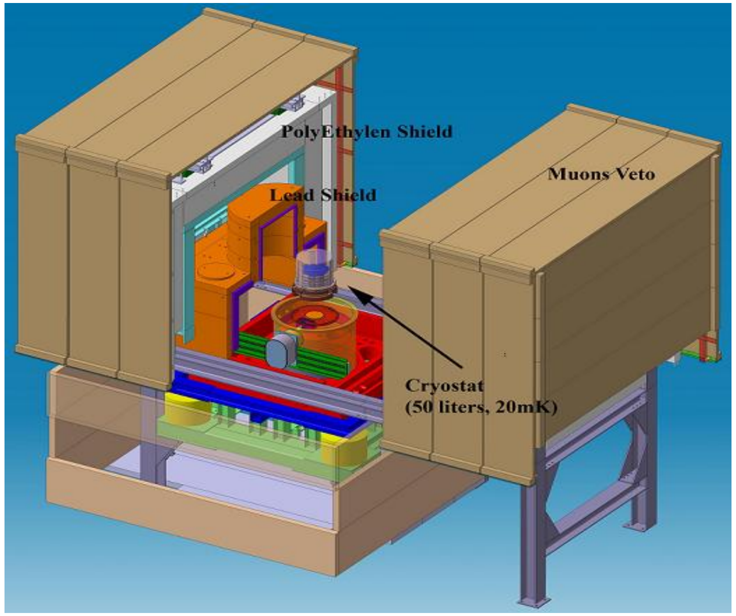


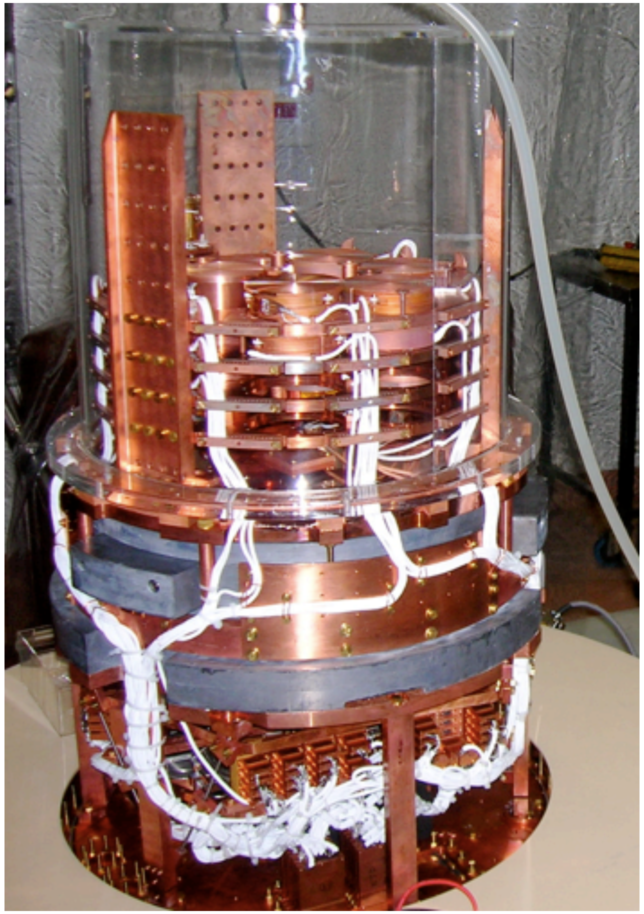
- Improved set up, PMT, n shield …
- Second science run since spring 2010
- Stopped in mai 2011, paper by few months ?
- Set up dismanteled

EDELWEISS-II @ LSM: largest progress in 1.5 y



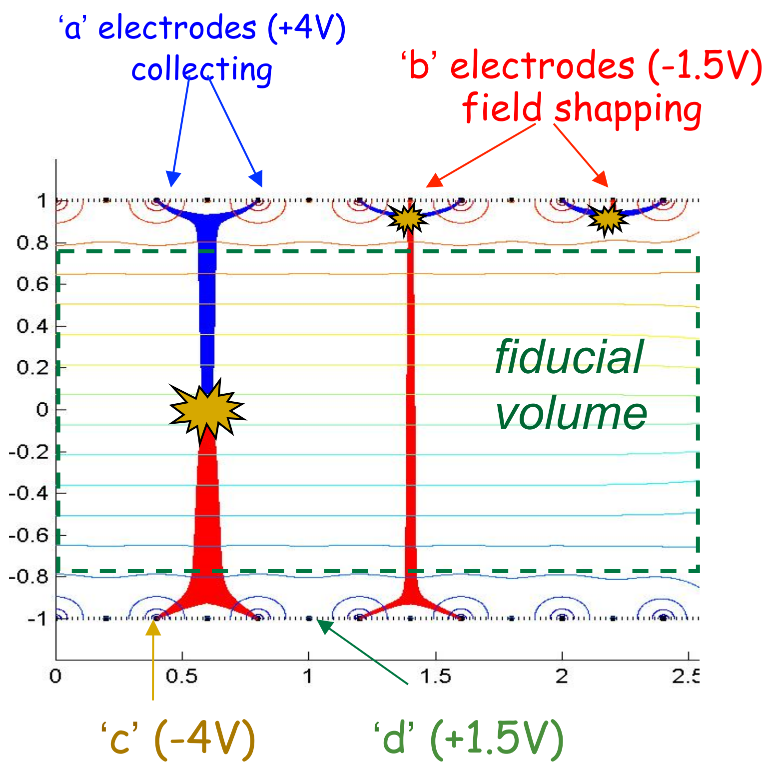
EDELWEISS-II infrastructure



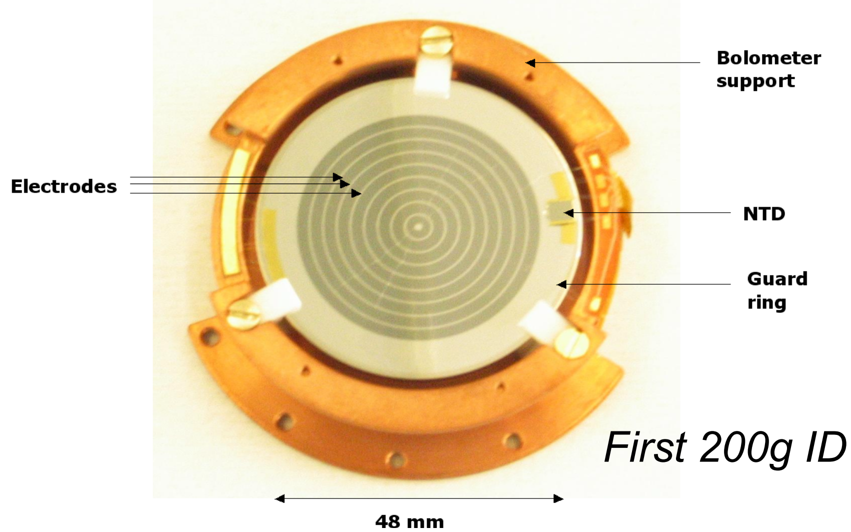


- Cryogenic installation (18 mK) :
  - Reversed geometry cryostat, pulse tubes
  - Remotely controlled
  - **Can host up to 40kg of detectors**
- Shieldings :
  - Clean room + deradonized air
  - Active muon veto (>98% coverage)
  - 50-cm PE shield, 20-cm lead shield
  - Side detectors : 1 t Gd scintillator for muon induced n , He3 counters,…

Ge heat/ionisation detectors with interleaved electrodes



the « ID » (InterDigit) detector



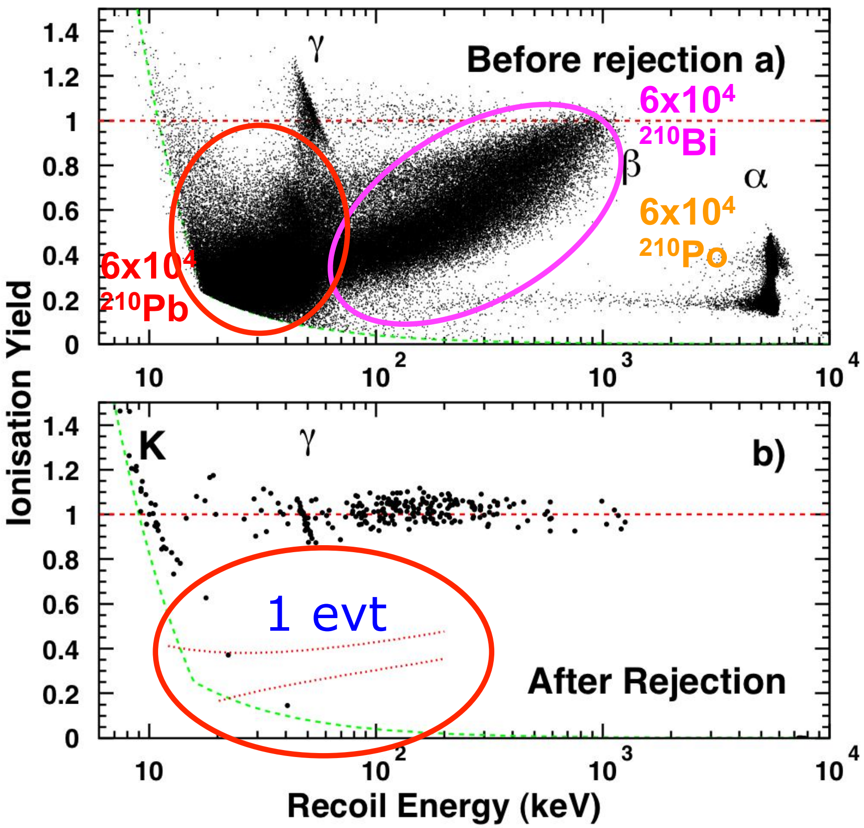
- Keep the NTD phonon sensor
- Modify the E field near the surfaces with interleaved electrodes
- Use 'b' and 'd' signals as vetos against surface events

- First detector built 2007
- 1x200g + 3x400g tested in 2008
- 10x400g **running 1 year 2009-2010**
- **800g detectors tested and running** 2010-2011

(NB : an alternative solution, NbSi films, studied for 10 years was abandoned in 2007)

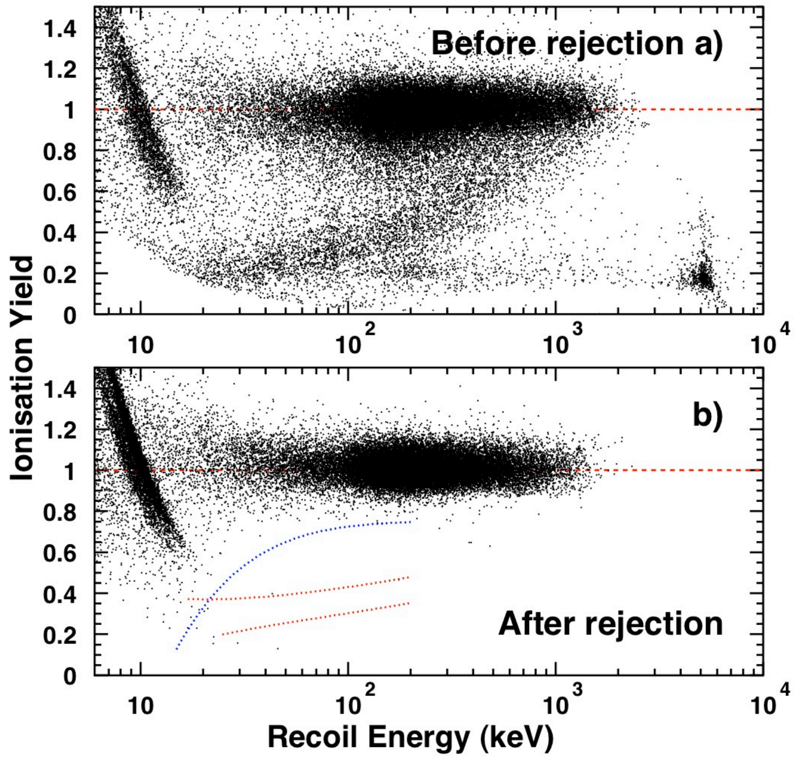
Efficient rejection of surface events (dominant bck)

^{210}Pb calibration (2008)



PLB 681 (2009) 305-309 [*arXiv:0905.0753]*

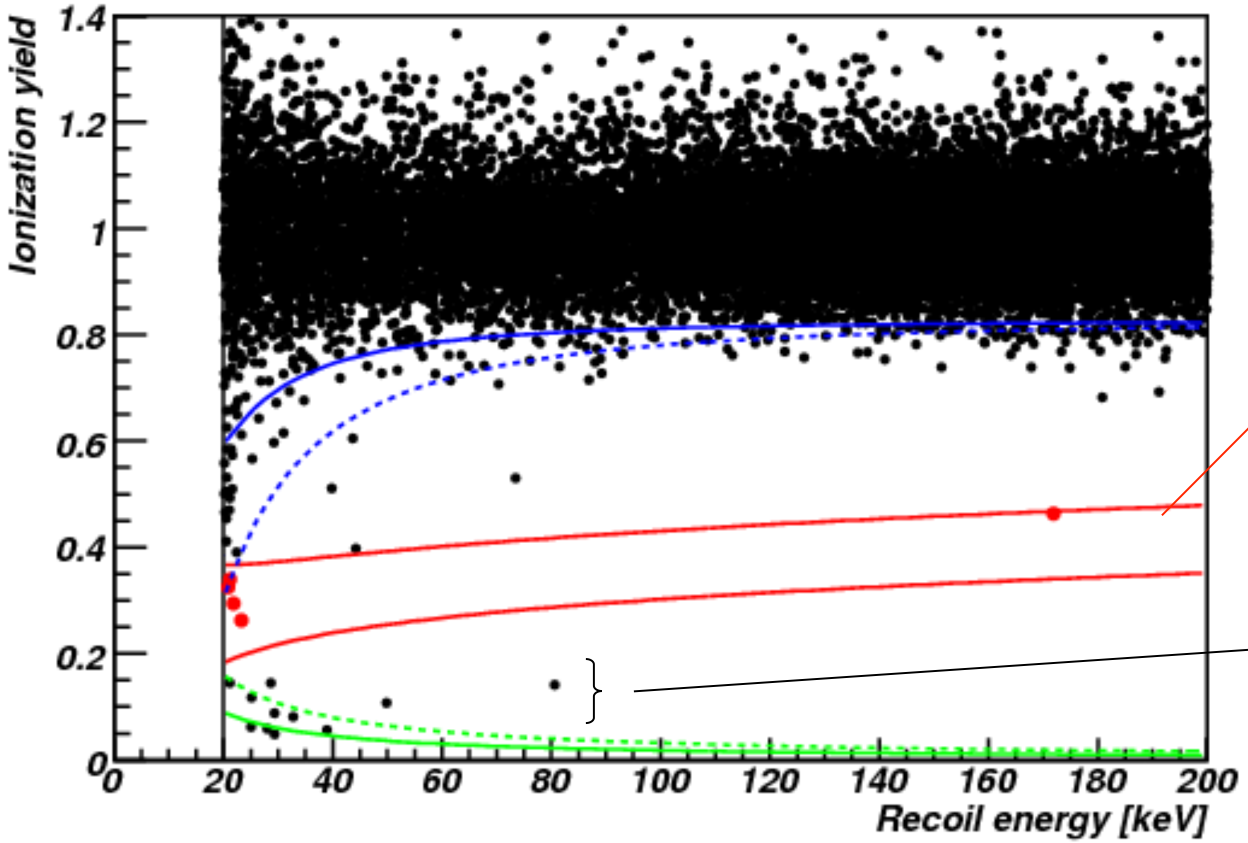
Background data



- Much better than anticipated !

WIMP search : final results

- 10 * 400 g detectors : 1.6 kg fid mass
- 13 months running (april 2009 =>
- Threshold fixed by acceptance and known background
- => 384 kg.d fiducial exposure

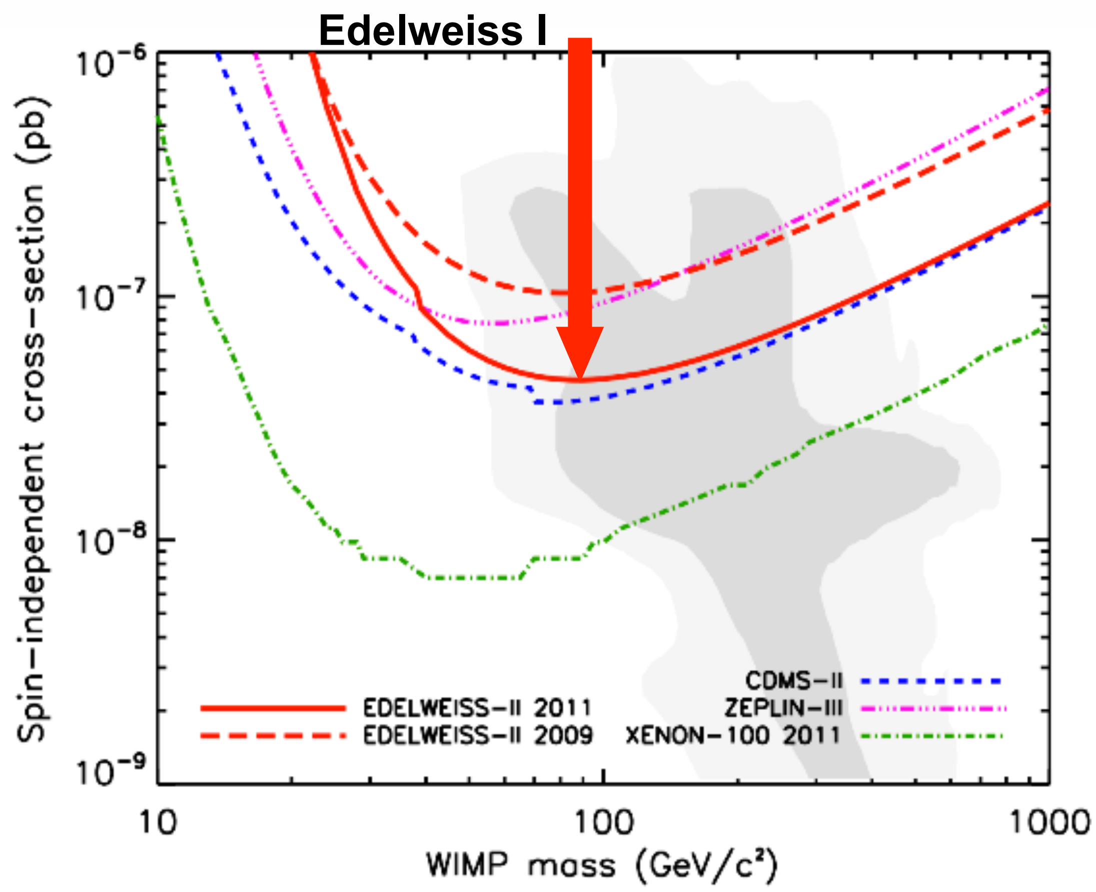


Five WIMP candidates:
- four 20.8 < E < 23.2 keV
- one @ 172 keV

« alpha tail »

Elastic WIMP scattering limit

- 4.4×10^{-8} pb at Mχ=85 GeV
- (x2.7 better than 2009 result, 35 x better than 2003)
- Sensitivity limited at low mass by background



- Backgrounds

- ***Gamma***: ^{133}Ba calib rejection x observed bulk γ <0.9
  (3x10^{-5}) (18000)
- ***Beta***: β source rejection x observed surface evts <0.3
  (6x10^{-5}) (5000)
- ***Neutrons*** *from* μ's: μ veto efficiency x observed muons <0.4
  (meas. > 92.8%) (0.008 evts/kgd)
- ***Neutrons*** *from rock*: measured neutron flux x Monte Carlo simu <0.1
  MC cross-check with outside strong AmBe source
- ***Neutrons*** *from Pb+PE+Cu+structure*:
  measured U limits x Monte Carlo simu <0.2
- ***Other neutrons*** *from within the cryostat (cables..)* <1.1

SUM < 3.0 for the whole WIMP run

arXiv:1103.4070

Combining Germanium data

arXiv:1105.3377v1 [astro-ph.CO] 17 May 2011

Combined Limits on WIMPs from the CDMS and EDELWEISS Experiments

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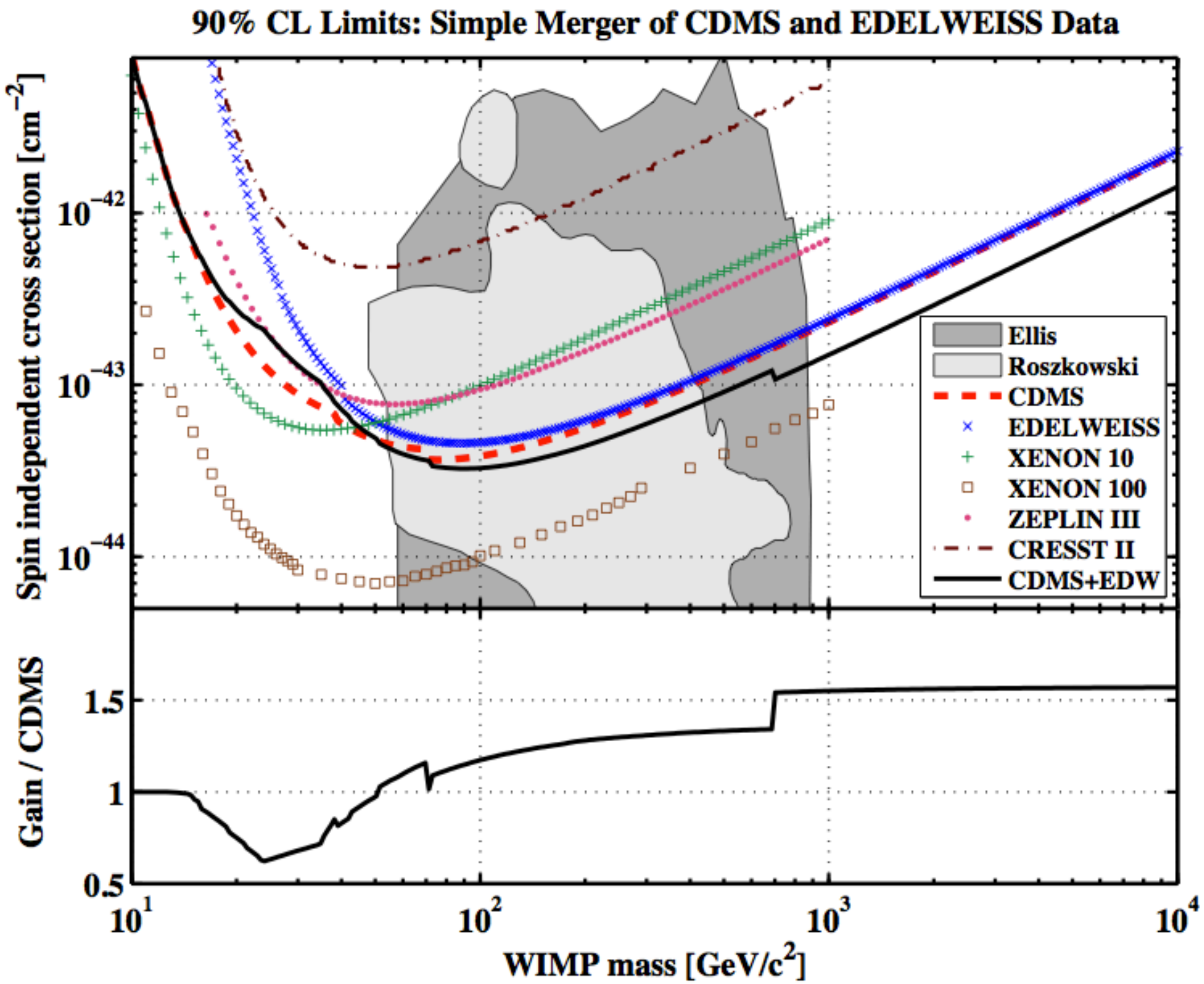
(Dated: May 18, 2011)

CDMS+EDELWEISS : the limits

1 TeV:
x2 behind Xe100

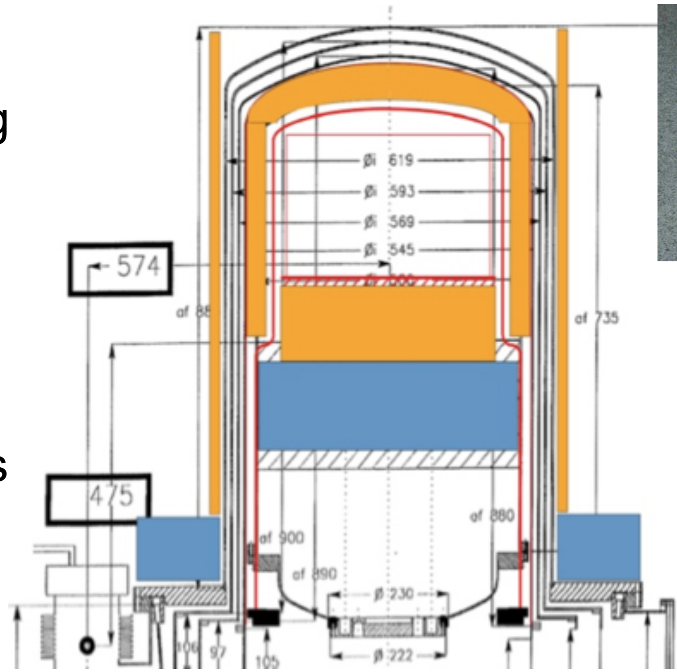
100 GeV:
x3 behind Xe100

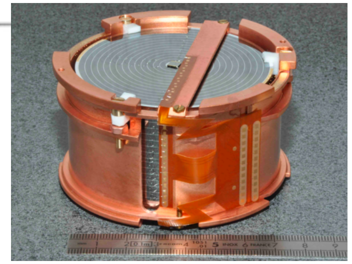
Below 70 GeV:
>x5 behind Xe100

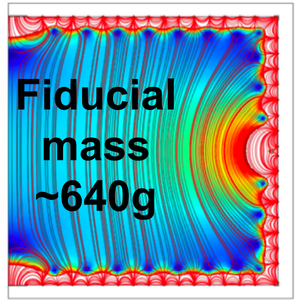


Prospects : $5x10^{-9}$ pb with EDELWEISS III

- <u>Infrastructure</u> : Upgrades of cabling cryogenics, acquisition and shielding **within the current EDW-II setup**
  - Special care with neutrons : additionnal inner PE shield



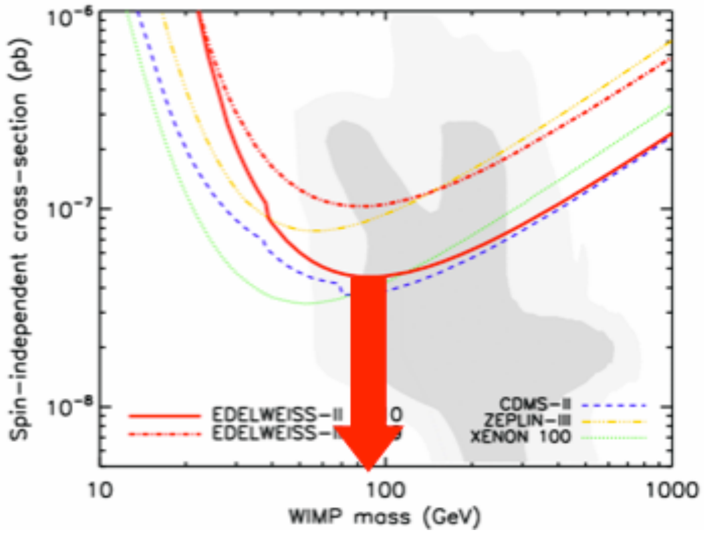




- <u>Detectors</u> : **~ 40 FID800** bolometers installed beginning 2012 : **26 kg fiducial**
  - ⇒ 3000 kg.d by end 2012

- Program funded (ANR 60%), under way

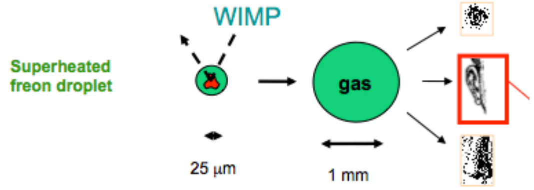
- Low threshold detectors investigated see G Gerbier@ PPC2011



Simple @ Rustrel (France)

Portugal, France, US

- Superheated droplet detectors
- 0.2 kg active mass
- 20 kg.d, reanalysis of first run
- Background subtraction
- Doubt : stability, established for 3 months ?



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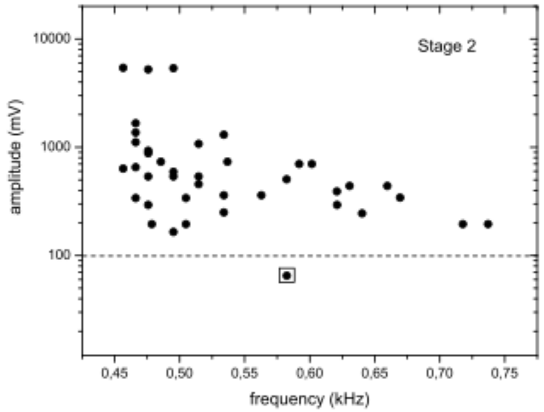
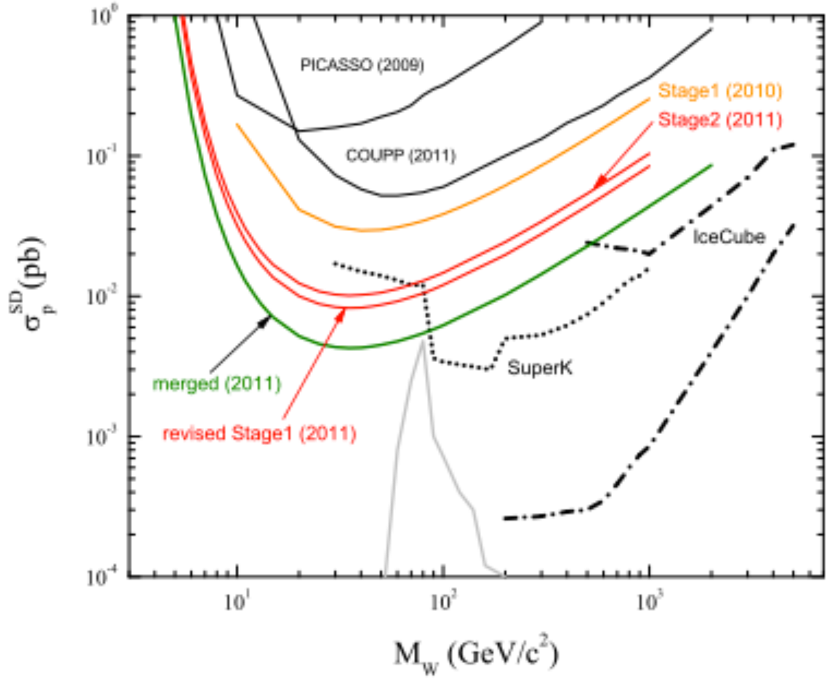


FIG. 1: scatter plot of the amplitudes and frequency of primary harmonic of each true nucleation event observed c the entire Stage 2 exposure. The boxed event below A ≤ mV is the rejected neutron event observed for pressures ≤ bar.

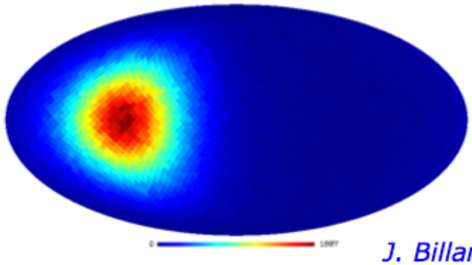


MiMac (MIcro-tpc MAtrix of Chambers)

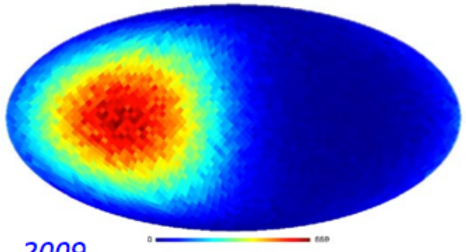
D Santos : LPSC Grenoble, IRFU Saclay, IRSN Cadarache

- Directional detector for WIMP galactic origin identification
- Demonstration of proof of principle

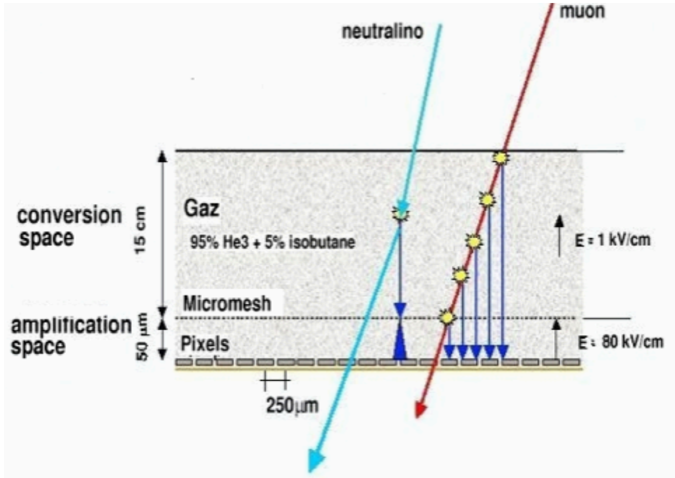
WIMP flux



Recoil events (He, M=20 GeV)

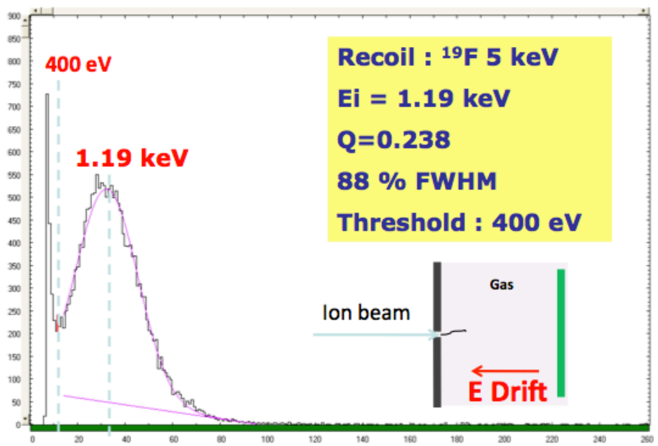


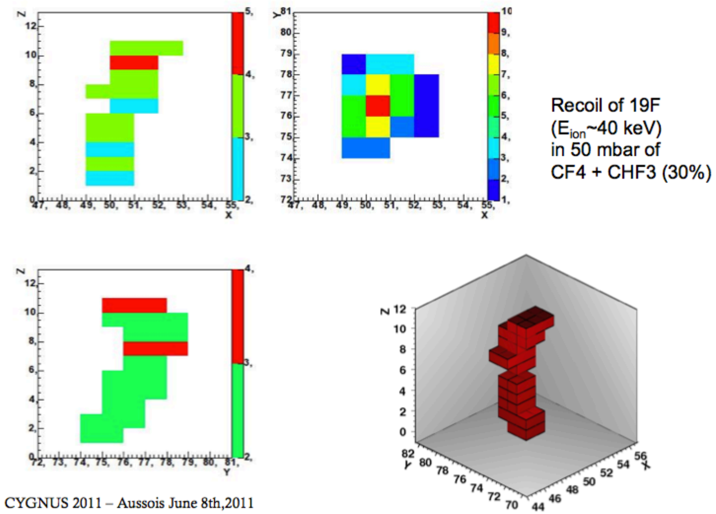
J. Billard et al., 2009



5keV ^{19}F Recoil in 60 mbar

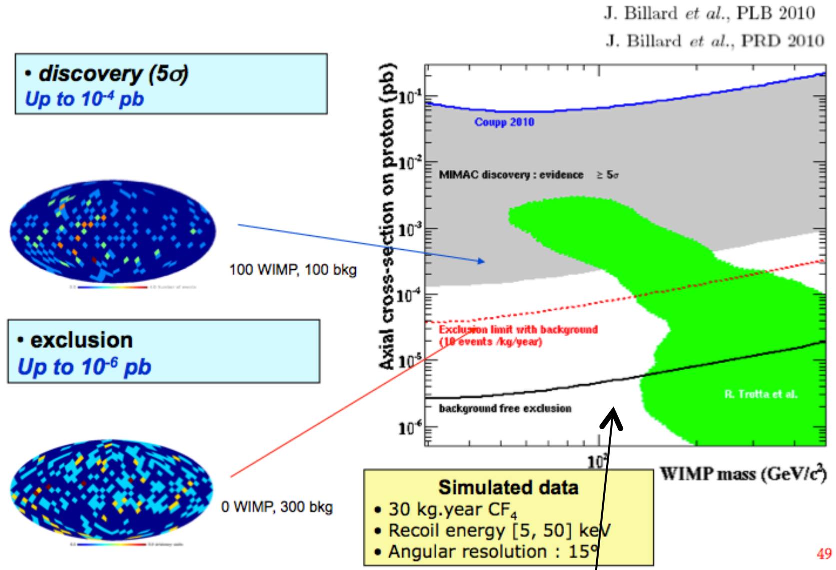
40mbar CF4+16.8mbar CHF3+1.2 mbar Isobutane



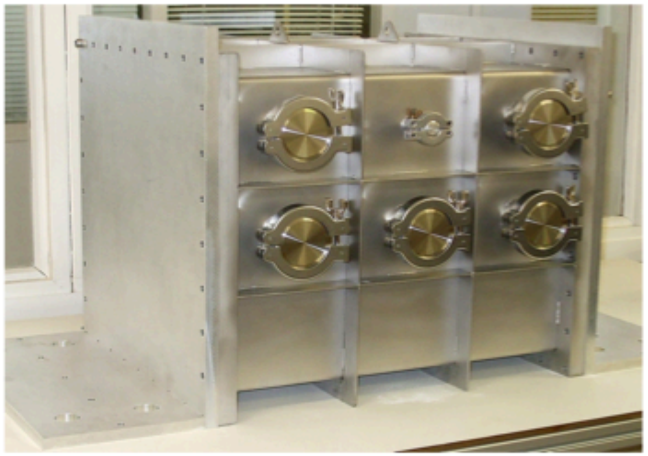


MiMac (MIcro-tpc MAtrix of Chambers)

- Complementary to scalar detection, p-SD MIMAC : Dark Matter discovery/exclusion
- Goal : 30 kg of CF4=> 50 m^3



Bi-chamber module (Modane)
2x (10x10x25 cm^3)
(November 2011 !)



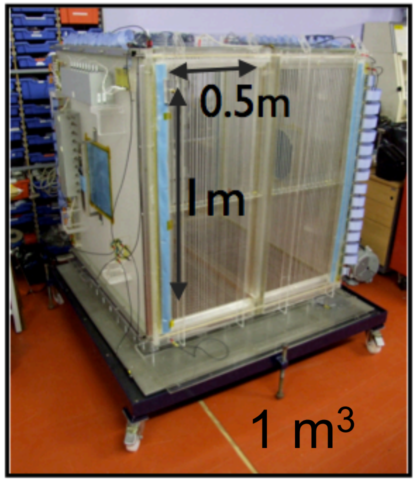
- 2011 : Prototype @ LSM
- 2012 : 1 m^3 chamber
- 20xx : 50 m^3 ,55 mb, 3 y

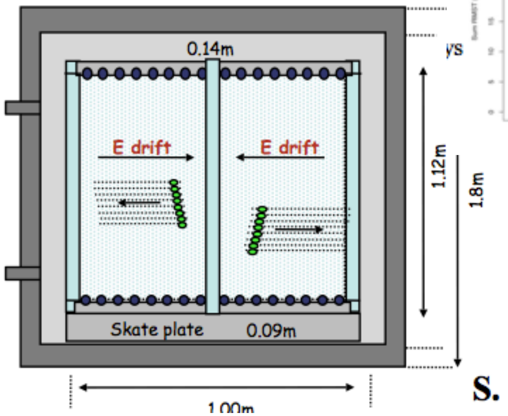
DRIFT @ Boulby

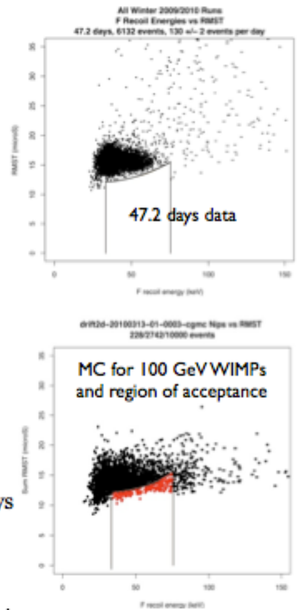
Occidental, UNM, USC, Sheffield, Edinburgh

- CS_2 gaz, 40 torr
- Radon background partially solved
- Goal : 24 m^3, 4kg target
- CPL willing to excavate for DTM at "no charge"

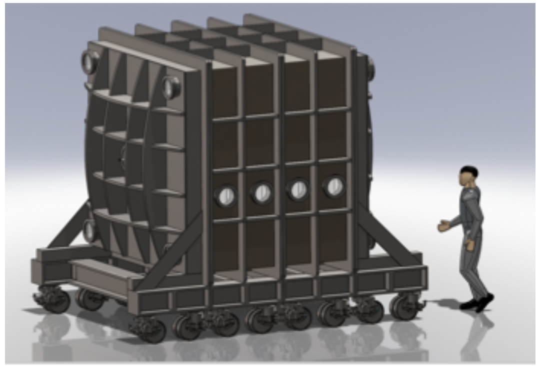
DRIFT II Concept

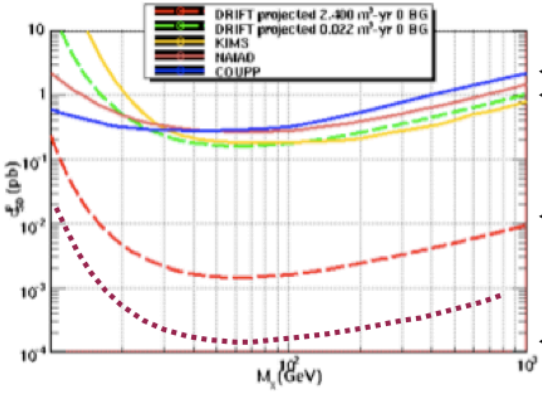






- Data from DRIFT II





- current limits
- DRIFT IId - 10 day run, zero background prediction
- DRIFT IId - 2.4 m³-years, zero background prediction
- DTM - 1 year run 4 kg.yr

ArDM 1 T prototype

Charge extraction from LAr to Gar, amplification and readout

Assumed baseline parameters:

Cylindrical volume,
drift length ≈ 120 cm

850 kg target

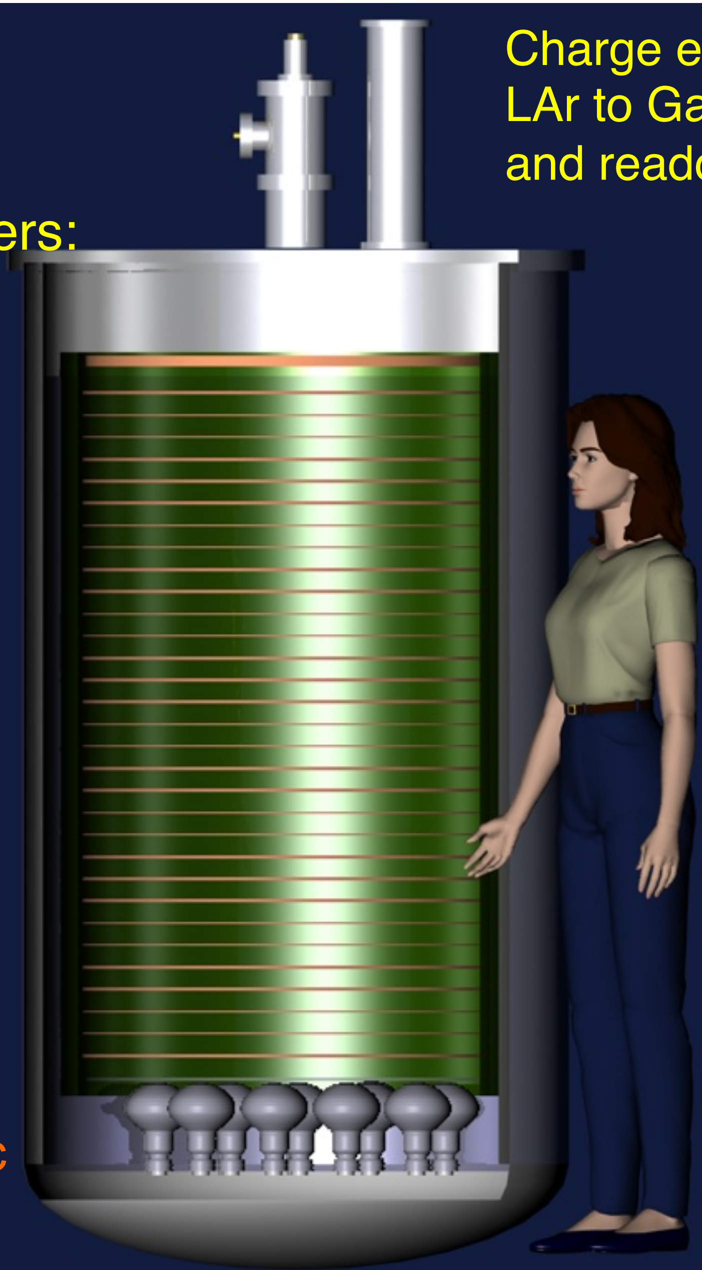
Drift field ≈ 4 kV/cm

Charge readout at top:
LEM gain ~700

Light readout collection
efficiency ≈ 1%

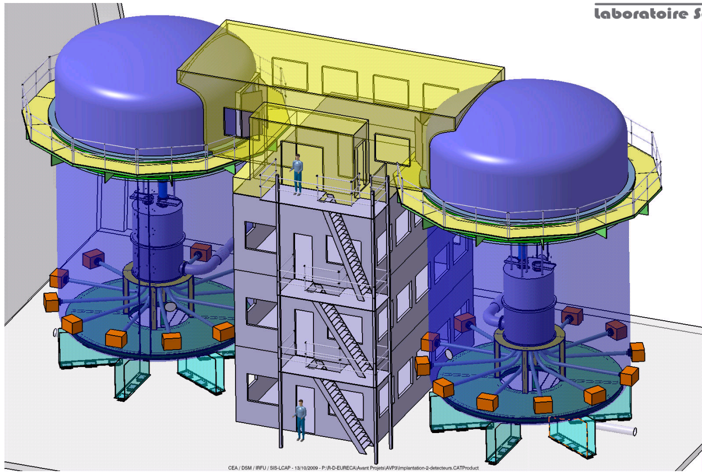
Single photon detection

- Issue : ^{39}Ar 1Bq/kg
- Not low activity
- Installation @ Canfranc this september

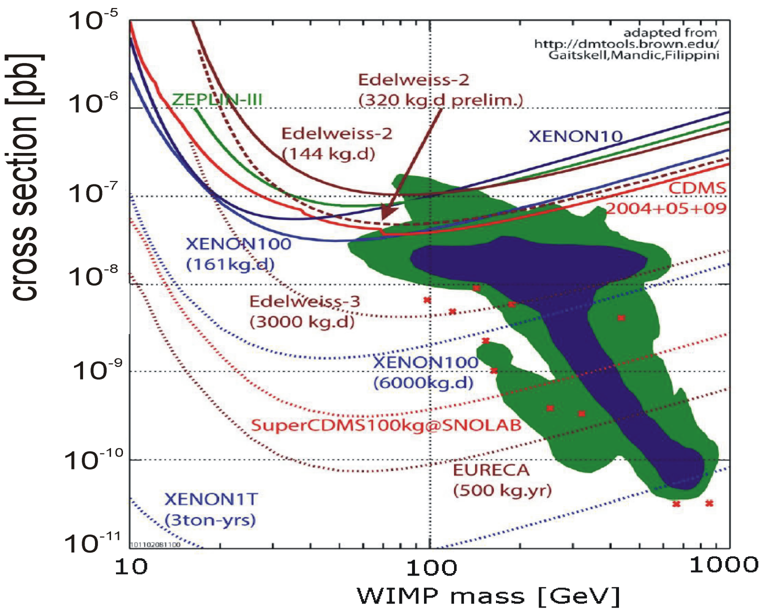


EURECA : goal $\sigma = 10^{-10}$ pb

- Search for WIMP SI interactions down to $\sigma \sim 10^{-10}$pb
- (~1 event/tonne/year)

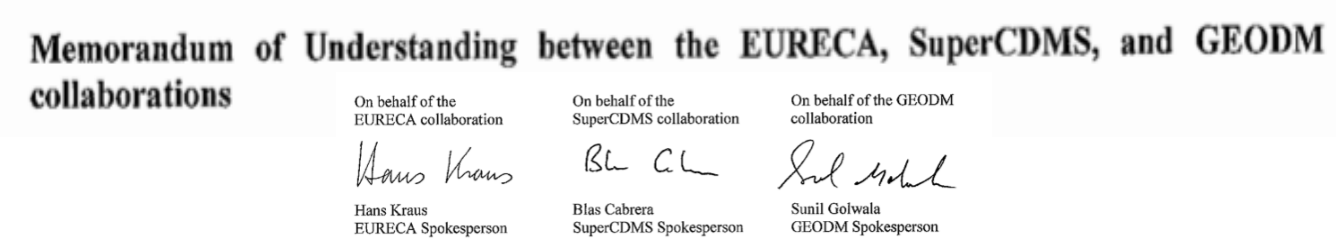


- CRESST, EDELWEISS, ROSEBUD & additional groups
- Cryogenic (<100mK) calorimeters
- Multiple target materials: Ge, CaWO4, ZnWO4….
- 2 phases
  Phase 1 :150 kg : 2015
  Phase 2 : 1 t : 2018
- Preferred site : ULISSE extension deepest in Europe



EURECA status & time line

- Progress on set up definition
- Collaborative work with SuperCDMS teams for shields, infrastructure, background & common “tower” and front end electronics design

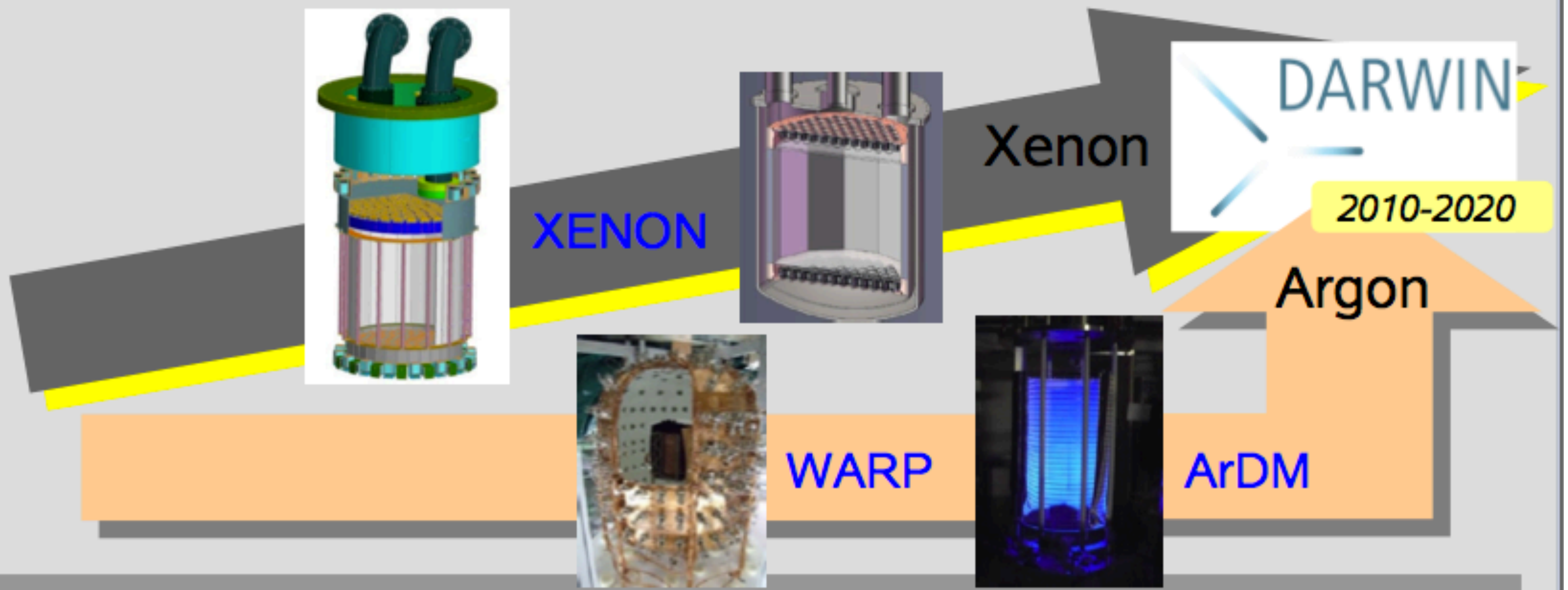


Memorandum of Understanding between the EURECA, SuperCDMS, and GEODM collaborations

On behalf of the EURECA collaboration	On behalf of the SuperCDMS collaboration	On behalf of the GEODM collaboration
Hans Kraus EURECA Spokesperson	Blas Cabrera SuperCDMS Spokesperson	Sunil Golwala GEODM Spokesperson

- DS in progress -partial ASPERA funding-
- CDR ready by end 2011
- Funding expected to be available by 2013 to start construction
- Application to EQUIPEX call in France in coming month
- Application to BMBF/ Helholtz in Germany

DARWIN - Overview



DARWIN – Dark Matter WIMP Search with Noble Liquids

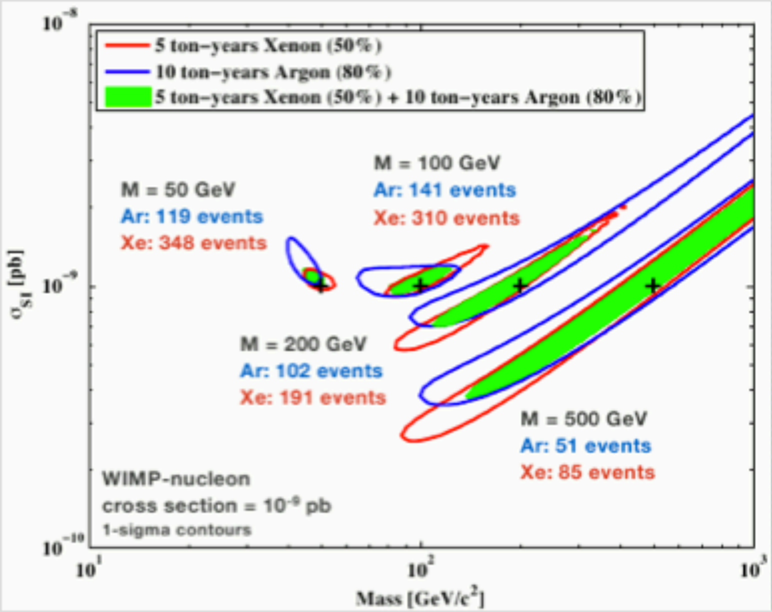
- *R&D and Design Study* for a next generation noble liquid facility in Europe. Approved by ASPERA in late 2009
- Coordinate existing European activities in LXe and LAr towards a multi-ton Dark Matter facility
- Physics goal: probe WIMP cross sections well below 10^{-47} cm²

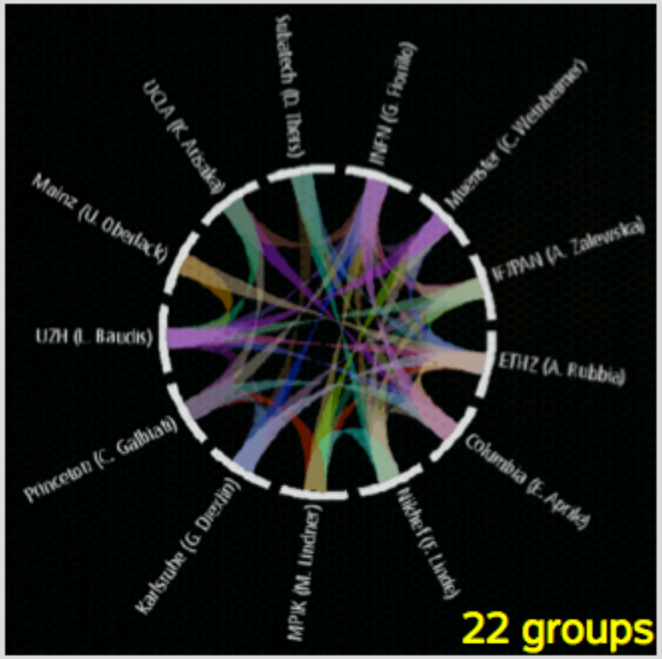
Goals and Structure

DARWIN

R&D and Design Study for
Light/Charge Readout, Electronics/DAQ,
Detector/Underground/Shield Infrastructure,
Material Screening/Backgrounds, Science Impact

Multiton LXe and/or LAr WIMP detector
find best choice/design, exploit complementarity?





ArDM, WARP, XENON Groups:
UZH (CH), INFN (I), ETHZ (CH),
Subatech (F), Mainz (D), MPIK (D),
Münster (D), Nikhef (NL), KIT (D),
IFJPAN (PL)
+ Columbia, Princeton, UCLA (USA)

http://darwin.physik.uzh.ch

Cygnus consortium

- White paper 2009
- Gathers all players in the field (DMTPC, Newage,..
- No clear strategy so far

Summary

- Important progress in EU cryogenic experiments (Edelweiss, CRESST, Rosebud-R&D) & effective US collaboration
- Important progress in R&D (not yet competitive) gaz detectors
- Alternative techniques interesting, should prove reliability
- Liquid argon ArDM starting
- Some DM candidates spark interest, DAMA check possible by ongoing ANAIS
- Large scale projects need depth & space