DARK MATTER DIRECT DETECTION STATUS AND PERSPECTIVES

G Gerbier IRFU Saclay

SUSY 2008 – Seoul june 19th

Few reminders

Last results (june 07=>april 08)

Prospects

Conclusion

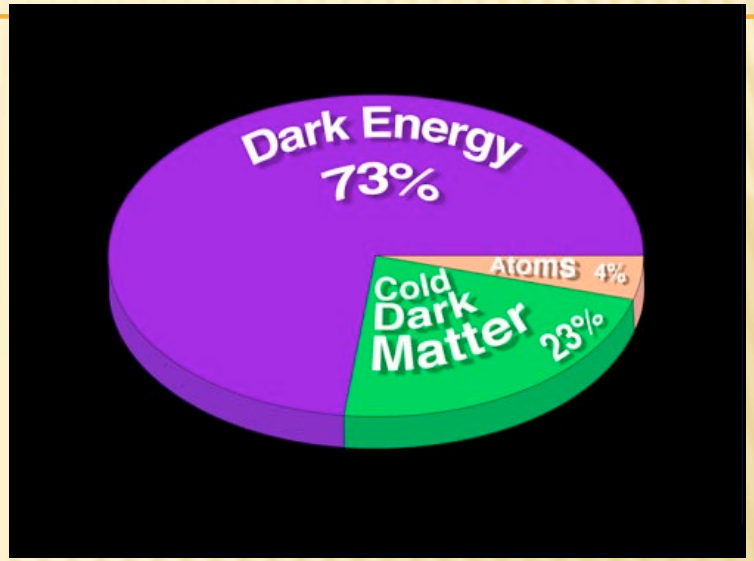
The Physics of Dark Matter

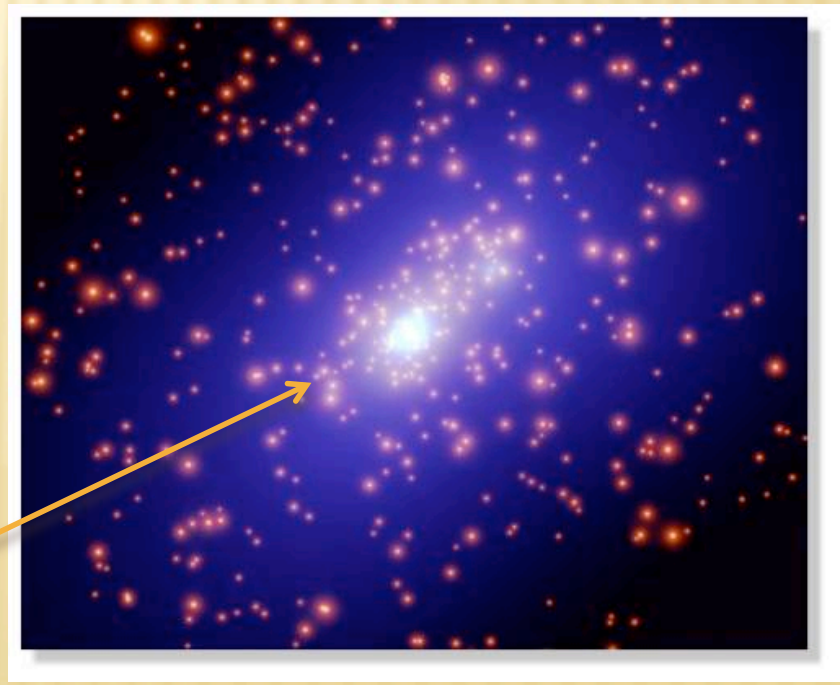
- Cold dark matter makes up nearly 1/4 of the mass/energy of the universe
- Particle candidates for CDM
  - WIMPs (GeV-TeV masses)
    - SUSY neutralinos
    - Kaluza-Klein excitations
  - Axions (10^{-3} -> 10^{-6} eV masses)
  - Pseudoscalar, Light DM
- Dark matter responsible for galaxy formation (including ours)
  - We are moving through a dark matter halo
- Standard halo assumptions

Maxwell-Boltzmann velocity distribution

V_0= 230 km/s, v_{esc}= 650 km/s,

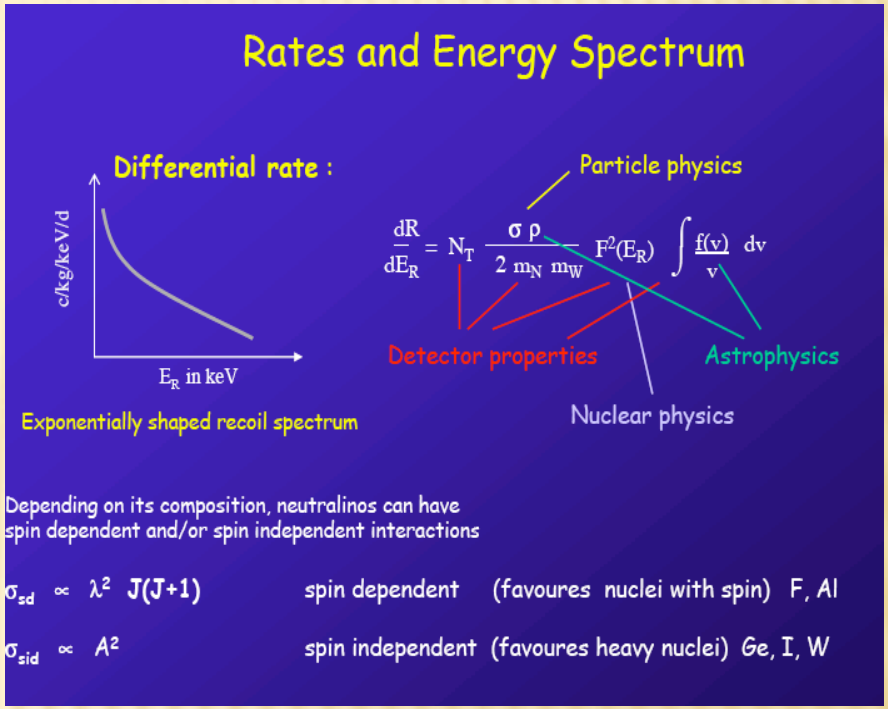
ρ = 0.3 GeV / cm^3





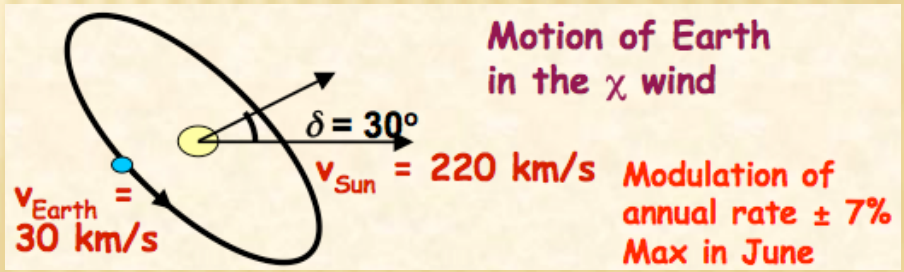
Our local galactic dark matter

- Wimp's interact on nuclei by elastic interaction
- We (Solar system, Earth) are sweeping the WIMP halo
- => rate and deposited energy are low and modulated



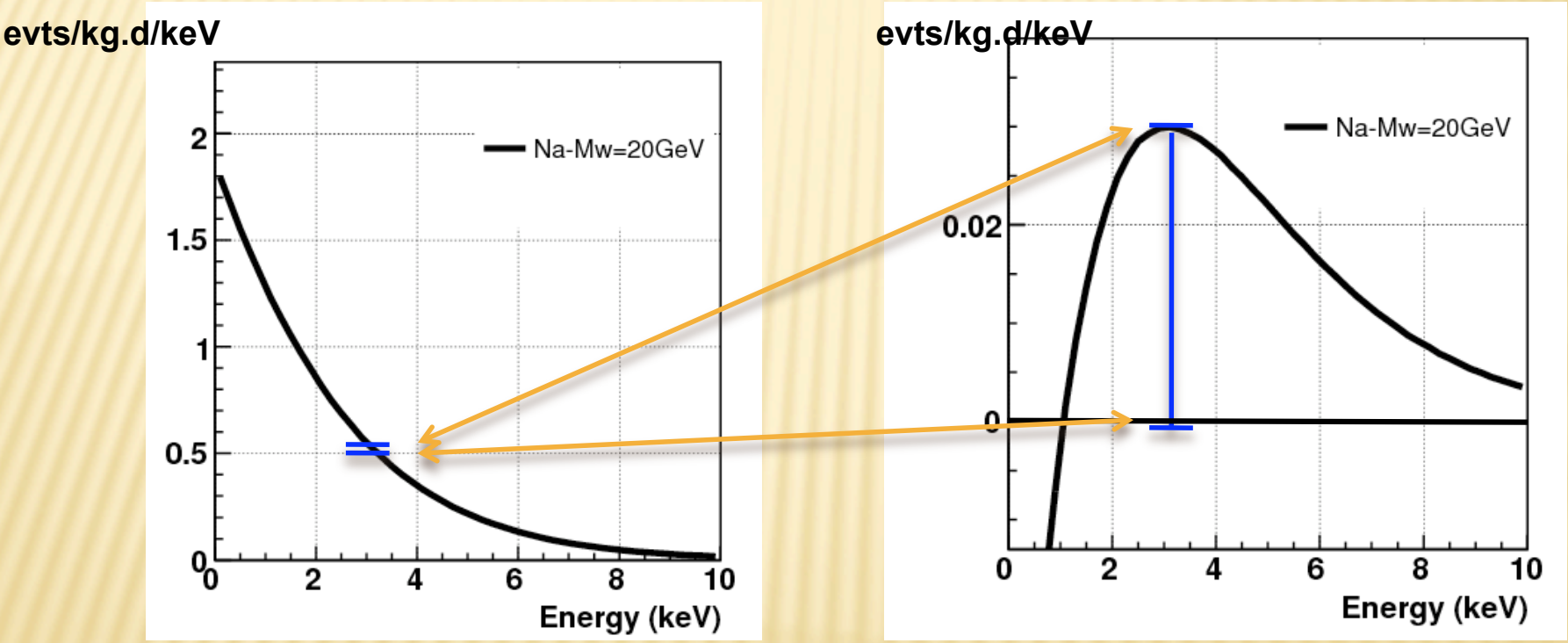
- => $S = S_0 + S_m \cos(\omega t)$

- => World is divided in 2 :
  - **S_0 hunters** : CDMS, XENON, COUPP, KIMS + others
  - **S_m discoverer** : DAMA



What energy spectrum/modulation expected ?

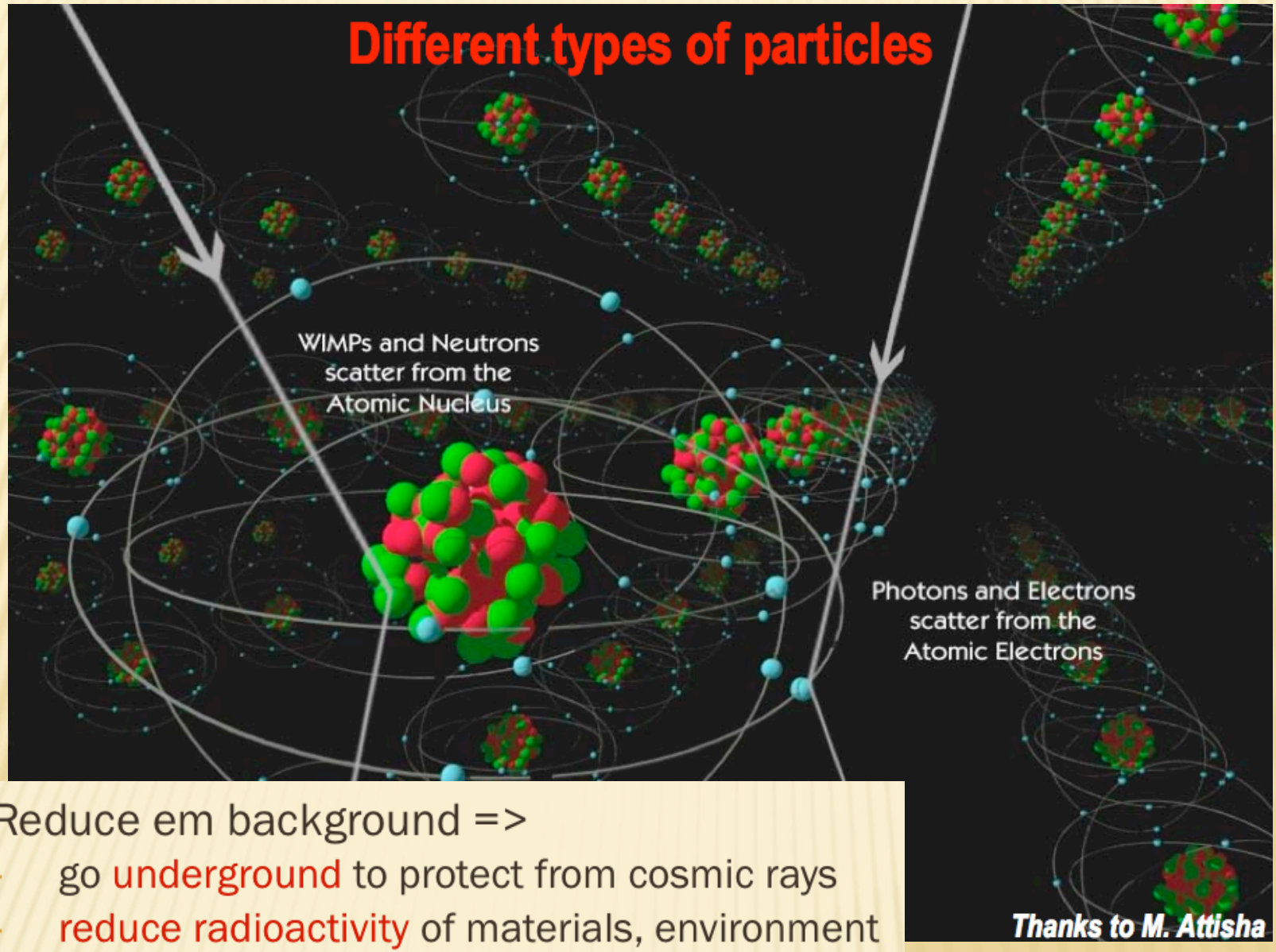
- Example of a 20 GeV mass WIMP interacting on a Na nucleus with standard halo assumptions



S0

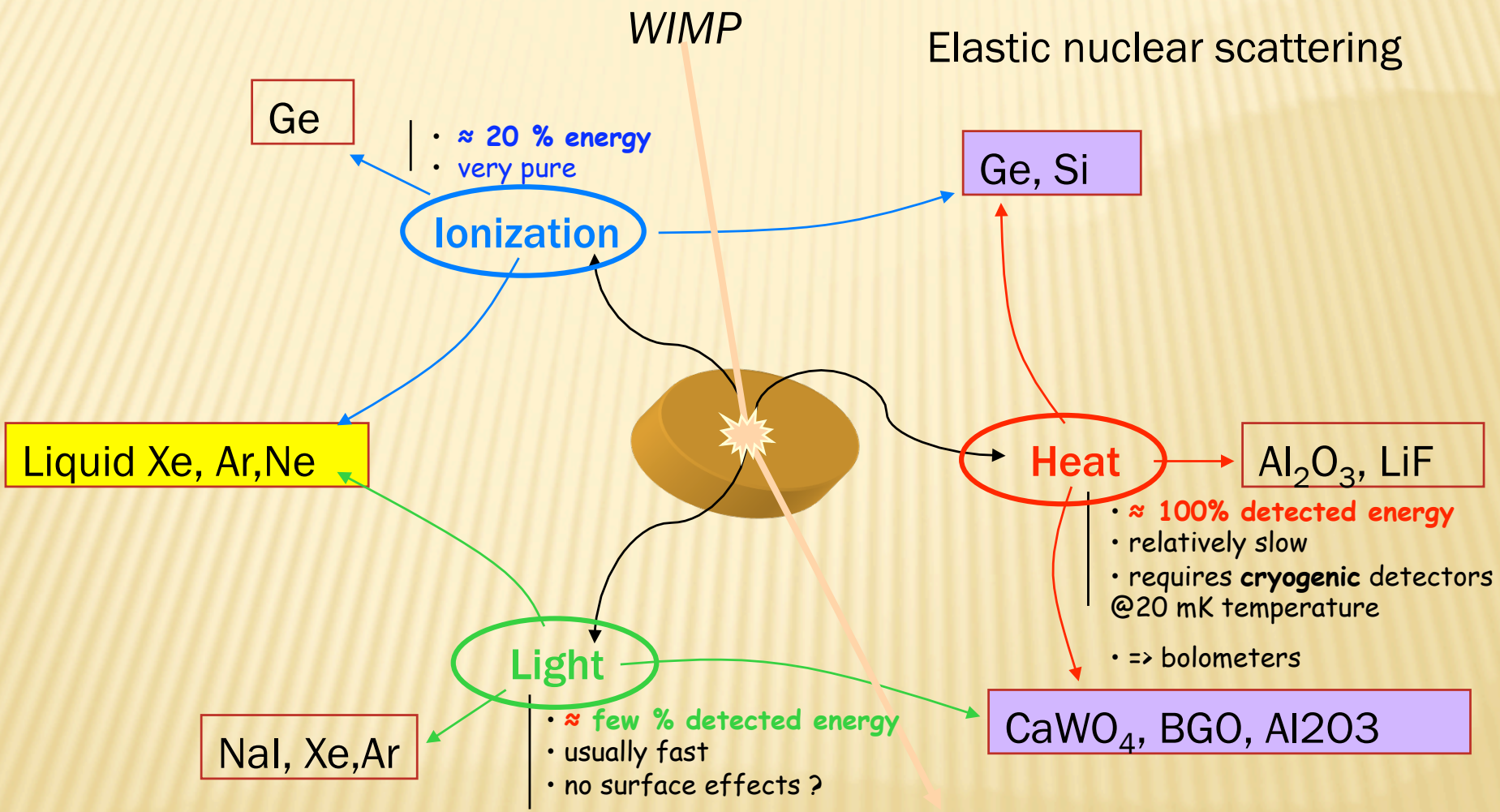
Sm (difference of spectra between june and december)

Basic interaction process (S_0 hunters)



- Reduce em background =>
  - go underground to protect from cosmic rays
  - reduce radioactivity of materials, environment

Direct detection techniques



+ Outsiders : metastable media, gaz...

Wimp direct detection : world wide …

Running experiments

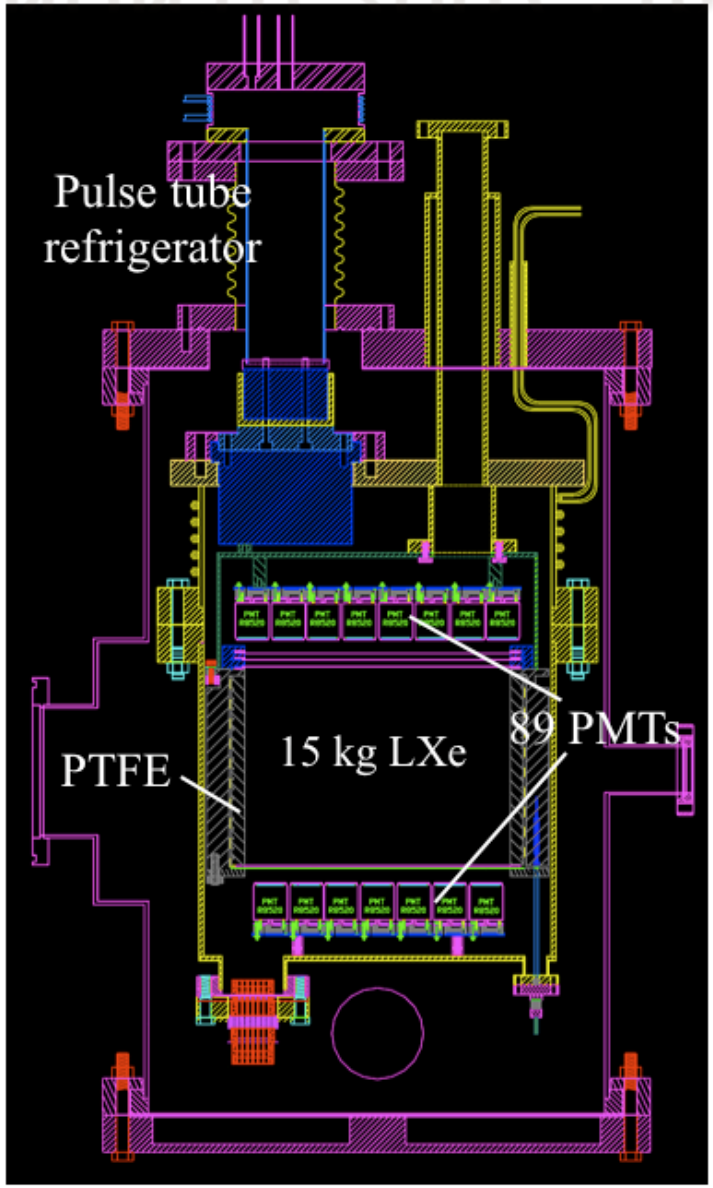
+ArDM, EURECA, SuperCDMS, XENON,XMASS II, LUX = 100kg to 1T projects
+ numerous R&D projects : CLEAN, Gaz (Newage, MIT), He3…

Liq scint
Cryo
Ge / solid scint
Gaz
Bubble

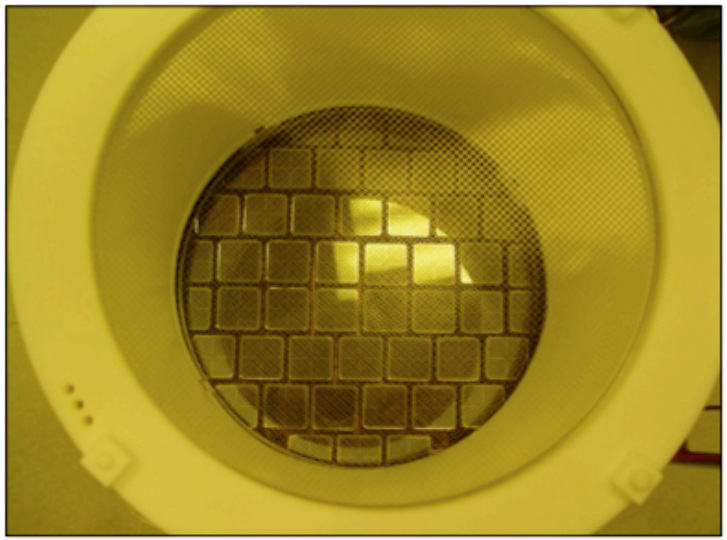
…and a fierce competition

- More and more expts coming in
- Concentrate on last 2007-2008 results
  - XENON10 may 07
  - CDMS march 08
  - KIMS sept 07
  - TEXONO oct 07
  - COUPP feb 08
  - DAMA april 08

XENON10 2007 : the new way ?



- *Pulse Tube refrigerator:* stable operation at 170 K
- *TPC active volume:* 20 cm (Φ) x 15 cm (H) - 15 kg
- *PTFE Teflon:* ~95% UV reflectivity at 175 nm
- *89 PMTs (R8520):* 20% QE, low radioactivity

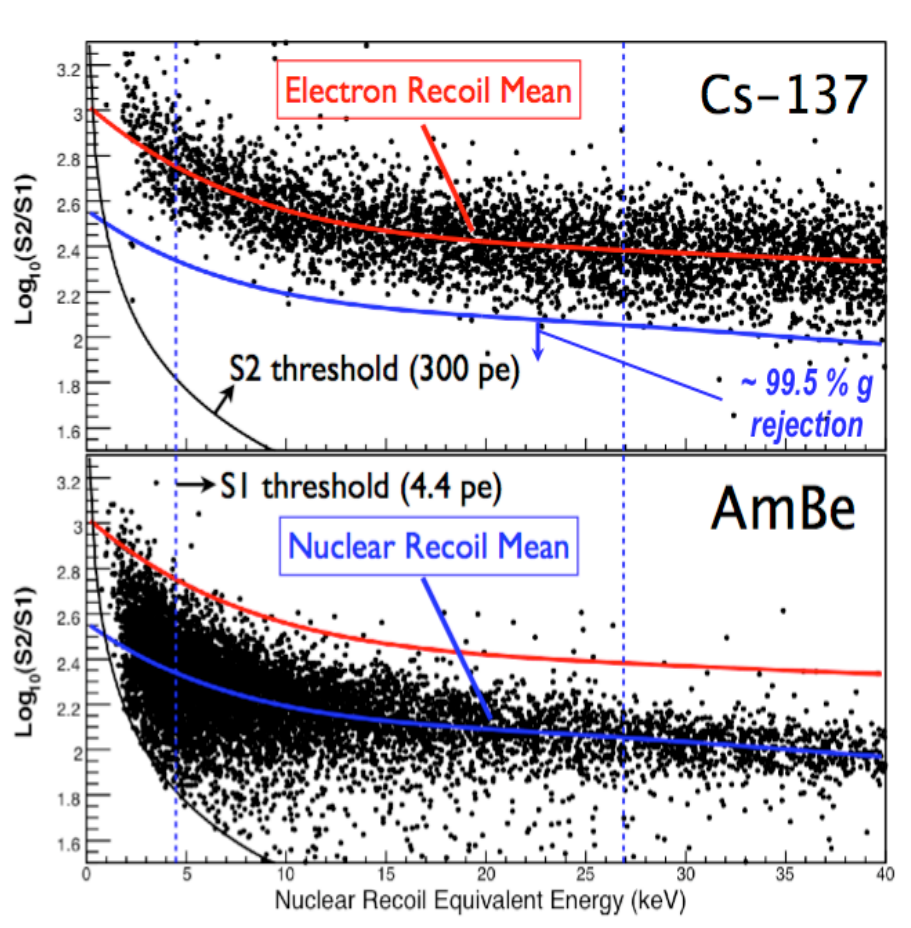


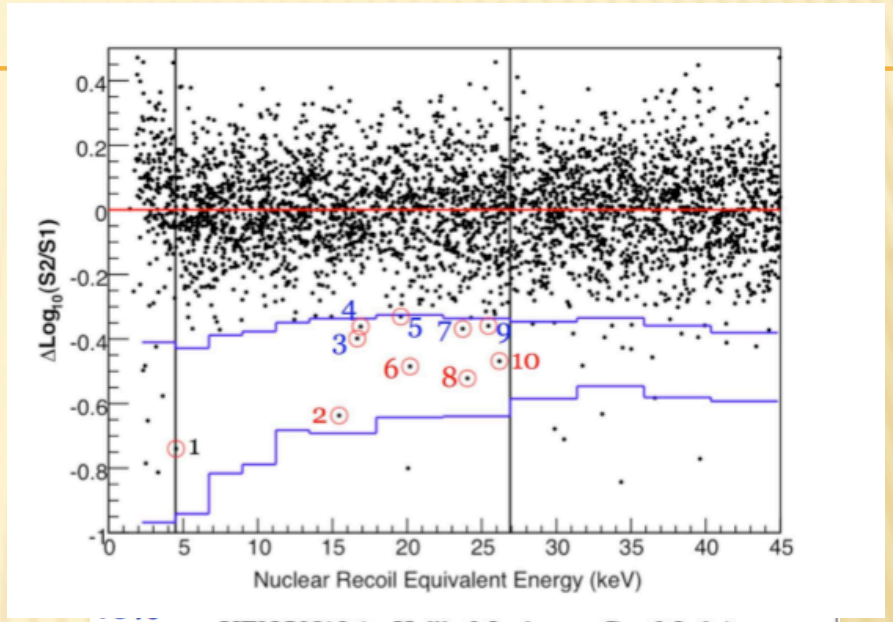
Double phase (liq,gaz) principle
Measure scintillation and ionisation
4.5 kg.d fiducial mass

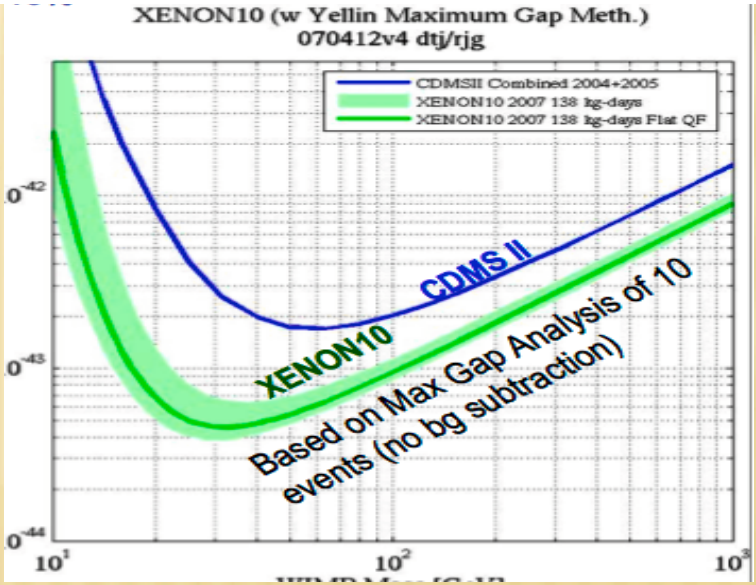
XENON 10 RESULTS

Data 58.6 days, 10 events in NR zone

Calibrations : discrimination parameter versus energy







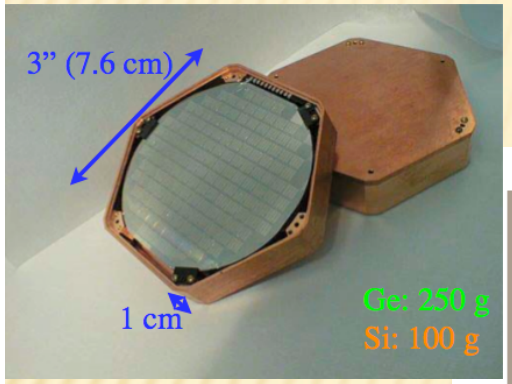
2007 : going to Xenon100

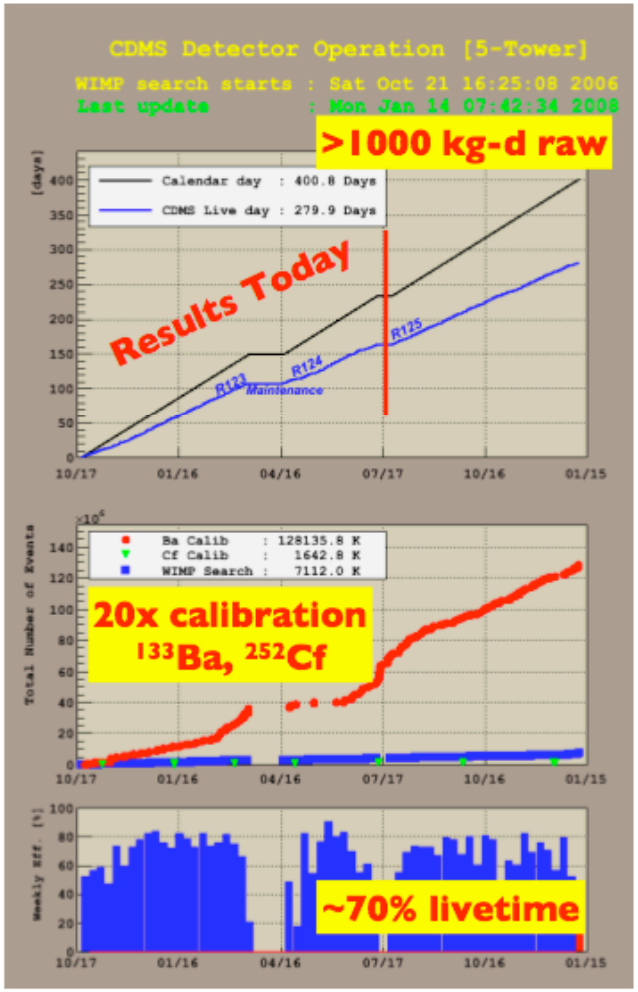
50 kg fid mass : see talk by E Aprile

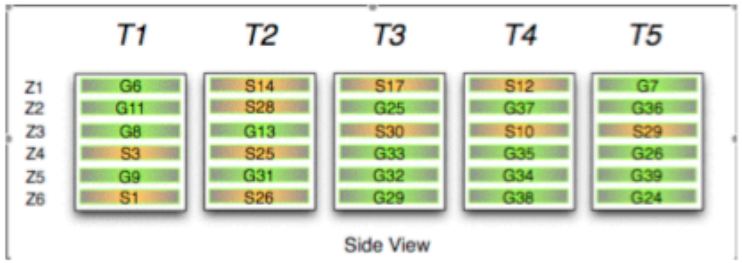
CDMS 2008 : so much better ?

First CDMS 5-Tower Results

Rupak Mahapatra







Three successful 5-T data runs so far:

- Run 123 (10/21-3/21): **430 kg-d** Ge (raw)
- Run 124 (4/20-7/16): **224 kg-d** Ge (raw)
- Run 125 (7/21-1/09): **465 kg-d** Ge (raw)
- Run 126 (1/17-date): **ongoing**

>10x the 2-Tower exposure so far!

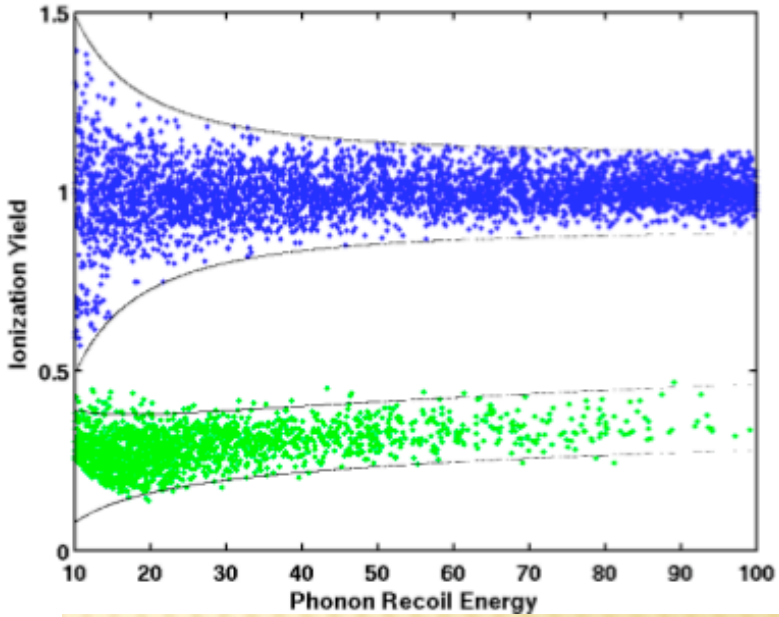
We have analyzed Run 123+124 Data

~Double exposure waiting to be analyzed

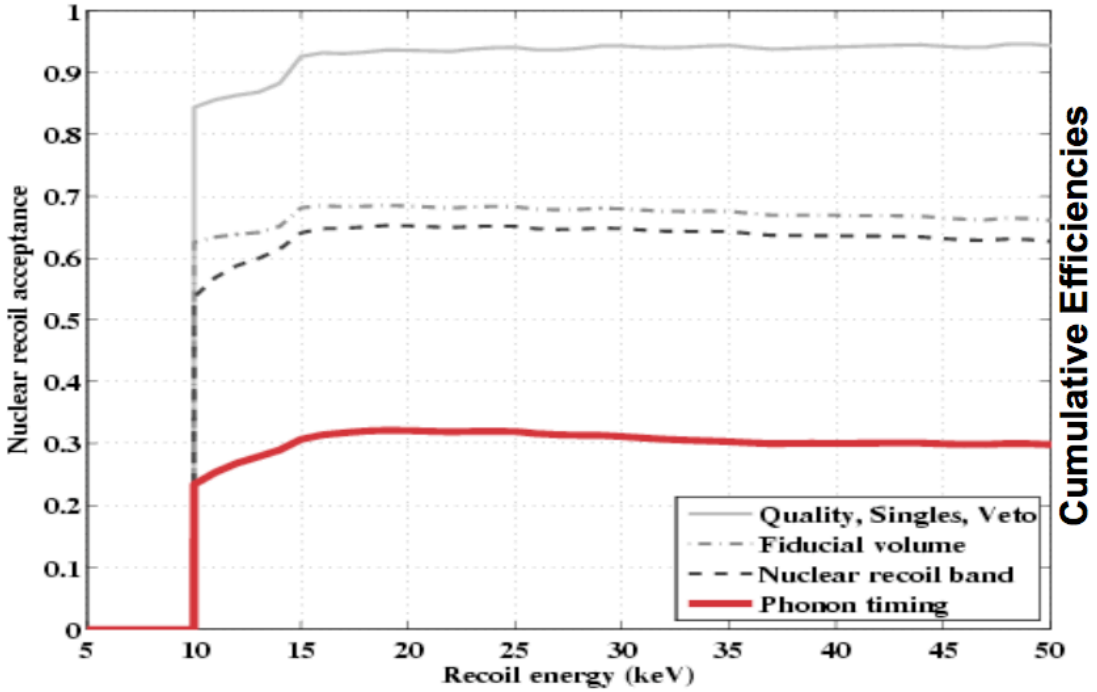
WIMP Candidate: Blind Analysis

All cuts set blind, without looking at signal

- In good Fiducial Volume
- In the Nuclear Recoil Band
- Not surface event: phonon timing cut
- Not a Multiple Scatter



Efficiencies



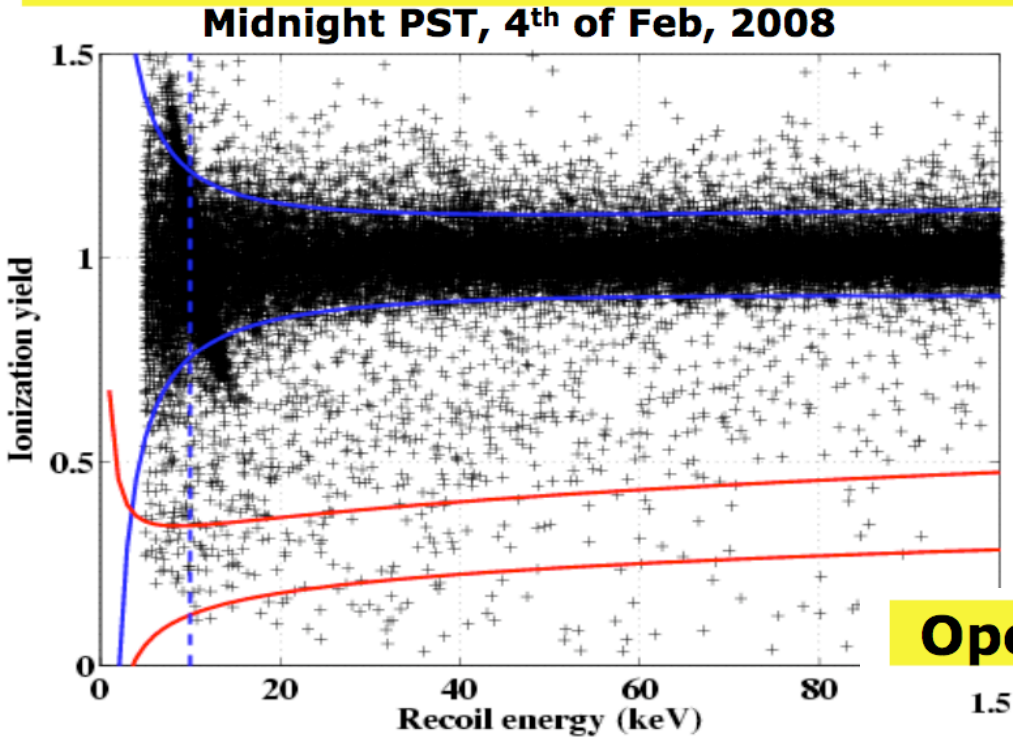
Efficiency plot includes effect of Fiducial Volume Cut

⇒Would expect roughly 650 kg.d * 30% effective/fiducial exposure= 200 kg.d

Actually used exposure is **125 kg.d**
7/19 detectors used because of "variations of performances" on run 124

WIMP search. Of the 19 Ge detectors, three suffering reduced performance from readout failures and one from relatively poor resolution, have been left out of the present report. The remaining 15 Ge detectors were used for the run 123 analysis. Eight of these detectors were excluded from WIMP search during the shorter run 124 due to systematic variations in performance between the two runs. Along with the Si detectors, the analysis of data from these detectors is ongoing and remains blind.

The WIMP Search Data

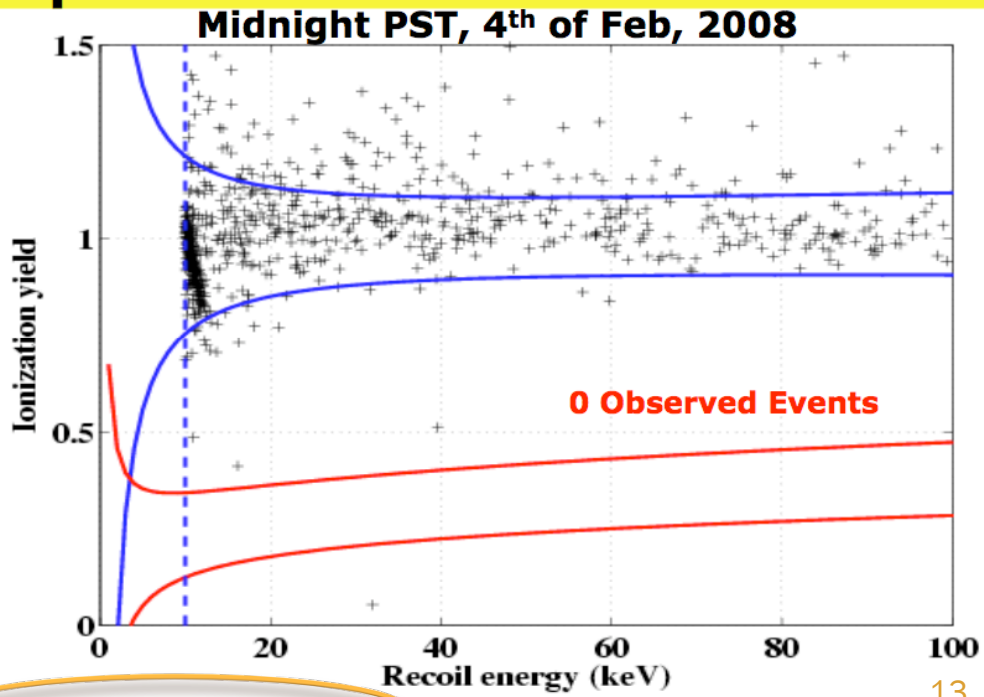


97 Singles in Signal region rejected by Surface Ev

Before cut on surface events
77 evts predicted in ROI

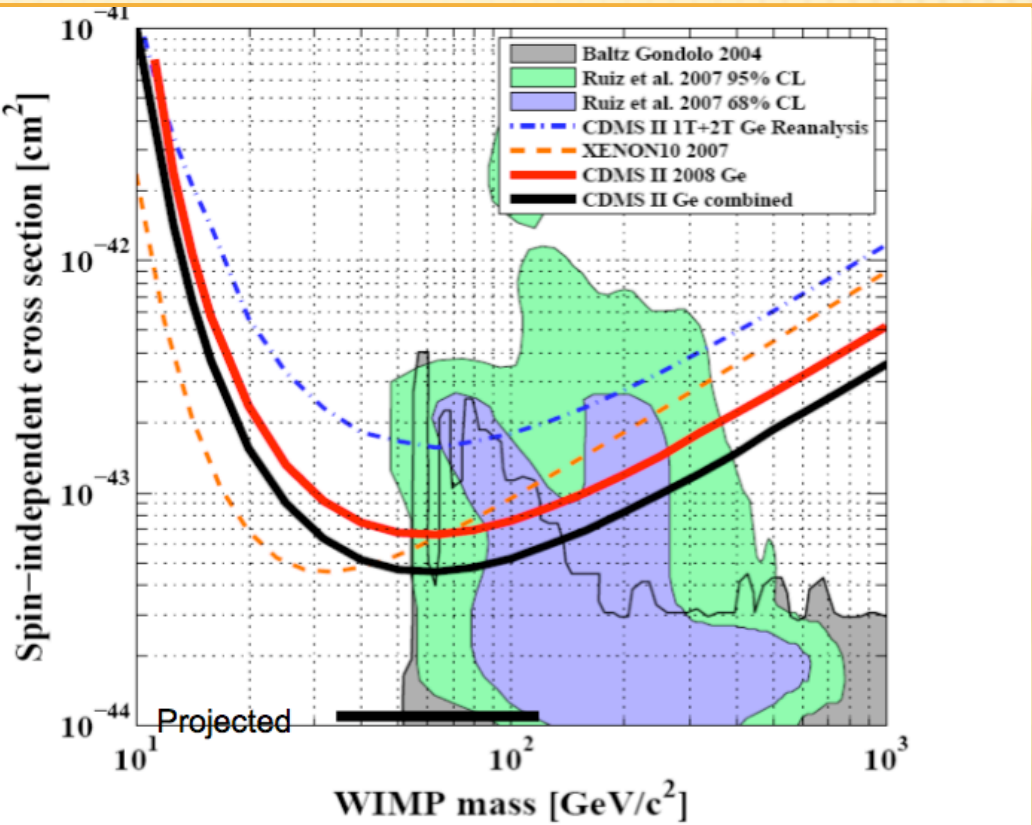
After applying cut on surface events
0.6 evt expected, none seen

Open The Box: Surface Event Cut



Expected Background: 0.6 + 0.5 surface events and < 0.2 neutrons

LIMITS



Reanalysis result from 1T+2T Data available in W. Ogburn's (Stanford) Thesis

- Same sensitivity as Xenon 10
- Could have expected better limits !?
- 1000 kg.d raw to be open in september

New comers : KIMS-07 TEXONO-07 COUPP-08

- KIMS constrains high mass SI
- COUPP constrains SD
- TEXONO constrains low mass SI
- => DAMA/LIBRA getting more and more in trouble

KIMS

Korea Invisible Mass Search

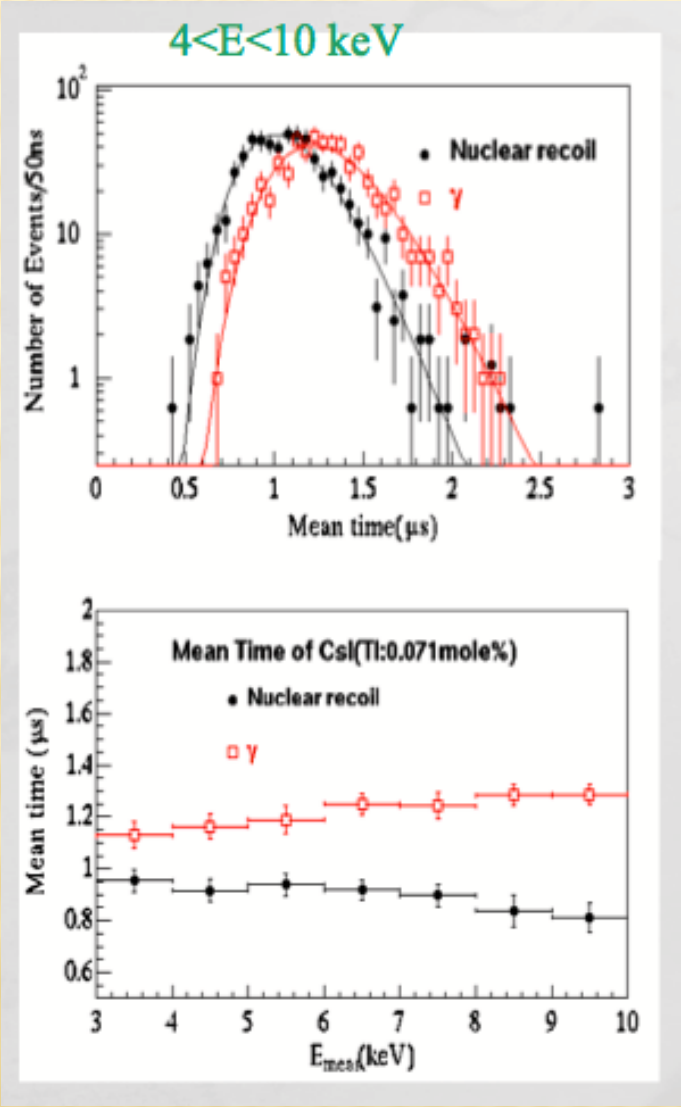
CsI(Tl)

	<Sp>	<Sn>
Cs-133	-0.370	0.003
I-127	0.309	0.075
Na-23	0.248	0.019

	CsI(Tl)	NaI(Tl)
Photons/MeV	~60,000	~40,000
Density(g/cm3)	4.53	3.67
Decay Time(ns)	~1050	~230
Peak emission(nm)	550	415
Hygroscopicity	slight	strong

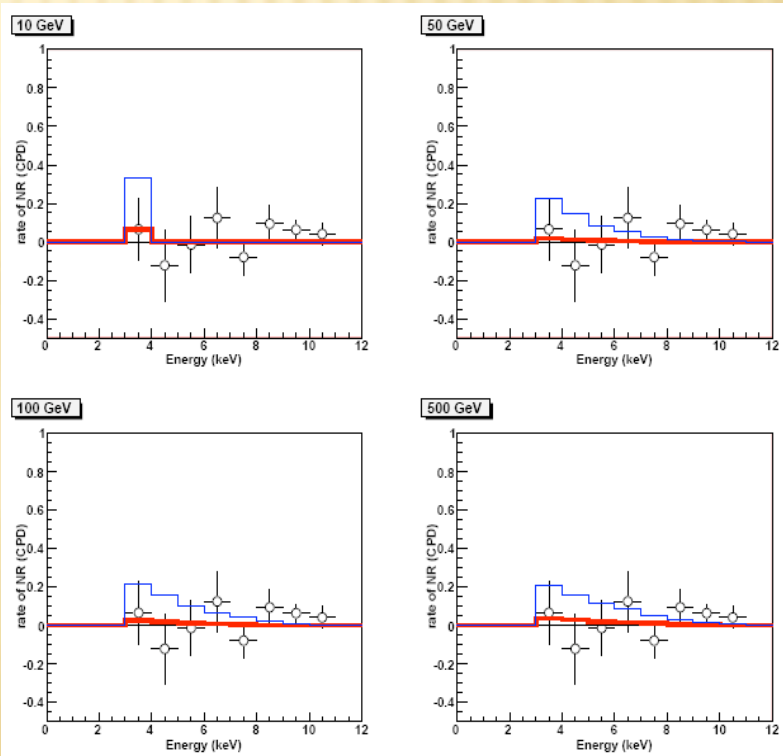
CsI(Tl) : 4 * 8.7 kg crystals

- Pulse shape discrimination on 3409 kg.d



Data used for this analysis

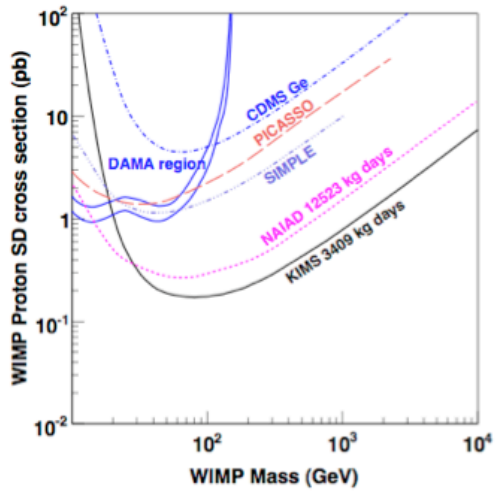
Crystal	p.e./keV	Mass(kg)	Data(kg·days)
S0501A	4.6	8.7	1147
S0501B	4.5	8.7	1030
B0510A	5.9	8.7	616
B0510B	5.9	8.7	616
Total		34.8	3409



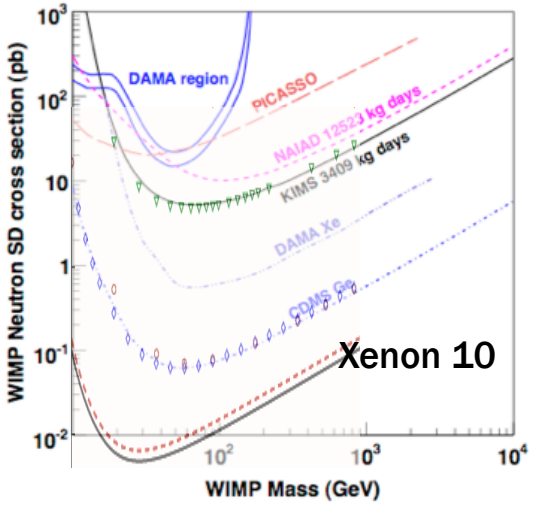
KIMS : results

- Direct comparison with DAMA (same nucleus) for SI coupling
- Best limits on proton SD X section

Spin dependent limits



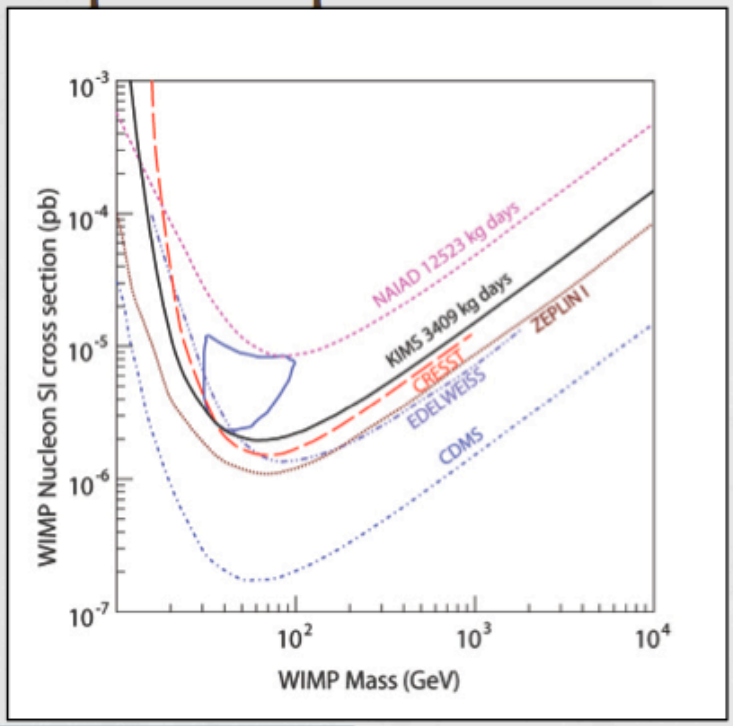
Pure proton case



Pure neutron case

- More this afternoon !

Spin independent limits



Nuclear recoil of ^{127}I of DAMA signal region is ruled out

PRL 99, 091301 (2007)

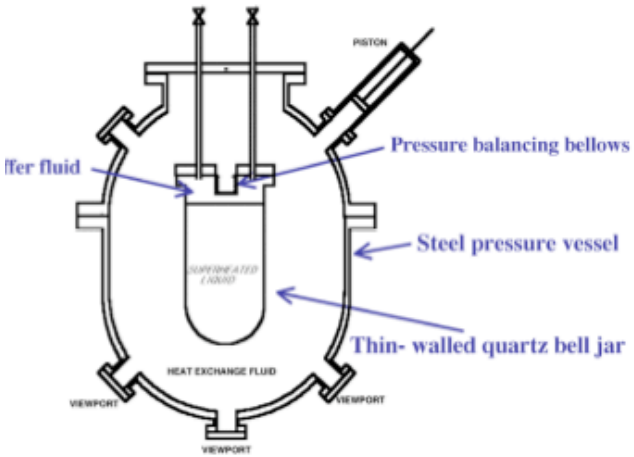
Latest News (sept 07)

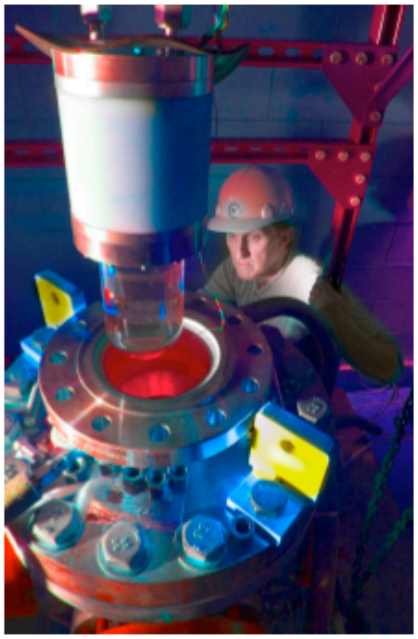
- 12 crystals(104.4kg) installed in the shield
- 1st Calibration run was over
- Started data taking for annual modulation
- Expect a stable data taking for more than a year

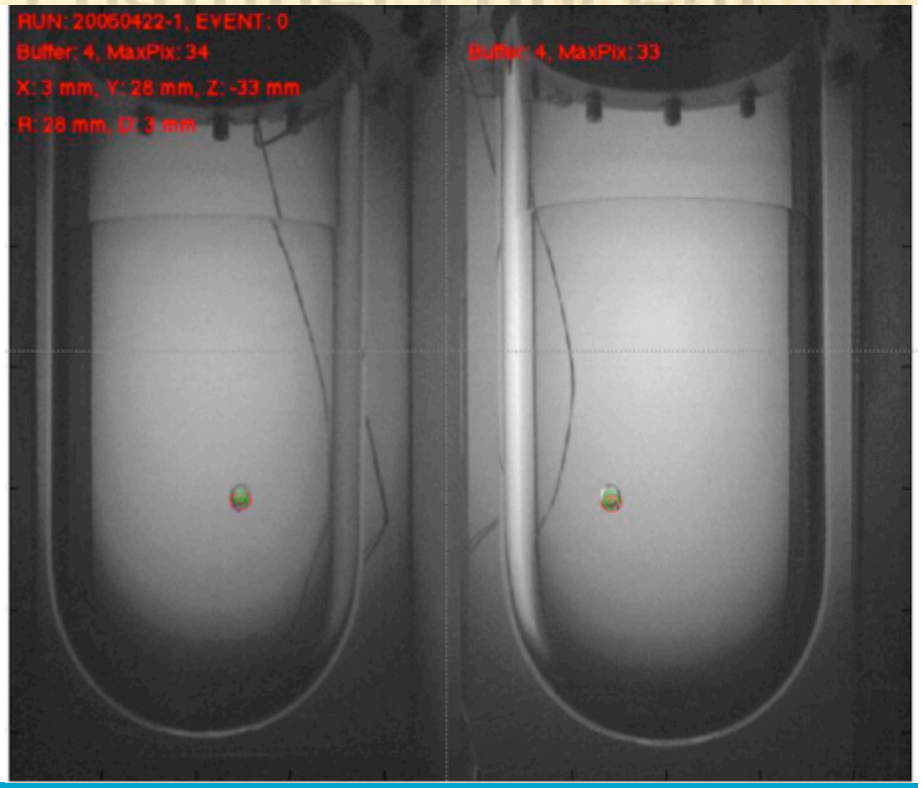
COUPP : the old bubble chamber concept

1-Liter Chamber in NuMi Tunnel

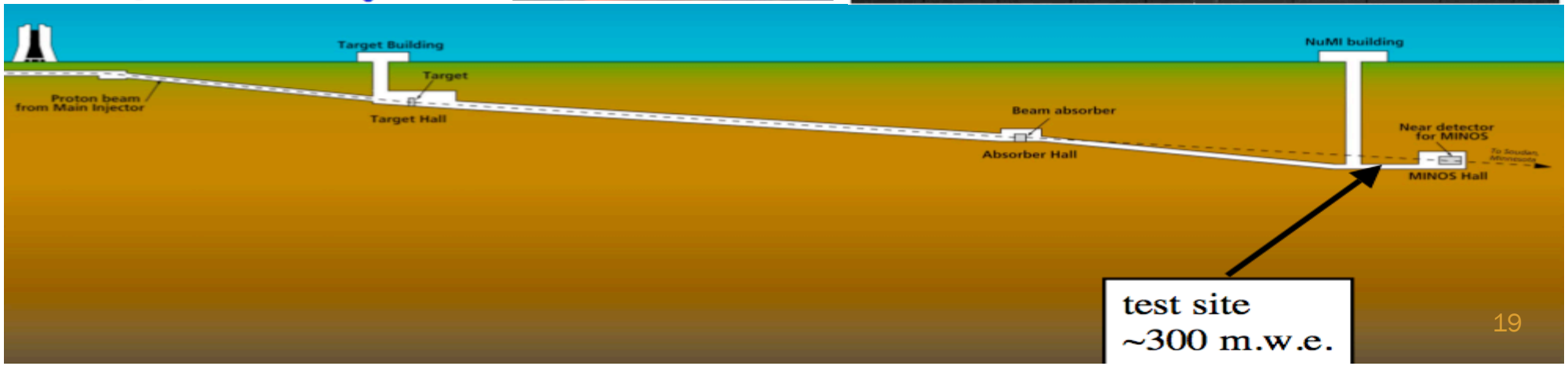
Design concept:





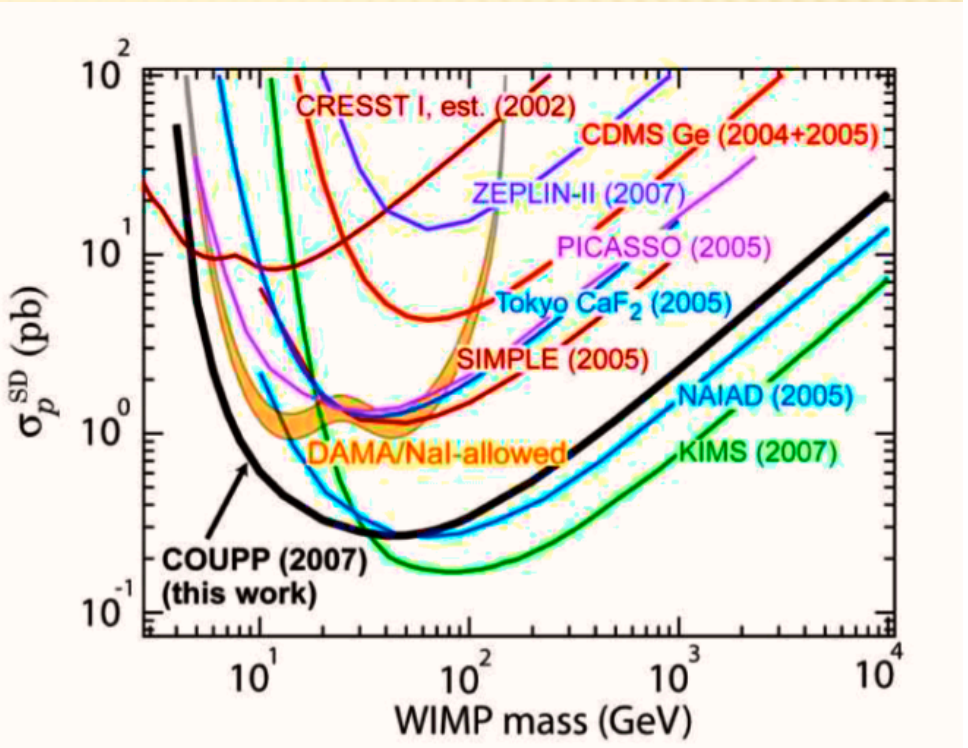


Target liquid: CF_3I



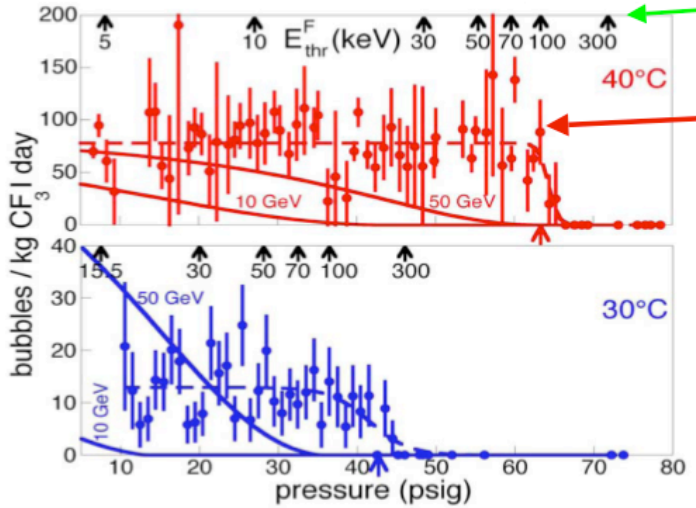
COUPP results

- Insensitive to em backg
- "Digital" response but
- Tuning of T and P allows energy scan



Data from 2006 Run

- Data from pressure scan at two temperatures.
- Fit to alphas + WIMPs



Energy Thr
In KeV

Radon background

Solid lines: Expected WIMP response for $\sigma^{SD(p)}$=3 pb

- Good sensitivity with 19F nucleus to SD pure p couplings (even in presence of high radon background)
- Building 20 and 60 kg vessels

TEXONO 07 (Taiwan, China, Turkey) low energy

- Ultra low energy Ge's (4 * 5g) at 77K operated at Kuo Sheng reactor with low threshold (eff >80 % @ 0.25 keV) 0.338 kg.d

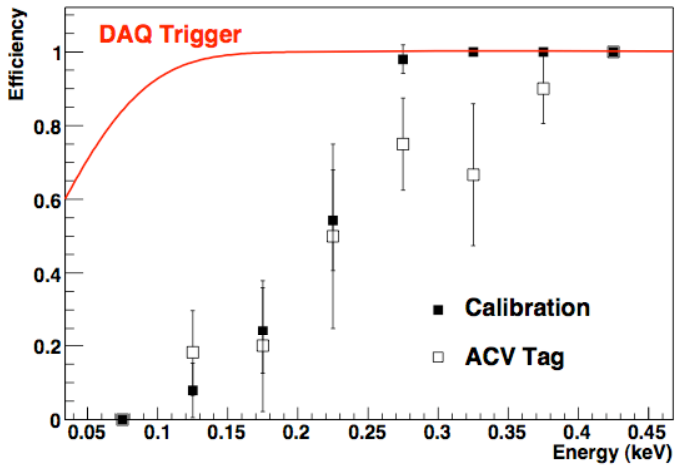


FIG. 3: Selection efficiencies of the PSD cut, as derived from the ^{55}Fe-source calibration and from in situ data with ACV tags. The solid line represents the trigger efficiency where physics events were recorded by the DAQ system.

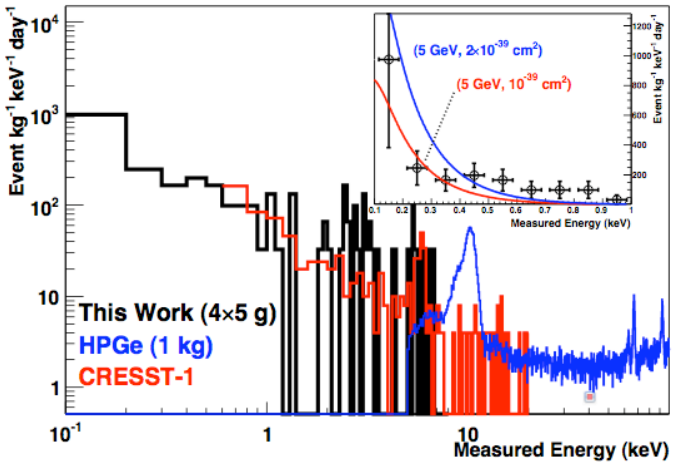


FIG. 4: The measured spectrum of ULEGe with 0.338 kg-day of data, after CRV, ACV and PSD selections. Background spectra of the CRESST-I experiment [9] and the HPGe [13] are overlaid for comparison. The expected nuclear recoil spectra for two cases of $(m_\chi, \sigma^{SI}_{\chi N})$ are superimposed onto the spectrum shown in linear scales in the inset.

Beware : arXiv:0806.1341 comment by Avignone et al. : rate at lowest energy may be underestimated

Low WIMP mass limits

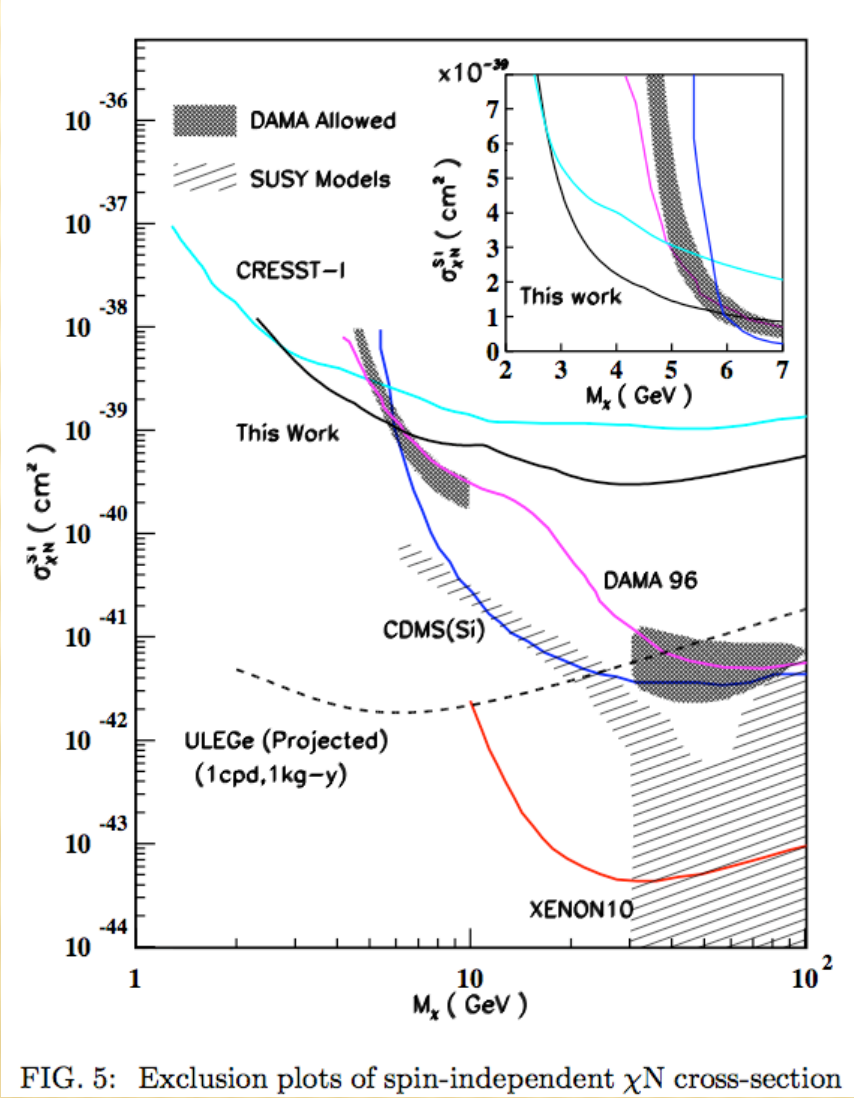
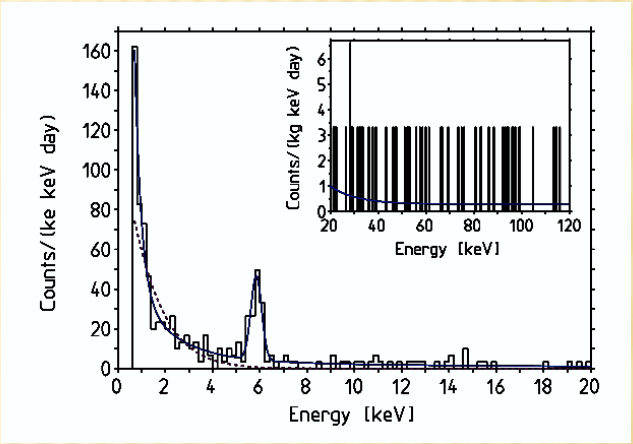
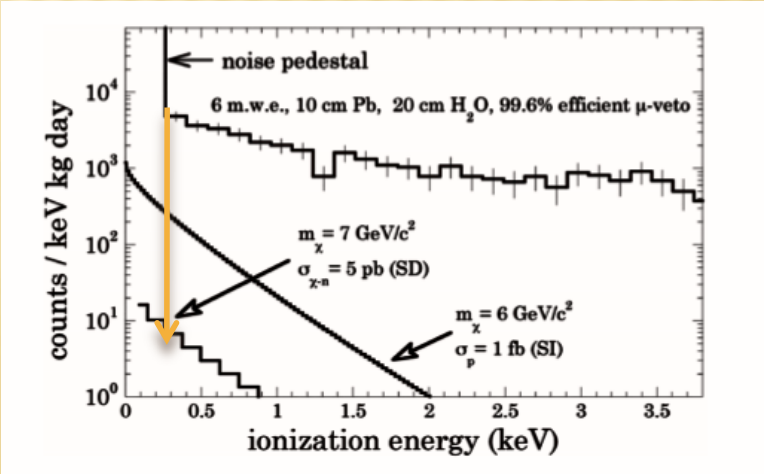


FIG. 5: Exclusion plots of spin-independent χN cross-section

- CRESST-1 finds also rising up of spectrum at LE threshold @ 0.6 keV, Al_2O_3 1.5 kg.d



- New large mass 475 g Ge with 0.33 keV threshold (Barbeau et al.)

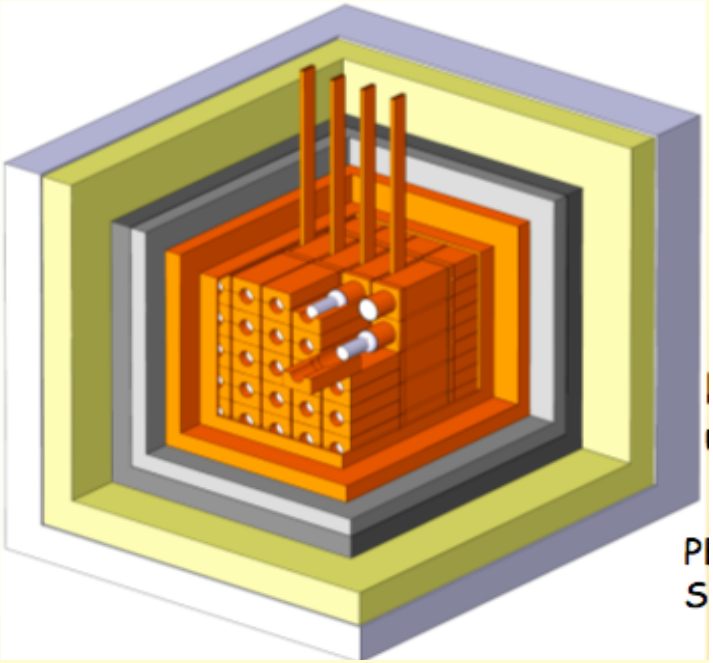


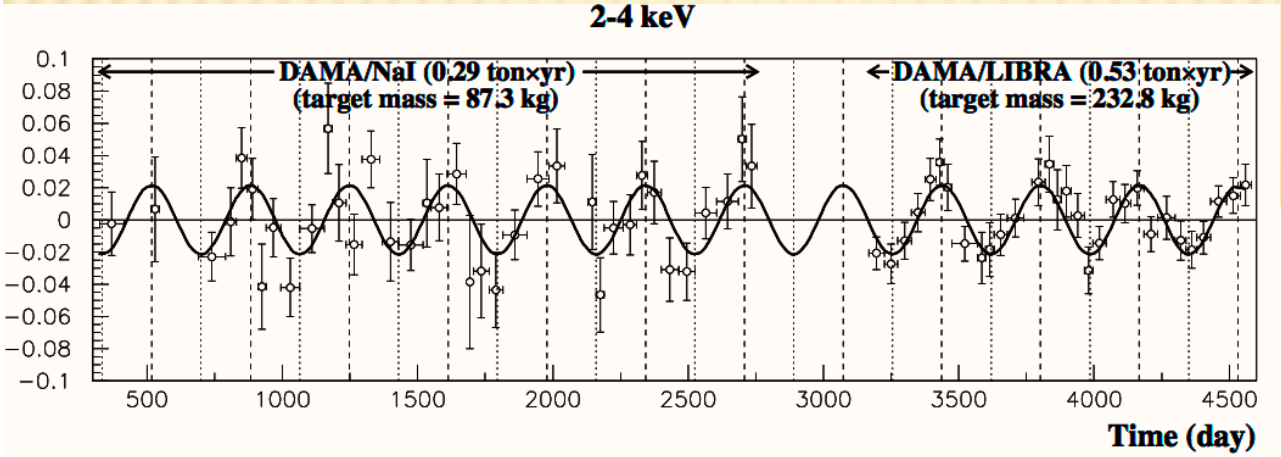
DAMA/LIBRA : modulation still there

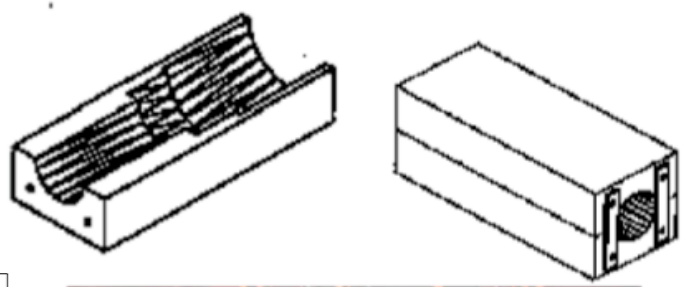
- 25 modules of 9.7 kg
- 4 years data taking (09/03 to 07/07)

=> 192 000 kg.d = twice DAMA exposure

- From 6 to 8.2σ







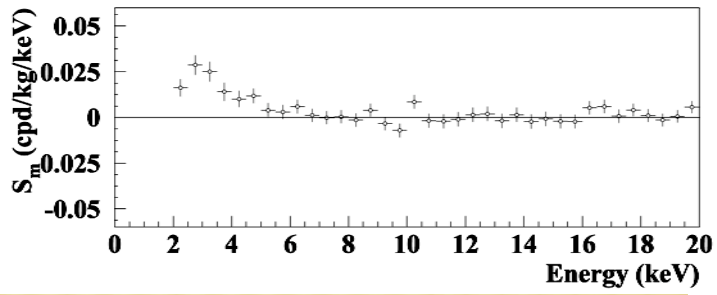
2-4 keV

A=(0.0215±0.0026) cpd/kg/keV

χ^2/dof = 51.9/66 **8.3 σ C.L.**

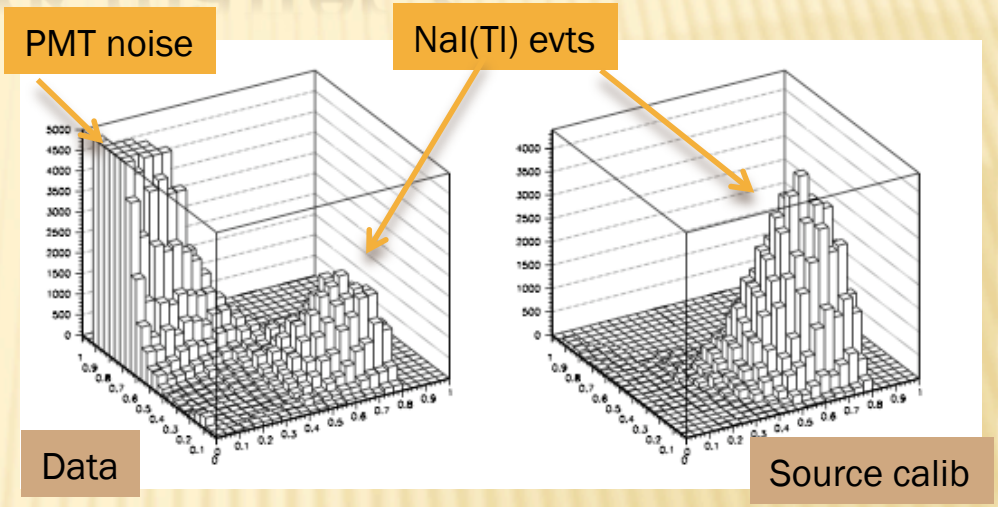
Absence of modulation? No

χ^2/dof=117.7/67 ⇒ P(A=0) = 1.3×10^{-4}

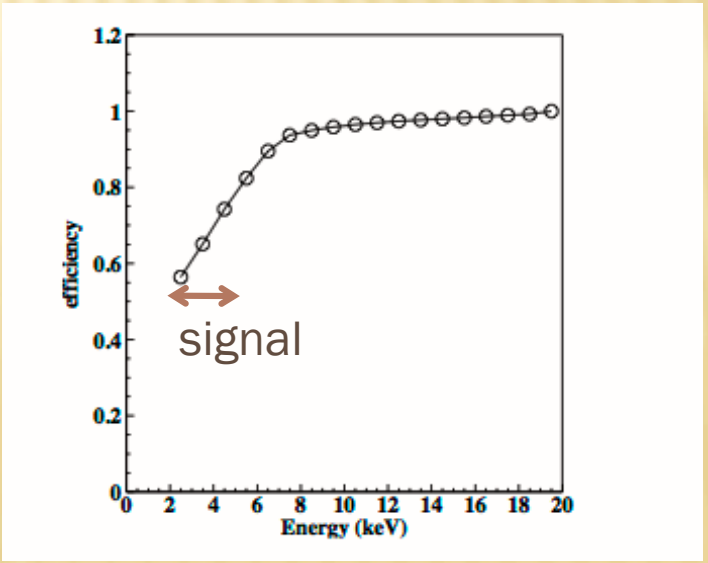


Is this evidence of dark matter ?

- **Exp questions to investigate**
- 1)Tricky analysis at threshold
  - Signal in energy window dominated by PMT noise
  - Signal at threshold in varying efficiency energy region
  - =>influence of cuts on noise rejection, signal power ?
  - => difference of efficiencies for signal and background ?

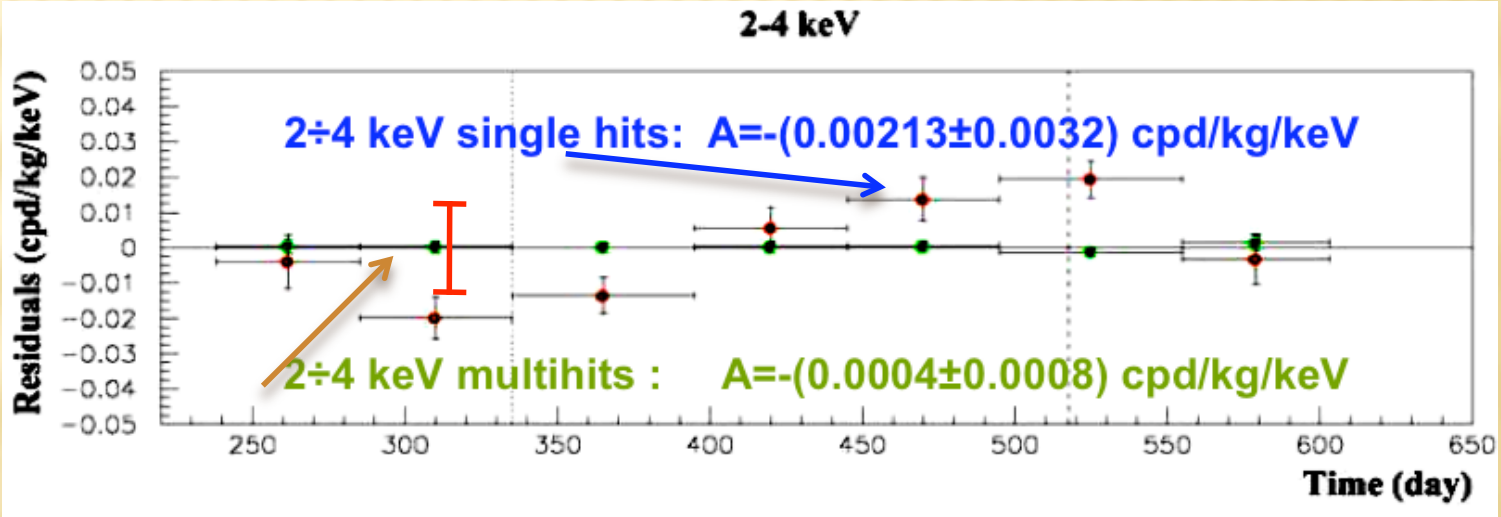


2-4 keV region : pulse shape analysis for PMT noise rejection



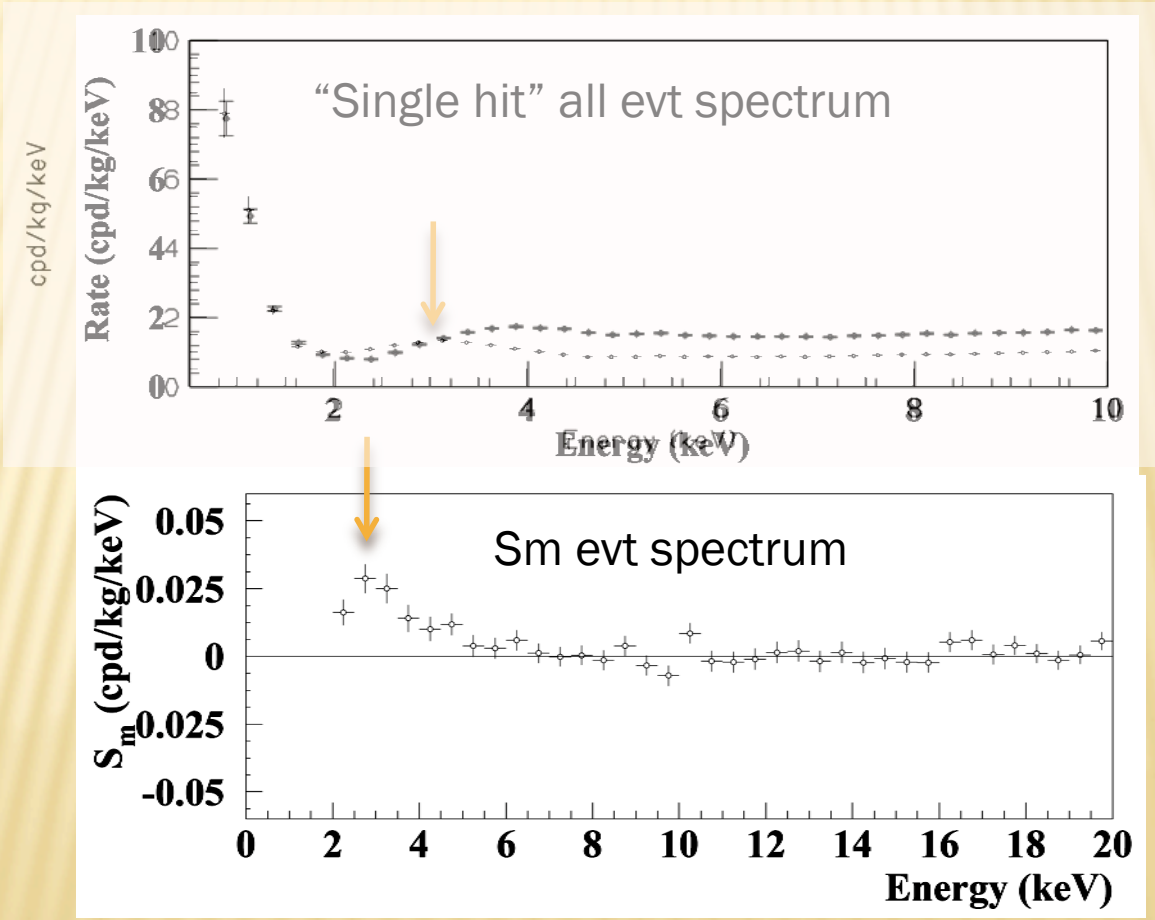
Is this evidence of dark matter ?

- 2) Multi hits vs single hit modulation evidence ?
  - Look obvious from below plot, but
  - Multihit rate is much lower (1/10)
  - Then expected modulated part and error also
  - => marginal statistics to be able to exclude a modulation in the multihit events (red bar)



Is this evidence of dark matter ?

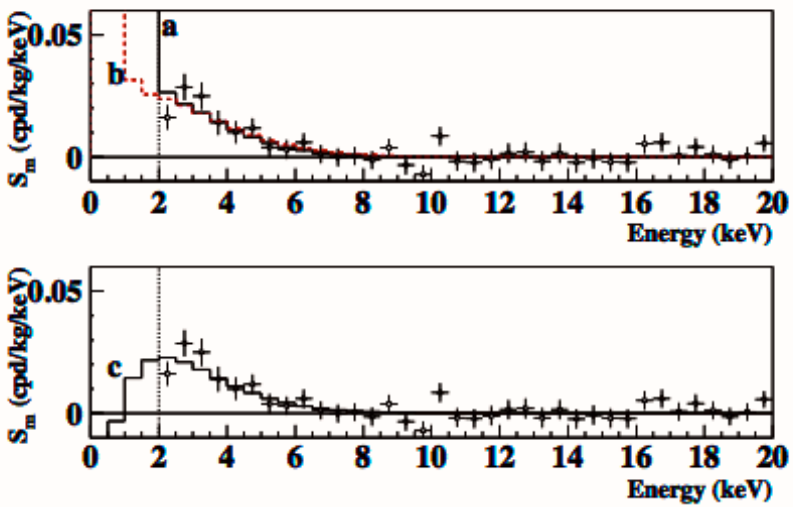
- 3) Coincidence of Sm signal with 3 keV peak of ^{40}K in all spectrum ?
  - Looks like the modulation of a peak ?
  - What is the expected contribution from ^{40}K ?



2003 spectrum

The “many possible scenario’s” 1 : WIMP’s

- “Classical” nuclear recoils of WIMP’s
- SI and/or SD mostly excluded by recent experiments
- => Tension increasing

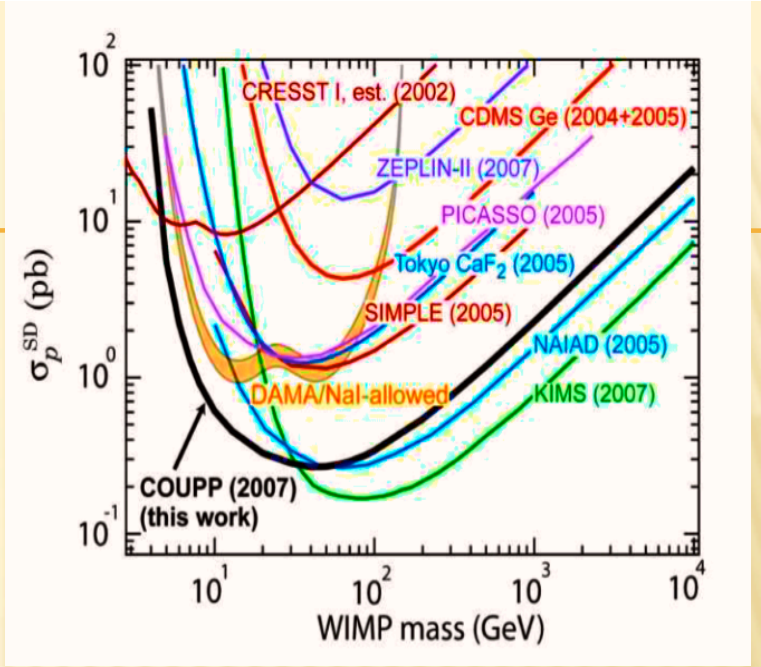


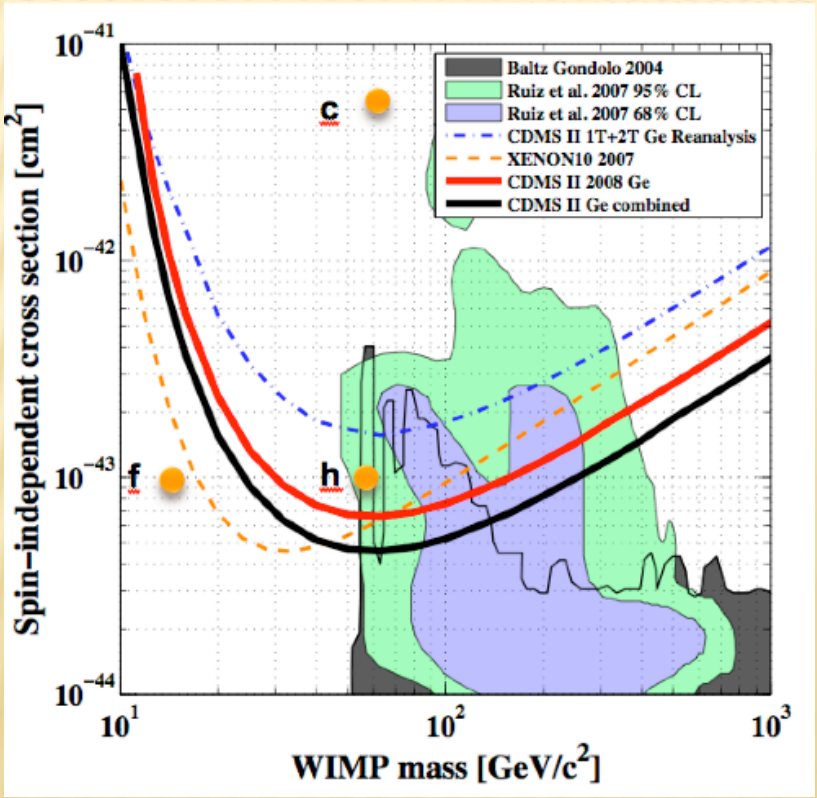
DM particle elastic scattering on nuclei, spin-independent (SI) and spin-dependent (SD) cross sections, local velocity = 170 km/s and nuclear cross section scaling laws as in [4]

Curve label	Halo model (see ref. [4, 34])	Local density (GeV/cm^3)	Set as in [4]	DM particle mass	$\xi\sigma_{SI}$ (pb)	$\xi\sigma_{SD}$ (pb)	θ (rad)	Channeling [9]
a	A5 (NFW)	0.2	A	15 GeV	3.1×10^{-4}	0	–	no
b	A5 (NFW)	0.2	A	15 GeV	1.3×10^{-5}	0	–	yes
c	A5 (NFW)	0.2	B	60 GeV	5.5×10^{-6}	0	–	no
d	B3 (Evans power law)	0.17	B	100 GeV	6.5×10^{-6}	0	–	no
e	B3 (Evans power law)	0.17	A	120 GeV	1.3×10^{-5}	0	–	no
f	A5 (NFW)	0.2	A	15 GeV	10^{-7}	2.6	2.435	no
g	A5 (NFW)	0.2	A	15 GeV	1.4×10^{-4}	1.4	2.435	no
h	A5 (NFW)	0.2	B	60 GeV	10^{-7}	1.4	2.435	no
i	A5 (NFW)	0.2	B	60 GeV	8.7×10^{-6}	8.7×10^{-2}	2.435	no
j	B3 (Evans power law)	0.17	A	100 GeV	10^{-7}	1.7	2.435	no
k	B3 (Evans power law)	0.17	A	100 GeV	1.1×10^{-5}	0.11	2.435	no

The WIMP scenario

- "Classical" nuclear recoils of WIMP's
- SI and/or SD mostly excluded by recent experiments, small window at low mass and/or non "non standard" halo
- => "Tension increasing"





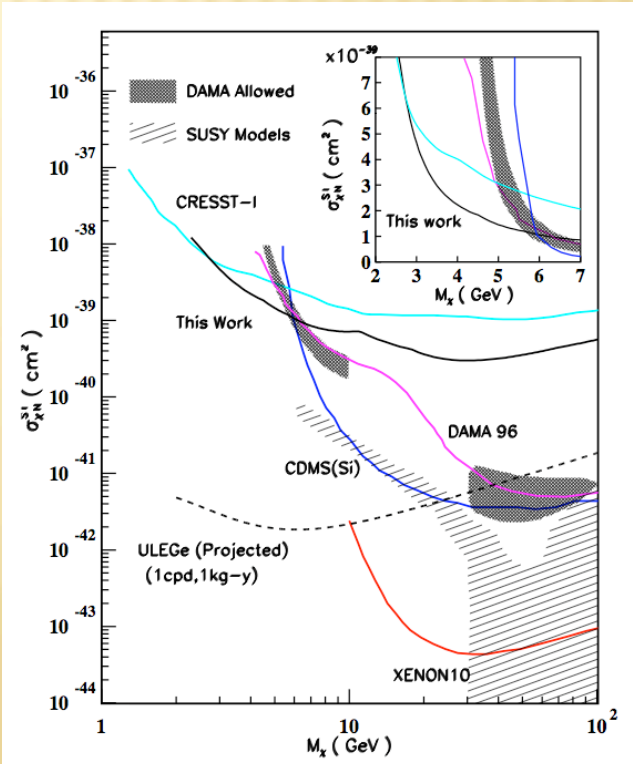
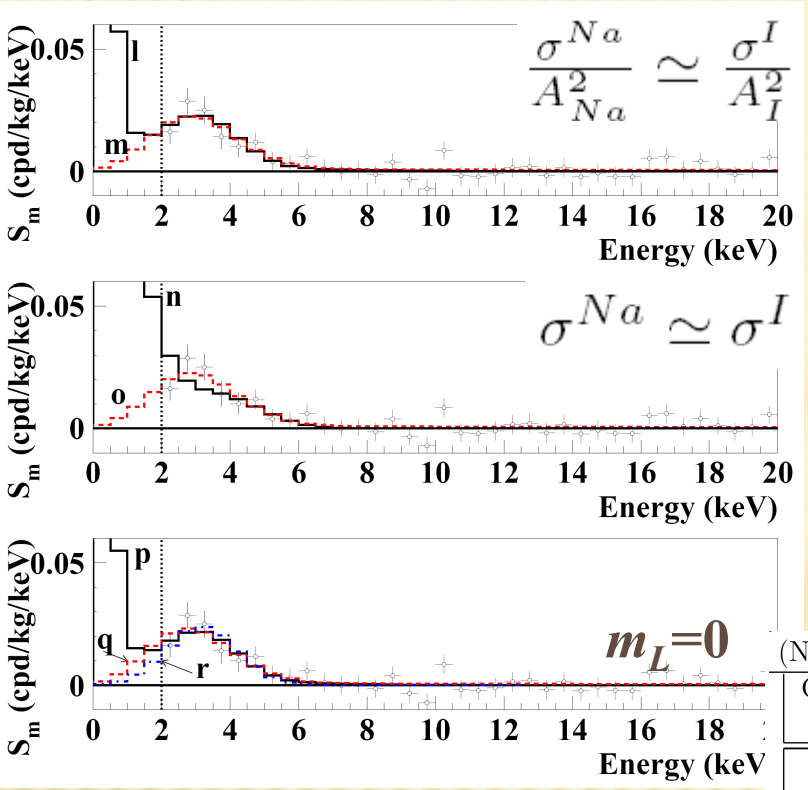
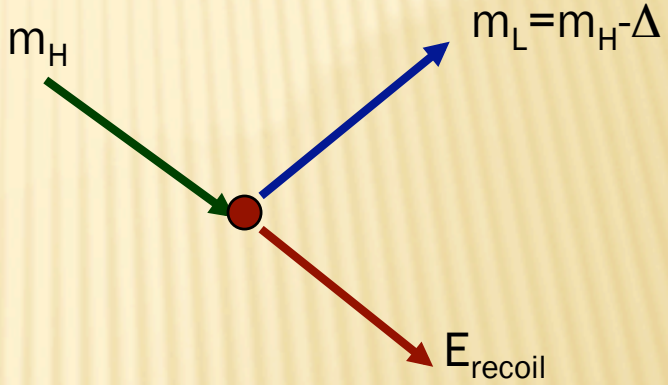


FIG. 5: Exclusion plots of spin-independent χN cross-section

Other possible scenario :light dark matter



inelastic interaction with electron or nucleus targets



Modulation from dependence of cross section on velocity

$$\sigma v \simeq a + bv^2$$

LDM candidate (arXiv:0802.4336)

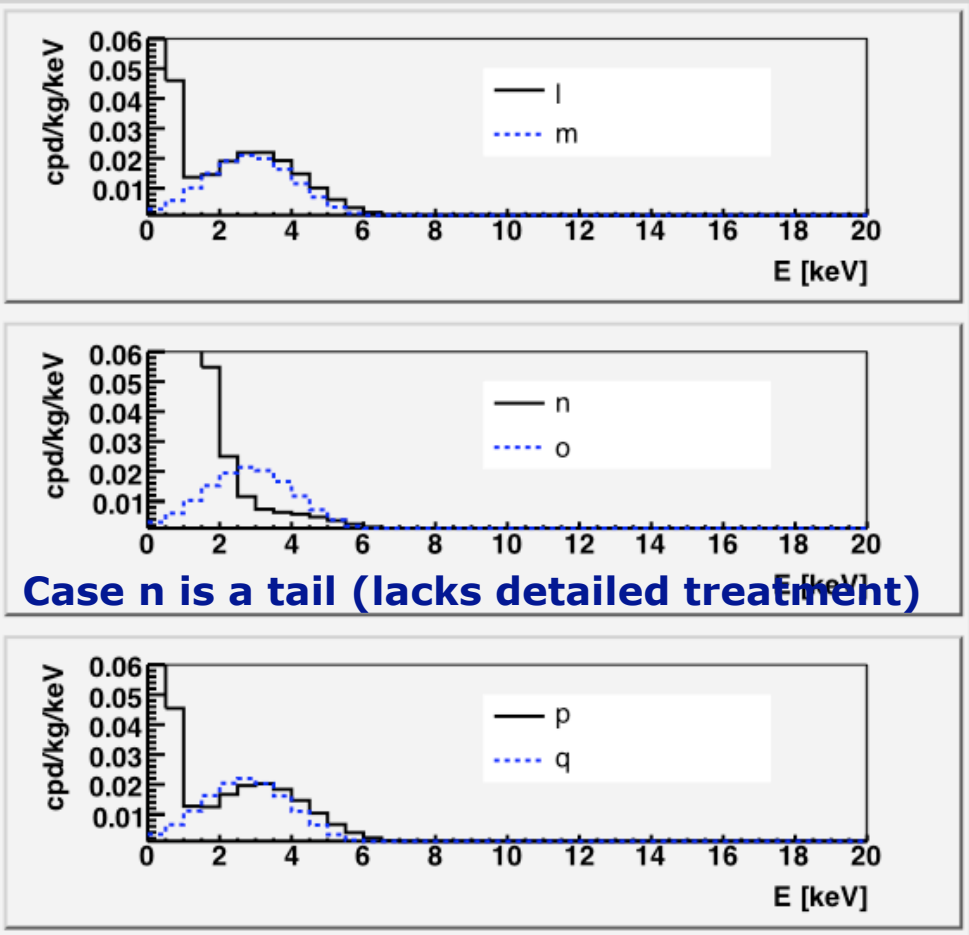
(NFW) halo model as in [4, 34], local density = 0.17 GeV/cm^3, local velocity = 170 km/s

Curve label	DM particle	Interaction	Set as in [4]	m_H	Δ	Cross section (pb)
l	LDM	coherent on nuclei	A	30 MeV	18 MeV	$\xi\sigma_m^{coh} = 1.8 \times 10^{-6}$
m	LDM	coherent on nuclei	A	100 MeV	55 MeV	$\xi\sigma_m^{coh} = 2.8 \times 10^{-6}$
n	LDM	incoherent on nuclei	A	30 MeV	3 MeV	$\xi\sigma_m^{inc} = 2.2 \times 10^{-2}$
o	LDM	incoherent on nuclei	A	100 MeV	55 MeV	$\xi\sigma_m^{inc} = 4.6 \times 10^{-2}$
p	LDM	coherent on nuclei	A	28 MeV	28 MeV	$\xi\sigma_m^{coh} = 1.6 \times 10^{-6}$
q	LDM	incoherent on nuclei	A	88 MeV	88 MeV	$\xi\sigma_m^{inc} = 4.1 \times 10^{-2}$
r	LDM	on electrons	–	60 keV	60 keV	$\xi\sigma_m^{e} = 0.3 \times 10^{-6}$

From Sm in NaI to S0 in Germanium for LDM

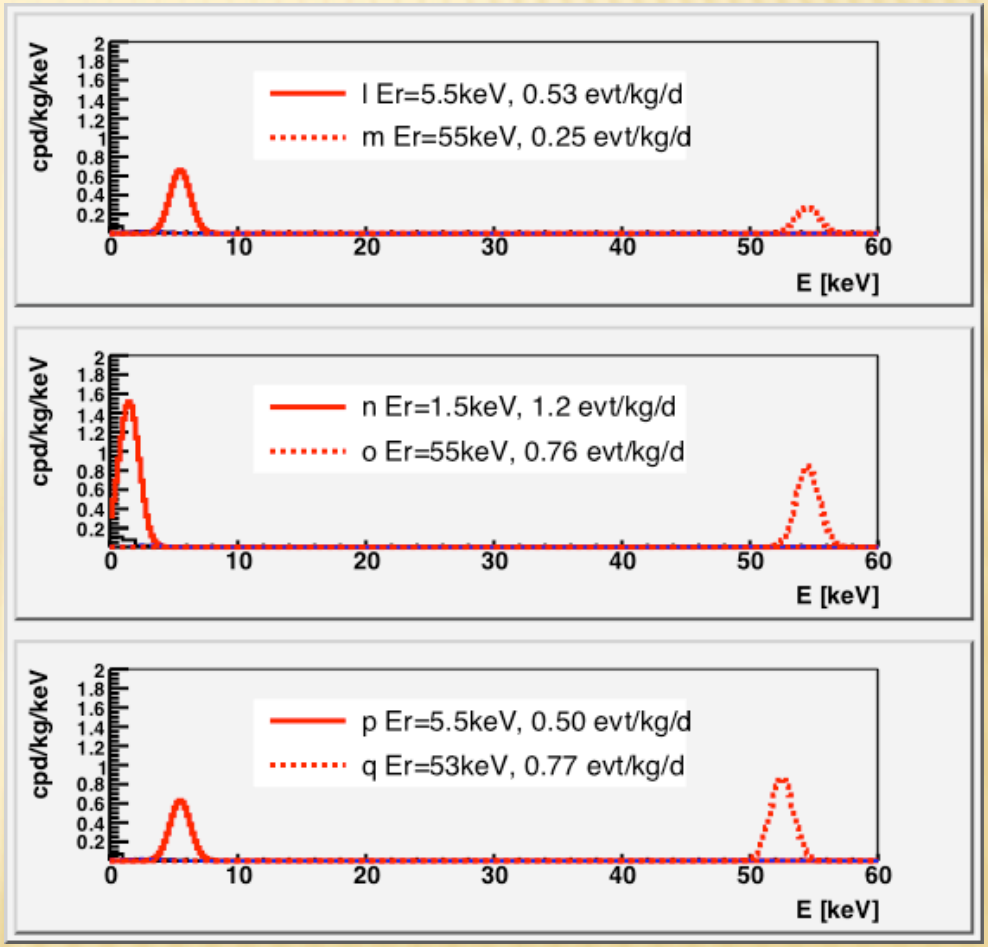
(First calculation within ILIAS network)

S_m NaI



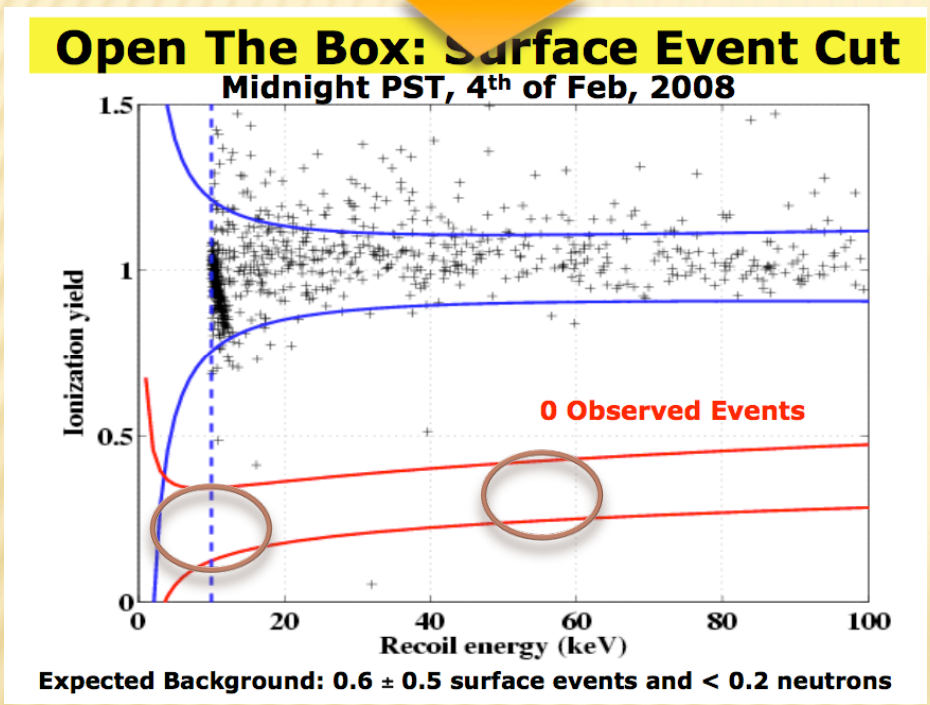
Case n is a tail (lacks detailed treatment)

S_0 Germanium

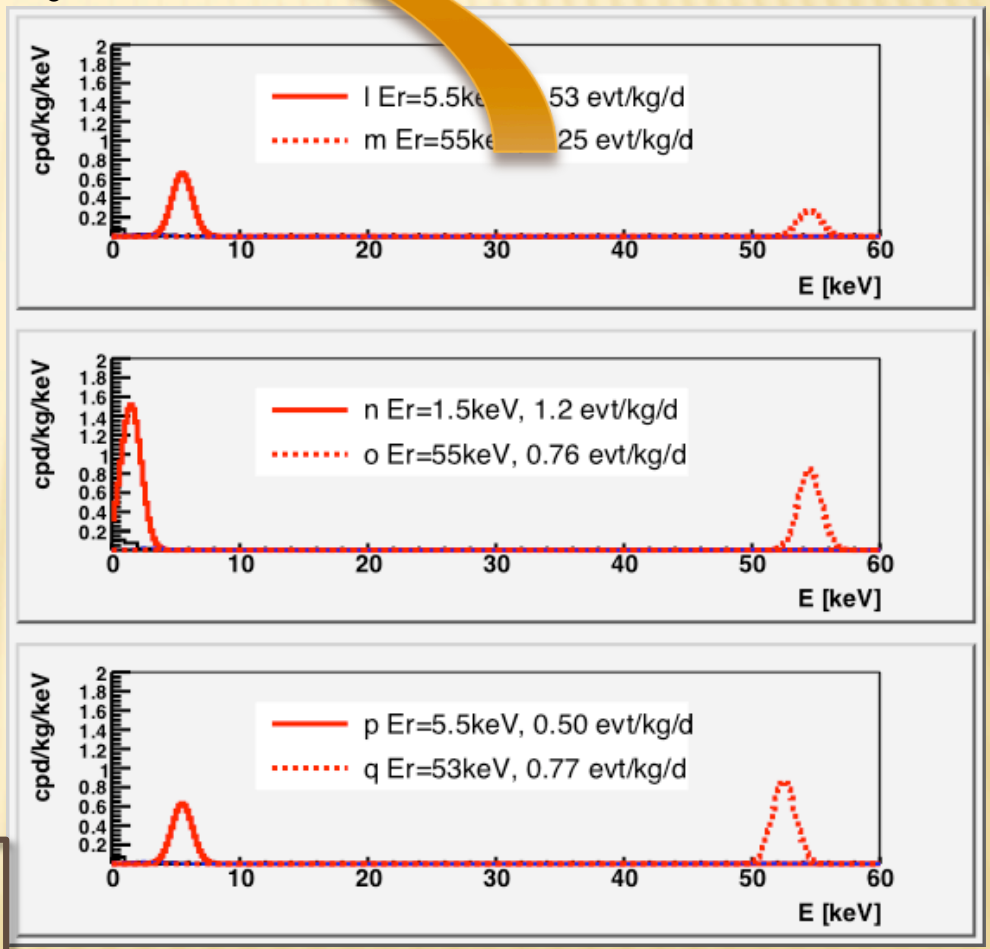


From Sm in NaI to S0 in Germanium for LDM

(First calculation within ILIAS network)



S_0 Germanium



Expect between 40 and 140 evts in these regions

DAMA LIBRA : how to go ahead ?

- Given the issue, the claim, the lack of consensus :
  - Remind Bahcall's proposal at TAUP2003
  - EU ILIAS proposal to provide working group for this
- For models which fits DAMA/LIBRA Sm, calculate S0 for other experiments and check
- "Duplicate" experiment : KIMS (CsI), ANAIS (NaI)
- Explore low energy/mass regions
- In any case, alternate observation by other experiment is needed

DAMA LIBRA : how to go ahead ?

- Given the issue, the claim, the lac
  - Remind Bahcall's proposal at TAUP2
  - EU ILIAS proposal to provide w
- For models which fits DAMA/ for other experiments and ch
- "Duplicate" experiment : KIM
- Explore low energy/mass reg
- In any case, alternate observ is needed

TAUP03: Some Comments

John Bahcall

DAMA

- DAMA sees a modulation at 6.3s
- Potentially, this is extremely important.
- Existing experiments cannot check this result directly.
- Therefore,
  - Appoint blue-ribbon committee with subpoena power
  - If no mistakes found, repeat experiment but better

Other experiments ?

- CRESST @ LNGS
- Edelweiss @ LSM/Fréjus
- ZEPLIN III @ Boulby

Taking new data

- WARP @ LNGS
- ANAIS, ArDM @ Canfranc

Preparing

- + many R&D's ongoing, apologies for non exhaustive list

CRESST SEPT07

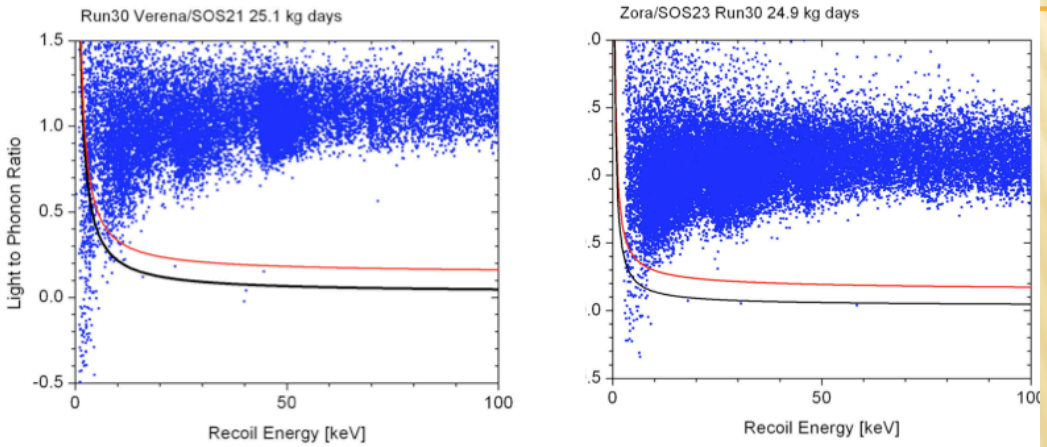
Upgrade

- installation of 66 SQUID
  ....channels to readout 33
  ....detector modules (10 kg);
  ....wiring, electronics, data
  ....acquisition...

- installation of PE neutron
  ....moderator and plastic
  ....scintillator μ-veto

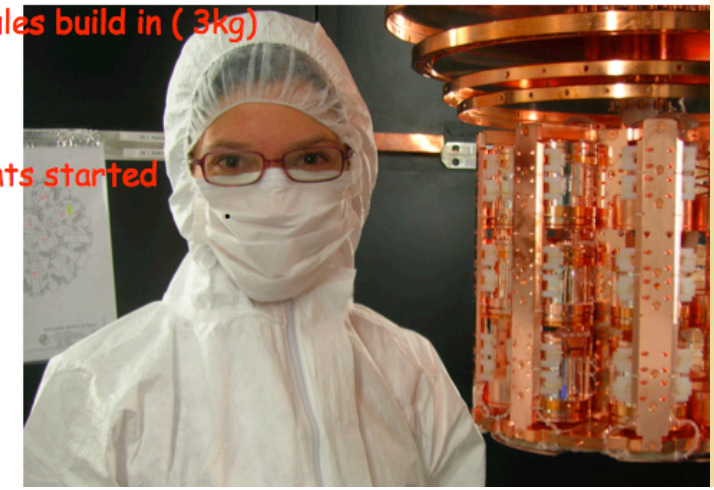
finished

Discrimination and background



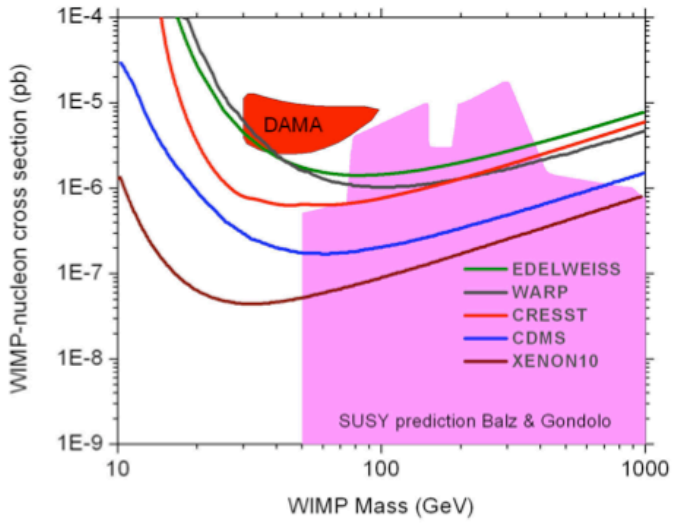
Comissioning run

- 10 detector modules build in (3kg)
- cryostat running
- first measurements started



Preliminary limits

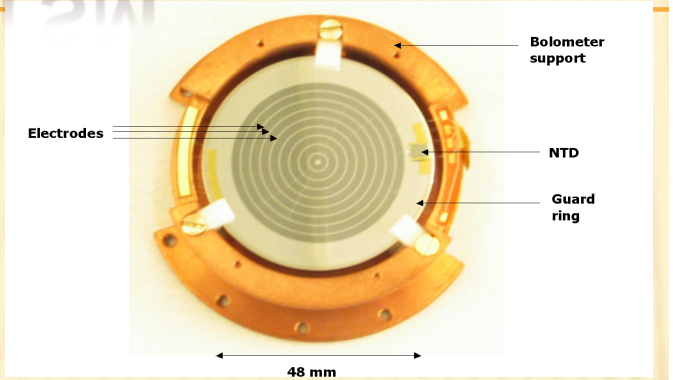
no neutron calibration yet

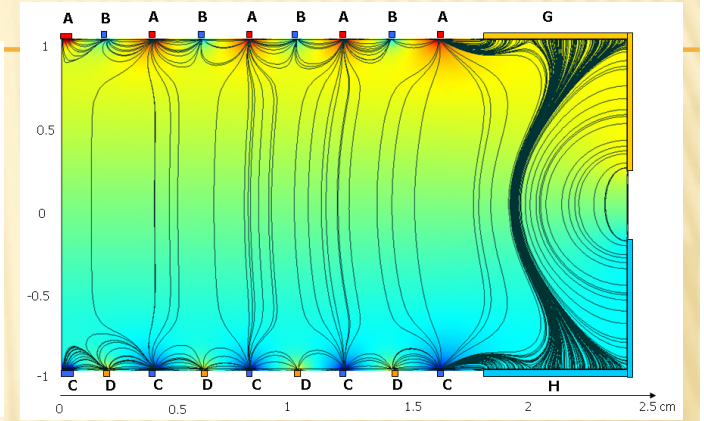


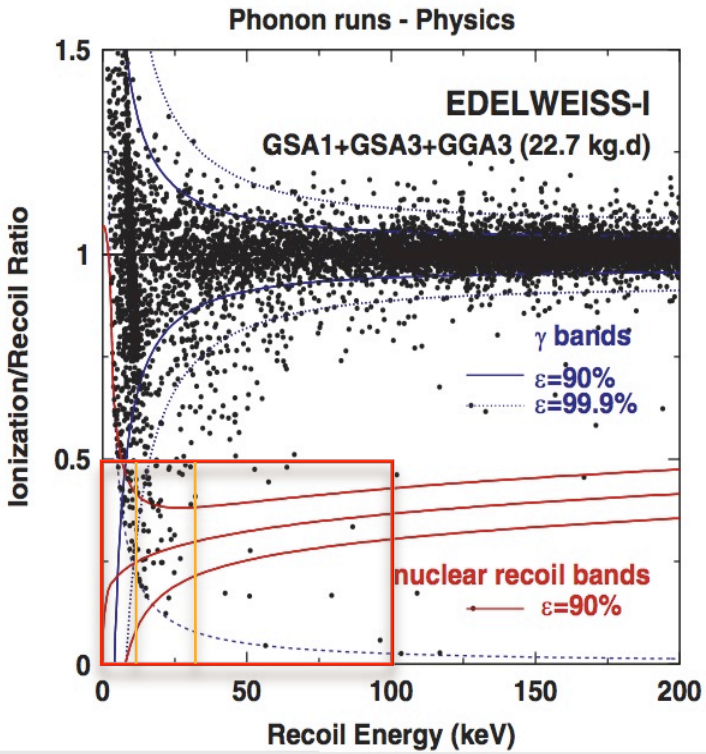
10 detectors being operated

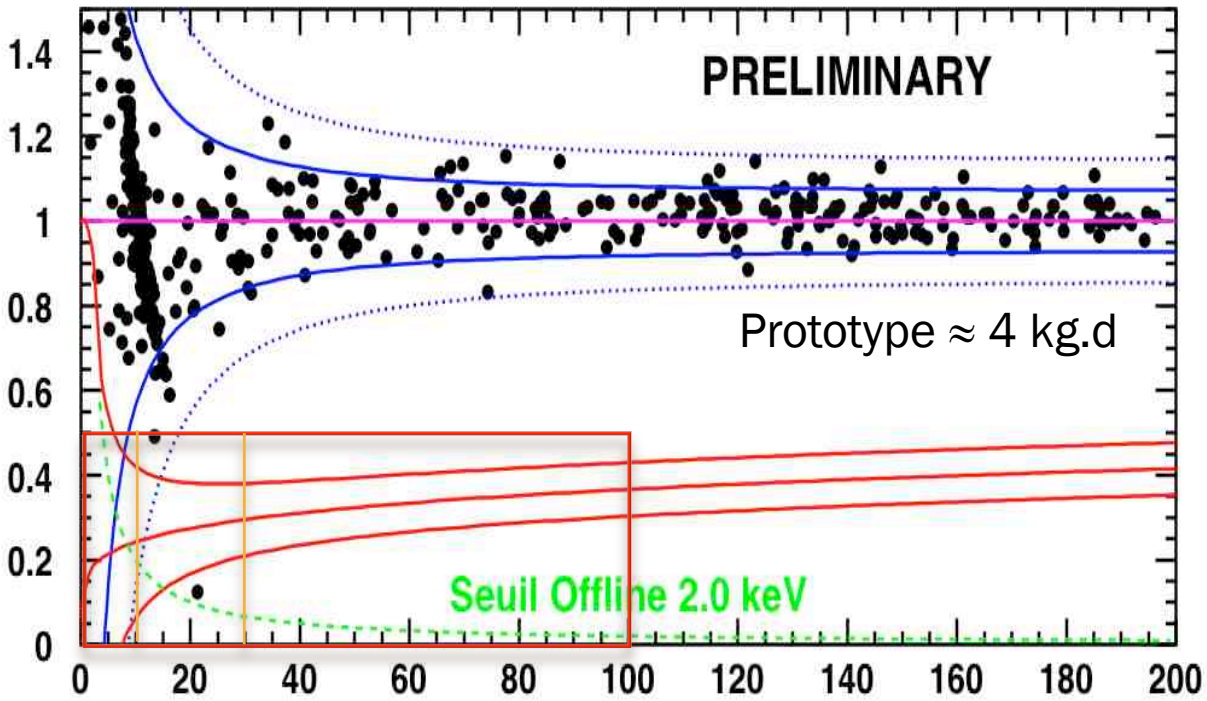
EDELWEISS @ LSM

- New surface event rejection detector
- 12 * 400g detectors in fabrication and operated by end 2008







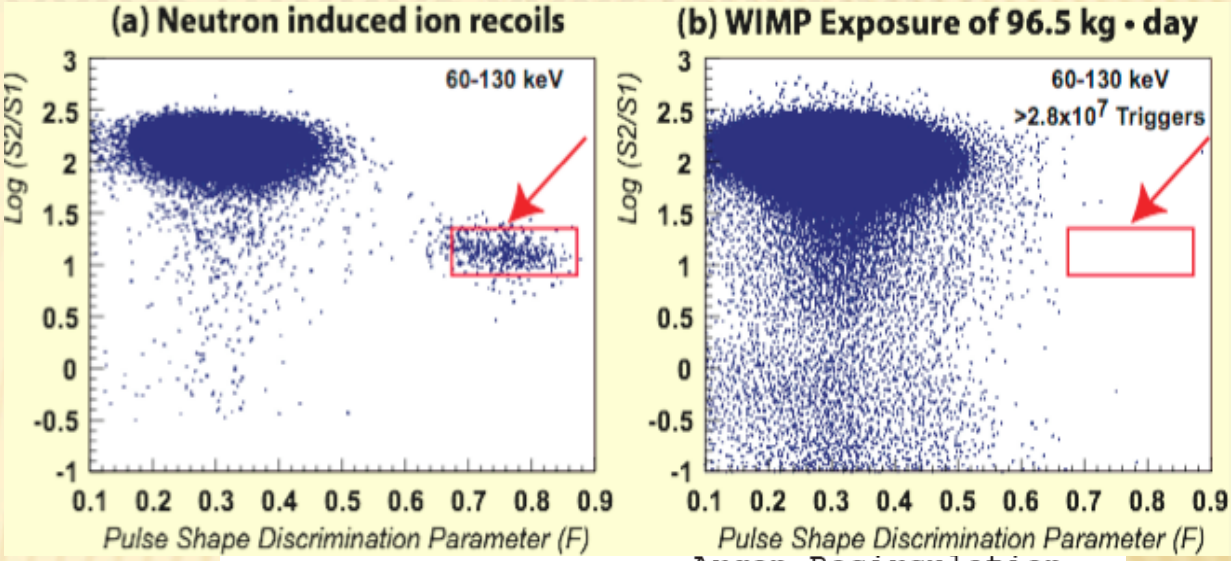


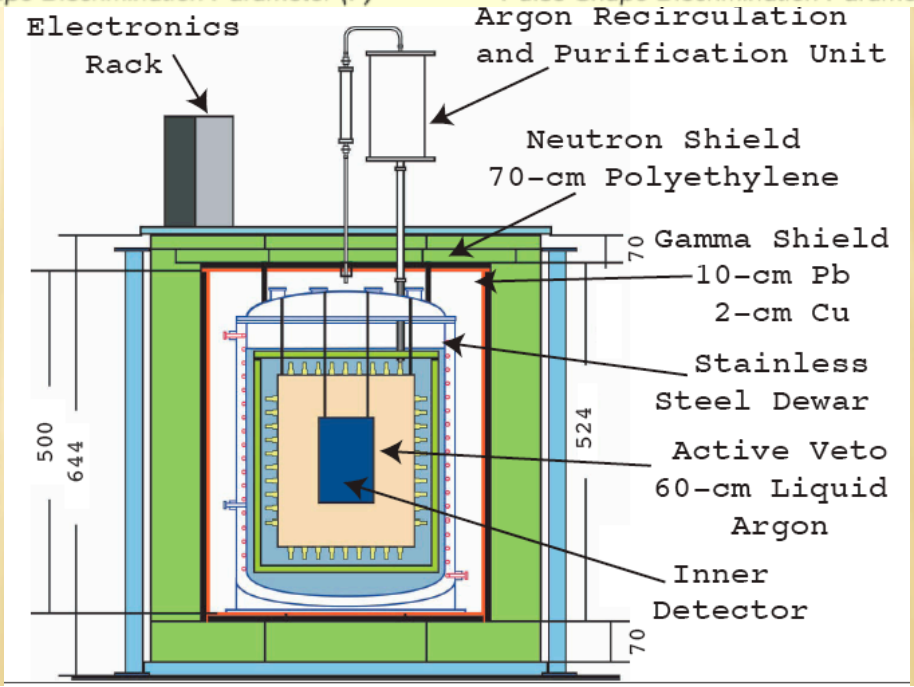
NTD 300g detectors EDW1 22.7 kg.d

Interdigit 200g 4 kg.d Ei threshold 2 keV
After surface evt rejection, no quality cut

WARP 140-kg detector (under construction)

- First liq Ar 2.3 l prototype operated
- =>Excellent discrimination demonstrated : S2/S1 + pulse shape
- Threshold still high
- A priori cheap but ^{39}Ar issue

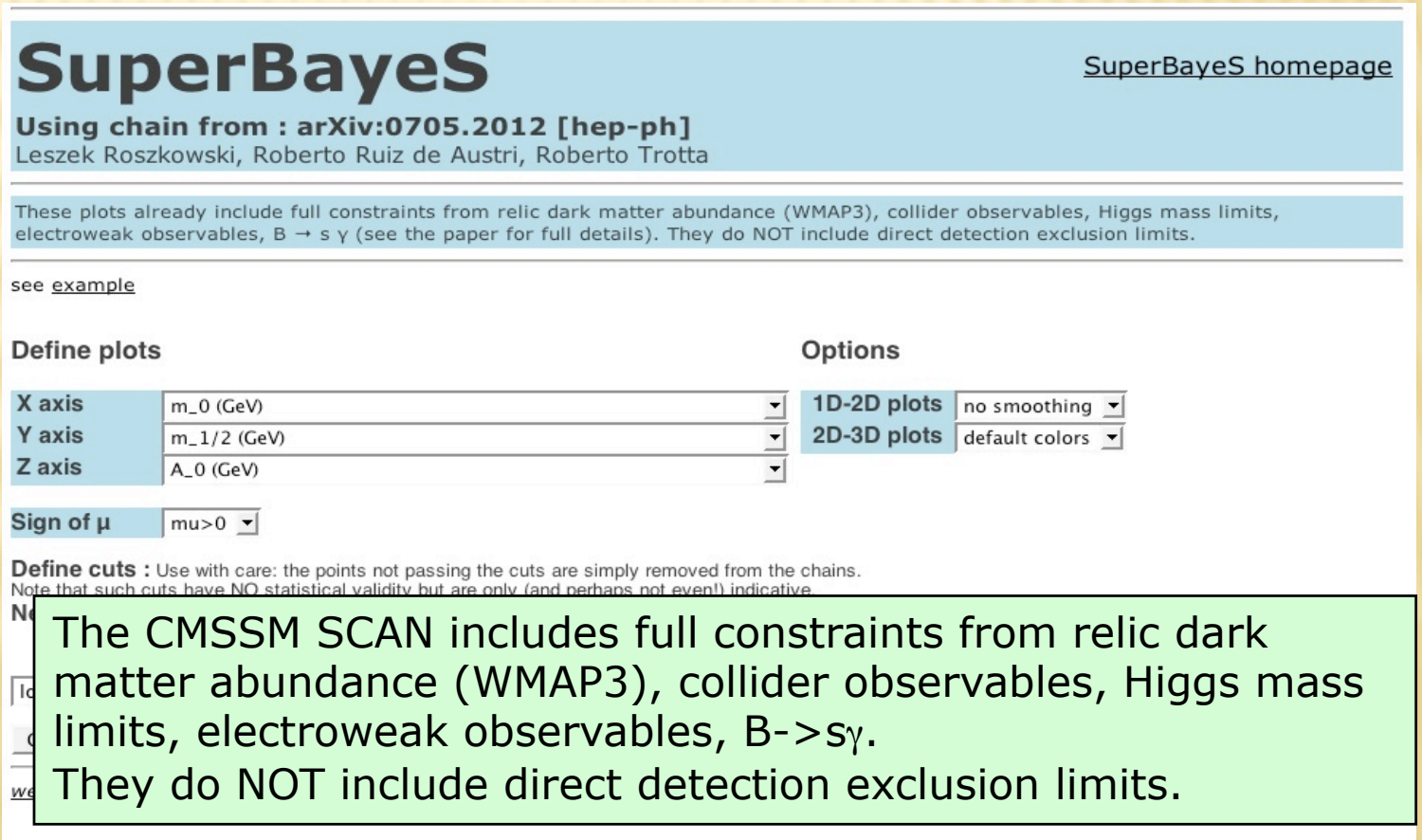




DAMNED : web tool for integrated DM /SUSY analysis

http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/

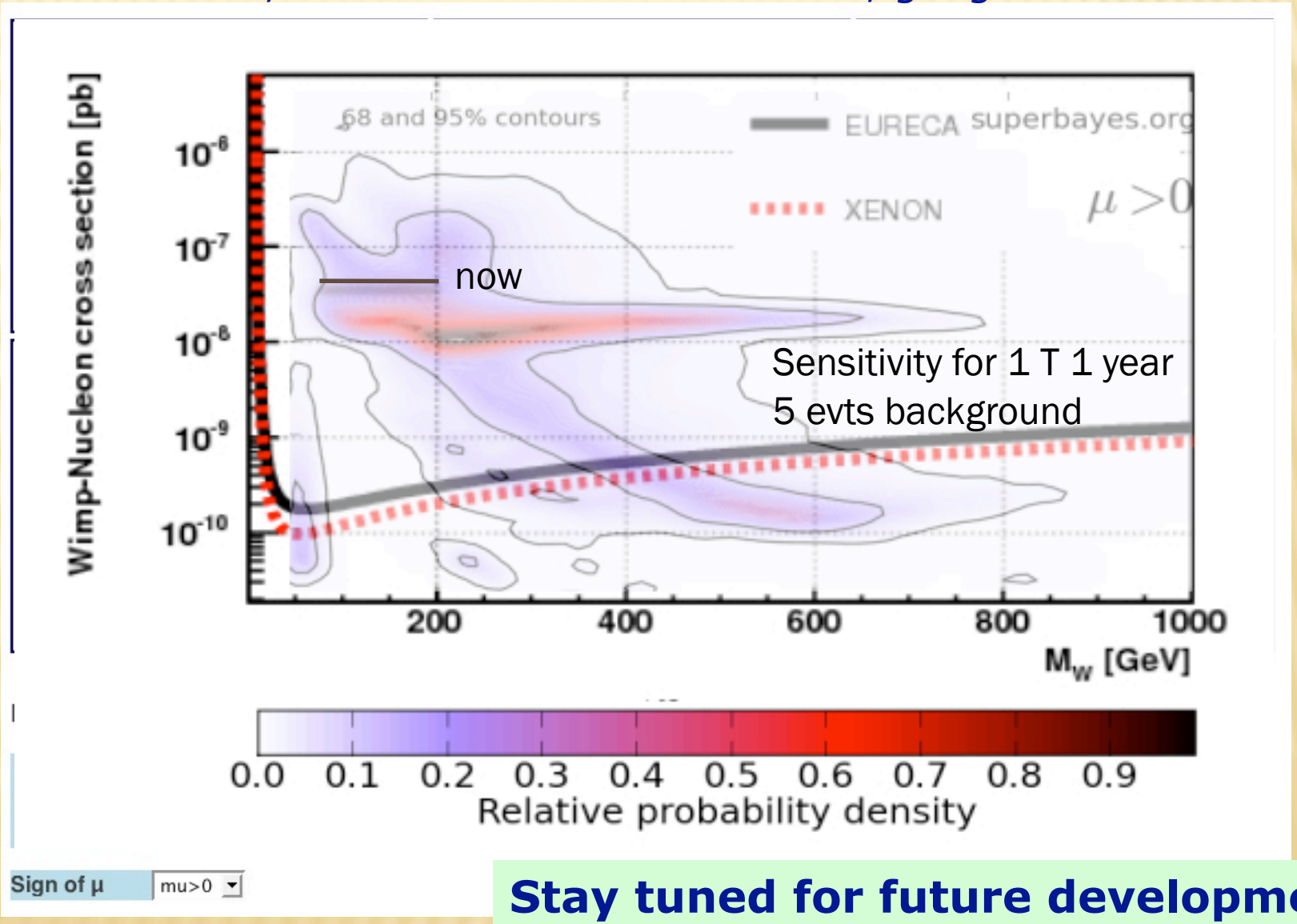
- ILIAS program supported
- Open to contributions by experimentalists and theorists
- Last update : SuperBayes online



The CMSSM SCAN includes full constraints from relic dark matter abundance (WMAP3), collider observables, Higgs mass limits, electroweak observables, B->sγ.
They do NOT include direct detection exclusion limits.

1D, 2D and 3D plots of CMSSM, dark matter, direct detection, collider, Susy spectrum quantities are interactively produced

Ex: WIMP mass , WIMP-nucleon cross section , gaugino fraction



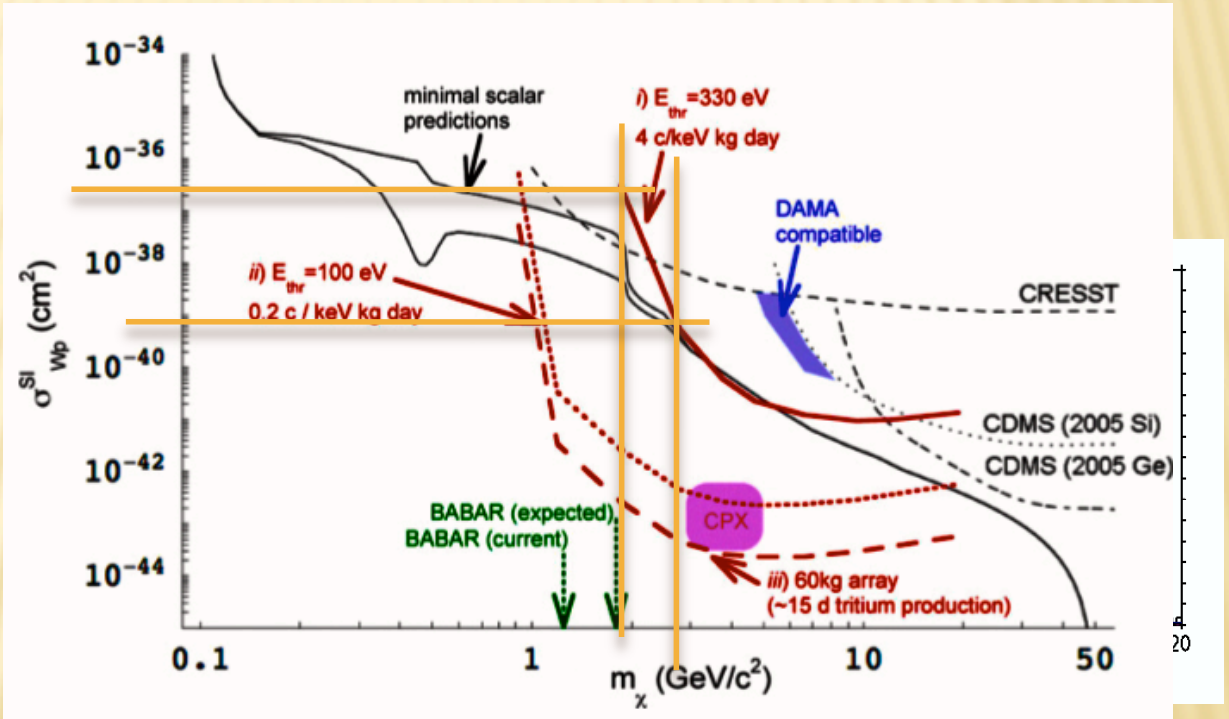
Stay tuned for future developments

Conclusions

- Large progress on WIMP SI and SD sensitivities
- Ton scale projects in preparation, many R&D's
  - EURECA (Cryo EU), XENON1T(Xe EU), LUX (Xe US), XMASS (Xe Japan)…
- DAMA/LIBRA signal still there
  - But standard WIMP hypothesis less and less likely
  - Alternate hypotesis can indeed be tested by existing expts
  - S0 prediction in all cases will help pointing where to look for
- Light WIMPs worthwile to explore, need keV /subkeV energy threshold and nuclear recoil identification
- More results to come within 1 year (this afternoon ?)
  - KIMS, XENON, CDMS, WARP, EDELWEISS, CRESST, ZEPLIN

Strategies for signal identification

- Reduce em background =>
  - go underground to protect from cosmic rays
  - reduce radioactivity of materials, environment
- Use property of nuclear recoil vs electronic energy deposition to establish discrimination method against radioactive background (2 – 3 parameters)
  1. cryogenic detectors
  2. scintillators
- Use self shielding to reject elec/neutron backgrounds
  1. large mass or
  2. large # of detectors
- Search for annual modulation of signal (signature) Sm
- Search for daily modulation by directional measurement: gazeous detectors (signature)


minimal scalar predictions
i) E_thr=330 eV
4 c/keV kg day
DAMA compatible
ii) E_thr=100 eV
0.2 c / keV kg day
CRESST
CDMS (2005 Si)
CDMS (2005 Ge)
CPX
BABAR (expected)
BABAR (current)
iii) 60kg array
(~15 d tritium production)
σ^SI_Wp (cm^2)
m_χ (GeV/c^2)
10^-34
10^-36
10^-38
10^-40
10^-42
10^-44
0.1
1
10
50