DARK MATTER DIRECT DETECTION STATUS AND PERSPECTIVES

G Gerbier IRFU Saclay

GDR SUSY – Strasbourg april 29th

Few reminders

Last results (june 07=>april 08)

Prospects

Conclusion

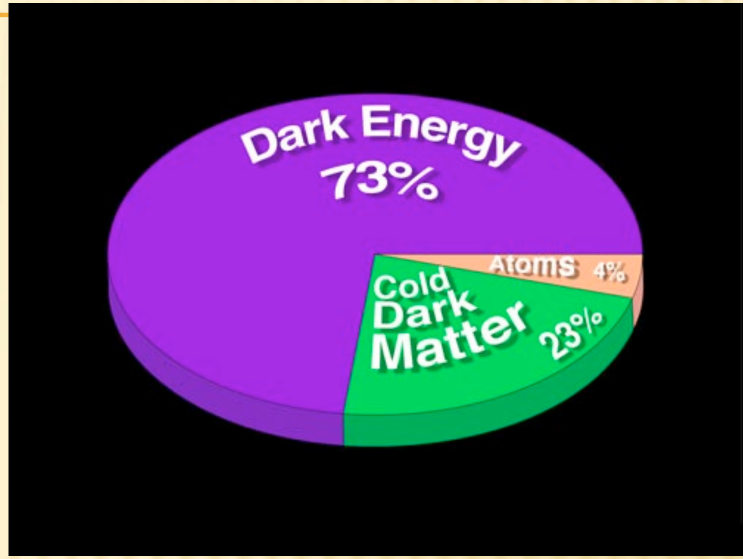
The Physics of Dark Matter

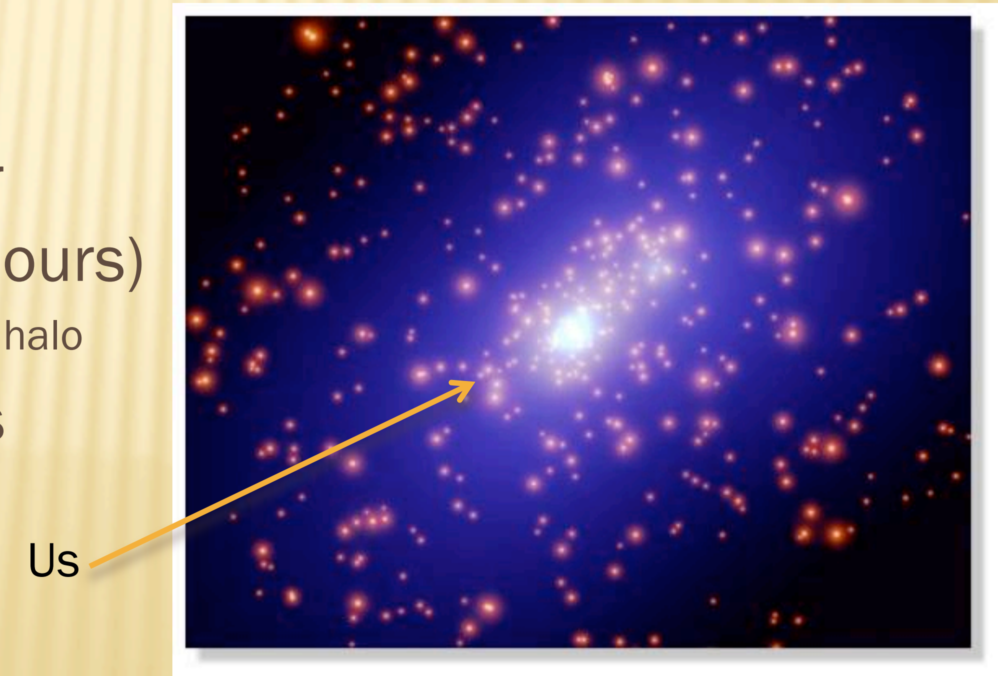
- Cold dark matter makes up nearly 1/4 of the mass/energy of the universe
- Particle candidates for CDM
  - WIMPs (GeV-TeV masses)
    - SUSY neutralinos
    - Kaluza-Klein excitations
  - Axions (10^{-3} -> 10^{-6} eV masses)
  - Pseudoscalar, Light DM
- Dark matter responsible for galaxy formation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

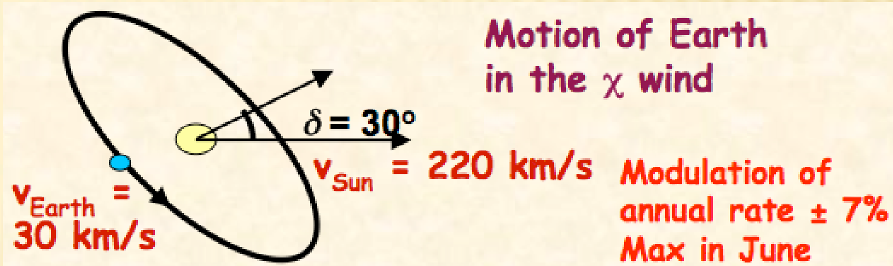
ρ = 0.3 GeV / cm^3



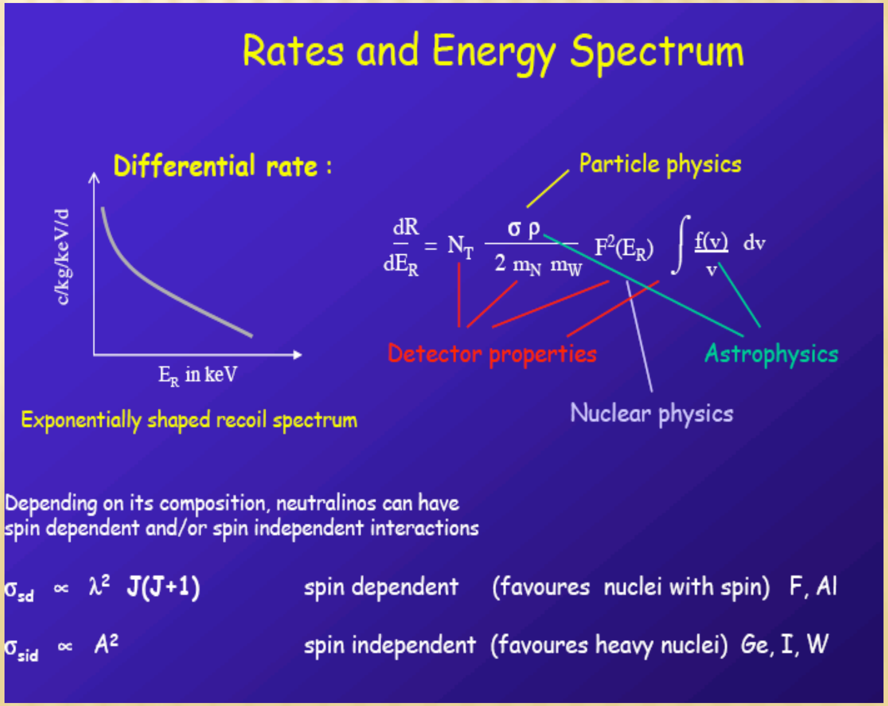


Our local galactic dark matter

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



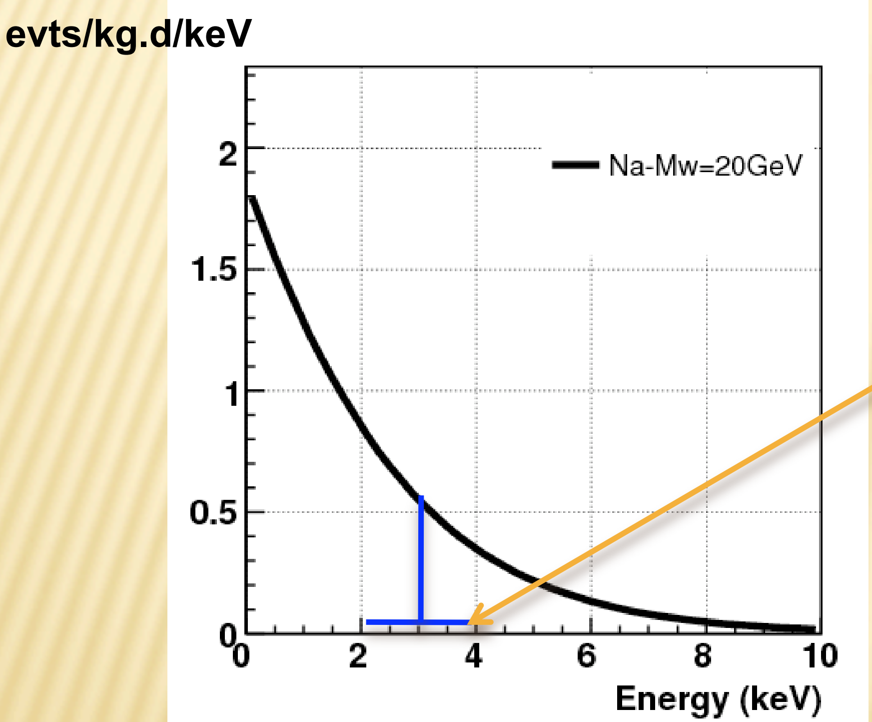
- => $S = S_0 + S_m \cos(\omega t)$
- => World is divided in 2 :
  - **S_0 hunters** : CDMS, XENON, COUPP, KIMS + others
  - **S_m discoverer** : DAMA



What energy spectrum/modulation expected ?

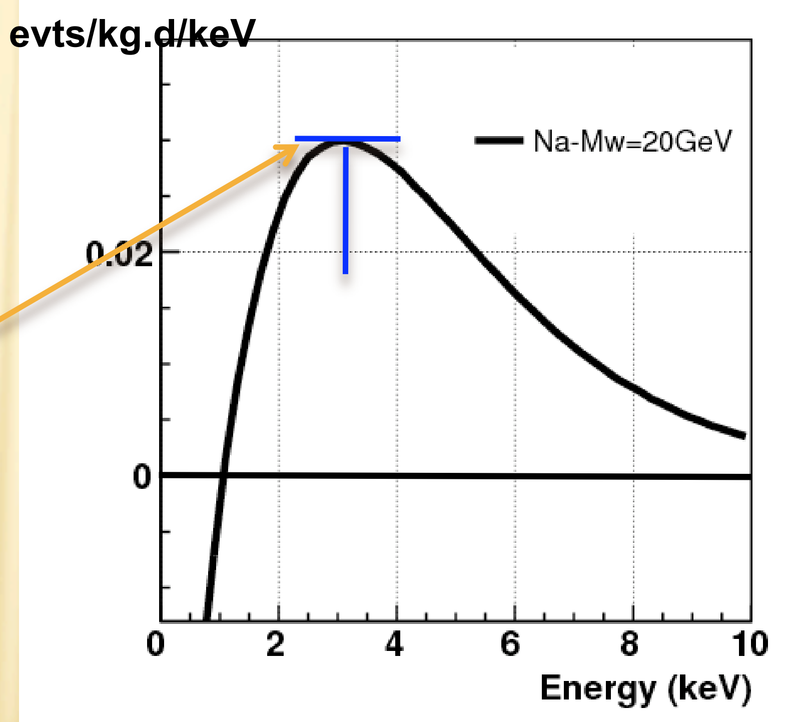
- Example of a 20 GeV mass WIMP interacting on a Na nucleus

S_0 exponential



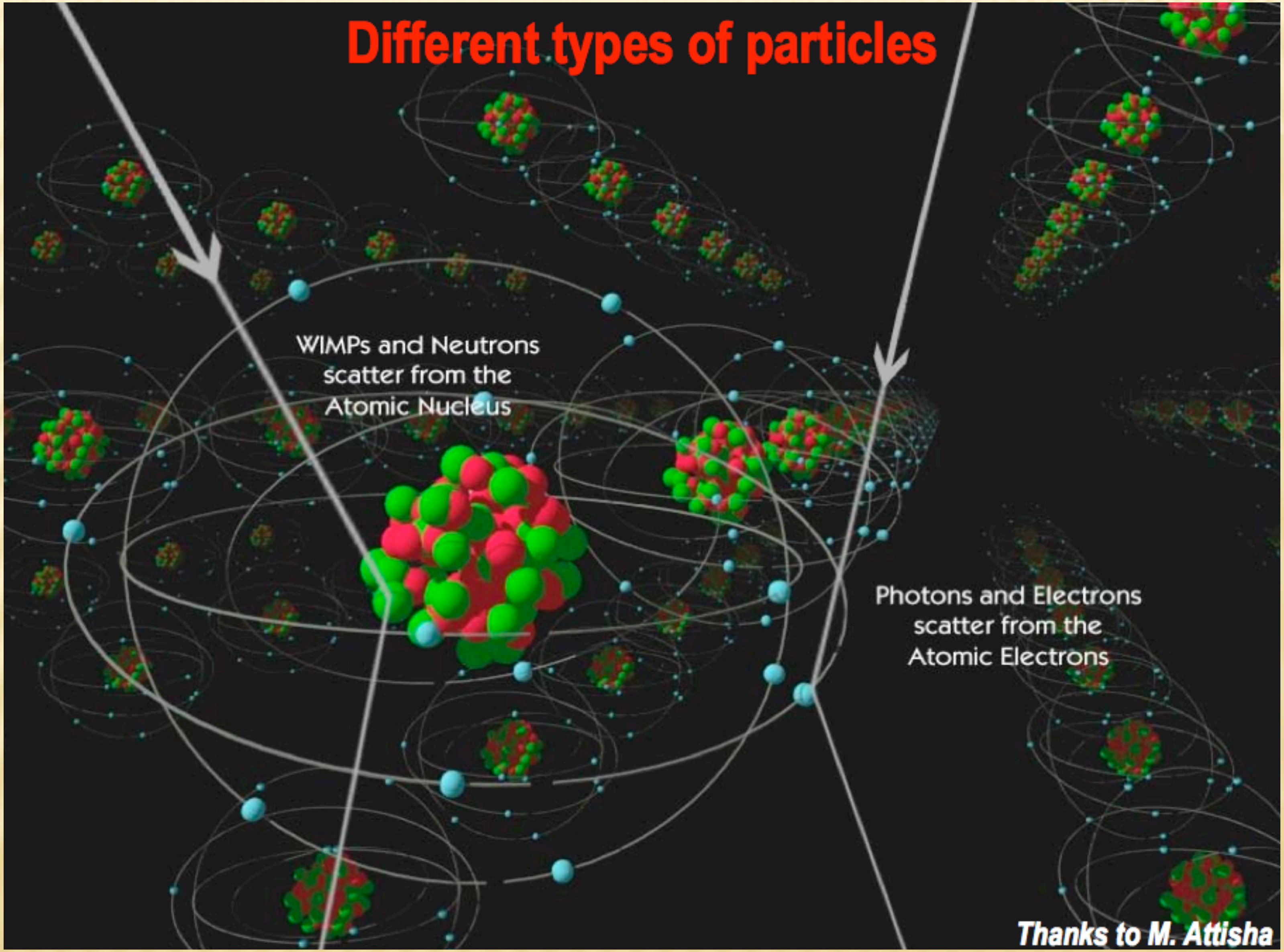
S

S_m has maximum



Sm

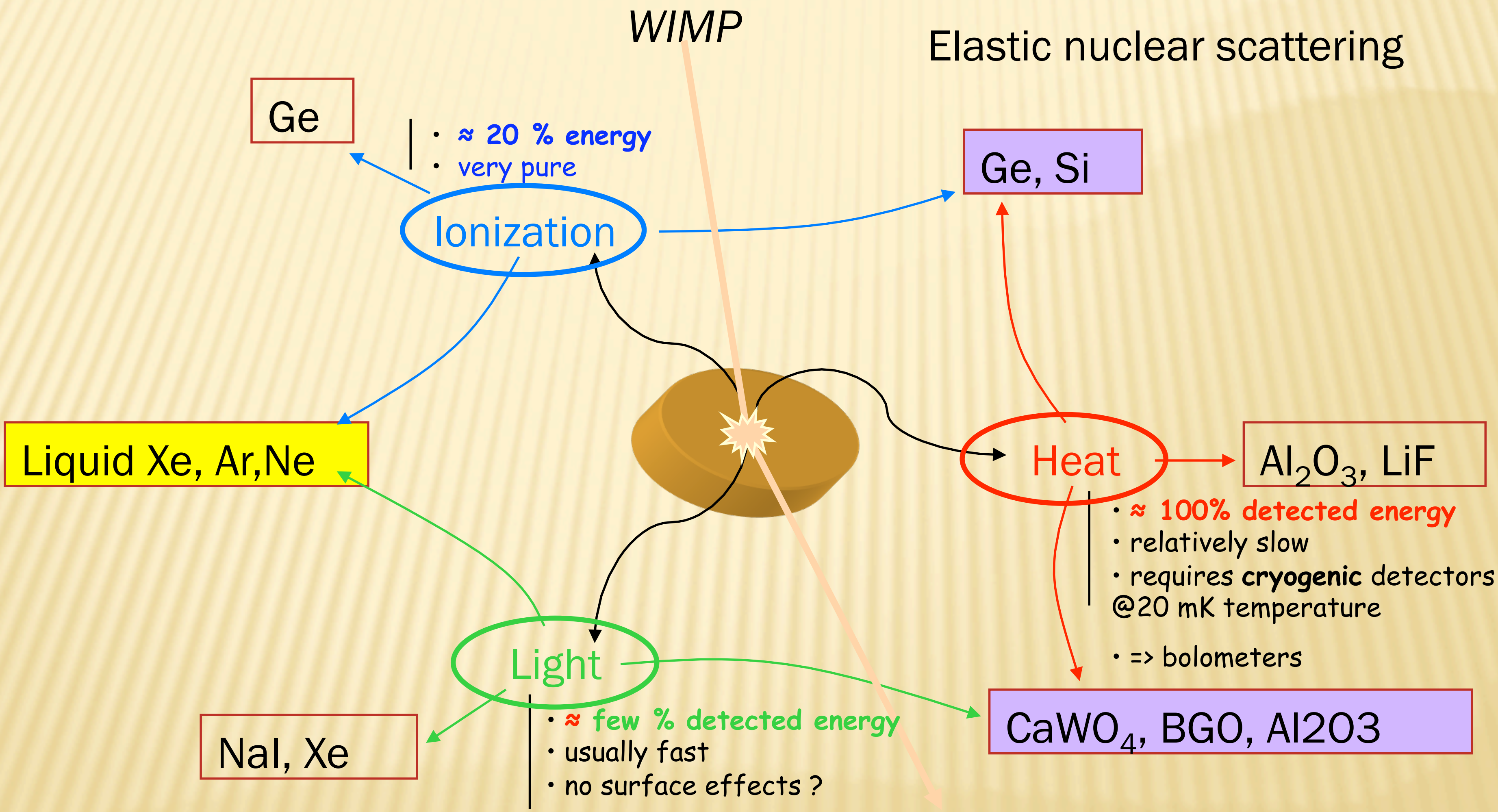
Basic interaction process (S_0 hunters)



Strategies for signal identification

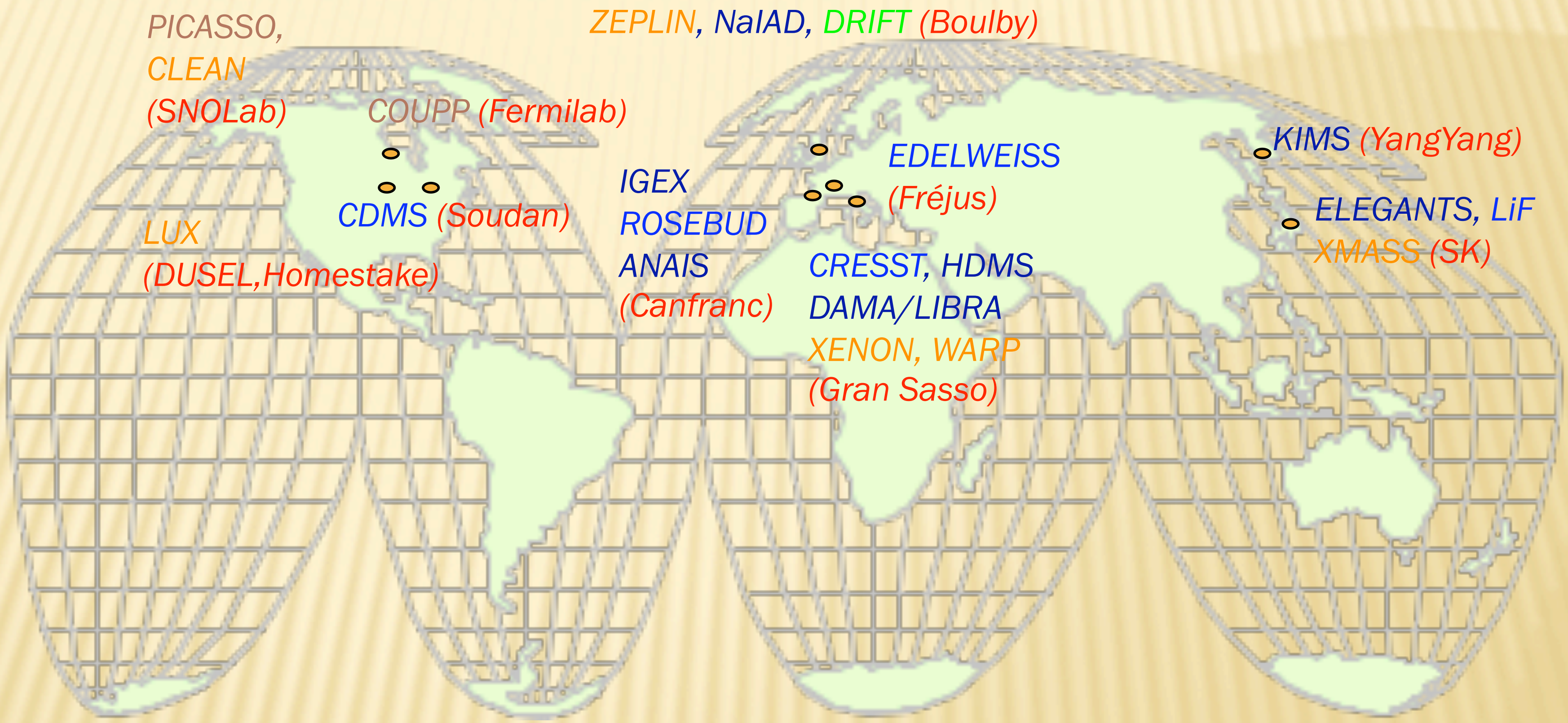
- In all cases
  - go underground to protect from cosmic rays
  - reduce radioactivity of materials, environment
- Use property of nuclear recoil vs electronic energy deposition to establish discrimination method against radioactive background (2 – 3 parameters)
  1. cryogenic detectors
  2. scintillators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

Direct detection techniques



+ Outsiders : metastable media, gaz...

Wimp direct detection : world wide …



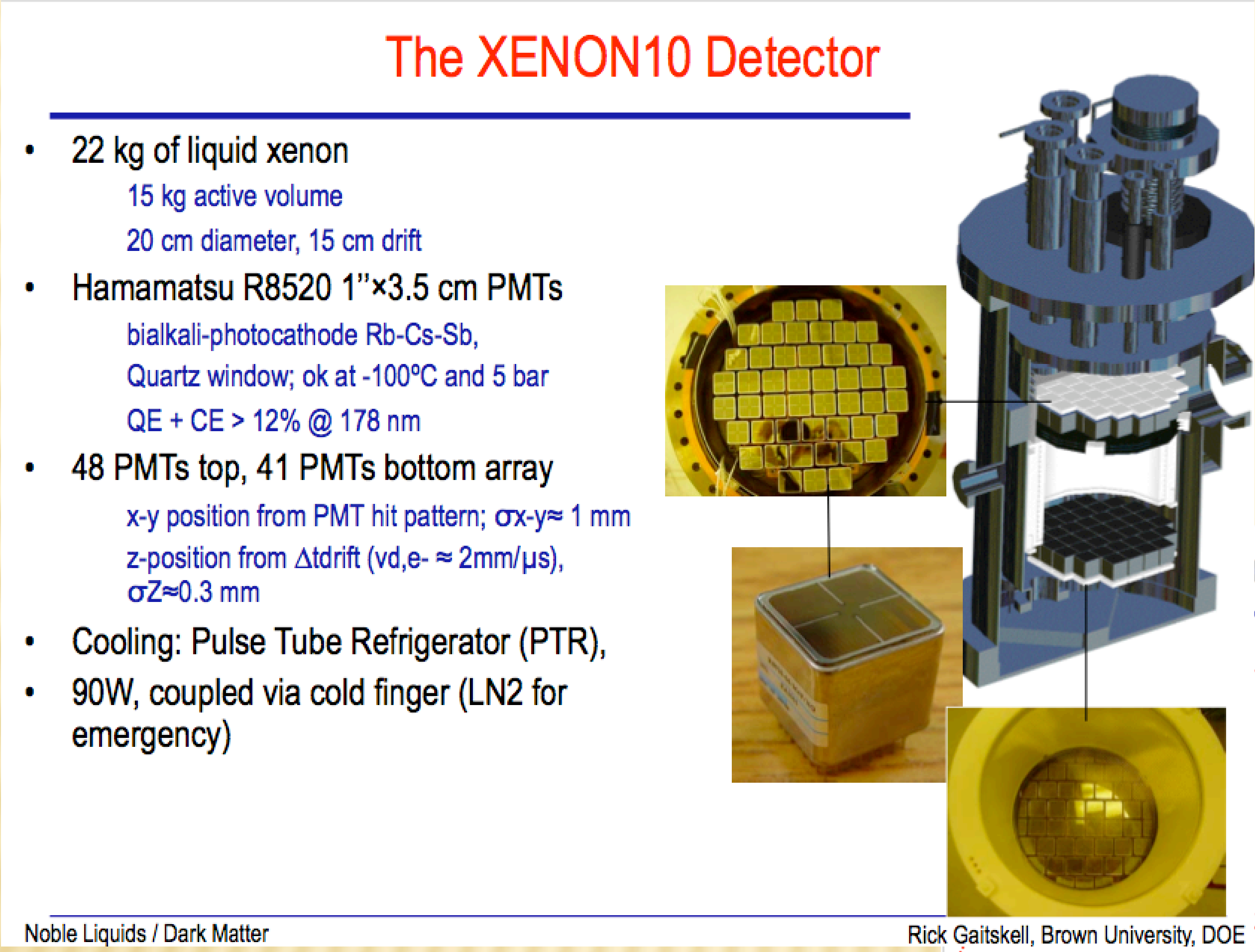
ArDM, EURECA, SuperCDMS, ELIXIR,XMASS II, LUX = 100kg to 1T projects
+ numerous R&D projects : Gaz (Newage, MIT), He3…

Liq scint
Cryo
Ge / solid scint
Gaz
Bubble

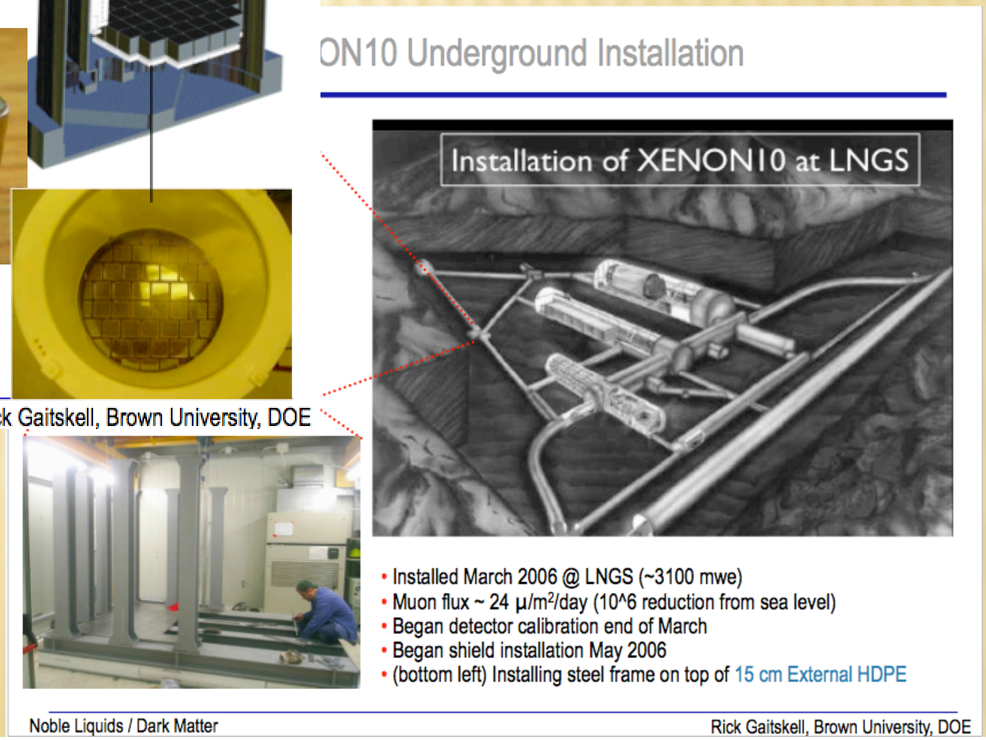
...and a fierce competition

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

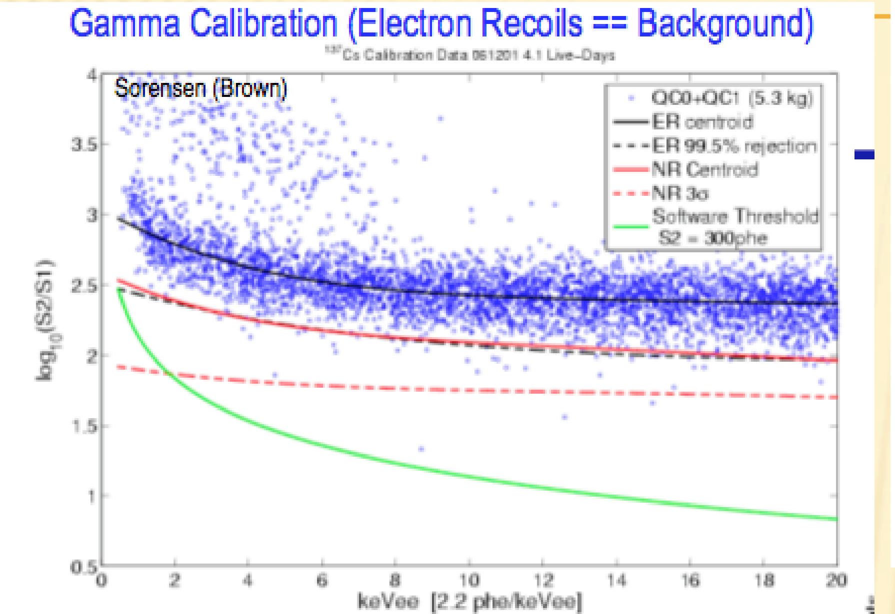
Xenon 2007 : the new way ?

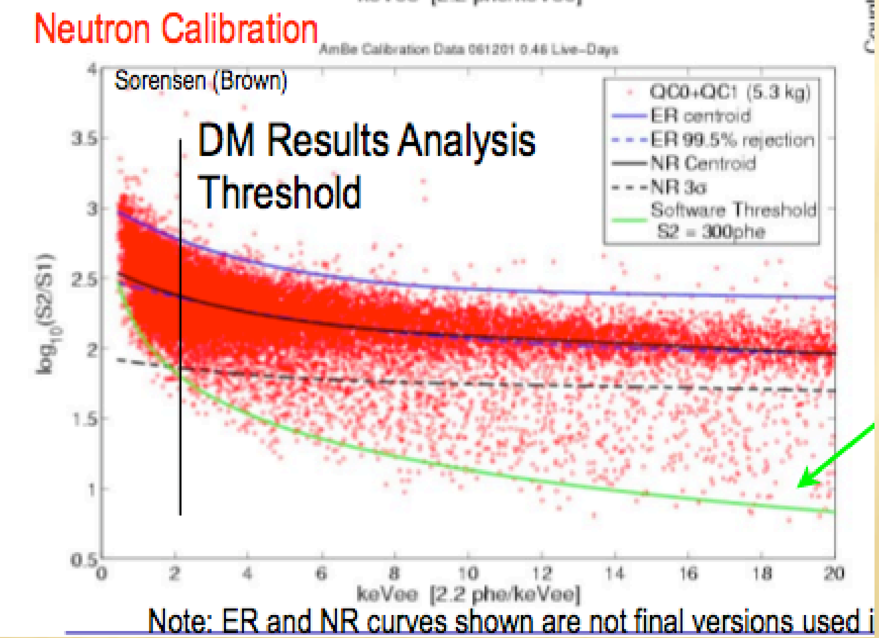


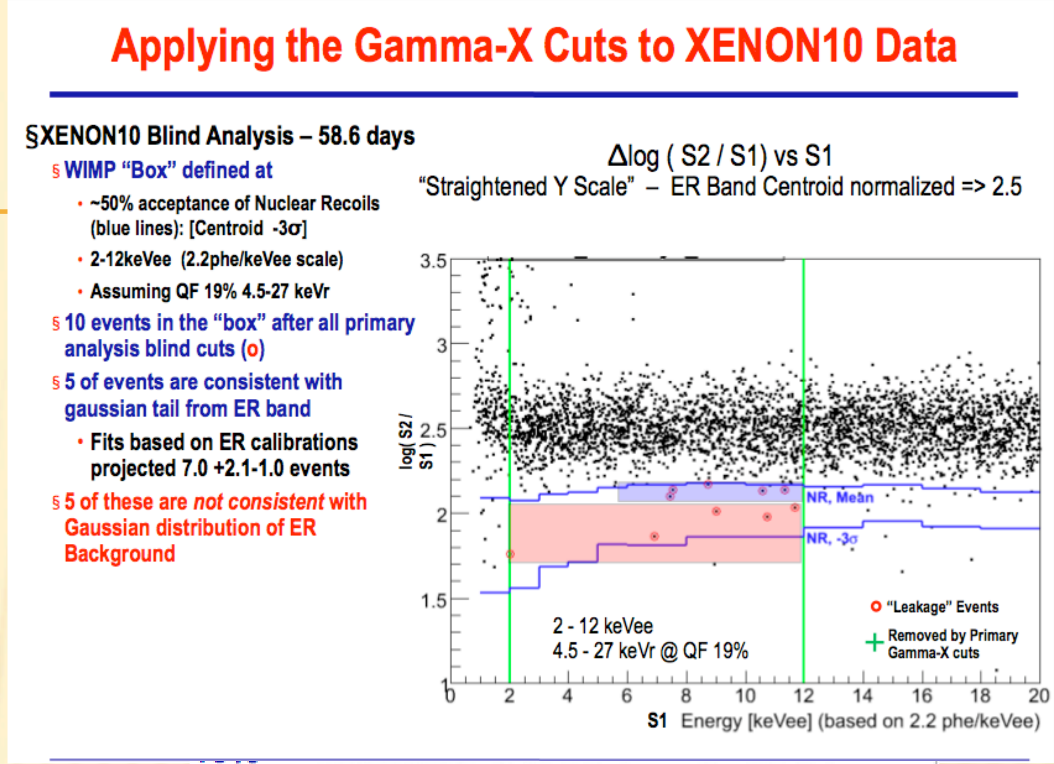
4.5 kg.d fiducial mass

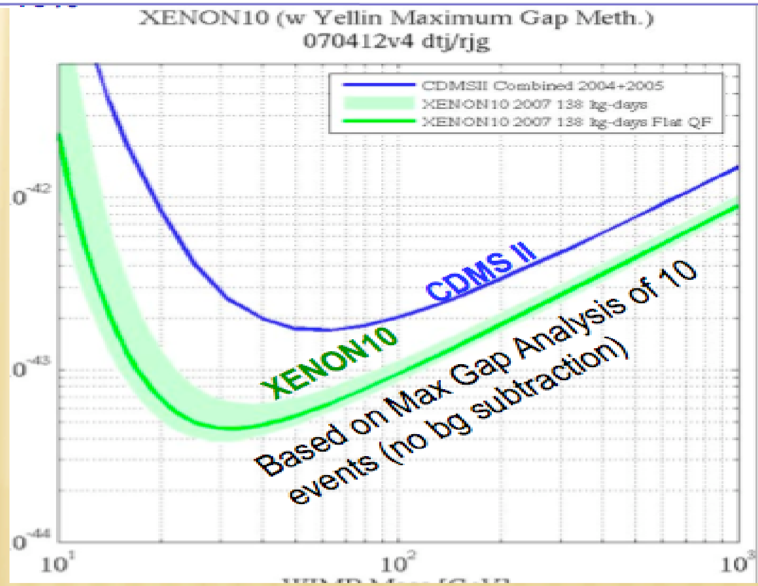


XENON 10 RESULTS :







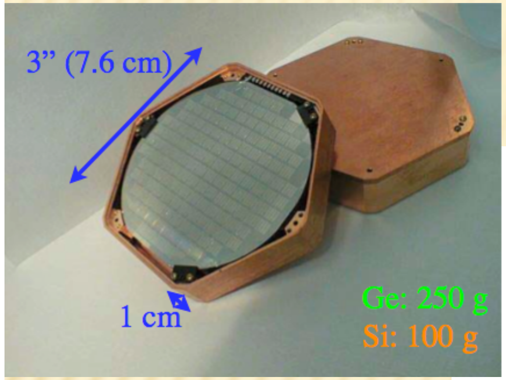


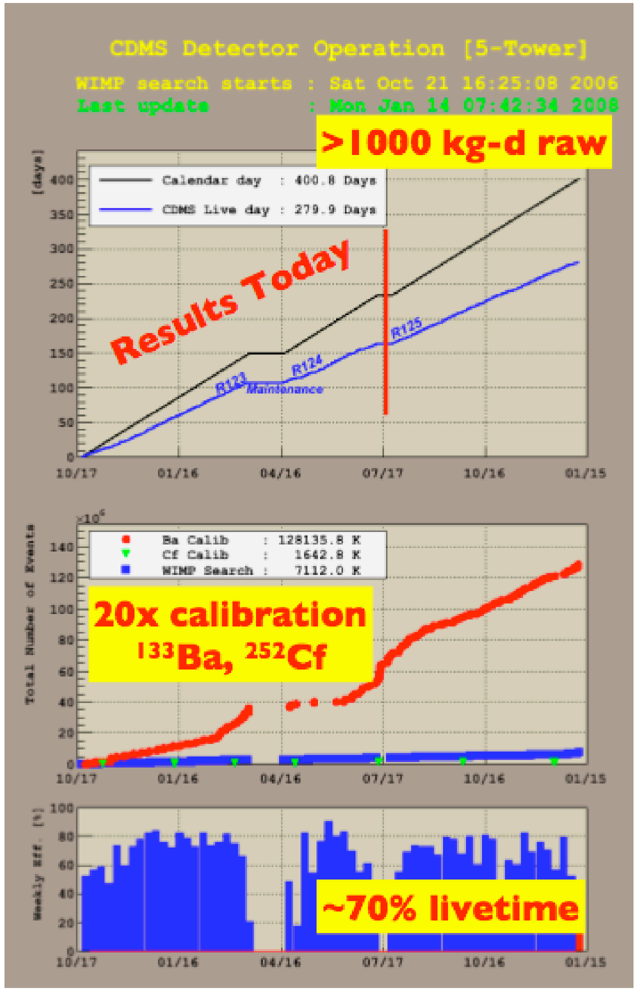
Taking new data, 2008 going to Xenon100

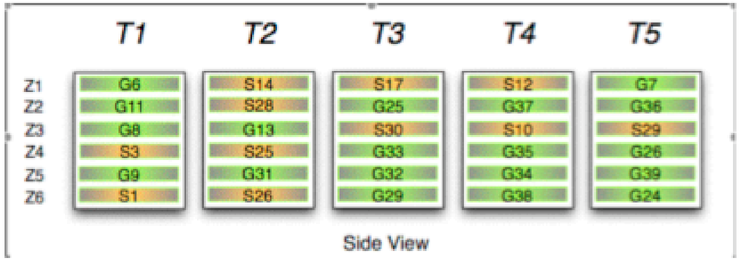
CDMS 2008 : so much better ?

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!

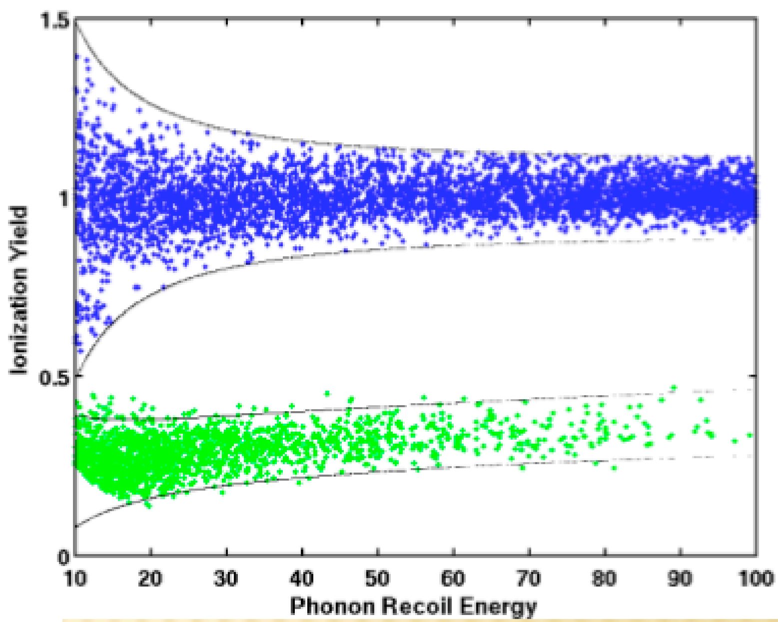
We have analyzed Run 123+124 Data

~Double exposure waiting to be analyzed

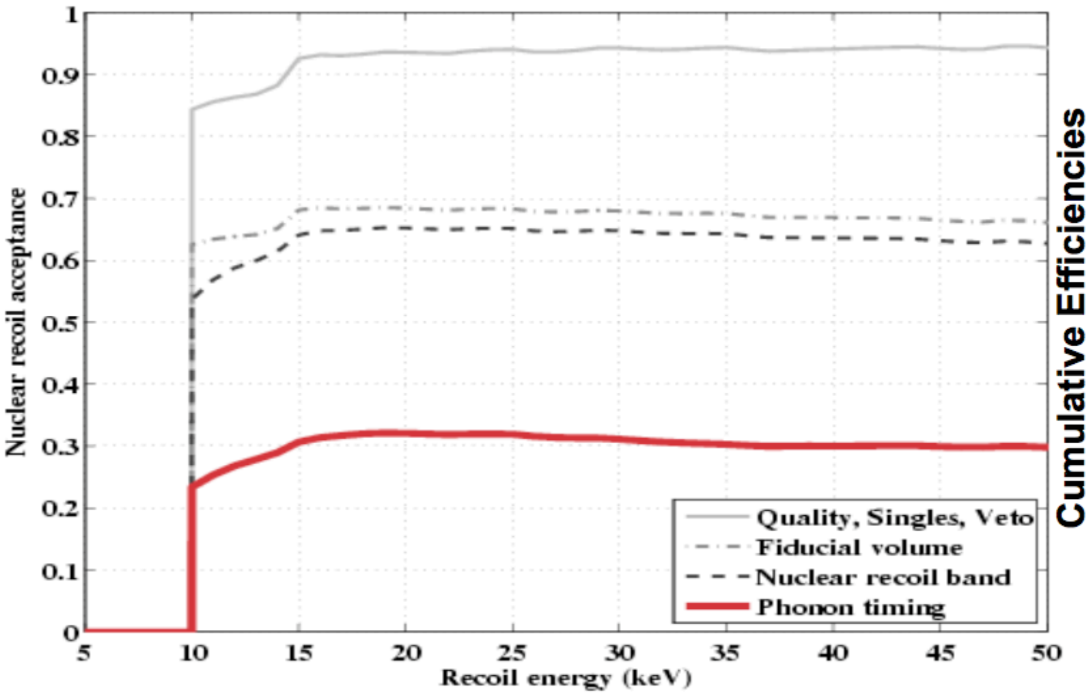
WIMP Candidate: Blind Analysis

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



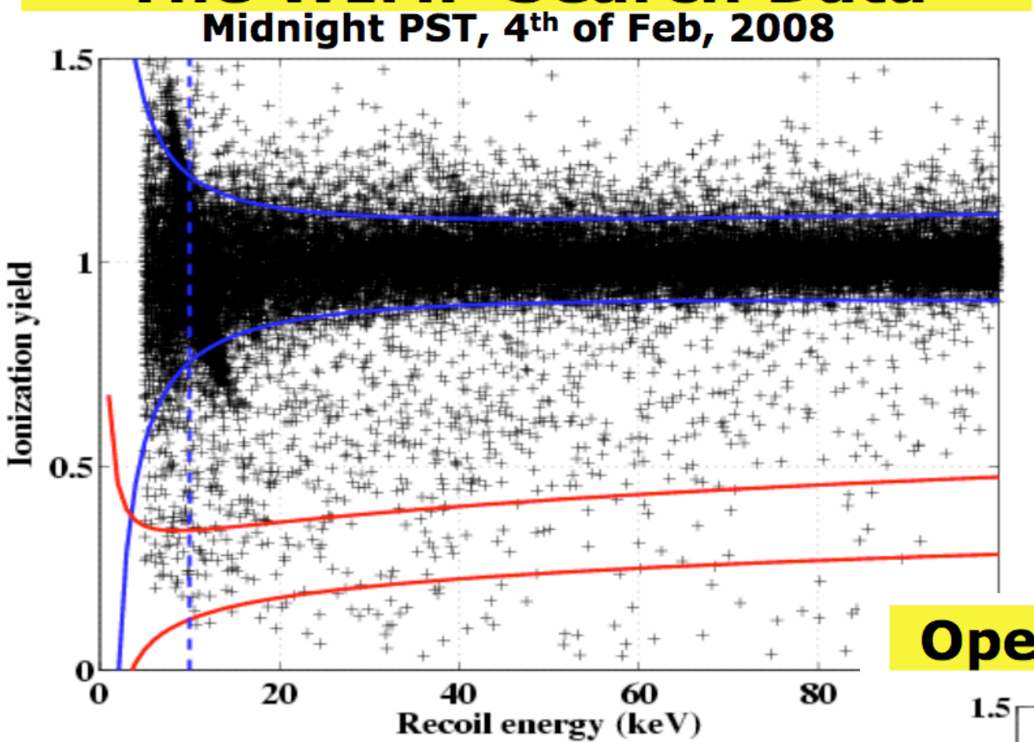
Efficiency plot includes effect of Fiducial Volume Cut

⇒Would expect roughly 650 * 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.

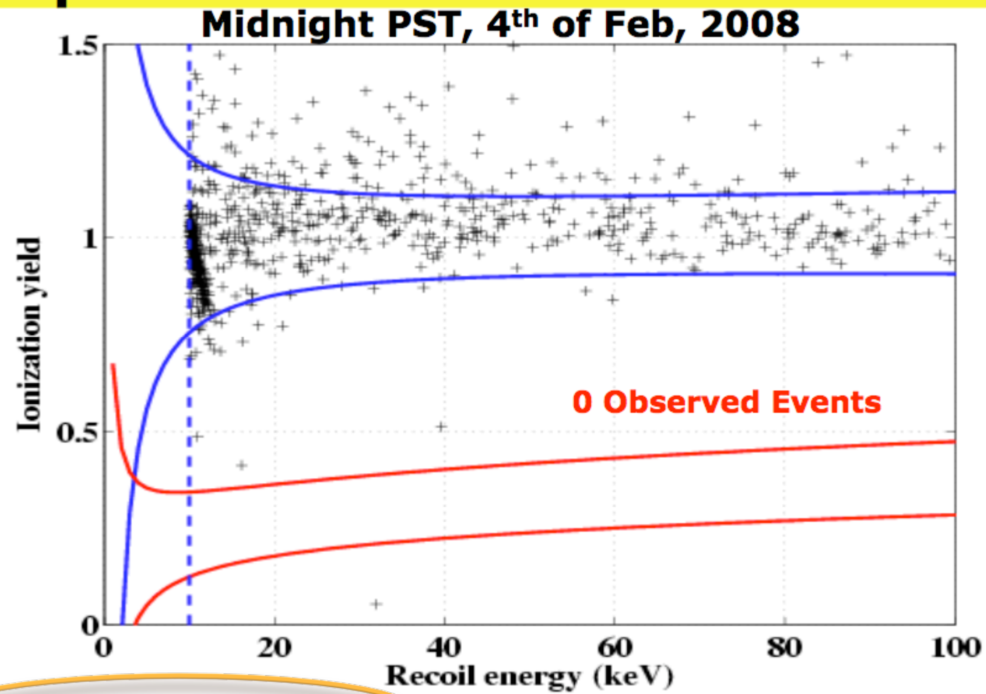
The WIMP Search Data



97 Singles in Signal region rejected by Surface Ev

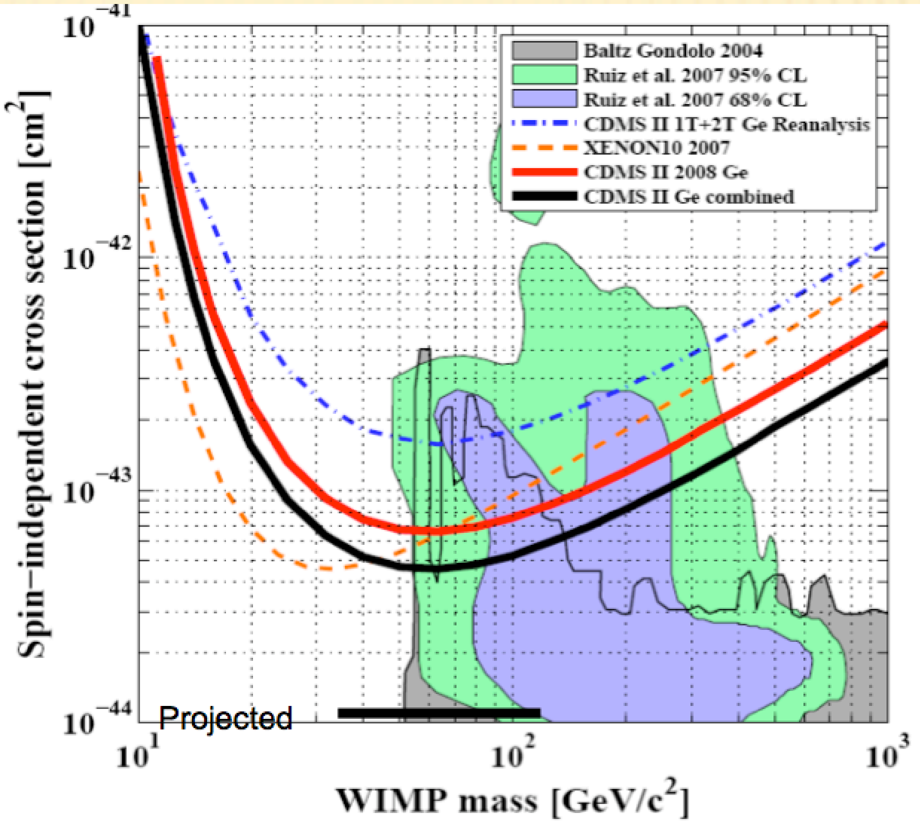
77 evts predicted in ROI

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 !?
- Goal : 10^{-8} pb by september

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

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

Yangyang Underground Laboratory

KIMS

Korea Invisible Mass Search

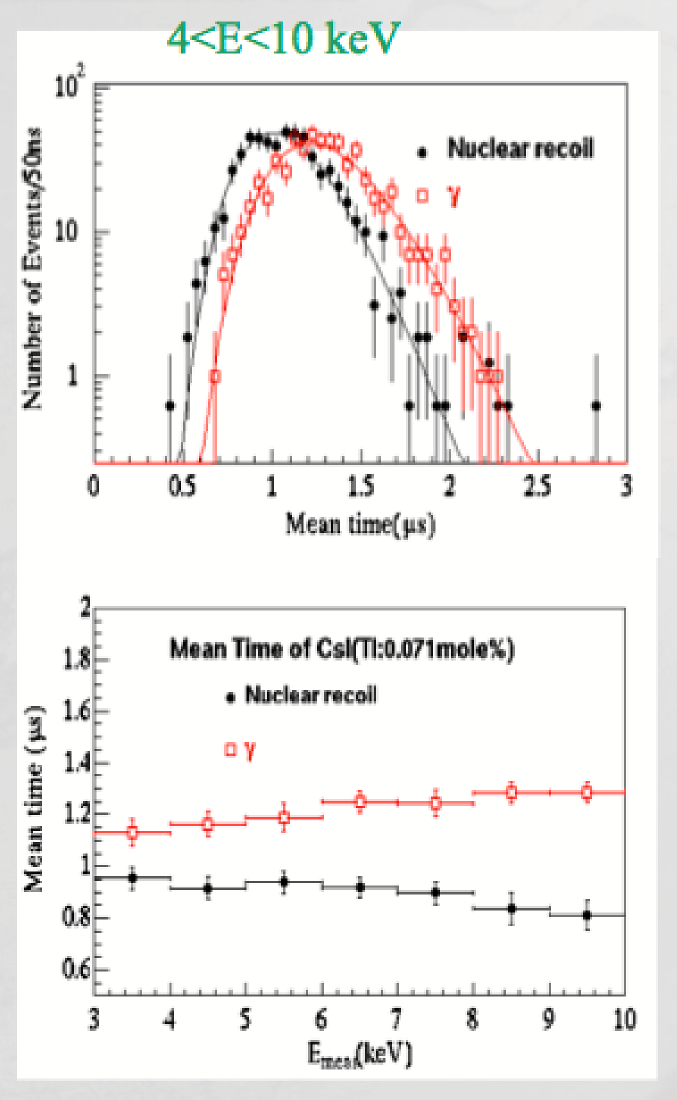
CsI(Tl)

	<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

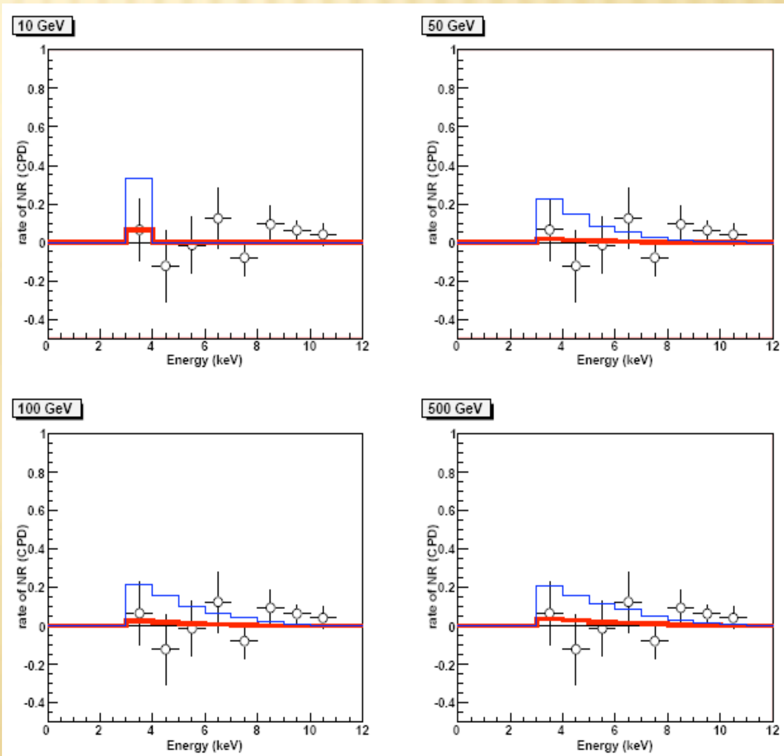
CsI(Tl) : 4 * 8.7 kg crystals

- Pulse shape discrimination on 3409 kg.d



Data used for this analysis

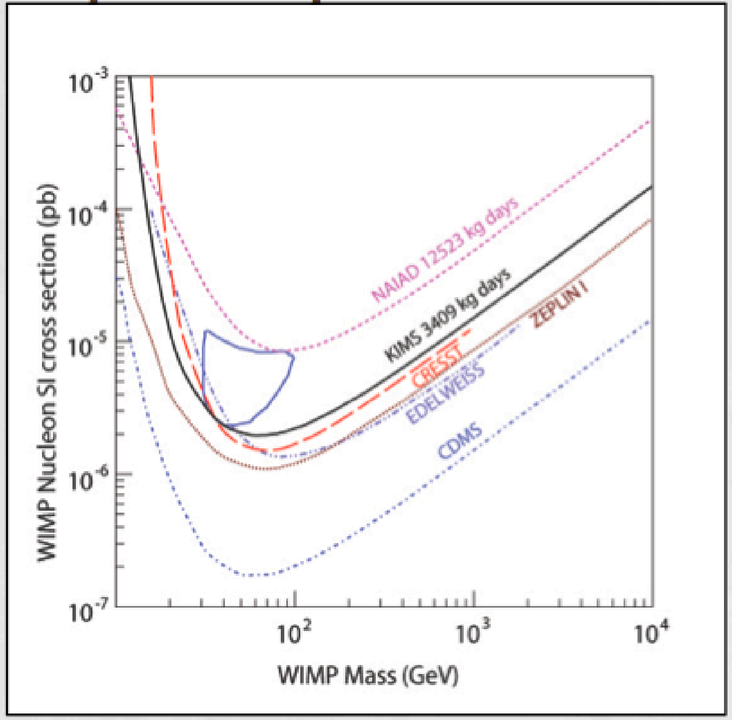
Crystal	p.e./keV	Mass(kg)	Data(kg·days)
S0501A	4.6	8.7	1147
S0501B	4.5	8.7	1030
B0510A	5.9	8.7	616
B0510B	5.9	8.7	616
Total		34.8	3409



KIMS : results

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

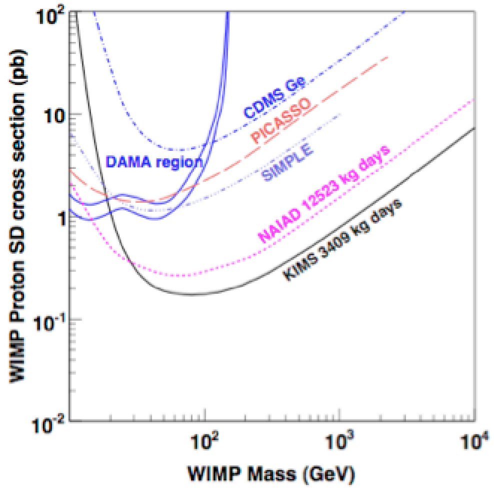
Spin independent limits



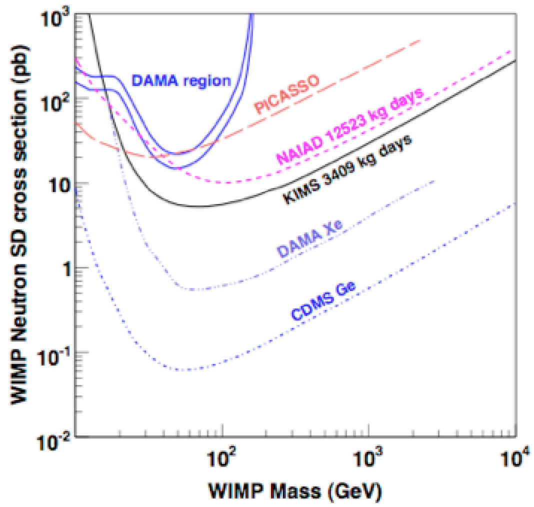
Nuclear recoil of ^{127}I of DAMA signal region is ruled out

PRL 99, 091301 (2007)

Spin dependent limits



Pure proton case



Pure neutron case

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

TEXONO 07 (Taiwan, China, Turkey) low energy

- Ultra low energy Ge's (4 * 5g) operated at Kuo Sheng reactor with threshold of 0.1 keV (eff >80 % @ 0.25 keV) 0.338 kg.d

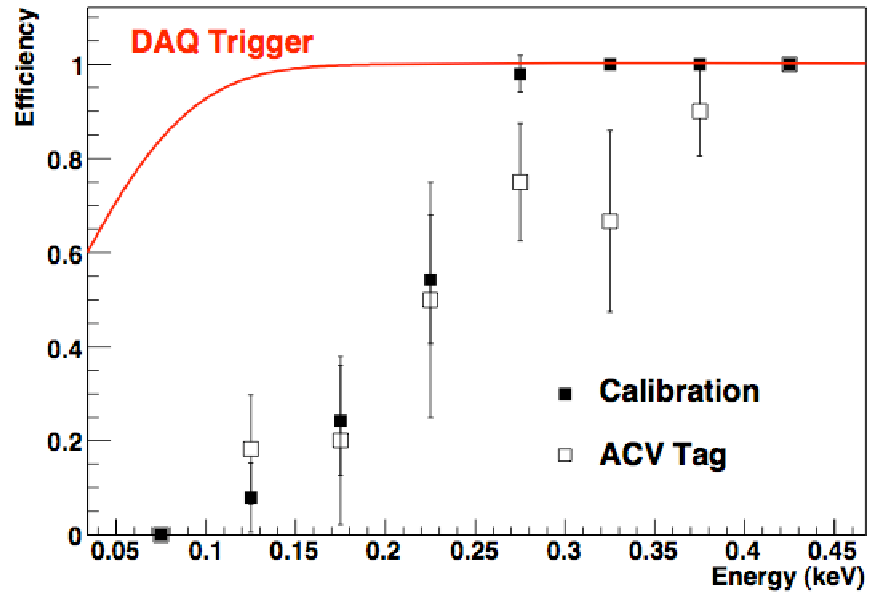


FIG. 3: Selection efficiencies of the PSD cut, as derived from the ^{55}Fe-source calibration and from in situ data with ACV tags. The solid line represents the trigger efficiency where physics events were recorded by the DAQ system.

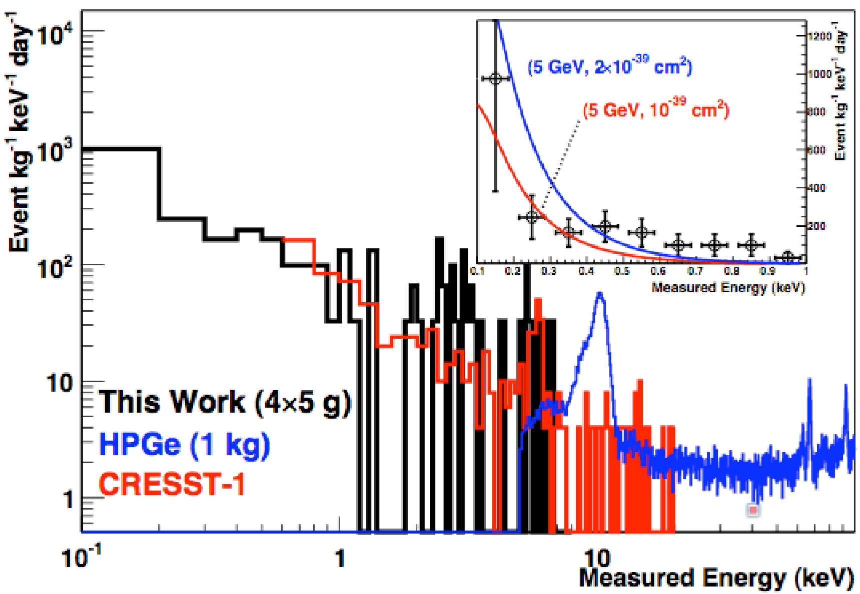


FIG. 4: The measured spectrum of ULEGe with 0.338 kg-day of data, after CRV, ACV and PSD selections. Background spectra of the CRESST-I experiment [9] and the HPGe [13] are overlaid for comparison. The expected nuclear recoil spectra for two cases of $(m_\chi, \sigma_{\chi N}^{SI})$ are superimposed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

TEXONO LIMITS

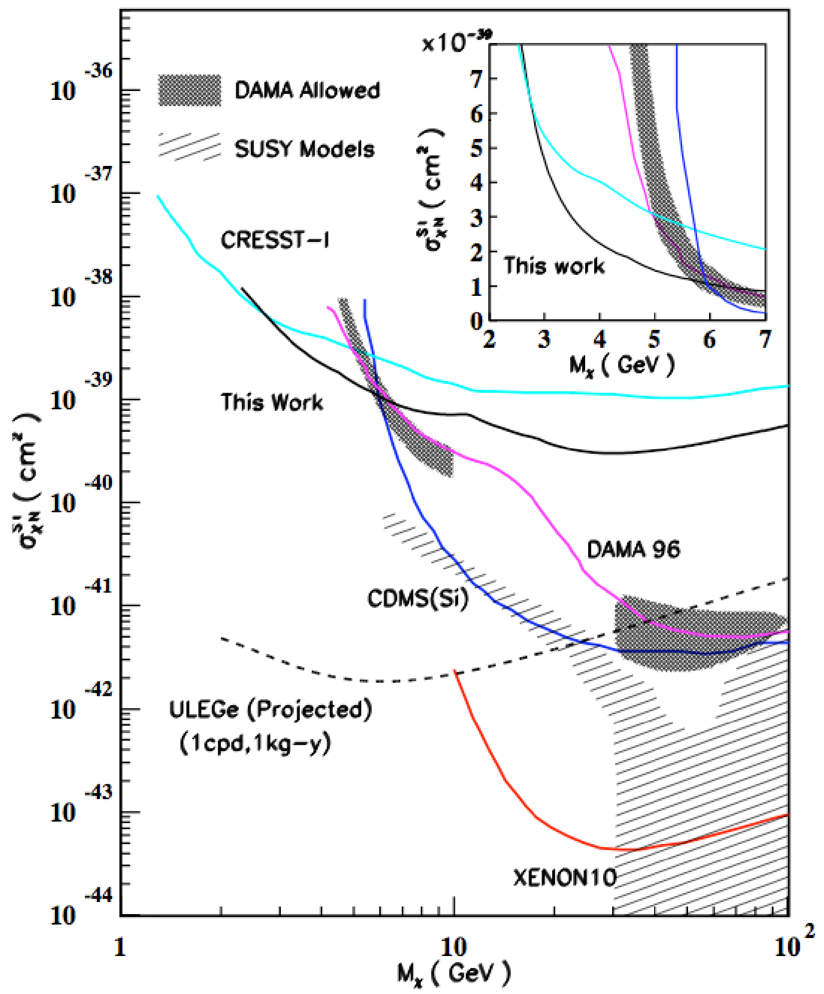


FIG. 5: Exclusion plots of spin-independent χN cross-section

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

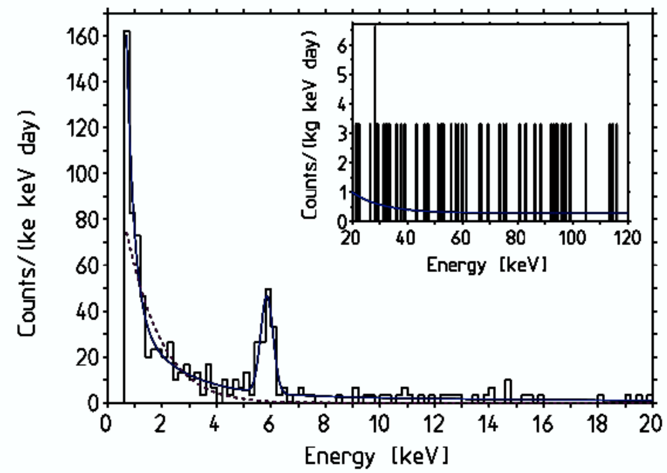


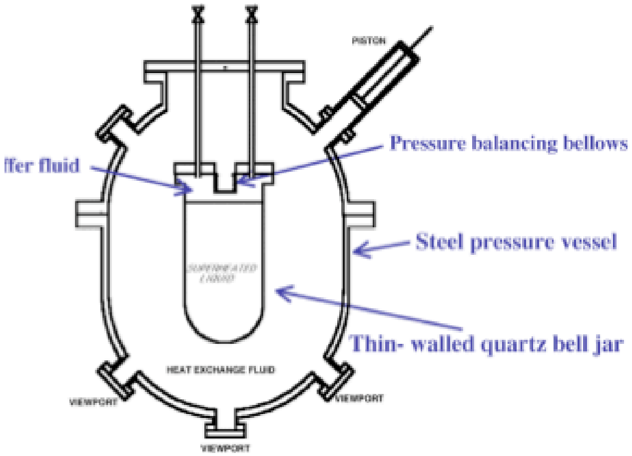
Figure 10: Energy spectrum of detector #8 during the dark matter run (1.51 kg days) in 200 eV bins.The insert shows the spectrum at higher energies. The fully drawn curve is an empirical fit to the experimental spectrum which serves for extracting dark matter limits. For illustration a 5 GeV WIMP excluded at 90% C.L is shown as a dashed curve.

- May be worthwhile exploring sub keV region

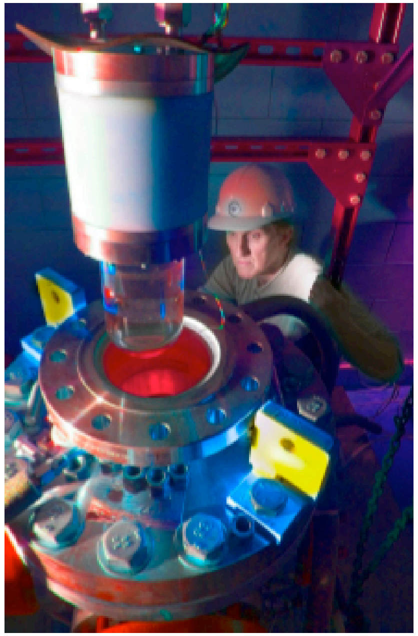
COUPP : the old bubble chamber concept

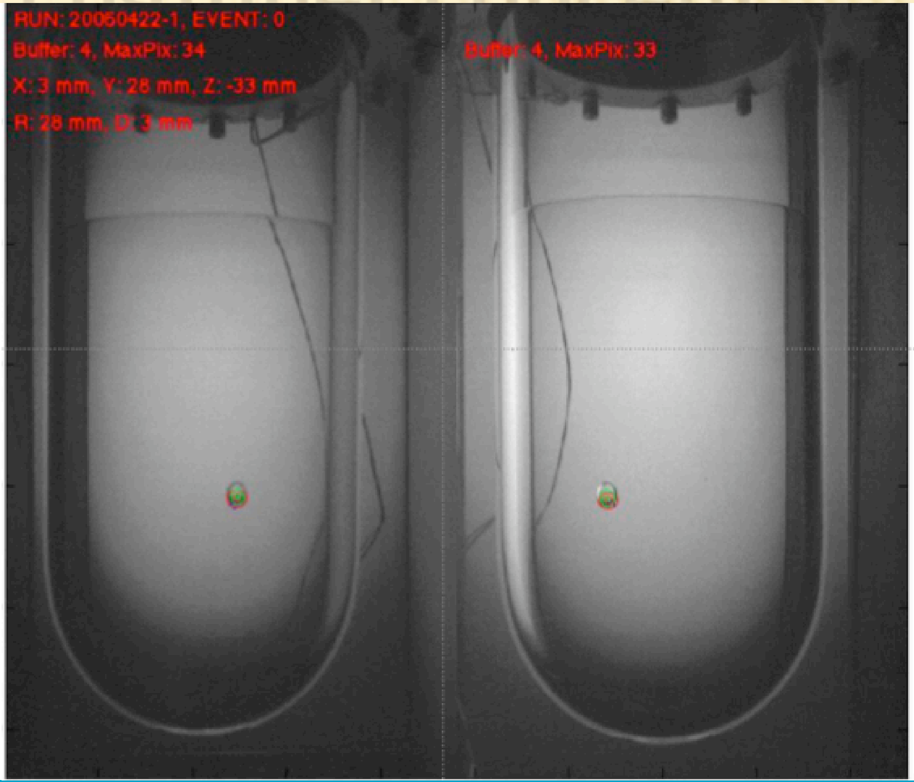
1-Liter Chamber in NuMi Tunnel

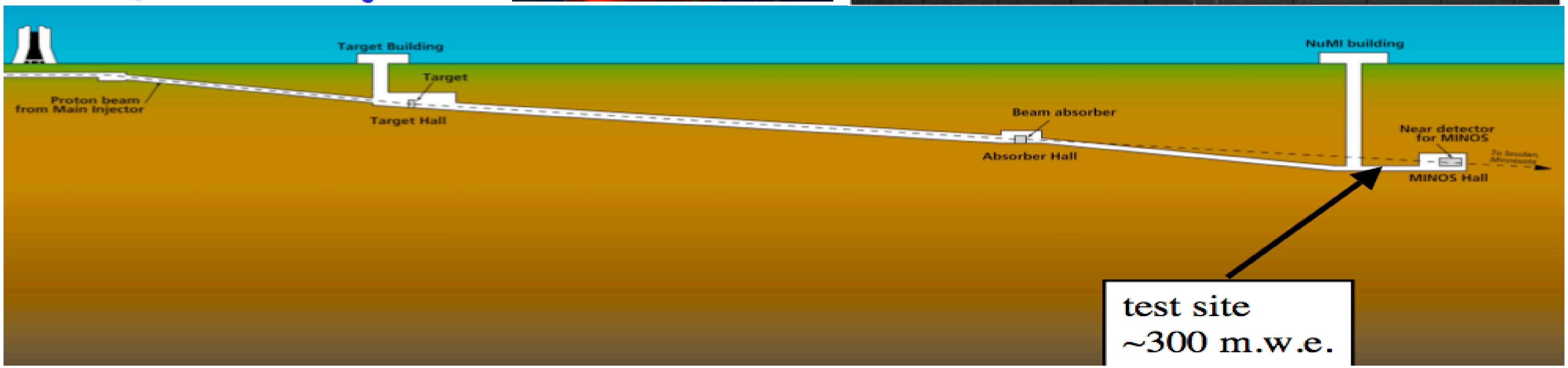
Design concept:



Target liquid: CF_3I

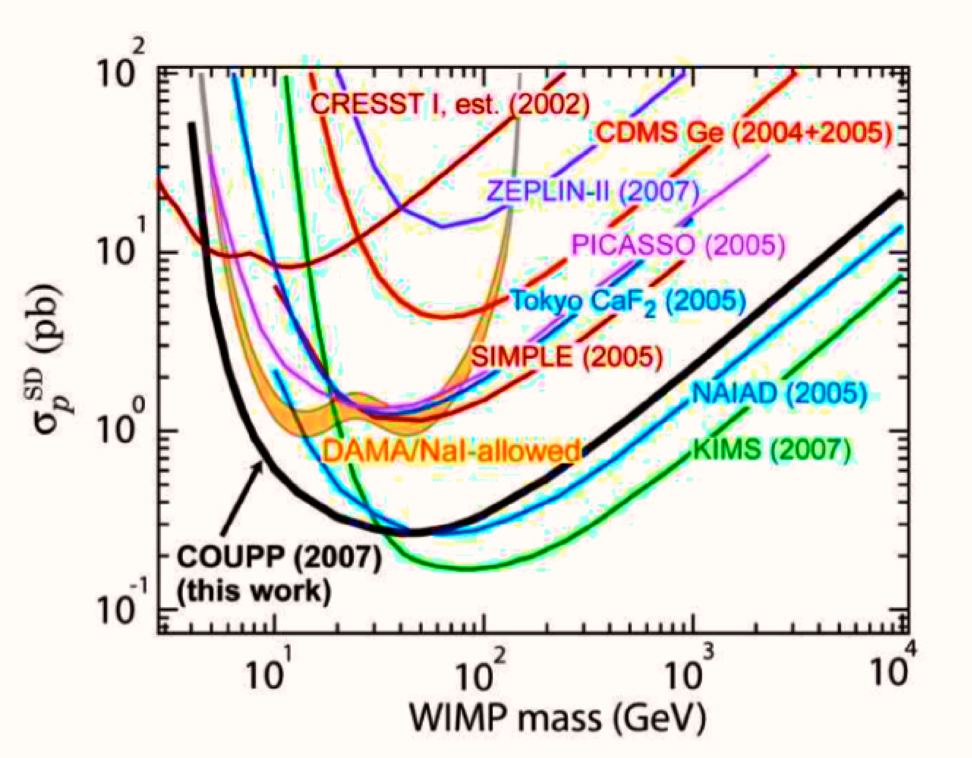


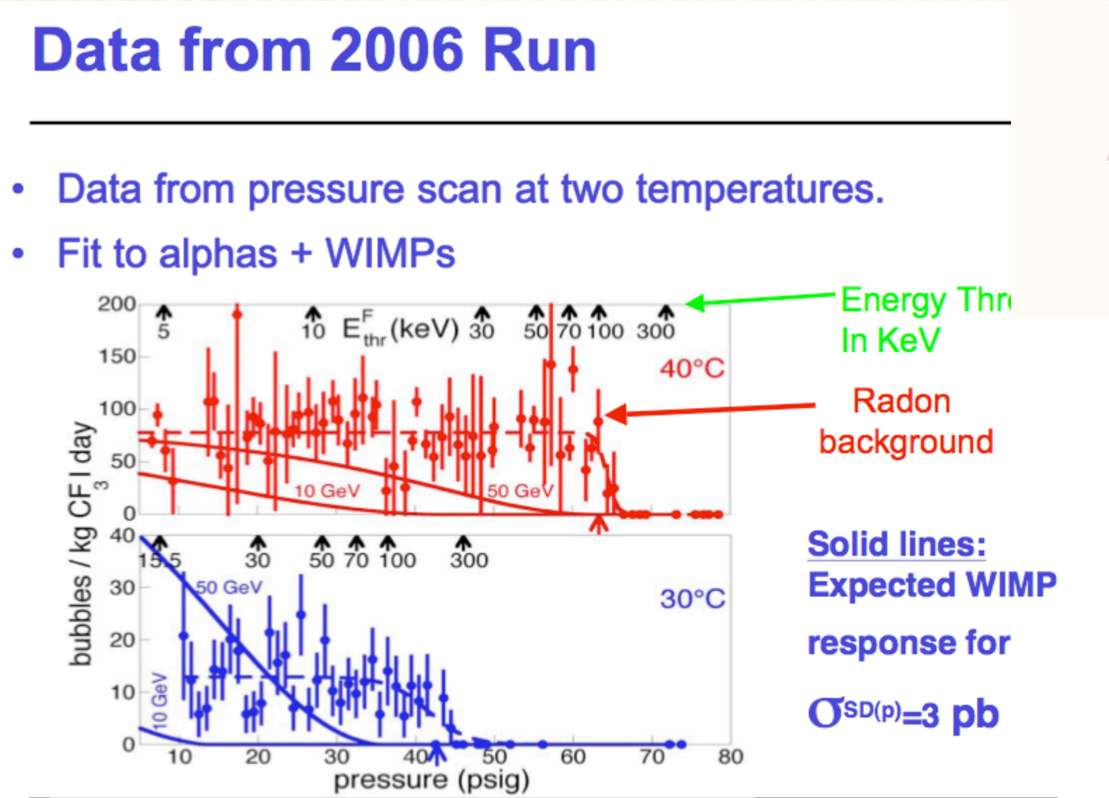




COUPP results

- Tuning T and P allows insensitivity to em background
- Rate dominated by radon





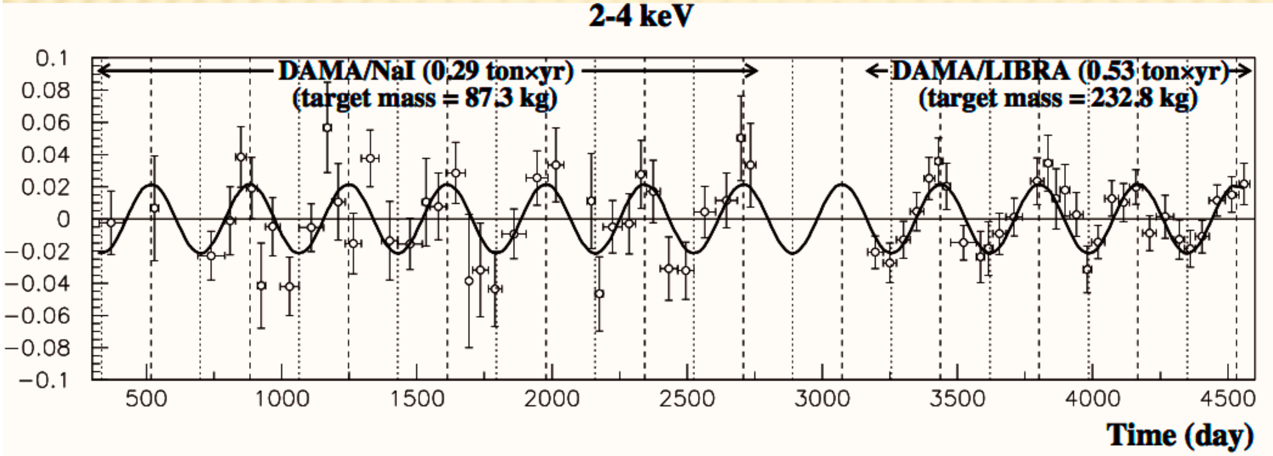
- Building 20 and 60 kg vessels

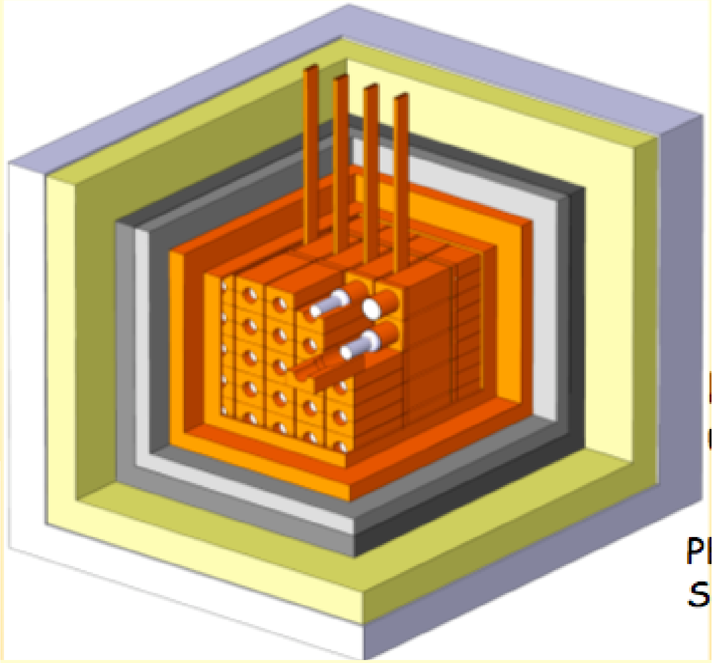
DAMA/LIBRA : immuable

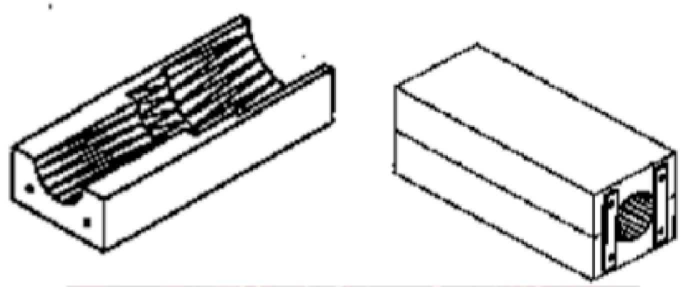
- 25 modules of 9.7 kg
- 4 years data taking (09/03 to 07/07)

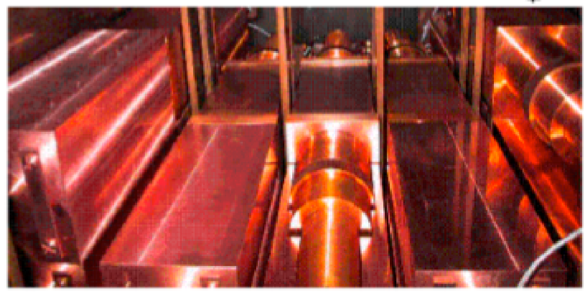
=> 192 000 kg.d = twice DAMA exposure

- 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}

2-6 keV

A=(0.0129±0.0016) cpd/kg/keV

χ^2/dof = 54.3/66 **8.2 σ C.L.**

Absence of modulation? No

χ^2/dof=116.4/67 ⇒ P(A=0) = 1.8×10^{-4}

Is this WIMP's ?

- Overall consistency ? Back to 11 years of data taking

Year	Exposure kg.d	Quoted Significance	Backway Statistical expectation	A and σA of Sm
1997	4 549		1.0	0.037 +-0.008 *2-12 keV*
1998	19 511	99.6 % CL	2.0	
1999	57 986	4 σ	3.6	0.022 +- 0.005 *2-6 keV*
2003	107 730	6.3 σ	4.9	0.020 +- 0.003 *2-6 keV*
2008	300 555	**8.2** σ	**8.2**	0.0131 +- 0.0016 *2-6 keV*

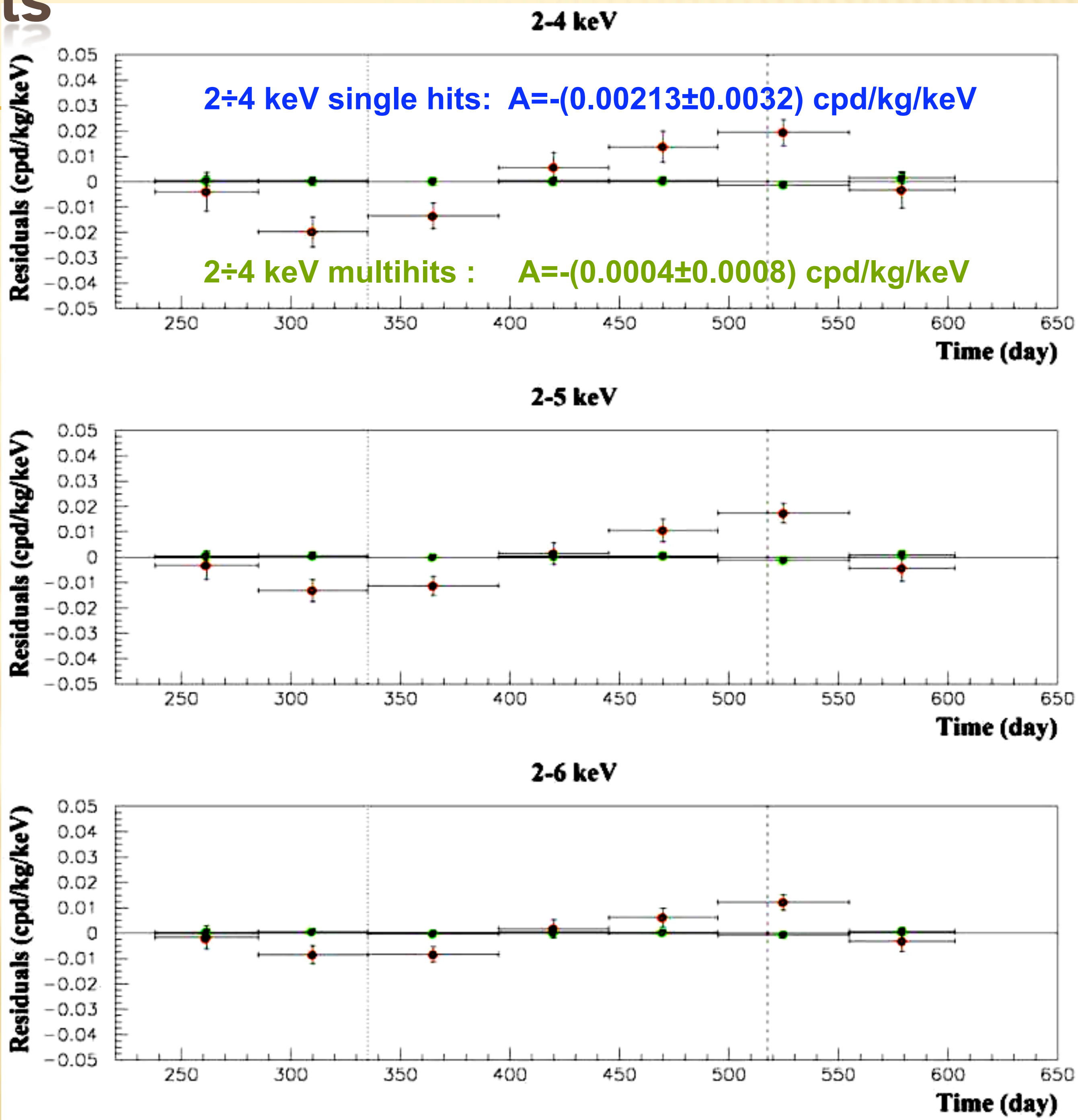
Questions about last data

- Multi hit events absence of modulation has very small error ? If true, statistical significance of signal should depend on the position of crystal. Tested ?
- Single hit spectrum varying : efficiency at LE ?
- 3 keV peak modulation ?
- If DM S_m present, then S_0 present, and backg+signal rate budget should be consistent
- Possible left over hypothesis could be LDM/electronic recoils

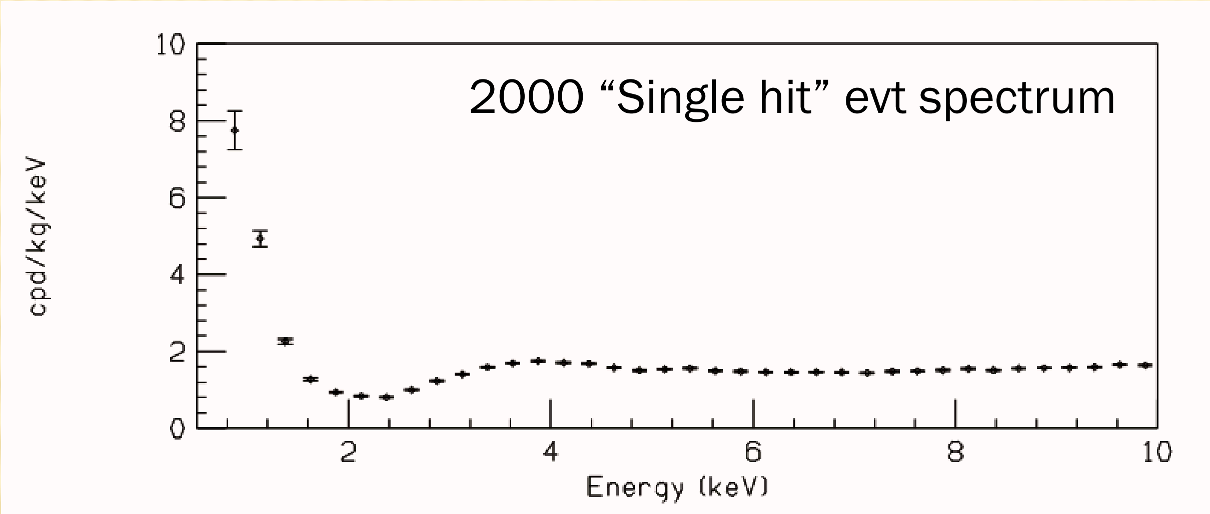
Multi vs single hits

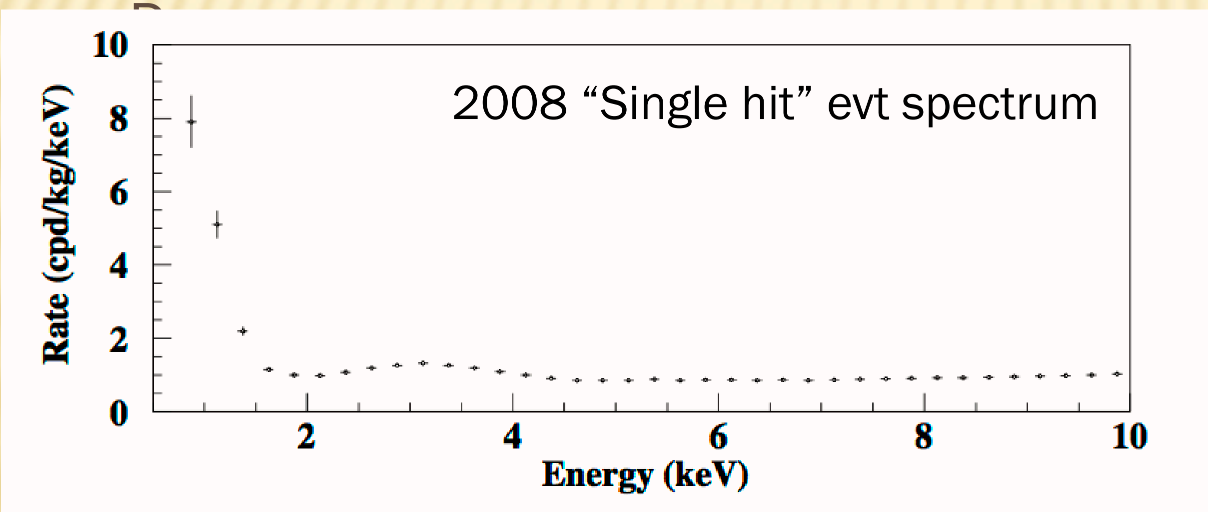
- Why error smaller for multi vs single hits ?
- 0.0008 vs 0.0032
- This would mean that coincident evts rate larger by factor more than 10 vs single ?
- Then expect statistical significance of signal of inner crystals much larger than outer ones.

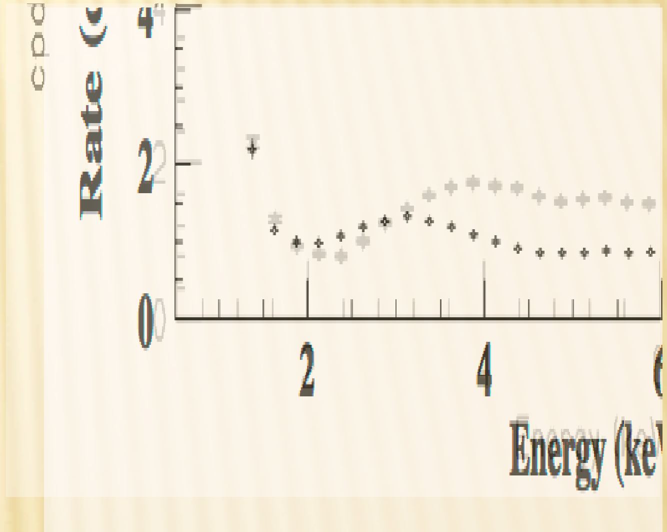
A	B	B	B	A
B	C	C	C	B
B	C	C	C	B
B	C	C	C	B
A	B	B	B	A



Single hit energy spectra along time

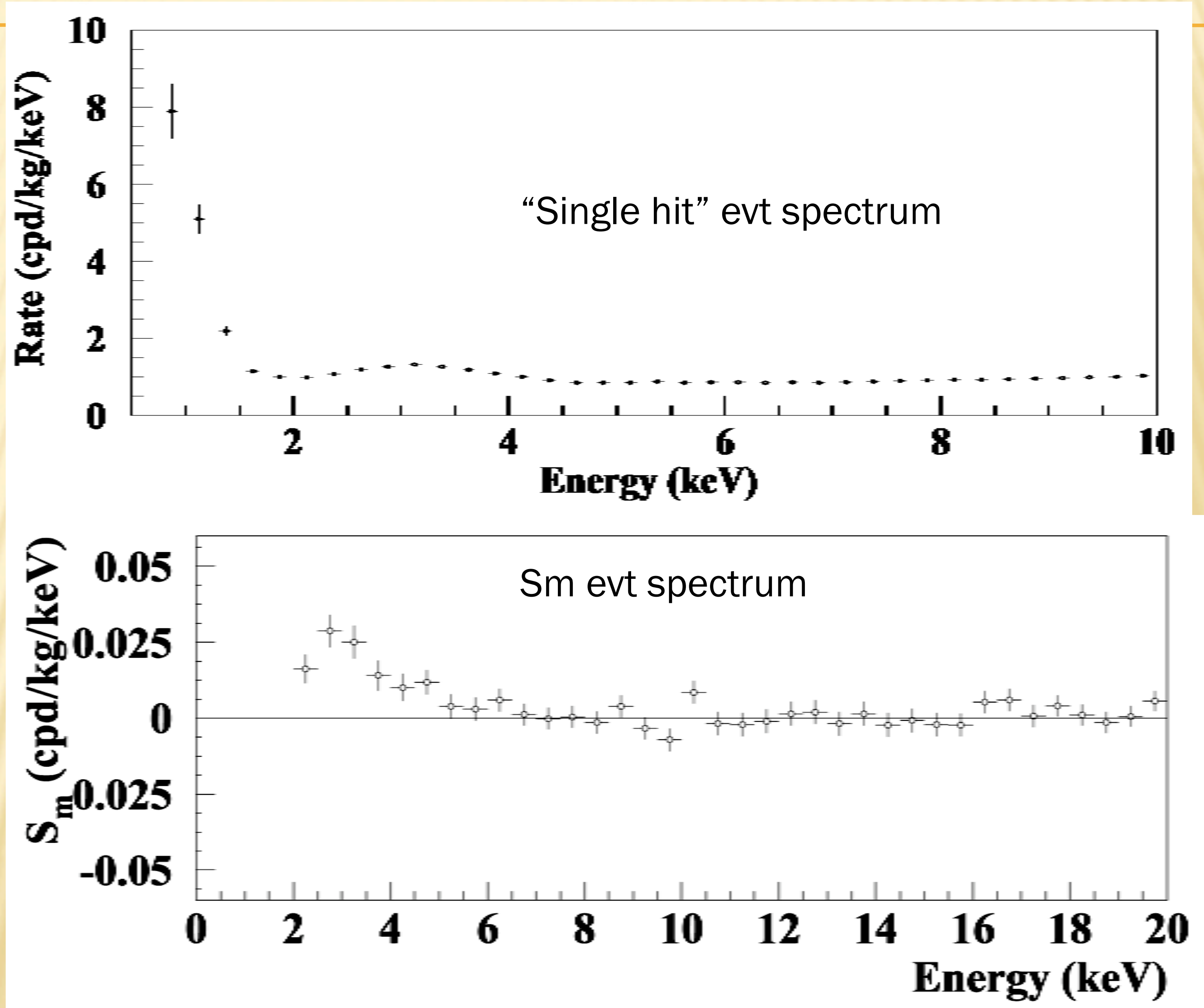






- Question of efficiency understanding (cut for PM noise) at low energy ?

Comparison of energy spectra of all and signal events

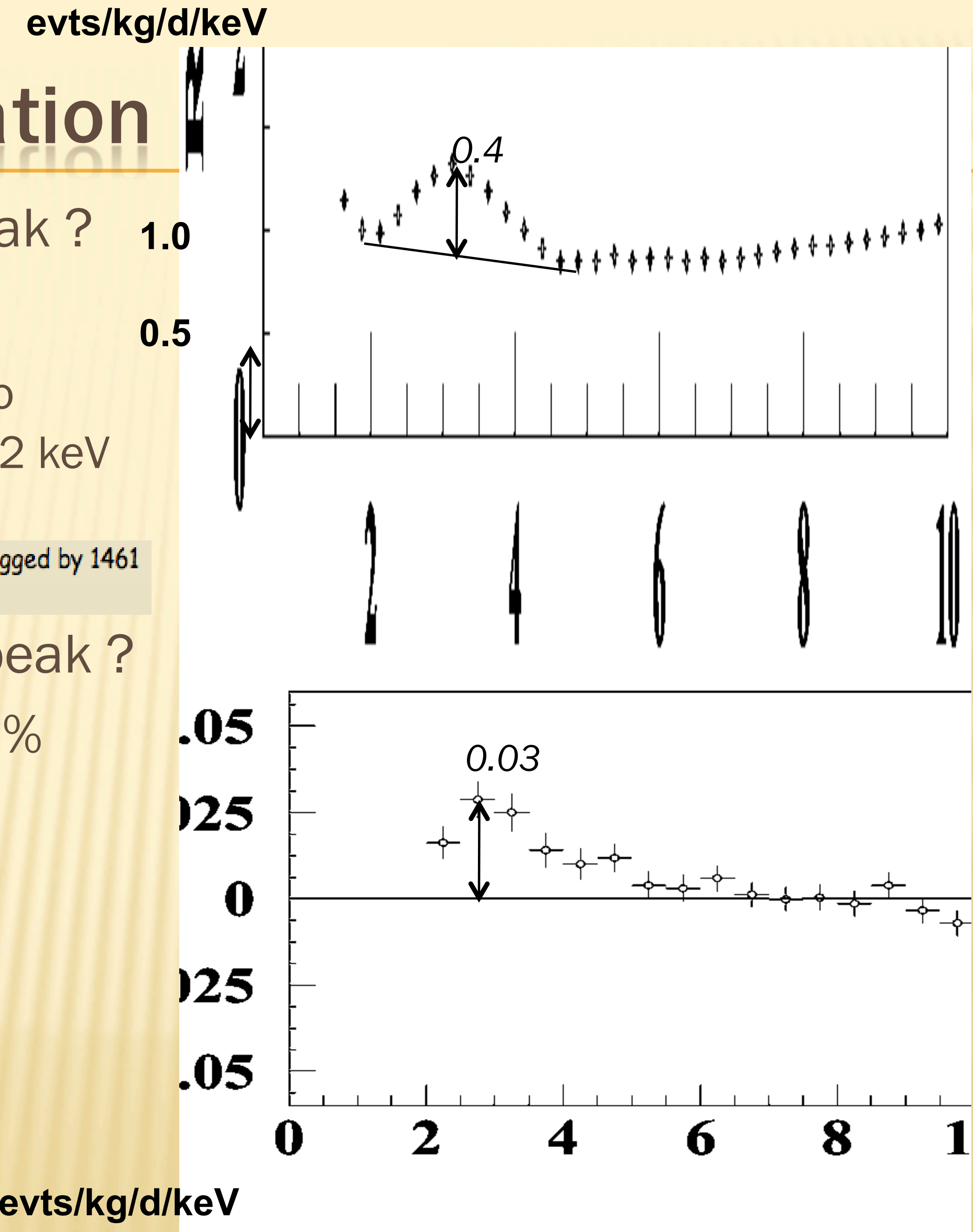


Spectrum modulation

- Modulation of 3 keV peak ?
- 3 keV peak is partly due to untagged ^{40}K X ray/Auger 3.2 keV coincident with 1.46 MeV

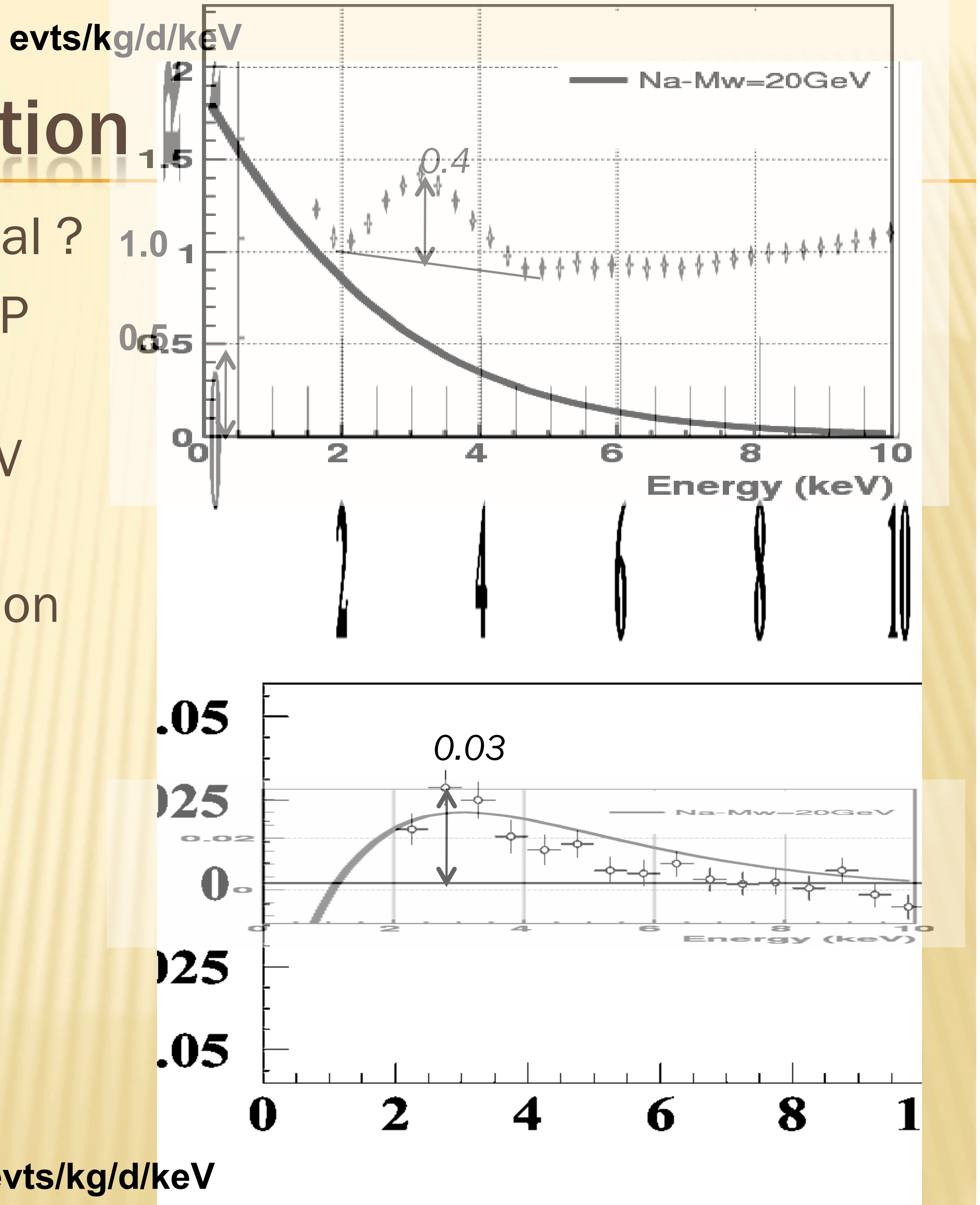
• Internal ^{40}K: 3.2 keV due to X-rays/Auger electrons (tagged by 1461 keV γ in an adjacent detector).

- Presence of axion like peak ?
- If yes, modulation > 10 %



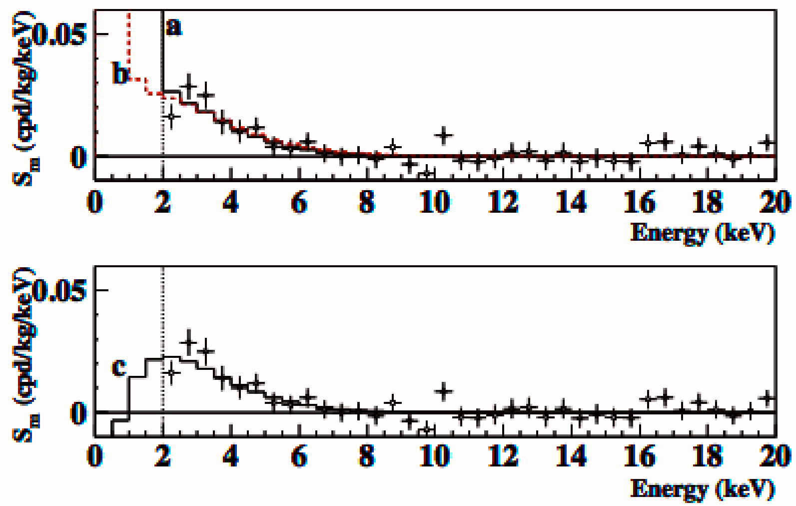
Spectrum modulation

- Modulation of exponential ?
- Example of 20 GeV WIMP interacting on Na
- => counting rate @ 2 keV saturated by WIMPs
- Showing the S contribution in each case to the total spectrum would help disentangling various hypothesis



The many possible scenario's 1

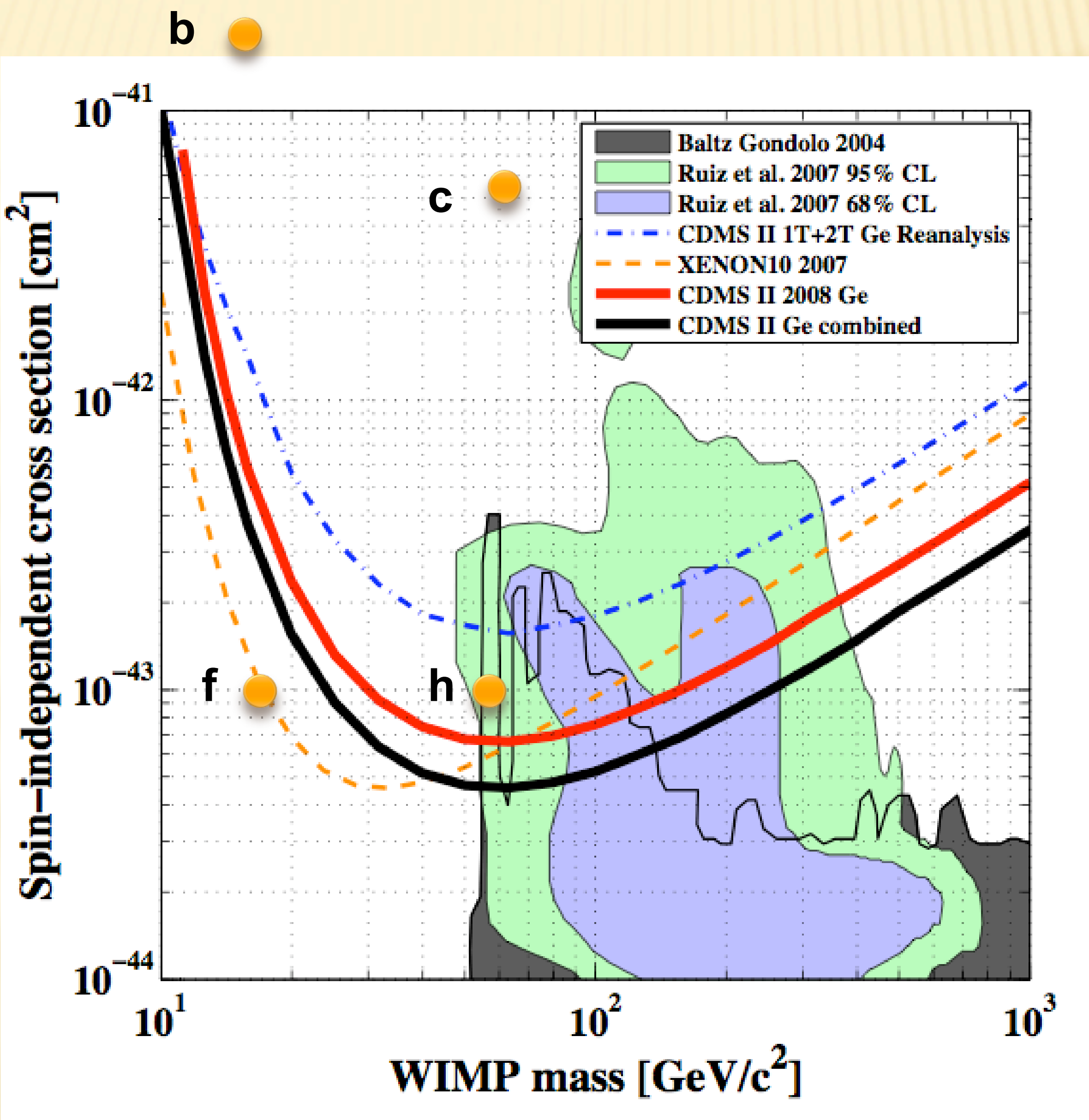
- "Classical" nuclear recoils of WIMP's
- SI and/or SD mostly excluded by recent experiments



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

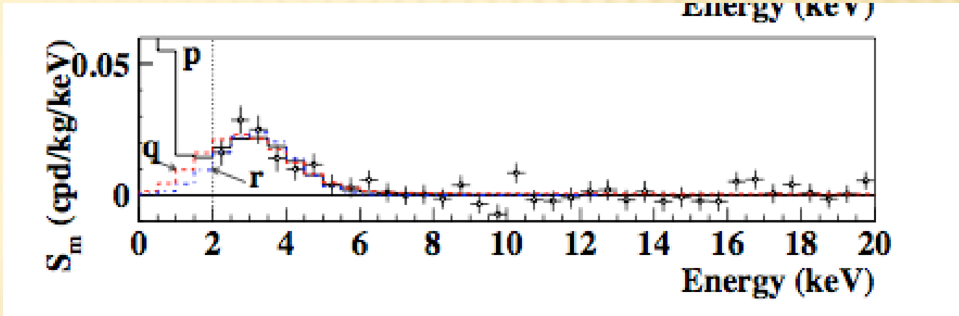
Curve label	Halo model (see ref. [4, 34])	Local density (GeV/cm^3)	Set as in [4]	DM particle mass	$\xi\sigma_{SI}$ (pb)	$\xi\sigma_{SD}$ (pb)	θ (rad)	Channeling [9]
a	A5 (NFW)	0.2	A	15 GeV	3.1×10^{-4}	0	–	no
b	A5 (NFW)	0.2	A	15 GeV	1.3×10^{-5}	0	–	yes
c	A5 (NFW)	0.2	B	60 GeV	5.5×10^{-6}	0	–	no
d	B3 (Evans 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

SI CASE


b
c
f
h
Baltz Gondolo 2004
Ruiz et al. 2007 95% CL
Ruiz et al. 2007 68% CL
CDMS II 1T+2T Ge Reanalysis
XENON10 2007
CDMS II 2008 Ge
CDMS II Ge combined
Spin-independent cross section [cm²]
WIMP mass [GeV/c²]
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10¹
10²
10³

The many possible scenario's 2

- Light DM (on nuclei) 30-100 MeV
- Pseudoscalar => electron recoil : 60 keV
- Total mass conversion : 3 keV (axion like)



Light Dark Matter (LDM) inelastic scattering and bosonic axion-like interaction as in [6, 11], A5 (NFW) halo model as in [4, 34], local density = 0.17 GeV/cm³, local velocity = 170 km/s							
Curve label	DM particle	Interaction	Set as in [4]	m_H	Δ	Cross section (pb)	Channeling [9]
l	LDM	coherent on nuclei	A	30 MeV	18 MeV	$\xi\sigma_m^{coh} = 1.8 \times 10^{-6}$	yes
m	LDM	coherent on nuclei	A	100 MeV	55 MeV	$\xi\sigma_m^{coh} = 2.8 \times 10^{-6}$	yes
n	LDM	incoherent on nuclei	A	30 MeV	3 MeV	$\xi\sigma_m^{inc} = 2.2 \times 10^{-2}$	yes
o	LDM	incoherent on nuclei	A	100 MeV	55 MeV	$\xi\sigma_m^{inc} = 4.6 \times 10^{-2}$	yes
p	LDM	coherent on nuclei	A	28 MeV	28 MeV	$\xi\sigma_m^{coh} = 1.6 \times 10^{-6}$	yes
q	LDM	incoherent on nuclei	A	88 MeV	88 MeV	$\xi\sigma_m^{inc} = 4.1 \times 10^{-2}$	yes
r	LDM	on electrons	–	60 keV	60 keV	$\xi\sigma_m^{e} = 0.3 \times 10^{-6}$	–
r	pseudoscalar axion-like	see ref. [6]	–	Mass = 3.2 keV		$g_{aee} = 3.9 \times 10^{-11}$	–

What about European flagships ?

- CRESST
- Edelweiss
- ZEPLIN III

All are taking new data

- WARP @ LNGS
- ArDM @ Canfranc

Preparing

Astron. Nachr. / AN , No. , 1 – 16 (2008) / DOI

Astroph:0804.1500v1

Status and Perspectives of Astroparticle Physics in Europe

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Bolometric detectors are operated at a temperature of 10-20 mK and detect the feeble heat, ionization and scintillation signals from WIMP interactions in crystals made, e.g., from germanium, silicon or $CaWO_4$. Present flagship experiments are CDMS in the USA, and CRESST (Gran Sasso Laboratory, Italy) and EDELWEISS (Fréjus Laboratory, France) in Europe.

Noble liquid detectors record ionization and scintillation from nuclear recoils in liquid xenon, argon or neon. XENON (Gran Sasso) and ZEPLIN (Boulby mine, UK) use liquid xenon targets of about 10kg mass, while WARP (Gran Sasso) and ArDM (Canfranc, Spain) operate, or prepare, liquid argon detectors. Actually the most recent significant step in the race for better sensitivities has been made by XENON (see Angle 2008 and Fig 1).

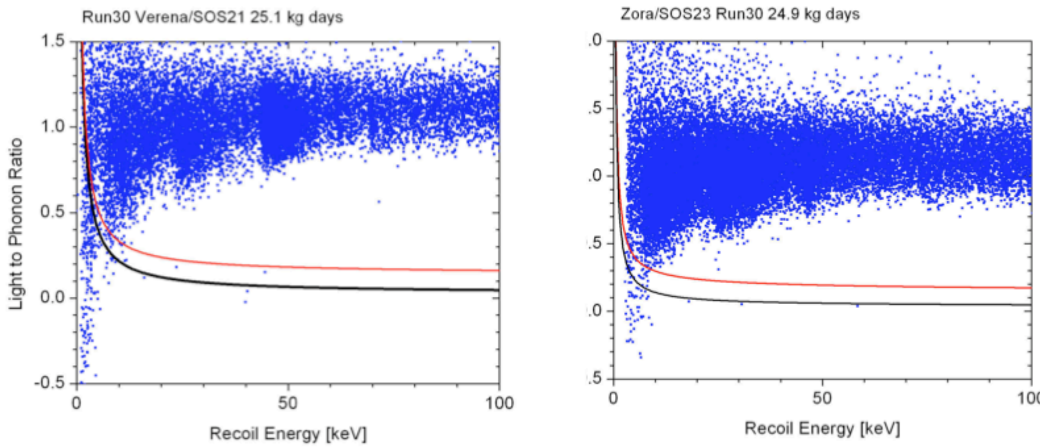
CRESST SEPT07

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

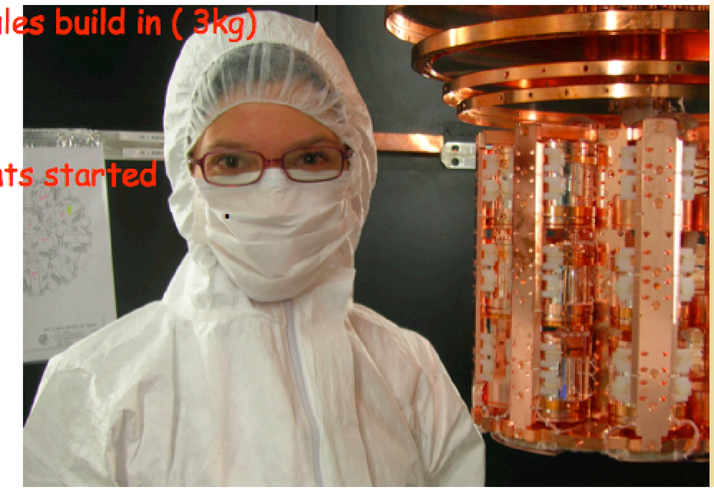
finished

Discrimination and background



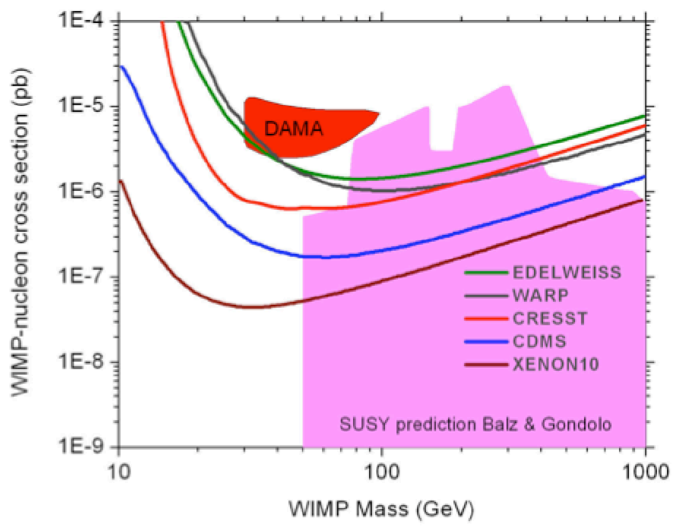
Comissioning run

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



Preliminary limits

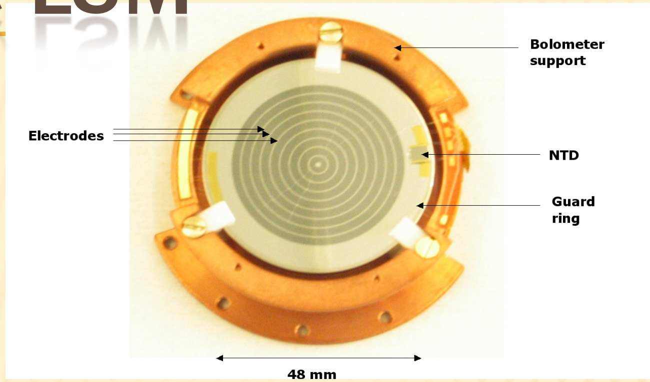
no neutron calibration yet

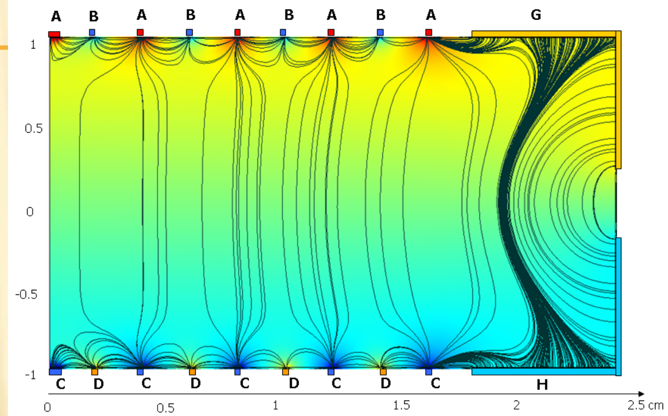


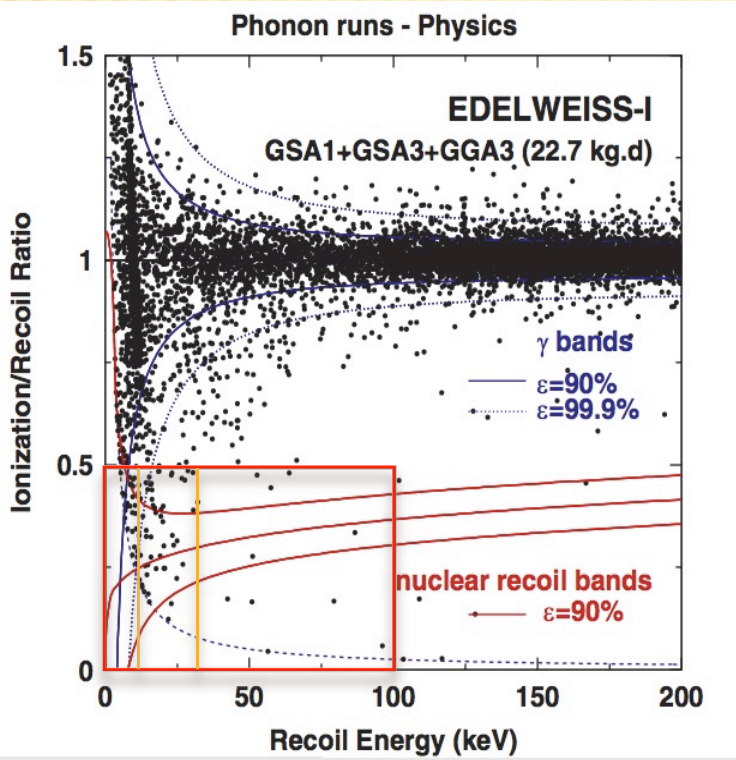
10 detectors being operated

EDELWEISS @ LSM

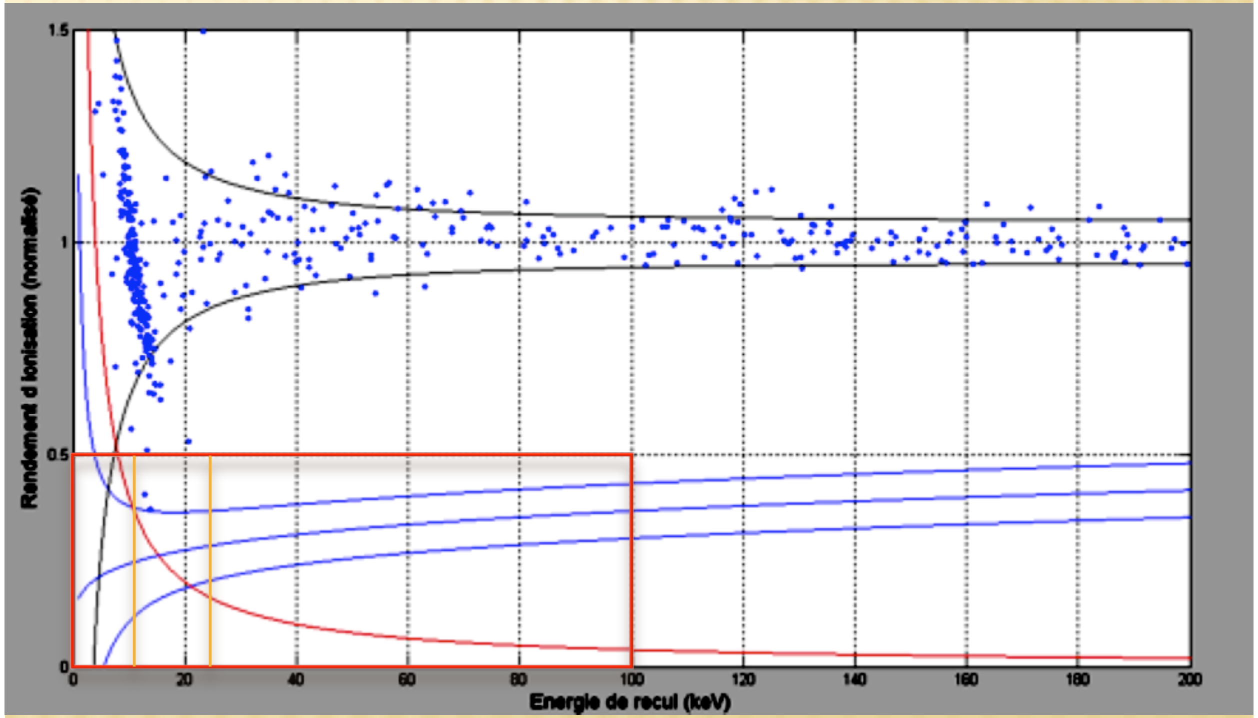
- The new weapon !
- 12 400g detectors in fabrication and mounted in EDW II cryostat







NTD 300g detectors EDW1 22.7 kg.d



Interdigit 200g 5.4 kg.d Ei threshold 4 keV

After surface evt rejection, no quality cut

Update of DAMNED website : SuperBayeS online

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

SuperBayeS

SuperBayeS homepage

Using chain from : arXiv:0705.2012 [hep-ph]

Leszek Roszkowski, Roberto Ruiz de Austri, Roberto Trotta

These plots already include full constraints from relic dark matter abundance (WMAP3), collider observables, Higgs mass limits, electroweak observables, B → s γ (see the paper for full details). They do NOT include direct detection exclusion limits.

see example

Define plots

X axis	m_0 (GeV)
Y axis	m_1/2 (GeV)
Z axis	A_0 (GeV)

Sign of μ	mu>0

Options

1D-2D plots	no smoothing
2D-3D plots	default colors

Define cuts : Use with care: the points not passing the cuts are simply removed from the chains. Note that such cuts have NO statistical validity but are only (and perhaps not even!) indicative.

New cut : **Range :** -- validate

low resolution (faster)

Click to run

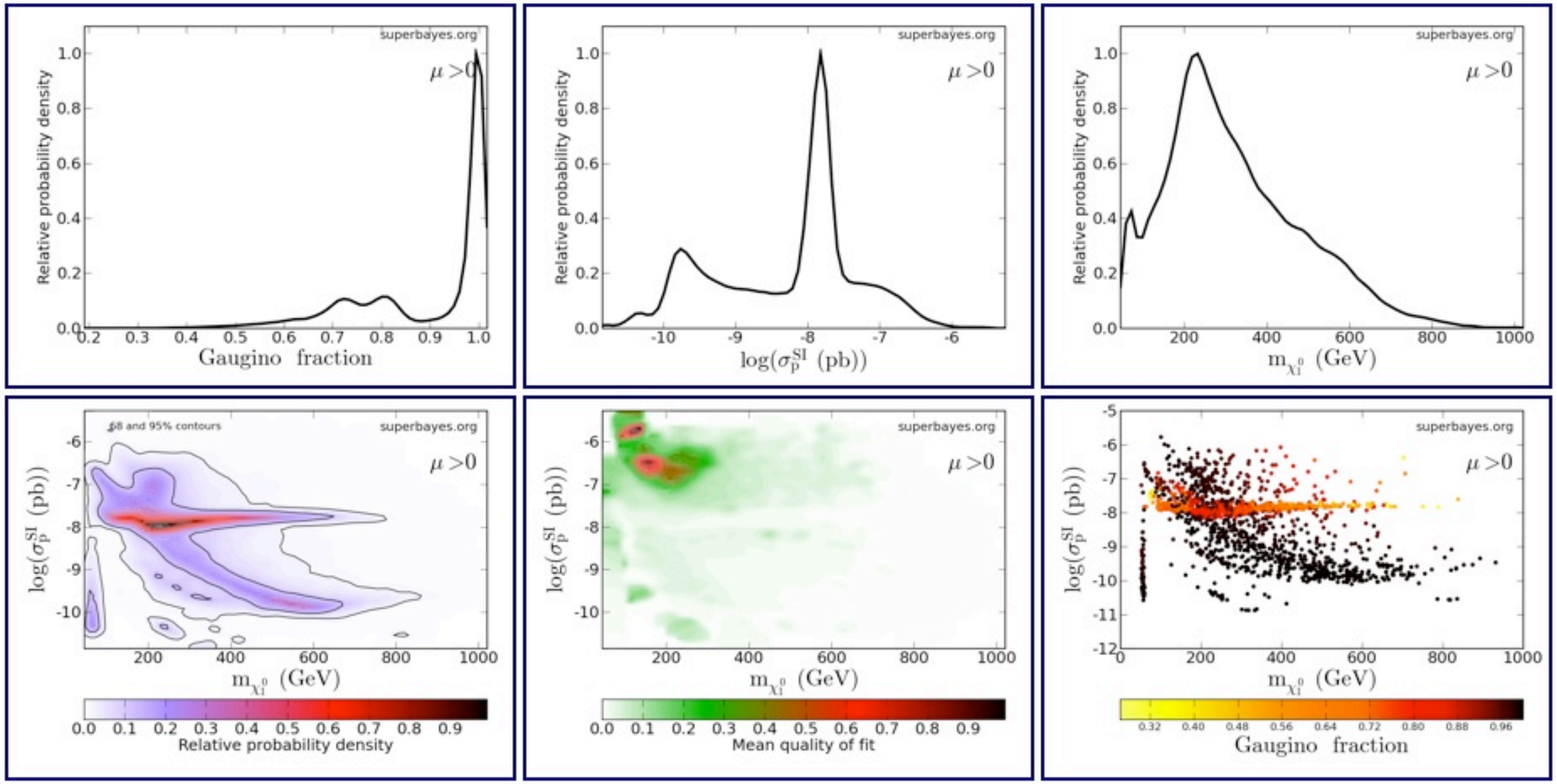
webmaster

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.

EXAMPLE : SuperBayeS online

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

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



Define plots

X axis	m_{χ_1^0} (GeV)
Y axis	log(σ_p^{SI} (pb))
Z axis	gaugino fraction

Sign of μ: mu>0

Options

1D-2D plots	smoothing
2D-3D plots	default colors

Stay tuned for future developments

Conclusions

- Large progress on WIMP SI and SD sensitivities
- More to come within 1 year
  - CDMS, KIMS, XENON 100, WARP, EDELWEISS, CRESST
- DAMA signal hypothesis can indeed be tested :
  - KIMS, COUPP, TEXONO in addition to CDMS, XENON …
  - SO prediction in all cases will help pointing where to look for
- Independently of DAMA, worthwile to explore keV and subkeV energies in reliable way (2 parameters)