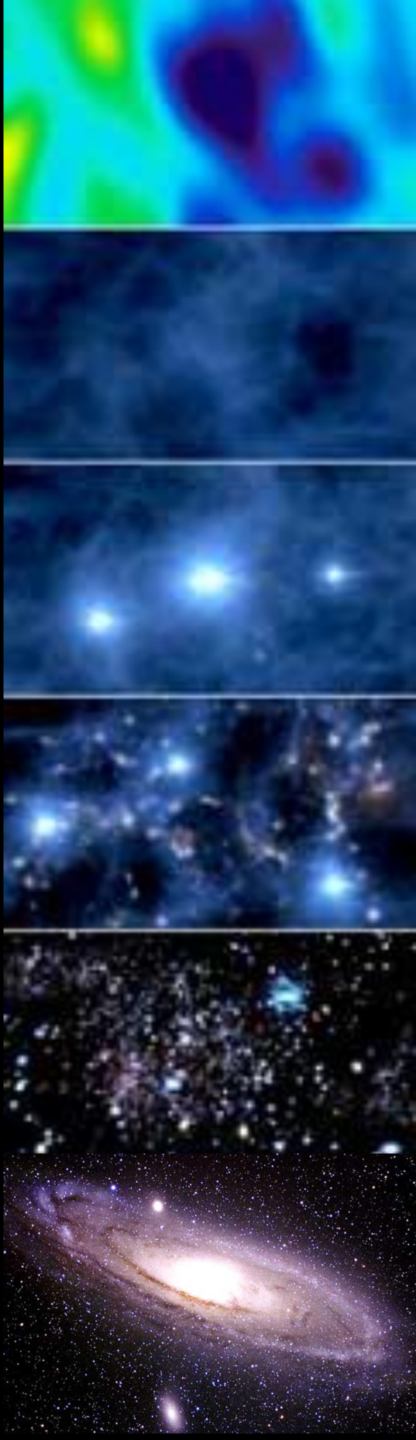
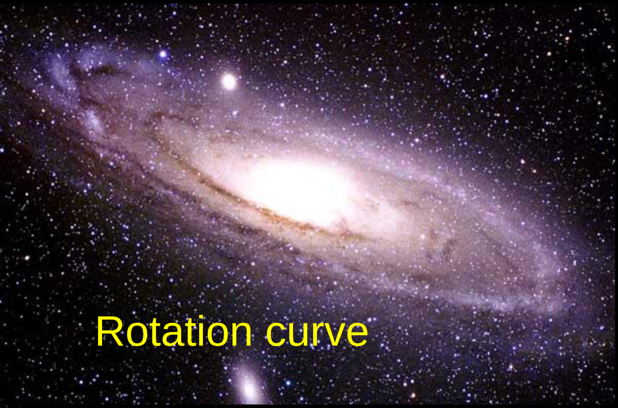
State of the Art of Searches for Dark Matter

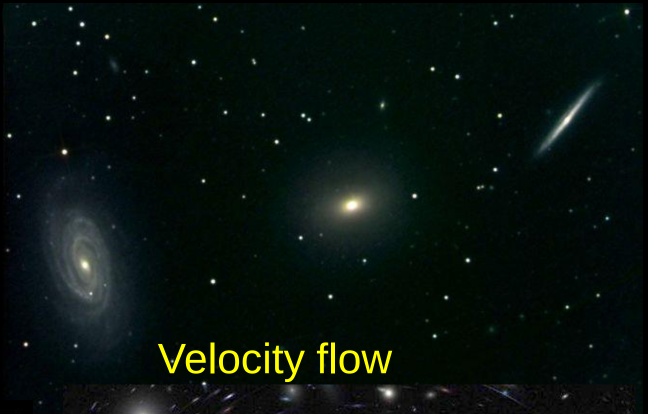
- Cosmological Evidence
- Theoretical Paradigms
- Experimental Approaches
- Outlook

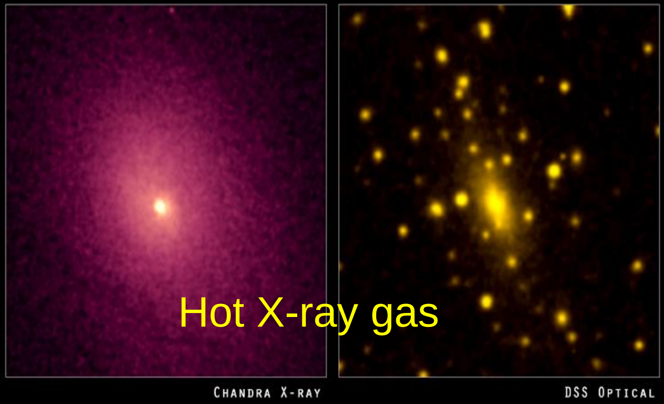


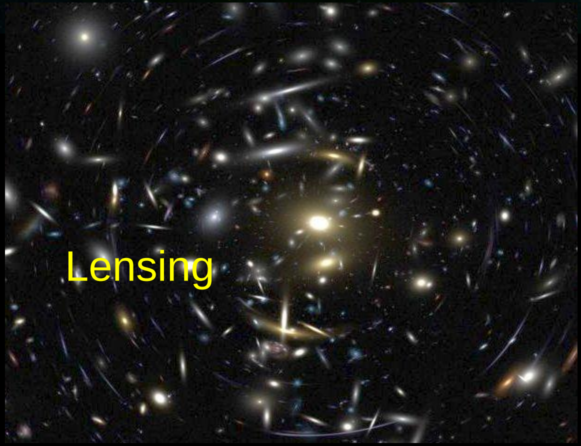
V. Zacek , Université de Montréal, CAP Congres 2014

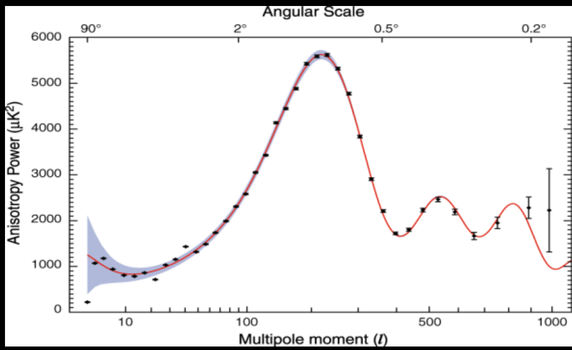
Convincing Evidence for Dark Matter at all Scales!



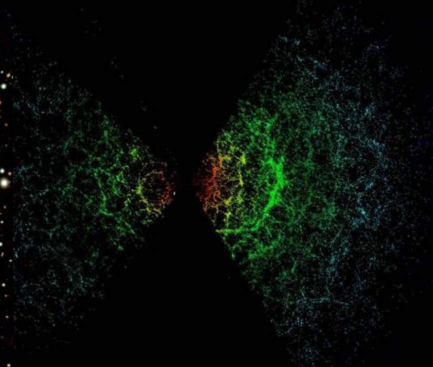


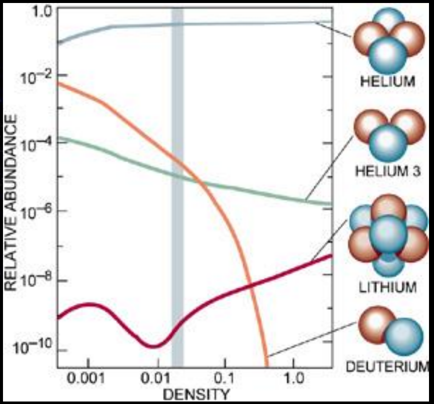




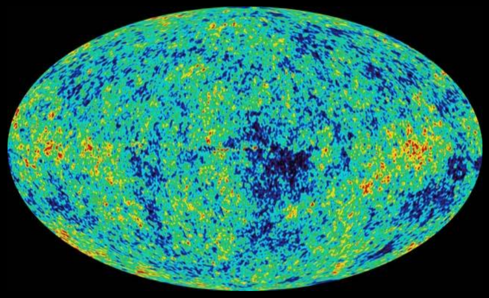


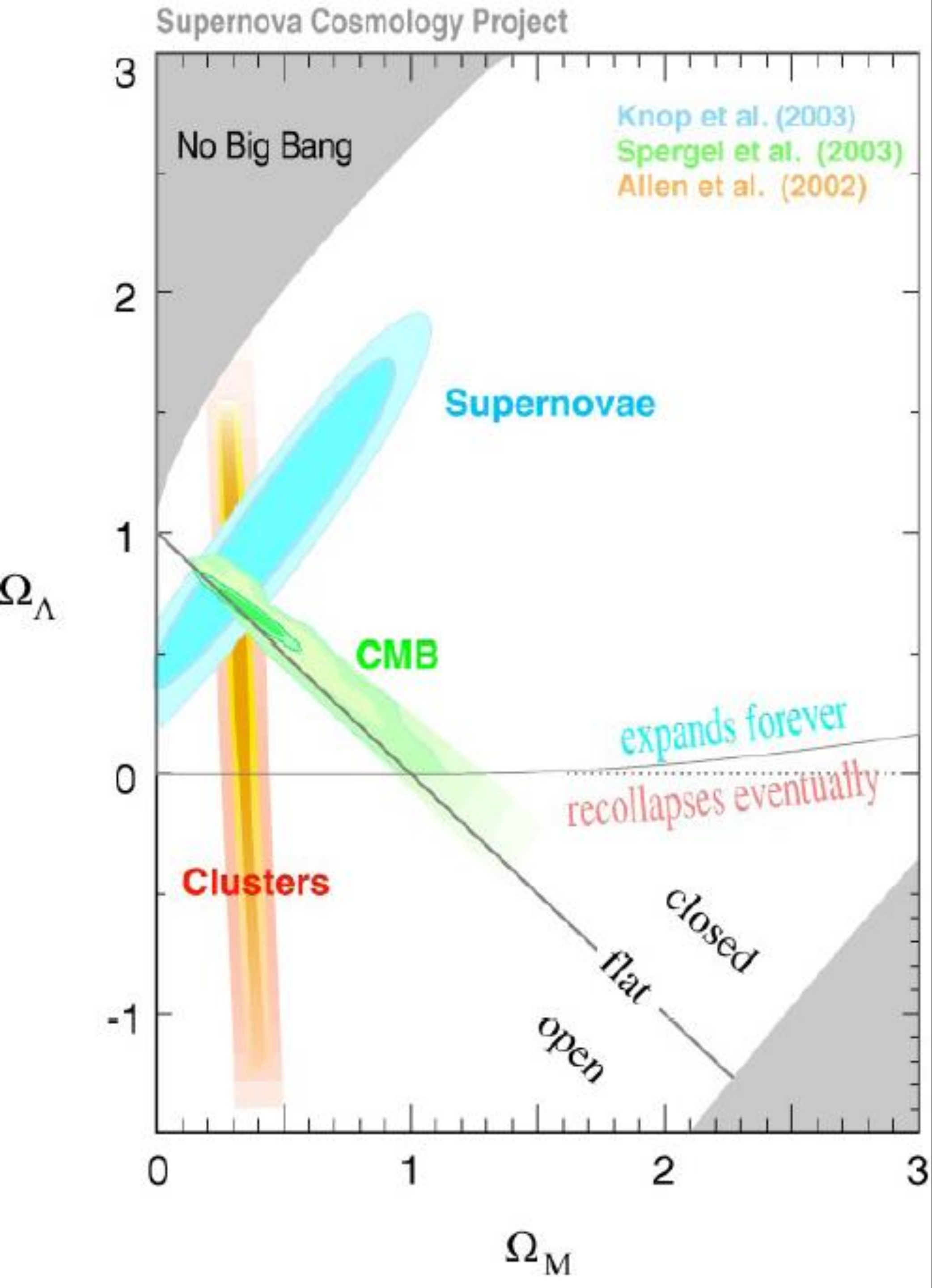

Bullet Cluster


Large scale structure

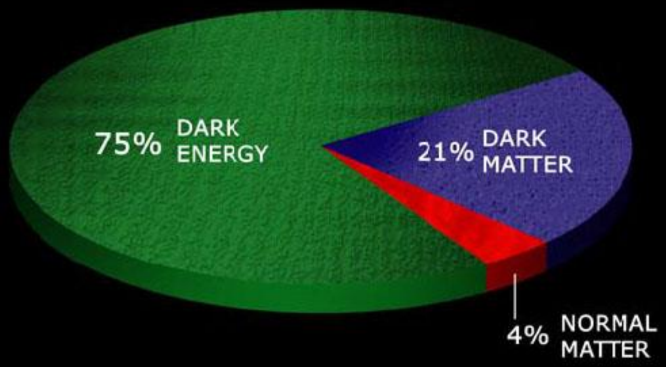


BB nucleosynthesis


CMB anisotropy

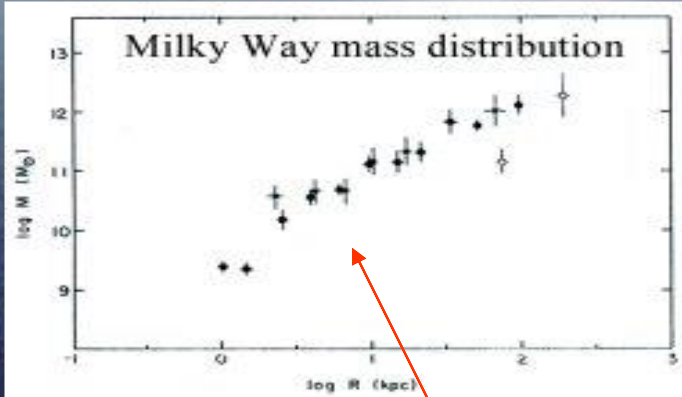


The Concordance Model

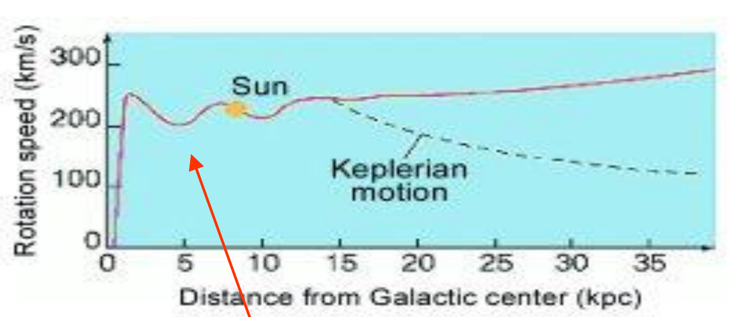


→ See talk by M. Dobbs

Dark Matter in Our Galaxy



Mass increases up to 200 kpc



Schematic flat rotation curve for the Milky Way galaxy

1kpc = 3.259 10^3 Ly

$$M(r) = \frac{v_{rot}^2 r}{G}$$

ρ_{DM} ~ **0.3 m_p/cm^3**

2MASS two Micron All Sky Survey

…only 5-10% of matter is visible!

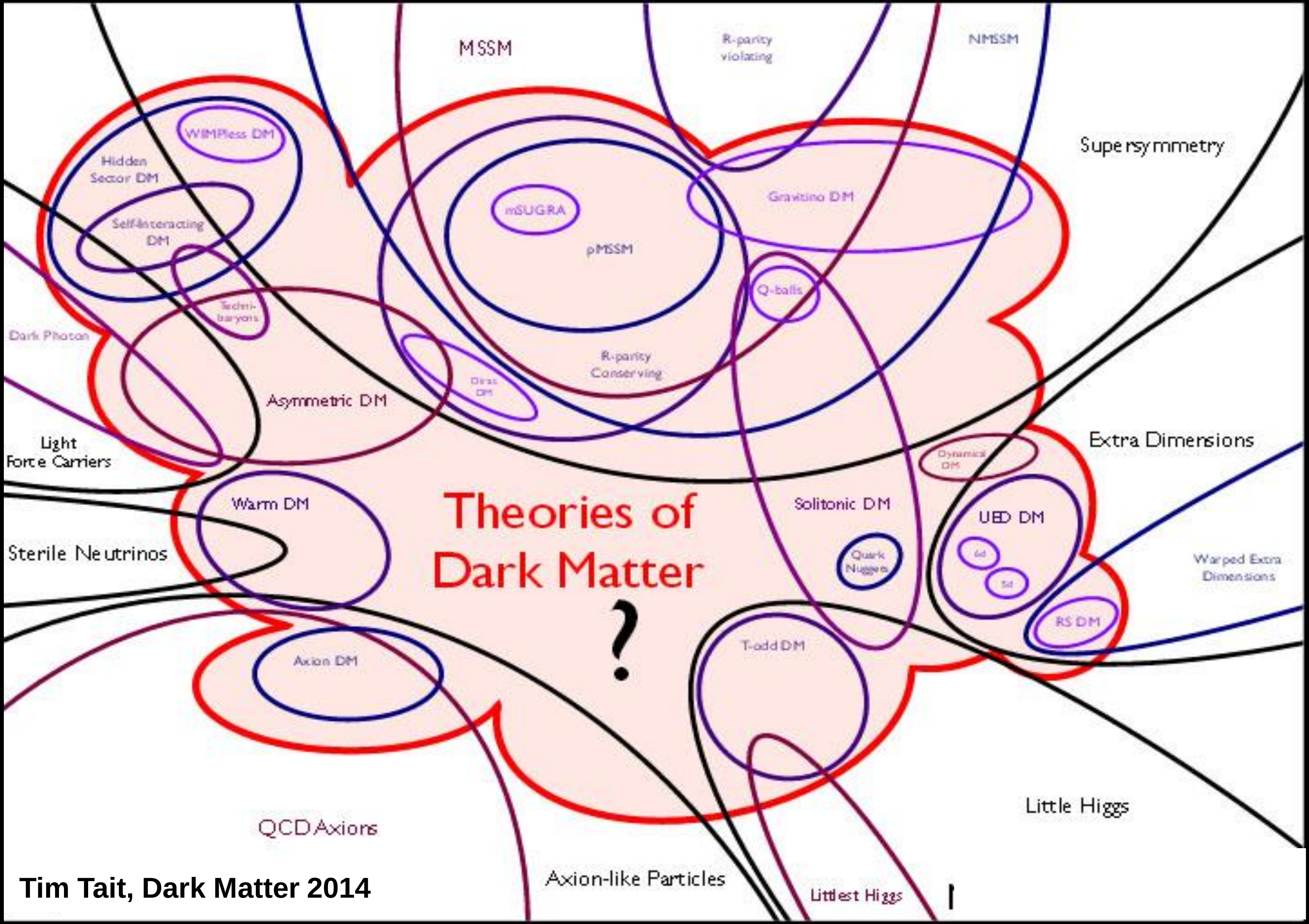
WHAT CAN DARK MATTER BE?

- cannot be baryons (CMB and light element abundance different)
- cannot be charged (CMB different)
- no MACHOS (are not there)
- stable or at least metastable ($\tau > 10$ Gyr)
- must be cold or warm to explain structure
- must clump on small scale (dwarf galaxies M/L ~ 1000)
- no sub-keV particles (unless axions or BE scalar condensates)
- self-interaction constrained ($\sigma/m < 1 cm^2 g^{-1}$ by halo structures)

Guidance by theory?

Galactic halos $\rightarrow$ see talk by D. Rout

No Lack of Options…



Therory → see talk by A. Ritz

The WIMP Miracle

Number density of relics shortly after BB: T >> M

Reduction due to
Hubble expansion

DM self annihilation

Boltzmann

$$\frac{dn_x}{dt} = -3Hn_x - n_x^2 \langle \sigma v \rangle (x\bar{x} \rightarrow ordinary\ matter) +$$

$$+ n_{ord}^2 \langle \sigma v \rangle (ordinary\ matter \rightarrow x\bar{x})$$

Particle production

- in equilibrium: creation = annihilation
- ordinary particles stay longer in equilibrium

Caveat…asymmetric DM, axions etc $\rightarrow$ different story)

The WIMP Miracle

$$n_x^{eq} \propto (mT)^{3/2} e^{-m/kT}$$

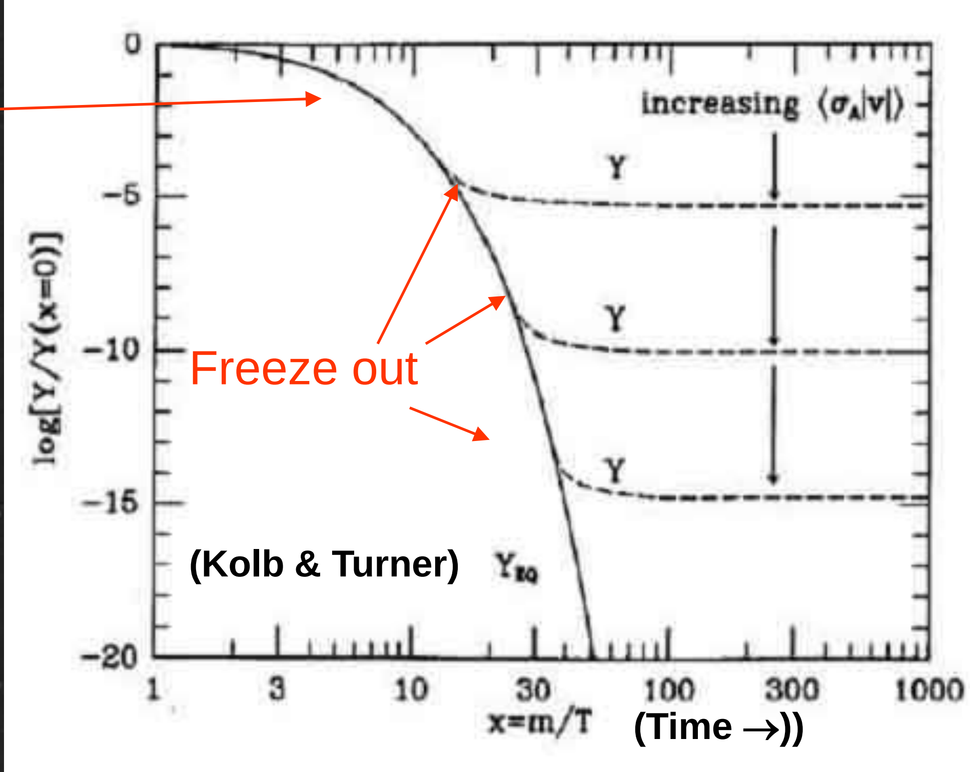
After freeze out:

$$\Omega_x \sim \frac{0.1pb}{\langle\sigma v\rangle h^2}$$

In order to get:

$$0.17 < \Omega_x < 0.25$$

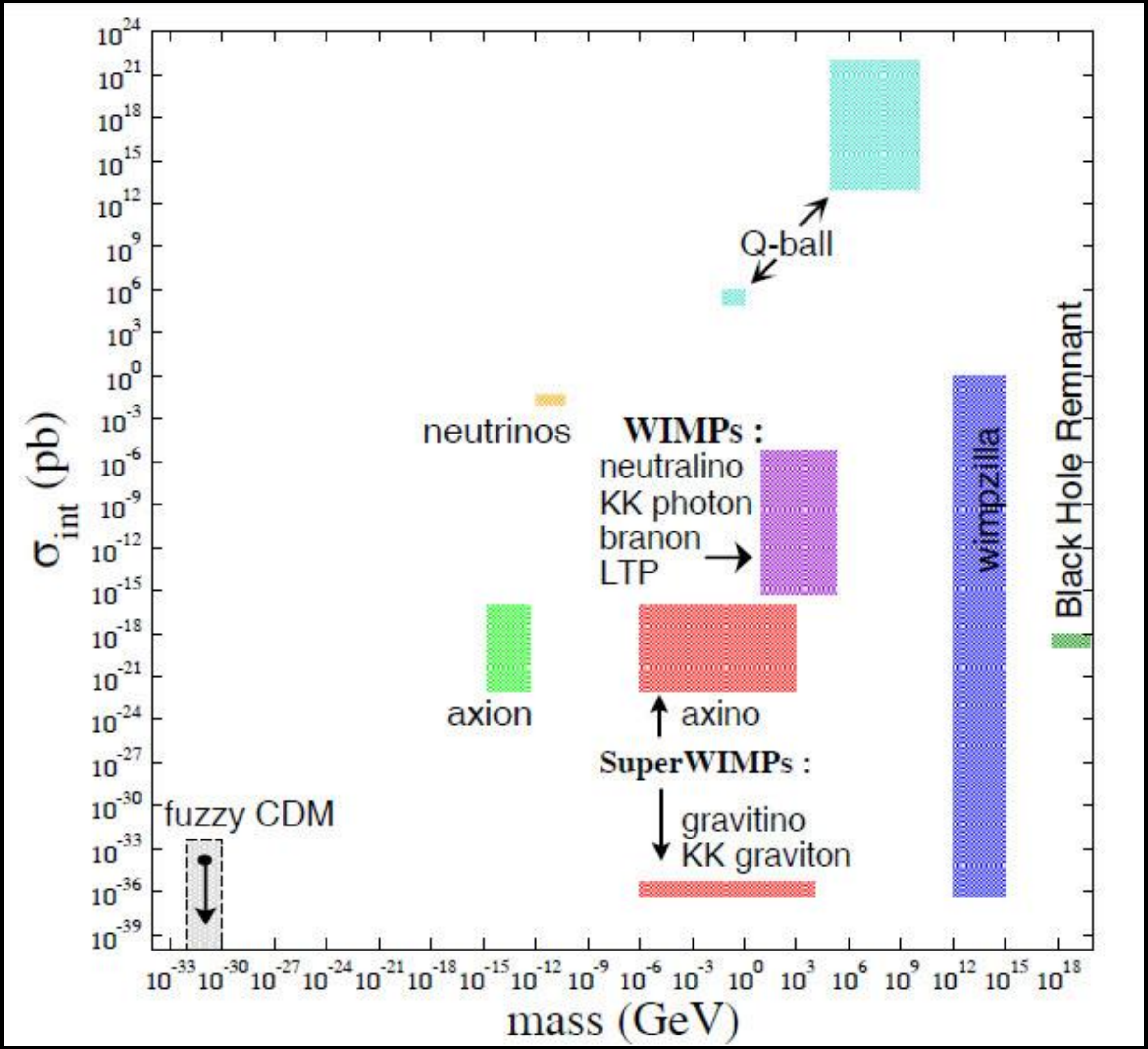
$\langle\sigma v\rangle \sim 3\text{x}10^{-26}\ \text{cm}^3\ \text{s}^{-1}$



…need stable particle which annihilates with electro-weak scale cross-section and e.w. scale mass (100 GeV)

Caveat…asymetric DM, axions etc → different story)

Dark Matter Candidates



The Neutralino: The preferred CDM Candidate

- χ_1 can be lightest stable super symmetric particle – LSP
- Majorana particle
- interaction with matter electro-weak
- can provide closure density
- relic population from early BB

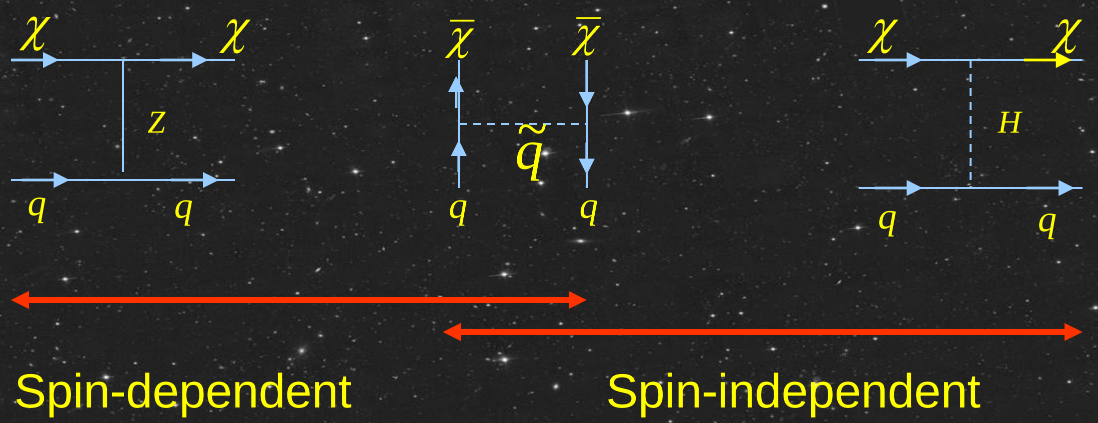
$$\chi_1 = N_{11}\tilde{\gamma} + N_{12}\tilde{Z} + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

"photino" "zino" higgsino" "higgsino"

Mχ 100 Gev - 7 TeV

SUSY structure cosmology

NEUTRALINO INTERACTION CROSS SECTIONS



General form of cross sections:

Enhancement factor

$$\sigma_A = 4G_F^{\,2}\left(\frac{M_\chi M_A}{M_\chi + M_A}\right)^2 C_A F(q^2)$$

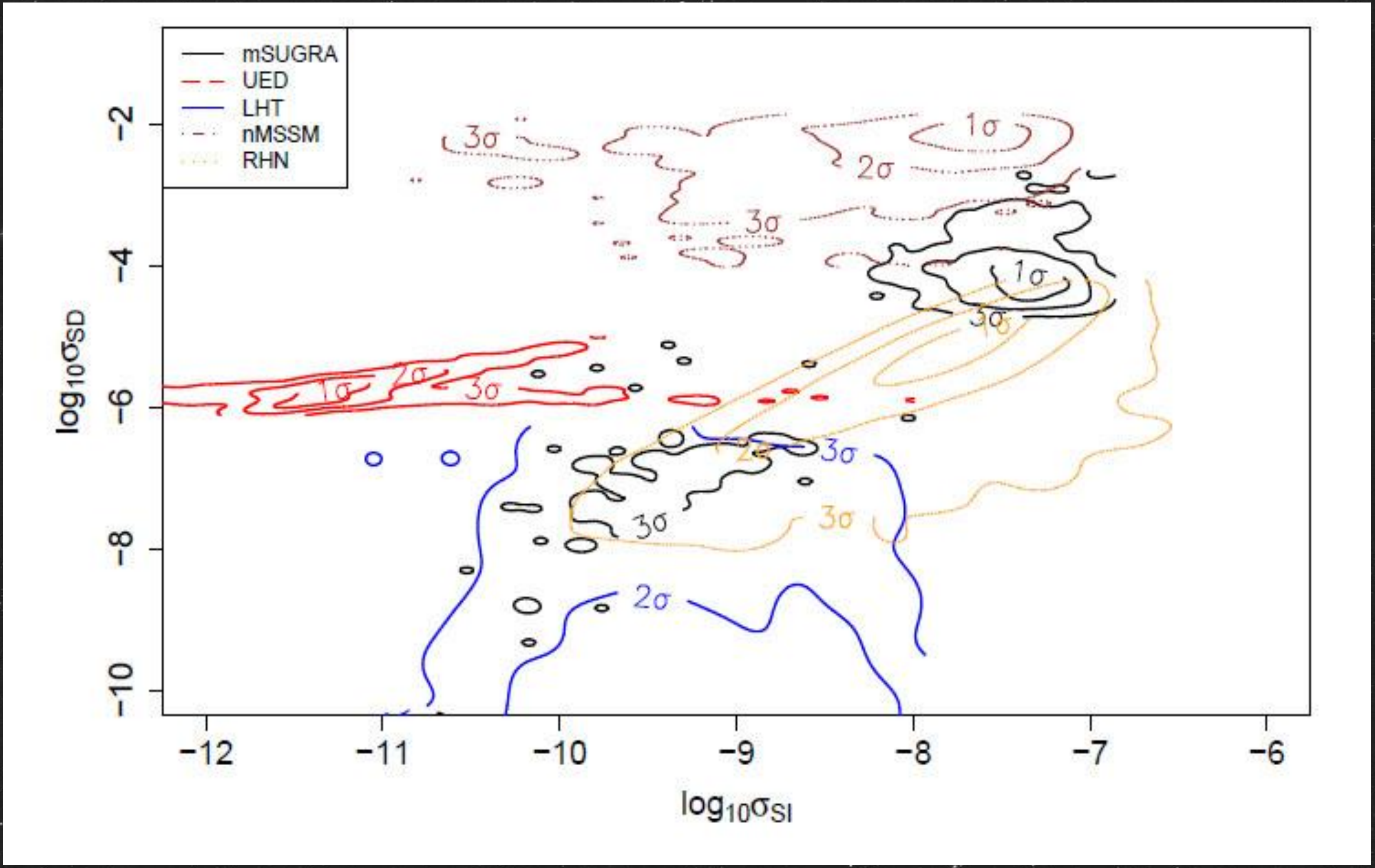
C_A^{SI} : Spin independent – coherent interaction $\propto A^2$

C_A^{SD} : Spin dependent interaction $\propto$ $<S_{p,n}>^2$

$F(q^2)$: nucl. form facor $\rightarrow$ important for large q^2 and large A

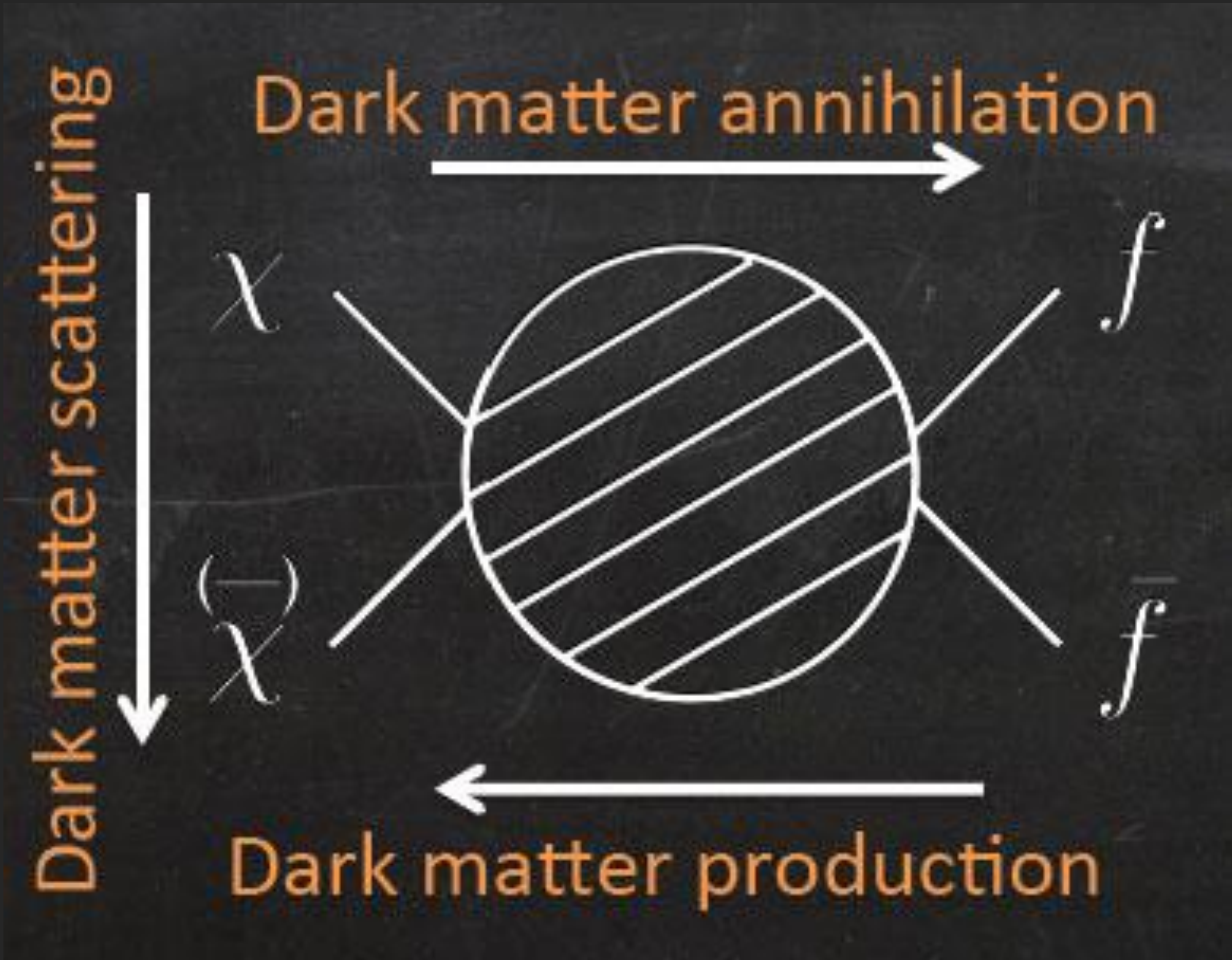
SPIN DEPENDENT - SPIN INDEPENENT

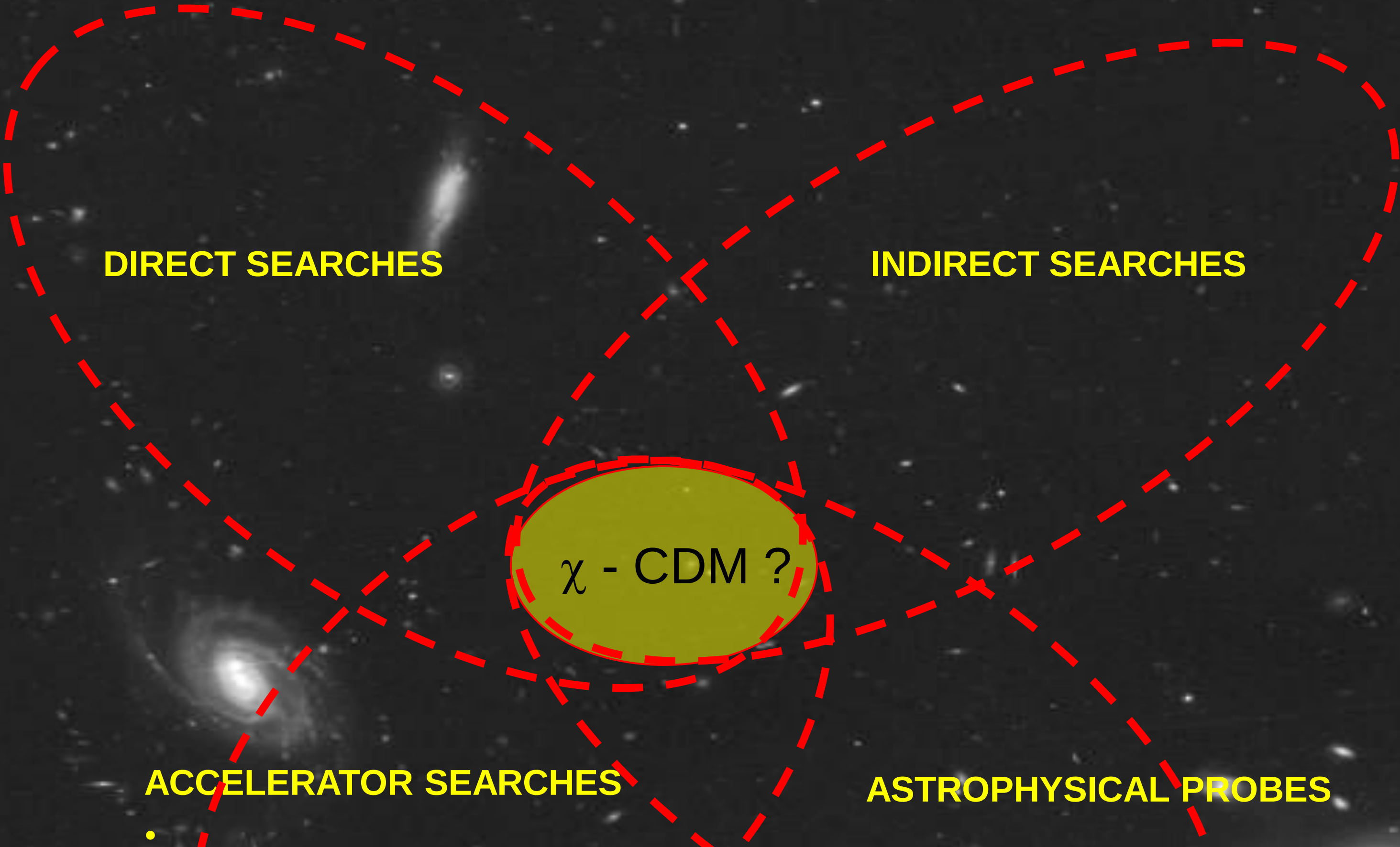
Spin independent



Spin dependent

Large SD x - sections possible for small SI x-sections !

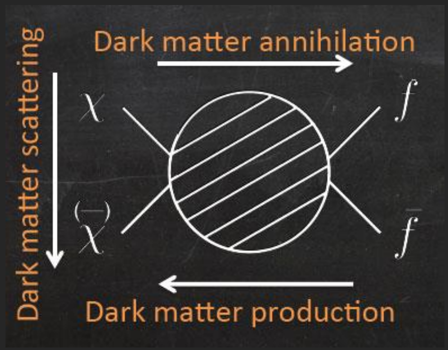

Dark matter annihilation
Dark matter scattering
Dark matter production
χ
$\overset{(-)}{\chi}$
f
$\bar{f}$

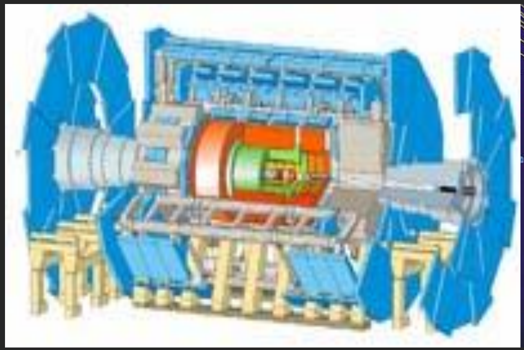


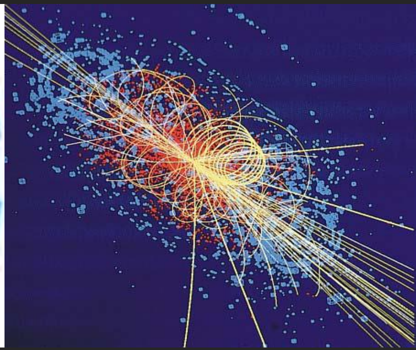
Complementarity !!!

- Discovery of cosmol. WIMP does not prove yet SUSY $\rightarrow$ accelerator searches
- LHC signal does not yet prove CDM discovery $\rightarrow$ (in) direct searches
- Candidate must meet astrophysical constraints

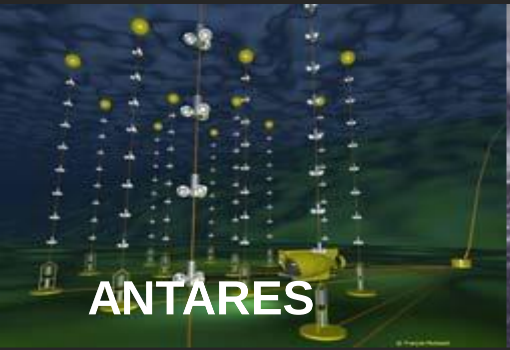
Searches for DM Particles

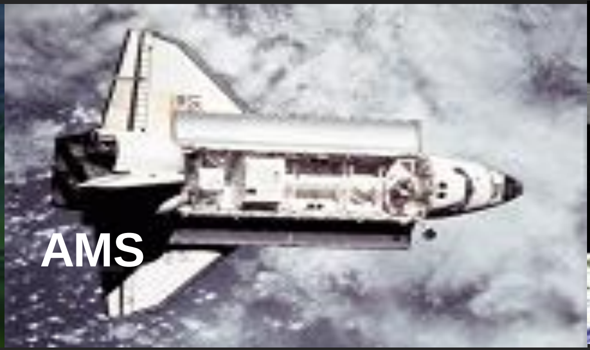


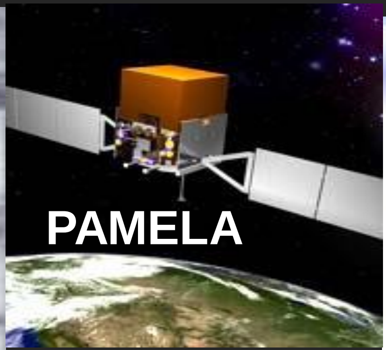


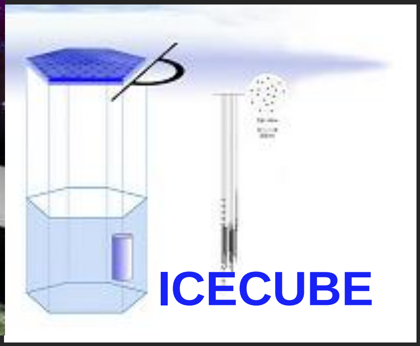


Production in situ at accelerators







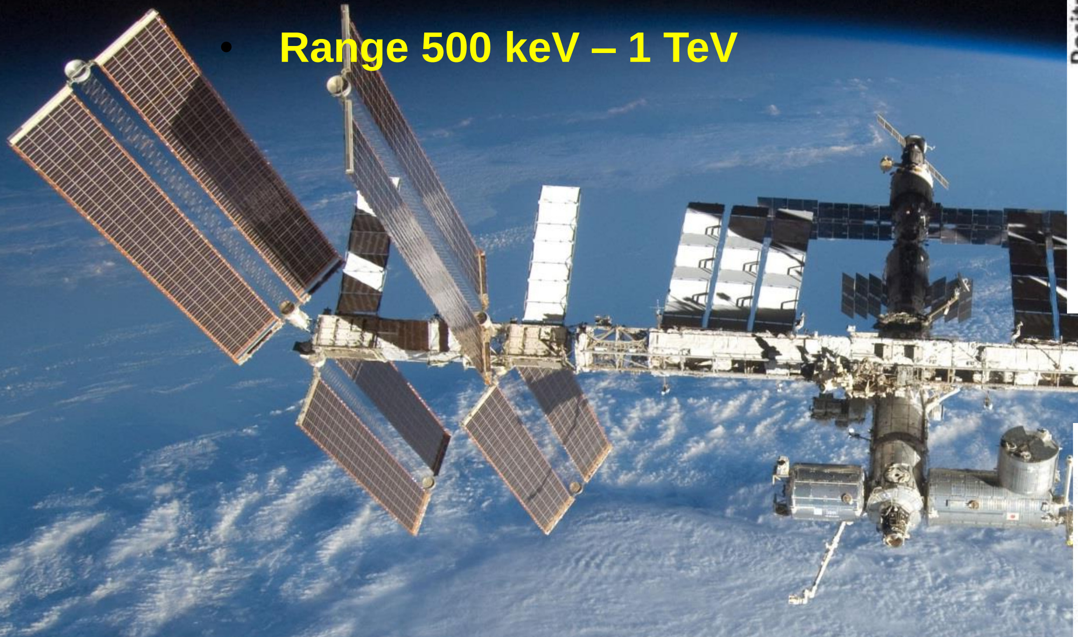


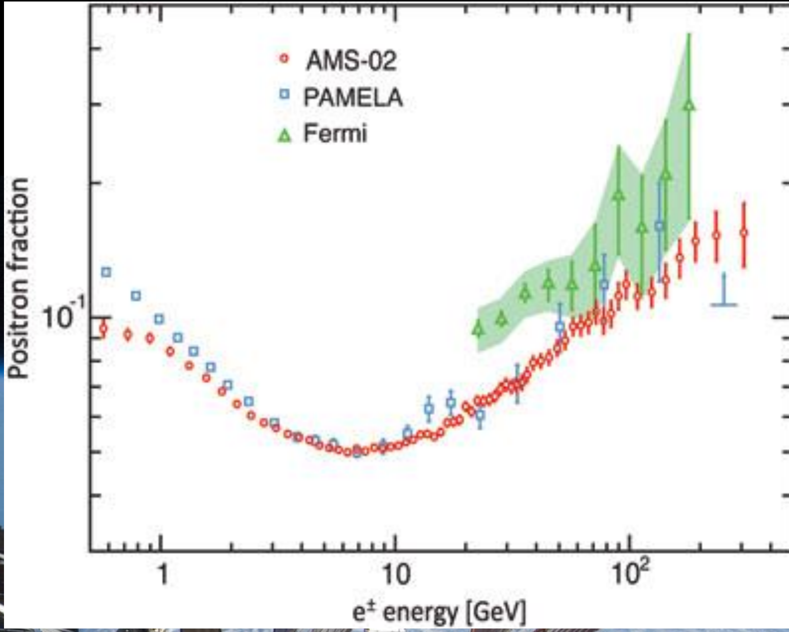
Indirect detection via DM annihilation in Sun, Earth, Galaxy
ν, γ-rays, anti-protons , positrons

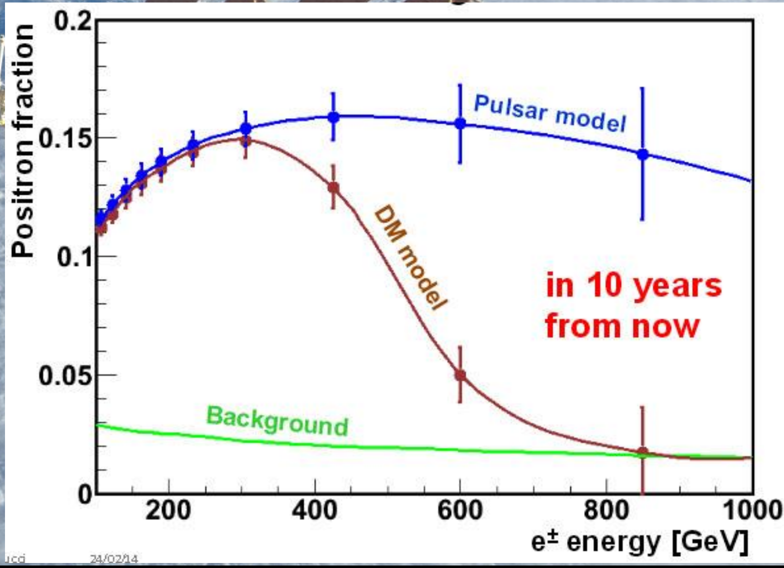
Direct detection in u/g laboratories

ALPHA MAGNETIC SPECTROMETER (AMS)

- Search for antimatter
- Since 2012 installed on ISS
- E.m. spectrometer 7.5t
- Supraconducting magnet 1m Ø
- Range 500 keV – 1 TeV

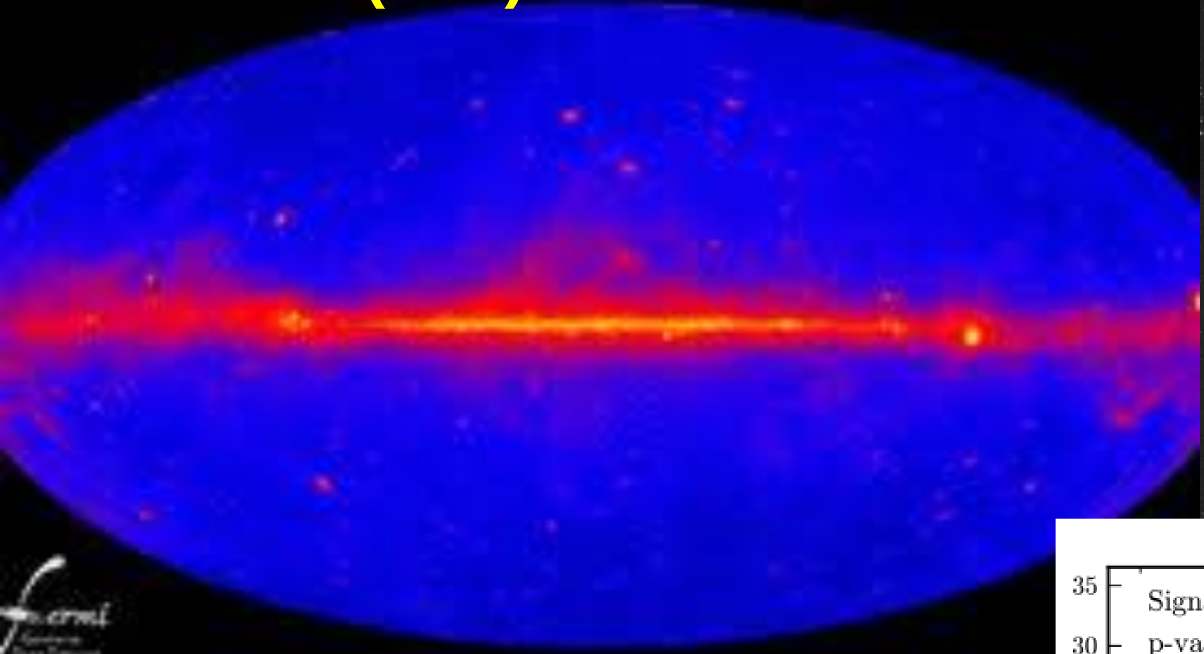






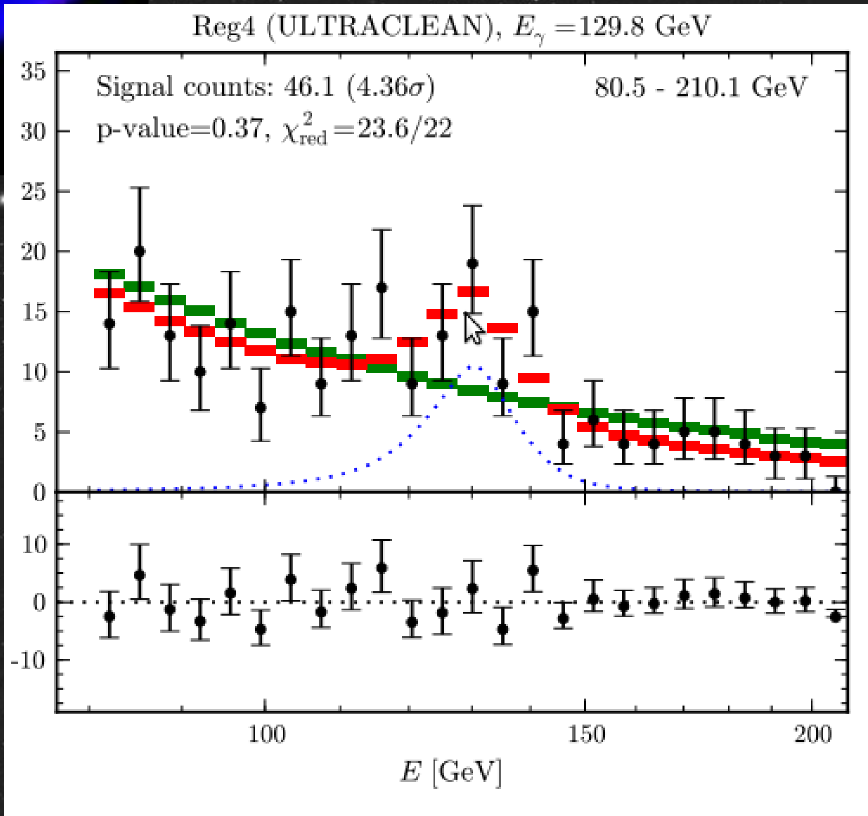
- April 4, 2013: excess of e^+ announced
- Rate slope decreases > 20 GeV
- implies a heavy DM WIMP
- or a new mechanism of acceleration in pulsars

FERMI (LAT) LARGE AREA TELESCOPE

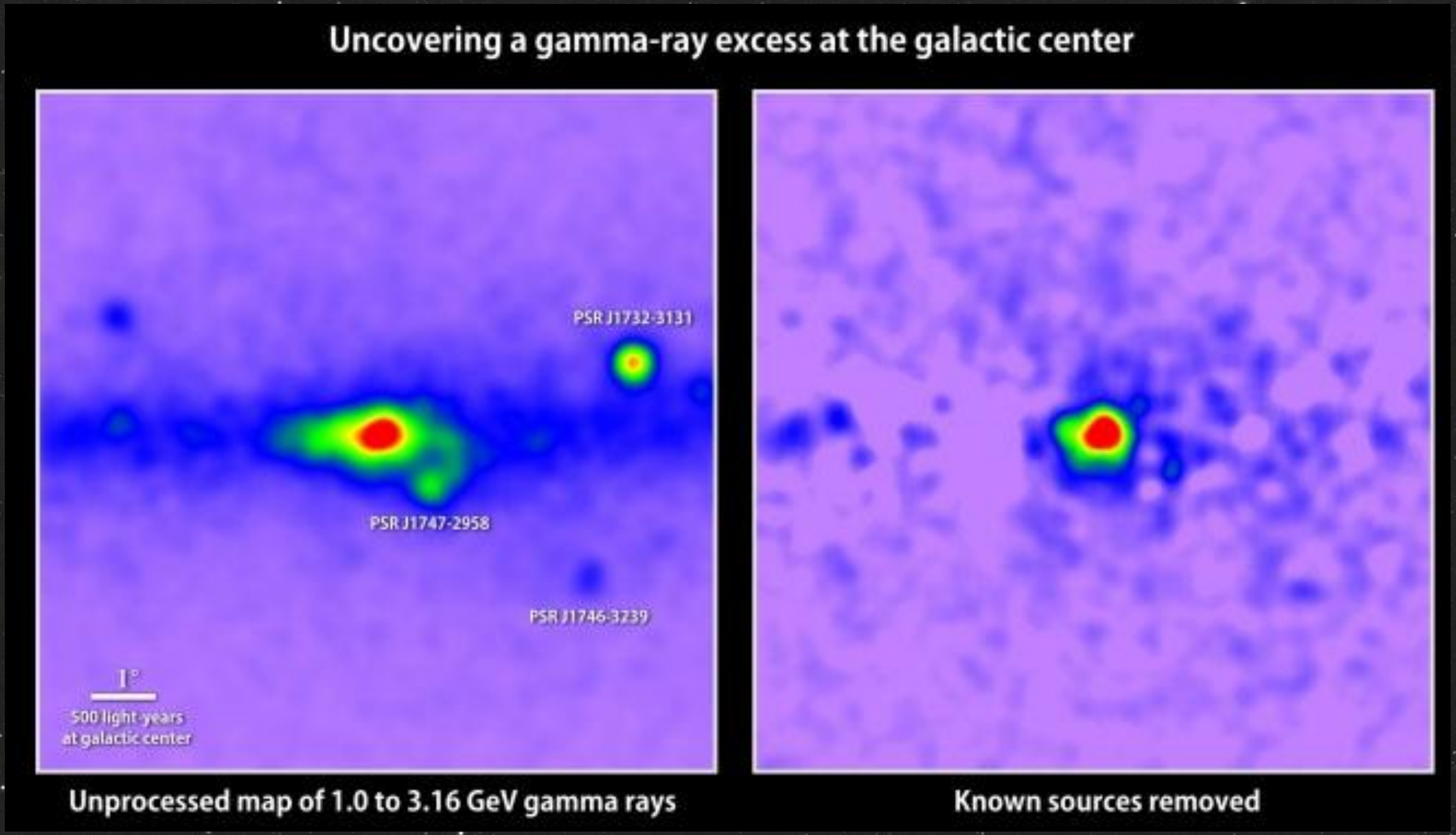


- HE γ-ray spectrometer
- Launched in 2008

- Nov. 2012 spike at 130 GeV -> gal. center
- Reanalysis: CR induced γ's in earth atm. ?
- Larger systematic uncertainty $\rightarrow$ no significant feature (2013)



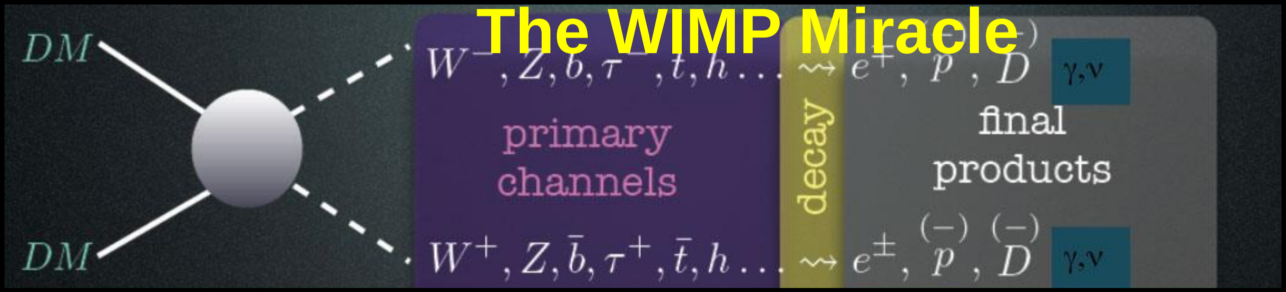
FERMI (LAT) LARGE AREA TELESCOPE

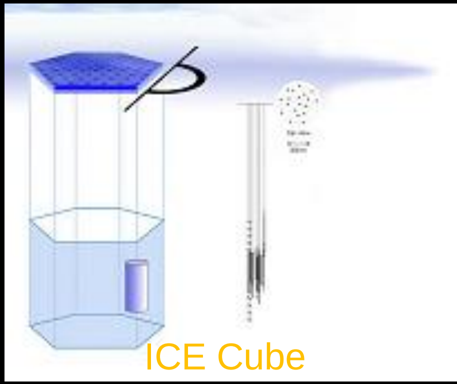


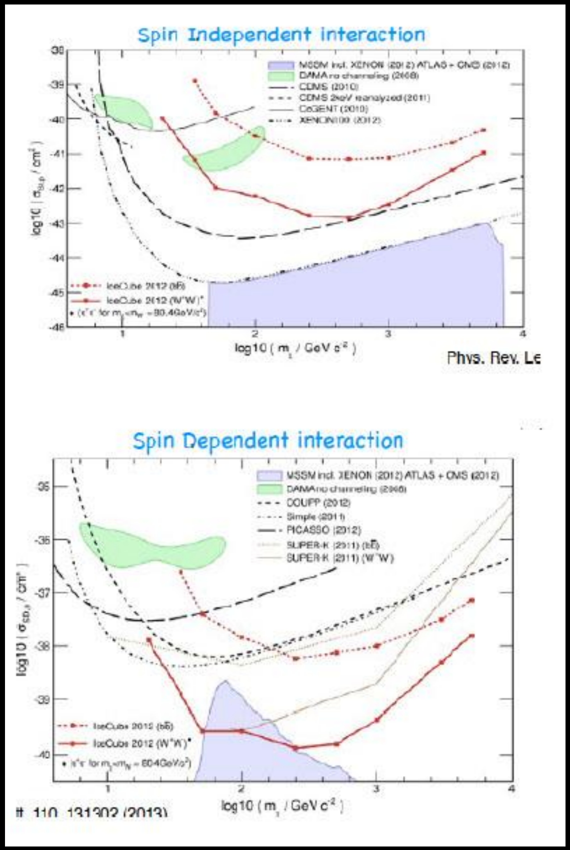
- γ rays peaked at gal. center with 7-12 GeV
- Consistent with thermal relics
- Emission distributed $\rho \sim r^{-1.3}$
- Spectrum not consistent w. msec pulsers and other backgrounds

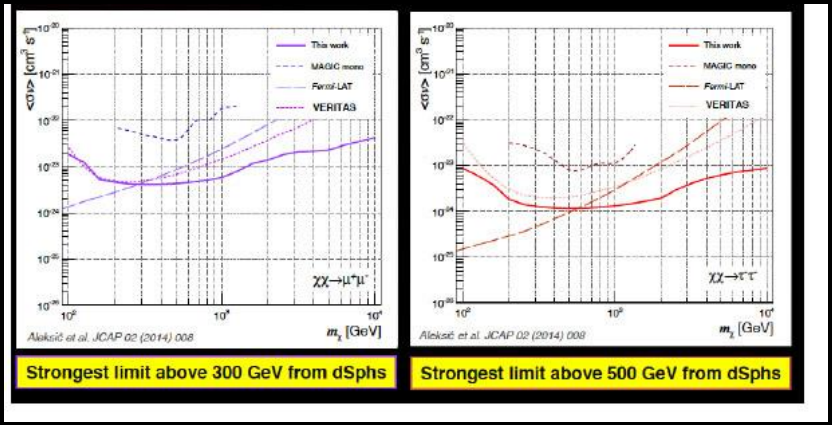
D. Hooper et al.; arXiv: 1110.0006

ICECUBE - MAGIC- HESS-VERITAS
The WIMP Miracle



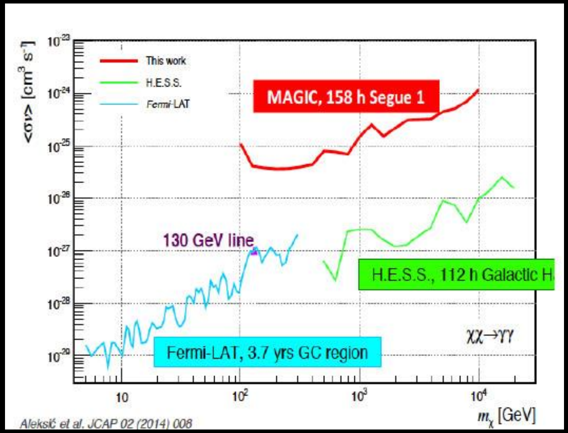






$\chi\bar{\chi} \to \mu^+\mu^-$

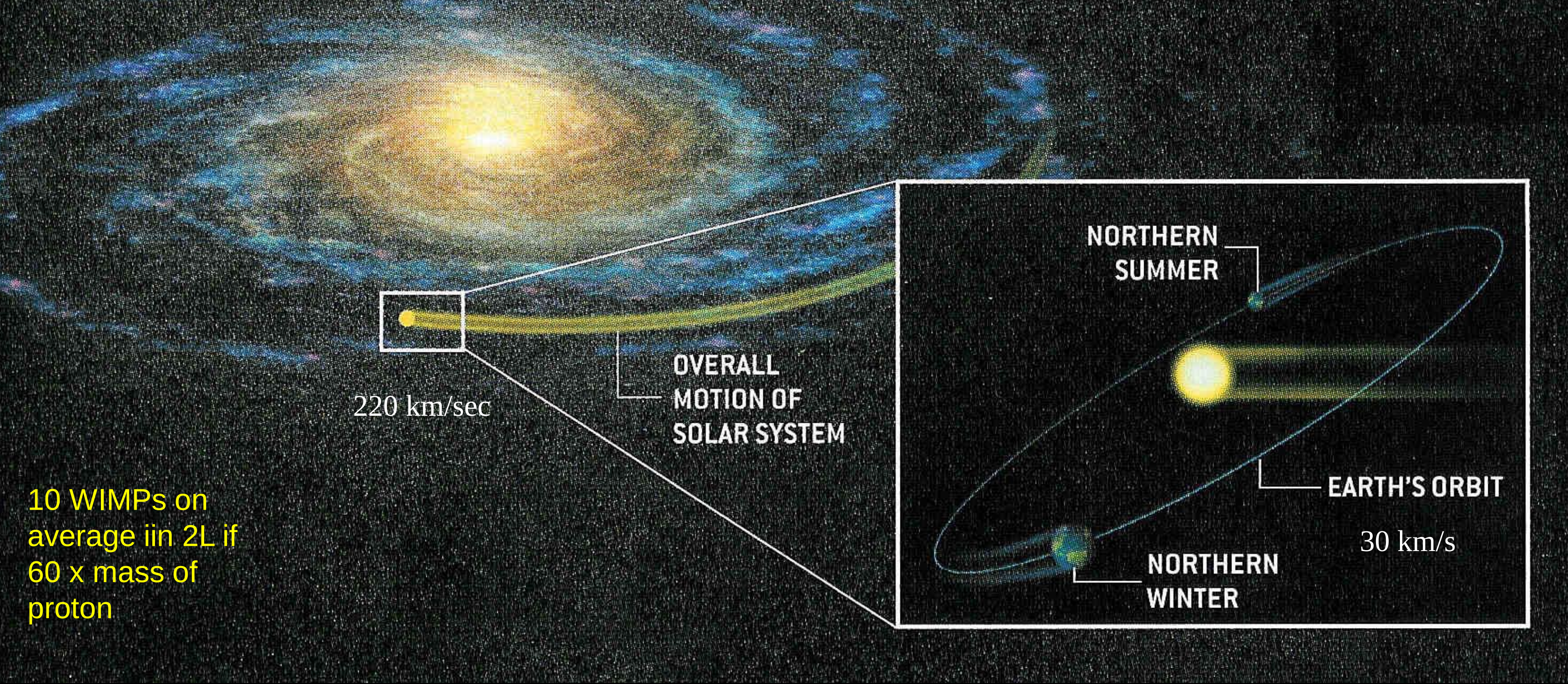
$\chi\bar{\chi} \to \tau^+\tau^-$



$\chi\bar{\chi} \to \ldots \nu\bar{\nu}$

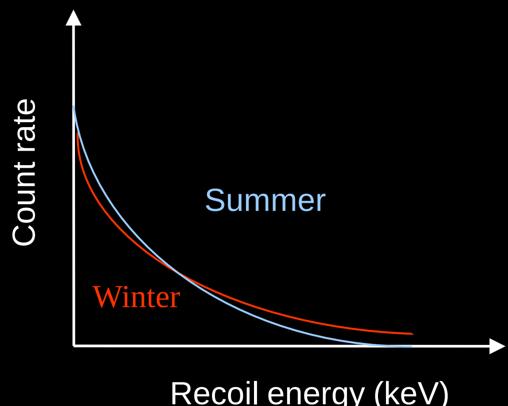
$\chi\bar{\chi} \to \gamma\gamma$

Direct Detection of DM Particles



10 WIMPs on average iin 2L if 60 x mass of proton

~ 10^9 particles traverse us on earth per second!

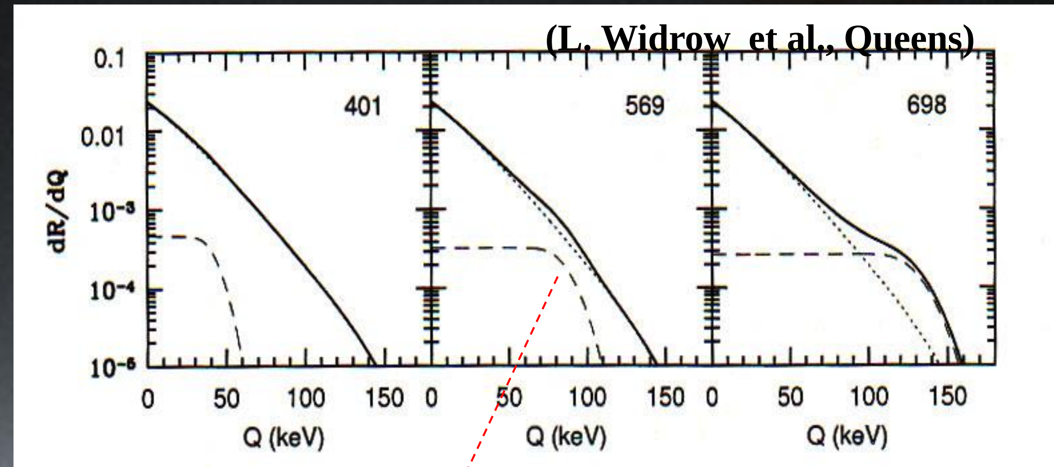


- Recoil energies: < 100 keV (10^{-7} E_{kin} (fruit fly)
- Rates: << 0.1 count /kgd
- Annual rate modulation ≈ 5 – 7%

A. Drukier, K. Freese, Spergel PRD 33(86)3495

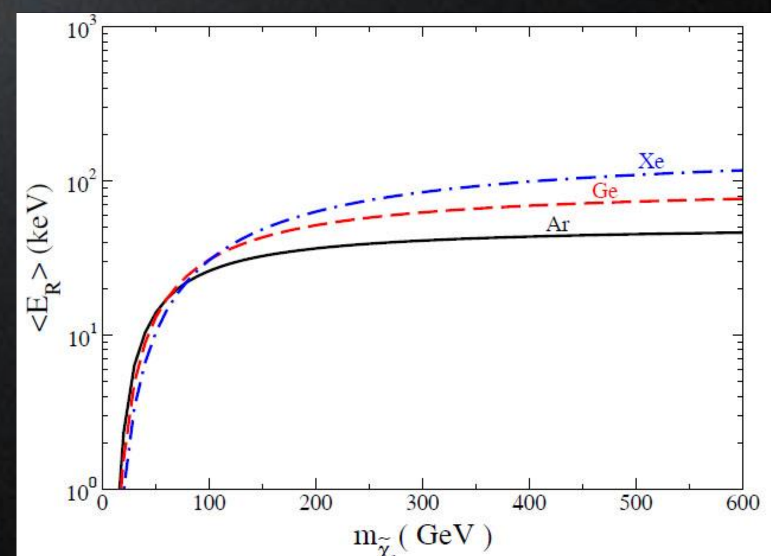
RECOIL SPECTRA & RATES

$$\frac{dR}{dE_r} = C \cdot \exp\left(-E_r \big/ \langle E_r \rangle\right)$$



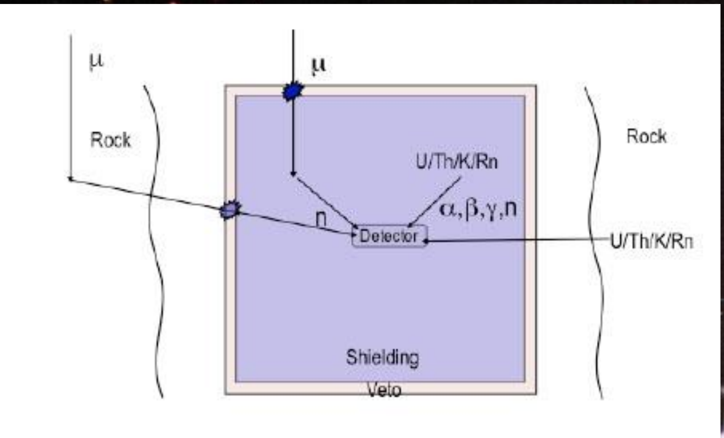
Extragalactic stream

$$\langle E_r \rangle \approx 2 \cdot \left(\frac{M_N}{1GeV}\right) \cdot \left[\frac{M_\chi}{M_\chi + M_N}\right]^2 [keV]$$



Could “measure” WIMP mass with several targets!

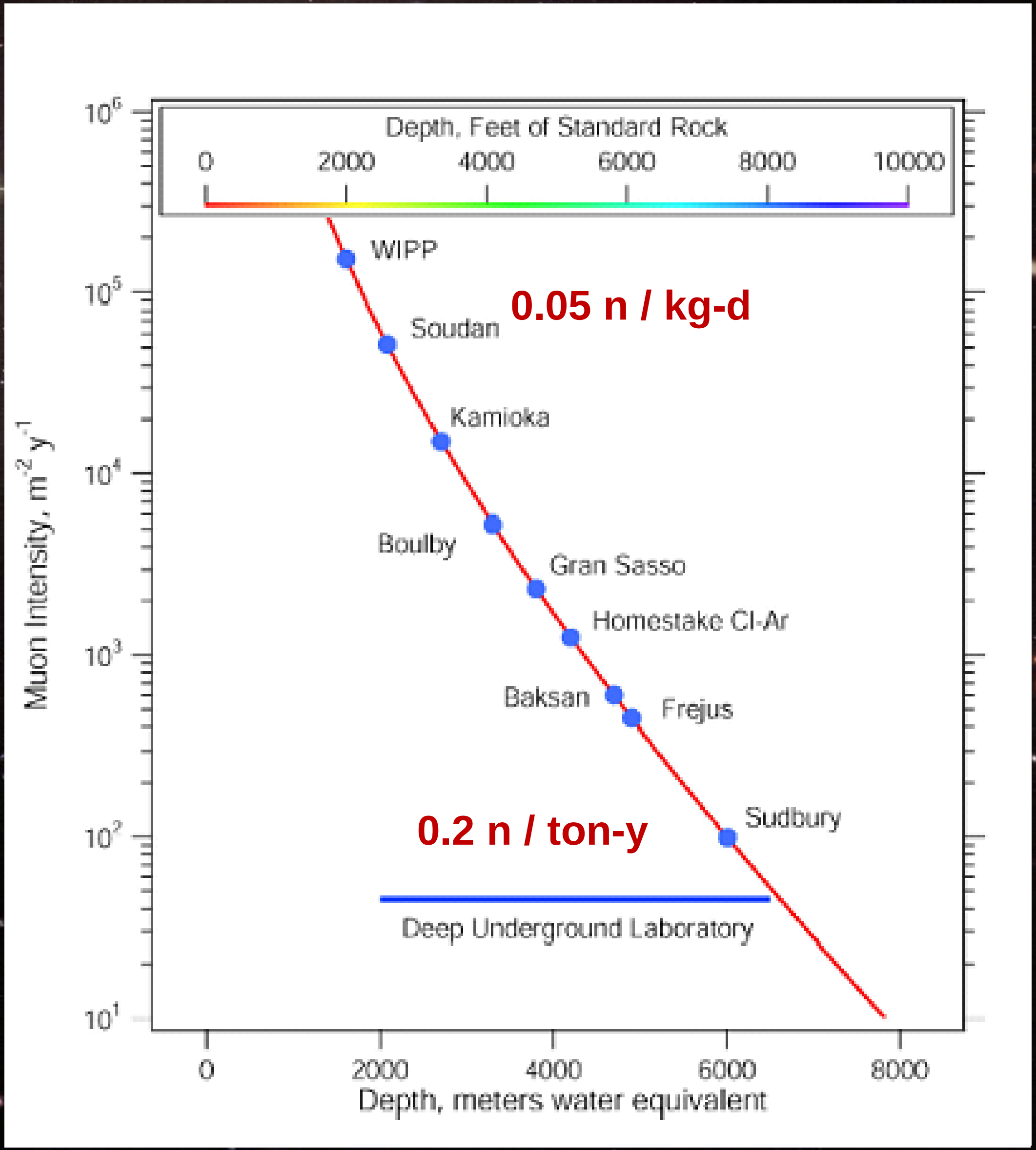
BACKGROUNDS



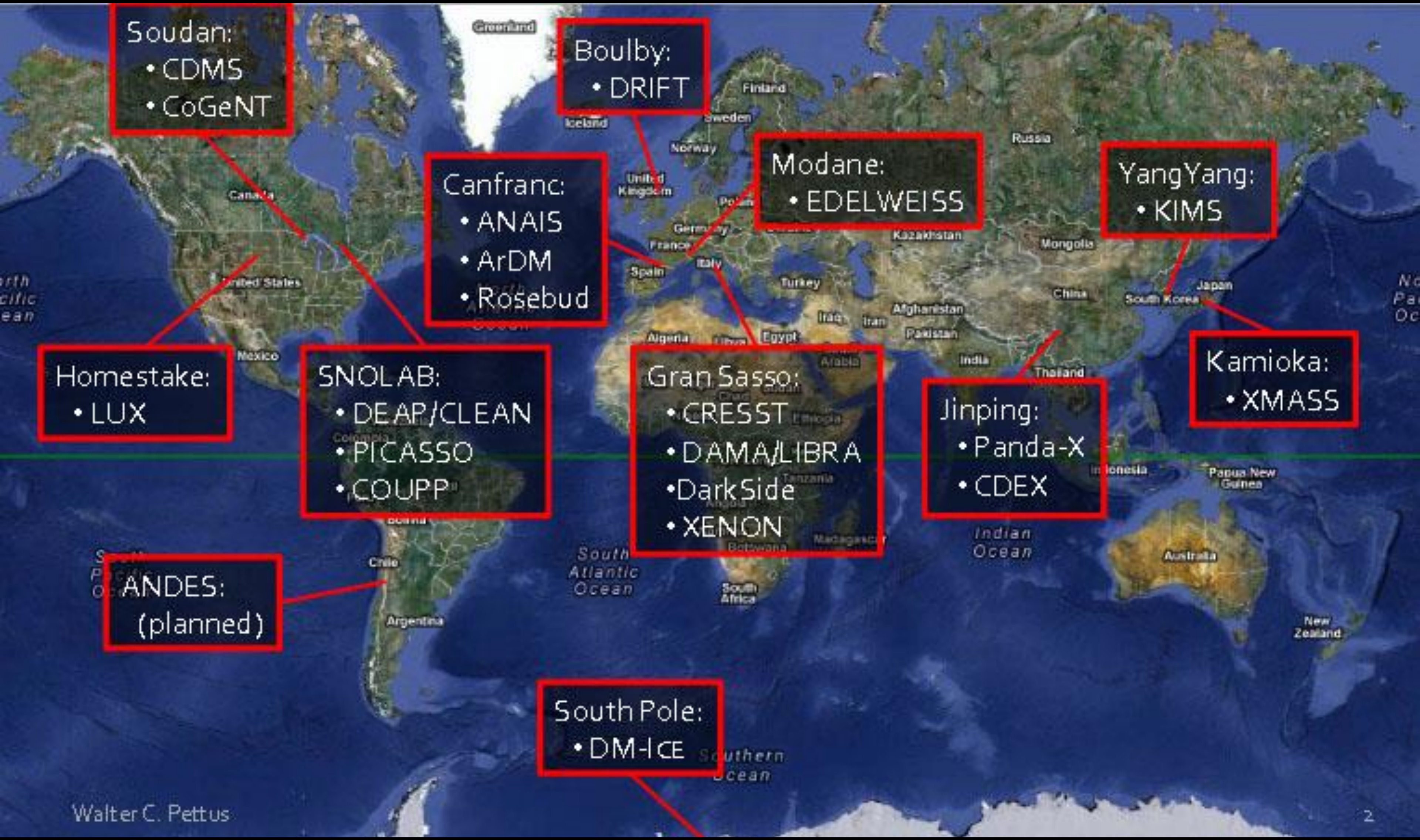
Neutron- production by

- **μ spallation in det. material**
- **det. shielding, rock**
- **U/Th (α,n) reactions in rock**
- **In det. material (<< 1ppb U/Th required)**

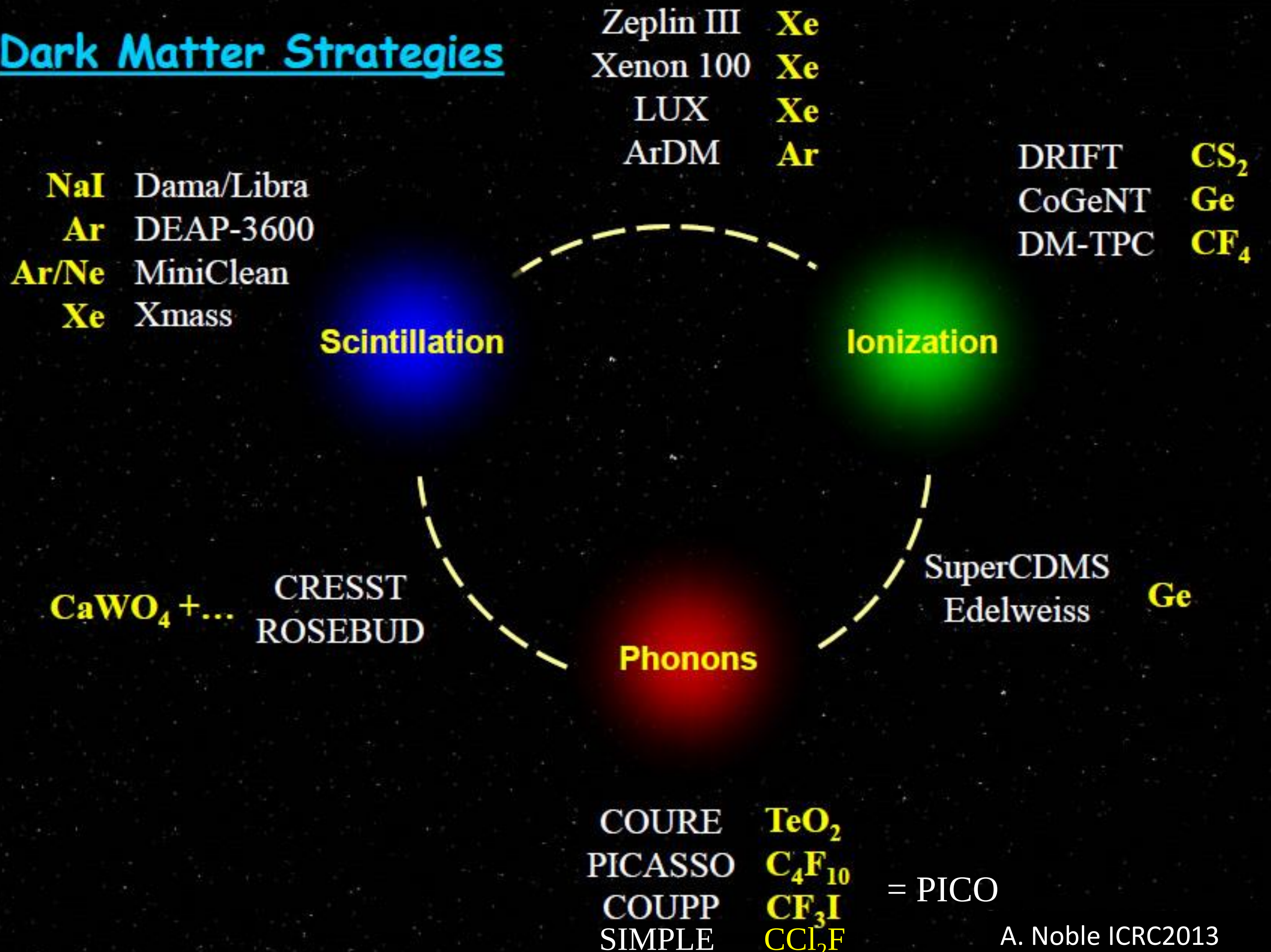
1 ppb ~ identify 1 person on the earth!



(Incomplete) Summary of Detection Activities

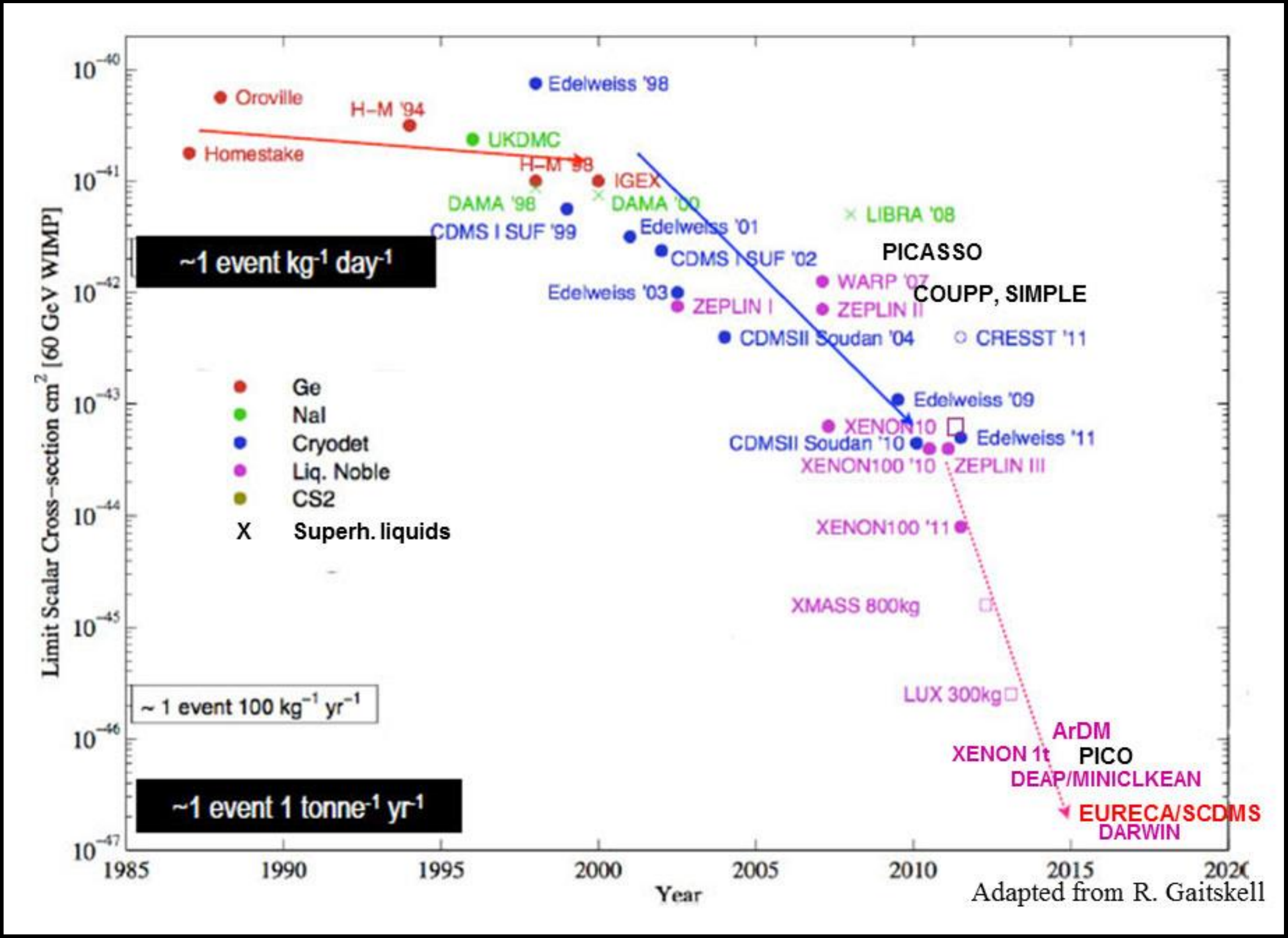


Dark Matter Strategies



RATES & LIMITS

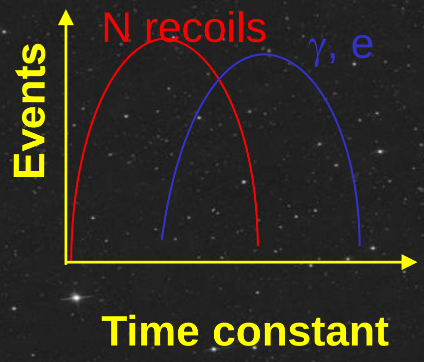
$$R_0 \cong \frac{403}{A}\left(\frac{GeV}{M_\chi}\right)\left(\frac{\rho_\chi}{0.3\ GeV/cm^3}\right)\left(\frac{\langle v_\chi \rangle}{230\ km/s}\right)\left(\frac{\sigma_A^{SD,SI}}{pb}\right)\frac{counts}{kg \cdot day}$$



SCINTILLATING CRYSTAL DETECTORS

Principle:

- crystals (NaI, CsI), Liquids (Xe, Ar, Ne, CaF_2(Eu)) emit light if hit $\propto$ radiation
- light collected by photo multipliers ($\varepsilon \sim 15\%$) or photo-diodes
- ΔE / photon ~ 15 eV
- light gain ~ 2-8 phe/keV



Background rejection:

- different pulse shape (time constant) for nuclear recoil or e, gamma induced events

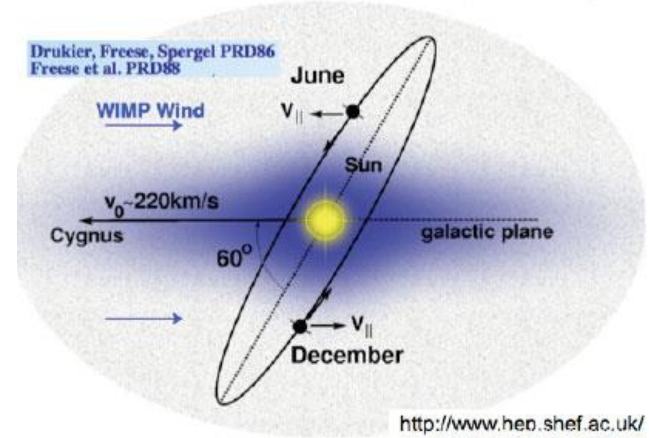
Experiments:

DAMA/LIBRA, NAIAD, ANAIS (250 kg NaI), KIMS (100 kg CsI),

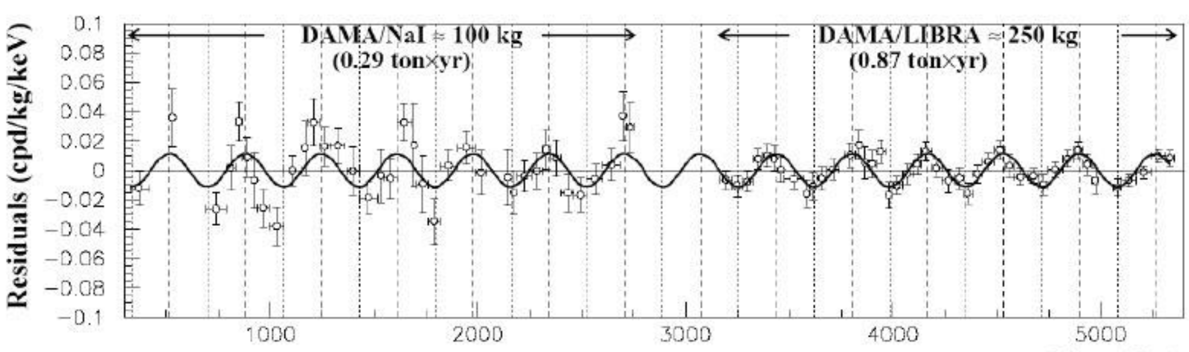
DM-ICE (17 kg NaI), AMORE (NaI)

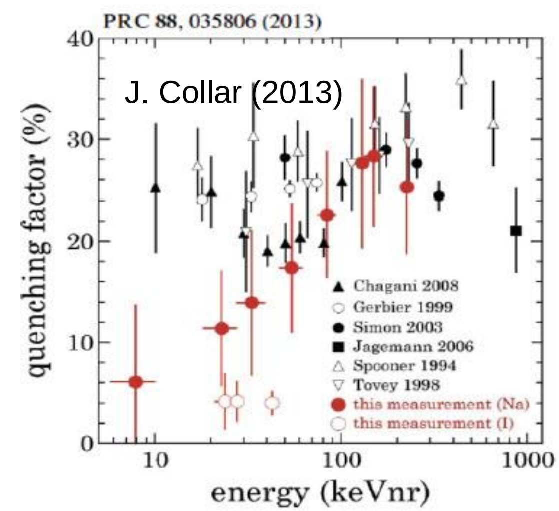
DAMA / LIBRA NaI (Gran Sasso)

- 250 kg of NaI crystals
- 13 annual cycles show a modulation at 8.9σ
- period T=1.00 $\pm$ 0.01 y; A = 0.0195 $\pm$ 0.003 cts/kg/d/keV
- modulation at low energies 2-6 keV
- total exposure 1.17 ton y
- **Signal: $M_\chi \sim 10 - 50$ GeV/c^2; $\sigma_{SI} \sim 10^{-6}$ pb**



R. Bernabei et al.; PLP 24(1998) 195, R. Cerulli, IDM2012





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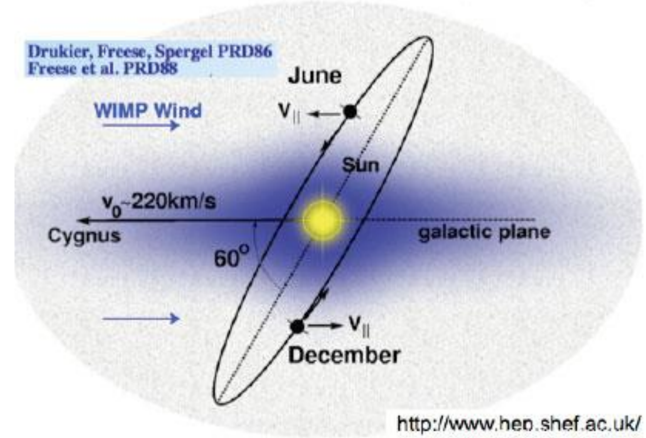
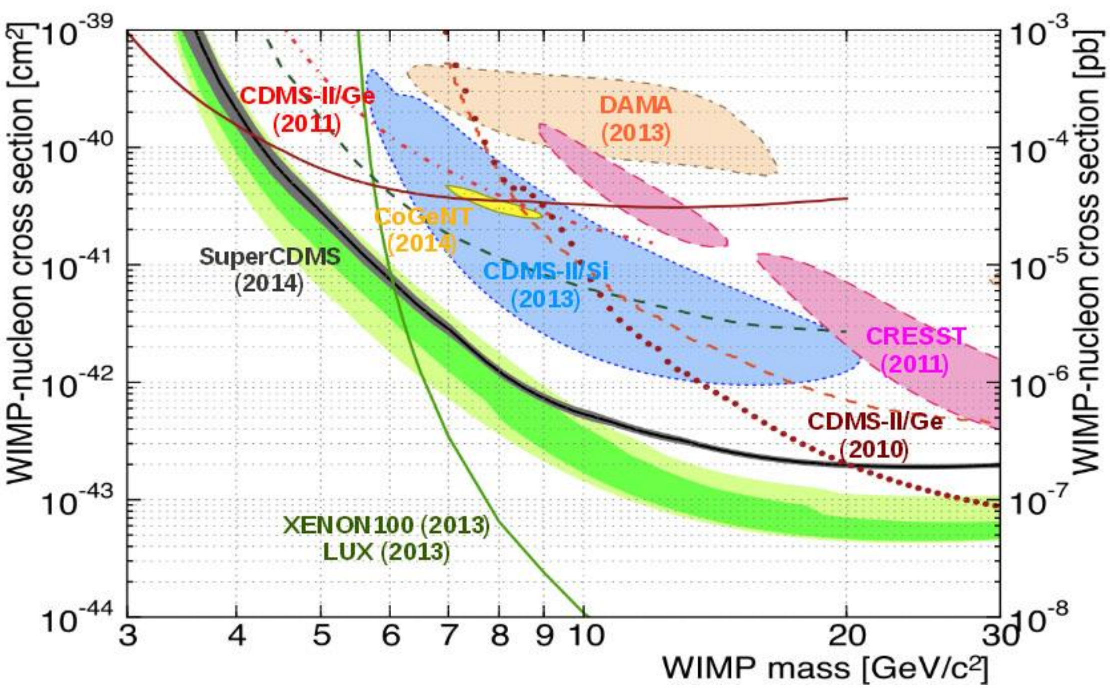
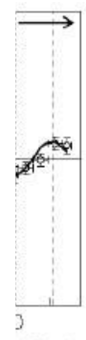
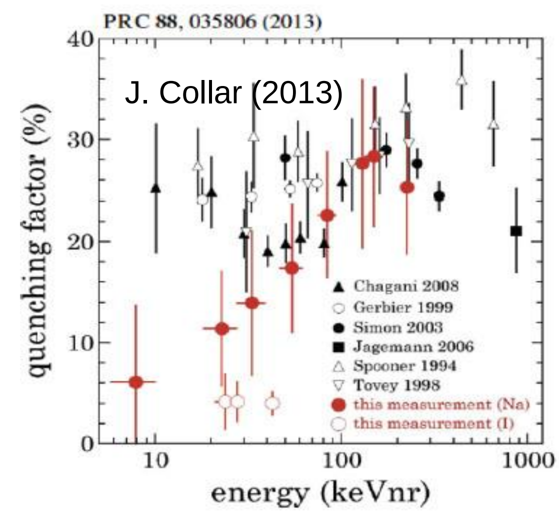


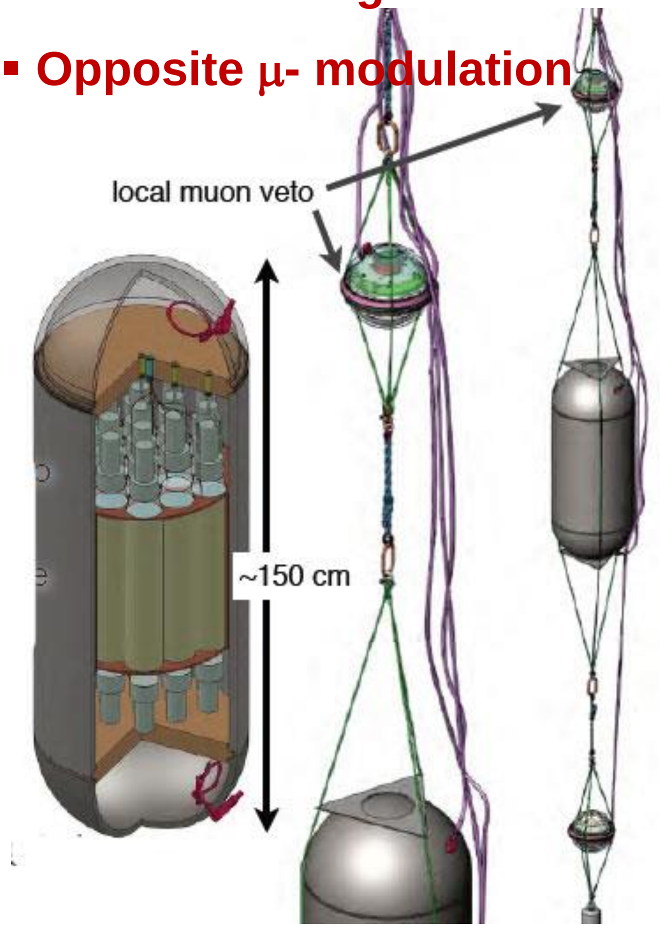


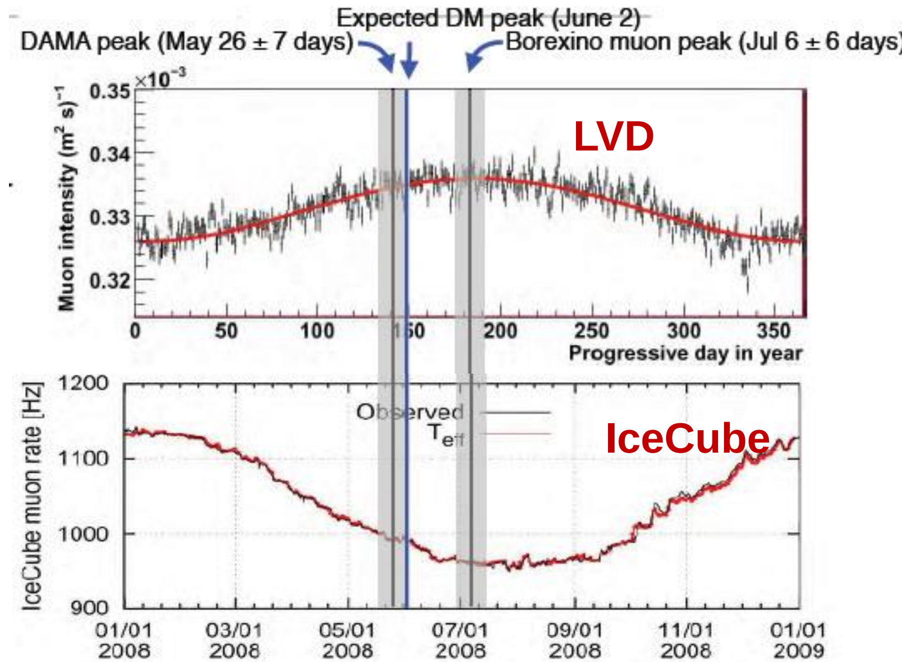




DM - ICE (South-pole)

- **Same detector as DAMA**
- **Addressing diff. systematic effects**
- **Different background**
- **Opposite μ- modulation**





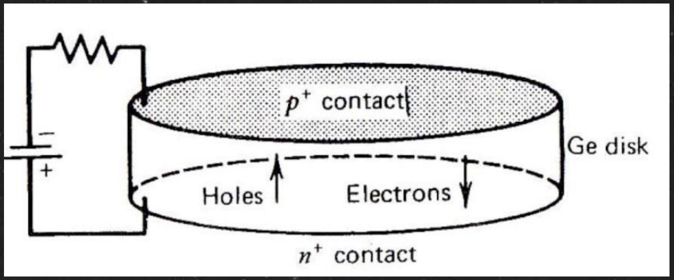
- 17 kg of Na(Tl) part of NaIAD (since 2011)
- 2500 m depth in the ice
- Near the center of IceCube for additional veto
- Data transmitted by satellite
- **Analysis under way!!**
- Next 250 kg on Northern hemisph.

First data: arXiv:1401.4804

GE- IONISATION EXPERIMENTS

Principle:

- High purity Ge- crystals (LN_2 Temperature)
- ΔE / e^- -ion pair: 3 eV
- low threshold: 0.5 keV_{ee}
- Resolution: 3% @ 10 keV



Background rejection:

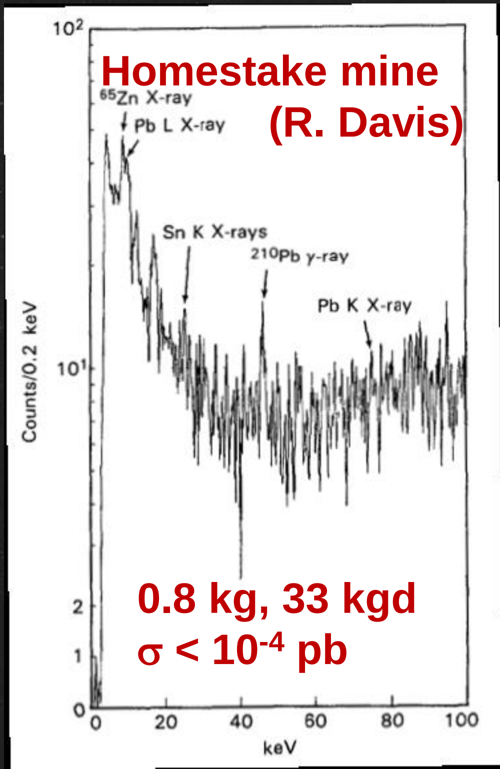
- high intrinsic purity
- anti-coincidence veto

Phys. Lett. B, 195 (1987)

First published limits

LIMITS ON COLD DARK MATTER CANDIDATES FROM AN ULTRALOW BACKGROUND GERMANIUM SPECTROMETER

S.P. AHLEN [a], F.T. AVIGNONE III [b], R.L. BRODZINSKI [c], A.K. DRUKIER [d,e], G. GELMINI [f,g,1] and D.N. SPERGEL [d,h]

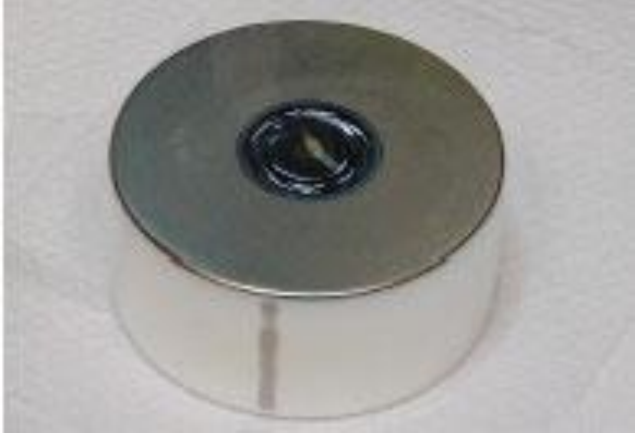


Homestake mine (R. Davis)

0.8 kg, 33 kgd
$\sigma < 10^{-4}$ pb

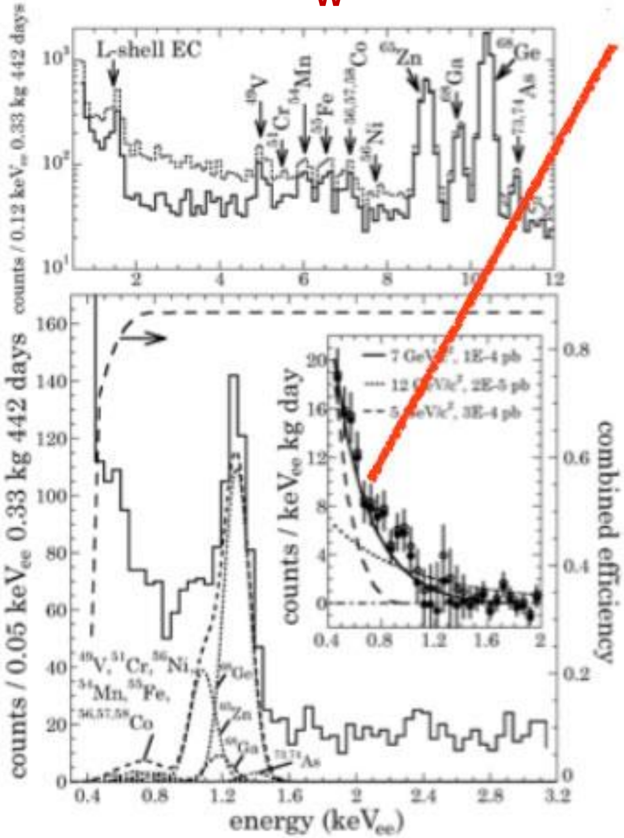
Experiments: IGEX, COSME, CoGENT, NeCaPSI, TEXONO, MALBEK…

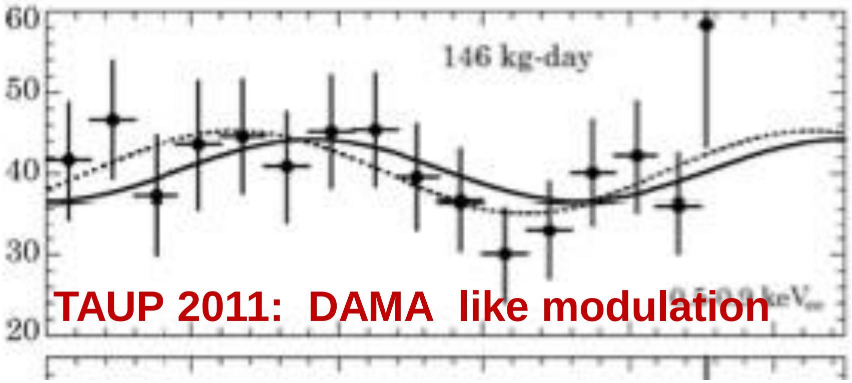
COGENT (SOUDAN-LAB)



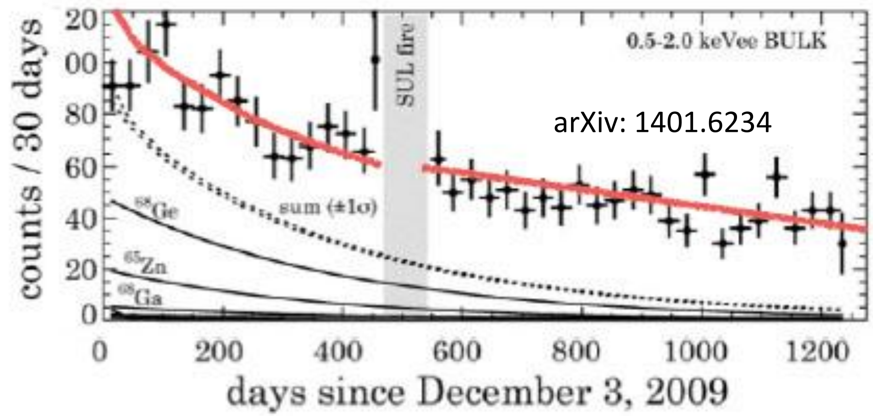
- Single 440 g HPGe crystal
- Point contact electrode: C↓ low noise
- Optimized for low E, low backg.
- Threshold @ 0.4 keV_{ee}

M_W = 7 GeV/c^2 spectrum!





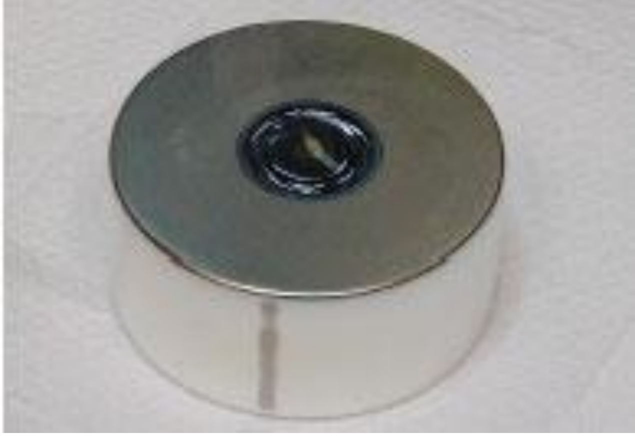
TAUP 2011: DAMA like modulation



arXiv: 1401.6234

Last 2 years of data appear flatter…

COGENT (SOUDAN-LAB)



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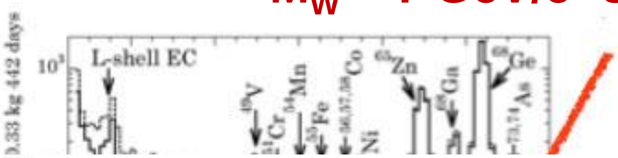
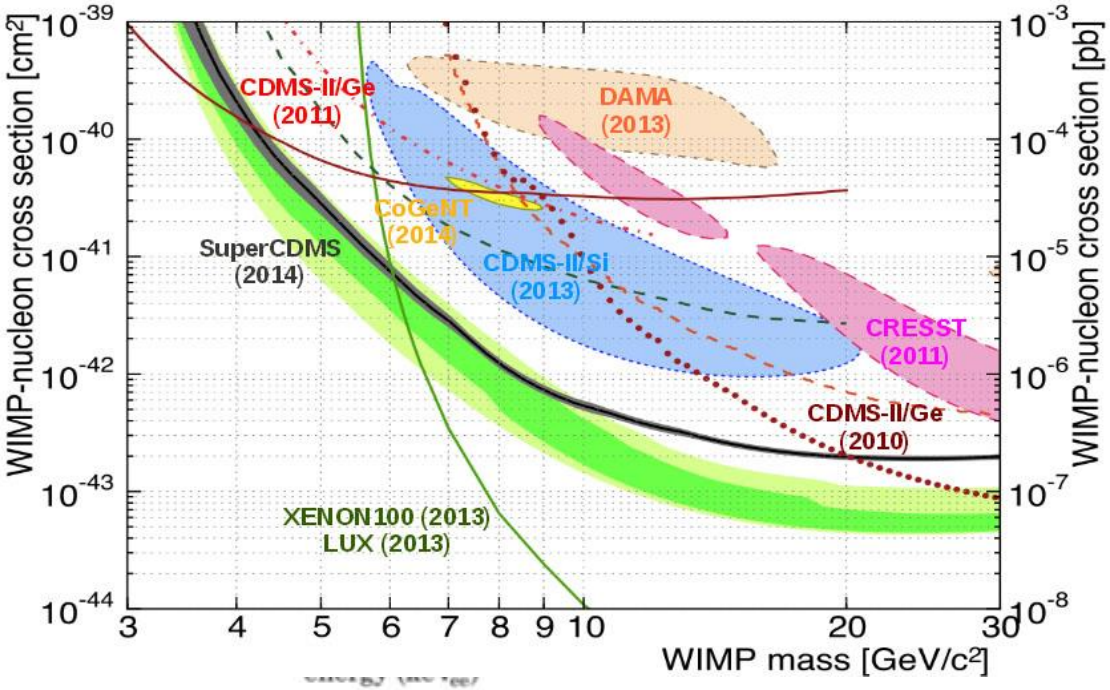
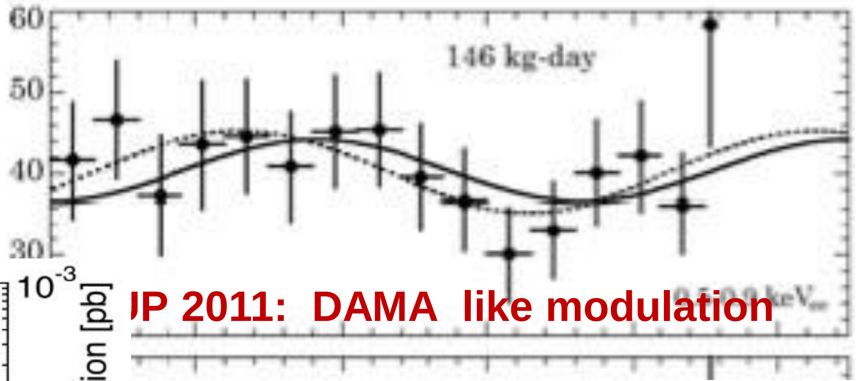
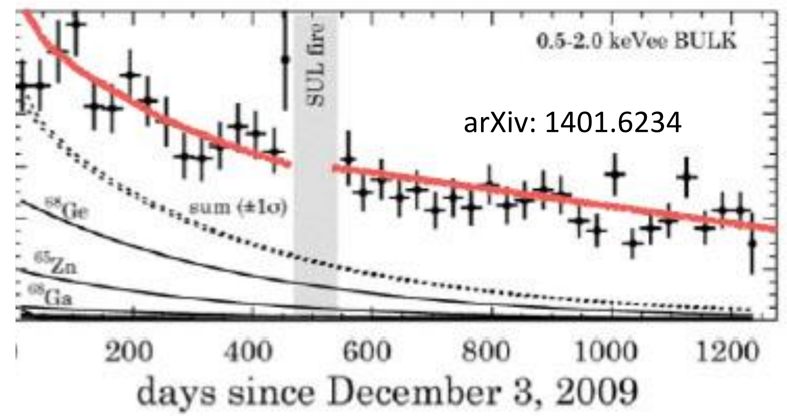






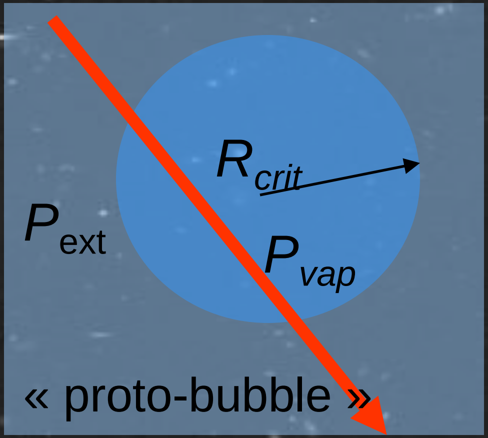
P 2011: DAMA like modulation



arXiv: 1401.6234

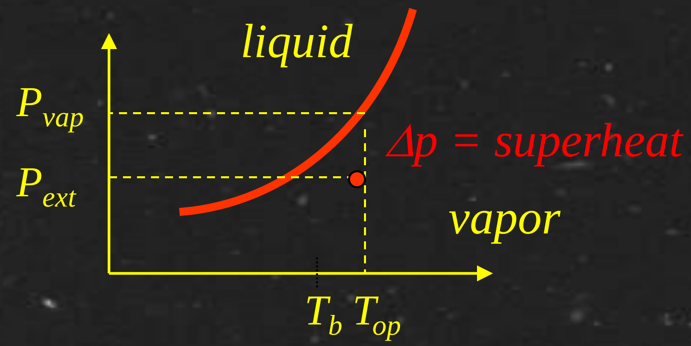
st 2 years of data seem flatter

SUPERHEATED LIQUIDS



Principle:

- Bubble chamber technique
- E_{th} ~ 1 keV for nuclear recoils
- full efficiency for nucl. recoils



$$E_{dep} = \frac{dE}{dx} \cdot R_{crit} \geq E_{\min}$$

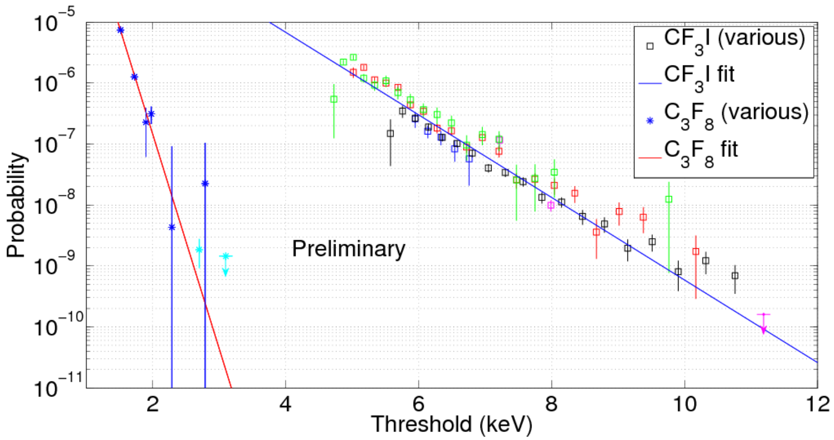
Background rejection:

- $dE/dx_{Bragg} \rightarrow$ discriminates recoil nuclei from γ, e, μ !
- gamma rejection better than 10^{10} at E_{rec}= 5 keV
- n rejected by multiple scattering

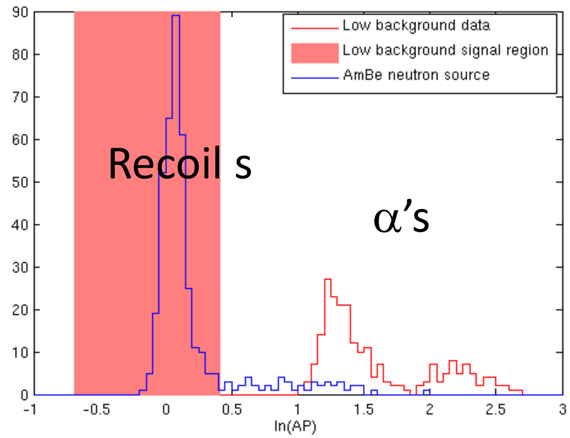
Experiments:

- SIMPLE, MOSCAB, PICASSO + COUPP = PICO

PICASSO – PICO at SNOLAB

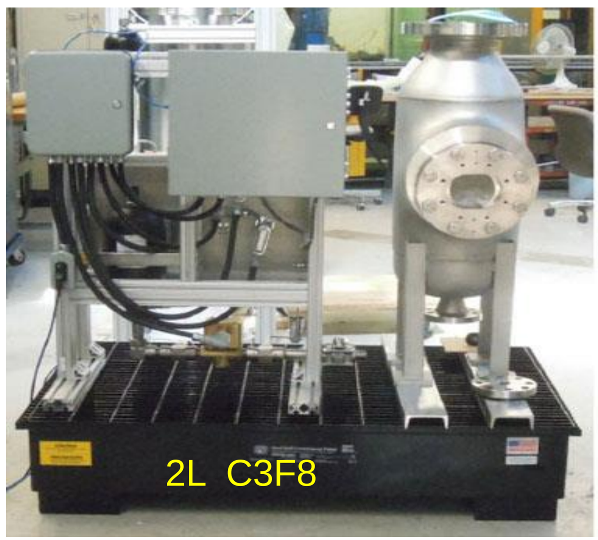


Excellent γ - discrimination



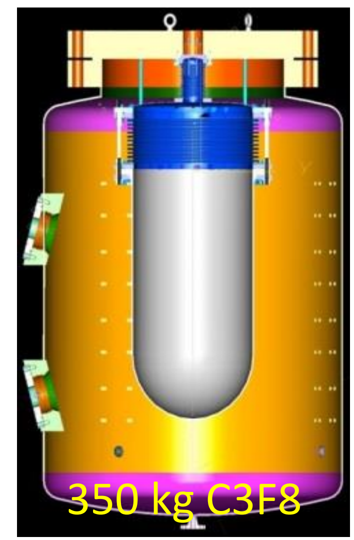
Acoustic α - recoil discrimination

PICASSO



PICO 2L

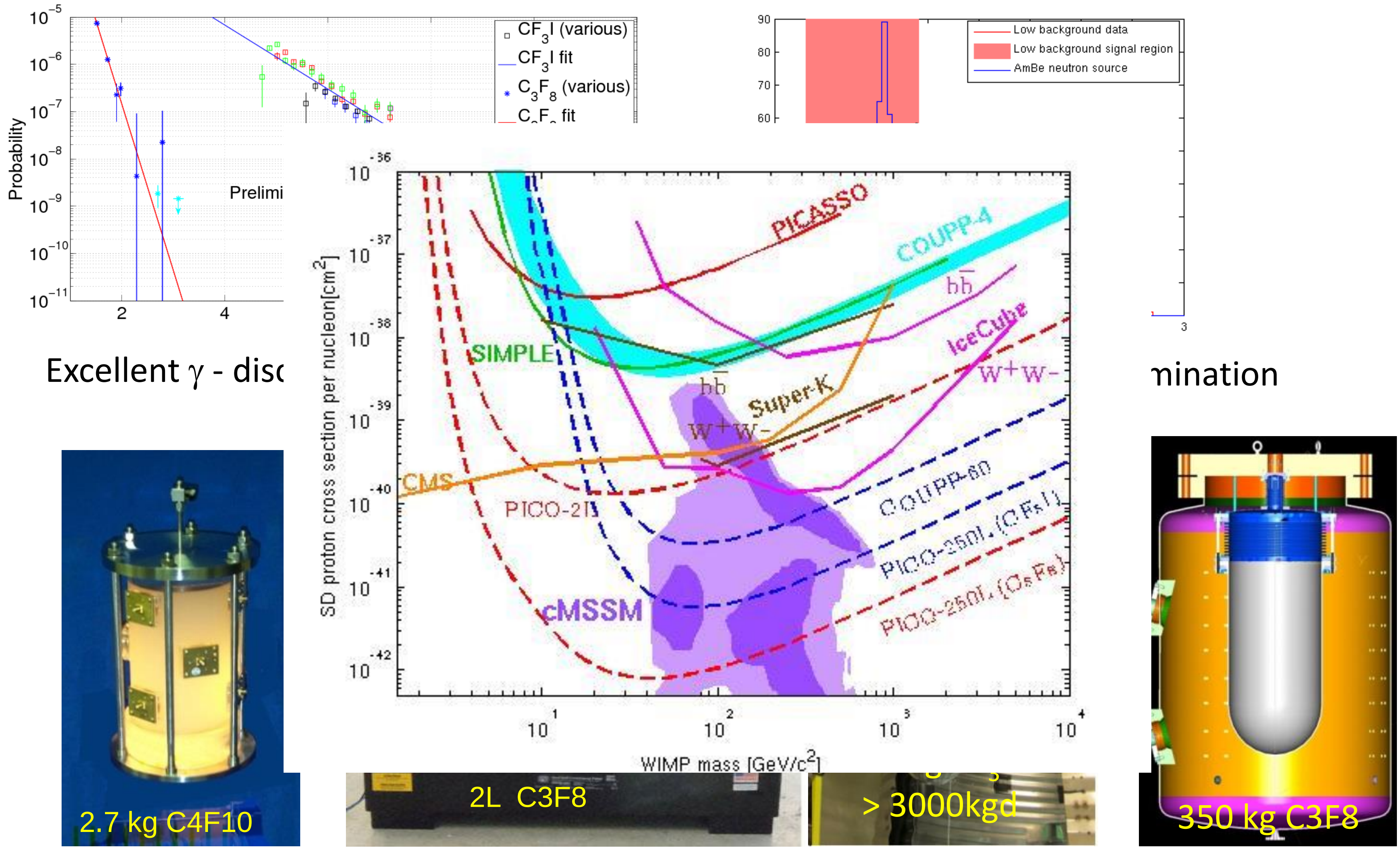
COUPP 60



PICO 250

→ talks by A. Robinson, C. Jackson, C. Amole, R. Podviyanuk, P. Mitra, M. Laurin

PICASSO – PICO at SNOLAB



PICASSO **PICO 2L** **COUPP 60** **PICO 250**

→ talks by A. Robinson, C. Jackson, C. Amole, R. Podviyanuk, P. Mitra, M. Laurin

LIQUID NOBLE GASES

Principle

- Single phase: LXe,LNe, LAr $\rightarrow$ scintillation
- Dual phase liquid /gas $\rightarrow$ scintillation + ionisation

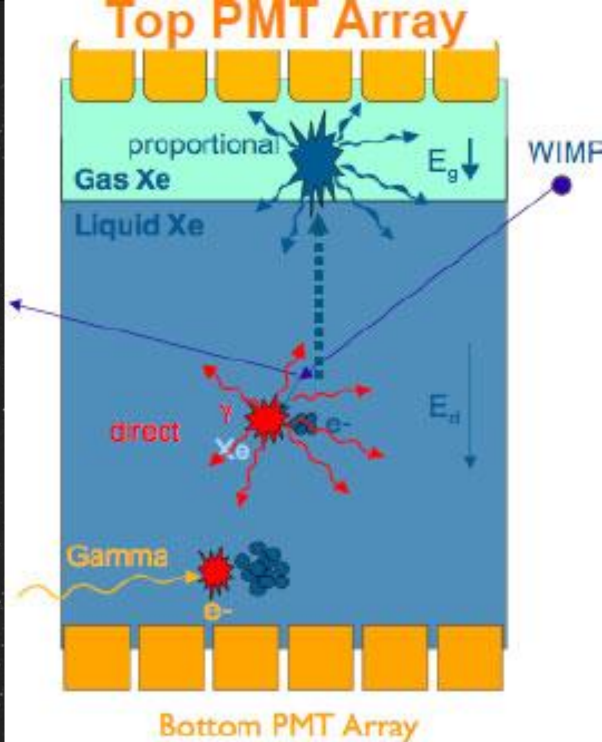
Background rejection:

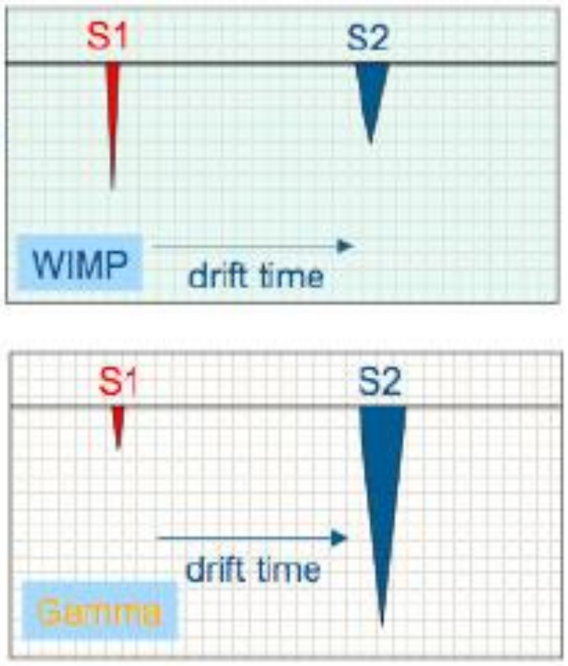
- pulse shape discrimination / single phase
- Xe^{*} +Xe recombination $\rightarrow$ UV γ (S1) 10:1 nuclear : electron
- double/phase: part of e^{-} drifted into gas phase
- sec. Ion. in strong field (10kV/cm) $\rightarrow$ delayed scint. γ's (S2)

Advantages:

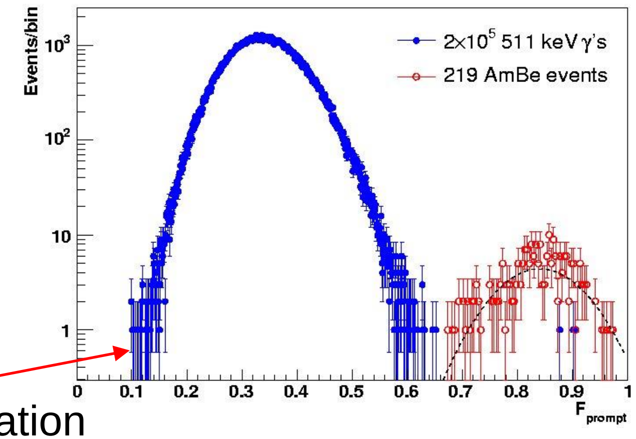
- large mass
- large A
- self shielding
- multiple n scatters
- Re-purification
- Good particle ID

Gas	Single phase	Double phase
Xenon	ZEPLIN I, XMASS	ZEPLIN, XENON, LUX
Argon	DEAP, CLEAN	WARP/ DarkSide, ArDM
Neon	CLEAN	SIGN

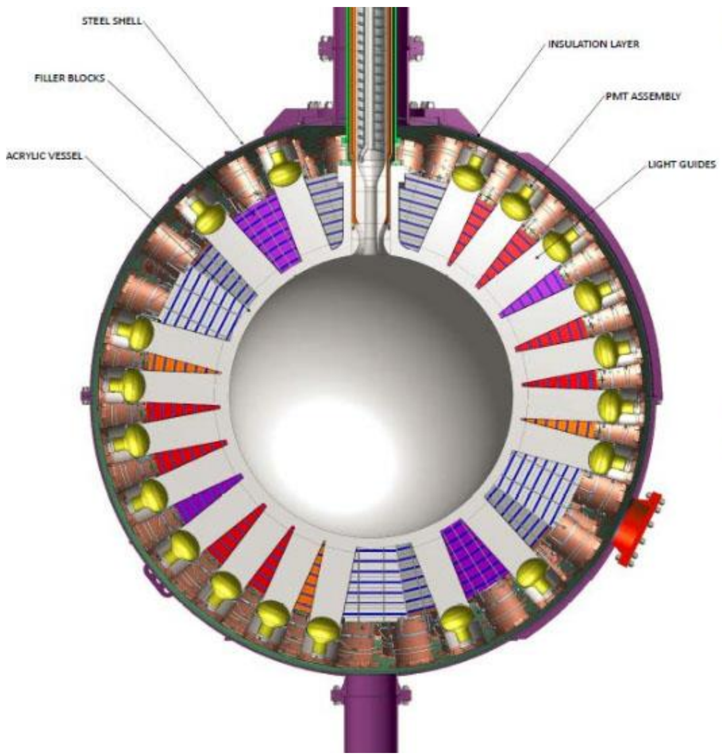




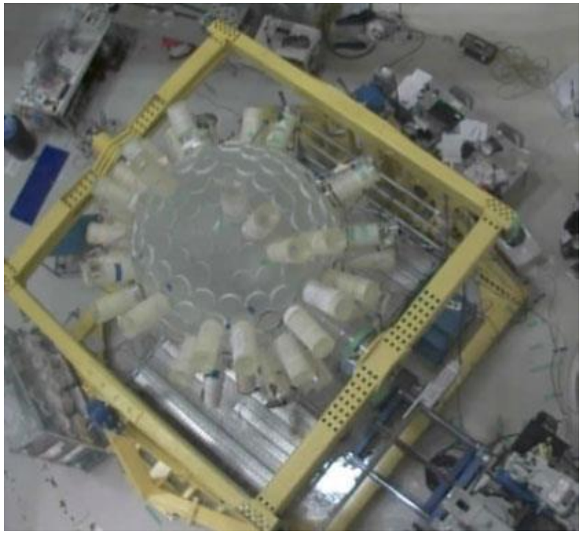
DEAP 3600 (SNOLAB)



- Detects scintillation light in LAr at 85K
- Threshold ~ 60 keV_r
- Excited dimers of Ar^*_2 in singlet/ triplet states
- Different lifetimes and S/T fraction depending on ionisation
- Designed for 10^9 PSD and 0.2 bkgd. /ton-year



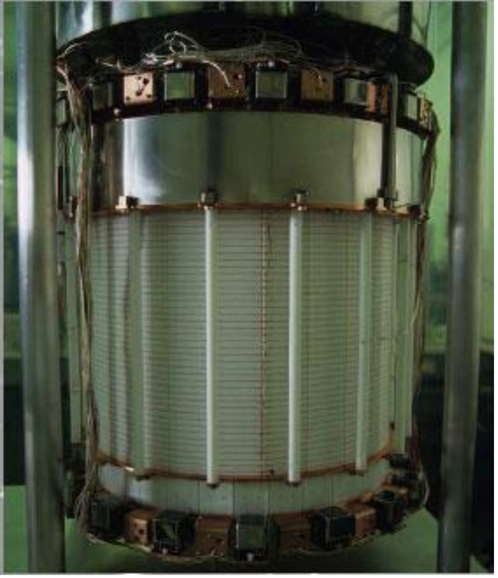
- 3600 kg LAr, 1000 kg fid.
- 50 cm light guides
- 253 PMT's →75% coverage
- Resurfaced in situ (Rn)
- Vessel inside 1 μm TPB WLS
- Detector in 8m water shield



Installation under way

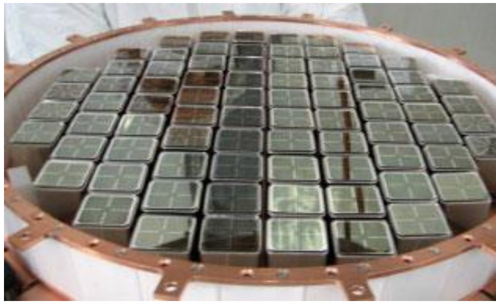
→ talks by A. Hallin, J. Bonat, P. Pasuthip


DEAP-3600
MiniCLEAN
• Under assembly
• 360 kg LAr
• 39Ar spike
• Later LNe
Courtesy F. Duncan



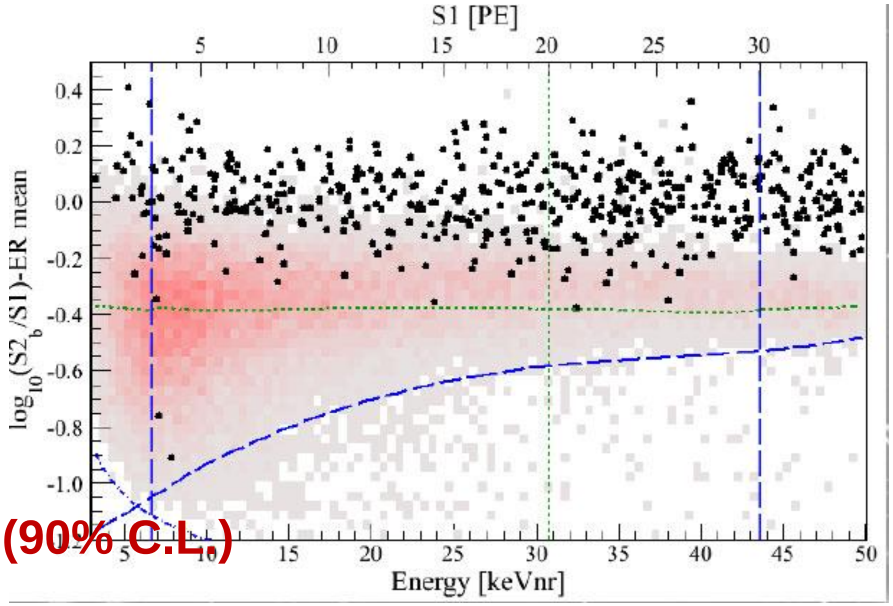
XENON 100 (Gran Sasso)

- 30 cm drift x 30 cm ∅ TPC
- 162 kg LXe (A=131)
- 241 1” PMT
- LXe veto around
- Kr: 19 ppt



2012 Results :

- Fid. Vol. 34 kg 224 days
- 2 events observed after unbldg.
- 1 ± 0.2 expected
- no events below threshold

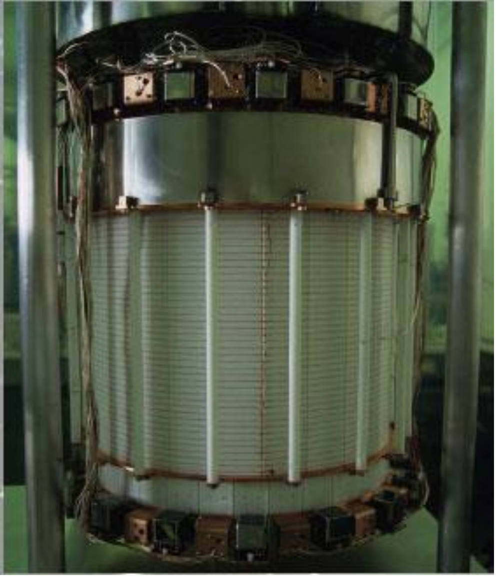


Upper limit: 2×10^{-9} pb for 55 GeV/c^2 (90% C.L.)

Continue data taking → 2014

Xe 1t commissioned May 2014

→ Scott Oser’s talk!



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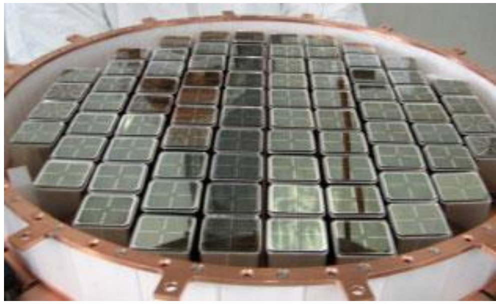

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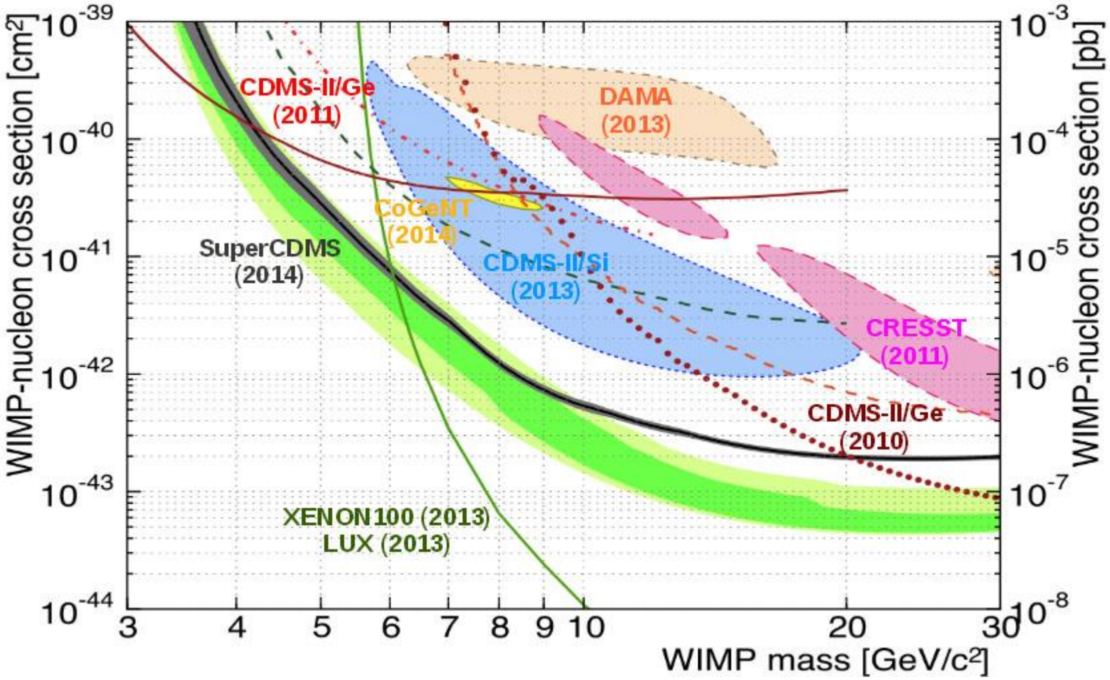
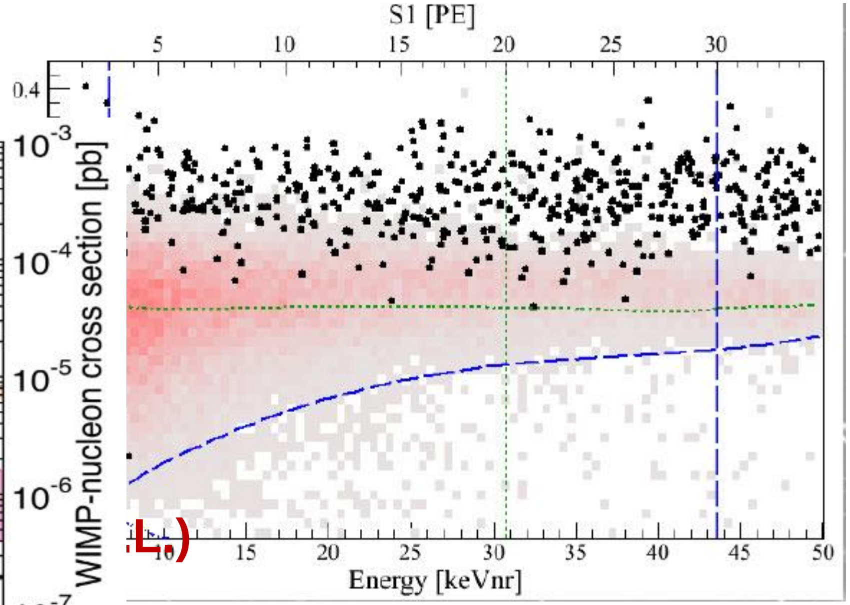




→ Scott Oser’s talk!

LUX at SURF (HOMESTAKE)

• 300kg LXe

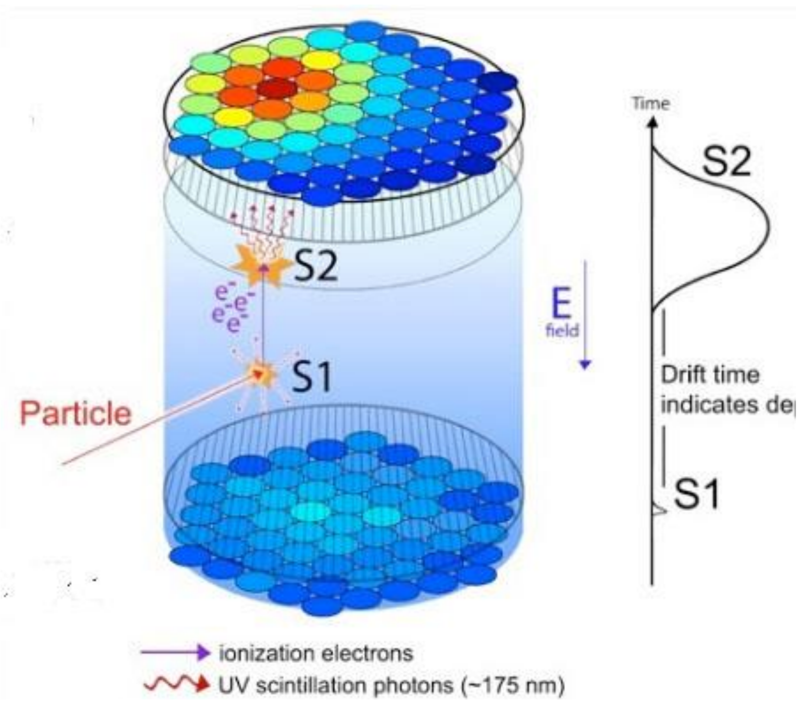
• Two phase detector

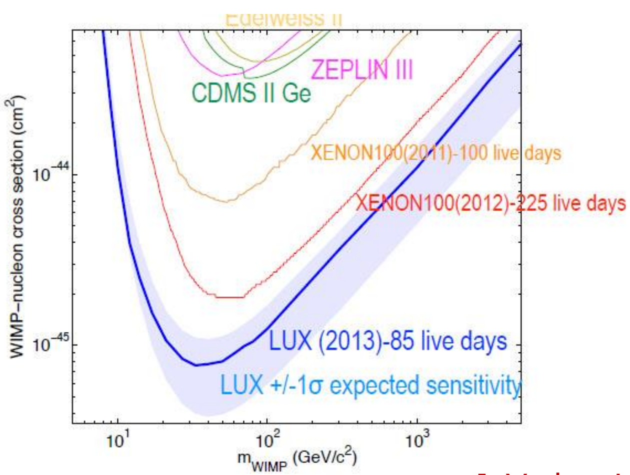
• Z- position from S1-S2 timing

• 3D imaging (mm resolution)

• Gamma,n background red. By self shielding

• Beta - gamma rejection > 99.5%



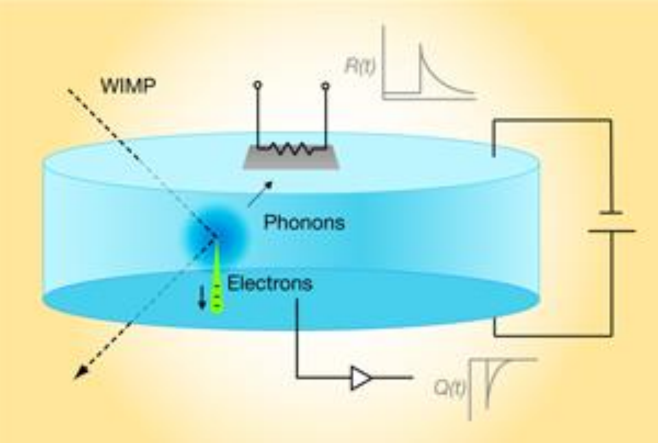


J. Verbus LLWI 2014

- Light WIMPS ruled out
- next LZ 6t fid.

→ Scott Oser's talk!

CRYOGENIC EXPERIMENTS

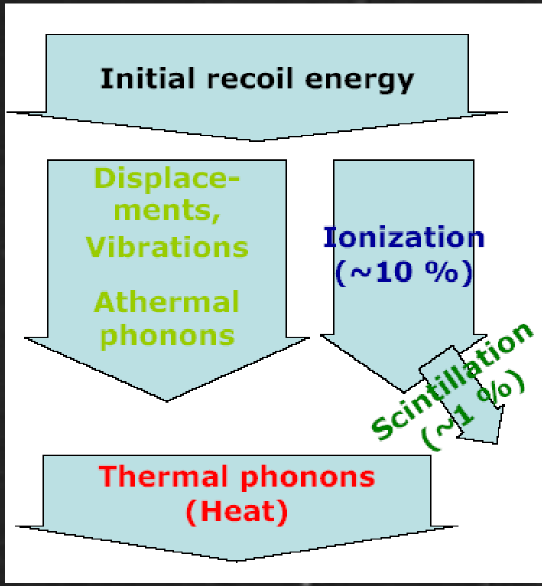


Principle:

- Crystals (Al_2O_3, Ge, Si, $TeO_{2)}$ $CaWO_4$ at sev. mK
- Particle interaction produces ionisation + phonons (heat)
- Energy per phonon ~ meV → FWHM 4.5 eV @ 6 keV_x
- Temperature rise measured by semi/superconducting thermometers

Background rejection:

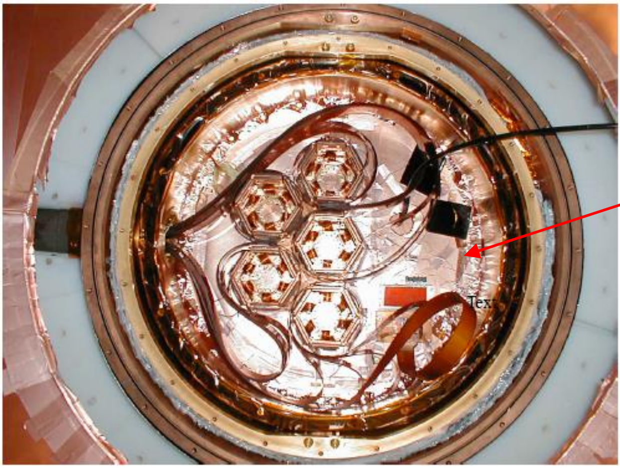
- Ionization / scintill. light yield depends on recoiling particle
- Compare phonon with ion. / scintill. Signal
- Surface events suppressed by interleaving ion./phonon sensors
- Potential for backg. free experiments

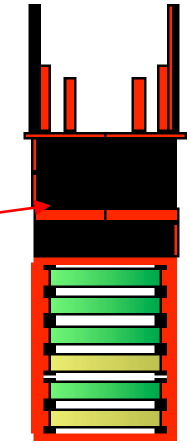


Experiments:

CDMS, CRESST (scint), ROSEBUD (scint.), CUORE, EDELWEISS,..

CDMS II (SOUDAN)

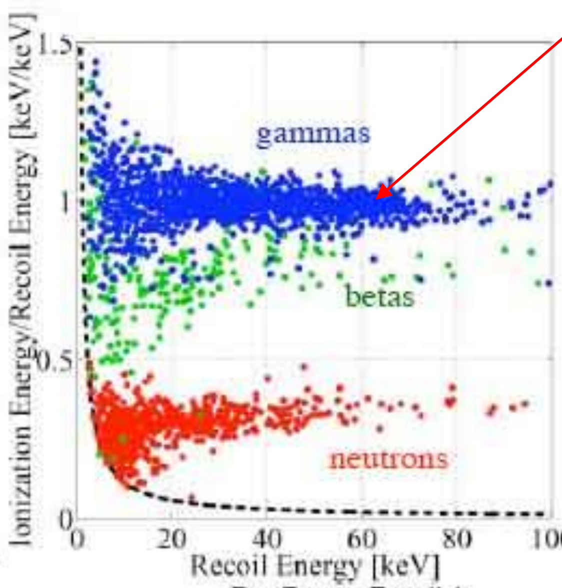




- 250 g Ge, Si ZIP detectors at 50 mK
- 5 towers w. 6 mod. since Oct. ‘06
- Total mass 4.5 kg Ge, 1.1 kg Si
- Ionisation + heat + risetime
- γ rejection > 99.9998 %, 99.75 for β’s

CDMS II SI

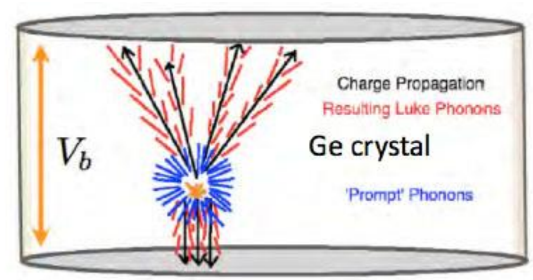
- April 2013 $\rightarrow$ 140 kgd
- 3 ev. , backg. 0.7 ev
- **σ_{SI} ~ 2 10^{-5} pb , M_W = 8.5 GeV/c^2**



Dan Bauer - Fermilab

superCDMS (SOUDAN)

- 577 kgd $\rightarrow$ July’13
- Low mass search ~ 6GeV
- **σ_{SI} < 10^{-42} cm^2 @ 8 GeV**
- CDMSII Si /CoGENT disfavored



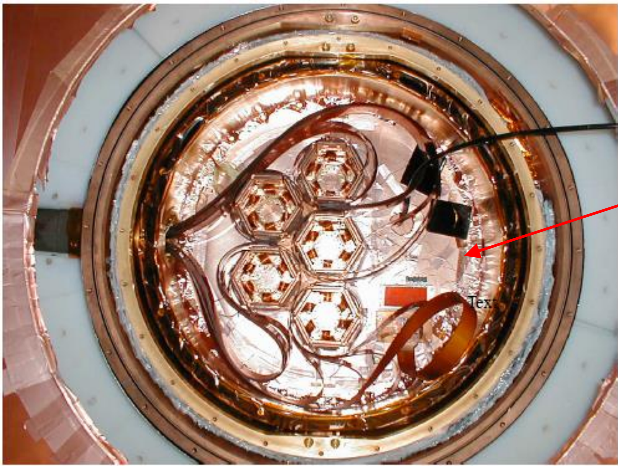
Apply large potential across crystal

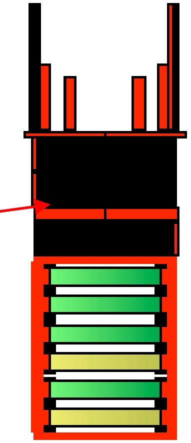
CDMS Lite

- Luke Neganov amplification $\rightarrow$ E_{th} <170 eV
- 0.6 kg sensitivity < 4 GeV

$\rightarrow$ talks by W. Rau, W. Page

CDMS II (SOUDAN)





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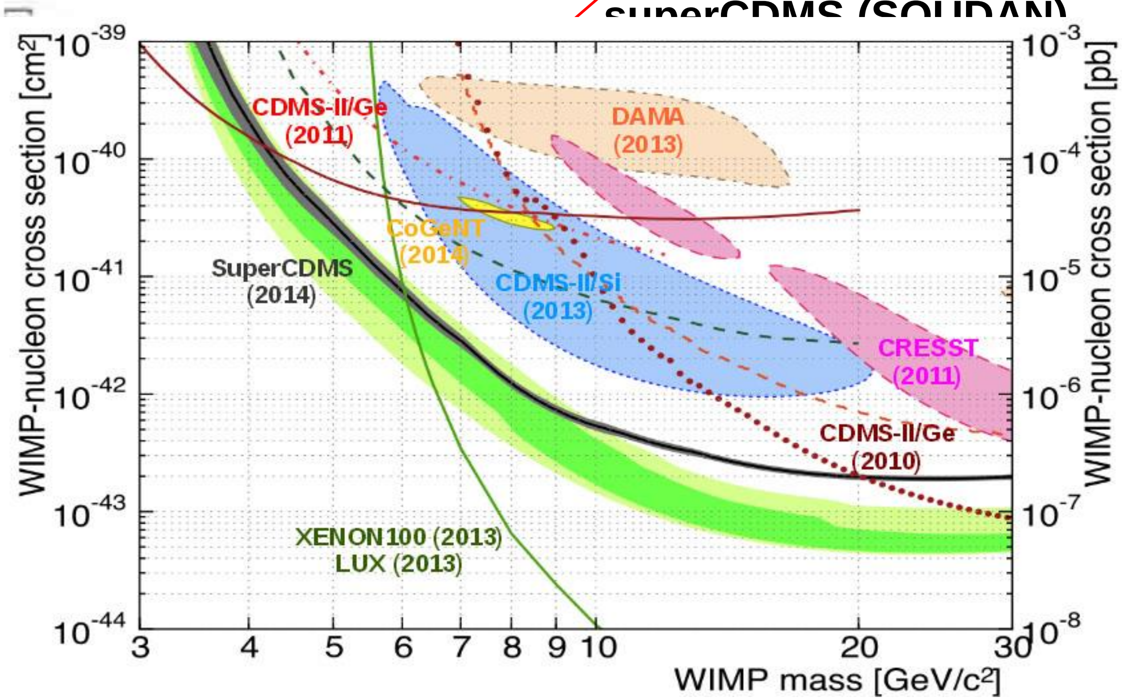

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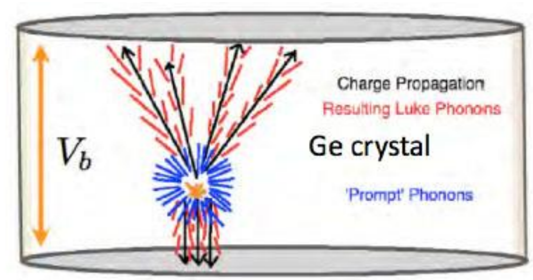


Apply large potential across crystal

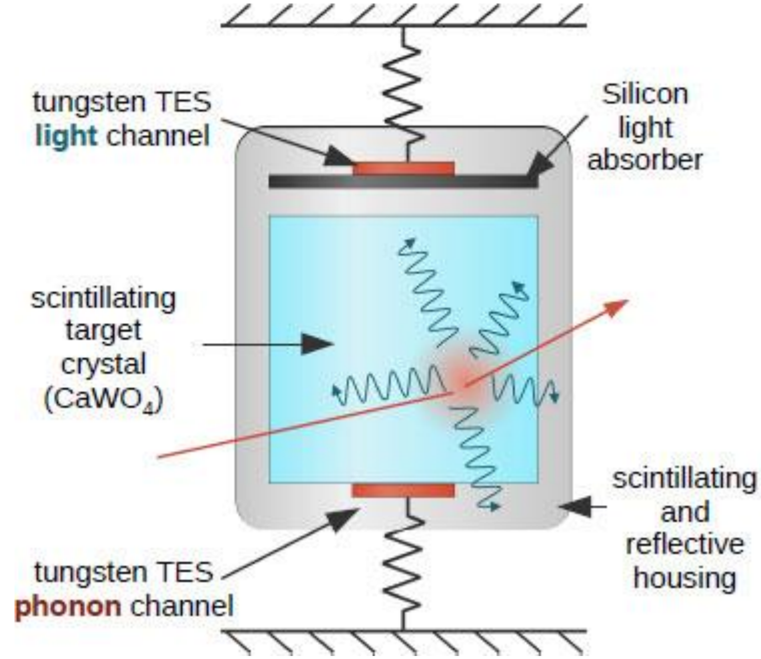
n $\rightarrow$ E_{th} <170 eV

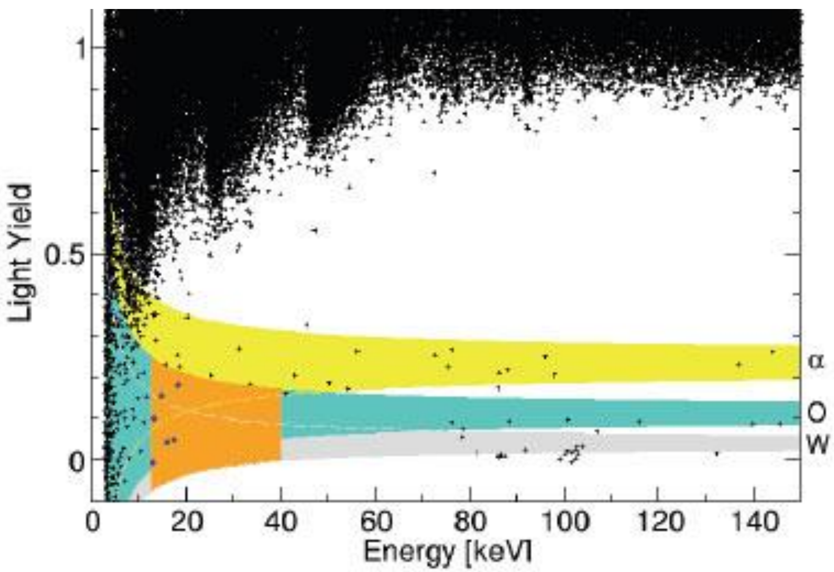
/

$\rightarrow$ talks by W. Rau, W. Page

CRESST II (Gran Sasso)

- 300 g crystals of $CaWO_4$
- Transition edge sensors @10 mK
- Phonon (energy) + light signal
- 3 different targets $\rightarrow M_W \sim 12, 25, 50$ GeV/c^2





C. Strandhagen, IDM 2012 ; arXiv 1109.07020:

Results:

- 8 Modules $\rightarrow$ 730 kgd
- 67 accepted events
- Two solutions:

M1: 25.3 GeV/c^2 σ_{SI} =1.6x10^{-6} pb @ 4.7 σ

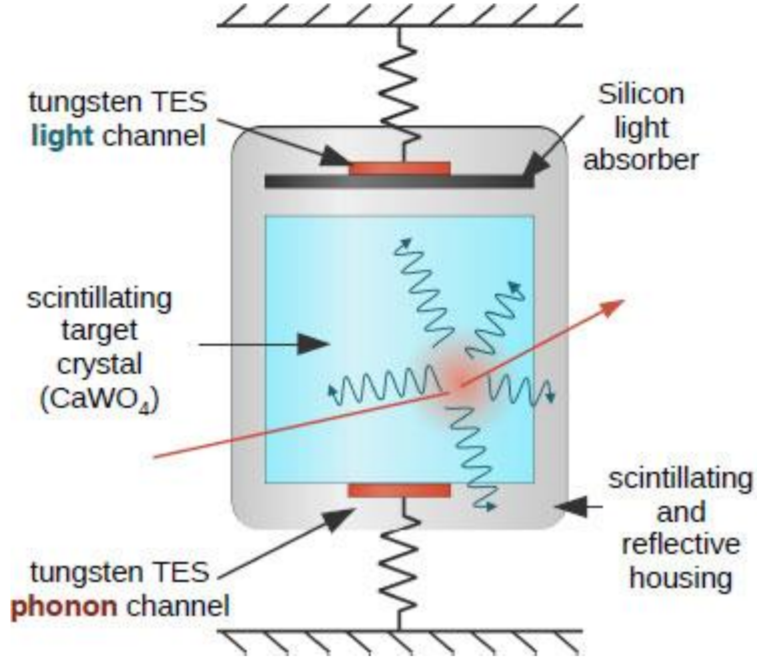
M2: 11.6 GeV/c^2 σ_{SI} =3.7x10^{-5} pb @ 4.7 σ

Light WIMP or Background?

2012: M1 < 2.5σ M2 < 1.9σ

$\rightarrow$ talk by P. Nadeu

CRESST II (Gran Sasso)



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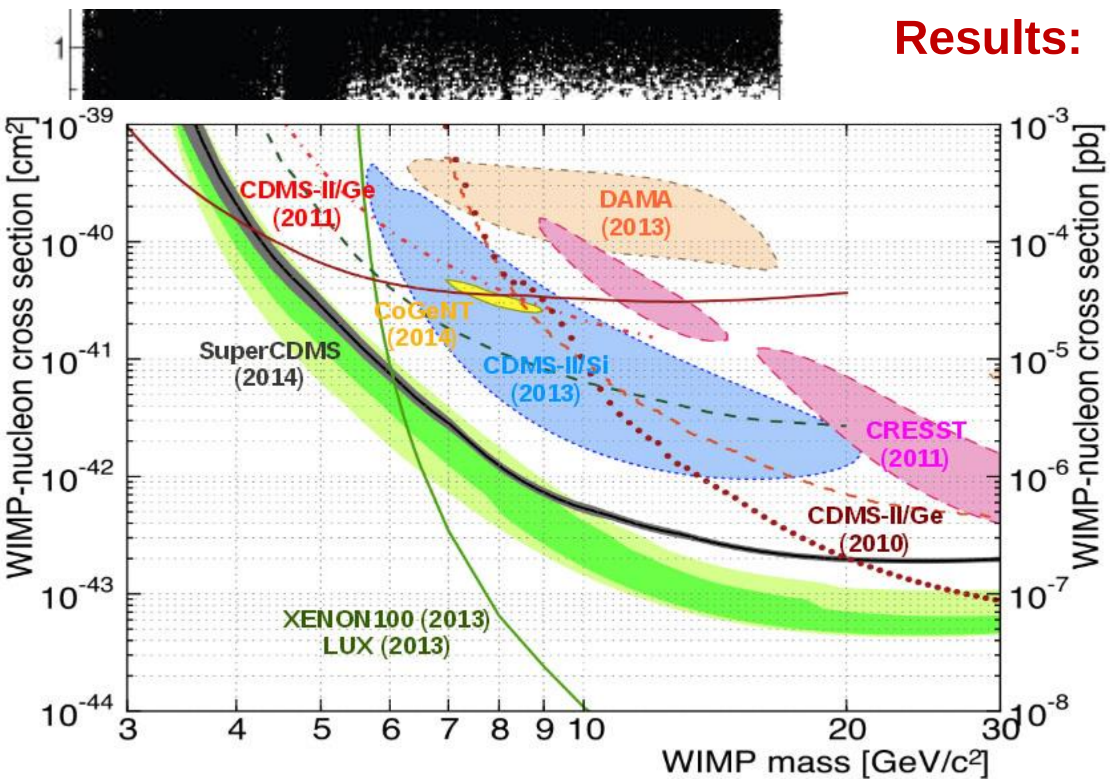

Results:

s → 730 kgd

ted events

tions:

eV/c² σ_{SI} =1.6x10^{-6} pb @ 4.7 σ

eV/c² σ_{SI} =3.7x10^{-5} pb @ 4.7 σ

Light WIMP or Background?

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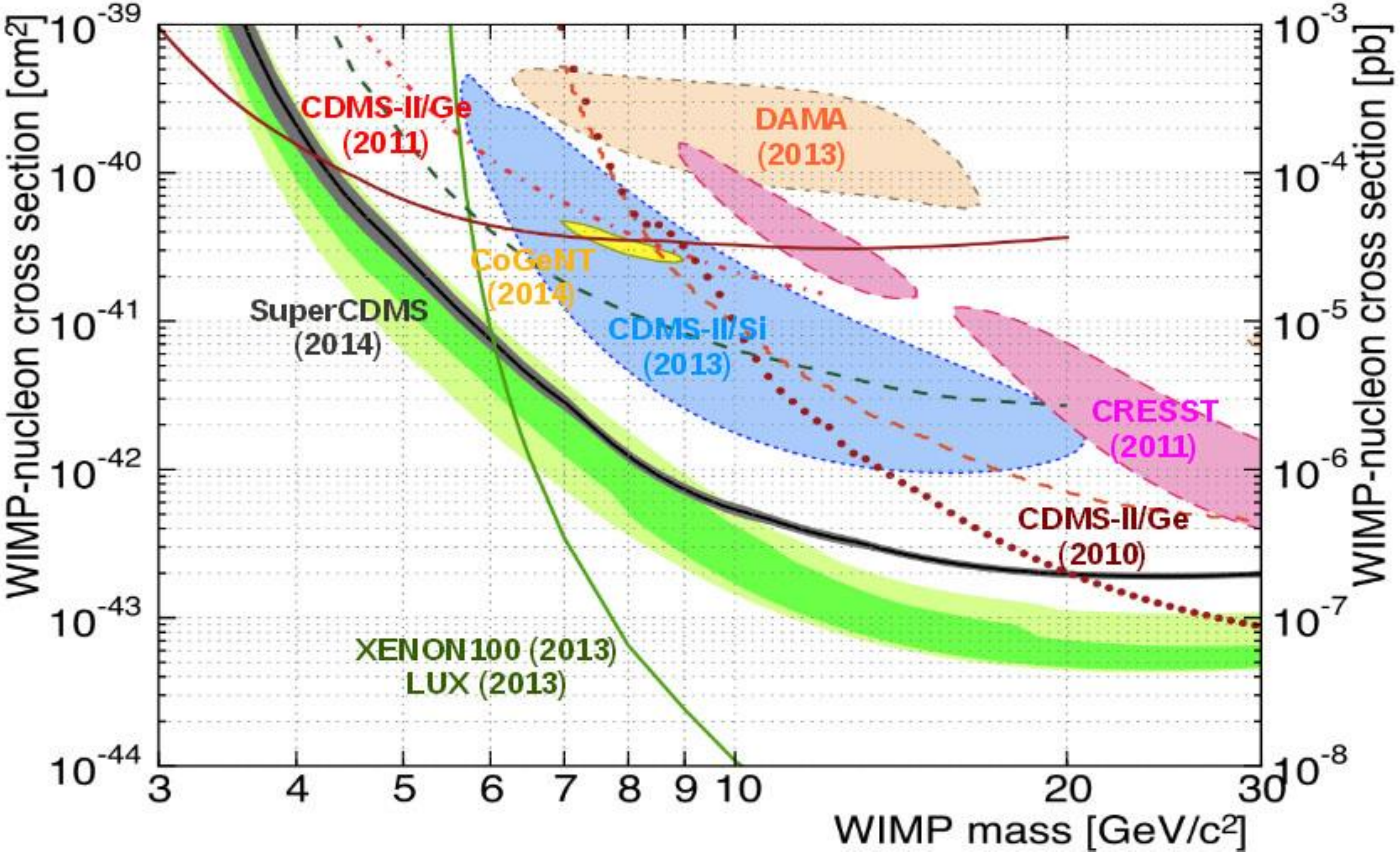
→ talk by P. Nadeu

CURRENT STATUS SPIN-INDEPENDENT SECTOR



CAN THESE RESULTS BE MADE COMPATIBLE ?

Proposed sources for DAMA's annual modulation:

- Ambient temperature variation
- μ-flux depends on atm. temperature/pressure
- Spallation neutrons from muons in rock
- Rn diffusion from rocks may be varying with time
- But no blank runs yet !

all explained away by DAMA

Detector Effects?

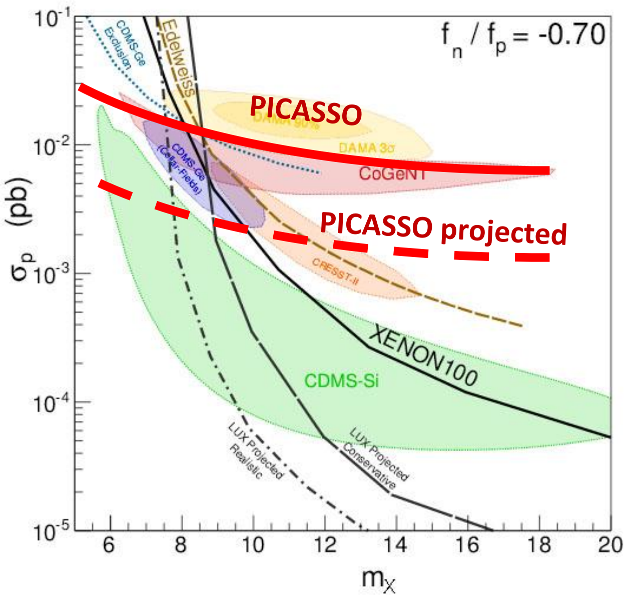
- Quenching & channeling (directional sensitivityin the crystal))
- Threshold effects, PMT noise?

Due to nature of DM?

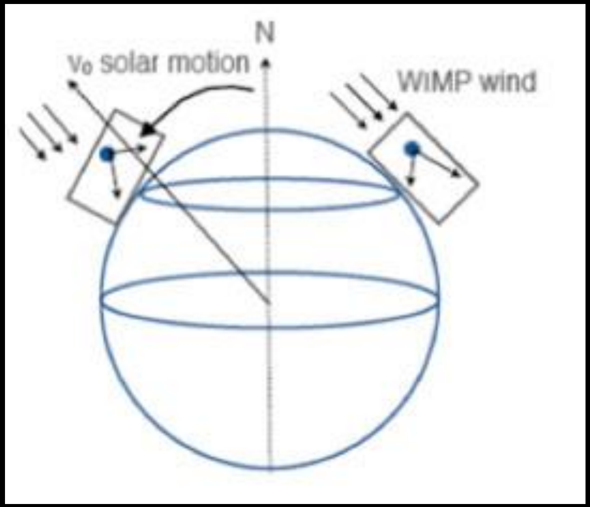
- Different exp.diff. sensitivities to candidates
- Isospin violating DM:
- e.g if $f_p = -f_n \rightarrow$ no Xe effect!

Astrophysical effects?

- different halo compositions, streams
- v_χ and ρ_χ different than expected

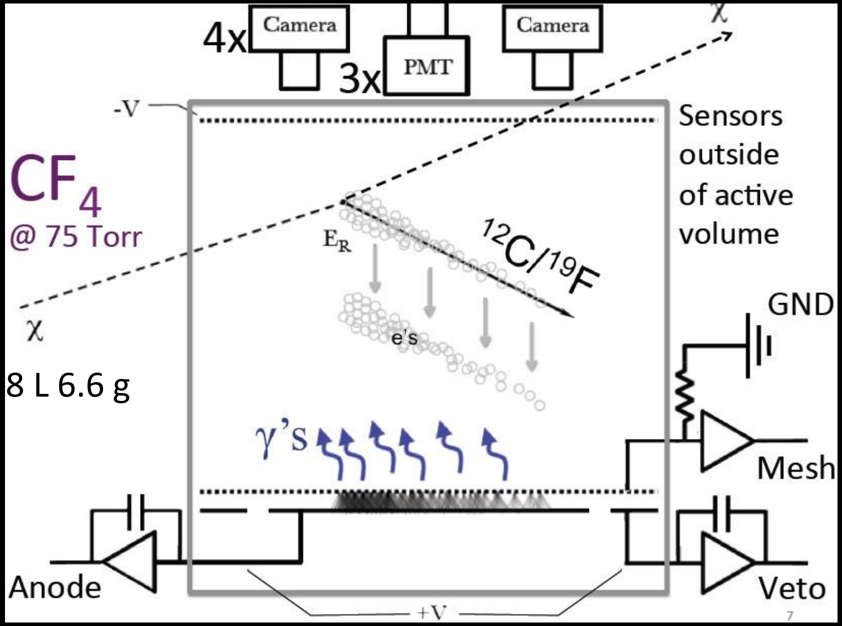


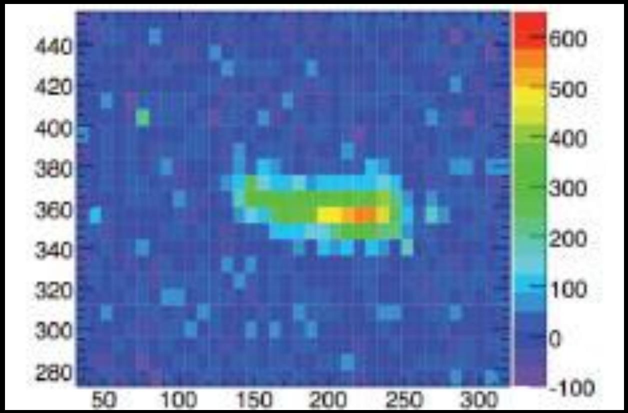
DIRECTIONAL WIMP DETECTION



- Strong day/night modulations expected
- Low pressure TPC's CF_4, CS_2

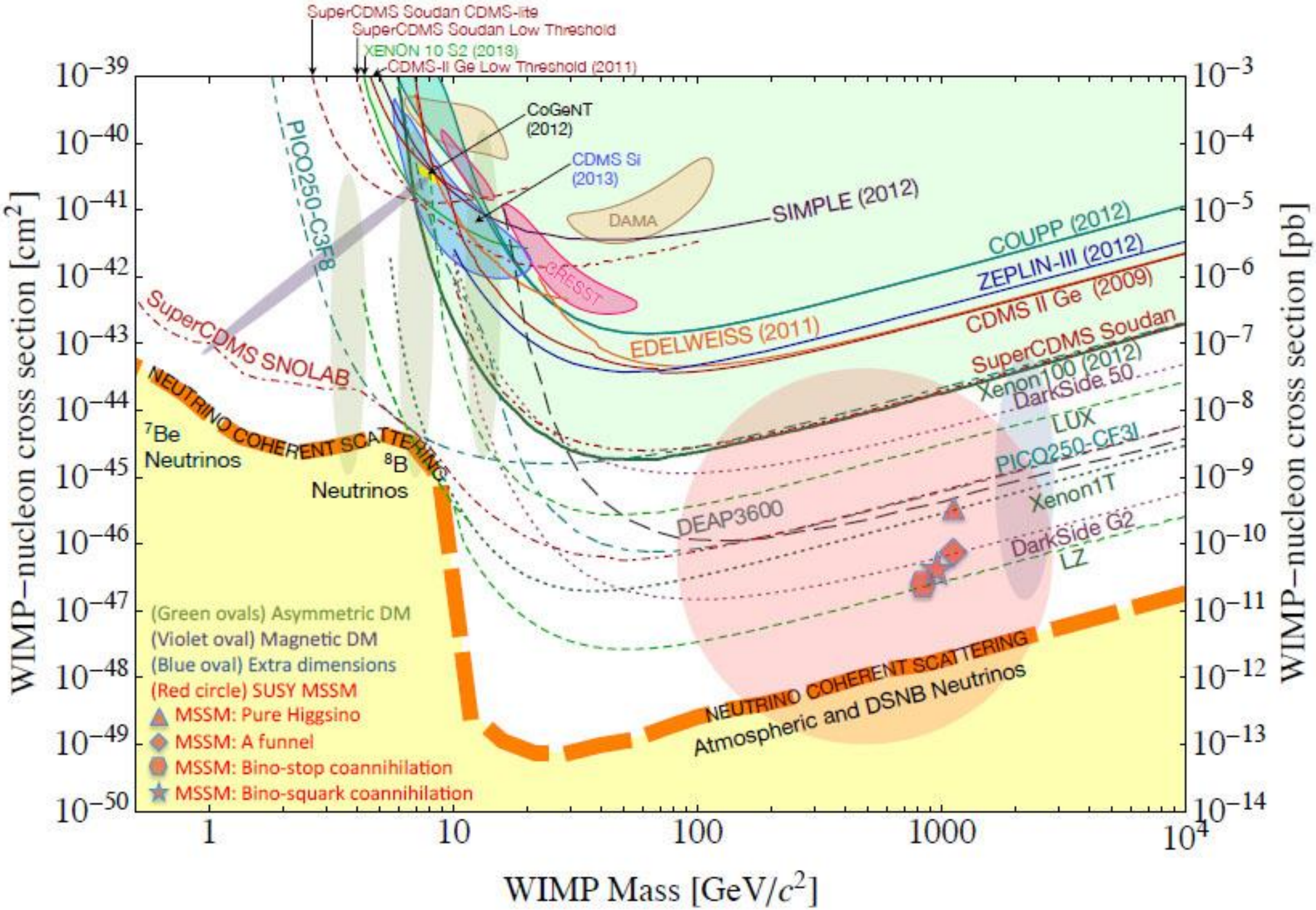
+ DRIFTII (140g) , MIMAC, NEWAGE, DMTPC





DMTPC: Nuclear recoil track

SUMMARY SPIN-INDEPENDENT SECTOR



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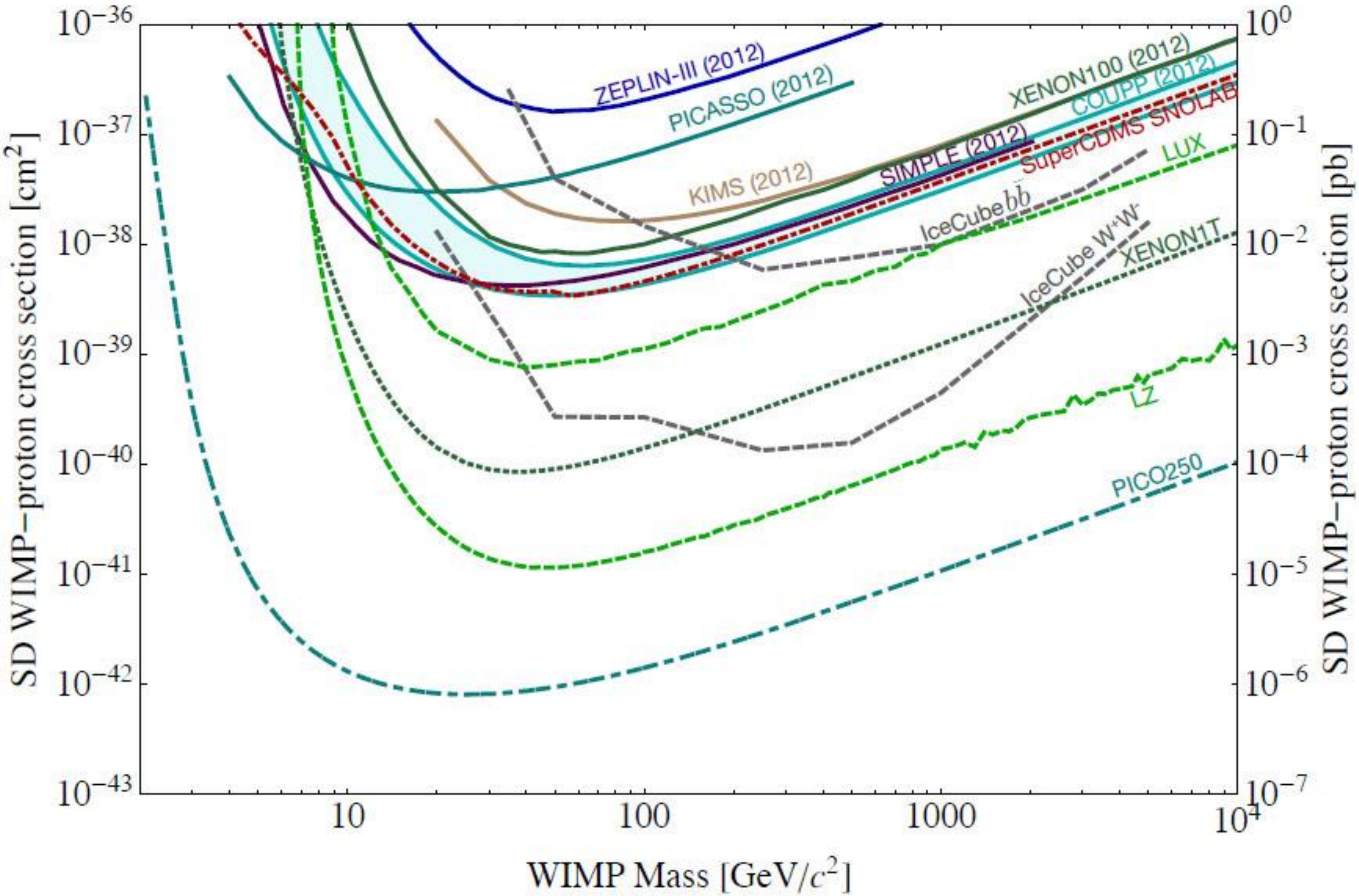
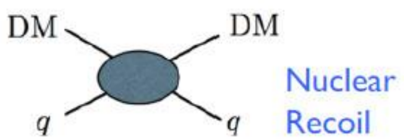
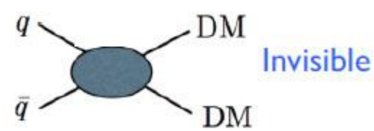
SUMMARY SPIN DEPENDENT SECTOR



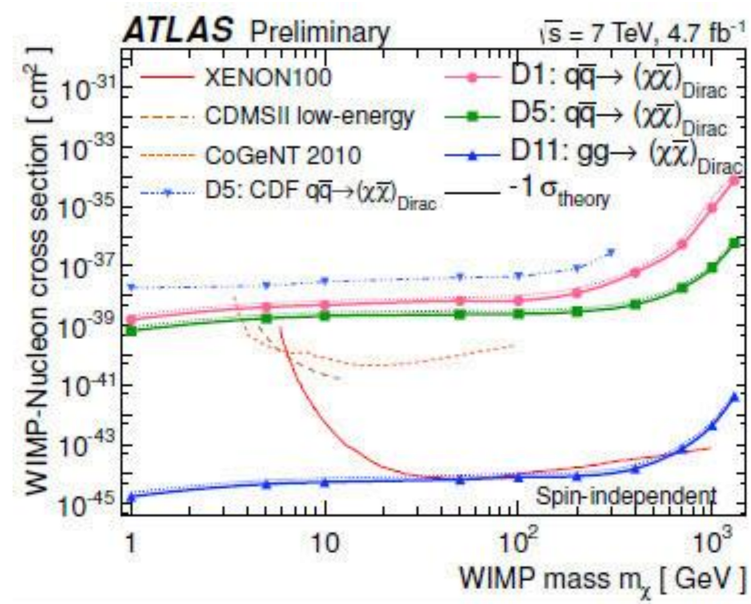
DIRECT DETECTION & LHC → MONO-JETS

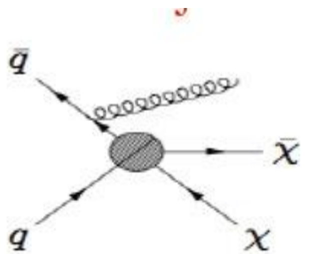


Direct searches (non-relativistic)

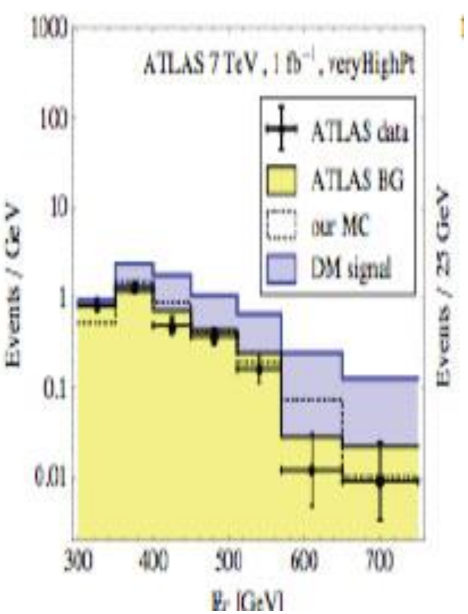


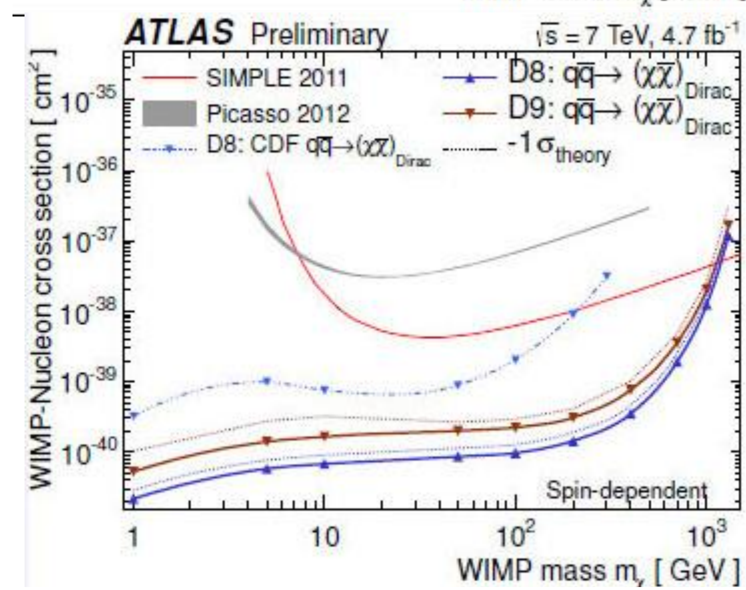
LHC searches (highly relativisic)





- Tagging by j / γ + E_t^{miss}
- Search for excess
- Suppose contact interaction
- Relate to direct σ_{SI}, $_{SD}$





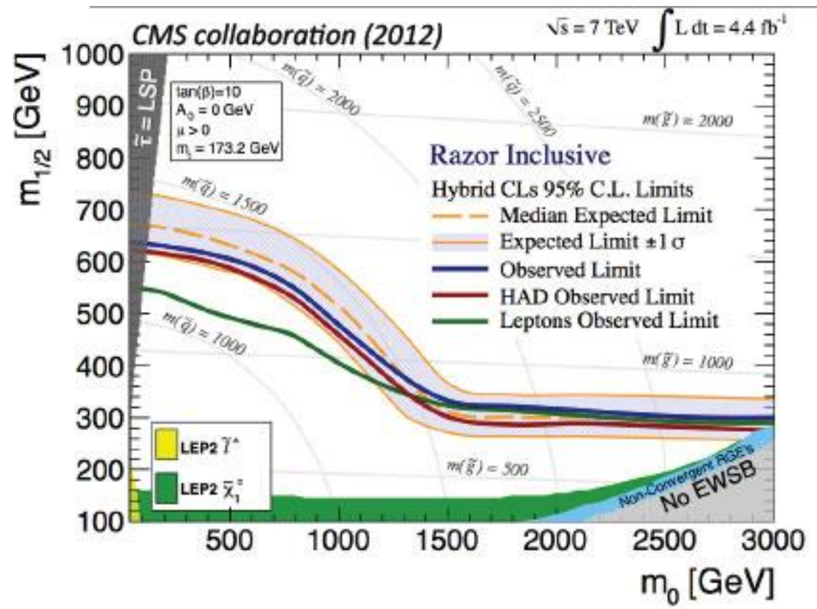
Impressive limits….

BUT:

...works only well for mediator masses > few TeV

DIRECT DETECTION & LHC → SUSY SEARCH

- cMSSM: m_0, $m_{1/2}$, A_0, $\tan(\beta)$, sign(μ)
- Apply contraints (closure density...)
- + LHC (non)-observational results

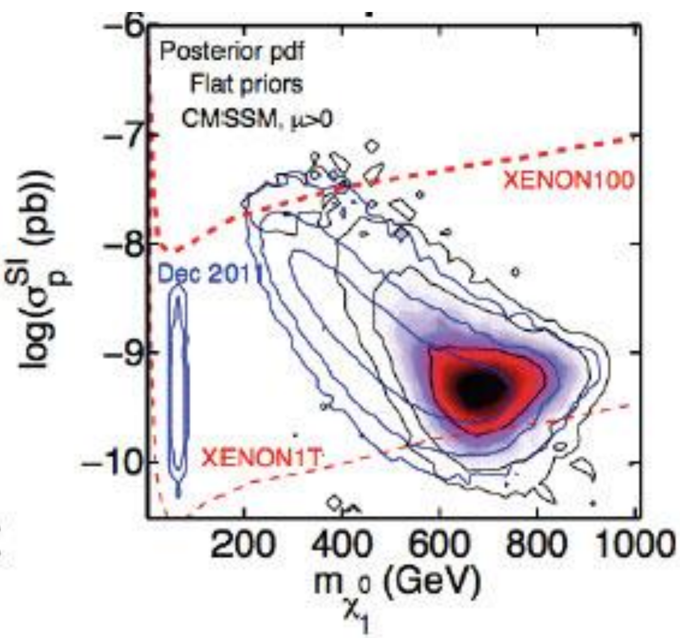


- LHC exclusion limits cut deep into cMSSM parameter space
- Add Higgs mass constraints...

M_W `> 500 GeV/c^2 + small x-sections!

BUT:

- SUSY parameter space large
- other models...UED etc



C. Strege, Dark Attack 2012

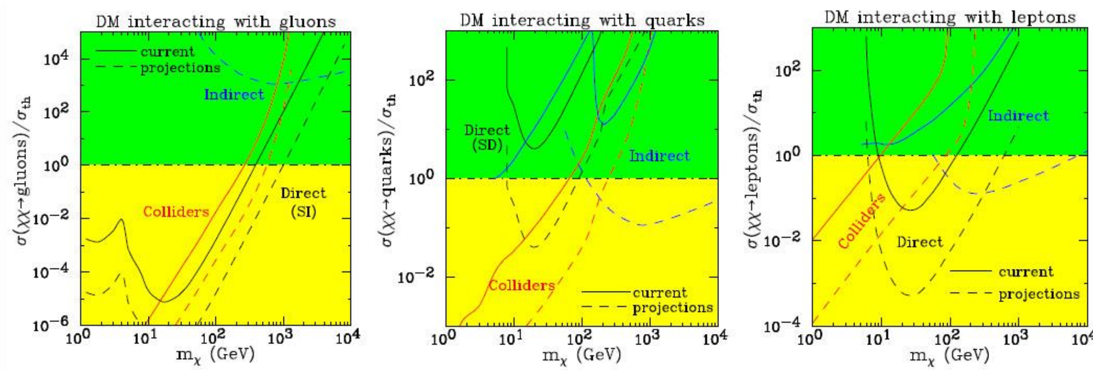
COMPLEMENTARITY OF SEARCHES

D. Bauer et al.; arXiv: 1305.1605

Effective operator approach:

$$\frac{1}{M_q^2}\,\bar{\chi}\gamma^\mu\gamma_5\chi\sum_q \bar{q}\gamma_\mu\gamma_5 q + \frac{\alpha_S}{M_g^3}\,\bar{\chi}\chi G^{a\mu\nu}G^a_{\mu\nu} + \frac{1}{M_\ell^2}\,\bar{\chi}\gamma^\mu\chi\sum_\ell \bar{\ell}\gamma_\mu \ell$$

Spin dependent — Spin independent — Coupling to leptons



$\sigma_{theo} = \sigma_{ann}$ for thermal WIMP to be DM

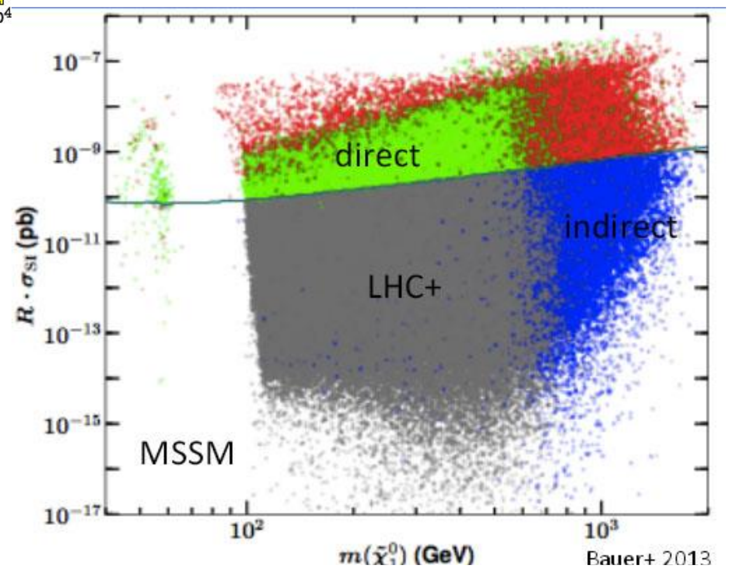
$\sigma_{obs} = \sigma_{theo} \rightarrow$ all DM discovered

$\sigma_{obs} > \sigma_{theo} \rightarrow$ one DM species discovered

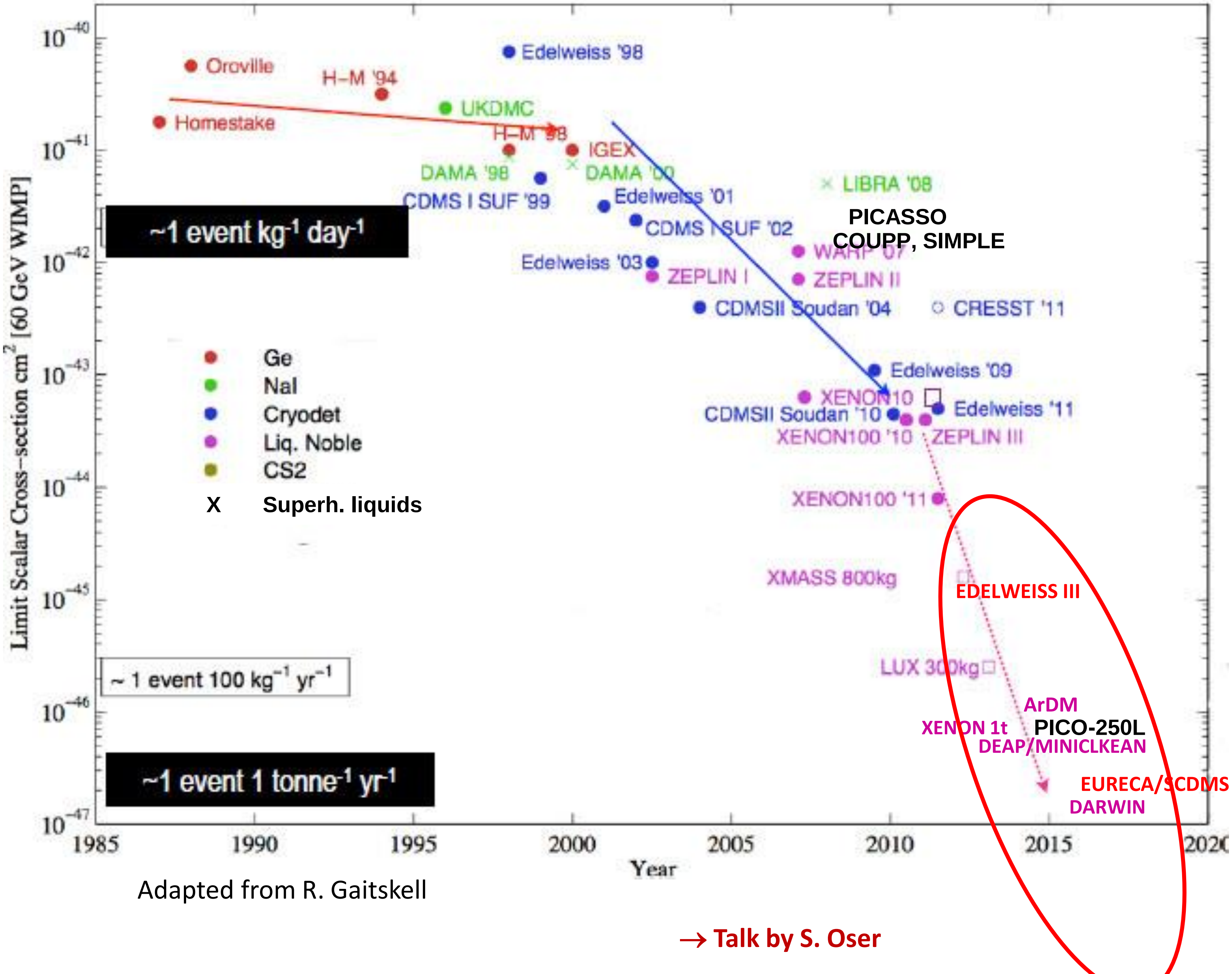
$\sigma_{obs} < \sigma_{theo} \rightarrow$ annihil. channels exist

Model independent approach to SUSY

- Scan of full parameter space in MSSM
- 20 input prameters
- Scan over all models (each dot is a model)
- Grey LHC region inaccessible to other searches



THE FUTURE OF DIRECT DM SEARCHES



Adapted from R. Gaitskell

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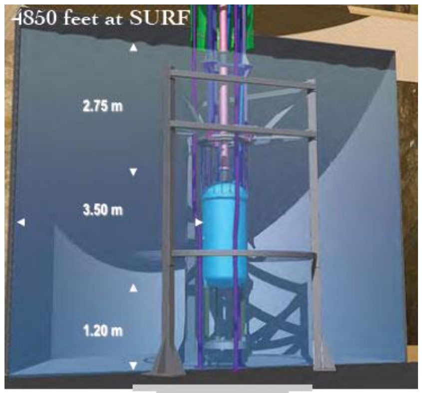
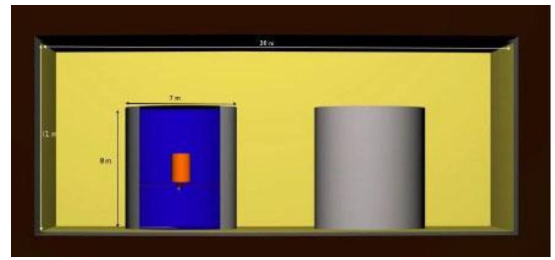
THE FUTURE OF DIRECT DM - SEARCHES

Trend towards a few very large experiments....

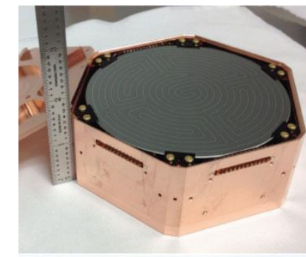
ArDM 850 kg



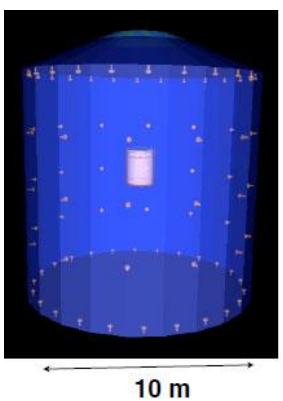
LUX 350 kg Xe



EURECA 0.1 -1t

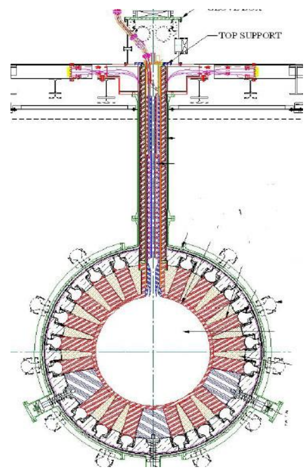


Super CDMS 0.2 t Ge
→ GEODM 1.5t Ge

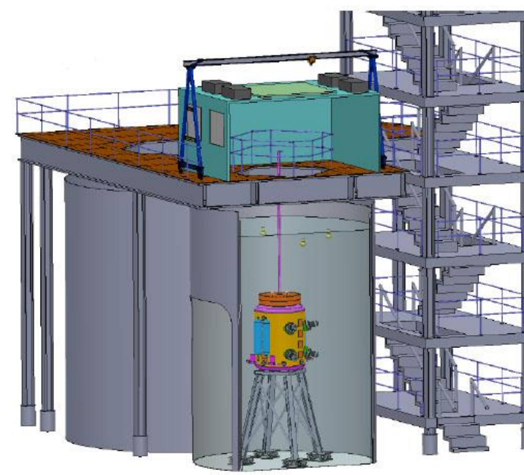


XENON 1t

DARWIN 20t Xe / Ar



DEAP 3.6 t Ar



PICO-250L

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SUMMARY AND CAVEATS

- Rapid progress in field
- Direct detection most promising
- Complementarity (collider, direct, indirect searches)
- Maybe DM not as simple as thought !
- Light WIMPS theoretically well motivated !
- New paradigms (asym DM, hidden sector, axions…)
- Need different techniques & targets
- Lots of astrophysical uncertainties (halo composition)
- ….but discovery possible any time!