Dark Matter: experimental techniques/ issues

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MultiDark
Multimessenger Approach for Dark Matter Detection

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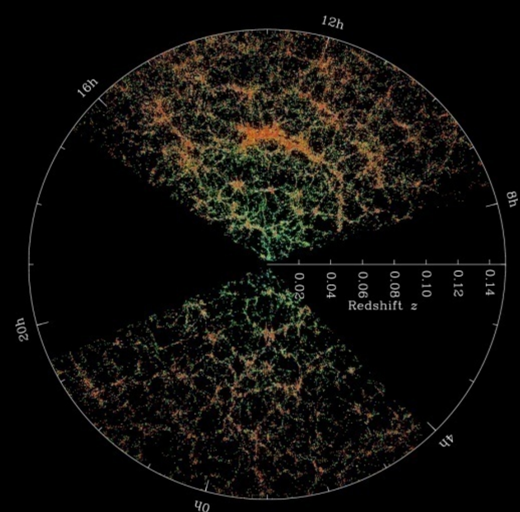
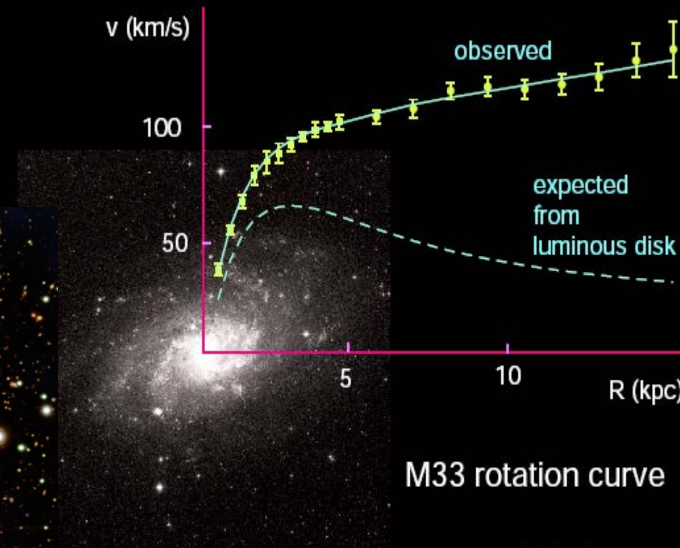
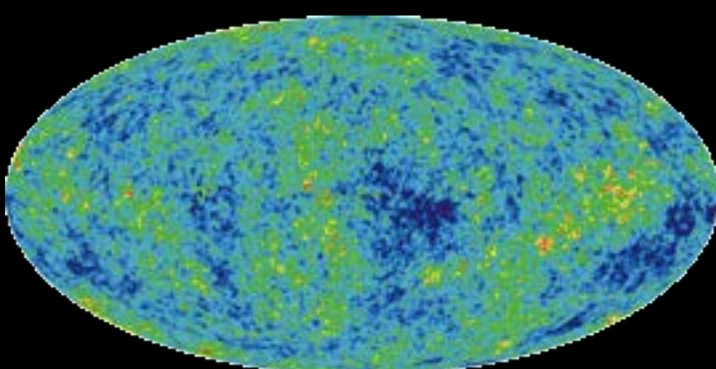
The Dark Matter Problem

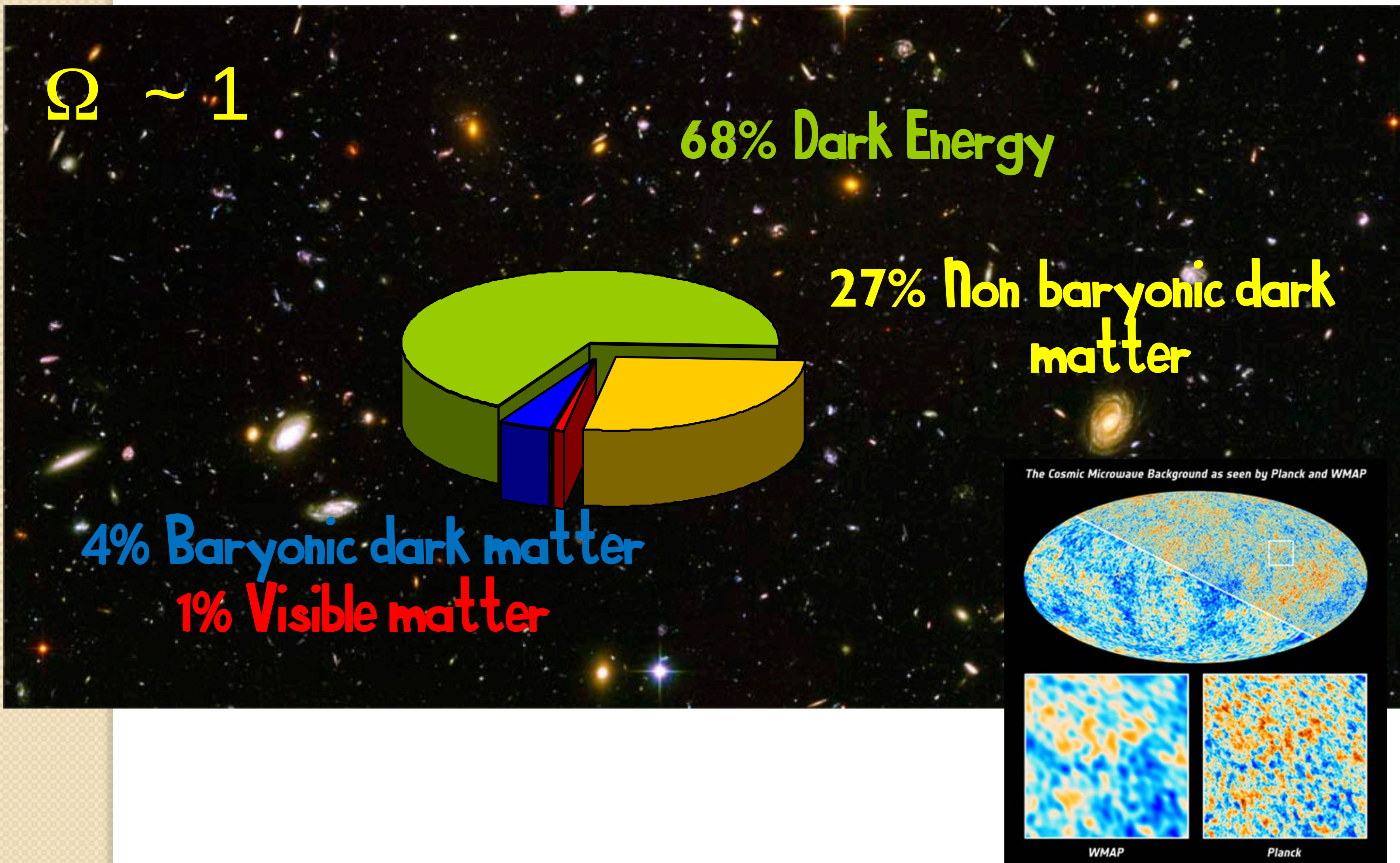
Evidences come from very different observational techniques at different scales and times of the Universe history



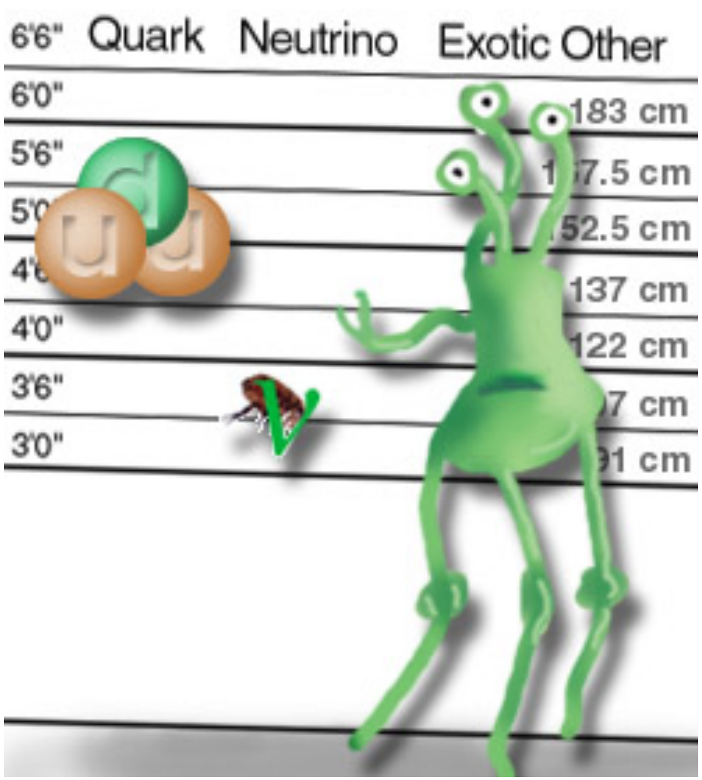




The Universe Recipe… after PLANCK



The Dark Matter Nature



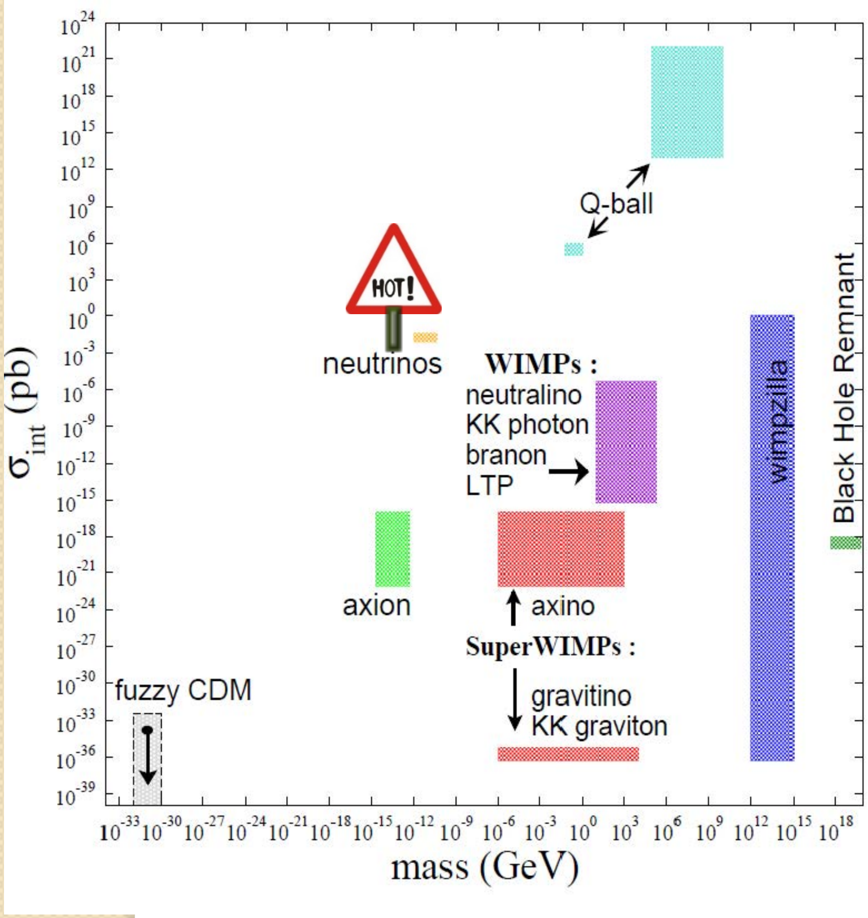
27% of the Universe consists of **unknown matter:**

- massive
- non baryonic
- neutral
- stable or very long lived
- non relativistic when structures formed (cold/warm)

Beyond the Standard Model of Particle Physics

Dark Matter Candidates

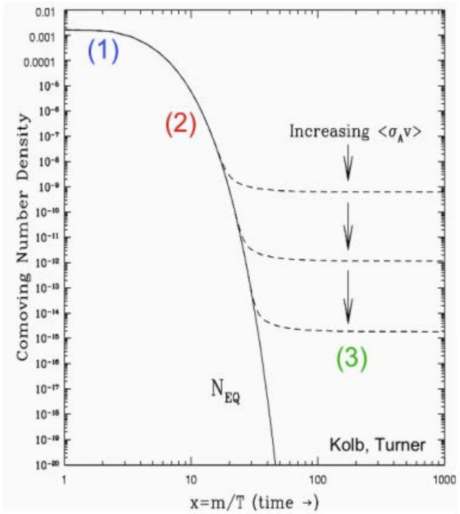
DM-Theory
D. Cerdeño



Some well motivated candidates

- Axions - ALPs
- Sterile neutrinos
- WIMPs
  - SUSY
  - Kaluza Klein
  - Little Higgs
  - ……

Dark Matter Candidates: WIMPs

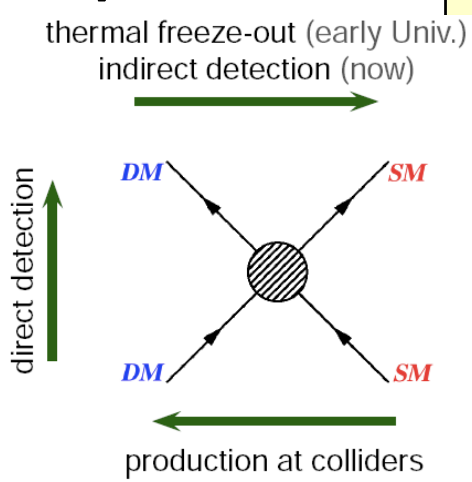


WIMPs are convenient DM candidates

If DM particle was in thermal equilibrium in the primordial soup at freeze out the annihilation cross section determined the relic abundance

WIMP MIRACLE

electroweak scale cross sections for a GeV particle produce the correct Ωc



WIMP DETECTION

Very few assumptions required

Other Dark Matter Candidates

Axions / ALPs

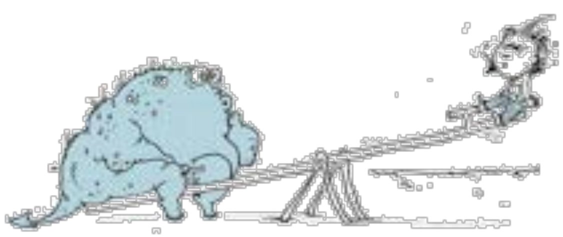
Axion would solve the strong CP problem and there is a strong physics case for them to exist, including dark matter
Pseudoscalar
Very light
Neutral

Cosmological and astrophysical limits allow smalll window mass: $10^{-6} - 10^{-2}$ eV.

ALPS Axion Like Particles and other WISPs are viable dark matter candidates.: vey light and very feebly interacting particles.

Sterile Neutrinos

Sterile neutrinos (Ni) are a natural ingredient of the most popular mechanism to generate neutrino masses the seesaw mechanism



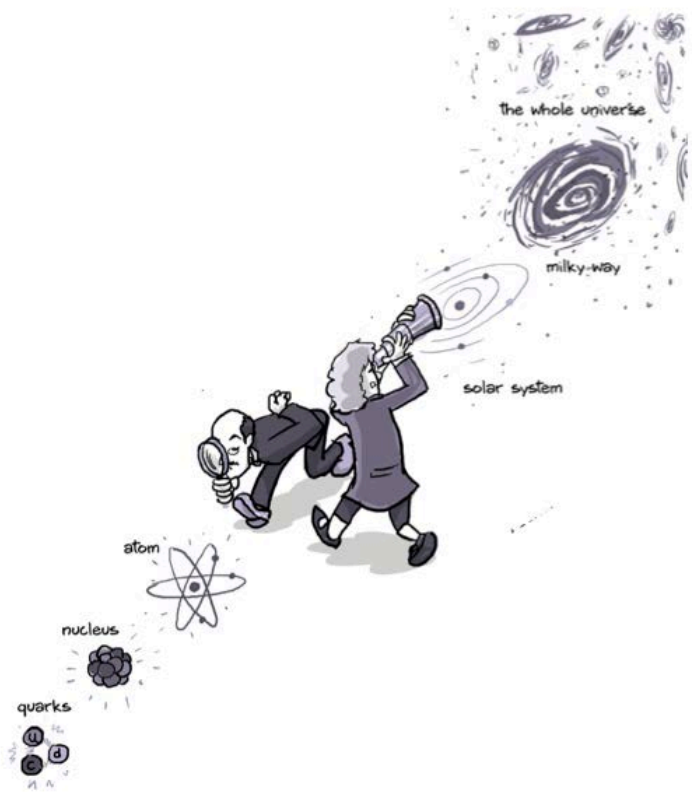
Sterile neutrinos are neutral leptons with no ordinary weak interactions except those induced by mixing with active neutrinos

But could have interactions involving new physics

The Dark Matter challenge

DM detection is a difficult task

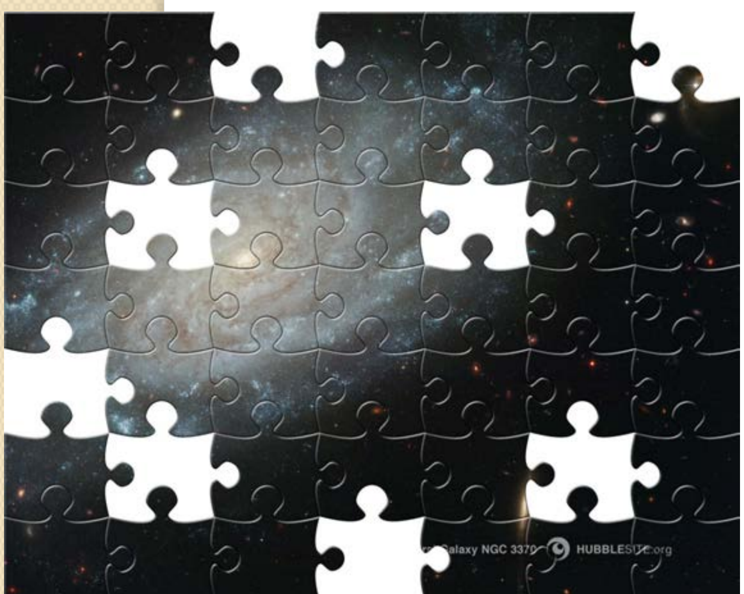
Challenge for:



- Astrophysics
- Cosmology
- Particle Physics
- Nuclear Physics
- Detector Physics
- ...

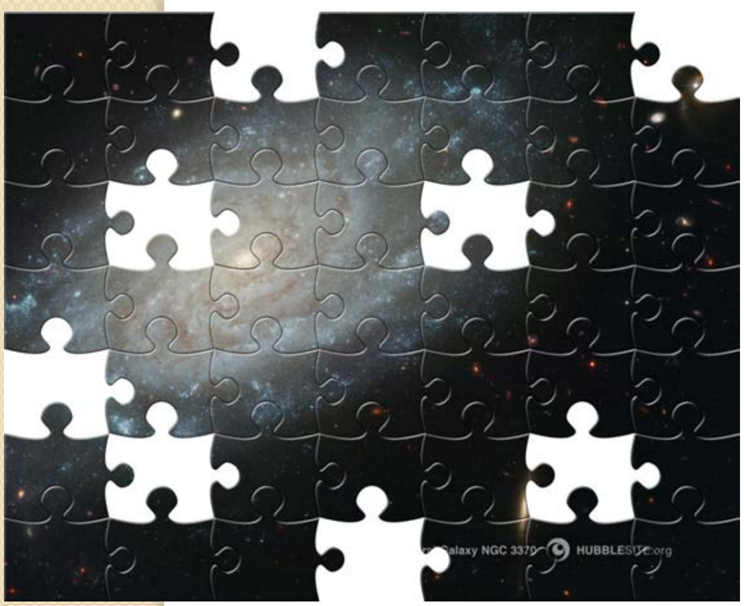
The Multimessenger Approach

To decouple unknown and uncertainties in such a challenge for experimental detection



- Multimessenger approach (direct vs indirect vs accelerator searches)
- Multitarget and multi-technique strategy

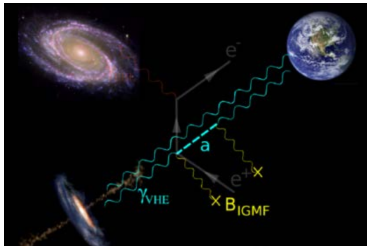
OUTLINE

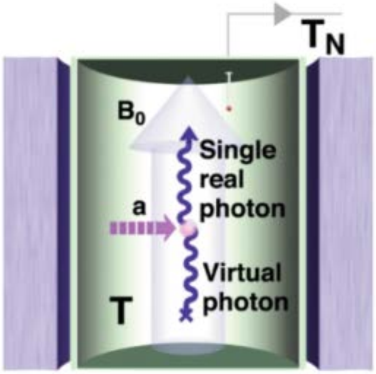


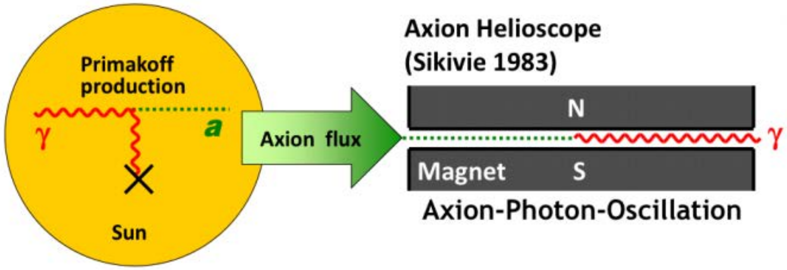
- Direct Detection of DM
  - Expected signal
  - Detection Mechanisms
  - Review of experimental status
- Indirect Detection of DM
  - Search Strategy
  - Review of experimental status

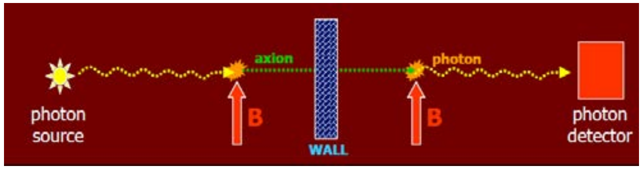
Axion Searches

- Astrophysical hints for axions/ALPs
  - Observation of gamma rays from distant sources (VHE transparency)
  - Anomalous cooling of white dwarfs
- Relic Axions part of galactic DM halo
  - Axion Haloscopes ADMX
- Solar Axions Look for axions produced in the Sun by Primakoff conversion of photons
  - Crystal detectors
  - Axion Helioscopes CAST / IAXO
- Axions in the lab
  - Laser experiments ("Light shining through wall")
    ALPS II / OSQAR

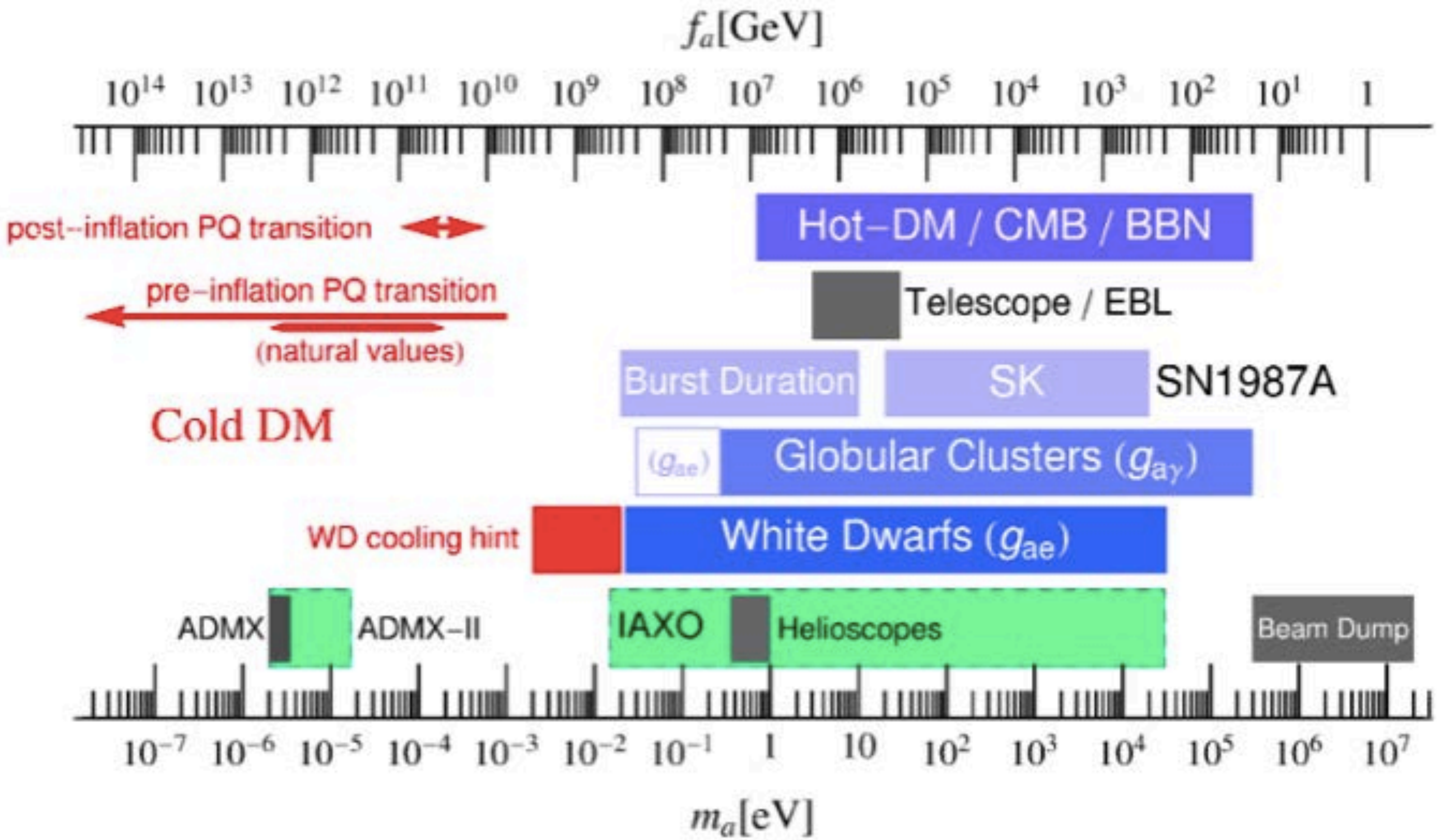






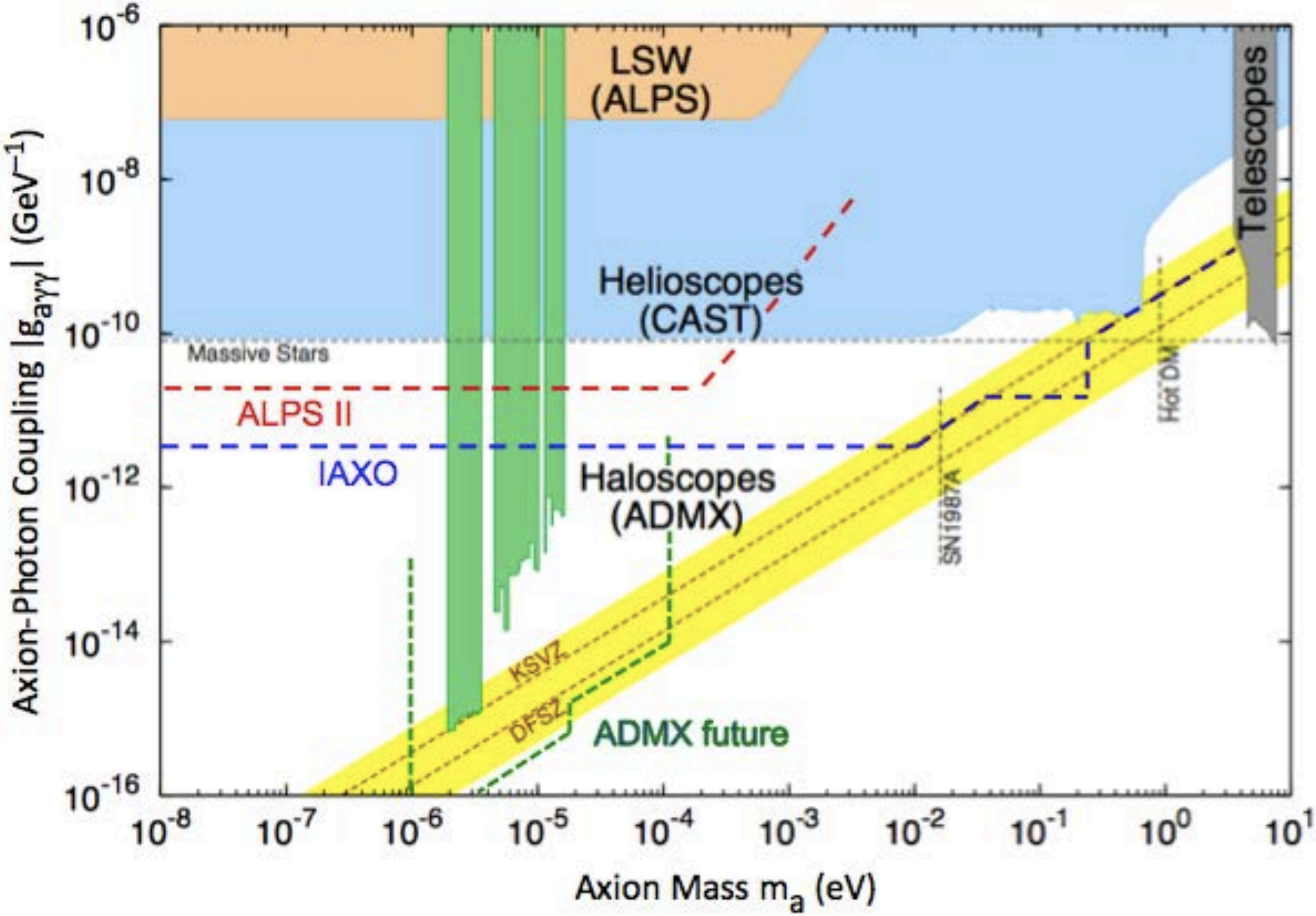


Axion Searches



P. W. Graham et al, Annu. Rev. Nucl & Part. Science 2015, vol 65

AXION-ALPs Searches



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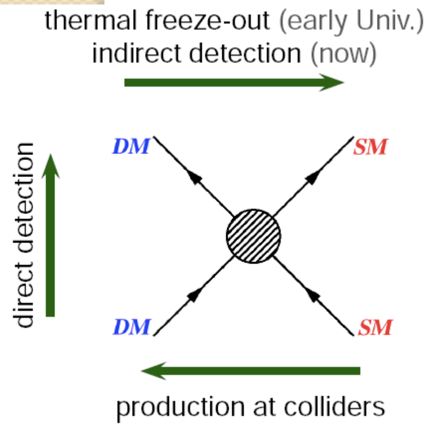
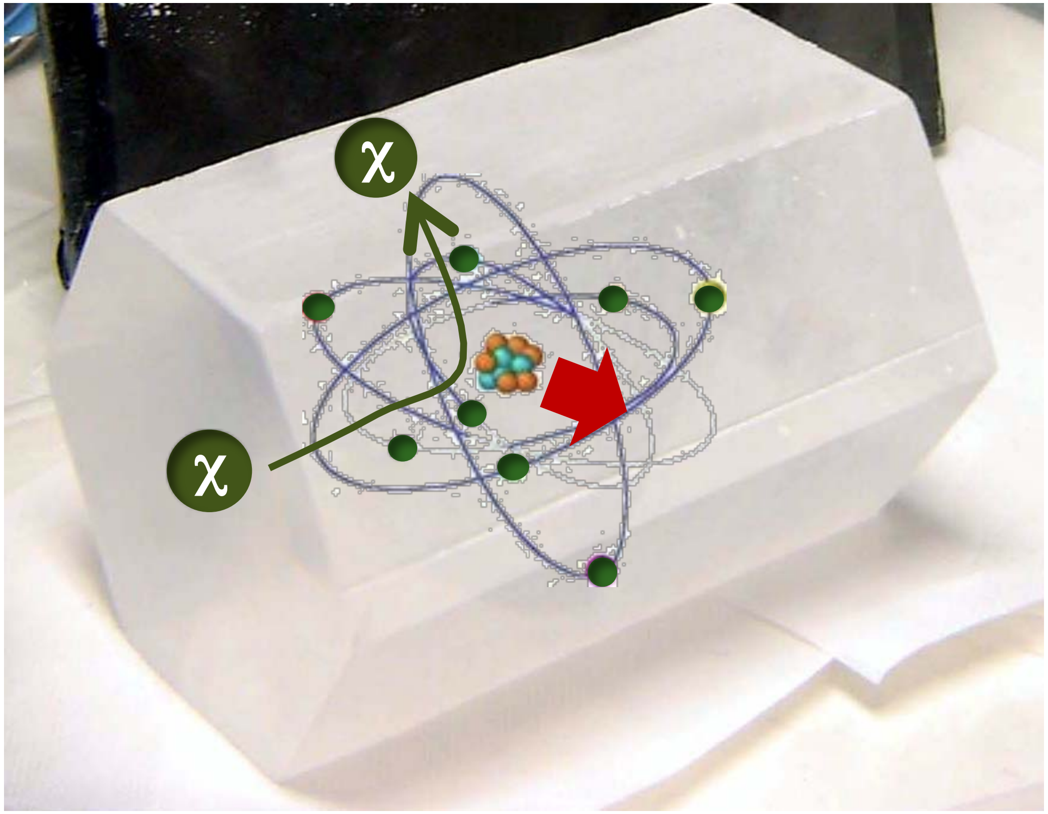
WIMP Direct Detection



Galactic WIMPs are suppossed to produce NUCLEAR RECOILS by elastic scattering off nuclei



Extreme non relativistic limit
Isotropic scattering in the CM reference frame

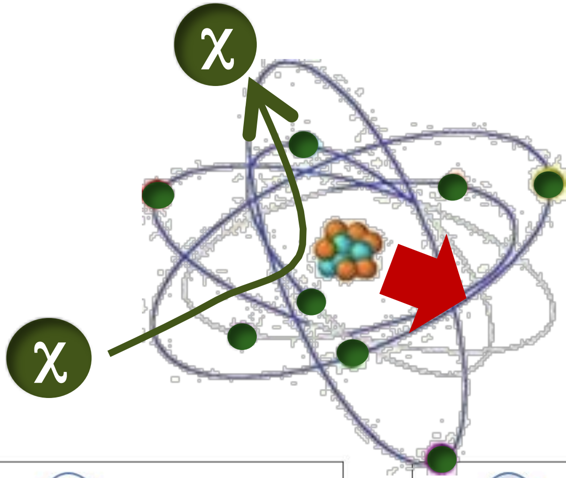
$$< p > \approx 6 - 70 MeV / c$$

$$10 GeV / c^2 < m_w < 1 TeV / c^2$$

Kinematics of elastic scattering

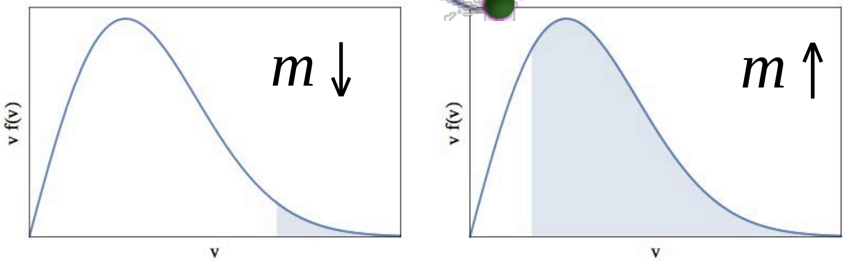
$$T_{recoil} = E_0 - E^f_{WIMP} = \frac{m_W{}^2 M_N}{(m_W + M_N)^2} v^2 (1 - \cos\theta)$$

$$T_{max} = \frac{2 m_W{}^2 M_N}{(m_W + M_N)^2} v^2$$



Kinematical mass matching

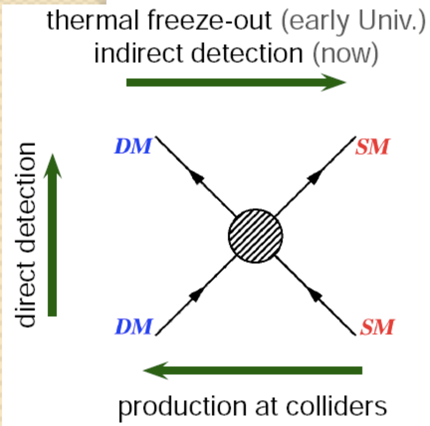
$$v_{min}{}^2 = \frac{(m_W + M_N)^2}{2 m_W{}^2 M_N} T_{threshold}$$



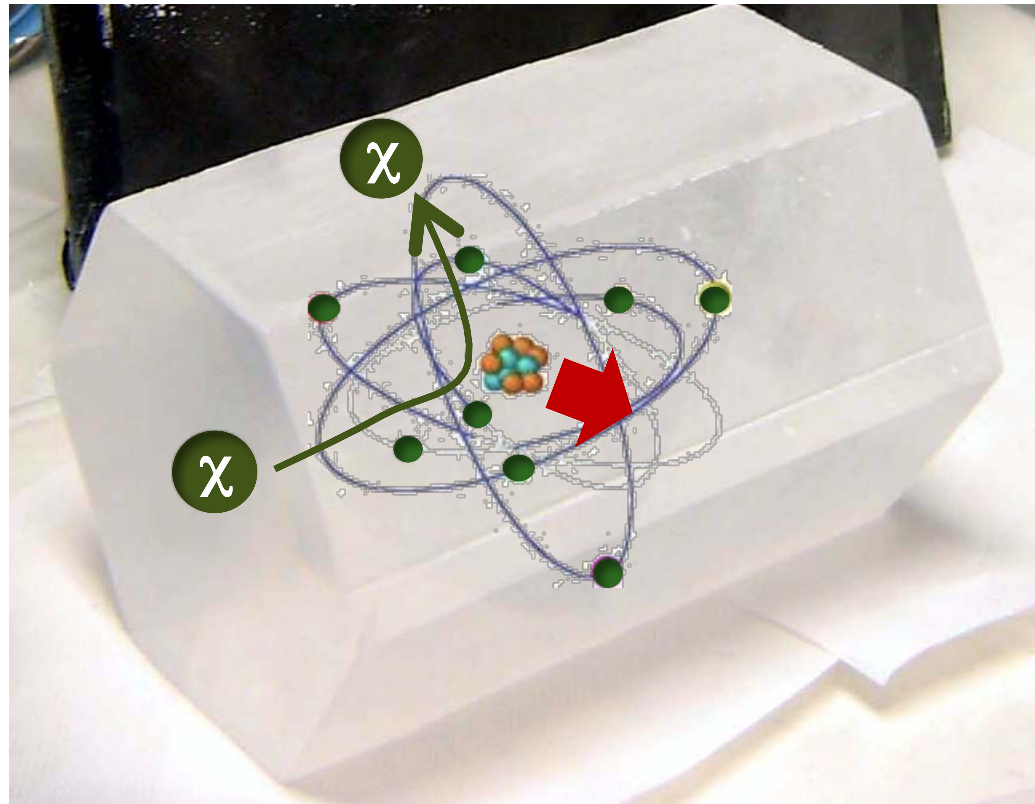
The whole WIMP phase space is not accesible →
Energy threshold is really important

$$< p > \approx 6 - 70 MeV/c$$

$$10 GeV/c^2 < m_w < 1 TeV/c^2$$



WIMP Direct Detection



Galactic WIMPs are supposed to produce NUCLEAR RECOILS by elastic scattering off nuclei

Detection Rate

$$\frac{dR}{dE_R} = n_{WIMPs}\, N_N \int f(v)\, v\, \frac{d\sigma_{WIMP-N}}{dE_R}\, dv$$

Dark Matter Halo model

Nuclear and Particle models

Dark Matter Interaction Rate

$$\frac{d\sigma_{WIMP-N}}{dE_R} = \frac{m_N}{2m_r^2} v^2 \left[\sigma_{SI} F_{SI}^2(E_R) + \sigma_{SD} F_{SD}^2(E_R)\right]$$

$$\sigma_{SI} = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

$$\sigma_{SD} = \frac{32 m_r^2}{\pi} G_F^2 \frac{J+1}{J}\left[a_p < S_p > + a_n < S_n >\right]^2$$

Effective WIMP couplings to neutrons and protons can be calculated for every theoretical model from the effective Lagrangian

Average nuclear spin content of the proton and neutron groups can require detailed nuclear model calculations, (as the SD form factors)

$$\frac{dR}{dE_R} = n_{WIMPs} N_N \int f(v)\, v \frac{d\sigma_{WIMP-N}}{dE_R} dv$$

Nuclear and Particle models

Dark Matter Interaction Rate

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To compare experiments!!!

-Normalize to nucleon cross sections

$$\sigma_{SI} \propto \frac{m_{WN}^2}{m_{Wn}^2} A^2 \sigma_{SI}^{nucleón}$$

$$\sigma_{SD} \propto \frac{m_{WN}^2}{m_{Wn}^2} \sigma_{SD}^{nucleón} \frac{4}{3} \frac{(J+1)}{J} \frac{1}{\bar{a}^2} \left(a_p\langle S_p\rangle + a_n\langle S_n\rangle\right)^2$$

$$\frac{dR}{dE_R} = n_{WIMPs} N_N \int f(v)\, v \frac{d\sigma_{WIMP-N}}{dE_R} dv$$

Nuclear and Particle models

Dark Matter Galactic Halo

nature physics

LETTERS

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Evidence for dark matter in the inner Milky Way

Fabio Iocco[1,2]*, Miguel Pato[3,4] and Gianfranco Bertone[5]

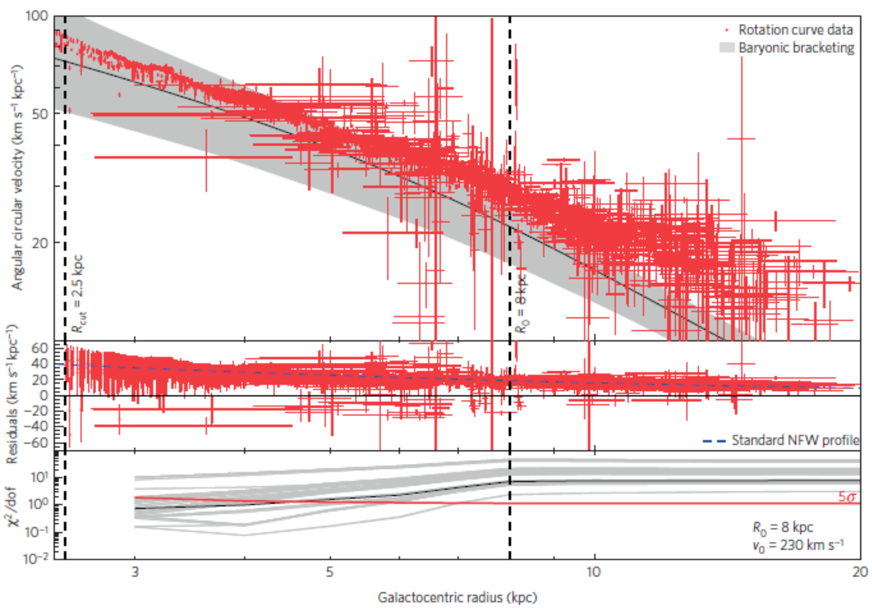
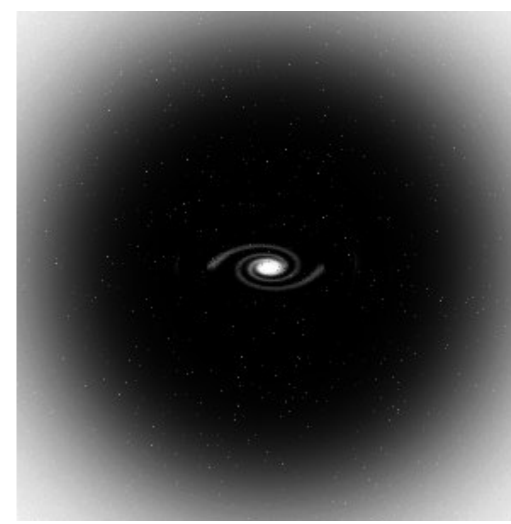


Figure 2 | Evidence for dark matter. In the top panel we show the angular velocity measurements from the compilation shown in Fig. 1 (red dots) together with the bracketing of the contribution of all baryonic models (grey band) as a function of Galactocentric radius. Error bars correspond to 1σ uncertainties, and the grey band shows the envelope of all baryonic models including 1σ uncertainties. The contribution of a fiducial baryonic model is marked with the black line. The residuals $(\omega_c^2-\omega_b^2)^{1/2}$ between observed and predicted angular velocities for this baryonic model are shown in the central panel. The blue dashed line shows the contribution of a Navarro-Frenk-White profile with scale radius of 20 kpc normalized to a local dark matter density of 0.4 GeV cm^{-3}. The bottom panel shows the cumulative reduced χ^2 for each baryonic model as a function of Galactocentric radius. The black line shows the case of the fiducial model plotted in black in the top panel, and the thick red line represents the reduced χ^2 corresponding to 5σ significance. In this figure we assume a distance to the Galactic Centre $R_0=8$ kpc and a local circular velocity $v_0=230$ km s^{-1}, and we ignore all measurements below $R_{cut}=2.5$ kpc.

The ubiquitous presence of dark matter in the Universe is today a central tenet in modern cosmology and astrophysics[1]. Throughout the Universe, the evidence for dark matter is compelling in dwarfs, spiral galaxies, galaxy clusters as well as at cosmological scales. However, it has been historically difficult to pin down the dark matter contribution to the total mass density in the Milky Way, particularly in the innermost regions of the Galaxy and in the solar neighbourhood[2]. Here we present an up-to-date compilation of Milky Way rotation curve measurements[3–13], and compare it with state-of-the-art baryonic mass distribution models[14–26]. We show that current data strongly disfavour baryons as the sole contribution to the Galactic mass budget, even inside the solar circle. Our findings demonstrate the existence of dark matter in the inner Galaxy without making any assumptions about its distribution. We anticipate that this result will compel new model-independent constraints on the dark matter local density and profile, thus reducing uncertainties on direct and indirect dark matter searches, and will help reveal the structure and evolution of the Galaxy.



Dark Matter Galactic Halo

The most simple model isotropic and spherical thermal distribution of non relativistic WIMPs

$v_{rms} \approx 270 km/s – 300 km/s$

$v_{esc} \approx 544\ km/s$

$$f(\vec{v}_{gal})d^3\vec{v}_{gal} = \frac{1}{v_0^3\pi^{3/2}} e^{-\frac{|\vec{v}_{gal}|^2}{v_0^2}} d^3\vec{v}_{gal}$$

Milky Way Rotation Velocity Curve determines halo mass density but not particle number density

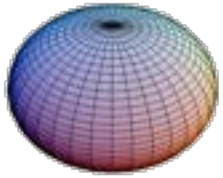
$$n_W = \frac{\rho_0}{m_W}$$

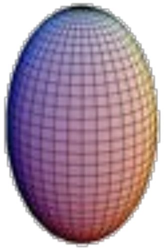
$\rho_0 \approx 0.2\text{-}0.4\ GeV/cm^3$

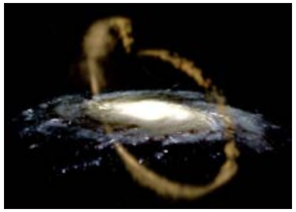
Haloes can be non spherical: triaxial, ellipsoidal, ...

Haloes can have sub-structure:

- Sub-haloes
- Dark Disk
- Satellites producing directional fluxes





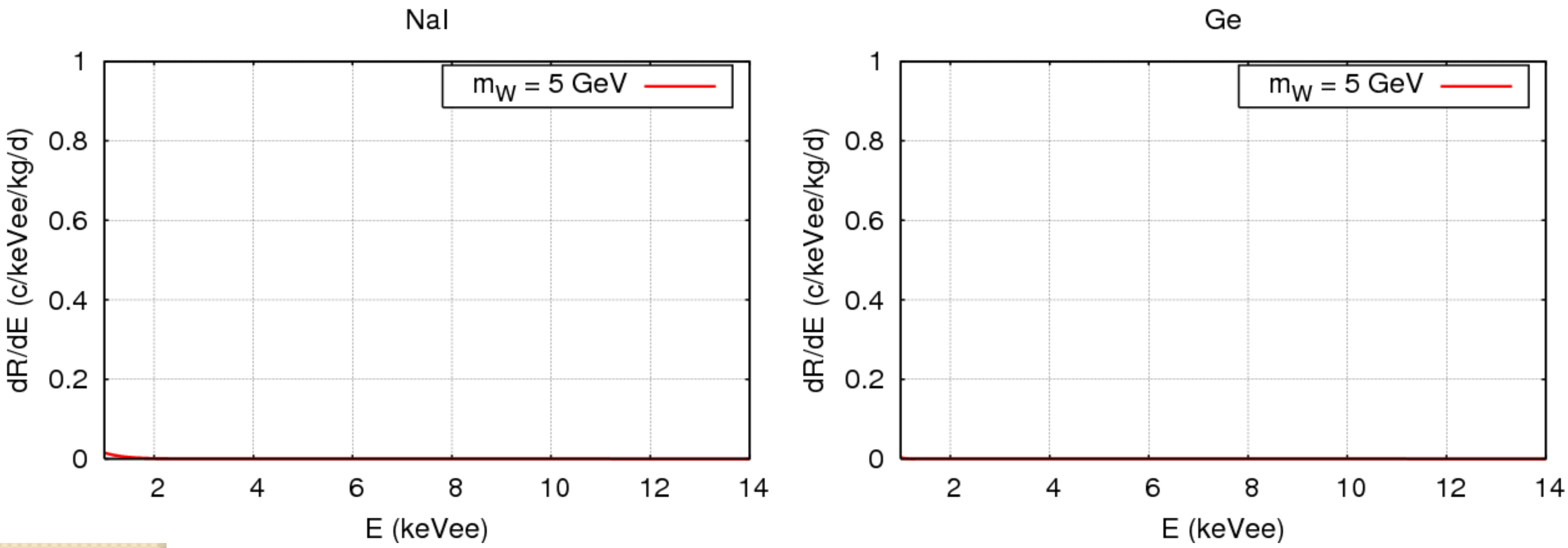


Dark Matter Interaction Rate

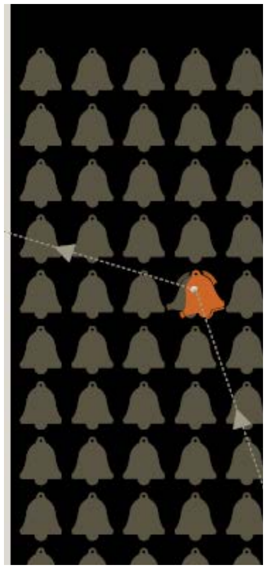
Recoil energy conversion into visible energy is strongly dependent on the technique, target, and particle interaction

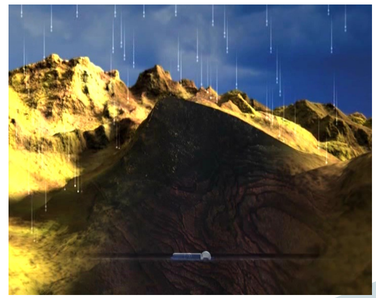
$E_R = Q\ E_{ee}$

$\sigma_{SI} = 7.2 \times 10^{-6}$ pb

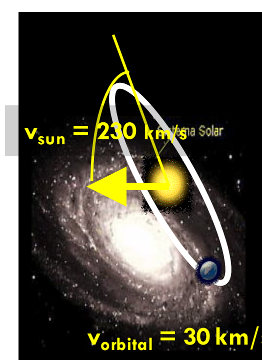


Strategy to face the Direct Detection of WIMPs inthe lab

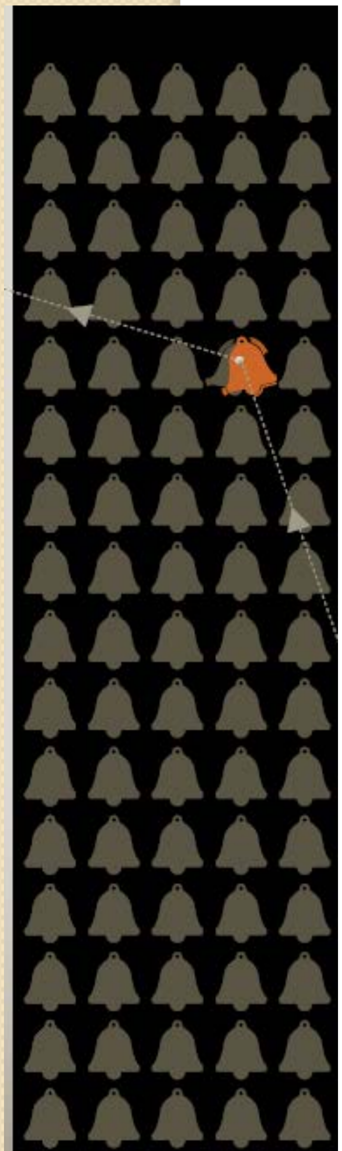




- We need very sensitive and radiopure Particle Detectors
- Experiments have to be shielded against all possible backgrounds and profit from active background rejection techniques
- Signatures of a Dark Matter interaction are very convenient for a positive result



Particle Detection Techniques

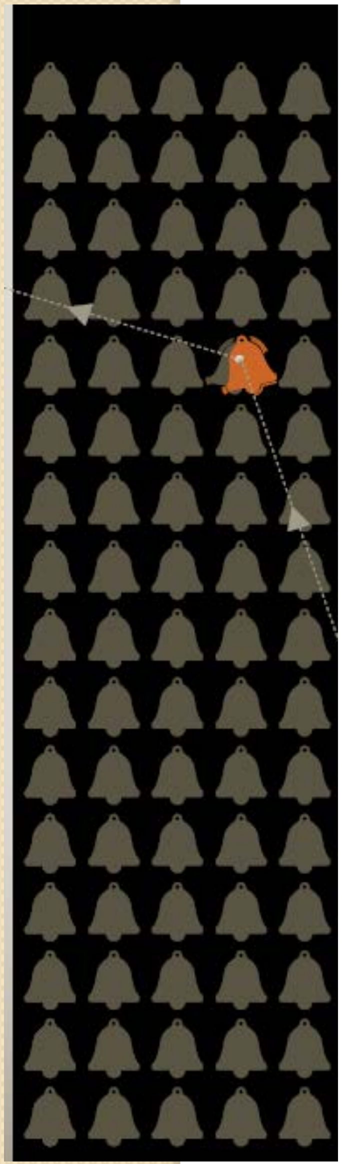


Detectors are those devices able to convert energy depositions of a particle passing through into a measurable signal

What Detectors are best suited for Dark Matter DIRECT DETECTION?

High Radiopurity Material	Wide Absorber Choice: Light+heavy isotopes, spin content
High Mass Availability	Modularity or spatial information on the interaction
Low Energy Threshold	Particle Discrimination capability
High Response to Nuclear Recoils	Low Price
Stability	State of the art

Particle Detection Techniques



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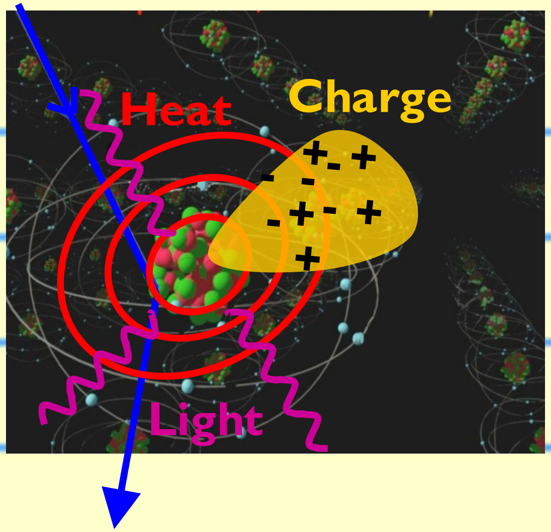
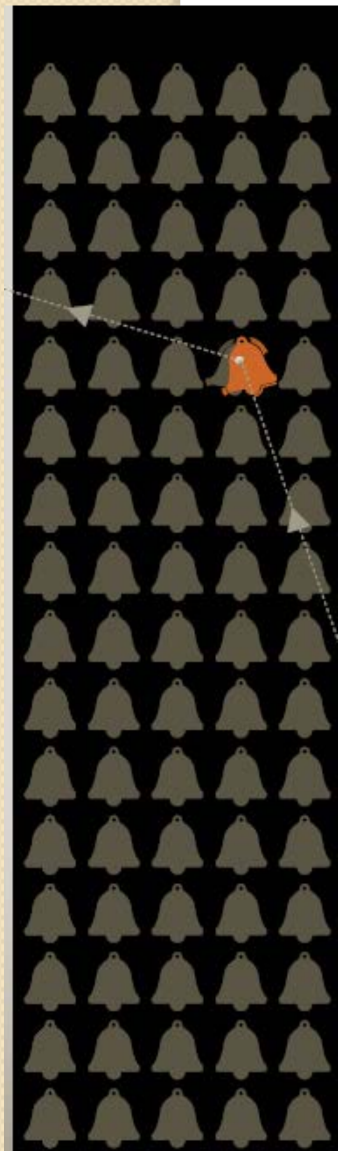
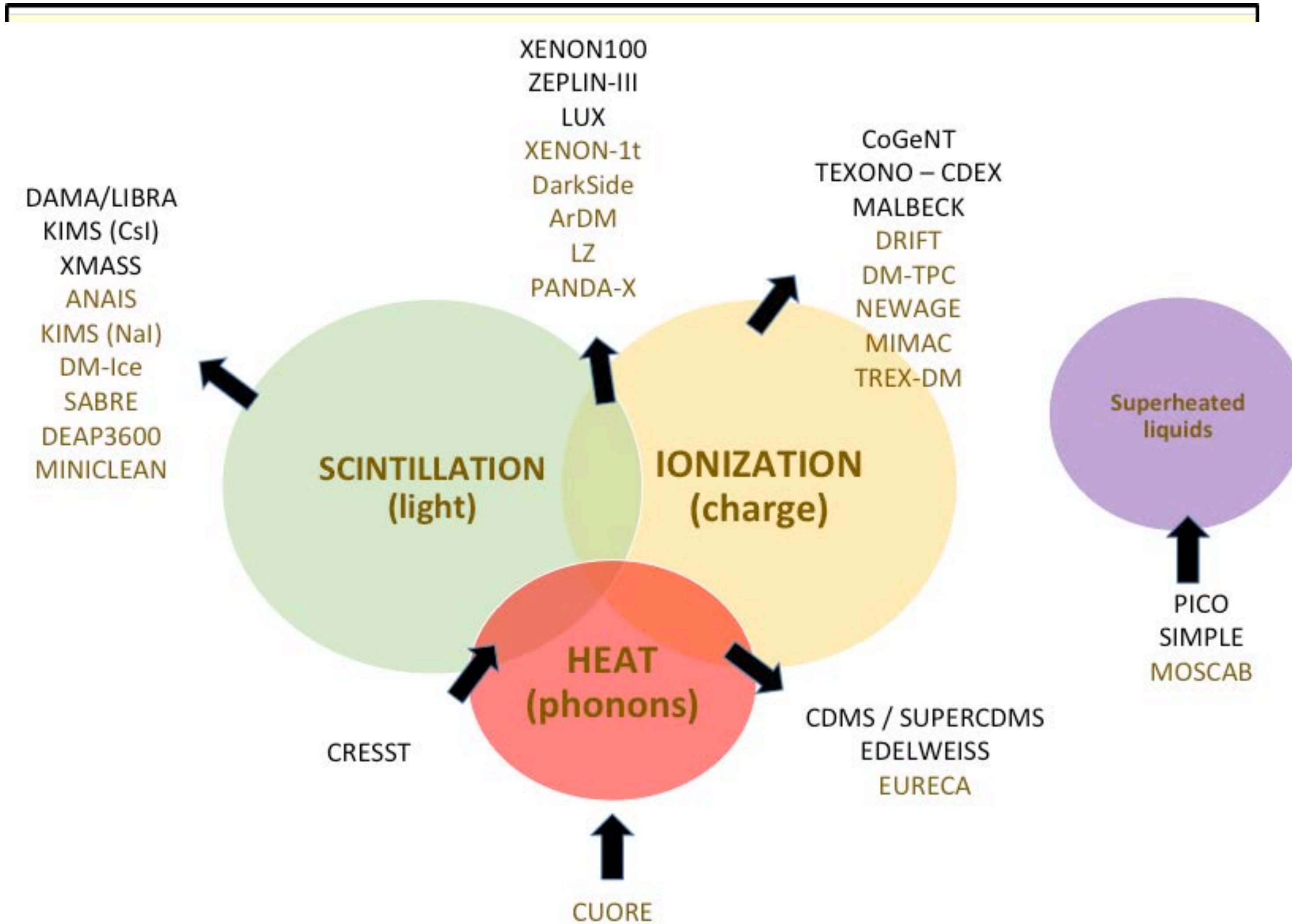


Energy conversion into VISIBLE signal is strongly dependent on the interaction mechanism, incident particle and target

HYBRID Detectors profit from the simultaneous measurement of two energy conversion channels for particle discrimination

Particle Detection Techniques





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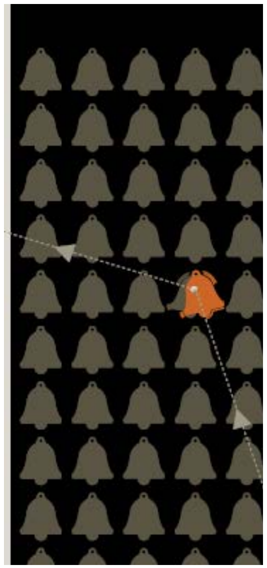

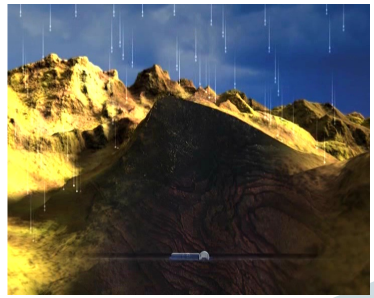

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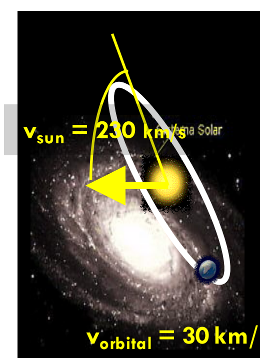
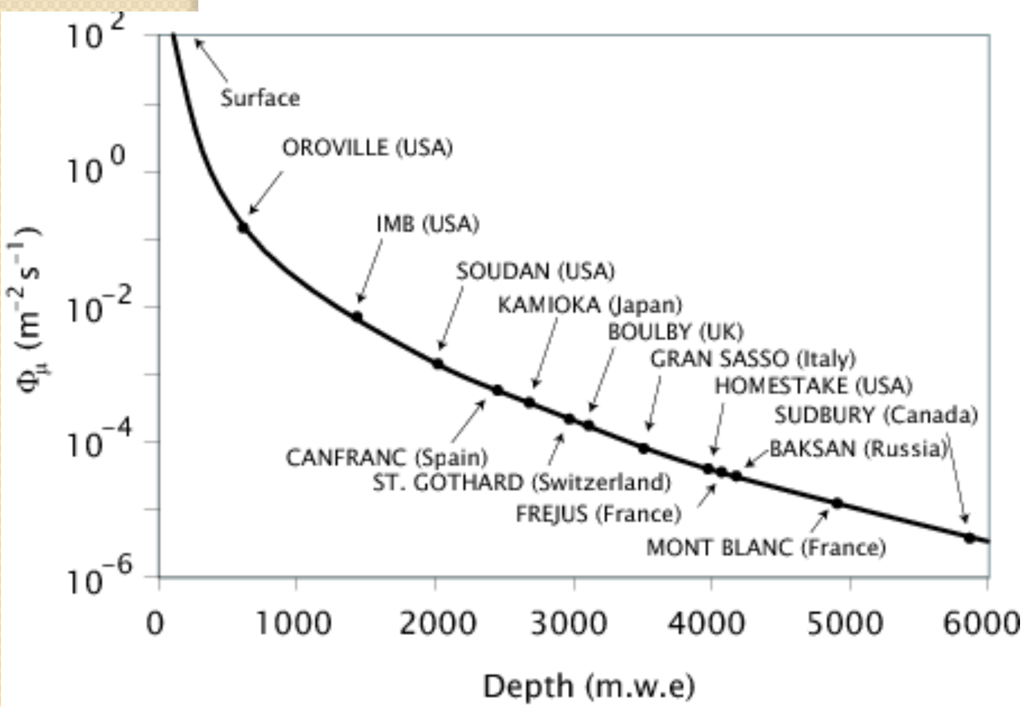
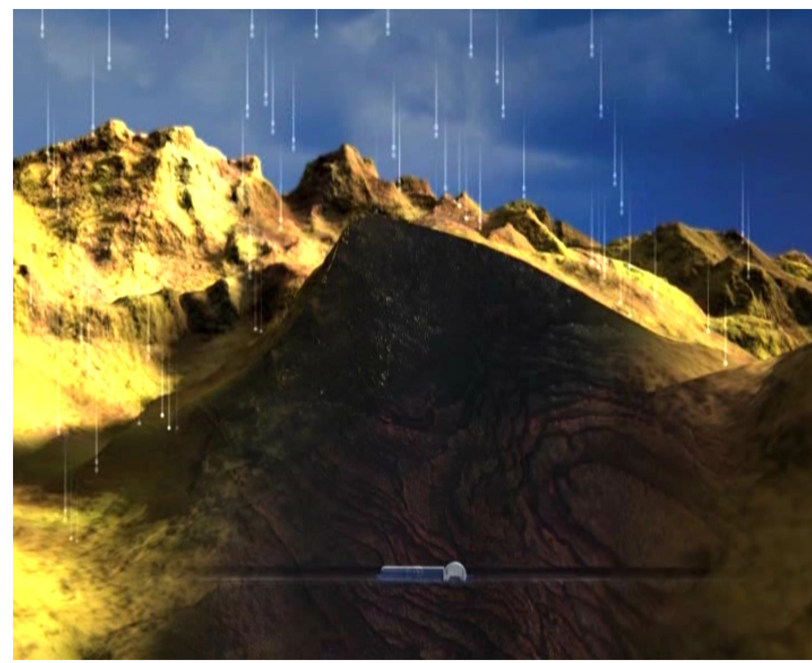


Shielding Strategies

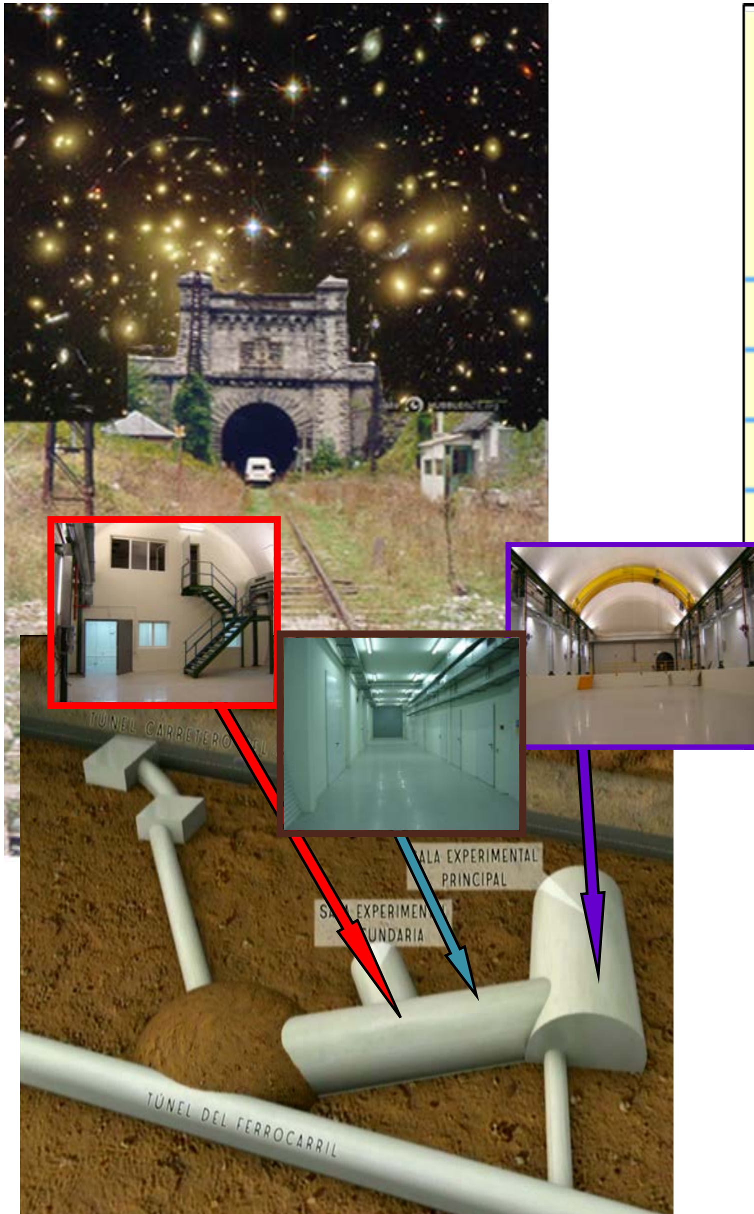
Background signals interferring with WIMP detection come from

-COSMIC Rays
-Environmental Radioactivity





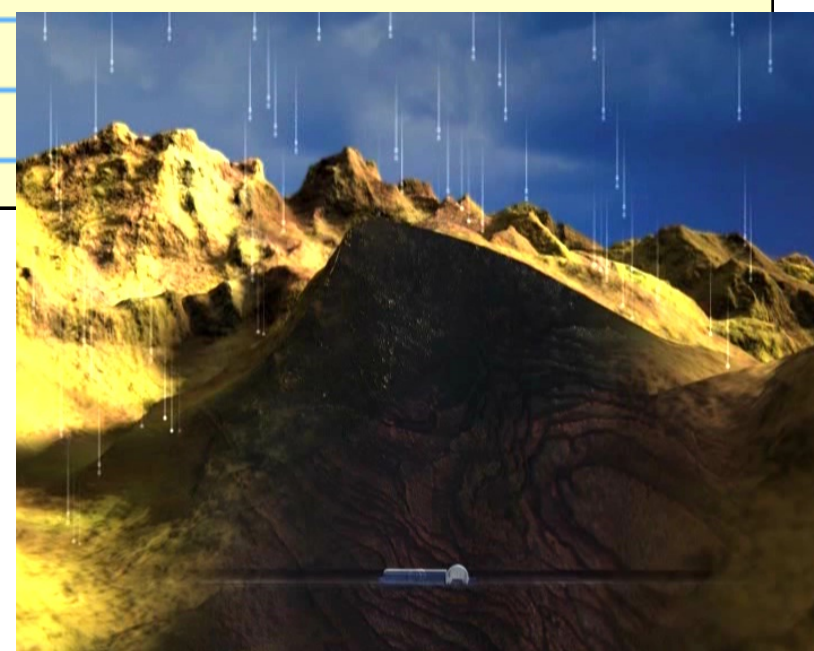
The Canfranc Underground Laboratory



Since 1985 an underground laboratory under the Pyrenees

2450 m.w.e. rock overburden

@ Somport railway tunnel



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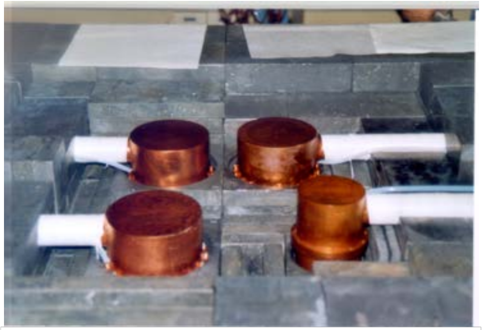
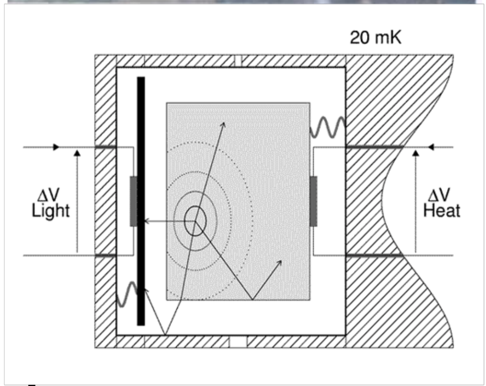


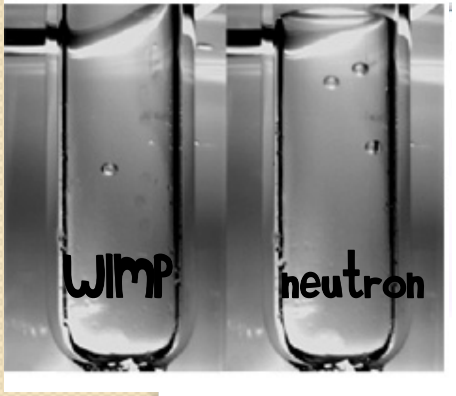


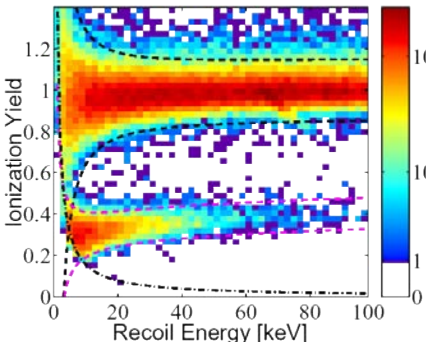
Convenient shieldings against:
Gammas, Neutrons, Muons, Radon intrusion

Active Background Rejection

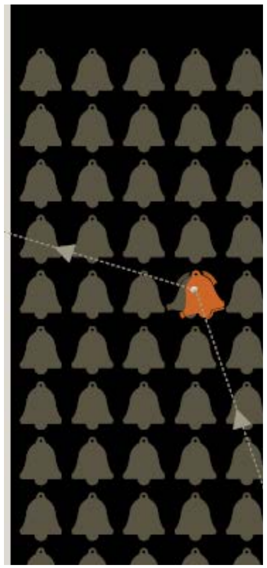
Nuclear recoils vs electron events

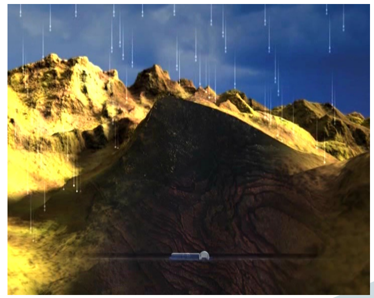
Neutron backgrounds under control considering multiple scattering and combination of different targets





Strategy to face the Direct Detection of WIMPs inthe lab

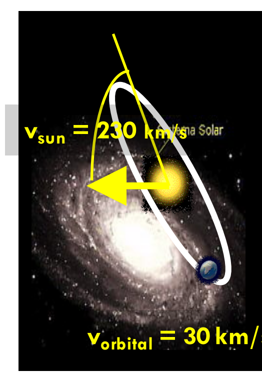




We need very sensitive and radiopure Particle Detectors

Experiments have to be shielded against all possible backgrounds and profit from active background rejection techniques

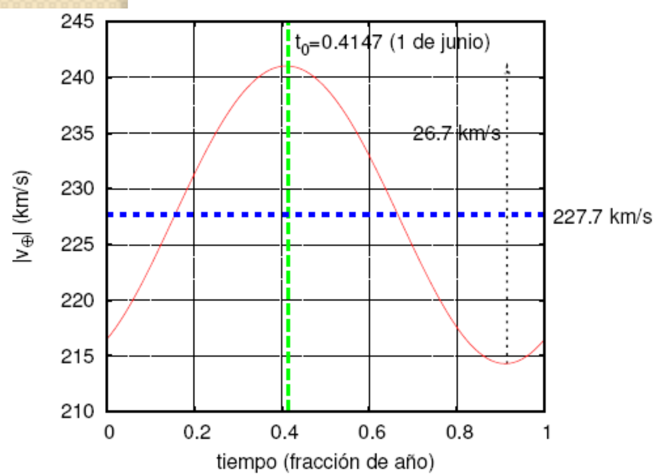
Signatures of a Dark Matter interaction are required for a positive result

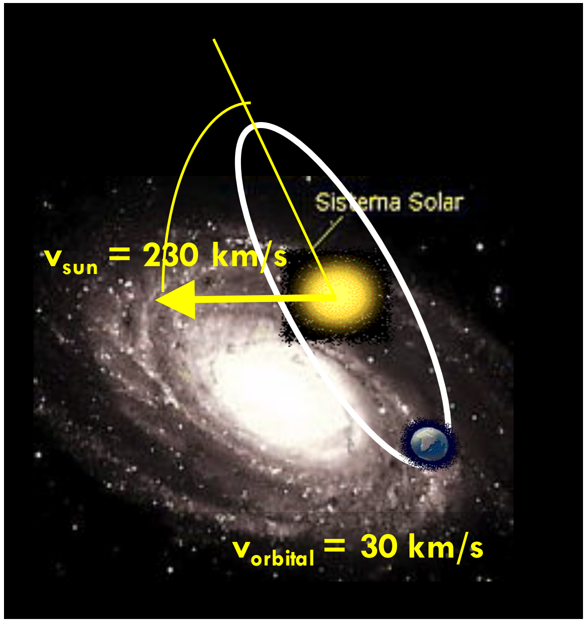


Dark Matter Signal Signatures

Positive identification of WIMP against backgrounds

- Annual modulation
- Directionality of recoils





$$\eta(t) = v_\oplus(t)/v_0 = \eta_0 + \Delta\eta cos\omega(t - t_0)$$

$$S_k(t) = S_{0,k} + S_{m,k} cos\omega(t - t_0)$$

Inverse modulation at very low energies

Small effect (<7% of S_0)

$\omega = 2\pi/365\ d^{-1}$

t_0 ~1st June

Review of the Experimental Status

One single experiment has reported evidence of a signal compatible with Dark Matter observing a model independent annual modulation

Other much sensitive experiments do not have any hint

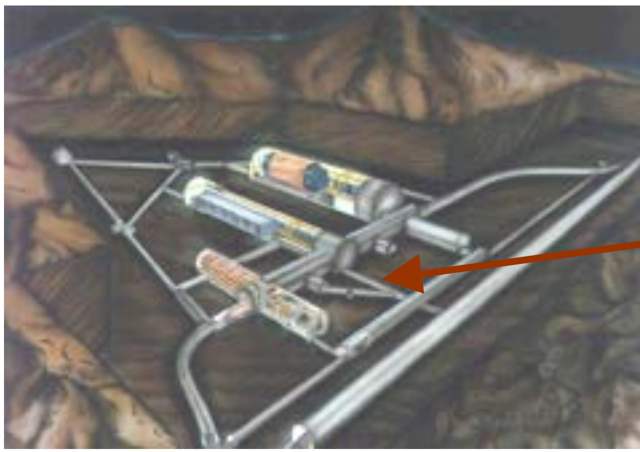
CONTROVERSIAL issue
Is possible a model independent confirmation or refutation?

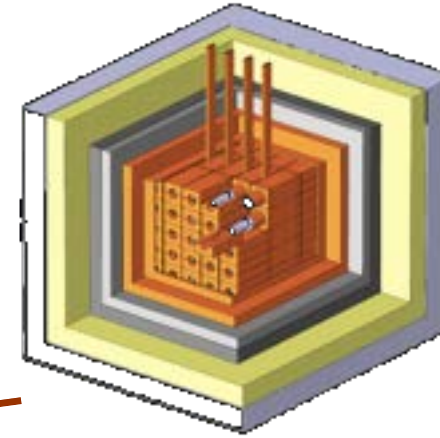
Many WIMP scenarios considering halo and particle models have been considered and reconciling experiments seems very difficult

Review of the Experimental Status

DAMA/LIBRA experiment

~250kg NaI(Tl) scintillators @ LNGS





Total exposure:
DAMA/NaI (100 kg NaI, 7 years, completed in 2002)
+ DAMA/LIBRA (250 kg NaI, 7 cycles, ongoing)
→ total exposure reported so far: 1.33 ton x year

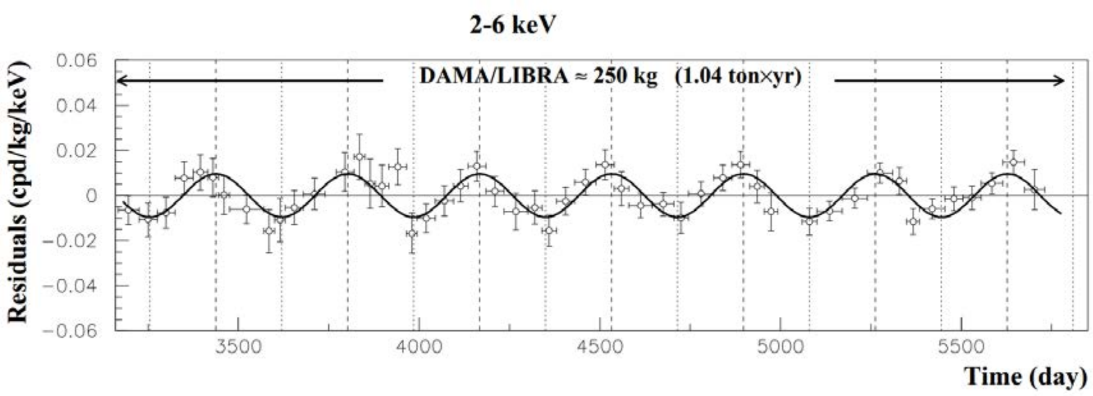
«Final model independent result of DAMA/LIBRA–phase1 » arXiv:1308.5109

Data taking ongoing after upgrade of PMTs

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result



A_m = 0.0112 ±0.0012 cpd/kg/keV
T = (0.998 ±0.002) y
T_0 = (144 ±7) d (2nd June=153)
No modulation above 6 keV

Evidence (9.3 σ C.L.) of an annual modulation of the *single-hit* events in the (2–6) keVee energy region satisfying all the requests of a DM component in the galactic halo

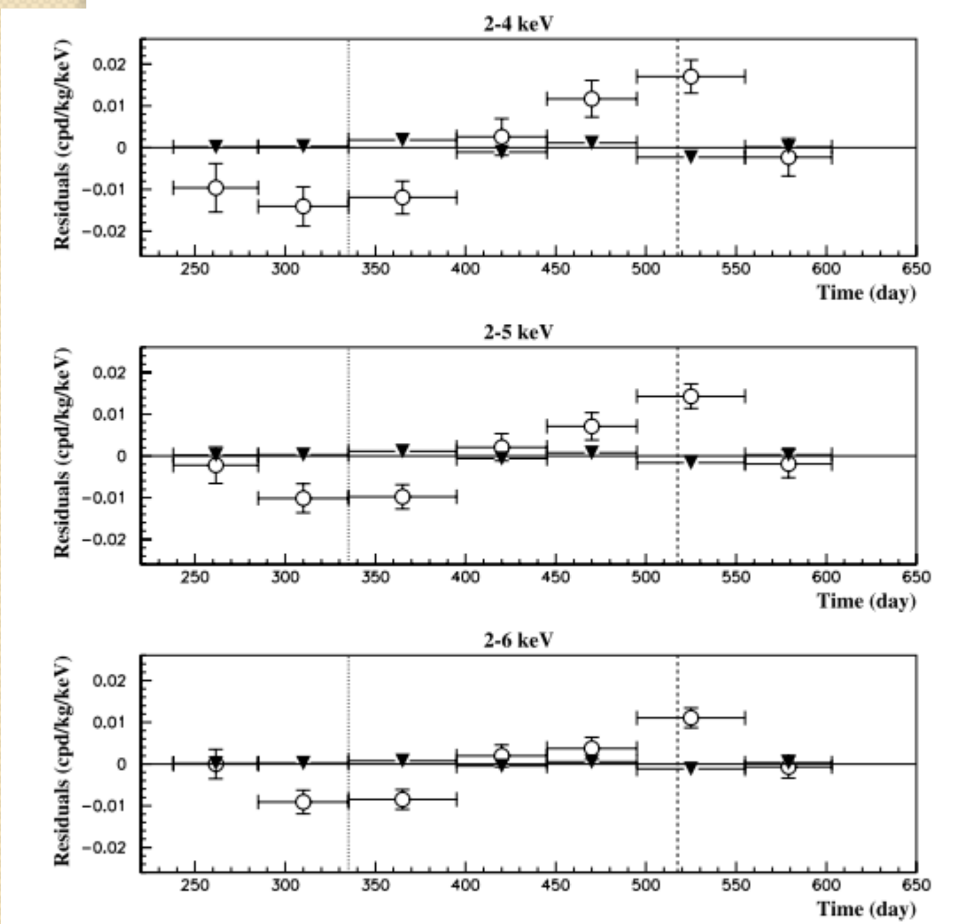
Total exposure:
DAMA/NaI (100 kg NaI, 7 years, completed in 2002)
+ DAMA/LIBRA (250 kg NaI, 7 cycles, ongoing)
→ total exposure reported so far: 1.33 ton x year

«Final model independent result of DAMA/LIBRA–phase1 » arXiv:1308.5109

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result



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No modulation above 6 keV

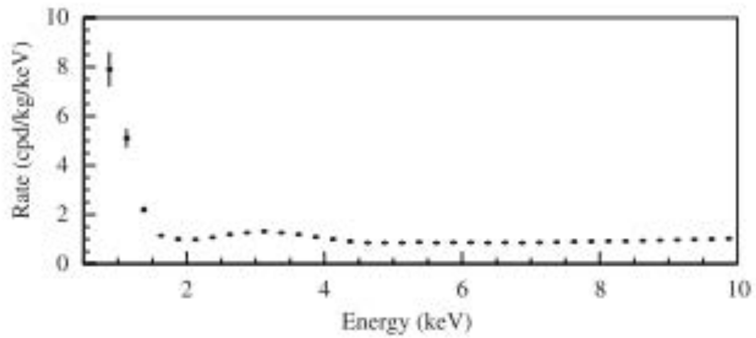
Evidence (9.3 σ C.L.) of an annual modulation of the *single-hit* events in the (2—6) keVee energy region satisfying all the requests of a DM component in the galactic halo

Modulation disappears when looking at multiple hit events due to background

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result



Average Rate at low energies at 1 evt/keV/kg day

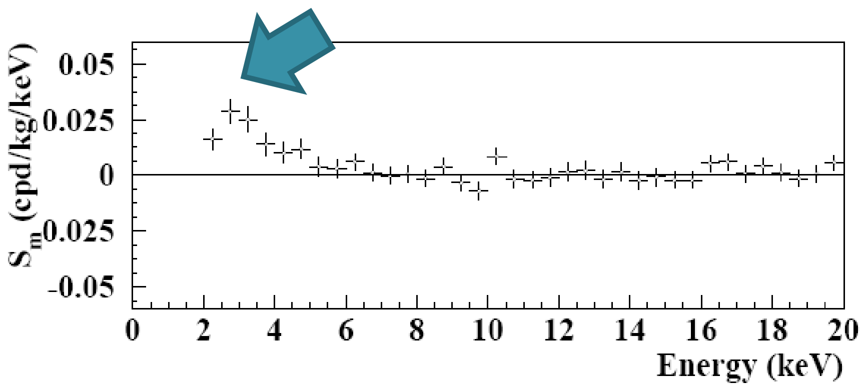


Figure 9: Energy distribution of the $S_{m,k}$ variable for the total exposure (0.82 ton×yr, DAMA/NaI & DAMA/LIBRA). See text. A clear modulation is present in the lowest energy region, while $S_{m,k}$ values compatible with zero are present just above. In fact, the $S_{m,k}$ values in the (6–20) keV energy interval have random fluctuations around zero with χ^2 equal to 24.4 for 28 degrees of freedom. See also Appendix A.

Modulation amplitude zero crossing could fix the WIMP mass and would be very distinctive!! Reducing threshold is important

Review of the Experimental Status

DAMA/LIBRA experiment

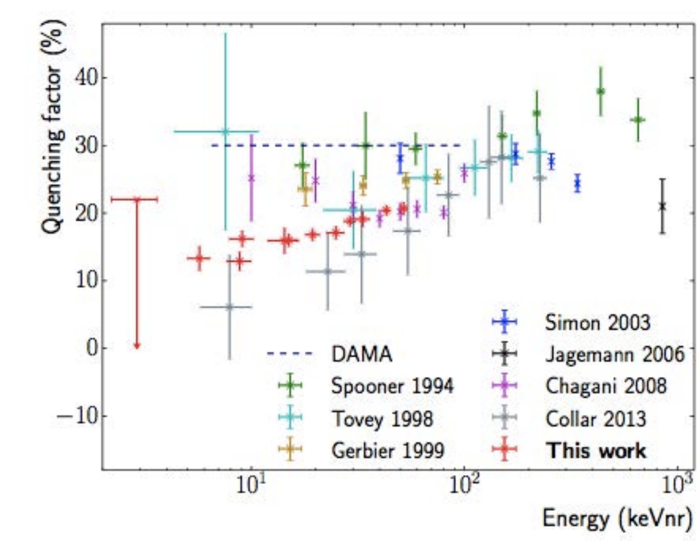
Annual Modulation

Systematics difficult to analyse

Still some things to understand better

Na and I Quenching Factors

Colaboración	Q Na	Q I
UKDMC	0,31	0,09
	$0{,}275 \pm 0{,}018$	$0{,}086 \pm 0{,}007$
DAMA	0,30	0,09
Saclay-NaI	$0{,}25 \pm 0{,}03$	$0{,}08 \pm 0{,}002$
ELEGANTS V	$0{,}4 \pm 0{,}2$	$0{,}05 \pm 0{,}02$

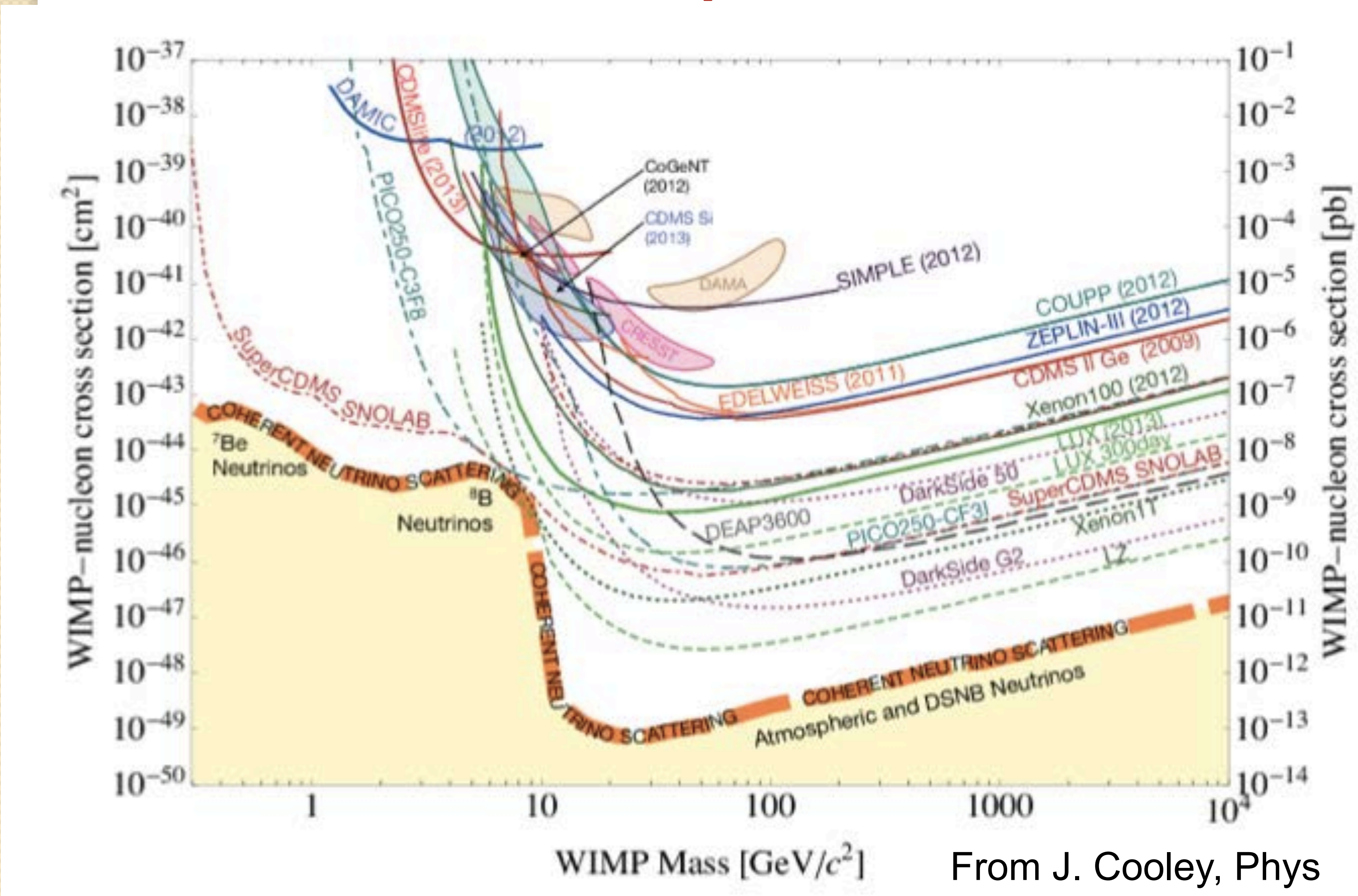


J. Xu et al, 1503.07212

Recent measurements point at strong energy dependence!!!

Review of the Experimental Status

Difficult to review all the experiments in the field!!!



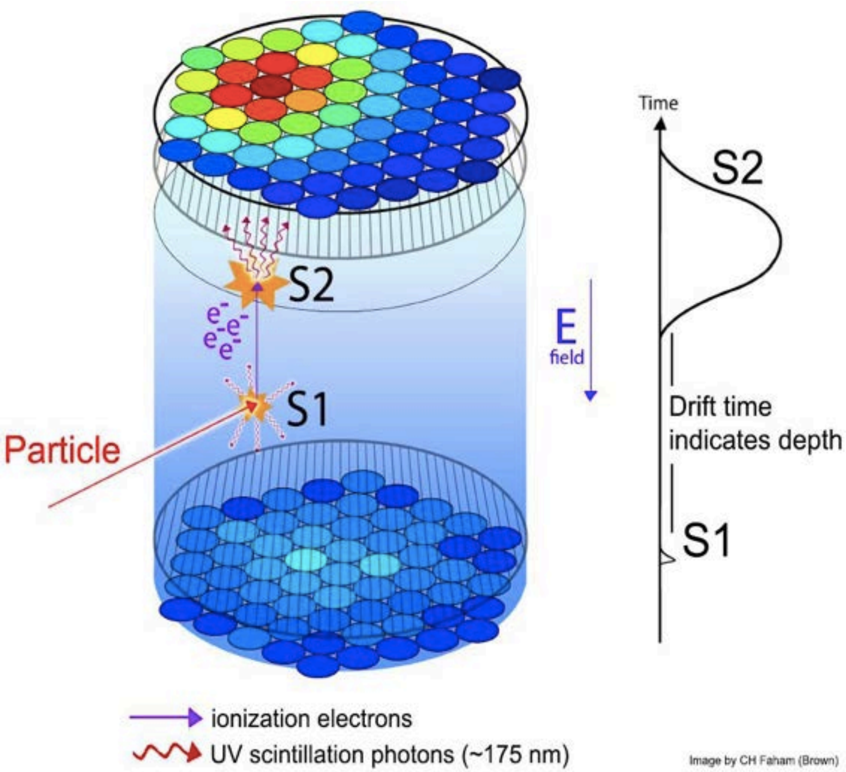
From J. Cooley, Phys Dark Universe 4 (2014)

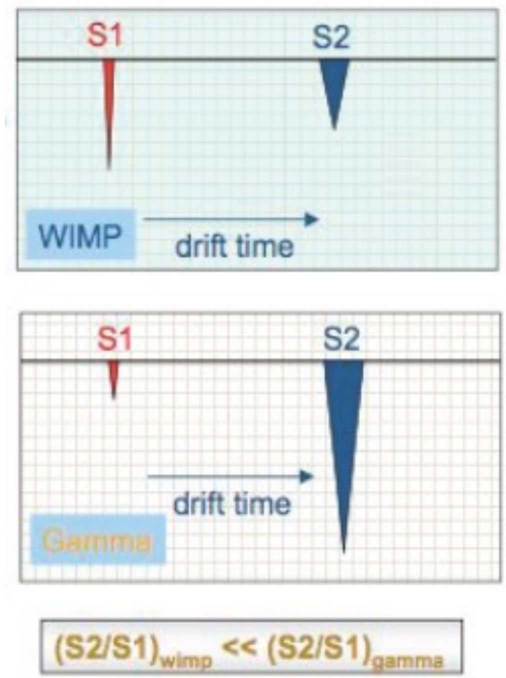
Review of the Experimental Status

Most sensitive experiments

Xe double phase TPC

LUX @ Sanford Laboratory (350 kg)





Review of the Experimental Status

Most sensitive experiments

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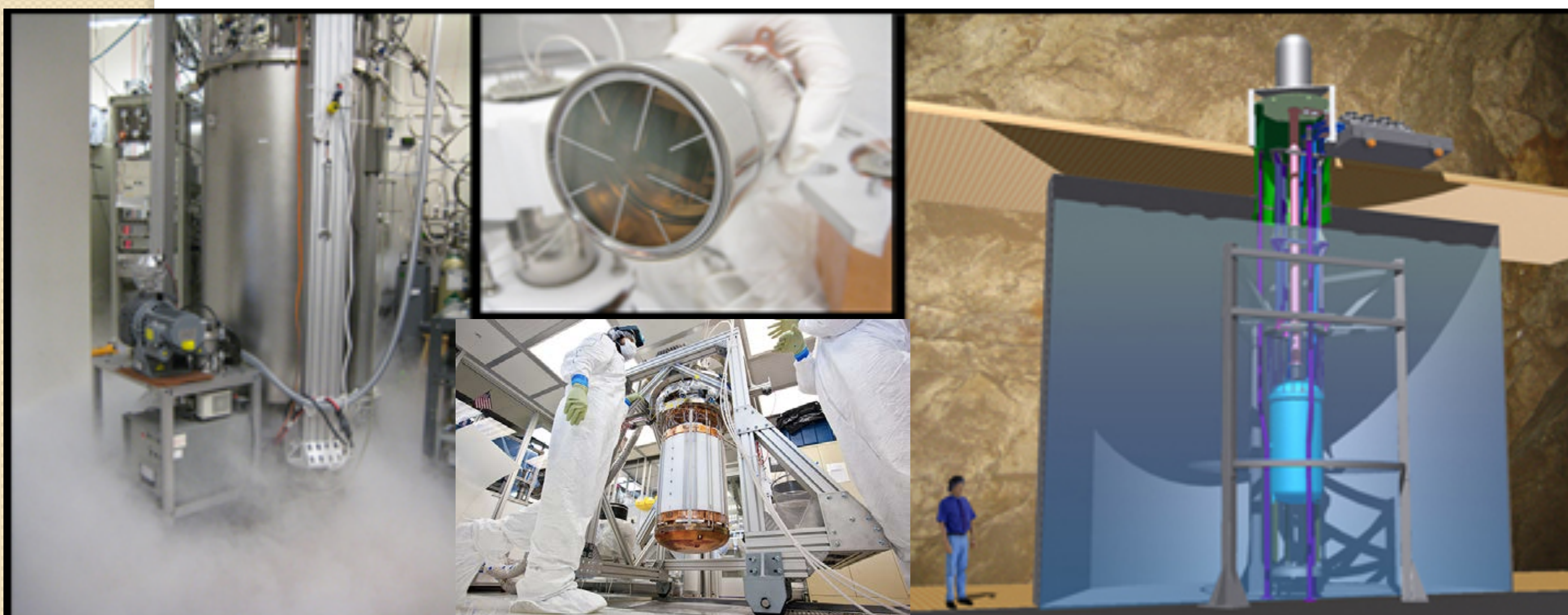

Review of the Experimental Status

Most sensitive experiments

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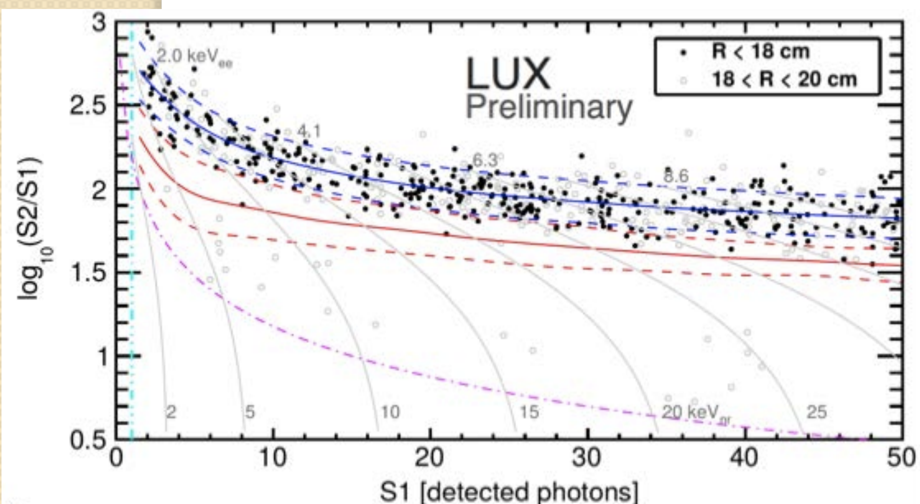
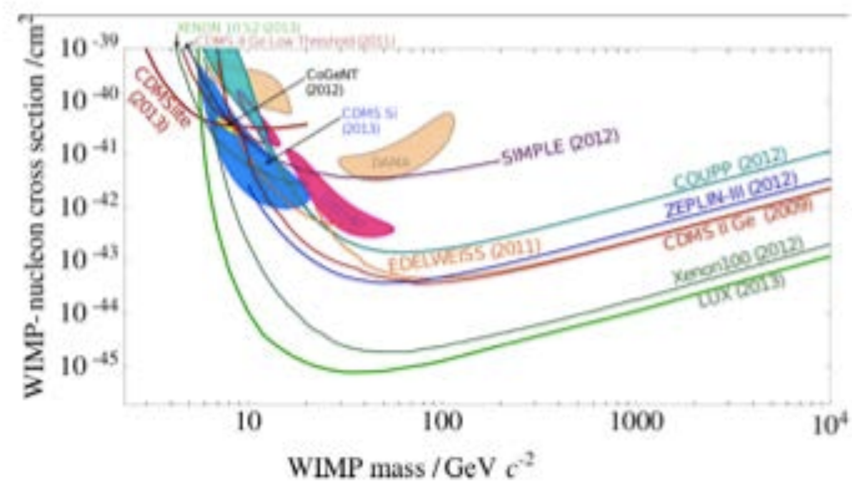




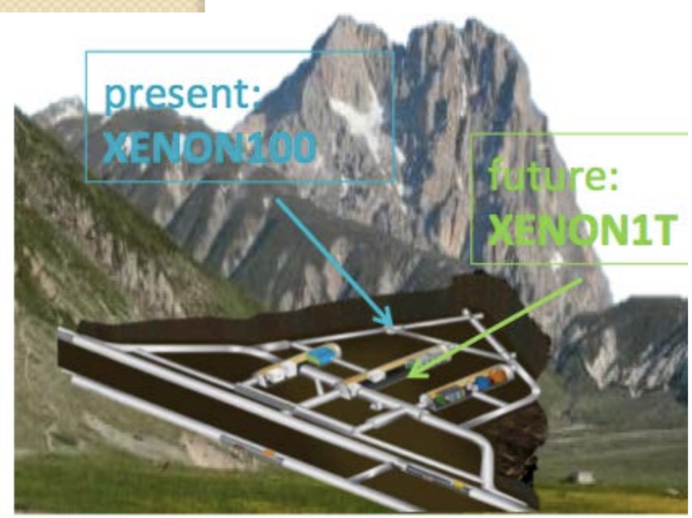
- **95 days** net (previously 85 d)
- **145 kg** fiducial (118 kg)
- conservative **1.2 keV** signal cutoff →**3.3 GeV** m_{min} (3.0 keV, 5.2 GeV)

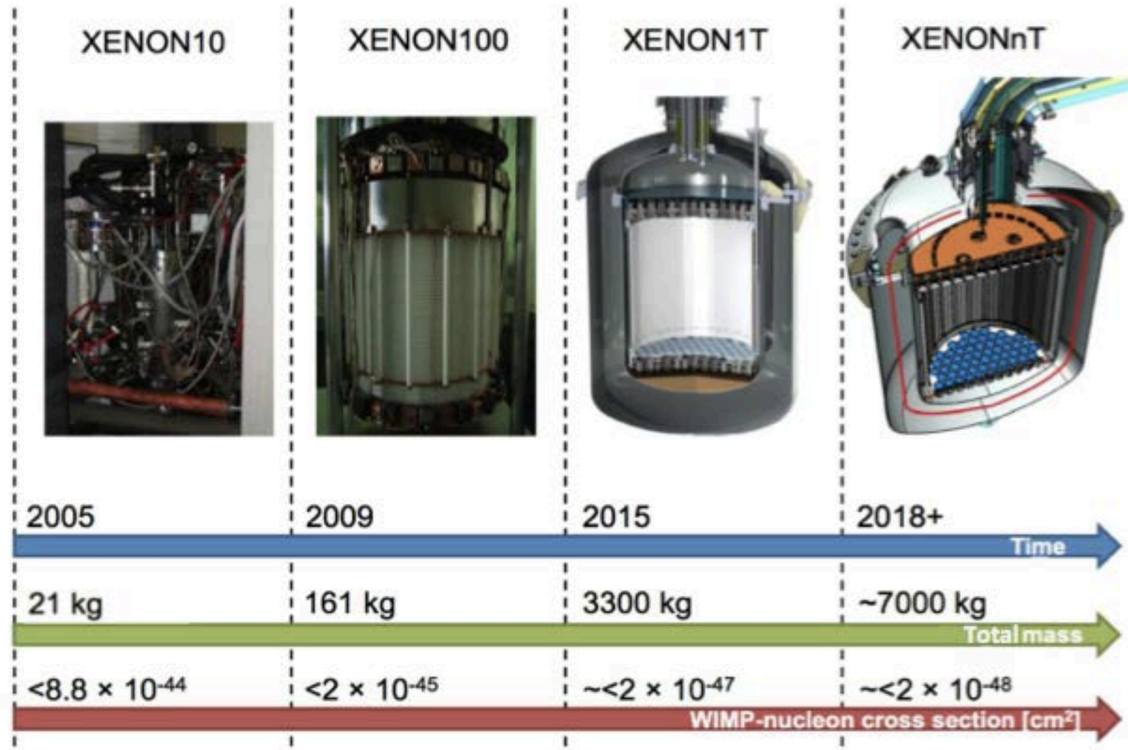
Review of the Experimental Status

Most sensitive experiments

Xe double phase TPC

XENON100 & XENON1T @ LNGS





Review of the Experimental Status

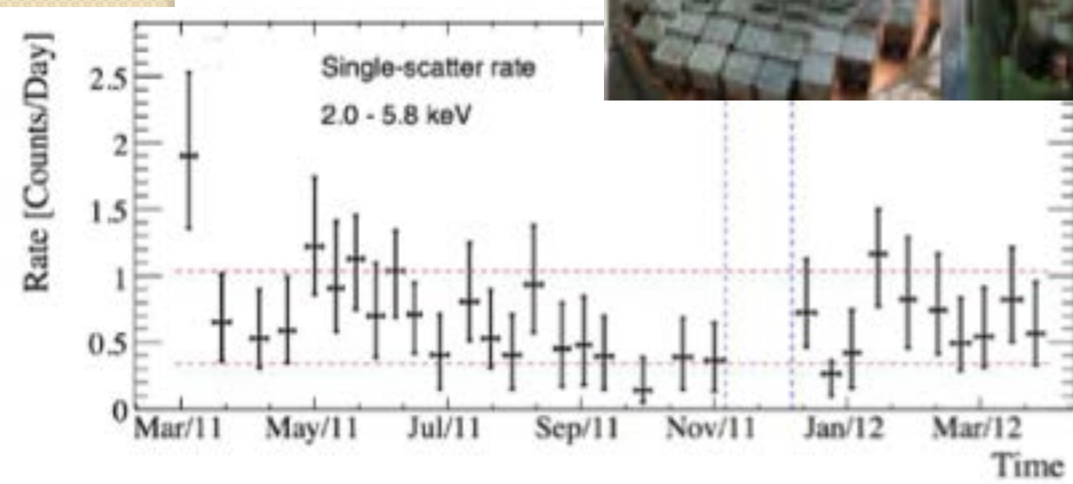
Most sensitive experiments

Xe double phase TPC

XENON100 &

- 161 kg LXe TPC

(62 kg target + 99 kg active veto)



Study of annual modulation with electron recoils

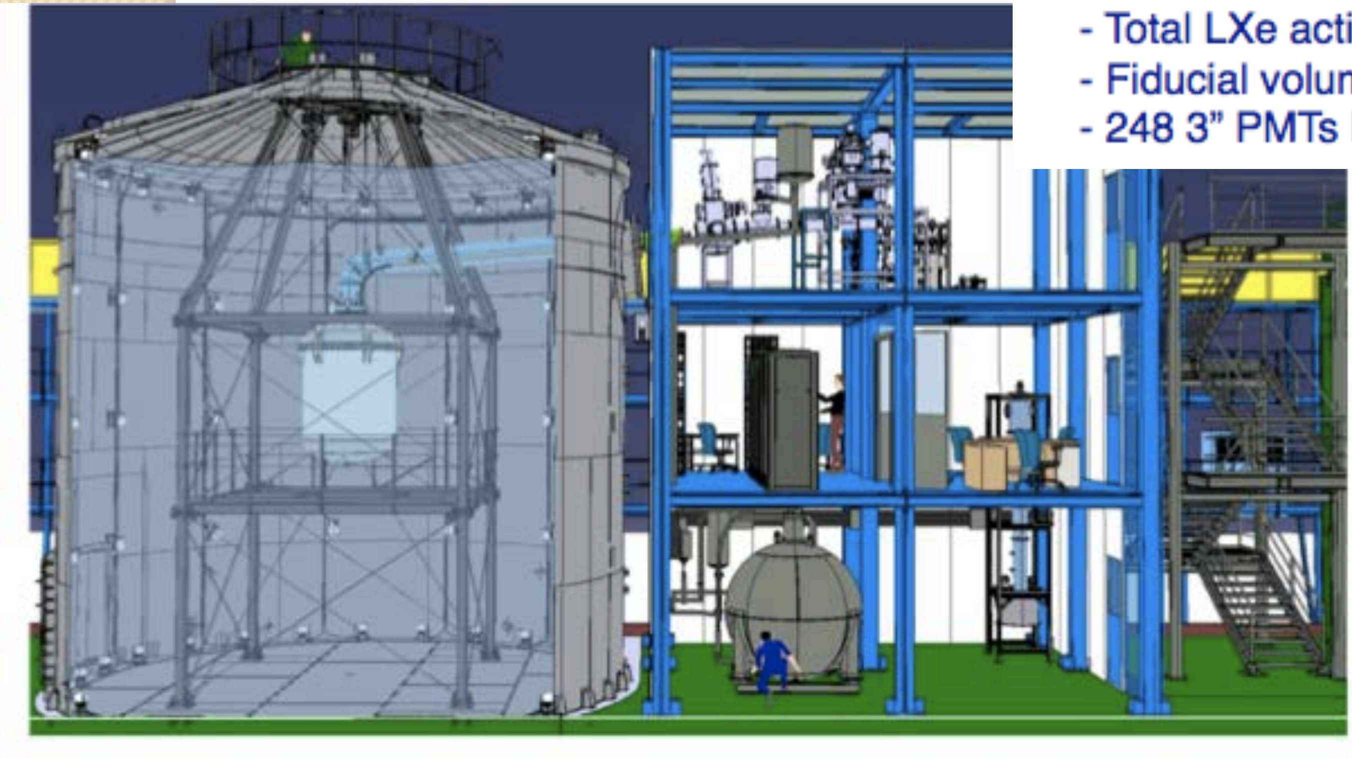
Review of the Experimental Status

Most sensitive experiments

Xe double phase TPC

XENON100 & XENON1T @ LNGS

- Total LXe mass: ~3.3 tonnes
- Total LXe active volume: ~ 2 tonnes
- Fiducial volume: ~1 tonne
- 248 3" PMTs Hamamatsu R11410-21

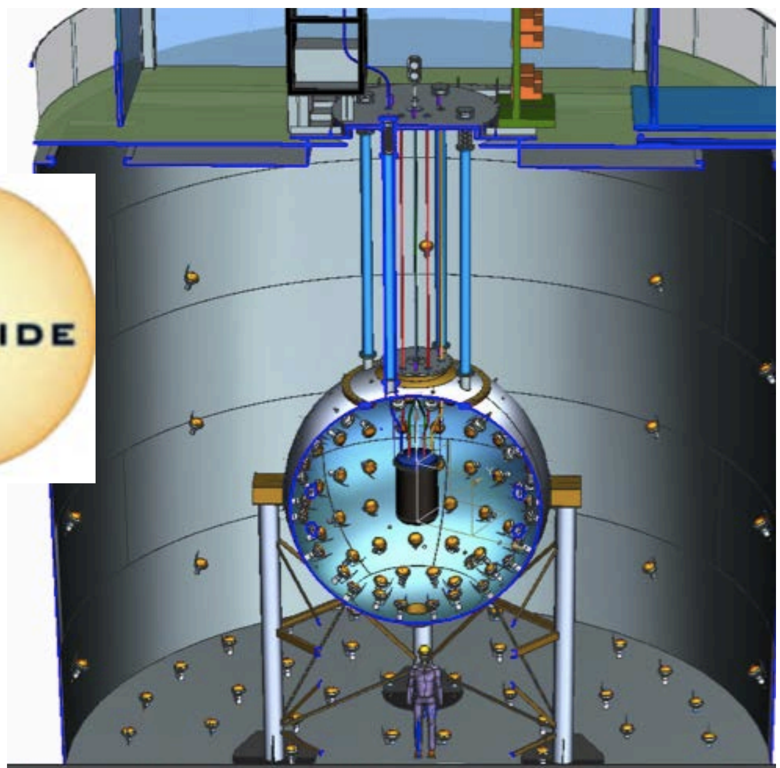


Review of the Experimental Status

Most sensitive experiments

Ar double phase TPC

DarkSide @ LNGS

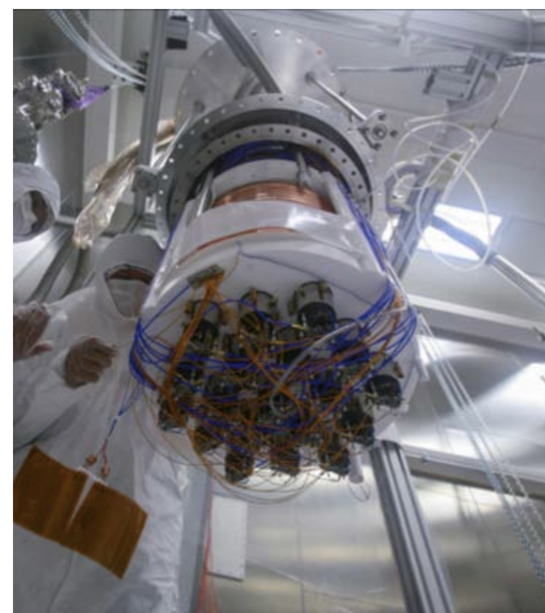


Pulse shape discrimination

Liquid Scintillator for n

Water tank for muons

Free from ^{39}Ar



Review of the Experimental Status

Most sensitive experiments

Ar double phase TPC

DarkSide @ LNGS

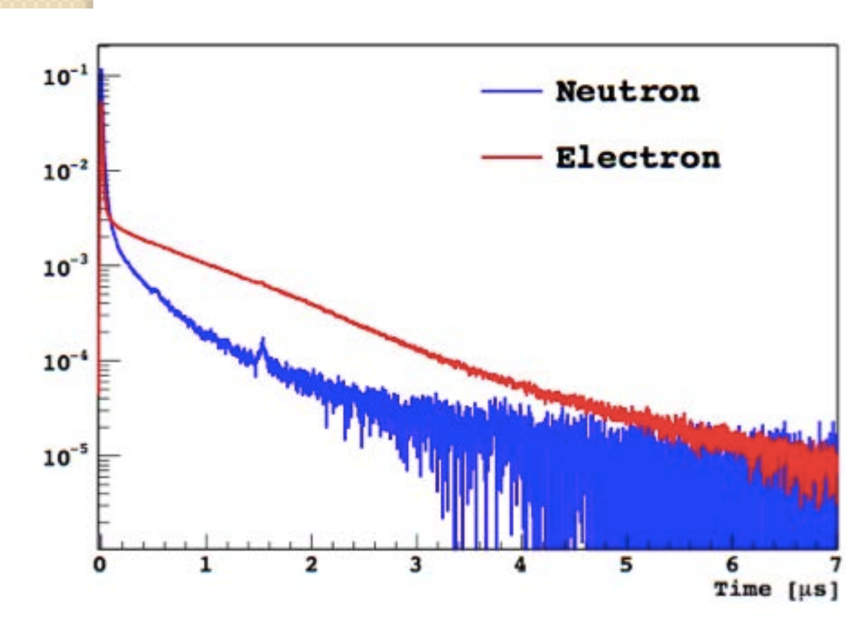
46 kg active 153 kg total

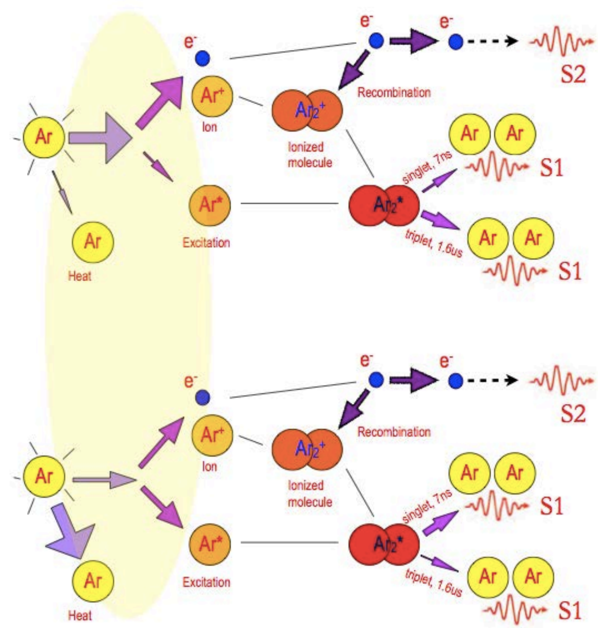
Pulse shape discrimination

Liquid Scintillator for n

Water tank for muons

Free from ^{39}Ar





ER

NR

Review of the Experimental Status

Most sensitive experiments

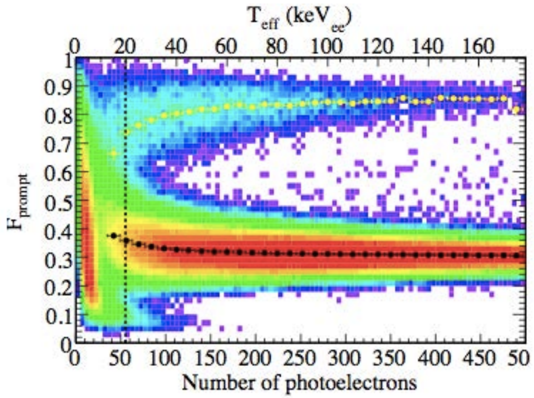
Ar single phase liquid scintillation detector

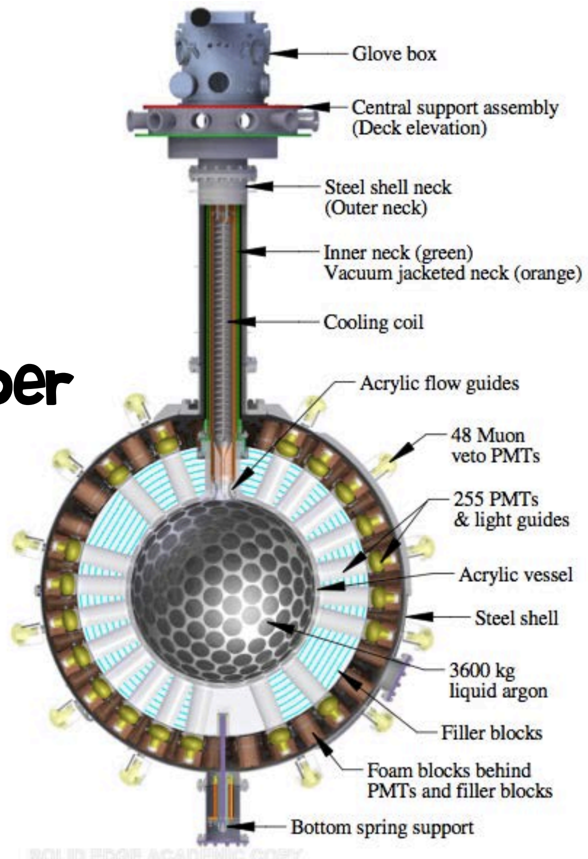
DEAP @ SNOLAB

3600 kg LAr

Excellent PSD capability

Cool down and Ar filling last September





Review of the Experimental Status

Most sensitive techniques

Scintillating Bolometers

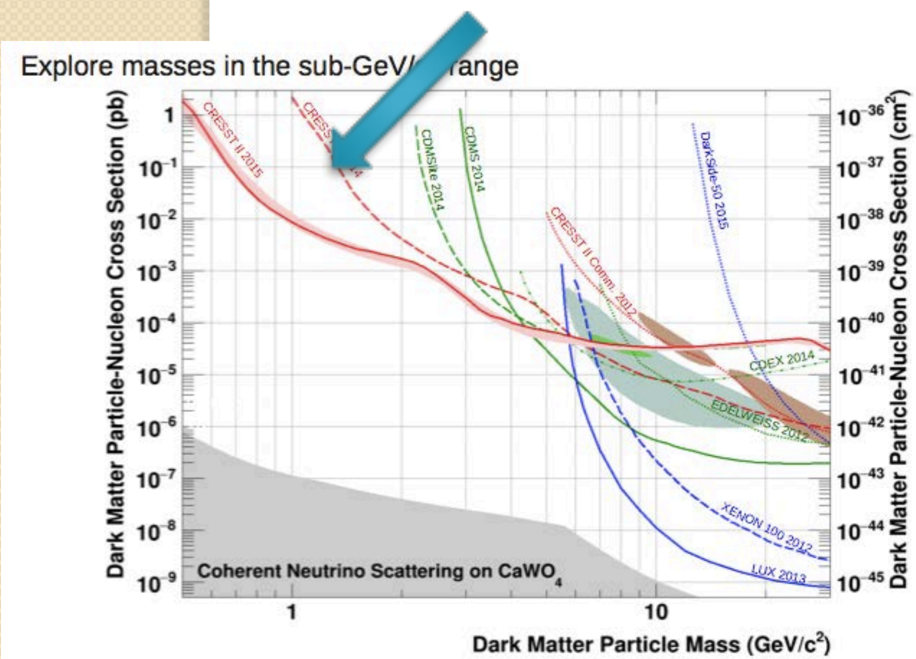
CRESST @ LNGS

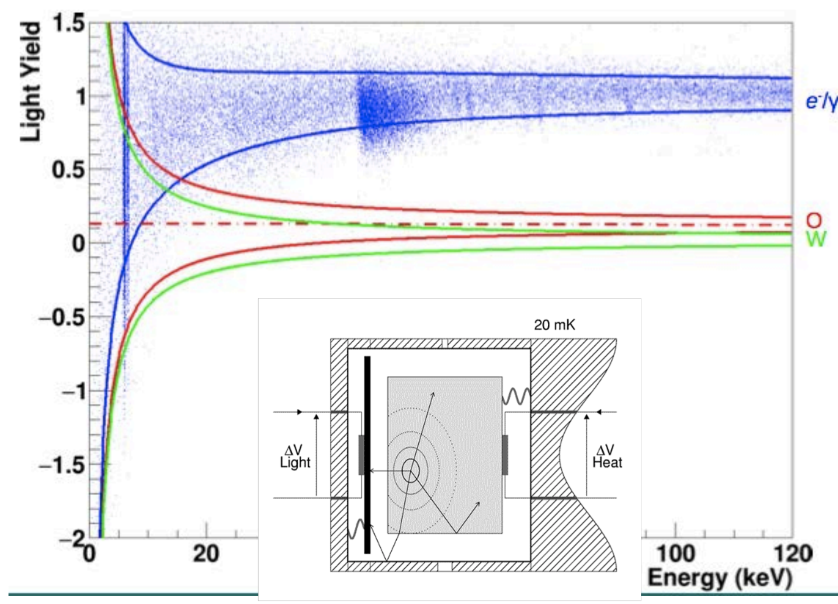
$CaWO_4$ bolometers

300 eV threshold

52 kg days exposure

Very good discrimination





Review of the Experimental Status

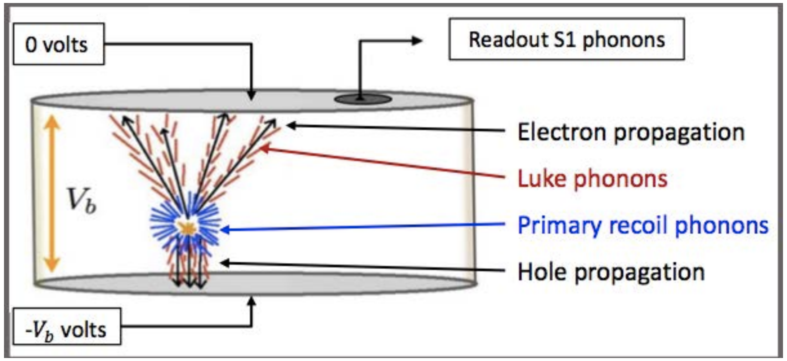
Most sensitive experiments

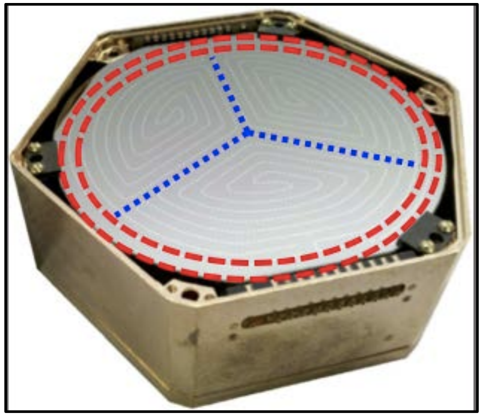
Heat Ionization Bolometers

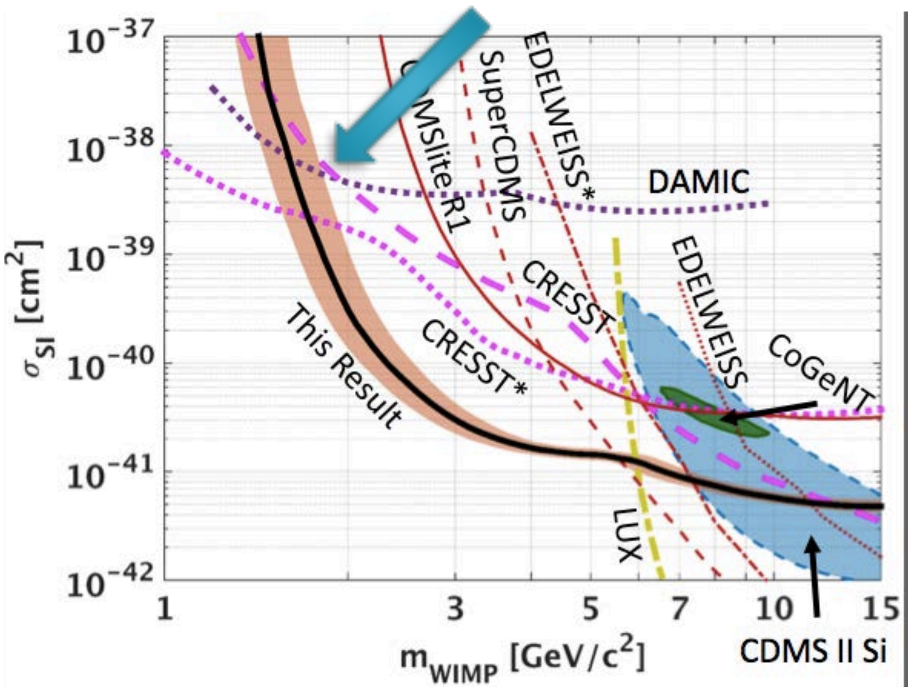
CDMS Lite @ SOUDAN

<100 eV Ionization Trigger
70 kg day exposure

Further improvement expected after moving into SNOLAB





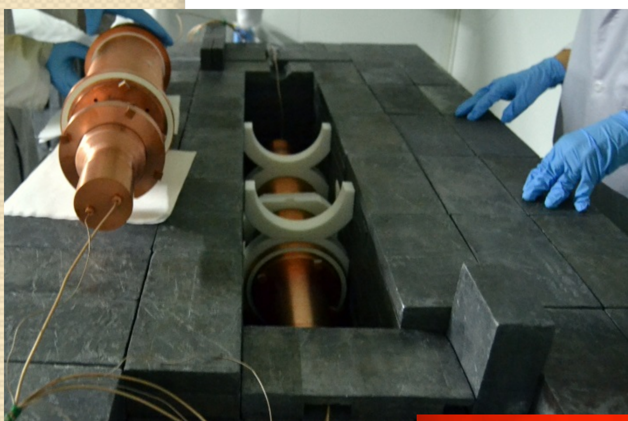


Review of the Experimental Status

Experiments trying to reproduce DAMA LIBRA signal

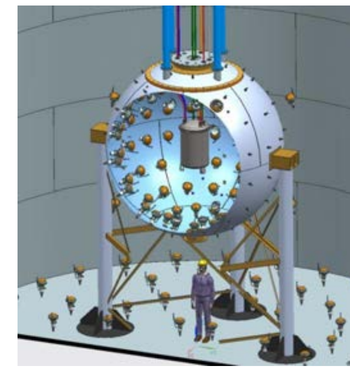
NaI scintillators (same target and technique)

ANAIS @ LSC (2000 - ...)

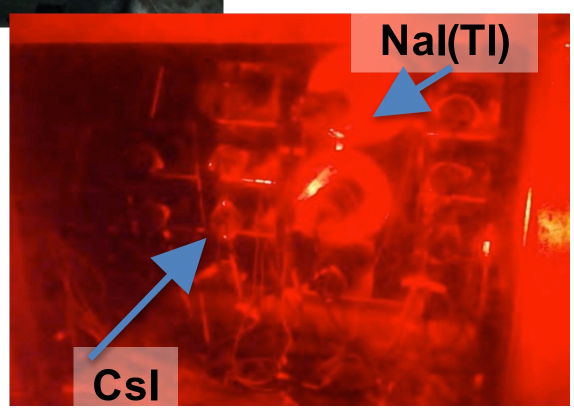


DM-ICE @ South Pole (2011 - ...)

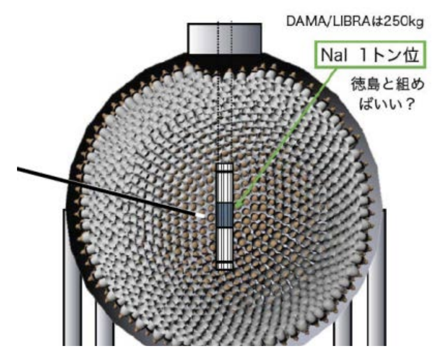
Annual modulation analysis recently published



SABRE project



KIMS @ Y2L (2013 - ...)



KAMLAND-PICO @ KAMIOKA (2014 - ...)

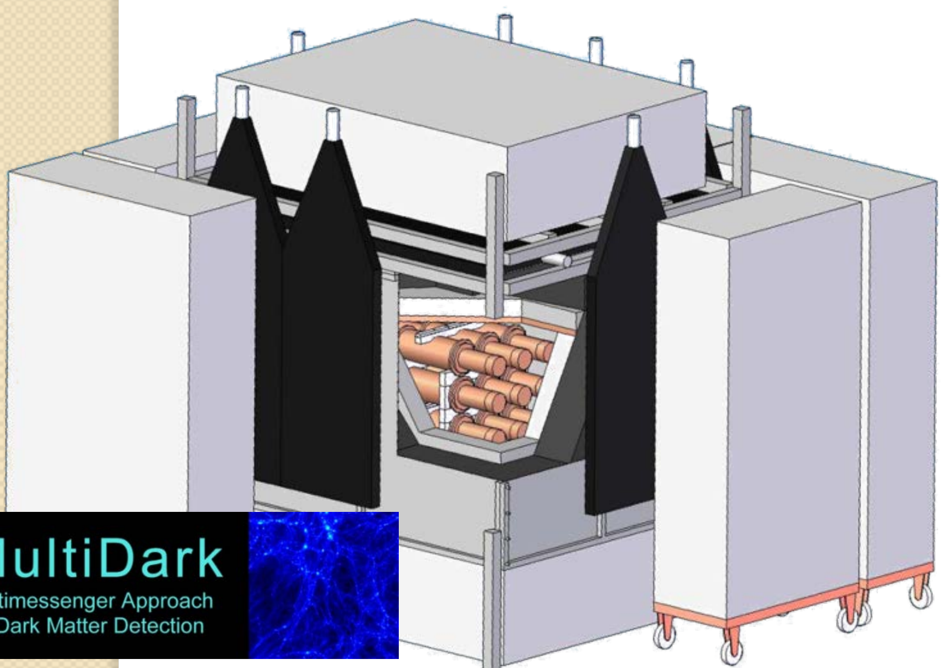
Review of the Experimental Status

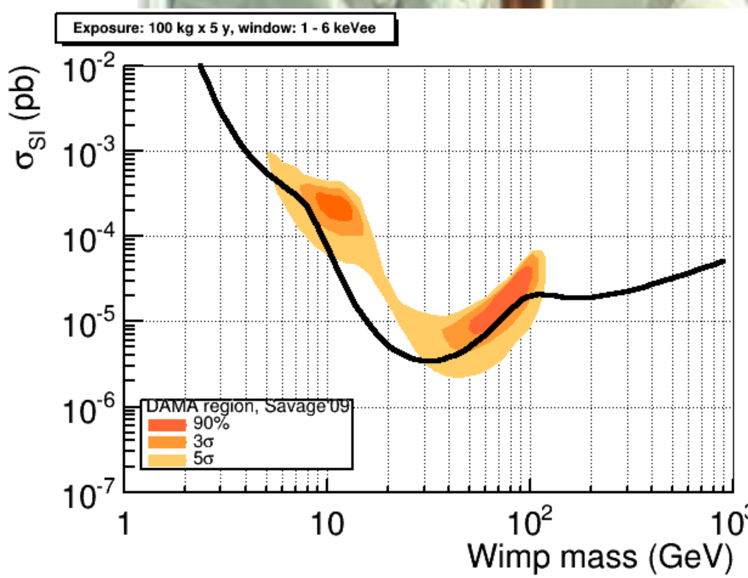
Experiments trying to reproduce DAMA LIBRA signal

NaI scintillators (same target and technique)

ANAIS @ Canfranc

112 kg of ultrapure NaI(Tl)





MultiDark
Multimessenger Approach
for Dark Matter Detection

COMBINED ANALYSIS of 220 kg NaI(Tl) with present background levels

112.5 kg at Canfranc, Spain

+

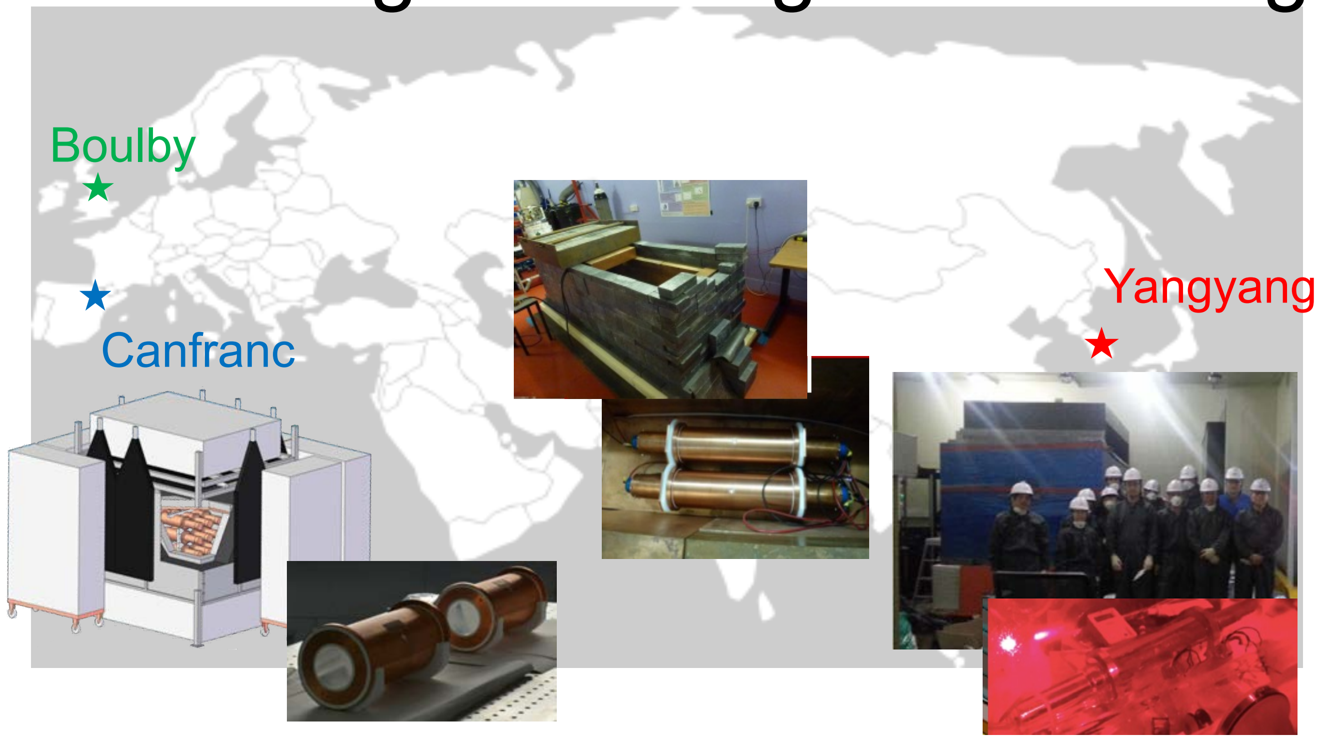
107 kg at Yangyang, South Corea

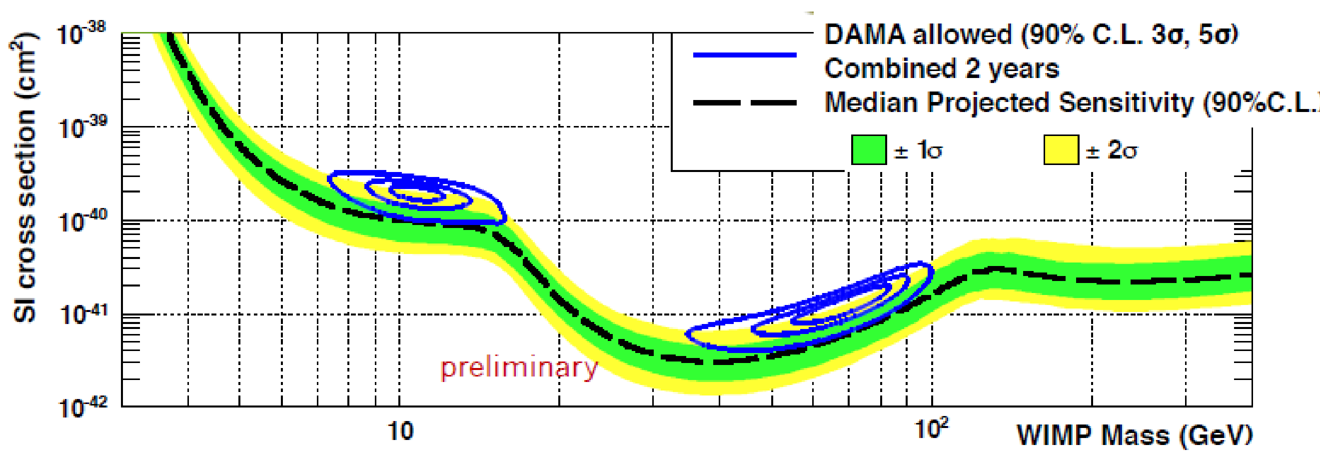
Data taking of both set-ups foreseen to start in 2016

Two years of data taking could explore the whole DAMA-LIBRA single out parameter space

ANAIS + DM-Ice + KIMS

112.5 kg 55 kg 52 kg





Review of the Experimental Status

Other Techniques

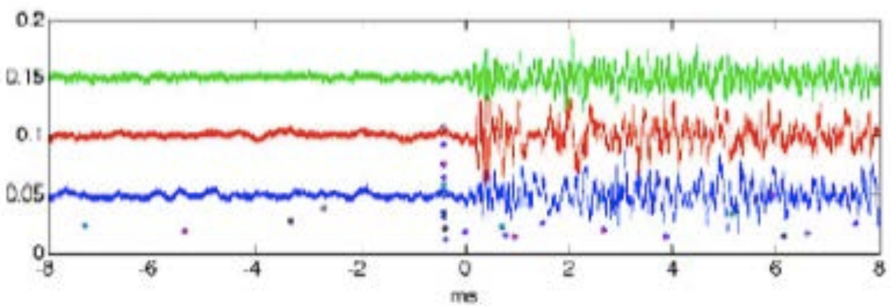
Bubble Chambers

PICO 60 @ SNO

F content interesting for SD sensitivity

Wide liquid choice able to tune target to different WIMP couplings

Optical and acoustical detection of the bubbles

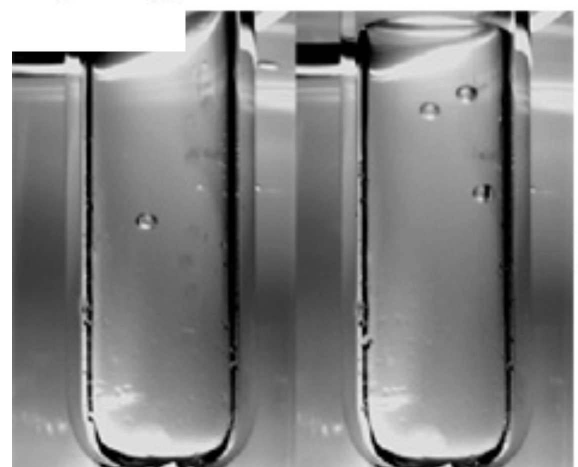


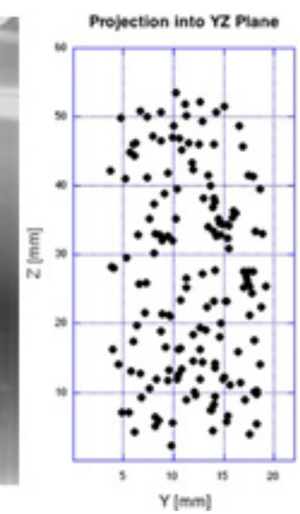
Alpha particles are louder and can be discriminated

Filled with 36.8 kg of CF_3I.

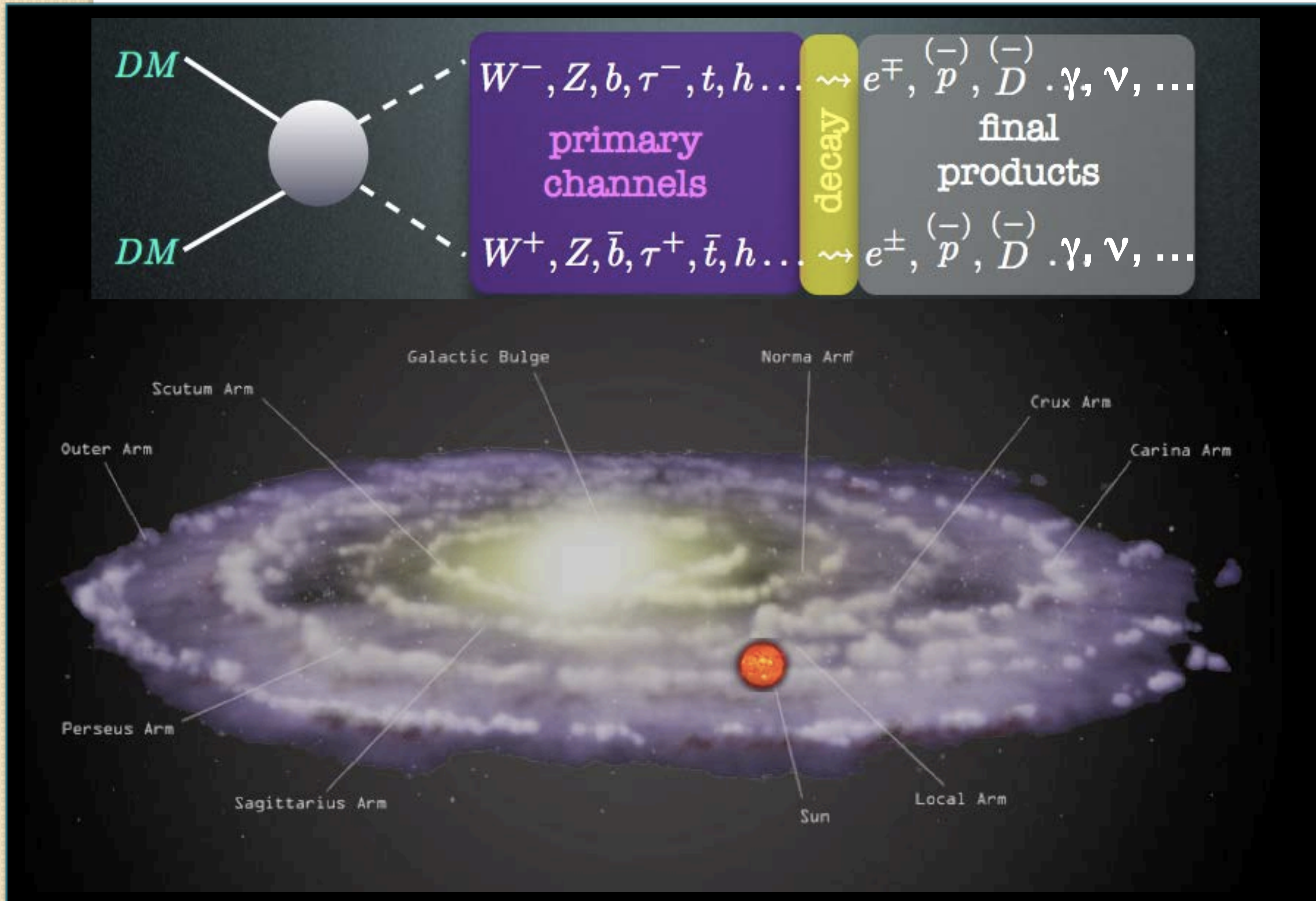
PICO-60 Run-1: June 2013 to May 2014.

Run-2 with C_3F_8 target in 2016.

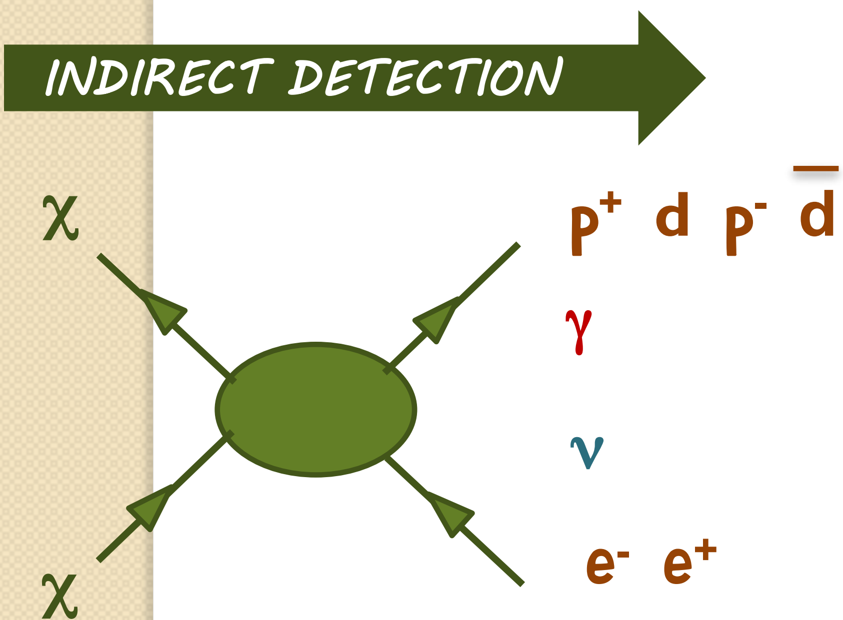


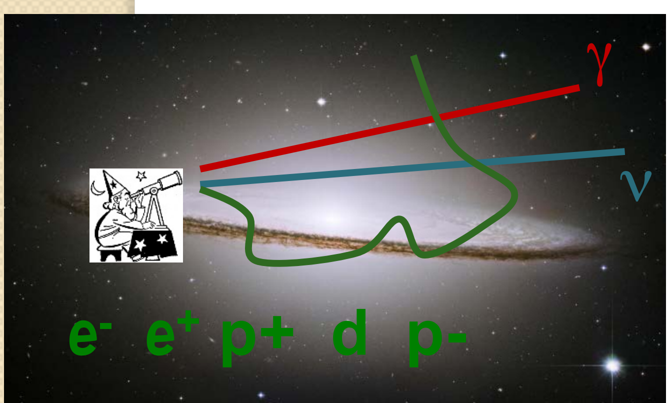


Dark Matter Indirect Detection



Dark Matter Indirect Detection





$$\frac{dR}{dt\,dA\,dE} = P \cdot J(\Delta\Omega)$$

$$P = \frac{\langle \sigma_{ann} v \rangle}{2 m_\chi^2} \cdot \sum_i BR_i \frac{dN_\gamma^i}{dE_i}$$

Particle Physics Model

$$J(\Delta\Omega) = \int_{\Delta\Omega} \int_{l=0}^{\infty} dl\, d\Omega \rho_\chi^2(l)$$

Astrophysics uncertainties

Dark Matter Indirect Detection

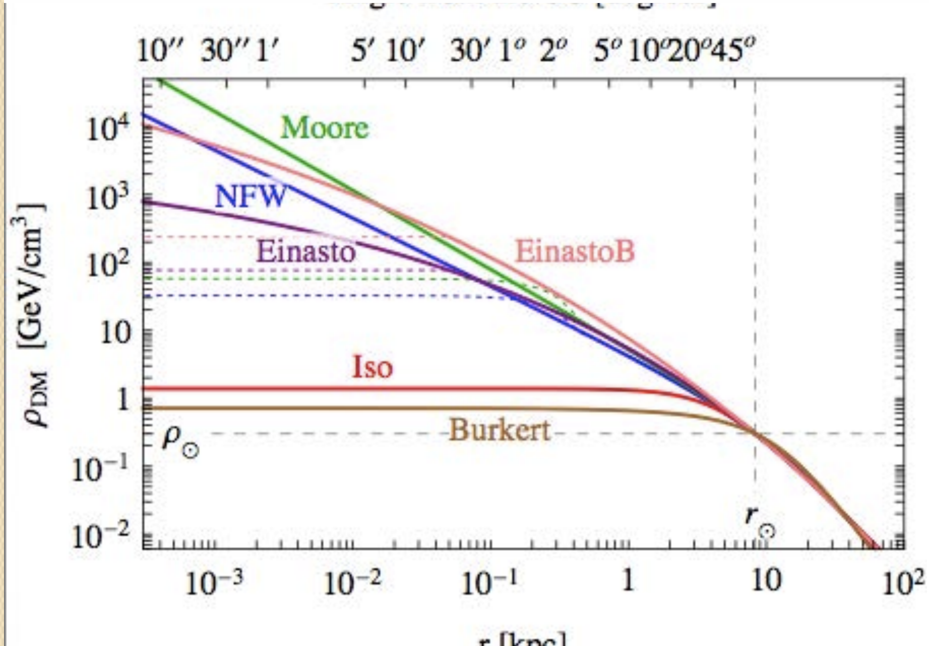
$$\text{NFW}: \quad \rho_{\text{NFW}}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

$$\text{Einasto}: \quad \rho_{\text{Ein}}(r) = \rho_s \exp\left\{-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^{\alpha}-1\right]\right\}$$

$$\text{Isothermal}: \quad \rho_{\text{Iso}}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

$$\text{Burkert}: \quad \rho_{\text{Bur}}(r) = \frac{\rho_s}{(1+r/r_s)(1+(r/r_s)^2)}$$

$$\text{Moore}: \quad \rho_{\text{Moo}}(r) = \rho_s \left(\frac{r_s}{r}\right)^{1.16}\left(1+\frac{r}{r_s}\right)^{-1.84}$$



$$\frac{dR}{dt\,dA\,dE} = P \cdot J(\Delta\Omega)$$

$$P = \frac{\langle\sigma_{\text{ann}} v\rangle}{2m_\chi^2} \cdot \sum_i BR_i \frac{dN_\gamma^i}{dE_i}$$

Particle Physics Model

$$J(\Delta\Omega) = \int_{\Delta\Omega}\int_{l=0}^{\infty} dl\, d\Omega\, \rho_\chi^2(l)$$

Astrophysics uncertainties

-halo models
-CR propagation

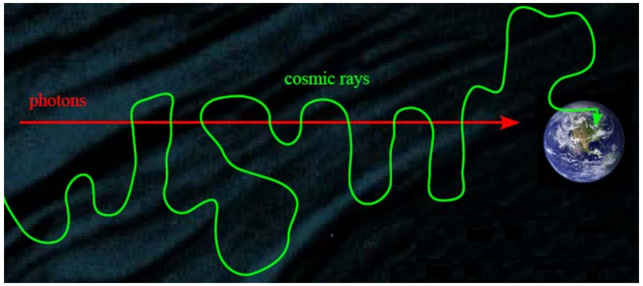
Dark Matter Indirect Detection

Particle	Experiments	Advantages	Challenges
Gamma-ray† photons	Fermi LAT, GAMMA-400, H.E.S.S.(-II), MAGIC, VERITAS, HAWC, CTA	point back to sources, spectral signatures	backgrounds, attenuation
Neutrinos	IceCube/DeepCore/PINGU, ANTARES/KM3NET, BAIKAL-GVD, Super-Kamiokande/Hyper-Kamiokande	point back to sources, spectral signatures	backgrounds, low statistics
Cosmic rays	PAMELA, AMS-02, ATIC, IACTs, Fermi LAT, Auger, CTA, GAPS	spectral signatures, low backgrounds for antimatter searches	diffusion, do not point back to sources

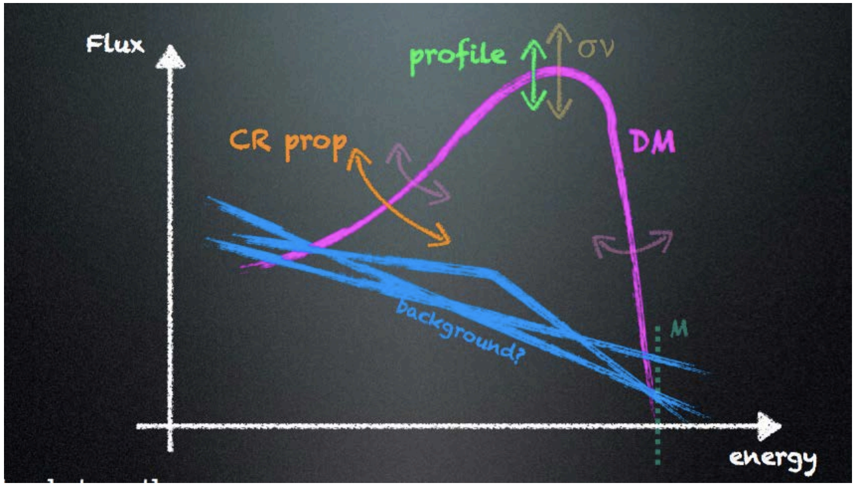
J. Gaskins, Contemporary Physics 2016

Charged Particles Detection

- Look for antimatter in order to beat background
- Key issue   Model the transport of charged cosmic rays throughout the galactic magnetic fields

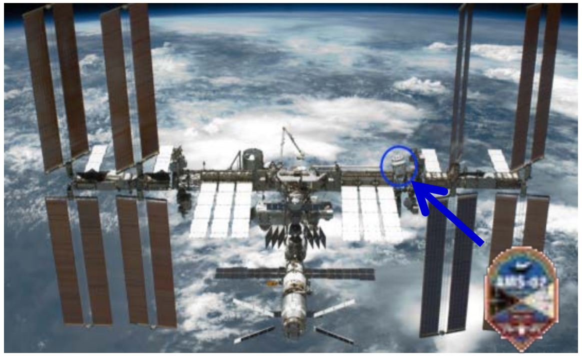


- Model background and search for an excess



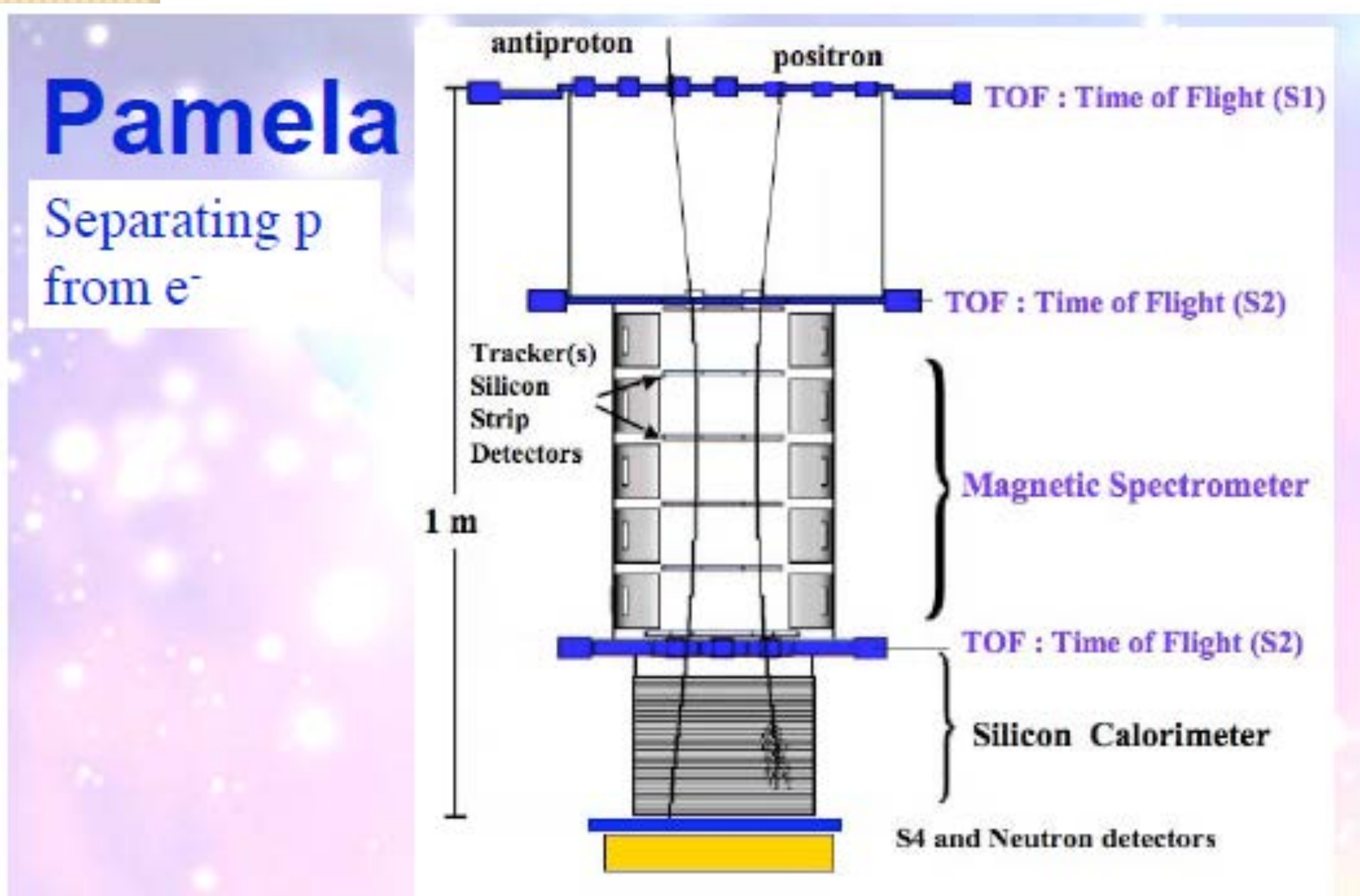
PAMELA

AMS-2 @ ISS



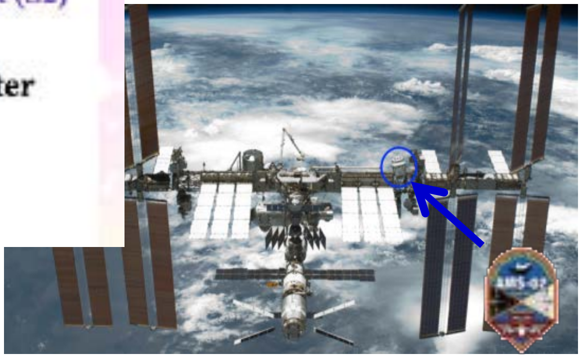
Charged Particles Detection

Complex Particle Detectors in the space



PAMELA

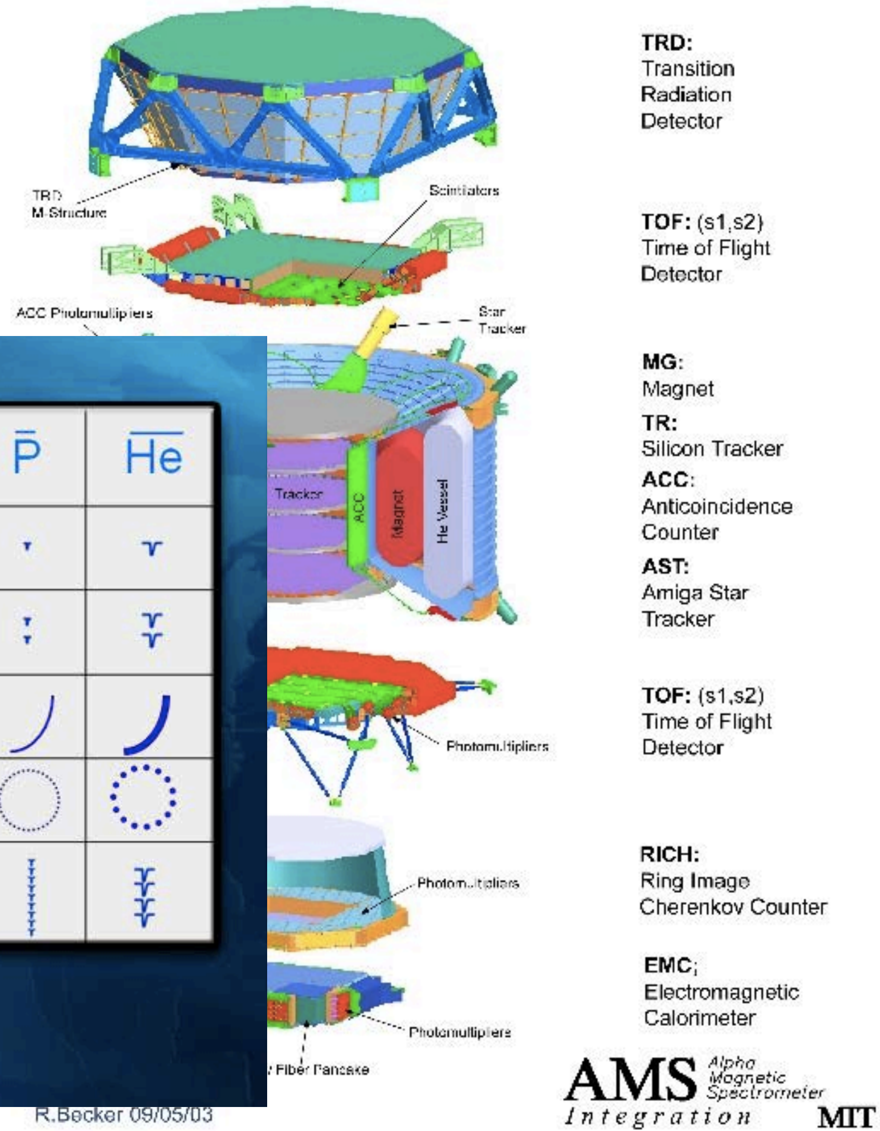
AMS-2 @ ISS

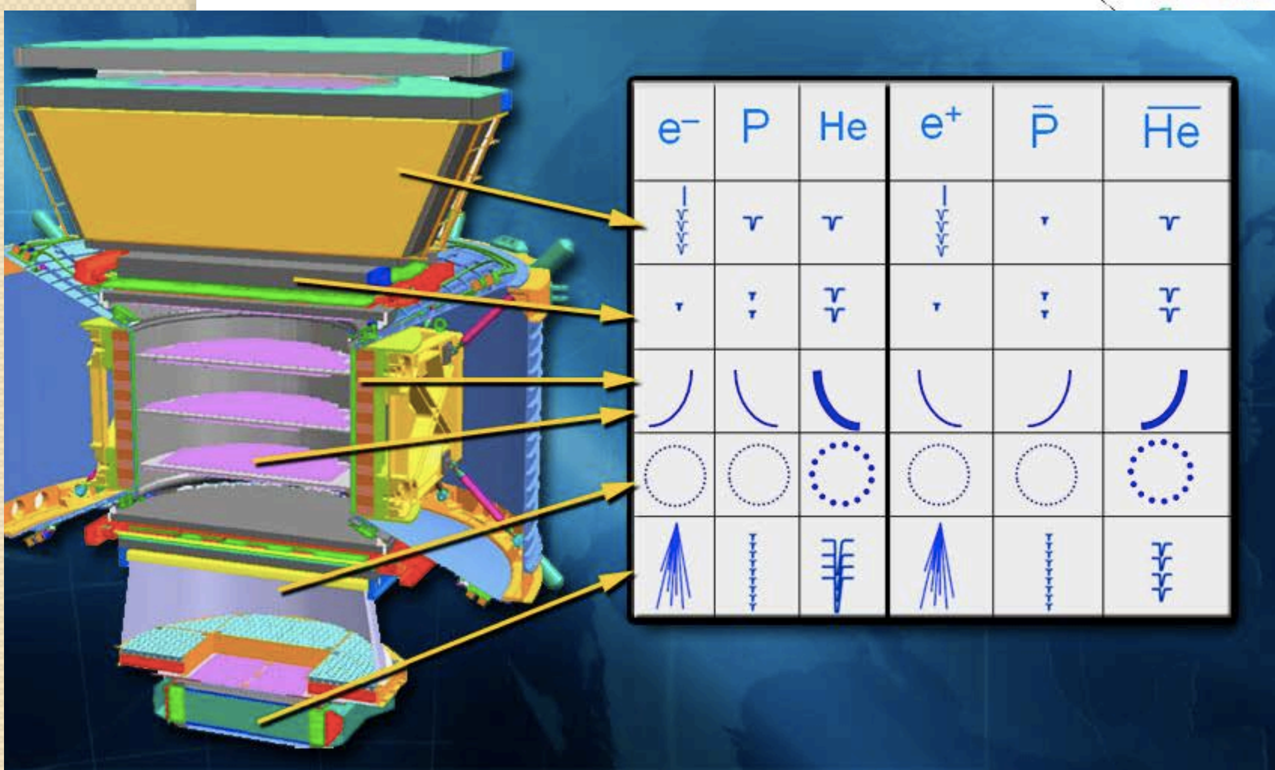


Charged Particles Detection

Complex Particle Detectors in the space

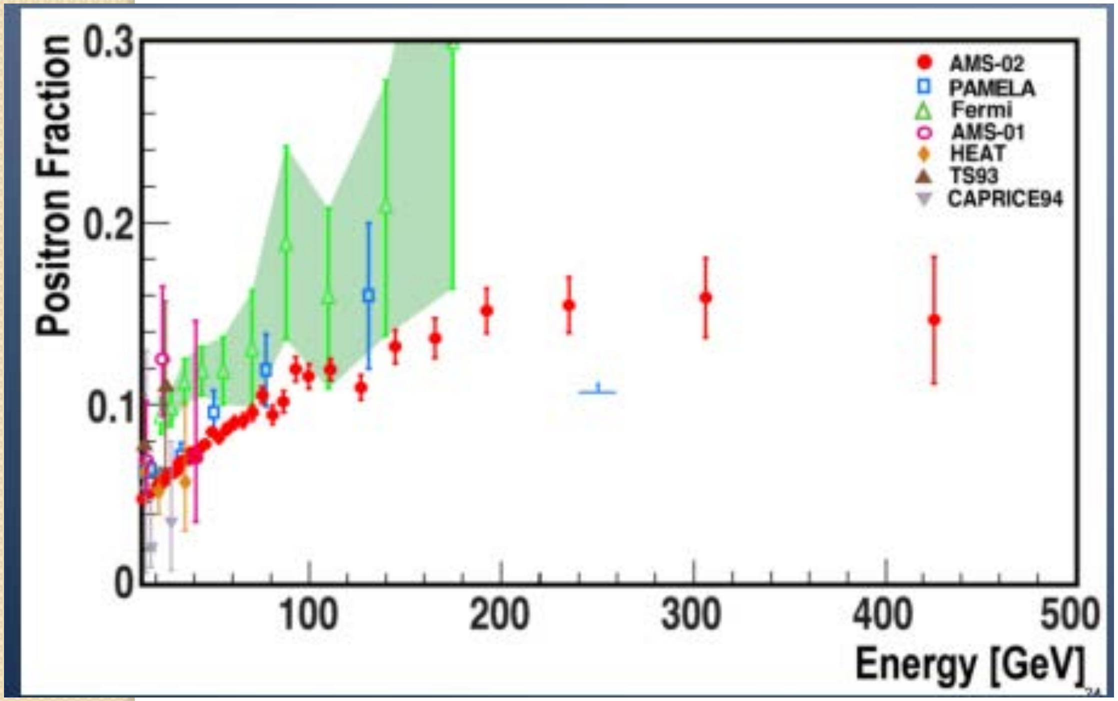
- electrons and positrons
- protons and antiprotons
- Light nuclei
- photons, etc.





Charged Particles Detection

POSITRON EXCESS
First hints by HEAT and AMS
Confirmed by PAMELA from 10-100 GeV & Fermi up to 200 GeV
Confirmed by AMS-2



DM Interpretation difficult
to match with models
Astrophysical explanation
possible

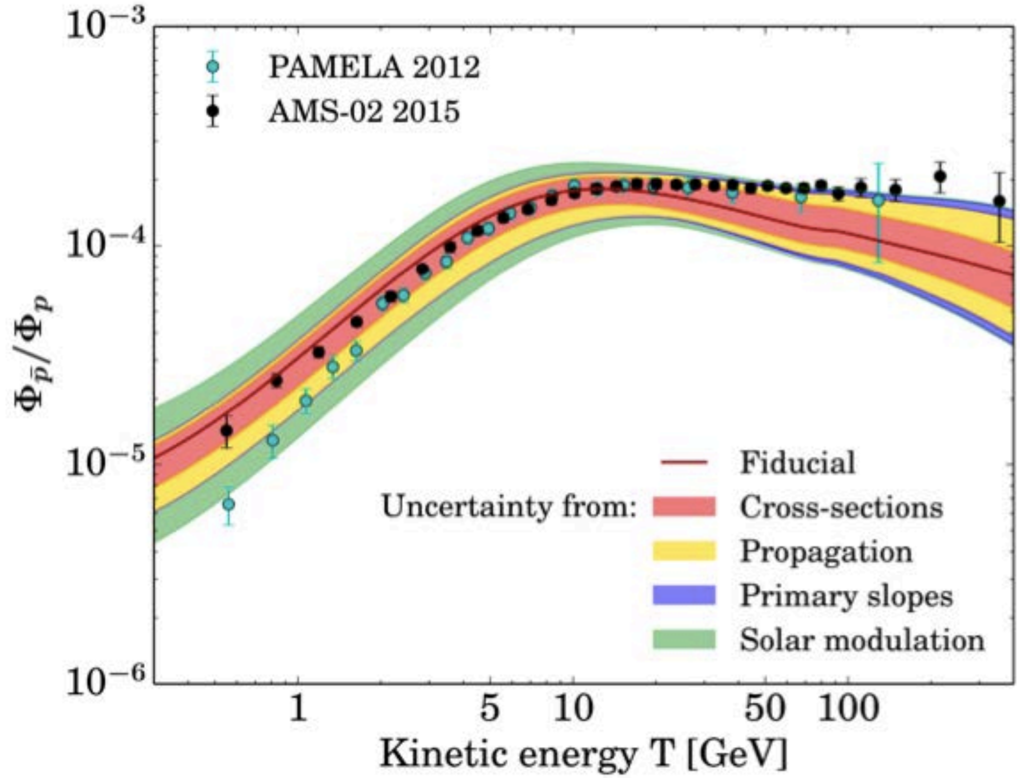
Charged Particles Detection

ANTIPROTON RATIO EXCESS

First hints by PAMELA but NOT CLEAR EXCESS AFTER AMS2

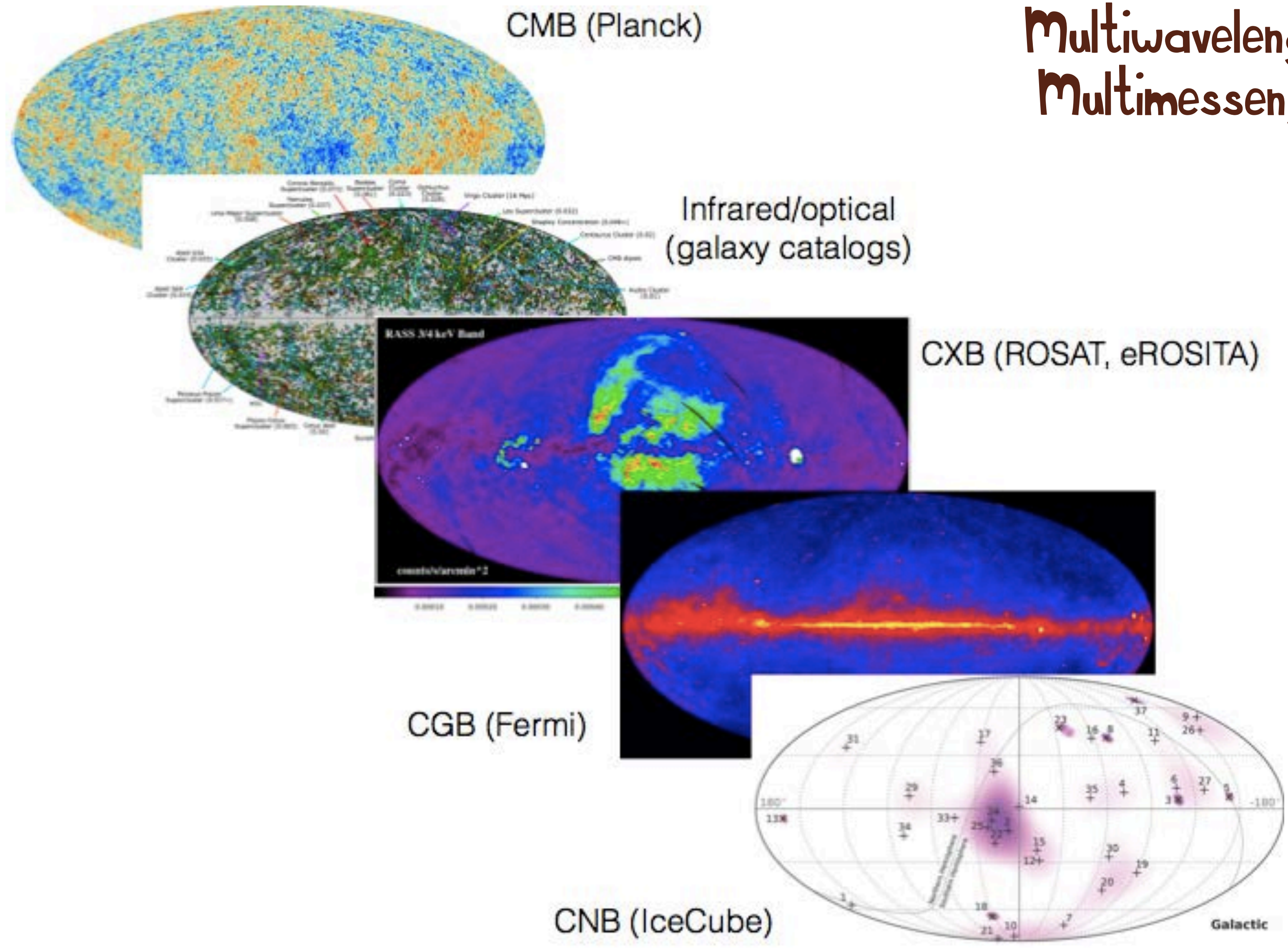
DM Interpretation possible but not necessary

ONLY LIMITS FOR ANTIDEUTERONS



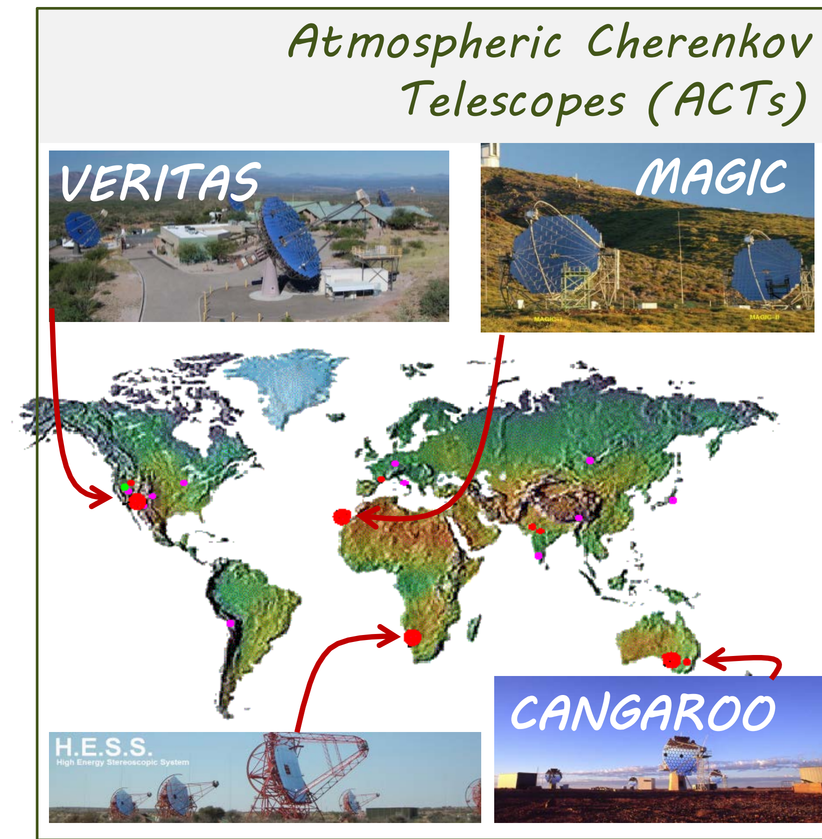
Gamma Rays and Neutrino Detection

Multiwavelength
Multimessenger

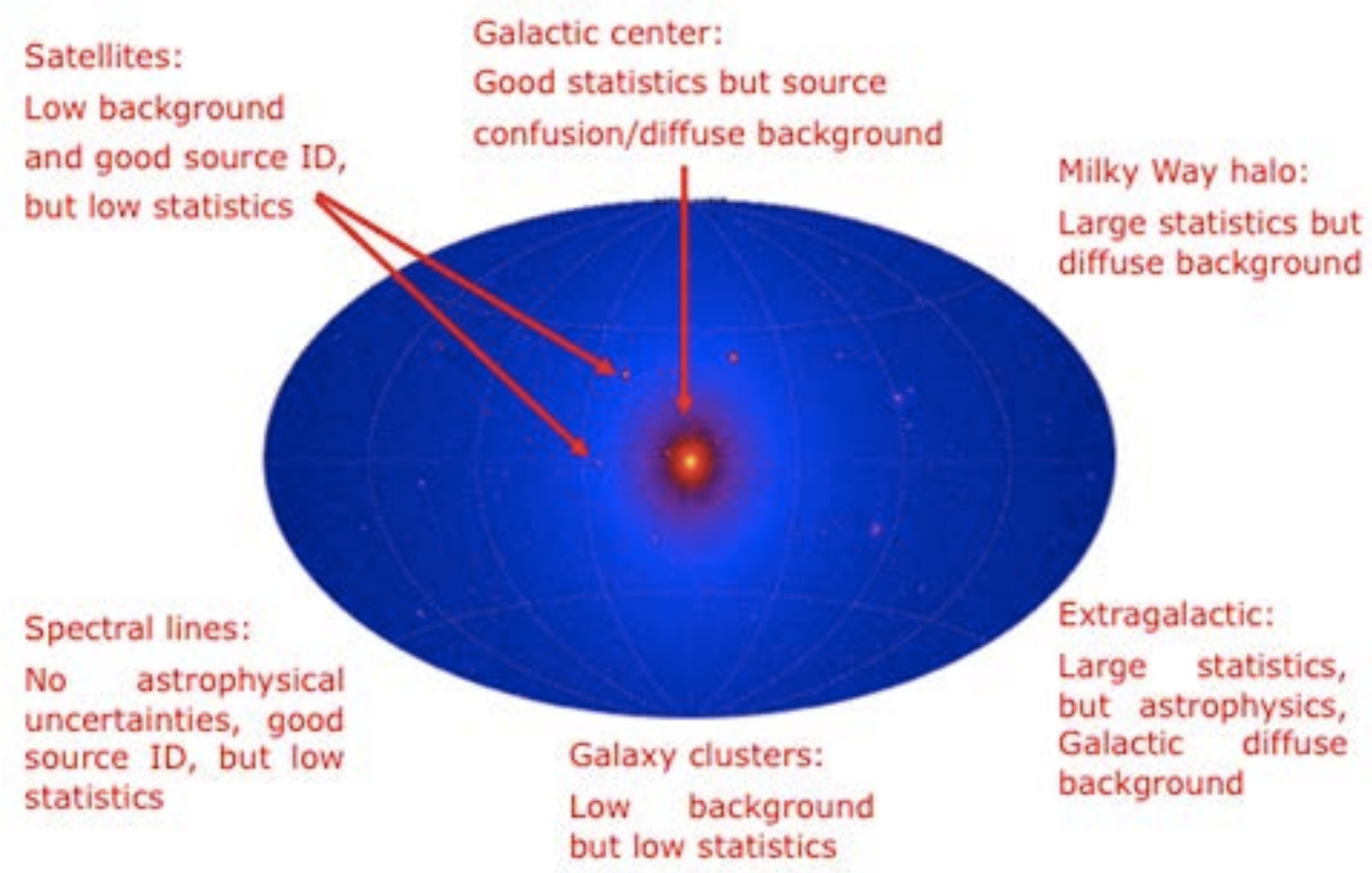


Gamma Ray Detection

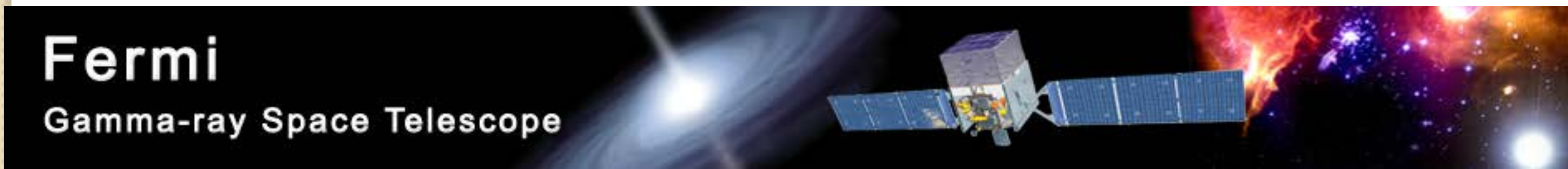
- Satellites
- Atmospheric Cerenkov Telescopes ACTs

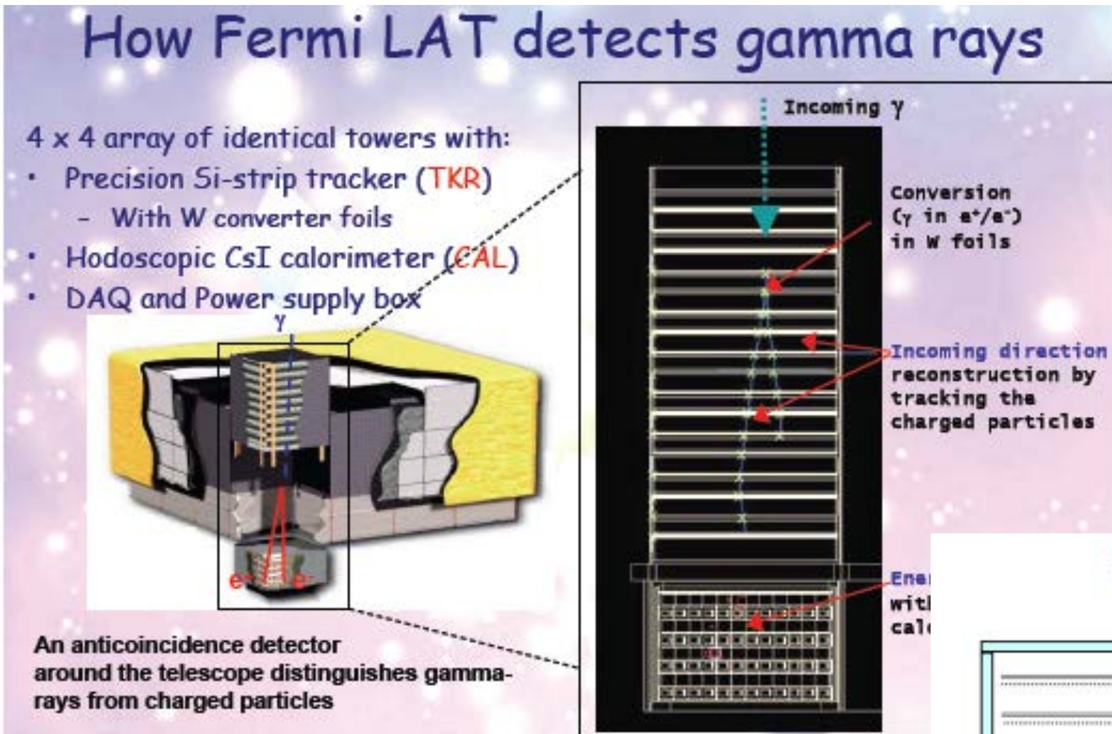


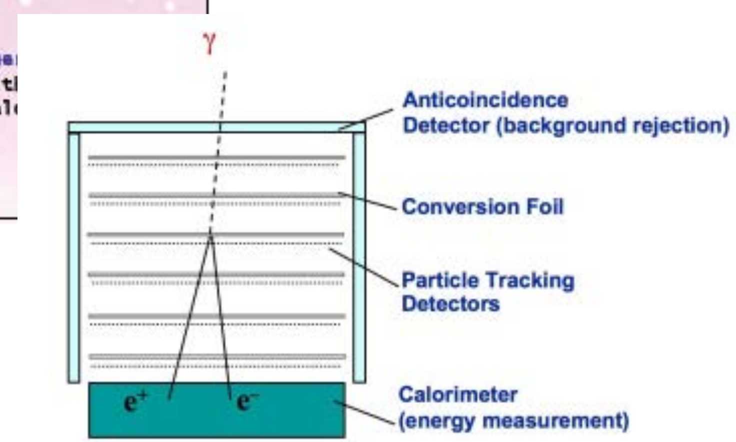
Search Strategies



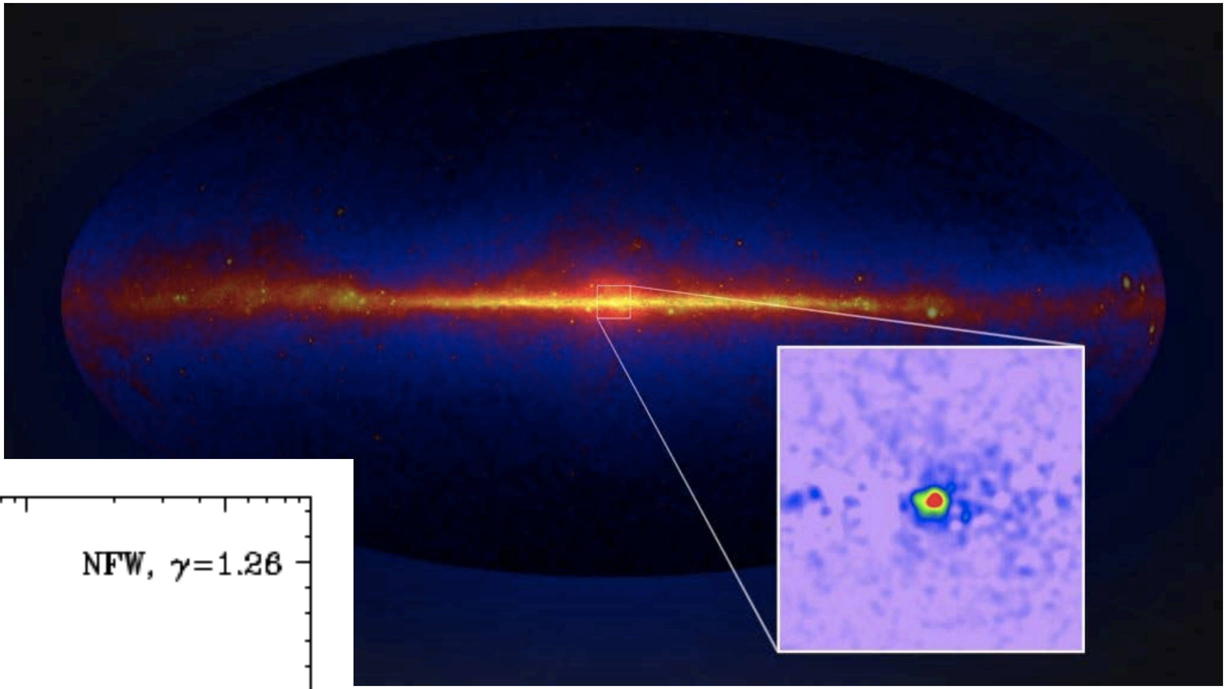
Gamma Ray Detection

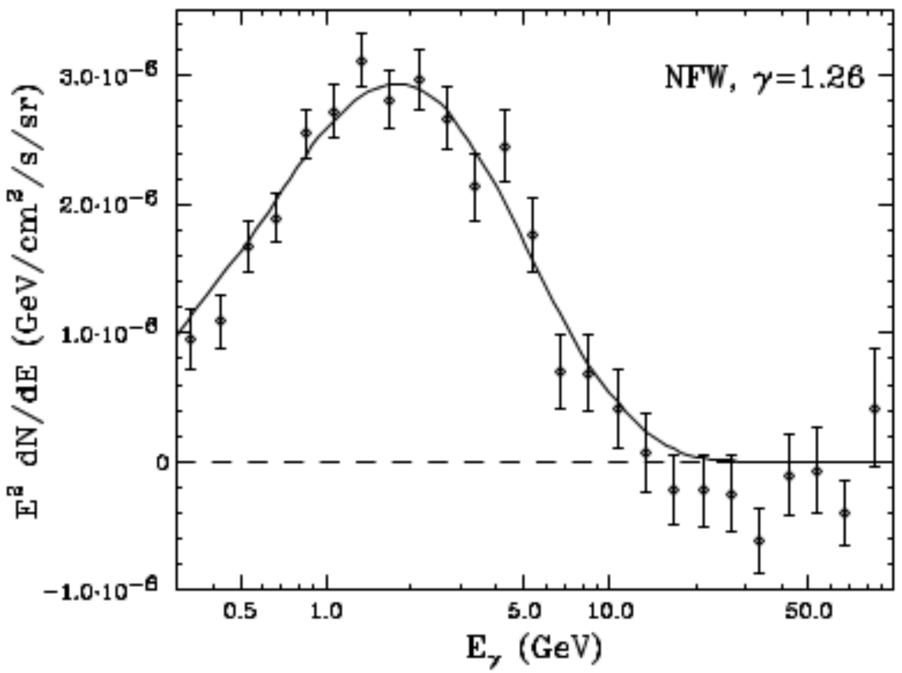






GeV Galactic Center Excess



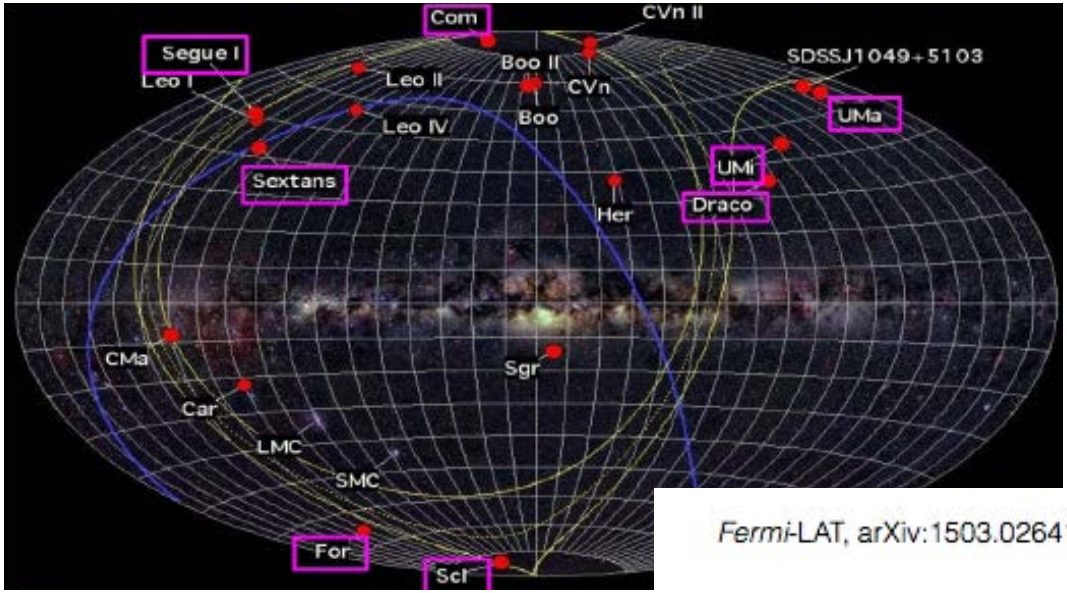


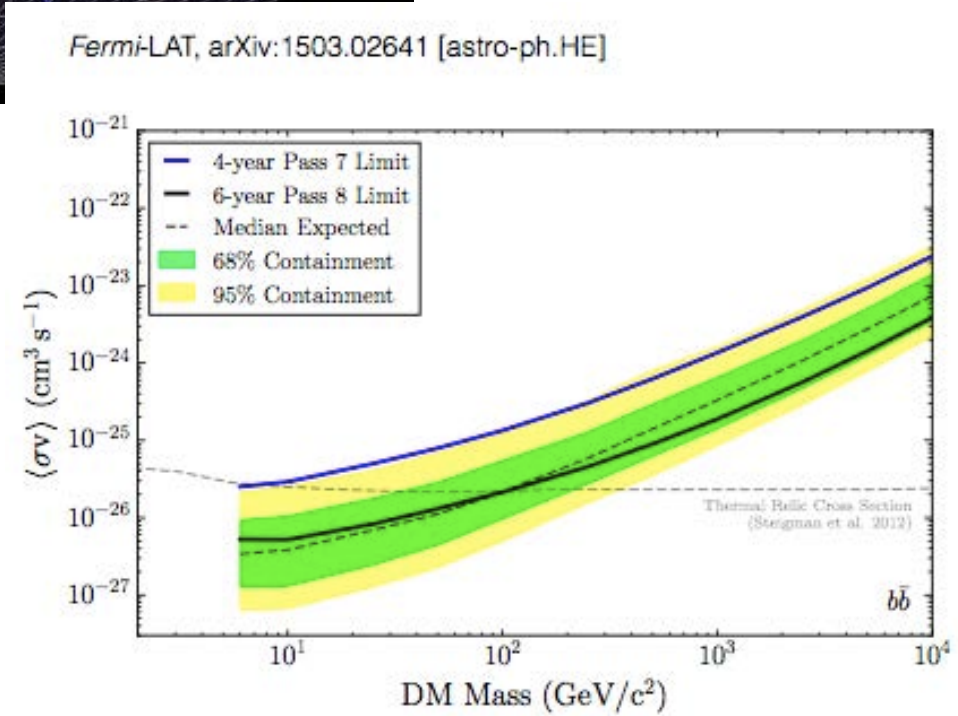
T. Daylan et al. arXiv:1402.6703v2

Annihilation of a dark matter particle with a mass between ~20-40 GeV could explain the excess

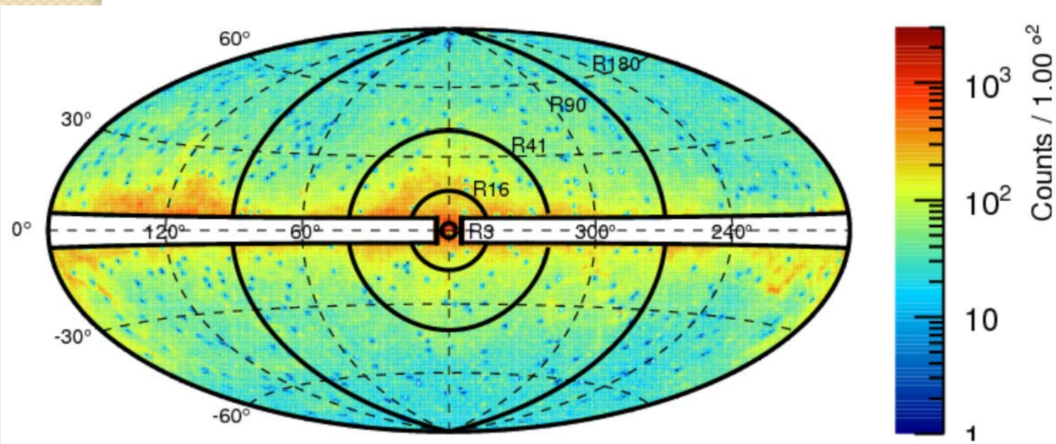
Antiproton should show hints
Millisecond pulsars could explain it

Searching for excess from dwarf galaxy satellites

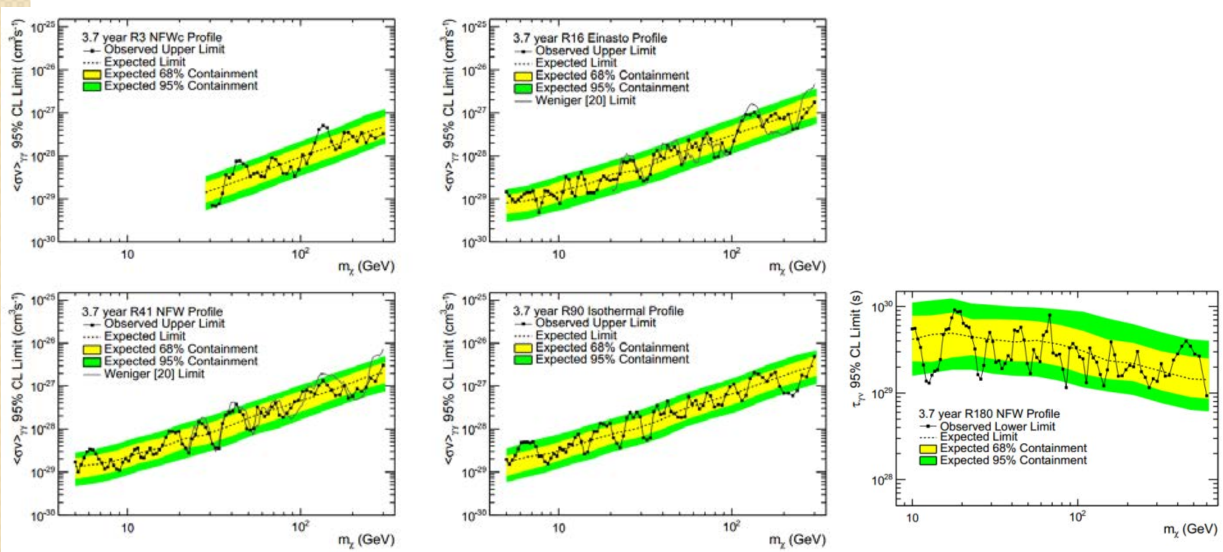




Searching for lines



- *3.7 years of data*
- *5 ROIs:*
  - *R3 (NFW Optimized)*
  - *R16 (Einasto Optimized)*
  - *R41 (NFW Optimized),*
  - *R90 (Isothermal Optimized)*
  - *R180 (DM Decay)*

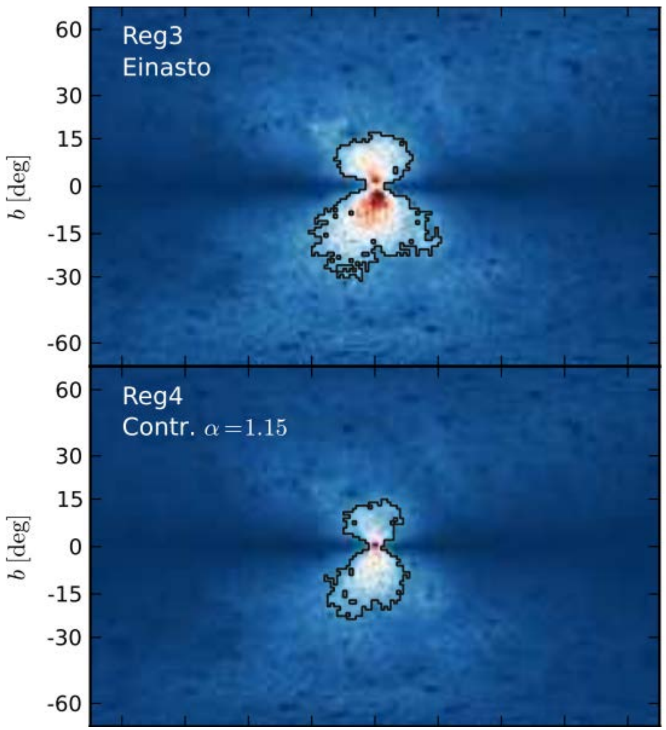


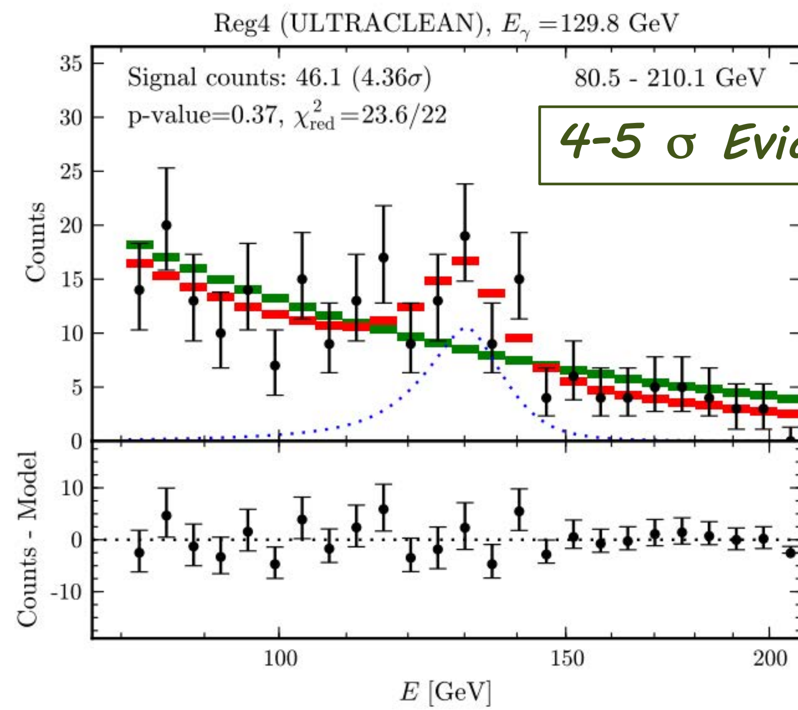
No evidence found!

M. Ackerman et al, 1305.5597v3

Evidence for 130 GeV line ?

43 moths Fermi LAT data +
new adaptive procedure to select optimized target regions depending on the profile of the Galactic dark matter halo.





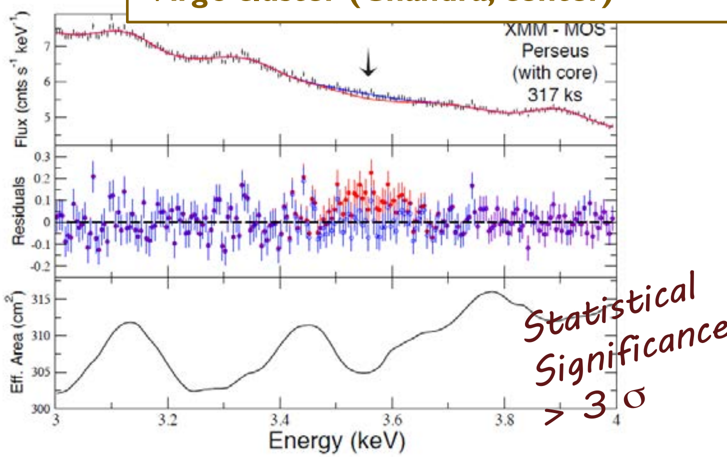
4-5 σ Evidence

Possible systematic effects involved
Similar line appears in limb view
Statistics of the evidence under question

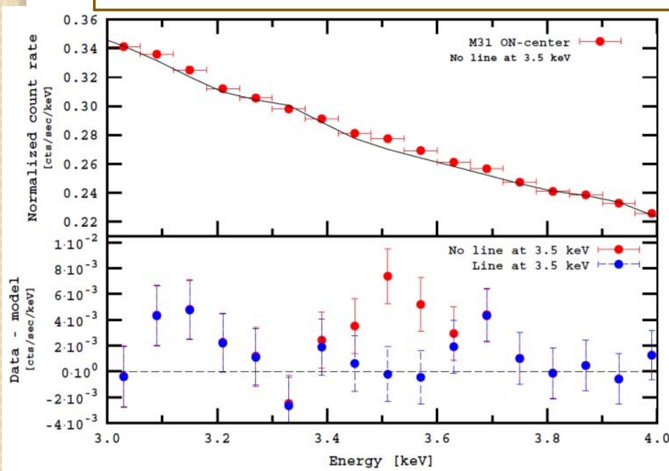
C. Weniger, 1204.2797v2

3.5 keV X ray line

73 galaxy clusters (XMM-Newton, center)
Perseus cluster (Chandra, center)
Virgo cluster (Chandra, center)



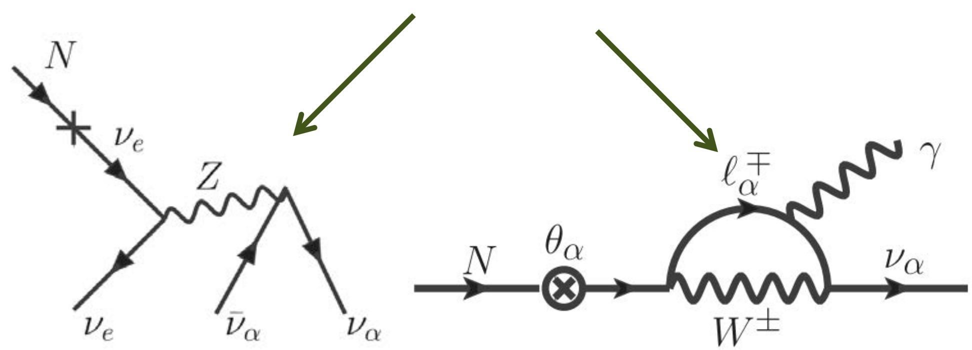
M31 galaxy (XMM-Newton, center & outskirts)
Perseus cluster (XMM-Newton, outskirts)



Line found in spectra from galaxies and galaxy clusters

Still controversial
possibility of atomic line or instrumental systematics

Could be produced by the decay of sterile neutrinos

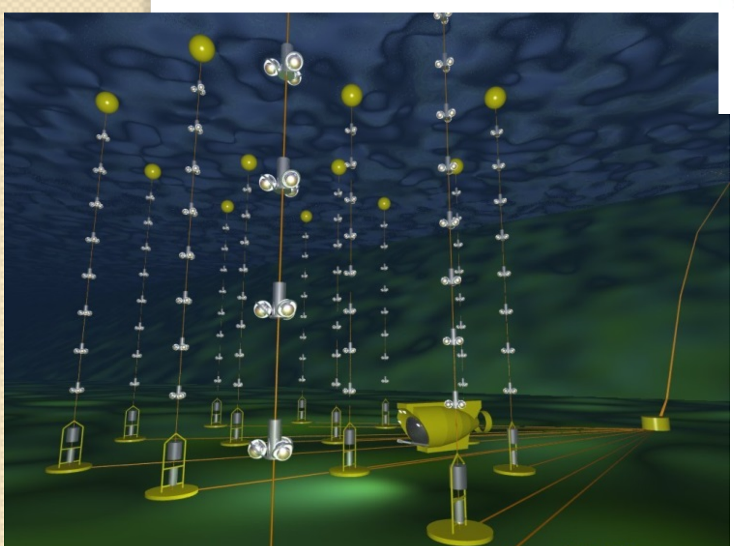


Neutrino Detection

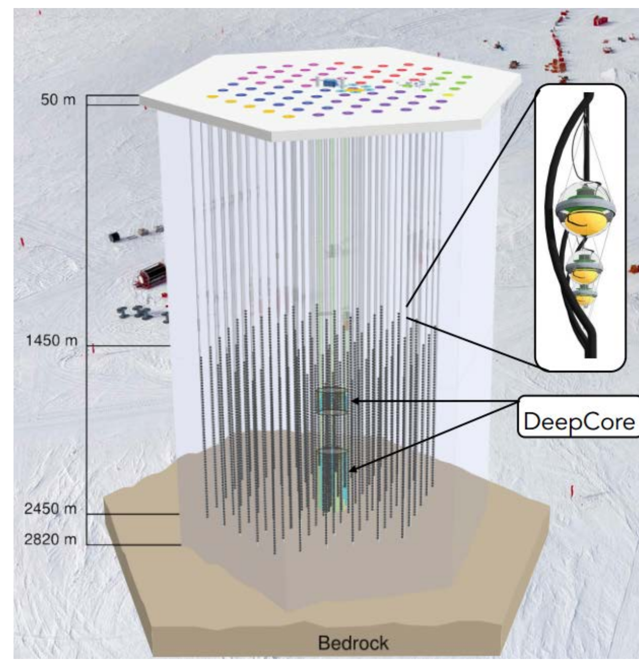
Cherenkov detectors under-ice or under-water

Detect the shower of secondary particles produced after ν interaction through Cherenkov light

ANTARES
(Under Mediterranean See)



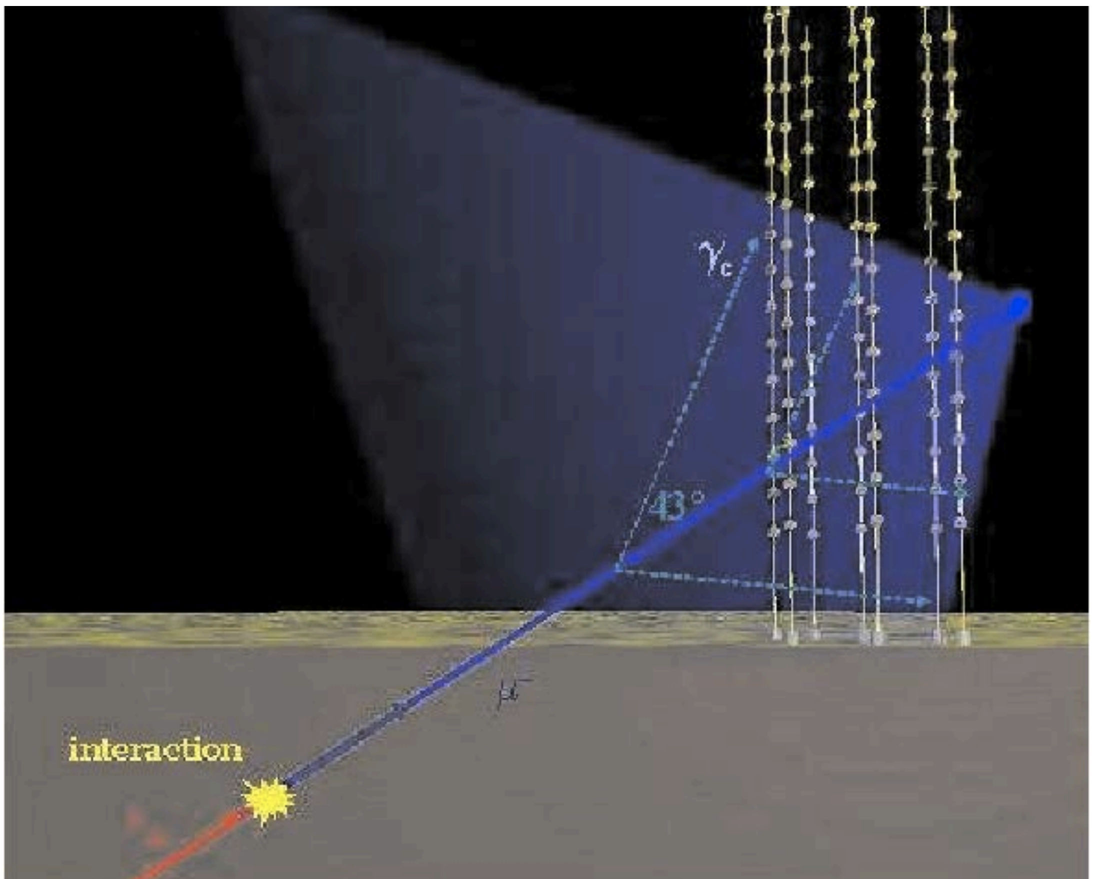
ICECUBE (South Pole)



Neutrino Detection

Cherenkov detectors under-ice or under-water

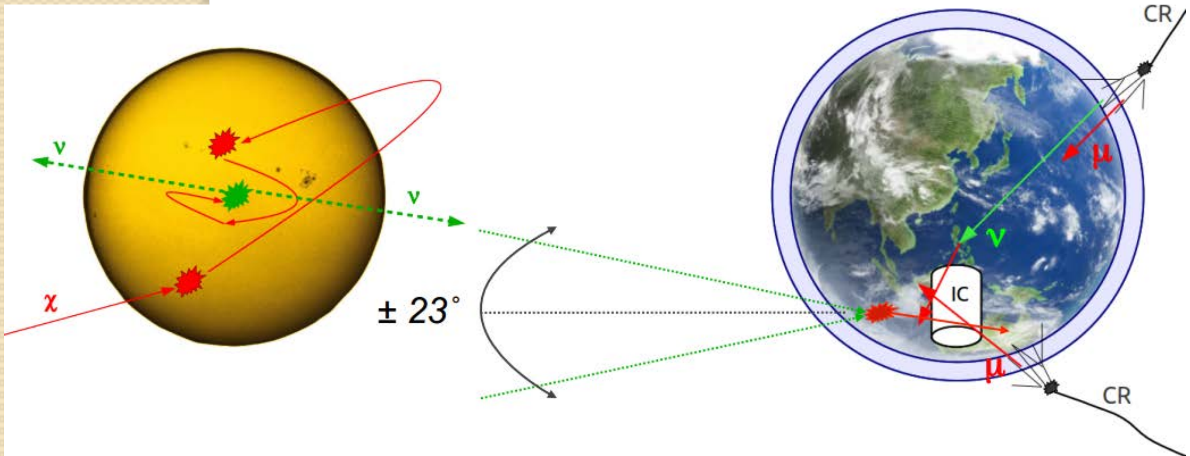
Detect the shower of secondary particles produced after ν interaction through Cherenkov light



Directionality

NEUTRINO ASTRONOMY

Neutrino Detection



High energy ν from the Sun

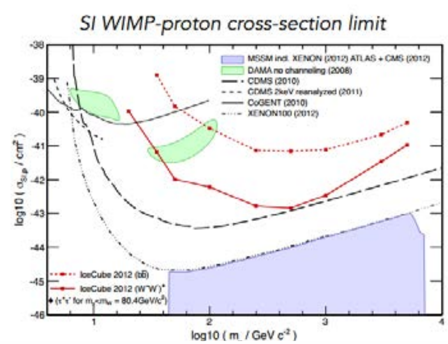
DM smoking gun

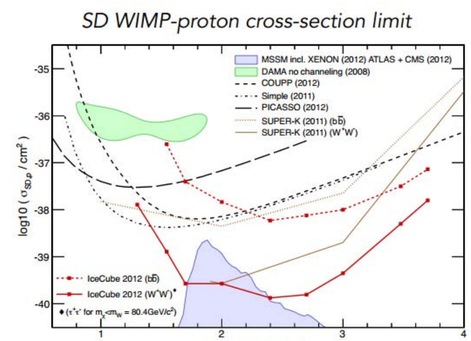
No known astrophysical processes able to mimic it

Borrowed from Matthias Danninge @ TAUP 2013

IceCube

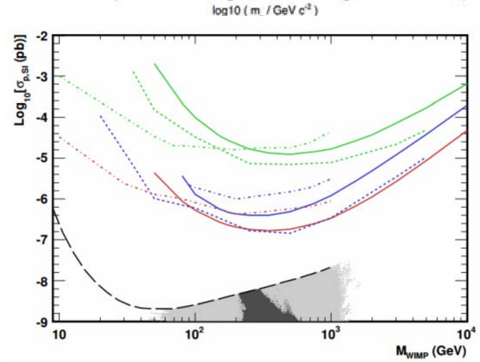
arXiv:1212.4097

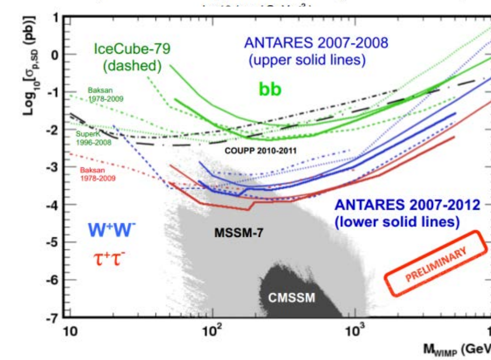




Antares

JCAP11(2013)032

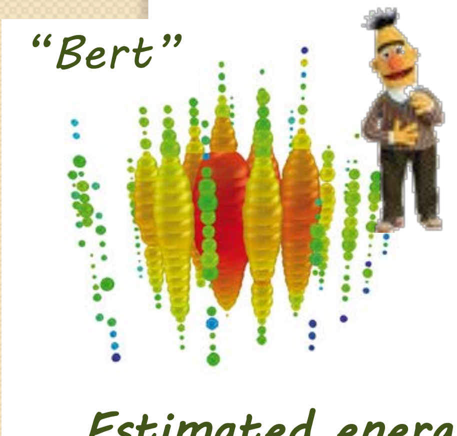




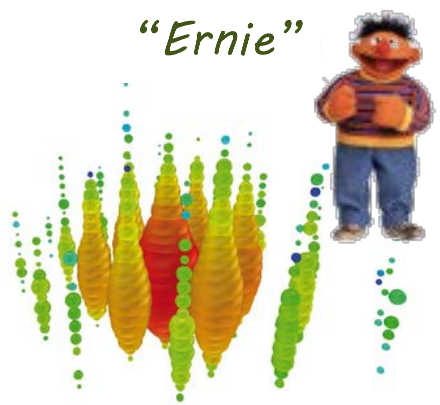
Neutrino Detection

PRL 111, 021103 (2013)

"Bert"

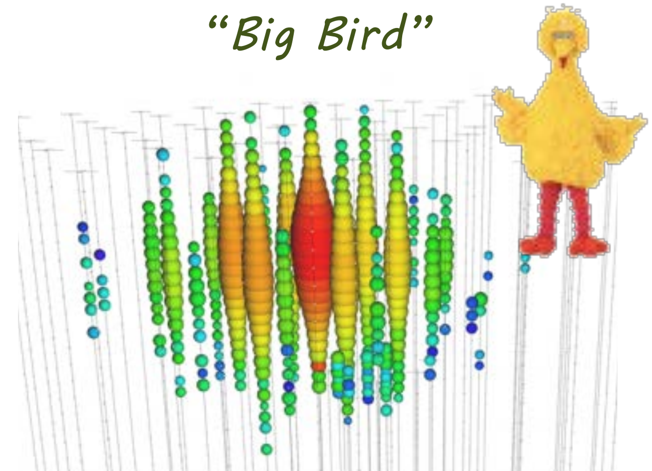


"Ernie"



+

"Big Bird"



Estimated energies:

1.04 ± 0.16 / 1.14 ± 0.17 PeV

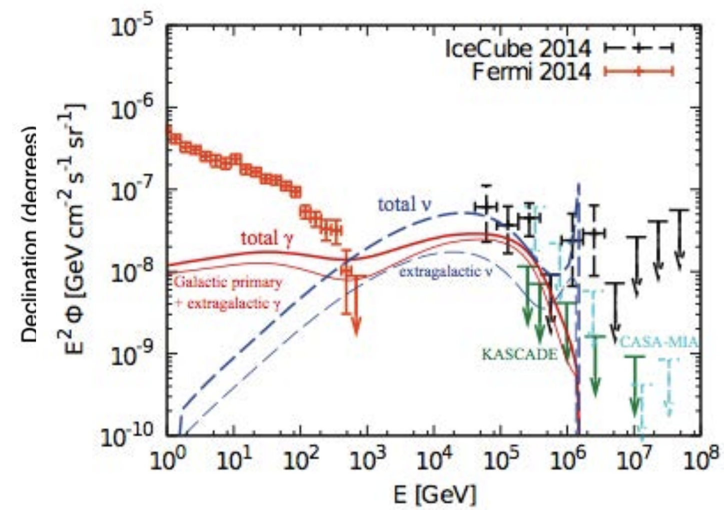
Estimated energy:

2 PeV

Line @1 PeV ?

It could be interpreted as super heavy decaying DM producing hadronic cascades

This model would produce excess in the diffuse gamma background testable with FERMI



Summary and Conclusions

Detectors applied in the search for DARK MATTER have improved their performances in an impressive way

Direct Detection is approaching the neutrino limit with the first ton experiments and only one "anomaly" pending to explain

Indirect Detection is accumulating much more hints of possible signals

- astrophysical backgrounds are not fully understood and difficult to model