Dark Matter: experimental techniques/ issues -2

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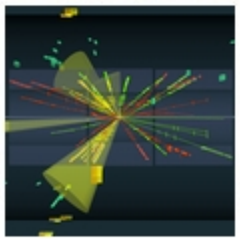


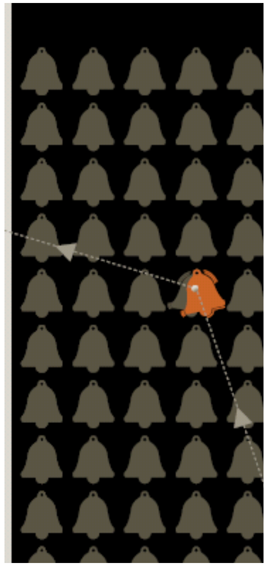
Taller de Altas Energías 2015
2015, 28-29th September
Benasque, HUESCA

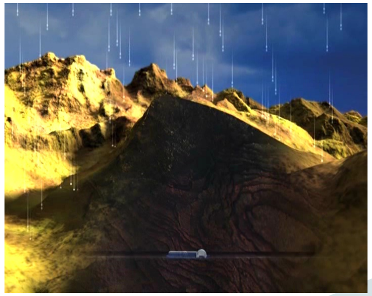
MultiDark
Multimessenger Approach for Dark Matter Detection

Universidad Zaragoza
1542

LSC
Laboratorio Subterráneo de Canfranc

Strategy to face the Direct Detection of WIMPs inthe lab

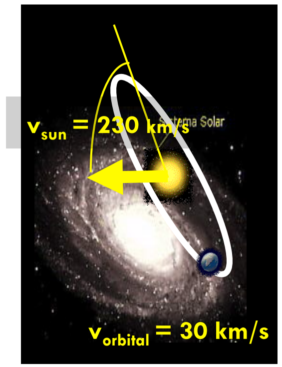




We need very sensitive and radiopure Particle Detectors

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

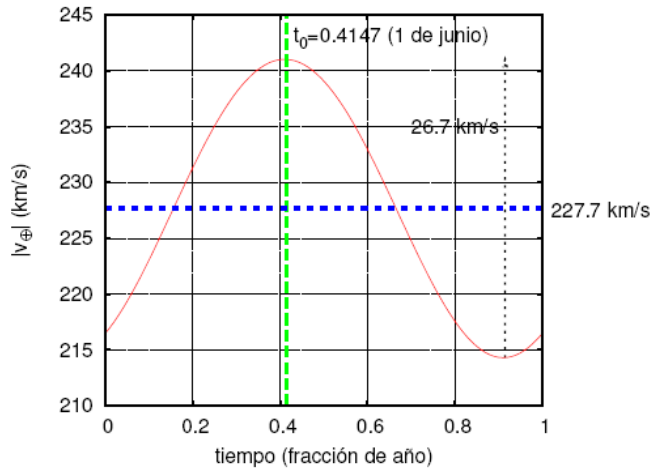
Signatures of a Dark Matter interaction are required for a positive result

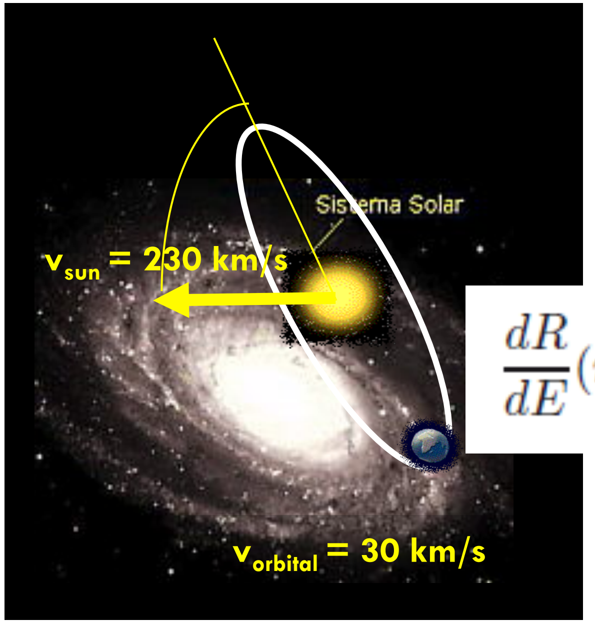


Dark Matter Signal Signatures

Positive identification of WIMP against backgrounds

- Annual modulation
- Directionality of recoils





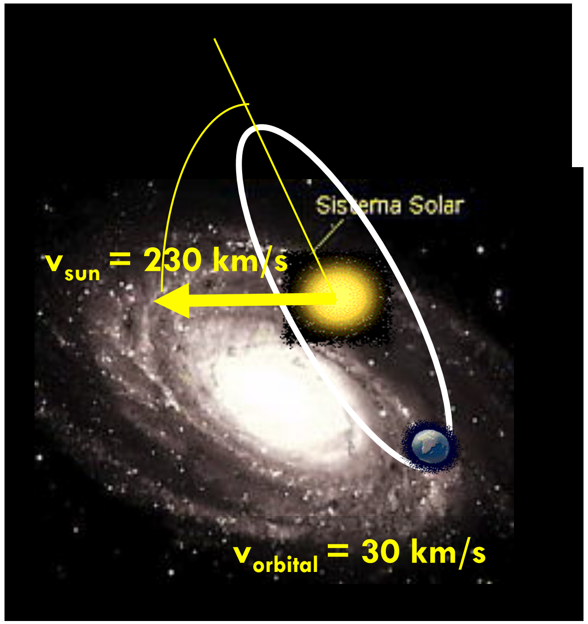
$$\eta(t) = v_\oplus(t)/v_0 = \eta_0 + \Delta\eta cos\omega(t - t_0)$$

$$\frac{dR}{dE}(\eta(t)) \approx \frac{dR}{dE}(\eta_0) + \frac{\partial}{\partial\eta}\left(\frac{dR}{dE}\right)_{\eta=\eta_0} \Delta\eta cos\omega(t - t_0)$$

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

Annual Modulation

Small effect (<7% of S_0)



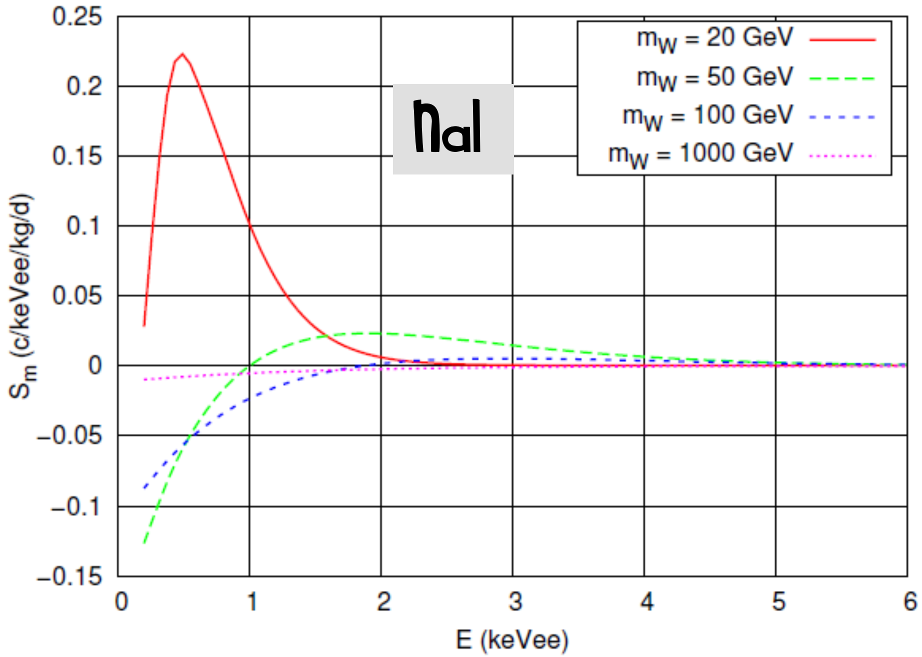


Figura 7.6: *Ritmos de interacción en un detector de NaI el 1 de junio y el 30 de noviembre para diferentes masas del WIMP y $\sigma_{SI} = 7{,}2 \times 10^{-6}$pb. Podemos observar que tanto la amplitud de la modulación como su signo varían según la energía y m_W.*

Inverse modulation at very low energies

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

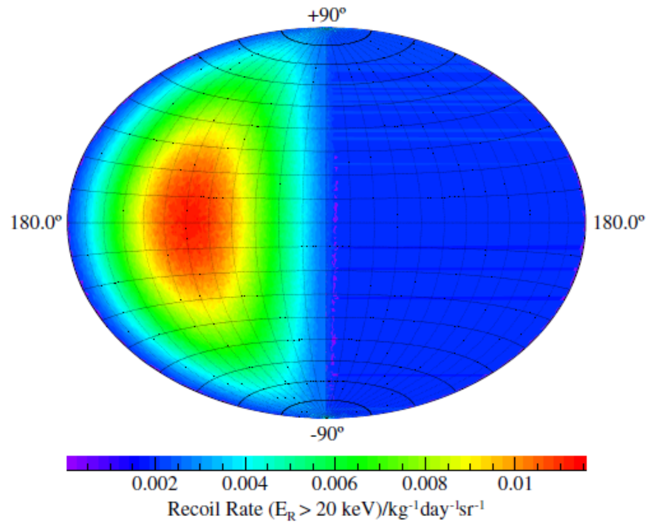
t_0 ~1st June

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

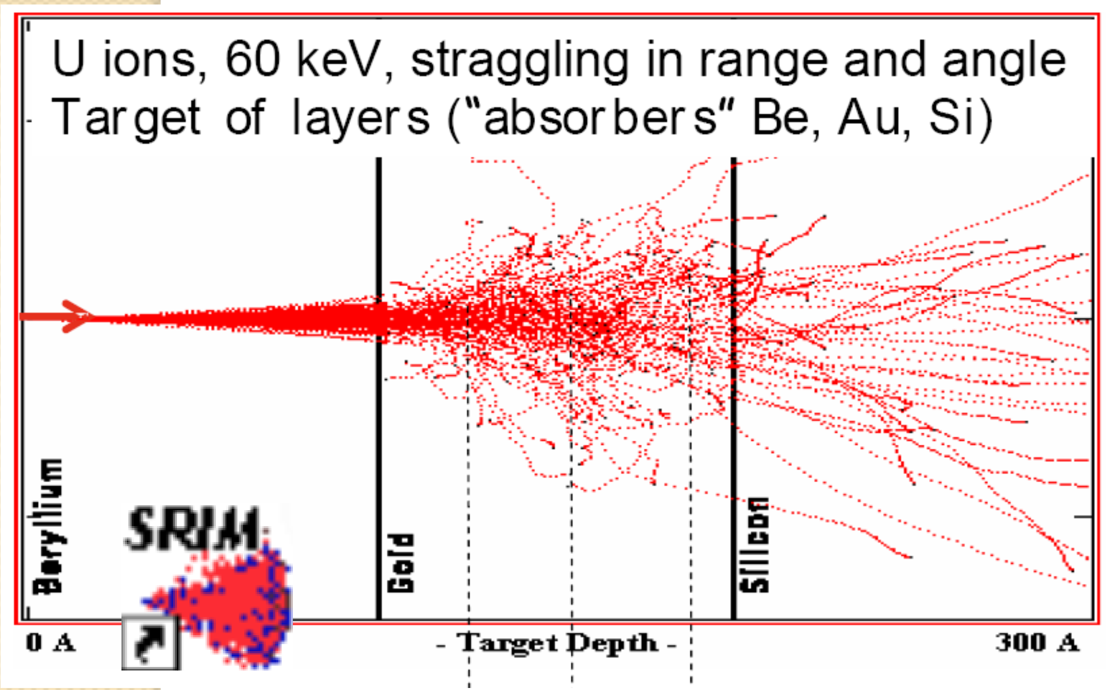
Dark Matter Signal Signatures

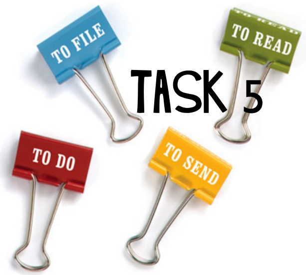
Positive identification of WIMP against backgrounds

- Annual modulation
- Directionality of recoils



ig. 1. The time averaged S recoil flux above 20 keV in Galactic (l,b) co-
rdinates for the standard halo model, if the senses of the recoils can be
neasured and the uncertainty in the reconstruction of the recoil directions
re included. The WIMP mass and cross-section are taken to be $m_\chi =$
00 GeV and $\sigma = 10^{-6}$ pb, respectively and the local WIMP density is
$_0 = 0.3$ GeV cm^{-3}.





Review of the Experimental Status

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

DAMA/NaI-LIBRA Experiment

Other much sensitive experiments do not have any hint

CONTROVERSIAL issue
Is possible a model independent confirmation or refutation?

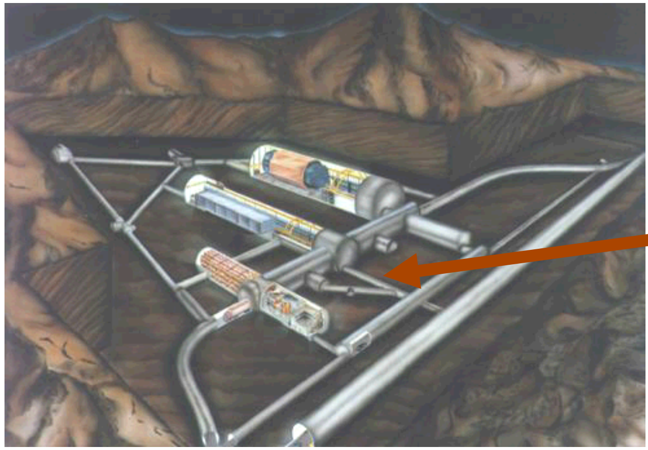
TASK 6

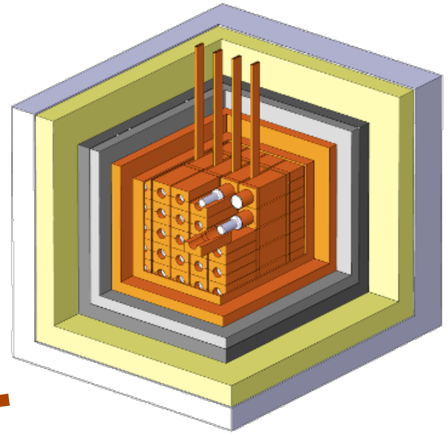
Make data public could have help?
Are we prepared for unexpected results?

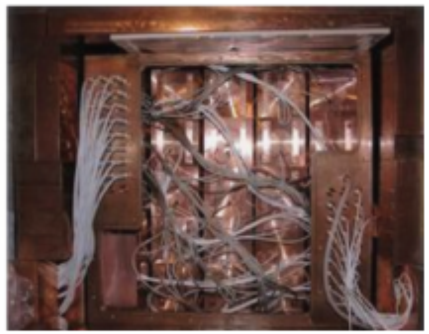
Review of the Experimental Status

DAMA/LIBRA experiment

~250kg NaI(Tl) scintillators @ LNGS





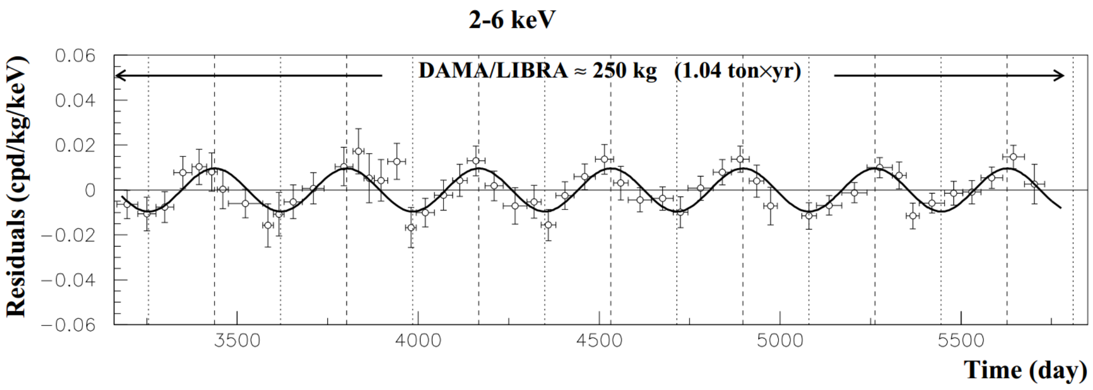


Total exposure:
DAMA/NaI (100 kg NaI, 7 years, completed in 2002)
+ DAMA/LIBRA (250 kg NaI, 7 cycles, ongoing)
→ total exposure reported so far: 1.33 ton x year

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

Review of the Experimental Status

DAMA/LIBRA experiment



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

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Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

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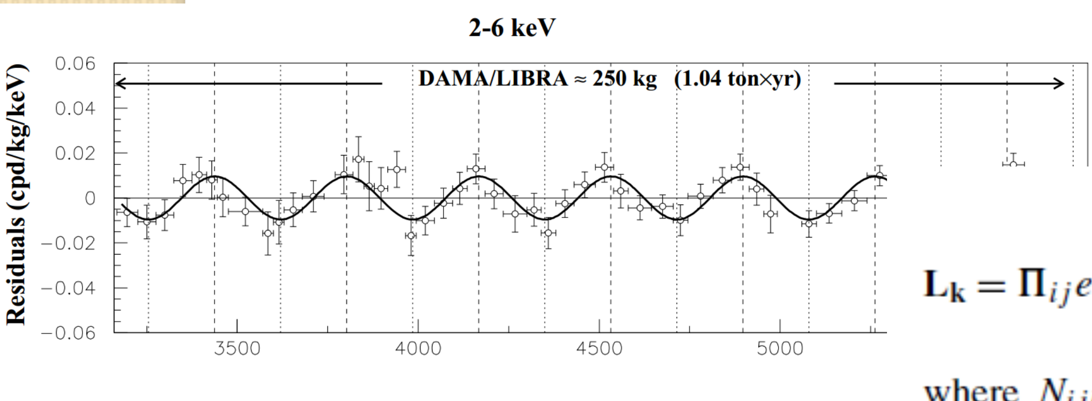

$$\mathbf{L_k} = \Pi_{ij} e^{-\mu_{ijk}} \frac{\mu_{ijk}^{N_{ijk}}}{N_{ijk}!} \quad (2)$$

where N_{ijk} is the number of events collected in the i-th time interval (hereafter 1 day), by the j-th detector and in the k-th energy bin. N_{ijk} follows a Poisson's distribution with expectation value $\mu_{ijk} = [b_{jk} + S_{0,k} + S_{m,k} \cdot \cos\omega(t_i - t_0)] M_j \Delta t_i \Delta E \epsilon_{jk}$. The b_{jk} are the background contributions, M_j is the mass of the j-th detector, Δt_i is the detector running time during the i-th time interval, ΔE is the chosen energy bin, ϵ_{jk} is the overall efficiency. The usual procedure is to minimize the function $y_k = -2\ln(\mathbf{L_k}) - const$ for each energy bin; the free parameters of the fit are the $(b_{jk} + S_{0,k})$ contributions and the $S_{m,k}$ parameter.

Total exposure:
DAMA/NaI (100 kg NaI, 7 years, c
+ DAMA/LIBRA (250 kg NaI, 7 cy
→ total exposure reported so far:

«Final model independent result of DAMA/LII

Review of the Experimental Status

DAMA/LIBRA experiment

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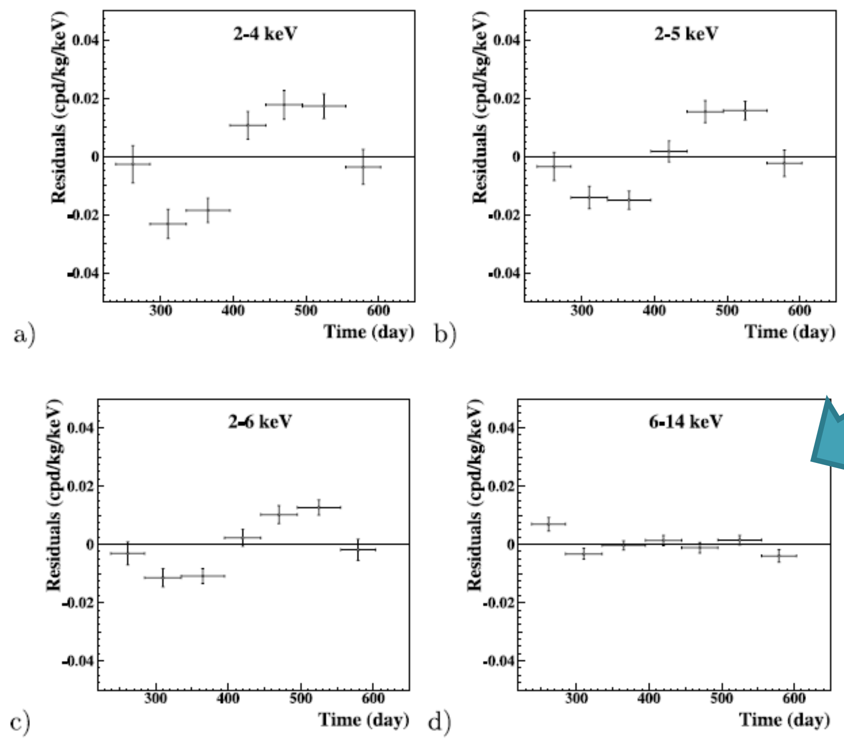


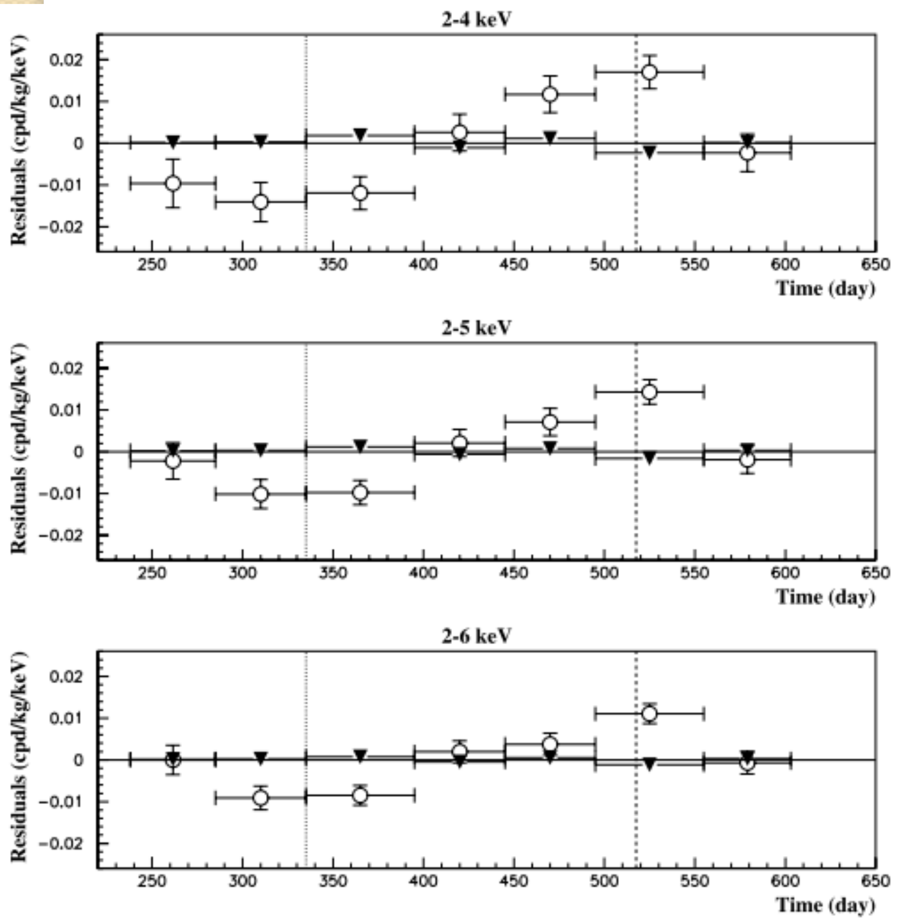
Evidence (9.3 σ C.L.) of an annual modulation of the *single-hit* events in the (2–6) keVee energy region satisfying all the requests of a DM component in the galactic halo

part: $\langle r_{ijk} - flat_{jk} \rangle_{jk}$. Here r_{ijk} is the rate in the considered i-th time interval for the j-th detector in the k-th energy bin, while $flat_{jk}$ is the rate of the j-th detector in the k-th energy bin averaged over the cycles. The average is made on all the detectors (j index) and on all the 1 keV bins (k index) which constitute the considered energy interval. The weighted mean of the residuals must obviously be zero over one cycle.

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result



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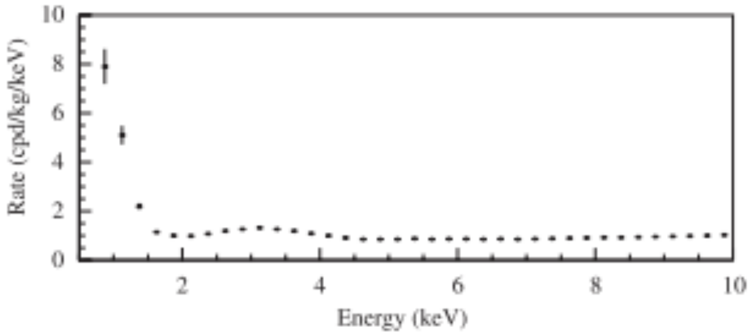
Evidence (9.3 σ C.L.) of an annual modulation of the *single-hit* events in the (2—6) keVee energy region satisfying all the requests of a DM component in the galactic halo

Modulation disappears when looking at multiple hit events due to background

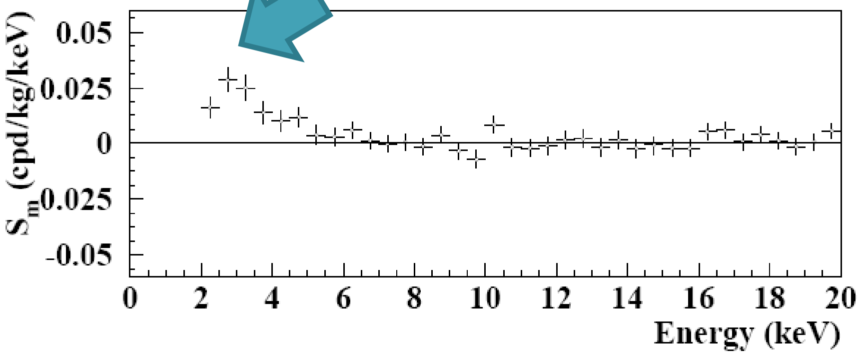
Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result



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



Modulation amplitude decreasing till negative?

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.

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

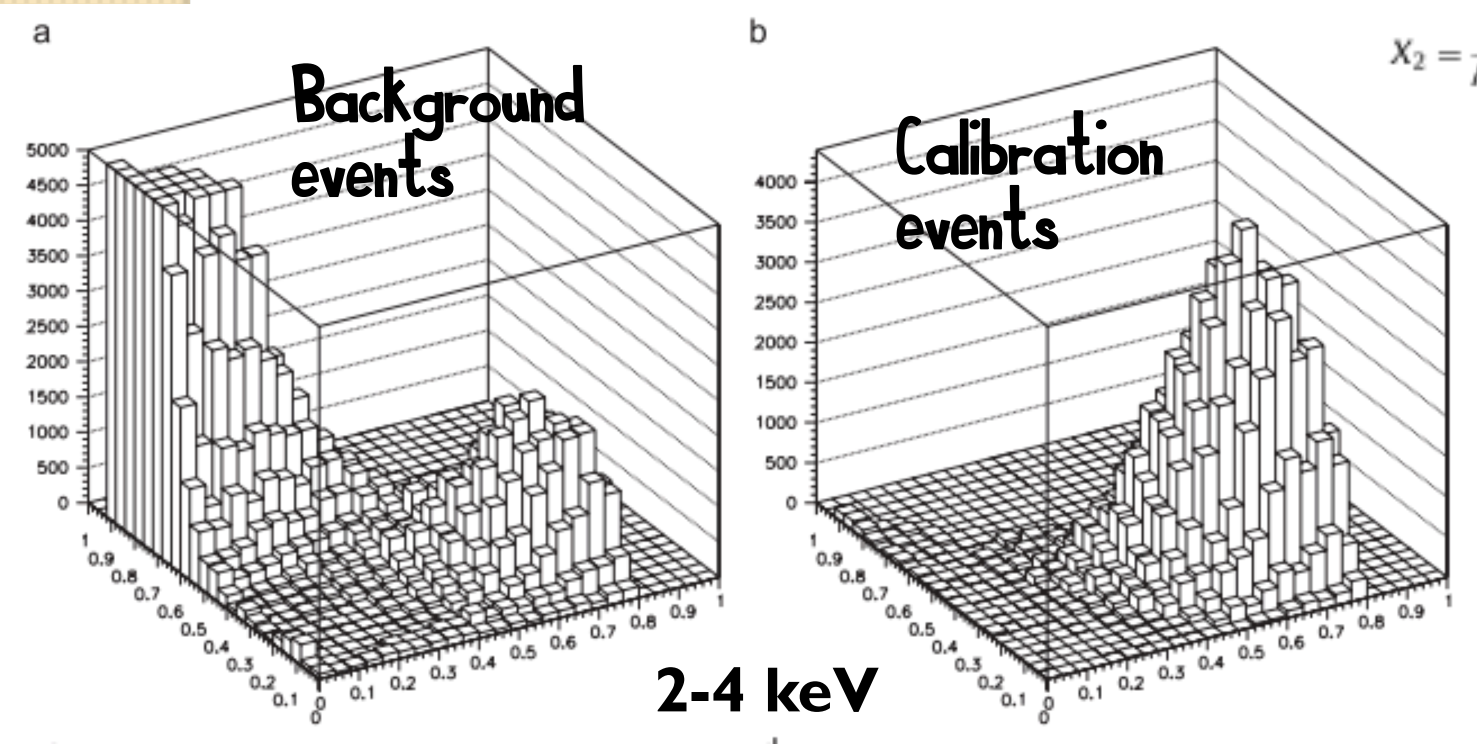
Annual Modulation

Systematics difficult to analyse.

Strong filtering has to be applied to data

$$X_1 = \frac{\text{Area (from 100 to 600 ns)}}{\text{Area (from 0 to 600 ns)}};$$

$$X_2 = \frac{\text{Area (from 0 to 50 ns)}}{\text{Area (from 0 to 600 ns)}}$$



2-4 keV

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

Annual Modulation
Systematics difficult to analyse.
Most obvious discarded

Analysis of the seasonal modulation of the cosmic muon flux in the LVD detector during 2001-2008.

Marco Selvi* on behalf of the LVD collaboration

$\phi\mu = (3.31 \pm 0.03)\ 10^{-4}\ (m^2\ s)^{-1}$
period $T = (367 \pm 15)$ days

$\delta\phi\mu = (5.0 \pm 0.2)\ 10^{-6}\ (m^2\ s)^{-1}$,
Phase $t0 = (185 \pm 15)$ days

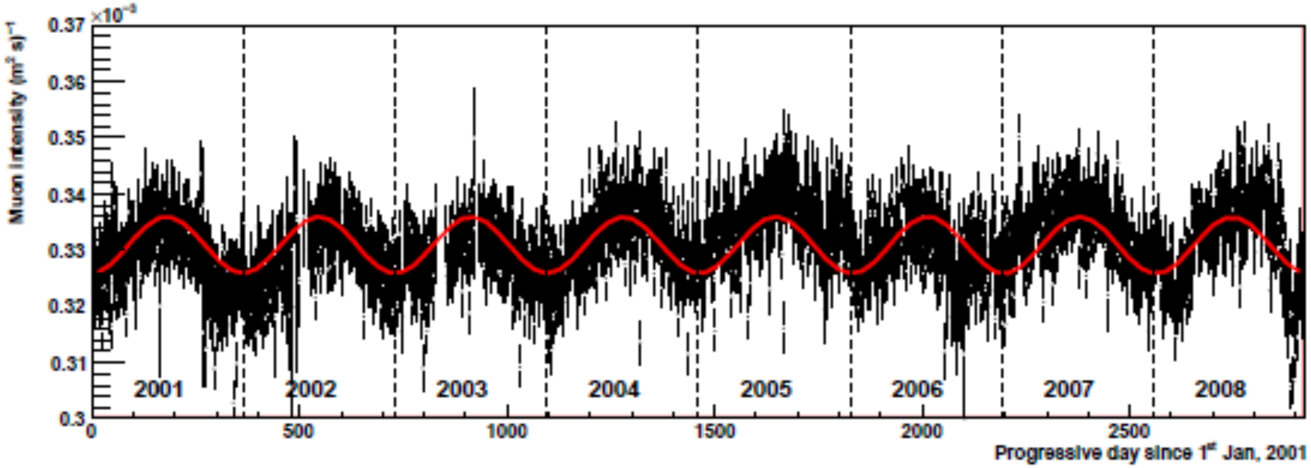


Fig. 2. Muon intensity along the 8 years of data acquisition. Each bin corresponds to one day, starting from 1st January, 2001 to 31st December, 2008. The error bars are the statistical uncertainty. The solid red curve is the result of a cosinusoidal fit to the data in the form shown in eq. 3 The vertical dashed lines separate each solar year.

MUON FLUX MODUATION AT LNGS

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

Annual Modulation
Systematics difficult to analyse.
Most obvious discarded

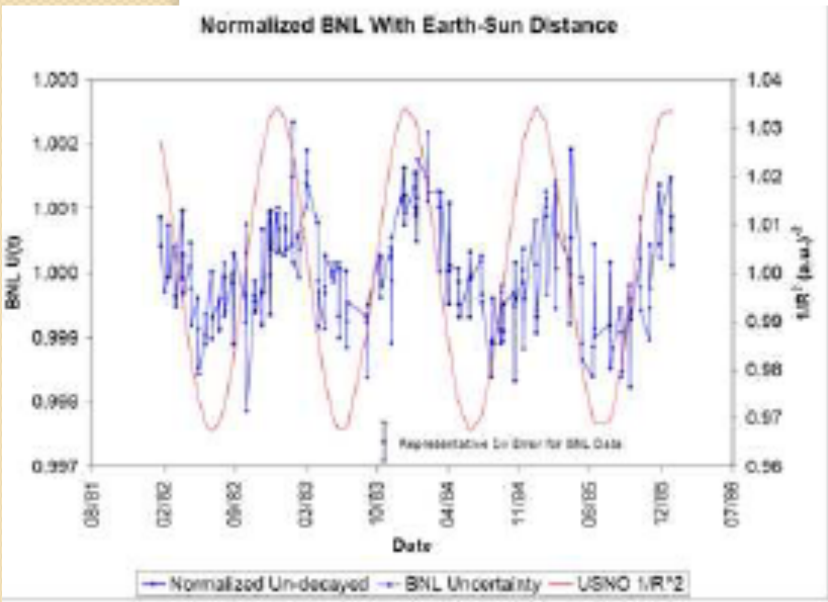
Evidence for Correlations Between Nuclear Decay Rates and Earth-Sun Distance

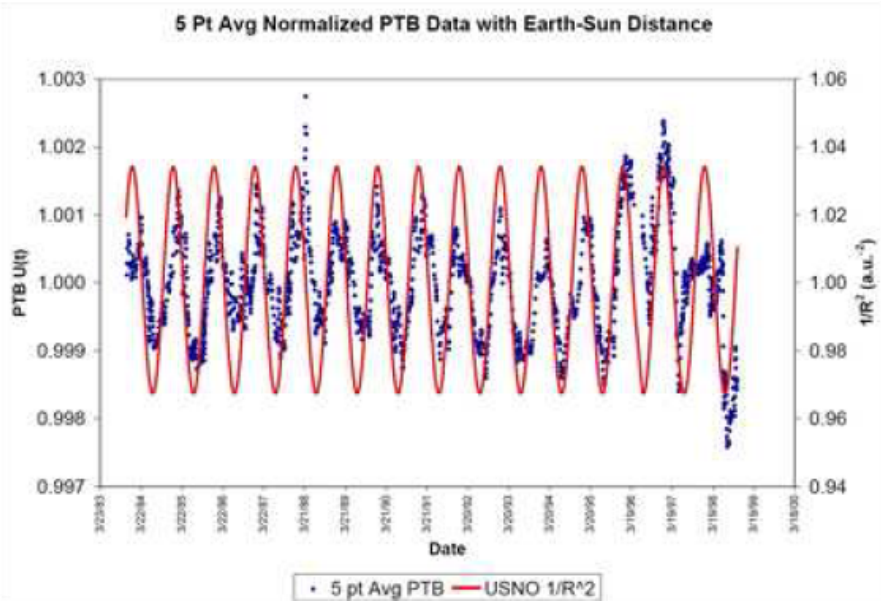
Jere H. Jenkins,[1] Ephraim Fischbach,[1,*] John B. Buncher,[1] John T. Gruenwald,[1] Dennis E. Krause,[1,2] and Joshua J. Mattes[1]

[1] *Physics Department, Purdue University, 525 Northwestern Avenue, West Lafayette, Indiana, 47907, USA*
[2] *Physics Department, Wabash College, Crawfordsville, Indiana, 47933, USA*

(Dated: August 25, 2008)

Modulation found in nuclear decay rate with maximum in February and minimum in August at 0.5% level





Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

Annual Modulation
Systematics difficult to analyse.
Most obvious discarded

Physics Letters B 710 (2012) 114–117

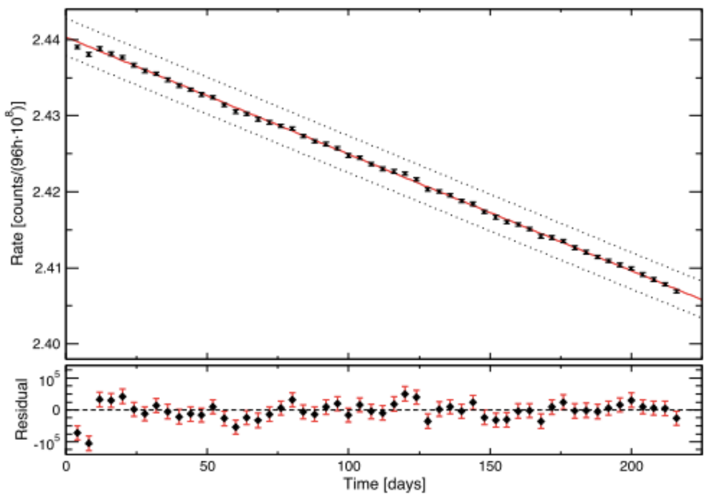
Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for time dependence of the ^{137}Cs decay constant

E. Bellotti [a], C. Broggini [b,*], G. Di Carlo [c], M. Laubenstein [c], R. Menegazzo [b]



Modulation found in nuclear decay rate with maximum in February and minimum in August at 0.5% level

Excluded at LNGS

Not clear the systematics

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

Ion Channelling

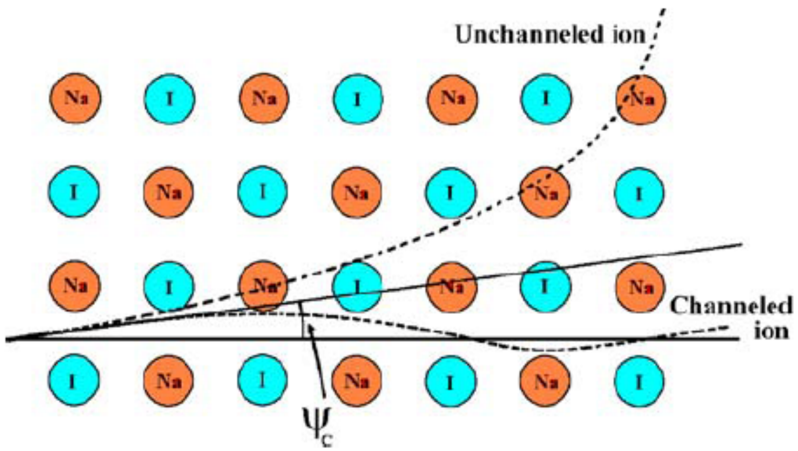


Fig. 1. Simplified schema of the channeling effect in the NaI(Tl) lattice. The axial channeling occurs when the angle of the motion direction of an ion with the respect to the crystallographic axis is less than a characteristic angle, Ψ_c, depicted there (see for details Sect. 2). Two examples for channeled and unchanneled ions are also shown (*dashed lines*)

Still some things to understand better

Anomalous very long ion penetration in crystalline targets when inciding in the direction of a symmetry axis or plane

Small angle scattering maintains the ion the open channel

Channeled ions loose their energy predominantly to electrons more scintillation light in NaI Tl for nuclear recoils channeled

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

Quenching Factor

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

Still some things to understand better

Non negligible uncertainties in the relative efficiency factor for nuclear recoils vs electron recoils

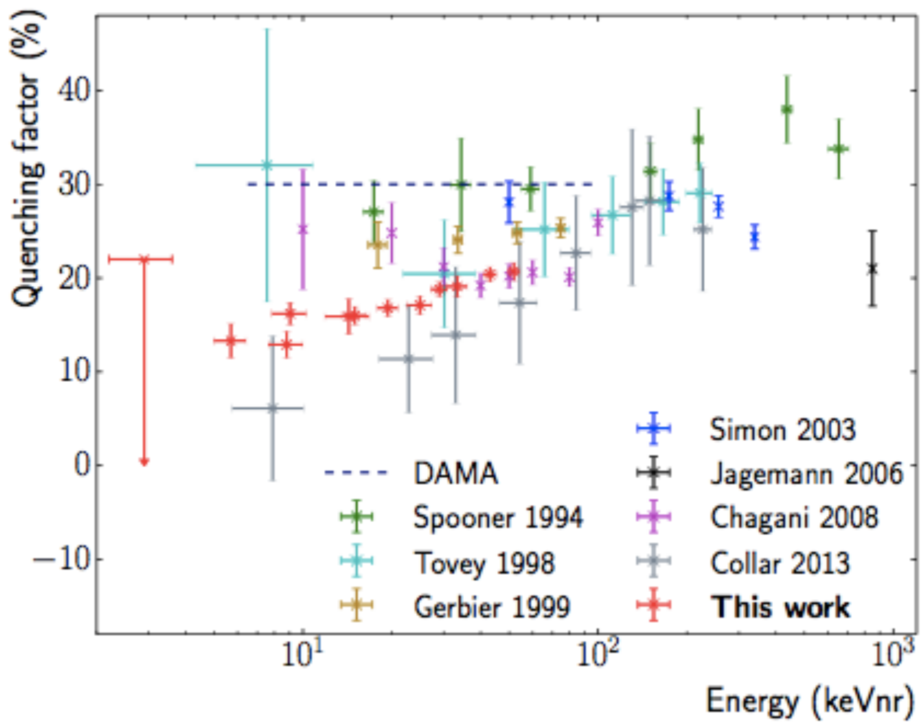
In the case of NaI detectors in the search for Dark Matter we have to know recoil energy scale for Na nuclei and I nuclei and are very different

Review of the Experimental Status

DAMA/LIBRA experiment

Model Independent Result

Quenching Factor



Still some things to understand better

Non negligible uncertainties in the relative efficiency factor for nuclear recoils vs electron recoils

In the case of NaI detectors in the search for Dark Matter we have to know recoil energy scale for Na nuclei and I nuclei and are very different

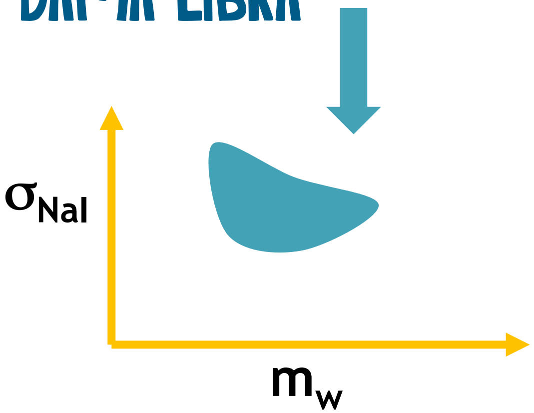
Recent measurements point at strong energy dependence!!!

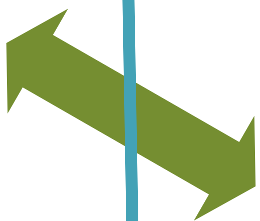
Review of the Experimental Status

DAMA/LIBRA experiment

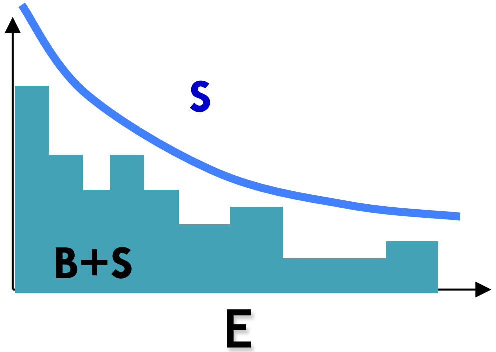
Comparison with other experiments

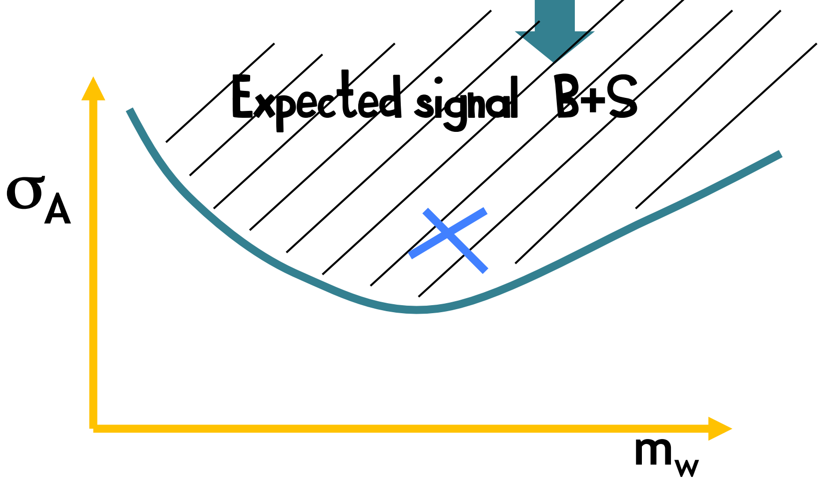
Apparent evidence from DAMA LIBRA





No evidence of signal in target A





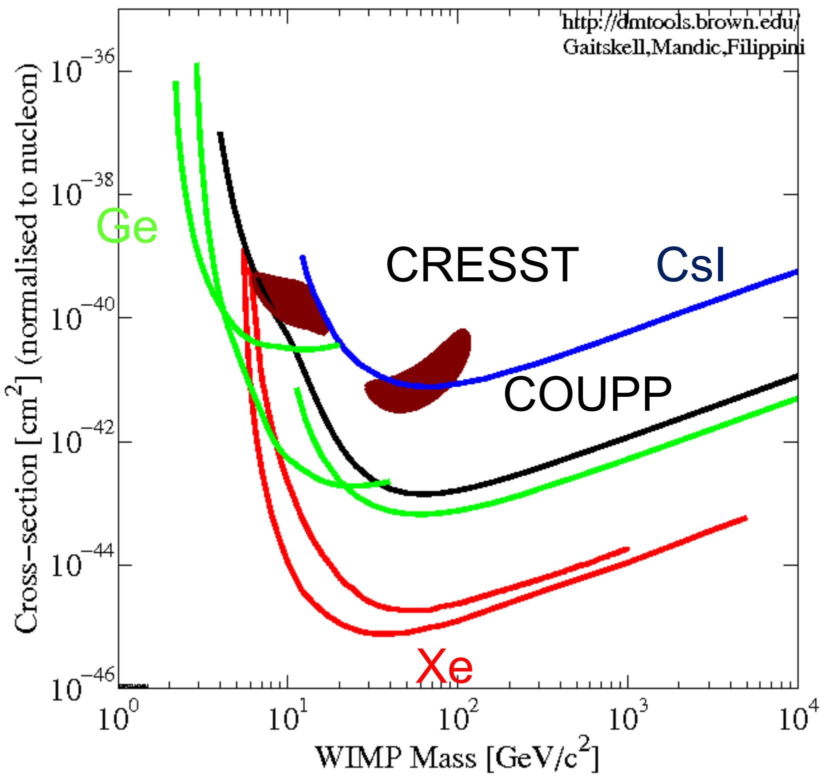
Comparison is model dependent

Review of the Experimental Status

DAMA/LIBRA experiment

Comparison with other experiments

Spin Independent Interactions



http://dmtools.brown.edu/

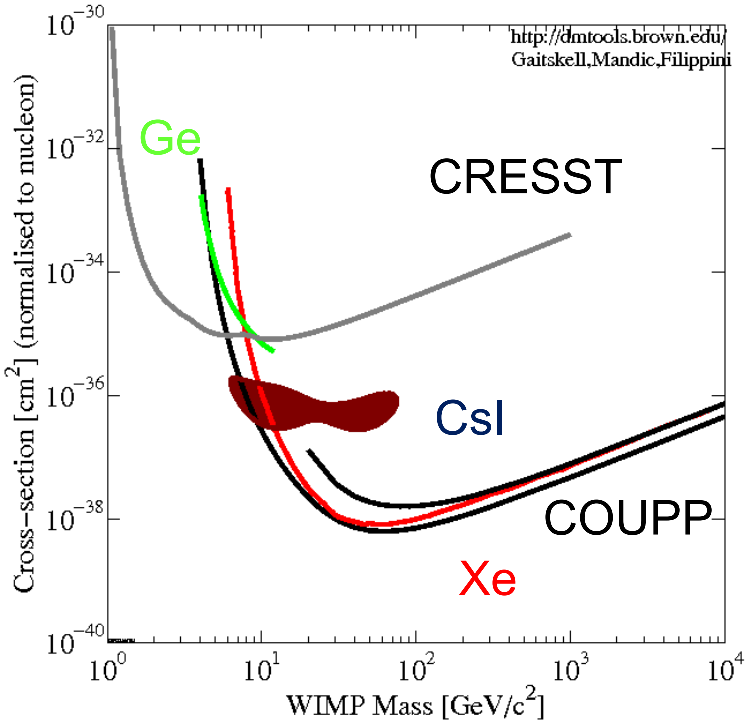
Review of the Experimental Status

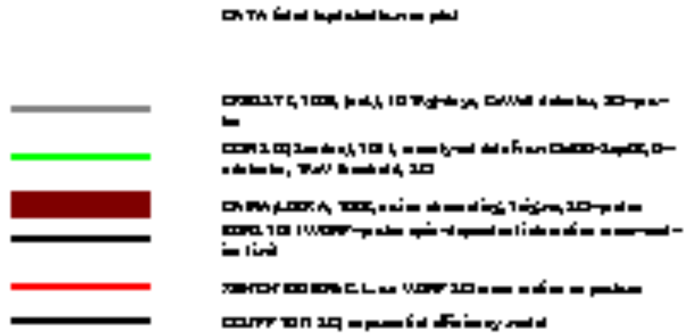
DAMA/LIBRA experiment

Comparison with other experiments

SPIN DEPENDENT INTERACTIONS

proton WIMP





http://dmtools.brown.edu/

Review of the Experimental Status

DAMA/LIBRA experiment

Comparison with other experiments

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

The race to detect dark matter has yielded mostly confusion. But the larger, more sensitive detectors being built could change that picture soon.

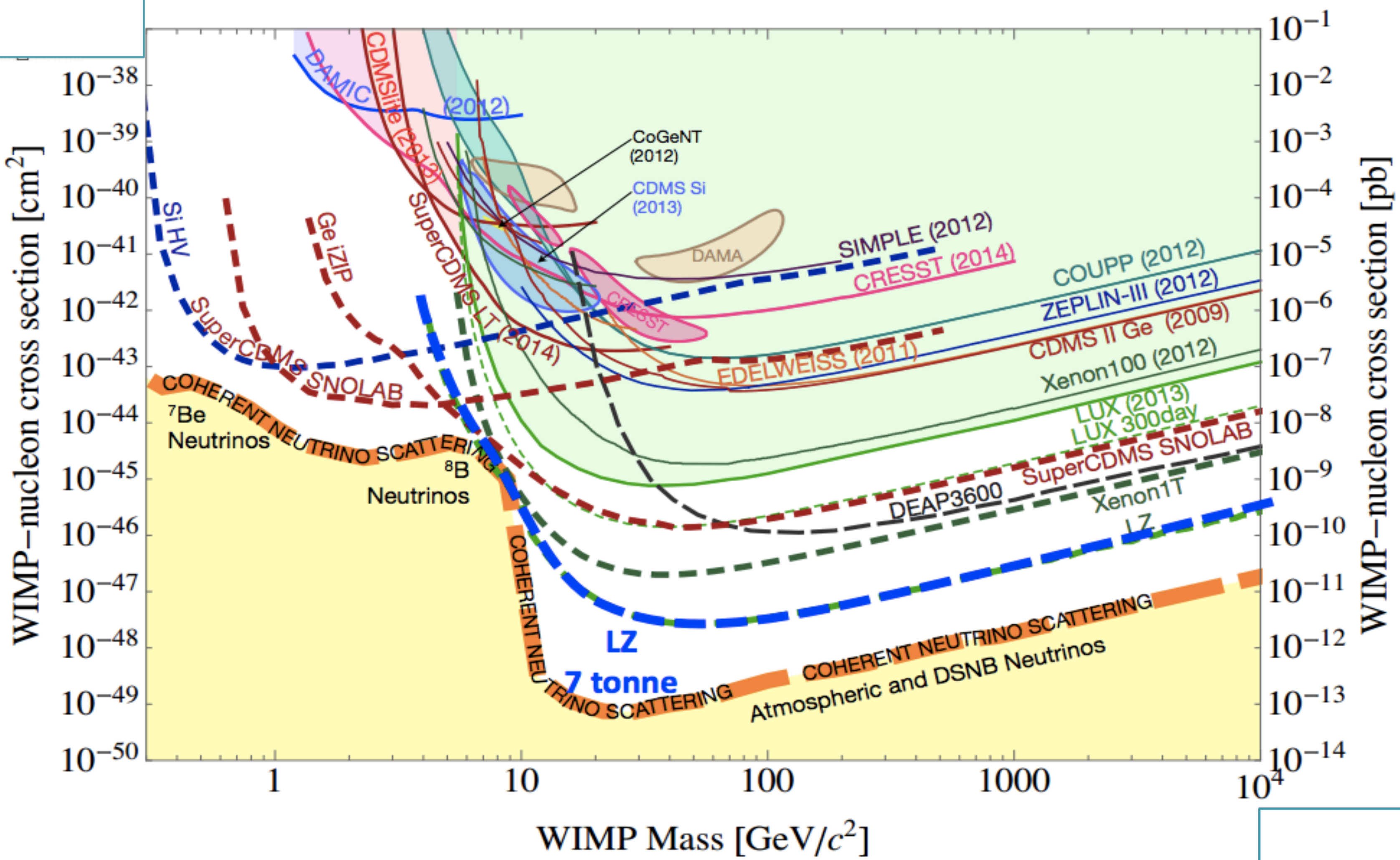
VERY EXCITING CHALLENGE FOR PHYSICS IF TRUE!

In order to decouple unknown and uncertainties from particle, astronomical and nuclear models we should combine:

- Different detection techniques
- Different target materials
- Different signal signatures

Review of the Experimental Status

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

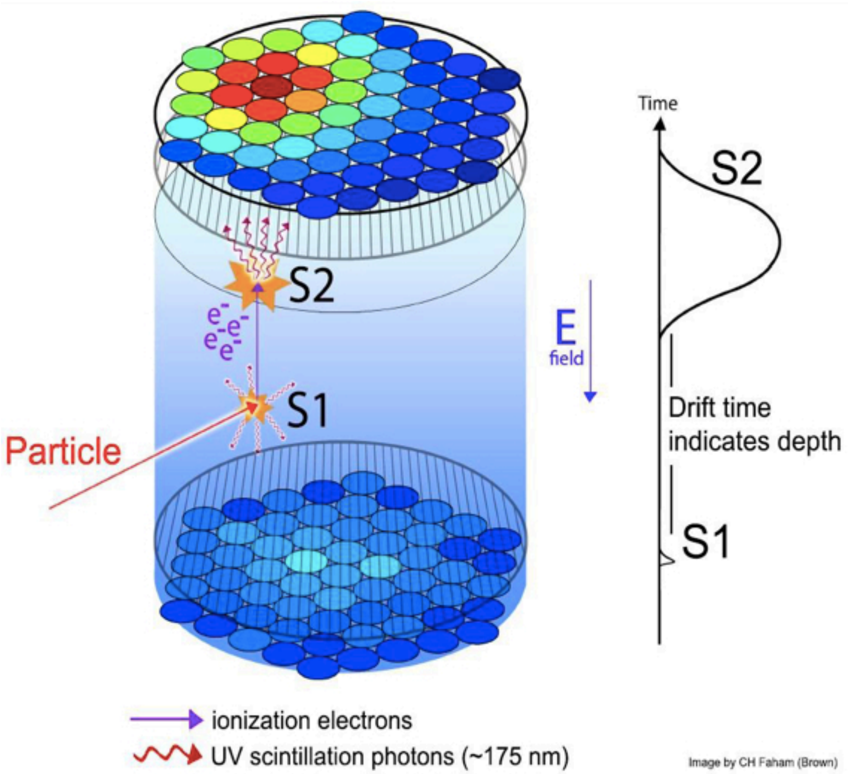


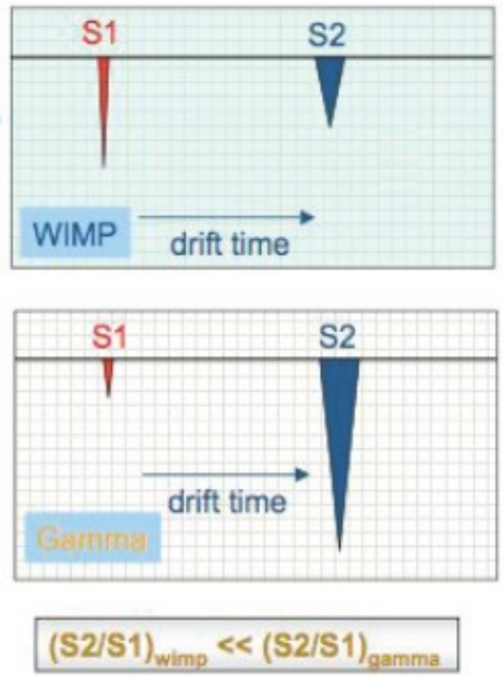
Review of the Experimental Status

Most sensitive experiments

Xe double phase TPC

LUX @ Sanford Laboratory (350 kg)





Review of the Experimental Status

Most sensitive experiments

Xe double phase TPC

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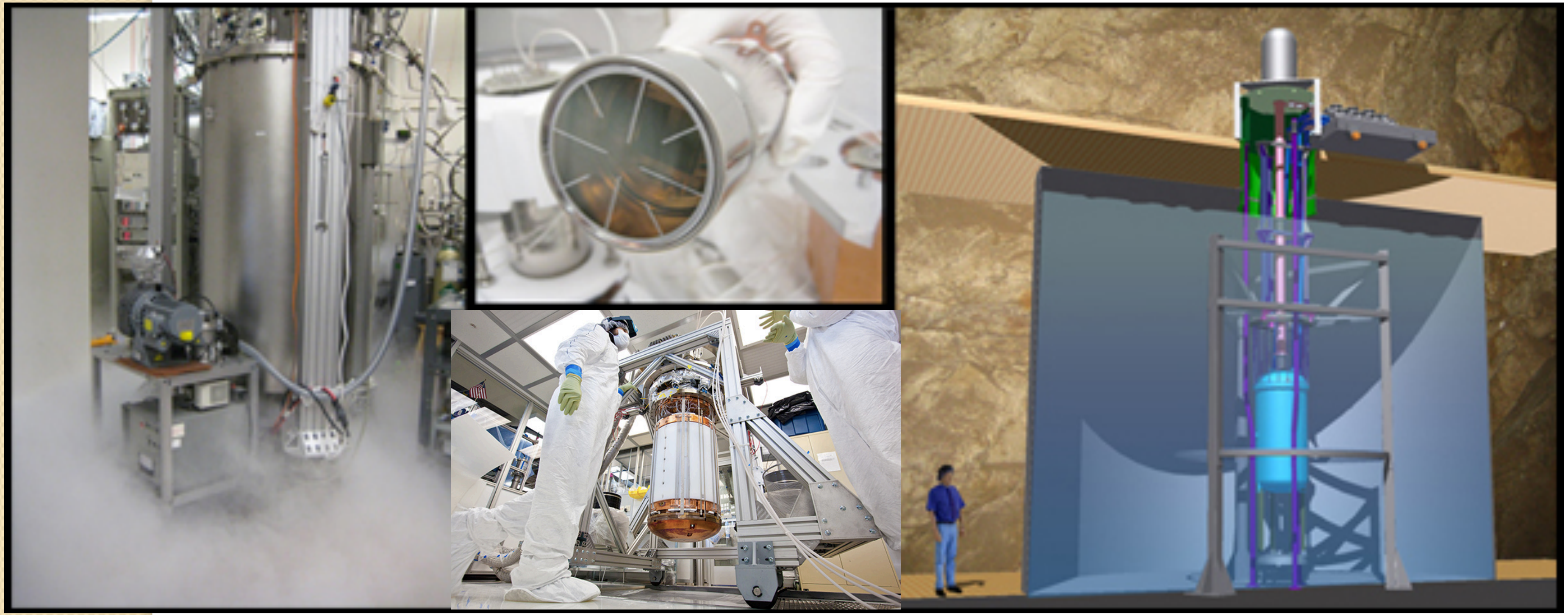

Review of the Experimental Status

Most sensitive experiments

Xe double phase TPC

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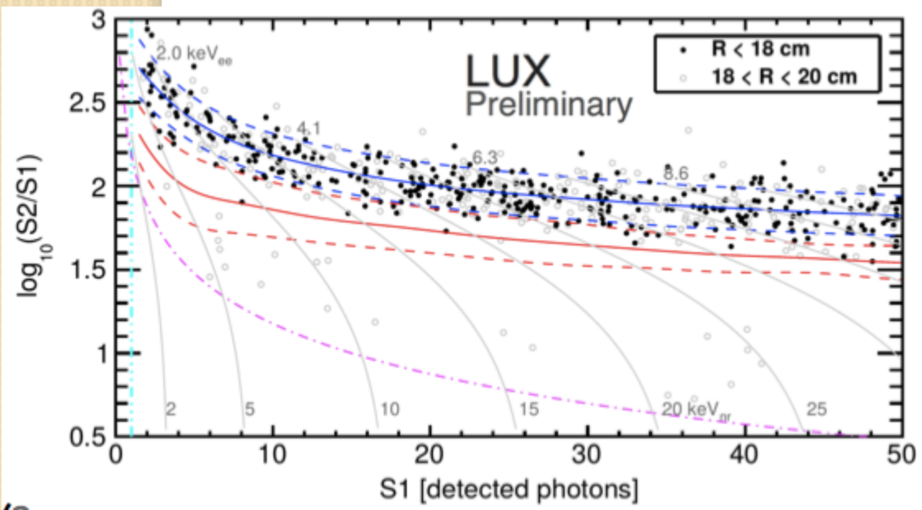
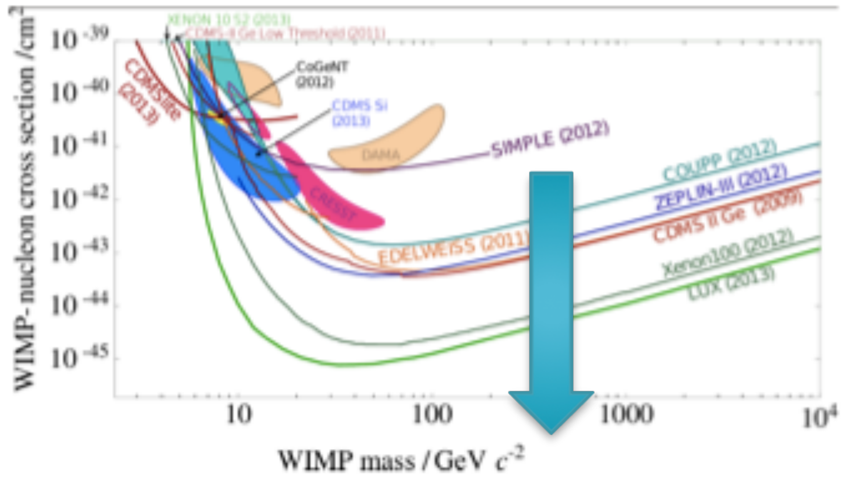




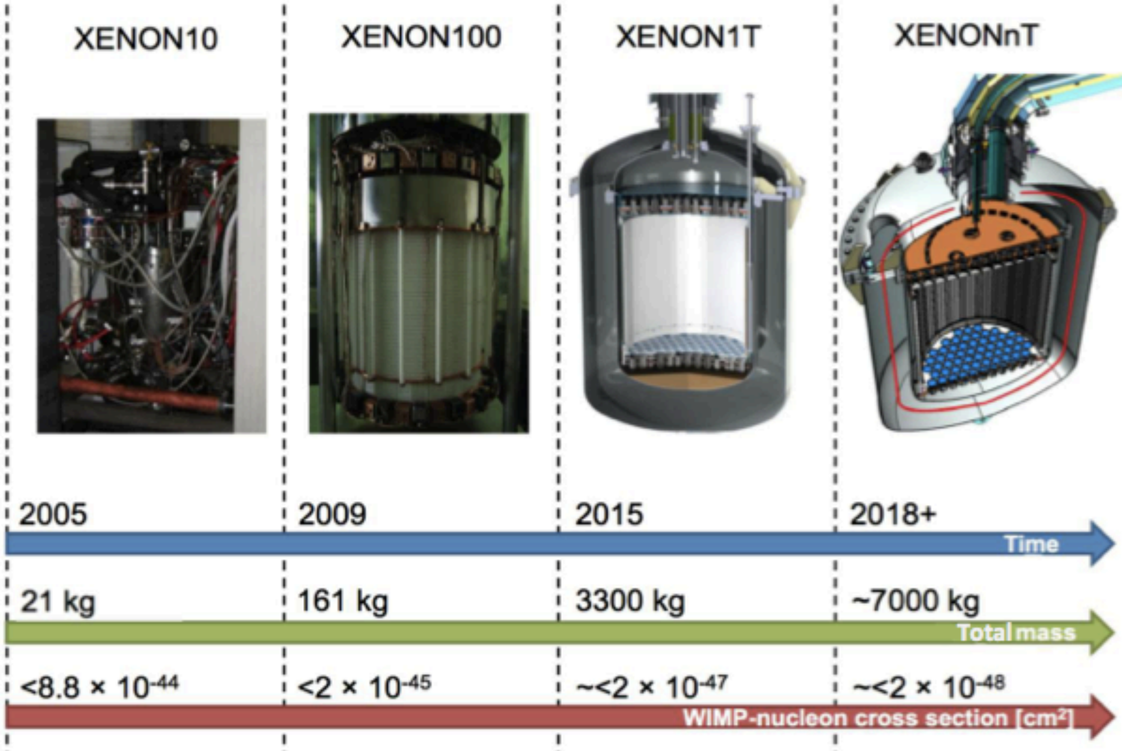
- **95 days** net (previously 85 d)
- **145 kg** fiducial (118 kg)
- conservative **1.2 keV** signal cutoff →**3.3 GeV** m_{min} (3.0 keV, 5.2 GeV)

Review of the Experimental Status

Most sensitive experiments

Xe double phase TPC

XENON100 & XENON1T @ LNGS



Review of the Experimental Status

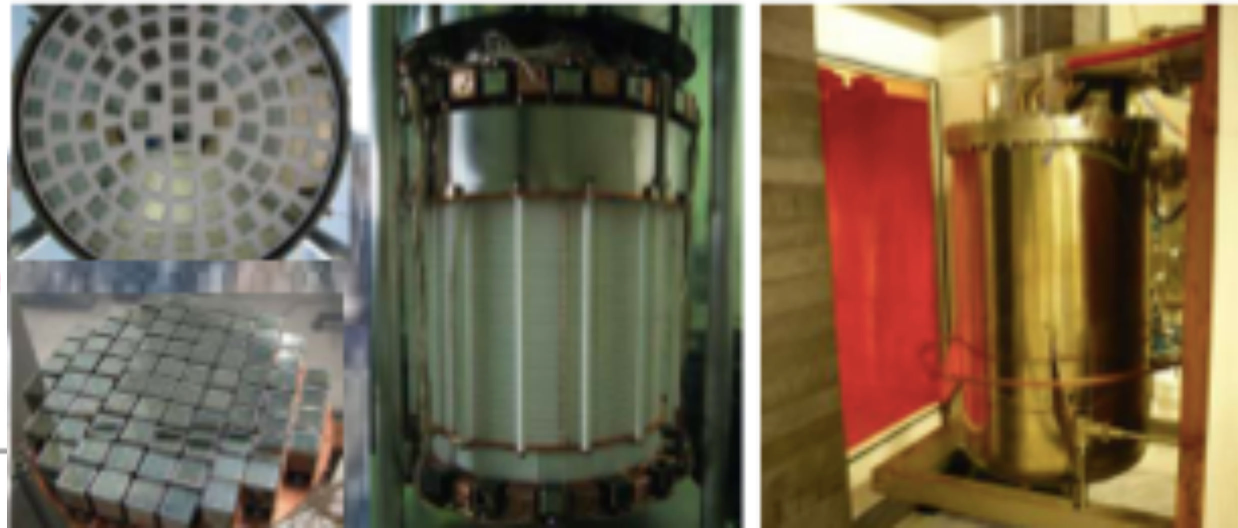
Most sensitive experiments

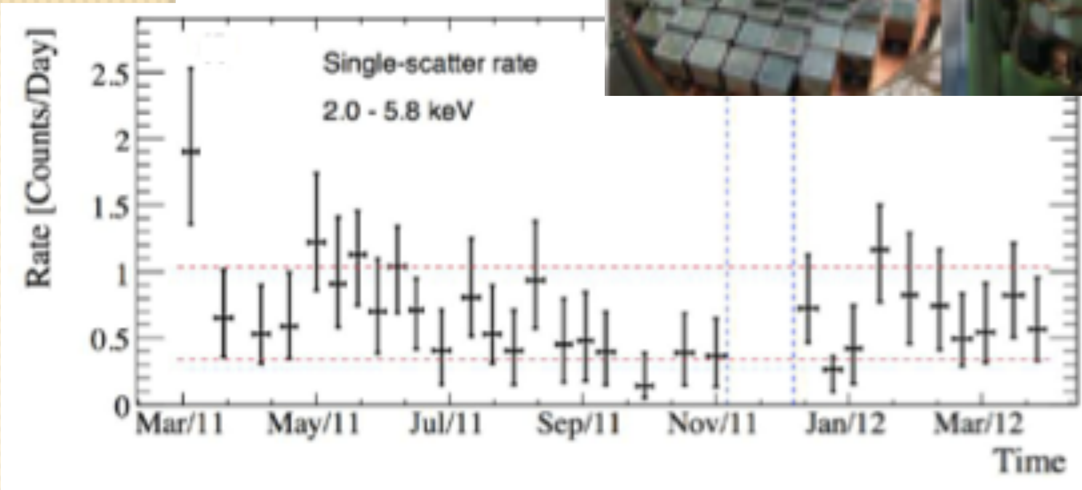
Xe double phase TPC

XENON100 &

- 161 kg LXe TPC

(62 kg target + 99 kg active veto)





Study of annual modulation with electron recoils

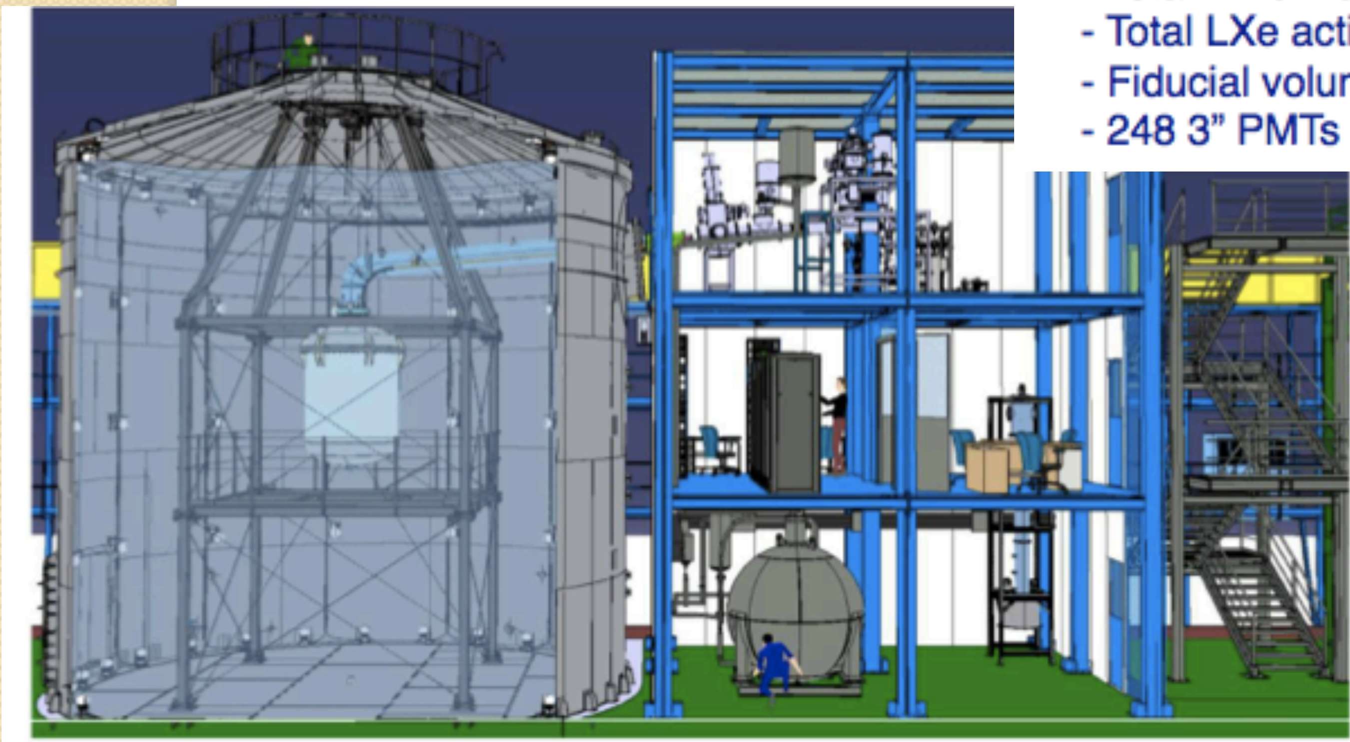
Review of the Experimental Status

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



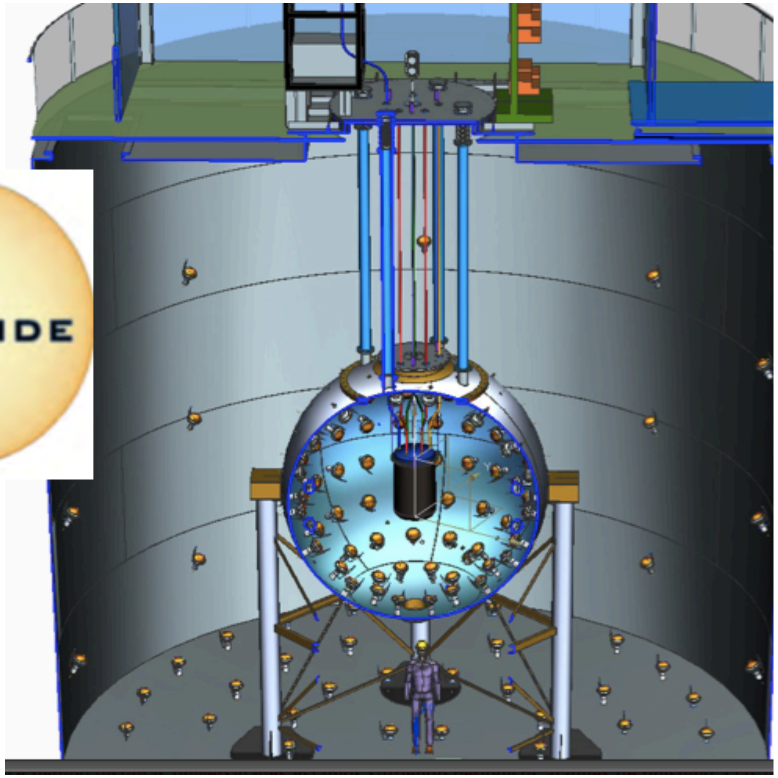
From 2015 on

Review of the Experimental Status

Most sensitive experiments

Ar double phase TPC

DarkSide @ LNGS

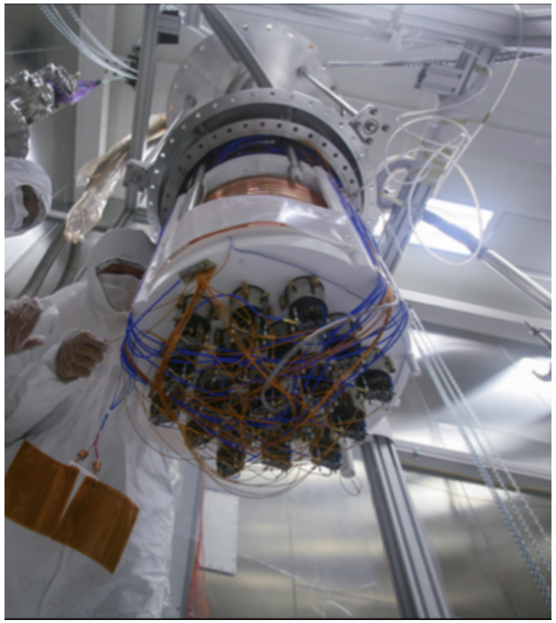


Pulse shape discrimination

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

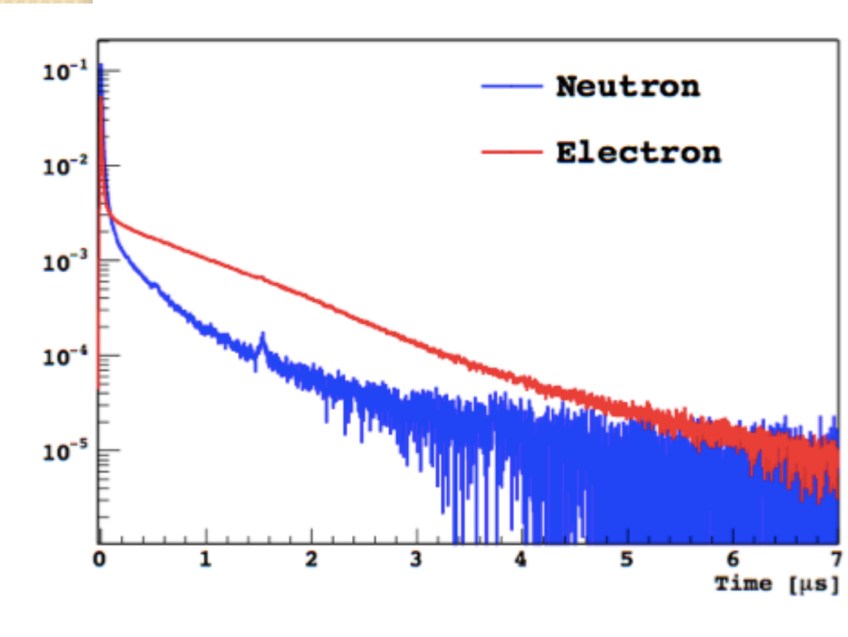
46 kg active 153 kg total

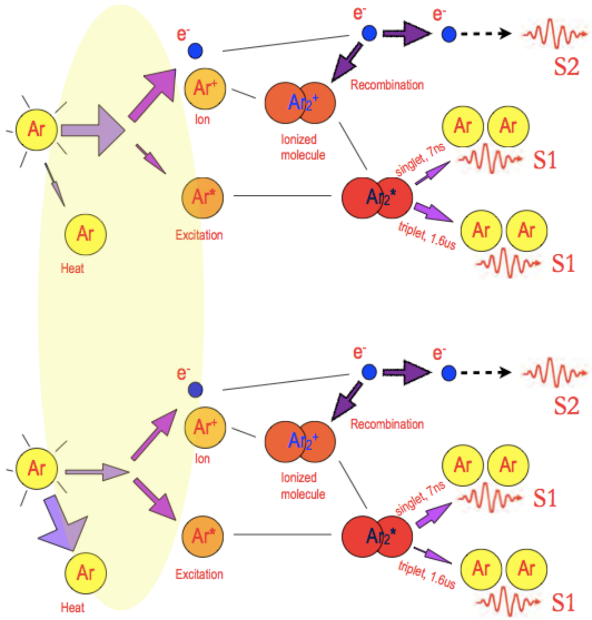
Pulse shape discrimination

Liquid Scintillator for n

Water tank for muons

Free from ^{39}Ar





ER

NR

Review of the Experimental Status

Most sensitive experiments

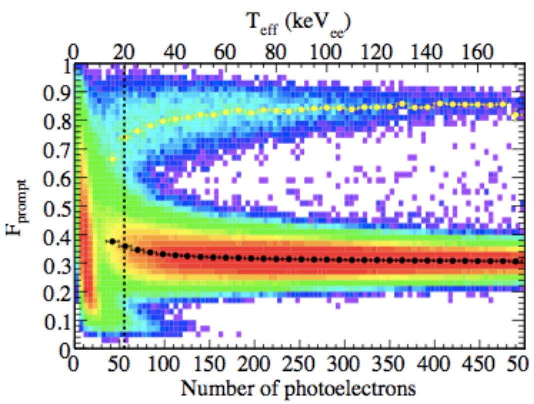
Ar single phase liquid scintillation detector

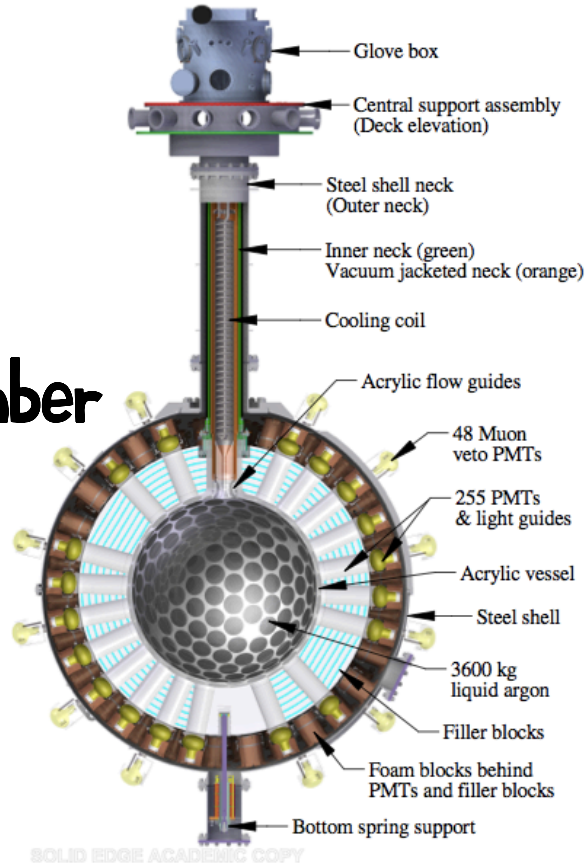
DEAP @ SNOLAB

3600 kg LAr

Excellent PSD capability

Cool down and Ar filling this September



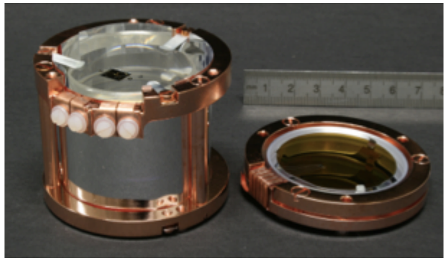


Review of the Experimental Status

Most sensitive techniques

Scintillating Bolometers

CRESST @ LNGS

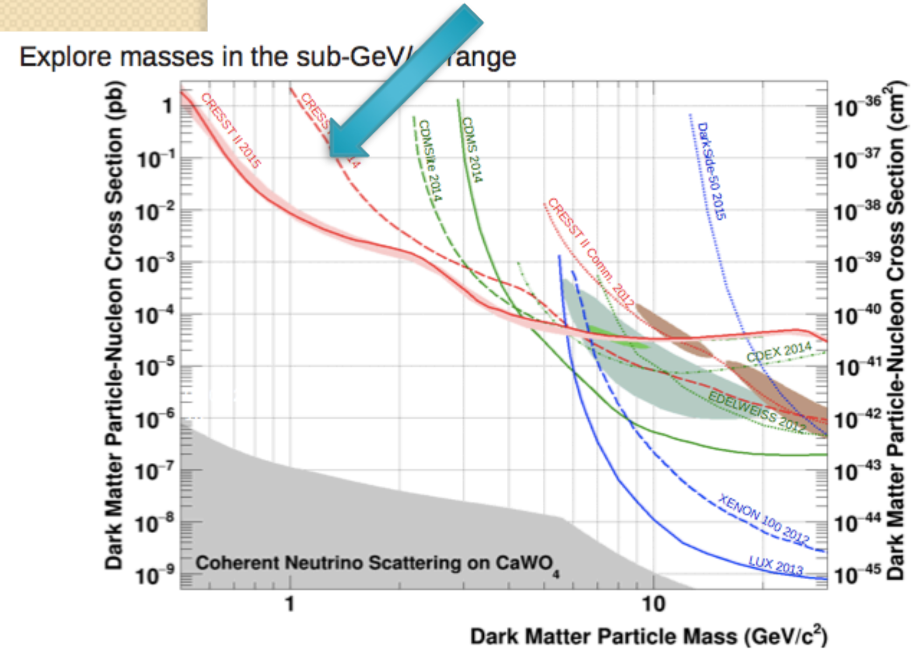


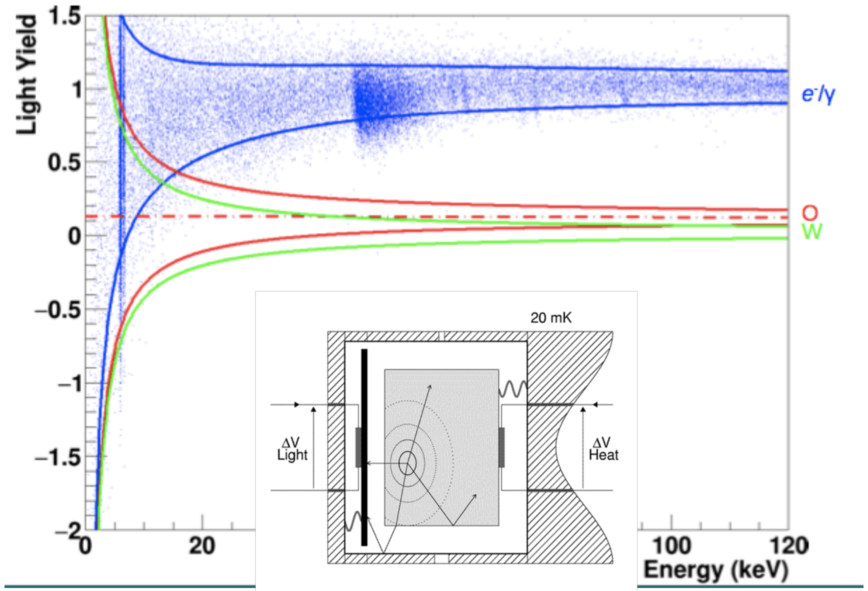
$CaWO_4$ bolometers

300 eV threshold

52 kg days exposure

Very good discrimination



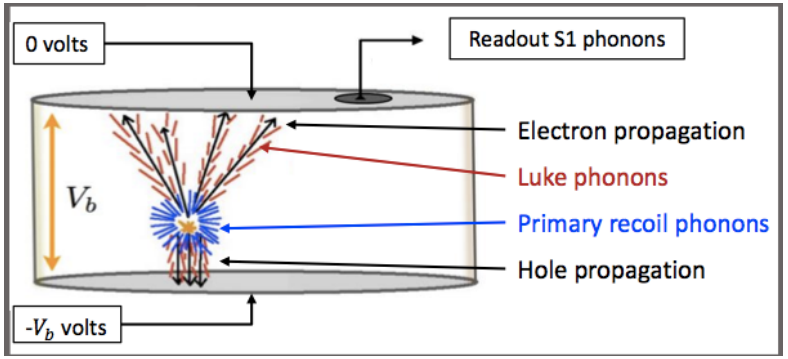


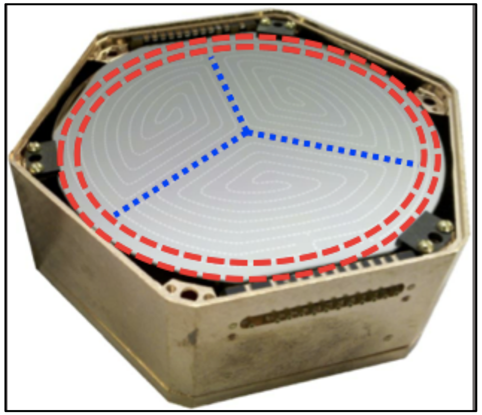
Review of the Experimental Status

Most sensitive experiments

Heat Ionization Bolometers

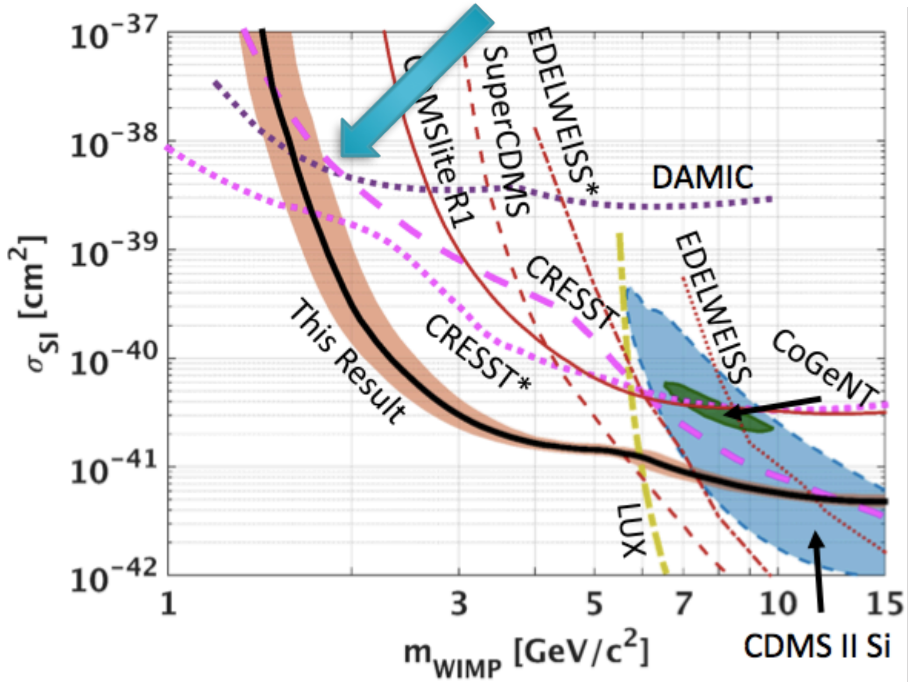
CDMS Lite @ SOUDAN





<100 eV Ionization Trigger
70 kg day exposure

Further improvement expected after moving into SNOLAB

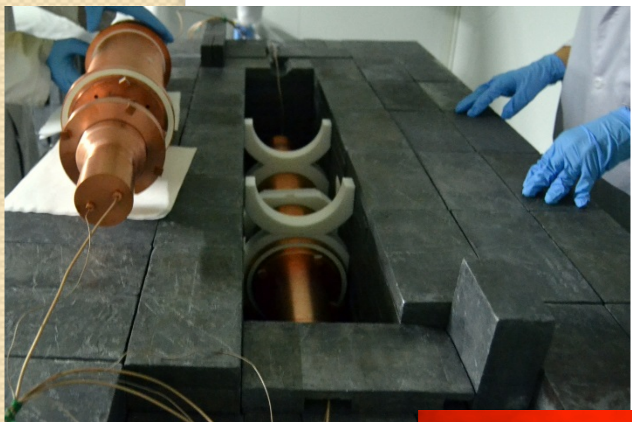


Review of the Experimental Status

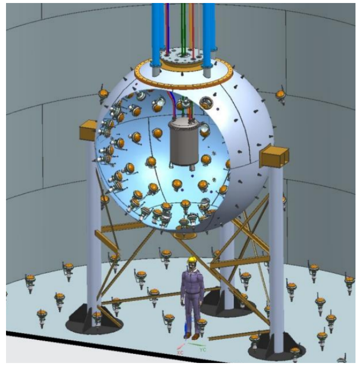
Experiments trying to reproduce DAMA LIBRA signal

NaI scintillators (same target and technique)

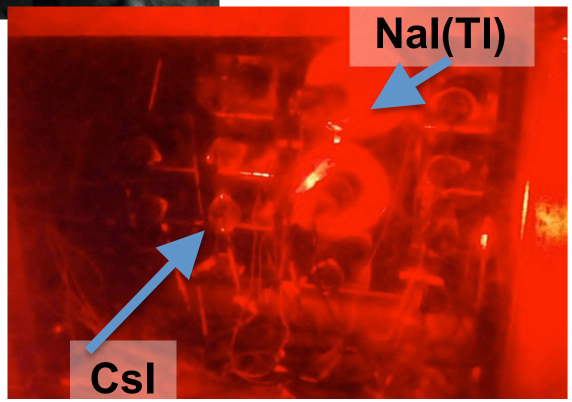
ANAIS @ LSC (2000 - ...)



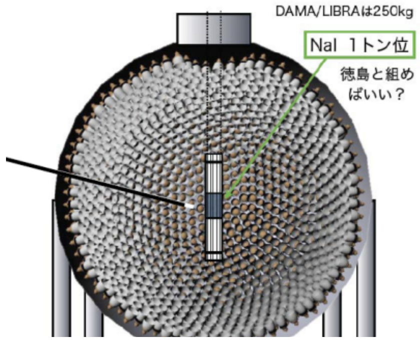
DM-ICE @ South Pole (2011 - ...)



SABRE project



KIMS @ Y2L (2013 - ...)



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

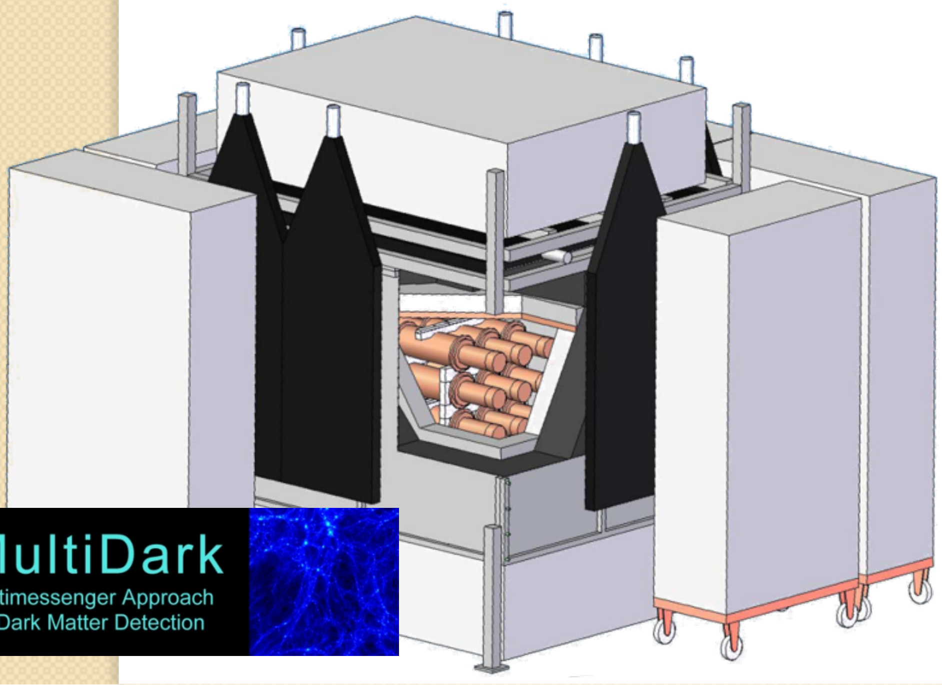
Review of the Experimental Status

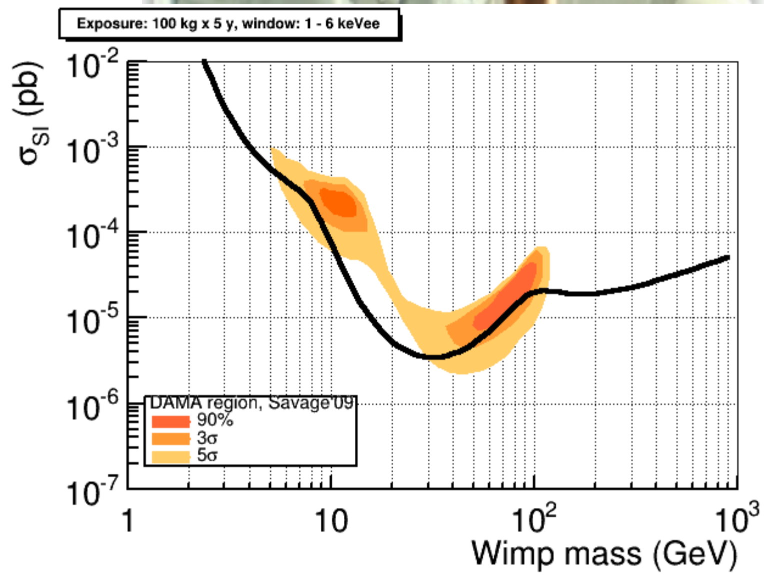
Experiments trying to reproduce DAMA LIBRA signal

NaI scintillators (same target and technique)

ANAIS @ Canfranc

100 kg of ultrapure NaI(Tl)





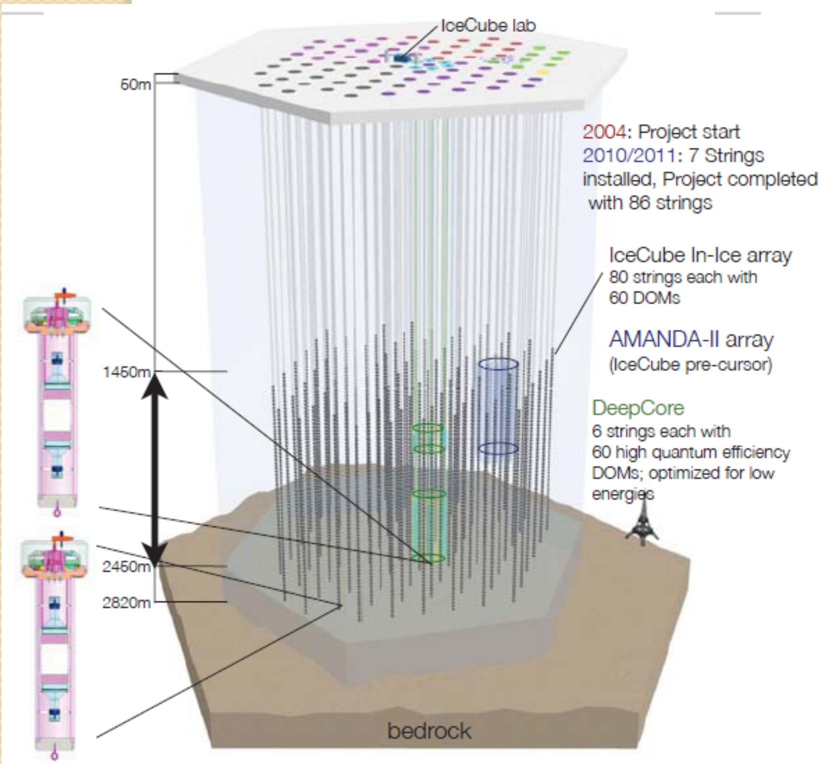
MultiDark
Multimessenger Approach for Dark Matter Detection

Review of the Experimental Status

Experiments trying to reproduce DAMA LIBRA signal

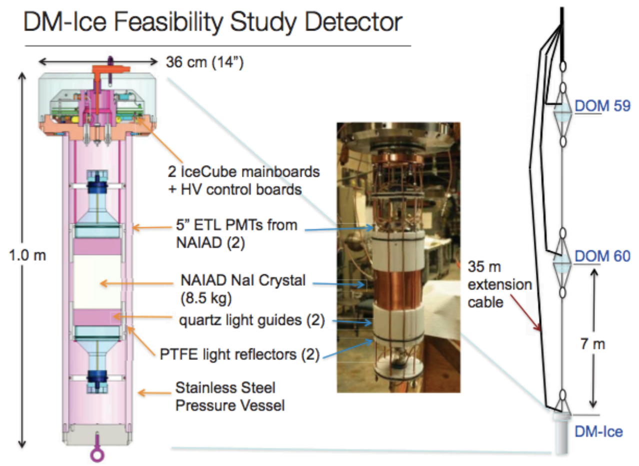
NaI scintillators (same target and technique)

DM ICE @ South Pole



SYSTEMATICS for annual modulation very different at southern hemisphere and ice environment

17 kg deployed in 2010



Review of the Experimental Status

Other Techniques

Bubble Chambers

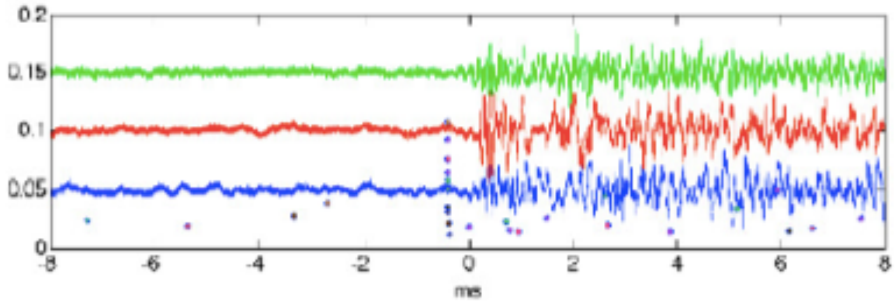
PICO 60 @ SNO

F content interesting for SD sensitivity

Wide liquid choice able to tune target to different WIMP couplings

Optical and acoustical detection of the bubbles

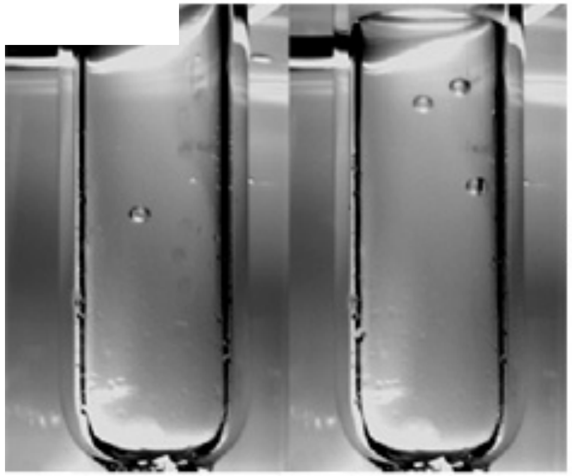
Alpha particles are louder and can be discriminated

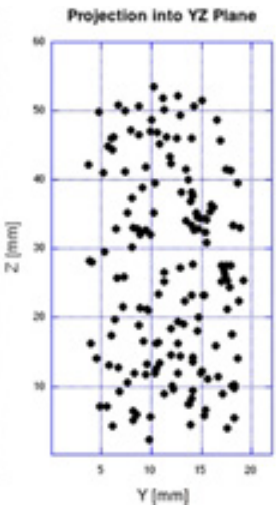


Filled with 36.8 kg of CF_3I.

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

Run-2 with C_3F_8 target in 2016.



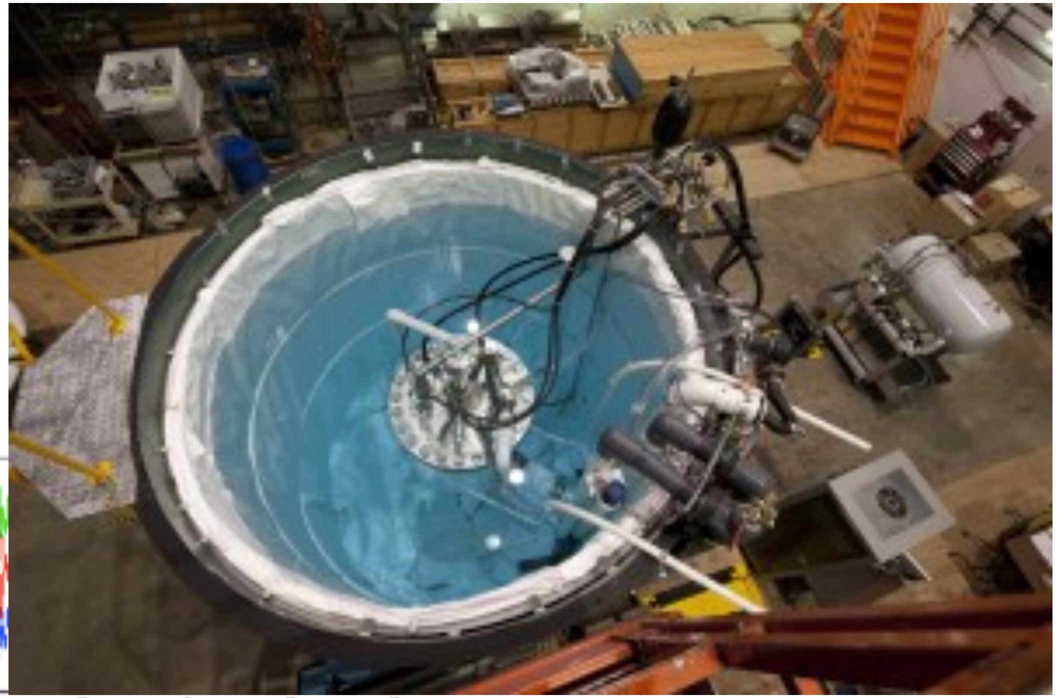


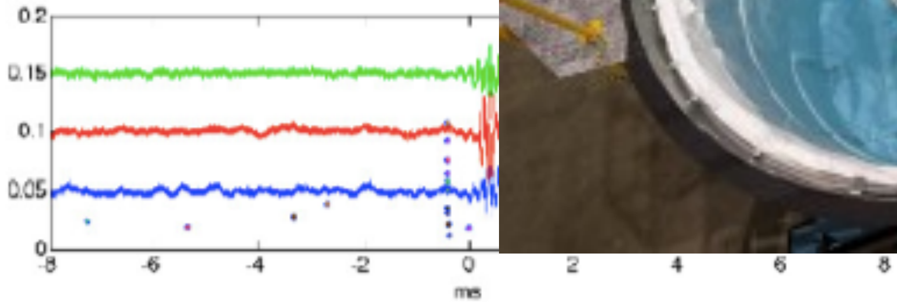
Review of the Experimental Status

Other Techniques

Bubble Chambers

PICO 60 @ SNO





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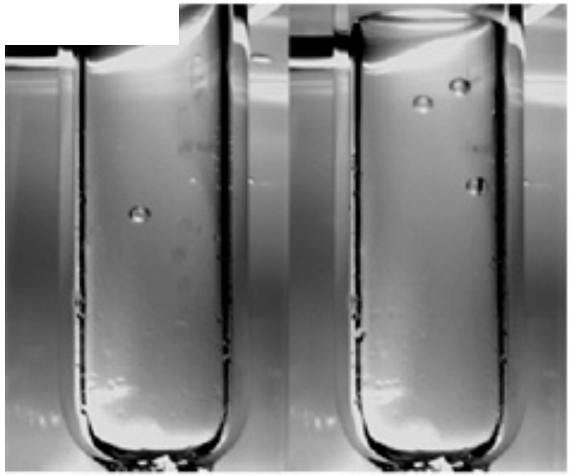
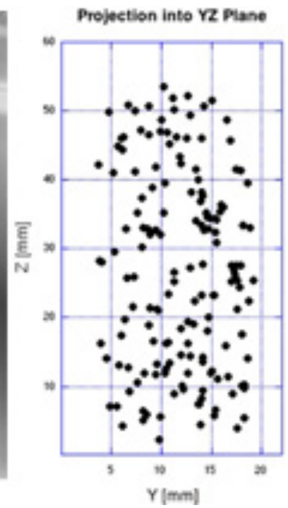




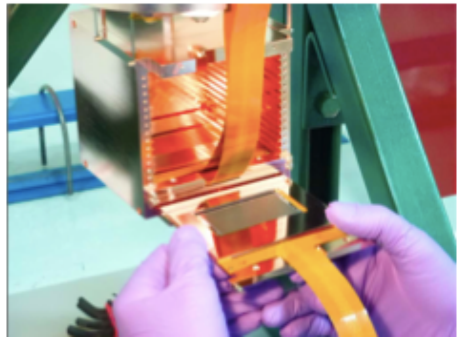
Review of the Experimental Status

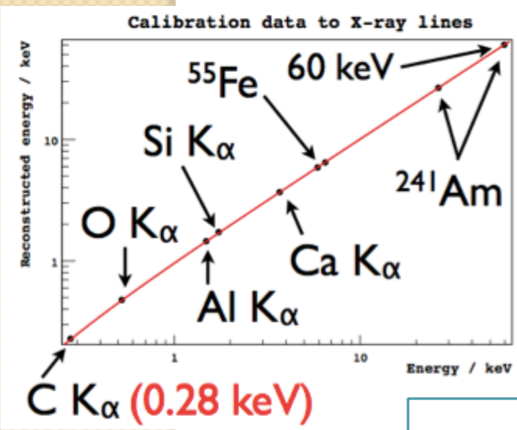
Other Techniques

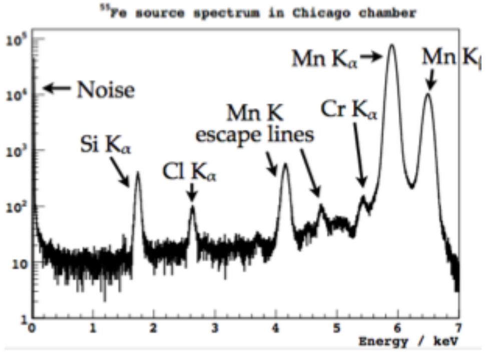
CCDs

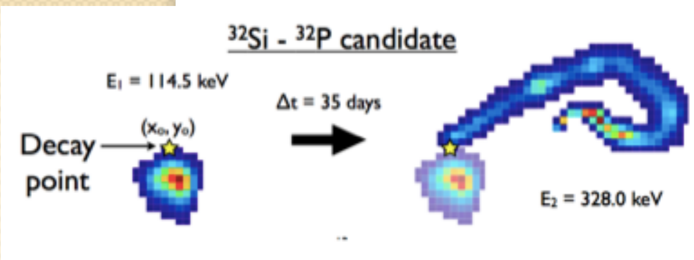
DAMIC @ Sno

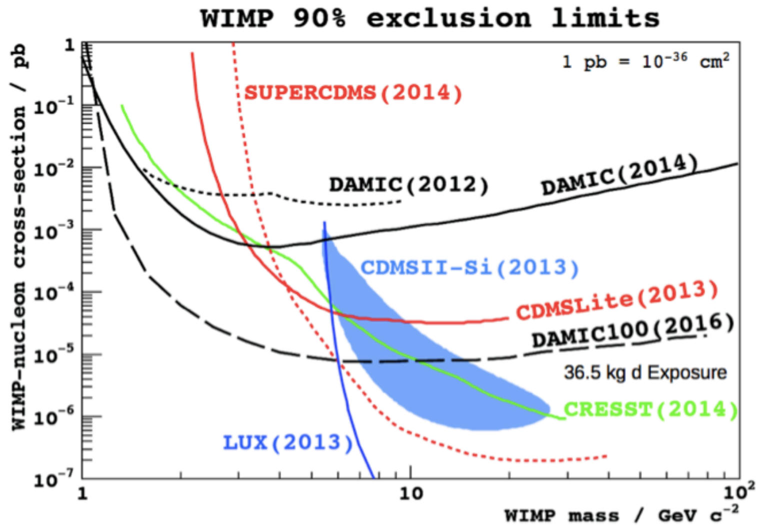
Very low threshold 40 eV/pixel
Excellent spatial resolution
Low exposure with good sensitivity











Review of the Experimental Status

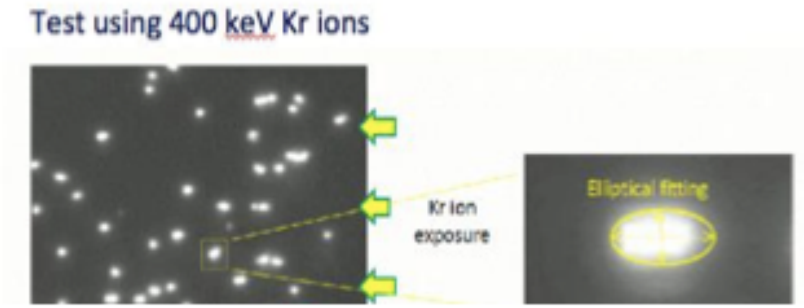
Directional Detectors Proposals

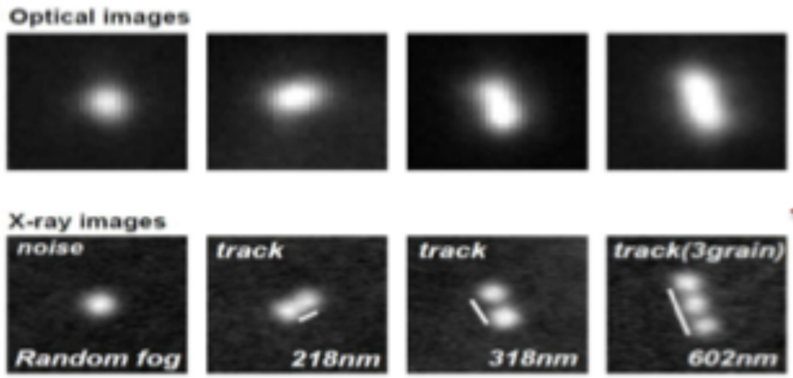
Nuclear emulsions

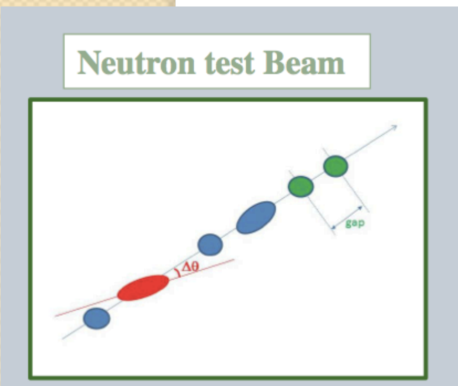
NEWS @ LNGS

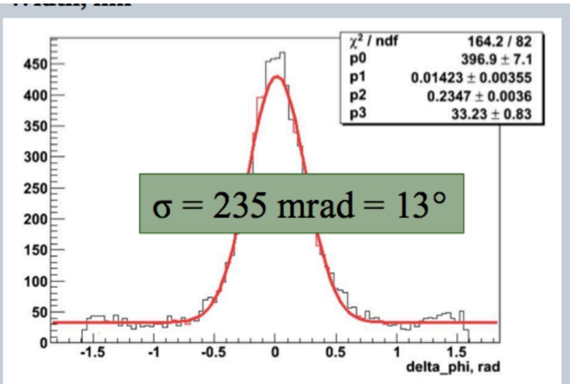
Nano Imaging Tracker

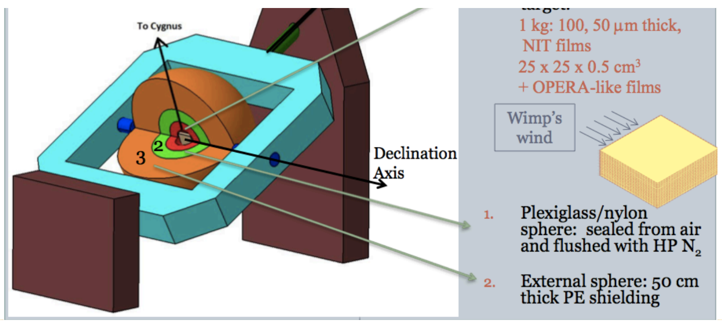
Ag Br Crystals 40 nm size
Readout of submicrometric tracks
Directional Sensitivity 13°











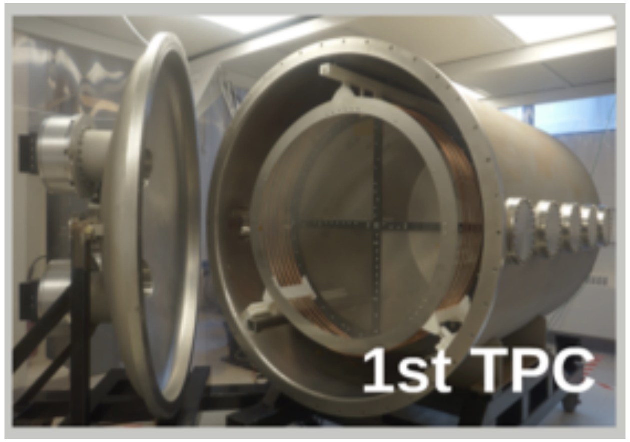
Review of the Experimental Status

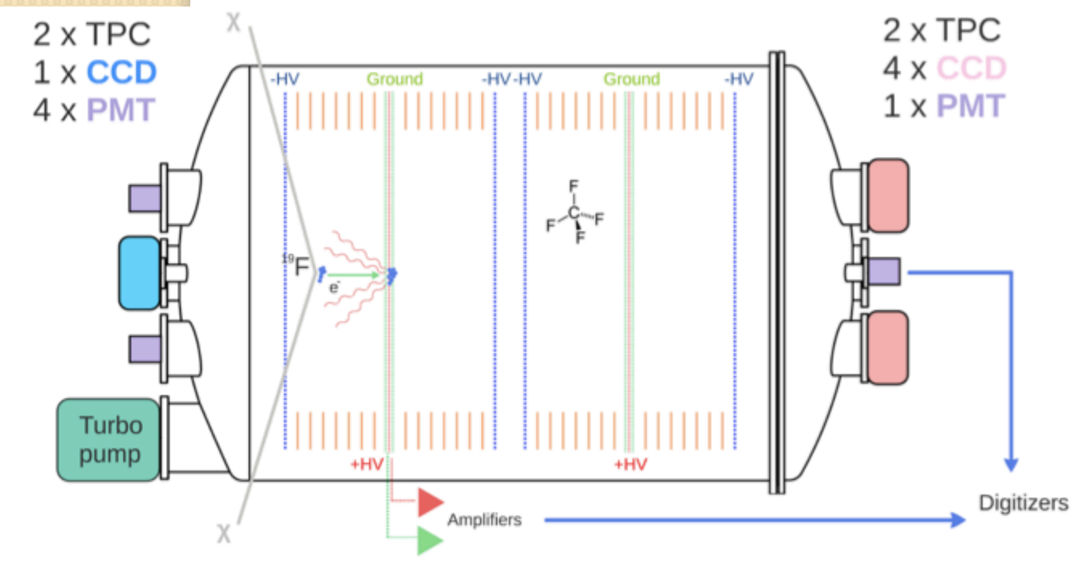
Directional Detectors Proposals

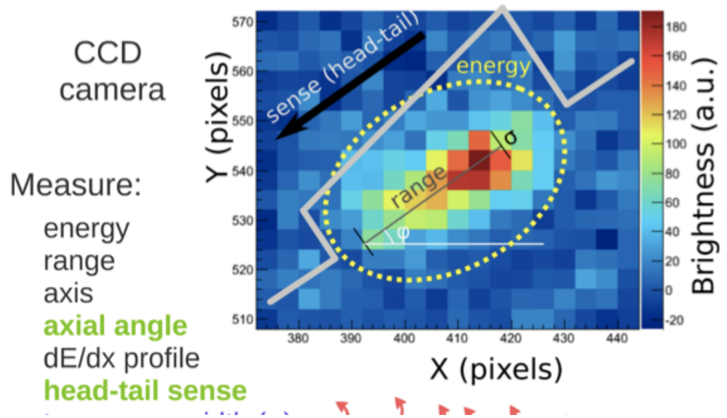
Low Pressure Gaseous Detectors

DM TPC @ SNOLAB

Modular Design
Scaling towards 1m^3







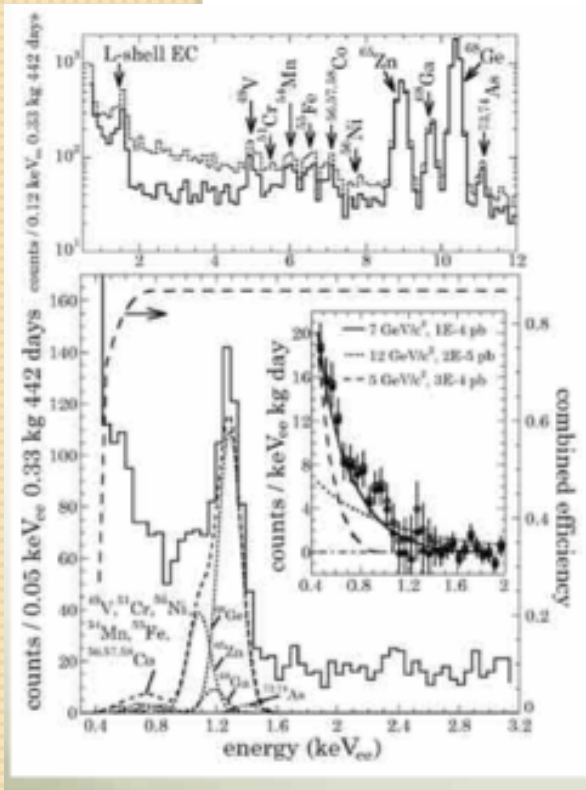
Review of the Experimental Status

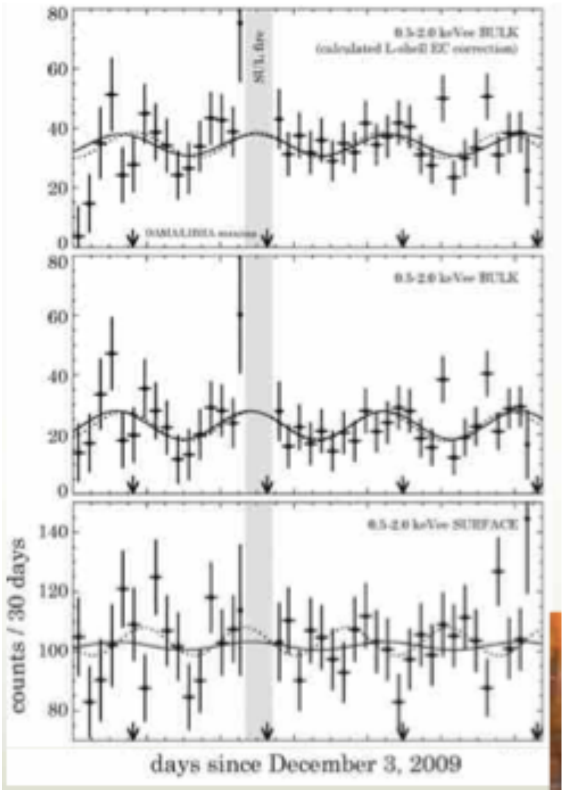
Other techniques

Semiconductor Detector

COGeNT @ SOUDAN

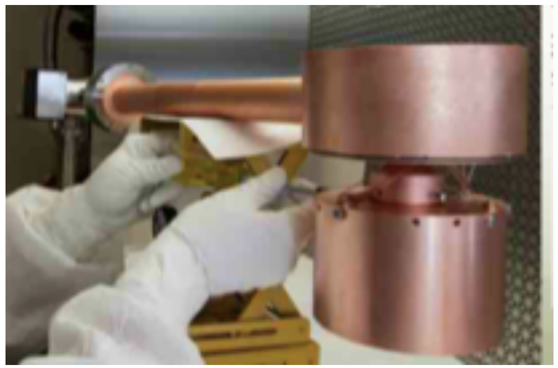
Ge target – 440g mass
500 eV threshold
P type Point Contact diode
Very low energy threshold



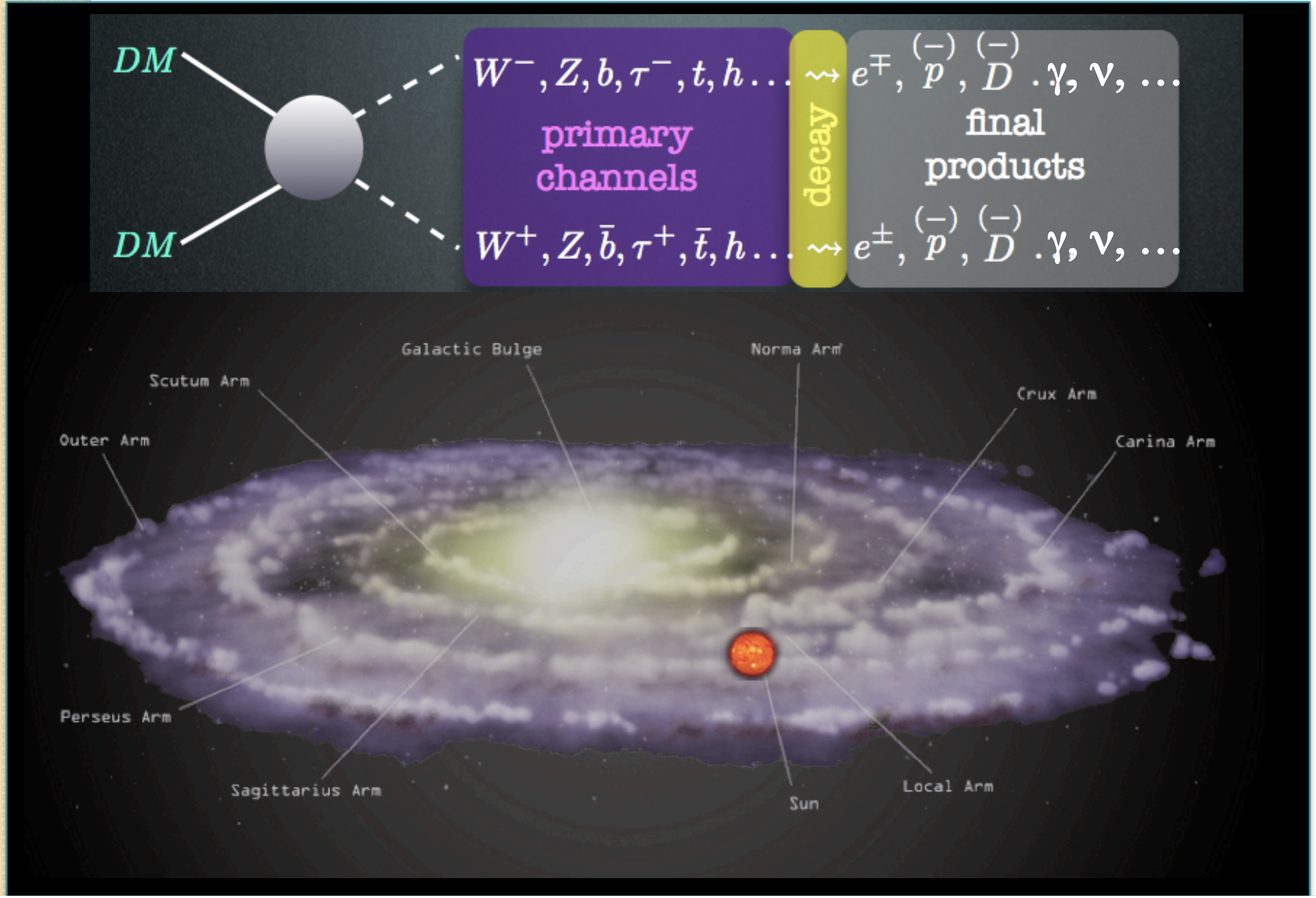


146 kg day
Irreducible excess of events
below 3 keVee

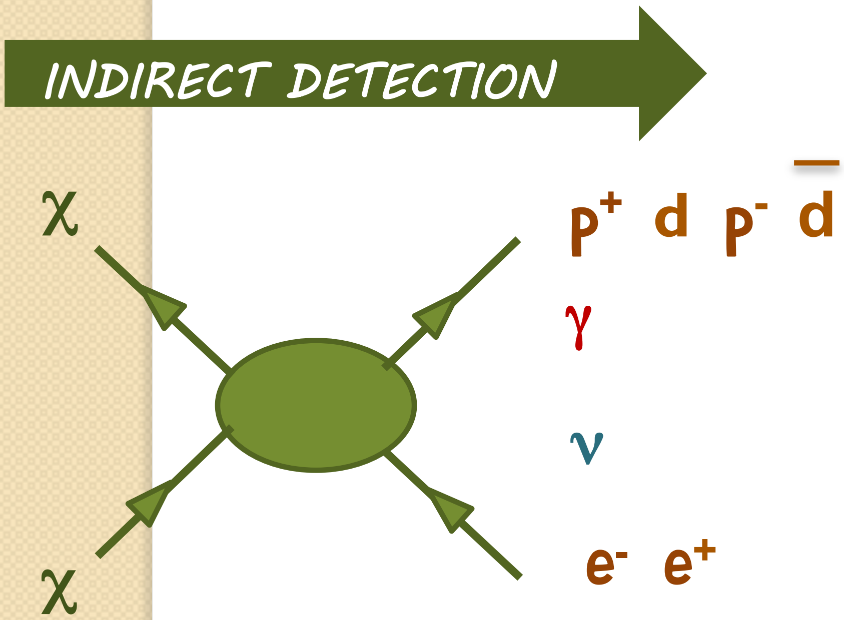
Annual modulation 2.2 σ



Dark Matter Indirect Detection



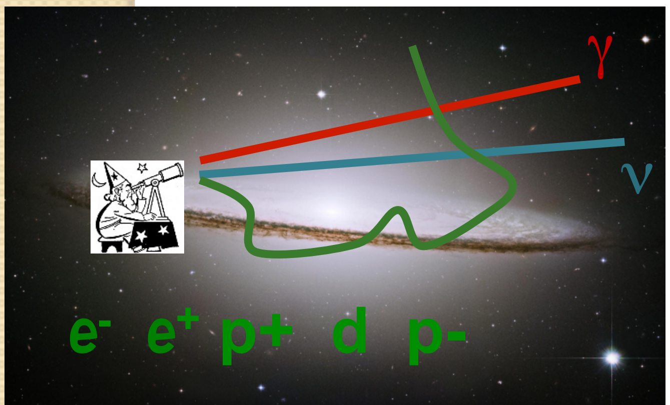
Dark Matter Indirect Detection



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

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

Particle Physics Model

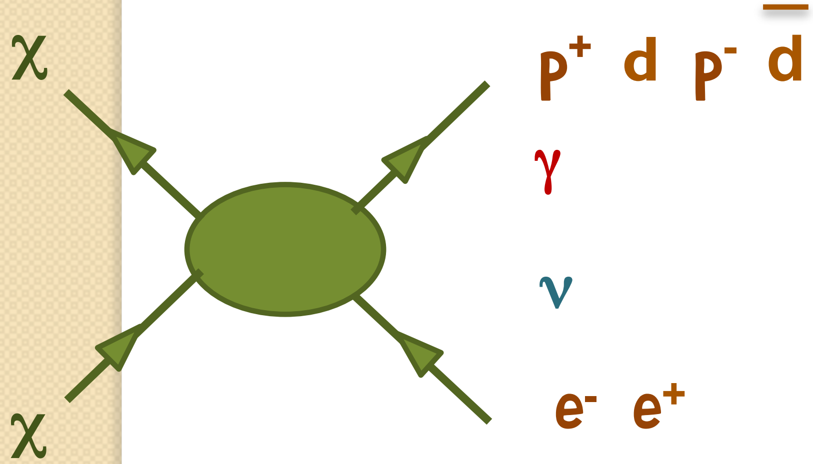


$$J(\Delta\Omega) = \int_{\Delta\Omega} \int_{l=0}^{\infty} dl\, d\Omega \rho_\chi^2(l)$$

Astrophysics uncertainties

Dark Matter Indirect Detection

INDIRECT DETECTION



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

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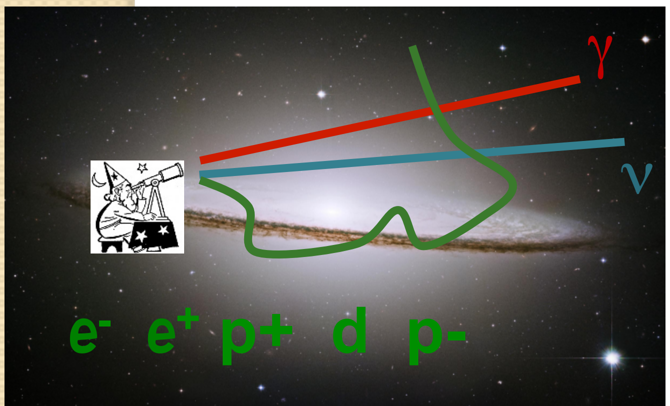
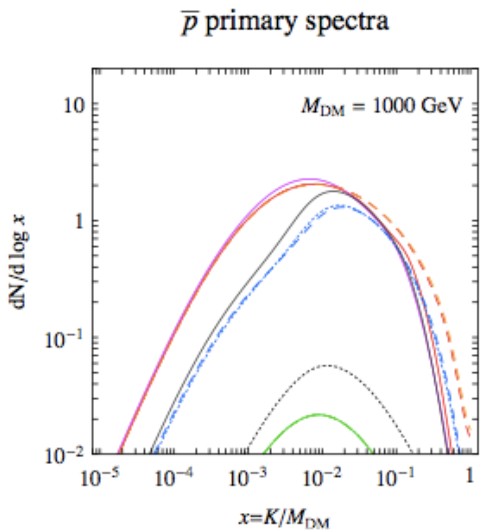
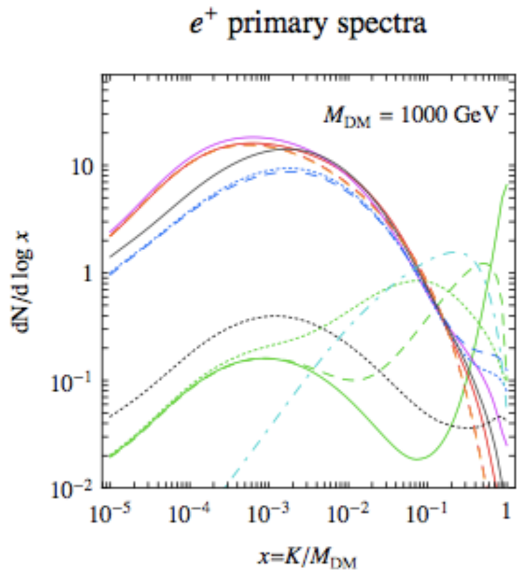
Particle Physics Model







Dark Matter Indirect Detection

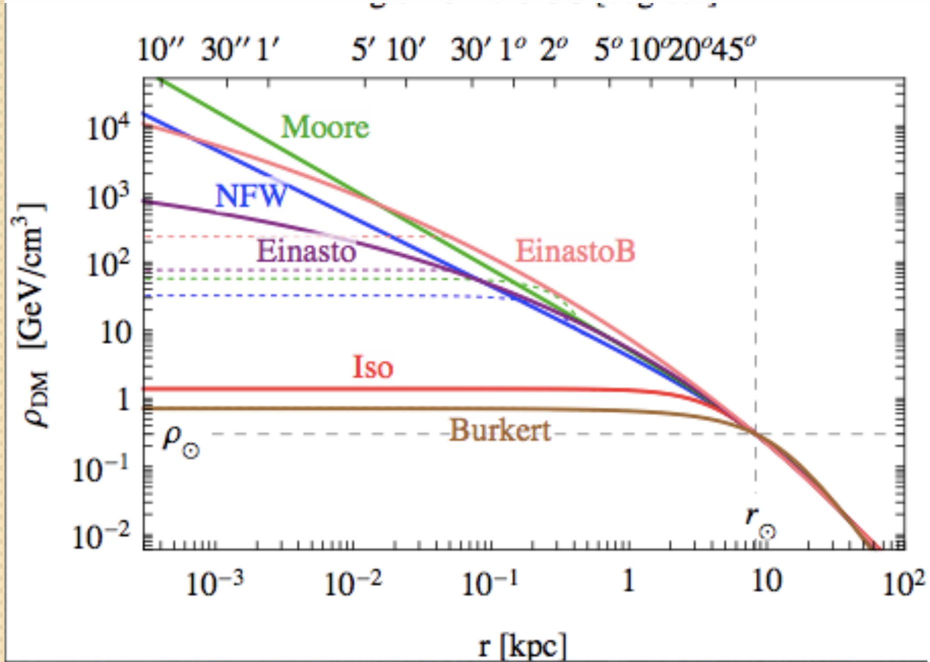
$$\text{NFW}: \quad \rho_{\rm NFW}(r) = \rho_s \frac{r_s}{r}\left(1+\frac{r}{r_s}\right)^{-2}$$

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

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

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

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



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

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

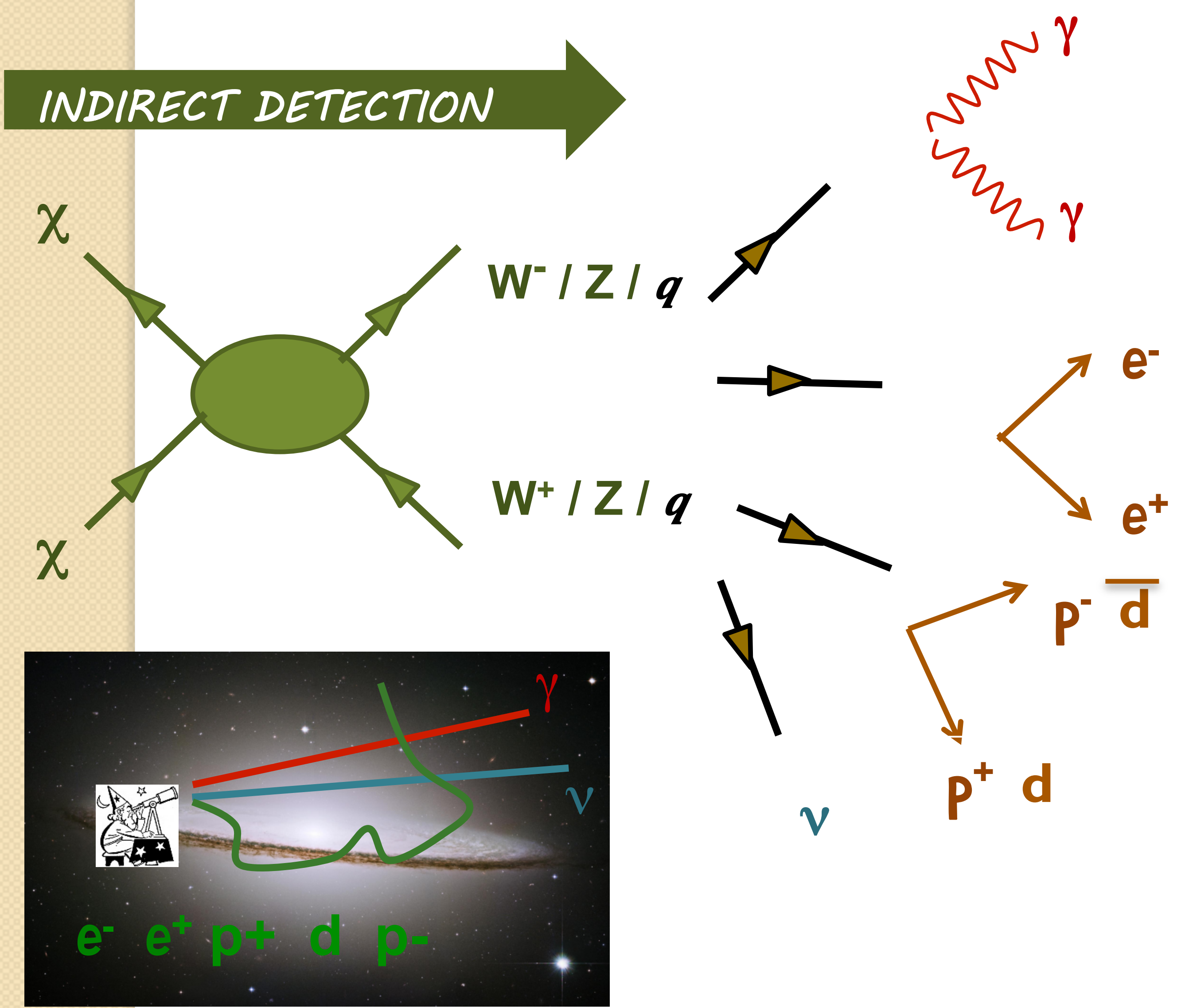
Particle Physics Model

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

Astrophysics uncertainties

- halo models
- CR propagation

Dark Matter Indirect Detection



Gamma rays

- HESS
- VERITAS
- MAGIC
- FERMI LAT

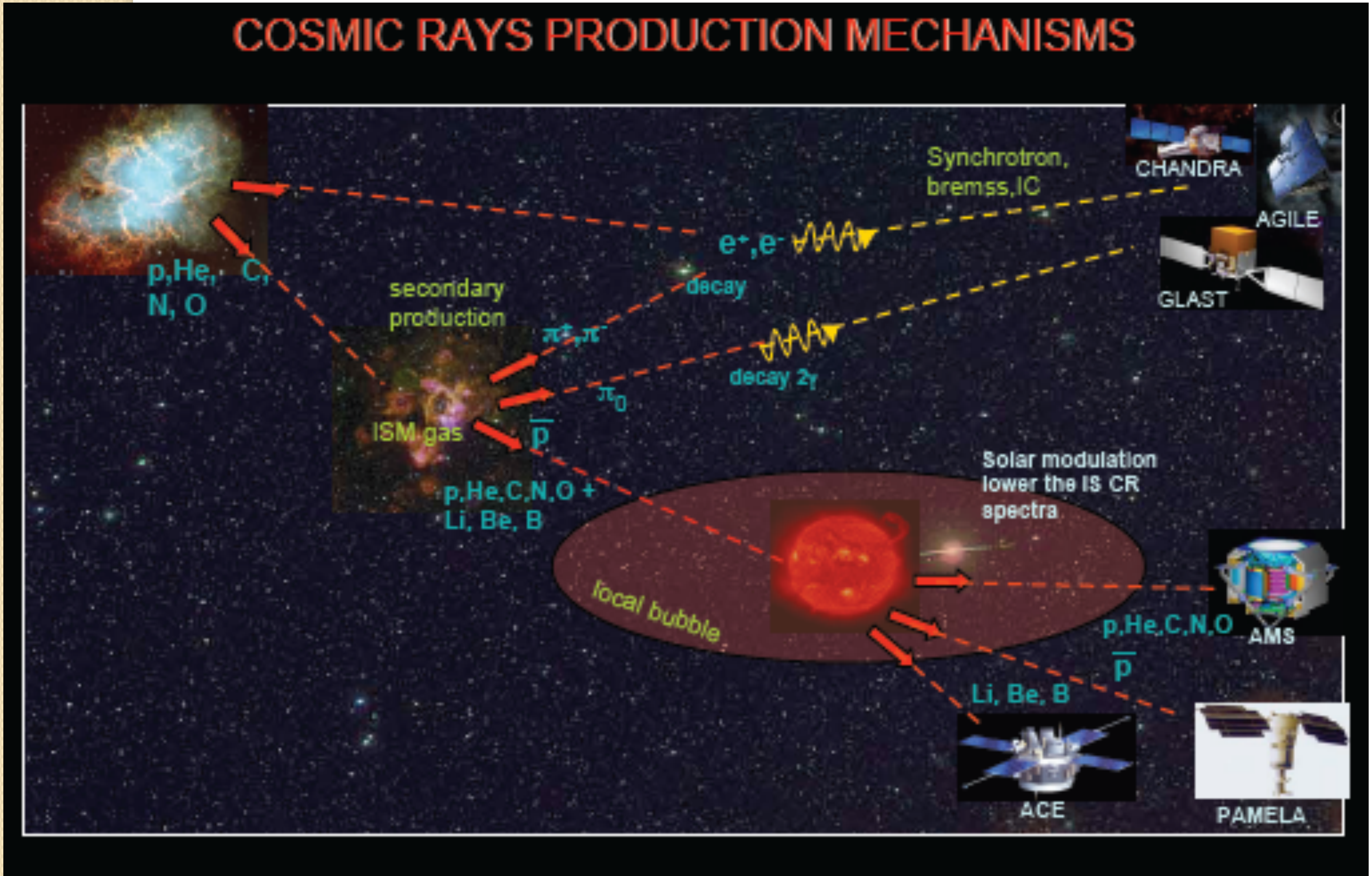
Neutrinos

- ICE CUBE
- ANTARES

Charged particles

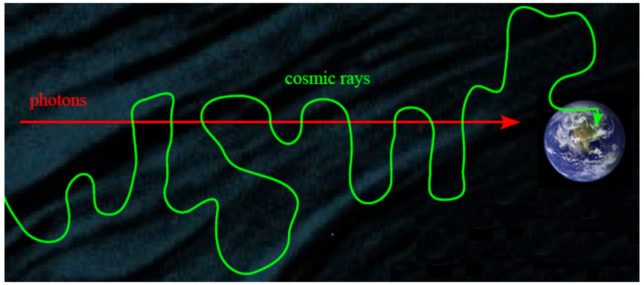
- HEAT
- PAMELA
- AMS 2

Dark Matter Indirect Detection



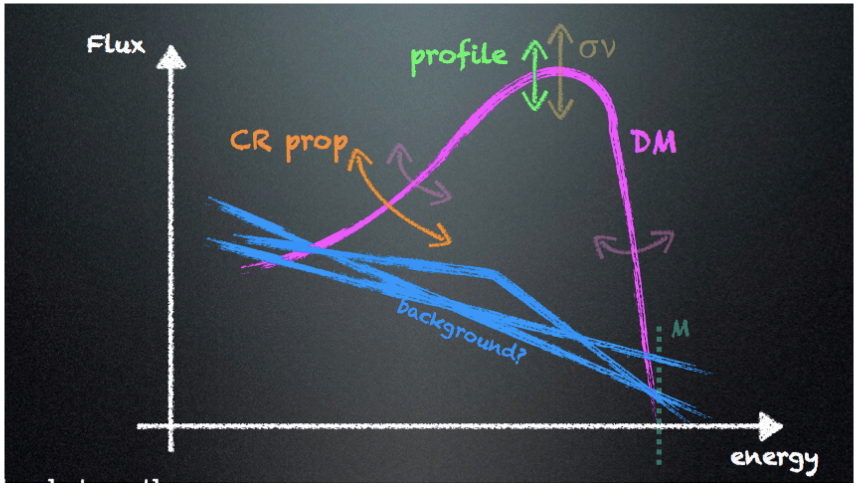
Charged Particles Detection

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

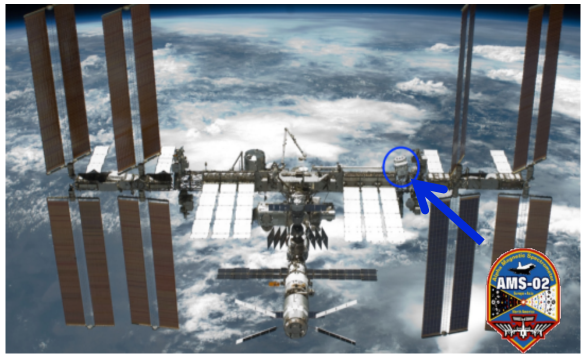


PAMELA

- Model background and search for an excess

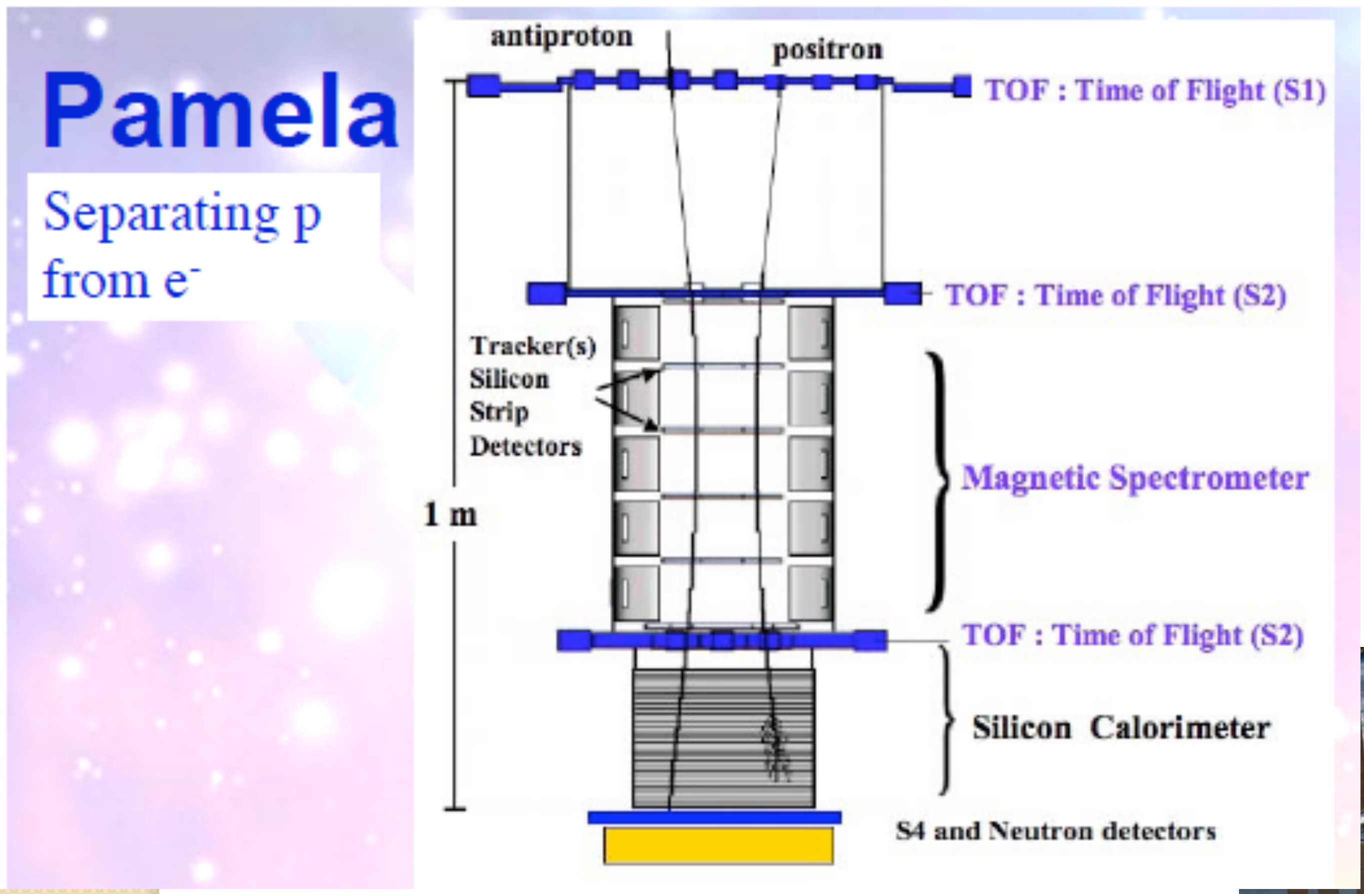


AMS-2 @ ISS



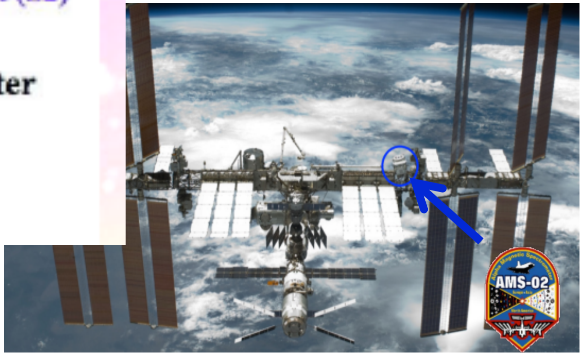
Charged Particles Detection

Complex Particle Detectors in the space



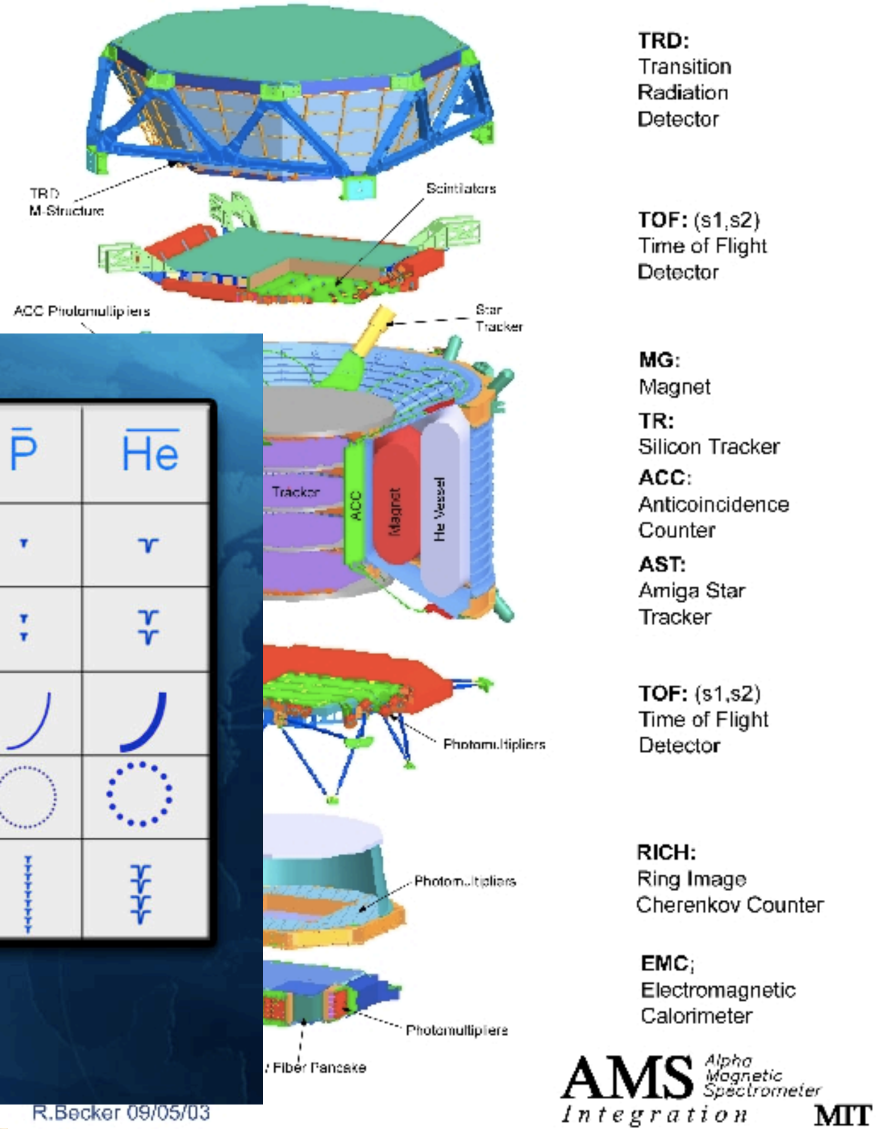
PAMELA

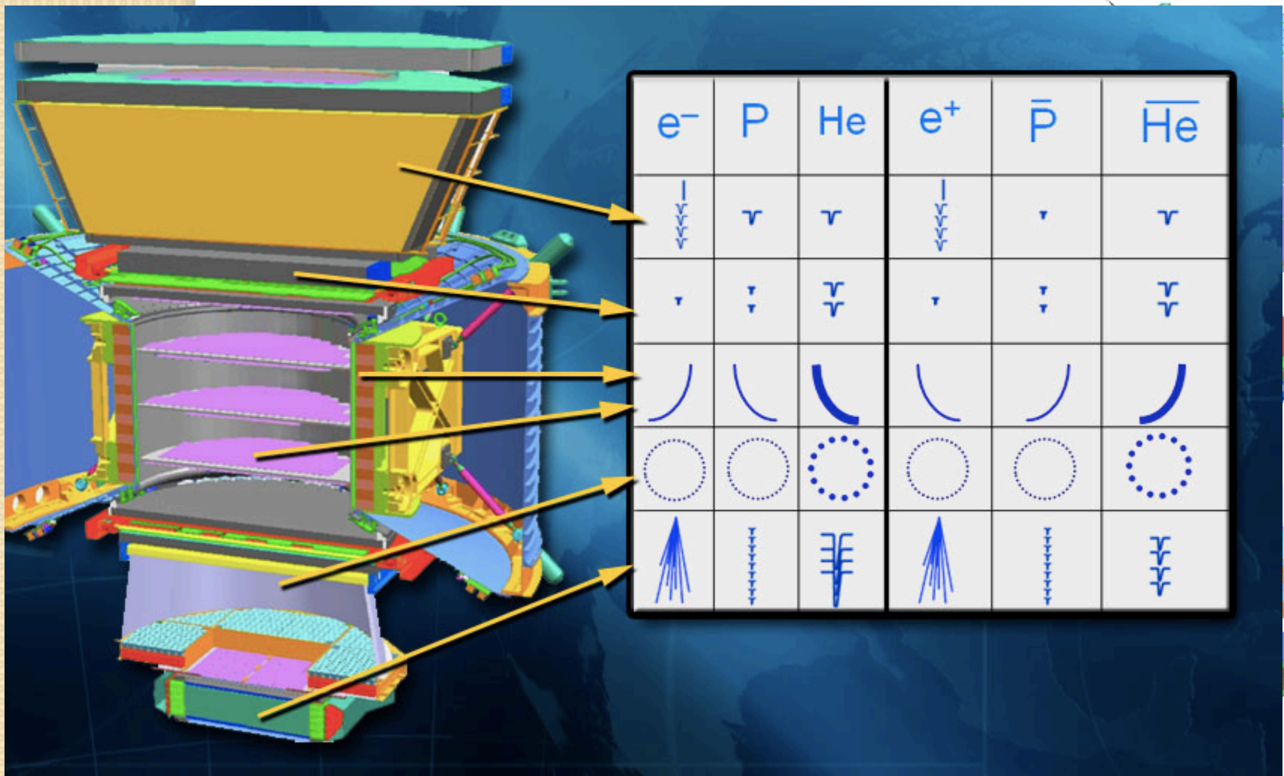
AMS-2 @ ISS



Charged Particles Detection

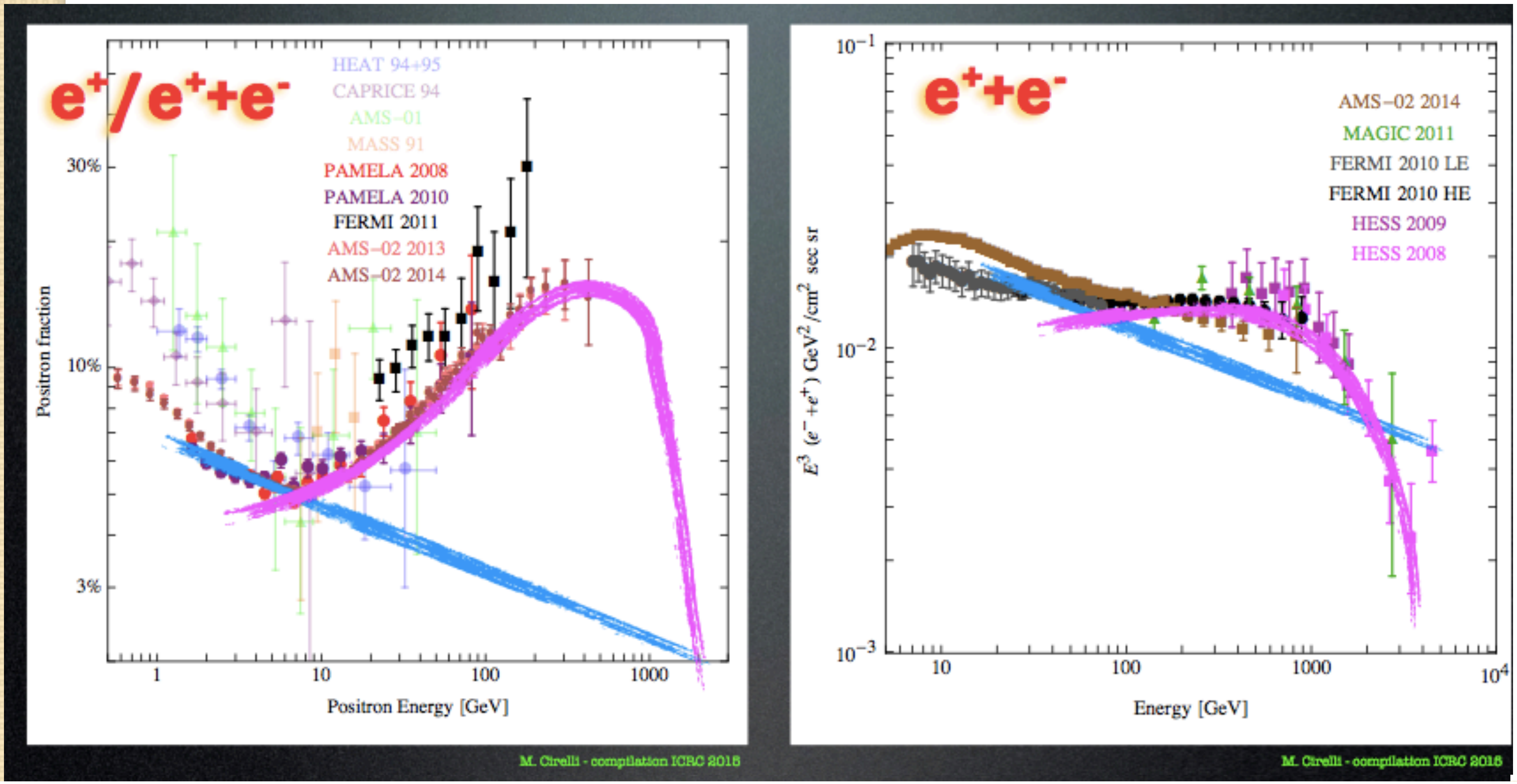
Complex Particle Detectors in the space
- electrons and positrons
- protons and antiprotons
- Light nuclei
- photons, etc.





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 up to 350 GeV

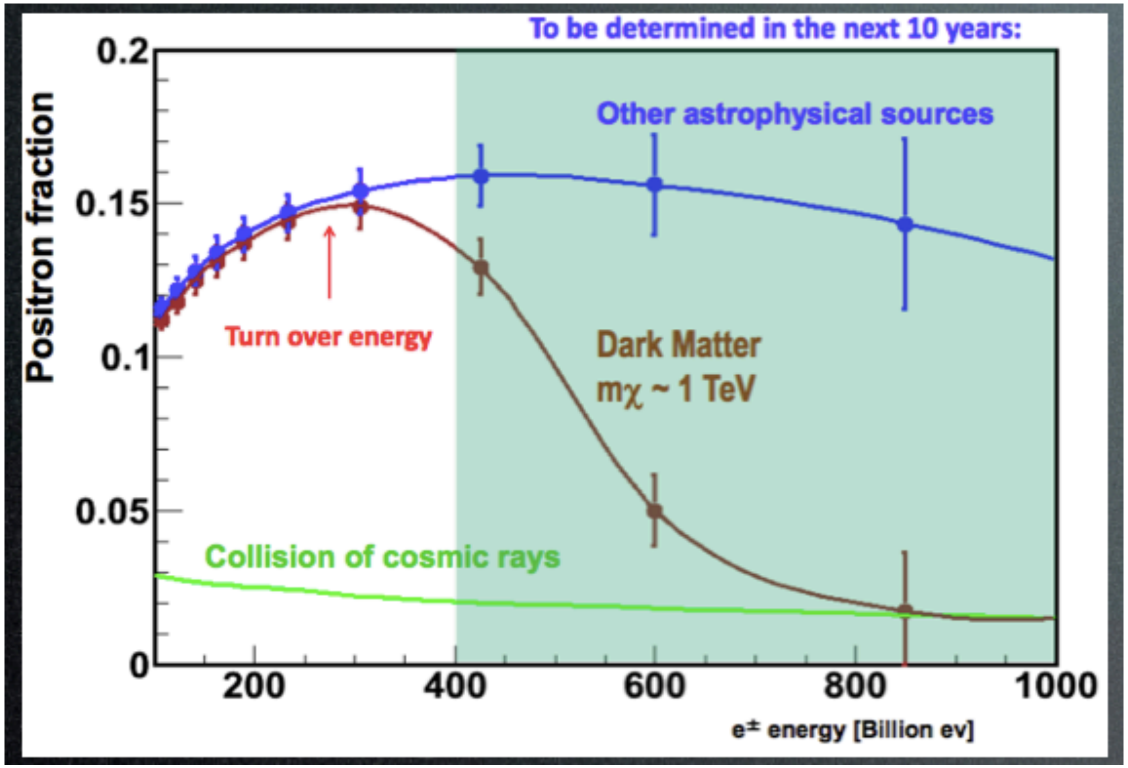


Charged Particles Detection

POSITRON EXCESS
First hints by HEAT and AMS
Confirmed by PAMELA from 10-100 GeV & Fermi up to 200 GeV
Confirmed by AMS-2 up to 350 GeV

DM Interpretation difficult to match with models

Astrophysical explanation possible



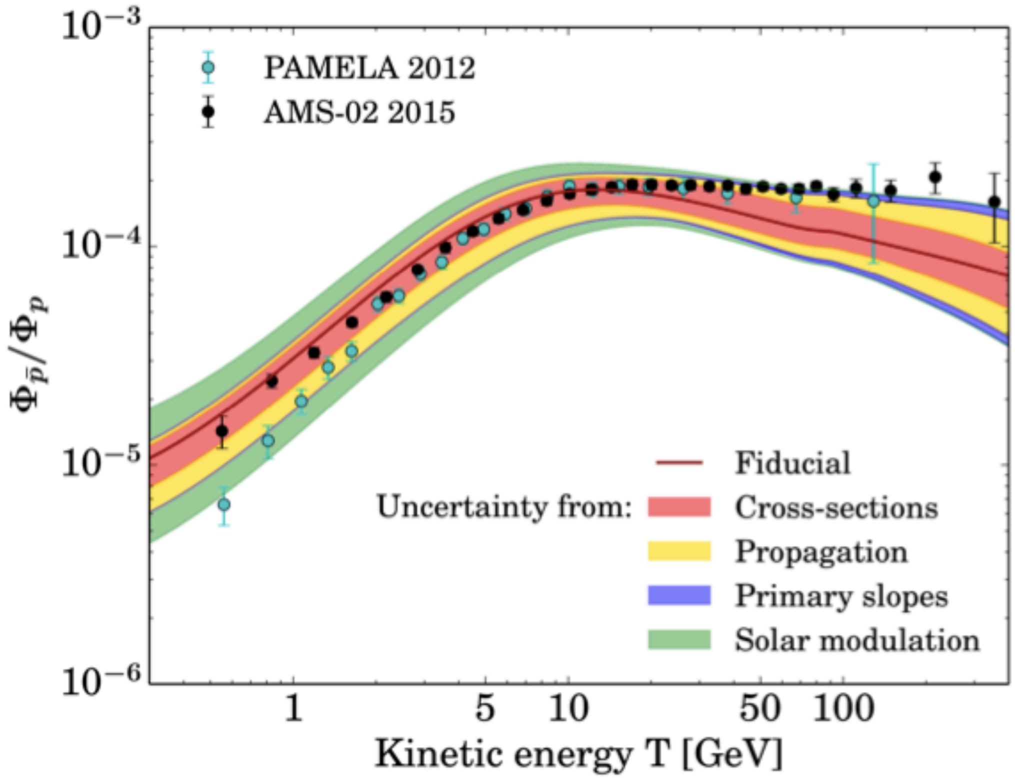
Charged Particles Detection

ANTIPROTON RATIO EXCESS

First hints by PAMELA but NOT CLEAR EXCESS AFTER AMS2

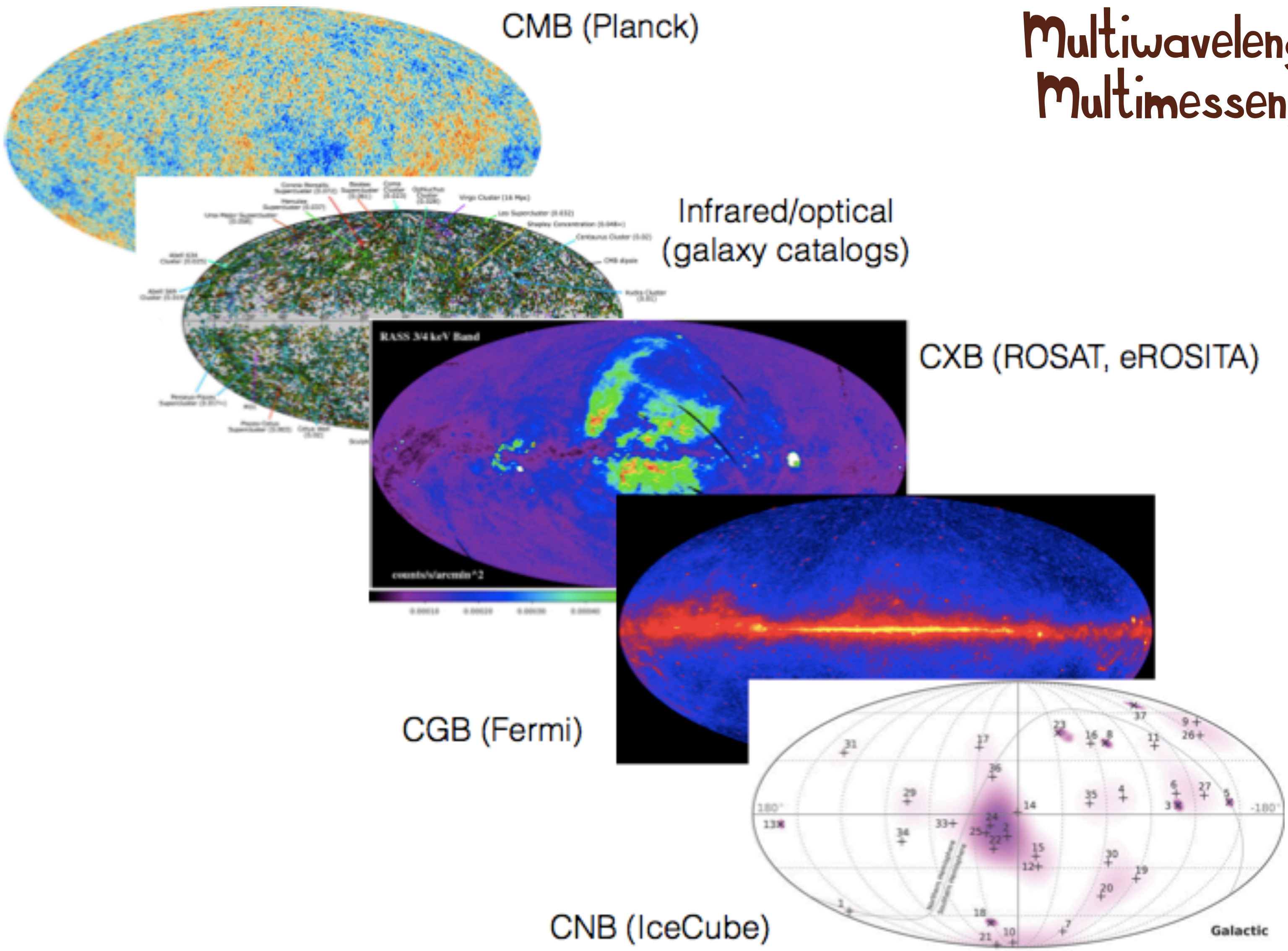
DM Interpretation possible but not necessary

ONLY LIMITS FOR ANTIDEUTERONS



Gamma Rays and Neutrino Detection

Multiwavelength
Multimessenger

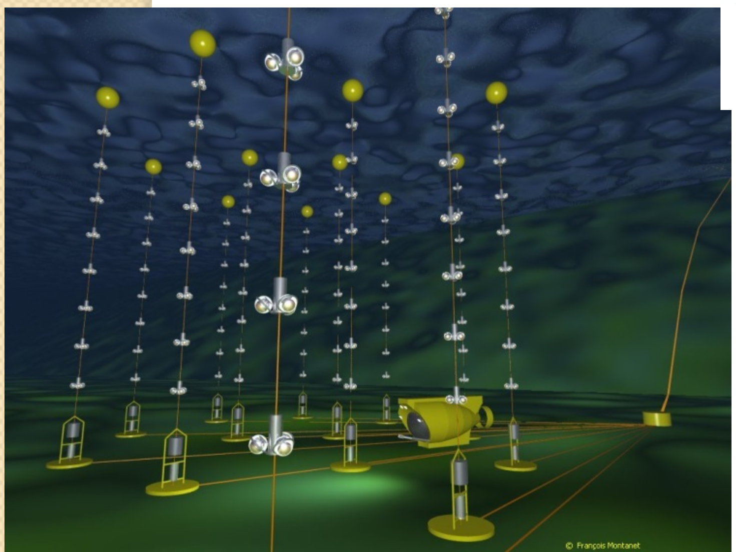


Neutrino Detection

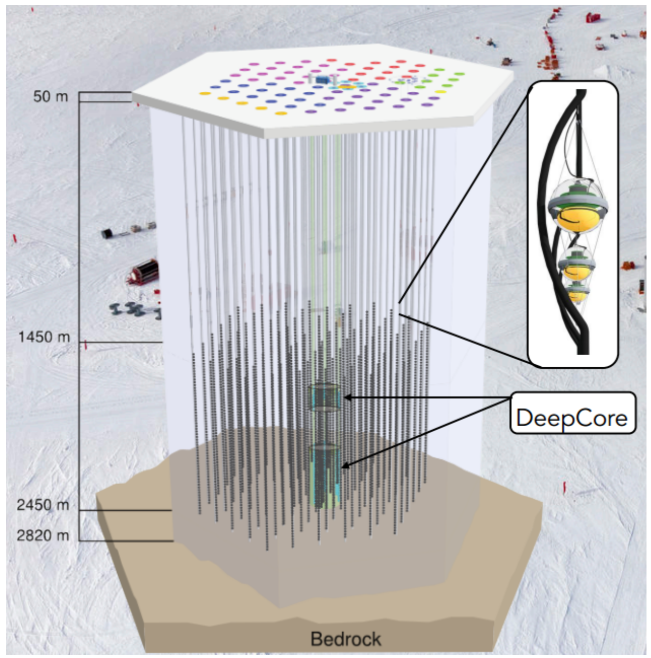
Cherenkov detectors under-ice or under-water

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

ANTARES
(Under Mediterranean See)



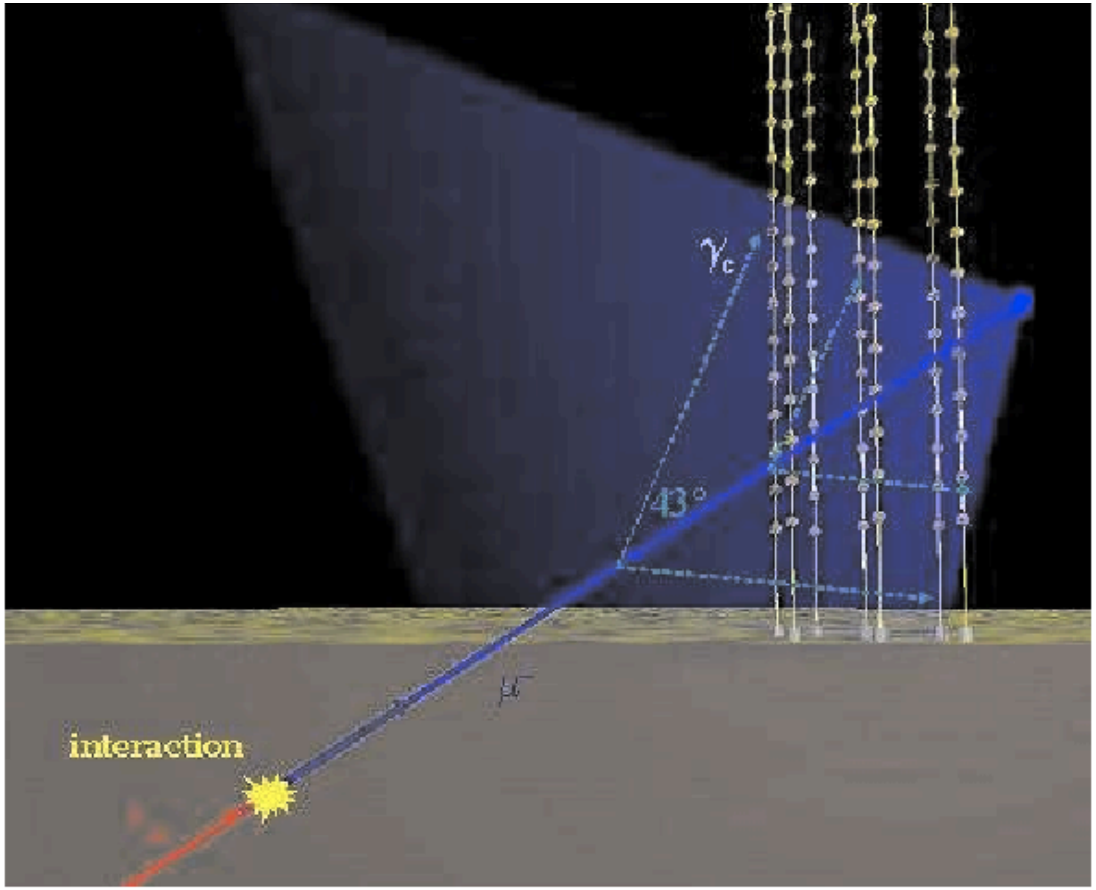
ICECUBE (South Pole)



Neutrino Detection

Cherenkov detectors under-ice or under-water

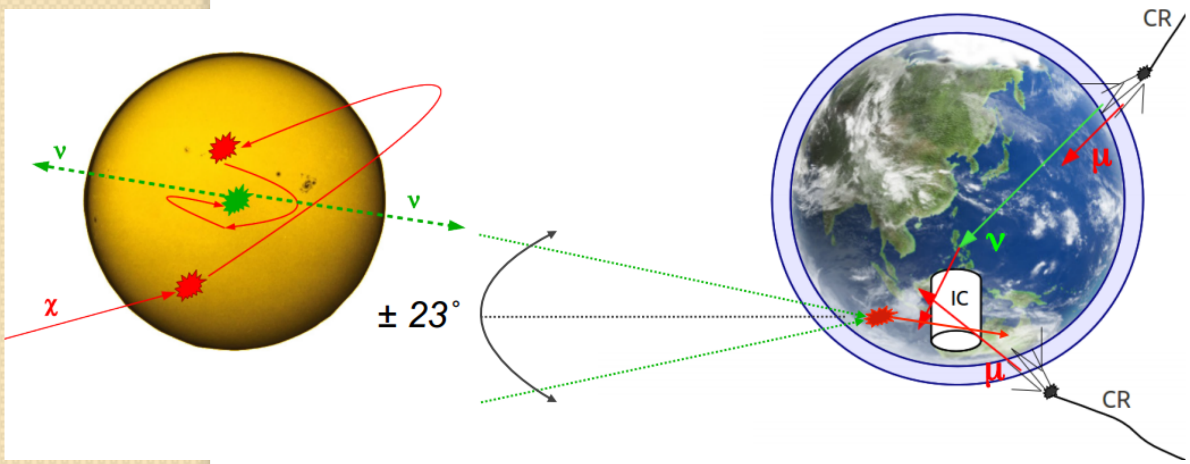
Detect the shower of secondary particles produced after ν interaction through Cherenkov light



Directionality

NEUTRINO ASTRONOMY

Neutrino Detection

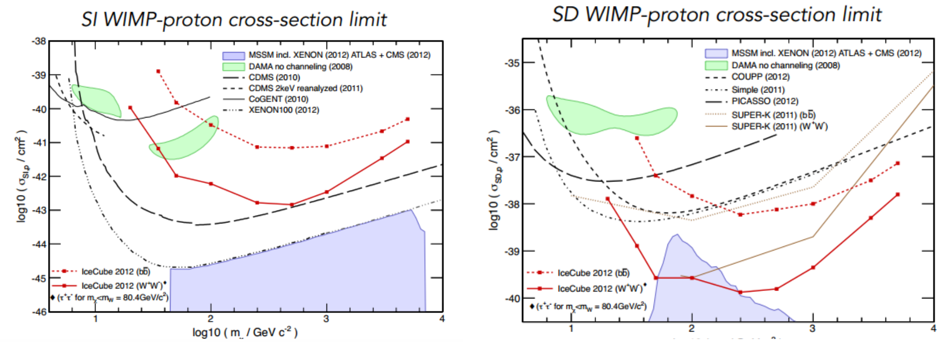


High energy ν from the Sun
DM smoking gun
No known astrophysical processes able to mimic it

Borrowed from Matthias Danninge @ TAUP 2013

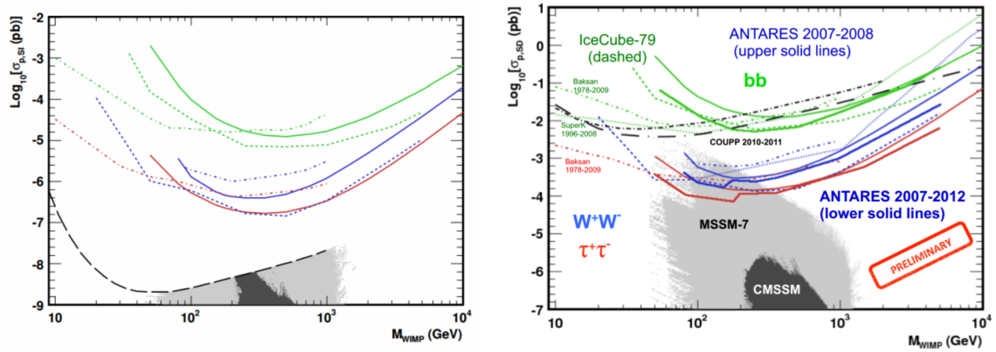
IceCube

arXiv:1212.4097



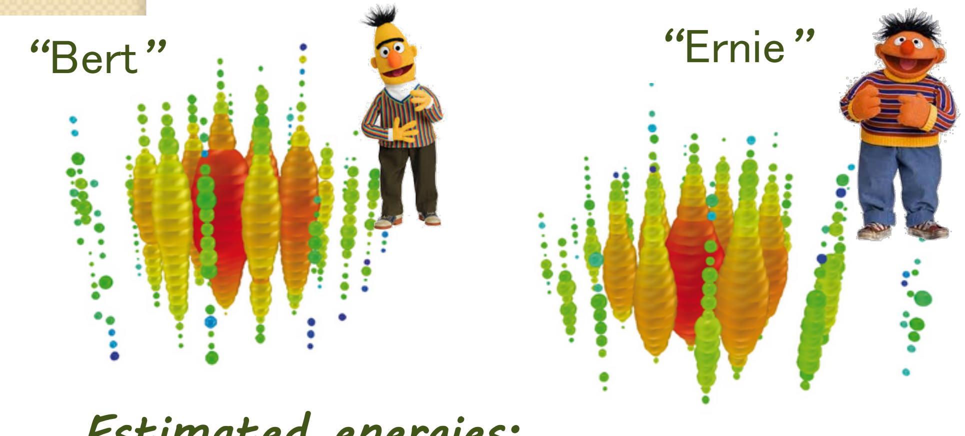
Antares

JCAP11(2013)032



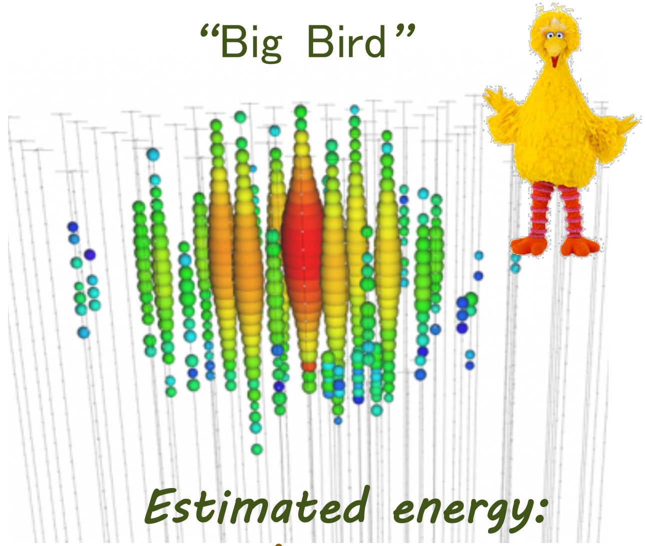
Neutrino Detection

PRL 111, 021103 (2013)



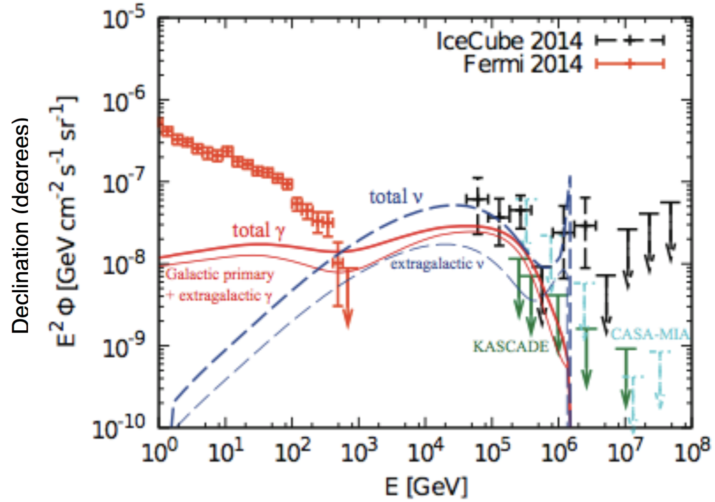
Estimated energies:
1.04 ± 0.16 / 1.14 ± 0.17 PeV

+



Estimated energy:
2 PeV

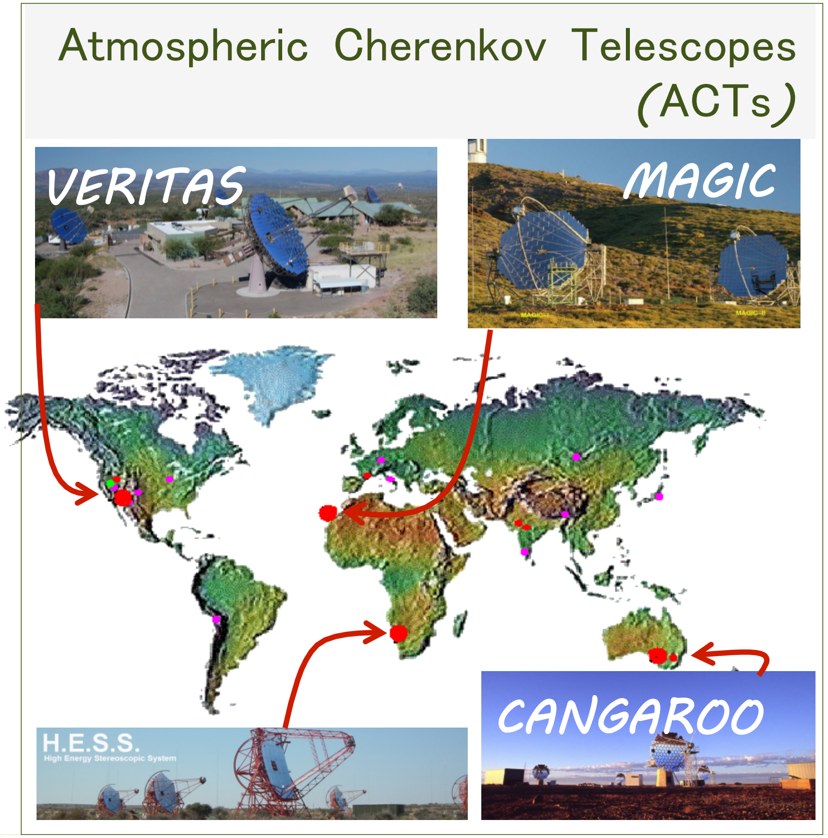
Line @1 PeV ?
It could be interpreted as super heavy decaying DM producing hadronic cascades
This model would produce excess in the diffuse gamma background testable with FERMI



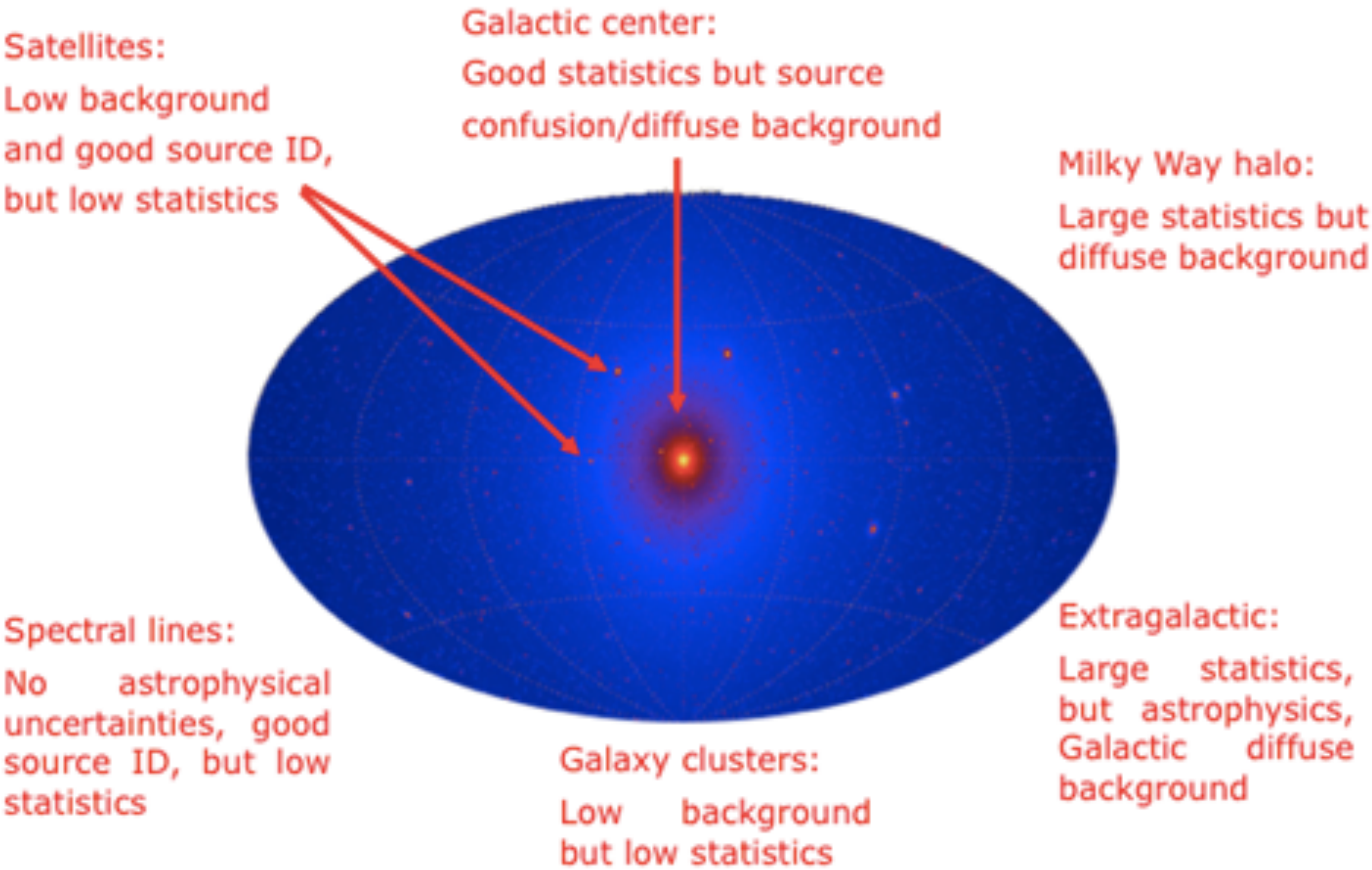
Gamma Ray Detection

- Satellites

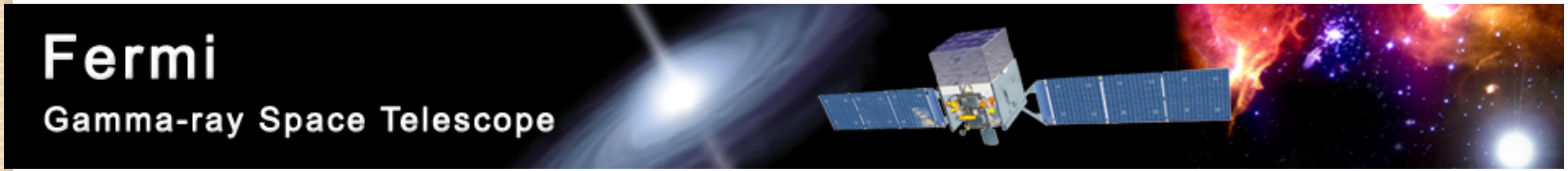
- Atmospheric Cerenkov Telescopes ACTs

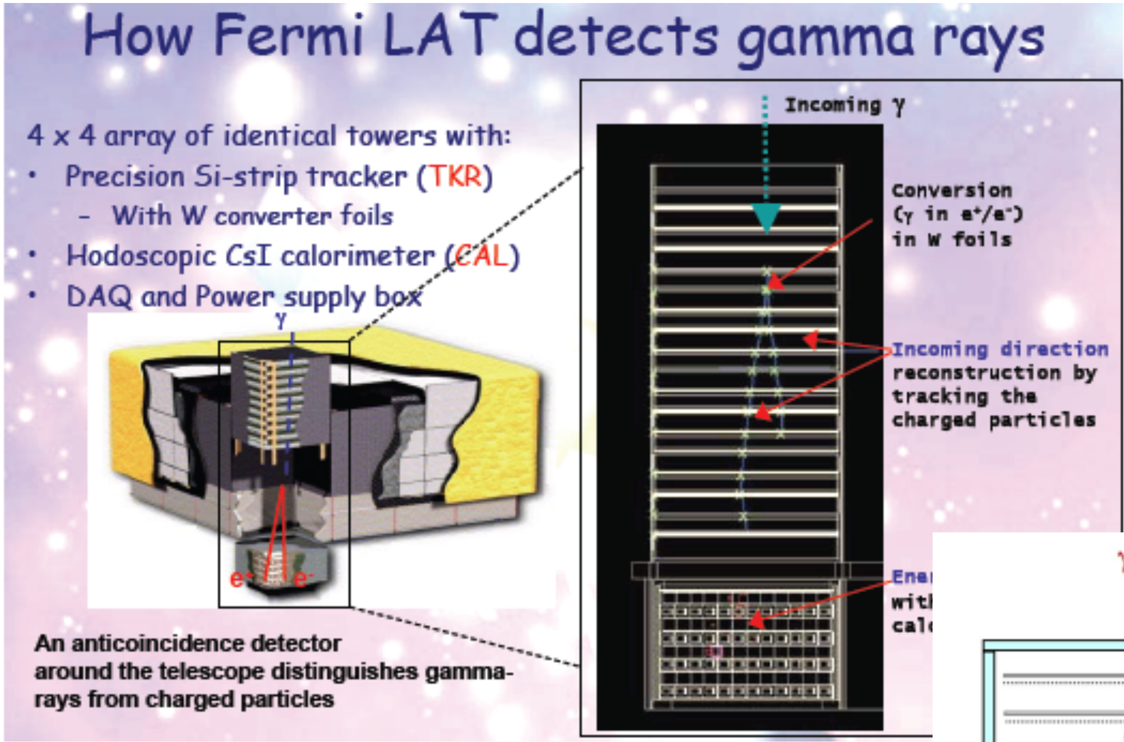


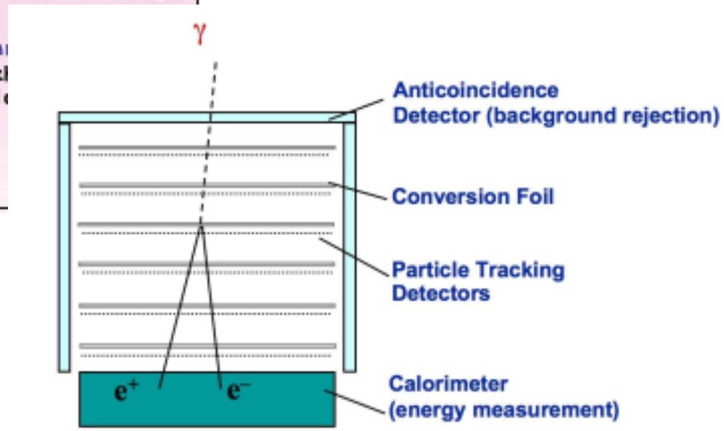
Search Strategies



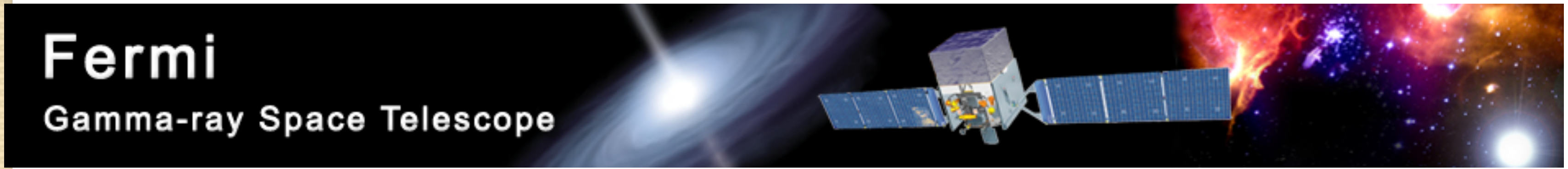
Gamma Ray Detection

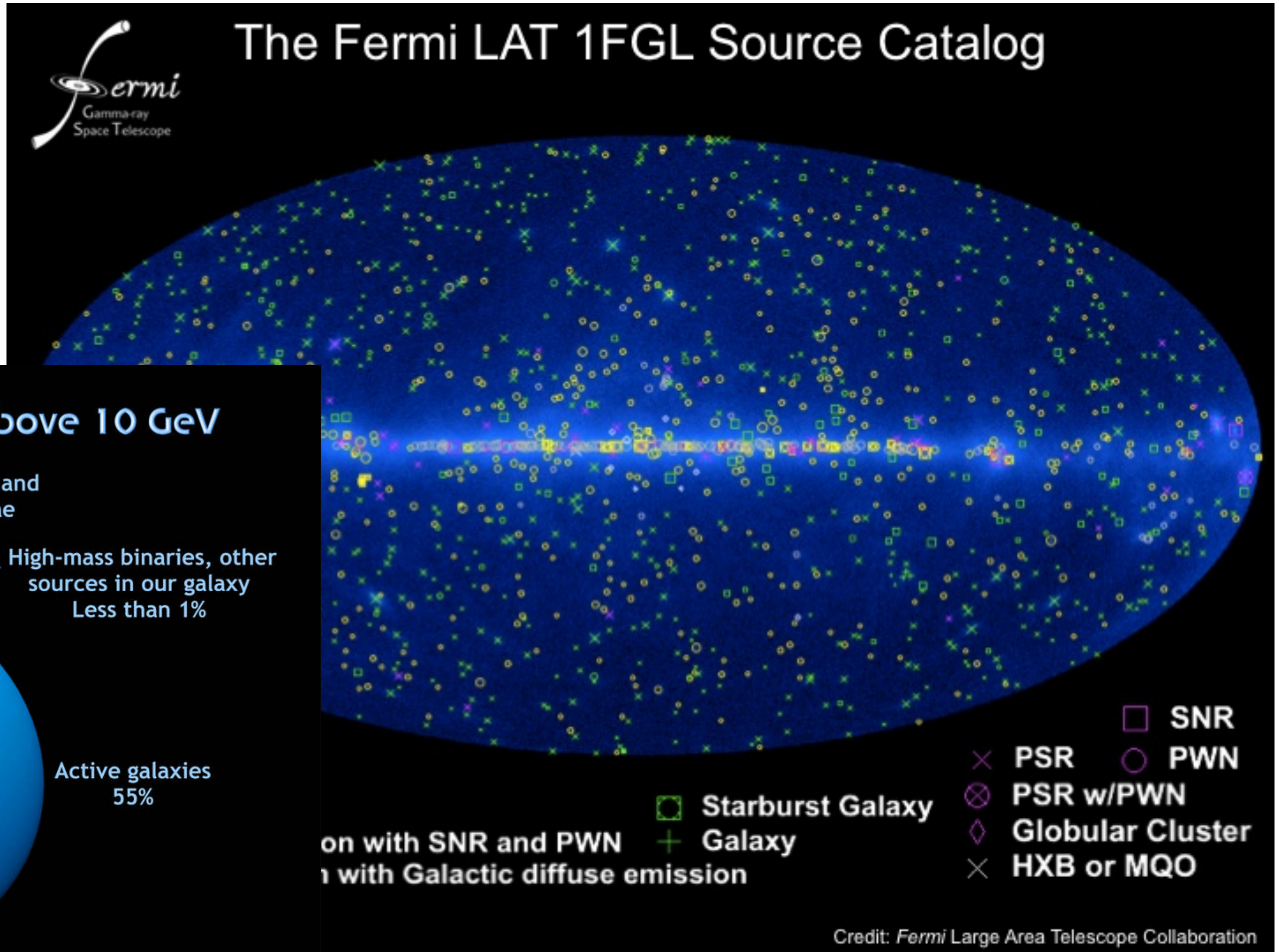


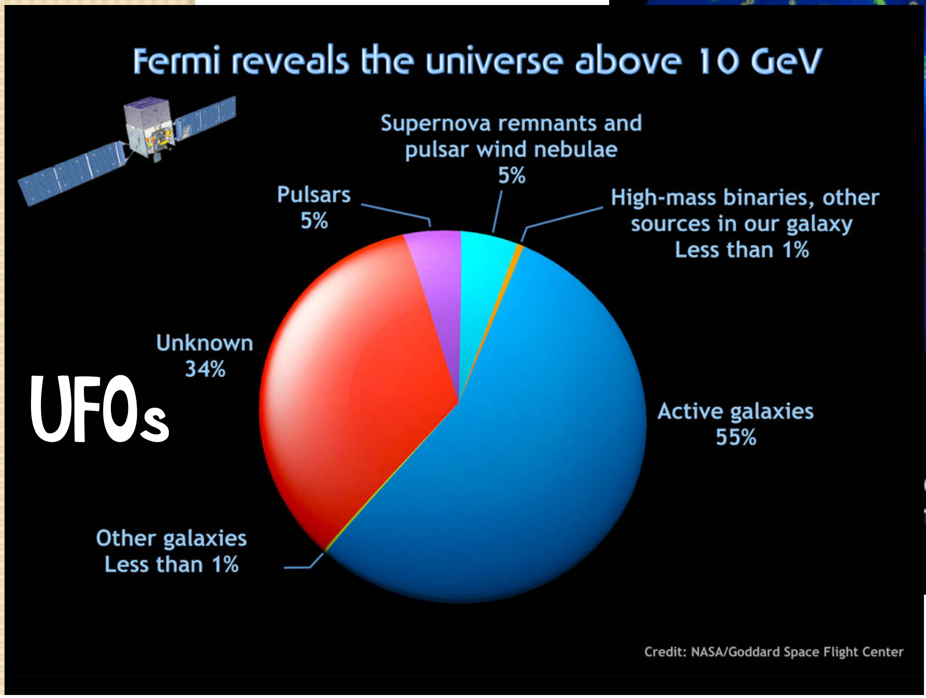




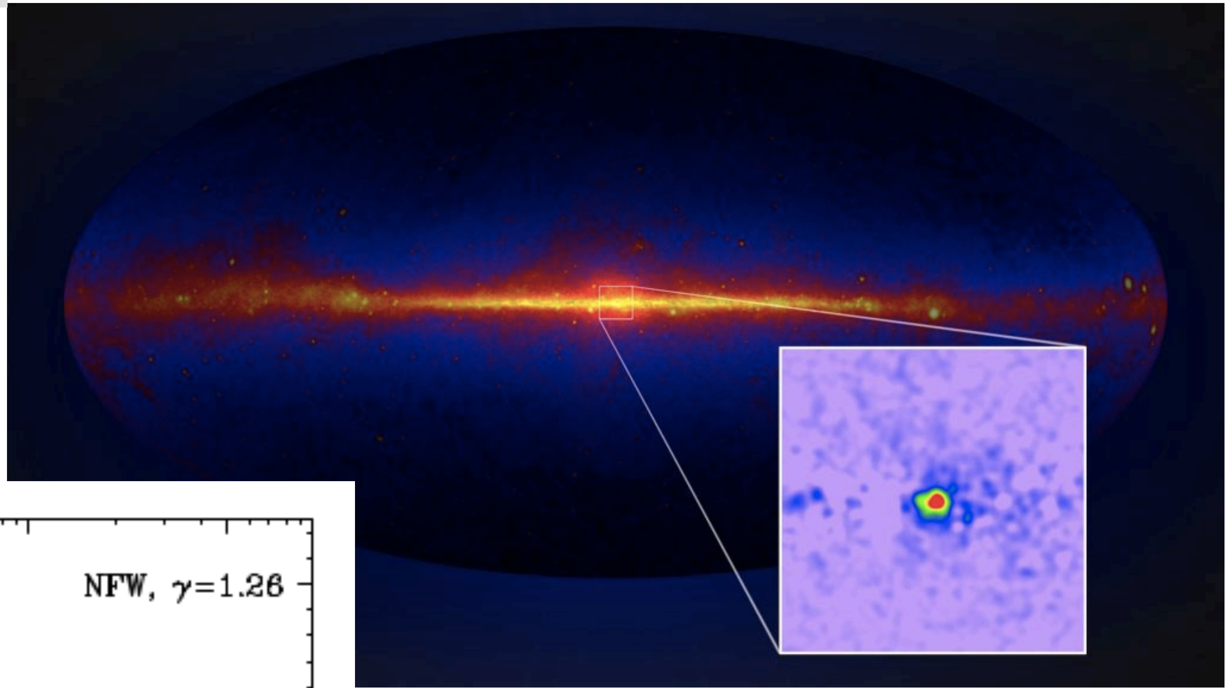
Gamma Ray Detection

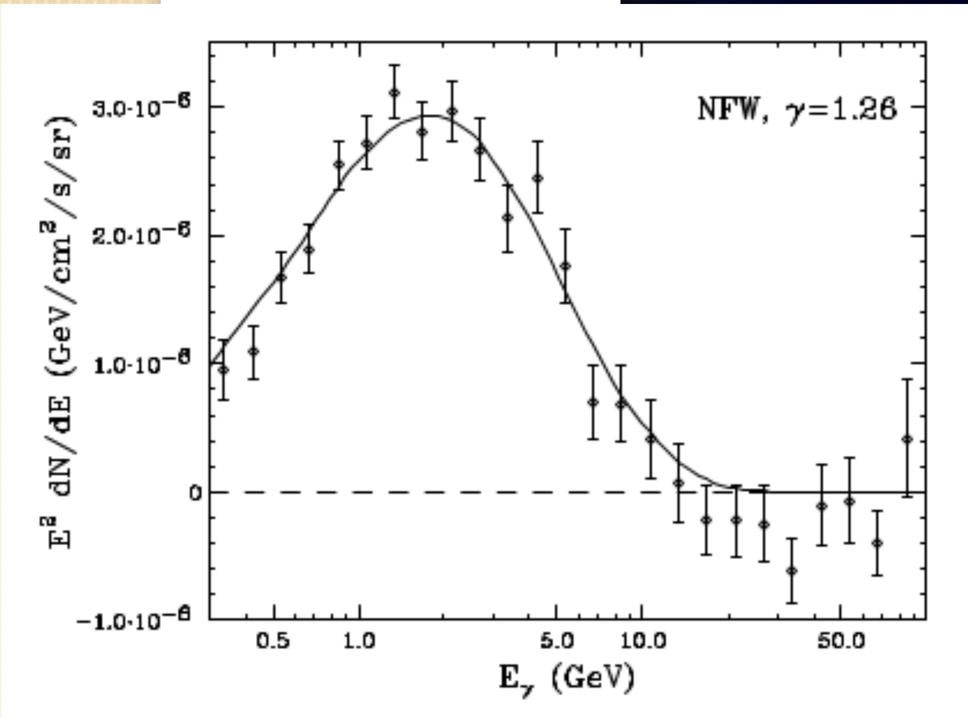






GeV Galactic Center Excess

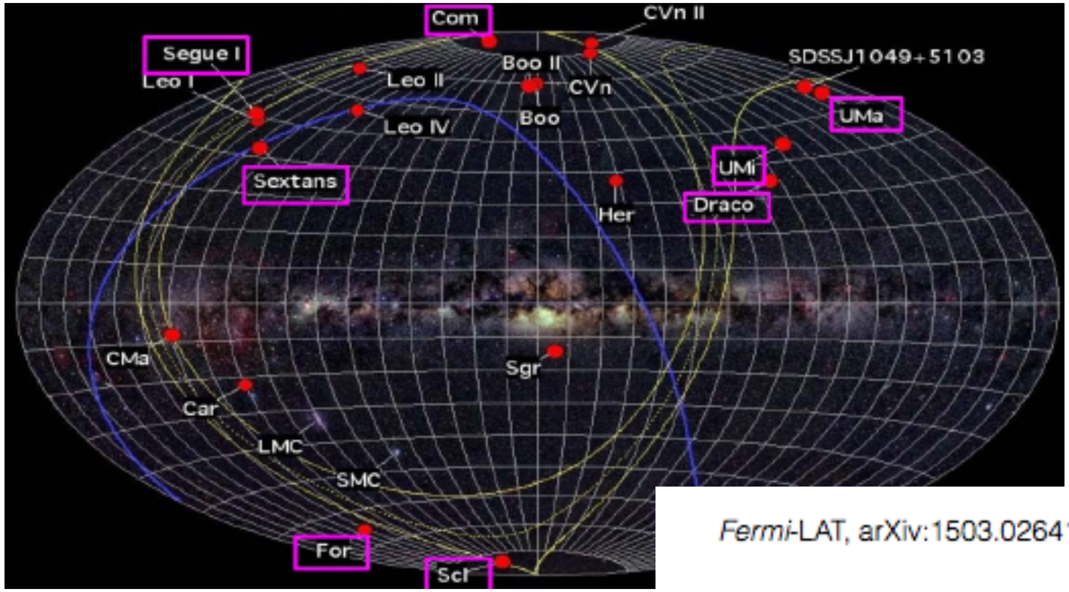




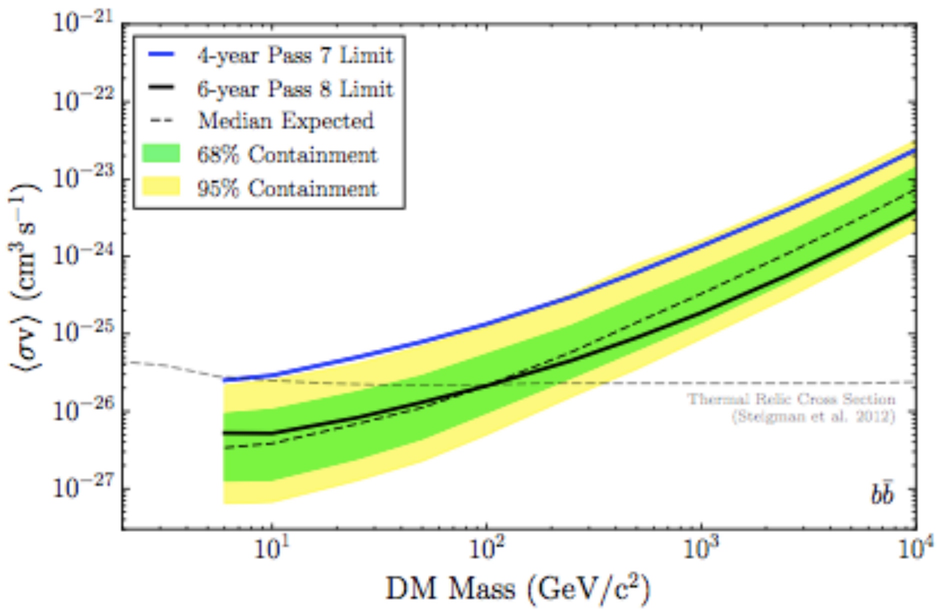
Annihilation of a dark matter particle with a mass between ~20-40 GeV could explain the excess

Antiproton should show hints
Millisecond pulsars could explain it

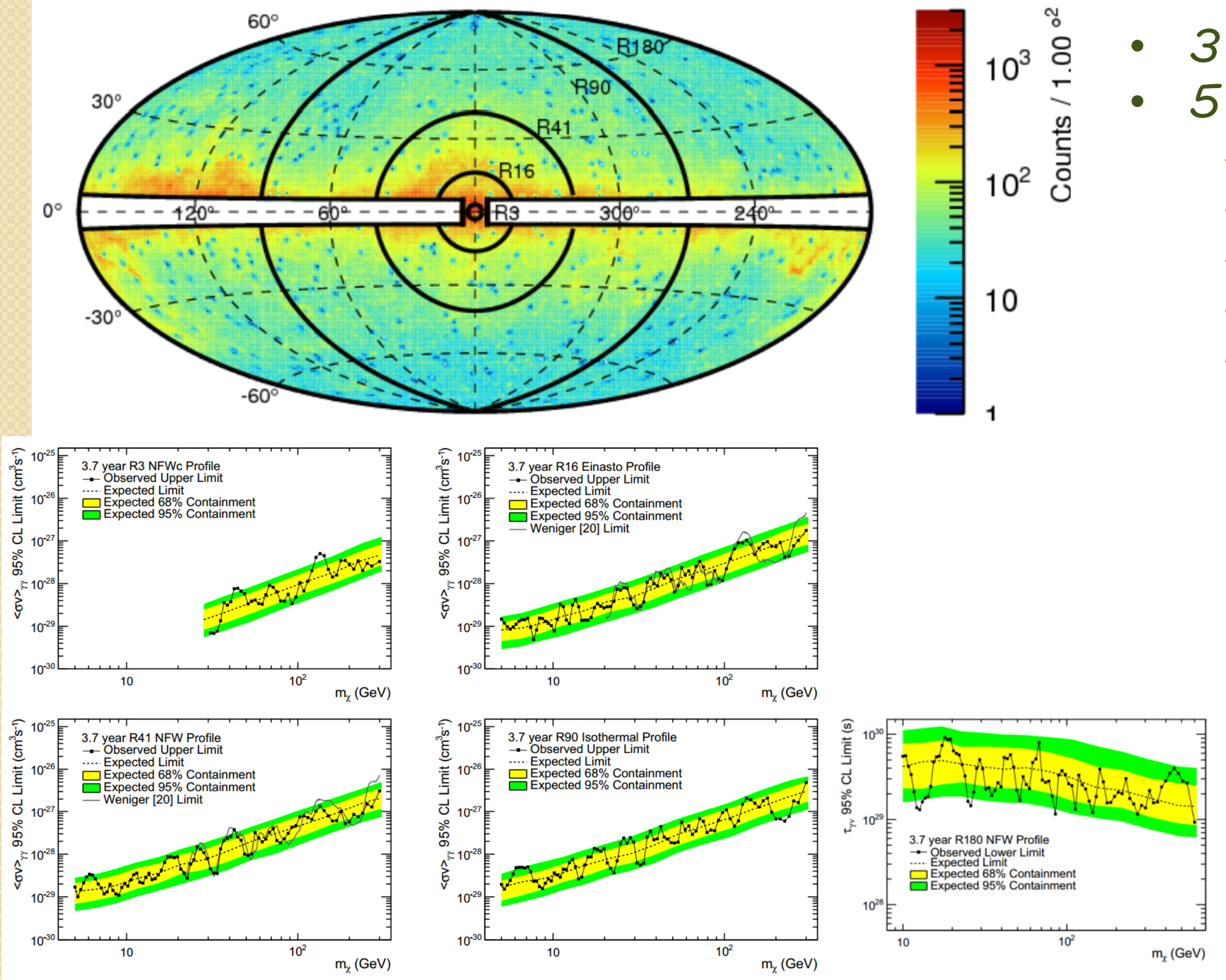
Searching for excess from dwarf galaxy satellites



Fermi-LAT, arXiv:1503.02641 [astro-ph.HE]



Searching for lines



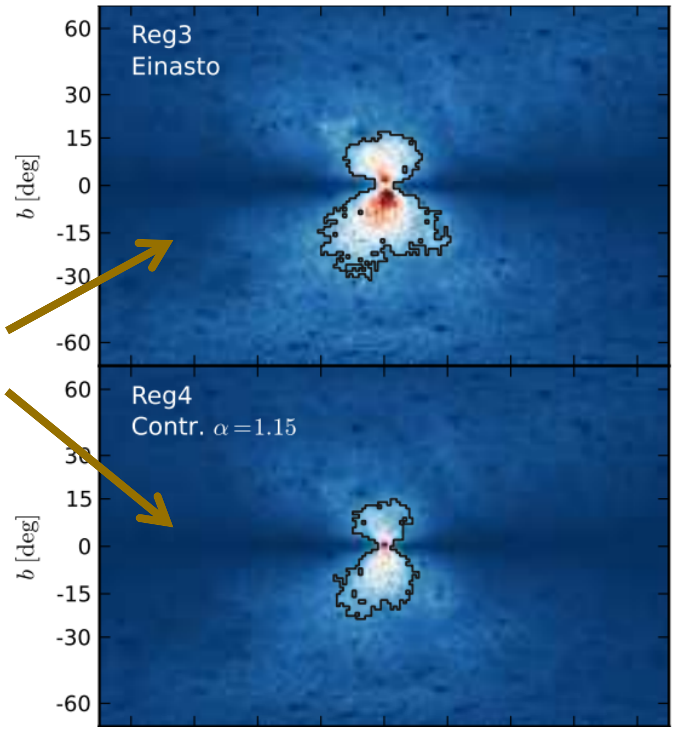
- *3.7* years of data
- *5* ROIs*:*
  - R*3* *(*NFW Optimized*)*
  - R*16* *(*Einasto Optimized*)*
  - R*41* *(*NFW Optimized*)*,
  - R*90* *(*Isothermal Optimized*)*
  - R*180* *(*DM Decay*)*

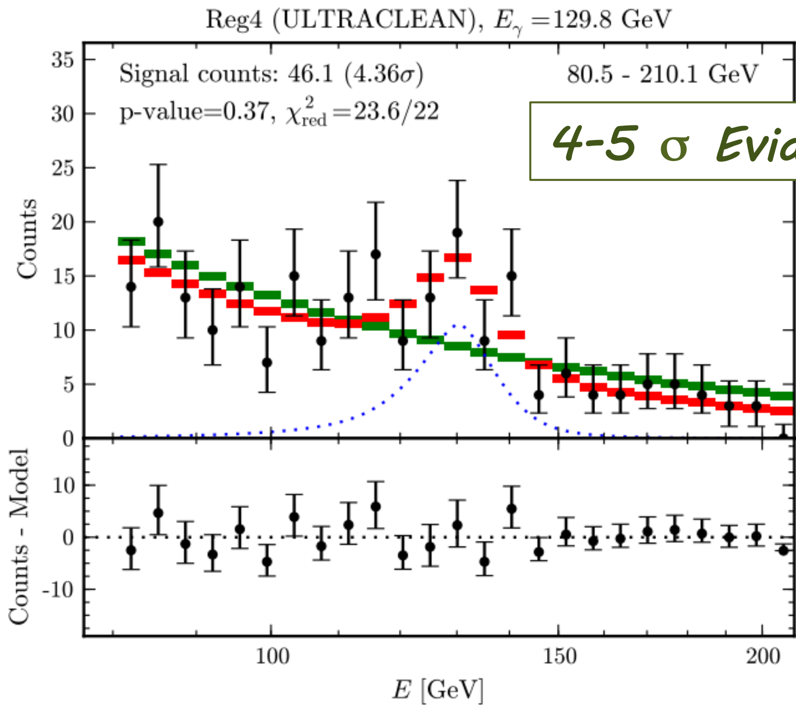
No evidence found!

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.

Signal particularly strong in 2 of the 5 analyzed sky regions



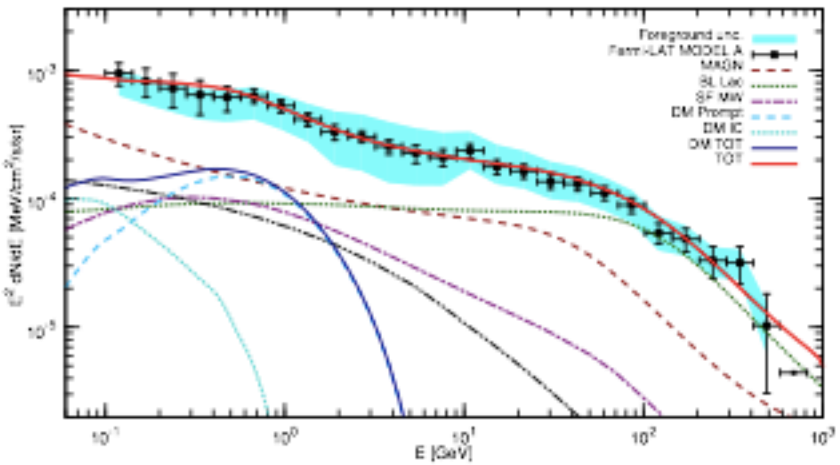


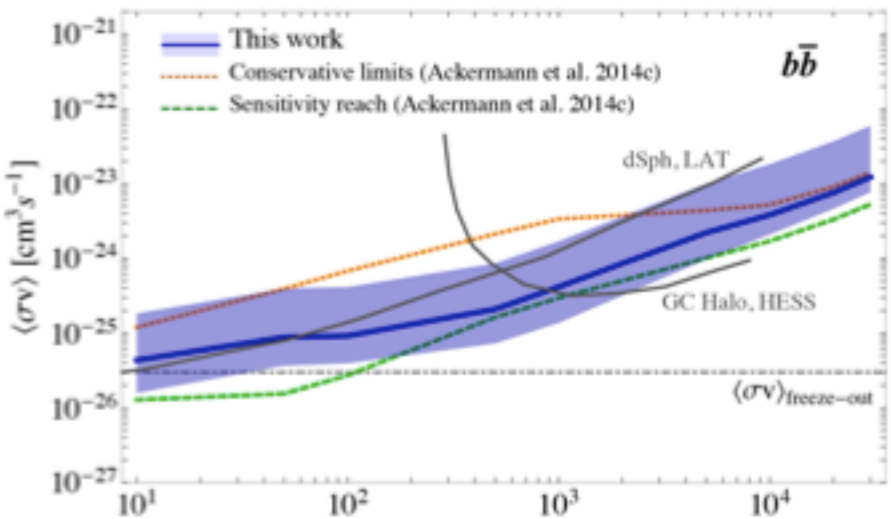
4-5 σ Evidence

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

Gamma Background spectrum

Di Mauro, Donato, *Phys.Rev. D* **91**, 123001 (2015)

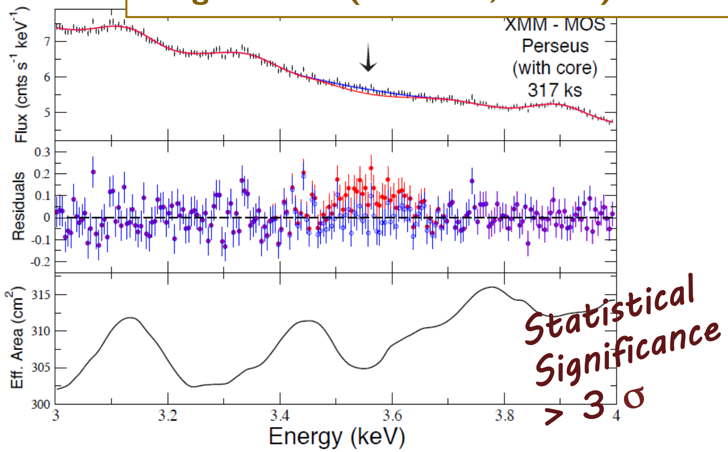




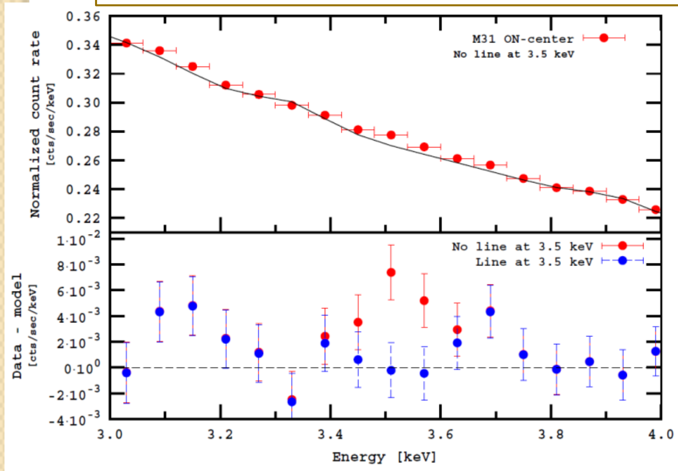
- **Annihilation**
  - Stringent constraints although with relatively large uncertainty (PASS 7)
- **Decay**
  - Stringent constraints (better than dwarf galaxies and galaxy clusters)
- Interesting implications for phenomenological models that address positron excess found with PAMELA and AMS-02

3.5 keV X ray line

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



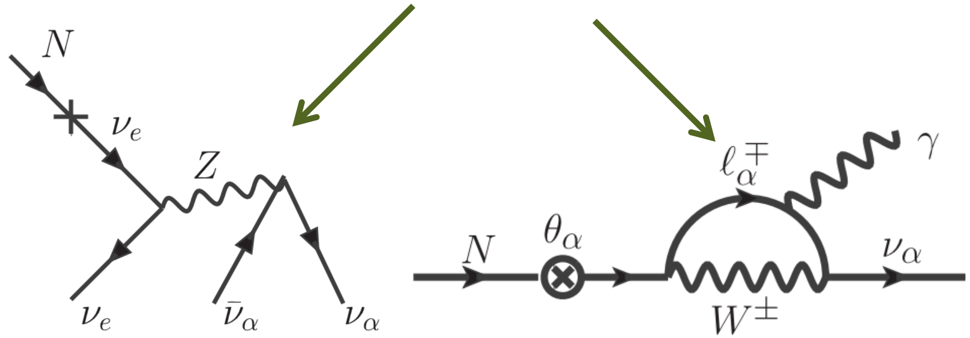
M31 galaxy (XMM-Newton, center & outskirts)
Perseus cluster (XMM-Newton, outskirts)



Line found in spectra from galaxies and galaxy clusters

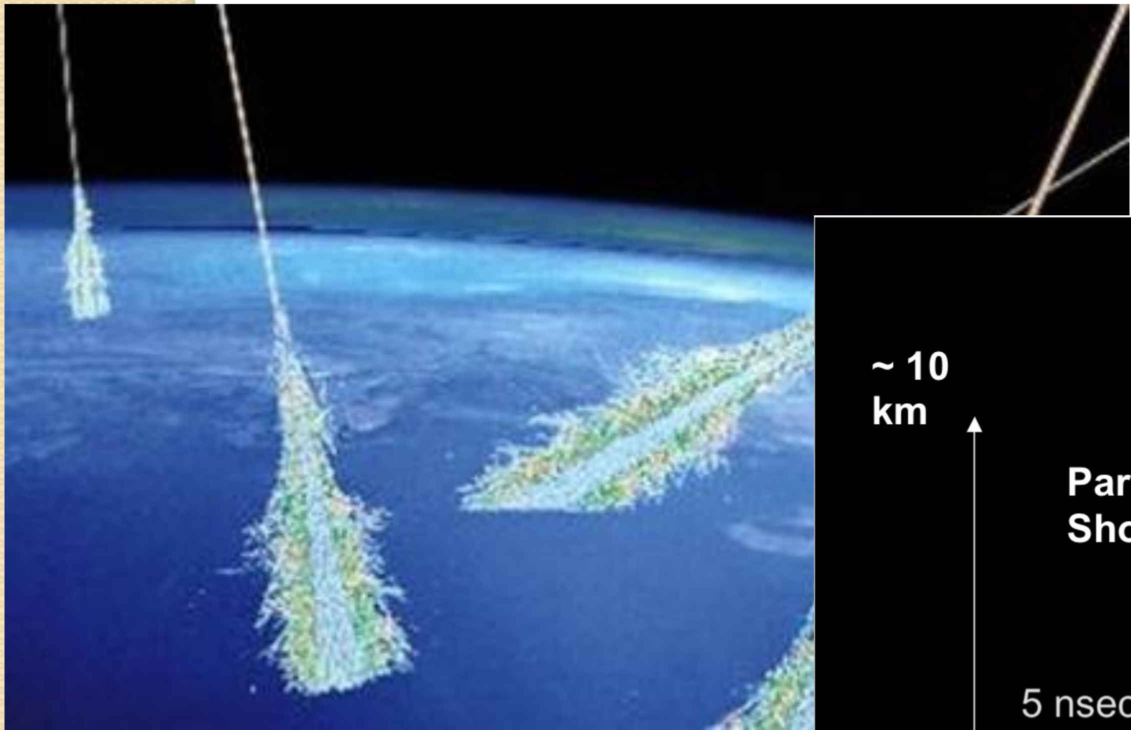
Still controversial
possibility of atomic line or instrumental systematics

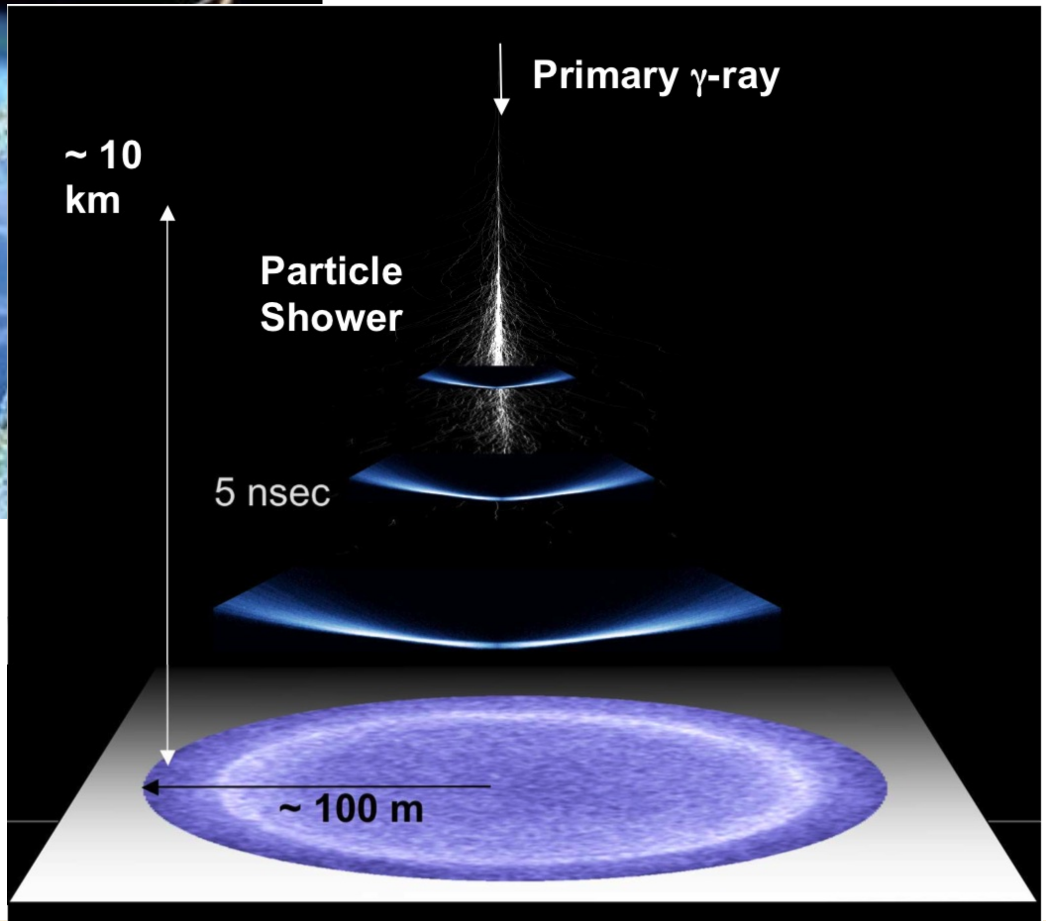
Could be produced by the decay of sterile neutrinos



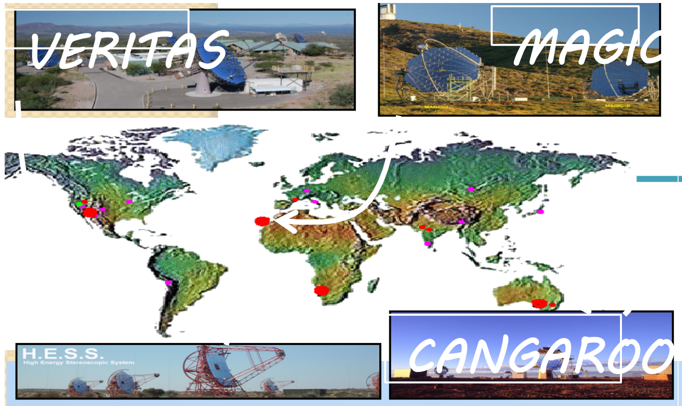
Atmospheric Cerenkov Detectors

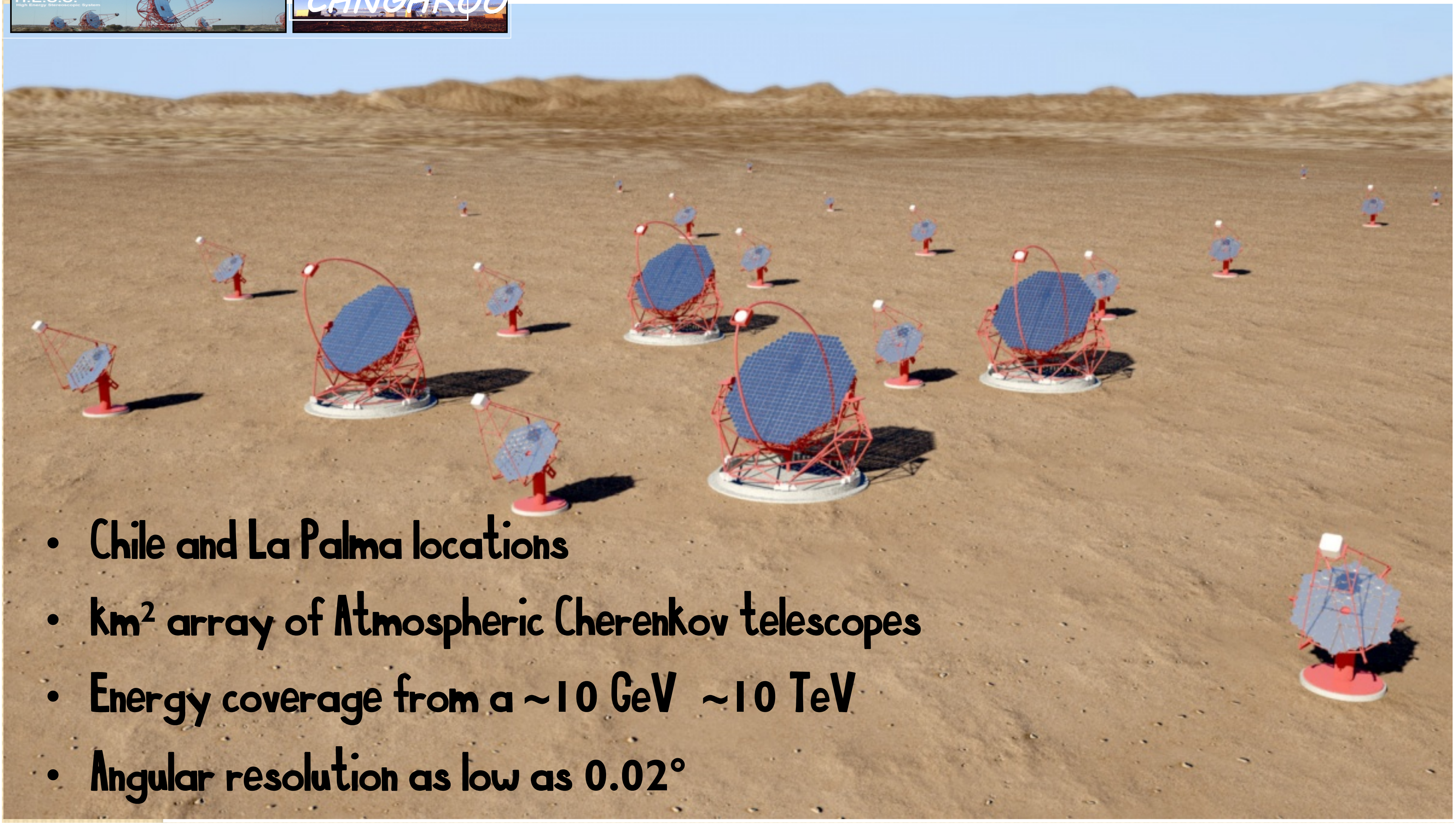
The atmosphere is the detector





CTA

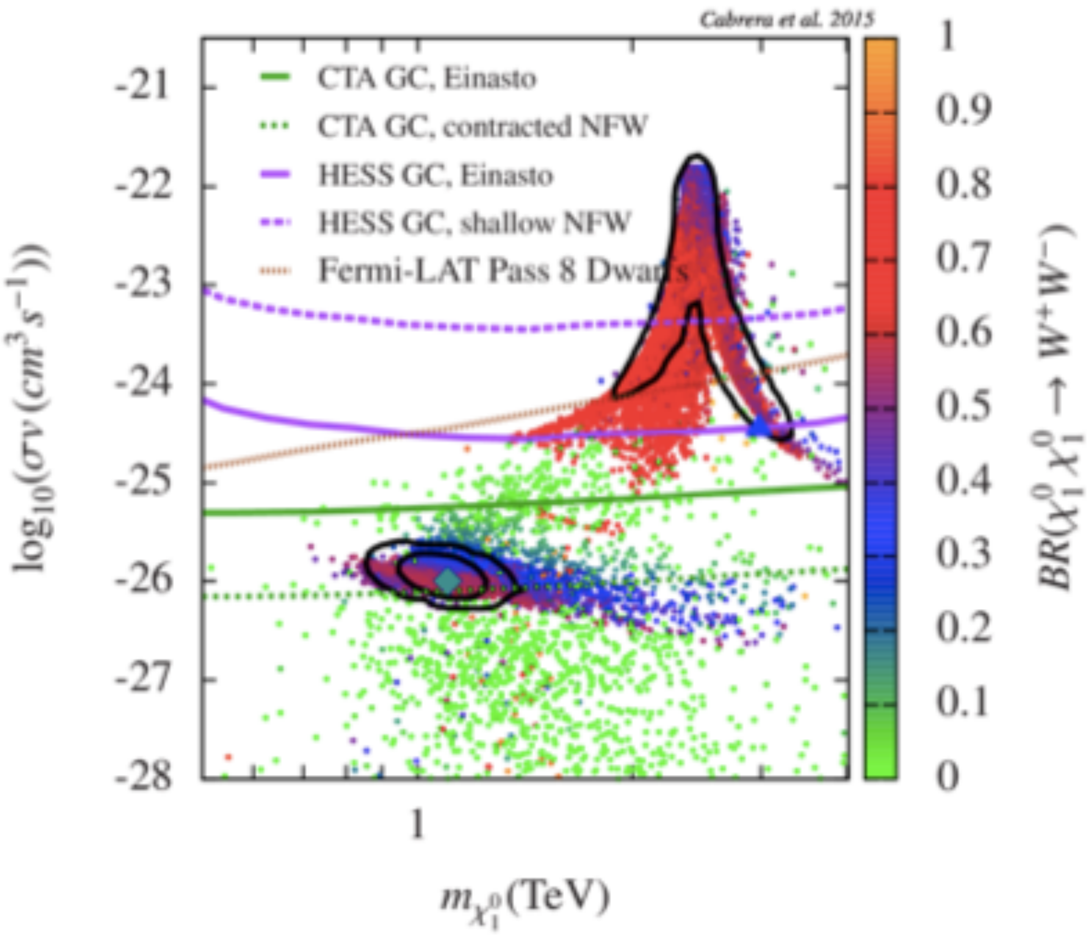




- Chile and La Palma locations
- km^2 array of Atmospheric Cherenkov telescopes
- Energy coverage from a ~10 GeV ~10 TeV
- Angular resolution as low as 0.02°

Atmospheric Cerenkov Detectors

TeV dark matter is motivated by LHC negative results on SUSY and will be reachable by CTA

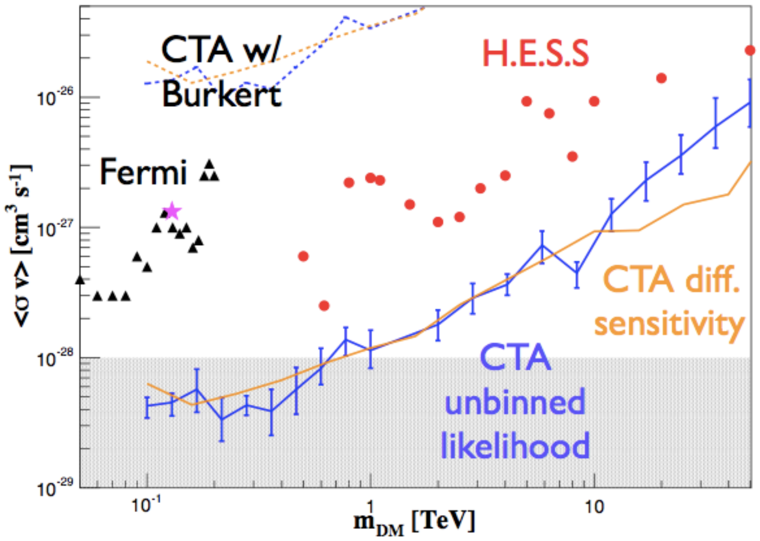


Atmospheric Cerenkov Detectors

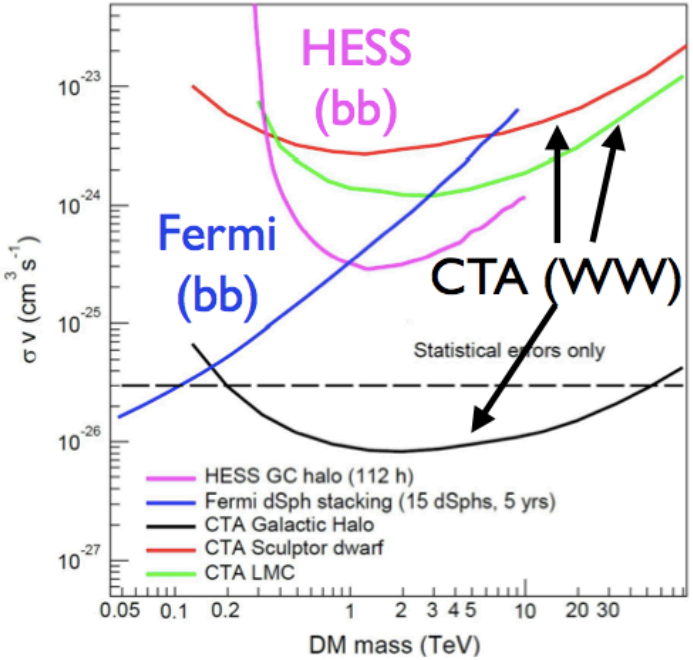
Sensitivity for different targets

Good prospects for the galactic center

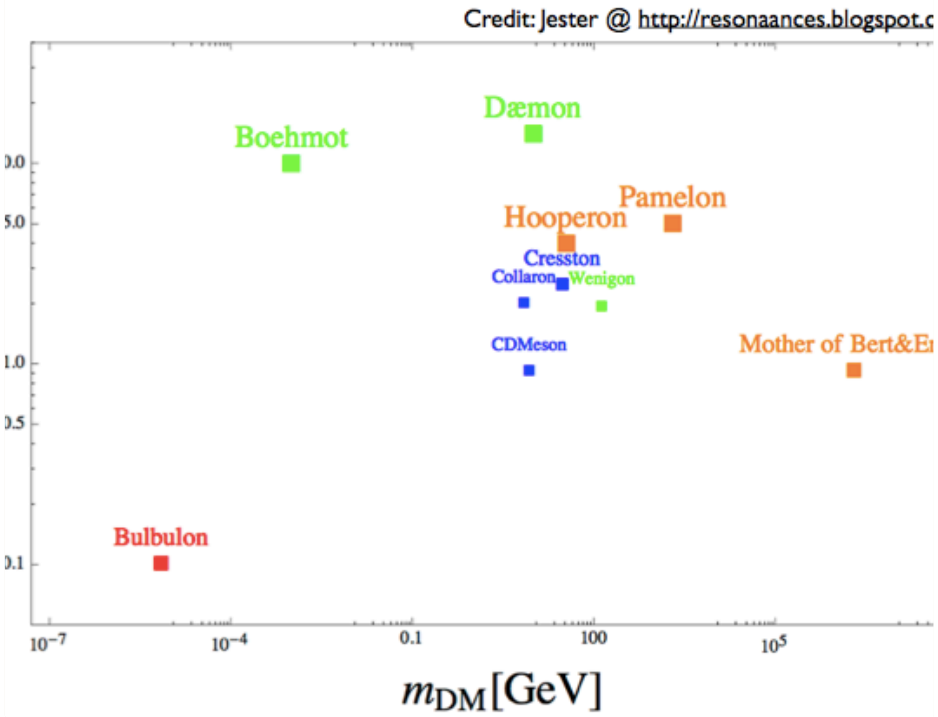
CTA: 500h, 1 deg around GC, Einasto



500h, WW / bb, different targets



Sensitivity to gamma ray lines



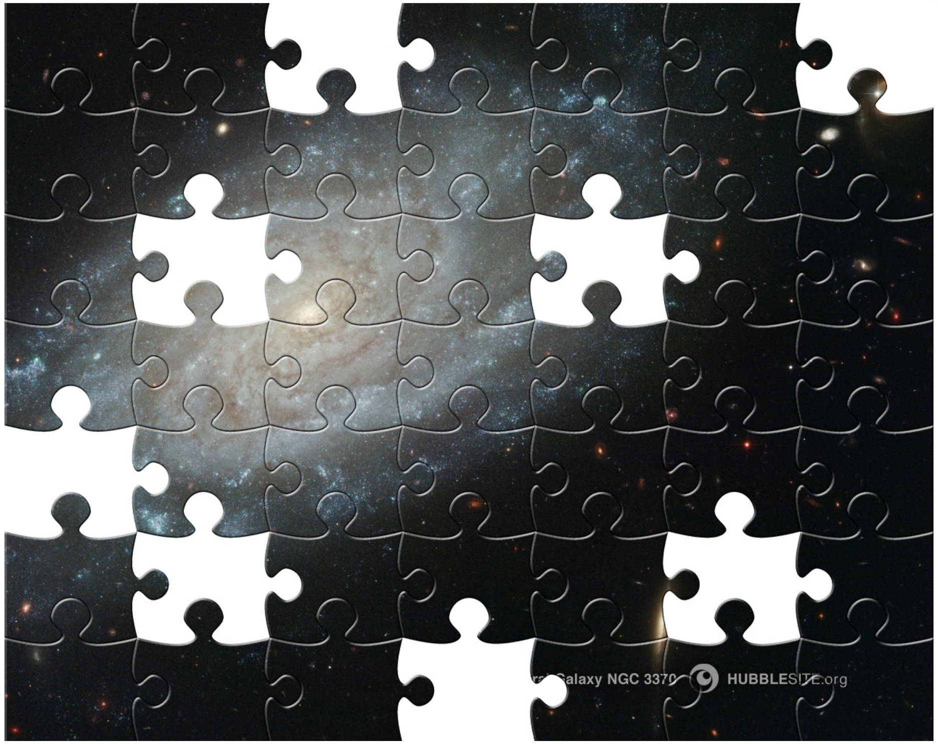
Anomalies have produced a continuous improvement in sensitivity of DM detectors and techniques

Most of these anomalies are expected to disappear very fast

Others do not

… like DAMA LIBRA

Next decade could be crucial to find the solution LHC CTA LZ SUPERCDMS XENON1T, …



Hopefully in the next decade the multimessenger approach will succeed to solve the dark matter problem

Acknowledgements

- C. Lacasta and D. Cerdeño complementary lessons
- TAUP2013 and 2015 slides from many speakers of the plenary and parallel sessions
- MultiDark Consolider Project meetings and private conversations with MultiDark collaborators