Astrofisica Nucleare e Subnucleare

Dark Matter Searches - II

ISAPP2013 Stockholm

from 29 July 2013 to 06 August 2013 | Djurönäset Conference Centre, Stockholm region

- Overview
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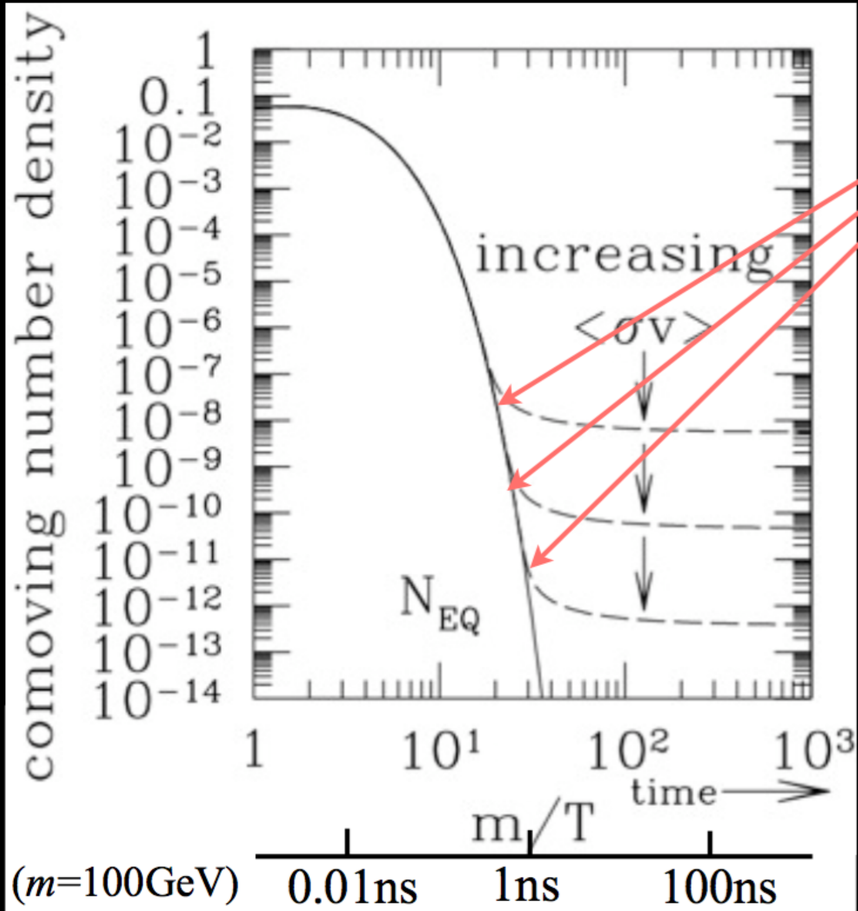
The International School for AstroParticle Physics (ISAPP) 2013, Djurönäset:

Dark Matter Composition and Detection, July 29 to August 6, 2013

Cosmic density of heavy active neutrinos



freeze-out

$\Gamma_{\rm ann} \equiv n\langle\sigma v\rangle \sim H$

annihilation rate *expansion rate*

$$\Omega_\chi h^2 \simeq \frac{3\times 10^{-27}{\rm cm}^3/{\rm s}}{\langle\sigma v\rangle_{\rm ann}}$$

$\Omega_\chi h^2 = \Omega_{\rm cdm} h^2 \simeq 0.1143$

for $\langle\sigma v\rangle_{\rm ann} \simeq 3\times 10^{-26}{\rm cm}^3/{\rm s}$

This is why they are called Weakly Interacting Massive Particles

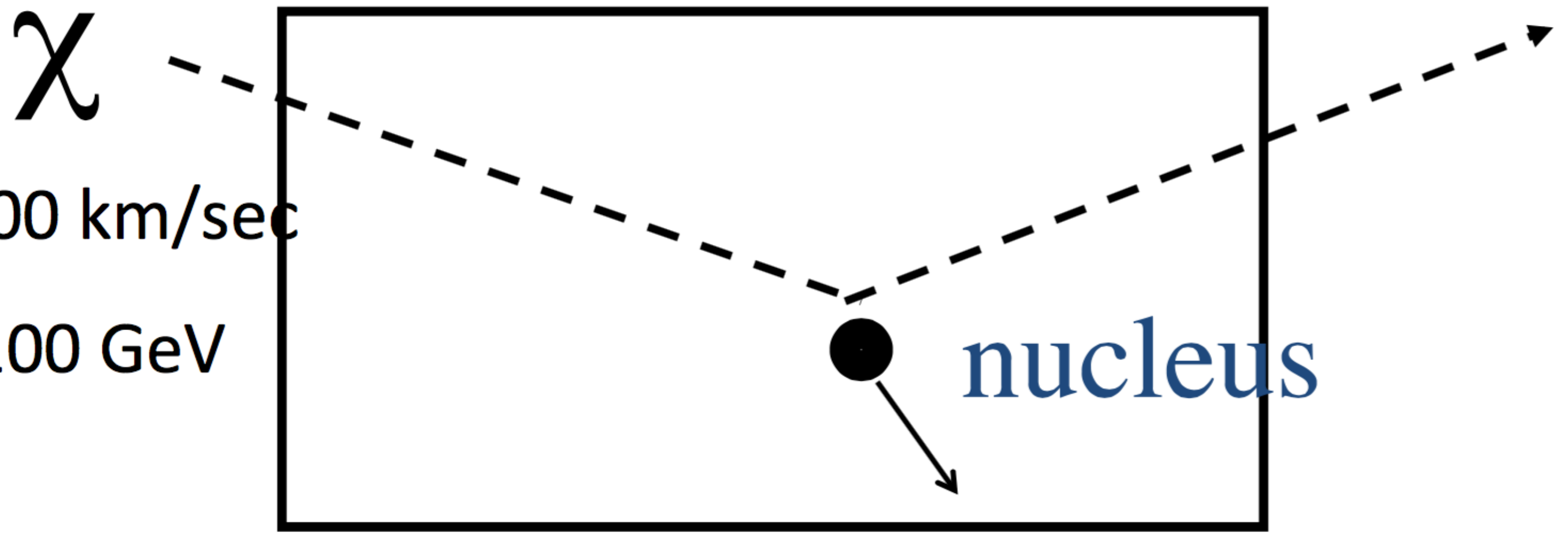
(WIMPless candidates are WIMPs!)

Direct detection:

$$\chi q \xrightarrow{\text{QCD}} \chi n \xrightarrow{\text{nuclear physics}} \chi N$$

$$\sigma_{\mathrm{WIMP-nucleus}} \sim 10^{-36}\,\mathrm{cm}^2$$

E.g., Ge or Xe detector



V~300 km/sec

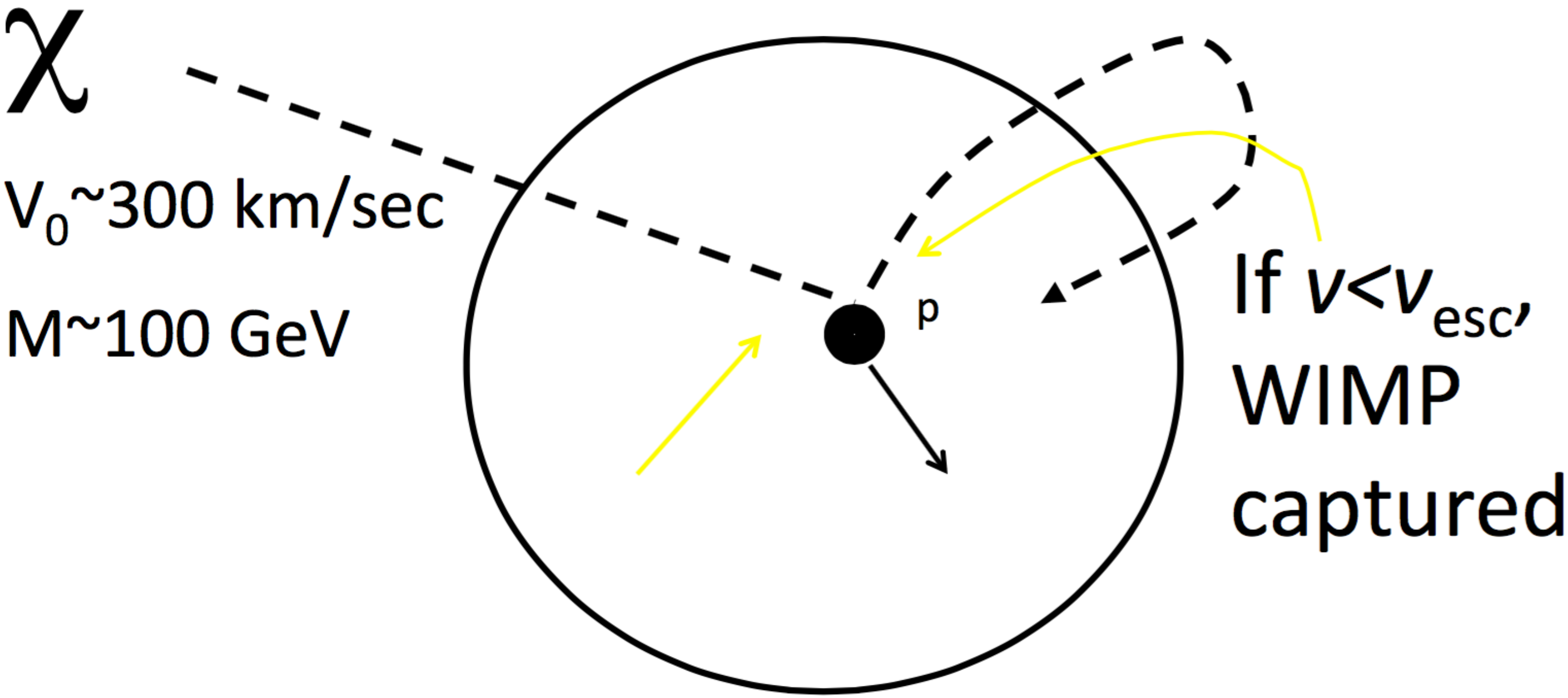
M~100 GeV

$E_{recoil} \sim (1/2)mv^2 \sim 50$ keV

Rate:

$$\begin{aligned} n\sigma v N_{\rm nuclei} &\sim (10^{-36}\,{\rm cm}^2)\left(\frac{0.4\,{\rm GeV/cm}^3}{100\,{\rm GeV}}\right)(3\times 10^7\,{\rm cm/sec})\left(\frac{6\times 10^{23}\,{\rm kg}^{-1}}{A}\right) \\ &\sim {\rm few\ kg}^{-1}\,{\rm yr}^{-1} \end{aligned}$$

Indirect Detection: Energetic neutrinos from WIMP annihilation in Sun/Earth



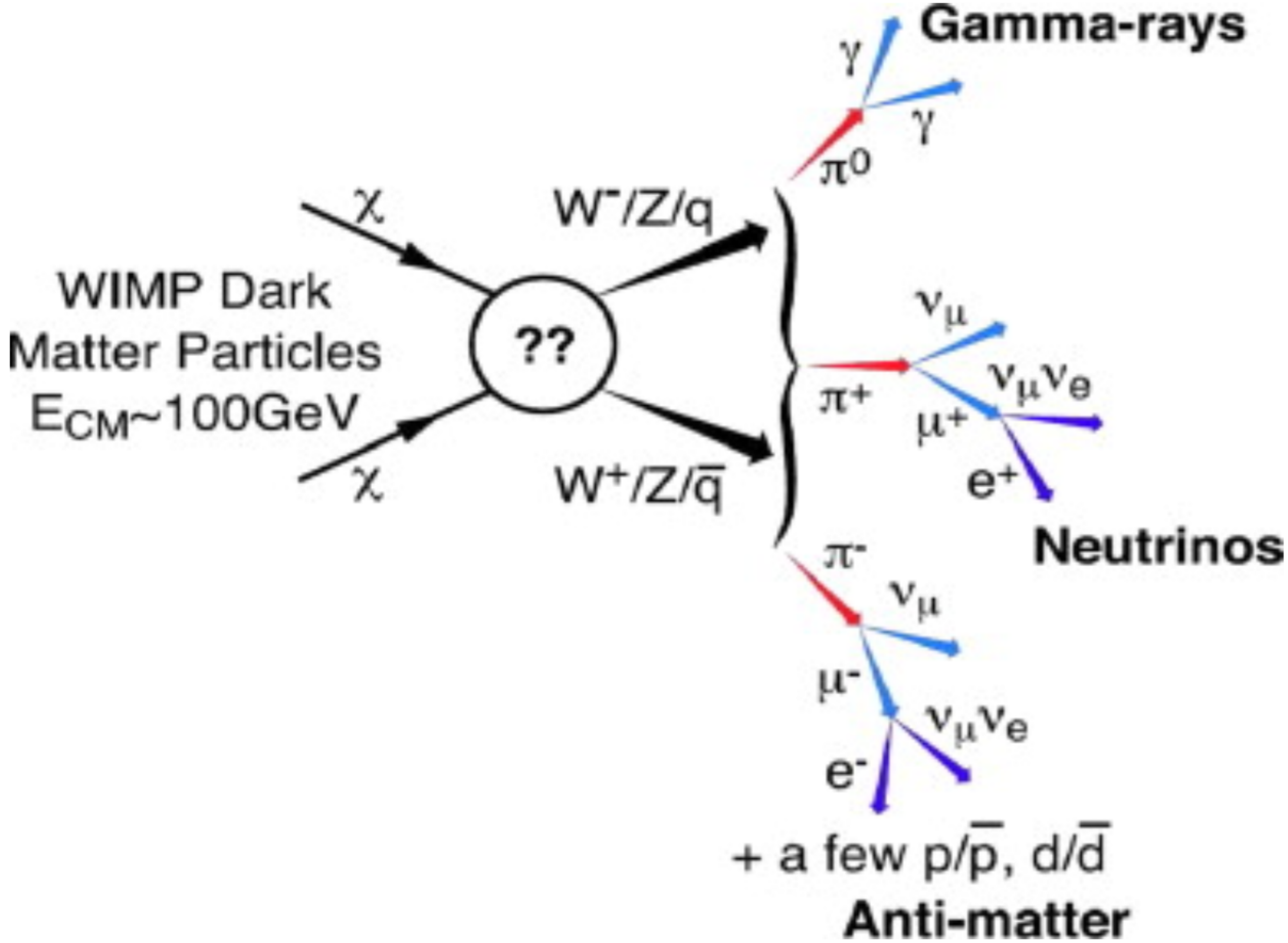
Inside Sun and/or Earth:

$$\chi\chi \to (W^+W^-, Z^0Z^0, q\bar{q}, l\bar{l}, \cdots) \to \nu\bar{\nu}$$

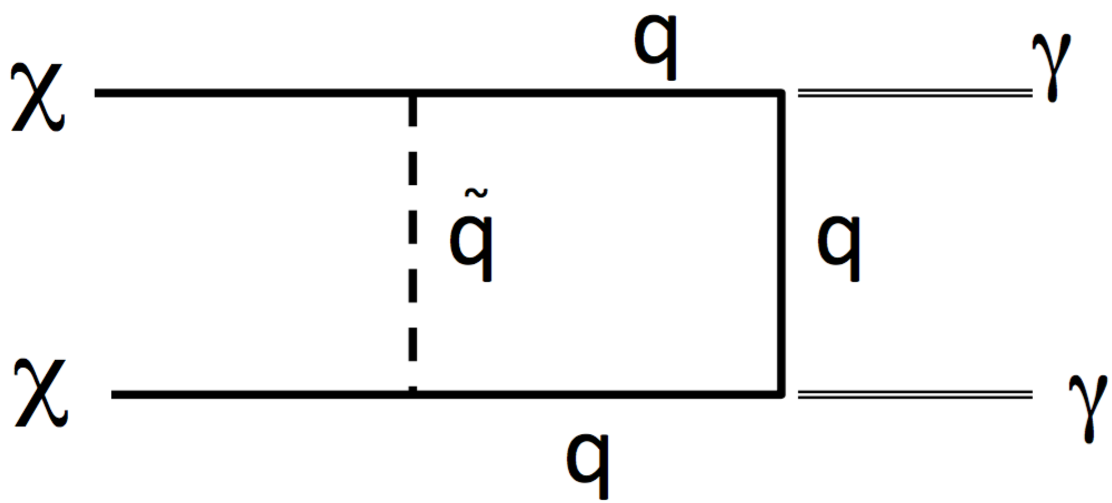
$$E_\nu \sim (1/10 - 1/2)m_\chi \sim 10 - 1000s\,\mathrm{GeV}$$

Neutrinos sought in, e.g., MACRO, IMB,
Super-Kamiokande, IceCube.....

Indirect detection: Exotic cosmic rays from WIMP annihilation in Galactic halo



Indirect Detection: Gamma-rays from WIMP annihilation in Galactic halo



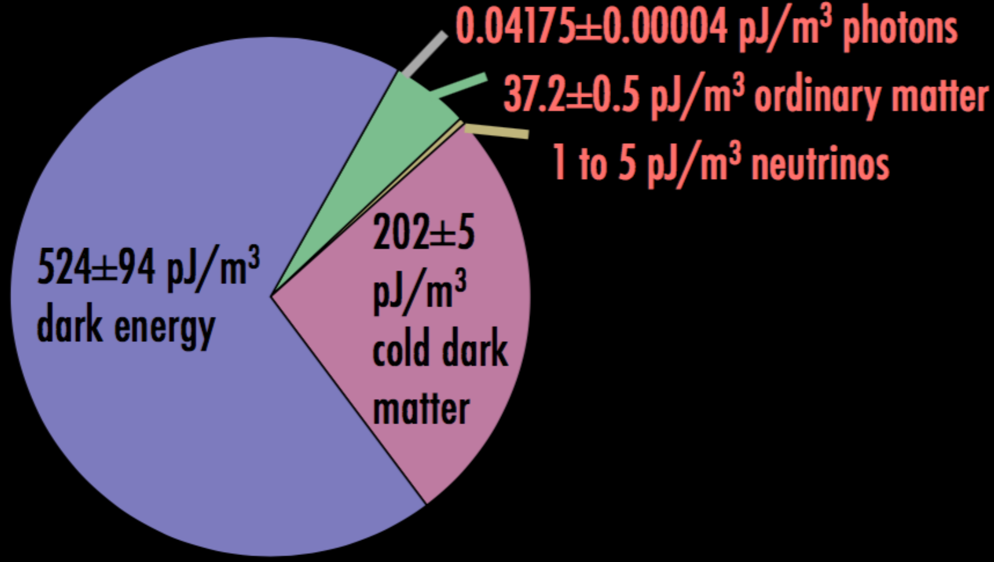
$$E_\gamma = m_\chi$$

Can be sought in Fermi, air Cherenkov telescopes (e.g, CTA)

The Magnificent WIMP
(Weakly Interacting Massive Particle)

- One naturally obtains the right cosmic density of WIMPs

  Thermal production in hot primordial plasma.



- One can experimentally test the WIMP hypothesis

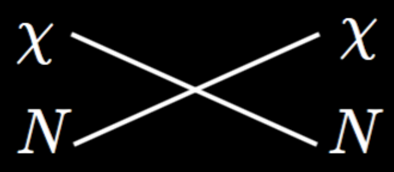
  The same physical processes that produce the right density of WIMPs make their detection possible

The magnificent WIMP

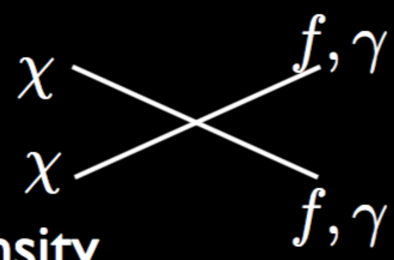
To first order, three quantities characterize a WIMP

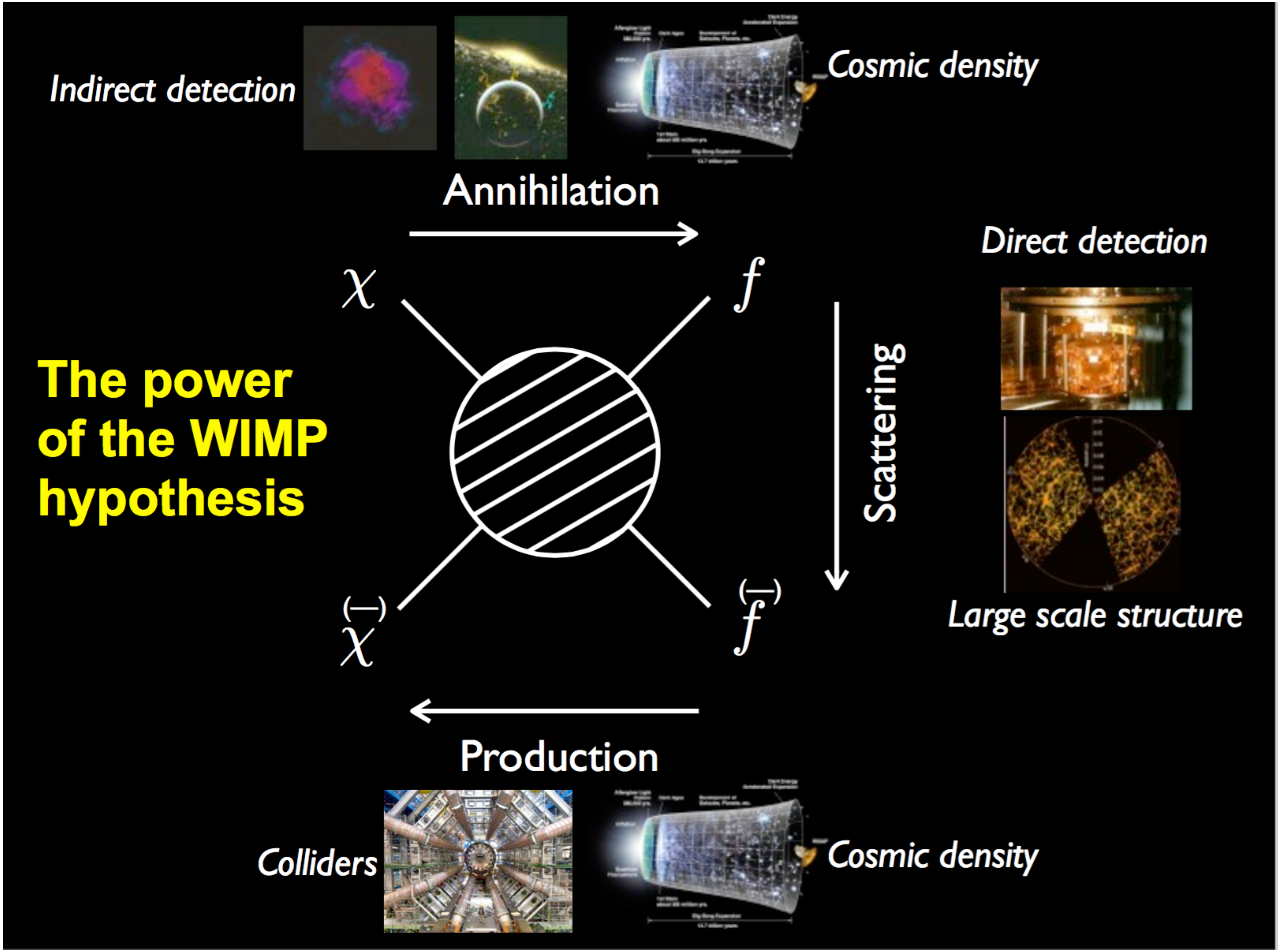
- Mass m
  - Simplest models relate mass to cosmic density: $1-10^4$ GeV/c^2

- Scattering cross section off nucleons σ_{XN}
  - Usually different for protons and neutrons
  - Spin-dependent or spin-independent governs scaling to nuclei



- Annihilation cross section into ordinary particles
  - $\sigma \simeq \text{const}/v$ at small v, so use σv
  - Simplest models relate cross section to cosmic density




Indirect detection
Cosmic density
Annihilation
Direct detection
The power of the WIMP hypothesis
Scattering
Large scale structure
Production
Colliders
Cosmic density

DARK MATTER
STATUS AND PERSPECTIVES

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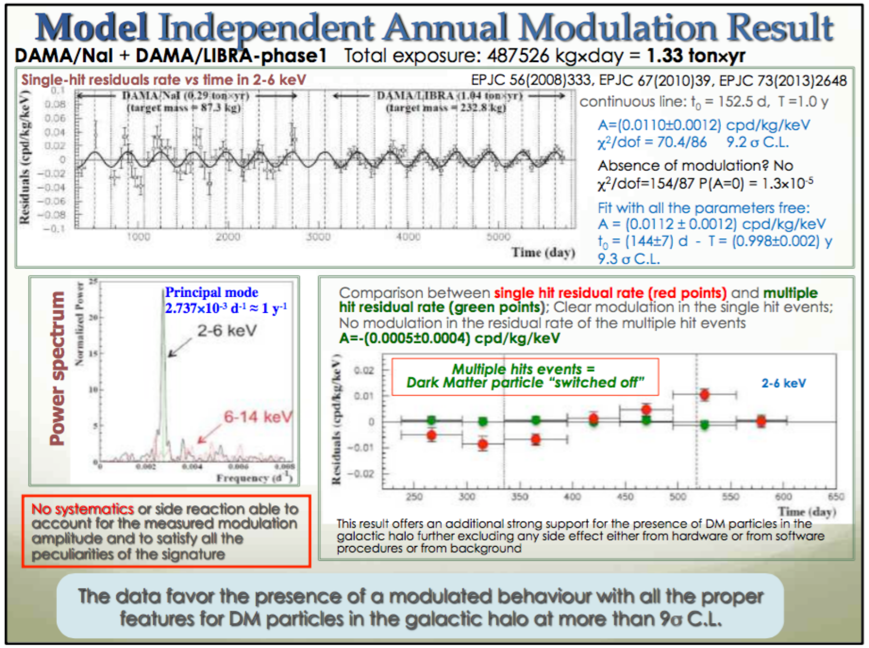
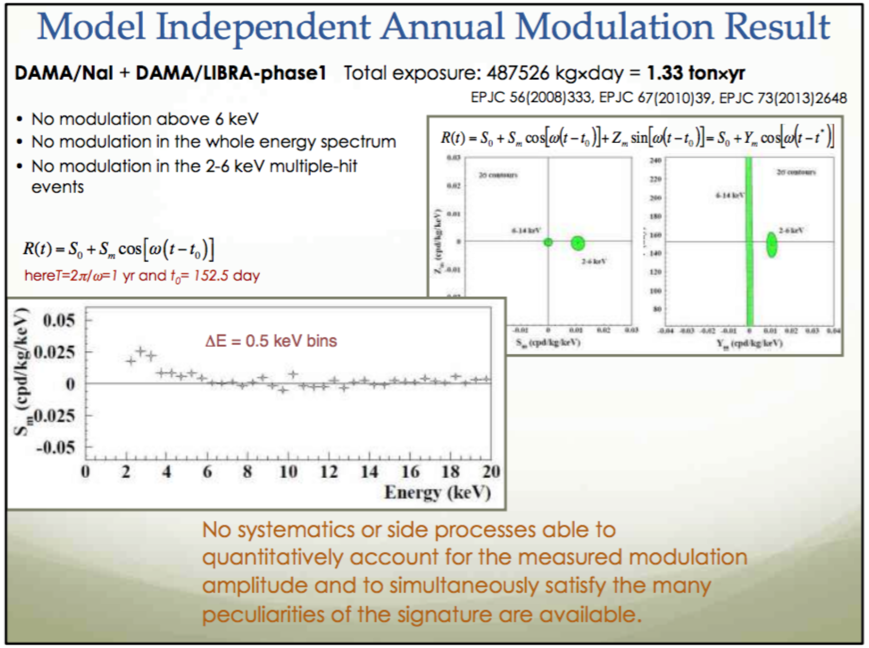
Giornate di studio sul Piano Triennale INFN
Centro "Le Ciminiere", Catania – 3.12.2015

Annual modulation: DAMA, 9.2σ with 1.33 ton x yr, 15 cycles





From Belli's talk at TAUP 2015, http://taup2015.to.infn.it

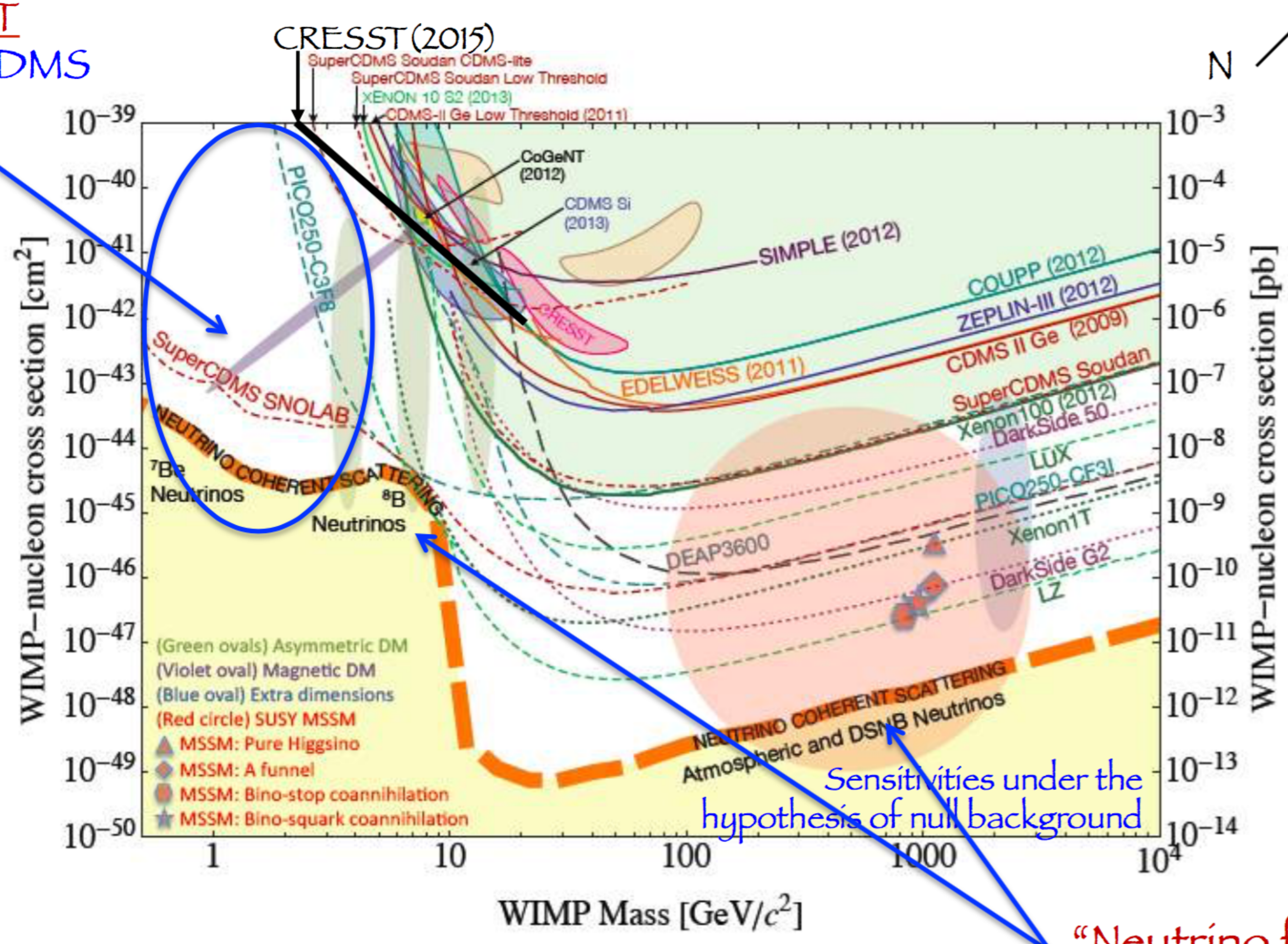
Compatible with: DM scattering on nuclei (5-100) GeV WIMPs
DM scattering on electrons (0.3-6) KeV ALPs

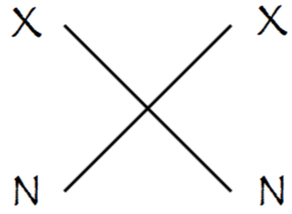
Light WIMPs window

CRESST

SuperCDMS

…





"Neutrino floor"

XENON1T (LXe)

DarkSide (LAr)

Lux, LZ, …

Bounds and expected sensitivities for DM-nucleus scattering
Under the hypothesis of contact-type interactions

Direct Dark Matter Searches

0- Context

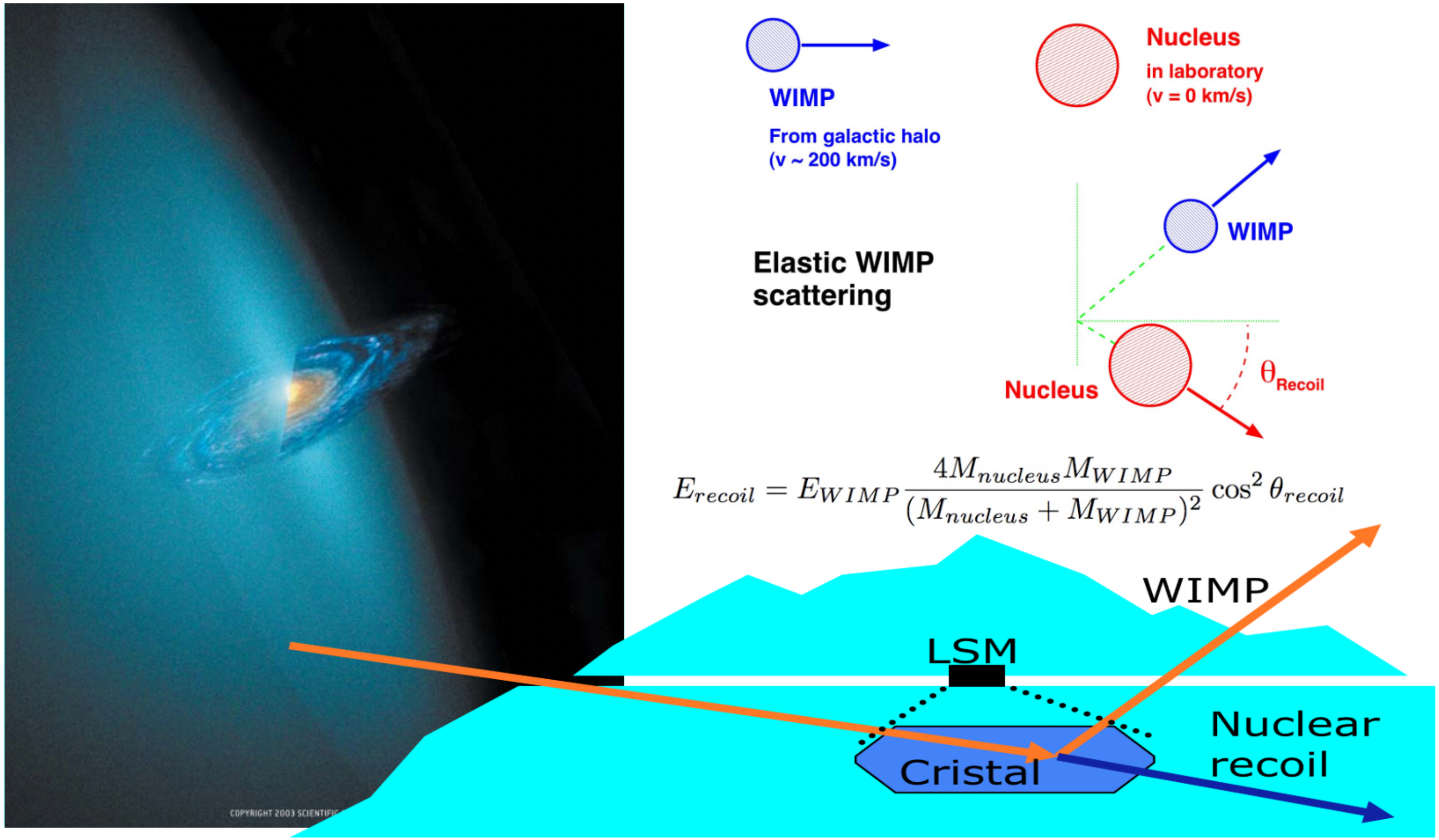
1- Elastic scattering rates

2- Detection principle: signal and backgrounds

3- Review of current experiments

J. Gascon
UCB Lyon 1, CNRS/IN2P3/IPNL

Direct search schematics

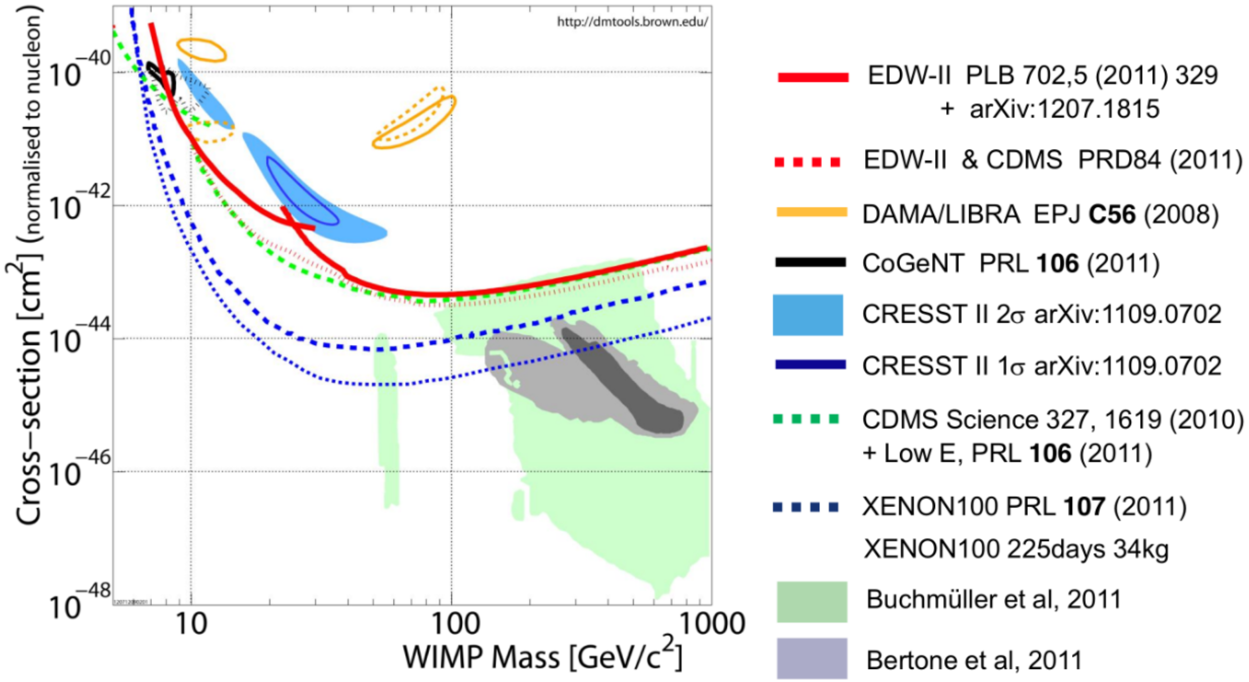


$$E_{recoil} = E_{WIMP} \frac{4 M_{nucleus} M_{WIMP}}{(M_{nucleus} + M_{WIMP})^2} \cos^2 \theta_{recoil}$$

Observables: Event rate, E_{recoil} , θ_{recoil} (recoil range is related to E_{recoil})

- We don't know (yet) what is the mass of the WIMPs
- We don't know (yet) what is the cross-section for WIMP-nucleus scattering
- Generic searches for ALL WIMPs masses M_W and ALL cross-section σ.
- A given experiment will be able to probe a certain region of (M_W, σ):

"exclusion plots"

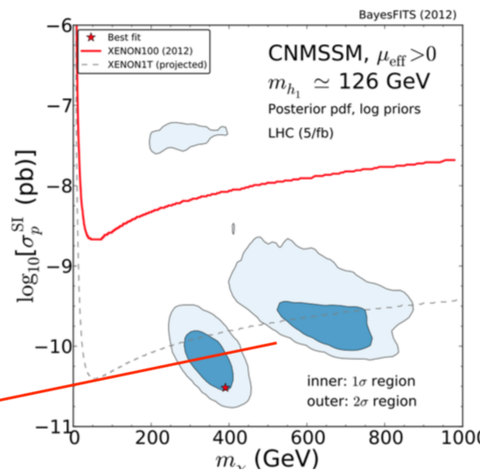


Apply to any particle able to scatter elasticaly on an atomic nucleus

(Neutralino χ, Kaluza-Klein, mirror, scalar...)

- *... If the kinetic energy of the WIMP* E_{WIMP} *is not too small*
  - $M_{WIMP} \sim 100\ GeV/c^2$ (supersymmetry) and v ~ 200 km/s correspond to an average $E_{WIMP} \sim 20$ keV (hard X ray).
- *... If* $M_{WIMP} \sim M_{nucleus}$
  - Optimal momentum transfer for $M_{WIMP} = M_{nucleus} \sim 100\ GeV/c^2$ corresponding to A ~ 100 g/mol
- *... If the scattering probability is not zero*
  - Small, otherwise already seen?
  - WIMP miracle suggests Weak scale
  - Weak force, supersymmetry:

kilo.day… to ton.year (10^{-10} pb).



PRD 87 (2013) 115010

Signals in direct searches

- Exponential recoil spectrum
- A^3 dependence of rate

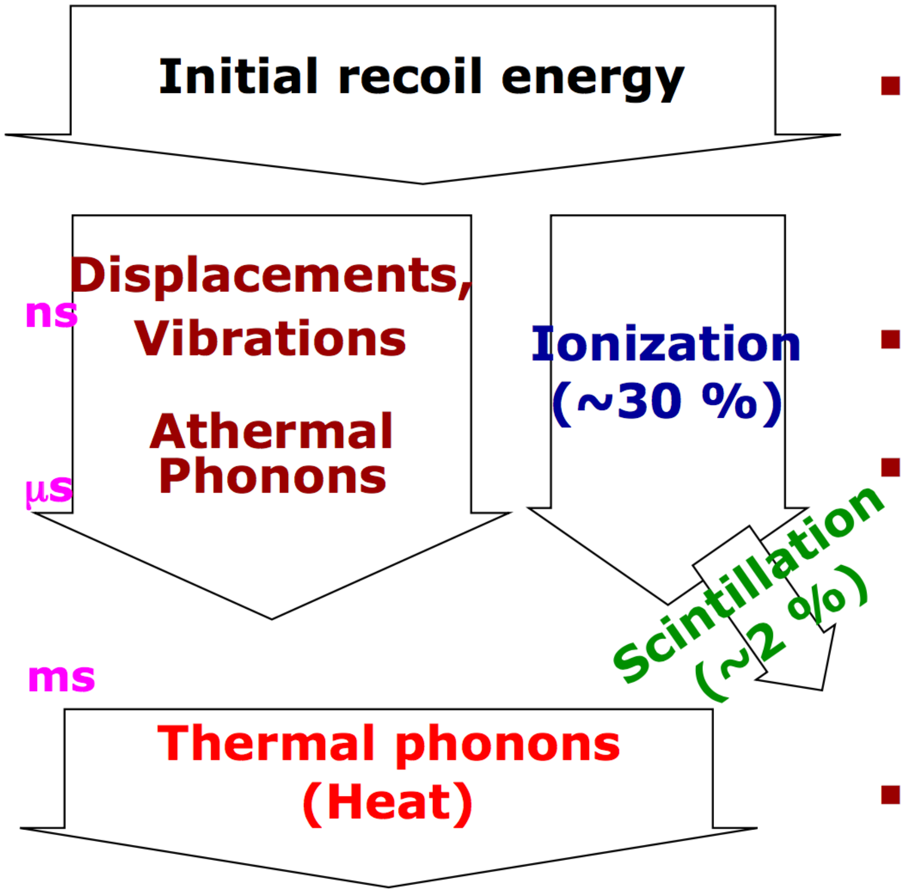
It's not a neutron-induced nuclear recoil ($\sigma = \pi R^2 \propto A^{2/3}$)

- No coincidence between adjacent detectors (detector array)
- Uniform rate within the fiducial volume (large detectors)

- Directionality (correlation with $\vec{v}_{SUN}$ direction): need to measure nuclear recoil trajectory
- Annual modulation (large statistics needed)

- ***Identification of nuclear recoils (vs electron recoils)***

Effect of a nuclear recoil in matter

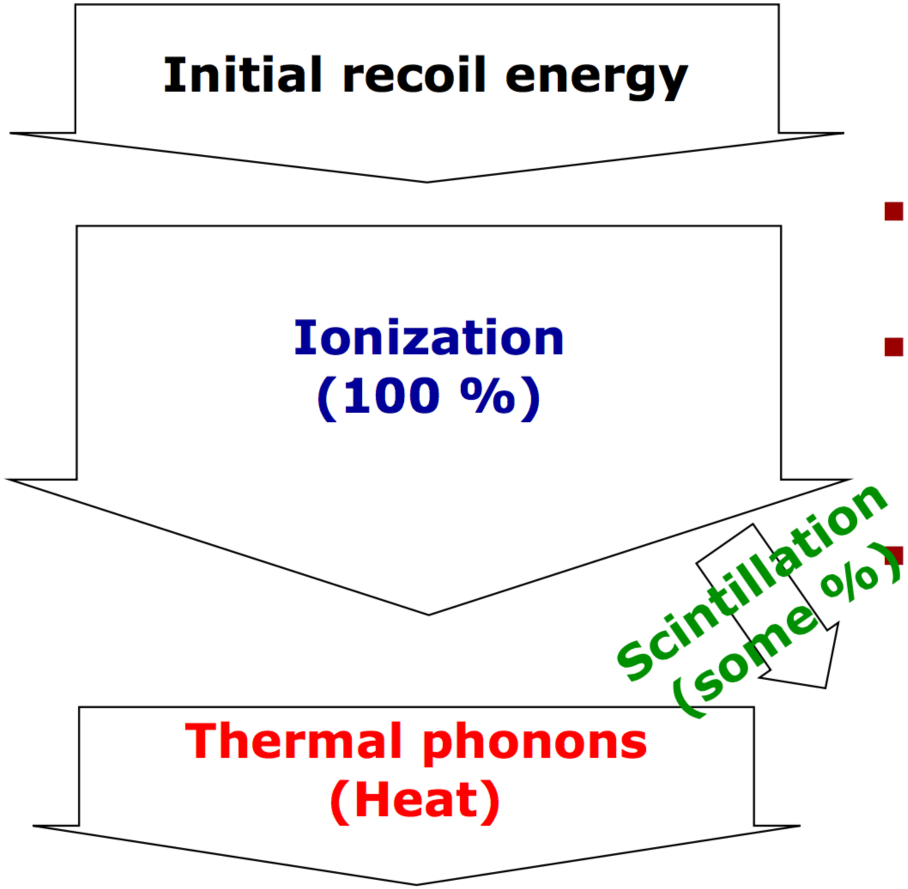


(+ Permanent crystaline defects?)

Two type of energy losses:

- Ion-ion collisions (producing displacements and vibrations in the crystal: athermal phonons): nuclear dE/dx.
- Ionization (electronic dE/dx)
- Cascade of collisions and mix of nuclear & electronic dE/x well described by Lindhard's theory + measured dE/dx
- In a closed system, after a while, all excitation decays into thermal energy -> rise in temperature

Effect of an electron recoil in matter

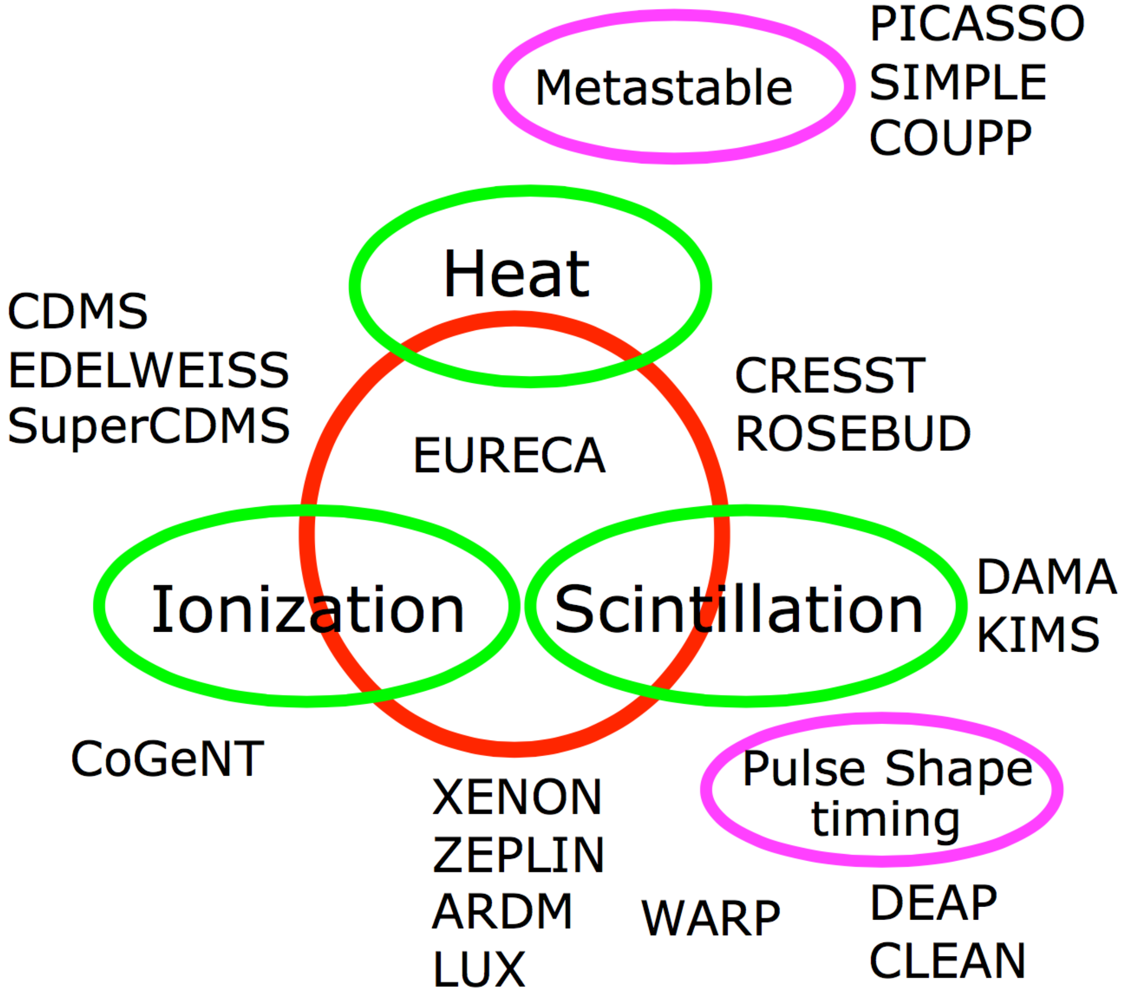


- Most common (long range) radioactive background: γ-rays, producing electron recoils (photoelectron, Compton)
- No ion-ion collisions only electronic dE/dx
- Comparing ionization and scintillation yields is a powerful tool to separate nuclear and electron recoils
- Other effects due to difference in dE/dx: density of energy deposit are not the same. This may also affect the risetime of the scintillation signal (pulse shape discrimination)

(+ No permanent crystaline defects?)

γ, β discrimination:

- Two simultaneous signals
  - Heat/Phonon
  - Ionisation
  - Scintillation
- Pulse shape discrimination
  - Noble gas/liq.
  - Cristal
- Other "dE/dx" related ideas



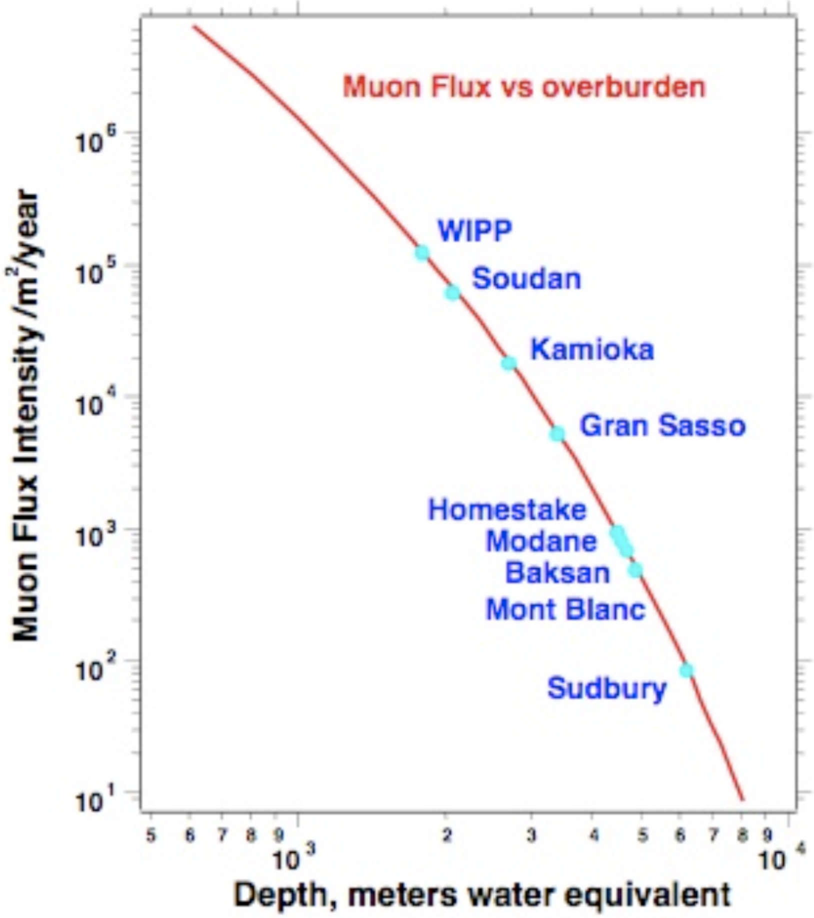
List of radioactive backgrounds

- Neutrons (~MeV) are a real nuisance because they create nuclear recoils, with recoil spectra comparable to those made by WIMPs
  - Can use ~3cm range to reject coincidences and use self-shielding
- Surface events (<1mm) matters because of mis-reconstruction problems

Type	Attenuation Range in solids	Finite Range	Produces neutrons	Produces nuclear recoils
Muon	100 m		Yes	
Gamma	Few cm			
Beta		<1 mm		
Alpha		<20 μm	Yes (~10^{-5})	
Neutron	3 cm			Yes

Radioactive background (1): cosmics

- About half of the radioactive background in your body is due to activation by cosmic rays
  - Direct hits: 1 /hand/second
  - Later decays of activated nuclei
- Solution: deep underground laboratories in mine or road tunnels
- Ex: LSM (Frejus tunnel)
  - 1.6 km of rock
  - 4.8 km equivalent of water
  - 5 μ / m^2 /day
  - ~1 nuclear recoil /kg/month from n in Pb shield: μ veto!



Radioactive background (2): Uranium + Thorium

- One of the most common radioactive background

^{238}U: $T_{1/2}$ = 4.5 x10^{9} years ^{232}Th: $T_{1/2}$ = 14 x10^{9} years

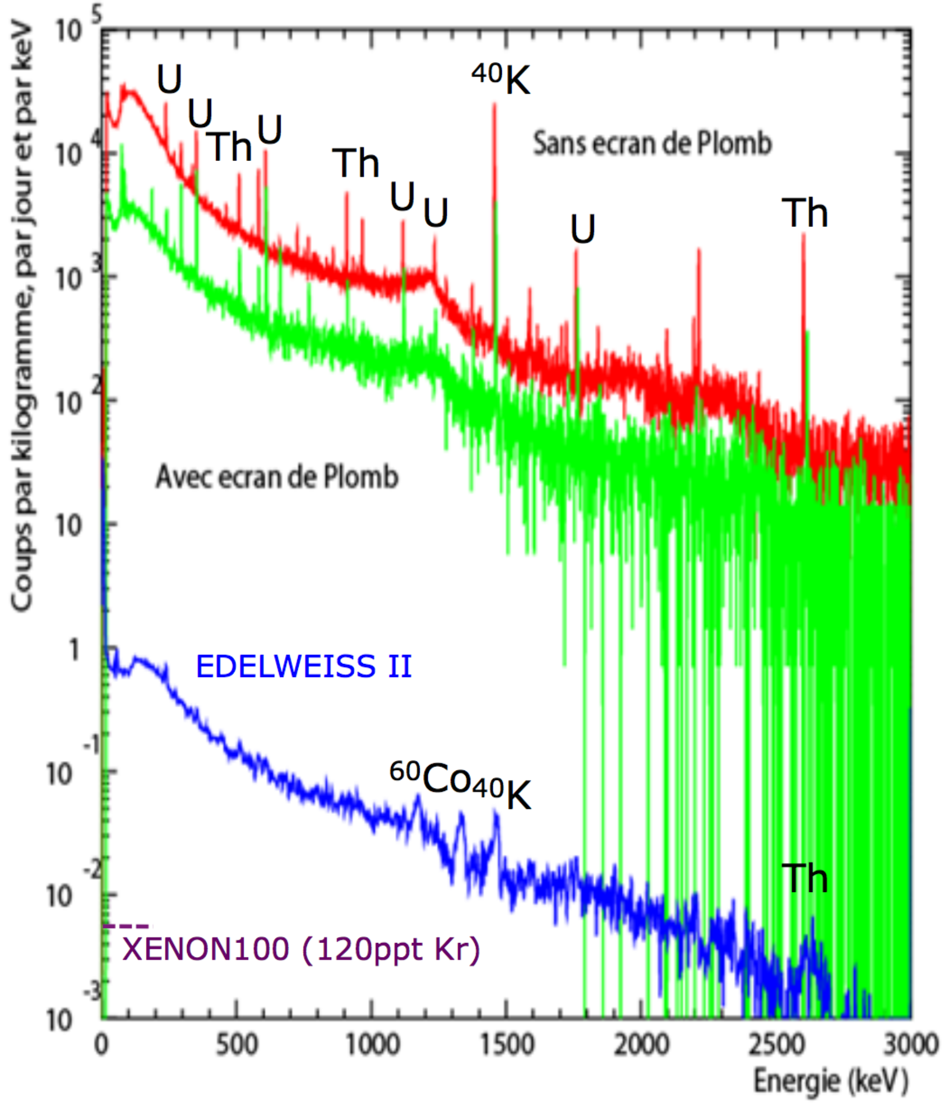
- Ratio 10^{-6}:1 in ordinary rock: ~10^{6} decay / kg / day
- Long decay chain down to ^{206}Pb and ^{208}Pb, respectively
  - Multiplies by ~10 the activity once the chain is in equilibrium
- Alpha and beta emitter ("contained" inside the rock)
  - Range of particles: Alpha = 20 microns, beta < 1 mm
  - *But some gamma's, + beta bremmstrahlung …*
  - *Neutrons from U fission + alpha reactions with Al, F, Pb, …*
- *Radon: 10^{6} produced per kg/day*
  - *Can escape the rock! Travels in air at sonic speed! Deposits ^{210}Pb daughters down to ~20 nm below the surface of all materials! Difficult to get rid with a $T_{½}$ of 22 years, + diffusion inside solids!*

Example of gamma background in Ge detector

- Red: natural background in a « normal » environment (Undergraduate students work there…)
- Green: ~5 cm lead shield (large Z), reduction x ~10
- Blue: EDELWEISS-II in LSM, before the rejection of electron recoils.

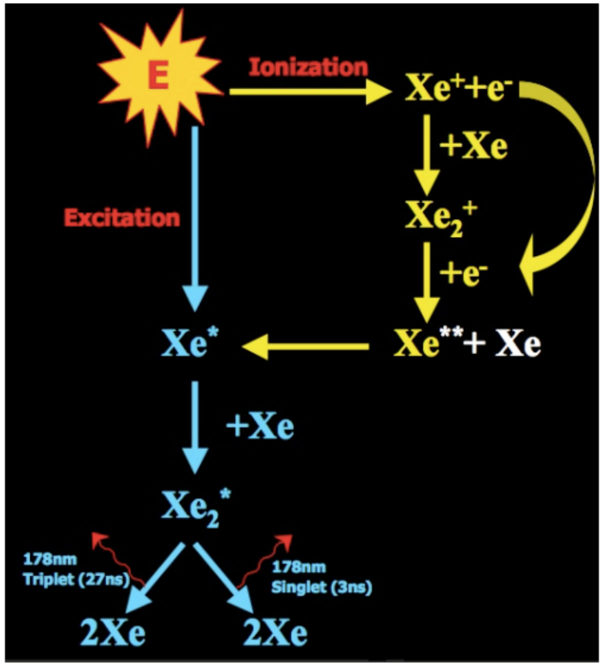
  Reduction 3x10^4 at ~50 keV (Pb shield, material selection)

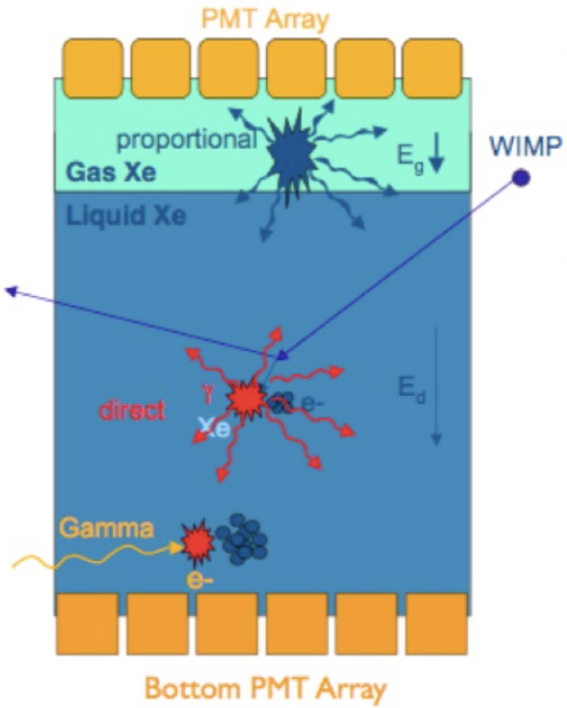
- Further reduction >10^4 after nuclear recoil identification

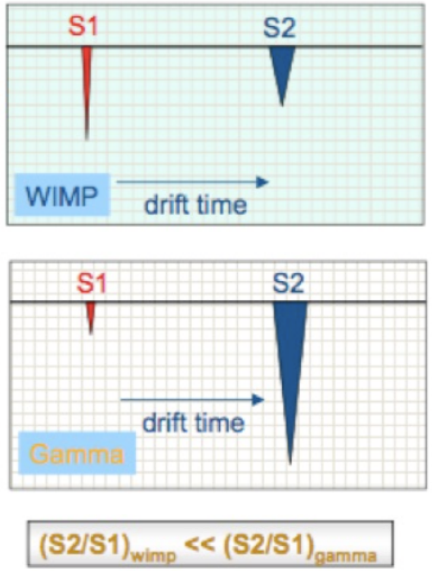


XENON S1/S2 discrimination

- Different scintillation (S1) and ionisation (S2) yields for nuclear / electronic recoils
- PMT array for (x,y), drift time for z : fiducial volume
- **Xenon 100**: 170 kg LXe, 34 kg fiducial, 30 cm drift, 98(top)+80(bottom) PM's
- *Trigger on 3 PM coincidence: bad energy resolution, but excellent noise suppression*
- 10 keV nuclear recoil: S1 ~ 5 P.E.   S2 ~ 800 P.E. (from ~30 ionization e^-)





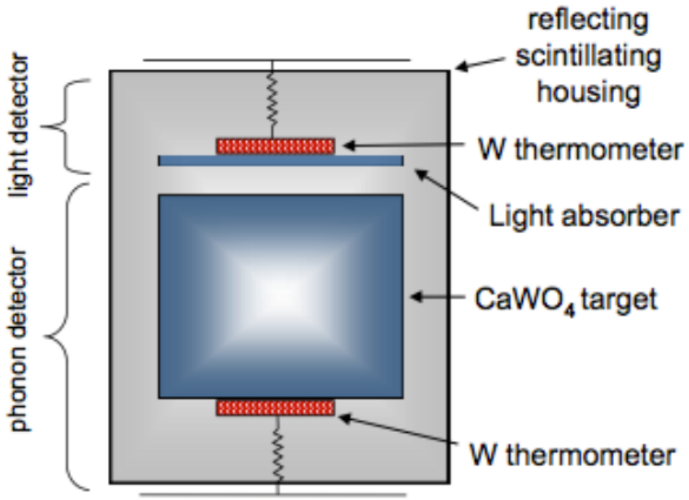


Heat-scintillation: CRESST

- 300 g $CaWO_4$ Crystals with Tungsten film thermometer
- Light detector = thin Si wafer + same type of thermometer
- 3 targets in same detector

  A = 16, 40 and 184

  Q = 0.10, 0.06 and 0.04



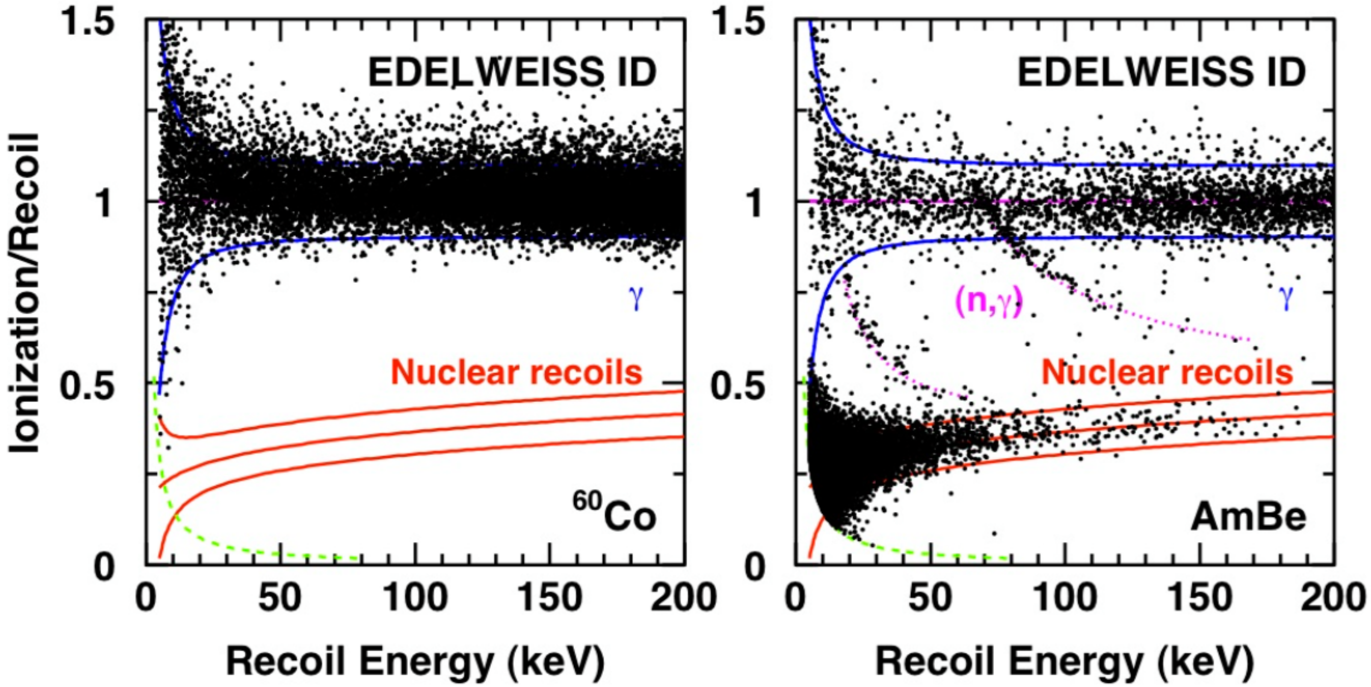
Reflecting scintillating housing to increase light yield

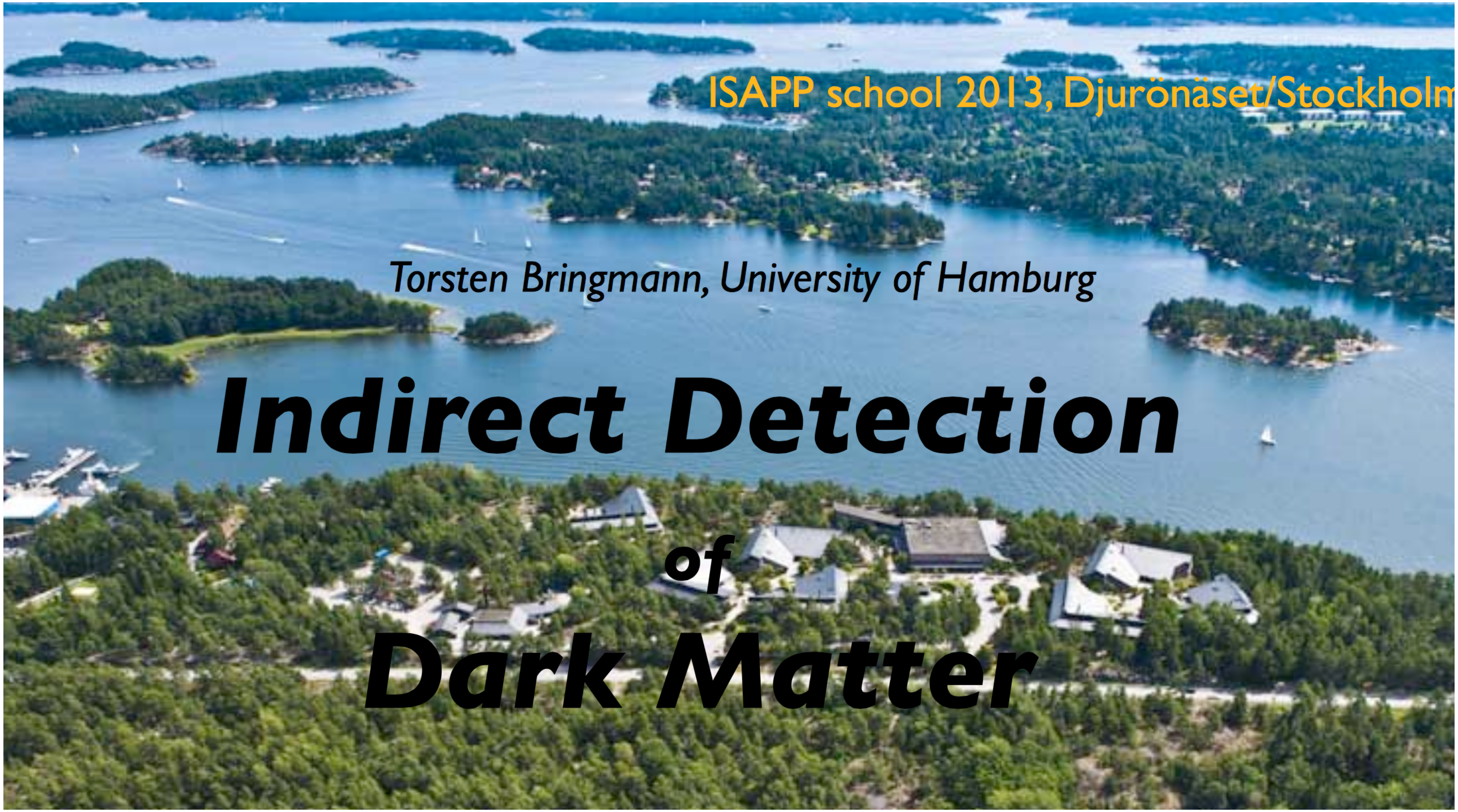
BONUS: tags $^{210}Po \rightarrow \alpha + ^{206}Pb$ two body decay

^{206}Pb recoil ~ W recoil

Nuclear recoil / gamma discrimination

- With good resolution on both ionization & heat, very clear discrimination based on the different ionization yields for *nuclear recoils* (WIMP or neutron scattering) and *electronic recoils* (β,γ decays)
  - discrimination of dominant background
  - Stable and reliable rejection performances

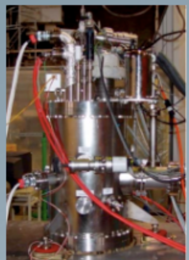


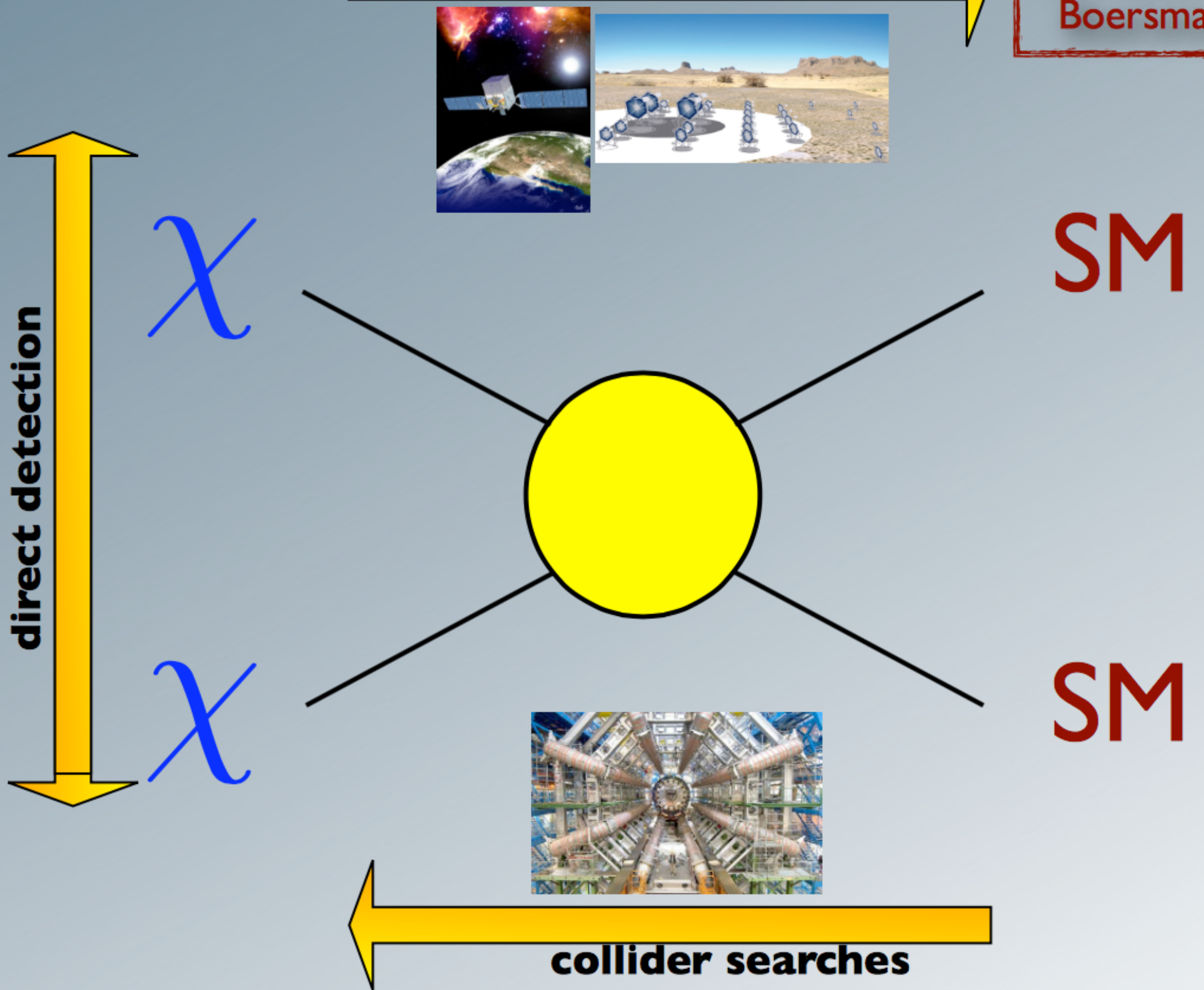

ISAPP school 2013, Djurönäset/Stockholm
Torsten Bringmann, University of Hamburg
Indirect Detection
of
Dark Matter

WIMPs do interact with the SM!

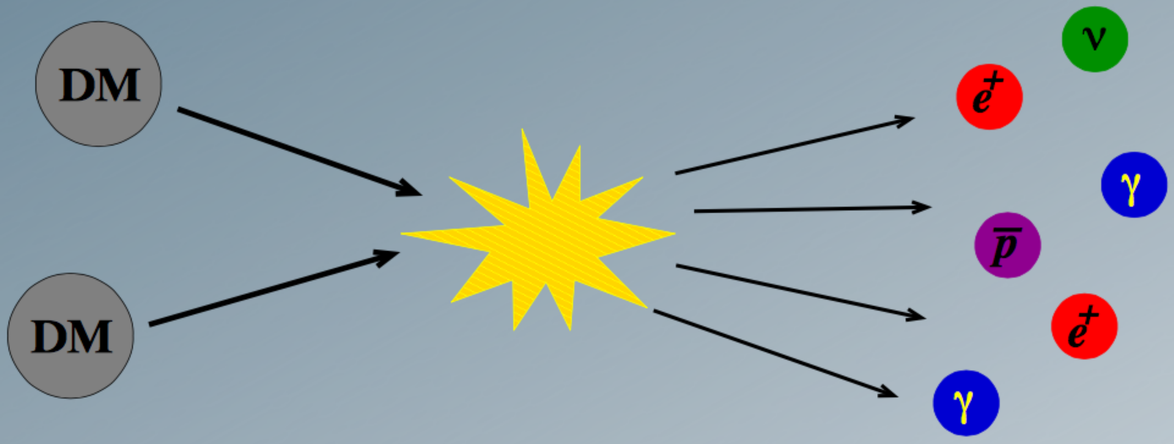
See also lectures by A. Melchiorri, J. Conrad, D. Boersma and F. Donato...

See lectures by J. Gascon





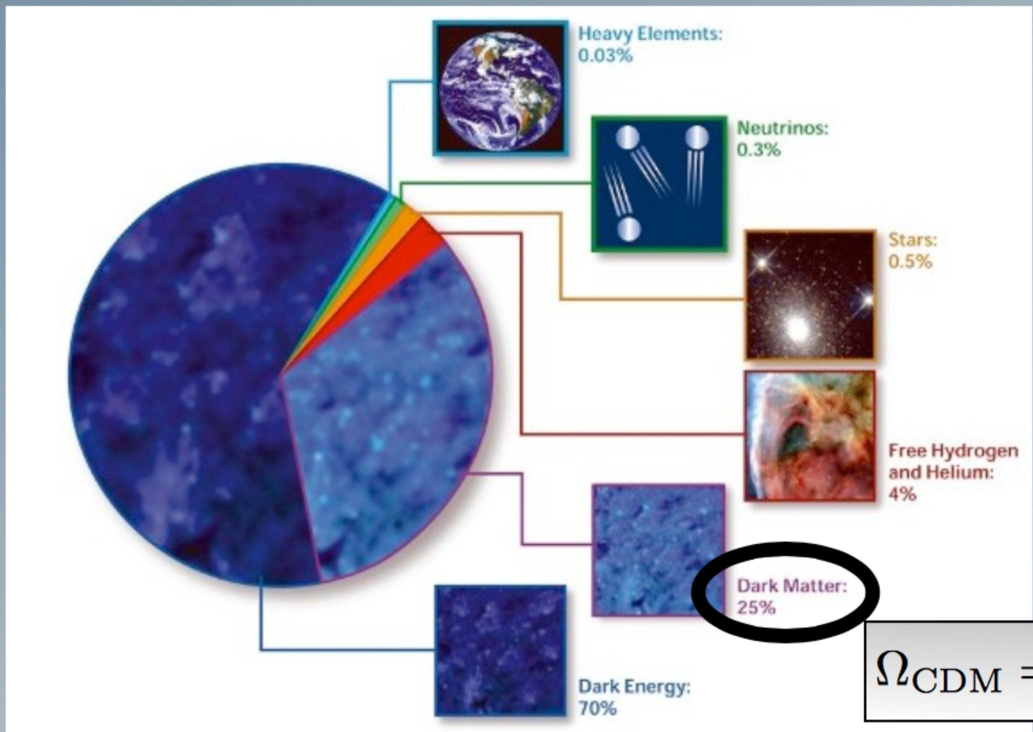
Indirect detection in one slide



- DM has to be (quasi-)stable against decay...
- … but can usually pair-annihilate into SM particles
- Try to spot those in cosmic rays of various kinds
- The challenge: i) absolute rates
  ⇝ regions of high DM density
  ii) discrimination against other sources
  ⇝ low background; clear signatures

Distribution of dark matter

- Annihilation sensitive to DM density *squared*
  ➔ need to know this quantity very well!



NB: in general

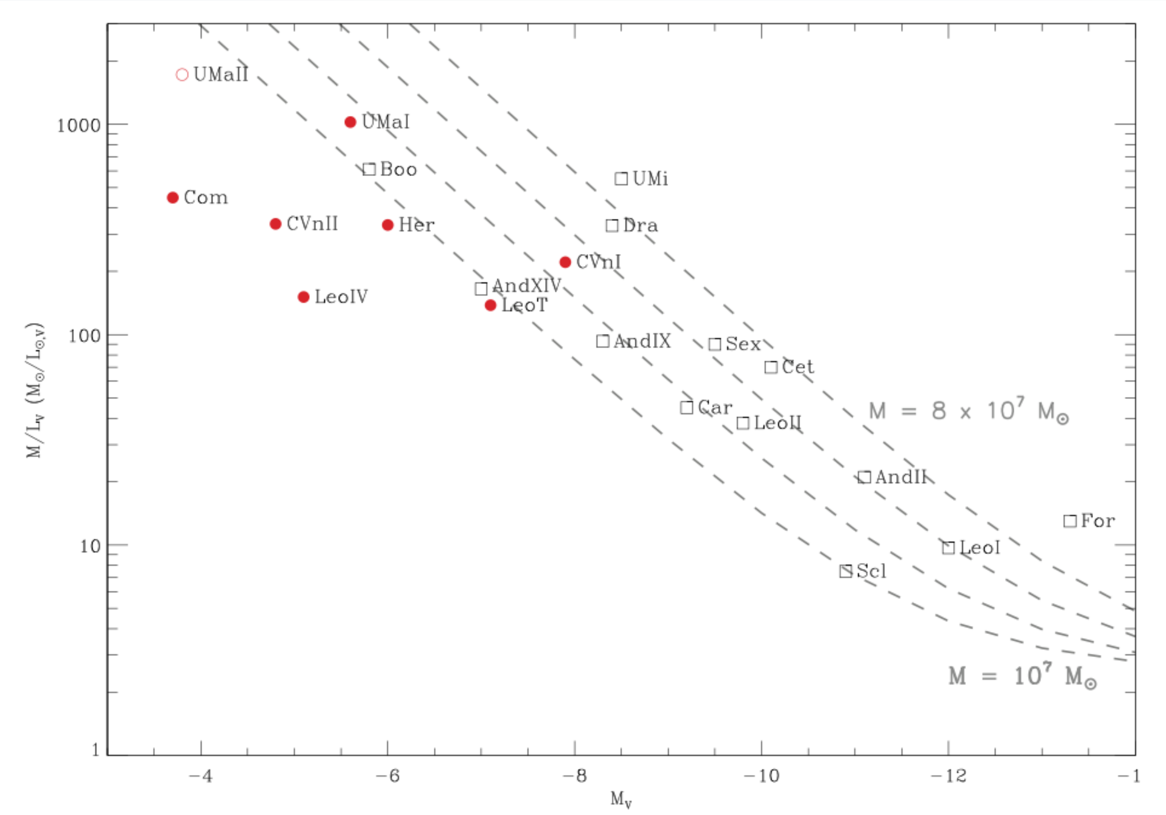
$$\Omega_\chi^{\rm local} \neq \Omega_{\rm CDM} \;!!!$$

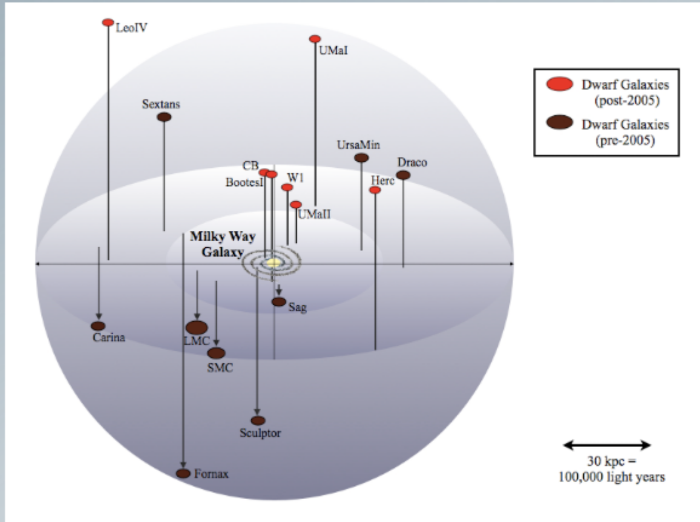
$\Omega_{\rm CDM} = 0.233 \pm 0.013$ on **large** scales

- [For comparison: *decaying* DM directly proportional to density]

Dwarf galaxies

- Use Jeans equation to relate observed velocity dispersion of stars to total mass distribution
  ➡ highest known mass-to-light ratios!





J.~D.~Simon, M.~Geha, ApJ 670, 313 (2007)

Substructure

- *N*-body simulations: The DM halo contains not only a smooth component, but a lot of substructure!
- Indirect detection effectively involves an averaging:

$$\Phi_{\rm SM} \propto \langle \rho_\chi^2 \rangle = (1+\mathrm{BF})\langle \rho_\chi \rangle^2$$

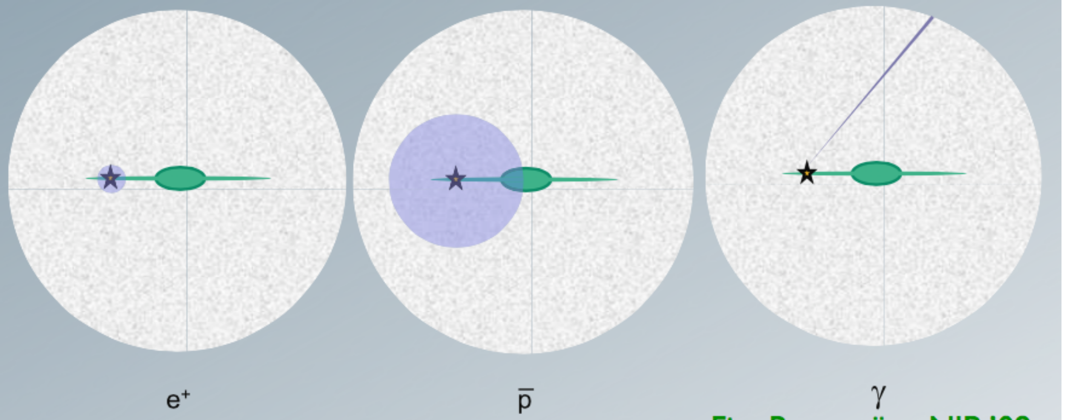
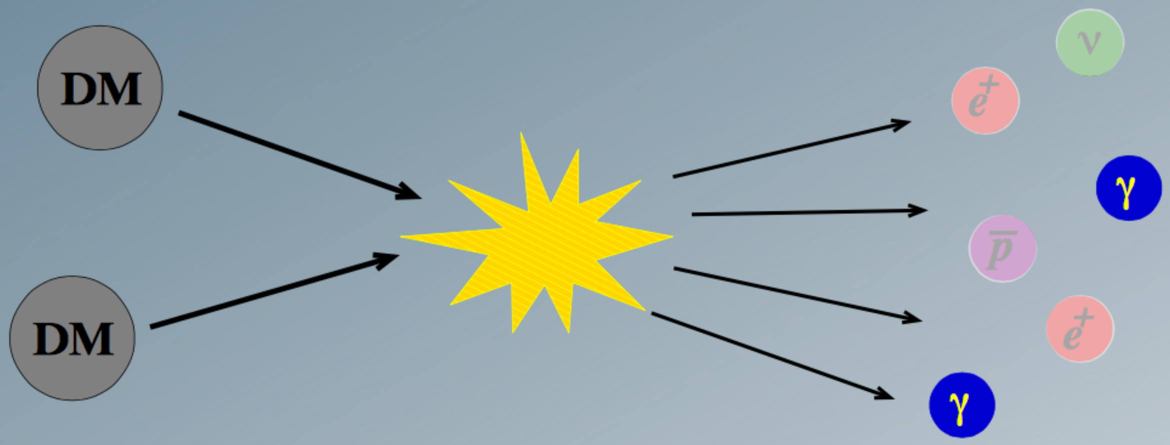


Fig.: Bergström, NJP '09

- "Boost factor"
  - each decade in $M_{\rm subhalo}$ contributes very roughly the same
    e.g. Diemand, Kuhlen & Madau, ApJ '07

    ⇨ *important to include realistic value for* $M_{\rm cut}$ *!*
  - depends on uncertain form of microhalo profile ($c_{\rm V}$ ...) and dN/dM (large extrapolations necessary!)

Indirect DM searches



Gamma rays:

- Rather high rates
- No attenuation when propagating through halo
- No assumptions about diffuse halo necessary
- Point directly to the sources: clear spatial signatures
- Clear spectral signatures to look for

Gamma-ray flux

The expected gamma-ray flux [GeV^{-1}cm^{-2}s^{-1}sr^{-1}] from a source with DM density ρ is given by

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma, \Delta\psi) = \int_{\Delta\psi} \frac{d\Omega}{\Delta\psi} \int_{\mathrm{l.o.s}} d\ell(\psi)\rho^2(\mathbf{r}) \; \frac{\langle\sigma v\rangle_{\mathrm{ann}}}{8\pi m_\chi^2} \sum_f B_f \frac{dN_\gamma^f}{dE_\gamma}$$

astrophysics | particle physics

for point-like sources: $\simeq (D^2\Delta\psi)^{-1} \int d^3r\, \rho^2(\mathbf{r})$

$\Delta\psi$: angular res. of detector

D : distance to source

$\langle\sigma v\rangle_{\mathrm{ann}}$: total annihilation cross section

m_χ : WIMP mass $(50\,\mathrm{GeV} \lesssim m_\chi \lesssim 5\,\mathrm{TeV})$

B_f : branching ratio into channel f

N_γ^f : number of photons per ann.

⇓ angular information + rather uncertain normalization

⇓ high accuracy spectral information

Local DM density

- standard value:

$$\rho_\odot^{\rm DM} \sim 0.3 \rightarrow 0.4 \frac{\rm GeV}{\rm cm^3}$$

...

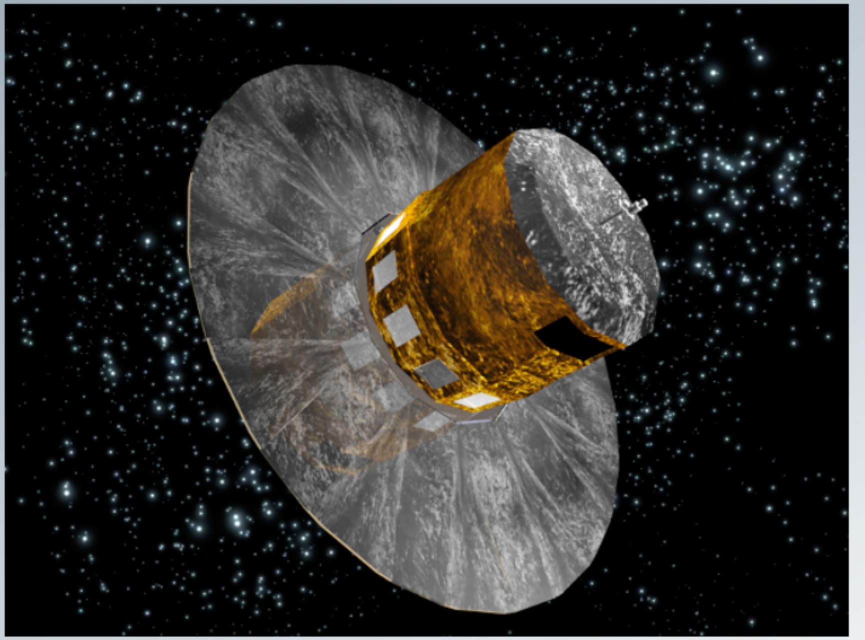
0.30 ± 0.05
Wydrow, Pim & Dubinski, ApJ '08

0.39 ± 0.03
Catena & Ullio, JCAP '10

0.43 ± 0.11 ± 0.10
Salucci et al, A&A '10

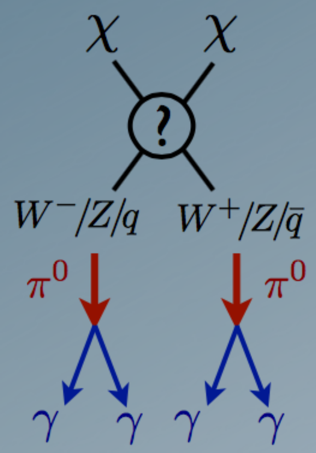
...

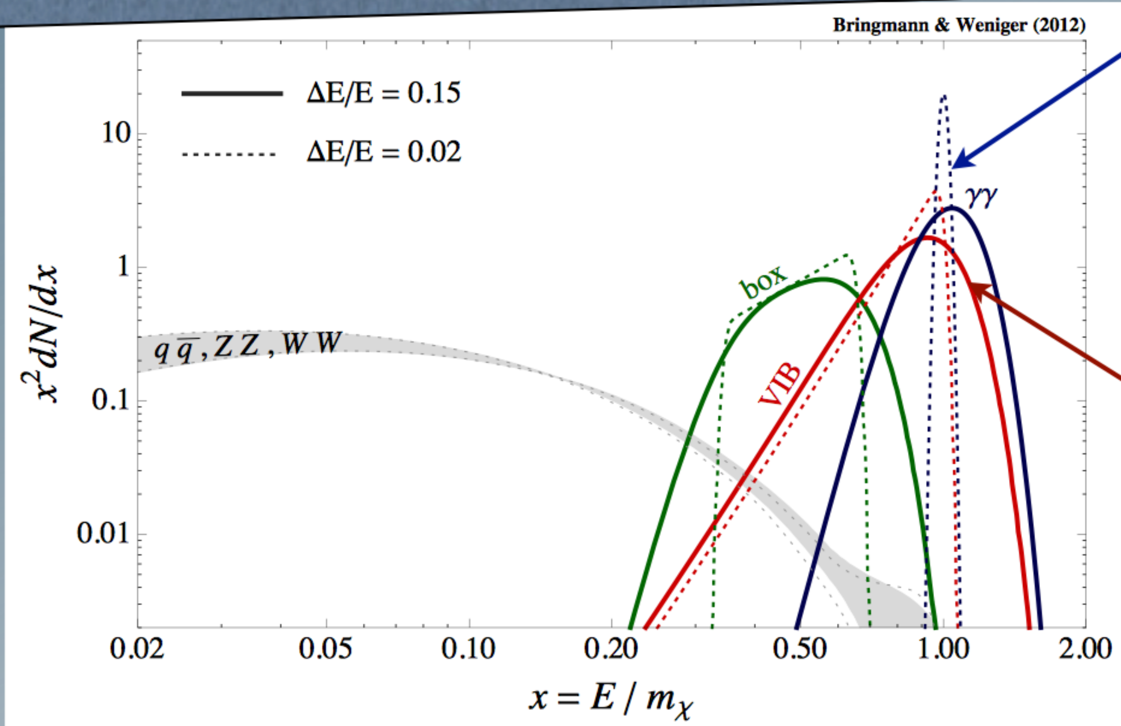
- Gaia (ESA mission, launch 11/13) will collect position and radial velocities of ~10^8 stars



➡ *will settle the issue…!*

Annihilation spectra





Monochromatic lines

$\chi\chi \to \gamma\gamma, \gamma Z, \gamma H$

$\mathcal{O}(\alpha_{em}^2)$

(Virtual) Internal Bremsstrahlung

$\chi\chi \to \bar{f} f \gamma, W^+ W^- \gamma$

$\mathcal{O}(\alpha_{em})$

Secondary photons

- *many* photons but
- featureless & model-independent
- difficult to distinguish from astro BG

➡ *good constraining potential*

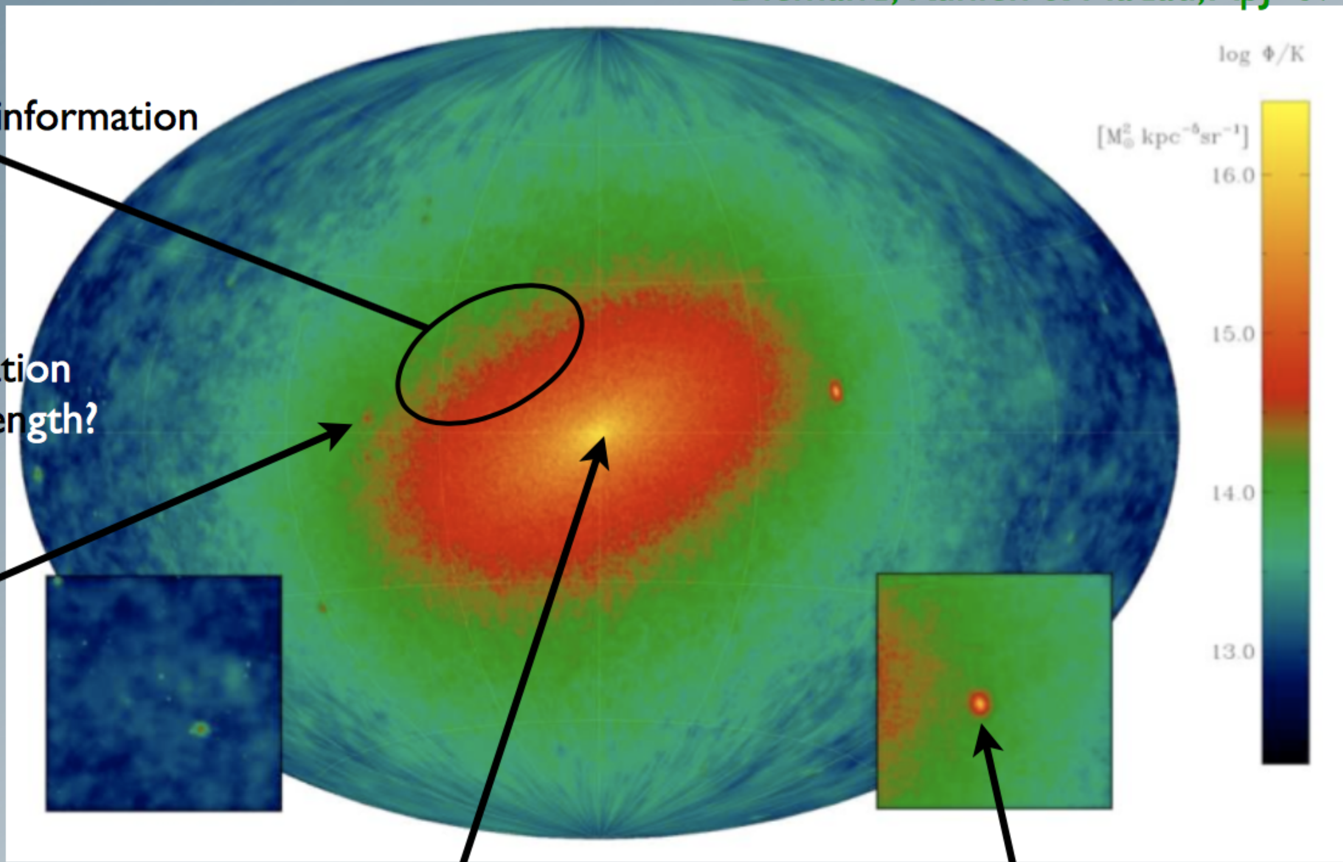
Primary photons

- direct annihilation to photons
- model-dependent 'smoking gun' spectral features near $E_\gamma = m_\chi$

➡ *discovery potential*

Possible targets

Diemand, Kuhlen & Madau, ApJ '07



Galactic halo
- good statistics, angular information
- galactic backgrounds?

Galaxy clusters
- cosmic ray contamination
- better in multi-wavelength?
- substructure boost?

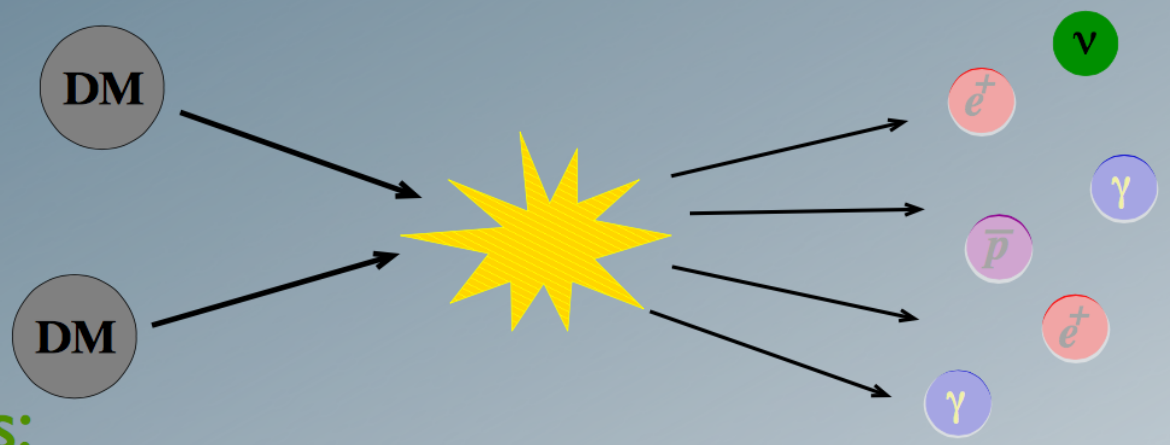
Dwarf Galaxies
- DM dominated, M/L~1000
- fluxes soon in reach!

Extragalactic background
- DM contribution from all z
- background difficult to model
- substructure evolution?

Galactic center
- brightest DM source in sky
- large background contributions

DM clumps
- easy discrimination (once found)
- bright enough?

Indirect DM searches



Neutrinos:

- Unperturbed propagation like for photons
- But signal significance (for the same target) usually considerably worse
- New feature: signals from the center of sun or earth!

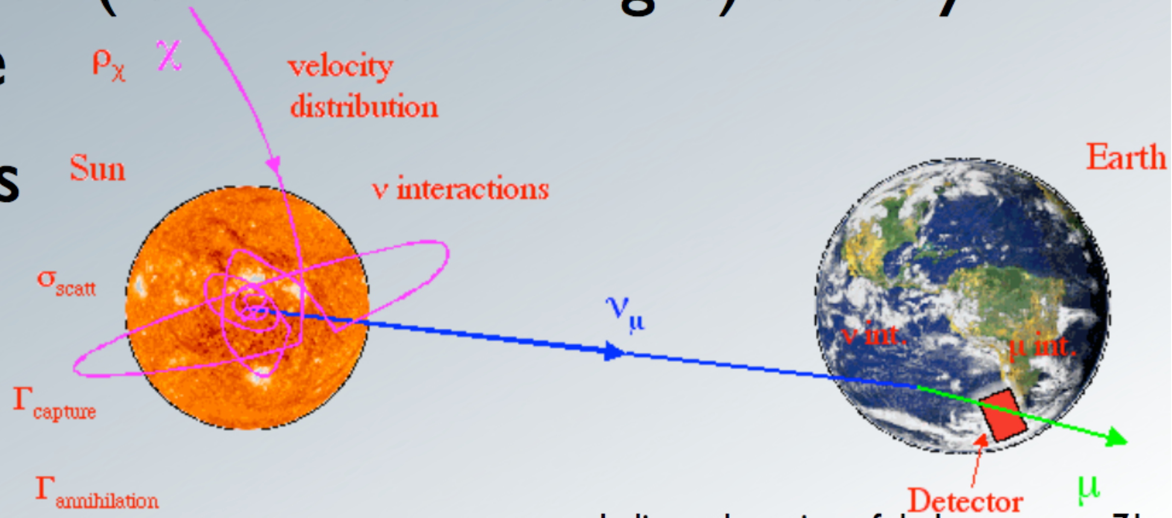
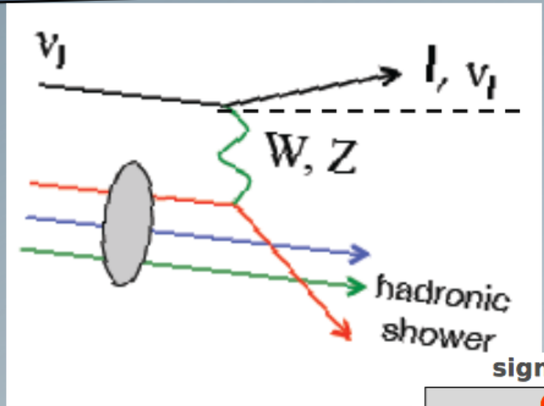


Fig. from J.Edsjö

Detection principle

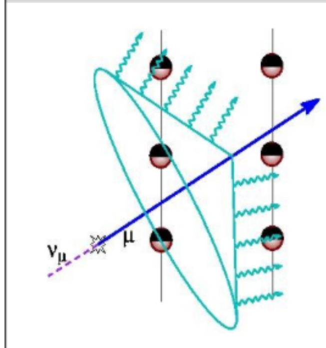


- Array of optical modules in transparent medium (ice/water) to detect Cherenkov light from relativistic secondaries
  (mostly sensitive to muons because they have the longest tracks)
- opening angle: $\Theta_{\mu\nu} \approx 0.7° \cdot (E_\nu / \mathrm{TeV})^{-0.7}$
  ⇨ possible to do neutrino astronomy!
- tiny *x*-sections & fluxes: *need HUGE volumes!*
- background muons:
  - down-going: atmospheric neutrinos
  - up-going: also induced by cosmic rays
    (hitting the atmosphere the far side of the earth)

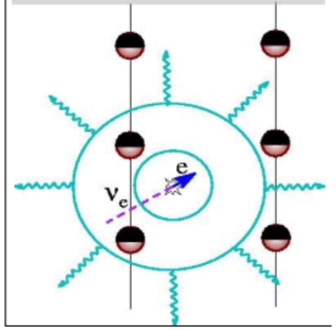
  ⇝ look for excesses in any given direction

signatures

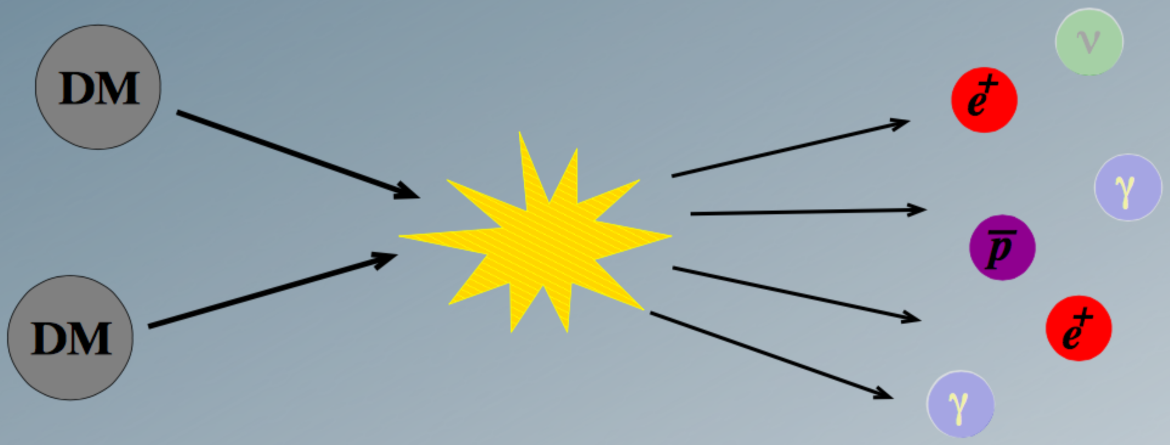
***O*(km) long muon tracks**



***O*(10m) cascades, ν_e ν_τ neutral current**



Charged cosmic rays



- GCRs are confined by galactic magnetic fields
- After propagation, no directional information is left
- Also the spectral information tends to get washed out
- Equal amounts of matter and antimatter
  ⇨ focus on antimatter (low backgrounds!)

Cosmic ray propagation

- Little known about Galactic magnetic field distribution
- Magnetic fields confine CRs in galaxy for $E \lesssim 10^3\,\mathrm{TeV}$
- Random distribution of field inhomogeneities
  $\rightsquigarrow$ propagation well described by diffusion equation

$$\frac{\partial\psi}{\partial t} - \nabla\cdot(D\nabla - v_c)\psi + \frac{\partial}{\partial p} b_{\mathrm{loss}}\psi - \frac{\partial}{\partial p} K \frac{\partial}{\partial p}\psi = q_{\mathrm{source}}$$

often set to 0 (stationary config.)

Diffusion coefficient, often $D \propto \beta(E/q)^\delta$

convection

energy losses

diffusive reacceleration $K \propto v_a^2 p^2 / D$

Sources (primary & secondary)

Analytical vs. numerical

How to solve the diffusion equation?

- Numerically
  - ⊕ 3D possible
  - ⊕ any magnetic field model
  - ⊕ realistic gas distribution, full energy losses
  - ⊖ computations time-consuming
  - ⊖ for most users a "black box"

e.g. GALPROP

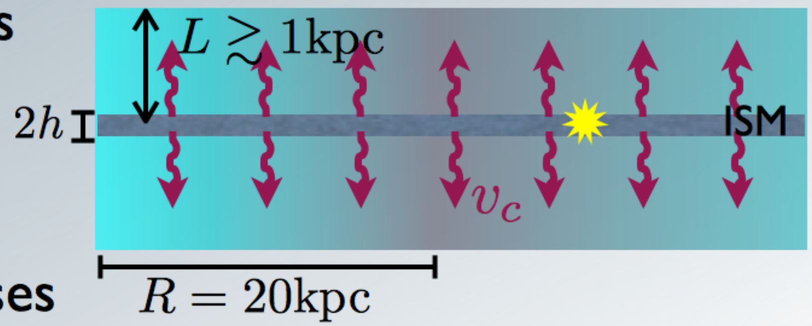
Strong, Moskalenko, …

DRAGON

Evoli, Gaggero, Grasso & Maccione

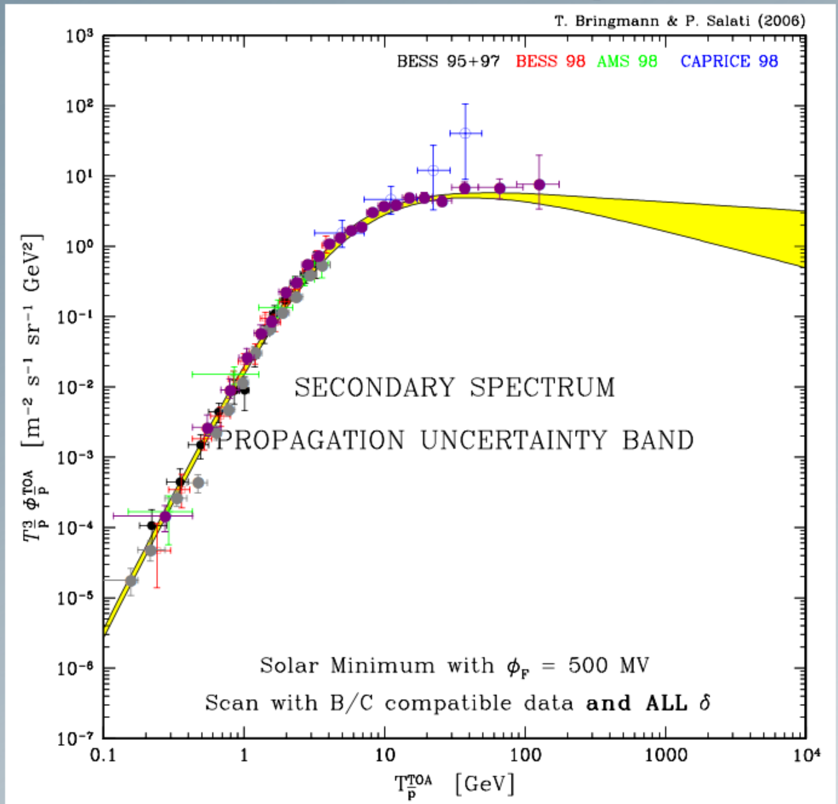
- (Semi-)analytically
  - ⊕ Physical insight from analytic solutions
  - ⊕ fast computations allow to sample full parameter space
  - ⊖ only 2D possible
  - ⊖ simplified gas distribution, energy losses

e.g. Donato, Fornengo, Maurin, Salati, Taillet, …



E.g. secondary antiprotons

- Propagation parameters $(K_0, \delta, L, v_a, v_c)$ of two-zone diffusion model strongly constrained by B/C
  Maurin, Donato, Taillet & Salati, ApJ '01
- This can be used to predict fluxes for other species:



TB & Salati, PRD '07

excellent agreement with new data:

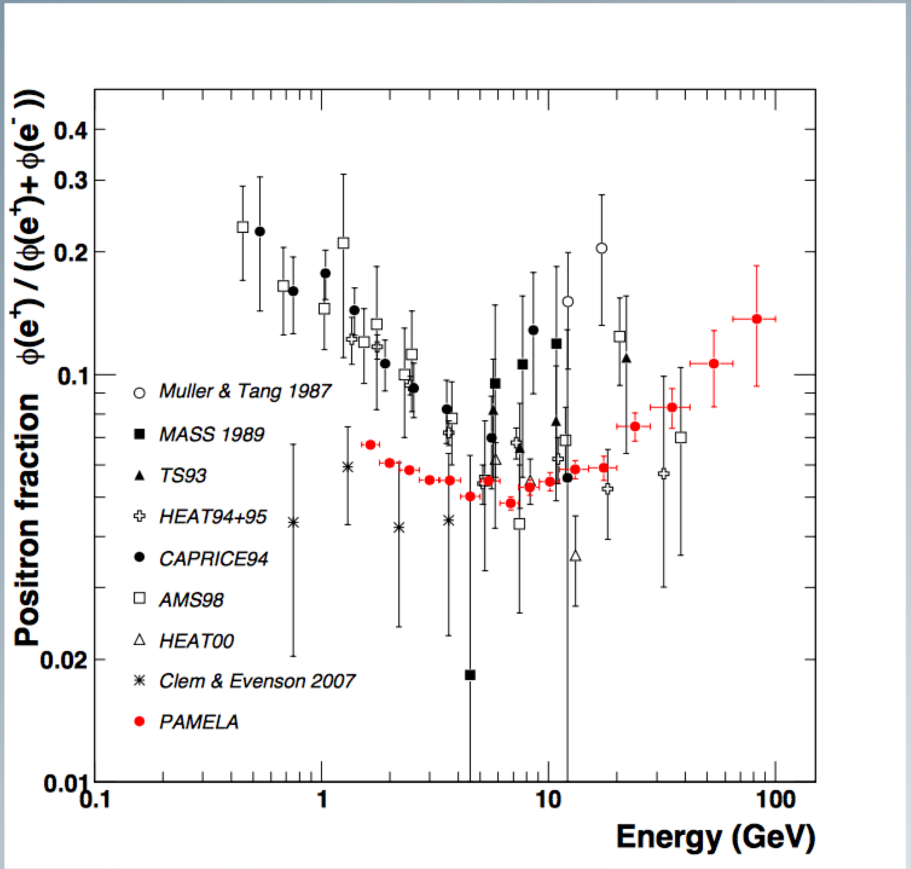
BESSpolar 2004
Abe *et al.*, PRL '08

PAMELA 2008
Adriani *et al.*, PRL '10

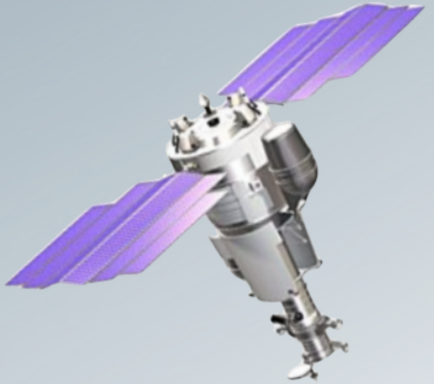
➡ very nice test for underlying diffusion model!

Positrons

Excess in cosmic ray positron data has triggered great excitement:



PAMELA

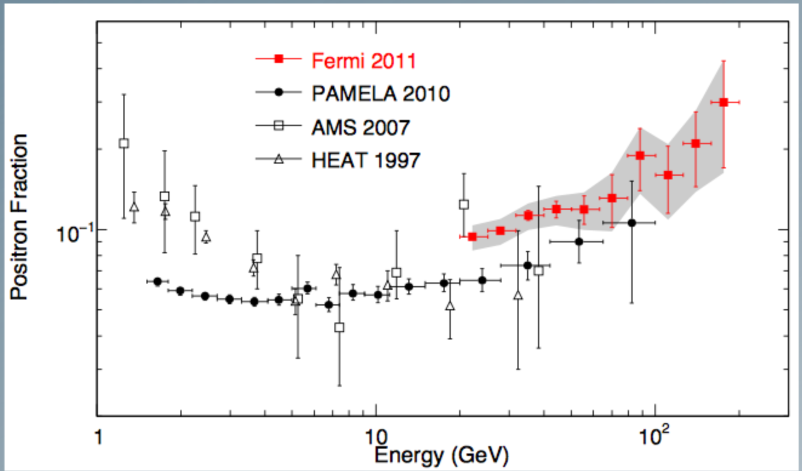


Adriani *et al.*, Nature '09

→ Are we seeing a DM signal ???

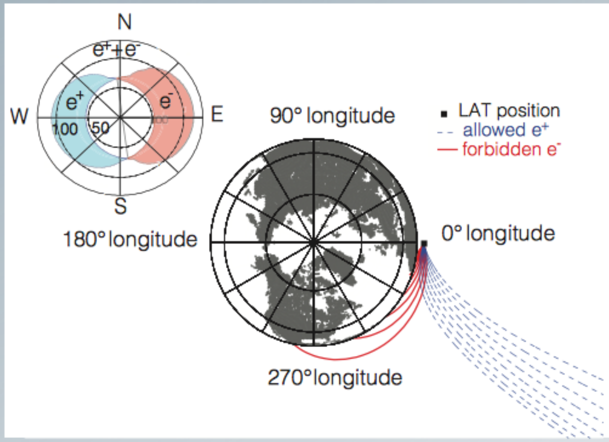
Independent confirmation

- By Fermi (!):

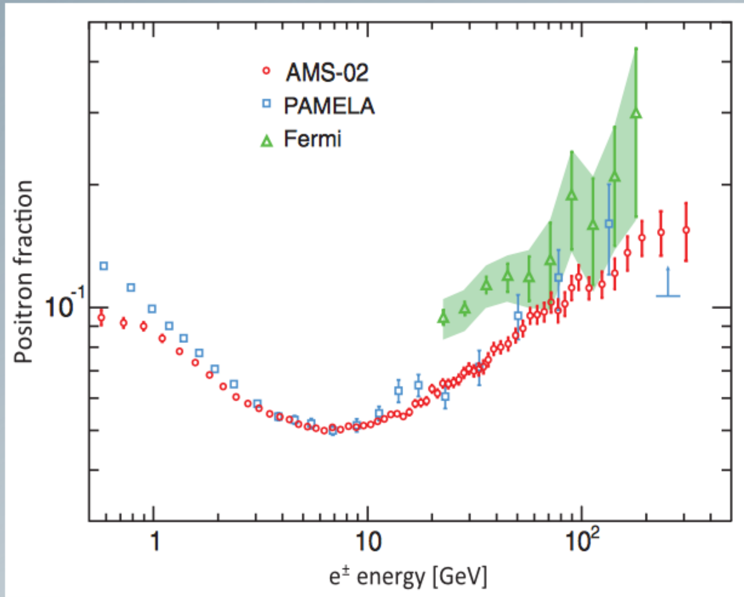


Ackermann et al., PRL '12

NB: Fermi does not have a magnet on board, but uses the earth magnetic field!



- By AMS:



Aguilar et al., PRL '13

S. Ting:

"Over the coming months, AMS will be able to tell us conclusively whether these positrons are a signal for dark matter, or whether they have some other origin"

Lepton propagation

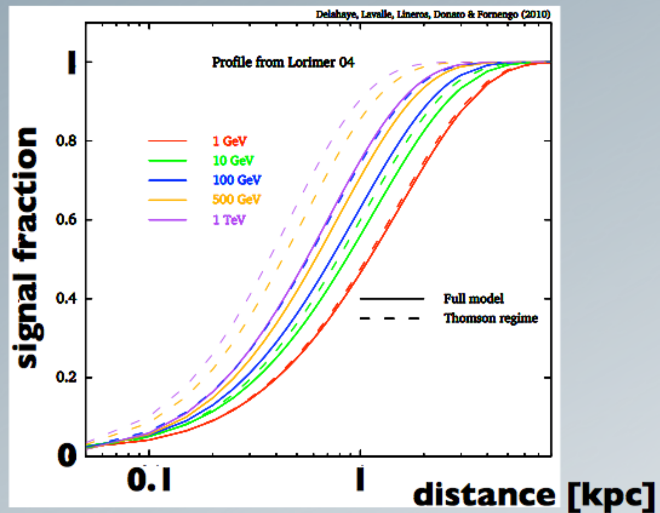
- $e^{\pm}$ can also be described in same framework as $\bar{p}$!

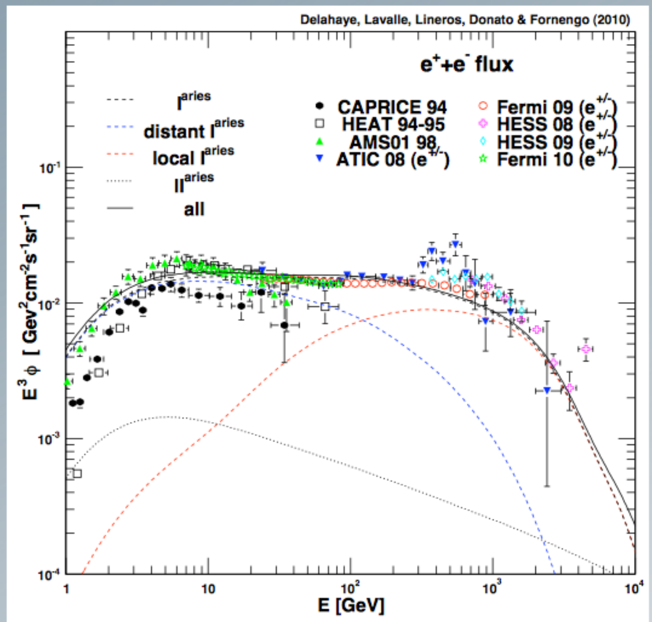
Delahaye *et al.*, PRD '08, A&A '09, A&A '10

- Main difference to nuclei:

energy losses are dominant
[synchrotron + inverse Compton]

➡ mainly locally produced
(~kpc for 100 GeV leptons)





- propagation uncertainties:
  - secondaries ~ 2-4
  - primaries ~5

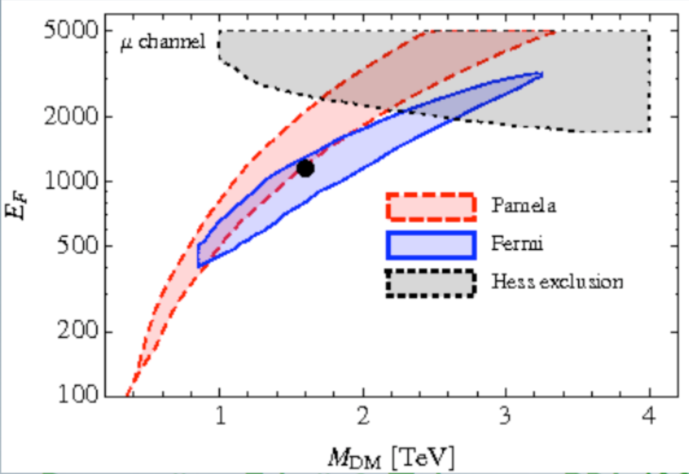
➡ need for local primary source(s) to describe data well above ~10 GeV

DM explanations

- Model-independent analysis:
  - strong constraints on hadronic modes from $\bar{p}$ data
  - $\chi\chi \rightarrow e^+e^-$ or $\mu^+\mu^-$ favoured
  - large boost factors *generic* – $\mathcal{O}(10^3)$

➩ highly non-conventional DM!

+ significant radio/IC constraints, see later!



Bergström, Edsjö & Zaharijas, PRL '09

- *and*: many good astrophysical candidates for primary sources in the cosmic neighbourhood:
  - pulsars Grasso *et al.*, ApP '09; Yüksel *et al.*, PRL '09; Profumo, 0812.4457
  - old SNRs Blasi, PRL '09; Blasi & Serpico, PRL '09
  - and further proposals...

take home message:

Positrons are certainly not the best messengers for DM searches!

DarkSUSY

Dark SUSY

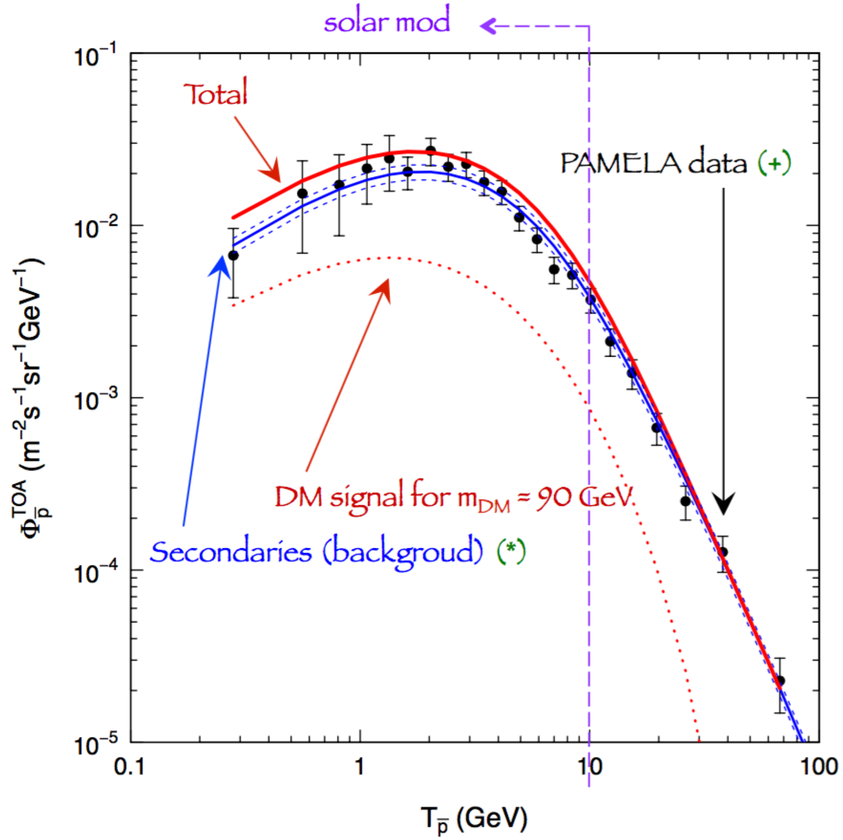
P. Gondolo, J. Edsjö, P. Ullio, L. Bergström, M. Schelke, E.A. Baltz, T. Bringmann and G. Duda

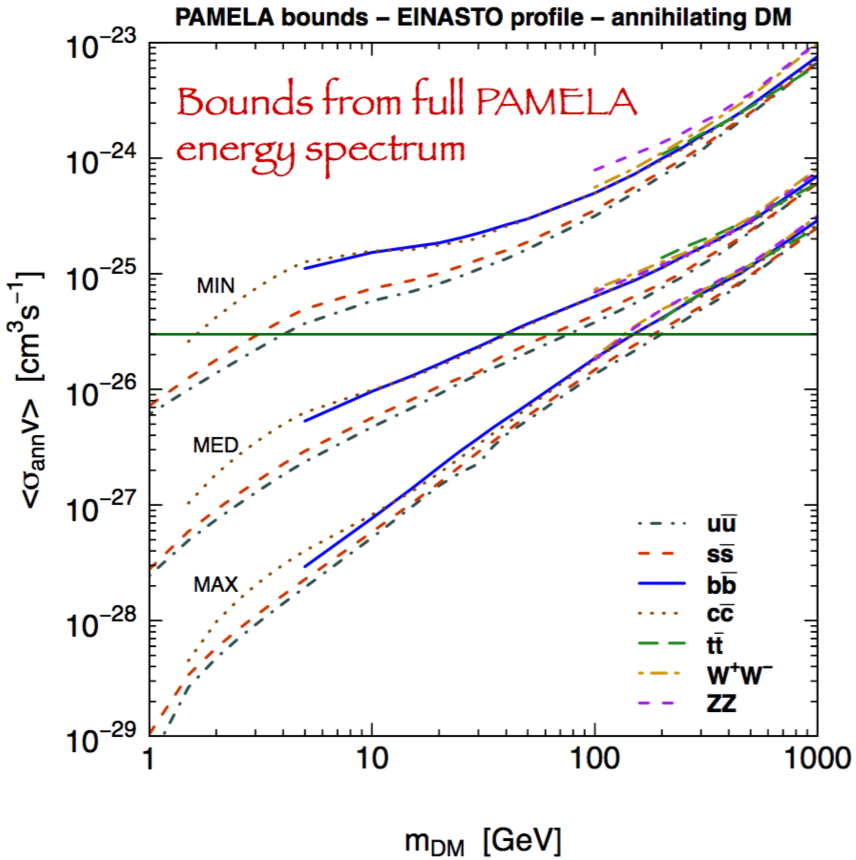
FREE DOWNLOAD ;)

http://darksusy.org

- Fortran package to calculate “all” DM related quantities:
  - *relic density + kinetic decoupling*
  - *generic SUSY models + laboratory constraints implemented*
  - *cosmic ray propagation*
  - *indirect detection rates: gammas, positrons, antiprotons, neutrinos*
  - direct detection rates
  - ...

Antiprotons





PAMELA

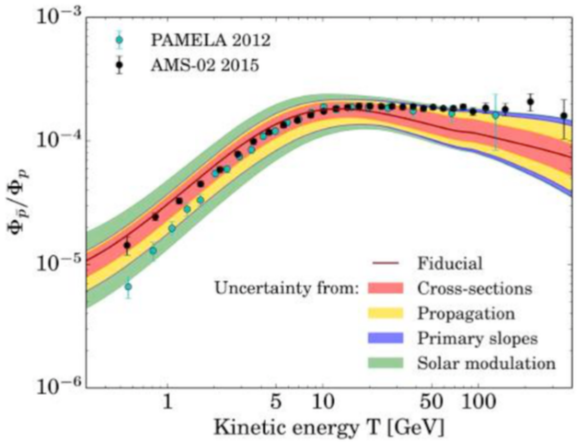
No evidence for deviation from astrophysical secondaries

Set stringent bounds on DM properties

Uncertainties from nuclear physics and galaxy transport

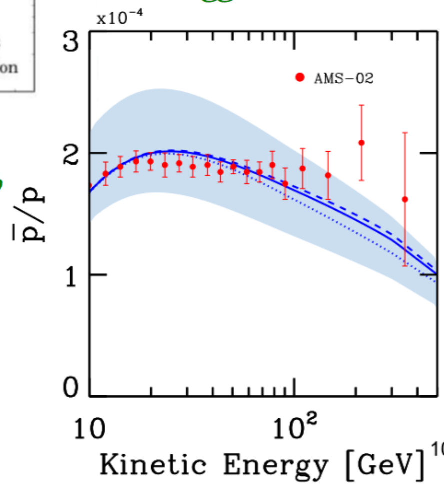
AMS-02 pbar/p

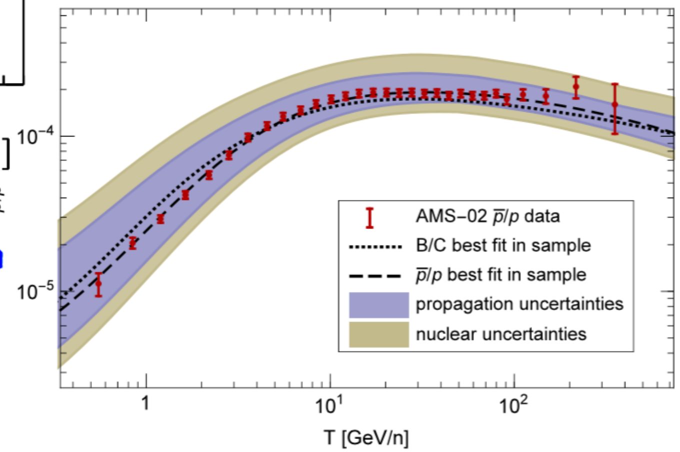
Kounine, 'AMS days at CERN, April 2015



Giesen et al., JCAP 1509 (2015) 023

Evoli, Gaggero, Grasso, arXiv:1504.05175



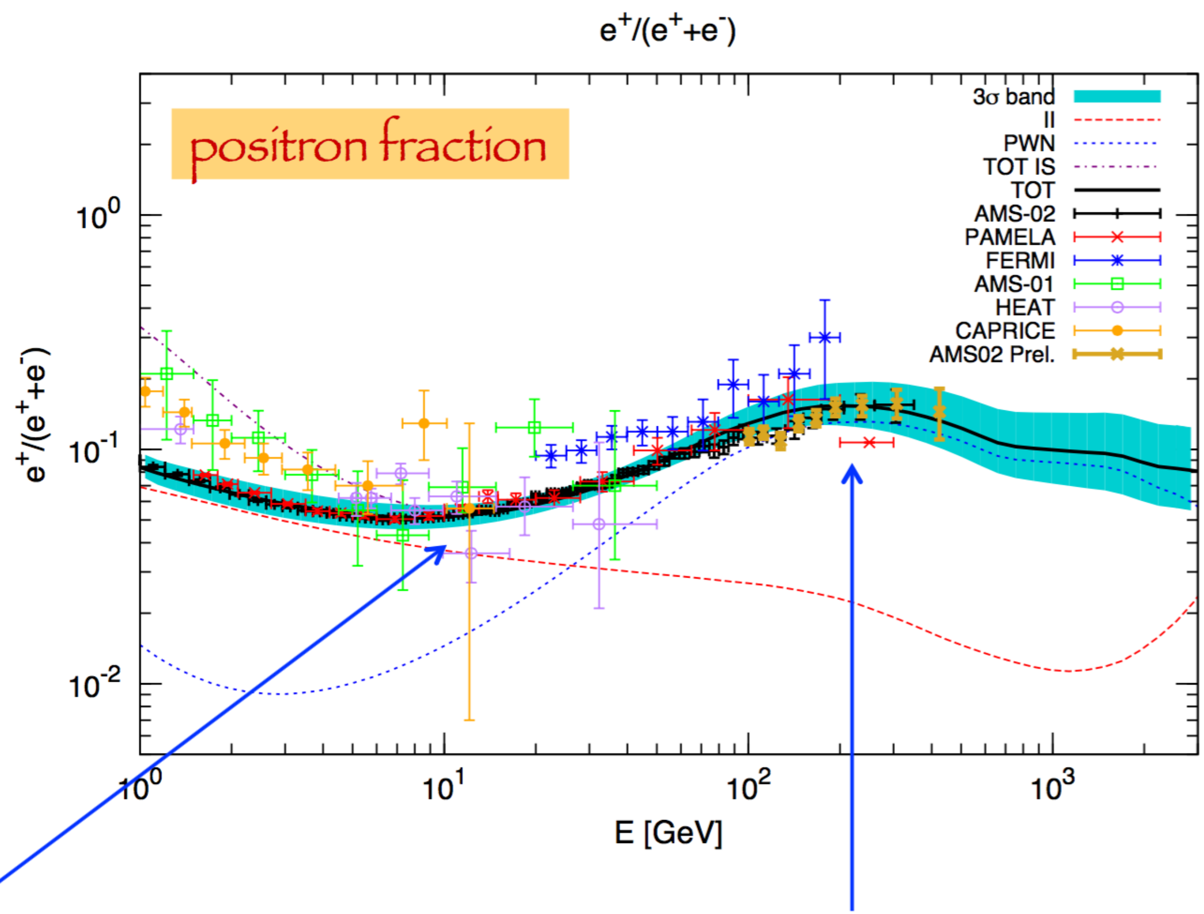


Kappl, Reinert, Winkler, JCAP 1510 (2015) 034

In addition AMS is bringing very detailed Information on cosmic rays nuclei (e.g. B/C) which will allow shaping the CR transport models (DRAGON, Galprop, Usine, non public codes)

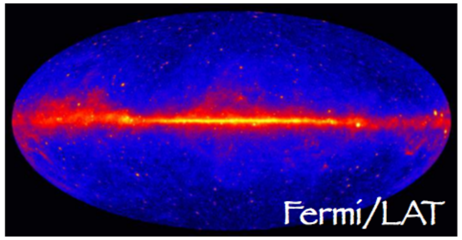
This is relevant for both DM signals and its backgrounds

Positrons

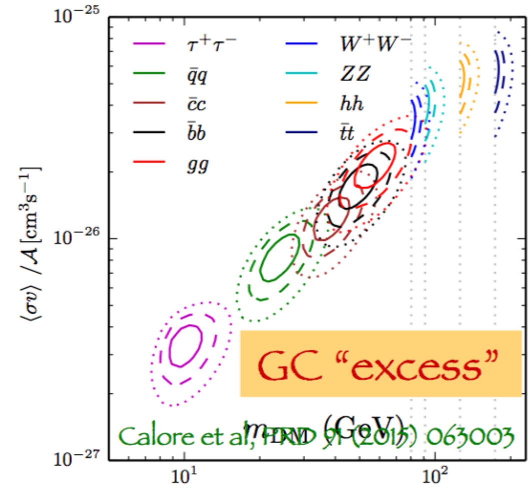


Low energies: reproduced by secondary production

High-energy: (local) sources needed



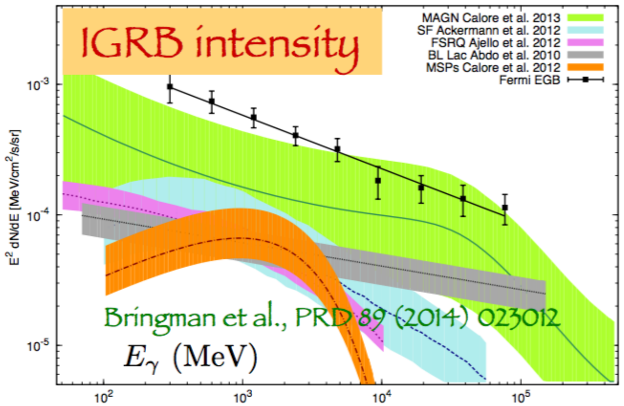
Gamma rays



Galactic center

Very interesting target, but difficult

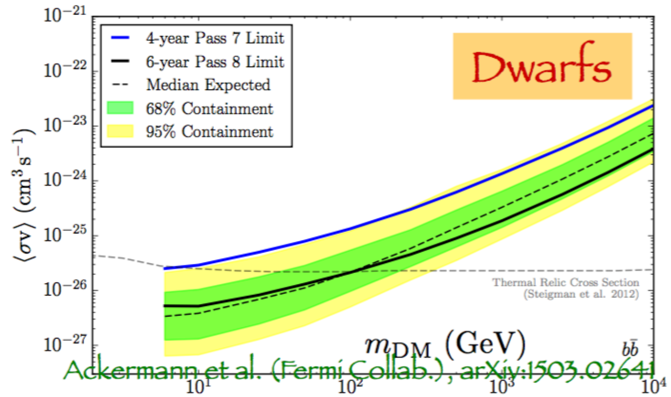
Potential hints, under hot discussion



Isotropic gamma ray background

Relevant for extragalactic DM

Complex to seperate a DM signal from astrophysical sources



Dwarf galaxies

One of the best targets (DM dominated)

Recently, new dwarfs have been discovered (DES): great potentiality

Gamma rays

- Higher energies (ground) : >300 GeV

  Probe TeV+ DM

  Targets

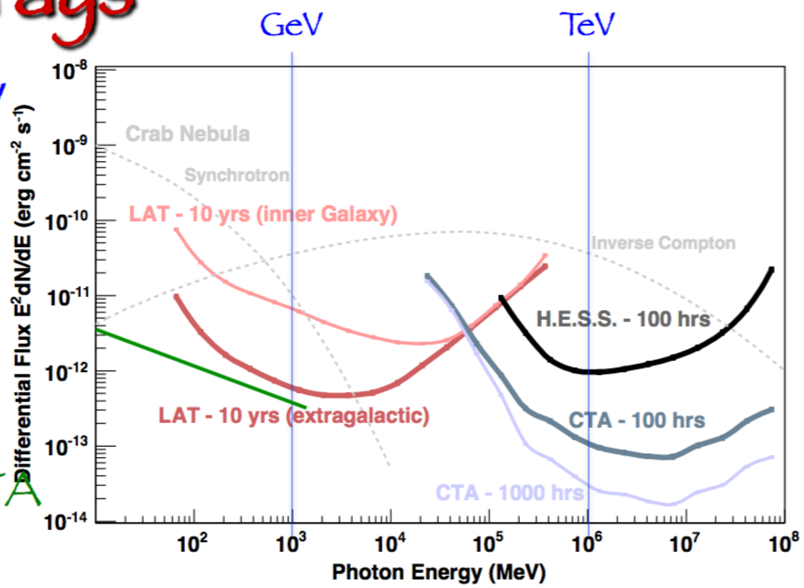
  Galactic center

  DM clumps

  dSphs galaxies

  Galaxy clusters

  Magic, HESS, Hawc, LHAASO, CTA



- GeV – TeV energies (space) or even higher

  Probe GeV-TEV DM

  Improved energy and angular resolution

  DAMPE (2 GeV – 10 TeV), GAMMA400, HERD (up to PeV), ...

- Lower energies (space) : MeV – GeV

  Probe subGeV DM or the low-energy tail of WIMP DM

  AstroGam, PANGU, ...