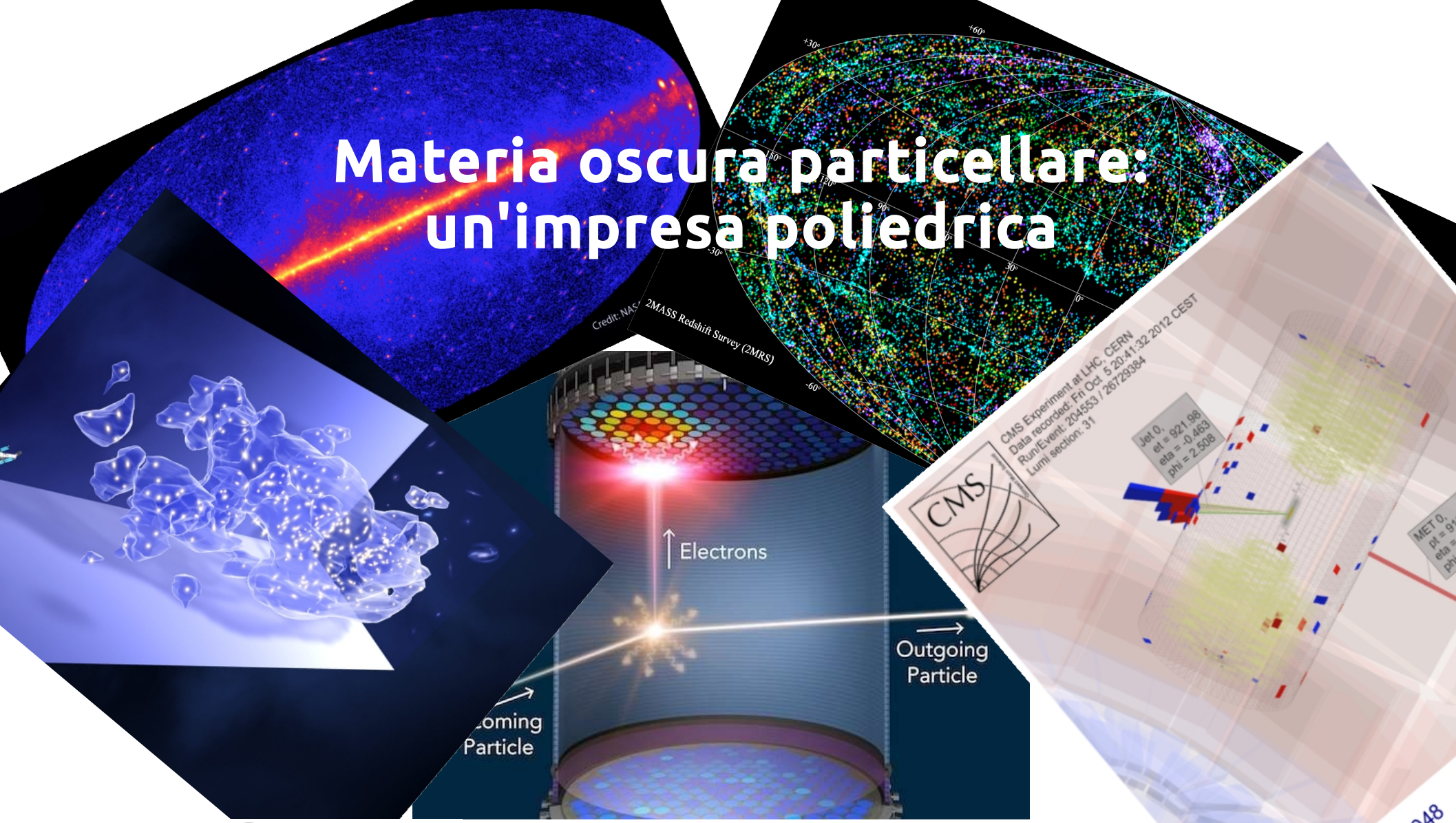
Materia oscura particellare: un'impresa poliedrica



Marco Regis
(Torino)

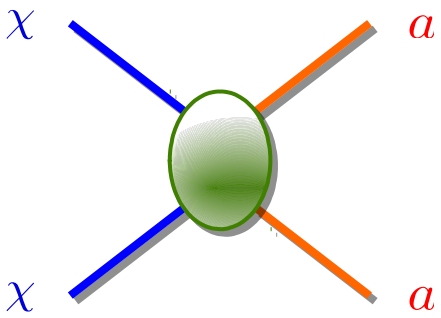
UNIVERSITÀ DEGLI STUDI DI TORINO

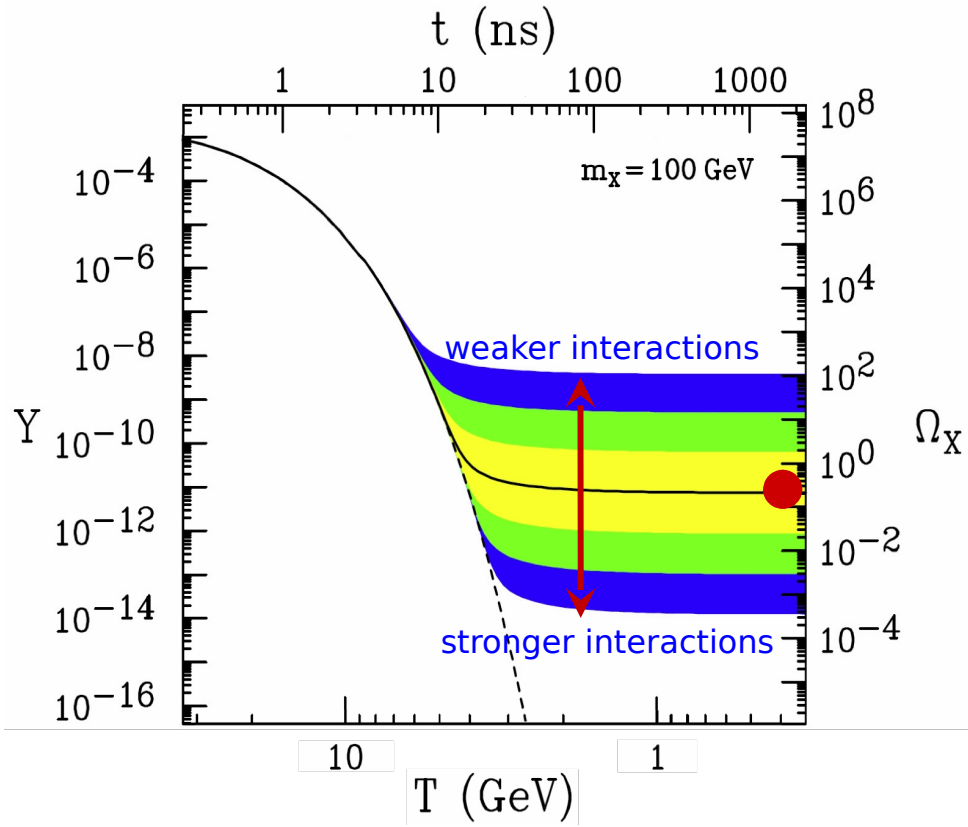
INFN
Istituto Nazionale di Fisica Nucleare

WIMP miracle

Assume DM is a particle in thermal equilibrium in the primordial bath:

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{ann} v \rangle (n^2 - n_{eq}^2)$$





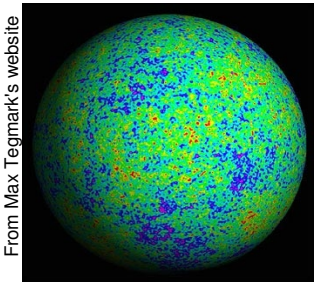
$\Omega_{DM} h^2 \sim 0.1/\langle \sigma_{ann} v \rangle_{|pb} \sim 0.1\ (m_{DM}/\lambda_{EW})^2\ (g_{EW}/g_{DM})^2$

The observed relic density requires weak interactions!

Physics beyond the standard model addresses electro-weak symmetry breaking

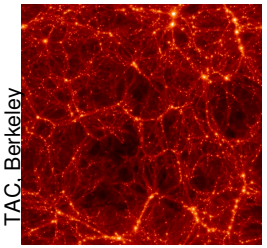
→ new particles are expected at ~ EW scale

Hints on DM nature



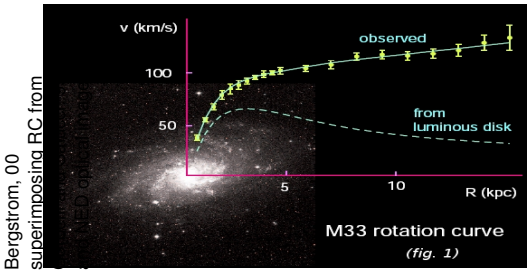
Cosmology

{ Non-baryonic ($\Omega_M \sim 6\,\Omega_b$)
Stable
(Thermally produced)



Structure formation → Cold (bottom-up hierarchy)

Cluster dynamics → "Weak" self-interactions
($\sigma_{DM}/m_{DM} < 1\ cm^2/g$)

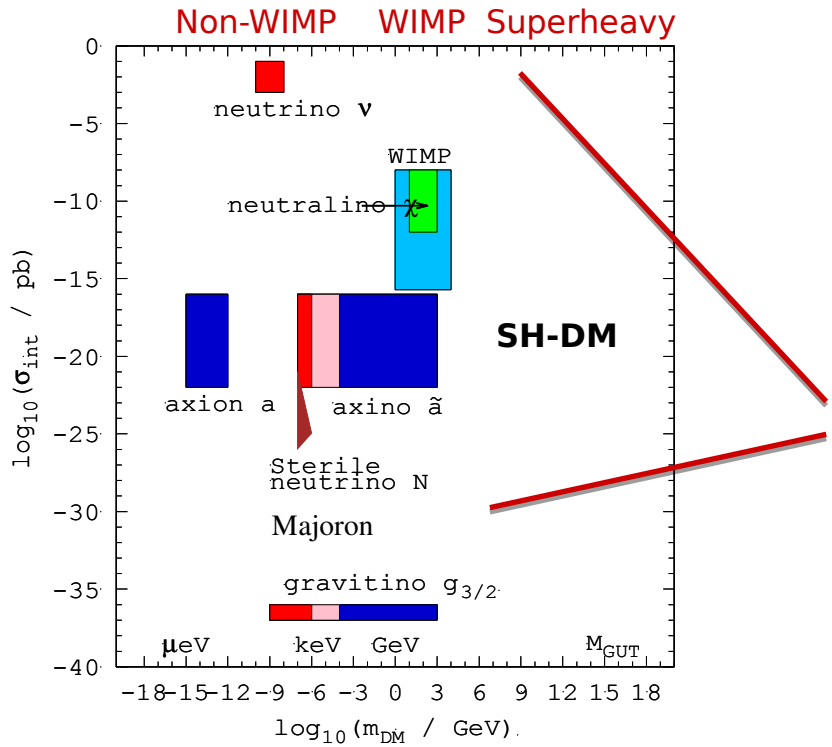


Galactic dynamics → Dissipationless
(suppressed e.m. or strong interactions)

Alternatives to WIMPs

WIMPs as mainstream DM: theoretical prejudice

- Modified gravity
- Non-Particle/Baryonic DM (e.g. primordial black holes)
- **Particle DM**



"Strong (-ish)": Self-interacting, Technicolor DM, ...

"EM (-ish)": Millicharged DM, Dipolo elettrico/magnetico, ...

Weak: WIMP, Sterile neutrino, ALPs, ...

Gravitational

WIMP interactions

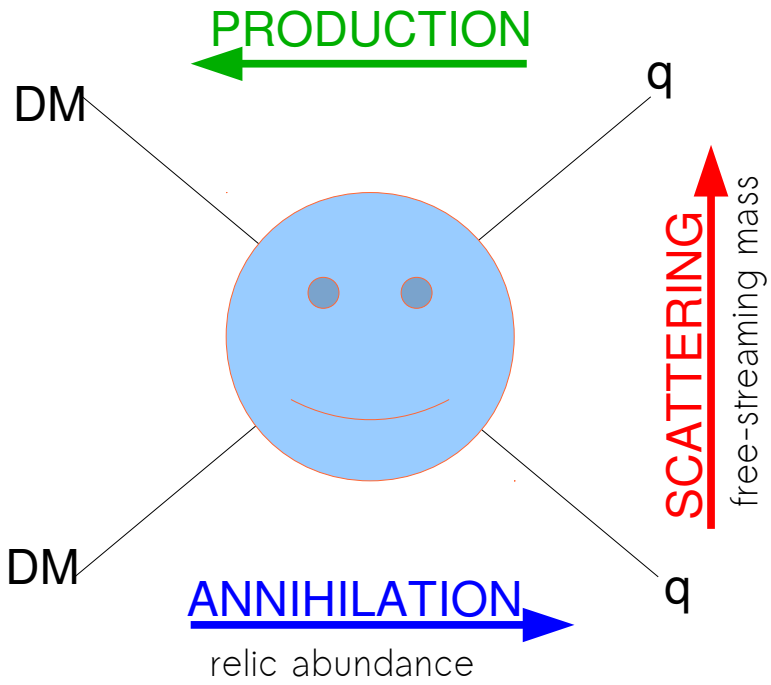
WIMPs have (weak BUT non-negligible) interactions with ordinary matter

WIMP detection strategies:

Production at colliders

Direct detection

Indirect detection

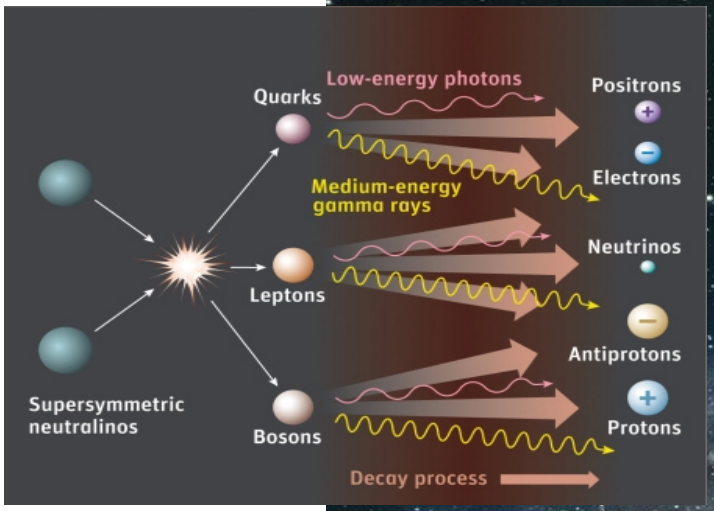


Indirect searches

Annihilations (or decays) of DM particles

in astrophysical objects

generate fluxes of "standard" detectable particles.



Energy of the process set by the **DM mass ~ GeV-TeV**

Indirect searches

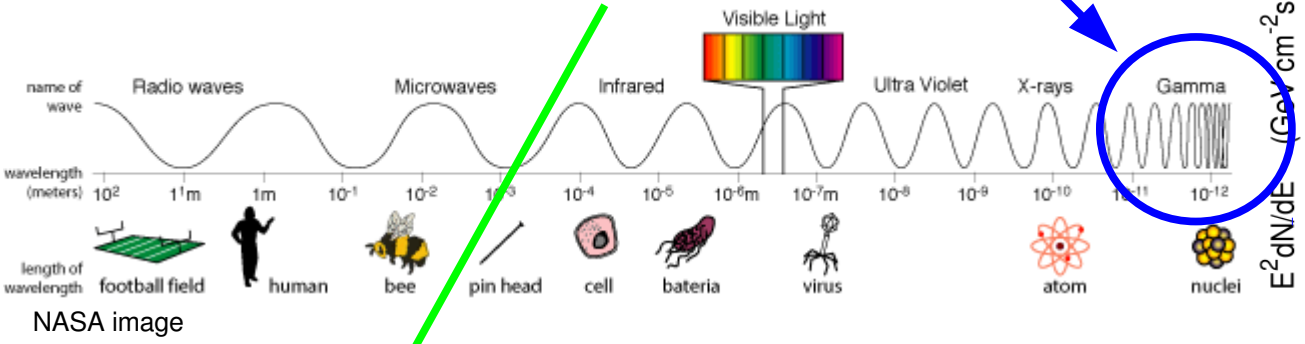
WIMPs are a primary source of

high-energy charged cosmic-rays,

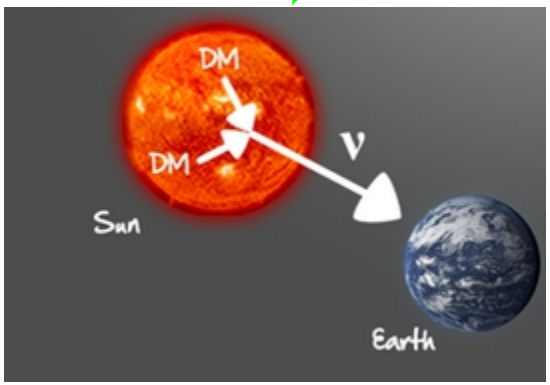
gamma-rays

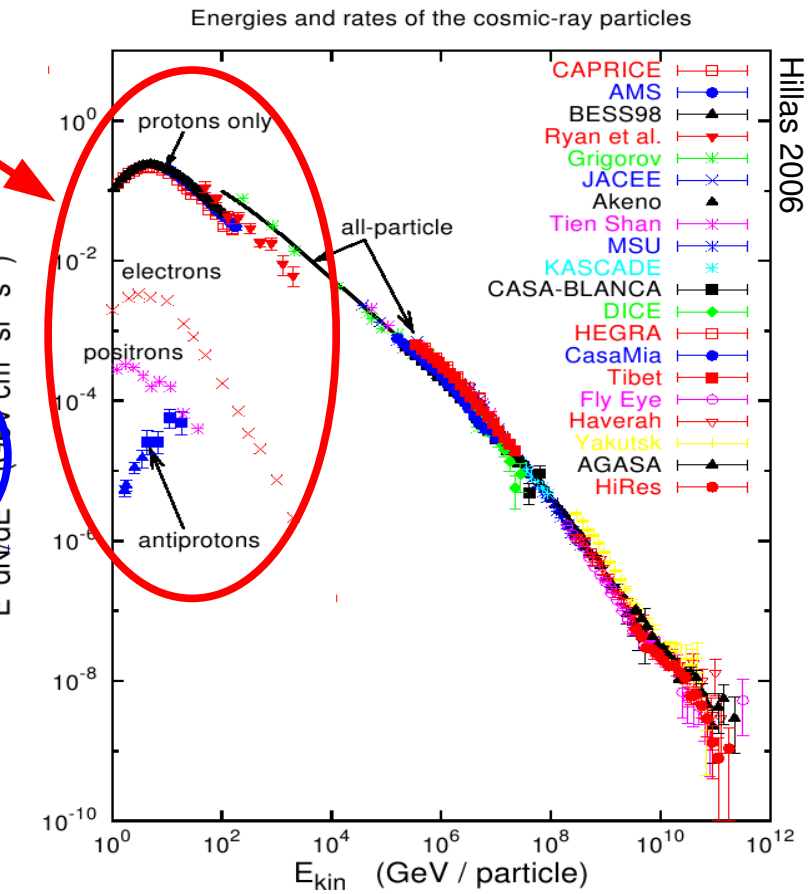
and

neutrinos



NASA image



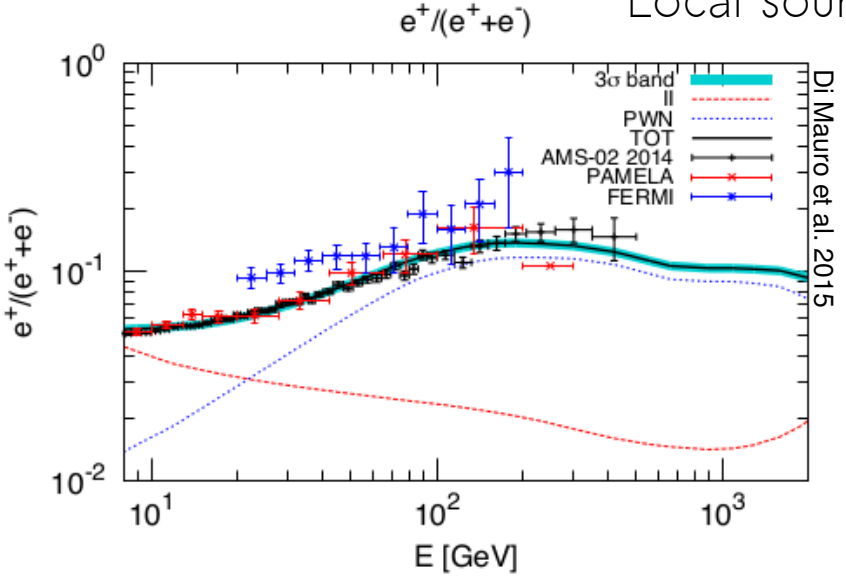


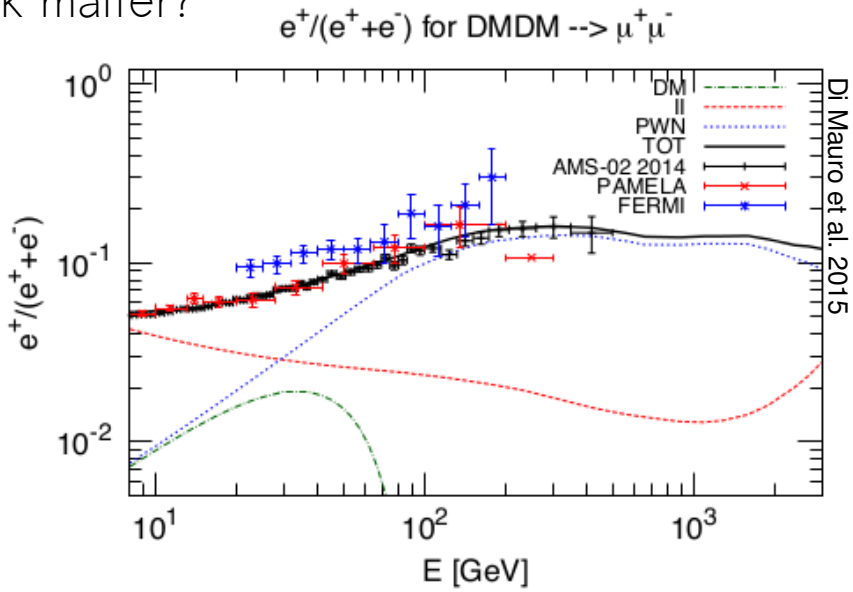
Plus radiative emission in the radio, X and gamma bands from WIMP induced e^+-e^-

Charged cosmic rays

POSITRON FRACTION above 10 GeV

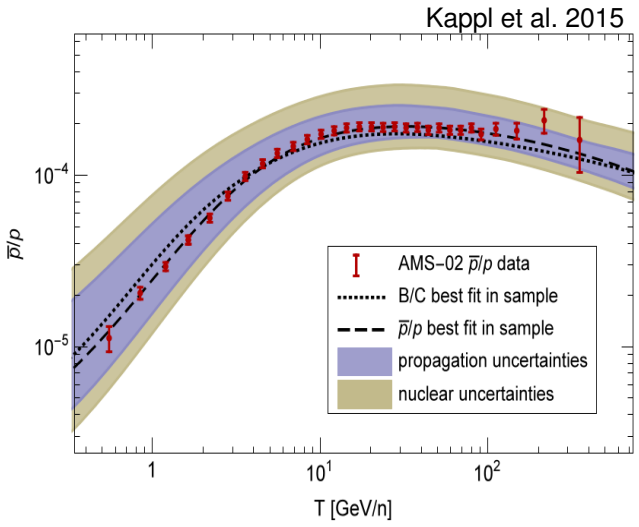
Local source: pulsars or dark matter?





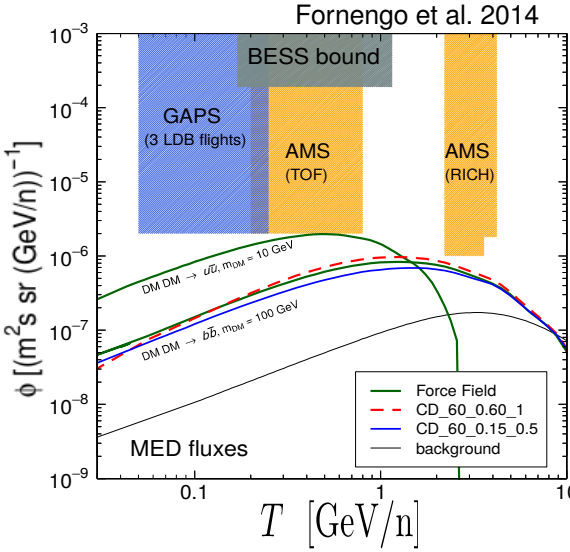
ANTIPROTON FRACTION

above 100 GeV: compatible with secondaries



ANTIDEUTERON

discovery channel for the future

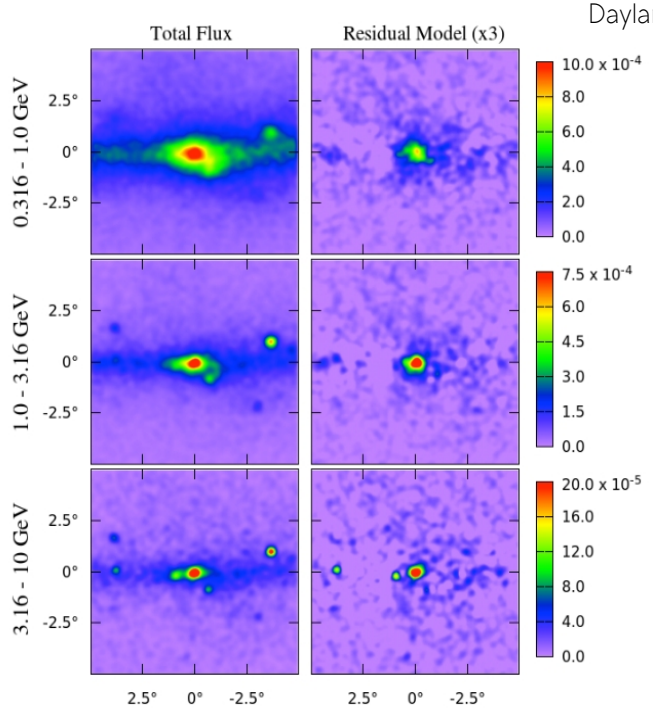


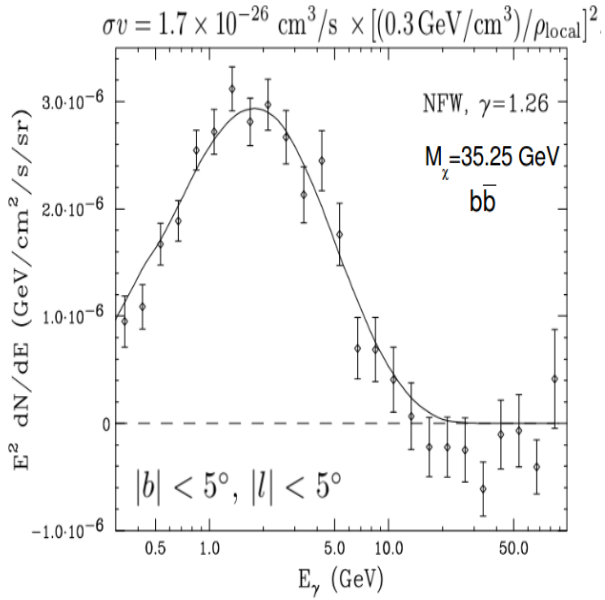
Gamma ray emission

Galactic Center "excess"

- possibly high DM density
- very rich and complex region

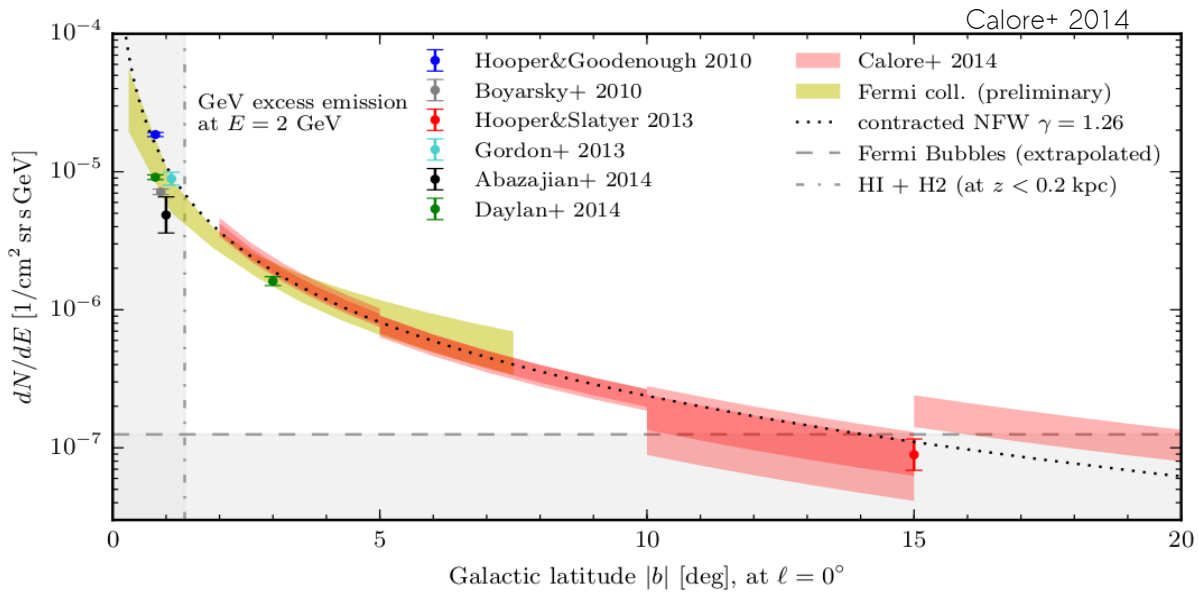
Daylan+ 2014





Difficult to make strong statements

Calore+ 2014

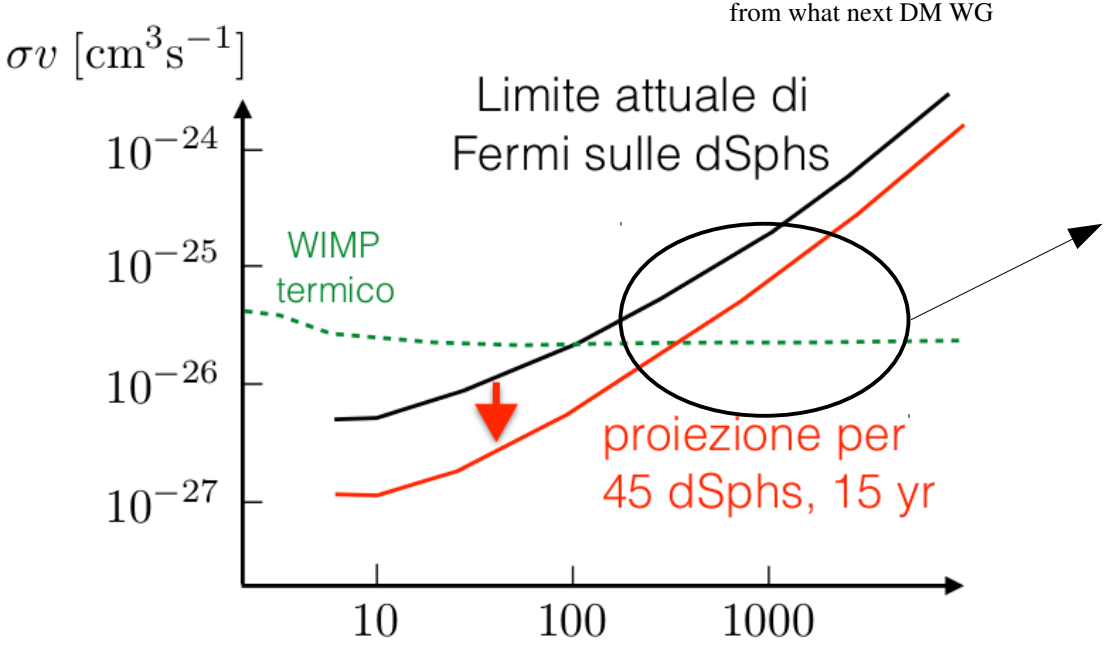


Gamma ray emission

Dwarf spheroidal galaxies

Cleaner target

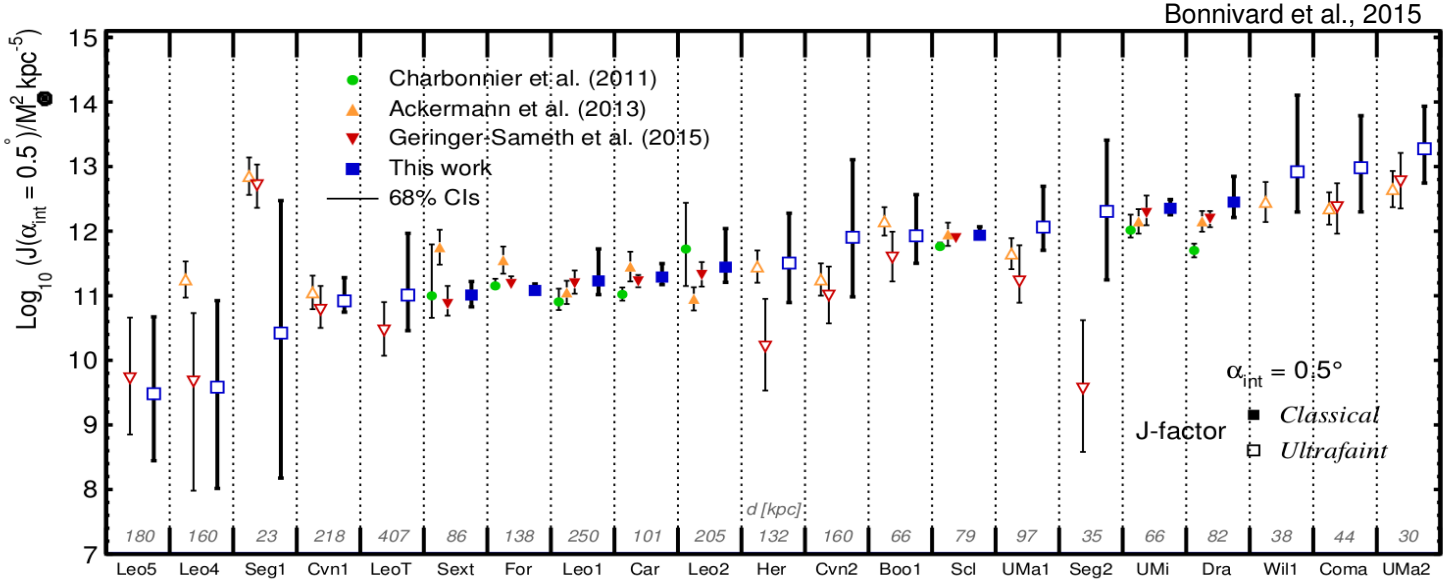
from what next DM WG



Synergy with Cherenkov Telescopes

even though...

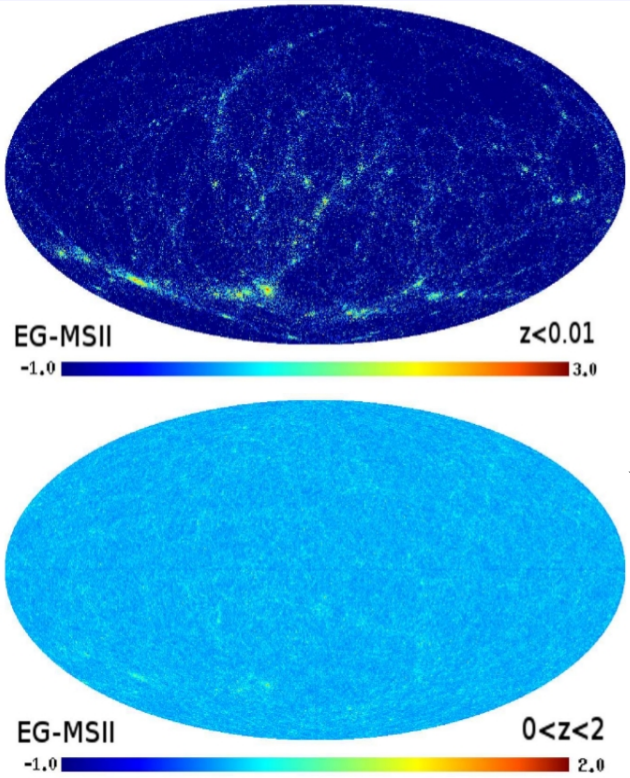
Bonnivard et al., 2015



Some "new" directions

WIMP angular correlations

Even if DM halos are too faint to be individually detected in gamma-rays, they form the most numerous population in the Universe.
The **DM "cumulative" signal** or its **spatial coherence** might be observable.



from Fornasa et al., 2013

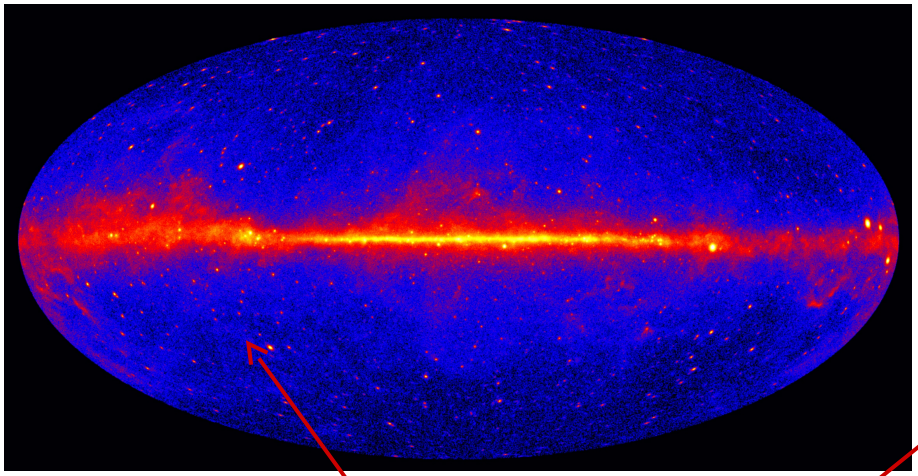
→ Dig into the unresolved extragalactic sky

- Stacking
- Statistical correlations of fluctuations

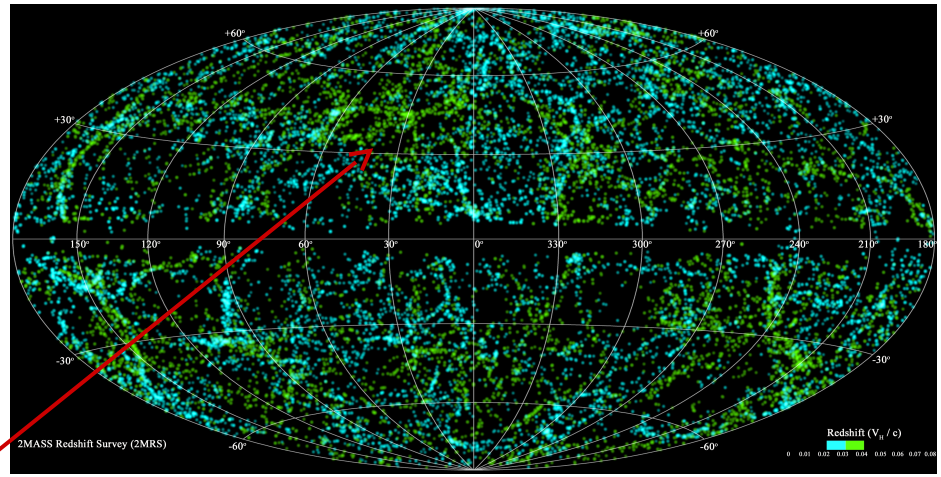
WIMP angular correlations

The idea is to have an **accurate tracer of the DM distribution** (gravitational potential) in the Universe, to be used as a filter in order to separate the DM non-gravitational signal from other astrophysical non-thermal emissions.

Fermi-LAT map

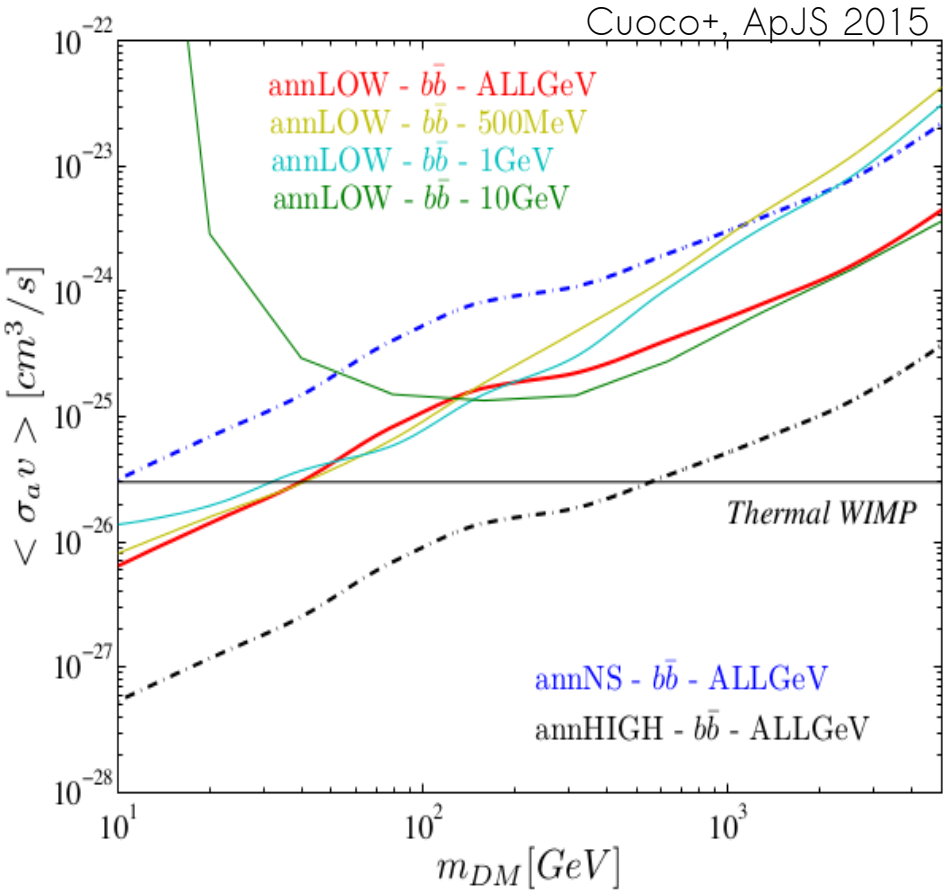


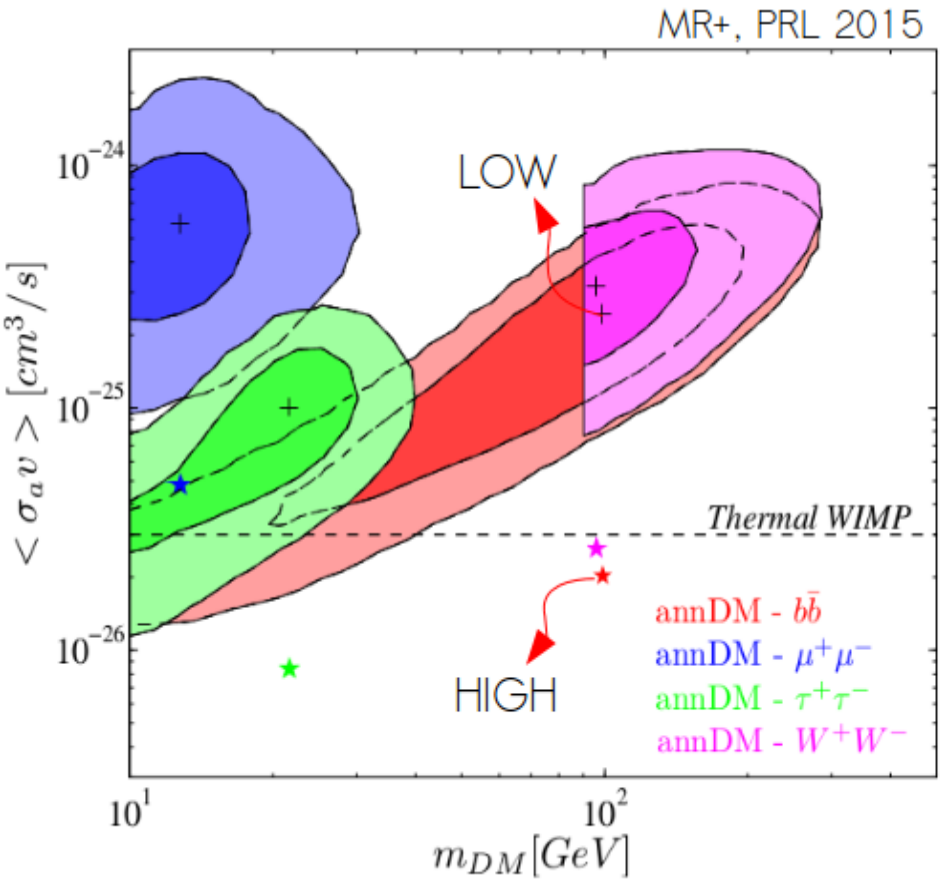
Gravitational tracer (lensing or galaxy catalog)



$$\langle I_i(\vec{n}_1) I_j(\vec{n}_2) \rangle \longrightarrow C^{ij}(\theta) \longrightarrow C_l^{ij}$$

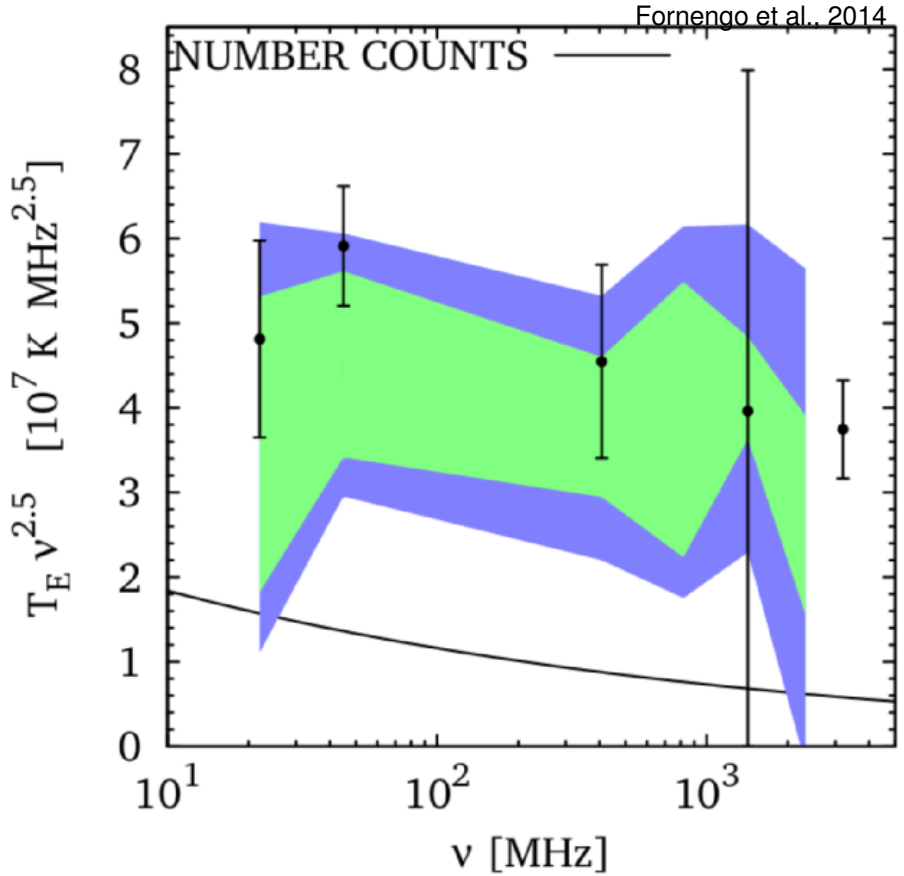
Cross correlations

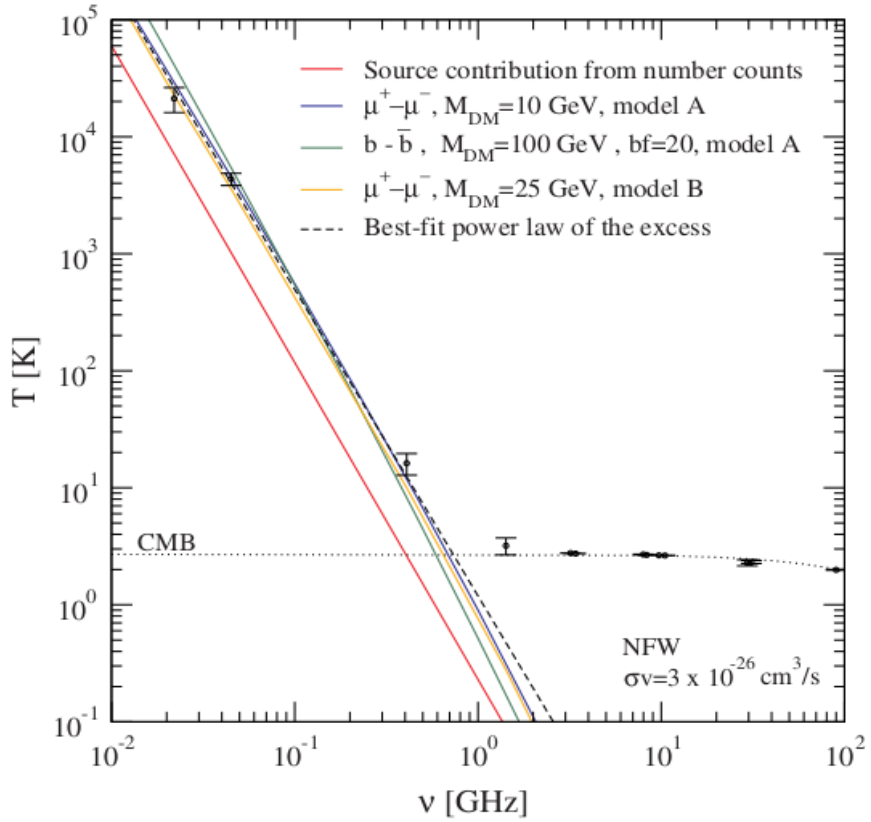




Radio waves from WIMPs?

The extragalactic radio background appears to be significantly **brighter** than extrapolation from number counts of AGN and SFG (**ARCADE-2** Collaboration, 2009)





Simplest solution for ARCADE excess:

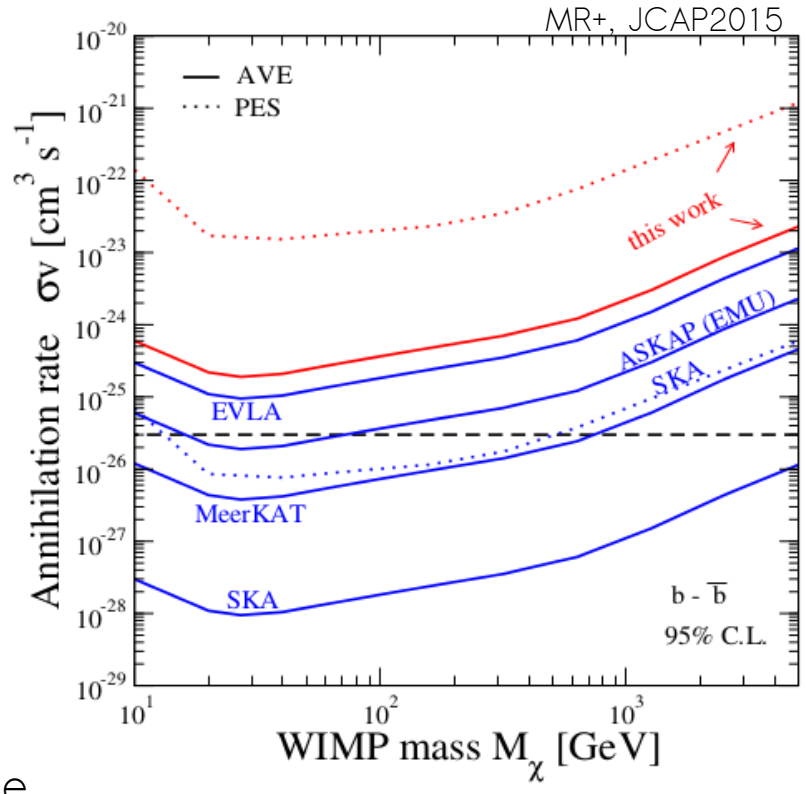
Radio background is produced by radio sources taking over in the counts at sub-mJy (Singal et al, 2010)

The excess can be explained in terms of synchrotron emission induced by WIMP annihilations

(Fornengo, Lineros, MR, Taoso, PRL 2011)

dSphs at radio waves

Synchrotron emission from electrons and positrons injected by WIMP annihilations if an ambient magnetic field is present.



Several observations with the ATCA telescope

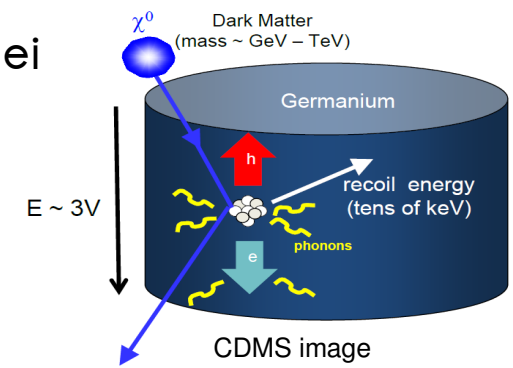
Direct and collider searches

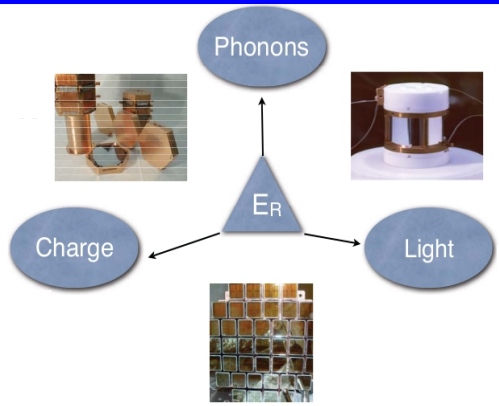
Direct detection

Scattering of WIMPs off target atomic nuclei

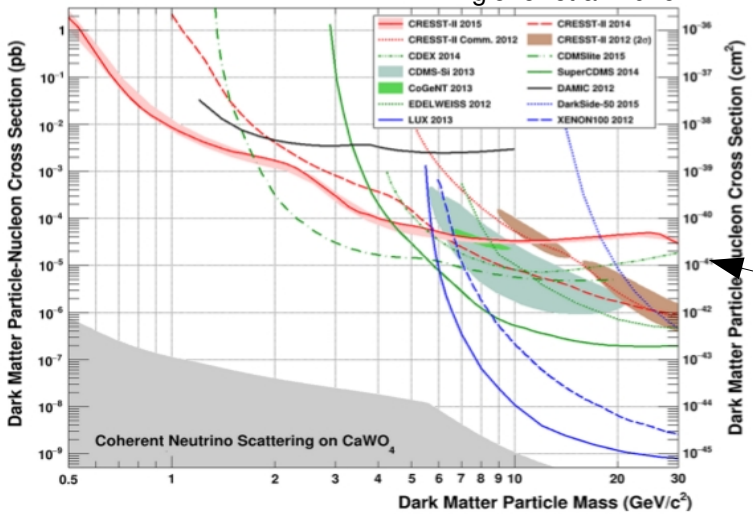
Recoil energy measured by

light, charge or phonons.

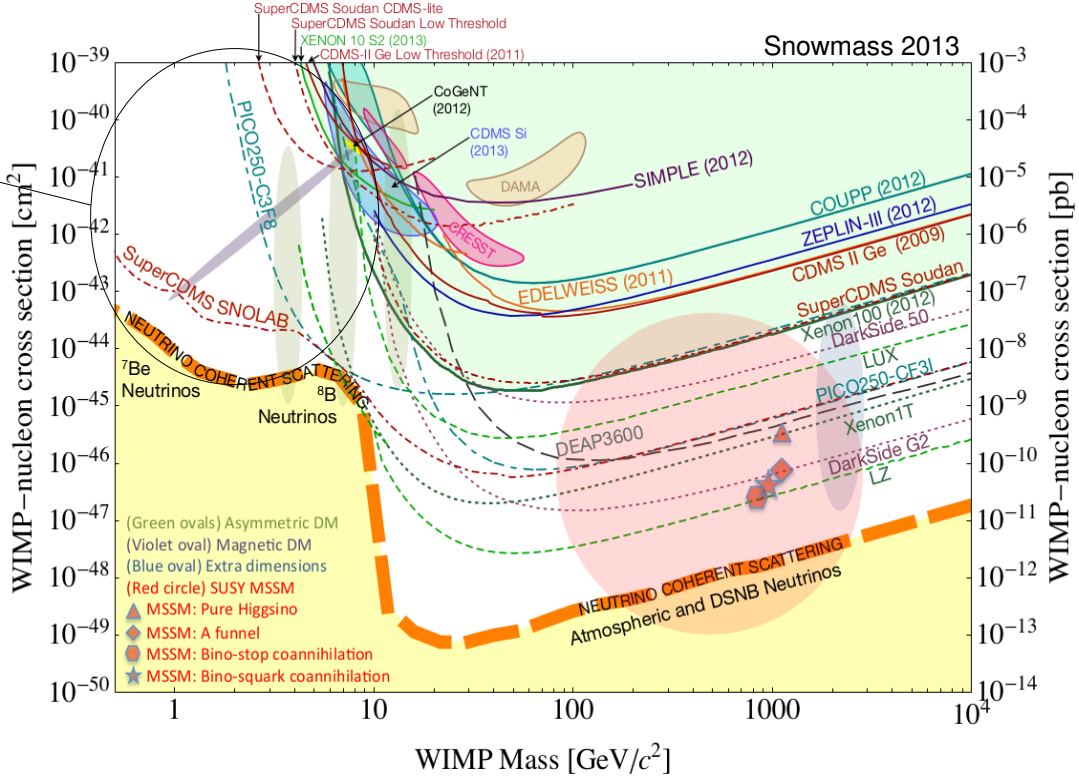




Angloher et al. 2016



Under the hypothesis of contact-type interactions



$$E_R = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1-\cos\theta)$$

$$R \sim N\,\sigma_{sc}\,v\,(\rho_{DM} / M_{DM})$$

Direct detection

Beyond the easiest case (contact scalar interactions)

- Full set of effective operators for DM - nucleus scattering

  Relevant for GeV-TeV DM

$\mathcal{O}_1 = 1_\chi 1_N$	$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^{\perp}_{\chi N}$
$\mathcal{O}_3 = -i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^{\perp}_{\chi N}\right)$	$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^{\perp}_{\chi N}$
$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$	$\mathcal{O}_9 = -i\vec{S}_\chi \cdot \left(\vec{S}_N \times \frac{\vec{q}}{m_N}\right)$
$\mathcal{O}_5 = -i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^{\perp}_{\chi N}\right)$	$\mathcal{O}_{10} = -i\vec{S}_N \cdot \frac{\vec{q}}{m_N}$
$\mathcal{O}_6 = \left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right)$	$\mathcal{O}_{11} = -i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$

Fitzpatrick et al., JCAP 1302 (2013) 004

+ interferences

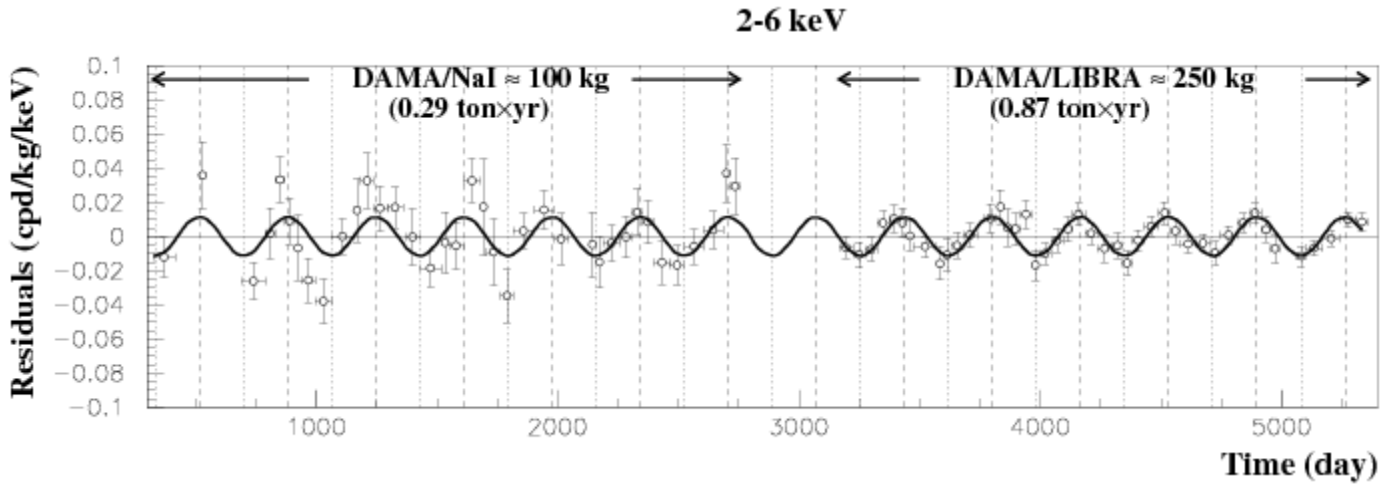
- Interactions on (bound) electrons — Relevant for keV – MeV DM

- DM phase space distribution in the Galaxy (esp. the high-v tail)
  - simulations
  - observations (GAIA)

Direct detection

Characteristic WIMP signatures

DAMA/LIBRA
annual modulation



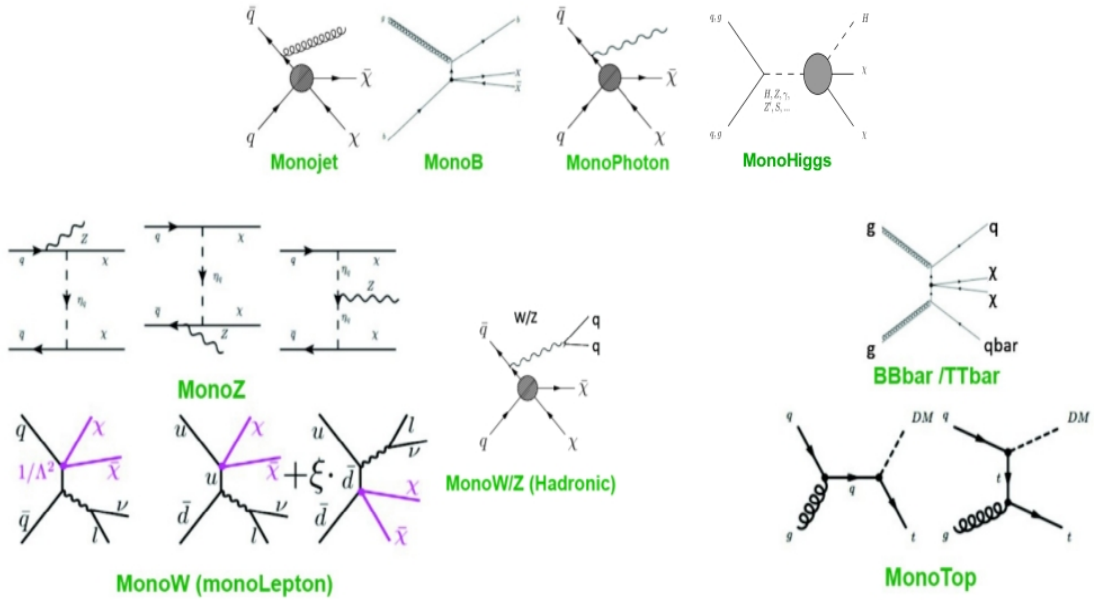
- Annual modulation: *ANAIS, KIMS, DM-Ice, SABRE*
- Diurnal modulation: *DAMA* with larger mass could likely access it
- Directionality: Nuclear emulsion (*NEWS*), Anysotropic crystals (*ADAMO*), Liquid Ar TPC, Negative Ion Time Expansion Chamber (*NITEC*), Carbon nanotubes, *DRIFT, MIMAC, DMTPC, NEWAGE, D3, …*

WIMPs at LHC

WIMPs do not interact in detectors

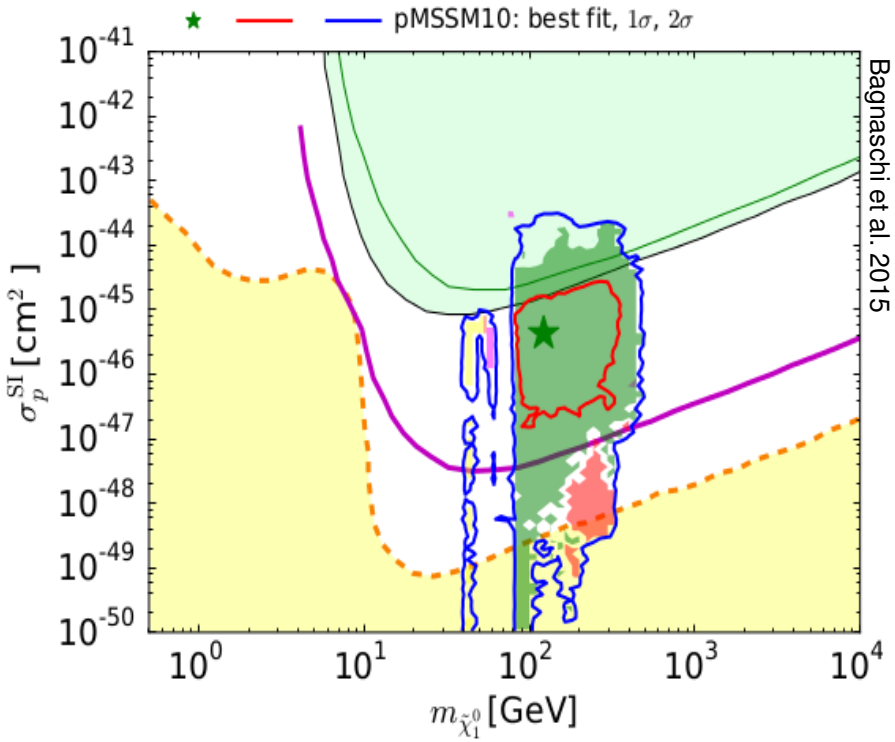
→ experimental signature is transverse momentum imbalance

No clear evidence for new physics so far at LHC.



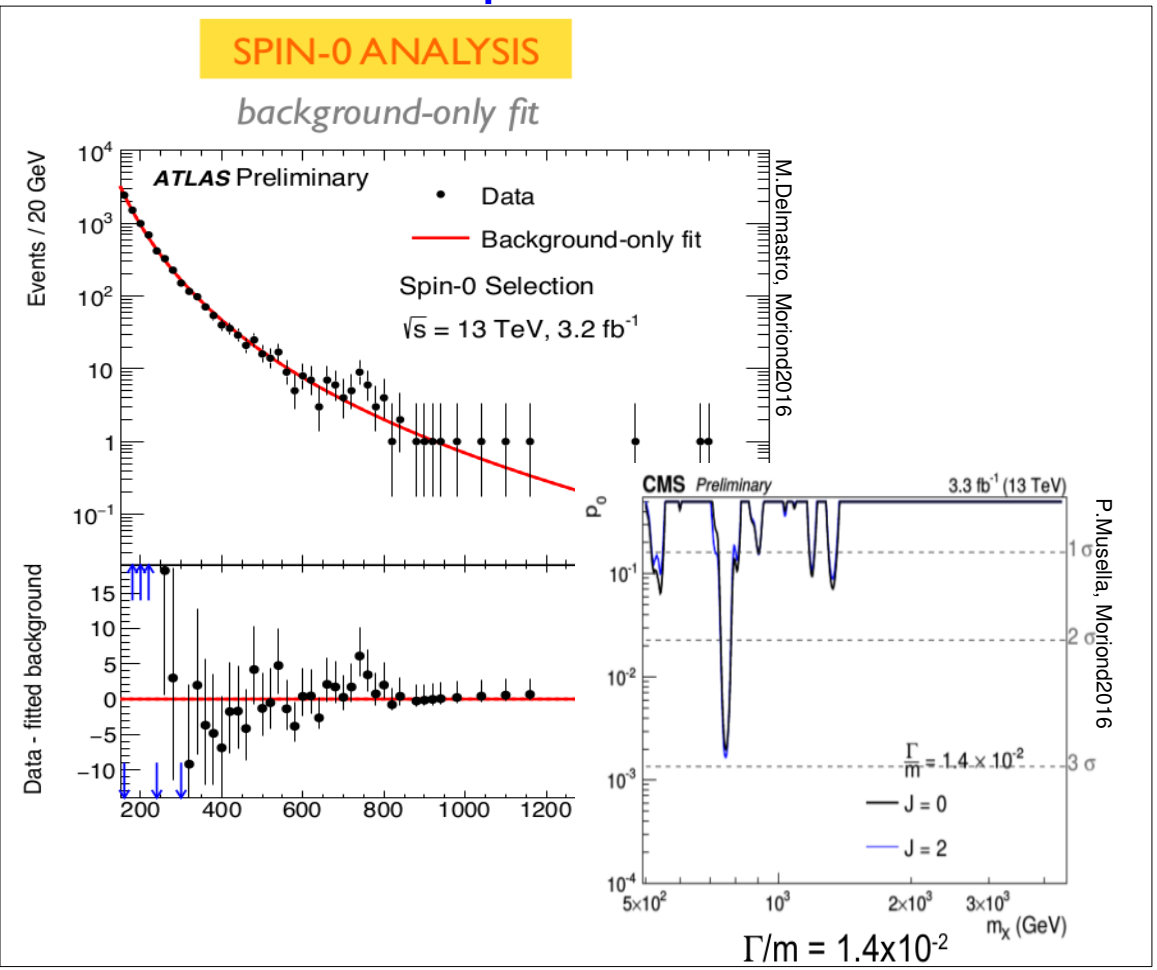
from S. Lowette's talk at TAUP2015

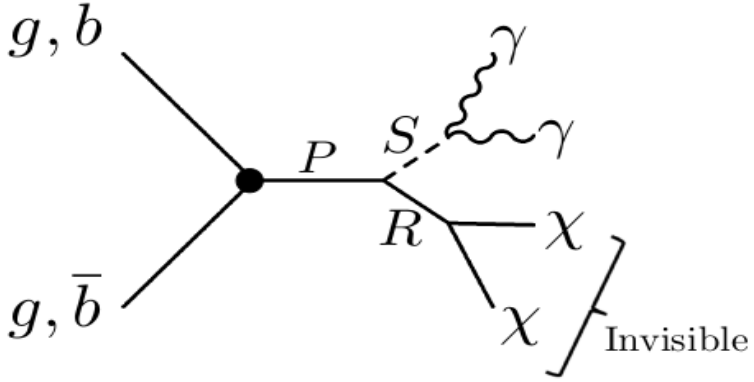
An example: pMSSM10 after Run 1



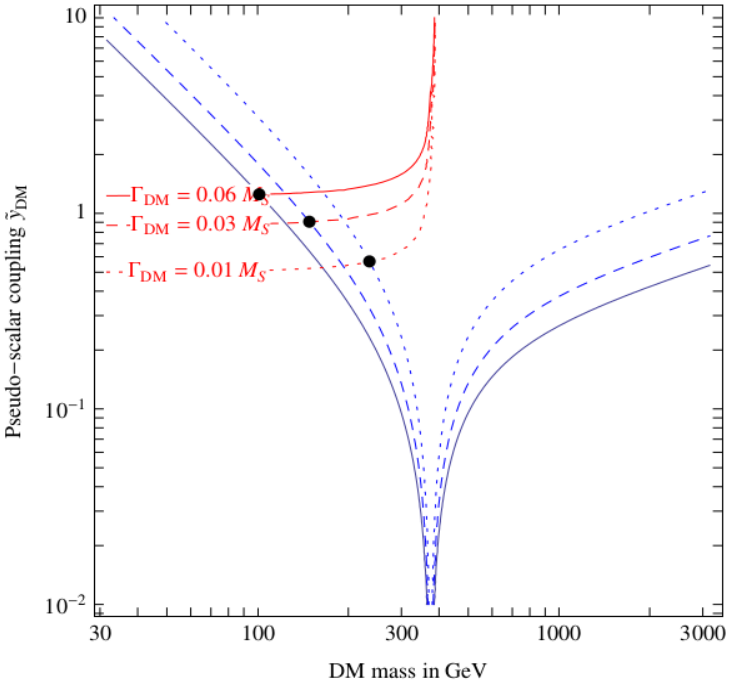
WIMPs at LHC

Diphoton resonance connected to DM production?





Franceschini et al. 2015



Conclusions