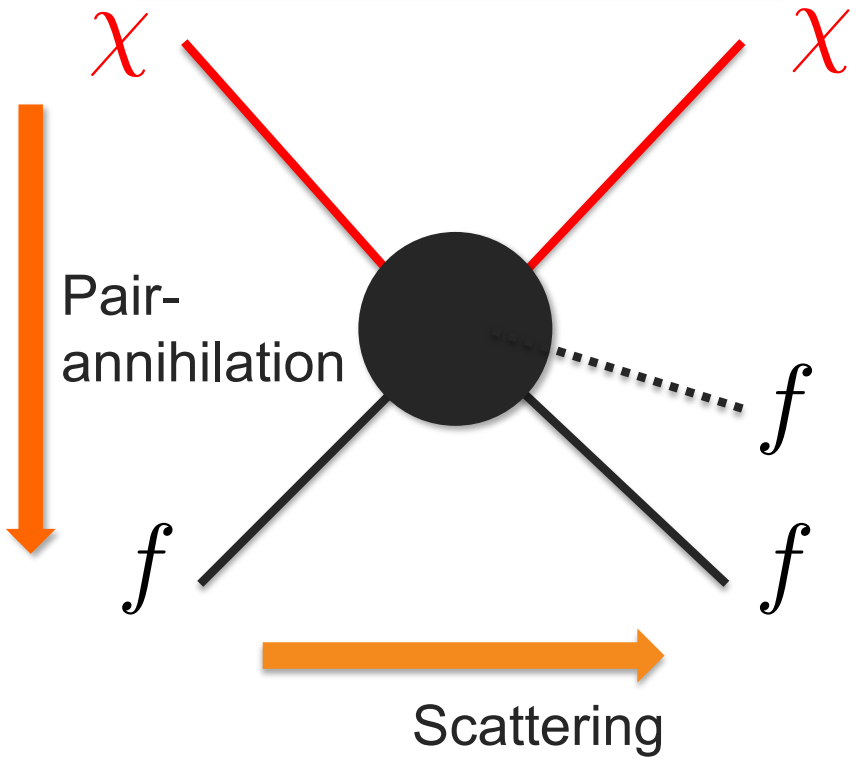
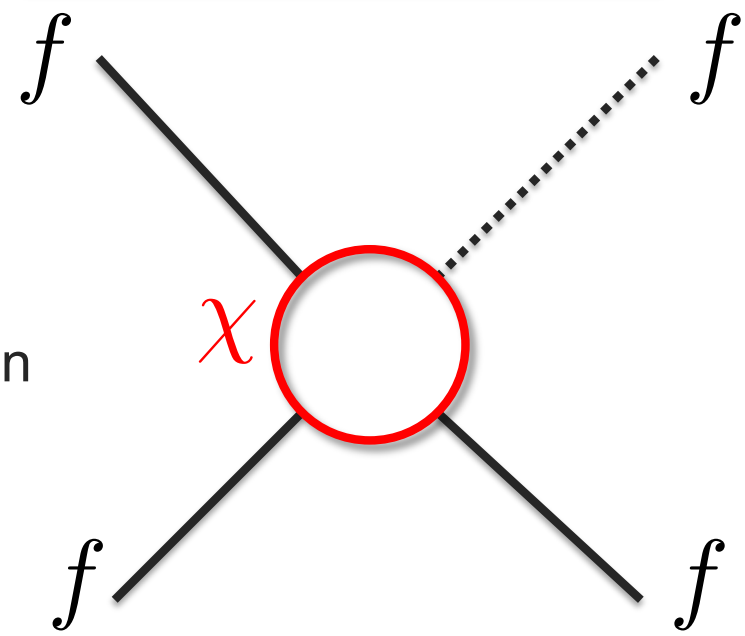
Contents

Processes where WIMPs contribute

WIMPs on external lines



WIMPs on internal lines



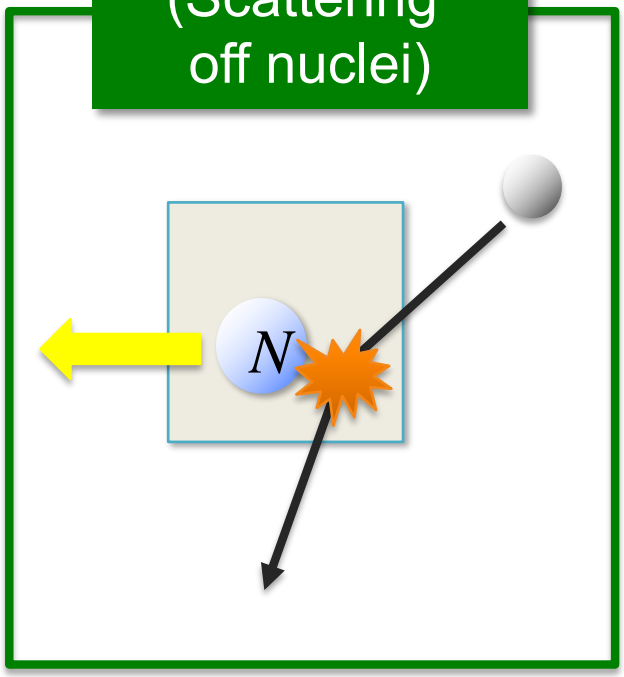
Radiative corrections to masses, rare processes

χ : WIMP f : Standard Model particles ($\#f$ arbitrary)

➡ Masses and interactions of WIMPs can be explored

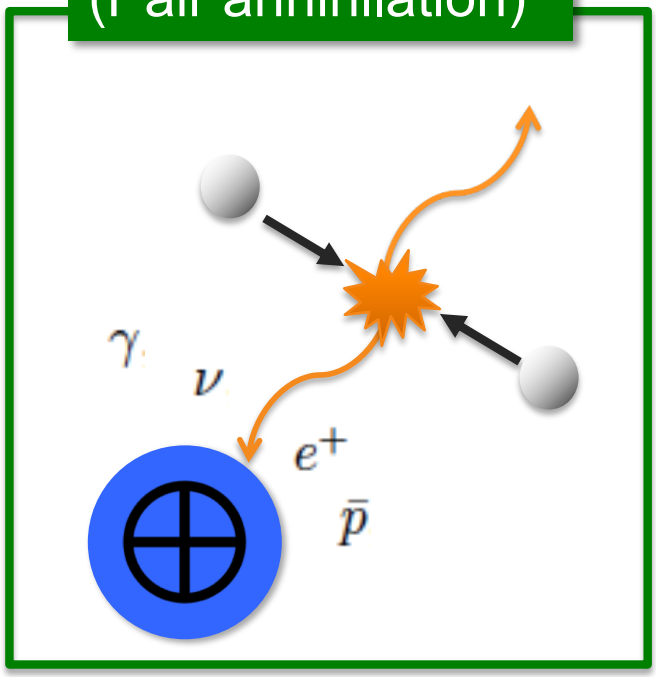
Strategy of searches for WIMPs

Direct detection (Scattering off nuclei)



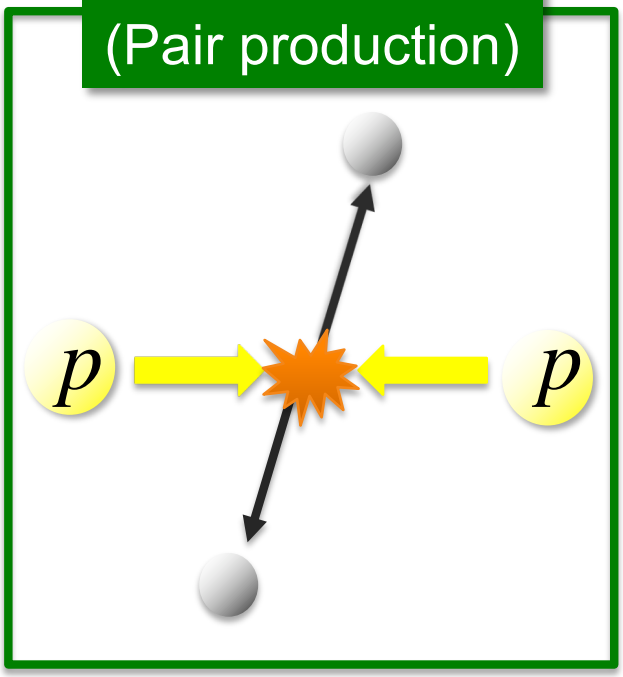
- XENON1T
- PandaX-II
- LUX
- etc.

Indirect detection (Pair annihilation)



- Fermi-LAT
- PAMELA
- AMS-02
- etc.

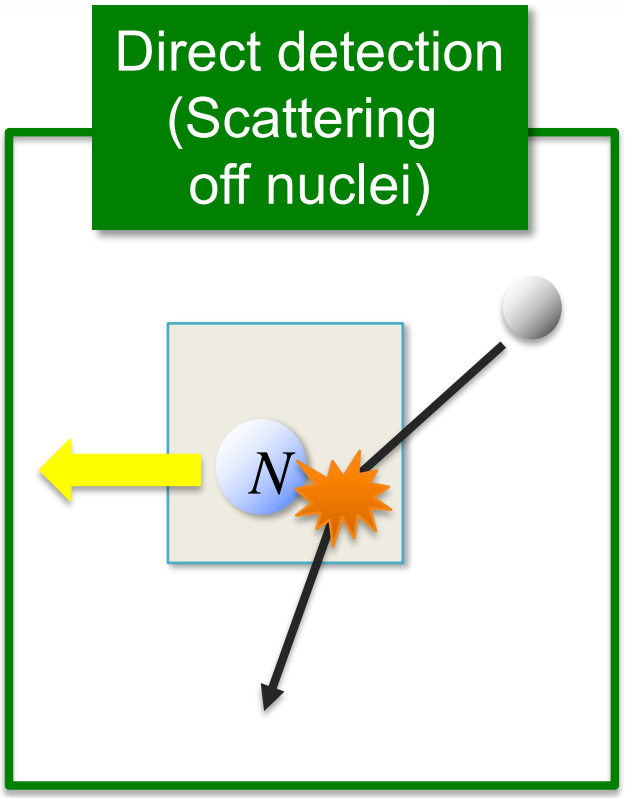
Colliders (Pair production)

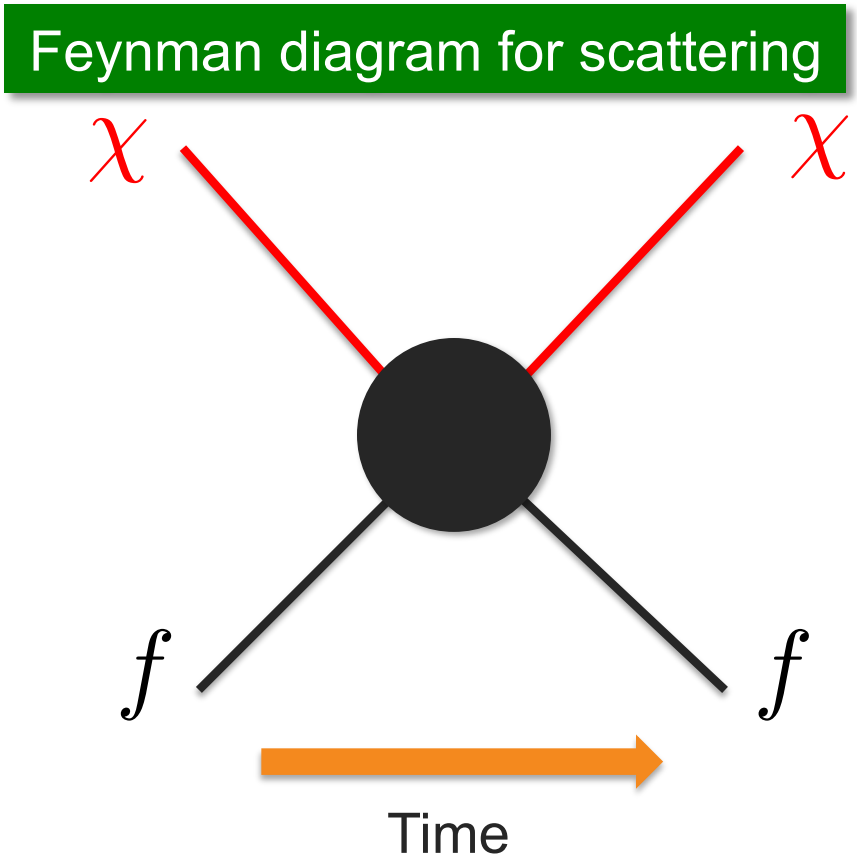


- LHC
- ILC
- etc.

More information on WIMPS will be collected in the near future

Direct detection



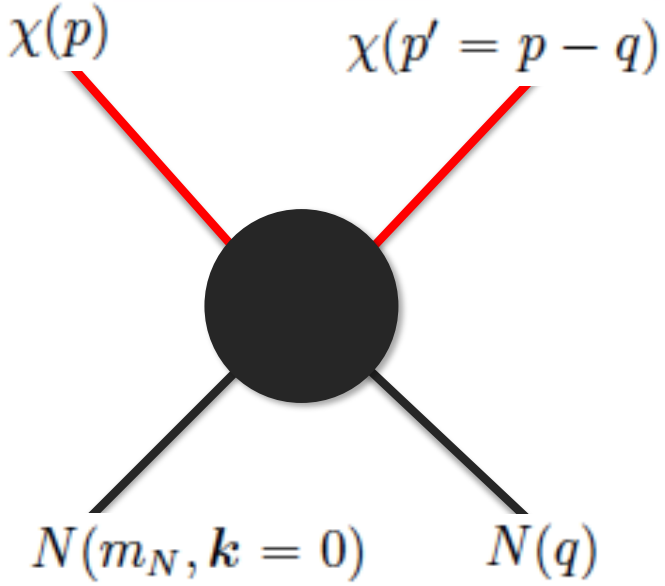


Basic idea

- To observe scattering of galactic dark matter particles off atomic nuclei in the detector material
- To constrain dark matter mass and cross section from event rates

Dark matter scattering off nucleus

Kinematics at the laboratory frame



- Speed of galactic DM χ : $v \sim 10^{-3} \ll 1$
- Deposited energy
  (recoil energy of the nucleus):

$$E_R = \frac{q^2}{2m_N} \qquad q \text{ : momentum transfer}$$

- Reduced mass: $\dfrac{1}{\mu_{\chi N}} = \dfrac{1}{m_\chi} + \dfrac{1}{m_N}$

$100\ \mathrm{GeV}$ for typical nuclei

$10\ \mathrm{GeV} - 1\ \mathrm{TeV}$ for typical WIMP DM

- Maximum recoil energy:

$$E_R^{\max} = \frac{2\mu_{\chi N}^2 v^2}{m_N} \sim 10 - 100\ \mathrm{keV}$$

- Maximum DM velocity for a given recoil energy:

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}}}$$

Event rate

- Expected event rate:

$$R \simeq N_T \Phi_\chi \sigma(\chi N \to \chi N)$$

N_T : # target nuclei

DM flux: $\Phi_\chi = n_\chi v = \dfrac{\rho_0}{m_\chi} v$

- Velocity distribution is approx. Maxwellain in the galactic frame

$$f(\boldsymbol{v}) = \frac{1}{\pi^{3/2} v_0^3} \exp\left(-\frac{v^2}{v_0^2}\right) \qquad \text{w/} \quad v_0 \simeq 220 \text{ km s}^{-1}$$

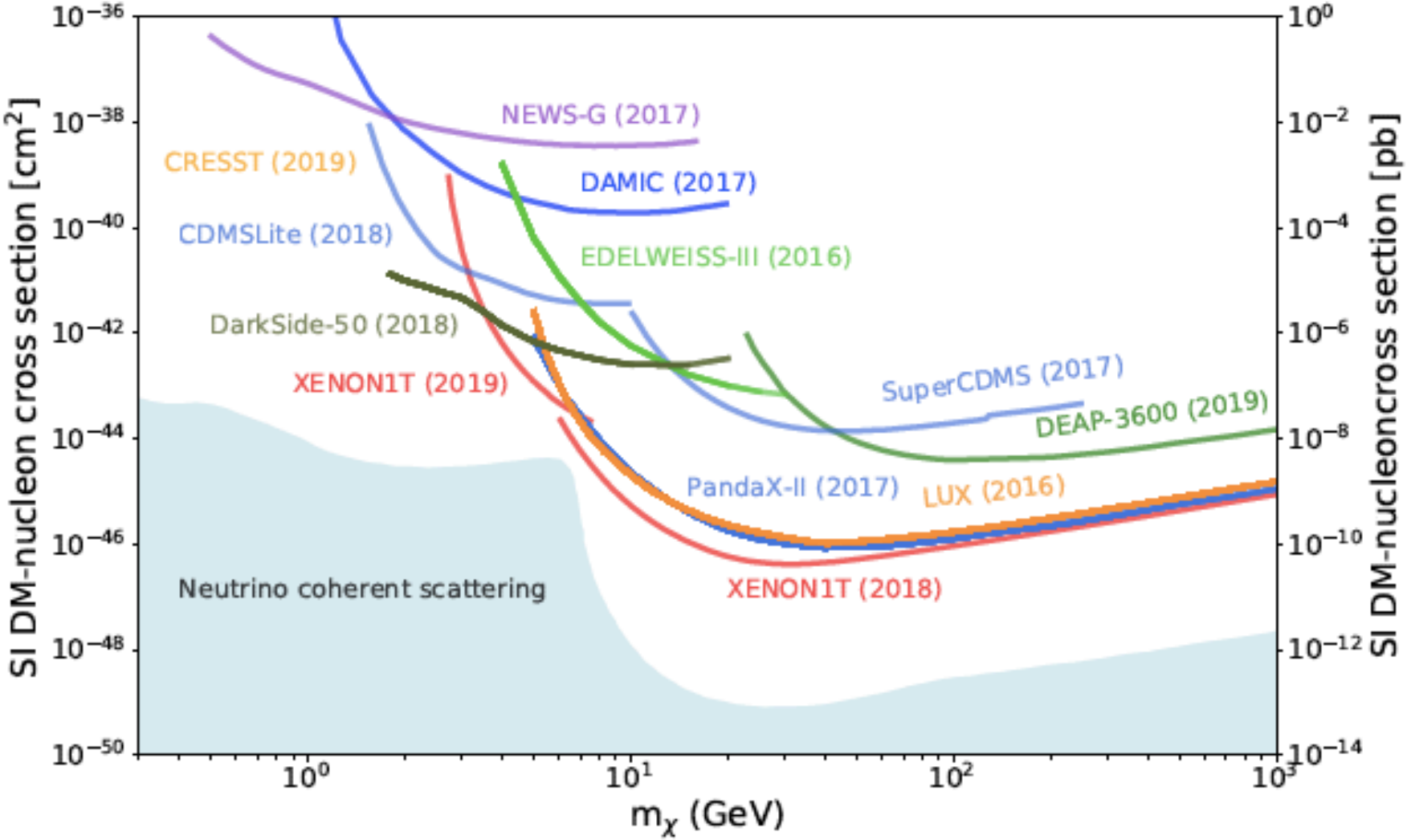
- Differential event rate:

$$\frac{dR}{dE_R} = N_T \frac{\rho_0}{m_\chi} \int_{v > v_{\min}} d^3 v \, v f(\boldsymbol{v} + \boldsymbol{v}_E) \frac{d\sigma}{dE_R}$$

$\boldsymbol{v}_E$: Earth's velocity

Upper limits on the DM-nucleon cross section

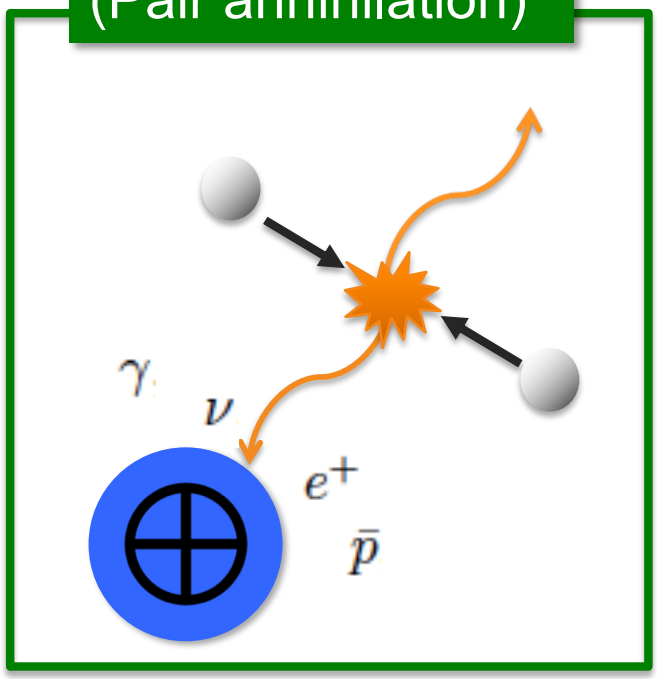
- Spin-independent cross section



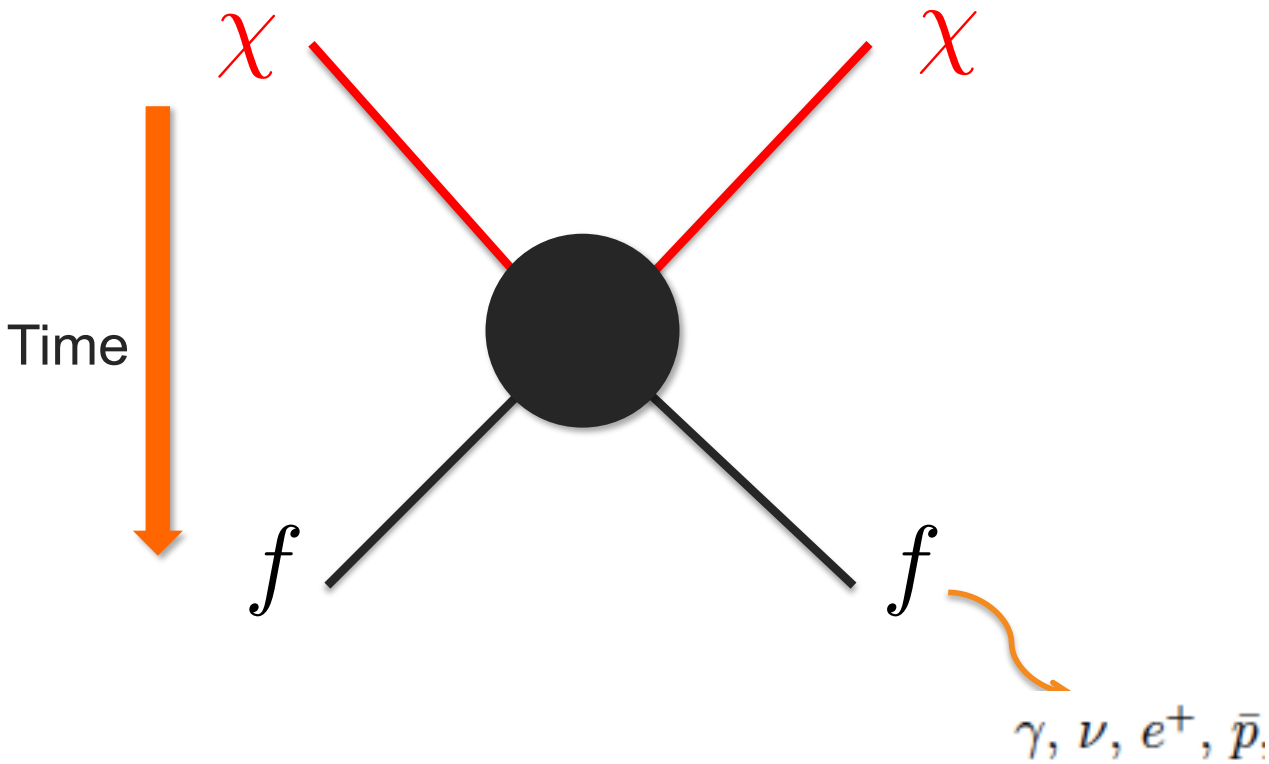
[PDG 2020]

Indirect detection

Indirect detection
(Pair annihilation)



Feynman diagram for pair-annihilation



Basic idea

- To search for the debris from DM annihilation (or decay), in particular, gamma rays, neutrinos, and anti-particles
- To constrain dark matter mass and cross section from event rates

Production rate of final state particles

Production rate of particle f per unit volume

- For annihilation

$$\Gamma_f^A = \frac{1}{2}\frac{\rho_{\rm DM}^2}{m_\chi^2}\langle\sigma v\rangle N_f^A$$

$\langle\sigma v\rangle$: Thermal average of cross section times velocity

N_f^A : # f produced in one annihilation event

- For decay

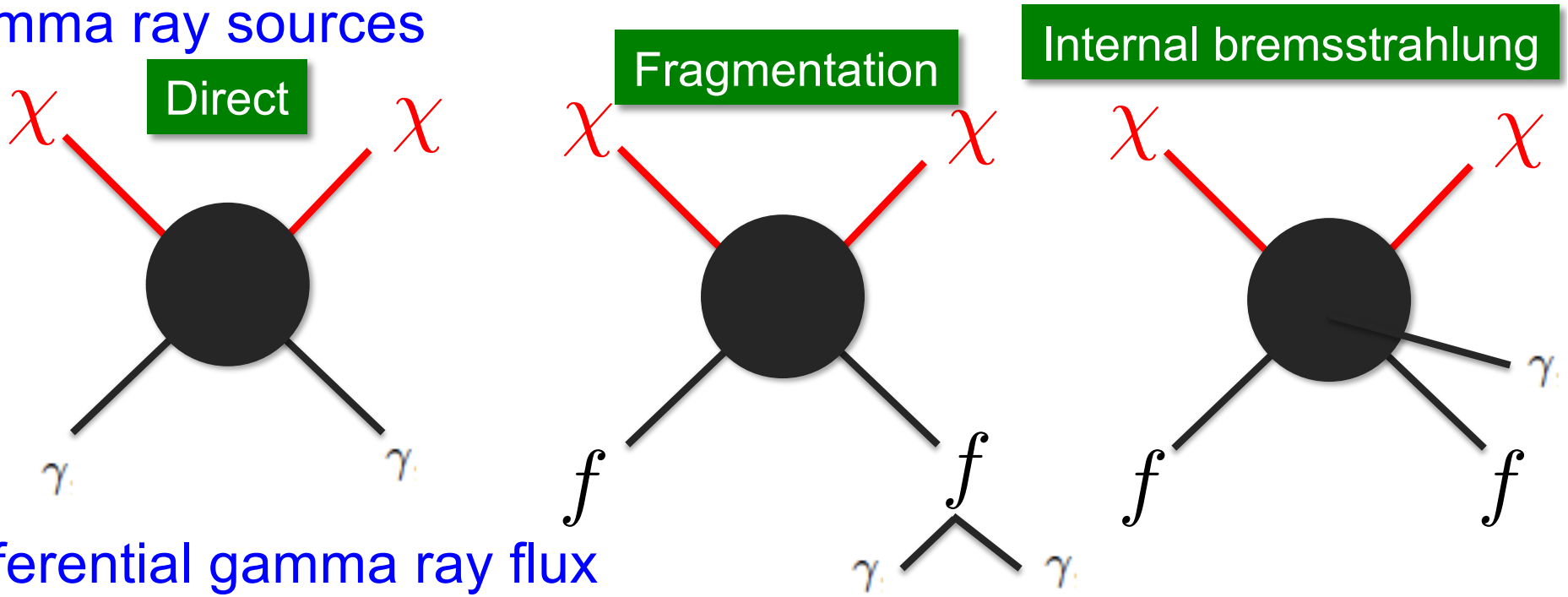
$$\Gamma_f^D = \frac{\rho_{\rm DM}}{m_\chi}\frac{1}{\tau_\chi}N_f^D$$

τ_χ : Lifetime of DM

N_f^D : # f produced in one decay event

Gamma ray flux

Gamma ray sources



Differential gamma ray flux

$$\frac{dN}{dE} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\frac{dN_\gamma}{dE} \times \int_{\Delta\Omega} d\Omega \int_{\mathrm{l.o.s.}(\psi)} dl\, \rho^2_{\mathrm{DM}}(l,\Omega)$$

Particle physics

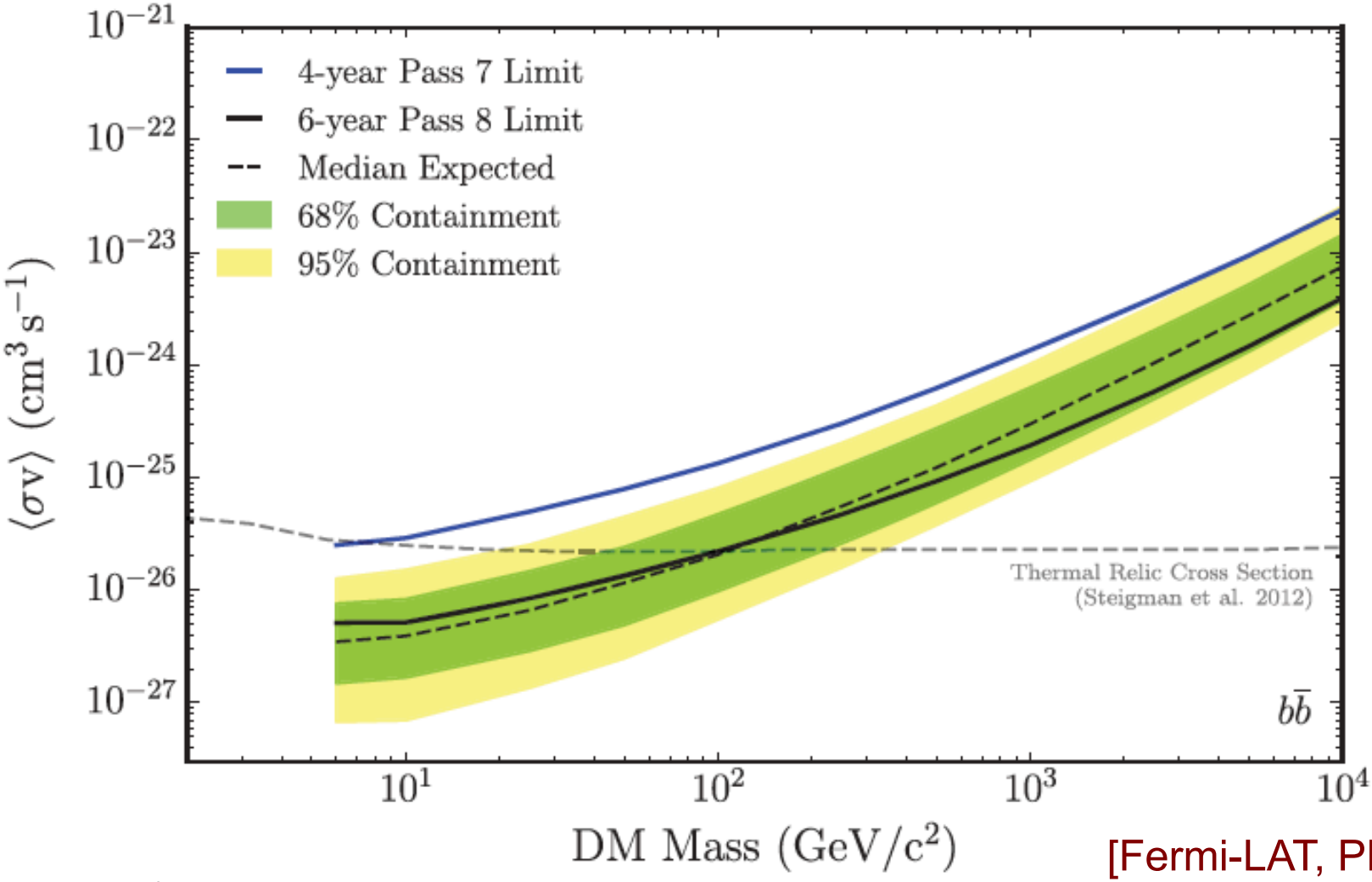
- Dependent on models

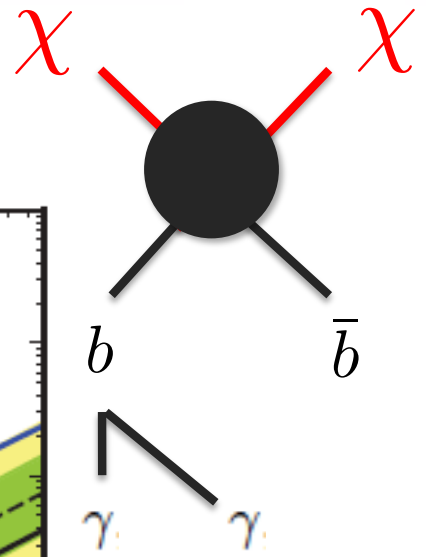
Astrophysics (J-factor)

- Dependent on uncertain DM profile

Upper limits on the pair-annihilation rate

- Gamma ray observation of dwarf spheroidal satellite galaxies (dSphs) of the Milky Way

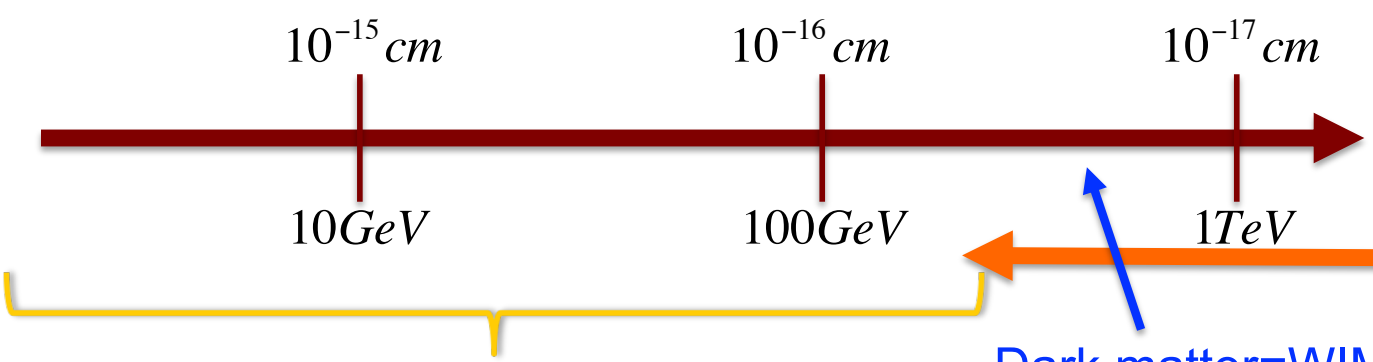




[Fermi-LAT, PRL115, no.23, 231301 (2015)]

Summary

- Particle physicists are seeking new theories that can account for the existence of dark matter

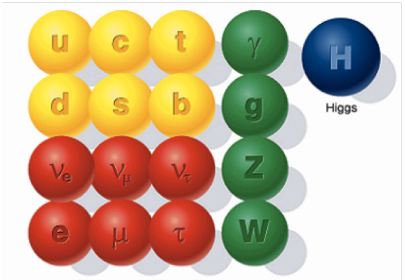


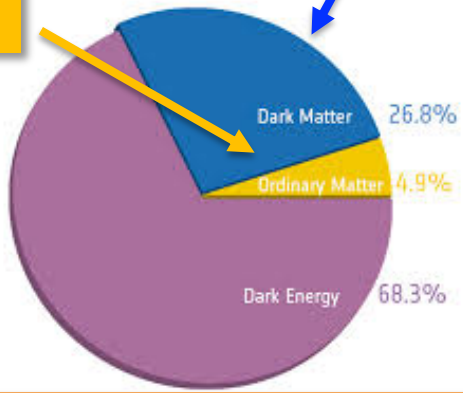
Exploring at collider and dark matte detection experiments

Dark matter=WIMP?

The Standard Model established

Universe





New models with dark matter

- Supersymmetry?
- Extra dimensions?
- Others?

Good time for starting dark matter physics