Signatures of dark matter in current and future neutrino facilities

E. Armengaud
CEA - DPhP
Cosmo/neutrino club - 16/01/2018

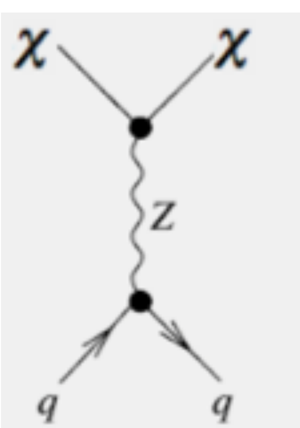
- Introduction / reminders
- Sensitivities in the « standard » scenario
- Recent « exotic » scenarios

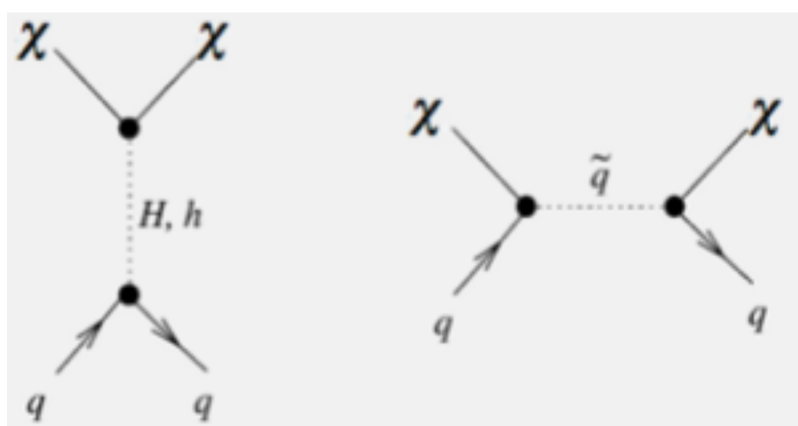
Introduction / reminders

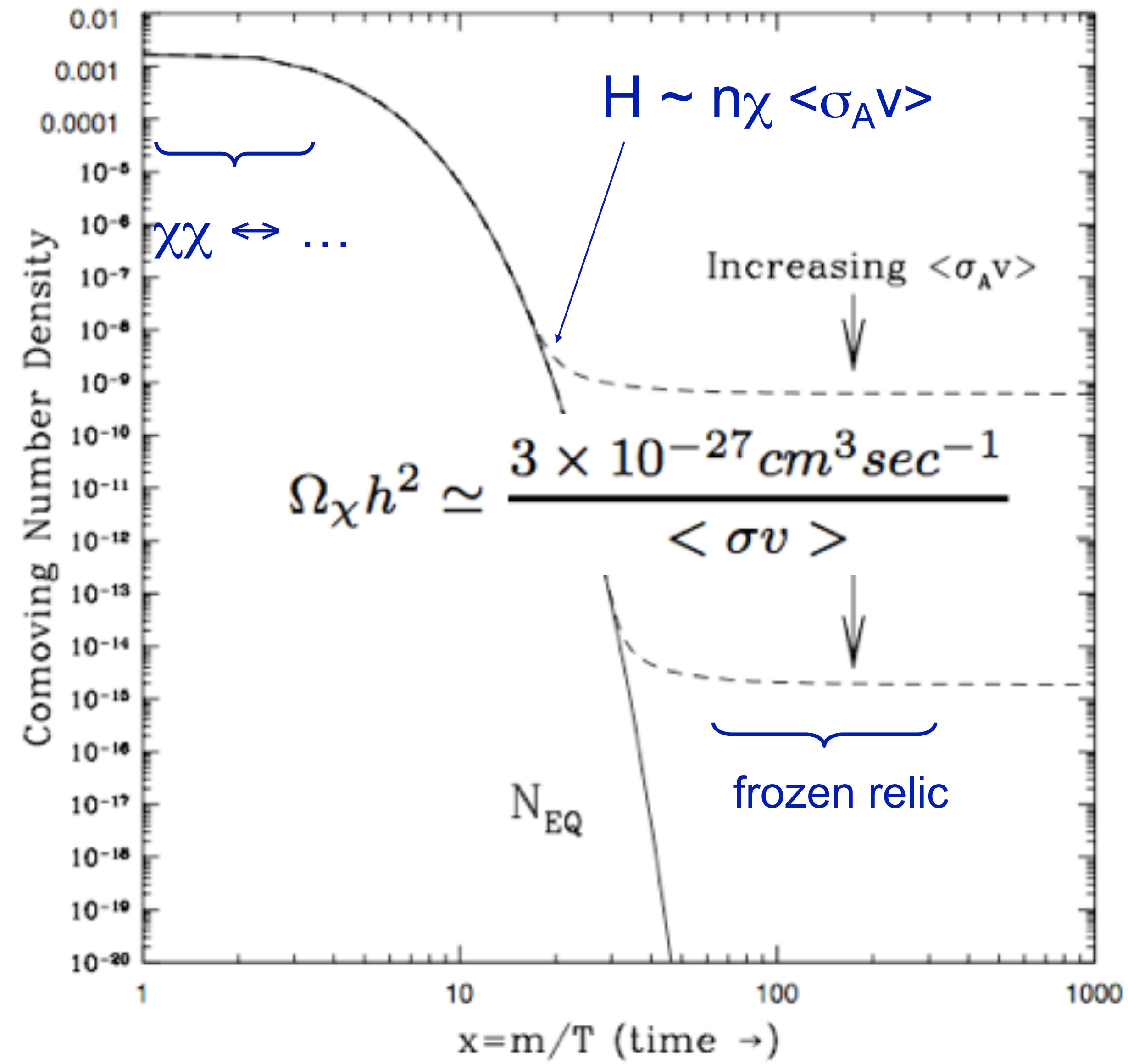
WIMP dark matter

- M ~ GeV - TeV
- Annihilation to SM => « WIMP miracle » for weak-scale cross-sections
- Associated coupling to nucleons : exchange of heavy particle

« spin-dependent » *« spin-independent »*







$$\Omega_\chi h^2 \simeq \frac{3 \times 10^{-27} cm^3 sec^{-1}}{< \sigma v >}$$

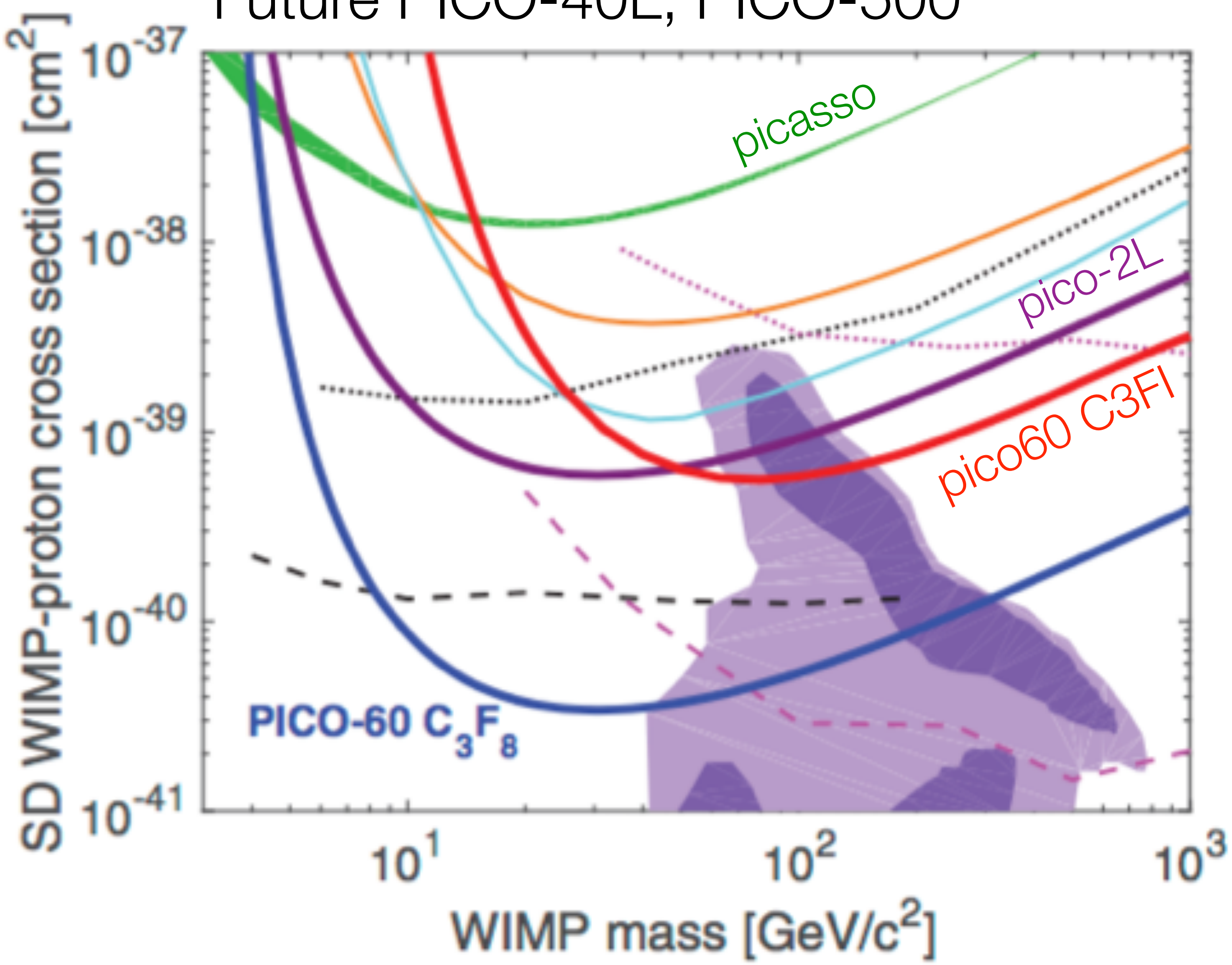
NOT COVERED HERE : scenarios of « light » WIMPs (~GeV) with

- no annihilation (relic density related to Ω_b, no indirect detection)
- light mediator (different coupling to nucleon, no LHC bound, potential strong self-scattering)

Coupling to nucleons : direct detection

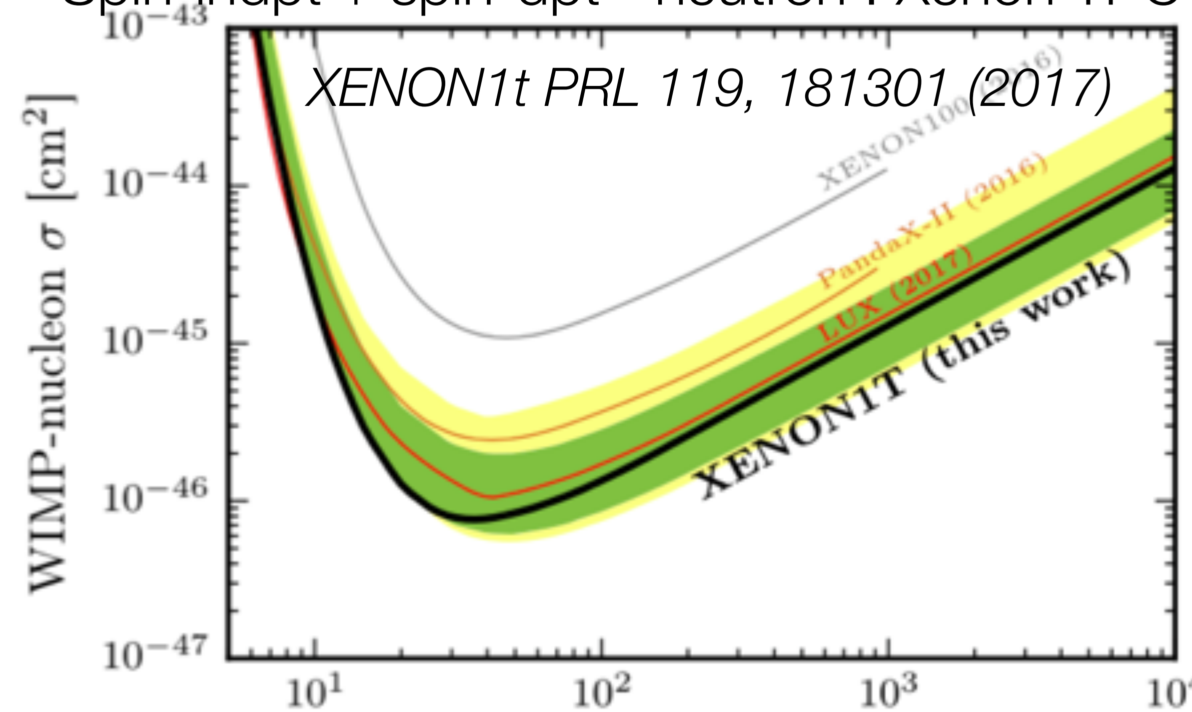
Elastic scattering in terrestrial detector : WIMP (galactic halo) + N

Spin-dpt - proton : bubble chambers
PICO-60 eg. PRL 118, 251301 (2017)
Future PICO-40L, PICO-500

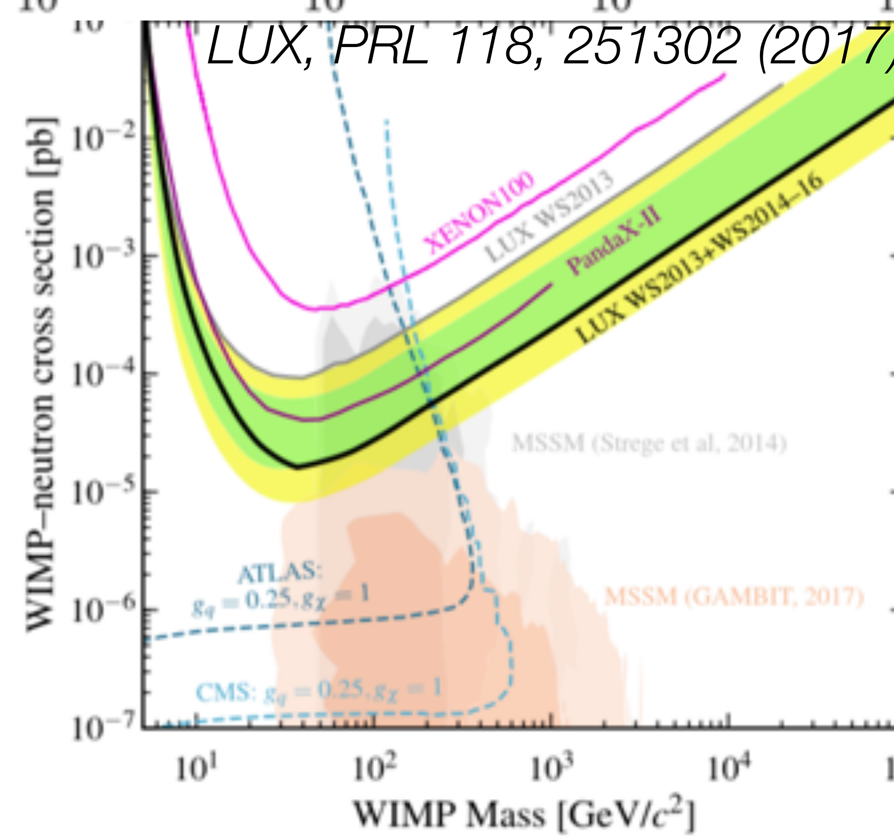


Spin-indpt + spin-dpt - neutron : Xenon TPC

XENON1t PRL 119, 181301 (2017)



LUX, PRL 118, 251302 (2017)



Annihilation to SM particles : indirect detection

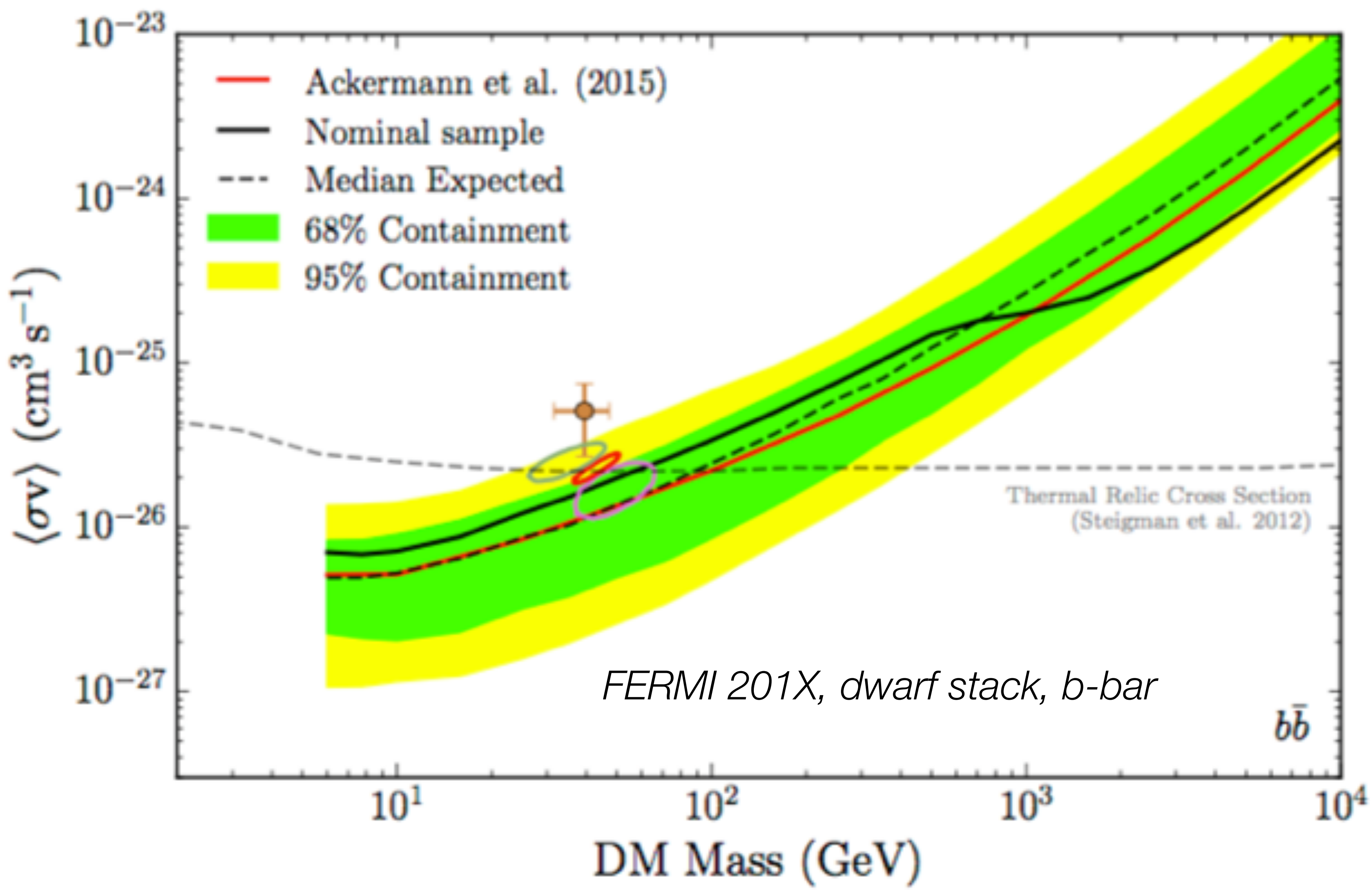
XX → (SM)(SMbar) → γ in DM-rich astrophysical target

Best target : depends on signal / background

Best target for gamma observatories : dwarf galaxies

Bound depends on considered SM annihilation channel :

- WW, bb, $\tau\tau$ depending on DM mass
- Light quarks usually suppressed



XX (→ SM-SMbar) → ν also possible
Best target = galactic center

Neutrinos from DM annihilation in the Sun

Gould, Seckel, Spergel .. ~1985
Hooper+ PRD 2009

- DM from galactic halo v ~ 270 km/s
- Collision with p, He in the Sun ⟹ bound DM « core »
- High DM density ⟹ annihilations
- Neutrinos escape

$$\dot{N} = C^{\odot} - A^{\odot} N^2 - E^{\odot} N,$$

capture ~ σ_{Xp}

annihilation ~ $\langle \sigma v \rangle_{th}$

evaporation

Equilibrium regime : $\sqrt{C_\chi A_{\chi\chi}} t_\odot \gg 1$

WIMPs have thermal distribution with T ~ T_{Sun}

ν fluxes ~ annihilation rate ~ capture rate

oscillation effects (incl. MSW)

Measure upward-going muons ⟹ **constrain σ_{Xp}**

Dependance on DM annihilation channels, eg. τ favored over b

Evaporation due to escape of the thermal tail of DM particles with v > v_{esc}

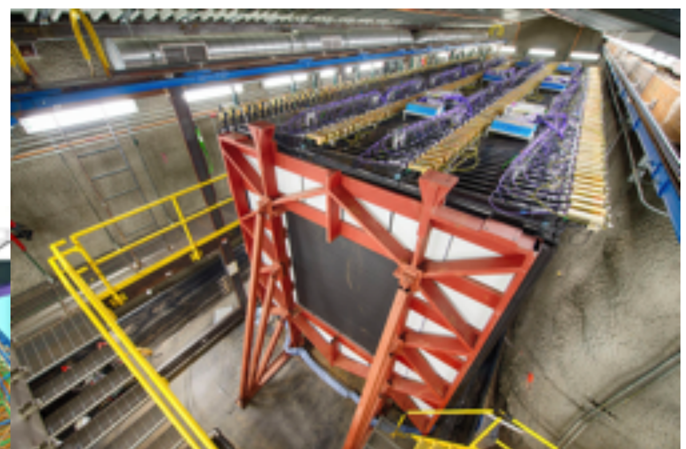
- negligeable for M > 4 GeV
- strongly suppressed DM core (and ν signal) for lower mass

NB : complementarity with DD : probe different DM velocities in halo
NB2 : case of asymmetric DM : no annihilation, no neutrinos
very dense DM core, can impact stellar physics

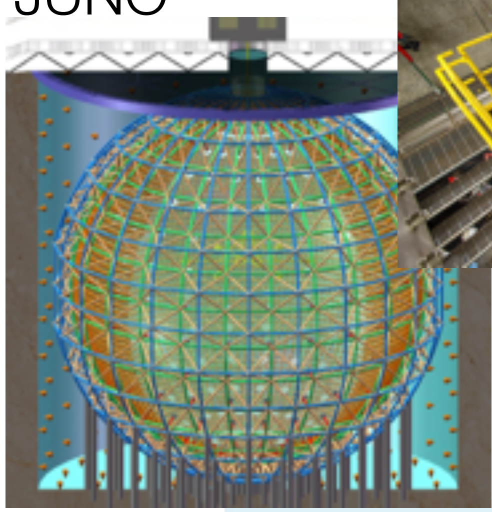
Sensitivities of current and future neutrino experiments

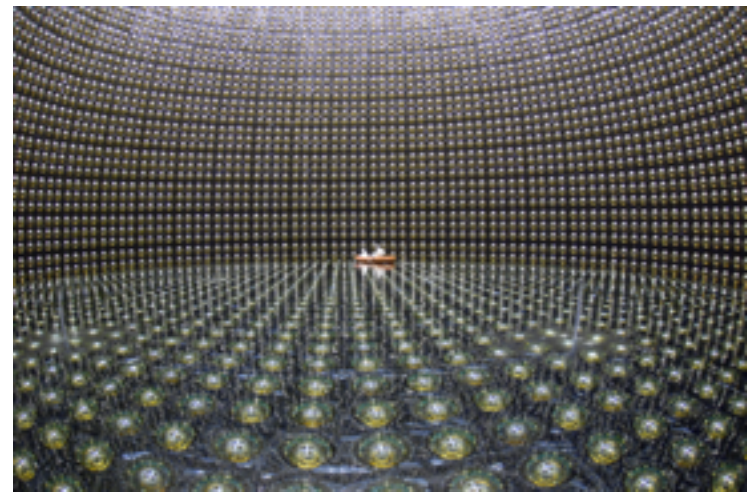
Large volume neutrino experiments

NOvA

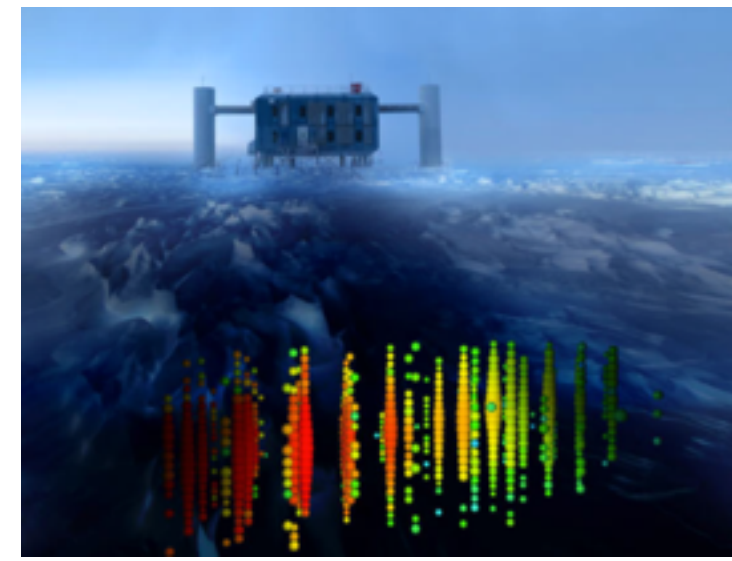


JUNO



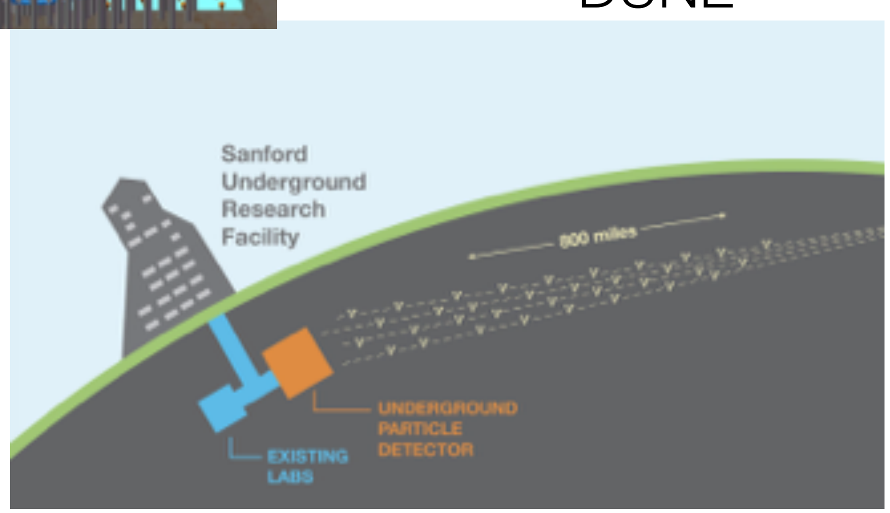


Super-Kamiokande

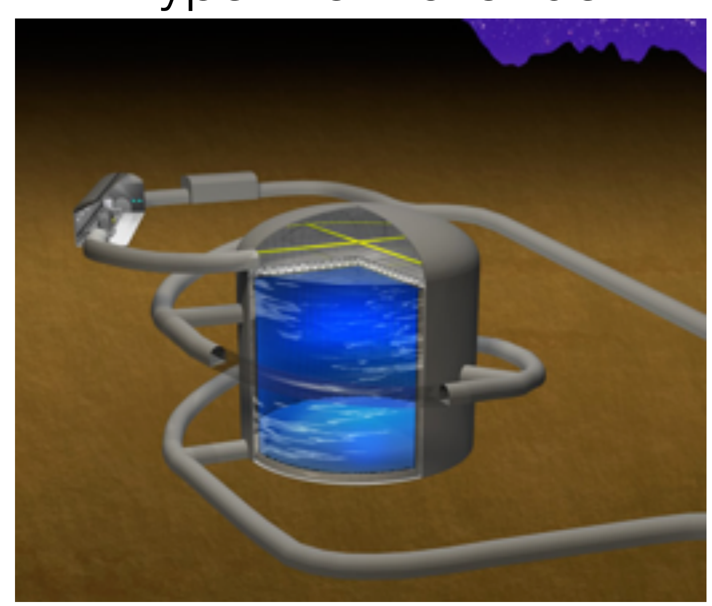


IceCube
DeepCore
IC-Gen2
Pingu ??

DUNE



Hyper-Kamiokande

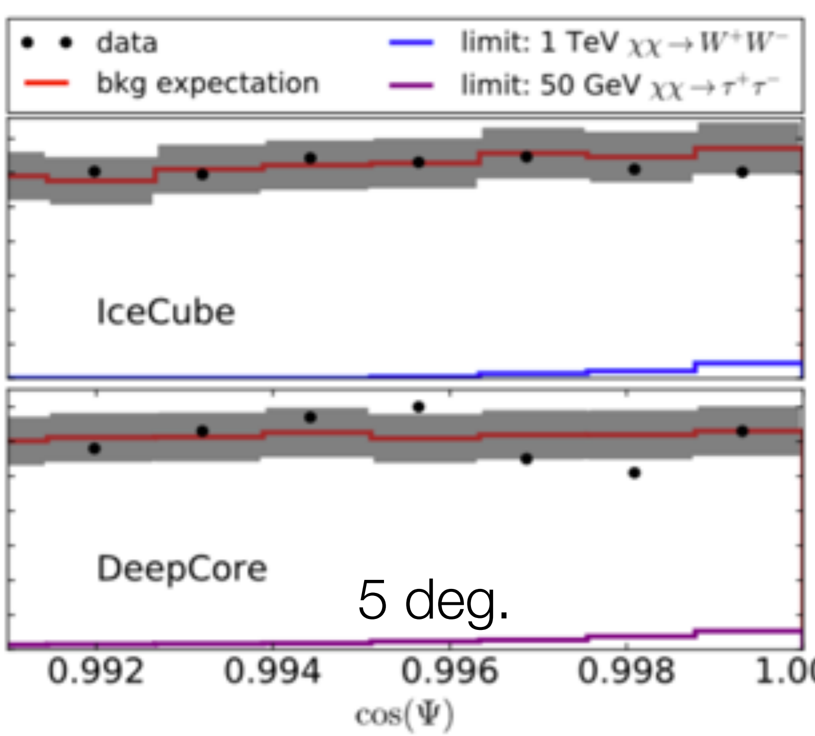


Solar DM neutrinos : IceCube

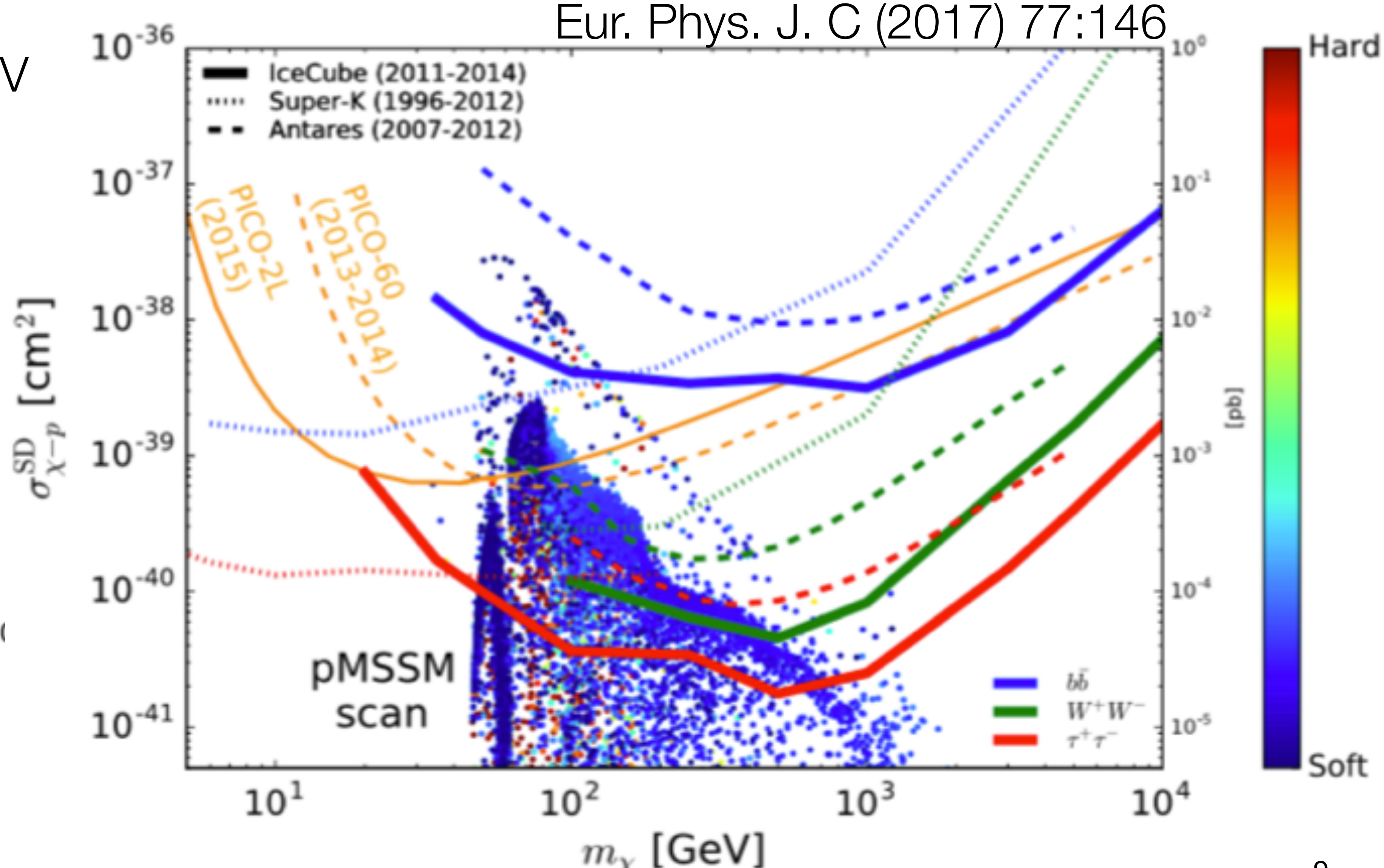
Natural ice, Cerenkov, km^3
E > 100 GeV
DeepCore E > 10 GeV

Data 2011-2014
upgoing ν_μ
bckgd limited

resolution ~ 6 deg @ 100 GeV



Eur. Phys. J. C (2017) 77:146



Solar DM neutrinos : SuperKamiokande

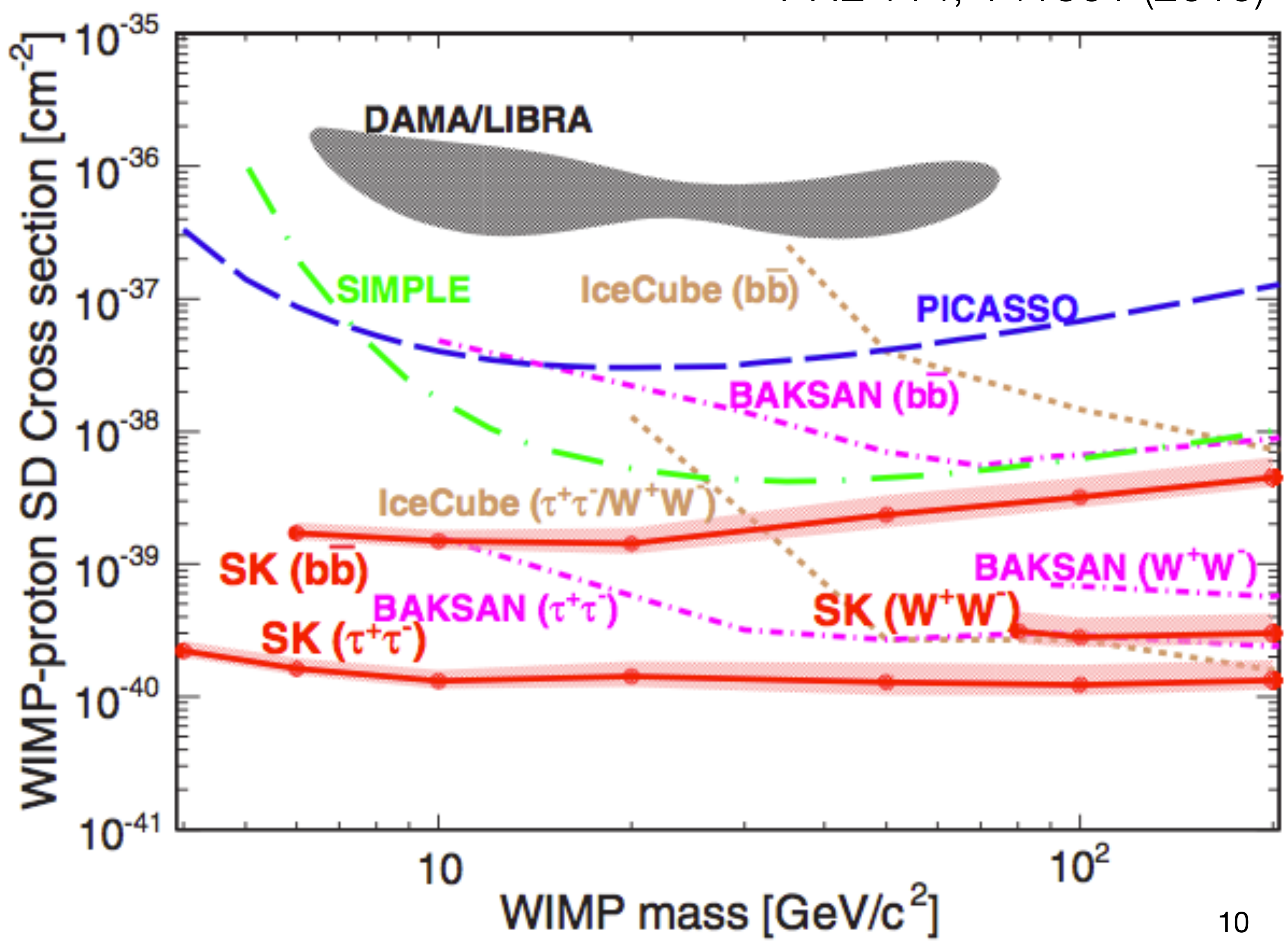
50 kton (22 fid.) water Cerenkov
$E_{vis} > 30$ MeV « high-E neutrinos »

PRL 114, 141301 (2015)

Subsamples
- Upward muons (interaction outside ID)
- Latest analysis : fully/ partially contained events (interaction inside ID, lower energy)

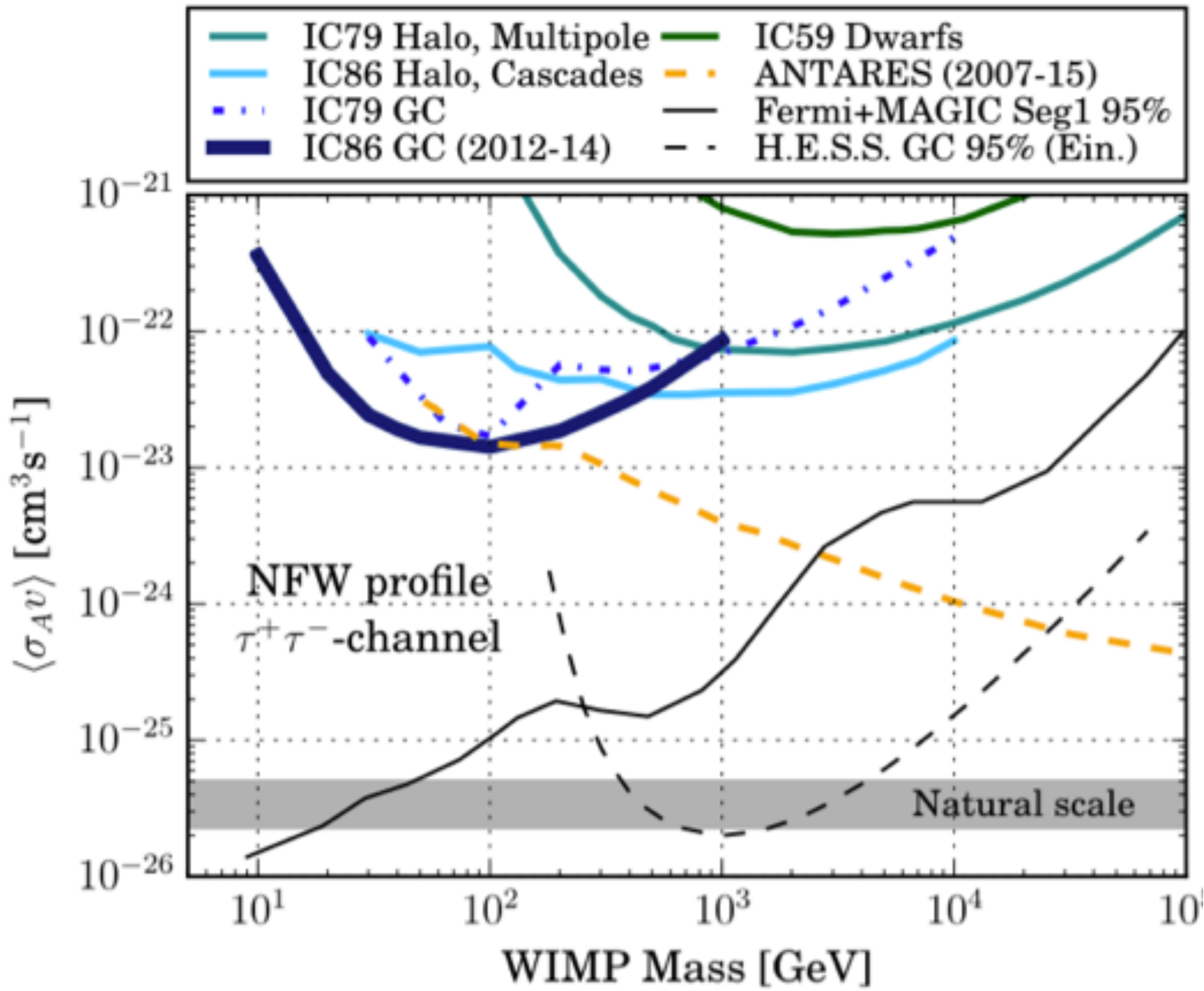
~ 4000 days (1996-2014)

Only M > 4 GeV : evaporation

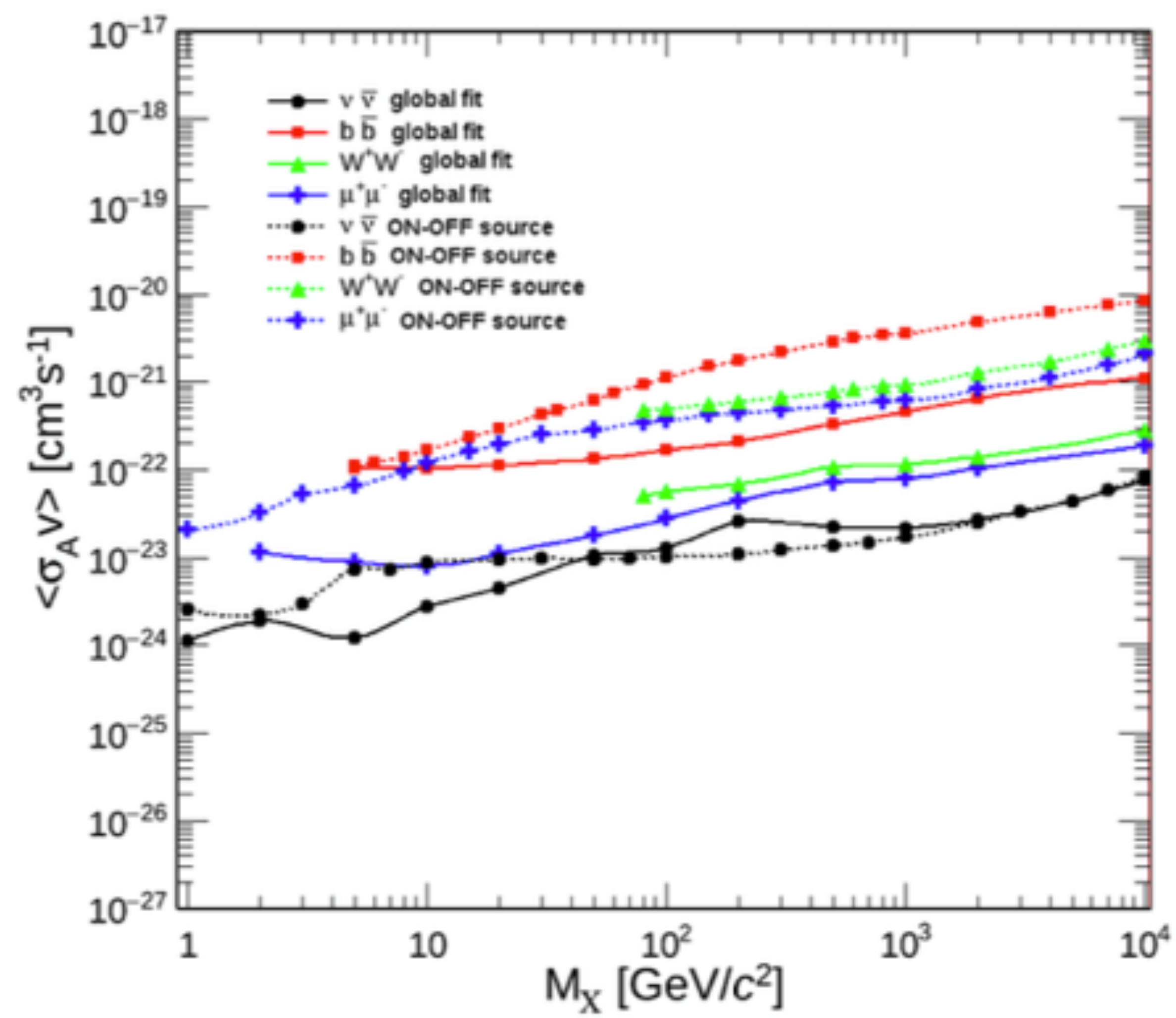


Neutrinos from DM in the galactic center

IceCube, Eur. Phys. J. C (2017) 77:146
ANTARES, Physics Letters B 769 (2017) 249–254



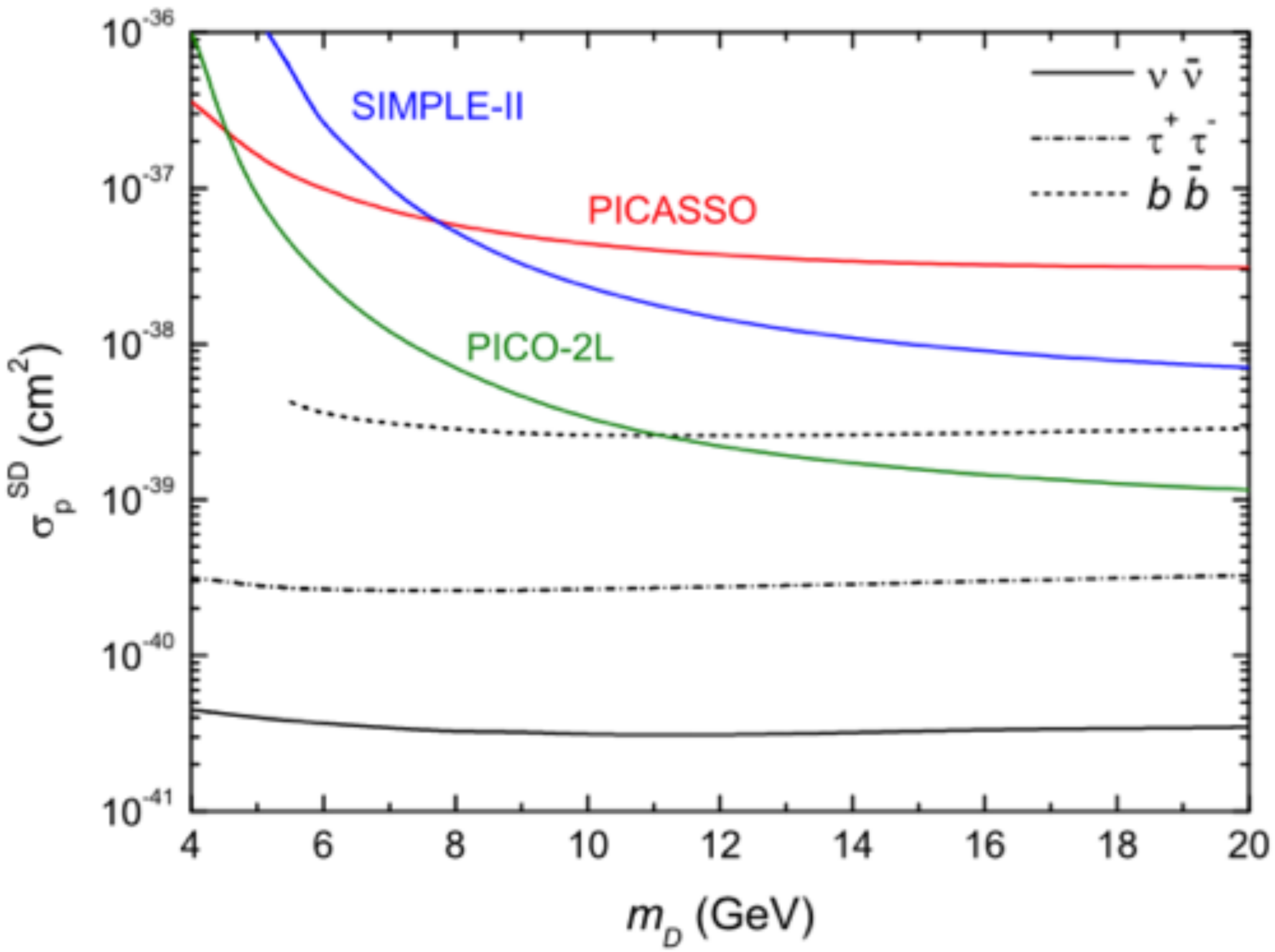
SK result (?)



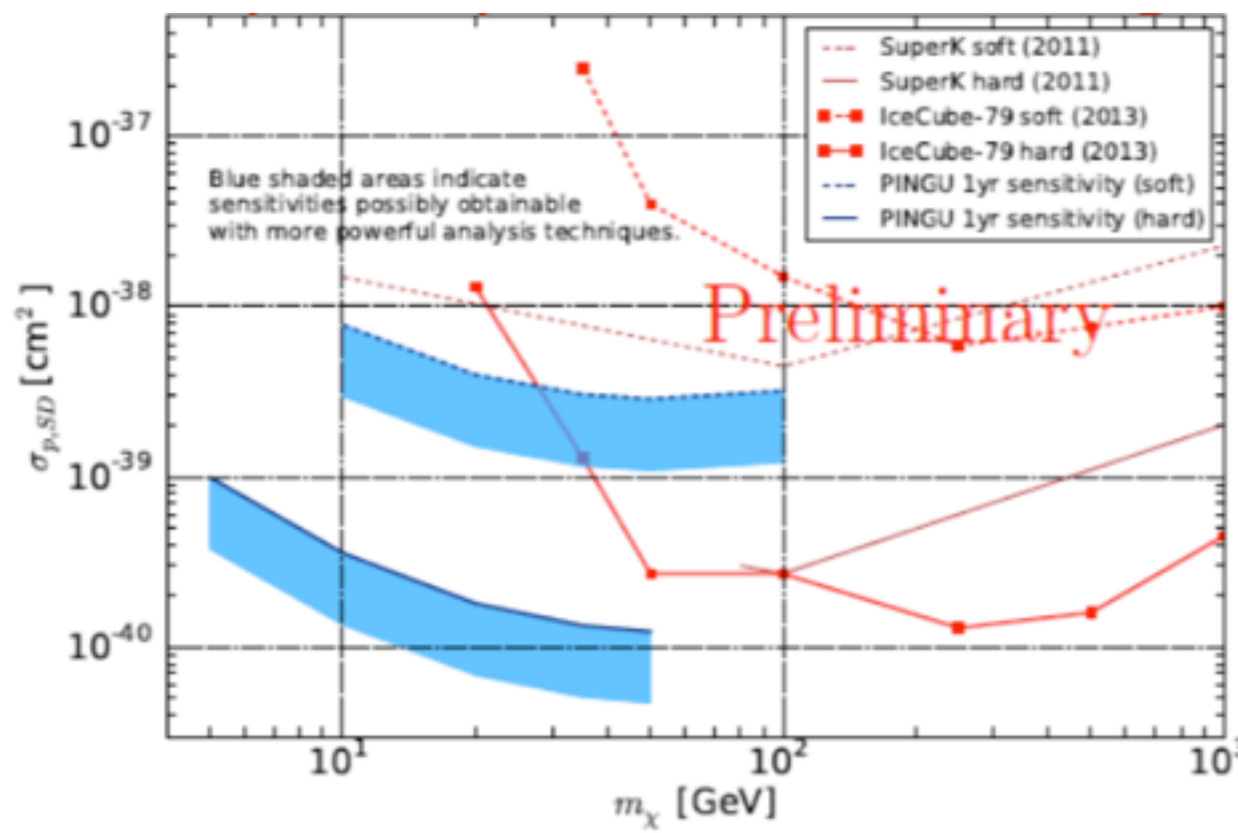
GC is below the horizon for ANTARES

Prospects

JUNO (20 kt LS)
ν_e CC with E_{vis} > GeV (10deg. resolution, e ID)
1511.04888
[Daya Bay ??]



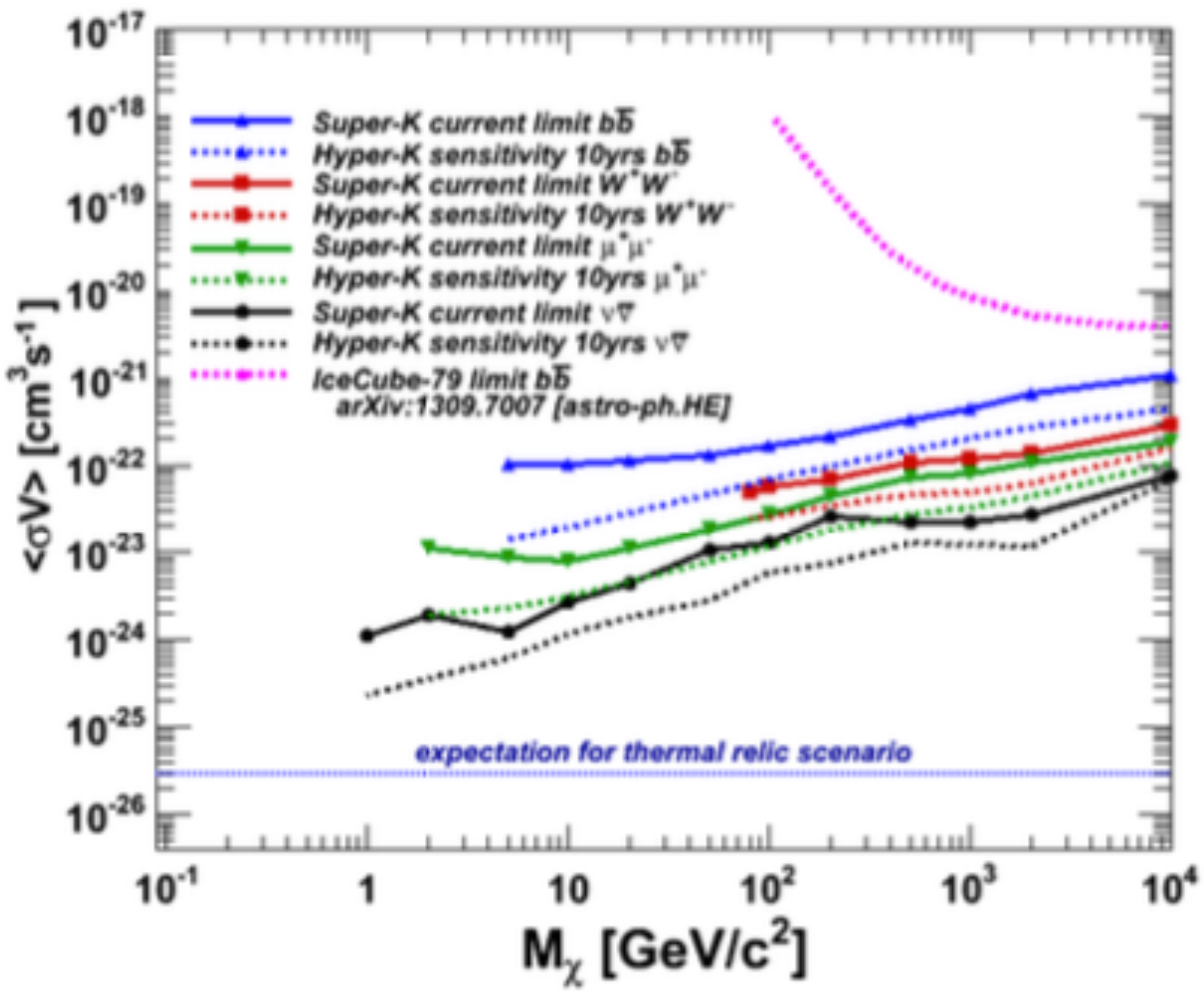
PINGU

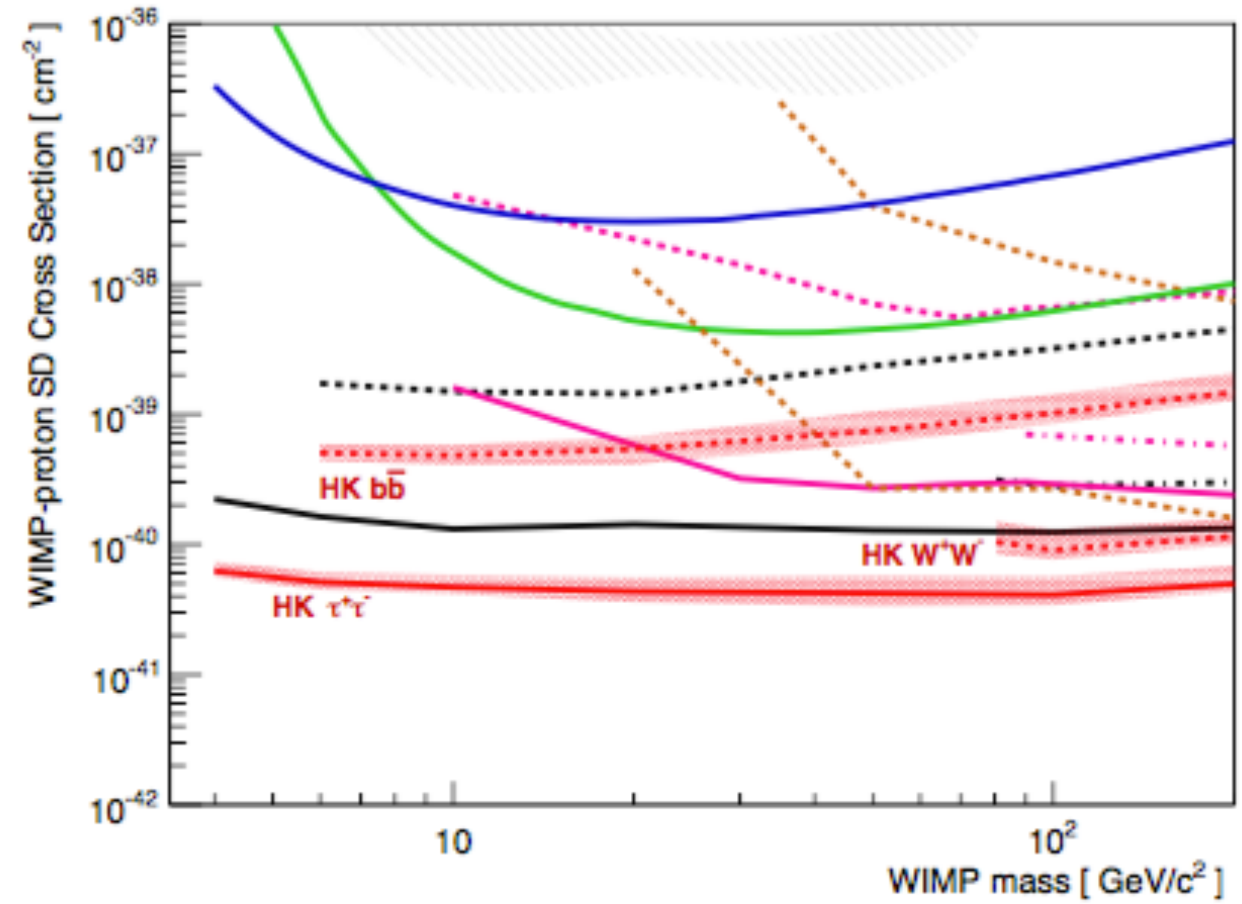


NOvA
LS, granularity, interaction ID
upward-going muon trigger (1511.00155)
pointing resolution 1.2 deg
measure ~ 1 evt / day

Prospects for Hyper-K / DUNE

- HyperKamiokande : fiducial (total) mass 187 (260) kton
WIMP search in design report based on SK



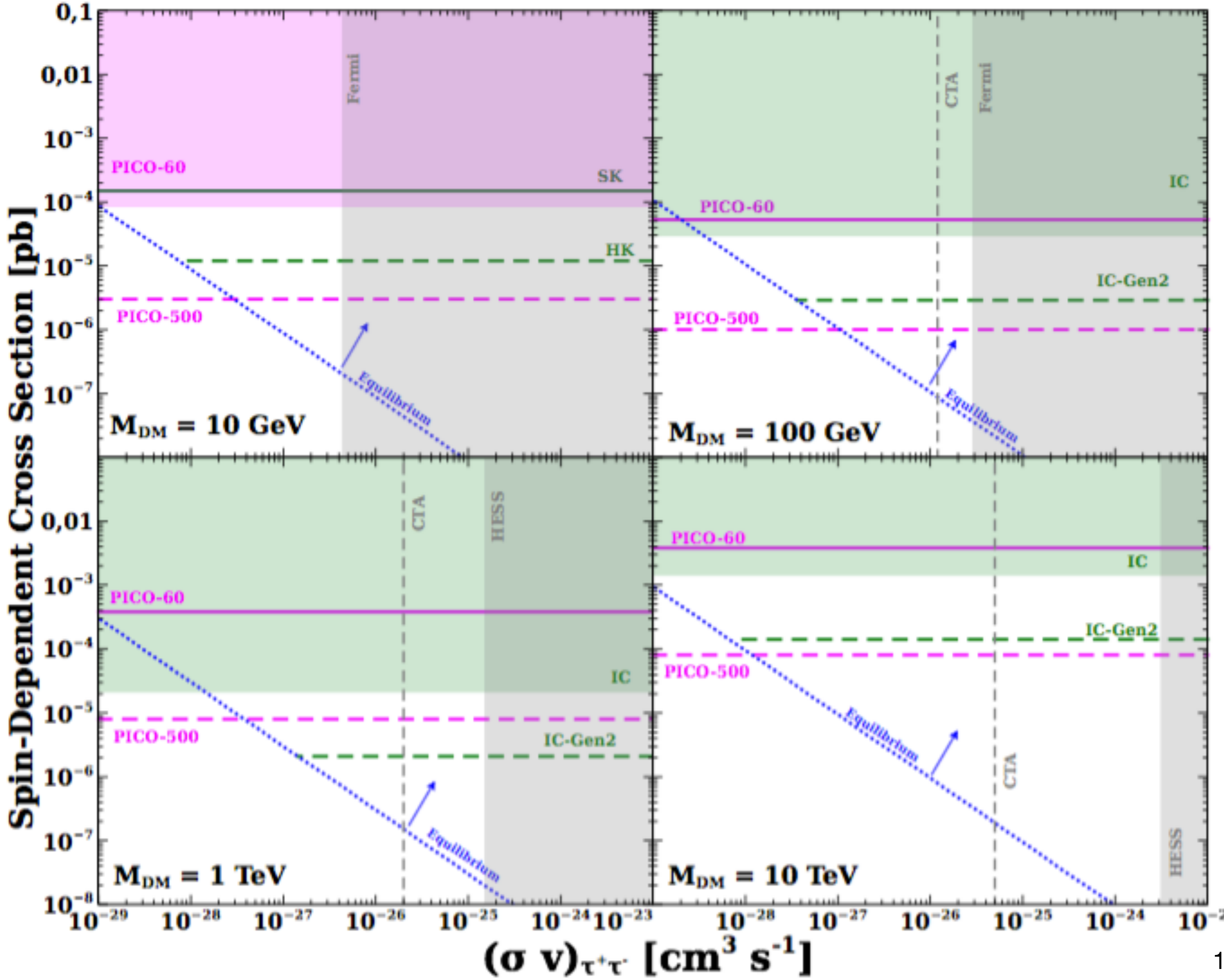


- DUNE : 40 kton lAr TPC
Solar WIMP sensitivity ?

Other prospects … (Fornengo+ JCAP12(2017)012)

tau channel

- Impact of PICO
- In some cases equilibrium assumption cannot apply anymore



Recent « exotic » scenarios

Mono-energetic ν from stopped mesons

DM annihilates to light quarks (usually suppressed)
In the Sun : hadronic cascade → **mesons (π, K), stopped in dense medium**
few to 10 % of annihilation energy
K decay : **235 MeV ν_μ**, π decay : 30 MeV ν_μ

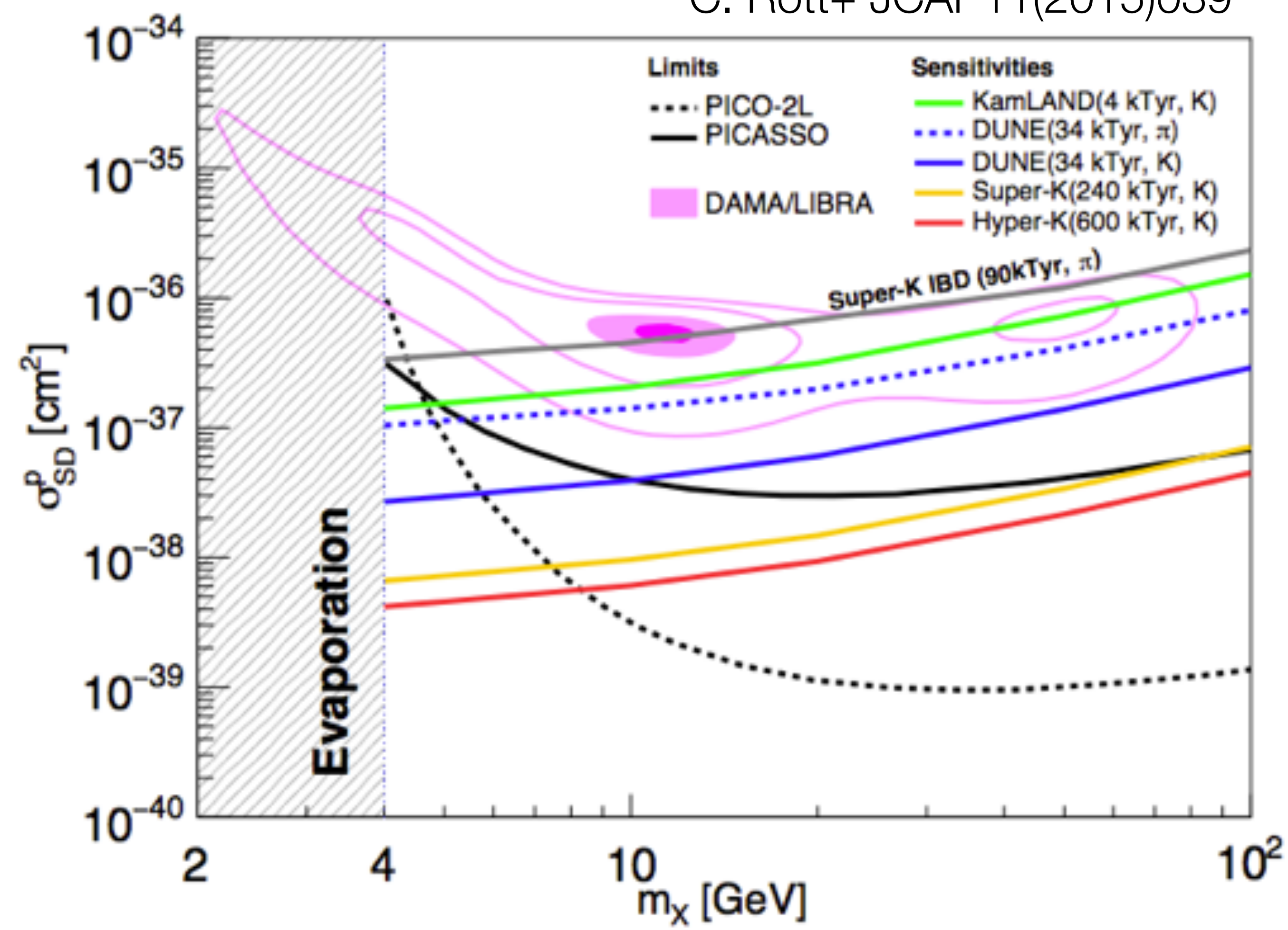
- Simplest detection : CC interaction $\nu_{e/\mu}$ + nucleus => Measure electron energy : HK > DUNE

- LAr also sensitive to low-E pions

- JCAP01(2017)016 : DUNE

  ν(235MeV)+^{40}Ar → l+p+^{39}Ar
  reconstruct full neutrino energy
  direction of recoiling p
  => sensitivity boosted to HK level

C. Rott+ JCAP11(2015)039

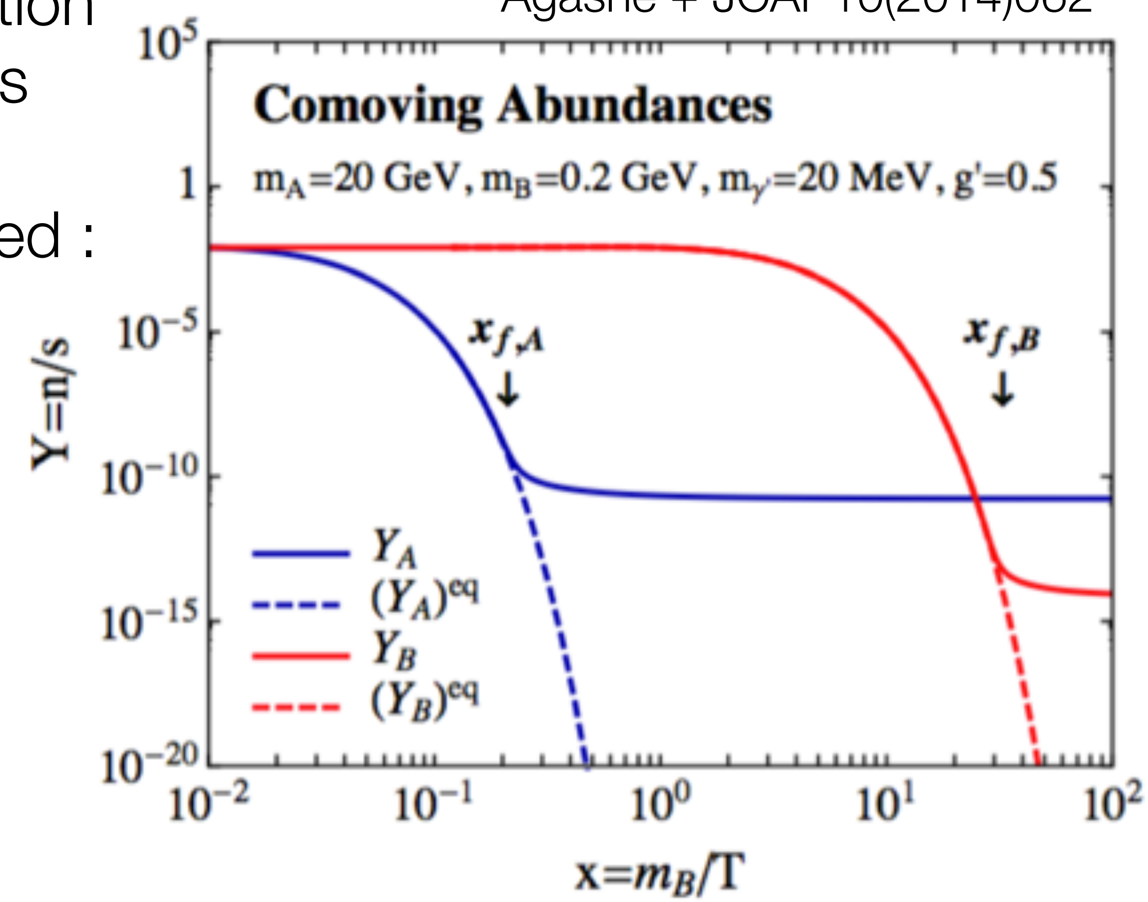


Boosted DM

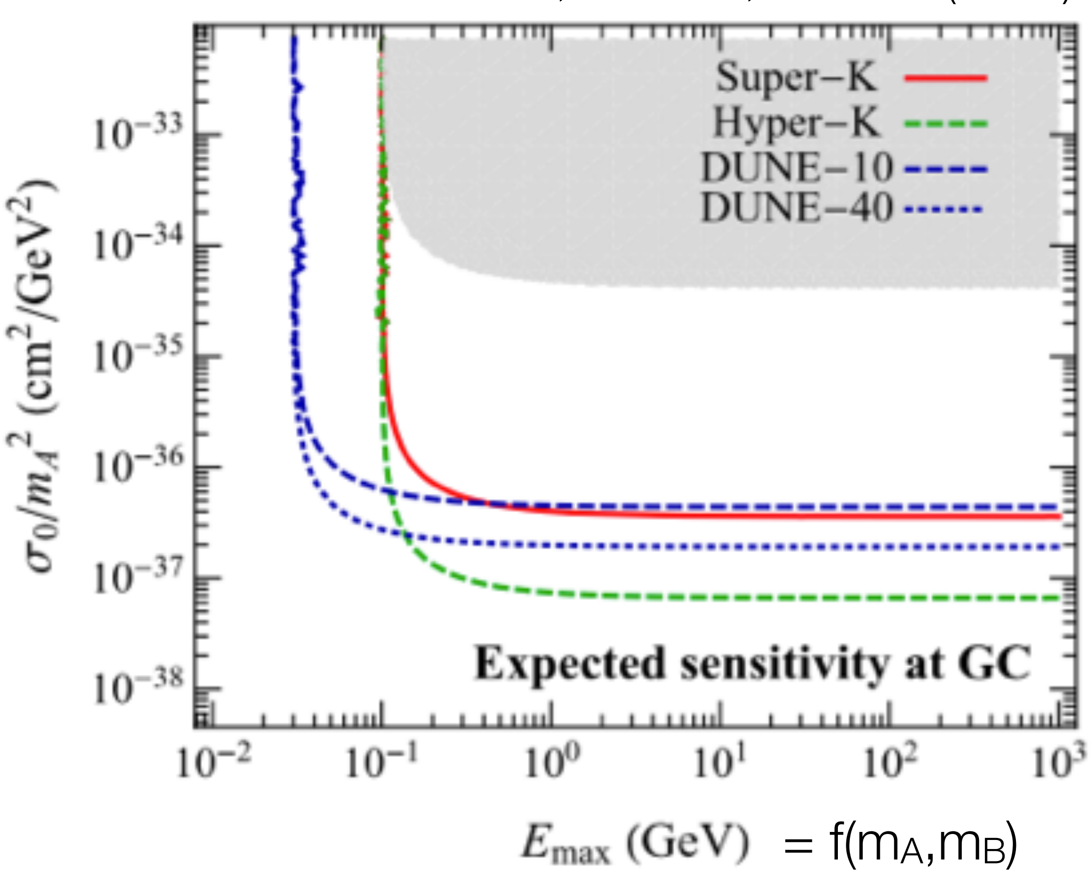
2-component DM (A and B)
A dominant species
@ Sun / GC : A → B (relativistic) by decay or annihilation
« boosted » B elastically forward scatters on electrons

Escape direct detection, neutrino detectors best suited :
high-E electron with direction

Agashe + JCAP10(2014)062



Necib+, PRD 95, 075018 (2017)



= f(m_A,m_B)

SuperK search : 1711.05278
electron evts with E > 100 MeV

Conclusion

- Neutrinos from WIMP DM : an old topic, already many relevant constraints (SK / IC mostly)
- Prospective for future expts : small progress
    - Background limited
    - Strong competition from DD expts (PICO)
    - IC-Gen2 : for M~TeV
    - HK (and DUNE to a smaller extend) : for some specific scenarios with M ~ few GeV