CF2 – Indirect DM Detection

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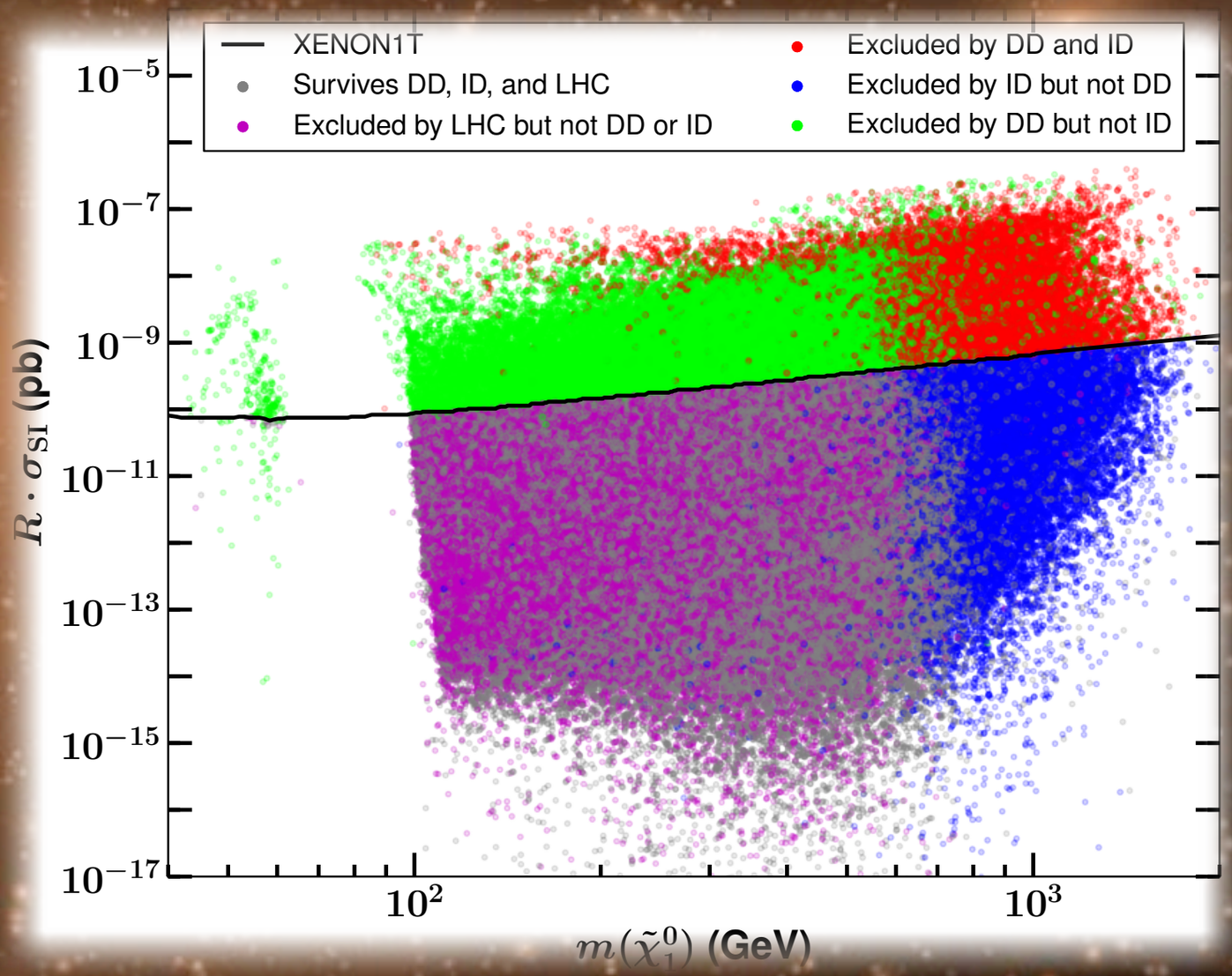
for the CF2 working group
Conveners: J. Buckley, D. Cowan, S. Profumo

Much important work for this topic by the CF4 subgroup

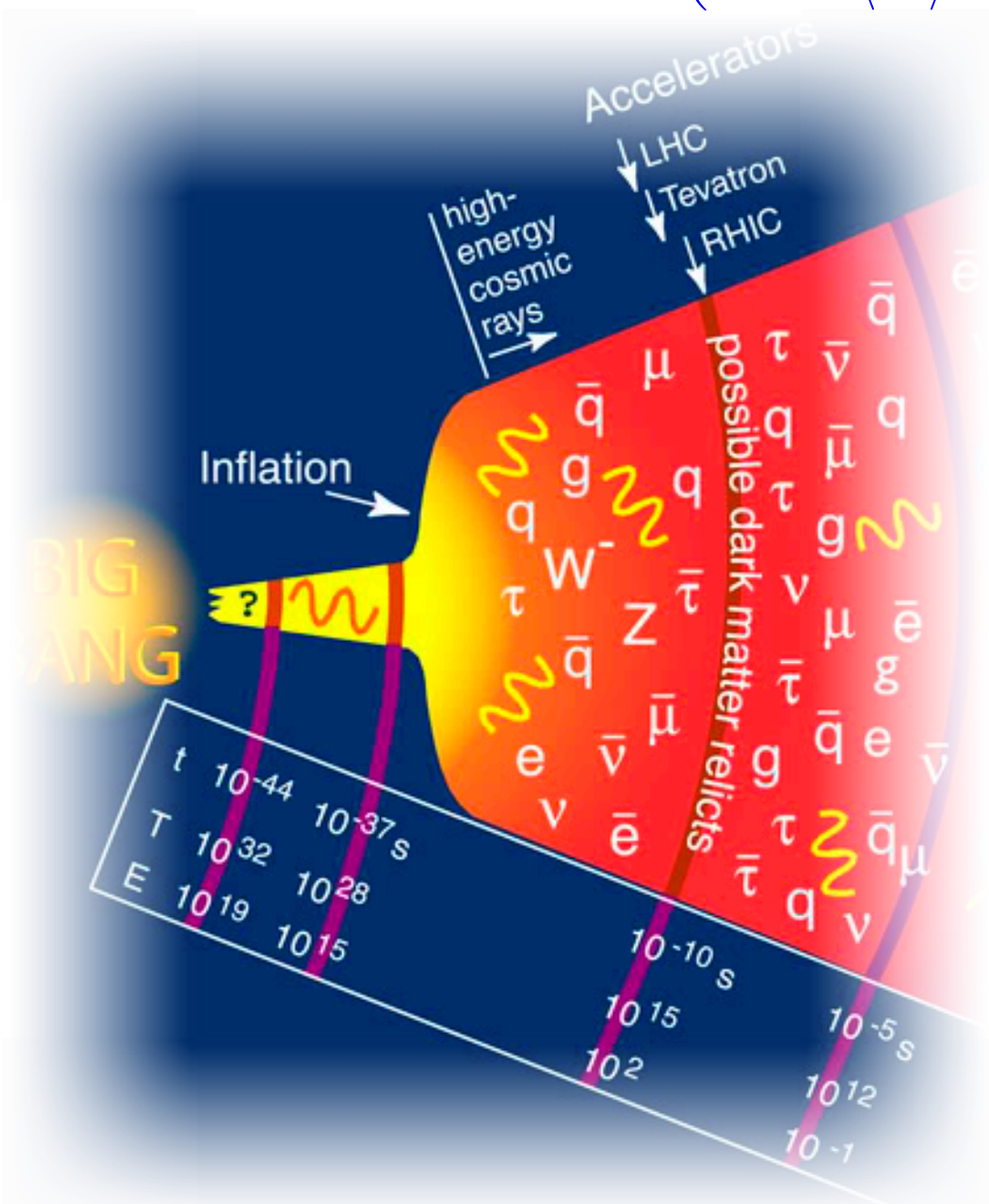
Facilities the topic of later talks in this session

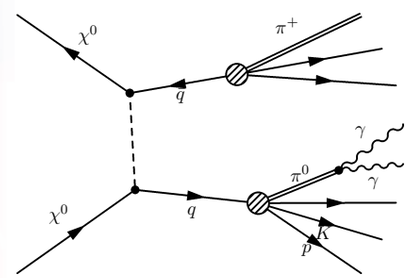


M. Cahill-Rowley, R. Cotta, A. Drlica-Wagner, S. Funk, J. Hewett, A. Ismail, T. Rizzo and M. Wood (SLAC and Irvine Particle Theory groups)

Indirect Detection Cross Section

DM relic abundance : $\Omega_\chi \approx \frac{0.1}{h^2}\left(\frac{3\times 10^{-26}\mathrm{cm}^3\mathrm{sec}^{-1}}{\langle\sigma v\rangle}\right)$





Annihilation Channel	Secondary Processes	Signals
$\chi\chi \to q\bar{q},\ gg$	$p, \bar{p}, \pi^\pm, \pi^0$	p, e, ν, γ
$\chi\chi \to W^+W^-$	$W^\pm \to l^\pm\nu_l,\ W^\pm \to u\bar{d} \to \pi^\pm,\ \pi^0$	p, e, ν, γ
$\chi\chi \to Z^0Z^0$	$Z^0 \to ll,\ \nu\bar{\nu},\ q\bar{q} \to$ pions	p, e, γ, ν
$\chi\chi \to \tau^\pm$	$\tau^\pm \to \nu_\tau e^\pm\nu_e,\ \tau \to \nu_\tau W^\pm \to p, \bar{p}$, pions	
$\chi\chi \to \mu^+\mu^-$		e, γ
$\chi\chi \to \gamma\gamma$ $\chi\chi \to Z^0\gamma$	 Z^0 decay	γ γ
$\chi\chi \to e^+e^-$		e, γ

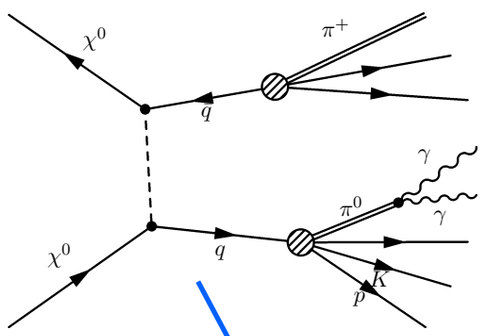
- The same interactions of WIMPs with standard model particles in the early universe (holding WIMPs in thermal equilibrium) imply interactions in the current universe.
- While the cross-section for a specific interaction (e.g., scattering off a nucleon) or annihilation channel is indirectly related to this decoupling cross section, *almost all annihilation channels produce photons and the total annihilation rate to photons is closely related to the decoupling cross section:* $\sim n_\chi^2\langle\sigma v\rangle$

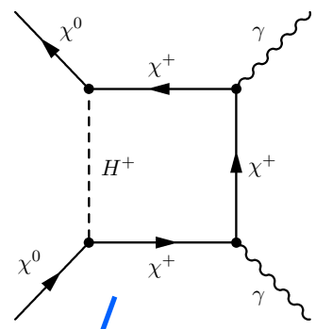
** Gamma-ray production by annihilation in the present universe is closely related to the decoupling cross section in the early universe with a natural scale* $\langle\sigma v\rangle \approx 3\times 10^{-26}\mathrm{cm}^3\mathrm{sec}^{-1}$

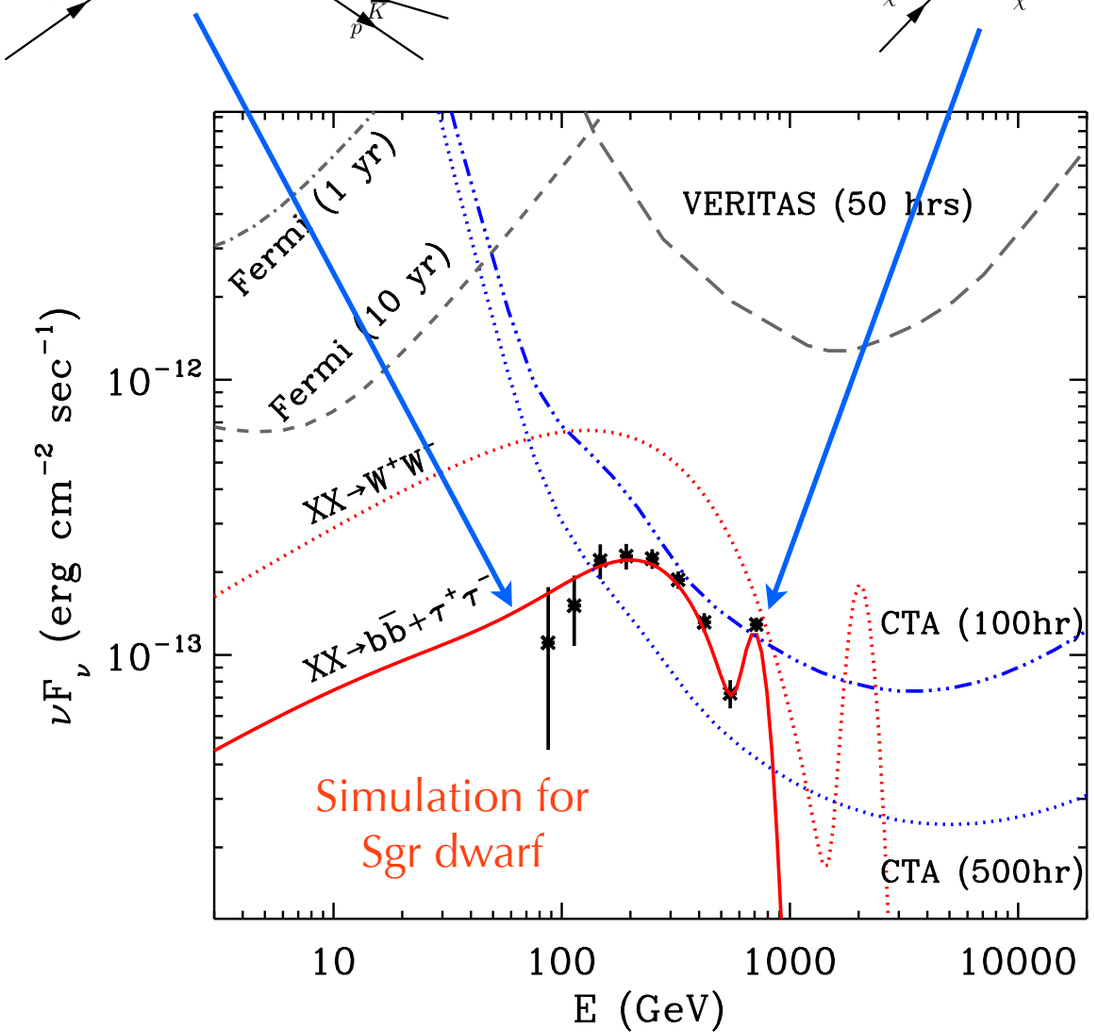
Particles from DM Annihilation

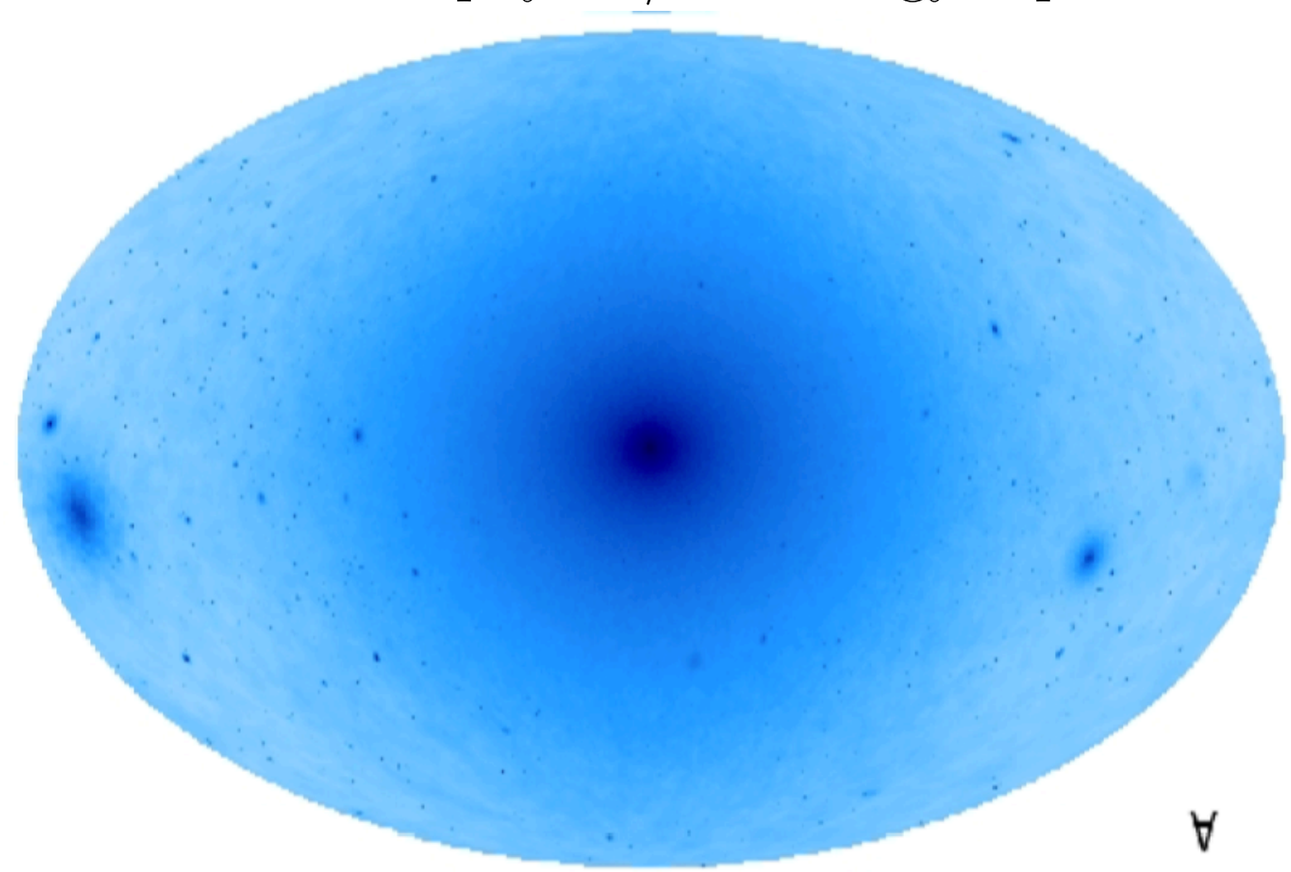
$$E_\gamma \Phi_\gamma(\theta) \approx 10^{-10} \underbrace{\left(E_{\gamma,\mathrm{TeV}} \frac{dN}{dE_{\gamma,\mathrm{TeV}}}\right) \left(\frac{\langle \sigma v \rangle}{10^{-26}\mathrm{cm}^{-3}\mathrm{s}^{-1}}\right) \left(\frac{100\,\mathrm{GeV}}{M_\chi}\right)^2}_{\text{Particle Physics Input}} \underbrace{J(\theta)}_{} \ \mathrm{erg\,cm^{-2}s^{-1}sr^{-1}}$$

$$J(\theta) = \underbrace{\frac{1}{8.5\,\mathrm{kpc}} \left(\frac{1}{0.3\,\mathrm{GeV/cm^3}}\right)^2 \int_{\text{line of sight}} \rho^2(l) dl(\theta)}_{\text{Astrophysics/Cosmology Input}}$$



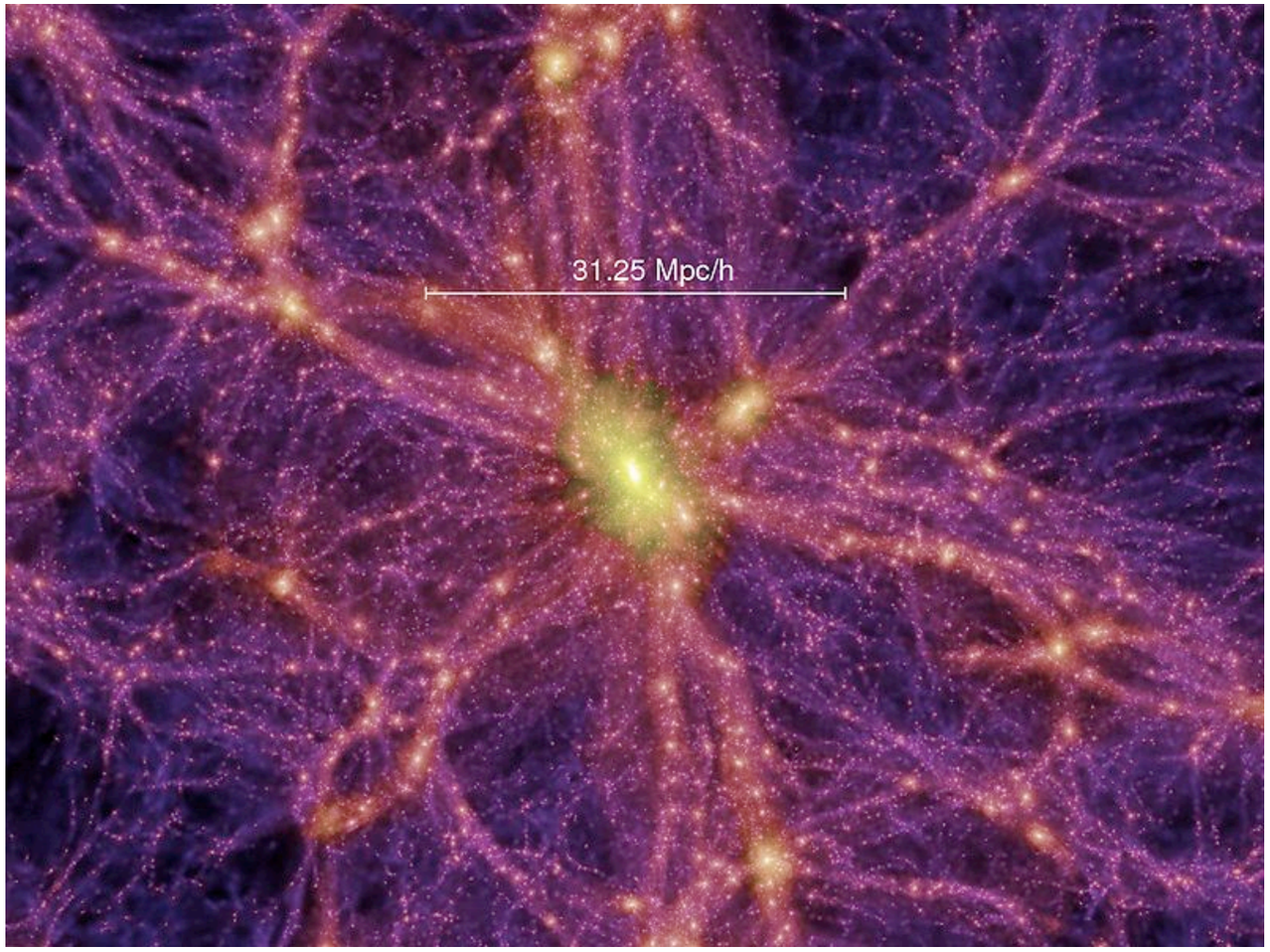




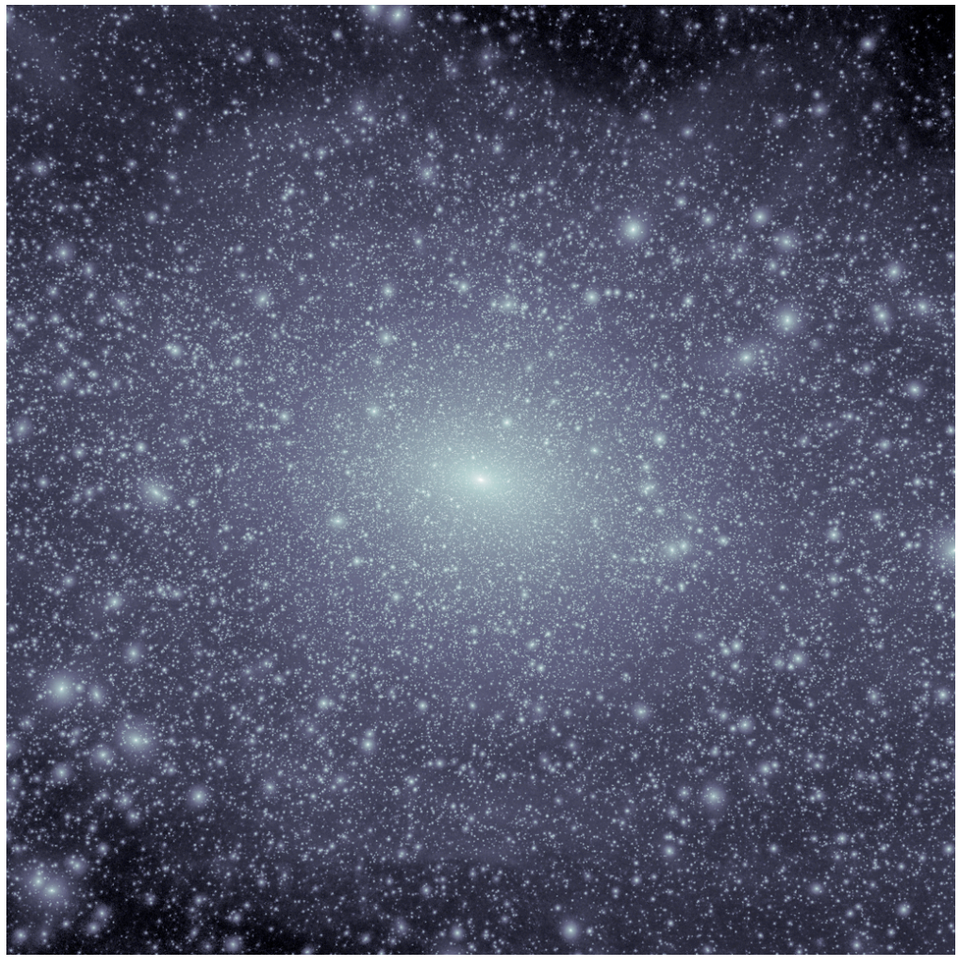


Line-of-sight integral of ρ^2 for a Milky-Way-like halo in the VL Lactea II ΛCDM N-body simulations (Kuhlen et al.)

Dark Matter Halos



(Millenium simulation)



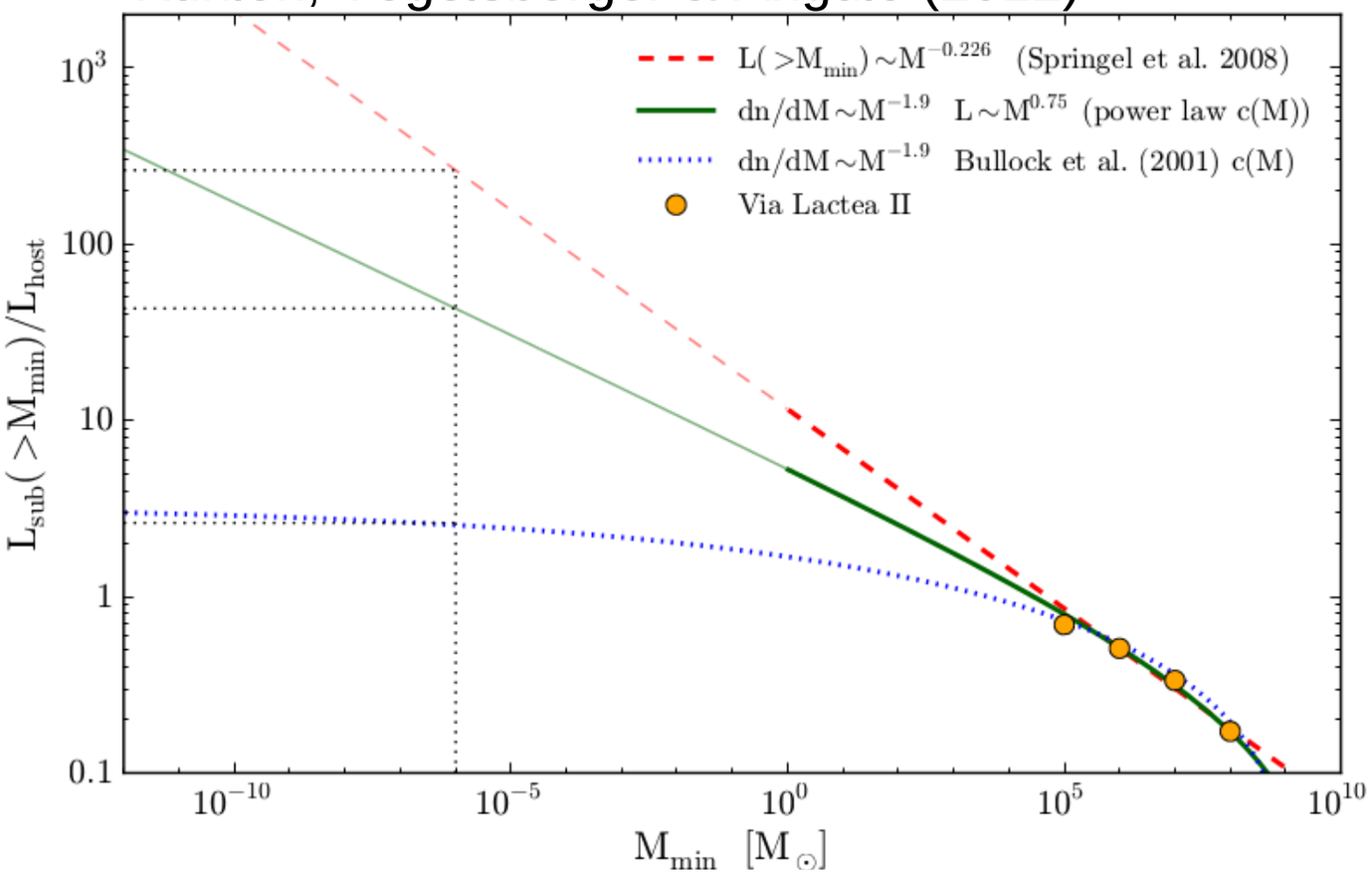
(VL Lactea II Simulation)

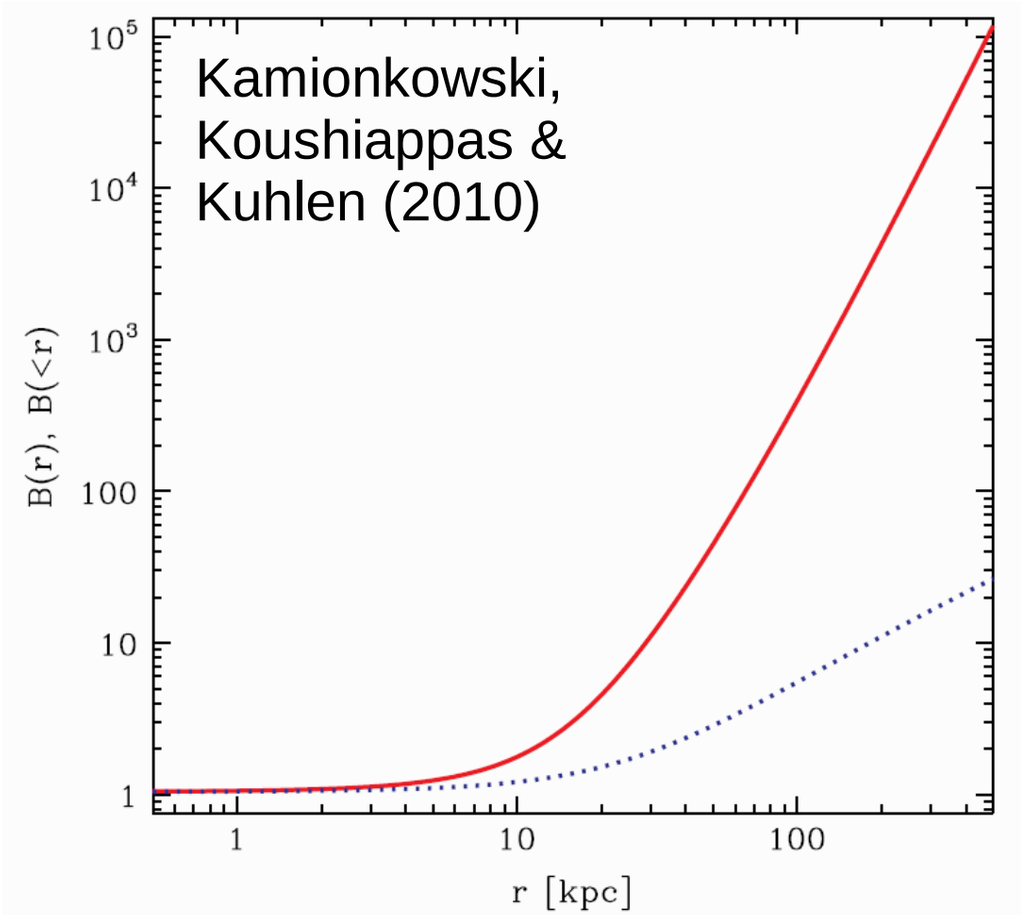
- Cold dark matter also required for structure formation. In regions of highest density, WIMPS (e.g., neutralinos) annihilate, forming standard model particles and photons

- Indirect detection can link a new particle created in a terrestrial accelerator to dark matter halos, for gamma-ray measurements providing a measurement of the halo profile and substructure.

Clumps & Boosts

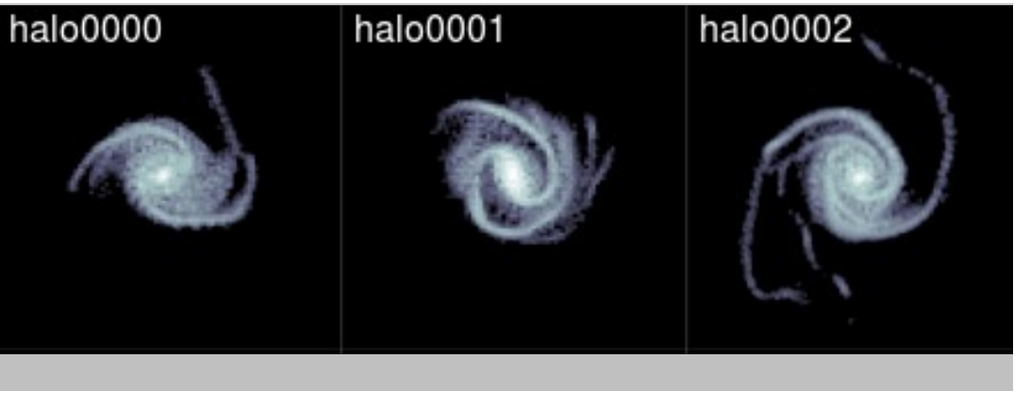
Kuhlen, Vogelsberger & Angulo (2012)

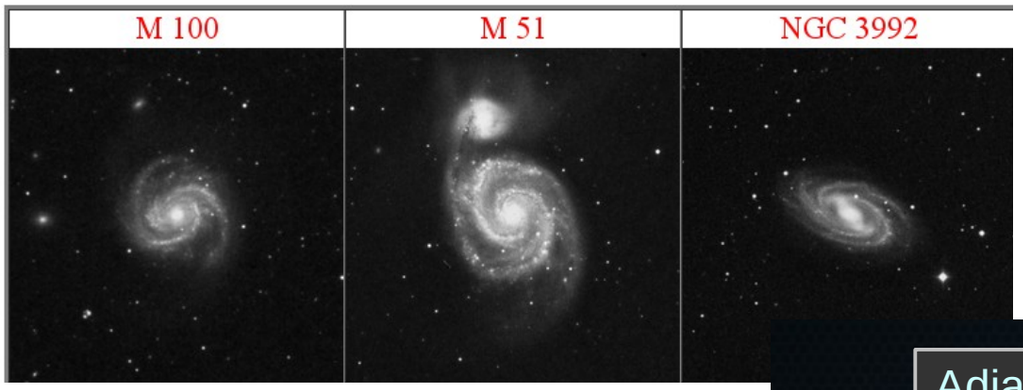




- Since annihilation signal is $\sim\rho^2$, substructure of halos could give large boosts in signal. While this is likely to be a factor for galaxy clusters, probably not a big factor in inner Galaxy (but extrapolating mass function and role of baryons is tricky)

Baryonic Feedback

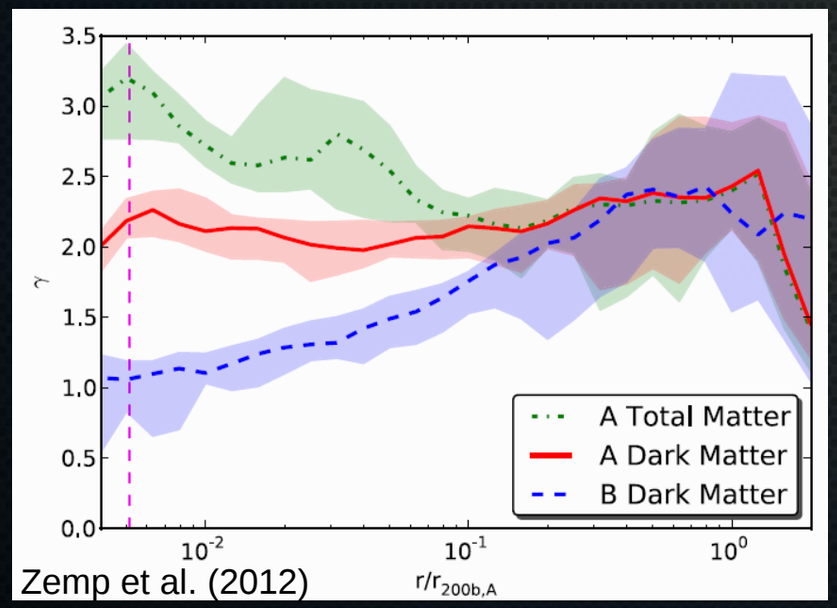




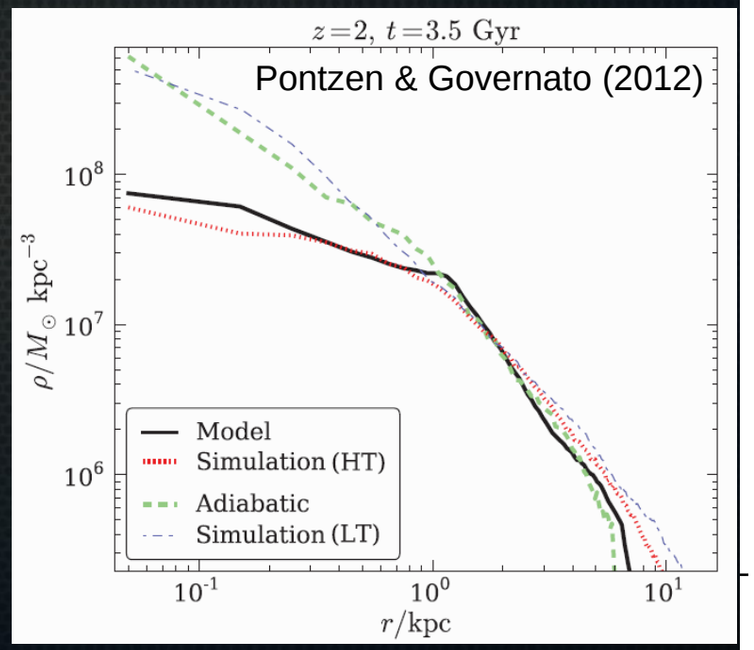
- Adding baryons to N-body simulations starting to give amazing results - similar morphology, Tully-Fisher relation.
- But jury is out on effects on Milky Way-like (or dwarf) halos.

Adiabatic contraction steepens the DM profile and **increases central DM densities**.

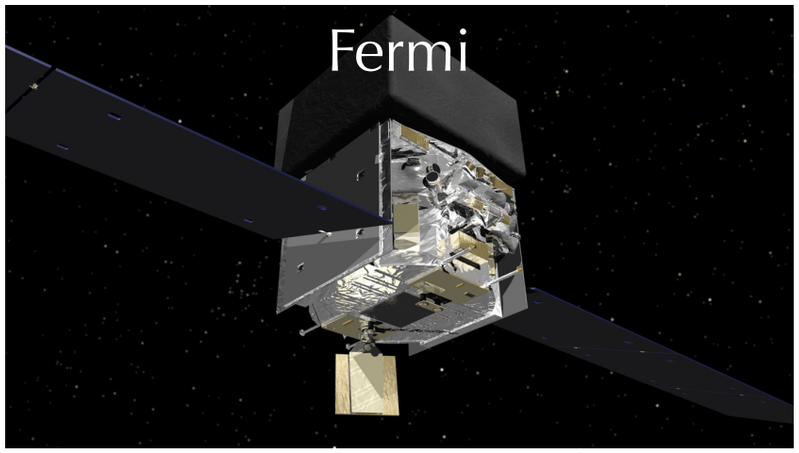
Impulsive supernova (or AGN) feedback **removes DM from the center** and flattens the DM cusp.



Zemp et al. (2012)

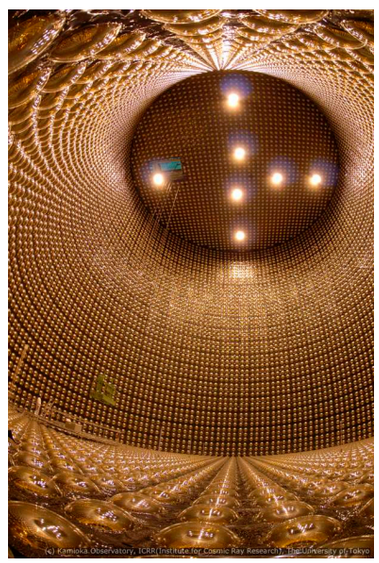


Indirect Detection

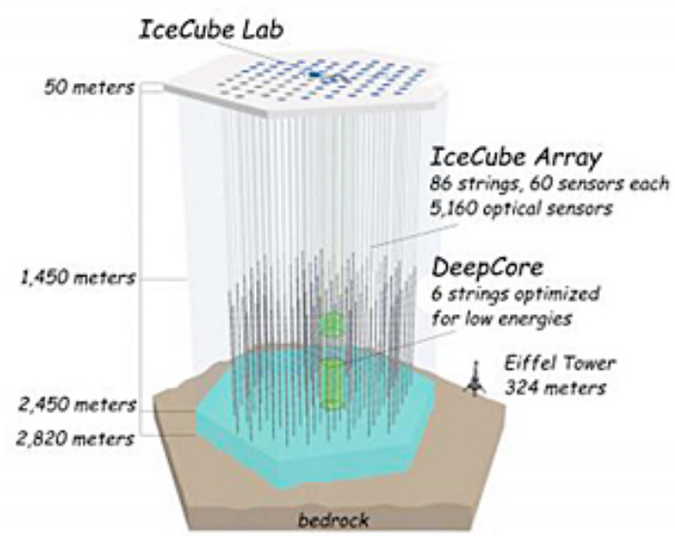


γ

Super-K

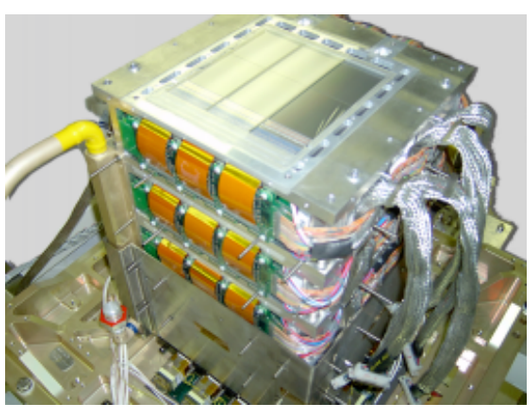


ν

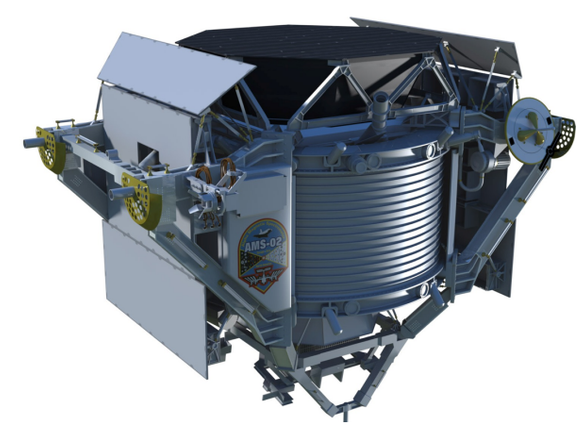


ICECUBE

PAMELA



$e^-, e^+, p, \bar{p}$

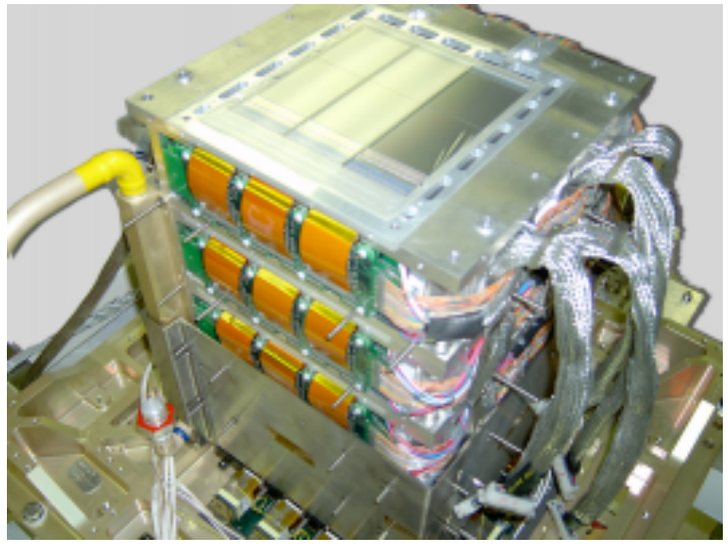


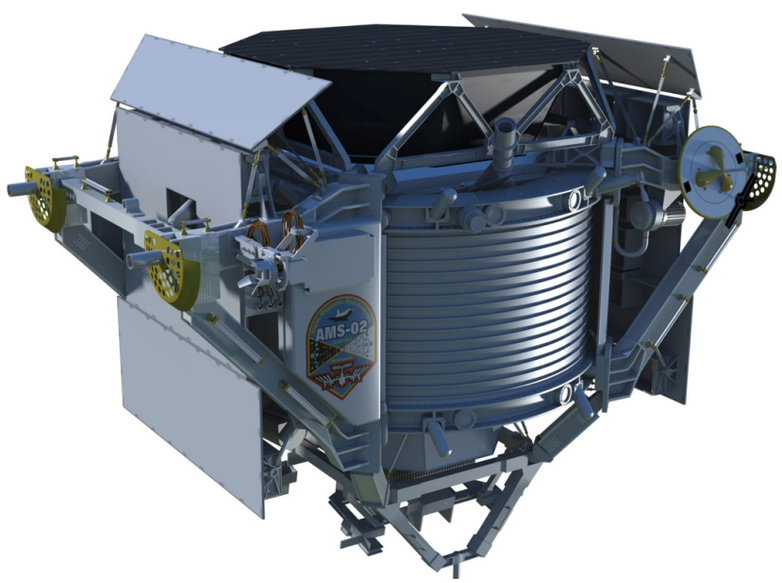
AMS

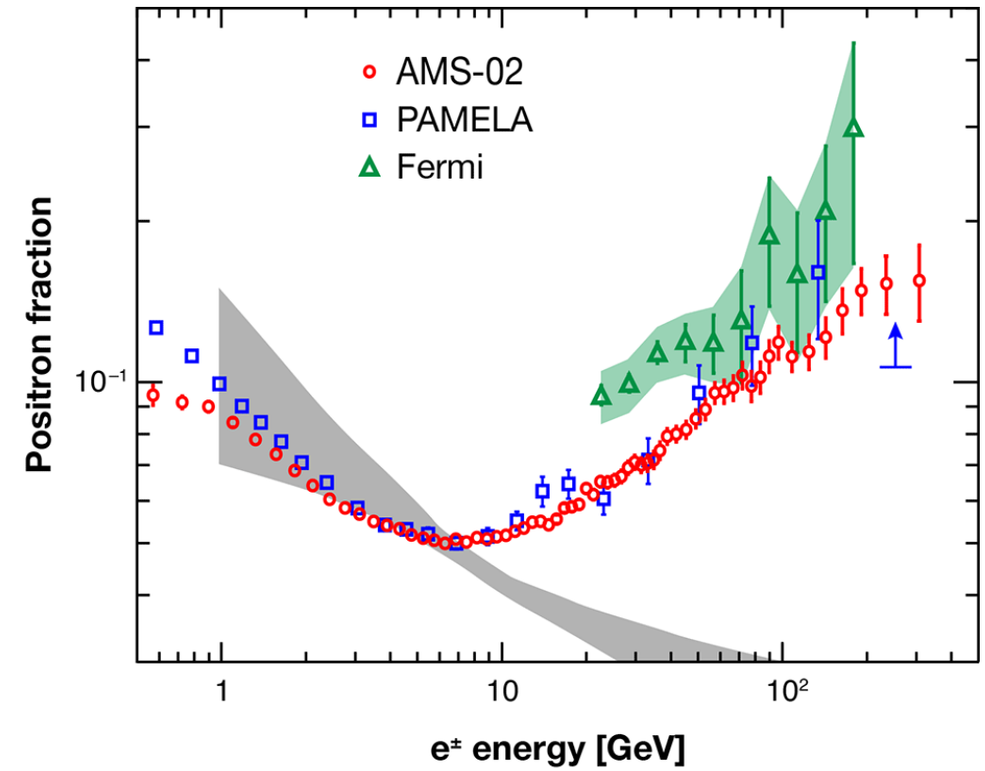
Current and Planned Experiments

Status	Experiment	Target	Location	Major Support	Comments
Current	AMS	e^+/e^-, anti-nuclei	ISS	NASA	Magnet Spectrometer, Running
	Fermi	Photons, e^+/e^-	Satellite	NASA, DOE	Pair Telescope and Calorimeter, Running
	HESS	Photons, e^-	Namibia	German BMBF, Max Planck Society, French Ministry for Research, CNRS-IN2P3, UK PPARC, South Africa	Atmospheric Cherenkov Telescope (ACT), Running
	IceCube/ DeepCore	Neutrinos	Antarctica	NSF, DOE, International *Belgium, Germany, Japan, Sweden)	Ice Cherenkov, Running
	MAGIC	Photons, e^+/e^-	La Palma	German BMBF and MPG, INFN, WSwiss SNF, Spanish MICINN, CPAN, Bulgarian NSF, Academy of Finland, DFG, Polish MNiSzW	ACT, Running
	PAMELA	e^+/e^-	Satellite		
	VERITAS	Photons, e^+/e^-	Arizona, USA	DOE, NSF, SAO	ACT, Running
Planned	CALET	e^+/e^-	ISS	Japan JAXA, Italy ASI, NASA	Calorimeter
	CTA	Photons	ground-based (TBD)	International (MinCyT, CNEA, CONICET, CNRS-INSU, CNRS-IN2P3, Irfu-CEA, ANR, MPI, BMBF, DESY, Helmholtz Association, MIUR, NOVA, NWO, Poland, MICINN, CDTI, CPAN, Swedish Research Council, Royal Swedish Academy of Sciences, SNSF, Durham UK, NSF, DOE	ACT
	GAMMA-400	Photons	Satellite	Russian Space Agency, Russian Academy of Sciences, INFN	Pair Telescope
	GAPS	Anti-deuterons	Balloon (LDB)	NASA, JAXA	TOF, X-ray and Pion detection
	HAWC	Photons, e^+/e^-	Sierra Negra	NSF/DOE	Water Cherenkov, Air Shower Surface Array
	PINGU	Neutrinos	Antarctica	NSF	Ice Cherenkov

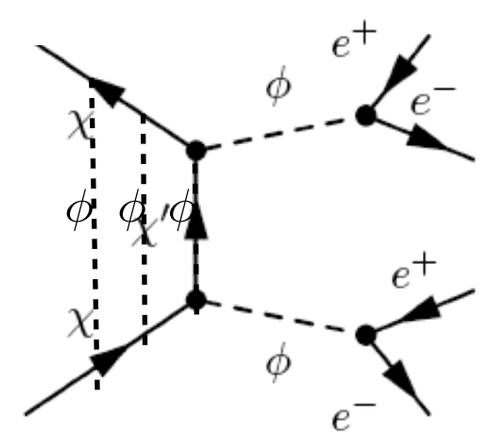
Positron Results





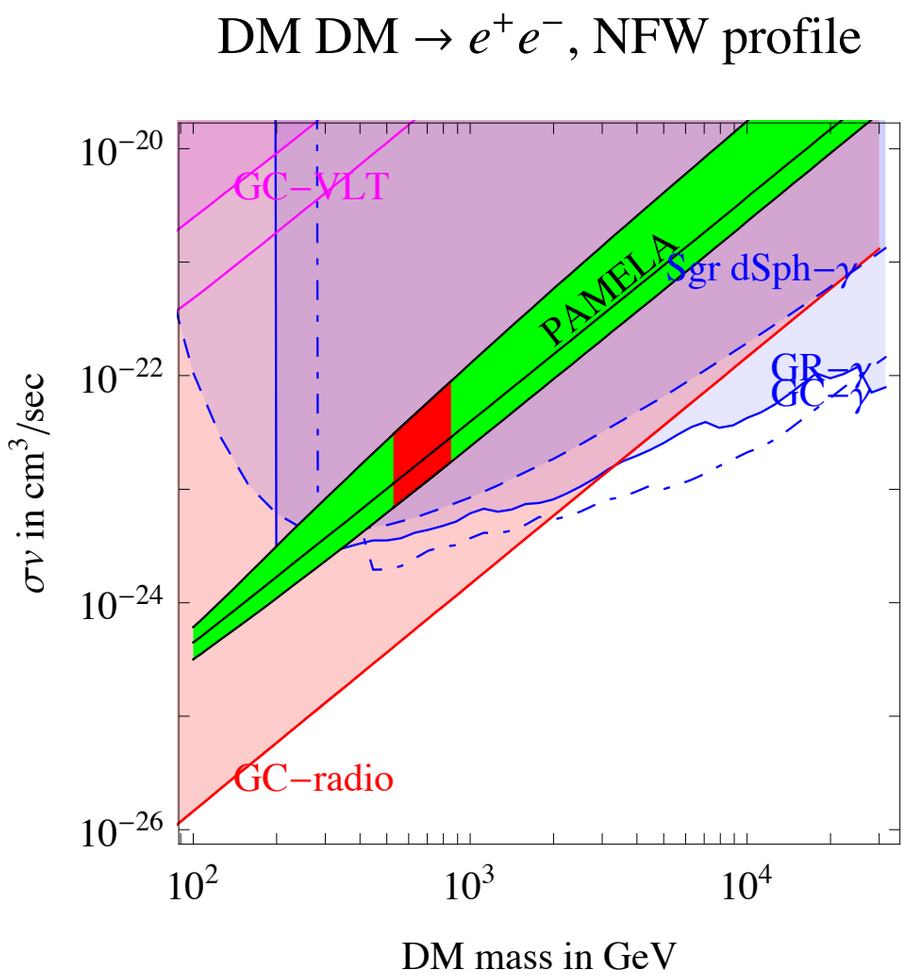


New dark sector force carrier giving a Sommerfeld enhancement, hadronic channels kinematically inaccessible (e.g., Arkani-Hamed, Finkbeiner, Slatyer and Weiner, 1999, PRD 79, 015014)



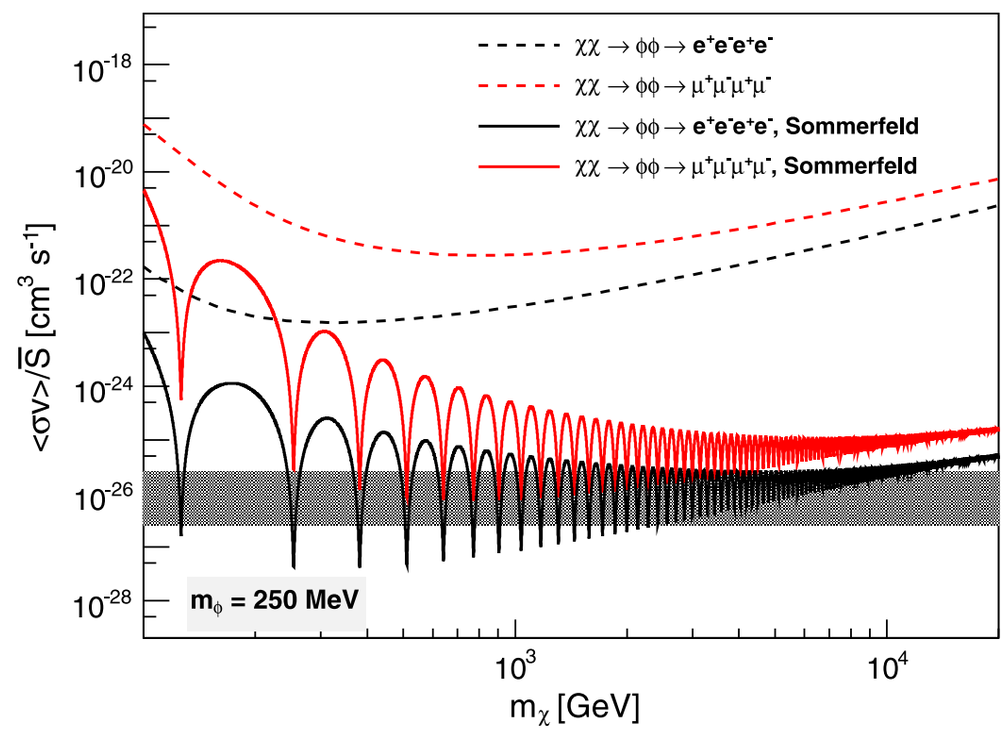
- Pamela results on positron excess are now confirmed by Fermi (using geomagnetic field) and AMS result.
- Signal may also be explained by some cosmic-ray propagation models, or by astrophysical sources such as pulsars.
- A DM interpretation requires a combined astrophysical/particle physics boost of 100 or more.

Shedding Light on Positrons



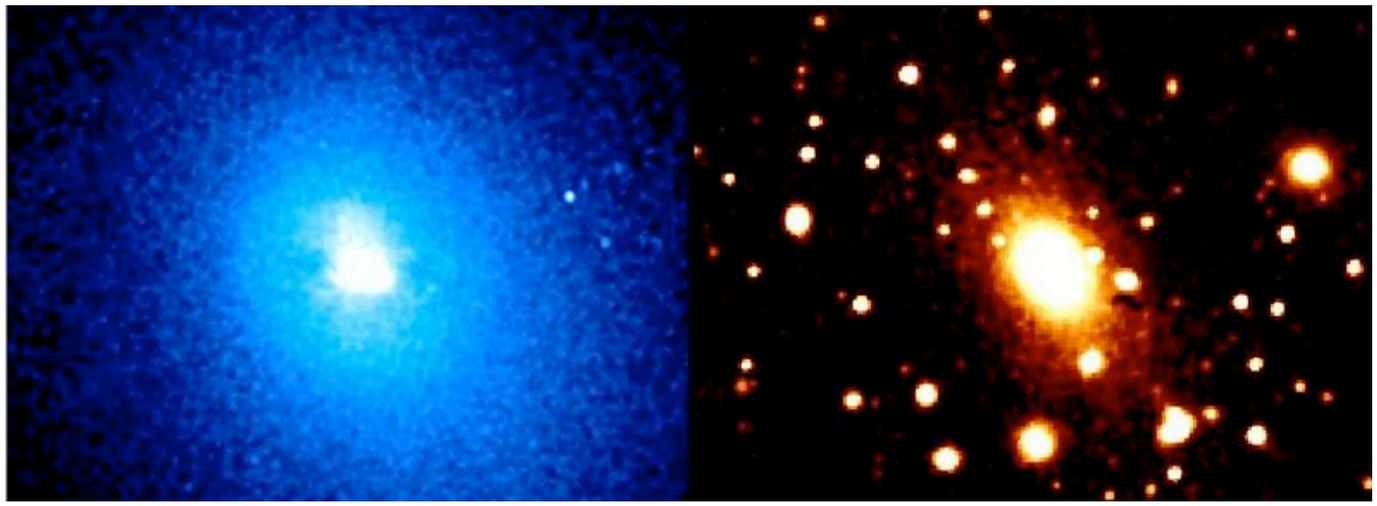
Radio Synchrotron and gamma-ray IC limits for Pamela scenario (Bertone, Cirelli, Strumia and Taoso, arXiv:0811.3744v3). *Note: Radio bounds are sensitive to assumptions about B-fields and diffusion, may be optimistic.*

VERITAS Segue Limits with Sommerfeld Enhancement

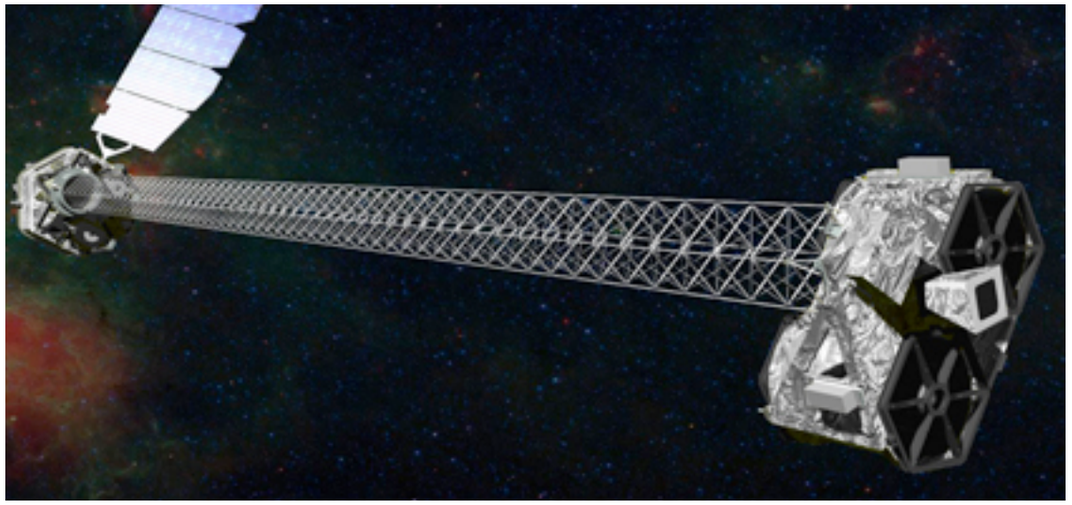


- PAMELA excess implies a large radio synchrotron and inverse Compton signal, and a boost in secondary gammas from the GC that are not observed.

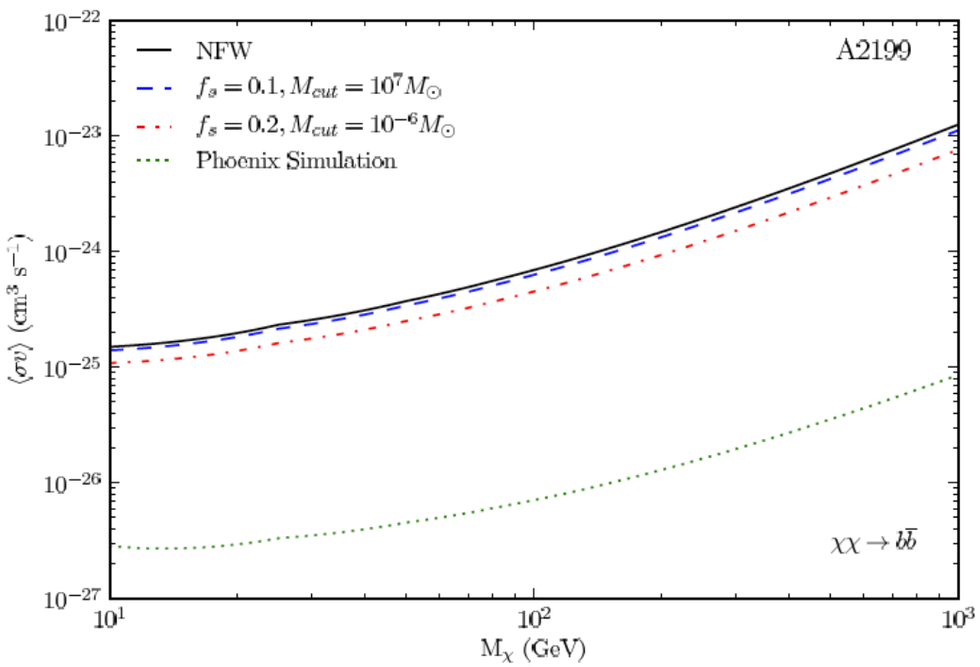
Astrophysical Constraints



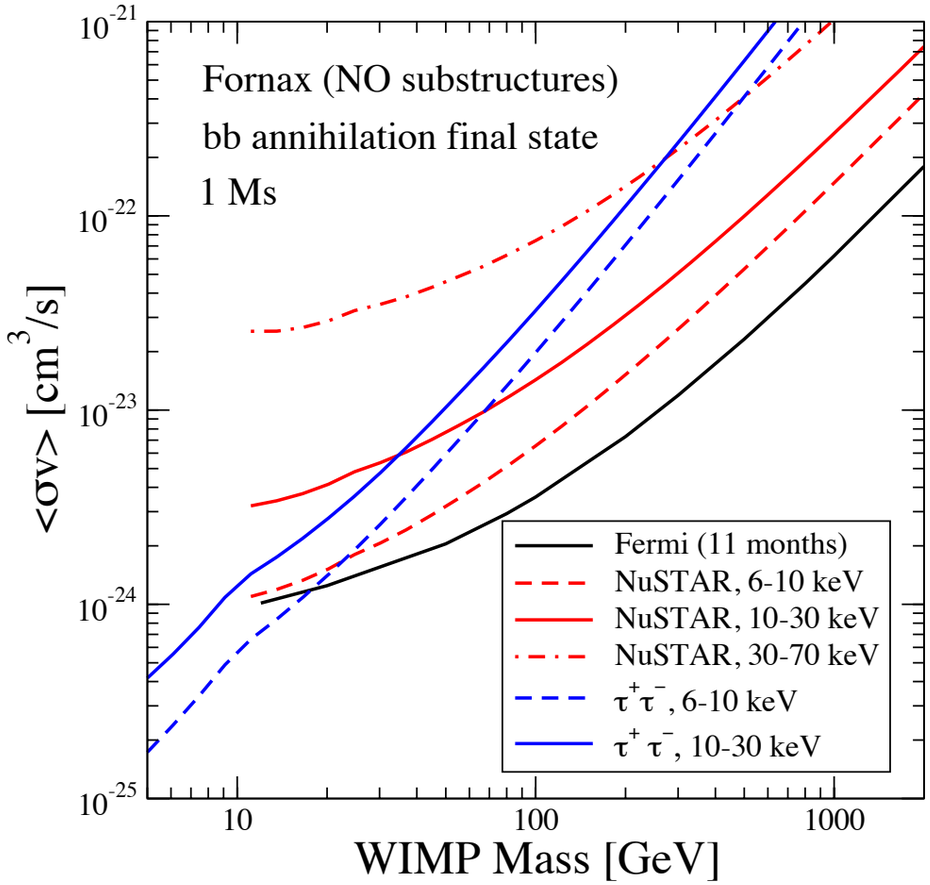
Projected X-Ray (NuSTAR) constraints on Fornax cluster compared with Fermi gamma-ray constraints



Radio Constraints on Galaxy Cluster (A2199)



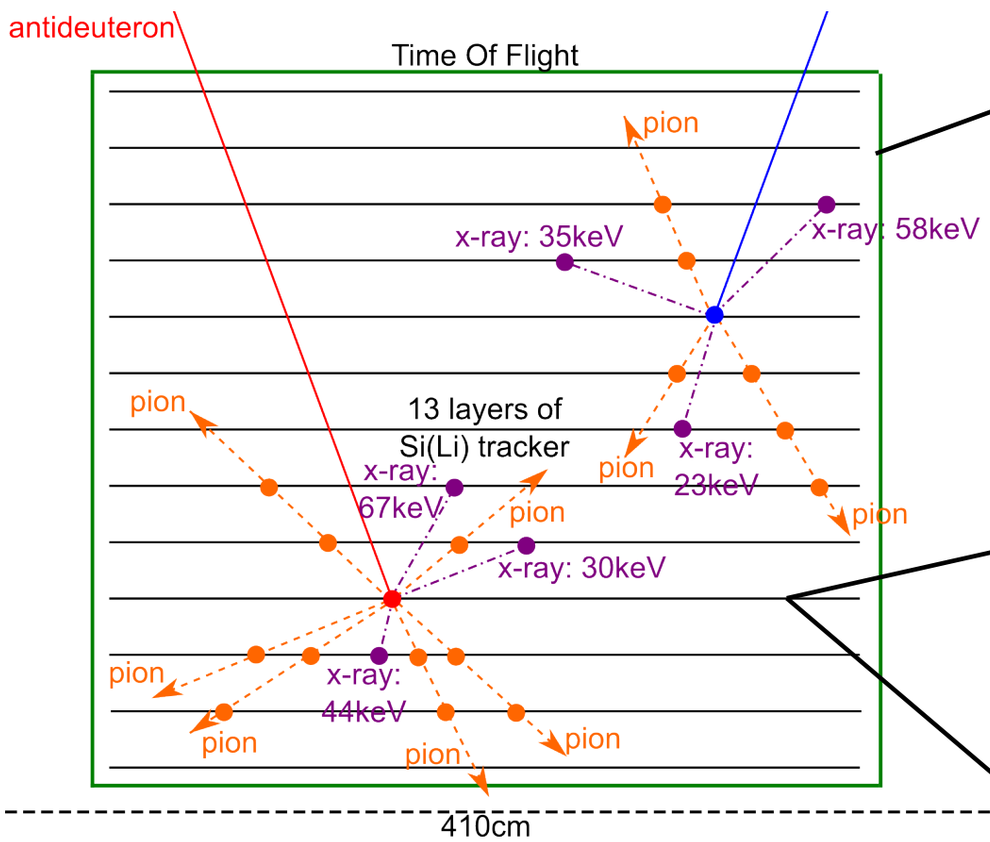
(SLAC CF Talk by T. Jeltema)

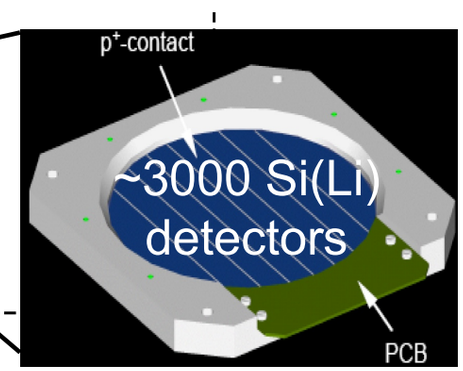


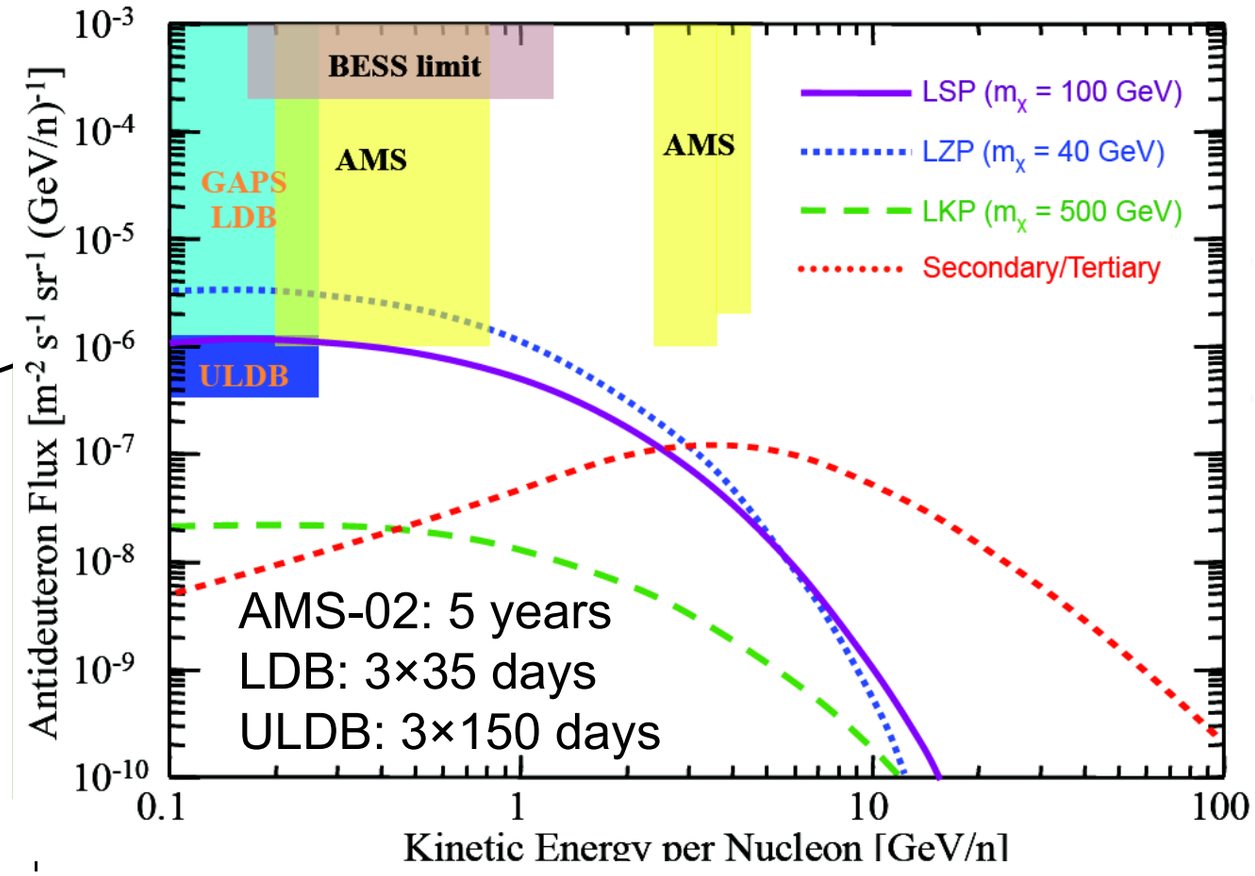
- When the magnetic field and diffusion are understood, radio constraints on DM can be important.
- Electrons up-scatter CMB photons, producing a measurable X-ray signal and DM constraints

Antideuteron Measurements

(SLAC CF Workshop talk
by P. von Doetinchem)

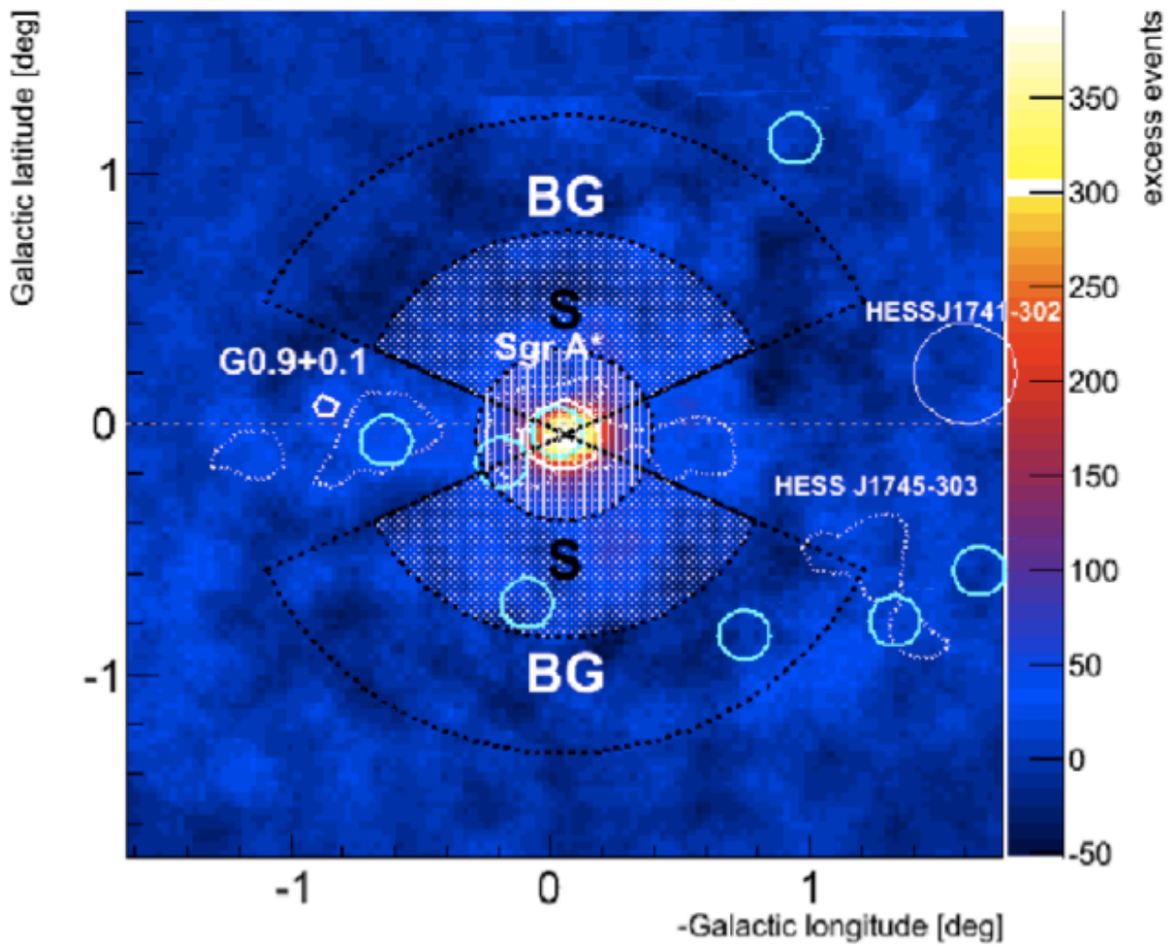




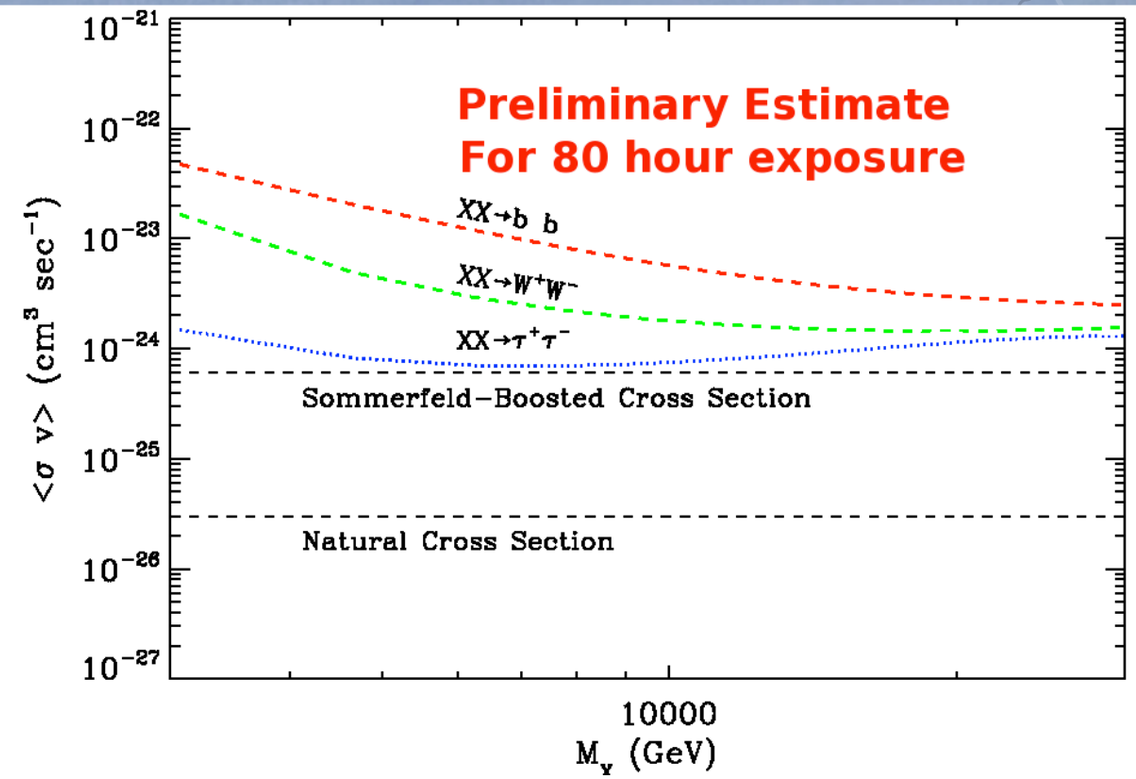


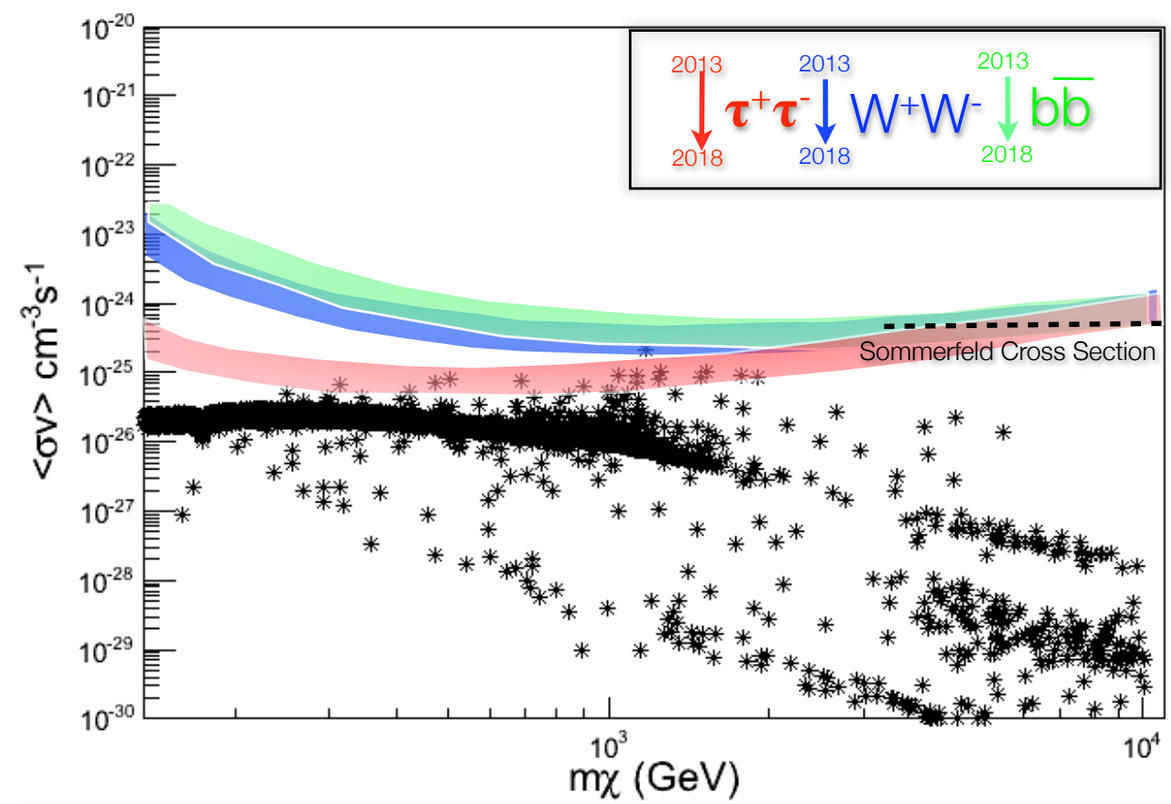
- GAPs looks for anti-deuterons (hard to produce as CR secondaries), uses TOF, X-rays from short-lived exotic atom, pion star from annihilation

VERITAS Projections



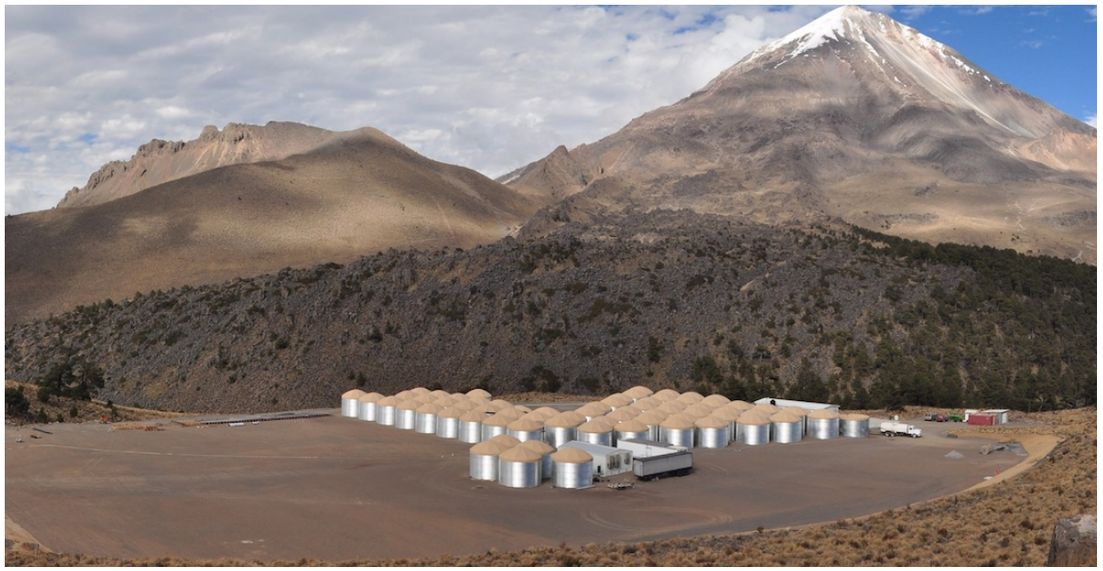
A. Smith et al. - Snowmass white paper

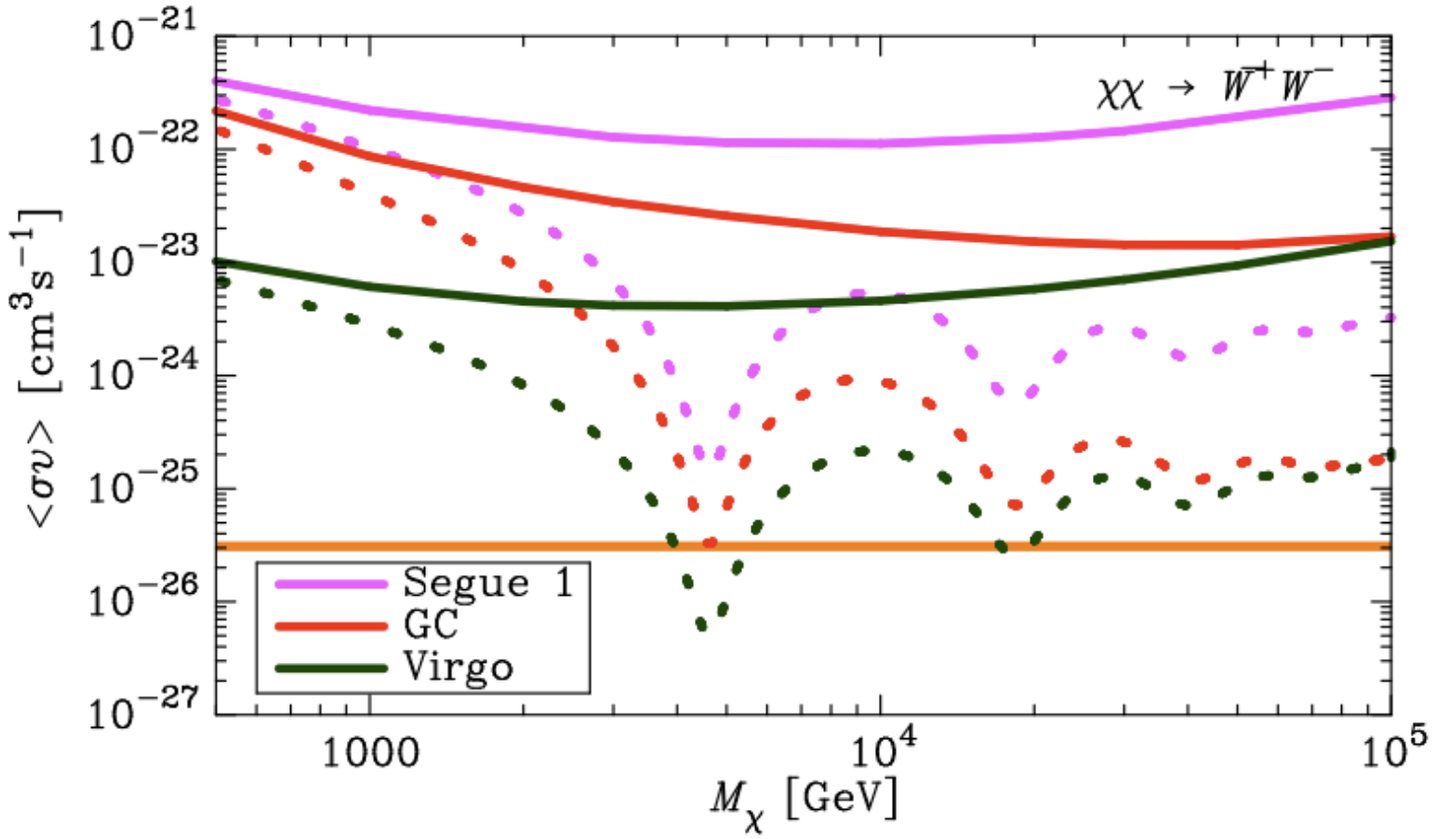


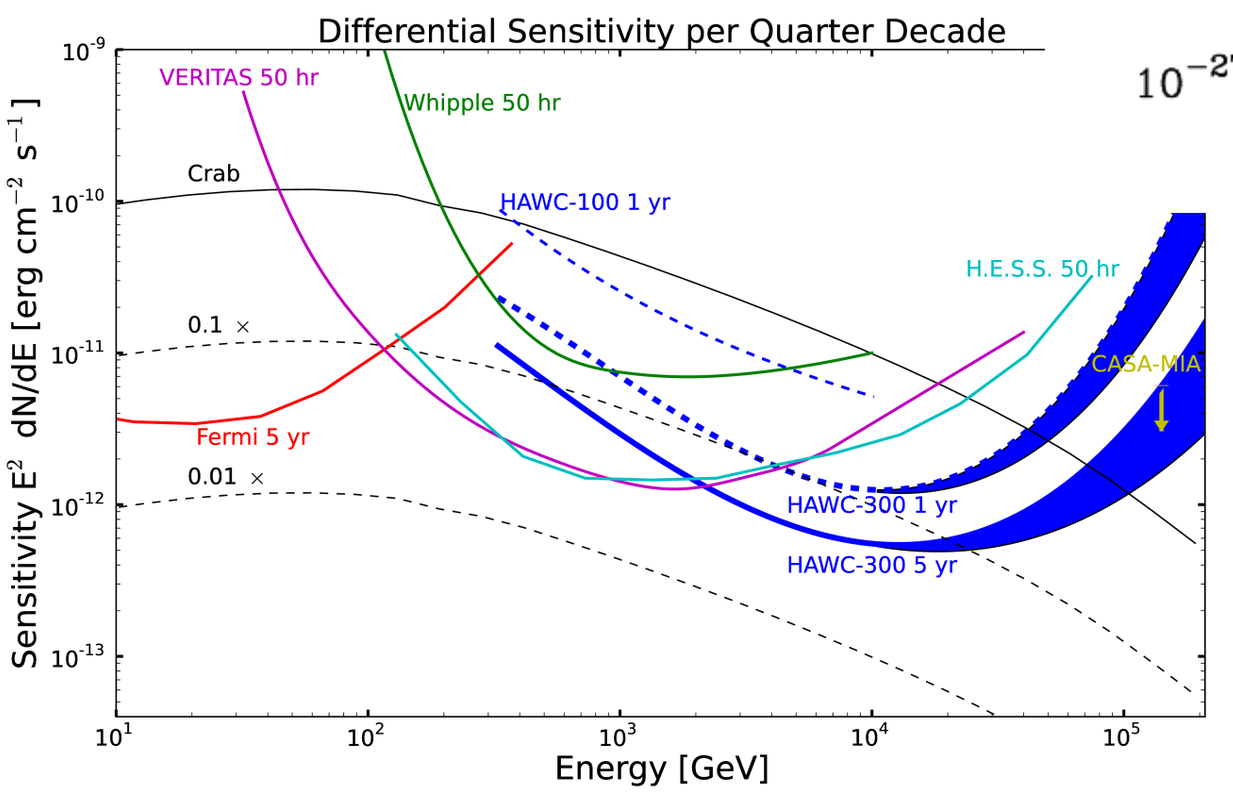


- With another 5 years, can push limits with VERITAS down into interesting cross-section regime

Dark Matter with HAWC

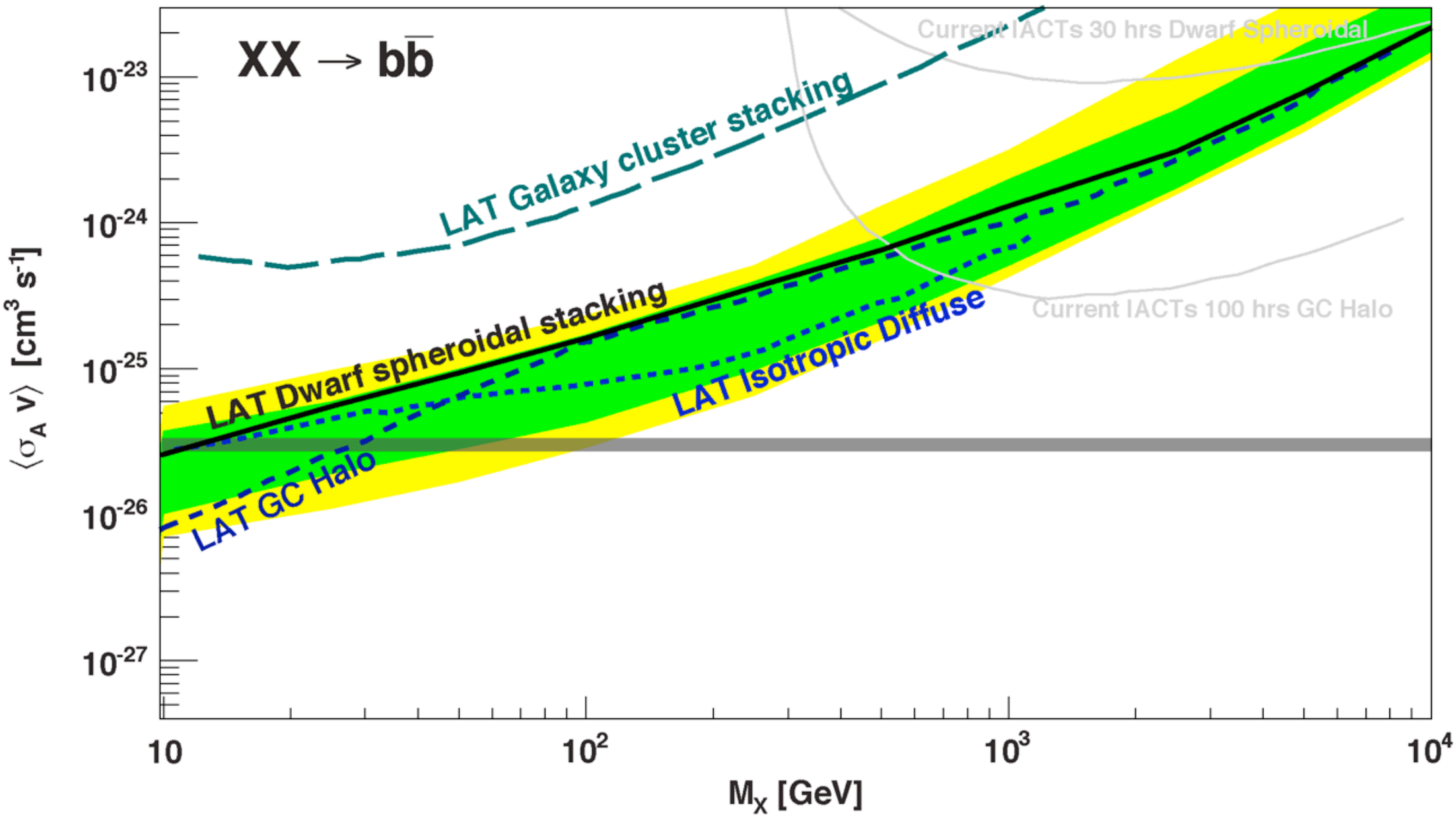






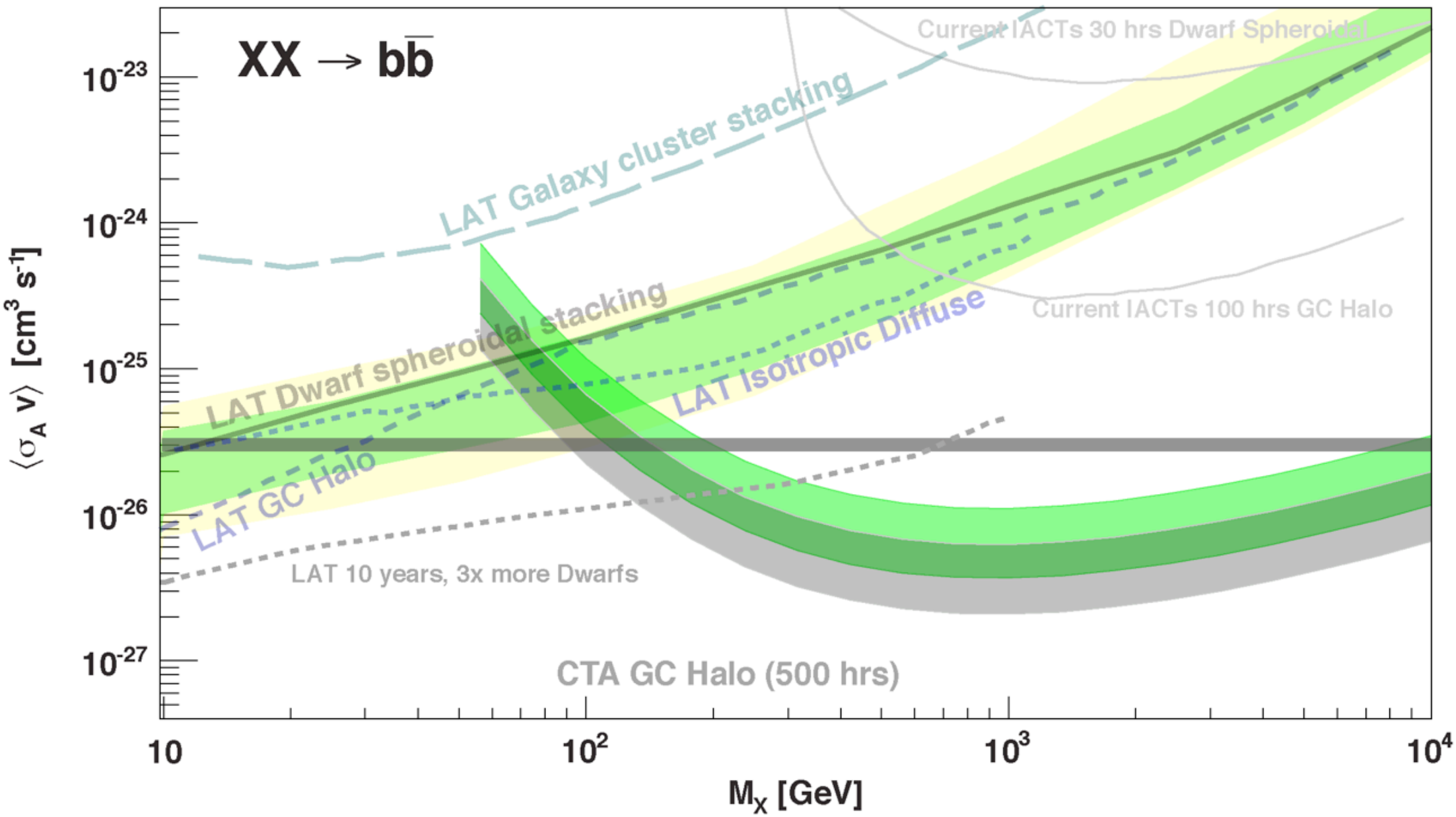
Dashed lines include Sommerfeld enhancement

CTA covers the high-mass WIMP space left open by Fermi-LAT



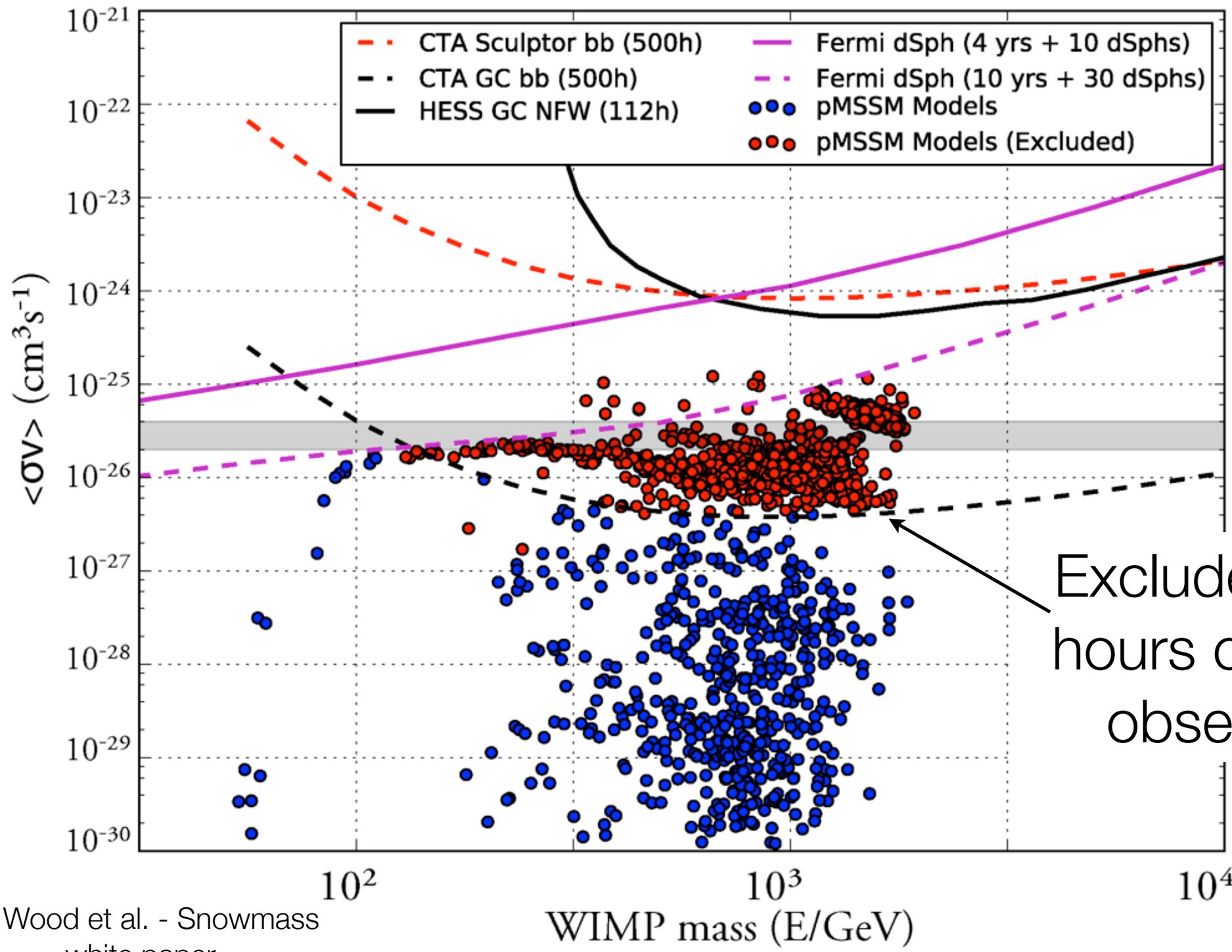
S. Funk CF6 parallel talk

CTA covers the high-mass WIMP space left open by Fermi-LAT



S. Funk CF6 parallel talk

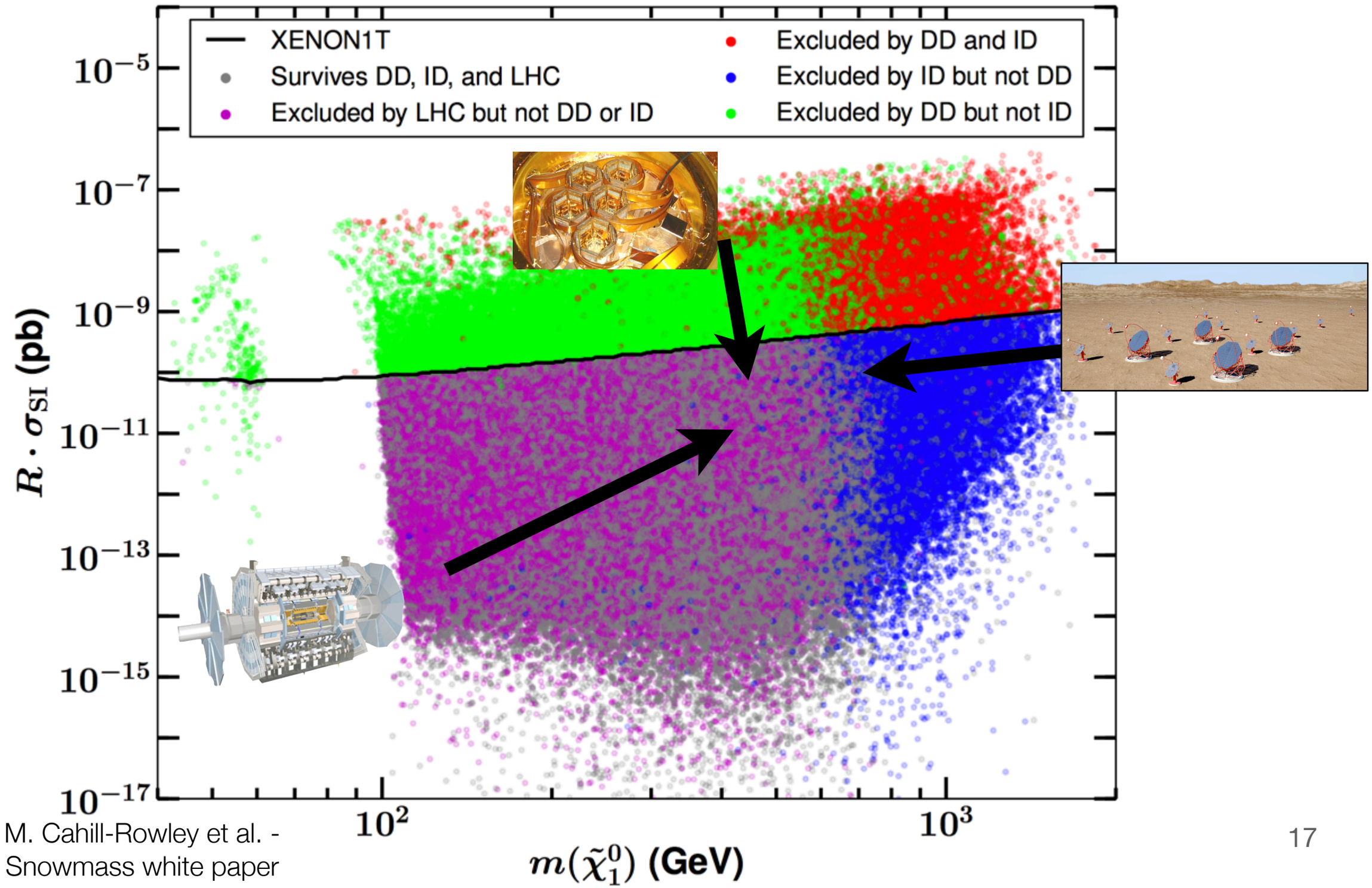
Vanilla dark matter WIMPs covered by ~2020



Excluded by 500 hours of GC halo observations

M. Wood et al. - Snowmass white paper

Complementarity -SUSY scan (pMSSM)



M. Cahill-Rowley et al. - Snowmass white paper

A Possible Timeline

e array

2013

YOU ARE HERE

2014

2015

2016

2017

2018

2020

LUX sees
elastic scat
consistent
mass <

Xenc
a simil

Mass: 150 +/- 0.1 GeV	Mass: 20 μeV
☑ Spin: > 0	☑ Spin: 0
☐ Stable?	☒ Stable?
Couplings:	Couplings:
☑ Gravity	☑ Gravity
☒ Weak Interaction?	☑ Weak Interaction
☐ Higgs?	☐ Higgs?
☑ Quarks / Gluons	☐ Quarks / Gluons?
☑ Leptons	☐ Leptons?
☑ Thermal Relic	☒ Thermal Relic?

A multi-pronged search strategy identifies a mixture of dark matter which is 50% classic WIMP and 50% axion.

Fermi observes a faint gamma ray line at 150 GeV from the galactic center.

Neutrinos are seen coming from the Sun by IceCube.

A positive signal of axion conversion is observed at an upgraded ADMX.

Observation at a Higgs factory indicates that the interaction with leptons is too strong to saturate the relic density.

Measure dark matter density profile of our Galaxy with CTA

S. Funk's extension to T. Tait's plenary talk

Gamma-400 & CALET

	Space-based instruments			
	Fermi LAT	AMS-2	GAMMA-400	CALET
Energy range, GeV	0.02-300	10-1000	0.1-3,000	10-10,000
Field-of-view, sr	2.4	0.4	1.2	
Effective area, m^2	0.8	0.2	~0.4	~0.1
Angular resolution (E>100 GeV)	0.2°	1.0°	~0.01°	0.1°
Energy resolution (E>100 GeV)	10%	2%	~1%	2%

Gamma-400 is a pair-conversion telescope with a deep (25 X_0) calorimeter

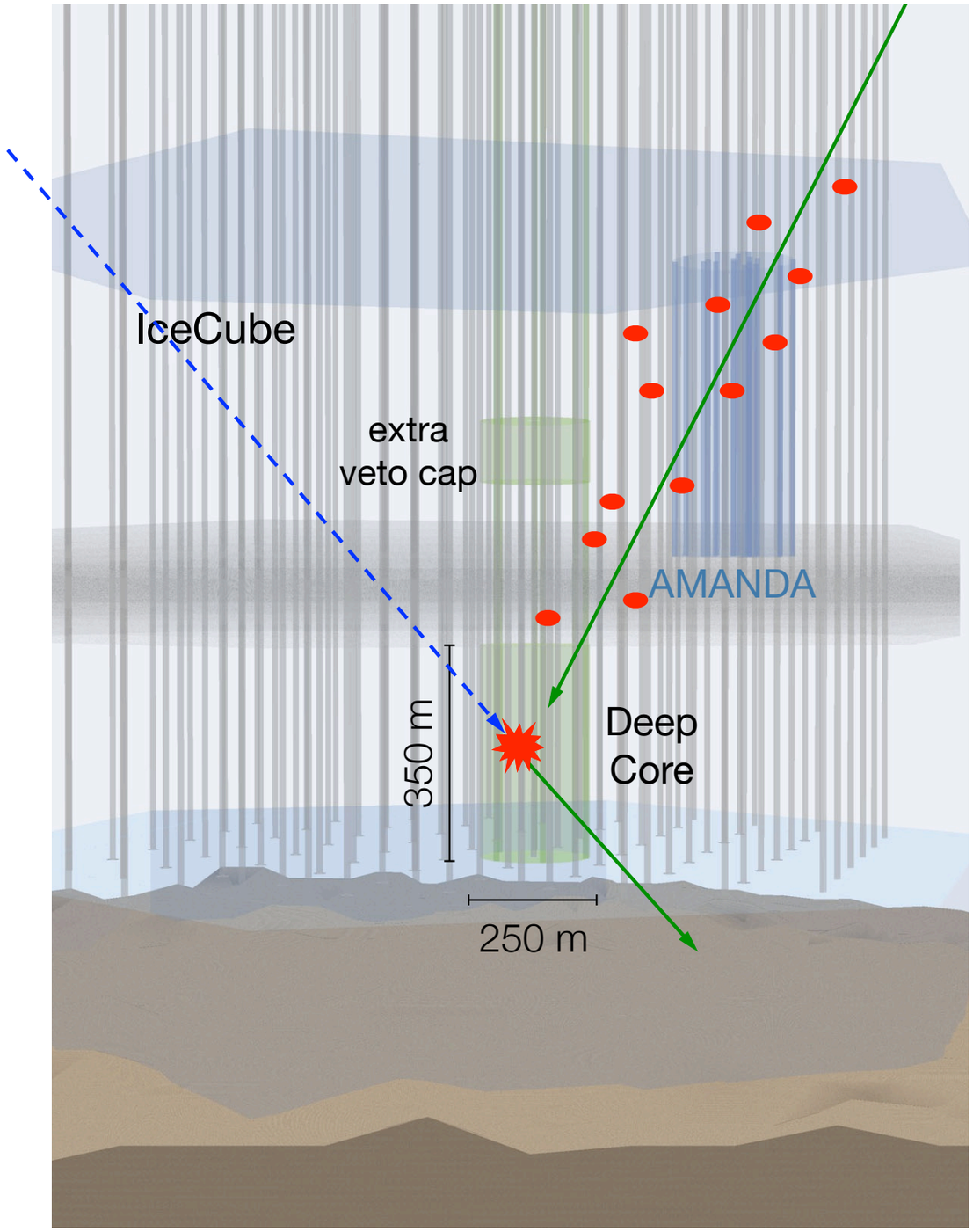
CALET is an imaging calorimeter with ~0.12 m^2 sr

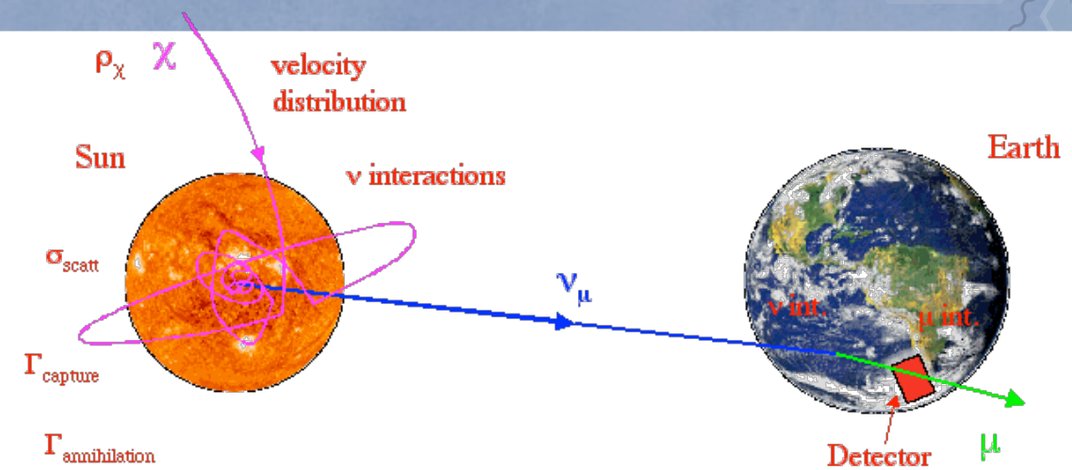
Good energy resolution for lines

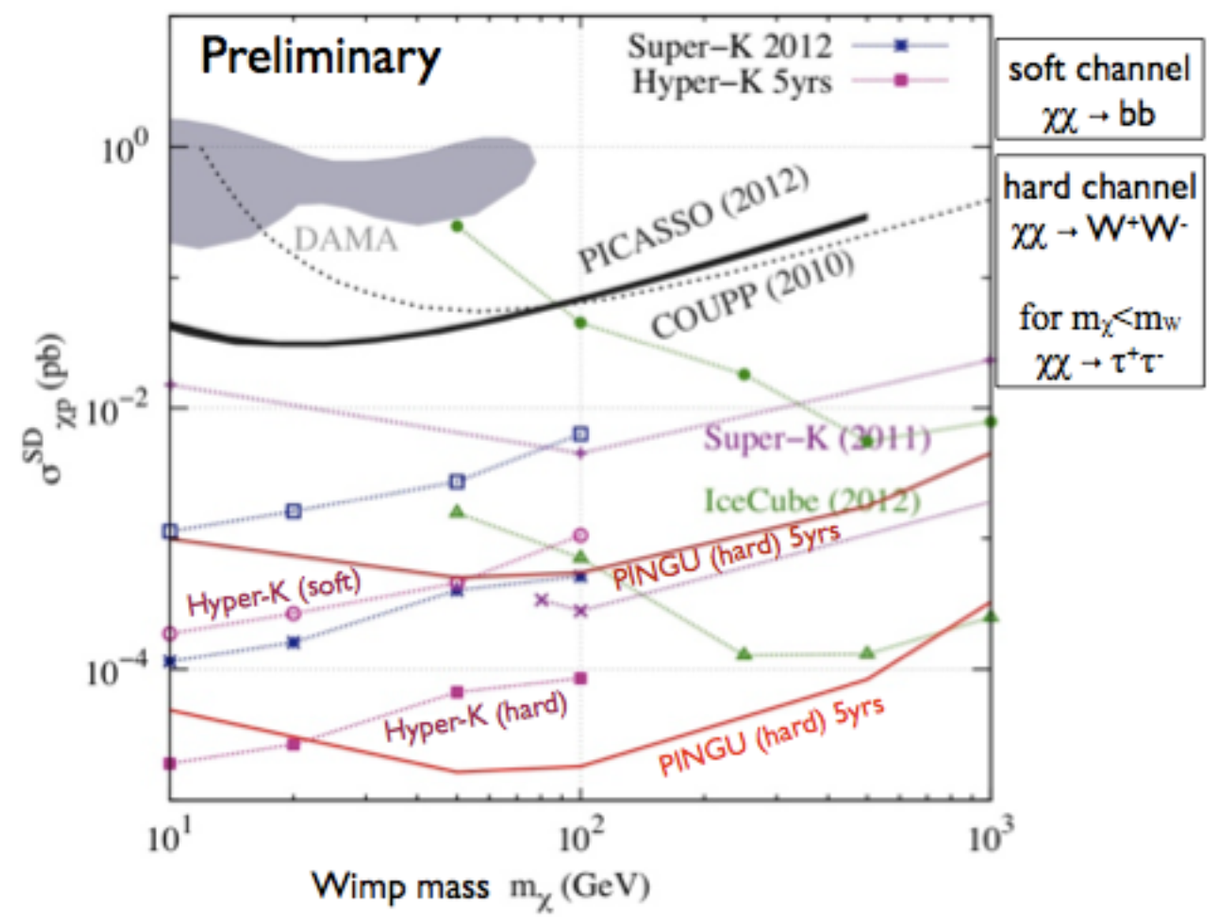
Angular resolution helps with removal of point source backgrounds

Hard to compete with Fermi-LAT and AMS on exposure

Neutrinos from the Sun

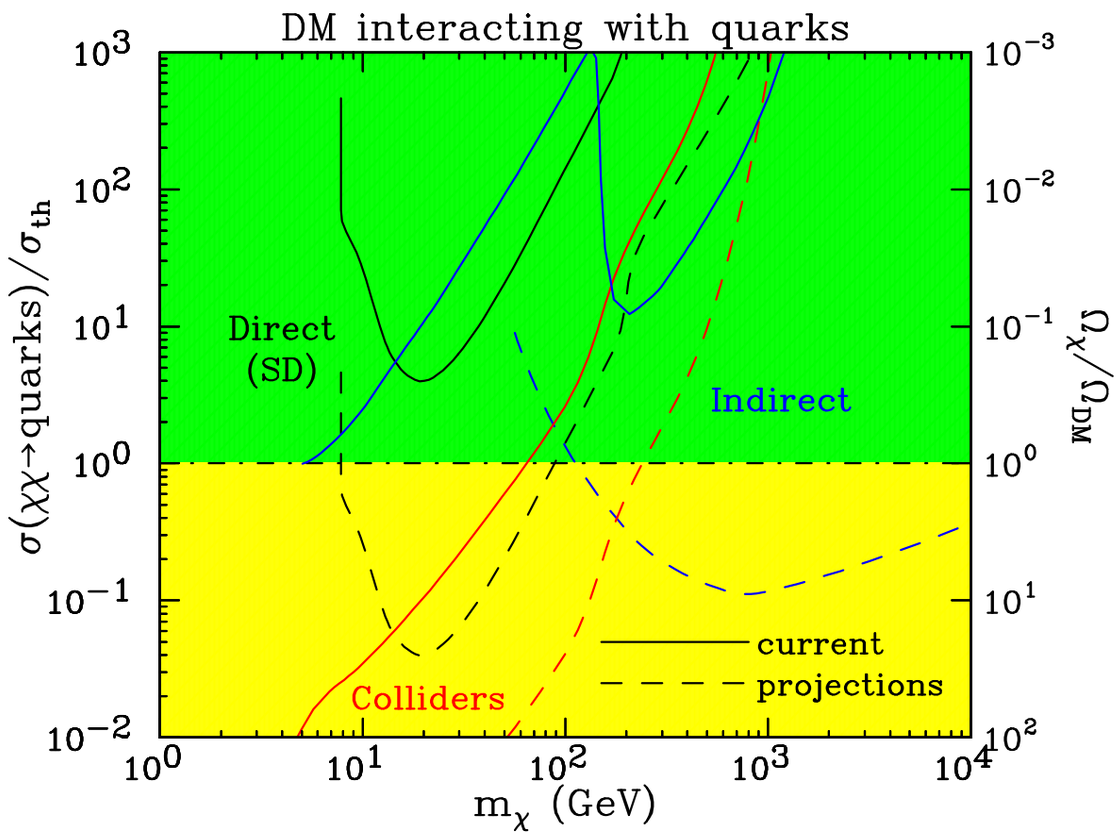


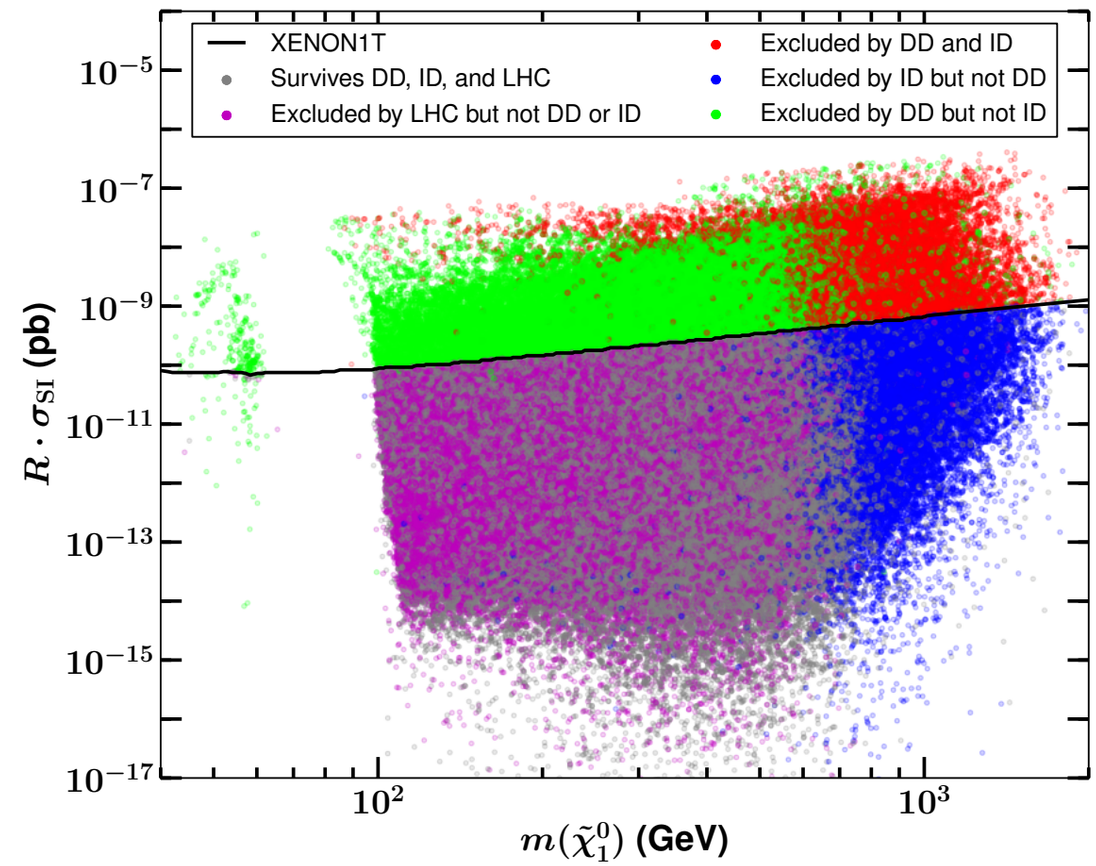




** Future neutrino experiments like the PINGU enhancement to IceCube/DeepCore offer the possibility of discovery of a smoking-gun signal (high energy neutrinos from the Sun), and may provide some of the best constraints on spin dependent cross sections.*

CF2 Key Findings





- CTA, with the U.S. enhancement, would provide a powerful new tool for searching for WIMP dark matter. The angular distribution would determine the distribution of dark matter in halos, and the universal spectrum would be imprinted with information about the mass and annihilation channels needed to ID the WIMP.
- Future neutrino experiments like the PINGU enhancement to IceCube/DeepCore offer the possibility of a smoking-gun signal (high energy neutrinos from the sun), and may provide some of the best constraints on spin dependent cross sections.
- Other astrophysical constraints such as low-frequency radio (synchrotron from electrons) or X-rays (inverse Compton scattering by electrons, sterile neutrino decay) can provide very powerful tests for DM annihilation for certain annihilation channels and provide constraints on decaying dark matter.
- Detailed theoretical studies with pMSSM, contact operators, realistic halo models are resulting in quantitative estimates of sensitivity, showing the complementary reach of different techniques.