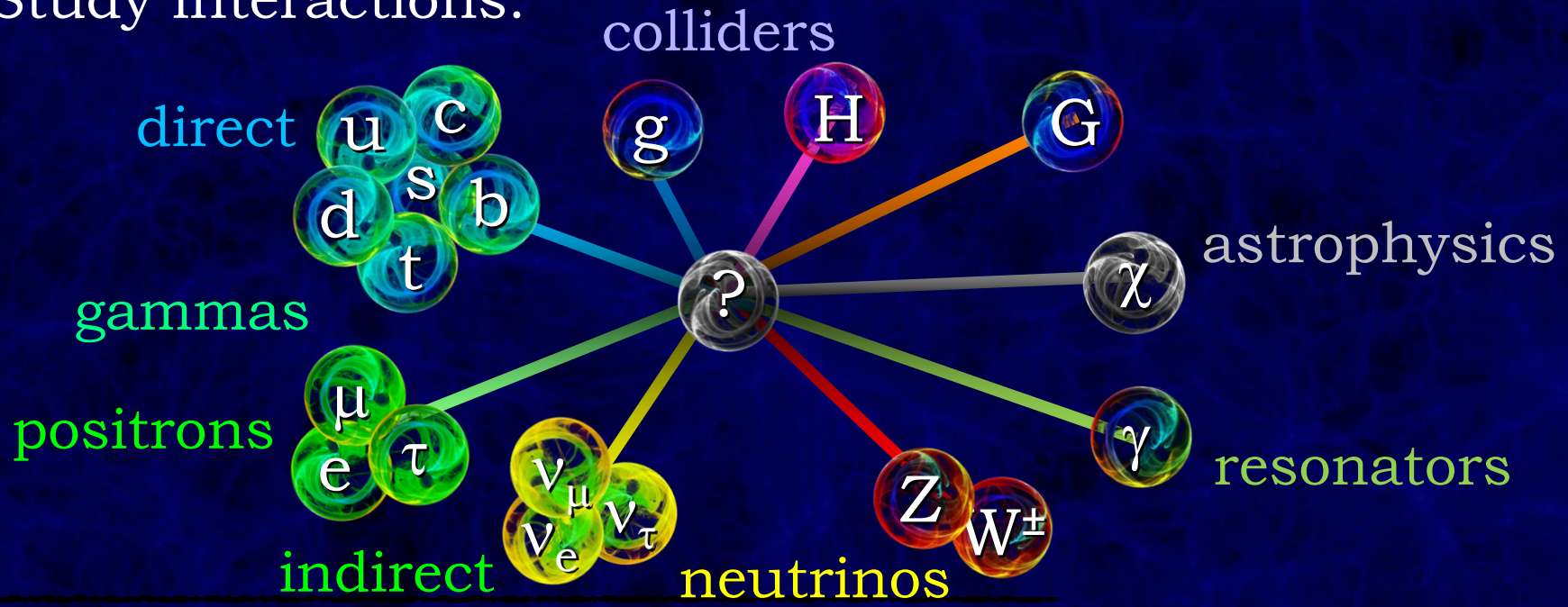
WIMP Dark Matter Searches: Progress and Plans

Rafael F. Lang
Purdue University
rafael@purdue.edu
Fermilab July 2017

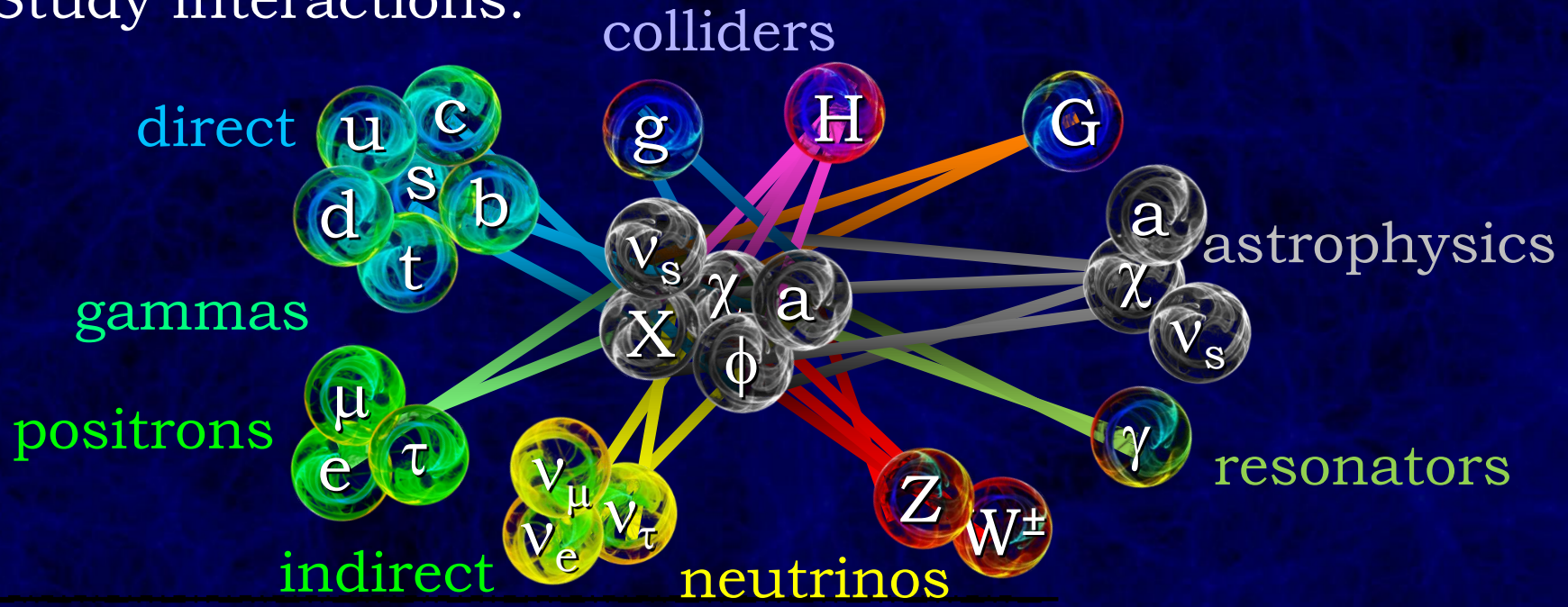
Dark Matter Has Been Discovered

- Have evidence at vast time & length scales
- What are the quanta of Dark Matter?
- Study interactions:



Dark Matter Has Been Discovered

- Have evidence at vast time & length scales
- What are the quanta of Dark Matter?
- Study interactions:



Possible Dark Matter Masses

bosonic | fermionic | composite

10^{-21}eV | μeV | meV | MeV | GeV | TeV | M_{Planck} | M_{solar}

wavelength doesn't fit in galaxies

2GeV: over-production bound

200TeV: unitarity bound

excluded by gravitational lensing

WIMPs

Axions

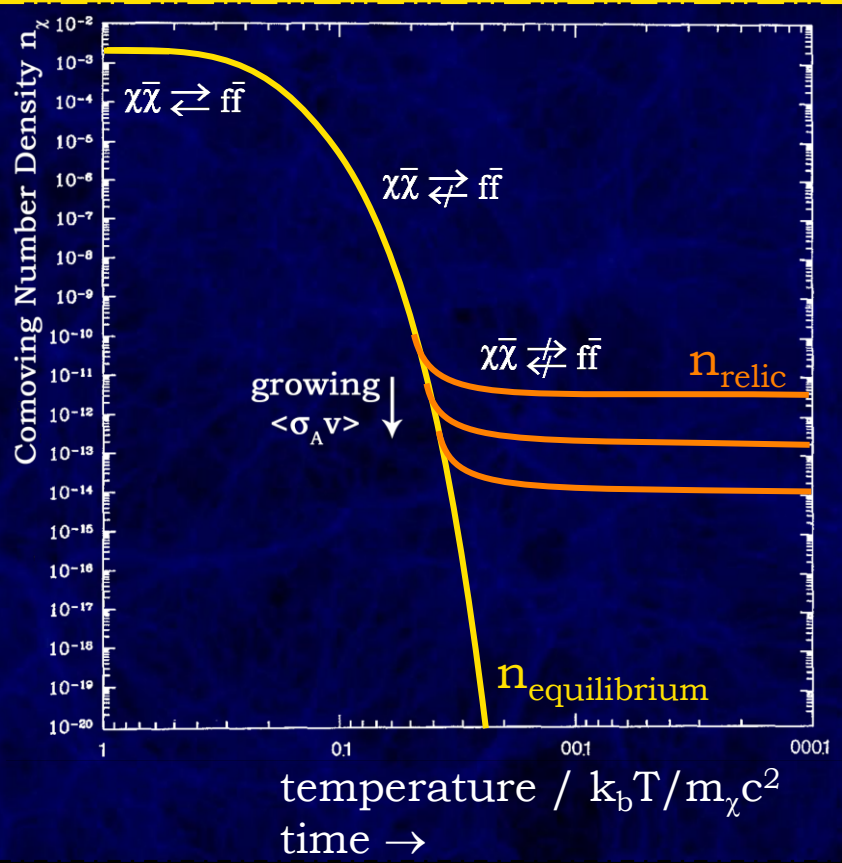
hidden photons

sterile neutrinos

asymmetric dark matter

primordial black holes

Thermal Relic Particles



from cosmology for any thermal relic:

$$\Omega_\chi \equiv \frac{n_\chi\, m_\chi c^2}{\varrho_{\mathrm{critical},0}} \approx \frac{10^{-26}\,\mathrm{cm}^2\,\mathrm{cm/s}}{\langle \sigma_A v \rangle}$$

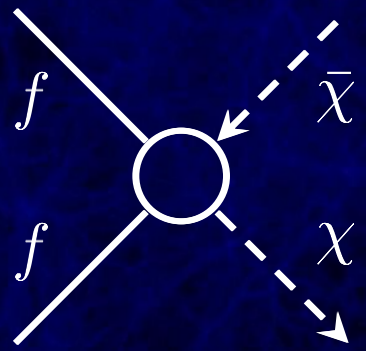
e.g. $v \sim 10^{-3} c$ and $\sigma \sim \sigma_{\mathrm{Weak}}$ ("WIMP miracle")

robust scattering prediction for direct detection:

$$\Gamma \propto \sigma \Phi = \sigma v\, \varrho_\chi \sim \frac{\sigma v}{\langle \sigma_A v \rangle} \sim \mathrm{const}$$

Crossing Symmetry

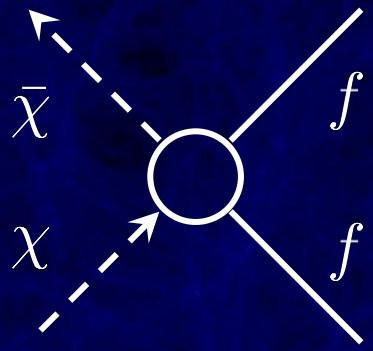
production



collider searches

"make it"

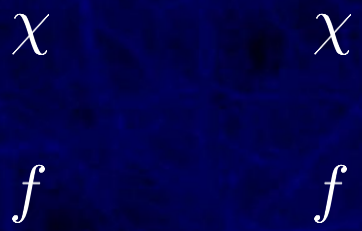
annihilation



indirect searches

"break it"

scattering

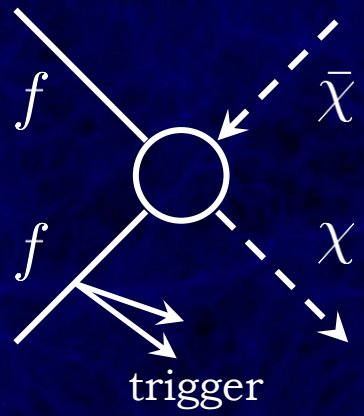


direct searches

"shake it"

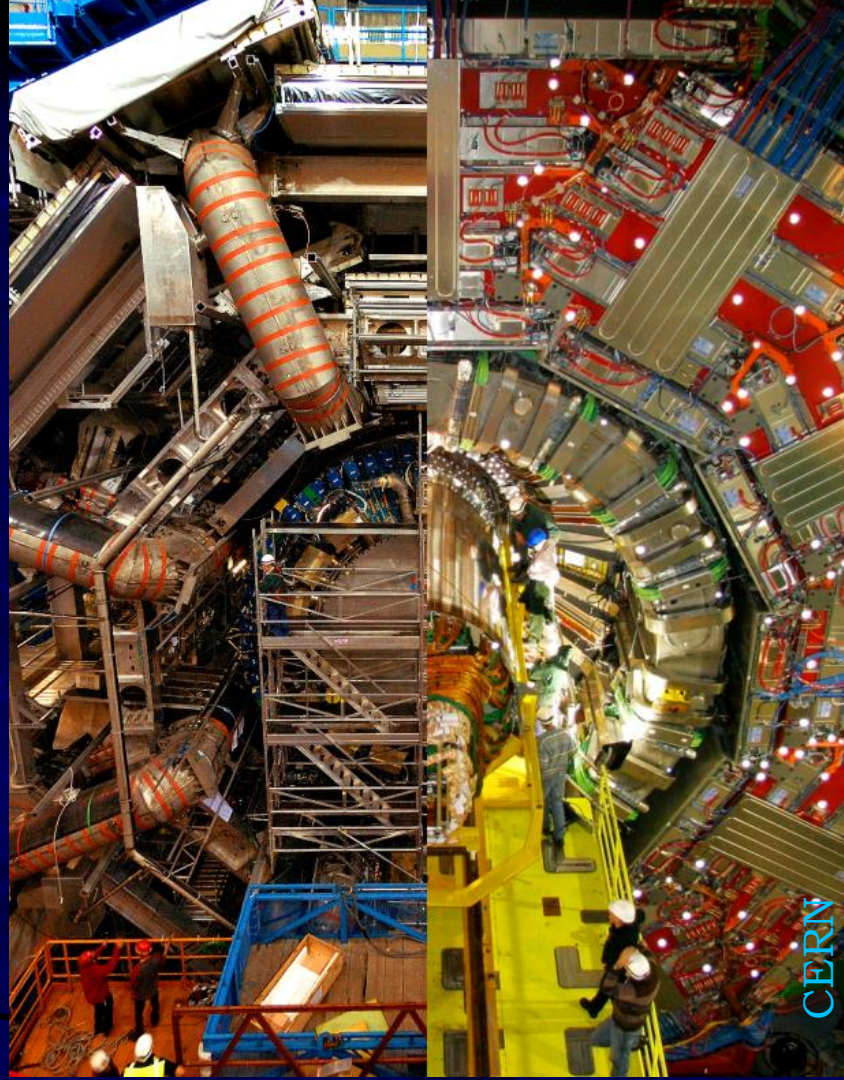
Collider Searches

Direct production of χ,
or decay of heavy particle into χ
Signature: missing transverse E



Buchmueller+ 1308.6799

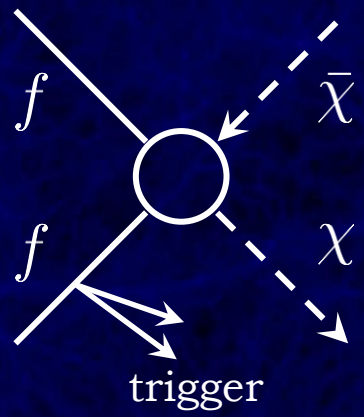
EFT approach:
validity issues

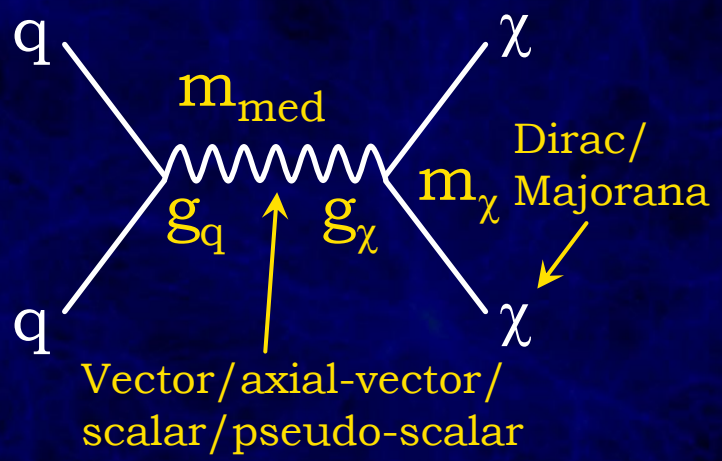


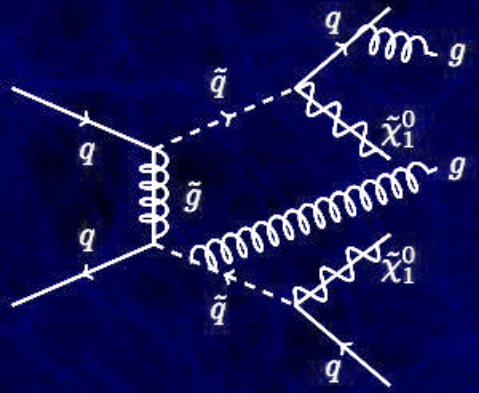
CERN

Collider Searches: Strategy

Direct production of χ,
or decay of heavy particle into χ
Signature: missing transverse Energy







EFT approach: validity issues

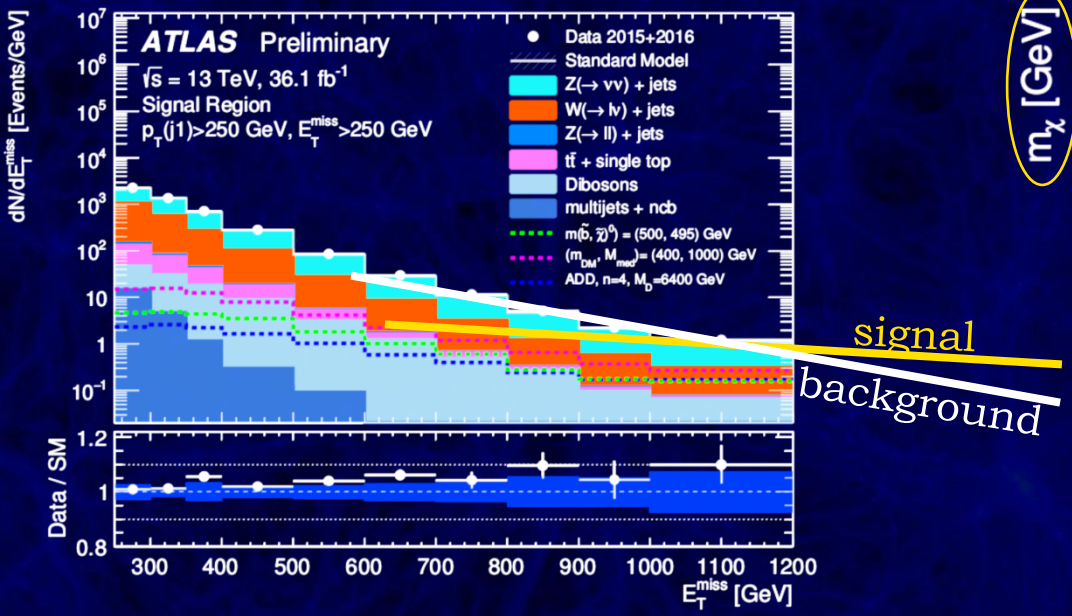
simplified model! arXiv:1506.03116

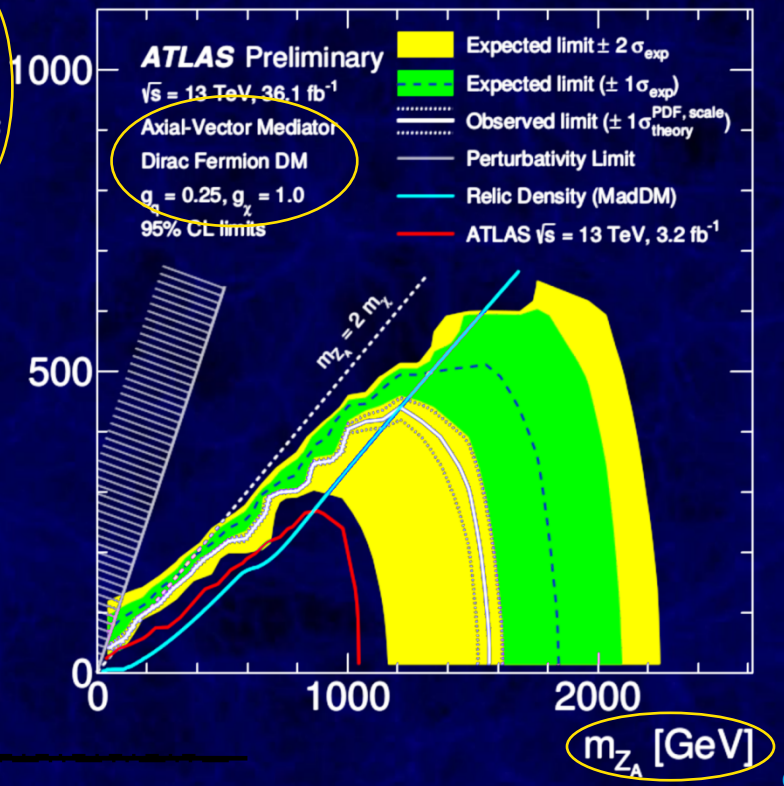
UV complete model: too specific

Buchmueller+ 1308.6799

ATLAS Mono-Jet Example

search for missing E_T: place limit on simplified model

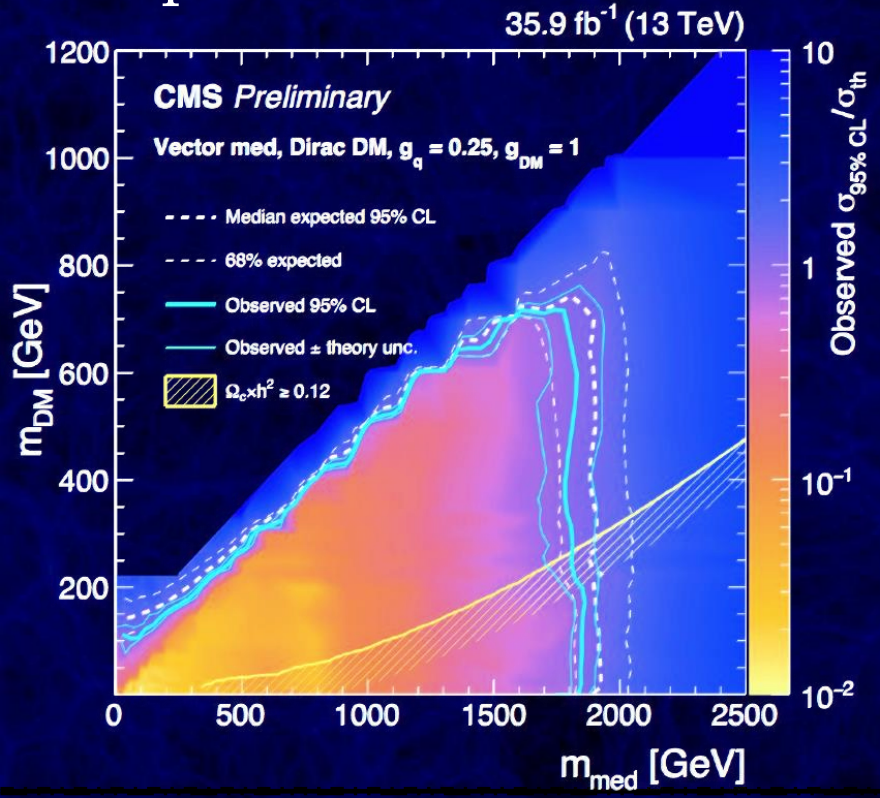




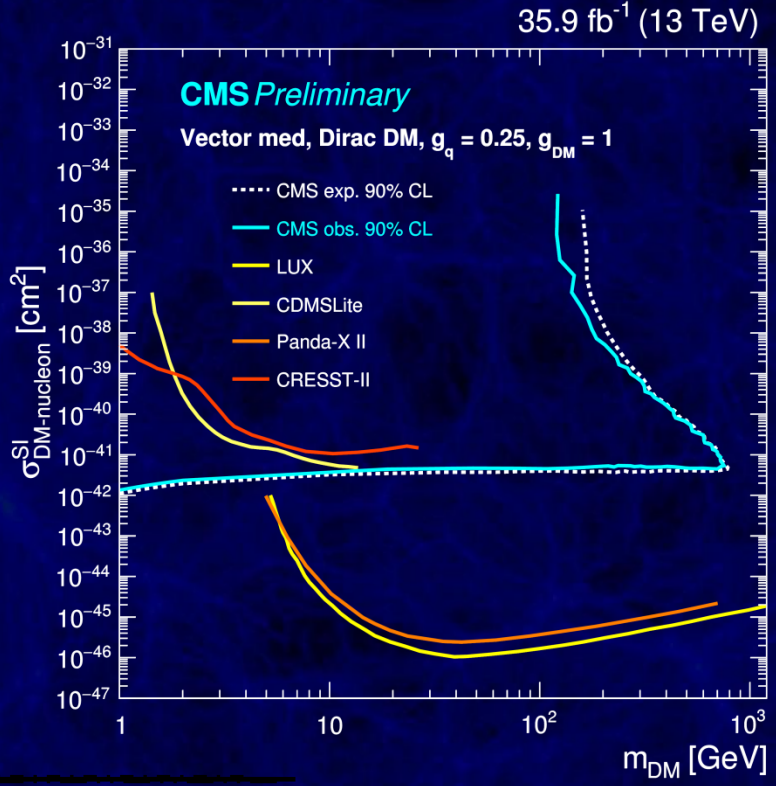
ATLAS ATLAS-CONF-2017-060

CMS Mono-Jet Example

simplified model:

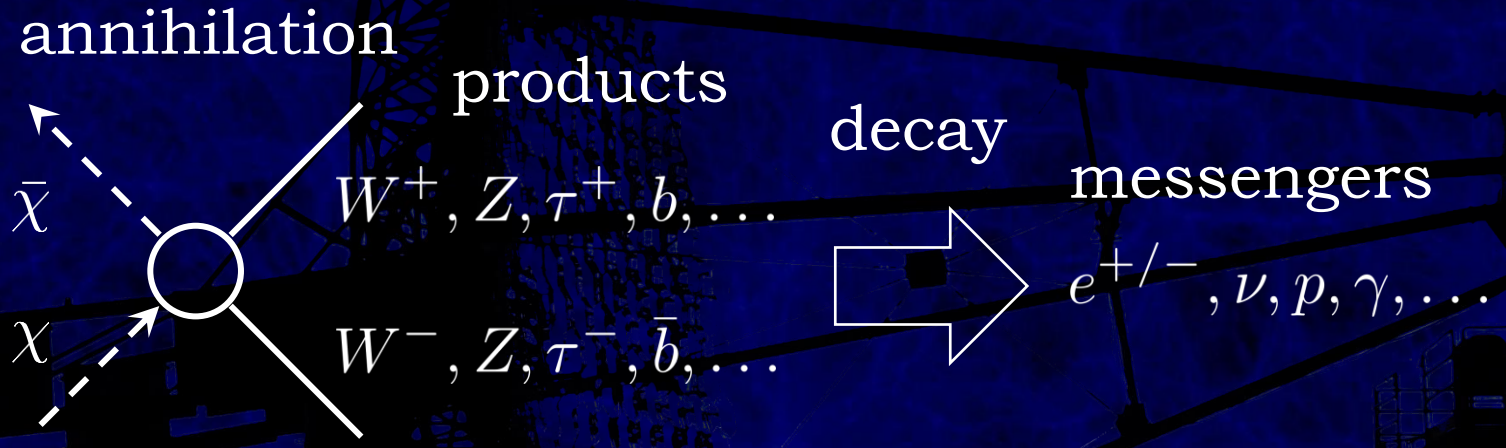


compare with direct searches:



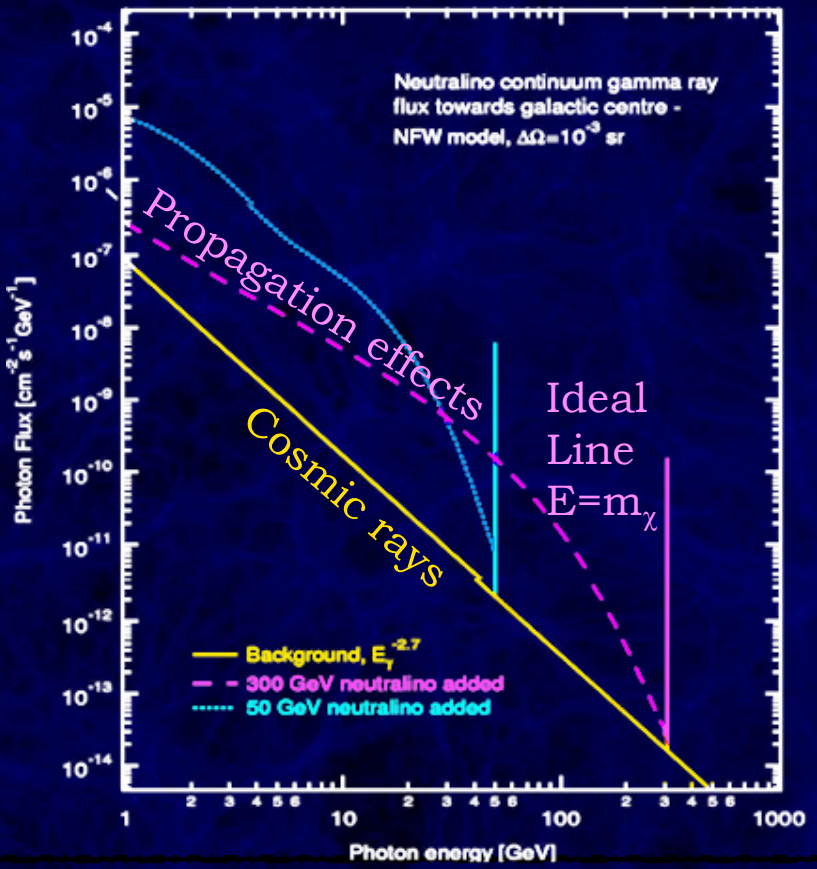
CMS CMS-PAS-EXO-16-048

Indirect Detection



D. Kieda

Indirect Detection 101



Bergstrom, Ullio & Buckley

Signal ∝ density^2: Halo uncertainties matter

search antiparticles: less background

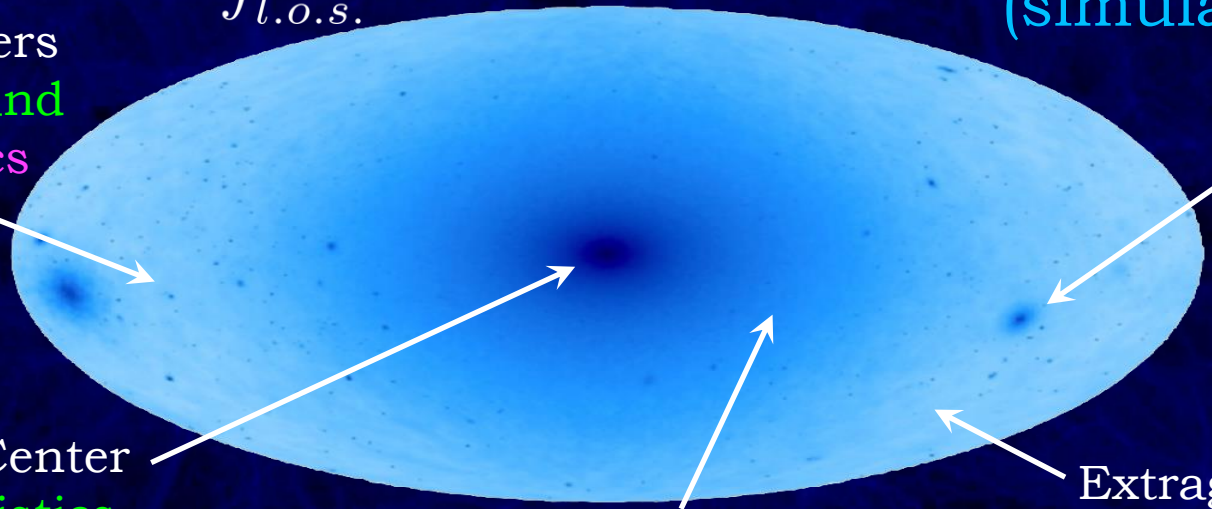
Expect line or bump

The J-Factor

Annihilation signal strength from VL Lactea simulation

"J-factor" $J(\psi) = \int_{l.o.s.} \varrho_\chi^2(r)\mathrm{d}l(\psi)$

(simulation)



Galaxy clusters
low background
low statistics

Dwarf Satellites
great signal/ background
low statistics

Galactic Center
good statistics
background uncertain

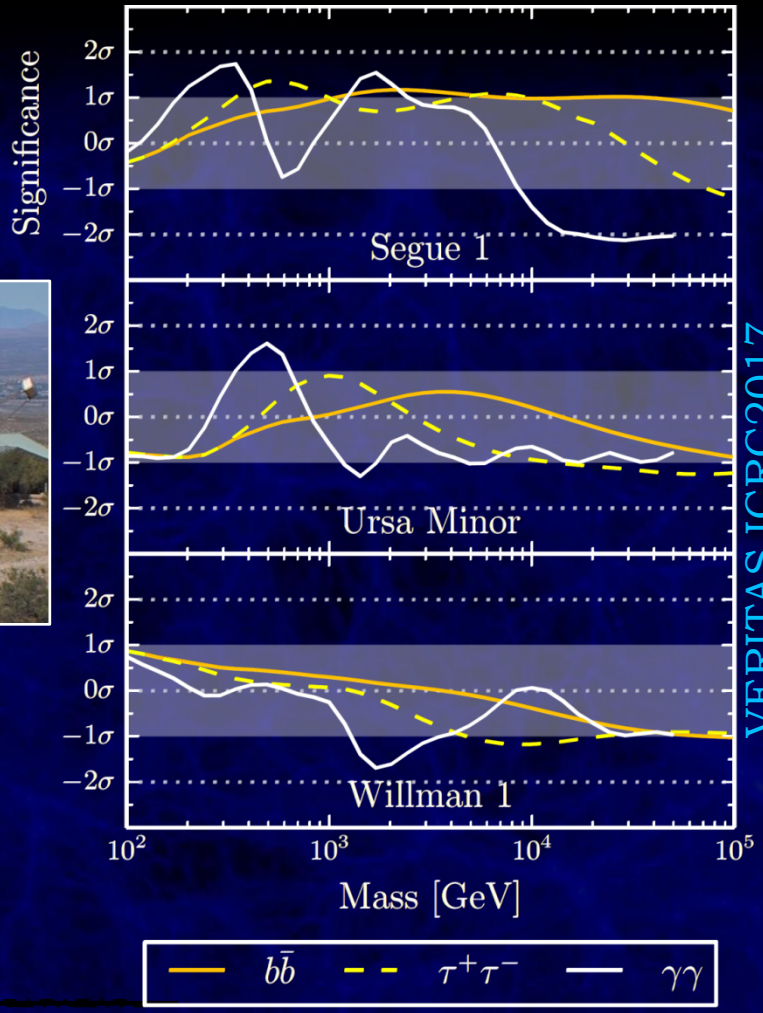
Milky Way halo
good statistics
diffuse background

Extragalactic
large statistics
ample astrophysics

arxiv 1310.7040

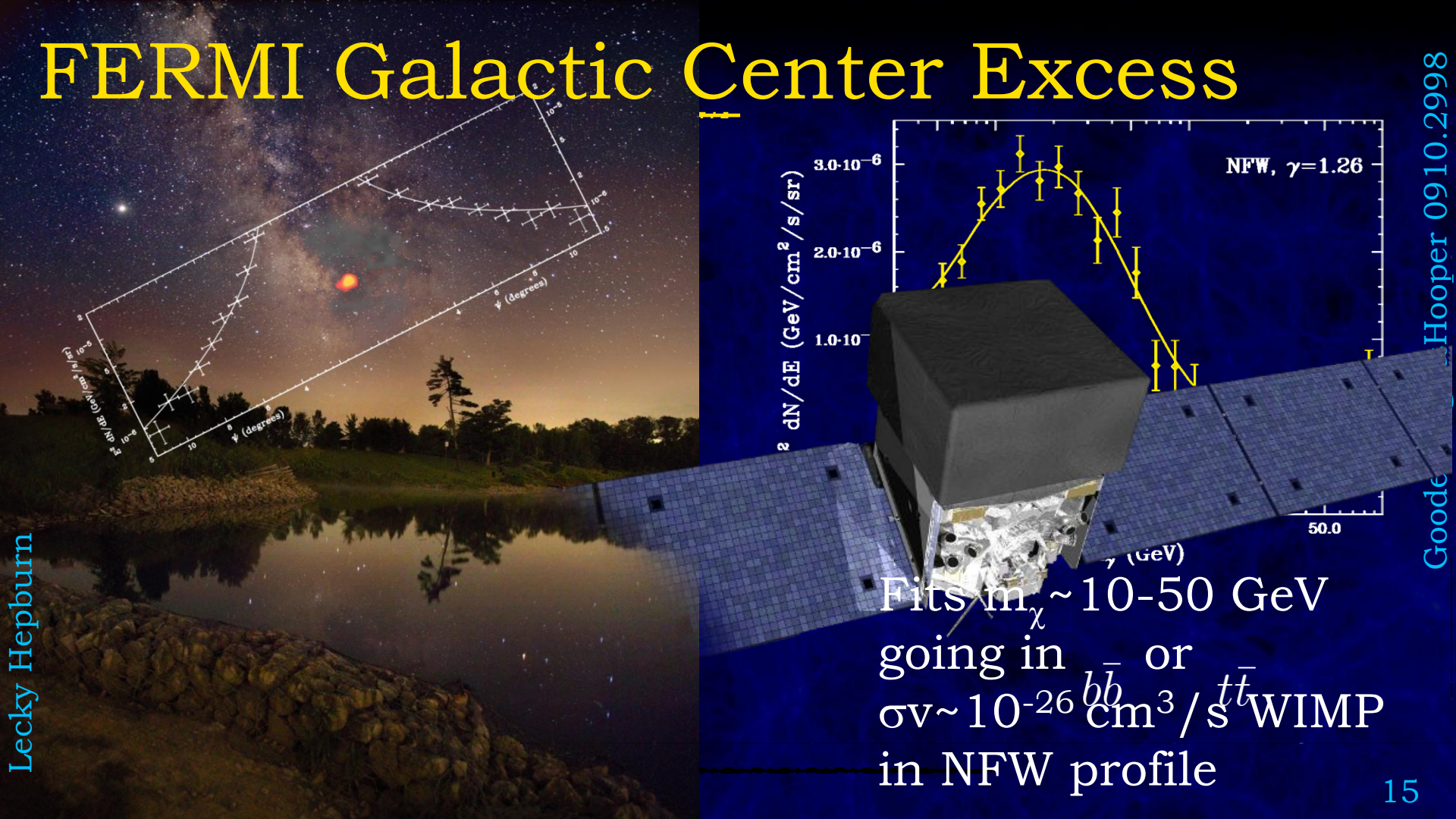
Air Cherenkov

MAGIC, H.E.S.S., VERITAS



e.g. search for excess from dwarf galaxies:

FERMI Galactic Center Excess



Fits m_χ~10-50 GeV going in $b\bar{b}$ or $t\bar{t}$

$\sigma v \sim 10^{-26}\ cm^3/s$ WIMP in NFW profile

Lecky Hepburn

Goode, Hooper 0910.2998

FERMI Galactic Center Excess

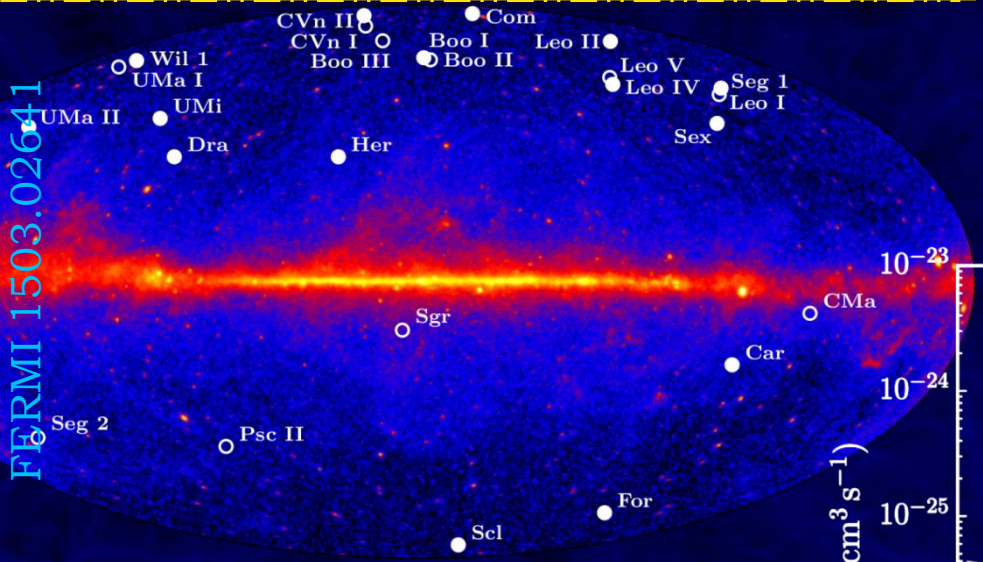
Counting statistics of excess somewhat prefer collection of point sources (pulsars) over smooth dark matter emission.

Need to find pulsars directly with upcoming surveys (MeerKAT, SKA)

Lee+ 1506.05124

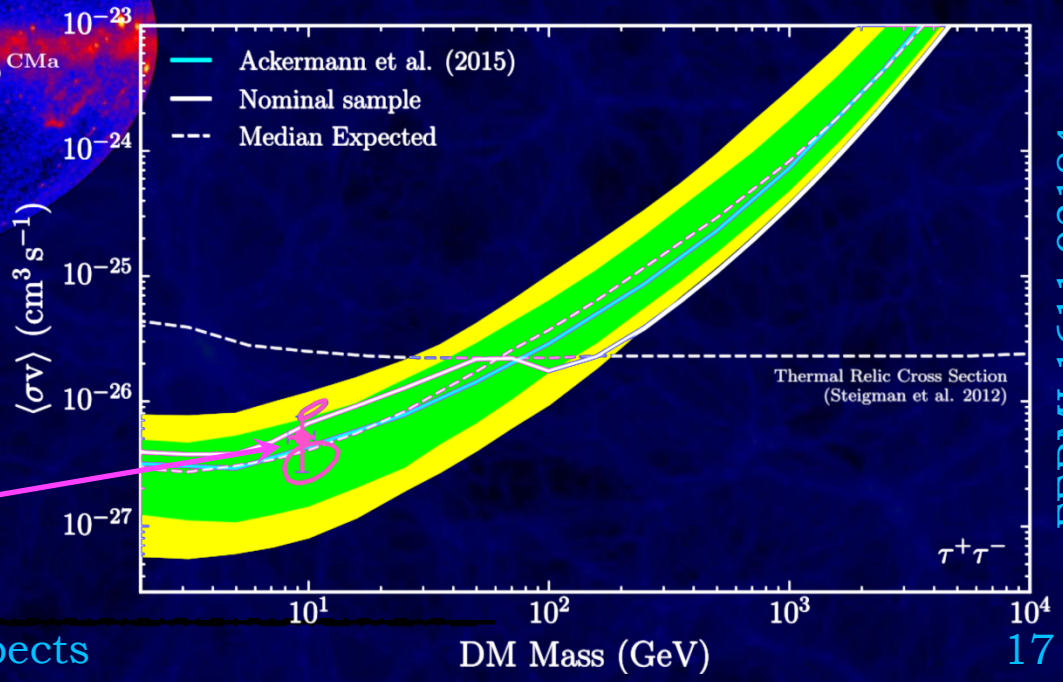
Lecky Hepburn

Dwarf Galaxies: Best Sig/Bck



FERMI 1503.02641

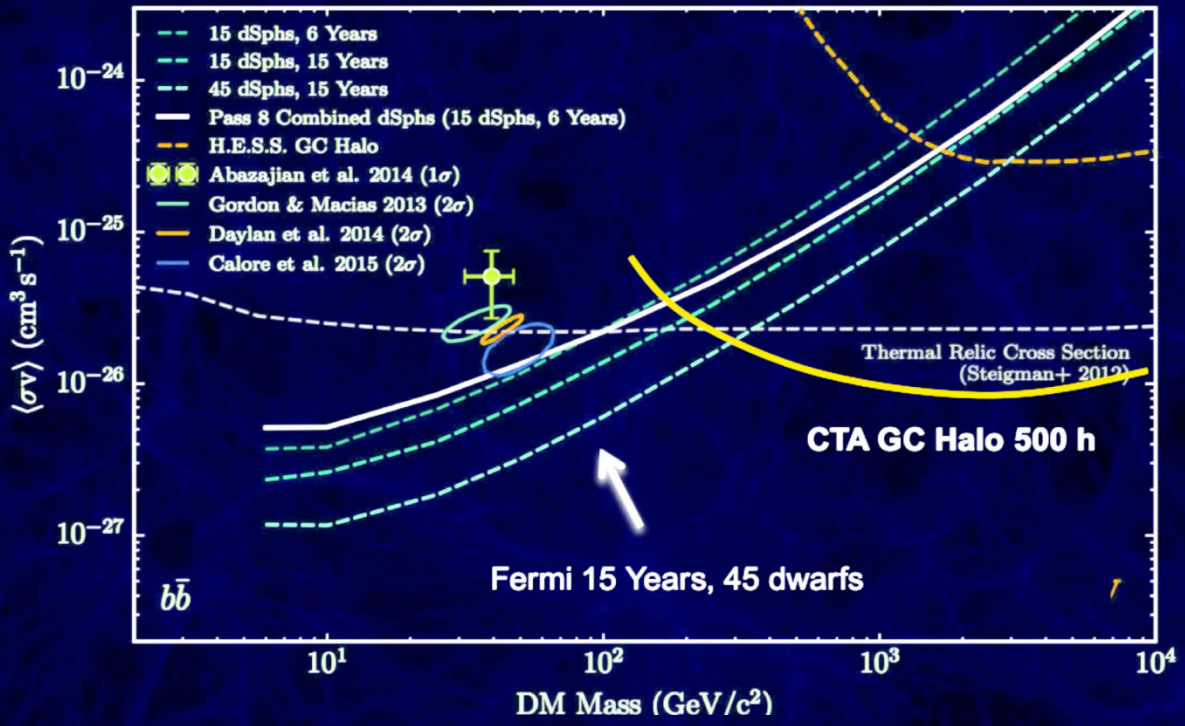
Dark matter-dominated systems



FERMI 1611.03184

some tension
with GC excess
await more dwarfs

Outlook: FERMI and CTA

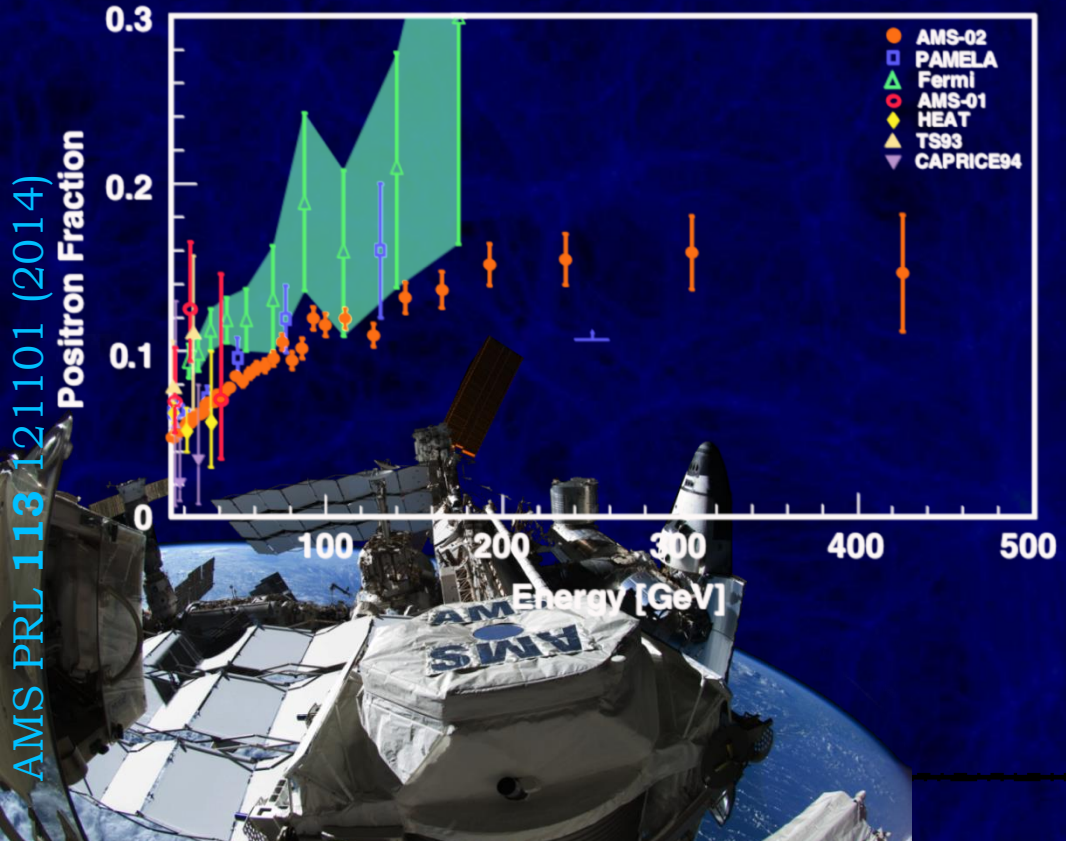


A.Morselli ICRC2017

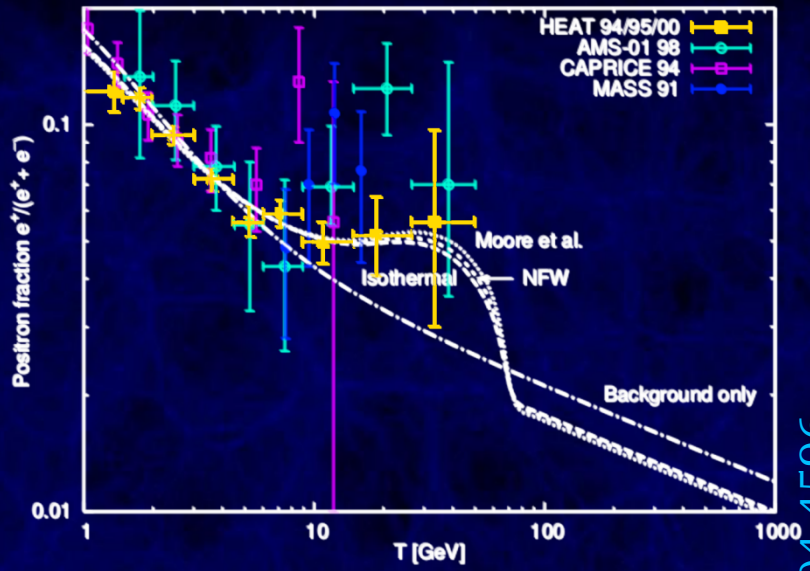
unige.ch

Positron Excess

Requires primary source:



AMS PRL **113** 121101 (2014)



"However, the predicted antiproton flux tends to be too large…"

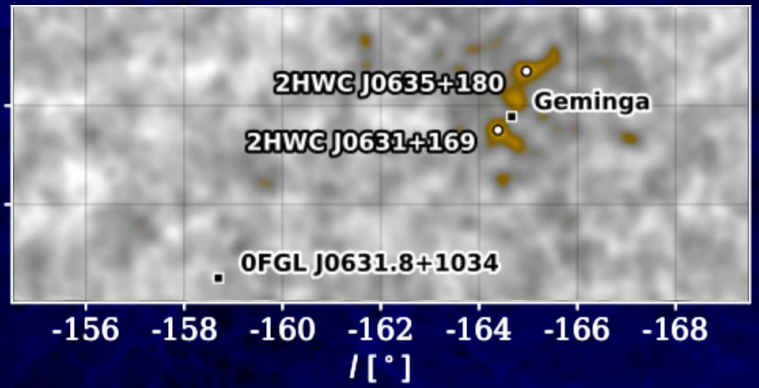
Need leptophilic model.

Ibarra&Tran 0804.4596

Positron Excess: Known Pulsars

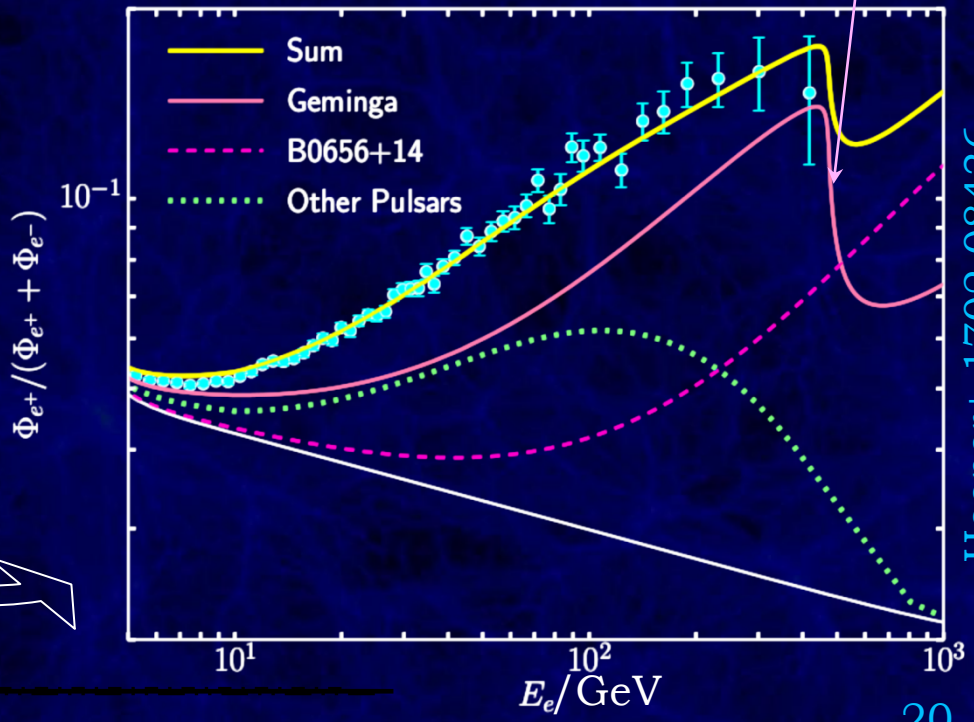
Positrons from known, nearby pulsars fit data nicely

HAWC 1702.02992



get high-energy emission from HAWC gamma catalog

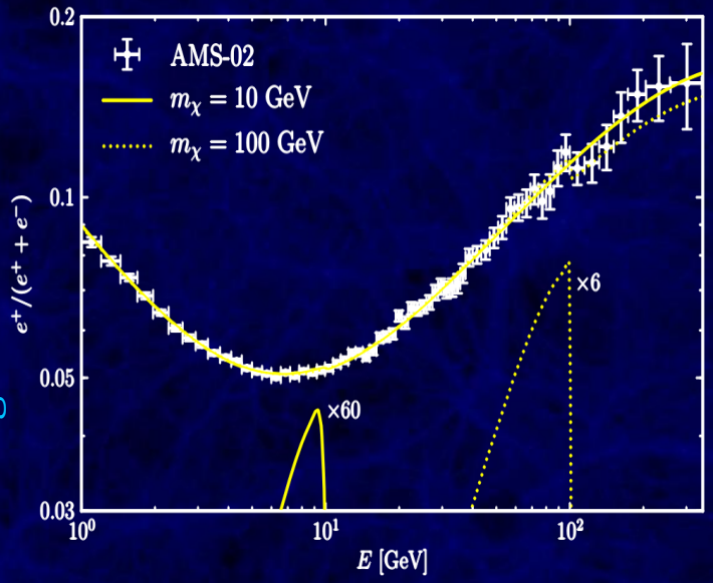
(cooling for $t_{Geminga}$~370ka)

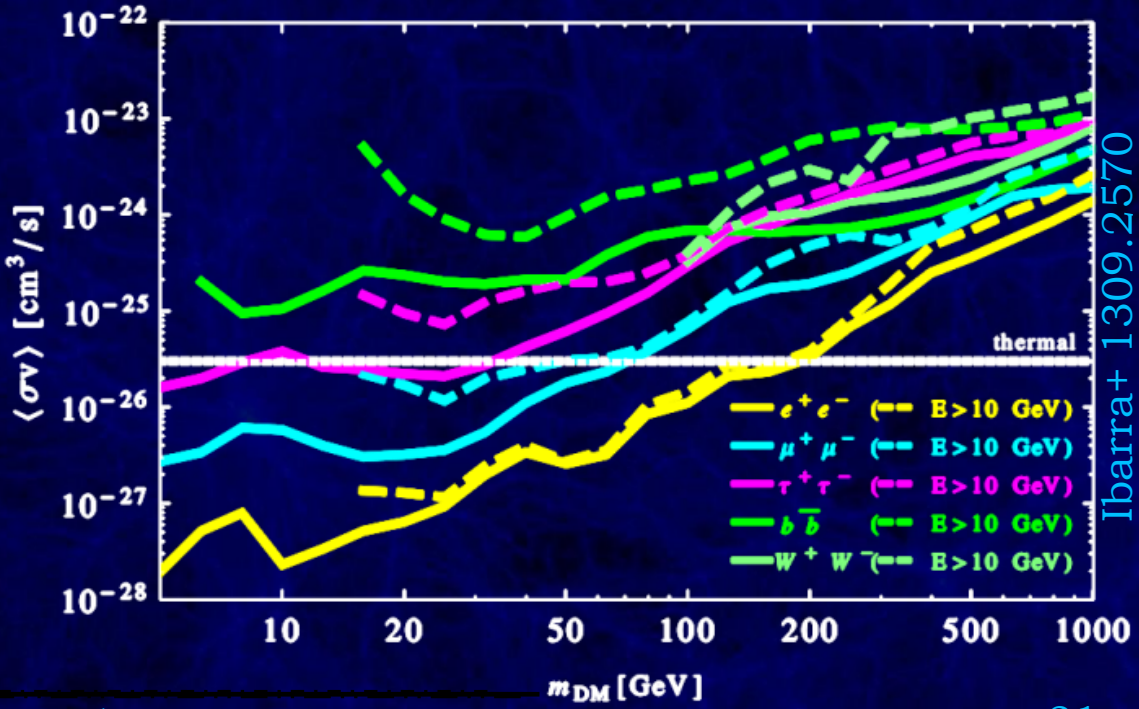


Hooper+ 1702.08436

Positron Excess: WIMP Limits

Bergström+ 1306.3983

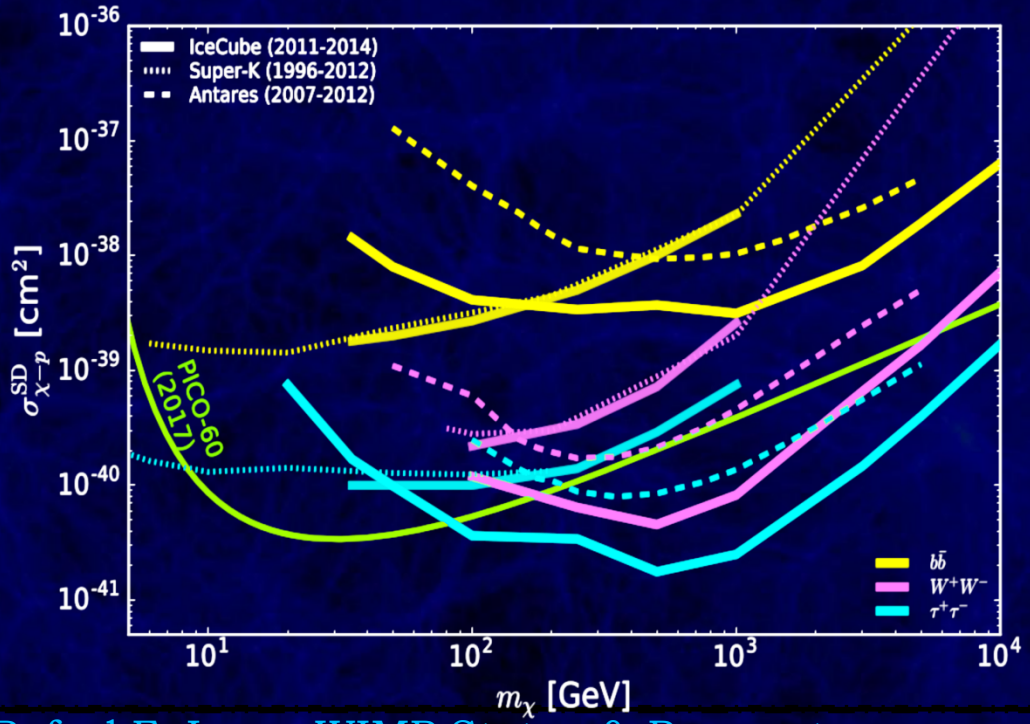


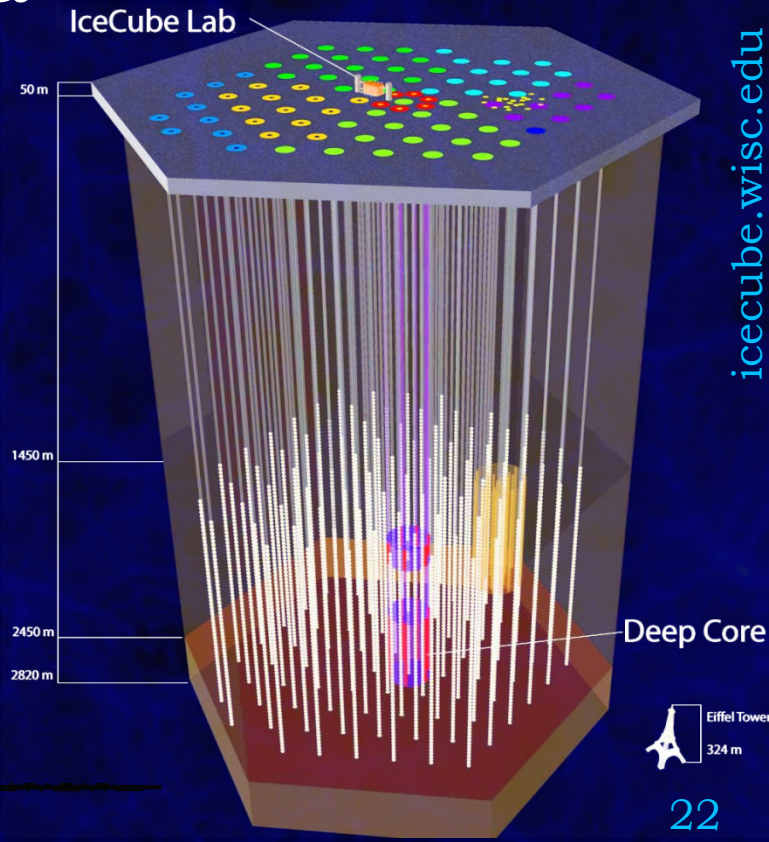


Ibarra+ 1309.2570

Neutrinos from Sun

WIMPs scatter in Sun, loose energy, accumulate, then annihilate

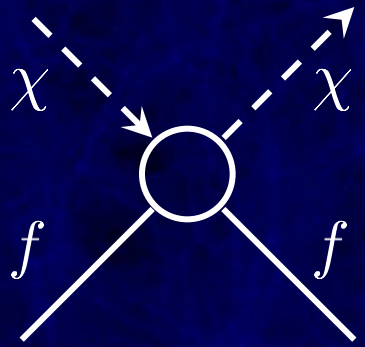


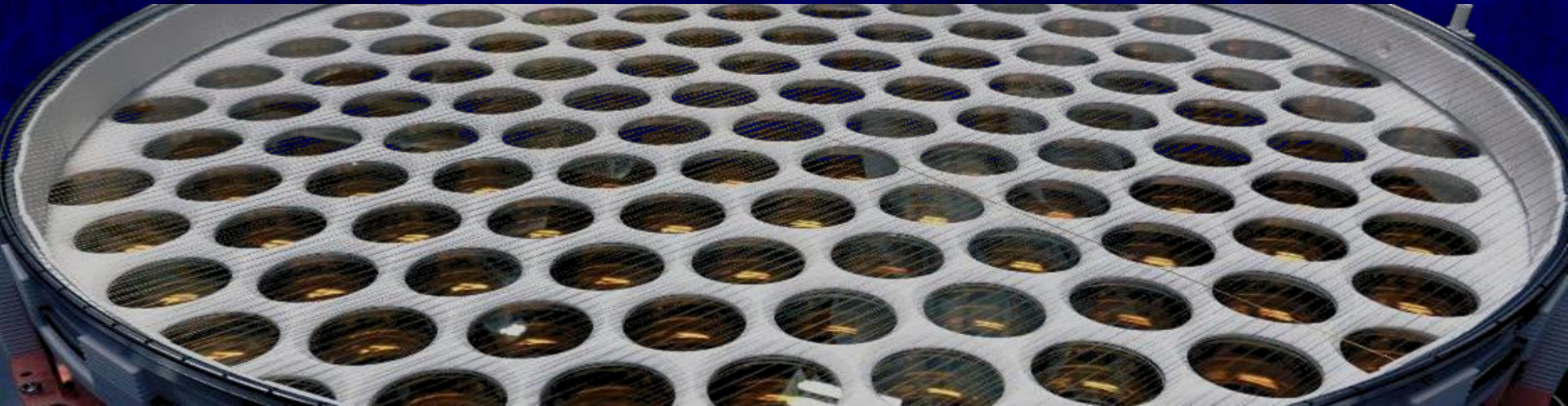


IceCube ICRC2017/Rott & 1612.05949

icecube.wisc.edu

Direct Detection





What to Expect from WIMPs

- rate: < few events per year, per tonne of target

$$N = n_{\text{target}} \Phi \, \sigma_{\chi,N} \, A^2 \qquad \text{or} \propto \sigma_{\chi,N} \, J(J+1)$$

- coherent scattering: heavy target

$$\frac{\lambda_{\text{deBroglie}}}{2\pi} = \frac{\hbar}{p} = \frac{\hbar c}{mc^2 \, v/c} \sim \frac{197\,\text{MeV fm}}{100\,\text{GeV}\,10^{-3}} \approx \text{fm} \approx r_{\text{nucleus}}$$

- recoil energies: low threshold

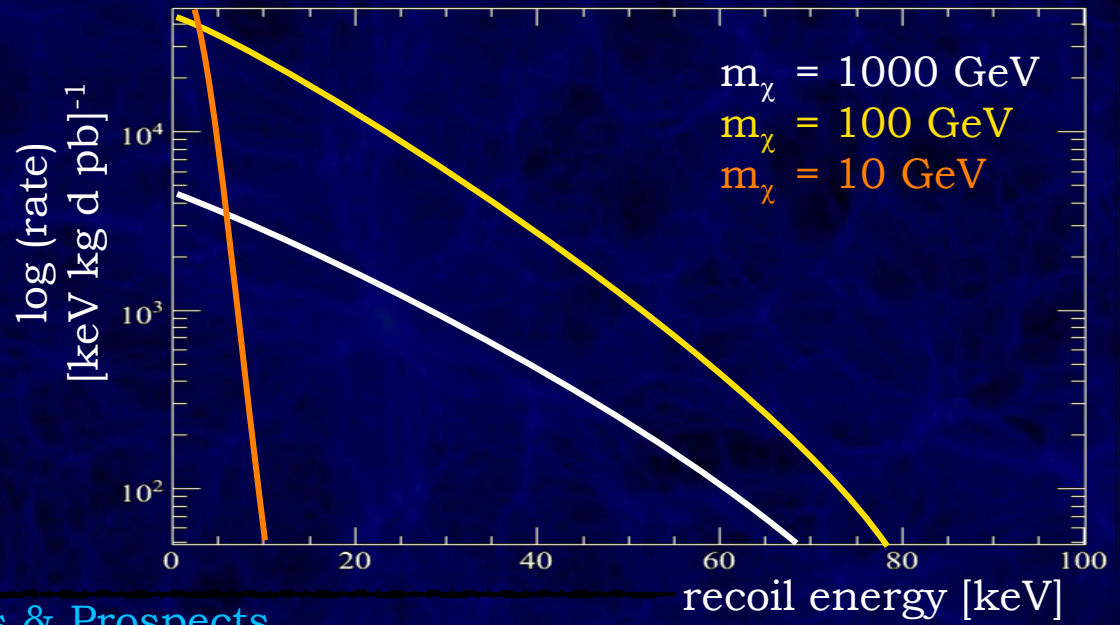
$$E_{\text{r,max}} \sim \frac{p_\chi^2}{2m_{\text{N}}} \sim \frac{\left(100\,\text{GeV/c}^2 \times 10^{-3}\text{c}\right)^2}{2 \times 100\,\text{GeV/c}^2} = 50\,\text{keV}$$

Recoil Spectrum

- nonrelativistic kinematics: simple falling exponential

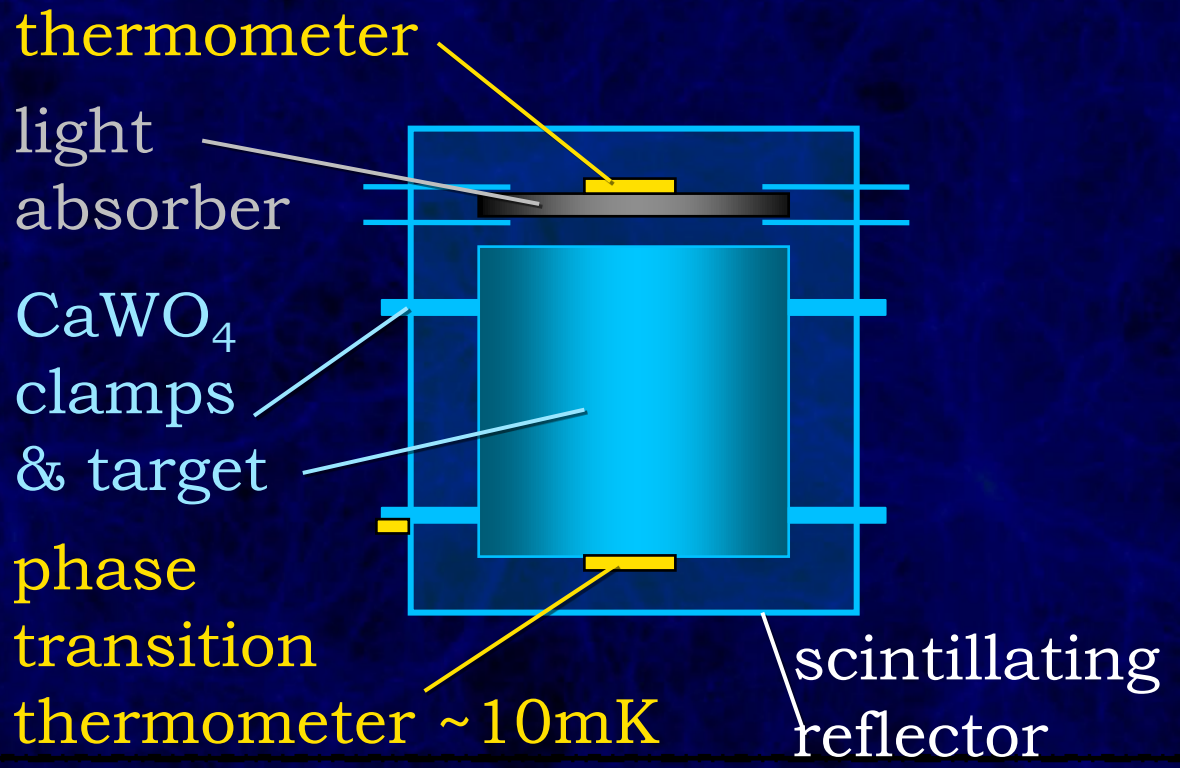
$$\frac{\mathrm{d}N}{\mathrm{d}E_r} \propto \Phi \propto \langle v \rangle \propto \int_{v_\chi}^{\infty} \frac{f_{\mathrm{MB}}(v)}{v}\,\mathrm{d}v \propto \mathrm{e}^{-v_\chi^2} \propto \mathrm{e}^{-E_r}$$

e.g. Xe target
$\sigma = 10^{-45}\mathrm{cm}^2$



CRESSTIII @Gran Sasso

Scintillating 24g $CaWO_4$ calorimeters

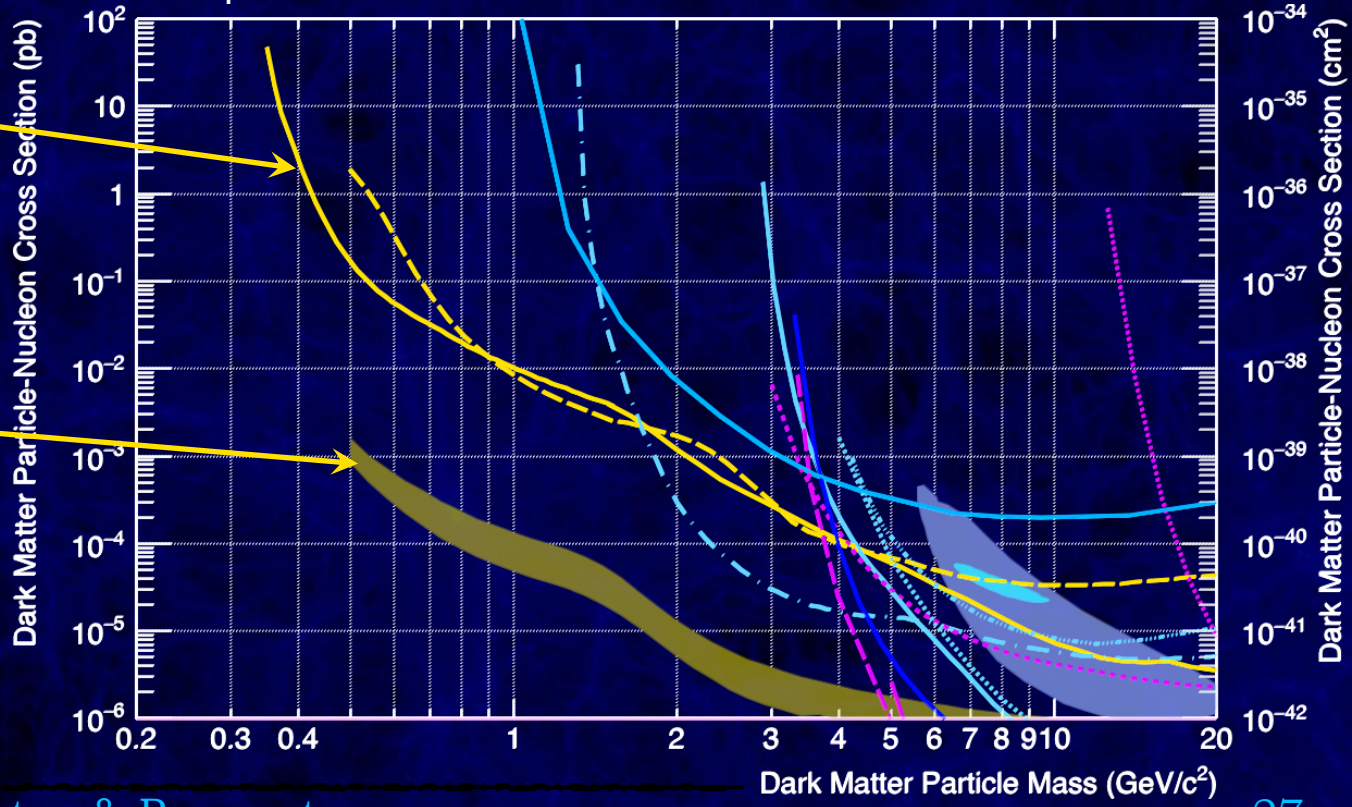


CRESSTIII @Gran Sasso

Scintillating 24g $CaWO_4$ calorimeters

2.2kg d limit
E>100eV
(30eV running!)

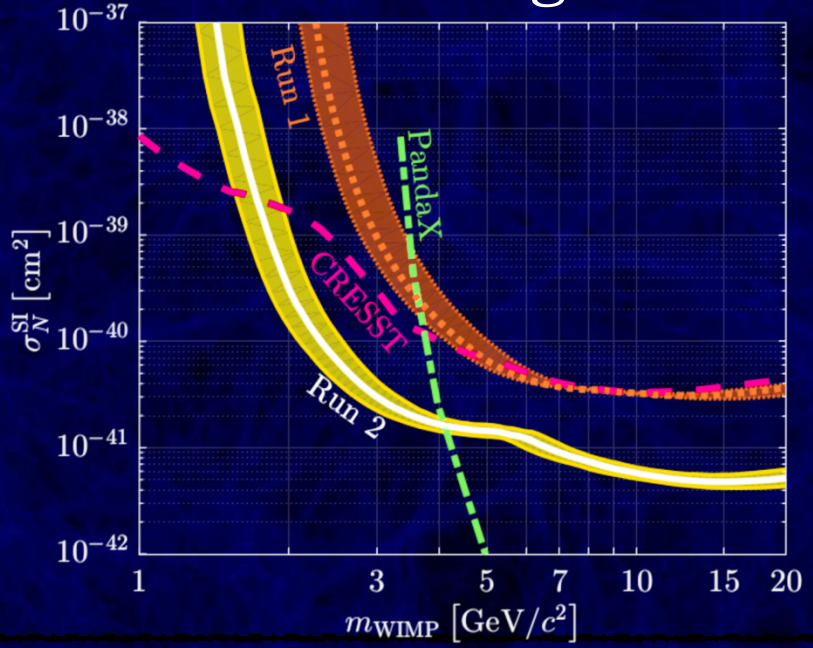
50kg d
sensitivity



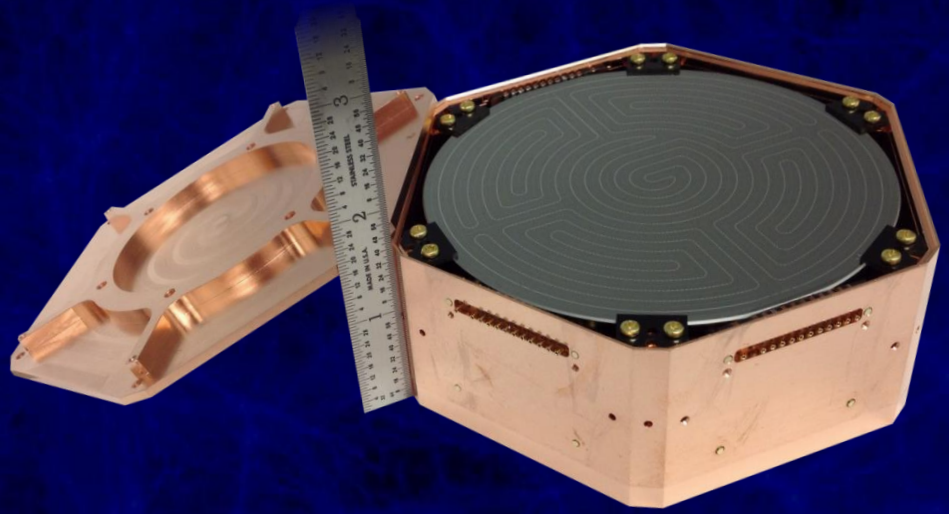
F.Petricca TAUP2017

SuperCDMS and CDMSlite

Germanium & Silicon @Soudan until 2015
phonons & ionization: SuperCDMS @SNOlab 2019+
ionization with Neganov-Luke amplification:



CDMS 1707.01632



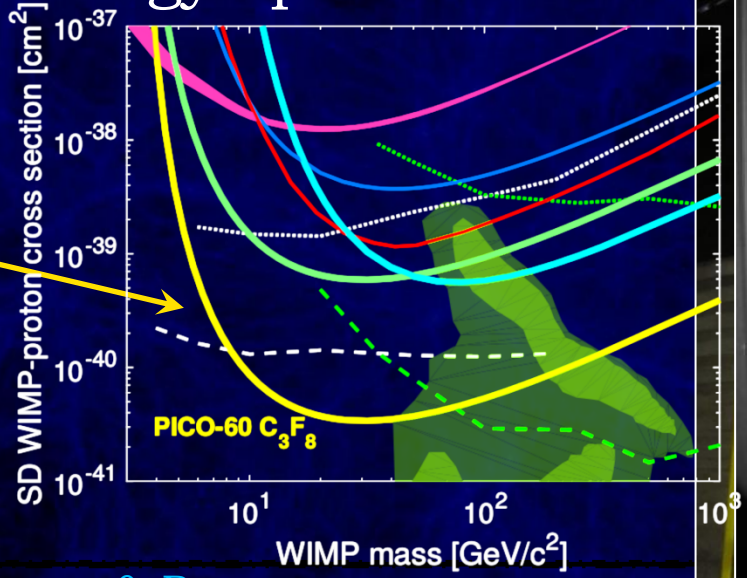
cdms.berkeley.edu

PICO @SNOLAB (=COUPP+PICASSO)

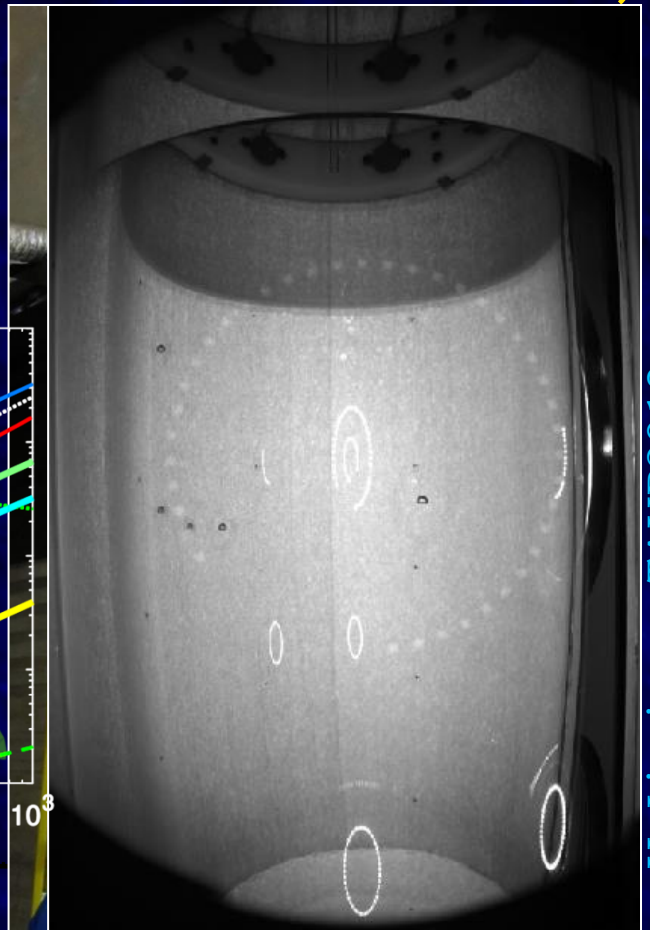
- CF_3I or C_3F_8 Bubble chambers
- Detector blind ($<10^{-10}$) to ER
- Acoustic alpha-NR discrimination
- Only integral energy spectrum

PICO 1702.07666

1167 kg d,
E>3.3keV



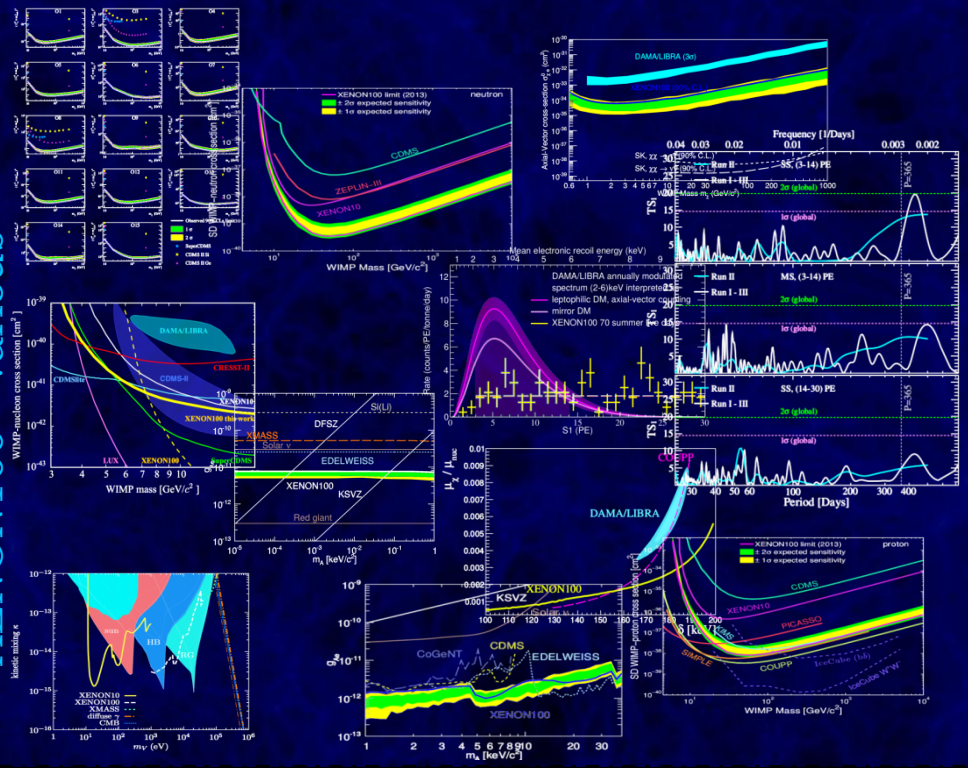
next: PICO40L
until 2019



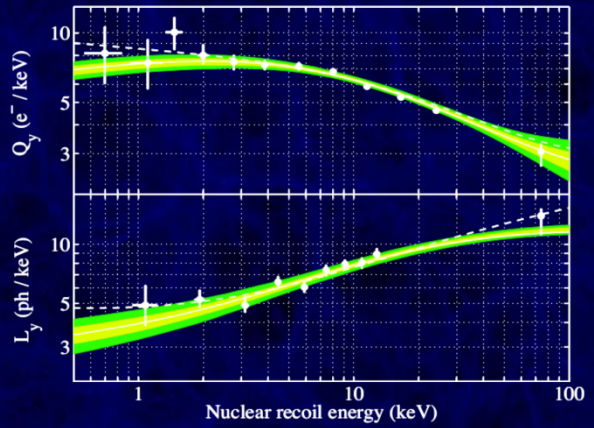
Rafael F. Lang: WIMP Status & Prospects

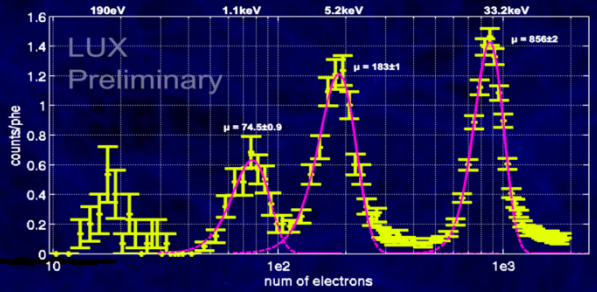
XENON100 & LUX

Large variety of models tested:



Excellent understanding of systematics

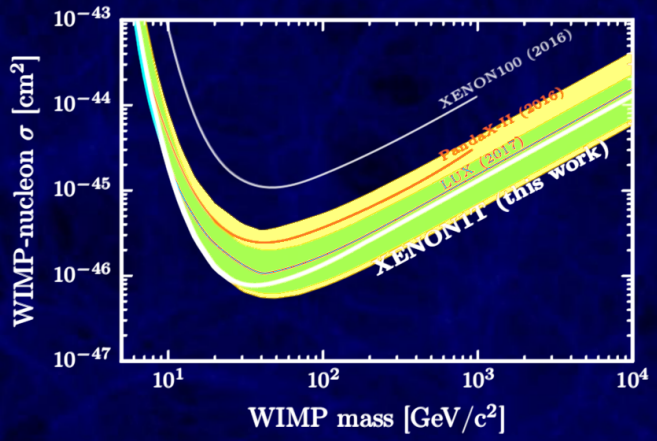




LUX 1512.03506 @ APS2015

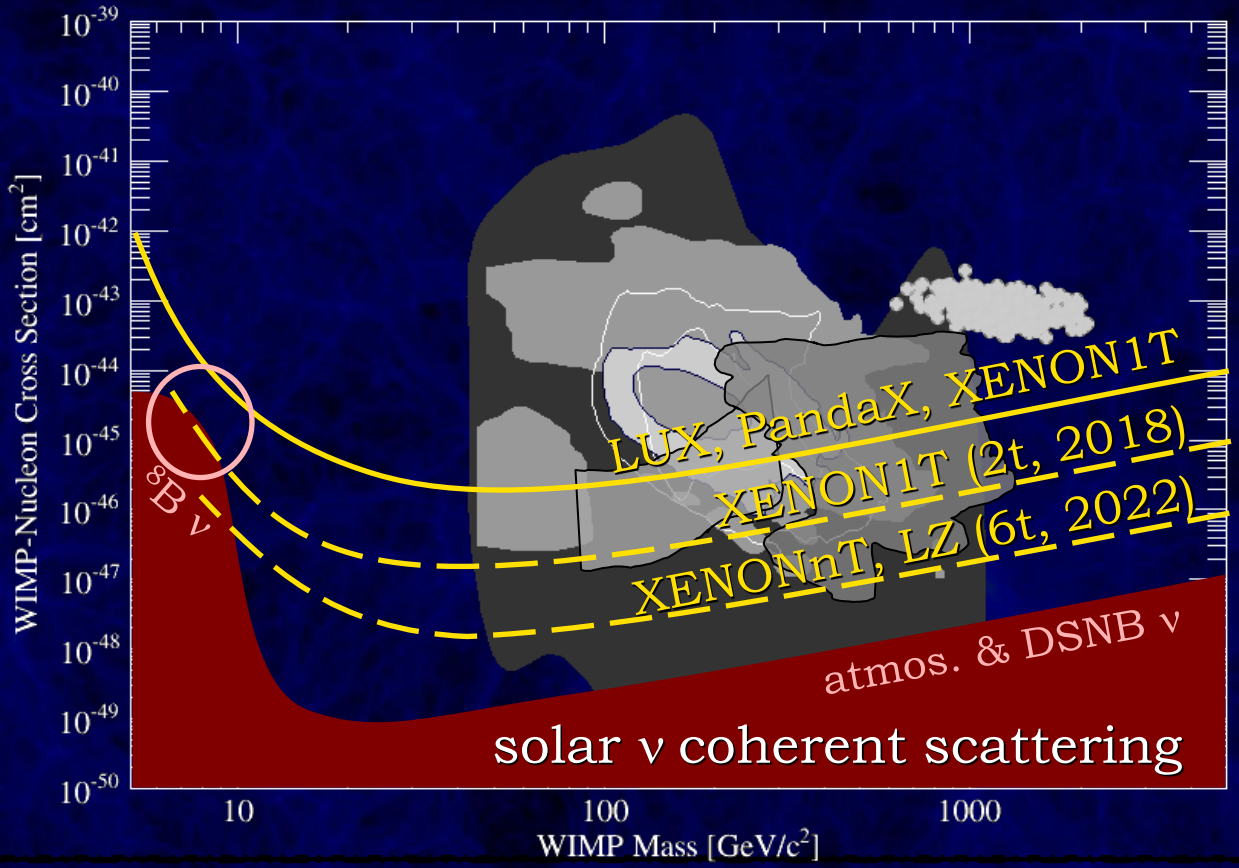
XENON1T

- 3t total, 2t active xenon target
- 30 live days limit published
- >100 live days on tape
- XENONnT & LZ with ~6t xenon starting 2020



XENON 1705.06655

Coherent Neutrino Nucleus Scattering



$\nu_x + N \rightarrow \nu_x + N$

once transferred momentum

$p > \hbar / r_{\text{nucleus}}$

get coherence effect as for WIMPs

$\sigma \propto A^2$

potential signal for XENON1T, measure with LZ & XENONnT

Supernova!

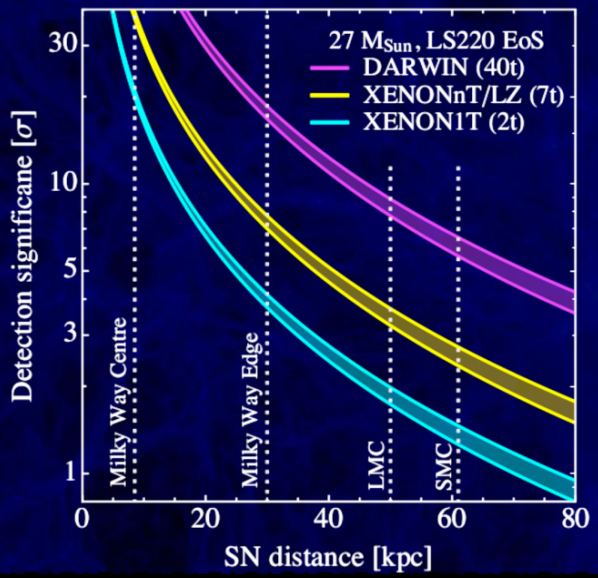
few second burst $\nu_x + N \rightarrow \nu_x + N$

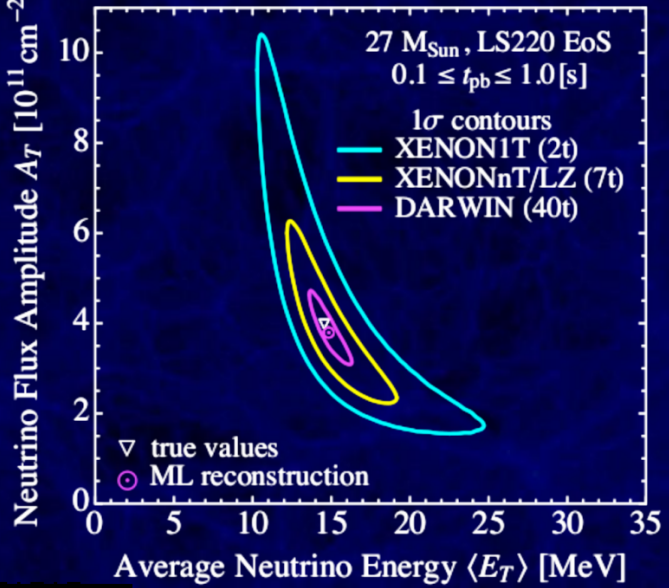
CC: $\mathcal{O}(0.1)\bar{\nu}_e$ per ton versus

CNNS: $\mathcal{O}(10)$ per ton

flavor-independent: complementary information

XENON1T sensitive across entire Milky Way:

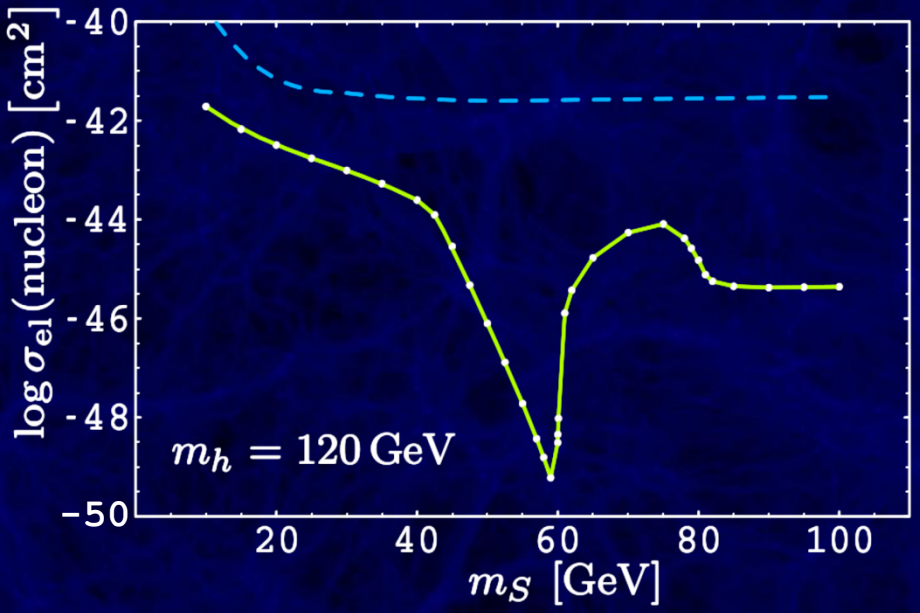


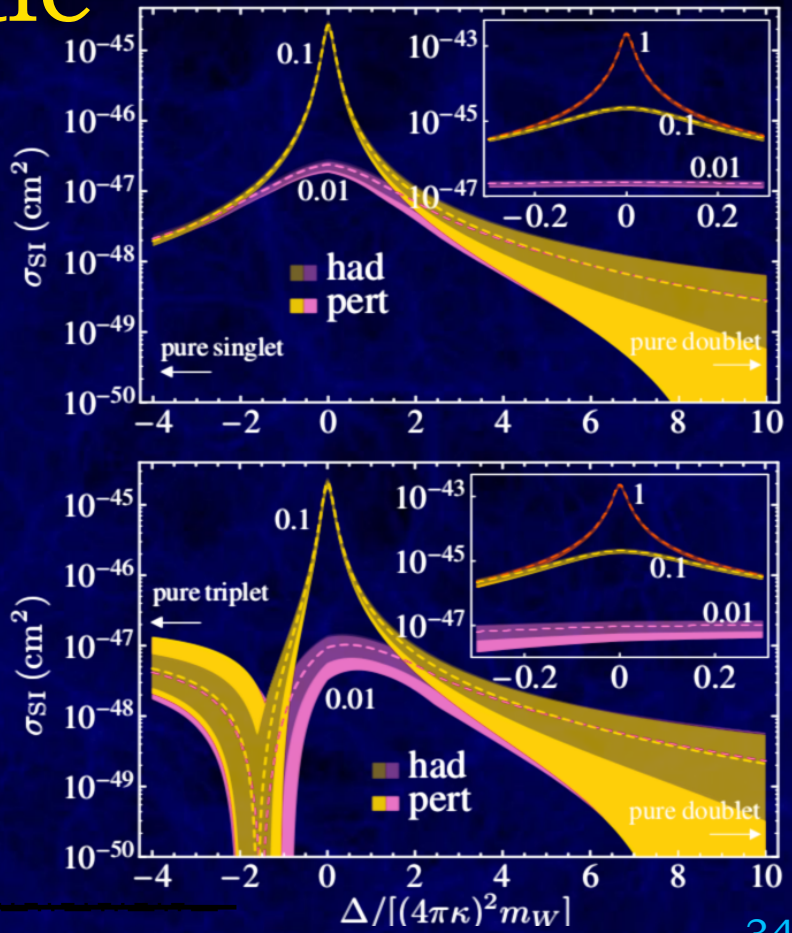


Rafael+ 1606.09243

Nature Sets the Scale

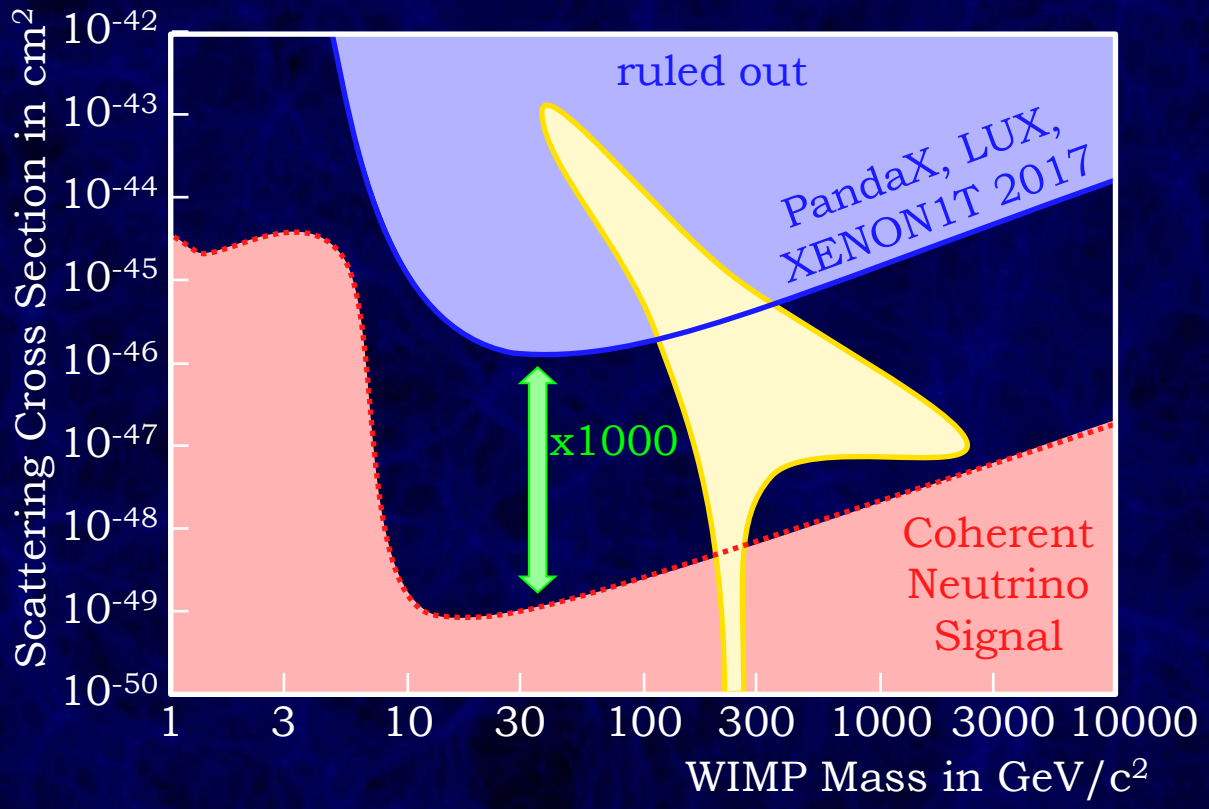
Burgess`+ 0011335





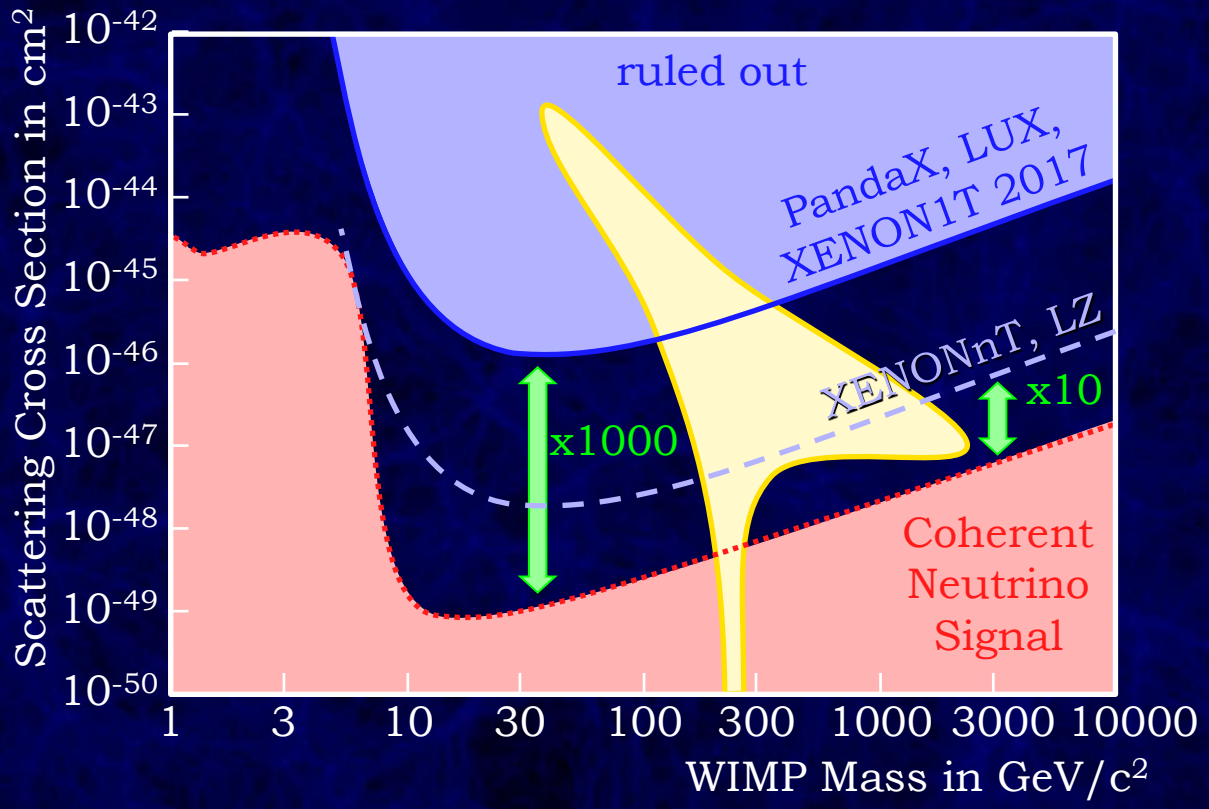
Hill&Solon 1309.4092

Direct Detection: Status



best limits set by liquid xenon TPCs

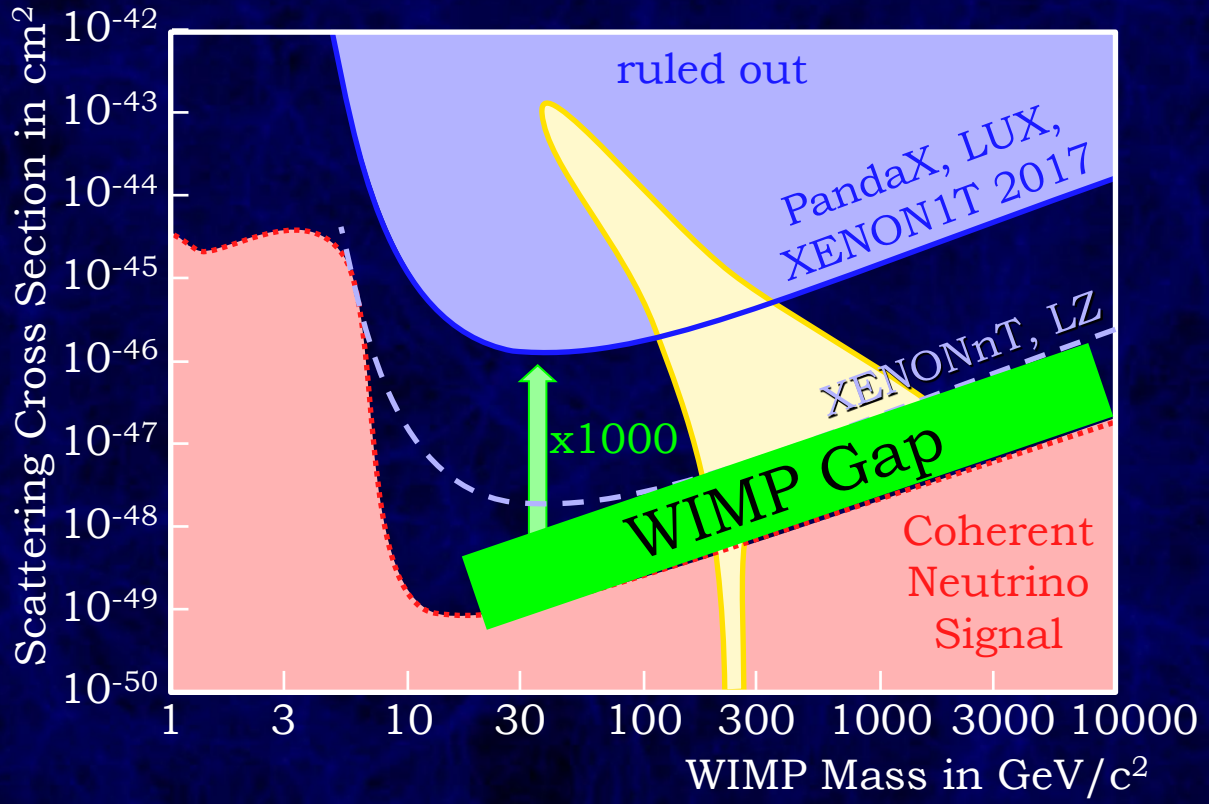
Direct Detection: Outlook



best limits set by liquid xenon TPCs

strong program to improve factor 100

Probe WIMPs down to Neutrinos



best limits set by liquid xenon TPCs

strong program to improve factor 100

WIMP gap remains after currently-funded experiments' program

WIMPs? Tenacity Required!

- WIMPs remain most compelling candidates
- Experiments now probe WIMP parameter space
- But only just so
- Have to keep going
- Cover most promising parameter space in coming years

devianart.net