Experimental Dark Matter Searches - Part 1

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Aug 1 2019
TRISEP summer school at TRIUMF


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8200


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Ladder
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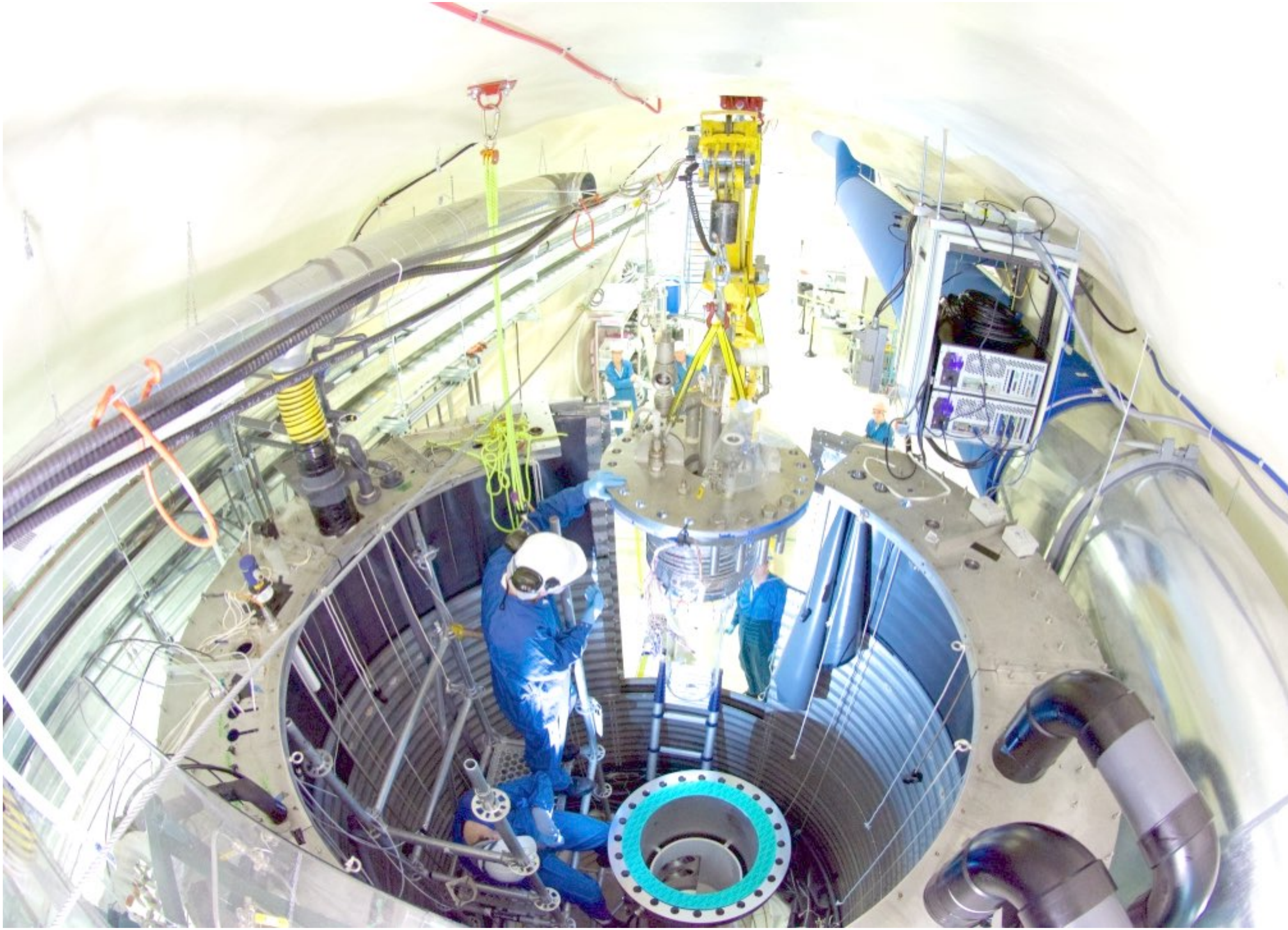
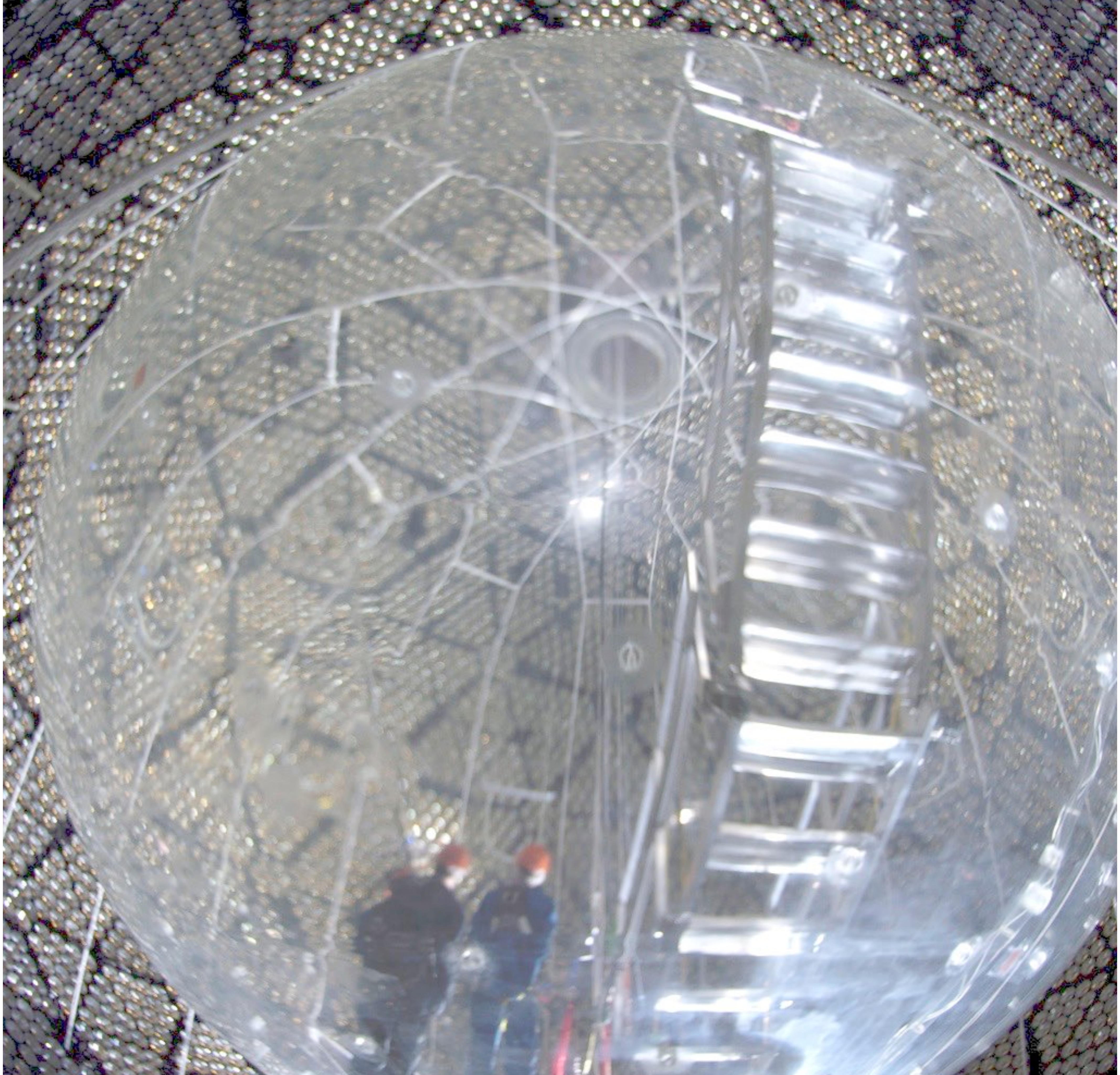




Outline

- Motivation
- Axions
- Lab Production Searches
- Indirect Searches

Start Here

Lambda-CDM model

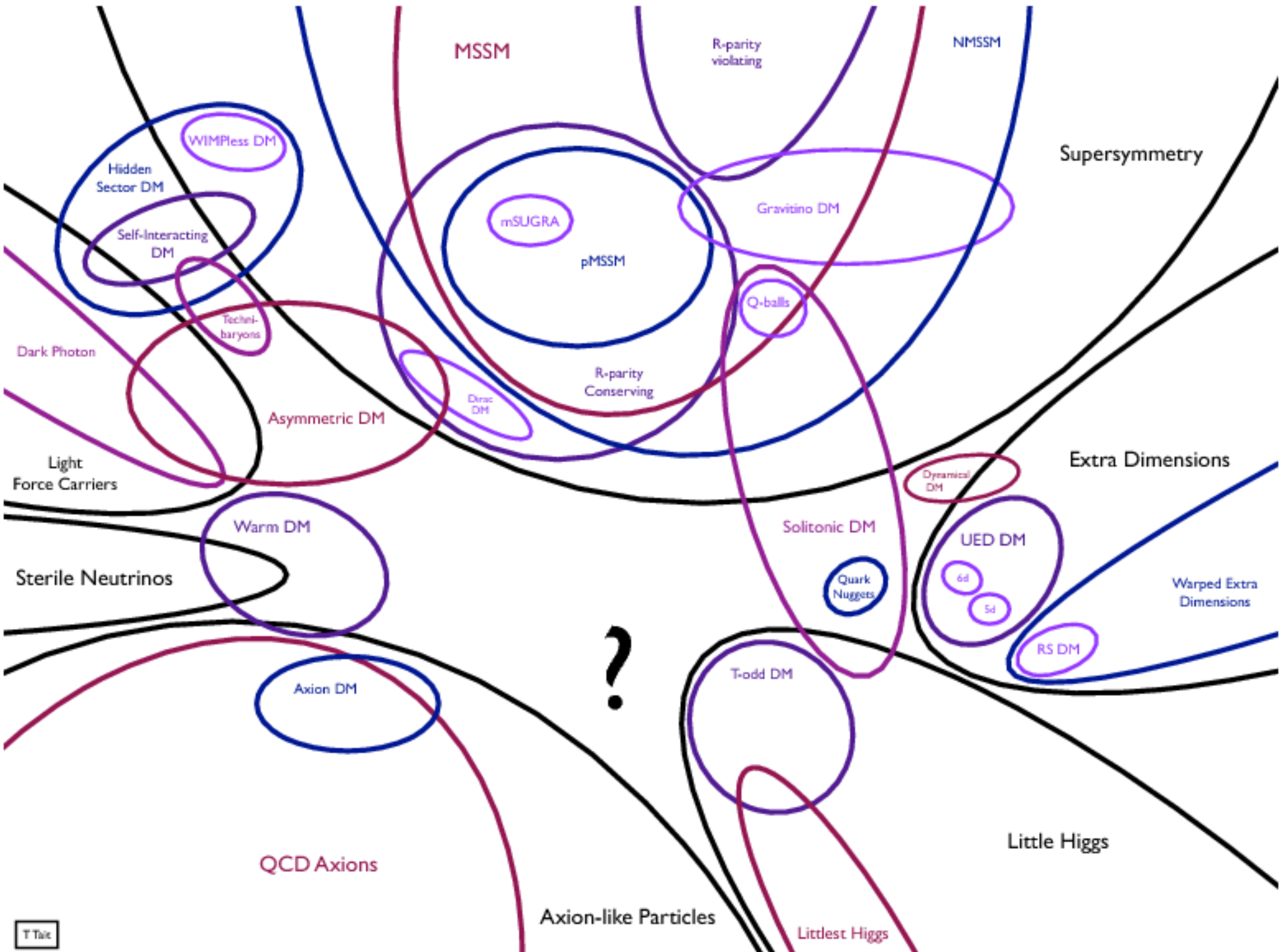
From Wikipedia, the free encyclopedia

"Standard cosmological model" redirects here. For other uses, see Standard model (disambiguation).

The **ΛCDM** (**Lambda cold dark matter**) or **Lambda-CDM** model is a parametrization of the Big Bang cosmological model in which the universe contains three major components: first, a cosmological constant denoted by Lambda (Greek **Λ**) and associated with dark energy; second, the postulated cold dark matter (abbreviated **CDM**); and third, ordinary matter. It is frequently referred to as the **standard model** of Big Bang cosmology because it is the simplest model that provides a reasonably good account of the following properties of the cosmos:

- the existence and structure of the cosmic microwave background
- the large-scale structure in the distribution of galaxies
- the abundances of hydrogen (including deuterium), helium, and lithium
- the accelerating expansion of the universe observed in the light from distant galaxies and supernovae

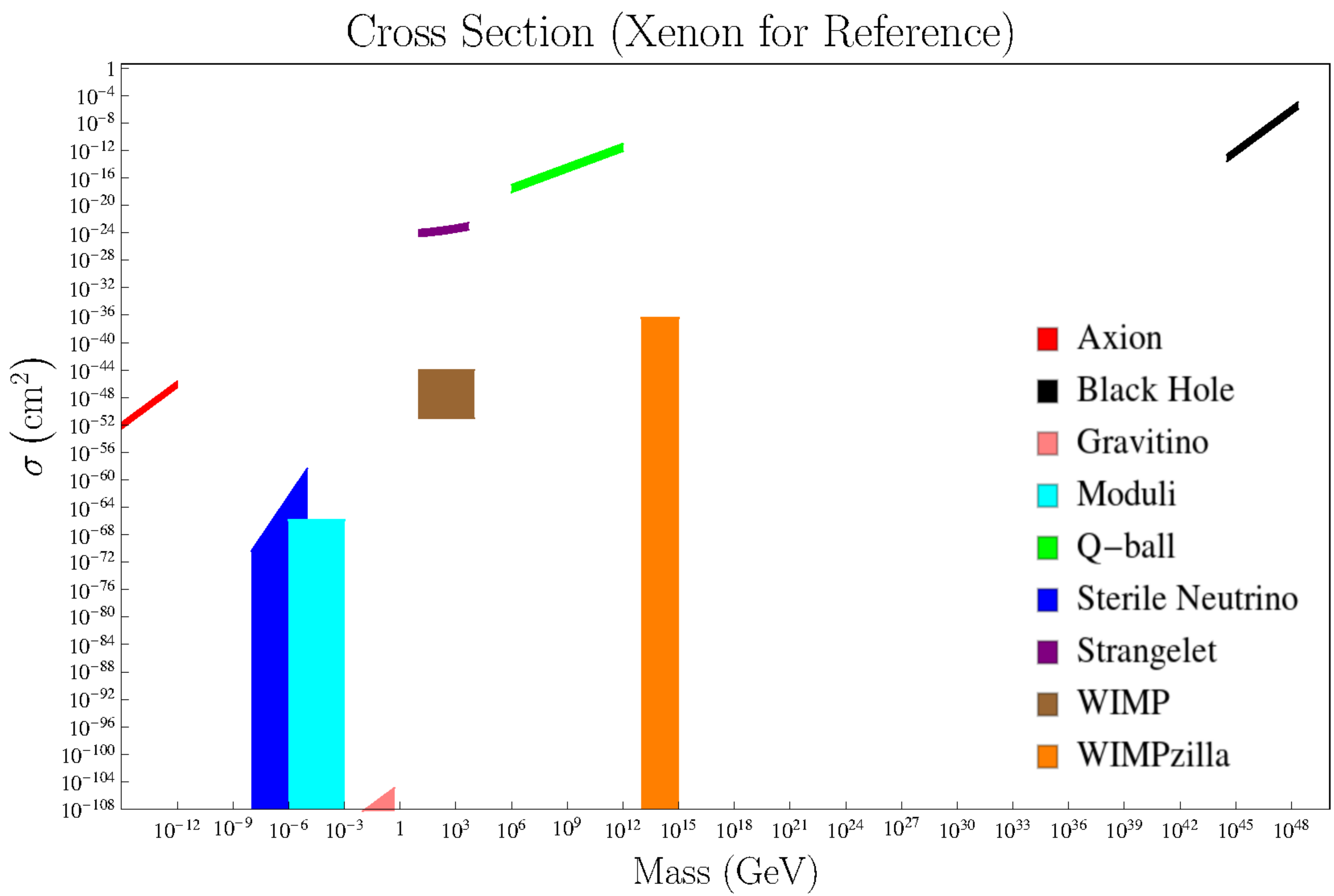
Dark Matter Landscape



T. Tait

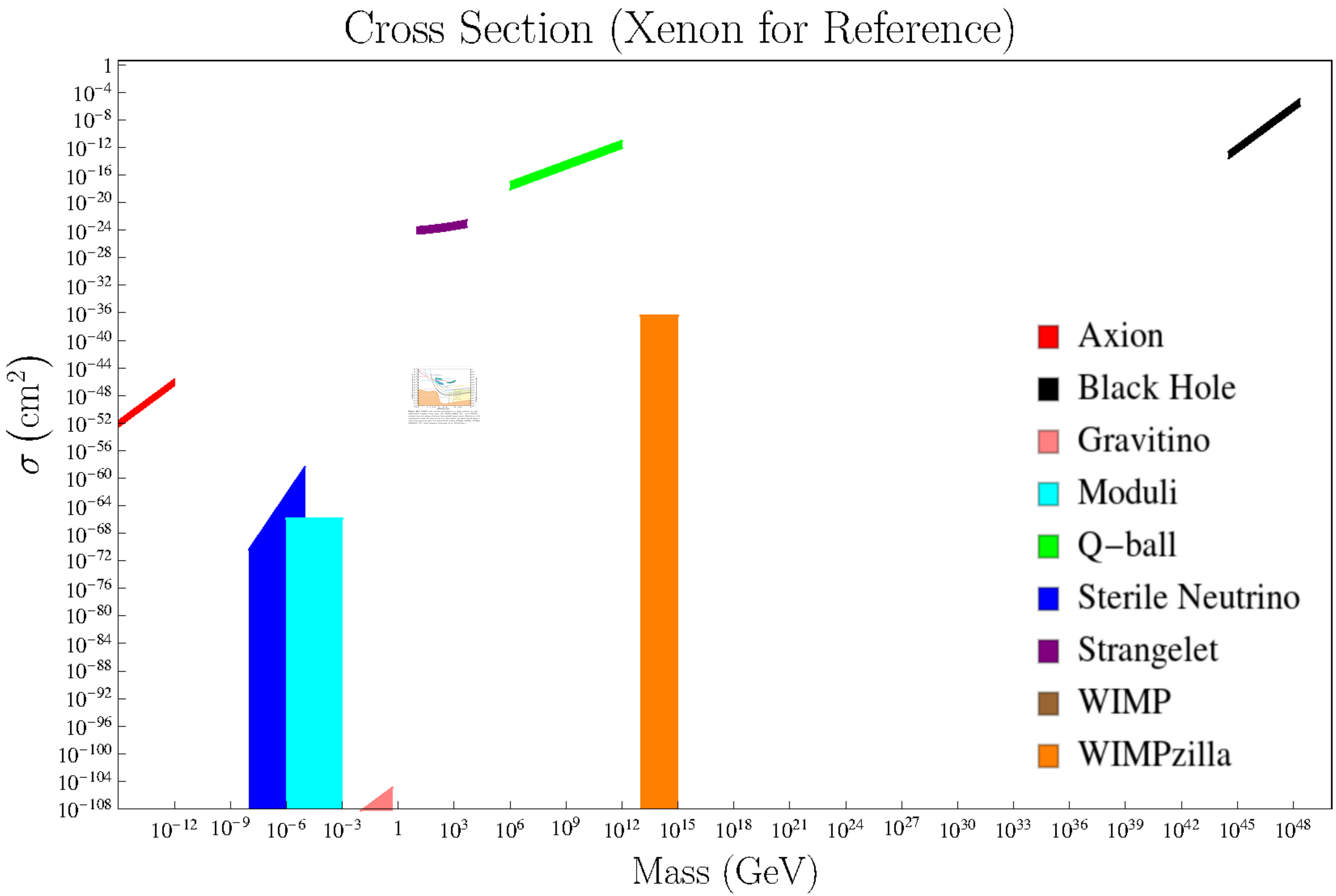
arxiv1310.8642

Parameter Space



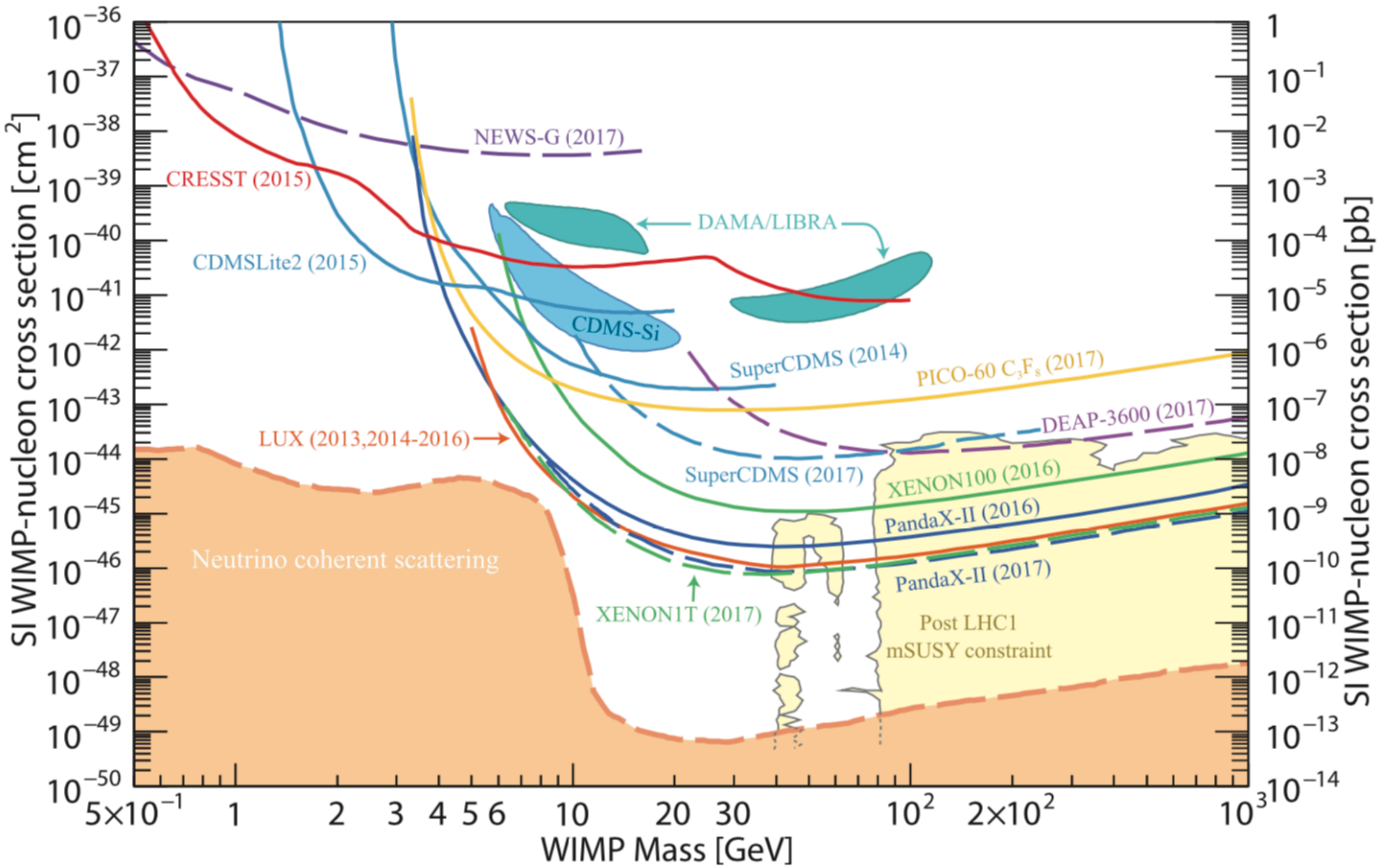
M. Tanabashi et al. (Particle Data Group), Phys. Rev. D **98**, 030001 (2018).

Parameter Space



M. Tanabashi et al. (Particle Data Group), Phys. Rev. D **98**, 030001 (2018).

Parameter Space



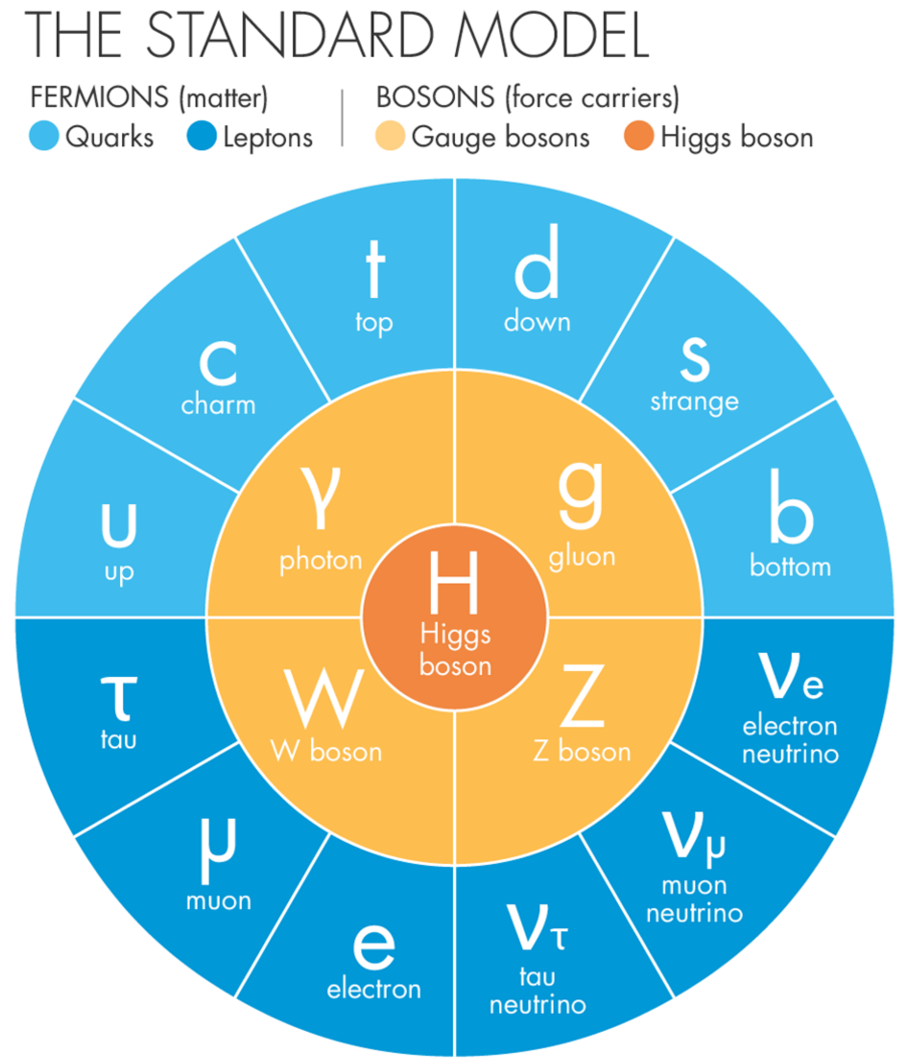
σ (cm^2)

Figure 26.1: WIMP cross sections (normalized to a single nucleon) for spin-independent coupling versus mass. The DAMA/LIBRA [72], and CDMS-Si enclosed areas are regions of interest from possible signal events. References to the experimental results are given in the text. For context, the black contour shows a scan of the parameter space of 4 typical SUSY models, CMSSM, NUHM1, NUHM2, pMSSM10 [73], which integrates constraints set by ATLAS Run 1.

M. Tanabashi et al. (Particle Data Group), Phys. Rev. D **98**, 030001 (2018).

DM properties

- Non EM interacting (no charge), hence "dark"
- Non-relativistic to explain galaxy formation
- Stable
- Massive (to explain gravitational effects)
- This leaves only particles that either have not been found yet, or that need extensions to the SM



What are we looking for, then?

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- Axions

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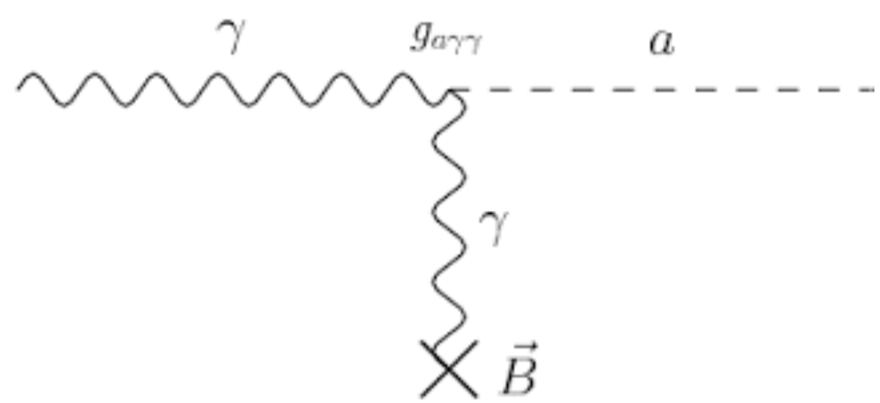
- Axions

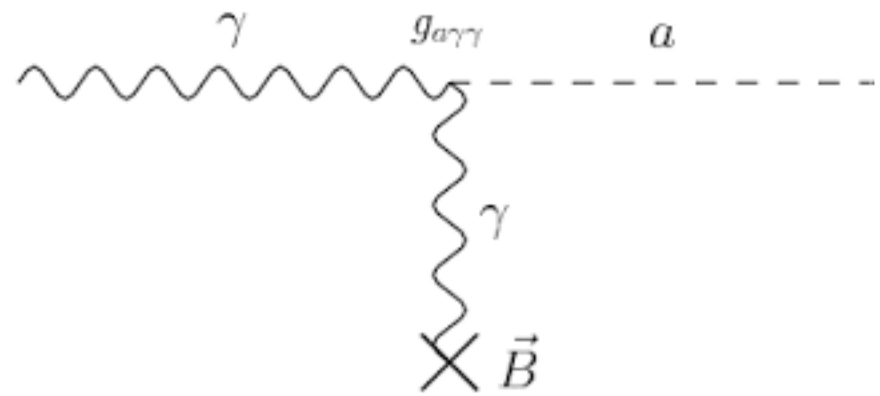
- WIMPs

Axions



- To address the strong CP problem a field (“axions”) are introduced. The axions ensure that no CP violation occurs in the strong interaction
- Because most heavy axions have been excluded based on cosmological parameters or direct observations, axions have to be light and can then be a dark matter particle (long-lived and potentially large matter density)
- There are two models: KSVZ and DFSZ. In the KSVZ model axions couple to hadrons, the DFSZ axions also couple to leptons
- Search experiments use the Primakoff effect

What do you need for Axions to interact?

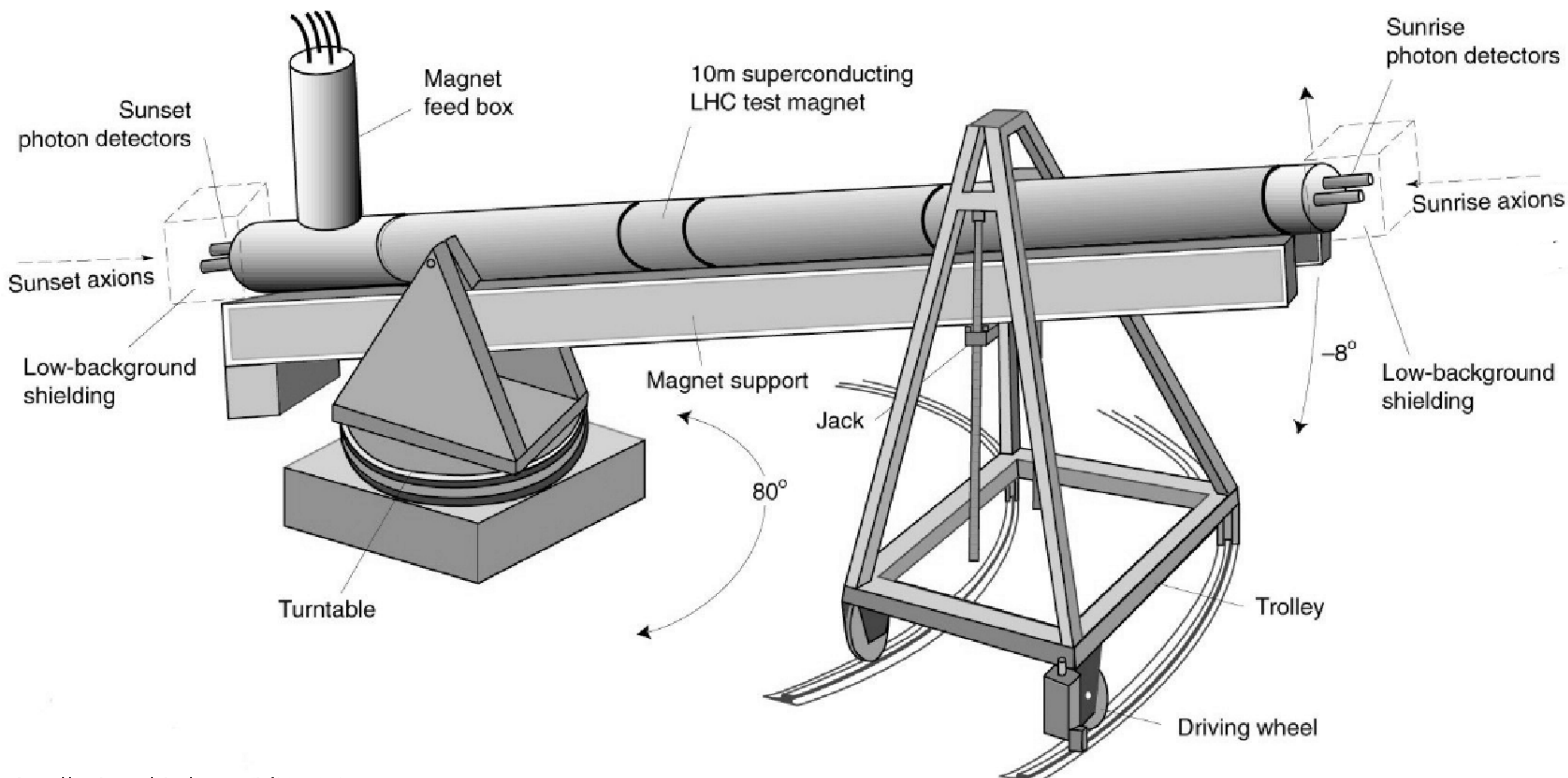


- For direct search experiments you need:
  - Strong magnetic field (stronger -> better)
  - Sensitivity to photons being created in your experiment

Axion Searches

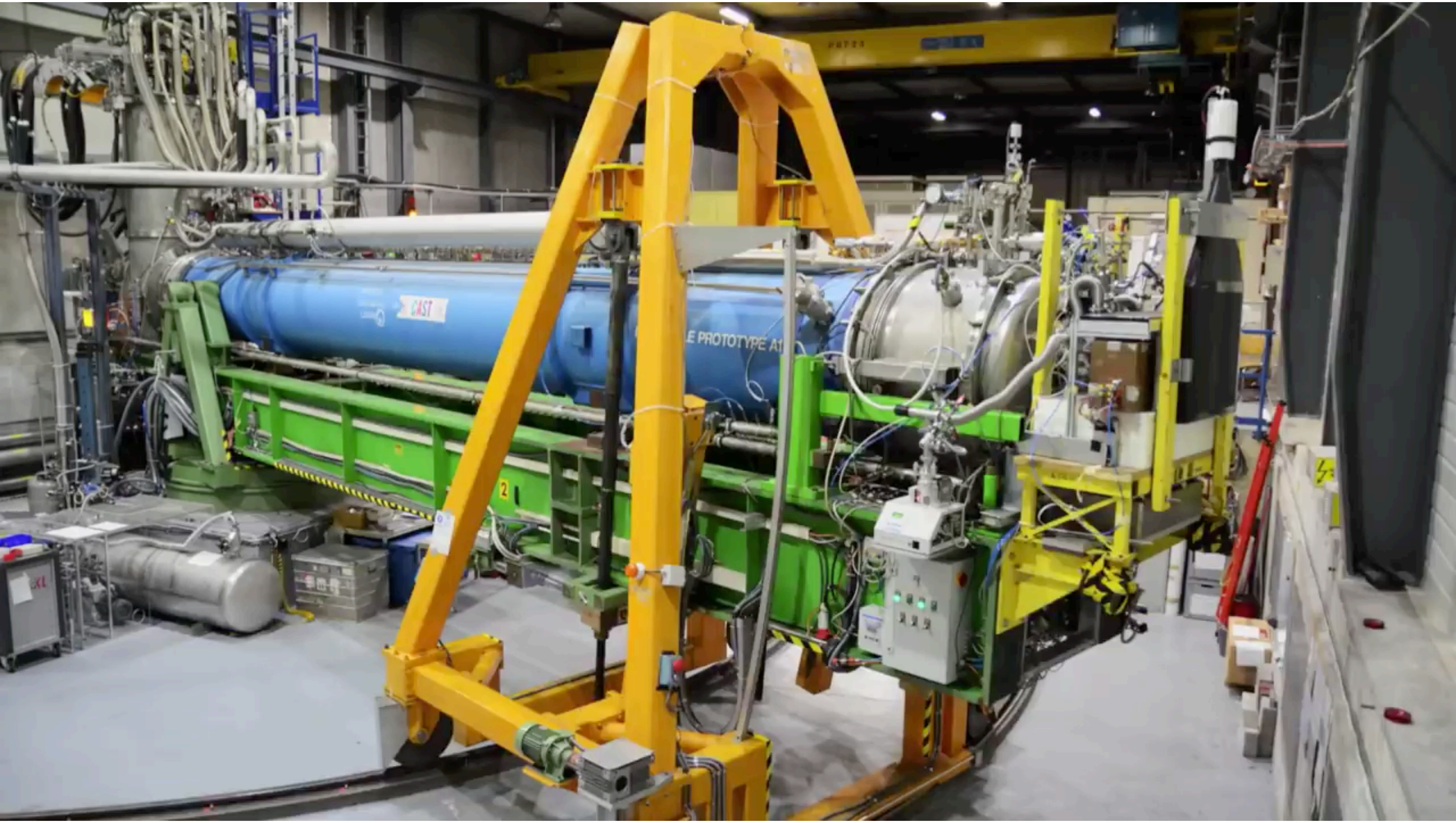
- There are two approaches for experimental realizations of axion searches
  - Solar axion telescopes, looking for axions created in the strong electric field of the sun’s core and
  - Cavity haloscopes
- This leads to the two most prominent experiments in the axion business: CAST and ADMX

CERN Axion Solar Telescope (CAST)

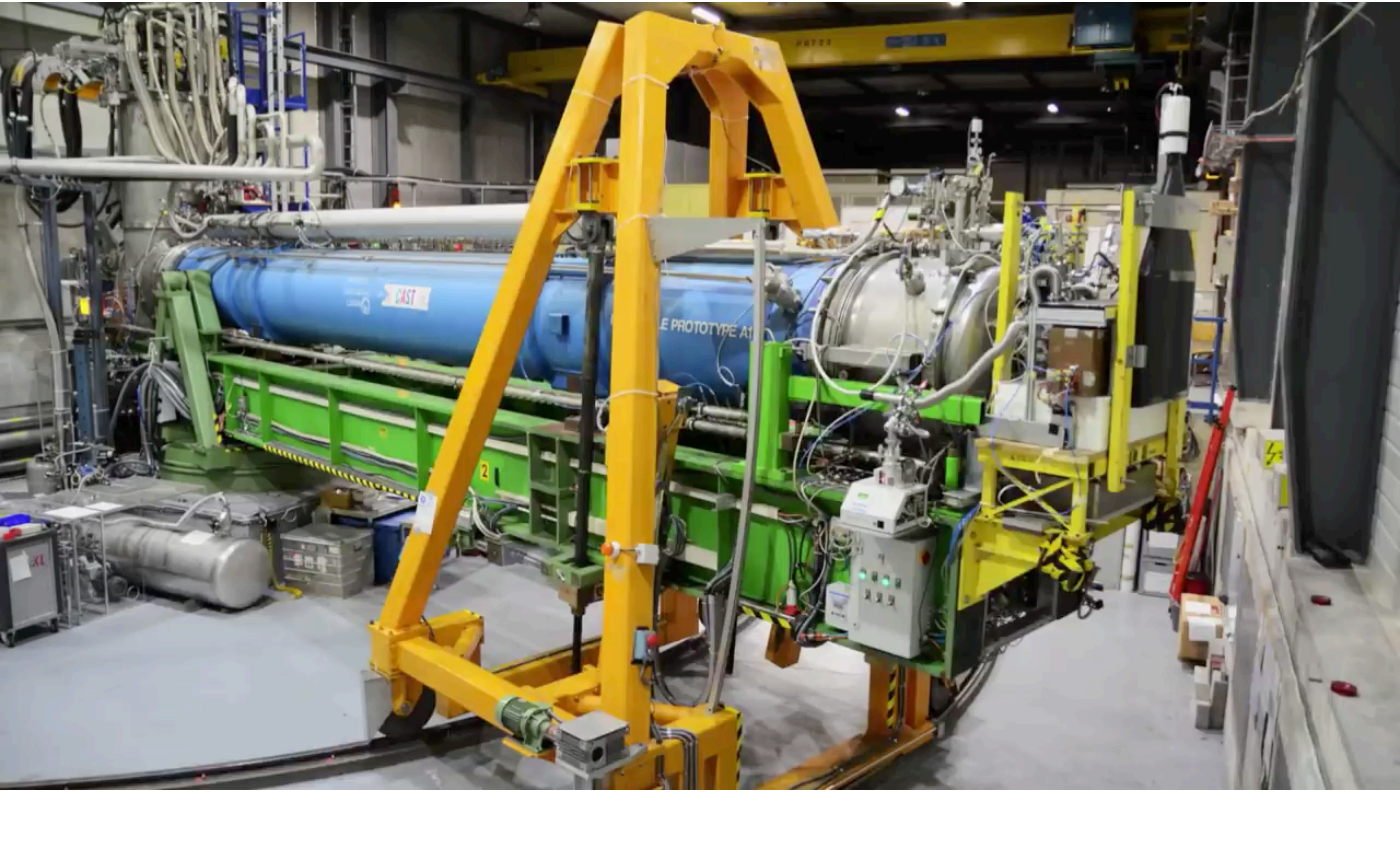


http://arxiv.org/abs/astro-ph/0211606

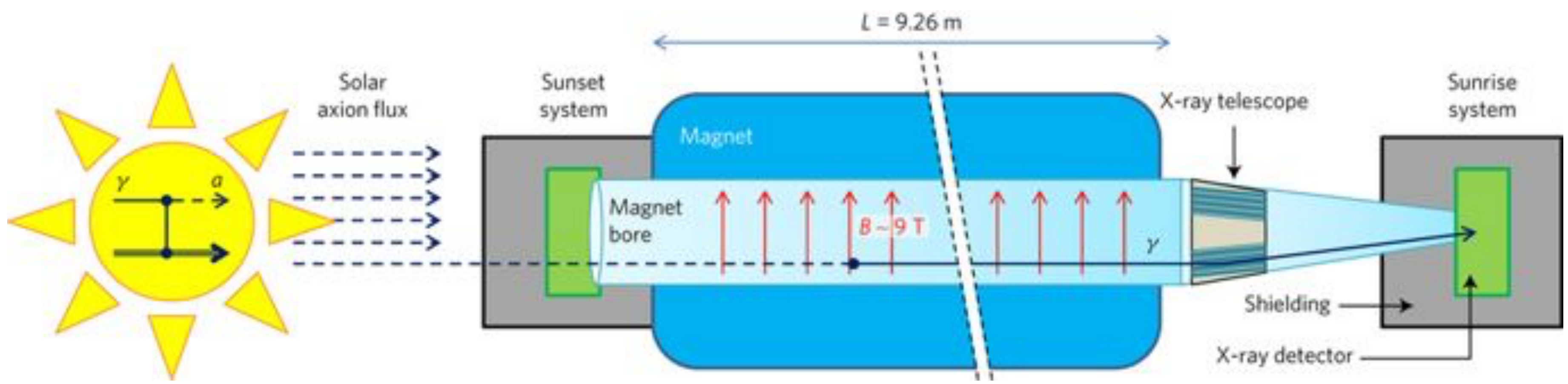
CAST video



CAST video

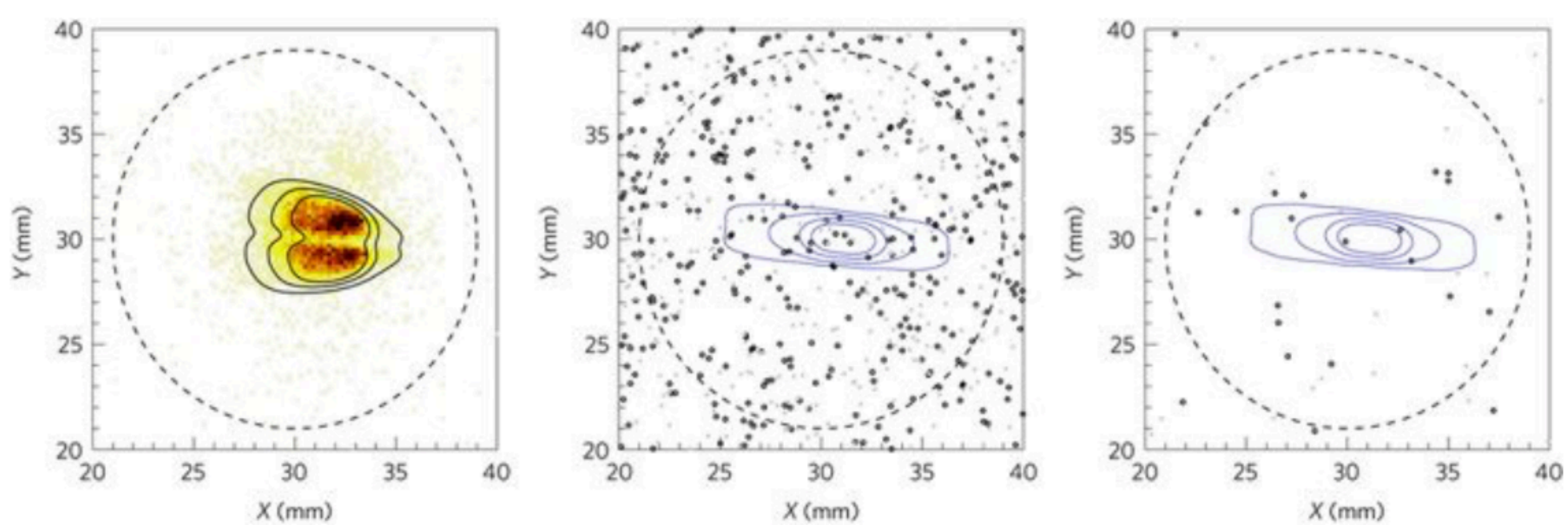


CAST detection



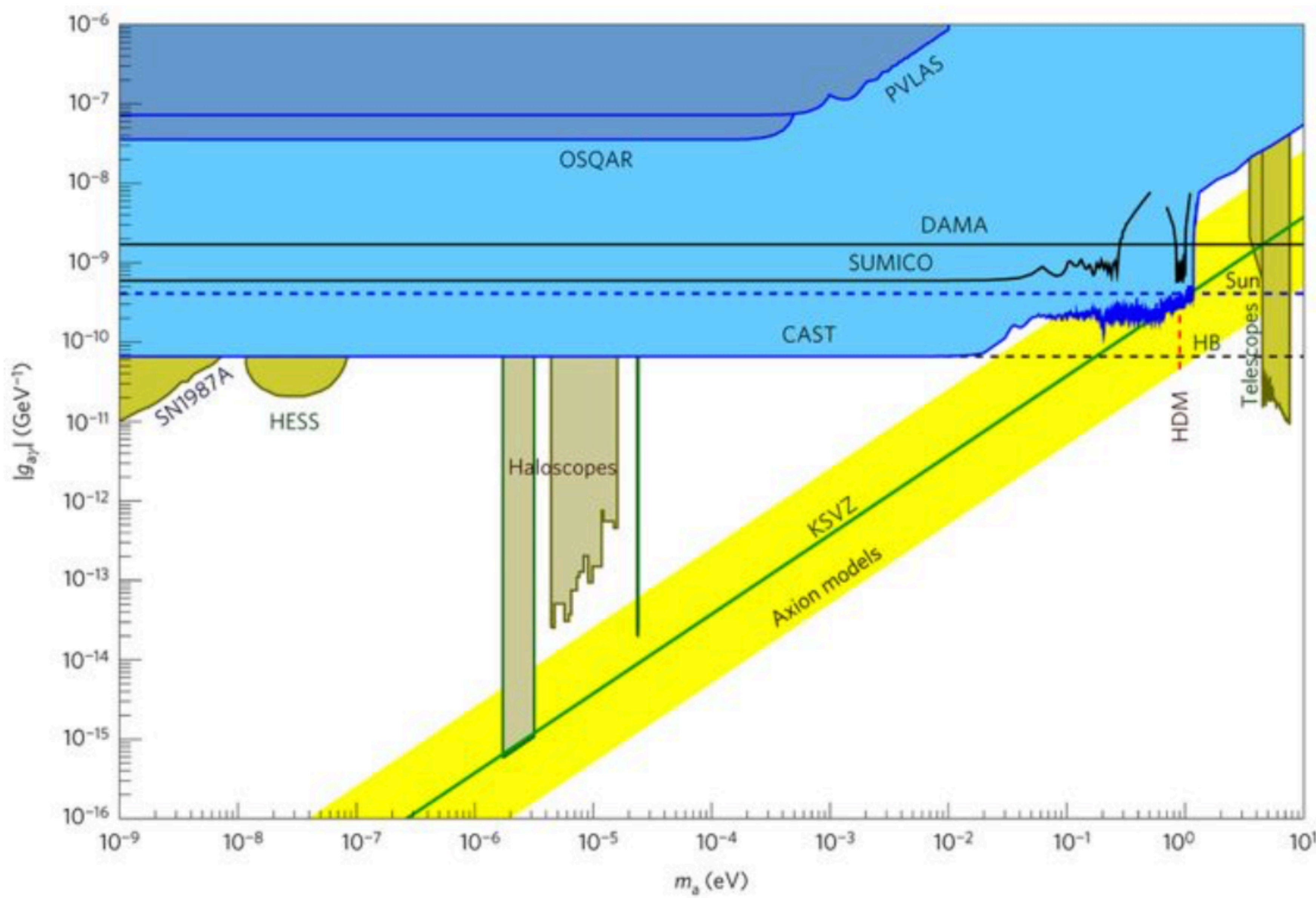
Nature Physics volume 13, pages584–590 (2017)

Figure 3: 2D hitmap of events detected in the sunrise detector in a typical *in situ* calibration run (left), as well as in the background (middle) and tracking (right) data (both K and L data sets of Table 1).



CAST Results

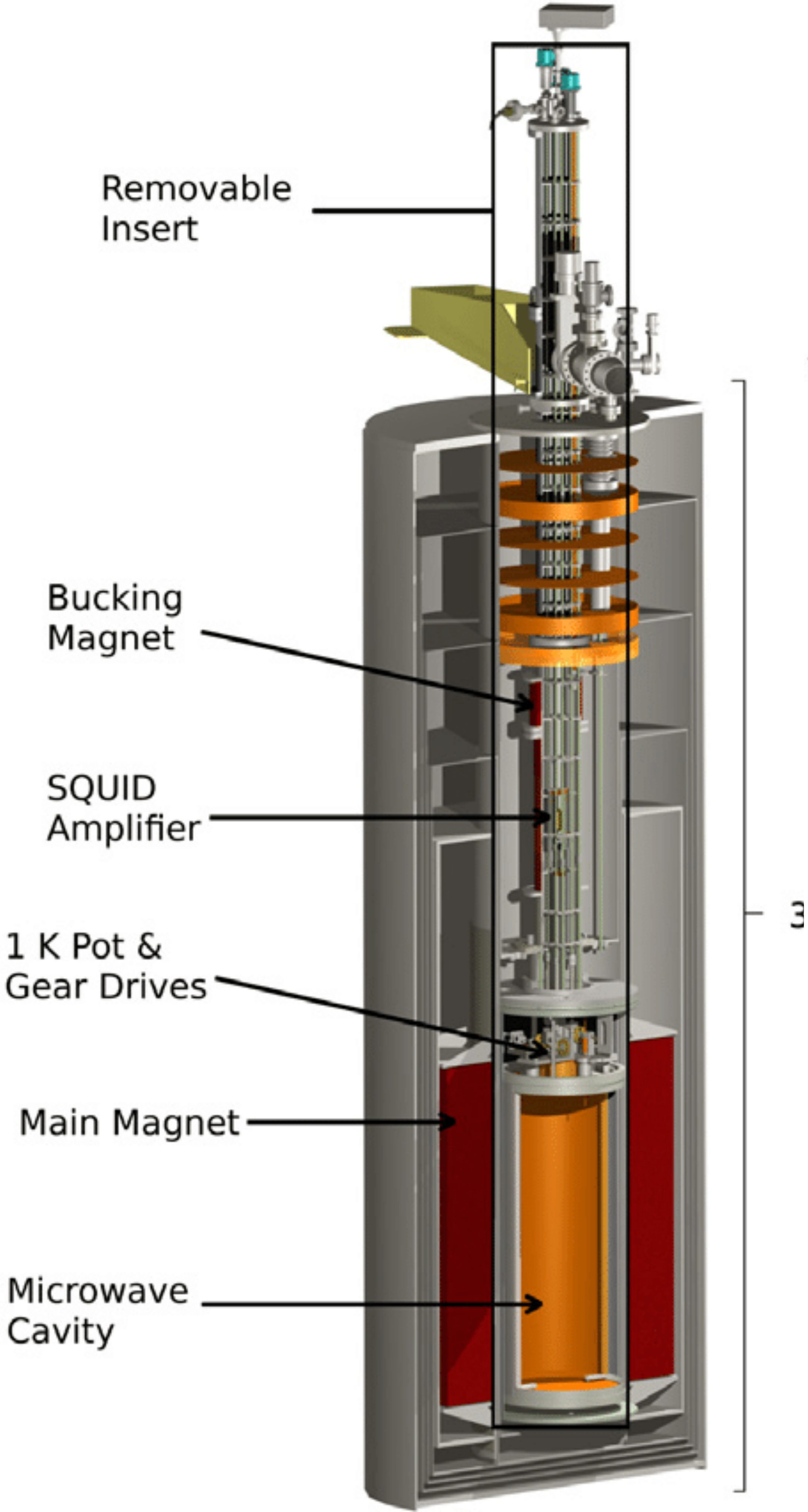
Figure 6: Constraints on the two-photon coupling $g_{a\gamma}$ of axions and similar particles depending on their mass m_a.

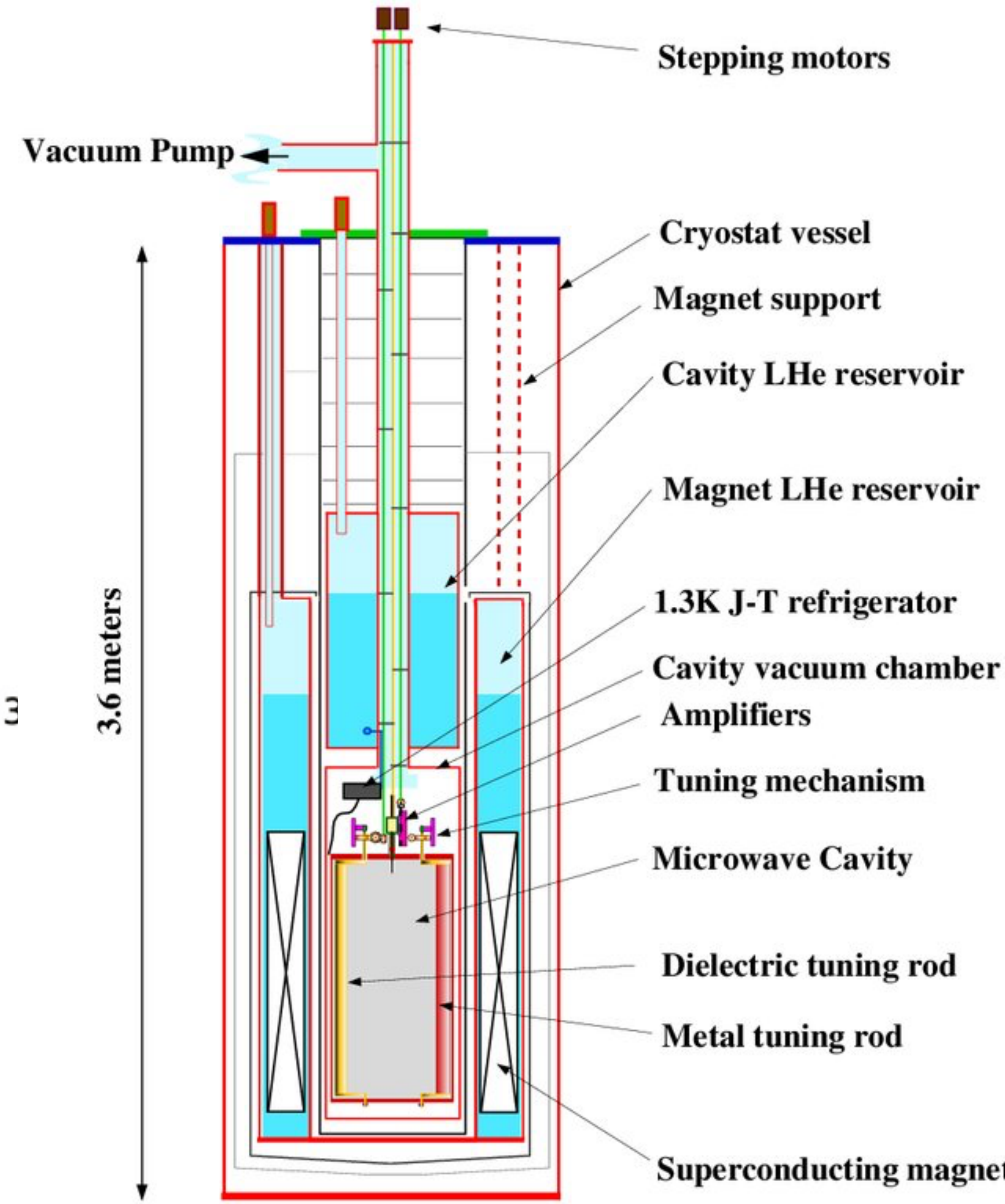


Nature Physics volume 13, pages584–590 (2017)

Axion Dark Matter eXperiment (ADMX)

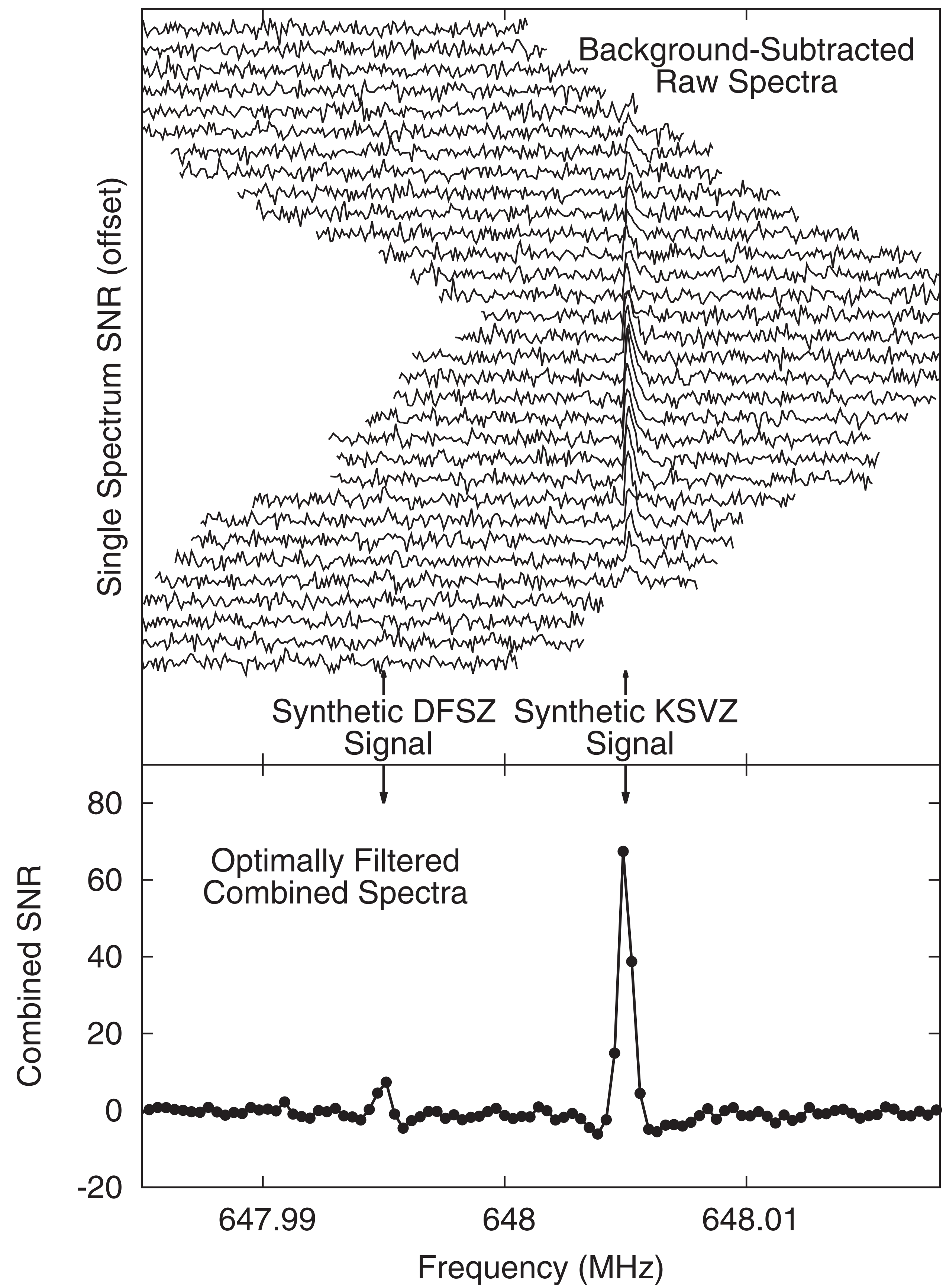
- A strong magnetic field (stronger -> better) surrounds a microwave cavity
- The cavity resonantly stimulates axion to photon conversions in the external background magnetic field
  (Requires a microwave cavity that matches the expected photon frequency for resonant production)
- Axions traveling along the B field lines are converted
- Sensitivity is proportional to the cavity volume and the background magnetic field squared
- The technological challenge here is to make tuneable cavities and very low noise amplifiers


Removable Insert
Bucking Magnet
SQUID Amplifier
1 K Pot & Gear Drives
Main Magnet
Microwave Cavity


Stepping motors
Vacuum Pump
Cryostat vessel
Magnet support
Cavity LHe reservoir
Magnet LHe reservoir
1.3K J-T refrigerator
Cavity vacuum chamber
Amplifiers
Tuning mechanism
Microwave Cavity
Dielectric tuning rod
Metal tuning rod
Superconducting magnet
3.6 meters

- Simulated signal, showing frequency scan during measurement campaign

- Cavity resonance frequency gets tuned by a tuning rod



Phys. Rev. Lett. **120**, 151301

Latest ADMX Results

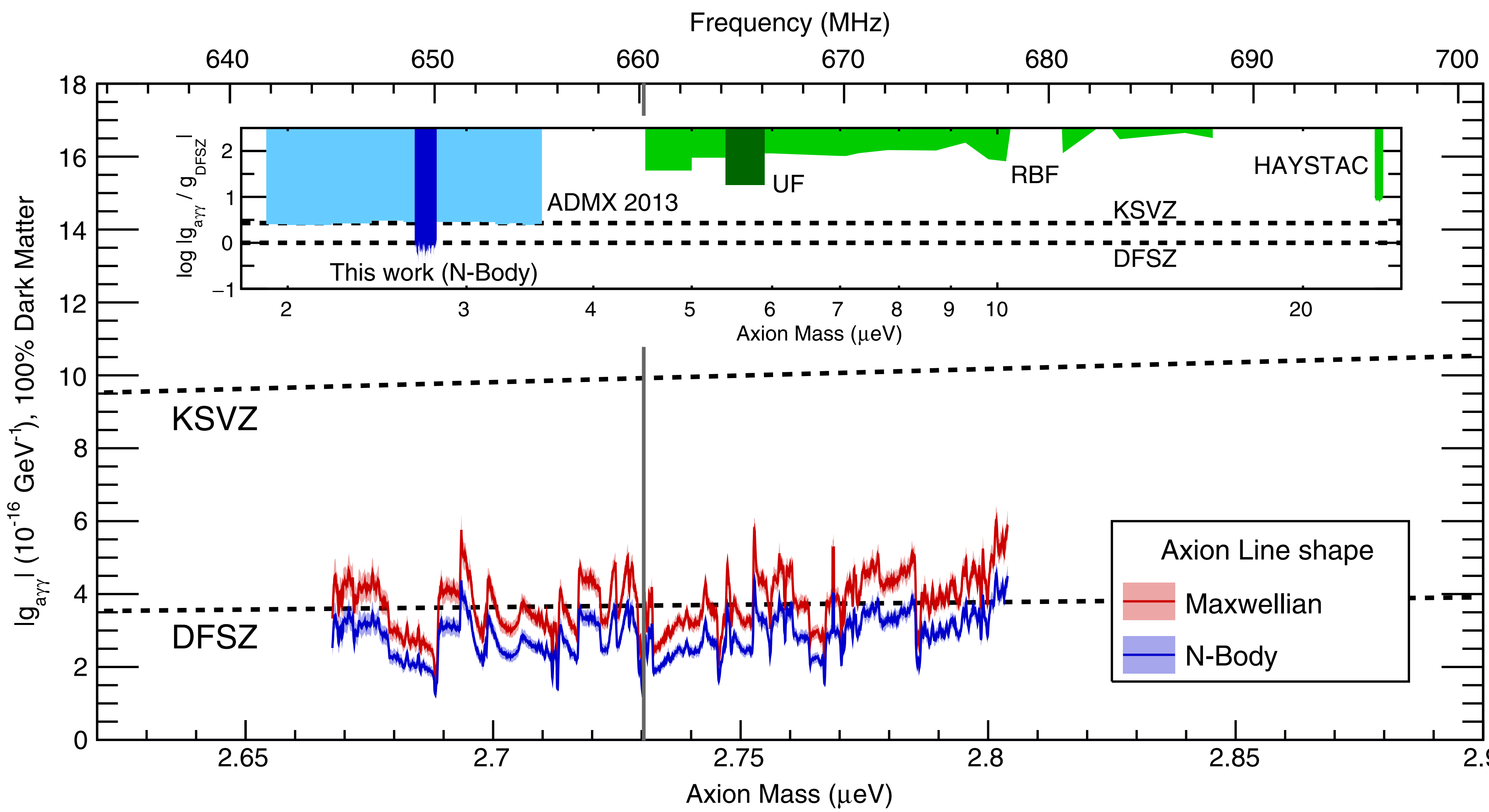


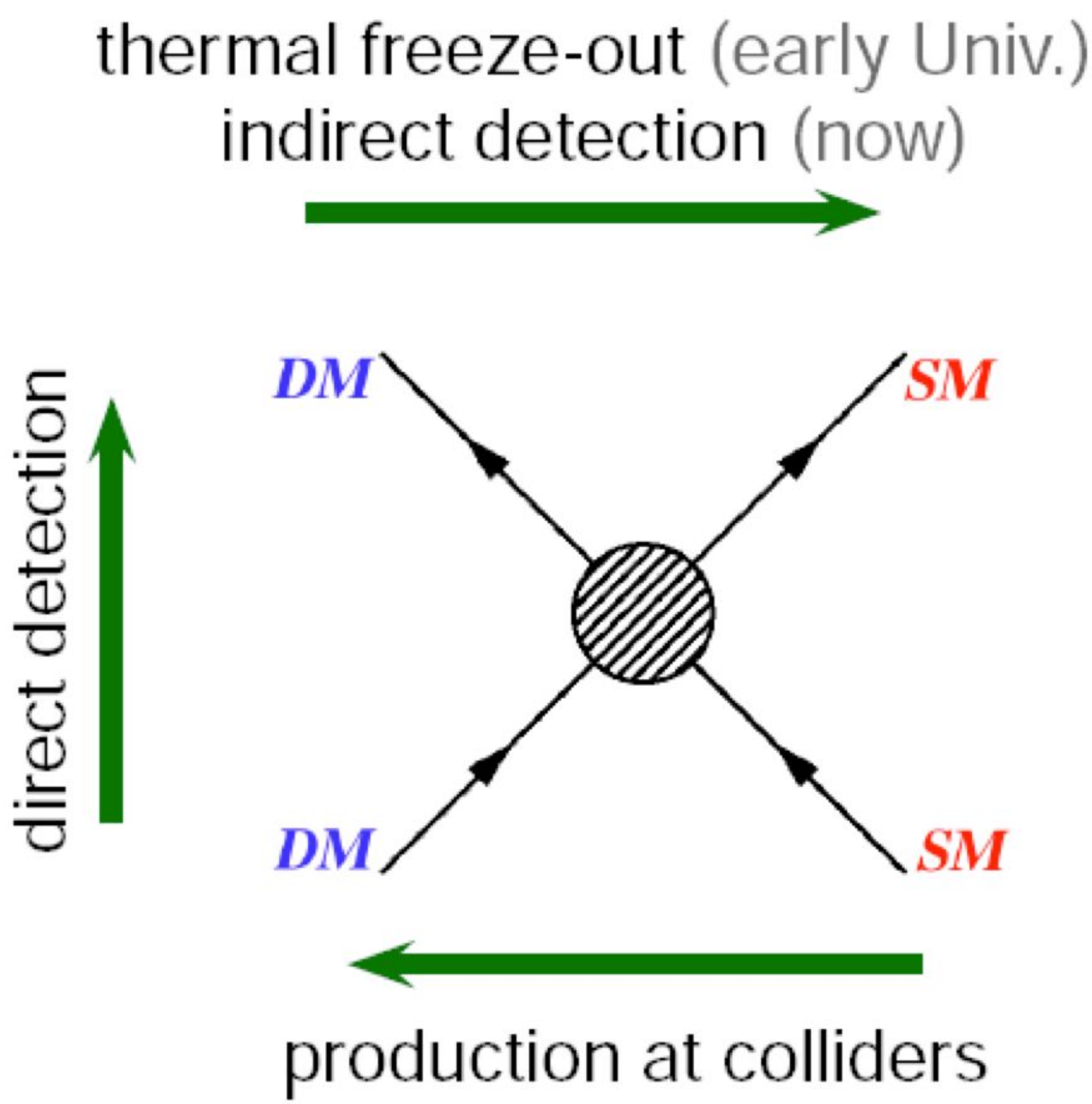
FIG. 4. The 90% upper confidence excluded region of axion mass and photon coupling $g_{a\gamma\gamma}$. The red line indicates the limit on axion-photon coupling with the boosted Maxwell-Boltzmann line shape from the isothermal halo model [39], while the blue line indicates the limit with the N-body inspired signal [37]. Colored regions indicate the systematic uncertainty range. The region 660.16 to 660.27 MHz marked by the gray bar was vetoed due to interference as described in the text. The inset shows the results in the context of other haloscope searches.

Phys. Rev. Lett. **120**, 151301

Summary

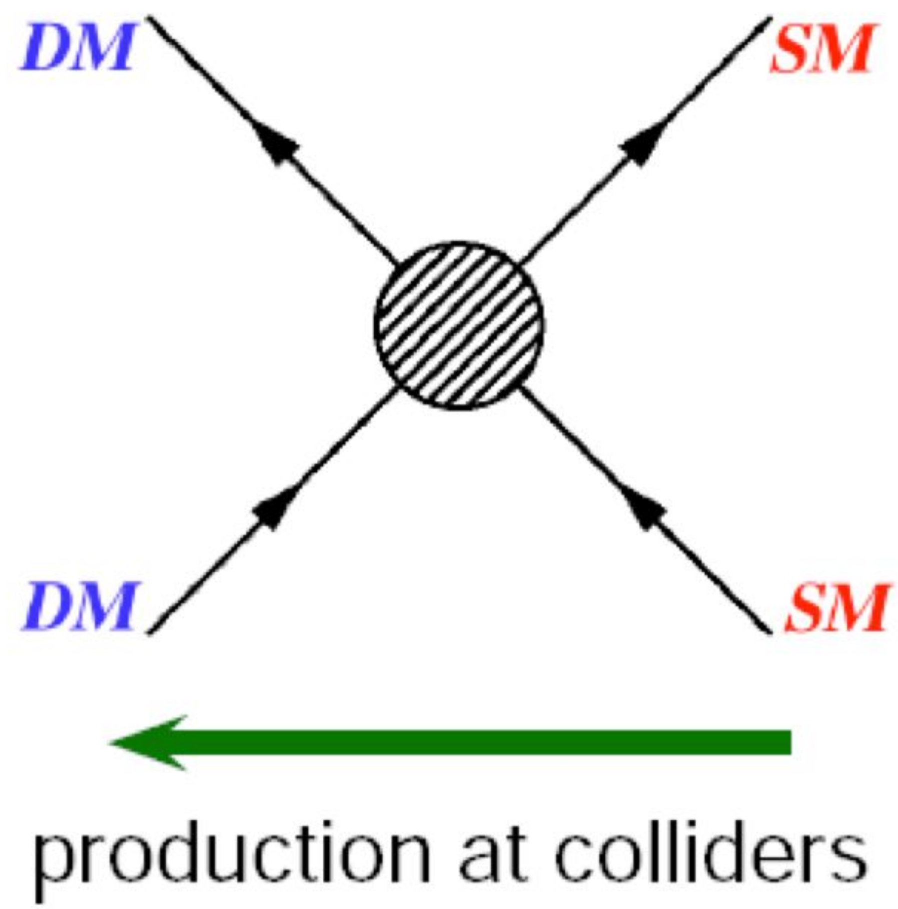
- No axions yet! 

WIMP Searches



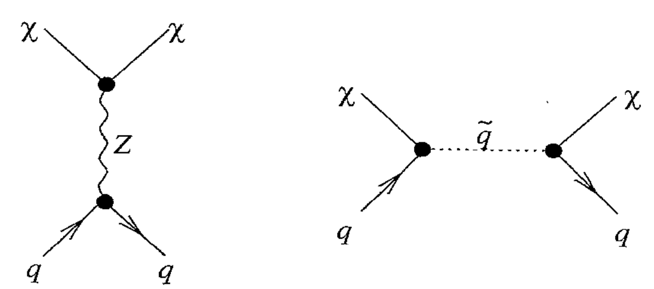
From yesterday’s lecture by G. Gelmini

WIMP Searches

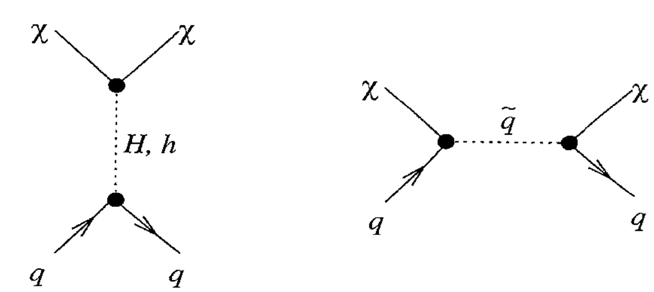


From yesterday's lecture by G. Gelmini

Spin-Dependent or Spin-Independent Interaction



Axial-vector, Spin-dependent

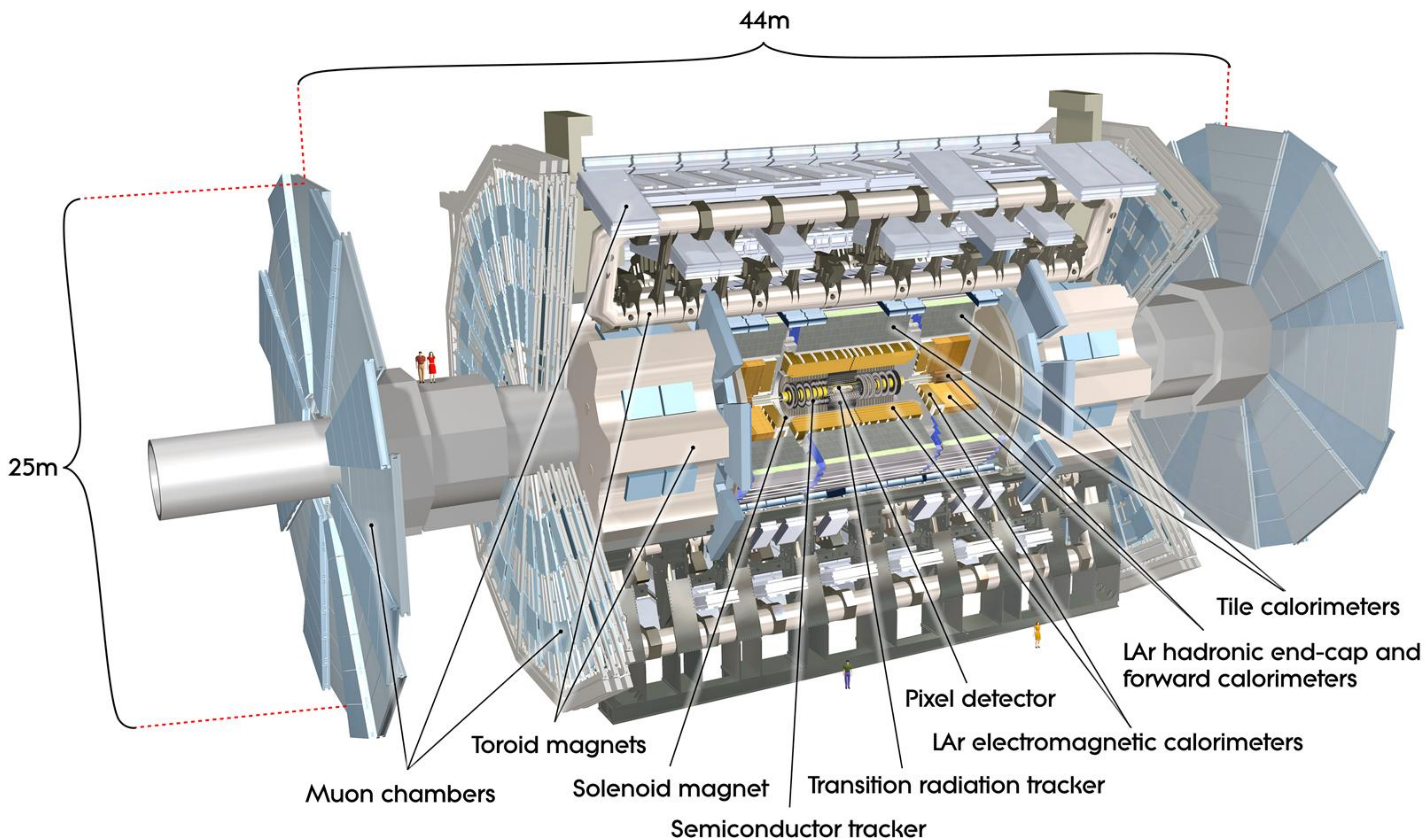


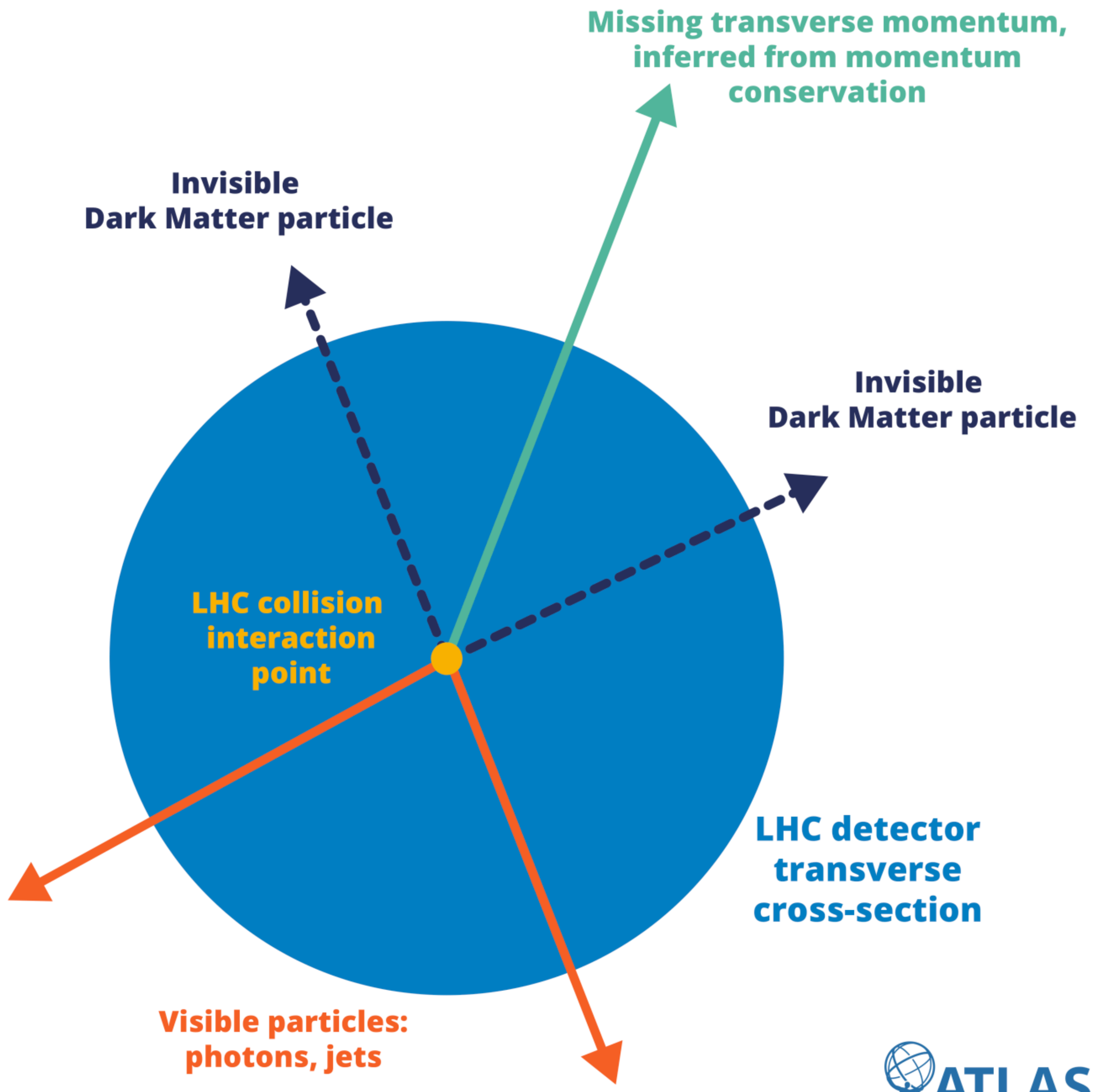
Scalar, spin independent

- The neutralino is a superposition of Higgsino, “Zino” and “photino”
- Squark exchange allowed for both types of WIMP interactions
- A spin-carrying, Majorana type neutralino would interact by Z^0 exchange and squark interaction
- A scalar neutralino couples to the Higgs

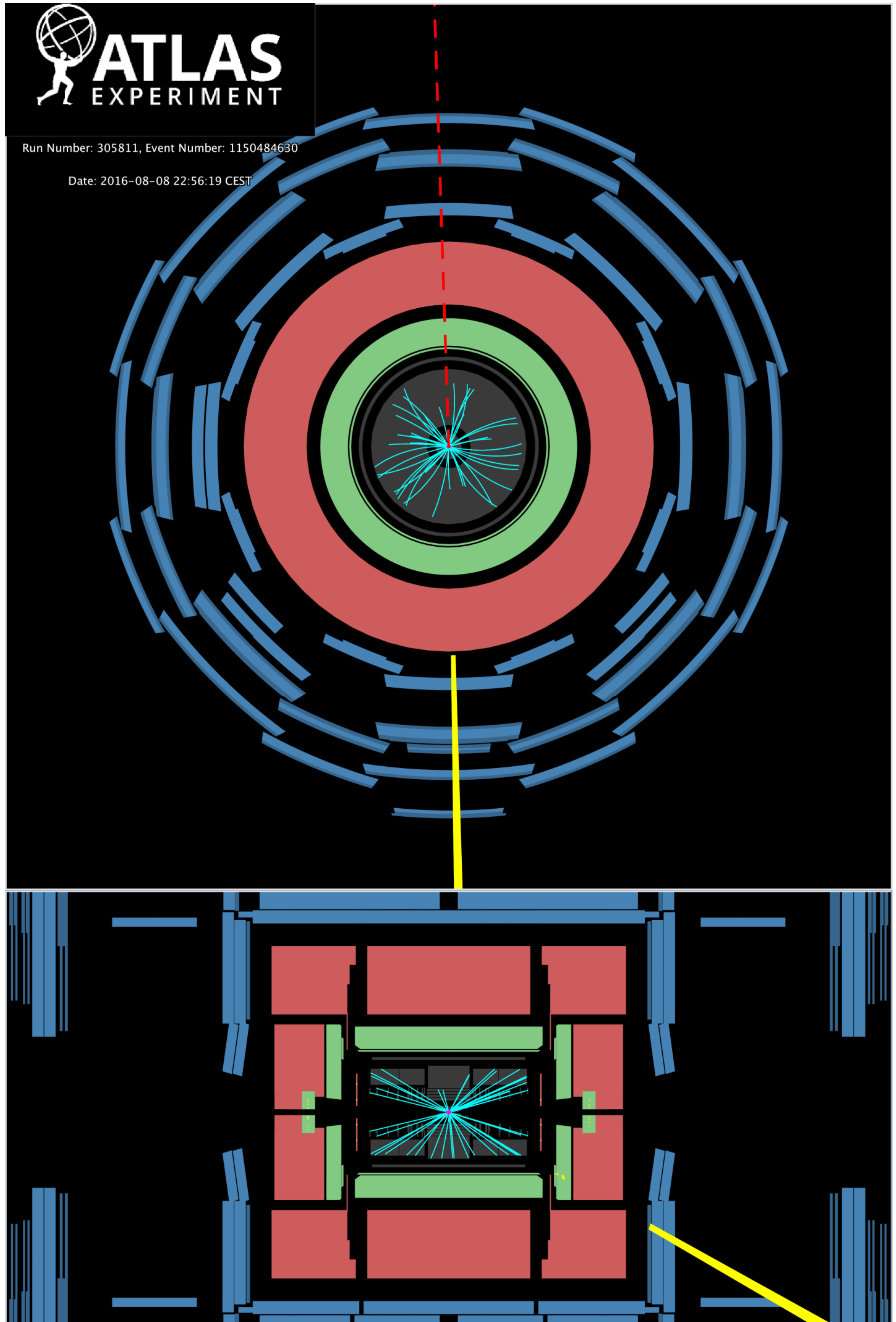
Lab Production

- If dark matter interacts at all with SM partiles, they should also be produced at the LHC
- Most searches at the LHC focus on event signatures where a large fraction of the momentum is missing (Missing E_T -> short MET)
- For a specific mediator mass the LHC experiment can then turn the observed rate limit into a cross section limit or exclude an area on the mediator mass dark matter mass plane
- ALTAS and CMS are competing for better sensitivity to missing transverse momentum


44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker



https://atlas.cern/updates/atlas-feature/dark-matter



https://atlas.cern/updates/atlas-feature/dark-matter

MET Distribution

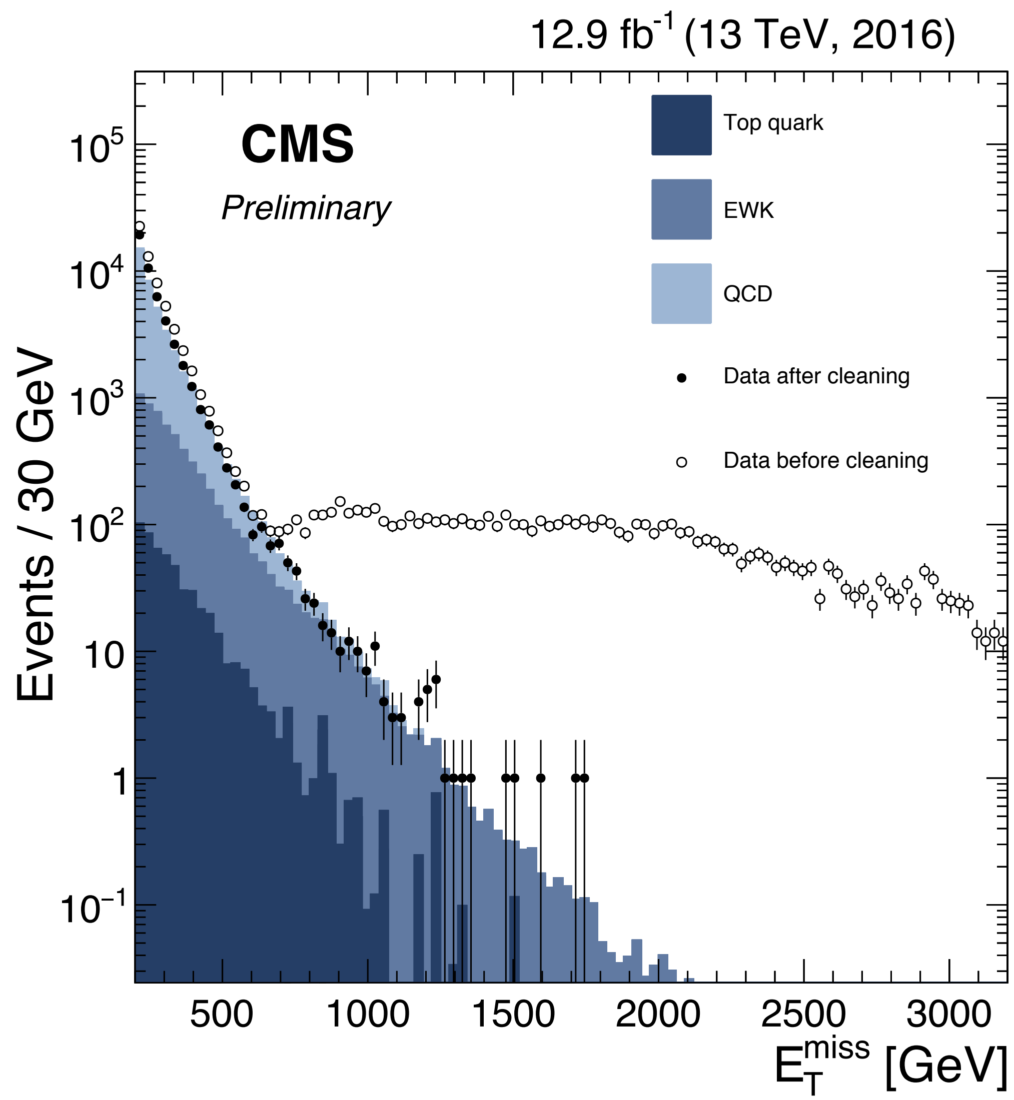
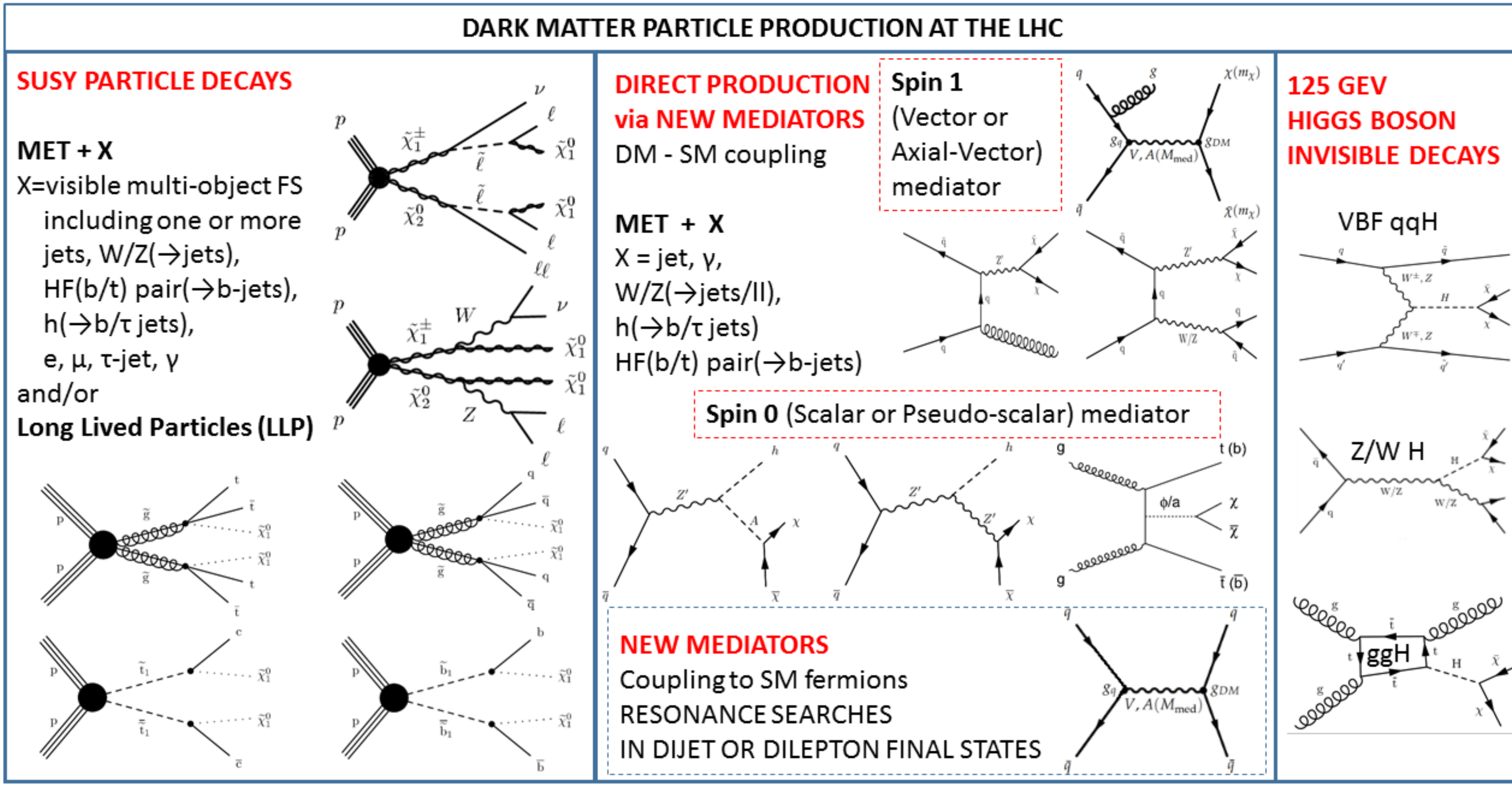


Figure 4

The $\not\!\!E_T$ distribution of events, termed as E_T^{miss} in the x axis, selected for high total hadronic energy and at least two jets with $p_{\mathrm{T}} > 400$ and 200 GeV, before (*open circles*) and after (*filled circles*) rejection of spurious $\not\!\!E_T$ backgrounds (84). The predictions of Monte Carlo simulations (*shaded areas*) are also shown. Strong noncollision background suppression is vital to $X+\not\!\!E_T$ analyses.

arXiv:1810.12238v1



arXiv:1809.06341v1, Marta Felcini

Spin-independent ATLAS Result

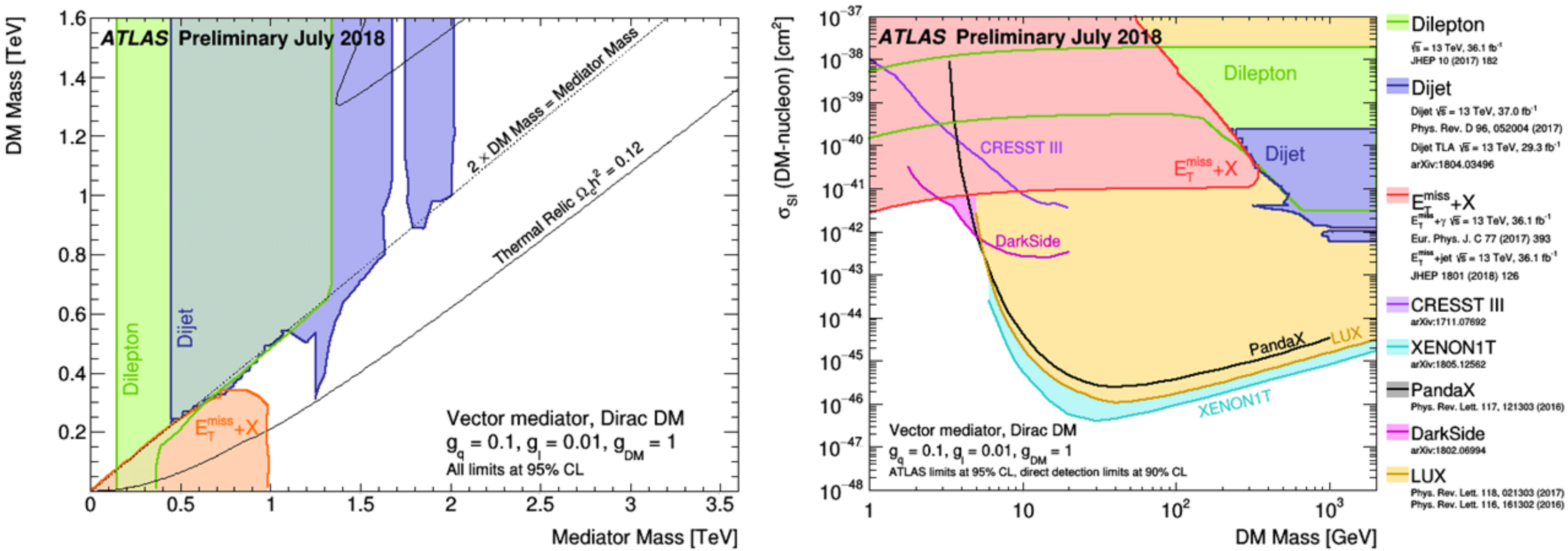
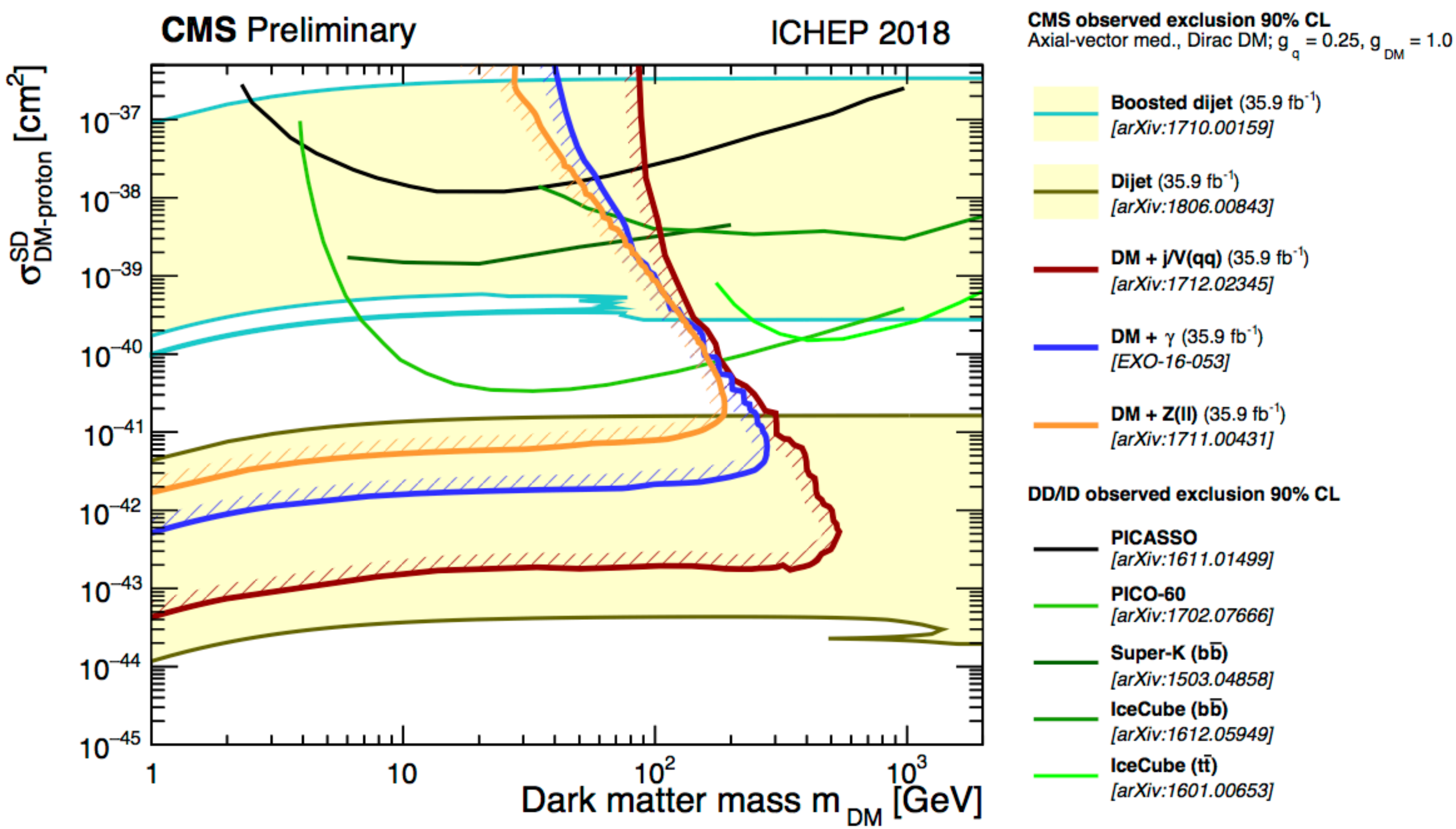


Figure 6 – MET+X and dijet/dilepton search results interpreted [58] in the context of simplified models: (left) excluded regions in the $m_{\rm DM} - m_{\rm MED}$ plane and (left) upper limits on the DM-nucleon scattering cross-section as a function of $m_{\rm DM}$, compared to results from DD experiments.

arXiv:1809.06341v1, Marta Felcini

Spin-dependent CMS Result



https://twiki.cern.ch/twiki/pub/CMSPublic/SummaryPlotsEXO13TeV/SD_CMSDD_Summary.png

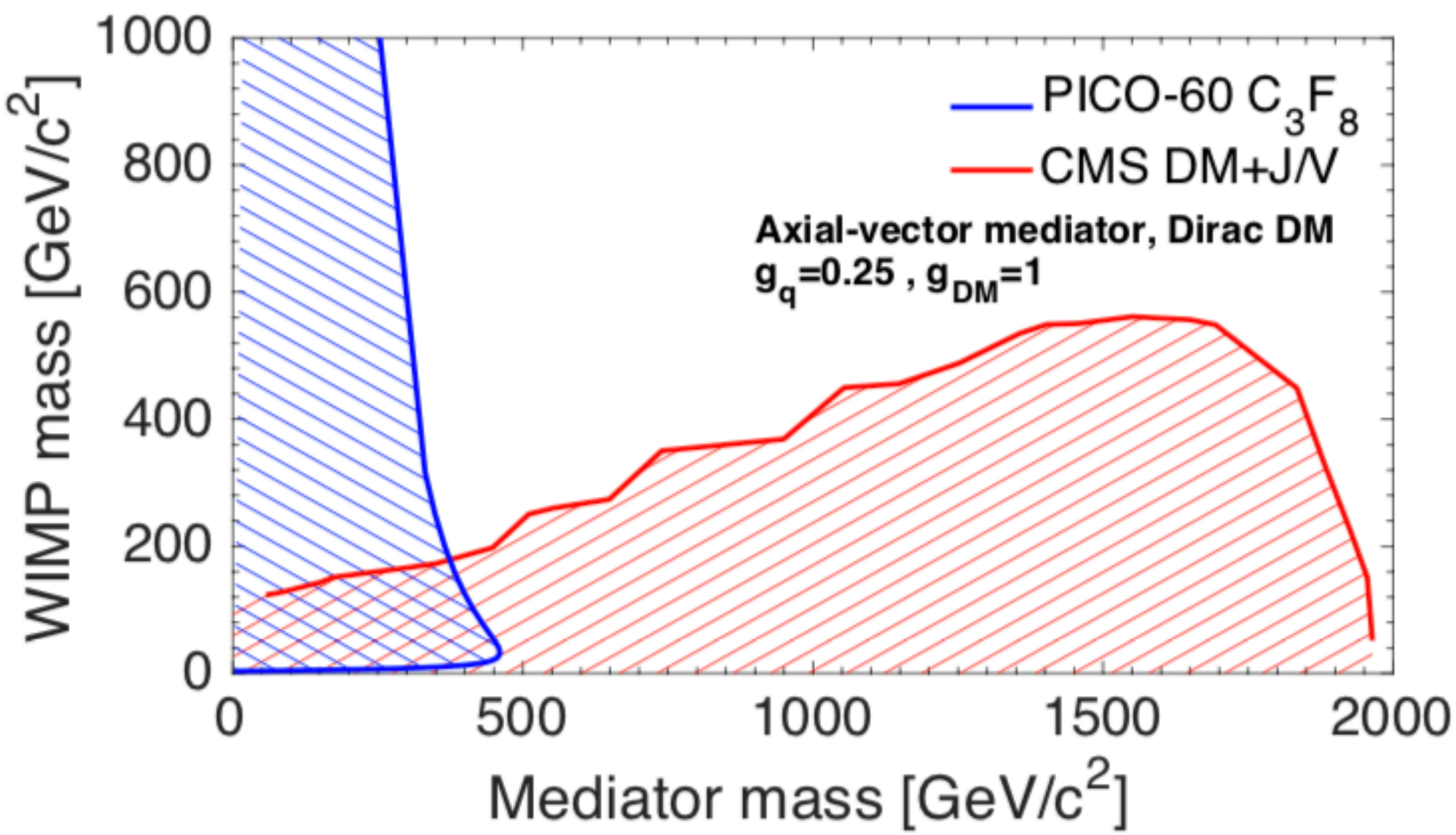


FIG. 6. Exclusion limits at 95% C.L. in the $m_{\mathrm{DM}} - m_{\mathrm{med}}$ plane. PICO-60 constraints (blue) are compared against collider constraints from CMS (red) [32] for an axial-vector mediator using the monojet and mono-V channels.

Phys. Rev. Lett. **118**, 251301 – Published 23 June 2017

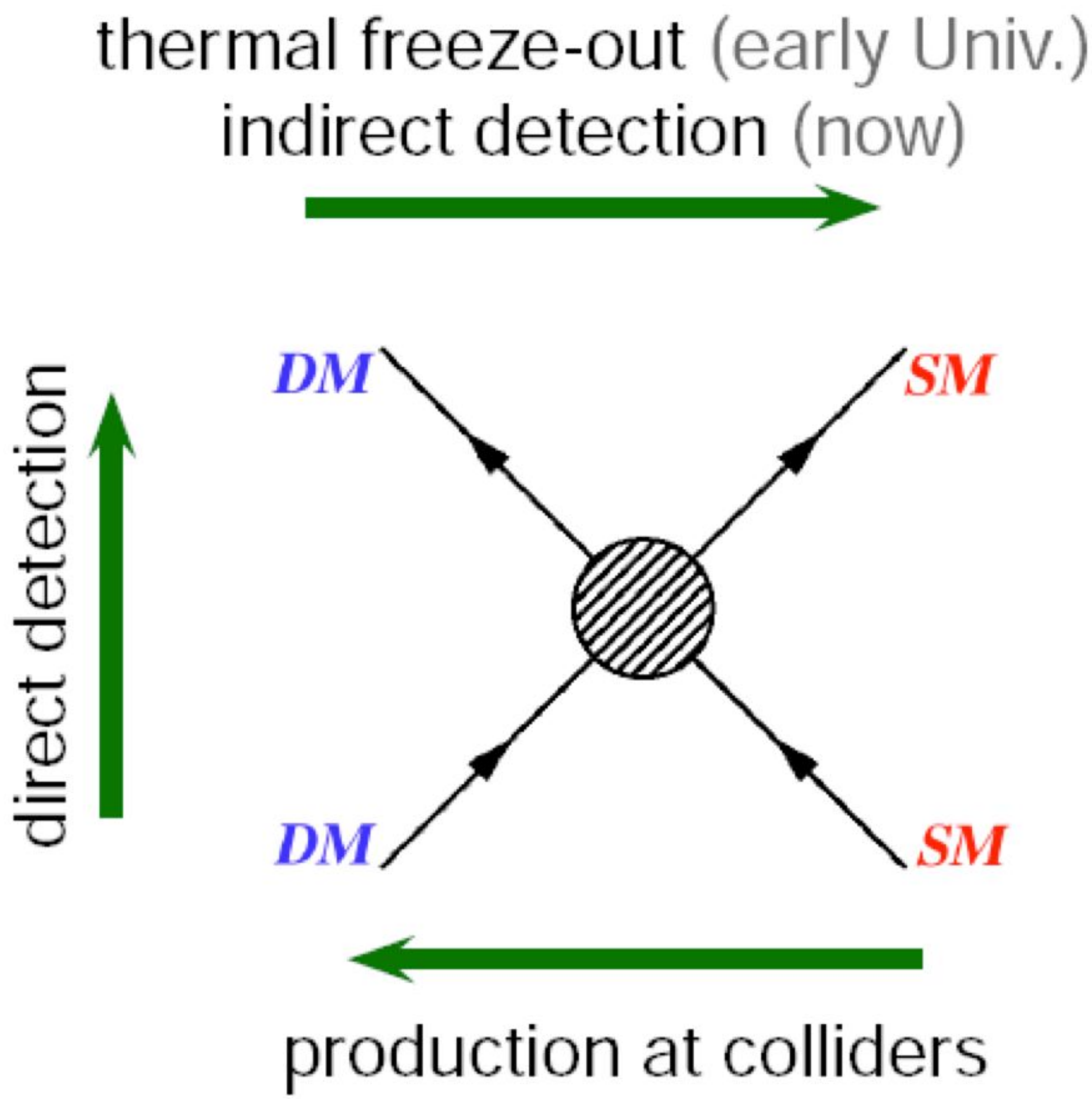
More ALTAS & CMS results

- For more details: look up recent BSM physics results on standard DM results and other couplings as starting point
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV#Dark_Matter_Summary_plots
- https://atlas.cern/updates/atlas-feature/dark-matter

Summary

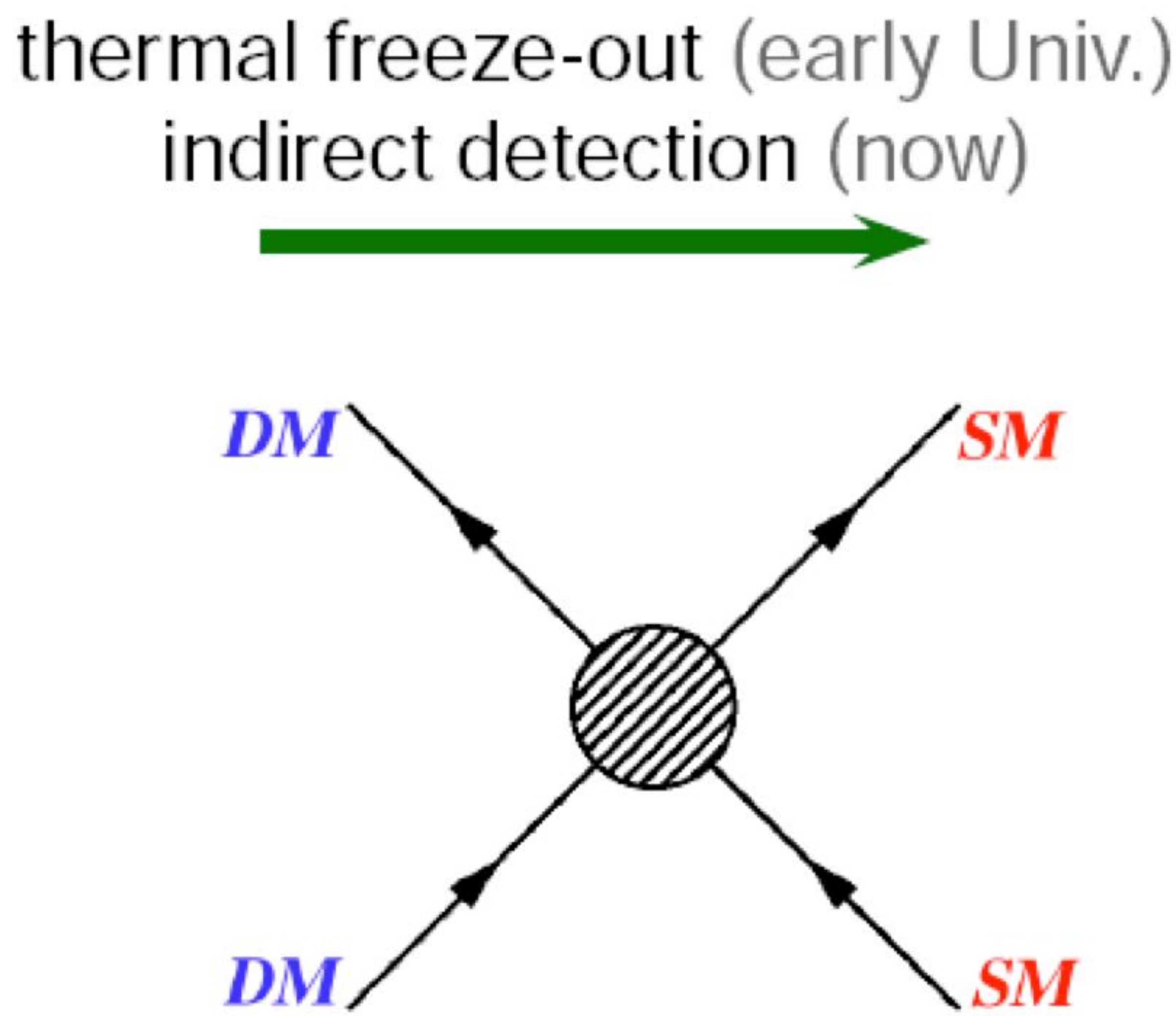
- No laboratory production of dark matter yet! 

WIMP Searches



From yesterday's lecture by G. Gelmini

WIMP Searches



From yesterday's lecture by G. Gelmini

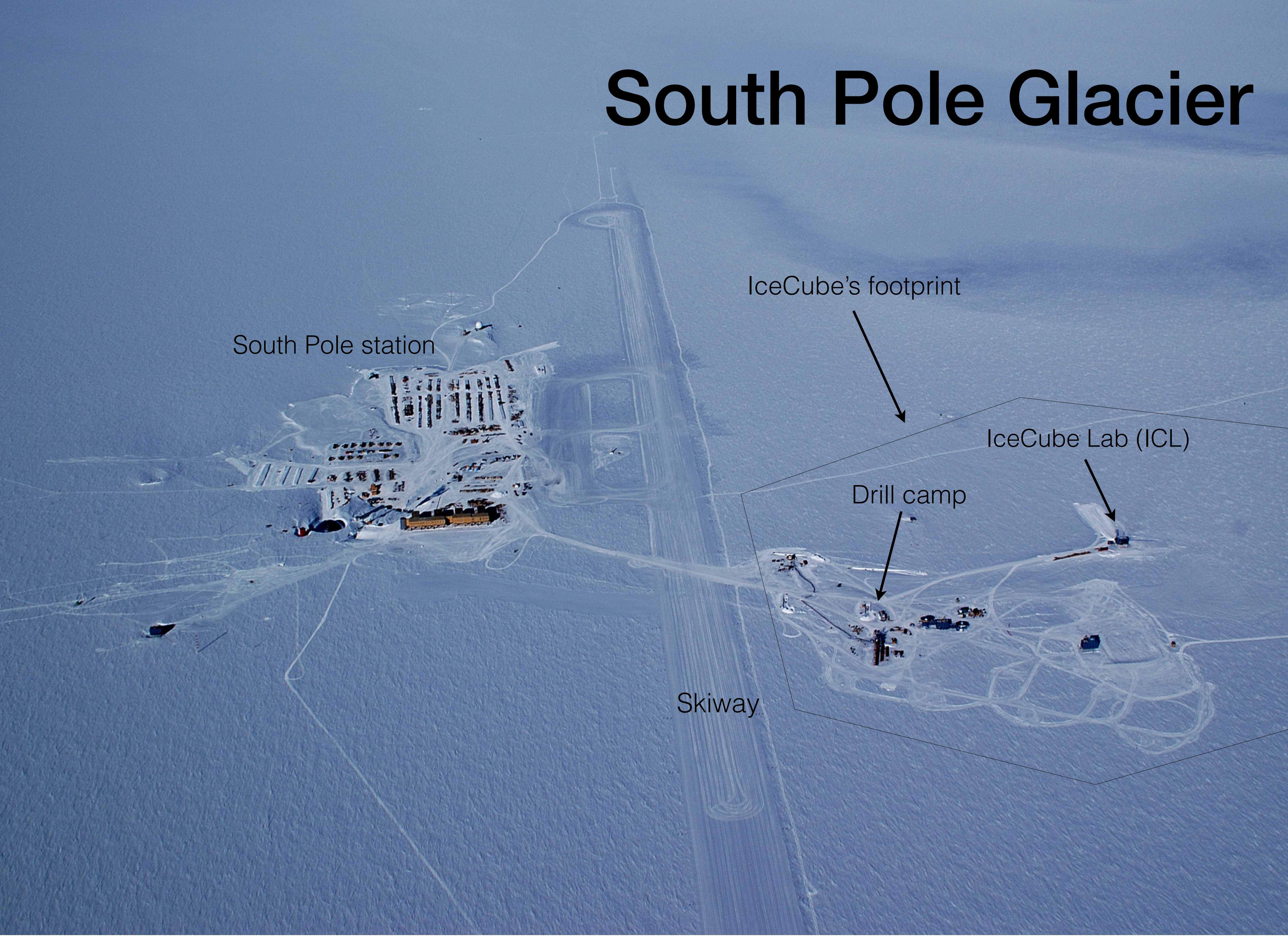
Indirect detection

- IceCube neutrino signal from galactic centre, sun and dwarf galaxies

- Fermi gamma rays from galactic centre

- Other (Pierre-Auger, HESS, VERITAS, Antares)

South Pole Glacier



The IceCube Neutrino Observatory

5160 PMTs

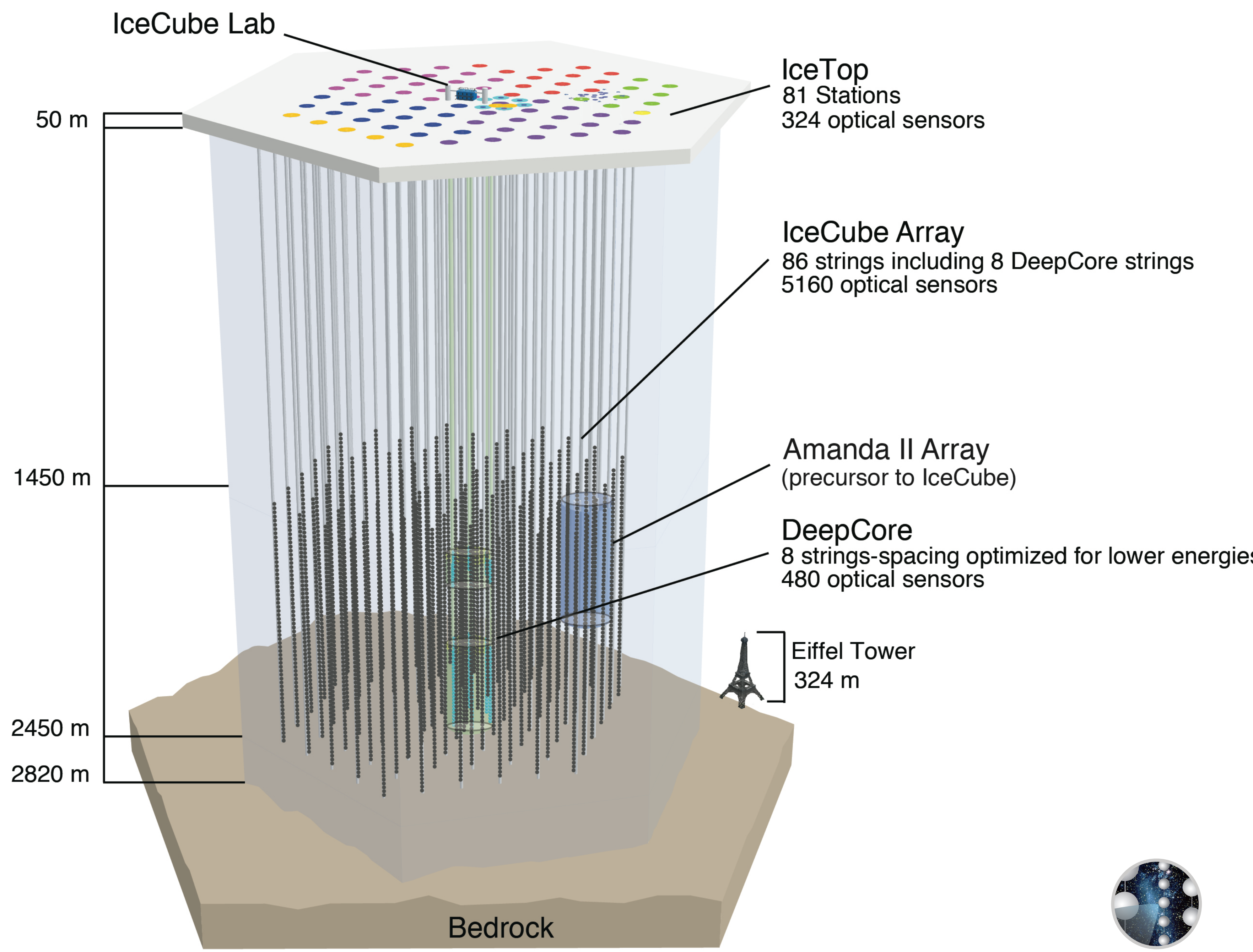
1 km³ volume

86 strings

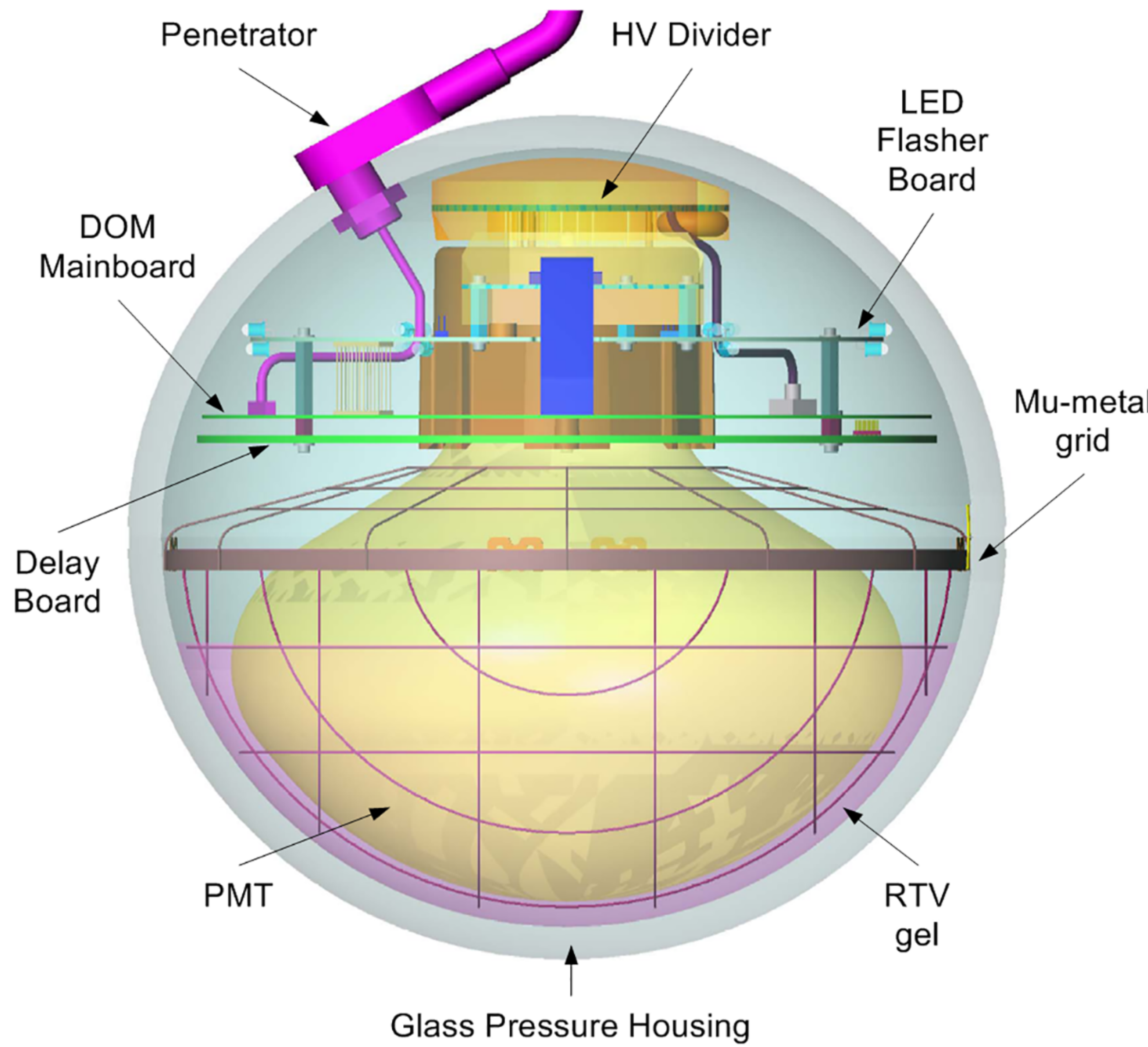
17 m vertical spacing

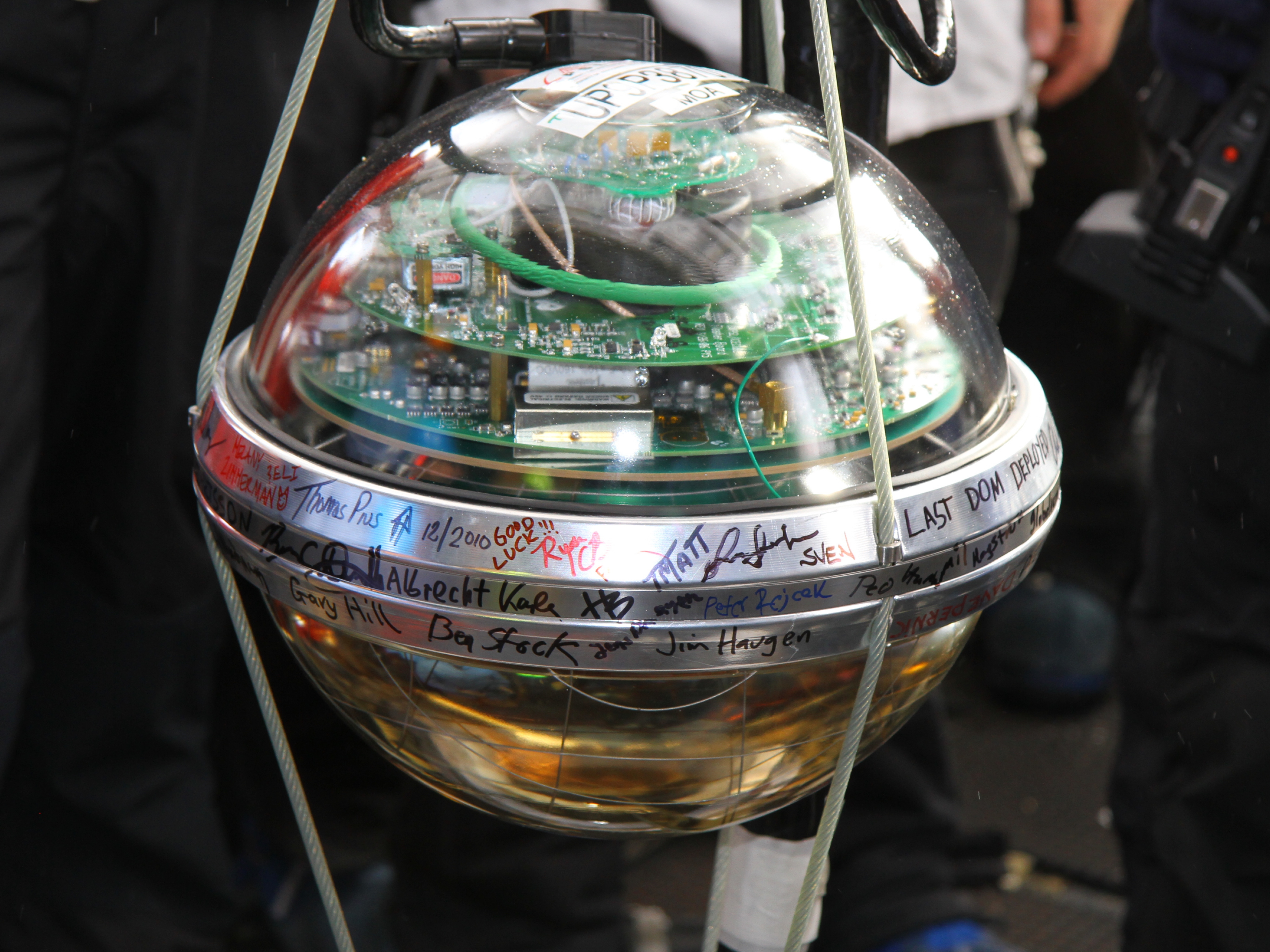
125 m string spacing

Completed 2010



The IceCube DOM



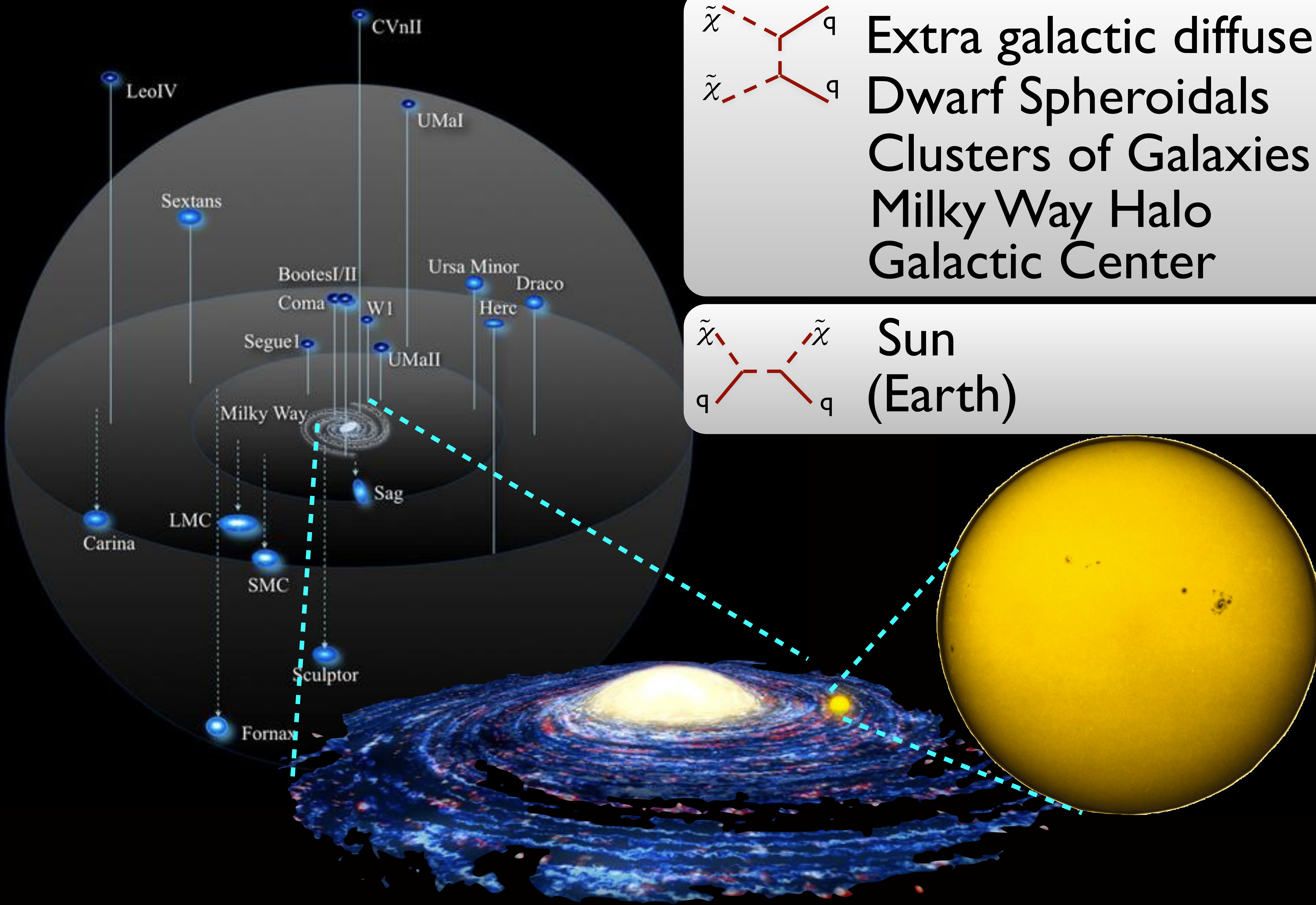


LAST DOM DEPLOYED
12/2010
GOOD LUCK!!!
SVEN
MATT
Albrecht Karle
Gary Hill
Ben Stock
Jim Haugen
Peter Rejcek
MOA

IceCube indirect dark matter search targets

Extra galactic diffuse
Dwarf Spheroidals
Clusters of Galaxies
Milky Way Halo
Galactic Center

Sun
(Earth)



Indirect Detection Model

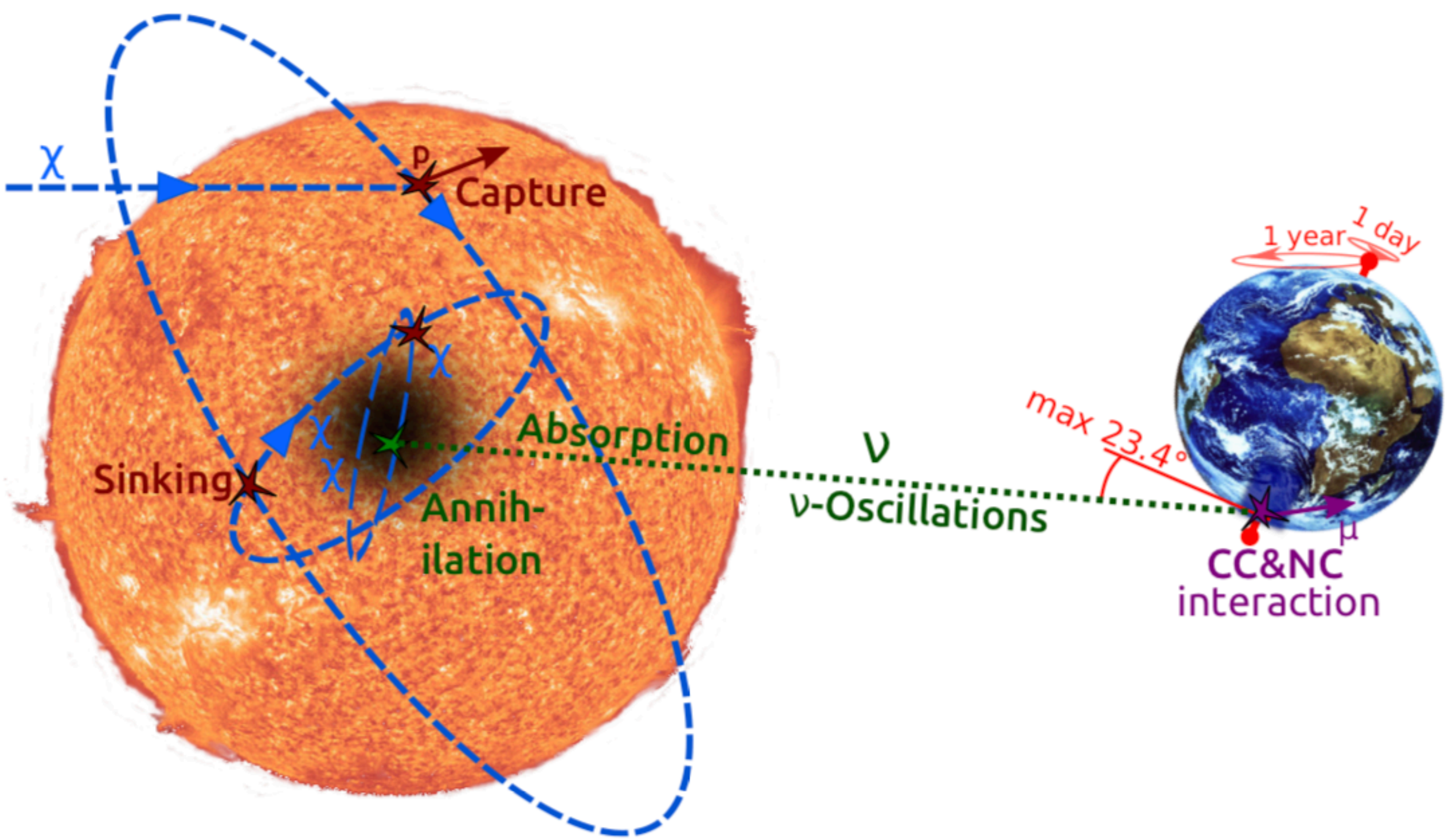
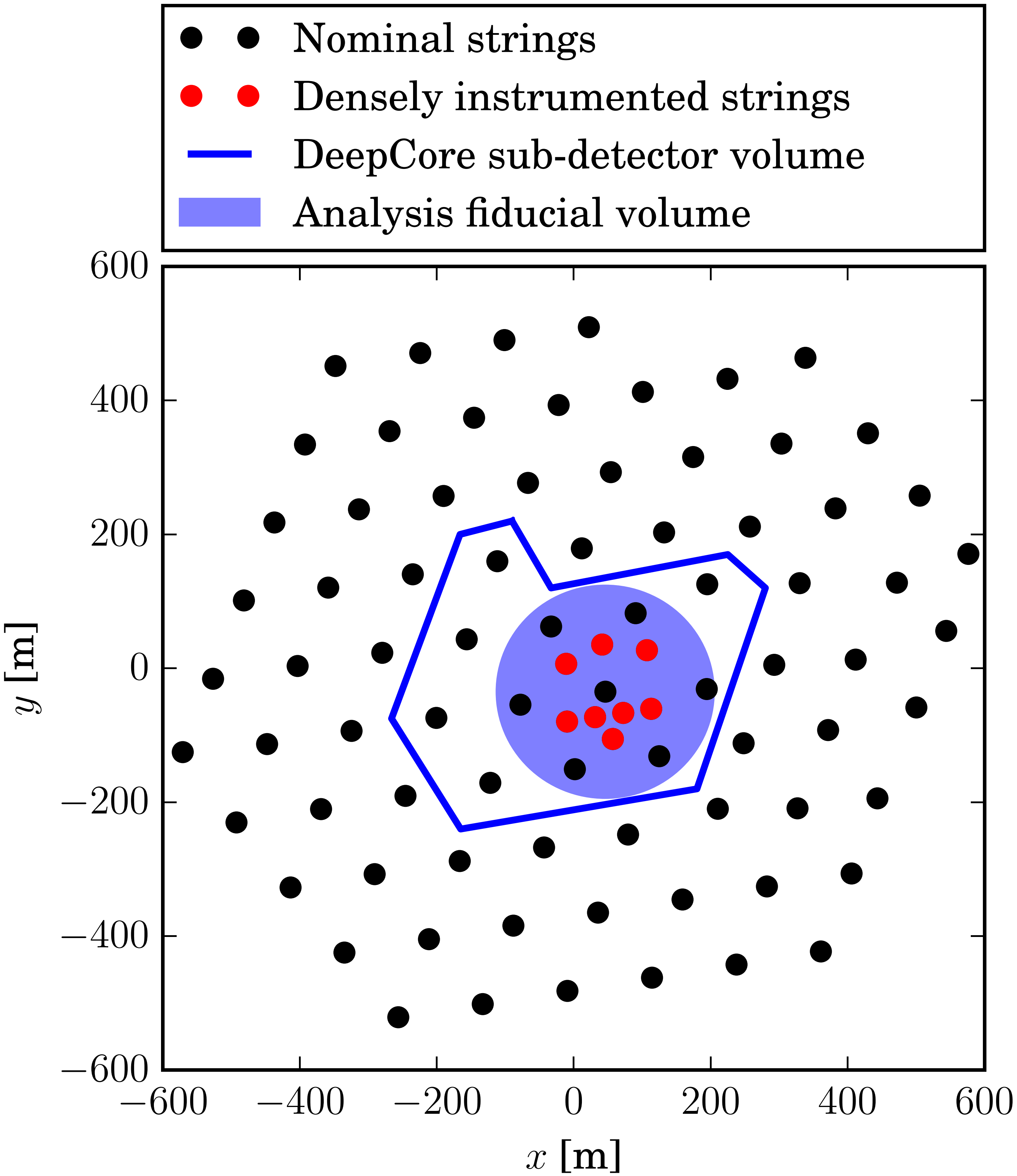


Figure 1.4: Illustration of the capture of WIMPs in the Sun, their annihilation and the resulting signal in neutrinos observable in a neutrino experiment at Earth.

PhD thesis M. Zoll, http://urn.kb.se/resolve?urn=urn%3Anbn%3Ase%3Asu%3Adiva-125341


Nominal strings
Densely instrumented strings
DeepCore sub-detector volume
Analysis fiducial volume
600
400
200
0
−200
−400
−600
y [m]
−600
−400
−200
0
200
400
600
x [m]

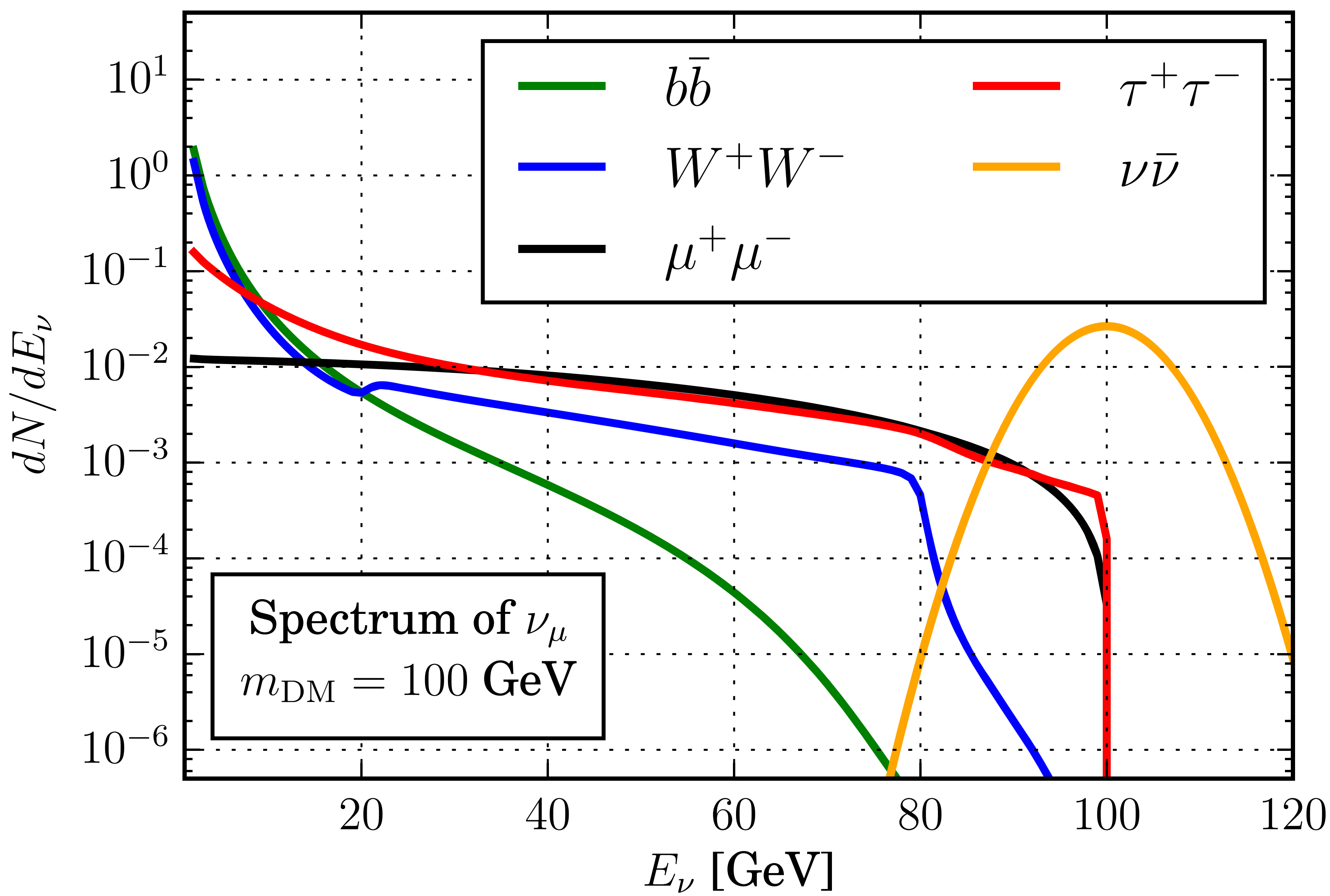


Fig. 2 Energy spectrum of muon neutrinos at Earth produced in the annihilation and subsequent decay of various Standard Model particles created in the annihilation of a 100 GeV WIMP. The line spectrum of the $\nu\bar{\nu}$-channel is modeled by a Gaussian with a width of 5% of m_{DM}

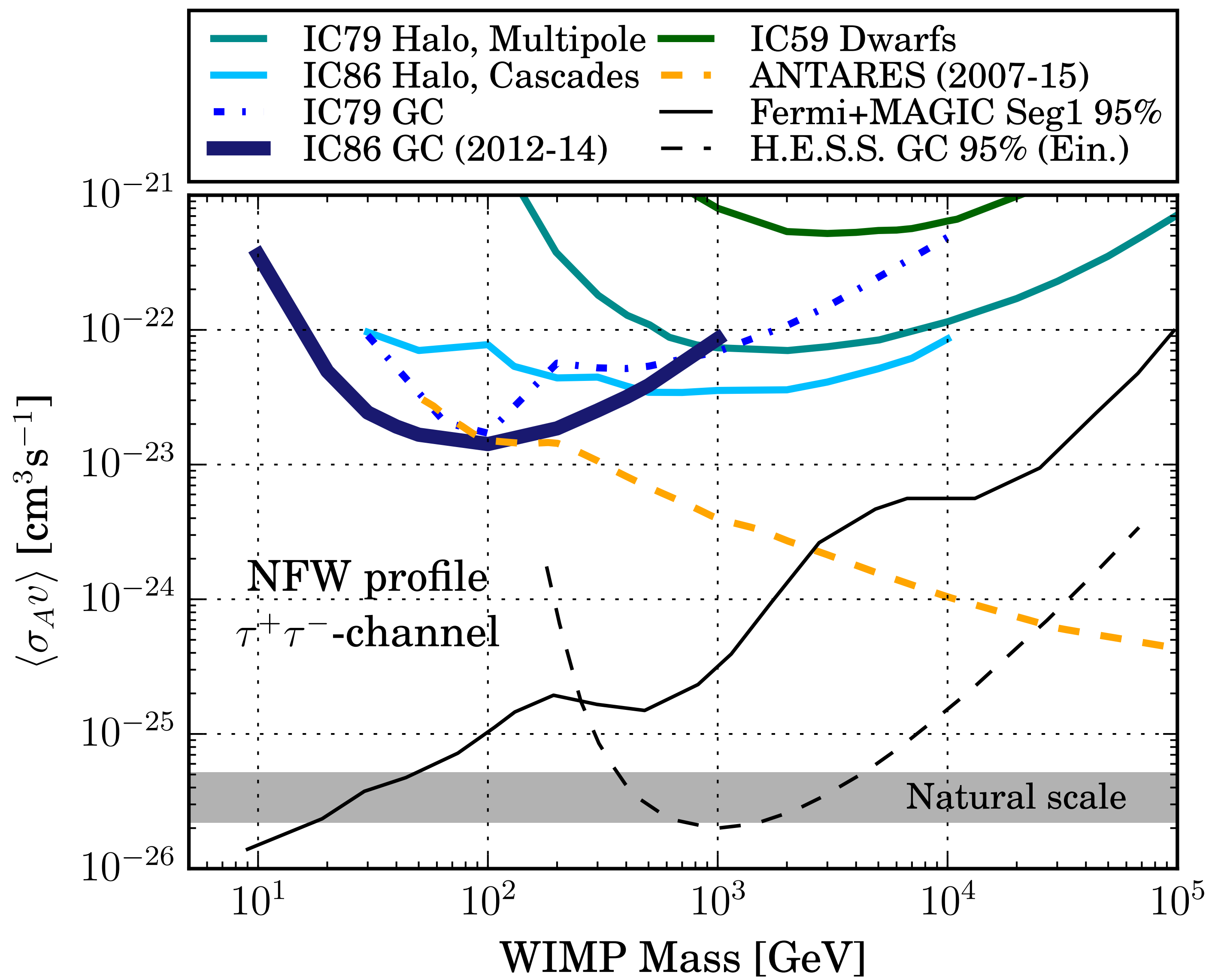


Fig. 8 Comparison of upper limits on $\langle\sigma_\mathrm{A} v\rangle$ versus WIMP mass, for dark matter self-annihilating through $\tau^+\tau^-$ to neutrinos, assuming the NFW profile. This work [IC86 (2012–2014)] is compared to other published searches from IceCube [28,38–40] and ANTARES [41]. Also shown are upper limits from gamma-ray searches from the dwarf galaxy Segue 1 (Seg1) by FermiLAT+MAGIC [42] and from the galactic center by H.E.S.S. [43]. The 'natural scale' refers to the value of $\langle\sigma_\mathrm{A} v\rangle$ that is needed for WIMPs to be a thermal relic [44]

Summary

- No indirect detection of dark matter yet!