

Dark Matter -- synergies

Sascha Caron
(Radboud University & Nikhef)

Synergy is the creation of a whole that is greater than the simple sum of its parts. The term synergy comes from the Attic Greek word συνεργία synergia from synergos, συνεργός, meaning "**working together**".

Objective of the talk:

Idea is to build some kind of
intra-experimental forum
@Nikhef to analyze different
topics/data in the field of
Dark Matter research

Various activities ongoing
already outside the typical
experimental Nikhef
programs → this talk

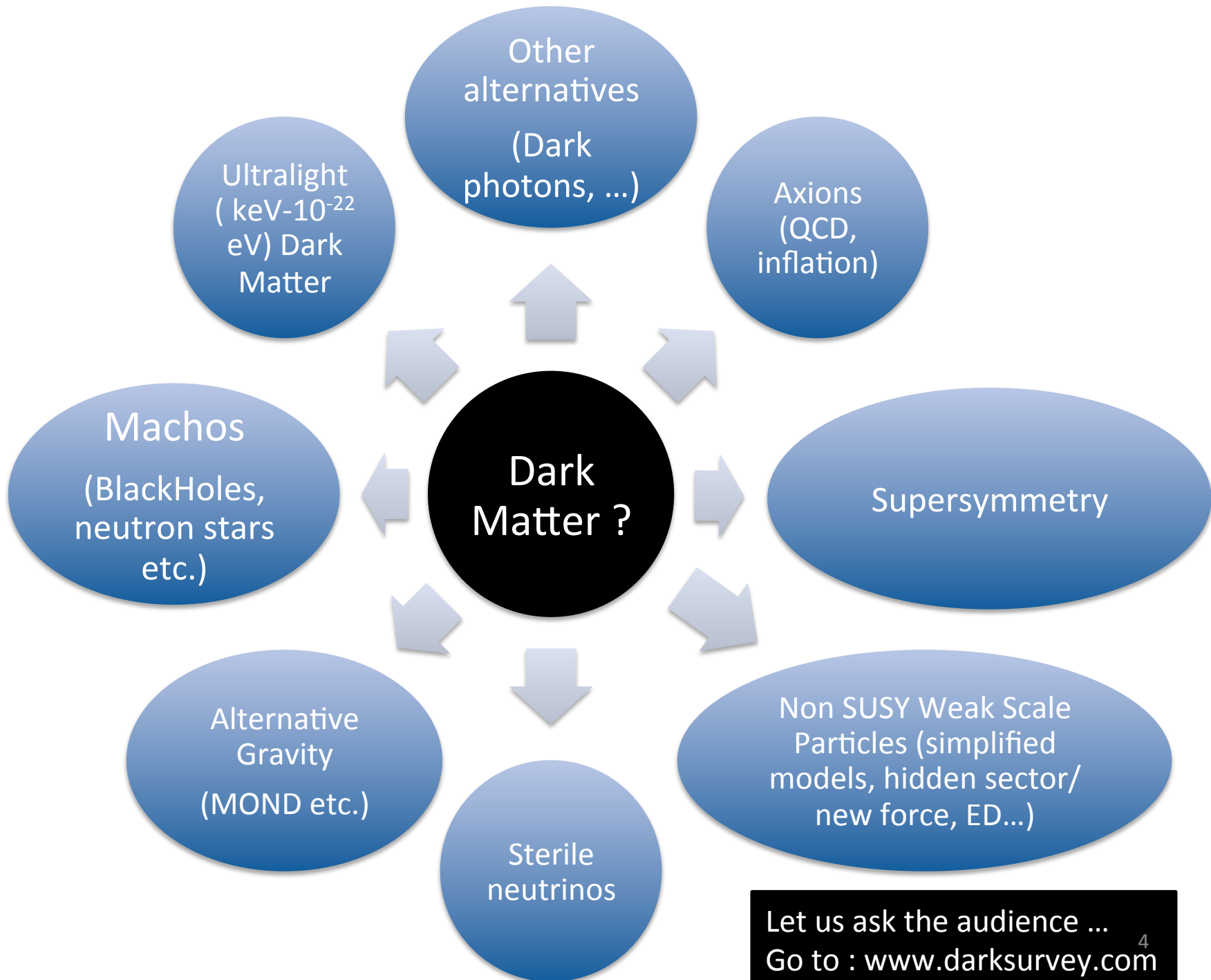
NijmegenDark Matter mailing list

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2	:	S.Caron@science.ru.nl
3	:	W.Beenakker@science.ru.nl
4	:	a.achterberg@astro.ru.nl
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6	:	b.stienen@science.ru.nl
7	:	bartsteeman.bs@gmail.com
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24	:	ruud.peeters@student.ru.nl
25	:	rvolmer11@gmail.com
26	:	sara.alderweireldt@cern.ch
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+Grappa + Xenone +

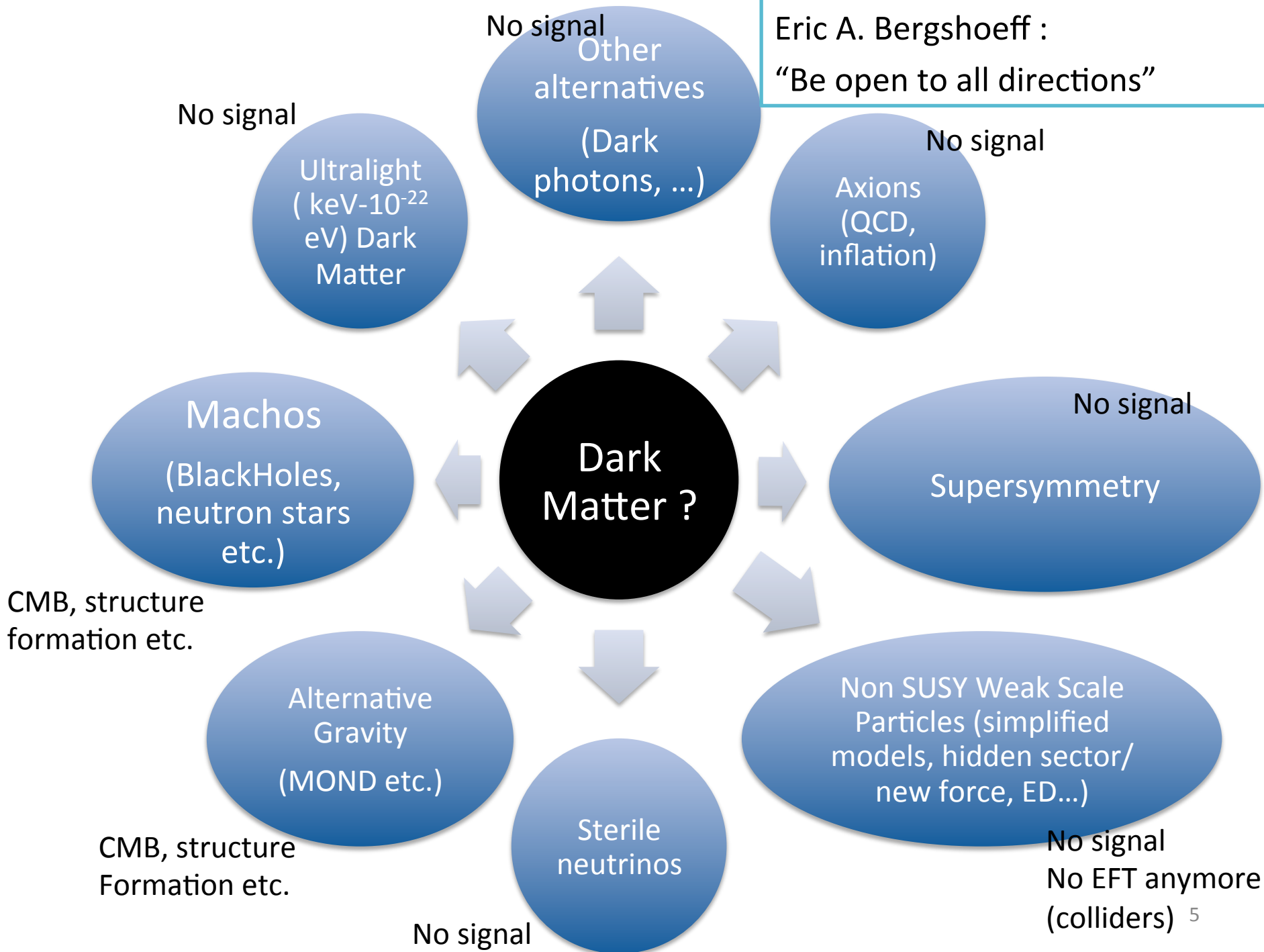
Reminder: Dark Matter candidates

- My/Your interest is in **physics beyond the Standard Model**
- Interestingly most valid extensions of the Standard Model provide a valid Dark Matter candidate
- Very likely **understanding the nature of Dark Matter is connected to the realm of beyond-the-standard-model physics**



Let us ask the audience ...
Go to : www.darksurvey.com

Eric A. Bergshoeff :
"Be open to all directions"

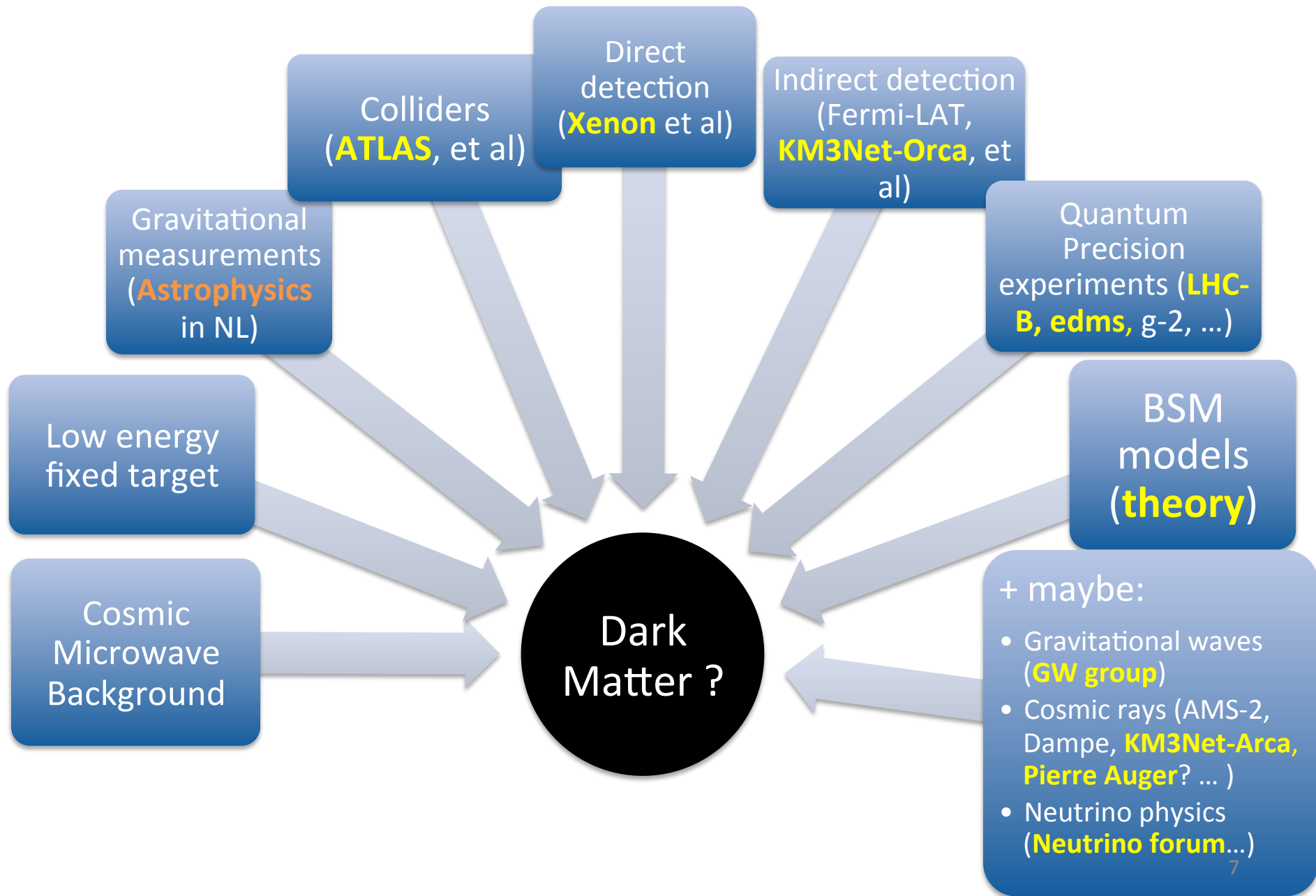


New en vogue ideas or bringing DM to the extremes...

- Two main parameter regions for sub-keV dark matter:
 - meV-keV: think of DM as a particle, can be absorbed onto target electrons in semiconductors or superconductors [e.g. Hochberg, Lin & Zurek '16-'17, Bloch et al '16]
 - 10^{-21} eV - meV: DM can be regarded as oscillating field, opens up a range of new detection methods targeting continuous wave signals (rather than individual particles). Axions - which could solve the strong CP puzzle of nuclear physics - lie in this range.

Semi or superconductors, low energy accelerators?

Nuclear Physics



Is there a Nikhef program that is not connected to Dark Matter ?

..very few papers on QGP (Alice) and DM

A bit on Axions

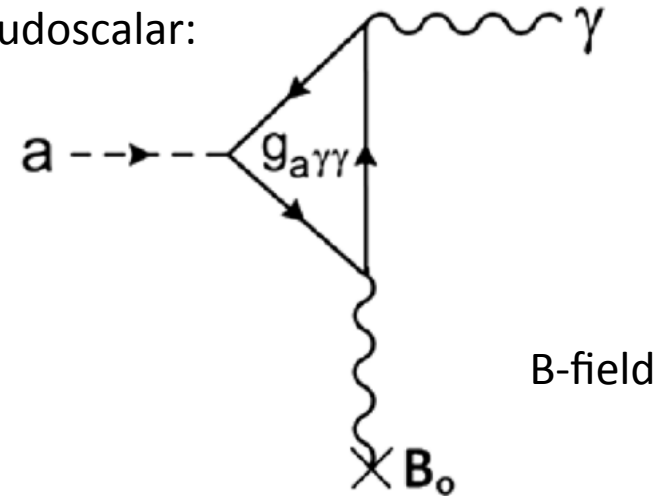
No CP violation in strong interactions (10^{-10})

→ explained by Peccei-Quinn theory with new broken global symmetry with a scalar field
(Axion, similar to Higgs mechanism)

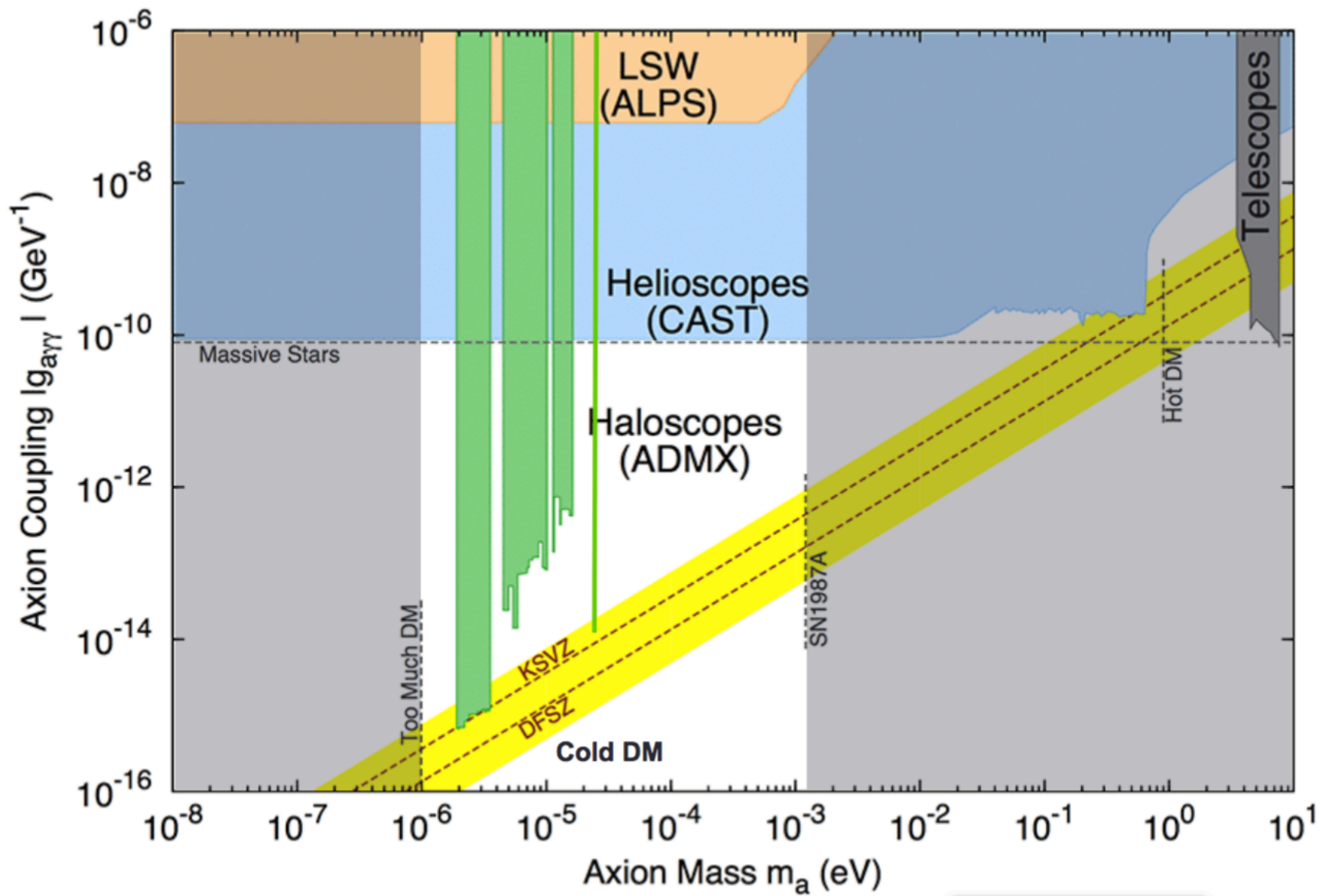
→ Light Axion could even be cold dark matter

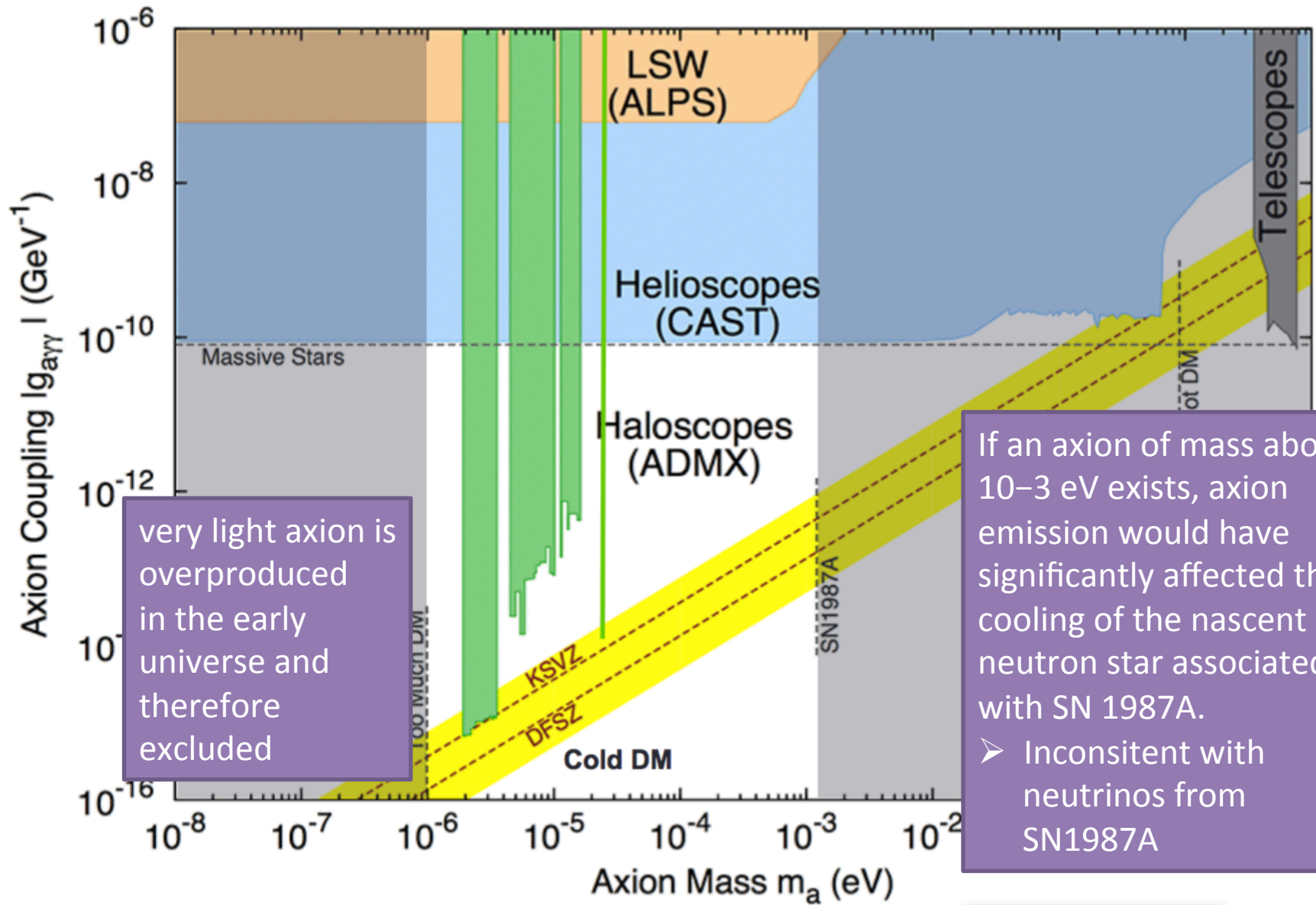
(they are produce non-thermically and can have very small velocities although having a very small mass)

Pseudoscalar:



Detection (reverse Primakoff effect):
Axion \rightarrow (B-field) \rightarrow Photons

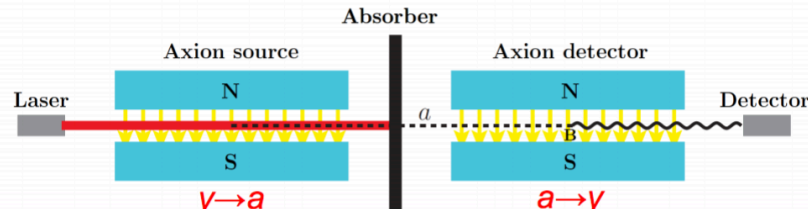




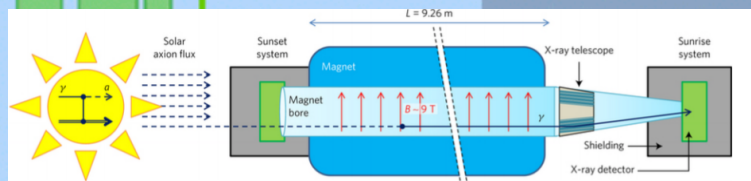
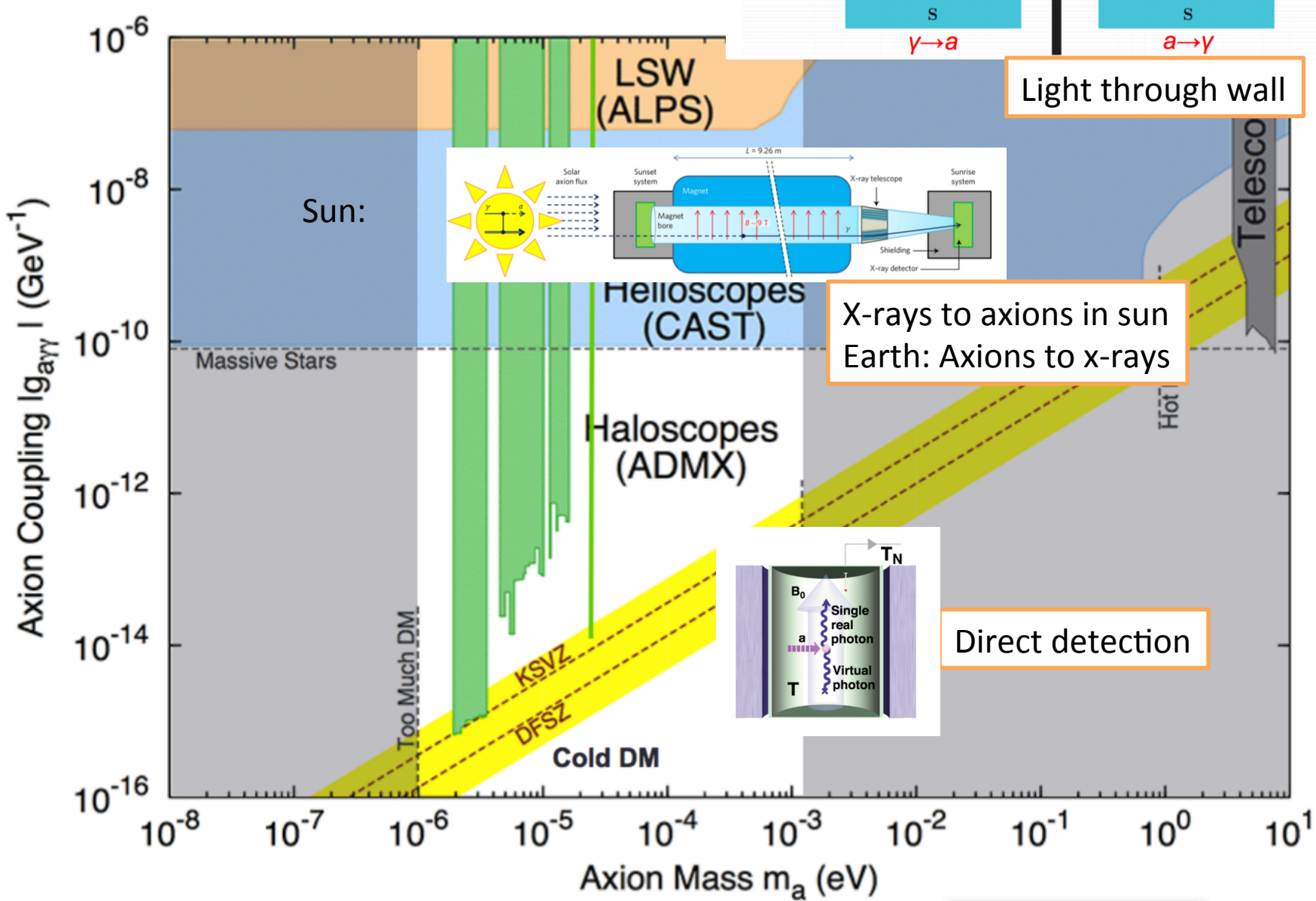
If an axion of mass above 10–3 eV exists, axion emission would have significantly affected the cooling of the nascent neutron star associated with SN 1987A.

➤ Inconsistent with neutrinos from SN1987A

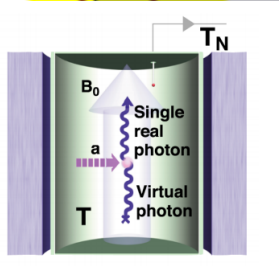
Production



Light through wall

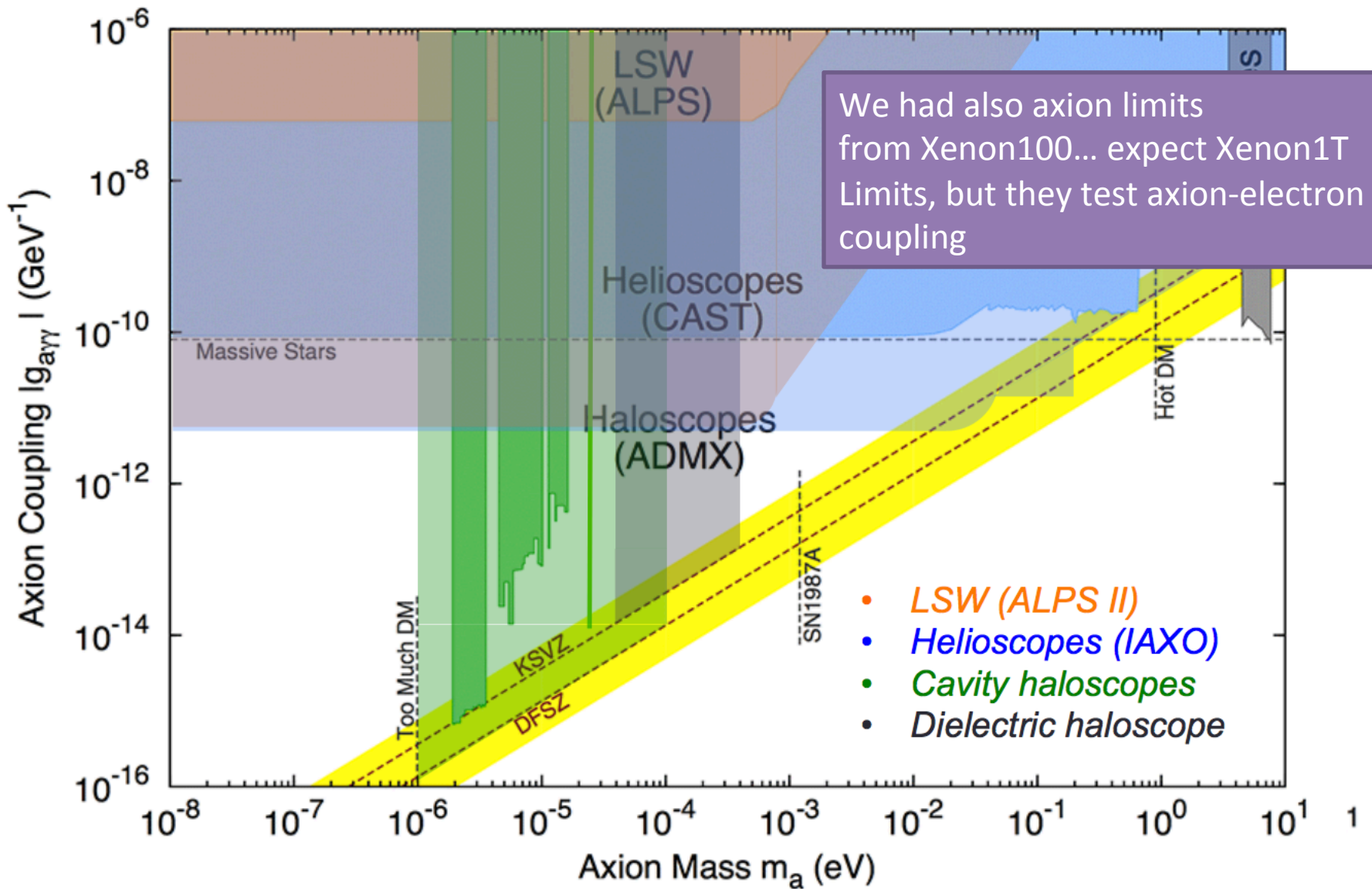


X-rays to axions in sun
Earth: Axions to x-rays



Direct detection

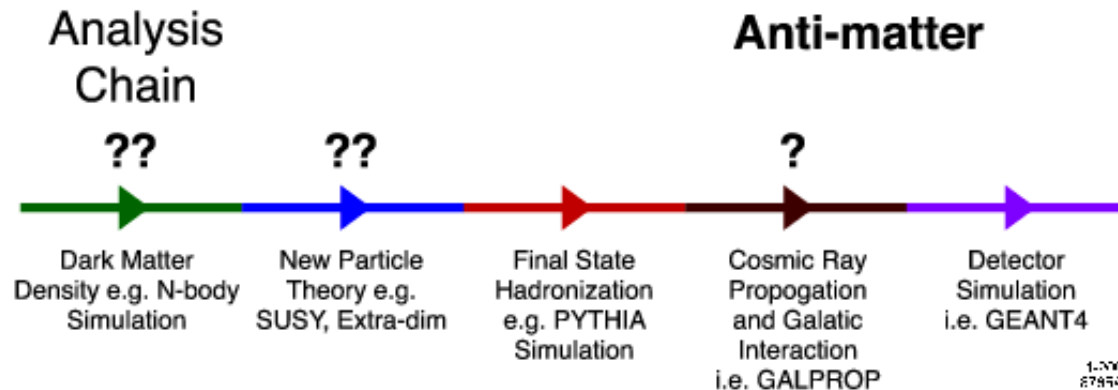
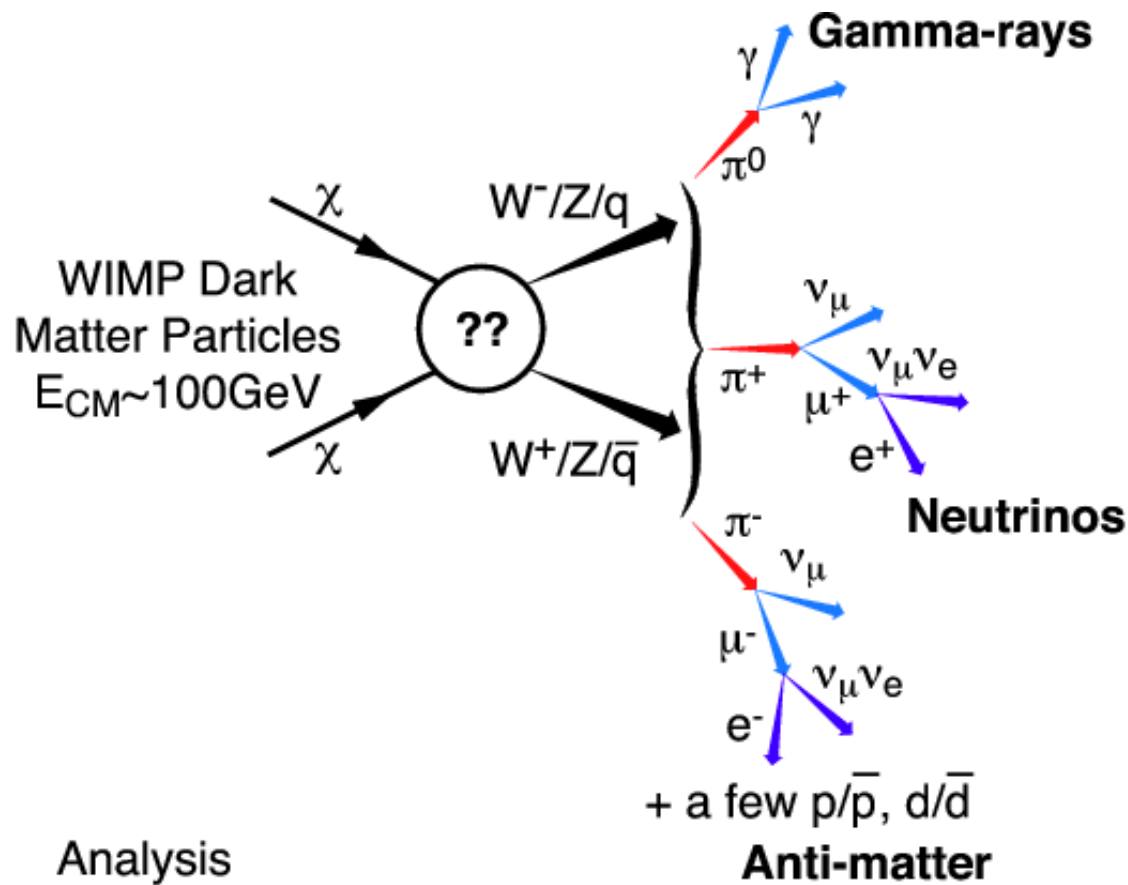
Future prospects



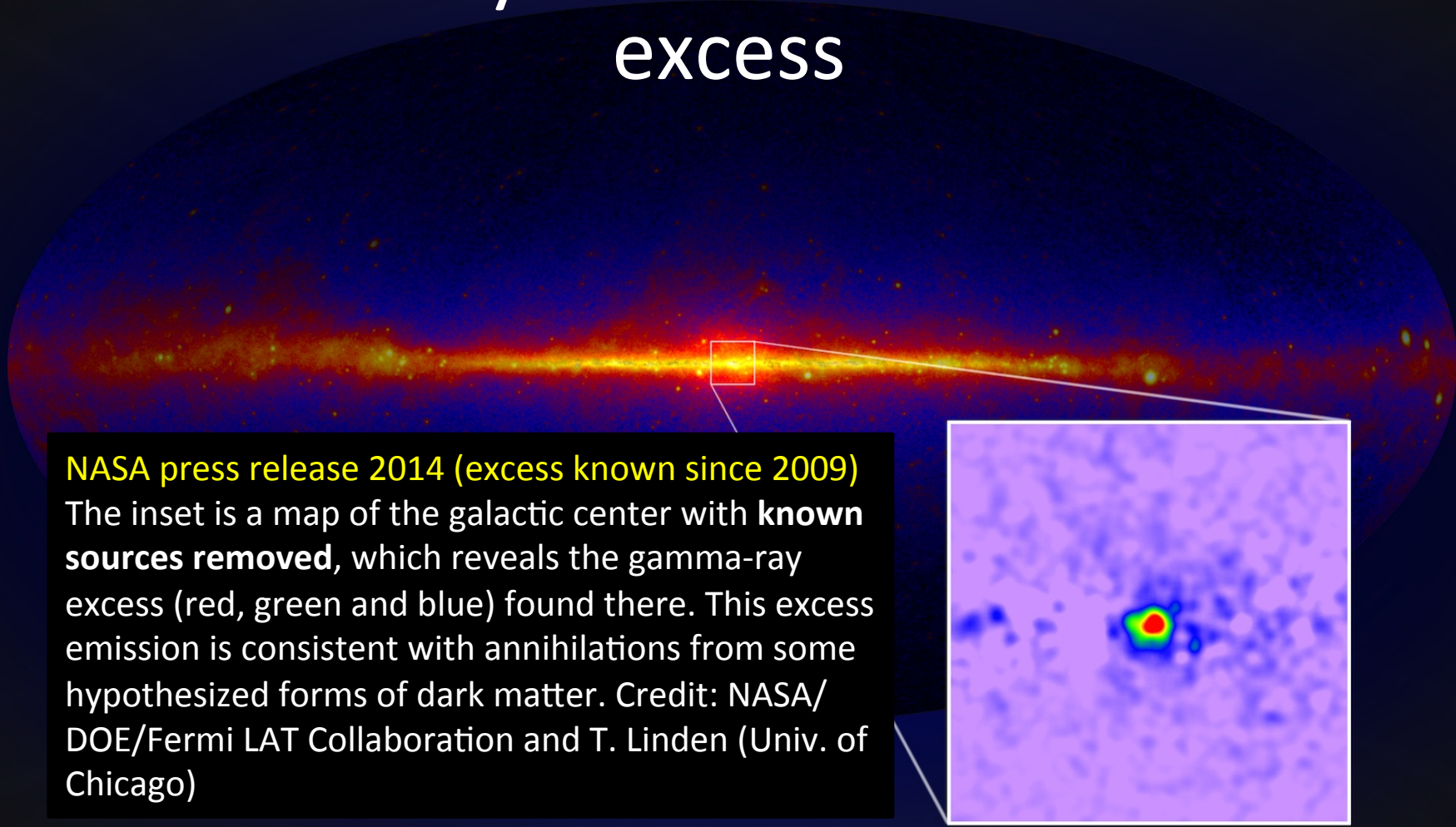
Let's have a look at WIMPs

Astrophysics

WIMP Astrophysics



Gamma rays & the Galactic Center excess



NASA press release 2014 (excess known since 2009)
The inset is a map of the galactic center with **known sources removed**, which reveals the gamma-ray excess (red, green and blue) found there. This excess emission is consistent with annihilations from some hypothesized forms of dark matter. Credit: NASA/DOE/Fermi LAT Collaboration and T. Linden (Univ. of Chicago)

Official paper in 2015

Fermi-LAT Observations of High-Energy Gamma-Ray Emission Toward the Galactic Center

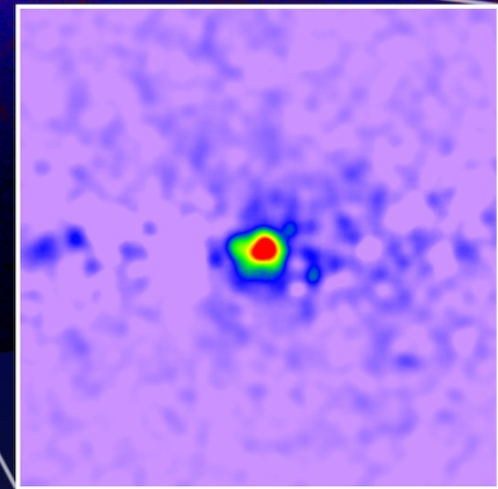
Fermi-LAT Collaboration (M. Ajello (Clemson U.) *et al.*). Nov 9, 2015. 29 pp.

e-Print: [arXiv:1511.02938](https://arxiv.org/abs/1511.02938) [astro-ph.HE] | [PDF](#)

Gamma rays & the Galactic Center excess

Isotropic or point sources (pulsars) ?

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Isotropic or point sources ?

Problem: required Milisecond Pulsars (MSP) should have been already detected by the FermiLAT
 → but no (isolated) MSP has been identified

A) Modelling from MSP population

B) Modelling from isotropic radiation (Dark Matter)

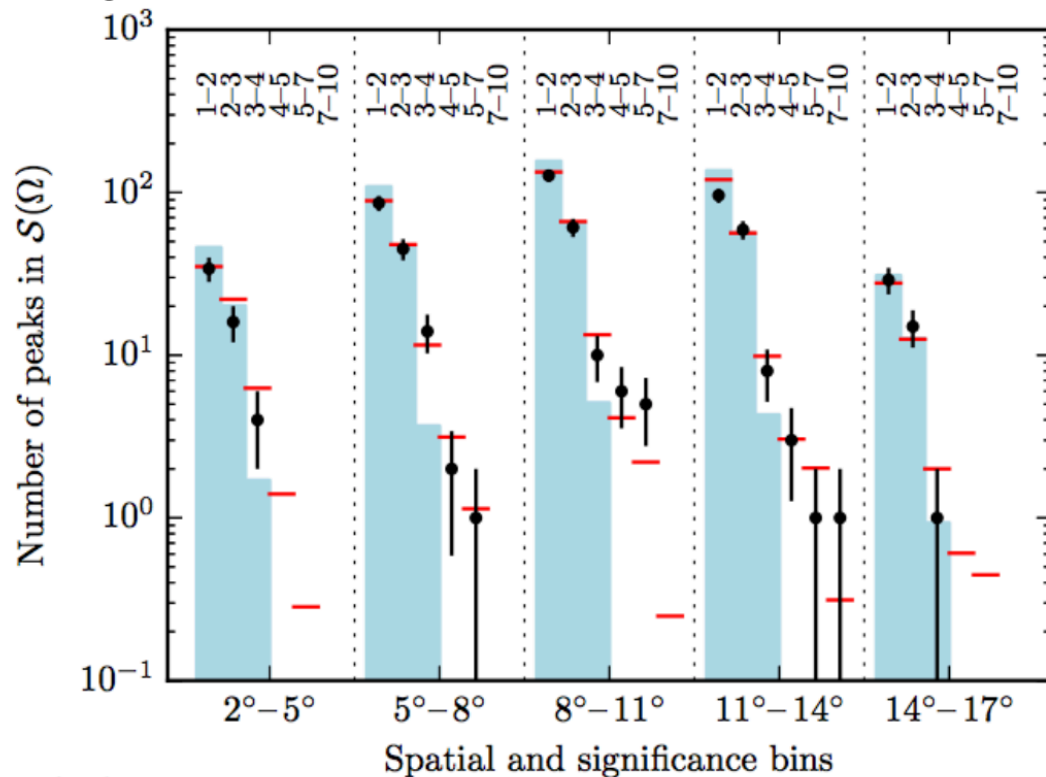
B) Modelling from isotropic radiation (Dark Matter)

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→ Determine discriminator for sources $S(\Omega)$

→ Compare distributions of number of source candidates

→ **10 sigma preference for A) over B)**



Blue -> No extra MSP
 Red -> Some extra MSP

However... are all excess photons from MSPs or is excess due to a mixture of different processes ?

Isotropic or point sources: A Deep Convolutional Network approach

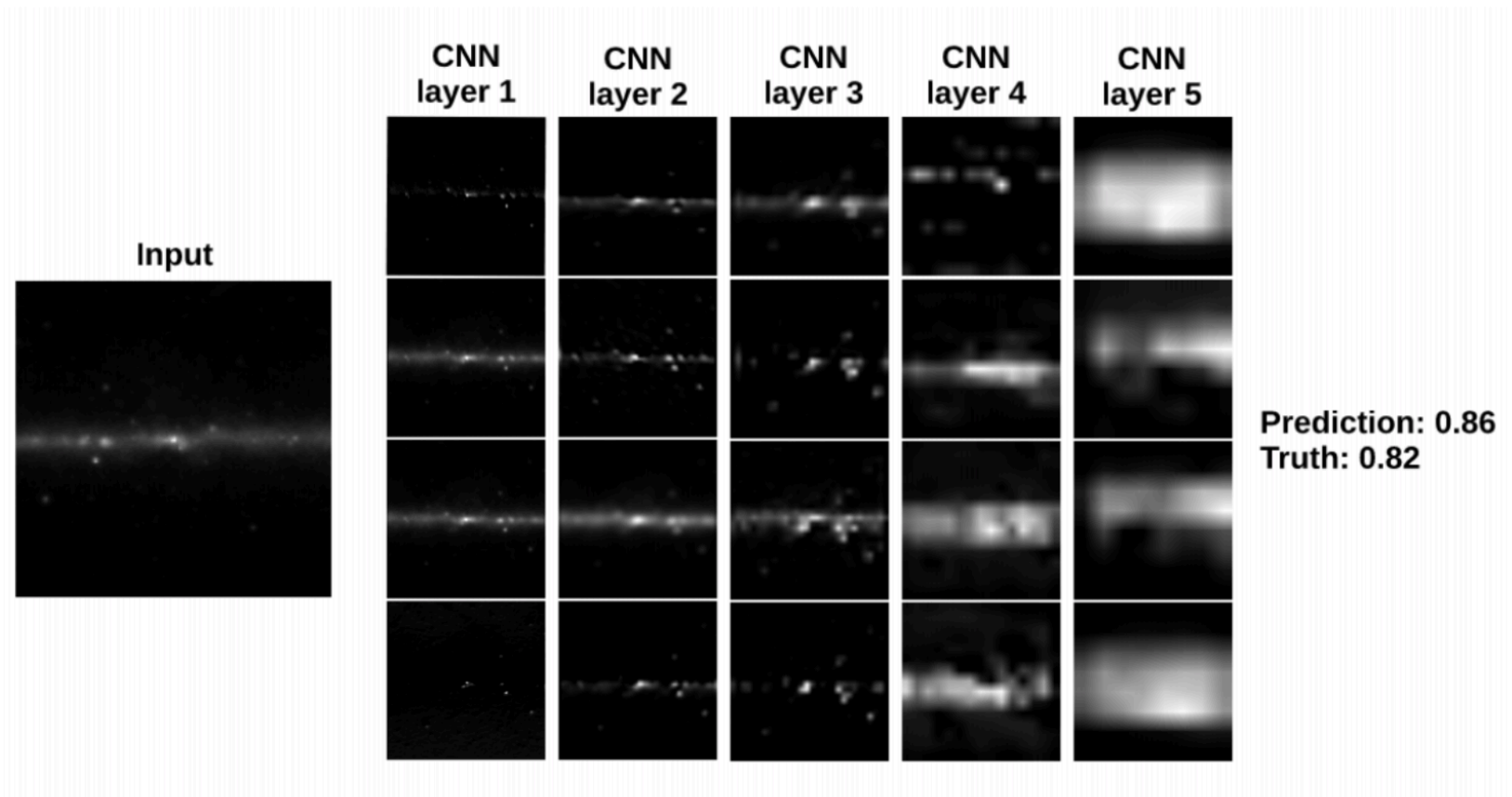
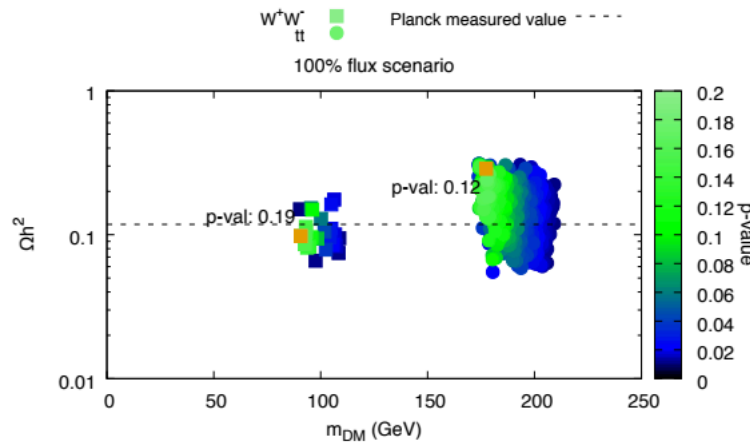


Figure 7: Activations of the different convolutional layers on a simulation. Each column

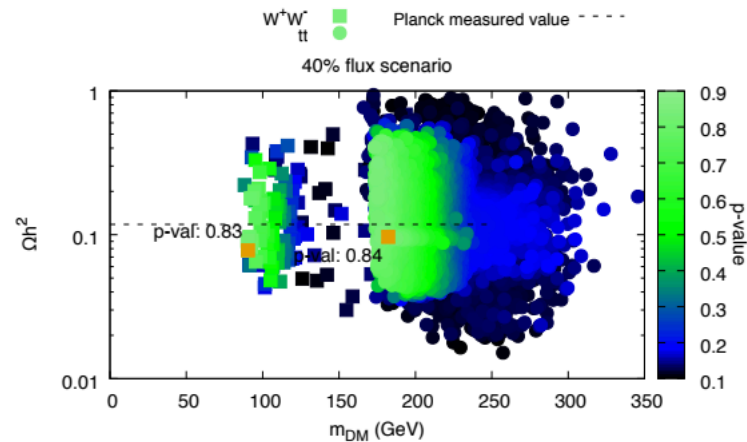
SUSY DM solutions re-investigated

Re-investigated SUSY solutions after new limits from direct detection and updated Fermi-LAT data

- Still valid solutions (Bino-Wino, Bino-Higgsino at 100-200 GeV)
- DM annihilates to pair of W bosons or top quarks (no constraints from spheroidal dwarf galaxy limits)
- Better fit if part of the excess comes from mili second pulsars



(a) Neutralino mass against Ωh^2
for the 100% scenario



(b) Neutralino mass against Ωh^2
for the 40% scenario

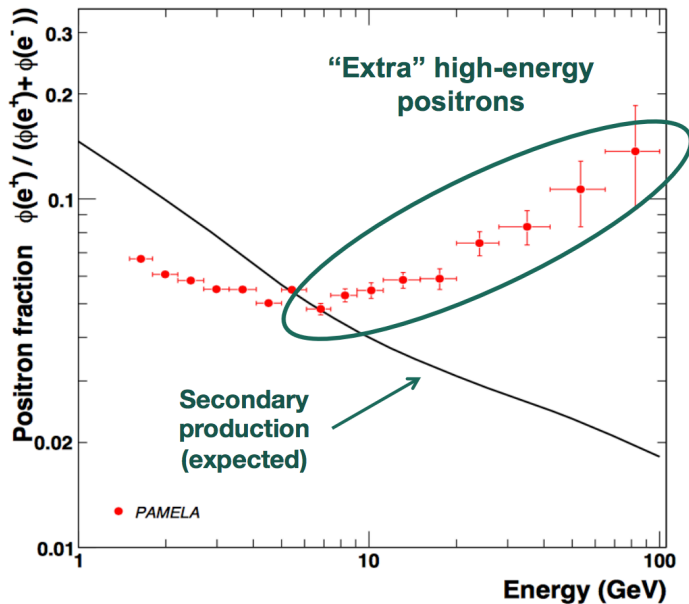
Cosmic Rays

End 2016: AMS-2 -- positrons

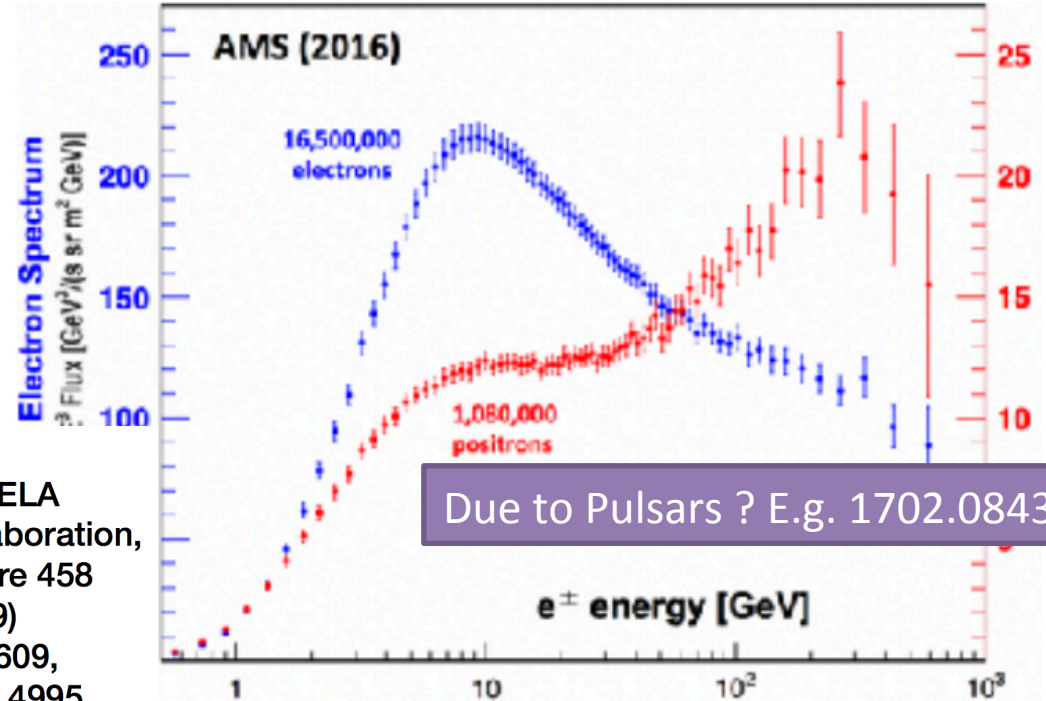
Ting, 8/12/16 CERN Colloquium

Positrons:

(similar excess in 2009 from Pamela, also fermi-lat etc.)



PAMELA
Collaboration,
Nature 458
(2009)
607-609,
0810.4995



Note: Positron propagation complicated (Galprop)

Conventional annihilating DM does not explain AMS-02 positron data (models with "active disc", or extremely tuned models)

2017: Dampe

Direct detection of a break in the teraelectronvolt cosmic ray spectrum of electrons and positrons

Dampe (satellite experiment) made the news recently with a new measurement of positron+electrons

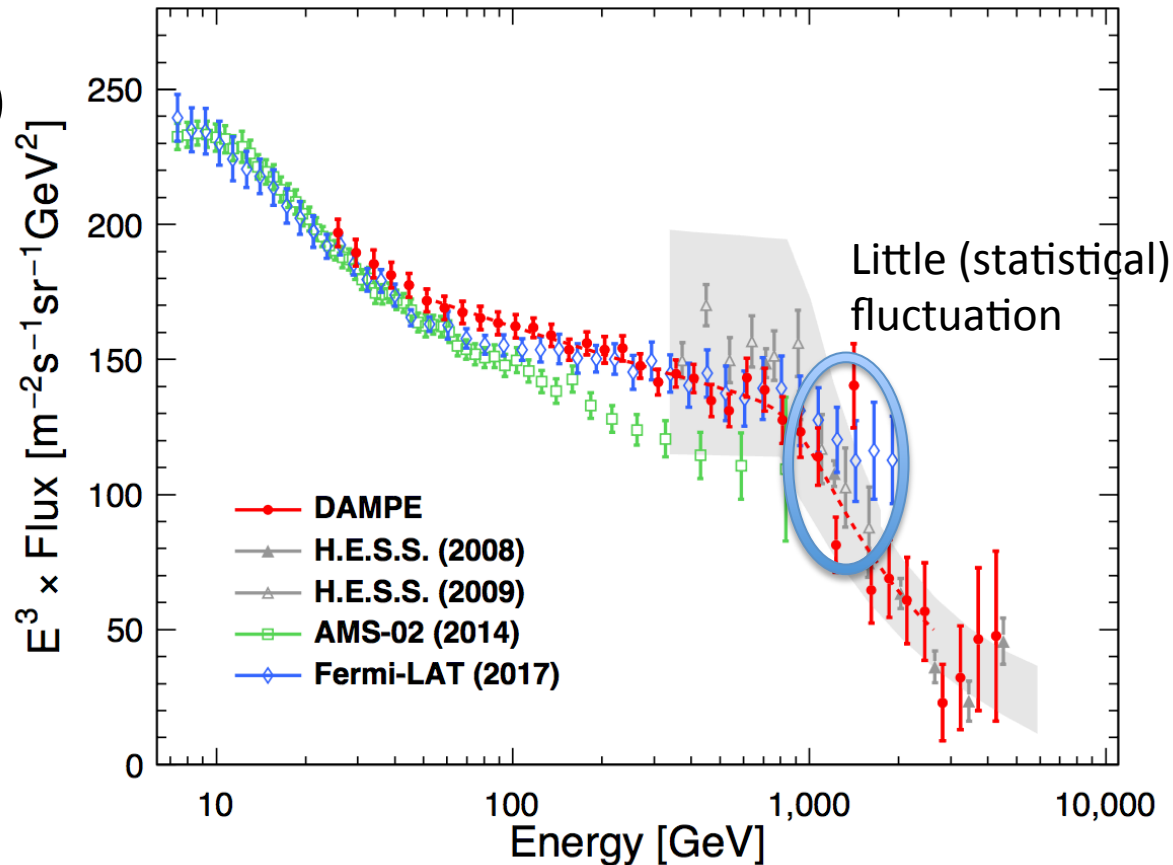
Confirms excess found by Hess of a broken powerlaw around 1 TeV

Could be due to “positron anomaly”

→A strange type of >1 TeV Dark Matter (e.g. leptophilic, large cross section...)

or **pulsars**...

arXiv 1711.10981

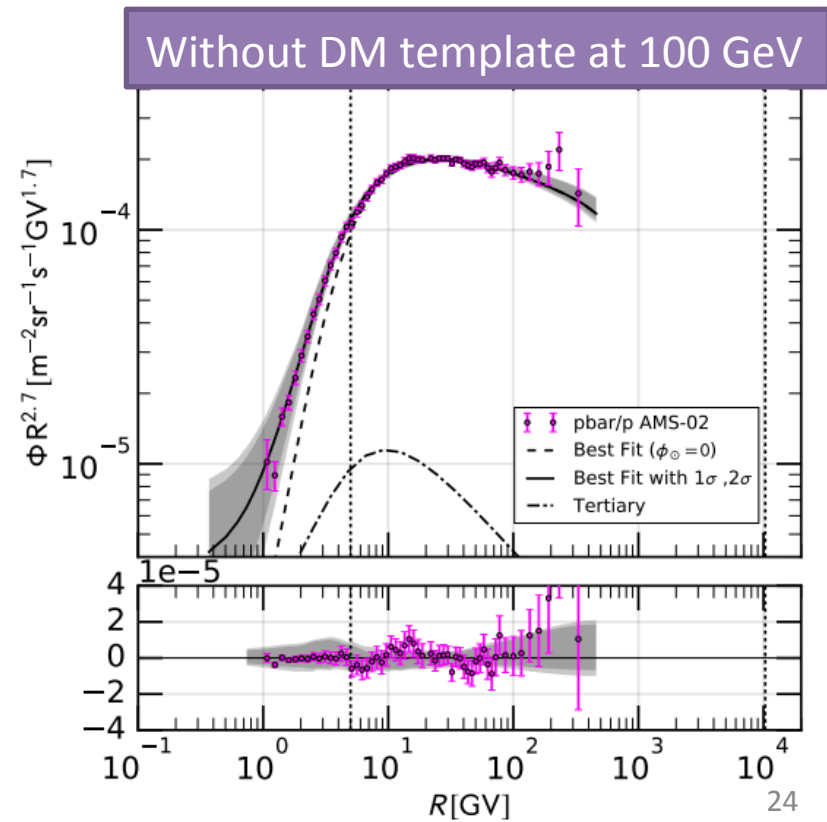
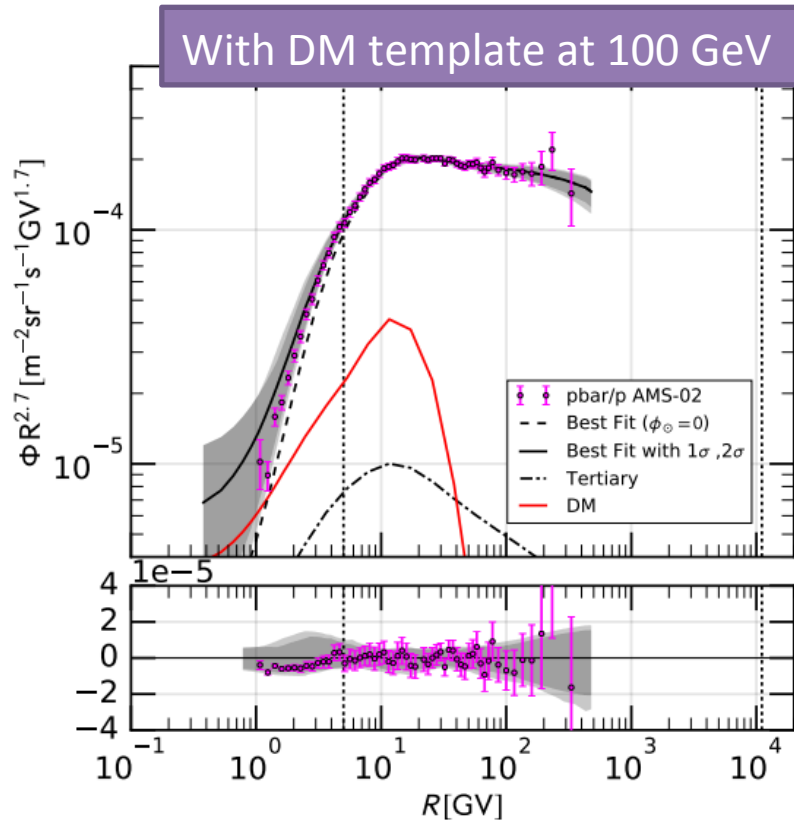
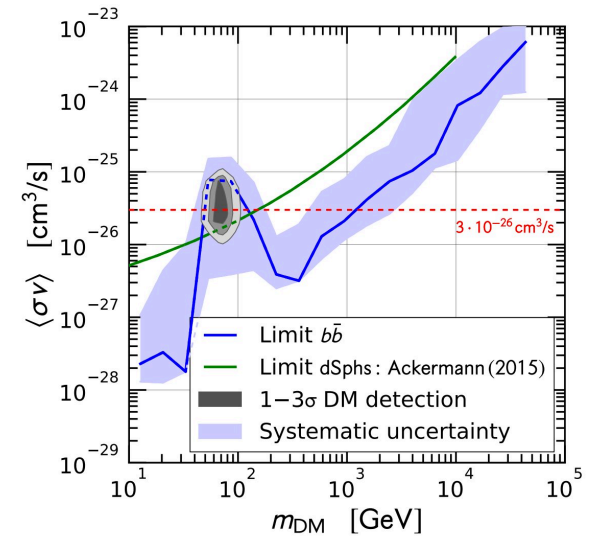


The cosmic ray spectrum (multiplied by E^3) measured by DAMPE. The red dashed line represents a smoothly broken power-law model that best fits the DAMPE data

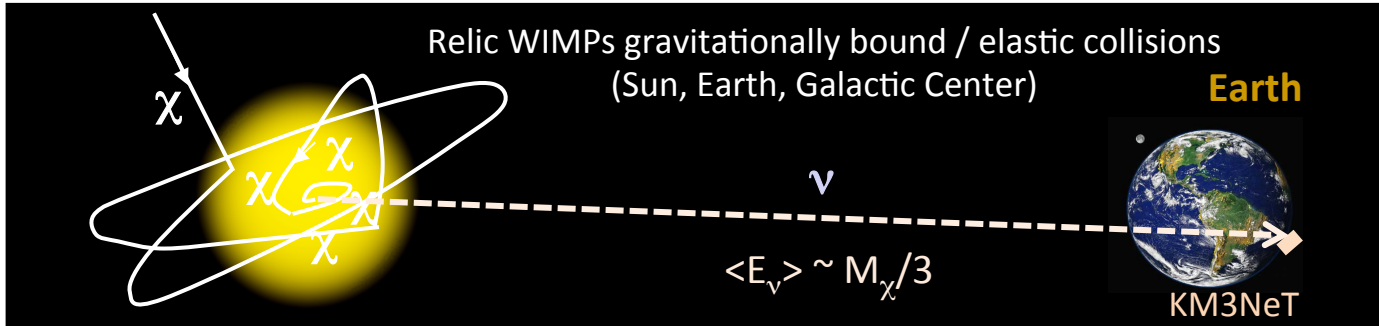
A Cuoco et al (Aachen)
1610.03071

Anti-proton spectrum AMS-2

Largely improved
fit of
Antiproton spectrum
**With DM template
at 100 GeV and
right thermal annihilation
cross section**

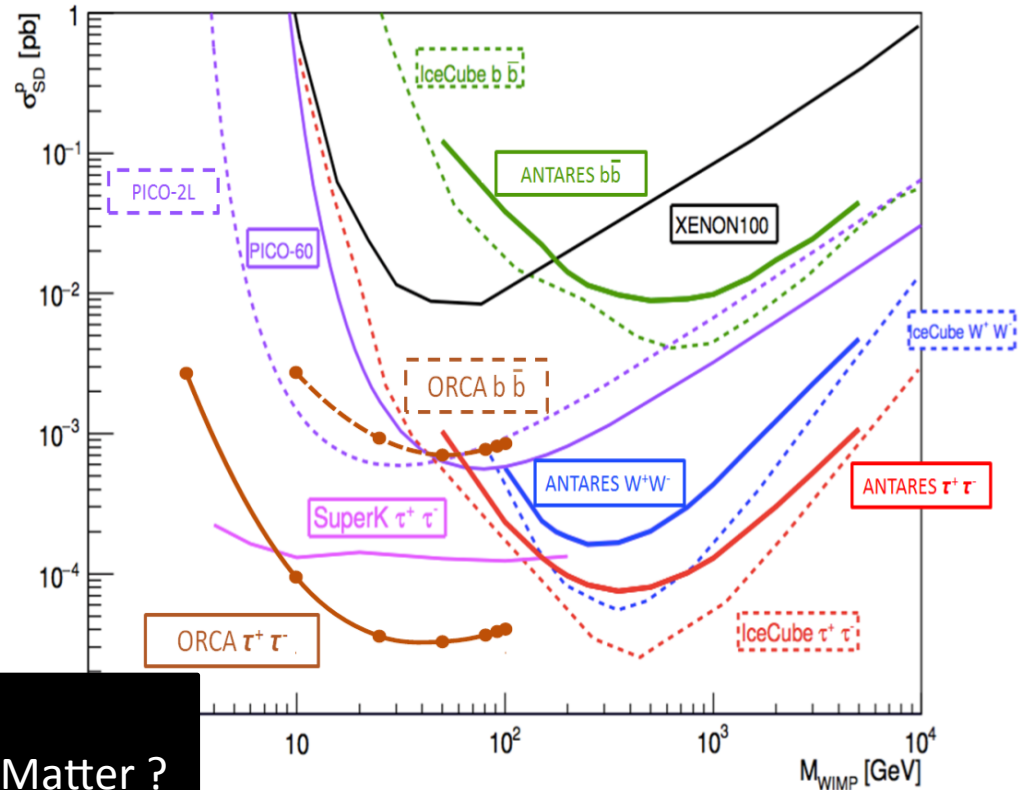


GeV Neutrinos



Detect neutrinos produced in dark matter annihilations in the sun, center of Earth or galactic center.
 → Best limits from sun.

If sun in DM equilibrium => limit largely independent on annihilation cross section, but dependent on spin-dependent DM-nucleon cross section

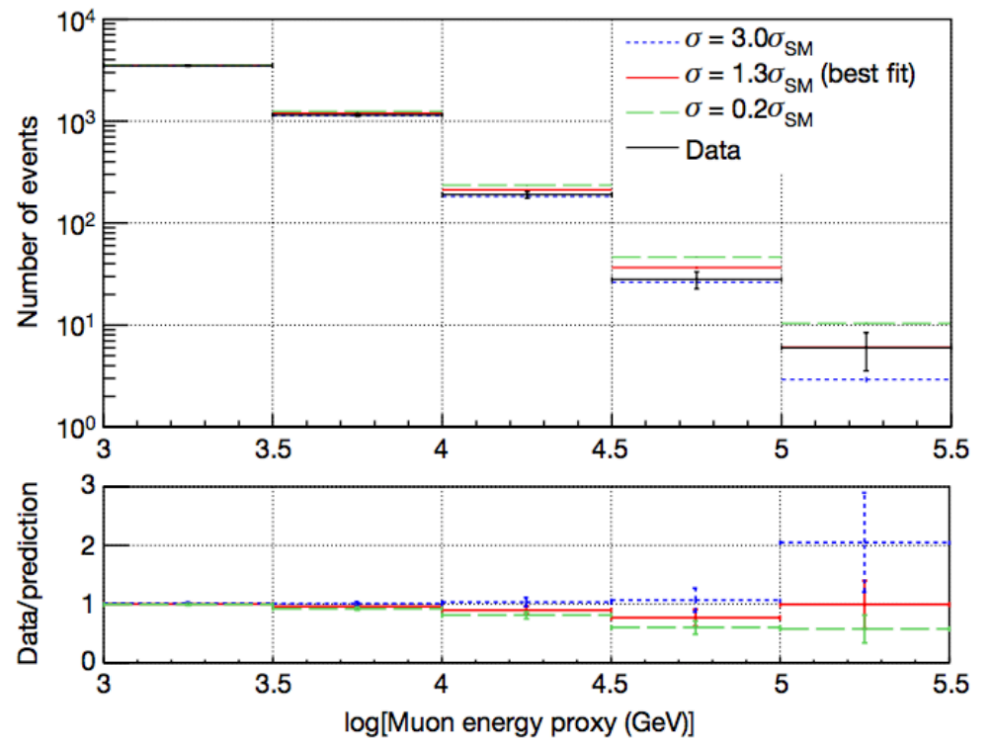
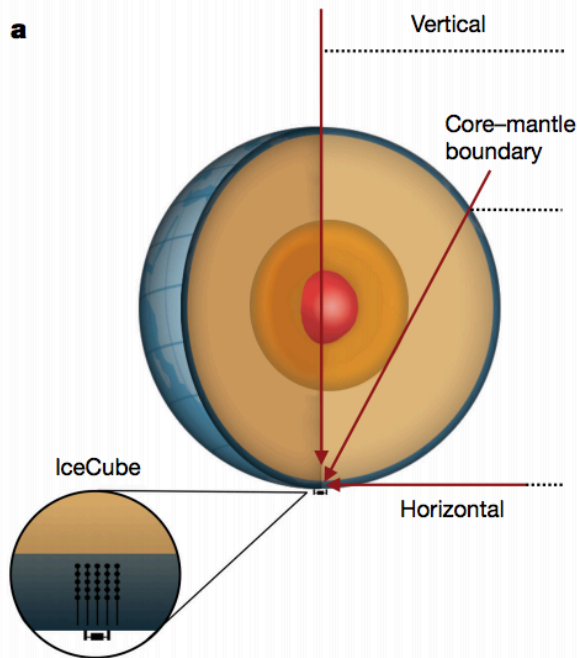


GeV neutrinos → **KM3Net-Orca** option
 Geometry improvement possible for Dark Matter ?

Working on this for Km3Net with students (Ralph, Camiel) + Aart/Wim...⁺²⁵

....up to 980000 GeV Neutrinos

Measurement of the multi-TeV neutrino interaction cross-section with IceCube using Earth absorption



Charged Current (remember from HERA?)
 Neutrino-nucleon interactions
 with up to 6-980 TeV in neutrino energy
 (centre-of-mass up to 1400 GeV)

➔ Future interesting measurements for physics beyond the SM

Possible with: KM3Net-ARCA
 Pierre Auger
 Future: Grande...

Dark Matter Models

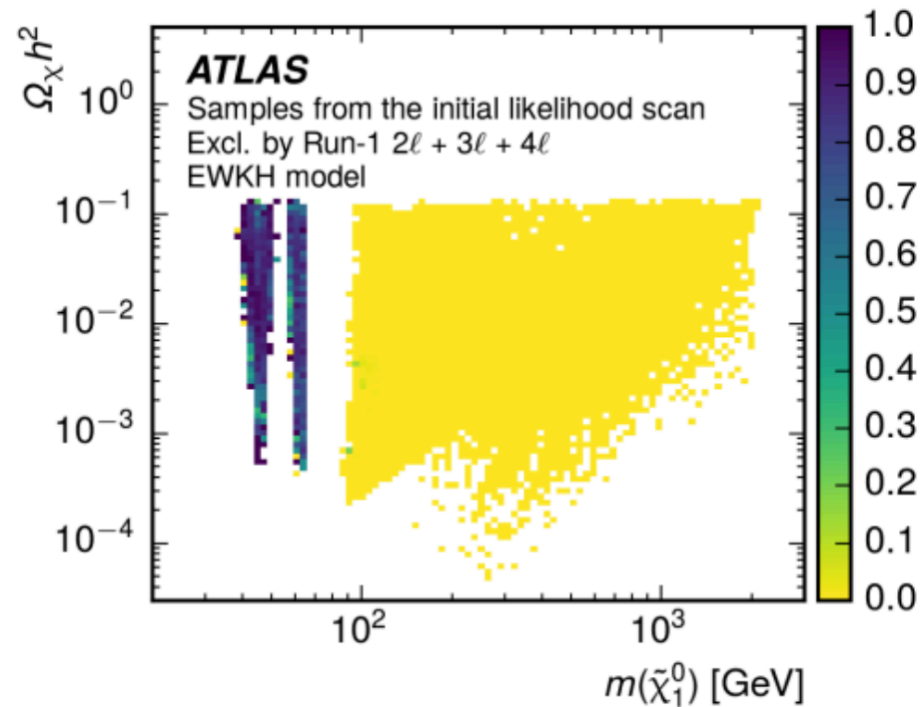
(SUSY Wimps and Axions,
no simplified models with a Z' today)

Models

Supersymmetry well motivated and provides a perfect DM candidate

→ Our question:

Is this still true post
LHC- run 1 ?

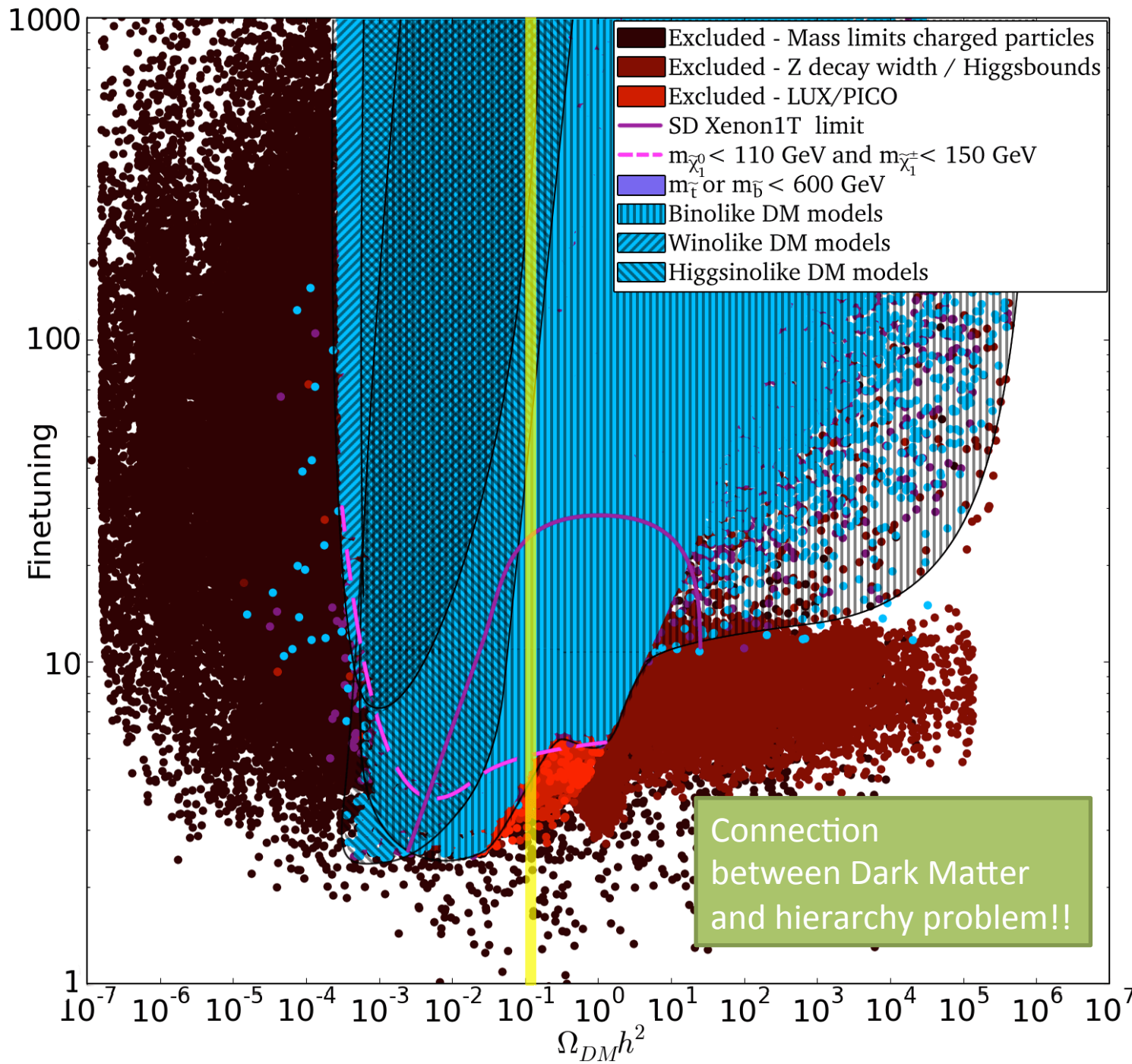


→ Idea: Connect motivation for SUSY (fine-tuning) with Dark Matter

Dark Matter relic density

- Same conclusion for some GUT scale models?
- Same conclusion for other FT measure?

- Future experiments for naturalness
- Role of diirect detection



Marrit Schutten,
Rob Timmermanns
et al.

edms

Limit on MSSM without complex phases etc.

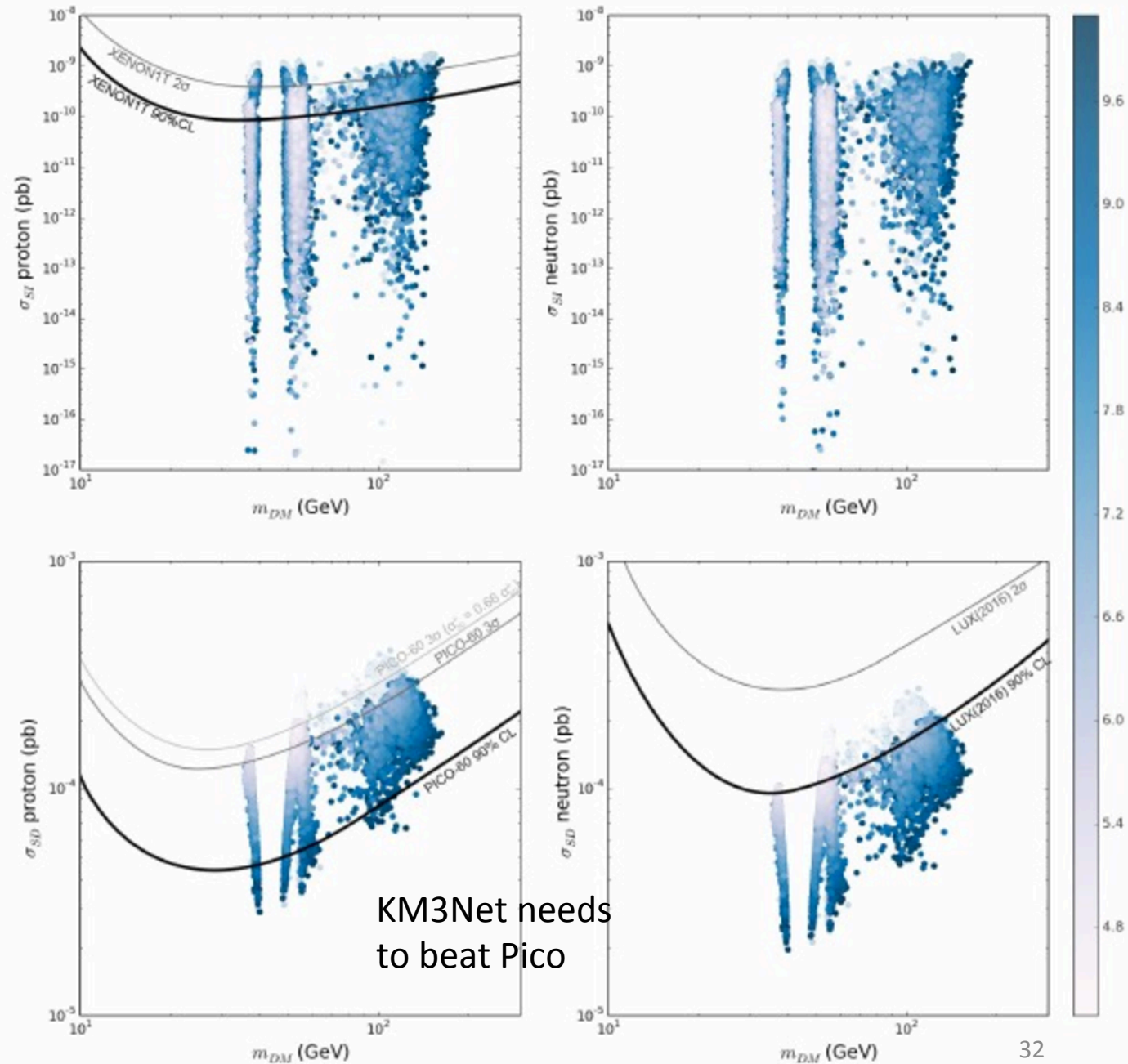
Direct detection

See Xenon-1T session,
here: Where are our
models ?

Lowest
Fine-tuned
SUSY Dark Matter
Models

→ Most important
Sigma_Spin-dependent
due to Z-higgsino
coupling

(PICO)



Dark Matter constrains and Data Science

DM model database at nikhef ?



Within
idark project
Dutch science
Center

Faruk Diblen
Jisk Attema

Collect model solutions in a database

Use them as target !

Use Machine Learning to interpolate between them → Generalization of DM searches

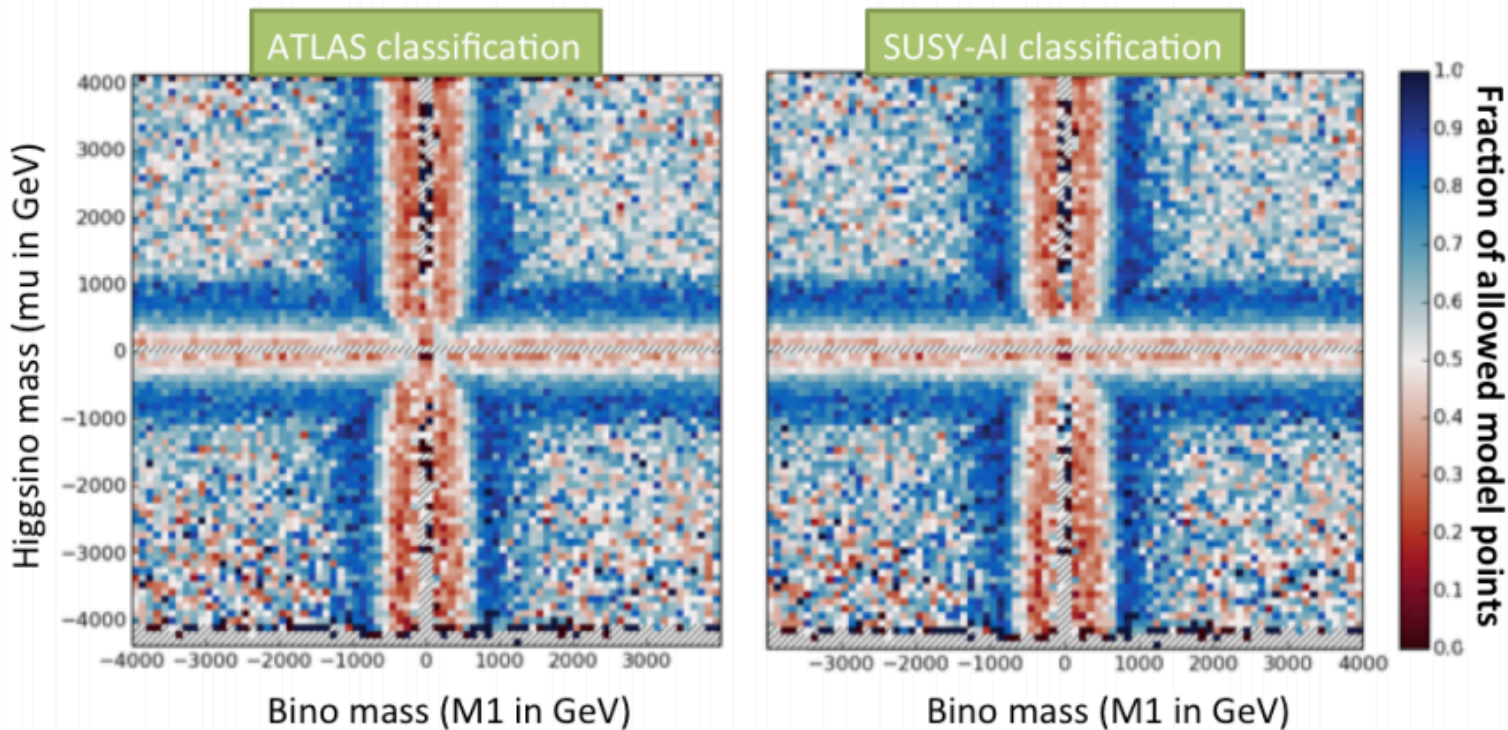
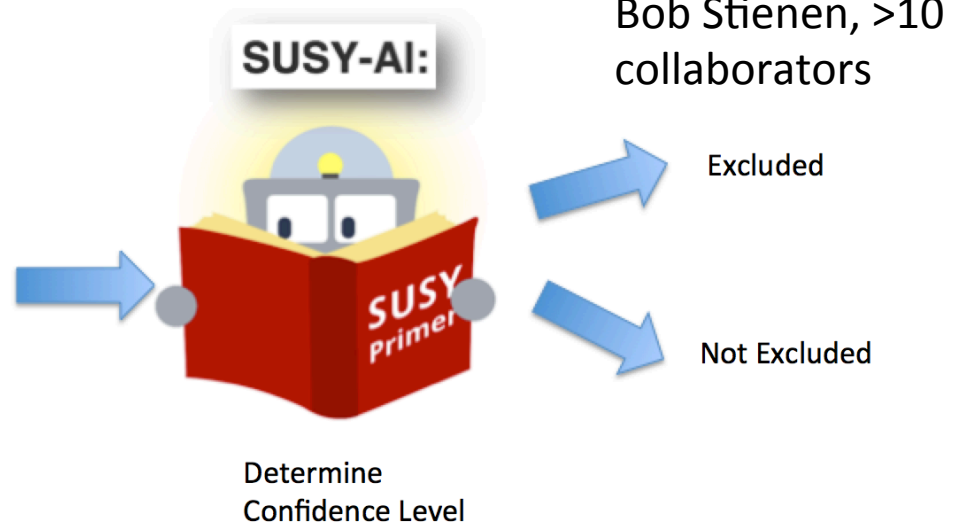
www.idarksurvey.com

BSM-AI

Encoding of model constraints with Machine Learning

Aim: Generic framework (**all** models)

Les Houches
Accord File



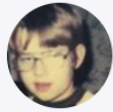
Darksurvey.com

Summary / Outlook

- Dark Matter status: many possibilities
- Interesting deviations still around 100 GeV → perfectly consistent with WIMP Dark Matter
- Excesses in electron/positrons → only consistent with heavy and very tuned Dark Matter models
- Provocative statement:
“Nikhef proposal on Dark Matter synergies”
- Extend into other directions
- Look systematically ... Maybe help from Machines...

Lorentz Center workshop: Dark Matter + Machine Learning (Jan. 2017)

Darksurvey.com



Sascha Caron @SaschaCaron · Dec 8

A survey 2: What is your favourite / best motivated Dark Matter candidate ?
Here are the alternatives:

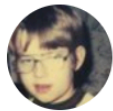
10% Modified gravity

20% Machos (Black Holes etc.)

70% something else

0% I tweet a better model

10 votes · 1 day left



Sascha Caron @SaschaCaron · Dec 8

A survey : What is your favourite / best motivated Dark Matter candidate ?
(see next tweet for alternatives)

44% Some kind of WIMP

32% Some kind of Axion

8% Ultralight DM (< keV)

16% Sterile neutrino

Picture from twitter

Positron Spectrum

