Dark Matter & Dark Sectors Discussion

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European Strategy for Particle Physics Update, UK Meeting
Institute of Physics, London
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ESPPU "Big Questions"

1) How do we search for dark matter, depending on its properties? What are the main differences between light Hidden Sector DM and WIMPs? How broad is the parameter space for the QCD axion?

2) What are the most promising experimental programs, approved or proposed, to probe the different possibilities in a compelling manner?

3) How to compare results of different search strategies in a more model-independent way?

4) **How will Direct and Indirect Dark Matter Detection experiments inform/guide accelerator searches and vice-versa?**

Dark Sectors

What is meant by a dark sector ?
A Hidden sector, with Dark matter, that talks to us through a Portal

| Standard Model | → | Portal | → | Dark Sector |

Portal can be the Higgs boson itself or New Messenger/s

Dark sector has dynamics which is not fixed by Standard Model dynamics
→ New Forces and New Symmetries
→ Multiple new states in the dark sector, including Dark Matter candidates

Interesting, distinctive phenomenology
Long-Lived Particles
Feebly interacting particles (FIP's)

(M. Carena, ESPPU Dark Sectors Summary Talk)

ESPPU Talks

Dark Matter and Dark Sector Parallel Sessions, May 13-14, 2019

Monday afternoon

Session 1 (1.5 hours) – Introduction and Synergies - Scientific Secretary: K. Zurek+J. Monroe, C. Weniger
- Talk 1: Dark Sectors and DM Models: from Ultralight to Ultraheavy   (25+5) H.Murayama (Berkeley and Tokyo)
- Talk 2: Dark Matter Direct Detection Searches   (25+5) J. Monroe (London)
- Talk 3: Indirect DM Detection Overview   (15+5) C. Weniger (Amsterdam)

Session 2 (2.5 hours) – DM at Colliders (joint w/ BSM) Scientific Secretaries: C.Doglioni (Lund), M.McCullough (CERN)
- Talk 4: How can/will Direct and Indirect DM Searches guide DM Searches at Accelerators? (25+5) M. Lisanti (Princeton)
- Talk 5: Theory: DM at Colliders   (25+5) M. McCullough (CERN)
- Talk 6: Experiment: DM at Colliders   (25+5) C. Doglioni (Lund)
- Discussion for Sessions 1 and 2   (60) All

Tuesday afternoon

Session 3 (1.5 hours) – Axions/ALPs - Scientific Secretaries: J.Jaeckel (Heidelberg) , B.Doebrich (CERN)
- Talk 7: Ultra-light DM (ALPS) Theory and Overview   (25+5) P. Agrawal (Harvard)
- Talk 8: ALPs: Lab Searches   (15+5) A. Lindner (DESY)
- Talk 9: ALPs: Helioscope Searches   (15+5) I. Irastorza (Zaragoza)
- Discussion for Axions/ALPs   (30) All

Session 4 (2.5 hours) – Fixed Target/Beam Dump - Scientific Secretaries: G.Krnjaic (Fermilab), K.Petridis (Bristol)
- Talk 10: Theory and Overview   (25+5) C. Frugiuele (Weizmann)
- Talk 11: Lepton Beams: LDMX@eSPS (NA64++ AWAKE ++)   (12+3) R. Poettgen (Lund)
- Talk 12: Proton Beams: SHiP@BDF QCD   (12+3) E. Graverini (EPFL)
- Talk 13: General Perspective   (15+5) C. Vallee (Marseille)
- Discussion for Fixed Target/Beam Dump   (70) All

(M. Carena, ESPPU Dark Sectors Summary Talk)

ESPPU Talks

Category: Facilities and experiments with "Dark Side" as key topic
(Id62) Argon : WIMP
(Id97) DARWIN: WIMP
(Id9) NA64++: middle mass
(Id12) SHiP : middle mass
(Id27) IAXO: WISP
(Id35, 50) AWAKE: WISP
(Id112) ALPII, JURA, IXAO, MADMAX etc : WISP
(Id113) VMB : WISP
(Id161) MAGIS-1K : WISP

Category: Facilities and experiments with "Dark Side" as a topic
(Id64) GW : WISP
(Id36) eSPS : middle mass
(Id94) FASER @ LHC : middle mass
(Id1) Sterile Neutrino at CERN : middle mass
(Id11) Belle II: middle mass
(Id137) Short Base-line neutrino at FNAL FCC: middle mas
(Id131) LBNF/DUNE : middle mass
(Id151) HI @ LHC   : middle mass
(Id75) MATHUSLA: WIMP and middle mass

Continue.
(Id132,133, 135) FCC: WIMP and middle mass
(Id136) HE-LHC: WIMP and middle mass
(Id152) HL-LHC: WIMP and middle mass
(Id77,145) ILC,CLIC: WIMP and middle mass
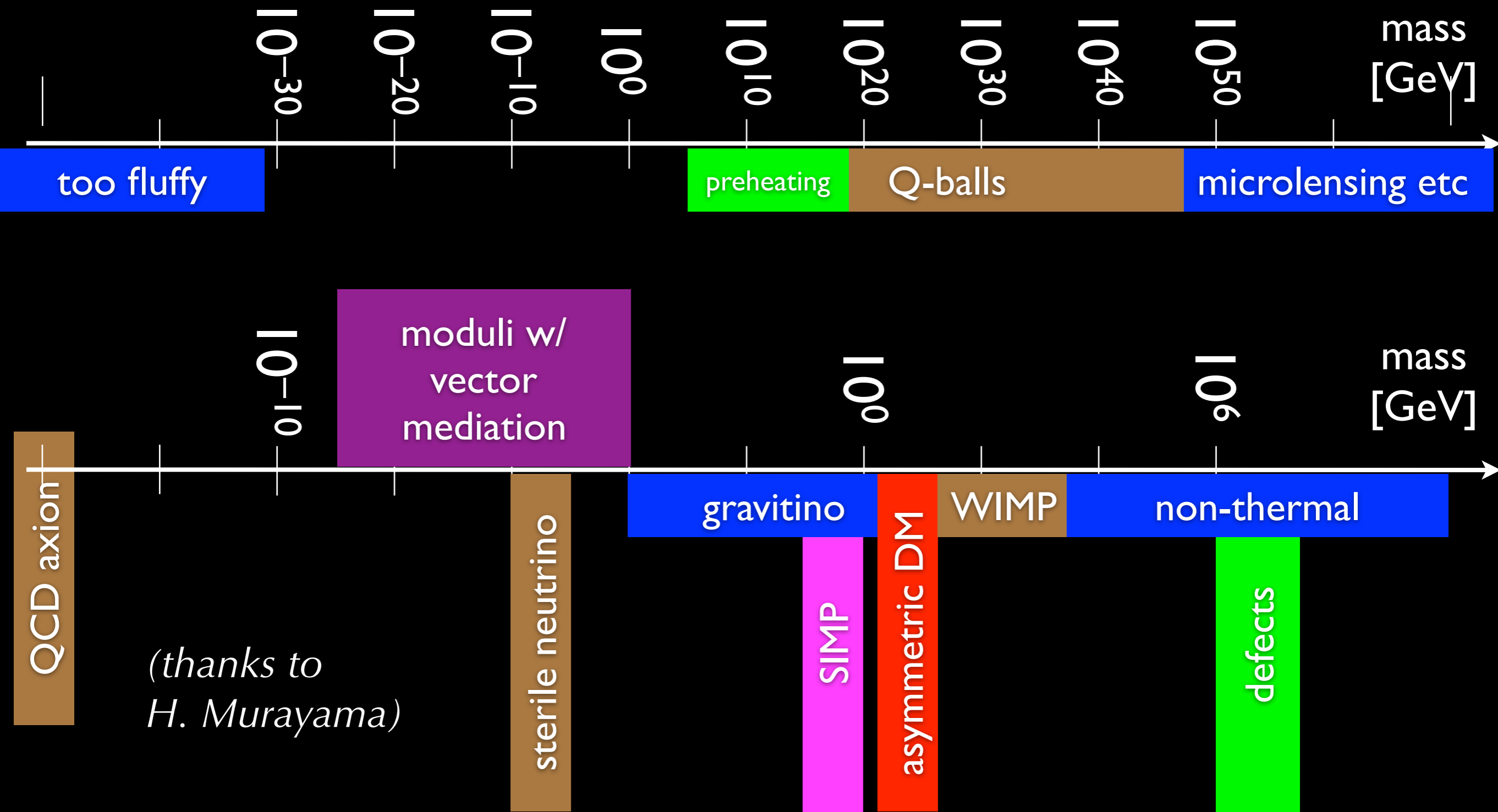
Category: Synergies on a global scale
(Id84) APPEC
(Id42,60,20) PBC study
(Id70) Neutrino global network

Category: National roadmaps and community
(Id40) Russia
(Id68) Slovenia
(Id69) Germany astroparticle
(Id78) Slovenia
(Id82,134) UK
(Id130, 138,165) Italy LNF,INLF
(Id149.150) US

(M. Carena, ESPPU Dark Sectors Summary Talk)

Model Space: Theorist's View

*Can't do justice to many many ideas in the literature!*

new sociology

- WIMP should be explored at least down to the neutrino floor
  - heavier? e.g., wino @ 3TeV
- dark matter definitely exists
  - naturalness problem may be optional?
- need to explain dark matter on its own
- perhaps we should decouple these two
- do we really need big ideas like SUSY?
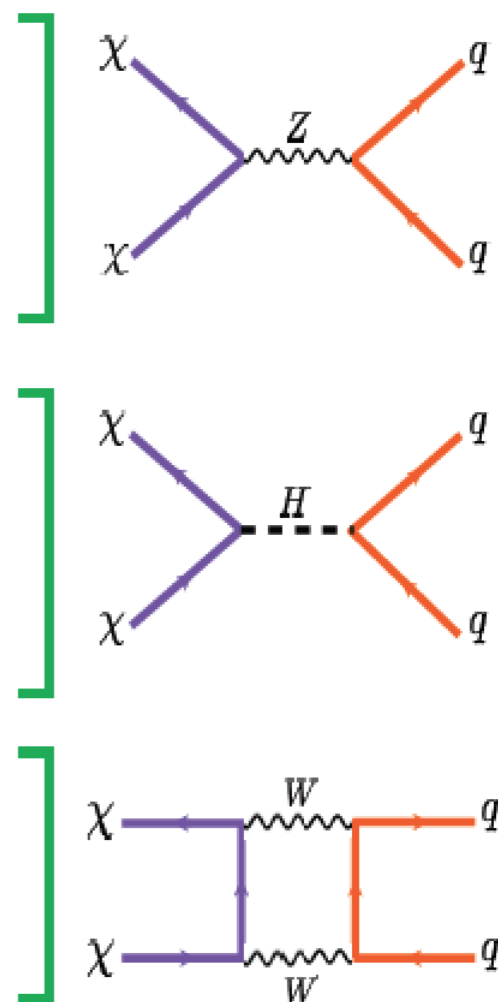- perhaps not necessarily heavier but rather lighter and weaker coupling?

(thanks to H. Murayama)
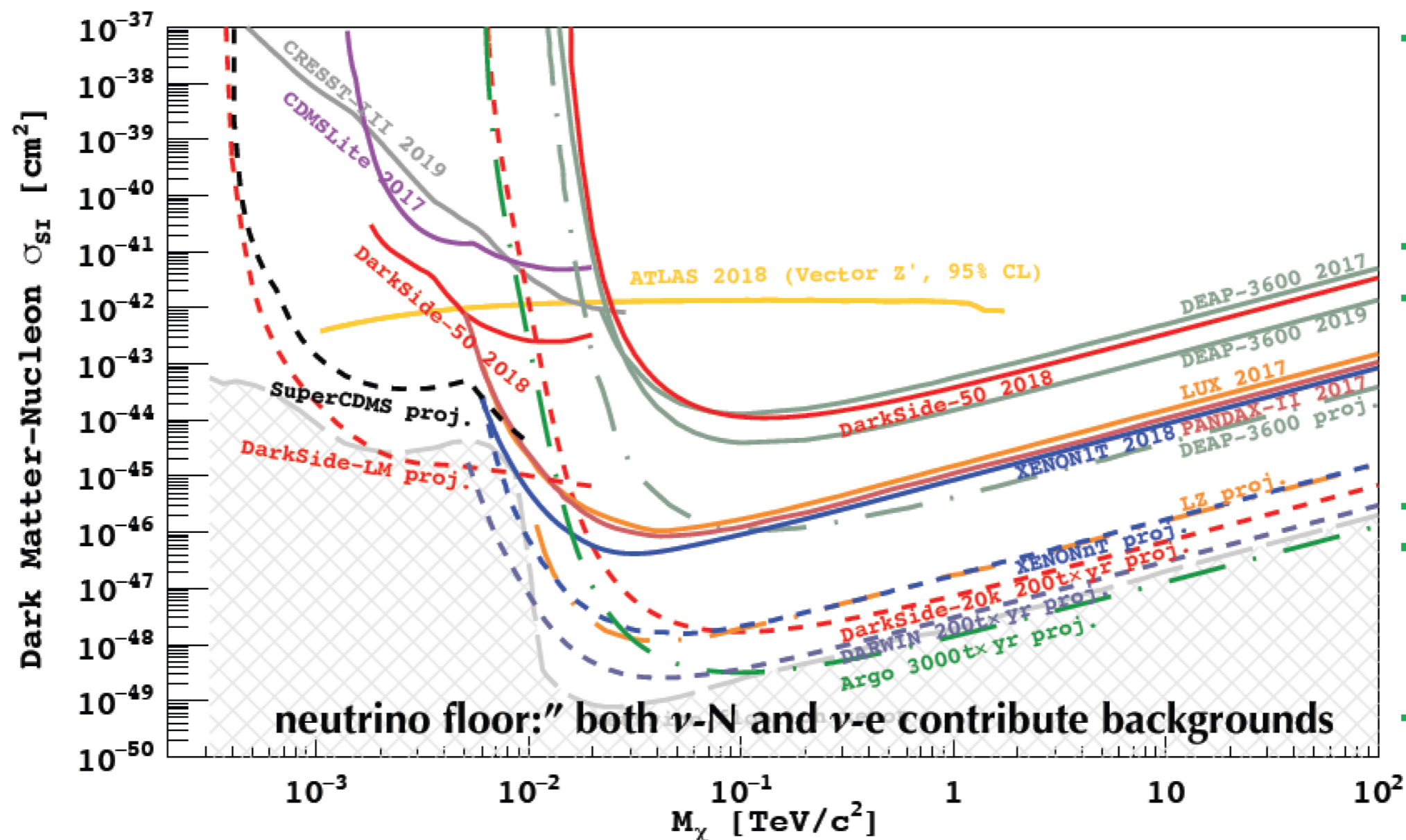
Marching down to the Neutrino Floor

(M. Carena, ESPPU Dark Sectors Summary Talk)

WIMP Standard Candles

- Still a viable solution for Thermal DM (e.g. in many SUSY extensions/regions)

- Being broadly probed by Direct and Indirect detection as well as Collider experiments

Pure Higgsino DM

- Thermal abundance requires Higgsino mass of about 1.1 TeV

- DD: Suppressed. Deep in neutrino floor region

- ID: Bounds strongly dependent on halo morphology.

- @ Hadron Colliders: Disappearing tracks
- @Lepton Colliders: Reach close to kinematic limit plus
                precision measurements extended reach

See more details on Colliders in P. Sphicas' talk

Talks by Lisanti, Monroe and McCullough

Departures from pure Higgsino (mixings with bino/singlino) can lead to rich phenomenology.
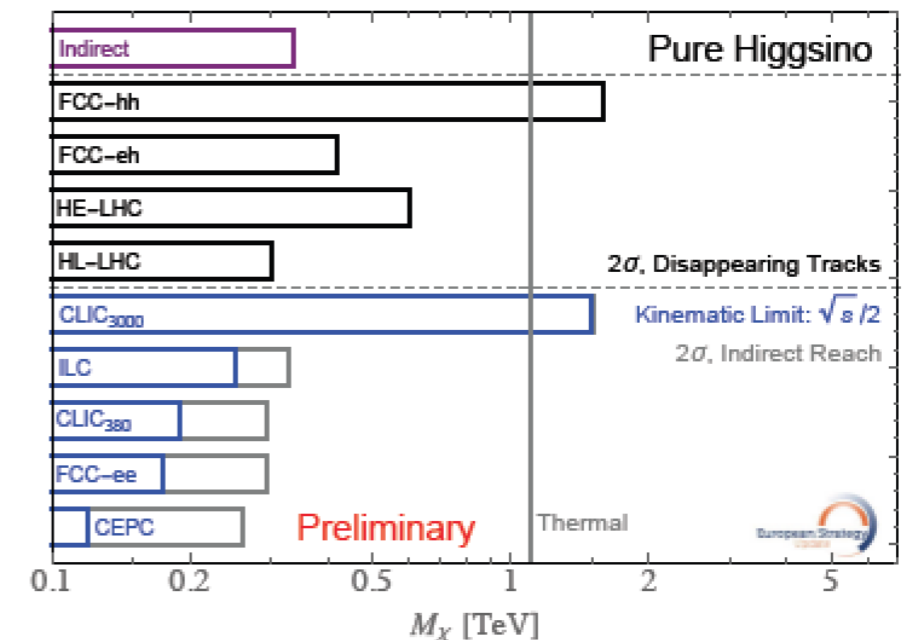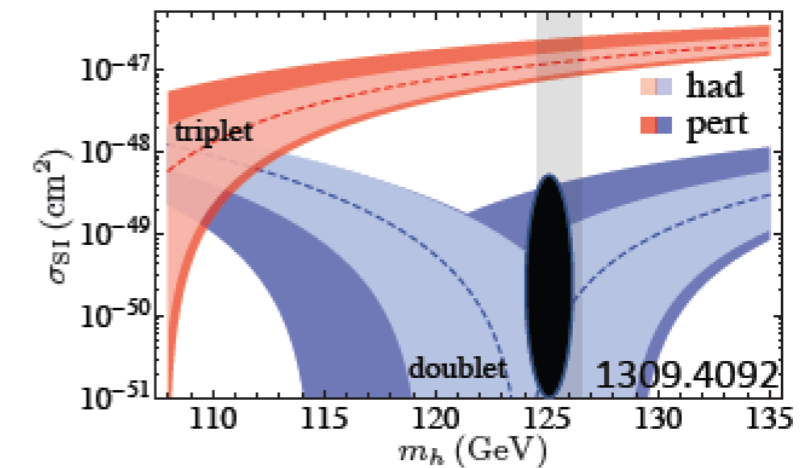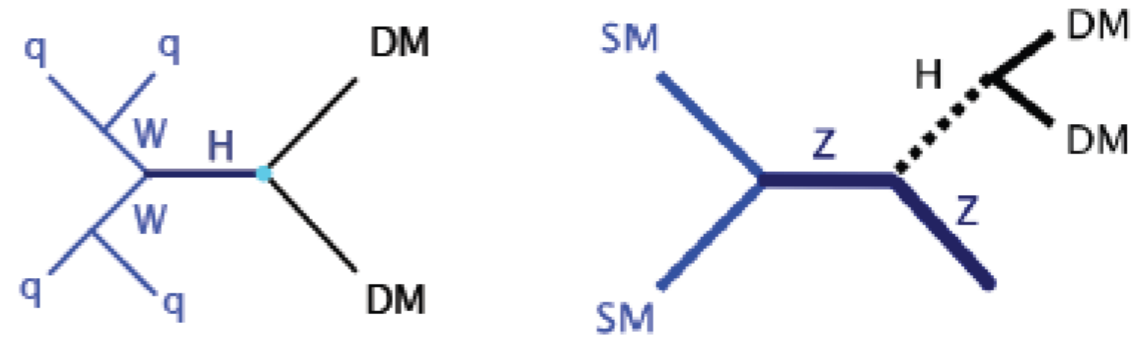

(M. Carena, ESPPU Dark Sectors Summary Talk)
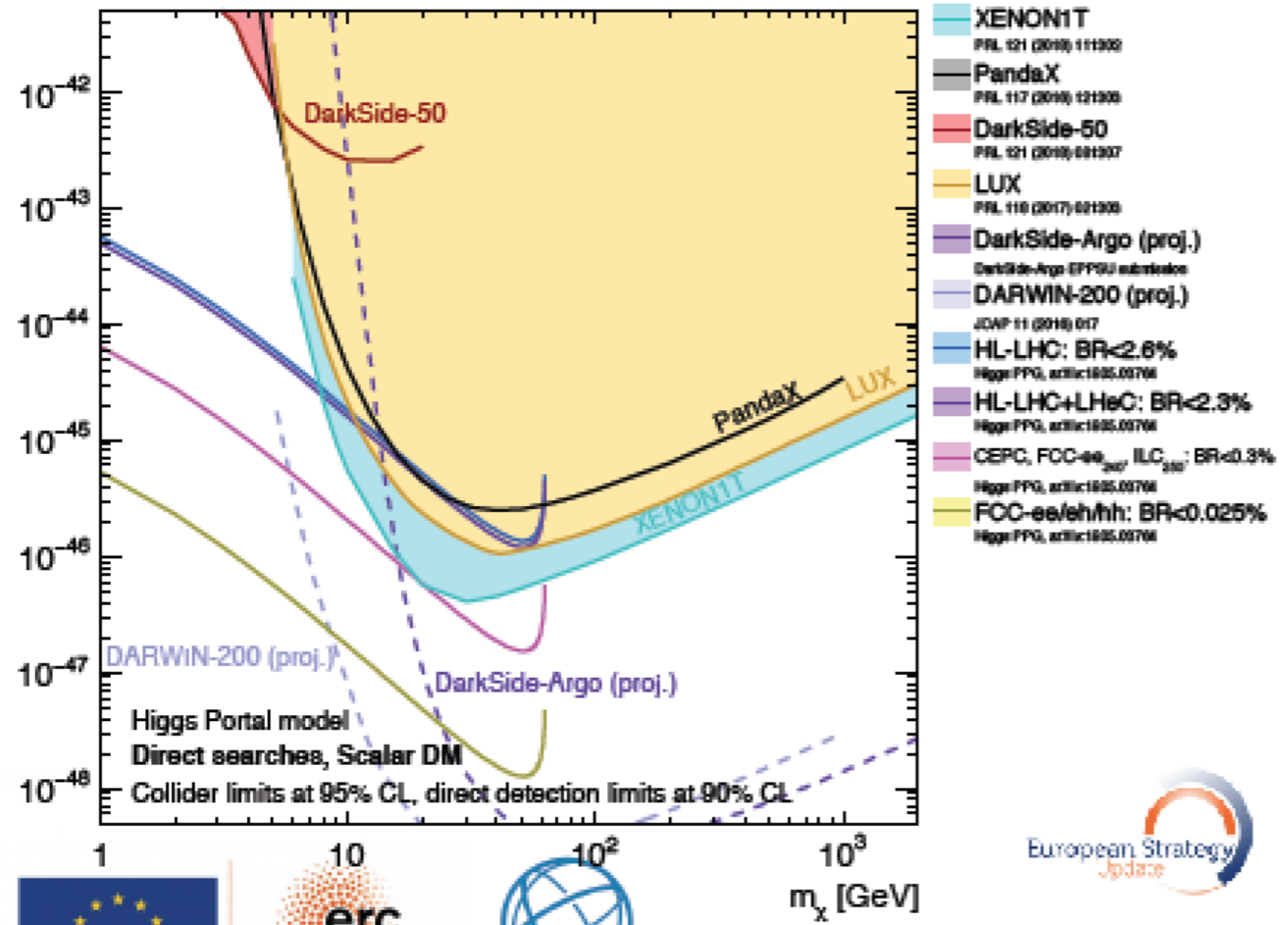
Higgs portal, plot for direct searches

- Limits on BR can be translated to limits in the DM-nucleon plane

$$\sigma_{\chi N} = \Gamma_{\text{inv}} \frac{8 m_N^4 f_N^2}{v^2 \beta m_h^3 (m_\chi + m_N)^2} g_\chi \left(\frac{m_h}{m_\chi} \right), \qquad (15)$$

arXiv:1708.02245

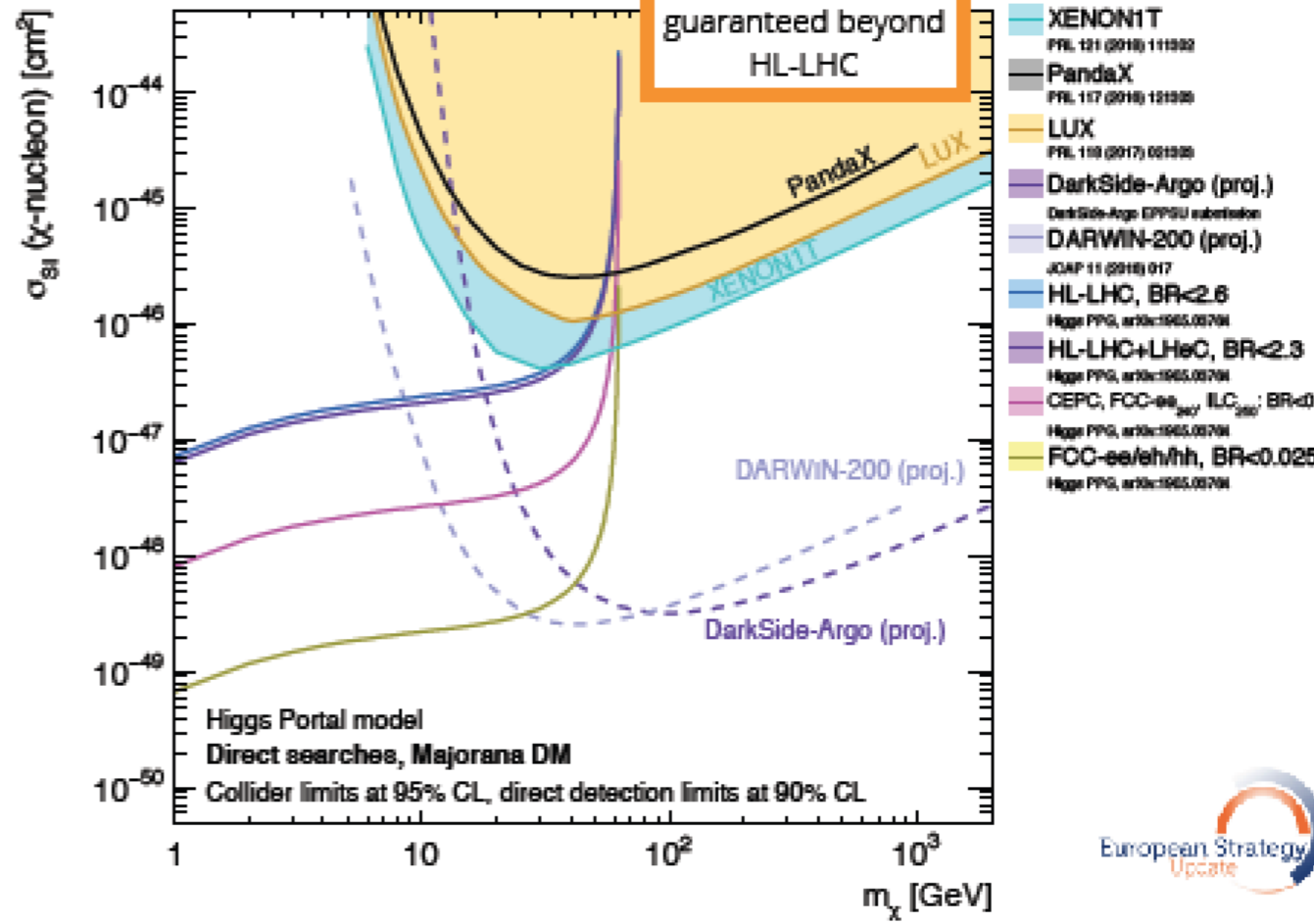where $g_S(x) = 1$,
$g_f(x) = 2/(x^2 - 4)$, $\beta = \sqrt{1 - 4 m_\chi^2 / m_h^2}$, $v = 246\,\text{GeV}$

Caveat: EFT validity in Higgs-DM interaction not guaranteed beyond HL-LHC

Preliminary, Granada May 2019

XENON1T
PRL 121 (2018) 111302
PandaX
PRL 117 (2016) 121303
DarkSide-50
PRL 121 (2018) 081307
LUX
PRL 118 (2017) 021303
DarkSide-Argo (proj.)
DarkSide-Argo EPPSU submission
DARWIN-200 (proj.)
JCAP 11 (2016) 017
HL-LHC: BR<2.6%
Higgs PPG, arXiv:1905.03764
HL-LHC+LHeC: BR<2.3%
Higgs PPG, arXiv:1905.03764
CEPC, FCC-ee$_{240}$, ILC$_{250}$: BR<0.3%
Higgs PPG, arXiv:1905.03764
FCC-ee/eh/hh: BR<0.025%
Higgs PPG, arXiv:1905.03764

Higgs Portal model
Direct searches, Scalar DM
Collider limits at 95% CL, direct detection limits at 90% CL

Preliminary, Granada May 2019

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Higgs PPG, arXiv:1905.03764
CEPC, FCC-ee$_{240}$, ILC$_{250}$; BR<0.3
Higgs PPG, arXiv:1905.03764
FCC-ee/eh/hh, BR<0.025
Higgs PPG, arXiv:1905.03764

Higgs Portal model
Direct searches, Majorana DM
Collider limits at 95% CL, direct detection limits at 90% CL

WIMP Standard Candles

- Still a viable solution for Thermal DM (e.g. in many SUSY extensions/regions)

- Being broadly probed by Direct and Indirect detection as well as Collider experiments

Pure Wino DM

- Thermal abundance requires Wino mass of about 2.9 TeV

- DD: just above the neutrino floor.
  Ballpark of DarkSide 20k-200t-yr,
  DARWIN 200t-yr and Argo 3000t—yr.

- ID: Wino only constitutes all the DM for density profiles not generically produced in simulations of Milky Way-like galaxies

- @ Hadron Colliders: Disappearing tracks
- @Lepton Colliders: Reach close to kinematic limit plus
  precision measurements extended reach

See more details on Colliders in P. Sphicas' talk
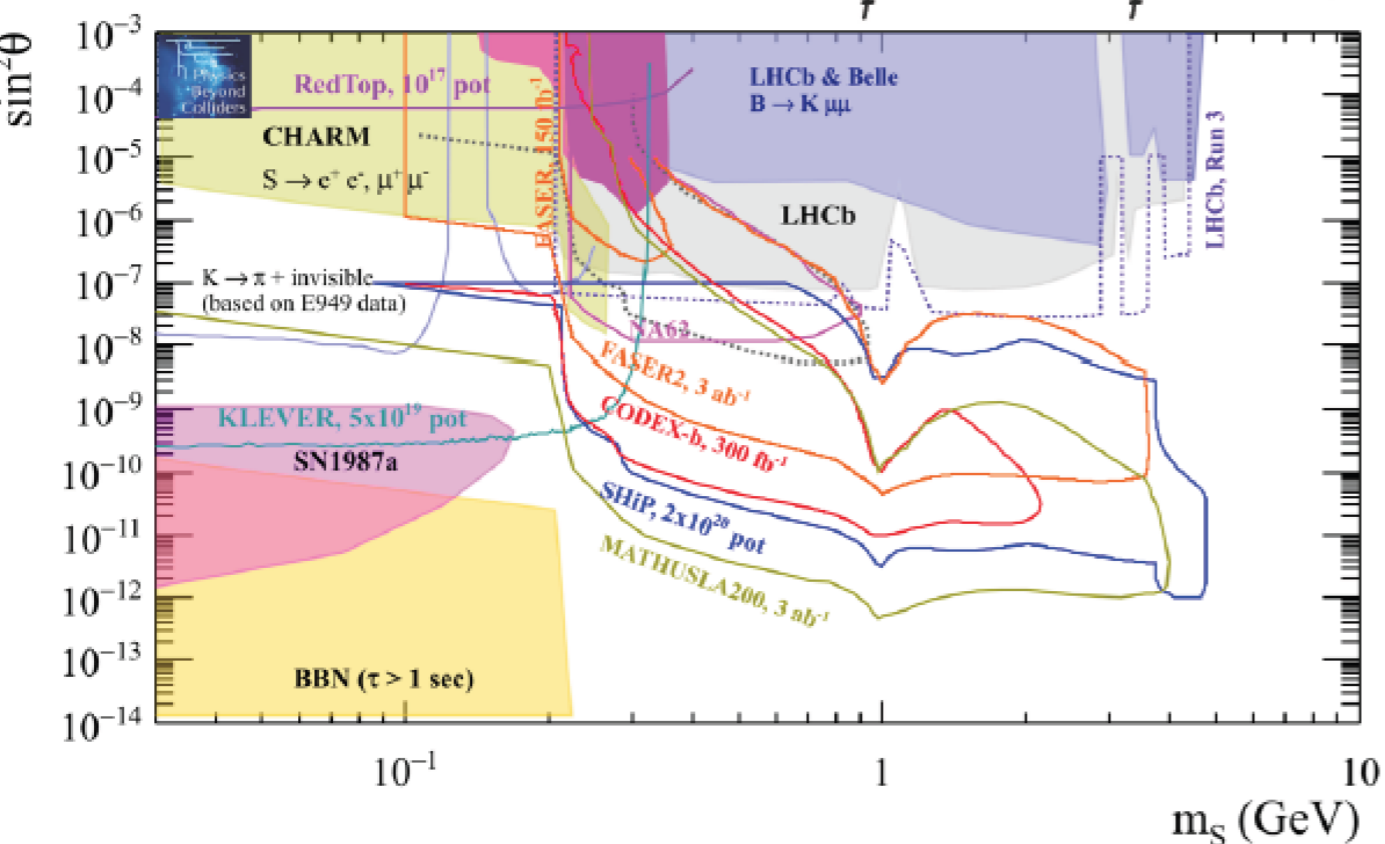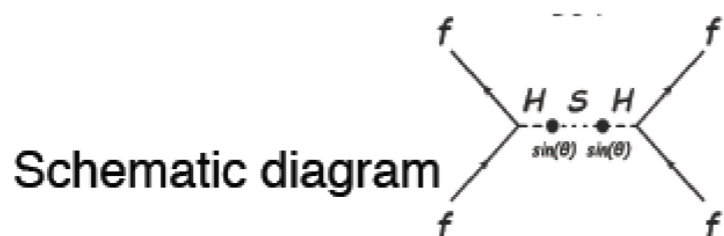
Talks by Lisanti, Monroe and McCullough
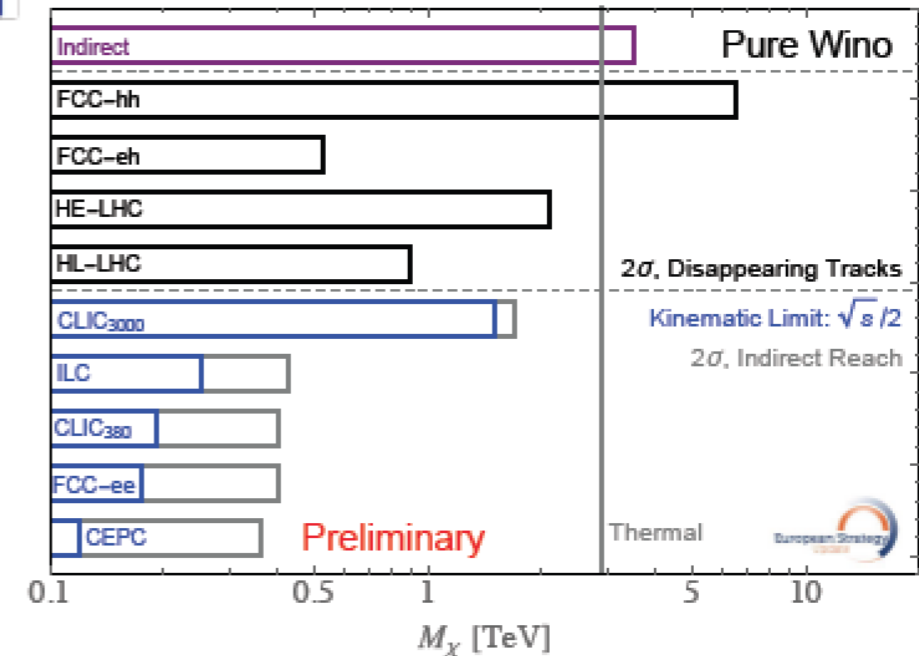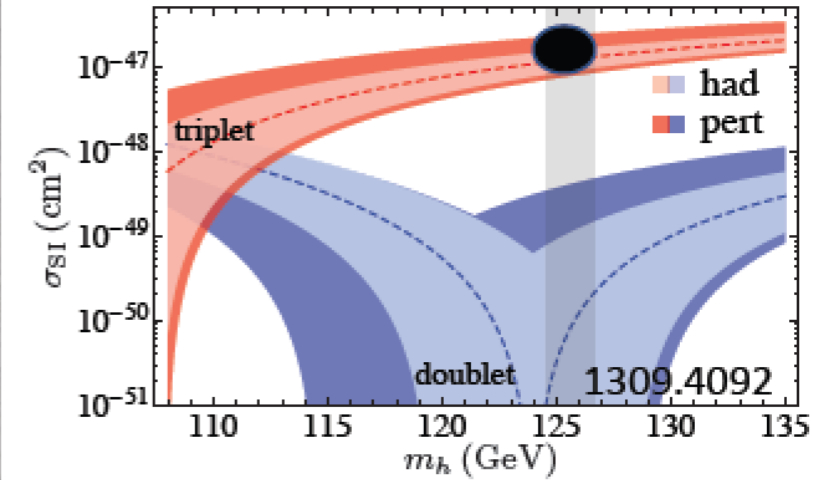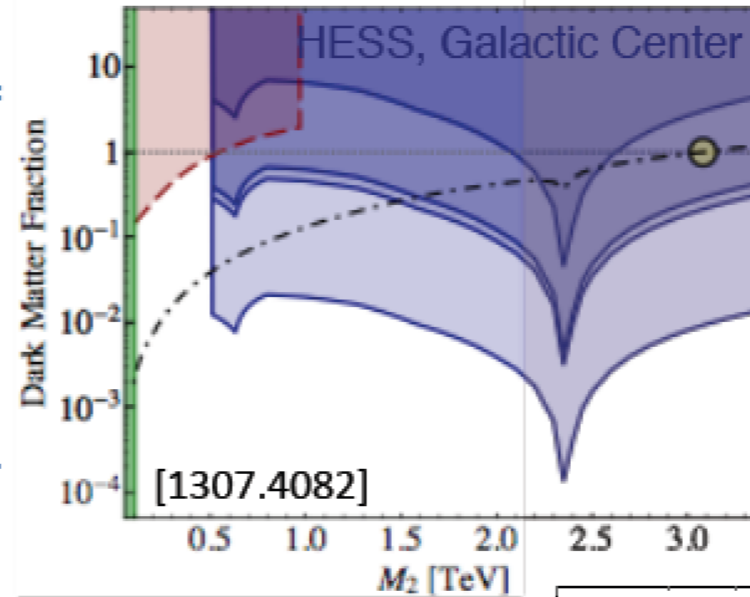
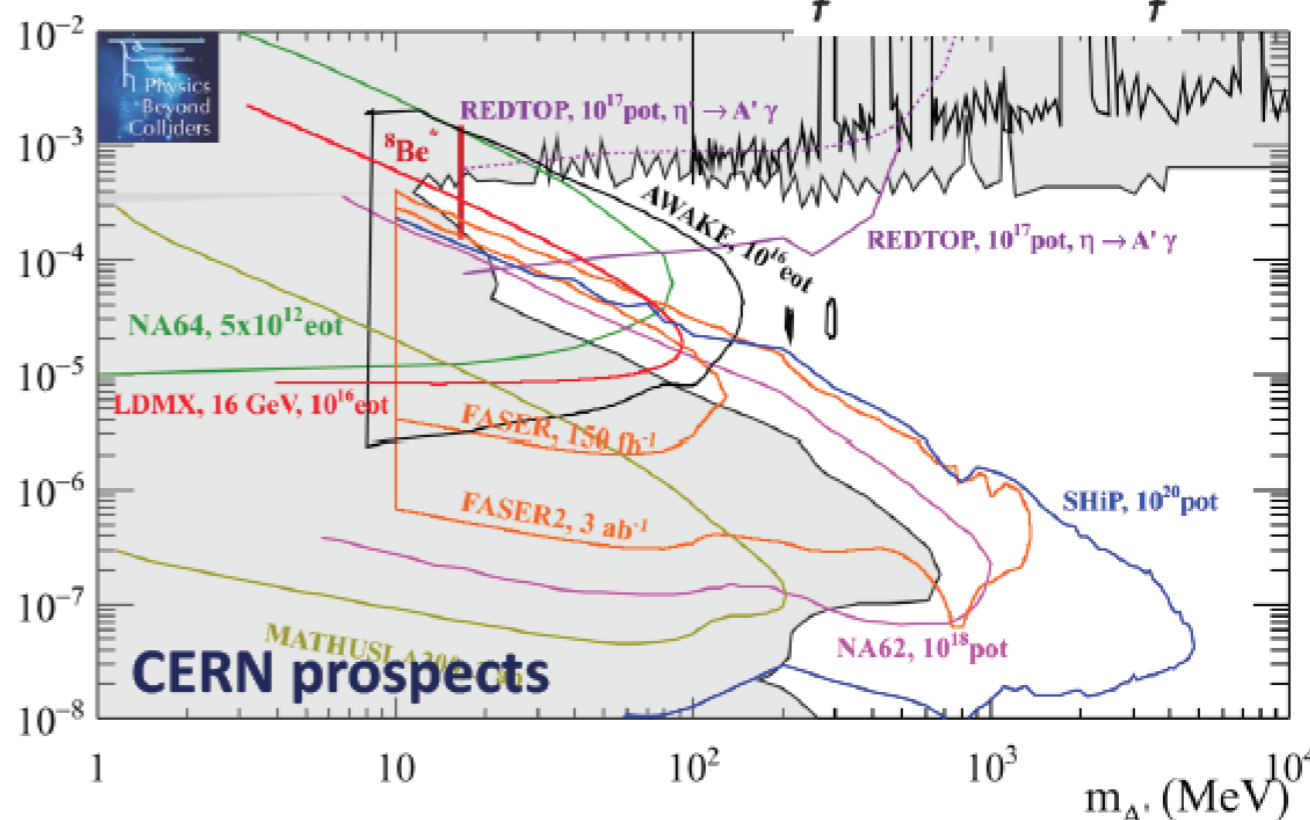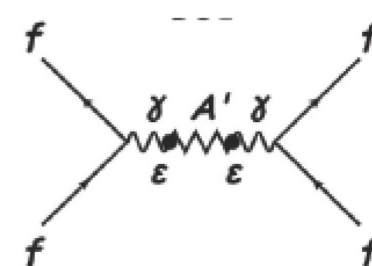*(M. Carena, ESPPU Dark Sectors Summary Talk)*

Dark photons/scalars → SM particles

C. Vallee's Talk

SHiP is a proposed beam dump experiment using 400 GeV protons from the SPS

Schematic diagram

Beam dump is complementary to collider based searches for feebly interacting particles (FIP)

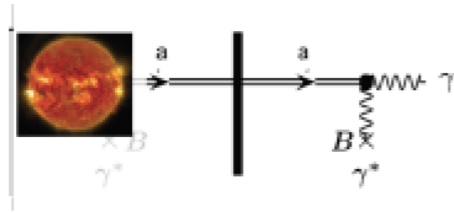See P. Sphicas' talk for details on Collider reach

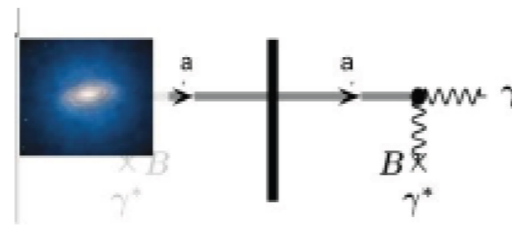*(M. Carena, ESPPU Dark Sectors Summary Talk)*

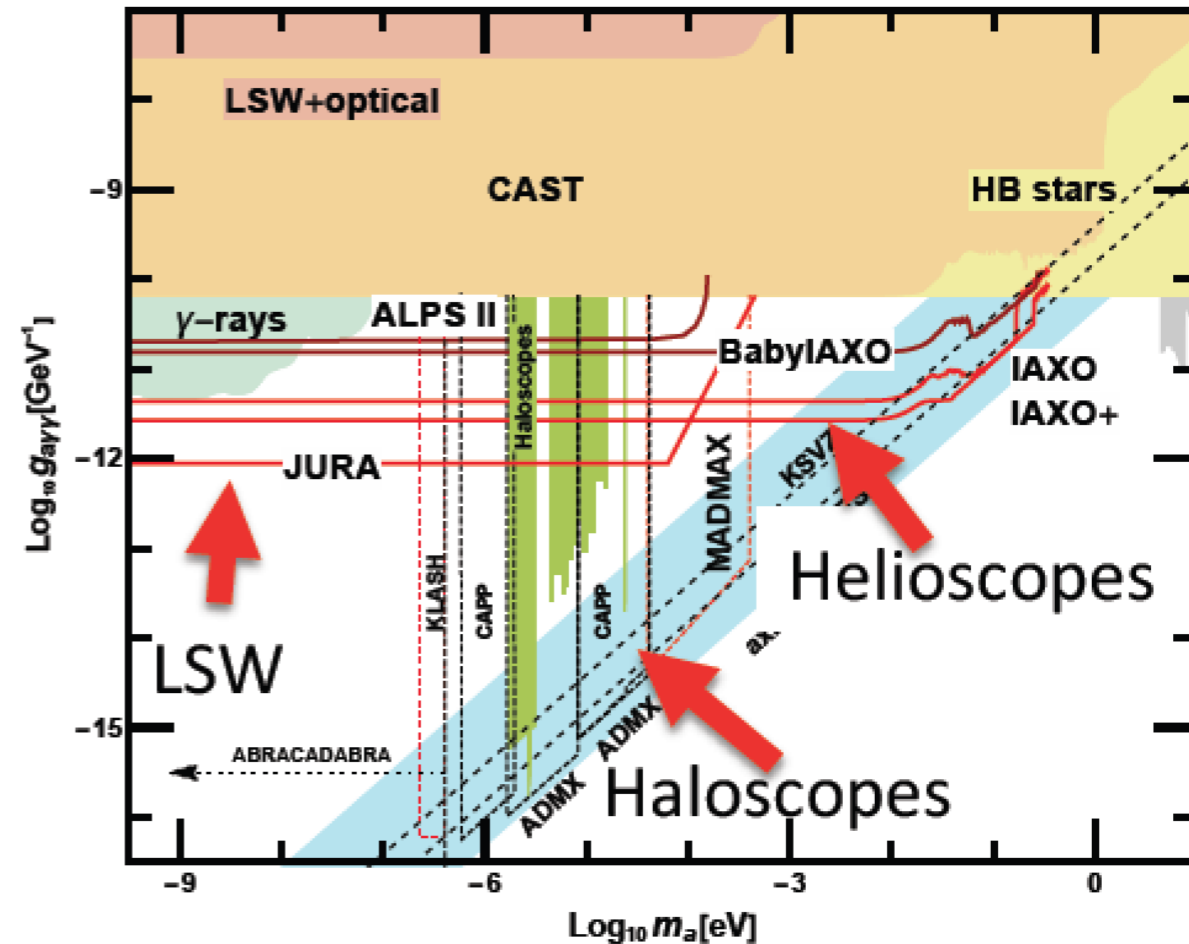## Axion/ALP searches: Mature Key Techniques

Helioscopes

- Build on success of CAST hosted by CERN
- Proposed BabyIAXO, leads to IAXO, with large discovery potential

Haloscopes
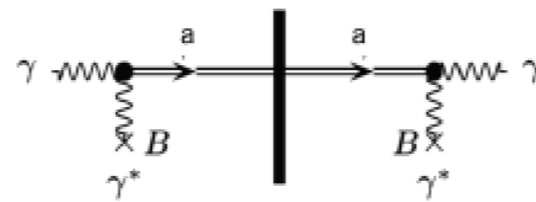
- ADMX (US) is leading the field
- In Europe, MadMax is new key player
- Smaller efforts developing new techniques

Light-shining-through-walls

- ALPS II is well underway
- STAX is a new idea RF based
- JURA is long term plan

Lindner and Irastorza's talks

Searches relevant for both QCD Axions and more general Axion-like particles (ALPs)

(M. Carena, ESPPU Dark Sectors Summary Talk)

Need for technology support and exchange between communities

- Technology challenges are shared between and beyond the communities engaged in dark matter searches.
- CERN and other large European National labs has relevant expertise and infrastructure for most/many of the big challenges, including vacuum over large volume, cryogenics, photosensors, liquid argon detectors, design and operation of complex experiments, software and data processing.
- Expanded support for dark matter research at CERN would stimulate knowledge transfer, increase coordination and synergies between experiments, and add guidance and coherence to the overall program.

Need for better coordination

- Consensus emerged on the need for more coordination between accelerator based, direct detection and indirect detection dark sector searches, for common interpretation of results.
- This will also be of fundamental importance to validate, through different channels, a possible dark matter discovery.

ESPPU "Big Questions" for Discussion
(*My* Views Only)

1) What should the degree of involvement of CERN be in Dark Sectors projects at CERN? (e.g. SHIP)

2) What should the degree of involvement of CERN be in Dark Sectors projects not at CERN? (e.g. IAXO, Direct Detection)

3) What should CERN's role be in astroparticle physics (e.g. collaboration around specific common technologies ? (small) Einstein Telescope partner? (large))

4) Should "APPEC" physics be part of ESPPU?

More Slides

WIMP Community Input to the ESPPU

9 submissions to ESPPU 2019 in track "dark matter",
2 focussed around direct detection (in Europe):
DARWIN and Global Argon Dark Matter Collaboration

Submissions are on 'observatory'-scale programmes, with multiple physics goals (dark matter of many kinds, neutrinos, rare processes) and decade-long time scales for operations

- (my view): community is undergoing a phase transition, similar to neutrino community pre-neutrino platform

Submissions identify areas of strong technical synergy across search strategies:

- cryostat technology
- large-volume cryogenics and purification
- TPC design and optimization, high voltage delivery
- silicon detectors for photon detection
- low-noise, cold readout electronics
- common challenges with LAr neutrino detectors (DAQ, optics, etc.)

WIMP Community Input to the ESPPU

Submissions aim for increased interaction between this community and CERN.

DARWIN:

The DARWIN experiment is a cornerstone of the European Astroparticle Physics program and should be considered as an essential part of the European Strategy for Particle Physics, especially in light of the complementarity of its dark matter program to the HL-LHC. DARWIN presents a unique opportunity to realize an observatory for low-background, low-threshold astroparticle physics in Europe, under European leadership. On the path towards becoming reality, DARWIN could directly benefit from the unique CERN expertise on cryogenics, large-scale vacuum systems, engineering, electronics, computing, etc. The collaboration would also benefit from interacting with the CERN theory group in designing new potential physics channels for the observatory, and with high-energy experimentalists and phenomenologists for combined data analysis projects.

Global Argon Dark Matter Collaboration:

We emphasize the importance of the infrastructure and expertise of CERN in underpinning the European research program in both dark matter and neutrino physics using liquid argon. Synergy with the Neutrino Platform cryostat developments has led to a significant design evolution of the DarkSide-20k detector. We encourage the European Strategy to recognize the importance of these shared technological developments and the role of CERN as an extraordinary catalyzing factor of discovery and feedback concerning the future directions to follow in the Argo program.