Dark matter direct searches with DarkSide and MadMax

Fabrice Hubaut
On behalf of the CPPM dark matter team

CPPM – Aix-Marseille Université, CNRS/IN2P3

Institut Physique de l'Univers

IPhU Dark Matter day, 26 Nov 2021

Direct DM searches at CPPM

❑ Participation to one WIMP and one axion search world-leading experiment

- Strong motivations from particle physics for WIMPs and axions
- **WIMP → DarkSide**: proven technology with innovative design → DS-20k (2025-)
  - ➢ 2nd generation experiment, high discovery potential GeV-TeV: structuring physics project
- **Axion → MadMax**: innovative concept → prototyping phase for validation (2021-25)
  - ➢ 1st generation experiment with unique potential: challenging cutting-edge R&D

❑ New team created at CPPM in 2020: direct dark matter searches

➔ Team members: 7.1 FTE [3.2 DR/PR, 2.9 IT, 1 PhD]

Chercheurs et enseignant-chercheurs

- José Busto (DarkSide)
- Fabrice Hubaut (Responsable d'équipe, DarkSide, responsable scientifique MadMax)
- Pascal Pralavorio (Responsable scientifique DarkSide, MadMax)
- Isabelle Wingerter-Seez (DarkSide)

Doctorants et post-doctorants

- Marie Van Uffelen (DarkSide) [IPHU grant]

Ingénieurs et techniciens

- Pierre Barrillon service instrumentation (responsable technique DarkSide)
- Stéphan Beurthey service mécanique (MadMax)
- Fabrice Gallo service mécanique (MadMax)
- Pierre Karst service mécanique (responsable technique MadMax)
- Daniel Labat service mécanique (MadMax)
- Emmanuel Le Guirriec service informatique (DarkSide)
- Jérome Royon service électronique (DarkSide)

- Synergies with existing activities at CPPM and other French/Marseille labs

Direct DM searches at CPPM

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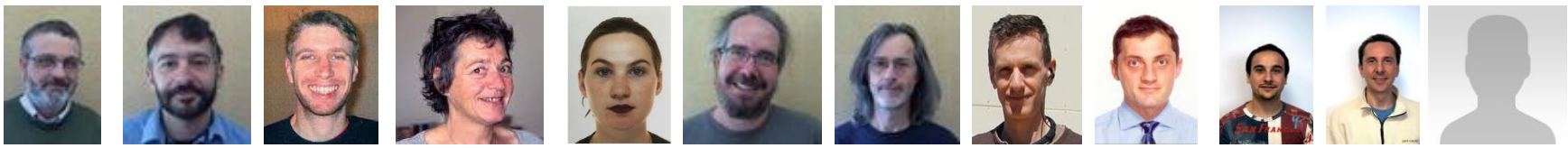

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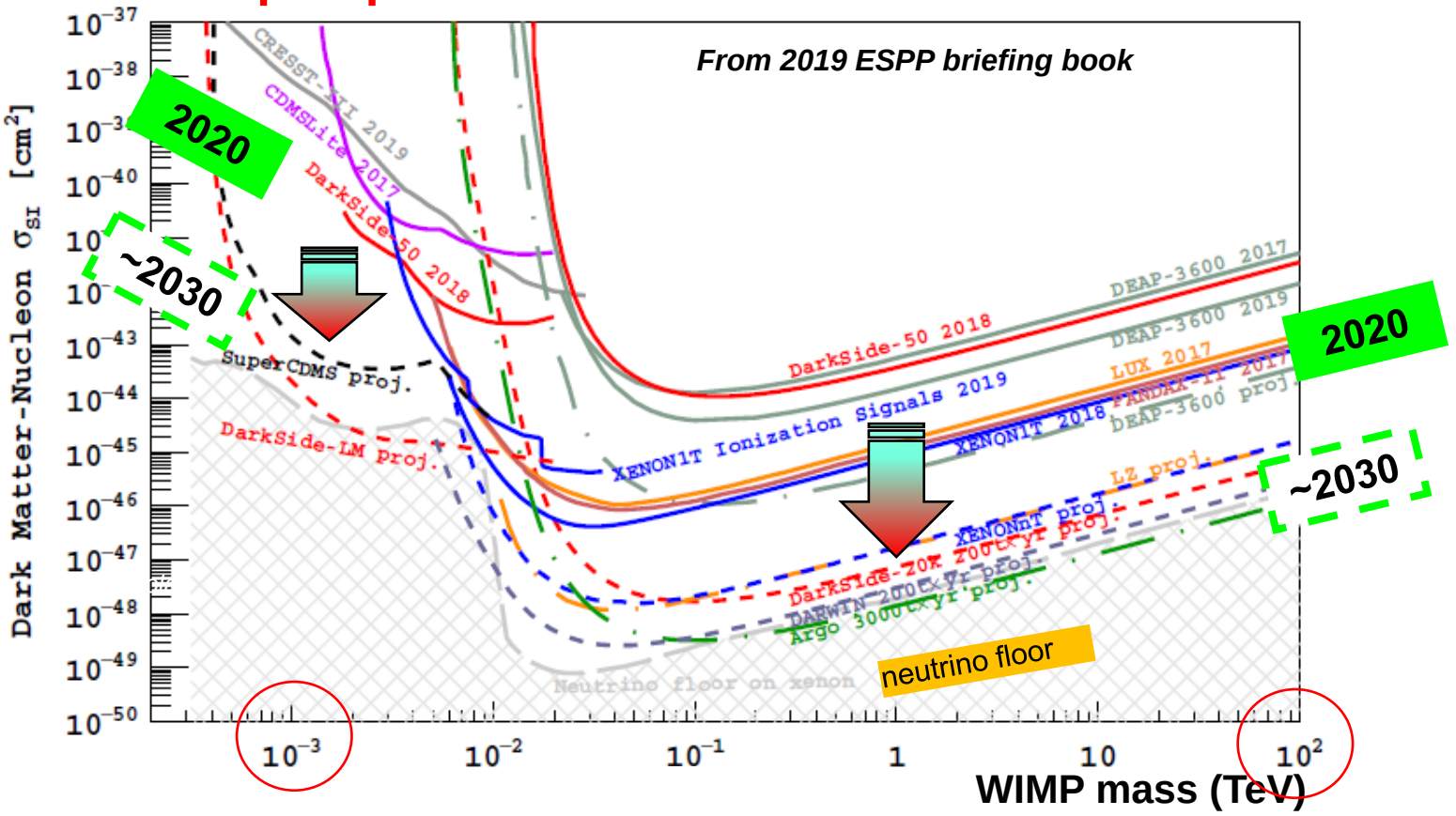
DarkSide sensitivity (WIMPs)

❑ Situation and prospects for dark matter WIMP direct searches



➔ TPC with noble liquid (Xe, Ar): best limits 1 GeV - 100 TeV

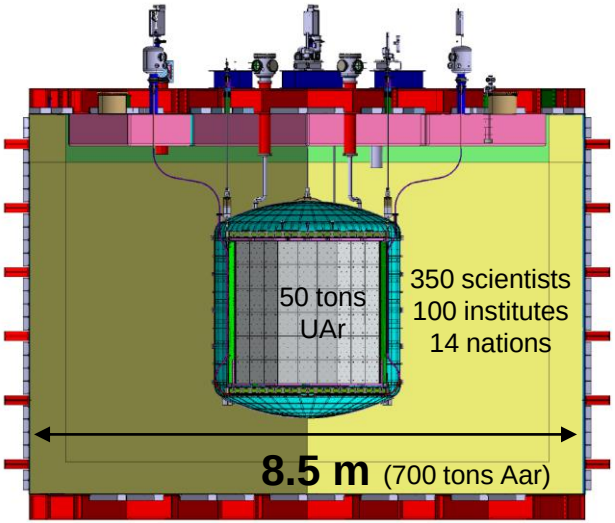
➔ Next decade decisive to probe WIMPs down to neutrino floor

APPEC 2017 recommendation : "strategy aimed at realising worldwide at least one ultimate Dark Matter detector based on xenon (~ 50 tons) and one based on argon (~ 300 tons), as advocated by DARWIN and Argo."

DarkSide at CPPM in a nutshell

- Calibration system for DS-20k: design/simulations, construction, installation, commissioning and operation
- Radon transparency/diffusion/emanation measurements
- Signal reconstruction algorithms with Artificial Intelligence
- Data analysis: DS50 [calibration + low mass analysis], prototypes

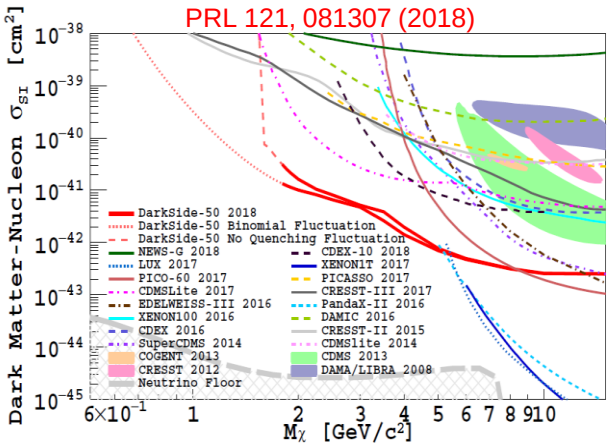
DarkSide-20k (Gran Sasso - 2025)
200k SiPM, 3.5x3.5x3.5 m^3



→ Largest TPC for DM search.
<0.1 background events over 10 years

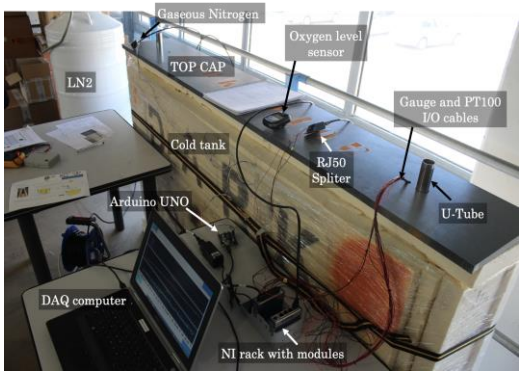
Low mass calibration/analysis (DarkSide-50 data)

PRL 121, 081307 (2018)



→ Best world sensitivity 2-6 GeV
→ 2022: foreseen improvements (refined calib published in 2021)

Calibration system mock-up at CPPM



Radon chamber at CPPM

IPhU-18 project (2021-2024)

With this project, we propose to prepare at best the direct searches for WIMPs that will be performed in the near future, through synergetic experimental and theoretical contributions.

Experiment (DarkSide) :

- Calibration
- Optimal separation between signal and background (using AI)

→ *Reduce experimental uncertainties*

Theory :

- Improve modelling of galactic halo local density & speed distribution
- Improve predictions for WIMP – nucleus cross sections (lattice QCD)

→ *Reduce theoretical uncertainties*

F. Hubaut	Optimal algorithms for signal/background separation (axis 1, see section 5)
P. Pralavorio	Optimal algorithms for signal/background separation (axis 1, see section 5)
I. Wingerter-Seez	Calibration of DarkSide-20k (axis 1, see section 5)

E. Nezri	Improved modelling of the galactic halo (axis 2, see section 5)
L. Lellouch	Fully-controlled QCD uncertainties on WIMP-nucleus cross-sections (axis 2, see section 5)
J. Lavalle	Improved modelling of the galactic halo (axis 2, see section 5)

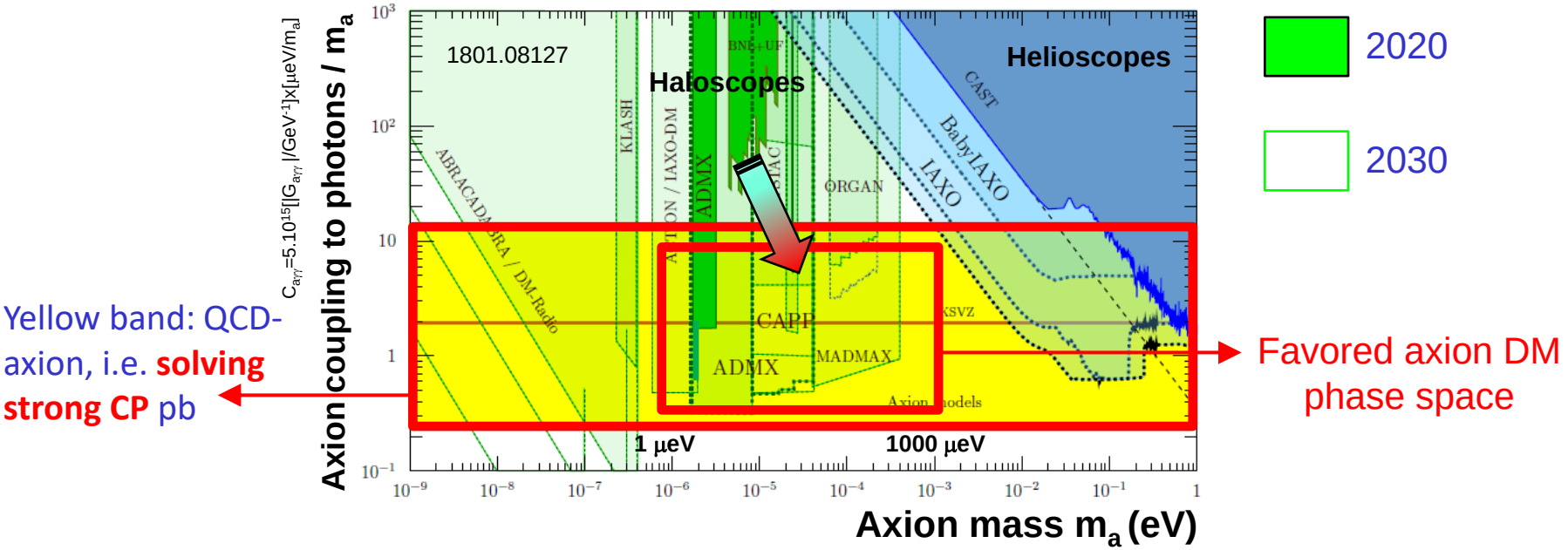
Institut Physique de l'Univers Aix-Marseille Université

Goal: be ready for 2025 *(start of DarkSide-20k data taking)* to have top contributions to first analyses

→ Ongoing project: collaboration CPPM-LAM-CPT-LUPM, 1 PhD (2021-2024)

MadMax sensitivity (axions)

❑ Situation and prospects for dark matter axion direct searches



- Only 1 experiment (ADMX) currently probes a (very small) part of the favored phase space
- Vast R&D program to improve signal sensitivity and expand range of axion mass search

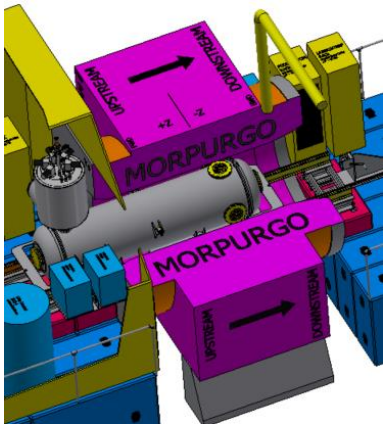
  ➔ **Next decade will be decisive, probing axion DM most favorable region**
- MADMAX targets "high mass" DM axions → exploit unique new experimental approach

  ➔ **Unique sensitivity of MADMAX in range m_a~40-400 μev**

MadMax at CPPM in a nutshell

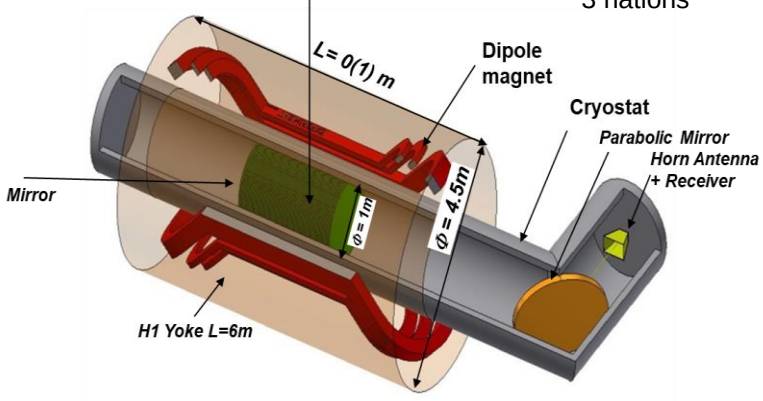
- Mechanics of the booster: design and construction (disk supports), precision metrology (at μm level)
- Supervision of protos tests in CERN magnet and construction of mechanical interfaces (ALP physics already in 2022!)

CERN Morpurgo magnet



MadMax (DESY - >2027)
80 dielectric disks in 10 T

50 scientists
9 institutes
3 nations



→ Technically challenging – need prototypes to validate techno

Disk metrology at μm level

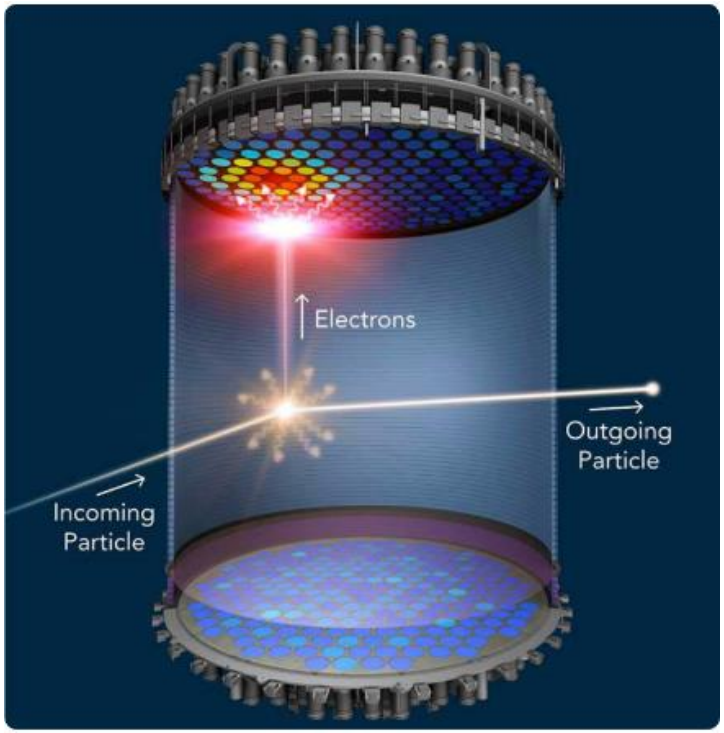
Disk support prototype

BACKUP

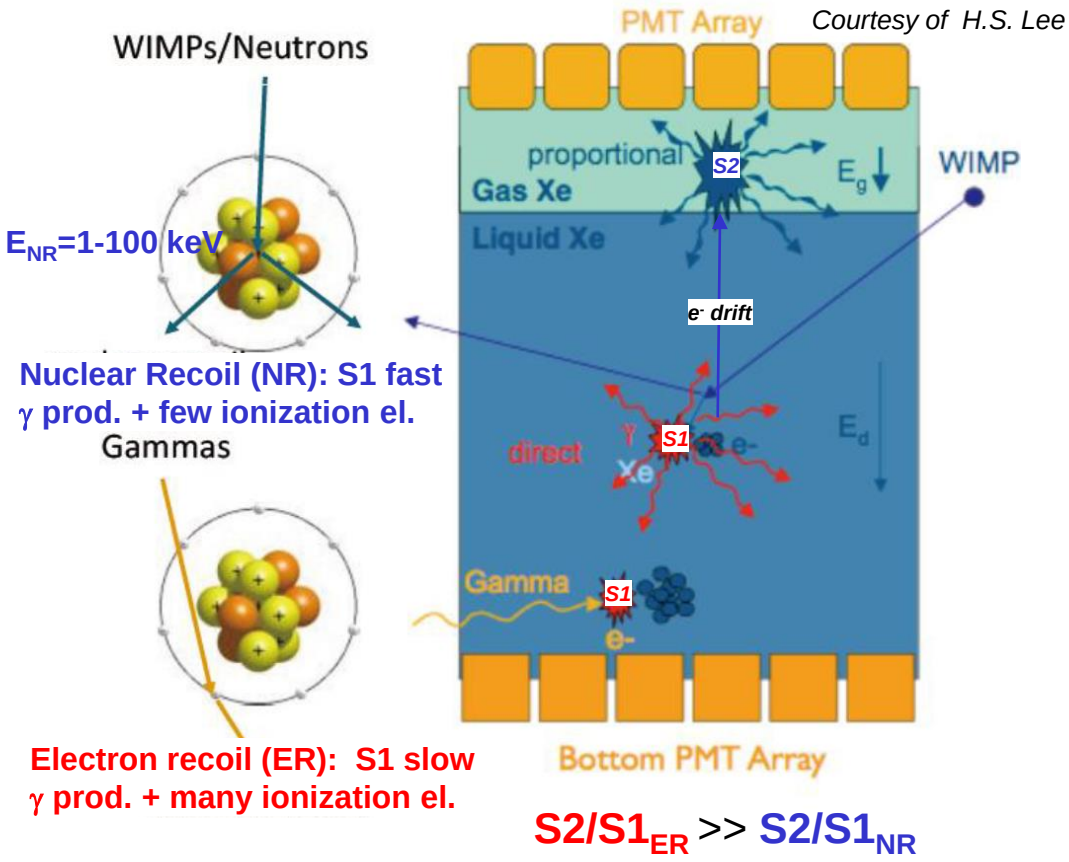
WIMP DM search: how?

❑ Principles of noble liquid/gas TPC experiments

- Cryostat hosting a Time Projection Chamber (TPC) equipped with photo-multipliers
- Dual phase TPC → scintillation signal (S1,~40 γ/keV*) followed by ionization one (S2,~50 e^-/keV*)



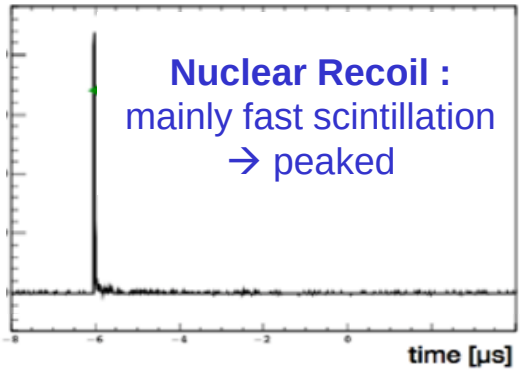
*for electron recoils

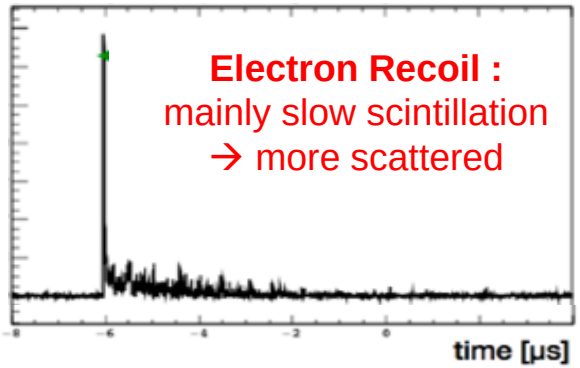


DarkSide

❑ LAr technology starts to be mature …

- **High removal of Electron Recoils → Background free at high WIMP mass**
  - ✓ S1 pulse shape discrimination : additional rejection depending on nuclear properties





  - ➢ In Xenon, slow scintillation is actually quite fast (27 ns instead of 6 ns for fast scint.)
  - ➢ In Argon, large difference between slow (1000 ns) and fast (6 ns) scintillations

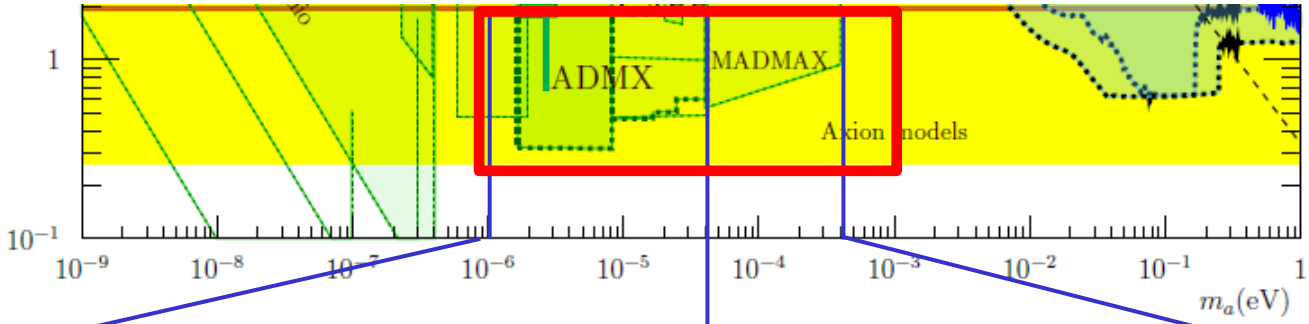
➔ Discrimination with rejection >10^8 (~none with LXe) thanks to intrinsic properties of Argon

✓TPC filled with Underground Argon (less ^{39}Ar) + Further purification (^{39}Ar, ^{85}Kr, O, H_2O)

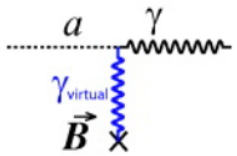
- **Merging of all world-wide LAr experiments in 2017** *(DEAP3600, DarkSide-50, miniCLEAN, ArDM → DarkSide-20k)* **:** most advanced technology from each experiments

Axion DM search: how?

- Convert axions into photons *[E field of O(10^{-12}. $\frac{B}{10\ T}$) V/m]* ➔ high magnetic field >> 1T
- Boost photon field *[up to P~10^{-22} W]* ➔ resonant cavities or emission at dielectric interfaces
- Scan over range of axion mass ➔ need tunable set-up



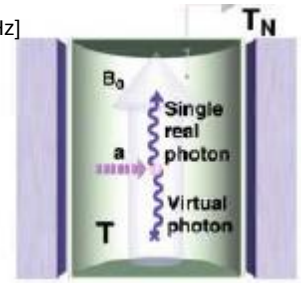
Primakoff effect $a\gamma^* \rightarrow \gamma$



1 μeV [0.25 GHz] **40 μeV** [10 GHz] **400 μeV** [100 GHz]

$[\nu_a=\nu_\gamma]$
→ Microwave regime

Cavities

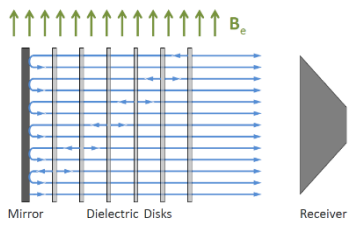


ADMX, HAYSTACK, CAPP

Multicavities, Very High B

RADES, ADMX-SideCar, CAPP, GrAHal

Cavity size too small + high noise



MADMAX

Dielectric haloscopes

[novel concept 2013]
Phys.Rev. D88 (2013) 115002

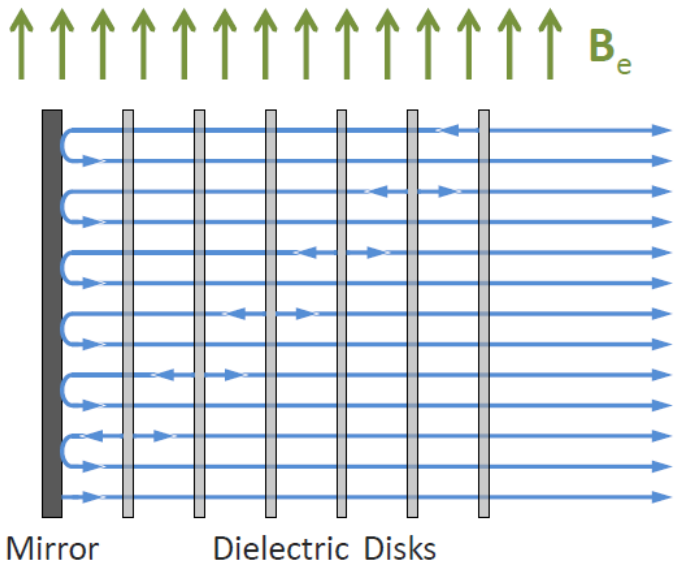
➔ **New ideas of last decade coming to maturity to scan preferred mass range**

MadMax concept

❑ Dielectric haloscope → MadMax experiment

- New experimental concept to alleviate cavity limitation at high m_a ($V \sim 1/m_a^3$)
- Stack of dielectric disks with mirror on one side, inside B field → wave emission at interfaces
- Adjustable distance between disks → constructive interferences → tune to scan over m_a

[spacing 20 mm for 40 μeV and 2 mm for 400 μeV]

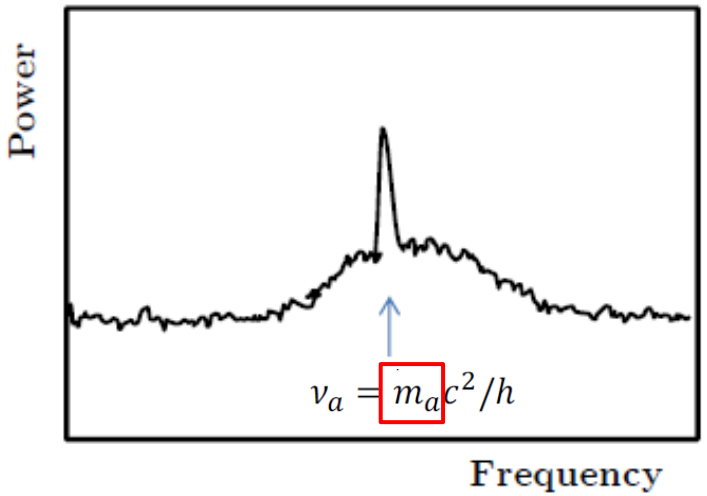


1611.05865

Power / Area

$$P/A = 2.2 \times 10^{-27}\,\mathrm{W\,m^{-2}} \left(\frac{B_e}{10\,\mathrm{T}}\right)^2 C_{a\gamma}{}^2\,\beta^2$$

Signal boost x10⁵



➔ **MadMax only capable to explore m_a=40-400 μeV** *(favored by post-inflation theory)*