Future Experiments

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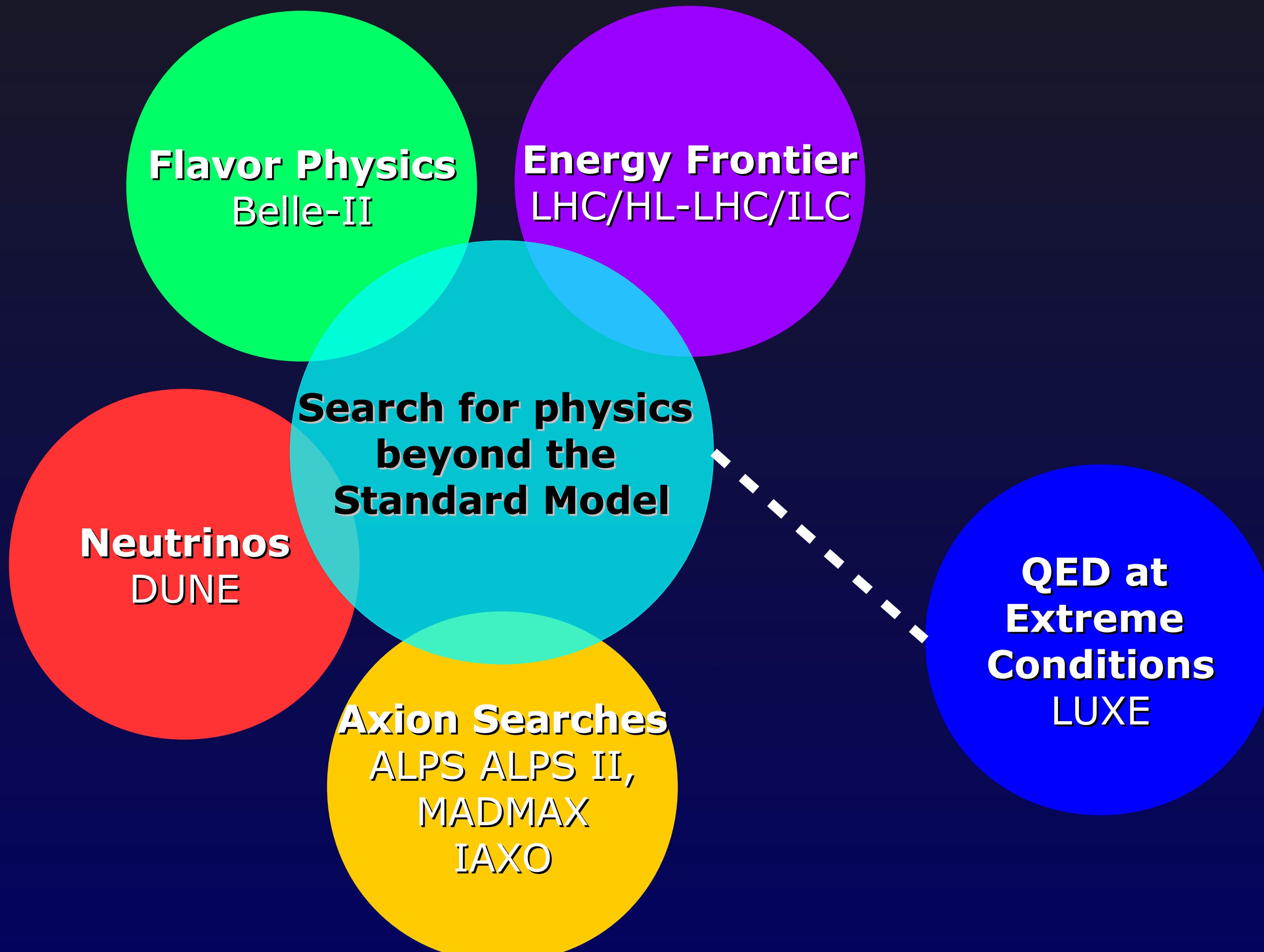
84th PRC 19/Oct/2017

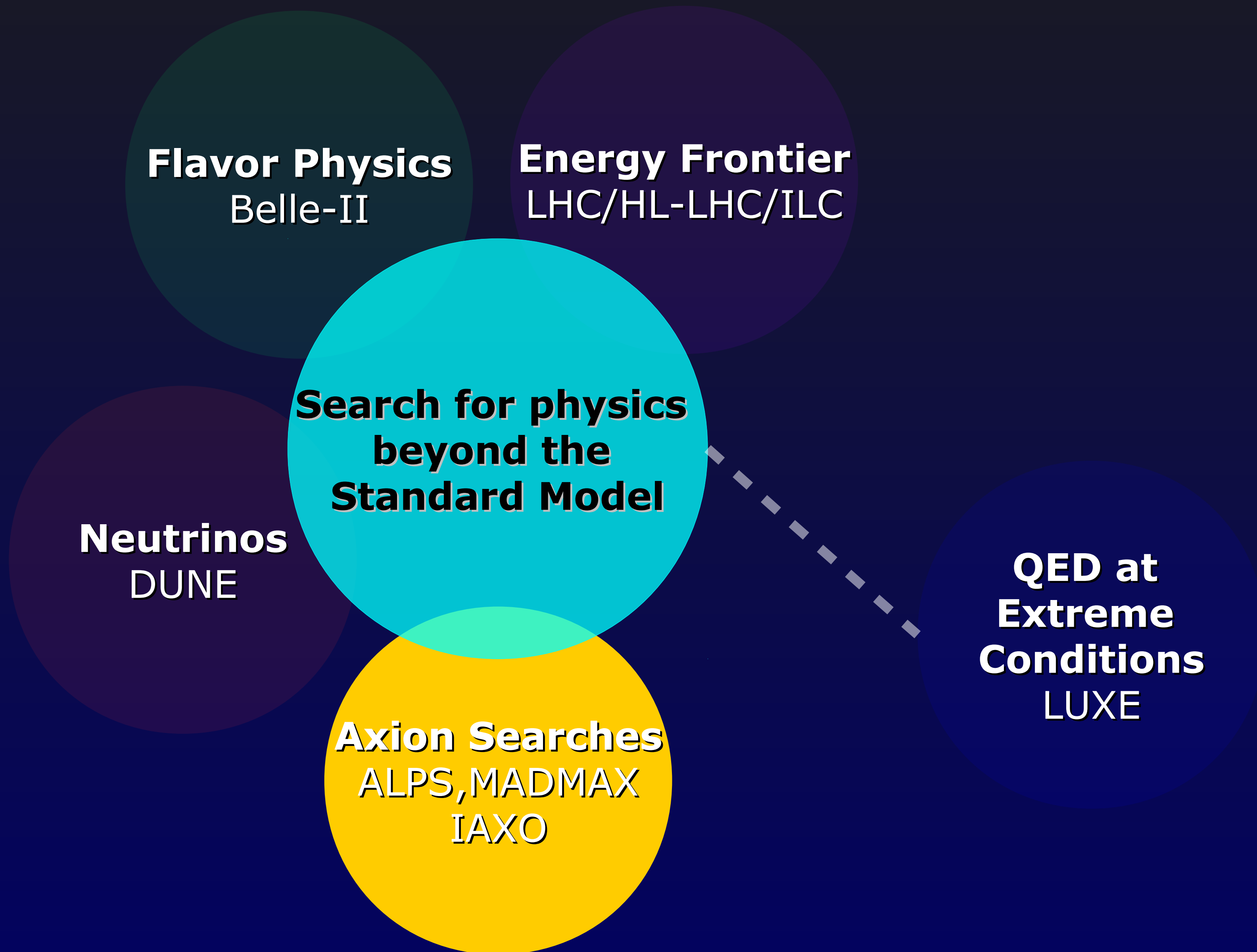
Physics motivation

- With the discovery of the Higgs Boson, the Standard Model is complete.
- However, there are many hints for physics beyond the Standard Model
  - e.g. Neutrino mass, CMB
- Key questions
  - Understanding the Higgs Boson
  - Neutrino physics and Lepton Flavor violation
  - Identify Origin of Dark matter
  - Understand Dark energy and inflation
  - New particles, interactions, and physical principles ?

Searching for new Physics



Searching for new Physics

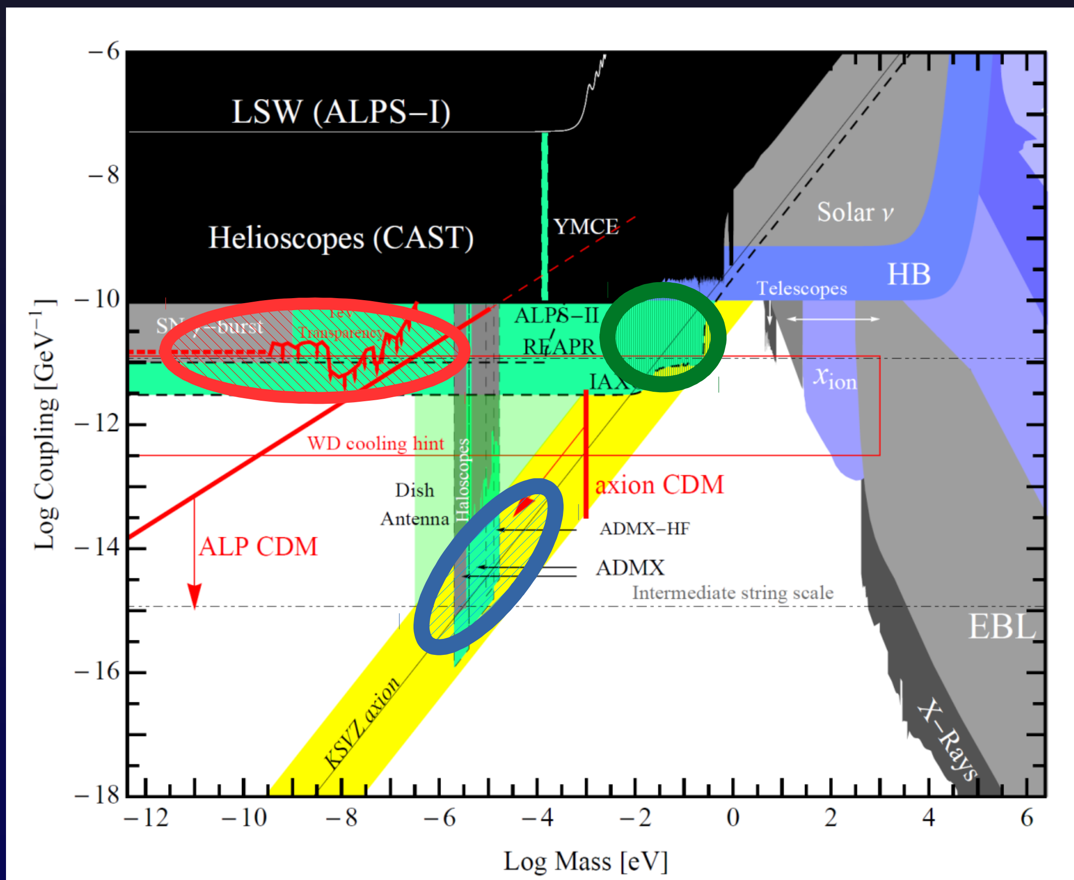


Axions in a nutshell

- Axions have been motivated by the QCD CP problem
  - Manifested e.g. in Neutron EDM measurements
- Axions
  - Very light
  - Weakly interacting
  - Interact with photons
  - Mass ~ coupling

- Axion-Like Particles (ALP)
  - Similar to Axions
  - Mass and couplings very model dependent
- Axion/ALPS
  - Cold Dark matter candidate
  - Astrophysical motivations
- Detection
  - Axion and ALPs experience mixing effects with photons in an external field, e.g. when propagating along the z axis in a transverse magnetic field

Axion Hotspots



Two-photon-coupling

axion-like particle mass

Three main regions of interest:

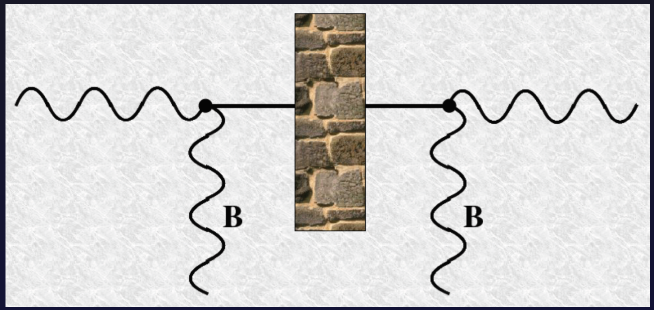
- Axion-like particles: "new physics" around 10^5 TeV.
- QCD axions: "new physics" around 10^5 TeV.
- QCD axions as dark matter: "new physics" around 10^9 TeV

TeV transparency

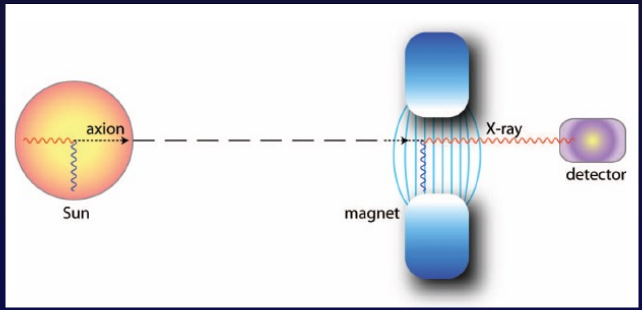
Stellar development

How to Search for Axions

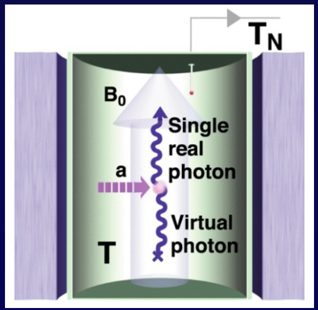
- Light-shining-through-walls
  - ALPS/ALPS II



- Helioscopes
  - CAST, **IAXO**

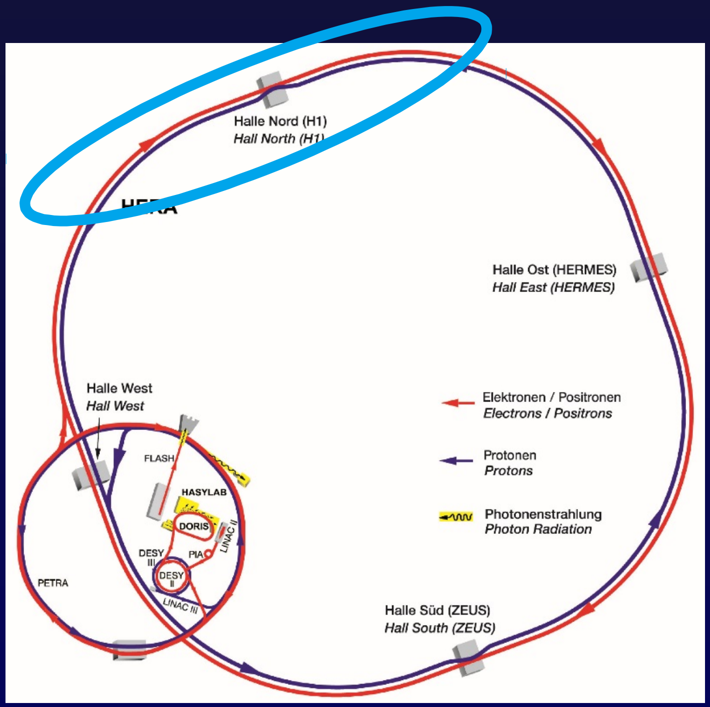


- Haloscopes
  - **MADMAX**



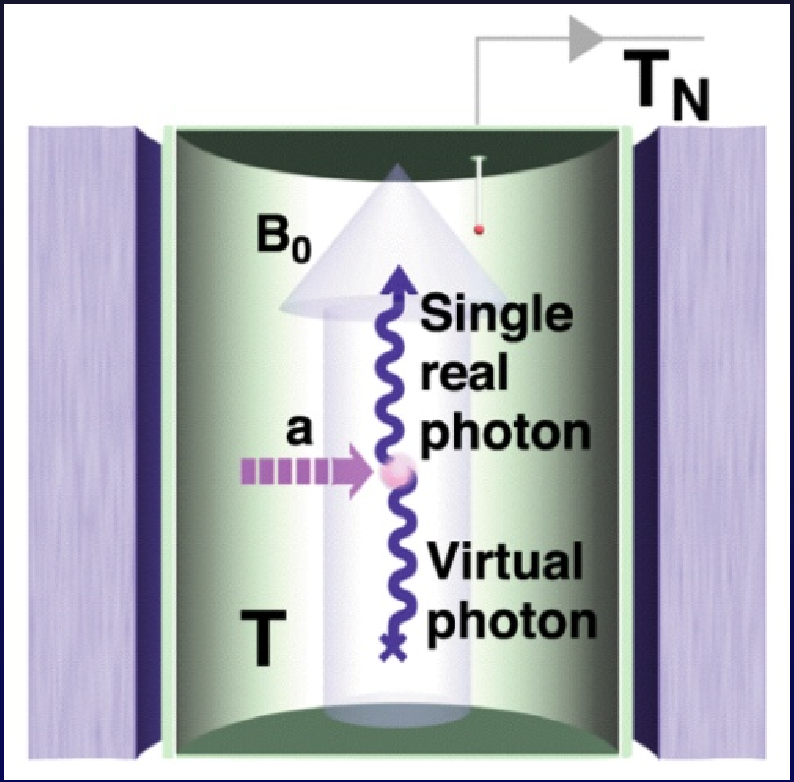
Current DESY Activities ALPS II

- ALPS II
  - Light Shining through a wall experiment
  - Hosted at DESY - HERA Nord
- Magnets:
  - Straightening of HERA dipole magnets demonstrated successfully.
  - Straightening of 20 HERA dipoles has started.
- HERA infrastructure:
  - Clearing of 200 m space in HERA tunnel has started.
  - Refurbishment of the cryogenics in the tunnel has just started.
  - Start point of DESY Kryo Platfrom
- Data taking could start in early 2020.



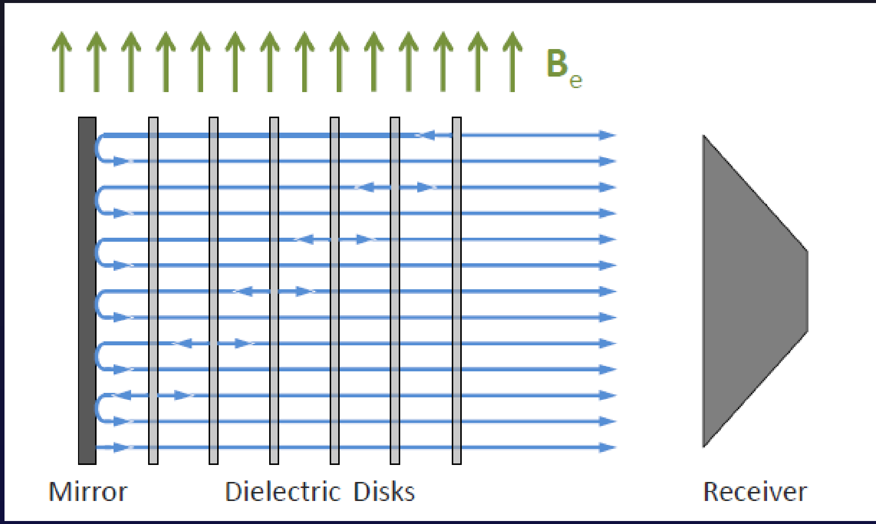
Haloscopes

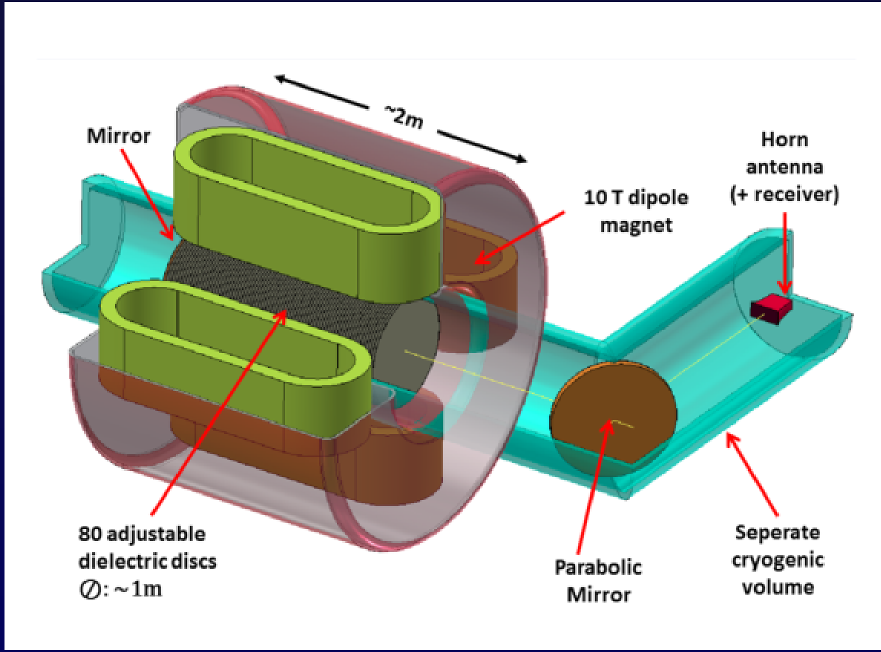
- Axion or ALP Dark matter
  - conversion into a photon inside a magnetic field
  - Direct detection of Axion/ALP dark matter!
- Best Sensitivity
  - Mass ~ resonant frequencies



MadMax

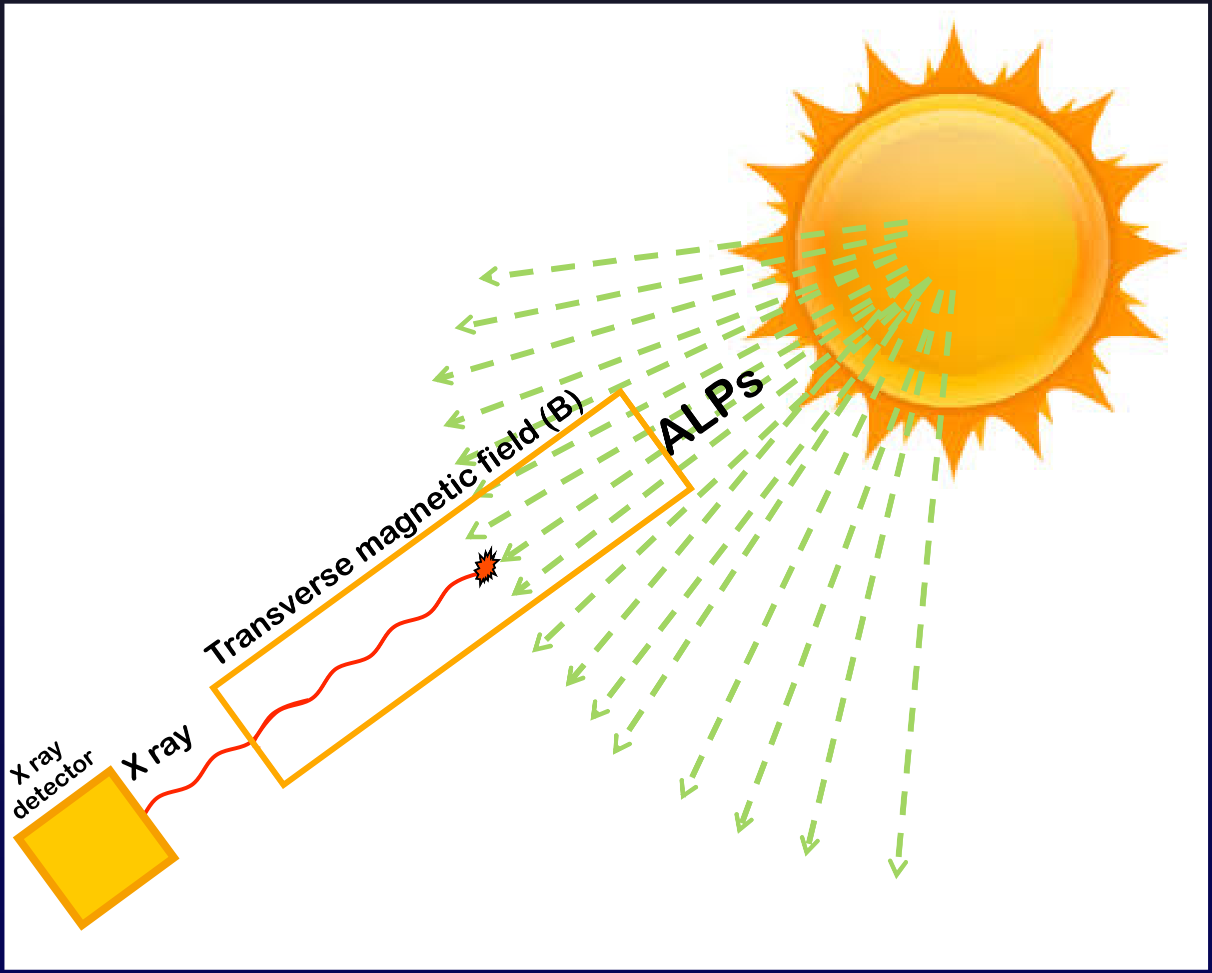
- Currently proposed experiment
- MADMAX collaboration
  - DESY, UHH, MPI, Saclay, Aachen, Zaragoza, Tuebingen
  - Collaboration formed yesterday
- A dielectic haloscope
  - Stack of dielectric layers in front of mirror
  - Induced power 10^{-27} W/m^2
- Dipole magnet:
  - B=10 T, A=1 m^2, L=2 m
- 80 dielectric discs
  - $LaAlO_3$ with ε=25
  - Amplification factor $10^5 \rightarrow 10^{-22}$ W/m^2
- Detector:
  - Horn Antenna + Receiver





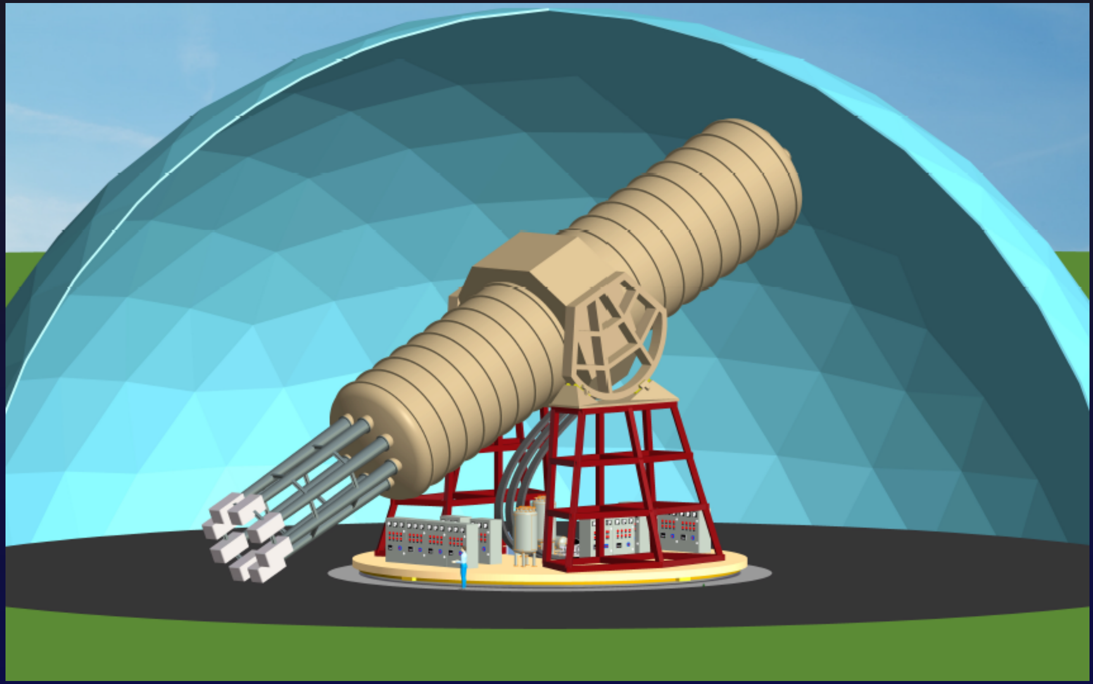
Helioscopes

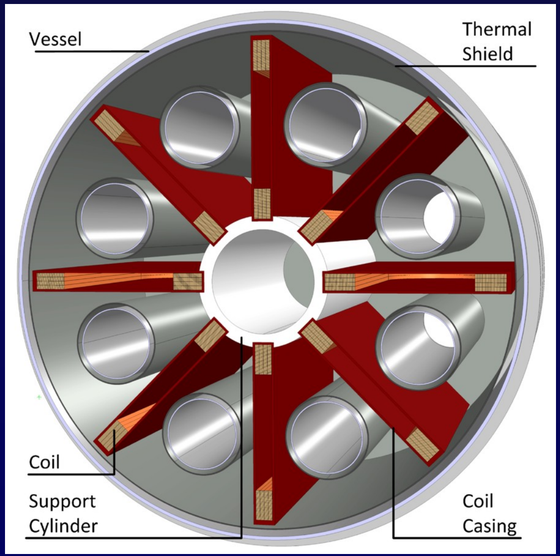
- Helioscope concept
  - Solar ALP to photon conversion in a magnetic field
- Technology successfully demonstrated in the CAST experiment
  - But no Axions found ...



IAXO

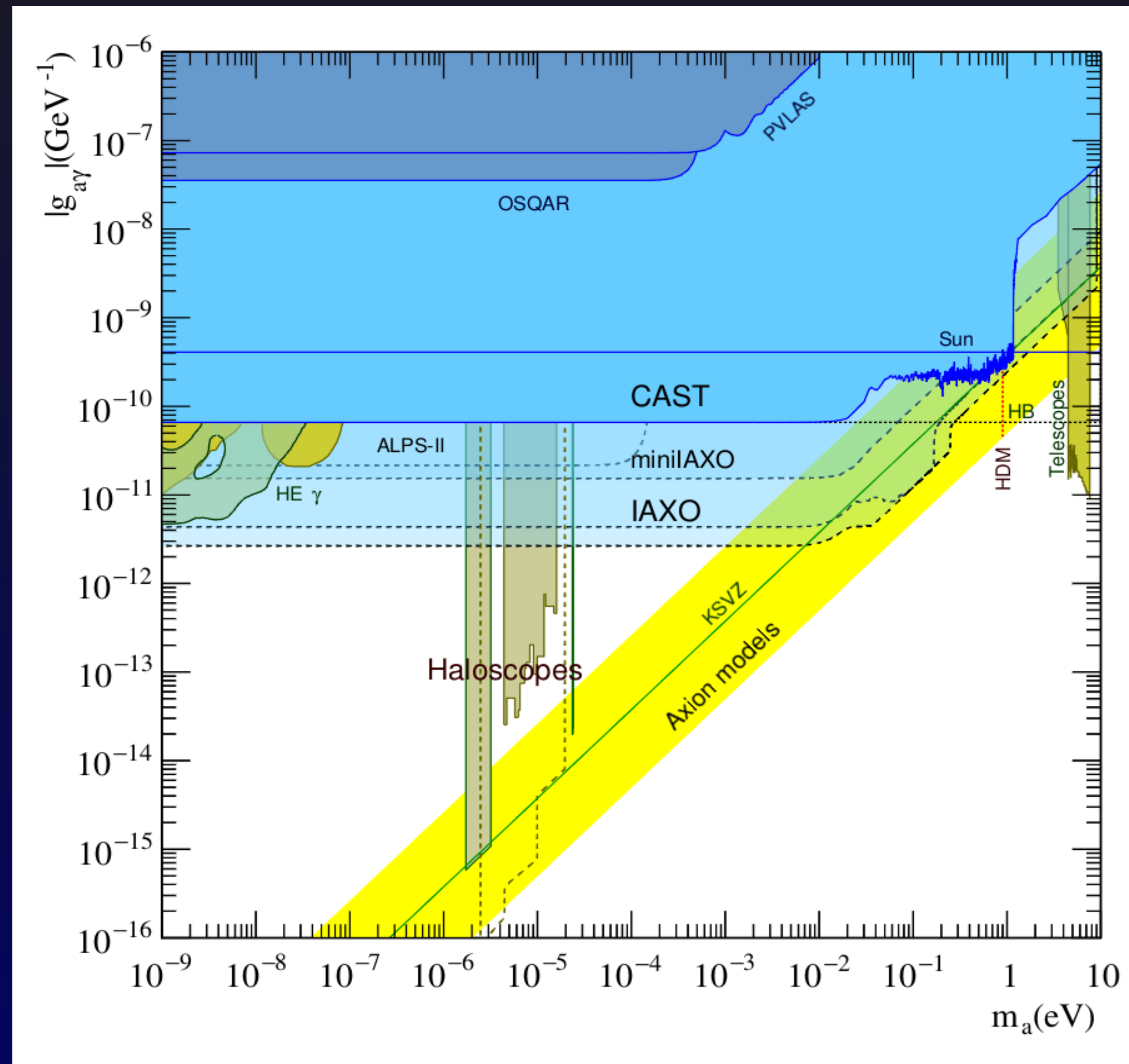
- IAXO is proposed by scientists out of 38 institutes from 9 countries.
  - CAST principle with dramatically enlarging the aperture
  - Use of toroid magnet similar to ATLAS @ LHC
  - X-ray optics similar to satellite experiments.
- IAXO "founding" meeting at DESY, July 2017
  - Indico



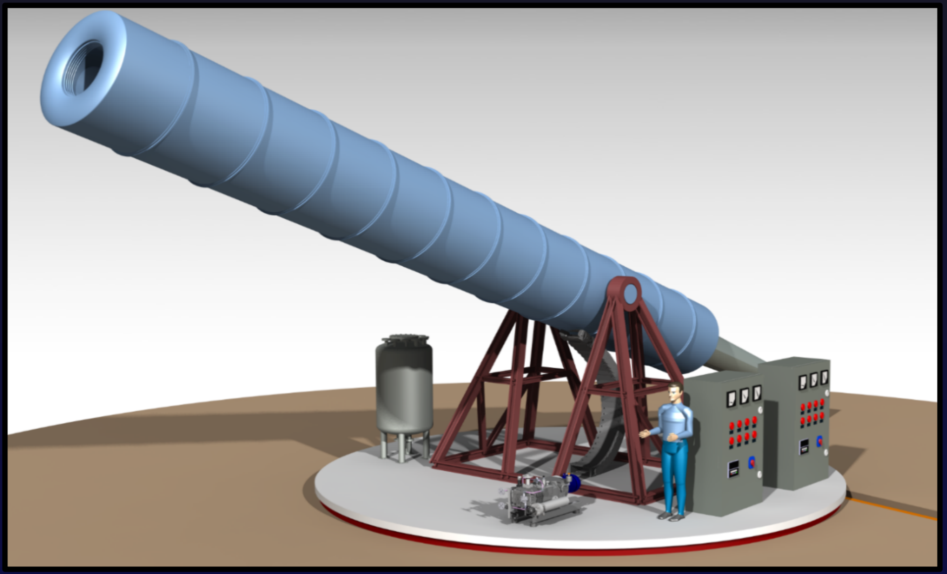


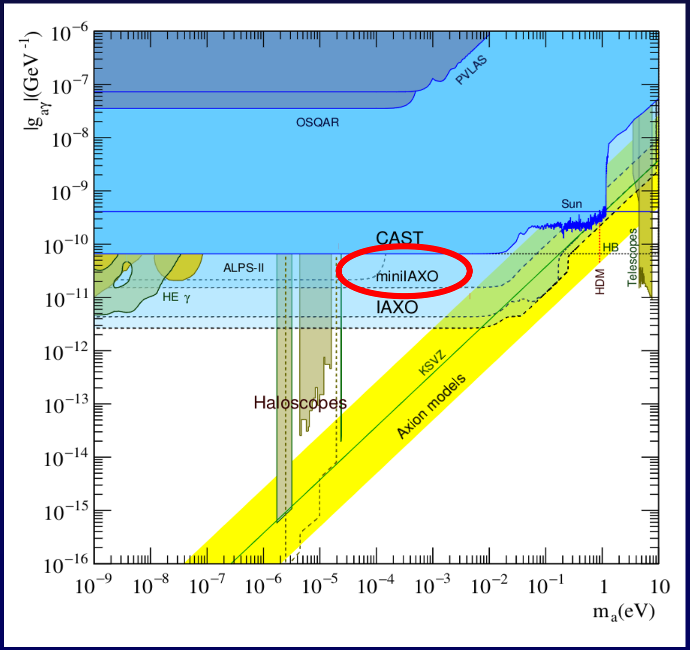
Magnet Design & Sensitivities

Property		*Value*	*Unit*
Cryostat dimensions:	Overall length	25	m
	Outer diameter	5.2	m
	Cryostat volume	~ 530	m^3
Toroid size:	Inner radius, R_{in}	1.05	m
	Outer radius, R_{out}	2.05	m
	Inner axial length	21.0	m
	Outer axial length	21.8	m
Mass:	Conductor	65	tons
	Cold Mass	130	tons
	Cryostat	35	tons
	Total assembly	~ 250	tons
Coils:	Number of racetrack coils	8	-
	Inner radius of bare coil, relative to racetrack center	500	mm
	Outer radius of bare coil, relative to racetrack center	884	mm
	Inner winding radius in corner	500	mm
Winding dimensions:	Winding pack width	384	mm
	Winding pack height	144	mm
	Length of inner turn	43.1	m
	Length of outer turn	45.5	m
	Turns/coil	180	-
Nominal Values:	Nominal current, I_{op}	12.3	kA
	Stored energy, E	500	MJ
	Inductance	6.9	H
	Peak magnetic field, B_p	5.4	T
	Average field in the bores	2.5	T
Conductor:	Conductor unit length per double-pancake	4.0	km
	Conductor length per coil	8.0	km
	Total conductor length (including reserve)	68	km
	Cross-sectional area	35×8	mm^2
	Number of strands	40	-
	Strand diameter	1.3	mm
	Critical current @ 5 T, I_c	58	kA
	Operating temperature, T_{op}	4.5	K
	Operational margin	40%	-
	Temperature margin @ 5.4 T	1.9	K
Heat Load:	at 4.5 K	~ 150	W
	at 60-80 K	~ 1.6	kW



BabyIAXO





- BabyIAXO
  - IAXO Demonstrator
- Staged Approach
  - Test new magnet design(s) and feed results into the full-scale IAXO design
  - Full test of IAXO detection scheme including optics detectors
- Extract early physics
  - Already very competitive

Axion Searches - Status in Germany

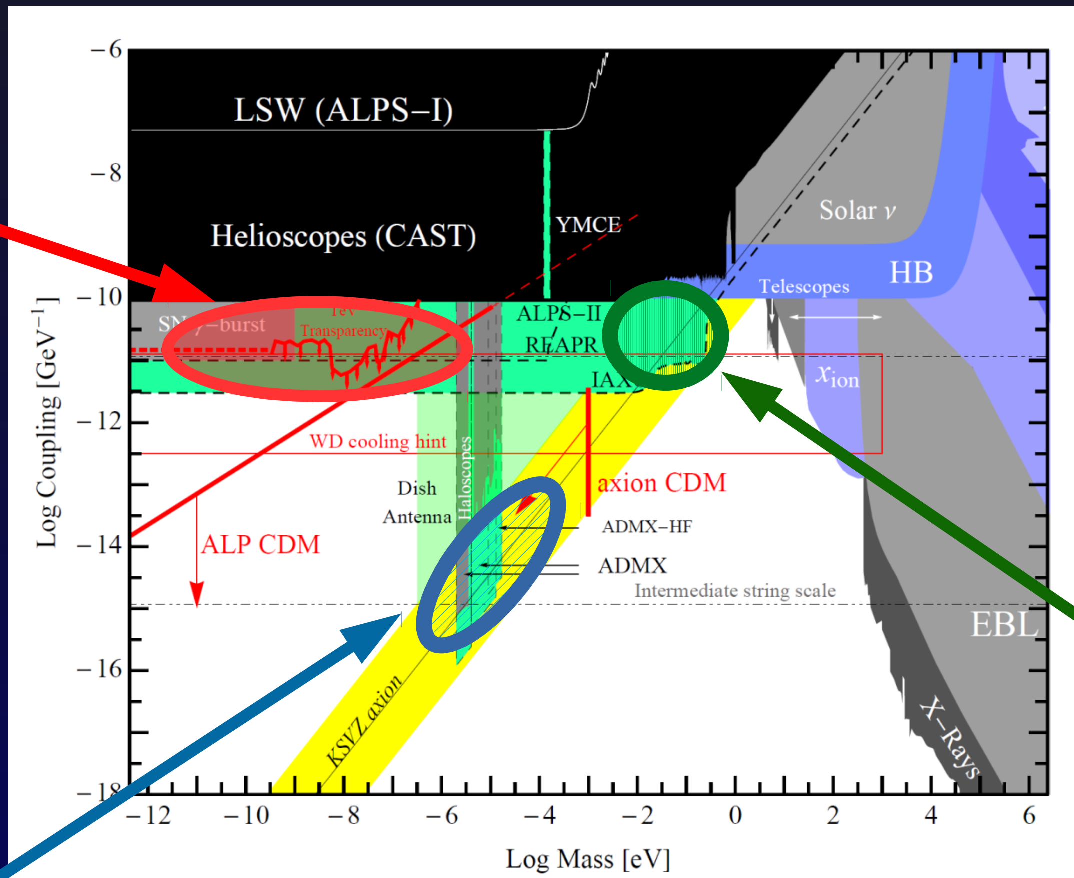
- Discussions in the Germany community (KET and KAT and KhuK)
- Workshop in April 2017 in Mainz
  - Conclusions are available here
  - *Axionen sind durch das CP Problem der starken Wechselwirkung motiviert und könnten astrophysikalische Phänomene erklären. Die in Deutschland verfolgten Ansätze ALPS II, IAXO, MADMAX, BRASS und CASPER sind international führend und decken komplementäre Bereiche der Axion-Phänomenologie ab. Sie sollten durch eine koordinierte Weiterentwicklung des Axion-Programms gestärkt werden. Für das große Helioskop IAXO sollten die Voraussetzungen für einen deutschen Standort geschaffen werden.*
- Discussions about hosting IAXO have started

Axions at DESY

- Long history in Axion searches
  - ALPS
  - ALPS-II
- Member of MADMAX and IAXO collaborations
- Potential host for both MADMAX and IAXO
- DESY Kryo Platform proposal to support MADMAX

Axions – a Summary

ALPS II



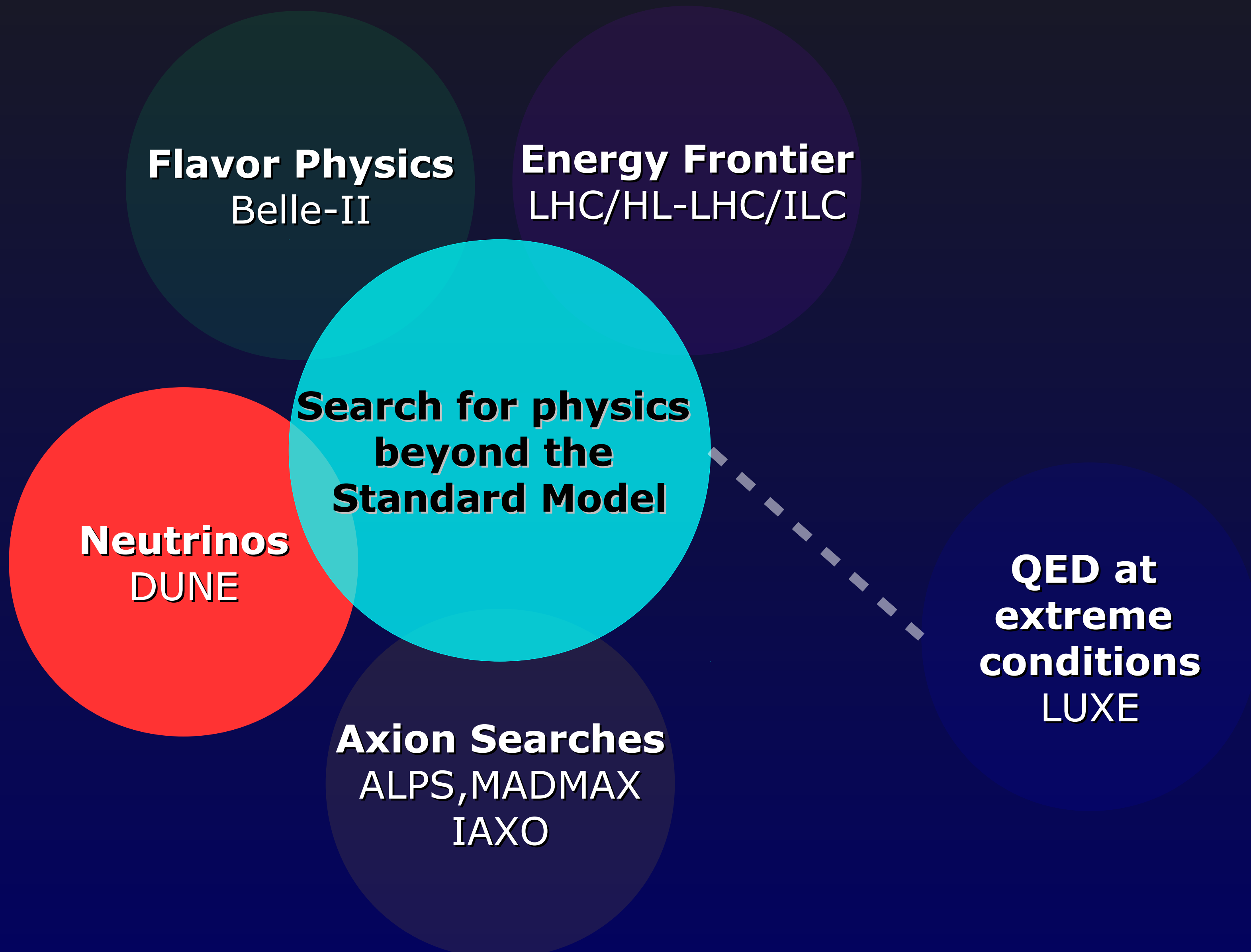
Two-photon-coupling

IAXO

MADMAX

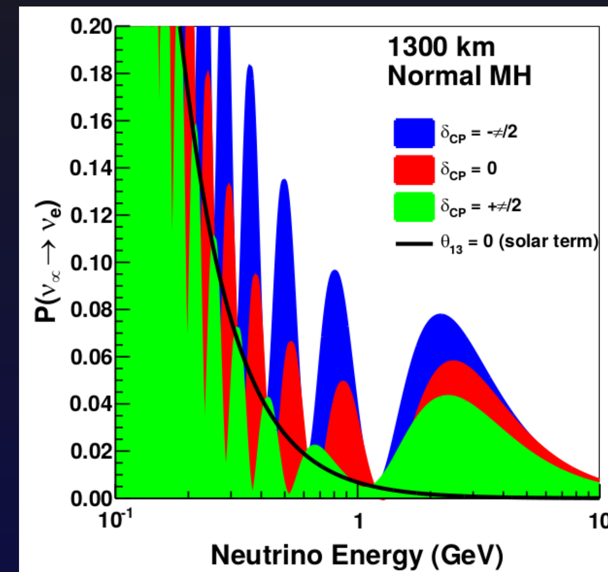
Axion-like particle mass

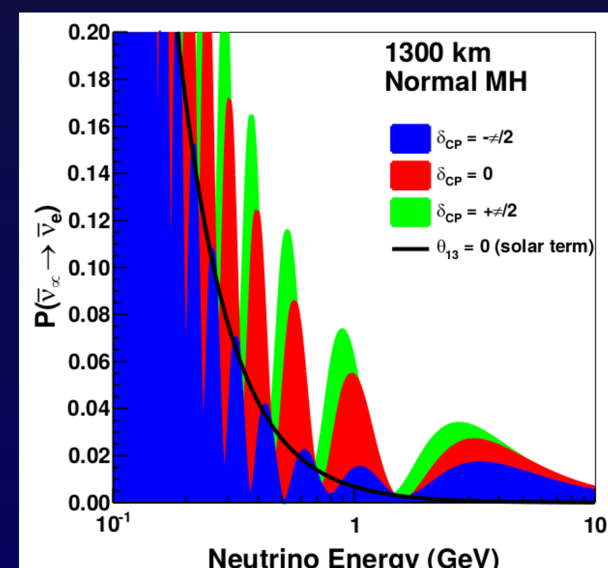
Searching for new Physics



Neutrino Oscillations

- Big questions in Neutrino Physics
  - Mass, Oscillations, Mixing
- Long-Base Line Experiments
  - Send well-defined neutrino beam to a Far Detector and measure the incoming neutrino flavor
  - Choose beam energy accordingly
  - On-axis/Off-axis beam
- Very successful approach
  - Minos (Fermilab), T2K (JPARC)

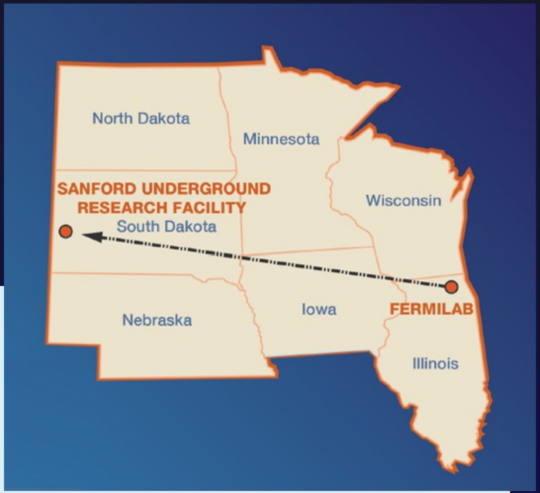


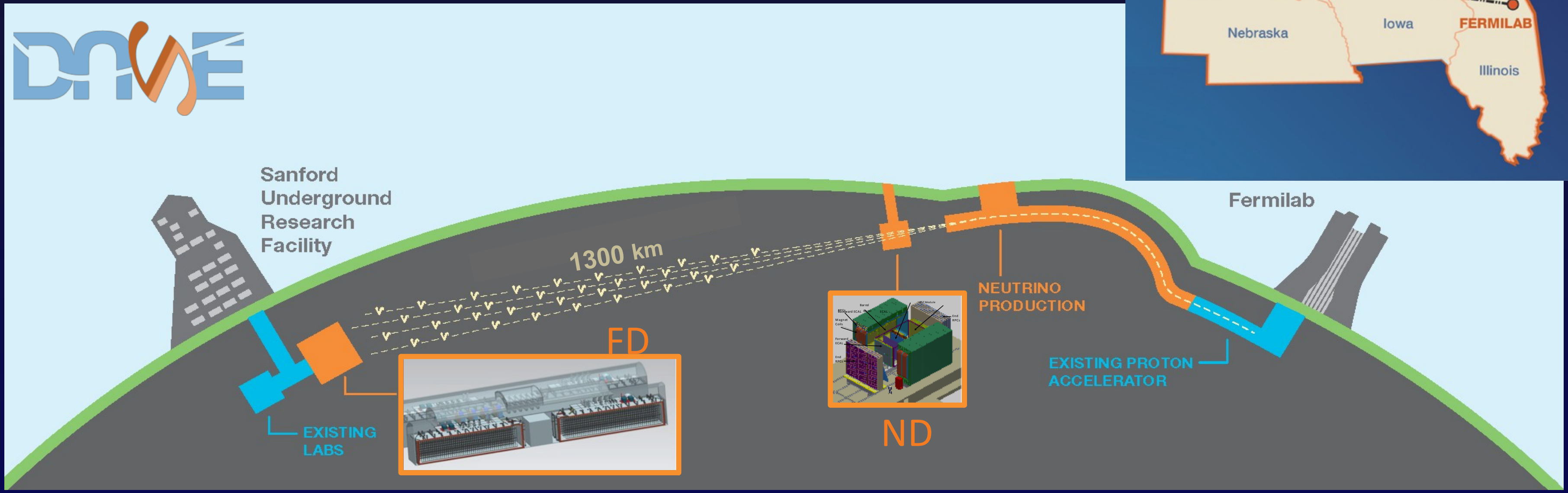


DUNE

Two main interlinked components:

- The Long Baseline Neutrino Facility LBNF - the neutrino beam at Fermilab
- The DUNE Experiment
- 1021 collaborators, 174 institutions, 30 countries



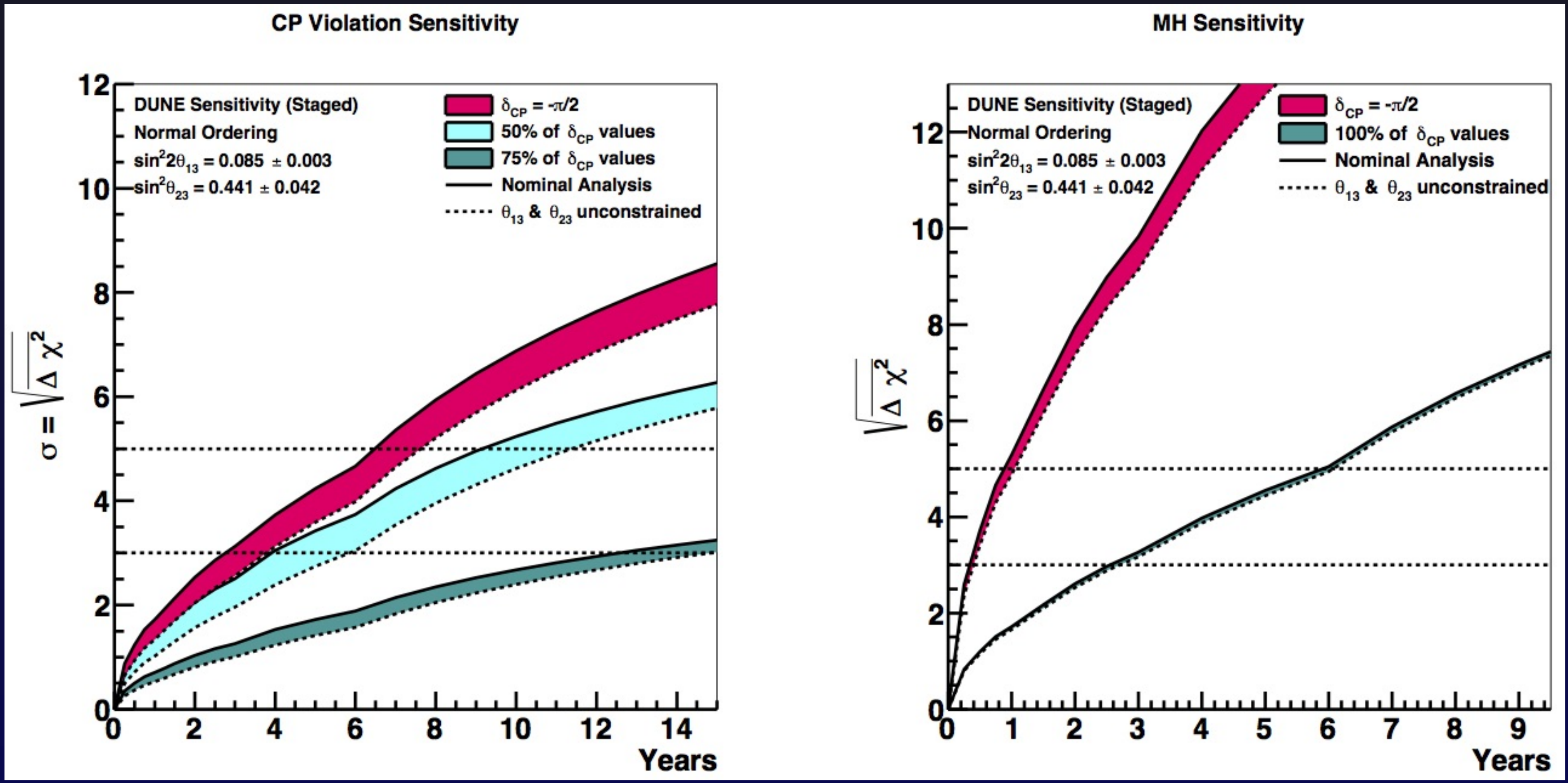


- Approximately 40 kt fiducial mass liquid argon Far Detector.
- Located 1300 km baseline at SURF’s 1478 m level (2,300 mwe).
- Compare ν_e with $\bar{\nu}_e$

Physics Potential at DUNE

- Precision measurements of the parameters that govern $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations:
  - Measure the CP-violating phase δ_{CP} , possibly discovering CP violation (if different from 0 or π)
  - Determine the neutrino mass ordering
  - Precise measurement of θ_{23}, including determination of the octant
- On-axis beam offers broad sensitivity for physics beyond the Standard Model, e.g. sterile neutrinos
- Search for proton decay, in particular in the mode $p \rightarrow K+\bar{\nu}$
- Measurement of the ν_e flux from a core-collapse supernova within the Milky Way, should one occur in the lifetime of DUNE

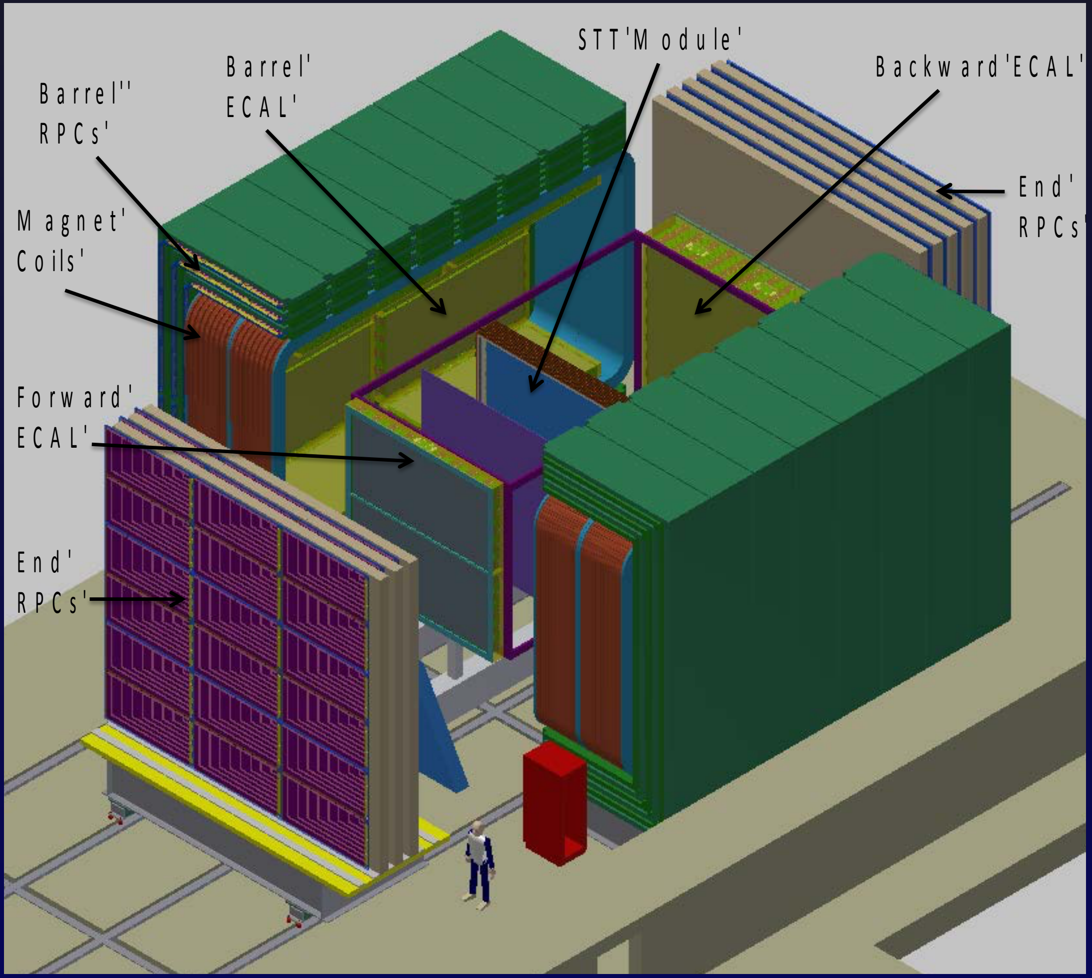
Sensitivities



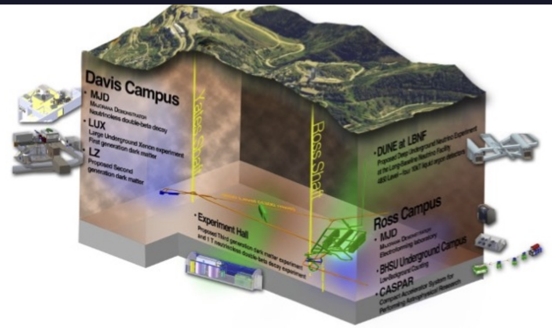
- **Year 1 (2026)**: 20-kt Far Detector with 1.07 MW (80-GeV) beam and initial ND constraints
- **Year 2 (2027)**: 30-kt Far Detector
- **Year 4 (2029)**: 40-kt FD and improved ND constraints
- **Year 7 (2032)**: upgrade to 2.14 MW (80-GeV) beam

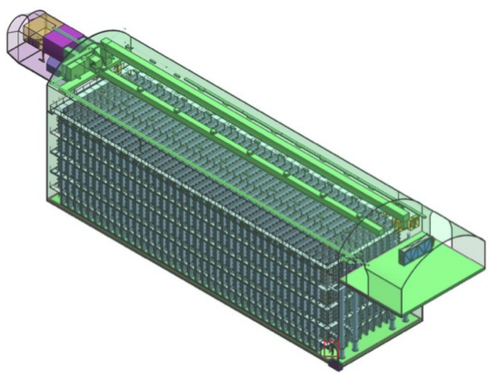
DUNE Near Detector

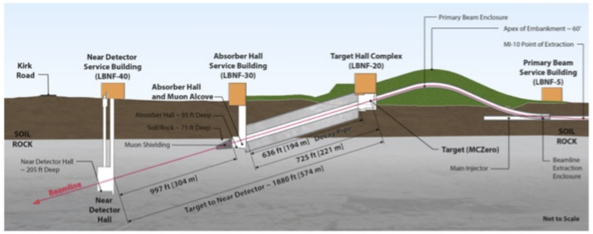
- Predicts CC, NC neutrino cross-section at the Far Detector
  - Focus E_ν = 8 GeV
  - Lepton and π^0 ID
- CDR Design
  - Dipol Magnet, Straw Tracker, Muon System
- CDR ECAL Design
  - ECAL Pb-Scint 10 X_0 (Forward 20 X_0)
  - 2600 strips, 320 x 2.5 x 1 cm
  - Readout using SiPM
- Near Detector design is moving towards a TDR



Timeline







2017: Far Site Construction Begins

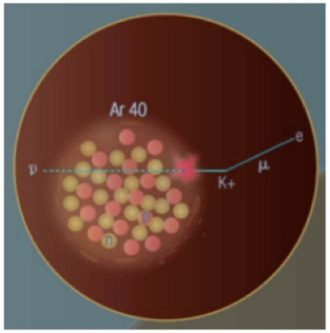
2018: protoDUNEs at CERN

2021: Far Detector Installation Begins

2024: Physics Data Begins (20 kt)

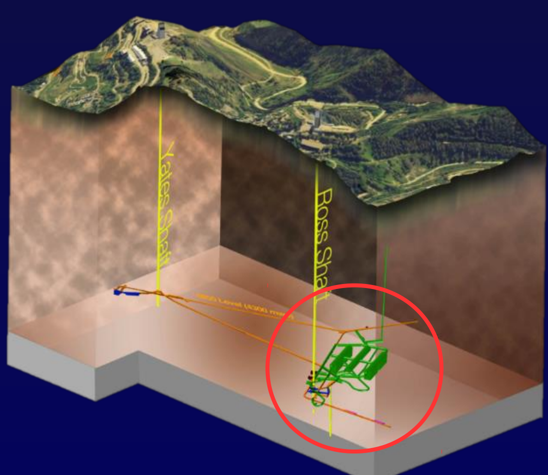
2026: Neutrino Beam Available

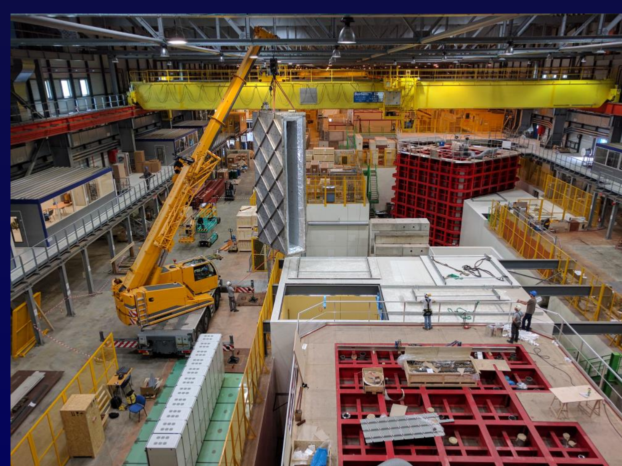
The CERN Neutrino Platform



DUNE Status

From Left: Fermilab Director N. Lockyer; Exec. Director of Programs G. Blair, STFC U.K.; Prof. S. Bertolucci, INFN Italy; Director for International Relations C. Warakaulle, CERN; Rep. R. Hultgren, Illinois; Rep. K. Noem, South Dakota; Senator M. Rounds, South Dakota; Senator J. Thune, South Dakota; Assoc. Director for HEP J. Siegrist, U.S. DOE; Deputy Assistant to the President and Deputy U.S. Chief Technology Officer M. Kratsios; South Dakota Governor D. Daugaard; Project Manager S. Lundgren, Kiewit/Alberici; Exec. Director M. Headley, SURF; and Chair of the Board C. Peterson, South Dakota Science and Technology Authority. *Photo Courtesy: Reidar Hahn, Fermilab.*





- LBNF/DUNE is an approved project in the US
  - Official Groundbreaking 21/July/2017
  - First fully international project in the US
- CERN is member of DUNE
  - Fully supported by Council
  - CERN Neutrino Platform
  - PROTO-DUNE under construction at the SPS North Hall
  - DUNE group established at CERN

DUNE Status in Germany

- Discussions in the Germany community (KET and KAT and KhuK)
- Workshop in February 2017 in Heidelberg
  - Conclusions are available here
  - *Eine zweifelsfreie Entdeckung der CP-Verletzung im leptonischen Sektor und die genaue Bestimmung der CP-Phase δ erfordern ein "long baseline" Beschleunigerneutrinoexperiment der nächsten Generation wie DUNE oder Hyper-Kamiokande. Während der Vollausbau von Hyper-Kamiokande in Standardmodell-Szenarien eine etwas höhere Empfindlichkeit erwarten lässt, öffnet der Breitband-Neutrinostrahl von DUNE den Vorteil von deutlich mehr Redundanz für die Suche nach Physik jenseits des Standardmodells. Wenn eine hinreichende Sichtbarkeit durch eine deutsche Beteiligung möglich ist, halten die Teilnehmer*innen die koordinierte Beteiligung an einem der beiden Experimente für sehr wünschenswert.*
- Several universities (and MPI and DESY) have started discussing a potential DUNE participation
  - Detector interests focused around Near Detector and highly granular calorimetry

DESY Interests in DUNE

Physics

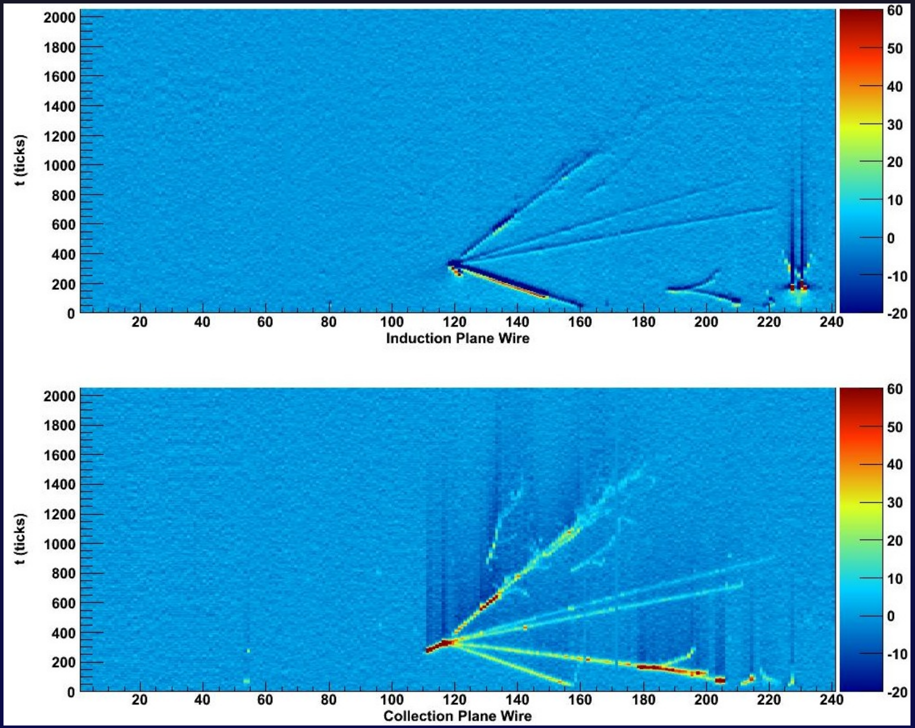
- Key topics
  - CP violation
  - Proton Decay
  - Neutrino Cross-sections building on DIS experience
- Rich physics program from 2026-2036+

Detector Contributions

- Near Detector ECAL
  - Ideally fits with DESY and German expertise in highly-granular calorimetry (CALICE AHCAL)
  - DESY II Test Beam Facility
- Key contribution to Near Detector

Reconstruction and Analysis

- Particle flow reconstruction
- Core Computing



DESY Neutrino Platform

- Combining DESY Expertise in Zeuthen and Hamburg
- ICECUBE (Zeuthen) & DUNE (Hamburg)
  - Detector design
  - Data analysis
- Theory and Combinations

Searching for new Physics

Flavor Physics
Belle-II

Energy Frontier
LHC/HL-LHC/ILC

Search for physics beyond the Standard Model

Neutrinos
DUNE

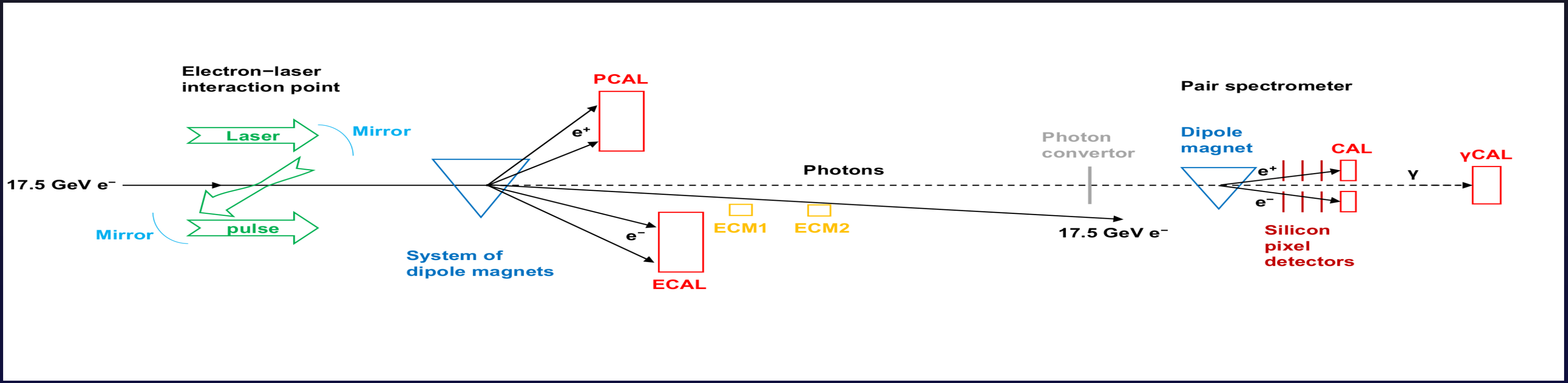
Axion Searches
ALPS,MADMAX
IAXO

QED at Extreme Conditions
LUXE

QED at extreme conditions

- QED has been thoroughly tested in the vacuum
  - But little is known about strong field QED where QED becomes non-perturbative.
- LUXE
  - Testing QED test in the strong field regime, so-called Schwinger regime $E \approx 1.3 \times 10^{18}$ V/m.
  - Effects calculated 80 years ago
- The experimental setup
  - Install a laser so that its photons ω, are colliding with the XFEL electron beam,
  - Two reactions of interest, $e^- + n\omega \rightarrow e^-\gamma$ and $e^- + n\omega \rightarrow e^- e^- e^+$
  - Detect photons, electrons and positrons
- Any deviations from the Schwinger QED prediction is a sign for new physics

LUXE

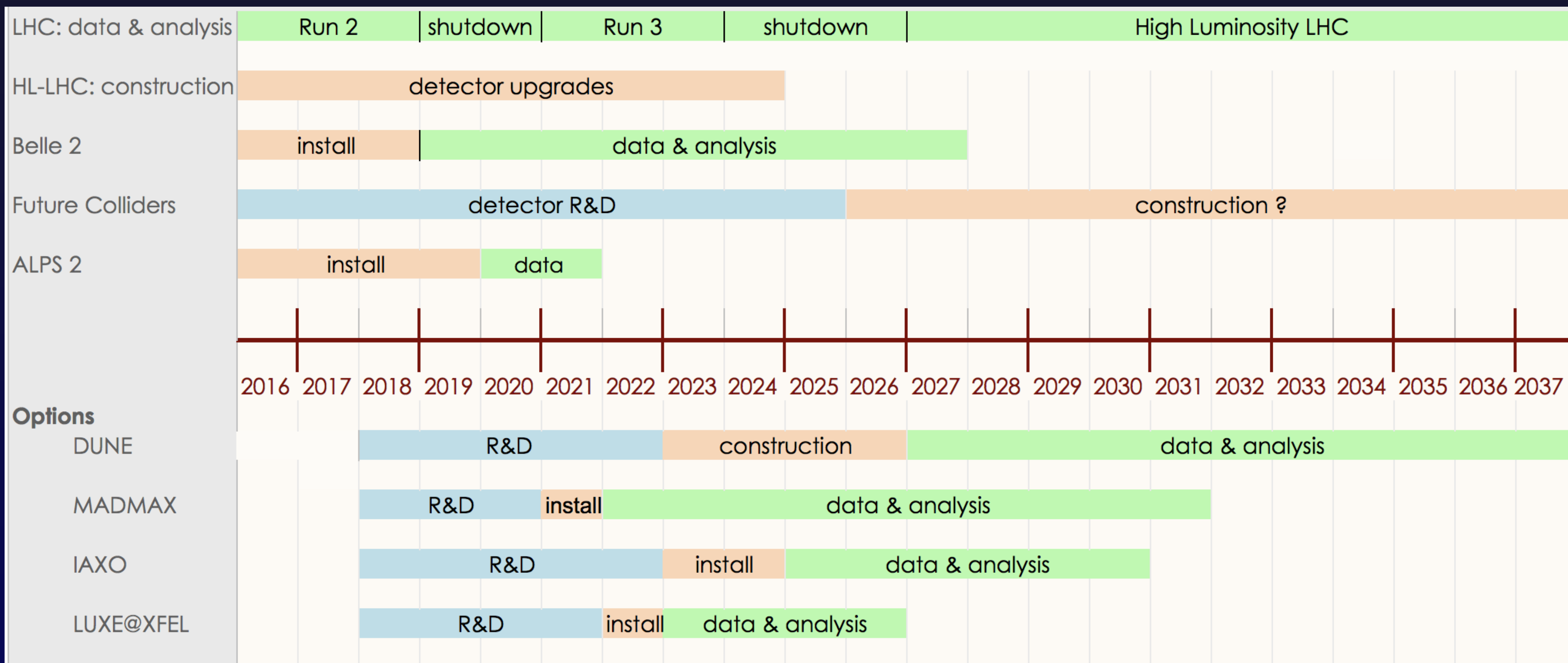


- DESY is unique
  - High intensity-High energy electron beam available
- Laser requirements
  - 500 nm Laser with 10^{21} W/cm^2
- Dimensions
  - 50 m long, 1.2 m width
- LUXE will perform a measurement, not set a limit
  - Any other result will be an indication of new physics
- Currently early design studies are ongoing to understand the feasibility

The LUXE location

XTD5 Tunnel at European XFEL

Potential Timeline



Conclusions

- Rich prospects for physics beyond the Standard Model
- New directions for the next decade
  - Axions
  - Neutrinos
  - QED at extreme conditions
- Complementarity to collider physics (LHC, e^+e^-)
- DESY is preparing the future now and is well positioned to play a leading role
- Acknowledgements
  - B. Heinemann, A. Lindner, A. Patwa, K. Peters, A. Ringwald, T. Schoerner-Sadenius, F. Sefkow, F. Simon