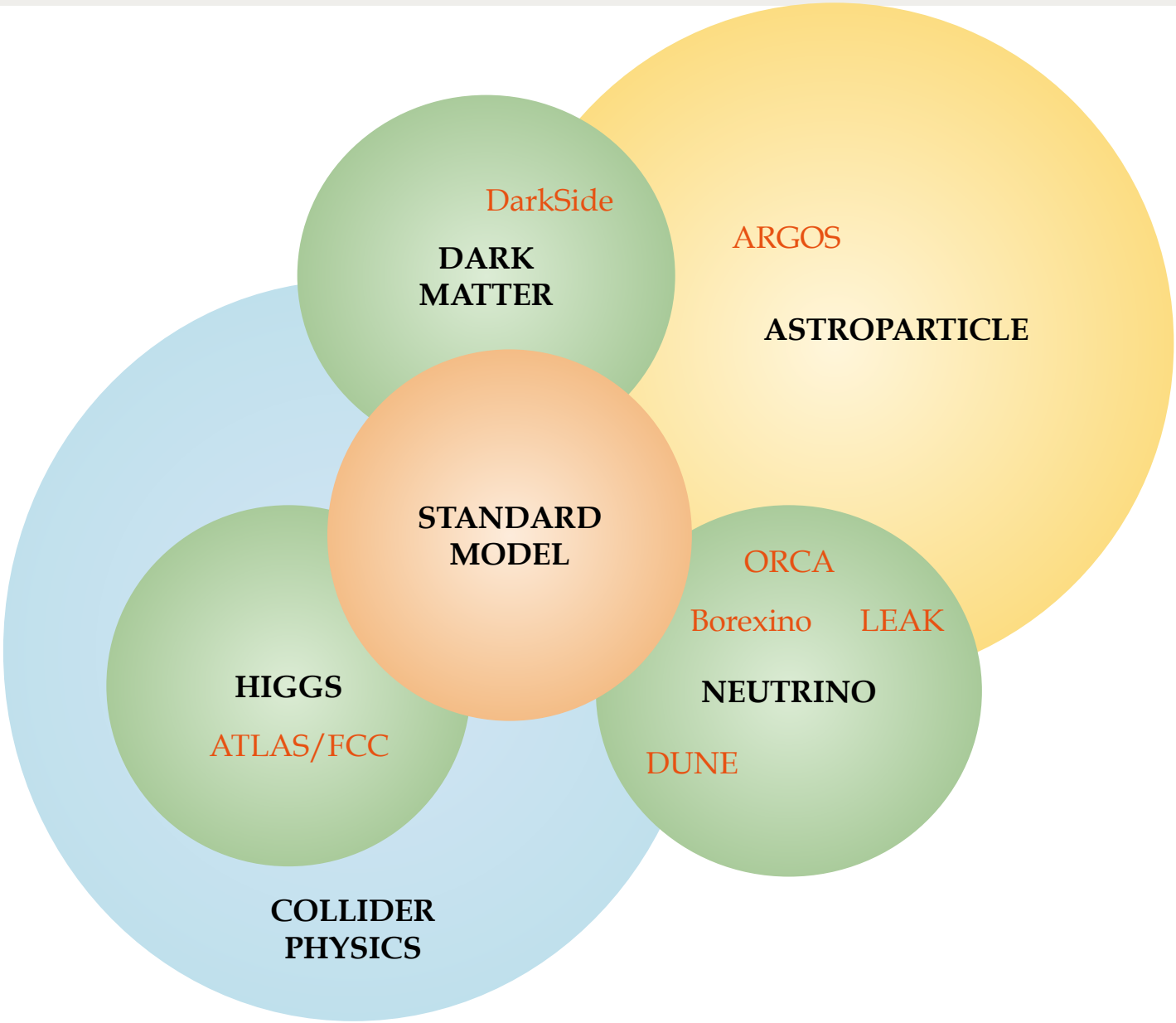
The Particles Group

Biennale APC 2022

The Particles Group



The Particles Group

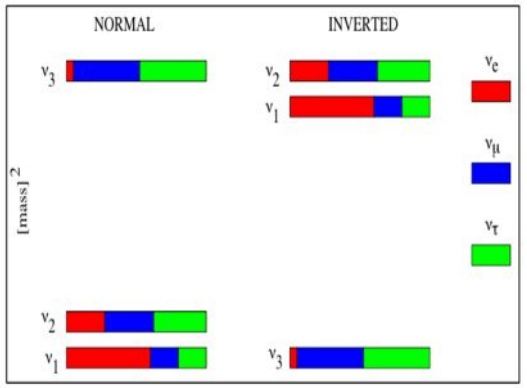
	Permanents	Project
UDP	M. Bomben	ATLAS/FCC
	A. Kouchner	KM3NET
	T. Patzak	DUNE
	A. Tonazzo	DUNE & DarkSide
	V. Van Elewyck	KM3NET
CNRS	G. Bernardi	ATLAS/FCC
	J. Coelho	KM3NET & DUNE
	J. Dawson	DUNE
	S. El Hedri	KM3NET
	D. Franco	DarkSide & Borexino
	G. Marchiori	ATLAS/FCC
	C. Mironov	DUNE
	S. Sacerdoti	DUNE
CEA	T. Lasserre	
Emeritus	M. Cribier	
	F. Vannucci	
	D. Vignaud	Borexino

Neutrino Oscillations

Atmospheric+LBL Reactor Solar

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

θ_{atm} θ_{13}, δ θ_{sol}



- 3 masses: Δm^2_{21}, Δm^2_{31}, mass ordering
- 3 mixing angles: θ_{12}, θ_{13}, θ_{23}
- 1 phase: δ_{CP}
- 2 Majorana phases?
- 1 or more sterile neutrinos?

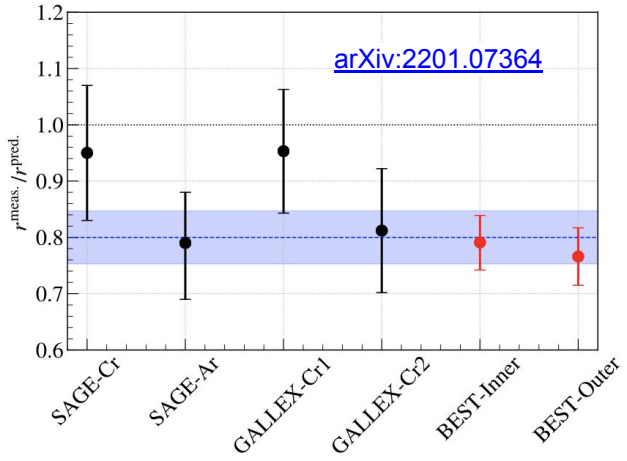
Current precision on oscillation parameters

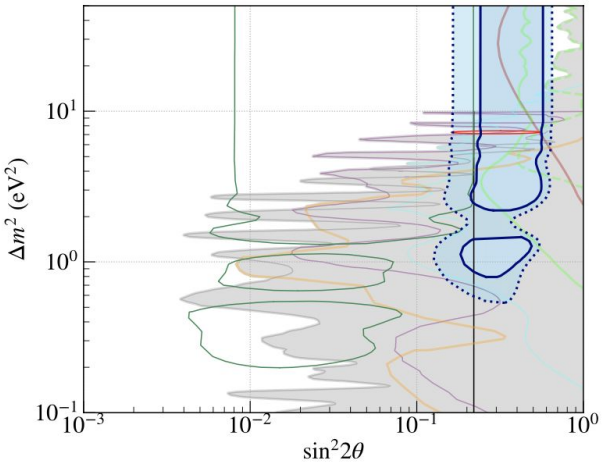
$\lvert \Delta m^2_{31} \rvert$	1.4%
Δm^2_{21}	2.2%
$\sin^2\theta_{13}$	3.8%
$\sin^2\theta_{12}$	4.4%
$\sin^2\theta_{12}$	~5%

Unknowns :
sign (Δm^2_{31})
δ_{CP}

News on Neutrinos

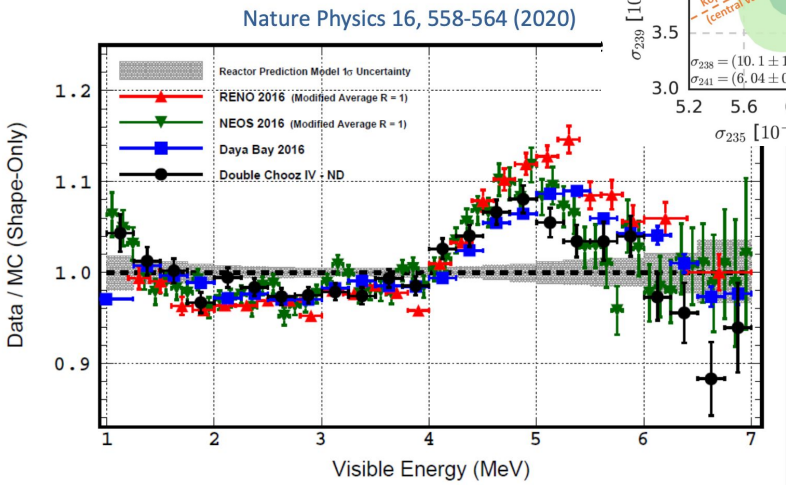
BEST: 4 σ evidence on Gallium anomaly

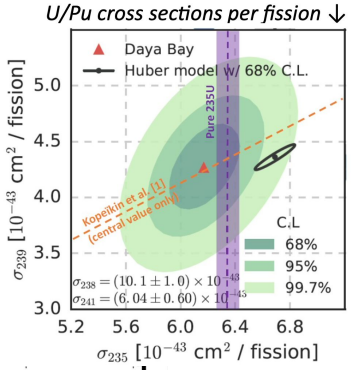




but rejected by PROSPECT and STEREO

Toward the solution of the **"bum**
at 5 MeV from reactor neutrinos





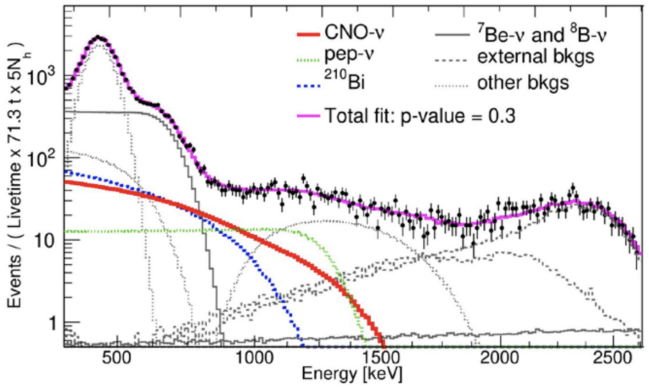
R. Jimenez, C. Pena-Garay, K. Short, F. Simpson and L. Verde (arXiv:2203.14247)

Bayesian evidence of neutrino normal hierarchy from cosmological observations and ground-based oscillation experiments: ***our main conclusion is that new data prefer "Strongly" if not "Decisively" the normal hierarchy, with odds over 100:1.***

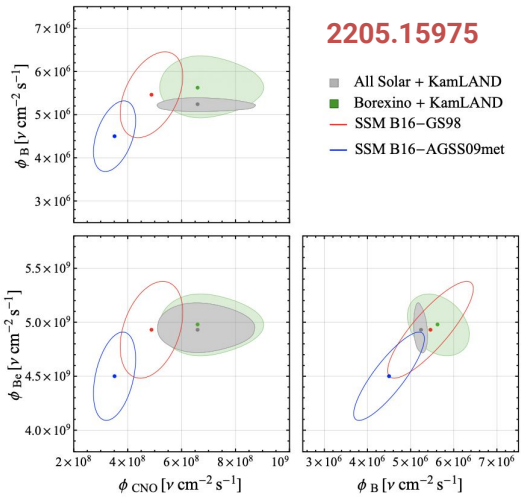
News on Neutrinos: BOREXINO

Borexino ended the data taking in 2021 but analyses are still ongoing

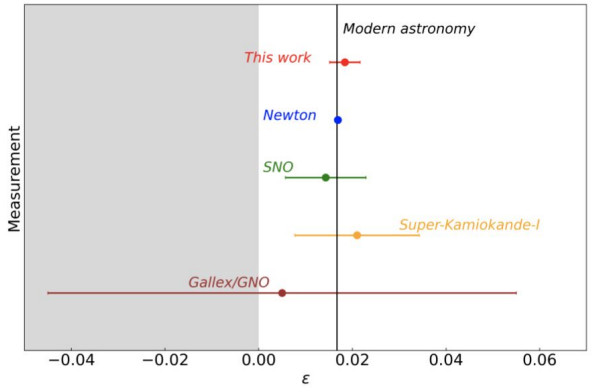
5 σ rejection of no-CNO hypothesis



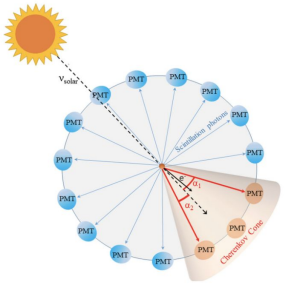
Low-Metallicity model disfavored at > 3 σ

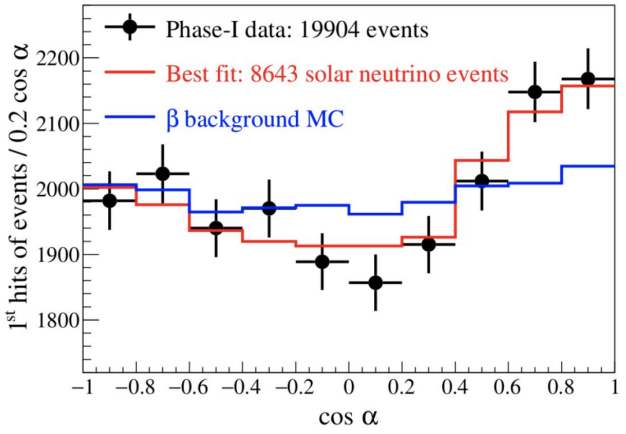


Independent determination of the Earth's orbital parameters with solar neutrinos in Borexino



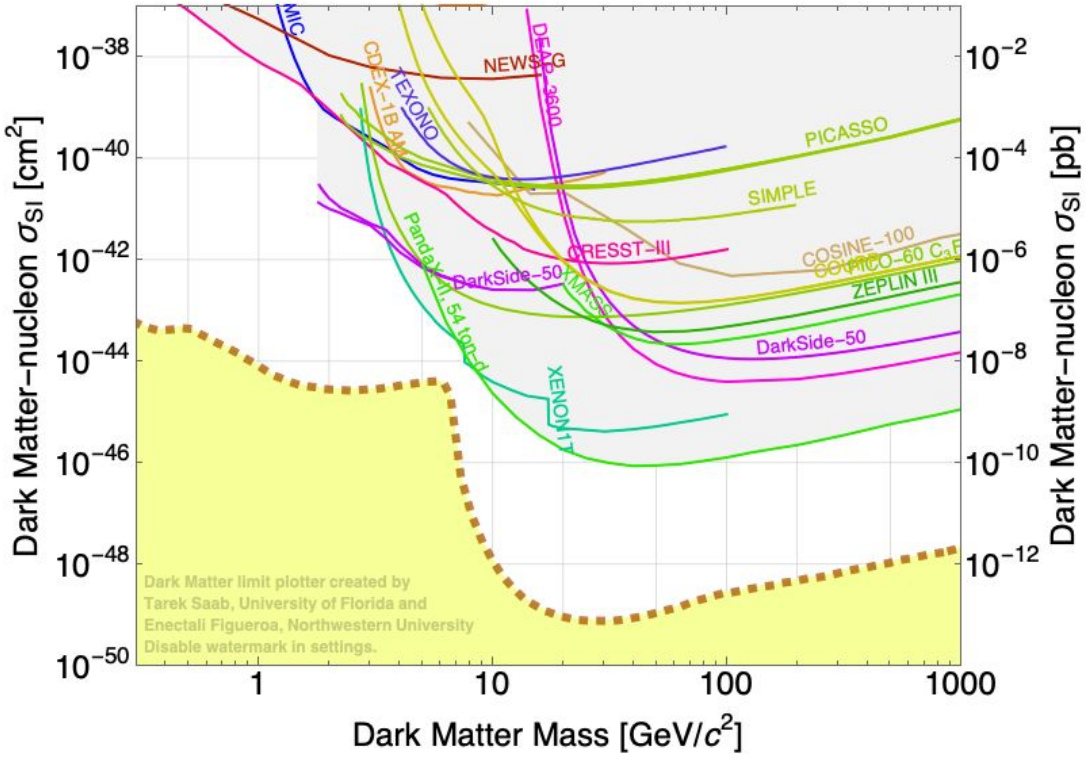
Directional Measurement of Sub-MeV Solar Neutrinos



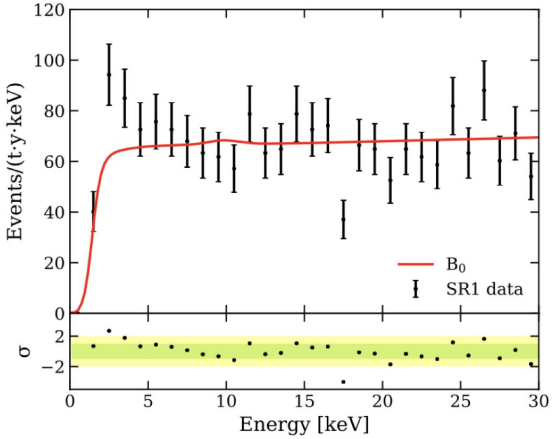


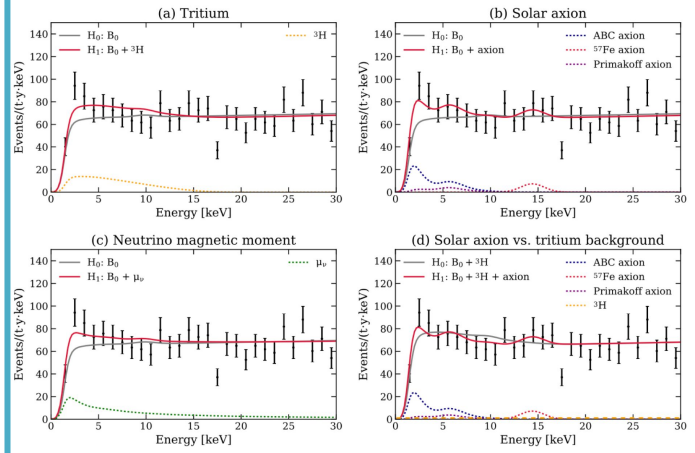
Direct Dark Matter Search

Noble Liquid TPCs dominated the sensitivity



Excess in XENON1T





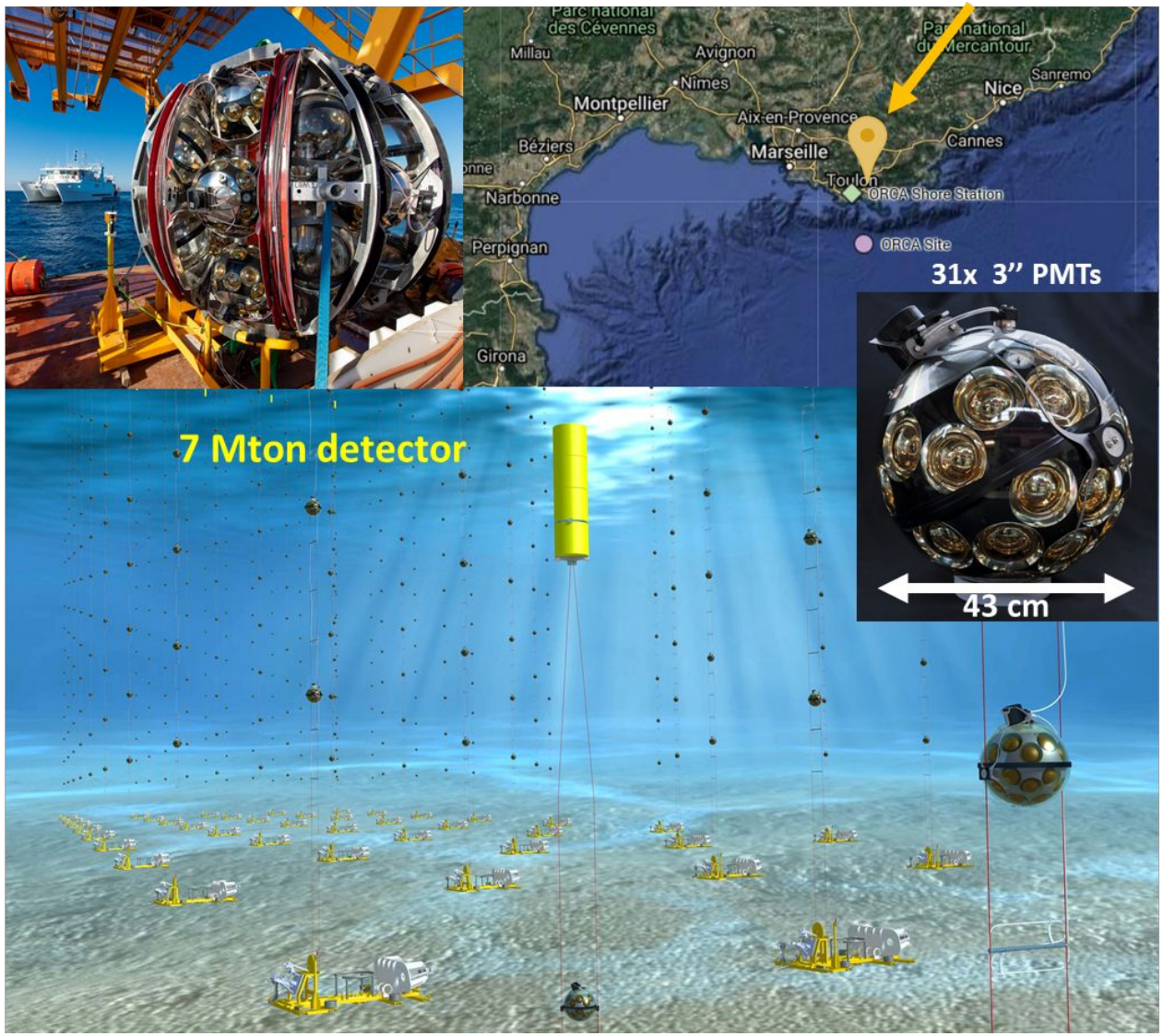
KM3NET/ORCA

Current team members

Particles
COELHO Joao
EL HEDRI Sonia
KOUCHNER Antoine
VAN ELEWYCK Véronique
GOOS Isabel
LIANG Shen
BENDAHMAN Meriem
MADERER Lukas
PEÑA MARTÍNEZ Santiago

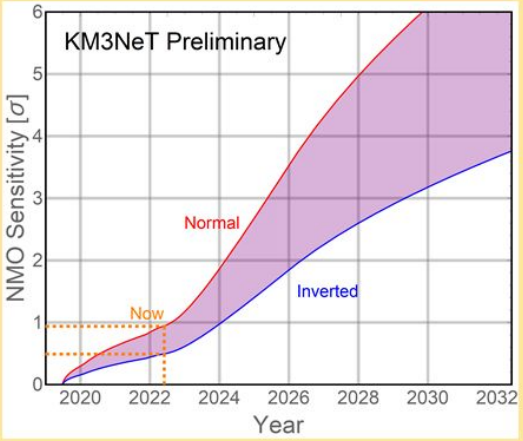
High-Energy Astrophysics
AUBLIN Julien
BARET Bruny
BECHERINI Yvonne
COLEIRO Alexis
CREUSOT Alexandre
DONZAUD Corinne
HAEGEL Leïla (Gravitation)
OUKACHA Enzo

Engineers & technicians:
BOUTONNET Claude
CHAMPION Cédric
COLONGES Stéphane
LESREL Jean
LINDSEY CLARK Miles



KM3NET/ORCA

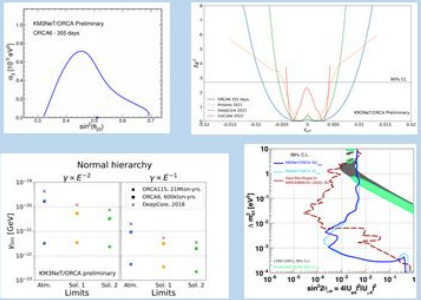
Main Goal



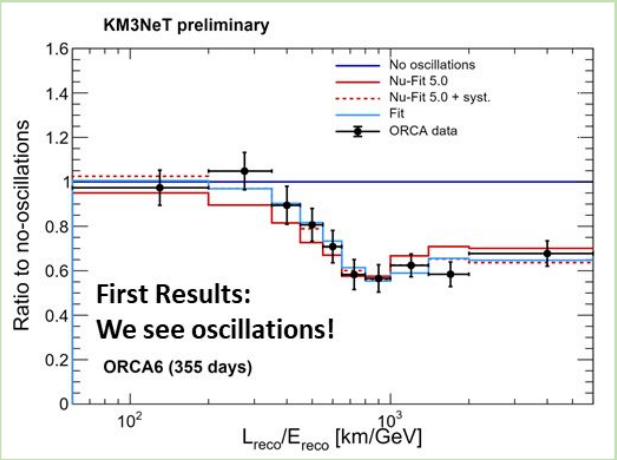
Measure the Neutrino Mass Ordering

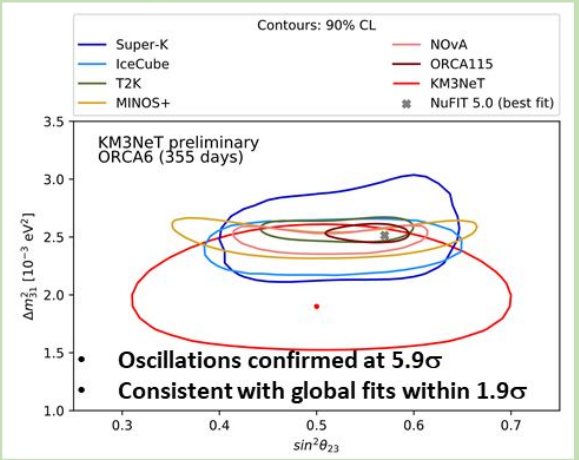
- Needs at least 30 Mton-years
- Now: ~1 Mton-year

Plus many tests of physics beyond the Standard Model



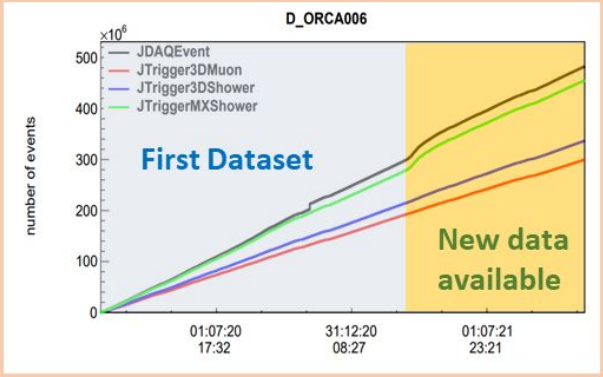
First Results: 354 kton-years

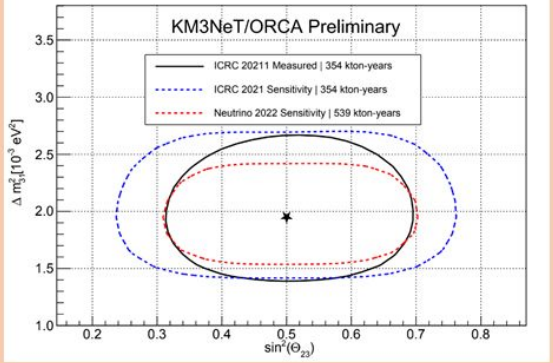




$$\Delta m^2_{31} = 1.95^{+0.24}_{-0.21} \times 10^{-3}\ \mathrm{eV}^2$$

$$\sin^2\theta_{23} = 0.50 \pm 0.10$$



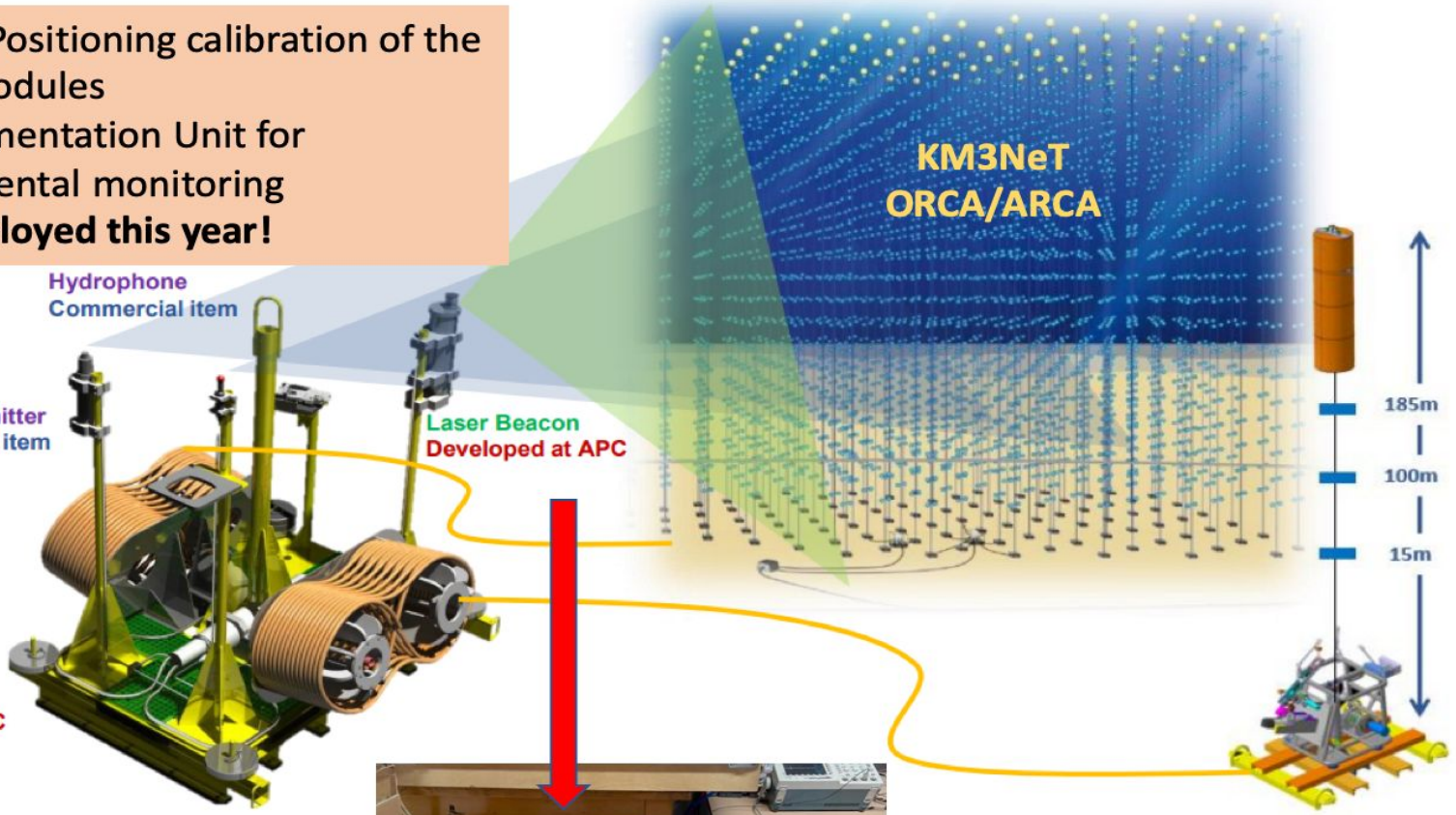


Upcoming: 540 kton-years (~4× statistical power)

Calibration Unit: APC Technical contribution to KM3NeT

- Time/Positioning calibration of the optical modules
- Instrumentation Unit for environmental monitoring

To be deployed this year!



Technical coordinator: A. Ilioni
+ B. Baret, C. Boutonnet, C. Champion, A. Creusot, S. Colonges, J. Lesrel,M. Lindsey Clark, VVE…

Astroparticle Research, Oceanography and Geology studies

LabEx UnivEarthS Interface Project: Collaboration APC-IPGP

Neutrino Tomography of the Earth:
Use atmospheric neutrinos to infer information on Earth's
electron density/matter density

Measured in neutrino oscillation patterns

$$N_e = \frac{N_A}{m_n} \times \frac{Z}{A} \times \rho_{matter}$$

Measured in neutrino absorption

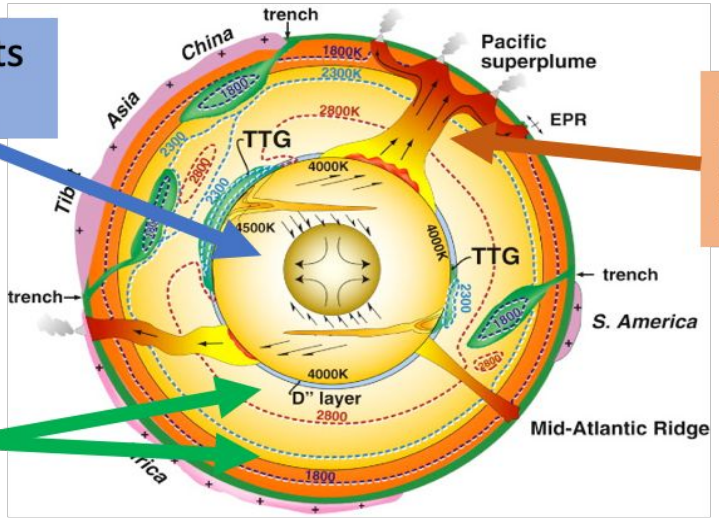
probes composition

probes matter density

...to address open questions in geophysics:

Presence of light elements in the outer core ?

Nature and composition of Large-scale inhomogeneities in the mantle ?

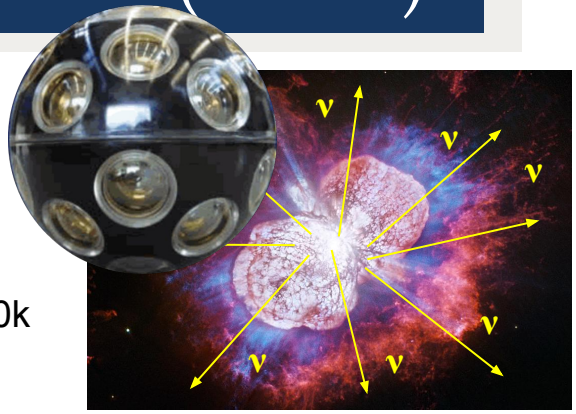


Nature/composition of transition zones ?

V. Van Elewyck (PI)
+ L. Maderer, J. Coelho,
E. Kaminski (IPGP),
A. Deuss (Utrecht U.)

Low Energy Analyses at KM3NeT (LEAK)

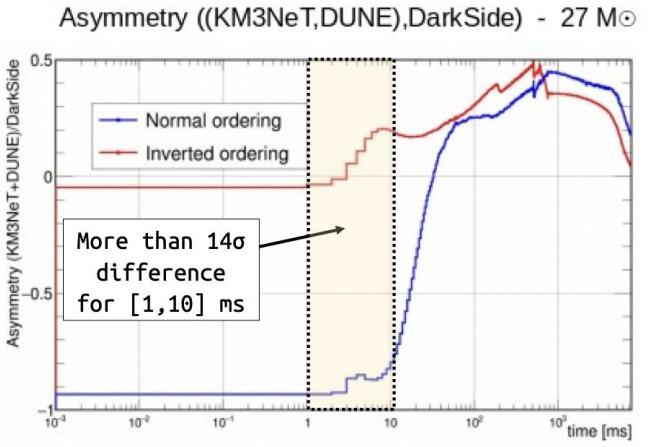
Characterize supernovae with neutrino telescopes



- **Target low-energy neutrinos** (~10 MeV) with KM3NeT
- Exploit the **complex structure** of the Digital Optical Modules (DOMs)
- Catalogue of neutrino spectra from **in-house supernova simulations**
- **Combine neutrino spectra** expected at KM3NeT, DUNE, DarkSide-20k

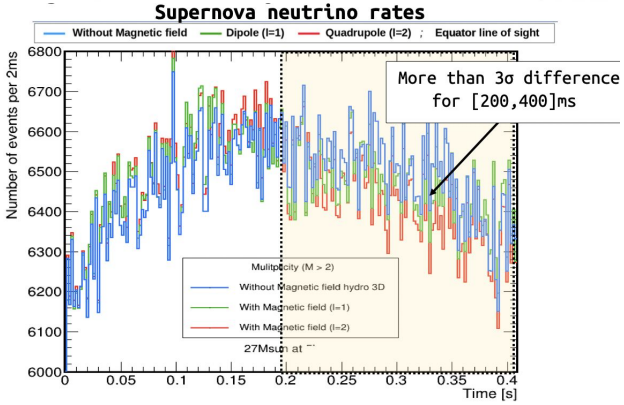
Team and current status

- Collaboration: AIM (CEA), LUTh, APC (KM3NeT, DUNE, DarkSide)
- **KM3NeT analysis:** identify O(10 MeV) neutrinos using dimensionality reduction on single-DOM observables
  Presented by G. de Wasseige at VIVNT 2021
- **CCSN localization by triangulation:** up to 140±20 deg^2 precision
- **Experimental synergies:** determine neutrino mass ordering
  Presented by M. Bendahman at ICRC 2021 and Neutrino 2022

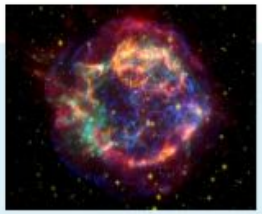


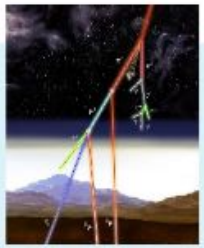
The future: magnetic fields and rotating stars

- **Add detector efficiency + background** for KM3NeT predictions
- From AIM and LUTh: supernova simulations with **magnetic fields, rotating progenitors, and different flavor evolution models**
- Design new observables and enhance KM3NeT's detection potential using machine learning techniques



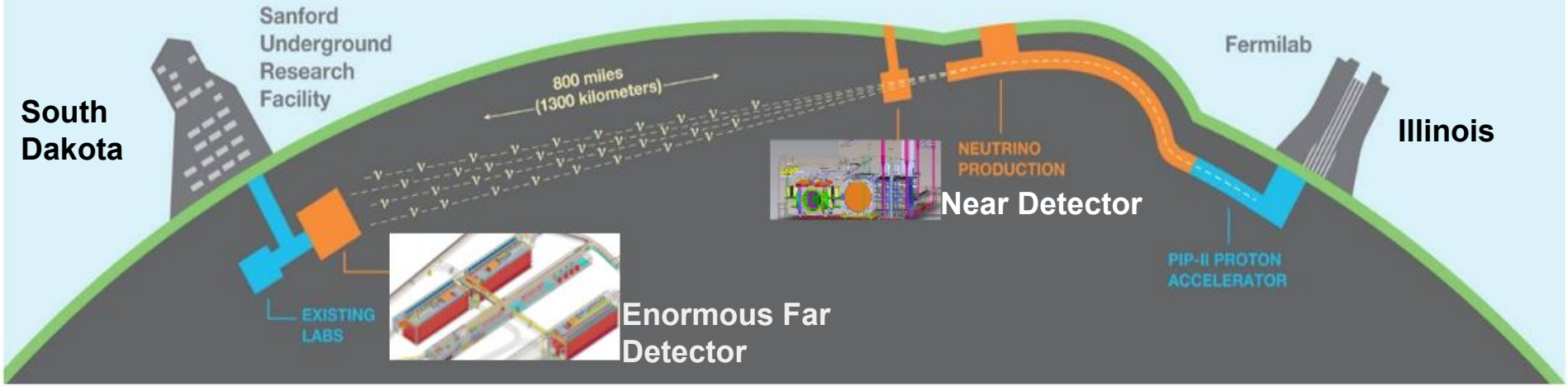
Deep Underground Neutrino Experiment





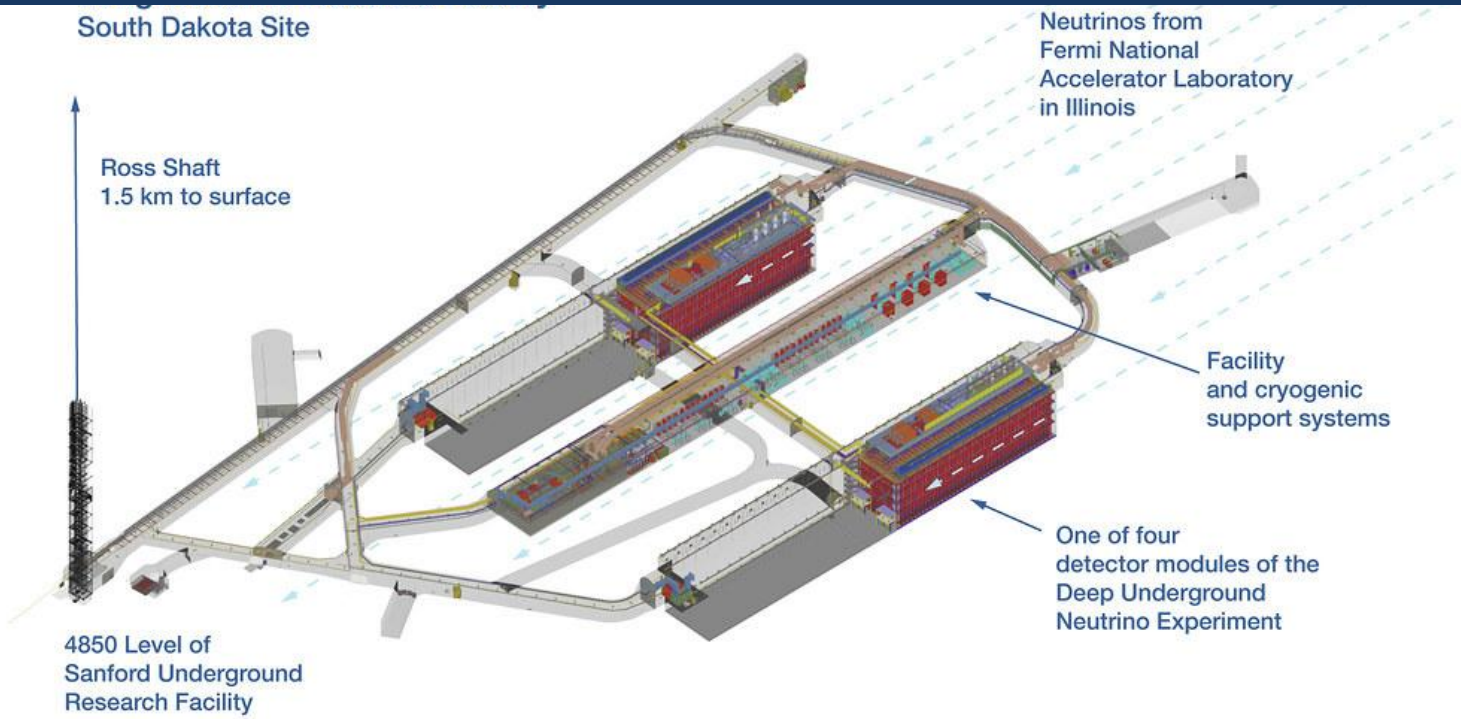
Under construction (expected first data: late 2020s)

- 1300km between FNAL and SURF
- wide-band energy spectrum of neutrinos
- liquid-argon detector technology



DUNE Physics goals

- Unambiguous, high precision measurem. of Δm^2_{32}, δ_{CP}, $\sin^2 2\theta_{13}$, $\sin^2\theta_{23}$ in one experiment
- Discovery sensitivity to CP violation, mass ordering, θ_{23} octant over a wide range of parameter values
- Sensitivity to MeV-scale neutrinos, such as from a galactic supernova burst
- Low backgrounds for sensitivity to BSM physics including baryon number violation

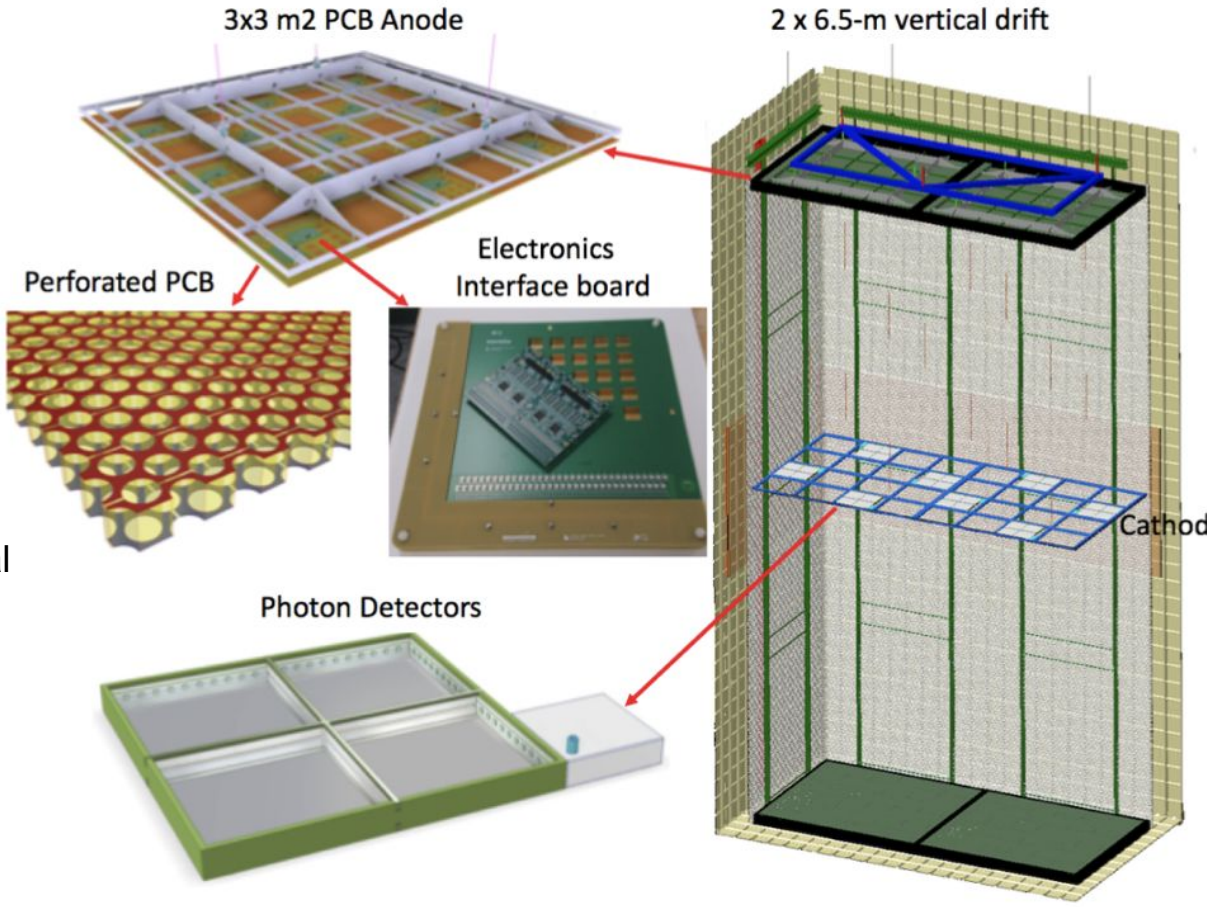


The Far Detector: four gigantic liquid-argon modules!

APC: working on the 2nd module, a vertical drift LAr TPC

- **Detector development:**
  - full-scale prototype building @CERN, to test technology feasibility (Proto-DUNE)
  - developing a photo-detection system
- **Analysis:**
  - data from ProtoDUNE
  - improvement of neutrino reconstruction algorithms

- Photons from LAr scintillation provide the timestamp and trigger of events in LArTPCs.
- Detector modules are very large → improved performance if placed on cathode
- Cathode = surface at -300kV!



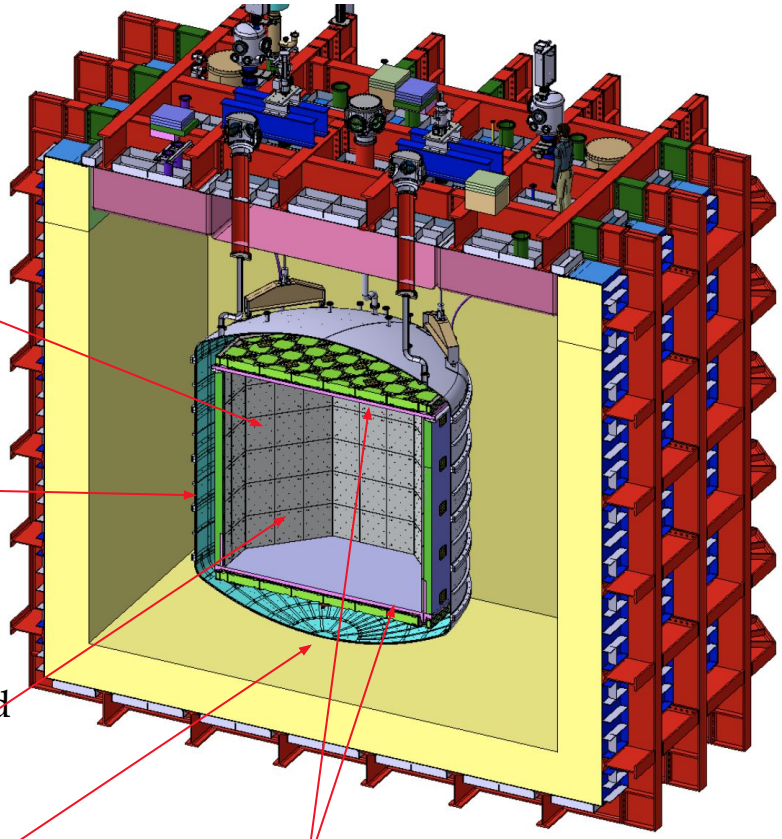
- Need to transmit photo-sensor signal using non-conductive materials
- Target: develop an analog-optical transmitter that can operate in LAr

Vertical drift LAr TPC

DarkSide-20k: Detector

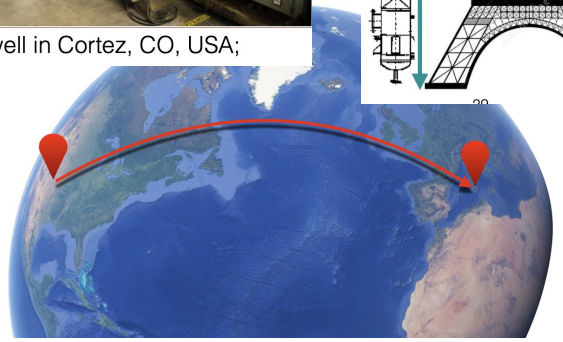
85 institutes, 15 countries, O(350) people

The Detector

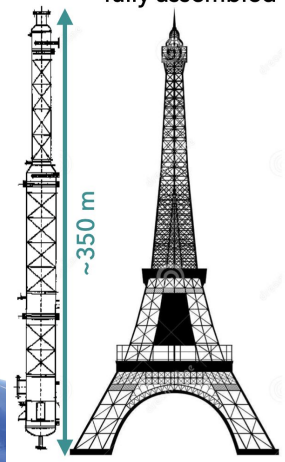


The Underground Argon Journy

• CO_2 well in Cortez, CO, USA;

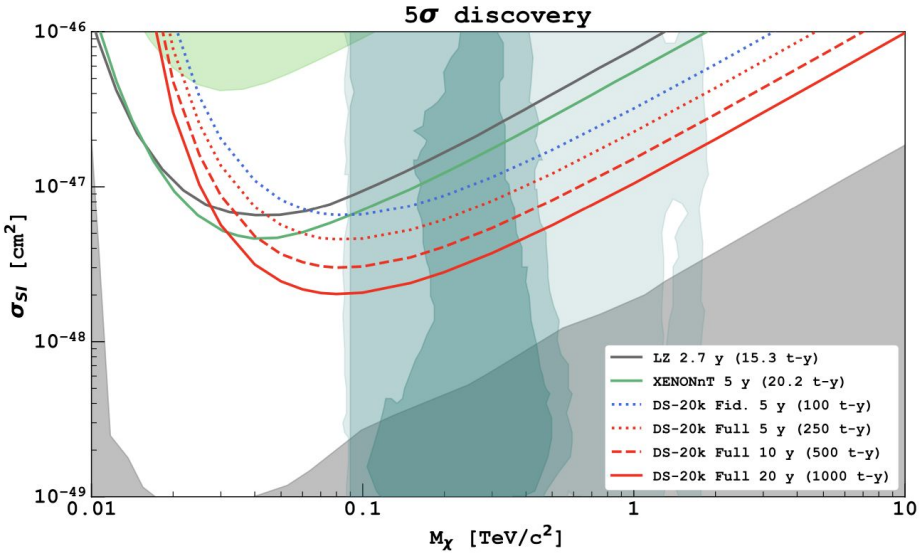


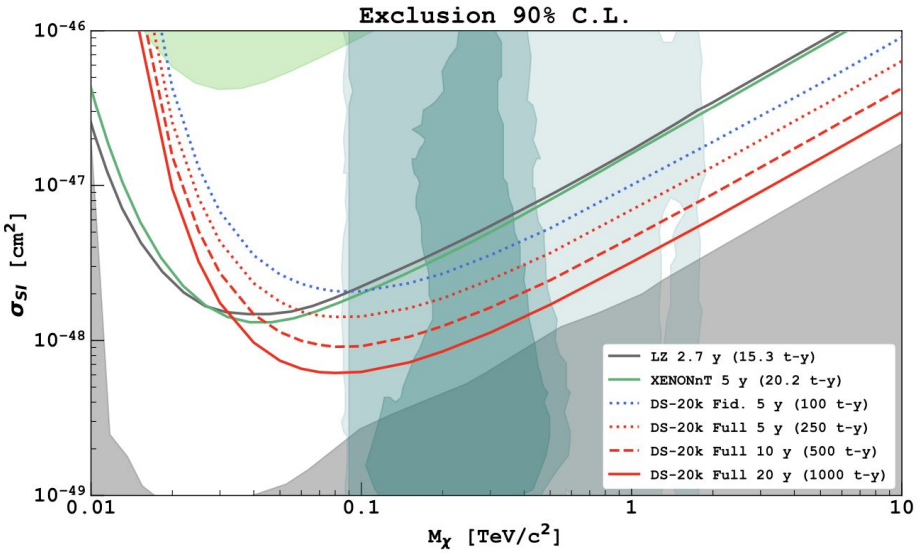
Sketch of ARIA when fully assembled



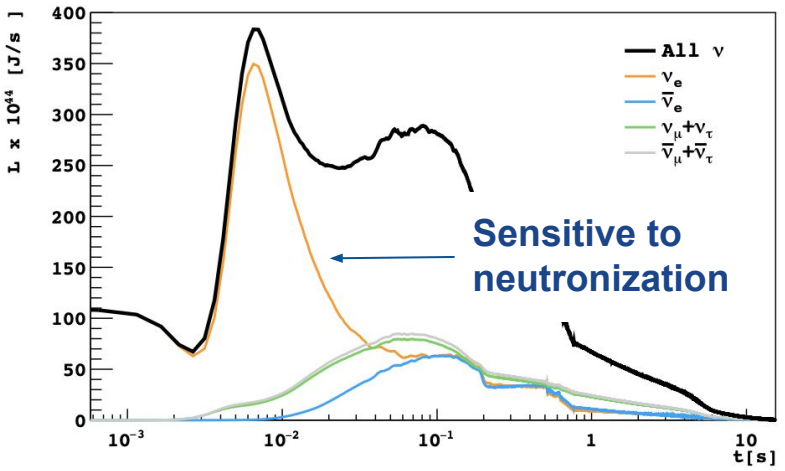
DarkSide-20k: Science

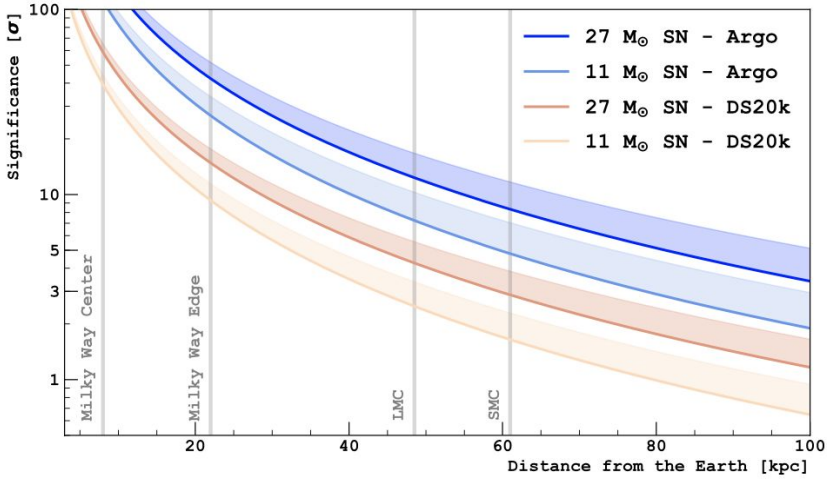
WIMPs



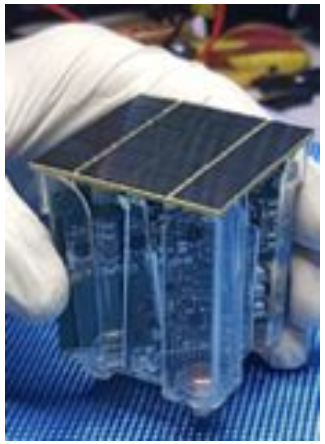


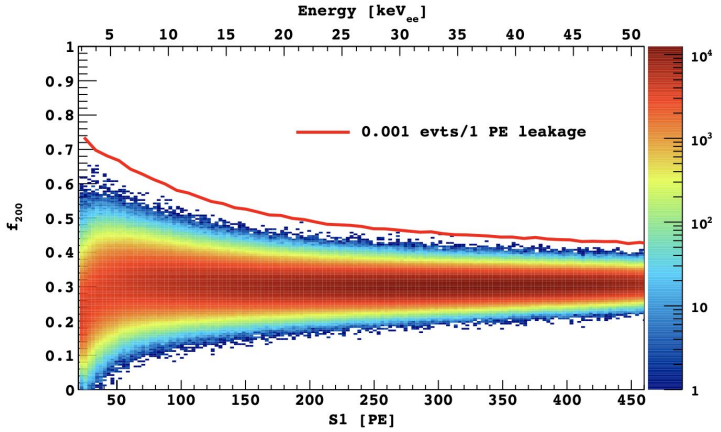
Supernova neutrinos via CENNS



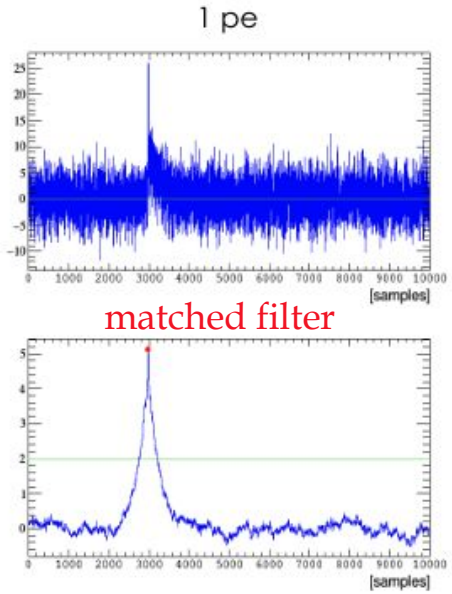


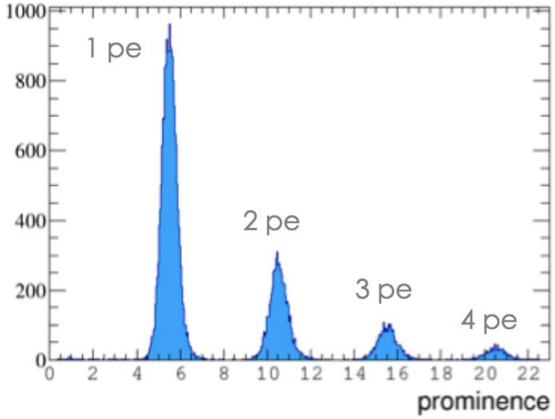
DarkSide-20k: Technology

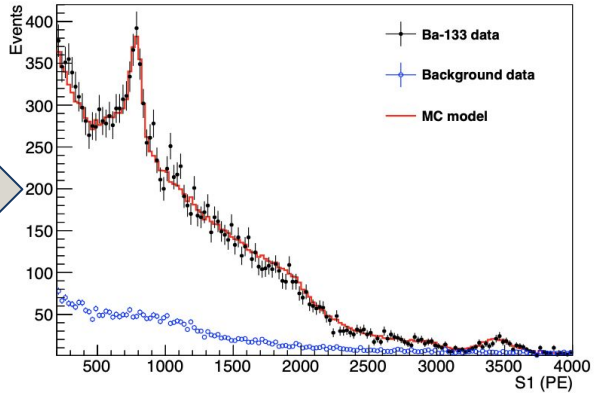




radiopurity + pulse shape discrimination + neutron veto: total background of <0.1 events in 200 t yr

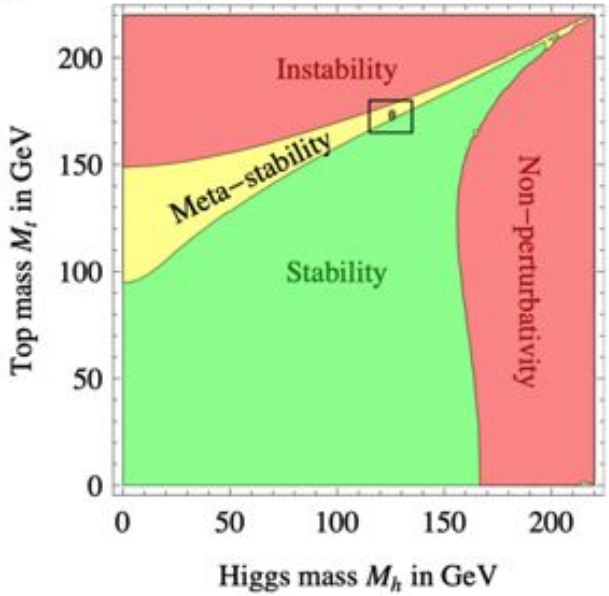






The Higgs Boson

- **Centerpiece of the Standard Model (SM)** of particle physics: scalar particle associated to the Higgs field, which is responsible for
  - spontaneous electroweak symmetry breaking
  - mass of weak gauge bosons and of elementary fermions
- **Discovered in 2012 by ATLAS and CMS at the Large Hadron Collider (LHC) at CERN**
- What we know **today agrees with SM** ($J^P=0^+$, **couplings** to W,Z and 3rd gen fermions), but several questions remain unanswered:
  - is it **fundamental or composite**?
  - is it the **only fundamental scalar** in SM?
  - are Yukawa couplings responsible for the **masses of all generations?** (so far: only 3rd gen established)
  - is it coupled to **new particles**?
  - does the **Higgs boson potential** really have the SM **shape** and what's the **value of the self-coupling λ**?
    - This can have cosmological implications (e.g. about EW vacuum stability and role of Higgs as inflaton)
- **Improving our knowledge about the Higgs boson:**
  - More LHC data: x3 by end of Run3 (2025), further x10 by end of HL-LHC (~2040)
  - Further in time: FCCee, a clean e+e- Higgs factory (feasibility study now, possible start ~2045)

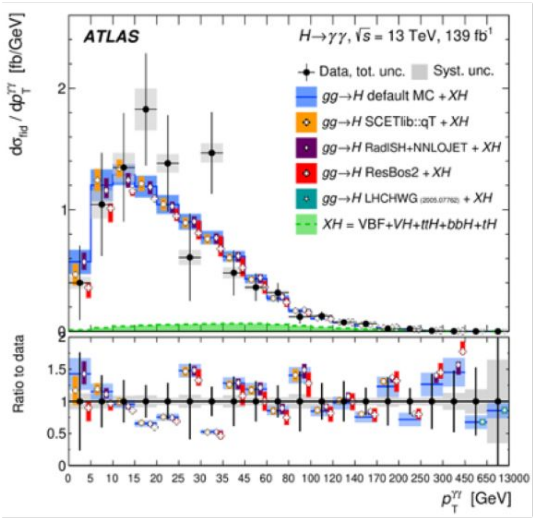


JHEP 08 (2012) 098

Selected recent highlights from the Higgs team

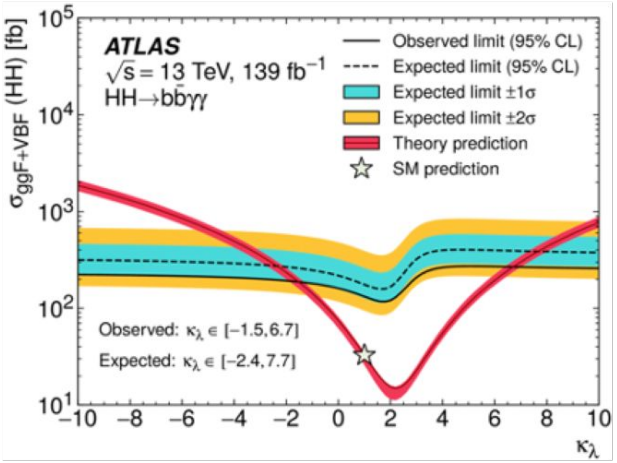
ATLAS: Mesure des sections efficaces fiduciaires différentielles du Higgs en 2 photons arXiv:2202.00487 [hep-ex]

=> allows constraining the (yet unmeasured) Higgs boson coupling to the charm quark



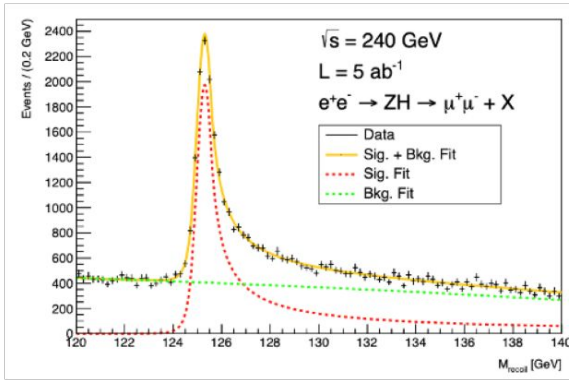
ATLAS: Recherche de HH->bbγγ pour la mesure de l'autocouplage du Higgs arXiv:2112.11876 [hep-ex]

=> allows constraining the shape of the Higgs field potential



FCC-ee: Measuring the mass and production cross section with ultimate precision arXiv:2106.15438 [hep-ex

=> consolidating physics case for FCCee, towards next update of European Strategy on Particle Physics (2025-2026)

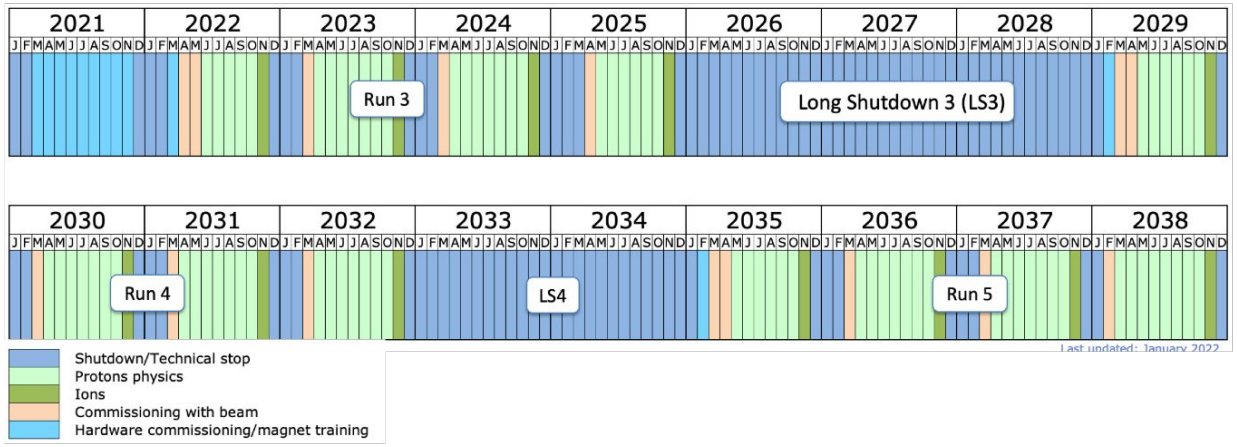


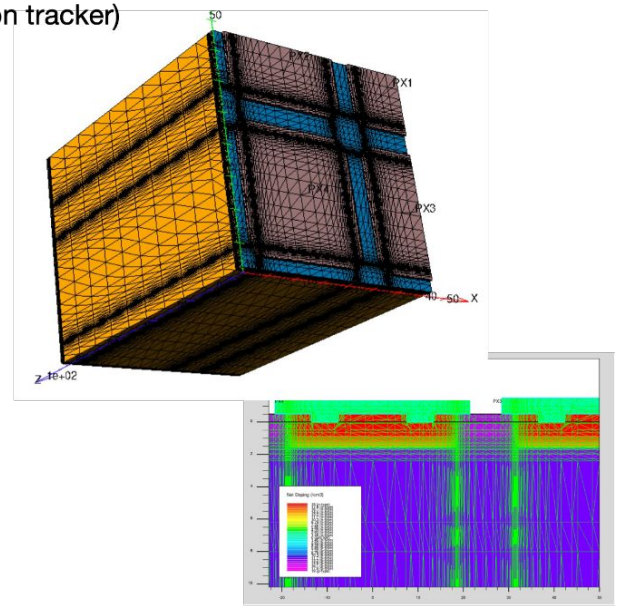
Significant work also on

* detector performance (photons, b-jets)
* detector running and upgrade: study of effects of radiation damage on ATLAS silicon tracker performance and how to implement them in simulation, software development and detector assembly&test for future upgrade of ATLAS silicon tracker

ATLAS and FCC: outlook

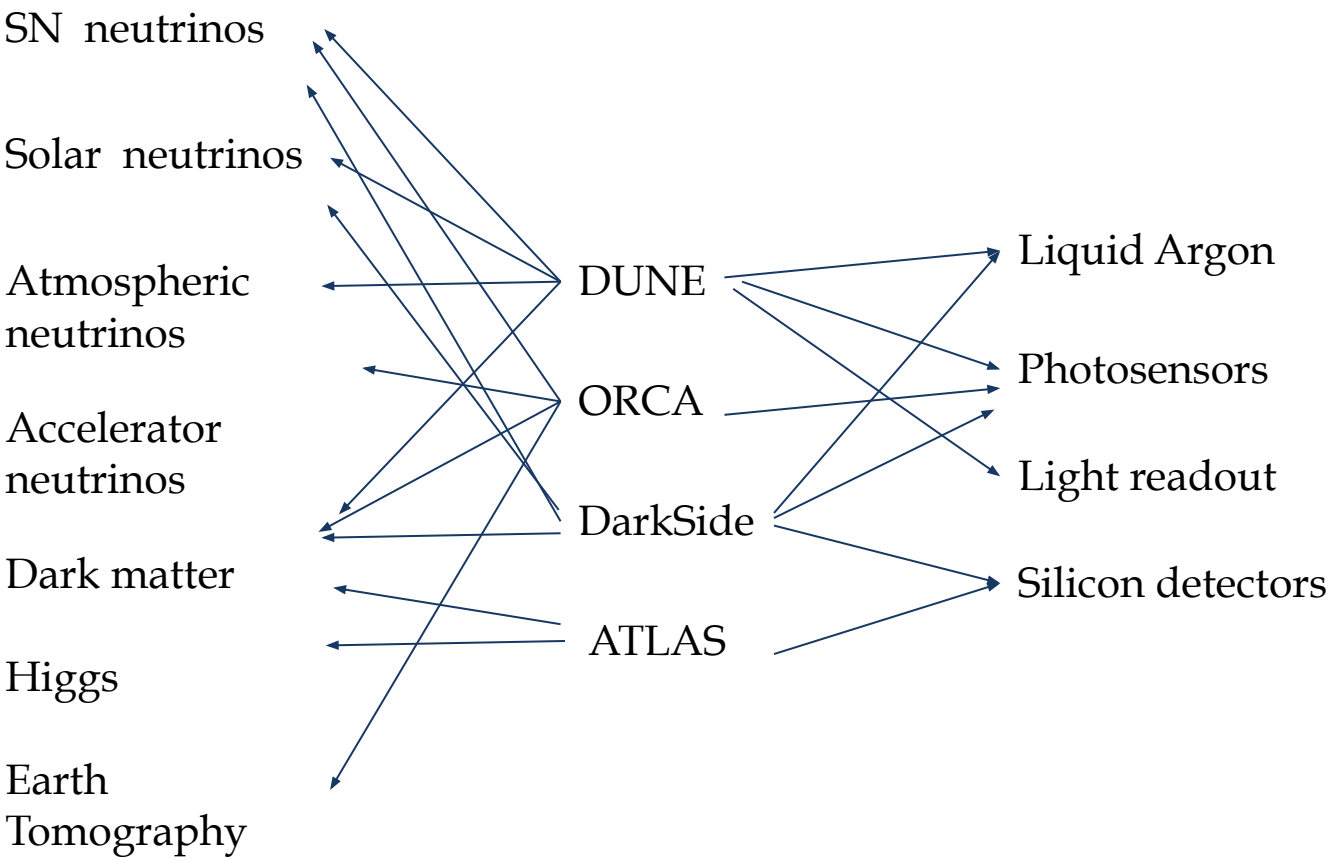
- **ATLAS/LHC**:
  - Exploit Run3 data to improve couplings measurement precision and further nail down allowed range of self-coupling (evidence of di-Higgs production ATLAS+CMS full Run3?)
    - ANR collaborative proposal submitted on Higgs self-coupling (2023-2027, 1 post-doc requested for APC)
  - Prepare high-luminosity phase (continue/increase software & hardware activities on silicon tracker)





- **FCC**:
  - Continue work on Higgs physics case studies
  - Get involved in simulation studies for detector R&D

Synergies and complementarity in science and technology



Thank you for the attention