

Mediator-based dark matter searches in Neutrino Telescopes



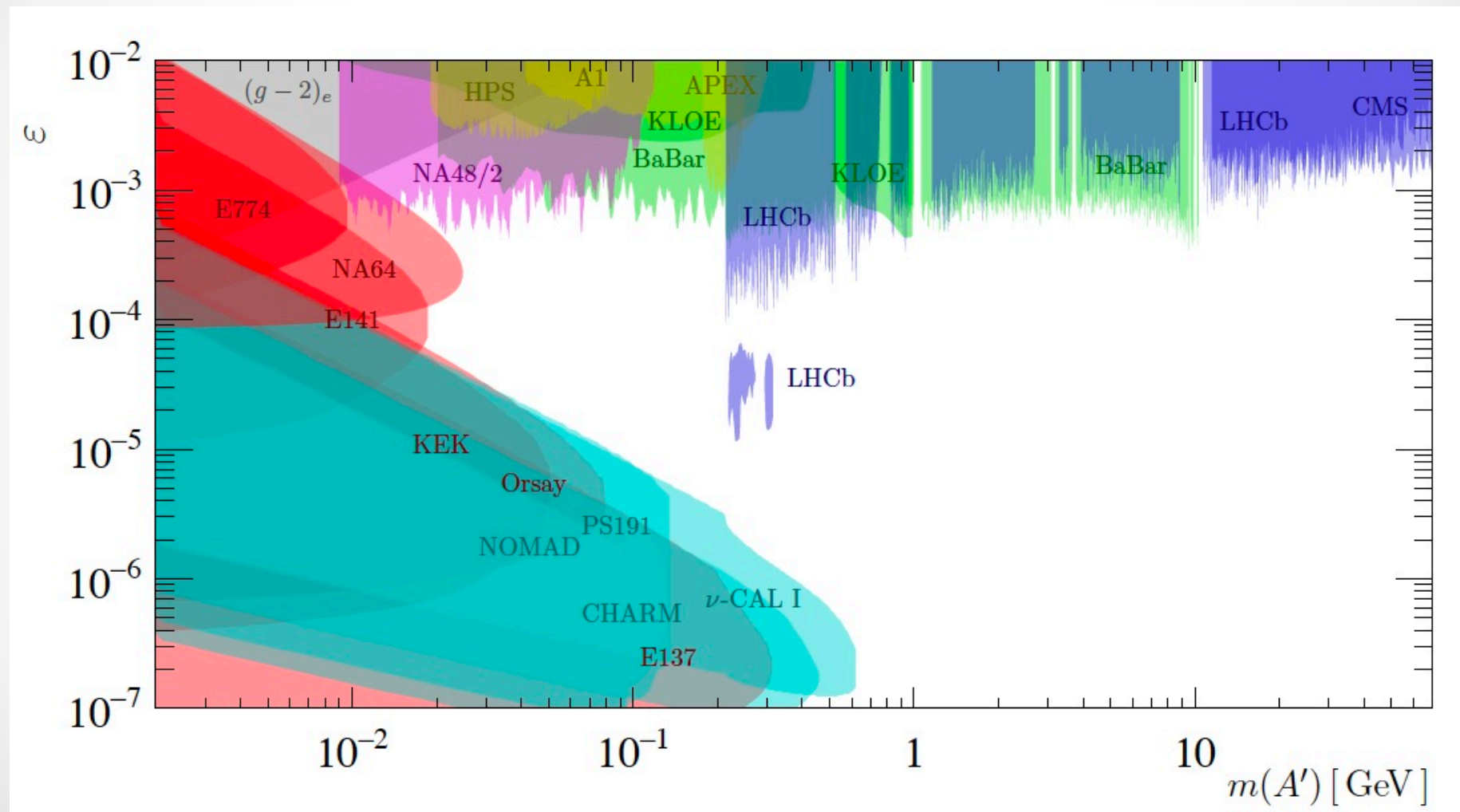
J. Brunner (CPPM)

P. Marquard (DESY)

J. Blümlein (DESY)

Dark photon searches 2021

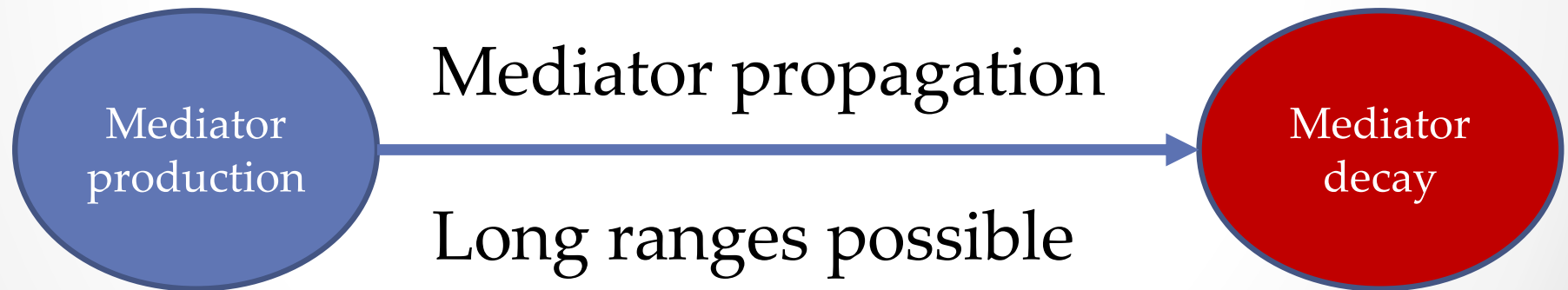
- NuCal 1 result still world leading



arXiv:2104.10280


Mediator-based dark matter

- concepts



Many more channels than just “dark photons”

- From PBC BSM meeting 01/06/2022 G. Lanfranchi



Sensitivity to the current standard PBC benchmarks

(as detailed in PBC-BSM Report, *J.Phys. G* 47 (2020) 1, 010501, [1901.09966](#) [hep-ex] Section 9)

- ✓ Vector Portal:
 - Minimal Dark Photon Model **(BC1)**
 - Dark Photon decaying to invisible final states **(BC2)**
 - Milli-charged particles **(BC3)**
- ✓ Scalar portal:
 - Dark scalar mixing with the Higgs **(BC4 and BC5)**
- ✓ Neutrino Portal:
 - Neutrino portal with electron-flavor dominance **(BC6)**
 - Neutrino portal with muon-flavor dominance **(BC7)**
 - Neutrino portal with tau-flavor dominance **(BC8)**
- ✓ Axion portal:
 - Axion portal with photon-coupling only **(BC9)**
 - Axion portal with fermion-coupling only **(BC10)**
 - Axion portal with gluon-coupling only **(BC11)**

For the ECN3 document
We stay with that

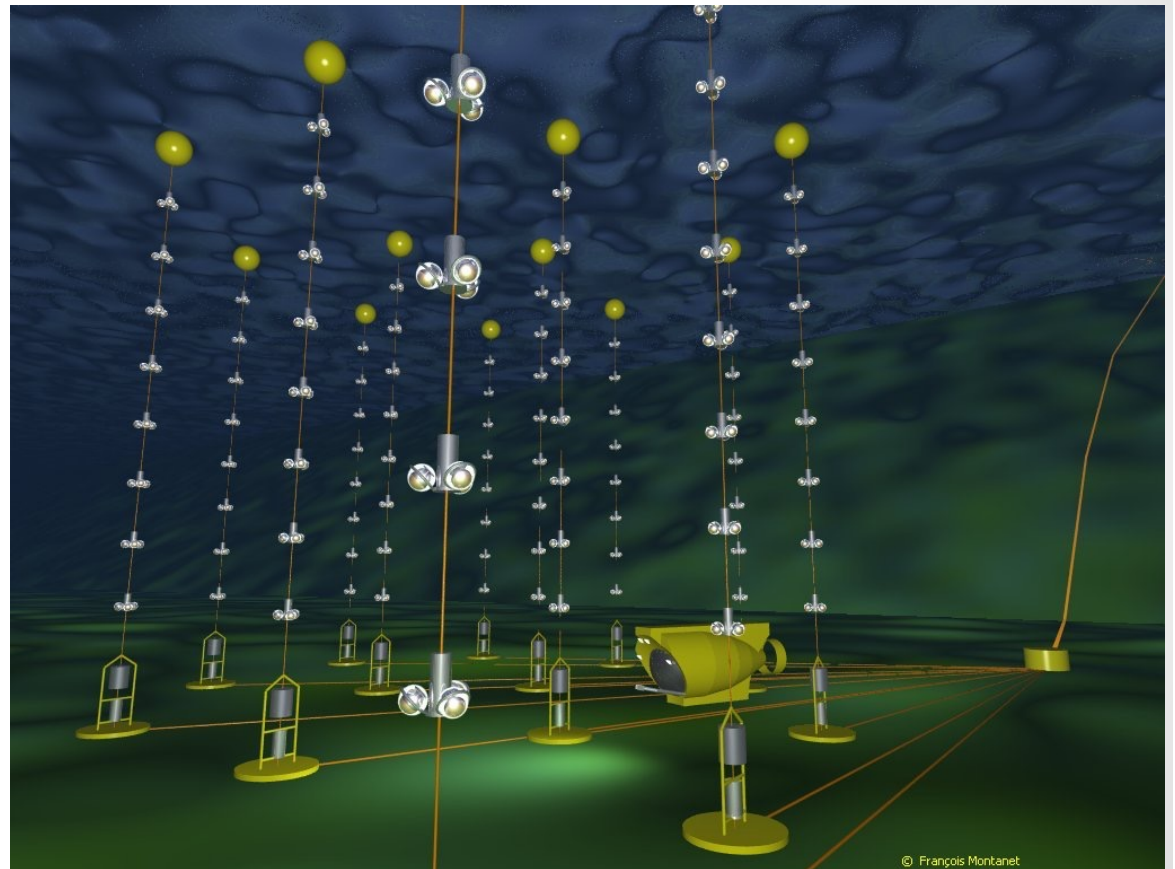
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This project

- Explore potential of **neutrino telescopes** to detect mediator-based dark matter
- Explore natural dark mediator production processes such as in **cosmic ray showers**

Neutrino telescopes in the Mediterranean Sea - ANTARES

- 12 detection lines
- 450m high
- 900 optical modules
- Detector construction started **2006**
- Detector completed in **2008**
- Continuous data taking until **2022**



Neutrino telescopes in the Mediterranean Sea - ANTARES

- Detector dismantled in 2022
- re-analysis of complete data set ongoing
- $\sim 15,000$ atm ν recorded



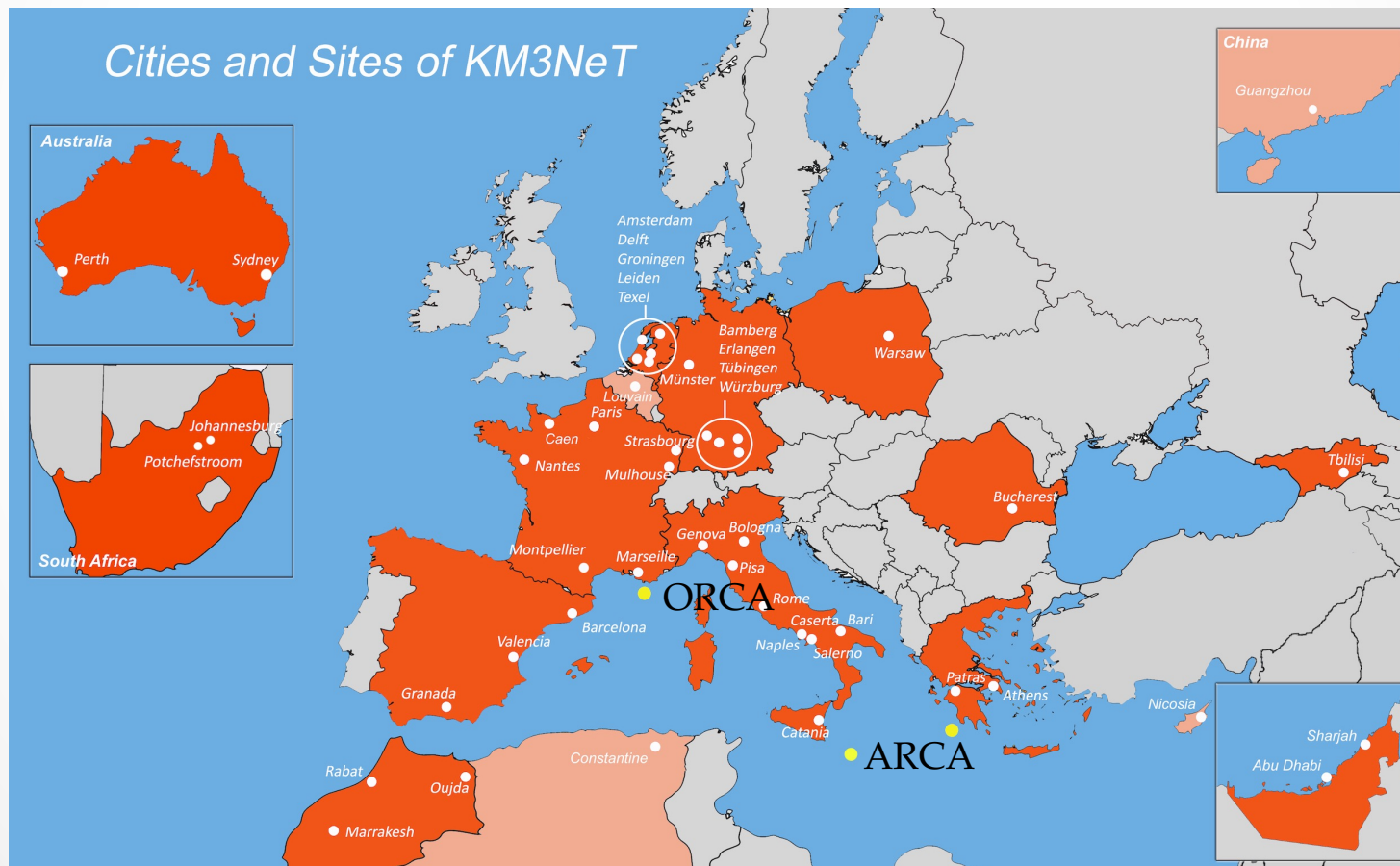
Neutrino telescopes in the Mediterranean Sea - ANTARES



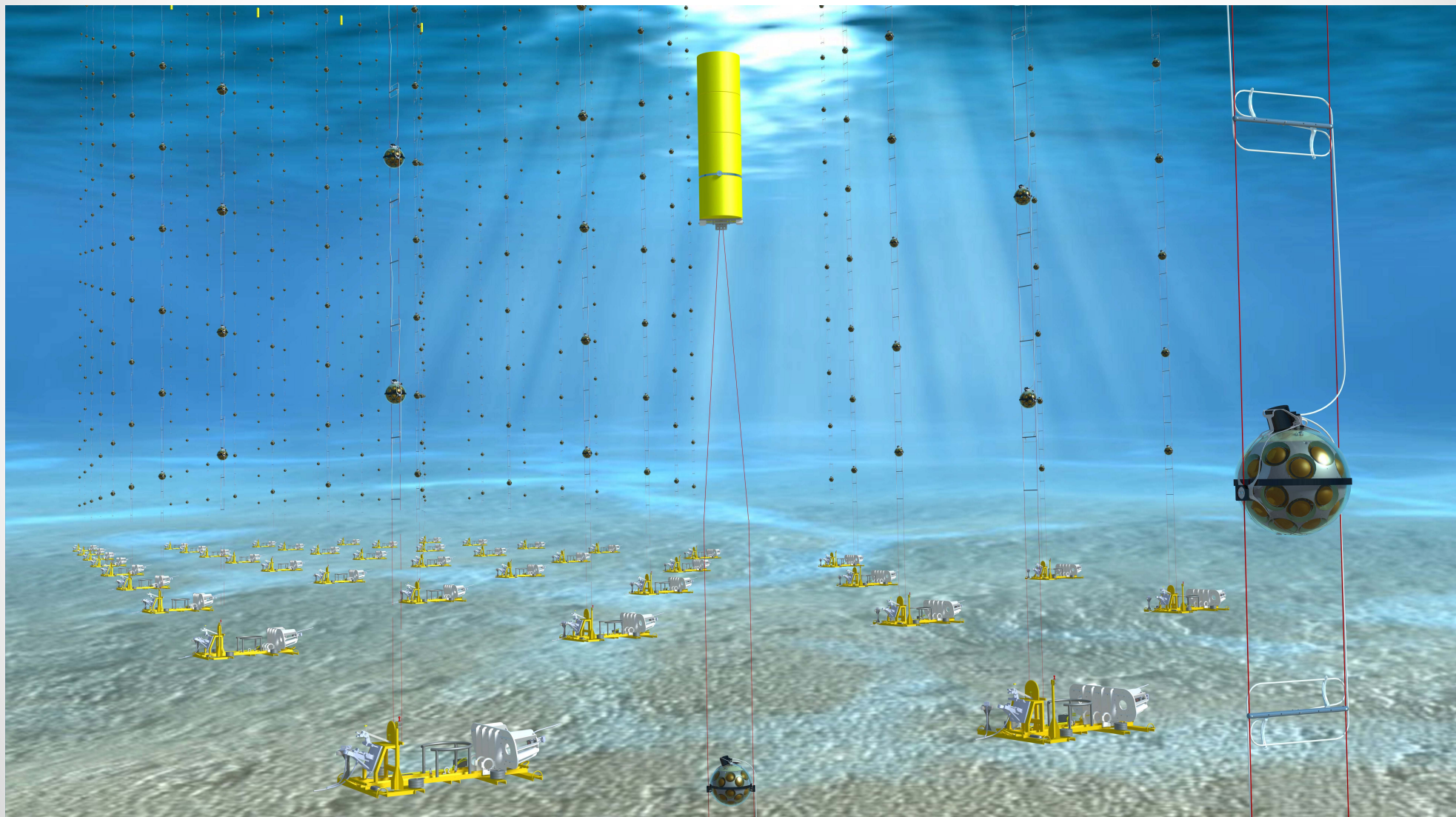
900 optical modules = pressure resistant glass spheres
plus 10 inch photo multiplier wait for second life

Neutrino telescopes in the Mediterranean Sea – KM3NeT

- Large international collaboration
- **ARCA** : TeV-PeV energies \leftrightarrow **ORCA** : GeV energies



Neutrino telescopes in the Mediterranean Sea – KM3NeT



Neutrino telescopes in the Mediterranean Sea – KM3NeT

Introduction: Technology



Digital Optical Module (DOM)

- Multi-PMT : 31 x 3" PMTs
- Gbit/s on optical fiber
- Positioning & timing



Detection Unit (DU)

- 18 DOMs
- Low-drag design

Deployment Vehicle



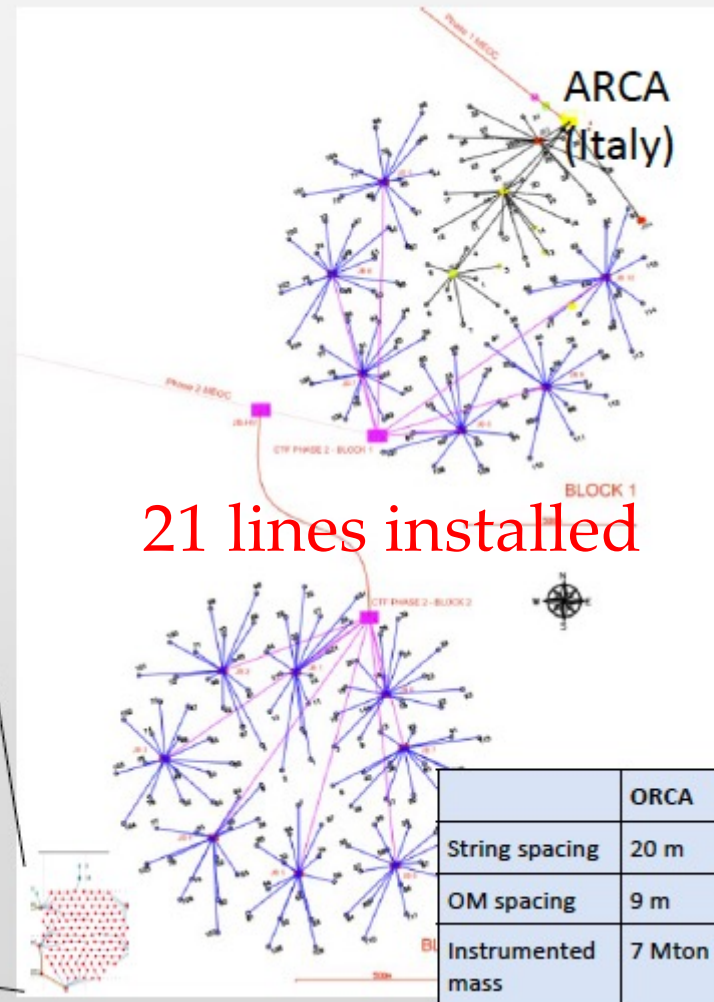
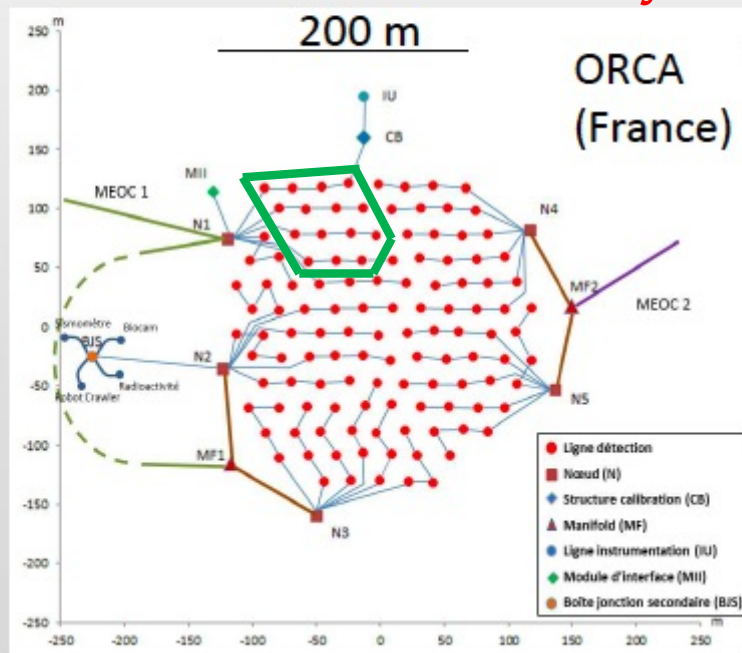
- Rapid deployment
- Multiple DUs per sea campaign
- Autonomous/ROV unfurling
- Reusable

Neutrino telescopes in the Mediterranean Sea – KM3NeT

- Under construction at two sites

Building blocks

15 lines installed
Since last Thursday



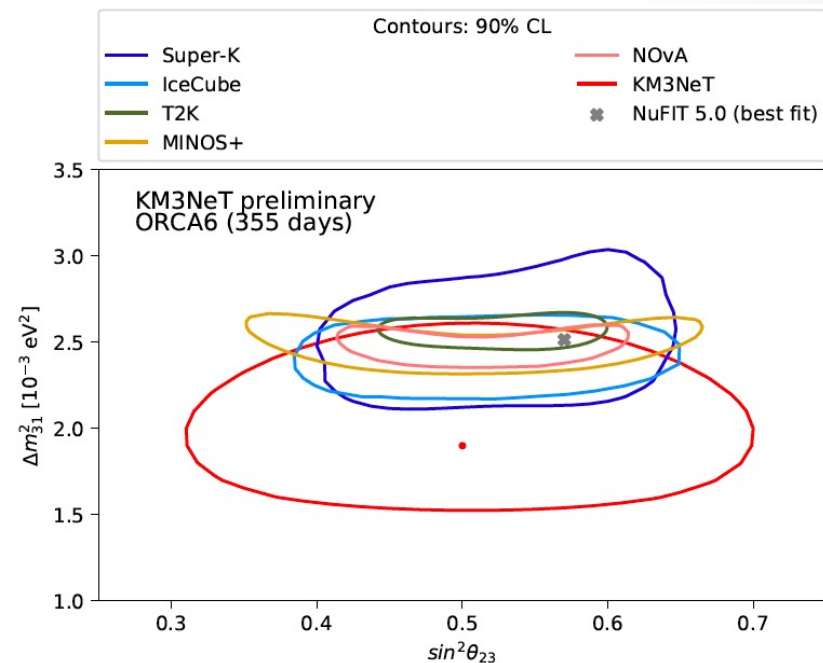
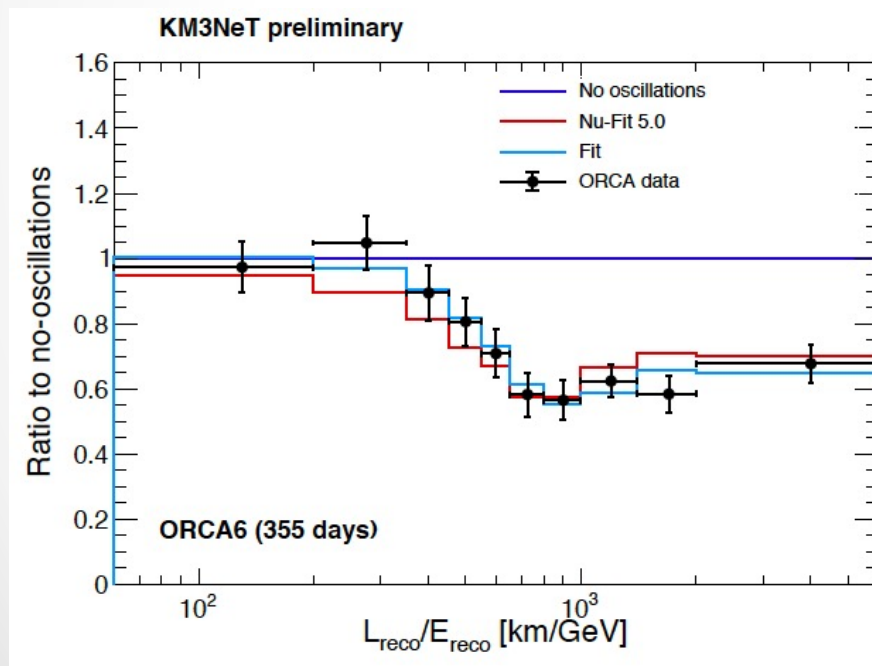
21 lines installed



	ORCA	ARCA
String spacing	20 m	90 m
OM spacing	9 m	36 m
Instrumented mass	7 Mton	500*2 Mton

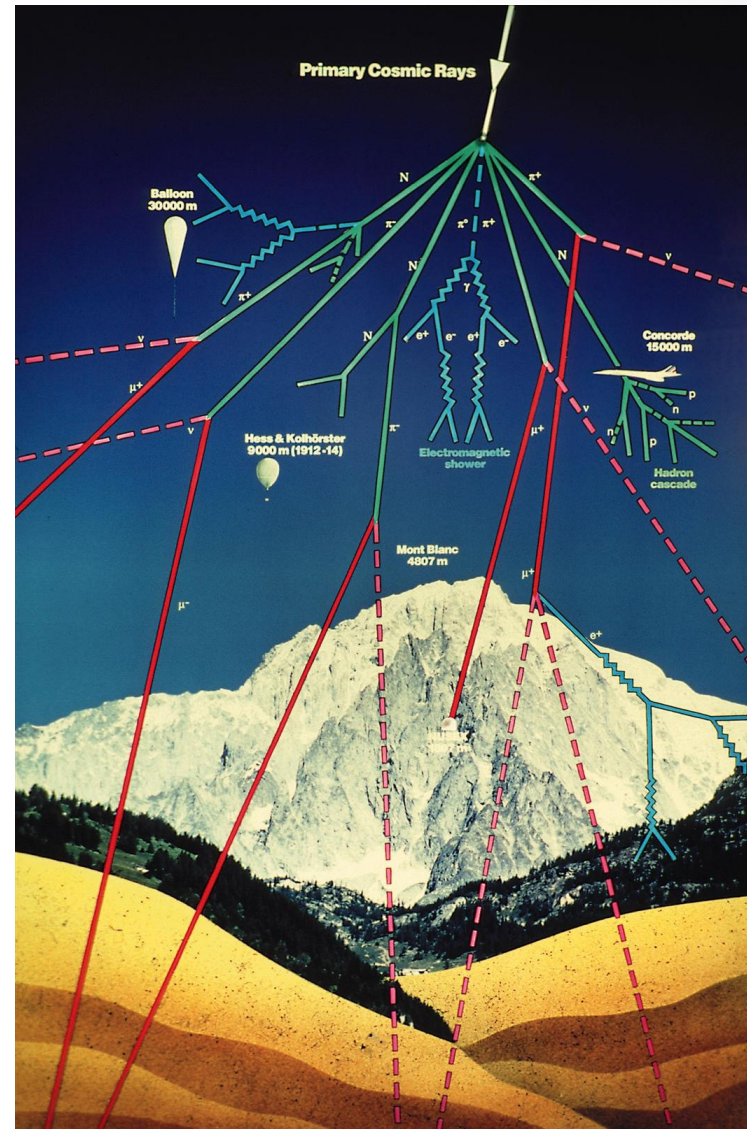
Neutrino telescopes in the Mediterranean Sea – KM3NeT

- Under construction at two sites
- **ORCA : GeV** energies : 6 lines & 1 year operations
- First physics results in 2020



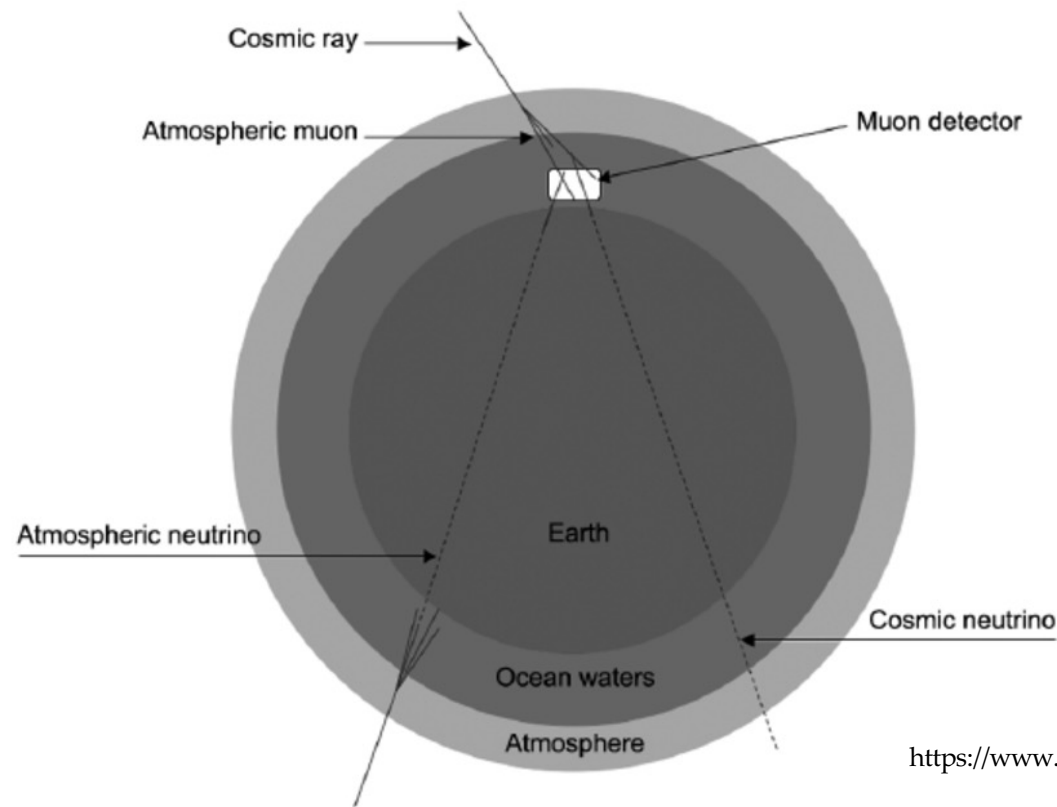
Cosmic ray showers

- Cosmic ray showers are a powerful neutrino source
- Potential source of dark mediators with coupling to quarks



Particles from CR showers

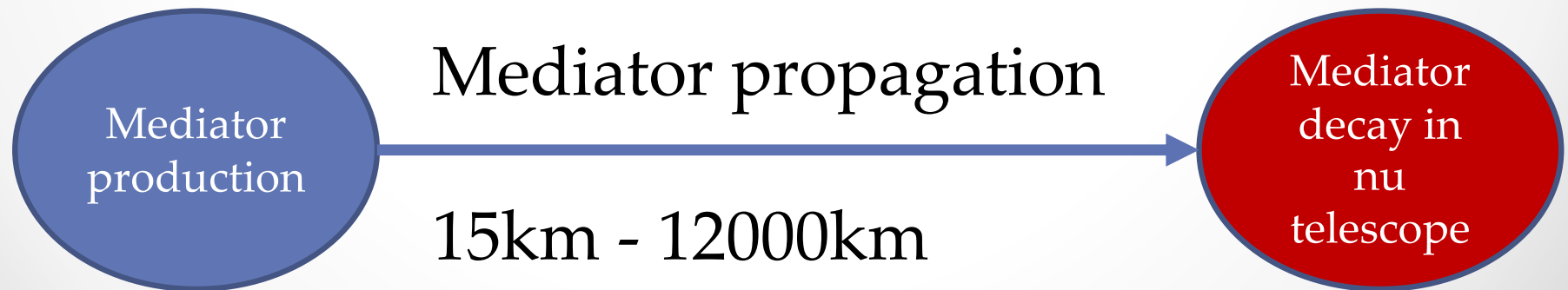
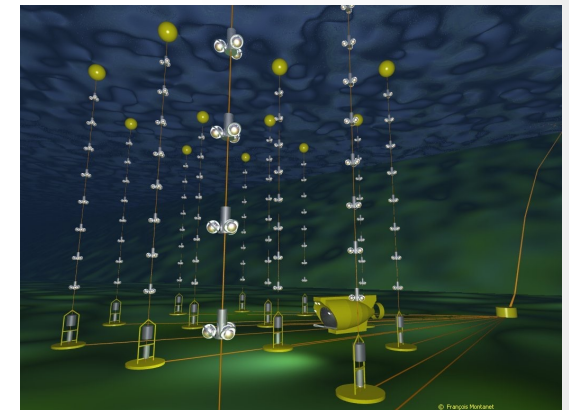
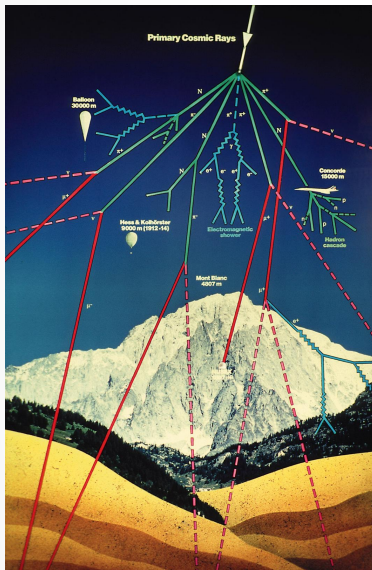
- Large range of energies accessible **GeV - PeV**
- Large range of baselines : **20km – 12000km**



<https://www.researchgate.net/publication/50301401>

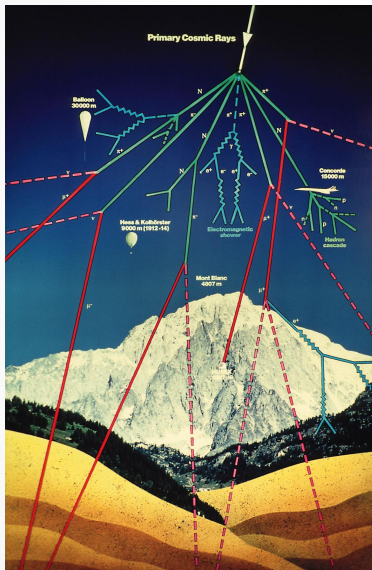
Example for mediator-based dark matter searches

- Mediator production in cosmic ray showers

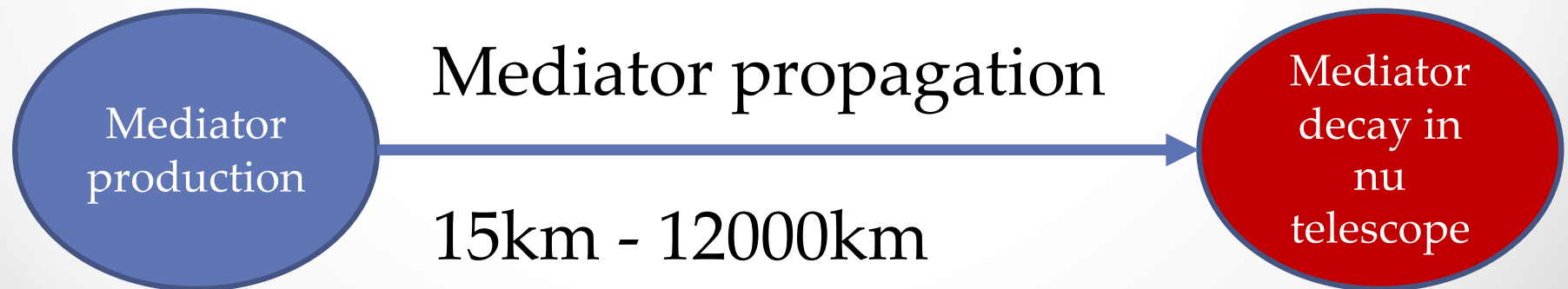
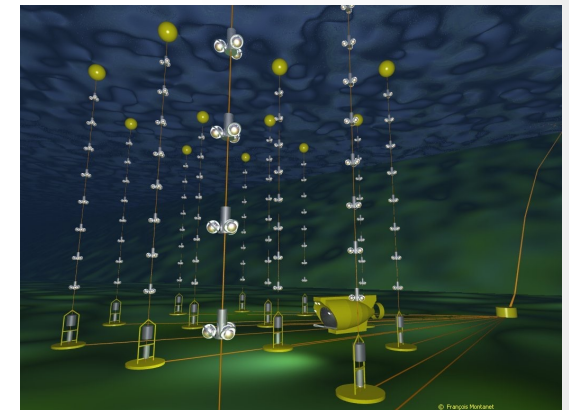


Example for mediator-based dark matter searches

- Propagation length \gg active detector decay path



In minimal models lifetime correlates inversely coupling
Non-minimal models : production and decay might be governed by different mechanisms



Potential for neutrino telescopes

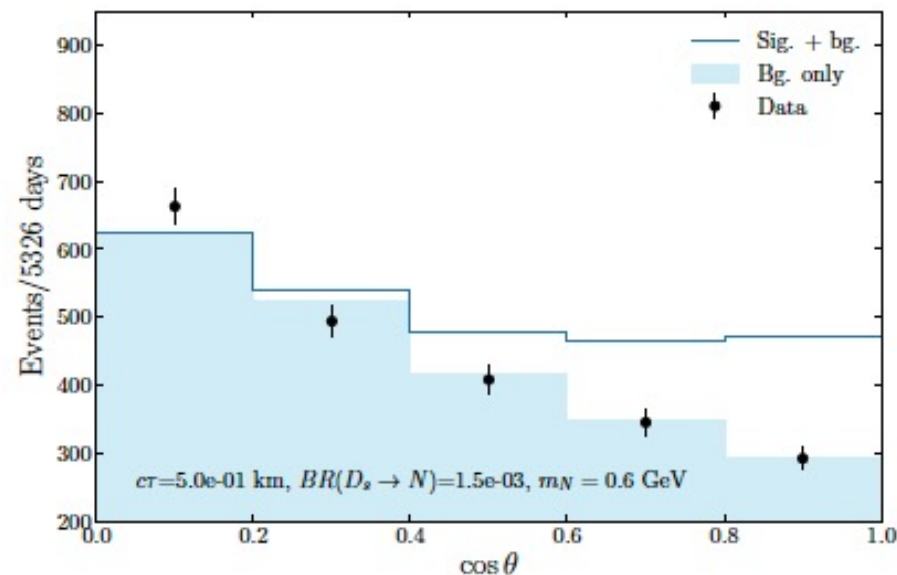
- Recently explored for IceCube and Superk

Searches for Atmospheric Long-Lived Particles

C. Argüelles,^a P. Coloma,^b P. Hernández,^b V. Muñoz,^b

arXiv:1910.12839

- Example : expected additional events in SuperK
- HNL hypothesis



Potential for neutrino telescopes

- Recently explored for IceCube and Superk

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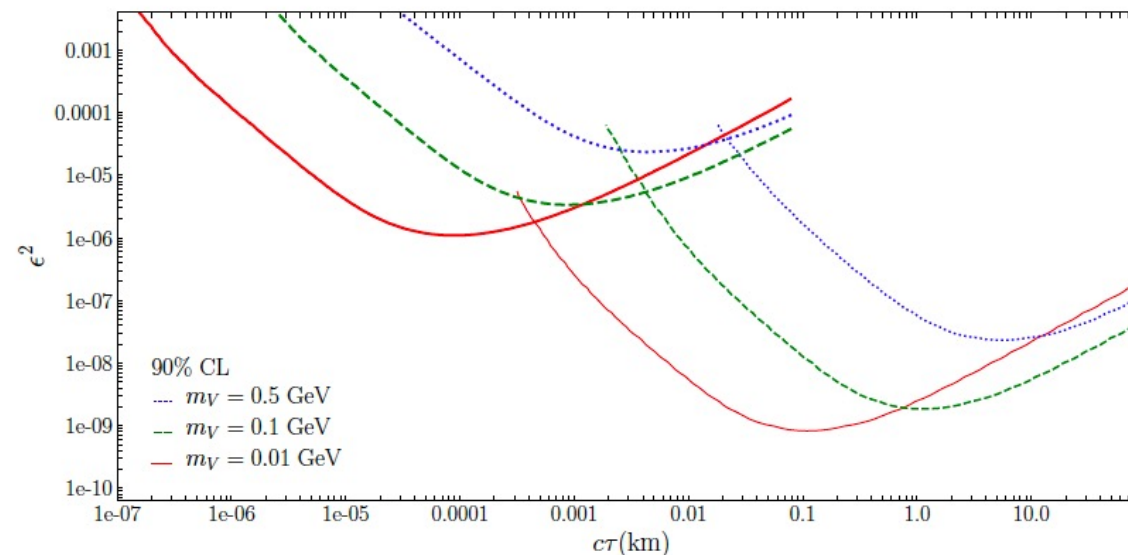
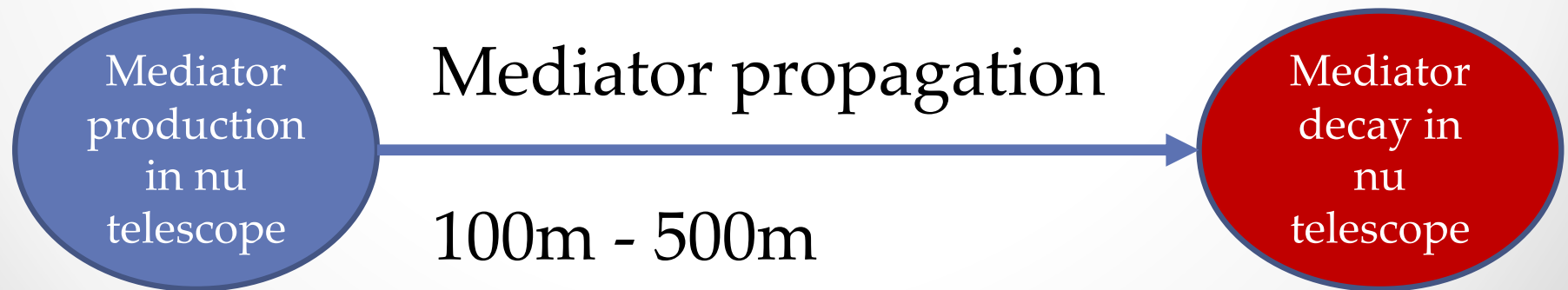
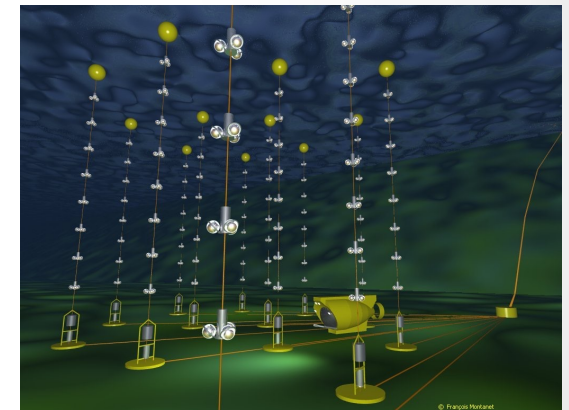
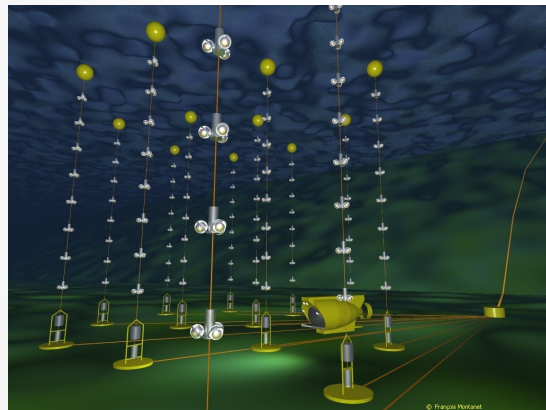


Figure 16. Limits on dark photons decays from IceCube (thick lines) and Super-Kamiokande (thin lines) on the ϵ^2 vs $c\tau_V$ plane including production from π_0, η decay and bremsstrahlung for $m_V = 0.01\text{GeV}$ (solid), 0.1GeV (dashed) and 0.5 GeV (dotted).

Example for mediator-based dark matter searches

- Mediator production and decay inside detector



Potential for neutrino telescopes

- Recently explored for IceCube - feasibility

Double Bangs from New Physics in IceCube

Pilar Coloma,^{1,*} Pedro A. N. Machado,^{1,†} Ivan Martinez-Soler,^{2,‡} and Ian M. Shoemaker^{3,§}

arXiv:1707.08573

- Signal : double-bang events in low energy !
- HNL hypothesis

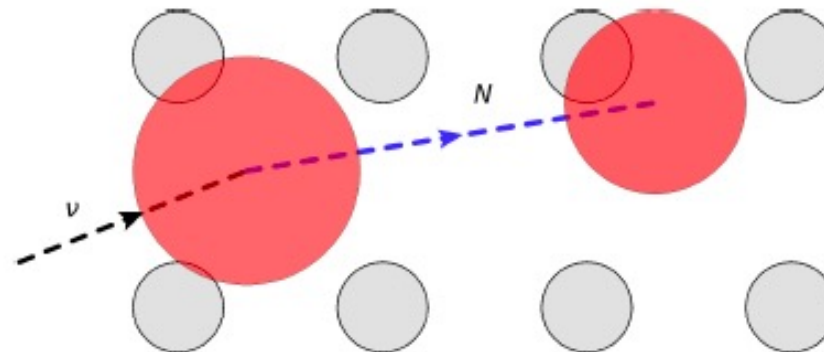


FIG. 1: Schematic illustration of a DB event in IceCube. An incoming active neutrino ν up-scatters into a heavy neutrino N , which then propagates and decays into SM particles. The small circles represent the DOMs while the large circles indicate the positions where energy was deposited.

Potential for neutrino telescopes

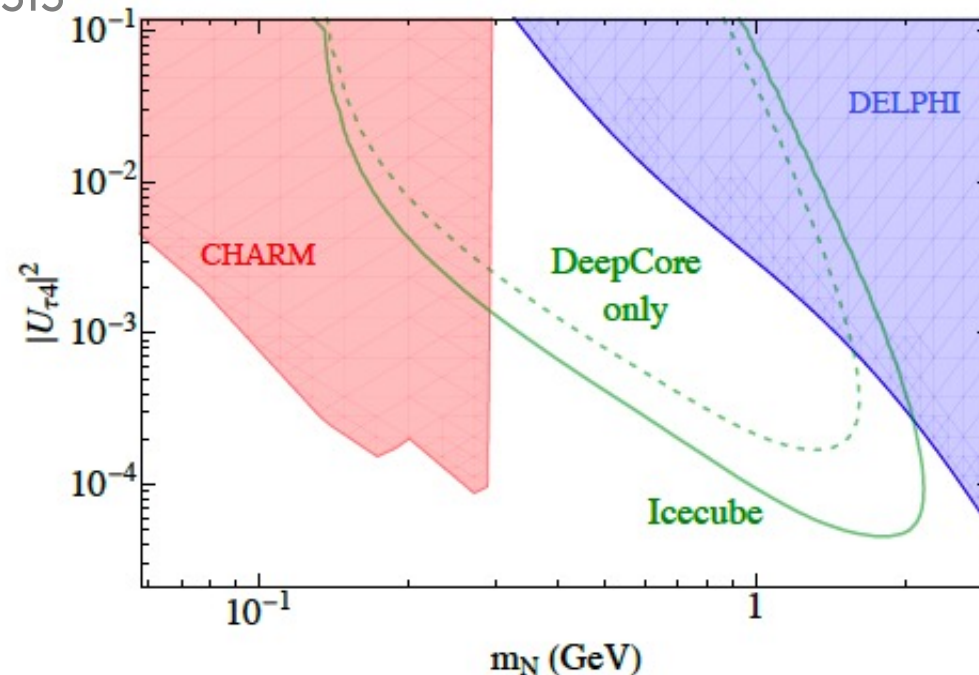
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Double Bangs from New Physics in IceCube

Pilar Coloma,^{1,*} Pedro A. N. Machado,^{1,†} Ivan Martinez-Soler,^{2,‡} and Ian M. Shoemaker^{3,§}

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- Competitive limits in coupling – mass space
- HNL hypothesis



Why DMLab

- Complementary competences in France / Germany
- France (CPPM)
 - Atmospheric neutrino flux
 - Modelling of exotic signals and background
 - Detector response (efficiency, resolutions)
 - Optimisation of signal/background for each analysis
- Germany (DESY)
 - Mediator production mechanisms
 - Bremsstrahlung, meson-mixing
 - Mediator decays (leptonic, hadronic)
 - Mediator radiative processes

Complications

- Man power needed to proceed
- PhD and/or Postdoc to be hired
- DMLab cannot provide man power but support programs (?)
- Financing ideally via ANR/DFG projects
- Caveat : DESY not eligible
- Suggestion from DMLab welcome
- PhD thesis in co-direction ??

Conclusion

- Mediator based dark matter searches is an exciting and relatively new field
- Neutrino telescopes are in a good position to contribute
- So far no analyses done for the Mediterranean neutrino telescopes !

backup