Dark (pseudo)scalar and photon searches in neutrino experiments

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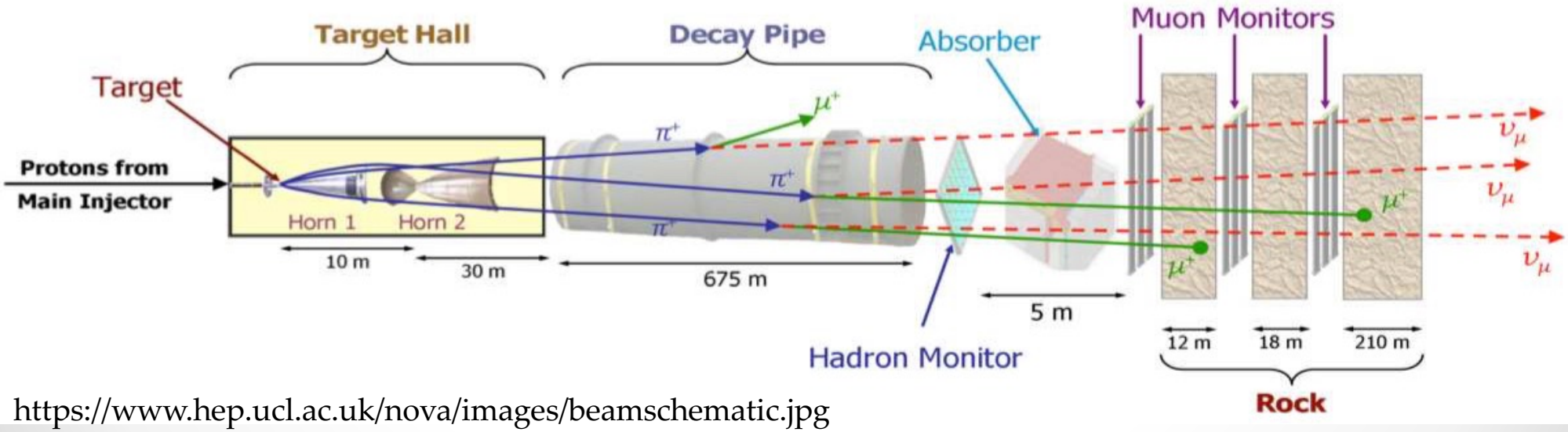
Neutrino beams

- Neutrinos can be created in proton+proton interactions and subsequent pion decays
- Rich source of dark particles with coupling to pions/protons



https://www.hep.ucl.ac.uk/nova/images/beamschematic.jpg

γ' production from π^o

Meson decays → mixture of γ & γ'

$\pi^o \rightarrow \gamma + \gamma'$

branching ratio $2\varepsilon^2$ for small ε

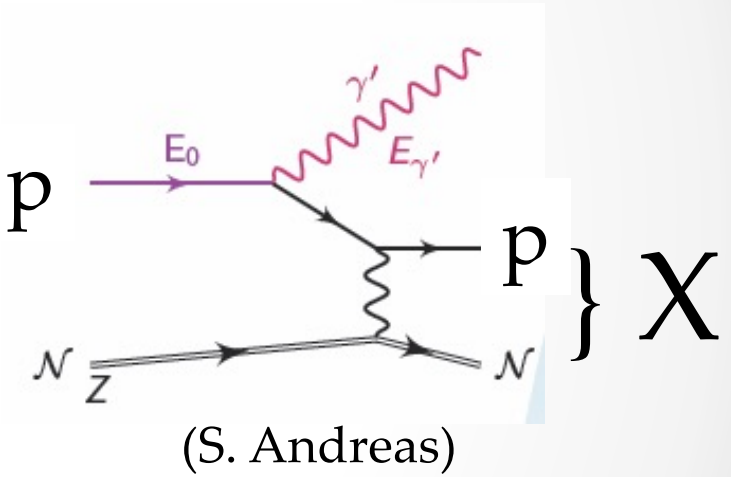
Full production cross section via π^o

$$\sigma(pp \to \gamma' X) = 2\epsilon^2 \left(1 - \frac{m_{\gamma'}^2}{m_{\pi^0}^2}\right)^3 \mathrm{Br}(\pi^0 \to \gamma\gamma)\sigma(pp \to \pi^0 X),$$

J.Blümlein, J. Brunner, Physics Letters B701 (2011) 155.

γ' production via bremsstrahlung

- Small-angle Initial-state Bremsstrahlung
- Details of p-N final state not considered
- Non-pertubative
- Calculation in William-Weizsäcker-Approximation

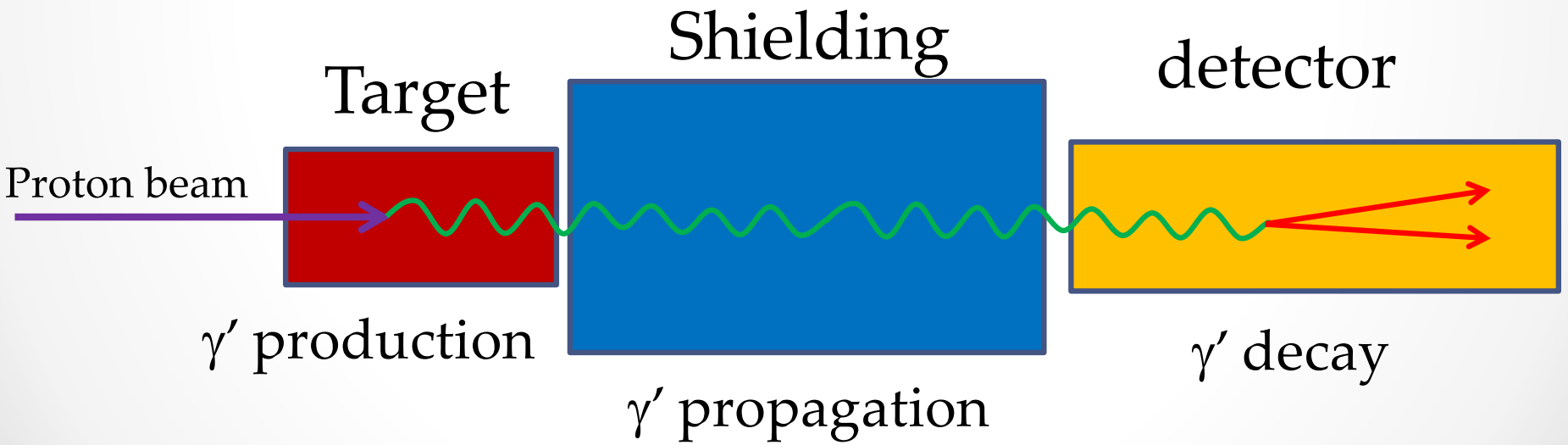


(S. Andreas)

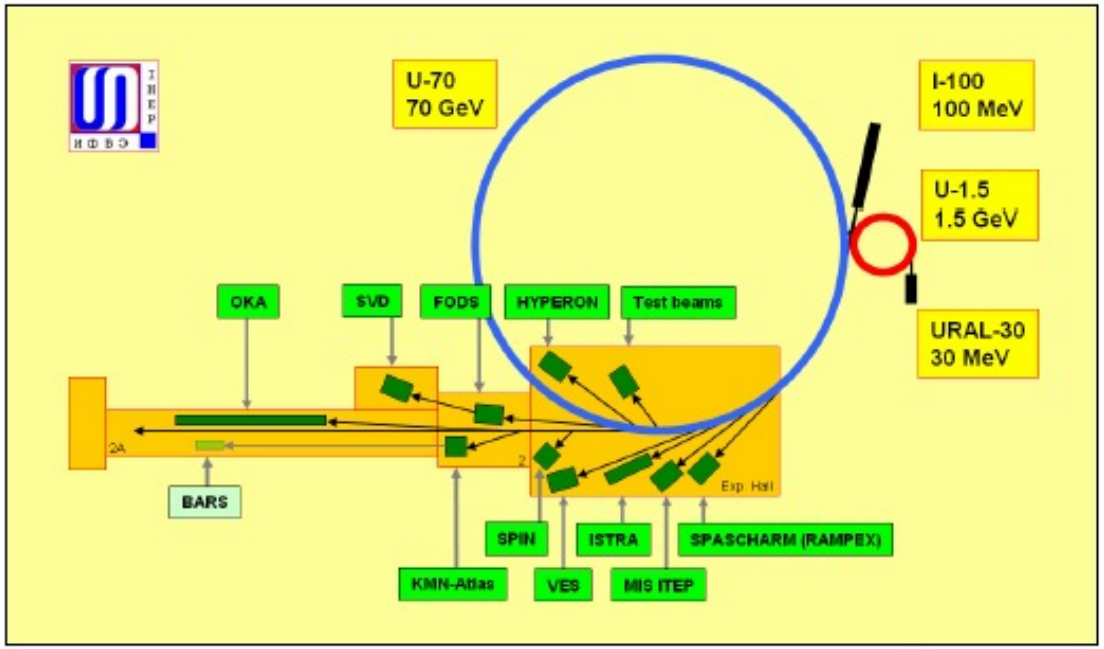
J.Blümlein, J. Brunner, Physics Letters B731 (2014) 320.

Neutrino beam in beam dump mode → dark photon beam

- Decay inside active detector volume
- Signal : lepton pair without hadronic activity



U70 Accelerator Protvino, Russia



4 machines (since Oct 2007):
- 2 linacs
- 2 synchrotrons

Modes:
- proton (default) URAL30-U1.5-U70
- light-ion (*d*, C) I100(2 of 3)-U1.5-U70

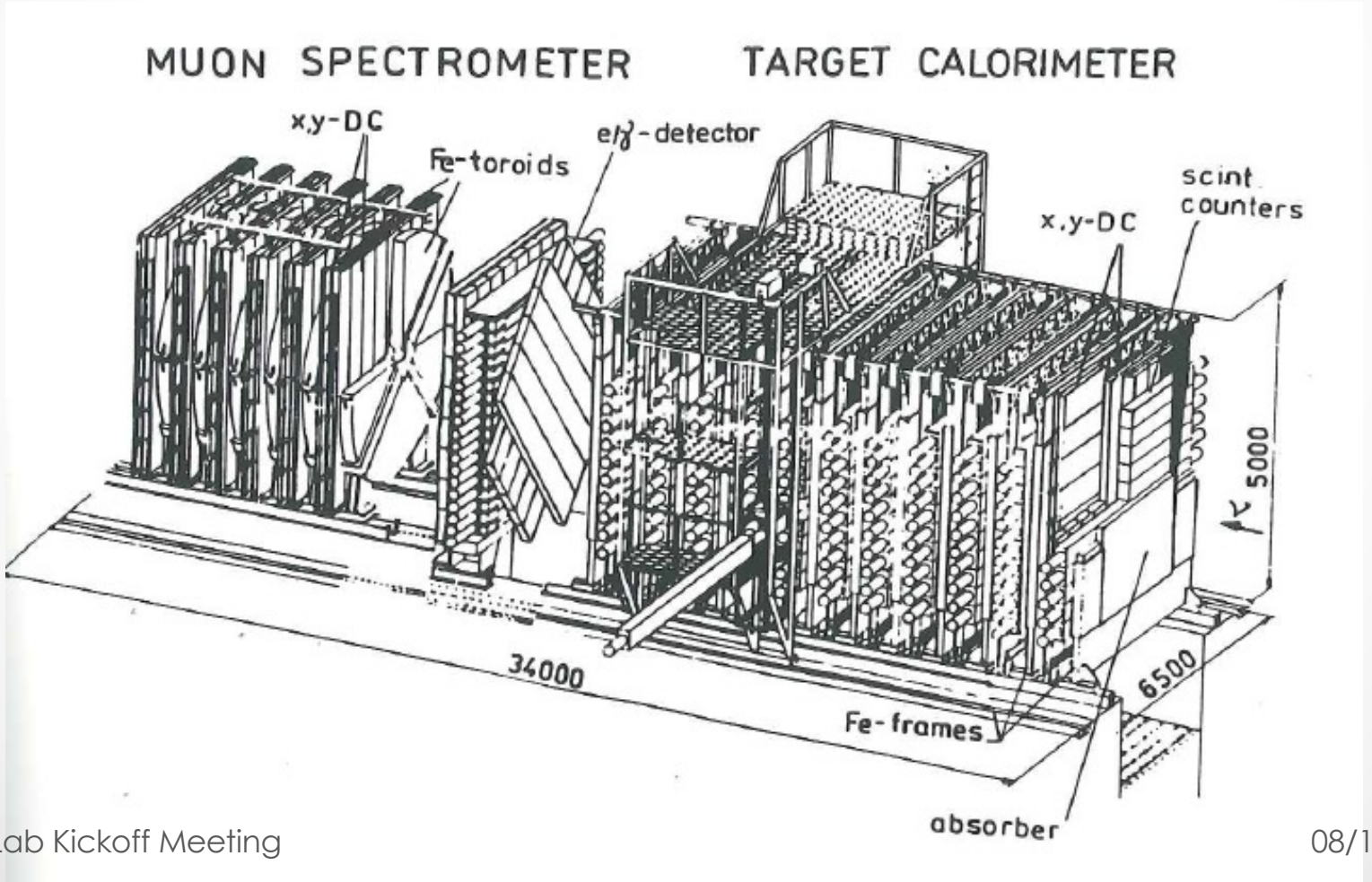
to note: OKA (#21), FODS (#22), stretcher (#25)

Light-ion:
- high energy 24.1-34.1 GeV/u
- intermediate energy 453-455 MeV/u

In a SIS-18, SIS-100 name convention:
- LIS-233 [T·m]
- LIS-6.9 [T·m]

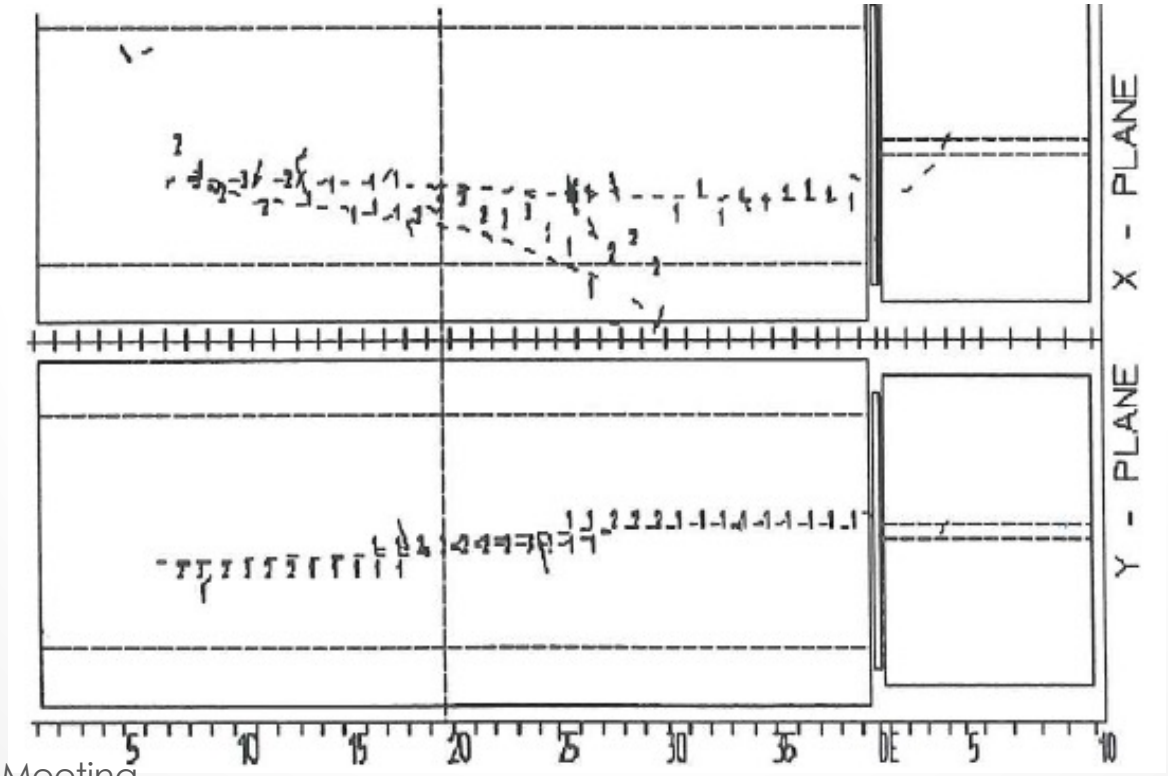
Detector : NuCal 1

- Classical Neutrino Calorimeter



Selected Dimuon-Event

- Small hadronic activity
- Muons almost colinear



Comparing setups

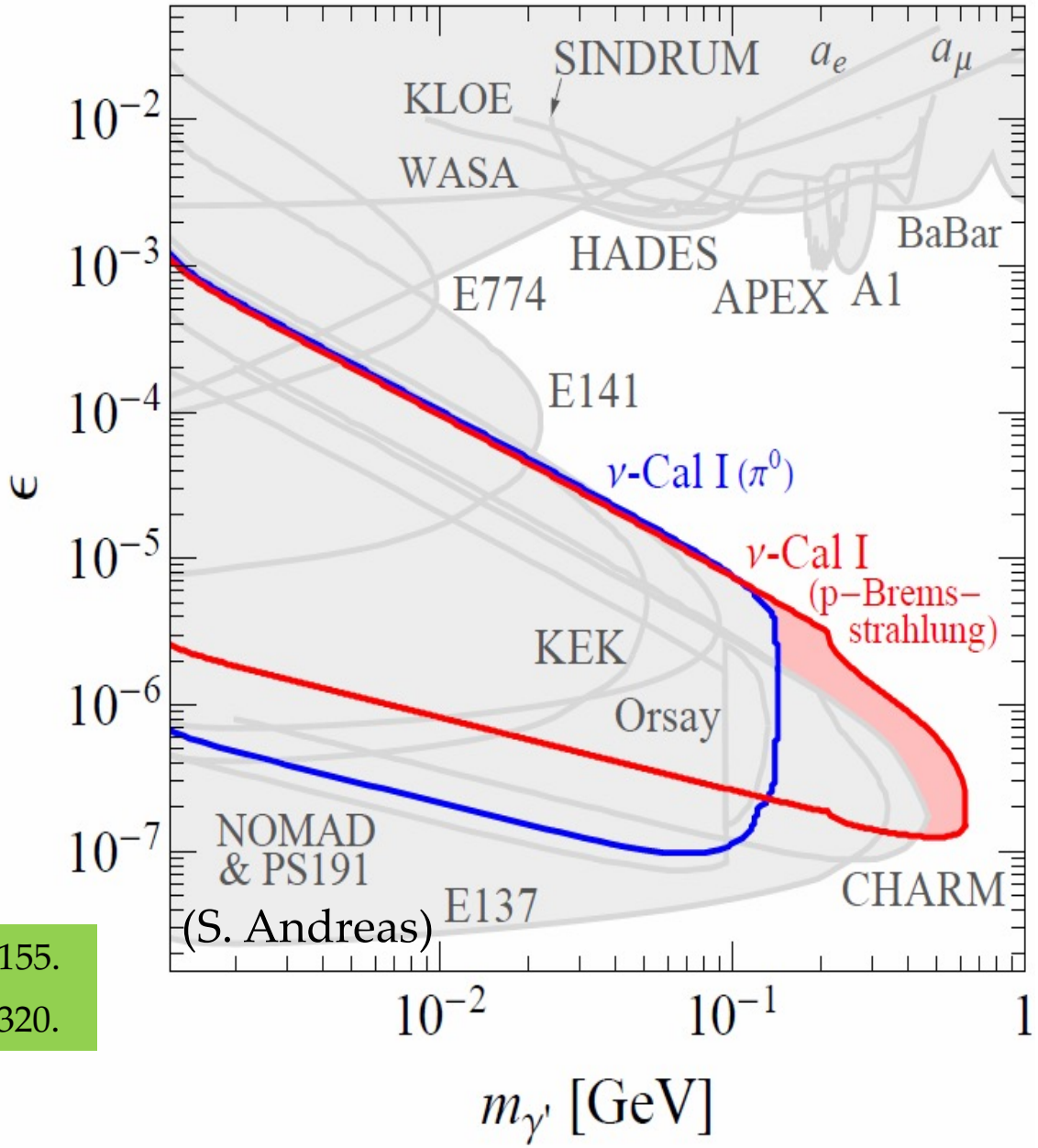
	Charm	PS191	NOMAD	NuCal	SHIP
BeamEnery	400 GeV	19.2 GeV	450 GeV	70 GeV	400 GeV
p.o.t.	$2.4\ 10^{18}$	$8.6\ 10^{18}$	$4.1\ 10^{19}$	$1.7\ 10^{18}$	$2.0\ 10^{20}$
Distance	480m	128m	835m	64m	60m
Detector	35m	12m	7.5m	23m	160m
Radius	1.5m	1.5m (?)	1.8	1.3m	2.5m

Charm, PS191, NOMAD (not designed to search for decay of heavy penetrating particles) have non-optimal design → large distance to target, short detector → incidentally also very similar sensitivities

NuCal and SHIP better suited, probe larger parameter space

Results from NuCal 1

- New regions can be excluded
- Large overlap of limits from existing proton beam dump experiments



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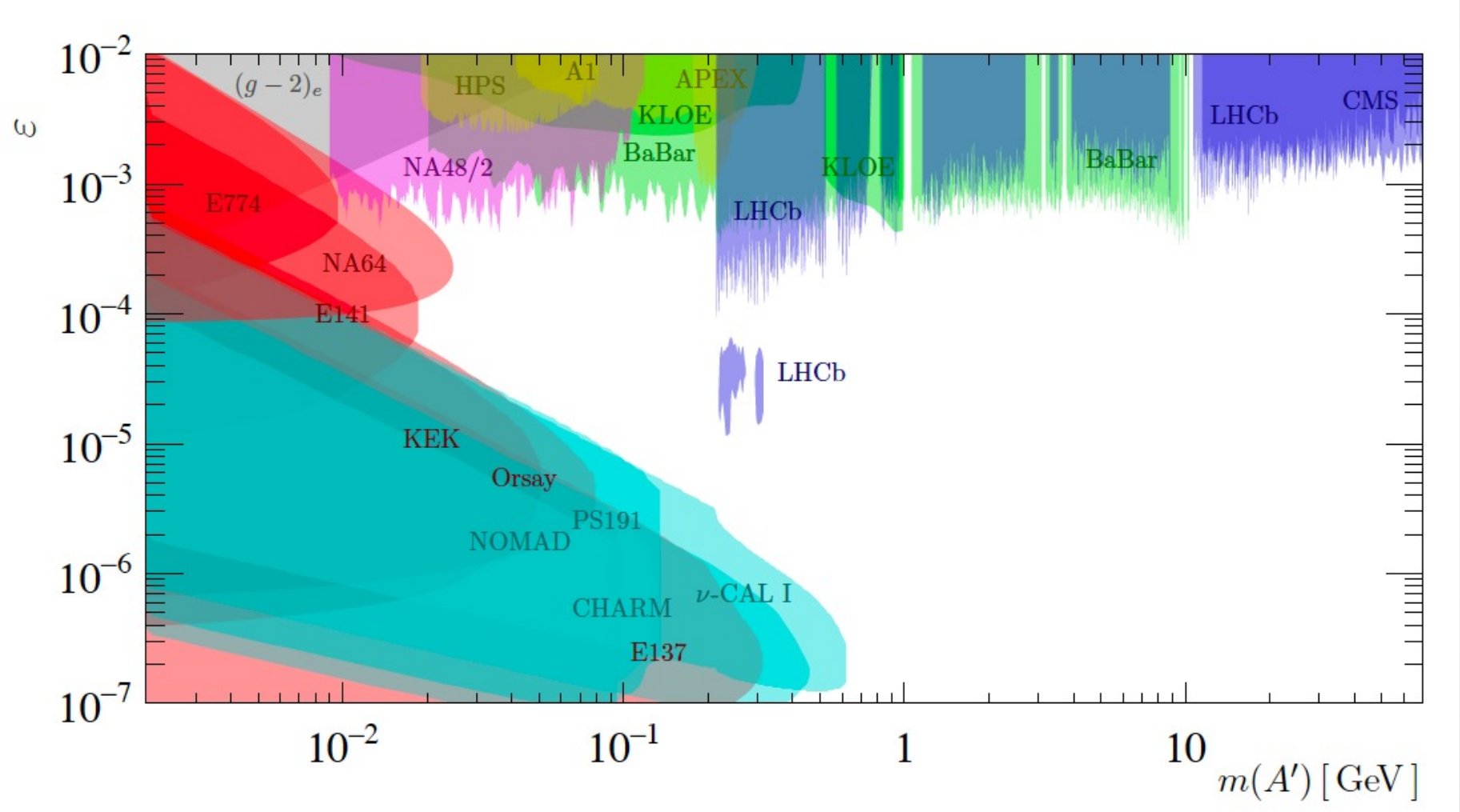
Summary of existing Result 2021

- NuCal 1 result still relevant

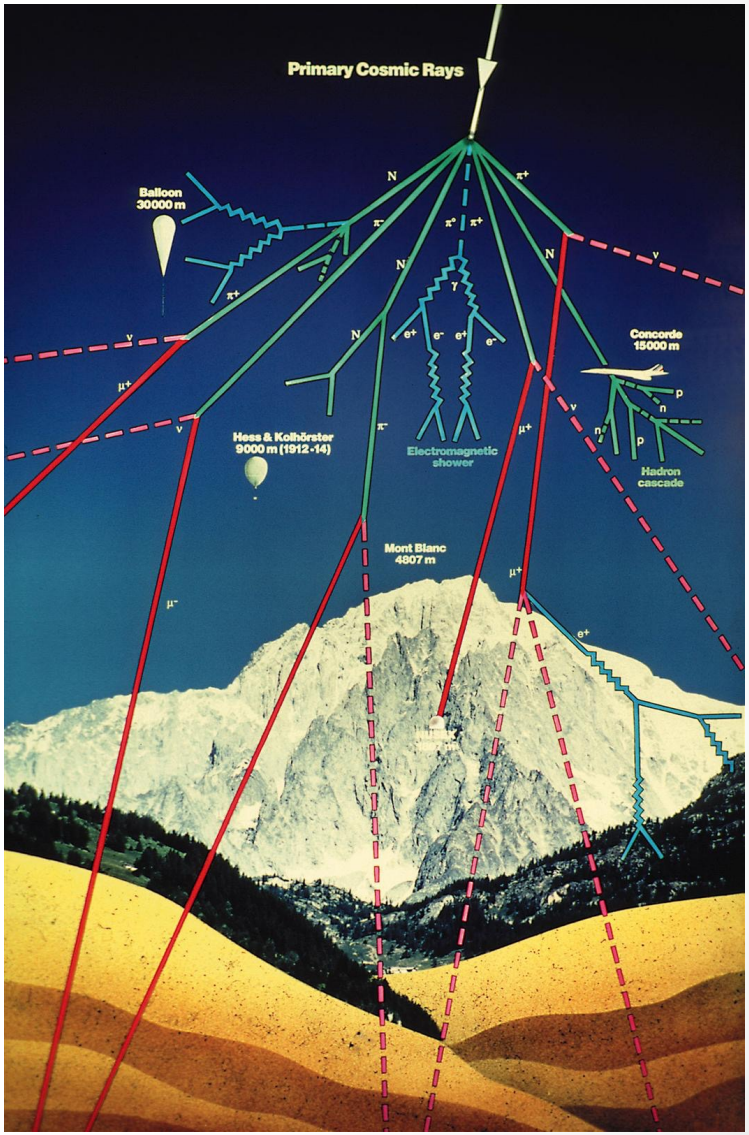


arXiv:2104.10280

Atmospheric neutrinos

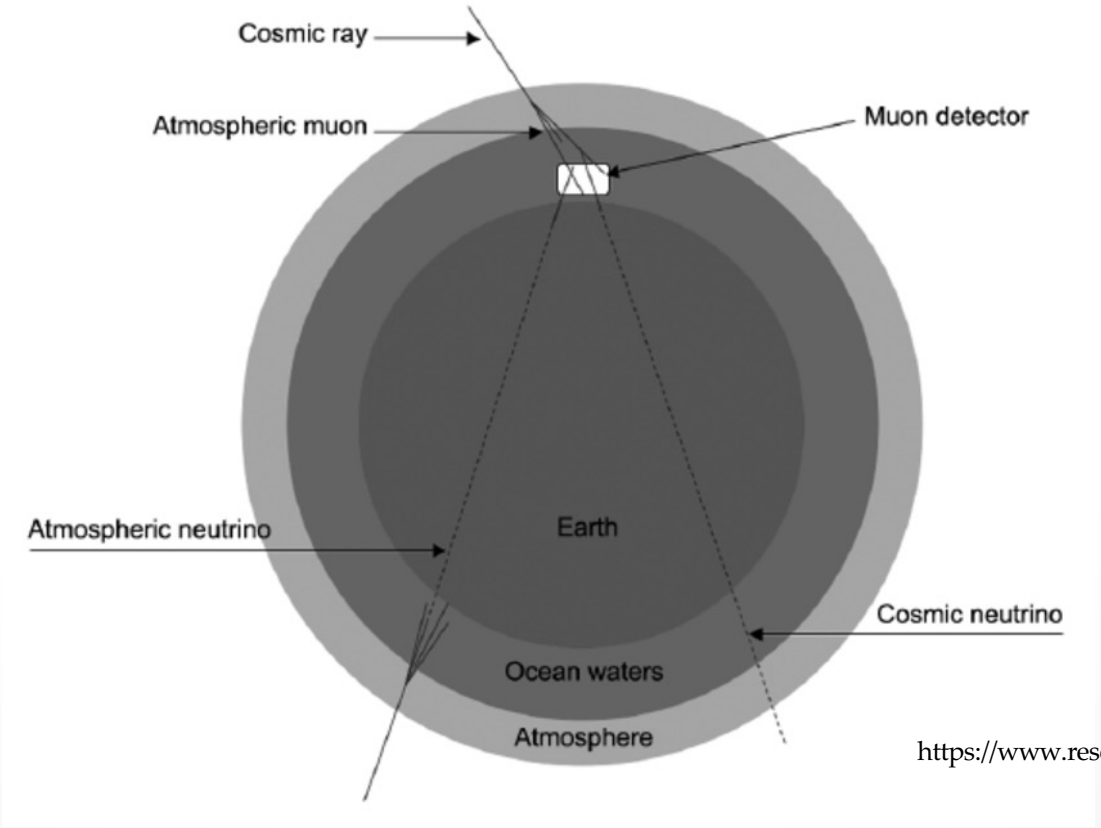
- Cosmics ray showers are a powerful neutrino source

- Potential source of dark mediator particles with coupling to pions and/or protons



Atmospheric neutrinos

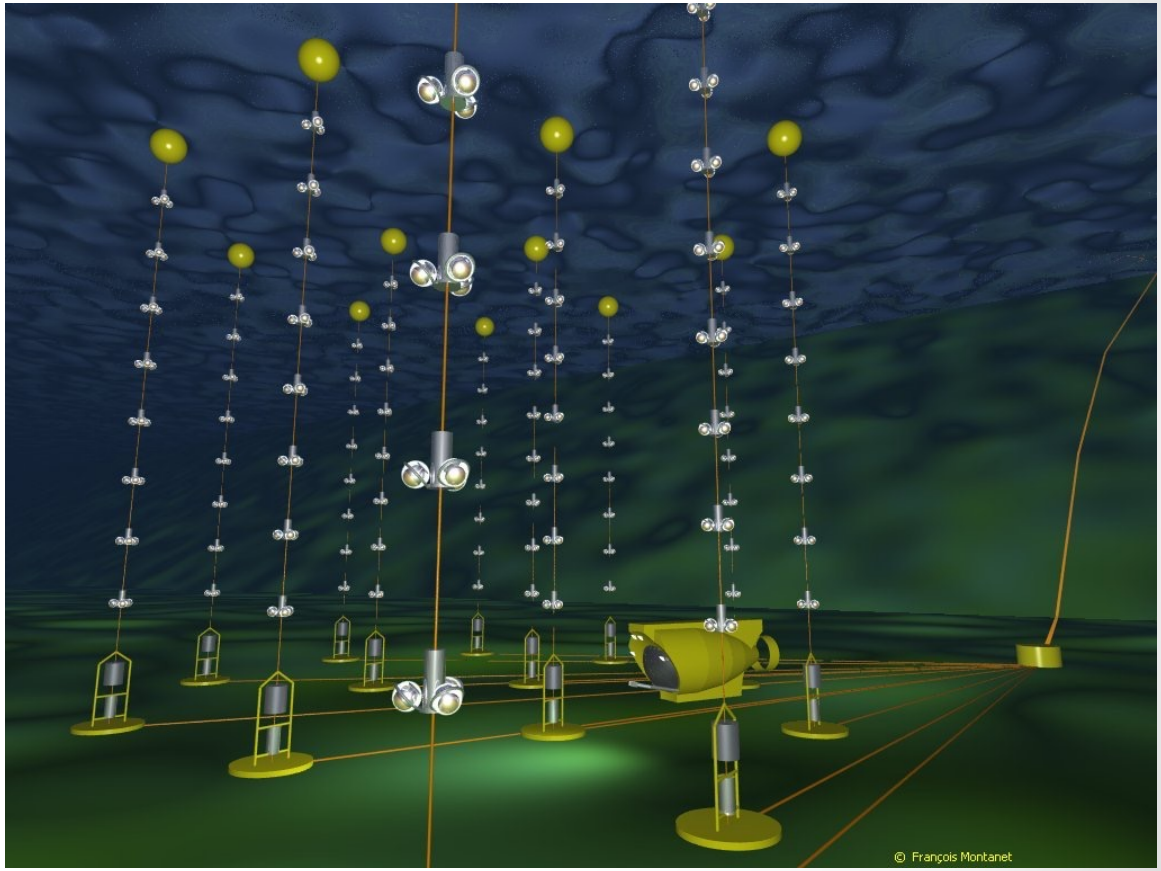
- Large range of energies accessible GeV - PeV
- Large range of baselines : 20km – 12000km



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

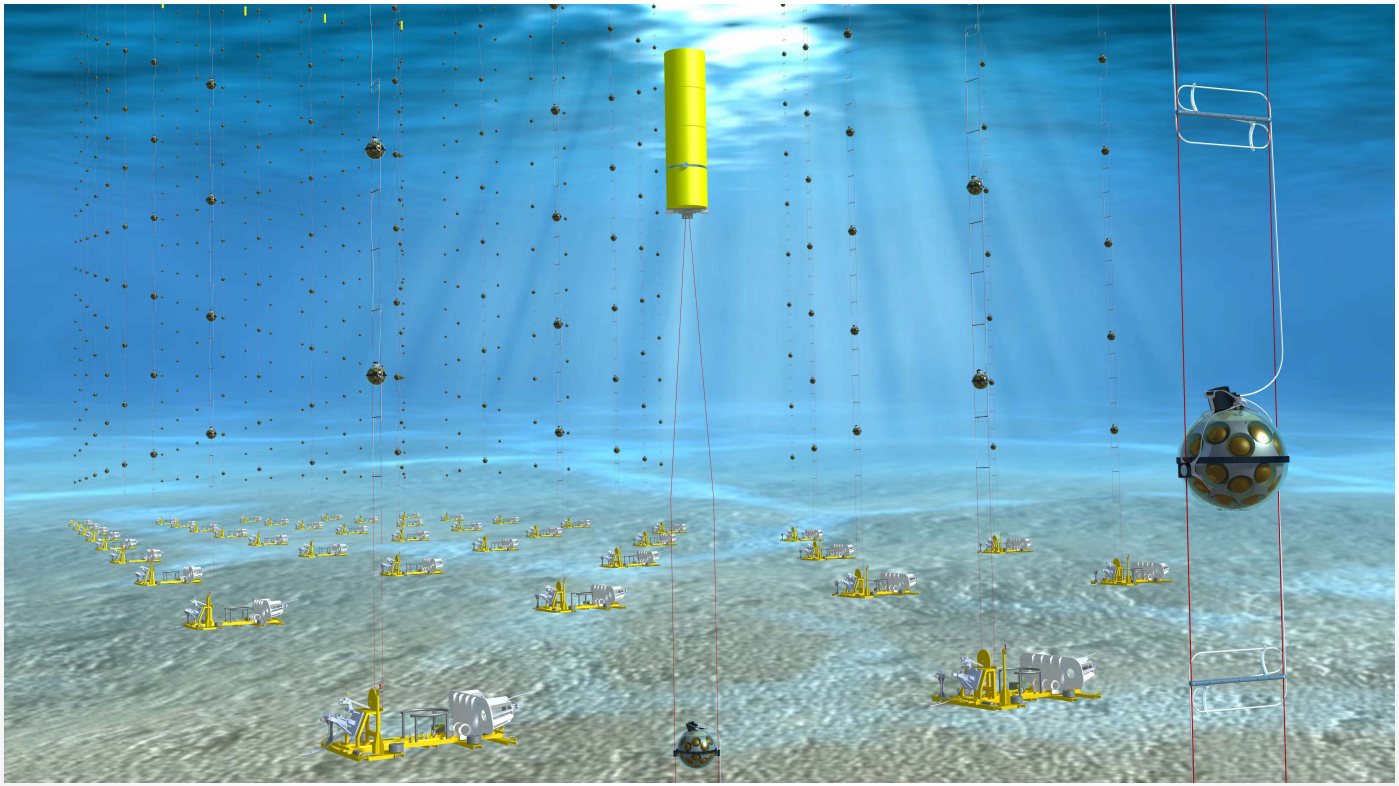
Neutrino telescopes in the Mediterranean Sea - ANTARES

- Continuous data taking since 2006
- Detector completed in 2008
- Rich data sample from more than 15 years
- ~15,000 atm ν recorded



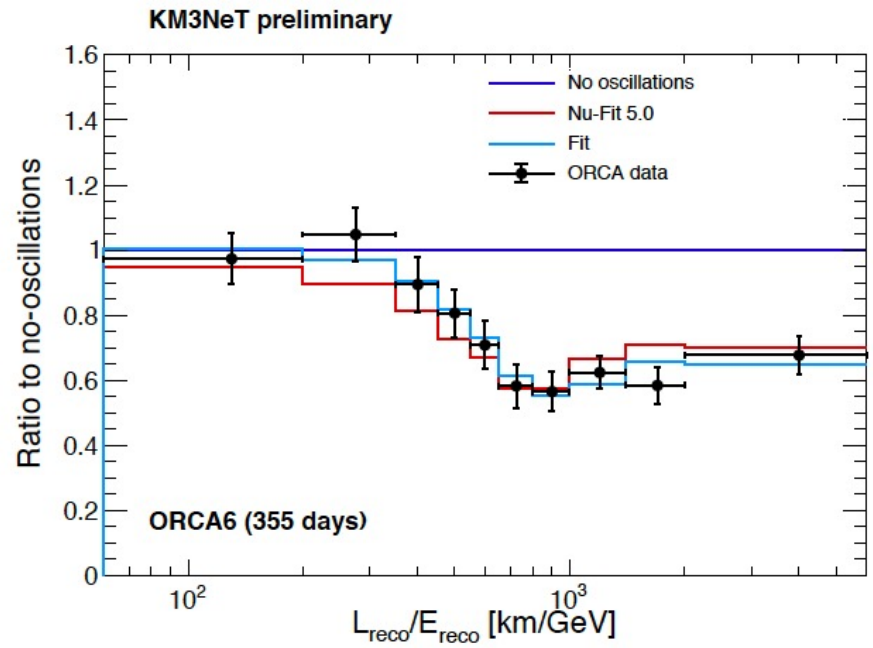
Neutrino telescopes in the Mediterranean Sea – KM3NeT

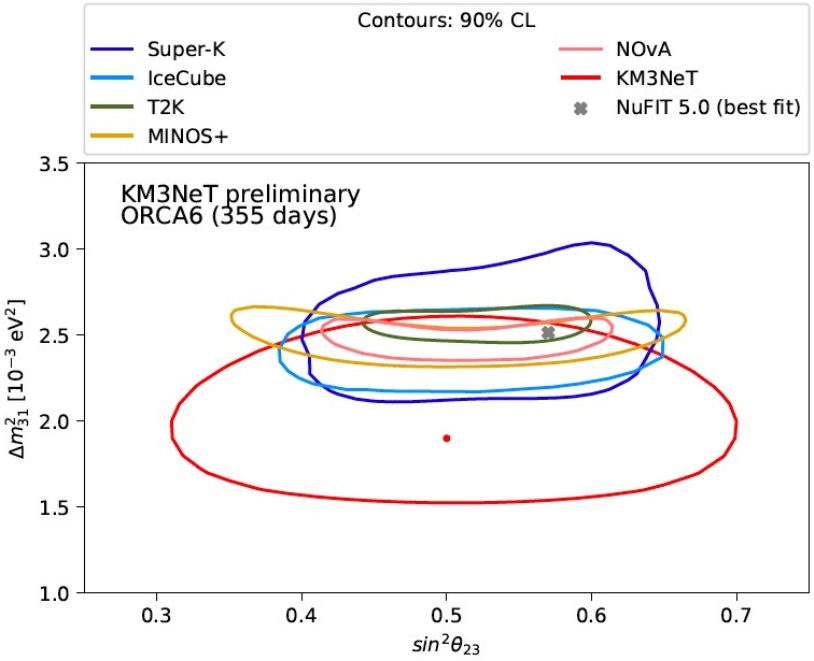
- Under construction at two sites
- ARCA : TeV-PeV energies, 8 lines operational
- ORCA : GeV energies : 10 lines operational



Neutrino telescopes in the Mediterranean Sea – KM3NeT

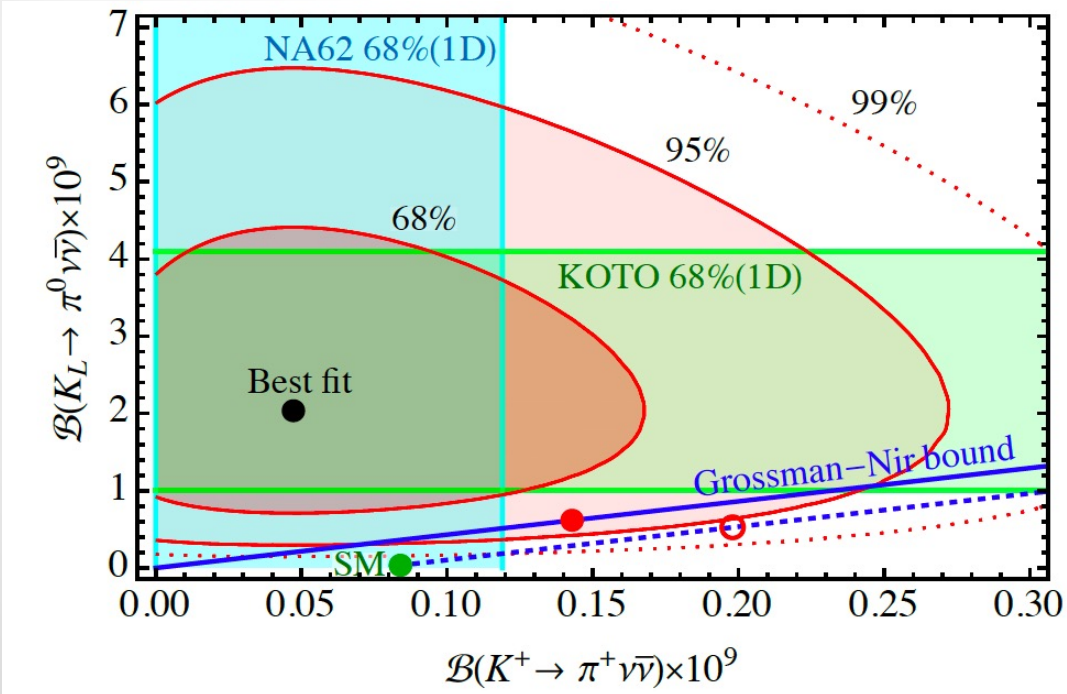
- Under construction at two sites
- ORCA : GeV energies : 6 lines & 1 year operations
- First physics results in 2020

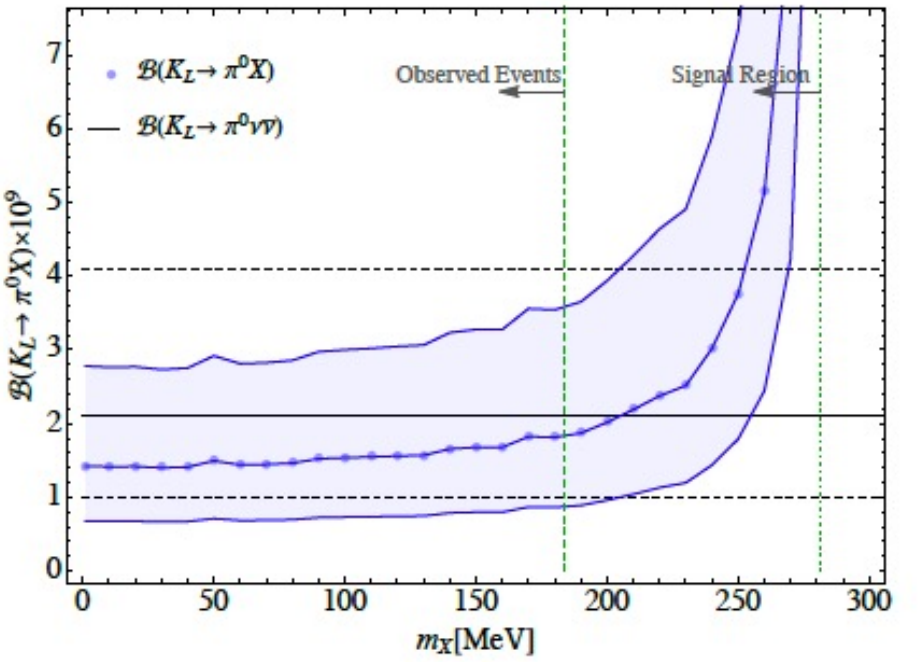




KOTO – rare Kaon decays

- Anomaly in K_L decays observed
  - 3 events versus 0.1 expected
- Could be interpreted as dark photon signal





arXiv:1909.11111

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

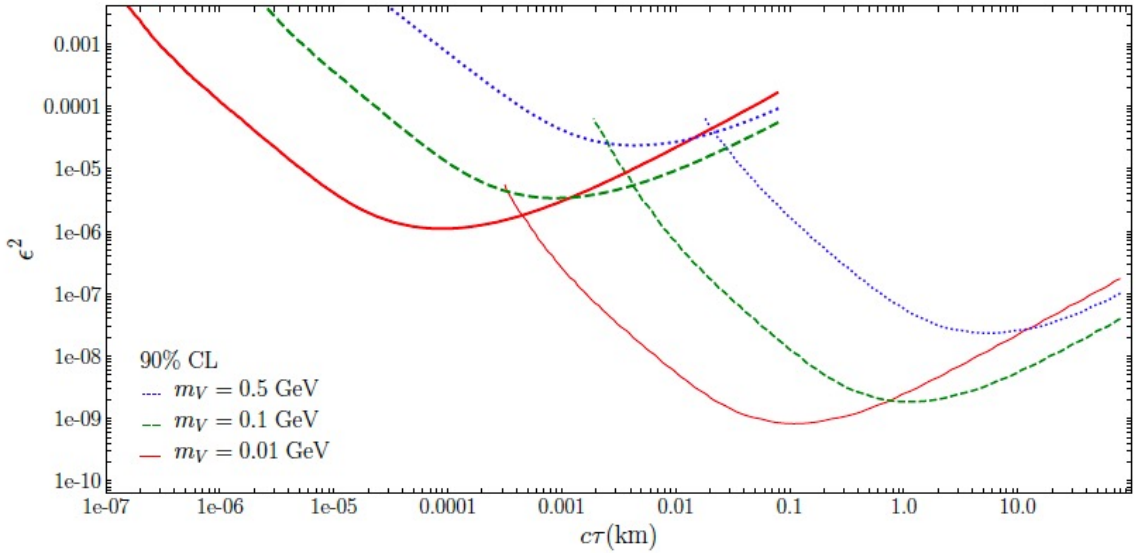


Figure 16. Limits on dark photons decays from IceCube (thick lines) and Super-Kamiokande (thin lines) on the ϵ^2 vs $c\tau_V$ plane including production from π_0, η decay and bremsstrahlung for $m_V = 0.01$GeV (solid), 0.1GeV (dashed) and 0.5 GeV (dotted).

Conclusion

- Dark (pseudo)scalar / photon search is an exciting and relatively new field
- Neutrino telescopes are in a good position to contribute

Program within DMLab

- creation of a phenomenological code to describe the production and decay of dark sector particles
- creation of a toy Monte Carlo to describe the detector response of a neutrino telescope for such a particle (KM3NeT / ANTARES)
- one or more related publications
- PhD thesis (candidate to be identified)
- Multiple short visits DESY ← → CPPM

backup