Neutrino Program KM3NeT/ANTARES/(proto)DUNE

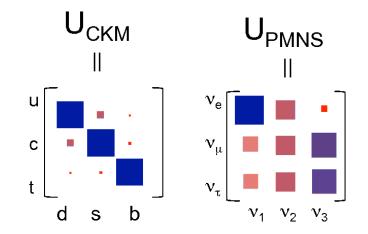
1. Introduction (Paul de Jong)
 2. KM3NeT data analysis (Rodrigo Gracia)

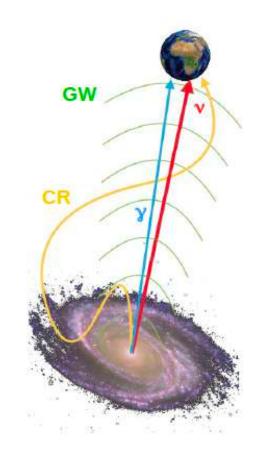
Neutrino Group Physics Ambitions:

- Neutrino properties through oscillations
 Neutrino mass ordering: normal or inverted?
 Mixing parameters, test of 3-generation framework
 CP-violation in neutrinos
- Astrophysics: neutrinos as messengers
 Find sources and study physics inside sources
 Multi-messenger: relation gravitational waves, CR, γ-rays
- Dark matter

Neutrinos from DM annihilation, sterile neutrinos

• Fundamental physics, BSM physics





Glossary:

<u>KM3NeT</u>: a km³ neutrino telescope in the Mediterranean Sea. One densely instrumented block **ORCA** (France): 10 effective volume [Mm³] KM3NeT / ANTARES Preliminary *neutrino oscillation physics* ARCA (1 block) 10^{3} Two large blocks **ARCA** (Italy): astrophysics with cosmic neutrinos 10² ORCA ANTARES 10 **ANTARES**: a predecessor, since 2007, near Toulon $v_{\mu} CC$ 10-1 10^{3} 10² 10⁵ 10⁴ 10⁶ 10

DUNE: Deep Underground Neutrino Experiment

at Sanford Underground Research Facility, Lead, South Dakota, USA 4 x 10kton Liquid Argon TPC, *neutrino oscillation physics* Neutrino/antineutrino beam from Fermilab (baseline 1300 km) A prototype single-phase LAr TPC **protoDUNE** built at CERN (beam data 2018, cosmics 2019)

neutrino energy [GeV]

The Nikhef Neutrino Group



Joined: Staff: *Daan van Eijk*

Postdoc: *Rodrigo Gracia Ruiz, Fatih Bay, Suzan Basegmez du Pree* PhD: *Bouke Jisse Jung* MSc: *Clara Gatius, Maarten Hammer*

Left: Postdoc: Bruno Strandberg

MSc: Enrique Huesca Santiago, Maarten Post, Max Briel, <u>Thijs van Eeden</u>

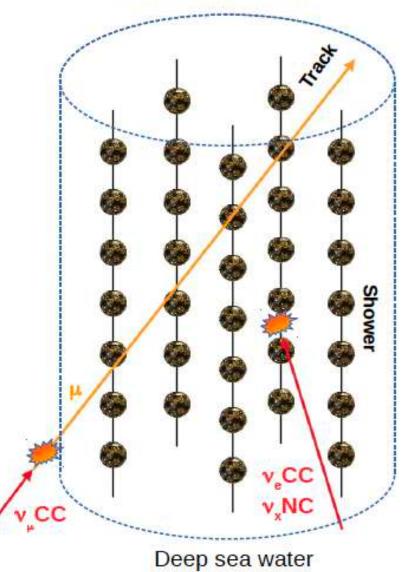
BSc students: Iris Reitsma, Maite Boden, Karlijn Kruiswijk, Jasper Bootsma Visitors from Ecuador: Harold Yepes Ramirez, Juan David Alcivar Espin, Genesis Marisol Mendoza Celorio

Funding: NWO Physics Programme "The Hidden Universe of Weakly Interacting Particles" VICI Aart Heijboer NWO Roadmap Grootschalige Wetenschappelijke Infrastructuur

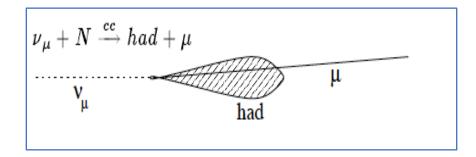
2020

Detection Principle

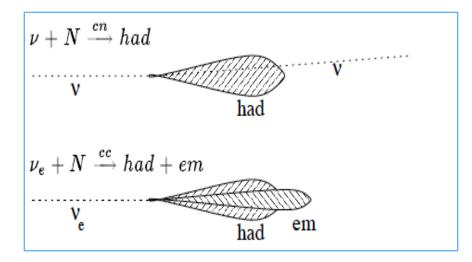
Instrumented volume

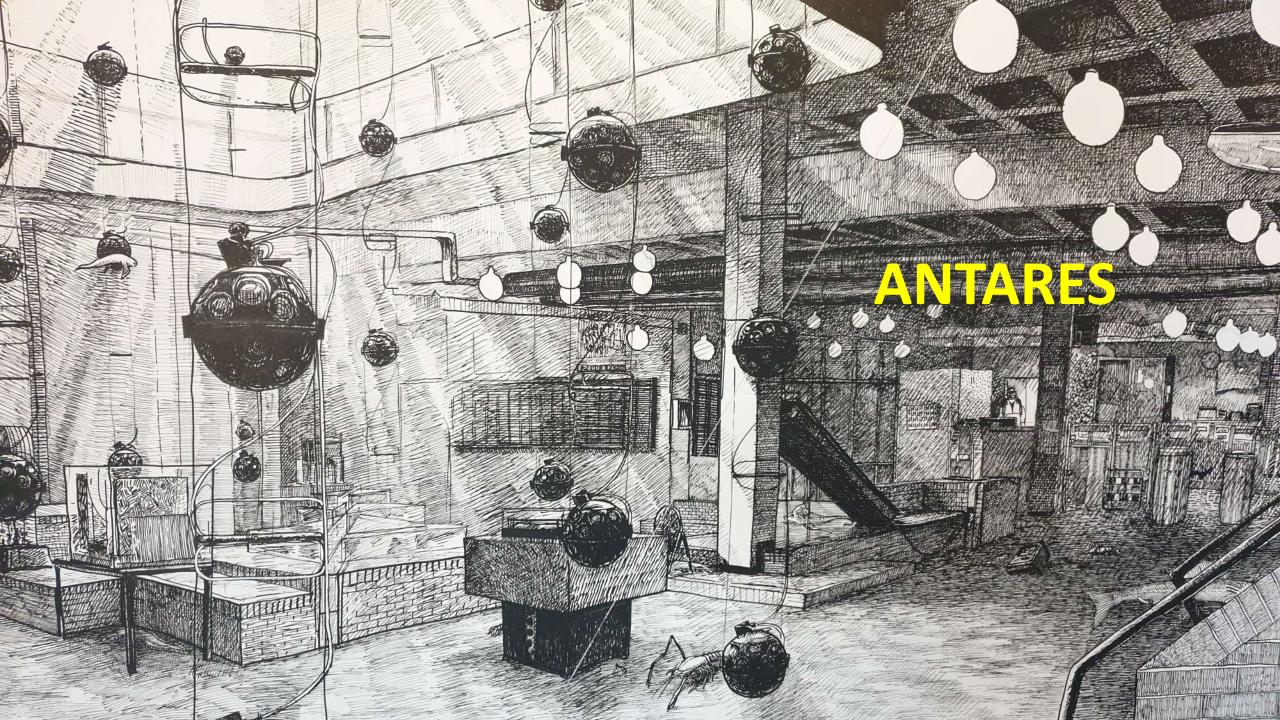


tracks



showers





ANTARES: 12 strings, ~0.01 km³, taking data since 2007, near ORCA site

Data

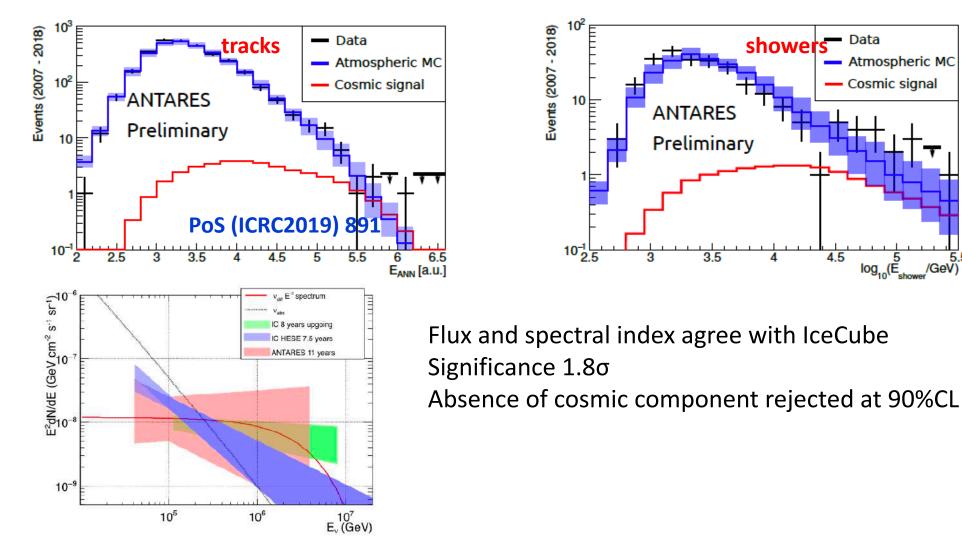
4.5

 Atmospheric MC Cosmic signal

log₁₀(E_{shower}/GeV)

shower

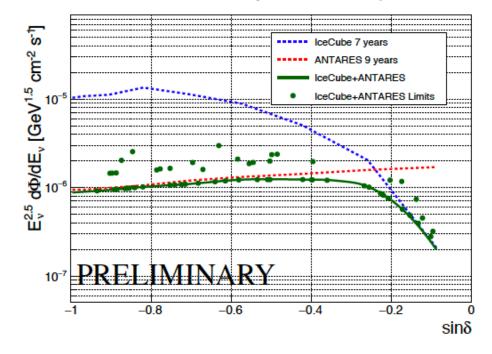
3.5





ANTARES

- No significant neutrino (point)source detected yet, but a few interesting locations to watch
- Extensive multi-messenger project to generate alerts after HE neutrino within 10 seconds and react after external alert (LIGO/VIRGO, GRBs, IceCube, ...) ANTARES to keep running until after completion LIGO/VIRGO O3
- Complementarity with IceCube in field of view



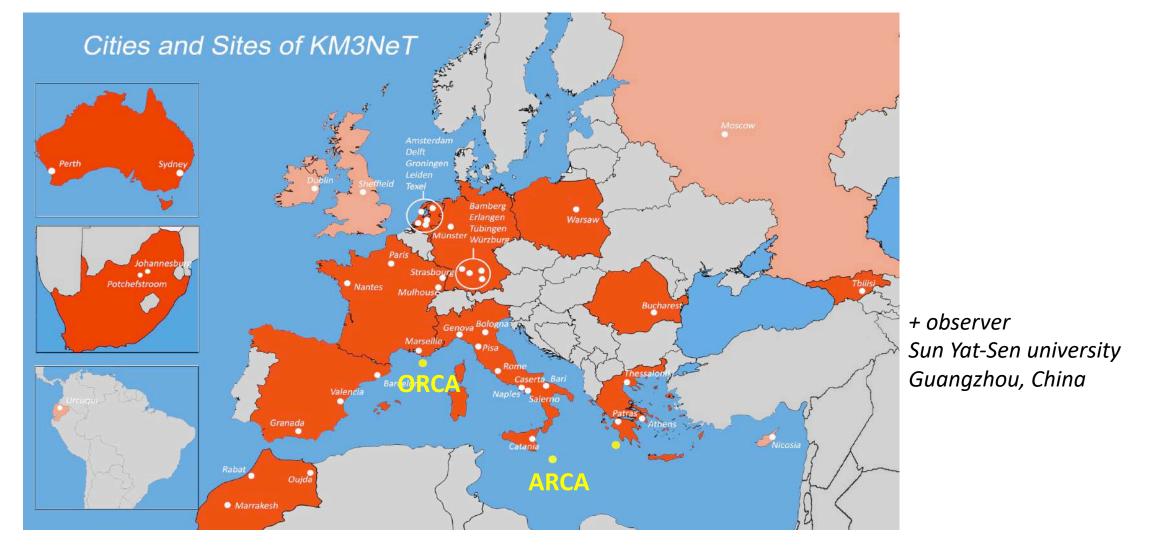
90% C.L. Sensitivity and Limits for $\gamma = 2.5$

ANTARES + IceCube combination of flux limits for sources in the Southern Sky (E^{-2.5} flux assumed)

Excellent case for large neutrino telescope

- in Northern Hemisphere
- with superior pointing resolution (water)
- capable of detecting all neutrino flavours
 → <u>KM3NeT</u>





- A. Heijboer *deputy spokesperson*
- D. Samtleben *co-leader Astronomy working group ANTARES conference committee*
- R. Bruijn *leader Cosmic Ray working group KM3NeT*
- E. Berbee project leader Mechanics

M. De Jong *leader H2020 Infradev project*D. Van Eijk *coordinator DU integration*E.-J. Buis *system engineer*A. D'Amico *project leader Optics*P. De Jong *publication committee*

Each KM3NeT Detection Unit (line, string) has 18 digital optical modules (DOMs) Each DOM is like a multi-facet insect eye with 31 PMTs

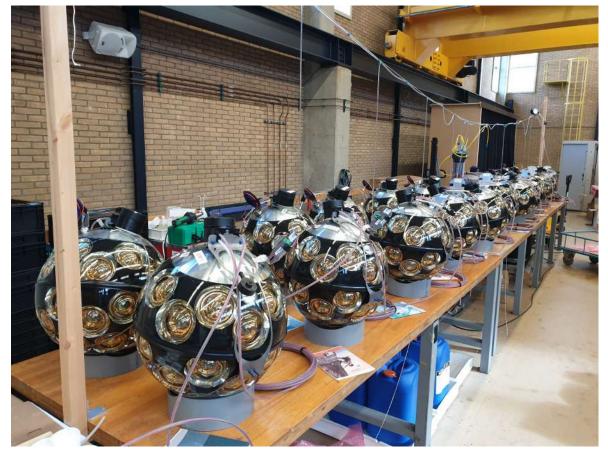
Phase 1 of KM3NeT: 6 DUs ORCA, 24 DUs ARCA

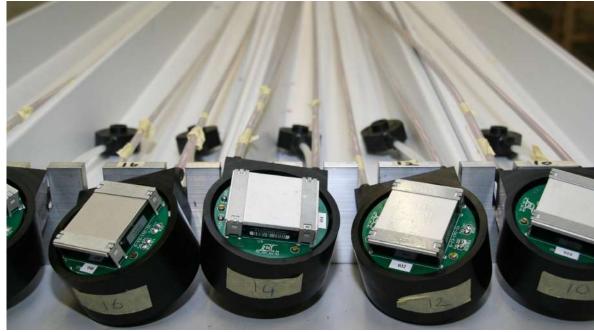
8 DOM production sites, 460/540 DOMs finished Nikhef quota of 218 DOMs reached in 2018





Detection Unit (DU) integration (5 sites, including Nikhef)





Vertical Electro-Optical Cable (VEOC) Produced at MCAP, Raamsdonksveer

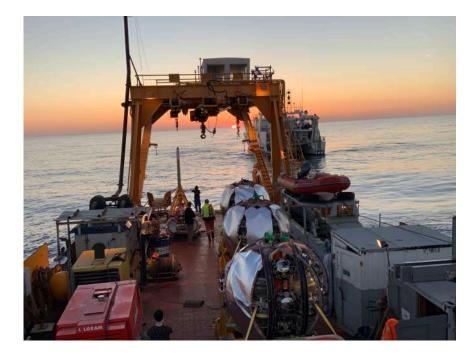
https://video214.com/play/zwP197khf81zsqoaj1u1bA/s/dark

Great effort by the Nikhef technical departments, MT, ET and CT. Thank you!

Status at **ORCA** site (F)

- First DU deployed September 2017
- Dec. 2017: short in power cable to shore
- Cable replaced 2018, DU had to be retrieved
- 5 DUs deployed since, but 1 retrieved (VEOC cable cut when deploying other DU)
- Now operational with 4 DUs
- 2 DUs ready, deployment Nov 2019 \rightarrow Jan 2020

→ See talk Rodrigo Gracia



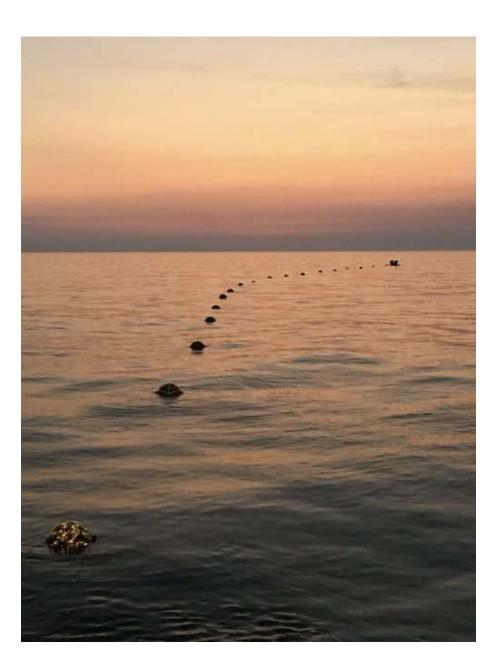




My Eureka Moment:

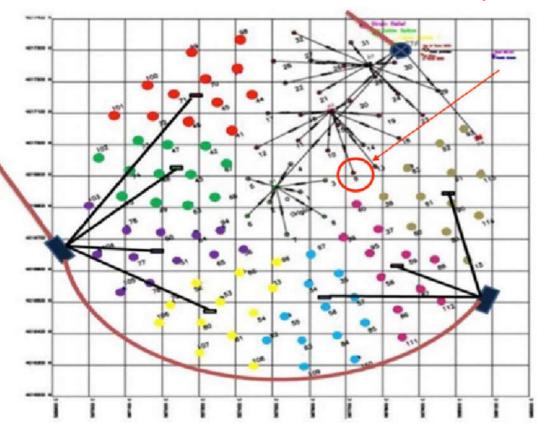
Buoyant force = Weight of displaced fluid

 \rightarrow DOMs float



Status at ARCA site (I)

- 1 DU operational and taking data
- Work on seafloor network in progress More advanced optical network (Nikhef)
- Spring 2020: temporary Junction Box to be deployed for 6 DUs now under construction
- Spring-Summer 2021: final (more reliable) junction boxes for 24 DUs



ARCA block 1 floor plan

Beyond phase 1: KM3NeT 2.0 (ORCA 115 DUs, ARCA 230 DUs)

Preparing for restart of production at Nikhef This time: mass production

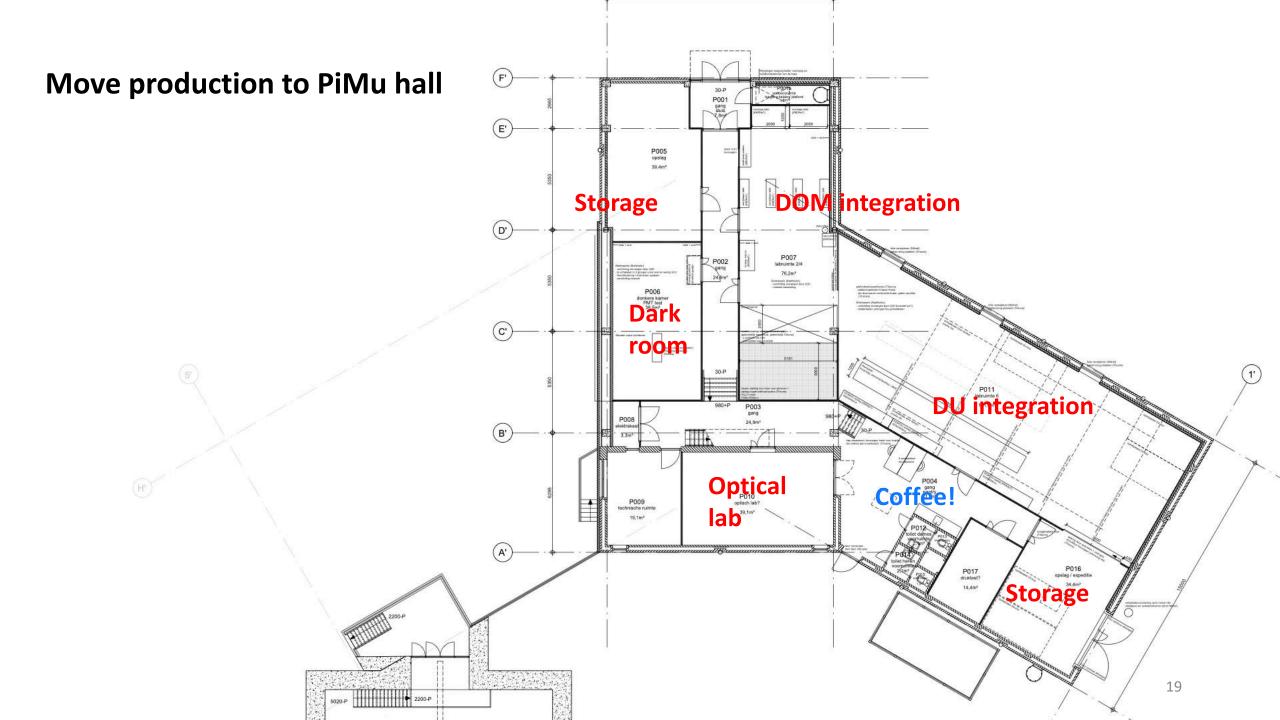


Procurement of components takes time
European tenders
Changes in components, changes in design
For support structure, 3D-printing → injection molding

Plan: ORCA: 13 DUs end of 2020 ~40 DUs end of 2021 Completion 2024

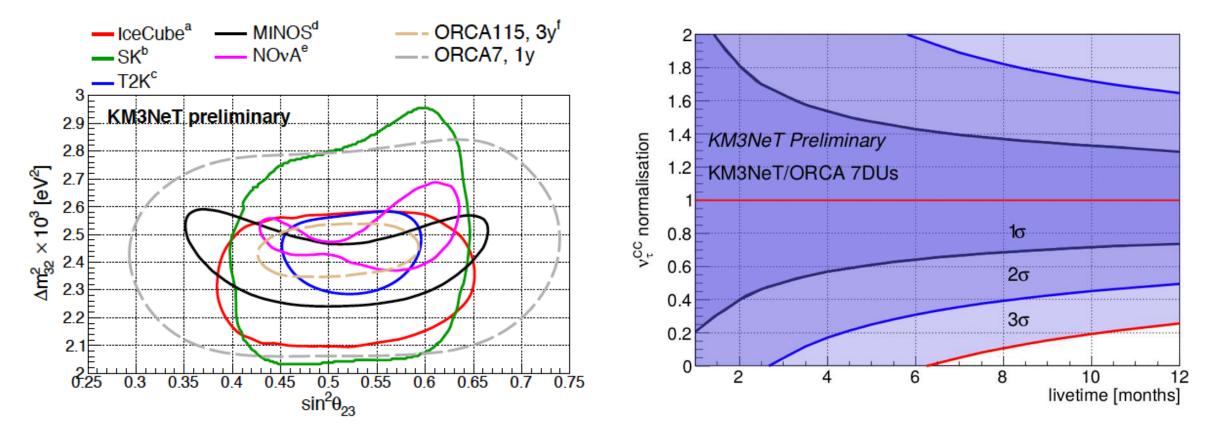
> ARCA: 6 DUs end of 2020 24 DUs end of 2021 Completion block 1 2024 Completion block 2 2026





Preparations for data analysis:

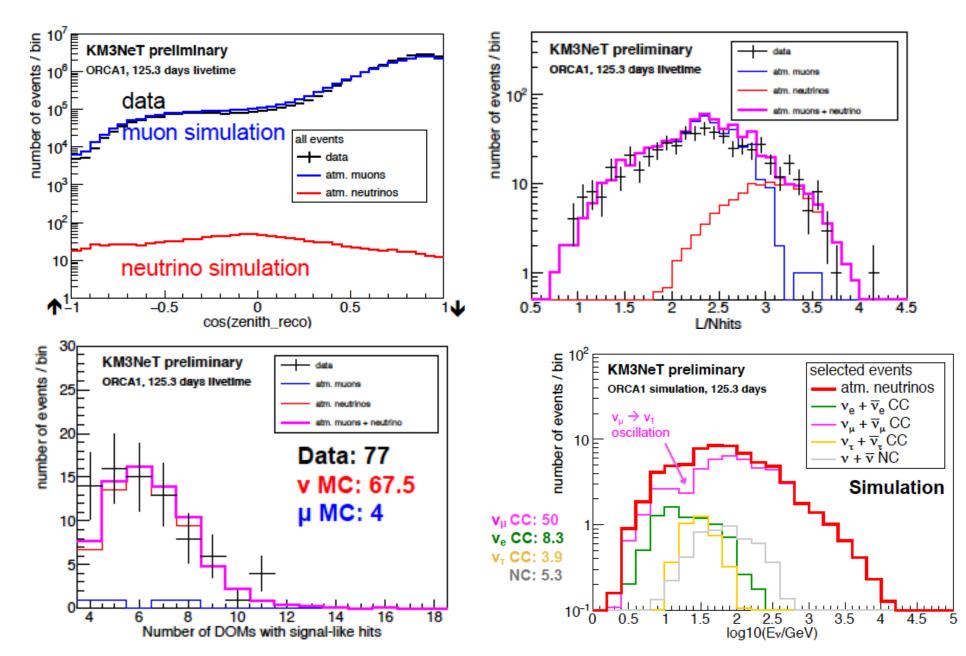
Oscillation studies for first data: MC production, reconstruction, Nikhef analysis framework



Oscillation parameter fit, 7 and 115 DUs

Tau neutrino flux normalization with 7 DUs

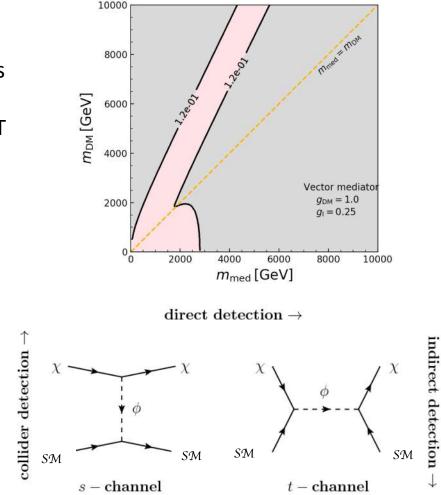
Atmospheric neutrino candidates selection in ORCA



Indirect Detection of Dark Matter

S. Basegmez du Pree

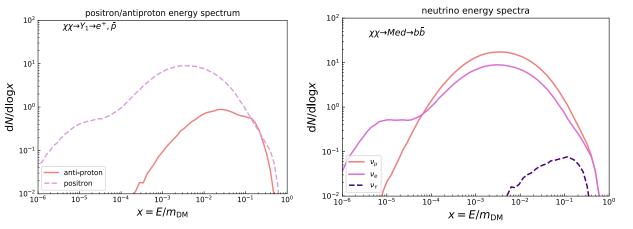
Thermal Relic Density



Development of an analysis framework with Simplified Dark Matter Models for the KM3NeT experiment

- Exploring the full capabilities of the KM3NeT (e.g probing large mass range and directional information)
- Insight to the observed Astrophysical excesses of AMS-02, Fermi-LAT
- Close collaboration with the theory and experiments:
 - Synergies between Nikhef, GRAPPA, UCLouvain and CERN

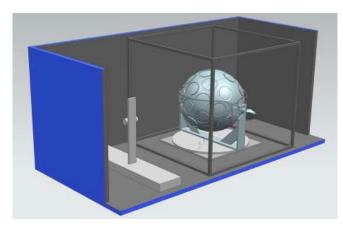
Annihilation Energy Spectra: $b\overline{b}$



Vector Mediator, M_{DM} = 100 GeV, M_{Med} = 100 GeV, g_{DM} =1, g_q=0.25

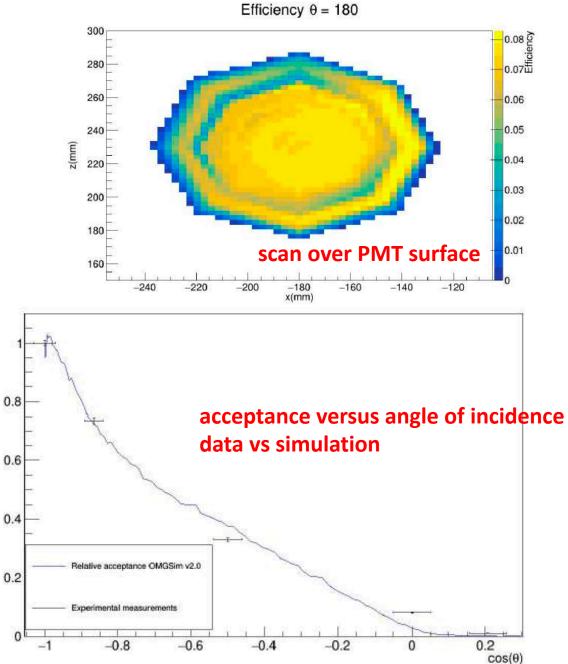
Hardware projects for students:

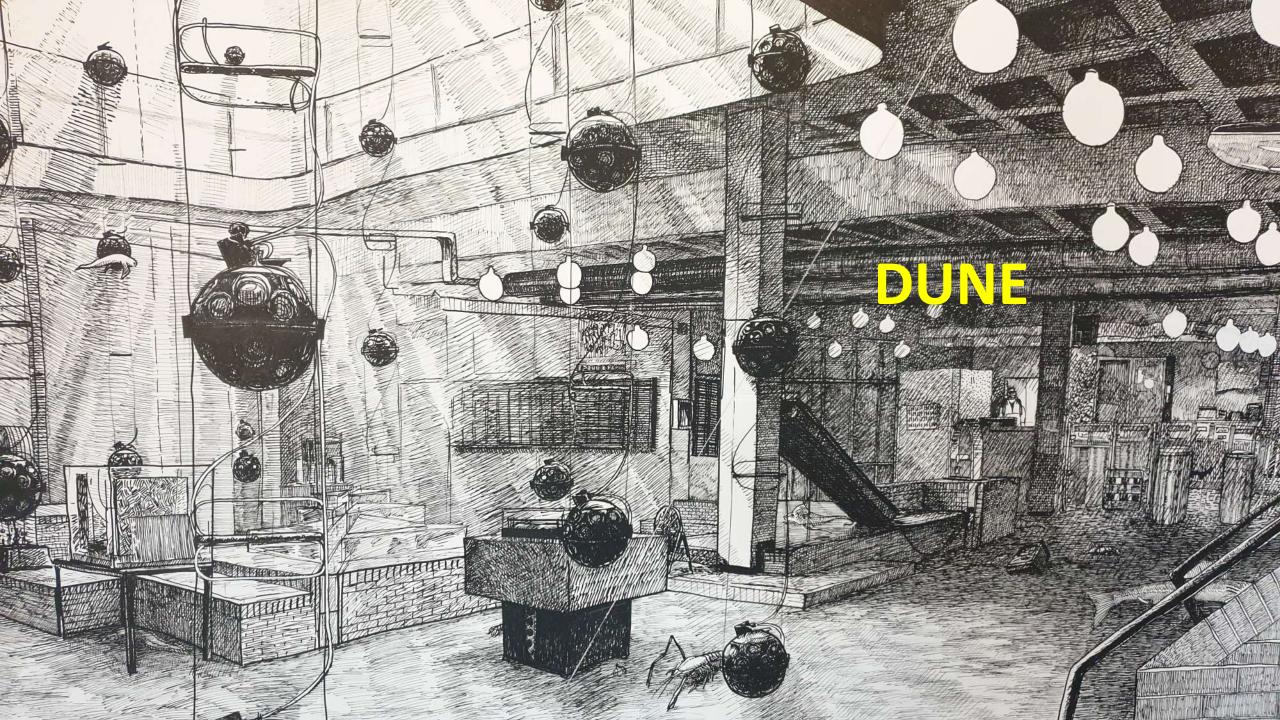
Watertank + DOM + laser: detailed scan of PMT angular acceptance



Th. van Eeden R. Bruijn

Relative acceptance

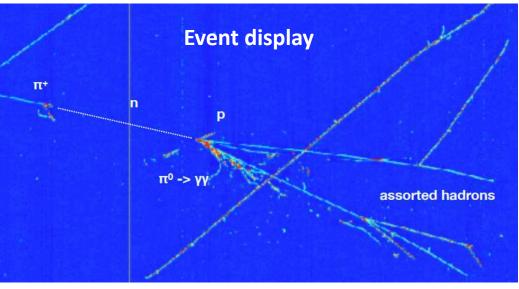




High-power wideband beam FNAL->SURF, 1300 km



Former Homestake mine Former Homestake mine

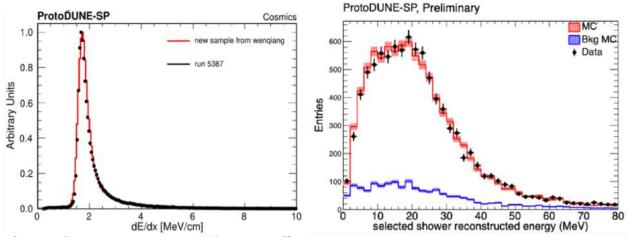


Single-phase ProtoDUNE progress

Took cosmics data throughout 2019 to study various detector effects

- now using FELIX based readout for the full setup

Better simulation + more sophisticated correction for space-charge effects mapped performance for energy reconstruction



dE/dx for cosmics

stopping cosmics: electron energy spectrum

Paper on performance results from ProtoDUNE-SP to be submitted in early 2020

- Frank Filthaut deputy chair of DUNE Authorship & Publications Board

Progress towards DUNE

Far Detector:

- Construction project in UK started in October
- 150 APAs + spares: 1 FD module
- USA: NSF funding requested for APAs for another FD module
- discussions started on technology for "module of opportunity"
 - also investigating possible cost reduction by doubling drift length

Near Detector: converged on principle: LAr TPC + magnetised "multi-purpose" detector (high-pressure (10 bar) GAr + calorimeter + muon system)

- movable so that different v energy spectra can be probed

Expect DOE LBNF/DUNE CD2/CD3a review in 2020

- essential ingredient: filling institute "responsibility matrix"

Nikhef: DAQ design (FELIX) and monitoring, grid computing ProtoDUNE data analysis, machine learning studies

