# Dark Matter and KM3NeT

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KM3NeT

MultiDark Multimessenger Approach for Dark Matter Detection

# Outline

- Introduction to KM3NeT
- Current status of KM3NeT
- Dark Matter
- Machine Learning

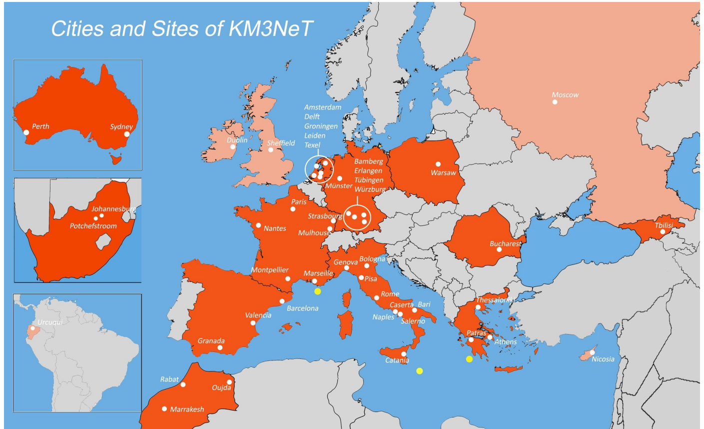
# What is KM3NeT?

KM3NeT is the successor to ANTARES and consists of two separate detectors:

- ARCA: Astroparticle Research with Cosmics in the Abyss
  - Goal: study neutrino sources and higher energy astrophysical neutrino from a diffuse flux

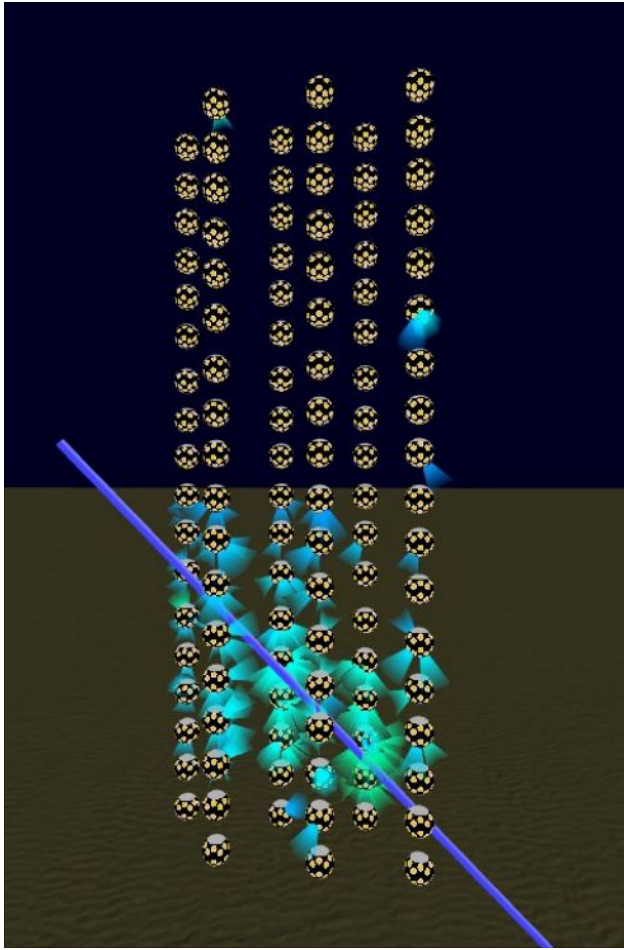
- ORCA: Oscillation Research with Cosmics in the Abyss
  - Goal: Study the properties of the neutrinos and neutrino oscillation

Both detectors are suitable for Dark Matter searches



# KM3NeT: Current Status

- ARCA: 2 lines currently deployed and taking data
  - 24 lines deployed by the end of 2021
- ORCA: 6 lines currently deployed and taking data
  - 29 lines built and most of these deployed by the end of 2021



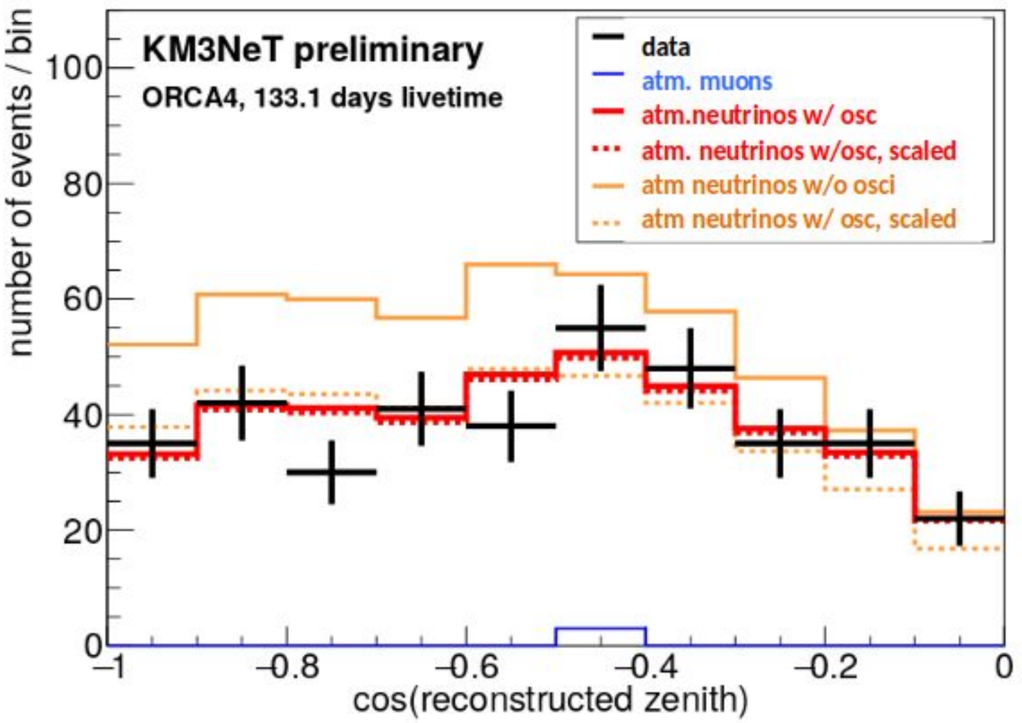
# ORCA4 Event Rate

Strict selection cuts to remove noise and atmospheric muons:

- 2019: 3ν per day with 4 strings for 6 months
- Since Jan 2020: 5ν per day with 6 strings

Neutrino oscillations have an effect on the zenith distribution:

- Oscillations reduce the number of detected events by ~30%
- The data favours the hypothesis of neutrino oscillations



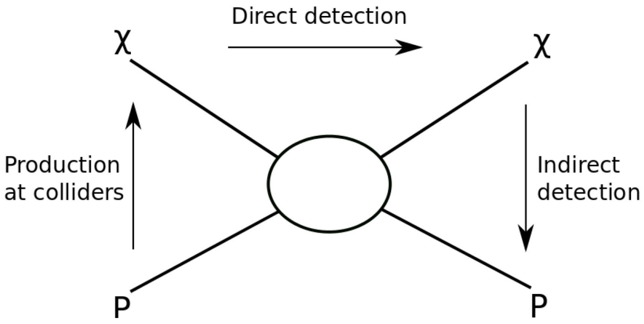

L. Fusco, J. Hofestädt, D. Stavropoulos. (KM3NeT collaboration), Neutrino2020, Poster #363

# Dark Matter: Indirect Detection

In KM3NeT we look for Dark Matter through indirect detection:

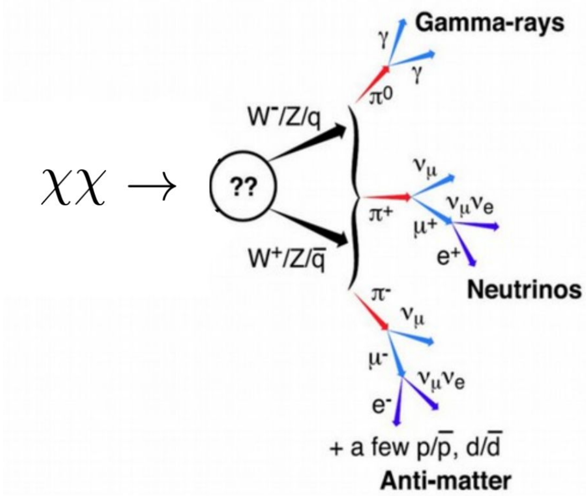
- Two DM particles annihilate to SM particles

- Observe neutrinos produced in this process




There are several different annihilation channels:

- W-bosons
- Quarks
- Muons, Taus
- Neutrinos




Neutrino fluxes are created and this is the signal we try to observe

# Dark Matter: Indirect Detection

Neutrino telescopes have several advantages:

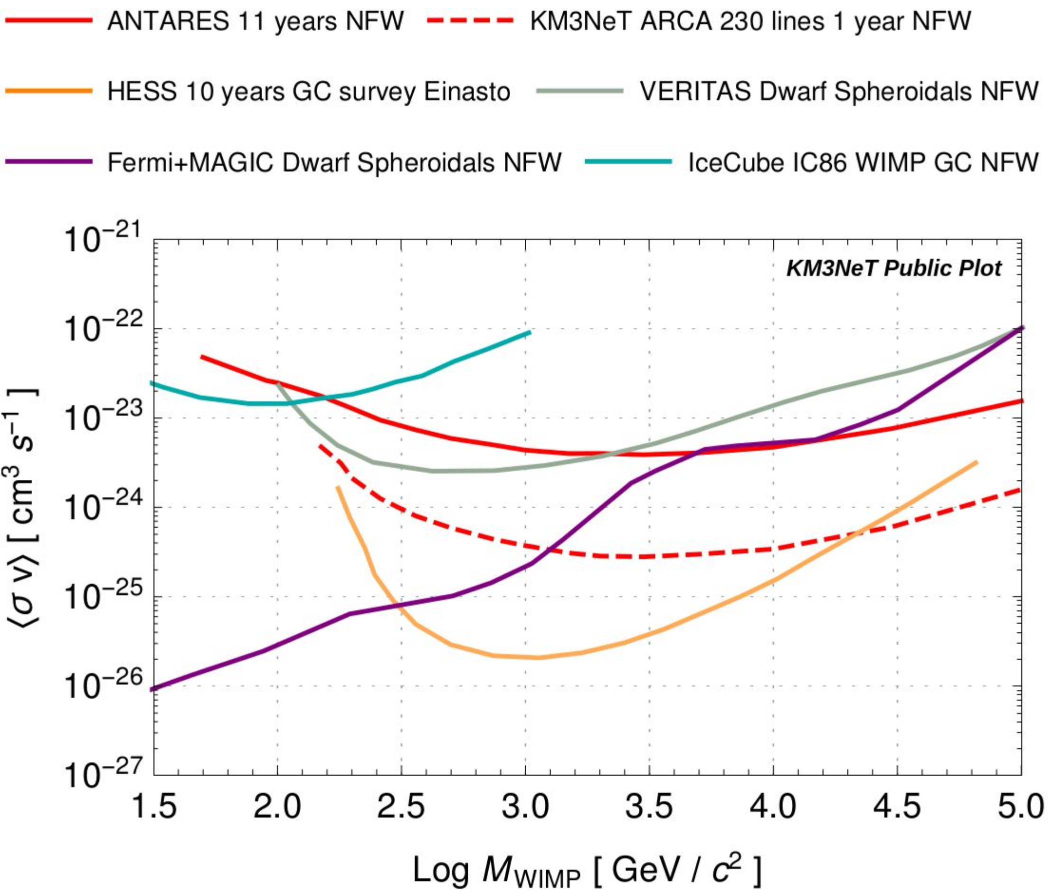
- Good sensitivity to annihilation cross section for large DM masses, in particular ANTARES and KM3NeT due to their position relative to the Galactic Center
- Almost no astrophysical background for searches for DM in the Sun
- Sensitive to the neutrino channel

# Dark Matter: Analyses

There are several Dark Matter analyses in KM3NeT:

- Galactic Center WIMPs with ARCA
- Galactic Center WIMPs with ORCA
- Galactic Center WIMPs with ANTARES
- Heavy secluded DM with ANTARES => Talk by Rebecca Gozzini
- Sun WIMPs with ANTARES => Talk by Chiara Poire

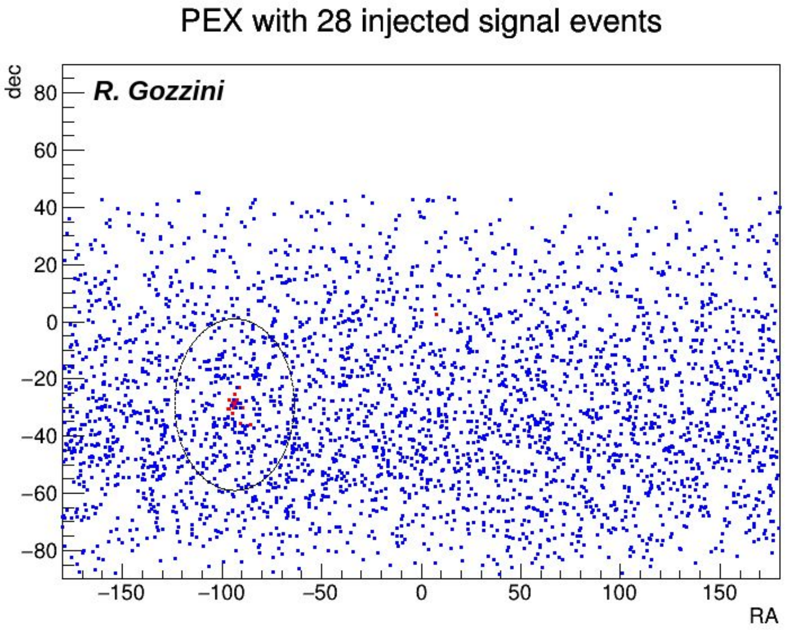
# Dark Matter: Sensitivities




The ARCA detector with 230 lines with a live time of 1 year is competitive with similar experiments

# Galactic Center WIMPs with ARCA

We need to determine the sensitivity of the ARCA detector to neutrinos from dark matter annihilation => Create Pseudo-experiments

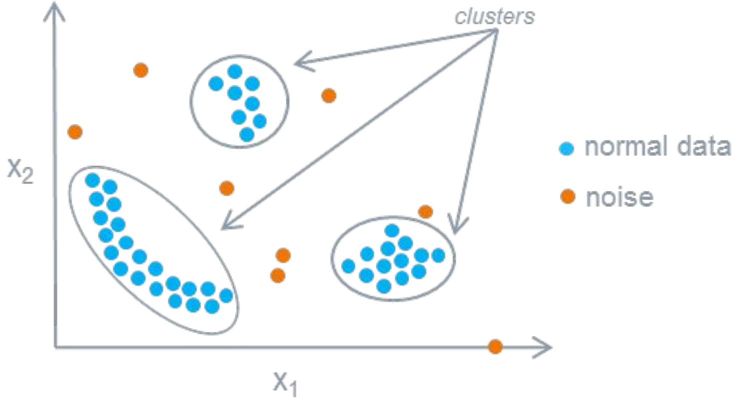



- We create a skymap of background
- We inject a specific number of signal events between 1 and 30
- Use a minimizer to find the number of signal events
- Potential to use a anomaly detection ML algorithm

# Machine Learning: Anomaly Detection

We have started a collaboration an signed an agreement with machine learning experts from Nikhef(S. Caron), the University of Amsterdam(S. Otten, G. Bertone) and IFIC(R. Ruiz) on anomaly detection:

- Learn a representation of the data which becomes the hypothesis
- Compare new data with the hypothesis and find differences or anomalies



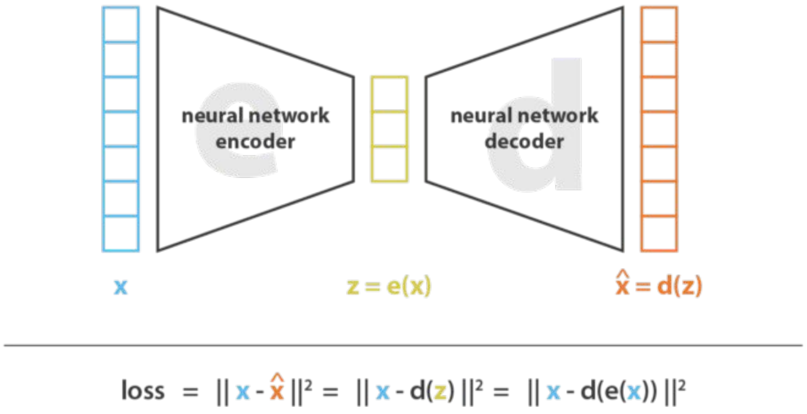
# Machine Learning: Autoencoders

Autoencoders are useful for anomaly detection because they find patterns in the training data, objects that do not fit these patterns are 'anomalies'.

An autoencoder consists of two parts:

- The encoder: reduces the dimensionality of the input in to a latent space vector

- The decoder: takes the latent space vector and tries to replicate the original input



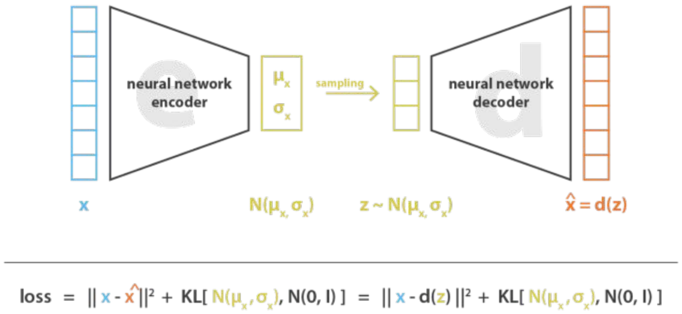

A latent space with too many dimensions can cause the network to learn an identity operation.

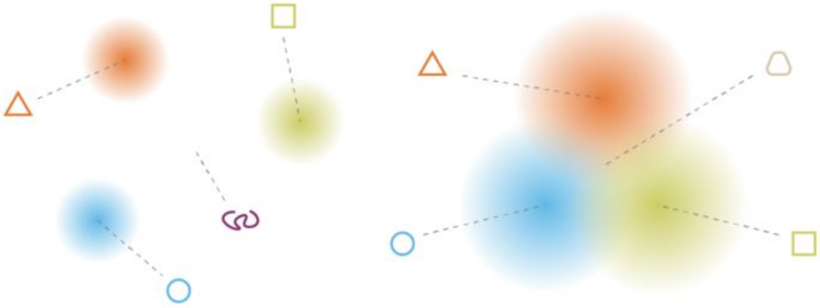
A latent space with too few dimensions prevents the decoder to properly reconstruct the output.

# Machine Learning: Variational Autoencoder

A variational autoencoder is a type of autoencoder where a latent distribution is created instead of a latent representation. A sample from this distribution is drawn to feed to the decoder.

A term is added to the loss function to force the distributions to be close to normally distributed gaussians.



# Machine Learning: Anomaly Detection

Three potential comparison scenarios exist:

- Data - Data: Compare different runs and make a quality estimate
- Data - MC: Determine how the data matches with the MC to either find problems in the MC, or perhaps new physics
- MC - MC: Insert a signal and distinguish it from the background MC

This last point applies to the pseudo-experiments mentioned earlier

# Conclusion

- The KM3NeT ARCA and ORCA detectors are under construction and progress is being made with the analyses

- We look to improve the dark matter galactic center analysis using anomaly detection techniques from Machine Learning

- To achieve this a collaboration has been started with external experts from Nikhef(S. Caron), the University of Amsterdam(S. Otten, G. Bertone) and IFIC(R. Ruiz)

# Backup

# ORCA Sun Sensitivities