



SAPIENZA  
UNIVERSITÀ DI ROMA

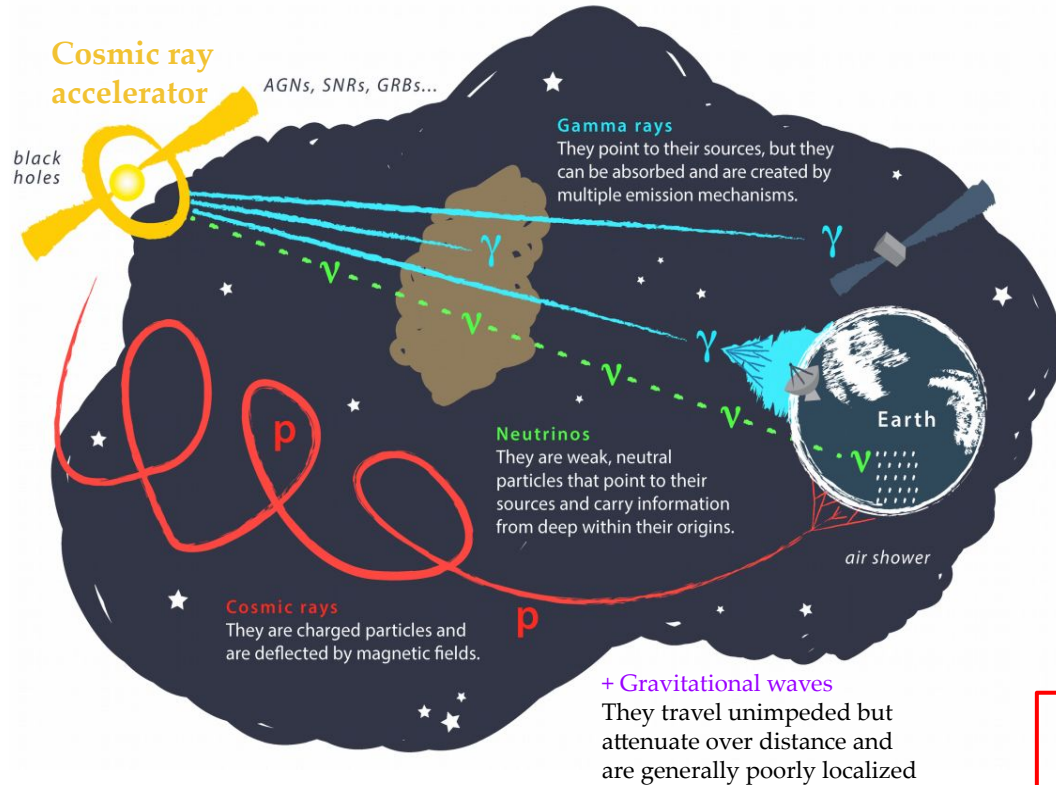


# The KM3NeT online processing for multi-messenger alerts

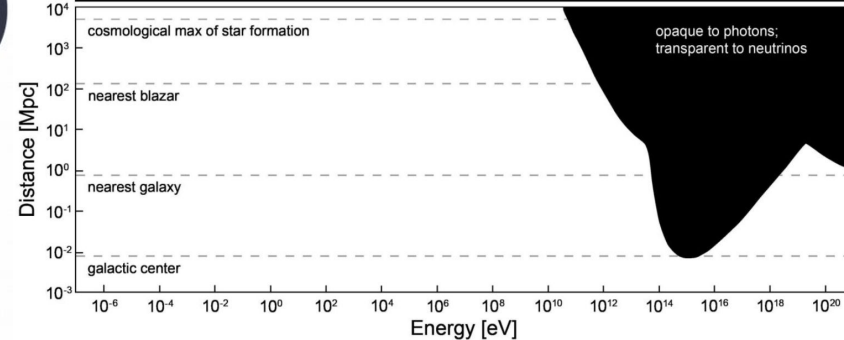
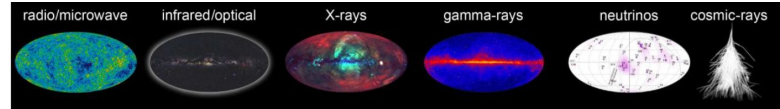
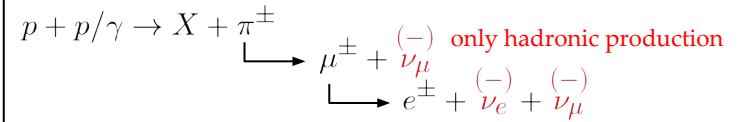
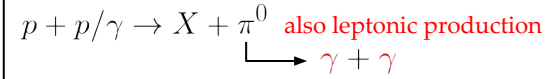
M. Mastrodicasa on behalf of the KM3NeT Collaboration

9<sup>th</sup> Roma International Conference on Astroparticle Physics , Frascati  
September 26, 2024

# The multi-messenger context

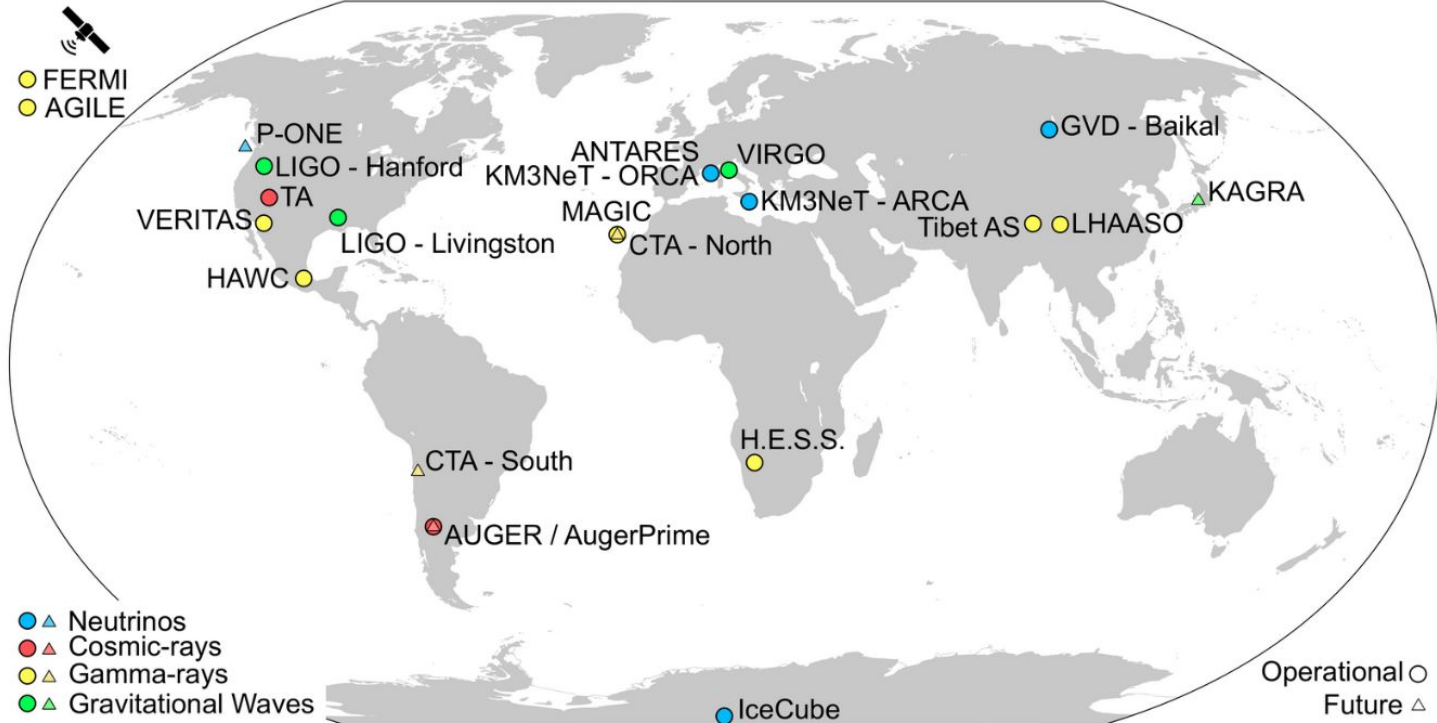


Hadronic scenario



Neutrinos are ideal messengers in the search for distant astrophysical sources

# Multi-messenger observatories



Different cosmic messengers have different observational strengths and provide complementary information about emitting sources → **early notifications between observatories is crucial to study transient phenomena**

# Multi-messenger observatories



**Mediterranean sea**

**South Pole**

**complementary to**

visibility in the upgoing sky

visibility in the upgoing sky

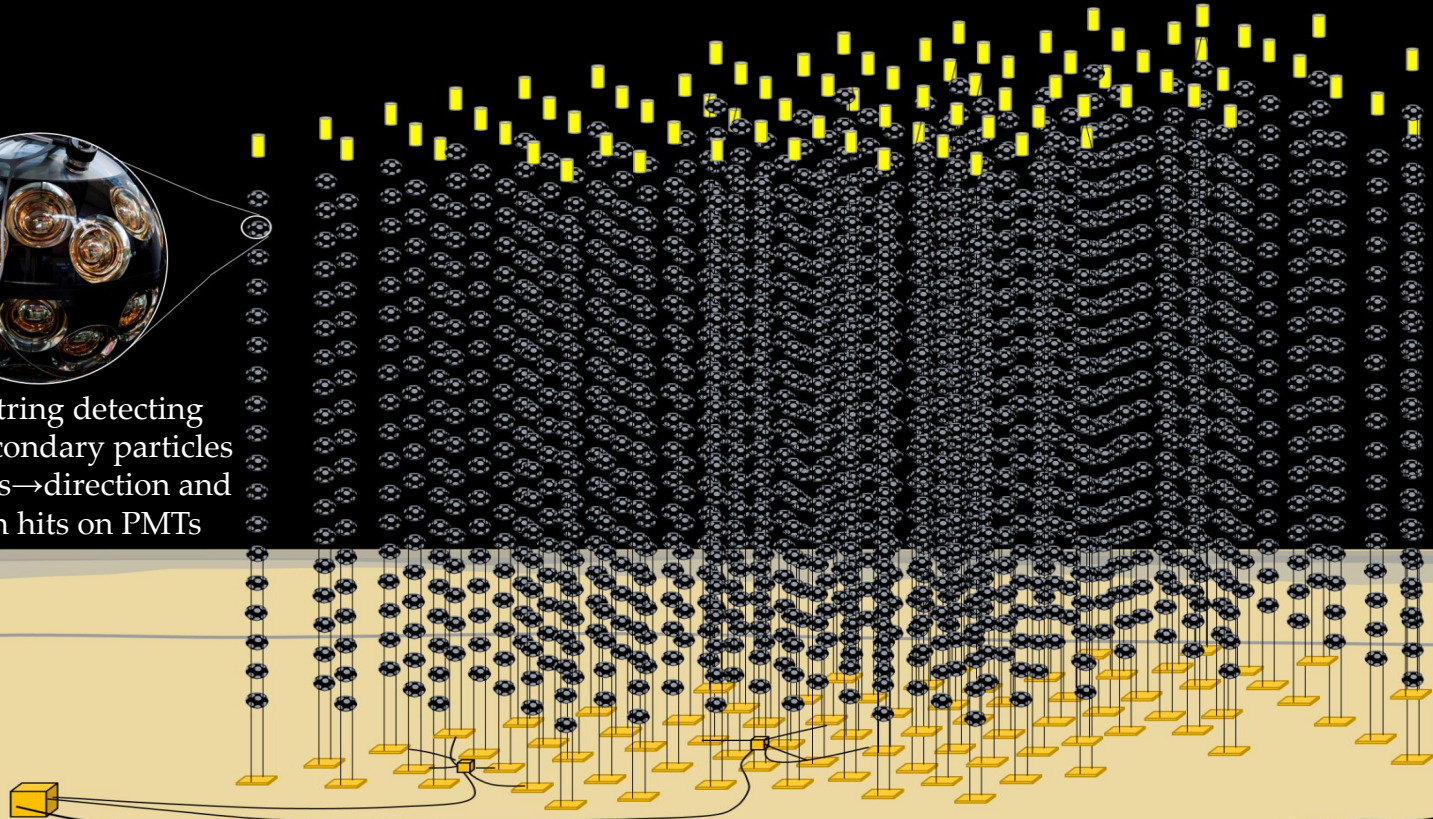
Different cosmic messengers have different observational strengths and provide complementary information about emitting sources. Early notifications between observatories is crucial to study transient phenomena

# KM3NeT: a neutrino telescope in the Mediterranean Sea

Digital Optical Module  
(DOM): 31 x 3" PMTs



Array of strings with 18 DOMs/string detecting Cherenkov light produced by secondary particles arising from neutrino interactions → direction and energy of neutrinos inferred from hits on PMTs

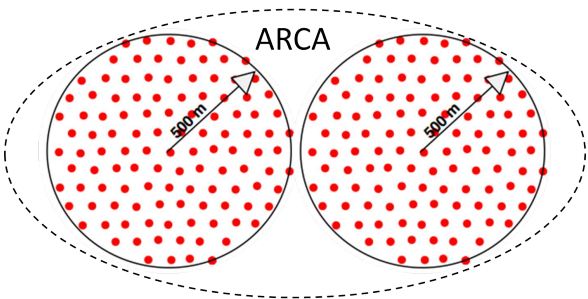


# Two detectors at two different sites



> 1 km<sup>3</sup> neutrino telescope under construction in the Mediterranean Sea

	<b>A</b> stroparticle <b>R</b> esearch with <b>C</b> osmics in the <b>A</b> byss ( <b>ARCA</b> )	<b>O</b> scillation <b>R</b> esearch with <b>C</b> osmics in the <b>A</b> byss ( <b>ORCA</b> )
<b>Location</b>	Italy, 100 km offshore Sicily	France, 40 km offshore Toulon
<b>Depth</b>	3450 m	2450 m
<b>String distance</b>	90 m	20 m
<b>DOM spacing</b>	36 m	9 m
<b>String height</b>	800 m	200 m
<b>Instrumented mass</b>	~ 1 Gton	~ 7 Mton
<b>No. strings</b>	115 × 2	115



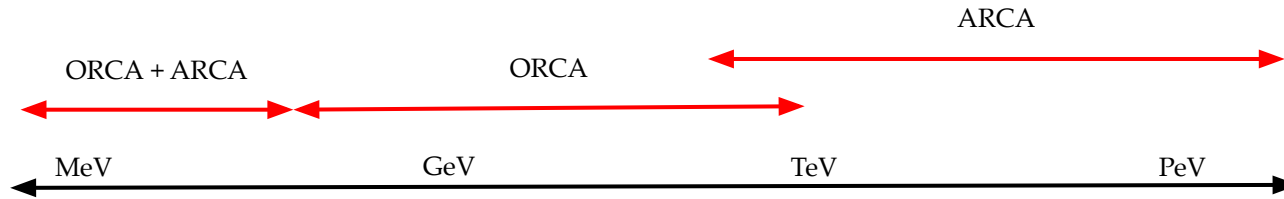
ORCA



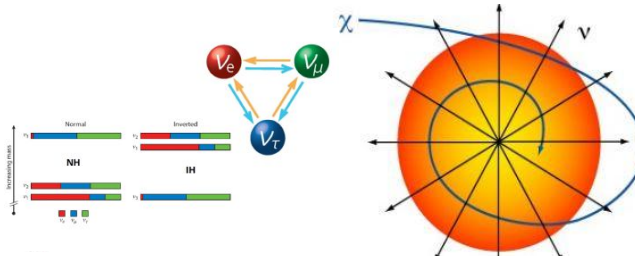
**ARCA (ORCA) currently taking data with 28 (23) strings!**

# KM3NeT physics

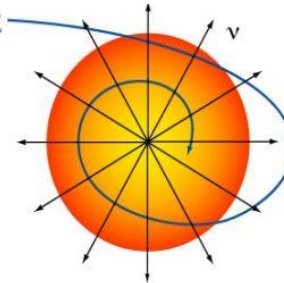
- **ARCA**: optimised to identify and study TeV-PeV astrophysical neutrino sources
- **ORCA**: optimised to study the intrinsic properties of neutrinos in the few GeV range



Supernova neutrinos



Neutrino oscillation/  
mass hierarchy



Dark Matter



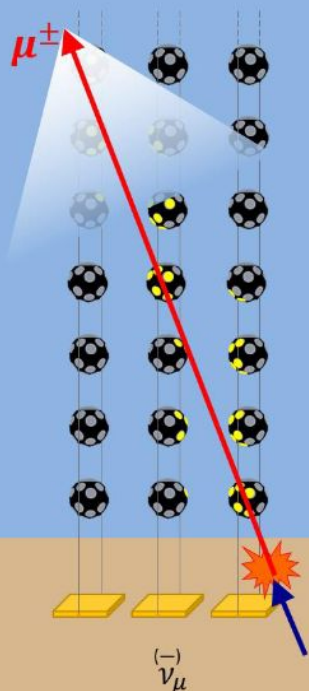
High energy neutrinos

Different primary goals but both can be used for neutrino astronomy from few MeV to few PeV

# Neutrino event topology

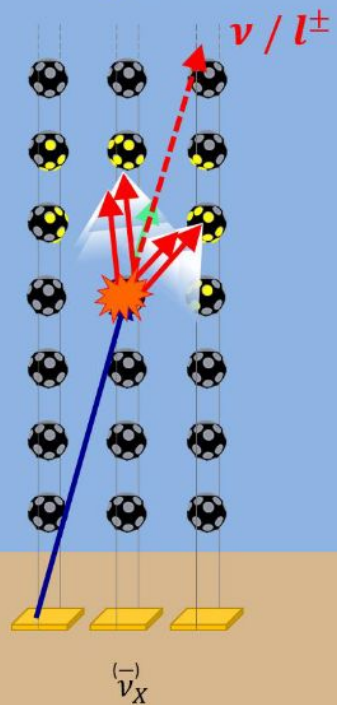
CC  $\nu_\mu$

1. track like events  
good directionality



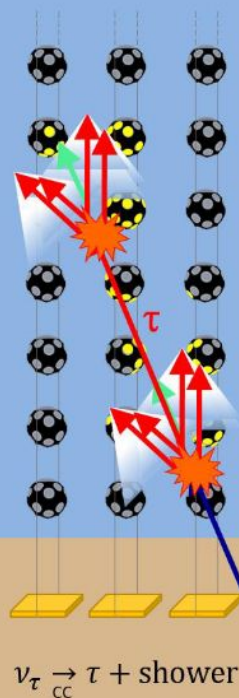
CC  $\nu_e$ + all flavours NC

2. shower like events  
good energy reconstruction

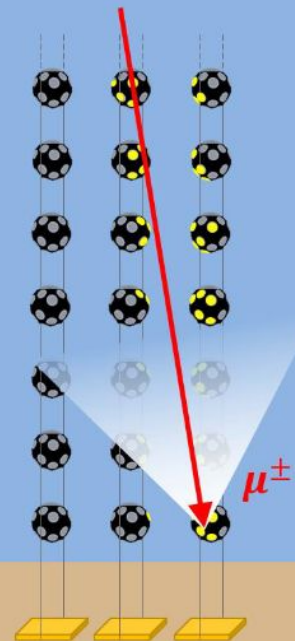


CC  $\nu_\tau$

3. "double bang"  
distinctive signature



Atmospheric muon  
BACKGROUND !!



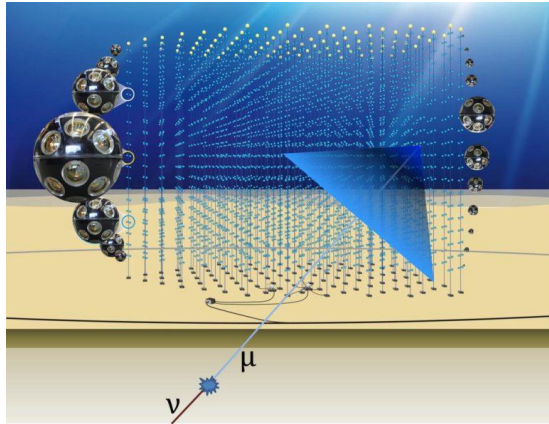
Atmospheric neutrino events are  
also BACKGROUND!

Rasa Muller



# The KM3NeT real-time multi-messenger program

KM3NeT ARCA and ORCA



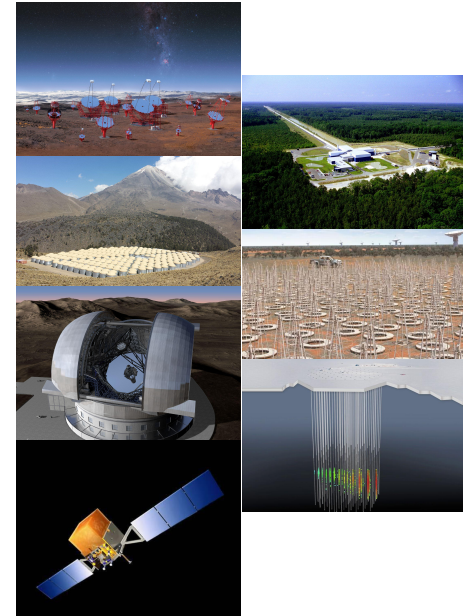
Follow-up of external alerts received from the multi-messenger community and search for spatial and temporal coincidences

LOADING...

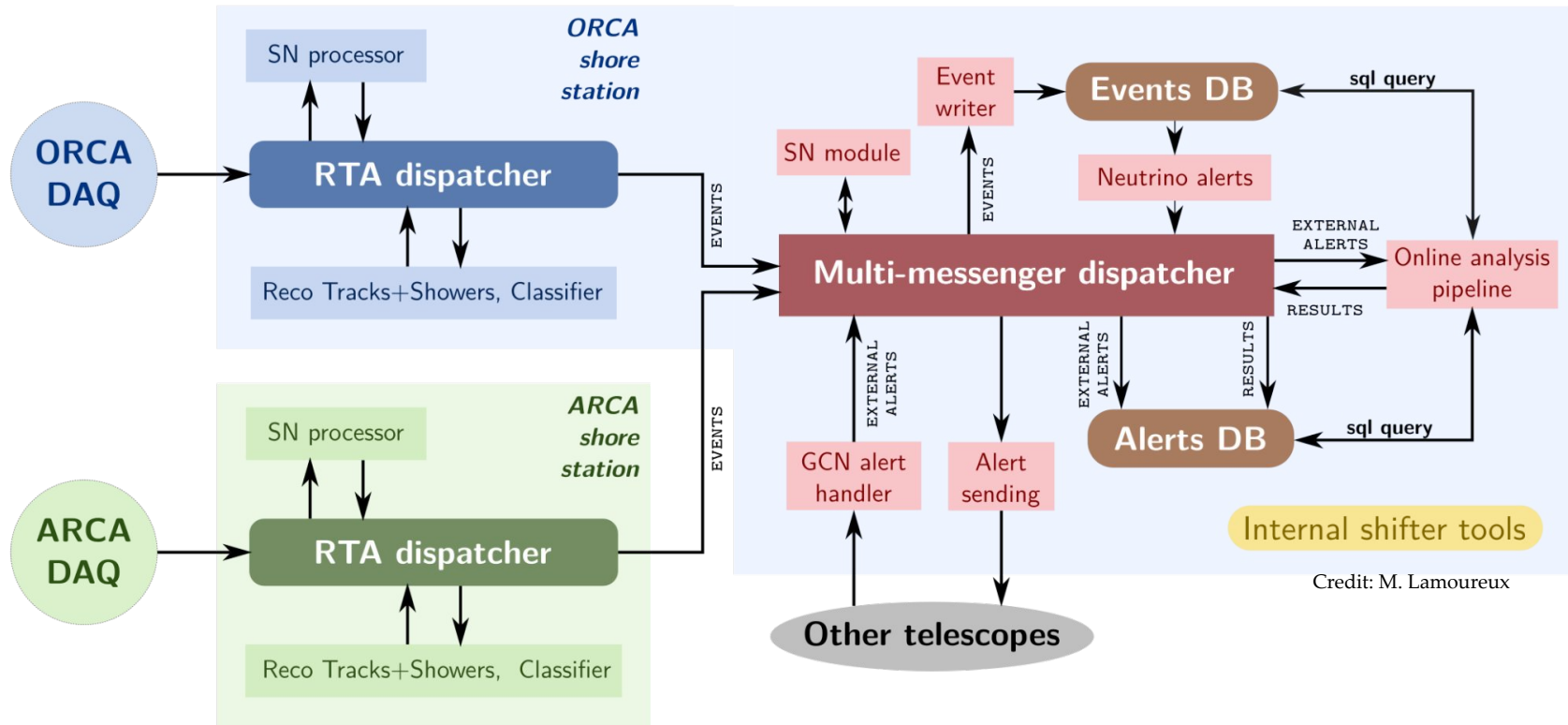


Sending of alerts when potentially interesting events are detected to trigger follow-ups

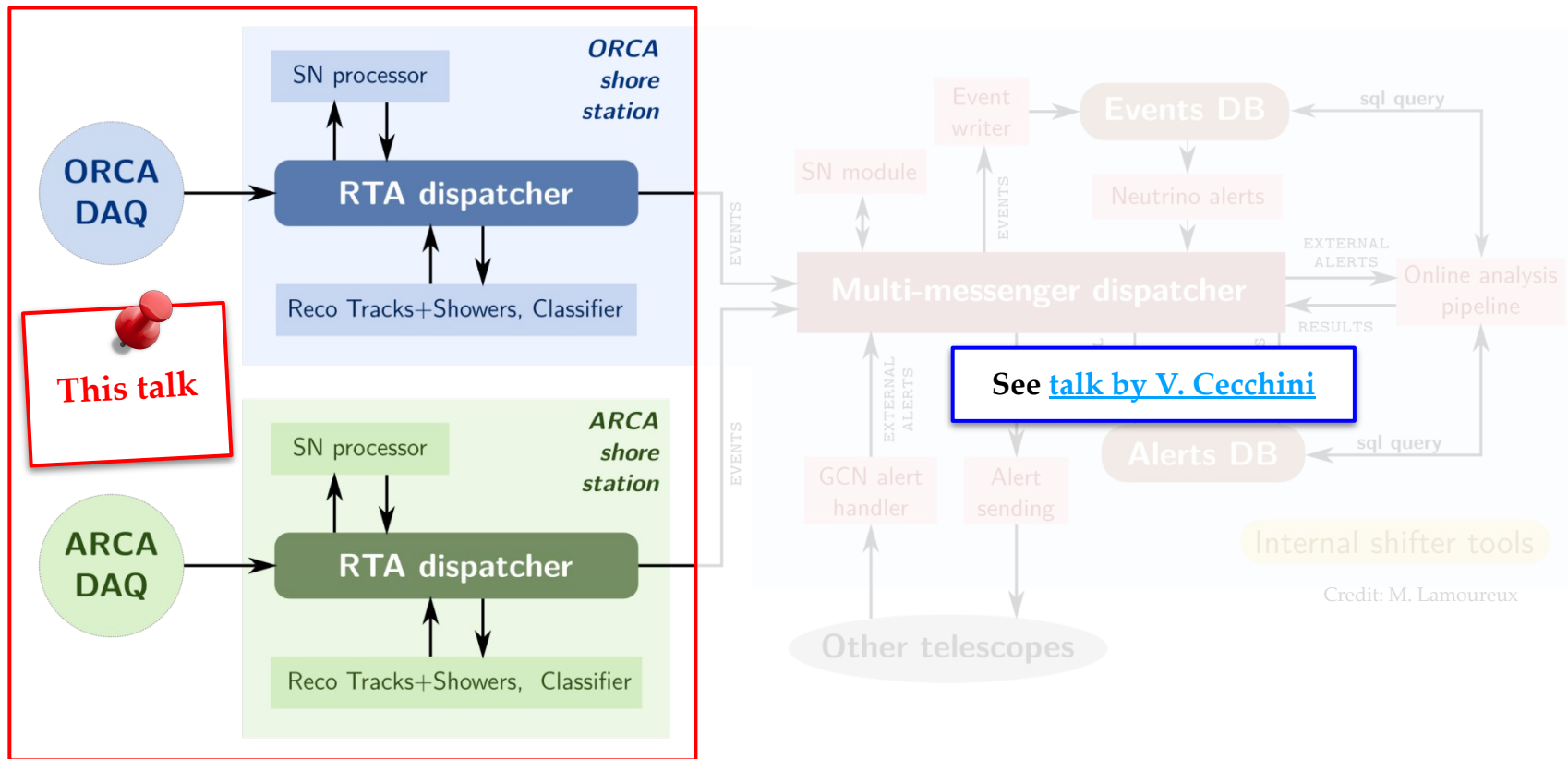
Multi-messenger community



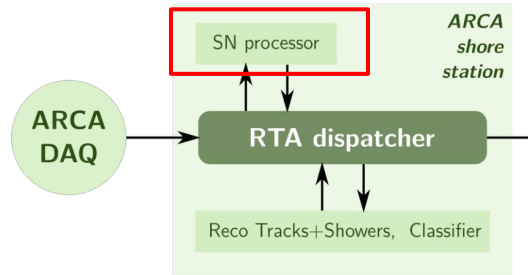
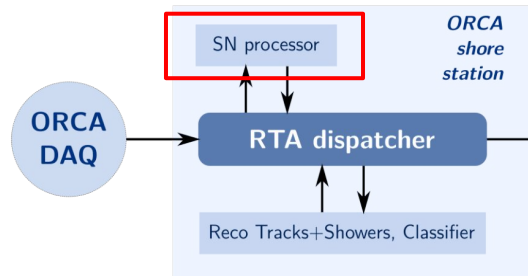
# The KM3NeT real-time analysis framework



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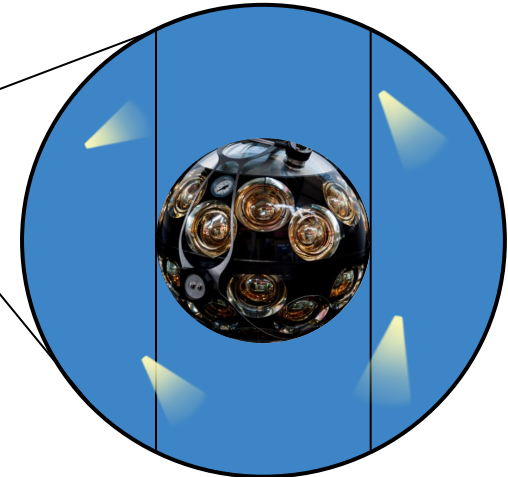
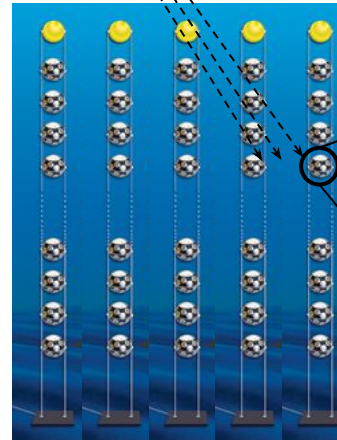


# The online CCSN analysis module



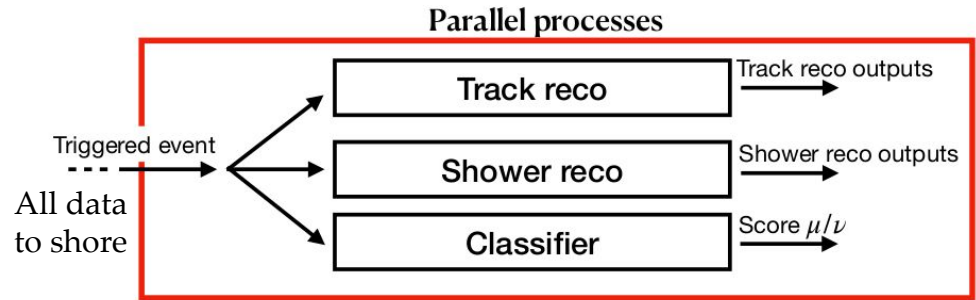
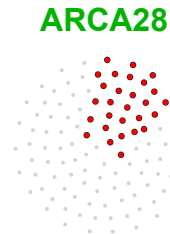
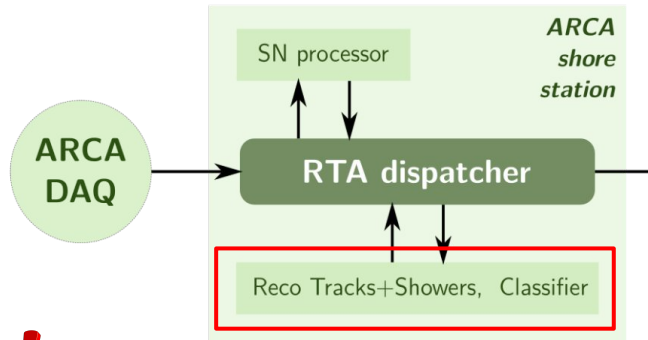
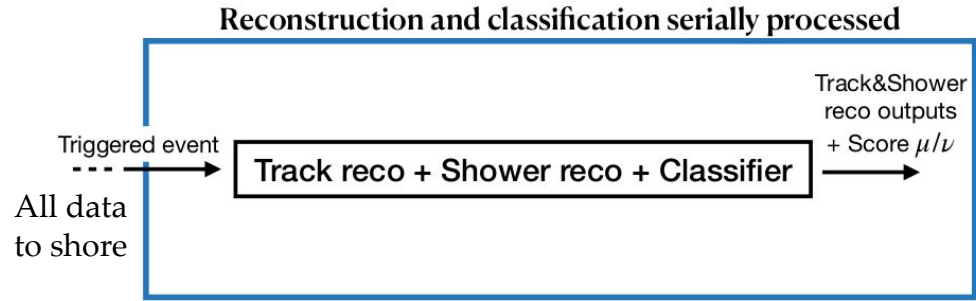
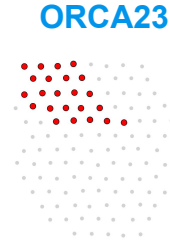
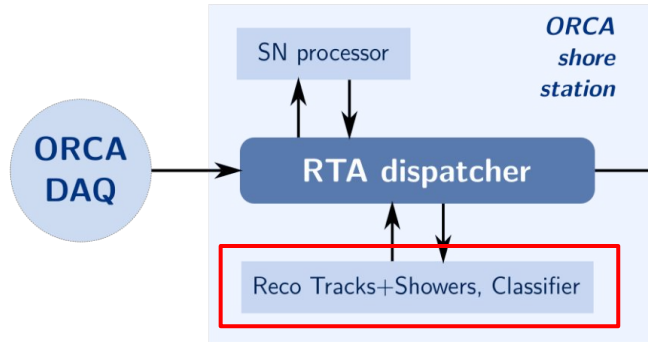
$\bar{\nu}_e, \nu_e, \nu_x$

The MeV core-collapse analysis module sends alerts to the SuperNova Early Warning System (SNEWS) with a **latency lower than 20 s** and a **false alarm rate less than 1/week**



MeV  $\bar{\nu}_e$  interact via inverse-beta decay  
→ short tracks visible in single DOMs  
→ **search for excess of coincidences between PMTs in single DOMs**

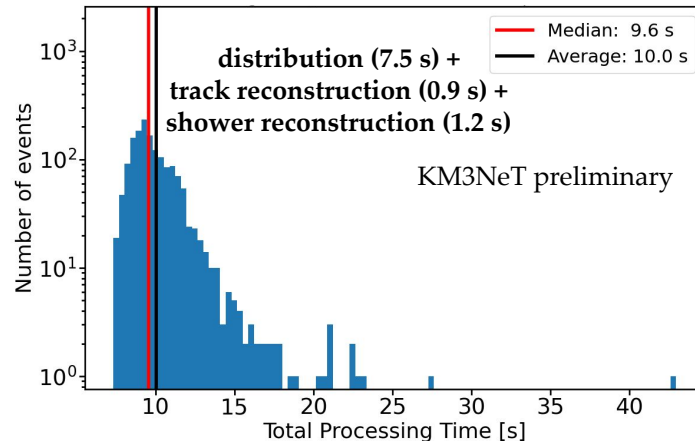
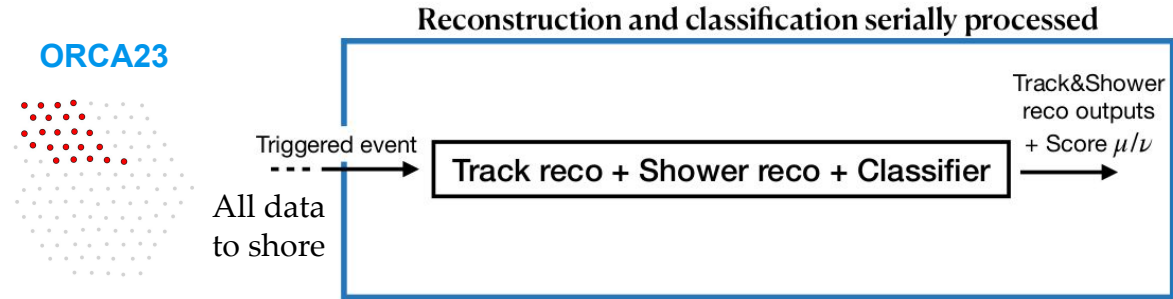
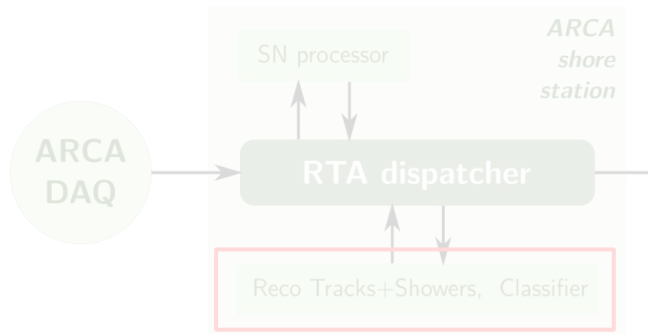
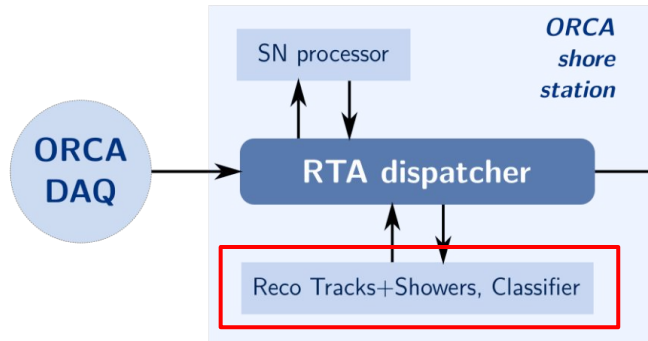
# The KM3NeT online reconstruction and classification



 **Multi-core processing in place to handle the high trigger rate**

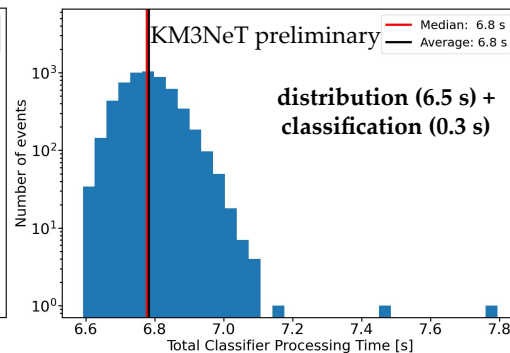
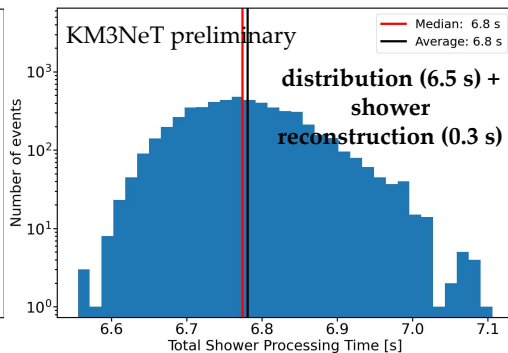
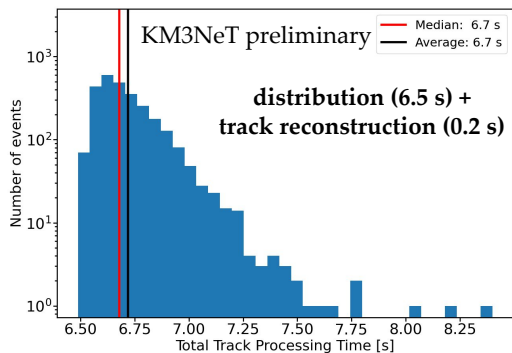
 [M. Mastrodicasa et al. \[KM3NeT\], PoS\(TAUP2023\)273](#)

# The KM3NeT online reconstruction and classification

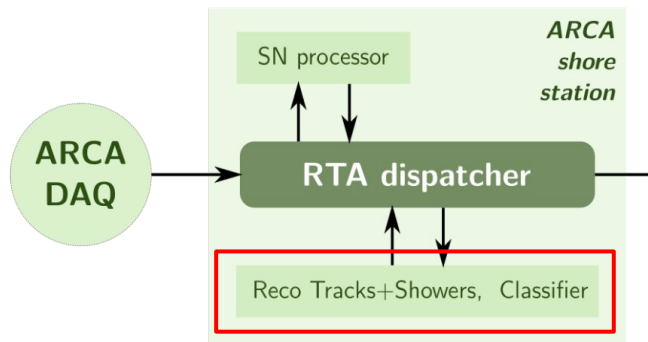


In median, ORCA events are processed and ready to be used in real-time analyses in **less than 10 s**

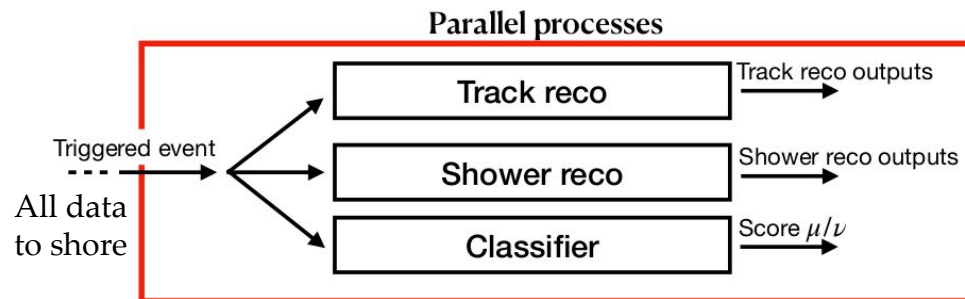
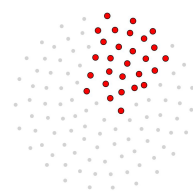
# The KM3NeT online reconstruction and classification



In median, ARCA events are processed and ready to be used in real-time analyses in **less than 7 s**

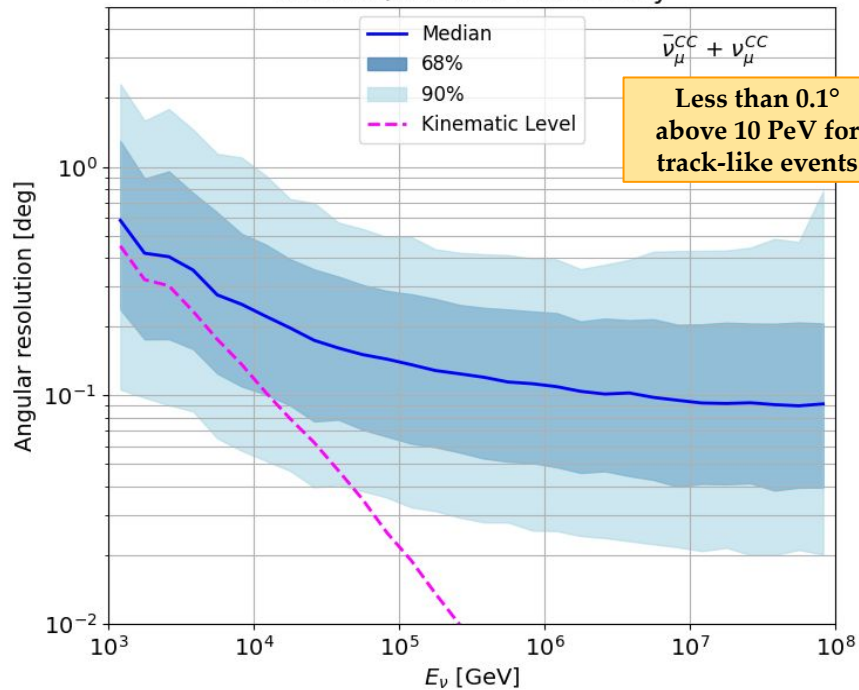


ARCA28

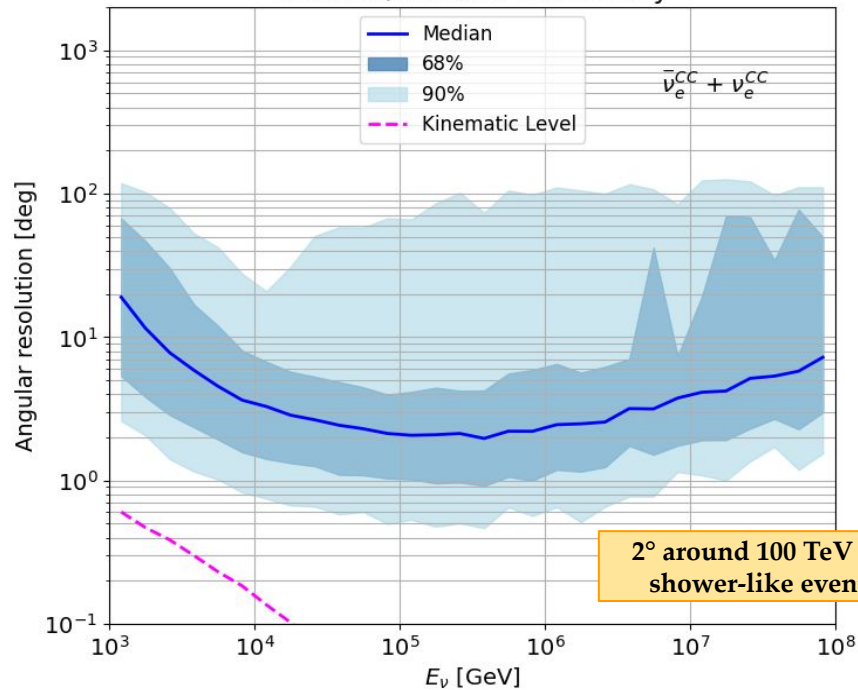


# KM3NeT/ARCA angular resolution

KM3NeT/ARCA28 Preliminary

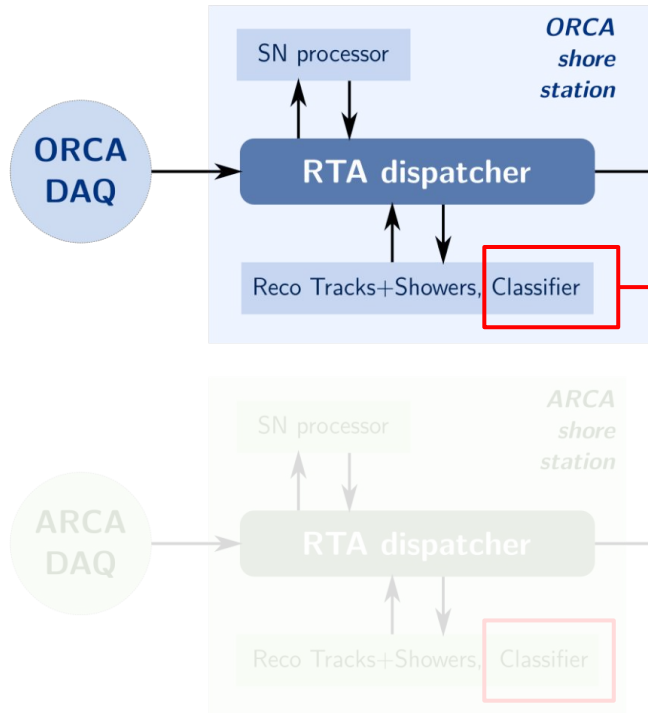


KM3NeT/ARCA28 Preliminary





# KM3NeT online event classification



## Boost Decision Tree (BDT) classifier

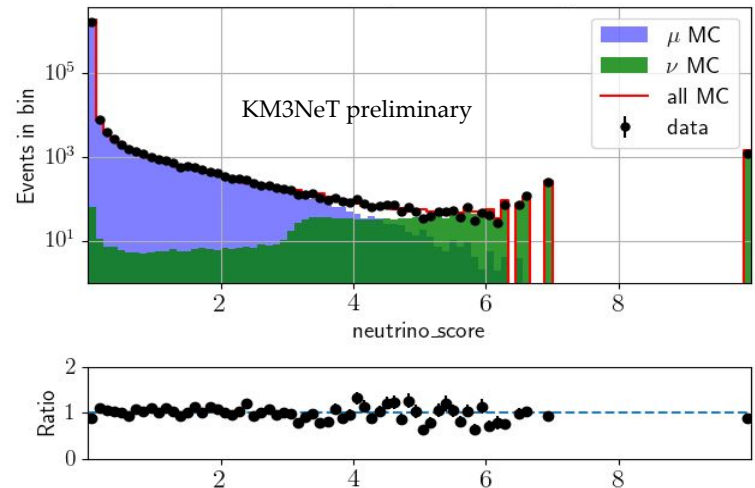
Score  $\mu/\nu$  between 0 and 1 to separate neutrinos from the atmospheric muon background



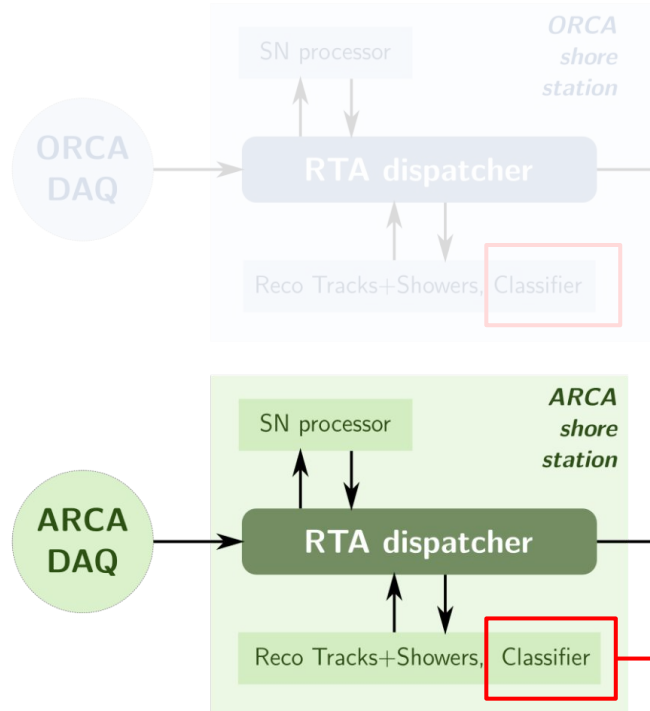
Transparency



Requires reconstruction output as input



# KM3NeT online event classification



## Graph Neural Network (GNN) classifier

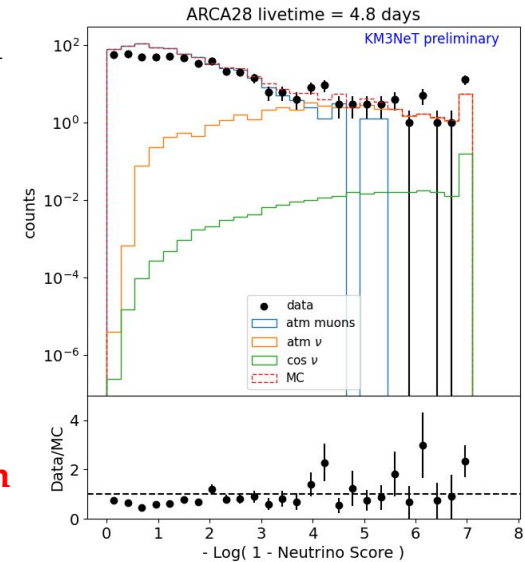
Score  $\mu/\nu$  between 0 and 1 to separate neutrinos from the atmospheric muon background



**No reconstruction output as input**

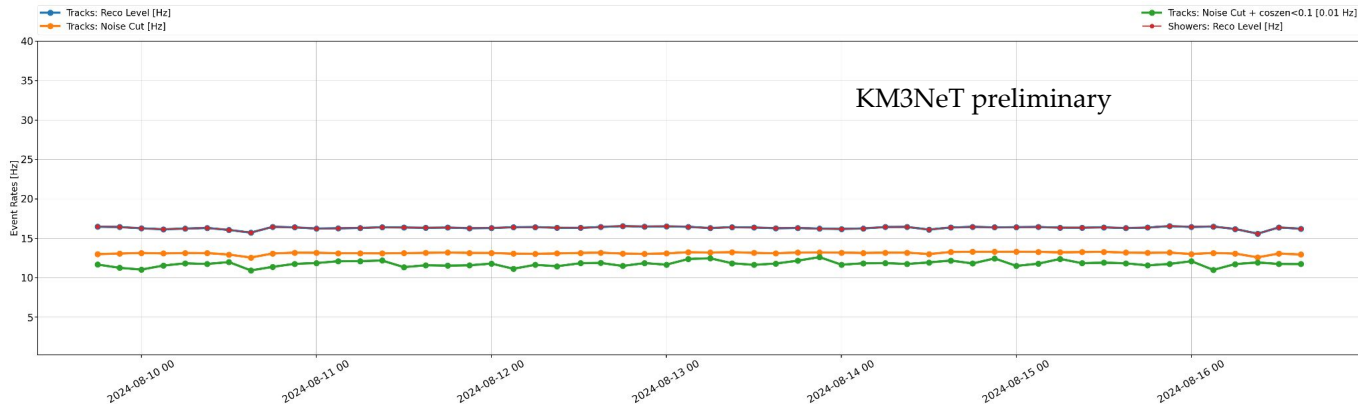
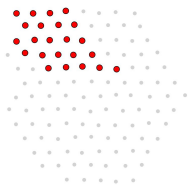


**Black box problem**

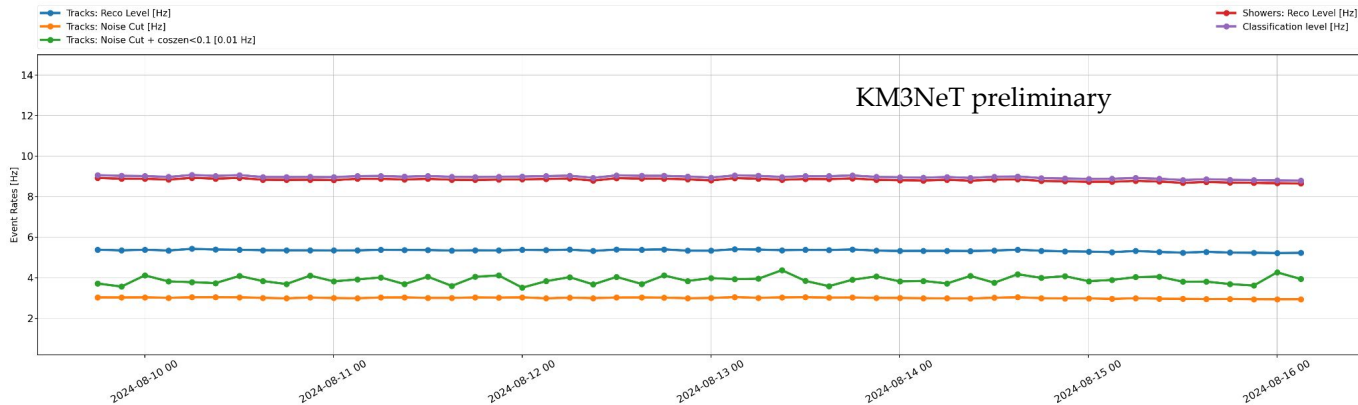
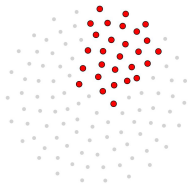


# KM3NeT online event rates

ORCA23



ARCA28



Events with a poor quality reconstruction are discarded after being processed

# Summary

- KM3NeT (ARCA + ORCA) is a neutrino telescope under construction in the Mediterranean Sea
- ARCA and ORCA can both be used to do neutrino astronomy from a few MeV to a few PeV
- ARCA and ORCA are currently taking data with 28 strings and 23 strings, respectively
- Real-time multi-messenger searches are a key component of the KM3NeT program
- The KM3NeT real-time analysis framework is operative, continuously reconstructing KM3NeT data and performing real-time follow-ups of external alerts
- ARCA and ORCA events are reconstructed and classified within the KM3NeT real-time analysis framework in less than 7 s and 10 s
- KM3NeT size is growing and work is ongoing to start sending alerts to the external multi-messenger community → most exciting time has to come yet!

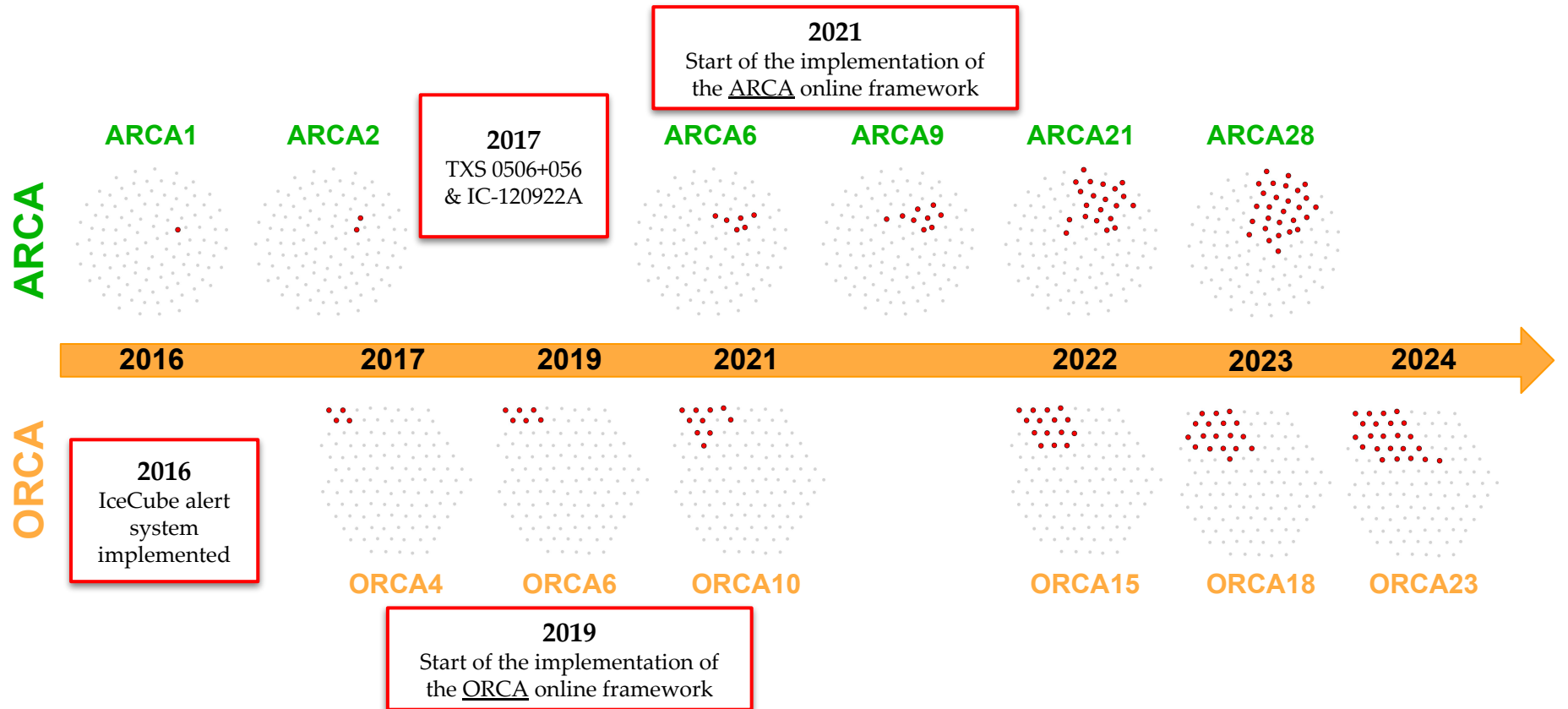


Thank you for your attention!



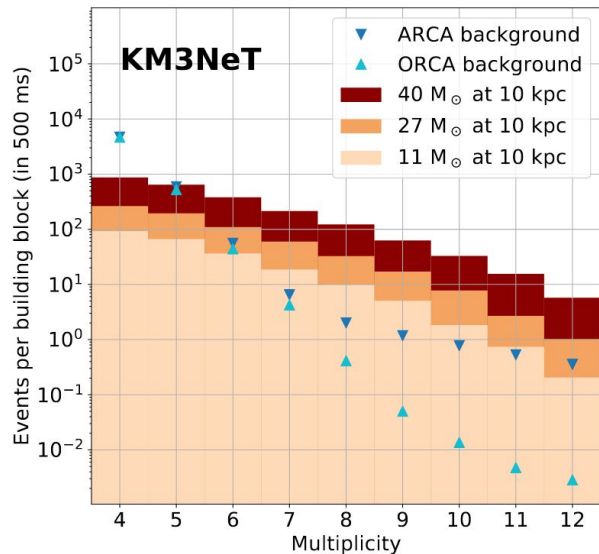
# Backup

# KM3NeT timeline

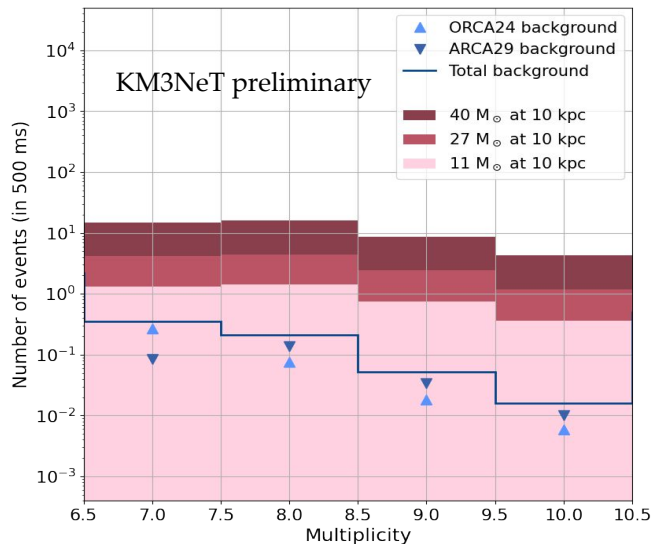


# Expected number of events for CCSNe

KM3NeT 115 strings



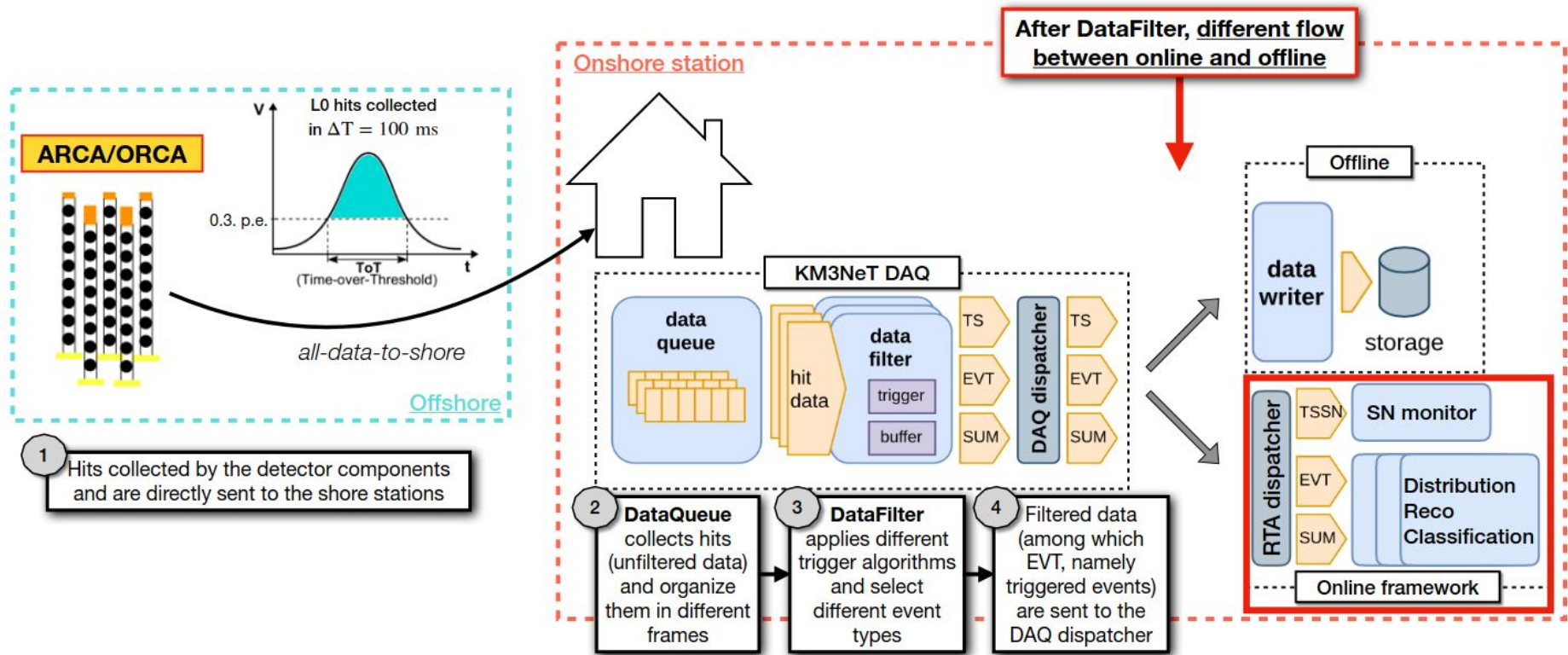
ARCA 29 strings + ORCA 24 strings



Multiplicity: number of unique PMTs involved in a coincidence

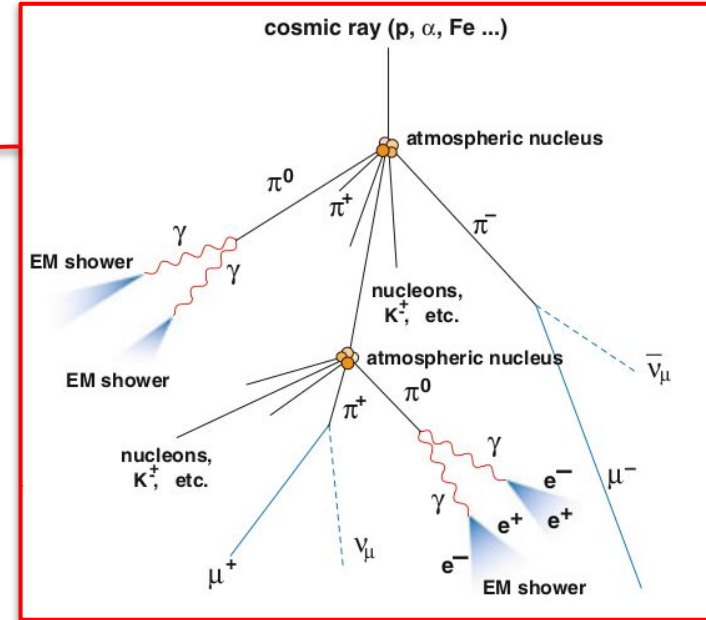


# KM3NeT data flow



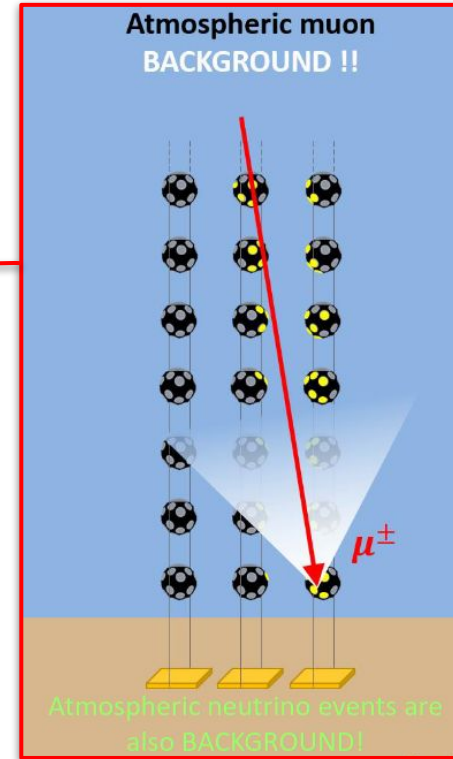
# Atmospheric background

- Interactions of cosmic rays in the atmosphere generate atmospheric muons and neutrinos
- Atmospheric muons and neutrinos can reach the detector
- Earth can be used as a screen for all particles, except neutrinos
- Looking at high energies, cosmic neutrinos flux is higher than that of atmospheric neutrinos



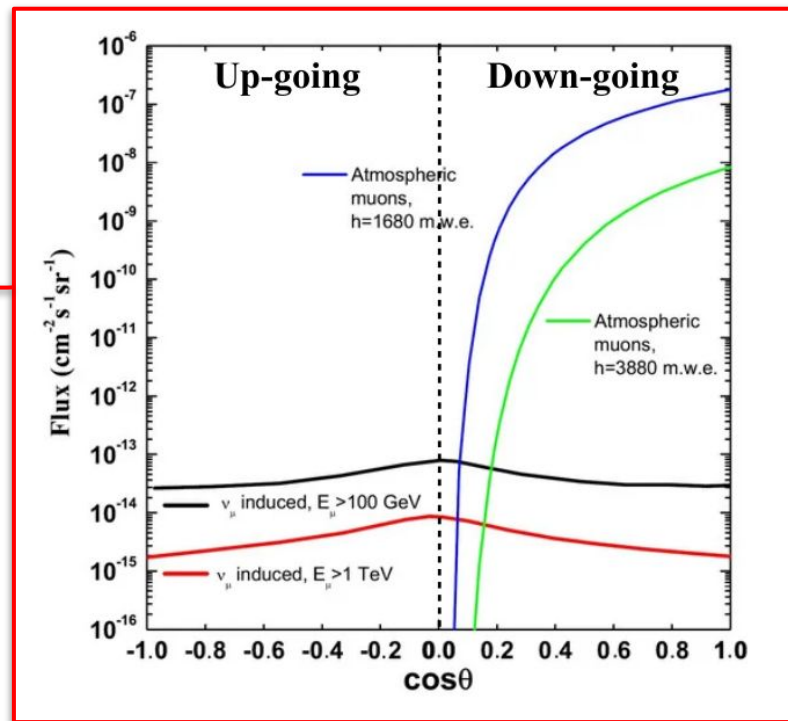
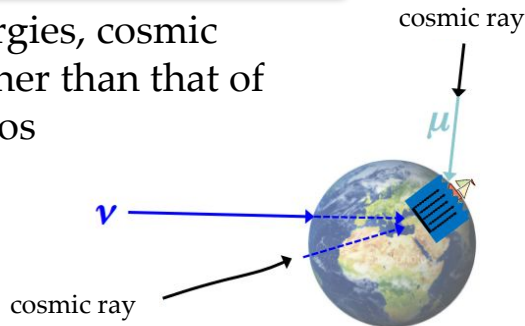
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