

KM3NeT open science

D. Dornic - 11/10/2022

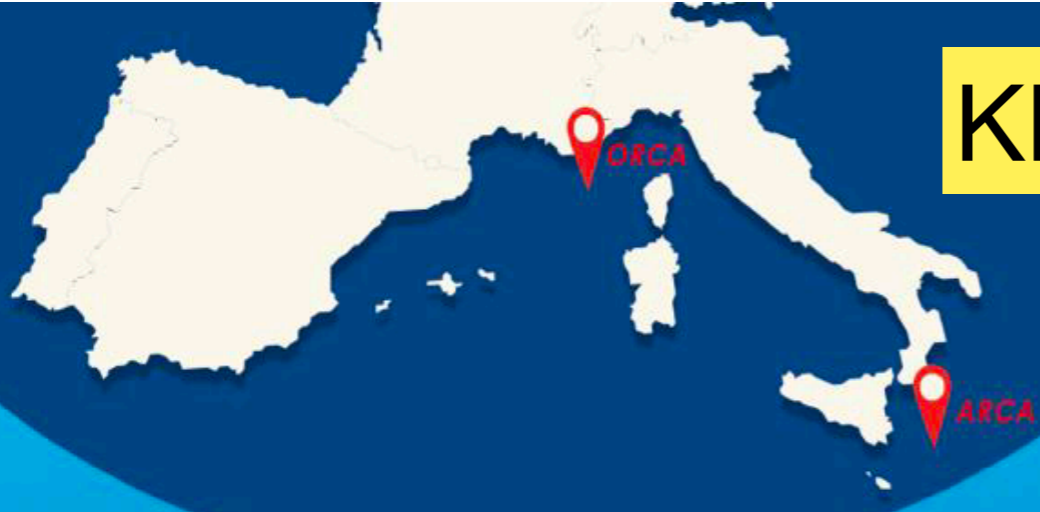
Astrophysique des Hautes Energies dans l'Observatoire Virtuel

(Stolen quite a lot of slides from J. Schnabel)

Plan

- Brief introduction on KM3NeT
 - KM3NeT neutrino alerts (real-time)
 - Providing archive data to the public
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- Virtual observatory
 - hoping to host ANTARES data
 - using VO format for alerts
 - initiative to develop further metadata with IVOA (common with CTA)
 - Common VHE format
 - IRFs
 - integrating with gammapy
 - common GW initiative (GW analysis pipeline Wavefier)

KM3NeT

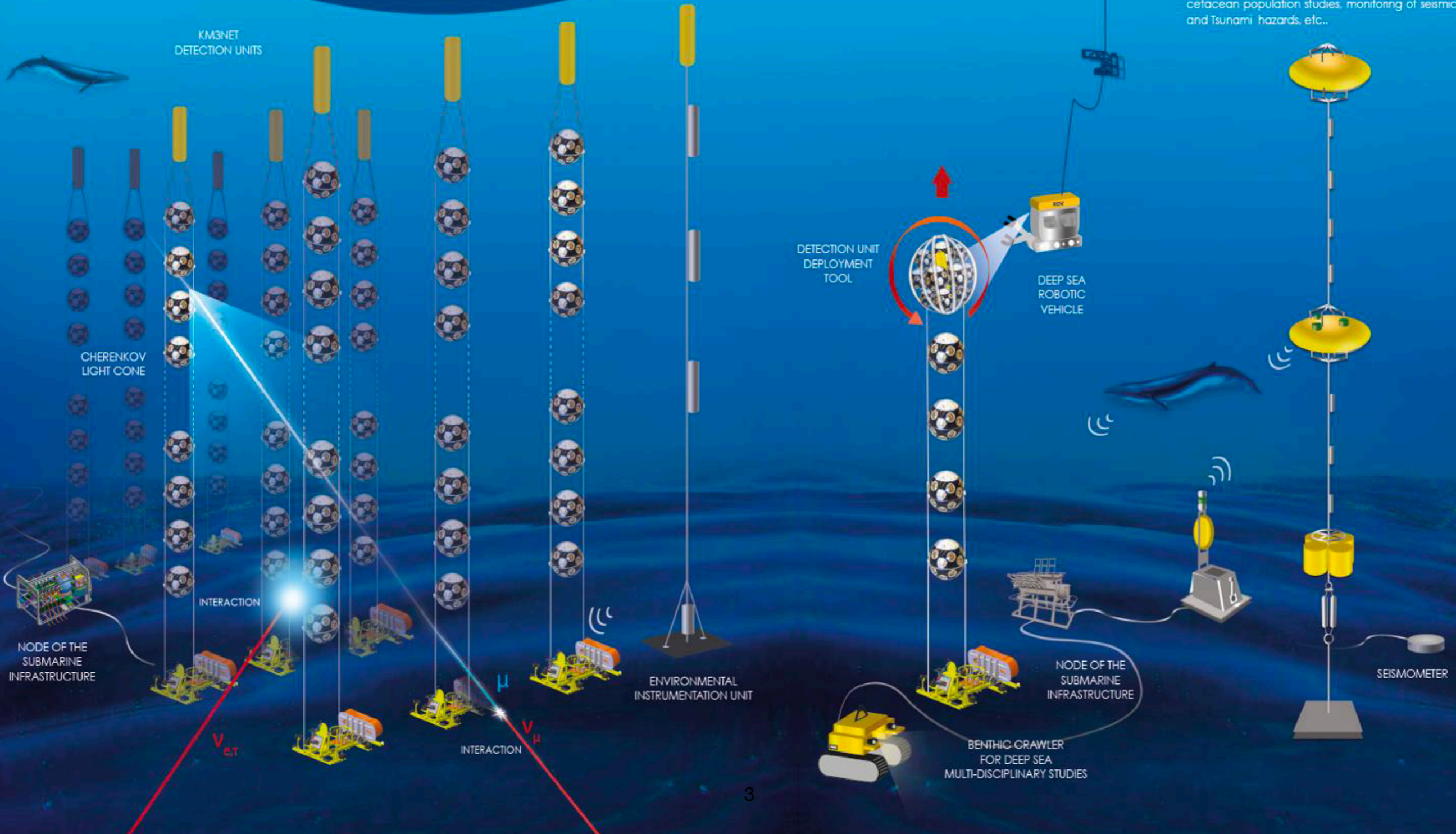


SURFACE SHIP FOR THE ROV

A NEW WAY TO STUDY THE ABYSS

KM3NeT is also a permanently cabled deep-sea observatory that enables the real-time acquisition of continuous, high-frequency, time series data for the study of the marine environment.

The synergetic science that can be addressed includes: climate change, ocean current circulation, biodiversity, bioluminescence, bioacoustics, cetacean population studies, monitoring of seismic and Tsunami hazards, etc..



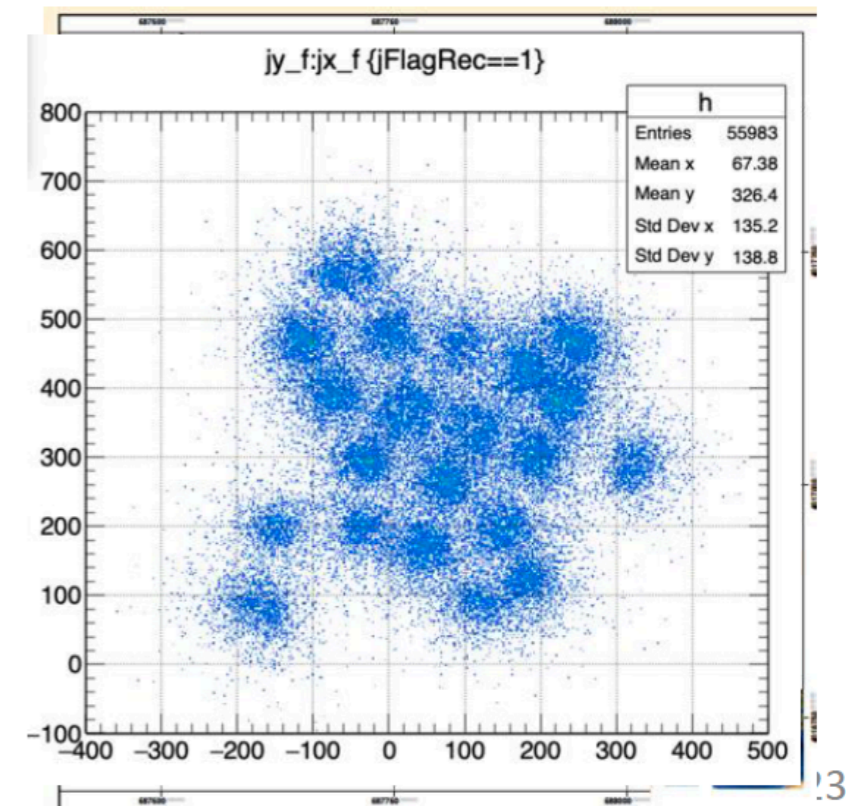
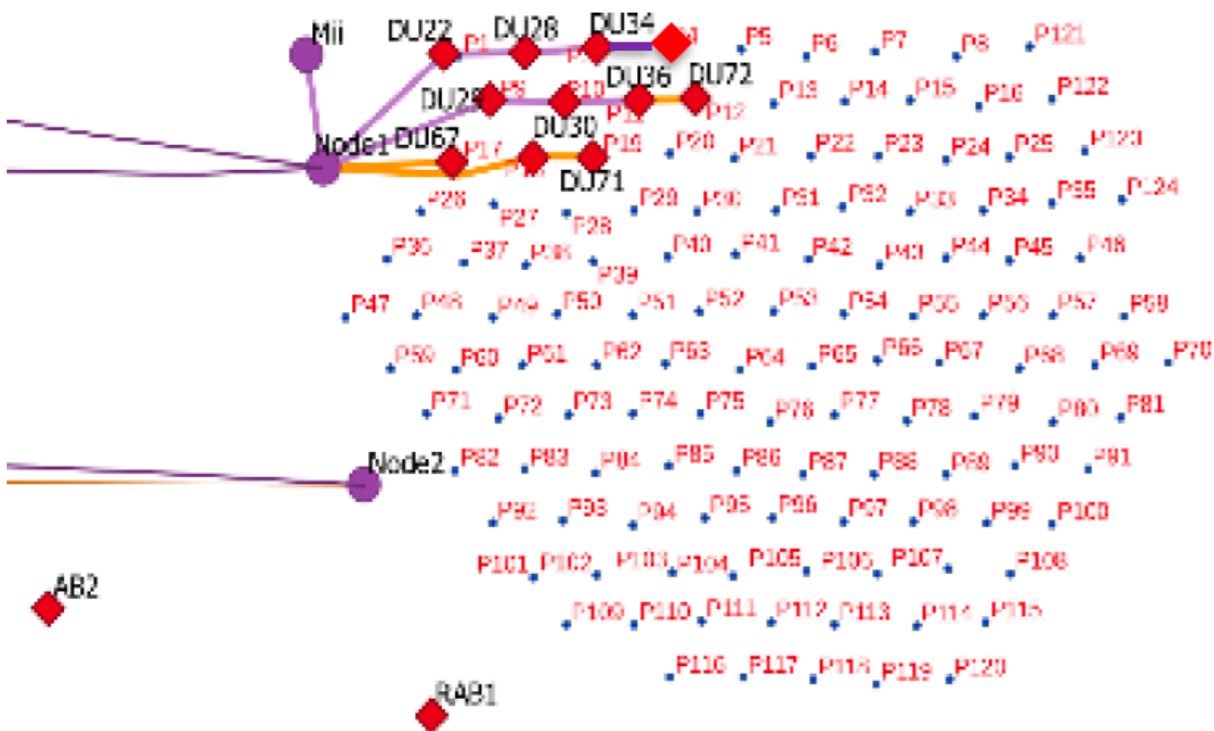
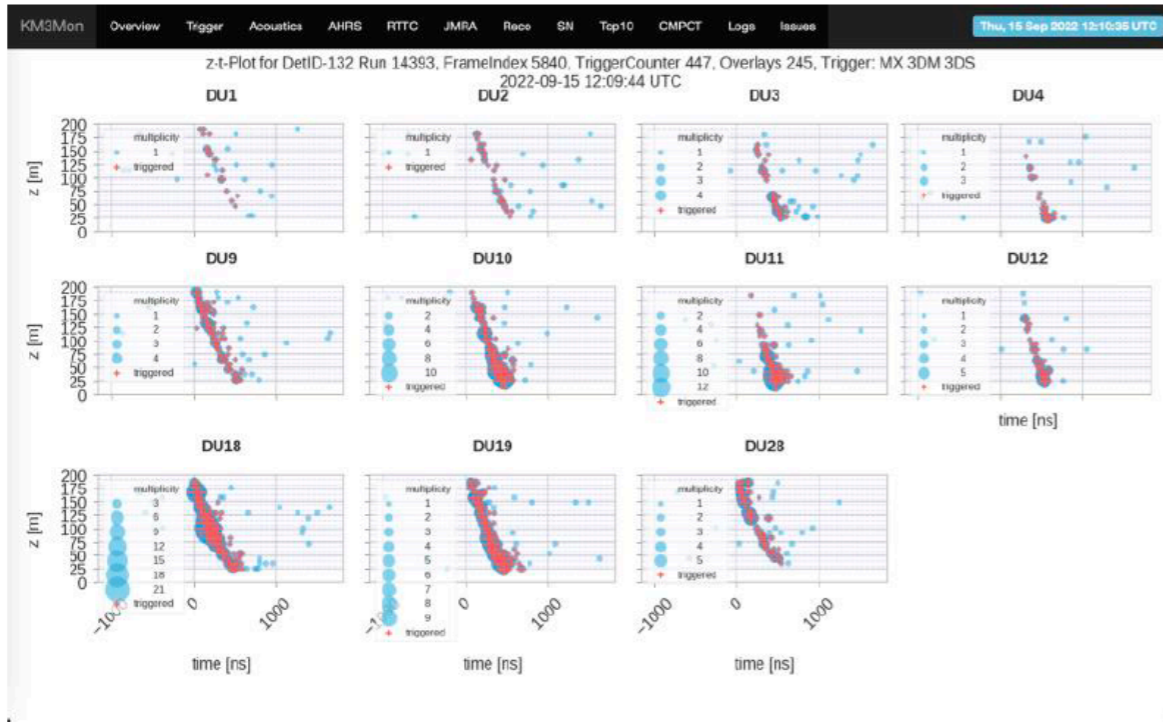


Current Status: 32 DUs operating

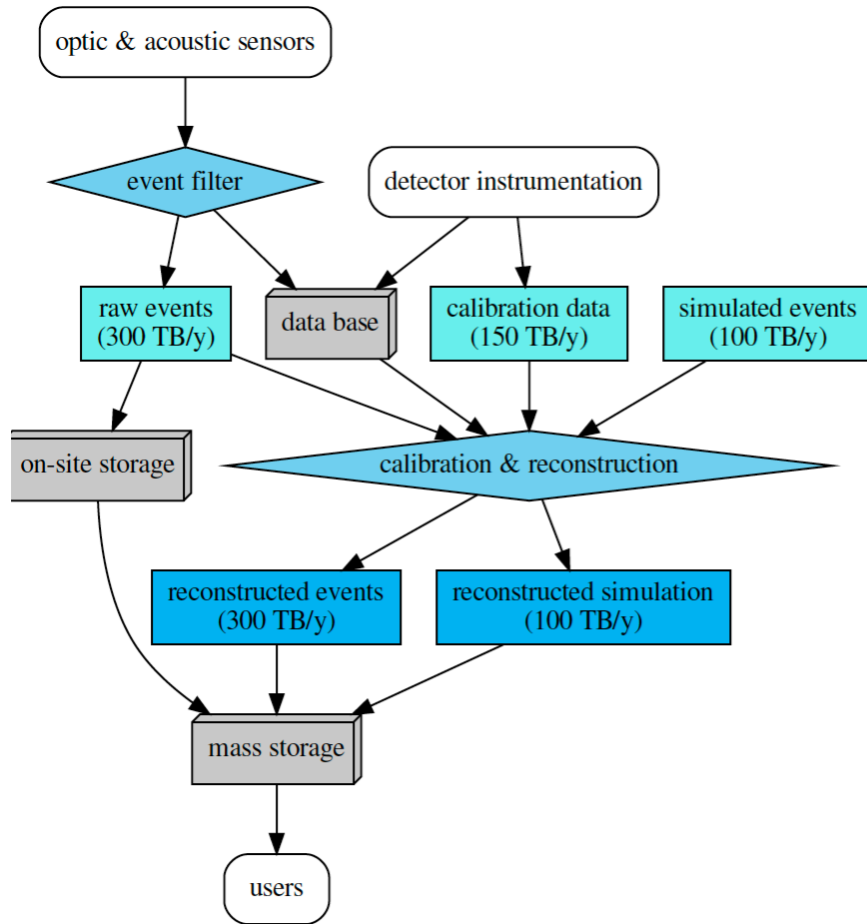
ORCA11

Online Zt plots

ARCA21



KM3NeT data generation



KM3NeT 2.0 Lol: arXiv: 1601.07459

RECONSTRUCTED EVENT	
event info	identifiers run_id, event_id, group_id data taking detector, frame index, overlays, trigger_counter, trigger_mask, utc_nanoseconds, utc_seconds simulation livetime, mc_id, time Nevents, Nfiles, weights
hits	[channel, dom, time, tot, triggered]
reconstructions /mctracks	direction(local), energy, position, length, time, reconstruction parameters

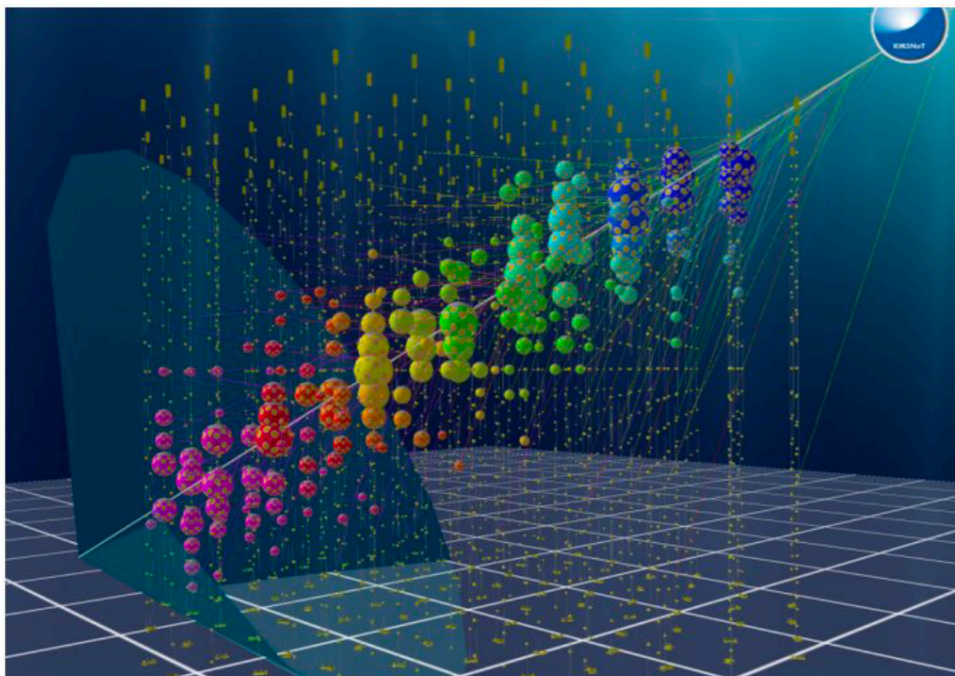
KM3NeT native data format: ROOT file, but also HDF5

„Full“ event (i.e. particle detection!)

event identification	detector status	<photon detections \bar{x} , t, A>
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„Reduced“ event

reconstructed particle properties	direction time energy, resolution ...
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Decl [deg]	RA [deg]	Nhit [deg]	Beta	MJD [days]
19.5	68.2	21	1.0	54138.3105
-60.0	26.5	33	0.8	54138.5830
-29.8	82.1	34	0.3	54140.2299
-8.6	271.8	41	0.3	54140.6394
-32.3	261.4	45	0.5	54142.7042
-66.7	149.9	52	0.8	54159.4158
-13.0	93.6	25	0.7	54160.4830
-26.2	266.7	28	0.8	54160.6180
23.5	121.7	41	0.5	54161.4361
-70.7	47.1	30	0.9	54165.5838
-55.0	284.4	36	0.5	54169.0685

Example files of KM3NeT ROOT files:
<https://github.com/KM3NeT/km3net-testdata>

KM3NeT data

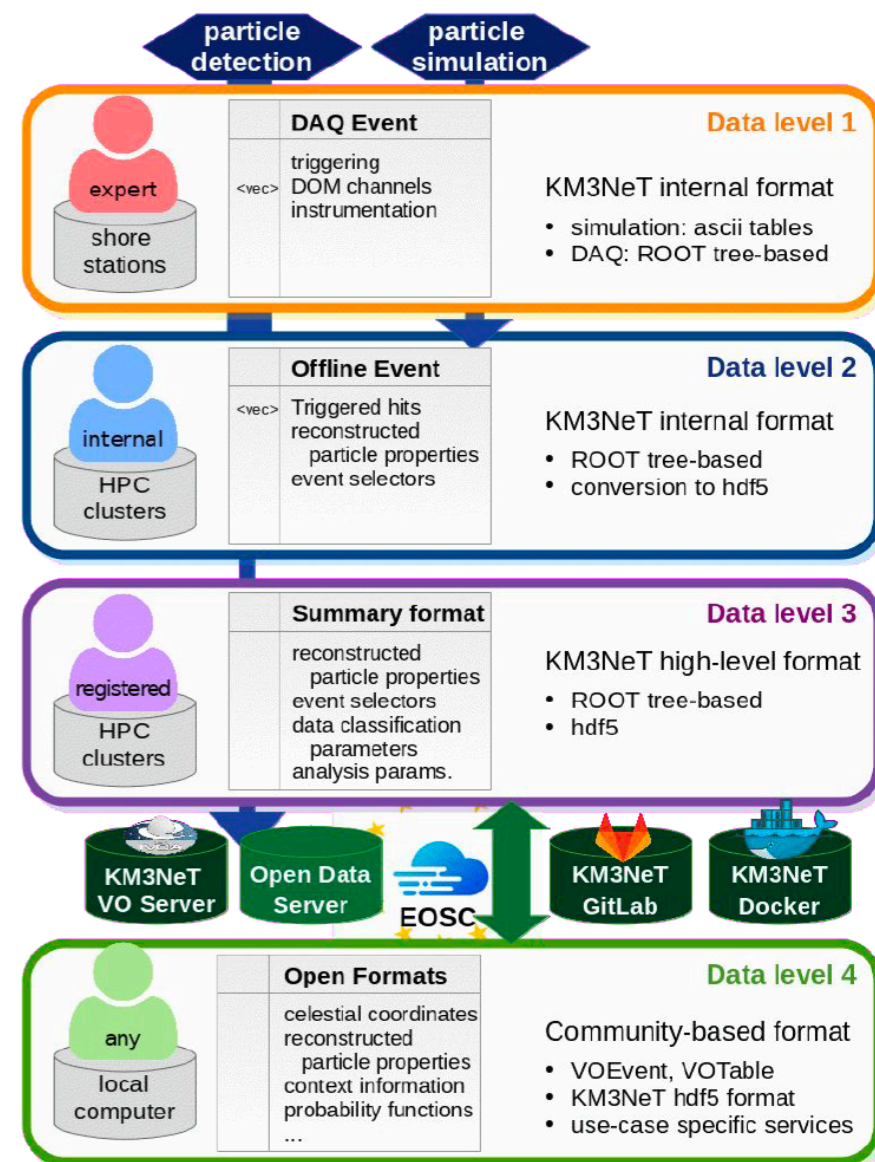
Particle event data

- Level 2 data: fully calibrated events, including hit information (ROOT files)
- Level 3 data: fully reconstructed event without hit information (ROOT, hdf5)
- Level 4: Selected data sets, single events (VOEvent, VOEvent)

Event simulation

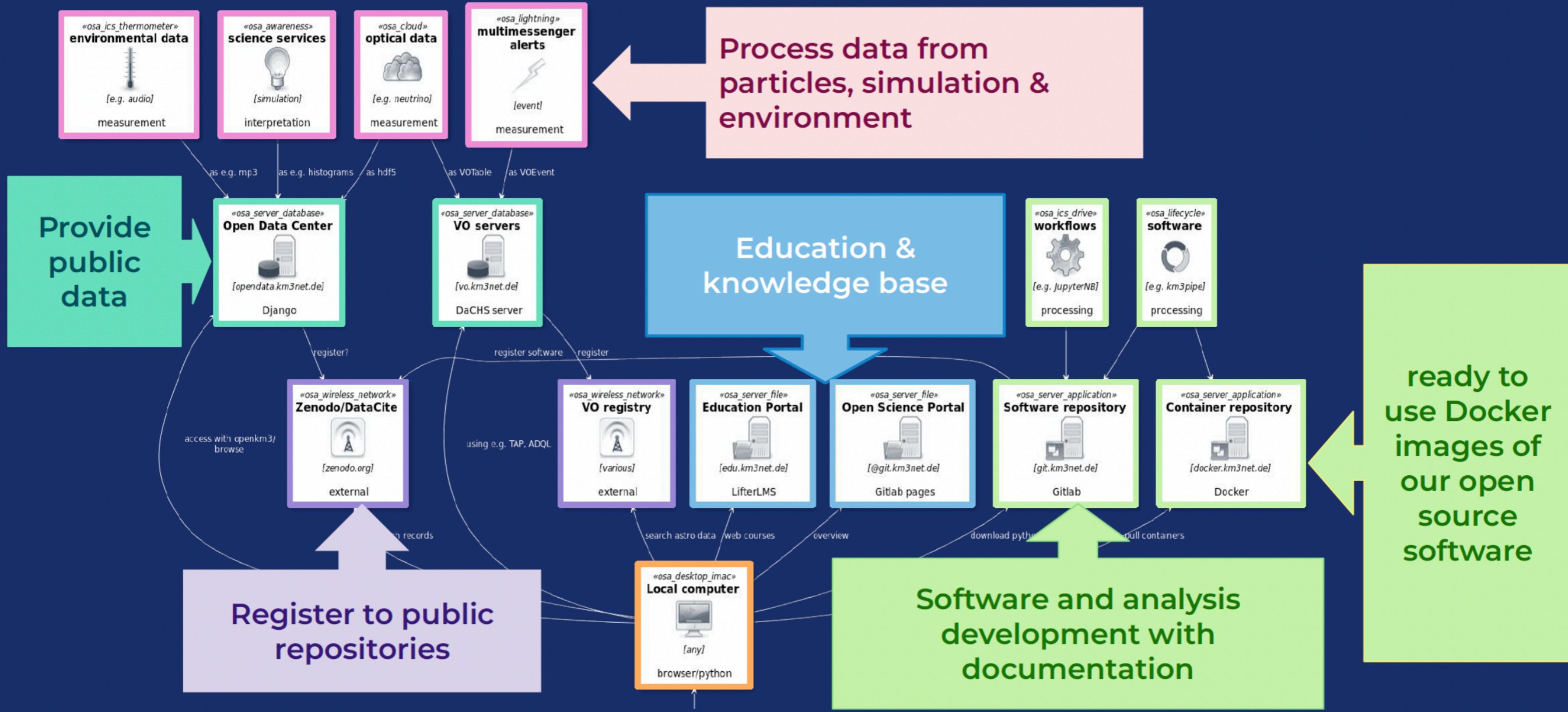
- Signal (cosmic neutrino) and background (atmospheric) events
- **Analogous processing to measurements**

+ calibration data
+ Oceanography data



KM3NeT open science tools

- Development of prototypes



VO server for KM3NeT

- Running server with DaCHS software
- Registered as data provider to the VO (ivo://km3net.org)
- Can publish data sets to the VO registry - done with Antares 2007-2017 data
- Data accessible through widely used tools in **astrophysics** (Aladin, Topcat ...)

Virtual observatory server

<http://vo.km3net.de/>

Dist. [arcsec]	MJD	Beta	number of hits	right ascension	declination	ID
2032.96	55926.0166	0.5	24	359.5	0.3	ANT4536
3020.36	57940.5225	0.5	29	359.3	-0.1	ANT8455
5359.52	56178.5081	0.3	54	0.4	-1.2	ANT4999
6001.19	55841.6068	0.9	27	0.3	1.9	ANT4092
8913.93	55954.107	0.3	44	2.2	-1.0	ANT4680
8953.08	56340.0737	0.2	39	358.4	2.1	ANT5618
10580.47	54462.2357	0.4	35	1.1	3.0	ANT0238
11096.03	54510.0353	0.2	43	2.6	-1.5	ANT0415
11303.16	56284.2811	0.7	64	2.6	2.1	ANT5411
11708.80	55968.0641	0.4	37	1.8	3.0	ANT4734
12383.00	58059.5025	0.5	26	357.3	-1.8	ANT8630

Information on resource 'ANTARES 2007-2017'

Neutrino candidates from full-sky search from 2007-2017

Services defined within this resource descriptor

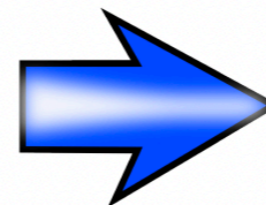
- [ANTARES 2007-2017](#)

Tables defined within this resource descriptor

- [ant20_01.main](#) – queryable through [TAP](#) and [ADQL](#)

[[Manage RD](#)]

Please report errors and problems to the [site operators](#). Thanks.



Integration of further (and legacy) ANTARES data in KM3NeT environment planned

Open data center for KM3NeT

Introducing: The KM3NeT Open Data Center

- For all data not publishable through the IVOA, serving as interface and/or server to the data
- Including also link to data sets on VO server
- Based on Django REST API
- Usable for event data sets (hdf5-files with standardized metadata), plots or services, environmental data ...
- Data accessible through webpage, through REST-API or python based package (openkm3)

Open Data Center

<http://opendata.km3net.de>



Open Data Center

Collection: One week of ORCA 4-line data

Description Events from one week of data taking with ORCA

Version 1.0

Further Info <https://open-data.pages.km3net.de/openscienceportal/articles/getting-started/#analysis-of-atmospheric-muon-dominated-dataset>

Resources in the collection

ORCA4 events file

Description: Events from data taking with 4 strings of ORCA

Resource record: [link](#)

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KM3NeT neutrino alerts

What data can KM3NeT provide?

In less than 1 minute, full reconstruction of tracks and showers with direction and energy estimation (for now 20s buffer that will be removed soon)

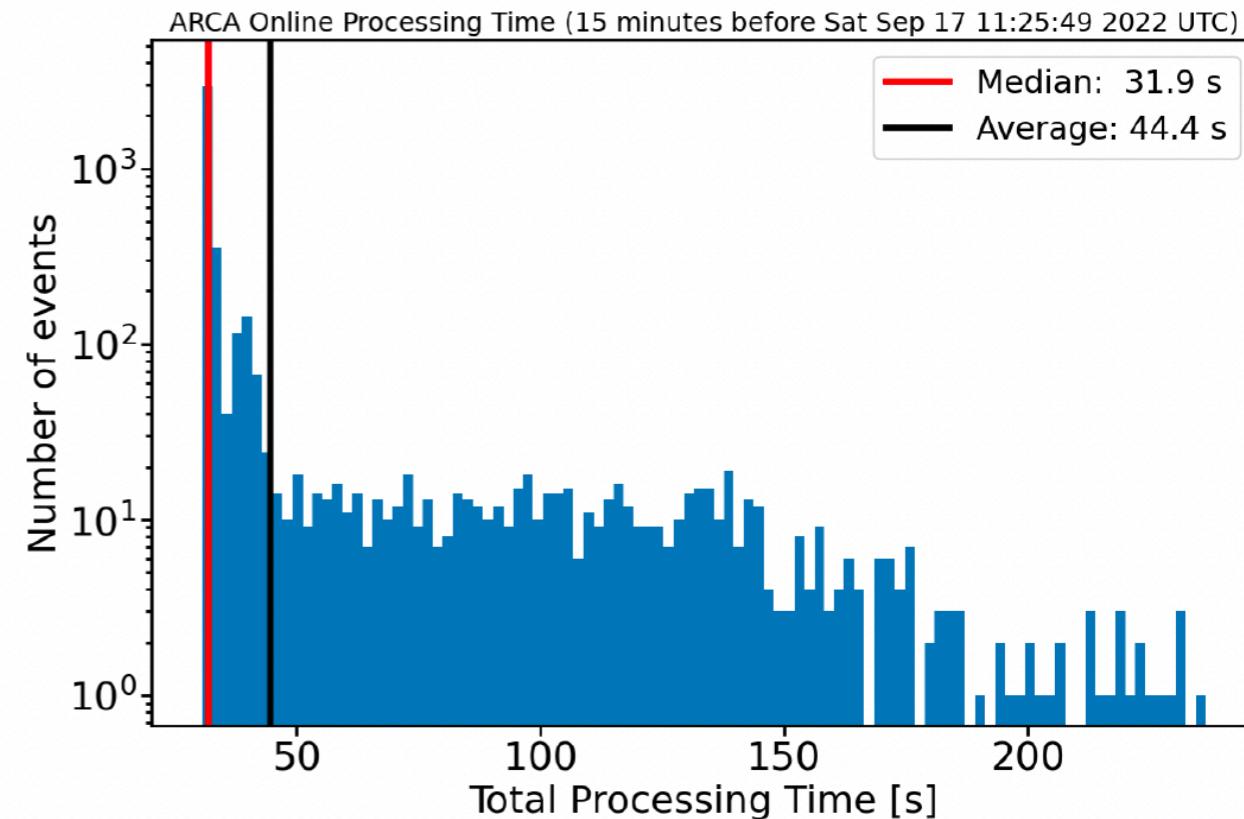
For every event, we have access to

reconstruction as tracks and as showers with:

- probability of neutrino (all flavors) vs muon for low energy

- probability of track vs shower for high energy

With a full detector (230 lines for ORCA, 115 lines for ORCA), we expect between 100 and 200 neutrinos per day



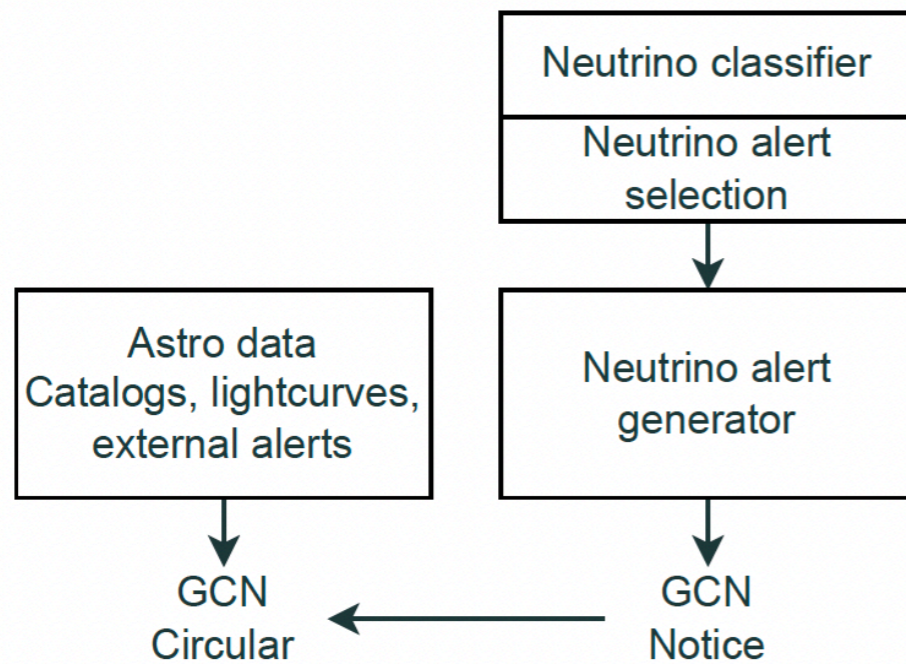
Total processing time of events with ARCA

KM3NeT neutrino alerts

Pure neutrino selection

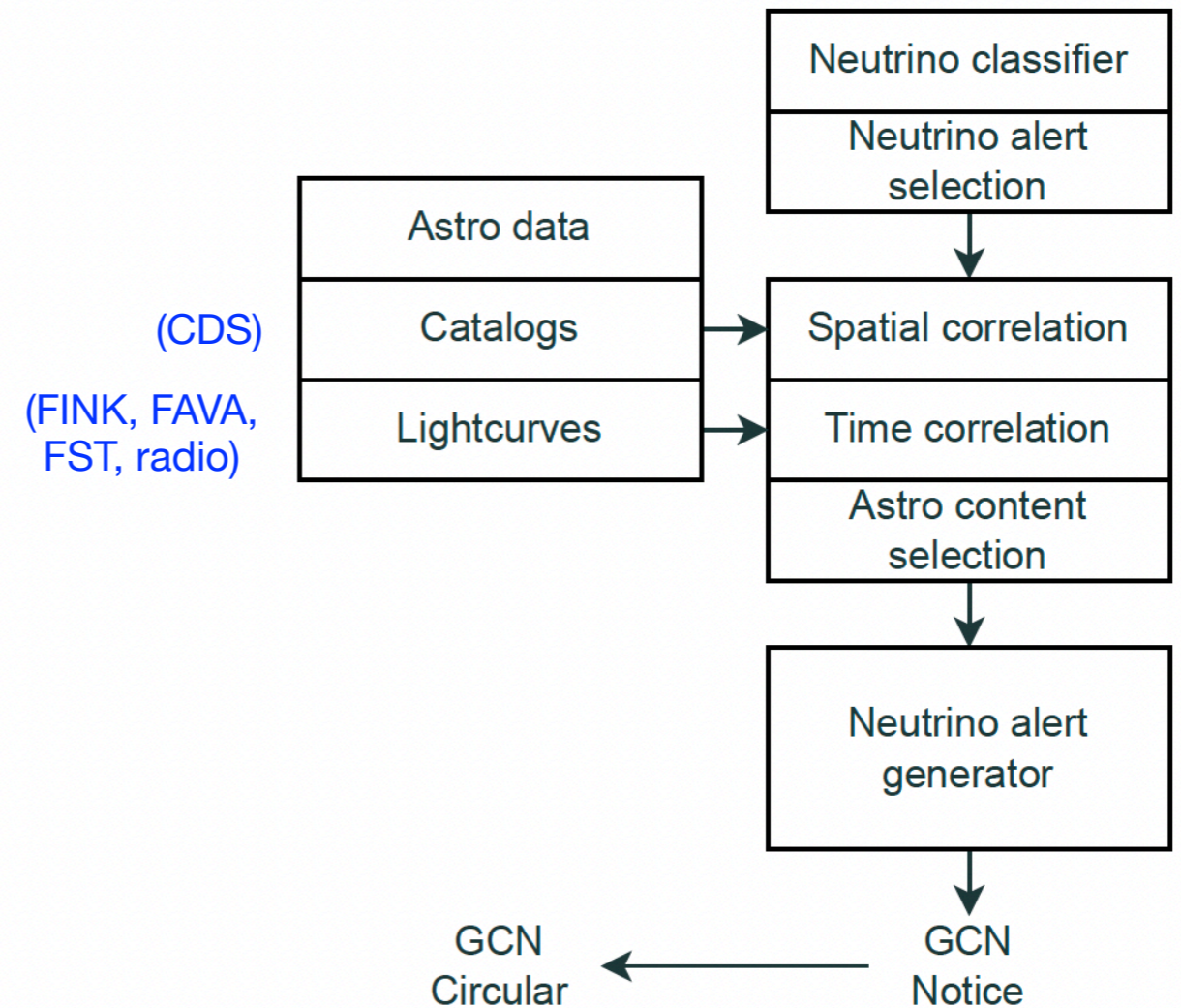
(Very) high energy and multiplet selection

Kept to not introduce bias in case of an unexpected source

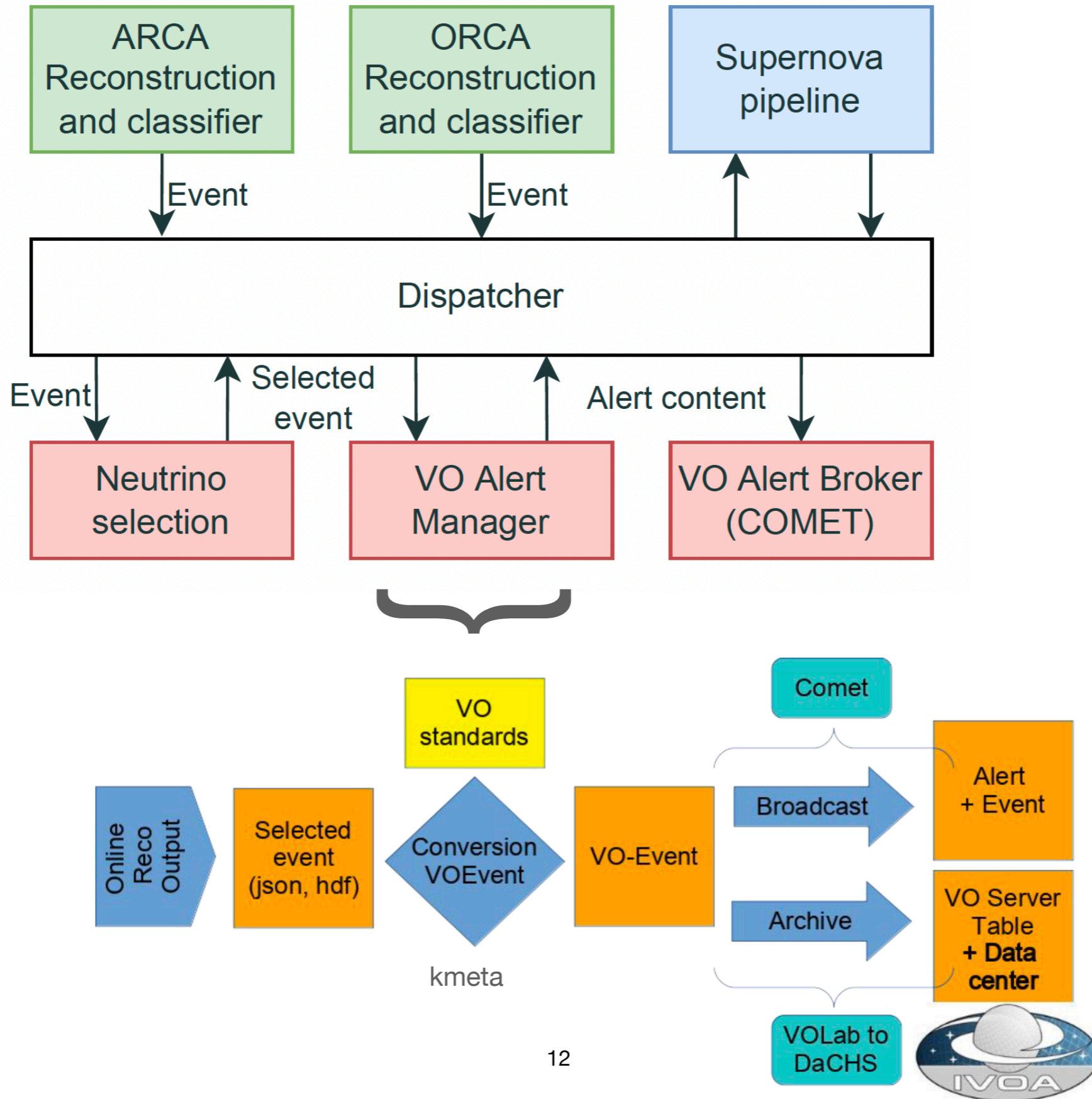


Mix neutrino-astro selection

Selection of neutrinos based on both the neutrino properties and the properties of the potential astrophysical source



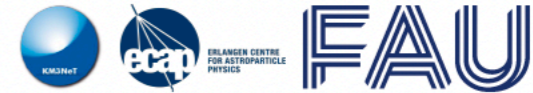
KM3NeT neutrino alerts



Open KM3NeT format

How to add relevant probability functions?

Adding instrument response, background and other auxiliary simulated information



No VO standard for neutrino regime - starting our own

- extended header with content identifier
- tabulated data (e.g. bin content, function values ...)
- ready for use in python environment

Example: Effective area for ANTARES 2007-17 Point Source search

```
ks.print_index()

annotated_aeff0
=====
header:
  name:          ANTARES 2007-2017 effective area
  description:   effective area for E-2 source sp
  contact:      antares.spokesperson@in2p3.fr
  instrument:   ANTARES
  license:      Creative Commons 4.0 Internation
  reference:    https://antares.in2p3.fr/public
```

```
plain = ks.get("annotated_aeff0") # not so nice, make i
plain.data

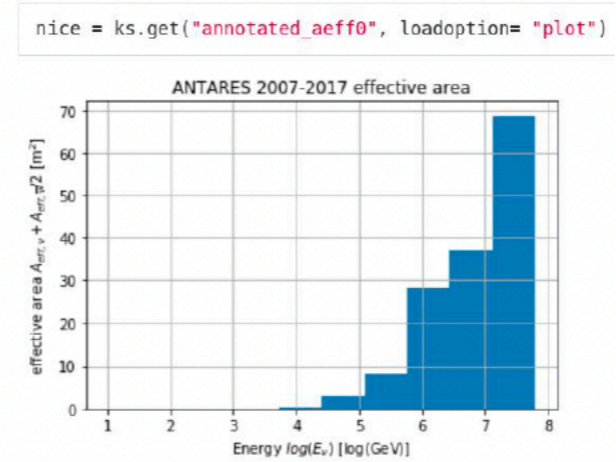
{'Log(E1/GeV)': [1.0,
1.2,
1.4,
1.6,
1.8,
2.0,
2.2,
2.4,
2.6,
2.8,
3.0,
3.2,
3.4,
3.6,
```

get as table

```
table = ks.get("annotated_aeff0", loadoption = "pandas")
table.data
```

	Log(E1/GeV)	Log(E2/GeV)	AEFF/m2
0	1.0	1.2	5.153940e-12
1	1.2	1.4	1.614220e-10
2	1.4	1.6	4.891220e-09
3	1.6	1.8	1.245090e-07
4	1.8	2.0	9.157530e-07
5	2.0	2.2	4.372520e-06

get as dataframe



get as plot

```
table.get_origin()

{'range': {'time': {'measurement_start': datetime.datetime(2007, 1,
'measurement_stop': datetime.datetime(2018, 1, 1, 0, 0),
'ktype': 'tbd'},
'zenith': {'min': -45, 'max': 0, 'ktype': 'tbd'}}}

table.get_paraminfo()

{'lower_edge': {'columnname': 'Log(E1/GeV)',
'name': 'Energy',
'description': 'logarithmic reconstructed energy of the neutrino',
'unit': 'log(GeV)',
'symbol': 'log(E_{\nu})'},
'upper_edge': {'columnname': 'Log(E2/GeV)',
'name': 'Energy',
'description': 'logarithmic reconstructed energy of the neutrino',
'unit': 'log(GeV)',
'symbol': 'log(E_{\nu})'},
```

get metadata

Open KM3NeT format

pip install git+https://git.km3net.de/open-data/openkm3

- dependency: pyvo for VO interface
- “KM3Store” as access point for all data + services

```
from openkm3.openio import KM3Store
ks = KM3Store()
```

```
table = ks.get("one_week_orca", ["events"], "pandas")
table.data
```

	angular_error	azimuth	dirz	energy	internalID
0	0.004341	5.108108	-0.968124	22.017775	km3net.44.615
1	0.001181	3.358250	-0.990520	128.639694	km3net.44.615
2	0.003534	6.146142	-0.744035	24.362326	km3net.44.615
3	0.008247	2.954967	-0.784588	15.714084	km3net.44.615
4	0.006967	5.618736	-0.529338	137.616933	km3net.44.615

- entries are data sets, single files or services
- access logic coded in package

```
ks.print_index(include_technical=True)
```

```
one_week_orca
=====
tables: ['events', 'group_info', 'header']
header:
    author:                b'The KM3NeT collaboration'
    contact:               b'opendata@km3net.de'
    instrument:            b'ORCA'
    license:               b'Creative Commons 4.0 International'
    measurement_start:    b'2019-10-03T06:00:00.544000000'
    measurement_stop:     b'2019-09-17T06:00:00.202000000'
    reference:            b'http://www.km3net.org/'
url:    http://vo.km3net.de:82/storage/one_week_orca.h5
type:   application/x-hdf5
local:  /home/jutta/Desktop/openkm3/examples/orca_data/.openkm3/one_week
```

Interfacing with other science communities

Providing IRFs and data in common analysis framework: start to work using the common used gamma-py package.



First test with km3irf (<https://git.km3net.de/km3py/km3irf>)

=> One joint CTA+KM3NeT analysis performed by Tim Unbehaun & Lars Mohrmann (<https://git.km3net.de/publications/public-results/cta-km3net-analysis>)

=> Follow-up initiative of the GADF since this year: VODF (Very-high-energy Open Data Format). Aiming to provide IRFs and Event lists in multiple contexts (including VO)

Start the development of the open data writer (converter from the KM3NeT data format to VODF)

