KM3NeT data modelling and VO activity

CEVO workshop 8th Dec 2021

J. Schnabel for the KM3NeT collaboration

ESCAPE - The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures has received funding from the European Union’s Horizon 2020 research and innovation programme under the Grant Agreement n° 824064.

Overview

- Neutrino event information: data levels and current platforms
- Finding a place for “supplementary information”
- Dealing with simulation: status on IRFs

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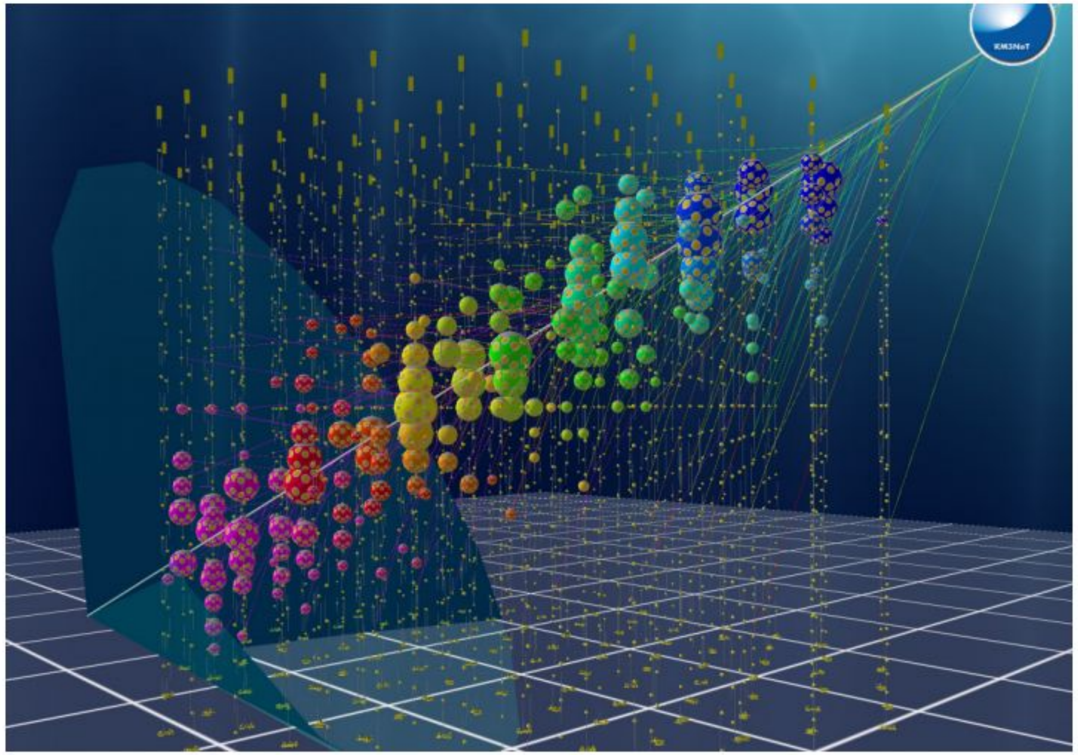
What does neutrino data look like?

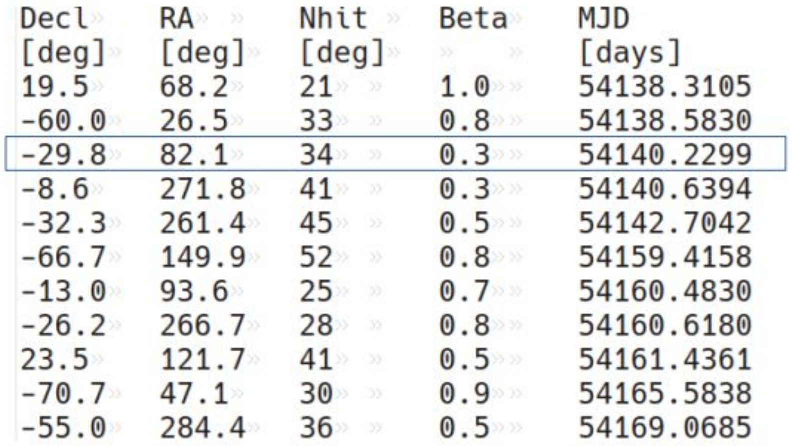
„Full“ event (i.e. particle detection!)

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



„Reduced“ event

reconstructed particle properties	direction time energy, resolution ...



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

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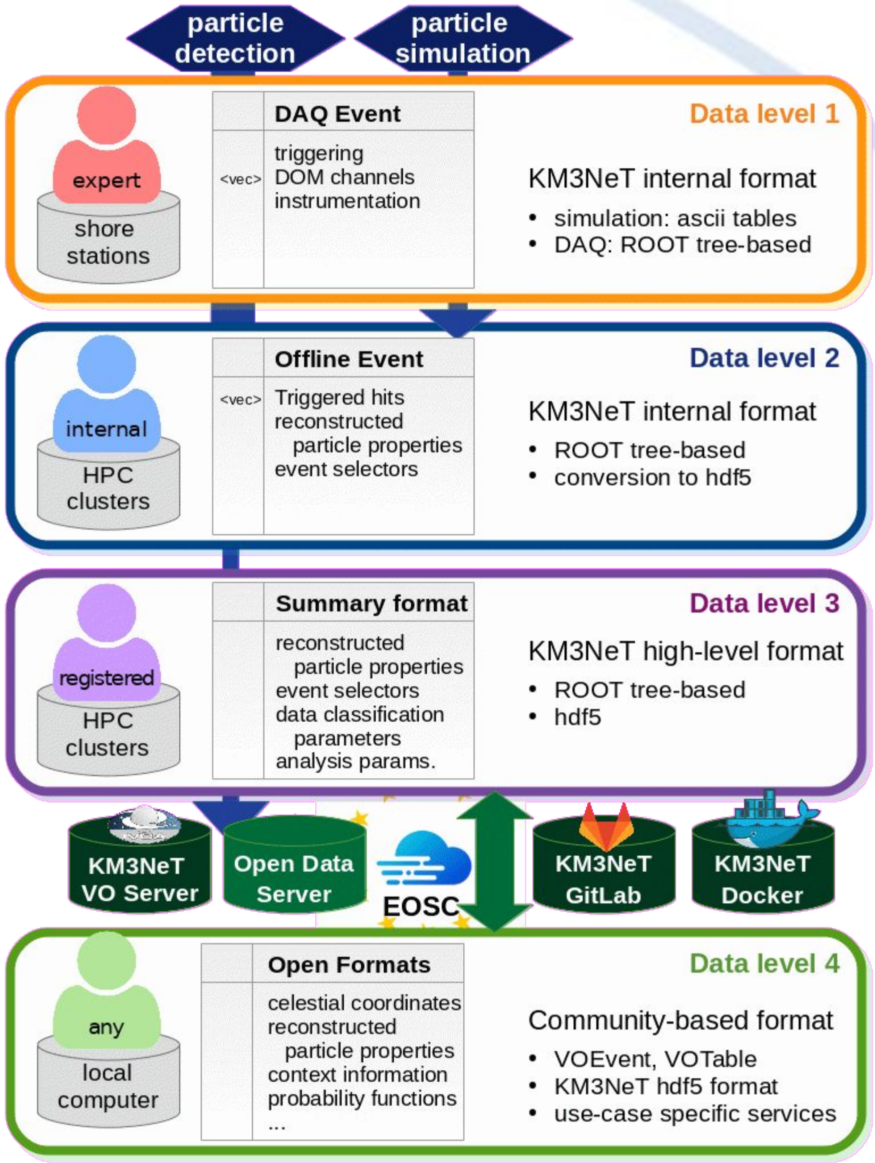
Data levels

Particle event data

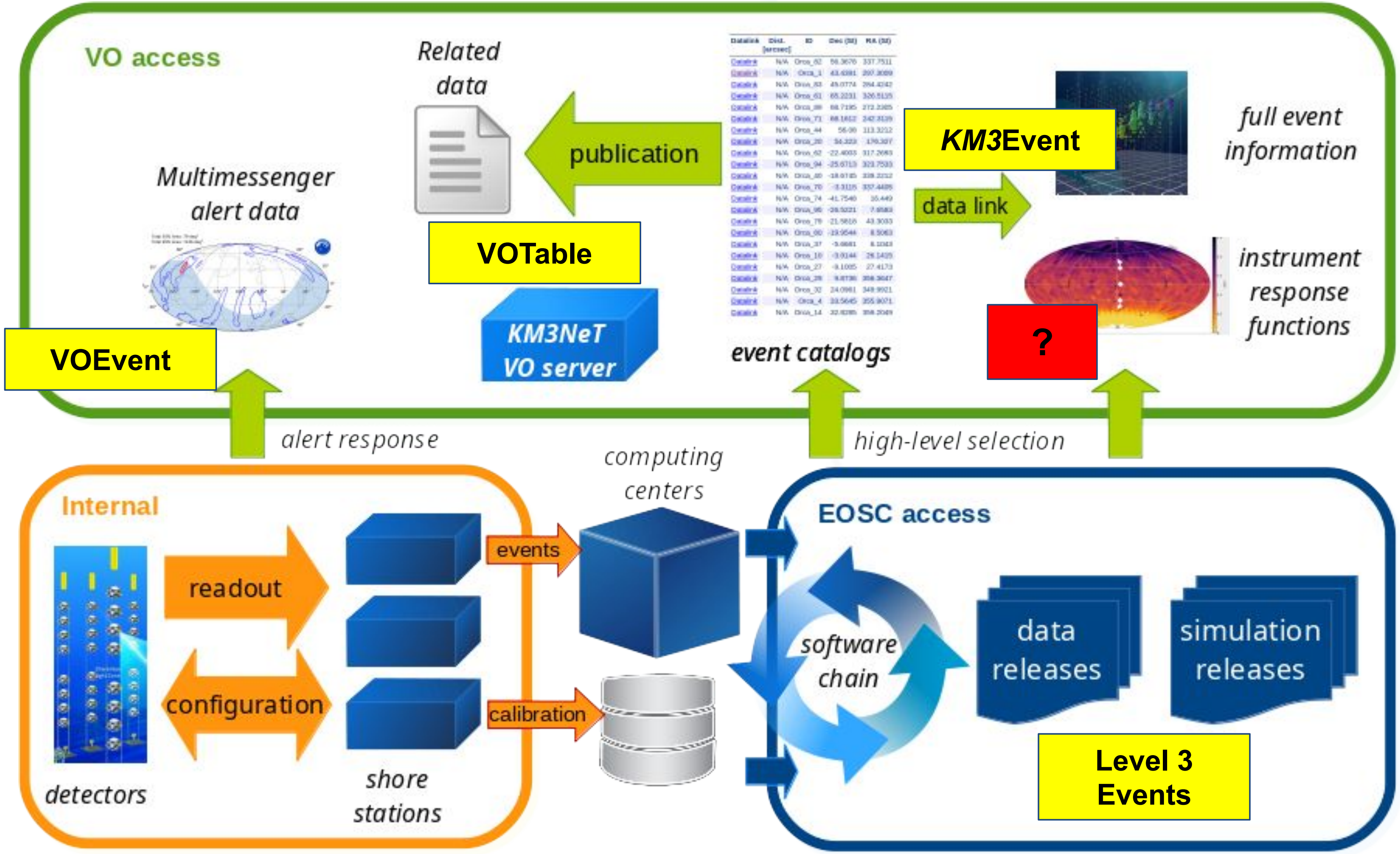
- Level 2 data: fully calibrated events, including hit information (ROOT files)
- Level 3 data: fully reconstructed event without hit information (ROOT, hdf5)
- Level 4: Selected data sets, single events (VOTable, VOEvent)

Event simulation

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



Where goes what …?



Datalink	Dist. [arcsec]	ID	Dec ([illegible])	R.A. ([illegible])
Datalink	N/A	Orca_62	58.3676	337.7511
Datalink	N/A	Orca_1	43.4381	207.3009
Datalink	N/A	Orca_83	49.0774	284.4242
Datalink	N/A	Orca_61	65.2231	326.5135
Datalink	N/A	Orca_88	68.7195	272.2305
Datalink	N/A	Orca_71	68.1612	242.3139
Datalink	N/A	Orca_44	56.90	113.3212
Datalink	N/A	Orca_20	54.323	170.327
Datalink	N/A	Orca_62	-22.4003	317.2683
Datalink	N/A	Orca_94	-25.6713	323.7533
Datalink	N/A	Orca_80	-18.0735	338.2212
Datalink	N/A	Orca_70	-3.3115	337.4405
Datalink	N/A	Orca_74	-41.7540	16.449
Datalink	N/A	Orca_96	-28.5221	7.8583
Datalink	N/A	Orca_79	-21.5816	43.3033
Datalink	N/A	Orca_00	-19.9544	8.5063
Datalink	N/A	Orca_37	-5.6681	8.1043
Datalink	N/A	Orca_10	-3.0144	28.1425
Datalink	N/A	Orca_27	-9.1005	27.4173
Datalink	N/A	Orca_28	9.8736	358.3647
Datalink	N/A	Orca_32	24.0961	348.9921
Datalink	N/A	Orca_4	33.5645	355.9071
Datalink	N/A	Orca_14	32.8285	358.2049

- In VO: Events are stored “without context”, based on specific publication
- Full simulation samples are not foreseen for publication at this point

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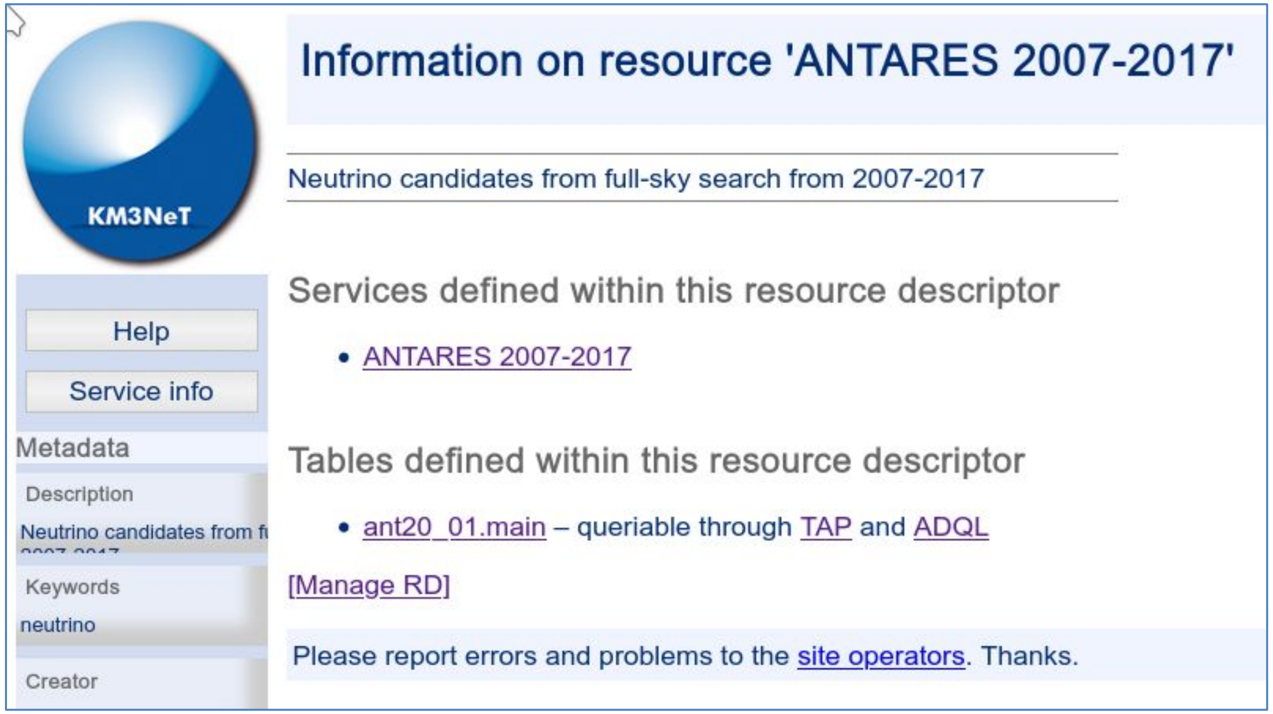
Current status on VO-compliant data

- 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/



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 – queriable through TAP and ADQL

[Manage RD]

Please report errors and problems to the site operators. Thanks.

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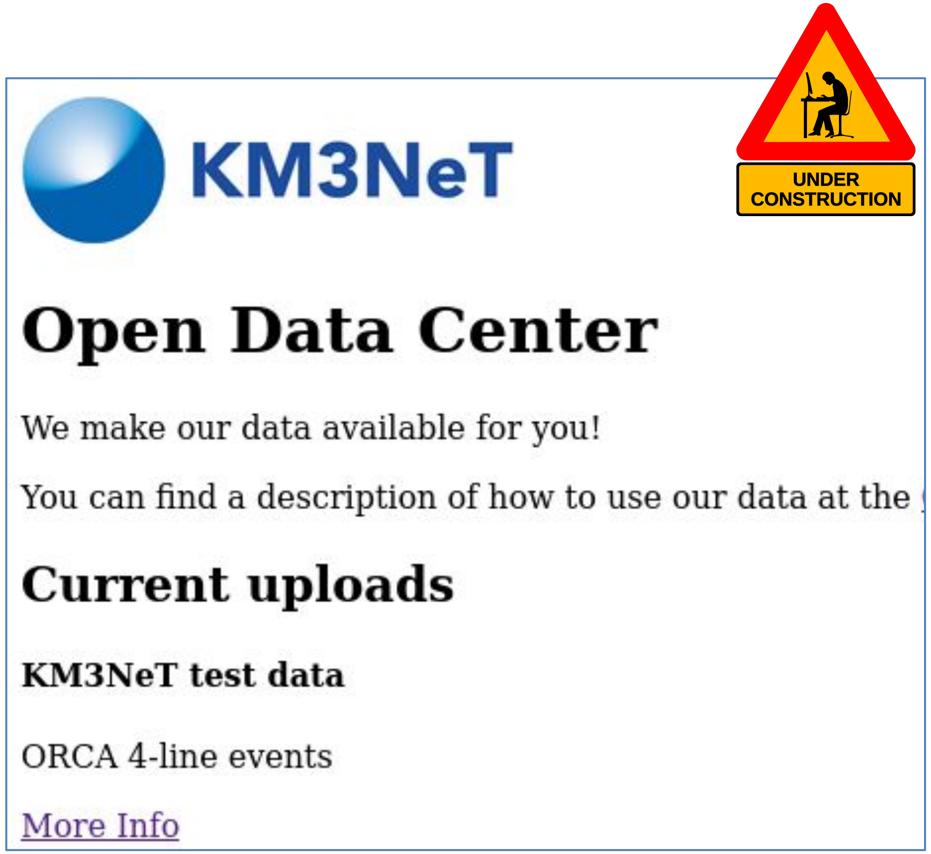
Interim solution: KM3NeT Open Data Center

- 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

We make our data available for you!

You can find a description of how to use our data at the

Current uploads

KM3NeT test data

ORCA 4-line events

More Info

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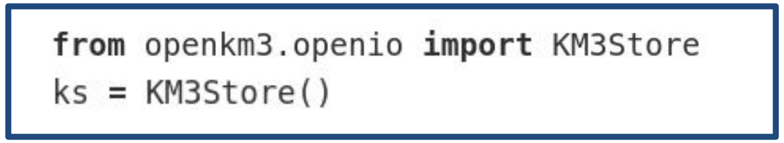
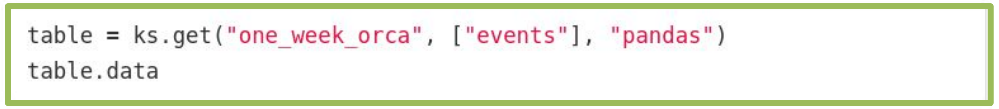
Accessing ODC: openkm3 in python

pip install git+https://git.km3net.de/jschnabel/openkm3

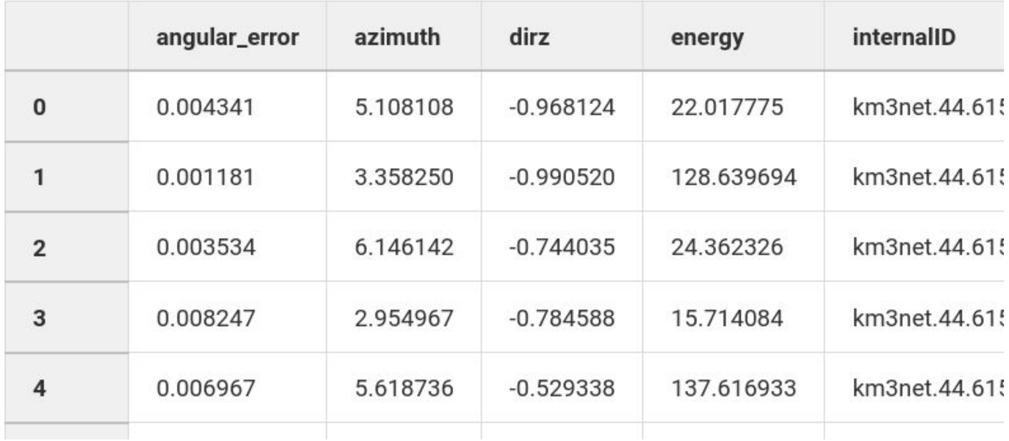
- dependency: pyvo for VO interface
- “KM3Store” as access point for all data + services



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

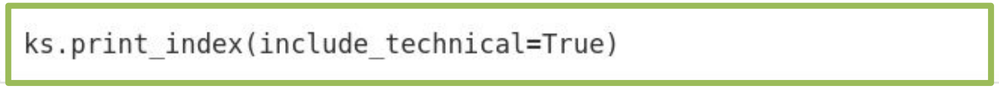


```
table = ks.get("one_week_orca", ["events"], "pandas")
table.data
```

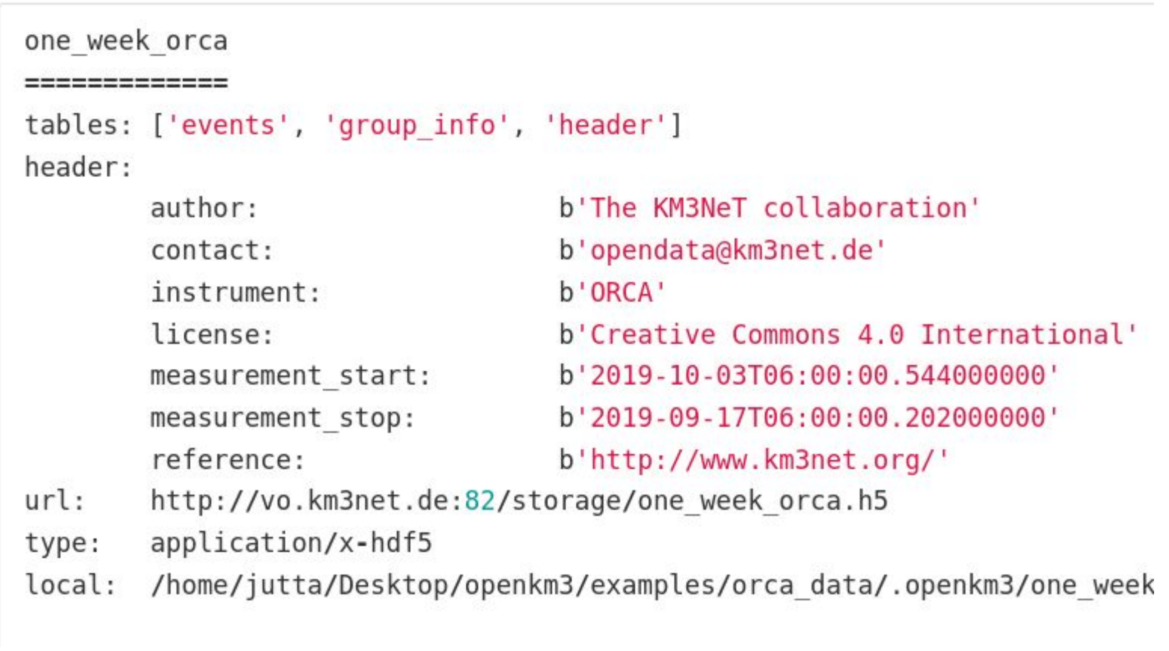


	angular_error	azimuth	dirz	energy	internalID
0	0.004341	5.108108	-0.968124	22.017775	km3net.44.61
1	0.001181	3.358250	-0.990520	128.639694	km3net.44.61
2	0.003534	6.146142	-0.744035	24.362326	km3net.44.61
3	0.008247	2.954967	-0.784588	15.714084	km3net.44.61
4	0.006967	5.618736	-0.529338	137.616933	km3net.44.61

- 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
```

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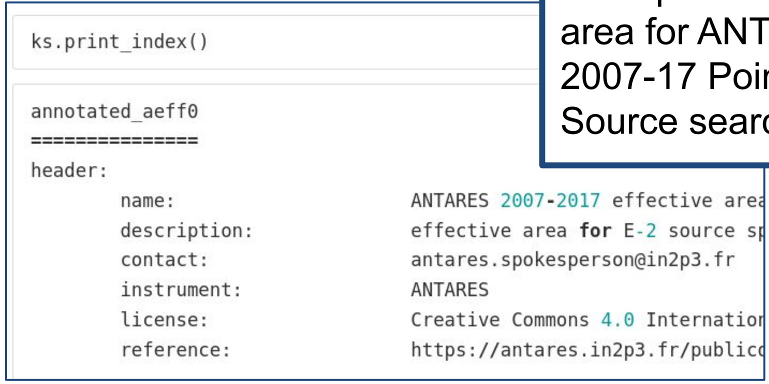
Including supplementary information

Information is provided as annotated text files, containing

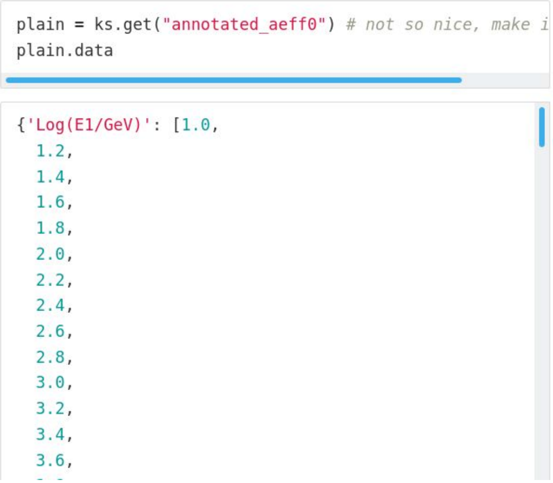
- extended header with content identifier
- tabulated data (e.g. bin content, function values …)
- ready for use in python environment



```
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/publicc
```

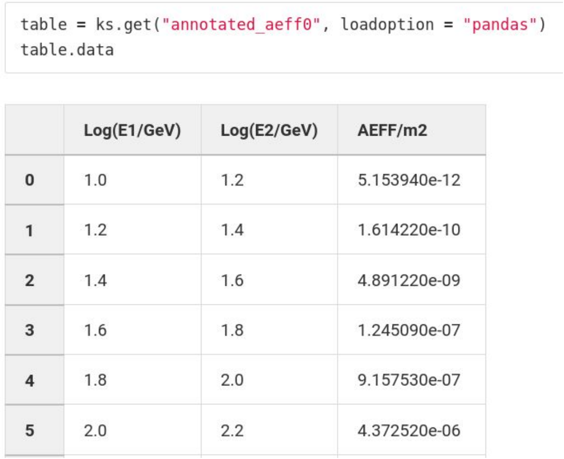
Example: Effective area for ANTARES 2007-17 Point Source search



```
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,
```

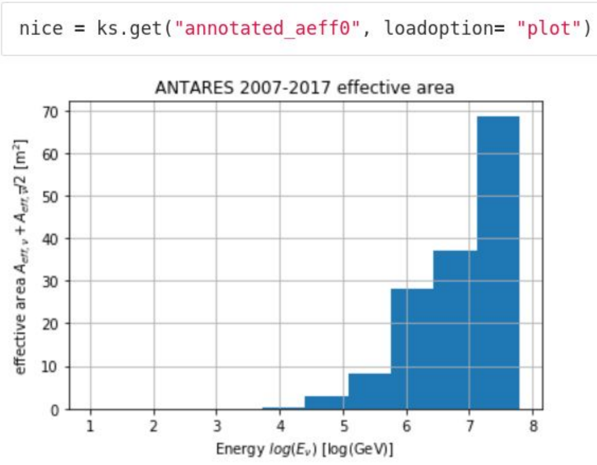
get as table



```
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

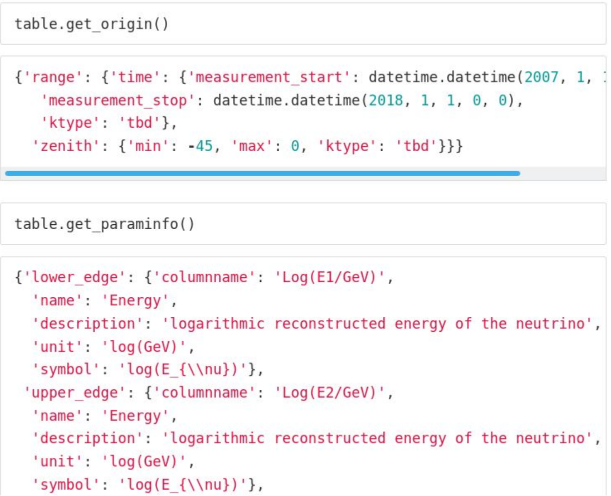
get as dataframe



```
nice = ks.get("annotated_aeff0", loadoption= "plot")
```

ANTARES 2007-2017 effective area
effective area $A_{eff,\nu} + A_{eff,\bar{\nu}}/2$ [m^2]
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
Energy $log(E_\nu)$ [log(GeV)]

get as plot



```
table.get_origin()
```

```
{'range': {'time': {'measurement_start': datetime.datetime(2007, 1, 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

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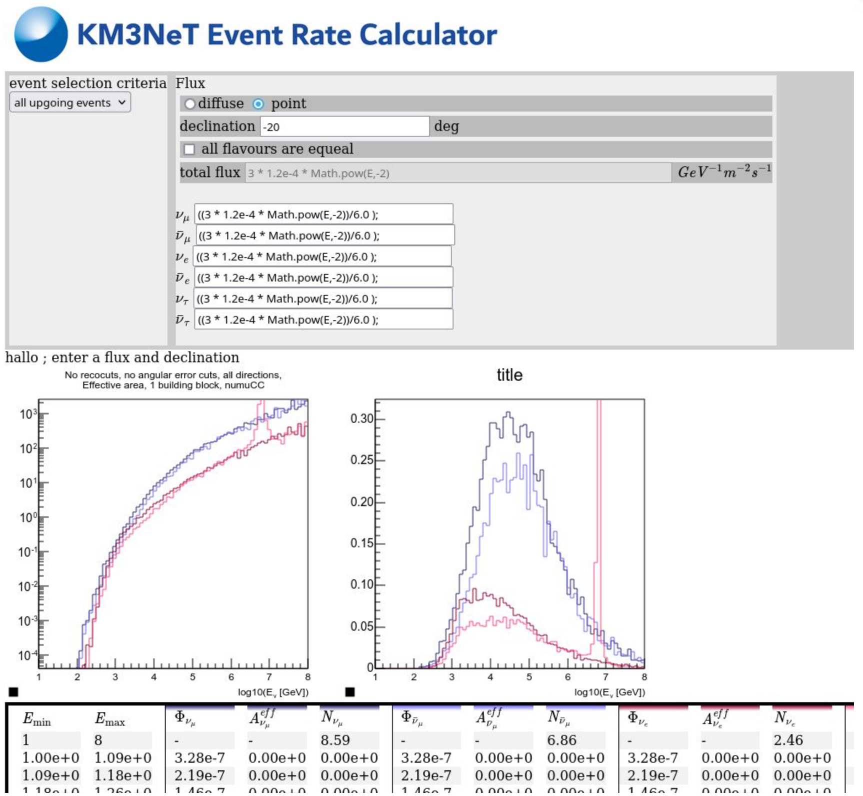
Current status of IRF

Providing detector response functions

- Detector responses for full detector created as **ROOT-Files with histograms** from simulation sets
- separated for **different neutrino types** with a **generic flux model**
- relying on a fixed **preselection of data** (cut levels)
- shown as function of **energy** and **zenith/azimuth**

Event Rate Calculator

- Webservice based on IRFs
- returns **effective area** and **number of events** over **energy** for given **declination, flux and source type** (diffuse / point source)
- currently only as (inofficial) web display, no API



KM3NeT Event Rate Calculator

event selection criteria: all upgoing events

Flux

○ diffuse ● point

declination -20 deg

□ all flavours are equeal

total flux 3 * 1.2e-4 * Math.pow(E,-2) $GeV^{-1}m^{-2}s^{-1}$

ν_μ ((3 * 1.2e-4 * Math.pow(E,-2))/6.0);

$\bar{\nu}_\mu$ ((3 * 1.2e-4 * Math.pow(E,-2))/6.0);

ν_e ((3 * 1.2e-4 * Math.pow(E,-2))/6.0);

$\bar{\nu}_e$ ((3 * 1.2e-4 * Math.pow(E,-2))/6.0);

ν_τ ((3 * 1.2e-4 * Math.pow(E,-2))/6.0);

$\bar{\nu}_\tau$ ((3 * 1.2e-4 * Math.pow(E,-2))/6.0);

hallo ; enter a flux and declination

$E_{\min}$	$E_{\max}$	Φ_{ν_μ}	$A^{eff}_{\nu_\mu}$	N_{ν_μ}	$\Phi_{\bar{\nu}_\mu}$	$A^{eff}_{\bar{\nu}_\mu}$	$N_{\bar{\nu}_\mu}$	Φ_{ν_e}	$A^{eff}_{\nu_e}$	N_{ν_e}
1	8	-	-	8.59	-	-	6.86	-	-	2.46
1.00e+0	1.09e+0	3.28e-7	0.00e+0	0.00e+0	3.28e-7	0.00e+0	0.00e+0	3.28e-7	0.00e+0	0.00e+0
1.09e+0	1.18e+0	2.19e-7	0.00e+0	0.00e+0	2.19e-7	0.00e+0	0.00e+0	2.19e-7	0.00e+0	0.00e+0
1.18e+0	1.26e+0	1.46e-7	0.00e+0	0.00e+0	1.46e-7	0.00e+0	0.00e+0	1.46e-7	0.00e+0	0.00e+0

Event rate calculator
https://www.nikhef.nl/~7Et61/aeffweb/

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Current status and questions

- Planning to make IRFs available through API as microservice
- Full simulation sets, even if released, probably not convenient for handling through VO
- With specialized KM3NeT software, services could be made available
  - Which services can we migrate, which only link to a data set in the VO?
  - Starting point could be the IRF service

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Backup: Models of Galactic Source Emissions with CTA and KM3NeT

Master thesis performed by Tim Unbehaun at FAU between CTA and KM3NeT (thesis)

- Datasets are provided for IRF generation
- IRFs are generated
- input models are fitted to current gamma-ray observations with various models
- A set of **jupyter notebooks** is provided
   a. performs the **actual scan of the hadronic contribution** and fits the models to the datasets for each step
   b. A notebook that plots the results of the scan and **computes confidence intervals** on the hadronic contribution for each source and scenario.

Preliminary summary of the analysis @KM3NeT Gitlab

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