

# High-energy neutrino data

## *Formats & Access*

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for the KM3NeT Collaboration*

IVOA standards for High Energy Astrophysics  
28/29th June 2023, Observatoire de Paris, France



## Neutrino data: short outline

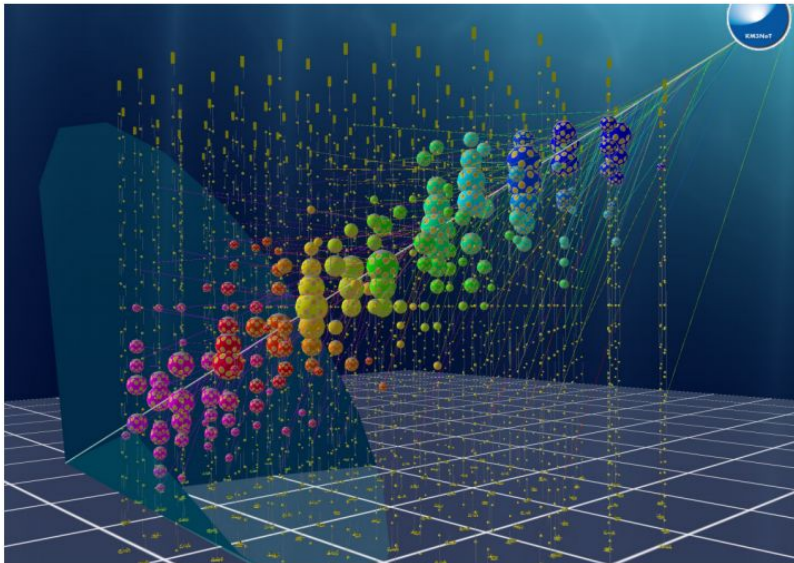
### KM3NeT Open Science: Current system

- Example: CTA & KM3NeT analysis
- Example: ANTARES legacy data

## Data format examples

## „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

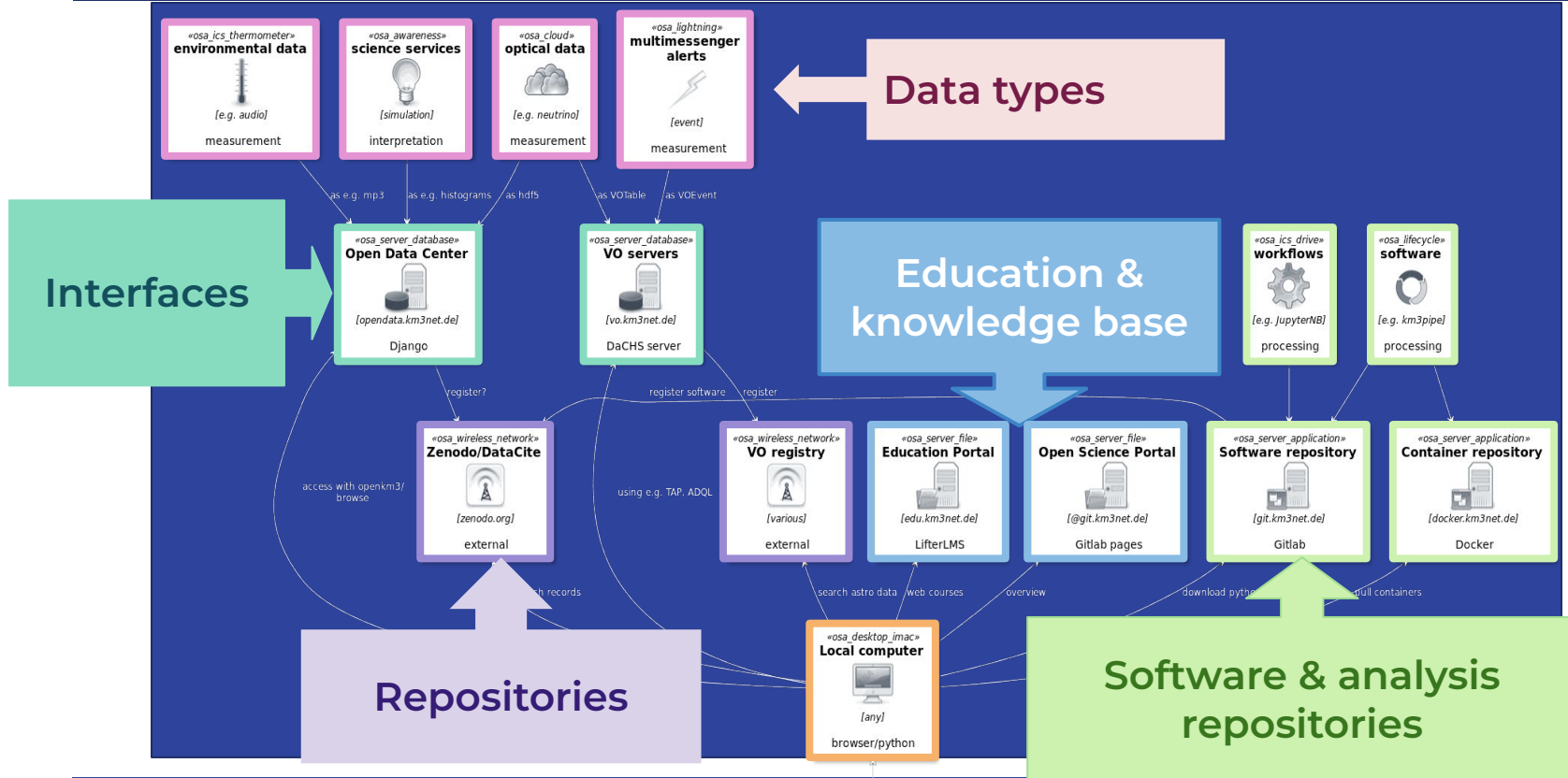


Example files of KM3NeT ROOT files:

<https://github.com/KM3NeT/km3net-testdata>

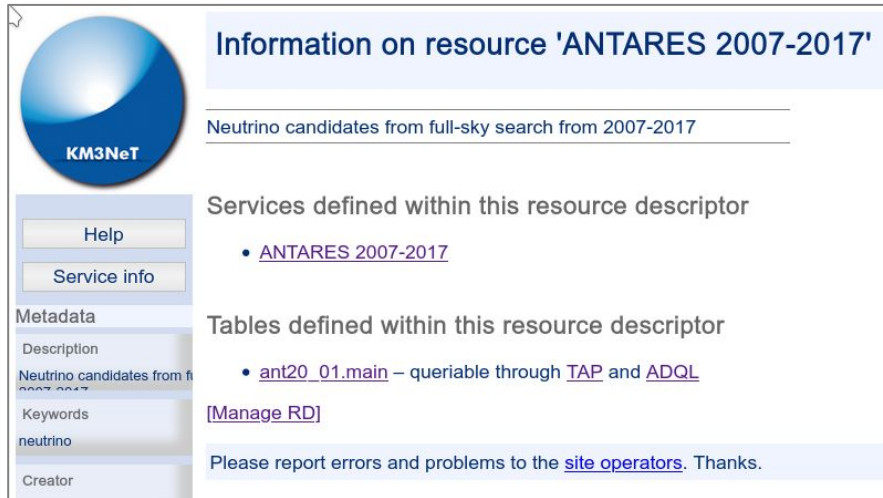
**Low countrate experiments!**

# The KM3NeT Open Science System



## Virtual Observatory

- ANTARES data as test data set ([vo.km3net.de](http://vo.km3net.de))
- Registered as data provider to the [VO](http://ivo://km3net.org) ([ivo://km3net.org](http://ivo://km3net.org))



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

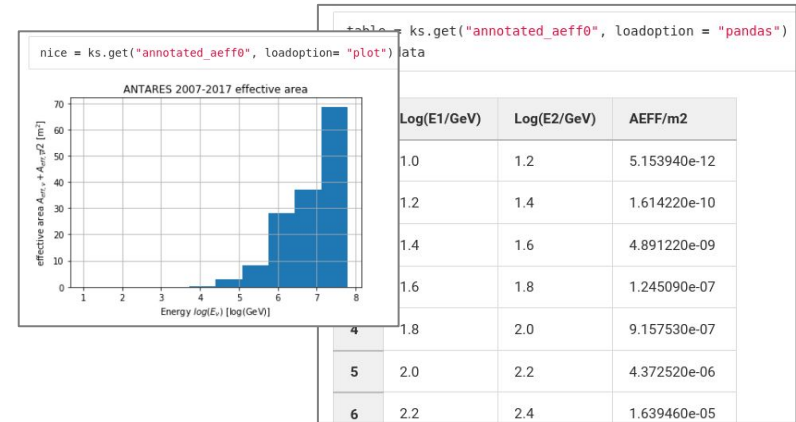
- [ant20\\_01.main](#) – queryable through [TAP](#) and [ADQL](#)

[[Manage RD](#)]

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

## Open Data Center

- Server for all “non-VO” data ([opendata.km3net.de](http://opendata.km3net.de))
- Self-defined formats, currently hdf5 for events

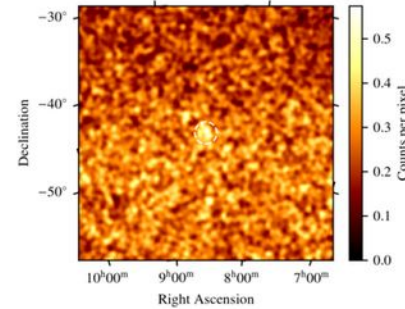


# Example 1: CTA + KM3NeT common sources

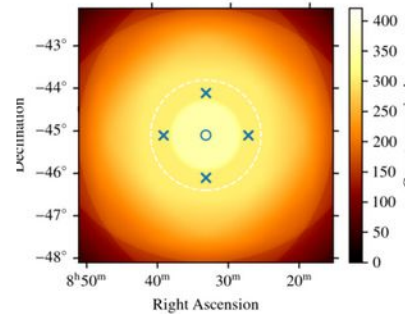
## Current material

Publication: Models of Galactic Source Emissions with CTA and KM3NeT (common analysis, not published yet), performed for 4 sources

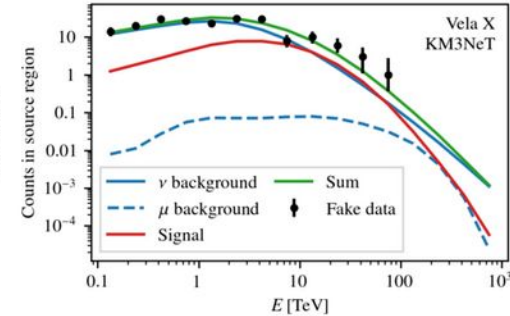
- **Paper & public git repository at same time**
  - Notebooks to create pseudo data sets and sensitivities from IRFs
  - using gammapy & GADF
  - Pushing to Zenodo for publication
- Basis for further development also in EOSC future
  - Pseudodata generation for KM3NeT computing intensive -> environment?



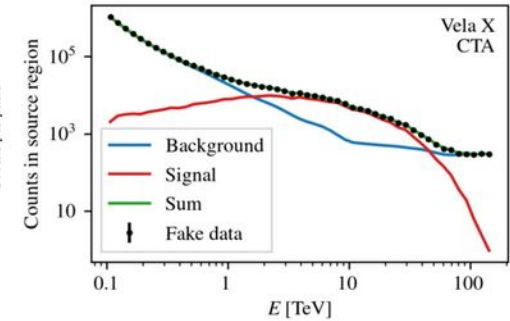
KM3NeT realization skymap for Vela X



CTA realization skymap for Vela X



KM3NeT spectrum for Vela X



CTA spectrum for Vela X

MC simulation of detector response

- TB of data
- Different neutrino flavours
- Different background models

Not (yet) public

IRFs in gammapy-compatible format (like CTA DL3)

- Effective area
- Energy dispersion
- Point Spread Function
- Background atmospheric muons
- Background atmospheric neutrinos

Public in repository  
Future: python package

Generation of pseudo data sets from visible area of sources

- Assuming 10 yrs
- Maps for binned zenith angles and energy from IRFs
- Data ~1GB per source

Generation per source  
O(day) - notebook & data sets offered

Likelihood analysis

Scan at HPC with many jobs

Script available, no notebook

# For format development: VODF integration

established  
2022

## VODF Steering committee

one representative per experiment,  
defining roadmap & goals

## VODF Lead Editors

Format development

## Conveners

Organization &  
Coordination of work

Documentation:

<https://vodf.readthedocs.io>

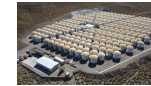
Source & Community:

<https://github.com/VODF/>

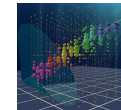


*Validation of standardized data formats  
and tools for ground-level particle-based  
gamma-ray observatories*

[doi:10.1051/0004-6361/202243527](https://doi.org/10.1051/0004-6361/202243527)



GADF @gammapy



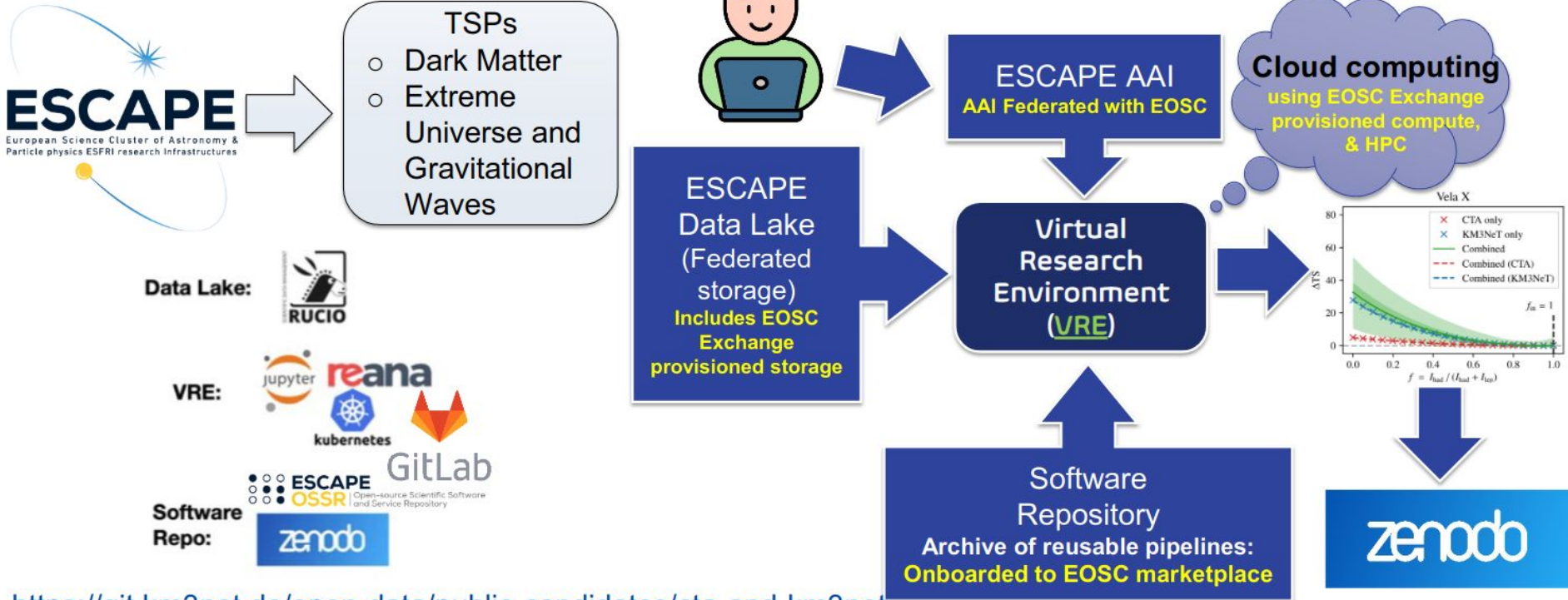
*Models of Galactic Source Emissions  
with CTA and KM3NeT (in preparation)*



# EOSC Future: Integration in VRE

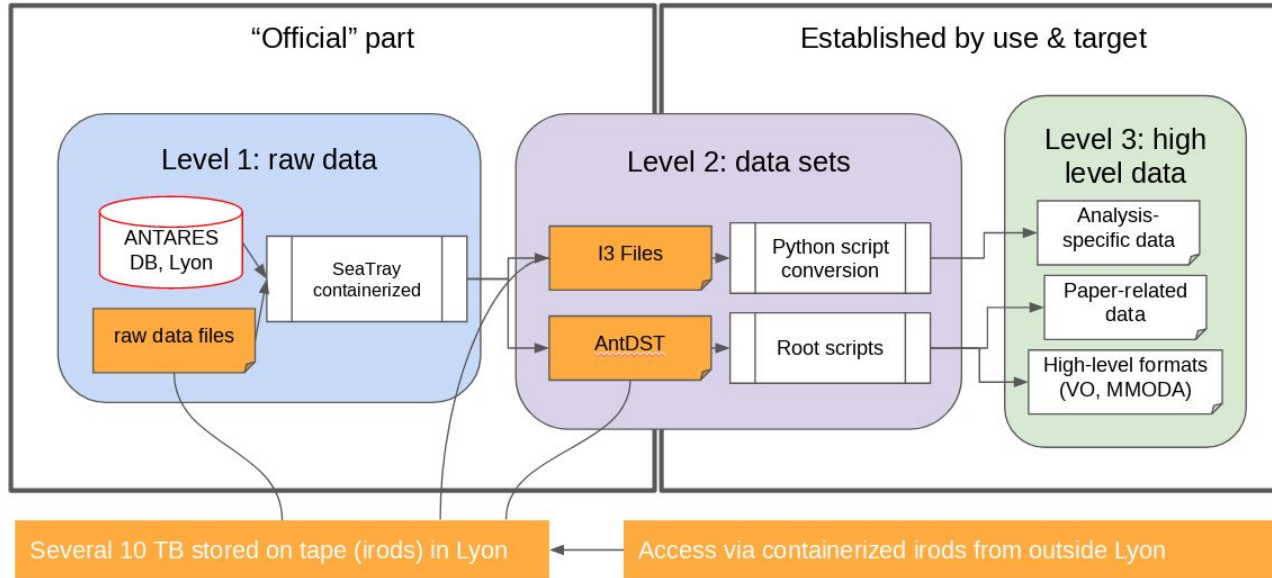
<https://projectescape.eu/>

From Misha Smirnov



<https://git.km3net.de/open-data/public-candidates/cta-and-km3net>

# Example 2: ANTARES legacy data



ANTARES decommissioned, roughly 2 decades of data

- Keep legacy data sets
  - Fully reconstructed events (data productions)
  - Corresponding Monte Carlo simulations
  - Acoustic data
- Ensure access to data through KM3NeT computing facilities
- Provide high-level data in data format with current standard

## Data

## Data sets for searches for cosmic neutrino point sources with ANTARES

### Foreword

Four data sets are available :

- Point sources search using [2007-2010 data](#) ;
- Point sources search using [2007-2012 data](#).
- Point sources search using [2007-2017 data](#).
-  Latest Data Release : Searches for non-standard neutrino interactions using [2007-2016 data](#).

In case this data is used in an analysis, please inform us and send an e-mail to the ANTARES spokesperson ([antares.spokesperson@in2p3.fr](mailto:antares.spokesperson@in2p3.fr)).

Data available on [webpage](#) as plots, “send e-mail”  
-> integrated in current status of OS system

## Data set for the 2007-2017 ANTARES search for cosmic neutrino point sources

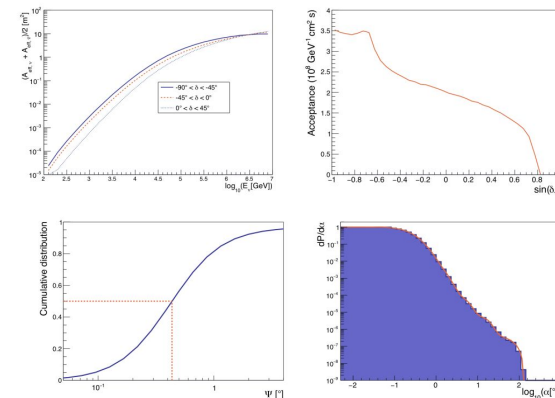
### Introduction

The present data set corresponds to the track sample ( $\mu$ on neutrino candidates) of a study meant to search for a point sources with data collected from January 2007 to December 2017 by the ANTARES neutrino telescope. Attached below are the effective area, the acceptance, the cumulative angular resolution distribution and the point spread function for an E-2 source spectrum. This sample encompasses the two previous released sets, with similar cuts. This increased lifetime amounts to 3125 days and to a total number of 8754 events.

More information on how the search was performed can be found in:

[G. Illuminati for the ANTARES Collaboration, PoS\(ICRC2019\)920](#)

[A. Albert et al., ApJL 863, L30 \(2018\)](#)



### Data

The data for the 2007-2017 period can be found in the following ASCII table:

Your name

Information is provided via ODC as annotated text files, containing

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

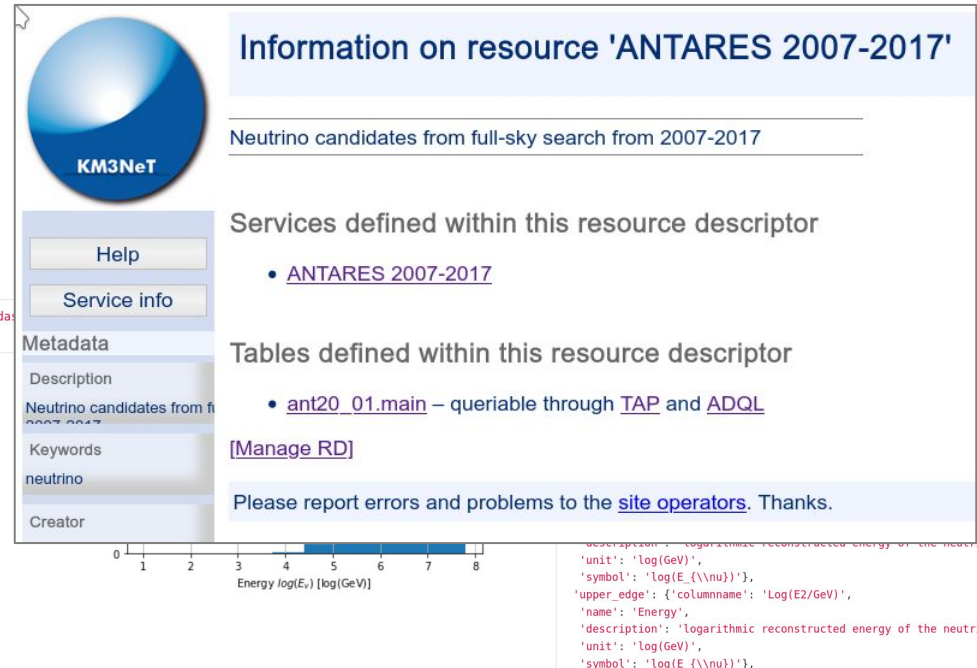
```
plain = ks.get("annotated_aeff0") # not so nice, make it  
plain.data
```

```
{'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,  
...]
```

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

```
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



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.

Metadata

Description: Neutrino candidates from full-sky search from 2007-2017

Keywords: neutrino

Creator: ...

Energy log(E<sub>v</sub>) [log(GeV)]

```
'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 as table

get as dataframe

get as plot

get metadata

Using the DMP as tool to develop strategy and include basic setup of data dissemination

- First DMP defined in 2017 in INFRADEV project
- Outline of old DMP following [Horizon 2020 DMP Template](#) (partially useful)
- Having review process in 2023 to rewrite, with external review panel

**What is the purpose of the exercise for us?**

- Use as reference document for
  - Resource requests at HPCs
  - Future requests for HR
  - Internal development strategy
- Illustrating
  - Data types and volumes
  - Integration of computing sites
  - High-level interfaces
  - Management strategy
  - Resource requirements (Computing & HR)

# Summary

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## Requirements for making neutrino data available

- Neutrino event lists can (more or less) easily (VOTable) be provided BUT
  - accompanied by IRFs -> proper linking needed
- For the future: Backlink to full data sets and MC simulations
- For specific analysis targets: “preprocessed” material (like pseudo data sets)
- Further processing from IRFs needed to make data well usable
  - Needs example workflows
  - Needs larger computing resources



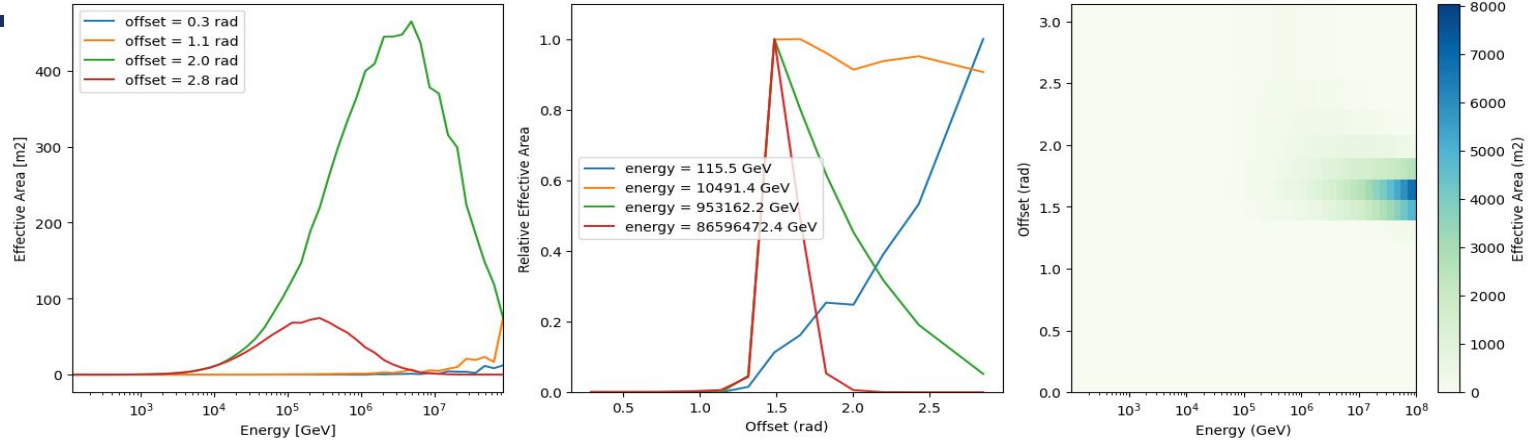
ERLANGEN CENTRE  
FOR ASTROPARTICLE  
PHYSICS



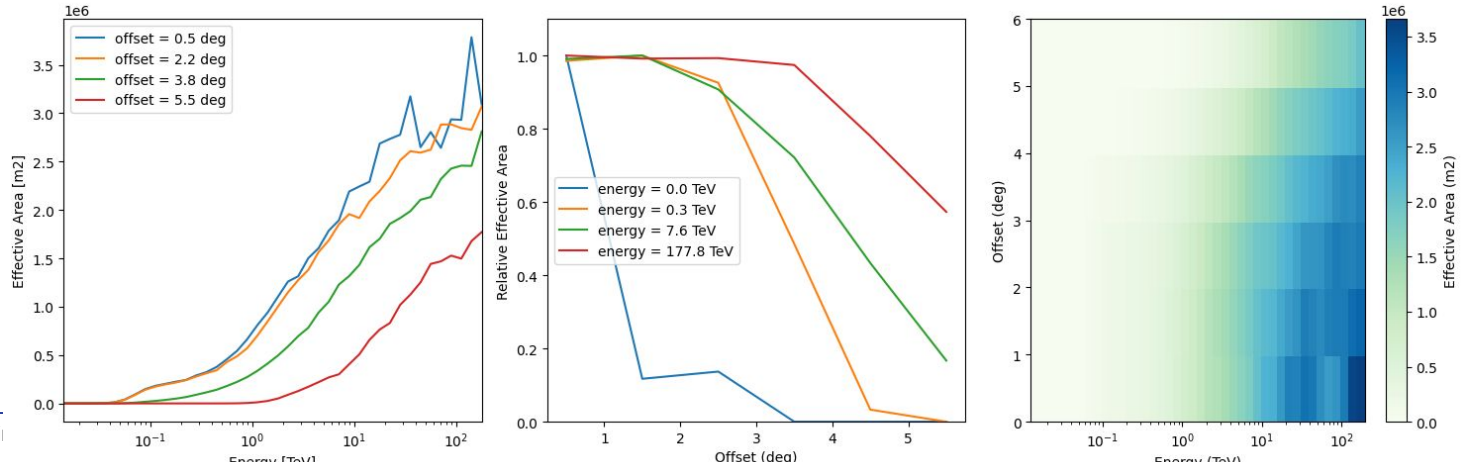
# Backup

# Comparing CTA and KM3NeT IRFs: Effective Area

KM3NeT



CTA

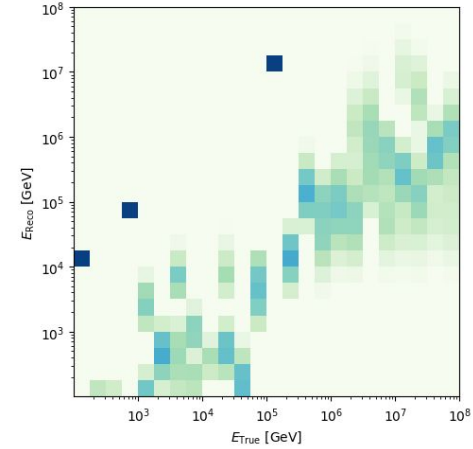
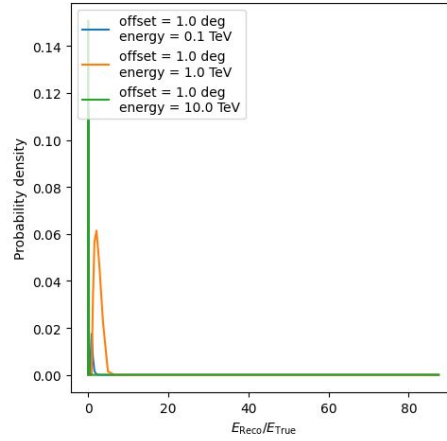
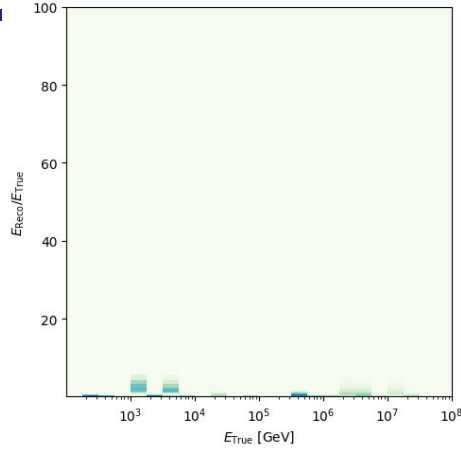


High-energy neutrino

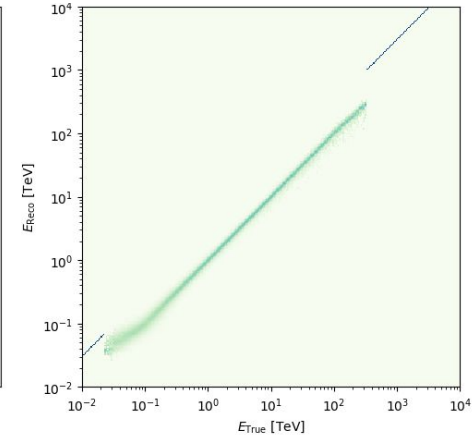
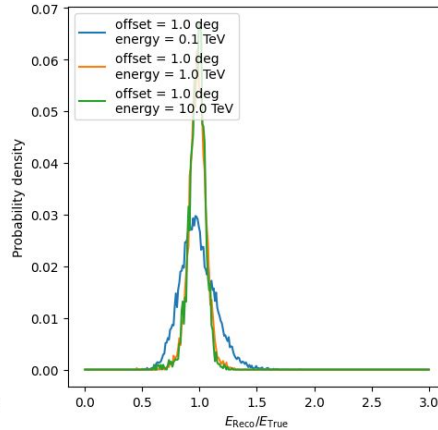
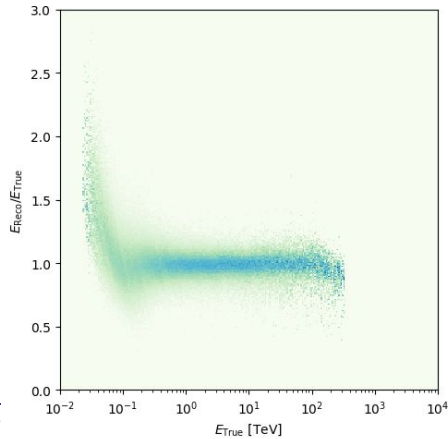


# Energy Dispersion

KM3NeT



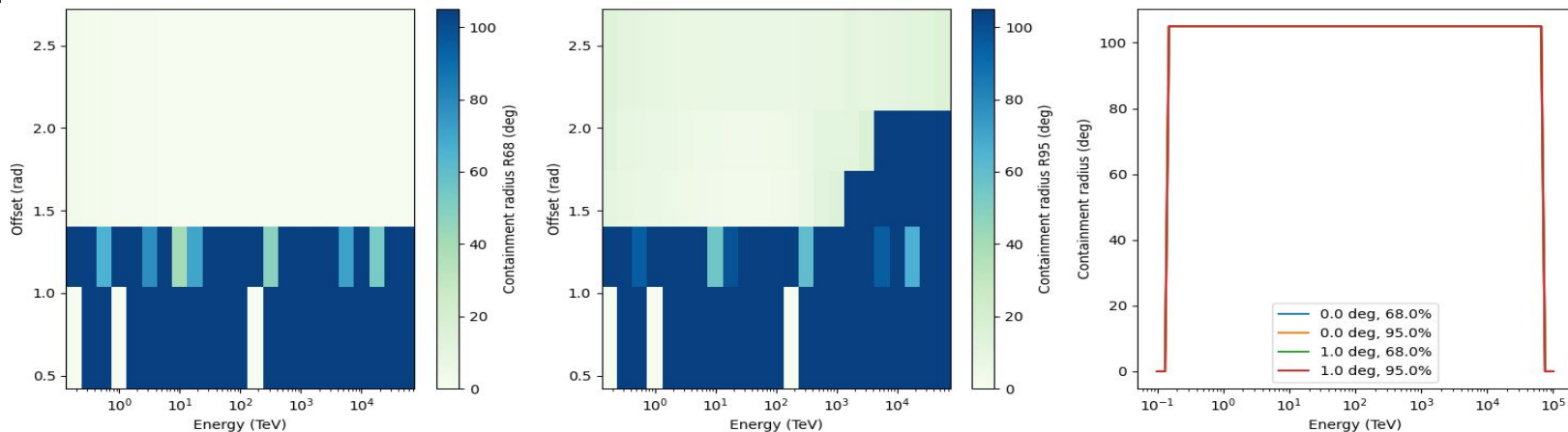
CTA



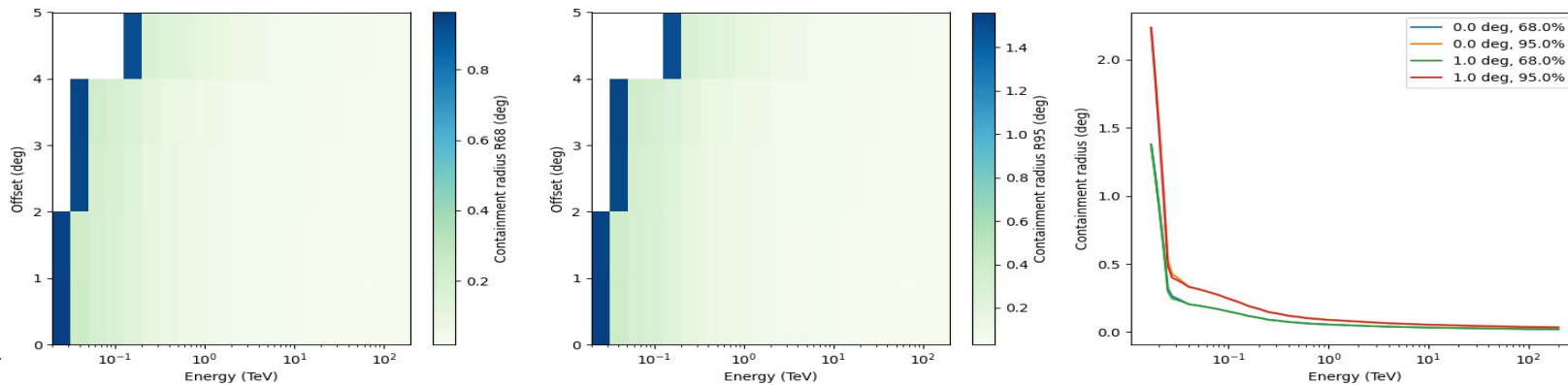
High-energy neutrino

# Point Spread Function

KM3NeT

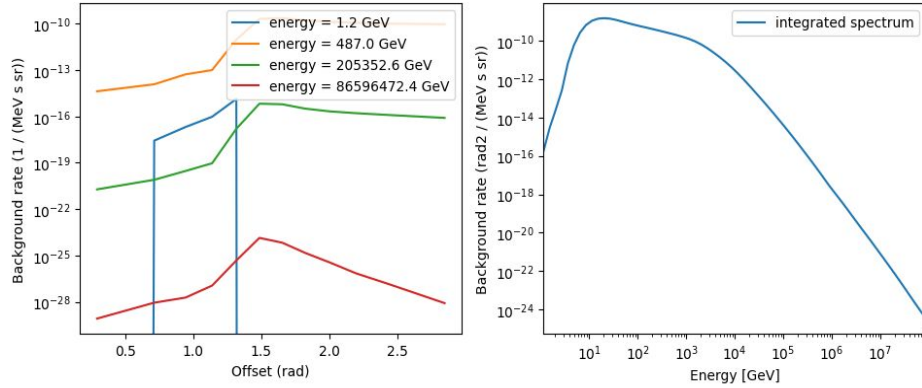


CTA

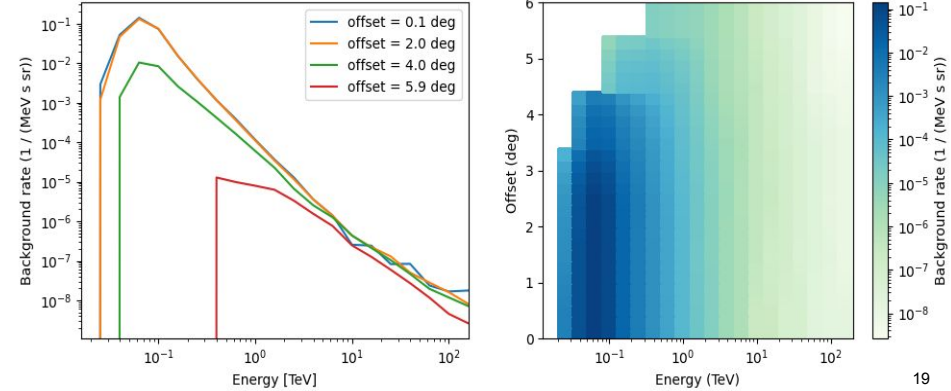
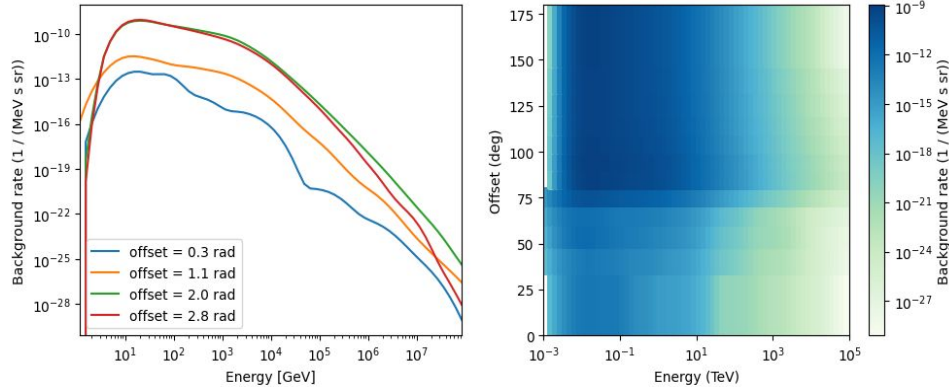
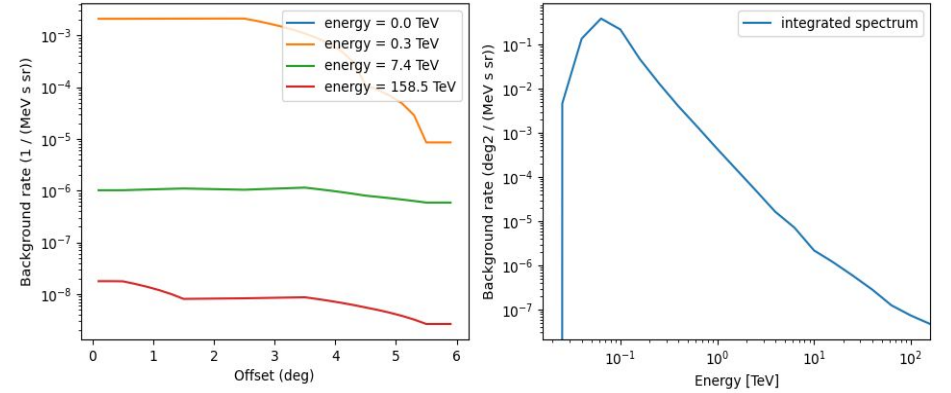


# Background

## KM3NeT



## CTA

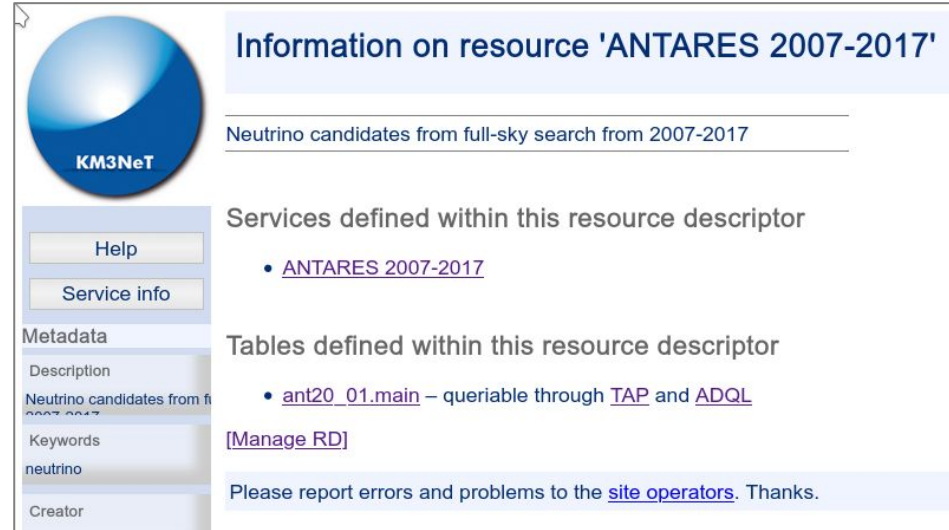


# Current status on VO-compliant data

- 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/>



The screenshot shows a web interface for the resource 'ANTARES 2007-2017'. On the left is a sidebar with a 'KM3NET' logo and navigation buttons for 'Help' and 'Service info'. Below these are sections for 'Metadata', 'Description', 'Keywords', and 'Creator'. The main content area is titled 'Information on resource 'ANTARES 2007-2017'' and contains the following text: 'Neutrino candidates from full-sky search from 2007-2017', 'Services defined within this resource descriptor' with a bullet point for '[ANTARES 2007-2017](#)', 'Tables defined within this resource descriptor' with a bullet point for '[ant20\\_01.main](#) – queryable through [TAP](#) and [ADQL](#)', and a '[Manage RD]' link. At the bottom, a light blue box contains the text: 'Please report errors and problems to the [site operators](#). Thanks.'

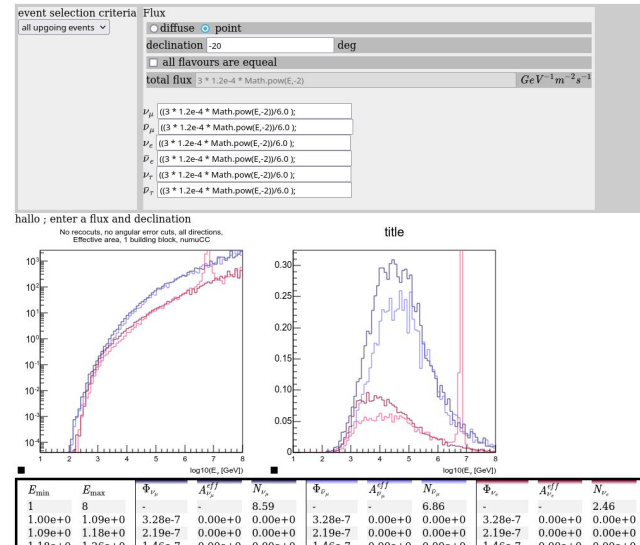
## Providing detector response functions

- 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 rate calculator

<https://www.nikhef.nl/~7Et61/aeffweb/>