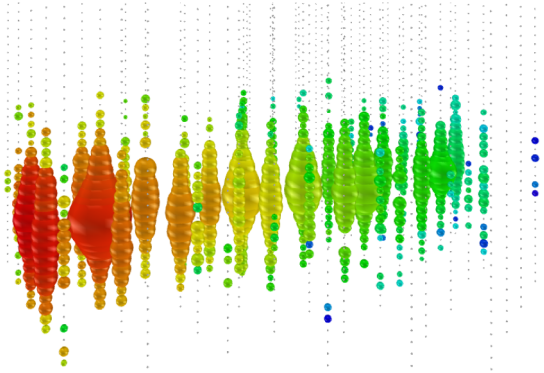
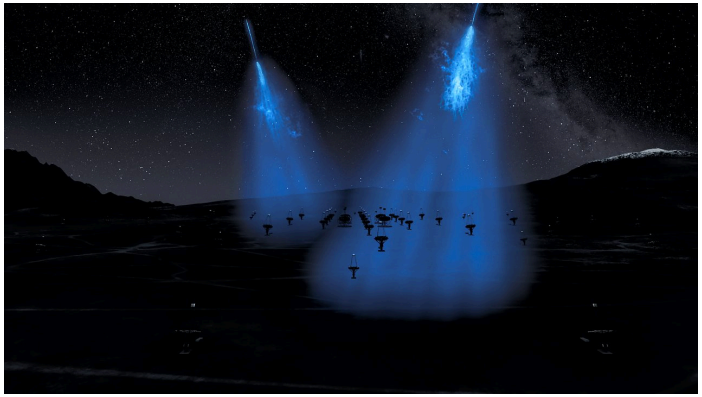
Fakultät Physik

astroparticle physics



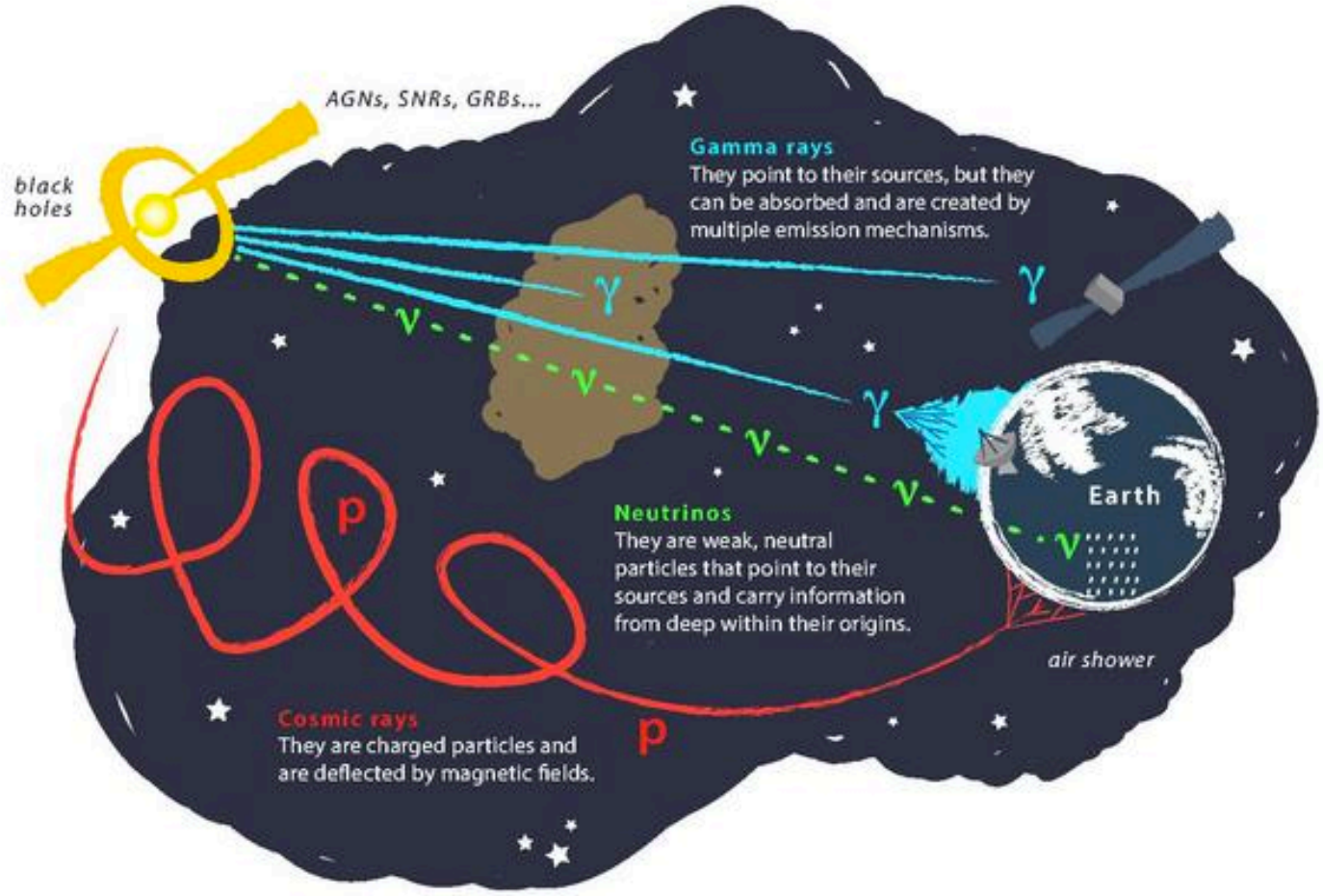


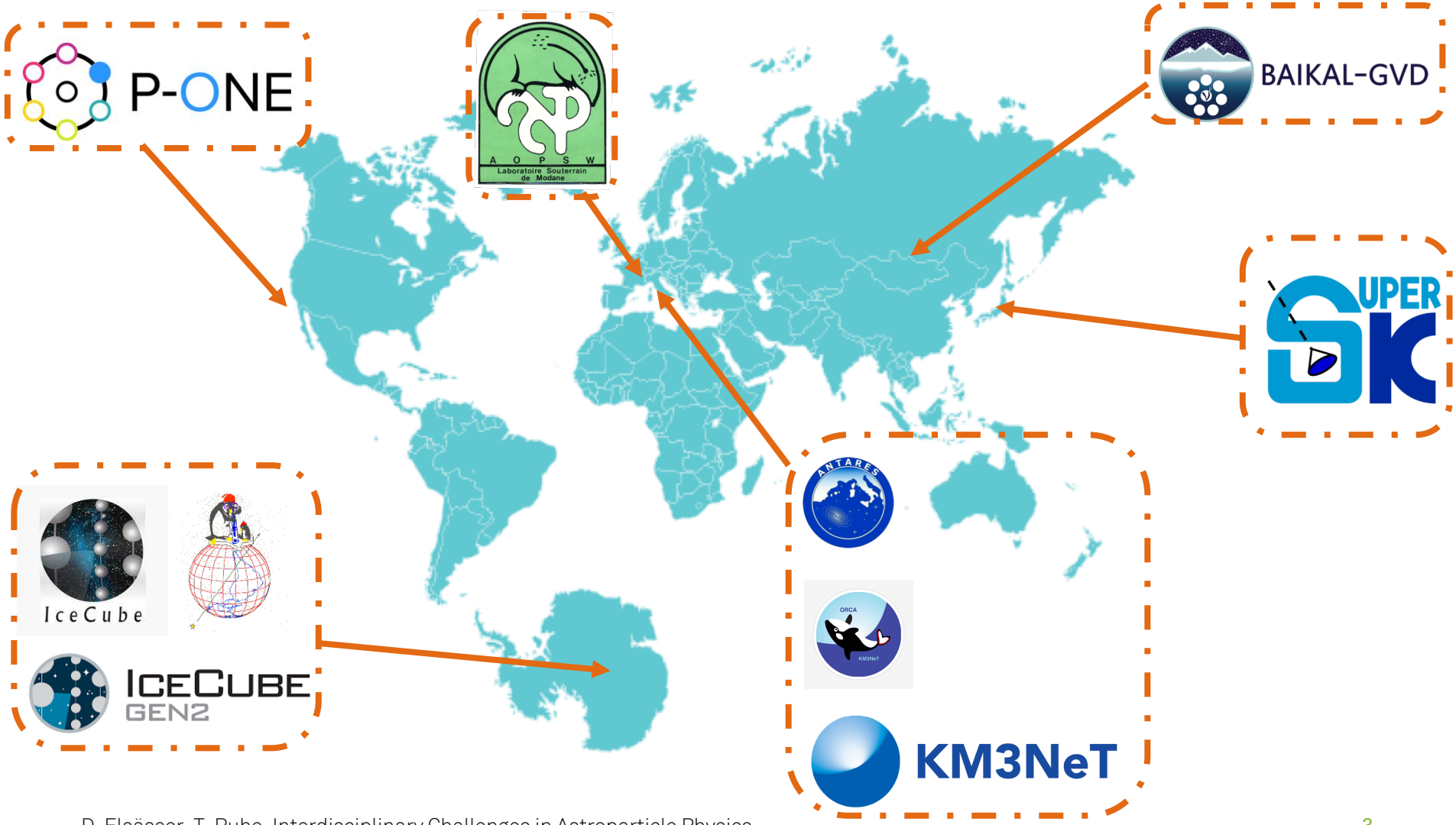
Credit: CTAO

Interdisciplinary Challenges in Astroparticle Physics

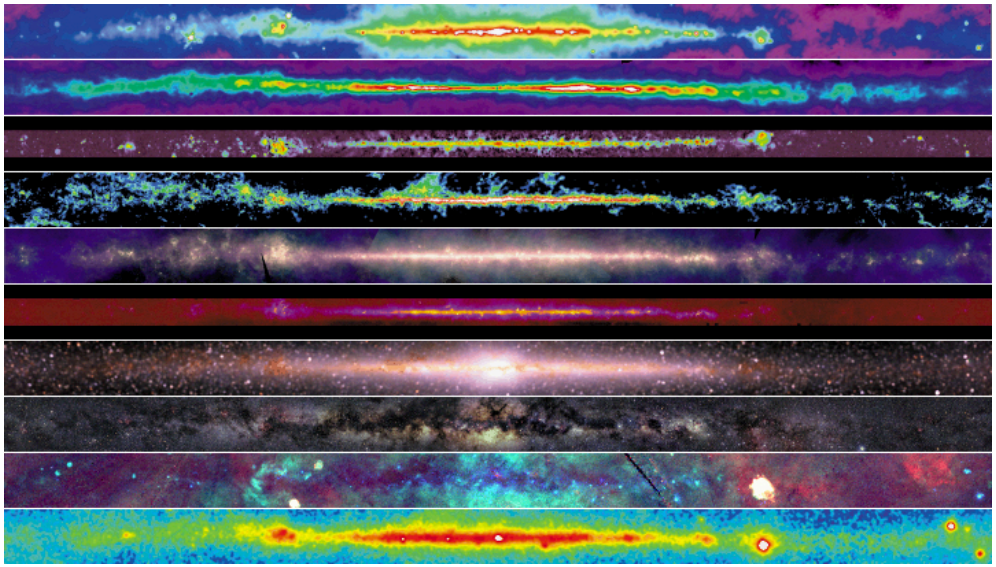
Dominik Elsässer, Tim Ruhe

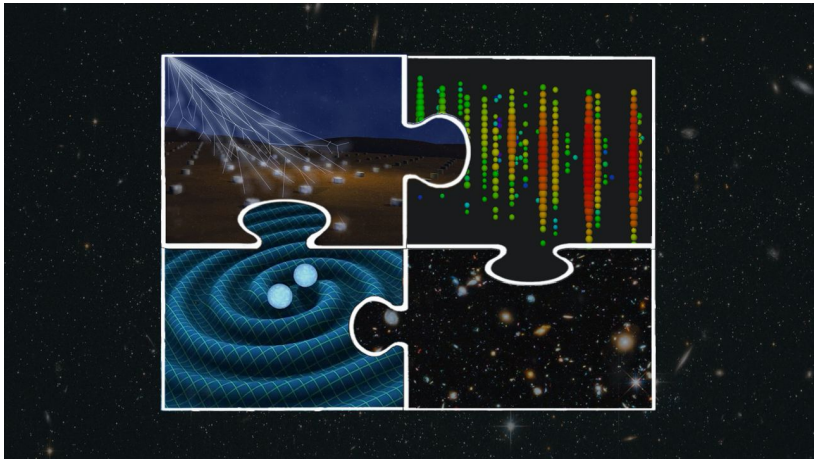
LAMARR CS & Physics Meet-Up


AGNs, SNRs, GRBs...
black holes
Gamma rays
They point to their sources, but they can be absorbed and are created by multiple emission mechanisms.
γ
γ
γ
ν
ν
ν
ν
Earth
p
Neutrinos
They are weak, neutral particles that point to their sources and carry information from deep within their origins.
air shower
Cosmic rays
They are charged particles and are deflected by magnetic fields.
p


P-ONE
A O P S W
Laboratoire Souterrain de Modane
BAIKAL-GVD
SUPER
IceCube
ANTARES
ORCA
KM3NeT
IceCube GEN2
KM3NeT

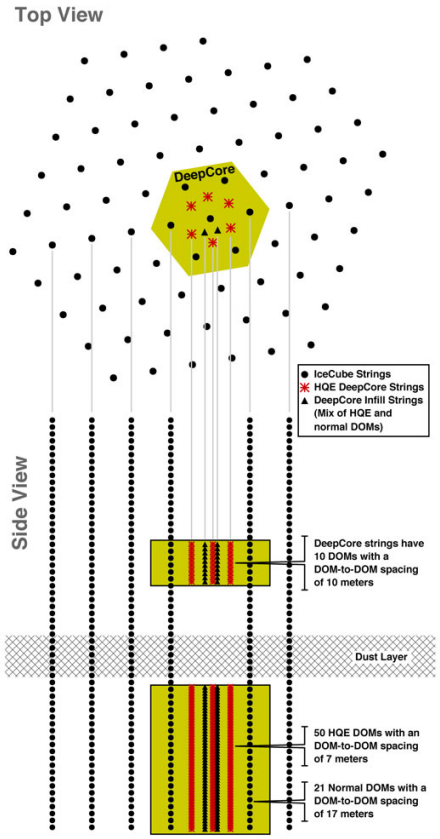
Multimessenger-Astronomy

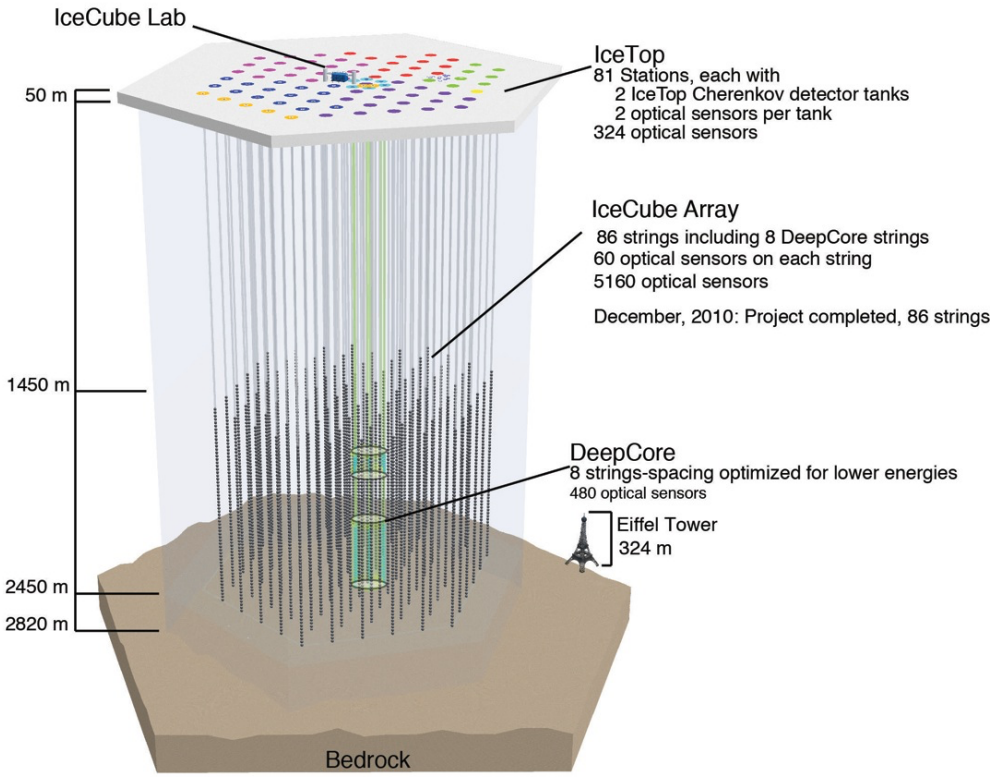




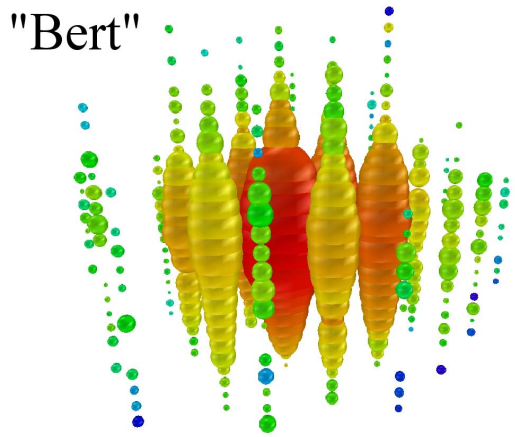
The Milky Way in Neutrinos
→ See Talk by M. Hünnefeld
(tomorrow at 9.50)

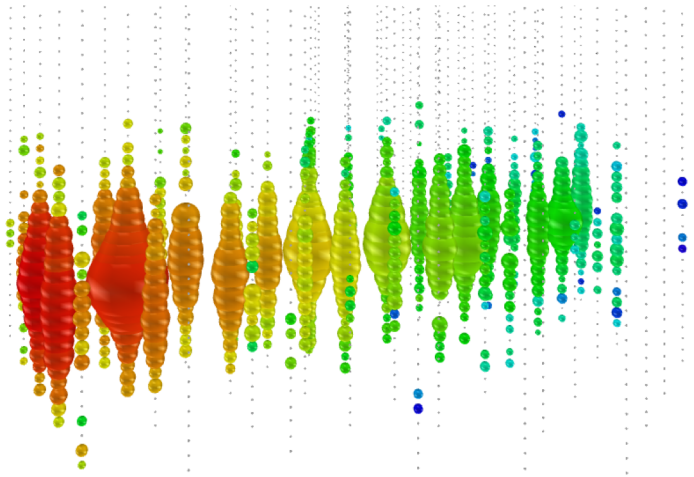
The IceCube Neutrino Observatory (at the South Pole)





IceCube Event Signatures





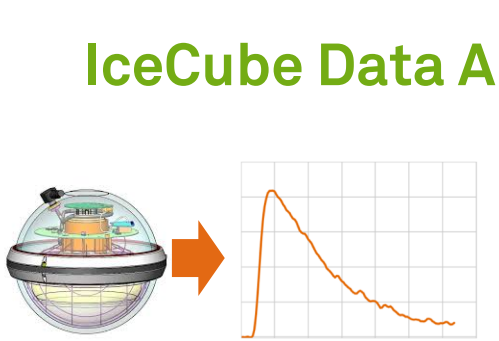
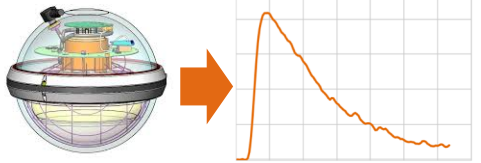
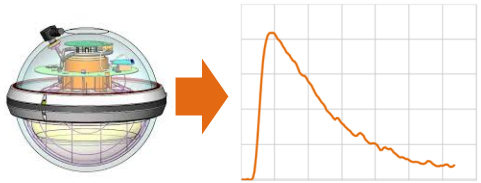
Cascade like events:

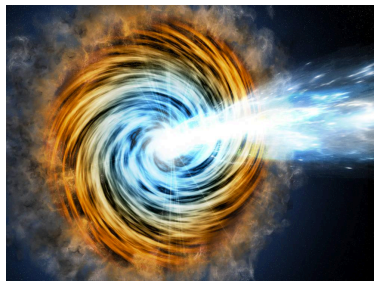
- ν_e - CC and all flavour NC interactions
- Interaction inside instrumented volume
- Poor angular resolution ~~≈ 15°~~ 5° (!!!)
- Good energy resolution

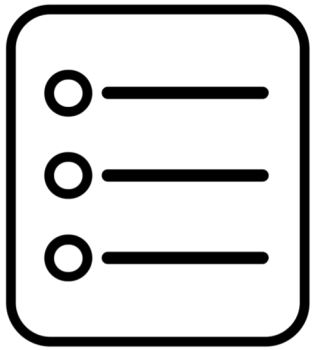
Track like events:

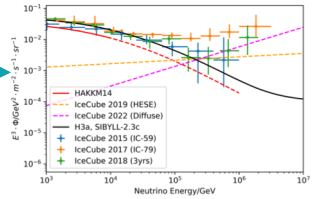
- ν_μ - CC interactions
- Interaction may happen outside instrumented volume
- Good angular resolution ≈ 1°
- Poor energy resolution

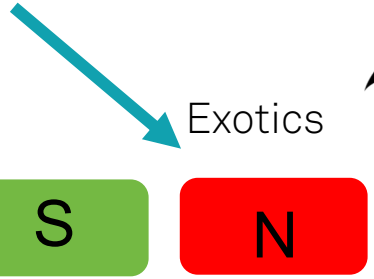
IceCube Data Analysis

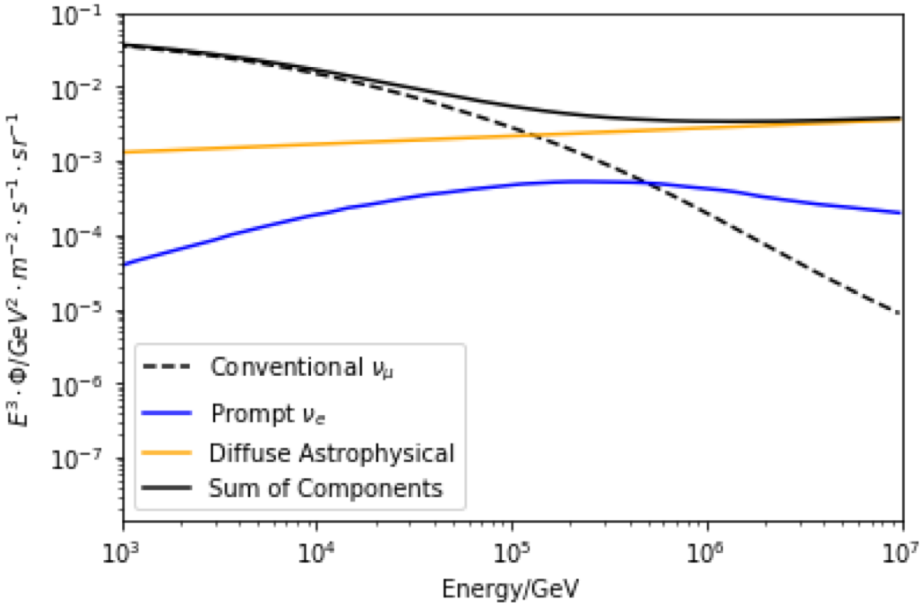


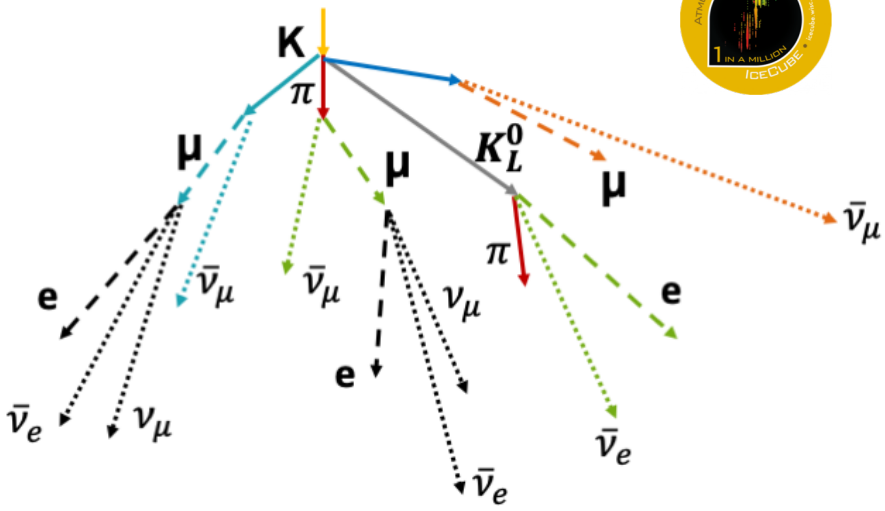


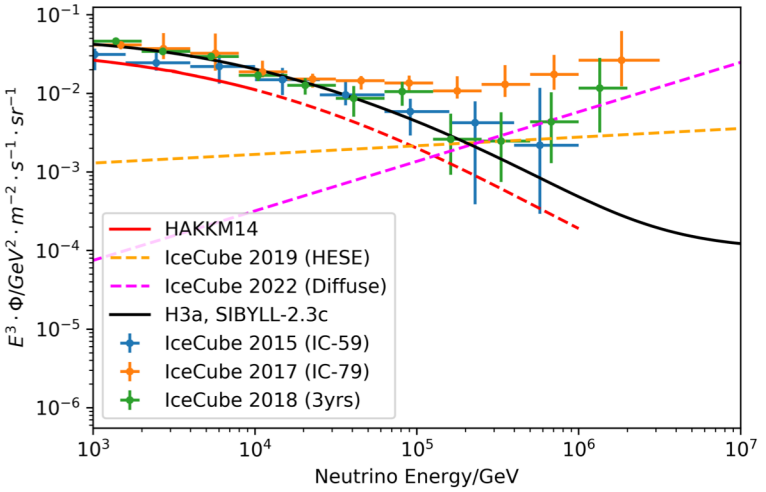




Diffrerent Components



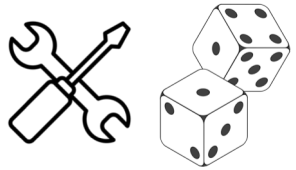


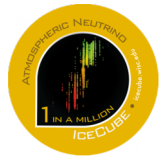


Measurable Spectrum is a sum of the differennt components.

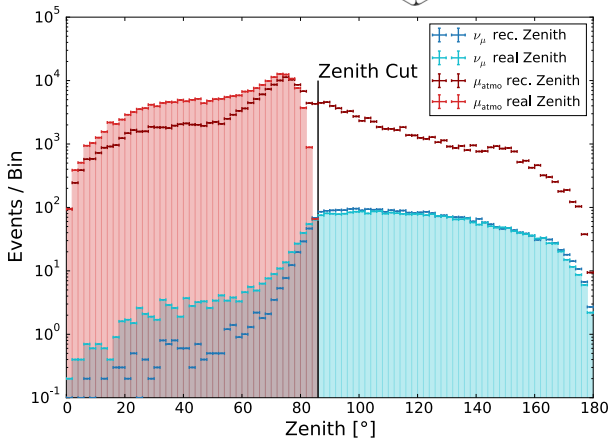
D. Elsässer, T. Ruhe, Interdisciplinary Challenges in Astroparticle Physics

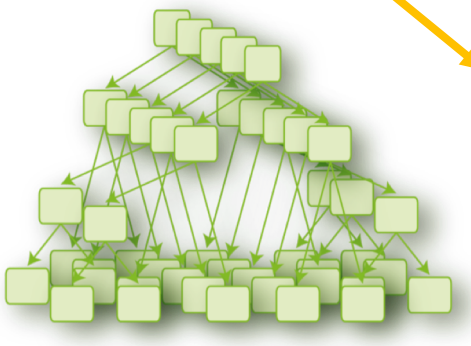
Dominant Background of Atmospheric Muons





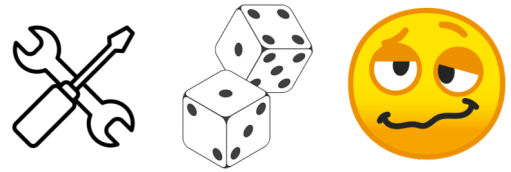
Atmospheric muons and atmospheric neutrinos originate from the same processes.

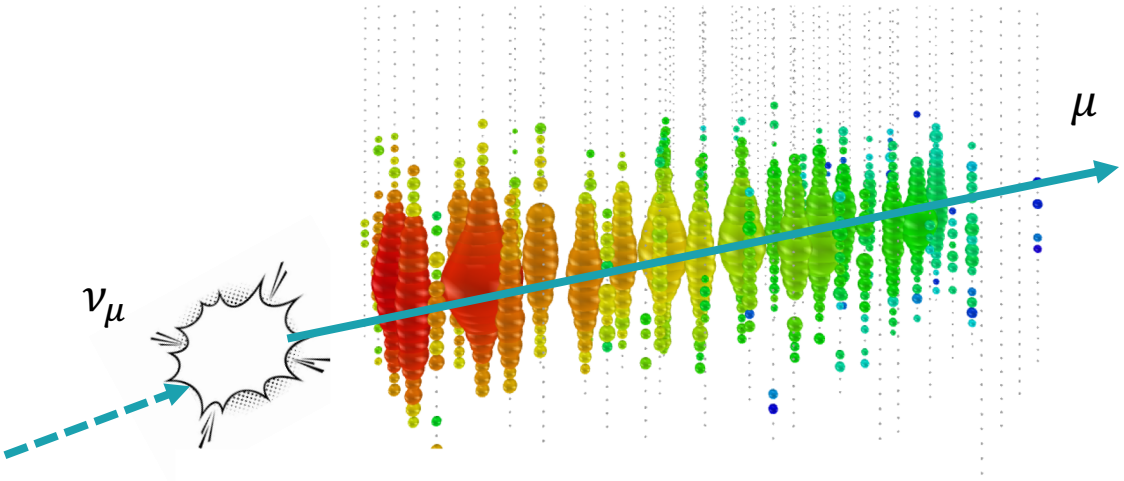




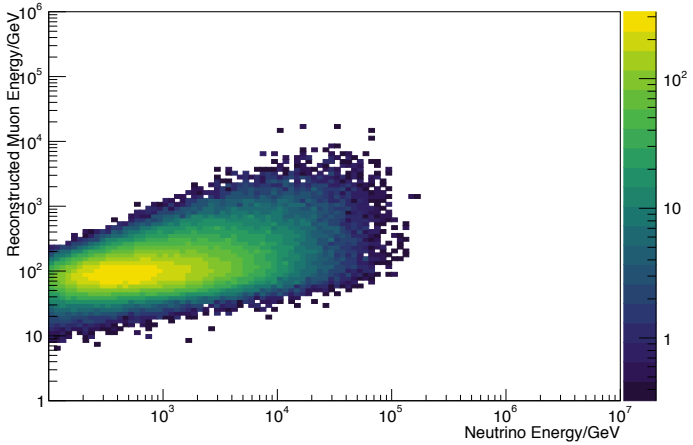
Purity well above 99.5%.

Reconstructing Neutrino Energy Spectra



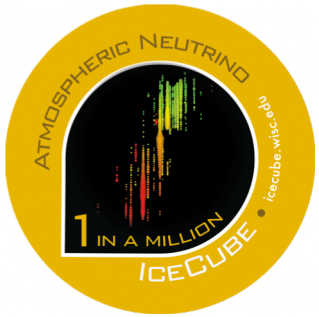


- indirect detection of neutrinos
- spectral reconstruction is based on energy estimators
- Additional smearing, due to several detector effects



$$\underbrace{\frac{dN_\mu}{dE_\mu}}_{\text{Muon energy spectrum}} = \int_{E_\mu}^{\infty} \underbrace{\left(\frac{dN_\nu}{dE_\nu}\right)}_{\text{Neutrino energy spectrum}} \underbrace{\left(\frac{dP(E_\nu)}{dE_\mu}\right)}_{\text{Physics of neutrino interaction}} dE_\nu$$

Four Challenges in Neutrino Astronomy



Signal-to-Noise Ratio

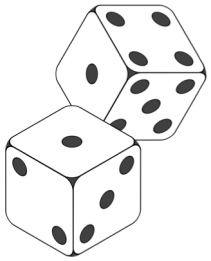


Image Source: By Steaphan Greene - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5535164

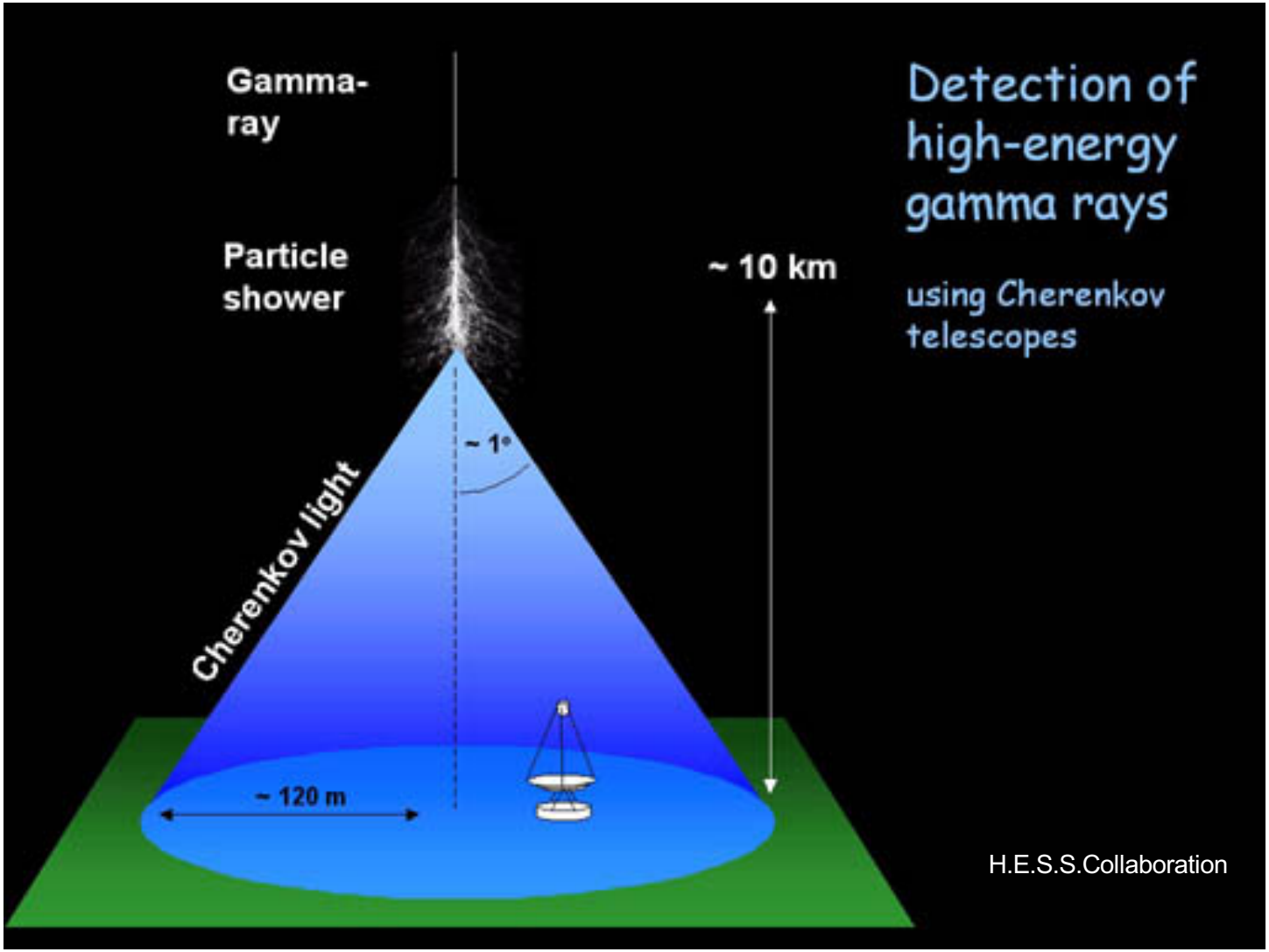
Simulation and Simulation Dependence

Variable Reconstruction

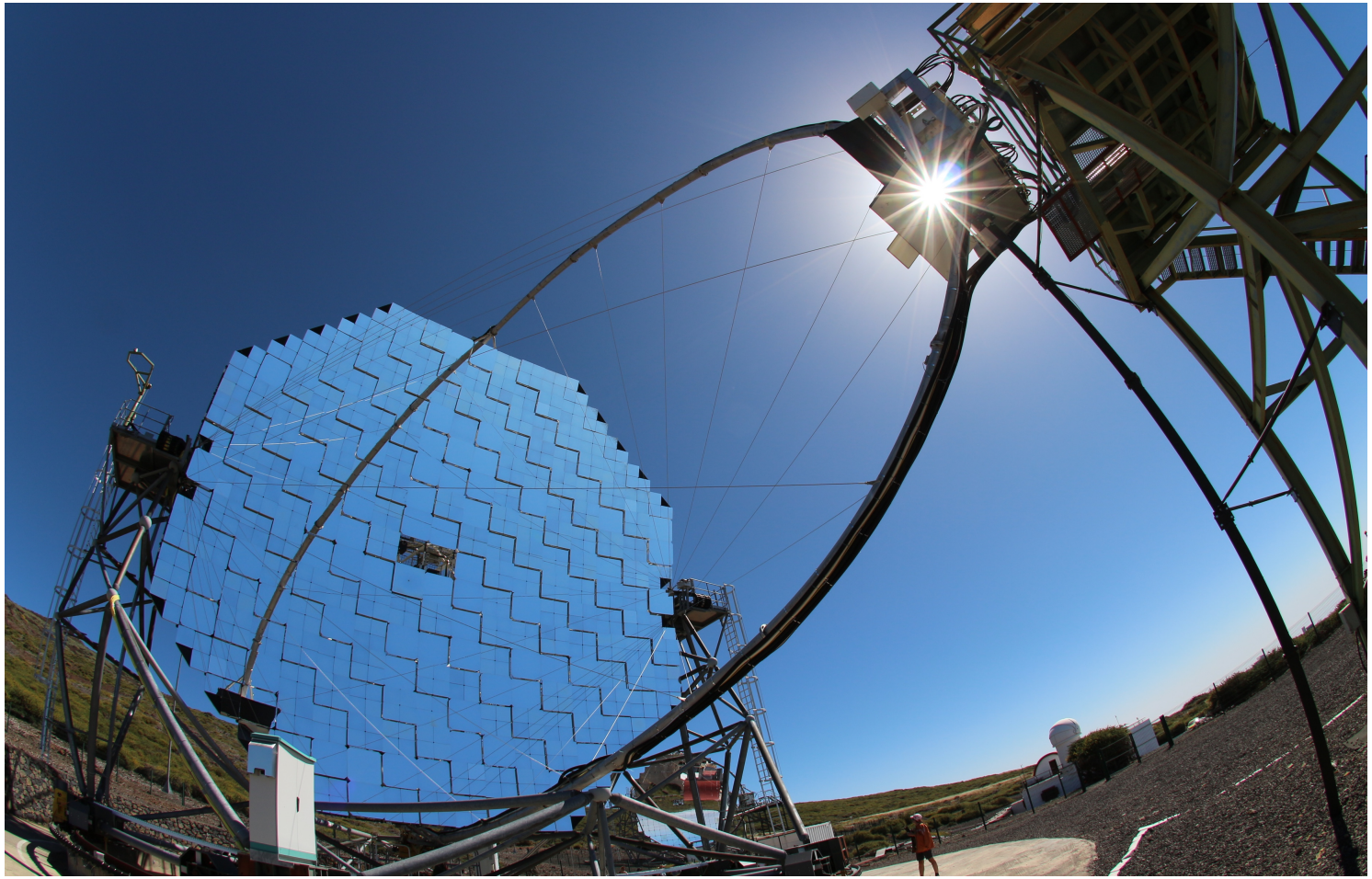
Ill-Posed Problems

Image Source: Von Google - https://github.com/googlei18n/noto-emoji/tree/v2018-08-10-unicode11/svg/emoji_u1f974.svg, Apache License 2.0, https://commons.wikimedia.org/w/index.php?curid=76923393

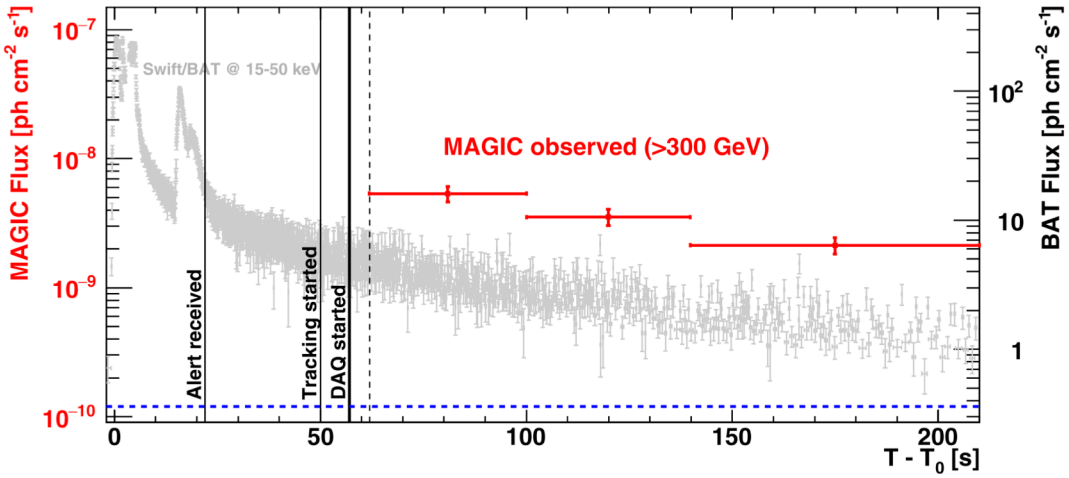
Imaging air Cherenkov telescopes



The present

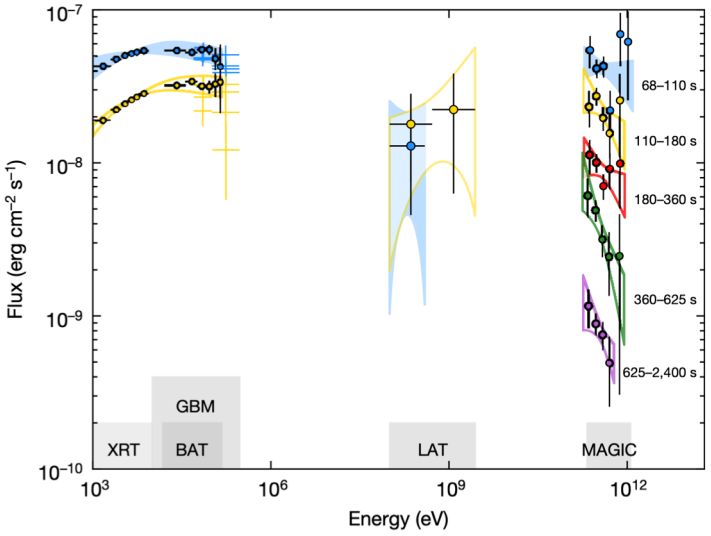


GRB 190114C: fast VHE follow-up



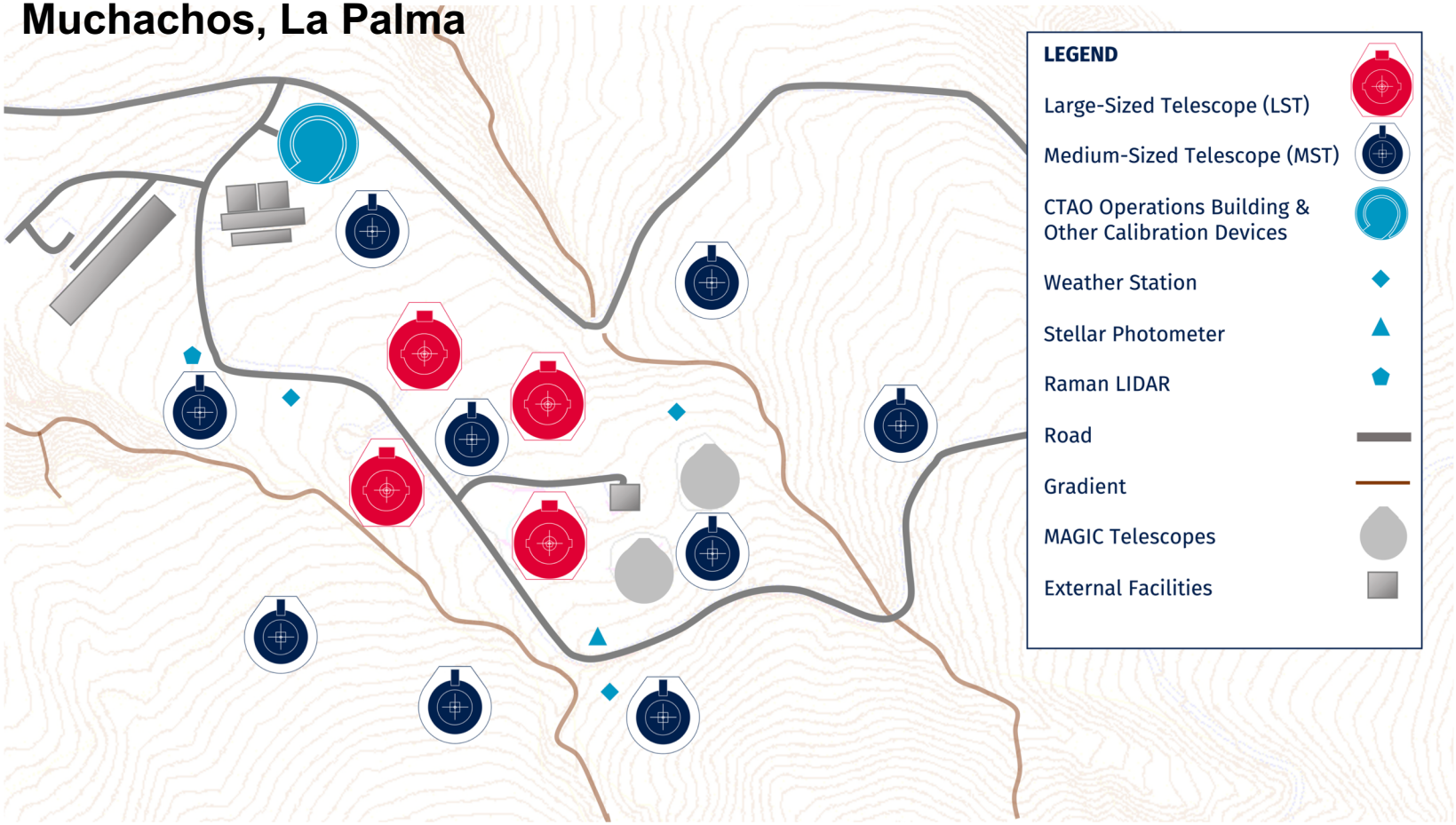
From: Nature 575, 455–458 (2019). https://doi.org/10.1038/s41586-019-1750-x

- „Long“ GRB, z = 0.4245
- MAGIC TeV follow-up after one minute
- Study of the temporal evolution of the afterglow emission
- High-energy peak can be modelled as inverse Compton emission



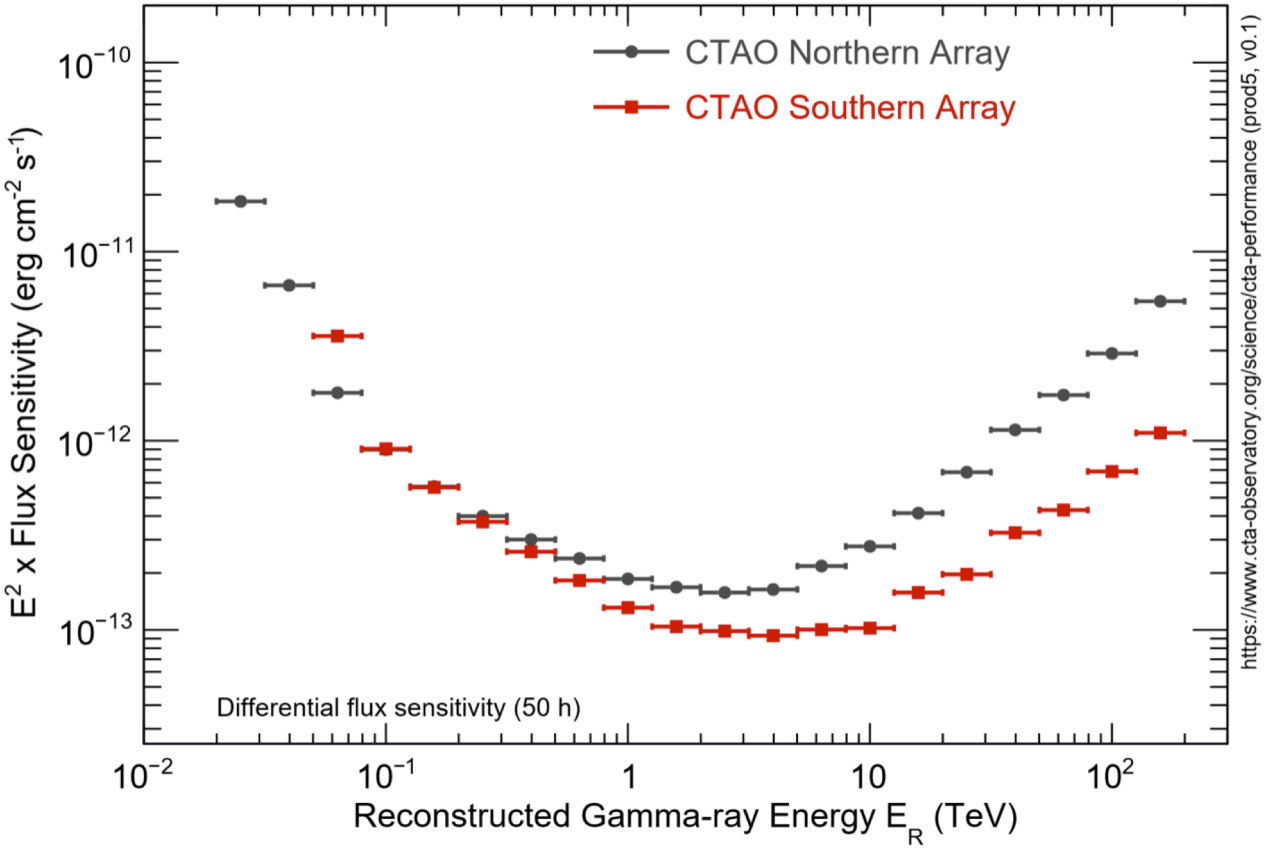
From: Nature 575, 459–463 (2019). https://doi.org/10.1038/s41586-019-1754-6

CTAO-NORTH Alpha Configuration at Roque de los Muchachos, La Palma



Credit: CTA

Projected CTAO sensitivity



Dominant Instrument:	**LST**	**MST**	**SST**

CTA-LST Project:
About **380 members**
(scientists/engineers/technicians) from **11 countries**
1 Telescope (soon to get siblings)

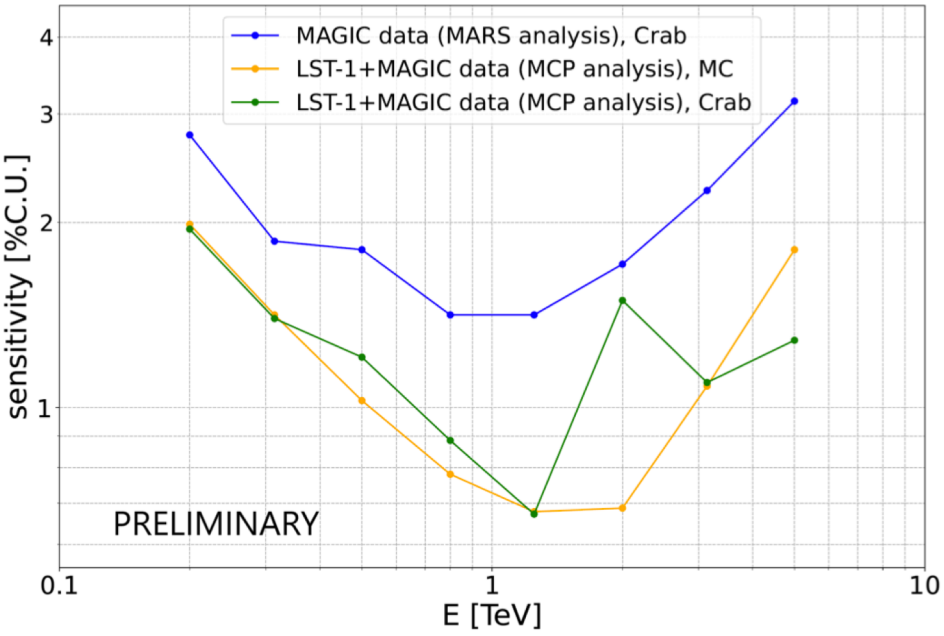
CTA-LST Project

CTA-LST Project

LST-1 and LST-1+MAGICs –> impressive science enabler

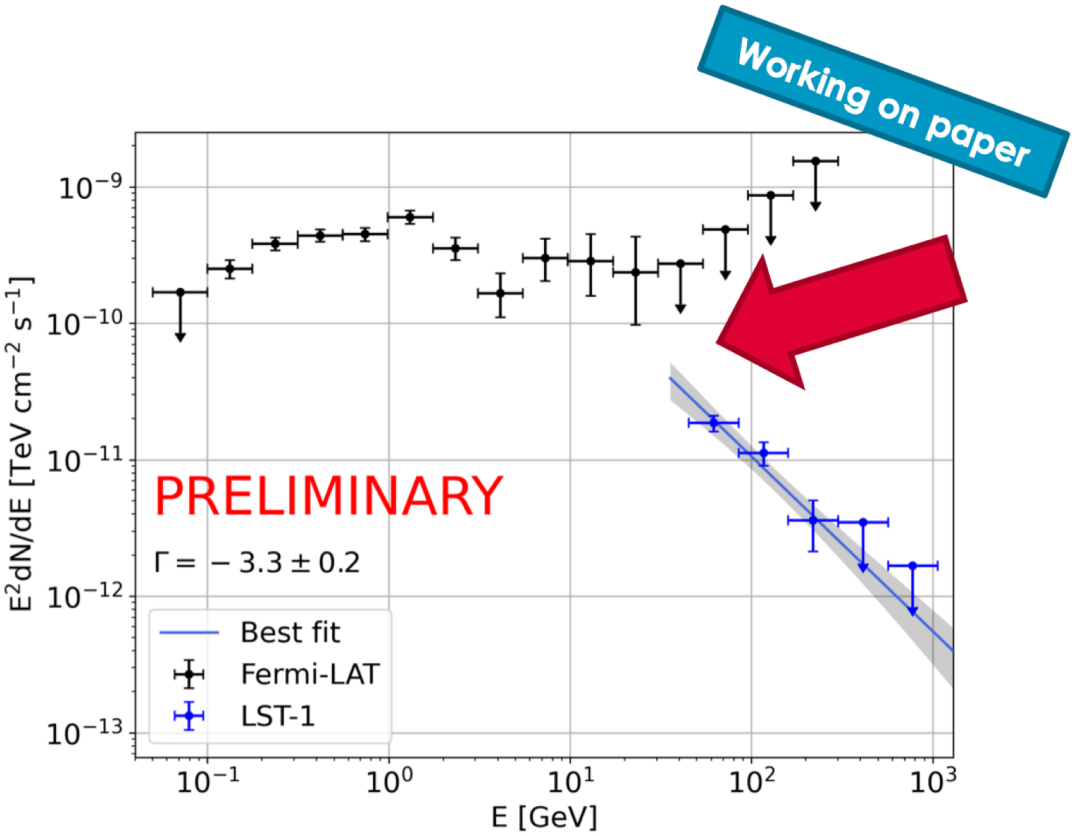
Development of analysis framework based on CTA tools to analyze MAGIC & LST-1 data:

- Dedicated MC simulations
- Validation of combined analysis using Crab Nebula data
- 3-telescope system sensitivity about 1.5 times better compared to MAGIC 2-tel
- Angular resolution improved by almost 20% (especially at low energies)
- Better reconstruction of events → energy resolution+

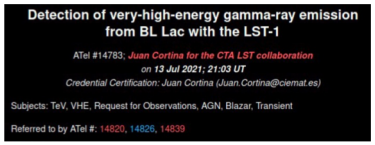


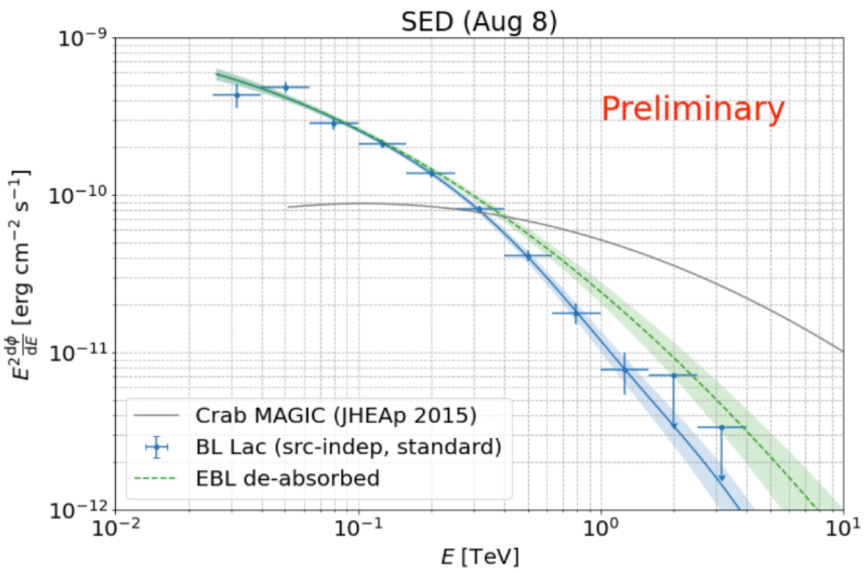
Nova RS Ophiuchi 2021

- First VHE – detected nova
- Symbiotic binary system → recurrent nova
- LST – 1 measured SED well compatible with those from H.E.S.S. and MAGIC
- Directly makes contact with Fermi – LAT data

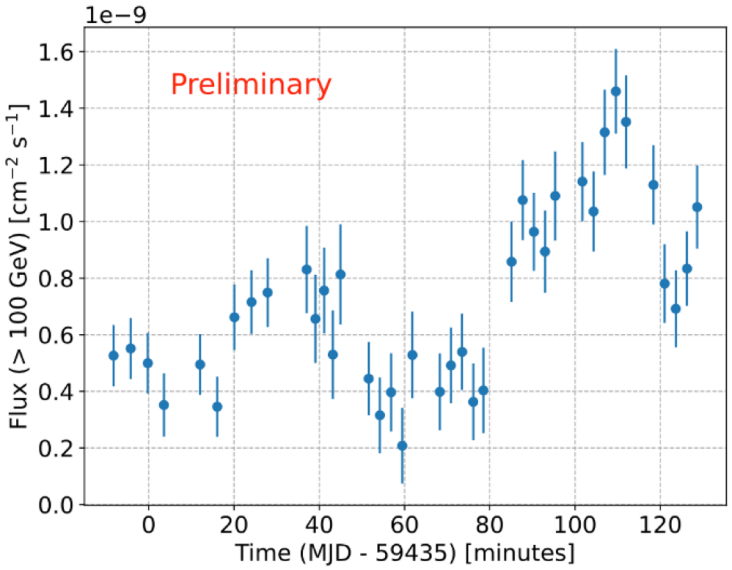


BL Lac in the Summer of 2021





Credit: CTA-LST Project



Credit: CTA-LST Project

- Energy Threshold: ~25GeV
- Intranight – variability may allow us to pinpoint acceleration mechanism

Conclusions

→The era of CTA physics has begun

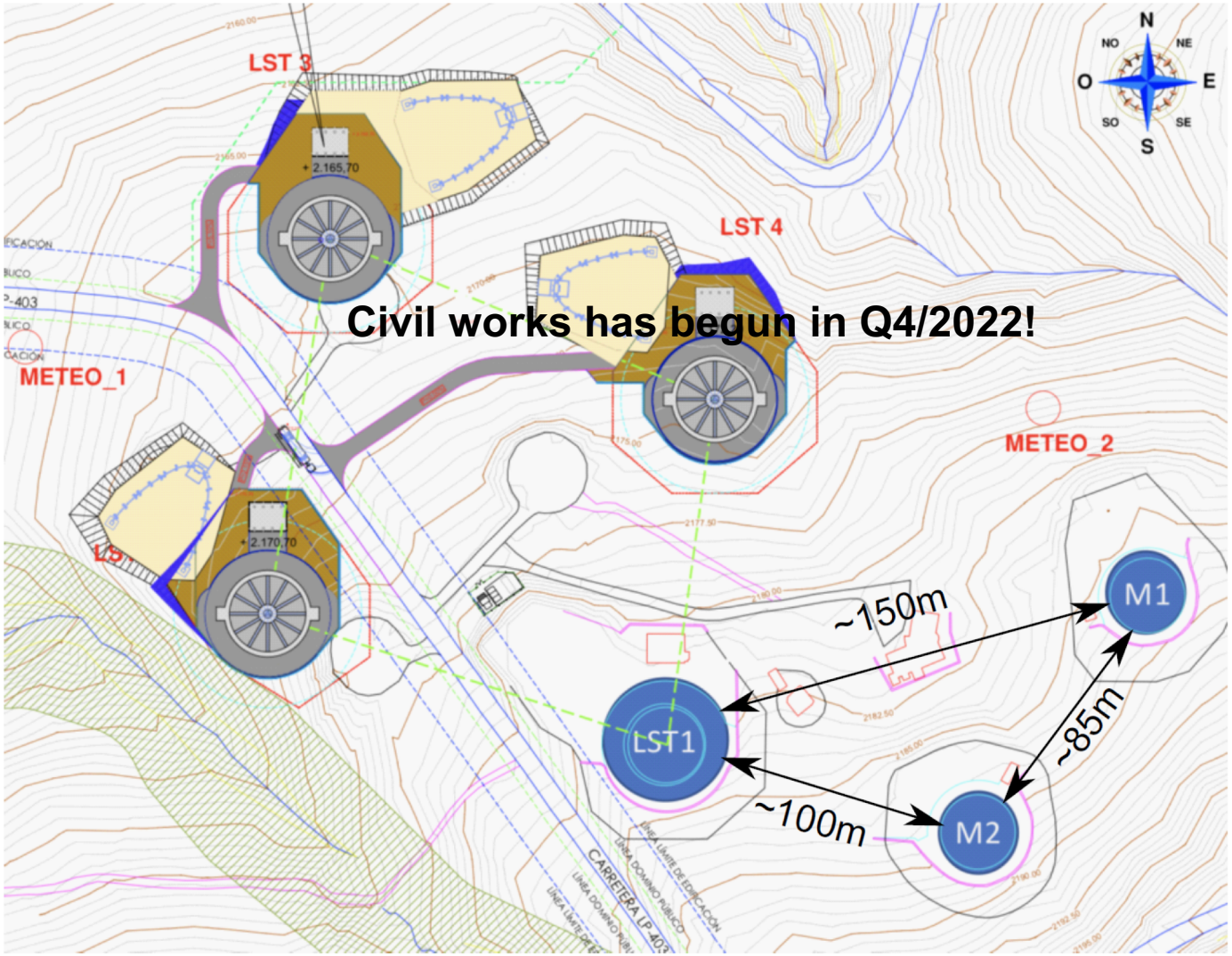
→LST performance follows CTAO requirements

→ Science program already up and running

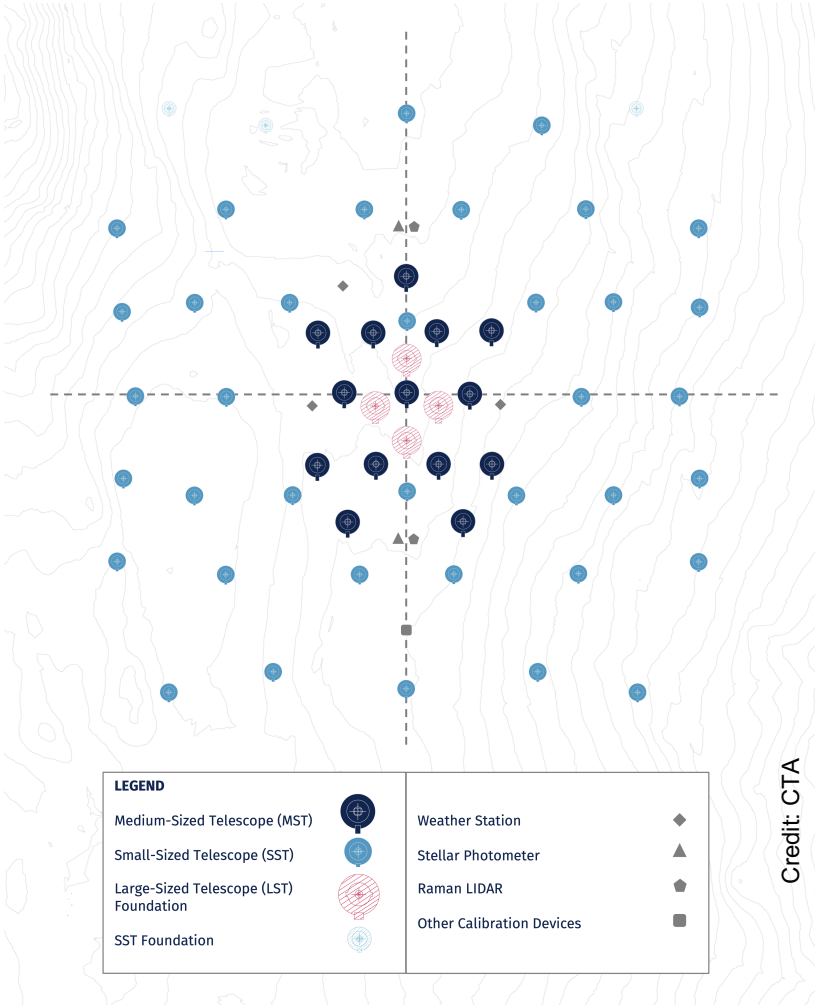
→Analysis chain development staying important

→Low energy sensitivity and initial physics results of LST-1 highlight the discovers potential of CTA

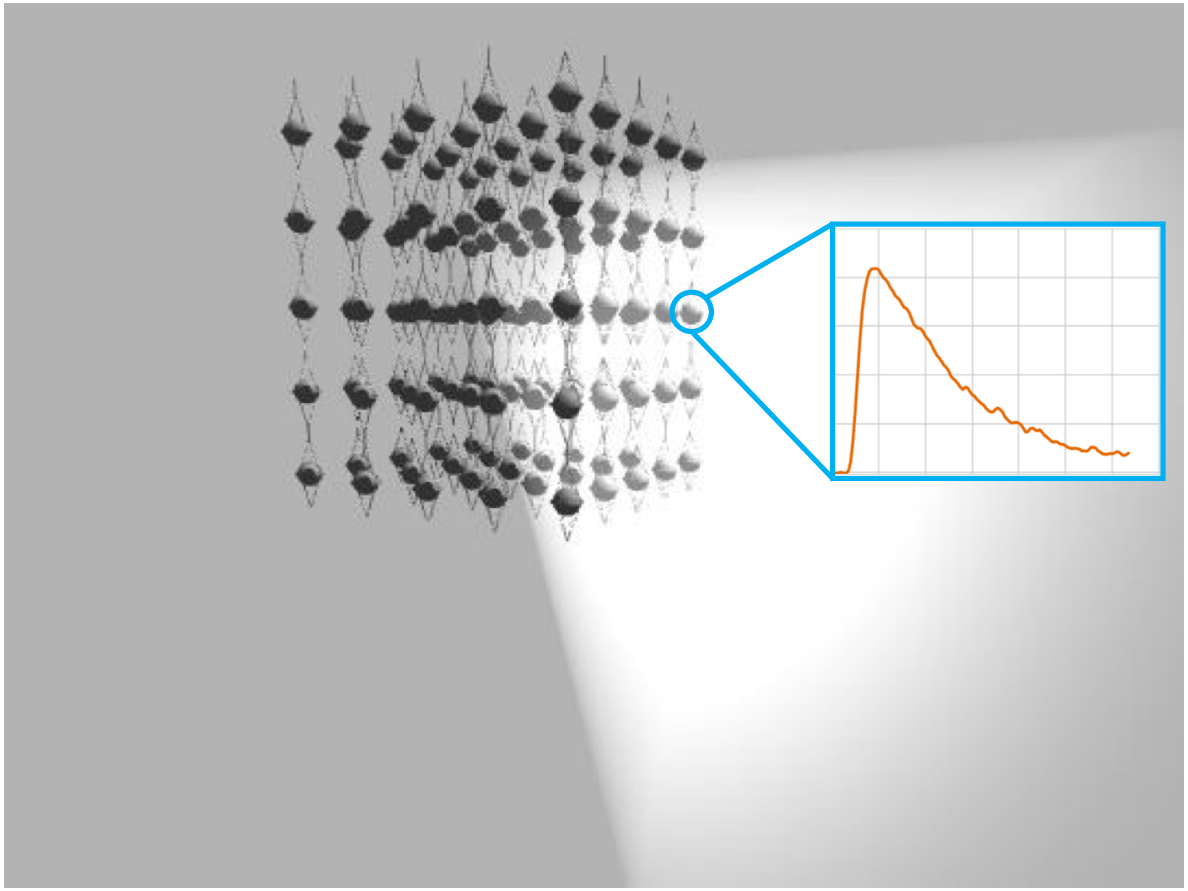
Backup slides


LST 3
LST 4
LST 1
METEO_1
METEO_2
Civil works has begun in Q4/2022!
M1
M2
~150m
~85m
~100m
N
NO
NE
O
E
SO
SE
S

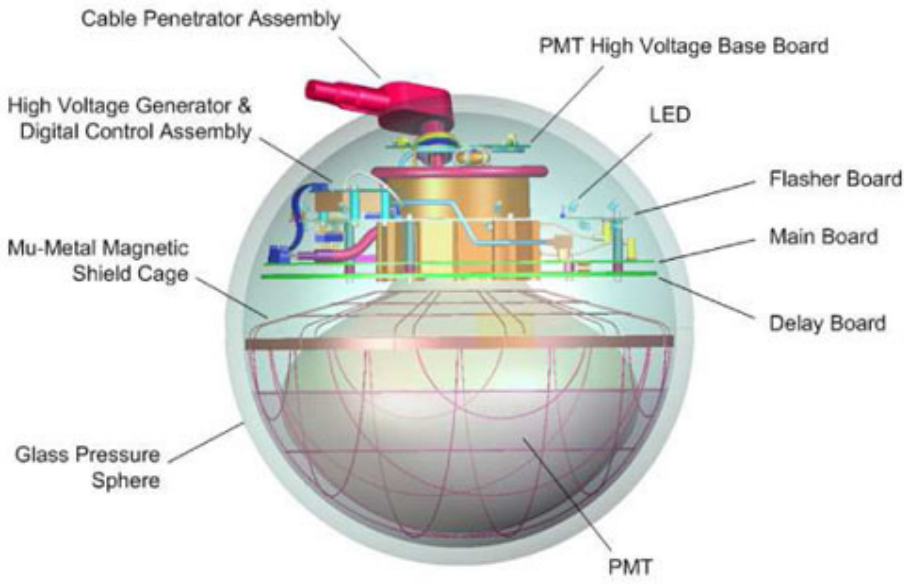
CTAO-SOUTH Alpha Configuration at Atacama Desert, Chile



IceCube Detection Principle



The Fundamental Unit of IceCube: The DOM

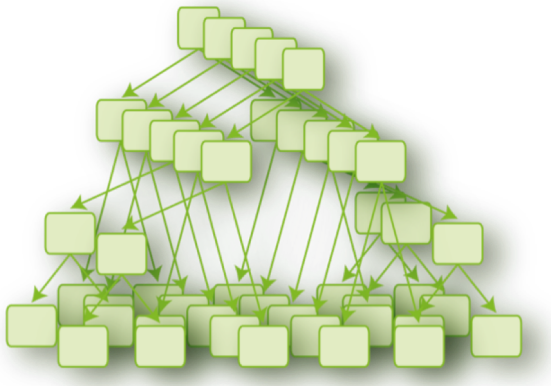


- Downward facing 10“ PMT (Hammamatsu R7081-02), 25% Peak QE
- High Voltage Supply
- Electronics
- Flasher LEDs
- Higher QE (34%) for DeepCore DOMs (Hammamatsu R7081MOD)
- Very few DOM failures (mostly during deployment)
- Slightly larger fraction of DOMs with *issues* (mostly non-standard Local Coincidence)

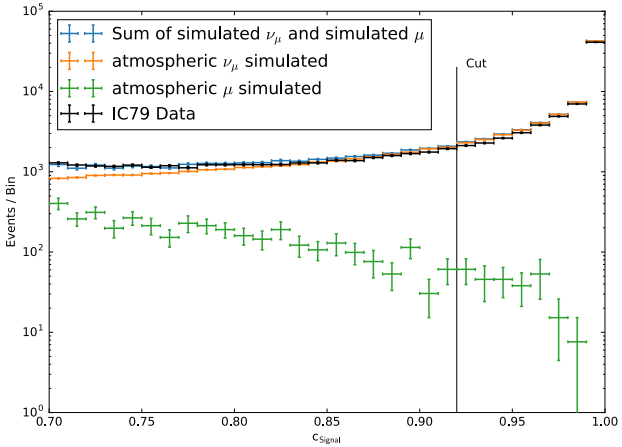
Background Rejection via Machine Learning

Initially	1219
blacklisted	1129
constant & useless	855
Correlation cut	323
Data/MC Clf	311
mRMR	60

+



+

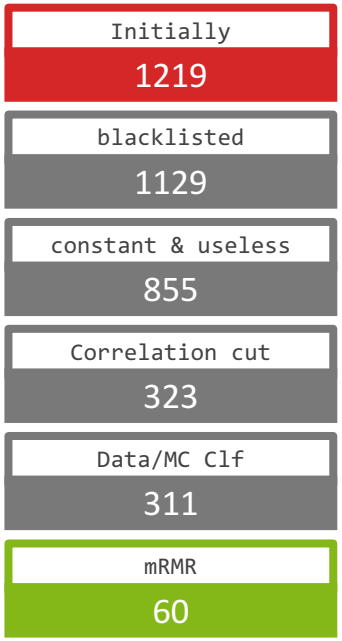


$$c_j = \frac{1}{n_{tress}} \sum_{i=1}^{n_{trees}} c_{ij}$$

M. Börner, PhD thesis (2018)

= Purity well above 99.5%.

Event Selection via ML I: Feature Selection



M. Börner, PhD thesis (2018)

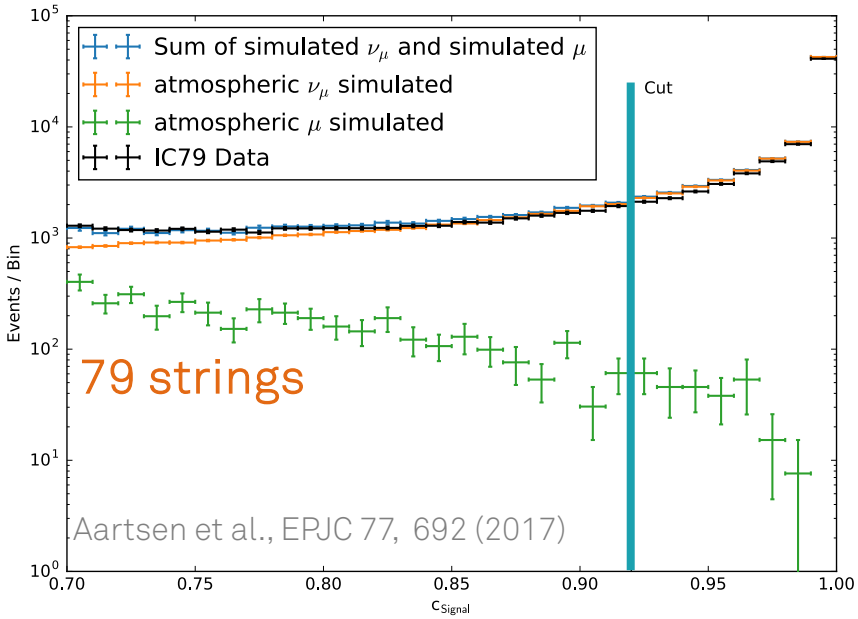
- Select features according to relevance and redundancy
- Feature set is built by iteratively adding features that fulfill the following criterion

$$\max_{x_j \in X - S_{m-1}} \left[I(x_j, c) - \frac{1}{m-1} \sum_{x_i \in S_{m-1}} I(x_i, x_j) \right]$$

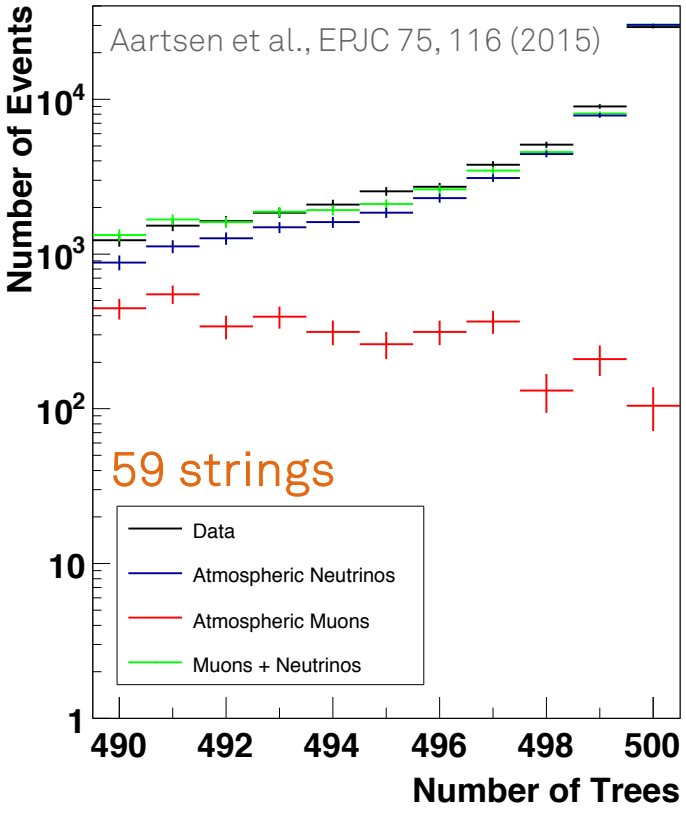
Peng, H.C., Long, F., and Ding, C., IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 27, No. 8, pp. 1226–1238, 2005.

Ding, C., & Peng, H., *Journal of bioinformatics and computational biology*, 3(02), 185-205. (2005)

Classifier Output



~ 200 neutrino candidates per day



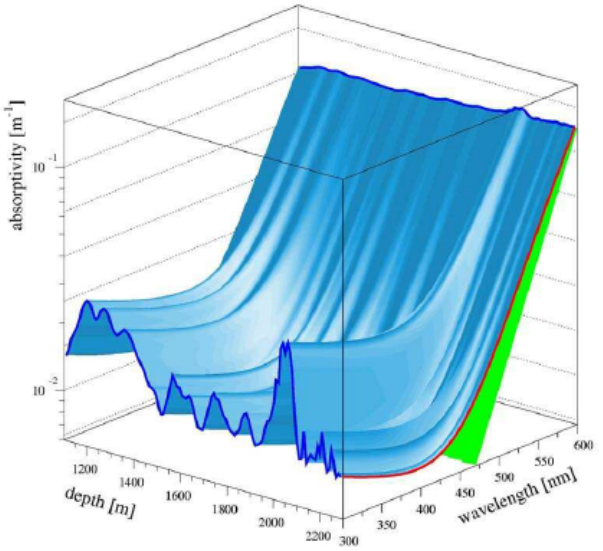
~ 80 neutrino candidates per day

Expected Purity well above 99.5% for both analyses.

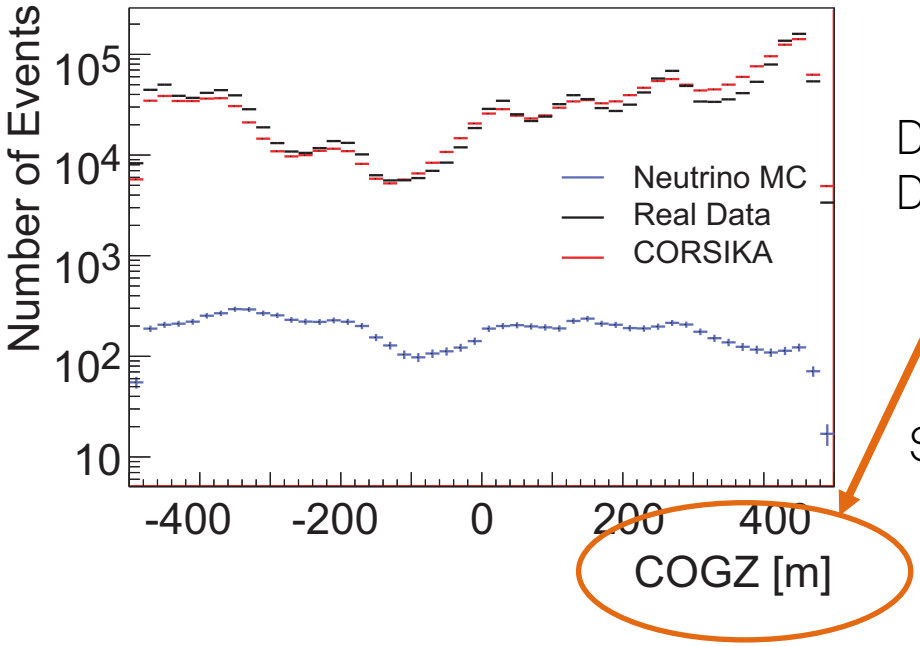
South Pole Ice as a Detection Medium

Natural Medium: Lots of inhomogenities, smaller and larger layers of dust.

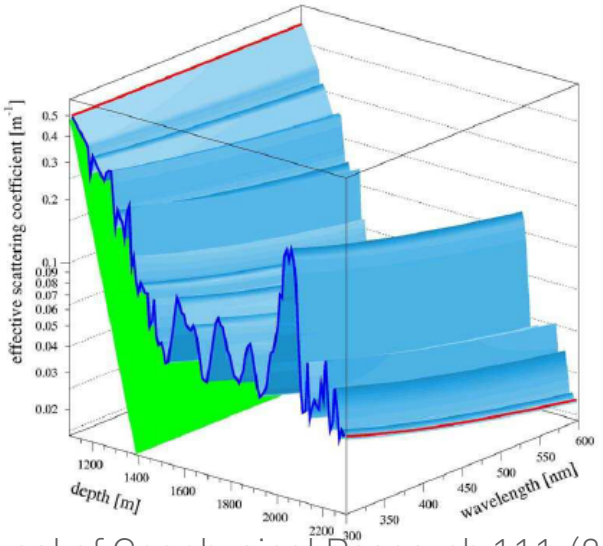
Absoprtion



Depth in Detector



Scattering

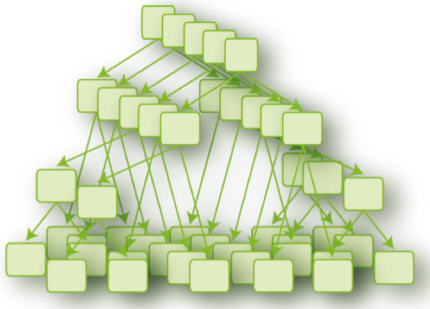


Ackermann et al., Journal of Geophysical Research 111, (2006)

A Typical Analysis Pipeline

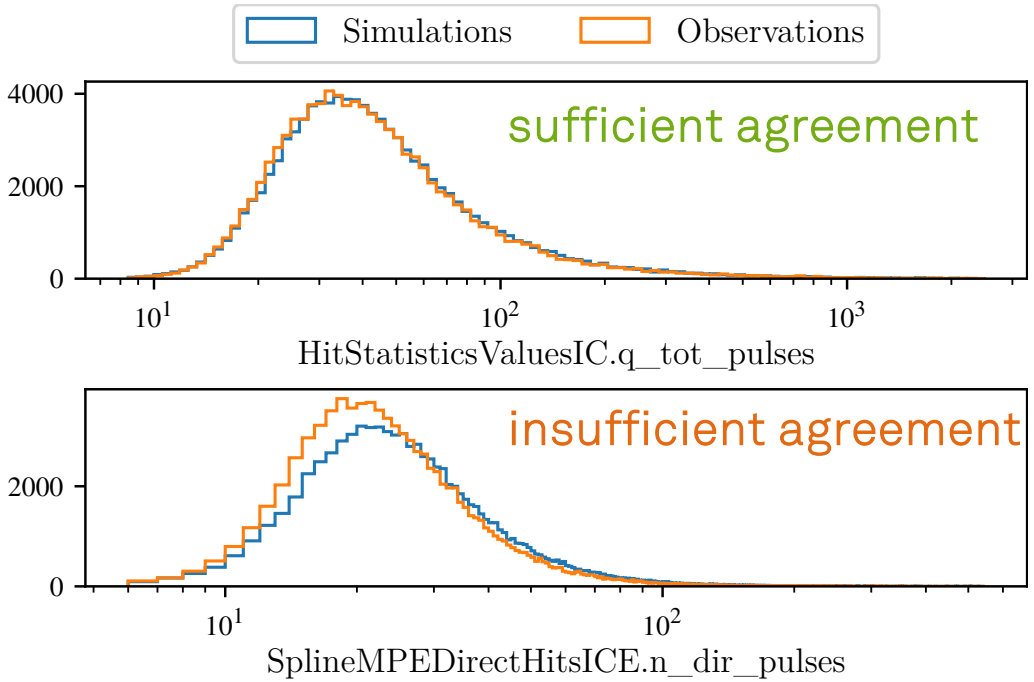
Variable Selection → Classifier Training → Cut on Classifier Output

Source: https://www.pinterest.com/pin/550354016946043419/



Picture: CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=14260

Detection of Data/MC Mismatches

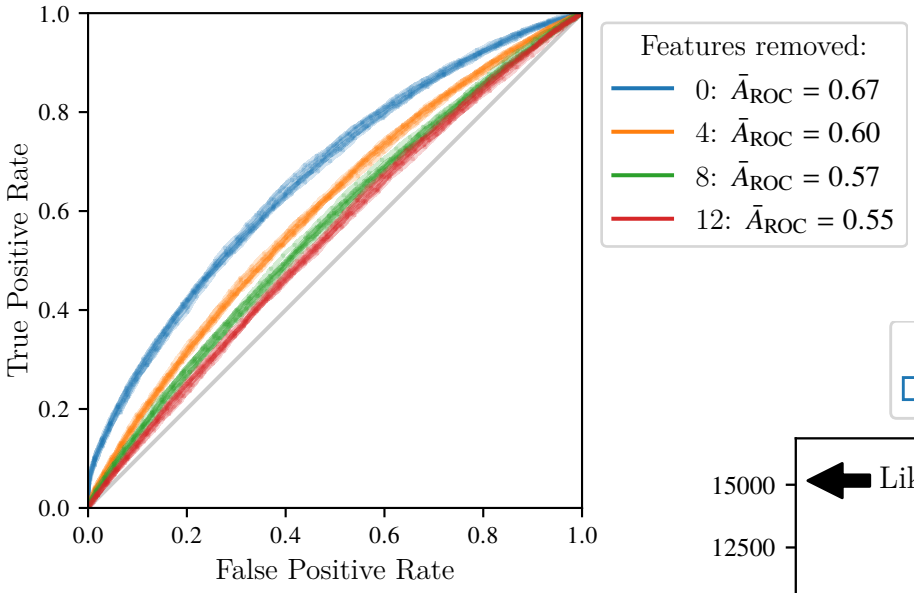


Graphics: M. Linhoff

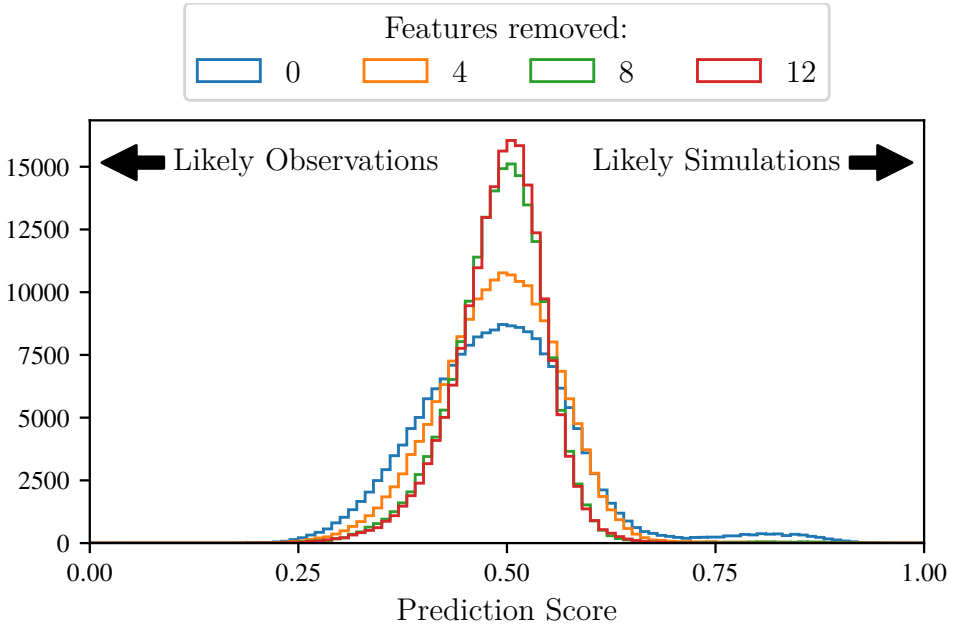
Challenges when inspecting distributions by eye:

- only looking at one-dimensional distributions
- Systematic errors in simulation will also affect correlations between features
- Which metric ???
- Which threshold ???

Detection of Data/MC Mismatches



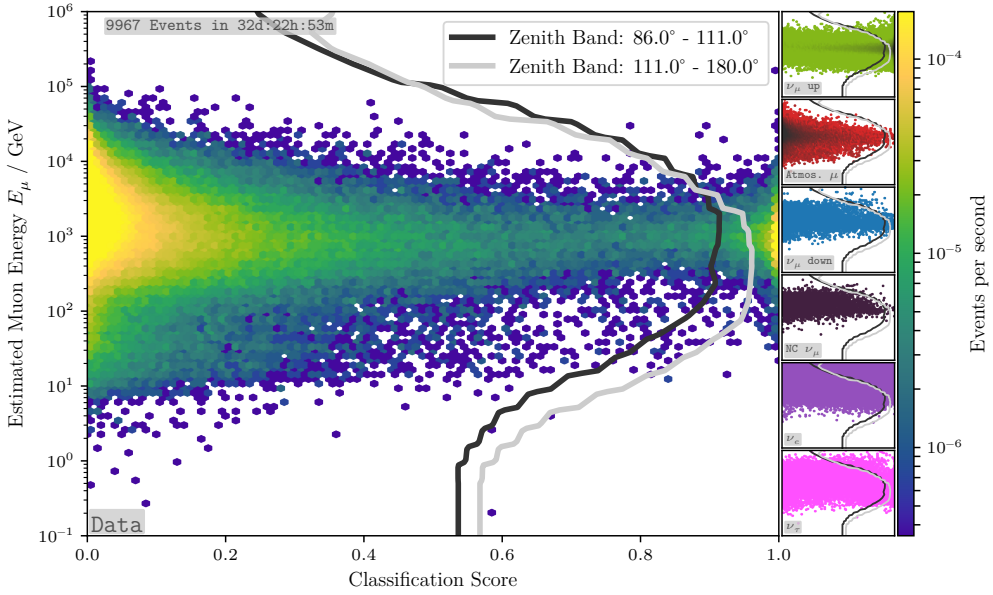
Area under Curve is close to 0.5 (close to random guess).



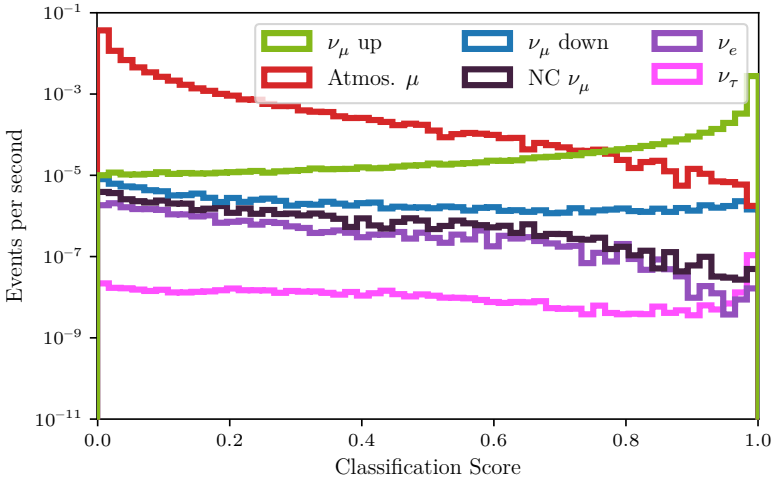
Prediction score centered around 0.5 (close to random guess).

Graphics: M. Linhoff

Advancements: Energy-Dependent Score Cut



~ 300 neutrino candidates per day



Classifier output is energy and zenith dependent.

Score cut as a function of energy and zenith.

M. Börner, PhD thesis (2018)