Deep Learning Transient Search with VERITAS

DESY gamma group meeting | 26.08.2021

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

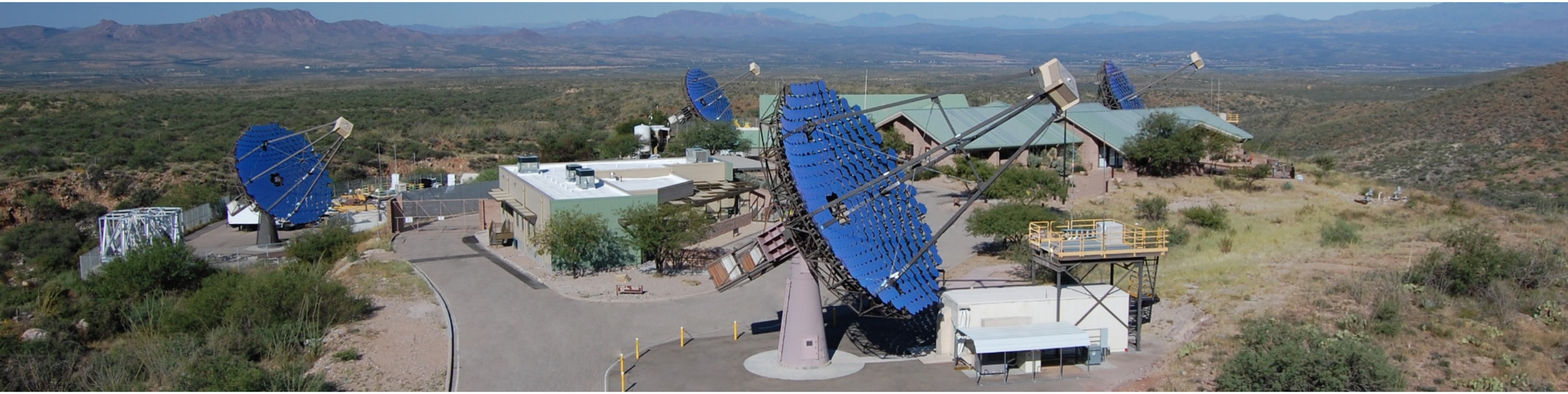
HELMHOLTZ Young Investigators

VERITAS

Universität Potsdam

DESY.

Transient Detection with VERITAS



VERITAS

- Array of 4 Imaging Air Cherenkov Telescopes
- Indirect detection of γ rays > 100 GeV
- Sensitive to 1% Crab in ~25h

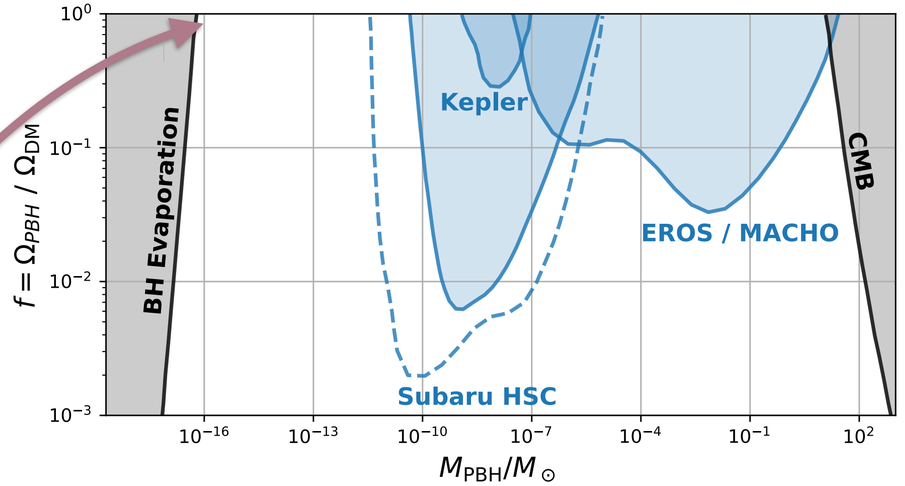
Transient signals

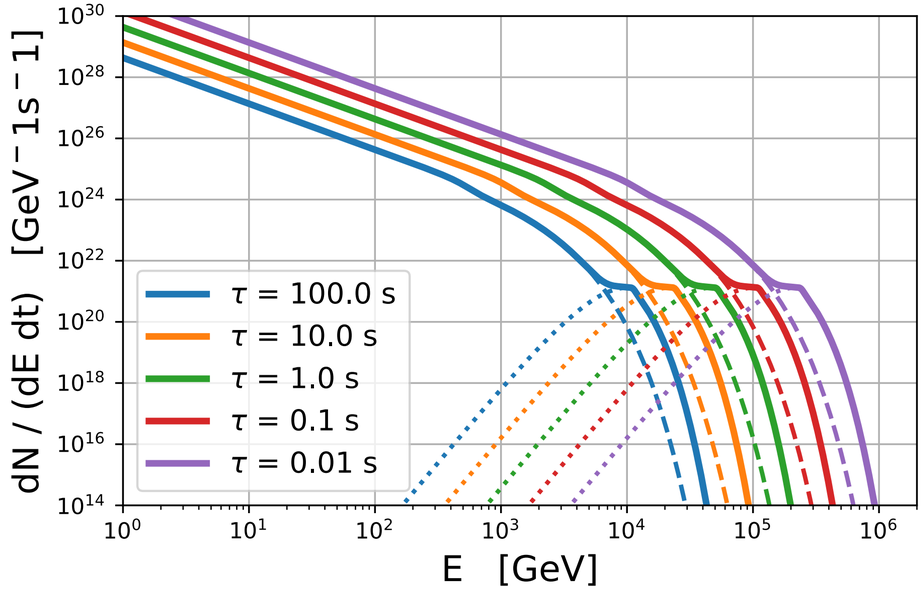
- Serendipitous location and time of occurence
- Candidates:
  - Gamma-ray bursts
  - Evaporation of primordial black holes
  - Flaring blazars
  - ...

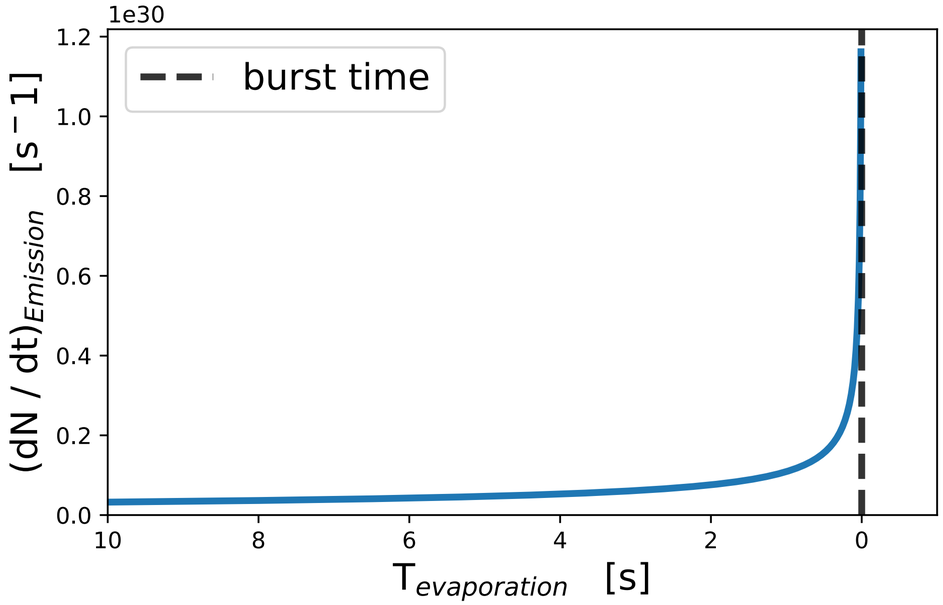
Need robust search method to detect transient signals!

Evaporation of Primordial Black Holes

- PBHs possibly formed in early universe by density fluctuations
- Loose mass due to Hawking radiation
- End in a burst that might be detectable at VHE gamma rays
- PBHs formed with $\sim 5 \times 10^{11}\,\mathrm{kg}$ should evaporate today



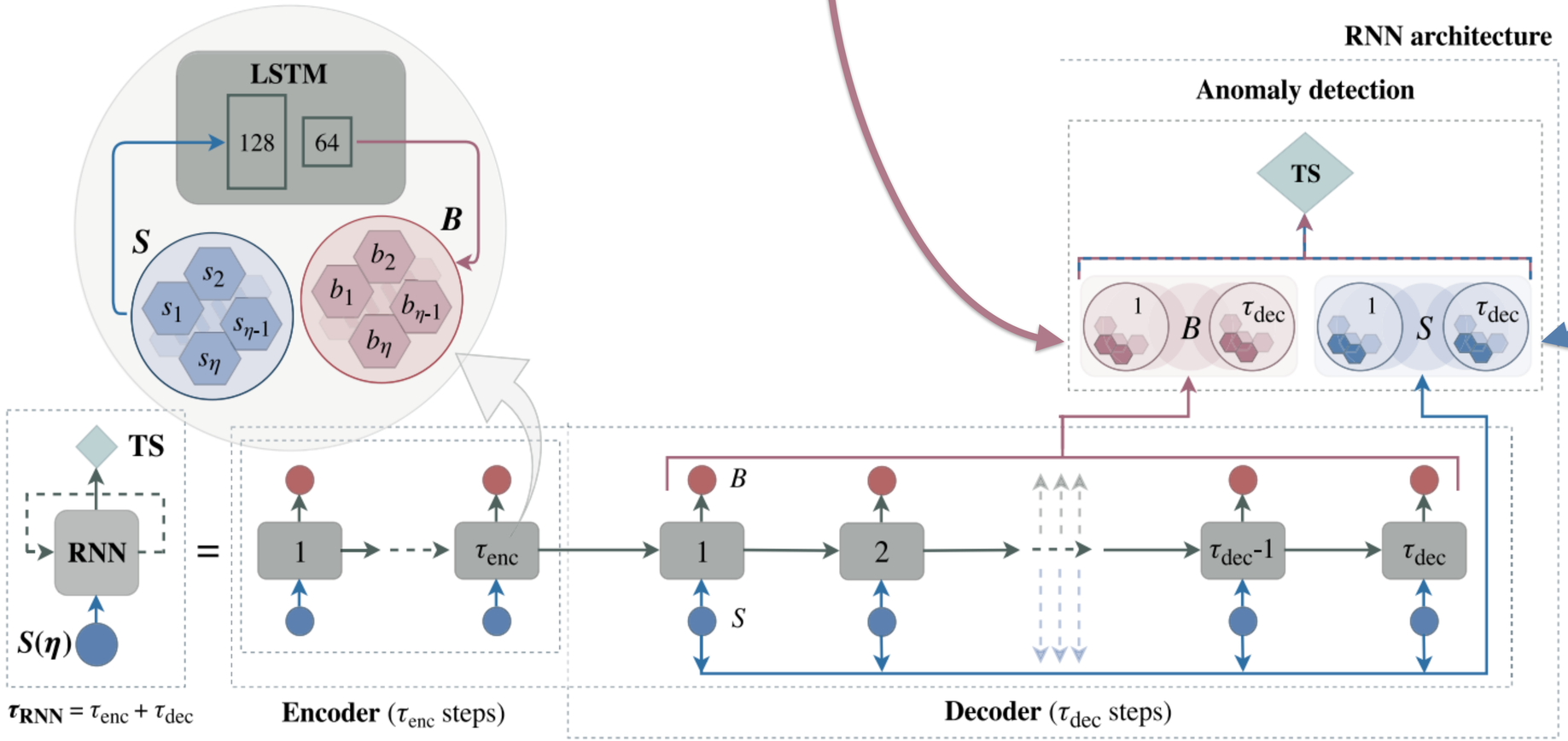




Deep Learning Transient Detection

- **Data drive** - insensitive to uncertainties in modelling of the instrument response
- Each step represents interval in time series and takes the **event counts** as inputs
- **Anomaly detection** trained with background data
  - Learns to predict the **expected background in decoder steps**

Transient detection by identifying enhanced **measured event counts**



I. Sadeh. ApJ, 894, 2020

Automatic Data Quality Monitoring

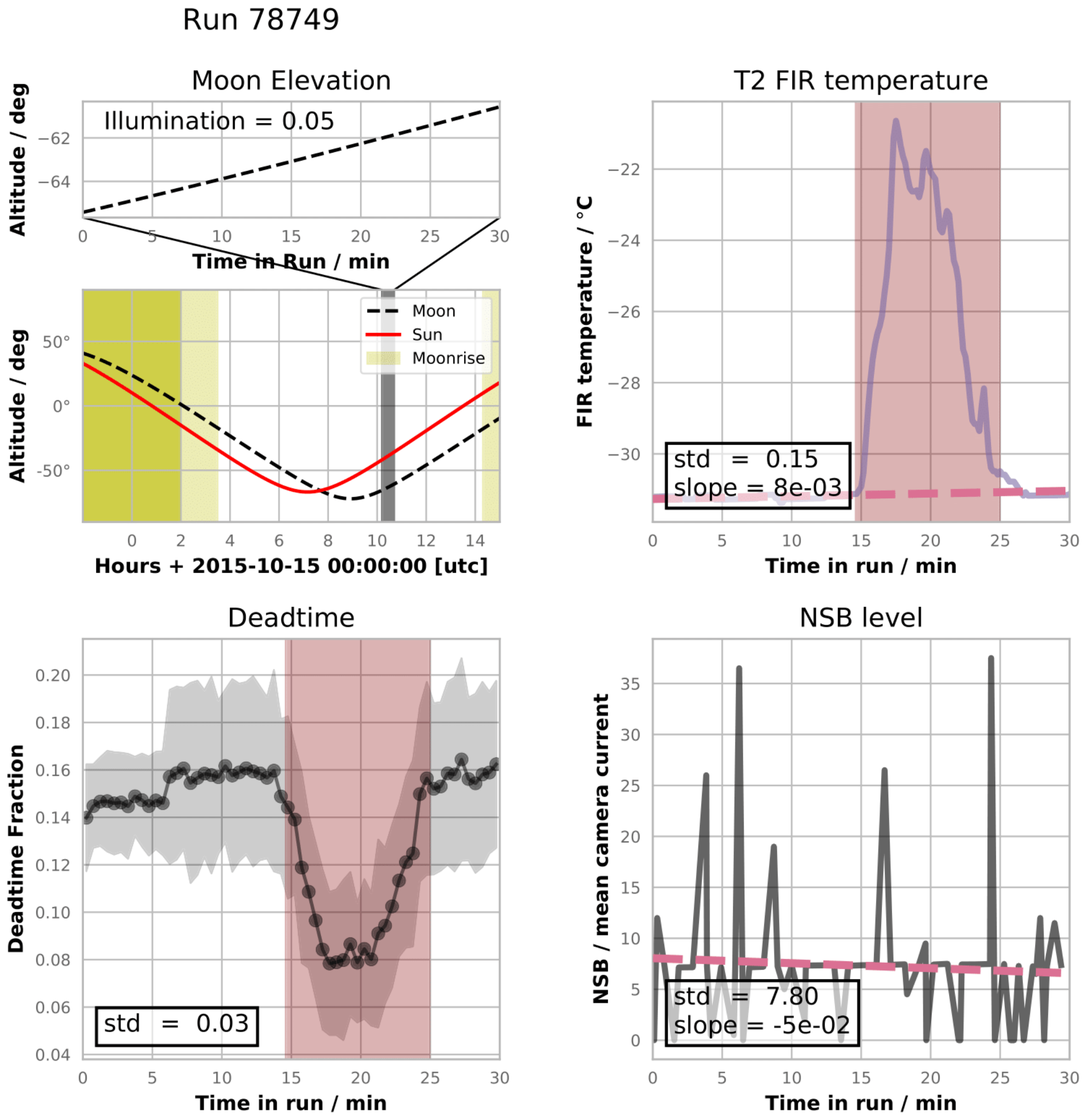
- Working with large dataset (~9 years)

- **Automatic DQM**
  - Usually bad data has lower event rates -> No false transient signals

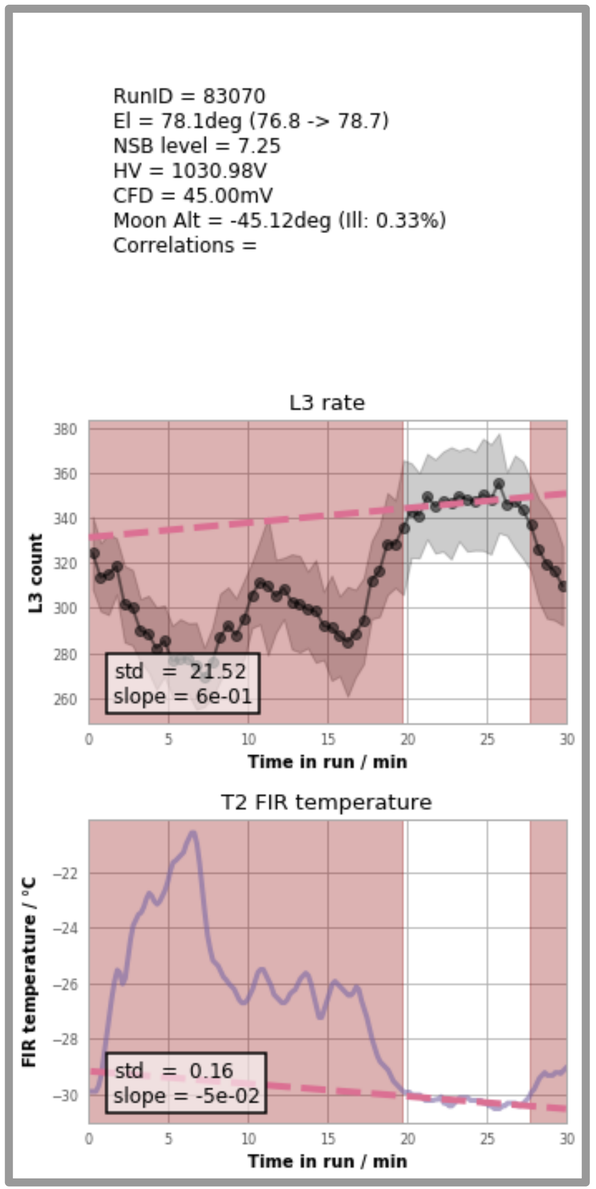
- Based on VERITAS internal data base
  -> no need to download data

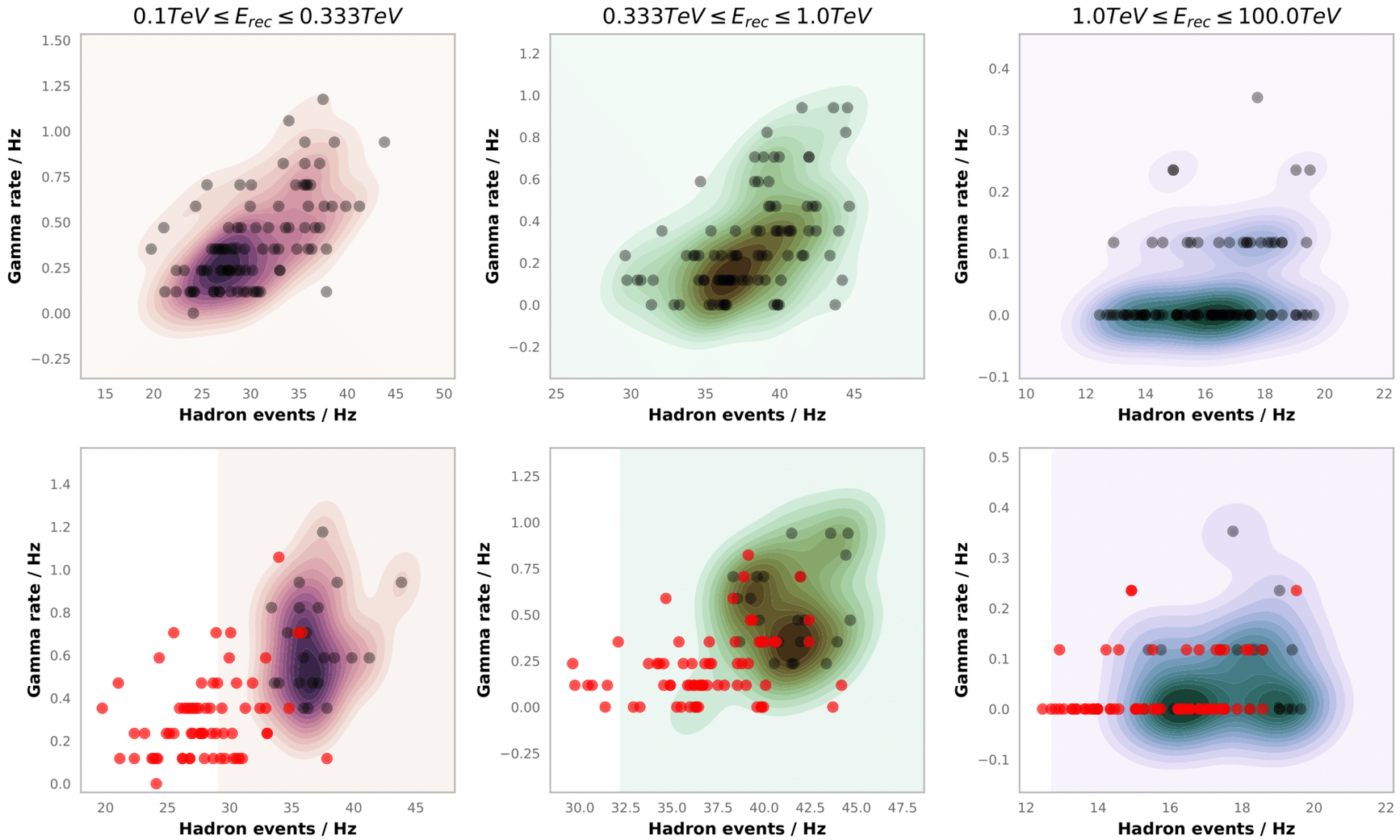
- python module to query general settings and set time cuts if required
  - spikes / drops in L3 rate
  - clouds
  - long trends (e.g. moon rise)

RunID = 78749
El = 74.2deg (71.5 -> 76.8)
NSB level = 7.30
HV = 1021.33V
CFD = 45.00mV
Moon Alt = -63.05deg (Ill: 0.05%)
Correlations =



Automatic Data Quality Monitoring



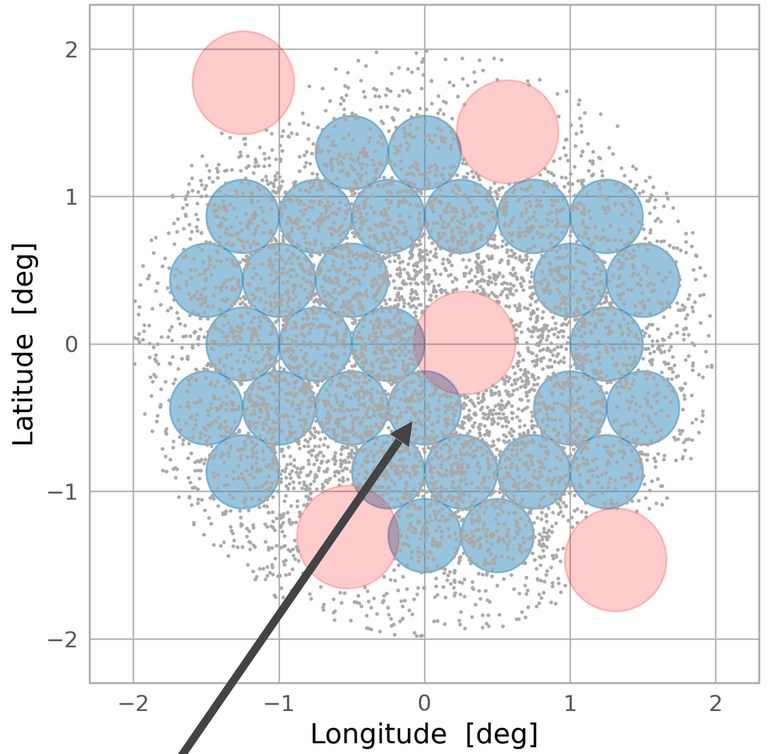


Training Data and Preparation

- **2730 hours** between 2012 and 2020 after quality selection
- Training with **background** data -> mask VHE sources and stars
- **Shuffle events** to remove potentially undetected transient signals

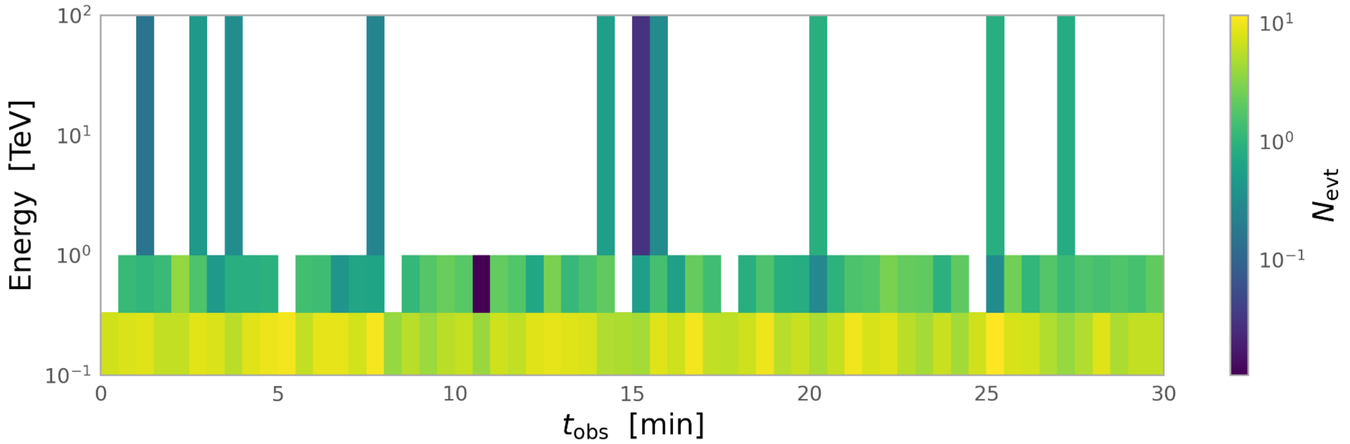
- Count events in bins of:

radius ROIs	0.25 deg
energy bins	[100 GeV, 330 GeV), [330 GeV, 1 TeV), [1 Tev, 100 TeV)
time steps	30s



- Two counting schemes:
  - loose γ / hadron cut and count events with **weighted with "γ-likeness"**
  - count only **γ-like** events

Per timestep and ROI:
3 energy bins with 2 counts --> **6 inputs**



Data Selection and Preparation

Auxiliary parameters

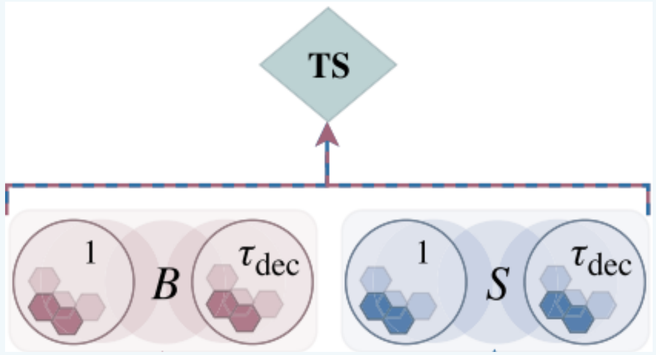
Learn systematic **changes in background** event rates

Parameter	*Description*	*Used*
l3_mean	Mean L3 trigger rate during time step	No
nsb_level	Mean charge in camera indicating NSB	No
azimuth	Azimuth of pointing position	Yes
sec(θ)	secant of the pointing zenith angle	Yes
ref_time	Time after August 1, 2012 in years	Yes
offset	Distance of ROI to camera center	Yes
multiplicity(η)	Average number of images at each time step and energy bin	Yes

TS Calculation

Based on **predicted** and **measured** event counts

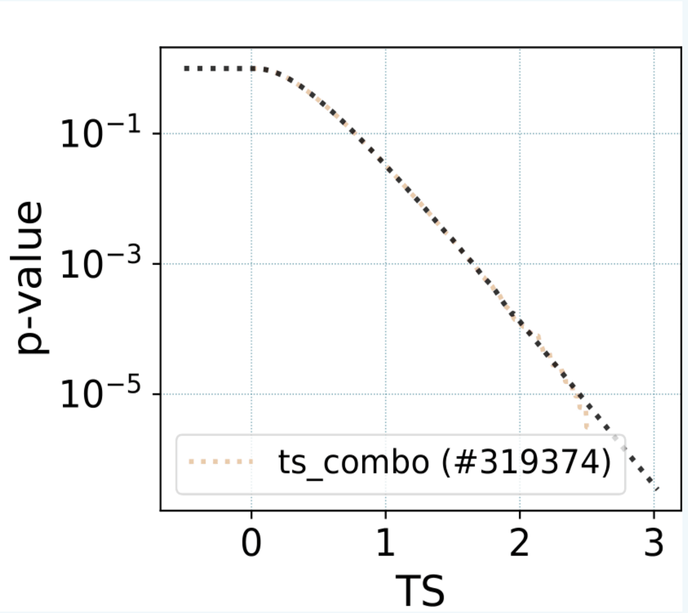
$$TS(\eta) = \frac{S(\tau_{\mathbf{dec}},\eta) - B(\tau_{\mathbf{dec}},\eta)}{\sqrt{|B(\tau_{\mathbf{dec}},\eta)| + 1}}$$



TS Interpretation

Map **TS to p-value** based on background data

Depends on expected background - **144 meta bins**

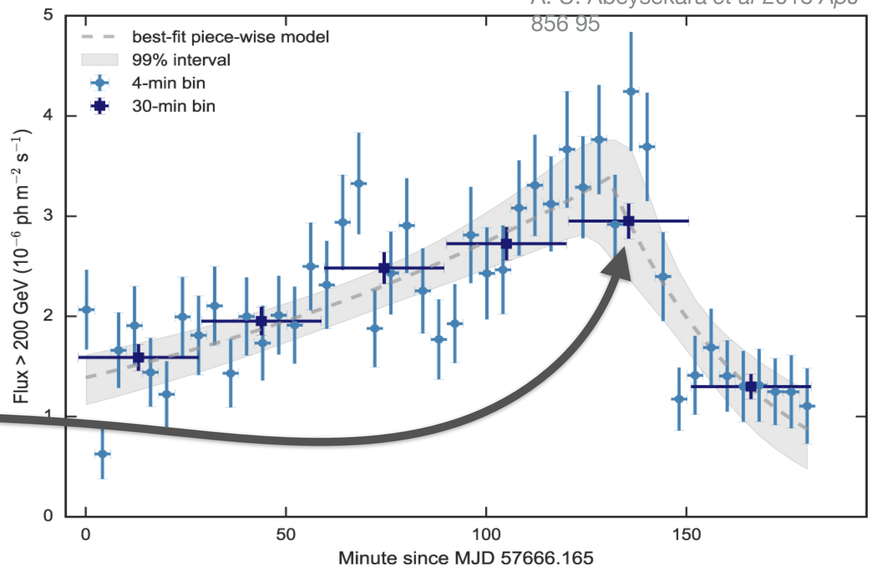


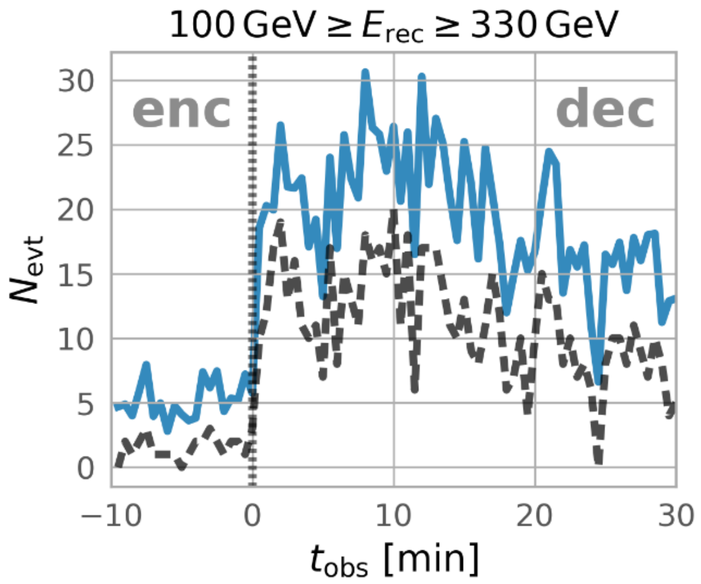
BL Lac

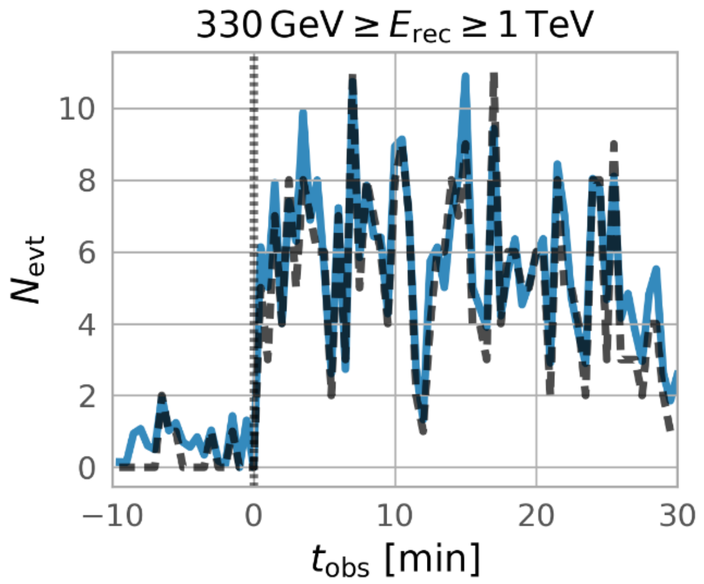
- Flare in October 2016 with flux up to **~1.8 C.U.** above 200 GeV
- Low state flux not detectable on this timescales with VERITAS

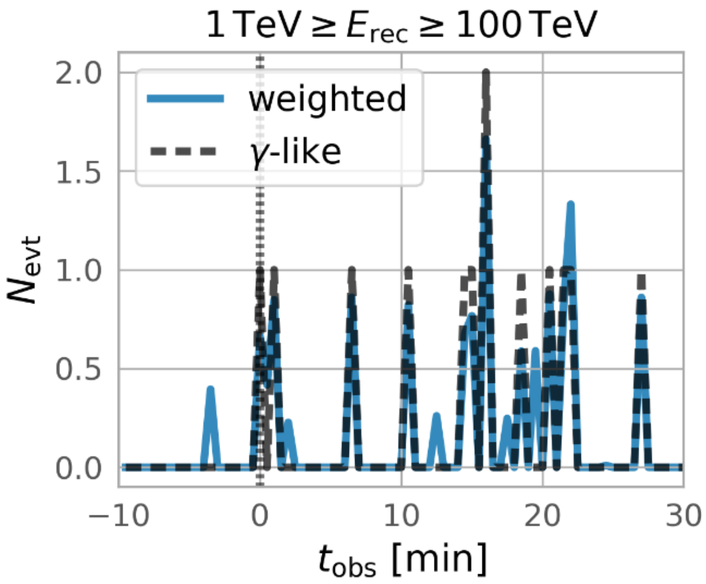
- Artificial time series for possible detection of the flare
  - **Decoder** steps from the 30 min **run with highest flux**
  - **Encoder** steps from low state with very similar observing conditions

A. U. Abeysekara *et al* 2018 *ApJ* 856 95



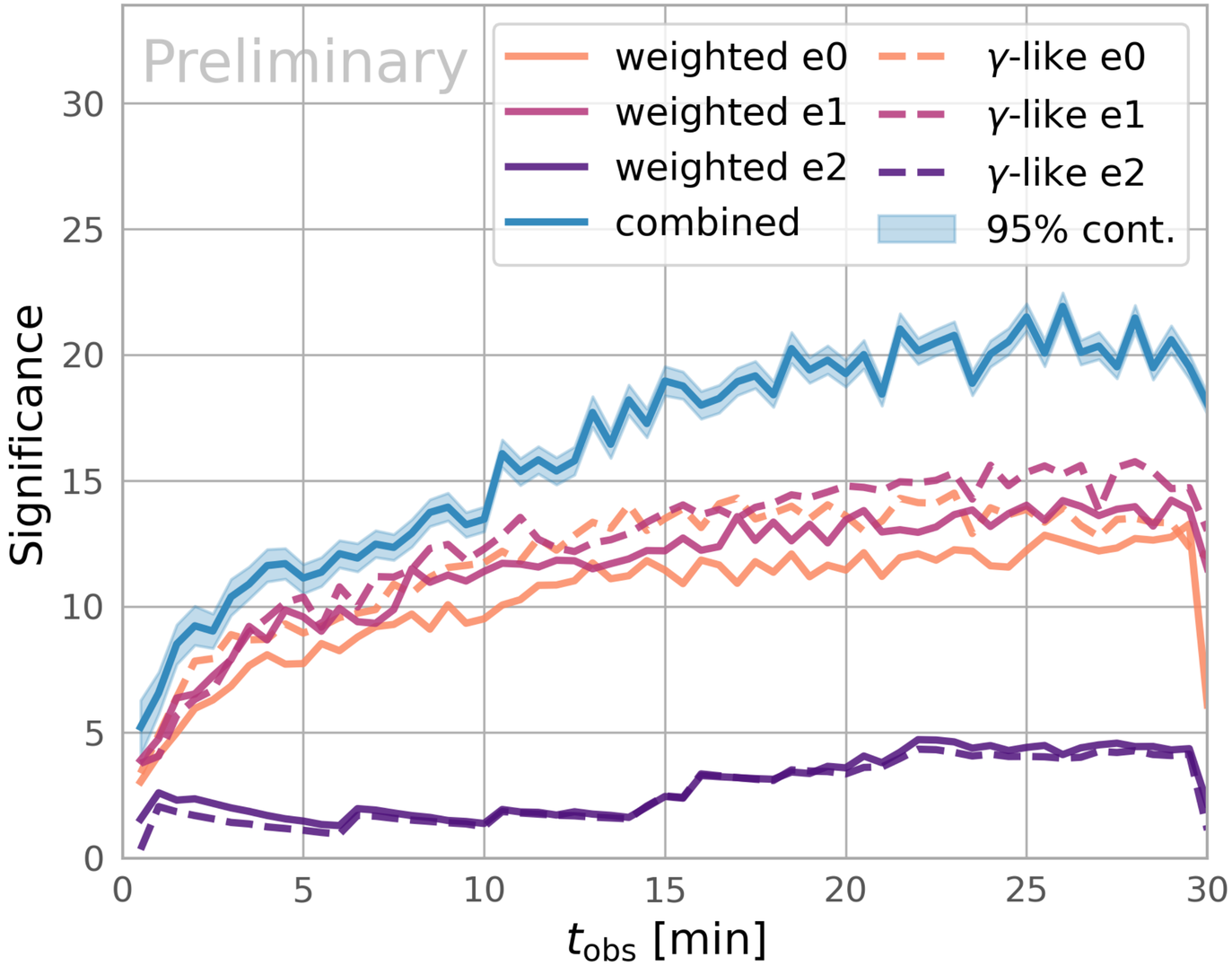






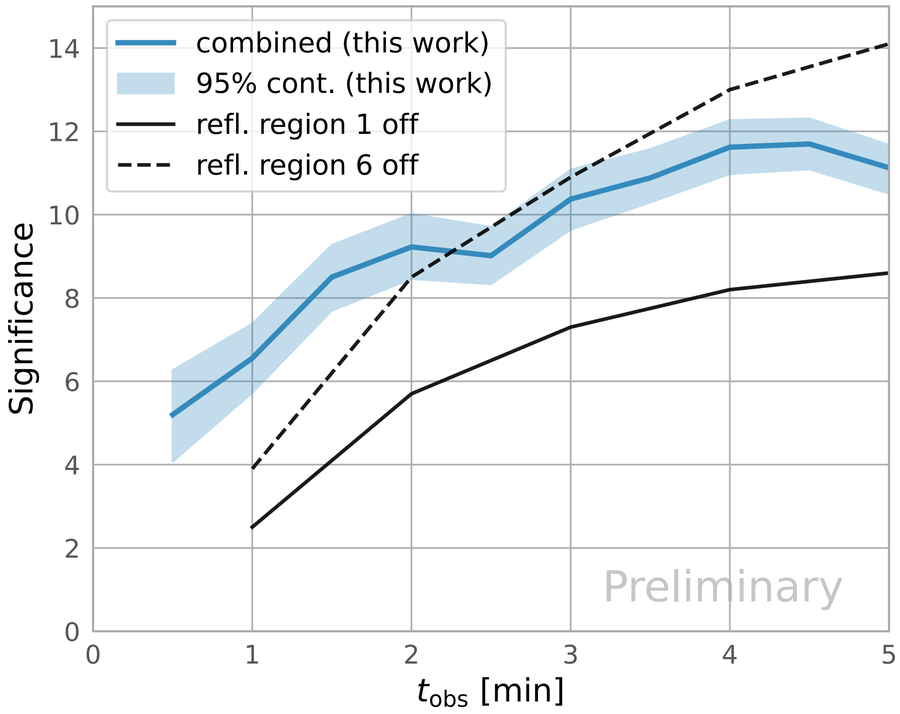
BL Lac - Detection

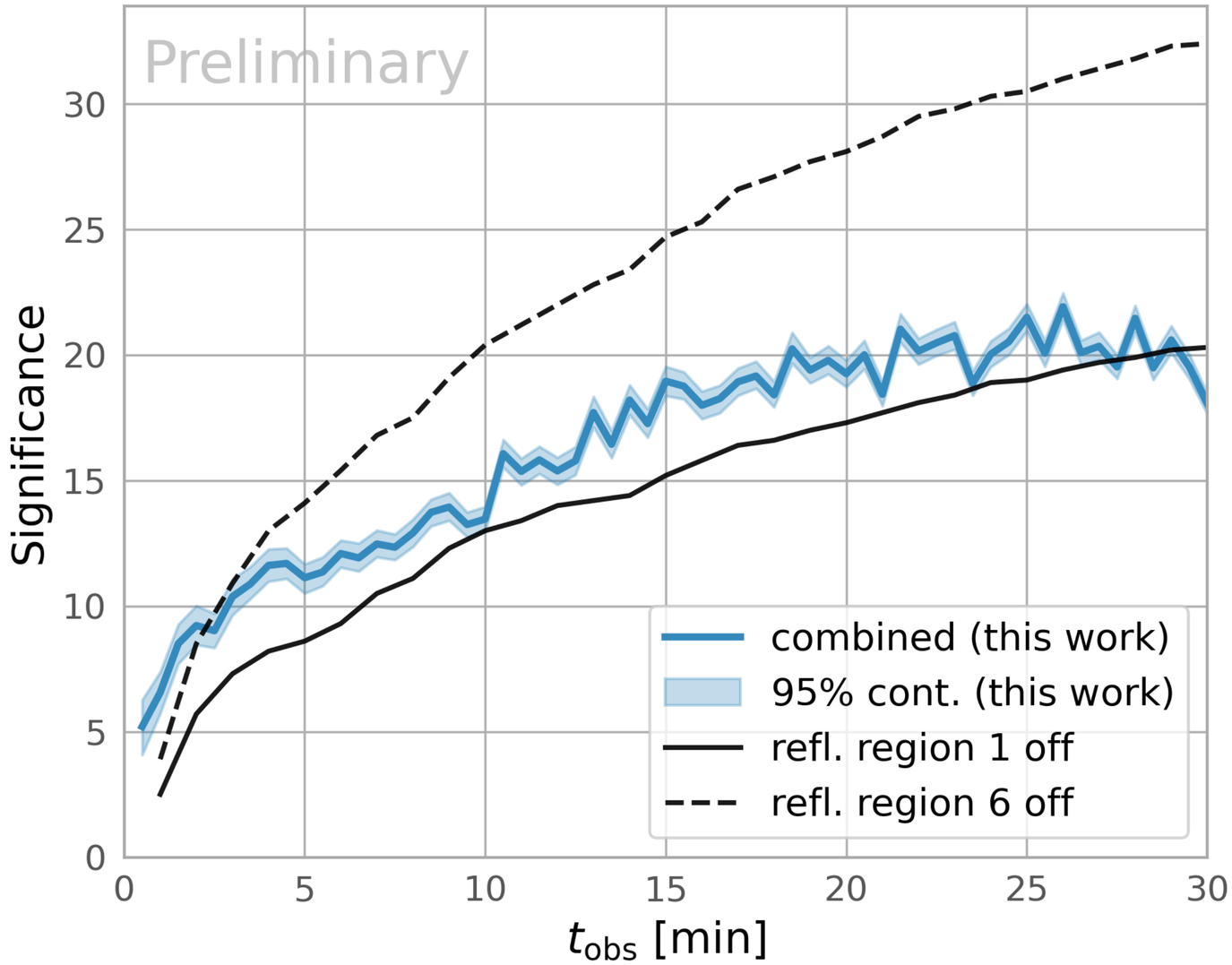
- Vary decoder length between **30 sec to 30 min** to study evolution of significance
- Contributions to overall significance from each of all **6 features**
- Dominated by **two low energy** bins
- Weighted and γ-like counting scheme provide **similar contributions**



BL Lac - Detection

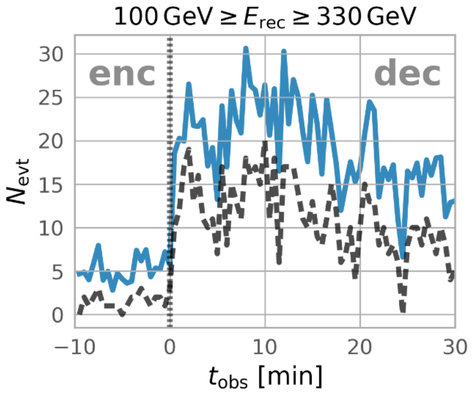
- Comparison to VERITAS standard analysis with **reflected region background** above 100 GeV
- Overall compatible results to **1 off region**
- Promising result for **short timescales**

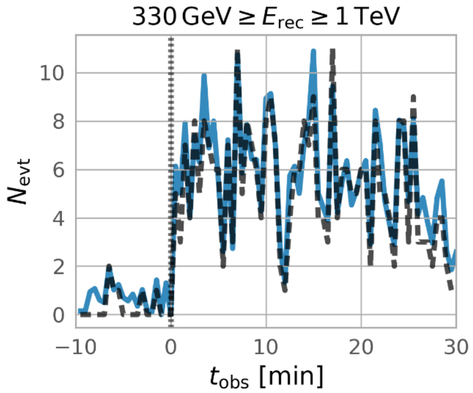


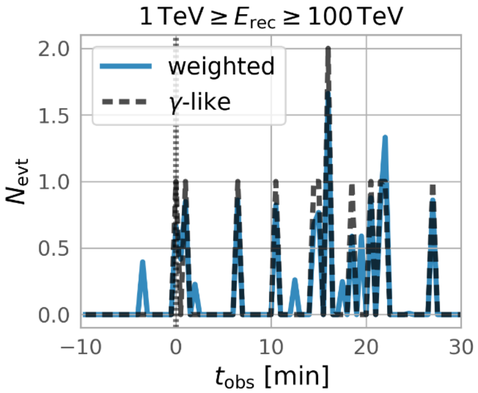


Summary

- Developed **pipeline** to prepare input data
- Studied required **auxiliary parameter** to predict background rates
- Promising results on **BL Lac** flare mimicking possible **follow-up** observation

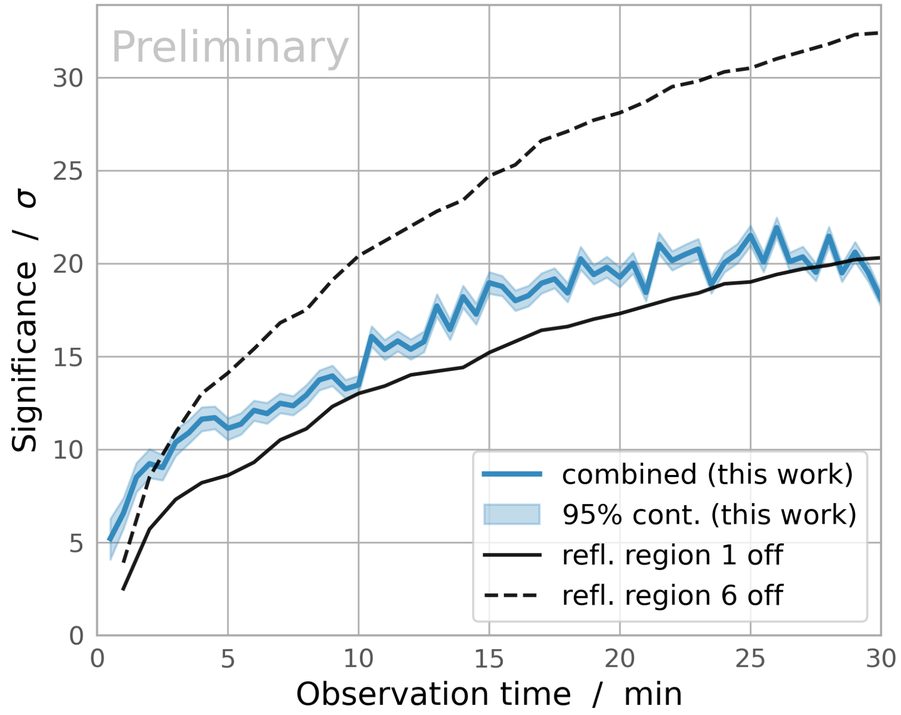






Next Steps

- Review parameters
- Simulate PBH bursts & inject it to shuffled background dataset
- Calculate limits for the PBH detection and compare to traditional methods
- Perform search in unblinded data set



Backup

Automatic Data Quality Monitoring

- **Preselected runlist of ~3500 good runs** (~1700) directly from DB information (weather, status etc.)
- Automatic DQM cuts ~7% of total time
- **Standard deviation of hadron rate** for each run w/ and w/o timecuts
  Proxy for how stable the rates are during one run