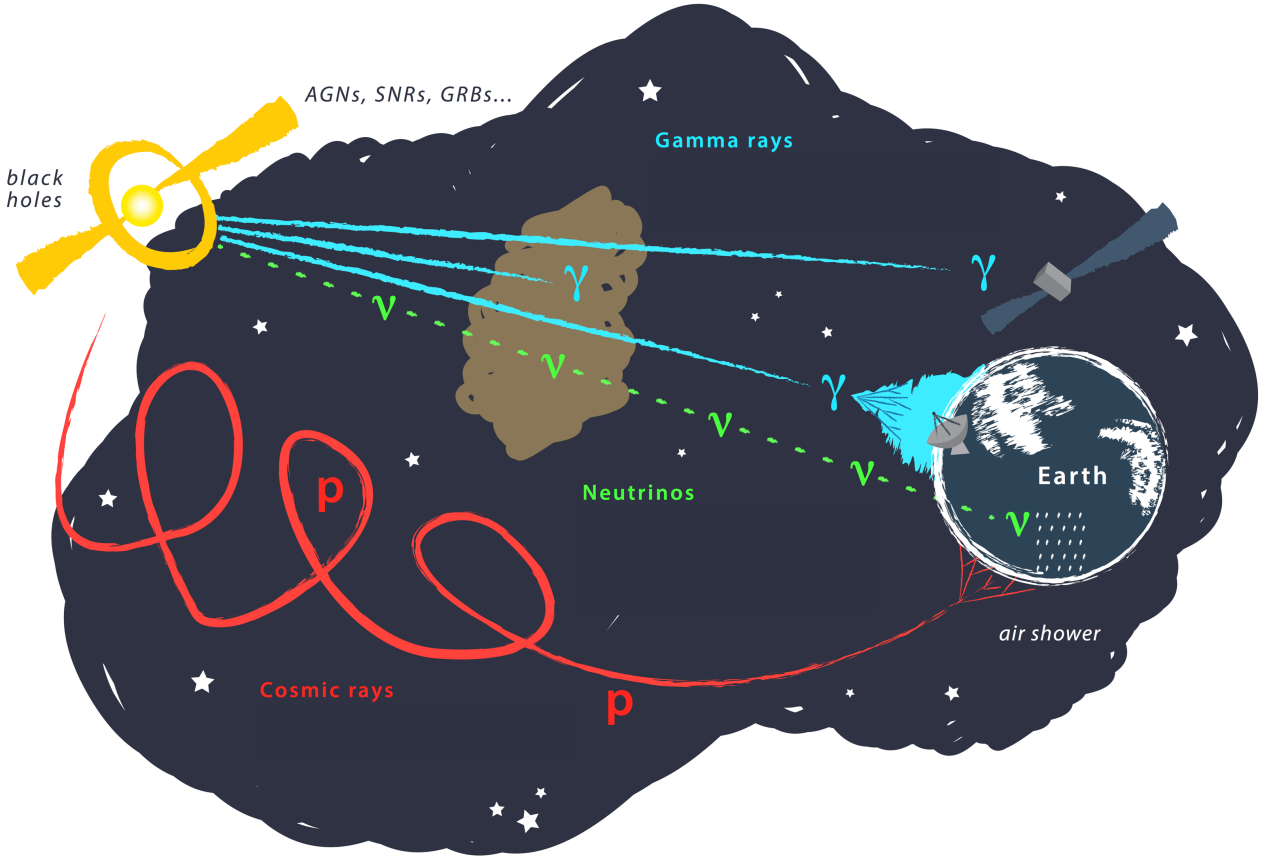
AMPEL - ZTF/IceCube program

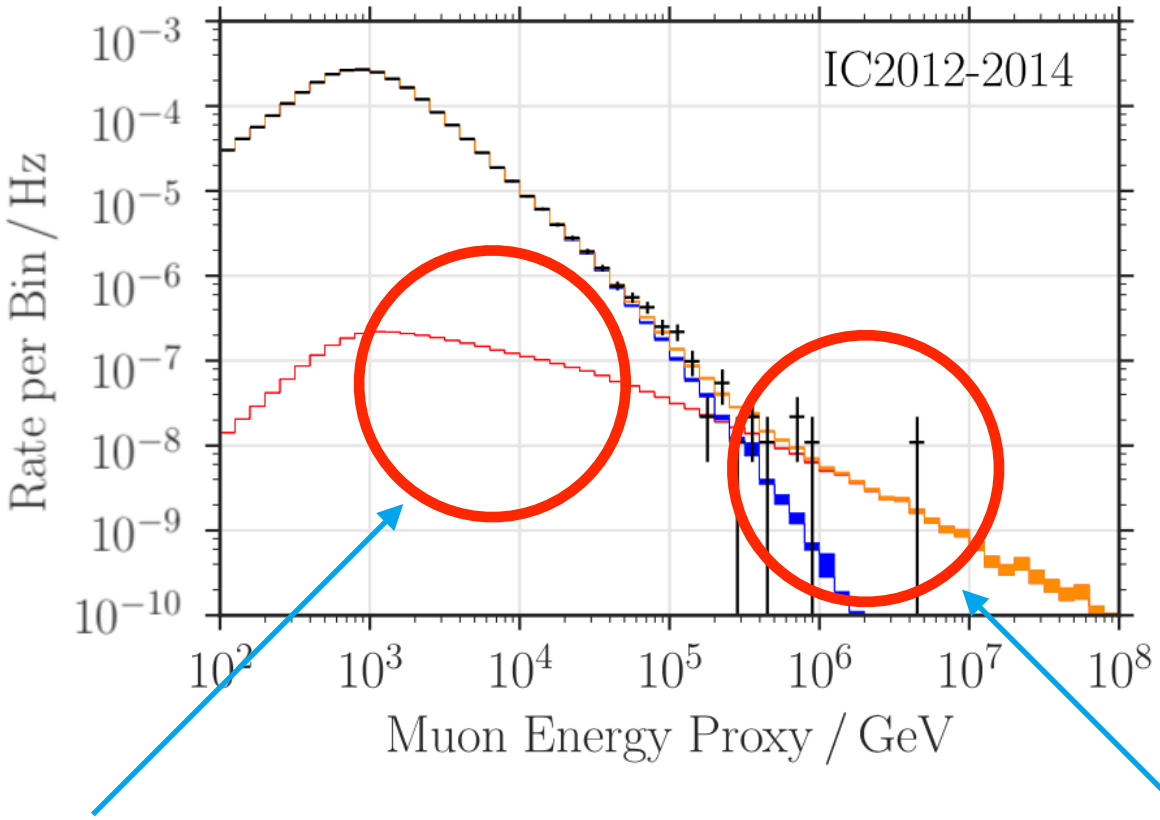


Ludwig Rauch
Berlin, 23.05.2019

HELMHOLTZ ASSOCIATION

DESY

Optical Follow-Up Program of High-Energy Neutrinos



Continuous:

Build catalogue by collecting many transients

Triggered:

Target of Opportunity program

Neutrino Target of Opportunity program

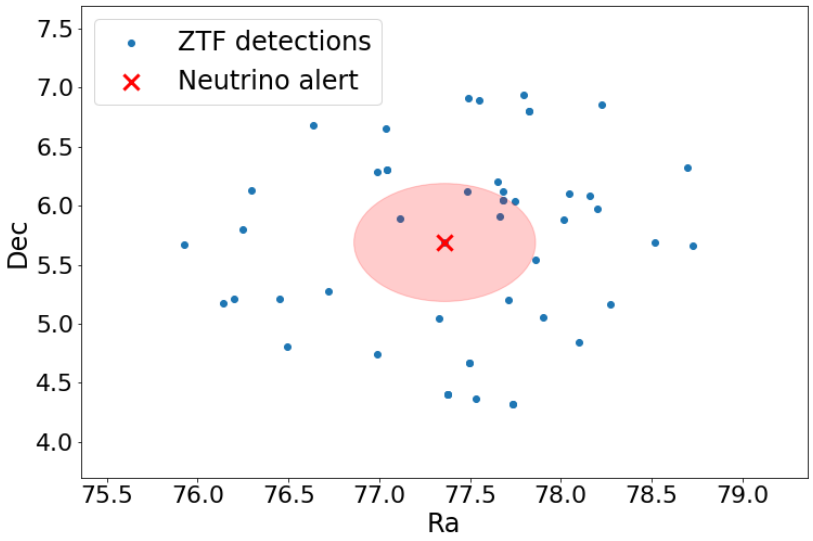
- We received ~7 IceCube alerts since start of ZTF
- One could be followed-up: no interesting candidates identified
- Reasons for non-observations: Sun distance too close, IceCube retractions, ZTF offline

Type	date	RA	Dec	Error	Comments
Doublet	2018-06-11 23:36:04.87	255.63	13.32	0.90	observed
EHE	2018-09-08 19:59:31.84	145.77	-2.52	0.34	Sun distance 22.68 deg
HESE	2018-10-14 11:52:19.07	225.18	-34.79	1.22	Sun distance 35.73 deg
EHE	2018-10-23 16:37:32.65	269.84	-8.89	0.29	camera down
HESE	2018-10-31 02:02:51.41	182.79	-68.39	1.22	retracted
HESE	2019-01-24 03:44:35	307.19	-32.29	1.23	Sun distance 13 deg
HESE	2019-03-31 06:55:43	337.79	-21.08	2.624	Sun too close

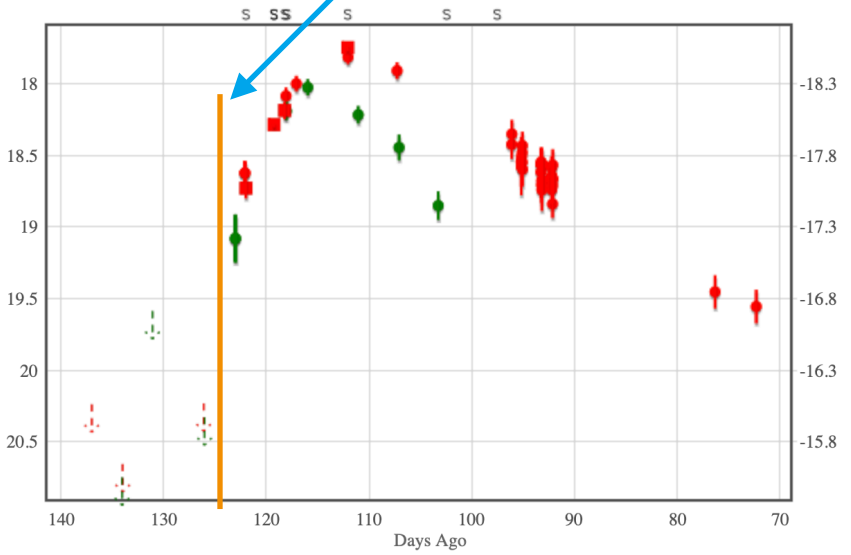
AMPEL ToO filter (T0):

AMPEL follow up analysis:

- Neutrino detection triggers search
- Cone search in neutrino uncertainty contour
- Require no prior photometric detections of object



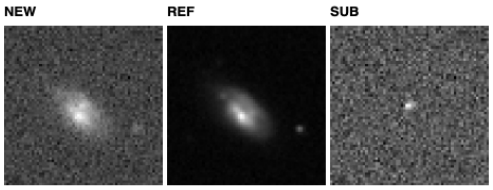
E.g. Neutrino emission at explosion time



Real-time Neutrino Correlation with IceCube

Alert Management, Photometry and Evaluation of Lightcurves: AMPEL

Transient positions from ZTF



Novel realtime alert management and trigger software

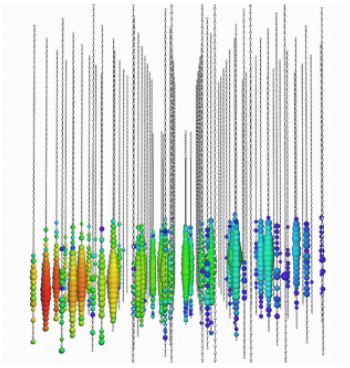
Trigger

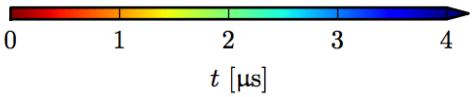
10^5 /d

1-2 /d

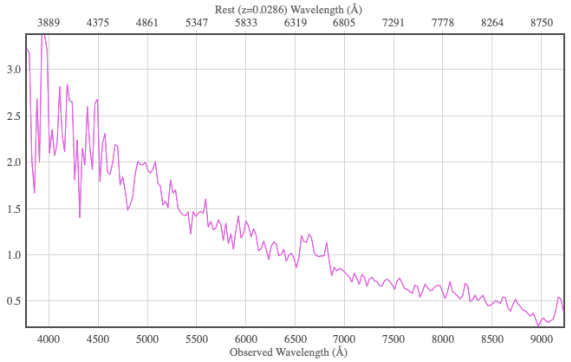
10^2 /d

Neutrino tracks from IceCube





Transient Spectrum



DESY.

Primary filter (T0)

Filter: Primary data reduction applied to all alerts

Parameters

```
# number of previous detections
# minimum duration of alert detection history [days]
# maximum duration of alert detection history [days]
# real bogus score from machine learning
# sexctrator FWHM (assume Gaussian) [pix]
# Difference: magap - magpsf [mag]
# number of bad pixels in a 5 x 5 pixel stamp
# distance to nearest solar system object [arcsec]
# minium distance from galactic plane. Set to negative to disable cut.
#search radius for GAIA DR2 matching [arcsec]
# significance of proper motion detection of GAIA counterpart [sigma]
# significance of parallax detection of GAIA counterpart [sigma]
# min gmag for normalized distance cut of GAIA counterparts [mag]
# max gmag for normalized distance cut of GAIA counterparts [mag]
# maximum allowed noise (expressed as significance) for Gaia match to be trusted
# maximum distance to closest PS1 source for SG score veto [arcsec]
# maximum allowed SG score for PS1 source within PS1_SGVETO_RAD
# reject alerts if the three PS1 sources are all within this radius [arcsec]
```

Information contained in alert

Automatic GAIA match

Automatic PanStarrs match

Correlation of two data streams (T2)

Perform maximum likelihood analysis

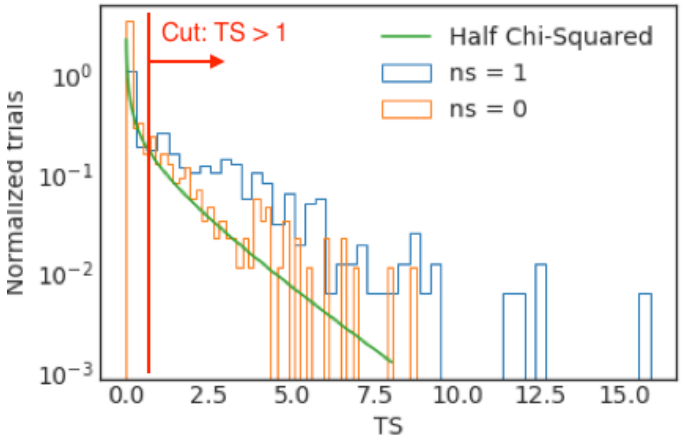
Maximum likelihood function

Position Energy Time

$$\mathcal{S}(E_\nu, \Delta T, \Delta\Psi, \sigma) = \frac{1}{2\pi\sigma^2} e^{(\Delta\Psi)^2/(2\sigma^2)} \cdot \epsilon_{\mathrm{sig}}(E, \theta, \gamma) \cdot Box(t_{start}, t_{end})$$

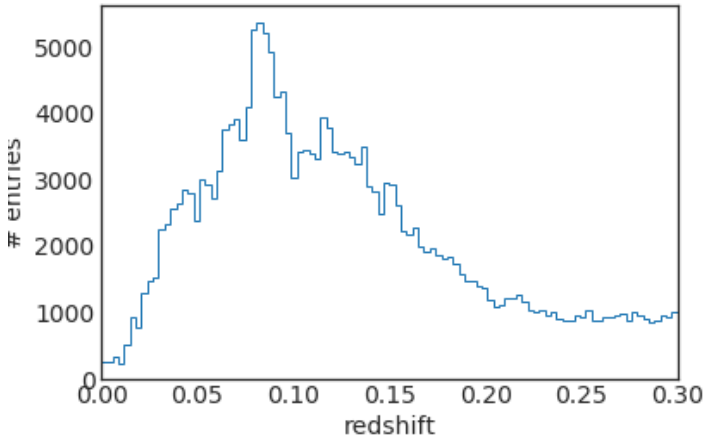
$$\mathcal{B}(E_\nu, \Delta T, \Delta\Psi) = \frac{\mathcal{P}(\sin\theta)}{2\pi} \cdot \epsilon_{\mathrm{BG}}(E, \theta)$$

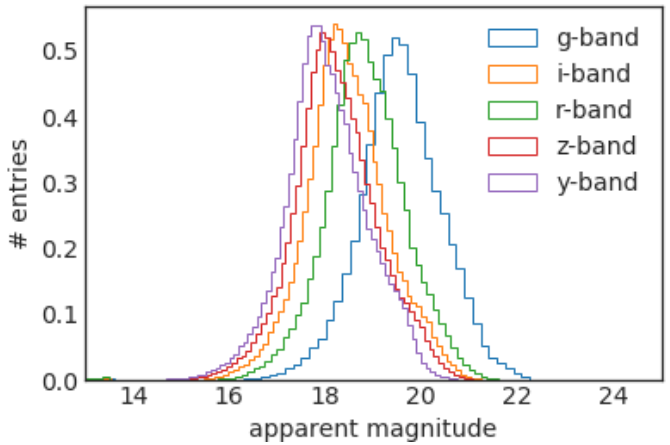
$$TS = -2\log\frac{\mathcal{L}(\mathrm{ns})}{\mathcal{L}(\mathrm{ns}=0)} = -2\sum_{\mathrm{i}=0}^{\mathrm{N}} \log\left(1 + \frac{\mathrm{ns}}{\mathrm{N}}\left(\frac{\mathcal{S}}{\mathcal{B}} - 1\right)\right)$$



Photometric redshift estimation (T2)

- SDSS and BOSS data
- > 3 x 10^6 Galaxies with spectroscopic redshift estimation and photometric data for u,g,r,i,z filters
- No full sky coverage
- But good for training machine learning algorithms

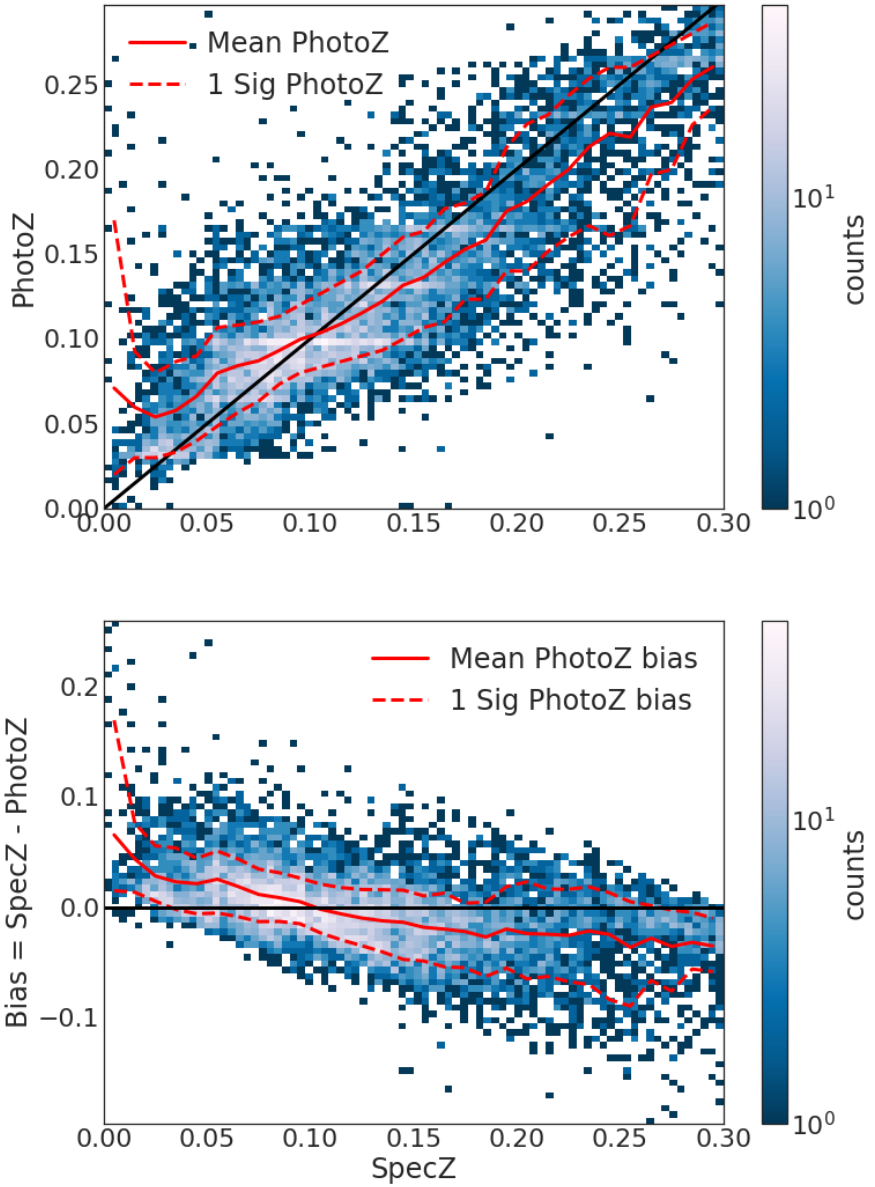




Use Pan-STARRS catalogue for photometric data (g,r,i,z,y)

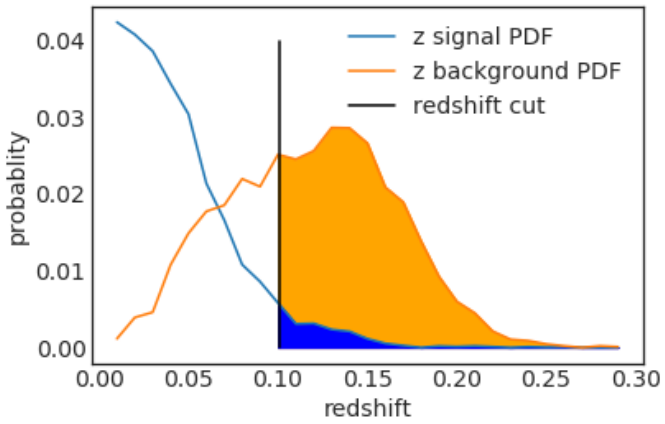
Results on training data

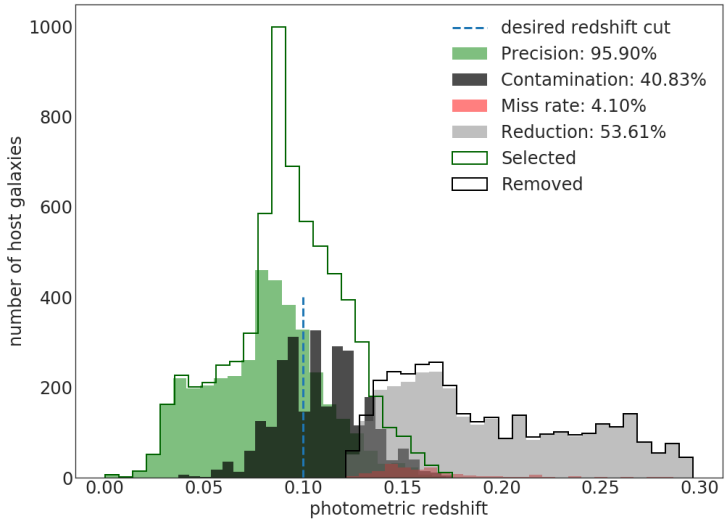
- Code is based on ANNZ2 package (developed by Iftach Sadeh et al.)
- Uses 100 random configurations of hyper parameters for boosted decision trees
- Trained BDTs are weighted according to their performance
- Software is embedded into AMPEL and optimised for computational speed.
- On average 0.5s per calculation
- Results on training data comparable to other results even though we are missing the u-band



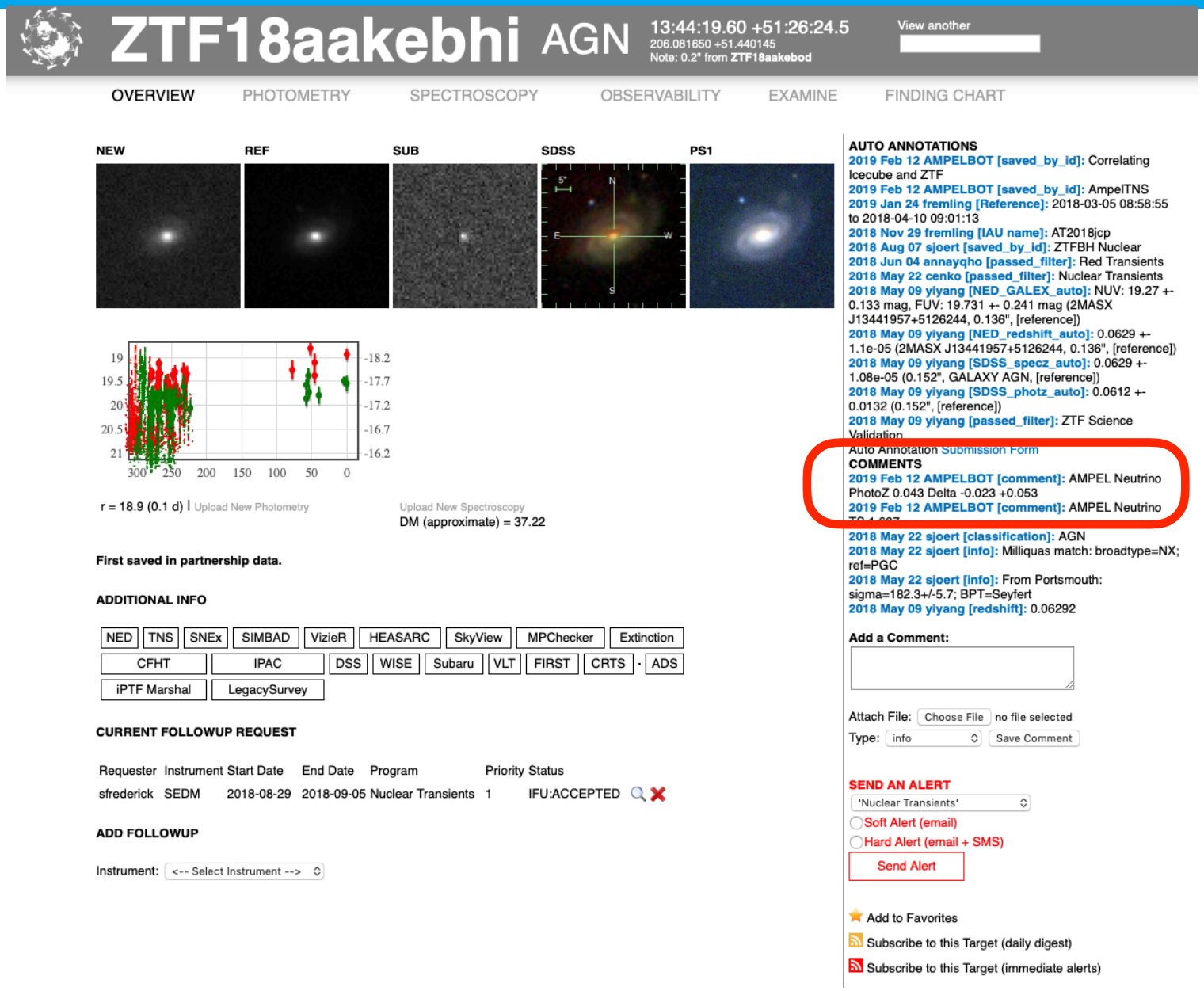
Photometric redshift (T2)

- Use photometric redshift for signal and background discrimination
- At redshifts larger than z=0.1:
  - Background: ~ 62 %
  - Signal < 5%
- Due to uncertainties of the redshift estimate we consider the error pdf
- Redshift cut on integral: Area of error pdf should be larger than 80% above a value of 0.1
- Using the area reduces the background rejection efficiency but minimises false negative rate





Transient selection is pushed to GROWTH marshal (T3)



Summary

AMPEL supports two types of neutrino programs:

Target of Opportunity

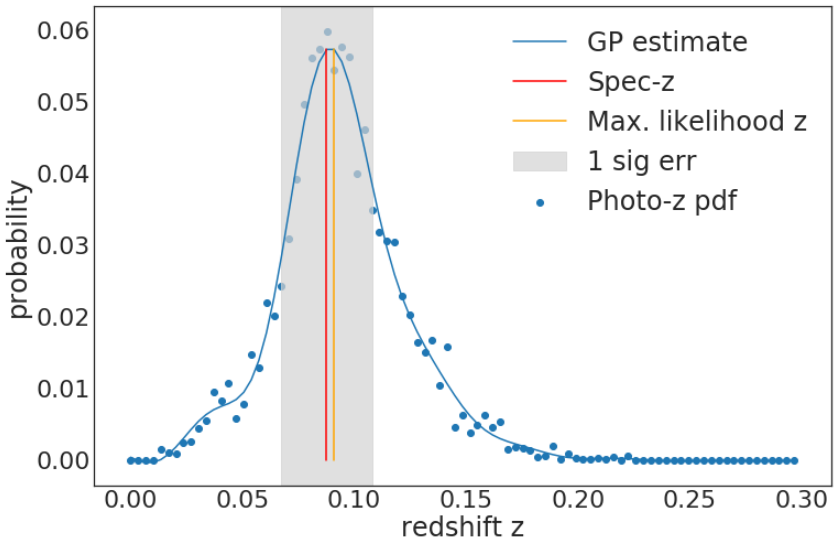
- Low rate of high-energy neutrinos
- High cadence of ZTF (3 days) allows to search for fast fading transients
- Spectroscopic classification available
- Large field of view to consider full error circles

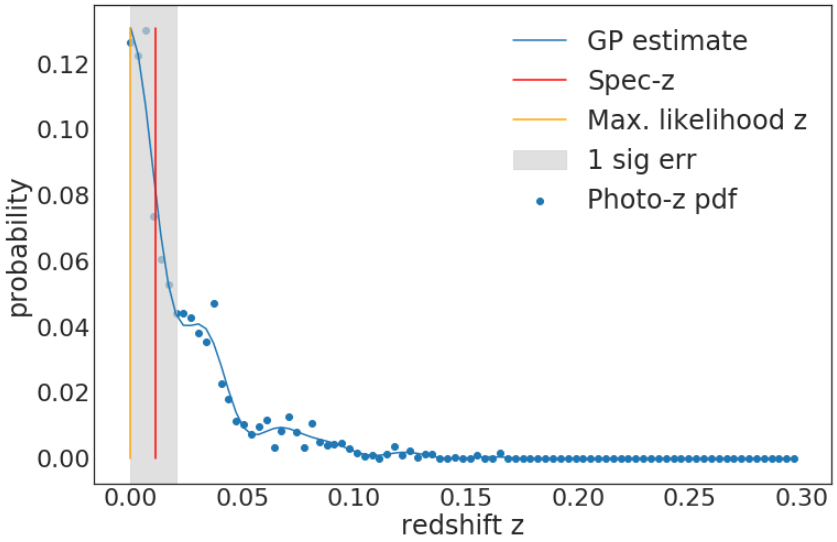
Stacking Analysis

- Continuous search for transients
- High rate of low-energy neutrinos
- Complete and magnitude limited transient catalogue

Uncertainty probability density function

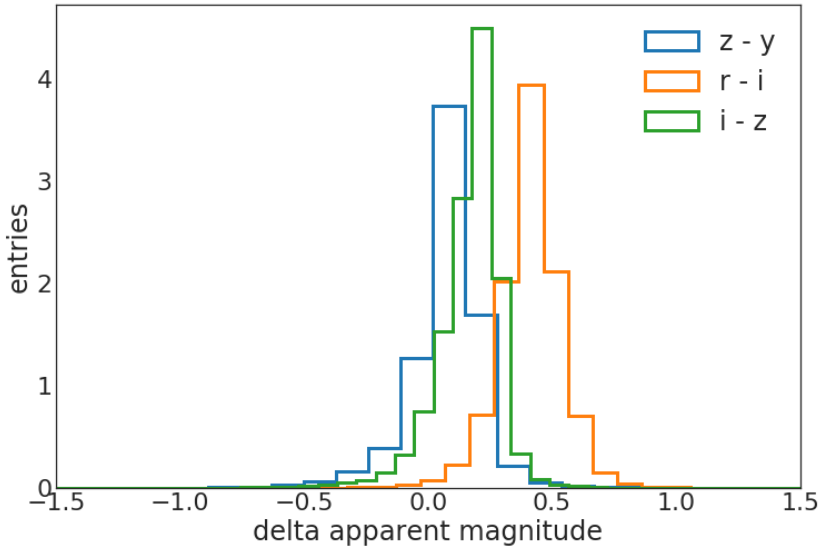
- Uncertainty pdf estimated by KNN method:
  - Use 100 nearest neighbours in feature space
  - Use scatter of estimates as uncertainty estimation
- Photo-z estimation challenging at the boundaries at low redshifts (z=0) and high redshifts (z=0.3)
- Upper lower limits of the redshift can still provide viable information for transient selection!



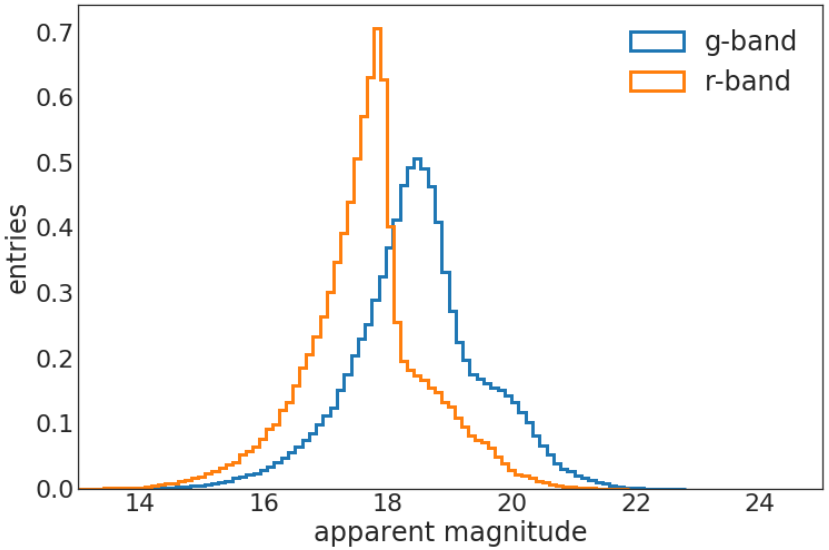


MLM input parameters

- Photometry: g,r,i,z,y
- Input parameters (all Kron mag.)
  - g
  - r
  - z-y
  - r-i
  - i-z



- Possible improvements:
- Galex catalogue (two more bands)
- Use other parameters e.g. galaxy size



Future ToO neutrino stream

Neutrino alert stream:

- GOLD:
  - 50% probability of astrophysical origin
  - ~10 events per year
- BRONZE:
  - 30% probability of astrophysical origin
  - ~18 events per year
- Expected number of ZTF follow ups
  - Only 50-75% of the 28 (due to sun distance, retractions, …)