The Cygnus Region - a prime target for TeV γ-ray emission.

Maria Krause
for the VERITAS Collaboration
CRISM Workshop Montpellier
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HELMHOLTZ GEMEINSCHAFT

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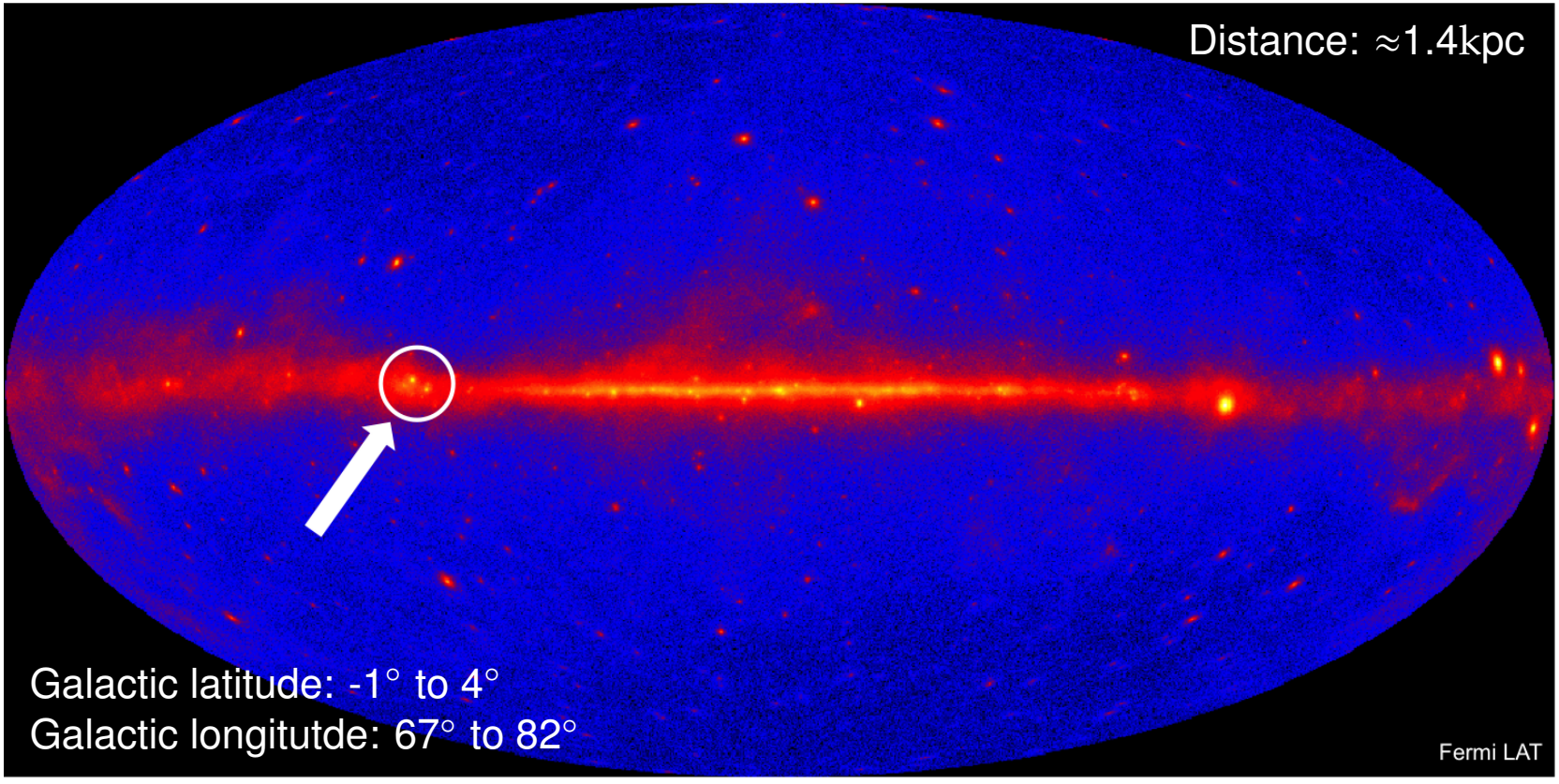
DESY

Outline

Why are we interested in the Cygnus Region?

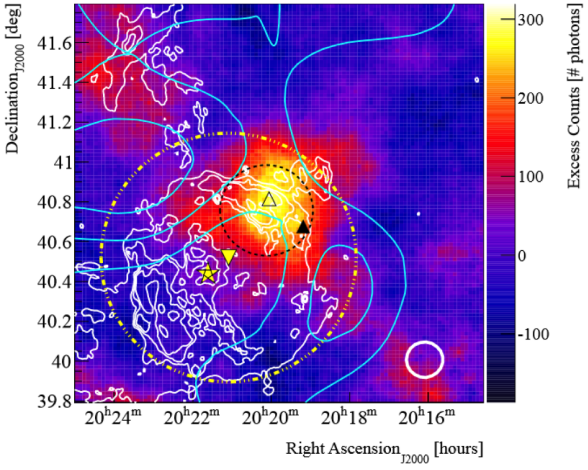
- Large complex consisting of molecular clouds, active star forming region, many potential VHE accelerators
- Measurement of diffuse γ-radiation in the GeV and TeV range

  (Prodanović et al., 2006; Bi et al., 2009)

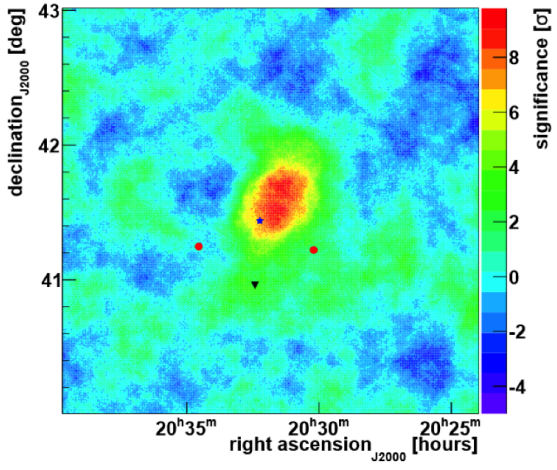


Why are we interested in the Cygnus Region?

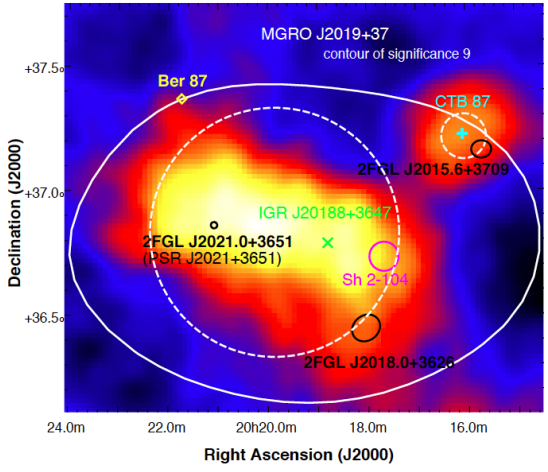
- This region is rich in VHE and HE emission.
- Discovery and idenfication of sources of diffuse γ-radiation
- VERITAS data from 2007 until 2012 (sky survey plus follow-up)
- Many sources discovered by HEGRA, Milagro and *Fermi* LAT



VERJ2019+407
(Aliu et al., 2013)



TeV J2032+4130
(Aliu et al., 2014)



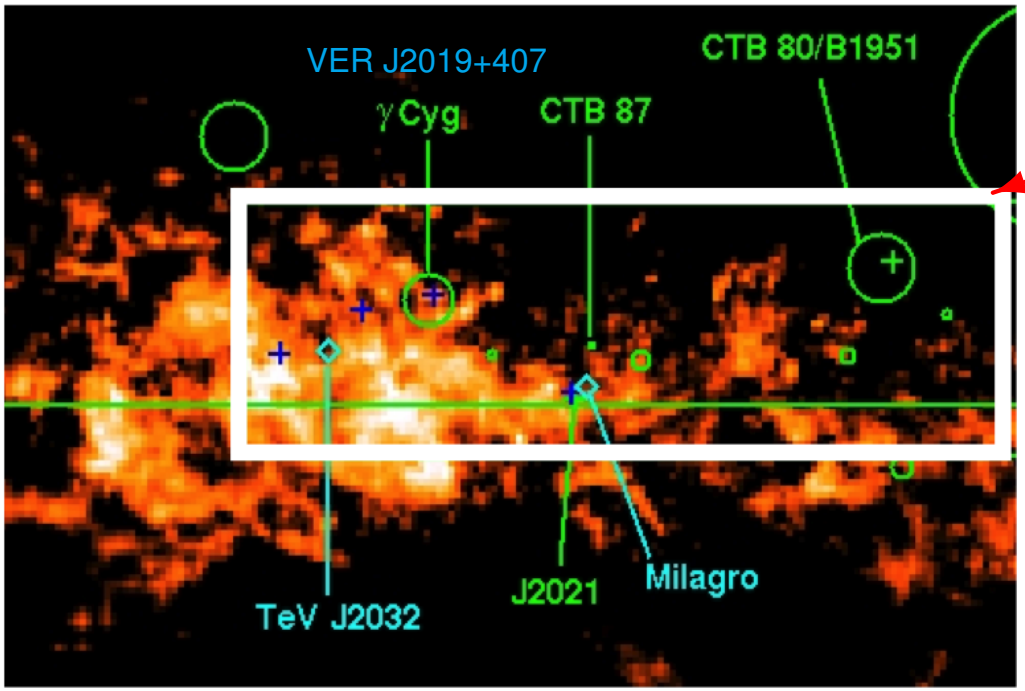
MGROJ2019+37
(Aliu et al., 2014)

The VERITAS Cherenkov Array.

- ✓ Four telescopes with a diameter of 12m, located in Arizona (US)
- ✓ Camera: 499 pixels (Upgrade in summer 2012)
- ✓ Field of View: 3.5°
- ✓ Energy range: $\approx$ 0.1-30TeV
- ✓ Energy resolution: 15-20% at 1TeV
- ✓ Angular resolution: $< 0.1°$ at a zenith angle of 20°
- ✓ Sensitivity: 1% Crab < 30h

VERITAS Cygnus Sky Survey.

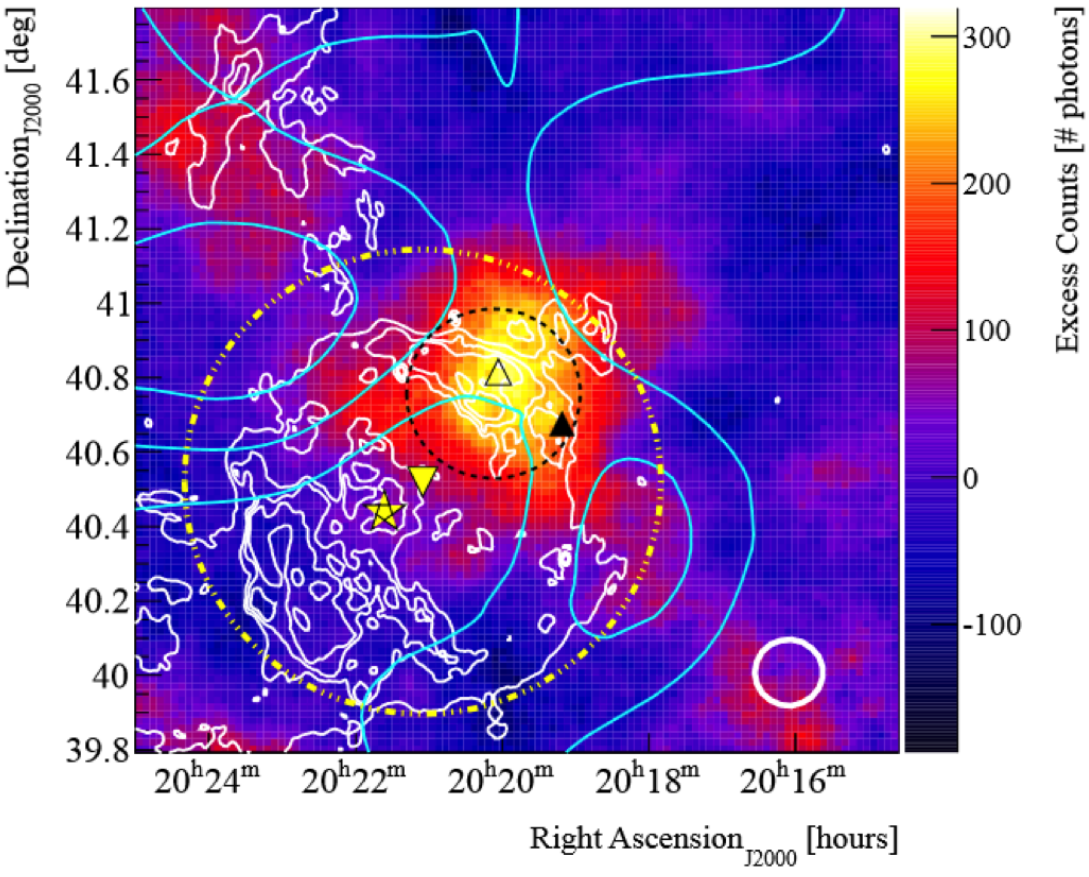
- Sky survey data from 2007 to 2009 (115h + 55h follow-up observations)
- Observation period between April and June, September and November



VER J2019+407 (γ-Cygni).

Aliu et al., ApJ 770, 93 (2013)

- First hints of γ-ray emission near SNR G78.2+2.1 during survey → Follow-up observations
- 18.6h, wobble mode, 3 and 4 telescope data
- 7.5σ post-trial significance
- Pulsar and the centroid of *Fermi* emission are displaced from VHE γ-ray source



Extension of $0.23° \pm 0.03°_{stat}{}^{+0.04°}_{-0.02°\,sys}$

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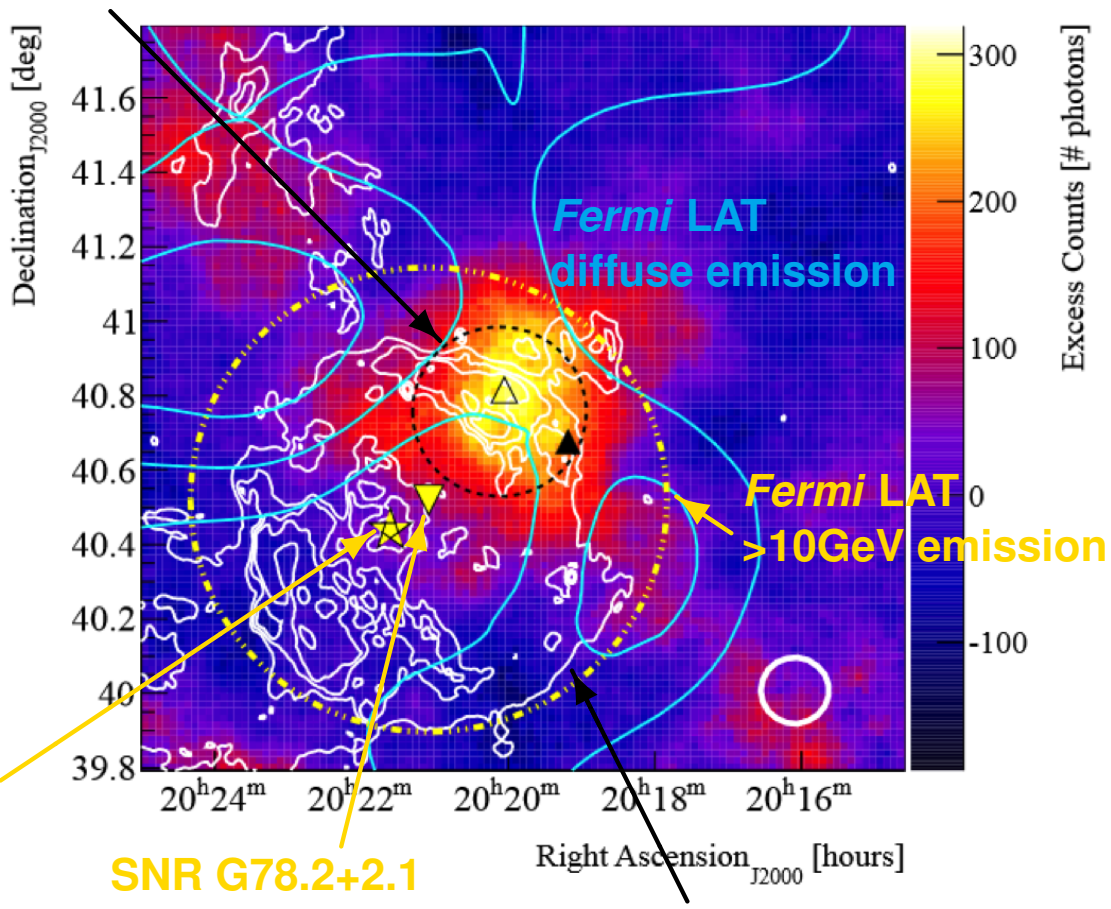

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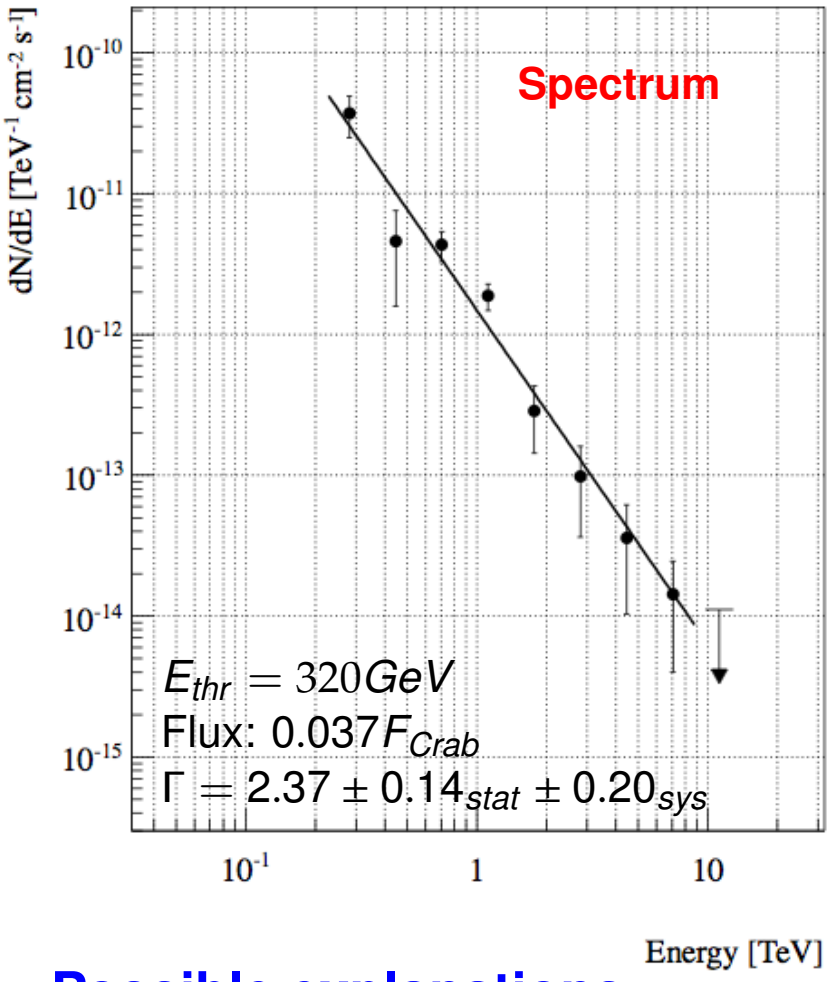
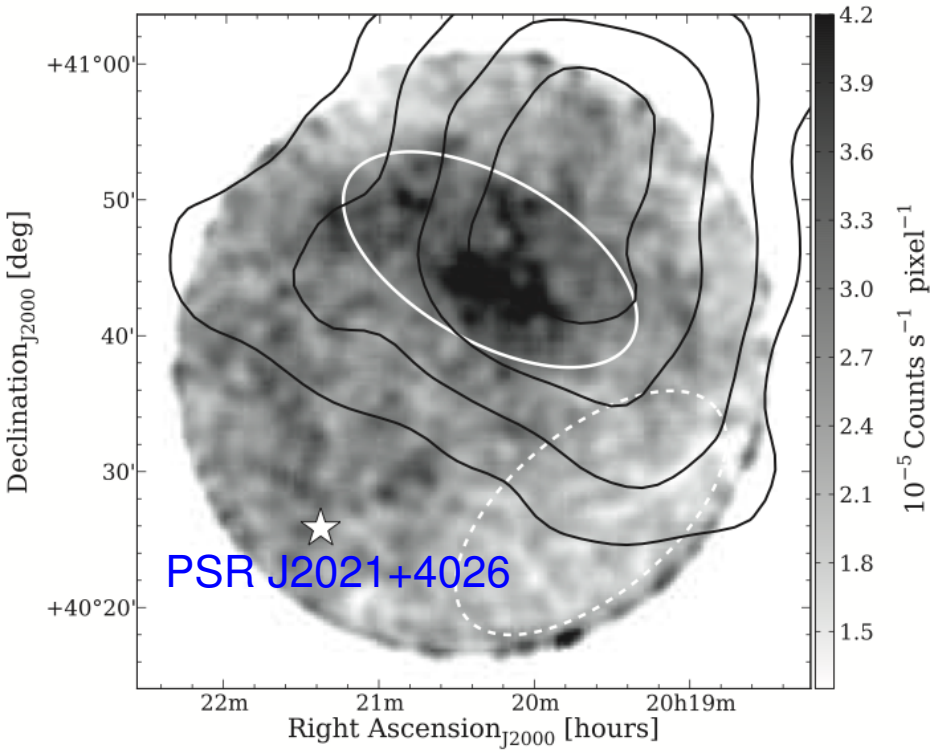


X-ray view of G78.2+2.1 with VER J2019+407 contours



Possible explanations:

Shocks at the interaction of the SN ejecta and the medium

PWN of PSR J2021+4026

PWN of unknown pulsar in line-of-sight toward SNR

TeV J2032+4130.

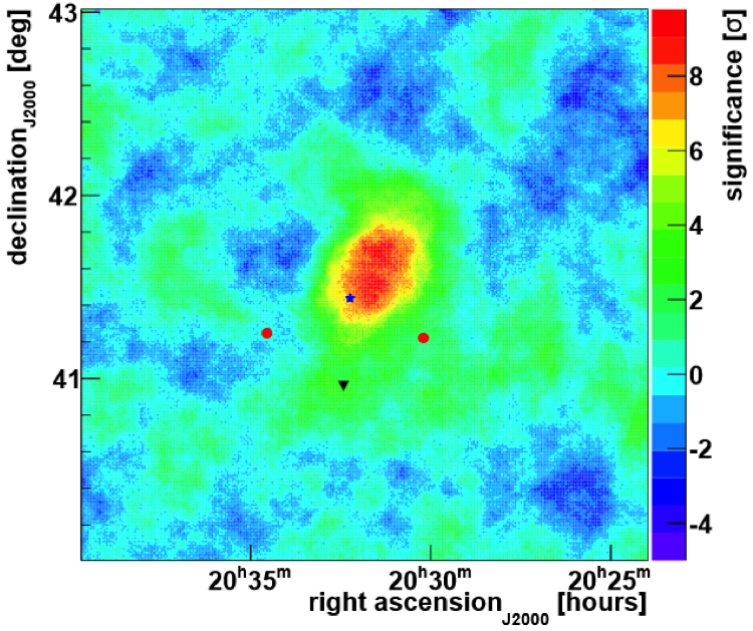
Aliu et al., ApJ 783, 16 (2014)

The first unidentified γ-ray source at very high energies (E>100GeV)

- Previous observations with HEGRA, Milagro, *Fermi* LAT etc.
- MGRO J2031+41: bright emission over a larger area of 3°×0.9° (Abdo et al., 2007)
- Data from 2009-2012, wobble and ON mode
- 48.2h, 3 and 4 telescope data, 8.7σ

$\Rightarrow$ VER J2031+415

- Hard spectrum, single PL: $\Gamma = 2.05$



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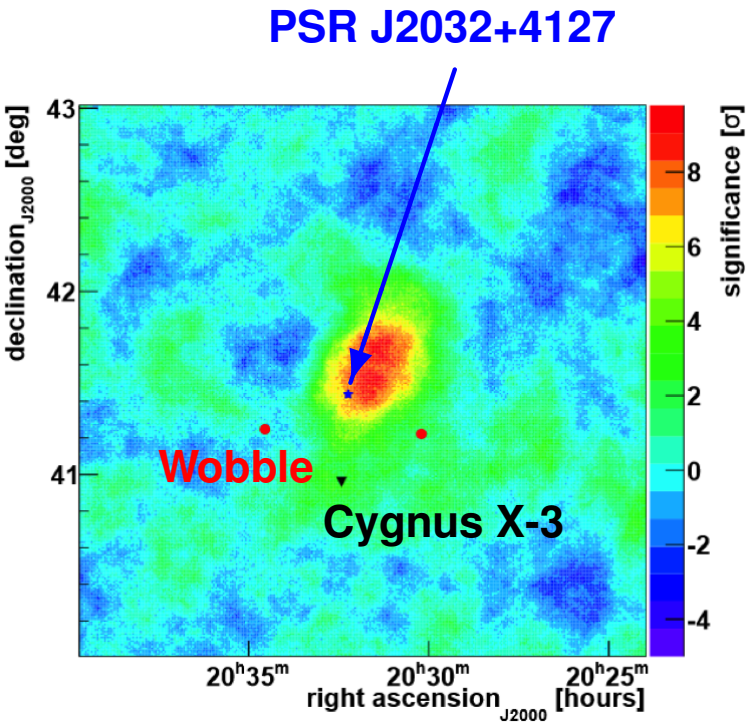

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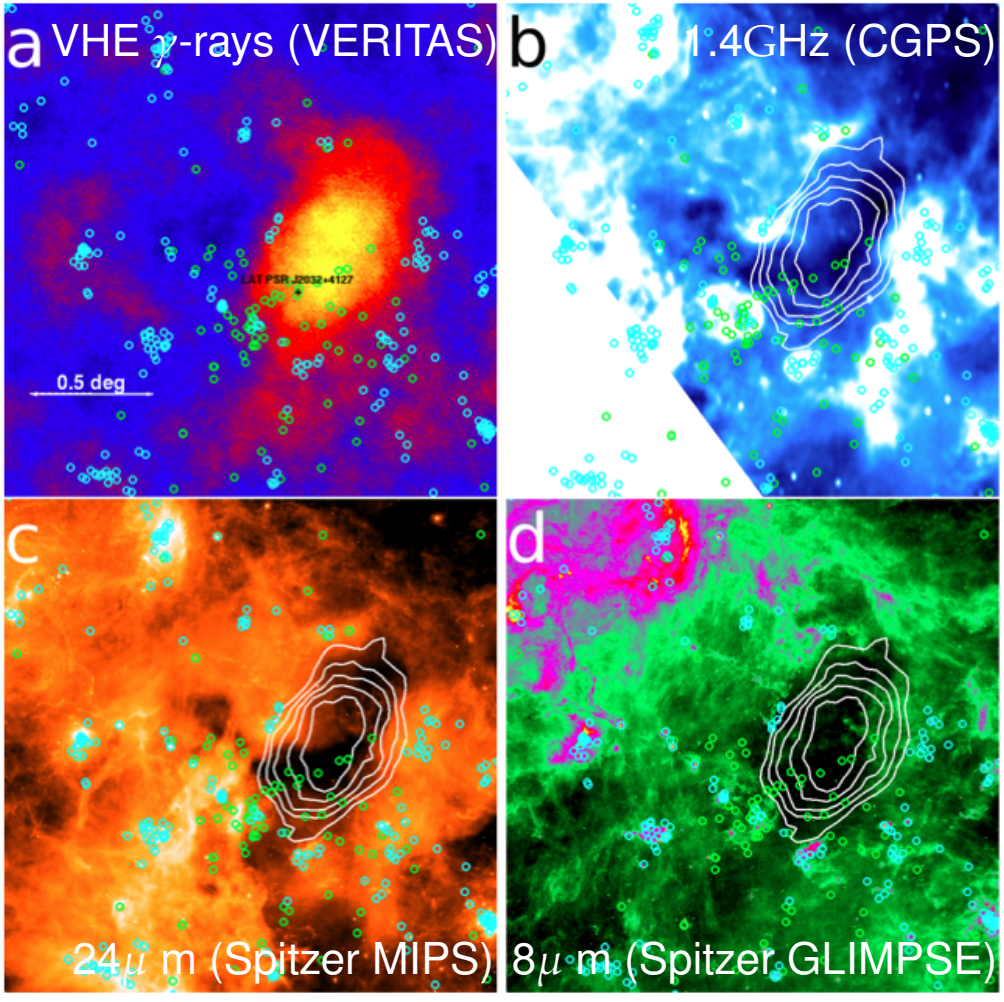
Multiwavelength Studies

- Blind search discovery with *Fermi* LAT: PSR J2032+4127 with $P = 142ms$
- Milagro observations with softer spectral index: $\Gamma = 3.2 \pm 0.2$

$\rightarrow$ Integration over larger region

- Observations at radio, X-ray and IR wavelengths

$\Rightarrow$ TeV γ-ray emission in a void



TeV J2032+4130.

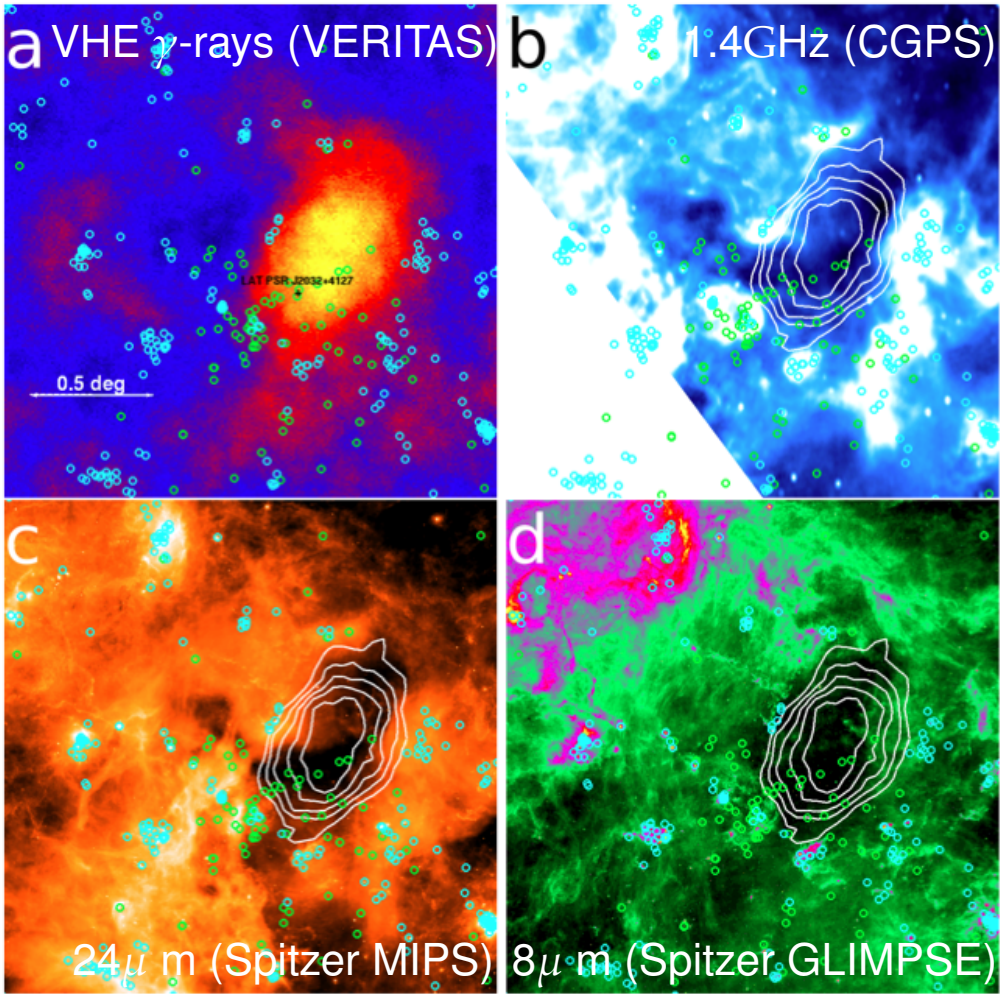
Aliu et al., ApJ 783, 16 (2014)

Scenarios

- Stellar winds from massive stars located in this region
- SNR expanding into the surrounding medium

→ No detected SNR shell but could be PWN

- PWN associated with *Fermi* LAT pulsar PSR J2032+4127
- Properties of pulsar are consistent with TeV PWN scenarios



MGROJ2019+37.

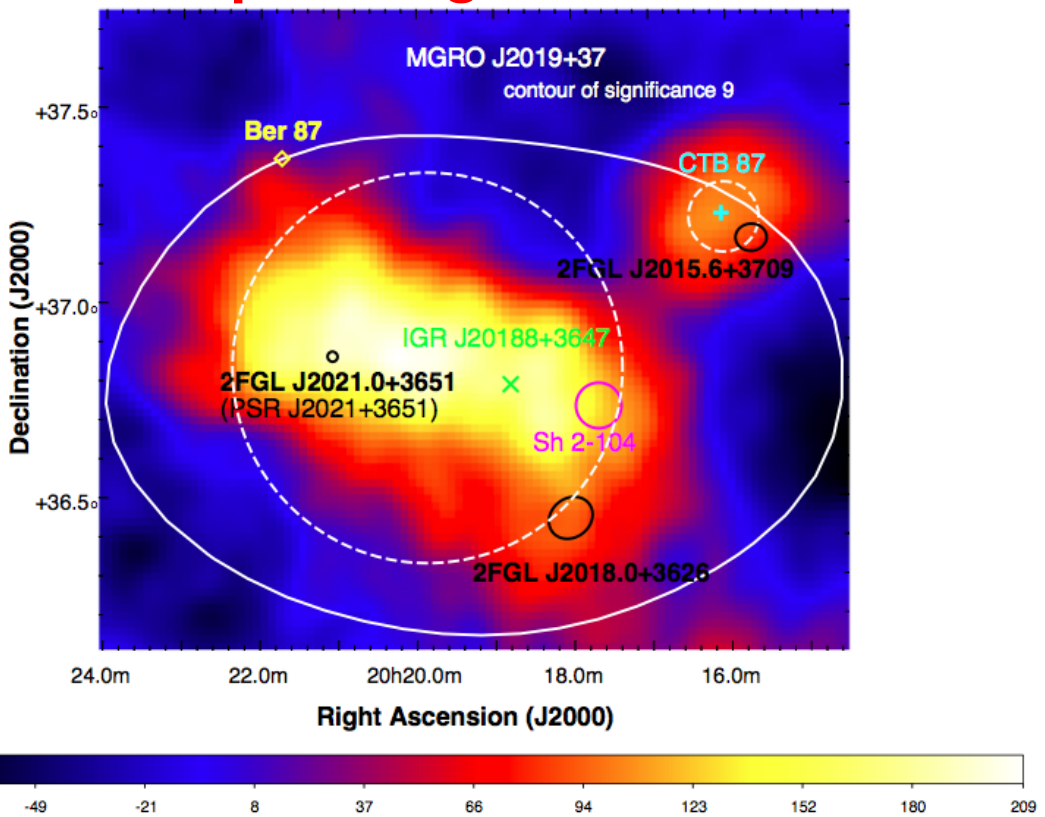
Aliu et al., arXiv: 1404.1841 (2014)

- Data from 04/2010 to 12/2010
- 70h, wobble mode
- Point and extended source analysis
- Two separate VHE emission regions

⇒ VER J2016+371: 5.8σ, $\Gamma = 2.3$, point source, consistent with CTB 87

⇒ VER J2019+368: 7.2σ, $\Gamma = 1.75$, extended emission, possibly multiple sources

Better angular resolution of VERITAS allows for a sharper image



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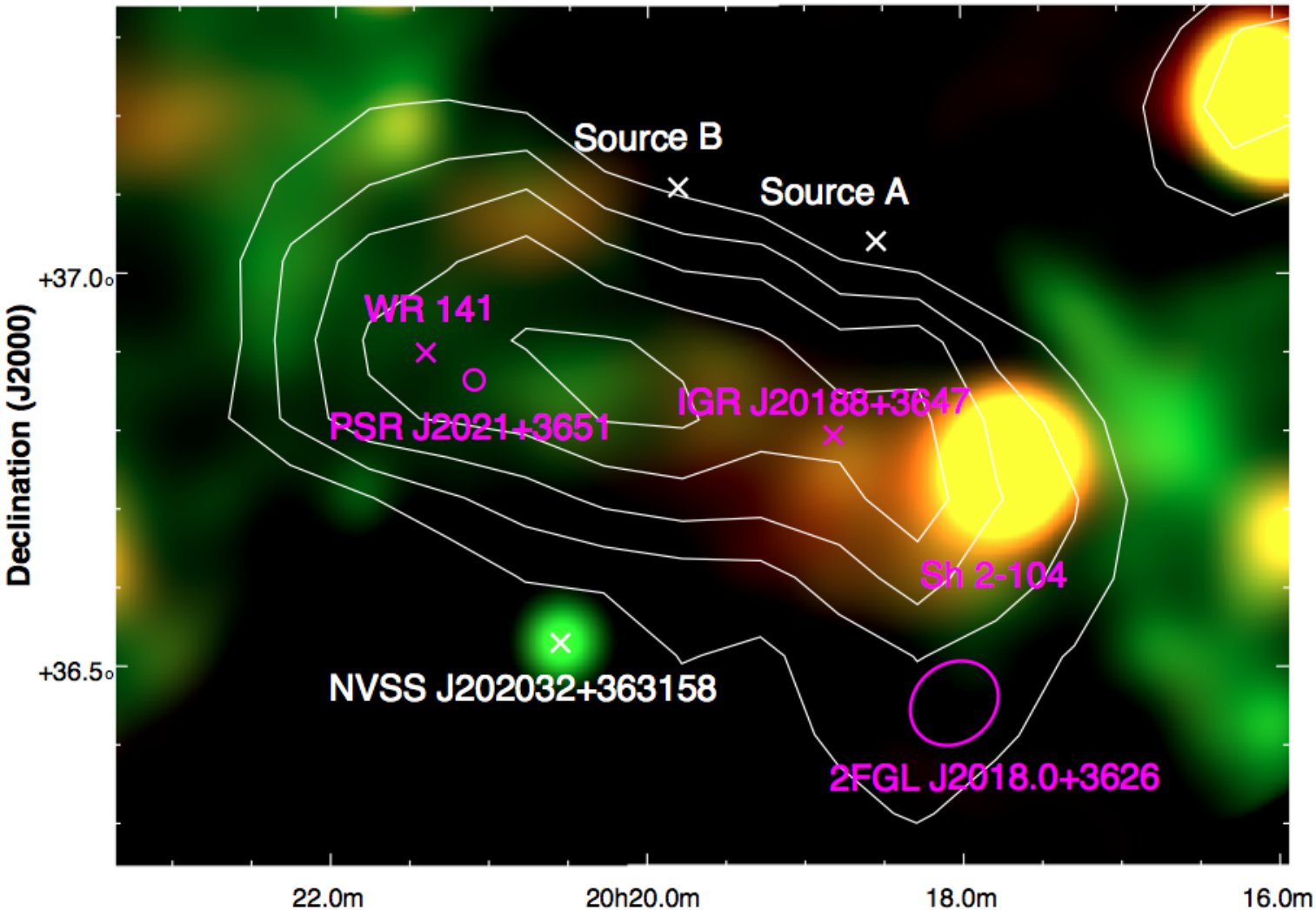
Radio image overlaid with VERITAS significance contours



What will be the next steps?

Complete analysis of the whole Cygnus region

- It's more than just an analysis of the sky survey!
- Data of about 330h (2007 to 2014)
- Average elevation angle of 70°

Why?

- Better analysis technique for extended sources and better quality cuts available
- Using Boosted Decision Trees and ctools
- Excellent opportunity for an efficient increase in TeV source detections, with the potential for discovery of unexpected VHE emission and/or source classes

Conclusion.

- Cygnus region is a very active region of VHE and HE γ-ray emission
- Many TeV sources and potential sources of cosmic ray acceleration are already identified
- Probably more sources available in this region
- Understanding the nature of the diffuse γ-ray emission coming from the Cygnus region
- Data available from 2007 until 2014 $\Rightarrow$ will be reanalyzed using advanced analysis techniques

$\Rightarrow$ Boosted Decision Trees

- Obtain a higher sensitivity!

Aim

- Develop a tool to analyze extended sources and diffuse emission with ctools (work in progress)

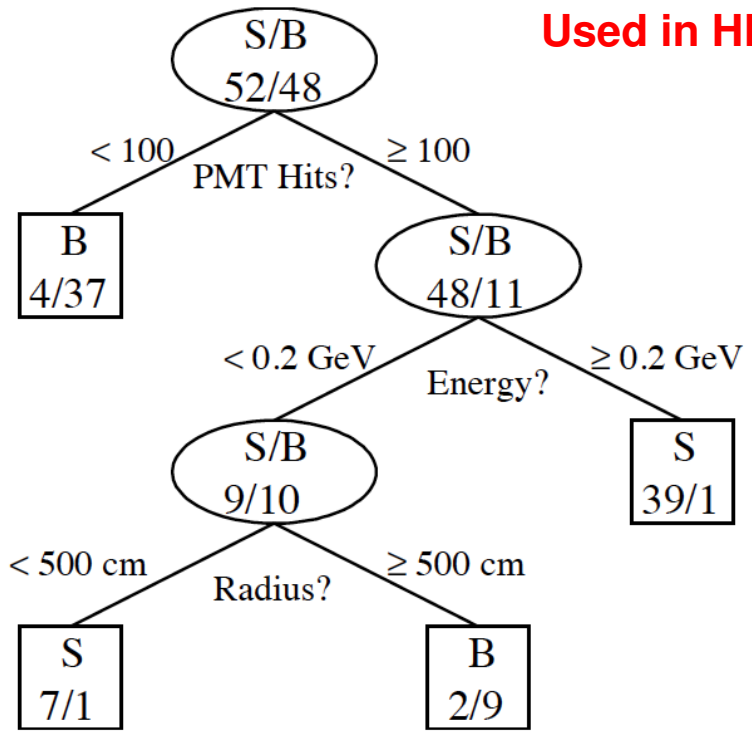
Questions?

I have no idea what you're talking about!!!

Backup

What are Boosted Decision Trees.

Toolkit for Multivariate Data Analysis with ROOT (TMVA) provides an algorithm called Boosted Decision Trees (BDTs).



Used in HEP

Roe et al., Nucl.Instrum.Meth. A543 (2005) 577-584

- Start with training sample at the root node
- Split the training sample at node into two ⇒ using cut that gives best separation gain
- Classify the terminal leaves as signal and background (depending on the majority of events or given a S/B propability)
- Reweight all incorrect decisions and retrain them ⇒ **Boosting**

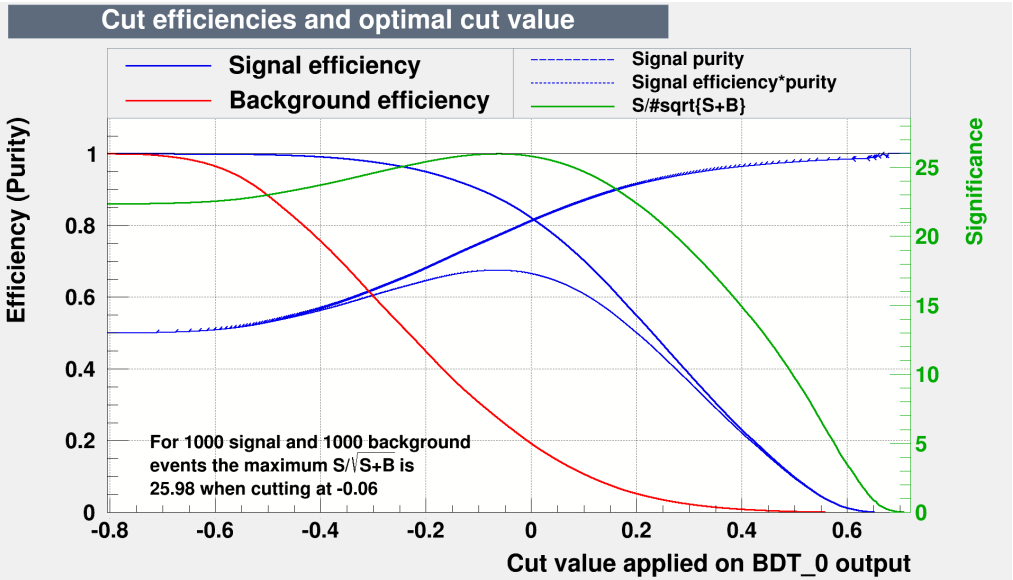
Why do we want to use Boosted Decision Trees?

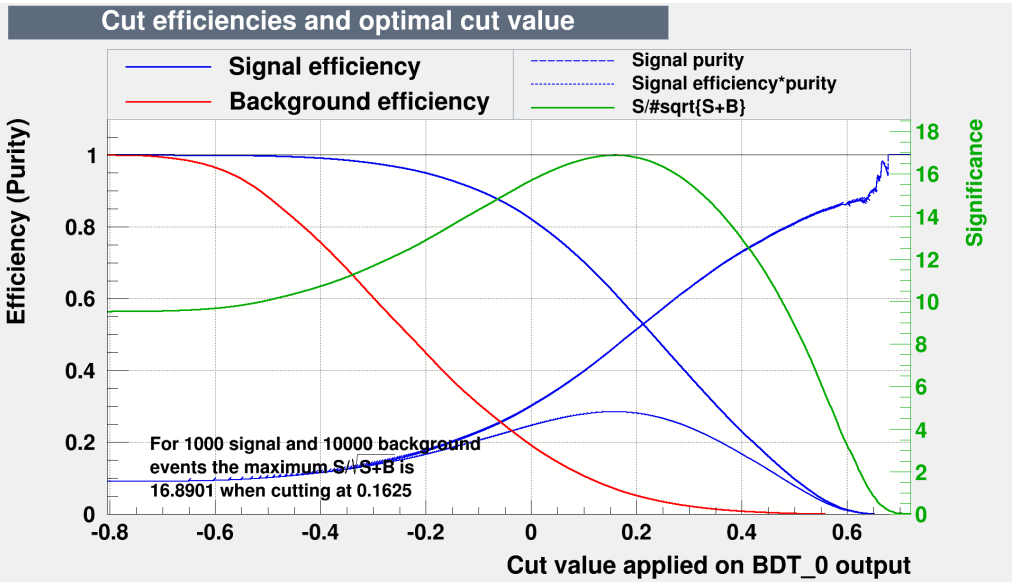
- Boosted Decision Trees (BDTs) are a useful tool for the Gamma-Hadron-Separation
- Better performance than the rectangular cuts
- Takes nonlinear correlations into account
- Simple to understand and interpret
- Achieve a higher sensitivity (see talk of Elisa during winter collaboration meeting)
- Already implemented in eventdisplay software but needs to be studied and optimized

How does it work?

- Signal training sample: MC simulations
- Background training sample: either data or MC simulations
- Cuts can be optimized in several energy and zenith angle bins
- TMVA weight files contain all the cut information, can be directly used in the effective area code

The output of TMVA





The cut value depends on the number of signal and background events

a) $\frac{S}{B} = 1 \Rightarrow$ cut=-0.06

b) $\frac{S}{B} = \frac{1}{10} \Rightarrow$ cut=0.16