Telescope Array search for photons and neutrinos with the surface detector data

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Telescope Array Collaboration

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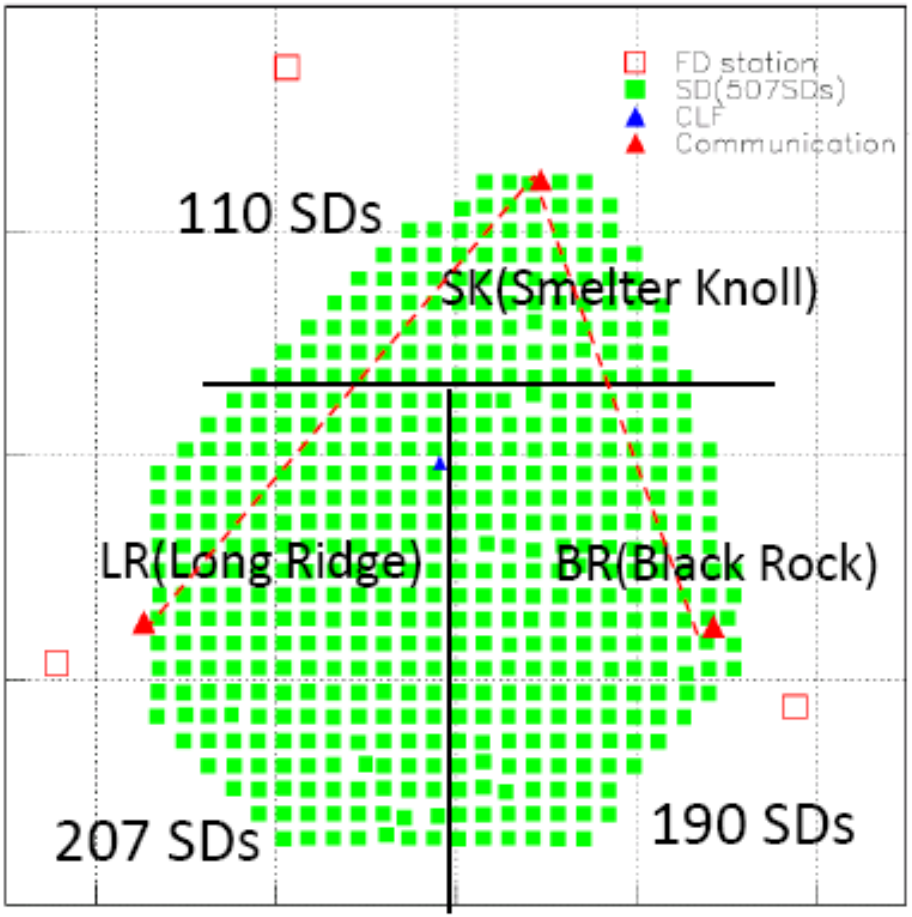
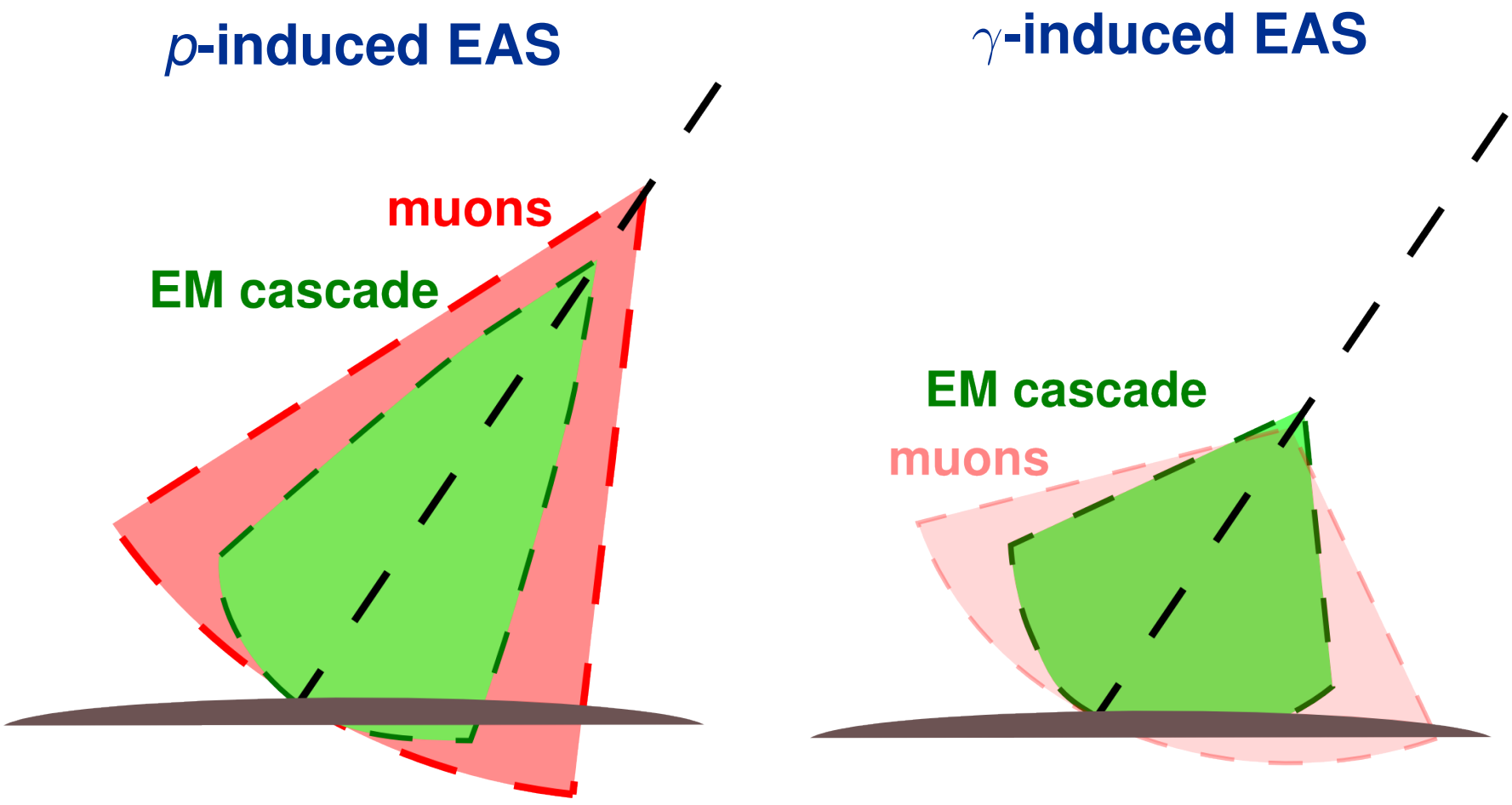
Belgium, Japan, Korea, Russia, USA

Telescope Array surface detector



- 507 SD's, 3 m^2 each
- 680 km^2 area
- 7 years of operation

Largest UHECR statistics in the Northern Hemisphere



Photon-induced showers:

- arrive younger
- contain less muons
- $\Rightarrow$ multiple SD observables affected:
  - **front curvature, Area-over-peak, number of FADC signal peaks, $\chi^2/d.o.f.$, S_b**

Data and Monte-Carlo sets

- Data collected by TA surface detector for the seven years:
  2008-05-11 — 2015-05-11
- p and γ Monte-Carlo sets with CORSIKA and dethinning

Stokes et al, Astropart.Phys.35:759,2012

Cuts for both data and MC:

- 7 or more detectors triggered
- core distance to array boundary is larger than 1200m
- $\chi^2/\text{d.o.f.} < 5$
- $\theta < 60^\circ$
- $E_\gamma > 10^{18.5}$ eV (E_γ is estimated with photon Monte-Carlo)

26118 events after cuts

Note: MC set is split into 3 equal parts: (I) for training the classifier, (II) for cut optimization, (III) for exposure estimate.

Photon search: list of relevant observables

1. Linsley front curvature parameter, a;
2. Area-over-peak (AoP) of the signal at 1200 m;

   Pierre Auger Collaboration, Phys.Rev.Lett. 100 (2008) 211101
3. AoP LDF slope parameter;
4. Number of detectors hit;
5. N. of detectors excluded from the fit of the shower front;
6. $\chi^2/d.o.f.$;
7. $S_b = \sum S_i \times r^b$ parameter for $b = 3$;

   Ros, Supanitsky, Medina-Tanco et al. Astropart.Phys. 47 (2013) 10
8. The sum of signals of all detectors of the event;
9. Asymmetry of signal at upper and lower layers of detectors;
10. Total n. of peaks within all FADC traces;
11. N. of peaks for the detector with the largest signal;
12. N. of peaks present in the upper layer and not in lower;
13. N. of peaks present in the lower layer and not in upper;

Multivariate analysis

- The Boosted Decision Trees (BDT) technique is used to build p-γ classifier based on multiple observables.

  Pierre Auger Collaboration, ApJ, 789, 160 (2014)

- root::TMVA is used as a stable implementation.

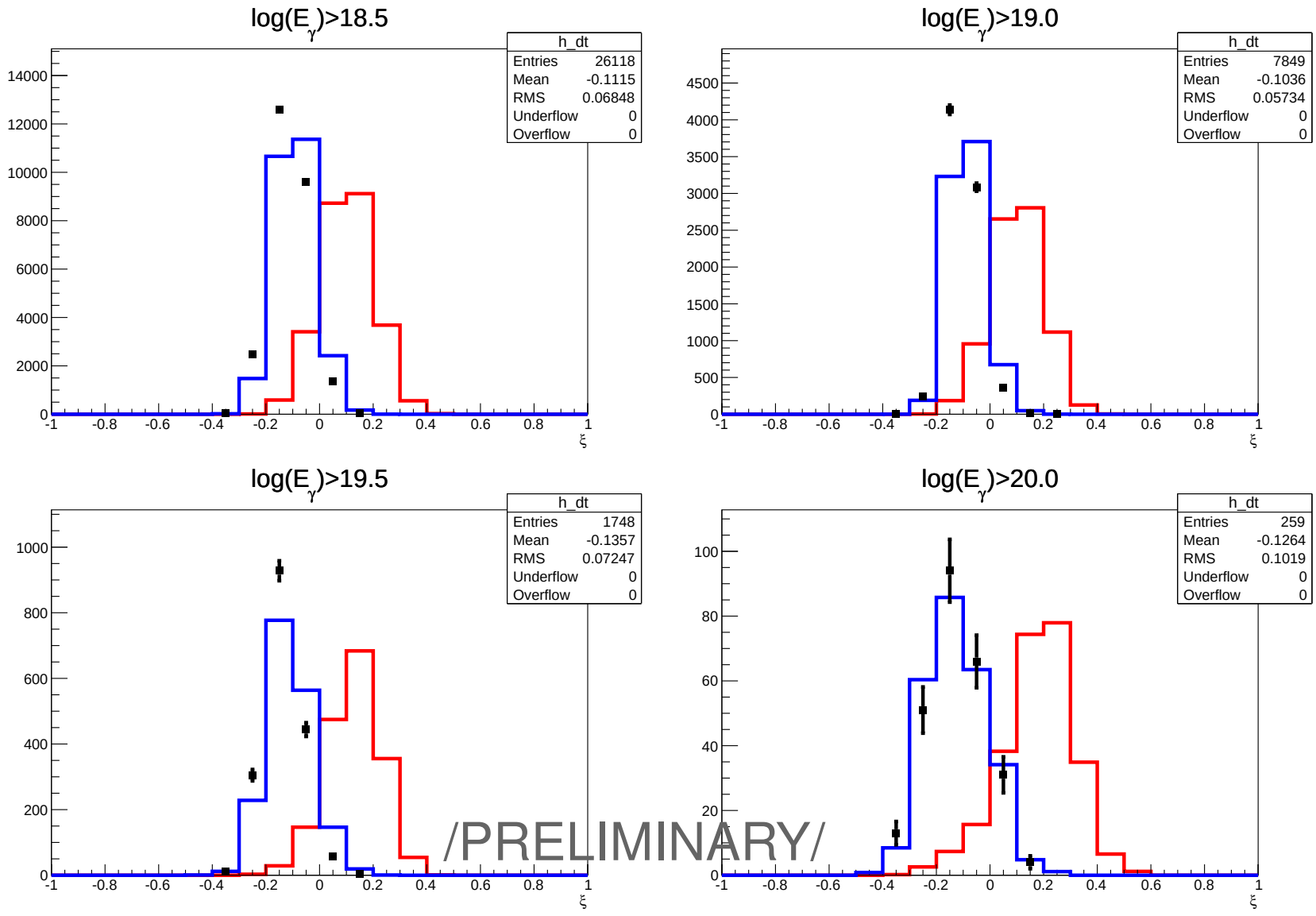
  PoS ACAT 040 (2007), arXiv:physics/0703039

- BDT is trained with Monte-Carlo sets: γ (Signal) and p (Background)

- BDT classifier is used to convert the set of observables for an event to a number $\xi \in [-1 : 1]$: 1 - pure signal (γ), -1 - pure background (p).

- ξ is available for one-dimensional analysis. The cut on ξ for the search is optimized using proton MC as a null-hypothesis.

Distribution of MVA estimator (ξ) for data and MC



data photon MC proton MC

Optimization of cut on ξ

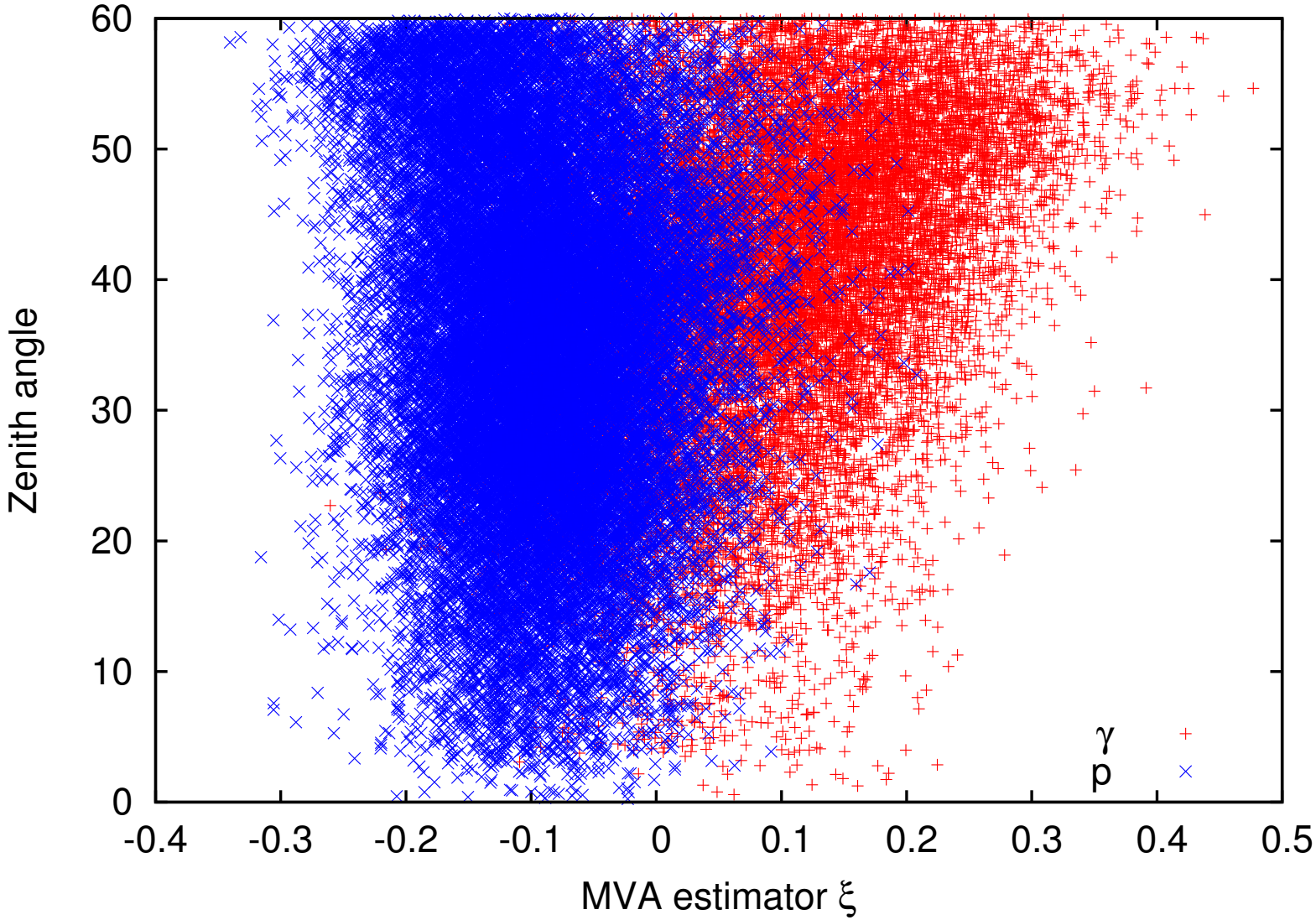
- The photon candidates are selected using the cut on ξ: $\xi > \xi_{cut}(\theta)$
- The cut is approximated as quadratic function of θ
- Cut is optimized in each energy range using proton Monte-Carlo
  - The merit factor is an average photon upper limit in the case of null-hypothesis (all protons)

Effective exposure

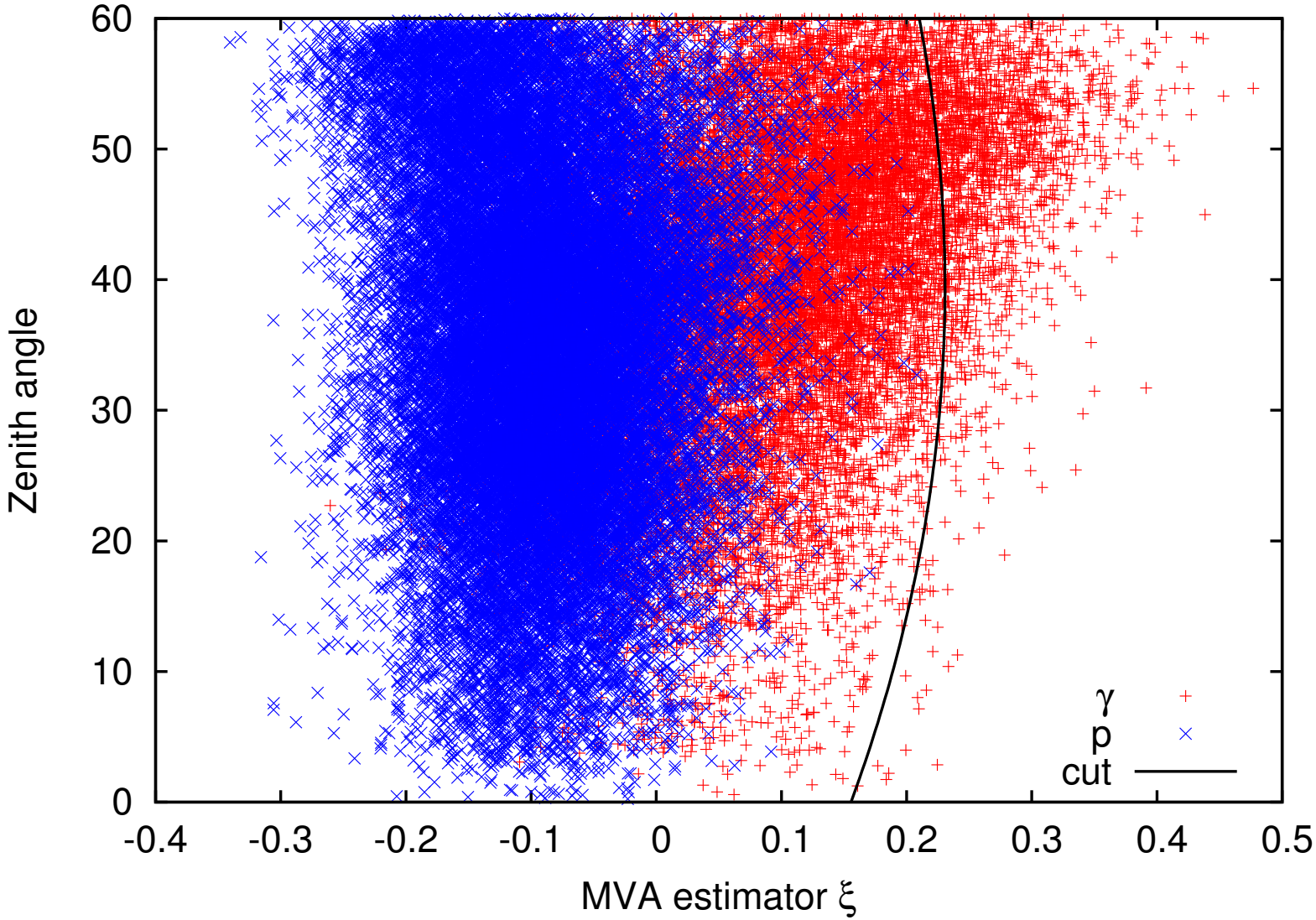
- Geometric exposure for $\theta \in (0^\circ, 60^\circ)$: **9340 km^2 sr yr**
- Effective exposure is estimated using photon MC assuming E^{-2} primary spectrum

E_0	$n_{det} \geq 7$	χ^2 and energy cut	ξ-cut	X_{eff} km^2 sr yr
$10^{18.5}$	11.5%	80.3%	11.2%	**96**
$10^{19.0}$	55.2%	79.2%	16.1%	**656**
$10^{19.5}$	78.3%	71.2%	27.9%	**1448**
$10^{20.0}$	91.0%	73.0%	44.6%	**2760**

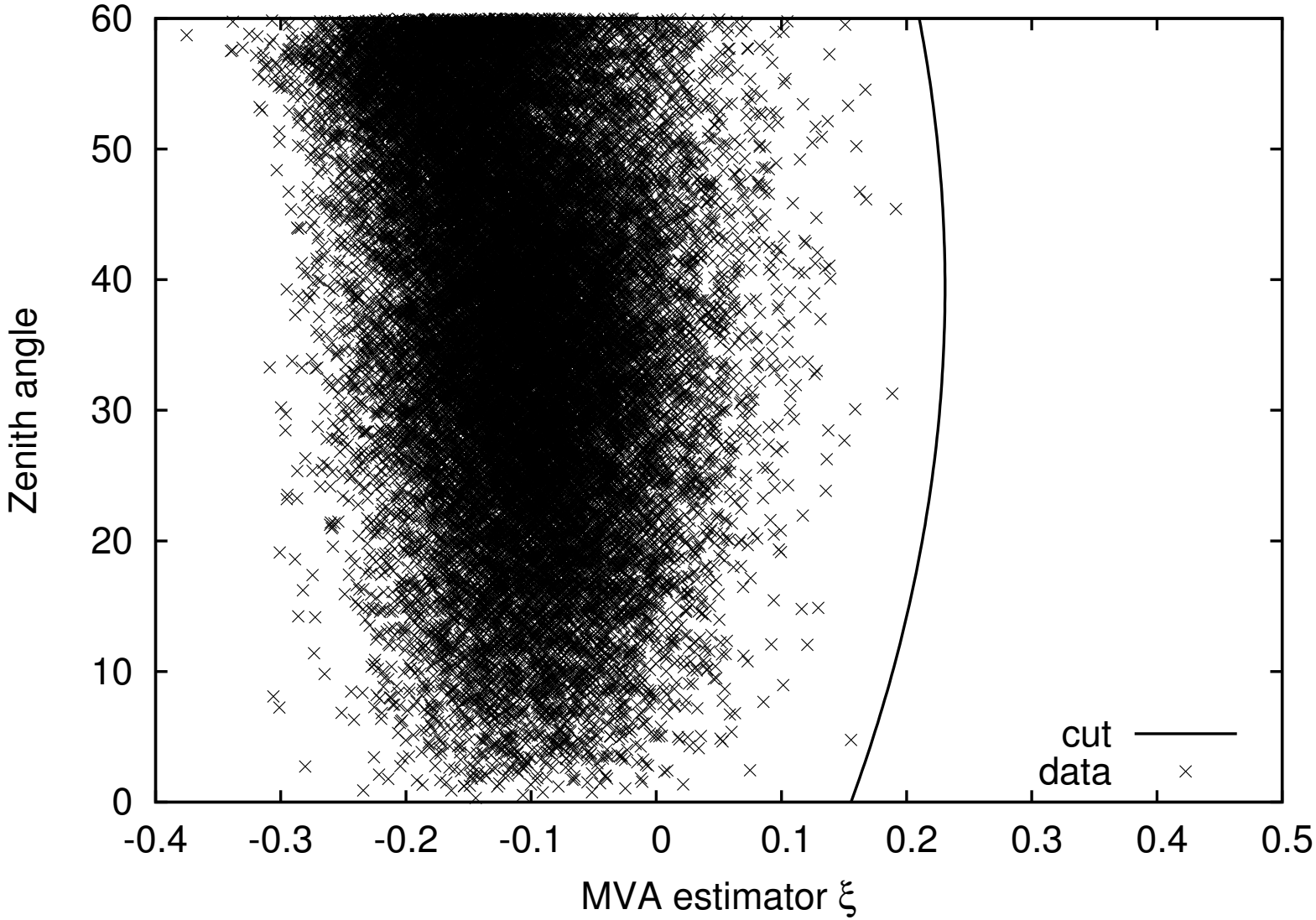
Zenith angle dependent cut on ξ: MC



Zenith angle dependent cut on ξ: MC

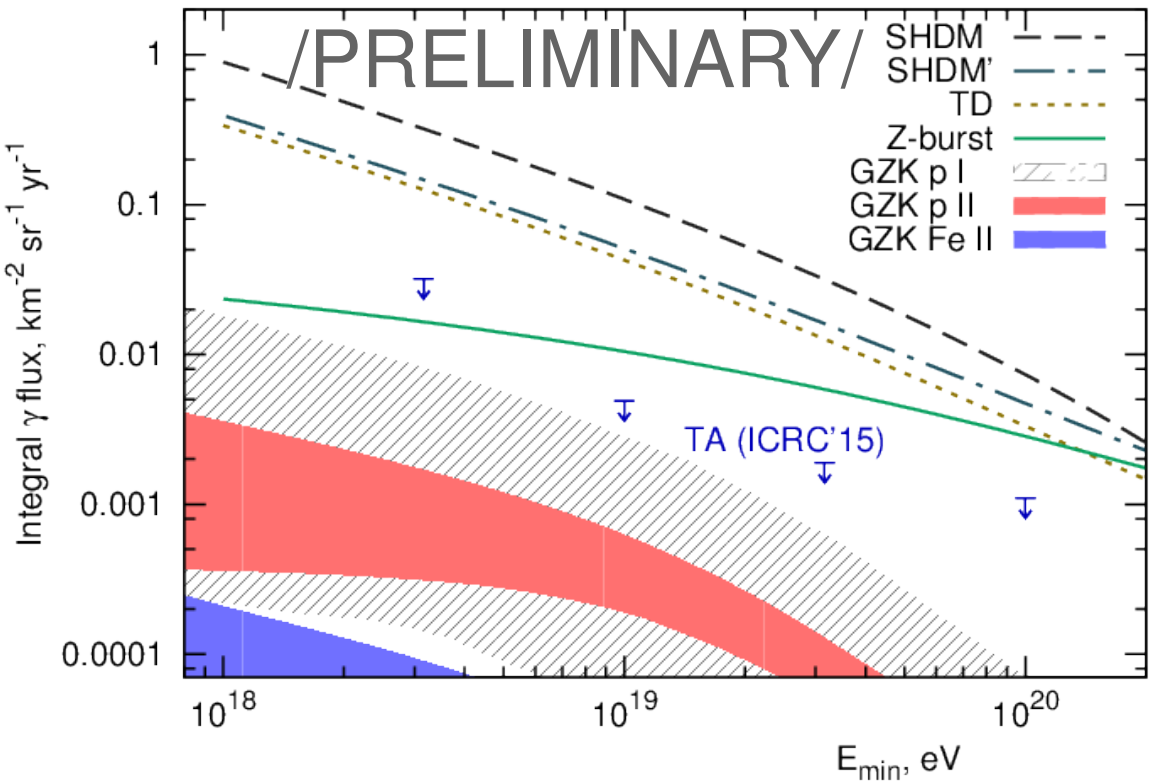


Zenith angle dependent cut on ξ: data



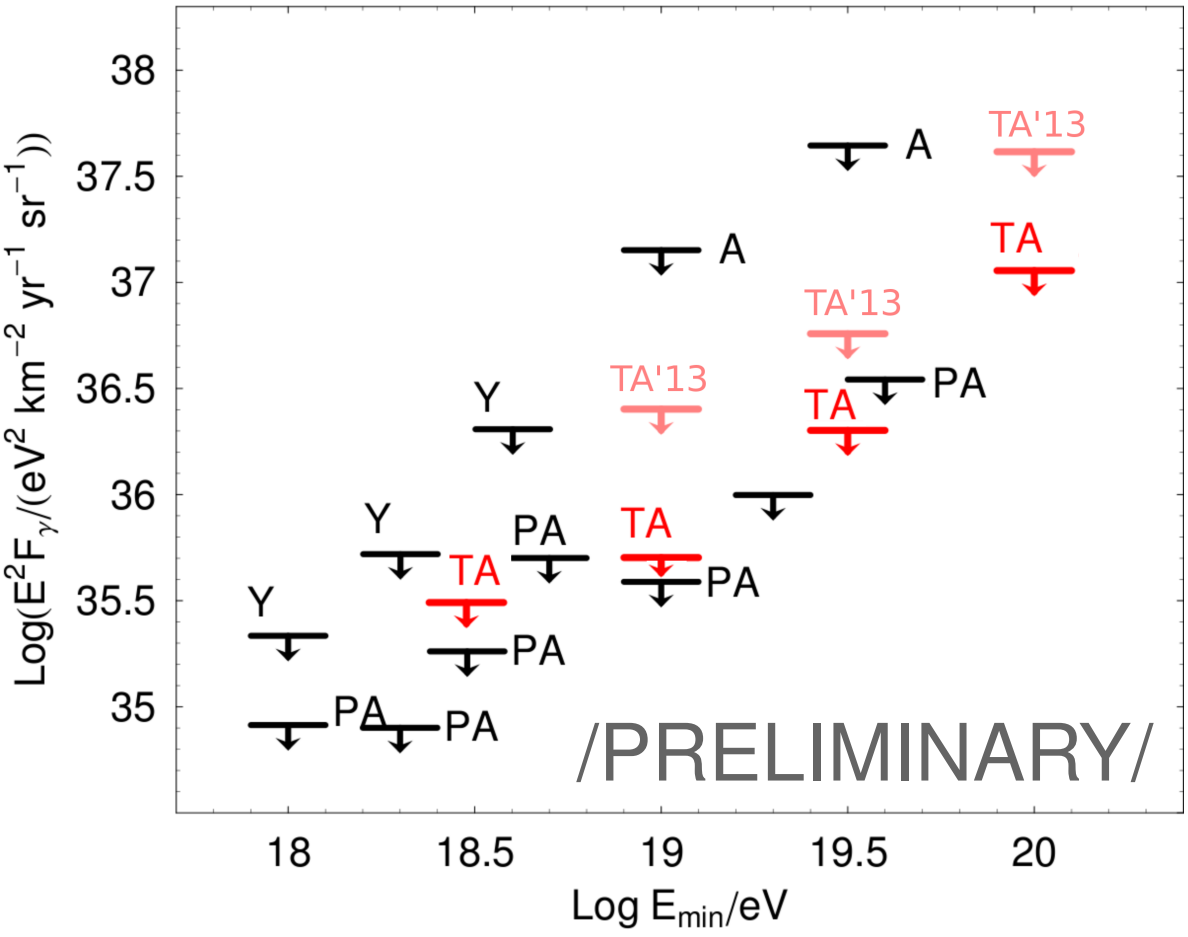
Results: photon flux limits

E_0	N. cand	$\bar{N}$ (95% C.L.)	X_{eff}	$F <$,$\mathrm{km^{-2}sr^{-1}yr^{-1}}$
$10^{18.5}$	0	3.09	96	**0.032**
$10^{19.0}$	0	3.09	656	**0.0047**
$10^{19.5}$	0	3.09	1448	**0.0021**
$10^{20.0}$	0	3.09	2760	**0.0011**



models from J. Alvarez-Muniz et al. EPJ Web Conf. **53**, *01009 (2013)*

Comparison with the other experiments



AGASA, Astrophys. J. **571**, *L117 (2002)*

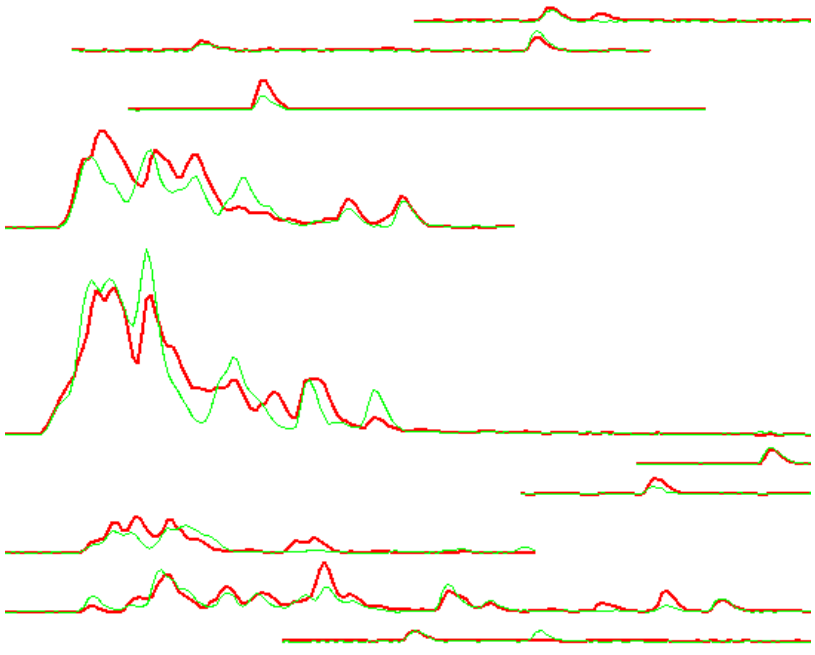
Yakutsk, Phys. Rev. **D82**, *041101 (2010)*

Auger, Astropart. Phys. **29**, *243 (2008); Astropart. Phys.* **31**, *399-406 (2009)*

Neutrino search strategy

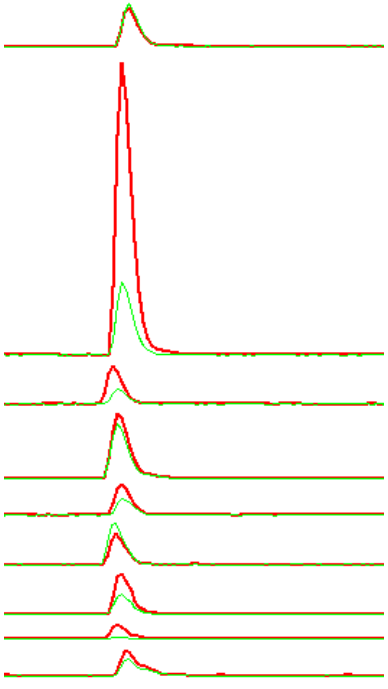
- Neutrino produces very inclined young shower

young shower, $\theta = 19.5°$



long, many peaks

old shower, $78.3°$

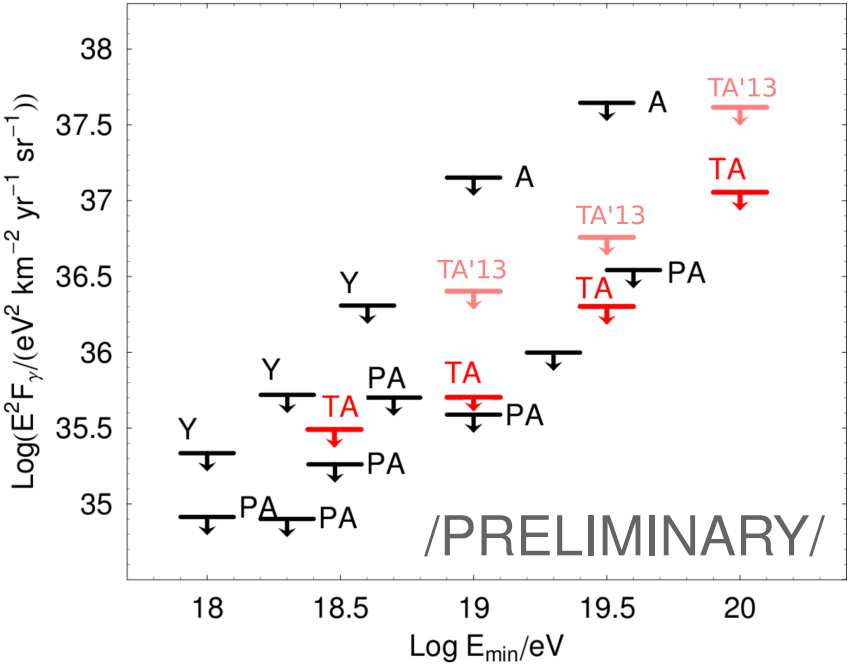


one peak

- Down-going ν search based on MVA is in progress

Conclusions and outlook

- A new technique for photon search based on the multivariate analysis
- Photon flux limits above $10^{18.5}$ eV



Ongoing searches:

- photon point sources
- down-going neutrino, $E > 10^{18}$ eV

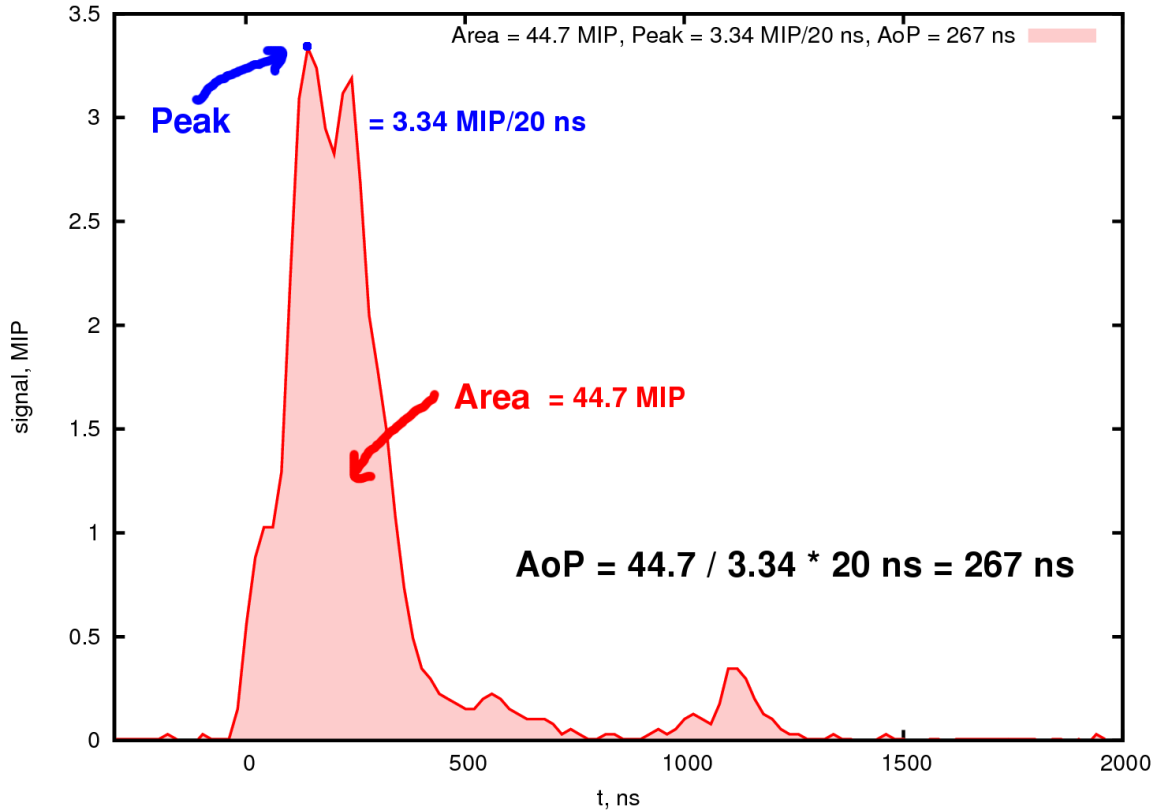
Backup slides

Impact of possible proton MC systematics

- Proton MC is used for MVA estimator training and cut optimization
- Systematics in proton MC affects the method sensitivity
  1. protons are closer to photons that data: exposure is underestimated
  2. data are closer to photons than protons: extra photon candidates in the data set
- In both cases the flux limits stay conservative

SD observable: Area over peak

- Consider a surface station time-resolved signal



- Both peak and area are well-measured and not much affected by fluctuations

- First introduced by Pierre Auger Collaboration in the context of neutrino search

Event reconstruction: fit functions

- Joint 7-parametric fit: x_{core}, y_{core}, θ, ϕ, S_{800}, t_0, a

$$f(r) = \left(\frac{r}{R_m}\right)^{-1.2} \left(1 + \frac{r}{R_m}\right)^{-(\eta-1.2)} \left(1 + \frac{r^2}{R_1^2}\right)^{-0.6}$$

$$LDF(r) = f(r)/f(800\ \text{m})$$

$$S(r) = S_{800} \times LDF(r)$$

$$t_0(r) = t_0 + t_{plane} + a \times 0.67\ (1 + r/R_L)^{1.5} LDF(r)^{-0.5}$$

$$R_m = 90.0\ \text{m},\ R_1 = 1000\ \text{m},\ R_L = 30\ \text{m}$$

$$\eta = 3.97 - 1.79(\sec(\theta) - 1)$$