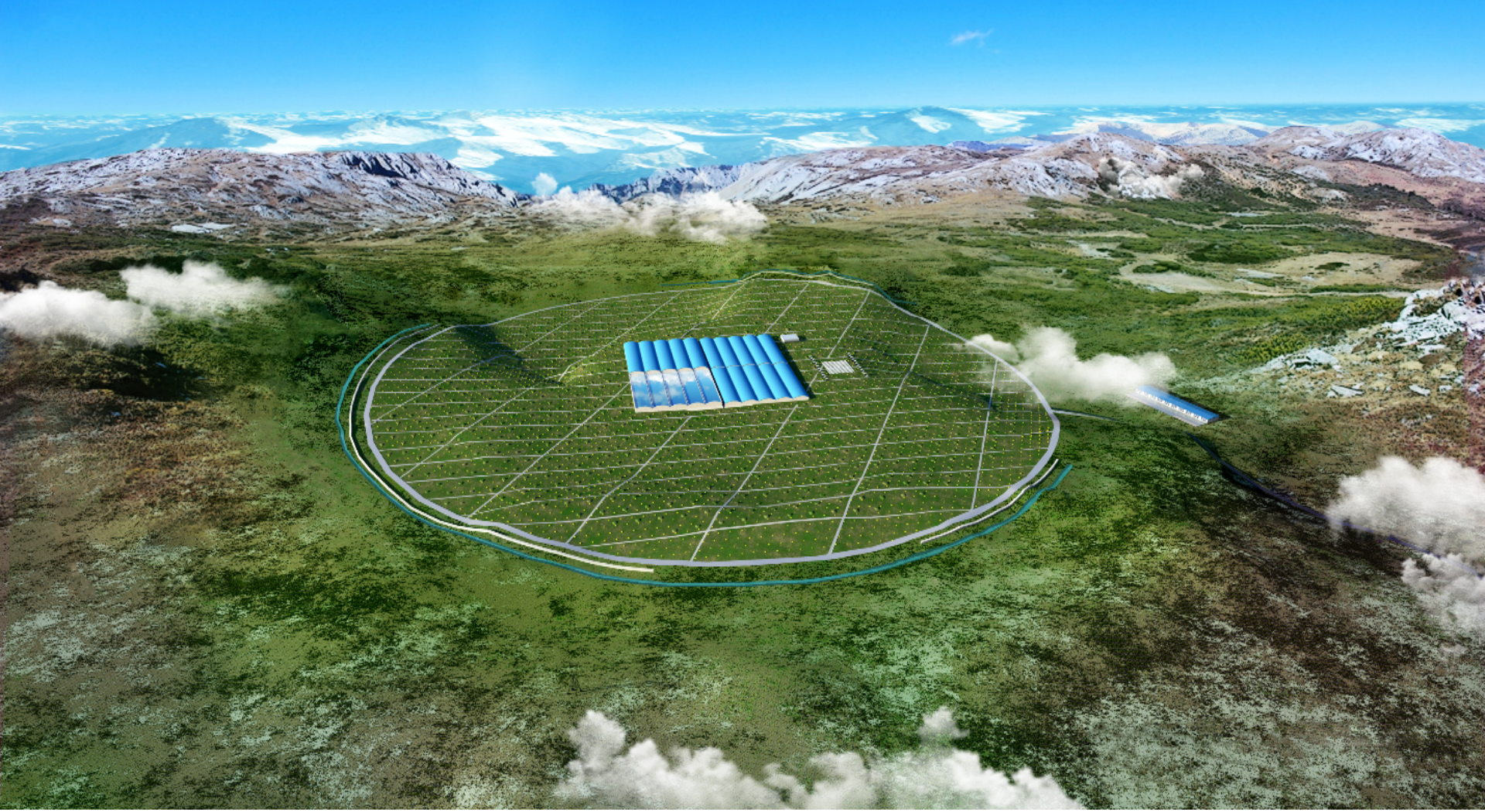


LHAASO-WCDA Detector and its physics

Min Zha / IHEP

KIAA-WAPII 17-19/08/2017

Outline

- Large high Altitude Air Shower Observatory
- LHAASO-WCDA physical target
- LHAASO-WCDA design and performance
- Real-time flare monitoring & GRB follow up observation
- Summary and outlook

Large High Altitude Air Shower Observatory

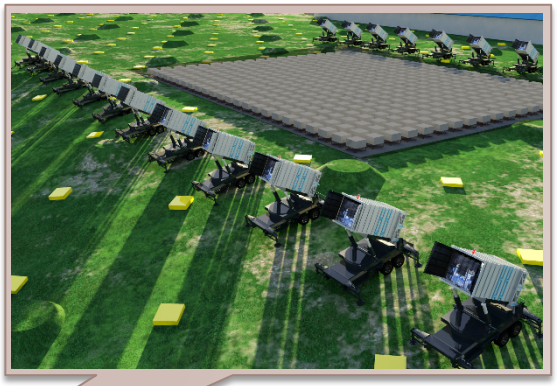


- Location: Haizishan mountain, Sichuan Province
- Coordinate: 29°21′30.7″N, 100°08′14.7″E;
- 4400 m a.s.l;
- 700 km to Chengdu;
- 8 km to the highest airport in the world;
- 50 km to Daocheng City, Sichuan Province. (3700 m)

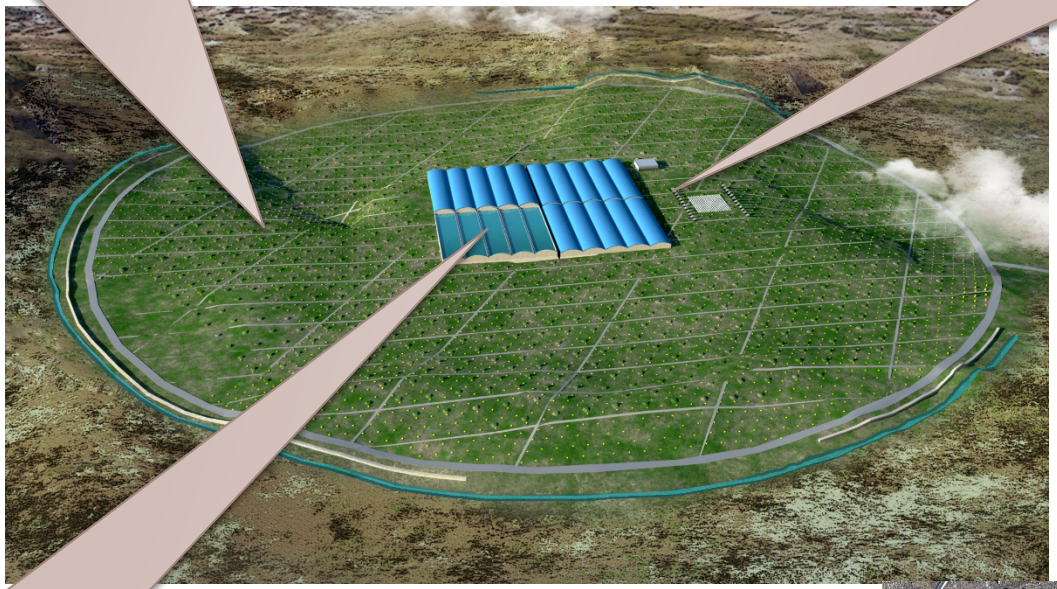


LHAASO



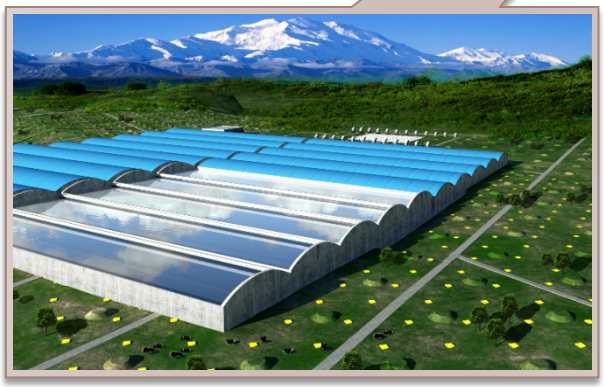


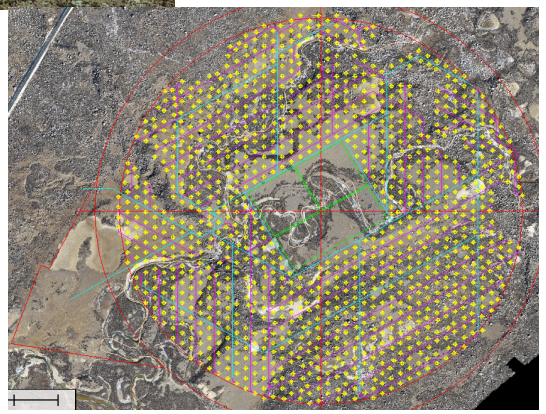
KM2A:
5195 EDs
1171 MDs



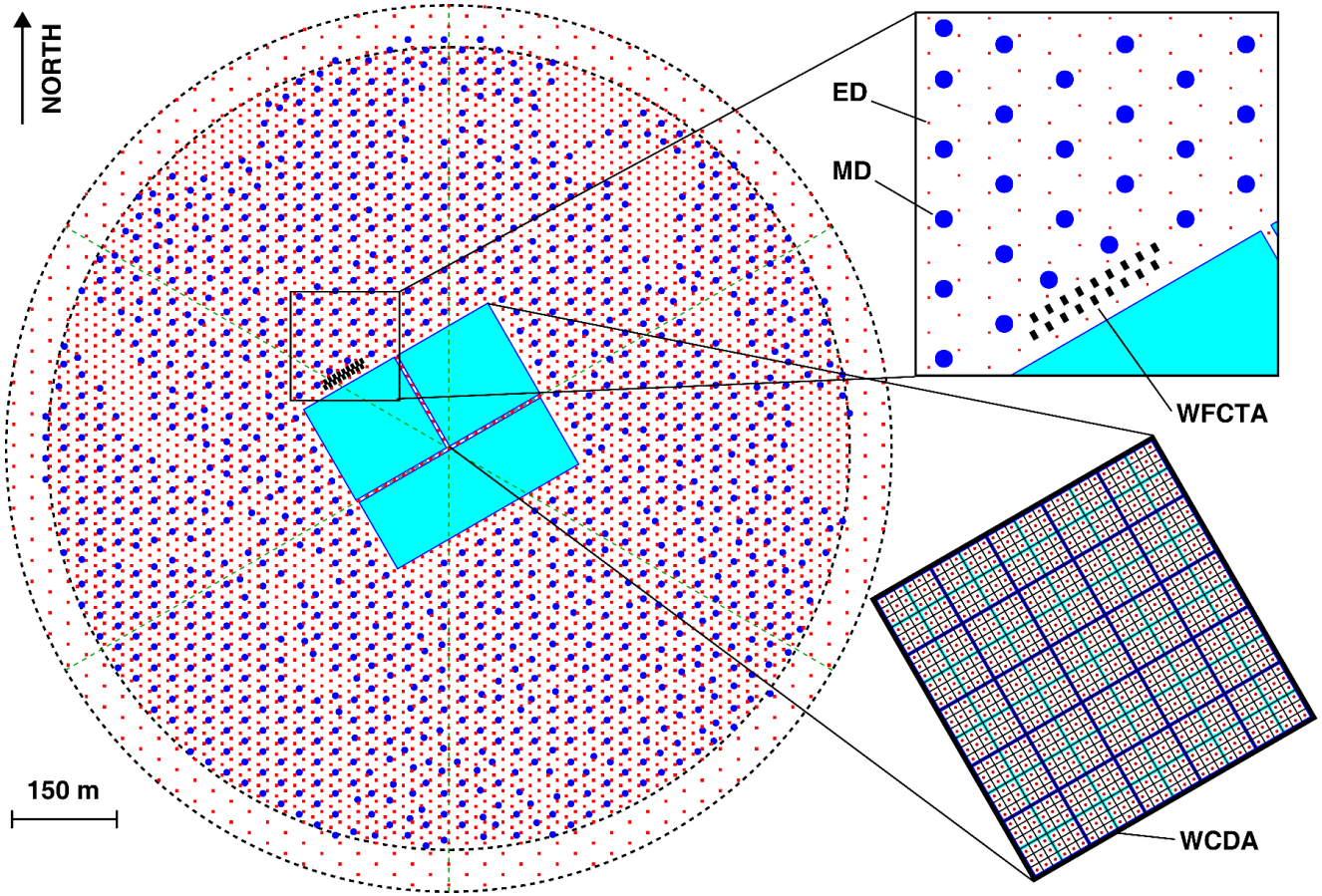
WFCTA:
16 telescopes
1024 pixels each

WCDA:
3120 cells
78,000 m^2





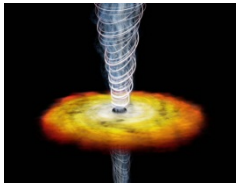
Layout of Detectors



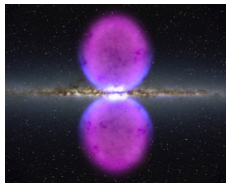
1 km^2 array
including 5195 scintillator detectors with are of 1 m^2 each and 15 m spacing
1171, underground water Cherenkov tanks with are of 36 m^2 each and 30 m spacing, for muon detection (total sensitive area ≈ 42,000 m^2).

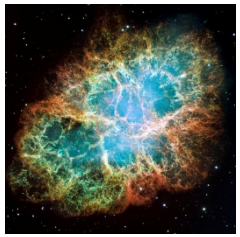
Physics Goals



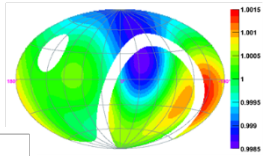


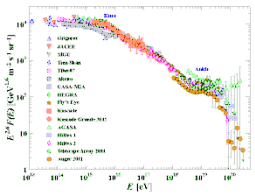
- VHE gamma sky survey (100 GeV-30 TeV):
  - Extragalactic sources & flares;
  - VHE emission from Gamma Ray Bursts;
  - Galactic sources;
  - Diffused Gamma rays.

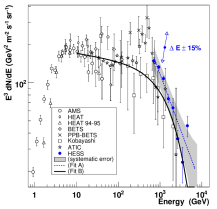


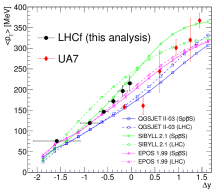


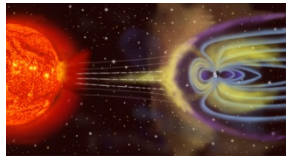
- Cosmic Ray physics (10 TeV-10 PeV):
  - Cosmic ray spectrum @ knee region with 1.5 inch PMT
  - Anisotropy of VHE cosmic rays;
  - Cosmic electrons;
  - Hadronic interaction models.



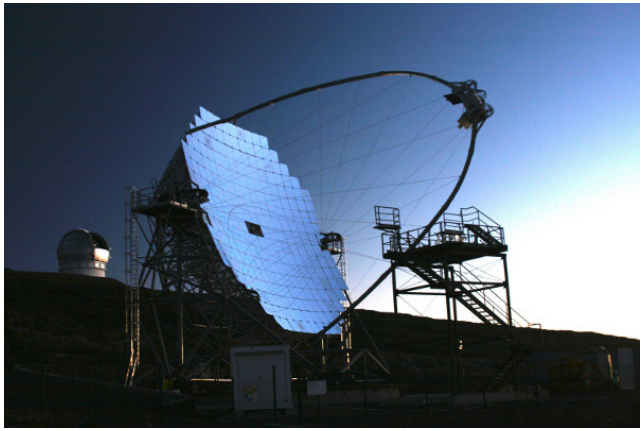






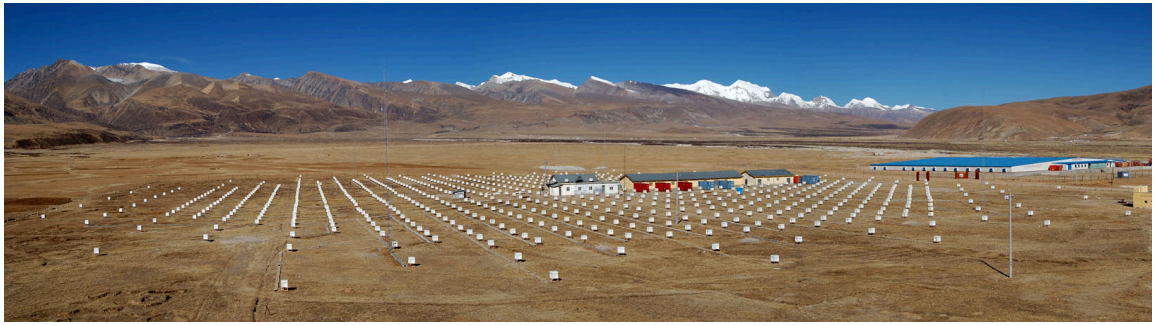


VHE γ-astronomy: Two Techniques



- IACTs: H.E.S.S., VERITAS, MAGIC, …
  - Good angular resolution (~0.1°);
  - Fair background rejection power;
  - Short duty cycle (~10%);
  - Narrow FOV (<5°);
  - Low energy threshold (~100 GeV);

➔ Mainly focused on deep observation.

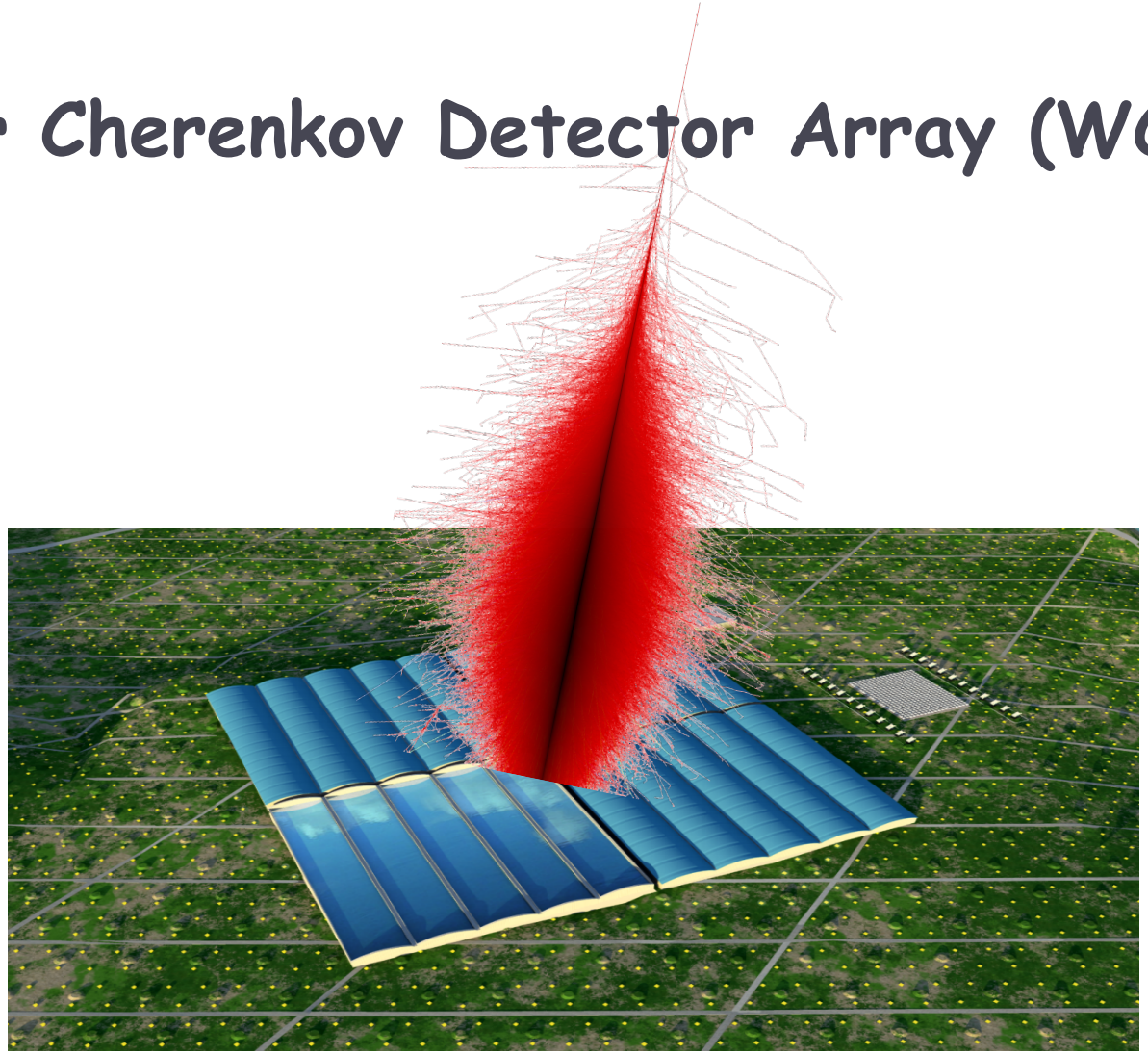


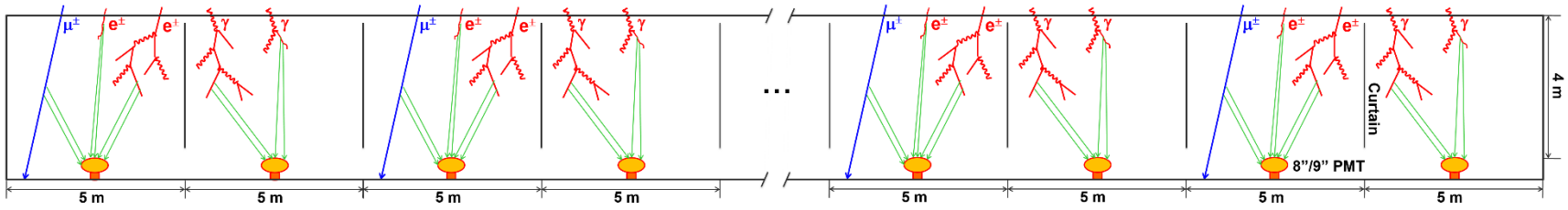


- Ground particle array: ASγ, ARGO-YBJ, Milagro, HAWC, …
  - Not-so-good angular resolution (~0.5°);
  - Poor background rejection power (but much elaborated in water Cherenkov);
  - Full duty cycle (>95%, ~10× IACT);
  - Wide FOV (>2/3π, ~150× IACT);
  - High energy threshold ➔ improved by construction at high altitude (~1 TeV);

➔ Good at sky survey, extended sources and flares.

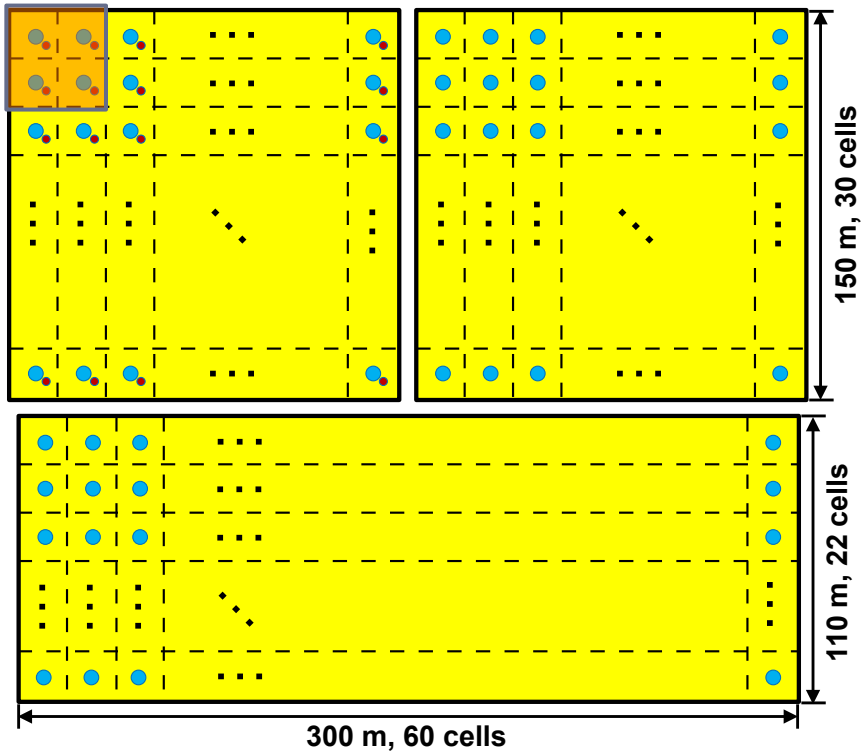
Water Cherenkov Detector Array (WCDA)

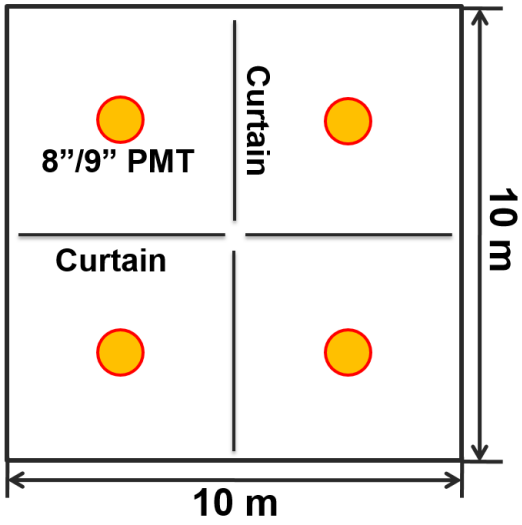


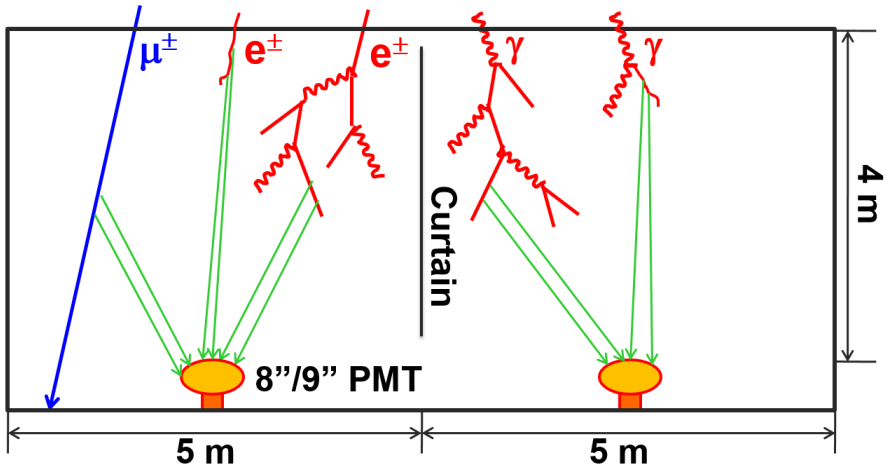


Cells of WCDA

- 3 water ponds:
  - 78,000 m^2 in total;
  - 4 m effective depth;
  - 3120 cells, with an 8"/9" PMT in each cell;
  - Cells are partitioned with black curtains.



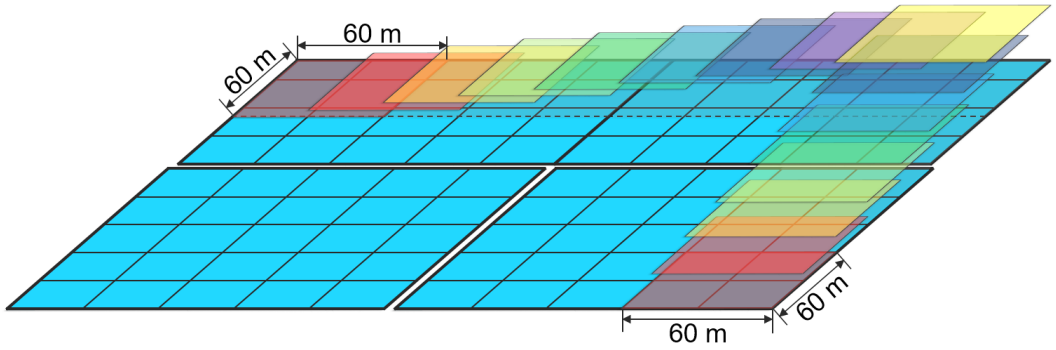


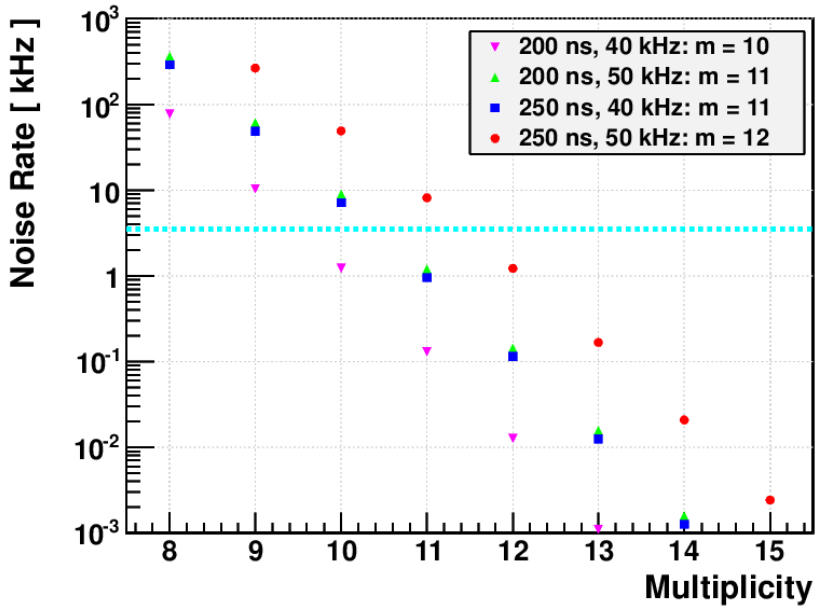


WCDA Specifications

Item	Value
Cell area	25 m^2
Effective water depth	4 m
Water transparency	> 15 m (400 nm)
Precision of time measurement	0.3 ns
Dynamic range	1-4000 PEs
Time resolution	<2 ns
Charge resolution	40% @ 1 PE 5% @ 4000 PEs
Accuracy of charge calibration	<2%
Accuracy of time calibration	<0.1 ns
Total area	78,000 m^2
Total cells	3120

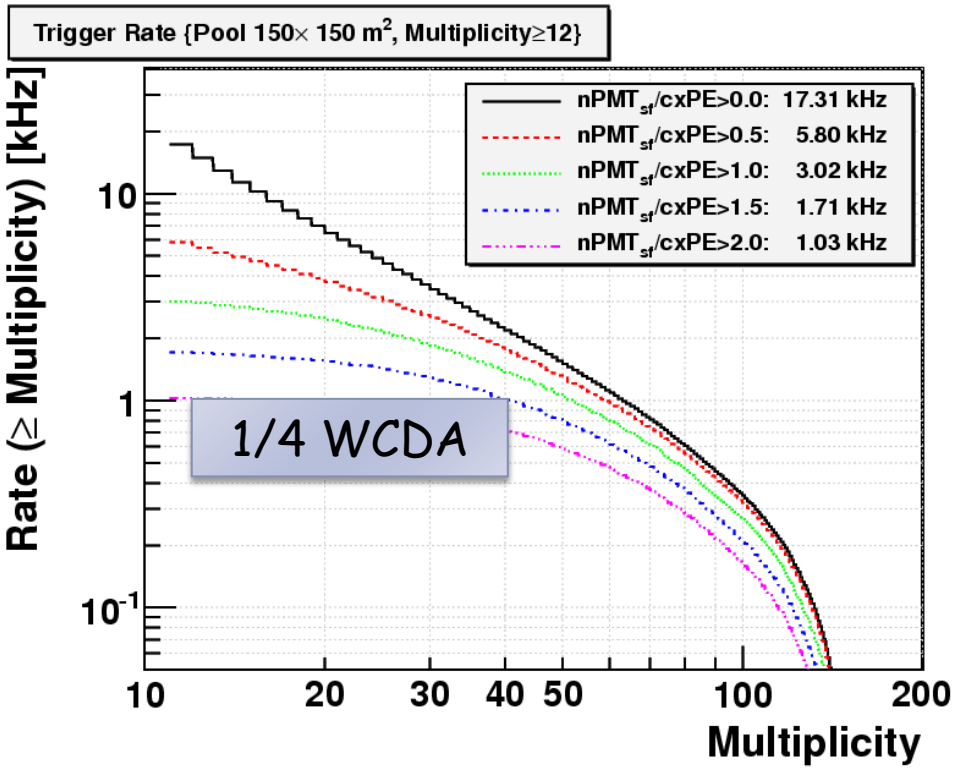
Trigger Clusters & Trigger Pattern





- Triggerless in hardware
  - every hit can be tagged with the absolute time.
- Cluster-based
  - Each trigger cluster governs 6×6×4 =144 cells;
  - Subdivided into 72 half-overlapped "trigger clusters";
- Pattern
  - number of fired PMTs in any trigger cluster ≥11 during any 250 ns, the array is triggered;
  - Noise trigger can be depressed to a level of <3.5 kHz.

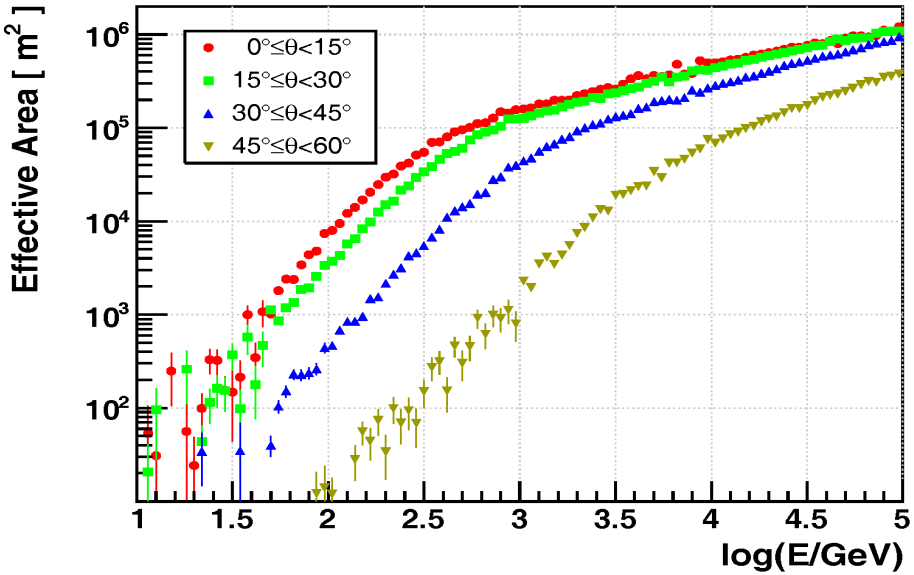
Trigger Rate & Data Volume

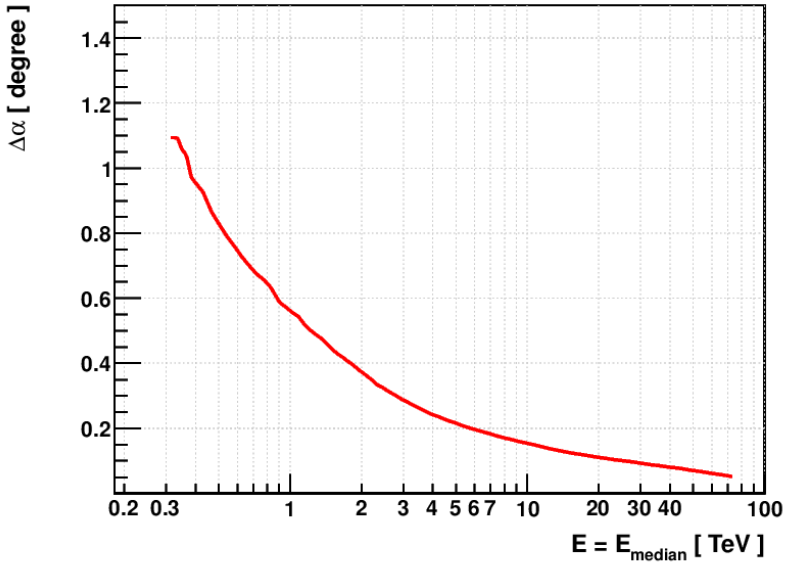


- Trigger rate:
  - ~ 63 kHz.
- DAQ raw input:
  - 100 bit/hit × 3600 hit × 35 kHz = 12 Gbps ~ 50 PB/yr.
- Data volume after soft trigger:
  - 128 bit/hit × (70 + 35 kHz × 2000 ns × 3120) hit × 63 kHz = 3 Gbps ~ 12 PB/yr.

Big data require an online pre-reconstruction solution.

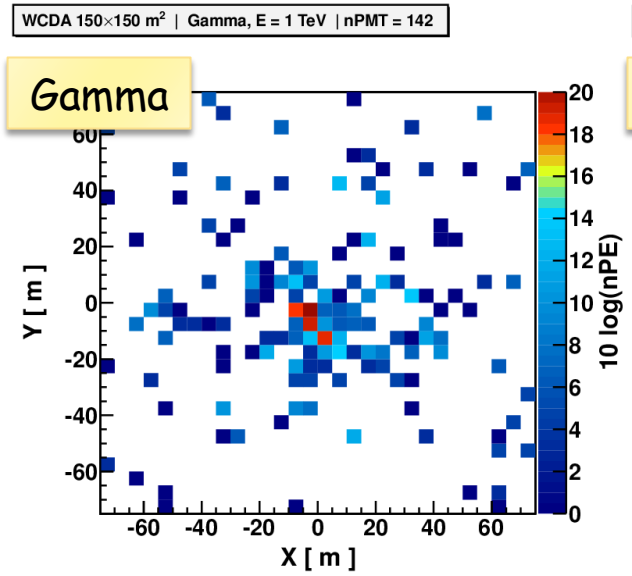
Effective Area & Angular Resolution

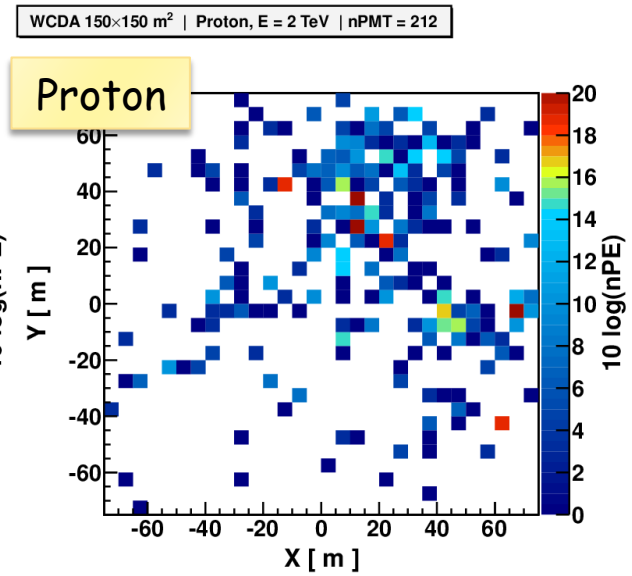


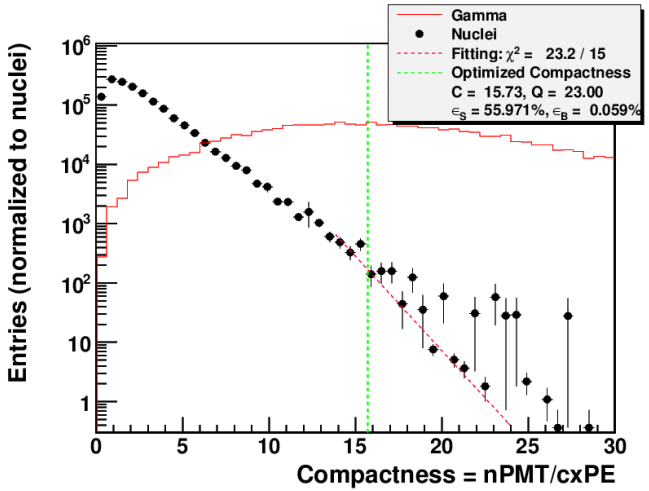


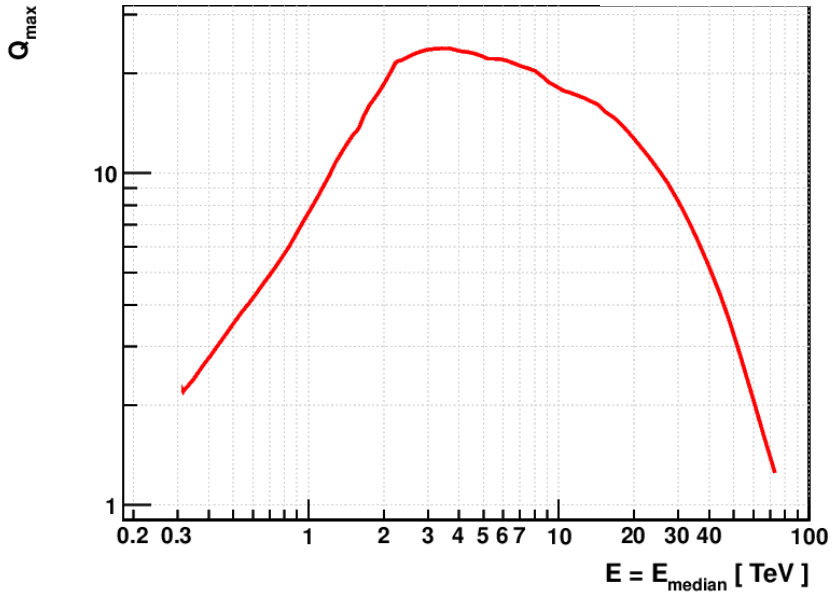
- Effective area:
  - ~1000 m^2 @ 100 GeV;
- Angular resolution:
  - Optimized bin size: 0.55° @ 1 TeV; 0.23° @ 5 TeV.

Gamma/proton Discrimination



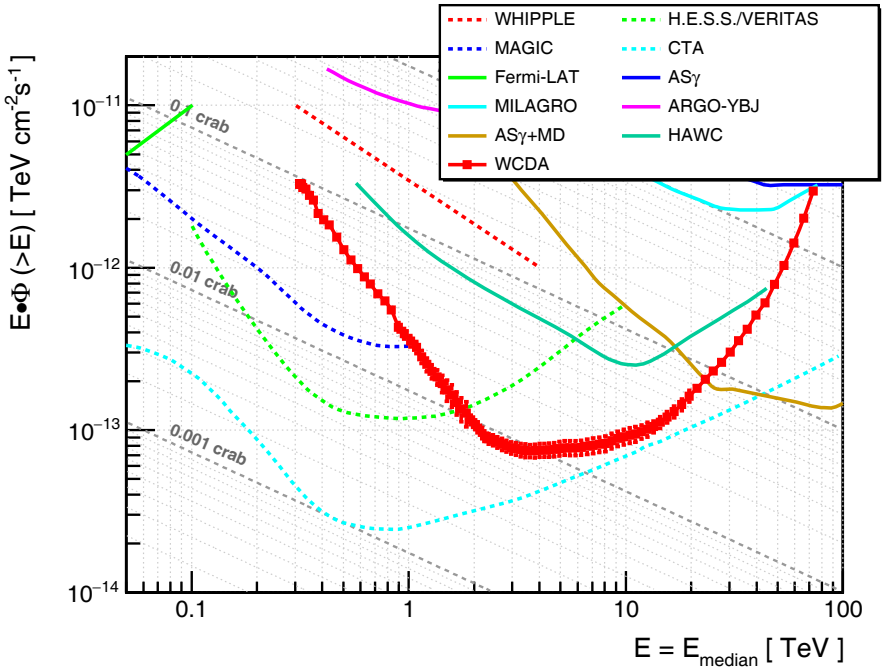




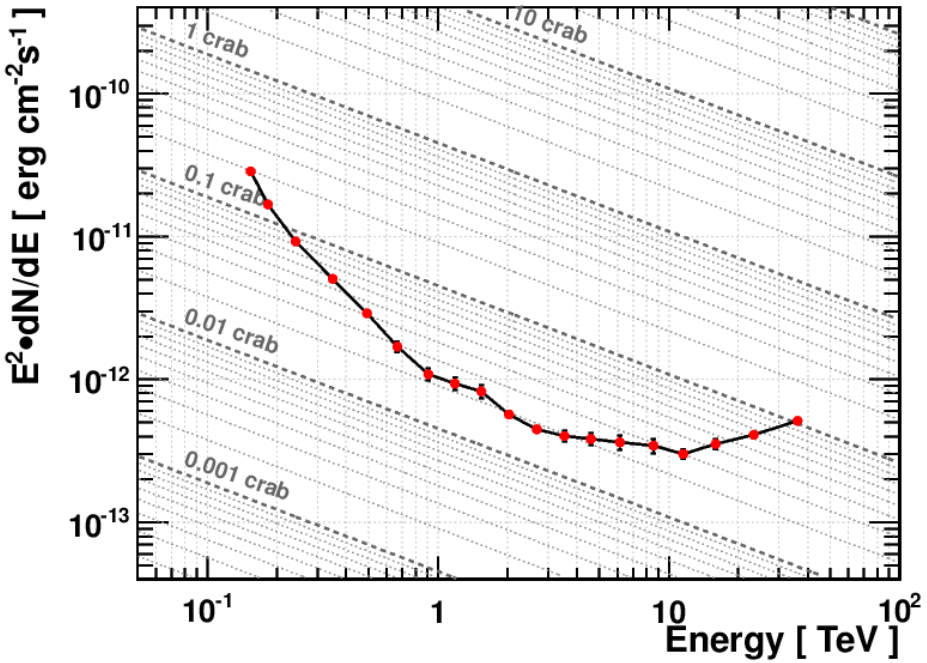


- Brightest "sub-core":
  - Signal of the brightest PMT outside the shower core region (e.g., 45 m);
- "Compactness" can be employed to reject cosmic ray background efficiently.

Sensitivity to crab-like sources



Integral

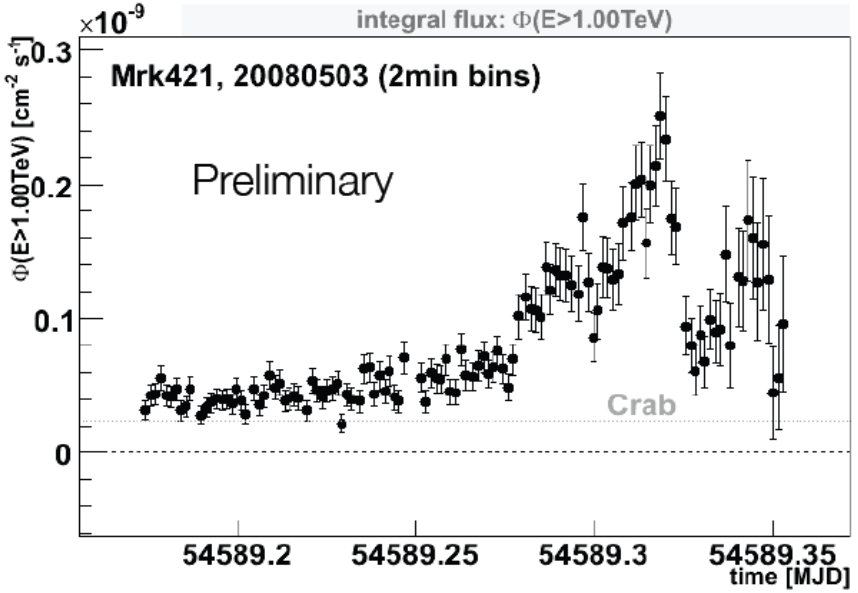


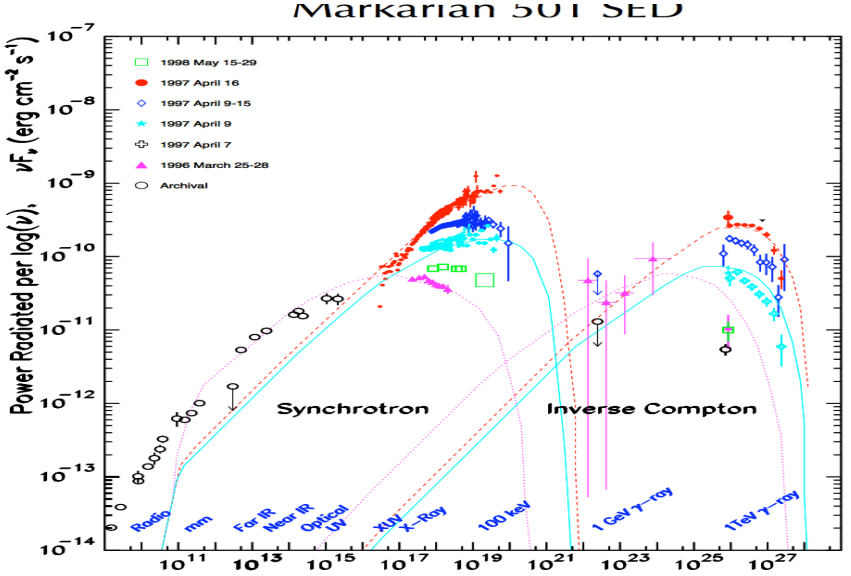
Differential

- 0.01 crab @ 2 TeV

AGN source characteristics

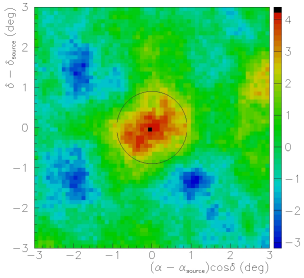
- Rapid variability
  - Time: from minutes, hours to month;
  - Flux: even tens times flux of Crab.
- SED: typicaly two-bump
  - radio – hard xray: synchrotron emission
  - High energy bump
    - Leptonic .vs. hadronic scenario
- Simultaneous variability of x-ray and TeV γ -rays supports SSC model and/or inverse compton with external photons

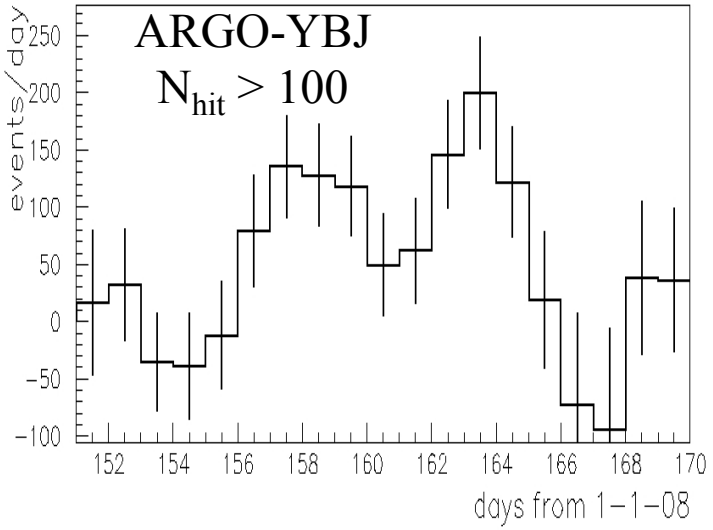


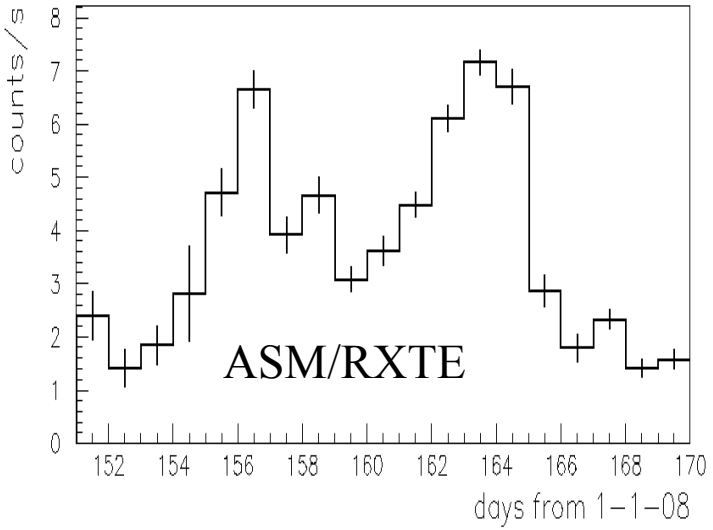


Physics from AGN alert and monitoring

- To collect many unbiased flare data;
- Flare alert can trigger multi-wavelength following-up observation;
- Correlation flares with other energy bands:
  - Correlations with x-rays, optical, radio, neutrinos to determine emission model;
  - Orphan flare search is a good probe for leptonic or hadronic emission model;
  - Role of external photon fields;
  - Intrinsic spectra vs. EBL-affected spectra
  - Extends TeV spectrum to high energies
- Cosmological feature from bright flare emission
  - Extragalactic background light
  - A good probe of exotic physics
    - To test Lorentz invariance violation;
    - ……



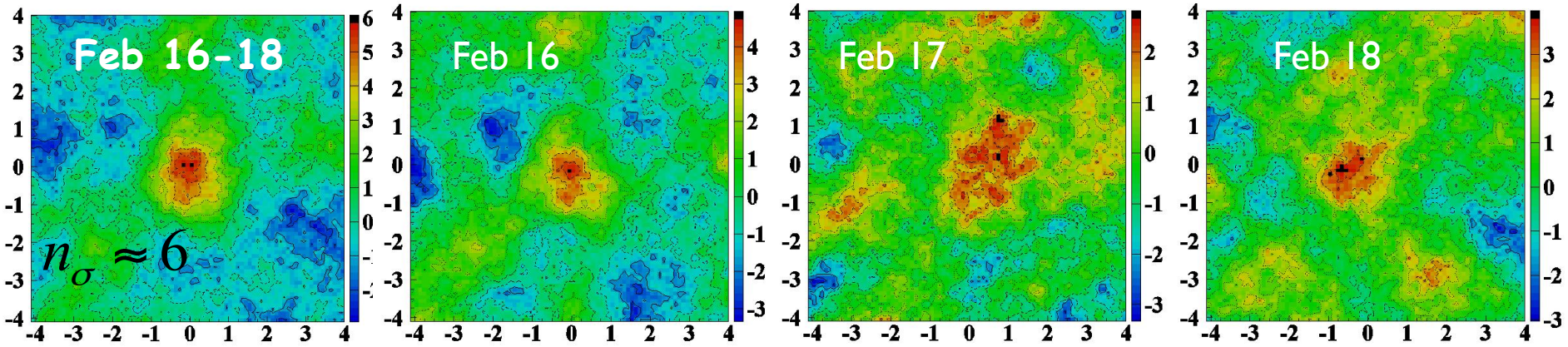




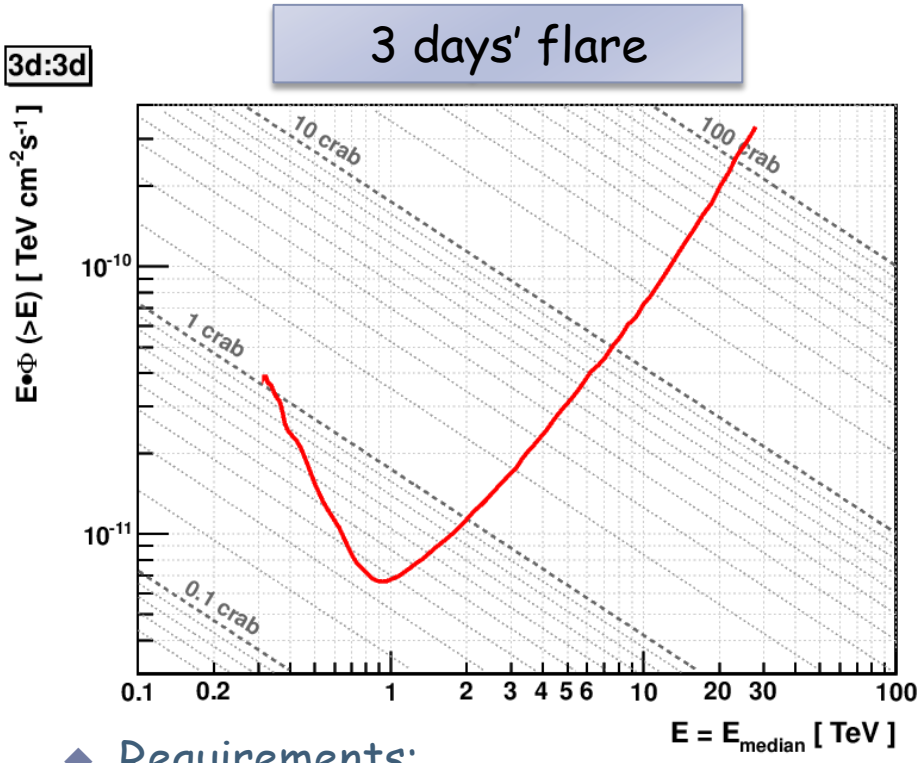
LHAASO-WCDA @ Flares

- Time & position is not predictable: difficult for IACT to detect;
- WCDA can monitoring over 2/3 sky for 6 hours per day regardless of sun, moon or weather
- WCDA can monitor most of the 60 known TeV emitting AGN and WCDA will rapidly notify multi-wavelength observation
- Light curve can be got from day to hour.

- A strong flare observed on February 16-18, 2010;
- First time that an EAS-array observed a TeV flare at 4-5 s on a daily basis
- Flux > 3 Crab units
- Peak flux (Feb 16) > 10



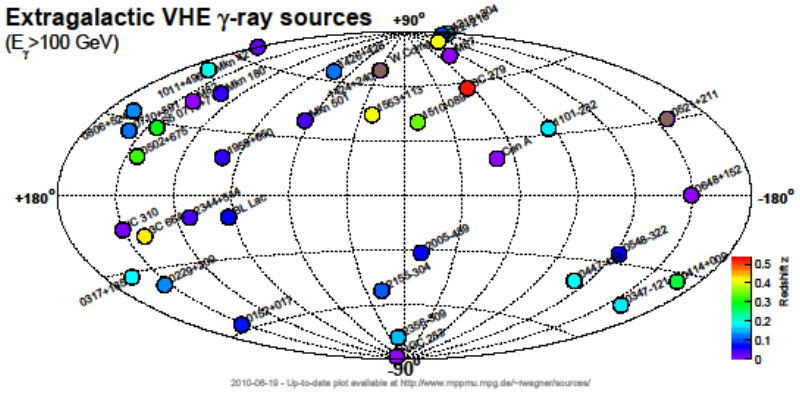
Sensitivity to Flares / GRBs



- Requirements:
  - 30 events;
  - 5 s.d.
- Calculation bases on a power law spectrum (λ=-2.62).
- Partly limited by statistics;
- 5σ/day: the detector can be very well calibrated by the Crab.

Duration	Sensitivity (Crab)
1 year	0.0066
6 months	0.0094
3 months	0.013
1 month	0.039
10 days	0.10
3 days	0.36
1 day	1.0
2 hours	3.5
1 hour	5.4
30 minutes	13
10 minutes	67
3 minutes	410
1 minute	2100

Real-time flare monitoring & alert @ARGO-YBJ



- 40 candidates： 39 + Crab
- Real time transportation（10 min.）
- Time: Nhit>100， within 2 hours；
- Aalert by email to the group；
- Alert threshold： $S_{max} \geq 4.30$
- Monitoring system hhhas worked from 02/2010/- 02/2013

Gmail by Google

Min Zha <zha.min@gmail.com>

20080402: Found an excess: 4.5004 (center 2.9824) s.d. from s000@d004

1 message

zham@ihep.ac.cn <zham@ihep.ac.cn> **Thu, Feb 10, 2011 at 4:08 AM**
To: min.zha@ihep.ac.cn, yao.chen@ihep.ac.cn, zhiguo.yao@ihep.ac.cn

Dear Colleagues,

Found an excess in nearby cells of Mkn_421!

I am happy to announce that we found an excess of 4.5004 s.d.
with Non = 31516 and Nb = 30698.735 from
the monitored source number 000 (Mkn_421: 166.1136, 38.2088)
in a total duration of 4 transits
(MJD 54555.46666 - 54558.90069, 2008/03/30 09:27 - 2008/04/02 21:23 UTC).

The center of this sky cell is 0.490 degree away from the source position.

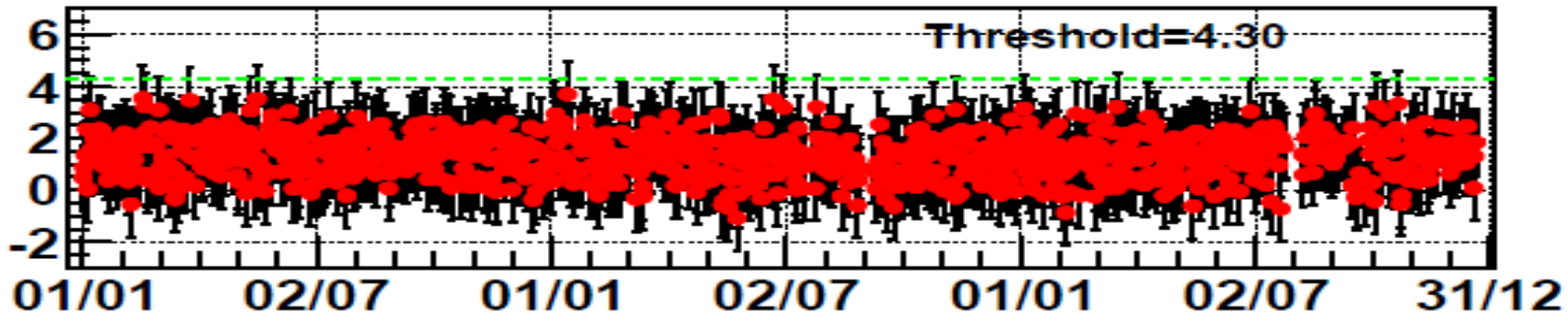
The significance of the center cell (0.150 degree away) is 2.9824 s.d.
with Non = 31416 and Nb = 30873.729.

The used data (362 files) are

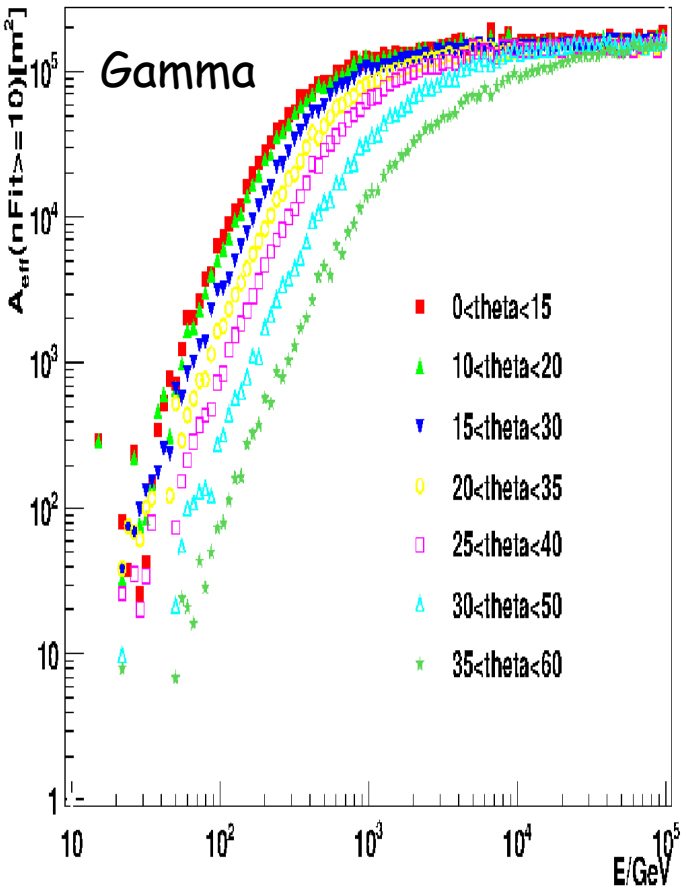
20080900927.015
..... (skipped)
20080932123.002

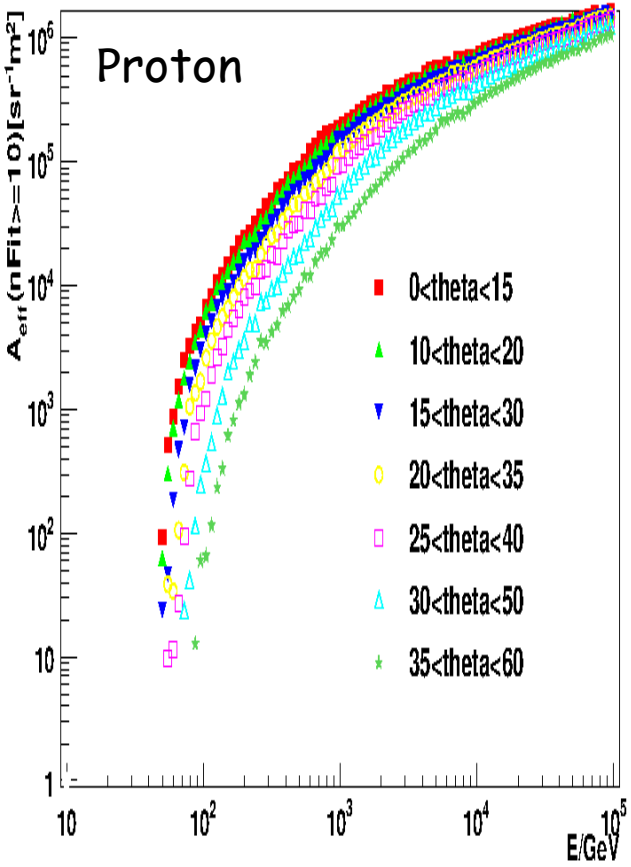
Note: Some runs may still be missing in this period, attributed to this
specific fast alerting mechanism.

cheers,
Robot



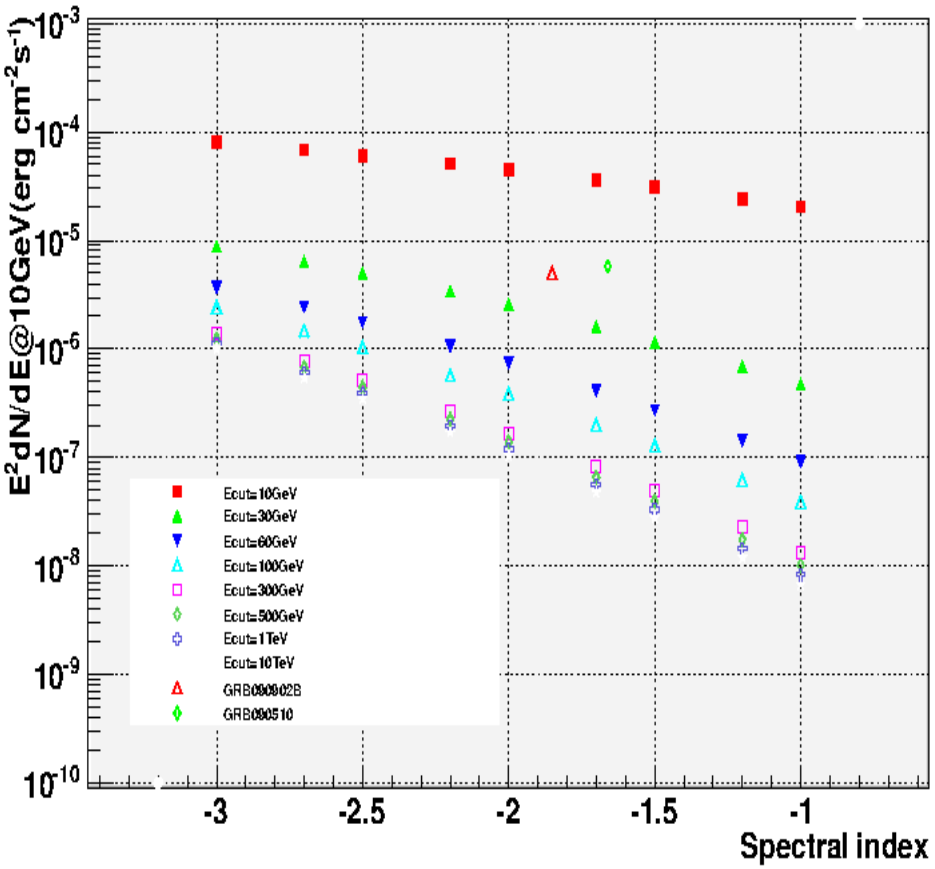
Effective areas @ shower mode





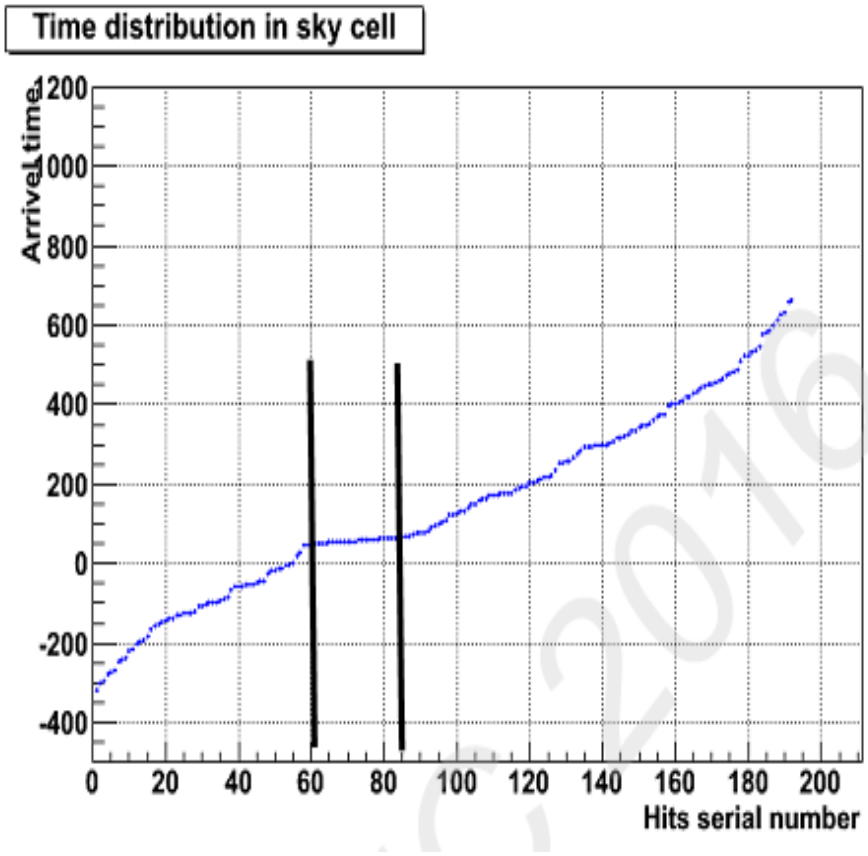
- effective area: $100m^2$@30GeV

Sensitivity @ shower mode



- Ecut ~ 30 GeV, WCDA can detect positive signal for GRB0902B and GRB090510-like

Low multiplicity technique: method 1



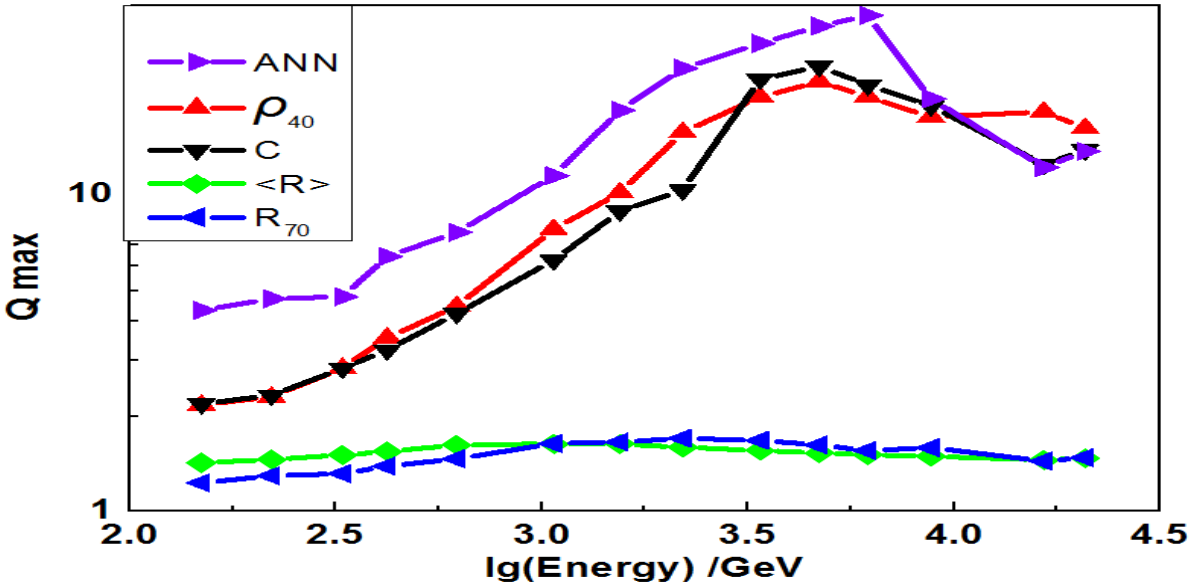
- Low multiplicity technique: loop all hits in arrival time in the plane perpendicular to the signal direction
- arrival time of 50 GeV gamma
- A smoothing length for example 1000 ns
- Different number of multiplicity is relative to different energy

-- continued : Low Multiplicity technique

- Triggerless mode
- Challenge: huge data volume;
  - compressing data
  - For example: Ncharge in 4 intervals
    - 1-4/ 4-10 / 10-50 />50;
    - Keep relative arrival time;
  - Data storage
    - 1hour duration from GRB alertGRB alert ± 0.5 h,
      - 100 hour data (300 x 1、3) → 200 TB
    - Every two week, no alert data will be cleaned.

gamma/proton separation：multivariate analysis

nFit	*Q*(*C*)	*Q*(*ANN*)	Increase	*Q*(*BDTG*)	Increase
10~20	2.19	4.33	97.72%	4.61	110.50%
20~50	2.52	5.51	118.65%	5.51	118.65%
50~100	4.23	7.64	80.61%	9.26	118.91%
100~200	6.48	15.25	135.34%	16.71	157.87%
200~400	12.16	23.75	95.31%	32.30	165.63%
400~800	21.75	22.53	3.59%	27.71	27.40%
>800	12.69	13.03	2.68%	17.96	41.53%



status of construction











Summary

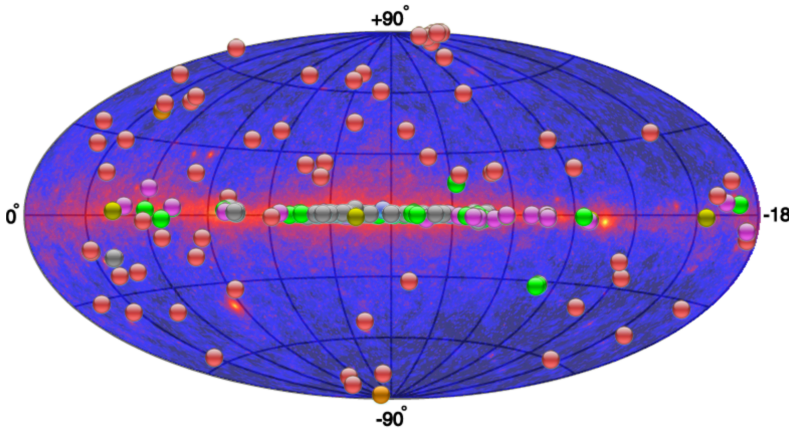
- LHAASO-WCDA, as a component of LHAASO project, is now under-construction in Haizishan, Daocheng. The first data collection with $\frac{1}{4}$ scale will be started in the end of 2018, the whole array will be working in the year of 2021.
- The sensitivity of LHAASO-WCDA reach to 1% crab flux at 2 TeV, it will play an important role in surveying measuring various Gamma ray sources.
- Detailed updates is still in working;

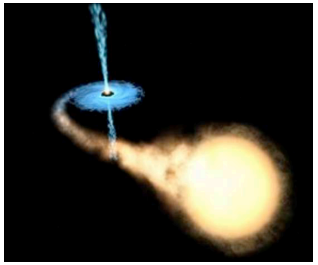
backup

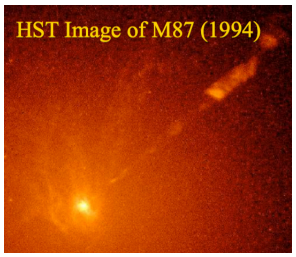
WCDA@The VHE gamma-ray sky

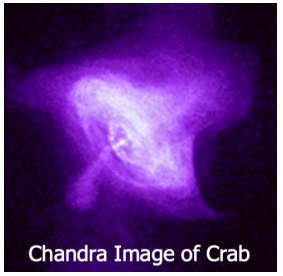
- Aug. 2016, 177 sources in TevCat;
- Flux range: 0.1% - 20 crab;
- Many different sources;
  - Active Galactic Nuclei
  - Pulsar wind Nebular
  - Supernova Remnants
  - x-ray Binaries, microquasar
  - Nearby Starbust, Galaxies, milky way
  - Molecular clouds
  - Galactic center
- 67 extragalactic VHE sources
  - 2 starburst galaxies:
    - M82 & NGC 253
  - 4 FR I radio galaxies:
    - M87, Cen A, NGC1275 & PKS 0625-35
  - 61 Blazars (with jets pointed us)

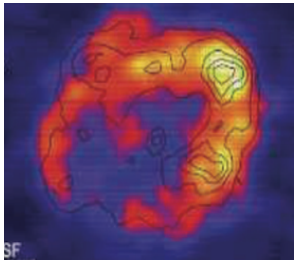
VHE r-ray sky map with Fermi-LAT sky map













Analysis chain

- 候选源的选定
  - HAWC: TeVCat + 2FGL blazar (z<1) +30 galactic TeV binaray candidates
  - @ARGO-YBJ： 40 objets
  - @WCDA: on-line /off-line
- 事例筛选和在线重建
  - 遍举法： 王晓洁报告
  - 速度的提高和优化: GPU
- 背景估计方法的研究
  - Surrounding/Equi-zenith/
- 时间、空间窗口的选取
- 预警的设置
- 实时搜寻结果的网页发布
- 超出结果的后续分析

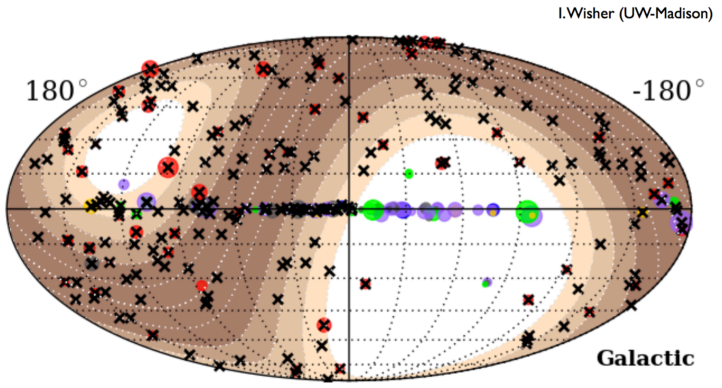


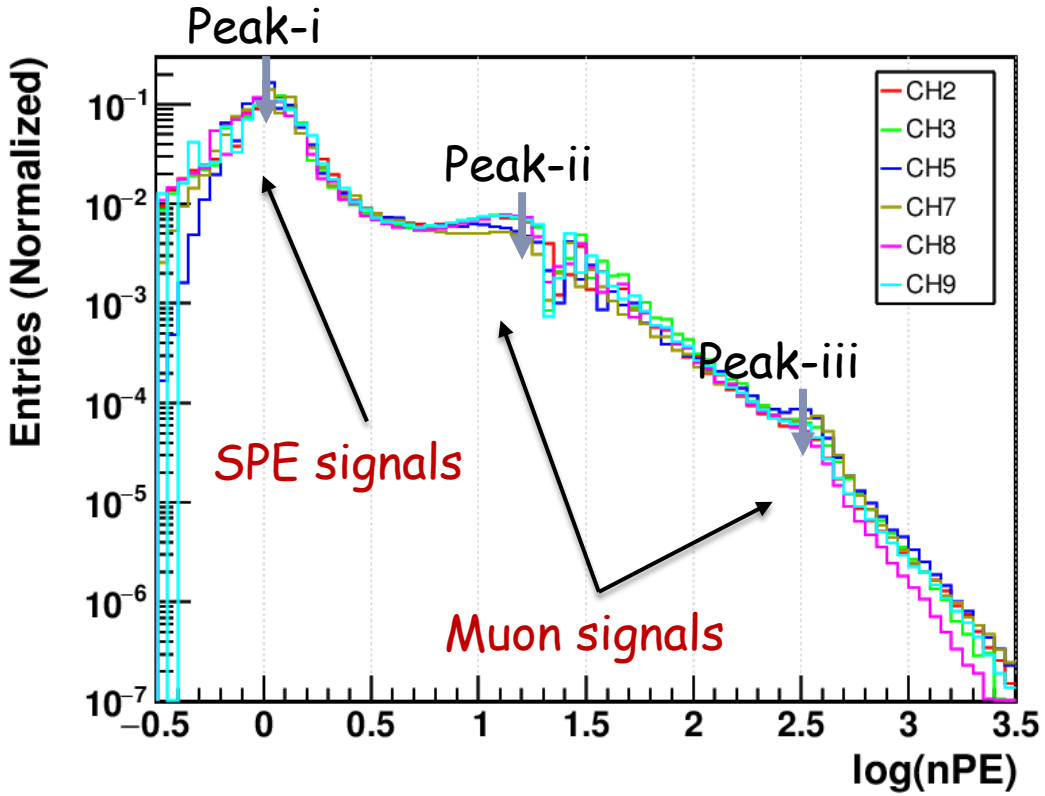
Table 1: List of selected candidates.

Nr.	Name	RA (degree)	DEC (degree)	E_{th} (GeV)	Flux($> E_{th}$) (crab)	index
0	Mrk 421	166.114	38.209	500	3.00×10^{-1}	-2.00
1	Mrk 501	253.468	39.760	300	6.60×10^{-2}	-2.20
2	1ES 2344+514	356.653	51.708	350	6.90×10^{-1}	-2.15
3	1ES 1959+650	299.995	65.151	600	2.00×10^{0}	N/A
5	1H 1426+428	217.136	42.672	280	1.40×10^{-1}	-3.55
6	M87	187.706	12.391	880	4.00×10^{-2}	N/A
8	1ES 1218+304	185.341	30.177	250	4.80×10^{-1}	-3.00
10	1ES 1101-232	165.907	-23.492	160	2.20×10^{-2}	-2.88
11	PG 1553+113	238.929	11.190	200	2.00×10^{-2}	-4.00
12	Mrk 180	174.110	70.158	200	2.50×10^{-2}	-3.60
14	BL Lacertae	330.680	42.278	200	2.50×10^{-2}	-3.60
15	1ES 0229+200	38.203	20.288	580	2.20×10^{-2}	-2.50
16	1ES 0347-121	57.347	-11.991	250	2.00×10^{-2}	-3.10
17	1ES 1011+496	153.767	49.434	200	6.70×10^{-2}	-4.00
18	3C 279	194.047	-5.789	100	7.07×10^{-1}	-4.10
19	RGB J0152+017	28.165	1.788	300	2.20×10^{-2}	-2.95
20	1ES 0806+524	122.455	52.316	300	1.80×10^{-2}	-3.60
21	W Comae	185.382	28.233	200	8.40×10^{-2}	-3.81
22	S5 0716+71	110.473	71.343	400	1.30×10^{-1}	N/A
23	3C 66A	35.665	43.036	200	5.50×10^{-2}	-4.10
26	RGB J0710+591	107.625	59.139	300	1.60×10^{-2}	N/A
27	PKS 1424+240	216.752	23.800	200	2.00×10^{-2}	N/A
28	NGC 253	11.890	-25.288	220	3.00×10^{-3}	-2.20
29	M82	148.843	69.661	700	1.20×10^{-2}	-2.60
30	VER J0521+211	80.480	21.190	200	5.00×10^{-2}	N/A
31	RBS 0413	49.966	18.759	200	2.00×10^{-2}	N/A
32	1ES 0414+009	64.218	1.090	200	5.00×10^{-3}	N/A
33	1ES 0502+675	76.985	67.650	350	4.00×10^{-2}	N/A
34	PKS 0447-439	72.353	43.836	N/A	N/A	N/A
35	PKS 1510-089	228.210	-8.900	N/A	N/A	N/A
36	RGB 0648+152	102.207	15.273	200	2.00×10^{-2}	N/A
37	IC 310	49.179	41.325	300	2.50×10^{-2}	N/A
38	VHE L3+C	172.530	-1.190	36	4.86×10^{5}	-6.31
39	Crab	83.633	22.014	200	1.00×10^{0}	-2.62

Calibration

- Water attenuation length
- PMT cell units
  - Time
    - LED+Fiber
    - Software method
  - Charge:
    - SPE (HG) , muon peak (LG), overlap
- Array
  - Pointing: moon shadow
  - PSF: moon shadow (cosmic ray), Crab Nebula (gamma)
  - Shower energy: moon shadow (cosmic ray), Crab Nebula (gamma)

Single channel charge distribution



LHAASO sensitivity

