The 7th International Workshop on Very High Energy Particle Astronomy (VHEPA2014)

- Next Generation Explorer for Cosmic Ray Origin -

T.Kifune

The University of Tokyo (emeritus)

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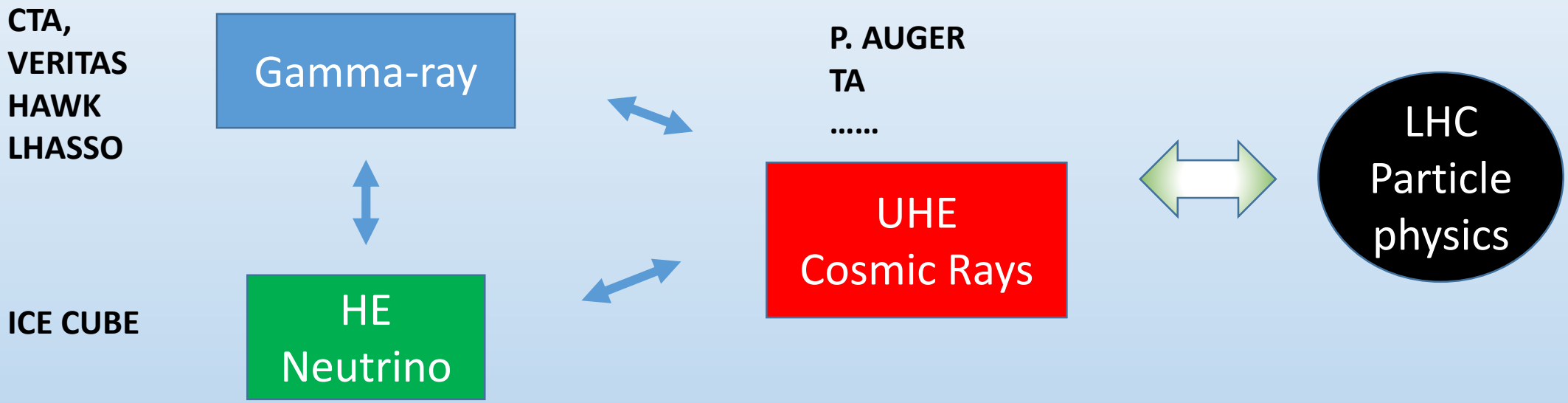
Discussions for exploring/developing "Very High Energy Particle Astronomy"

To see from many different viewpoints



Is the present status "complete enough" to further explore "Particle Astronomy" ?

Questions, Comments, Advices, Suggestions, ……..

- ASHRA/NTA for VHEPA

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Discussions for exploring/developing "Very High Energy Particle Astronomy"

• Gamma, Neutrino, and Gravitational Wave from Cosmic Ray Origin (provisional)	Ioka
• LHC for Cosmic Ray Origin (provisional)	Menjo
• Cosmic Ray Acceleration Mechanism	Ohira
• X-ray and Gamma-ray Observations of Cosmic-ray Accelerators	Uchiyama
• VERITAS and HAWC: Windows on Cosmic Particle Acceleration From 0.1-100 TeV	Smith
• Auger Results on Cosmic Ray Origin: Status and Plans	Kampert
• The latest IceCube results and the implications	Mase
• Telescope Array results on UHE Cosmic Rays and the plan	Sagawa
• Neutrino Connection with Cosmic Ray Origin	Reno
• Diffuse neutrino fluxes and GZK neutrinos with IceCube	Ishihara
• Radar Chamber for Detection of UHE Neutrinos	Chiba
• Future Prospects of UHE neutrino detection with Electromagnetic Fields	Hanson
• UHE neutrinos at the Pierre Auger Observatory	Alvarez-Muniz
• Neutrino Telescope Array (NTA)	Hou

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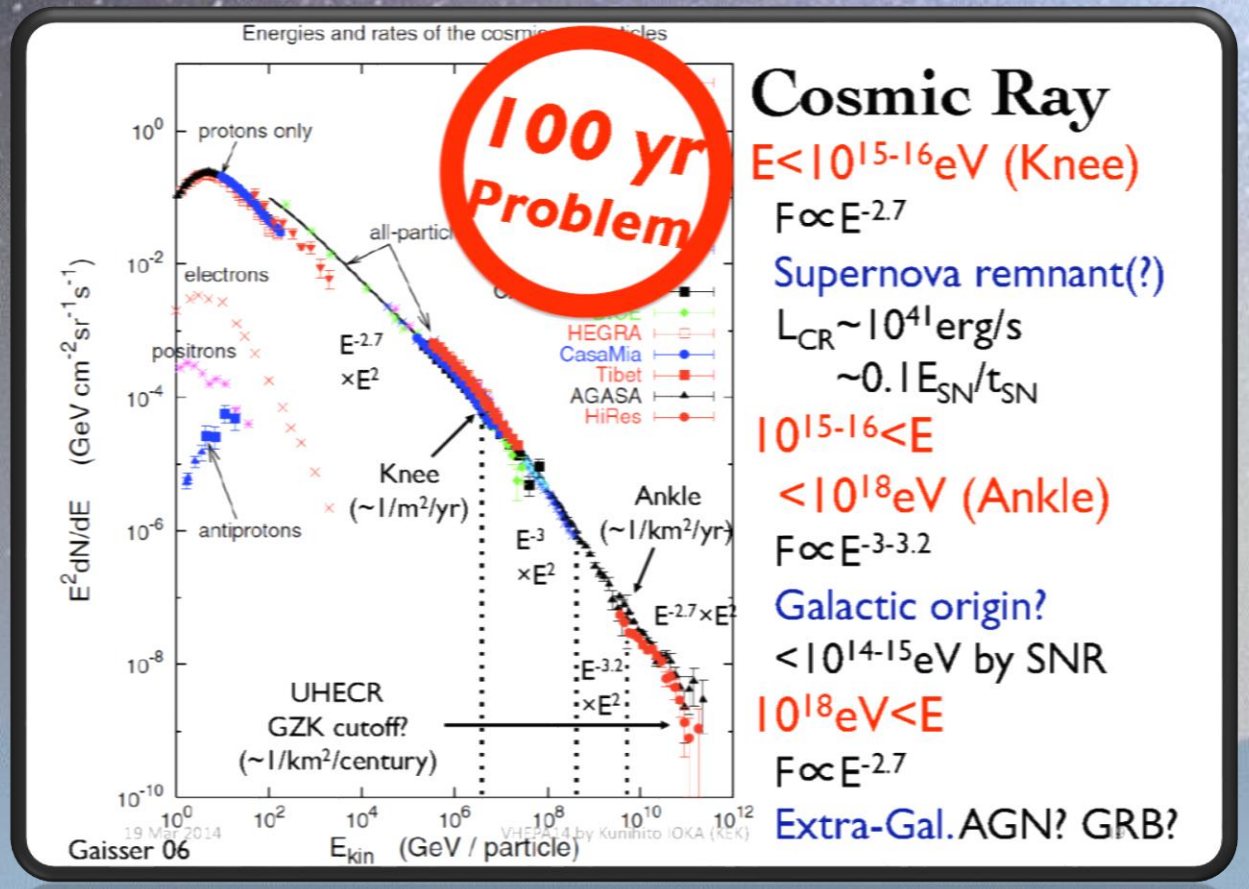
Cosmic Ray Origin(s)



Cosmic Ray

$E<10^{15\text{-}16}$eV (Knee)

$F\propto E^{-2.7}$

Supernova remnant(?)

$L_{CR}\sim10^{41}$erg/s

$\sim0.1E_{SN}/t_{SN}$

$10^{15\text{-}16}<E$

$<10^{18}$eV (Ankle)

$F\propto E^{-3\text{-}3.2}$

Galactic origin?

$<10^{14\text{-}15}$eV by SNR

10^{18}eV$<E$

$F\propto E^{-2.7}$

Extra-Gal. AGN? GRB?

- ***Multi-wavelength up to Gamma-ray***
  - SN-GRB, Supernova remnant, Fermi bubble, …
  - CTA is coming soon
- ***Cosmic-ray***: $e^{\pm}$, He/p, UHECR GZK cutoff, …
- ***Neutrino***: PeV ν sources = UHECR sources?
- ***Gravitational wave***: Macronova, NS-NS/BH?
- ***Radio***: Fast radio bursts are PeV accelerators?

21 Century: Multi-Messenger Era

19 Mar 2014 VHEPA14 by Kunihito IOKA (KEK) 100

K. Ioka (KEK)

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VHE Particle Accelerators

Particle accelerations

Diffusive shock acceleration (1st order Fermi)

Turbulent acceleration (2nd order Fermi)

Shear acceleration

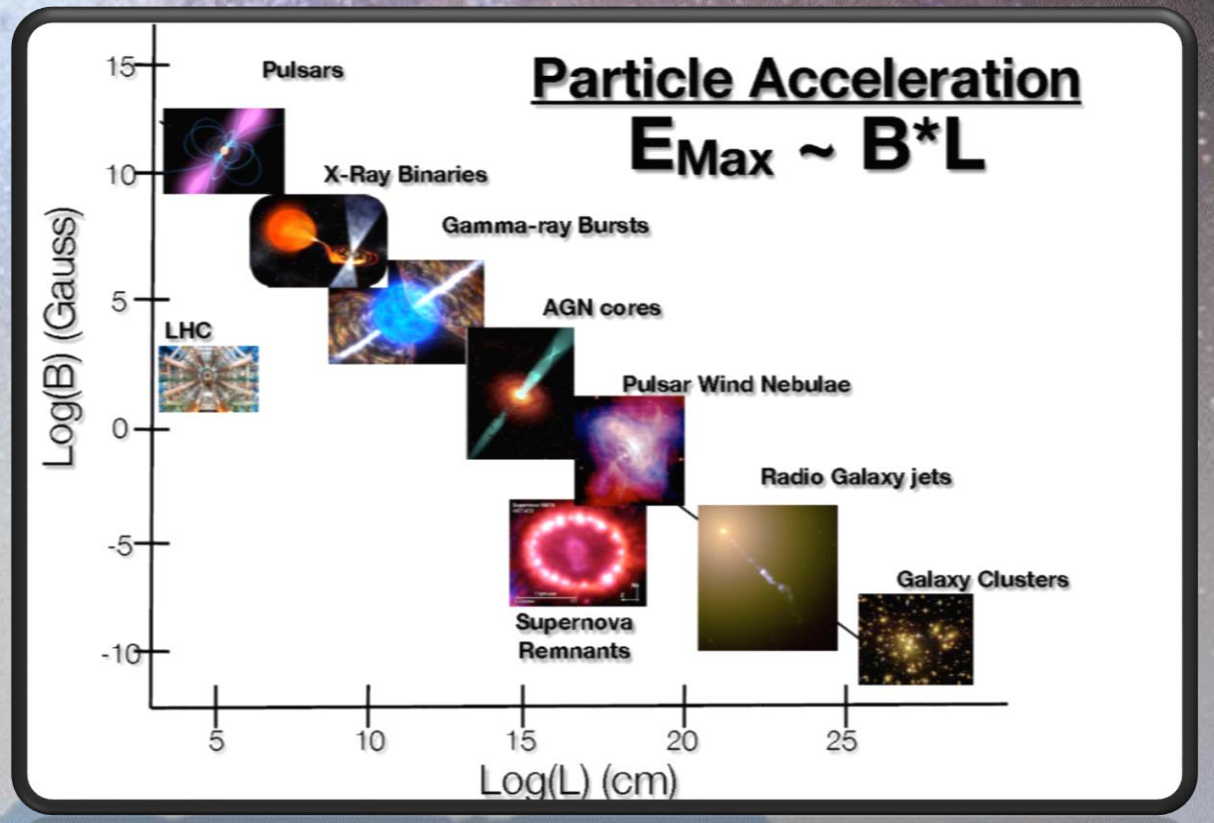
Surfing acceleration

Shock drift acceleration

Acceleration in the magnetic reconnection

Direct acceleration by electric fields and so on.

Y. Ohira (Aoyama)



A. Smith (Utah)

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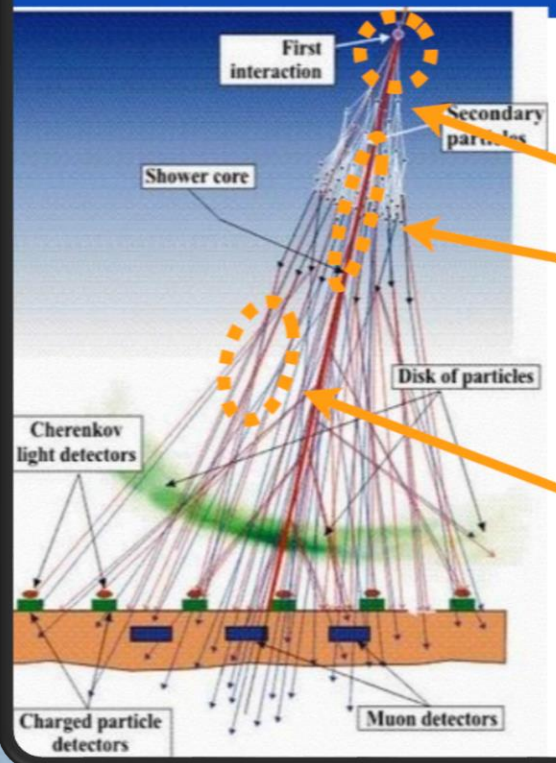
Understanding Air-shower is Essential

Key parameters for Air Showers

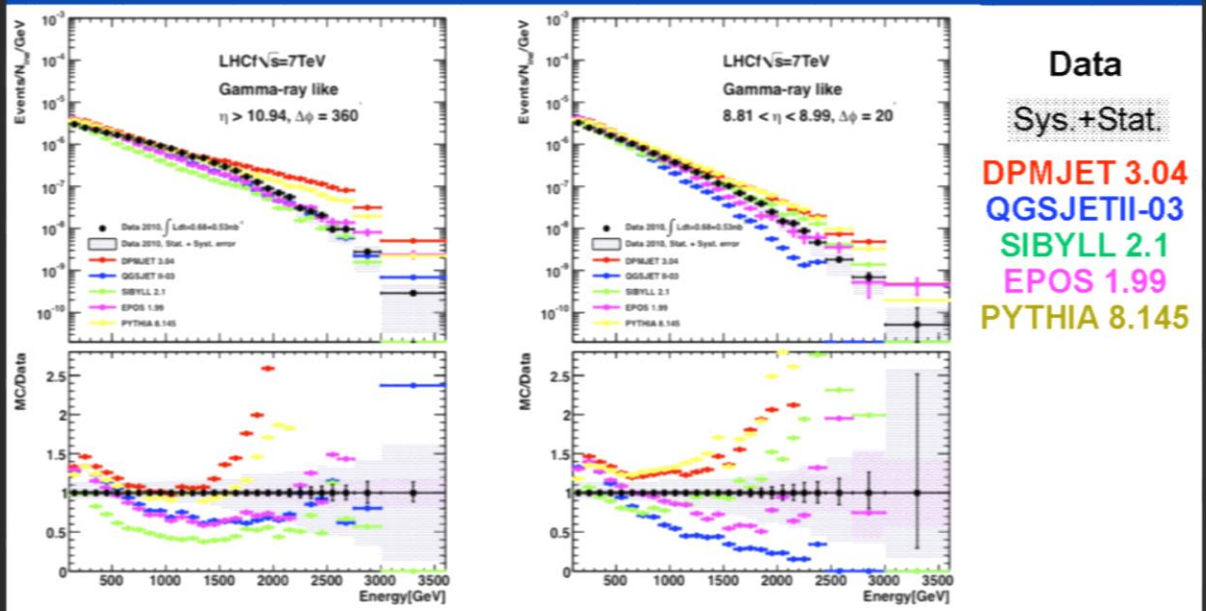


Key Parameters

- Inelastic Cross Section
  →TOTEM, ATLAS, CMS,ALICE
- Forward Energy Spectrum
  →LHCf, ZDC and etc.
- Inelasticity k= 1-p_{lead}/p_{beam}
  →LHCf, ZDC and etc.
- Secondary interactions

+Nuclear Effect @ CR-Air

Photons at 7TeV p-p



- No model can reproduce the LHCf data perfectly.
- Data points are on the middle of MC predictions except E < 500GeV.

Multi-particle Formation at VHEPA2014

Particle	GeV -	TeV -	PeV -	EeV -
Photon	Fermi	VERITAS HAWC	HAWC	Auger
Nucleon	(done)	(done)	HAWC	Auger TA
Neutrino	(done)	IceCube ------→	NTA	Auger ARIANNA …

Black: operating, Blue: constructing, Red: plan

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Elementary particles and Universe

素粒子的宇宙像

Particle accelerators

Fermi Lab Tevatron	W = 2TeV
CERN Lep	91-136GeV
LHC	**14 TeV**
linear collider	0.5 – 1 TeV

beyond standard model

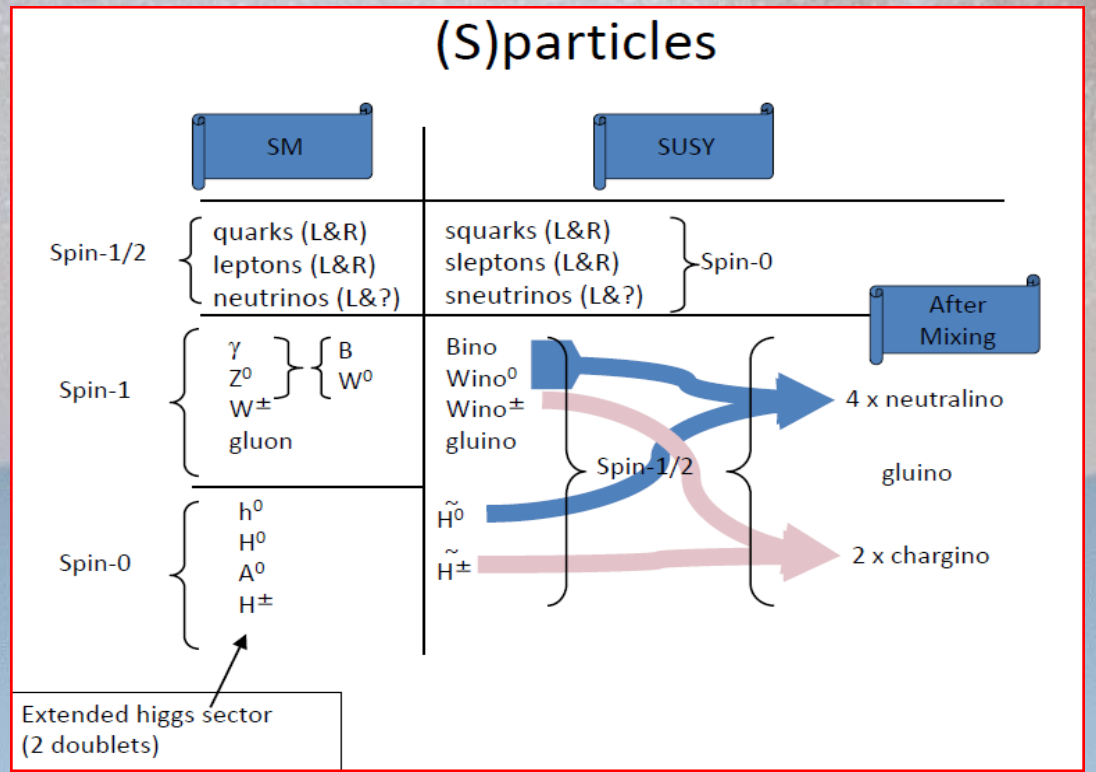
Center of mass energy W

$E\, m_p > W^2 \rightarrow E > 10^{17}$ eV

$E\, \varepsilon > W^2 \rightarrow E > 10^{26\text{-}30}$ eV

But LIV ?

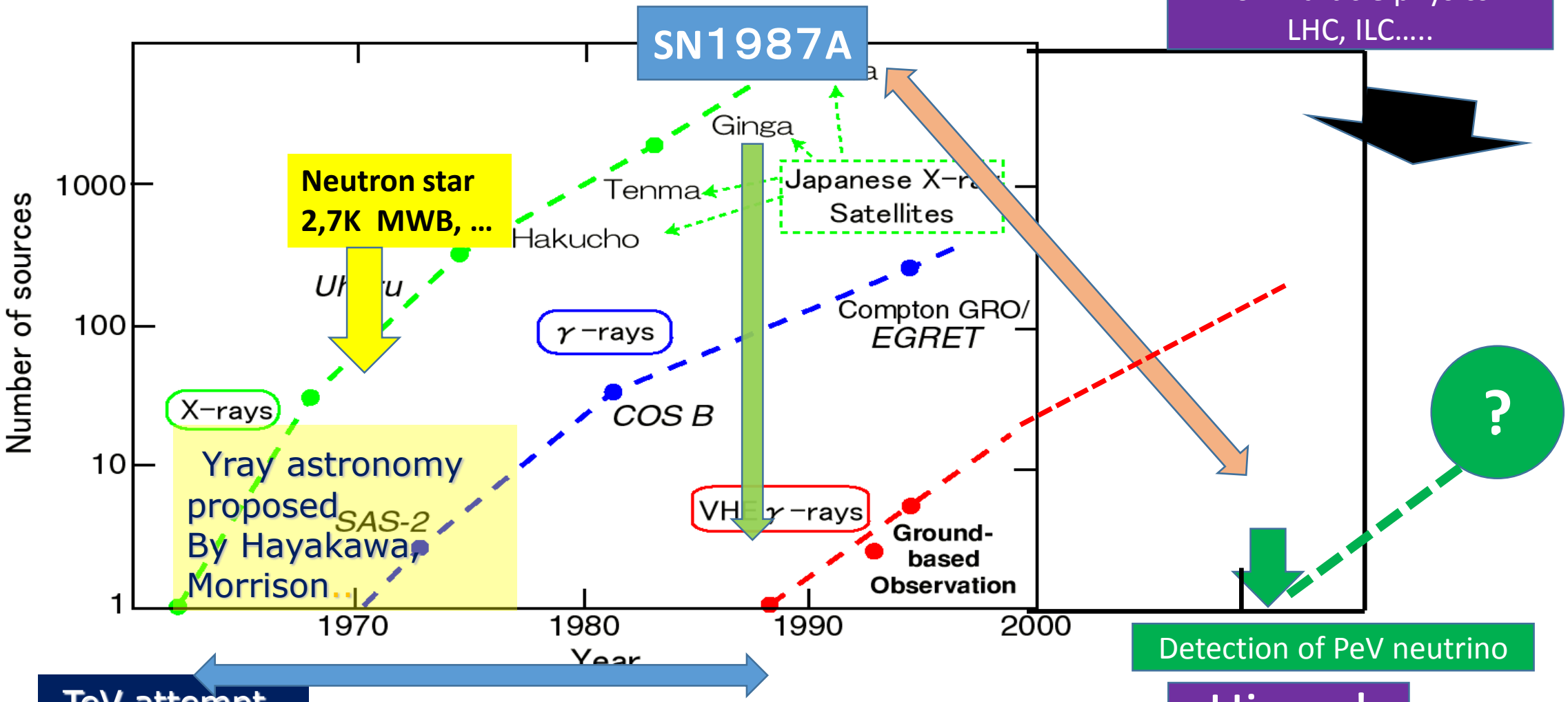
$E\, \varepsilon > W^2 \rightarrow E > 10^{13\text{-}17}$ eV



Present status in ≈ 50 years time scale

From the viewpoint of CRs

From Particle physics…
LHC, ILC…..



Detection of PeV neutrino

Higgs !

TeV attempt
Chudakov,
Porter, o o o

Breakthrough
by IACT

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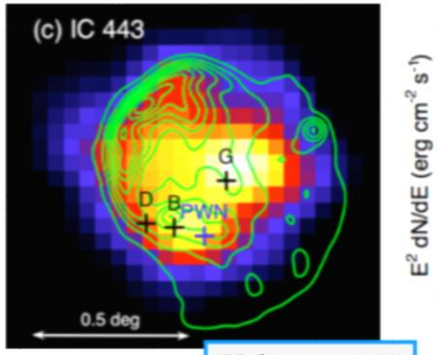
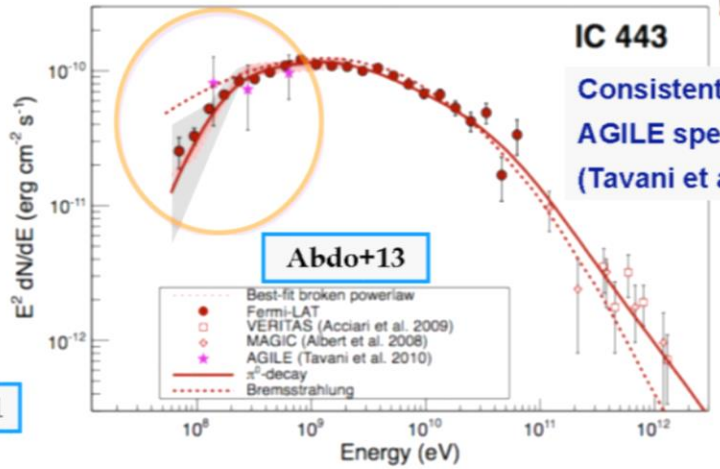
Powerful Photon Morphology with Fermi

Signature of π^0-decay Gamma-rays



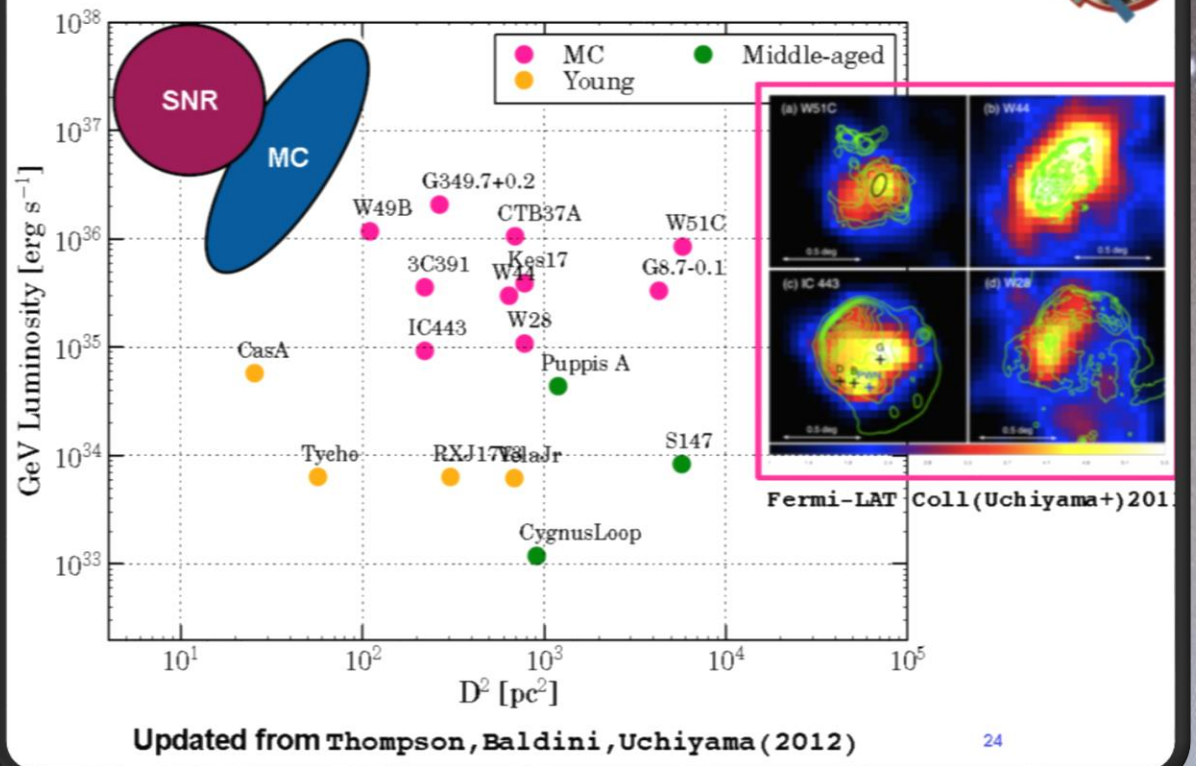
Uchiyama+11



- ☑ Our previous papers reported spectra only >200 MeV.
- ☑ Here we report spectra down to 60 MeV thanks to:
  - ✱ Recent update ("Pass-7") of event reconstruction, which largely improved effective area at low energies.
  - ✱ Increased exposure time: 1 yr ➜ 4 yr

Sub-GeV spectra of IC443/W44 agree well with π^0-decay spectra.

SNRs Detections with Fermi



Uchiyama (Rikkyo)

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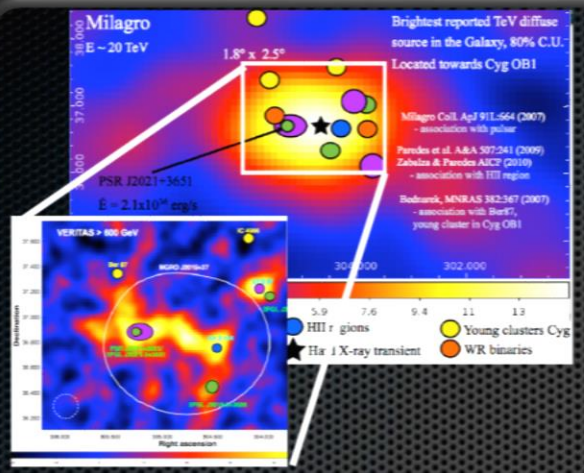
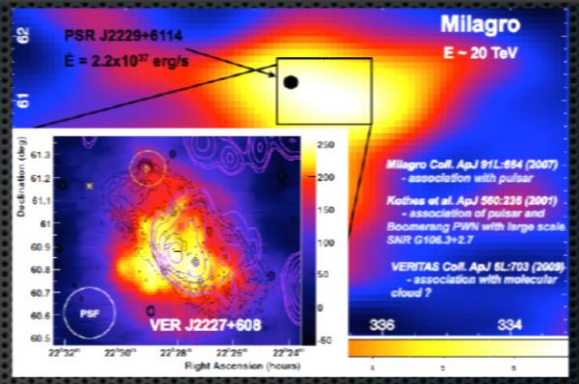
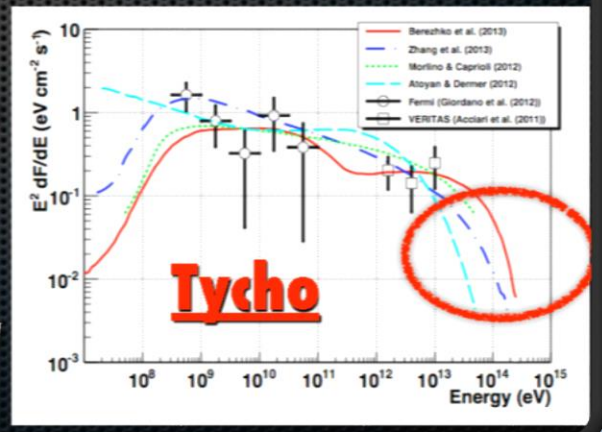
Powerful Photon Morphology & Survey with VERITUS/MIRAGRO/HAWC

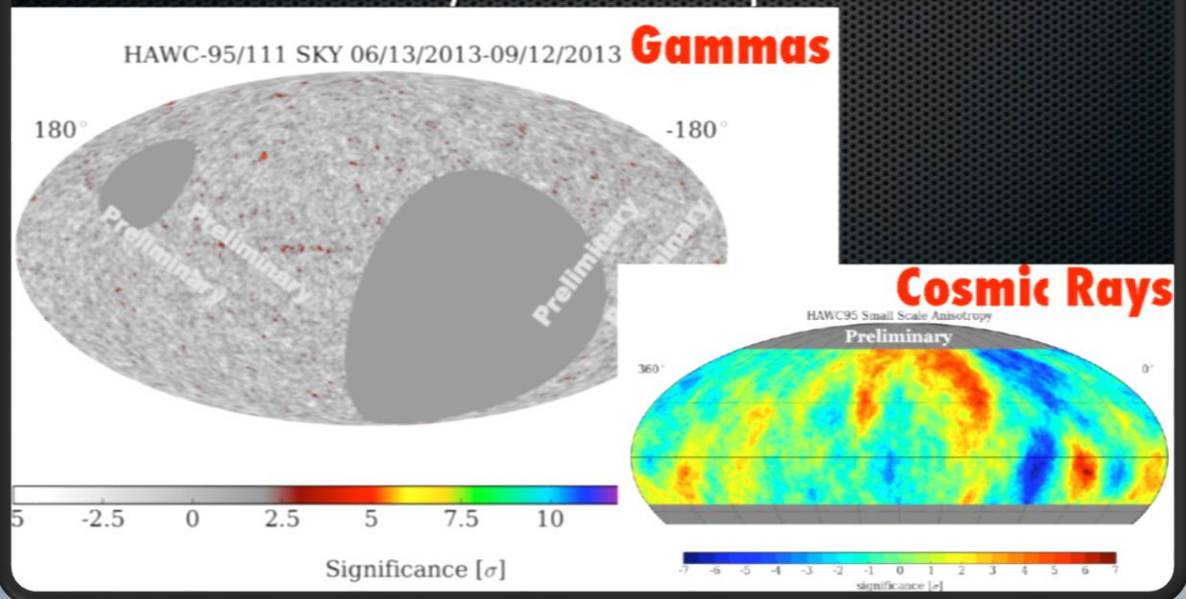




Success of combining Milagro and VERITAS data already demonstrated: multiple overlapping sources revealing complicated networks of emission. With HAWC, this will only improve as well as allowing for combined spectra will allow for distinction between emission models



-HAWC will provide ~15x more sensitive observations of the multi-TeV sky, with nearly 100% duty cycle. Array to be fully commissioned Fall 2014, initial results already indicate excellent performance ahead



A. Smith (Utah)

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distance to emission sources,
Propagation

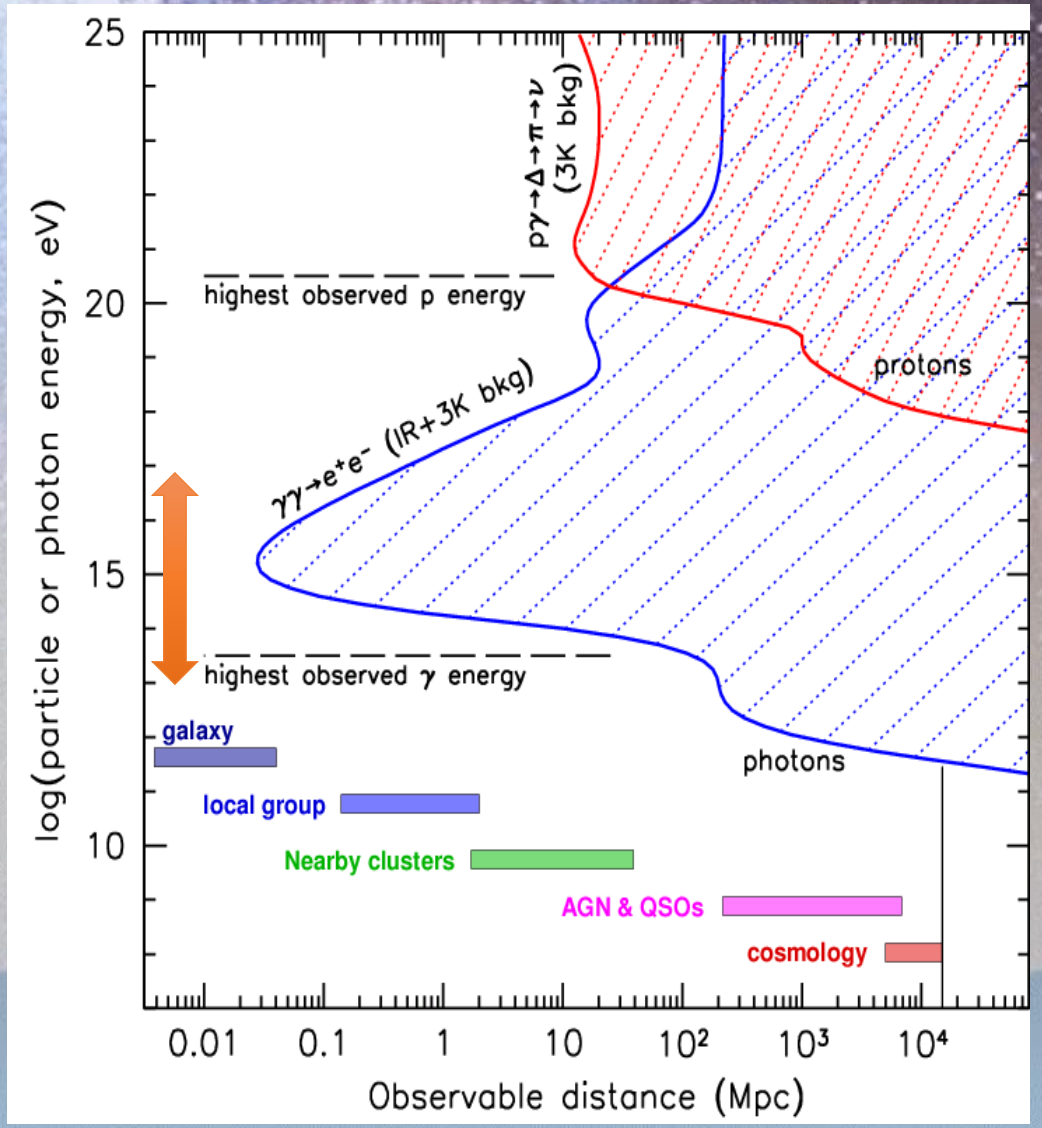
Seek for Unknown Region

Seek and Check

Nearby Local Universe and
$\gamma\gamma \rightarrow e^+e^-$ (IR+3K BG) Suppress

above 10TeV
with Ashra NTA IACT Survey

Discovery Nearby Sources?
New "Super GZK" Impact?



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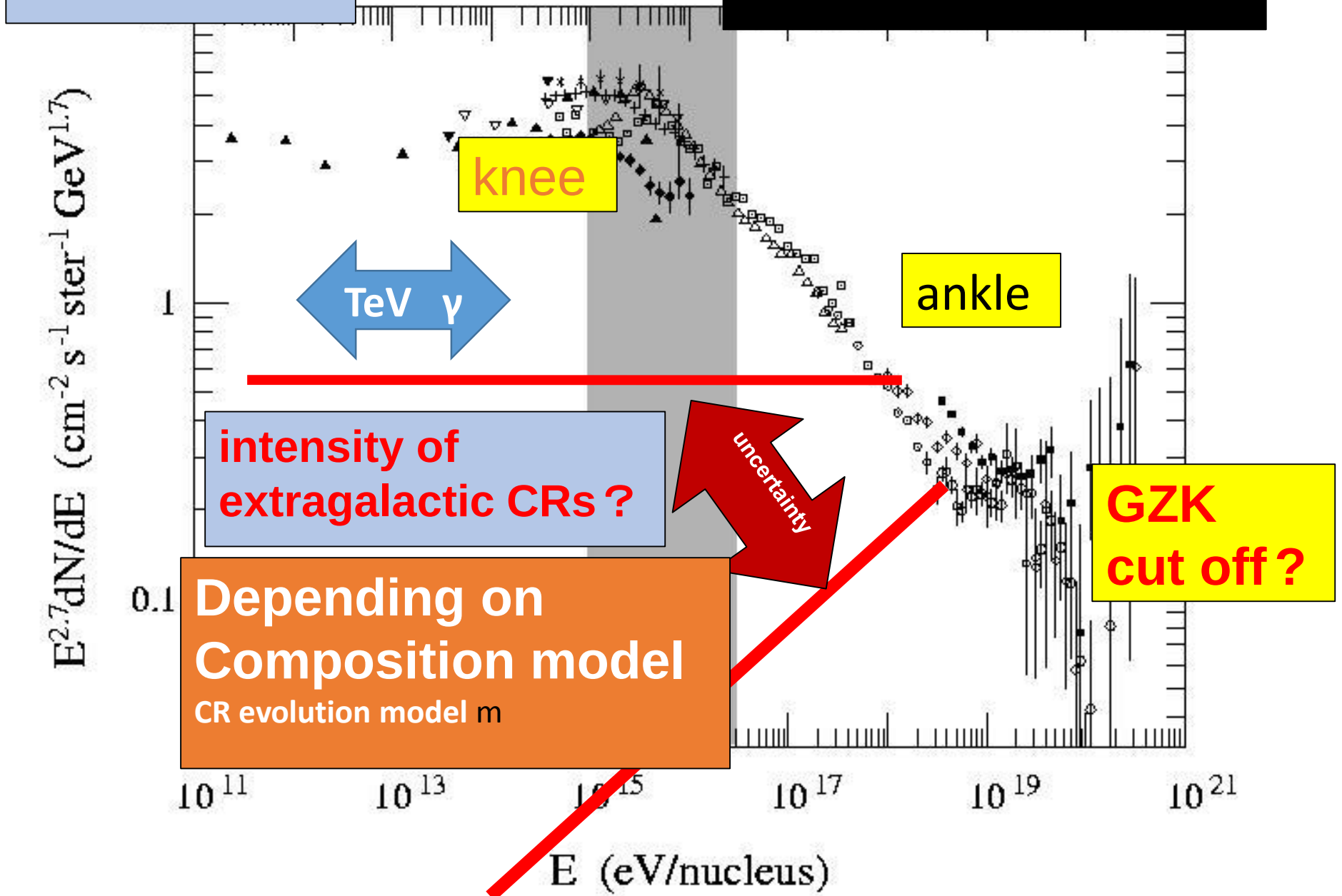
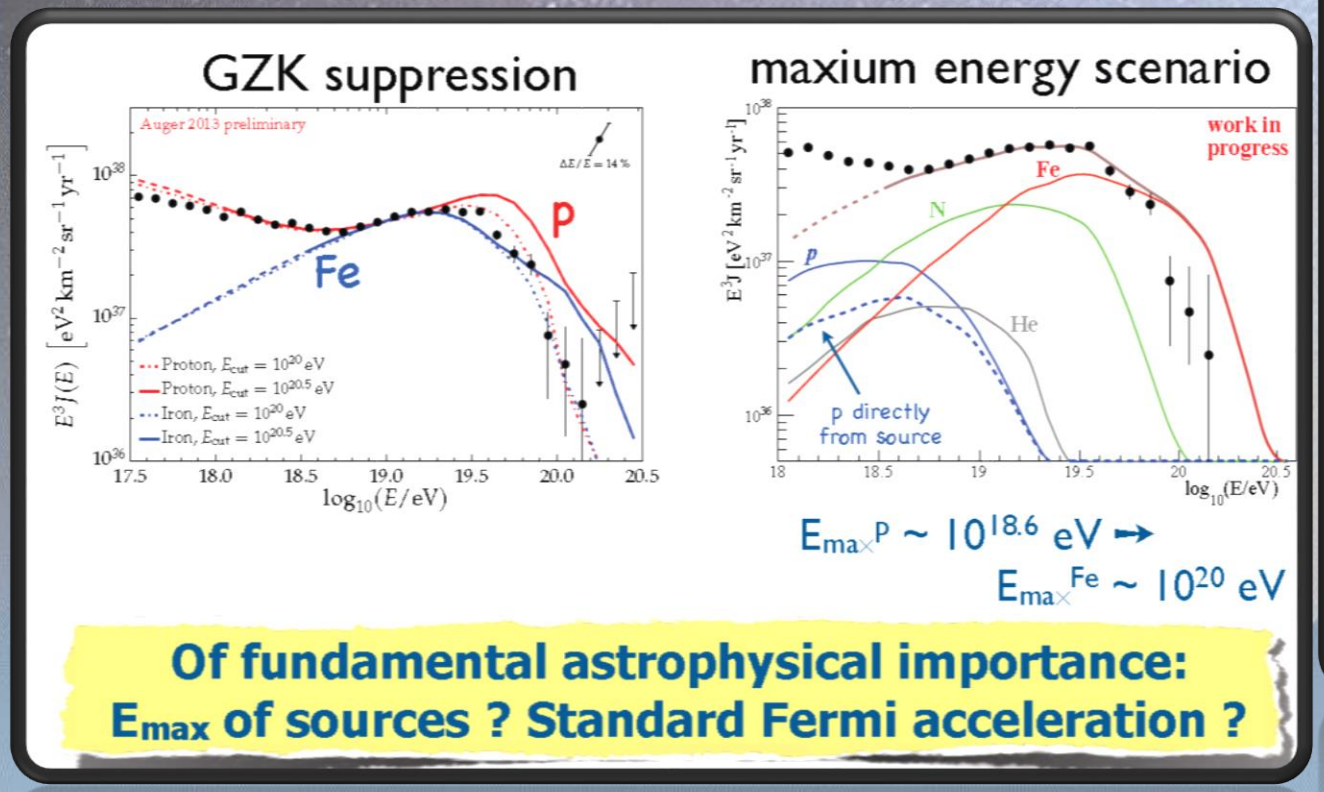
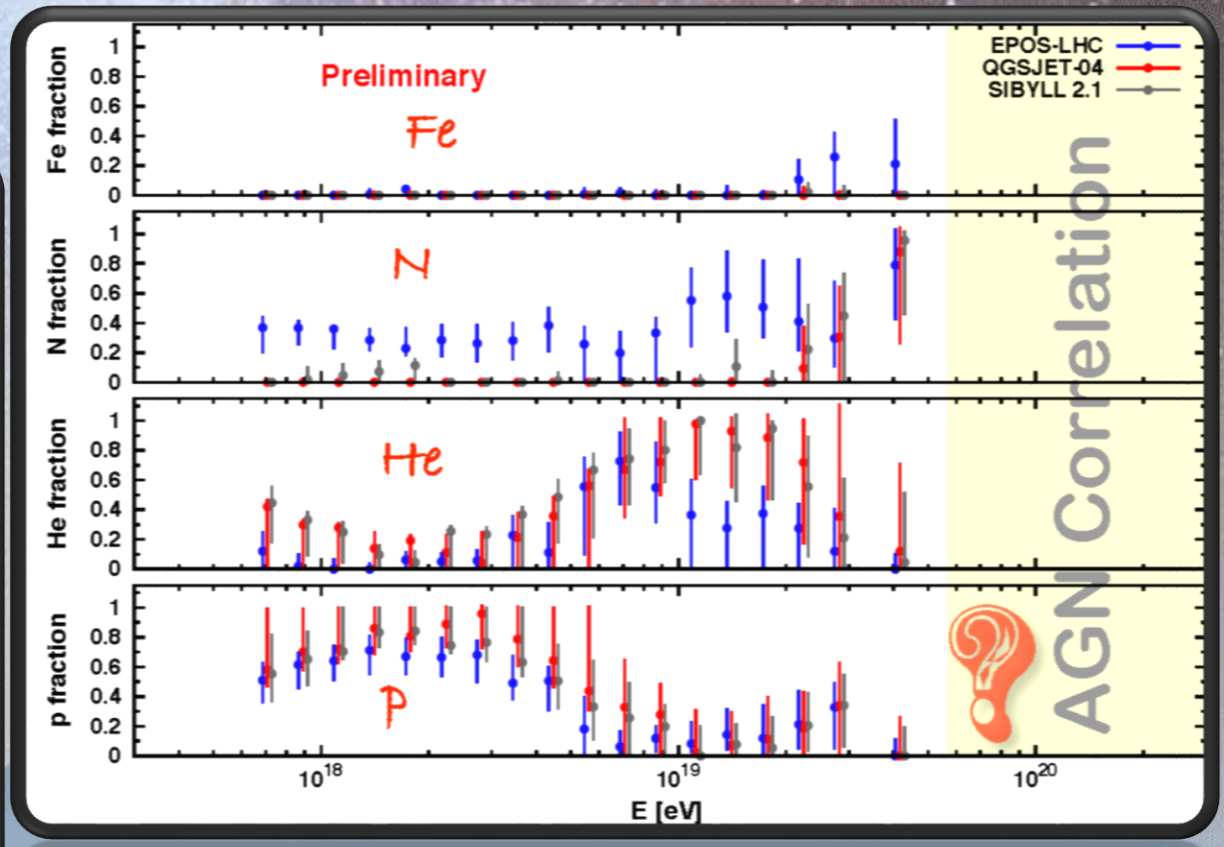
CR flux × $E^{2.7}$

in other galaxies ?



Importance of Nearer CR Sources & Composition Change





Kampert (Auger spokesperson, Wuppertal)

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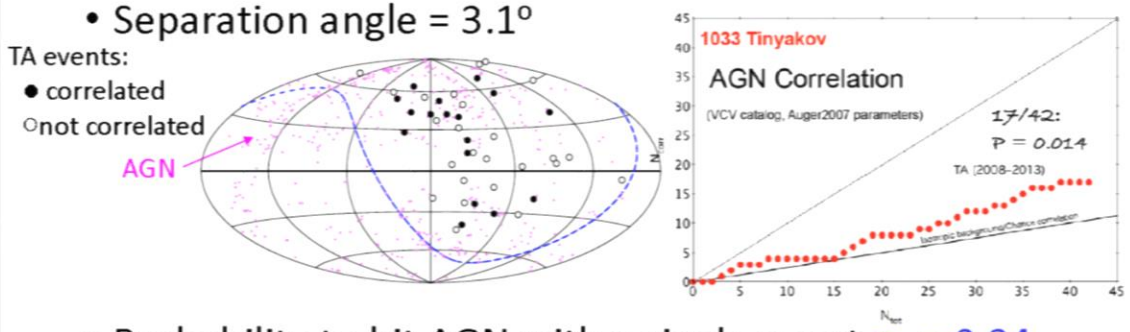
Indication CR Origins with TA

Correlations with AGN

- 472 AGN from 2006 Veron catalog with z < 0.018
- E > 57 EeV, zenith angle < 45°, N = 42 (5 yr)
- Separation angle = 3.1°

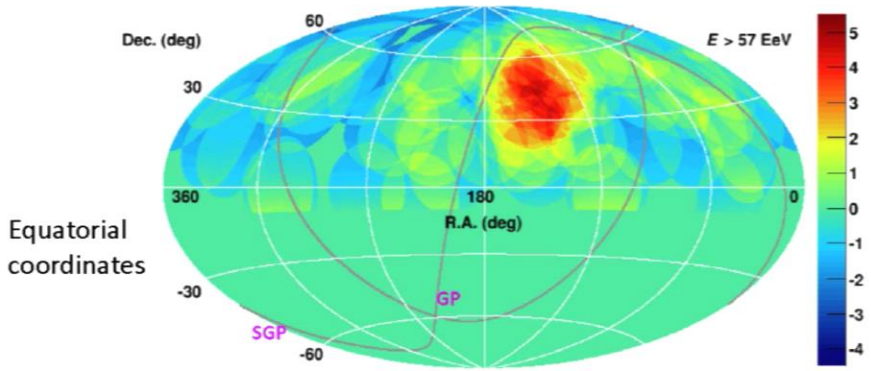


- Probability to hit AGN with a single event $p_o = 0.24$
- 17 events correlate out of 42 (0.40) $\Longrightarrow p = 1.4\%$

K. Sagawa (Tokyo)

Significance Map

Oversampling with a 20° radius for 72 events above 57 EeV



- Statistical significance 5.1σ (before correction)
- Chance probability: 3.6σ (1.4×10^{-4})

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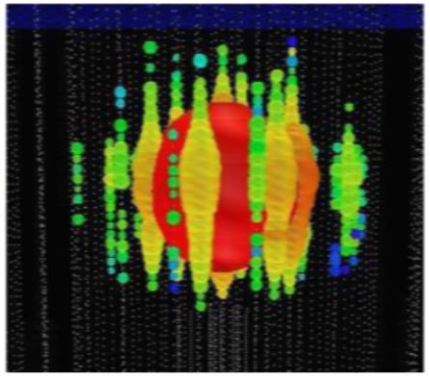
Direct Evidence of CR Origin with VHE ν

May, 2011 - May, 2012 (350.9 days), IC86 configuration

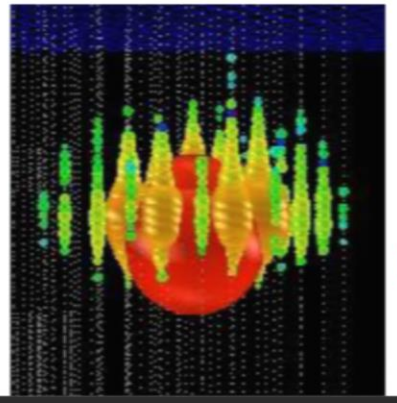
PRL 111, 021103 (2013)

Either CC interaction of ν_e or NC interaction of any flavor ν

"Bert"
Aug., 9th, 2011
Run 118545
-Event 63733662
NPE: 7.0 x 10^4
NDOM: 354
1.04±0.16 PeV



"Ernie"
Jan, 3rd, 2012
Run 119316
-Event 36556705
NPE: 9.6 x 10^4
NDOM: 312
1.14±0.17 PeV



	event rate in 615.9 days
Atmospheric muons	0.038 ± 0.004
conventional atmospheric neutrinos	0.012 ± 0.001
prompt neutrinos*	0.033 ± 0.001
total background	**0.082 ± 0.004**

* R. Enberg et al., PRD78, 043005 (2008)

Significance: 2.8σ

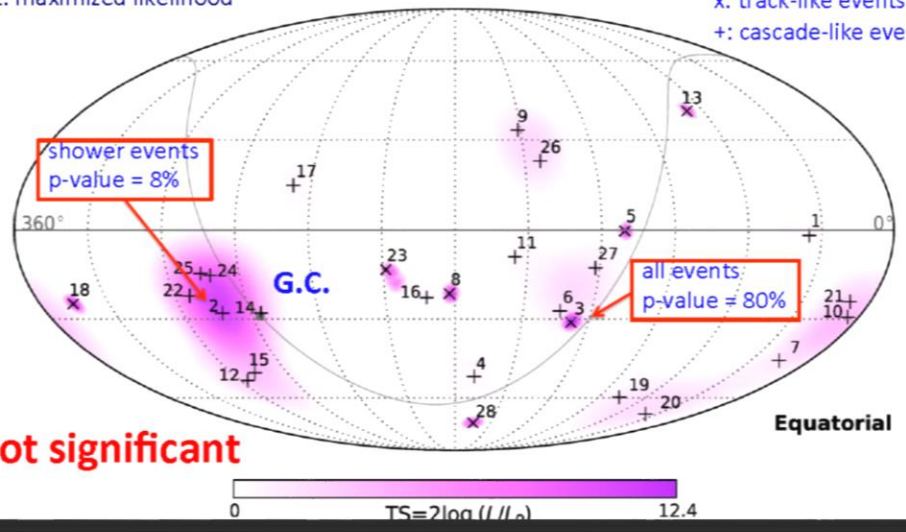
Highest energy neutrinos ever seen!

Sky map and the significance

Test null hypothesis against the most likely
L0: null hypothesis
L: maximized likelihood

Science, 342, 1242856 (2013)

x: track-like events
+: cascade-like events



Not significant

K. Mase (Chiba)

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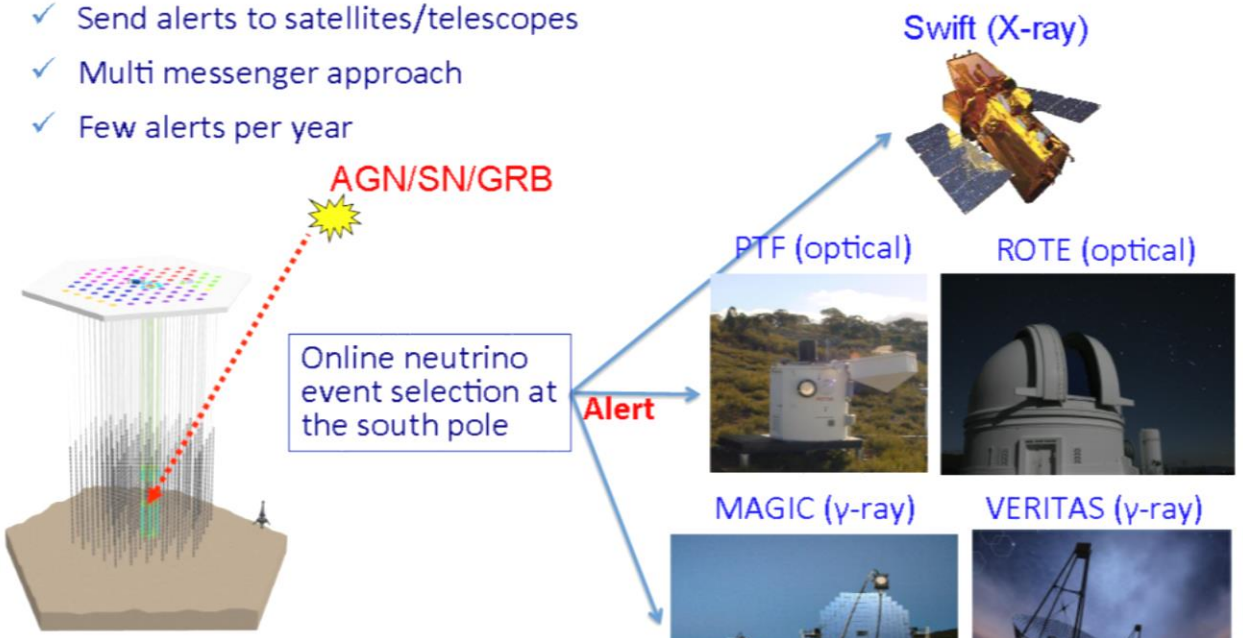
Toward VHE ν, γ, CR campaign

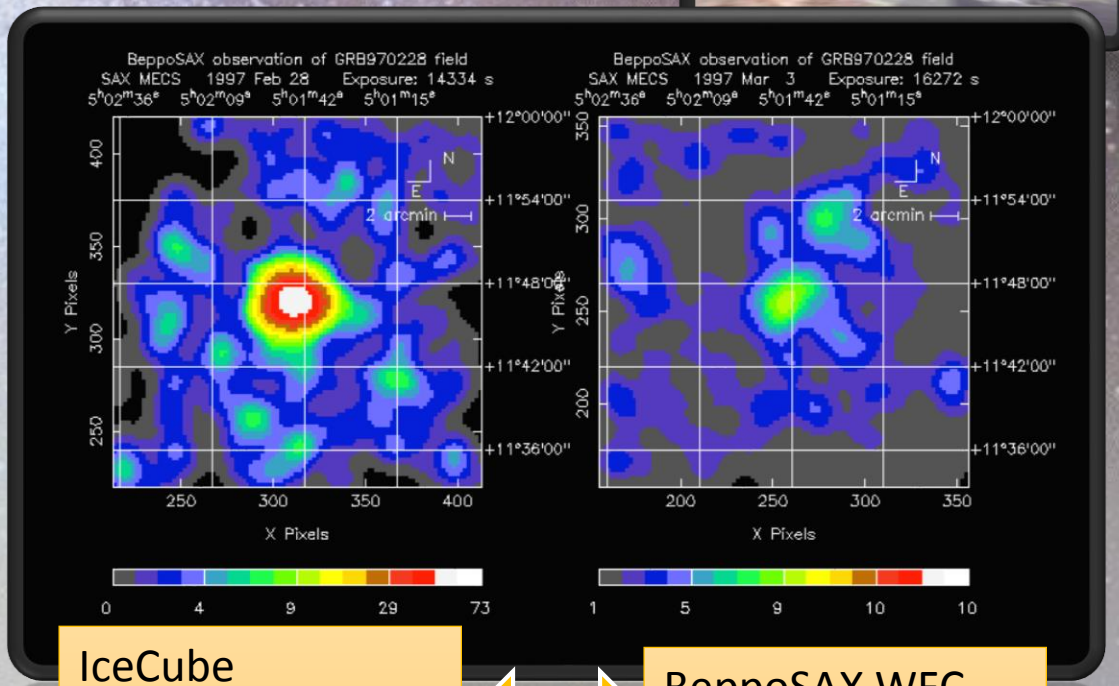
IceCube follow-up programs

- ✓ Send alerts to satellites/telescopes
- ✓ Multi messenger approach
- ✓ Few alerts per year



EHE online alert is coming

K. Mase (Chiba)



IceCube
Track ~1deg.
Cascade ~10deg.

BeppoSAX WFC
3-5 arcmin.

More accuracy and sensitivity to realize Multi-particle Obs.

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Cosmogenic ν

Range of predictions – cosmogenic neutrino flux

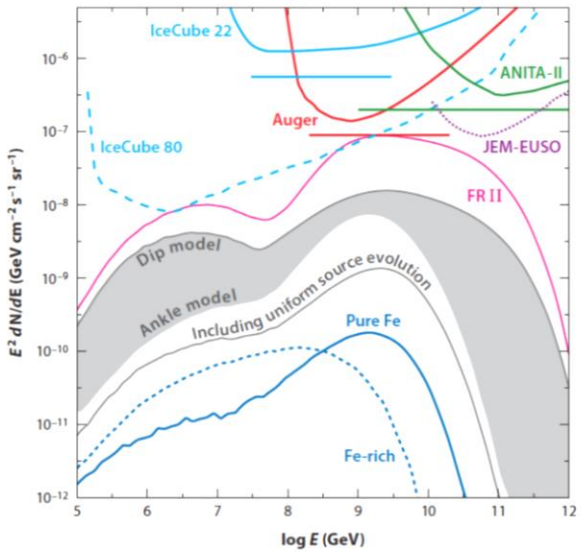
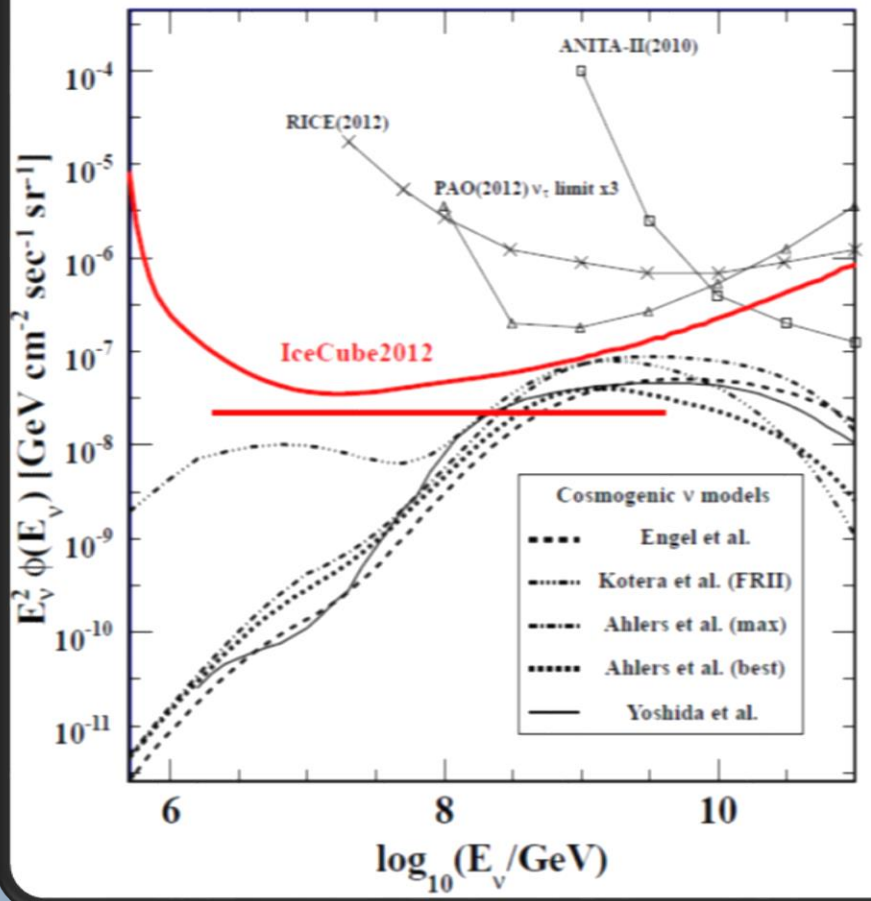


Fig. from Kotera & Olinto, Ann. Rev. Astron. Astrophys. 49 (2011).

M. H. Reno (Iowa)

Model independent quasi-differential upper limit



- Including Energy PDF of the two events
  - PeV region upperlimits are weaken by the 2 event observation
- Significantly improved from the previous upperlimits
- IceCube becoming more and more sensitive to cosmogenic fluxes above ***100 PeV (10^8 GeV)*** and started to constrain the highest energy comsic-ray source evolutions
- E^{-2}flux integrated limit taking into 2 observations

$E^2\varphi(\nu e+\nu\mu+\nu\tau) = 2.5\times10^{-8}\mathrm{GeV}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ (1.6 PeV – 3.5 EeV)

A. Ishihara (Chiba)

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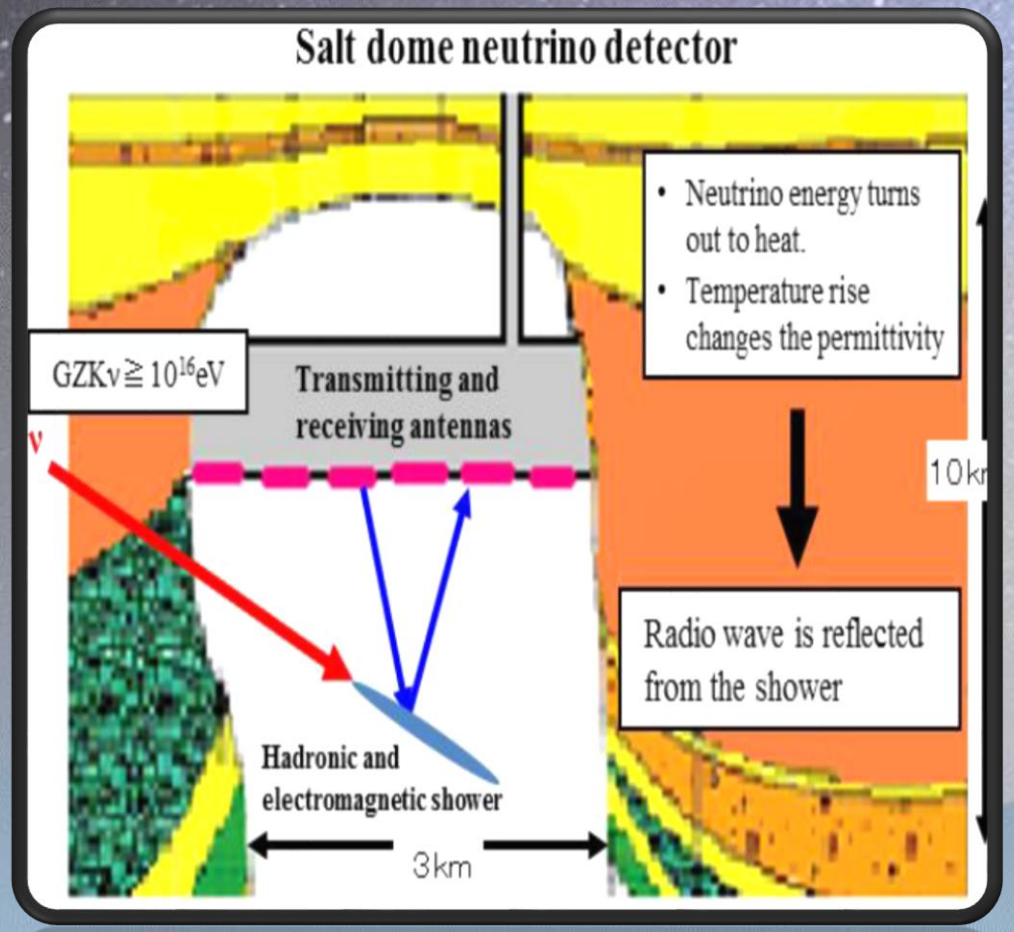
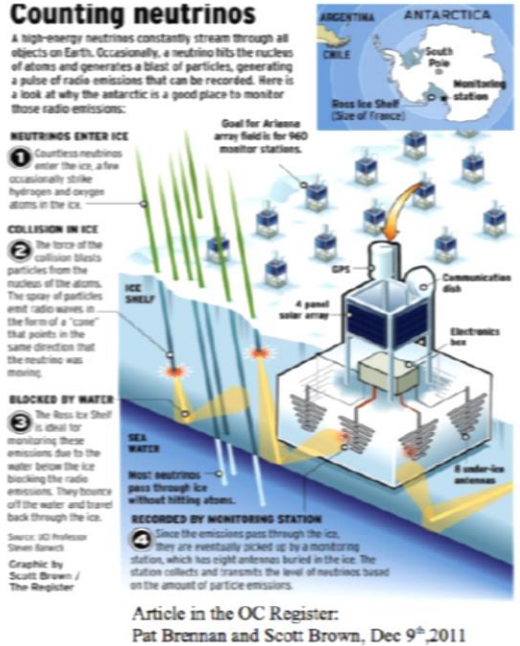
EM Field Technique for UHE ν



M. Chiba (Tokyo Metropolitan)

ARIANNA - Antarctic Ross Ice Shelf Antenna Neutrino Array



Article in the OC Register:
Pat Brennan and Scott Brown, Dec 9th,2011

- Attenuation lengths ≈ 500 m, high relfection
- Far from backgrounds, close logistics
- PhD Dissertation, Jordan Hanson (2013 UCI)
- PhD Dissertation, Joulien Tatar (2014 UCI)
- "Design and Performance of the Autonomous Data Acquisition System for the ARIANNA High Energy Neutrino Detector." S. Kleinfelder for ARIANNA collab. IEEE Transactions on Nuclear Science, v.60 (2), 2013
- "A Radio Detector Array for Cosmic Neutrinos on the Ross Ice Shelf" S.R. Klein for ARIANNA collab. IEEE Transactions on Nuclear Science, v.60 (2), 2013

J. Hanson (Kansas)

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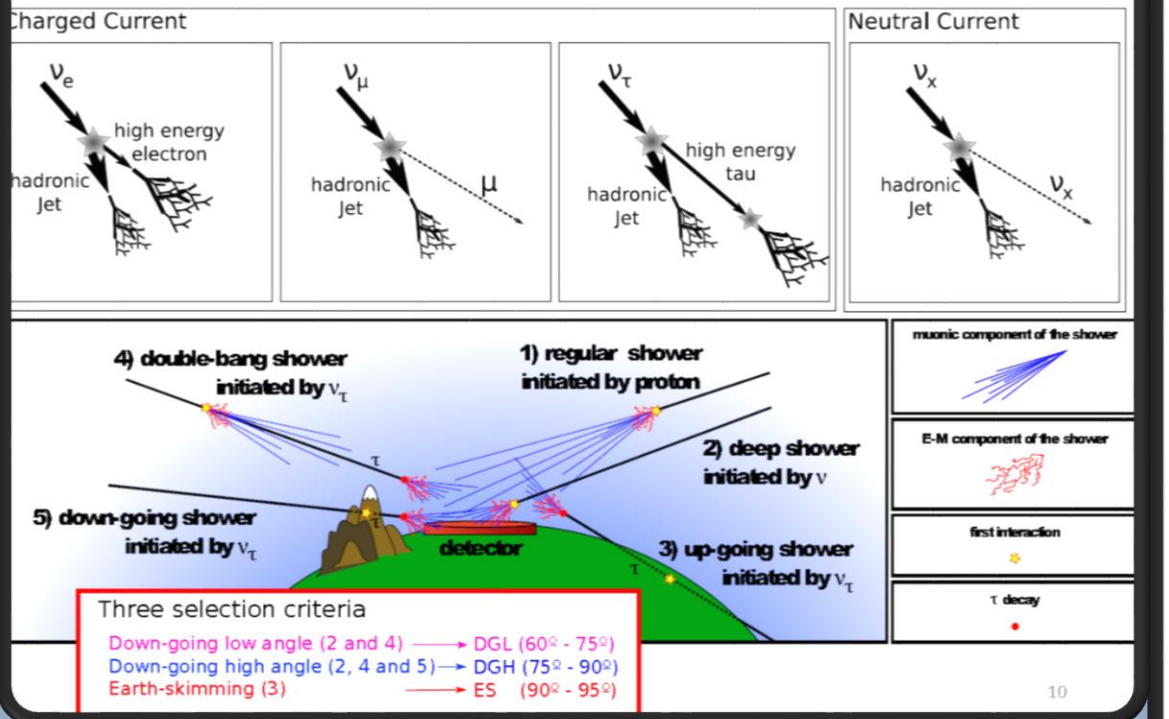
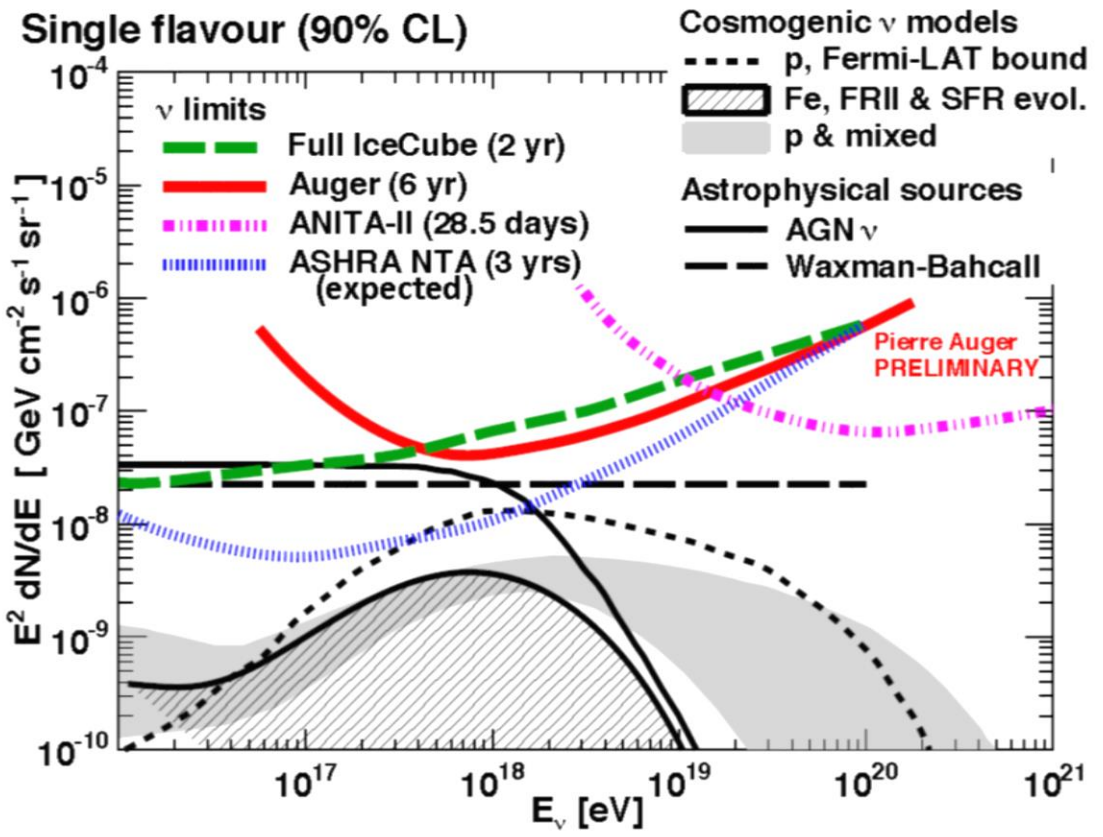
Strong Diffuse ν Limit with Pierre Auger

Sensitivity to all flavours & channels



J. Alvarez-Muniz (Santiago de Compostela)

Differential limits to diffuse flux of UHEν



All limits converted to single flavour and given per half a decade of energy

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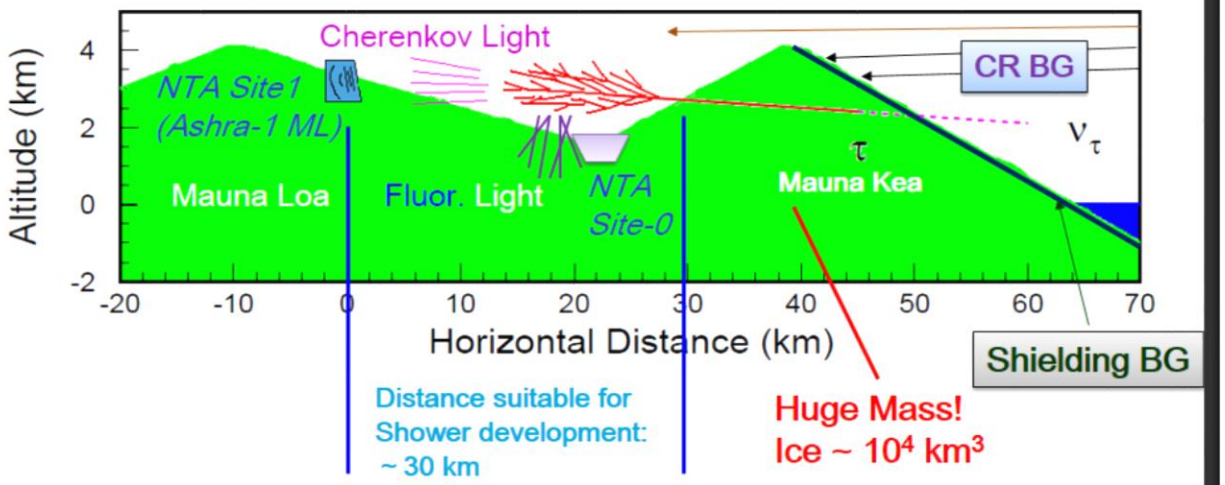
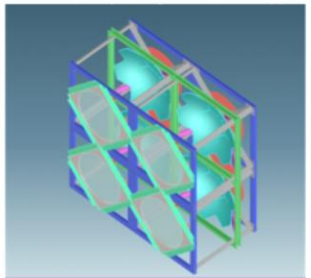
High-resolution Pointing ν with NTA

Earth-Skimming τ Shower Imaging Method

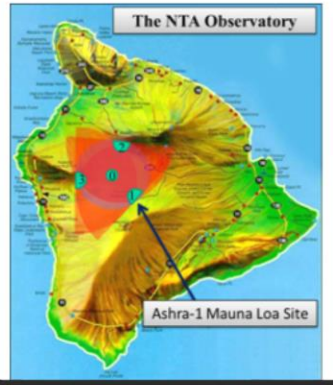


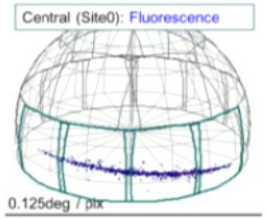
Ashra-1 really demonstrated this method !
(ApJ, 736 (2011) L12)

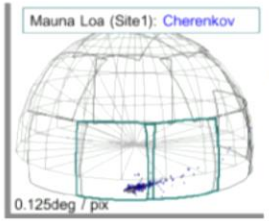
Ashra NTA

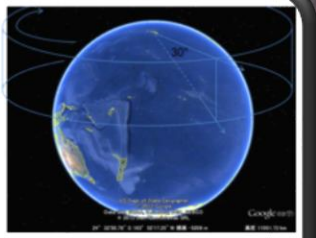


=> Concept of NTA Detector Unit with
Ashra-1 LC x 1.5 scaled-up x 4
+ same trigger & readout
=> Effective input pupil size: ϕ3m

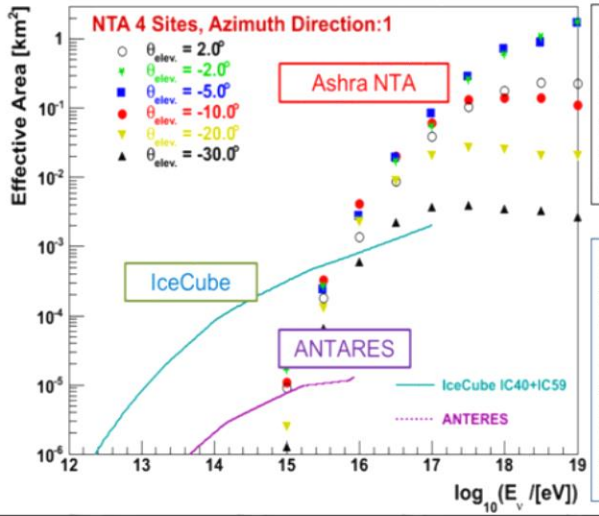








PeV-EeV ν_τ survey in 30deg(ele.) x 360deg(azi.) x 400Mpc(depth) with 0.2deg pointing assuming GRB ν_τ fluence



Azimuth-1 :
Assuming a point source in the dir. of azimuth of Mauna Kea summit from Site0 (center).

References
IceCube:
Nature 484 (2012) 351 Suppl. Info. Fig.S2 Model Independent
ANTERES:
ApJ 743 (2011) L14 Fig.2 (Right)
Declination Range -90<δ<-45 deg

G. W.-S. Hou (Taiwan)

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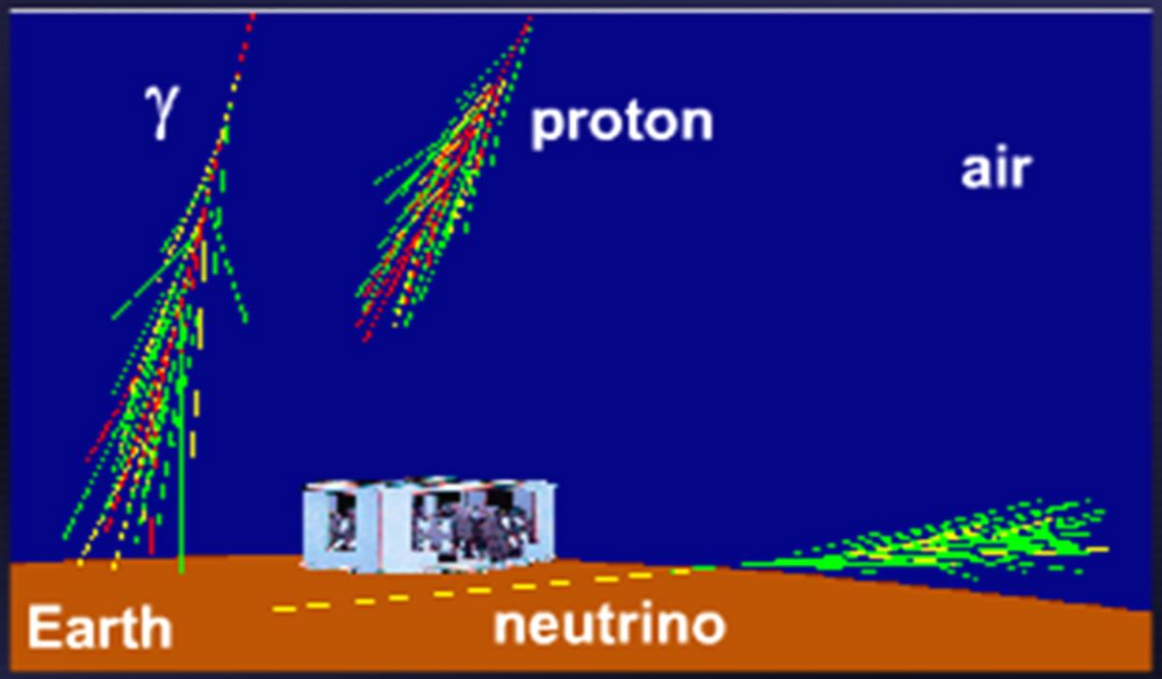
Essential Combination
Astrometry & Spectroscopy



protons, γs => light emission after interaction with the air
neutrinos => light emission after interaction with and passing through the earth

ν & γ => Astrometry
N & γ => Spectroscopy

Hadronic / Leptonic Search for CR Origin(s)

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Thanks

on behalf of Organizing Committee

.... Front-line invited speakers from around the world have presented aspects of forefront research achievements at this Workshop, in accordance with its purpose. Contributions to the Workshop are of great value to all participants and future development of the CR field ....

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See and Hope

I see that the workshop is a perfect venue to

- discuss all issues (scientific and technical) openly and frankly so that great ideas could be made greater with imperfections removed

I hope that this workshop will be able to

- Formulate plans to realize the identified opportunities
- If necessary, collaborations could be formed to realize these opportunities.

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