# Cosmic ray primary composition studies through the Gerasimova-Zatsepin effects of heavy nuclei at LAAS （the **L**arge **A**rea **A**ir **S**hower experiments)

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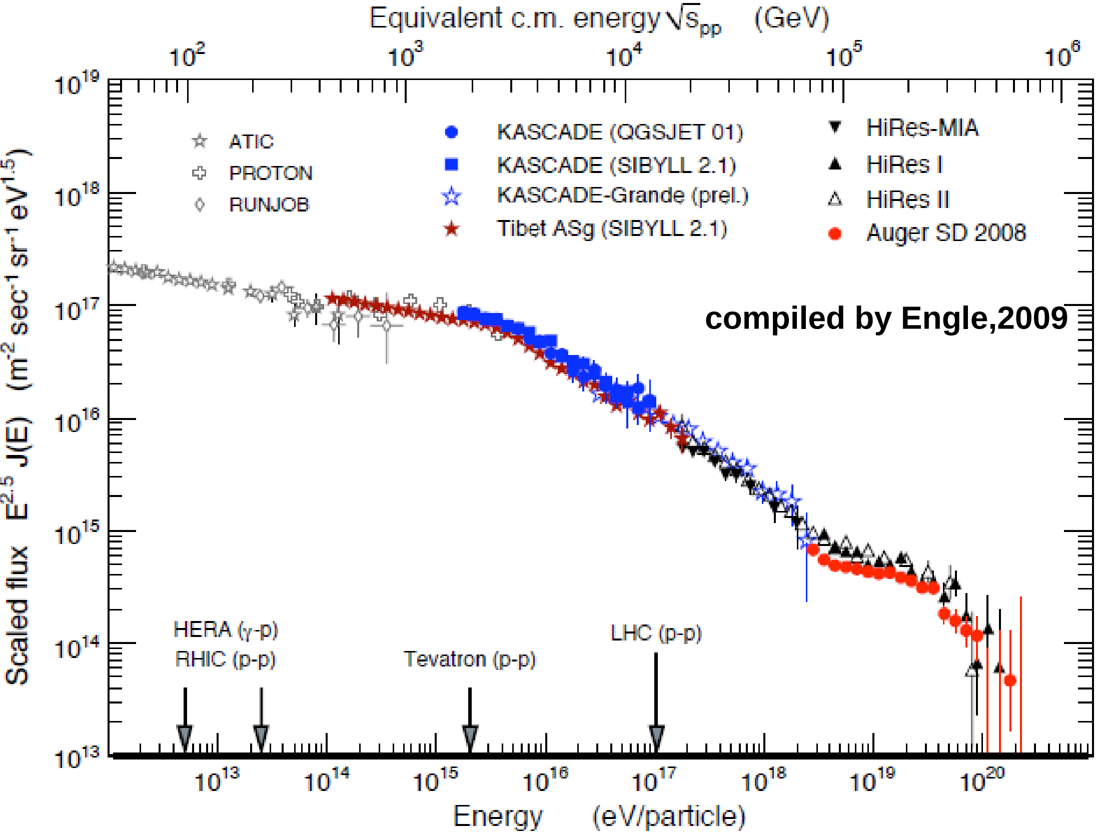
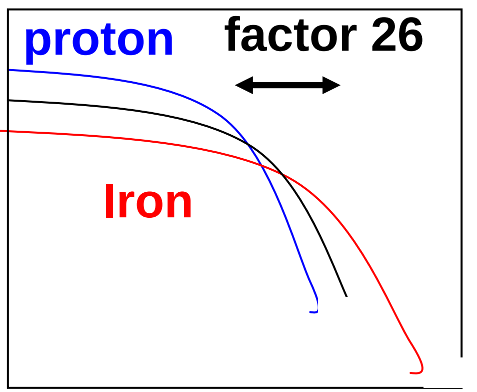
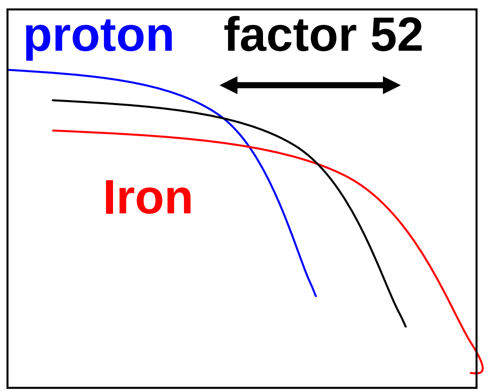
- Elemental compositions above the knee energies
  - Source/Acceleration mechanism
  - Propagation process
  - Hadronic interaction
- Direct observations have been carried out up to several × $10^5$GeV
- Indirect observations with EAS array technology have been done by means of Xmax studies and Inverse problem approaches

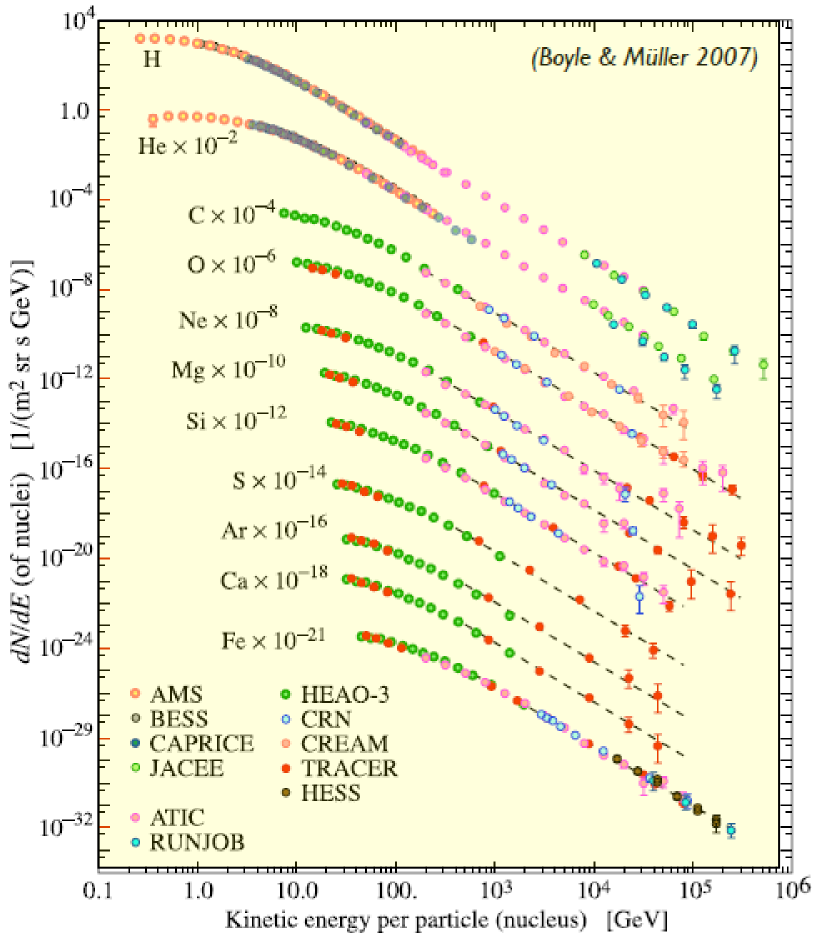



acceleration/propagation




interaction



# The photodisintegration of cosmic ray nuclei by Solar photons ⇒ proposed by Gerasimova, Zatsepin in 51's、60's

Suwa (Aoyama)(95)
Median-Tanco Watson(99),Epele et al., (99),
Fujiwara (04),Lafebre et al.,(08)

- Processes
  - Cosmic ray heavy nuclei above $10^{17}$eV and solar photons(~1eV)
    - at the rest frame of nuclei, photon energy be Lorentz-boosted to1MeV
  - Fragment nuclei（Z/A=0.5),proton（Z/A=1),neutron(Z/A=0)
    - traveling towards the Earth and deflected by the interplanetary magnetic field
    - resulting deflections depend on their rigidities
  - At the Earth
    - Multiple and simultaneous EASs observed in the very large area

- Experimental tasks
  - **large SΩT, time synchronization（GPS$\mu$ sec), angular resolution**
  - Low threshold energy for detectors because of fragment originated EASs
  - **Energy resolution required to estimate the energies of primary particles**

# Numerical approaches to estimate GZ event rates.

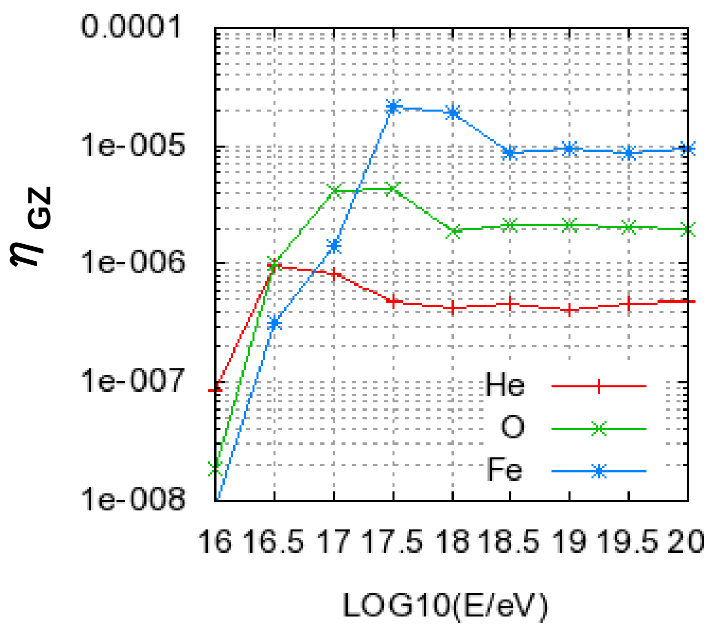
- assumptions
  - Trajectories of fragments in Solar system magnetic fields（Akasofu-Grey-Lee) from 5AU towards to the Earth → $10^{-8}$ AU step with the correction of the field strength.
  - Primary elements：Iron nuclei, Oxygen, He
  - Photodisintegration cross section（Epele et al.）
  - Energy: $10^{16}$~$10^{20}$eV
  - Energy spectrum

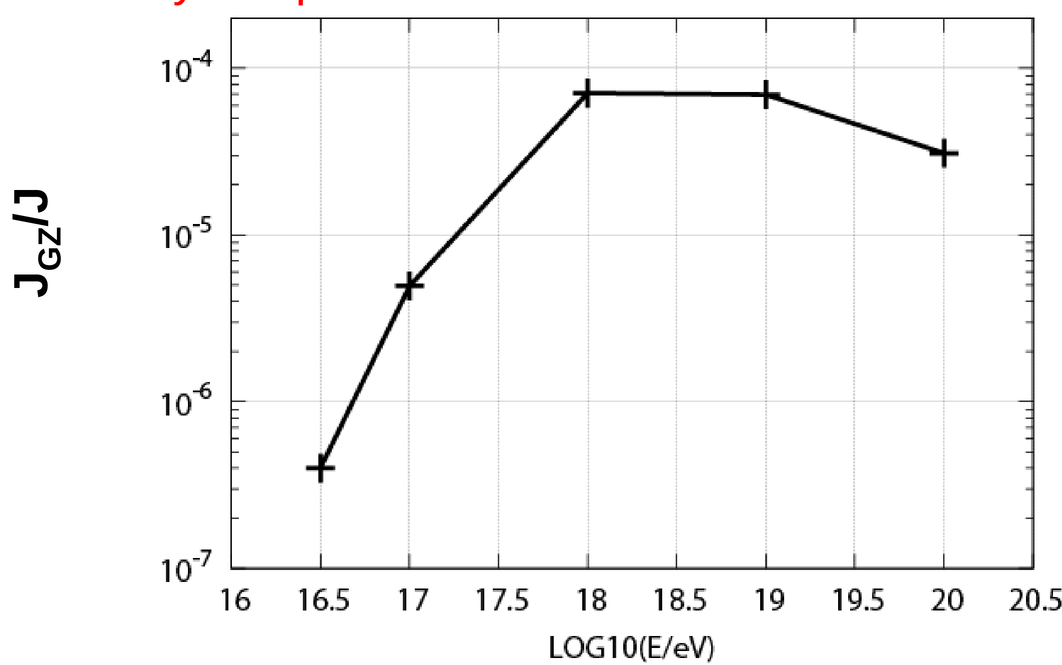
$$J(E) = \sum_Z J_z(E) \qquad J_z(E) = J_{0,Z}\left[\frac{E}{E_0}\right]^{\gamma_Z}\left[1+\left(\frac{E}{E_p Z}\right)^{\gamma_1}\right]^{-\gamma_2}$$

$$E_0 = 10^{12}\,\mathrm{eV} \quad E_p = 4.5\times10^{15}\,\mathrm{eV} \quad \gamma_1 = 1.9 \quad \gamma_2 = 1.1 \qquad \text{Horandel(2003)}$$

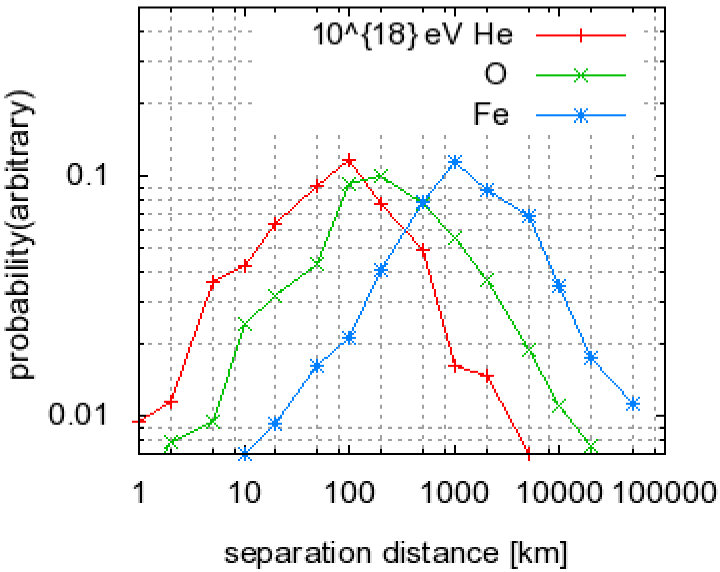
  - GSL were used in numerical integration thistime.

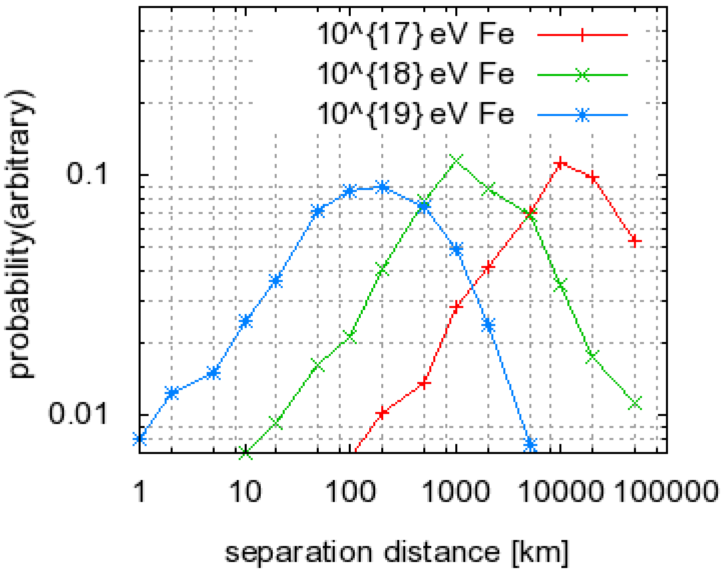
- Results:
  the probability of GZ events $\eta_{GZ}$ and expected flux ratio $J_{GZ}/J$ (separation<$2R_E$)
  - dominated at more than $10^{17}$eV but very low probabilities :$10^{-4}$～$10^{-5}$



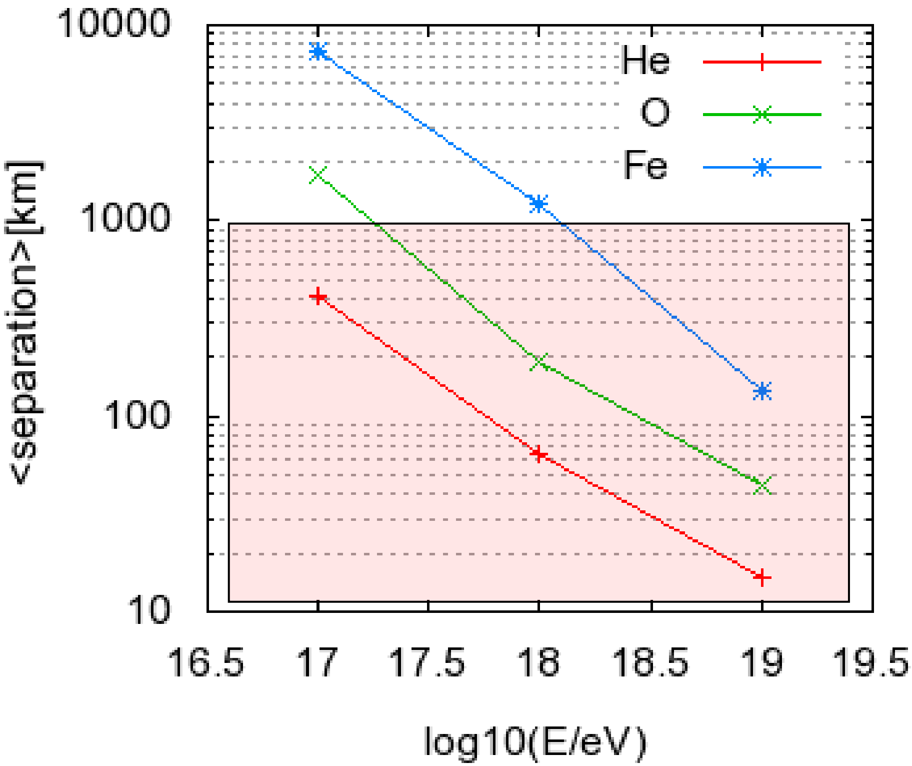



# Numerical result :separation distance vs. primary energy



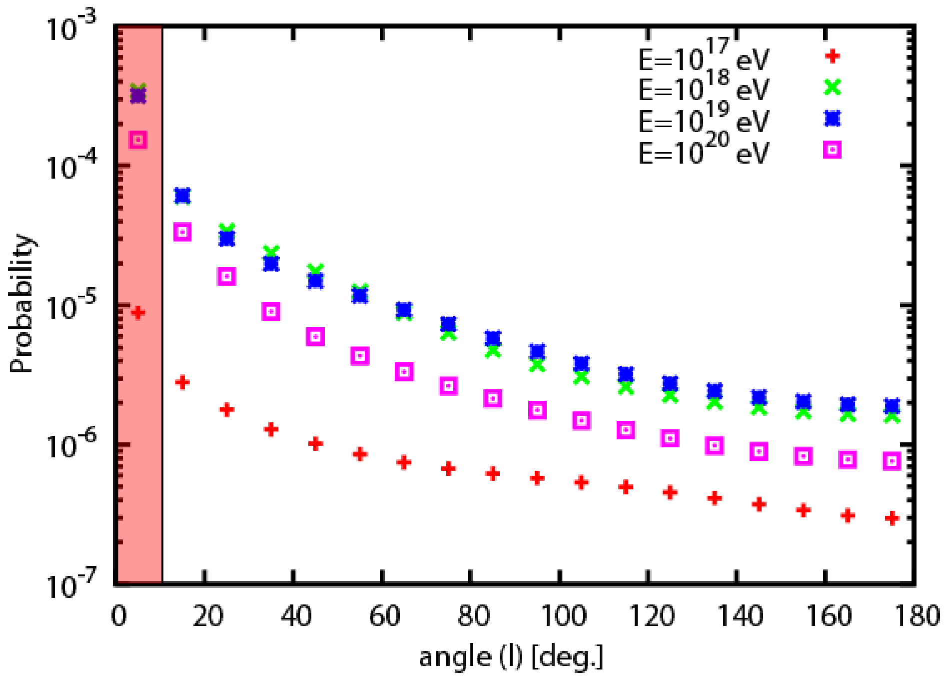

- The EAS distance between proton and nuclei fragments at the Earth
  - independent of nuclei
  - simply shifted distribution
  - Average separation propotional to $E^{-1}$

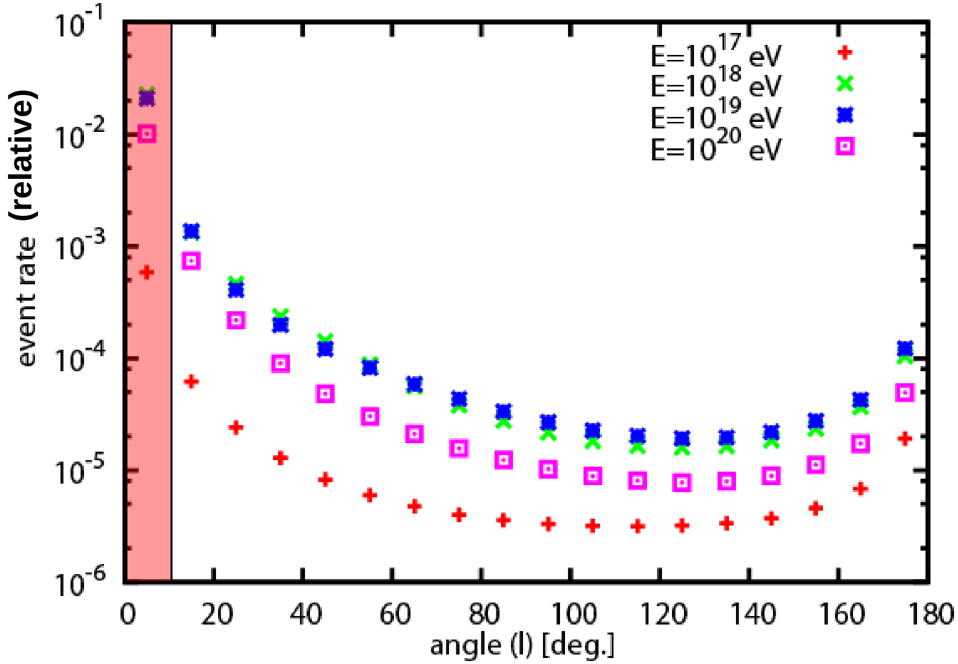



**Typical <separation> ~ LAAS experiments**

**Fe primary $10^{18}$eV ⇒1200km $10^{19}$eV ⇒150km**

# The correlation of solar direction of fragmentation probabilities Kanai,Fujiwara(2004)



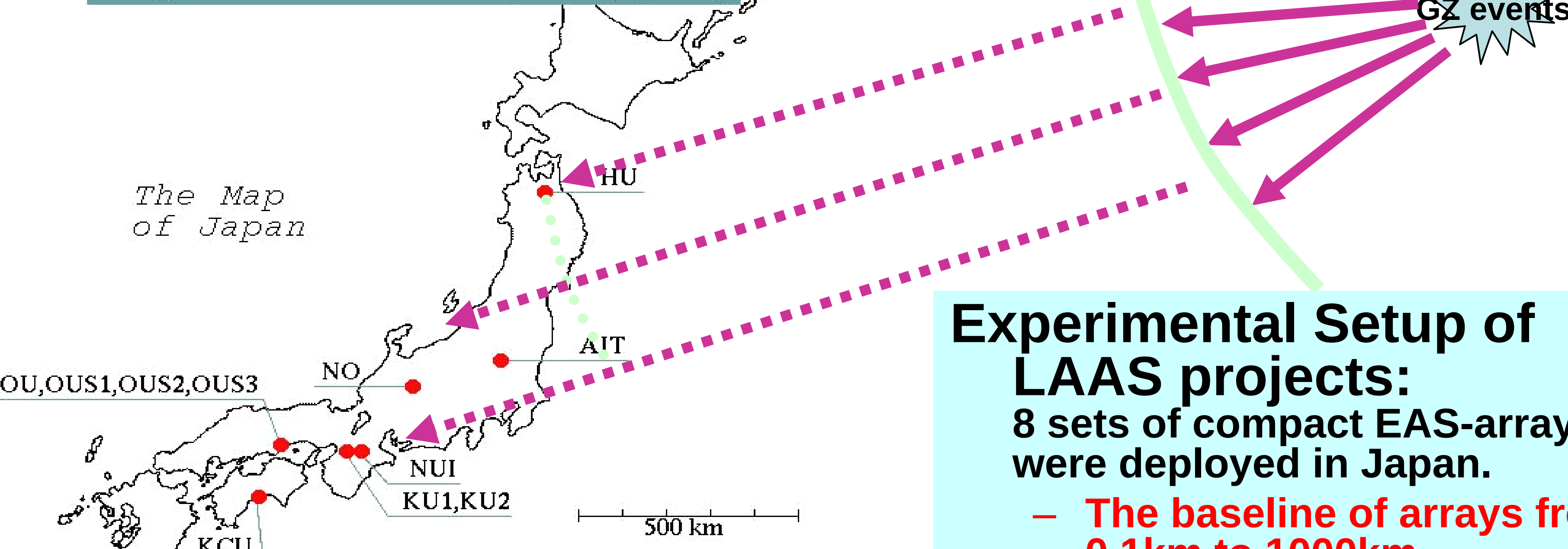

$$P = 1 - \exp\left[ -\int_0^\infty d\xi \frac{1}{\lambda(\xi)} \right]$$

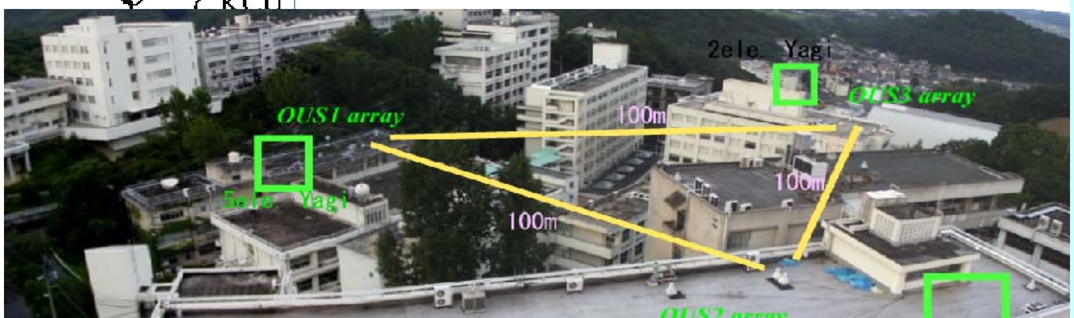
Nearest distance from the sun ($R_{SUN}$=0.005AU)
10deg.→0.17AU
20deg.→0.34AU

Too strng field strength
Lafebre et al.(2008)

- The probabilities *P*
  - Enhanced at day-side and night-side

## Large Area Air Shower (LAAS) group



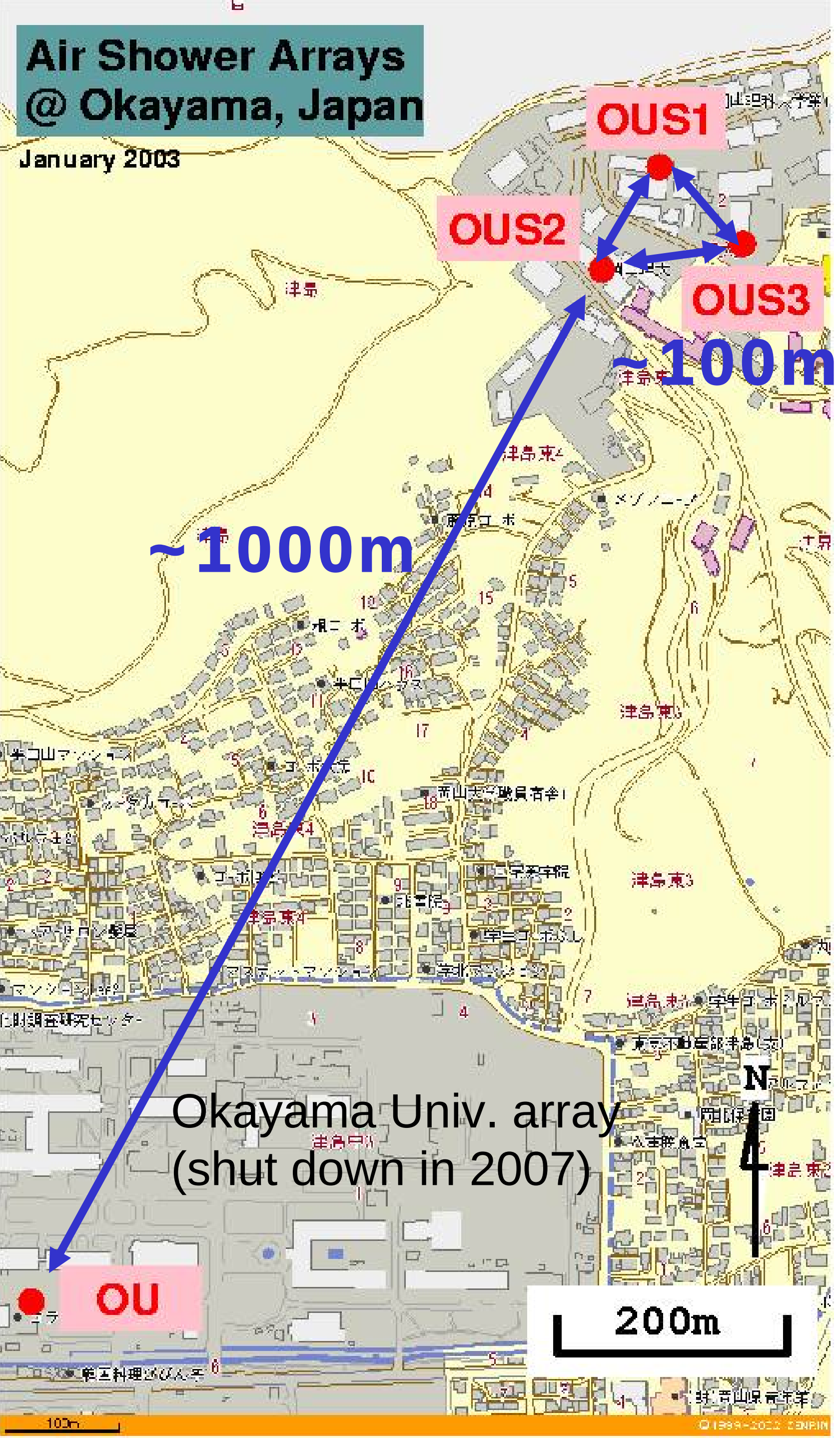




| Institute name | | Latitude (N) | Longitude (E) | Distance from HU (km) |
|---|---|---|---|---|
| Hirosaki Univ. | HU | 40° 35’ | 140° 29’ | ------- |
| Kinki Univ. | KU | 34° 39’ | 135° 36’ | 786.8 |
| Nara Univ. of Industry | NUI | 34° 35’ | 135° 41’ | 787.9 |
| Okayama Univ. | OU | 34° 41’ | 133° 55’ | 872.7 |
| Okayama Univ. of Science | OUS | 34° 42’ | 133° 56’ | 871.6 |

# Experimental Setup of LAAS projects:

**8 sets of compact EAS-array were deployed in Japan.**

- **The baseline of arrays from 0.1km to 1000km**
- **Typically, 8 plastic scintillation counters (50cm x 50cm x 5cm)**
- **300 to 400 m² EAS array size at the flat roof in each campus.**
- **TDC signals for EAS angle determinations**
  **angular resolution ~7degree**
- **GPS maintained 10MHz UTC timestamp system ( time resolution ~1 microsecond)**




# Short baseline EAS arrays in Okayama area.

<u>Okayama Univ. (OU) to</u>

<u>Okayama Univ. of Science (OUS)</u>

4 arrays in this area

- ✓ OUS—OUS ~100m

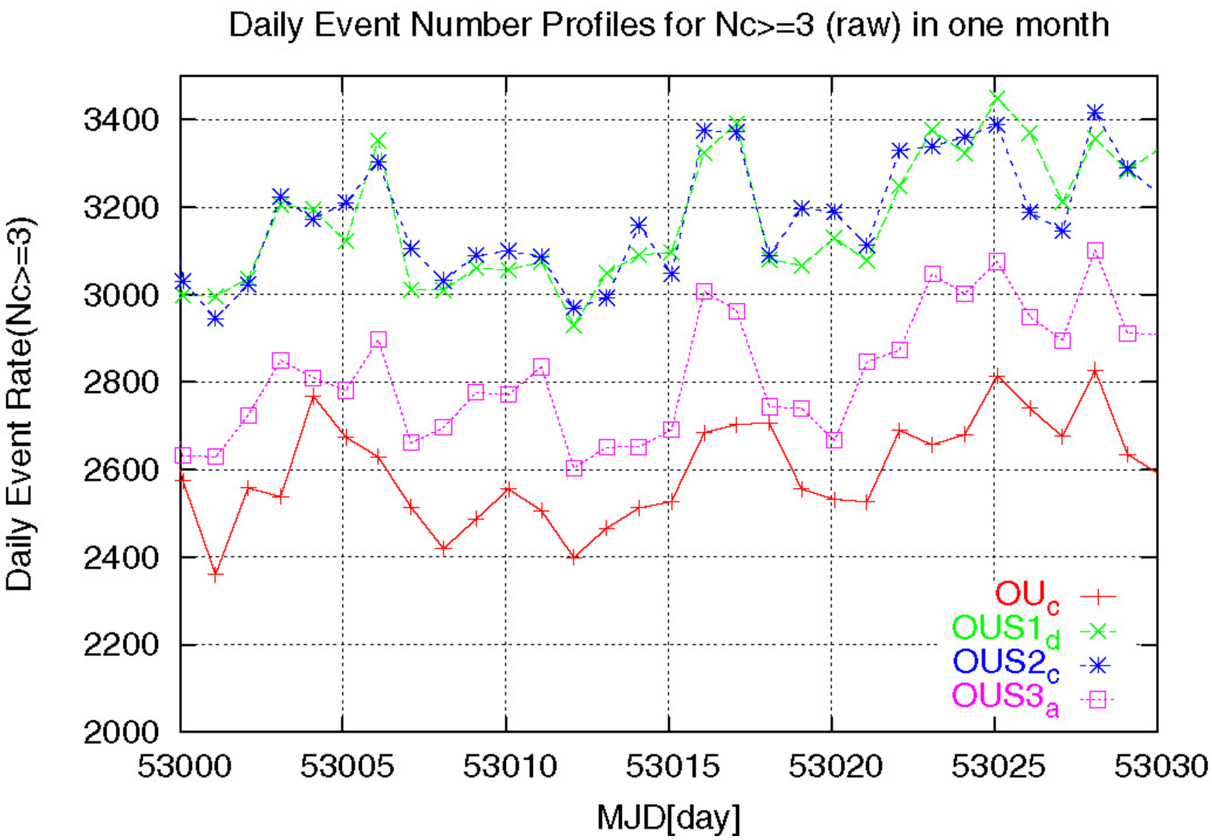
  OUS—OU ~1000m

- ✓ GPS-synchronized timestamp

  (1μs accuracy ; Furuno GT-77)

- ✓ since 12/2002

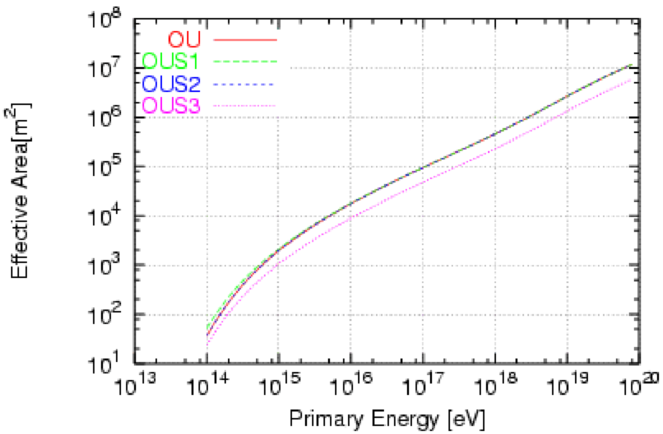
# Event rate profiles at 4 arrays

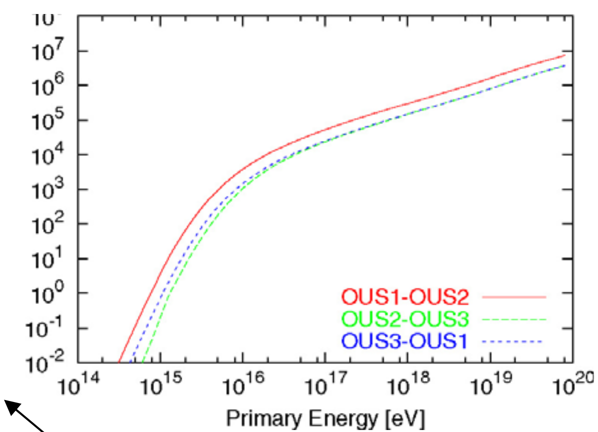


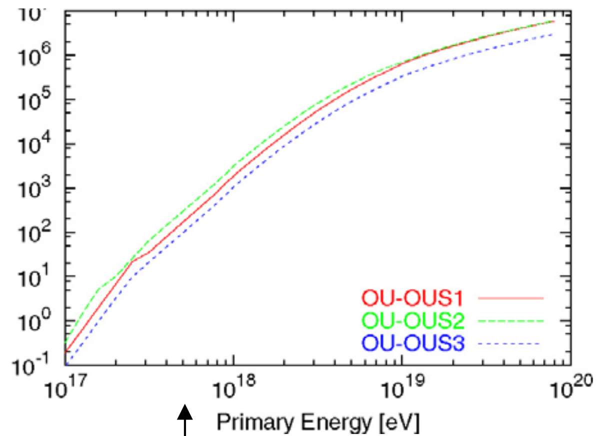

Homogeneous observation at each EAS array

# Simulation: primary energy regions

- Effective Area dependences for single array, OUS123 combinations and OU-OUS123 combinations.



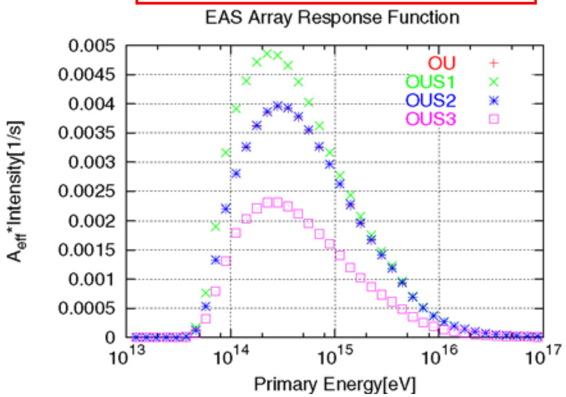

single

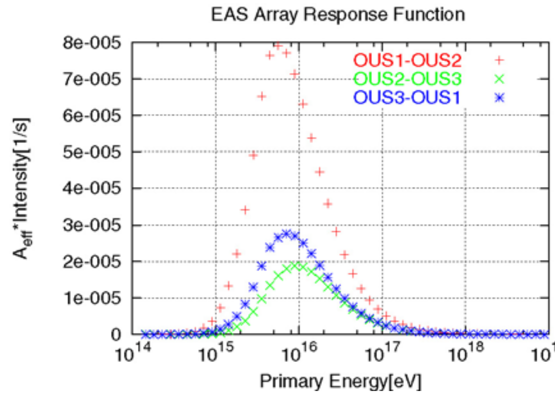
OUS-OUS

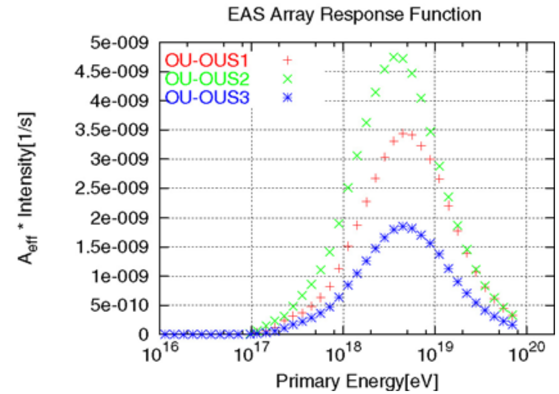
OU-OUS

- Response functions

$E_{th}$ ~ 0.1-1PeV



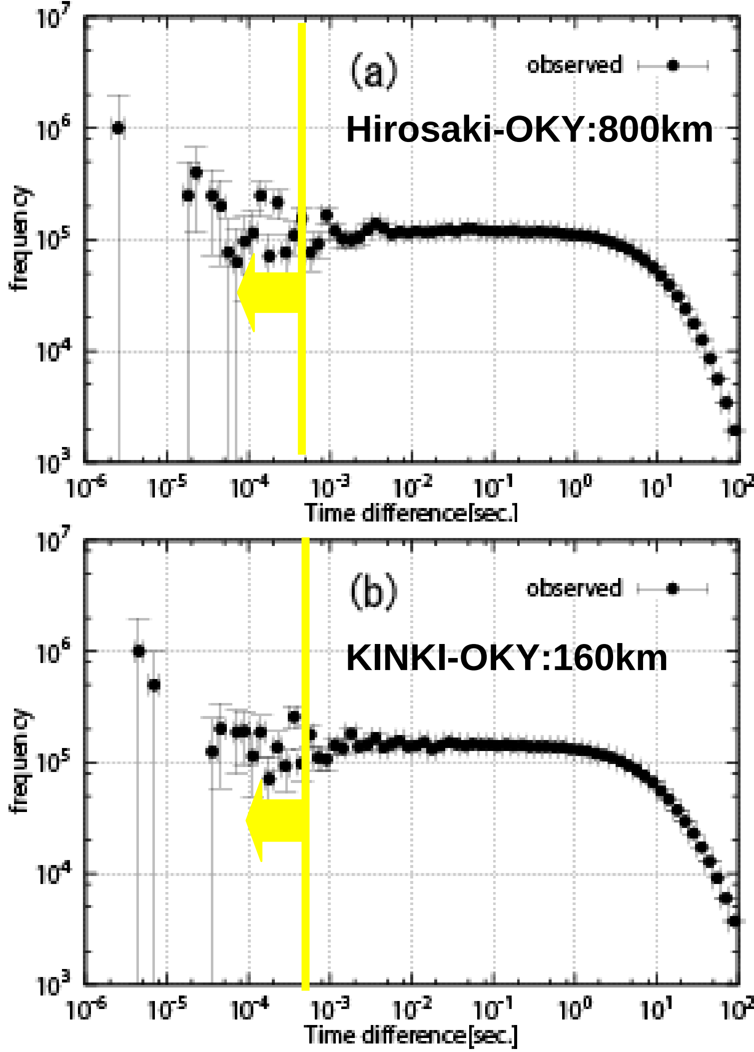



# Data Analysis:

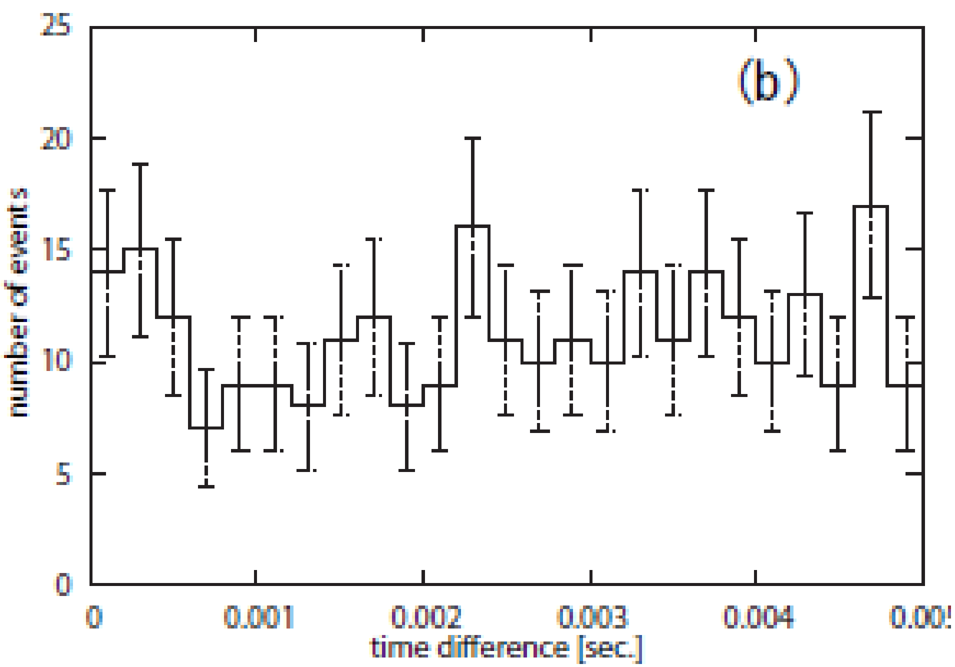
to search for simultaneous and parallel EAS events

- Data period
  - 1996/Sep (2 arrays) -2007/Jan(9 arrays)
  - 65M events
- Event selection criteria
  - $E_{threshold}$>5 PeV ( >5 coincidence )
  - Baseline combinations
    - more than 100km
      Hirosaki U.-Okayama U. 800km
      Hirosaki U.-Nara U and Kinki U. 700km
      Okayama –Nara U and Kinki U. 150km
- EAS arrival time difference (T.D.)
  - within 5 millisecond due to geographical features (considering separation elongation factor pointed out by Lafebre et al. 2008)
- EAS angular distance (A.D.)
  - within 15 degree (typical angular resolution of arrays :7degree)

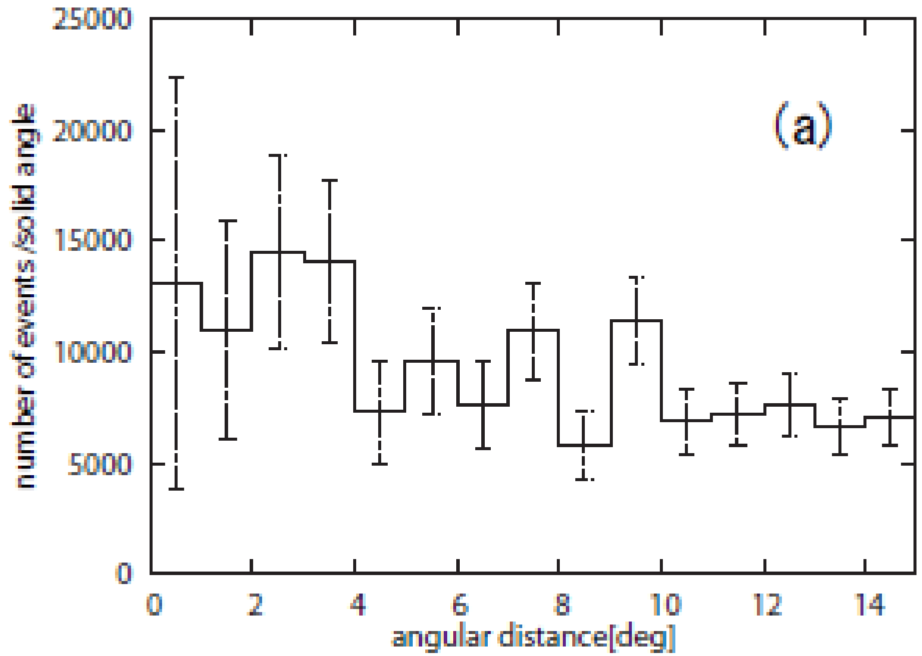


# Experimental results

- 287EAS pairs were selected among 65M events
  - within T.D. <5ms and A.D.<15deg




**Time difference (T.D.) distribution of selected EAS pairs**

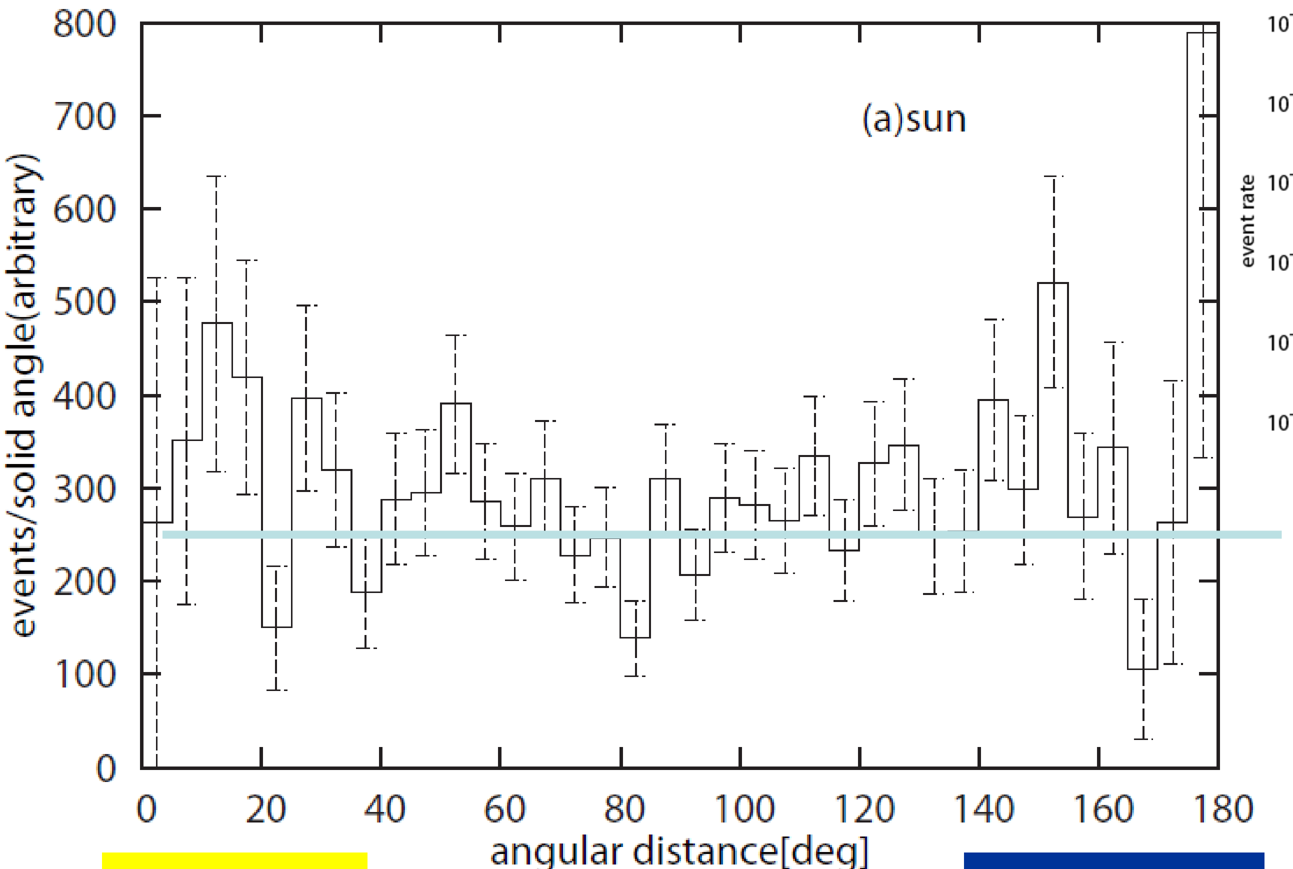



**Angular distance (A.D.) distribution of selected EAS pairs**

# Angular distance correlation to the Sun

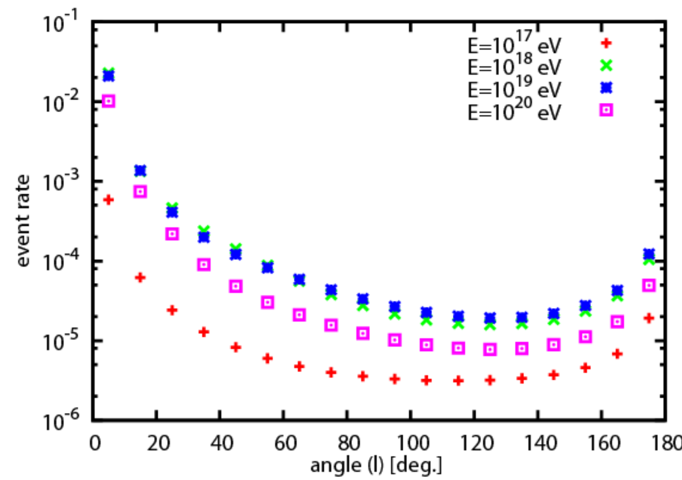
287 pairs→574 EASs

- head-on collision of photon with nuclei in day-side and night-side
  - In the direction near the Sun, trajectory deviation became large to be detected.（Lafebre 2008）




DAY-SIDE

NIGHTSIDE



# Conclusions

- Numerical calculation have been performed for LAAS experimental setting.
- LAAS data  from up to Jan. 2007 have been analyzed.
  - GZ candidates  defined as T.D.<5millisecond and A.D.<15degree
    287 EAS pairs were selected and analyzed for the  correlation of arrival direction to the Sun.
  - T.D and A.D. distributions themselves were uniform.
  - Their were no significant GZ event enhancement in the day-side and night-side direction. The distribution still seems to be uniform, instead of GZ effect indeed.
  - Energy estimation for each EAS were not completed because of restricted array size.
- Plan
  - The new EAS array(OUS5) in Okayama Univ. of Science(2.5km distance form our campus) have started observing EAS events from Dec/2009.
  - Linsley's  EAS time structure methods for EAS energy estimation with compact arrays have been  implemented for LAAS EAS arrays
    (Poster presentation)

# Linsley's EAS time structure method

- E>$10^{16}$eV
  - EAS core position can not be determined by lateral structure analysis with small array(20m x 20m).
  - The outskirts of EAS will be hit to the EAS array.
  - Linsley predicted the relation between core distance *r* and EAS thickness σ empirically.
  - The EAS thickness measurement system were installed.

- Status
  - OUS1 array maintained with Linsley's method.
  - OUS4 array were implemented with zenith angle restrictionsystem.
  - OUS5 array started observation, located at 2.5 km distance from the OUS campus.