LHAASO Status and Prospects on Energy Spectrum Measurements of CR Protons, Helium and Heavy Nuclei

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- LHAASO Detector Arrays
- Scientific Aspects
- Prospects:
  - γ-ray Astronomy (WCDA, Scin.+MD Array)
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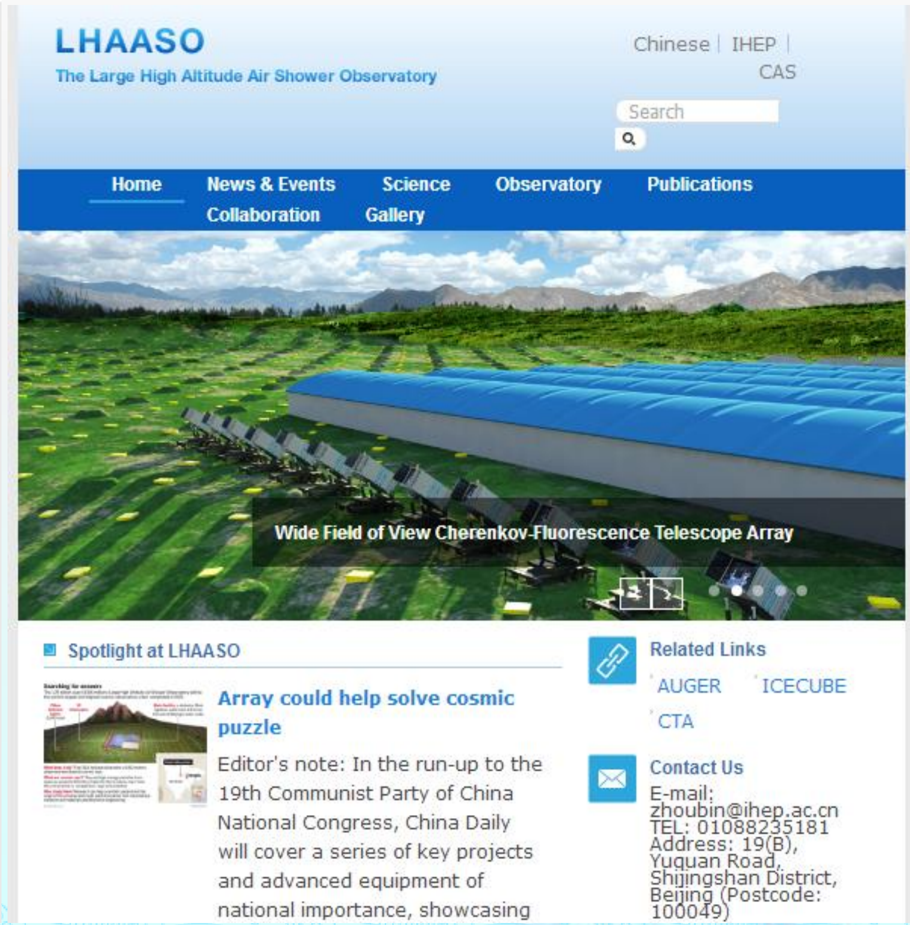
    - Multi-parameter Measurements of Showers
    - Separation between Species (MVA)
    - Energy Measurement
    - Expectations about the knees
    - Energy Scale
- Construction Status
- Summary

Large High Altitude Air Shower Observatory

LHAASO

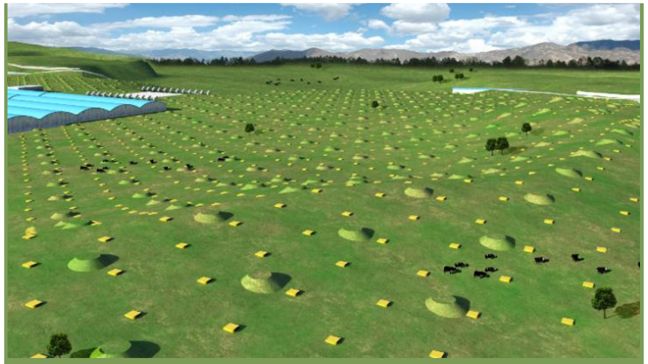
- General info is available at the web sites

http://ihep.cas.cn/lhaaso （Chin）　　http://english.ihep.cas.cn/lhaaso （Eng）

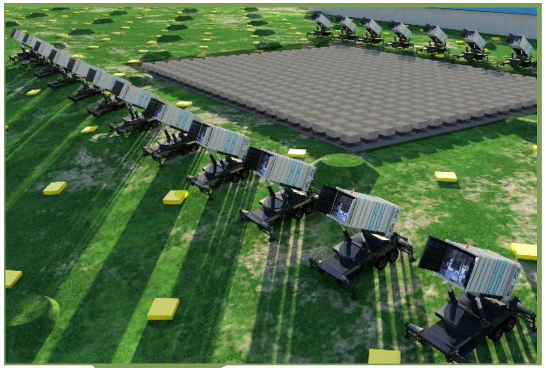


Large High Altitude Air Shower Observatory

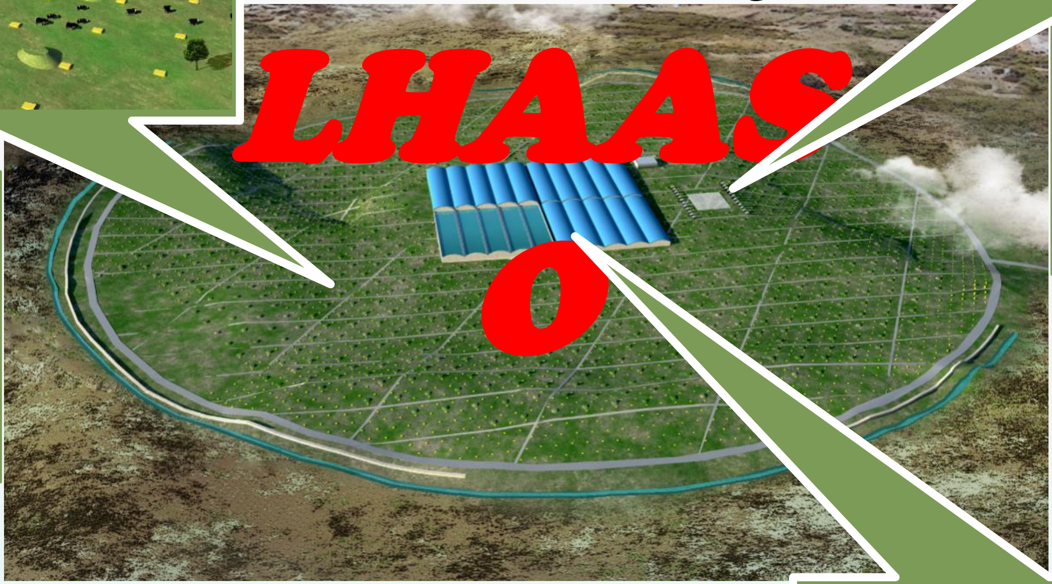
LHAASO



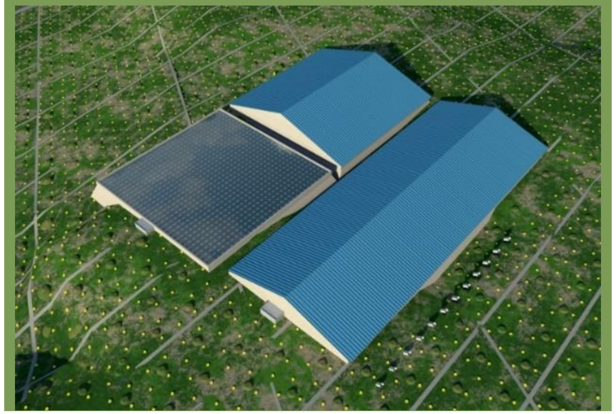
KM2A:
• 5195 Scin's: 1 m^2, 15m spacing
• 1171 MDs: 36 m^2, 30m spacing

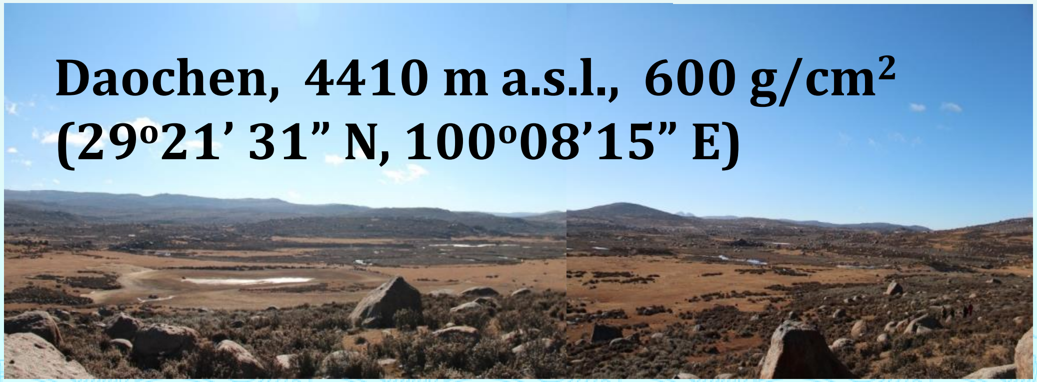


WFCTA:
18 Cherenkov telescopes (1024 pixels/telescope)

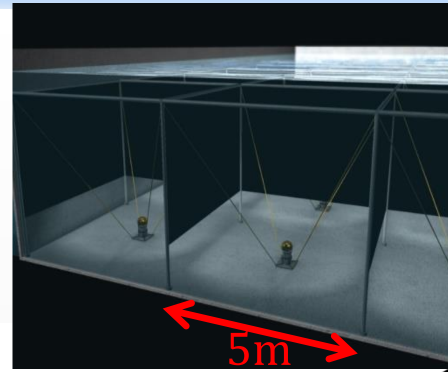


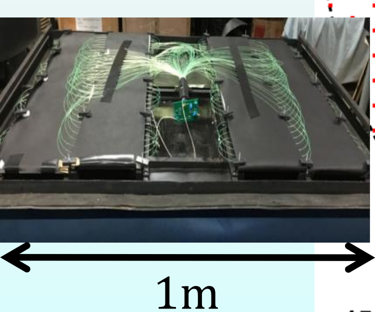
WCDA:
3120 cells (25m^2/cell)

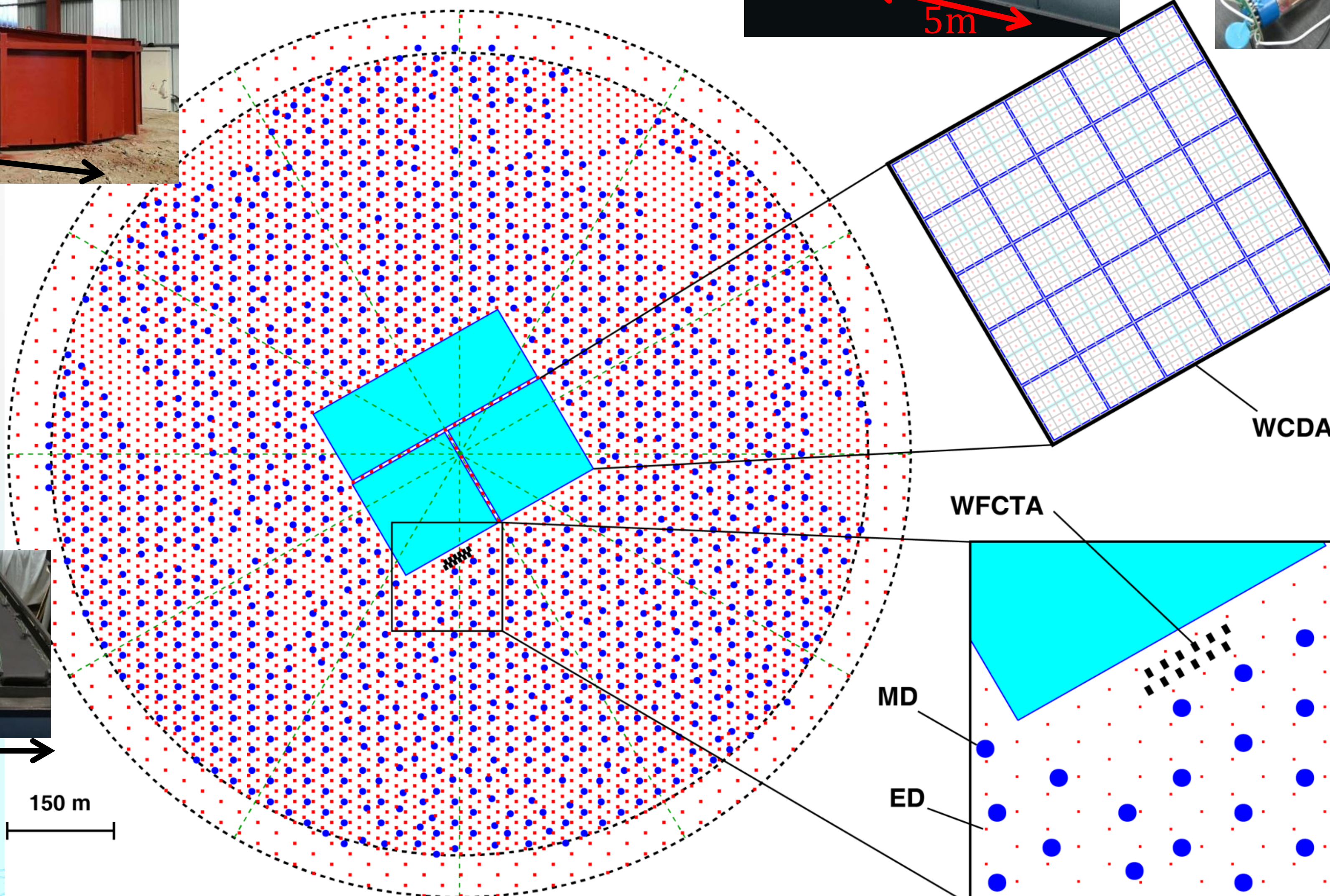




Detector Layout in LHAASO

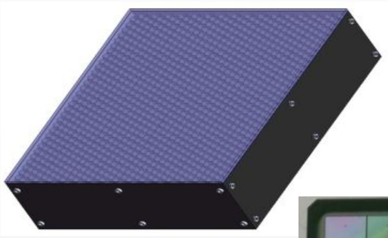


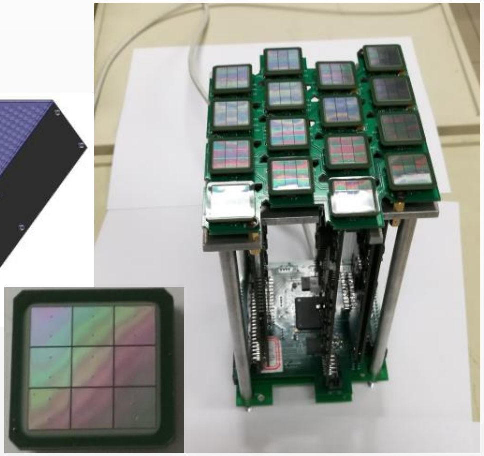


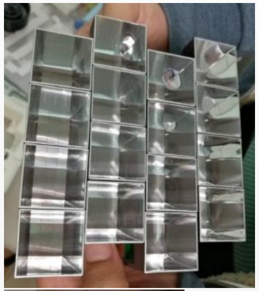


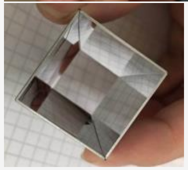
Wide FoV C-Telescope Array

Fully portable telescopes allow reconfiguring the array for CR detection in 3 energy ranges









- Movable telescope housing
- Rotating from 0° to 90° in elevation

- 5 m^2 spherical aluminized mirror
- Reflectivity of 85%

- 32×32 SiPM array
- FoV of 16°×16°
- 0.5° pixel
- 1-4000 PE nonlinearity less than 5%

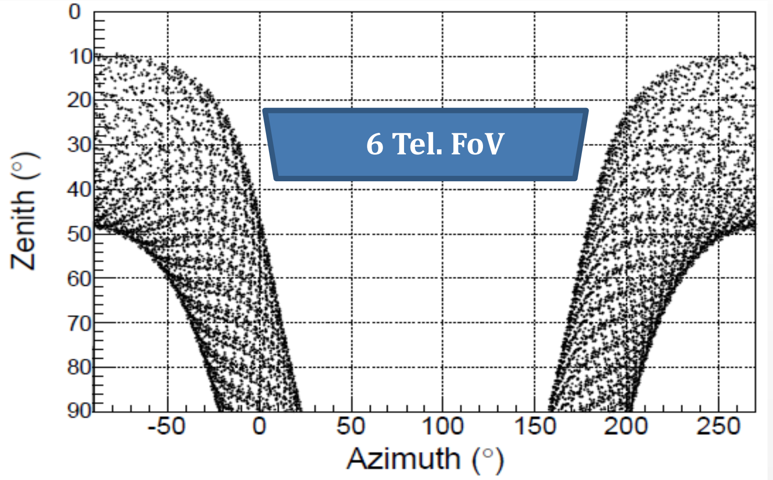
- 4×4 20μm SiPM sub-cluster
- 50 MHz FADC
- Temperature-compensation power supply
- T-stamp from WR network

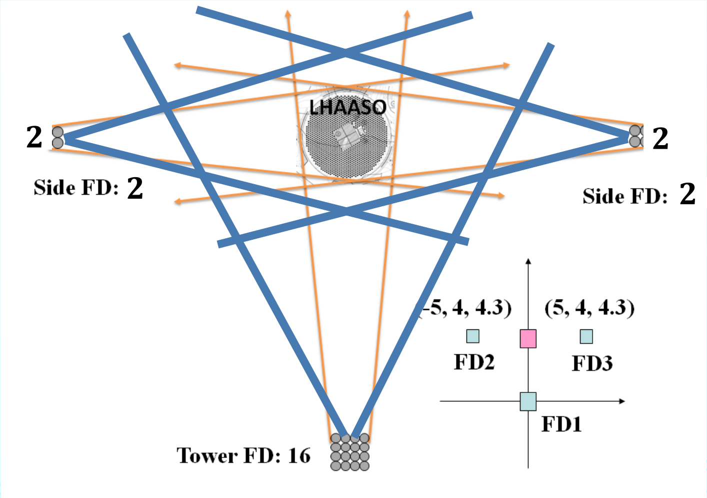
- Aluminized Winston cones
- Cut-off angle 30° with efficiency of 93%
- Filter transmission of 92% in 310 - 550 nm

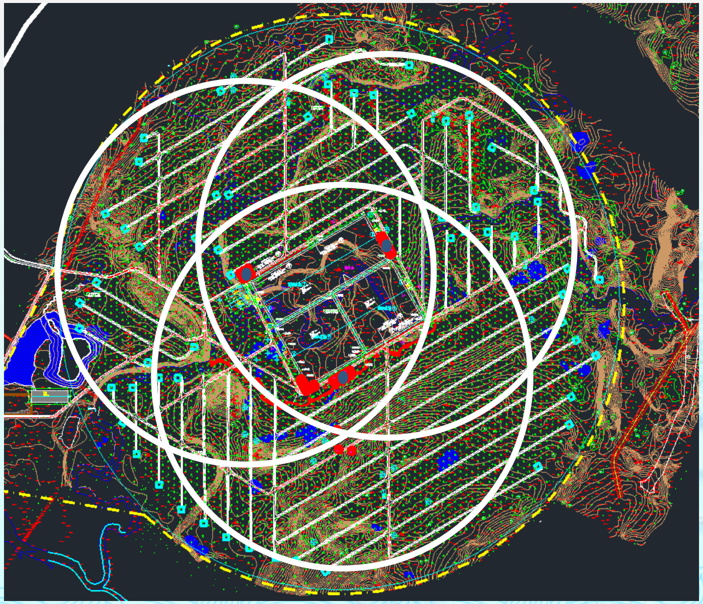
Elevation of 60 toward North
with full-moon duty cycle >30% above 100 TeV

Layout for Three Energy Range

- **0.1-10 PeV in 2019**
  - **pure proton and pure Helium spectra**
  - **6 C-Tel's (60 in elevation) + 1st pool**
- **1- 100 PeV in 2021**
  - **Pure iron or heavy nuclei (MgAlSi+Fe) spectra**
  - **18 C-Tel's (45 in elevation)+ Scin.+ MD array**
- **>100 PeV in 2023**
  - **2nd knee**
  - **20 F-tel's + MD array**







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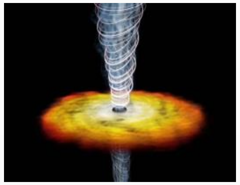
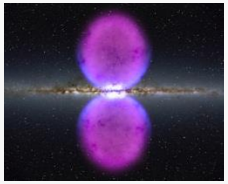
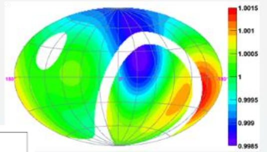
Physics of LHAASO

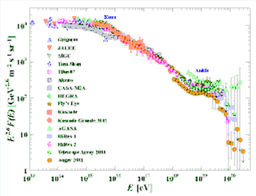
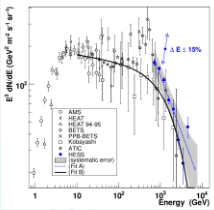
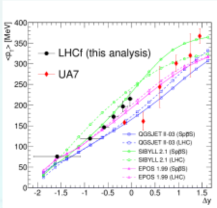
- VHE gamma sky survey (100 GeV-1 PeV):
  - Galactic sources;
  - Extragalactic sources & flares;
  - VHE emission from Gamma Ray Bursts;
  - Diffused Gamma rays.

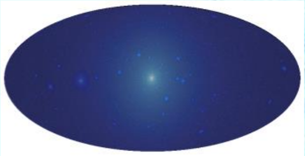
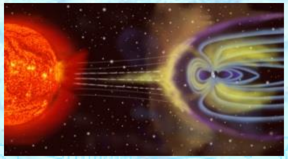

- Spectrum measurement at the high end:
  - Nature of the acceleration: leptonic or hadronic;
  - Origin of cosmic rays – 100 years' mystery.



- Cosmic rays
  - Spectra of CR Species;
  - Anisotropy of VHE cosmic rays;
  - Cosmic electrons / positrons;

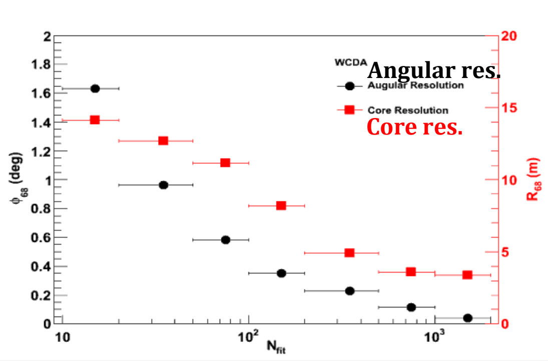




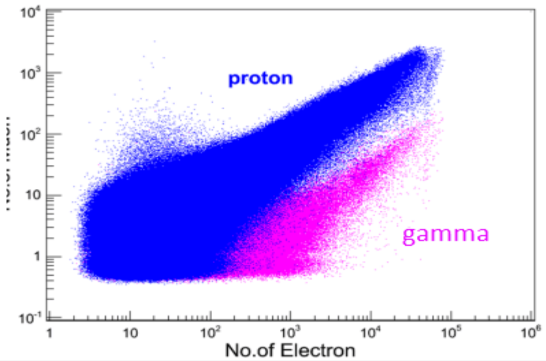
- Miscellaneous:
  - Gamma rays from dark matter;
  - Sun storm & IMF.

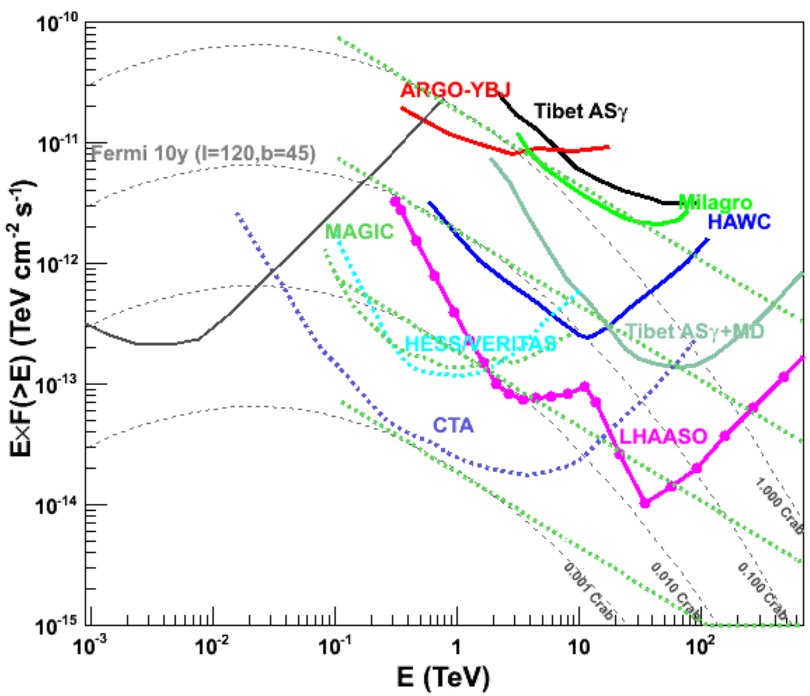
Sensitivity to gamma ray sources

- **Integral: 1% Crab unit @3TeV & 50TeV**

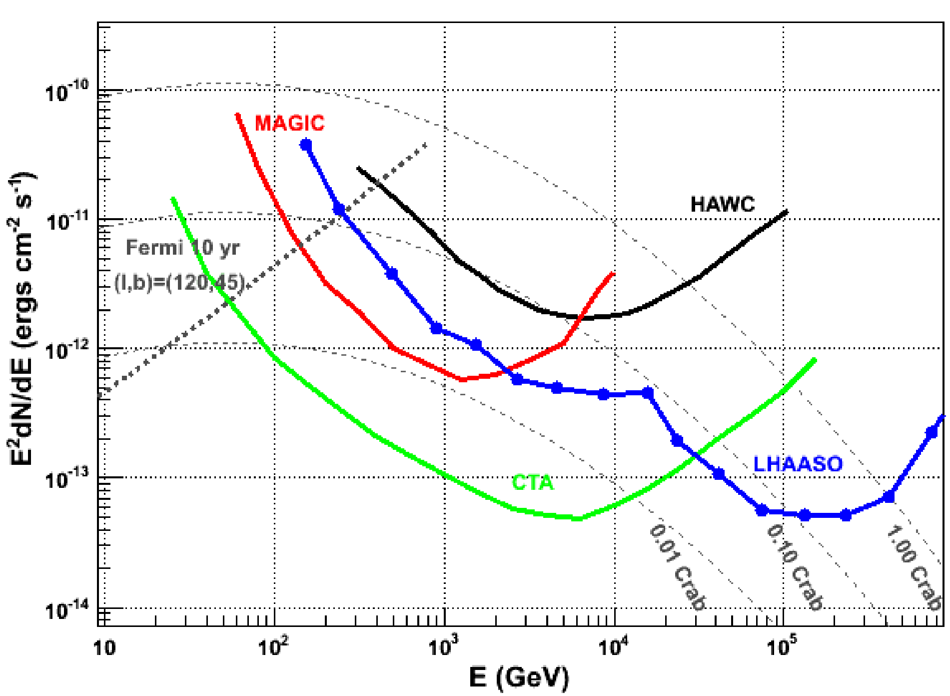




Integral

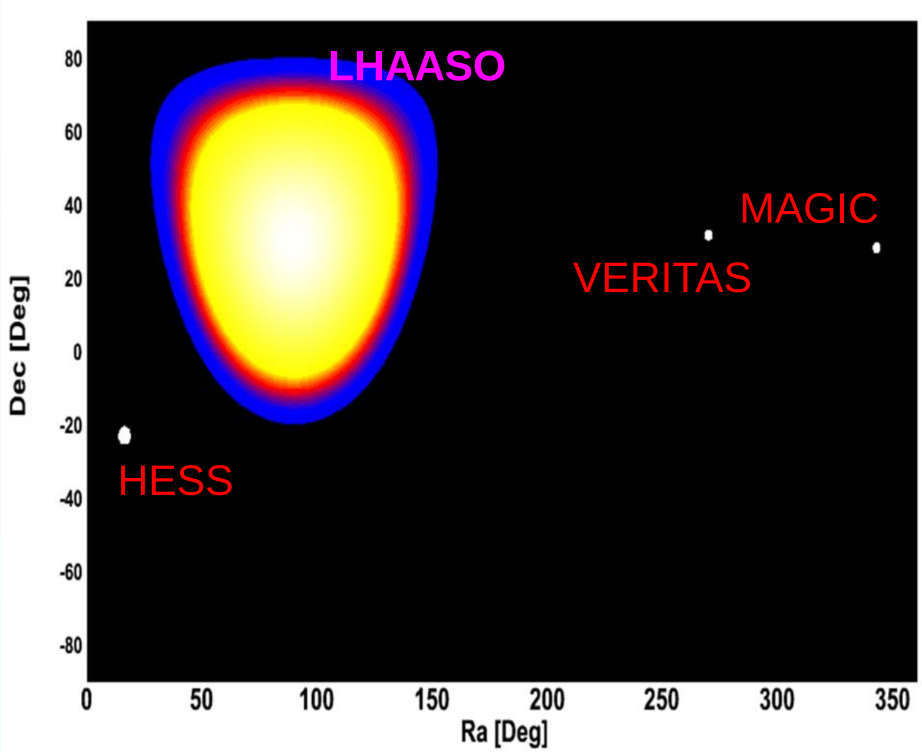


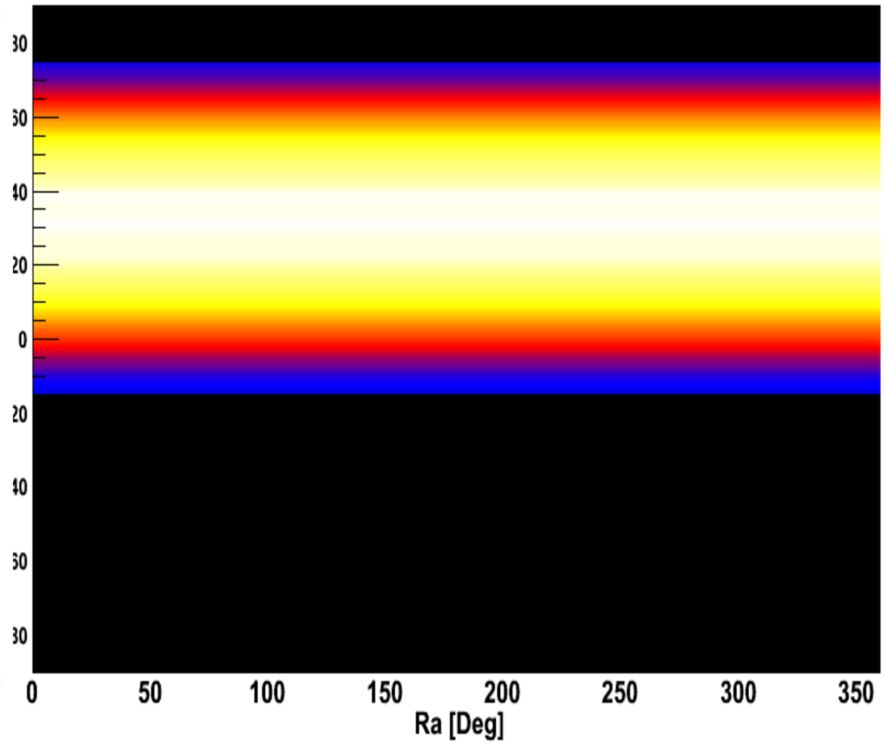
differential



Wide FOV gamma ray astronomy

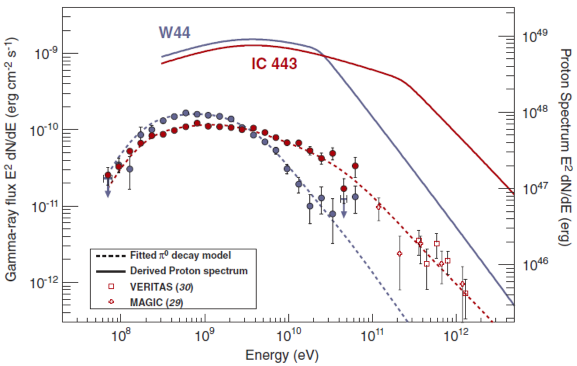
- **High sensitivity**
- **Wide FOV:**
  - **1/7 of the sky at each moment**
  - **60% of the sky every day**





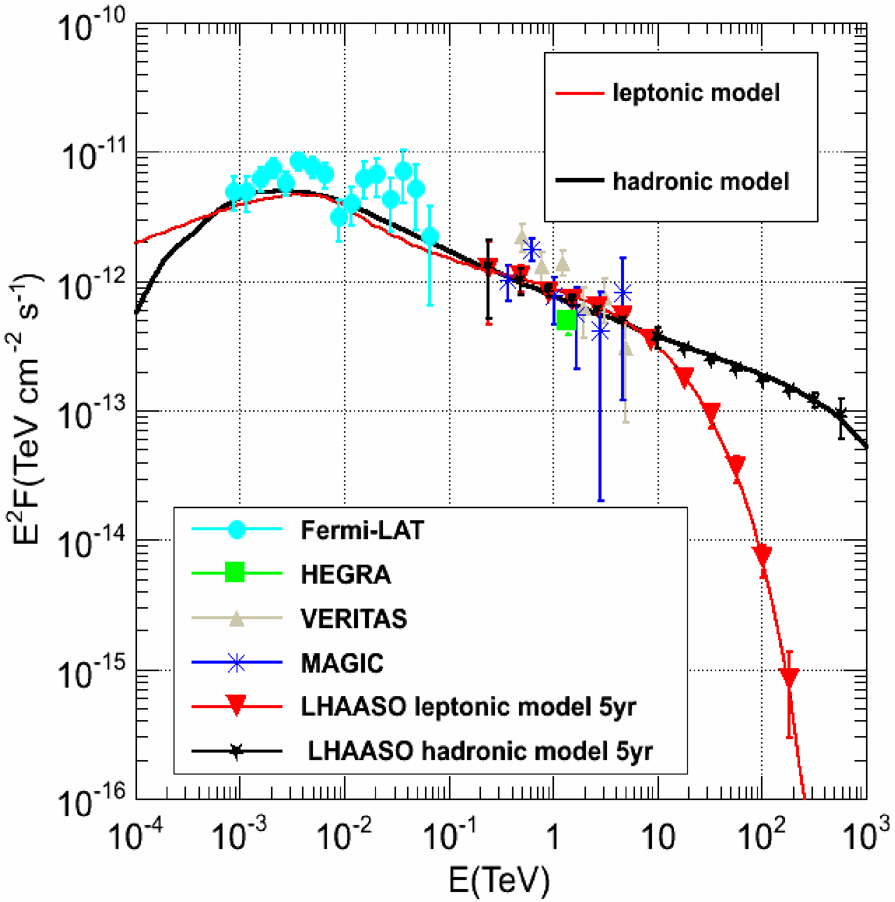
➢Hadronic vs. Leptonic

Characteristic signatures of π^0 decay:
at highest energy by LHAASO

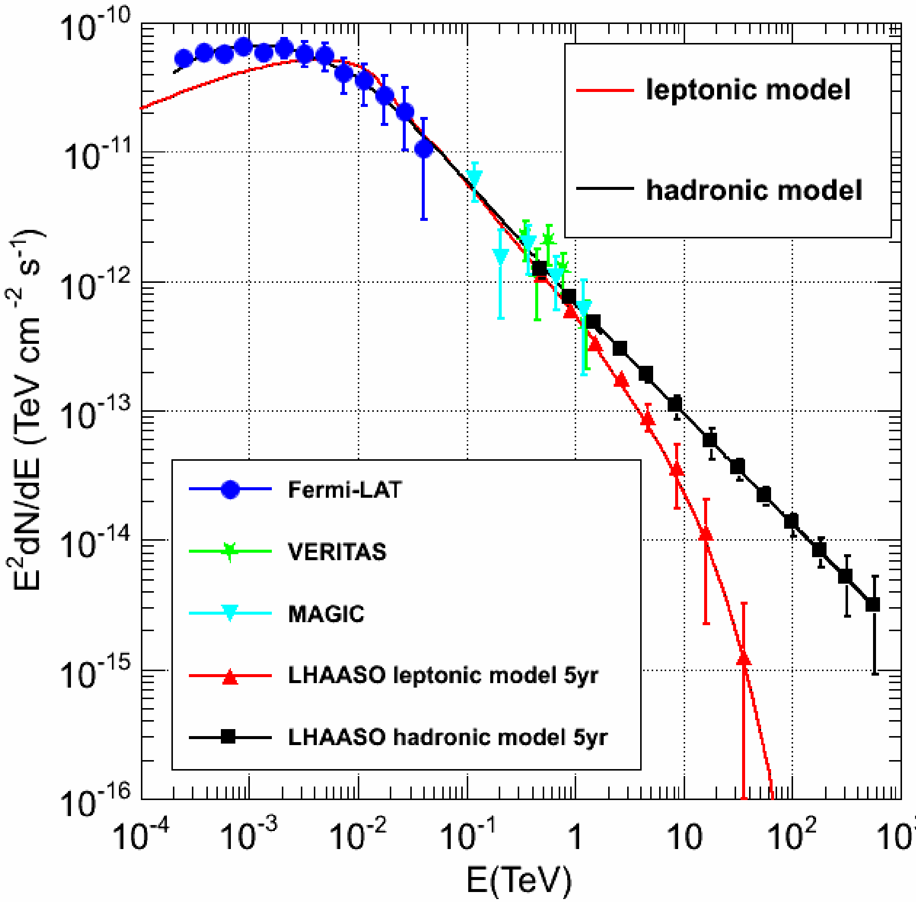


10.1126/science.1231160

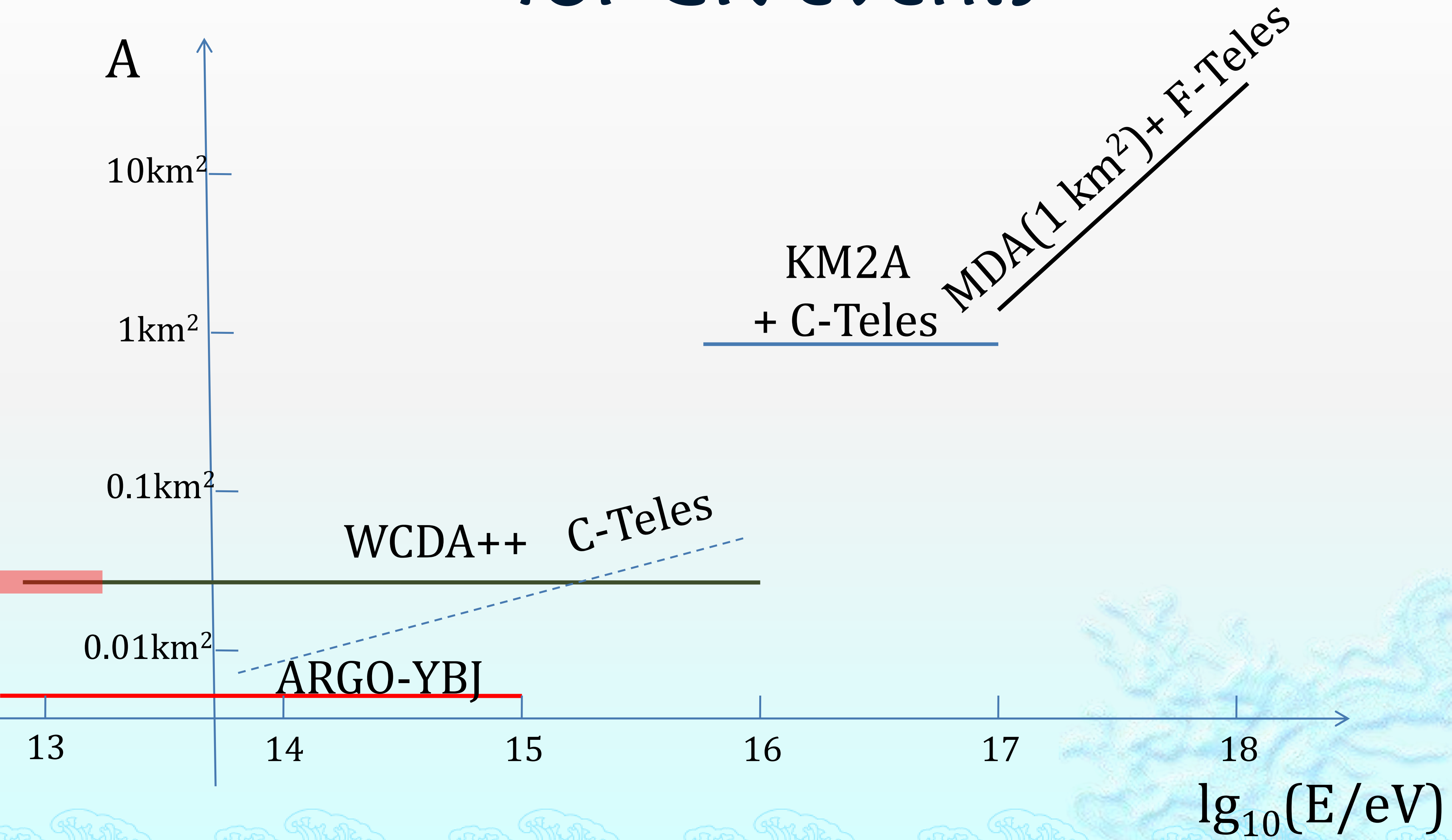
Cassionpeia A Historical SNRs



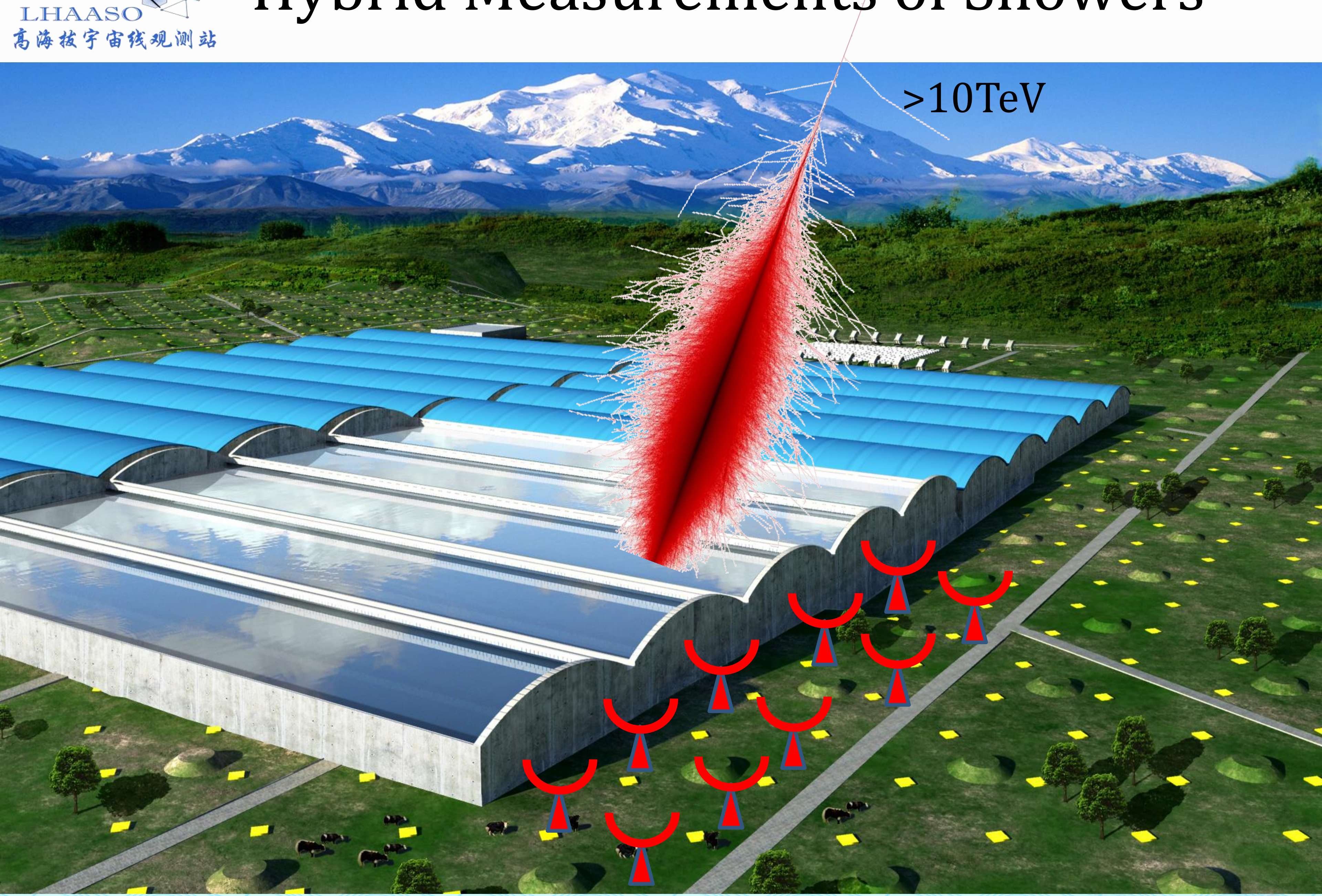
IC443 interacting with molecular clouds



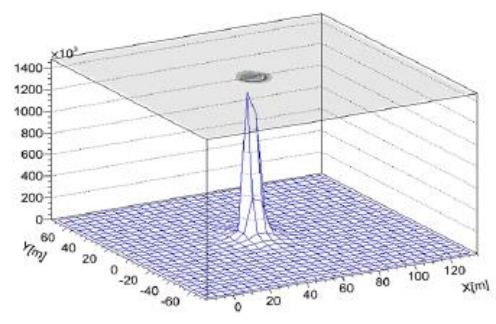
Aperture of LHAASO for CR events



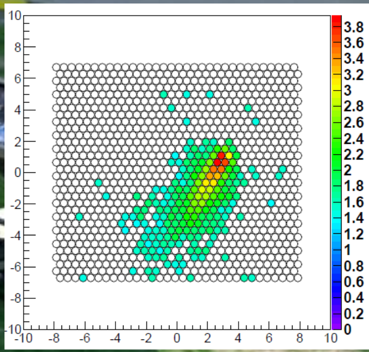
Hybrid Measurements of Showers

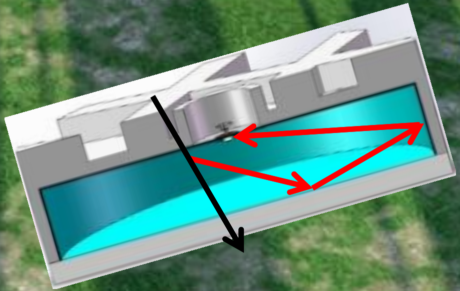


Prospects of P, He knees
from 100TeV to 10PeV



- **WCDA**
  - Core reconstruction: 3m
  - Arrival direction reconstruction: 0.3°
  - Energy flux near the core
- **WFCTA**
  - SIZE (total PE in image)
  - Width, Length
  - Distance between arrival directions to the image center
- **KM2A**
  - Total Muon number





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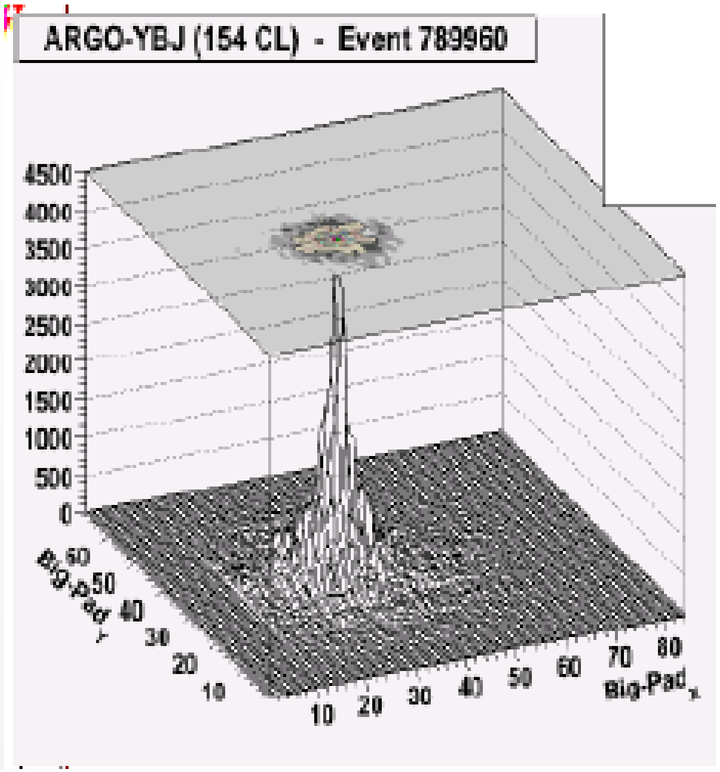
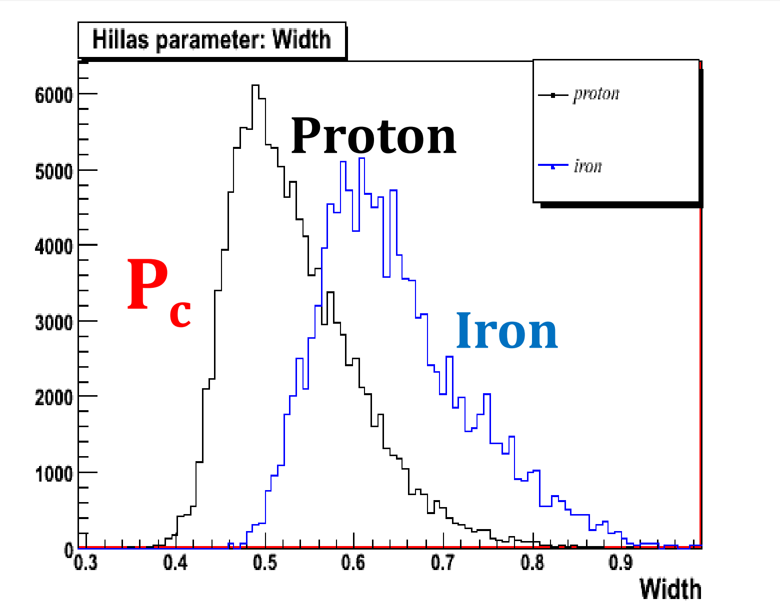
-- WCDA++: full coverage detector

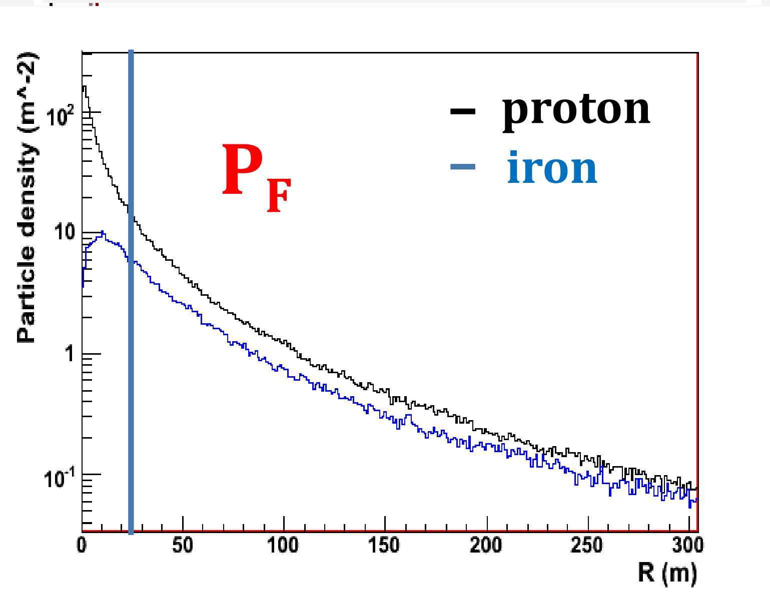
- lateral distribution in core region → mass sensitive

-- Cherenkov Telescope: shower development information

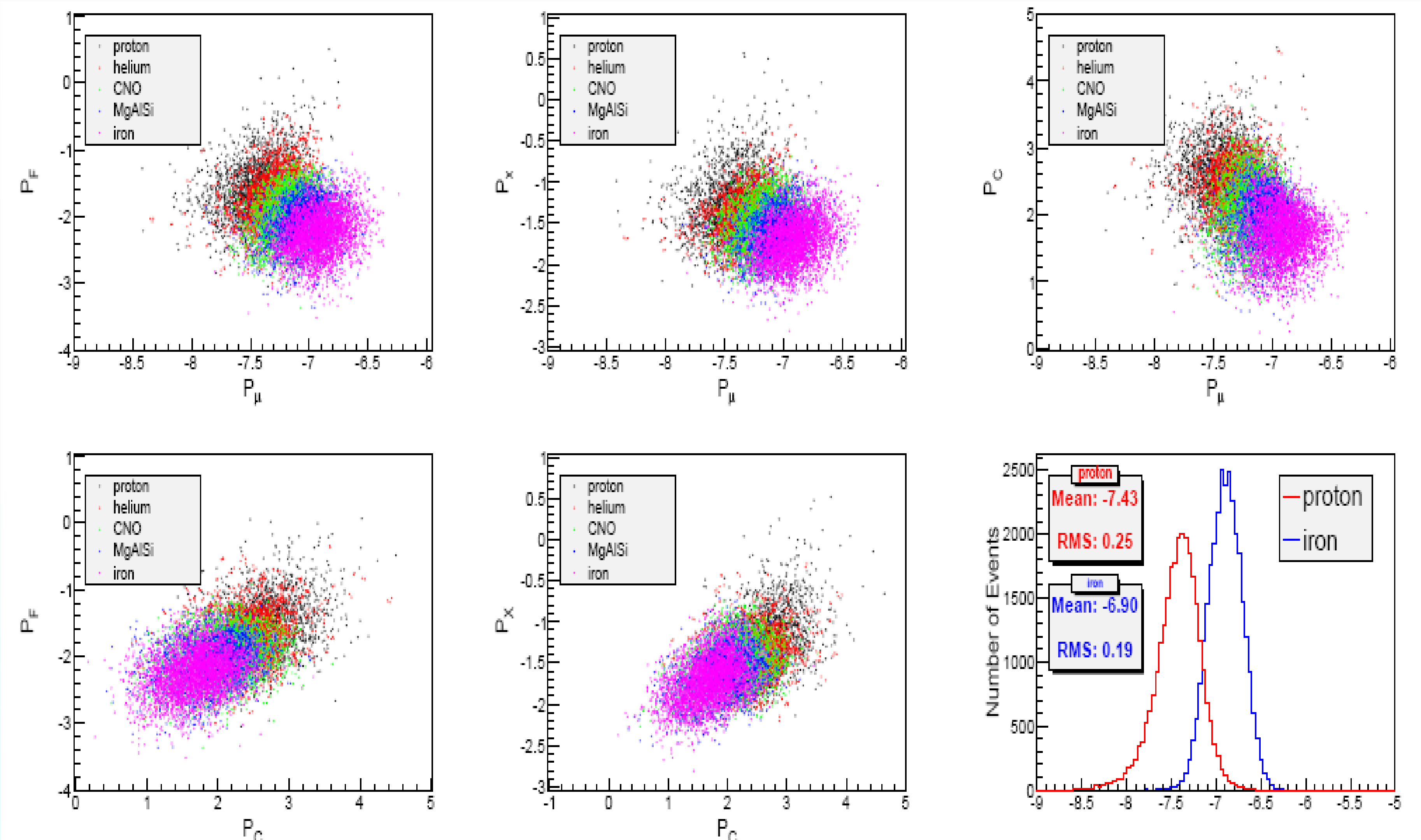
- Hillas parameter → mass sensitive







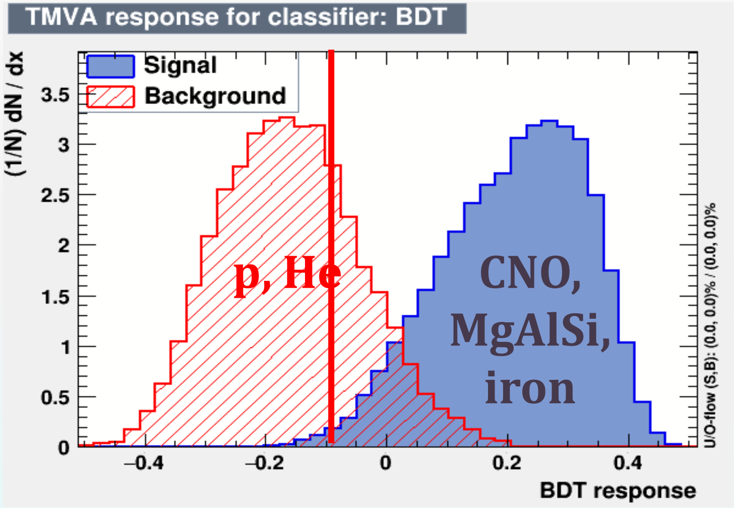
Multi-parameter analysis



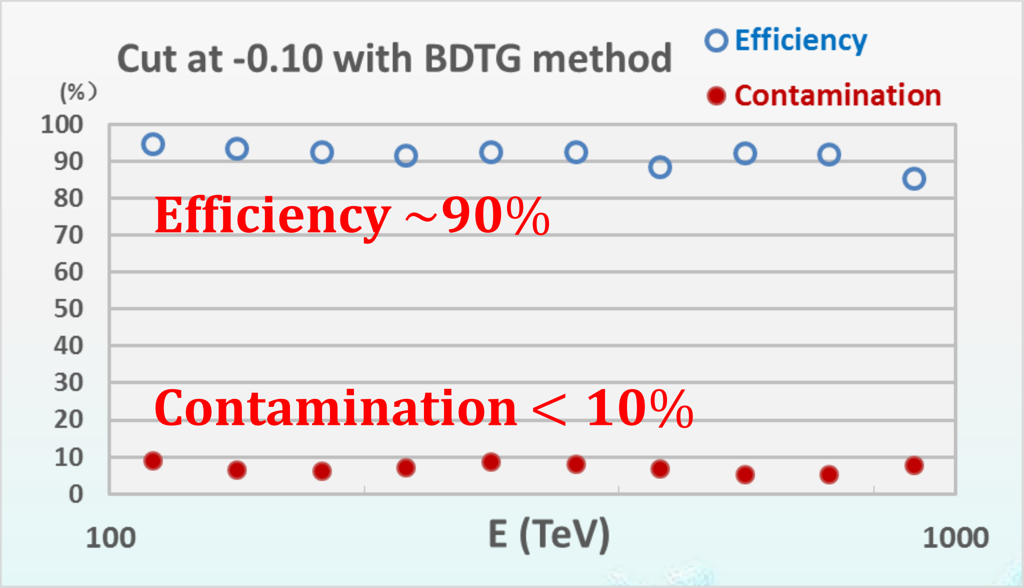
P_μ

MVA method for p,He / heavy separation

With the Multi-Variate Analysis methods (e.g. neural networks and boosted decision trees), good separations for p/iron and p+He/heavy nuclides identification can be obtained.

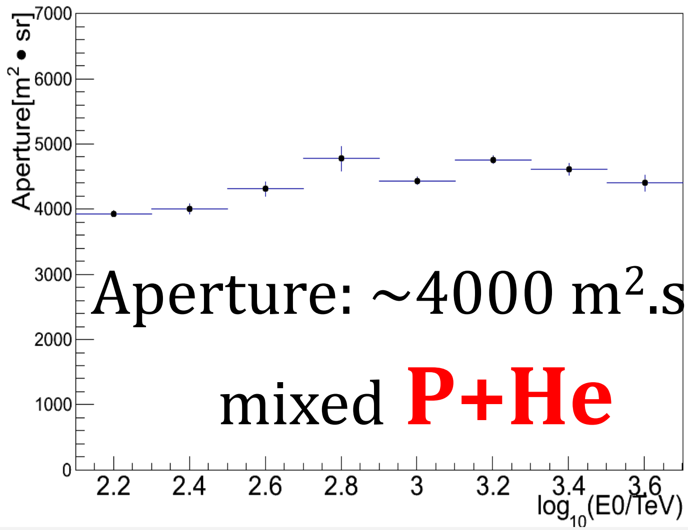


Separation of light (p+He) and heavy nuclei by the BDT (Boost Decision Trees) method.



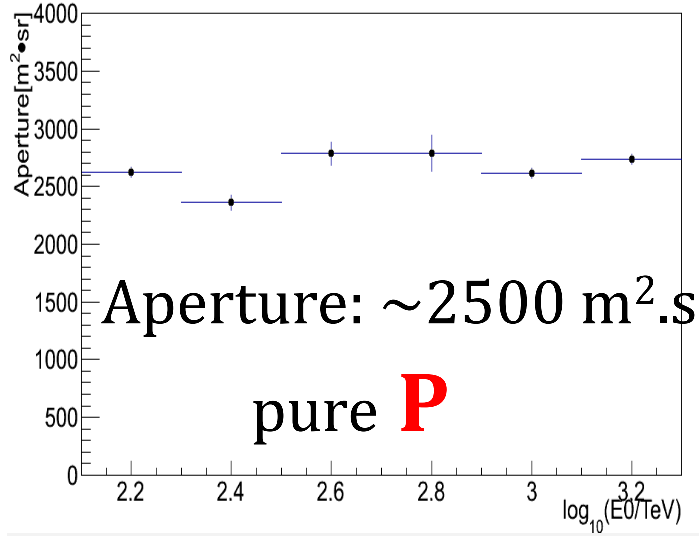
The contamination is calculated based on the Hörandel model.

Apertures and E-resolution



Aperture: ~4000 m^2.sr

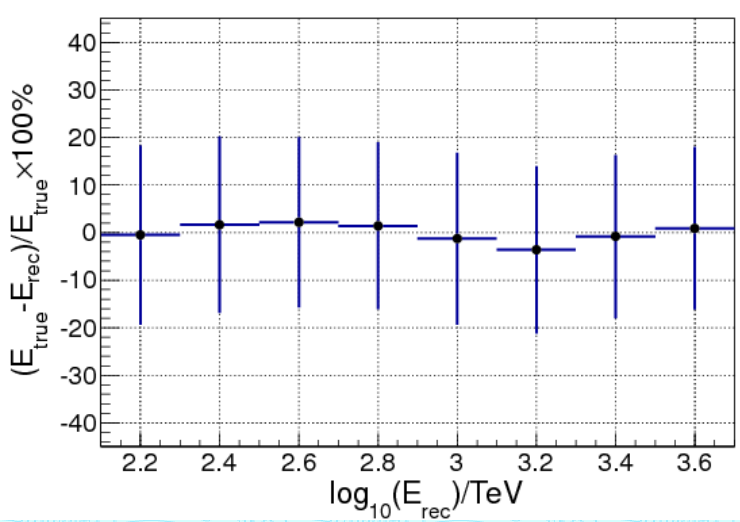
mixed **P+He**

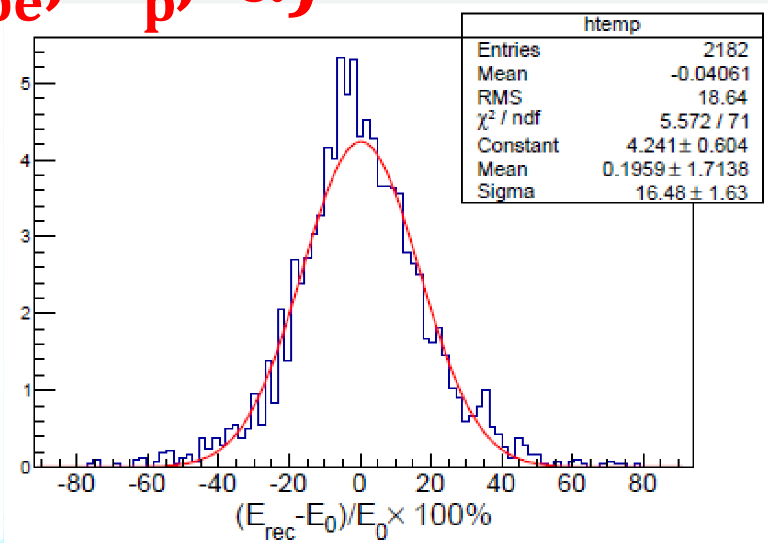


Aperture: ~2500 m^2.sr

pure **P**

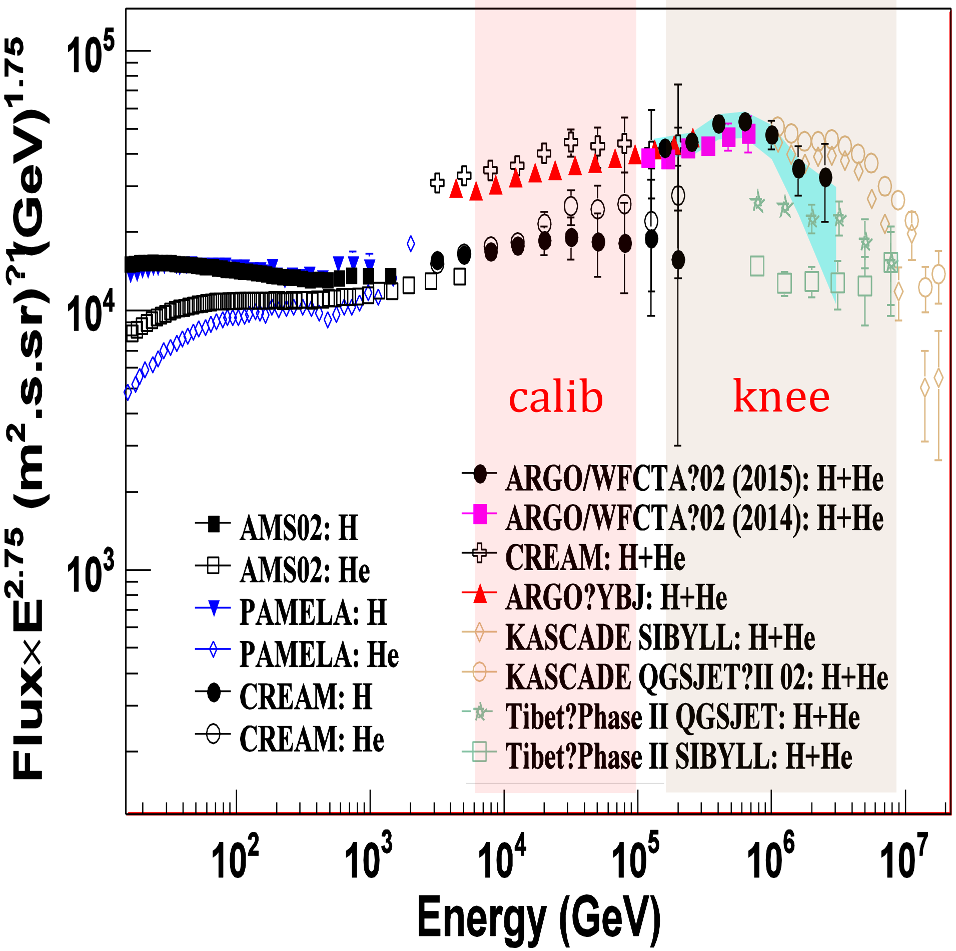
$$E = E(\Sigma N_{pe};\ R_p,\ \alpha)$$

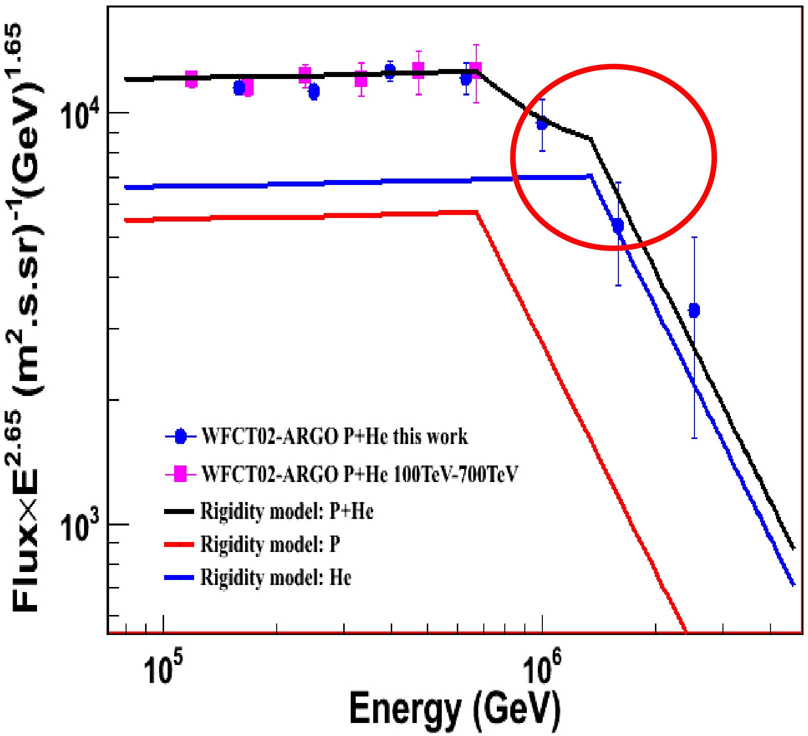




Cosmic Ray Physics: Charged Nuclei knees of spectra of individual species

Using only two parameters, at ARGO-YBJ: E_{knee}-700 TeV, Phys.Rev.D 92092005 (2015)





Proton spectrum with Rigidity model and H:He=1:1.2

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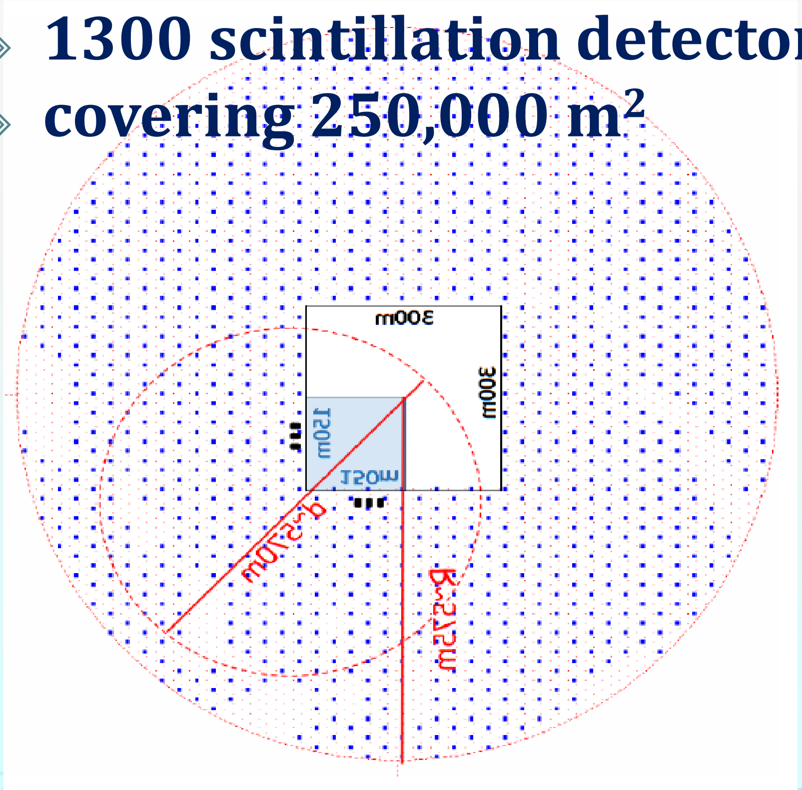
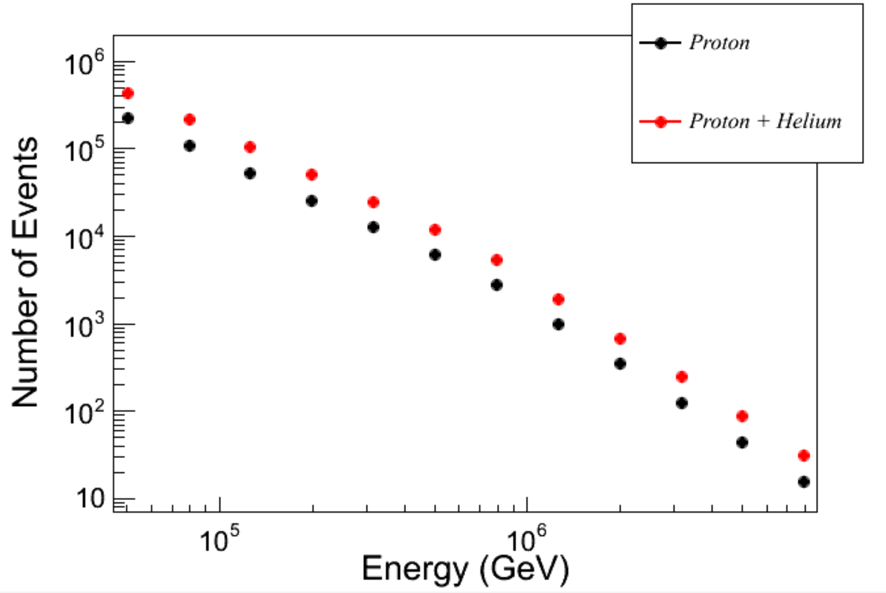
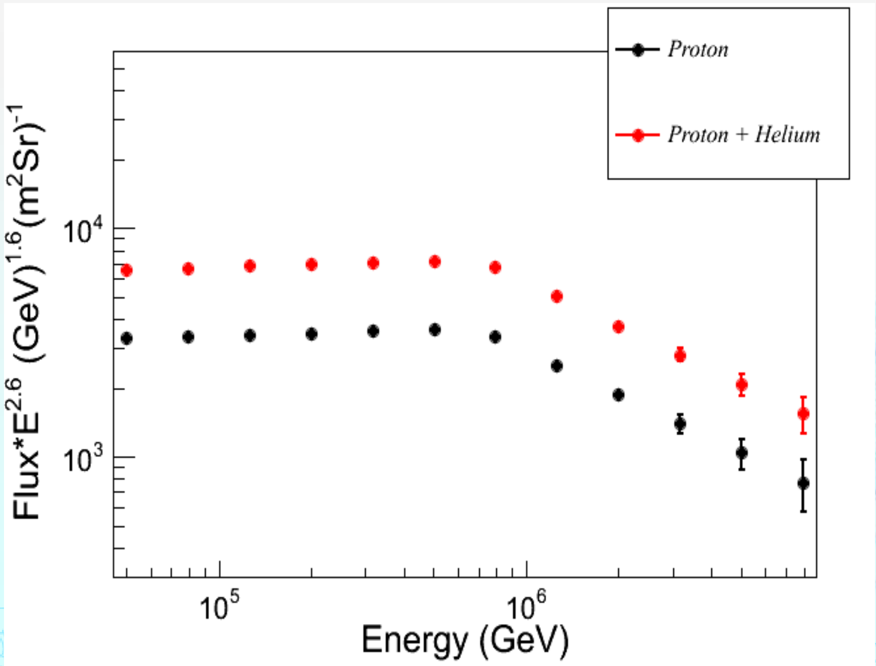
Performance of 1/4 LHAASO

- **6 WFCT telescopes**
- **22,500 m^2 water Cherenkov detector**
- **300 muon detectors**
- **1300 scintillation detectors**
- **covering 250,000 m^2**

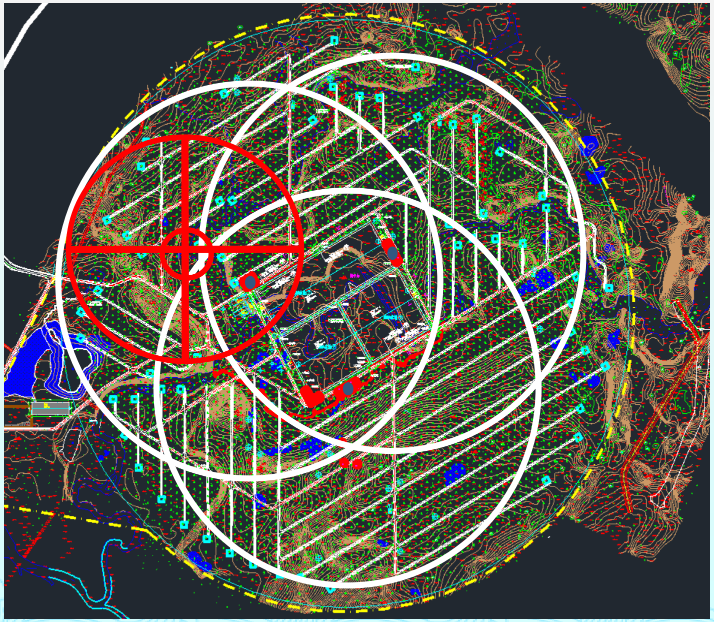


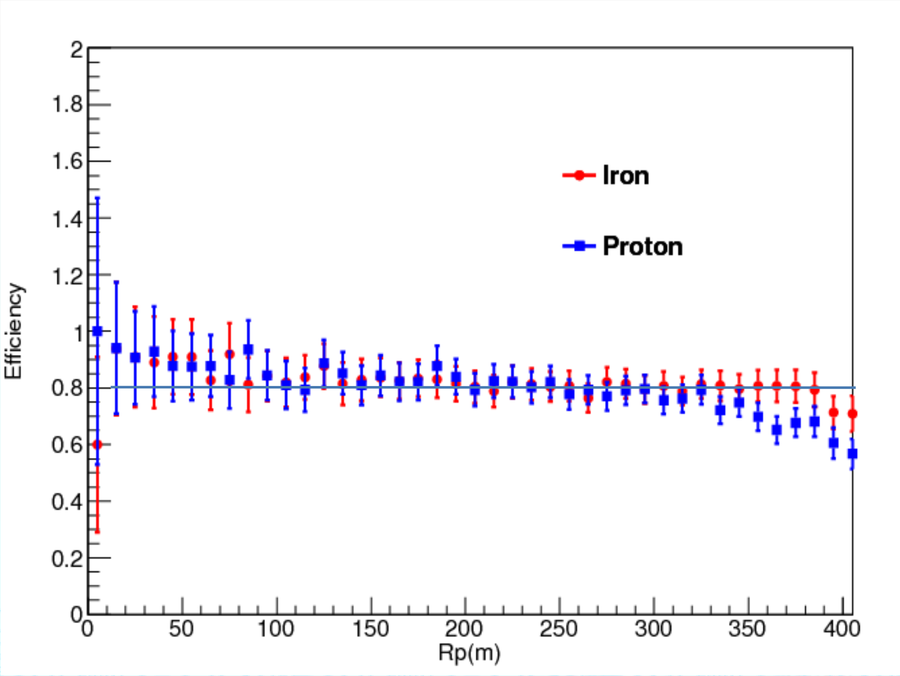




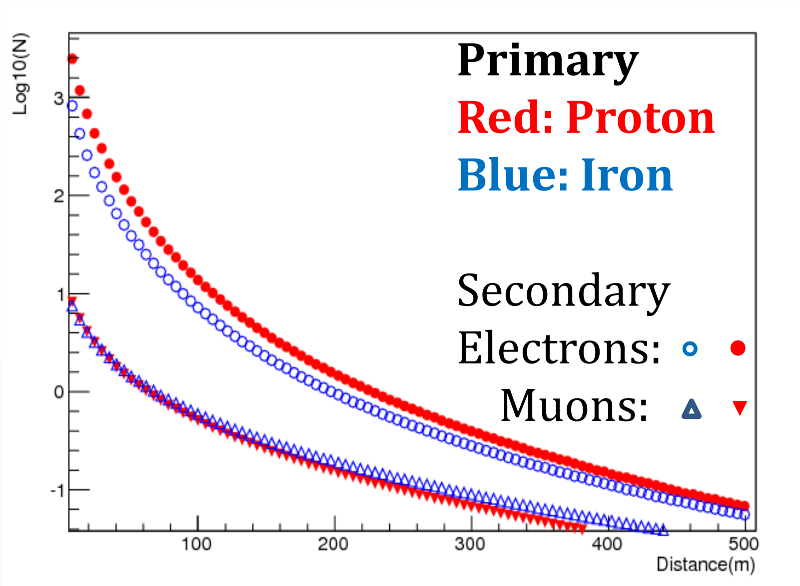
E>10 PeV: tel's + whole array
clean Fe sample and Fe-knee

- AS core resolution: <3 m (EDA)
- AS arrival direction resolution: ≤0.2°(EDA)
- Trigger efficiency for E>7 PeV: >80% up to 350 m
- Energy resolution: ~20% (CT)

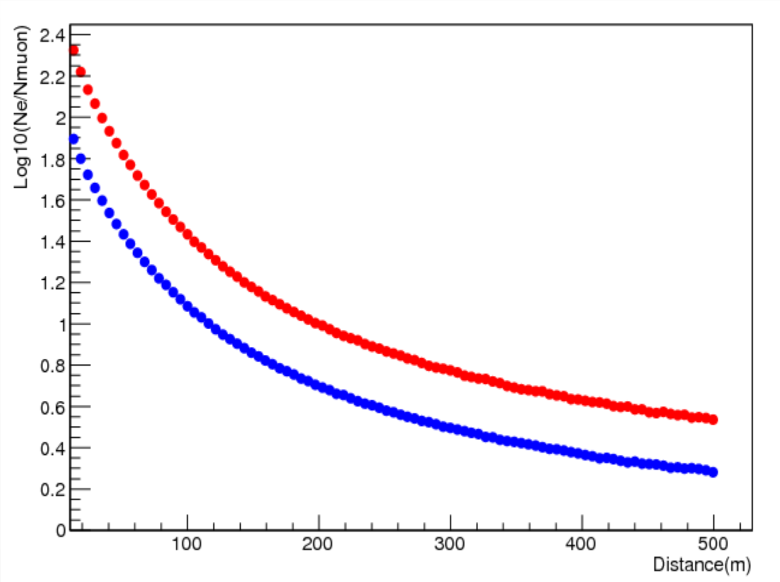




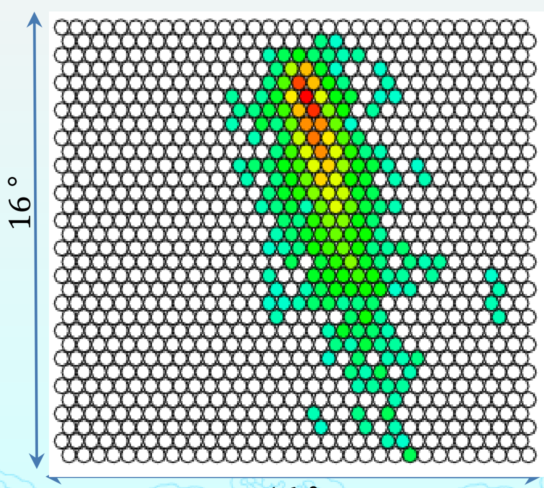
Muon-contents of showers

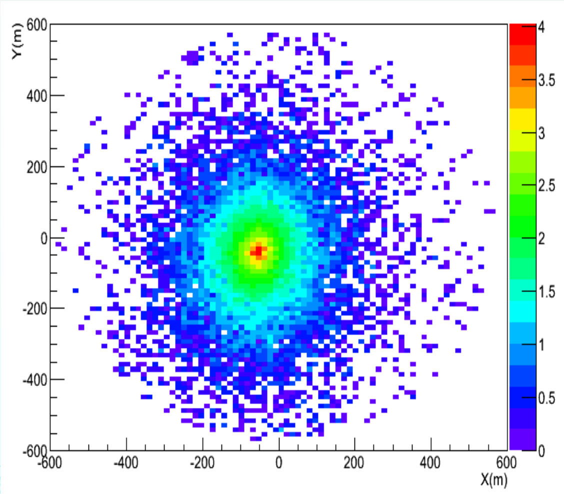


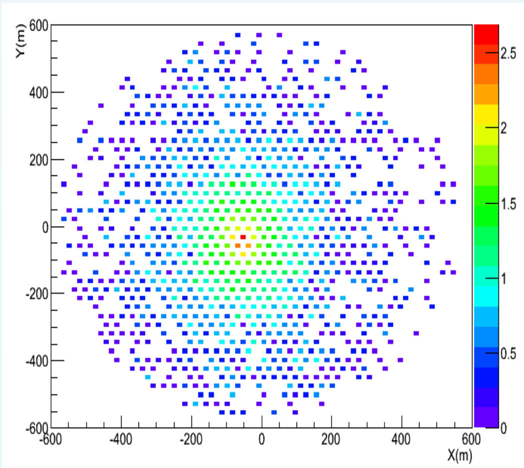
Lateral distribution of e/γ and μ



Lateral distributions of Log10(N_{ch}/N_{μ})





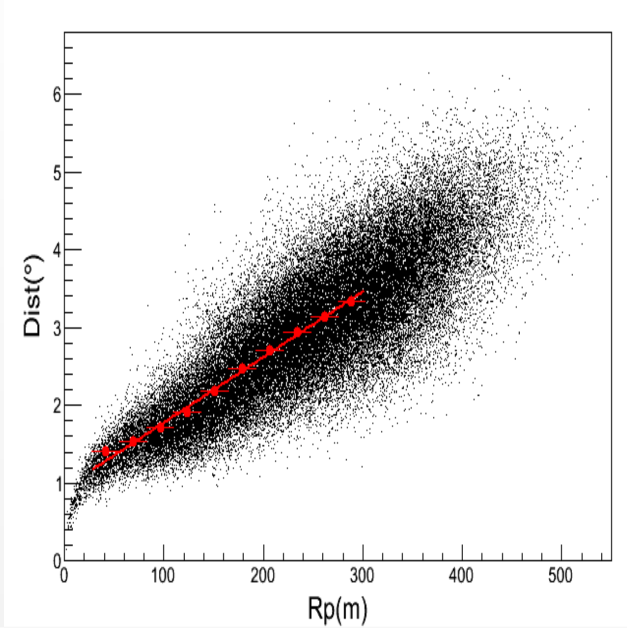


Proton, 20PeV

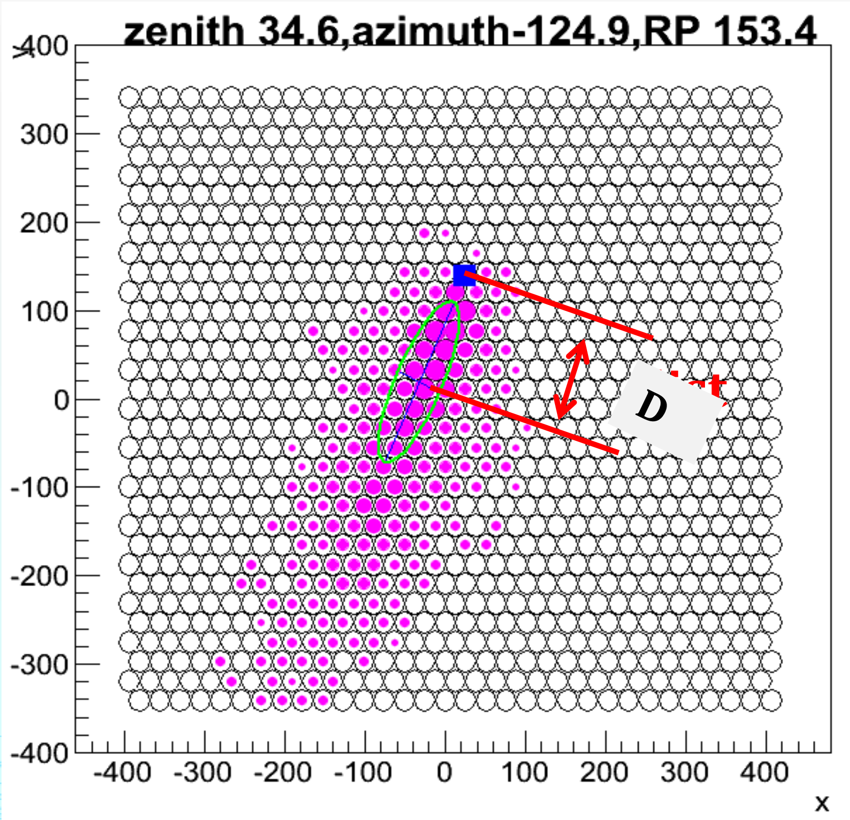
X_{max} Reconstruction

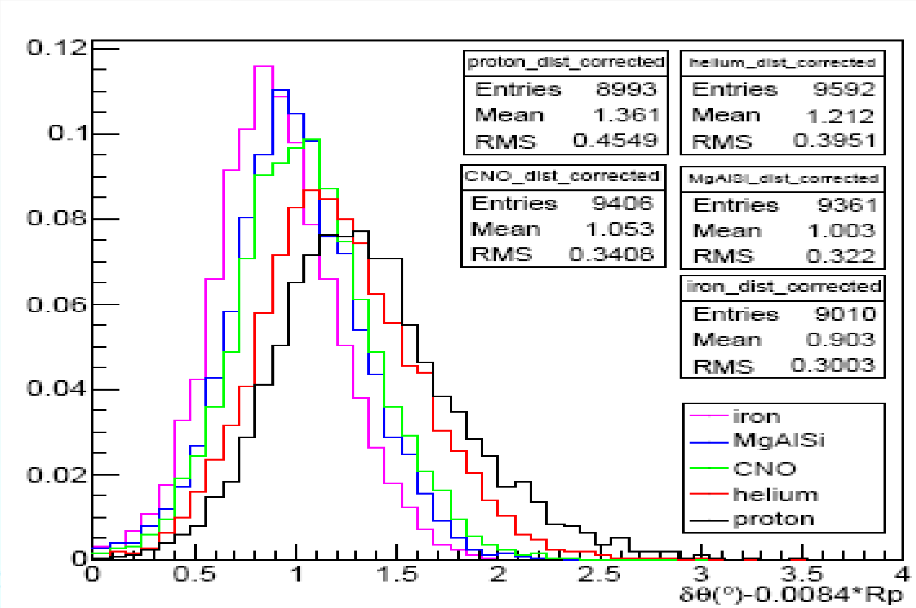
- **D**: angular distance between the shower direction and the gravity center of the image
- **D** is R_p dependent (geometrical effect)
- For events with R_p smaller than 300m,

  $D \sim 0.0084 * R_p \quad (50m < R_p < 300m)$



P_X





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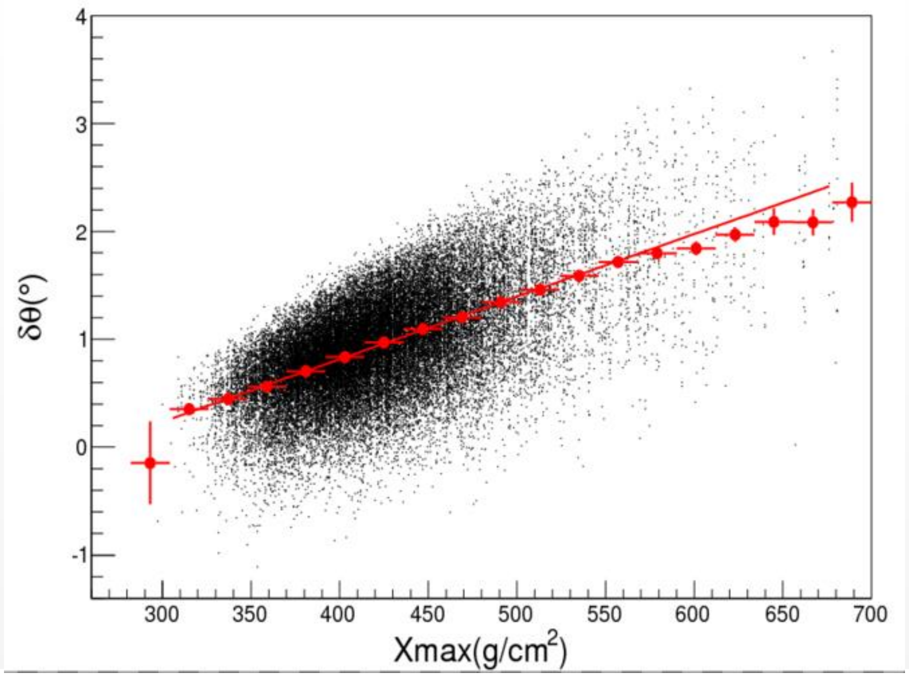
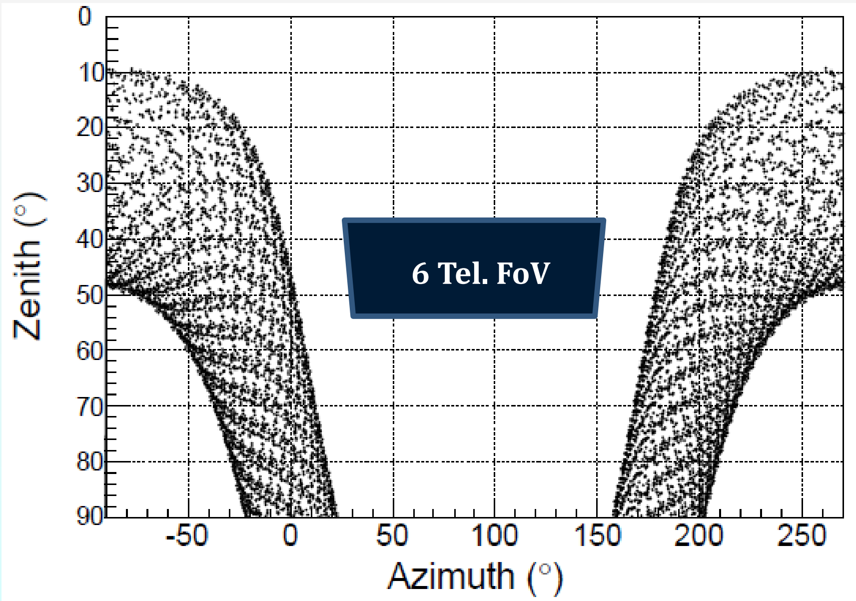
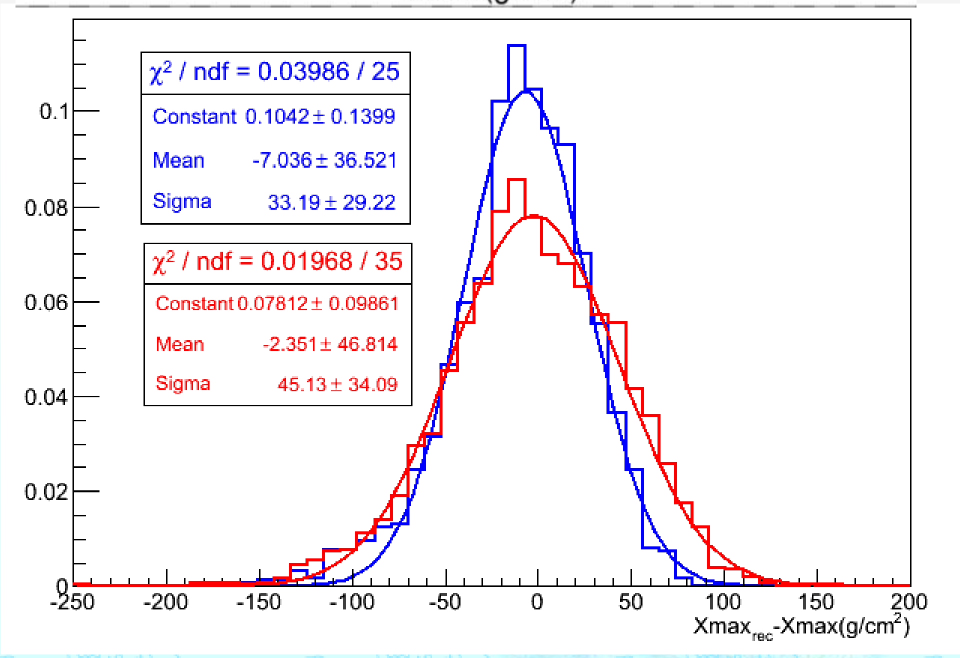
X_{max} reconstruction:

$((D-0.0084*R_p)+1.44)/0.0056$

Resolution : 33 g/cm² for iron
45 g/cm² for proton







Unbiased measurement of heavy species

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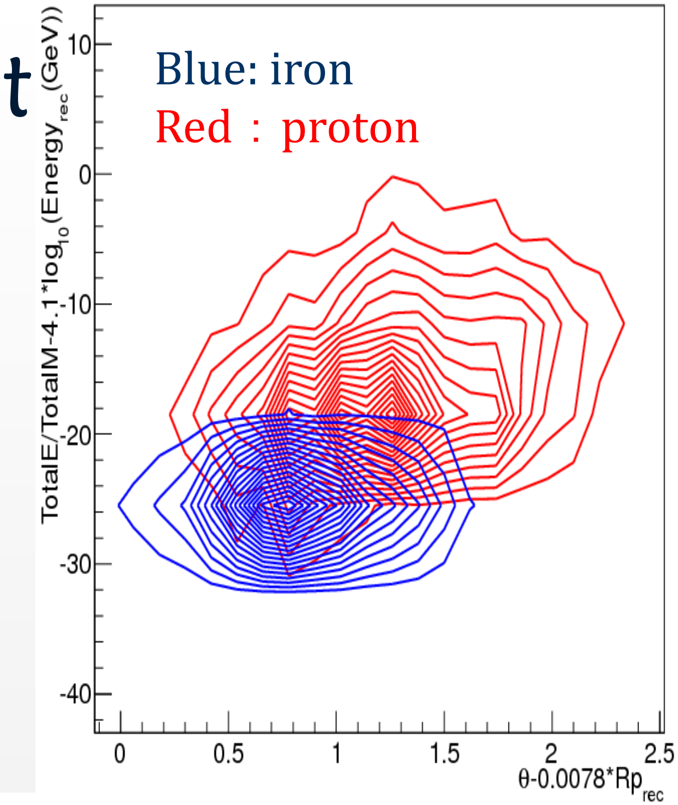
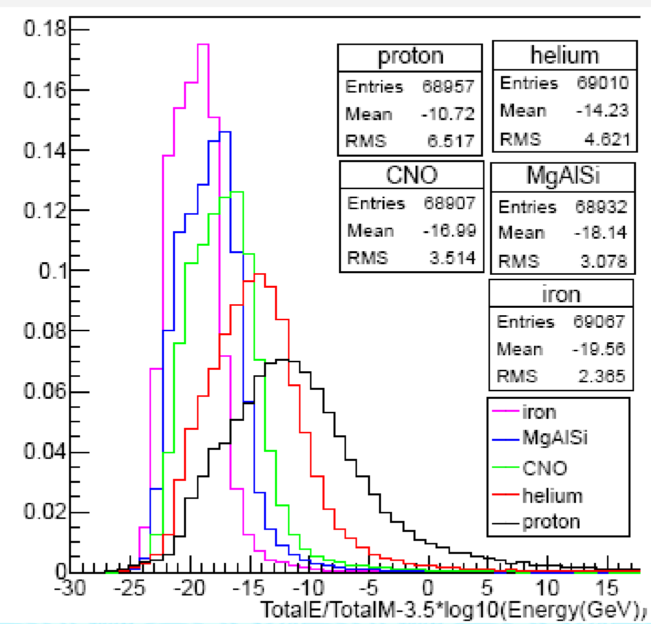
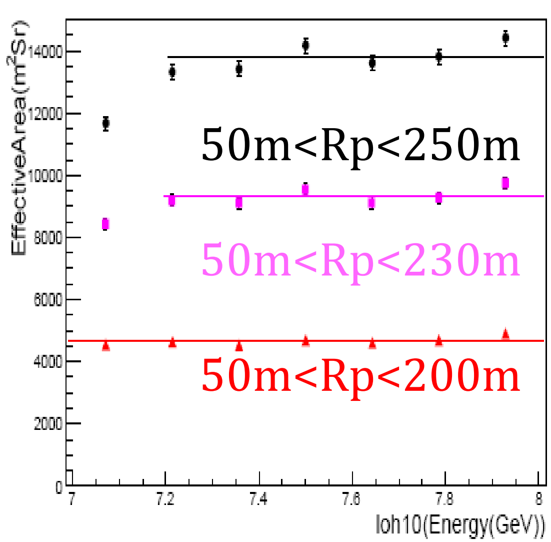
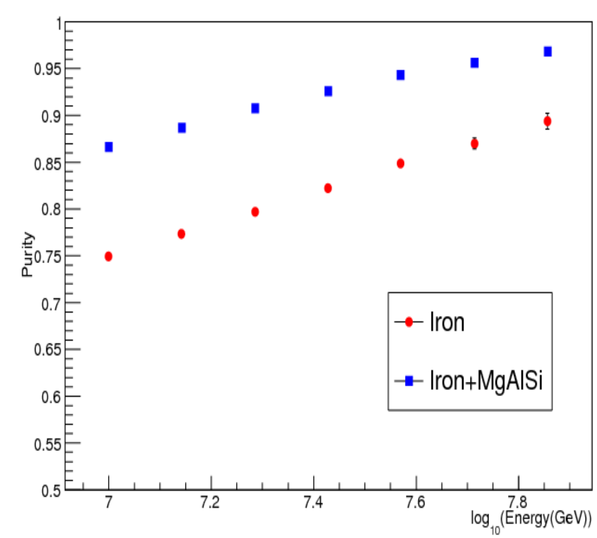
- Aperture: ~0.25×10^6 m^2sr
- Iron selection:
  - μ-content and X_{max} 2-variable analysis
  - Expected Fe event rate: 0.2M/yr with a duty cycle of 15%
- The goal: the spectrum of pure Fe or mixed heavy components and their knees



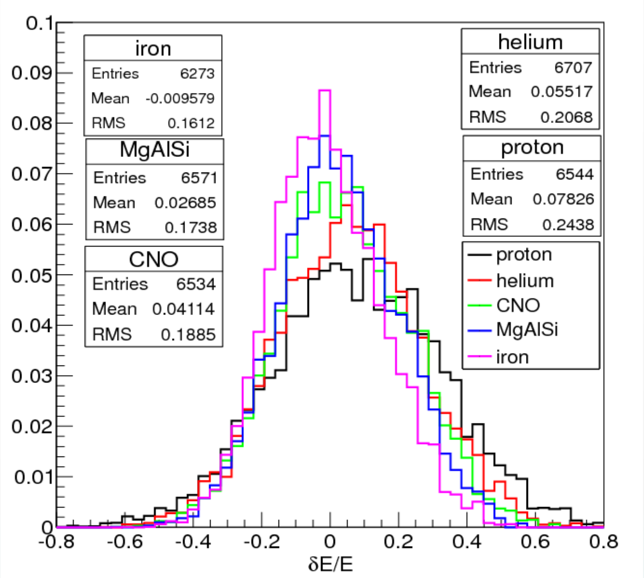


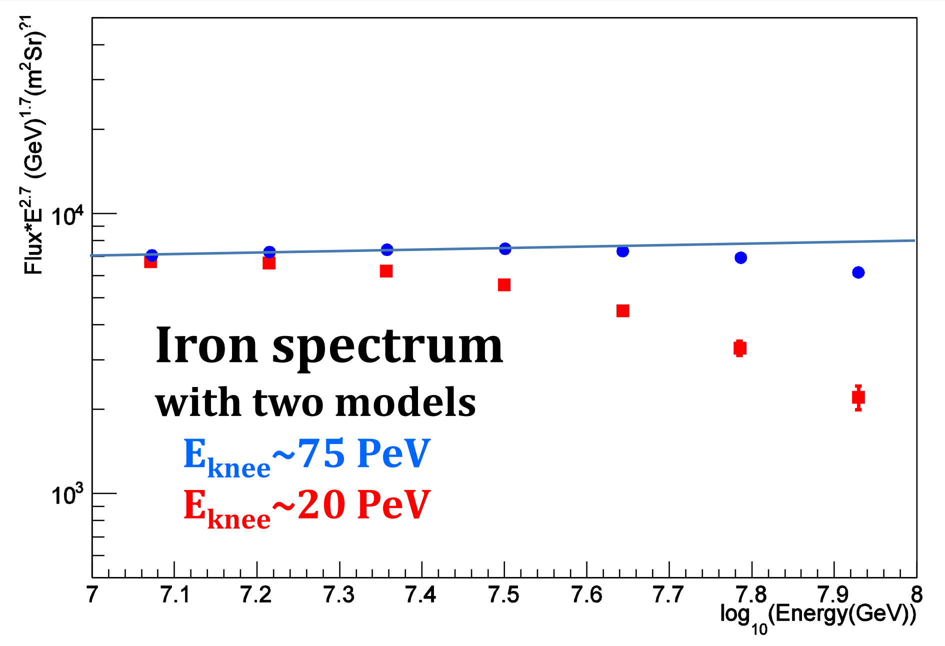


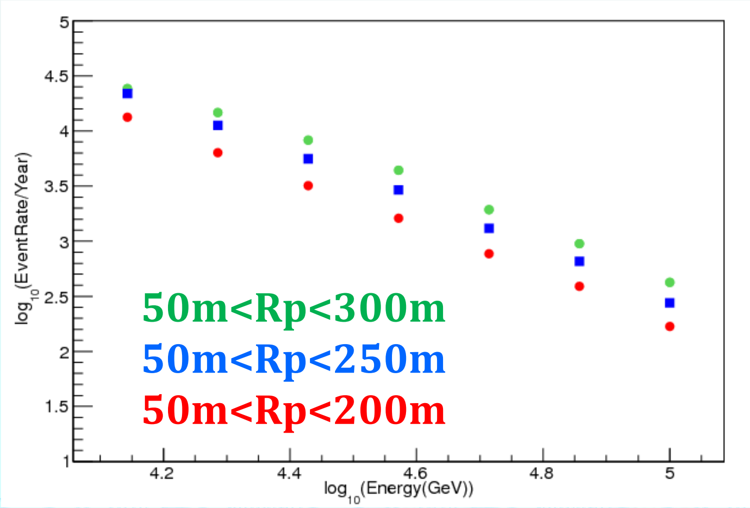


Energy Reconstruction & Event Rate Expectation

- Energy resolution 16% for iron showers
- The knee, if exists, will be measured significantly in 1-yr observation







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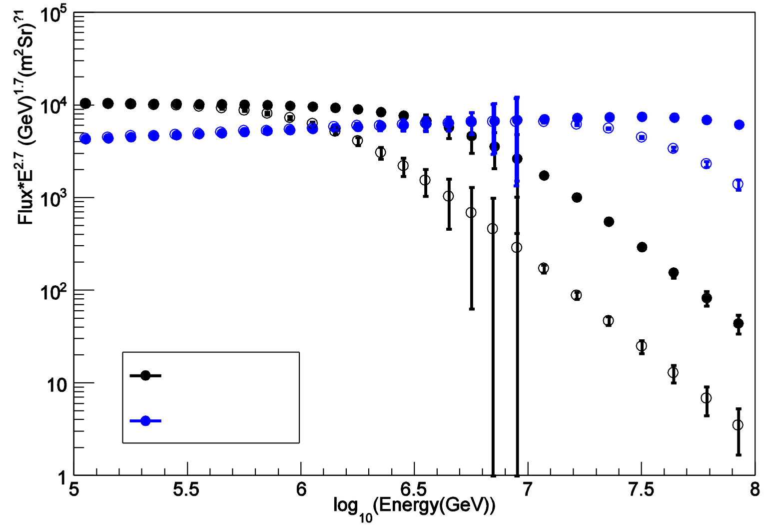
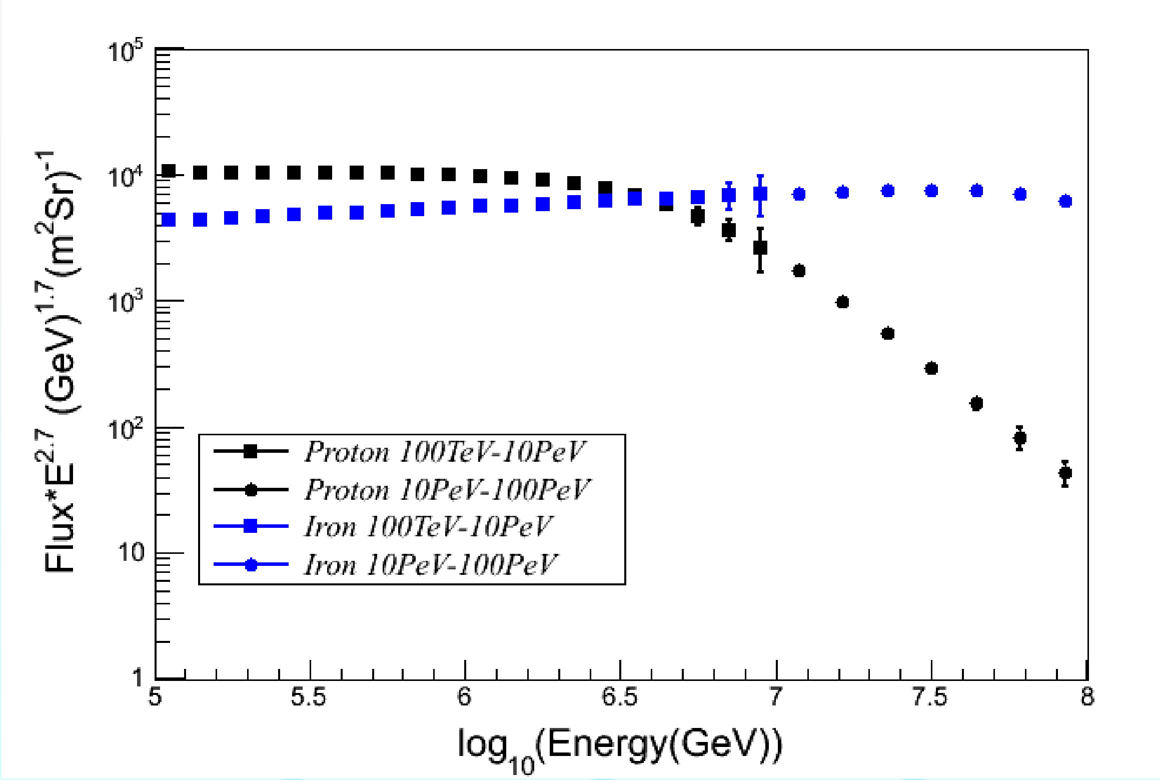
Proton and Iron knees by LHAASO

LHAASO 5 yrs





100TeV 1PeV 10PeV 100PeV

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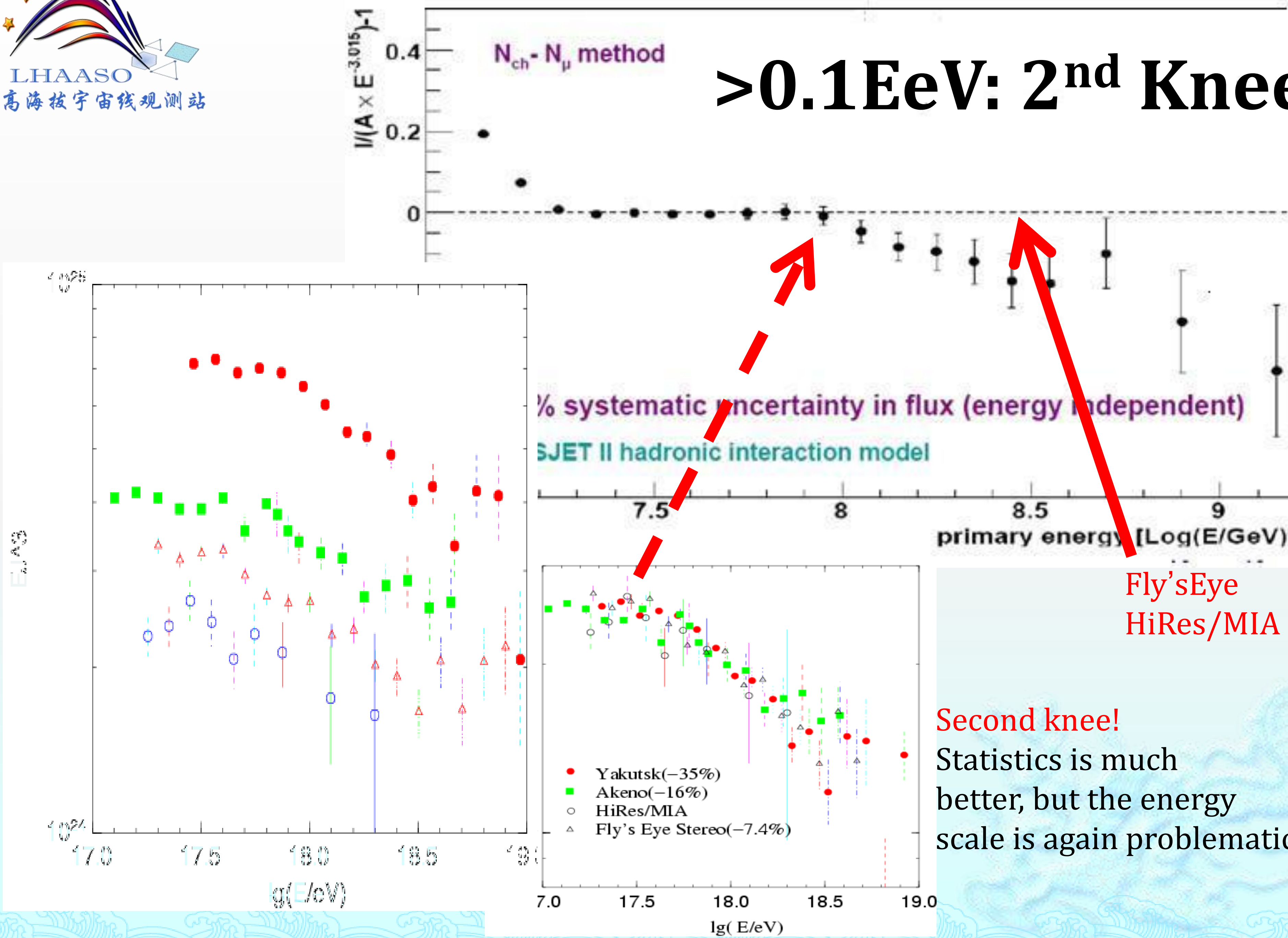
>0.1EeV: 2^{nd} Knee



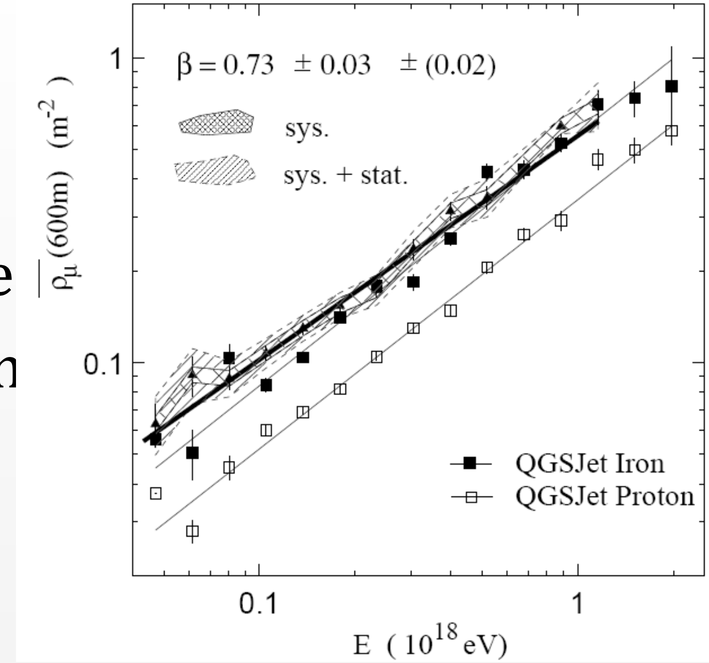
Fly'sEye
HiRes/MIA

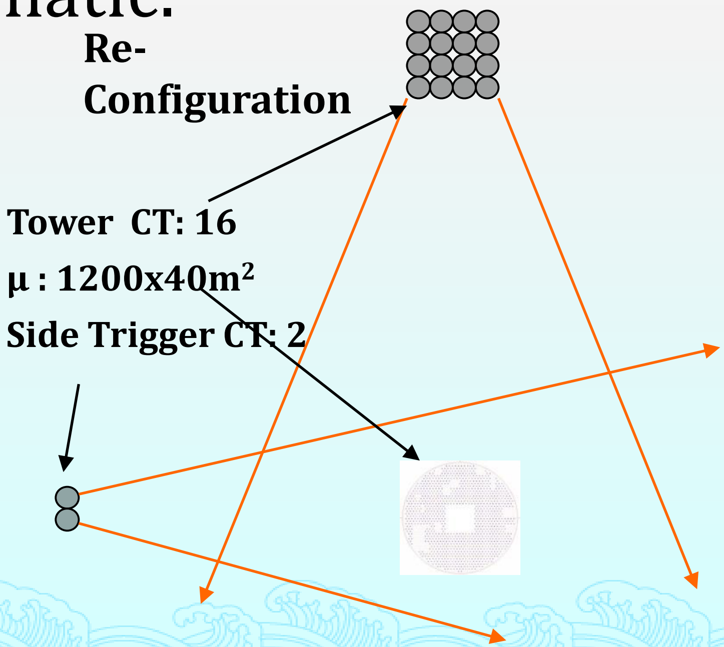
Second knee!
Statistics is much better, but the energy scale is again problematic.

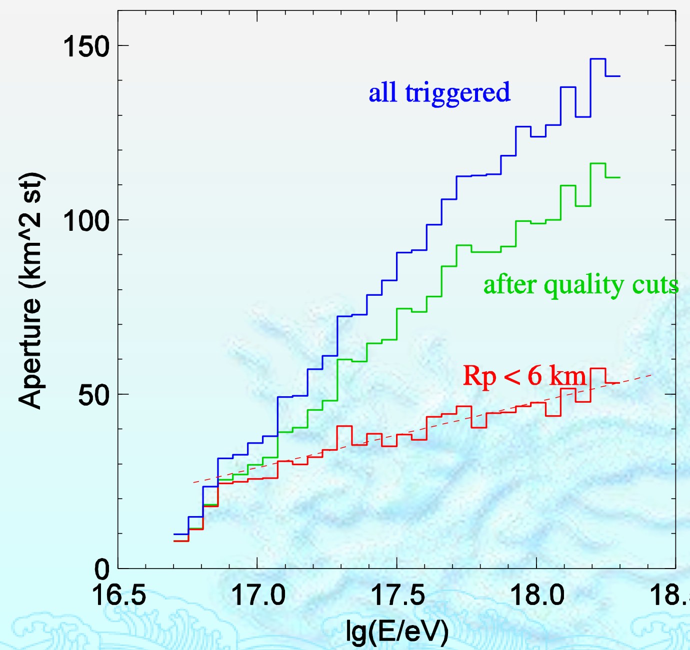
Still Energy Scale

- Calibration between C-tele and F-tele
- Calibration between TUNKA and F-tele
- Calibration between LHAASO/F-tele an
  other F-tele arrays?

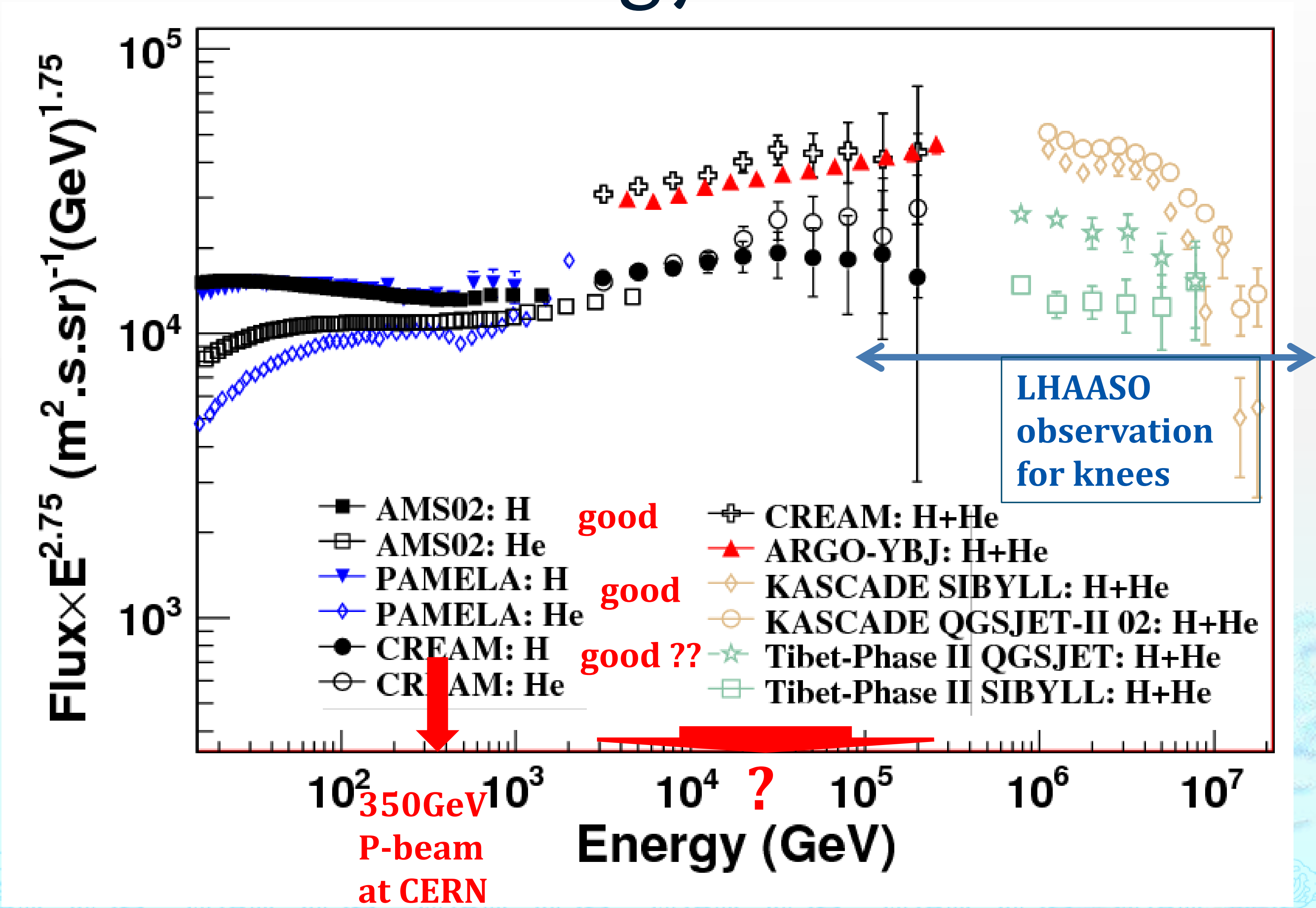
But not only…… muon-content is also problematic.







Energy Scale



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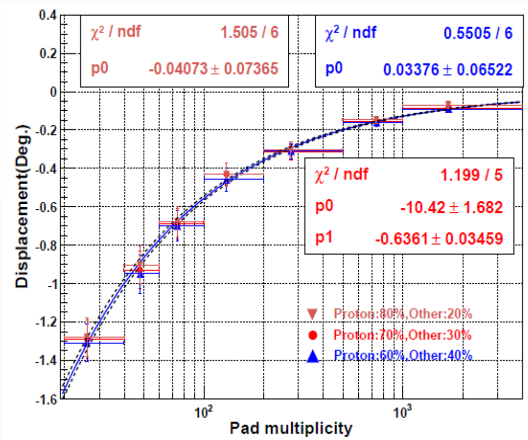
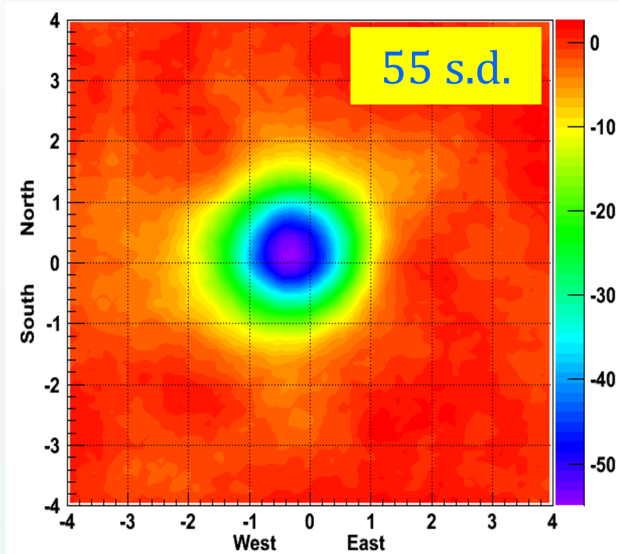
Energy scale in experiment

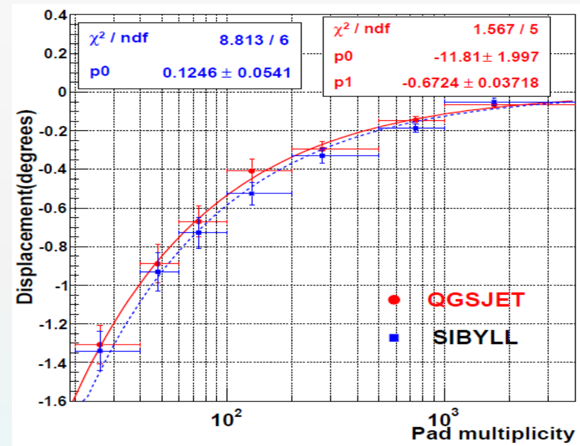
ARGO-YBJ : Moon Shadow displacement

$$N \approx 21 \cdot (E_{TeV}/Z)^{1.5}$$

1 – 30 (TeV/Z)





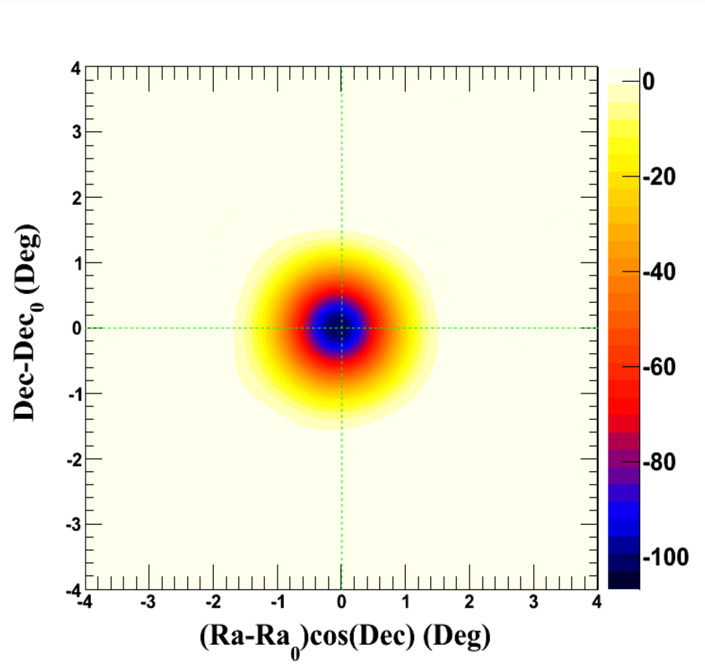


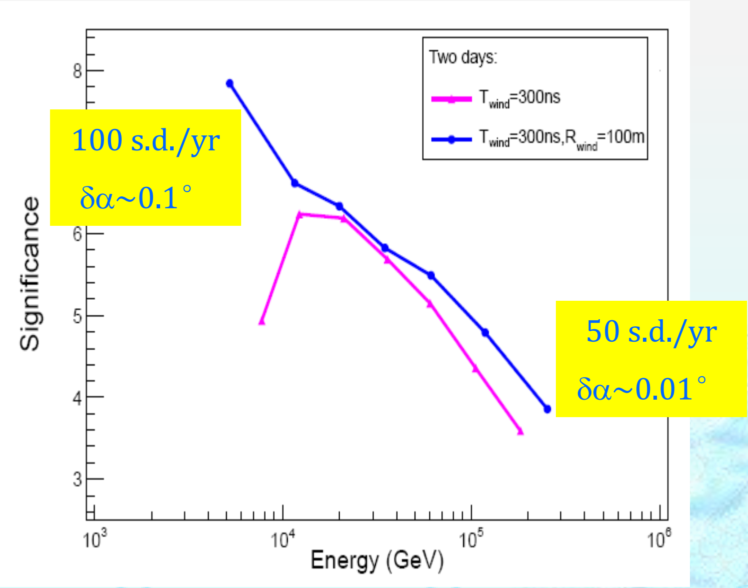
The energy scale uncertainty: smaller than 13%:

- the assumed primary CR chemical composition (7%)
- the uncertainties of different hadronic models (6%)

LHAASO E-Scale

- Water pools: 300 GeV – 10 TeV
- Scin.+MD array: 10- 300 TeV
- Systematic error: ~8% (using pure proton sample)
- Telescope array will pick up the scale by using the hybrid events with the Scin.+MD array in 30- 300 TeV



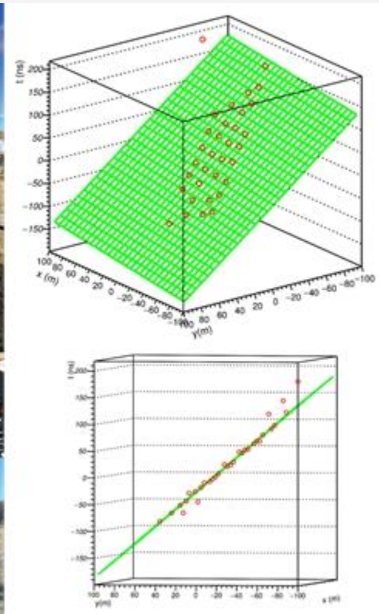


Construction

- #1 pool（150X150 m^2）is build up.
- 2018/01/31 covered, internal installation
- 2018/04, #2 & #3 pools are started simultaneously

- 2018/02/04, first 33 scintillator detectors deployed.

The 1st LHAASO event



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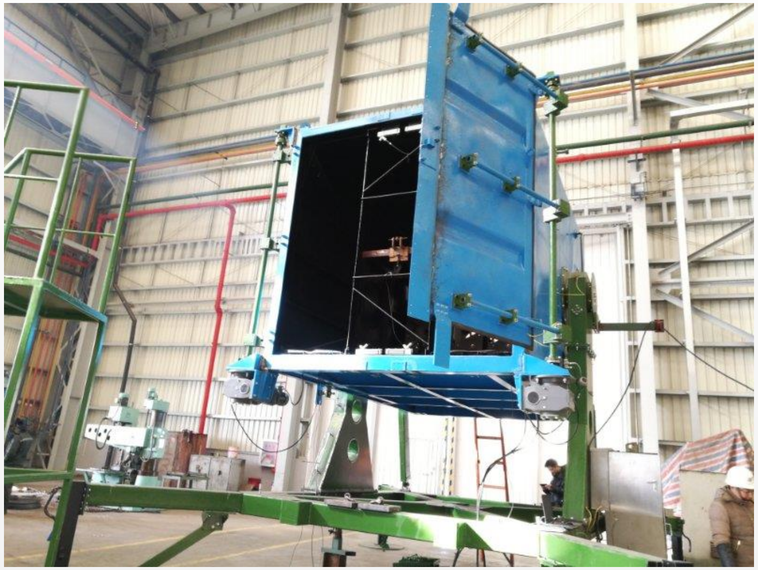
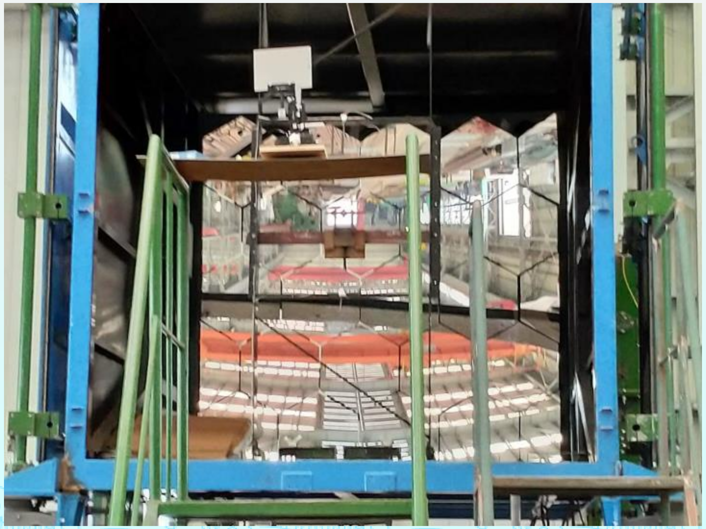
Construction

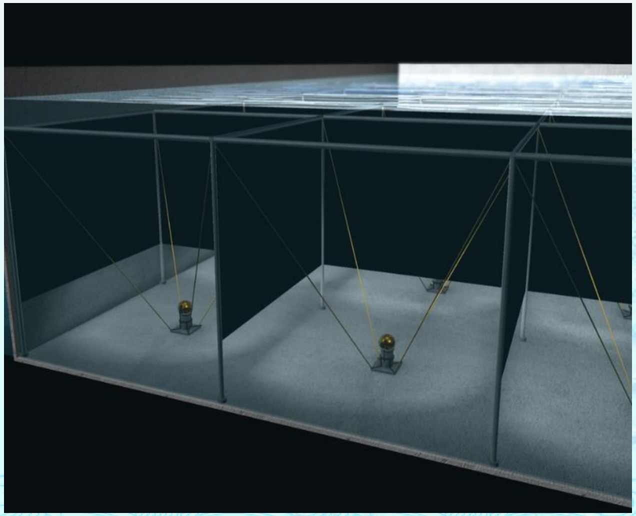


1st fan-less WR switch

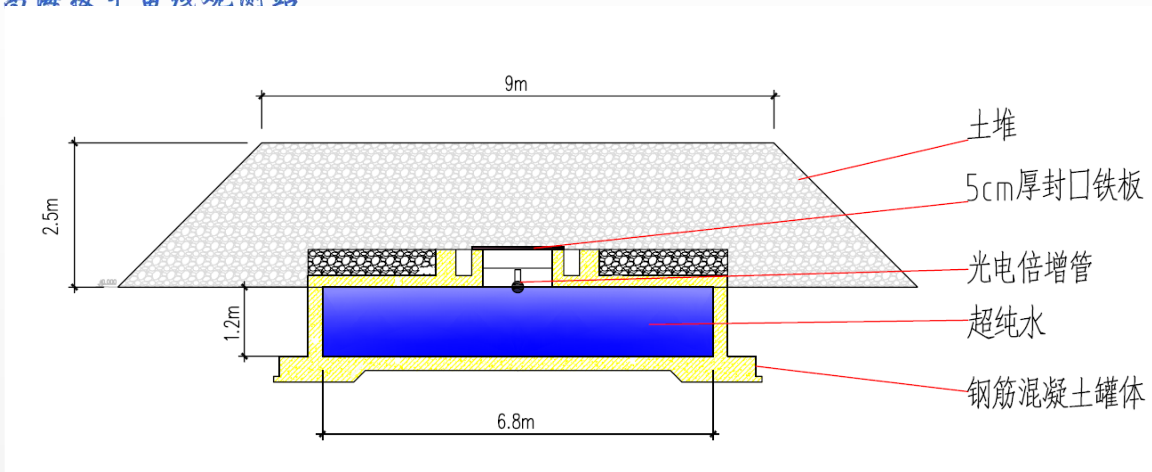
Spot size of 6 mm

1st telescope





MD Progresses



MD Deploying Schedule:

First tank in May

1, in 2018, 300 MDs

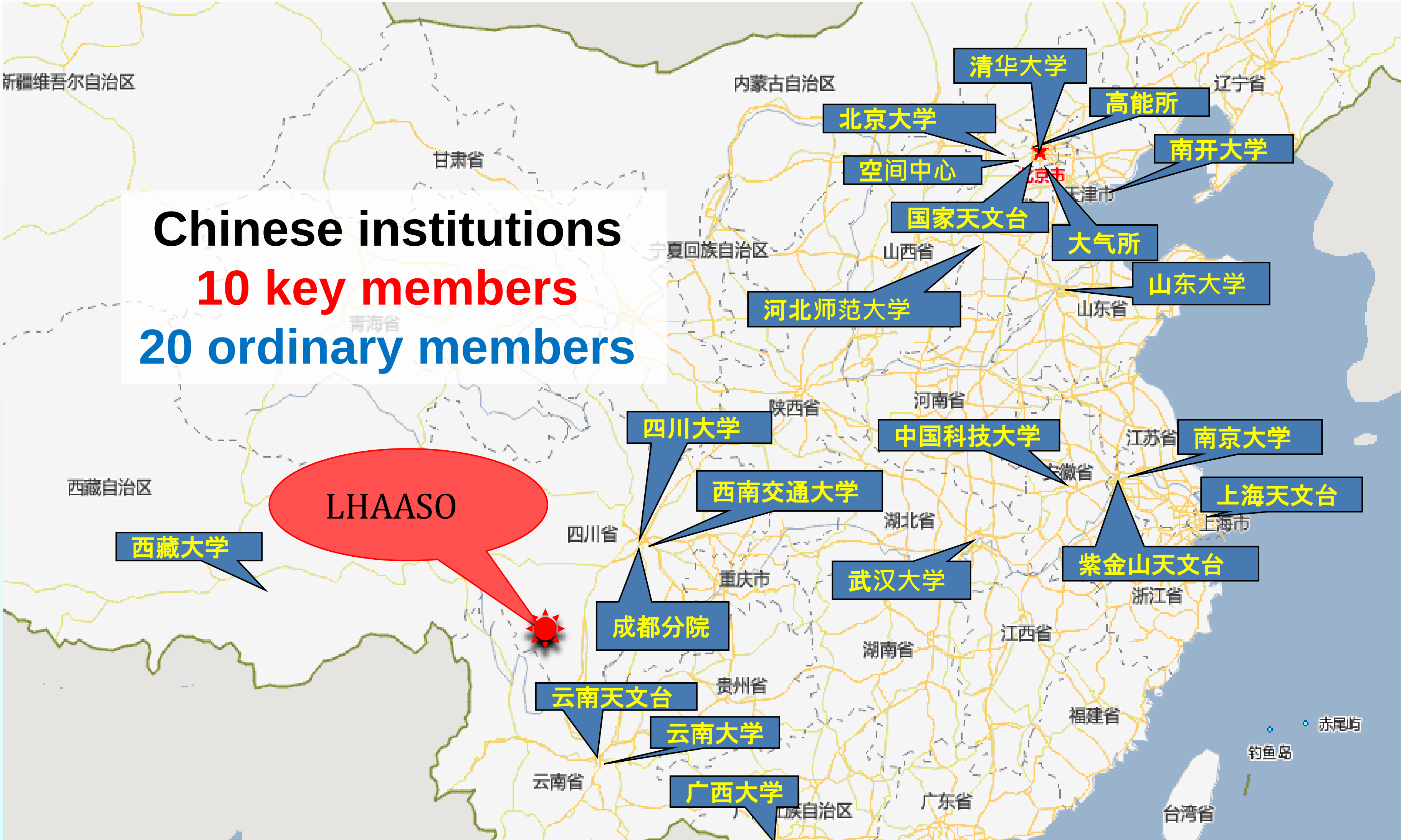
2, in 2019, 415 MDs

3, in 2020, 456 MDs

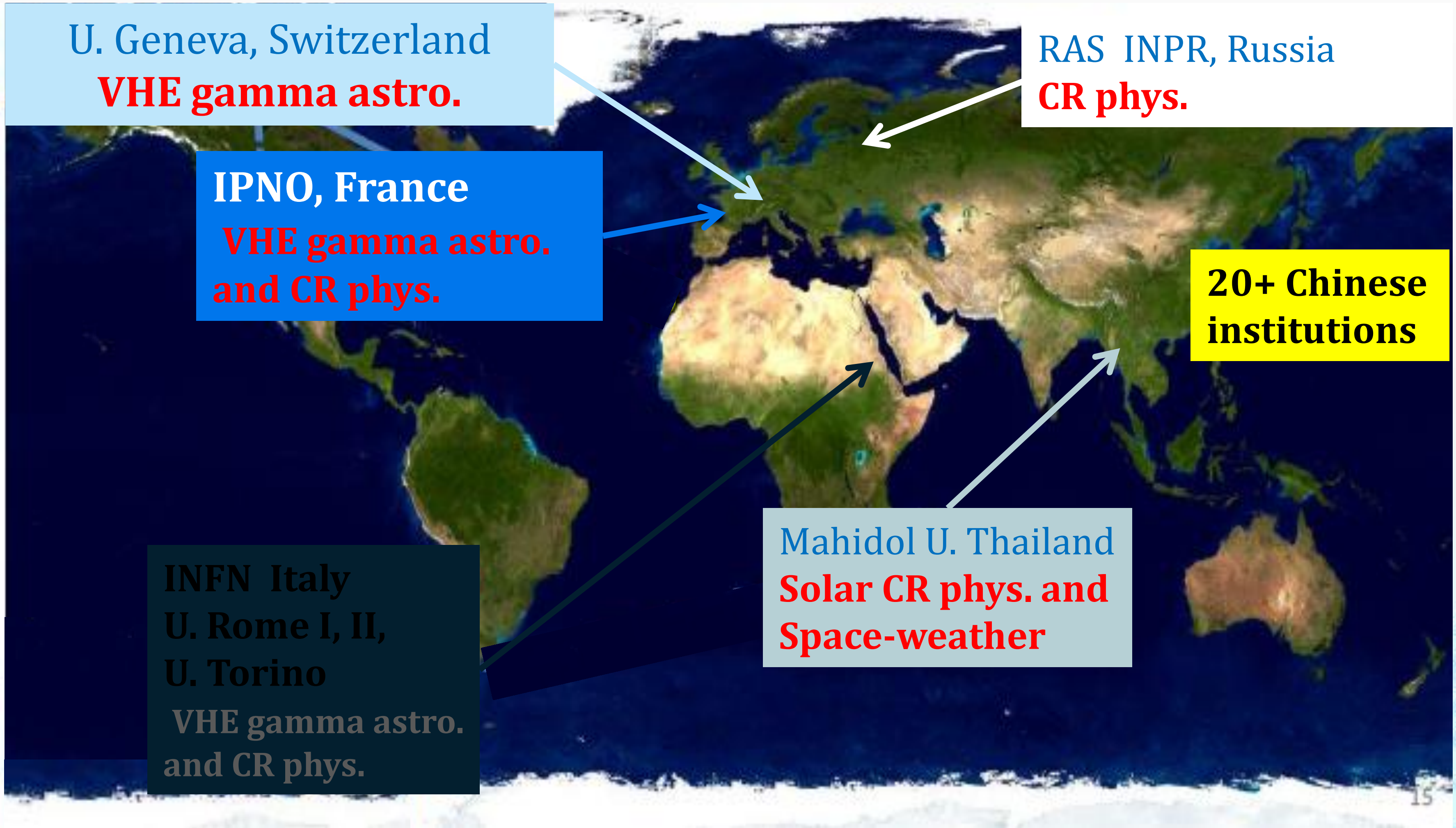
➢ Liner

LHAASO Collaboration

Chinese institutions
10 key members
20 ordinary members



LHAASO Collaboration (growing)



Summary

- LHAASO observatory
  - Unique on 10 TeV gamma ray monitoring
  - Window for evidences of hadronic origin of cosmic rays
  - Provides also crucial CR data in the region of knees
- Individual mass groups are expected to be separated out below 100PeV, knees of their spectra will be well measured
- An energy scale with ~8% uncertainty will be established below 300 TeV by using moon shadow of the pure composition cosmic rays
- Detector construction started June 2017 and infrastructure May 2016.
- LHAASO has been funded mainly by China with 20+ domestic institutions joined for 25 sub-systems
- International Coll. is growing……

Welcome to join LHAASO Coll. !

LHAASO picture of the year 2017-11-17 20:00