3rd Annual MT meeting

Detector Technology and Systems

High-Energy Astroparticle Physics

Detection Technologies and Future Challenges

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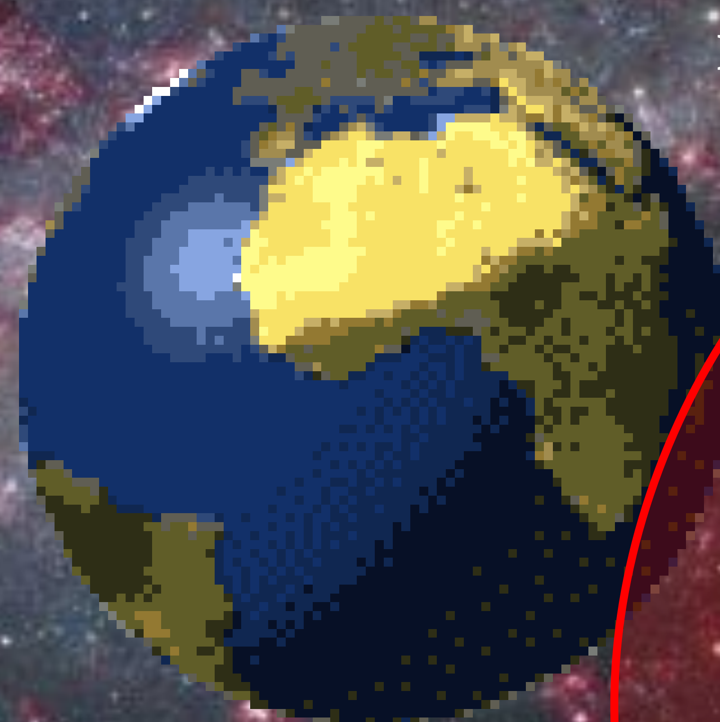
Astroparticle Physics

particle physics

neutrino properties

dark matter

magnetic
monopoles



atmospheric
neutrinos

solar neutrinos

gravitational waves

cosmic rays

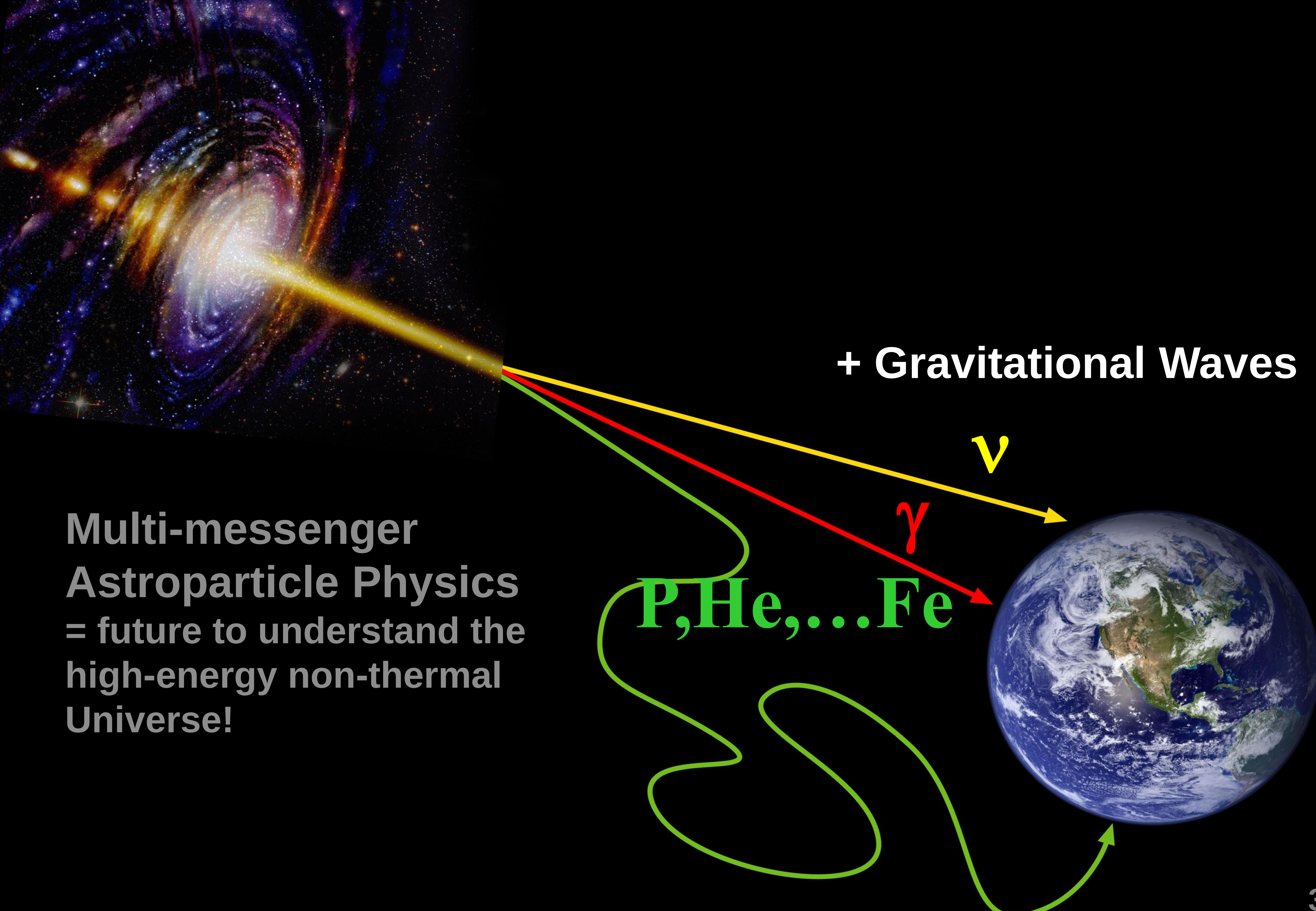
gamma
astronomy

neutrino
astronomy

Astrophysics

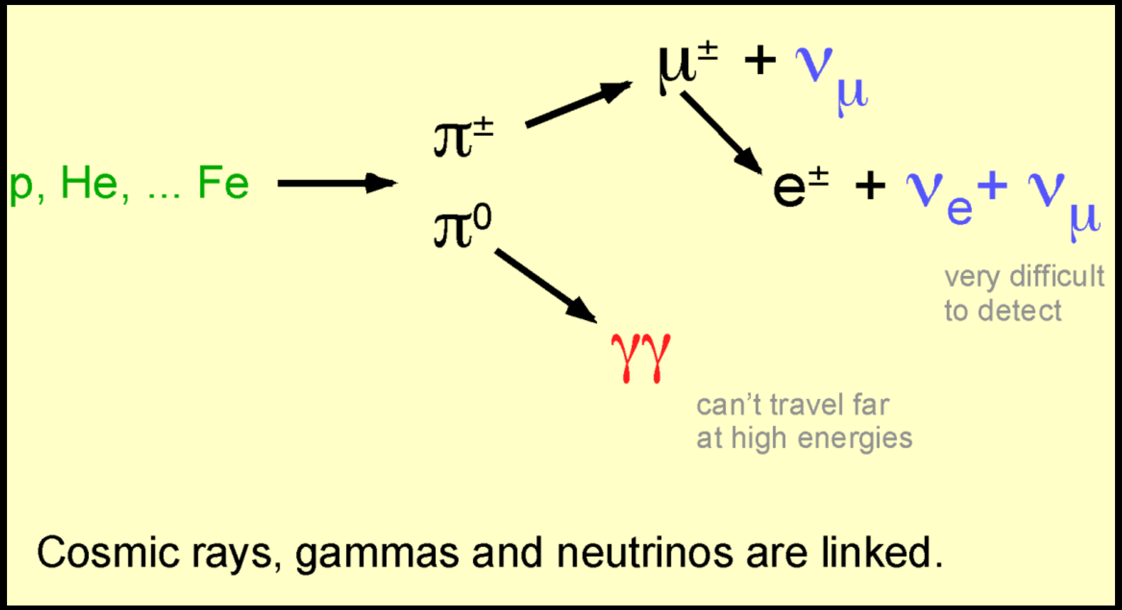
High-Energy
Astroparticle Physics

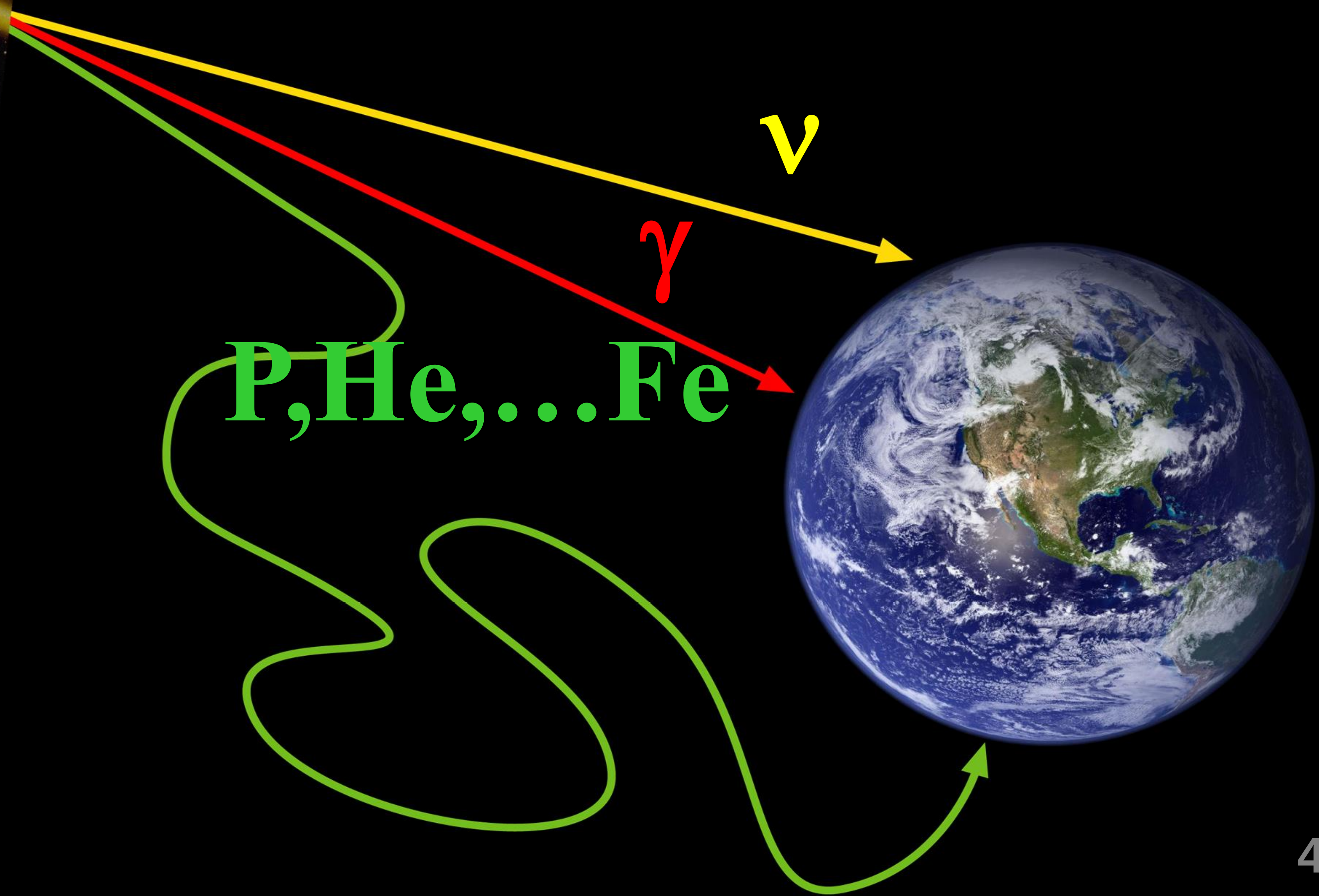
Multi-messenger Approach in Astroparticle Physics



Multi-messenger Astroparticle Physics
= future to understand the high-energy non-thermal Universe!

Multi-messenger Approach in Astroparticle Physics

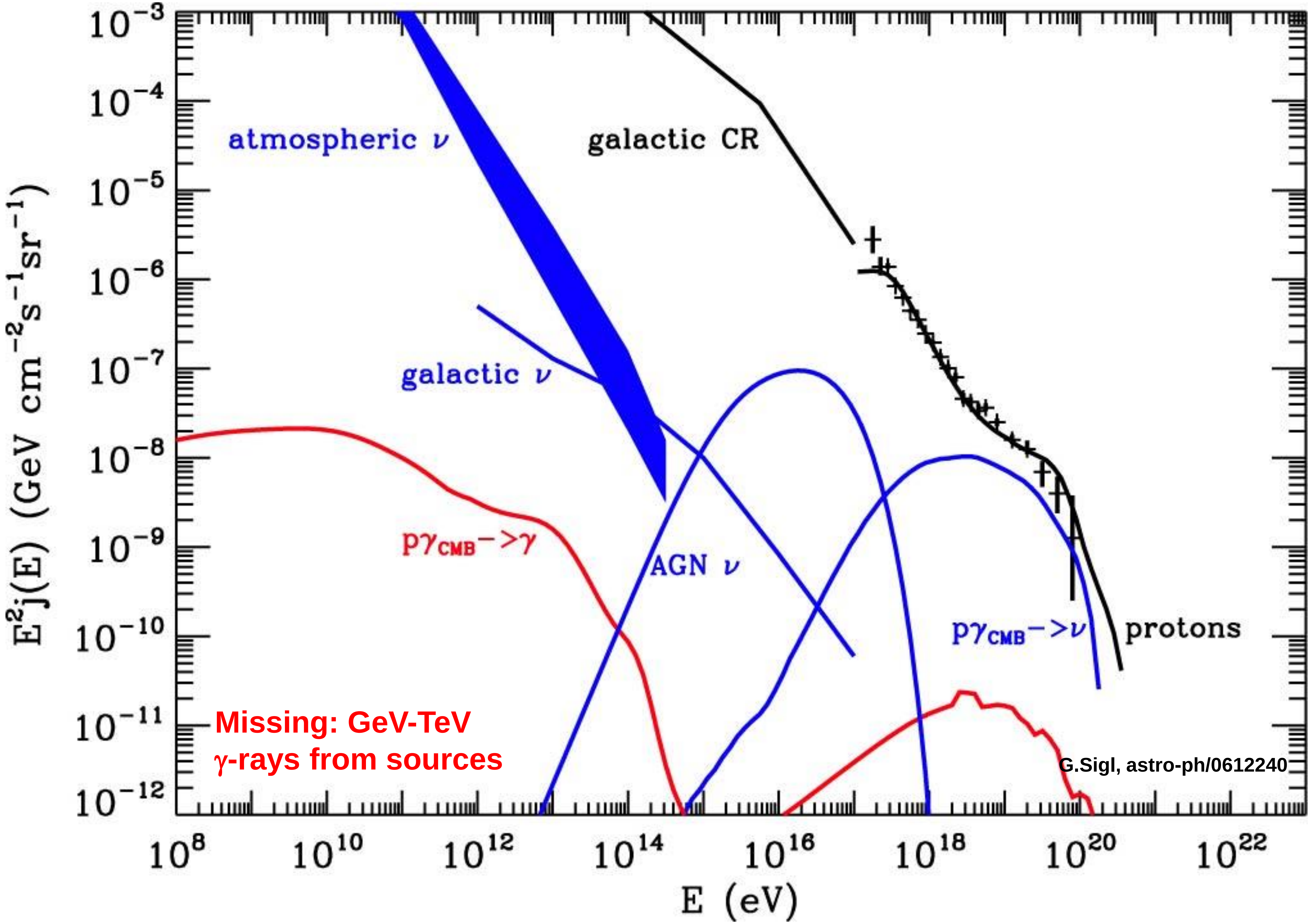




GZK:

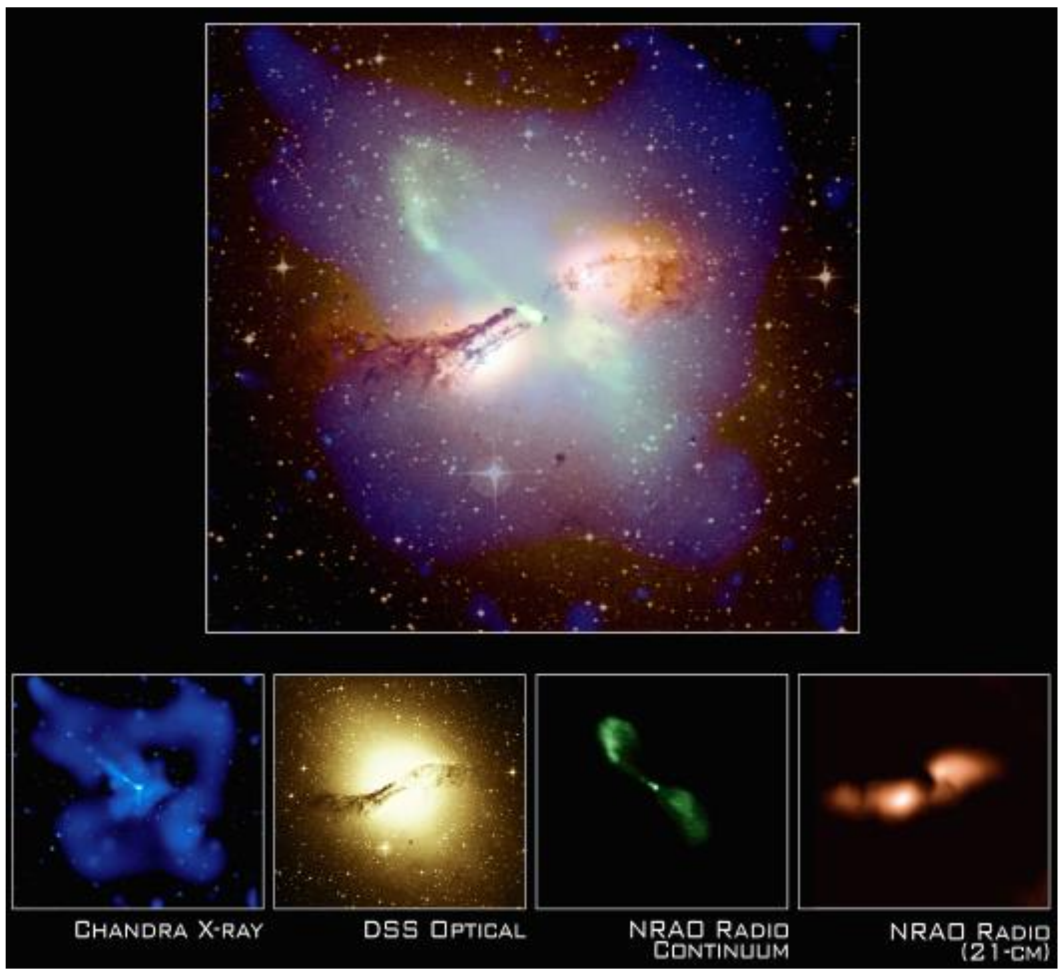
$$p + \gamma_{2.7K} \rightarrow \Delta^{+}(1232)$$
$$\rightarrow p + \pi^{0} \rightarrow p\gamma\gamma$$
$$\rightarrow n + \pi^{+} \rightarrow pe^{+}\nu$$

High Energy Universe: nuclei, γ's, and ν's



Can we do Particle Astronomy?

i.e. multi-messenger observations of individual sources?
example: Centaurus A (NGC 5128, Cen A)



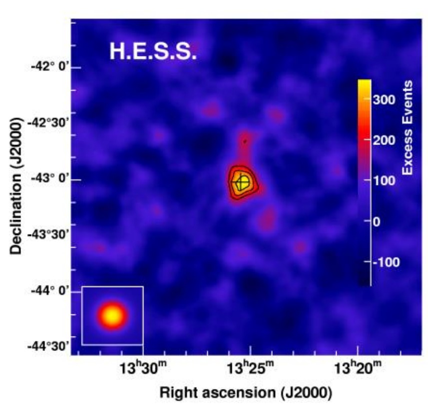
- closest radio-loud (d ~ 3.4Mpc) AGN
- one of the best studied active galaxies
- observed at many frequencies: from radio to X-ray

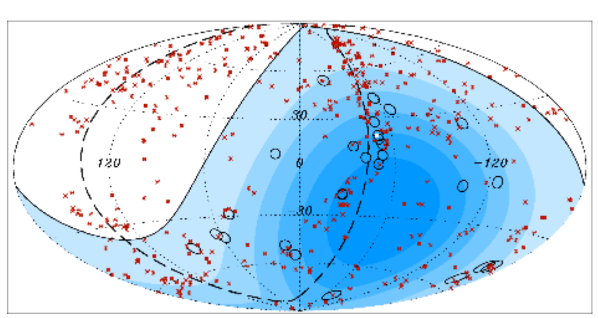
• Gamma-rays

70's: Narrabri [Grindlay et al., 1975]
90's: EGRET [Sreekumar et al., 1999]
Feb. 2009: Fermi-LAT [Abdo et al., 2009]
March 2009: H.E.S.S. [Aharonian et al, 2009]

• UHECRs

2007: PAO [Abraham et al., 2007]
possible, but no agreement [Lemoine, 2008]
2014: Hotspot TA [Abassi et al.2014]
Cen A in hotspot region





• Neutrinos

no observation ... yet
➔ detailed calculations and predictions!

The High Energy Universe

the facilities

- **Gamma Rays**

  H.E.S.S. / MAGIC + CTA

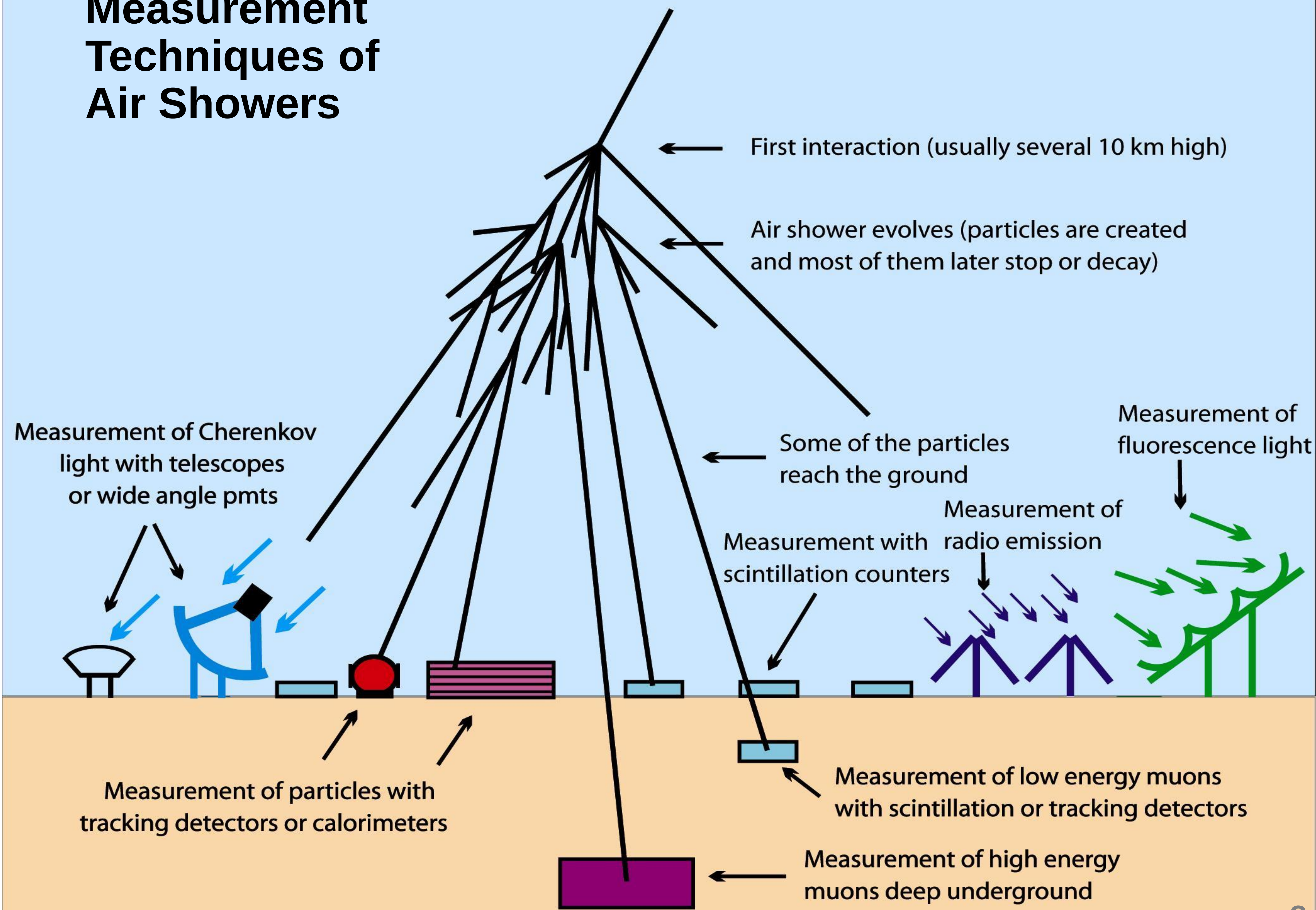
- **Neutrinos**

  IceCube / IceCube-Gen2 + KM3NeT

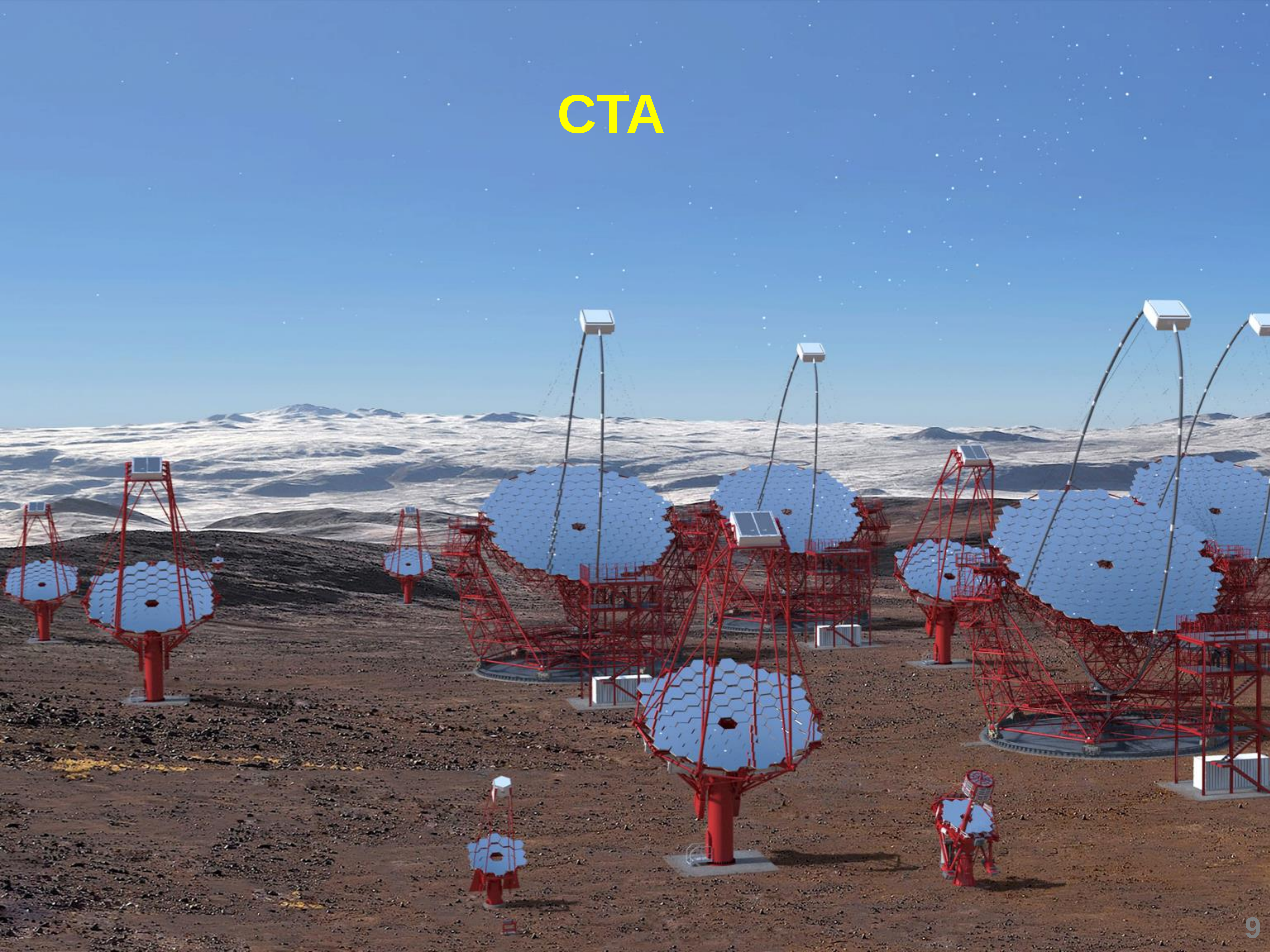
- **Charged Cosmic Rays**

  Pierre Auger / AugerPrime + JEM-EUSO

Measurement Techniques of Air Showers

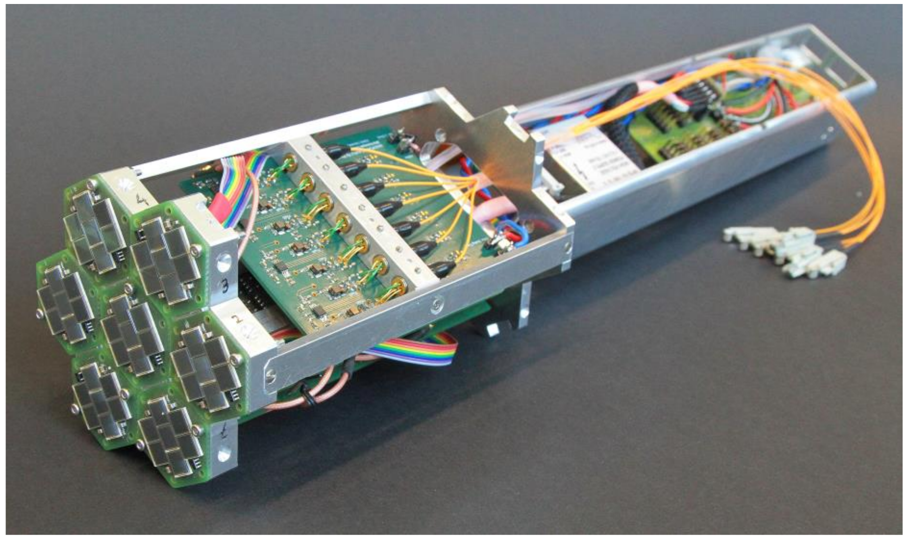


CTA



CTA: Mirrors and Cameras

- **Cameras**
  - MST PMT cameras
  - SST prototype with SiPM = ASTRI
  - Sensors and electronics
  - Data transport
- **Mirrors**
  - Mass production
  - construction



SiPM are particularly fit
for gamma-ray astronomy,
• Operation during Moonlight
~ 30% larger duty cycle
• No evidence of ageing
• Lightweight and robust cameras
• Excellent single PE sensitivity
• High PDE at ~ 40%

An incomplete list of possible CTA upgrades (start in ~10y)

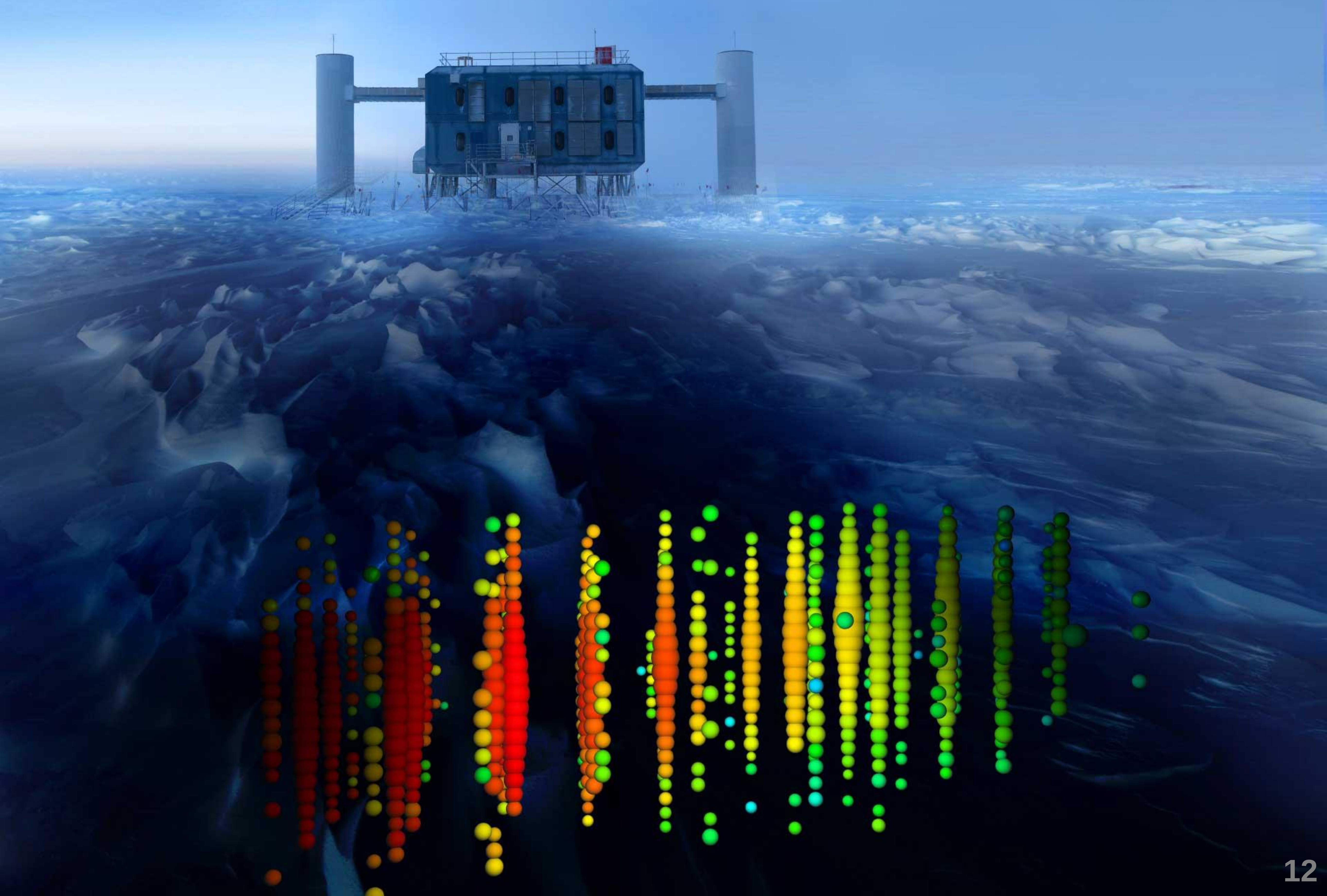
W. Hofmann, CTA meeting, Munich 2014

- CTA Upgrades
  - Energy threshold
    - Higher QE sensors (LST)
    - Larger telescopes
    - High-altitude location (5@5)
    - Dense telescope array & novel trigger (STAR)
  - Eff. area
    - More telescopes
    - Larger spacing
    - Non-imaging Cherenkov system (~HISCORE)
  - Background rejection
    - Higher-resolution images (~SCT)
    - Higher intensity in images – higher QE or size
    - Denser telescopes – more images
    - Muon detection (e.g. Tibet MD)
  - Angular resolution
    - Higher-resolution images (~SCT)
    - Higher intensity in images – higher QE or size
    - Denser telescopes – more images
  - Field of view
    - Wide-field imager (~ASHRA, EUSO, GAW)
    - Non-imaging Cherenkov system (~HISCORE)
    - Water Cherenkov detector (~HAWC)
    - Particle detector array (e.g. YBJ)
  - Duty cycle
    - Water Cherenkov detector (~HAWC)
    - Particle detector array (e.g. YBJ)

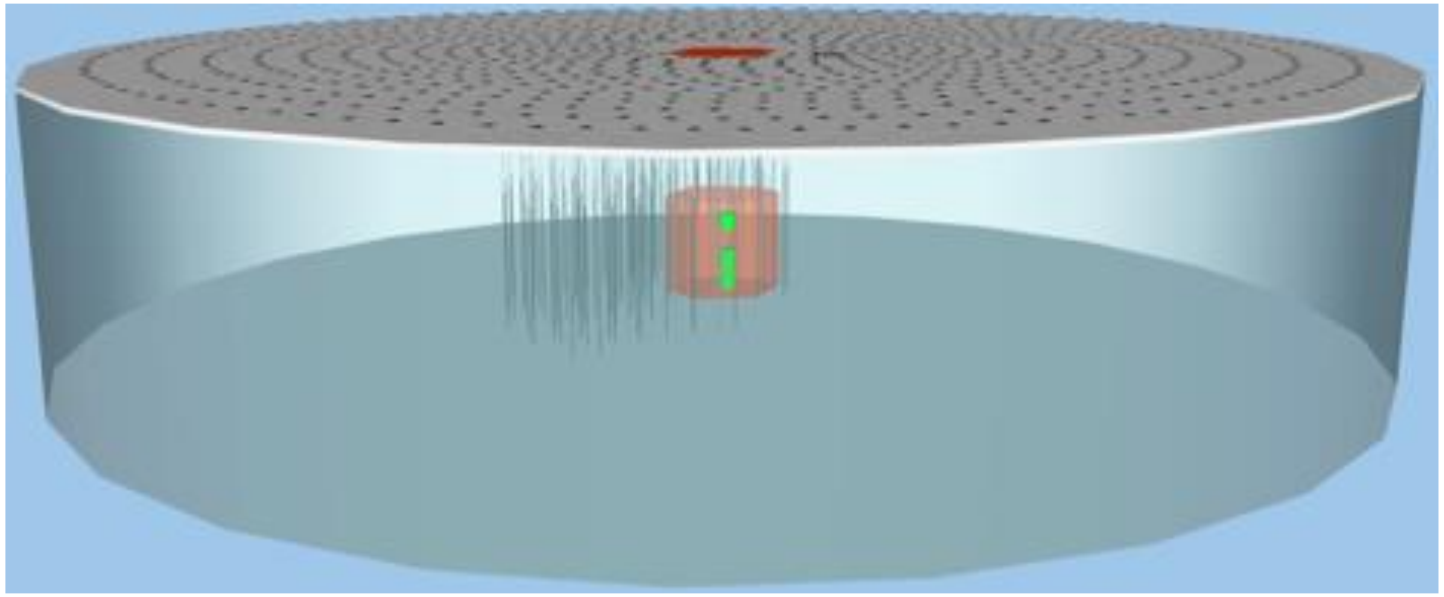
PMT developments **Non-imaging systems** **Particle detectors**

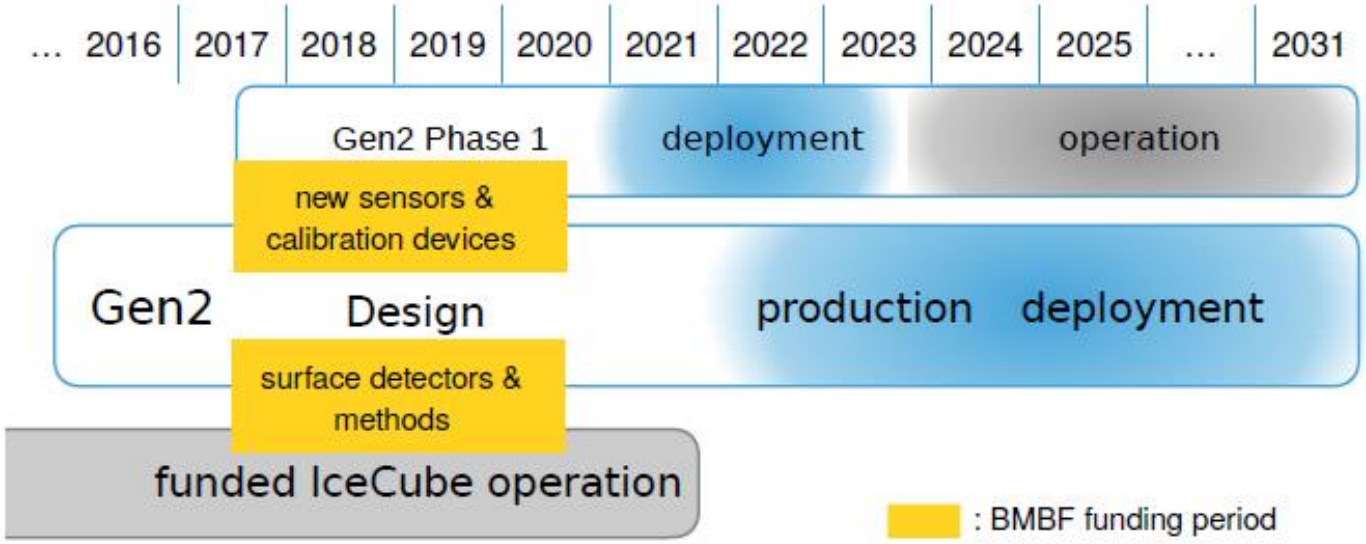
🡐 Future MT topics?

IceCube-Gen2



IceCube-Gen2 – surface array





Main goals:

- **Search / detection of PeV photons from galactic center**
- **Veto for IceCube-Gen2 EAS-neutrinos**
- **CR composition**

Combination of particle detector array with radio antennas and other technologies to optimize the array?
← Hybrid detector

Optical Modules
IceCube-Gen2 – KM3NeT – ORCA – PINGU - GVD

mDOM

PoS(ICRC2015)1147

36 cm

- directional information
- more sensitive area / module

(Erlangen, Münster, DESY)

D-Egg

PoS(ICRC2015)1137

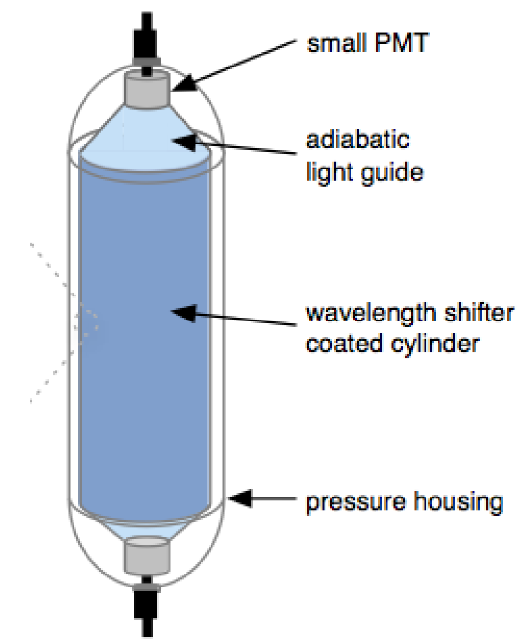
30 cm

- directional information
- more sensitive area / module
- smaller geometry

(Chiba)

WOM

PoS(ICRC2015)1134



11 cm

- more sensitive area / module
- small diameter
- lower noise rate

(HU Berlin, Mainz, DESY)

LOM

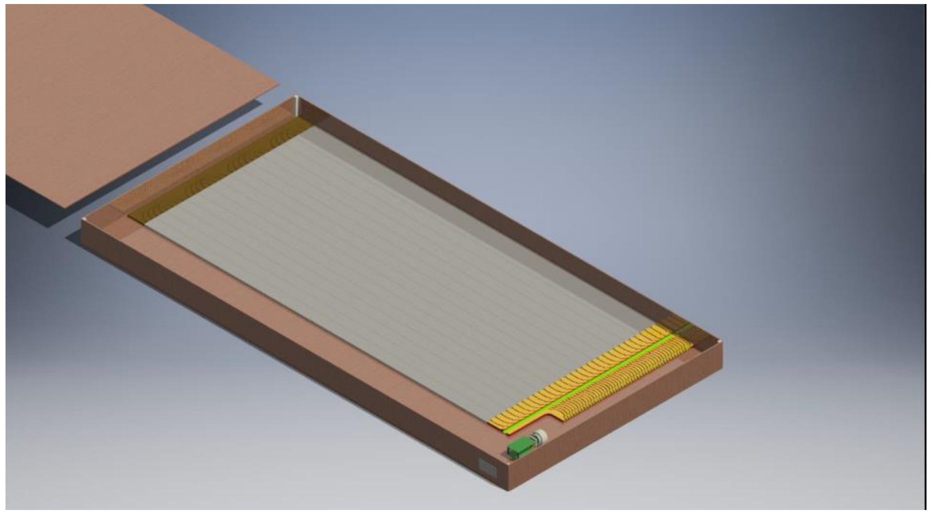
13 cm

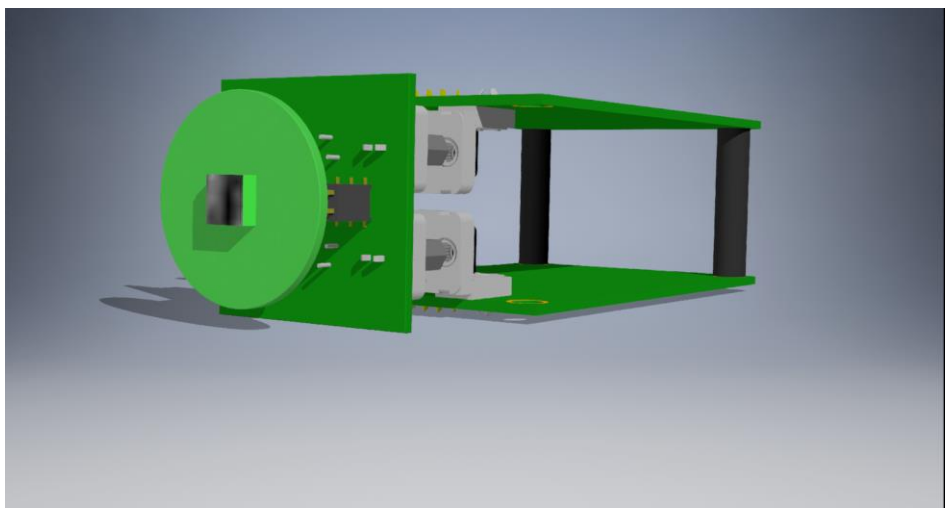
- small diameter
- directional info.
- more sens. area / module

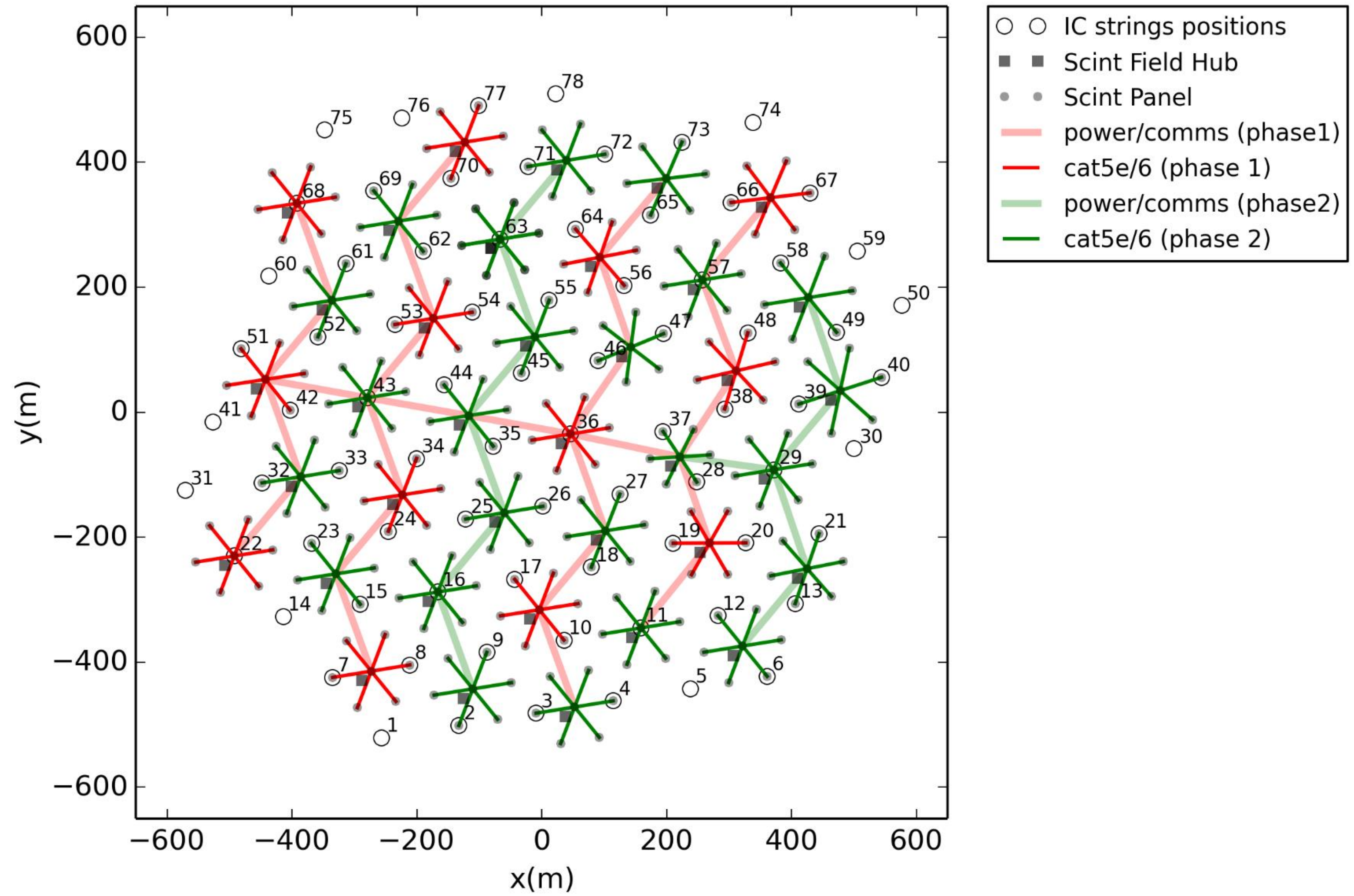
(UW Madison)

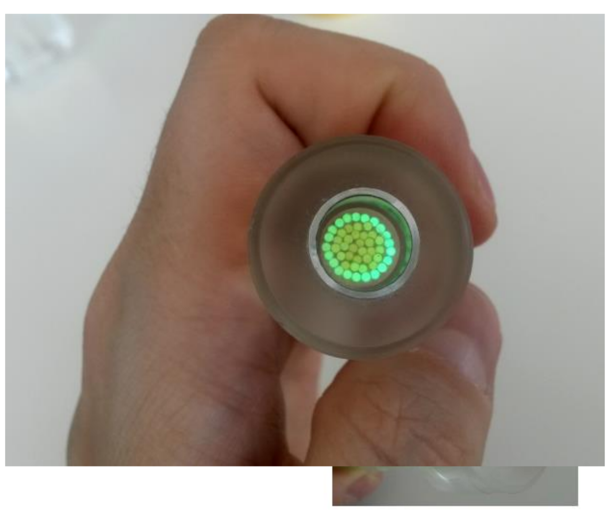
- **Cost efficient instrumentation**
- **Robust mechanics adapted to environment**
- **Flexible electronics**
- **Easy deployment**

IceScint – prototype surface array









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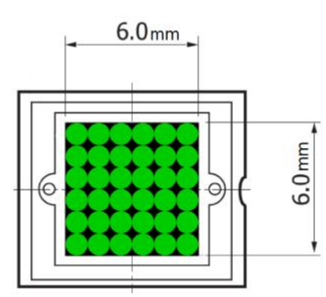
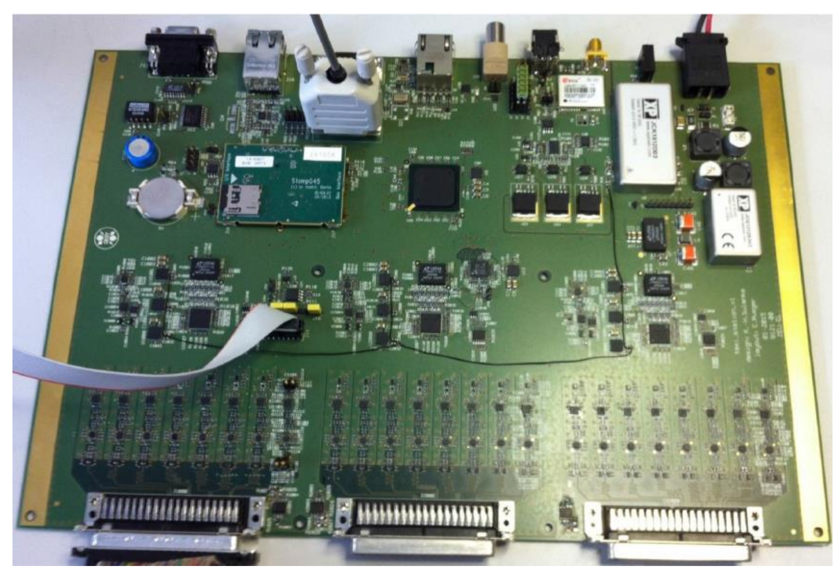


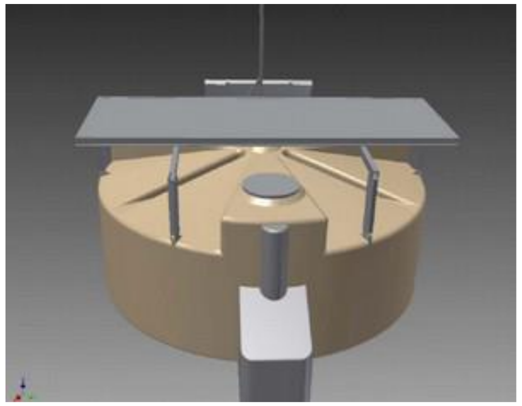
Arrangement of fibers



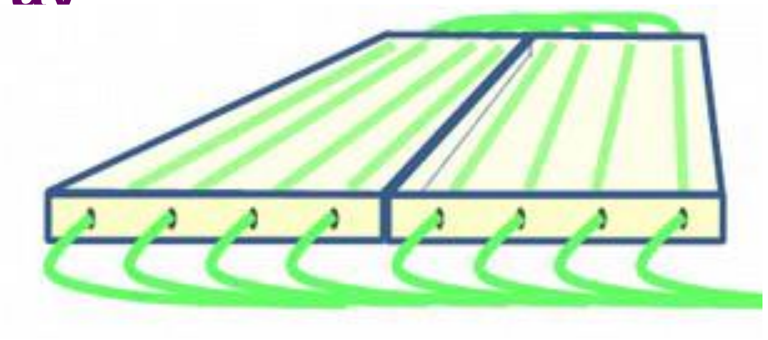
Planned to be built in 2017-2021

Pierre Auger Observatory
AugerPrime

AugerPrime (the upgrade)
to improve mass sensitivity above 10^{19} eV



1) New Electronics for Surface Detector
2) Enhanced Muon/Electron Detection in Surface Detector Array



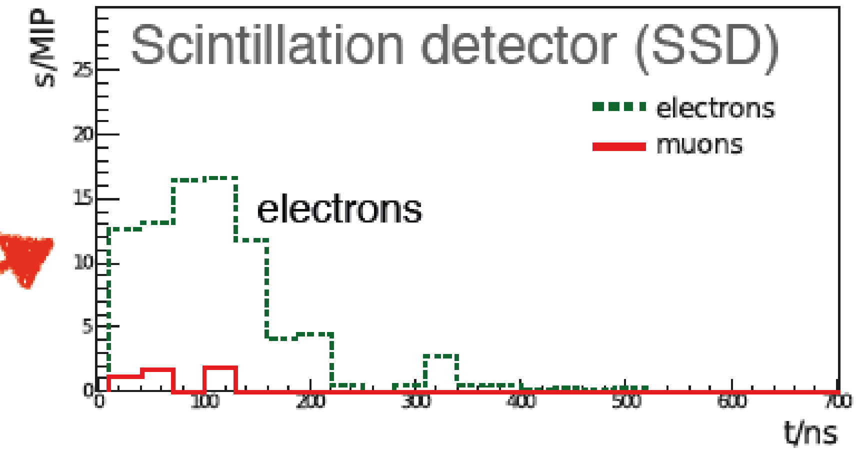
Main aims of Auger Upgrade
1. **Origin of flux suppression**
(GZK energy loss vs. maximum injection energy)

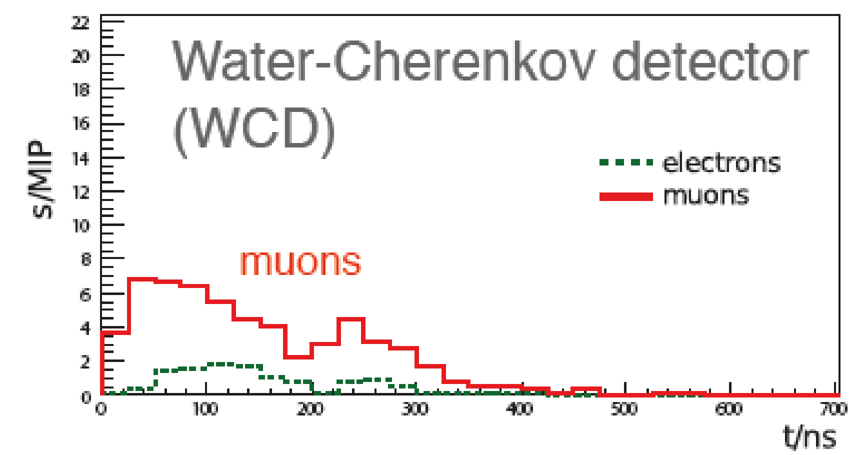
2. Proton contribution of more than 10%
at E > 6×10^{19} eV, particle astronomy?

3. New particle physics beyond the reach of LHC?

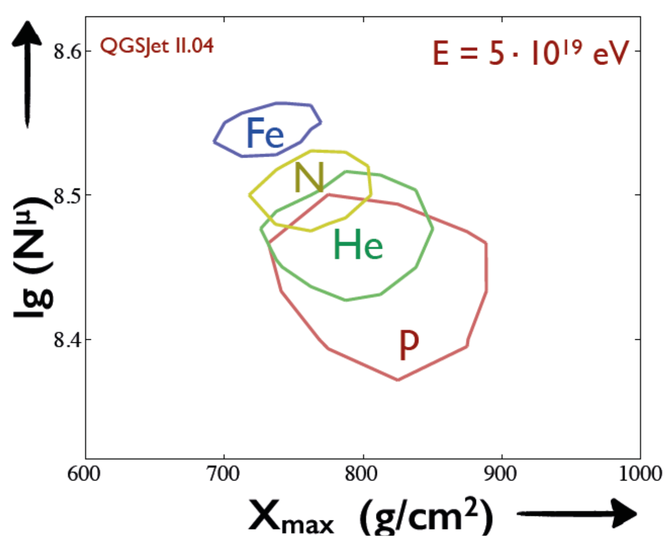
AugerPrime installation until 2018/19
Measurements until 2025
➔ same event statistics as collected so far

AugerPrime Technique





Muons may even outperform X_{max} at highest energies !



$$S_{\mu,\mathrm{WCD}} = a\,S_{\mathrm{WCD}} + b\,S_{\mathrm{SSD}}$$

1660 x 4m² sensitive area

Readout of scintillator modules by PMT or SiPM?

Application of the Radio Detection Technique in future Experiments

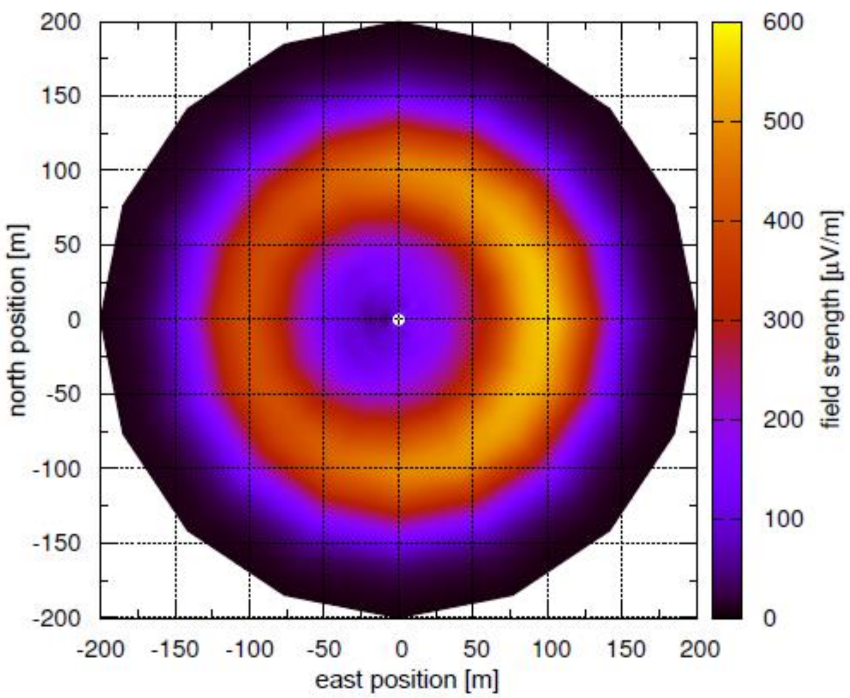
Energy, Xmax, and direction are reconstructable with sufficient accuracy

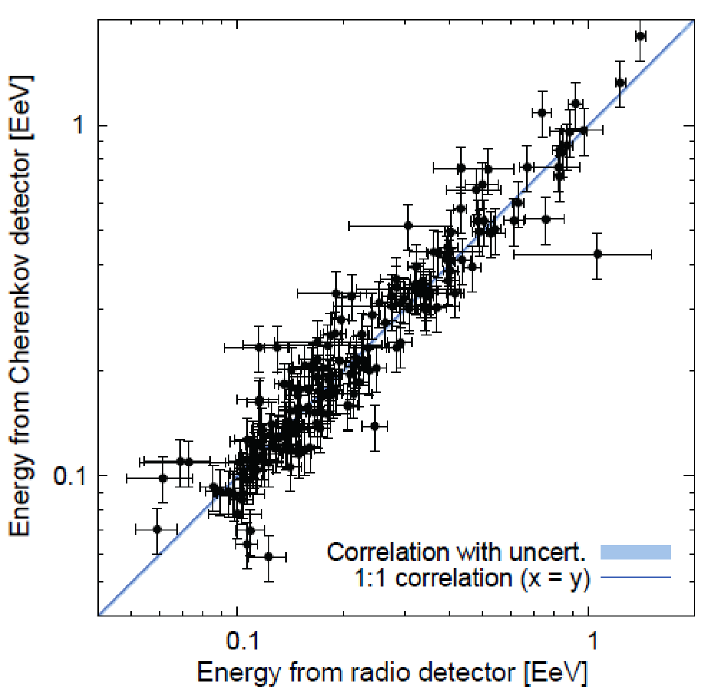
- Emission understood
- Energy (AERA/Tunka-Rex): $\sigma<15\%$
- Xmax (LOFAR et al): $\sigma\sim 20 g/cm^2$
- Direction : no problem $\sigma<1^o$
- Horizontal air shower detection possible and promising

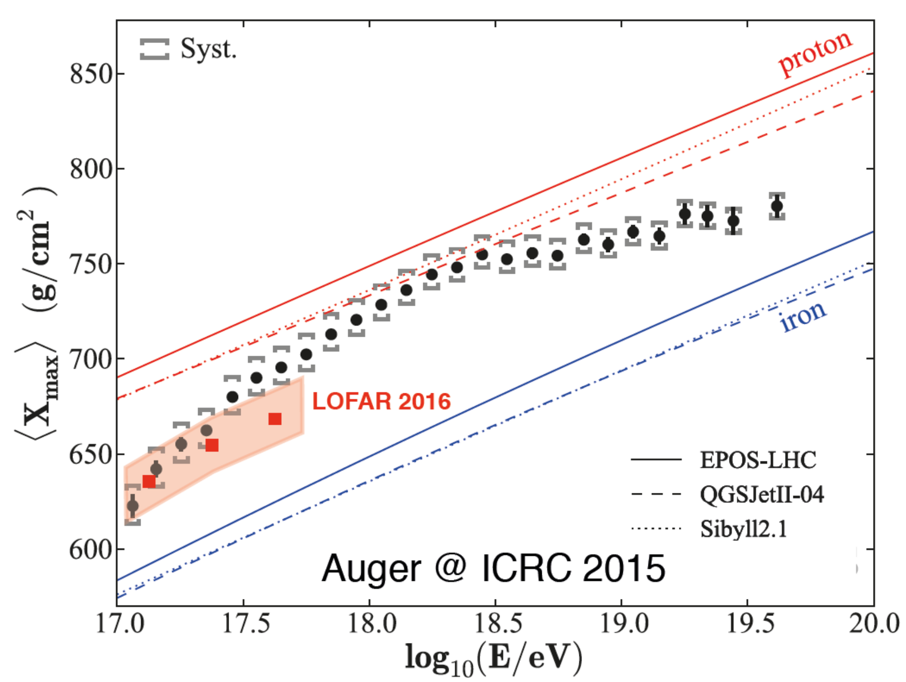
Tim Huege
Phys.Rept.
620 (2016) 1-52

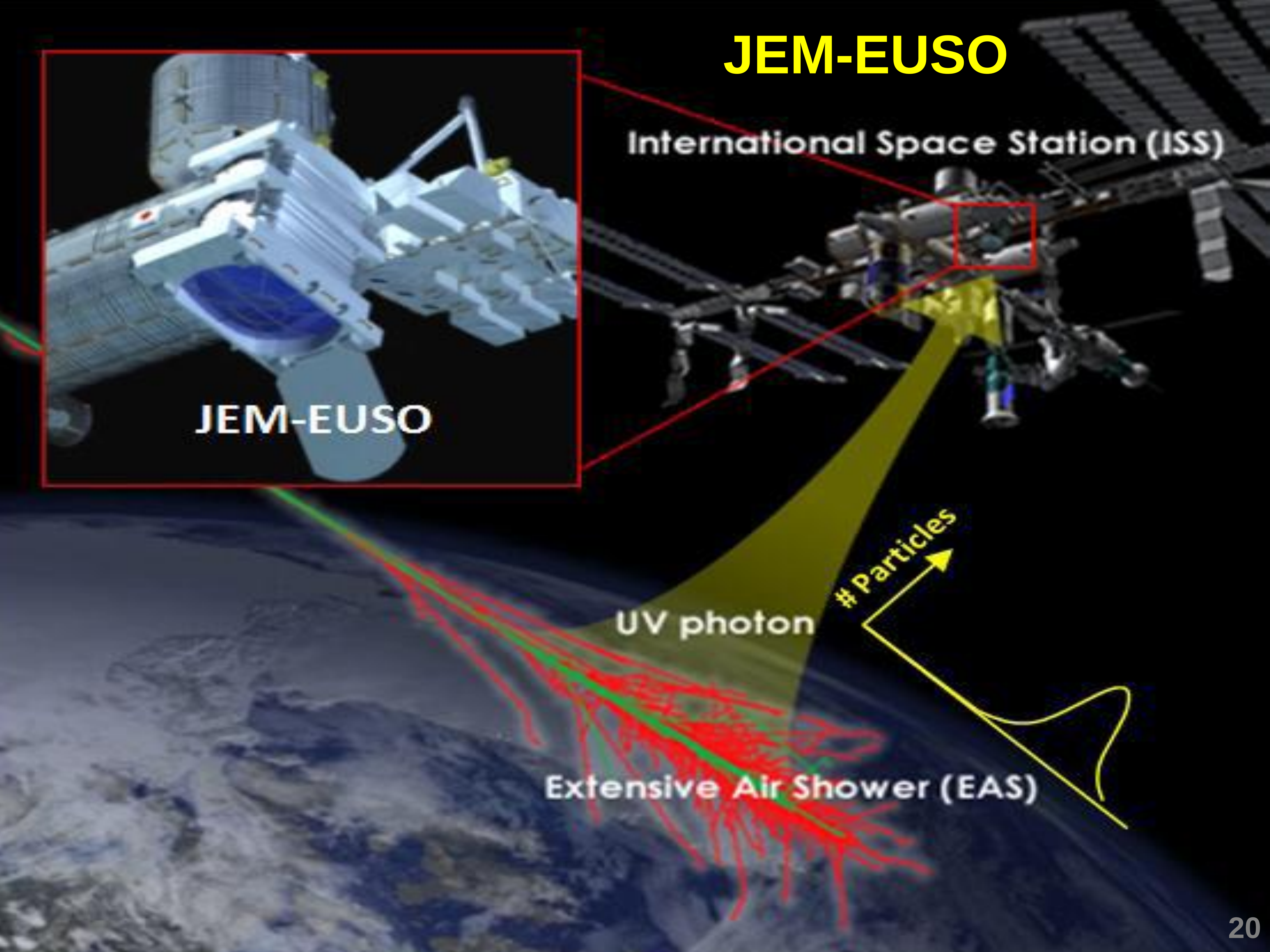
Advanced radio stations (AERA, LOPES, LOFAR, Tunka-Rex, SKA, …) are able to considerably enhance CR reconstruction capabilities!

← ready for application needs to be optimized for science cases





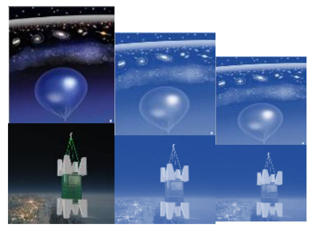



JEM-EUSO
International Space Station (ISS)
JEM-EUSO
#Particles
UV photon
Extensive Air Shower (EAS)

Air Shower Observations from Space

2014 | 2017 | 2020 | 2023

TA-EUSO
Continuous operation

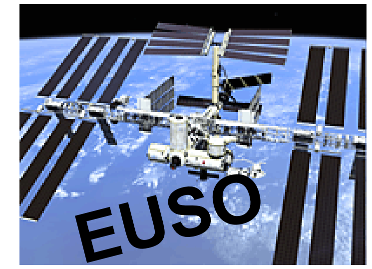


EUSO-Balloon
1st flight 2014

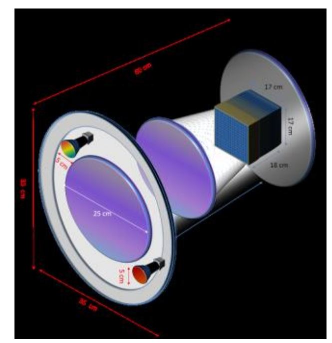
Launch 2017 cancelled

? - - - →

AO from NASA in 2016?
for ISS 2021-24:
Probably not as too low exposure



EUSO-SPB (NASA)
Preparation in work
(including small SiPM-camera)
Launch spring 2017



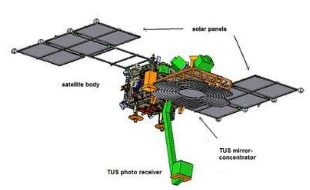
Baseline design change to
SiPM-PDM?

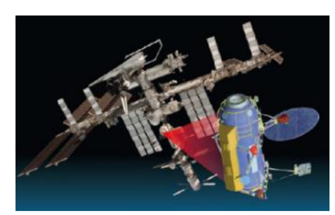
Mini-EUSO on ISS
appoved for 2018)

M5 mission
Free flyer?

esa
European Space Agency

TUS





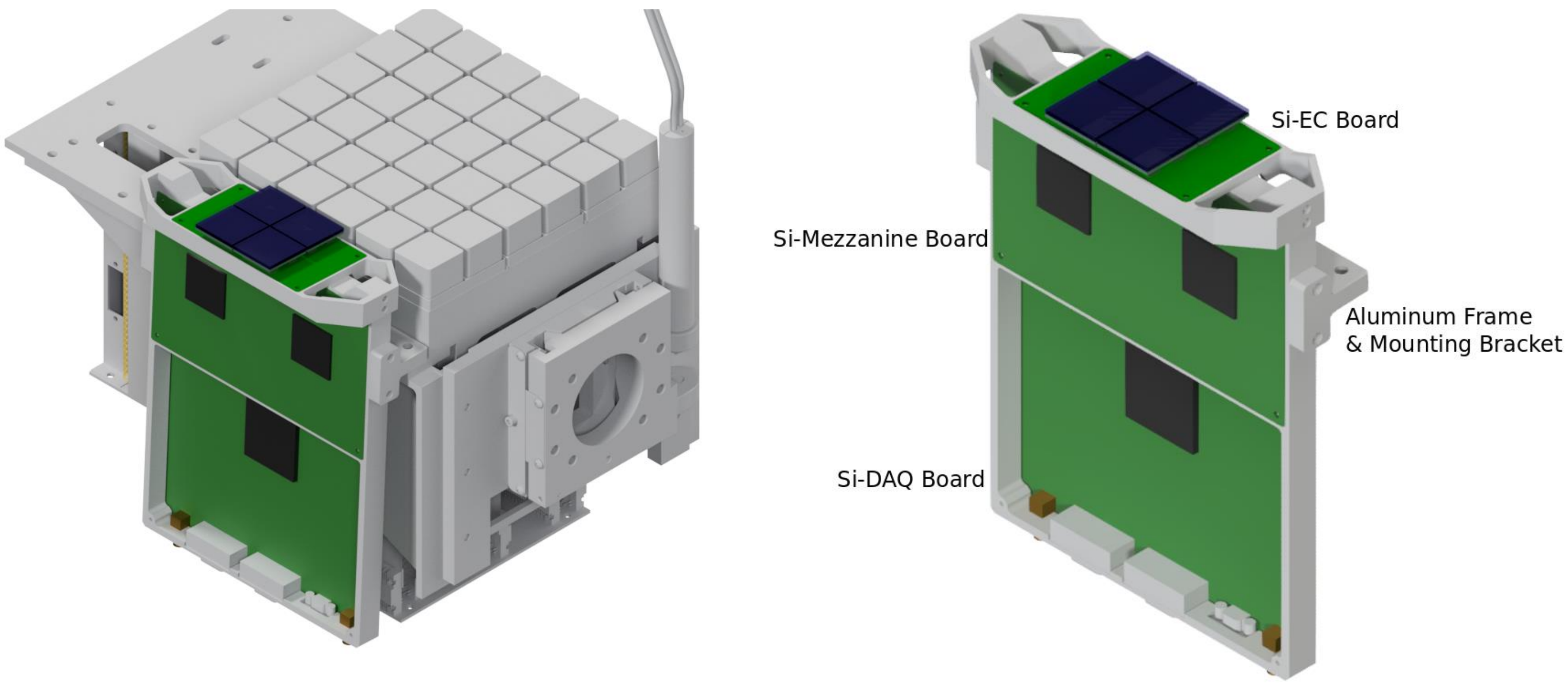
"K-EUSO"

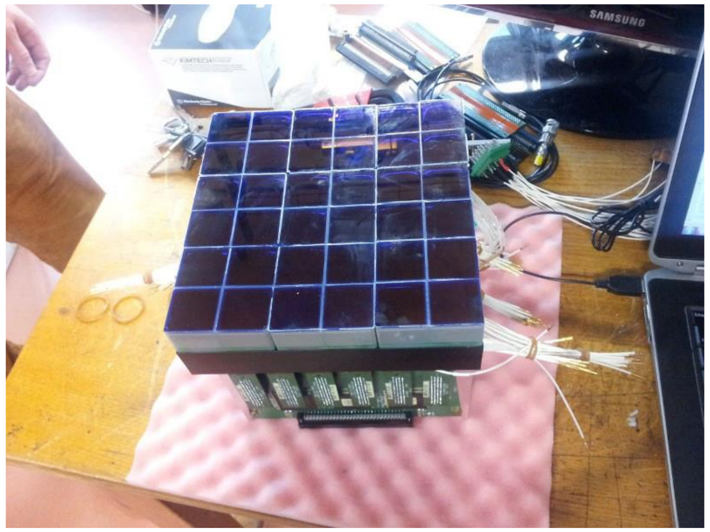
Need new baseline concept of focal surface based on SiPM!

SiPM camera for EUSO-SPB (launch spring 2017)

Goal: design of large-area camera based on SiPM for EUSO-FF

SiECA: “proof-of-principle” for a SiPM UV cosmic ray detector in (near) space





Main issues:

- **large sensitive area = high filling factor** (to avoid dead space and light cones)
- **sensitivity to fluorescence light** (UV-range 290-440 nm to cover full spectrum)
- **fast readout** (specific ASIC, digital SiPM, monolithic SiPM/ASIC readout)
- **characteristics and calibration** (single photon efficiency)
- **mechanical structure = integration** (to fit a focal surface)

Considerations for EUSO-FF

Is the technology of SiPM ready to be used for a future mission?

Focal surface requirements:

4m diameter ➔ 12.5 m^2

➔ 16.000 SiPM arrays (á 64 channels) = 1,024 Million channels

Costs: 64 channels = 1700€ ➔ 27 M€ x 0.6 (reduction) ➔ 16 M€
minimum is just the waver area (1€/mm^2) ➔ 12.5 M€

Needed Development:

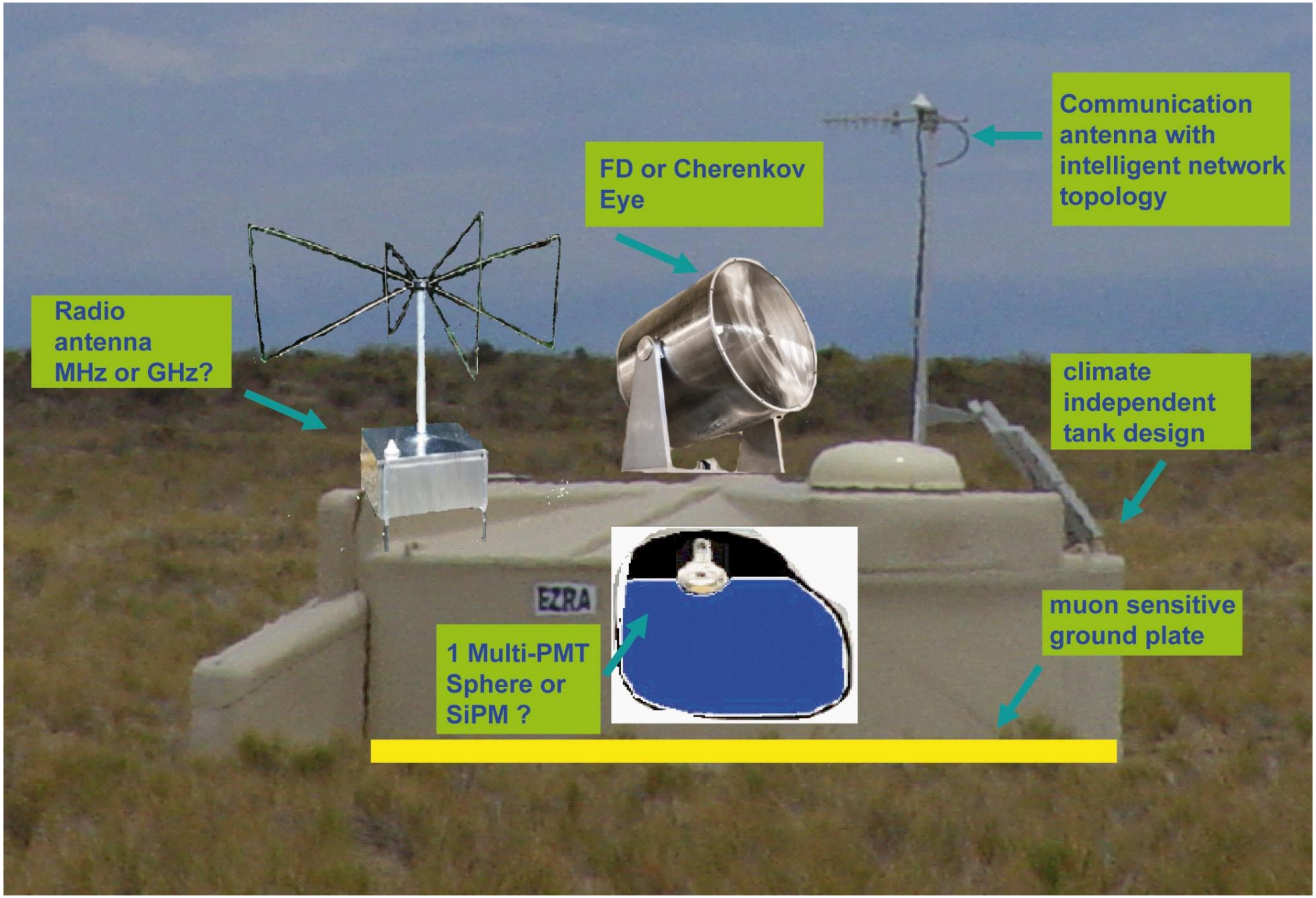
Monolithic SiPM+ASIC arrays (weight, cables, connectors, …)
Integrated filter for fluorescence spectrum (weight)

Power supply: custom made (not anymore problem….low voltage with 50-60V)
Temperature control / cooling: challenging engineering design, but possible

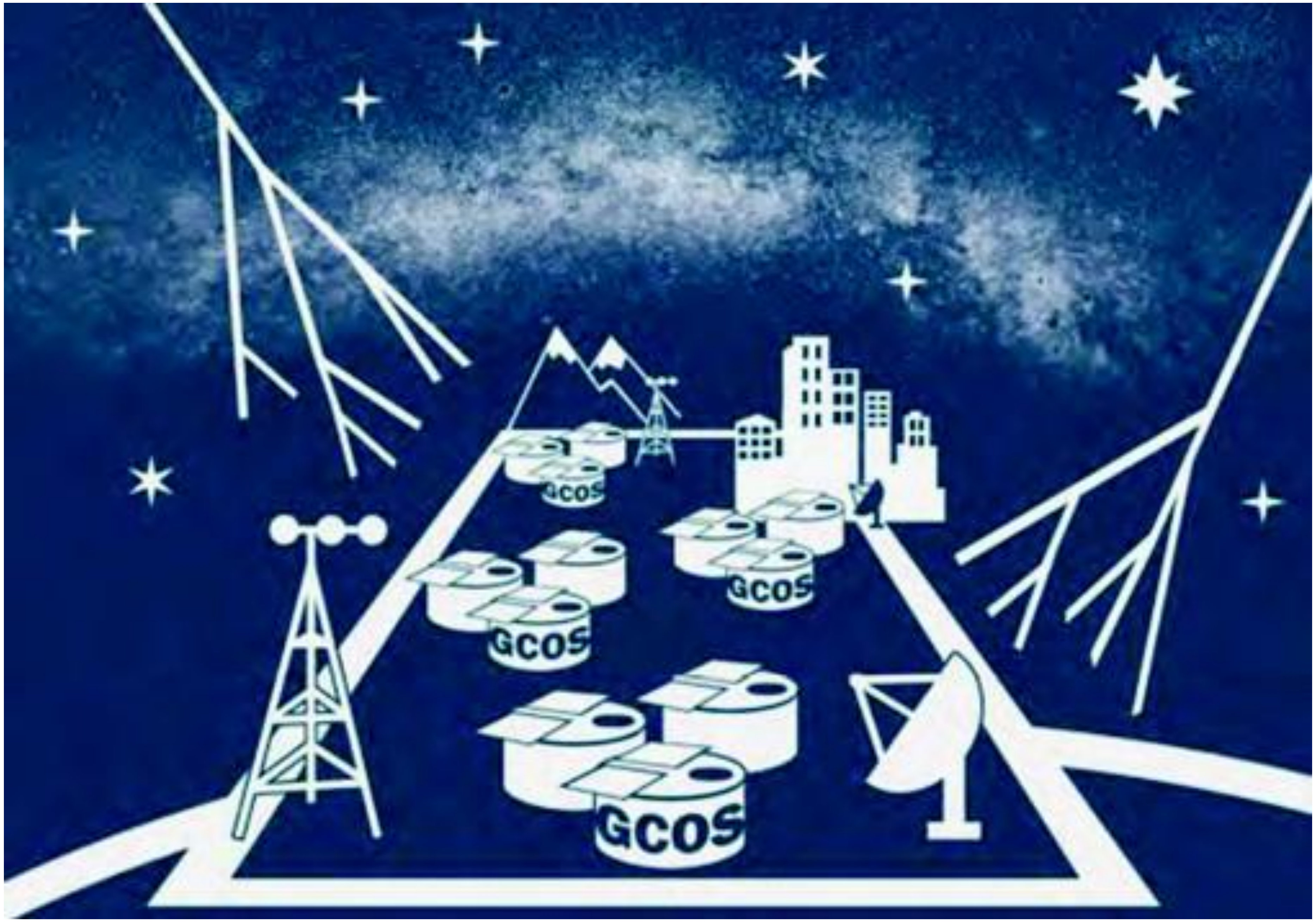
➔ **Million dollar business:**

filter+SiPM+ASIC (temperature control) + power
in a modular design connected to a CPU

Future (next generation) surface detector:



GCOS = Global COSmic ray observatory



Helmholtz (D) large infrastructure Roadmap

p-astronomy with sources

- Global, few sites, N+S
- ca. 90,000 km^2 (x30 Auger)
- Optimal detector for composition-sensitivity

- Design in 2020-25
- Operation 2025-2050
- Cost 390 M€ (120 M€ European contr.)
- Operation cost 6 M€/y

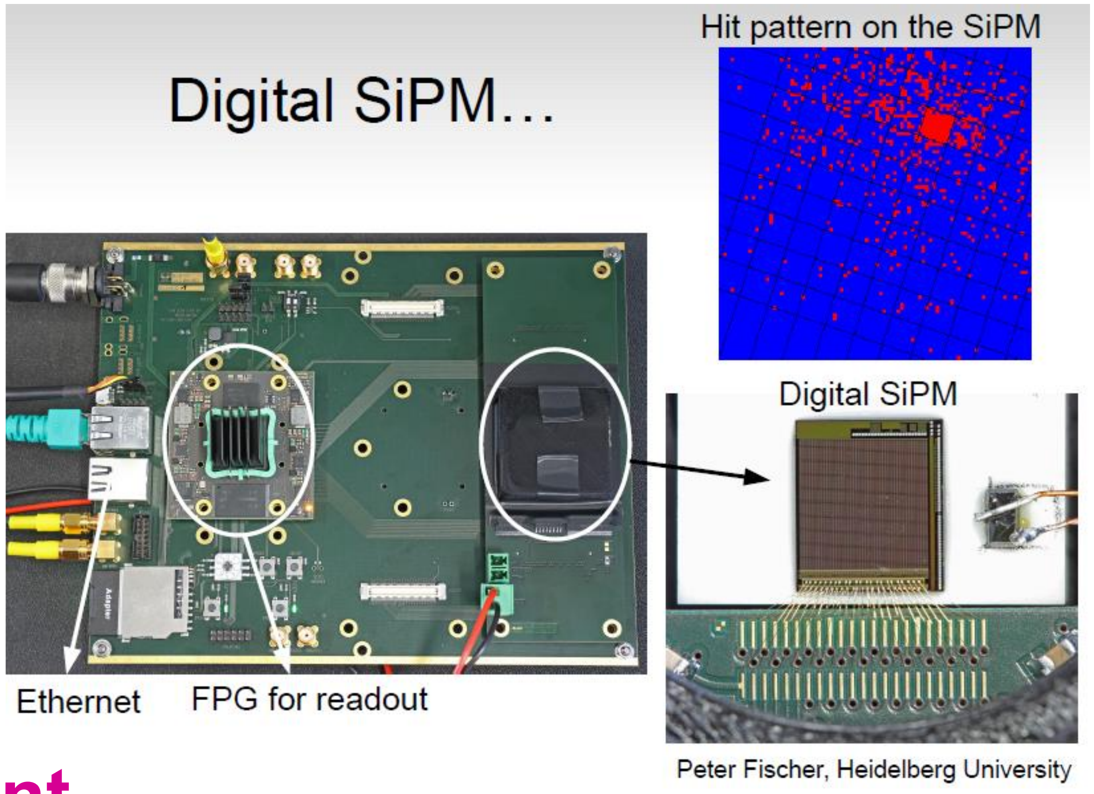
Requirements for (SiPM) Electronics

Further Development:

Monolithic SiPM+ASIC arrays

And next step:

filter+SiPM+ASIC
(temperature control) + power
in a flexible, modular design
connected to a CPU

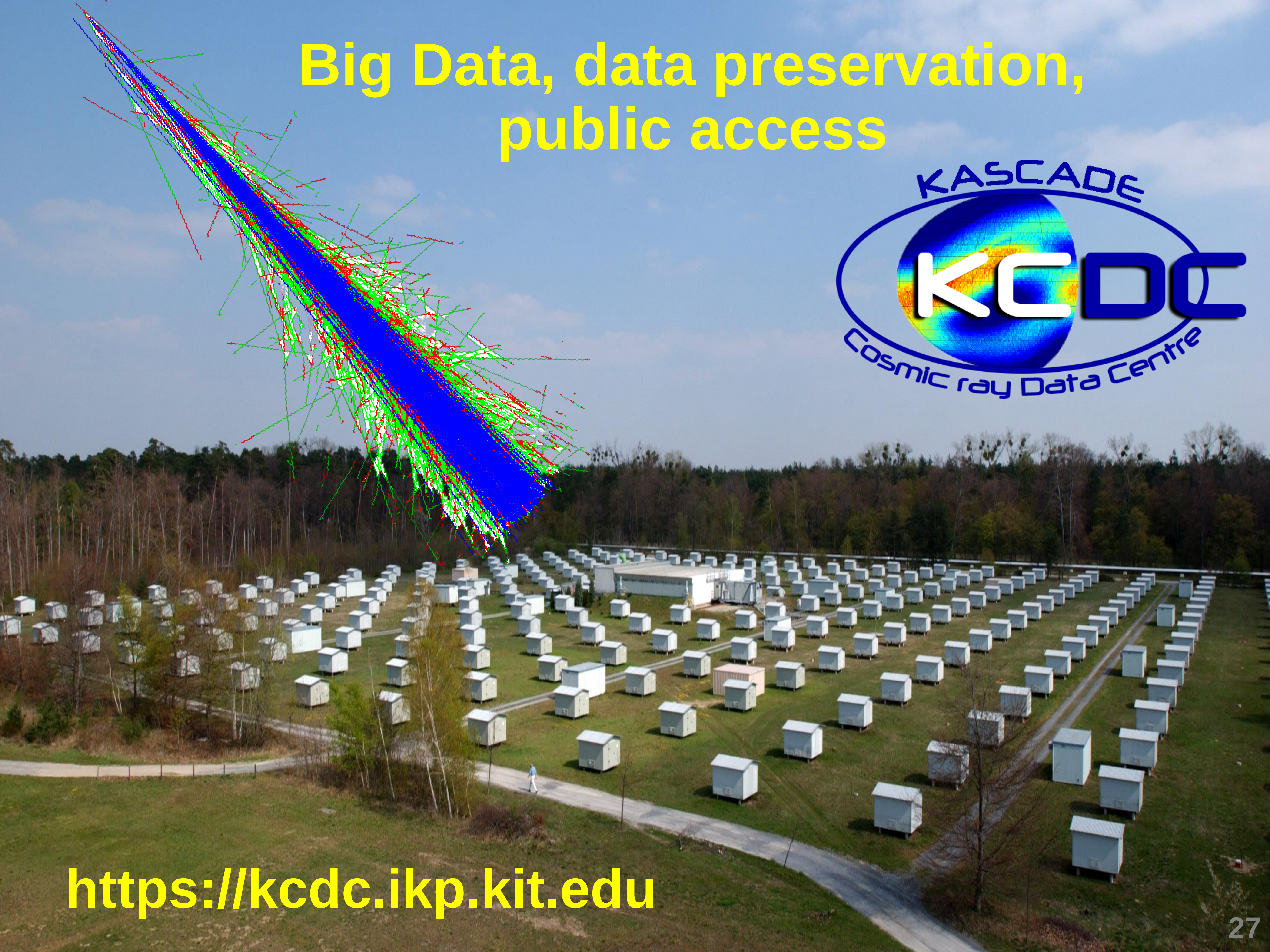


- **Cost efficient instrumentation**
- **Robust mechanics adapted to environment**
- **Easy deployment**

Requirements for ASIC Development for EUSO-like devices, e.g.:
(compared to presently available Citiroc)

- **Larger number of channel input: 64, 128, 256?**
- **5 ns timing resolution and pulse shaping**
- **Low power consumption (2mW/ch or less)**
- **Internal biasing for flat fielding/temperature control**
- **Bin length selectable from 250ns-5µs**
- **Internal biasing for flat fielding/temperature control**
- **….**

Big Data, data preservation, public access



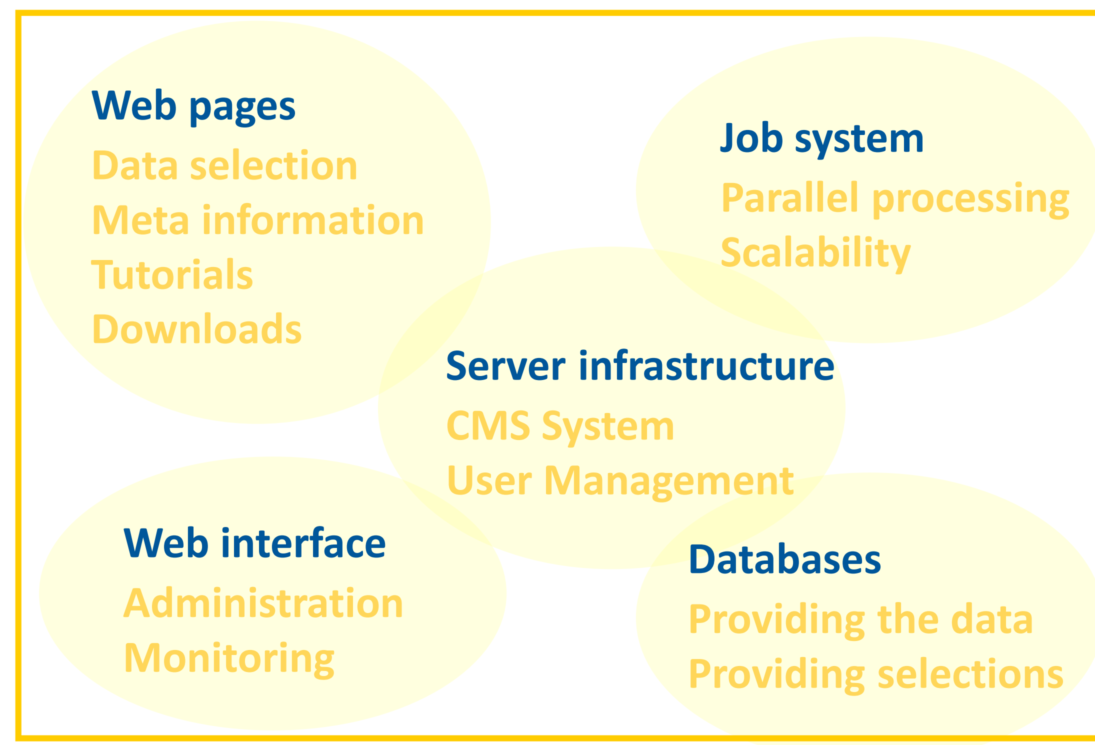
https://kcdc.ikp.kit.edu

KCDC in a nutshell

#KCDC_KIT

- providing open access to astroparticle physics research data as required by funding agencies

- **data provider**
  - follows the “Berlin Declaration on Open Data and Open Access”
  - free, unlimited, open access to KASCADE cosmic ray data
  - selection of fully calibrated quantities
  - reliable data source
  - guaranteed data quality
- **information platform**
  - experiment description
  - meta information for data analysis
  - physics background
  - use of modern web technologies
  - tutorials focused on teachers and pupils
- **as long-term digital data archive**
  - archive of software and data
  - for the collaboration
  - for the public



https://kcdc.ikp.kit.edu/

Initiative for a (global) Data Center in Astroparticle Physics ?

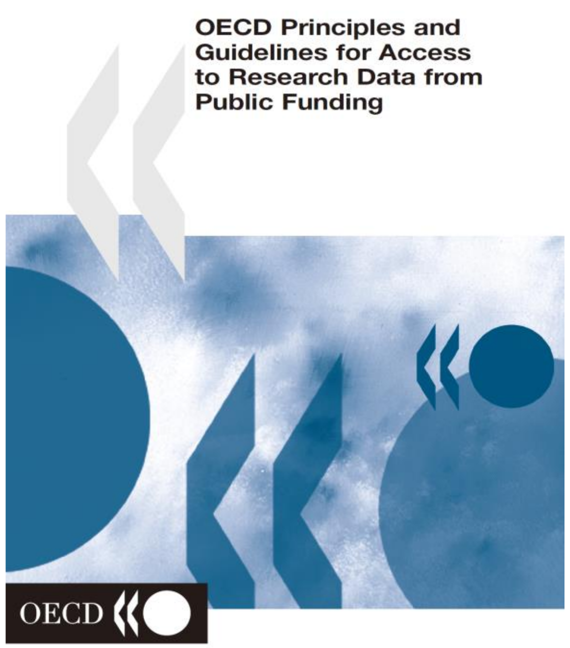
- First for High-Energy Astroparticle Physics?
  - Larger facilities, more data, request for multi-messenger analysis?

Tasks

- Provide sustainable access to scientific data
- Archiving of Data and Meta-Data
- Providing analysis tools
- Development area for multi-messenger analyses (e.g. Deep Learning)

Elements

- Advancement, generalization of KCDC
- In direction of a virtual Observatory (like in astronomy)
- In direction of Grid and DPHEP (like in particle physics)
- „Digitale Agenda der Bundesregierung“
- OECD Principles and Guidelines for Access to Research Data from Public Funding



➔ High demand in (German and international) Community ! (?)

➔ Needs dedicated efforts and ressources

Future Technological Challenges for Exploring the High-Energy Universe

<u>A few examples:</u>

- **Application of the radio detection technique**
- **Particle detectors for large sensitive area (scintillators)**
- **Development of Optical Modules**
- **SiPM vs. PMT**
- **Readout electronics ASICs**

  ➔ **hybrid detector modules with integrated electronics (harsh environments)**
- **Computing; Data Preservation; Data transport; Data Release; ….**

  ➔ **infrastructure for multi-messenger astroparticle physics**
- **….**