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iThemba
LABS
Laboratory for Accelerator
Based Sciences

Cosmic Rays – Origin, Composition Interactions and Applications

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Advanced Nuclear Science and Technology Techniques Workshop
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Outline

- **What is Cosmic Radiation?**
 - Discovery and nature of cosmic radiation
 - Interaction of cosmic radiation in the earth's atmosphere
 - The all-particle cosmic ray spectrum
 - The Cosmic Microwave Background Radiation (CMBR)
 - Big science experiments in cosmic radiation
- **Some Experiments in Cosmic Ray Physics**
 - Early experiments in cosmic rays
 - Kascade-GRANDE Experiment
 - The Cosmo-ALEPH Experiment
 - The Pierre Auger Observatory
- **Our work in Cosmic Ray Muon Physics**
 - Momentum spectrum and charge ratio of cosmic ray muons in CosmoALEPH
 - Coincidence measurements at Kenyatta University
 - Outreach activities



What are cosmic rays?



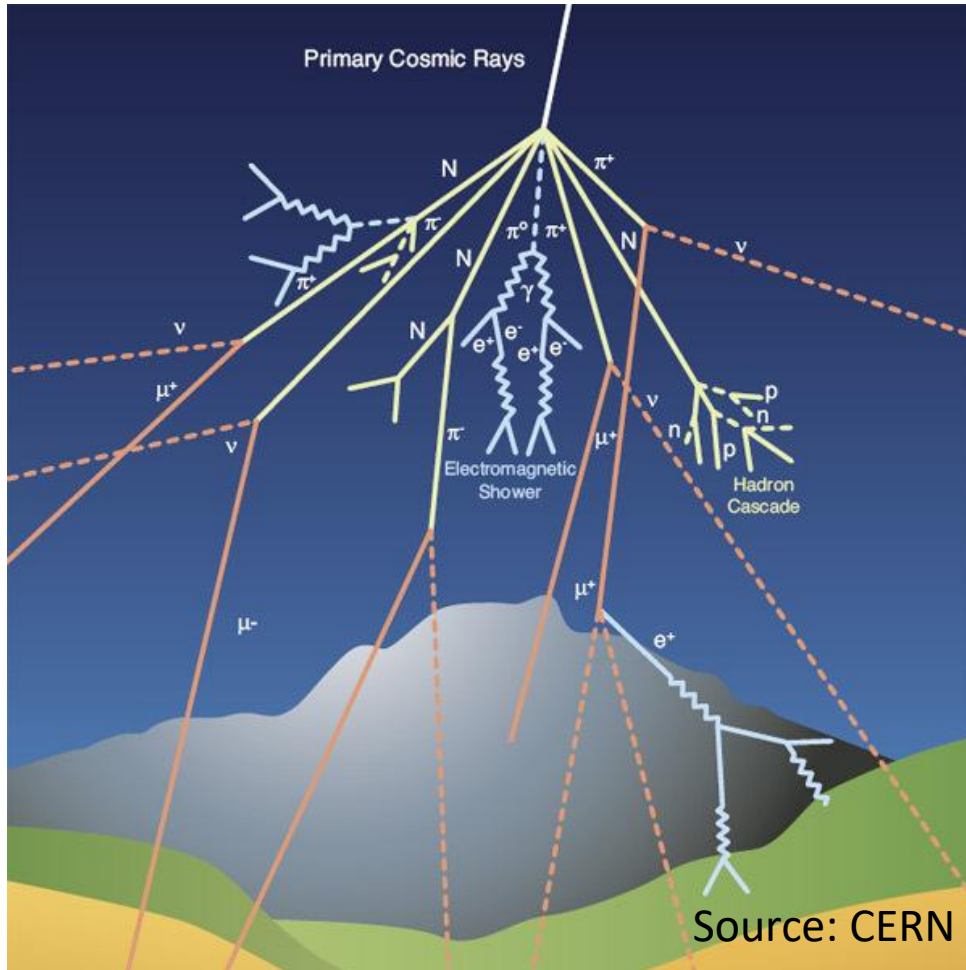
1912: Victor Hess using a balloon to measure ionizing radiation

Discovery of cosmic radiation

- 1909 – Theodore Wulf
 - used an electrometer
 - reported increased ionization levels at the top of Eiffel tower compared to ground level
- 1912 – Victor Hess (NP 1936)
 - used electrometers on a balloon up to a height of 5300 m above the ground
 - Reported higher ionization levels than the ground
 - Origin of ionization not earth



What are cosmic rays?



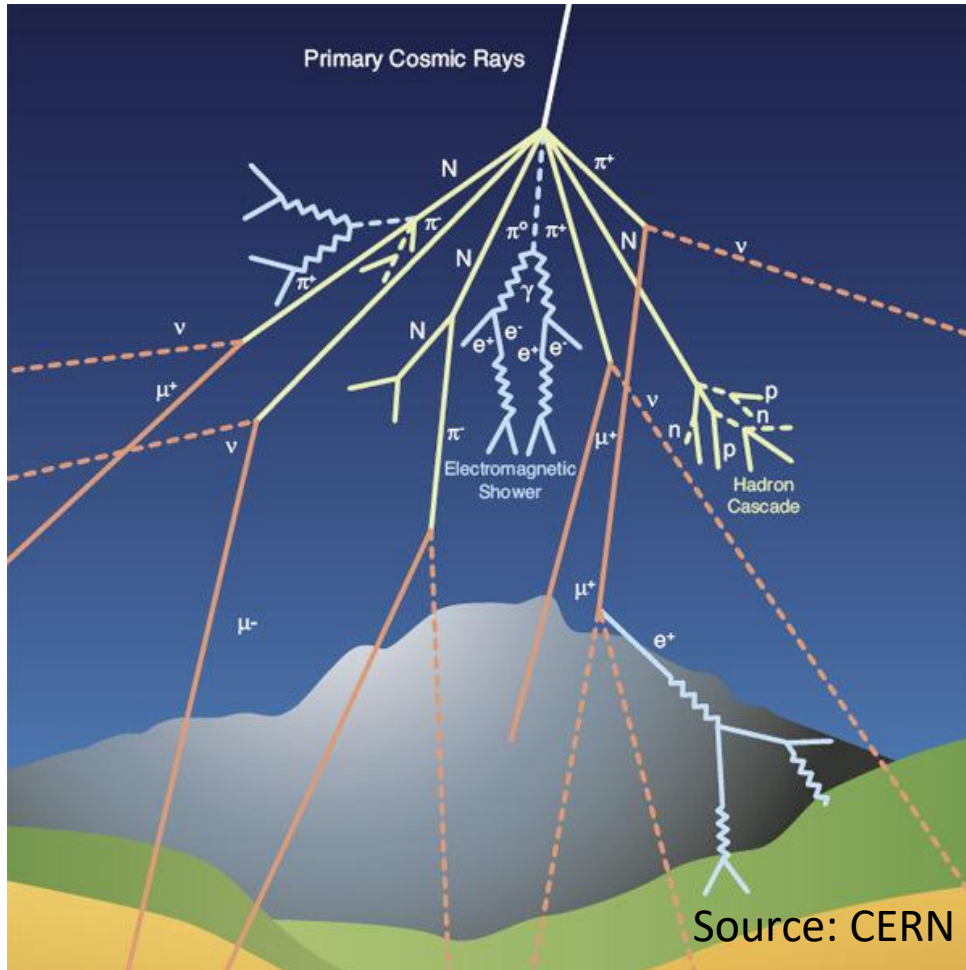
Formation of extensive air showers

CR interactions in the earth's atmosphere

- Primary composition - 85% protons, 12% He, 3% Fe ...
- Interaction of primary cosmic radiation leads to production of secondary cosmic ray component
- Secondary component – kaons, pions, e-m photons, muons, neutrinos, electrons, positrons, neutrons etc.
- Formation of Extensive Air Showers (EAS)
- Cosmic ray muons are a robust component of the EAS

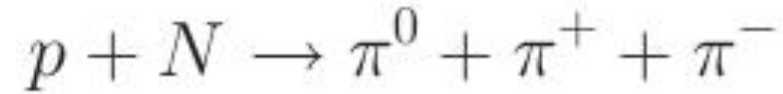


What are cosmic rays?

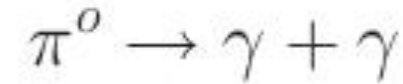


Formation of extensive air showers in the earth's atmosphere

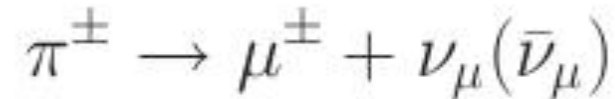
CR interactions in the earth's atmosphere



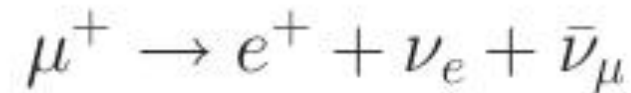
Primary proton interacts to produce pions



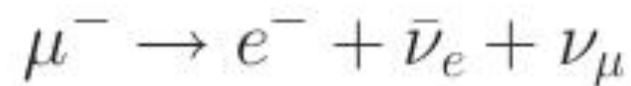
Neutral pions decay into gamma-ray photons



Charged pions decay into muons and producing neutrinos and anti-neutrinos



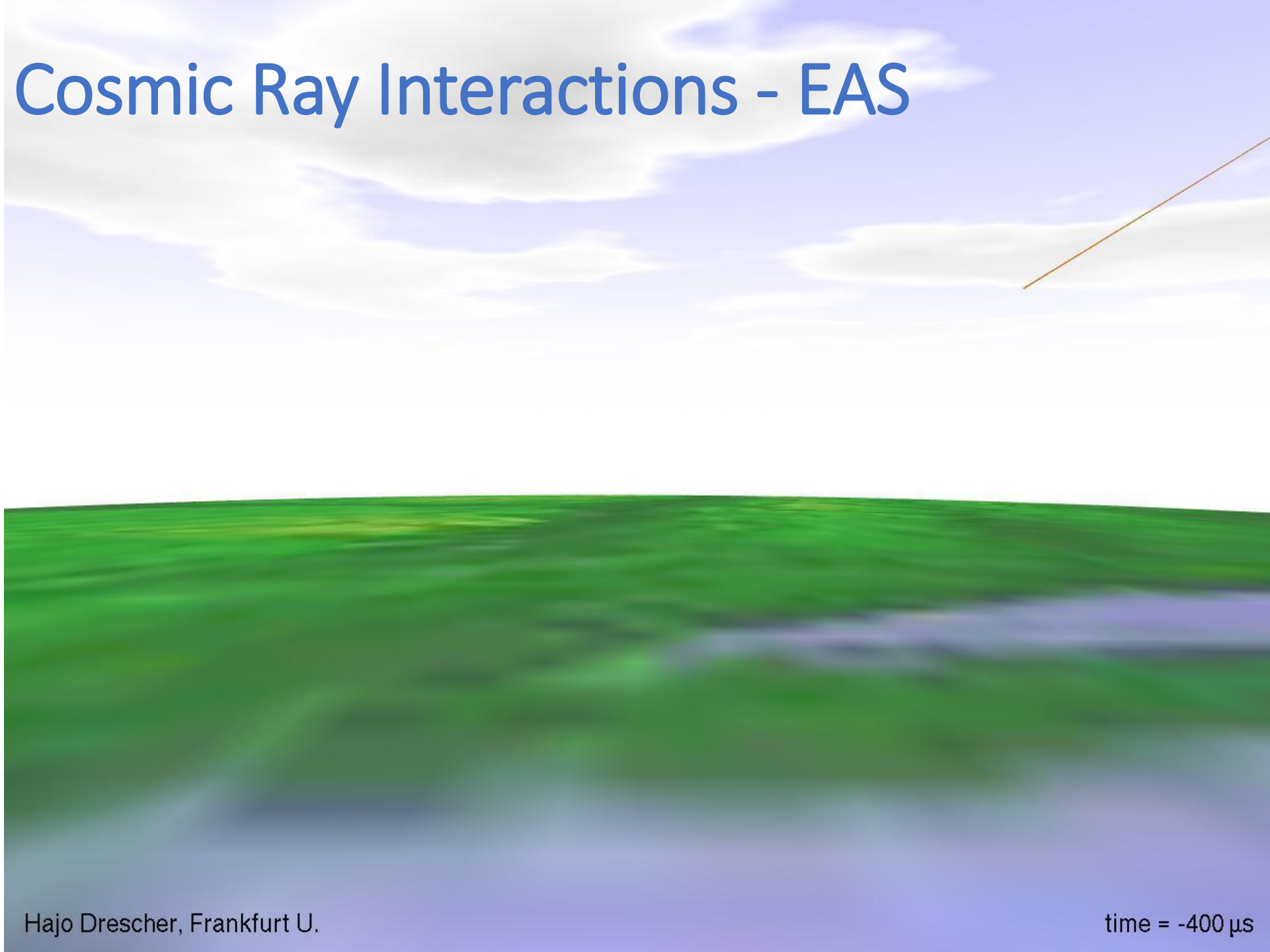
Muons decay into electrons/positrons and producing neutrinos and anti-neutrinos





Cosmic Ray Interactions - EAS

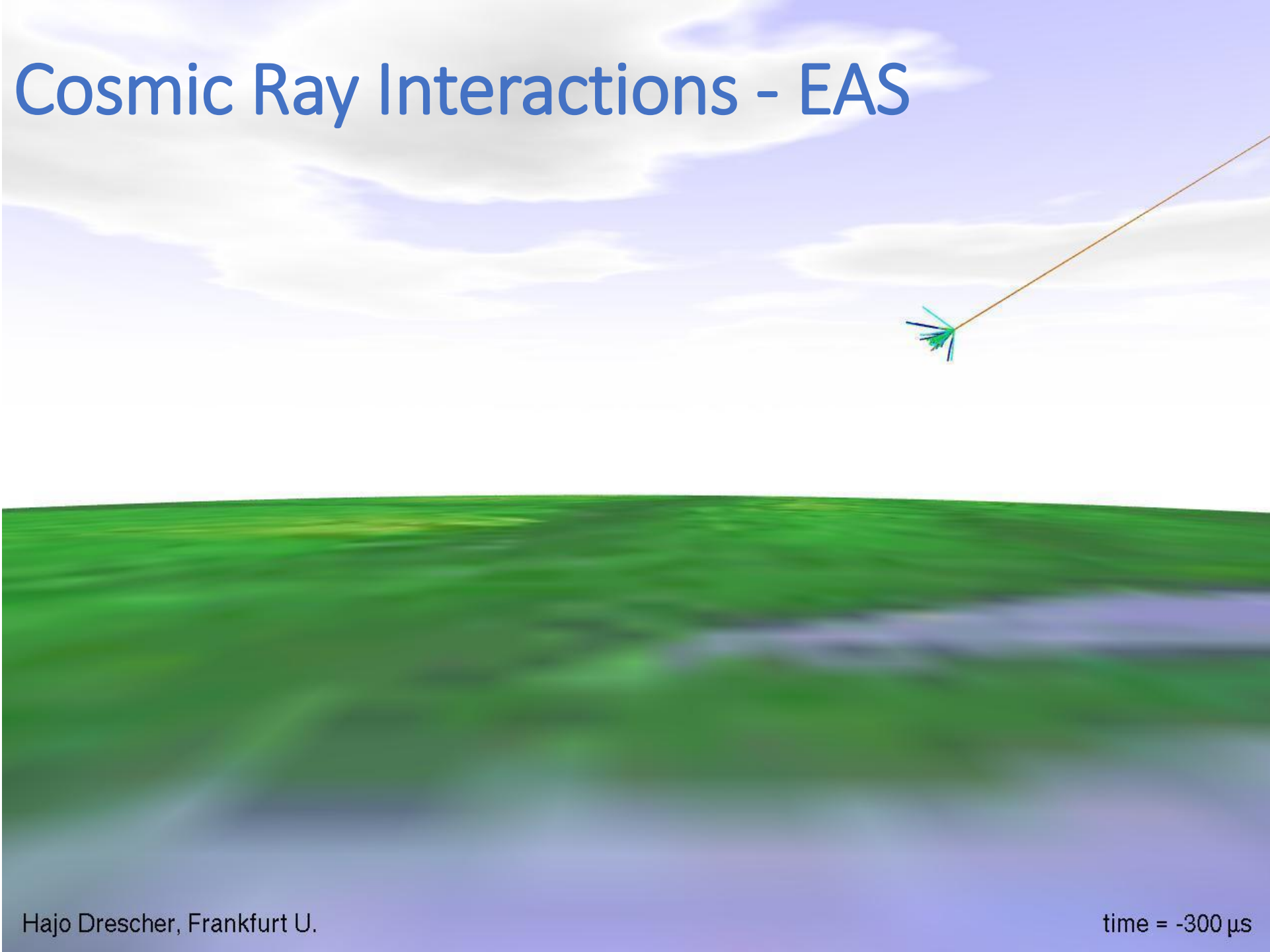
Proton
Photons
Electrons
Positrons
Muons
Neutrons





Cosmic Ray Interactions - EAS

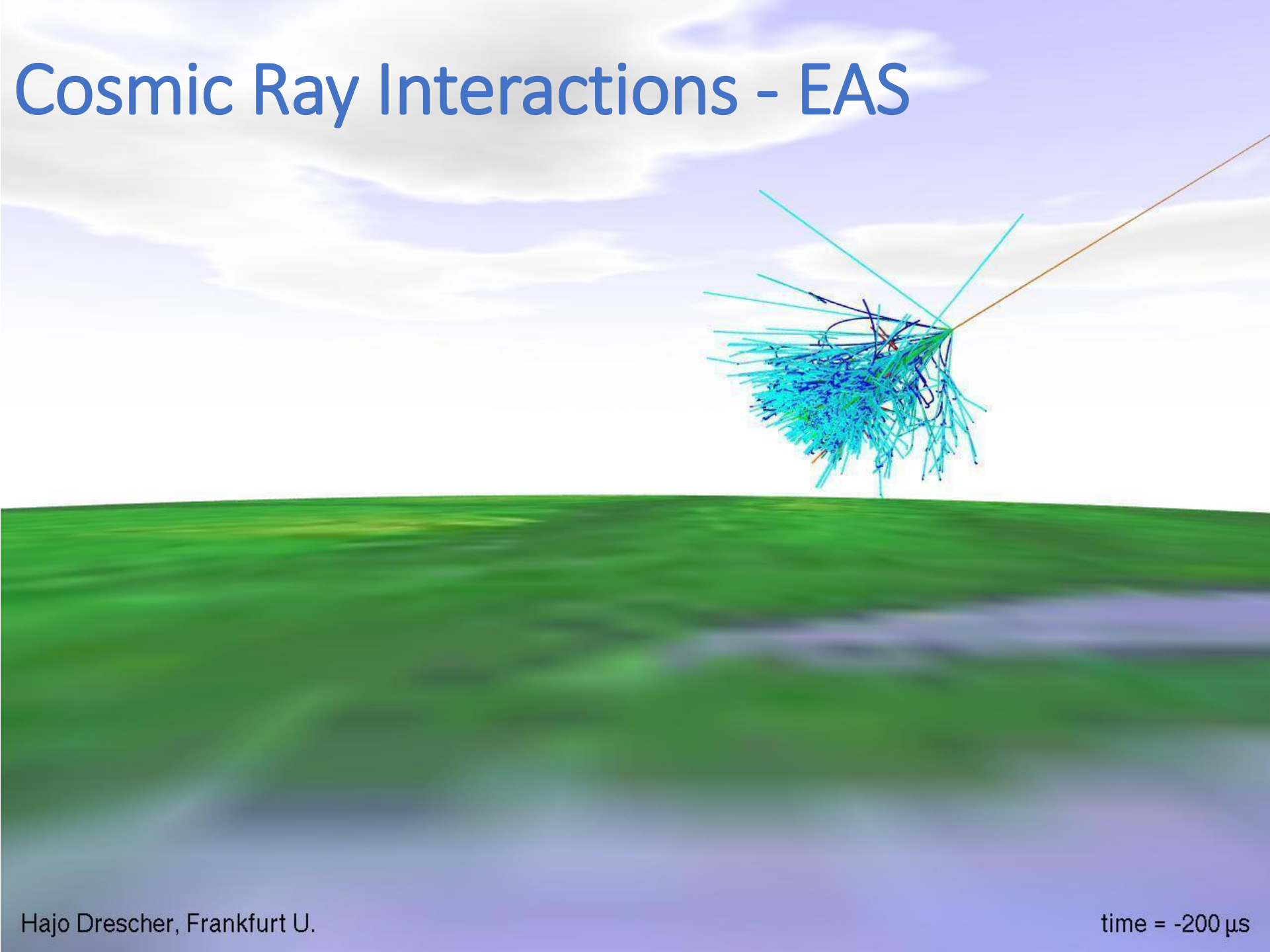
Proton
Photons
Electrons
Positrons
Muons
Neutrons





Cosmic Ray Interactions - EAS

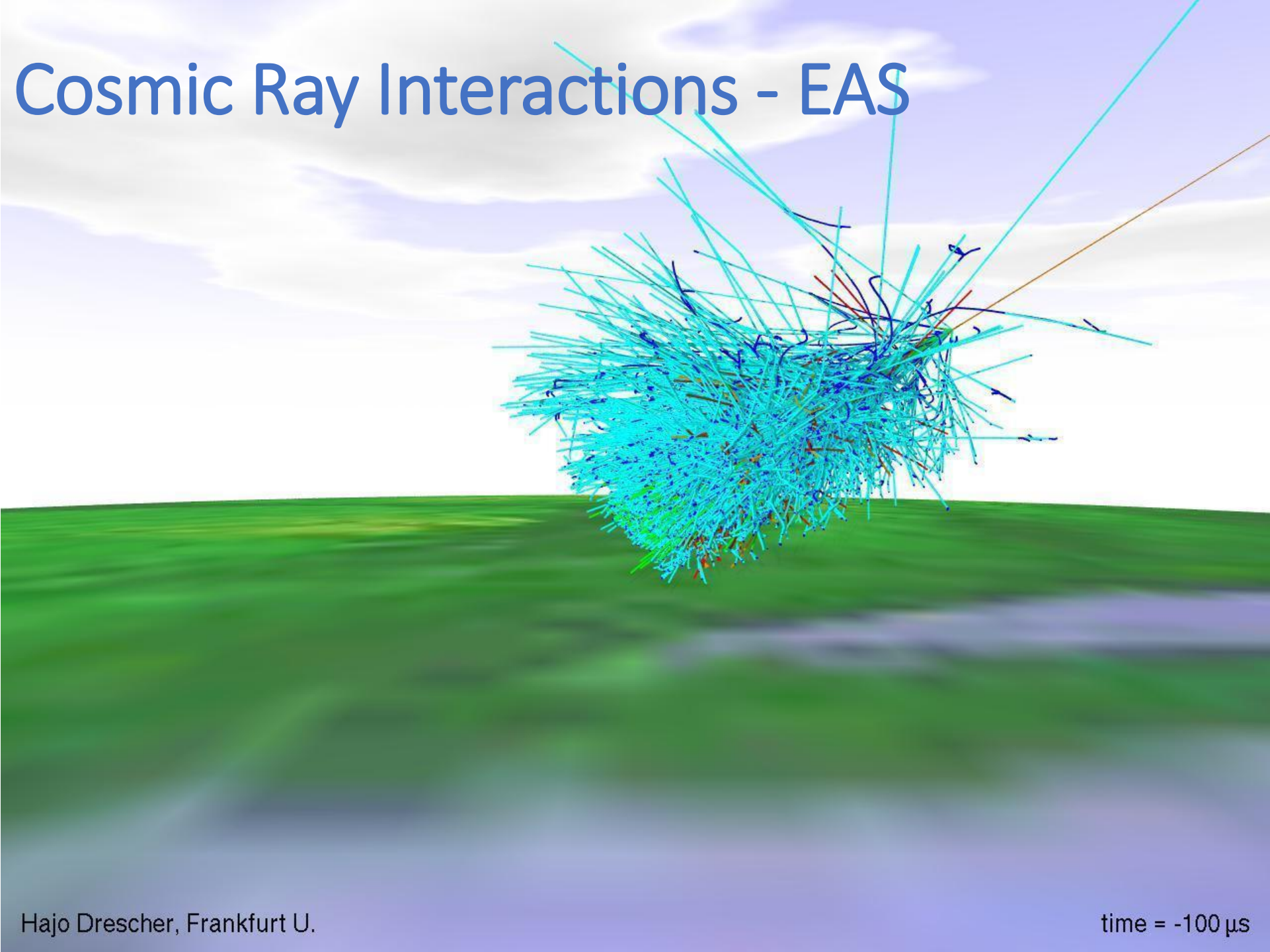
Proton
Photons
Electrons
Positrons
Muons
Neutrons





Cosmic Ray Interactions - EAS

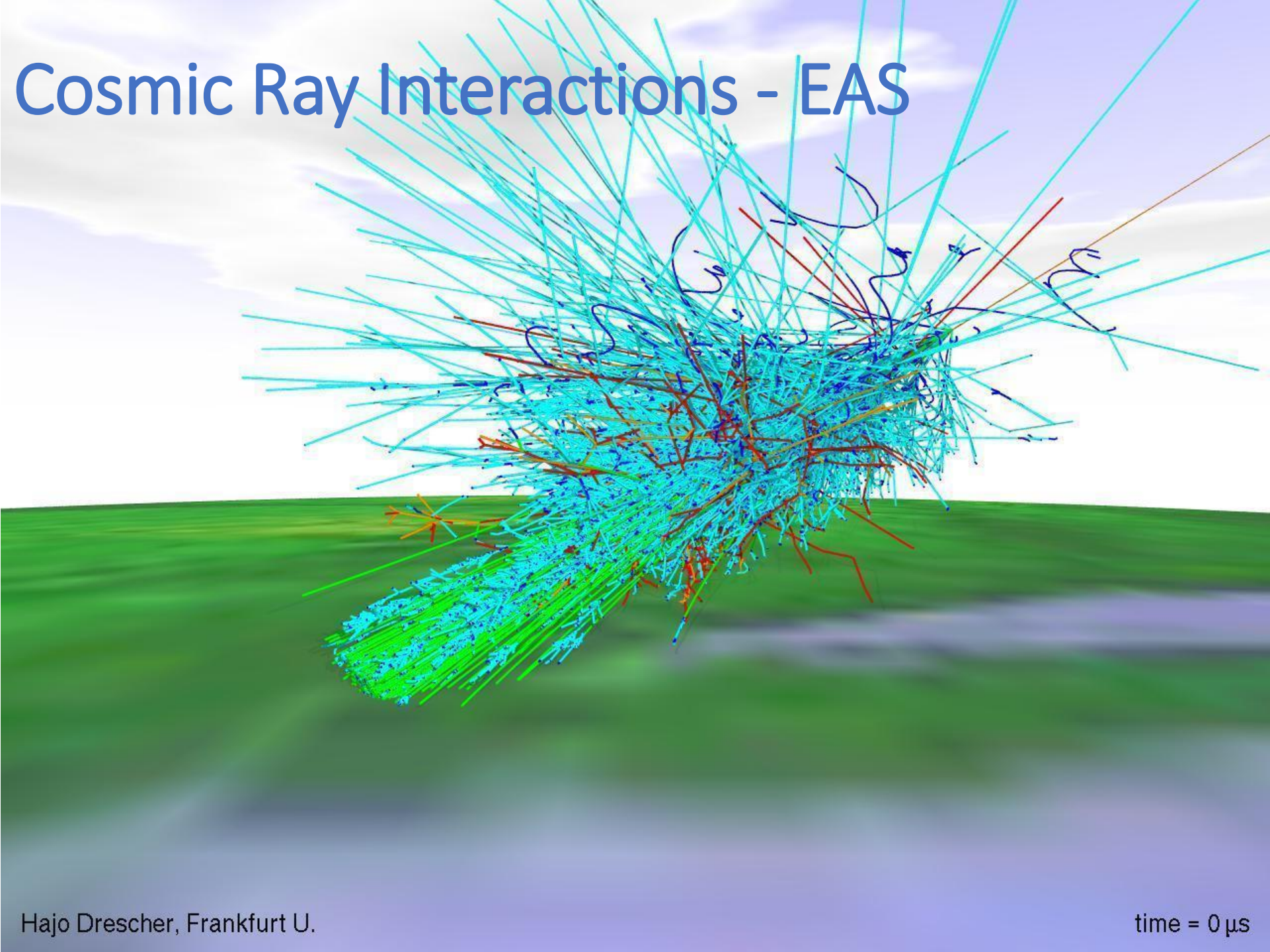
Proton
Photons
Electrons
Positrons
Muons
Neutrons





Cosmic Ray Interactions - EAS

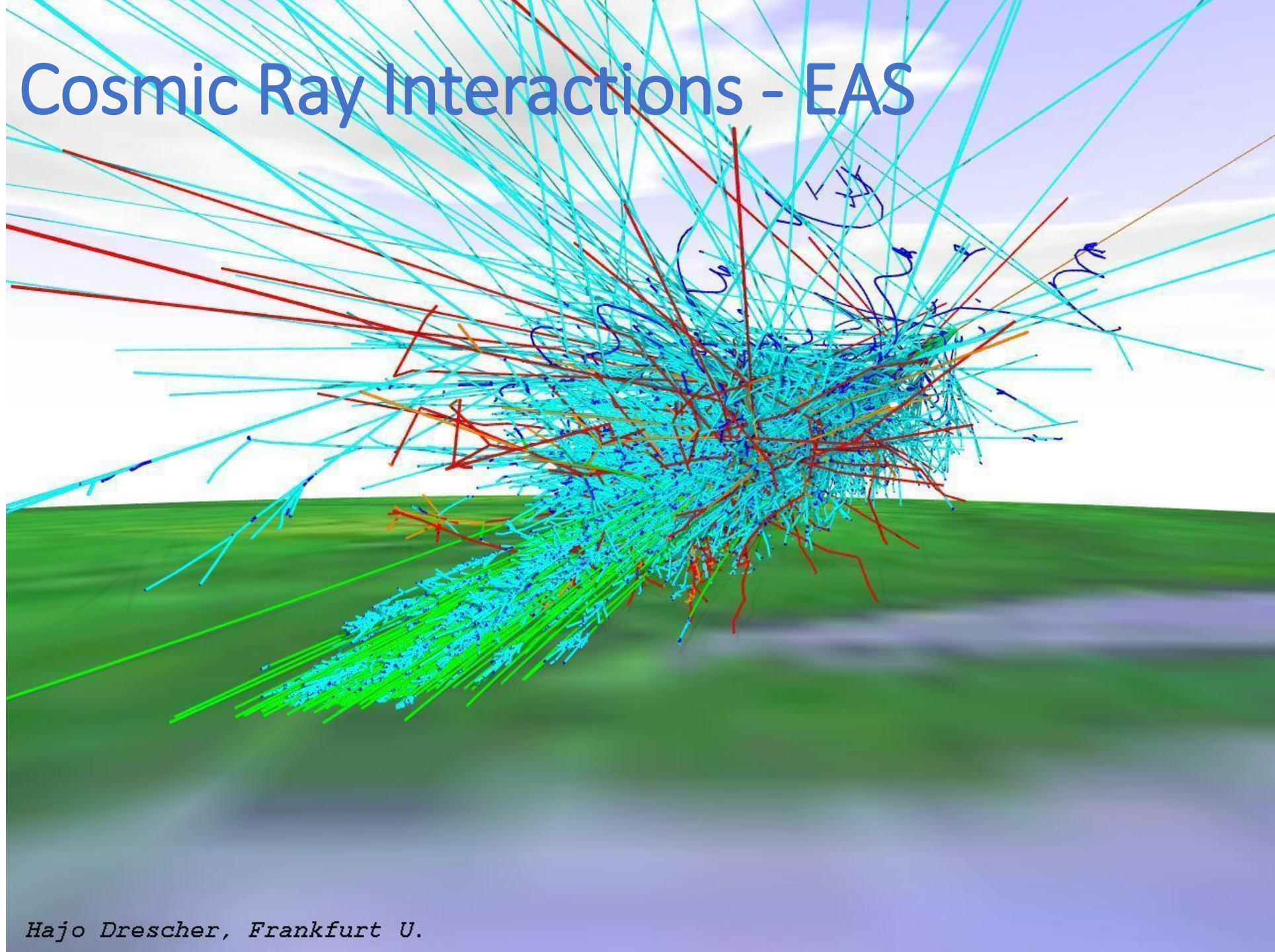
Proton
Photons
Electrons
Positrons
Muons
Neutrons





Cosmic Ray Interactions - EAS

Proton
Photons
Electrons
Positrons
Muons
Neutrons



Hajo Drescher, Frankfurt U.



Cosmic Ray Interactions - EAS

Components of EAS that can be measured:

- muons,
- electrons,
- photons,

Physics investigations:

- momentum and/or energy spectrum of the secondary particles,
- shower development (lateral and longitudinal) and coincidences,
- energy spectrum and chemical composition of primary particles, etc.

Theoretical descriptions ...

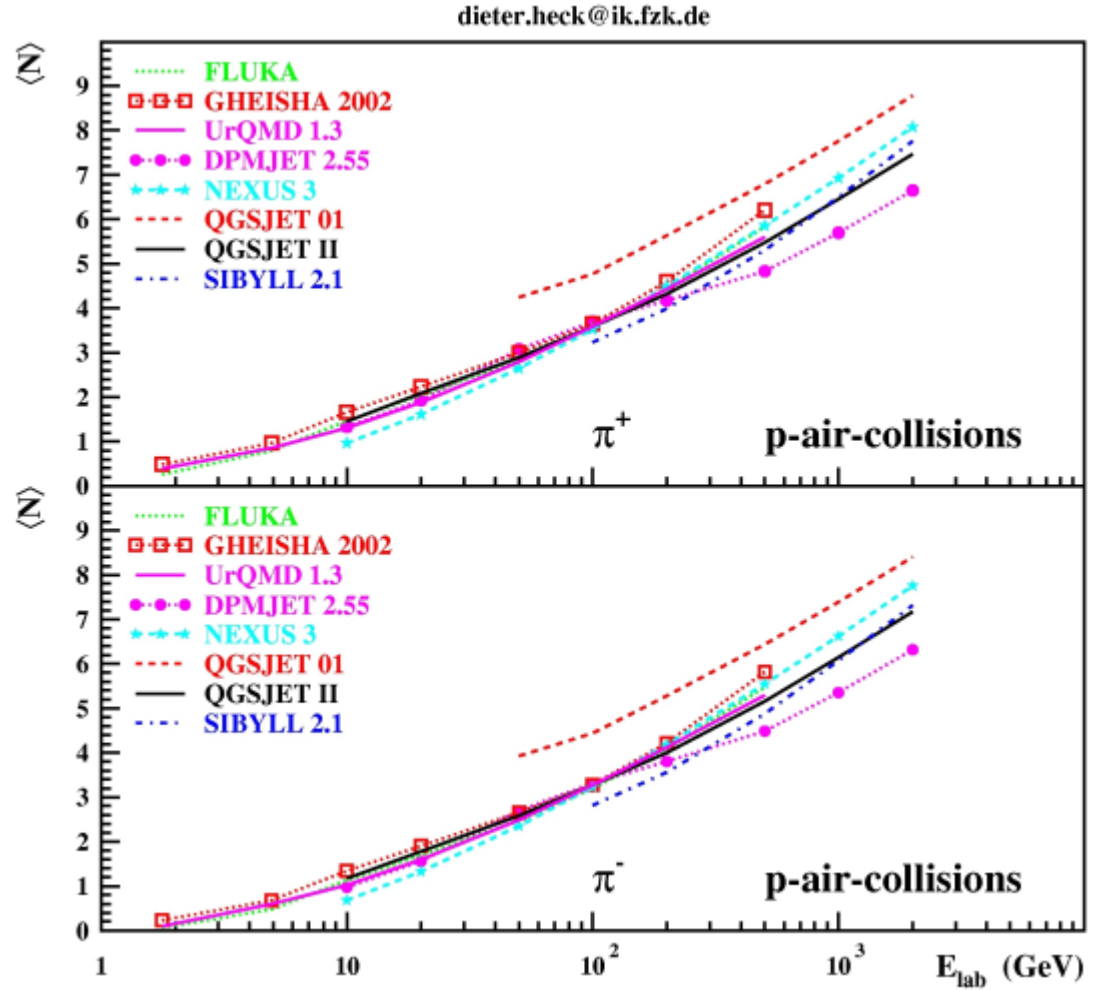
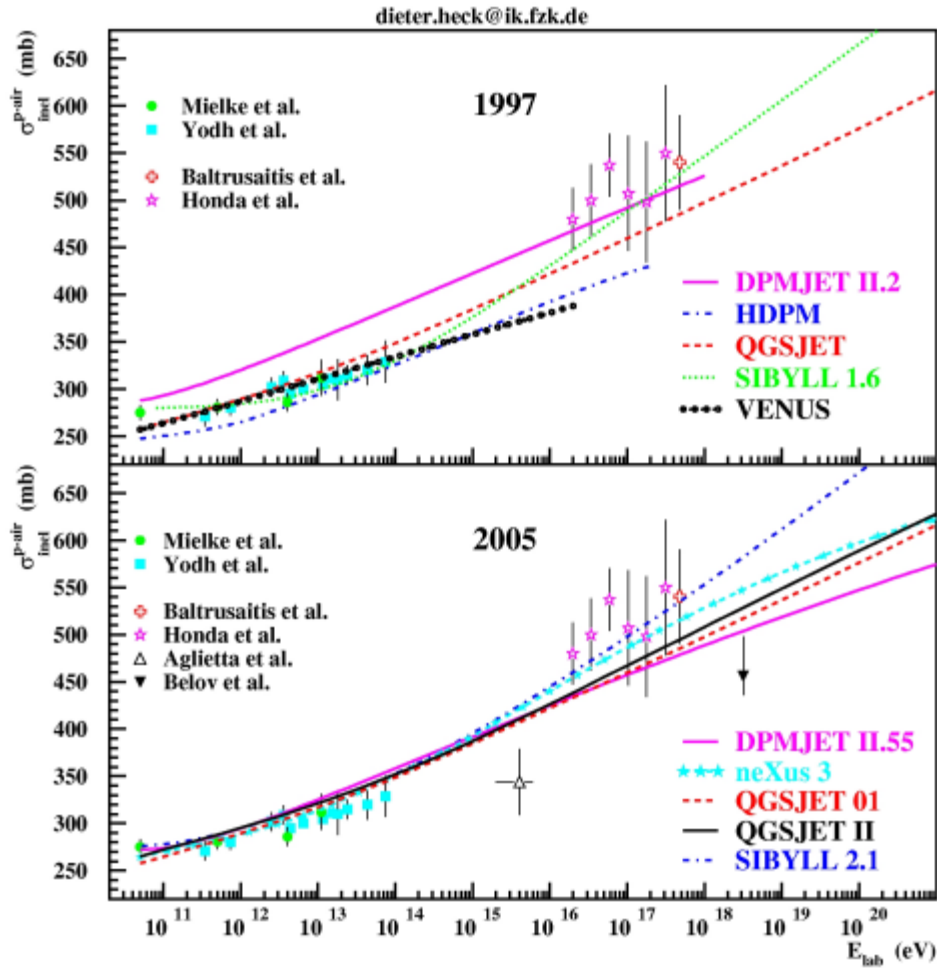
- based on hadronic interaction models.

Descriptions depend on:

- cross sections for;
 - primary particle (eg. proton) - air collisions
 - secondary particle (eg. pion, kaon) - air collisions
 - nucleus - air collisions
- and the inelasticity of the collisions.



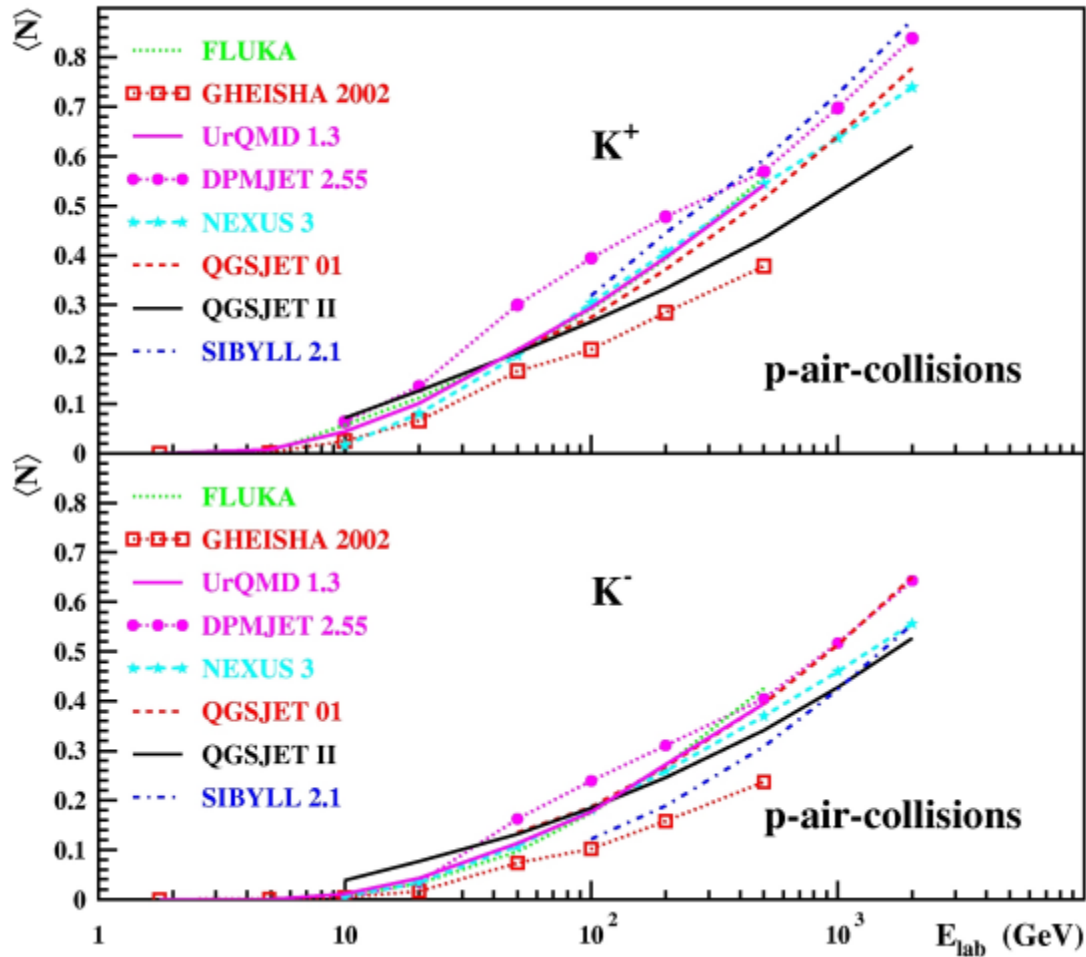
Cosmic Ray Interactions - EAS





Cosmic Ray Interactions - EAS

dieter.heck@ik.fzk.de



Descriptions depend on:

- cross sections for;
 - primary particle (eg. proton) - air collisions
 - secondary particle (eg. pion, kaon) - air collisions
 - nucleus - air collisions
- and the inelasticity of the collisions.

Determining:

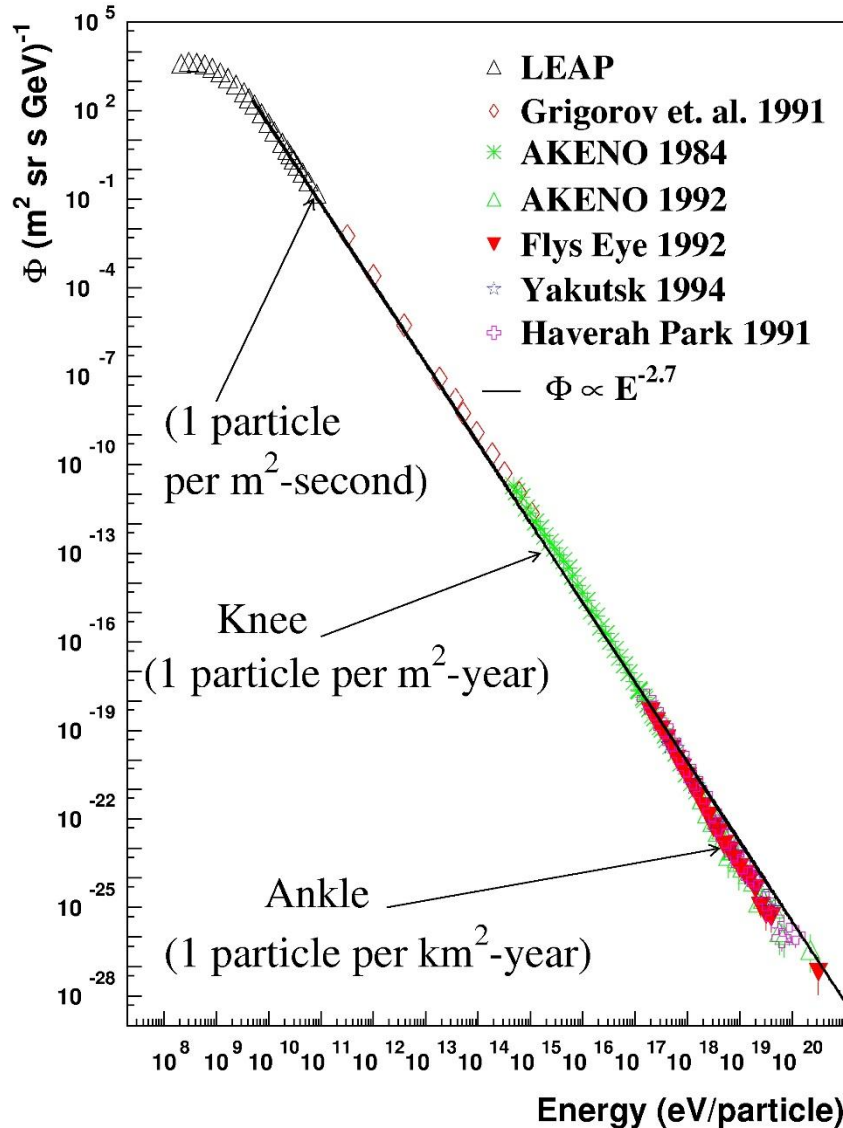
- production and composition of secondary particles;
 - their multiplicities, transverse momentum distribution etc.

Models Tests:

- using EAS components.



What are cosmic rays?



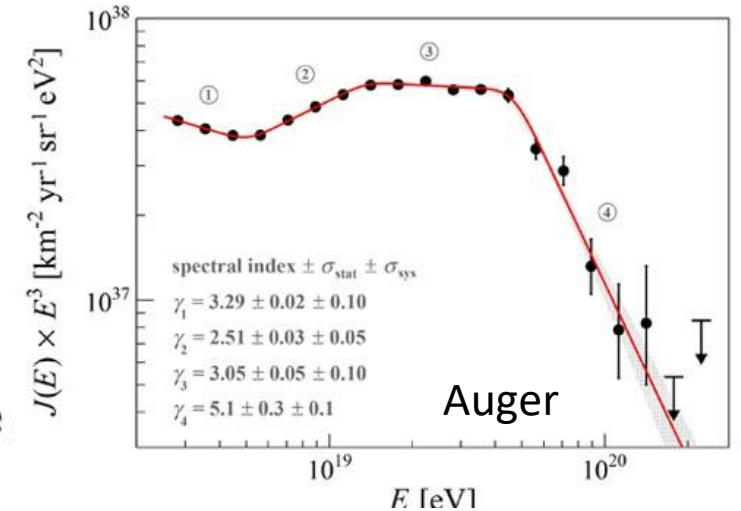
The all-particle cosmic ray spectrum

- Spectrum described by;

$$\Phi \propto E^{-\gamma}$$

- Changes in spectral index

$$\gamma \approx \begin{cases} 2.7 & \text{upto the knee} \\ 3.1 & \text{beyond the knee} \end{cases}$$



More information:

Features of the energy spectrum of cosmic rays above 2.5×10^{18} eV using the Pierre Auger Observatory

The Pierre Auger Collaboration, Phys. Rev. Lett. 125, 121106 (2020)

[arxiv.org/abs/2008.06488] [[doi: 10.1103/PhysRevLett.125.121106](https://doi.org/10.1103/PhysRevLett.125.121106)]

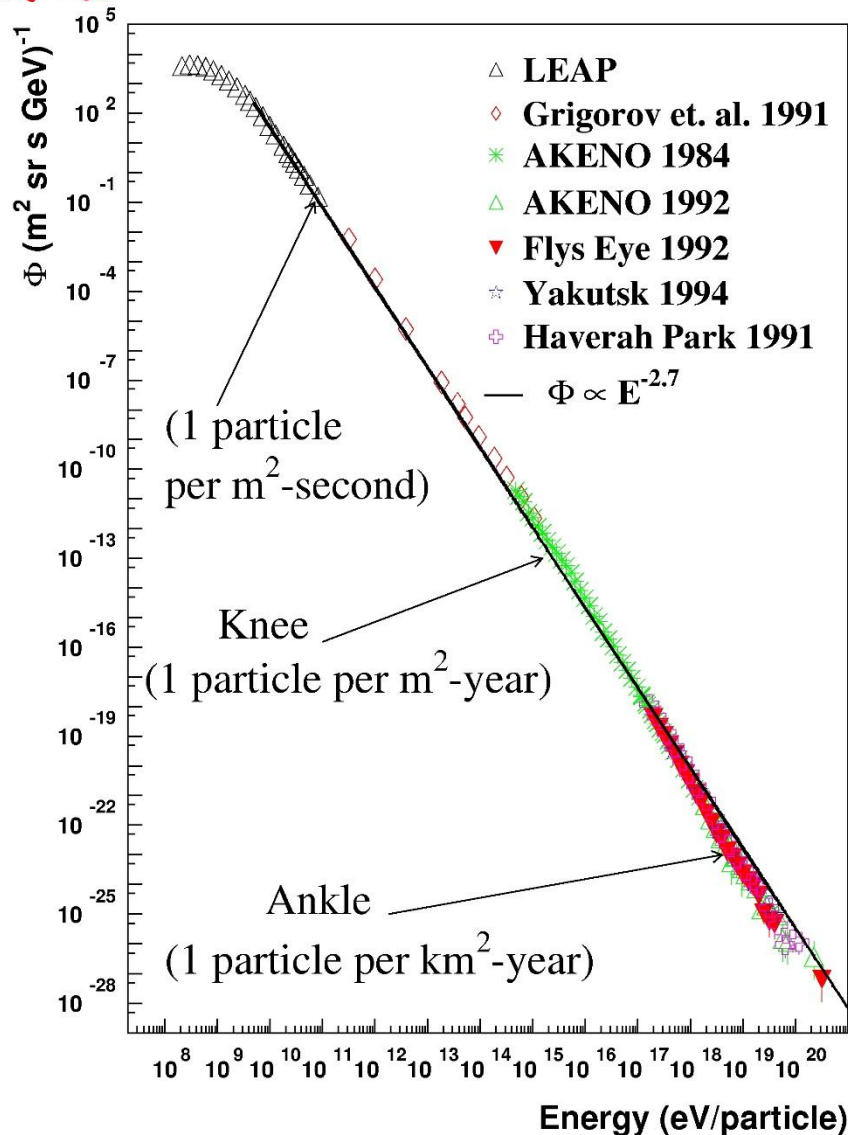
Measurement of the cosmic ray energy spectrum above 2.5×10^{18} eV using the Pierre Auger Observatory

The Pierre Auger Collaboration, Phys. Rev. D 102, 062005 (2020)

[arxiv.org/abs/2008.06486] [[doi: 10.1103/PhysRevD.102.062005](https://doi.org/10.1103/PhysRevD.102.062005)]

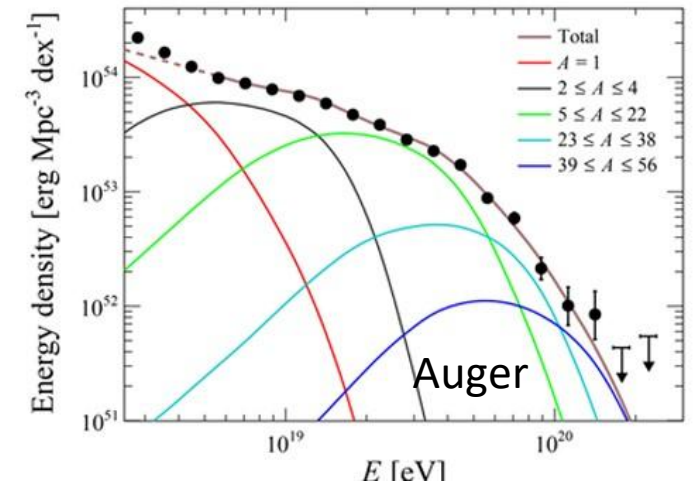


What are cosmic rays?



The all-particle cosmic ray spectrum

- Changes in spectral index
- Chemical composition
 - Maximum acceleration
 - GZK effect



More information:

Features of the energy spectrum of cosmic rays above 2.5×10^{18} eV using the Pierre Auger Observatory

The Pierre Auger Collaboration, Phys. Rev. Lett. 125, 121106 (2020)

[arxiv.org/abs/2008.06488] [[doi: 10.1103/PhysRevLett.125.121106](https://doi.org/10.1103/PhysRevLett.125.121106)]

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The Pierre Auger Collaboration, Phys. Rev. D 102, 062005 (2020)

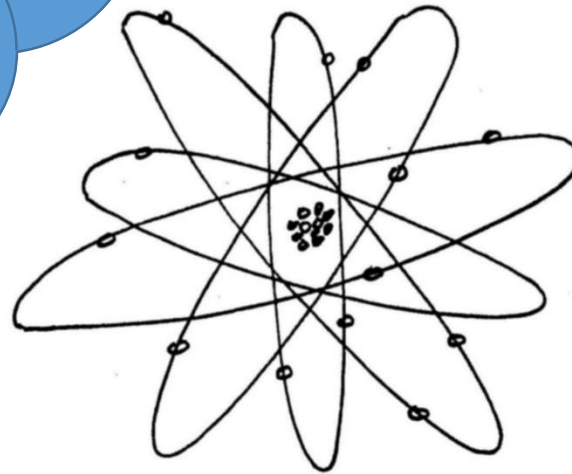
[arxiv.org/abs/2008.06486] [[doi: 10.1103/PhysRevD.102.062005](https://doi.org/10.1103/PhysRevD.102.062005)]



All – particle cosmic ray spectrum

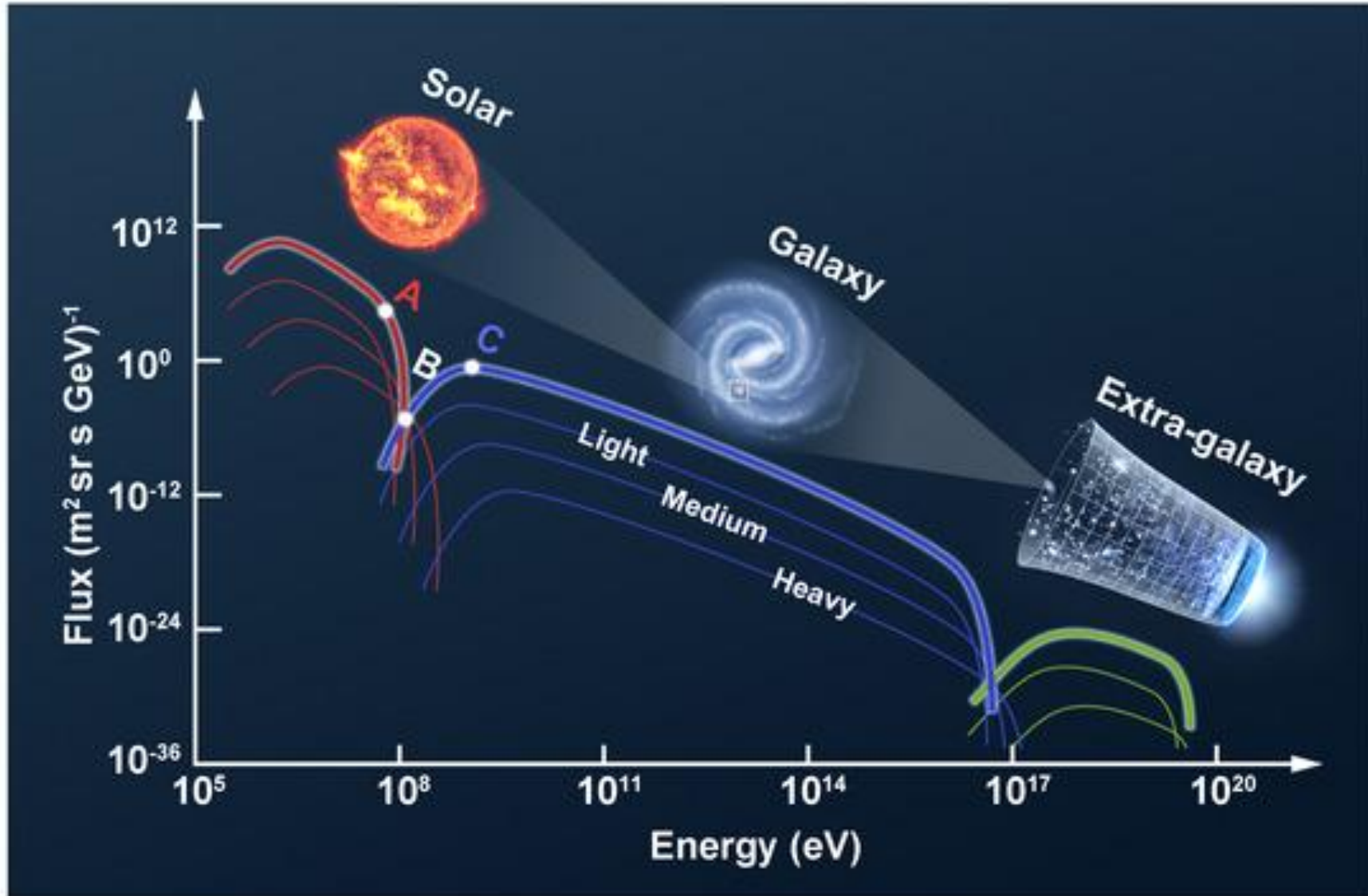
Where do they come from?

What do the numbers mean?



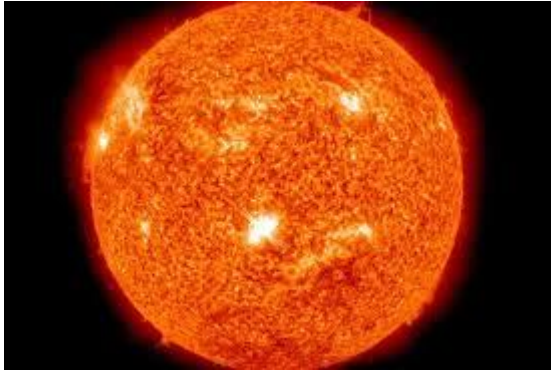


Sources of Cosmic Rays





Sources of Cosmic Rays



Sun



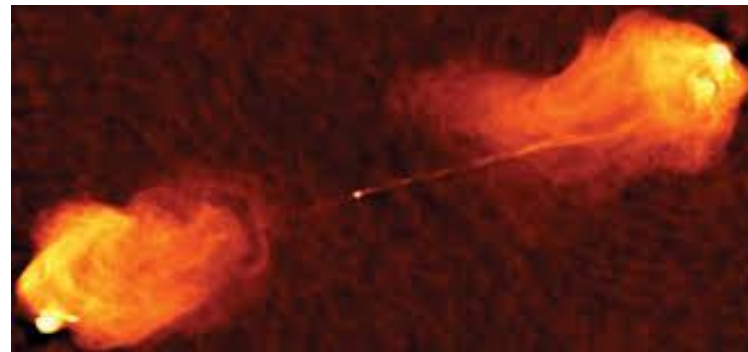
Black Holes



Crab Nebula



Supernovae

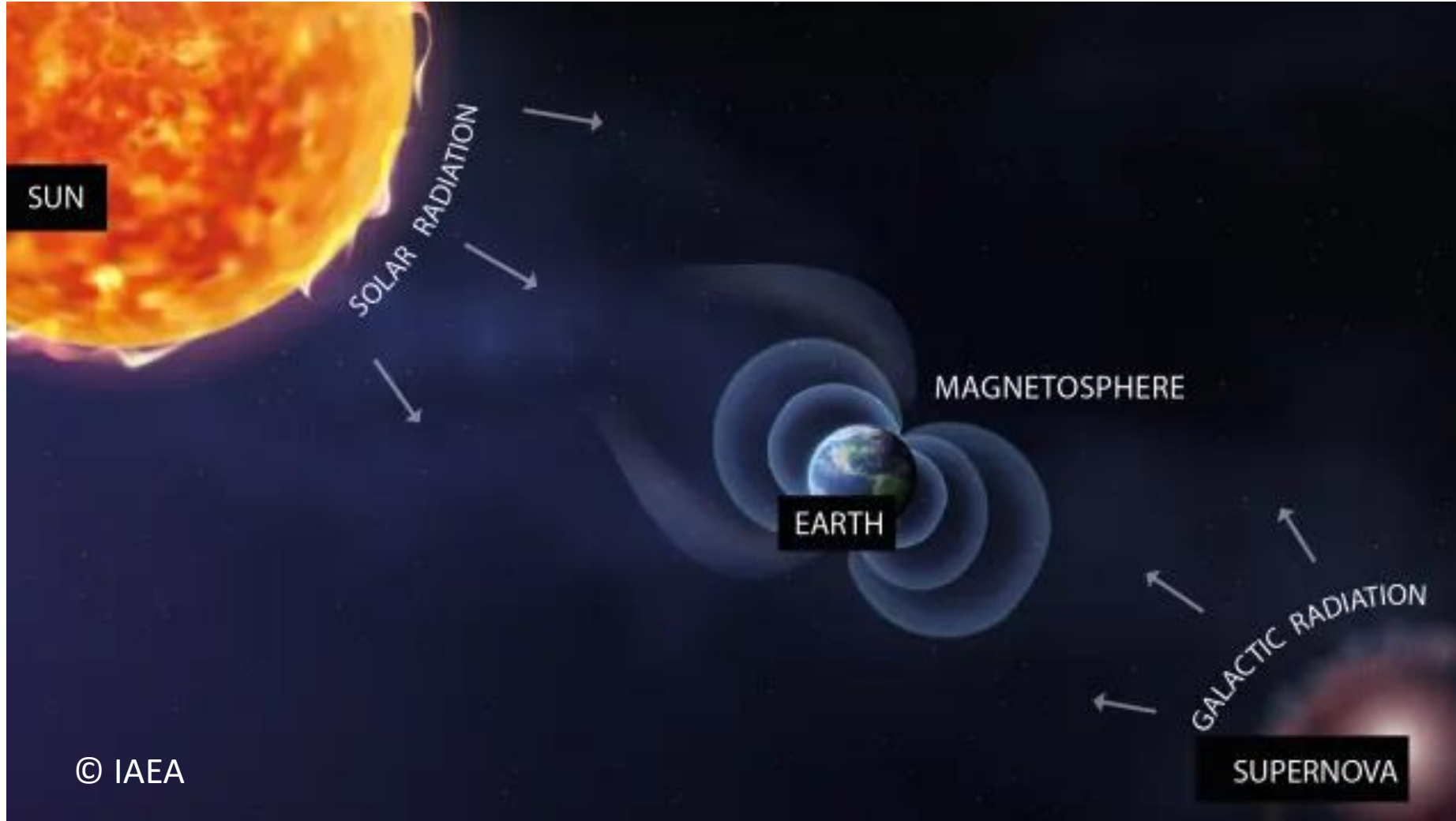


AGNs





Sources of Cosmic Rays



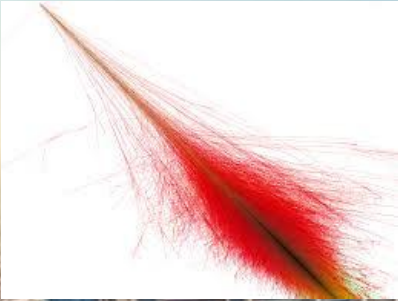
The magnetic field of the earth provides a shield for charged cosmic ray particles

The magnetosphere deflects cosmic rays and provides protection from solar flares

[More information](#)



Flux of Cosmic Ray Particles



**At least one particle with
Energy above 10^{15} eV**

During a regular football match

FIFA laws of the game

Law 1: field of play: 110 m x 75 m

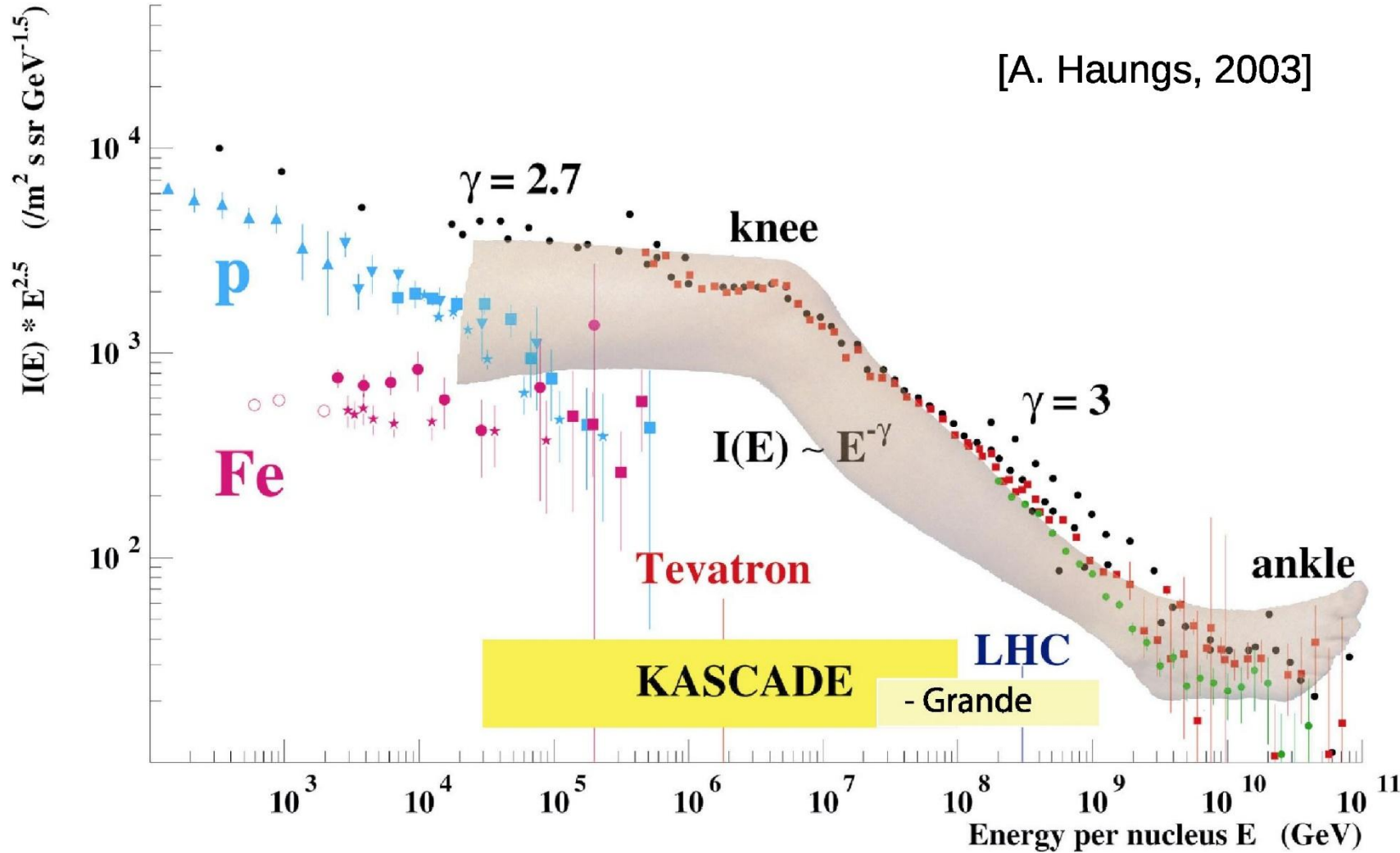
Law 2: duration of match: 2 x 45 min

www.fifa.com



The “knee” on the all-particle cosmic ray spectrum

[A. Haungs, 2003]



Changes in the spectral index between 10^6 and 10^7 GeV

Origins:

- Galactic leakage?
- Maximum acceleration?
- Unknown effects?

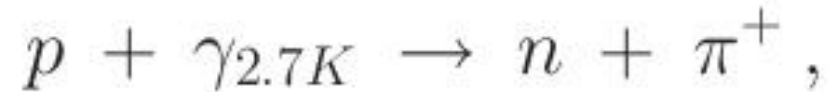
Chemical composition:

- p, He, C, Fe ...
- Polygonato model?

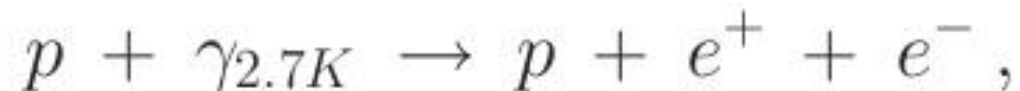


An end to the all-particle cosmic ray spectrum?

Protons with energies greater than 6×10^{19} eV interact with CMBR photons losing energy via photo-pion production,



or pair-production,

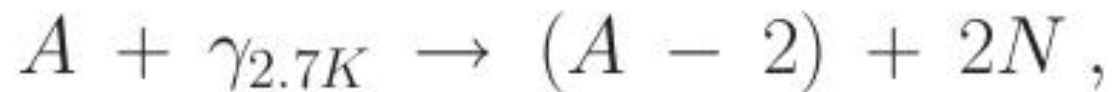
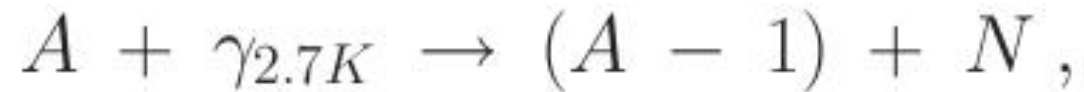


losing a large fraction of their energy.

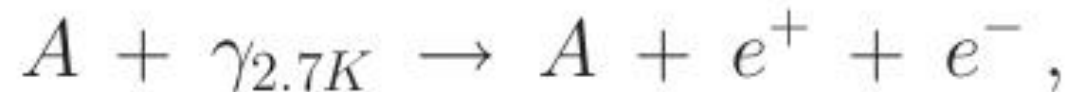


An end to the all-particle cosmic ray spectrum?

Heavier nuclei of mass A suffer photo-disintegration,



or pair-production,

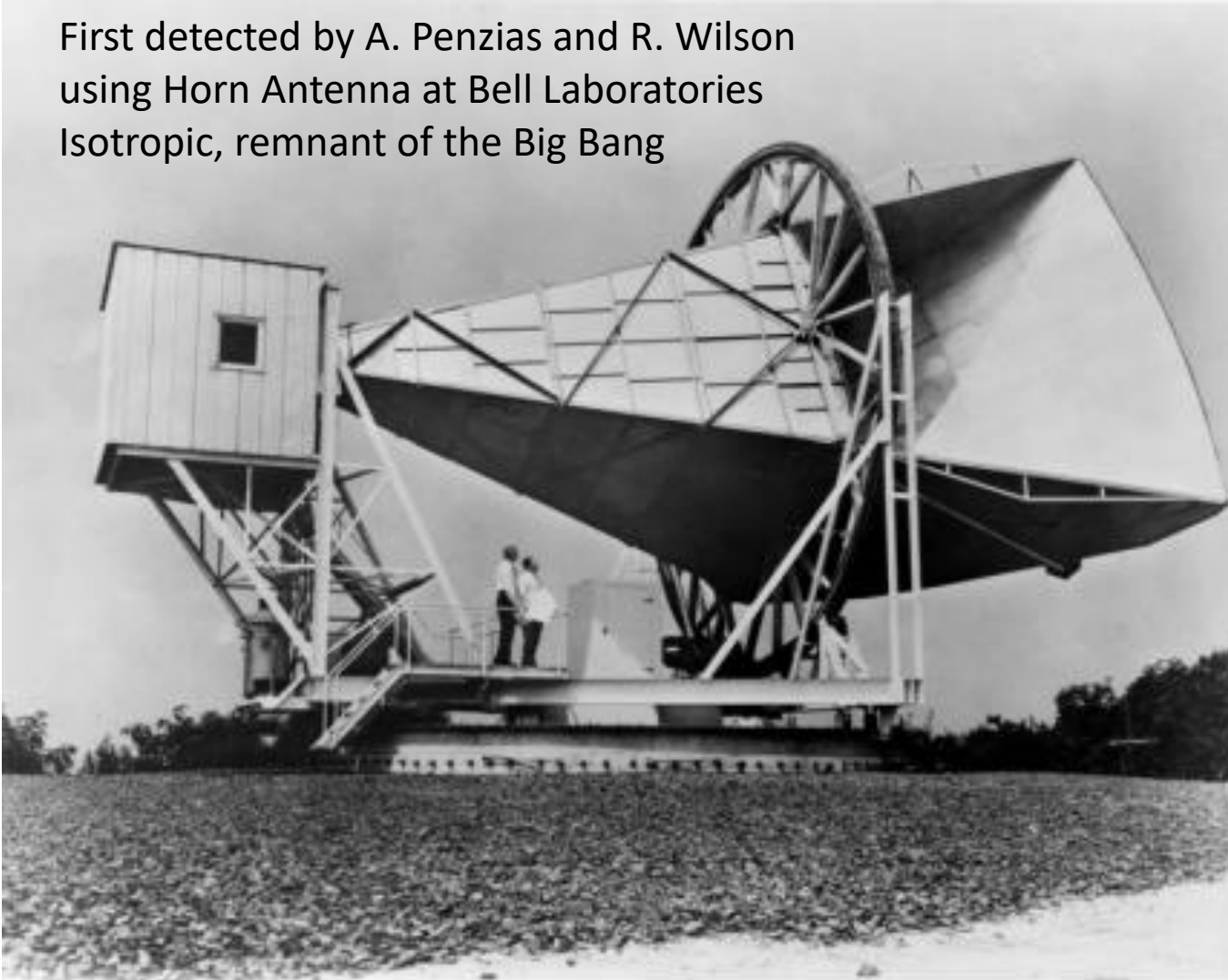


where N is a nucleon. These processes lead to a drastic cut-off on the cosmic ray energy spectrum at those energies and is known as the Greisen-Zatsepin-Kuzmin (GZK) cut-off



The Cosmic Microwave Background Radiation (CMBR)

First detected by A. Penzias and R. Wilson
using Horn Antenna at Bell Laboratories
Isotropic, remnant of the Big Bang



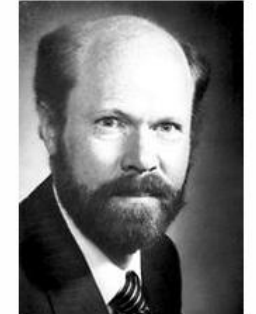
The Nobel Prize in Physics 1978



**Pyotr Leonidovich
Kapitsa**
Prize share: 1/2



Arno Allan Penzias
Prize share: 1/4

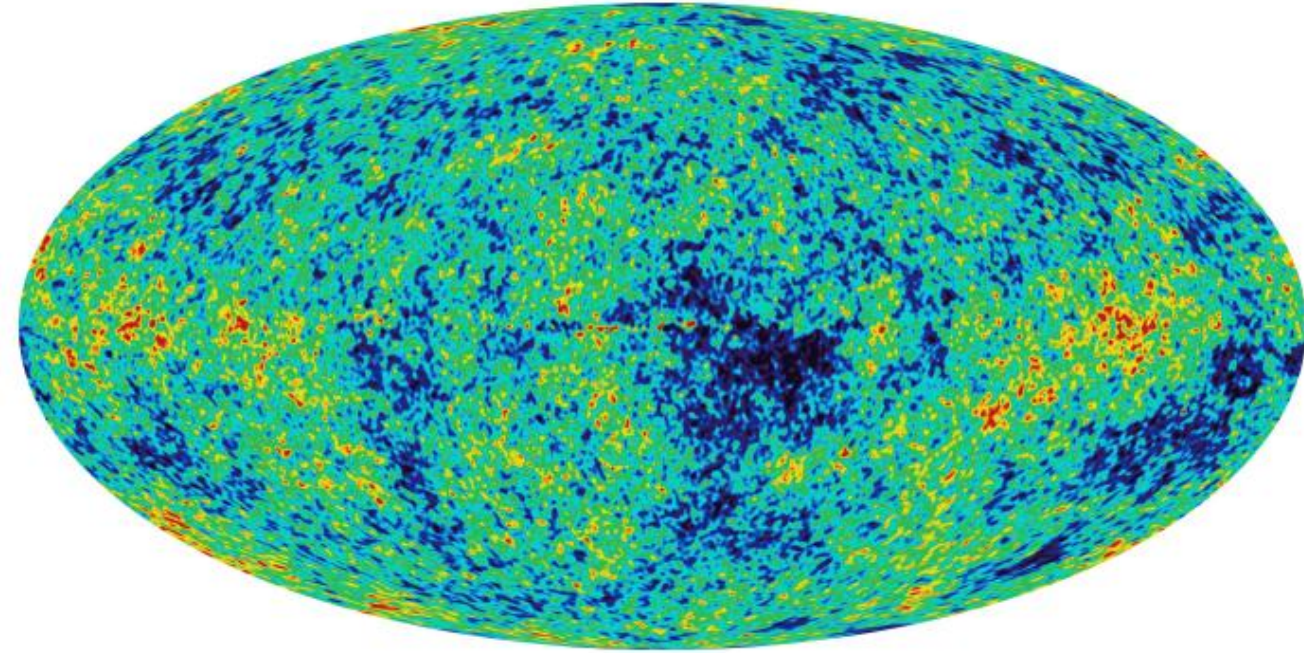
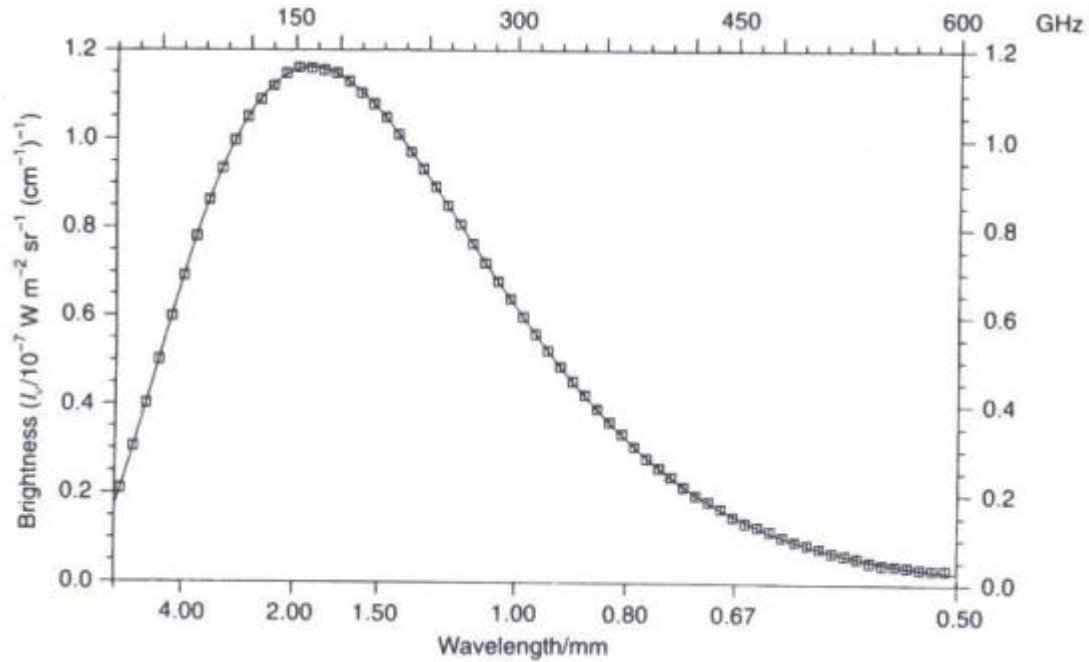


Robert Woodrow Wilson
Prize share: 1/4

The Nobel Prize in Physics 1978 was divided, one half awarded to Pyotr Leonidovich Kapitsa "for his basic inventions and discoveries in the area of low-temperature physics", the other half jointly to Arno Allan Penzias and Robert Woodrow Wilson "for their discovery of cosmic microwave background radiation".

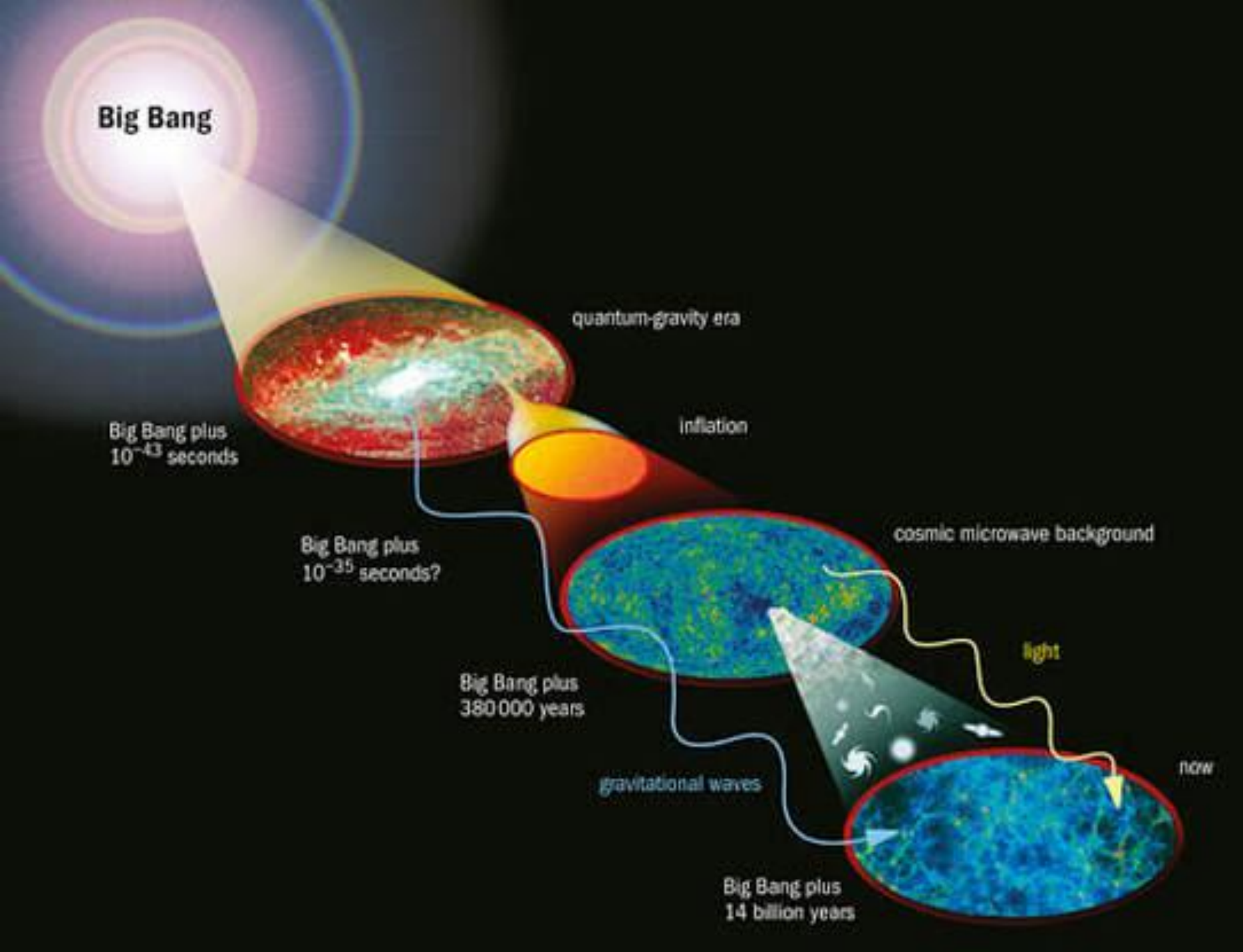


The Cosmic Microwave Background Radiation (CMBR)



COBE results - energy spectrum fits that of a black body, $T \simeq 2.7\text{K}$
COBE = COsmic Background Explorer

WMAP results - isotropic CMBR with small fluctuations
WMAP = WILKINSON MICROWAVE ANISOTROPY PROBE

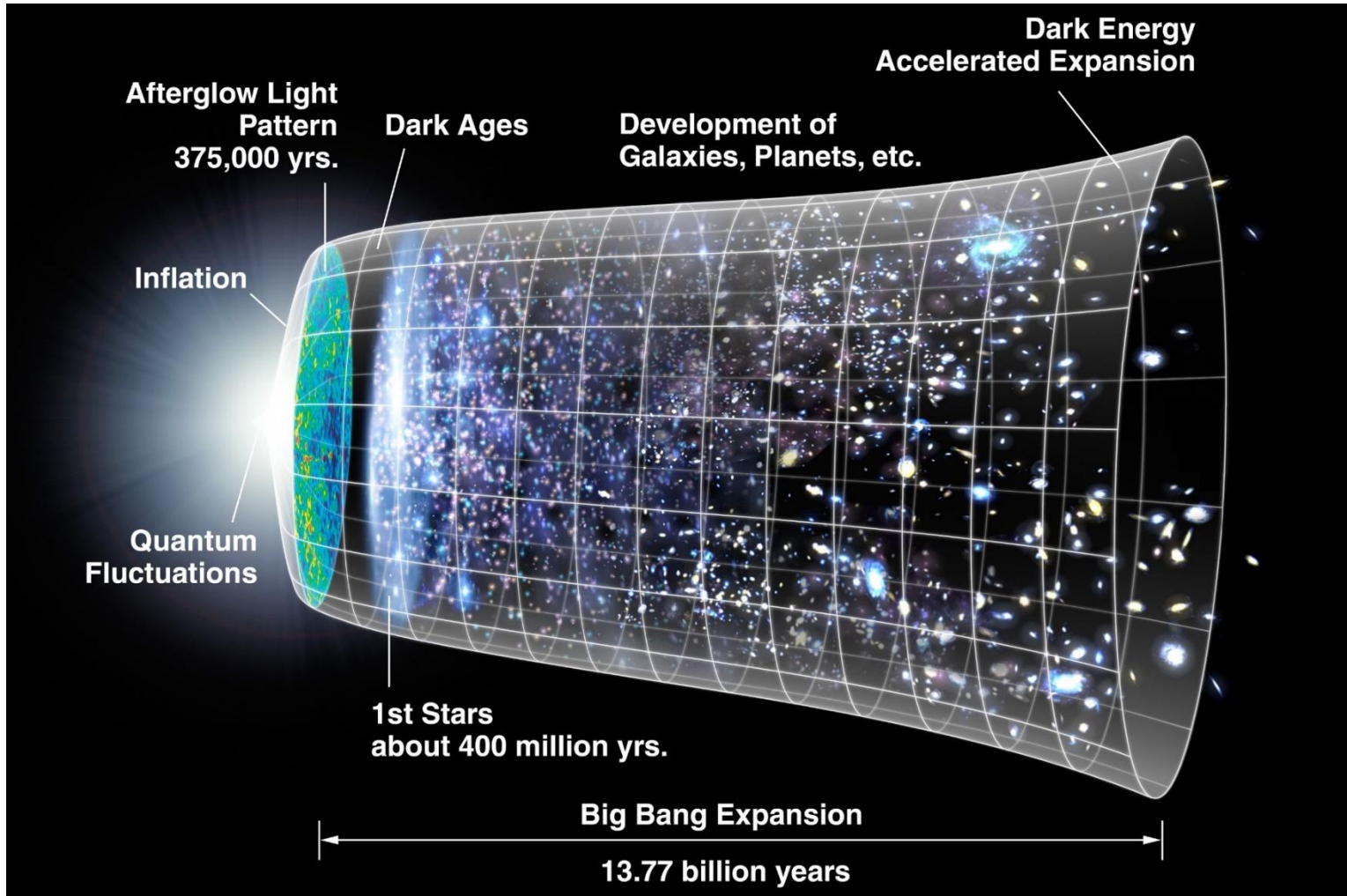


The Cosmic Microwave Background Radiation (CMBR)

... a relic of the Big Bang



Big Bang



Open Questions

- What caused the Big Bang?
- What was there before the Big Bang?
- What happened immediately after the Big Bang?
- What is the fate of the Universe?

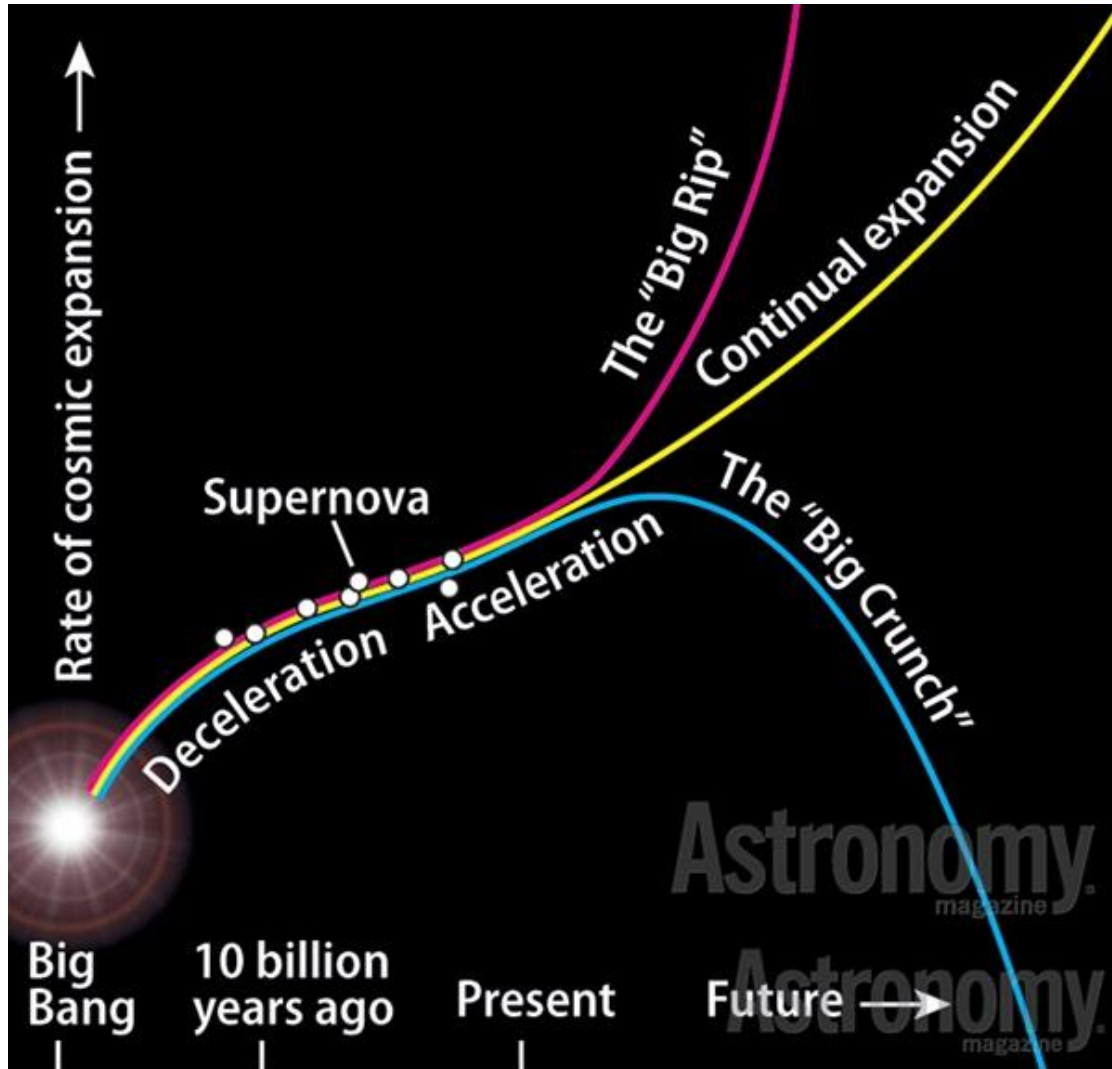


Big Bang

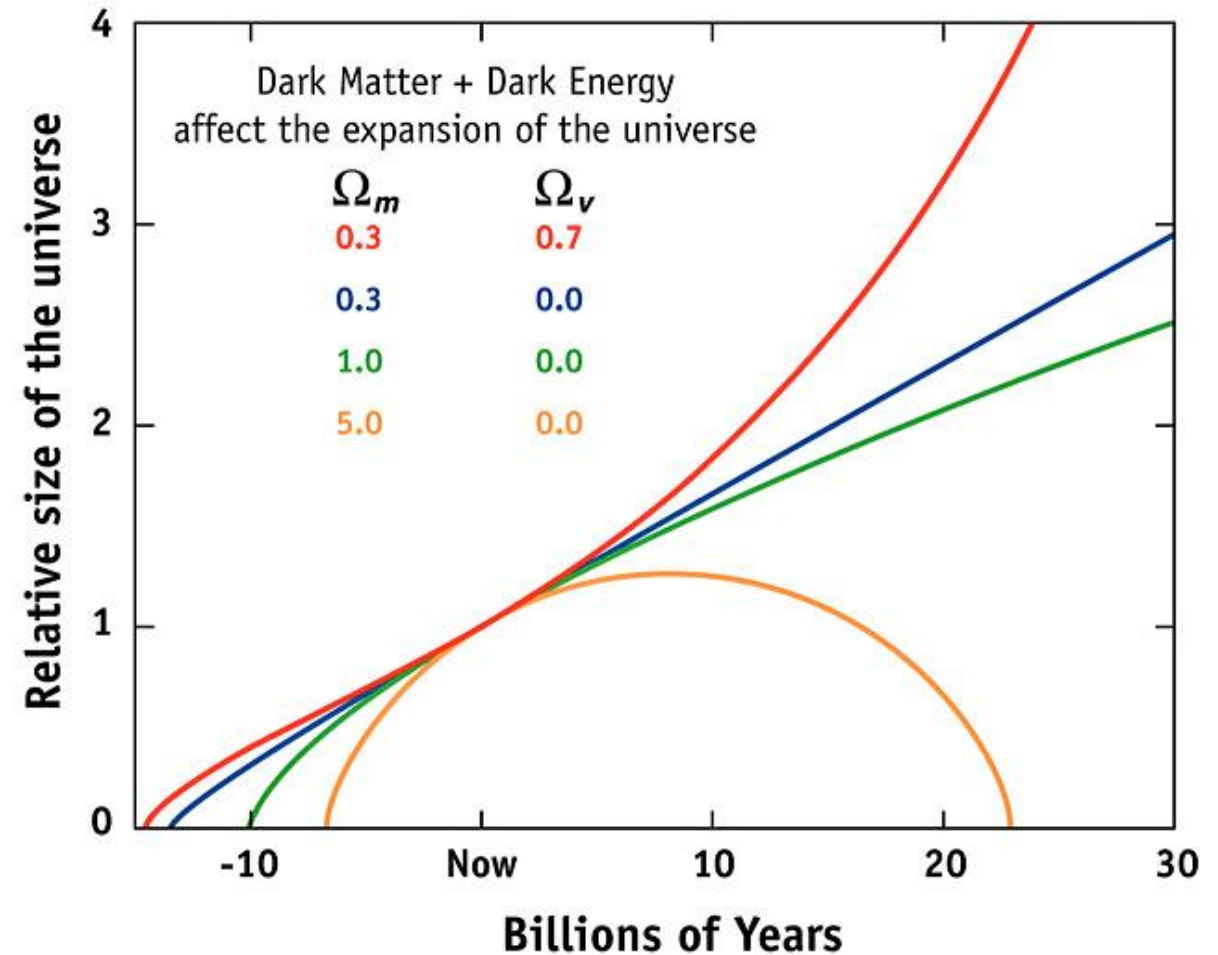




What is the fate of the universe?

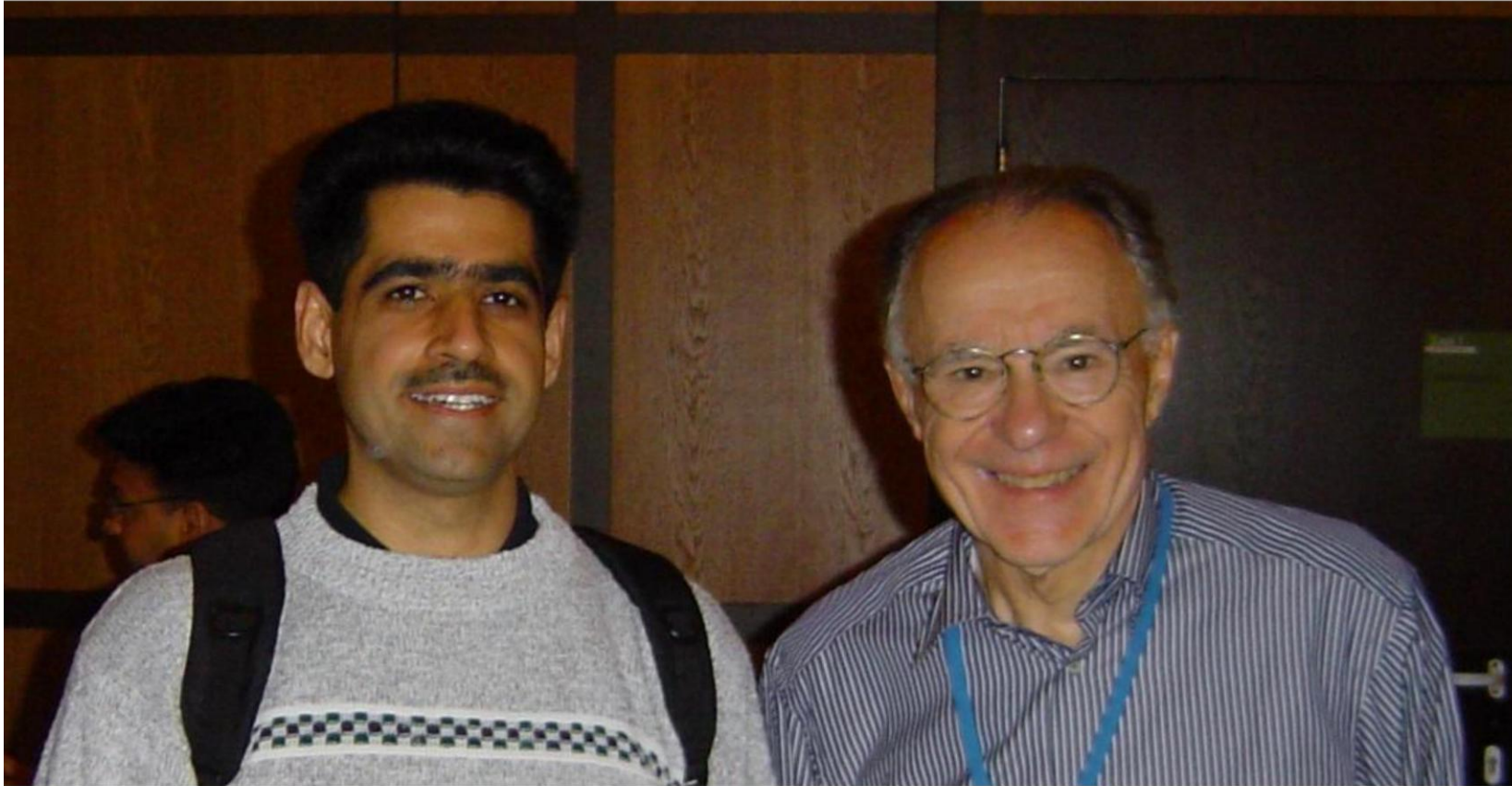


EXPANSION OF THE UNIVERSE





What is the fate of the universe?

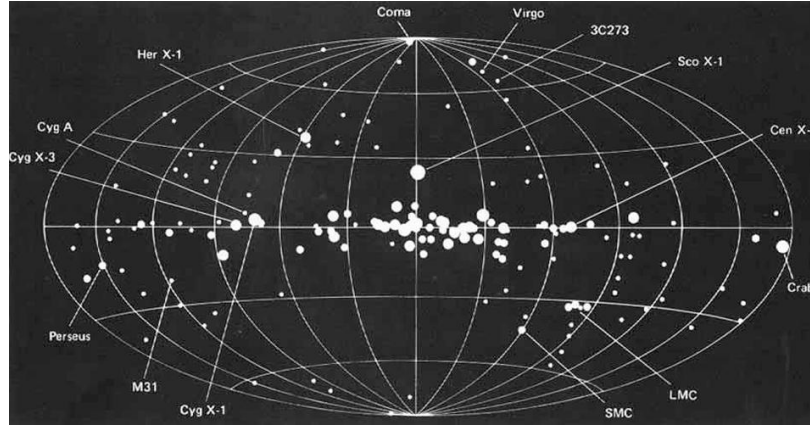
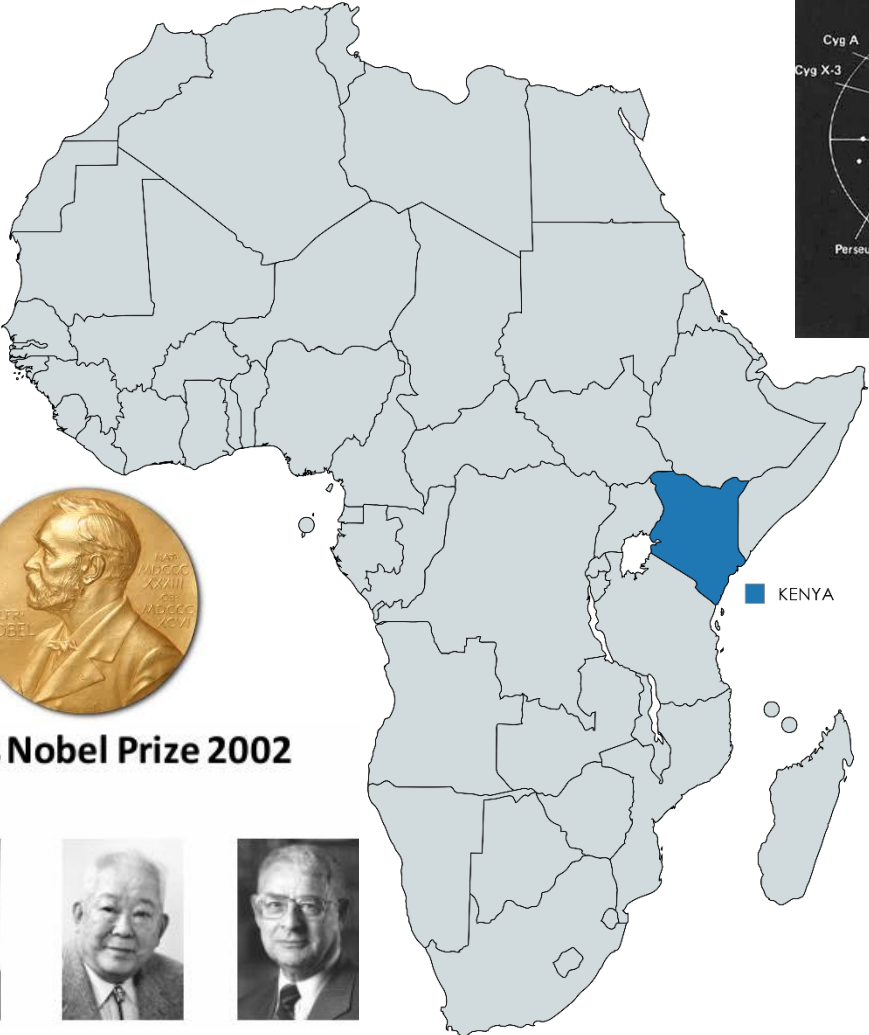


“... on the
fate of the
universe ...
your guess is
as good as
mine ...”
Arno Penzias

Nadir Hashim with Arno Penzias (Physics Nobel Prize, 1978) during a meeting with Physics Nobel Laureates in June/July 2004 at Lindau, Germany. Nadir Hashim was a Ph.D. student at Siegen University under DAAD scholarship and on study leave from Kenyatta University, Nairobi, Kenya.



X-Ray Sources with the UHURU Satellite



Also known as X-ray Explorer Satellite SAS A

Launched on 12.12.1970 at the San Marco Platform in Malindi, Kenya

First satellite dedicated to X-ray Astrophysics

Discovery and detailed study of binary X-ray sources – Cen X-3, Vela X-1, Her X-1, Cygnus X-1





X-Ray Sources with the UHURU Satellite



Physics Nobel Prize 2002



Raymond Davis Jr. and Masatoshi Koshiwa "for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos" and **Riccardo Giacconi** "for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources."

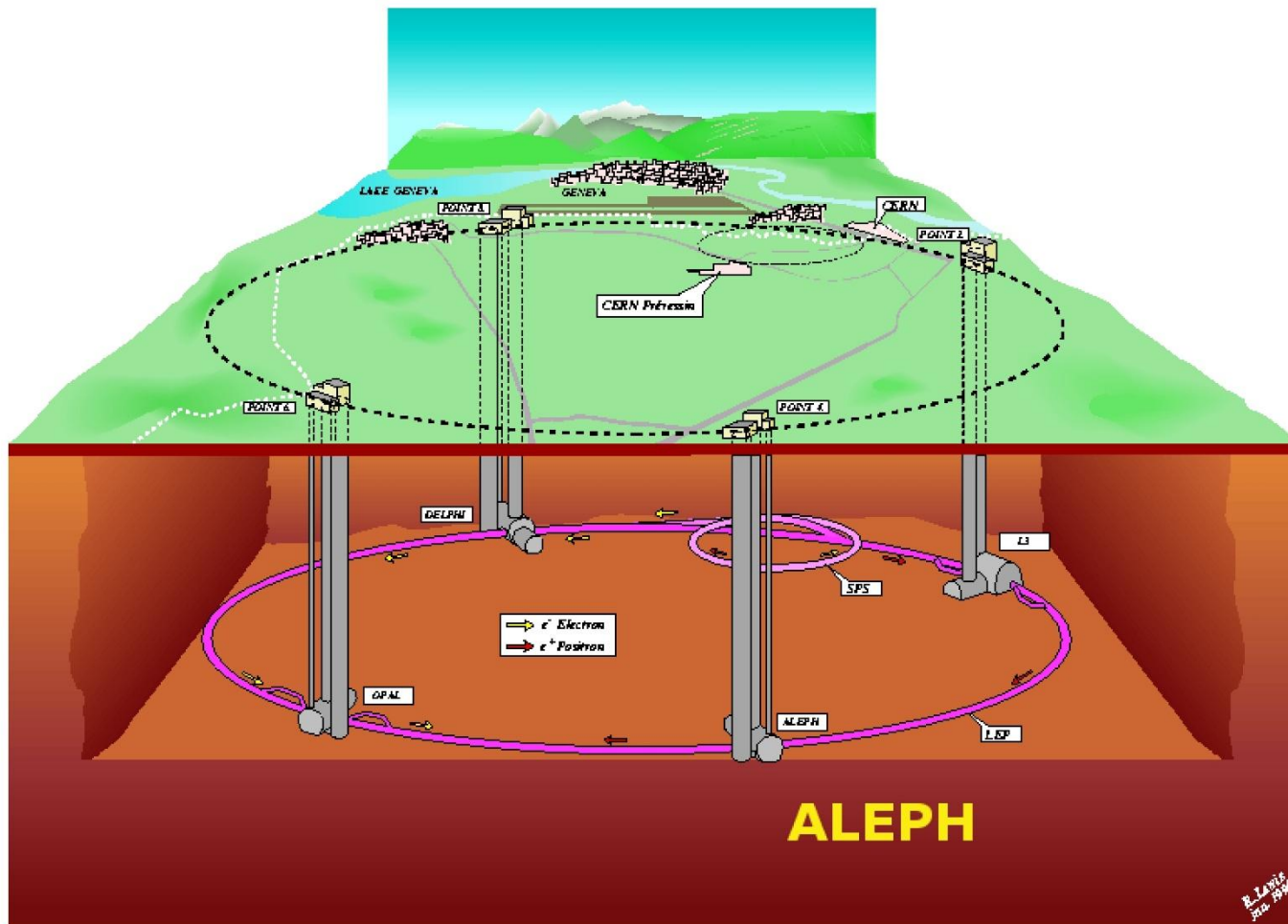


Measurements of Cosmic Rays



The CosmoALEPH Experiment at CERN

LEP at CERN (Geneva) , CosmoALEPH -320 m.w.e.



Science goal:

Momentum spectrum and charge ratio of cosmic ray muons

Experiment:

CosmoALEPH at CERN

ALEPH at 140 m underground or 320 m.w.e.

Monte Carlo Simulations:

CORSIKA – for the simulation of EAS in the atmosphere

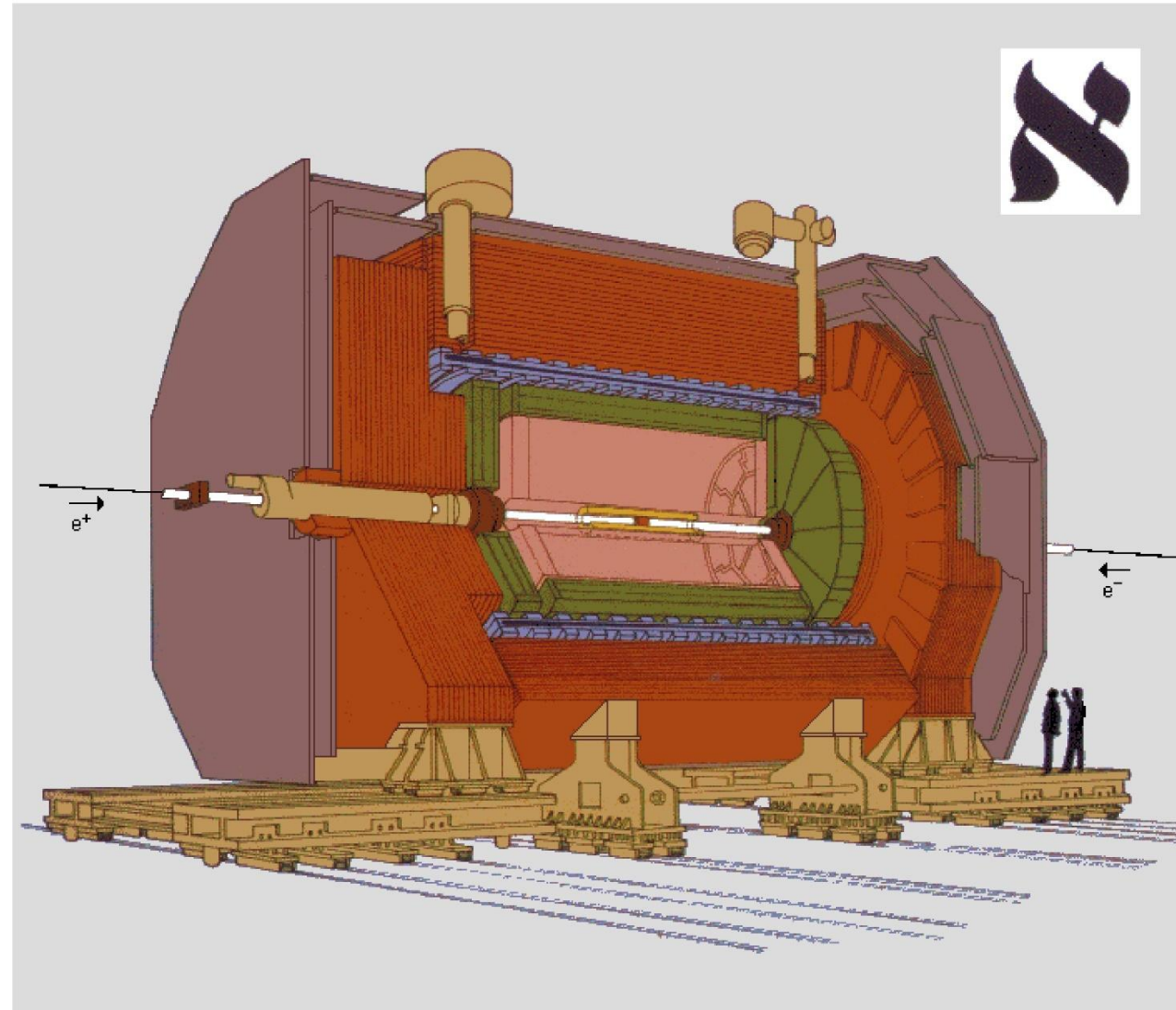
GEANT – for the simulation of particle interactions in the detector











CosmoALEPH Experiment at CERN

ALEPH:

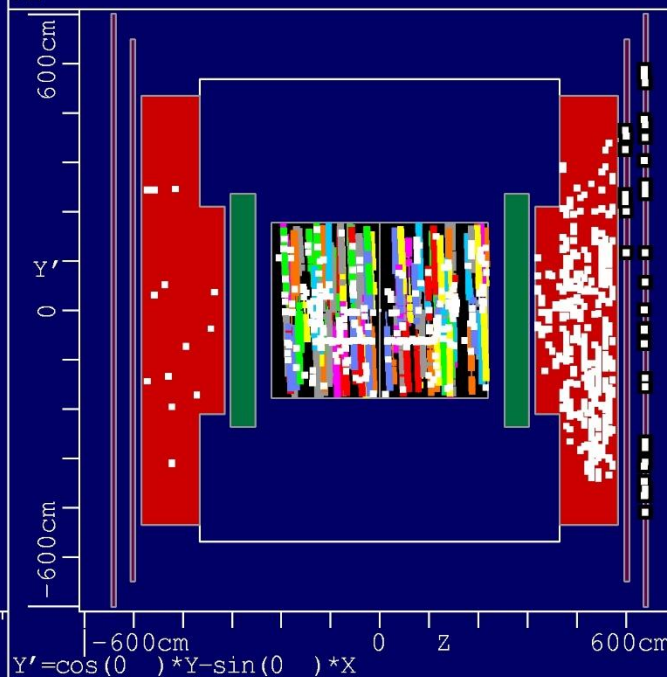
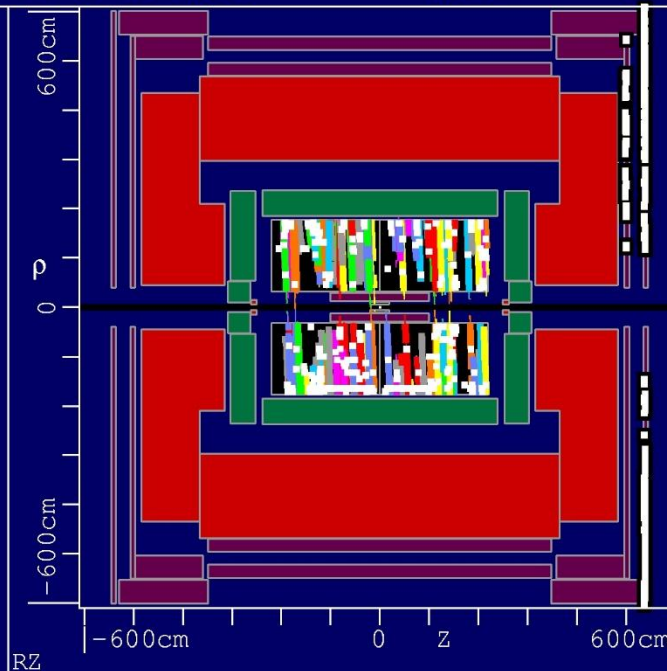
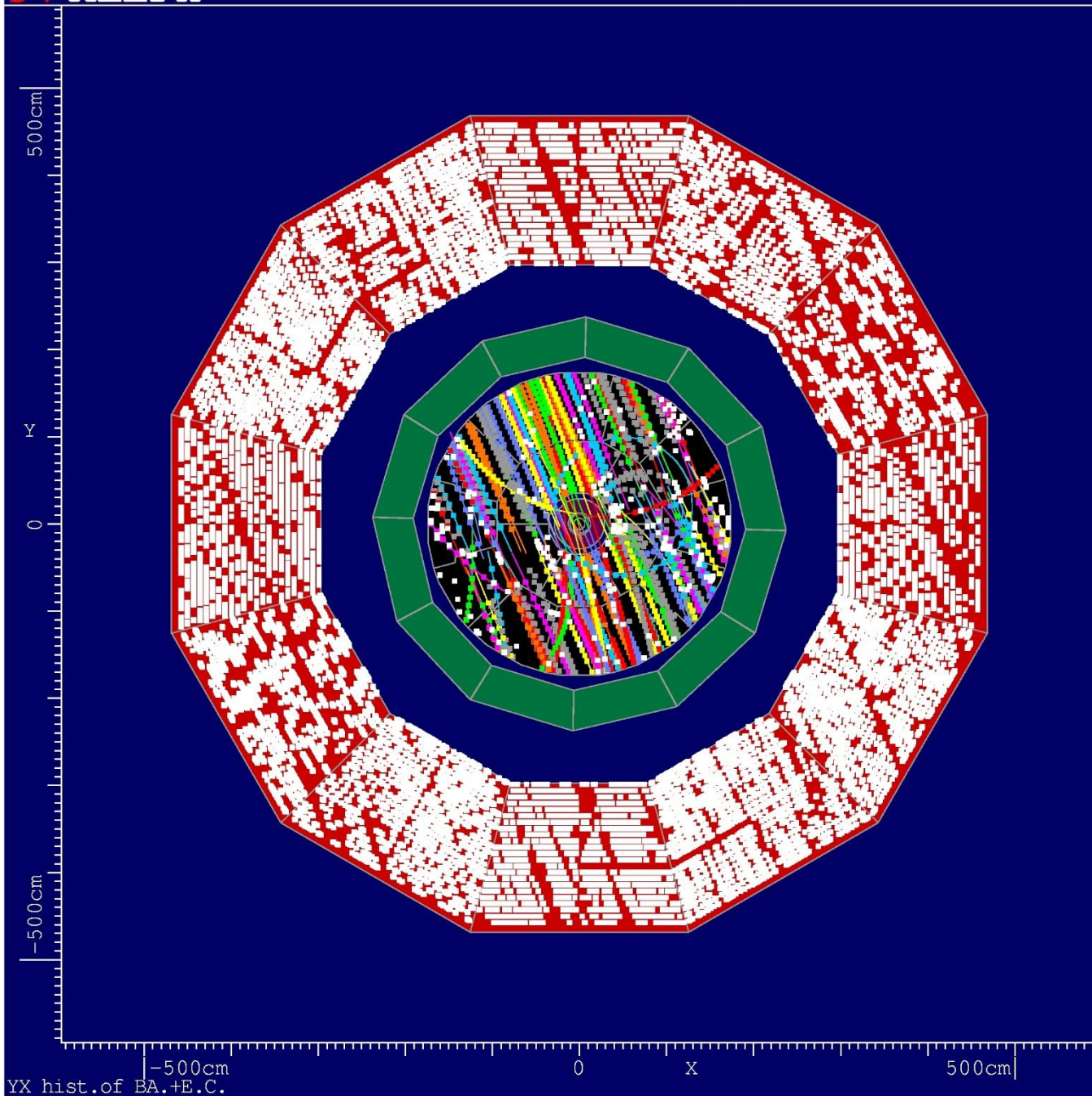
Built for $e^+ e^-$ physics
Capability to measure muons
Used to measure cosmic ray muons



-  Vertex Detector
-  Inner Tracking Chamber
-  Time Projection Chamber
-  Electromagnetic Calorimeter
-  Superconducting Magnet Coil
-  Hadron Calorimeter
-  Muon Chambers
-  Luminosity Monitors

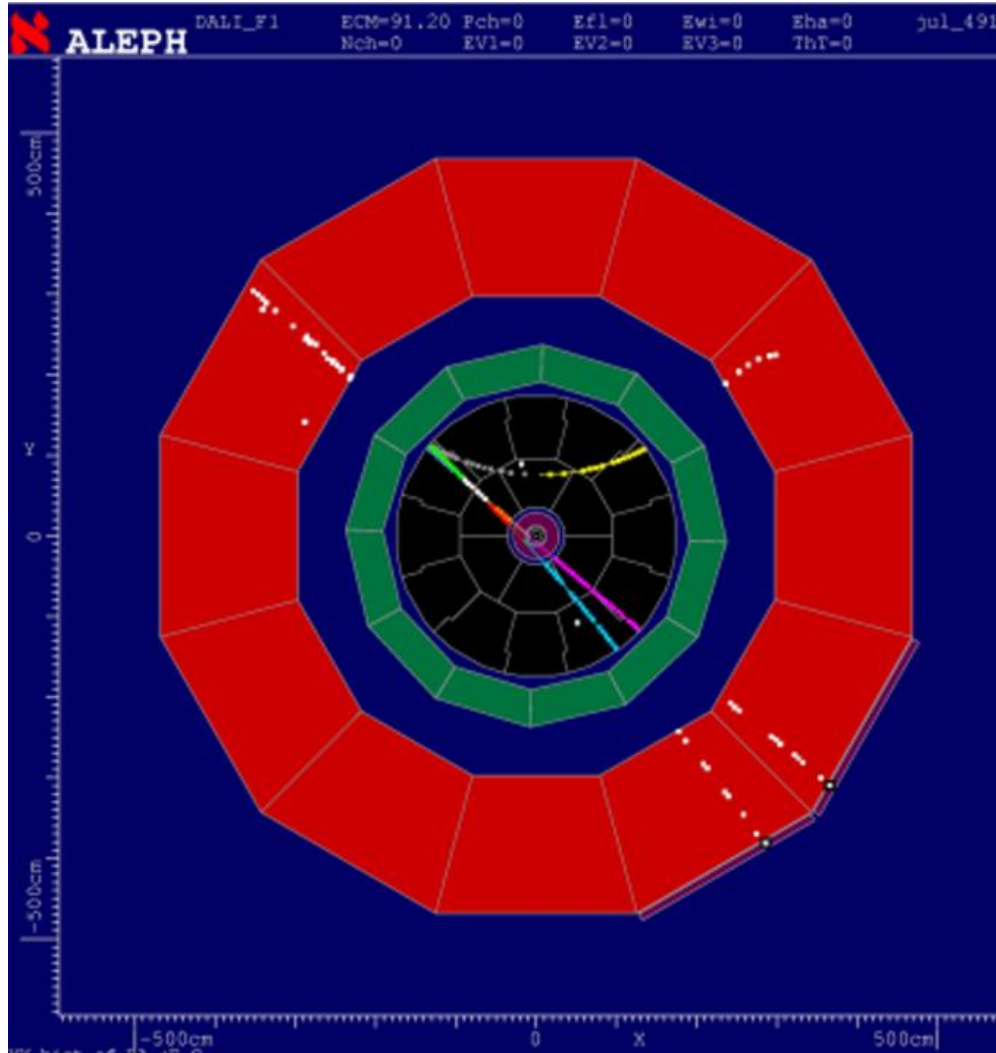


Multi-Muon Event in ALEPH





CR Muon Trident Process in ALEPH - 2006



- Muon pair produced by the interaction of cosmic ray muon in the detector: $\mu (Z, \mu^+ \mu^- Z) \mu$
- Over 10^6 dedicated cosmic ray muon events analyzed.
- Two candidate events observed, consistent with theoretical expectations by KKP taking into account nuclear form factor.

PRL 96, 021801 (2006)

PHYSICAL REVIEW LETTERS

week ending
20 JANUARY 2006

Muon-Pair Production by Atmospheric Muons in CosmoALEPH

F. Maciuc,^{1,*,\dagger} C. Grupen,² N.-O. Hashim,² S. Luitz,³ A. Mailov,² A.-S. Müller,⁴ A. Putzer,⁵ H.-G. Sander,⁶ S. Schmeling,⁷ M. Schmelling,¹ R. Tcaciuc,² H. Wachsmuth,⁷ Th. Ziegler,⁸ and K. Zuber⁹

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²Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany

³SLAC M/S 41, 2575 Sand Hill Road, Menlo Park, California 94025, USA

⁴FZ Karlsruhe, Institut für Synchrotronstrahlung, D-76021 Karlsruhe, Germany

⁵Kirchhoff-Institut für Physik, Universität Heidelberg, D-69120 Heidelberg, Germany

⁶Fachbereich Physik, Universität Mainz, D-55099 Mainz, Germany

⁷CERN, CH-1211 Geneva 23, Switzerland

⁸Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

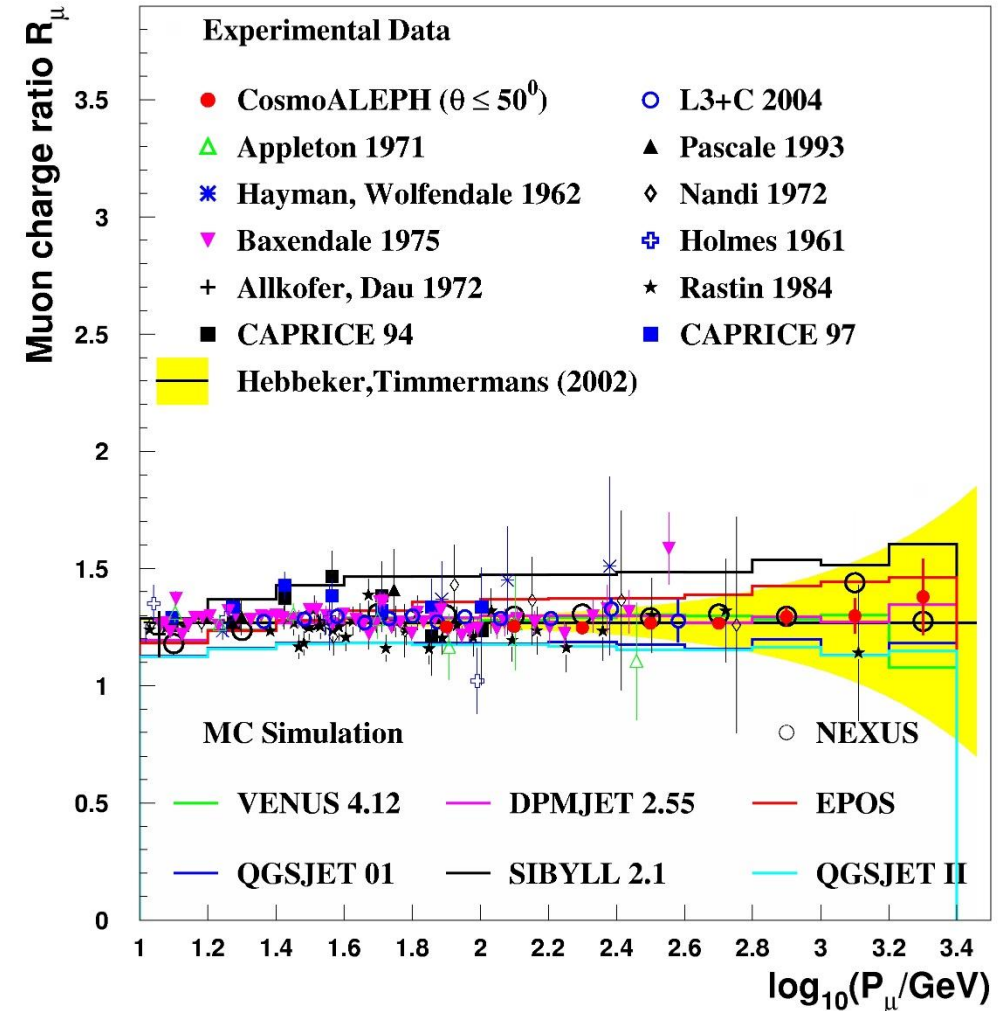
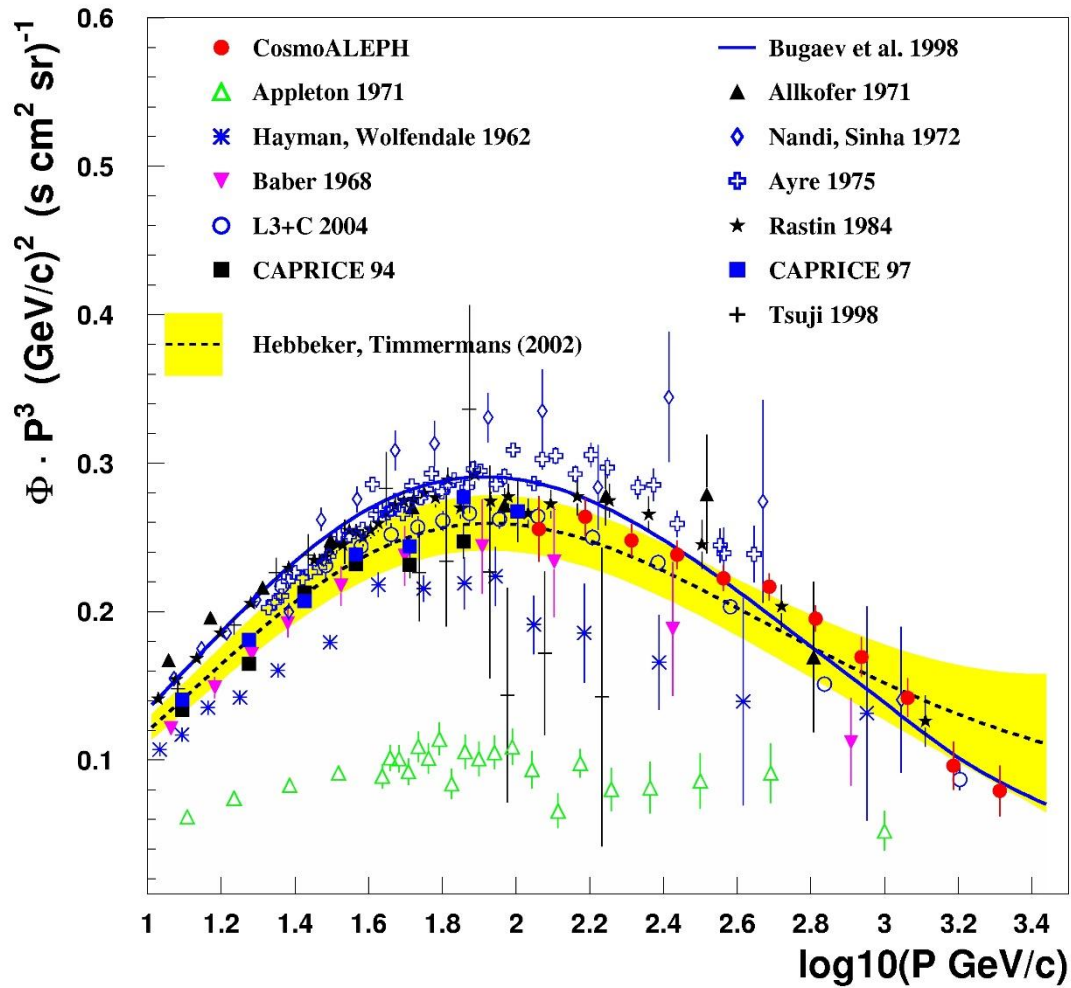
⁹Department of Physics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, United Kingdom

(Received 1 August 2005; published 19 January 2006)

<https://cds.cern.ch/record/941159/files/PhysRevLett.96.021801.pdf>



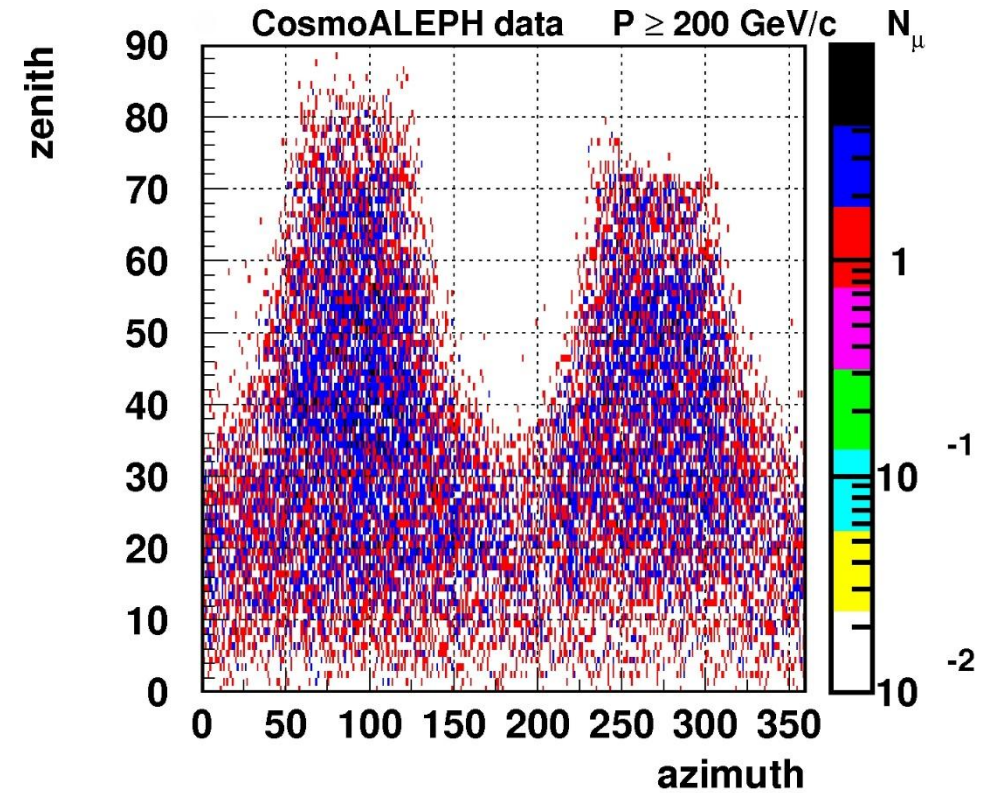
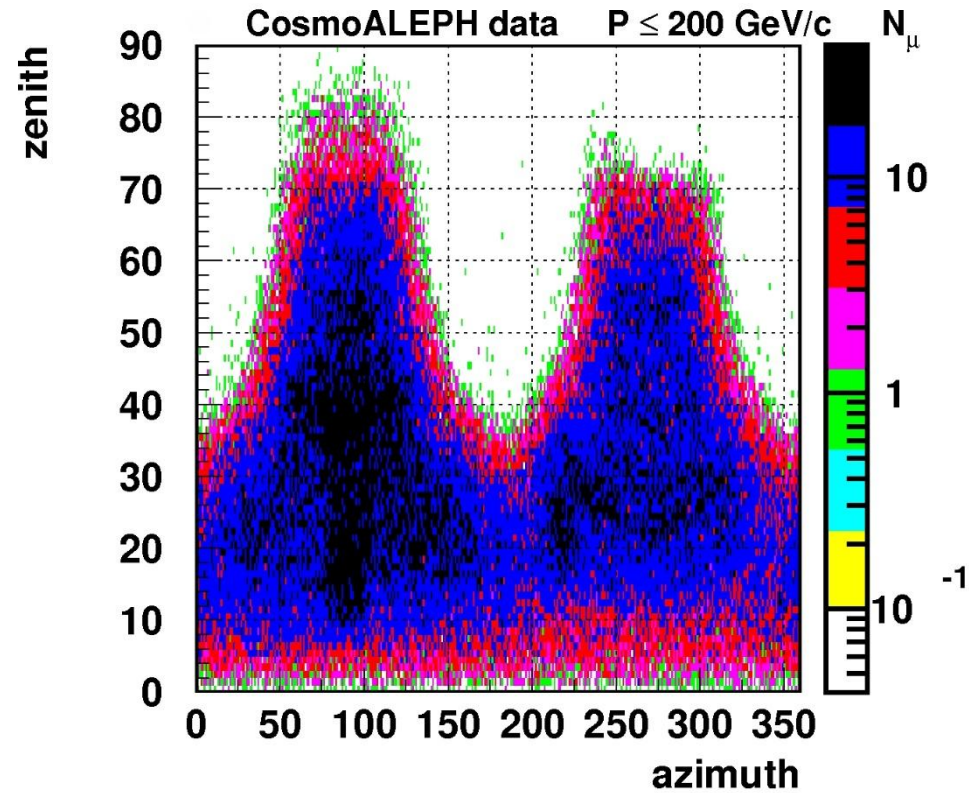
My work with cosmic ray muons



[More information](#)



My work with cosmic ray muons



Observations:

more muons through the access shafts
less muons from the jura mountain

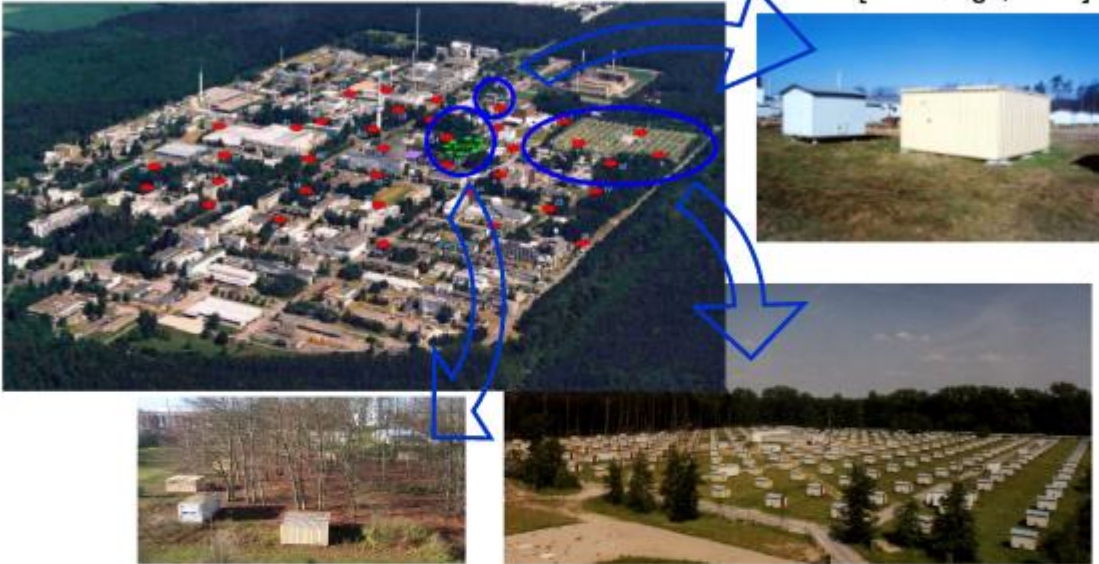
[More information](#)



The KASCADE-GRANDE Experiment


KASCADE-Grande
 = Karlsruhe Shower Core and Array Detector + Grande

[A. Haungs, 2003]

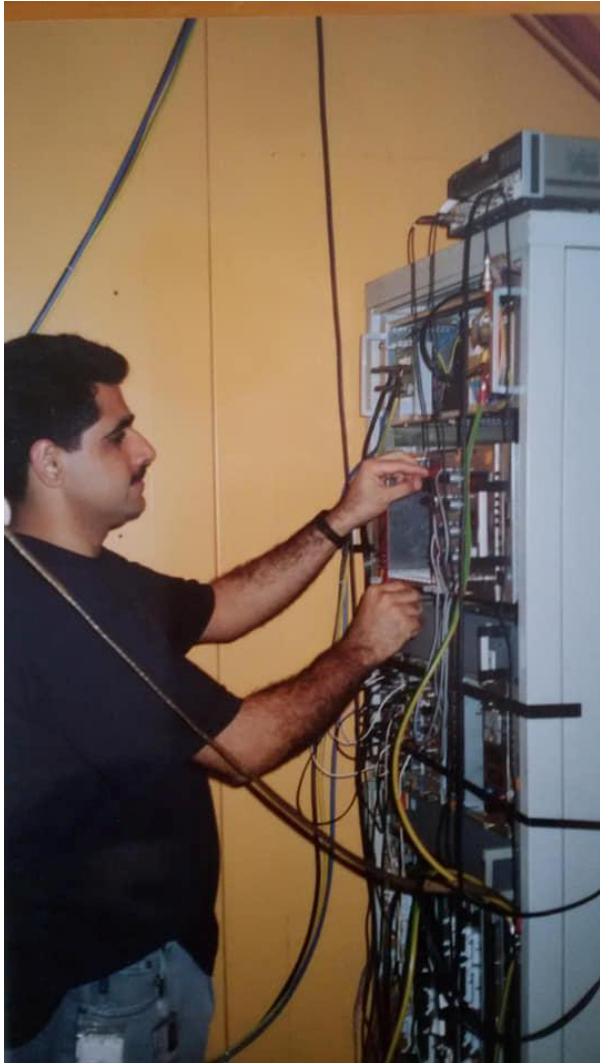


Detector	Particle	Area[m ²]	Threshold[MeV]
Grande Array (plastic scintillator)	$e/\gamma + \mu$	370	5
Piccolo Array (plastic scintillator)	$e/\gamma + \mu$	80	5
KASCADE Array (liquid scintillator)	e/γ	490	5
	μ	622	230
Muon Tracking Detector (streamer tubes)	μ	128x4	800
Central Detector			
Calorimeter (liquid ionisation chambers)	h	304x8	50000
Top Cluster (plastic scintillator)	e/γ	23	5
Top Layer (liquid ionisation chambers)	$e/\gamma + \mu$	304	5
Trigger Layer (plastic scintillator)	μ	208	490
Multiwire Proportional Chambers	μ	129x2	2400
Limited Streamer Tubes	μ	250	2400

- location: Karlsruhe, Germany
- array: surface detectors and muon tunnel
- measurements: electron and muon events
- analysis: particle number densities, mass and energy distribution



The KASCADE-GRANDE Experiment



**Summer 2003:
Calibration of the sampling
calorimeter at CERN**

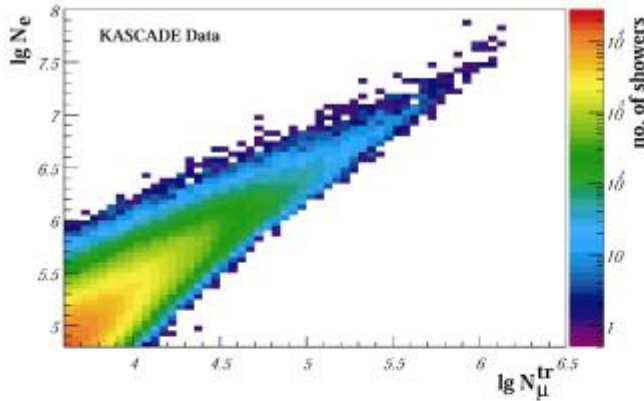
[S. Plewnia, Th. Berghoefer, J. Bluemer, P. Buchholz, J. Engler, N.O. Hashim, J.R. Hoerandel, R. Lixandru, J. Milke, W. Walkowiak, J. Wochele. A sampling calorimeter with warm-liquid ionization chambers. Nuclear Instruments and Methods. A556 \(2006\) 422 – 432](#)



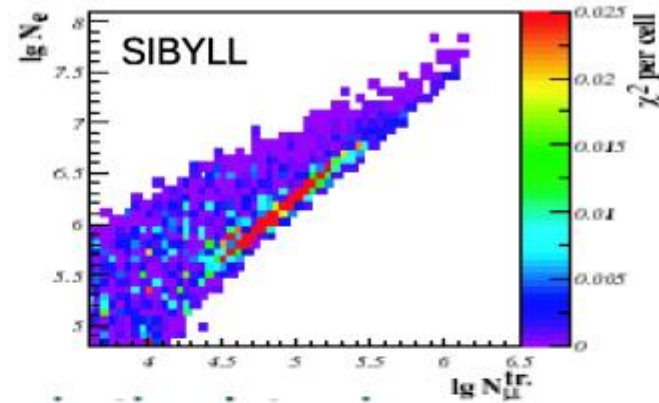


The KASCADE-GRANDE Experiment

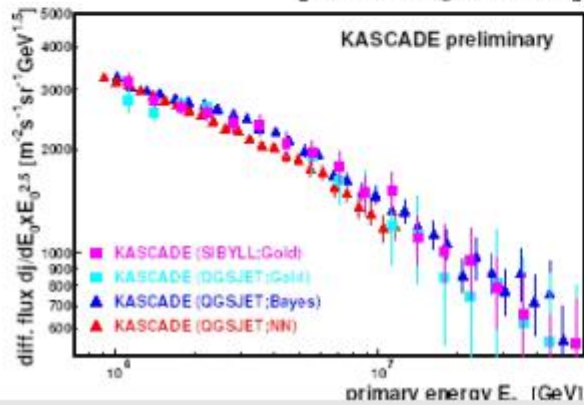
[A. Haungs, 2003]



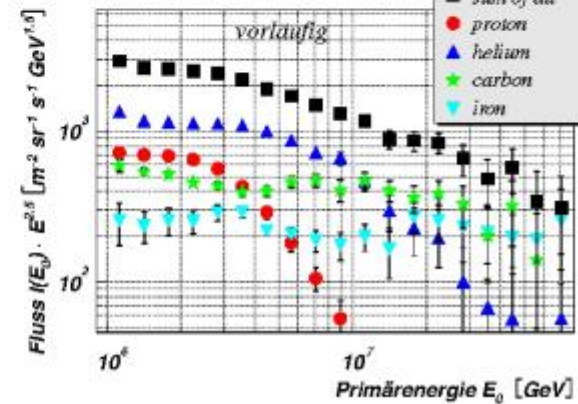
[A. Haungs, 2003]



[A. Haungs, 2003]



[A. Haungs, 2003]





The Pierre Auger Observatory

Auger North Lamar, Colorado, USA

**northern
hemisphere**

~20000 km²



**The world's largest
Astro-Particle Physics Experiment**

3000 km²

Auger South Malargüe, Argentina

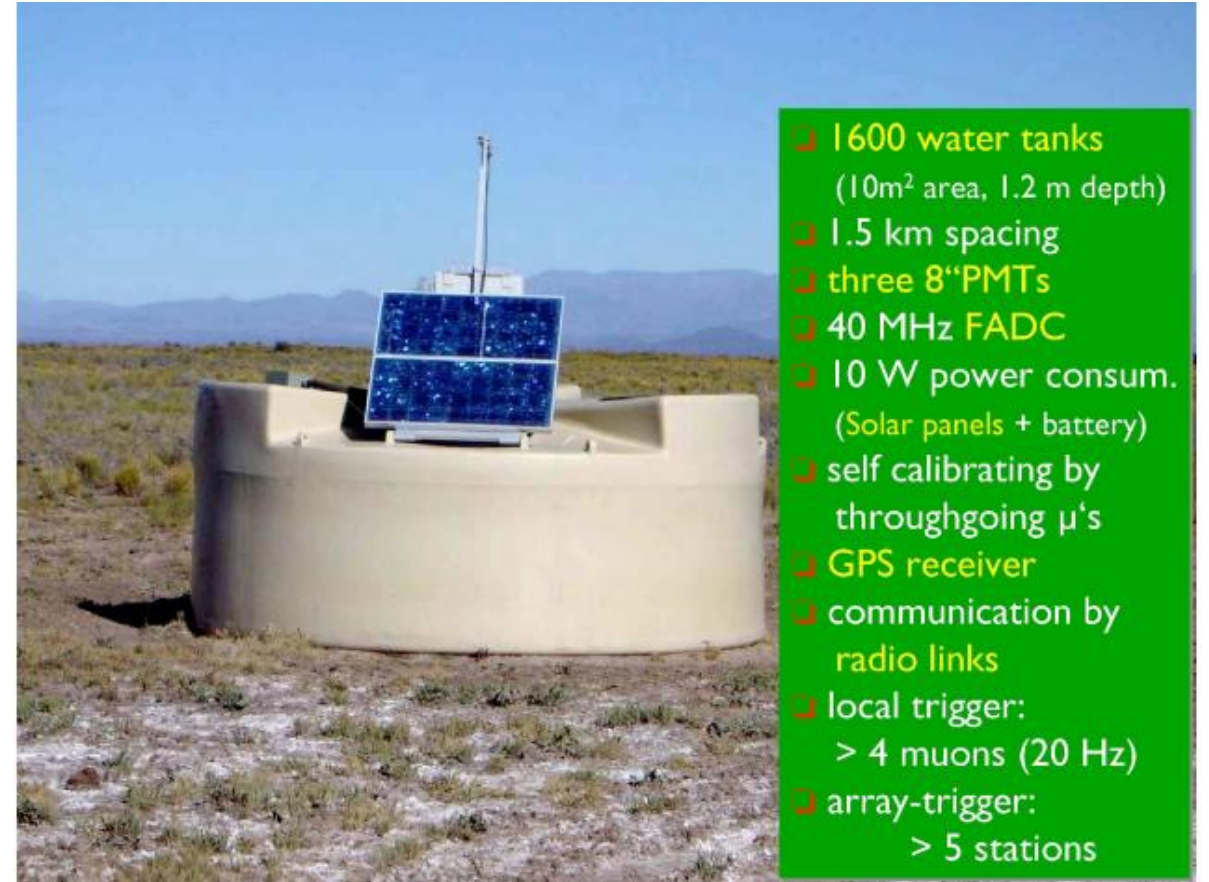
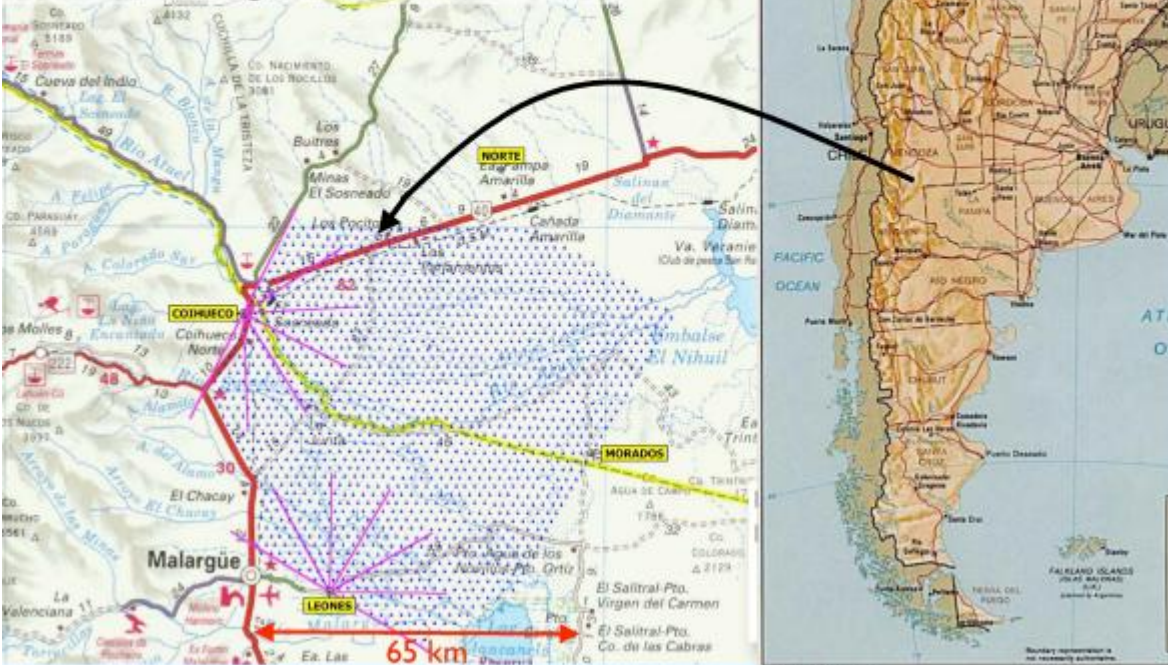
**southern
hemisphere**



The Pierre Auger Observatory

Southern Site

Pampa Amarilla; Province of Mendoza
3000 km², 875 g/cm², 1400 m



- ❑ 1600 water tanks
(10m² area, 1.2 m depth)
- ❑ 1.5 km spacing
- ❑ three 8" PMTs
- ❑ 40 MHz FADC
- ❑ 10 W power consum.
(Solar panels + battery)
- ❑ self calibrating by
throughgoing μ 's
- ❑ GPS receiver
- ❑ communication by
radio links
- ❑ local trigger:
> 4 muons (20 Hz)
- ❑ array-trigger:
> 5 stations

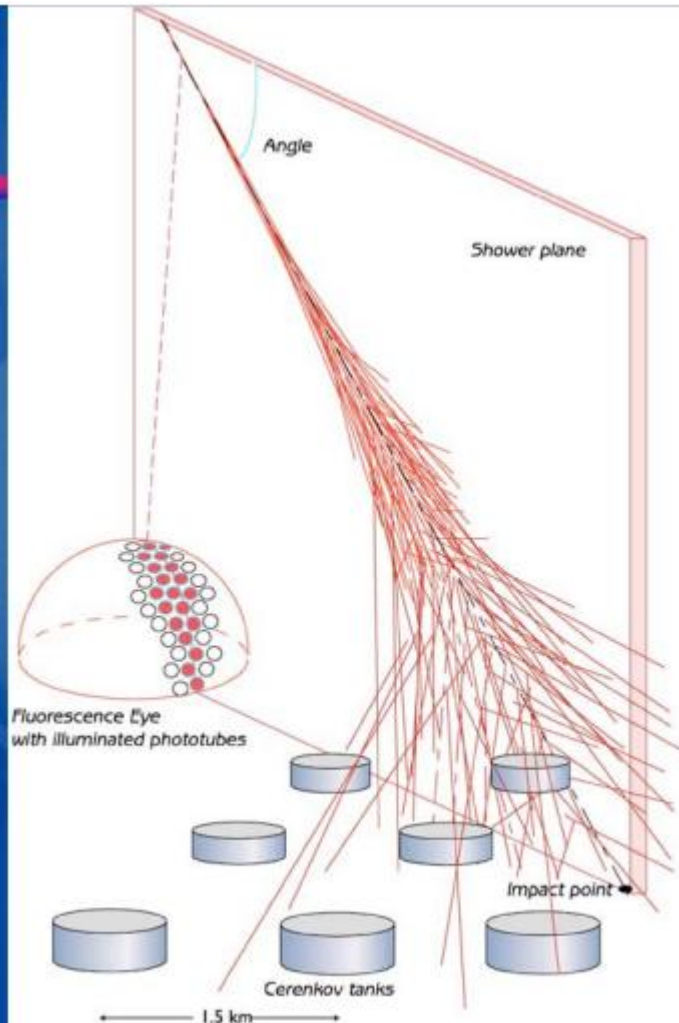


The Pierre Auger Observatory

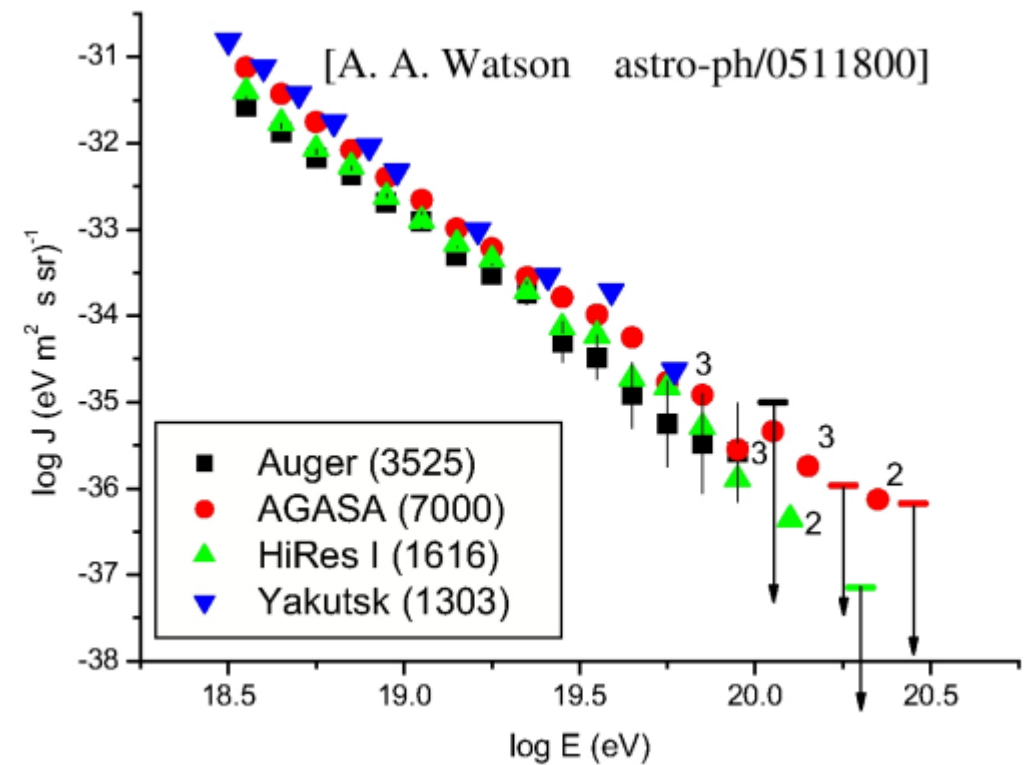
Idea of Hybrid Experiment

- optimal resolution in E , θ , m ...
- independent techniques \Rightarrow control of systematics
- ☞ fluorescence detector: 'model independent' E -meas.
- ☞ surface detector: 100% duty cycle

\Rightarrow Data of high quality & statistics



Some of the early detections of UHECR at the Pierre Auger Observatory





Cosmic Ray Muon Physics at Kenyatta University



Cosmic Ray Muon Work at Kenyatta University



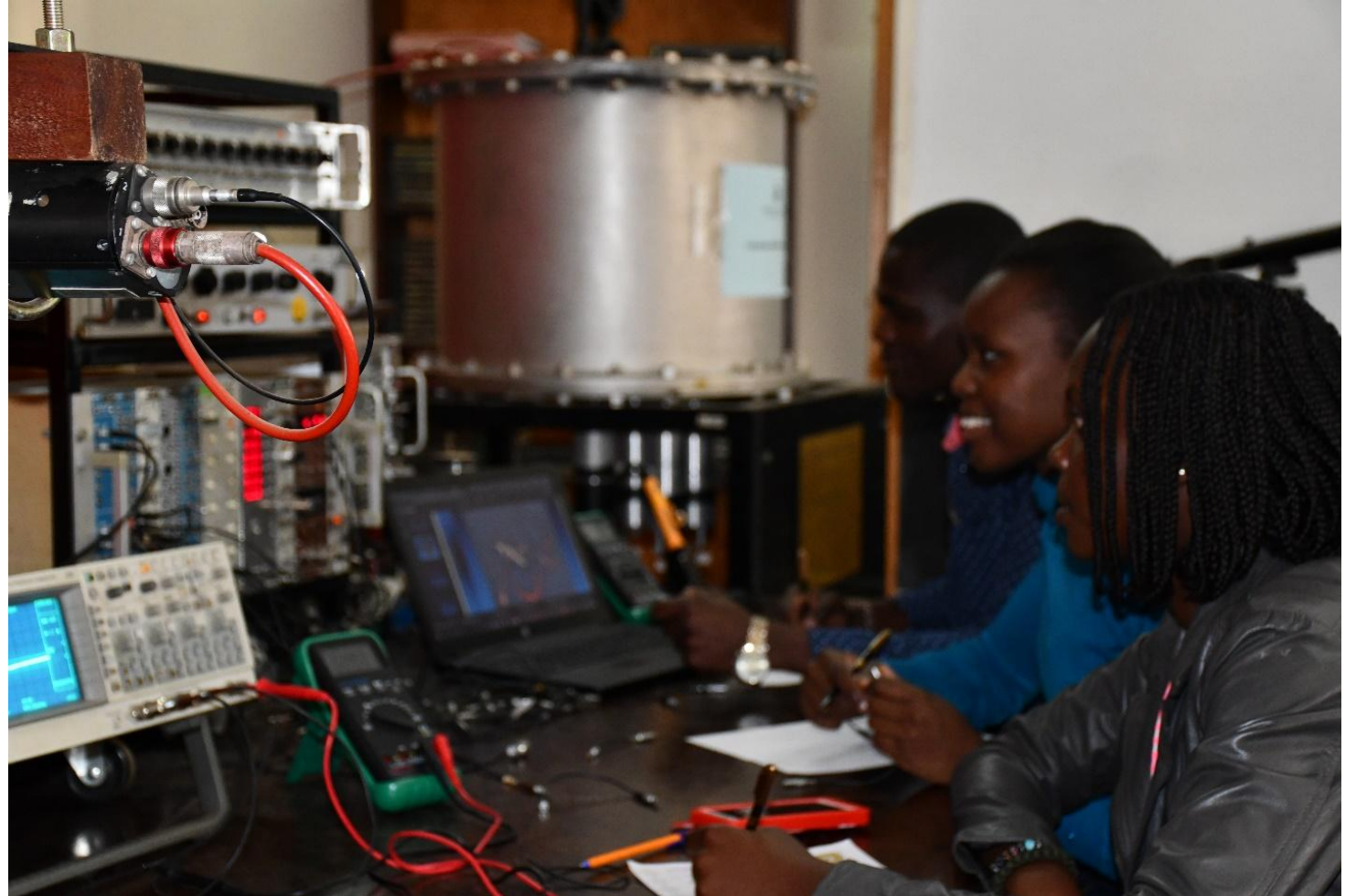
"We are collecting muons from cosmic ray air showers and try to understand their flux!"

- Detection and measurement of cosmic ray muons
- Monte Carlo simulations
- Cosmic ray muon coincidences
- Variation of cosmic ray muon flux with zenith angle
- Outreach – Engaging the Youth



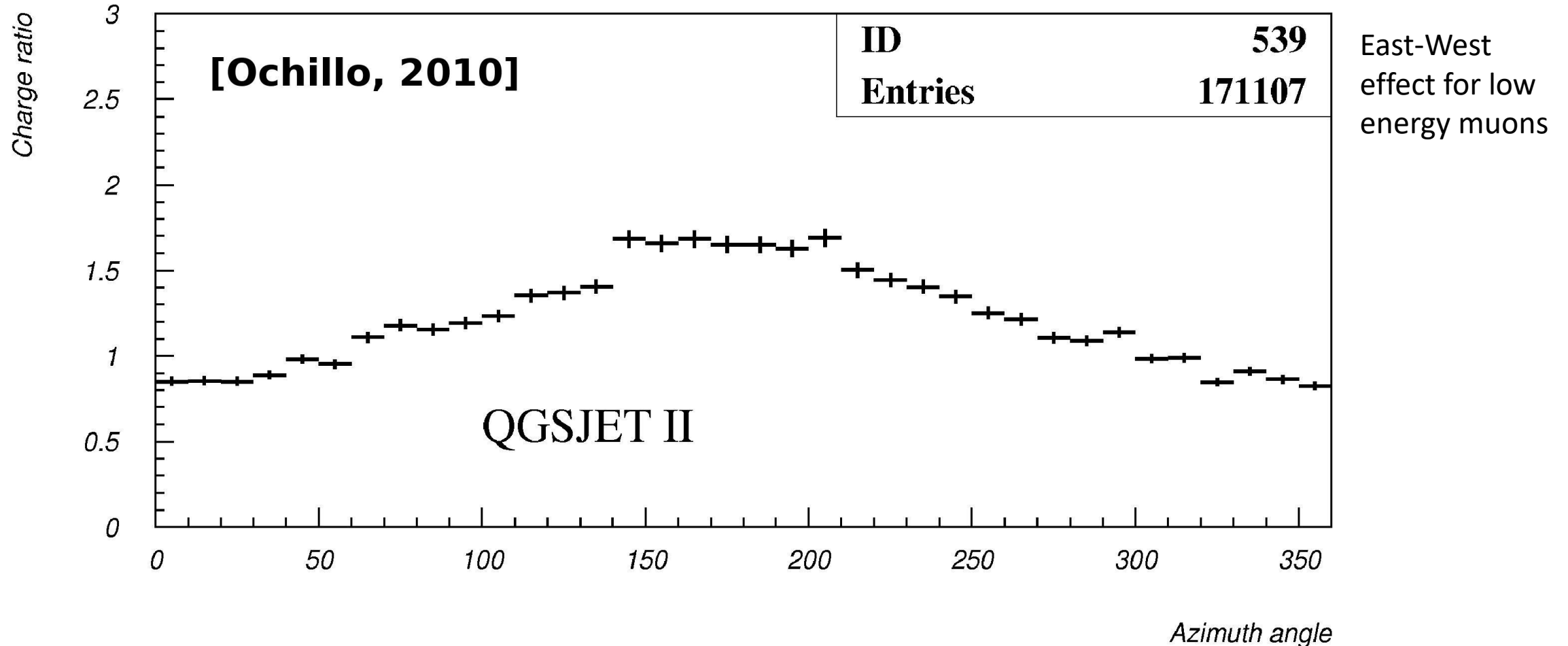
Experimental Facilities

- Detectors
 - ✓ Plastic Scintillators
 - ✓ NaI(Tl)
- NIM crates with
 - ✓ Amplifiers
 - ✓ Discriminators
 - ✓ Logic gates
 - ✓ Counters



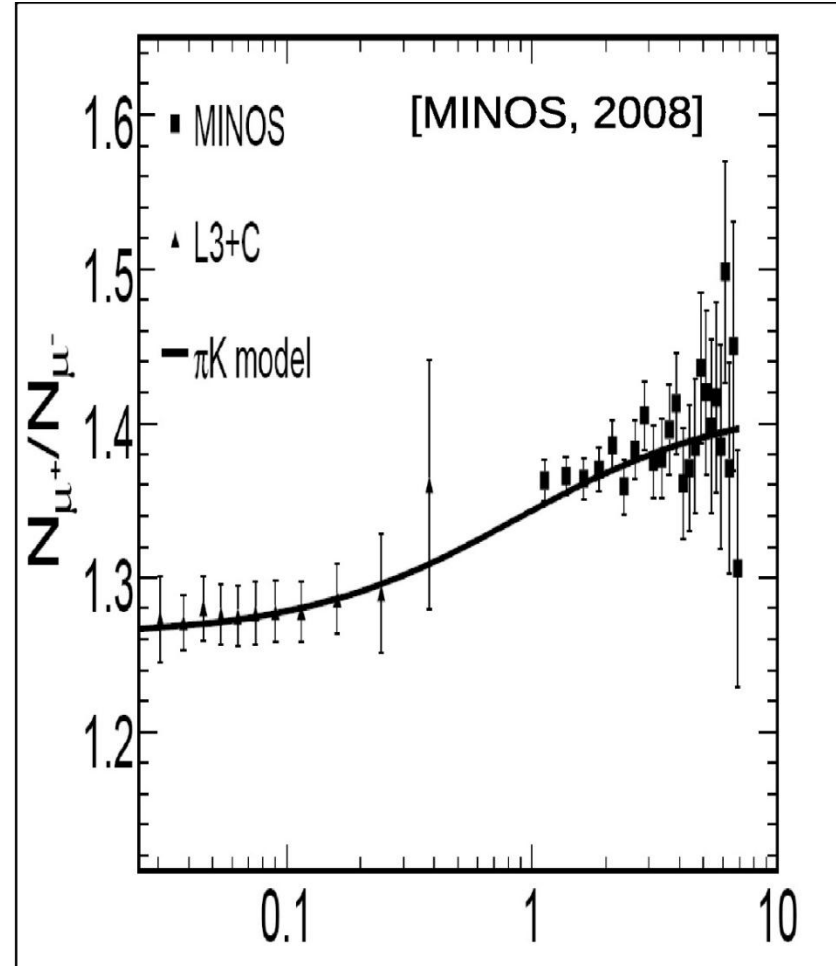
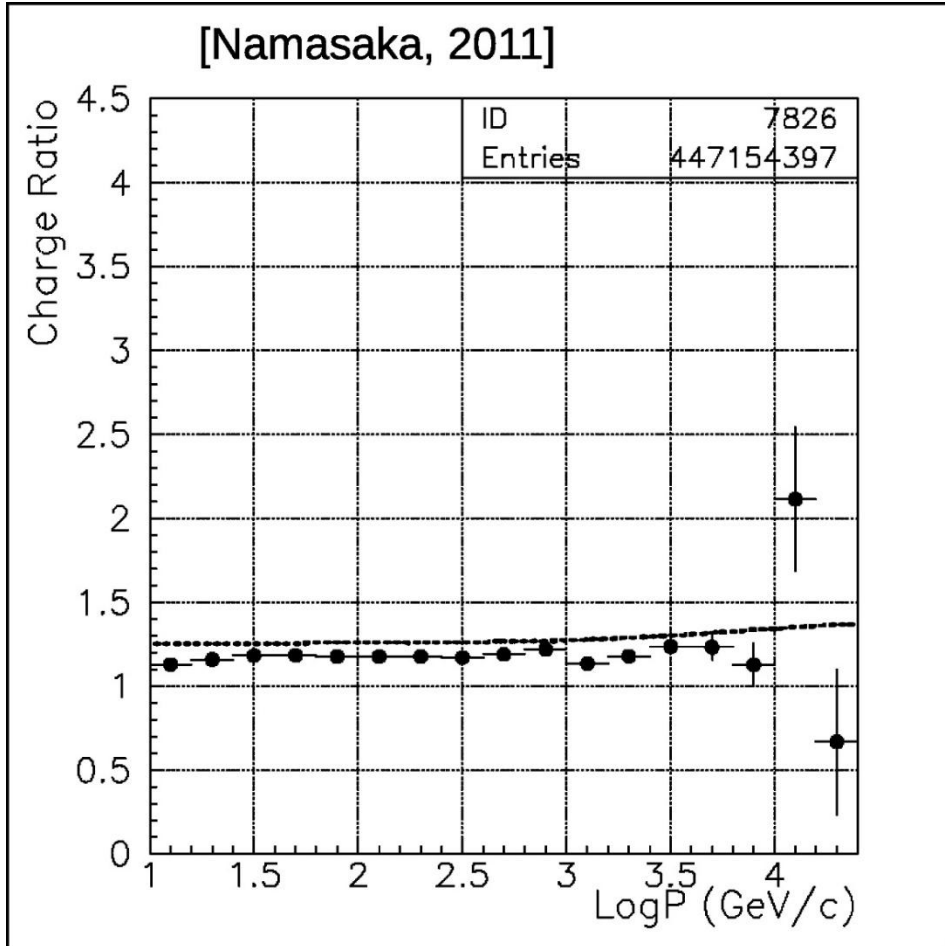


Students' work at KU – Monte Carlo simulation of extensive air showers





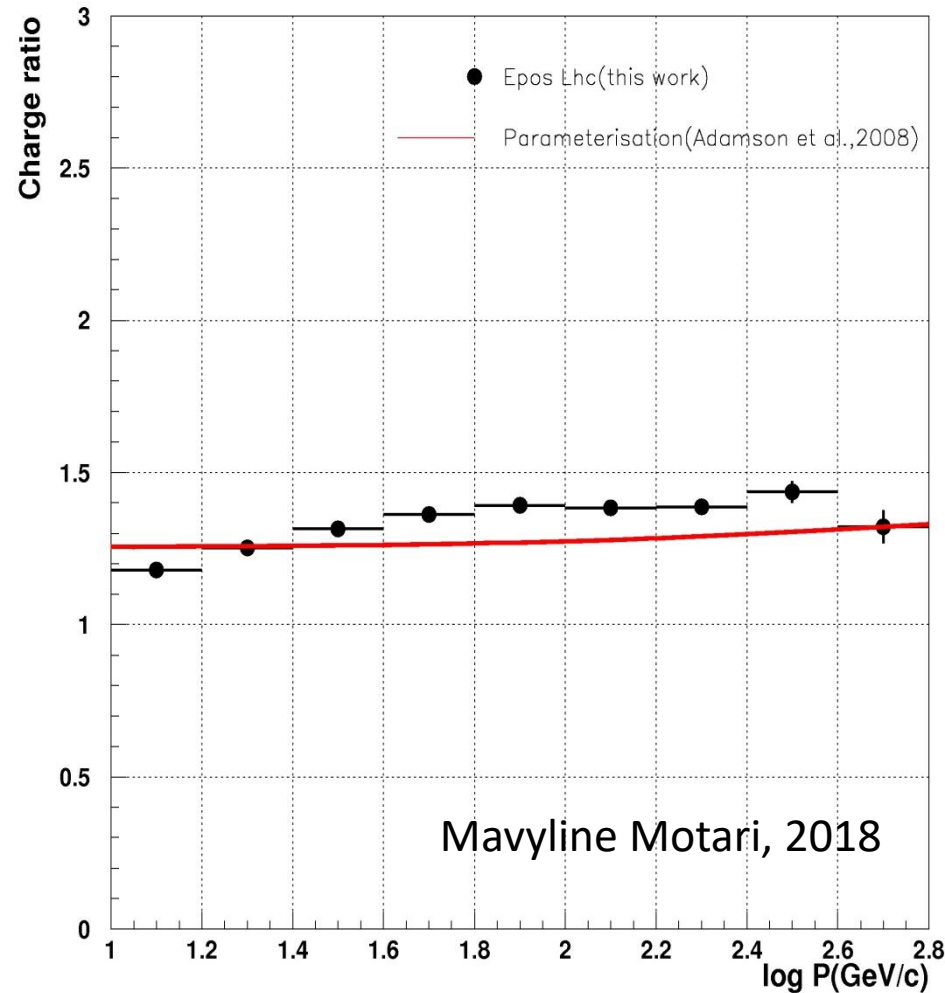
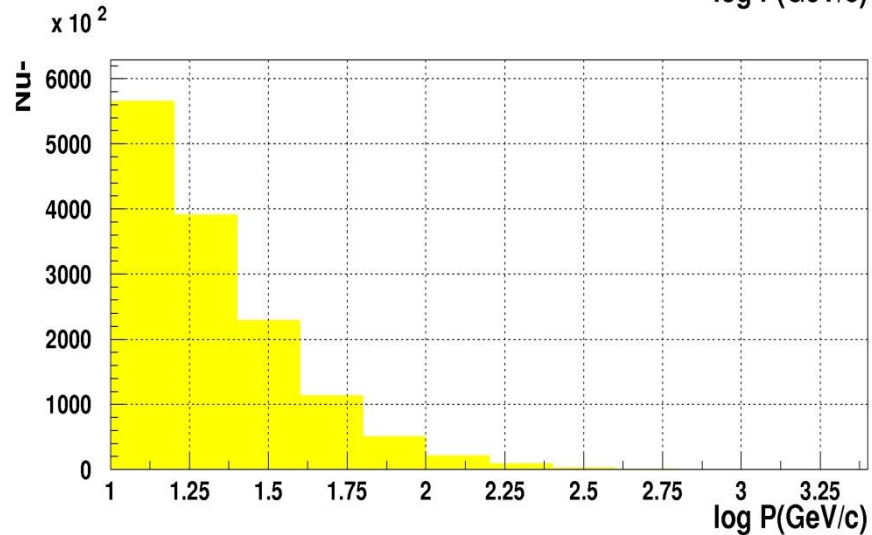
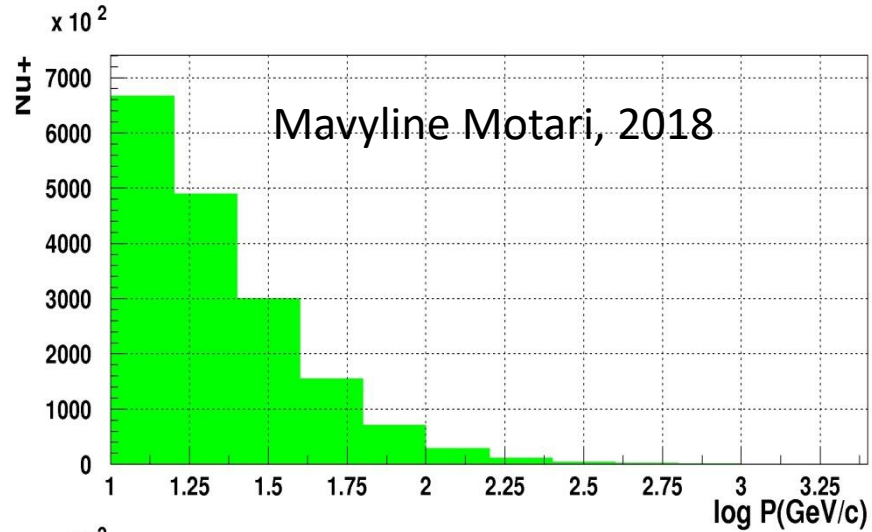
Students' work at KU – Monte Carlo simulation of extensive air showers



Kaon contribution to the cosmic ray muon charge ratio at high energies



Students' work at KU – Monte Carlo simulation of extensive air showers



Extensive Air Showers (EAS) simulated using CORSIKA

Proton primary

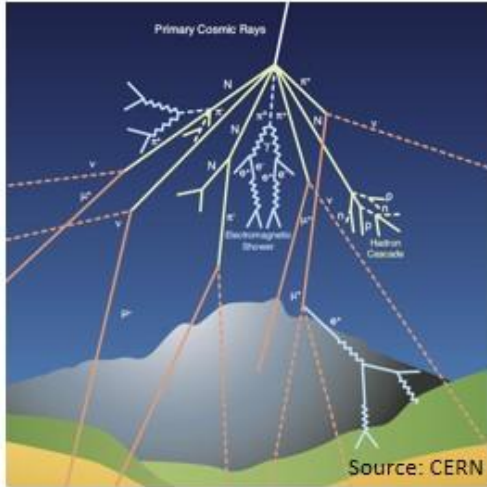
Charge ratio of cosmic ray muons computed



Measurement of Cosmic Ray Muons at Kenyatta University

Nadir Hashim¹, Claus Grupen², Naftali Kimani¹, Samuel Mburu¹, Peninah Mugo¹, Livingstone Ochilo³

¹Kenyatta University, KENYA. ²Siegen University, GERMANY. ³Jaramogi Oginga Odinga University of Science and Technology, KENYA.



Source: CERN

General introduction

- Primary composition – 85% protons, 12% He, 3% Fe ...
- Production of Extensive Air Showers (EAS)
- Cosmic ray muons – a robust component of EAS

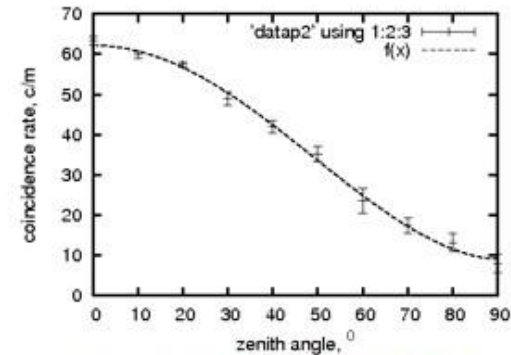
Experimental facility

- Water tank
- Plastic scintillators
- Photo-multiplier tubes
- NIM modules for signal processing

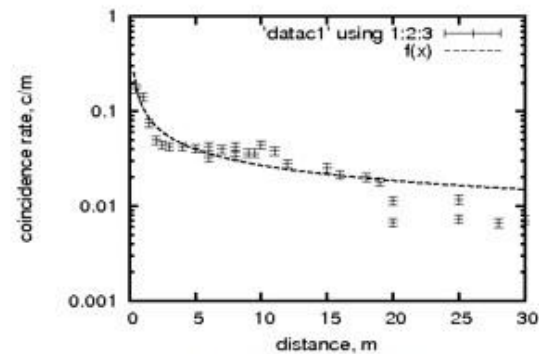


Experimental set-up for the detection and measurement of cosmic ray muons

Preliminary results



Variation of cosmic ray muon flux with zenith angle



Variation of cosmic ray muon coincidences with distance between detectors

- ✓ Plastic scintillators operated in coincidence
- ✓ Zenith angle varied from 0 to 90 degrees
- ✓ Data is consistent with \cos^2 zenith angle
- ✓ Distance varied from 0 to 30 m
- ✓ Data is consistent with the NKG function

Corresponding Author

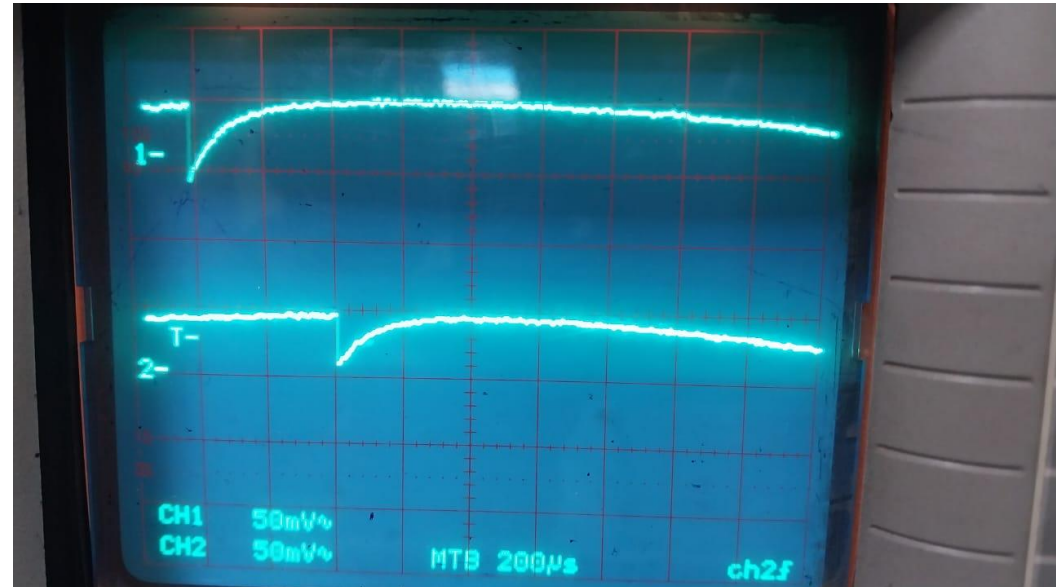
hashim.nadir@ku.ac.ke



Cosmic Ray Muon Work at Kenyatta University



Two sodium iodide – NaI(Tl) detectors were used for the detection and measurement of cosmic ray muons



Two cosmic ray muons each passing through the two detectors, separated by some 400 micro seconds. They are clearly NOT in coincidence. They are unlikely to be from the same shower



Cosmic Ray Muon Work at Kenyatta University

The data was fitted with the following function,

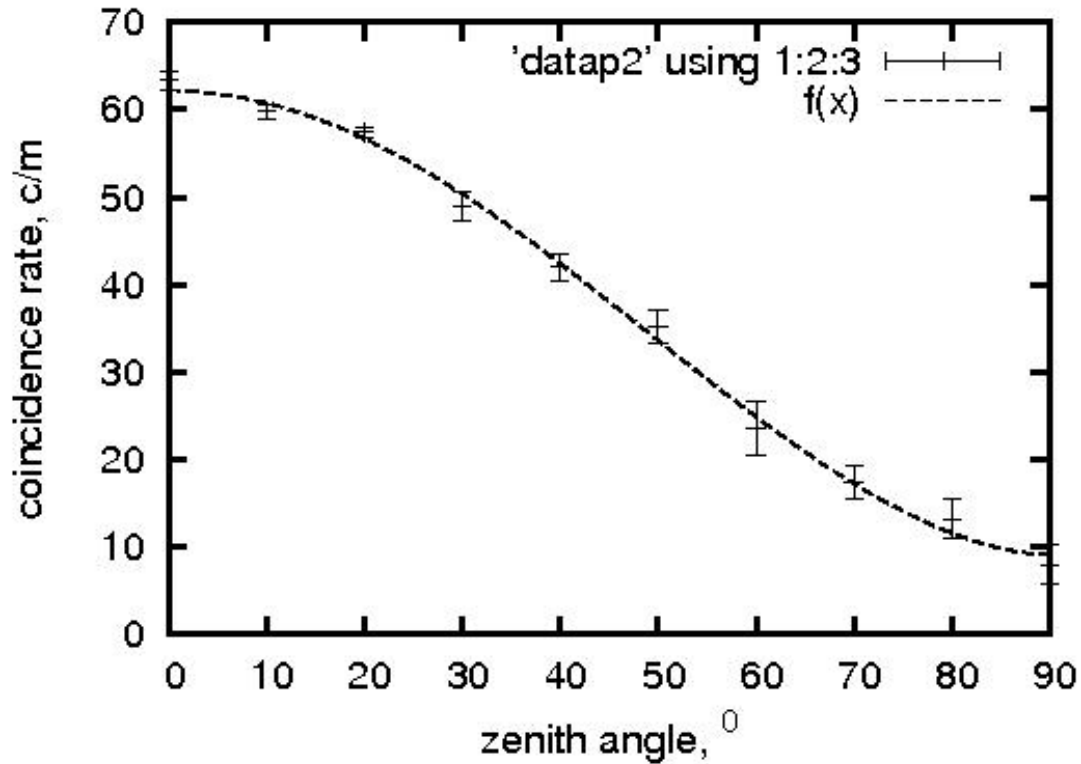
$$I(\theta) = a \cos^b(\theta) + c$$

The fit results are as follows

Final set of parameters		Asymptotic Standard Error	
=====		=====	
a	= 53.0492	+/- 1.237	(2.331%)
b	= 1.74951	+/- 0.1098	(6.274%)
c	= 9.12126	+/- 1.085	(11.89%)

correlation matrix of the fit parameters:

	a	b	c
a	1.000		
b	-0.302	1.000	
c	-0.760	0.720	1.000



Jackson Kisingu



Cosmic Ray Muon Work at Kenyatta University



Contents lists available at [ScienceDirect](#)

MethodsX

journal homepage: www.elsevier.com/locate/methodsx



Lateral distribution cosmic ray muon coincidences up to 36 m

Veronica N. Kihagi^{a,*}, Samuel M. Chege^a, Nadir O. Hashim^a, Naftali K. Kimani^a,
Claus Grupen^b

^aPhysics Department, Kenyatta University, P.O. Box 43844 Nairobi, Kenya

^bUniversity of Siegen, Germany



Veronica N. Kihagi, Samuel M. Chege, Nadir O. Hashim, Naftali K. Kimani, Claus Grupen, Lateral distribution cosmic ray muon coincidences up to 36 m. *MethodsX*, Volume 12, 2024, 102715, ISSN 2215-0161,

<https://doi.org/10.1016/j.mex.2024.102715>

https://www.sciencedirect.com/science/article/pii/S2215016124001699?ssrnid=4727561&dgcid=SSRN_redirect_SD

ARTICLE INFO

Method name:
Two-fold coincidence technique

Keywords:
Muons
Lateral distribution
Two-fold coincidence
Hourly variations
EPOS LHC model

ABSTRACT

Primary cosmic ray particles comprise about 85 % protons, 12 % helium, 3 % iron, and heavier elements. These particles interact with the Earth's atmosphere, generating the Extensive Air Showers (EAS). Among the particles produced are pions and kaons, which decay into cosmic ray muons. In this research, the lateral distribution of cosmic ray muons was measured using two-fold coincidences. Four NaI (TI) detectors and the associated electronics were used in the measurements of cosmic ray muons. The detectors were positioned from 0 to 36 m at regular intervals. The muon count rate was observed to decrease as the distance between the detectors increased. The measurements were fitted to the Nishimura–Kamata–Greisen (NKG) function to analyze the lateral distribution. Monte Carlo (MC) simulations of EAS were performed using the Cosmic Ray Simulations for the KASCADE Grande (CORSIKA) program. The simulations made use of EPOS and GHEISHA models for high and lower energies respectively.

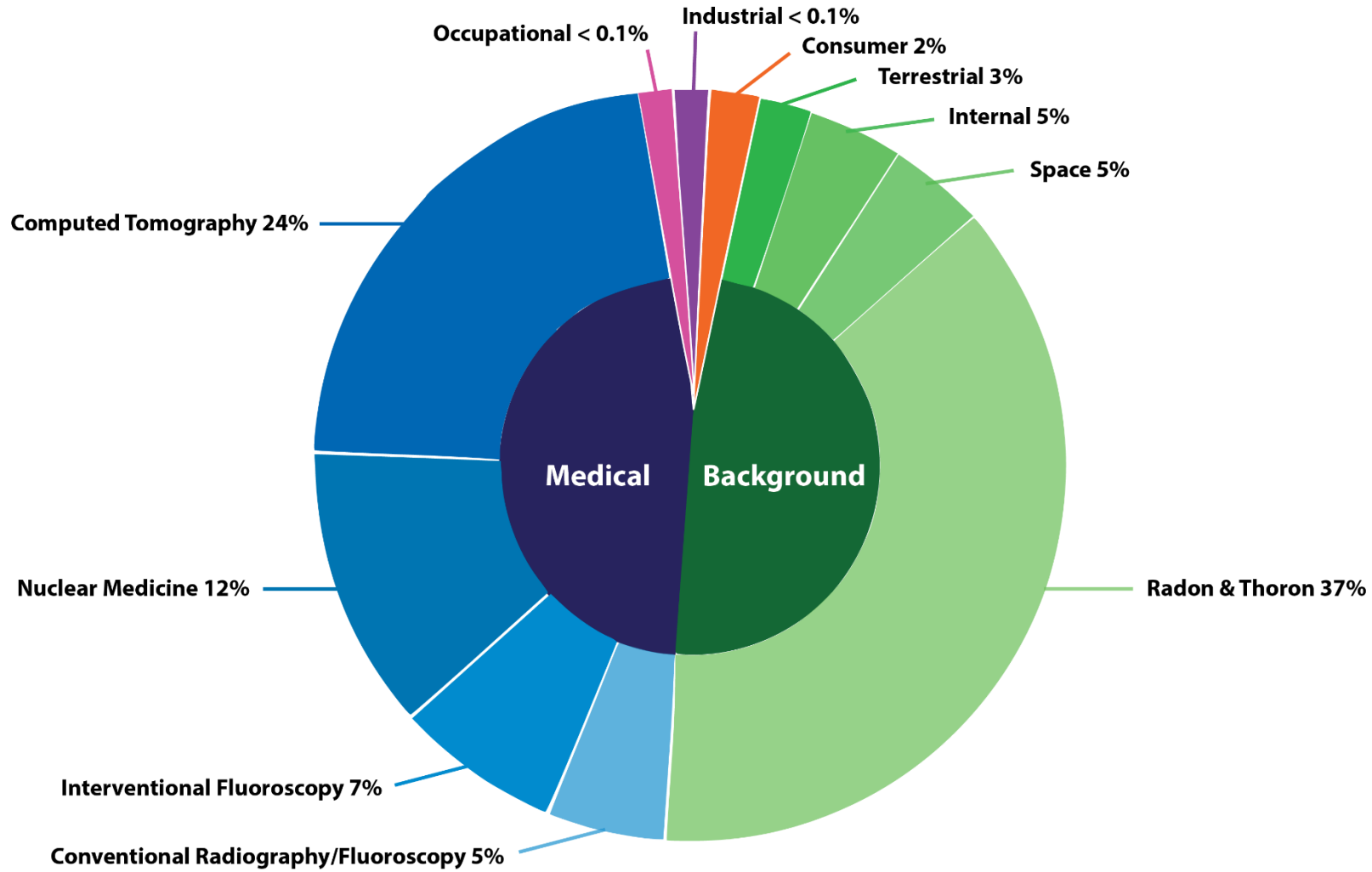
- The measurements for the two-fold coincidence are consistent with the NKG function.
- The simulated and measured data were found to be in agreement.
- The knowledge gained from the lateral distribution of cosmic ray muons is essential for the understanding of the development of extensive air showers.



Cosmic Radiation in the Aviation Industry



Sources of Radiation Exposure



Average Annual Radiation Dose

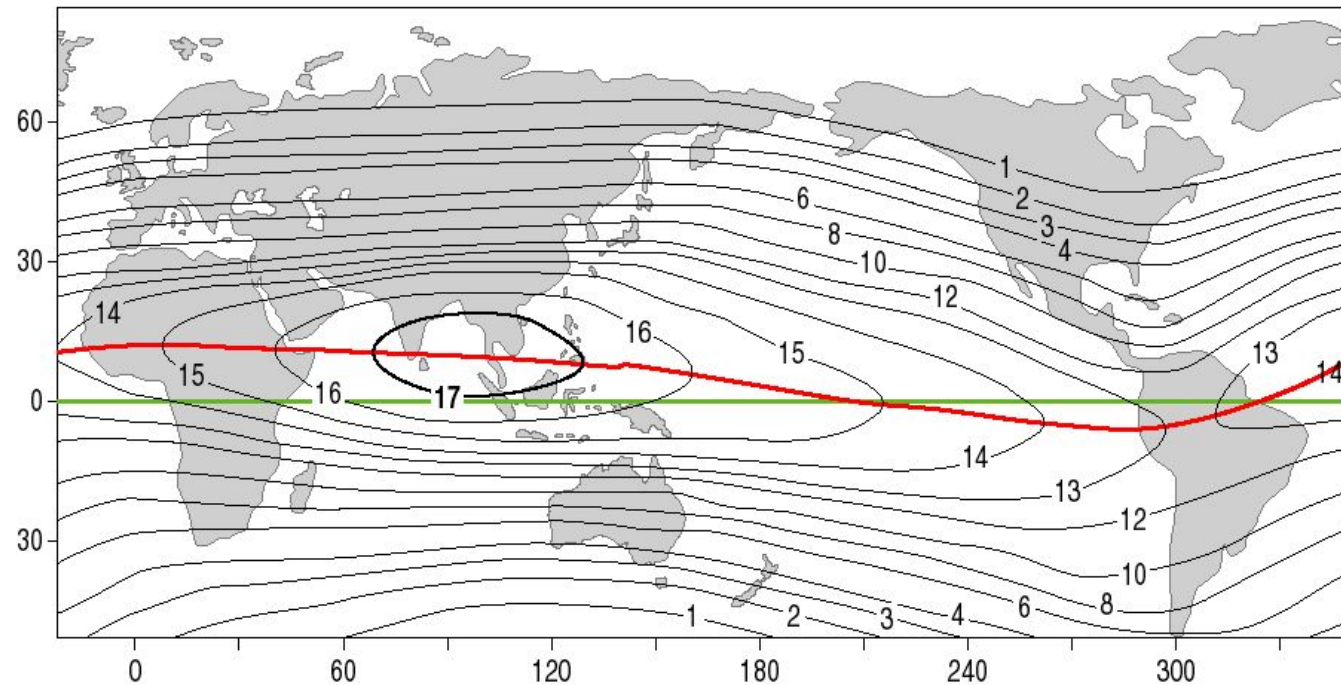
Sources	Radon & Thoron	Computed Tomography	Nuclear Medicine	Interventional Fluoroscopy	Space	Conventional Radiography/Fluoroscopy	Internal	Terrestrial	Consumer	Occupational	Industrial
Units											
mrem (United States)	228 mrem	147 mrem	77 mrem	43 mrem	33 mrem	33 mrem	29 mrem	21 mrem	13 mrem	0.5 mrem	0.3 mrem
mSv (International)	2.28 mSv	1.47 mSv	0.77 mSv	0.43 mSv	0.33 mSv	0.33mSv	0.29 mSv	0.21 mSv	0.13 mSv	0.005 mSv	0.003 mSv

(Source: National Council on Radiation Protection & Measurements, Report No. 160)



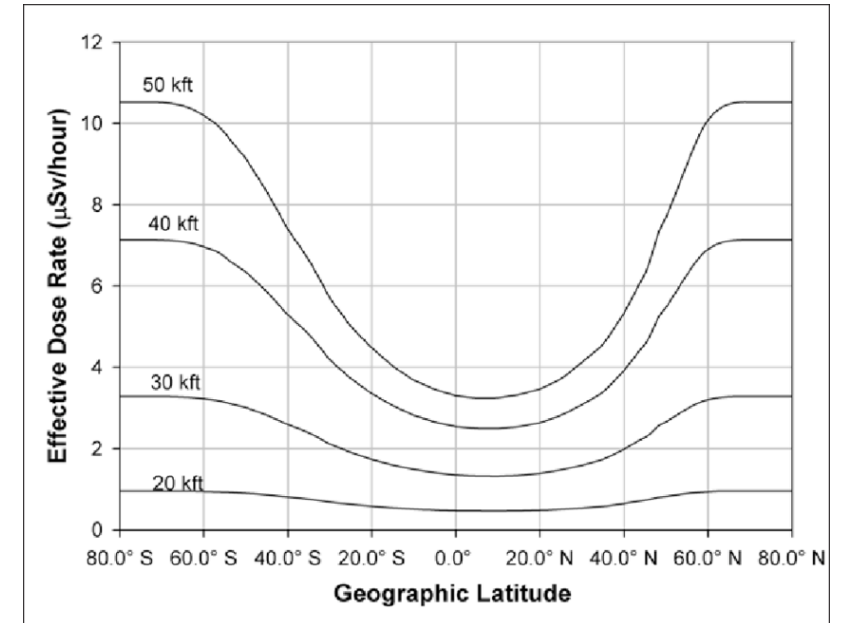
Human exposure to cosmic radiation

Vertical cutoff rigidity (GV) for Epoch 1980



Cutoff rigidity field (GV) ——— geomagnetic equator ——— geographic equator

Source: Jonah Williams

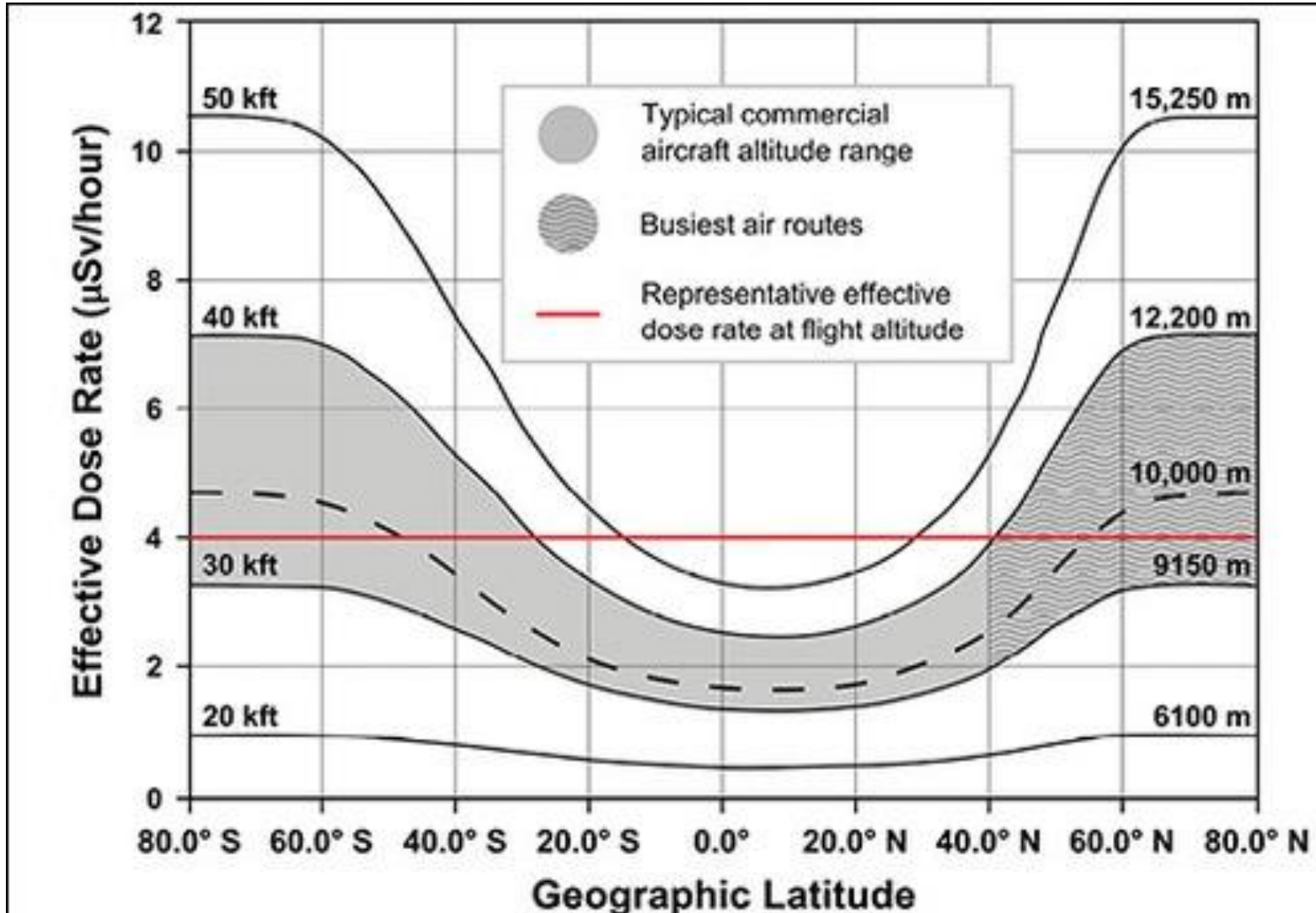


Note the lower dose rate about the equator

Source: Wallace Friedberg and Kyle Copeland



Human exposure to cosmic radiation



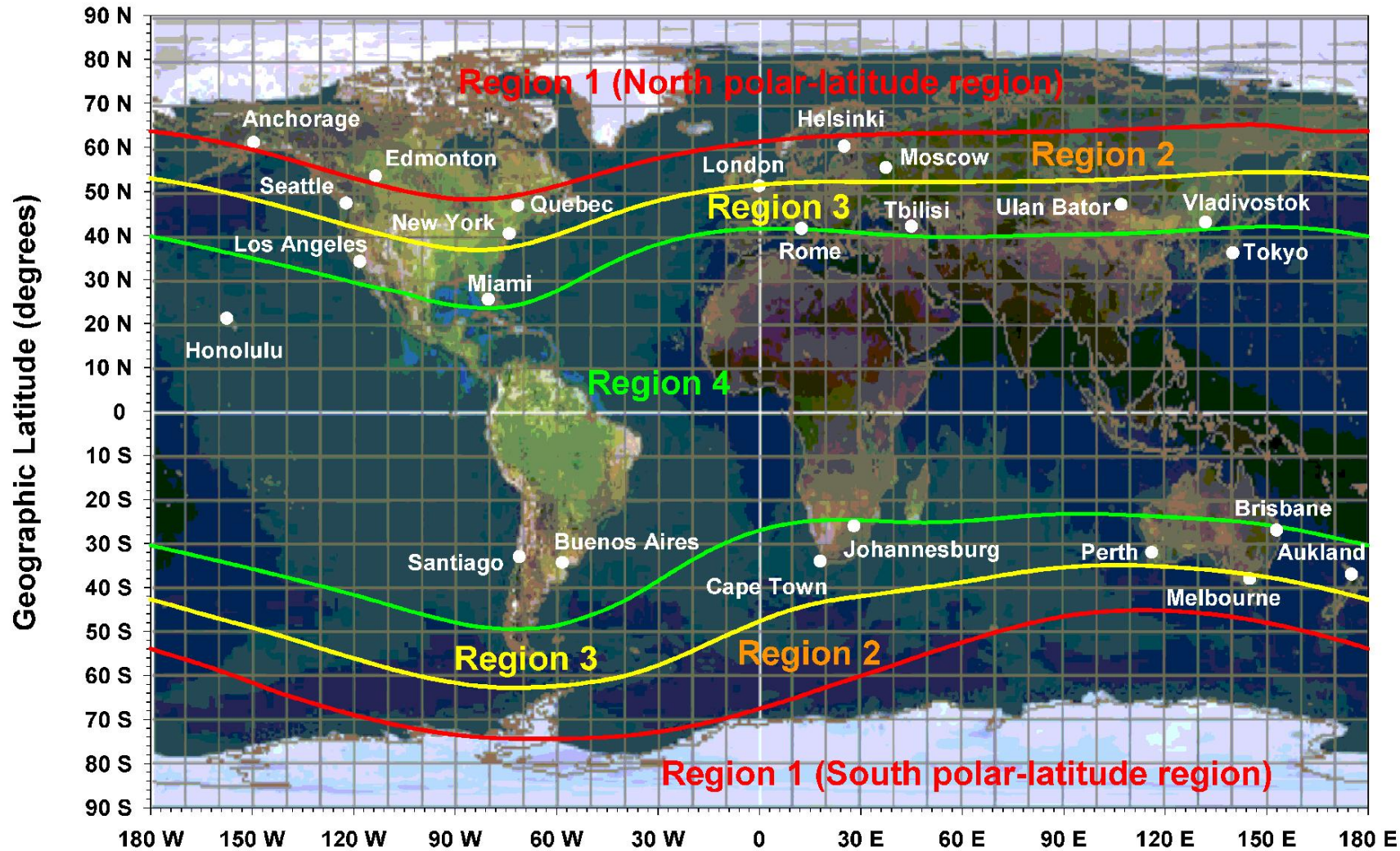
Note:

- ✓ Lower dose rate about the equator
- ✓ Limitation of flights away from the equator
- ✓ Limitation of flight at high altitudes
- ✓ Need for regulation of cosmic radiation dose for workers in the aviation industry

Source: Ulf Stahmer. American Association of Physics Teachers



Human exposure to cosmic radiation



Solar radiation map

Region 1 – North polar and South polar regions – highest dose

Region 4 – equatorial region – lowest dose

Source: Federal Aviation Authority

https://www.faa.gov/data_research/research/med_humanfacs/aero_medical/radiobiology/solarradiation/



Regulating exposure to cosmic radiation

Considerations

- **Flight routes**
- **Duration of flights**
- **Condition of the worker**



Regulating exposure to cosmic radiation

Dosimetry for exposures to cosmic radiation in civilian aircraft

KS ISO 20785-1:2012

Part 1 Conceptual Basis for Measurements

KS ISO 20785-2: 2011

Part 2 Characterization of instrument response

KS ISO 20785-3: 2015

Part 3 Measurements at Aviation Altitudes

KS ISO 20785-4: 2019

Part 4 Validation of Codes



**Kenya Bureau of
Standards**
Standards for Quality life

More Information:

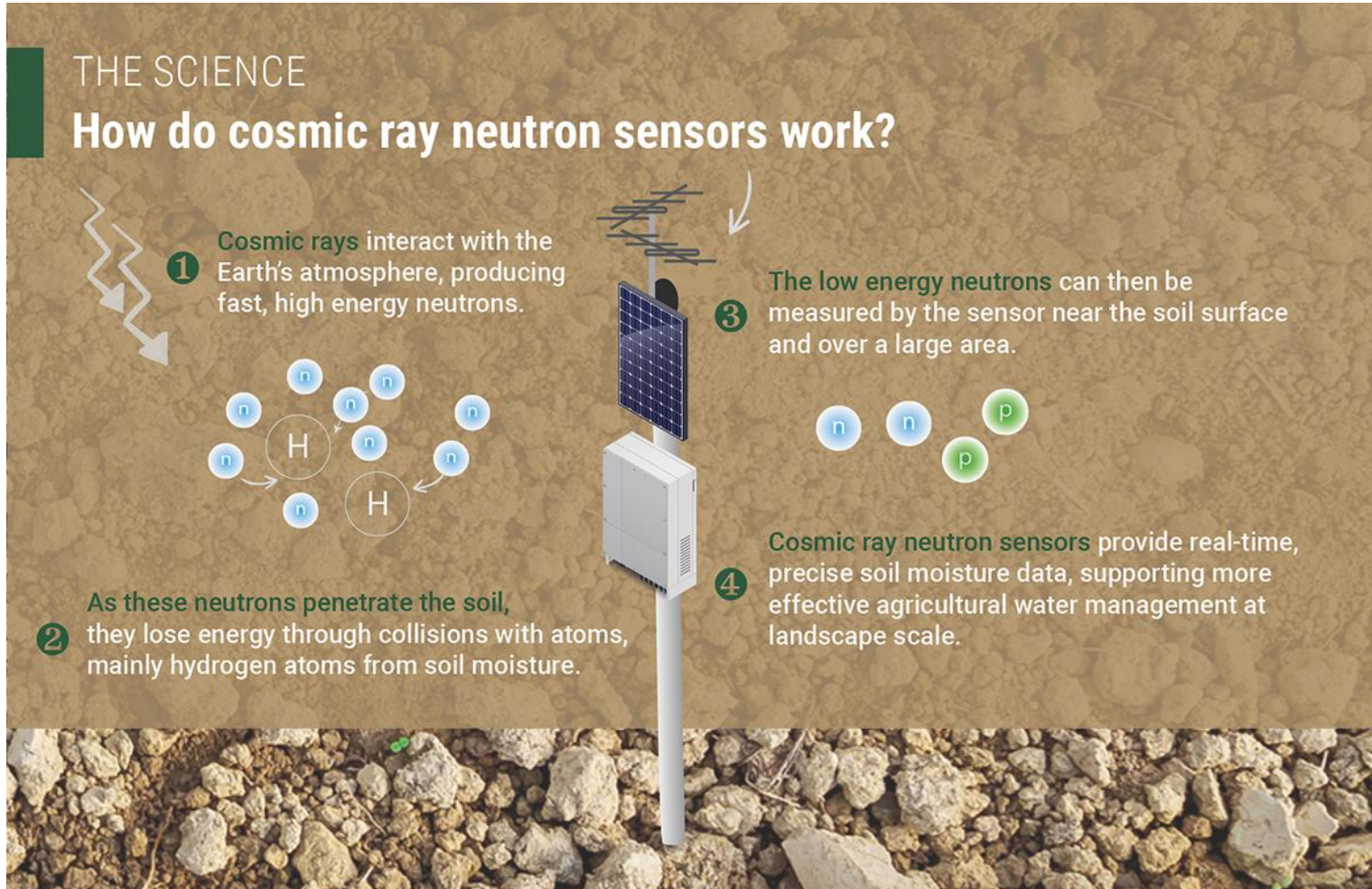
<https://www.kebs.org/>



Cosmic Ray Applications



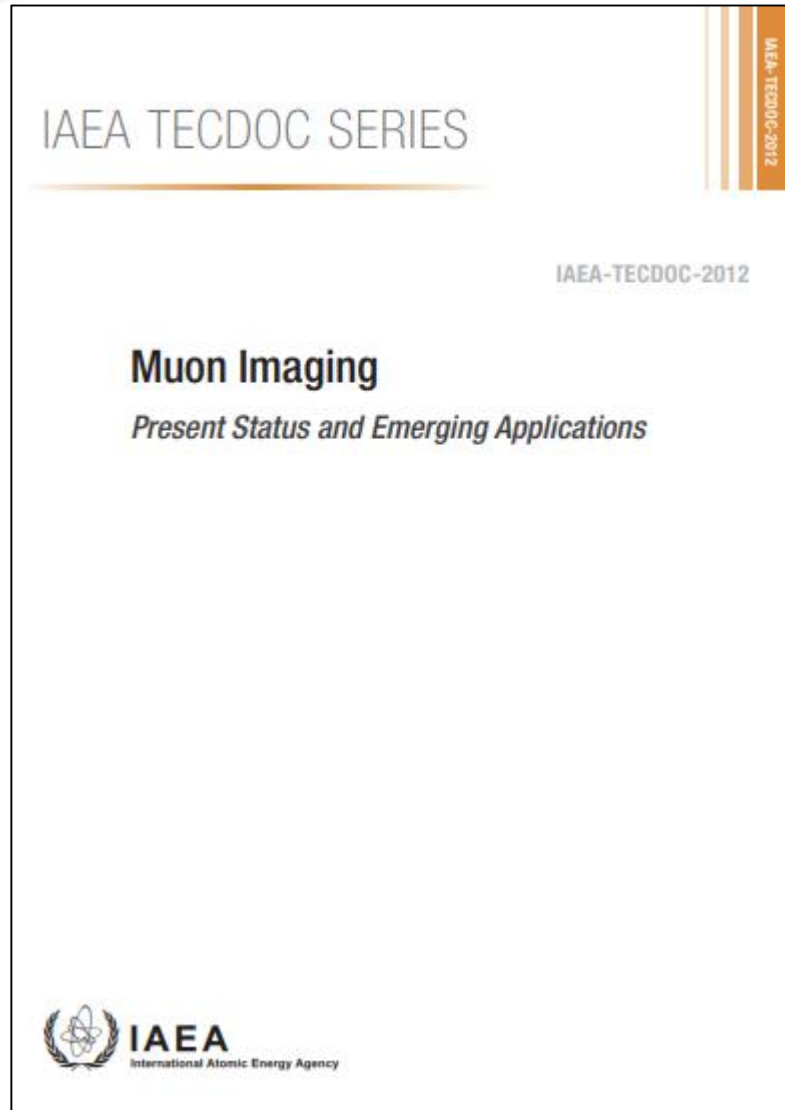
Cosmic Ray Neutron Sensor



[More information](#)



Muon Imaging



Applications:

- Civil Engineering and Underground Applications
- Industrial Applications
- Muon Transmission Radiography
- Volcanology
- Archaeology
- Security Applications (Border and Facilities)
- Nuclear Waste Characterization
- Nuclear Safeguards and Materials Control

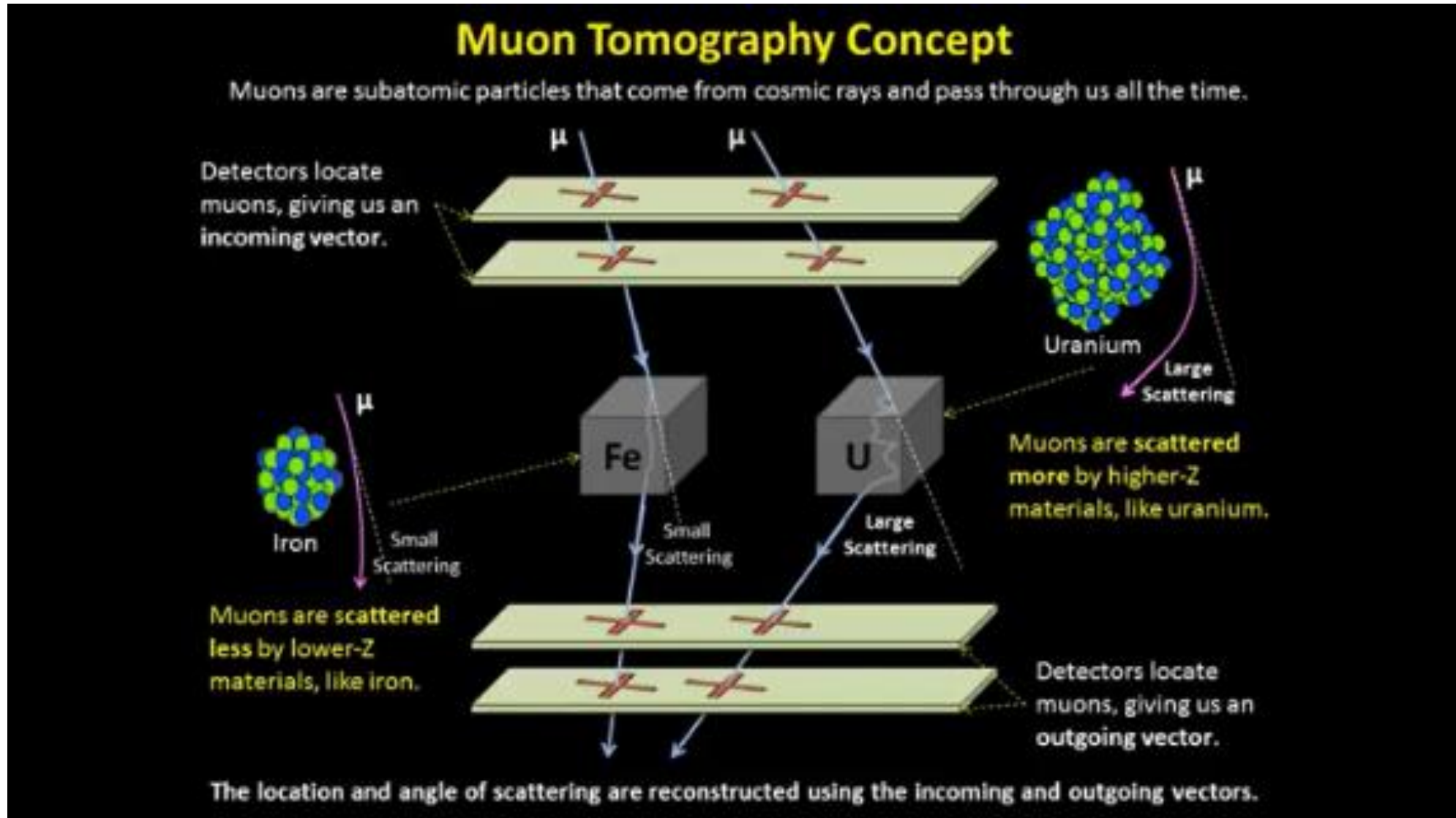
More Information:

IAEA-TECDOC-2012

<https://www-pub.iaea.org/MTCD/Publications/PDF/TE-2012web.pdf>



Muon Tomography



<https://research.fit.edu/hep/hohlmann-research-group/research/muon-tomography/>

MUON GEOTOMOGRAPHY

HOW DOES IT WORK?



Nature accelerates cosmic rays with up to 10,000 times more energy than the Large Hadron Collider (LHC)

By measuring the flux of cosmic ray radiation with underground sensors, we are able to construct a 3D model of the density of the earth above our sensors.

This allows us to identify and image dense mineral ore bodies, air voids & caves, tunnels, and other structures with a density contrast to the surrounding rock

COSMIC RAY MUONS

High energy protons impinging on the upper atmosphere produce pions, which can then decay to muons.



MUON FLUX IS UNIFORM ON SURFACE

Muons arrive at earth's surface from all directions and lose energy as they pass through the ground.



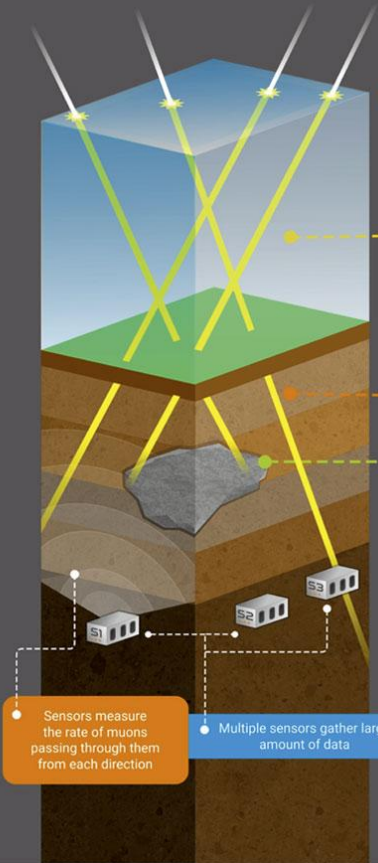
MUON SCATTERING

High energy muons undergo minimal scattering. They travel in straight lines



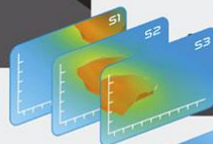
MUONS LOSE ENERGY FASTER IN DENSE MATERIAL

Muons lose energy in matter via ionization. Due to an additional high density object, there is a deficit of muons from a particular direction.

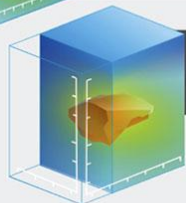


Sensors measure the rate of muons passing through them from each direction

Multiple sensors gather large amount of data



The muon rate in each particular direction is used to create an "X-ray Image" of the overburden above the sensors



Multiple images can be combined in an inversion for 3D distribution of subsurface density

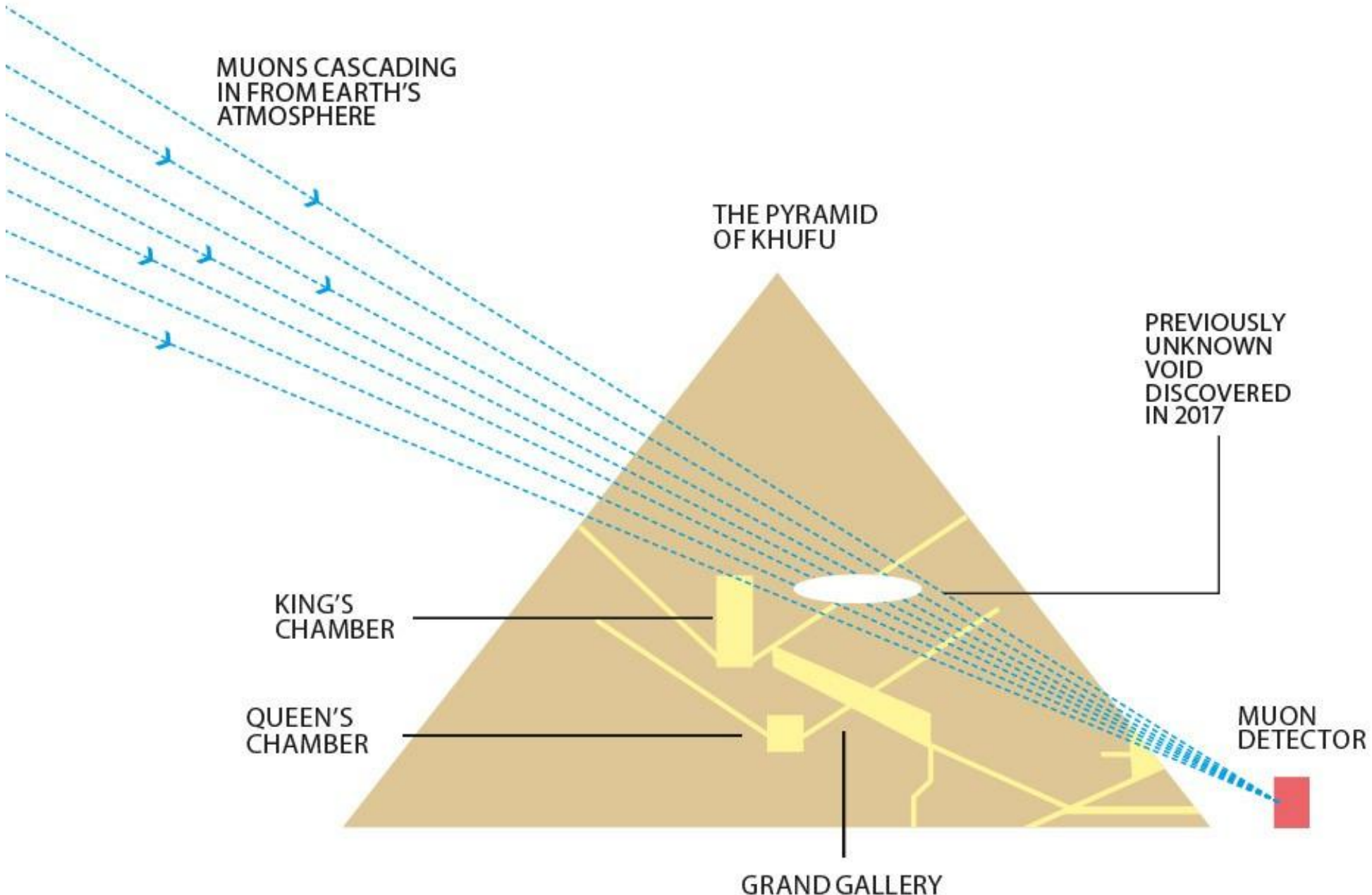


Basic idea:

Use of cosmic ray muons to image large scale structures

- ✓ Mountains
- ✓ Pyramids

Understand hidden structures
Map resources

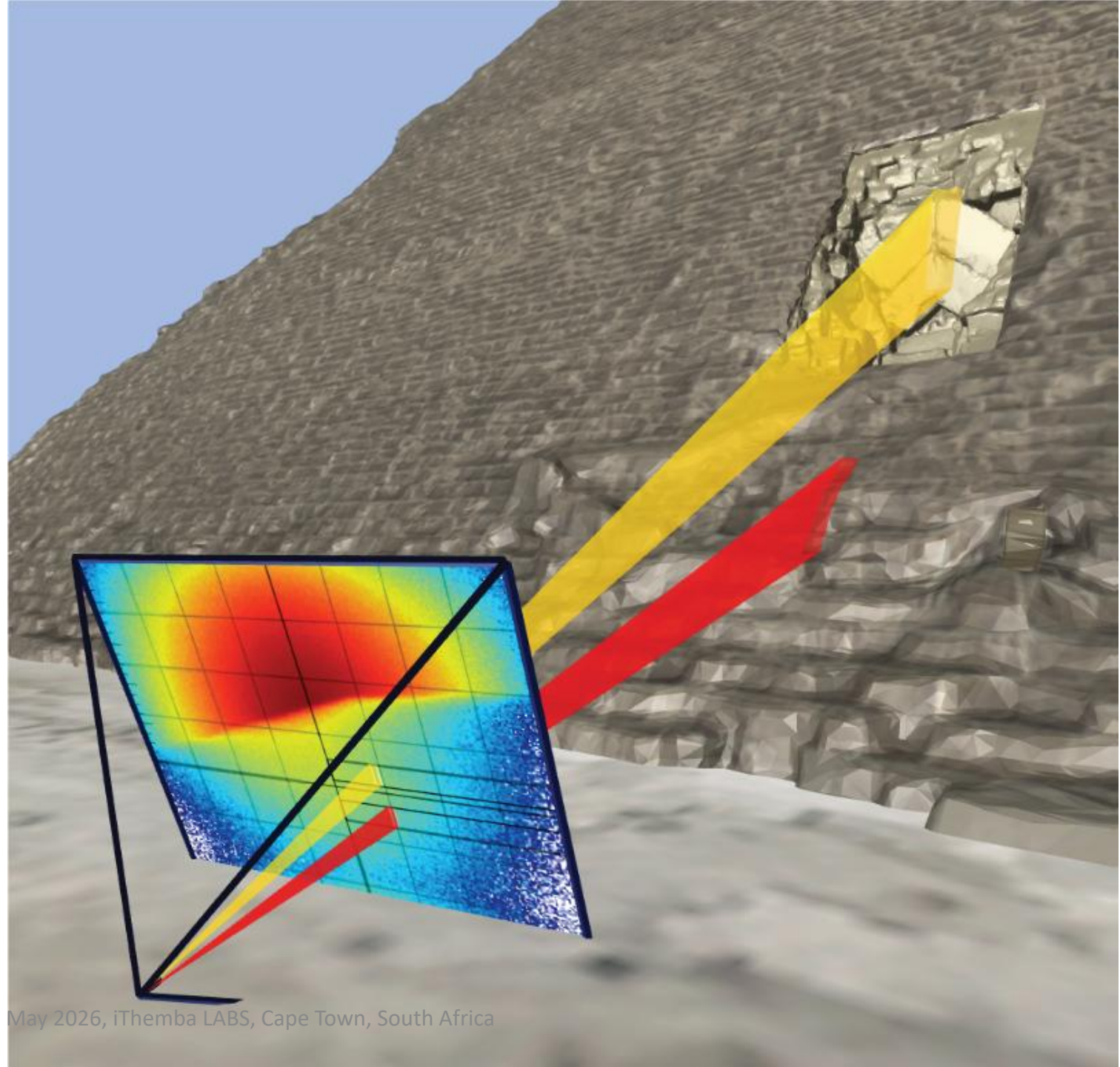




Basic idea:

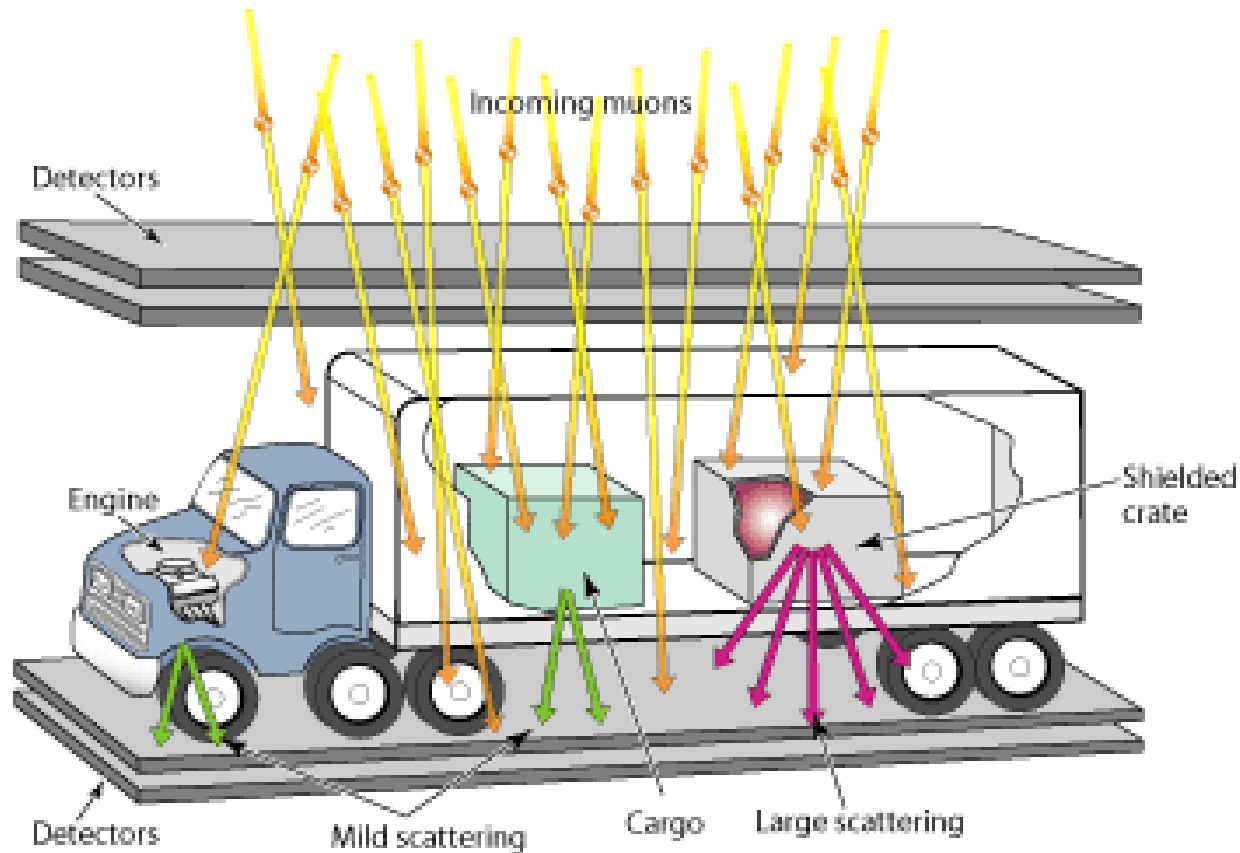
Reconstruction of muon flux

- ✓ Changes in density
- ✓ Different materials
- ✓ Voids





Muon Radiography



Basic idea:

Use of cosmic ray muons to image large scale structures

- ✓ Inspection of cargo
- ✓ Imaging buildings



Outreach Activities



Outreach Activities

International Cosmic Day 13 November 2025

University undergraduate and postgraduate students attend lectures and experimental sessions in cosmic ray physics



University postgraduate students demonstrate the measurement of cosmic ray muons in the laboratory

[More information](#)



1st March 2024

University undergraduate students taking part in the analysis of the data from the Pierre Auger experiment.

Topics covered:

Cosmic rays -

Origin, interaction in the atmosphere, detection and measurement, extensive air showers.

Human exposure to cosmic radiation.

Applications of cosmic radiation

[More information](#)





18th March 2026

University undergraduate students taking part in the analysis of the data from the Pierre Auger experiment.

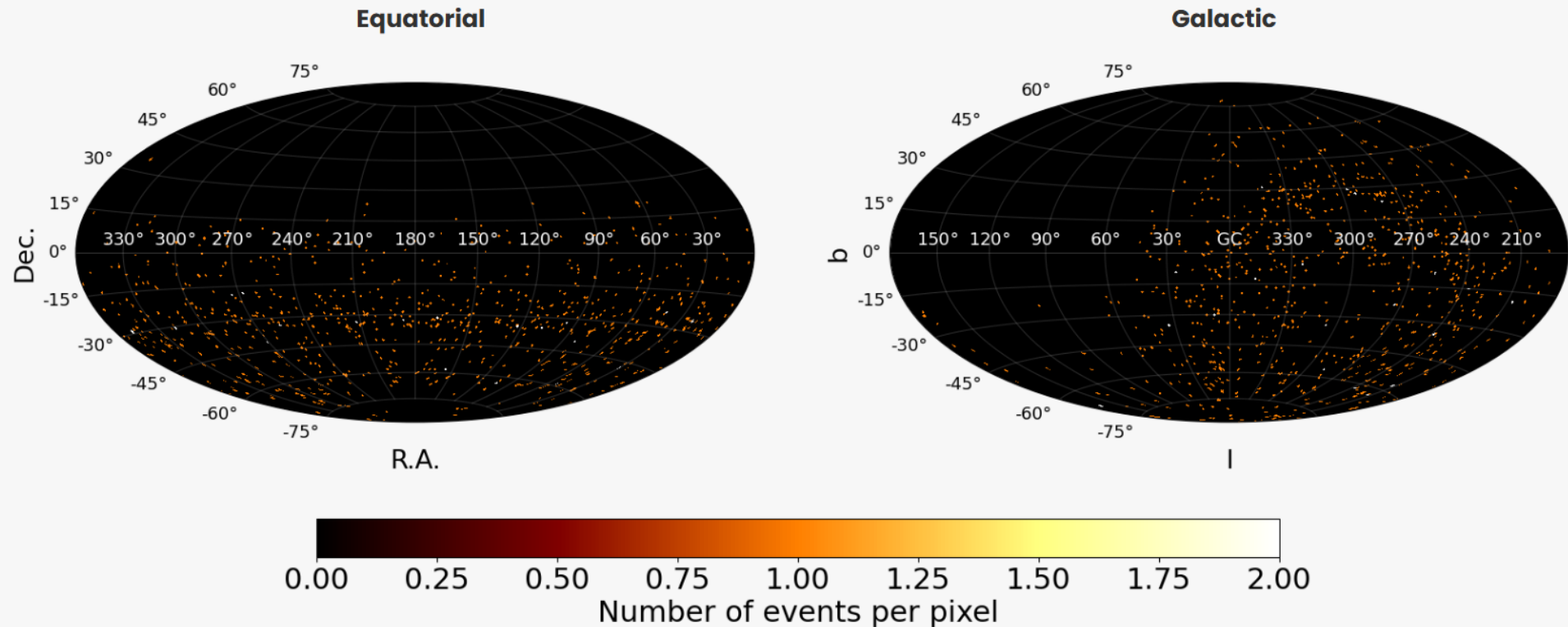
Topics covered:

Cosmic rays -Origin, interaction in the atmosphere, detection and measurement, extensive air showers.
Human exposure to cosmic radiation. Applications of cosmic radiation.

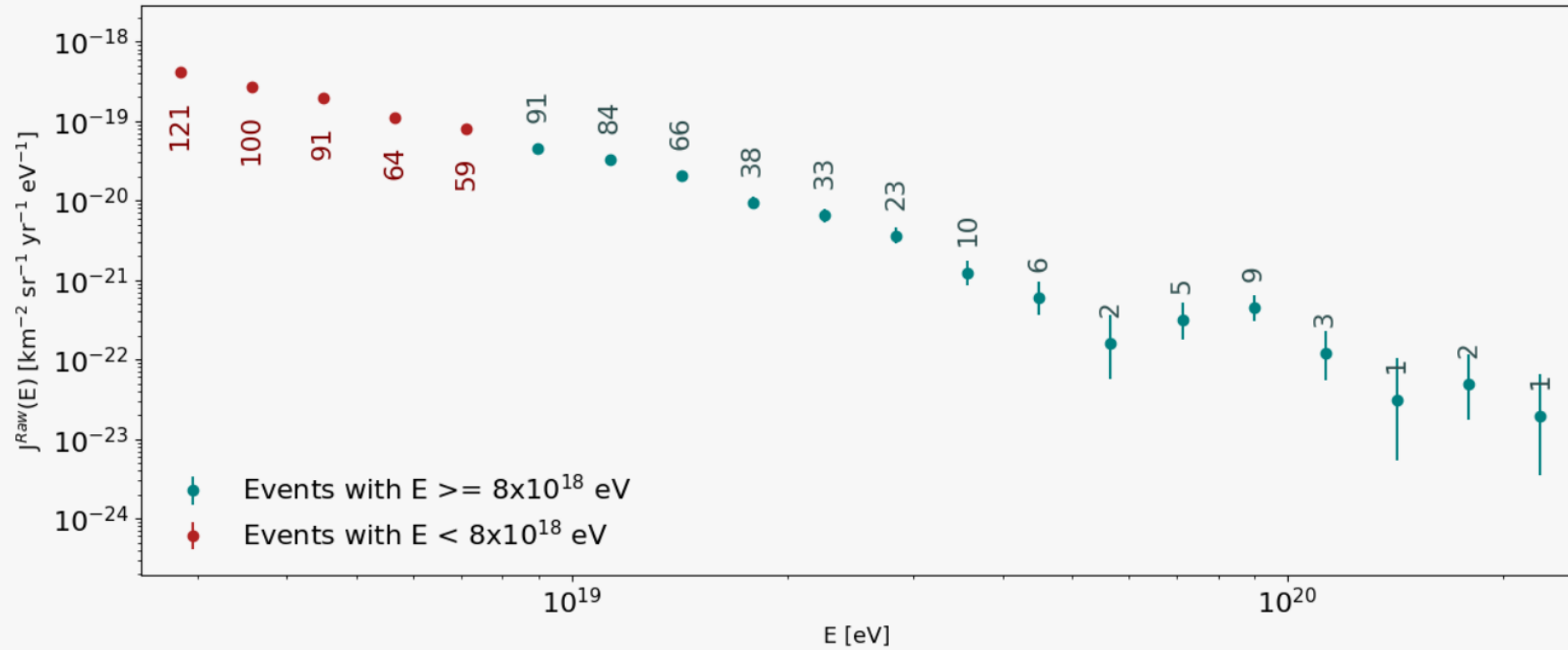
Count Map

POINTS

PIXELS



Spectrum with event counts



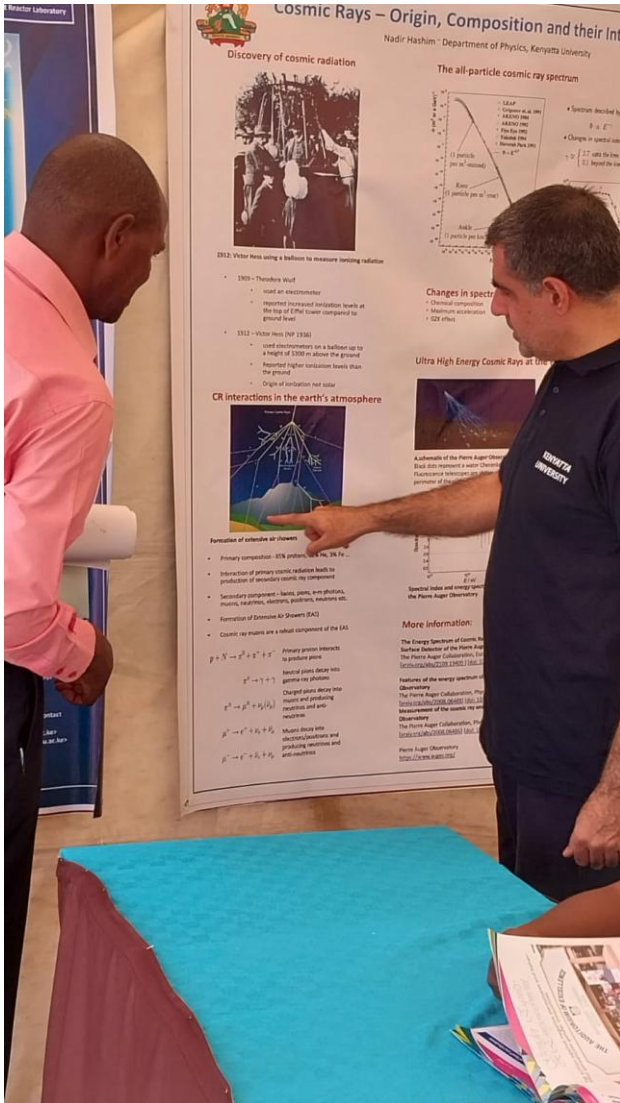


Outreach Activities

Annual Career Week
27th January 2024

- Excellent opportunity to:
- ✓ interact with high school students,
 - ✓ disseminate knowledge, and
 - ✓ share ideas for careers in STEM

- Topics discussed:**
- Cosmic rays
 - Origins
 - Interactions
 - Detection and measurements





International Cosmic Day at Kenyatta University - 2023



21st November 2023

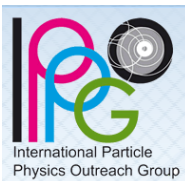
University postgraduate students demonstrate the measurement of cosmic ray muons in the laboratory

[More information](#)

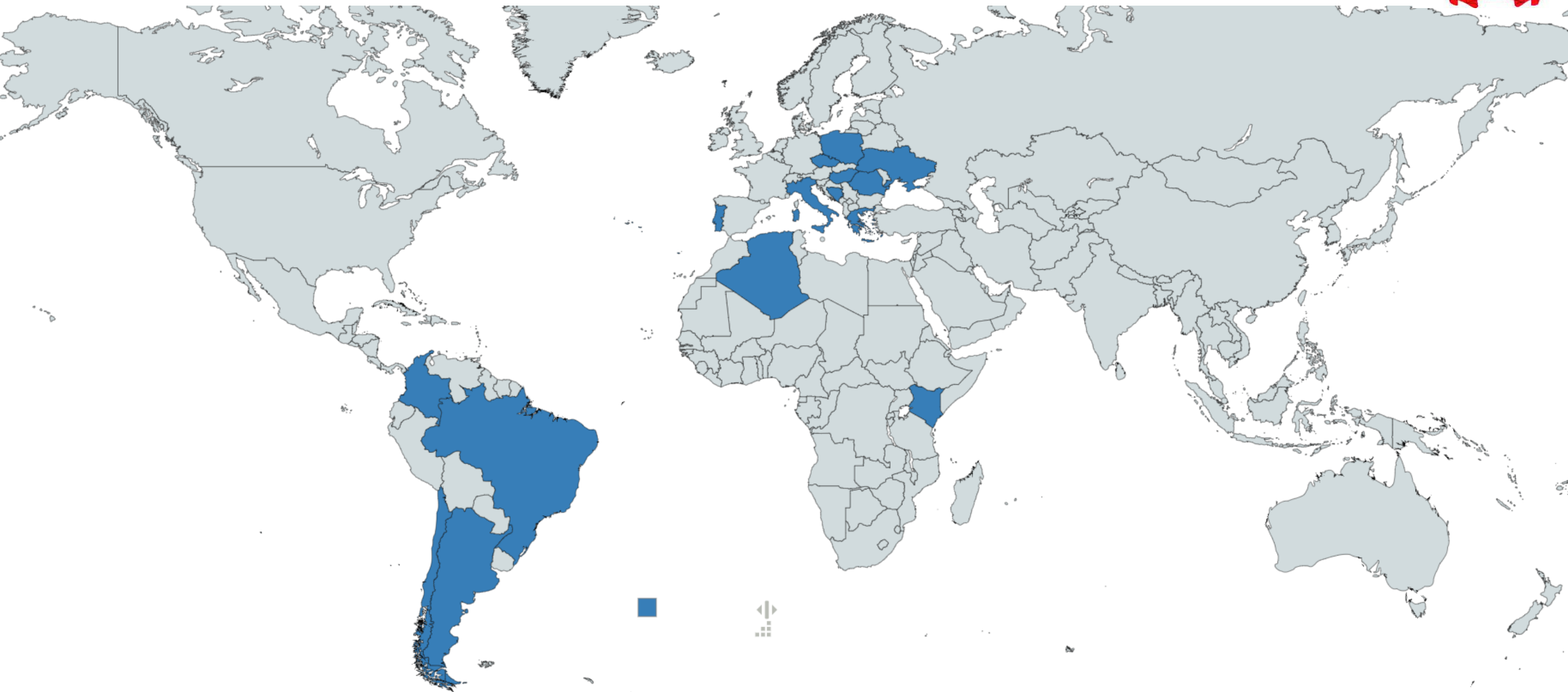
21st November 2023

University undergraduate and postgraduate students attend lectures and experimental sessions in cosmic ray physics





International Masterclass at Kenyatta University – 2026



ANSTT 6, 18 – 22 May 2026, iThemba LABS, Cape Town, South Africa



Global Engagements in Cosmic Ray Physics Outreach

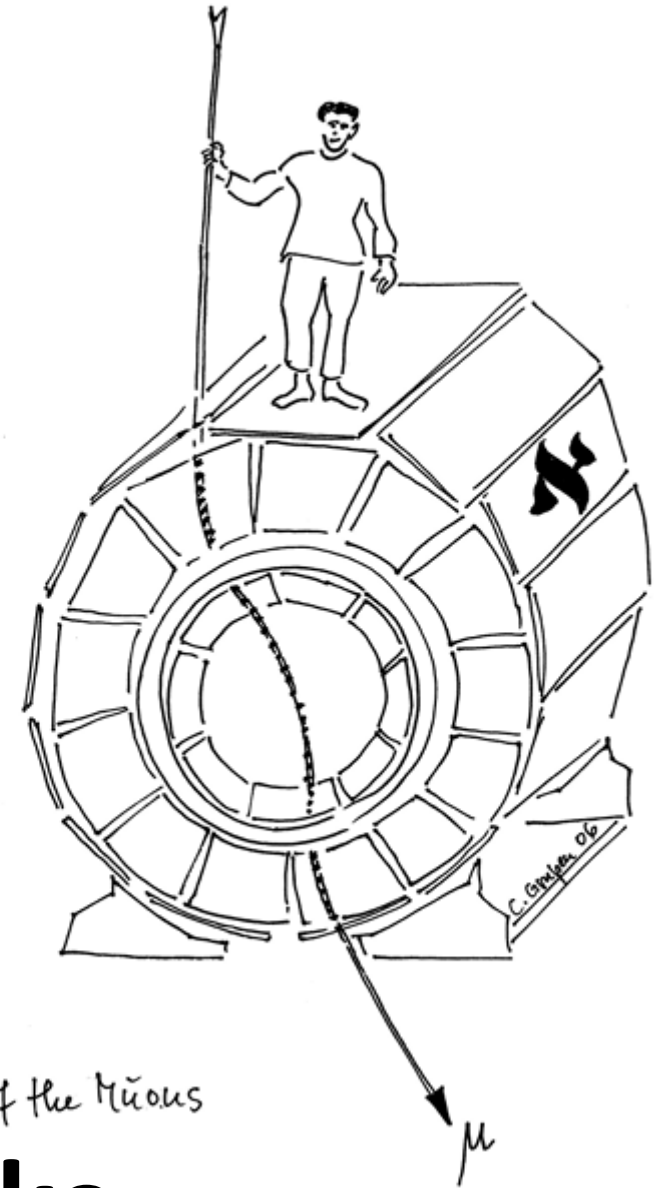


- ❑ Close to 100 institutions world-wide participate in the [International Cosmic Day](#)
- ❑ There is low participation in Africa
- ❑ Kenyatta University in Kenya has participated in the five last years
- ❖ These events provide excellent opportunities to build cosmic ray physics outreach in Africa.



Acknowledgements

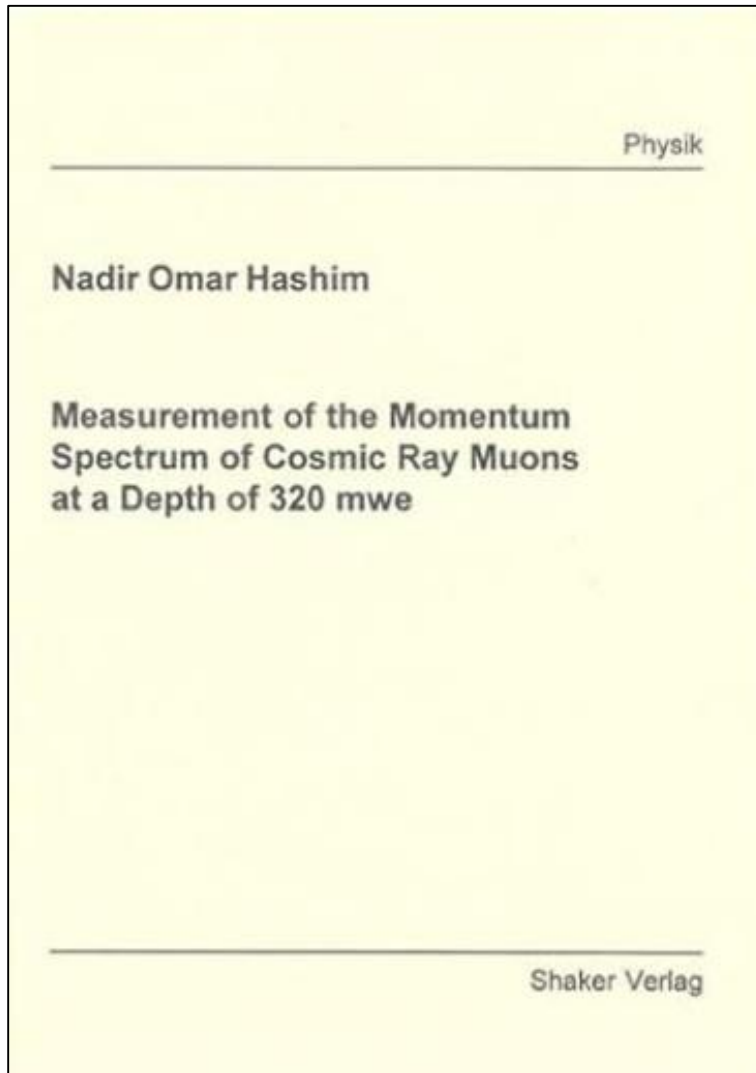
- CosmoALEPH Collaboration
- German Academic Exchange Service (DAAD)
- Kenyatta University
- Siegen University
- Postgraduate Students –
Samuel Mburu Chege, Veronicah Kihagi,
Jackson Kisingu, Mumbi Njoroge



Thank you
hashim.nadir@ku.ac.ke



Further Reading



Nadir Omar Hashim (2007). Measurement of the Momentum Spectrum of Cosmic Ray Muons at a Depth of 320 Mwe (Berichte Aus Der Physik) Paperback. Shaker Verlag GmbH, Germany.

ISBN-10 : 3832264450

ISBN-13 : 978-3832264451



Further Reading



Nuclear Physics B - Proceedings Supplements

Volumes 175–176, January 2008, Pages 286-293



Cosmic Ray Results from the CosmoALEPH Experiment

C. Grupen^a, N.-O. Hashim^{a b}, B. Jost^c, F. Maciuc^b, S. Luitz^d, A. Mailov^a, A.-S. Müller^e, A. Putzer^f, B. Rensch^g, H.-G. Sander^h, S. Schmeling^c, M. Schmelling^b, R. Tcaciuc^a, H. Wachsmuth^c, Th. Ziegler^c, K. Zuberⁱ

<https://doi.org/10.1016/j.nuclphysbps.2007.11.014>



Further Reading

Astroparticle Physics 49 (2013) 1–5

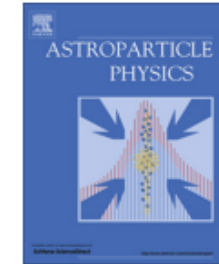


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Spectrum and charge ratio of vertical cosmic ray muons up to momenta of 2.5 TeV/c



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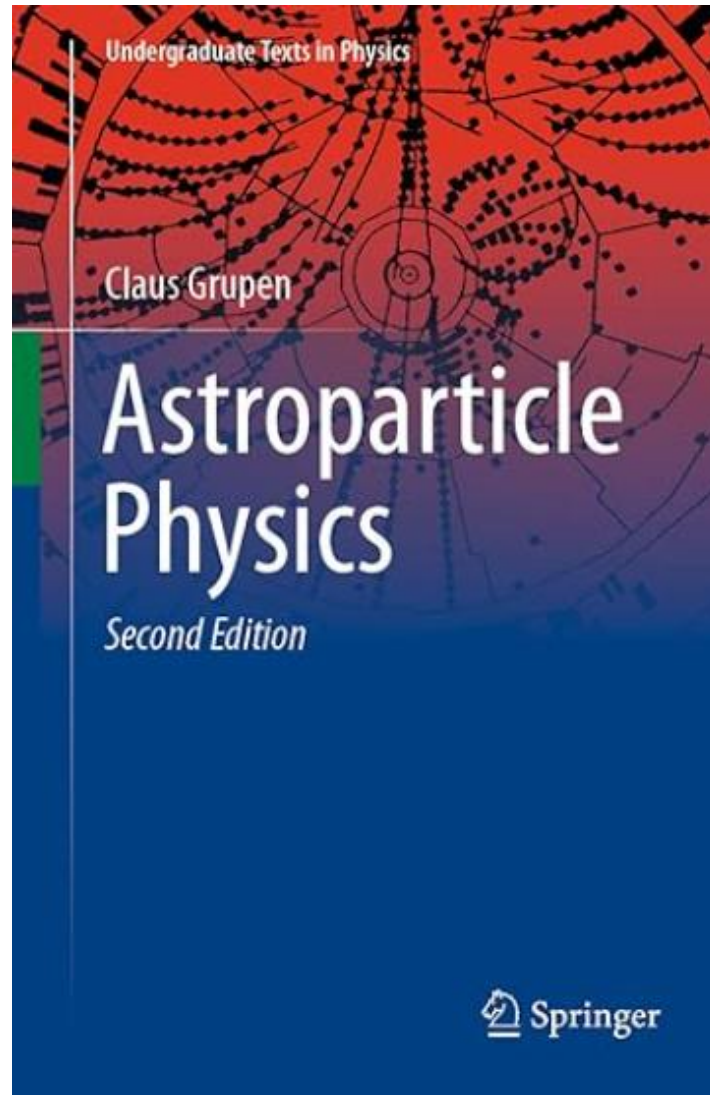
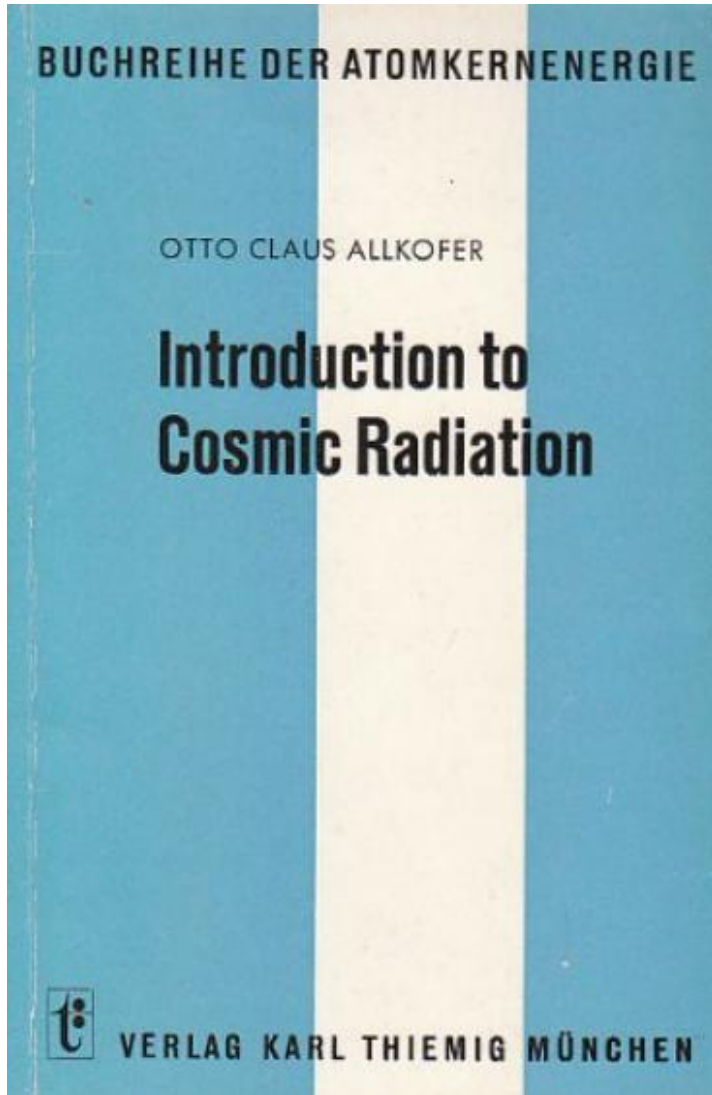
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ⁱ SIX Telekurs Ltd., Zurich, Switzerland

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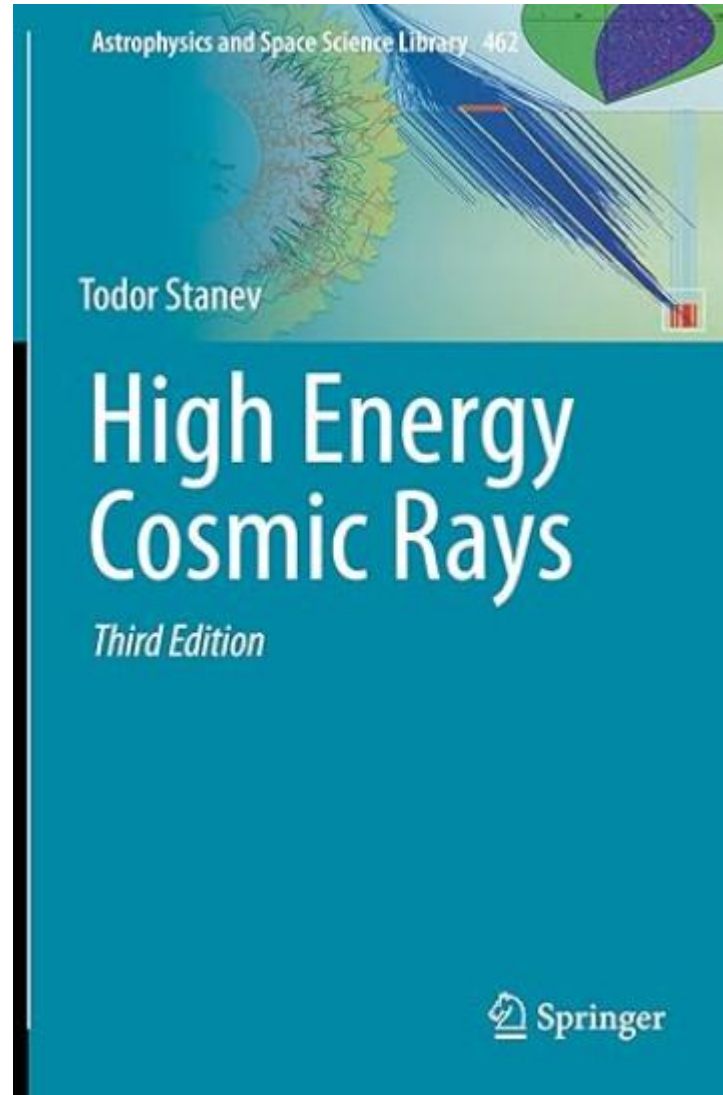
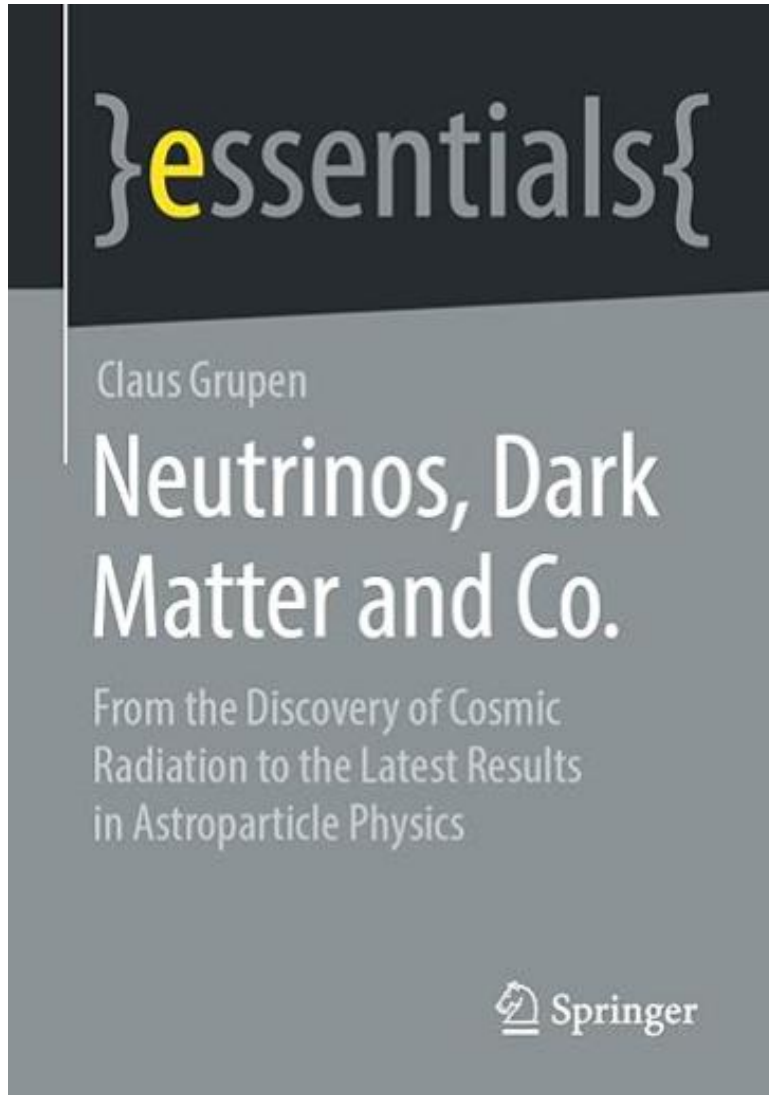
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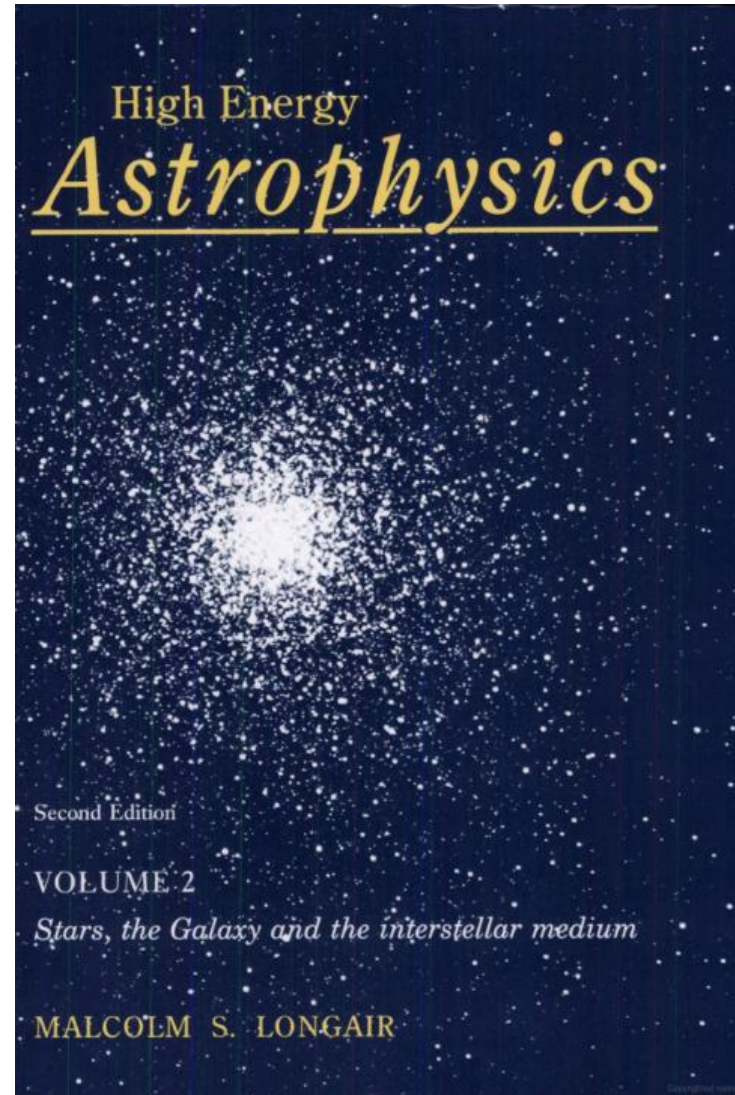
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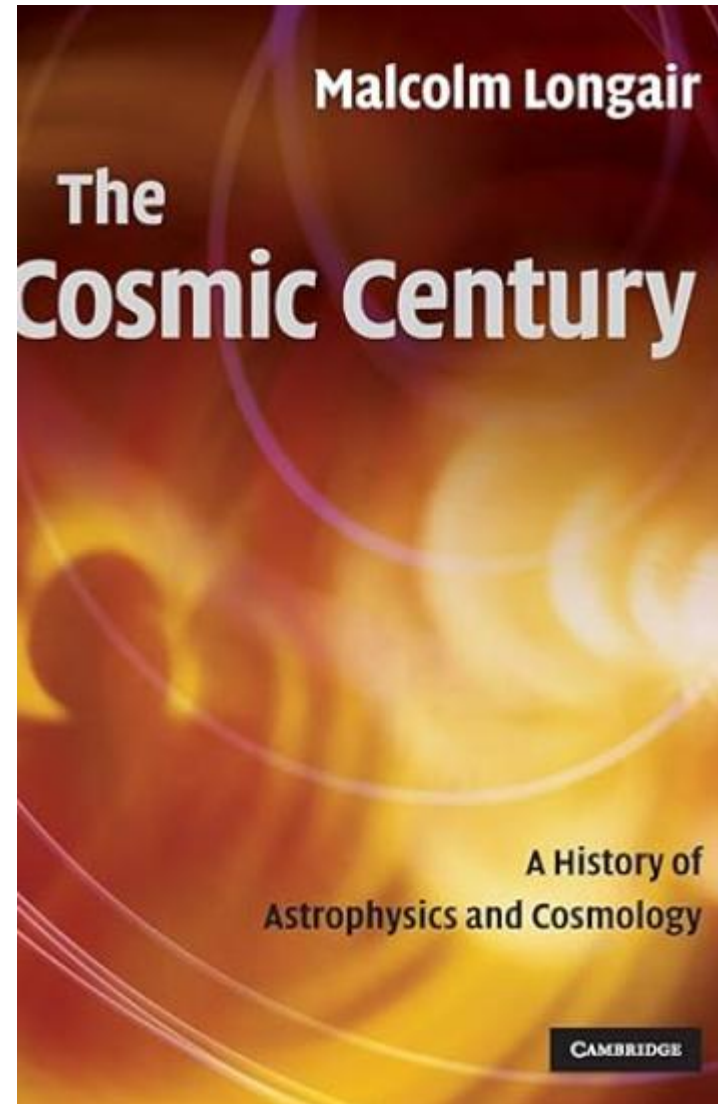
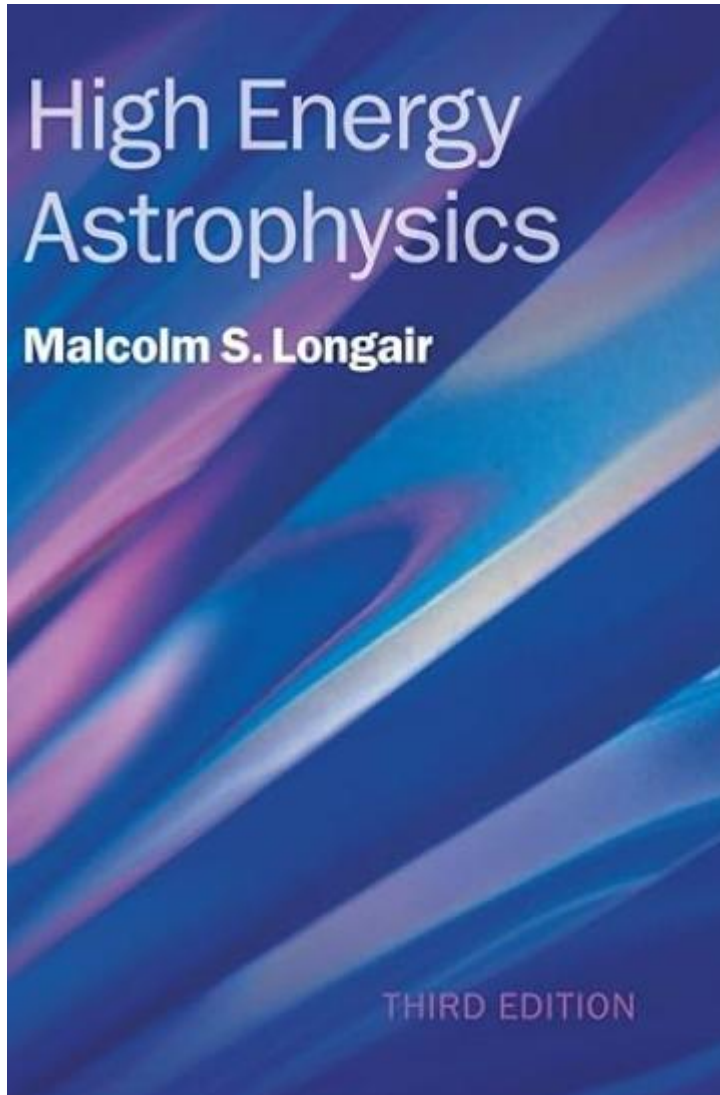
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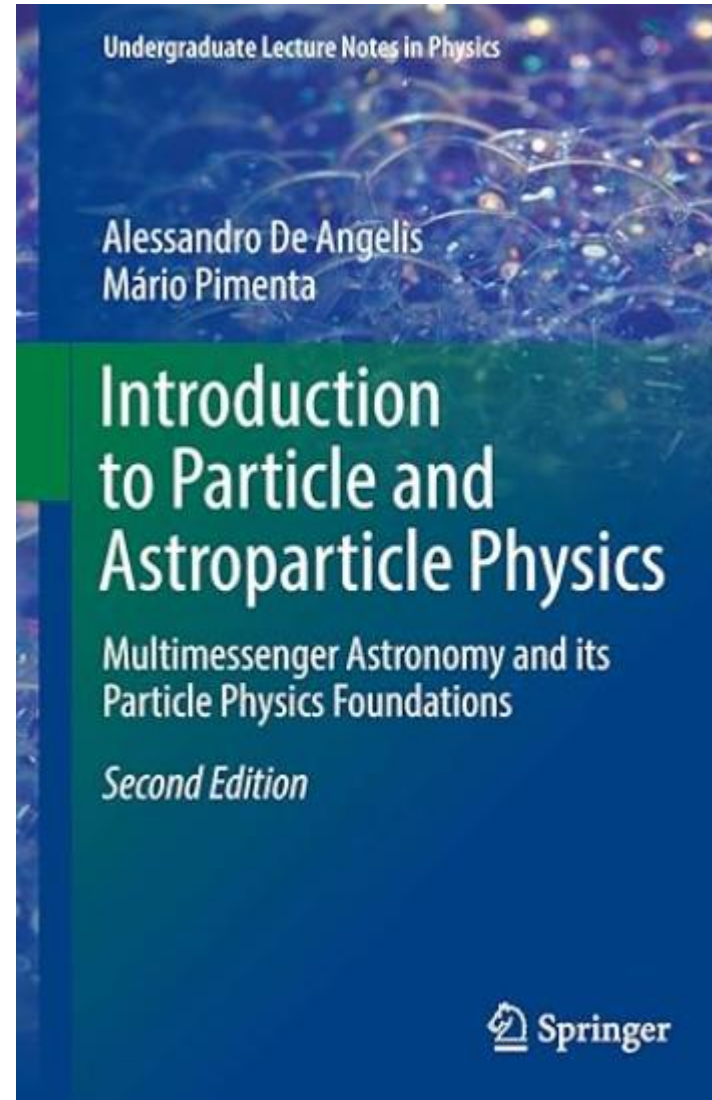
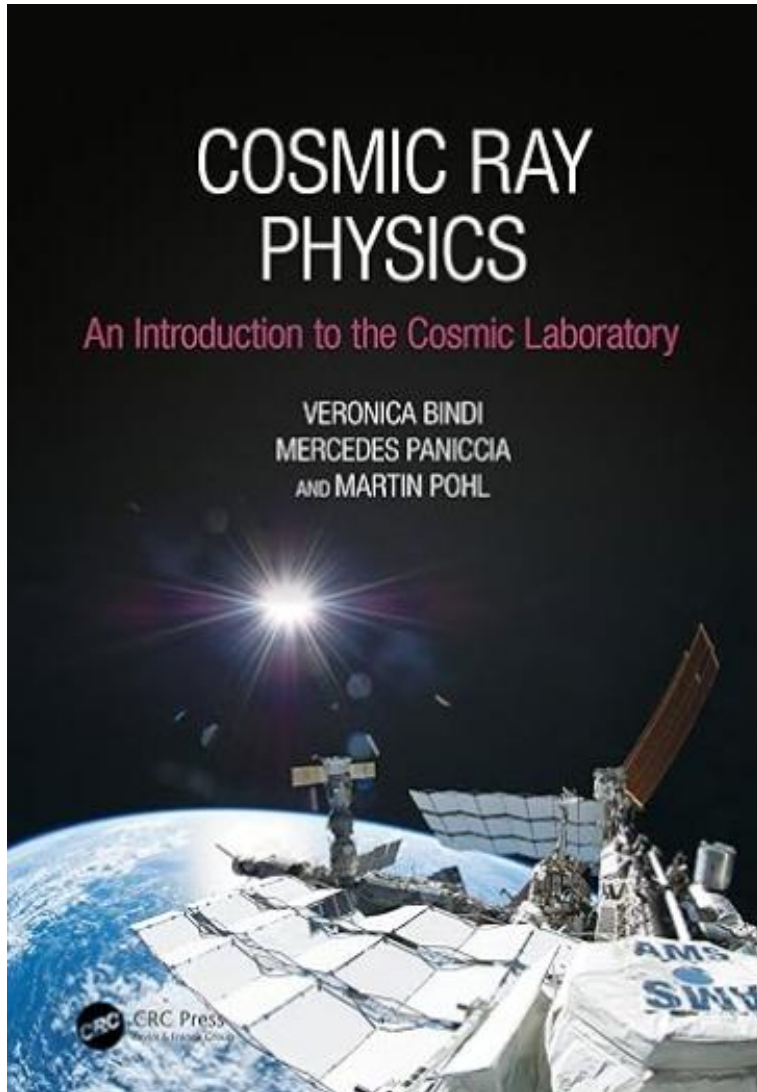


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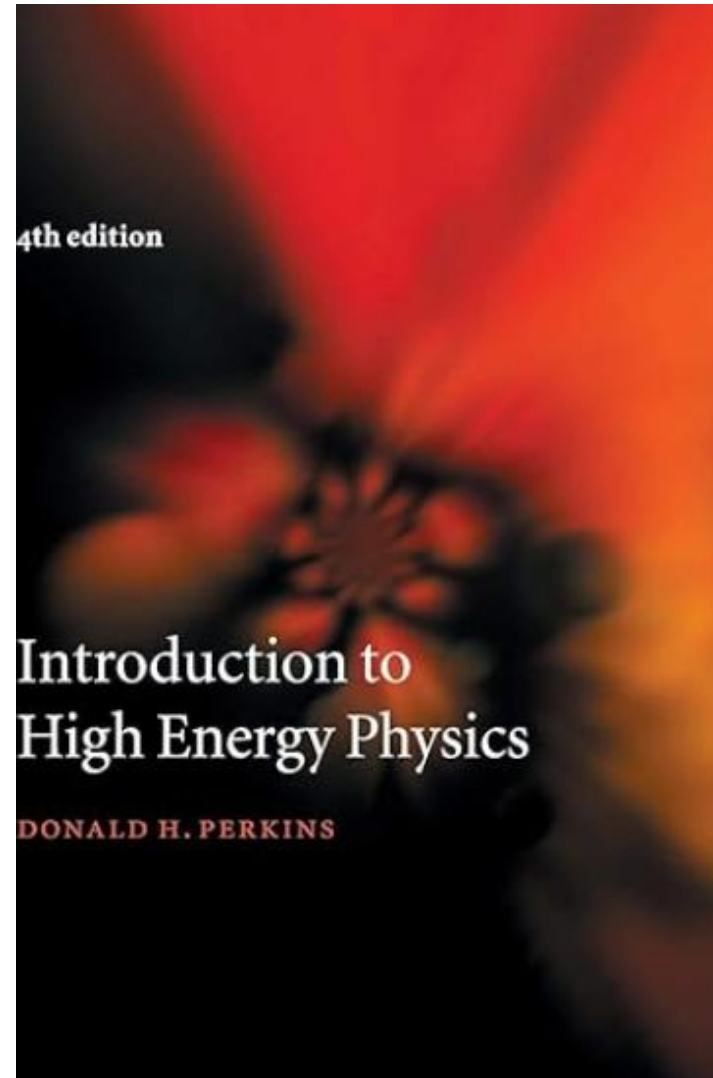
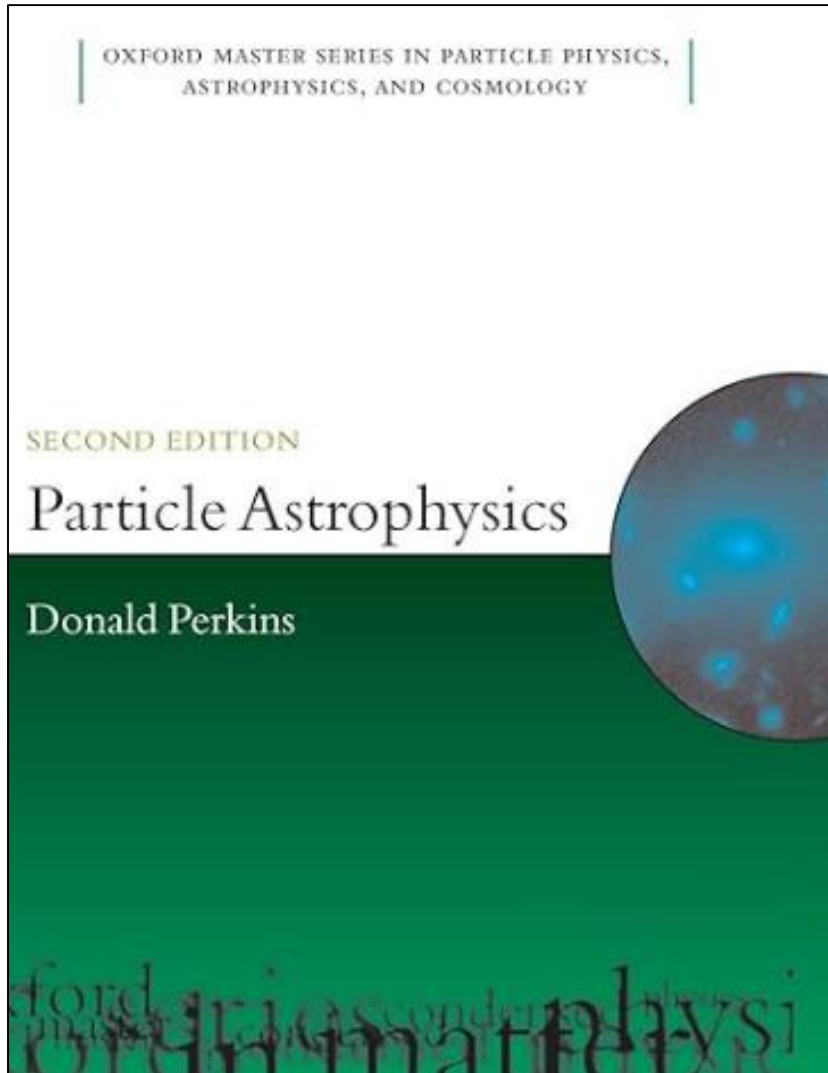
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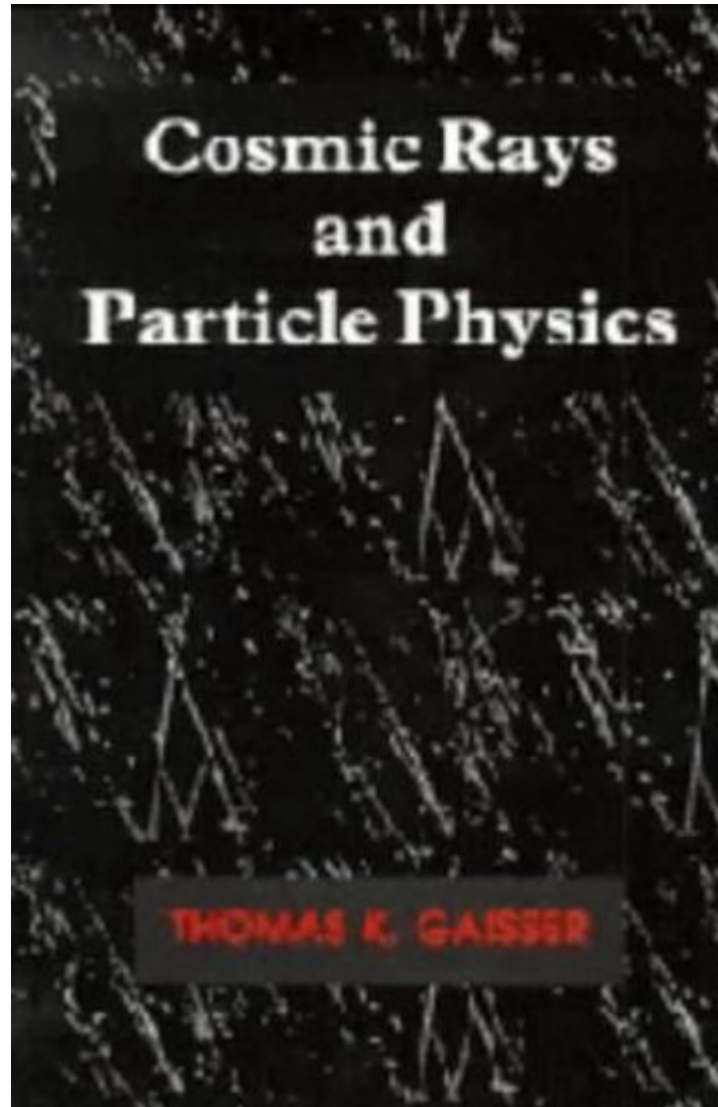
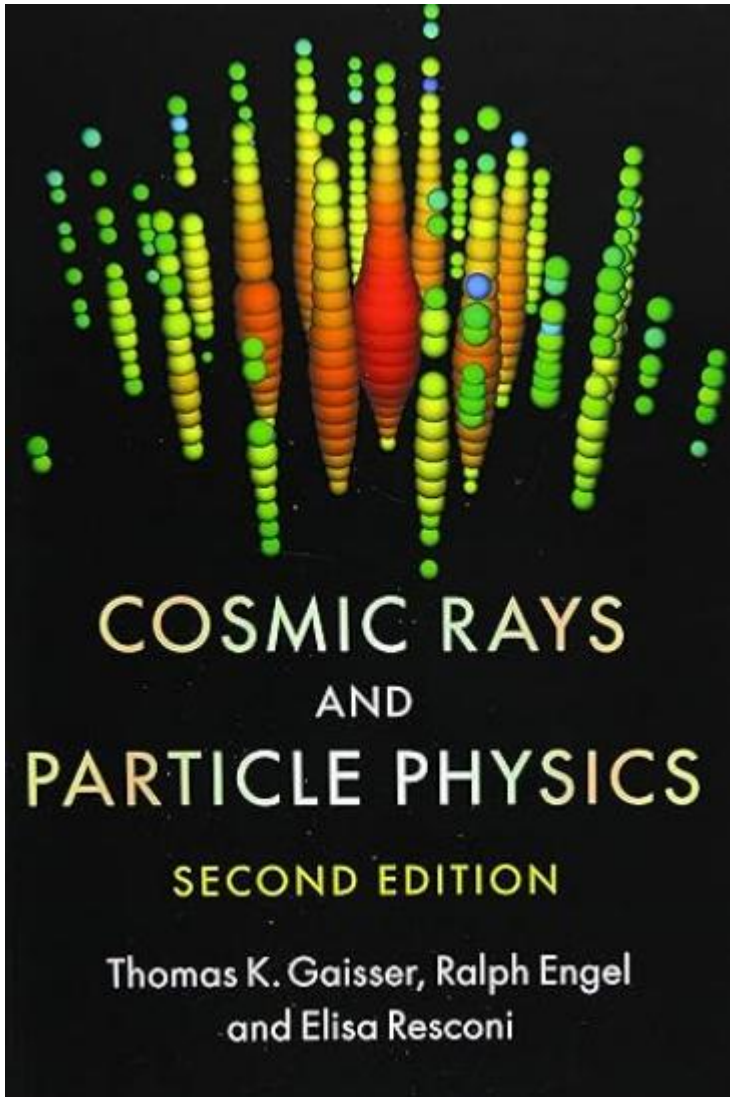


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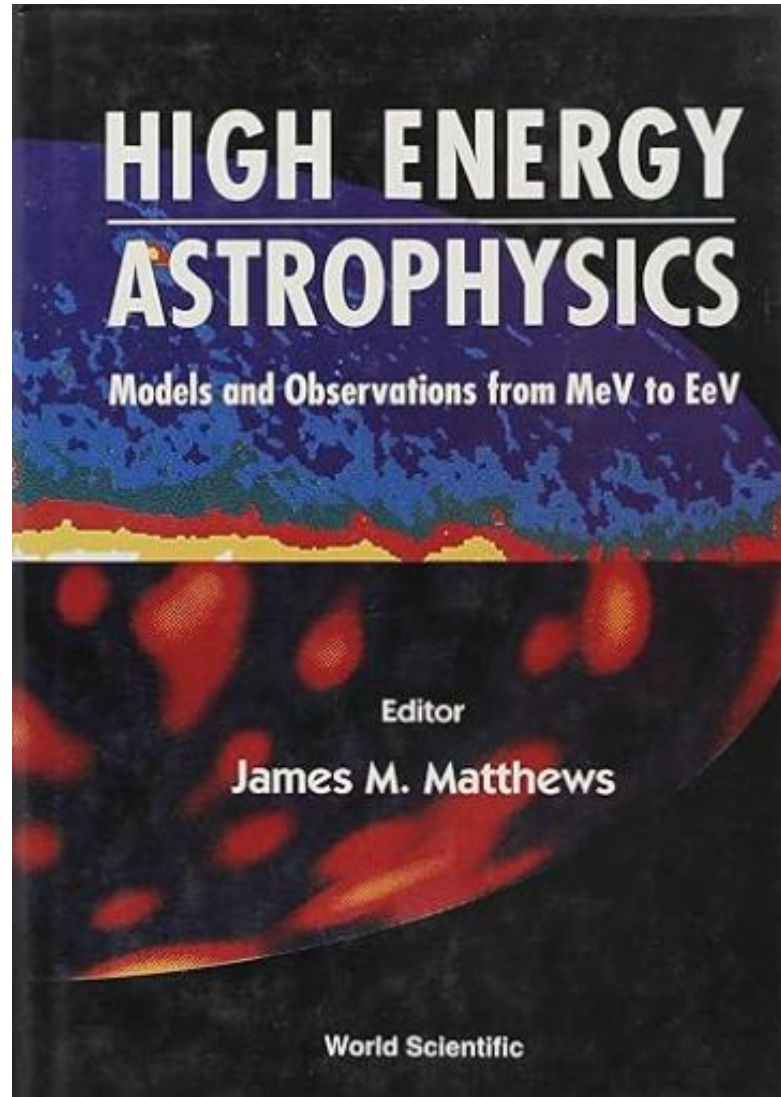
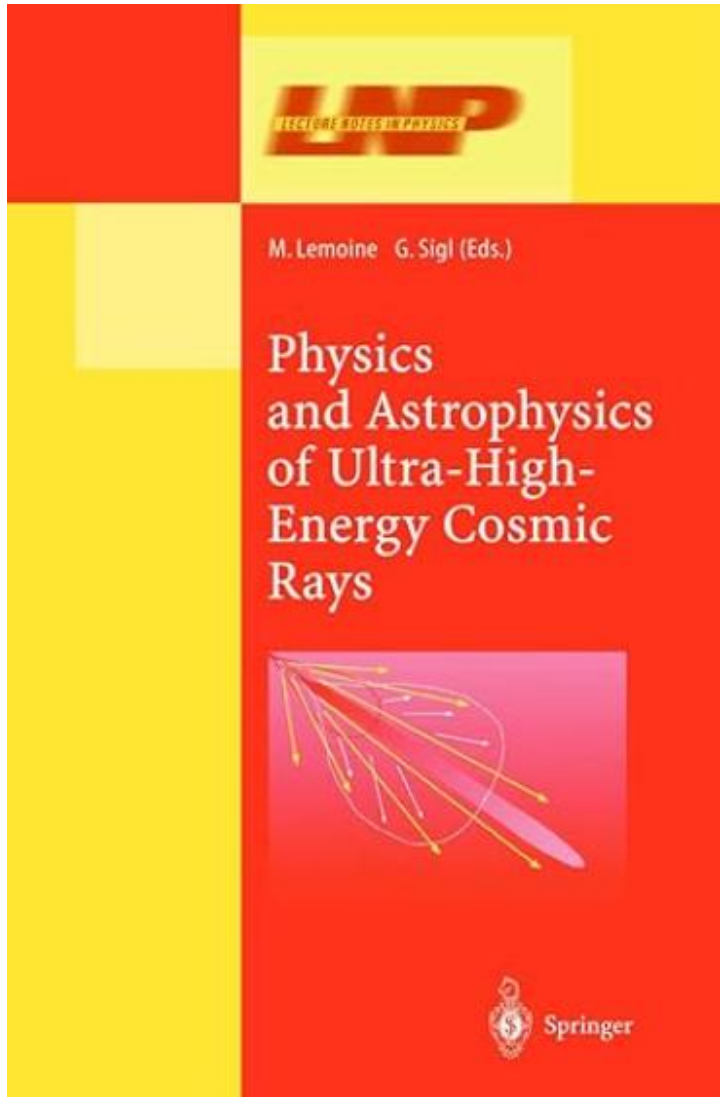


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