technische universität dortmund

Experimentelle Physik Vb
Astroteilchenphysik

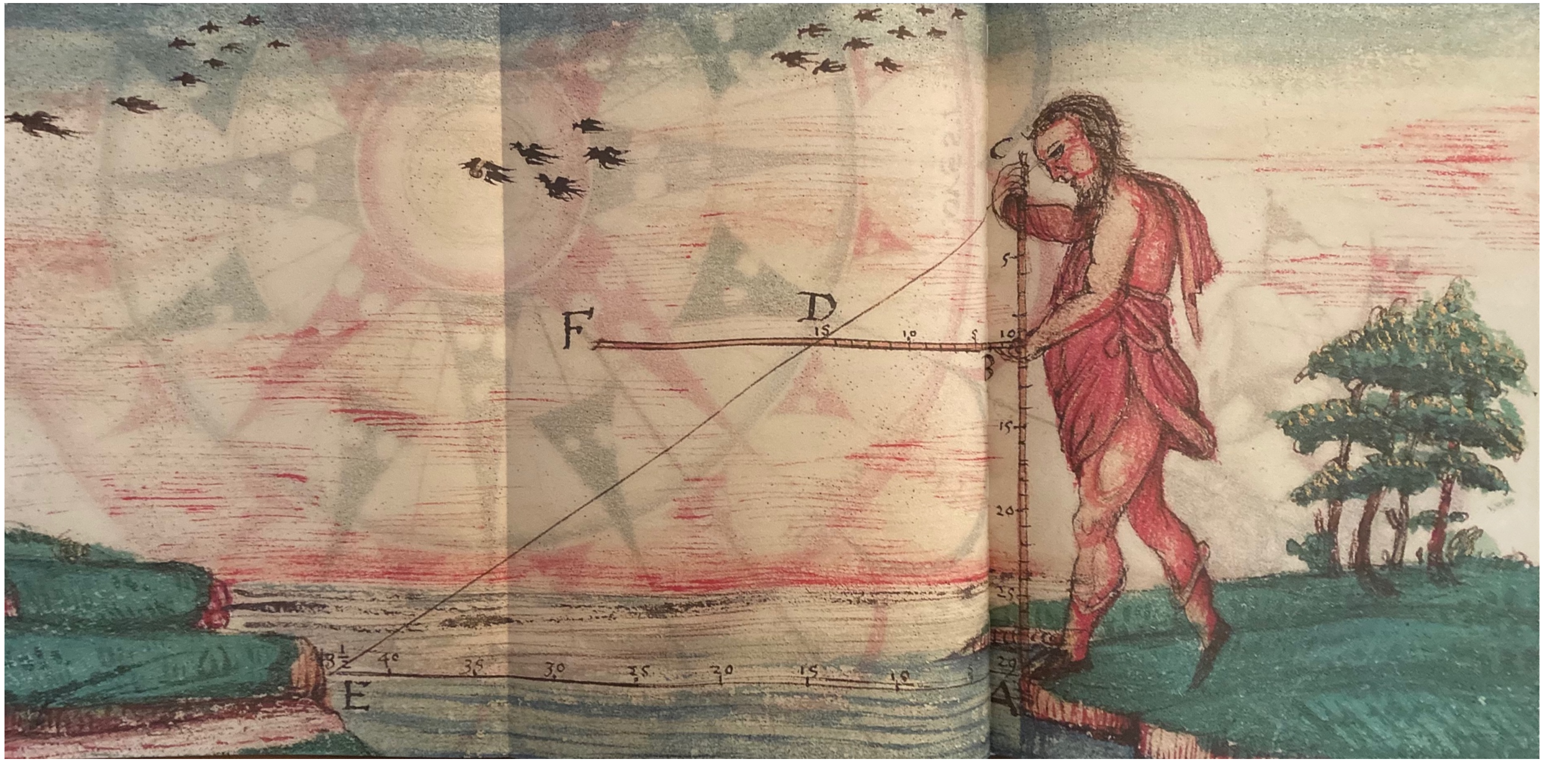
RAPP Center

Methods and Perspectives for Astroparticle Physics

Prof. Dr. Dr. Wolfgang Rhode

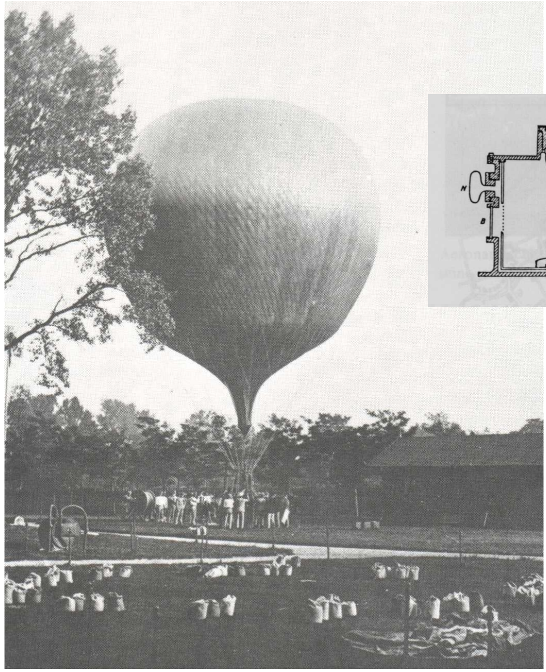
Modern Astro- and Astroparticle Physics

Methods and Perspectives for Astroparticle Physics

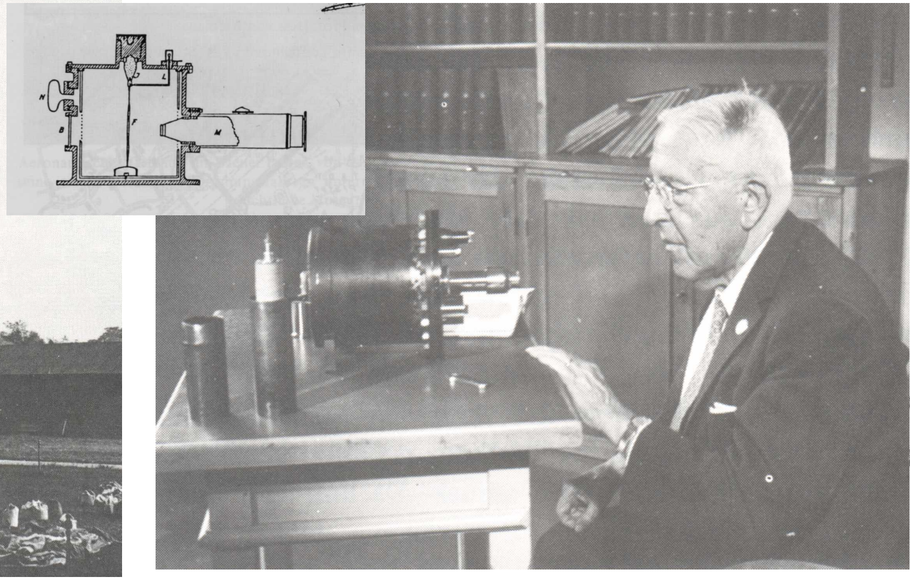


From: Jaques Devault, Oeuvres Nautiques 1583, Facsimile Taschen Verlag o.J.

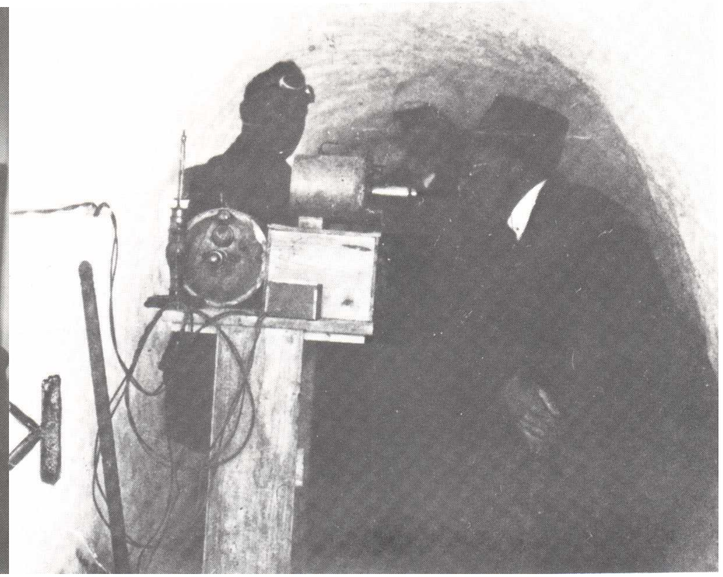
From where do we come?



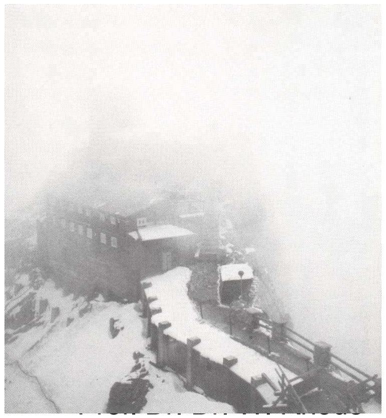
V. Hess, 1911/12



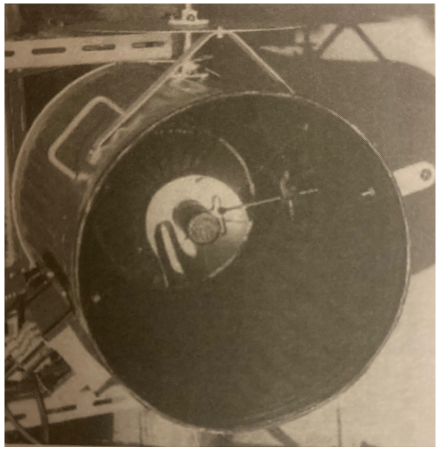
V.F. Hess 1960; „Strahlungsapparat“ 1927-1931



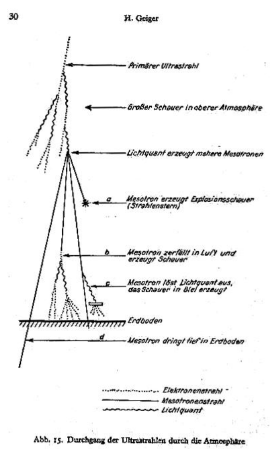
W. Kohlhörster in einem Eisstollen im Eiger-Gletscher, 1923



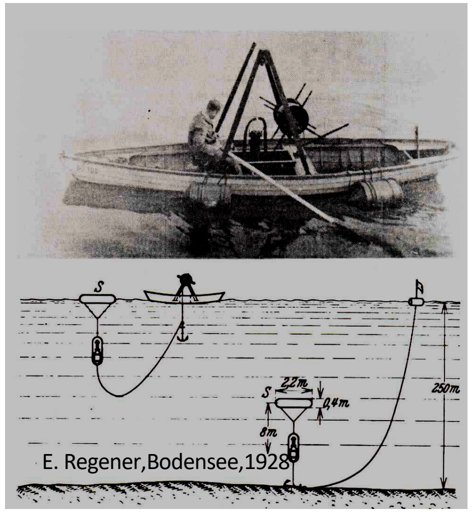
„Höhenstrahlungs-Labor“ auf der Zugspitze, 2960 m



First Cherenkov Counter
Galbraith/Jelly 1953

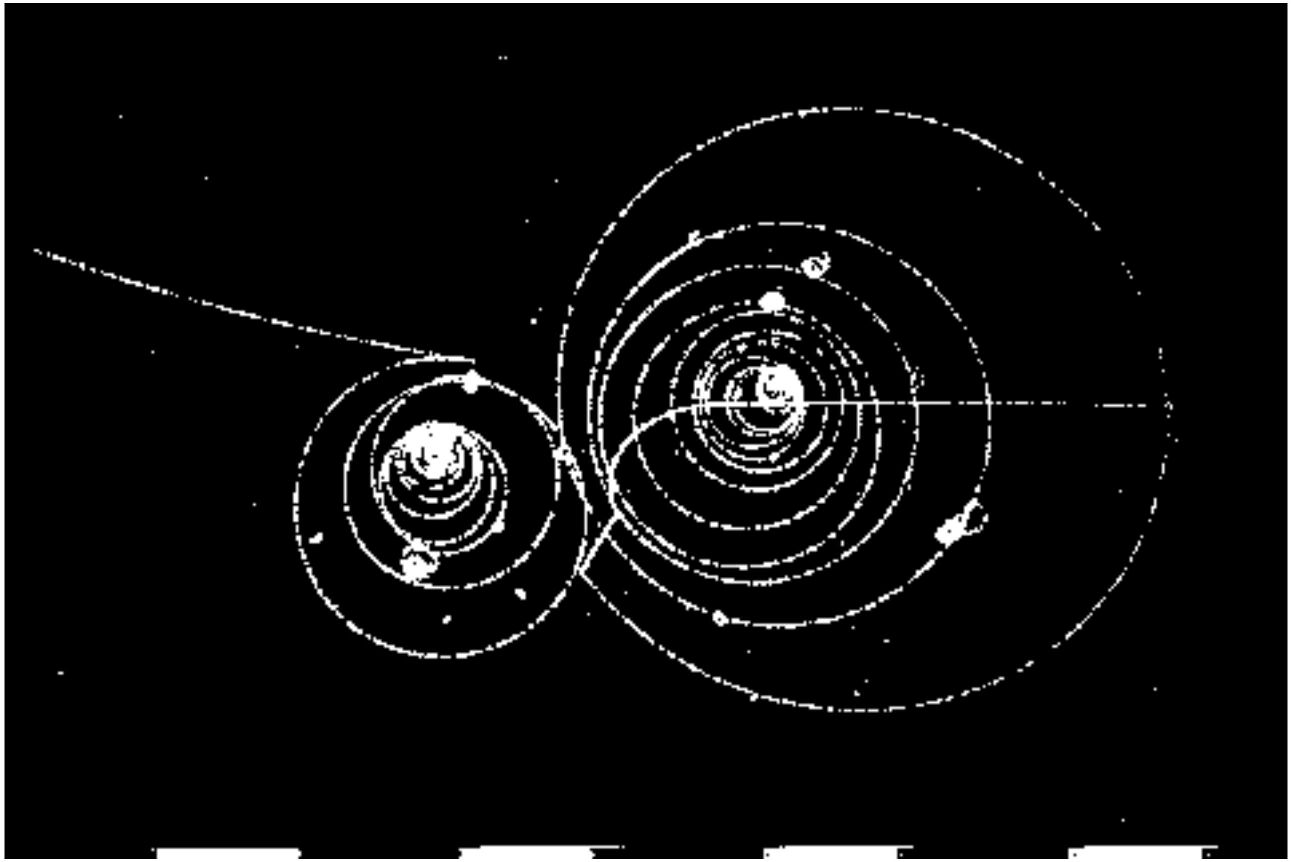


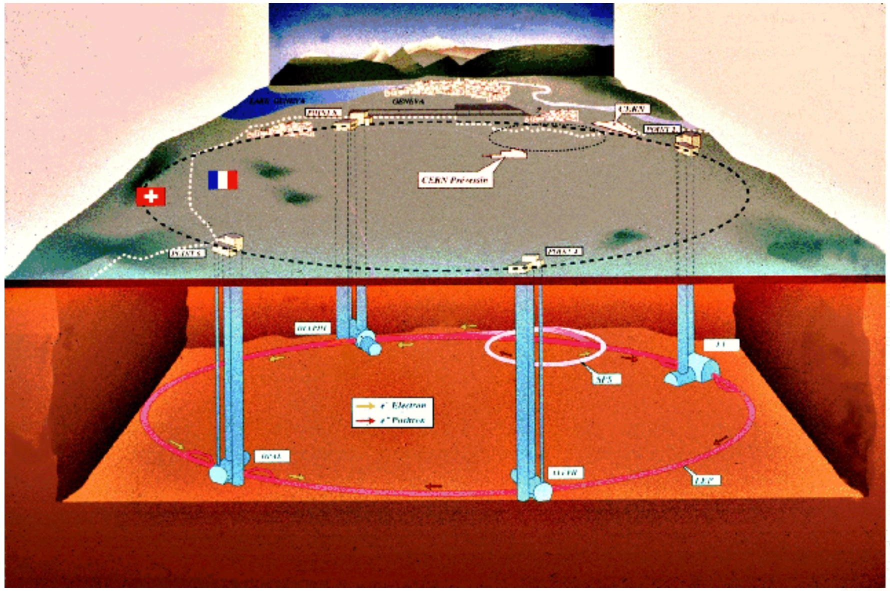
Die kosmische Ultrastrahlung als Forschungsproblem
Hans Geiger, 1940



E. Regener,Bodensee,1928

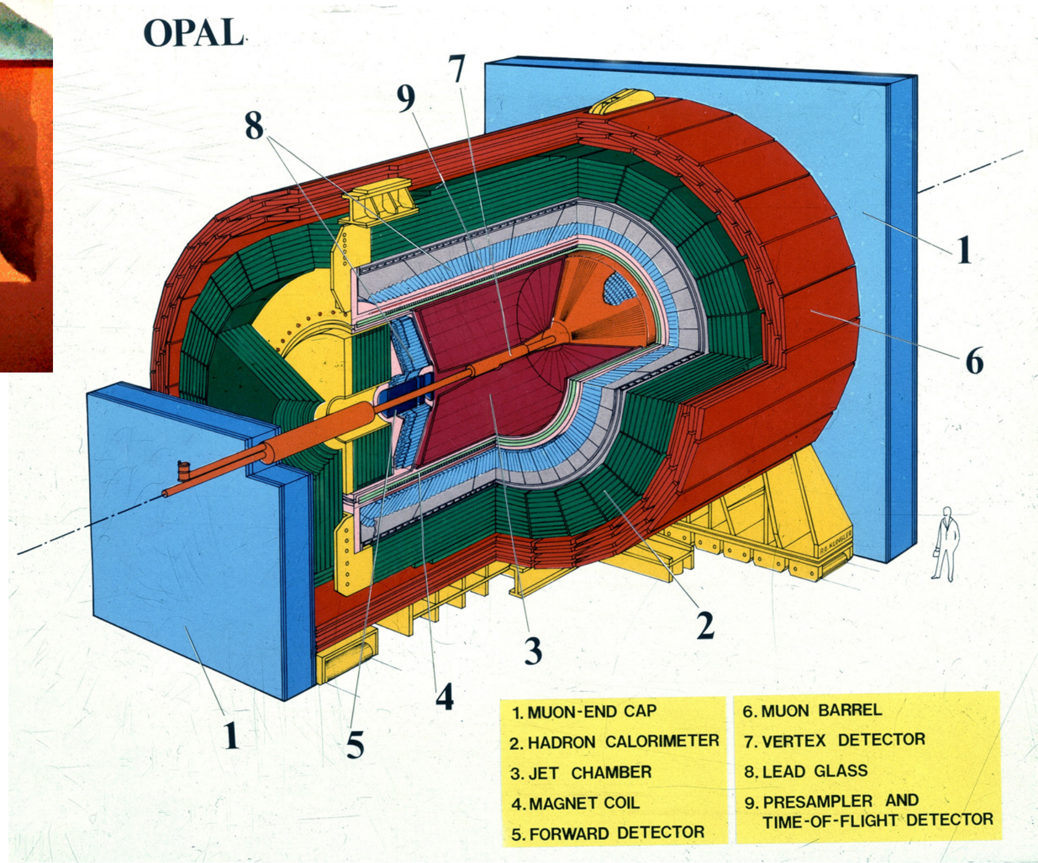
What to focus on ?



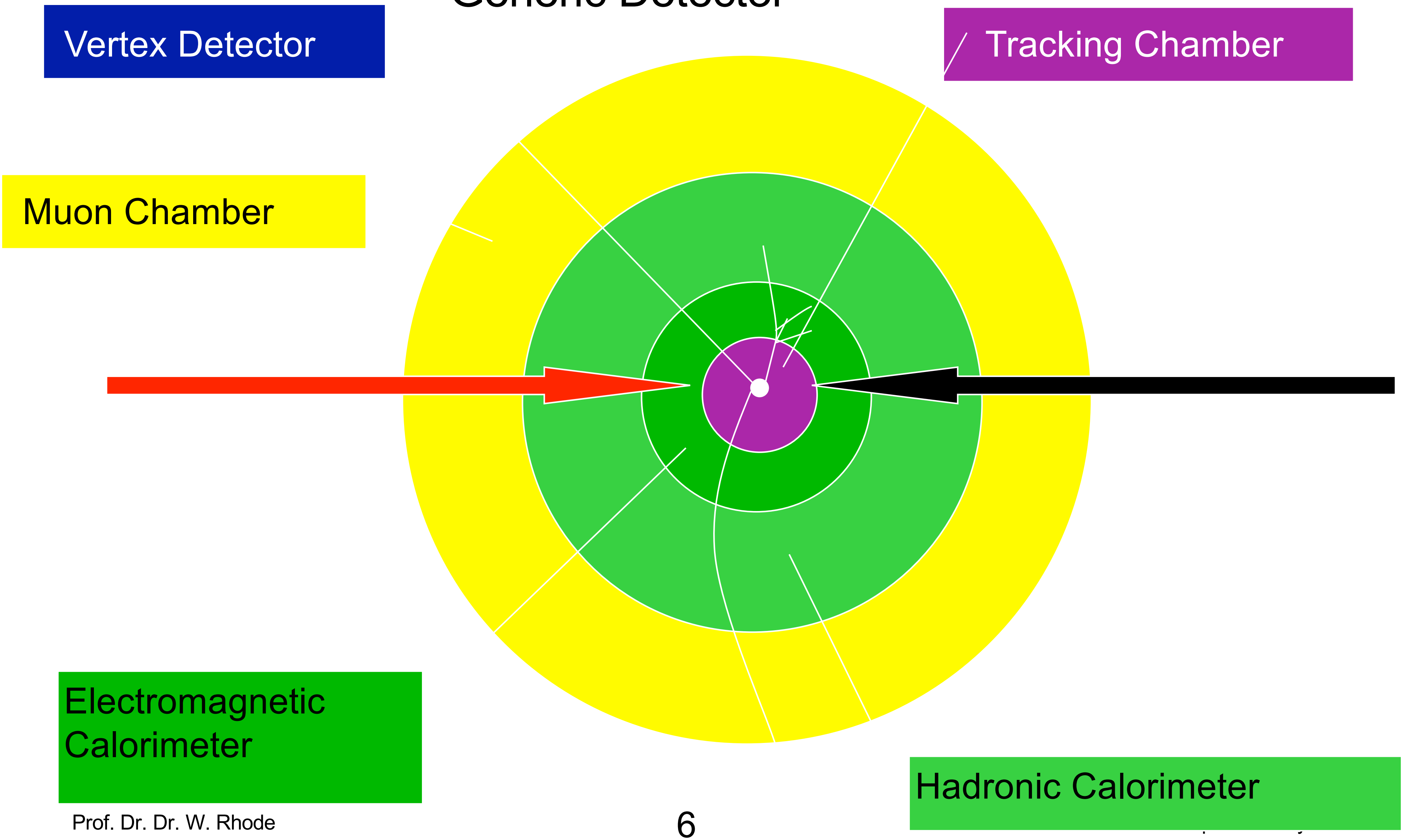


In the 1980s and 1990s:

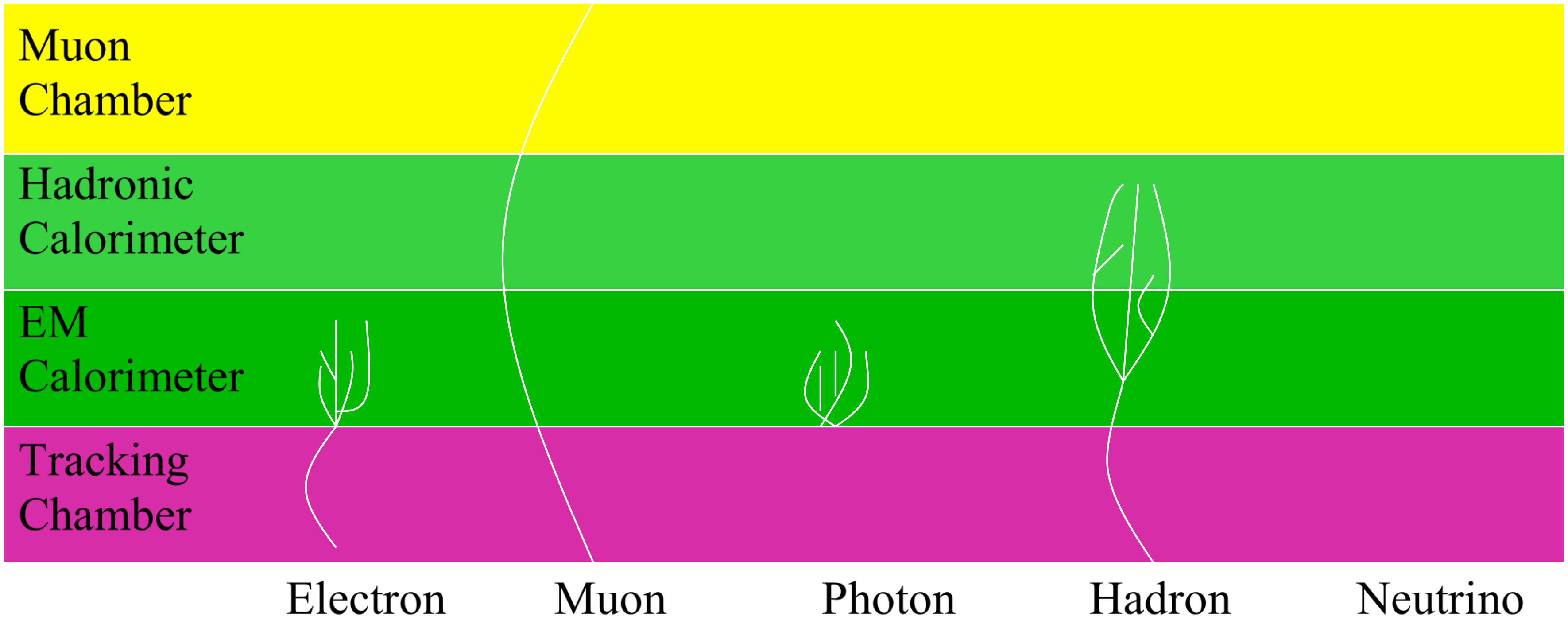
LEP / OPAL et al.



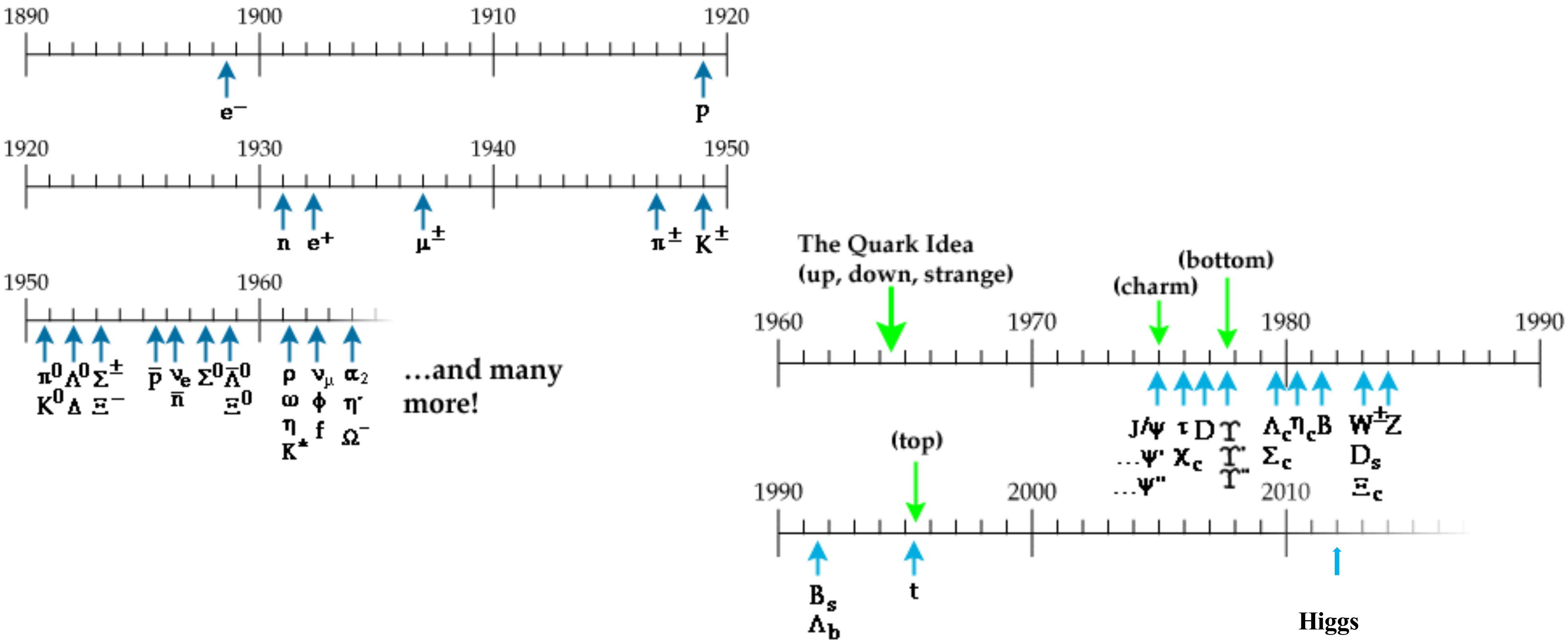
Generic Detector



Particle Identification



Discovery of Particles



Why are we here?

- Not for particle physics?
- To lever our view and unfold it on the sky?
- Why should one do so?

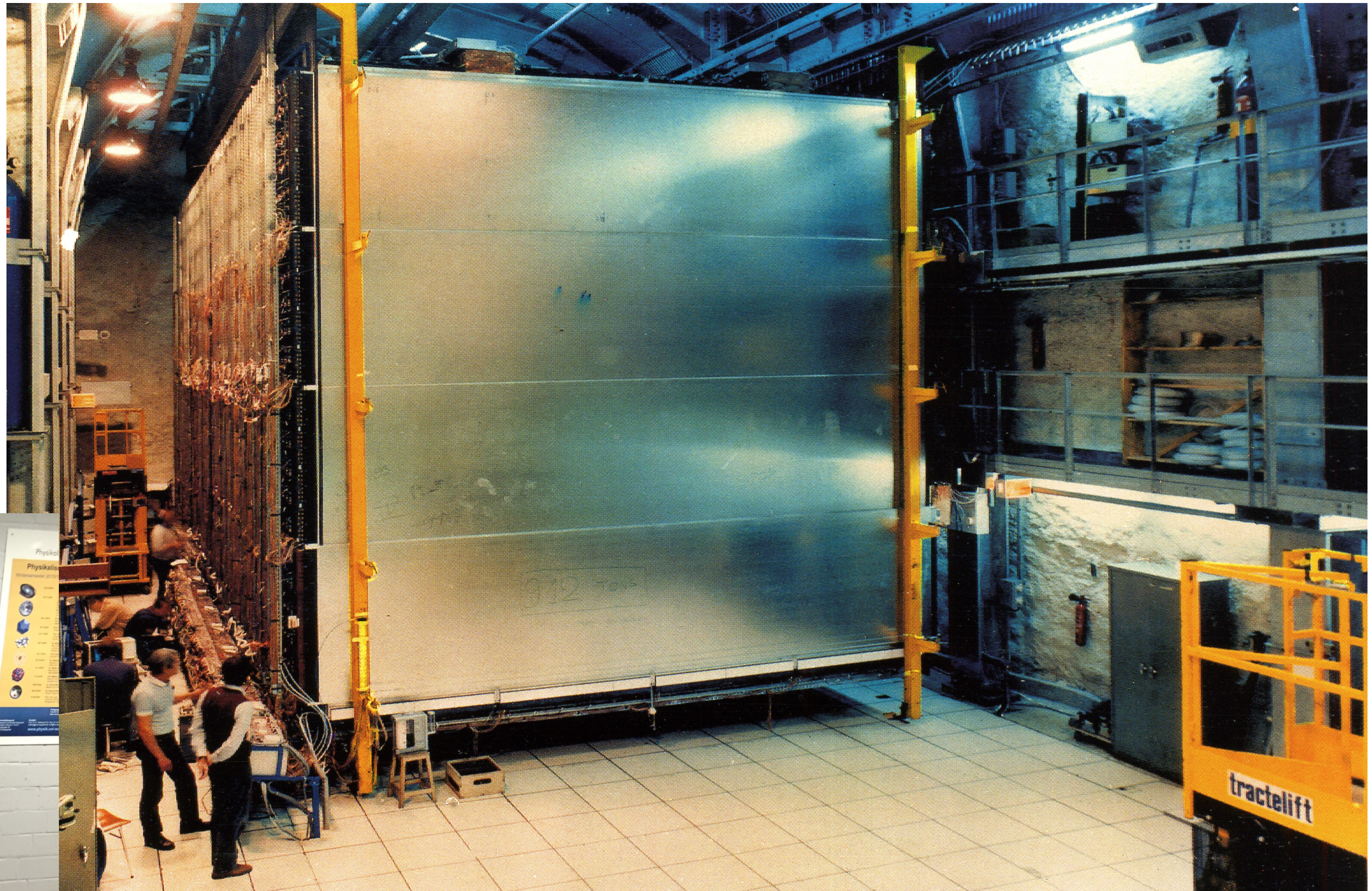
Andrei Sacharov (1967)

Conditions for matter-antimatter asymmetry:

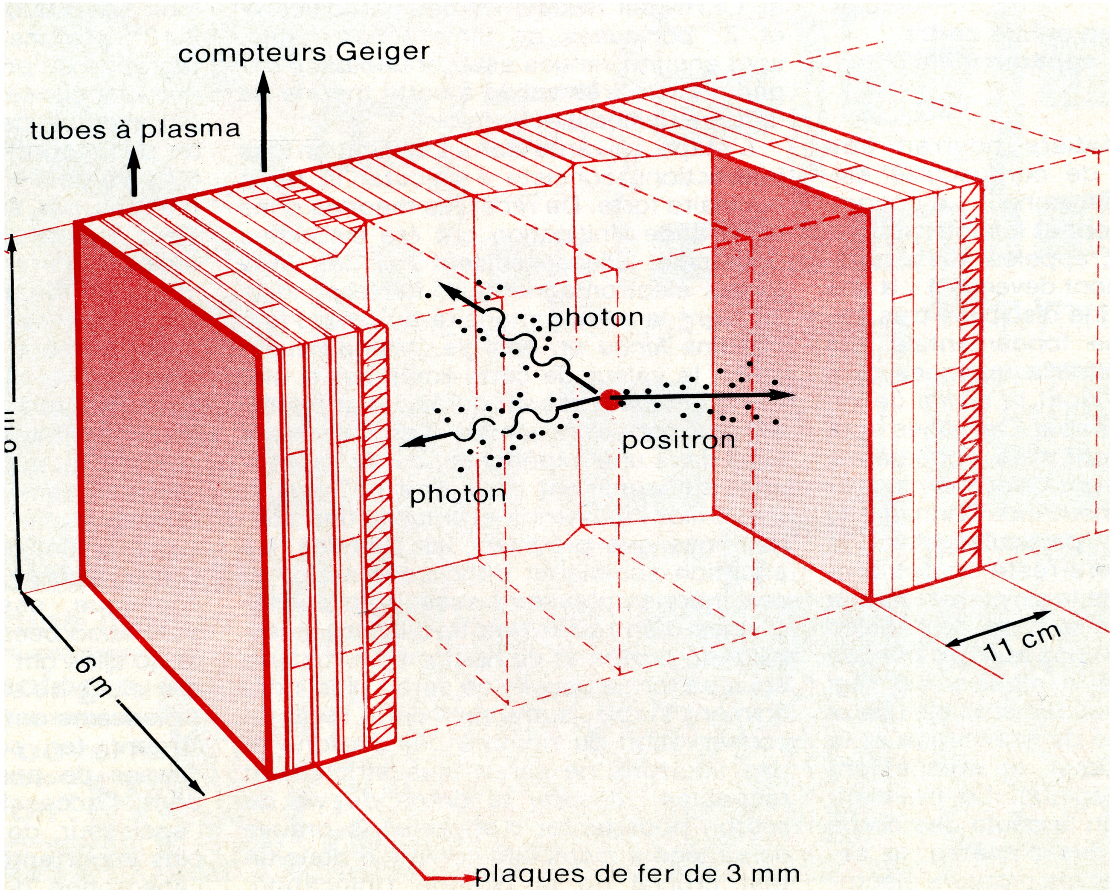
- C and CP violation
- Universe not in thermo-dynamic equilibrium state
- **Proton unstable ! (?)**

Search for the Proton Decay: Accelerator-less Particle Physics

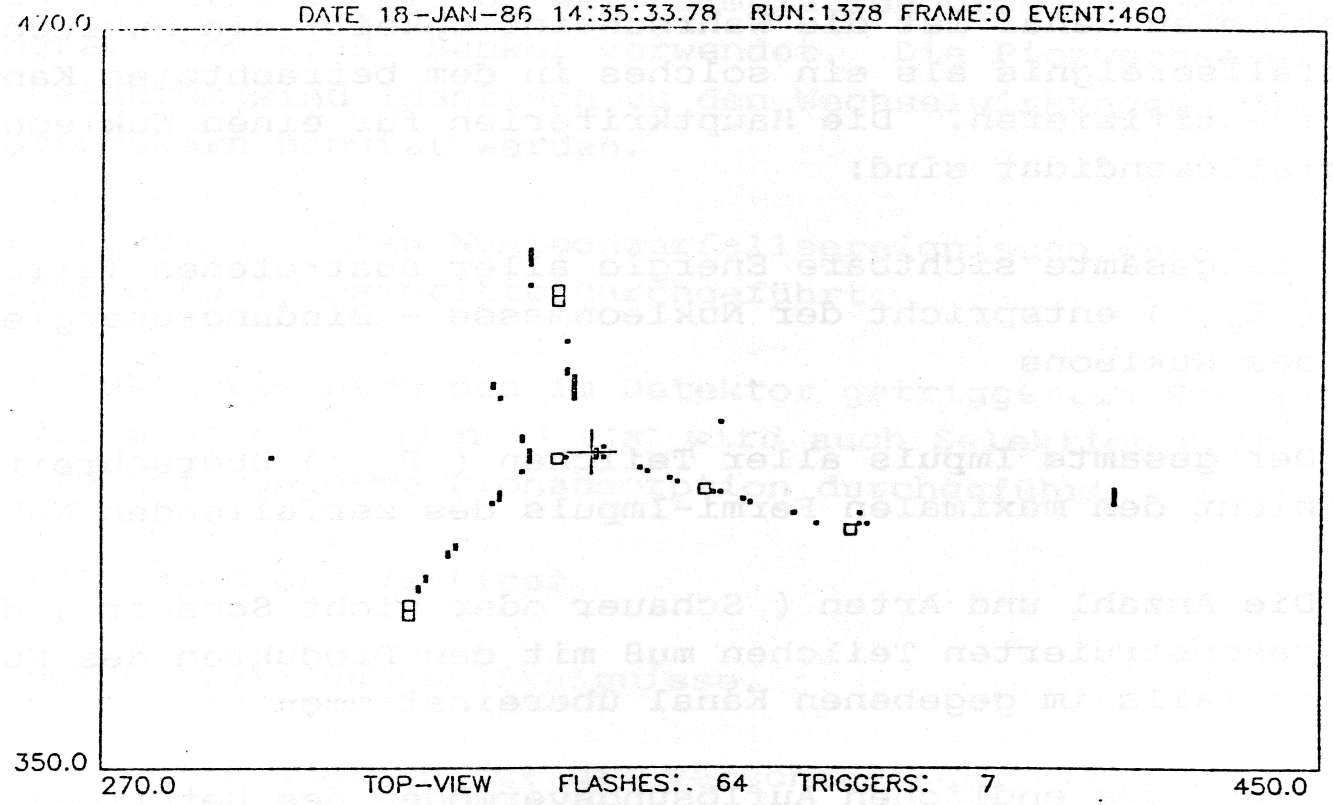
A O P S W
Laboratoire Souterrain de Modane



Searched-for Signature of the Proton Decay



Proton Decay or Neutrino Interaction?



Limits to proton lifetime (e.g.).

Physics Letters B 269 (1991) 227–233
North-Holland

PHYSICS LETTERS B

Lifetime limits on $(B-L)$-violating nucleon decay and di-nucleon decay modes from the Fréjus experiment

Fréjus Collaboration

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Y. Benadjal, D. Blum, C. Boudarios, B. Dudelzack, P. Eschstruth, S. Jullian, D. Lalanne, F. Laplanche, C. Longemare [2], C. Paulot [3], O. Perdereau, P. Roy, G. Szklarz
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L. Behr, B. Degrange, U. Nguyen-Khac, S. Tisserant [4]
LPNHE-Ecole Polytechnique, Route de Saclay, F-91128 Palaiseau, France

C. Arpesella [5], P. Bareyre, R. Barloutaud, A. Borg, G. Chardin, J. Ernwein, J.F. Glicenstein, L. Mosca, L. Moscoso
DPhPE, CEN-Saclay, F-91191 Gif-sur-Yvette Cedex, France

J. Becker [6], K.H. Becker, K. Daum, B. Jacobi, B. Kuznik, J. Löffler, H. Meyer, W. Rhode, M. Schubnell [7] and Y. Wei
Bergische Universität-Gesamthochschule Wuppertal [8], W-5600 Wuppertal, FRG

Received 31 July 1991

The fully contained events recorded in the Fréjus detector are used to search for $(B-L)$-violating nucleon decay and di-nucleon decay processes. No signal is found for a sensitivity of 2.0 kiloton year. The lower limits on the partial lifetime for the various nucleon decay modes range from 5.4×10^{30} yr for $p\to\mu^-\pi^+K^+$ to 1.0×10^{32} yr for $pn\to e^+n$. We also quote limits on neutron and di-neutron decay into three and two neutrinos respectively.

Table 2
Lower limits on the nucleon lifetime at 90% CL for $(B-L)$-violating nucleon decay and nucleon decay via virtual meson exchange. For each decay mode the detection efficiency ϵ, the expected neutrino induced background B, the number of observed candidates N_C, the upper limit on the contribution of a possible signal at 90% CL S_{90} and the lower limits on the ratio of the nucleon lifetime over the unknown branching ratio into the considered decay mode without (τ'_N/BR) and with (τ_N/BR) background subtraction is given. If no background events are selected from the simulated neutrino sample (with a sensitivity of 12.8 kty) a value of $B<0.1$ is given corresponding to an upper limit of 66% CL on this background.

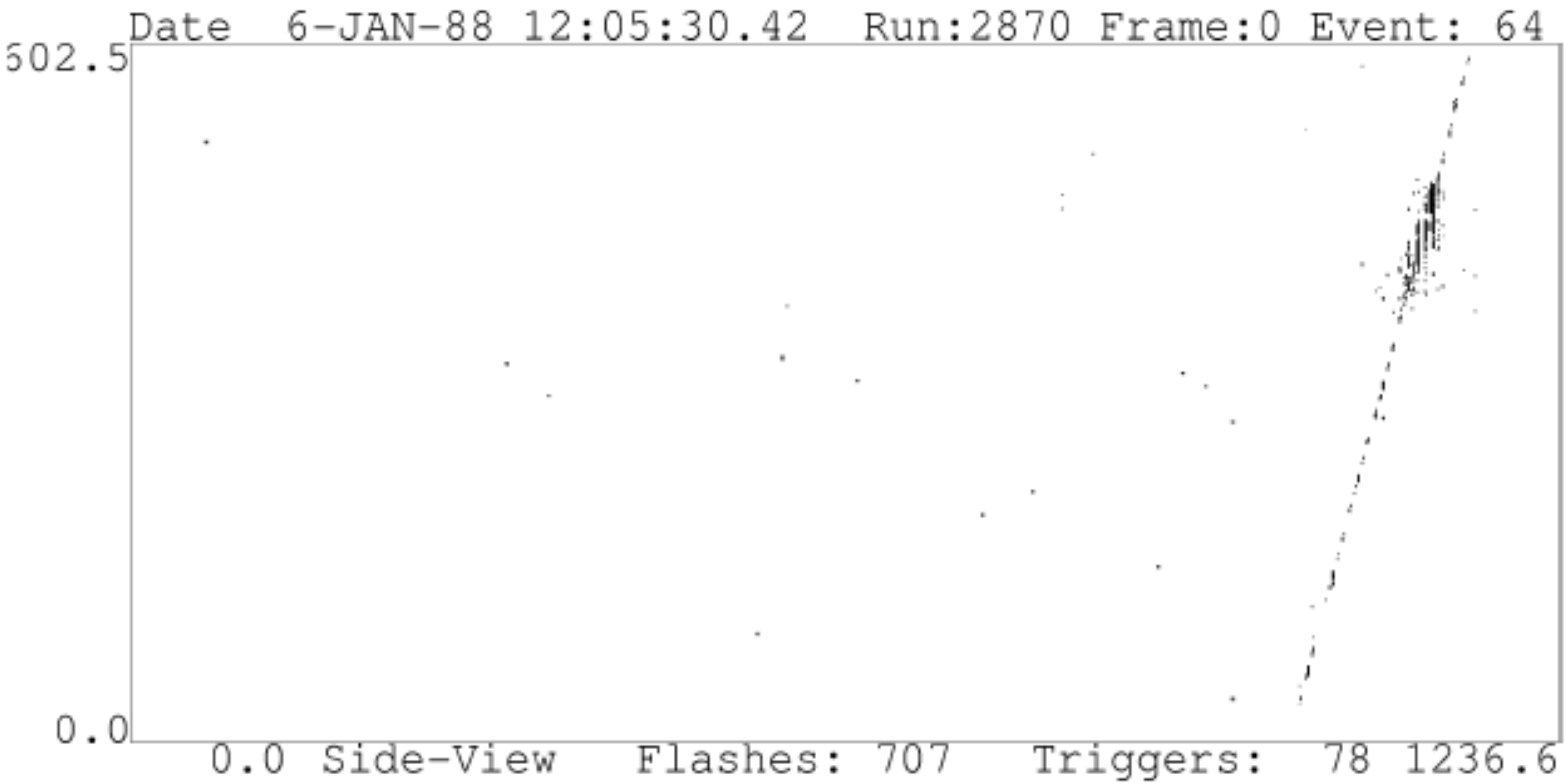
$\Delta(B-L)$	$\Delta B=1$	ϵ (%)	B	N_C	S_{90}	τ'_N/BR (10^{31} yr)	τ_N/BR (10^{31} yr)
2	$n\to\gamma\nu$	32.3	6.86	10	8.76	1.4	2.4
	$n\to e^-e^+\nu$	26.5	<0.10	0	2.30	7.4	7.4
	$n\to e^-\mu^+\nu$	17.0	<0.10	0	2.30	4.7	4.7
	$n\to\mu^-\mu^+\nu$	15.1	1.40	0	2.30	4.2	4.2
	$p\to e^+\nu\nu$	21.1	6.08	11	10.57	0.7	1.1
	$p\to\mu^+\nu\nu$	16.2	11.23	7	4.34	0.8	2.1
	$n\to e^-\pi^+$	19.8	1.09	0	2.30	5.5	5.5
	$n\to\mu^-\pi^+$	11.7	1.40	0	2.30	3.3	3.3
	$n\to e^-K^+$	21.7	2.96	3	4.38	2.1	3.2
	$n\to\mu^-K^+$	20.4	2.18	0	2.30	5.7	5.7
	$p\to e^-\pi^+\pi^+$	15.9	2.50	1	2.91	2.3	3.0
	$p\to\mu^-\pi^+\pi^+$	9.4	1.72	1	3.06	1.4	1.7
	$n\to e^-\pi^+\pi^0$	15.0	0.78	1	3.36	2.5	2.9
	$n\to\mu^-\pi^+\pi^0$	12.1	0.78	0	2.30	3.4	3.4
	$p\to e^-\pi^+K^+$	16.5	2.50	3	4.62	1.4	2.0
	$p\to\mu^-\pi^+K^+$	4.5	0.78	2	4.61	0.5	0.5
0	$pn\to e^+n$	42.3	6.40	5	4.56	5.0	10.3
	$pn\to\mu^+n$	52.0	5.93	7	6.42	5.0	8.9
	$pp\to e^+p$	33.7	0.16	0	2.30	8.2	8.2
	$pp\to\mu^+p$	43.4	2.96	2	3.53	4.5	6.8
	$pp\to e^+\Delta^+$	23.1	1.40	1	3.14	3.3	4.1
	$pp\to\mu^+\Delta^+$	21.5	4.84	2	3.15	2.3	3.8
	$pn\to e^+\Delta^0$	16.5	1.25	1	3.19	4.8	5.7
	$pn\to\mu^+\Delta^0$	19.1	6.86	2	2.93	4.0	7.1
	$nn\to e^+\Delta^-$	14.2	2.96	2	3.53	1.7	2.6
	$nn\to\mu^+\Delta^-$	20.4	6.71	4	3.86	1.7	3.4

Consequence

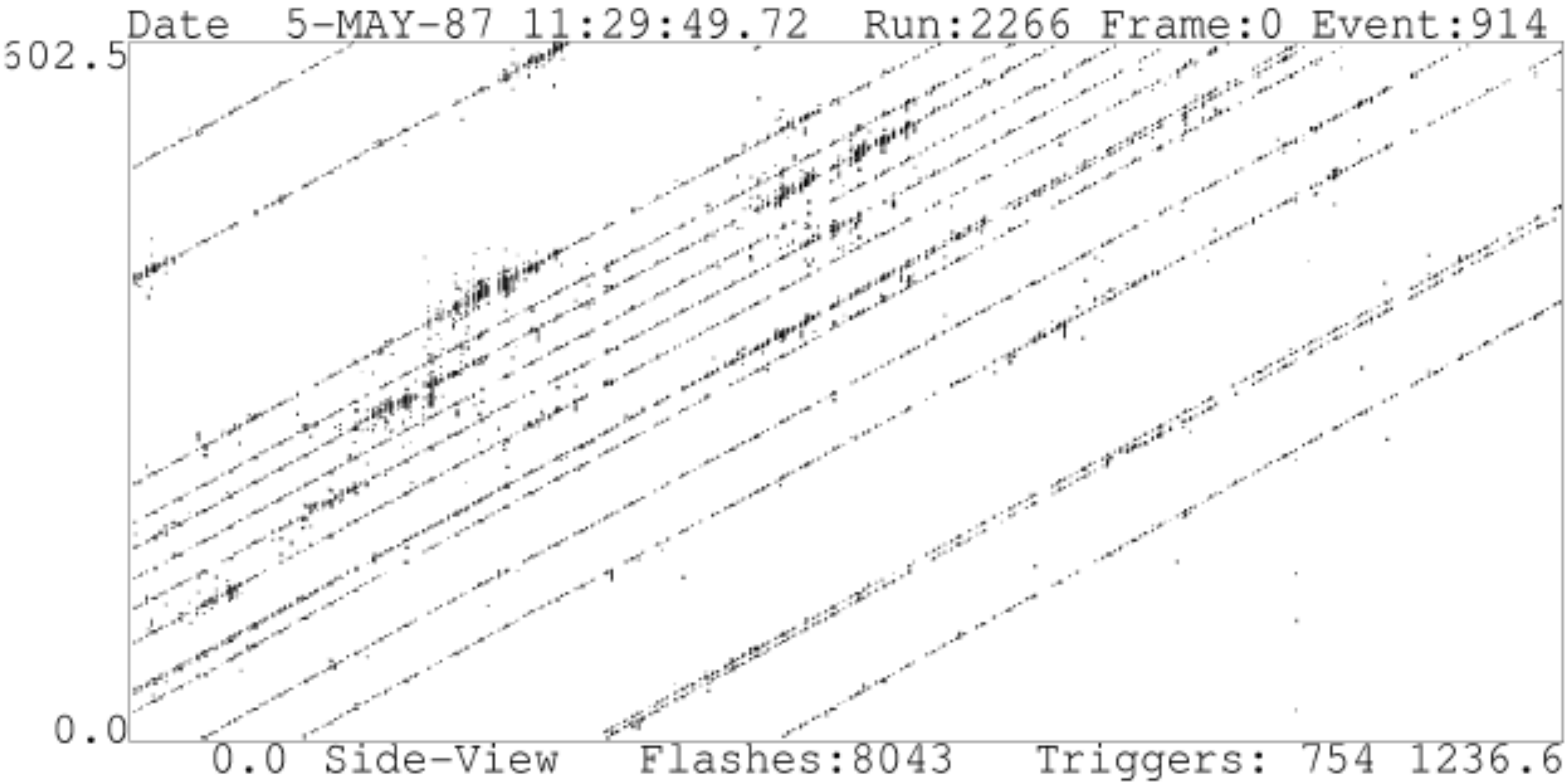
Minimal SU(5) and minimal SUSY SU(5) excluded.

What about an Underground Analysis ?

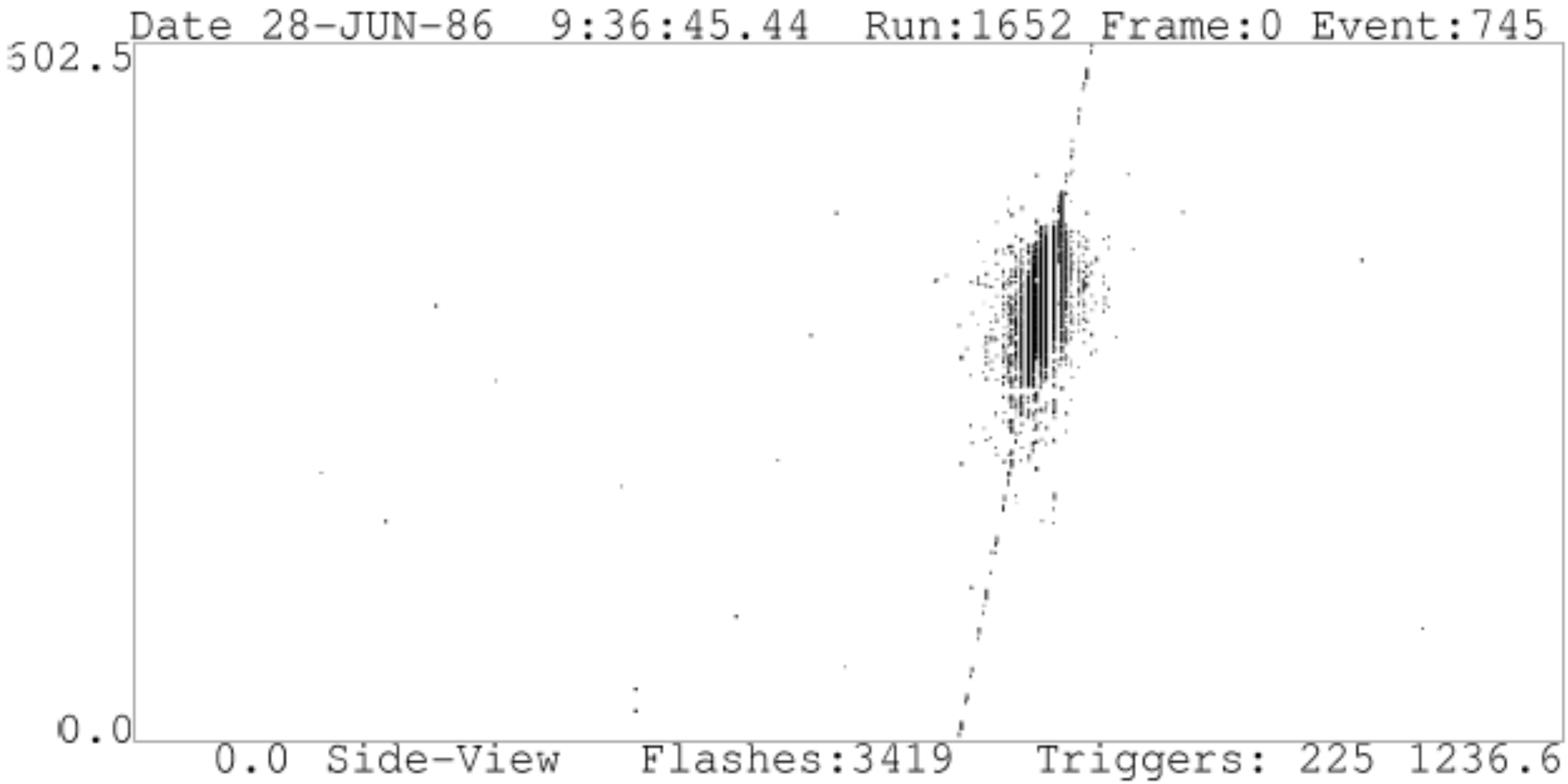
Observed Events: Throughgoing Muons



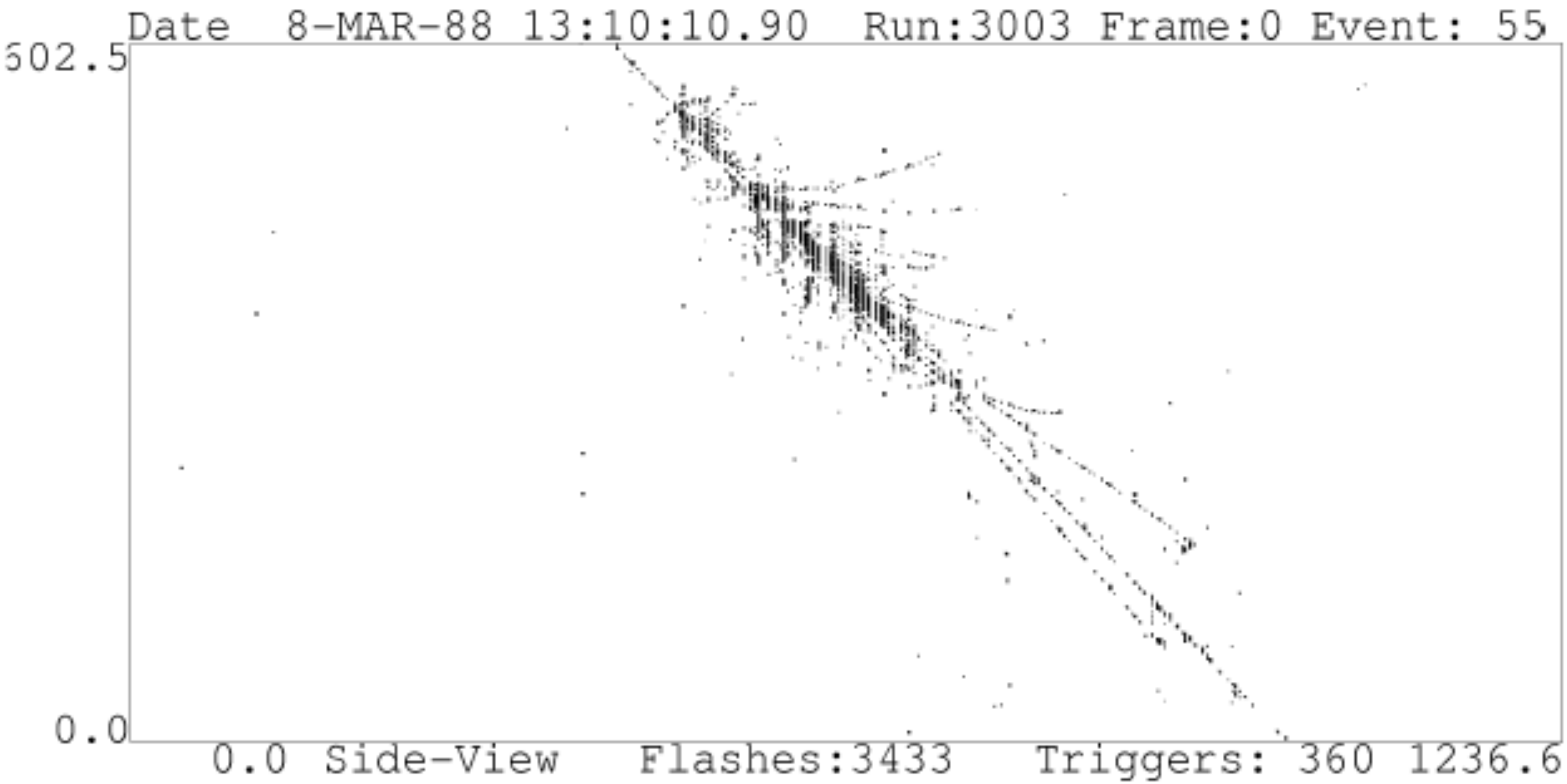
Observed Events: Multiple Muons



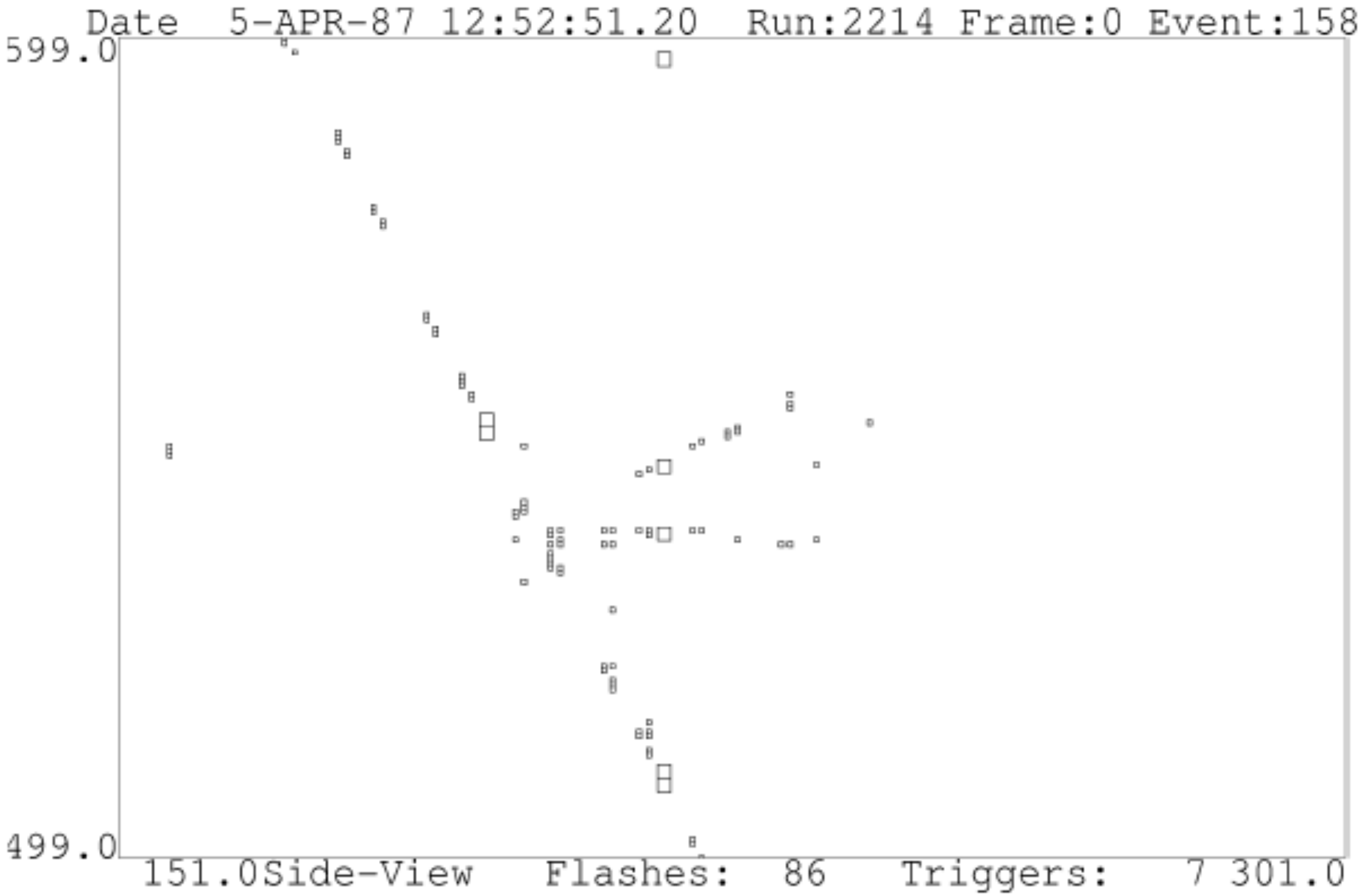
Observed Events: Throughgoing Muons + Brems



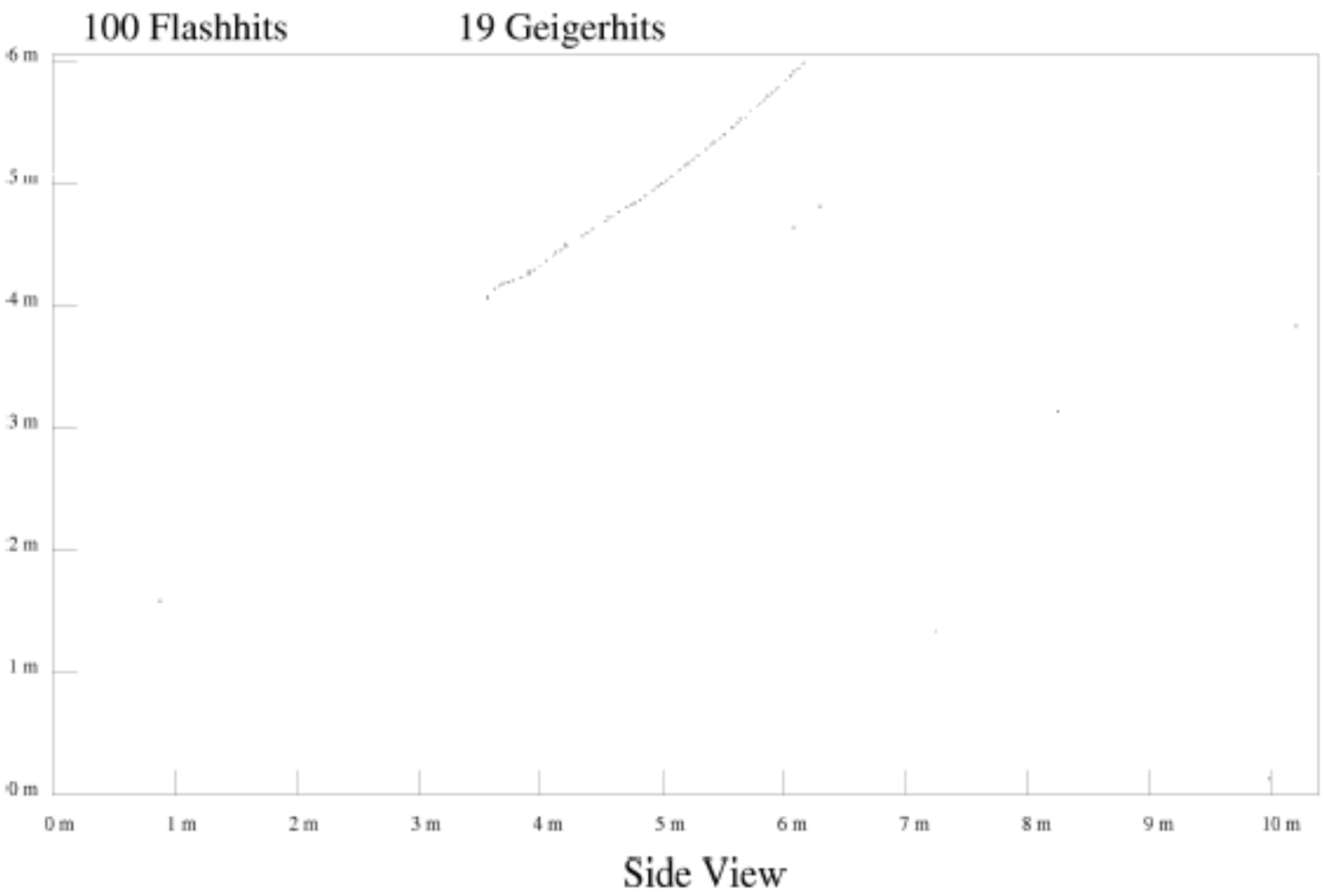
Observed Events: Throughgoing Muons + Hadronic Interaction



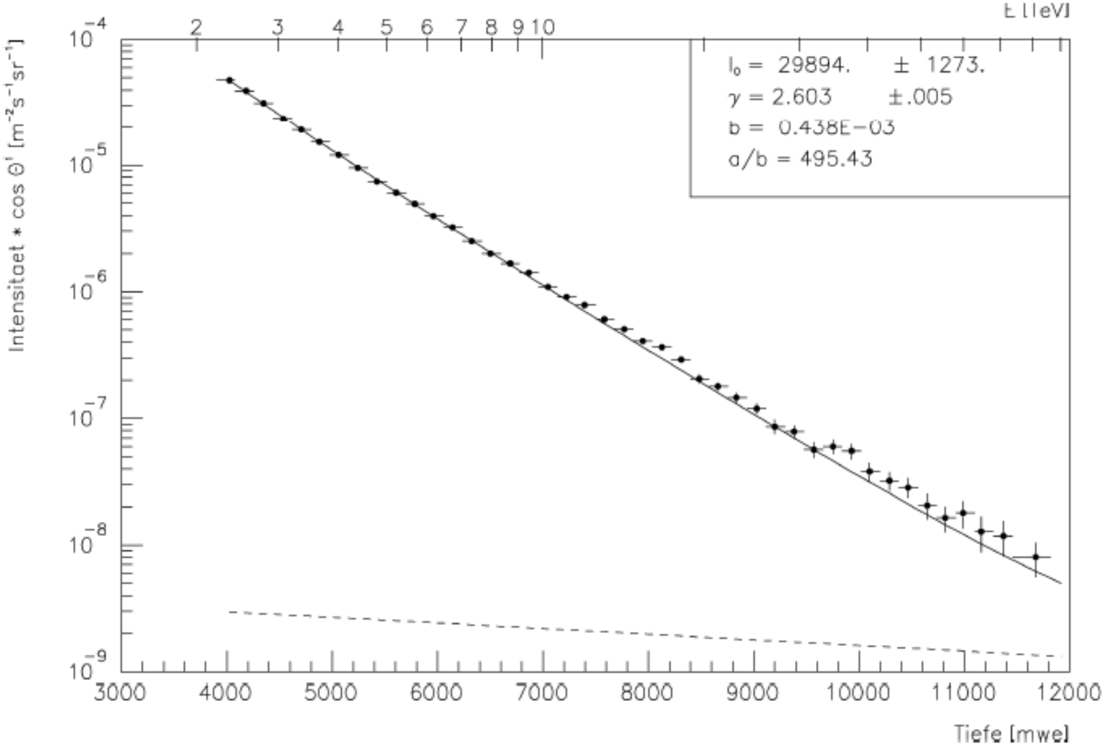
Observed Events: Throughgoing Muons + π^0 - Decay

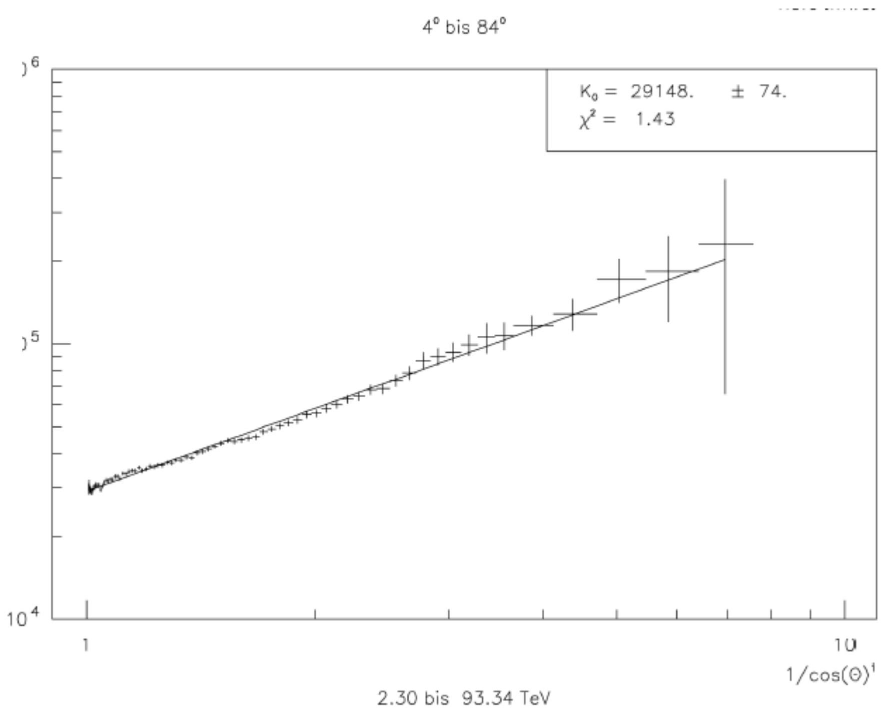


Observed Events: Stopping Muon



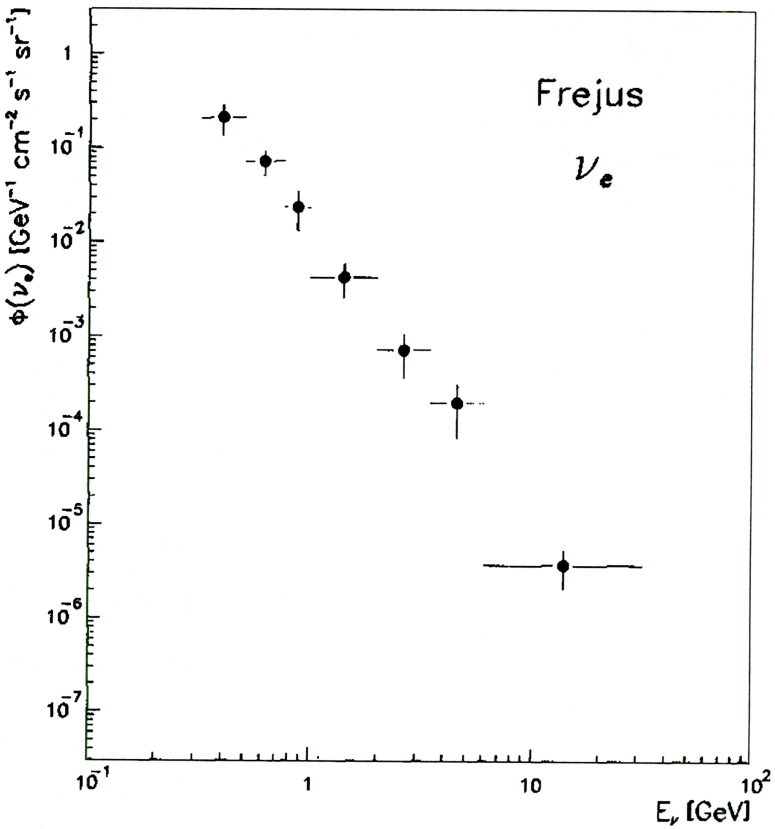
Results: Depths, energy, and angular dependence of the atm. muon flux

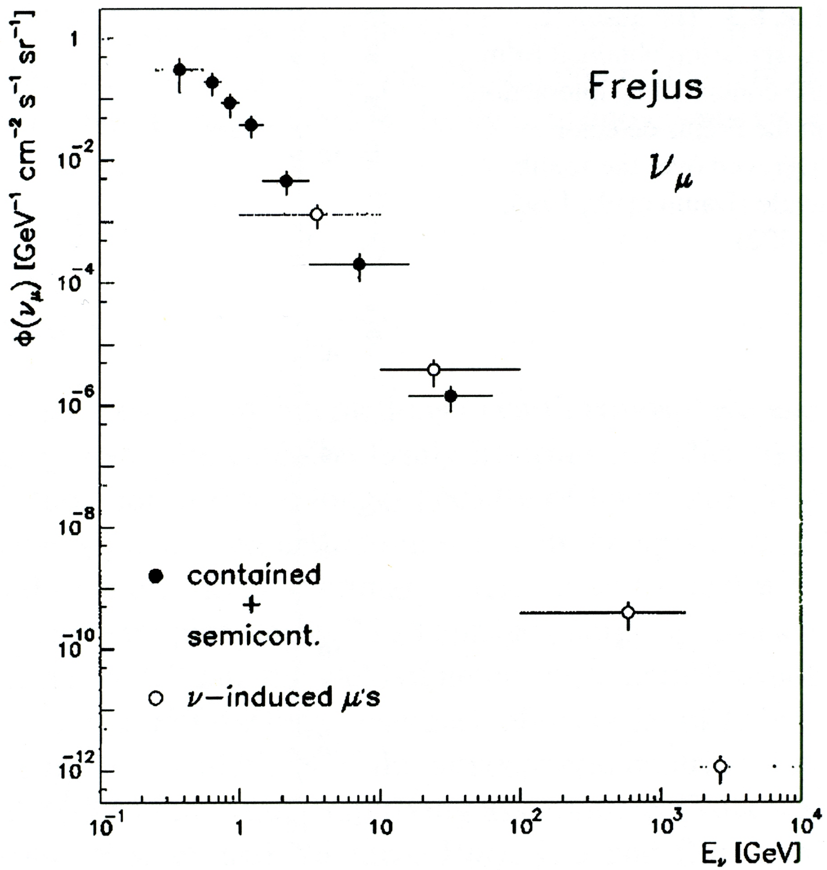




- Prompt ?
- Cross Section?
- Angular Effect?
- Monte Carlo ?

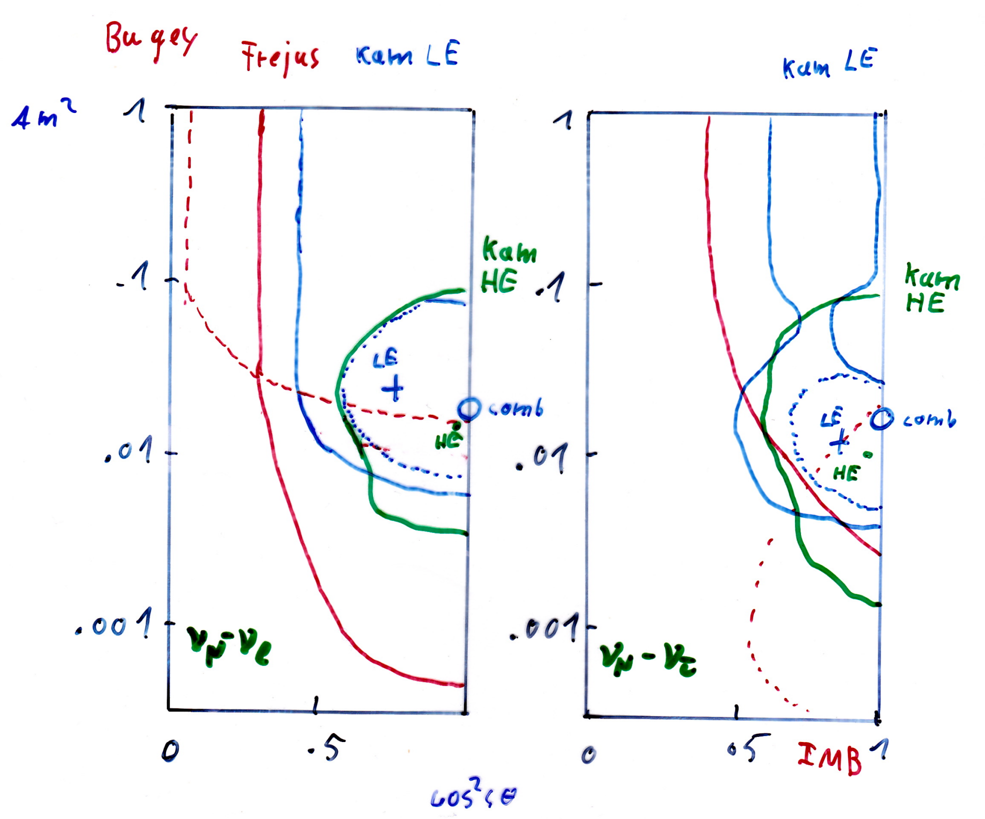
Energy spectra of atmospheric electron and muon neutrinos.





$$P(\nu_i -> \nu_j) = \sin^2 2\Theta \cdot (1.27 \cdot \Delta m^2 \cdot L/P_\nu)$$

Neutrino Oscillations ?



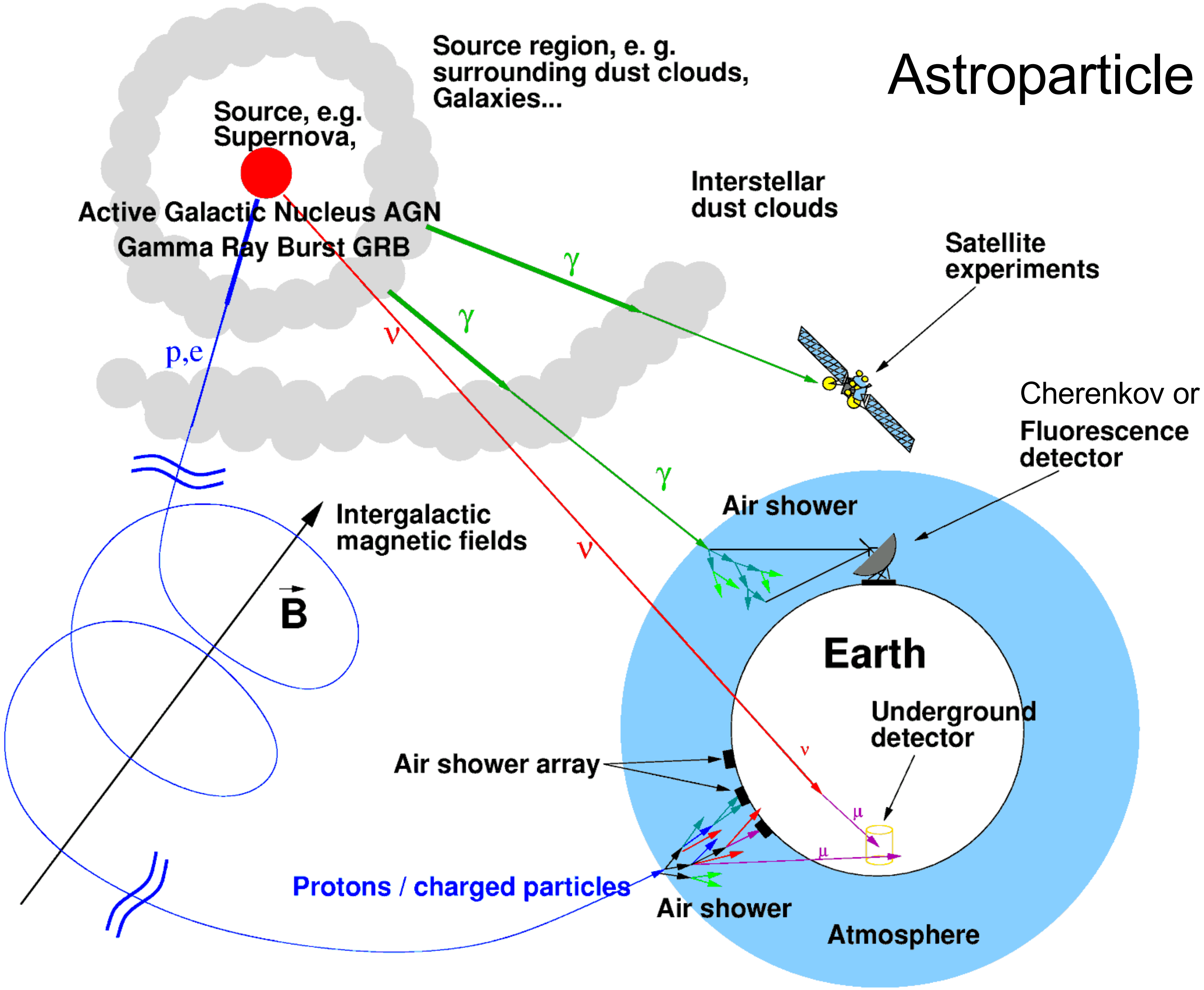
Consequence

(after Super Kamiokande & SNO)

Non-zero neutrino masses.

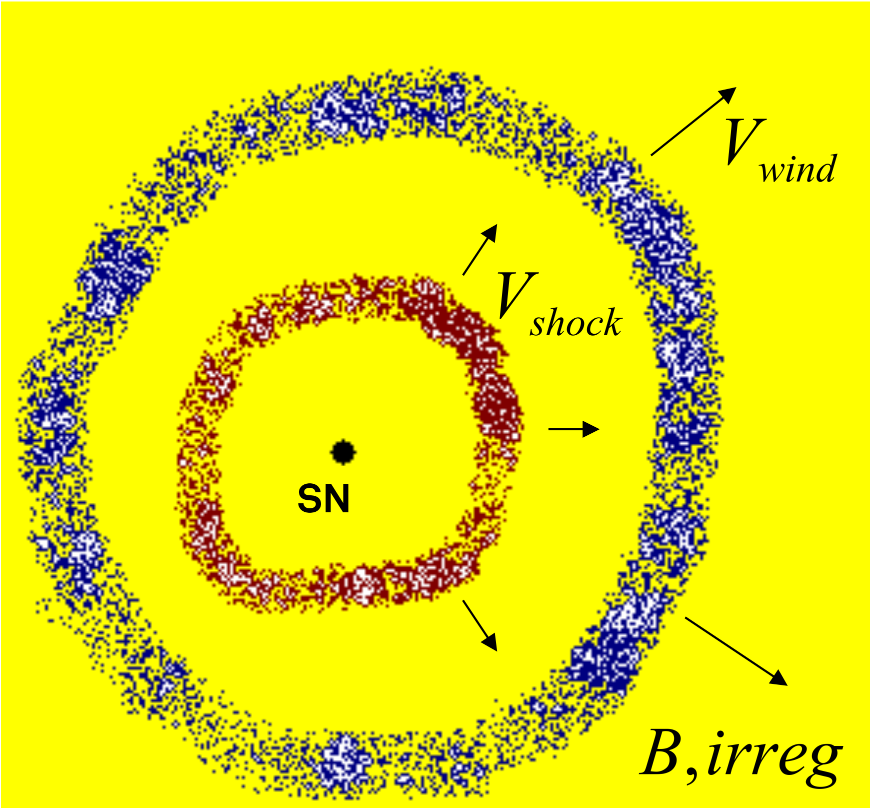
Extension of the Standard Model

Astroparticle Physics



Fermi-Acceleration (Typ II)

$$E_1 = E_0 + \varepsilon \cdot E_0 = E_0 \cdot (1+\varepsilon)$$



$$E_n = E_0 (1+\varepsilon)^n$$

$$n = \frac{\ln(E/E_0)}{\ln(1+\varepsilon)}$$

$$E \le E_0 (1+\varepsilon)^{t/T_{cycle}}$$

$$\gamma \cong \frac{1}{\varepsilon} \times \frac{T_{cycle}}{T_{esc}}$$

$$Energy / time \times vol \approx N_{obj} / vol \times E_{obj} \times \frac{effi}{T_{life}}$$

or
cs

Particle Physics

$$\Phi_p \sim E^{-2}$$

$$p\gamma \rightarrow \Delta^+$$

$$\Delta^+ \rightarrow \pi^0 p, \quad \pi^0 \rightarrow \gamma\gamma$$

$$\Delta^+ \rightarrow \pi^+ n, \quad n \rightarrow p\, e^- \bar{\nu}_e$$

$$\pi^+ \rightarrow \mu^+ \nu_\mu, \quad \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

$$pp \rightarrow \ldots$$

$$E_\nu = {}^4\!/_3\, E_\gamma$$

$$\frac{\Phi_\gamma}{\Phi_{\nu_\mu}} = \frac{2}{1}$$

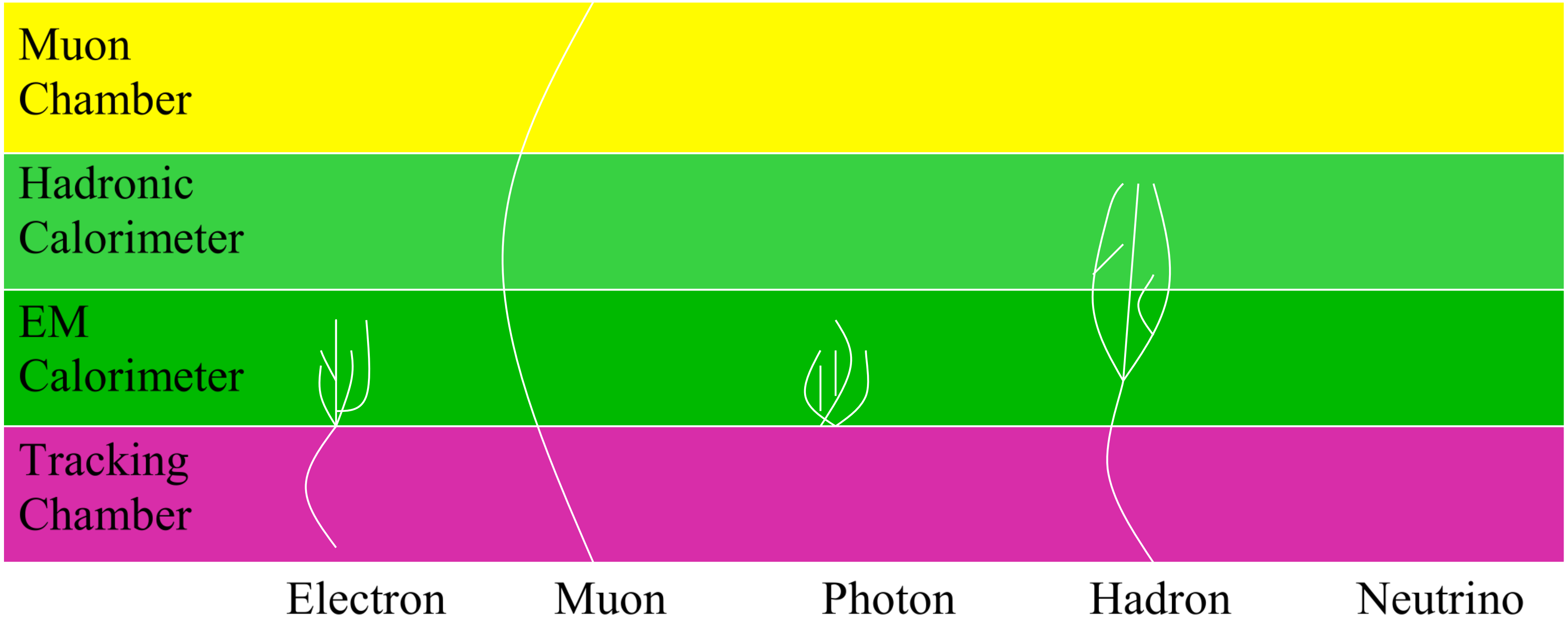
$$\frac{\Phi_{\nu_\mu}}{\Phi_{\bar{\nu}_\mu}} = \frac{1}{1}$$

$$\frac{\Phi_{\nu_\mu}}{\Phi_{\nu_e}} = \frac{1}{1}$$

Look at the Sky !

- With Gammas : ... → HEGRA → H.E.S.S., MAGIC → FACT → CTA
- With Nuclei : ... → KASCADE, HEGRA → AUGER
- With Neutrinos: ... → AMANDA, ANTARES → IceCube, Km3NET →
- With Radio: ... → LOFAR →
- ... all those wonderful preceding talks !

The whole sky?



All subdetectors located at different places of the Earth ! ☹
Multi-Messenger Astronomy is needed but only sometimes possible?

technische universität dortmund

Cherenkov Telescope Ring

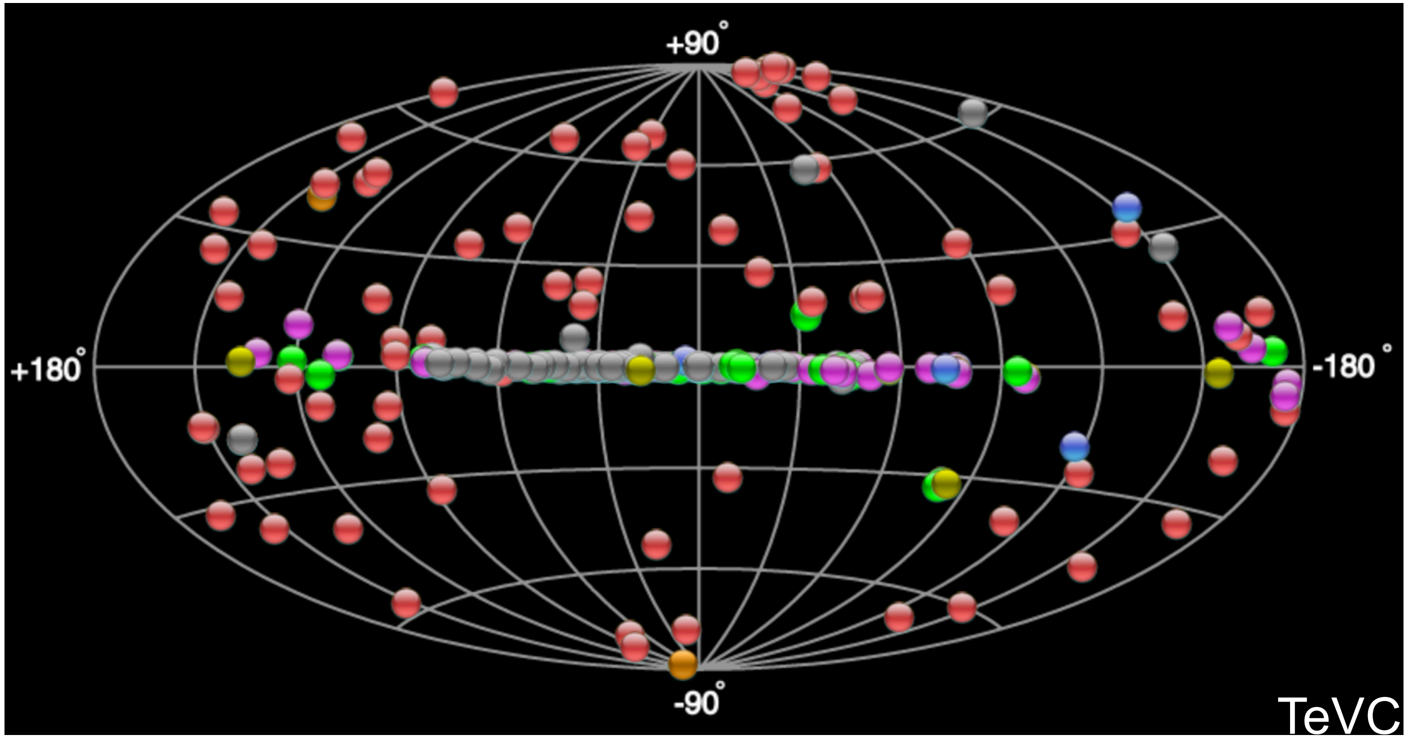
An Idea for World-Wide Monitoring of the VHE Sky

Dominik Elsässer , Wolfgang Rhode, Tim Ruhe,
M. Nöthe, K. Brügge
TU Dortmund

Where we are :

- Several highly successful VHE facilities (VERITAS, H.E.S.S., MAGIC, FACT, HAWC)
- CTA prototypes progressing well
- Lots of interesting sources to study and physics problems to solve

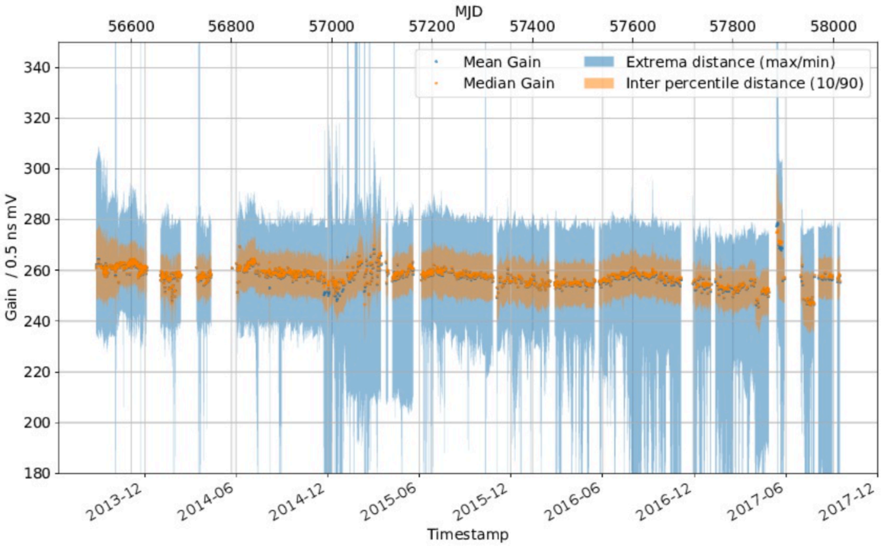
The VHE Sky in 2018: A VHE success story



Why is there even a need to act now?

- First full CTA science operations horizon still beyond typical university education timescales. Need to conserve expertise and provide continuity in education!
- Lingering hard physics questions still unanswered: Acceleration mechanisms, CR luminosity
- Multi – messenger astronomy picking up tremendous speed: Gravitational waves & IceCube neutrinos
- Strong motivation for near-instantaneous observation capability

FACT: A highly successful technology & methods pioneer

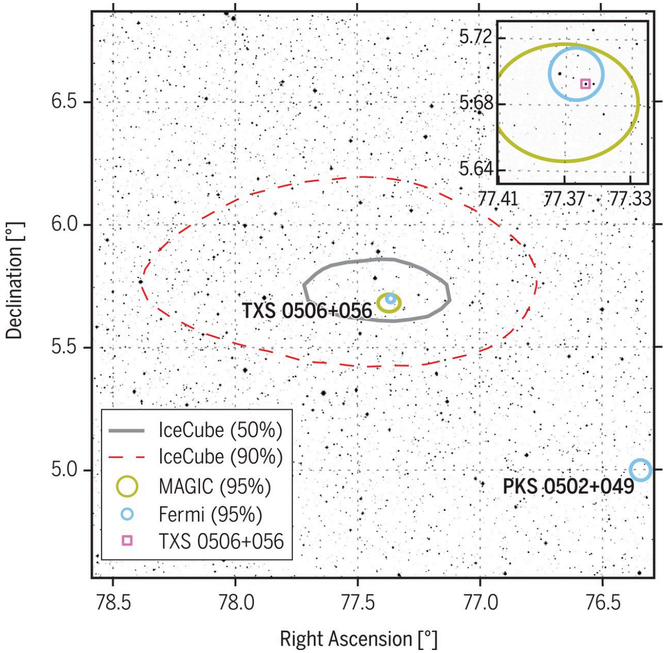


FACT/ J. Buss

FACT achievements towards future instruments

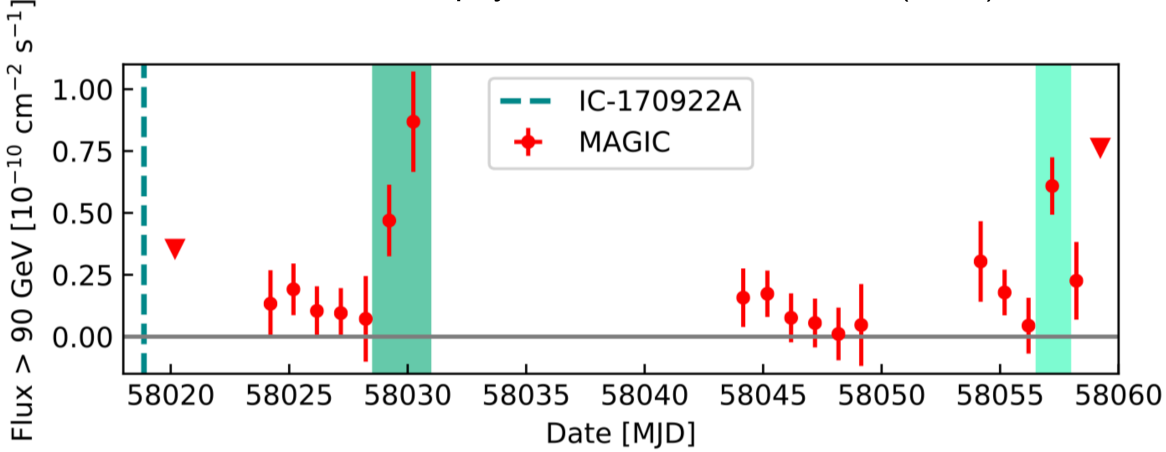
- Suitability of SiPM – cameras for dense monitoring of sources even under difficult conditions
- Demonstrated reliability, robotic operations!
- Public data set: https://fact-project.org/data/
- High – performance public analysis software developed: https://github.com/fact-project/fact-tools

TXS 0506: Harbinger of the neutrino point – source era



Science 13 Jul 2018:
Vol. 361, Issue 6398

The Astrophysical Journal Letters, 863 (2018) L10



What can we do to preserve & greatly expand VHE monitoring & follow – up capabilities worldwide?

Proposal

Three pillars:

A) Preserve, maintain and upgrade existing facilities well into the CTA era

B) Build upon the expertise gained from prototypes & precursor experiments (FACT, but also the CTA prototypes)

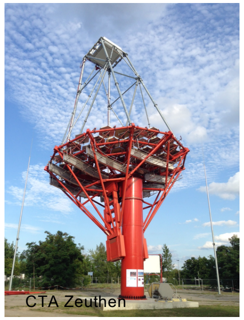
C) Form group of international partners to complete a ring of IACT facilities covering a wide range of longitudes and latitudes:

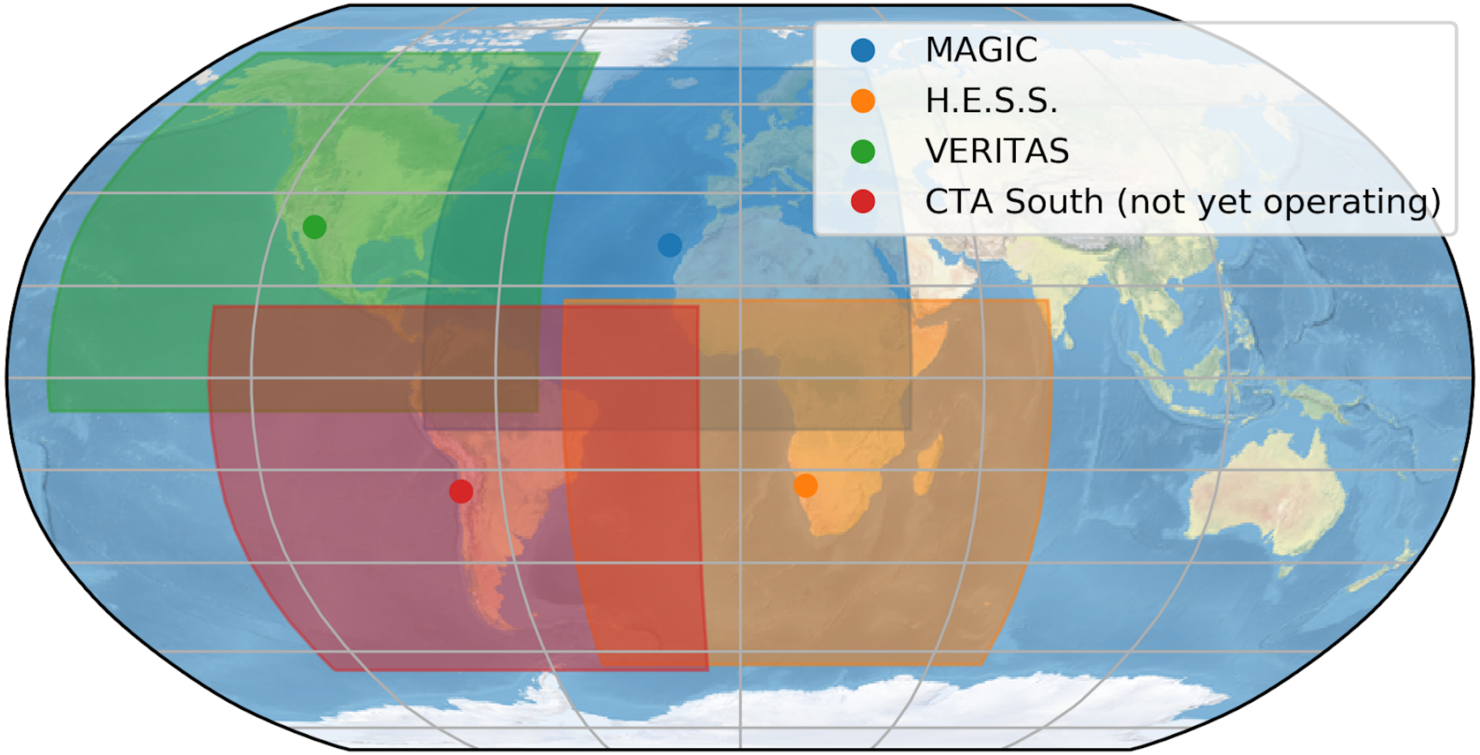
Cherenkov Telescope Ring

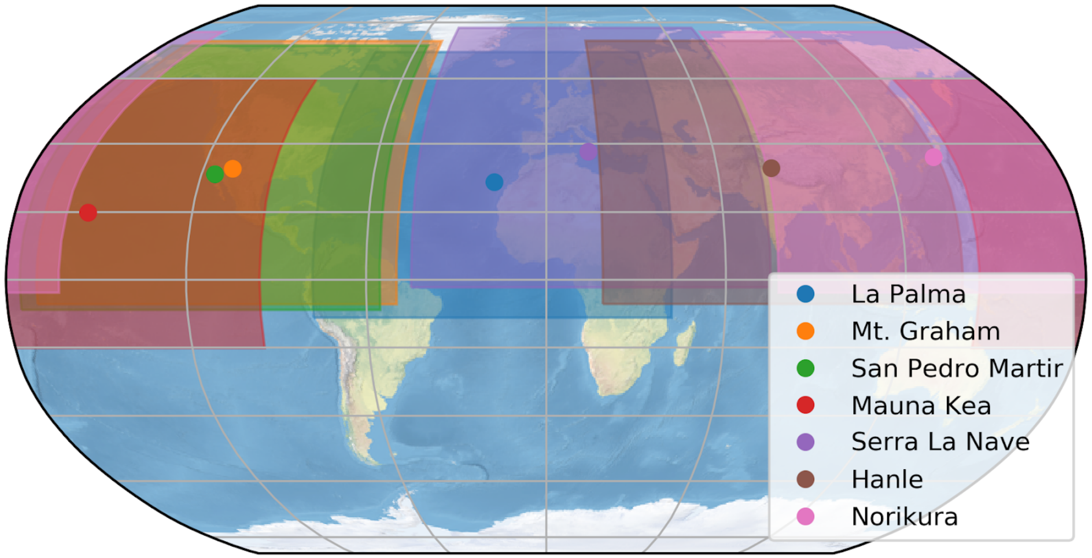
- Achieve few percent Crab flux sensitivity above ~150GeV per site

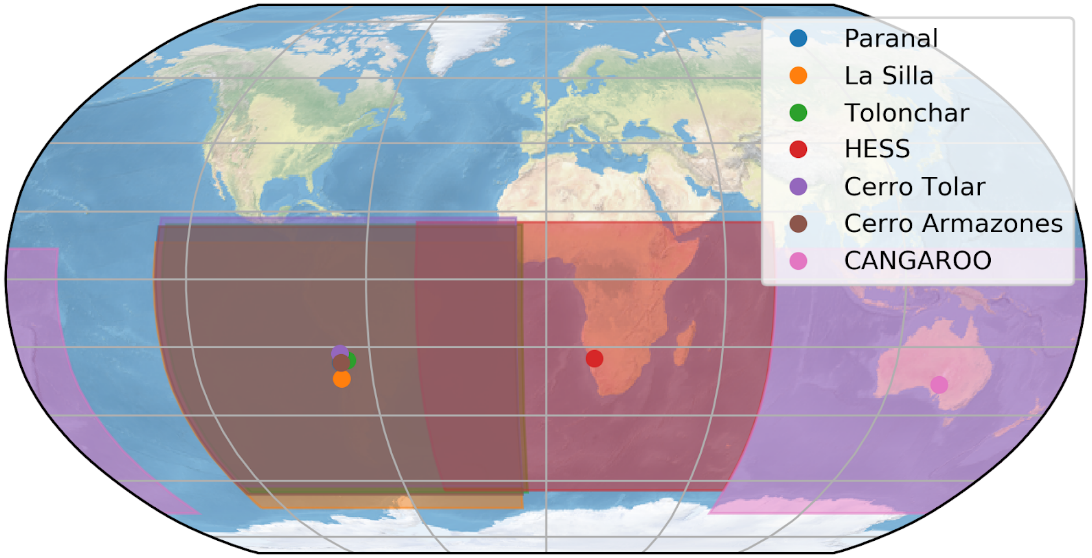
- This will open up the Universe out to z~1, including amongst others the VHE - detected FSRQ population

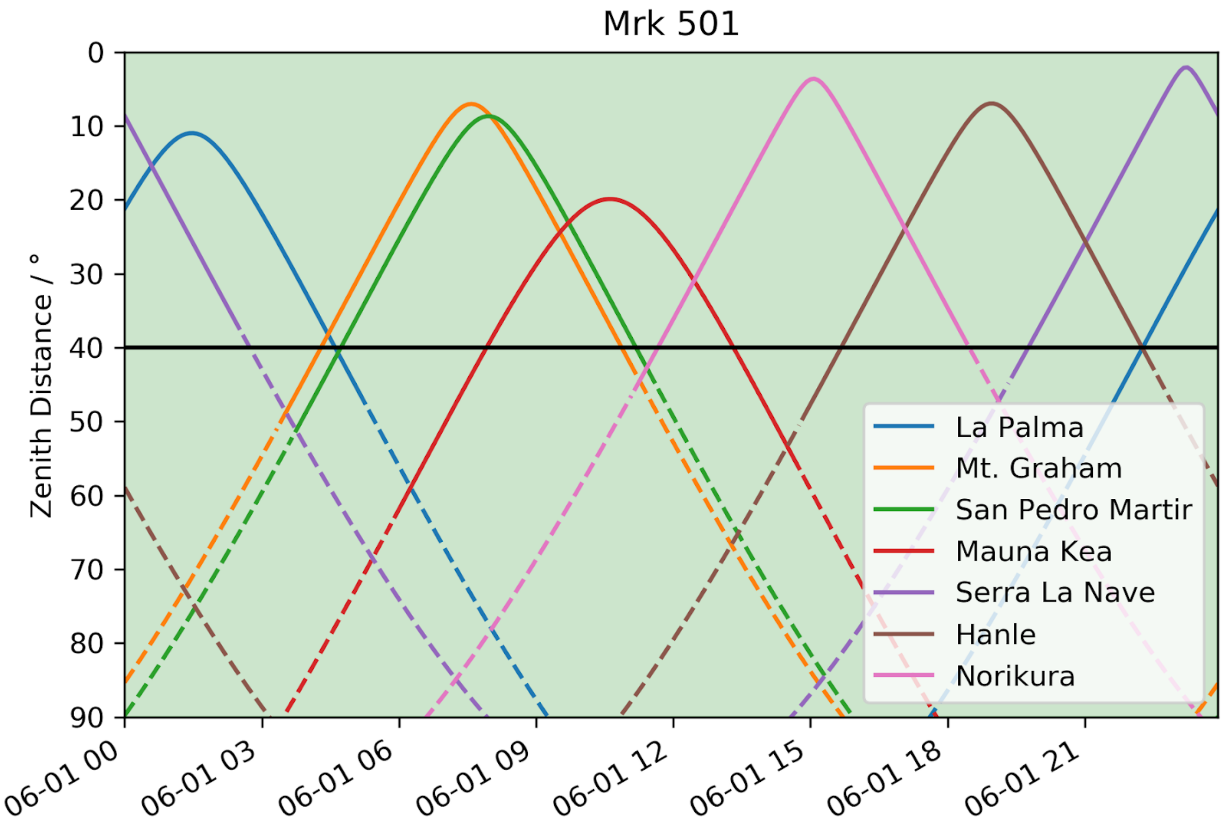
- Baseline telescope can be "MST - like", meaning ~90sqm mirror area, modular camera with state-of-the-art readout and SiPM sensors. Projected price tag per site 350k – 500k Euros




MAGIC
H.E.S.S.
VERITAS
CTA South (not yet operating)


La Palma
Mt. Graham
San Pedro Martir
Mauna Kea
Serra La Nave
Hanle
Norikura


Paranal
La Silla
Tolonchar
HESS
Cerro Tolar
Cerro Armazones
CANGAROO


Mrk 501
Zenith Distance / °
0
10
20
30
40
50
60
70
80
90
06-01 00
06-01 03
06-01 06
06-01 09
06-01 12
06-01 15
06-01 18
06-01 21
La Palma
Mt. Graham
San Pedro Martir
Mauna Kea
Serra La Nave
Hanle
Norikura

Key Point: CTR is not meant to compete with CTA, but to “bridge the gap” in a temporal sense, pertaining equally to construction timescales and observational coverage.

→ CTA will provide deep coverage and wide energy range, while CTR can complement time series

→ CTR can provide alerts to CTA

- Strong physics motivation for expanded world – wide monitoring capability
- Can be achieved with realistic efforts now by building upon existing facilities & expertise from pioneering instruments (CTA, FACT, et al.)
- Additional motivation: technological and educational continuity into the CTA era

How do we understand the new data?

From Probability to Knowledge

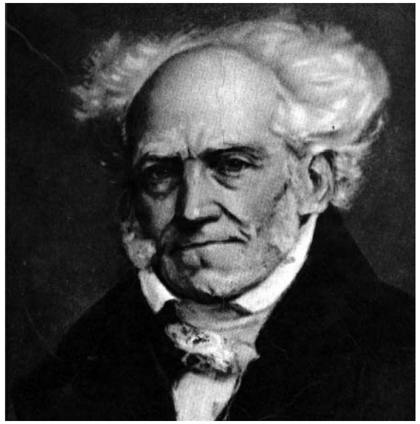
Platos Cave

World explanation:

What requirements does one place on the explanation?

How does one get from the "effect" to the "cause"?

Arthur Schopenhauer (1788 – 1860)



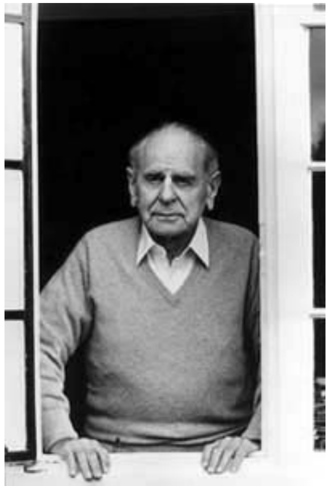
The Fourfold Root of the Priciple of The Sufficient Season:

- Logic
- Mathematics,
- Experiments ←→ uncertain knowledge
- Motivation / Teleological Action

Interpretations of probability

- Ignorance of in principal determinable details leads to a simplified representation. (Statistical Mechanics)
- Ignorance of non-computable details leads to generalized representations. (Differential equations for the description of the system not solvable, smallest changes of initial conditions lead to different results, chaos theory).
- Mathematical probability and physical law coincide. There are no physical substructures under the probability description.

Karl Popper (1902-1994)



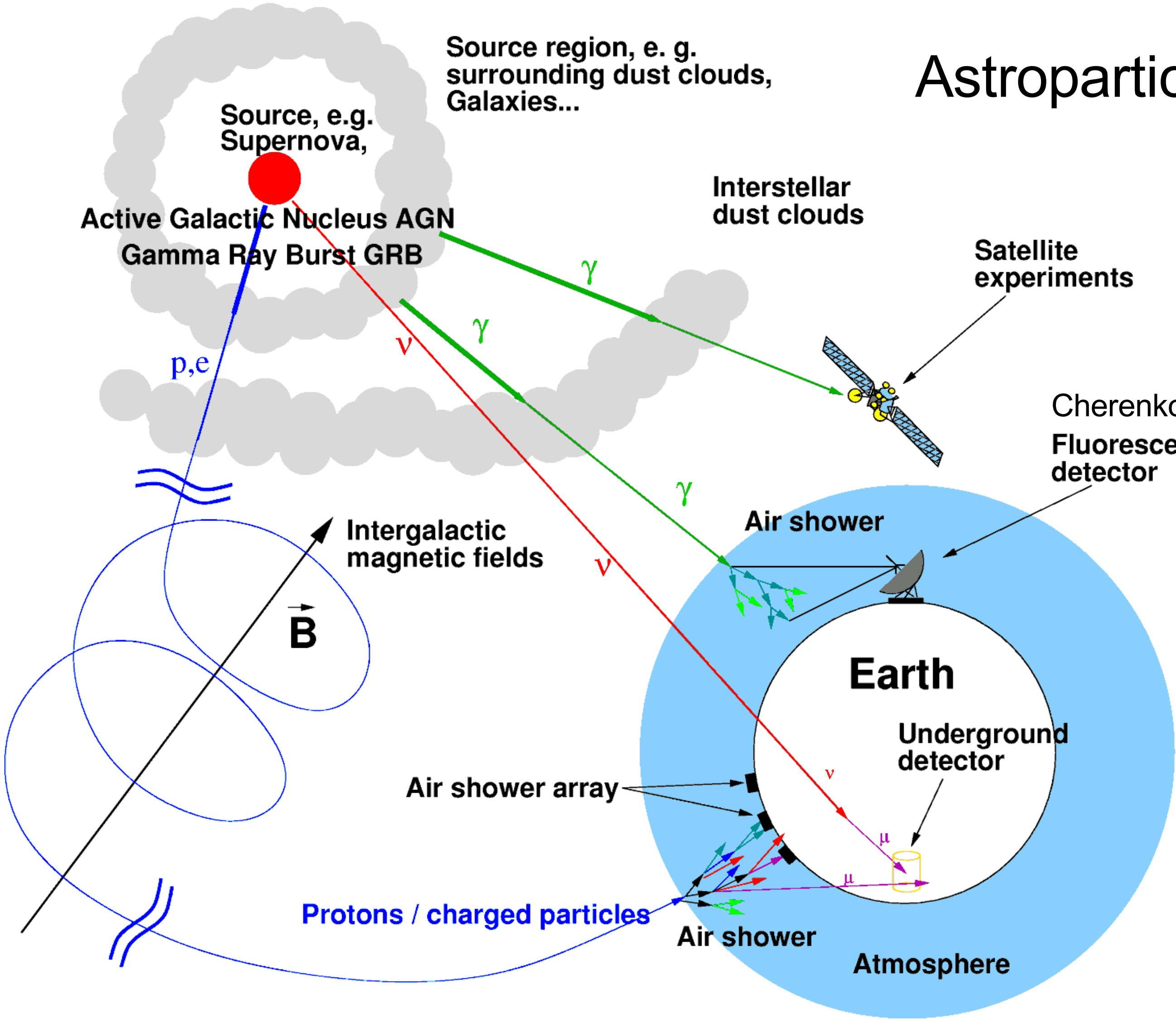
The logic of scientific research

Can theories be proven?

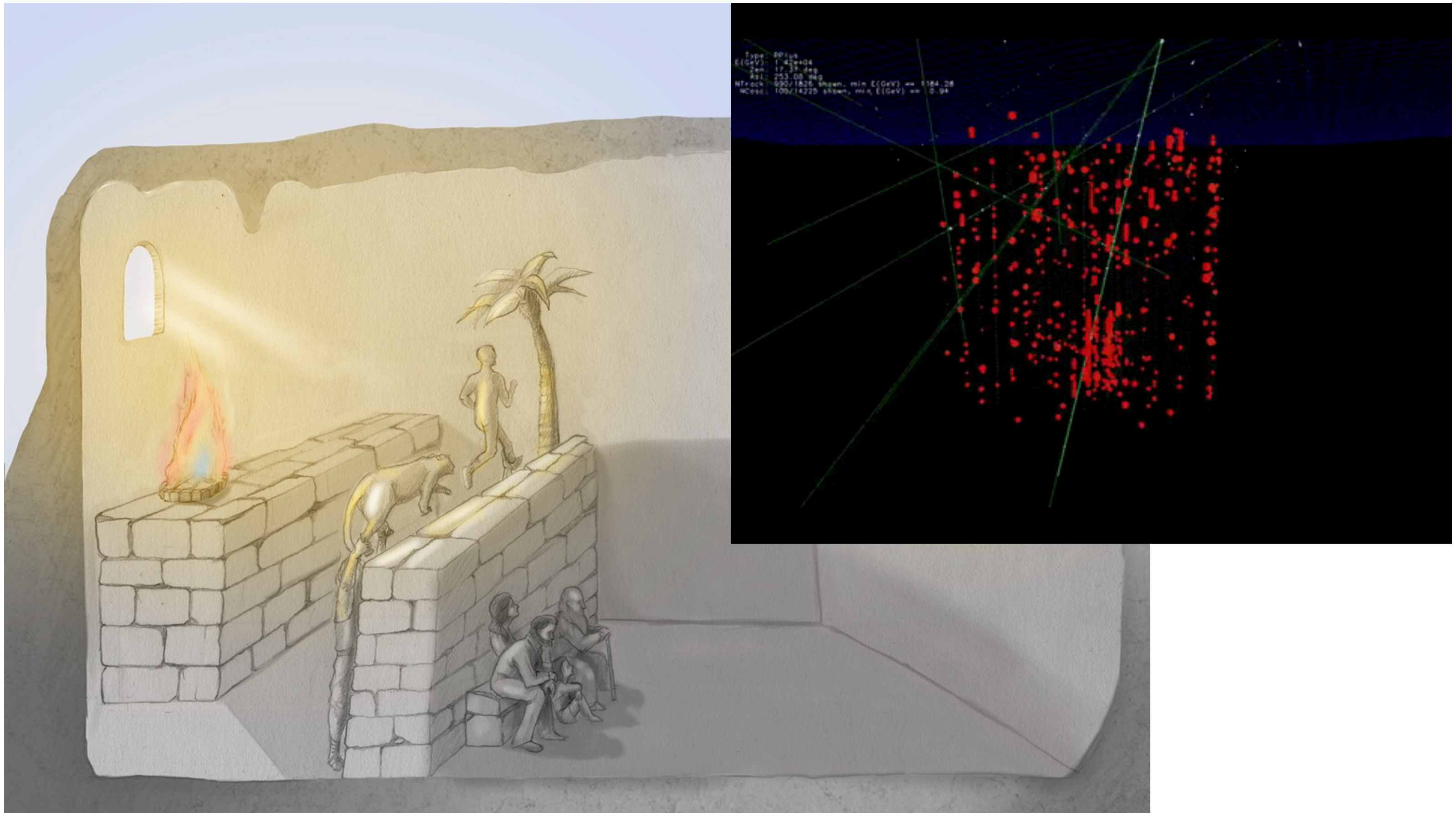
Progress in theory building through falsification:
Critical Rationalism

Is this how science develops? -> Imre Lakatos (1922-1974)

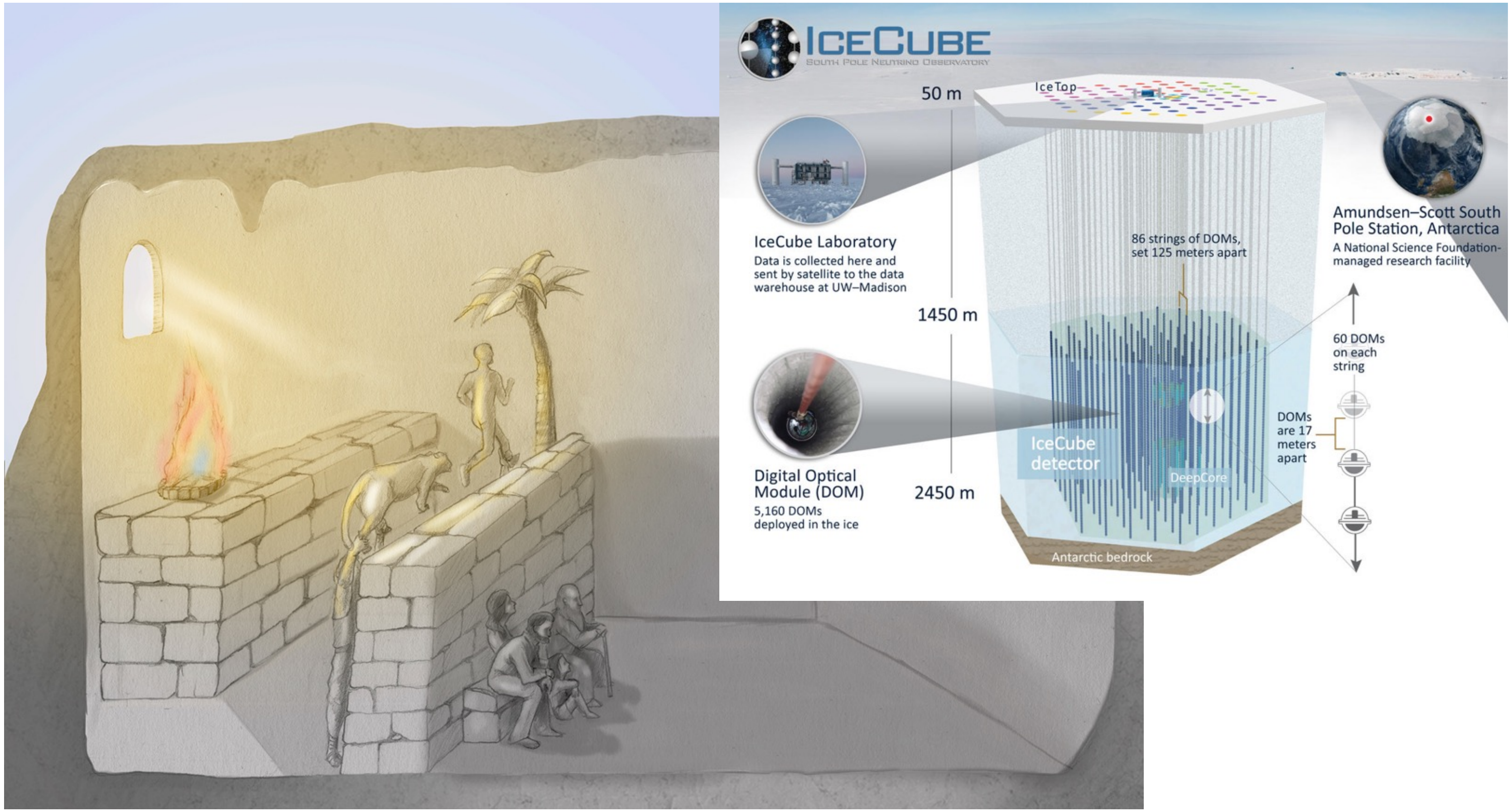
Astroparticle Physics



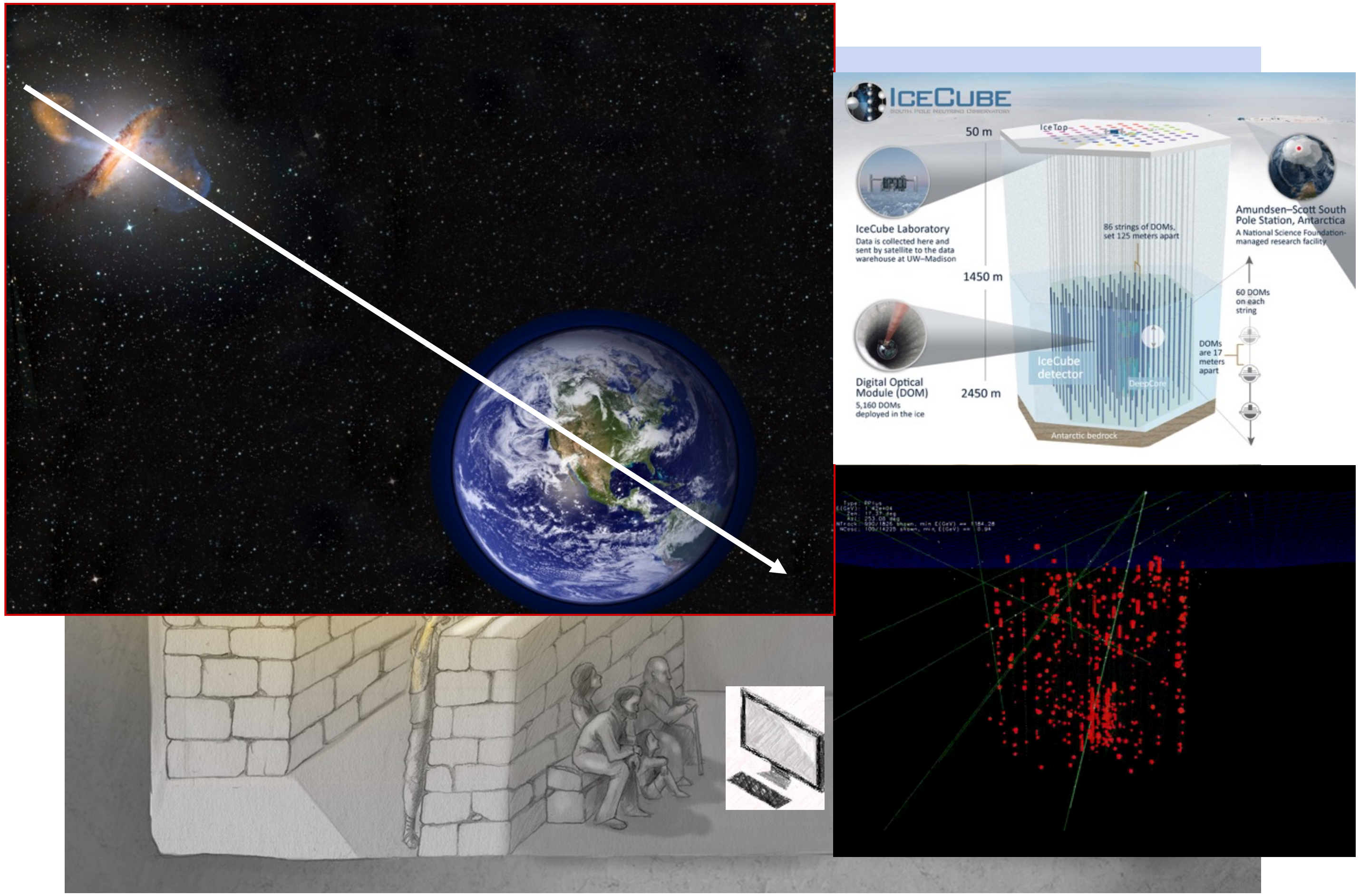
Platons Cave Revisited



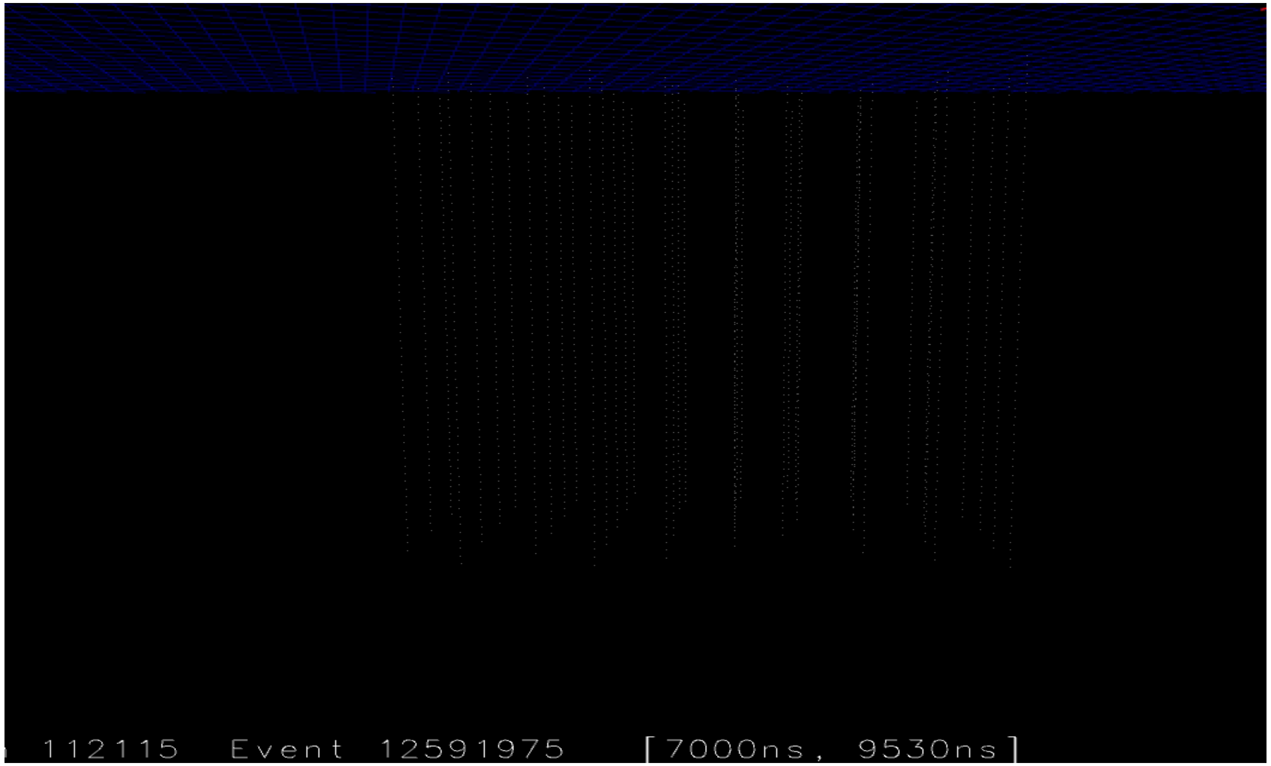
Platons Cave Revisited



Platons Cave Revisited

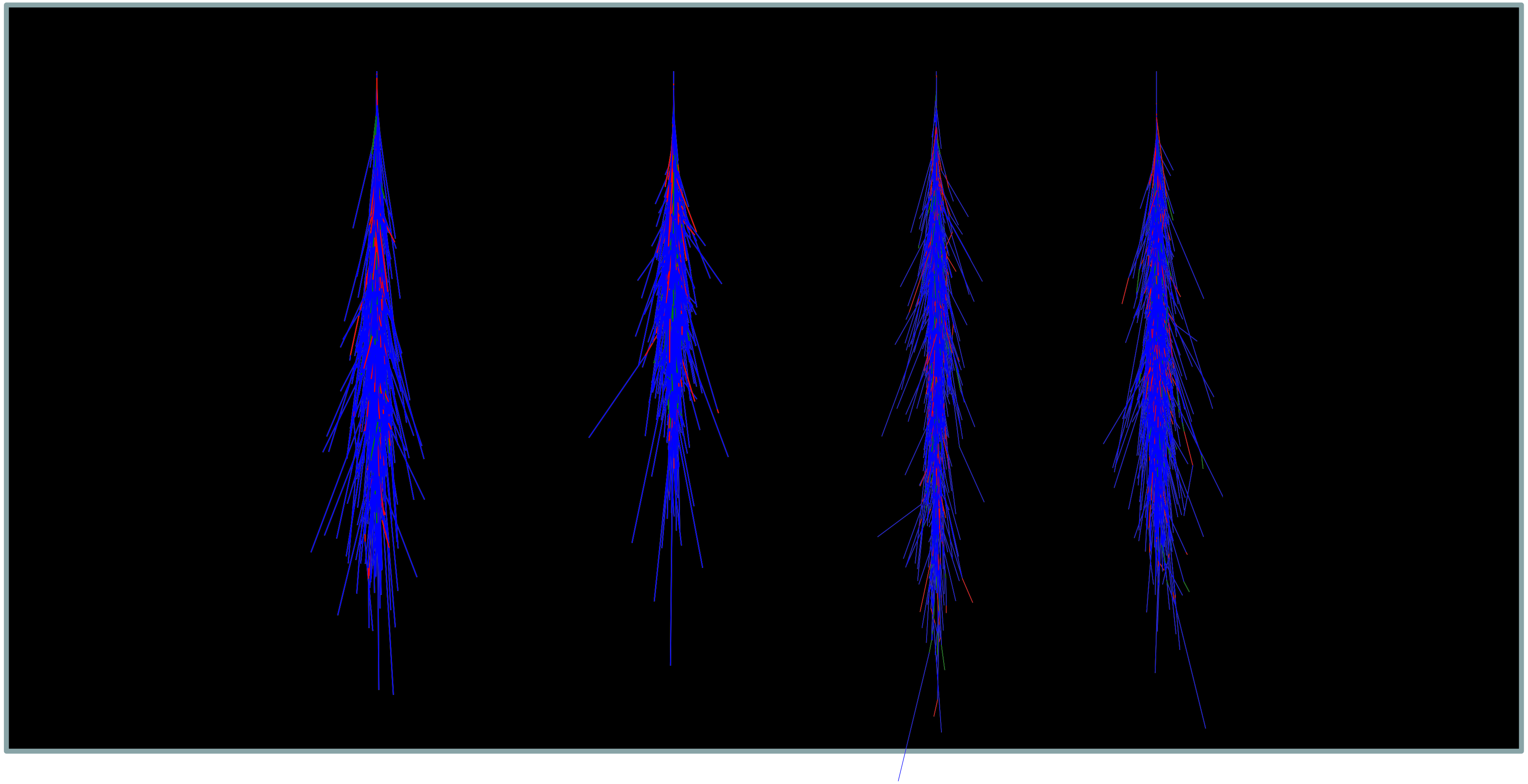


Monte Carlo: A Virtual Parallel World



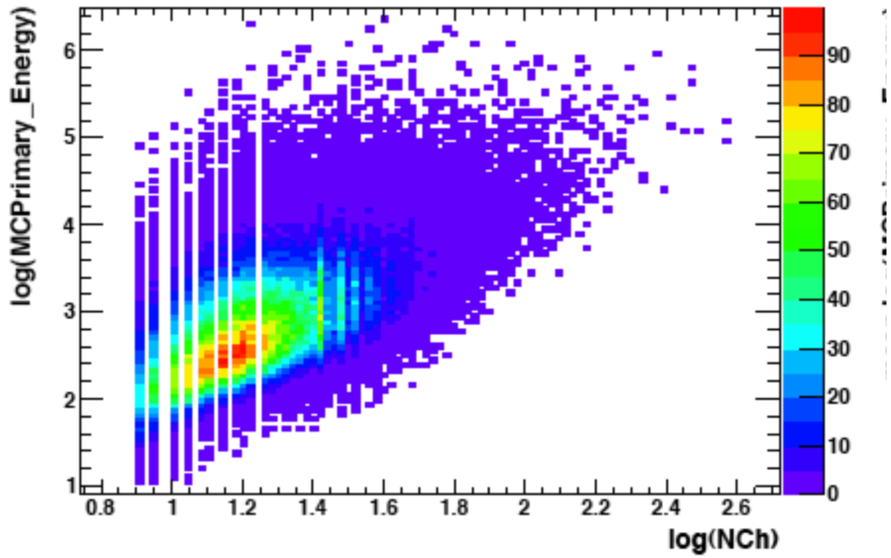
Muon in the IceCube Detector

Monte Carlo: Same Start, Other Form



Monte Carlo:
True Energy vs Number of Hit Photomultipliers

CAUSE: LOGARITHM (TRUE ENERGY)



Reversal of the Direction of Conclusion

Effect: Logarithm (Number of hit photomultipliers)

„The Cave Allegory (mathematical)"

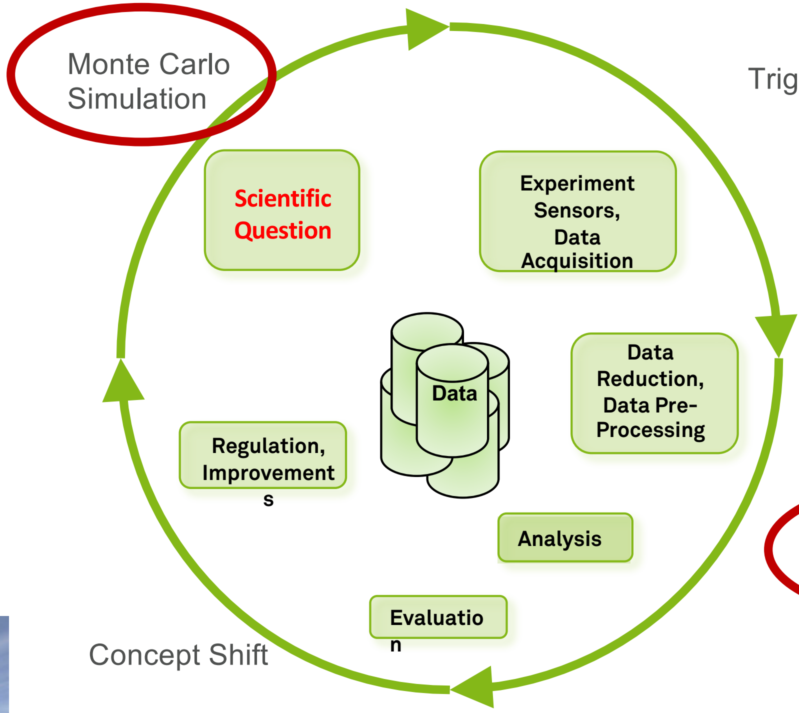
Fredholm Equation of the 2nd kind

$$g(y) = \int_c^d A(y,x) f(x) dx + b(y),$$

measurement **kernel(← MC)** **searched** **underground (←MC)**

- g(y), f(x) (static) binary? → World of Language and Logic
- g(y), f(x) mathematical functions ? → World of classical physics
- g(y), f(x) (dynamic) probability distributions? → World of „big data analysis"

Computer Science View



Trigger

Streams

Signal Identification

Storage

Inverse Problems

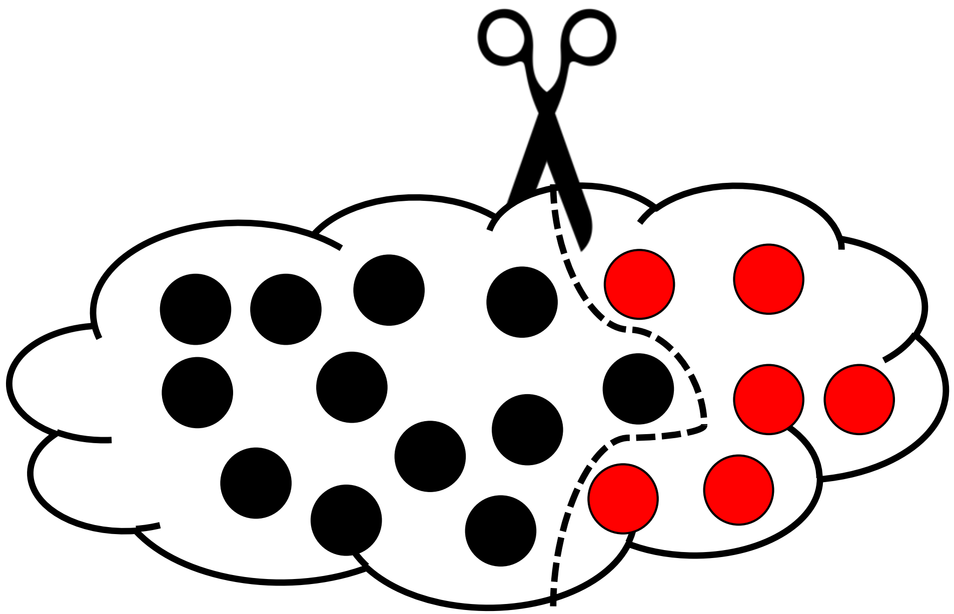
Concept Shift

Complex Programming Models

Evaluation

$$g(y) = \int_c^d A(y,x) f(x) dx + b(y),$$

Signal – Background – Separation



Discriminant Analysis

Random Forests

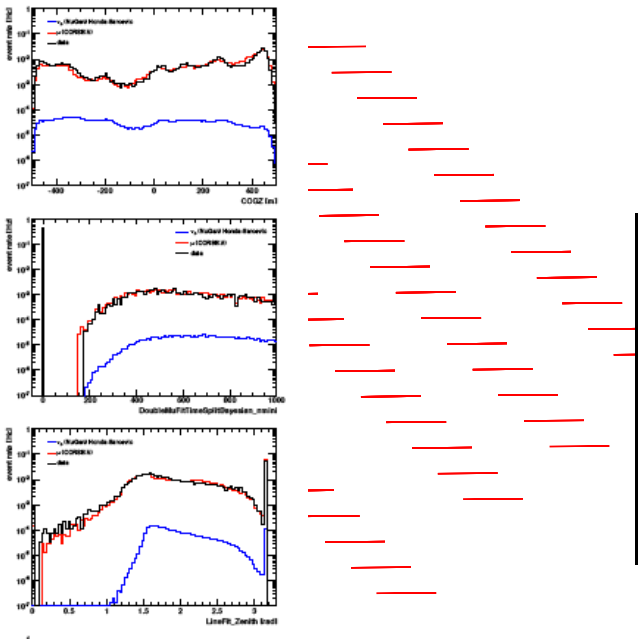
Neuronal Nets

Deep Learning

...

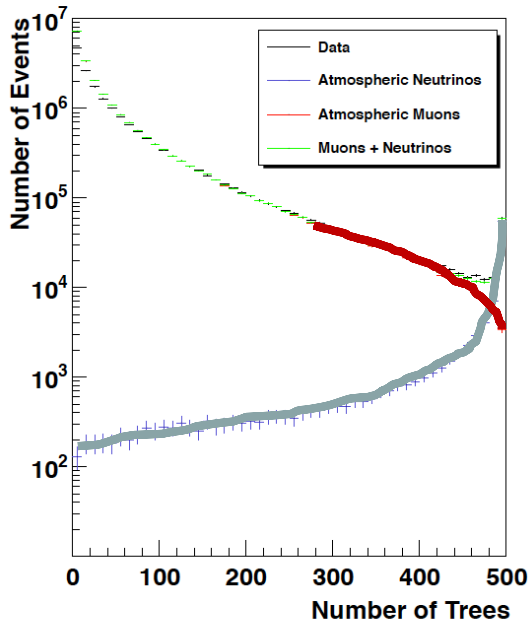
Data Mining: Paradigm I:

MC description of signal and background is perfect !

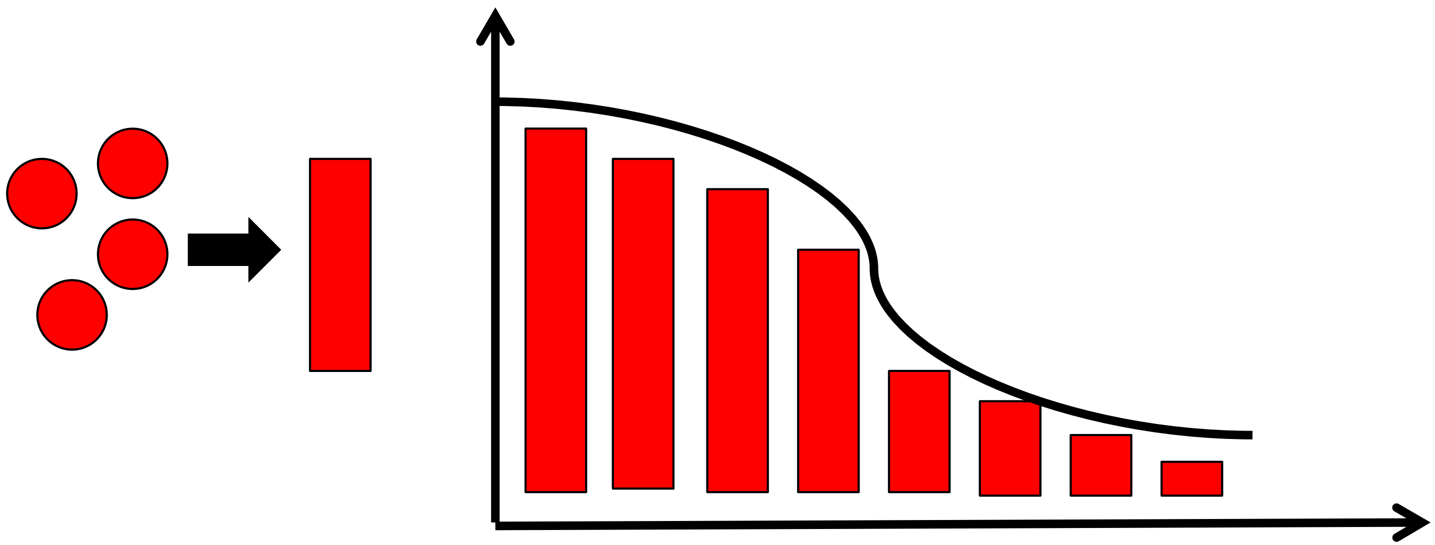


Data Mining Methods, e.g.:

Random Forest
Supported Vector Machine
Boosted Decision Tree
ADA2 boost
Deep Learning
....

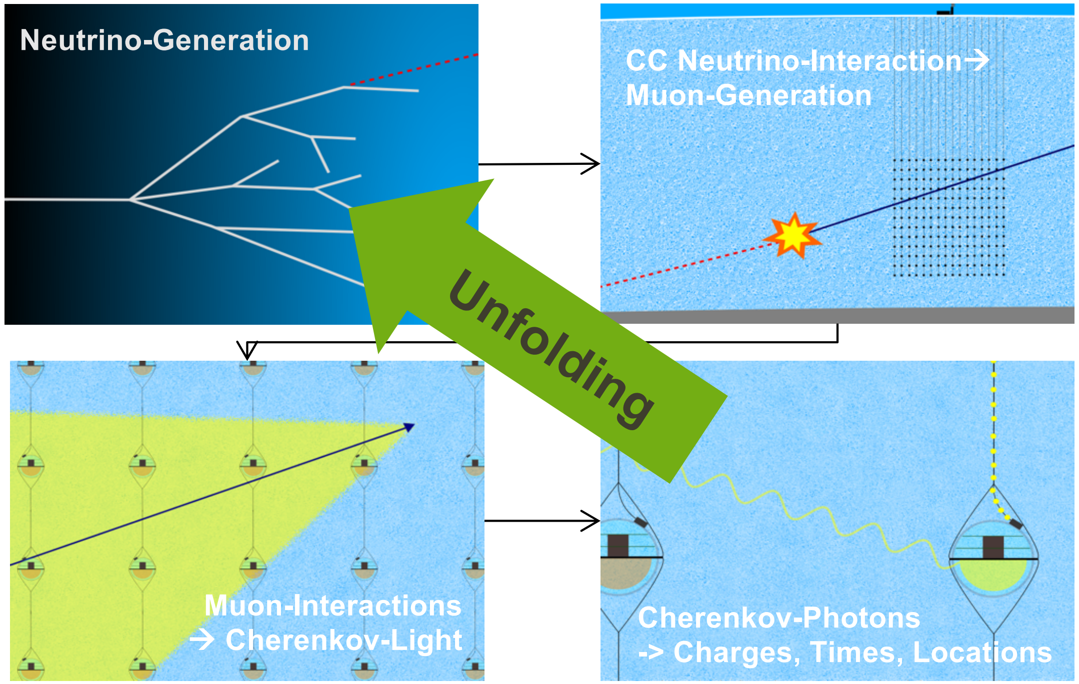


Unfolding:
Solution of the inverse Problem (Deconvolution)

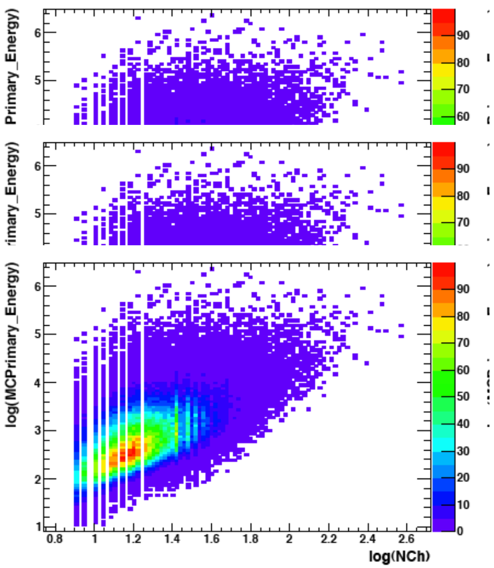


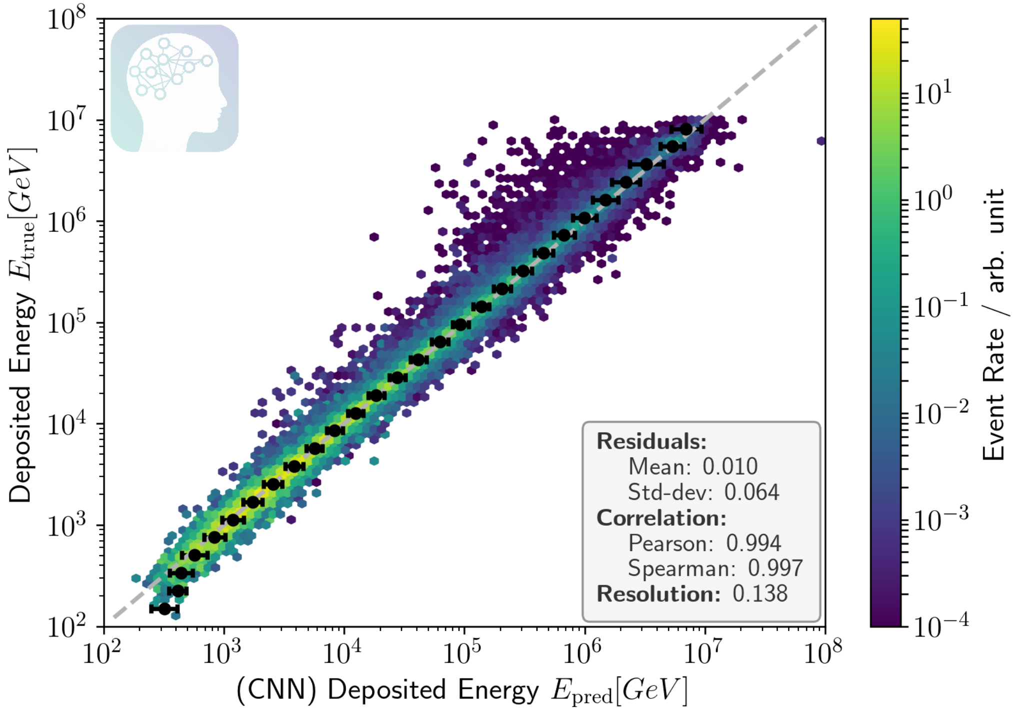
(many) Charges, Times, Locations → physical distributions
e.g. energy, angular, or mass spectra

Unfolding requires Paradigm II:
exact MC description of the signal is unknown

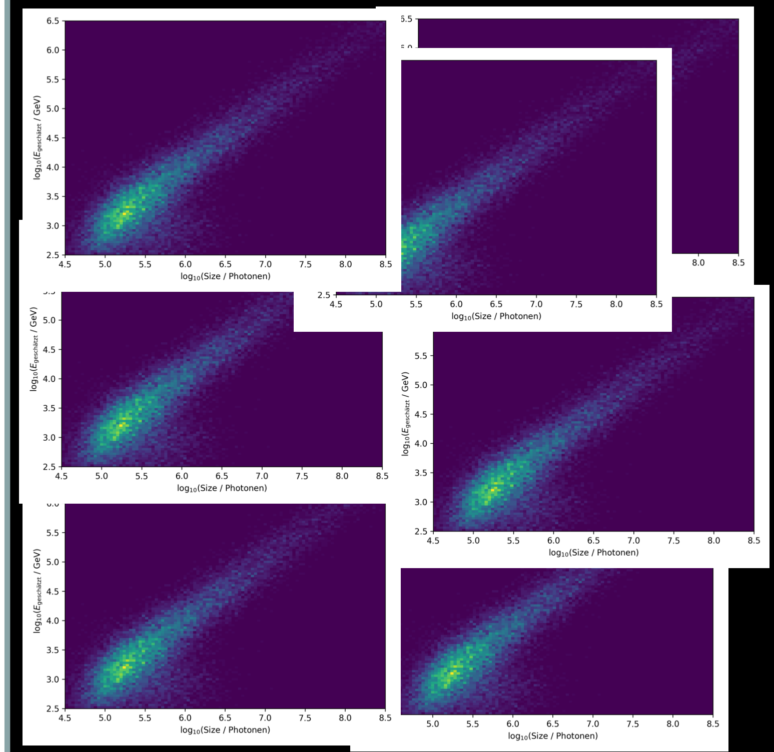


Search for optimal correlation (e.g. by Deep Learning Methods)





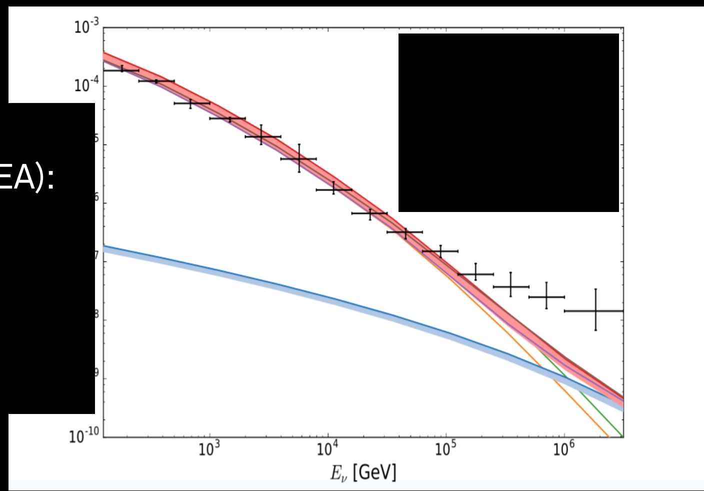
Unfolding (different algorithms)



Inverses Problem
(e.g. classification DSEA):

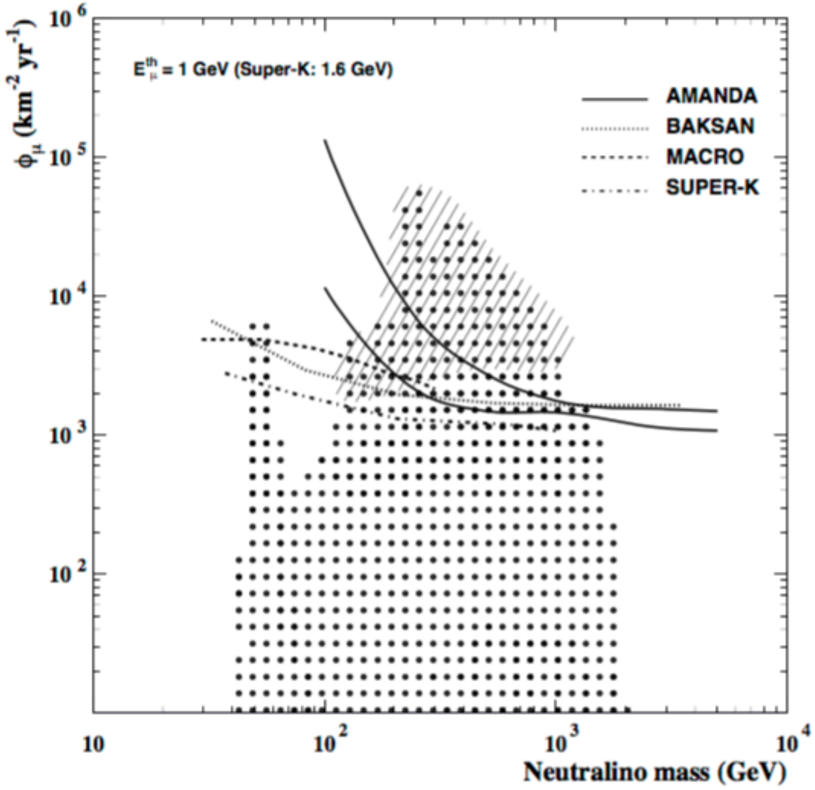
Regularized
multidimensional
algorithms

Example:
Neutrino Energy Spectrum



Collapse of the multidimensional probability cloud into physical measurement points

Remark: Monte Carlo in Theoretical Physics



Search for possible signals depending on a large number of free parameters

From Probability to Knowledge: "Probabilistic Rationalism".

Classical approach based on:

- Individual observations / measurements
- Logical binary judgments
- Single test of dedicated theories
- Falsification

Modern approach based on:

- Measurement of very large amounts of data
- Probability statements
- Iterative testing of families of theories
- Significance determination

Astroparticle Physics ideal application due to the simple structure of the experiments

Summary

▪ Turn the inside out	Historical Perspective
▪ Unfold the view on the sky	Cherenkov Telescope Ring
▪ Understand new methodological requirements	Data Science / Probabilistic Rationalism