INSTRUMENTS FOR HIGH ENERGY ASTROPARTICLE PHYSICS

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OVERVIEW:

- INTRODUCTION
- GENERAL DETECTION PRINICIPLES: CALORIMETRY AND LIGHT DETECTORS
  CALORIMETRY AND IONISATION MEASURENMENTS
  SHOWER PROCESSES IN ABSORBERS
- DETECTORS FOR UHE COSMIC RAYS
- DETECTORS FOR GROUND-BASED VHE GAMMA ASTRONOMY
  HE/VHE GAMMA ASTRONOMY WITH SATELLITES
- DETECTION OF HE NEUTRINOS
  VHE COSMIC NEUTRINOS
- DETECTION OF E E COSMIC RAYS
  GROUND-BASED
  FLUORESCENT DETECTORS ON GROUND
  FLUORECSENT DETECTORS FROM SPACE
- COMMENTS ON OTHER HIGH ENERGY ASTROPARTICLE PHYSICS DETECTORS
- SUMMARY/CONCLUSIONS

WHY THIS LECTURE ?

SUGGESTION:

FORMATION OF SOME WORKING GROUPS TO DESIGN A TOY DETECTOR
GROUPS OF 4-6 MEMBERS, MIXTURE OF THOSE WHO WANT TO WORK MORE ON EXPERERIMENTAL ASPECTS AND MORE ON THE PHYSICS.

SUGGESTED THEMES:

7. A BALLOON EXPERIMENTTO MEASURE CHARGED PARTICLES
8. A BALLOON EXPERIMENT TO MEASURE GAMMA QUANTA
9. A NEW CHERENKOV TELESCOPE IN A SPHERE OF WATER FOR RAPID MOVEMENTS
10. A CHERENKOV TELESCOPE WITH A STATIC MIRROR
11. SCINTILLATOR ARRAY EXPERIMENT
12. A WILD-CARD EXPERIMENT
13. DESIGN A FEW (5-7) EXPERIMENT TO MEASURE THE SPEED OF LIGHT IN A TRANSPARENT MEDIUM

POSSIBLY 2 GROUPS FOR EACH GOAL
TRY CRASY IDEAS AND GIVE SOME JUSTIFICATIONS
DO NOT COPY DESIGNS THAT YOU FIND ON THE WEB
CHOOSE AND START WITH SOME PHYICS GOALS
CHOOSE A NICE NAME FOR THE PROJECT
MAKE VERY COARSE ESTIMATES OF THE COSTS
LIST ALSO SOME ORGANISATION STRUCTURES AND PROBLEMS
CALIBRATIONS AND RESOLUTION
ADD YOUR OWN IDEAS
MAKE A 1-2 PAGE DESCRIPTION OF THE PROJECT

THE GROUP WITH THE BEST IDEA WILL GET A MAGNUM BOTTLE OF ANNA DE CORDORNIU

ENERGY CONVERSIONS

$$c = \lambda\ \nu$$

$$E = h_{bar}\ \omega \quad = \ h\ \nu$$

$$h_{bar} = 6.58.10^{-22}\ \text{MeV sec}$$

$$c = 3.10^{8}\ \text{m/sec}$$

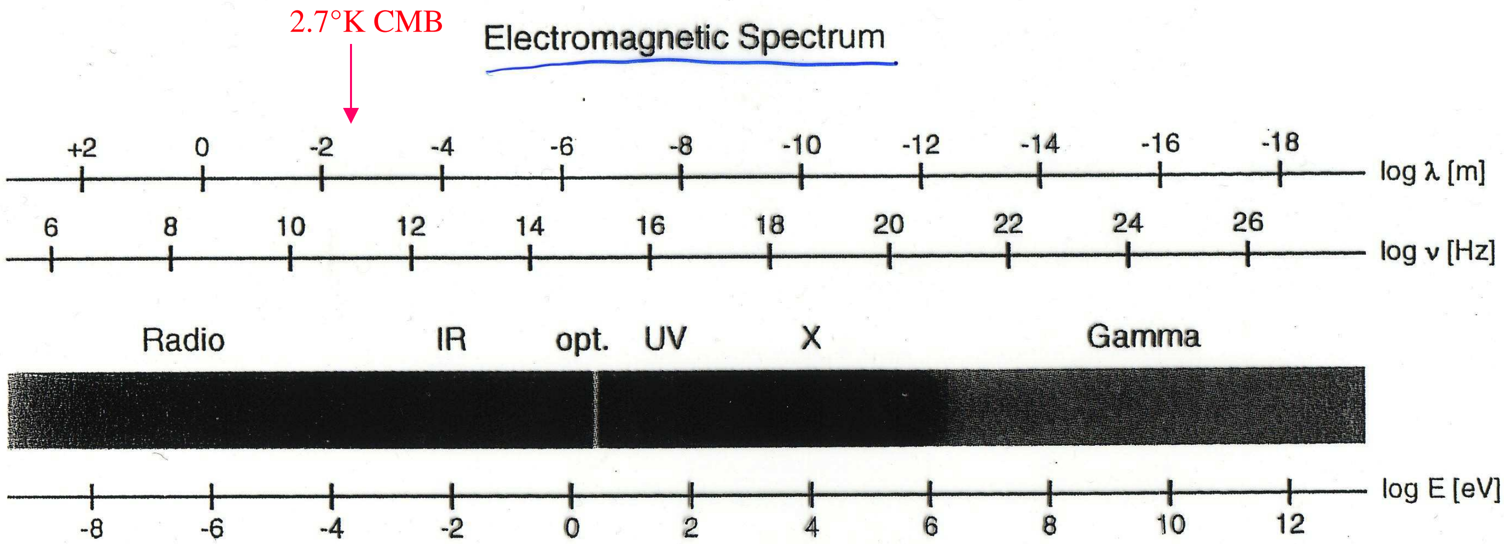
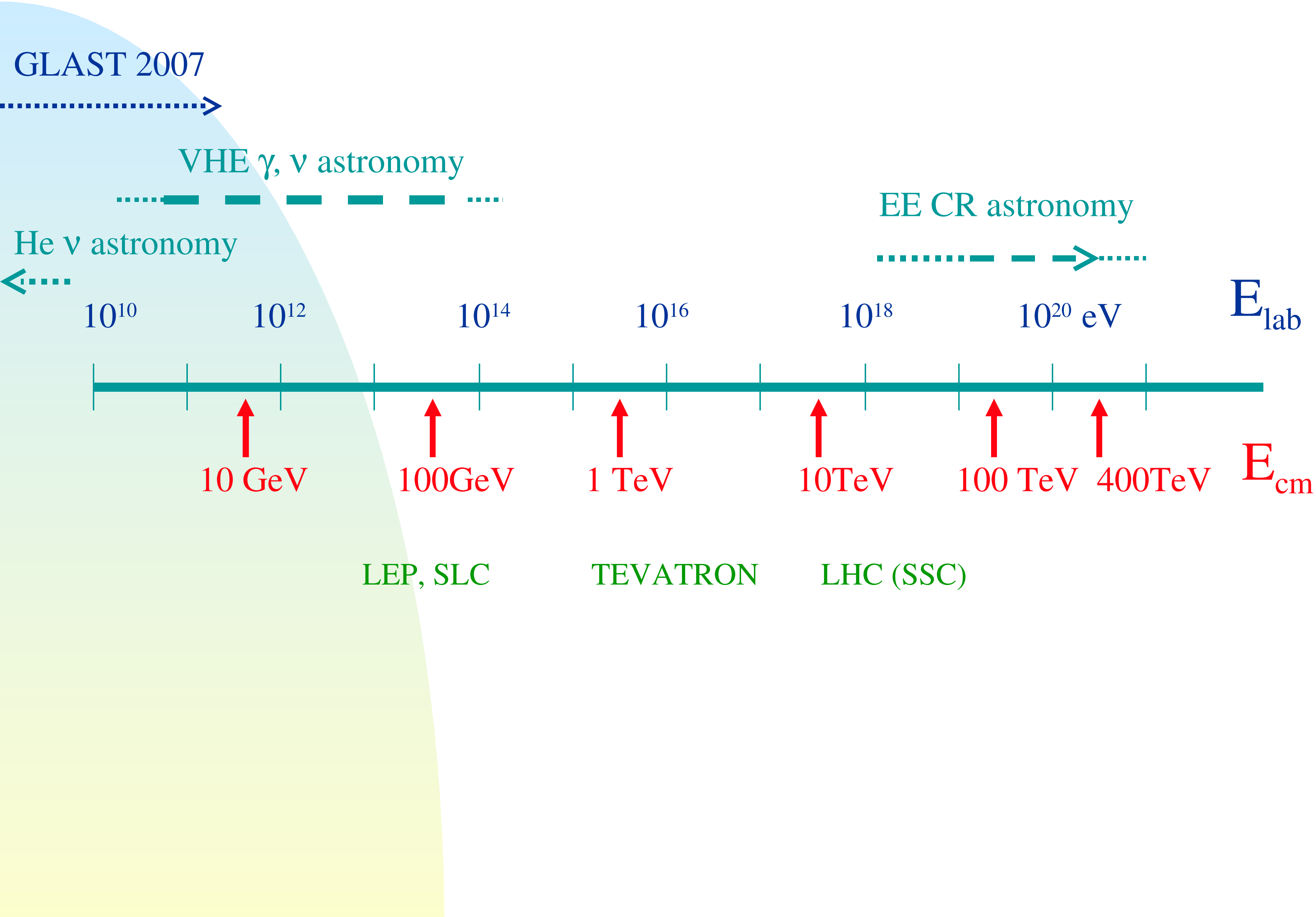


Fig. 1.1. The electromagnetic spectrum, from radio to γ-ray energies. The electromagnetic radiation can be characterized either by its photon energy (measured in eV) or by its frequency (measured in Hz) or by its wavelength (measured in m)

COMPARISON E_{cm} vs. E_{lab}



A FEW NUMBERS, ABBREVIATIONS, SOME USEFUL UNITS

EUROPE: ASTROPARTICLE PHYSICS
US: PARTICLE ASTROPHYSICS

MIXED USE OF 'HIGH ENERGY':

- global: all cosmic particles with $E > 10^6$ eV (area of particle interactions)
- specific: for particles with a specific range in energy:
  - HE: 1(few)10^6 eV to few 10^9 eV

MIXED USE OF THE WORD 'DETECTOR'

- sometimes an entire set of instruments for an experiment
  - example: the GLAST satellite, the AUGER detector, ATLAS
- sometimes a specific element of an instrument
  - example Photomultiplier, Proportional chamber…

A FEW NUMBERS, ABBREVIATIONS, SOME USEFUL UNITS II

GeV : Giga electron Volt = 10^{9} eV

TeV: Tera electron Volt = 10^{12} eV,

PeV: 10^{15} eV,

EeV: 10^{18} eV

For many calculations: c=h=1

CR: Cosmic Rays

γ: Gamma Rays

SN: Super Nova, SNR: Super Nova Remnant

Definition of some energy ranges

VHE: Very High energy was 10^{10}- 10^{14} eV (Definition range sliding with time), now few 10^{9}-10^{12} eV

UHV: Ultra High Energy $\geq 10^{14}$ eV

EE: Extreme High Energy > 1018 eV, now used mainly for E above 10^{19} eV

HEP: High Energy Physics

THERE EXIST HIGH ENERGY PARTICLE PROCESSES IN OUR UNIVERSE, WE NEED TO UNDERSTAND THEM IF WE WANT TO UNDERSTAND OUR UNIVERSE

HIGH ENERGY COSMIC RAYS (E > few MeV/GeV)

- THE EARTH IS CONSTANTLY EXPOSED TO A HIGH ENERGY PARTICLE FLUX FROM THE UNIVERSE: THE SO-CALLED COSMIC RAYS
- > 10000 /m^2 sec on top of the atmosphere
- we are mostly protected by the atmosphere due to interaction and shower processes in upper part of the atmosphere.
- we are still hit by a flux of secondary particles (muons, electrons), 50-200 /m^2 sec, part of the natural radioactivity
- CR: protons, a,… Fe , few electrons, gammas, neutrinos?, (Dark matter particles?)
- we do not know from where these particles come (most likely sources: SNRs) we do not know how they get the high energy : acceleration or may be some from decays of very massive particles.
- most likely acceleration mechanism: shock wave acceleration in SNRs
- spectrum of the CRs follows typically a power law with coefficient -2 to -3

- HIGHEST OBSERVED PARTICLE ENERGY : 3 10^{20} eV (one per 100 km^2 and year) more energy than the fastest tennisball
- 1912: discovery of Cosmic Rays by Victor Hess
- Around 1950: discovery of cosmic x-rays, (low energy), by satellite borne detectors
- 1961: start of the low energy(GeV) γ-astronomy with the launch of Explorer 11
- 1989: discovery of the first TeV γ source (Crab nebula, Whipple collaboration)

1912, VIKTOR HESS WEIST BEI BALLONFLÜGEN DIE EXISTENZ EINER RADIOAKTIVEN STRAHLUNG NACH, DIE MIT DER HÖHE ZUNIMMT

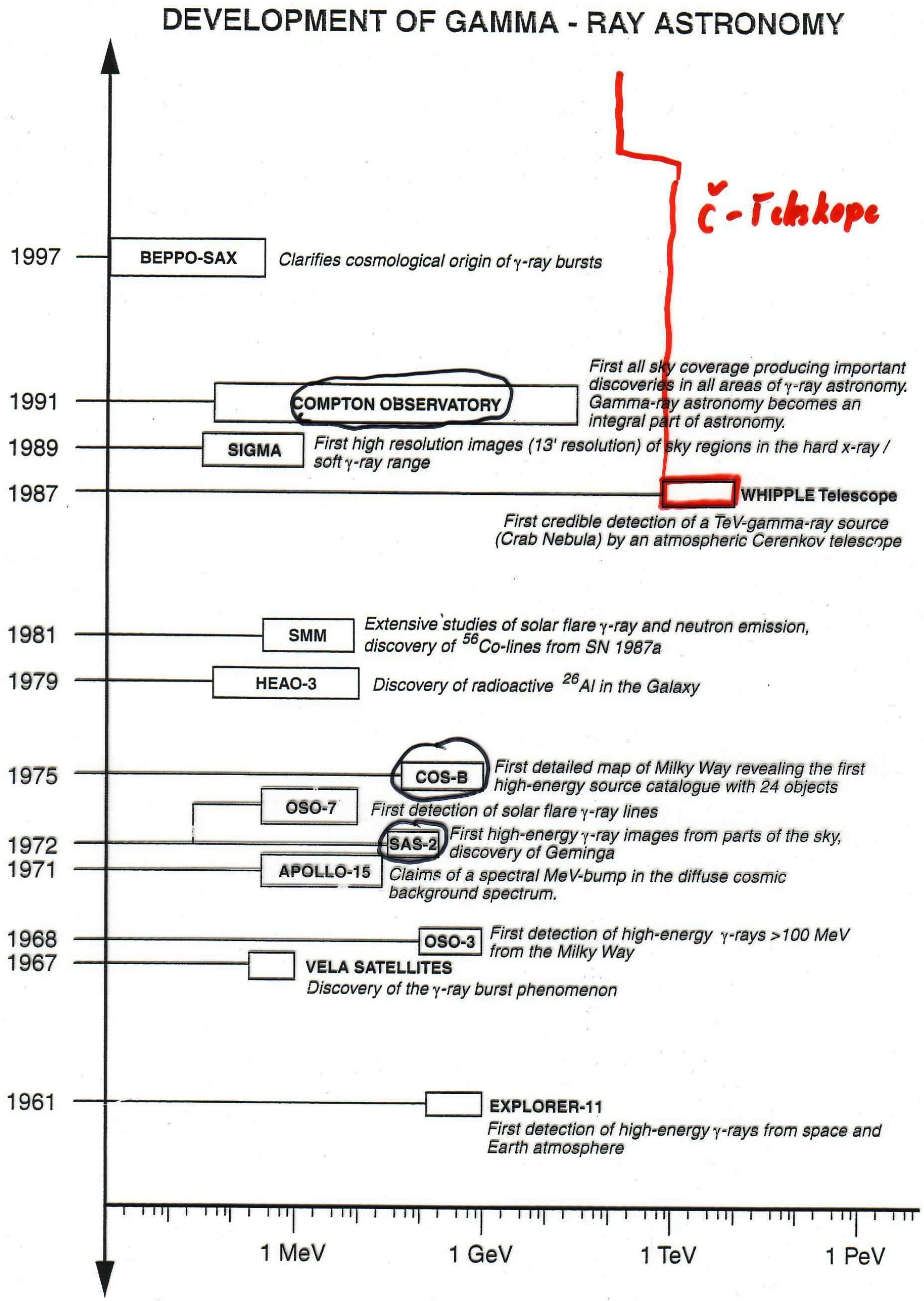


Fig. 1.2. Timeline of the development of γ-ray astronomy

EXAMPLE OF THE DEVELOPMENT OF THE FIELD OF HE,VHE γ ASTRONOMY

HIGH ENERGY ASTROPARTICLE PHYSICS IS A RAPIDLY EXPANDING FIELD OF FUNDAMENTAL RESEARCH

AREAS OF ASTROPARTICLE PHYSICS

- GAMMA-RAY (γ) ASTRONOMY
- ν ASTRONOMY (LOW AND HIGH ENERGY)
- STUDY OF THE CHEMICAL COMPOSITION OF COSMIC RAYS ABOVE 10^{12} eV
- STUDY OF THE HIGHEST ENERGY (> 10^{19} eV) COSMIC PARTICLES
- DARK MATTER SEARCHES (WIMPS)
- NUCLEAR ASTROPHYSICS
- (GRAVITATIONAL WAVE PHYSICS)

- BOUNDARIES NOT ALWAYS CLEARLY DEFINED
- ULTIMATE GOAL: CONTRIBUTE TO UNDERSTAND OUR UNIVERSE COMPLETELY
- PARTICLES AS INFORMATION CARRIERS FROM OUR UNIVERSE: ‘MESSENGERS’
- SEARCH FOR PARTICLE PHYSICS (EXAMPLE WIMPS, NEUTRALINO. TOPOLOGICAL DEFECTS, RELIC PARTICLES.?GRAVITON?
- LINKS TO CLASSICAL ASTRONOMY

THE DISTANCE ISSUE

WE CANNOT EXPLORE OUR UNIVERSE BY GOING TO THE DIFFERENT REGIONS

WE NEED MESSENGERS FROM HIGH ENERGY COSMIC EVENTS, COSMIC ACCELERATORS… TO EXPLORE THE RELATIVISTIC UNIVERSE (ASTRONOMERS USE THE WORD ‘NON-THERMAL UNIVERSE’)

POSSIBLE MESSENGER PARTICLES (MUST BE LONG LIVED, RELATIVISTIC):

MASS

0

- gamma rays (γ)
- ν_e, ν_μ, ν_τ and their antiparticles
- e, positron
- Baryons, heavy ions (p,pbar, He……………….Fe)
- Neutral baryons (neutron)

heavy

- Exotic particles (WIMPS, Neutralinos ????)

- Indirect messengers: radiowaves, photons.. from synchrotron radiation

THE TIME ISSUE

HOW CAN WE LEARN SOMETHING ABOUT OUR UNIVERSE ?

THROUGH ASTRONOMICAL OBSERVATIONS

NEARLY ALL OUR OBSERVATIONS ARE MADE THROUGH DETECTION OF **ELECTROMAGNETIC WAVES (PHOTONS) resp.** ELECTROMAGNETIC PARTICLES. (γs)

NAME OF FIELD	ENERGY RANGE	MAIN INSTRUMENTS
RADIOASTRONOMY	10^{-9} to 10^{-3} eV	RADIO ANTENNAS
INFRARED ASTRONOMY	10^{-3} to 0.72 eV	SATELLITE BORNE TELESCOPES, TERR. TELESCOPES
OPTICAL ASTRONOMY	0.72 to 0.39 eV	TELESCOPES
ULTRAVIOLET ASTRONOMY	0.39 to 10^{2} eV	TELESCOPES ON SATELLITES
X-RAY (ROENTGEN) ASTRONOMY	10^{2} to 10^{6} eV	X-RAY DETECTORS ON SATELLITES AND BALLONS
GAMMA ASTRONOMY	> 10^{6} eV	**< 20 GEV; γ DETECTORS ON SATELLITES** OR BALLONS
		OBSERVATION GAP 10-300 GeV (up to 2003)
		> 350 GEV: **CERENKOV TELESCOPES**
		> 10**14 eV: LARGE SCINTILLATOR ARRAYS
		> 10**18 eV also AIR FLUORESCENCE DETECTORS
EE-CR ASTRONOMY	>FEW 10^{19} eV	ULTRALARGE SCIN-ARRAYS, FLUORECENT DETECTORS

THE GENERAL EXPERIMENTAL CHALLENGES IN HIGH ENERGY ASTROPARTICLE PHYSICS

- OBSERVATIONAL SCIENCE

- INITIAL PARAMETERS NOT UNDER CONTROL AS IN HEP
  ENERGY , TIME, (PATRICLE TYPE), (DIRECTION)

- FLUXES ARE VERY LOW -> NEEDS ULTRA-LARGE DETECTOR VOLUMES

- HIGH ENERGY -> CALORIMETRIC DETECTORS TO CONVERT INITIAL ENERGY INTO OBSERVABLE QUANTITIES. VARIANT FOR ν-DETECTORS: RANGING OUT MUONS

- INITIAL PARTICLE->INTERACTION IN CALORIMETER MATERIAL -> SHOWER->
- <u>-> OBSERVABLES ->ELECTRONS, IONS, PHOTONS</u>, -> we have to learn about
- shower physics and ionisation detectors and photon detectors photon
- (-> RADIO WAVES ???)
- (->ACOUSTICAL SIGNALS ???)

THE COSMIC RAY SPECTRUM
Mostly protons, α,.. heavy ions

FRACTION OF γs UNKNOWN
< 10^{-4} from Galactic Plane
< 10^{-5} isotropic
Local γ emission spots(stars) can reach γ fluxes of a few % of CR BG
For typ. angular resolution of 0.1°

BASICALLY NOTHING IS KNOWN ABOUT THE COSMIC ν FLUX

Charged CR are 'bad messengers' γs are 'good messengers' but
-> <u>γ/hadron SEPARATION A BIG EXPERIMENTAL CHALLENGE</u>

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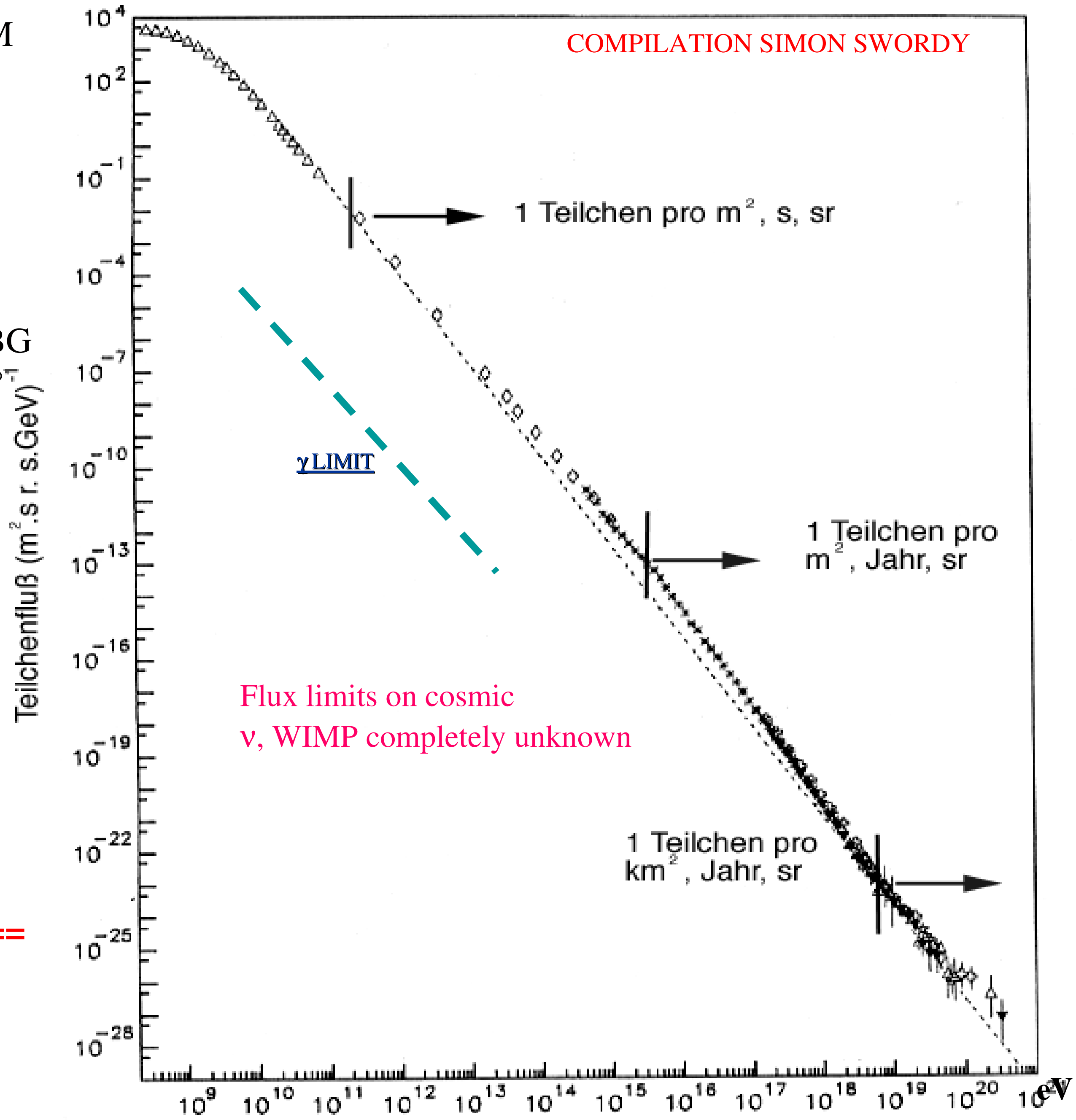
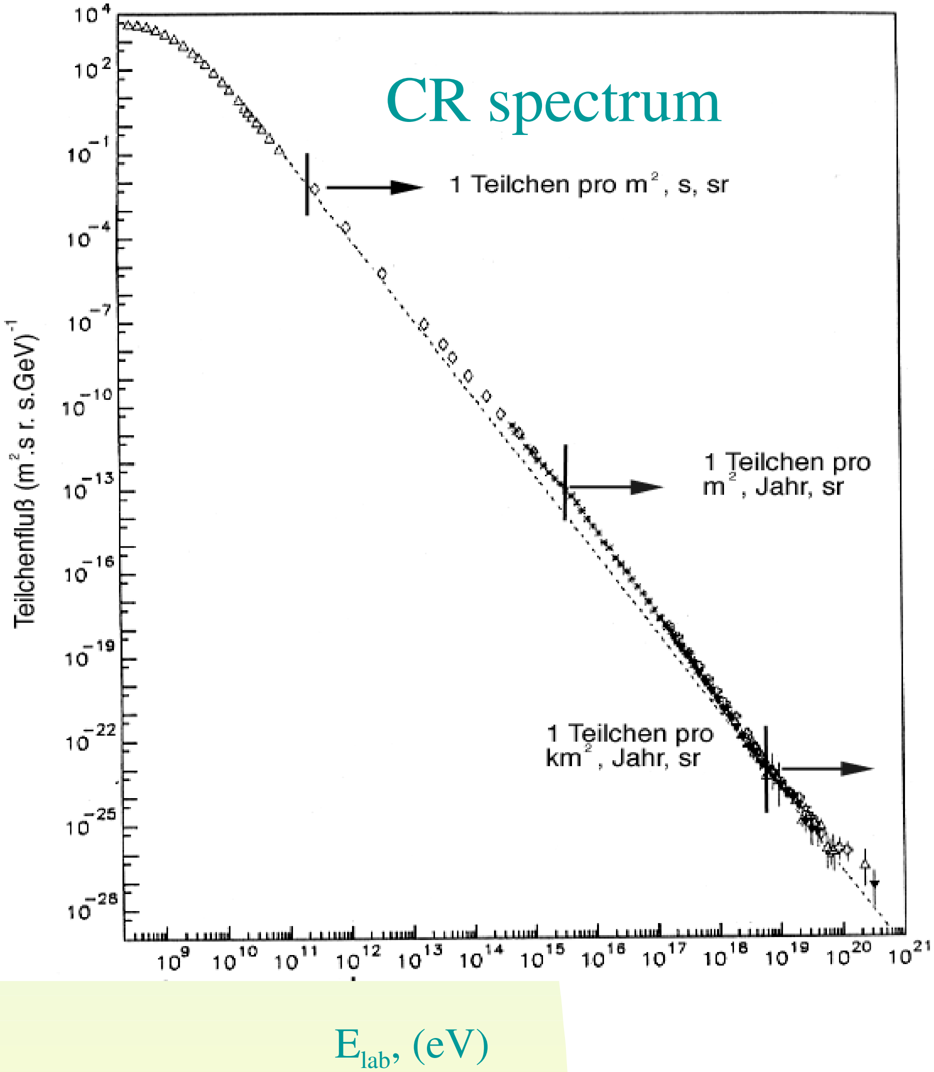




CONCEQUENCES OF STEEPLY FALLING FLUXES:

DETECTORS ARE ONLY USEFUL FOR 2 (AT MOST 3) DECADES IN ENERGY

->NEED TO ADOPT DETECTOR AREA(VOLUME) TO FLUX

EXAMPLES

γ-ASTRONOMY

EGRET (20 MEV-1 GEV) 2 A4 PAGES

CHERENKOV TELESCOPES (100 GEV-10 TeV): 10^4 m^2

ν-ASTRONOMY

SUPERKAMIOKANDE (E> 10 MeV) 29000 tons

ICECUBE (E> 100 GeV) 10^9 tons

Why are γs good messenger particles (so rare)
And why are the charged CR bad messenger particles (so many)

The galactic magnetic field issue!
Our galaxy is filled with a weak magnetic field (order 0.1-few μGauss)

Due to deflections of charged particles all info about initial directionality is lost
No correlation with location of generation

We can only learn about the average chemical composition of the CR
Good measurements up to few 10^{10} eV (balloon, satellite borne detectors ->AMS)

Only at the highest energies (> 10^{19} eV) charged particles are minimally deflected
-> can be correlated with possible location of their origin

-> Extreme energy CR astronomy becomes possible
But fluxes extremely low

Zur Anzeige wird der QuickTimeª
Dekompressor ÒFoto - JPEGÓ
benštigt.

OTHER PARTICLES THAT COULD IN PRINCIPLE ACT AS COSMIC MESSENGERS

(MUST BE NEUTRAL)

Neutron, neutrino (WIMP, possible part of the Dark Matter)

Neutron: too short lifetime 11 min (885.7 ±0.8 sec, ct =2.655 10^8 km)
Only above 10^{18} eV: could just fly a distance center of our galaxy-earth before mostly decaying
Processes to generate high energy neutrons: hadronic interactions, photo-desintegration of heavy nuclei
Neutrons have a mass (939.56 MeV) -> time info lost

Neutrino (3 families, can mix-but no change in direction) : weakly interacting particles
-> very difficult to detect
-> needs huge detector volumes (km3, AMANDA, ANTARES, BAIKAL, ICECUBE)
Origin of high energy neutrinos: mostly from π, μ decays
Neutrinos have a very small mass (<1 eV) -> time info lost

Note: in future: neutrino astronomy will be complementary to γ -astronomy
Side comment: in principle a ν mass limit can be set from SN or GRB γ, ν obs.
Only two cosmic ν sources seen (sun, SN 1987 A)

WHAT DO WE WANT TO KNOW FROM OUR MESSENGERS?

•INCOMING DIRECTION

TO CORRELATE WITH SOURCE
(HIGH ANGULAR RESOLUTION)
(BACKGROUND REJECTION)
(EXTENDED SOURCES)

•IDENTIFICATION OF PARTICLE

IS IT THE CORRECT MESSENGER?
γ?
ν(6 possible)
type of nucleous, (chemical composition)
(REJECTION OF BACKGROUND)

•ENERGY

MEASURE SPECTRA

•TIME

TO CORRELATE WITH COSMIC EVENTS. (MOSTLY EASY)
LIGHT CURVES
EXAMPLES: PULSARS, SN EXPLOSIONS
PULSARS, GAMMA-RAY BURSTS

WHEN WE WANT TO MEASURE THE MESSENGER PARTICLES WE HAVE TO GO TO PLACES WHERE THEY ARE IN THEIR ‘NATIVE FORM’
i.e., BEST ABOVE THE ATMOSPHERE

DIFFICULT AND COSTLY TO BRING DETECTORS ABOVE ATMOSPHERE
THERE IS ALSO THE FLUX PROBLEM

THE EARTH ATMOSPHERE IS A GOOD SHIELD AGAINST CR (ex νs)
->GOOD ABSORBER -> CALORIMETRY
AIR: 1.2 g/ccm 20% O_2, 78 % N_2, rest Ar, Co2…

< Z/A>0.4991,
Nuclear collision length 62 g/cm2
Nuclear Interaction length 90g/cm2
Min Ionisation Loss (b 98%) 1.815 MeV/g cm2
Radiation length 36.66 g/cm2 304 m at 1 atm

Density distribution as function of altitude follows exponential with 7.8 km scale height (temperature correction ..)

Rule of thumb: shielding of atmosphere 10 m Water equivalent
===

SHOWER PROCESSES AND CALORIMETRY

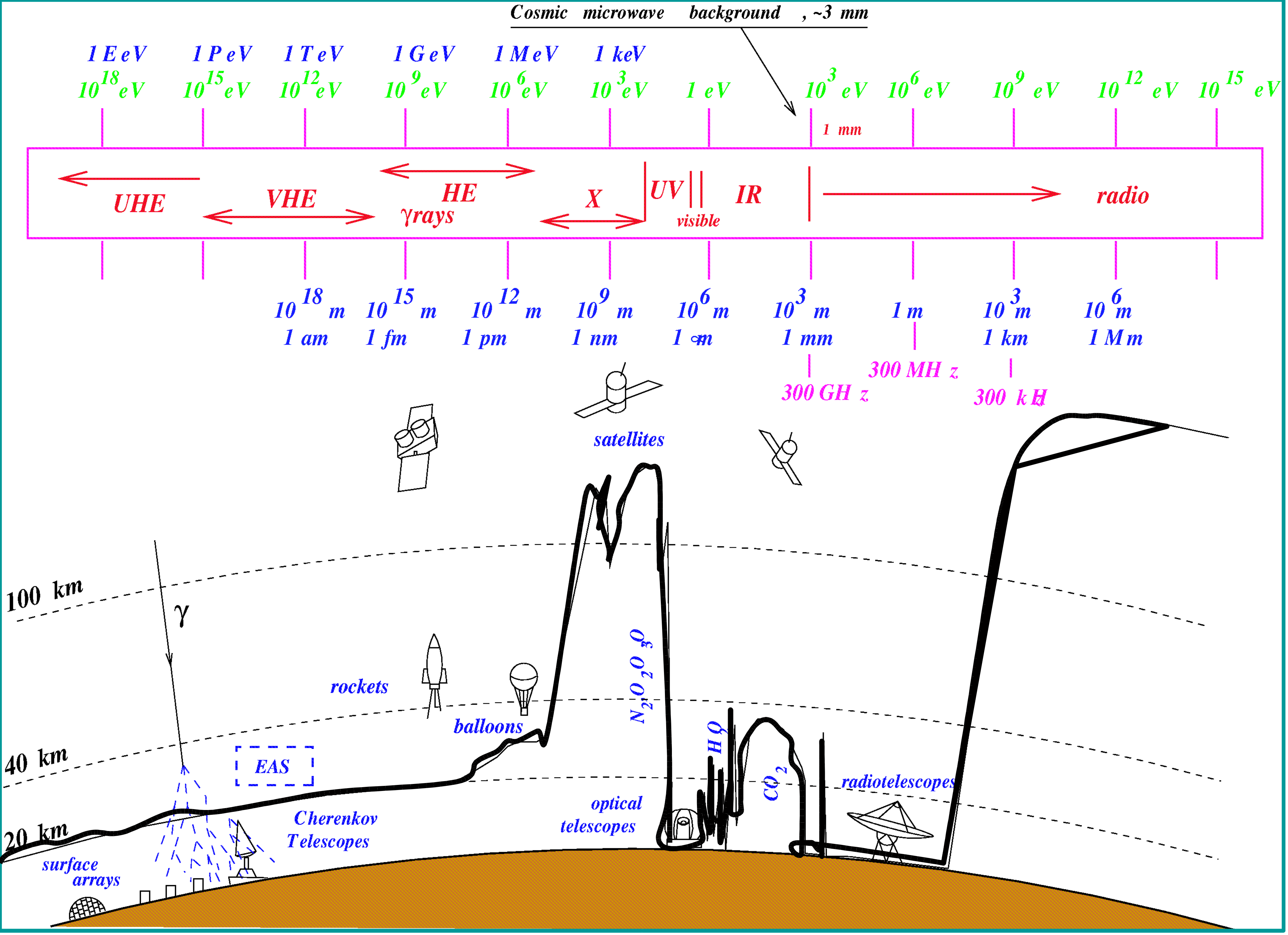
- THE EARTH ATMOSPHERE IS NOT TRANSPARENT VHE γ, e, hadrons

- COSMIC PARTICLES INTERACT IN THE ATMOSPHERE AND CREATE SHOWERS OF SECONDARY PARTICLES

- DEPENDING ON ENERGY THE SHOWERS STOP HIGH UP OR REACH DOWN TO GROUND

- MAGNETIC SPECTROMETERS ARE UNSUITED FOR CHARGED CR PARTICLES. (NEED TO BE MOUNTED ON SATELLITES (BALLOONS) TOO SMALL TOO HEAVY, TOO POWERHUNGRY, NOT SENSITIVE ENOUGH (ONLY FOR HE CRs.)

- ν s NEARLY NEVER ABSORBED BY THE ATMOSPHERE


Cosmic microwave background, ~3 mm
1 EeV
1 PeV
1 TeV
1 GeV
1 MeV
1 keV
10^{18} eV
10^{15} eV
10^{12} eV
10^{9} eV
10^{6} eV
10^{3} eV
1 eV
10^{3} eV
10^{6} eV
10^{9} eV
10^{12} eV
10^{15} eV
1 mm
UHE
VHE
HE
γrays
X
UV
visible
IR
radio
10^{18} m
1 am
10^{15} m
1 fm
10^{12} m
1 pm
10^{9} m
1 nm
10^{6} m
10^{3} m
1 mm
1 m
10^{3} m
1 km
10^{6} m
1 Mm
300 MHz
300 GHz
300 kHz
satellites
100 km
γ
rockets
balloons
N_2, O_2, O_3
H_2O
CO_2
40 km
EAS
radiotelescopes
optical telescopes
Cherenkov Telescopes
20 km
surface arrays

CALORIMETERS FOR PARTICLE DETECTION
(MAIN PARTS: ABSORBER + DEVICE TO MEASURE THE SIGNAL)
THE EARTH ATMOSPHERE IS A GOOD ABSORBER WITH SPECIFIC FEATURES

· CALORIMETER: COMMON INSTRUMENTS IN HEP RESEARCH

· DEVICE TO MEASURE THE ENERGY OF A PARTICLE (CHARGED OR NEUTRAL)

· MAIN PROCESS: HIGH ENERGY PARTICLE PRODUCES A SHOWER OF SECONDARY PARTICLES WHICH WILL BE MOSTLY/ALL ABSORBED IN MATERIAL

· PRIME MEASURABLE INFORMATION: IONISATION / SCINTILLATION OR CHERENKOV LIGHT

(THE SHOWERING PROCESS SHORTENS VERY MUCH THE OVERALL LONGITUDINAL TRACK ABSORPTION BY IONISATION)

· TYPICAL CALORIMETER LENGTH GROWTH WITH ln (E)

· TYPICAL CALORIMETER LENGTH AT GeV/TeV ENERGIES: 20-25 r.l(for em calorimeters), 8-12 had. Absorption length

· CAN MEASURE THE ENERGY/ ENERGY RESOLUTION IMPROVES WITH ENERGY

· FULLY ACTIVE CALORIMETERS VS SAMPLING CALORIMETERS

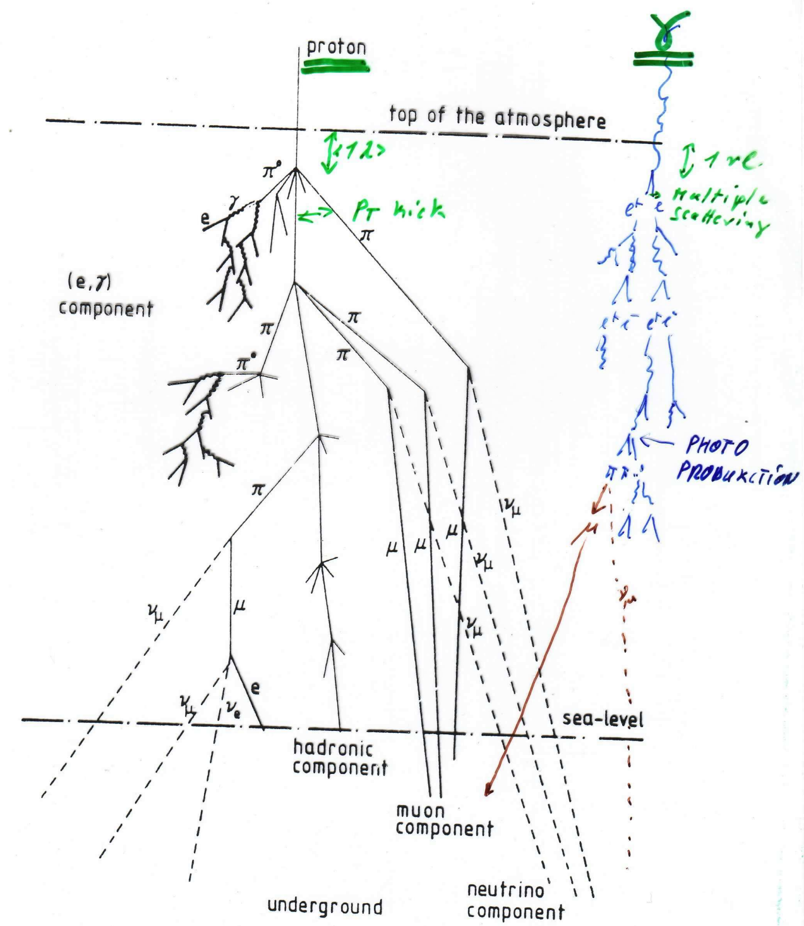
· CALORIMETERS CAN PROVIDE DIRECTIONAL INFORMATION ->NEEDS APPROPRIATE SENSOR STRUCTURE

· SHOWERING PROCESS IS A STOCHASTIC PROCESS -FLUCTUATIONS INFLUENCE THRESHOLD AND ENERGY RESOLUTION….

CALORIMETERS CAN, DUE TO SHOWERING PROCESS, WIDEN VERY MUCH THE INFORMATION (-> HELPS TO OVERCOME PARTLY THE FLUX PROBLEM, BUT RUINS ALSO SOME OF THE PRIMARY INFORMATION

COMPONENTS OF AN AIR SHOWER

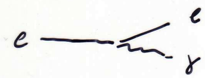
27 rl
11 had.ab.l



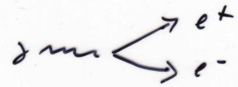
SIMPLIFIED MODEL FOR AN ELECTROMAGNETIC SHOWER (Heitler 1944)

ONLY TWO ALTERNATING PROCESSES + IONISATION LOSS

BREMSSTRAHLUNG



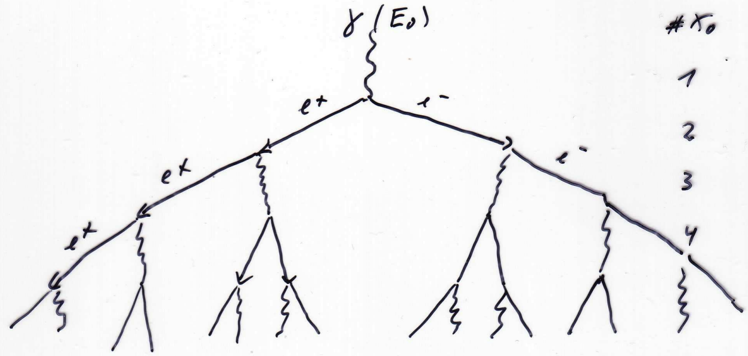
PAIR PRODUCTION



NEGLECT PHOTO PRODUCTION

ASSUME ENERGY SPLIT 1:1

ASSUME $1 X_0$ FOR PROCESS $E_{in} \to 2 E_{fin}$



$\# X_0$	N_i
1	1
2	2
3	4
4	8
	16

AFTER $n X_0$ $\quad N_t = 2^n \quad E_i = \frac{E_0}{N_t}$

AT AROUND 86 MeV IONISATION LOSSES DOMINATE

86 MeV CALLED CRITICAL ENERGY

↳ SHOWER DIES OUT

$$N_{max} \approx \frac{E_0}{E_c}$$

$$X_{max} = \lambda \frac{\ln\left(\frac{E_0}{E_c}\right)}{\ln 2}$$

/ X_{max} : POSITION OF SHOWER MAX IN UNITS OF X_0

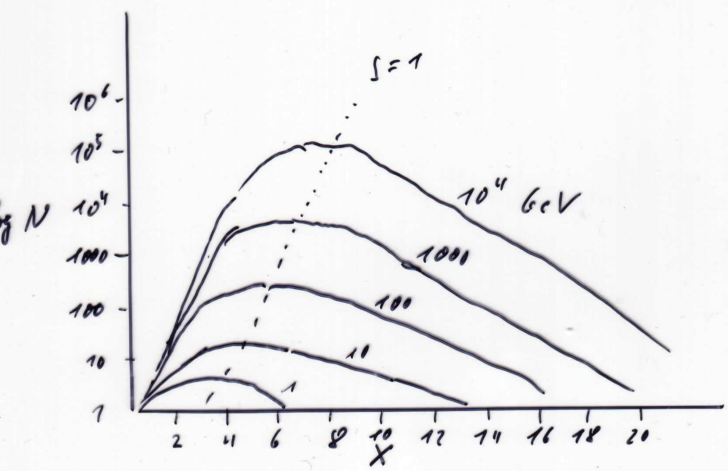
λ MATERIAL CONST

GREISEN, ROSSI SOLVED DIFF. EQUATION
FOR SOME FURTHER SIMPLIFICATIONS

$$N_{e^+e^-}(X, E_0) = \frac{0.31}{\sqrt{\ln \frac{E_0}{E_c}}} \, e^{X(1 - 1.5 \cdot \ln s)}$$

$$s = \text{AGE PARAMETER} = \frac{3X}{X + \ln \frac{E_0}{E_c}}$$

FOR $s < 1$ N GROWS
FOR $s = 1$ N max
FOR $s > 1$ N FALLS



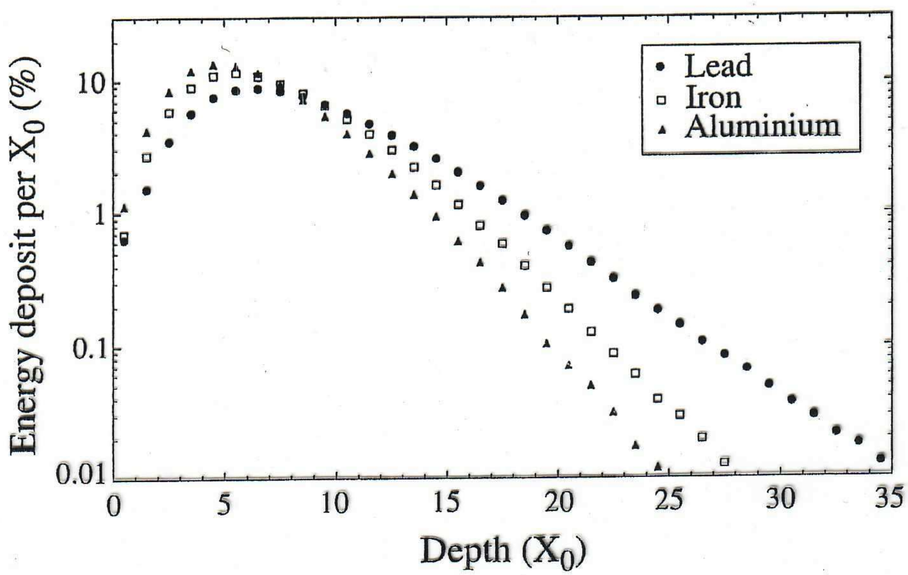
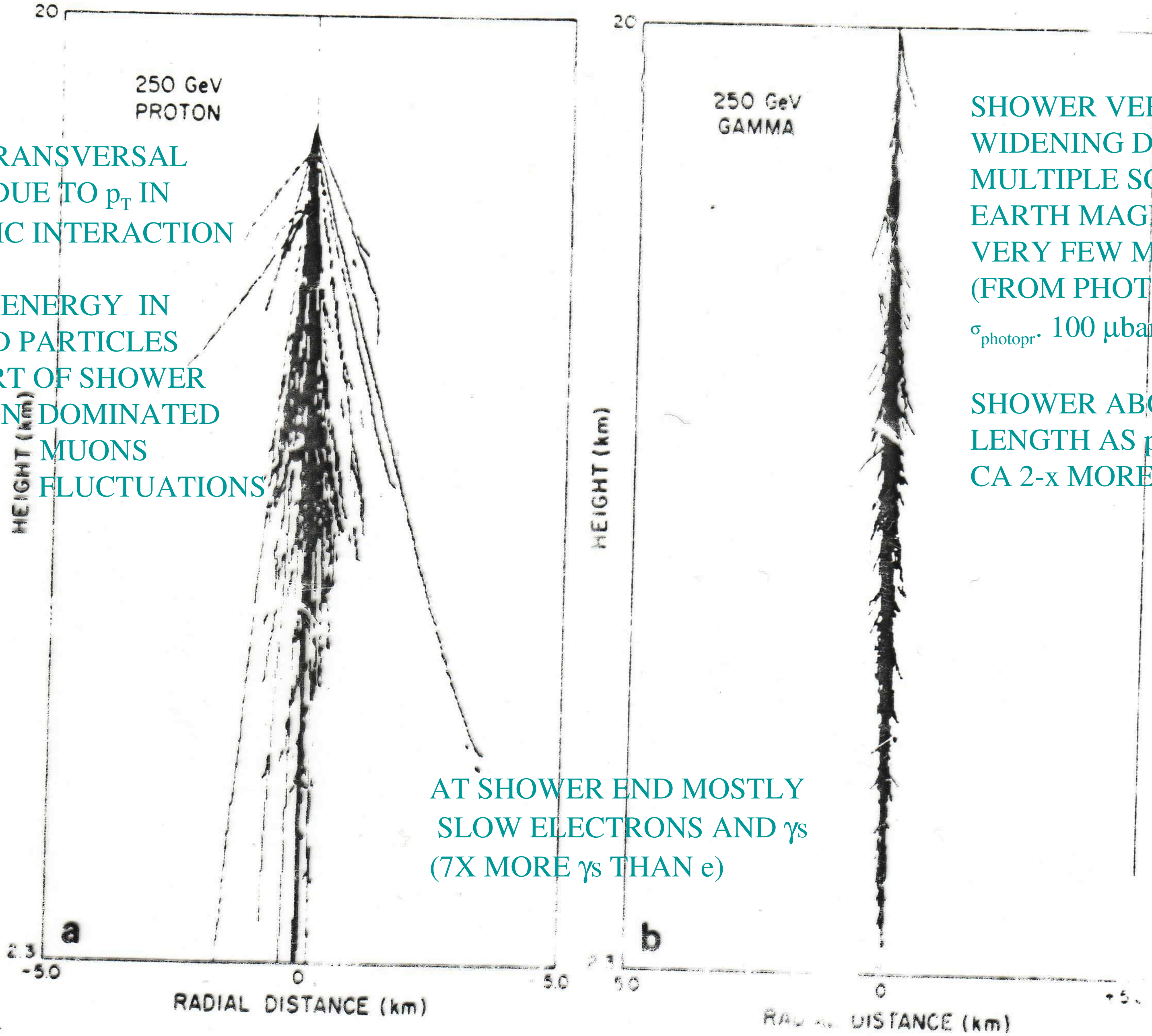


FIG. 2.12. Energy deposit as a function of depth, for 10 GeV electron showers developing in aluminium, iron and lead, showing approximate scaling of the longitudinal shower profile, when expressed in units of radiation length, X_0. Results of EGS4 calculations.

MC SIMULATIONS OF A PROTON AND A γ INDUCED AIR SHOWER OF 25 GEV



WIDER TRANSVERSAL
SPREAD DUE TO p_T IN
HADRONIC INTERACTION

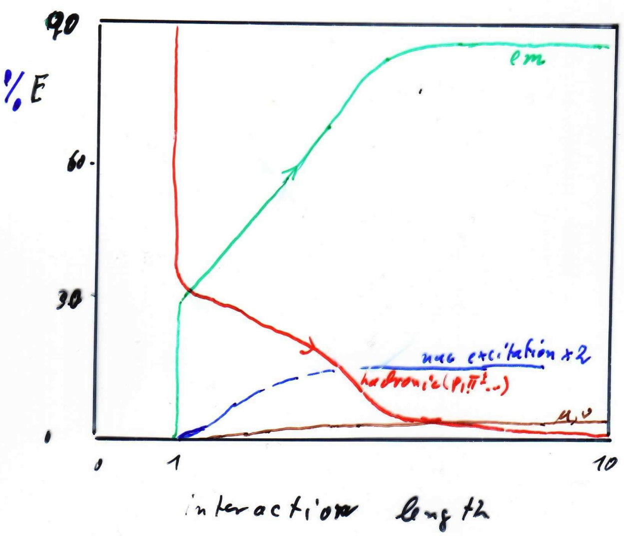
NOT ALL ENERGY IN
CHARGED PARTICLES
LAST PART OF SHOWER
ELECTRON DOMINATED
SOME MUONS
LARGER FLUCTUATIONS

SHOWER VERY NARROW
WIDENING DUE TO
MULTIPLE SCATTERING
EARTH MAGNETIC FIELD
VERY FEW MUONS
(FROM PHOTOPROD.
$\sigma_{photopr.}$ 100 μbarn

SHOWER ABOUT SAME
LENGTH AS p-SHOWER
CA 2-x MORE CLIGHT

AT SHOWER END MOSTLY
SLOW ELECTRONS AND γs
(7X MORE γs THAN e)

ENERGY PARTITION IN THE AIR CALORIMETER
FOR AN UHE PROTON



AT E_i = 10 GeV ~ 30% IN NUCLEAR EXCITATION !

$p + x \rightarrow \ \dots \ \pi^\pm \pi^0$

$\hookrightarrow \gamma\gamma \rightarrow$ feeds em fraction

$\pi^\pm + X \rightarrow \dots \pi^\pm \pi^0$

$\hookrightarrow \gamma\gamma$

⇒ at the end: hadronic induced shower converted dominantly into em comp.

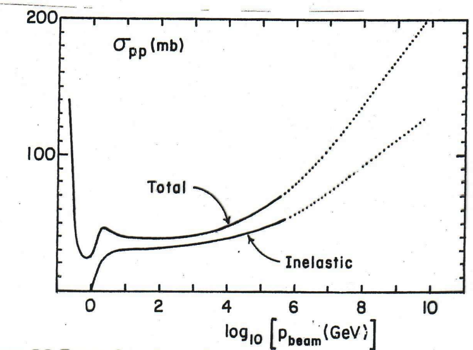


Figure 5.2: Energy dependence of σ_{pp}.

σ_{pp}

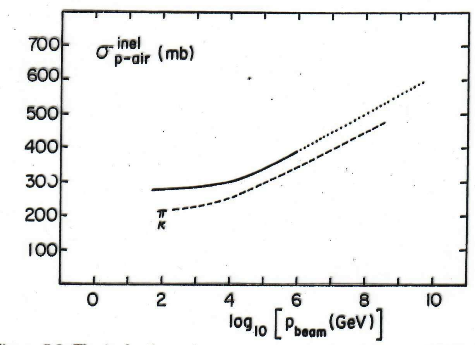


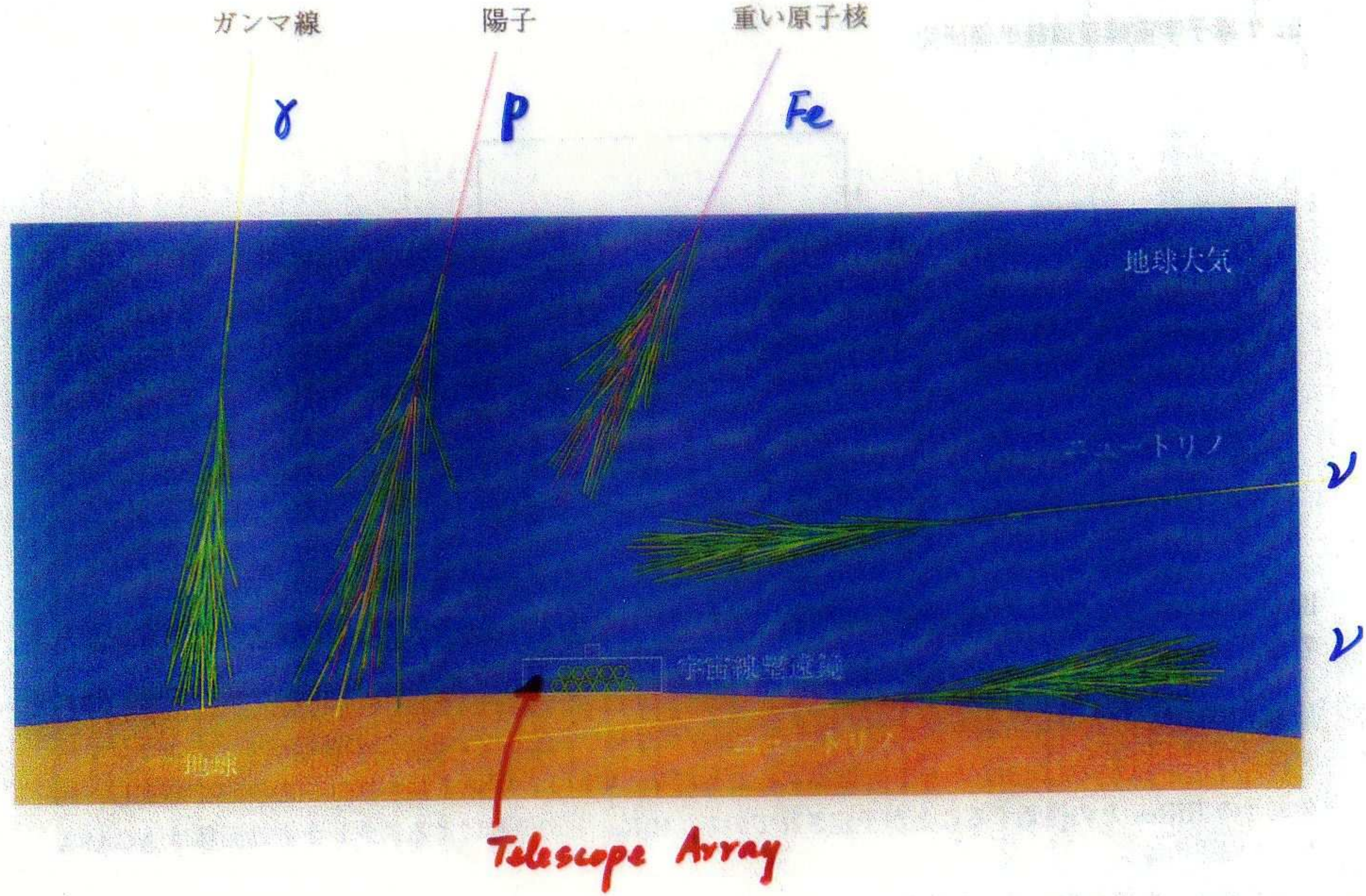
Figure 5.3: The inelastic p–air cross section predicted from a QCD minijet model.

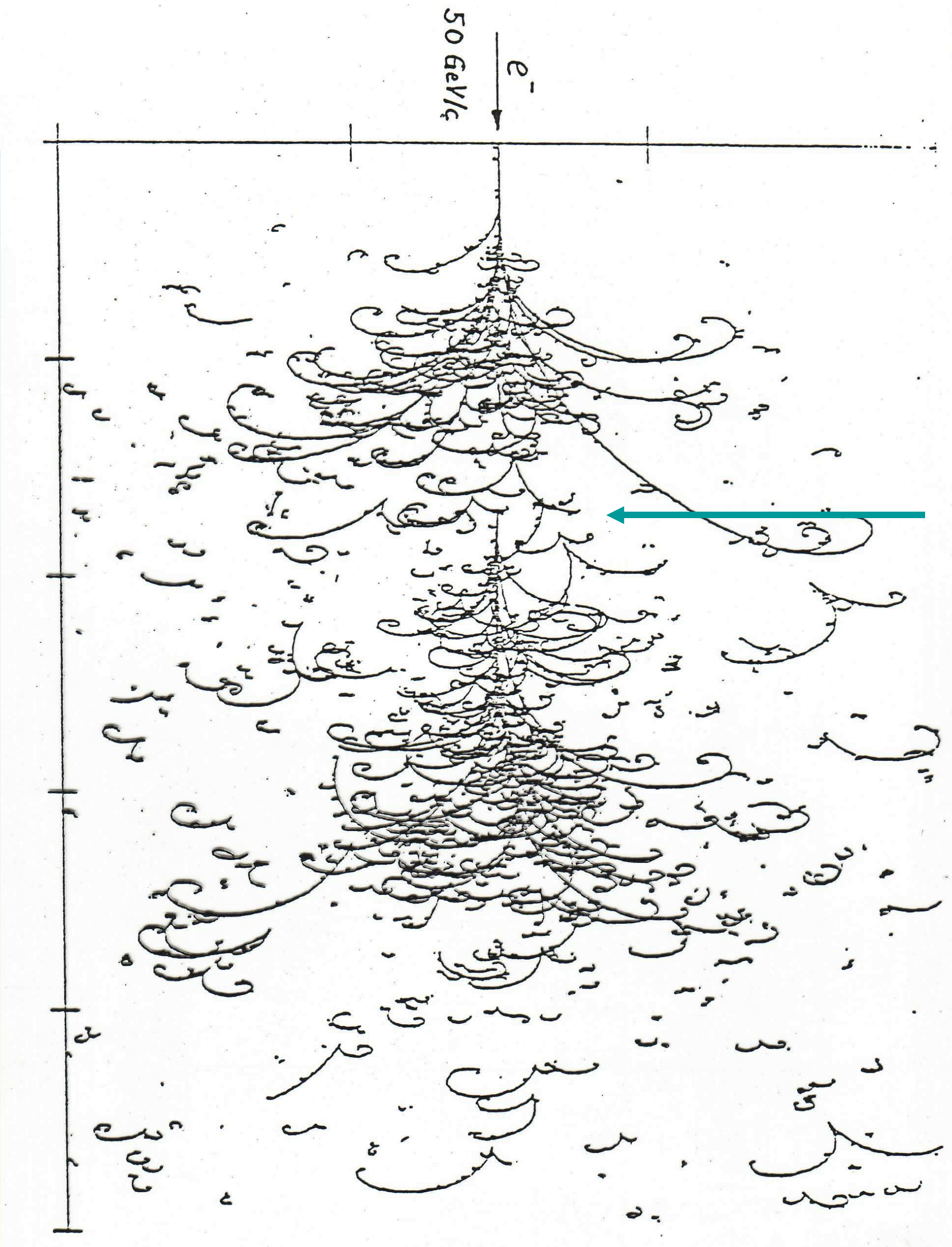
$\sigma_{p\,air}$

$\sigma_{\gamma \to e^+e^-}$ ~ 500 mb

$\sigma_{\gamma} \to$ had. ~ 100 μb

Examples air showers





RARE PHOTO OF AN em SHOWER

CERN,
50 GeV ELECTRON IN HEAVY
LIQUID BUBBLE CHAMBER

Note unusual structure of low
Particle density in area of expected
Shower maximum

DETECTION METHOD, GENERAL COMMENTS

HIGH ENERGY γ's (10 MeV- 10 GeV)
CAN ONLY BE DETECTED BY HIGH FLYING BALOON BORNE OR SATELLITE BORNE DETECTORS
NORMALLY THE FLUXES ARE HIGH -> SMALL DETECTORS SUFFICIENT
VERY GOOD CHARGED HADRON REJECTION BY ANTICOINCIDENCE SHIELD
REJECTION EFFICIENCY 10^8 (EGRET)
SATELLITE BORNE DETECTORS (0.1 m^2) ONLY USEFULL UP TO 1-10 GeV (->300 GeV,GLAST)

VHE γ 's (100 GeV-10 TeV)
INITIATE ELECTROMAGNETIC (EM) SHOWERS IN THE ATMOSPHERE (electrons, γ's)

- O) **MULTIPLICATION PHASE UNTIL ENERGY PER SECONDARY PARTICLE AROUND 80 MeV**
- P) **THAN IONISATION LOSSES DOMINANT AND SHOWERS DIE OUT**
- Q) **HADRONIC PRODUCTION BY SO-CALLED PHOTOPRODUCTION PROCESSES VERY SMALL-**
- R) **-> VERY FEW μ EXPECTED**
- S) **VHE em SHOWERS END HIGH UP IN THE ATMOSPHERE -> PARTICLES DO NOT REACH GROUND**
- T) **CHARGED PARTICLES ONLY DETECTABLE WITH DETECTORS AR VERY HIGH MOUNTAINS**

UHE γ's (10,100 TeV -1 PeV)
EM SHOWERS REACH GROUND
-> CAN BE DETECTED BY DETECTORS AT GROUND (SO-CALLED TAIL CATCHER CALORIMETER)

VHE HADRONIC PARTICLES (Few GeV - ..TeV)
INITIATE HADRONIC SHOWERS, MUCH MORE COMPLEX
CANNOT BE CORRELEATED WITH STELLAR OBJECTS- NOT USEFUL FOR ASTRONOMICAL STUDIES OF DISCRETE OBJECTS, BUT CHEMICAL COMPOSITION IMPORTANT INFORMATION

DETECTION METHOD, GENERAL COMMENTS, CONT.

VHE HADRONIC PARTICLES,CONT.
SOME MEASUREMENTS WITH HIGH FLYING MAGNETIC SPECTROMETERS +PARTICLE ID POSSIBLE
SERIOUS BG FOR γ ASTRONOMY

UHE HADRONIC PARTICLES (> few TeV- few PeV)
INITIATE HADRONIC SHOWERS.SHOWER TAIL CAN REACH GROUND
USELESS FOR ASTRONOMY OF SPECIFIC OBJECTS, CHEMICAL COMPOSITION IS AN IMPORTANT QUESTION
SERIOUS BG FOR γ ASTRONOMY

EE COSMIC RAYS(CAN BE HADRONS, γs OR νs)
CREATE VERY LARGE HADRONIC AIR SHOWERS, HIGH PARTICLE FLUX ON GROUND
CORRELATION WITH COSMIC OBJECTS POSSIBLE

HE νs (10 MeV- 10 GeV)
DUE TO WAEK INTERACTION CREATE SELDOM A REACTION, PENETRATE ATMOSPHERE WITHOUT SIZEABLE INTERACTION. PRODUCE MEASURABLE PARTICLES VIA WEAK INTERACTION (NEUTRAL/CHARGED CURRENT) INTERACTIONS PRODUCING MUONS ALLOW 'RANGING' OF MUONS. HE νs MESSENGERS OF NUCLEAR REACTIONS (FUSION IN THE SUN…)
HE ν ASTRONOMY: SN EXPLOSIONS, DIFFICULT TO CORRELATE WITH POINT SOURCES
VERY DEMANDING BACKGROUND REJECTION

VHE νs (100 GeV- few TeV)
WEAKLY INTERACTING, CAN PRODUCE em SHOWERS, MUONS (can be ranged out), HADRONIC SHOWERS
ONE NEEDS ENORMOUS DETECTION VOLUMES. CAN BE CORRELATED WITH POINT SOURCES
VERY DEMANDING BACKGROUND REJECTION

THE ATMOSPHERE IS A VERY 'TRICKY' CALORIMETER

(NOT LIKE CALORIMETERS FOR HEP)

•LOW Z MATERIAL

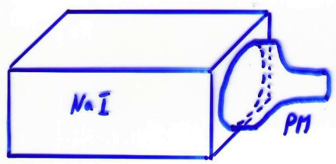
•EXPONENTIAL DENSITY DISTRIBUTION (xmax much more compressed)
•CHANGES PERMANENTY ITS MASS, DISTANCE TO THE OBSERVER
(DUE TO EARTH ROTATION)
*HAS NO CONFINING WALLS -> BACKGROUND LIGHT
*CAN CHANGE ITS TRANSMISSION IN AN UNPREDICTABLE WAY ((FOG..)
-> NEEDS INSTRUMENTS TO CONTROL IT: LIDAR ….. -> YOU NEED GOOD INFO ABOUT WEATHER
•CHERENKOV LIGHT NOT EXACTLY PROPORTIONAL TO ENERGY LOSS BY
•IONISATION
•A FULLY ACTIVE CALORIMETER BUT NOT COMPENSATING
•(AROUND 1 TEV:PROTON INDUCED AIR SHOWERS PRODUCE ABOUT HALF OF THE LIGHT COMPARED TO EM SHOWERS)

NO TEST BEAMS FOR CALIBRATION: RELY ON MC SIMULATIONS

TYPES OF CALORIMETERS

ELECTROMAGNETIC CALORIMETERS	HADRONIC CALORIMETERS

TOTAL ACTIVE



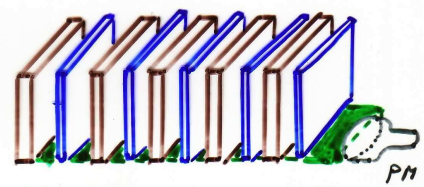
20-30 rad. length

Lead glass
($\check{C}$-radiator)

SCINTILLATION EM CALORIMETER

BEST RESOLUTION !

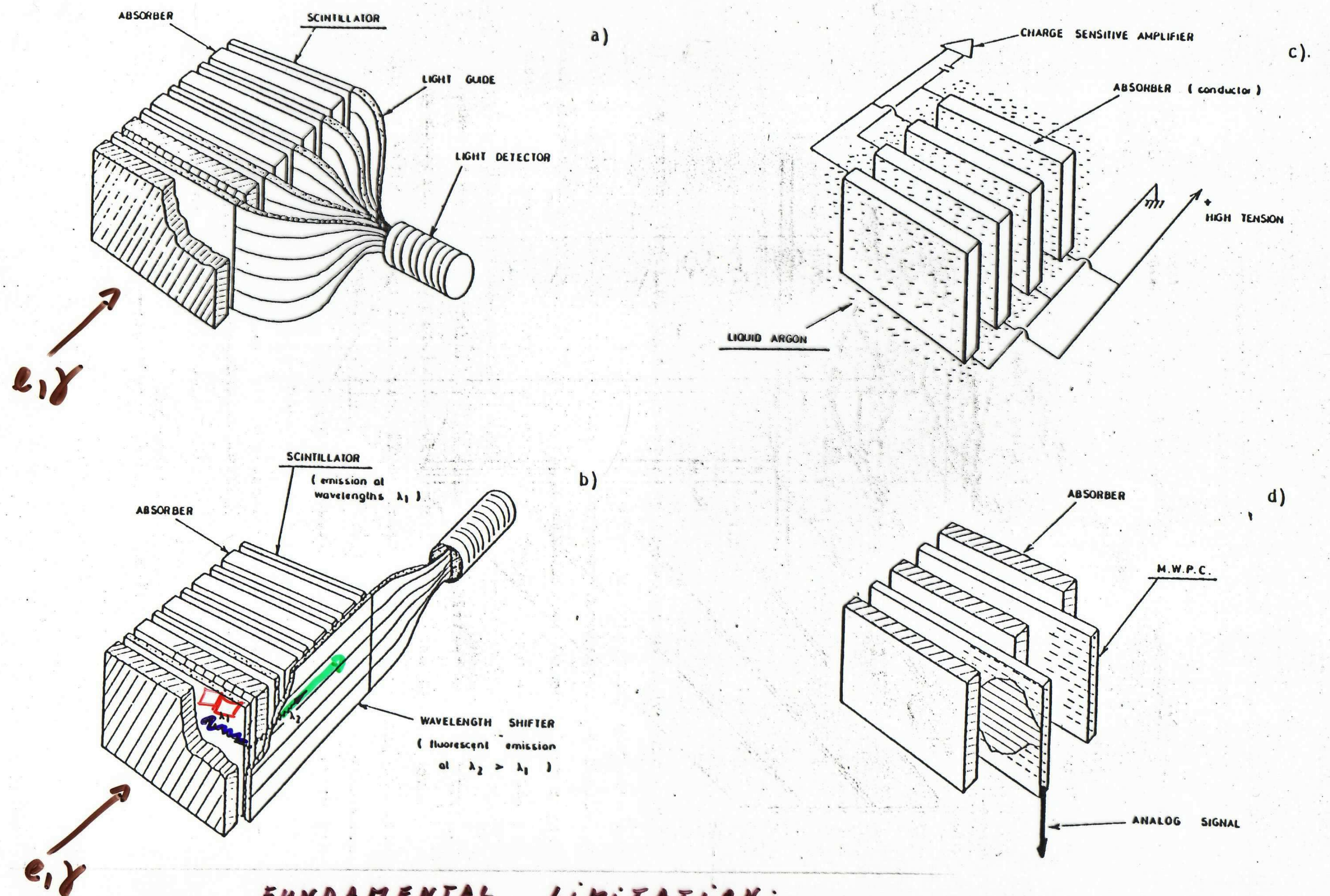
SAMPLING



20 - 30 rad. length
4 - 6 hadr. interact. length

passiv: Pb, Fe, U, ...

activ : Scintillator, liquid Ar
Gas counters, ...



FUNDAMENTAL LIMITATION:

ENERGY LOSS OF electrons (e^{+}) FLUCTUATES BETWEEN ACTIVE AND PASSIVE MATERIAL

ARTIST VIEWOF A PROTON INDUCED AIR SHOWER + OBSERVABLES

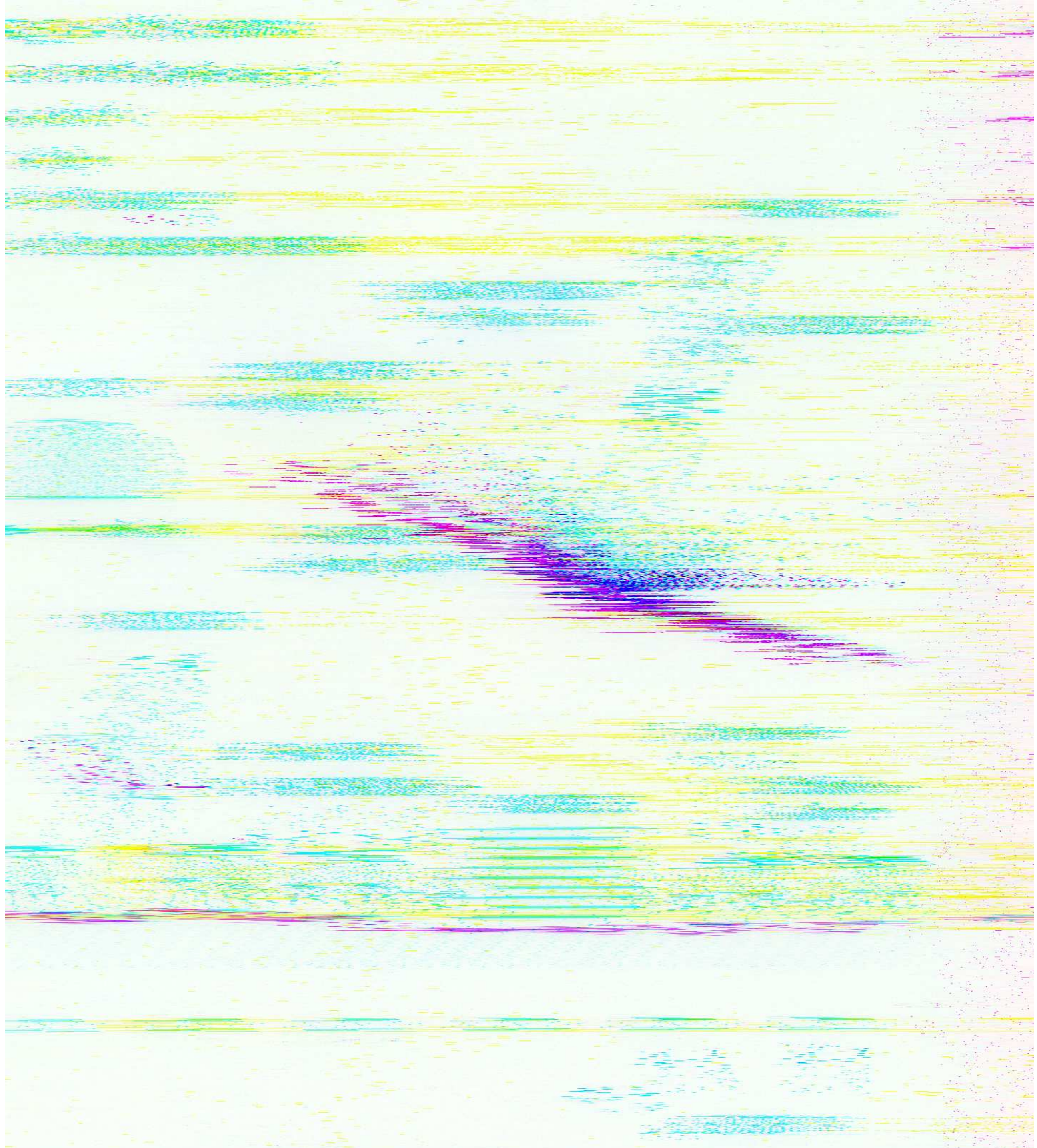
AIR MASS 1:
27 rad.length
11 hadronic abs. length

Zur Anzeige wird der QuickTimeª
Dekompressor ÒFoto - JPEGÓ
benštigt.

CARTOON

SHOWER FRONT (FLASH PHOTO BEFORE HITTING GROUND)

DETECTOR CONCEPTS



Detector Family for CR Observations

(Not for ν Detectors)

shower particles stop at high altitude

→ only light to ground

- → air Cerenkov light
  - → C-Telescope, >$5x10^{11}$eV
  - → C-Matrix, E>10^{13}eV
- → air fluorescence
  - → Fly`s Eye, E>10^{16}eV

nly at clear, moonless nights
fficiency ≈ 5-15% / year)

shower particles reach ground

- → energetic core → ground based calorimeter (area problem)
- → particle counting, timing → Scintillation counters, Geiger counters, water Cerenkov c.
- → particle direction → drift chamber, prop. chamber, Geiger chamber, all multilayer

deeply penetrating particles
(≥ 20 RL: "Muon")

→ buried Muon counters:
Scintillator, Geiger...

ν-detectors > $1km^3$, underground

CALORIMETERS (GENERAL)

FOR HEP APPLICATIONS ONE USES DENSE MATERIALS FOR CALORIMETERS

FOR VHE γ ASTRONOMY (CR STUDIES) ONE HAS TO RELY WHAT NATURE CAN PROVIDE AS ABSORBERS RESPECTIVELY AS CALORIMETER

THE ATMOSPHERE
(WATER, ICE for ν detection)

FOR VERY HIGH ALTITUDE DETECTORS (HIGH MOUNTAINS, BALLOON BORNE DETCTORS , SATELLITE BORNE DETECTORS) ONE HAS TO USE HEP TYPE MASSIVE ABSORBER CALORIMETERS.

PROBLEMS AND SOLUTIONS FOR ATMOSPHERIC CALORIMETERS

LOW PARTICLE FLUXES -> NEEDS LARGE ABSORBER AND READOUT ELEMENTS
NATURAL ABSORBERS HAVE LOW DENSITY -> SHOWERS VERY EXTENDED -> LATERAL EXTENSIONS MUST BE LARGE AND READOUT ELEMENTS MUST COPE WITH THIS PROBLEM

LARGE CR BACKGROUND -> NEEDS DETAILS OF THE SHOWER DEVELOPMENT->SHOWER IMAGING
NOTE : POINT SOURCES WILL STAND OUT OF THE BG (LIKE STARS AGAINST THE NIGHT SKY LIGHT BG
-> ISOTROPIC OR DIFFUSE OR EXTENDED γ SOURCES VERY DIFFICULT TO DETECT

SEARCH FOR UNKNOWN OBJECTS
-> THE IMAGING CALORIMETER MUST HAVE LARGE ANGULAR ACCEPTANCE OR 'GUIDANCE' FROM EXTERNAL INSTRUMENTS (RADIO TELESCOPES, X-RAY SATELLITES, HE γ SATELLITES, CANDIDATE CATALOGES, THEORETICAL PREDICTIONS

HADRONIC INTERACTION /CALORIMETERS

- HADRONIC ABSORPTION LENGTH IN AIR ABOUT A FACTOR 2.5 LONGER THAN em ABSORPTION LENGTH

  BUT NR OF SECONDARIES MUCH LARGER

  1/3 OF SECONDARIES ARE π^0's -> $\gamma\gamma$ -> FUEL em COMPONENT

  -> HADRONIC SHOWERS AT THE END DOMINATED BY em SUBSHOWERS

- SECONDARY MUONS FROM π k DECAYS CAN BE A VIABLE SIGNATURE OF HADRONIC SHOWERS

  π,k -> $\mu\,\nu$
  MUONS DO NOT INTERACT HADRONICALLY -> NOT STOPPED IN THE ATMOSPHERE, CAN ALSO DECAY
  μ -> e $\nu\,\nu$

- PART OF THE ENERGY IN HADRONIC SHOWERS TRANSPORTED AWAY BY muons and ν's
  PART OF THE ENRGY IN HADRONIC SHOWERS -> NUCLEAR EXCITATION

  -> NOT ALL OF PRIMARY ENERGY DUMPED IN THE ATMOSPHERE

CALORIMETER MATERIAL COST AN ISSUE: USE FROM NATURE
(EXAMPLE: ν DETECTOR FOR ASTRONOMY MUST BE > 10^9 TONS)

POSSIBLE NATURAL CALORIMETER MATERIALS
(MUST BE TRANSPARENT FOR MEASURABLE QUANTITIES):

ATMOSPHERE, WATER, ICE

ALL HAVE THEIR SPECIFIC PROBLEMS

'EXOTIC' MATERIALS:
PURIFIED AND ACTIVATED OIL (LIQUID SCINTILLATOR)
LIQUID PURIFIED ARGON, XENON
(MAINLY IONISATION BUT ALSO SCINTILLATION, BECOMES IMPORTANT FOR LARGER VOLUMES)

PROCESSES GENERATING PHOTONS

S) SCINTILLATION IN AIR (N_2 FLUORESCENCE)
T) CHERENKOV RADIATION IN AIR, WATER, ICE

SOME SPECIFIC PROBLEMS COMMON TO ALL EXPERIMENTS

THE YIELD OF SCINTILLATION OR CHERENKOV LIGHT YIELD IS EXTREMELY LOW. ORDER 10^{-5} TO 10^{-3} OF TOTAL PRIMARY ENERGY (EXCEPTION IN L-Ar,Xe, LIQUID SCINTILLATOR)

•-> NEED OF VERY LARGE PHOTON DETECTORS
OPTICAL CONCENTRATOR ELEMENTS HELP BUT ARE ALSO NOT CHEAP:
MIRRORS, FRESNEL LENSES, WINSTON CONE CONCENTRATORS
FLUORESCENT FLUX CONCENTRATORS

•NEED OF PIXELIZED SENSORS TO OVERCOME VARIOUS BACKGROUNDS
γ-HADRON SEPARATION IN γ ASTRONOMY
TO REJECT BACKGROUND LIGHT
• TO DETERMINE DIRECTION OF SHOWERS

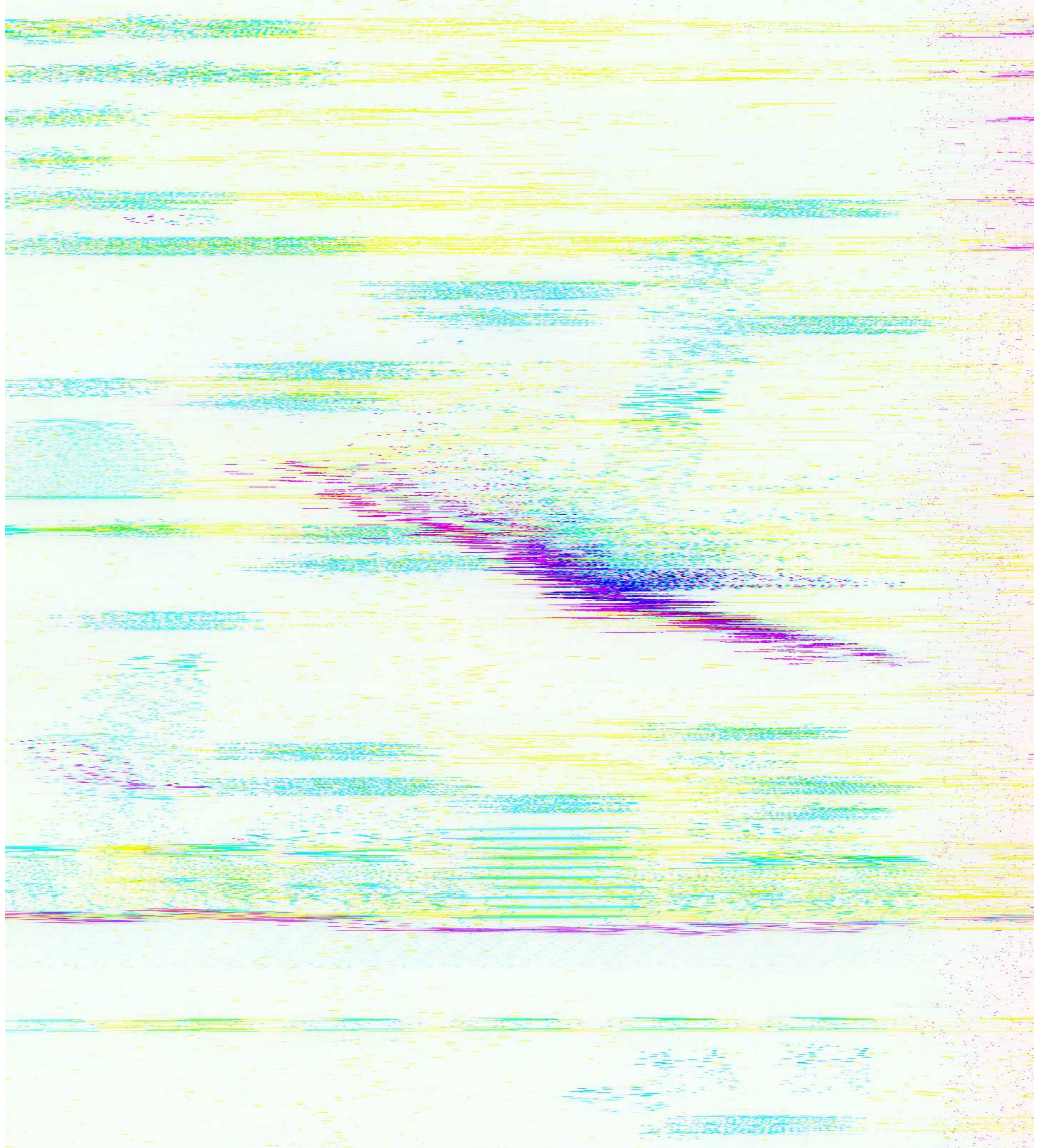
•NEED OF FAST PHOTON DETECTORS
nsec TIME RESOLUTION FOR CHERENKOV TYPE DETECTORS
10 - FEW 100 nsec TIME RESOLUTION FOR SCINT. LIGHT DETECTORS

EARTH ROTATES: CALORIMETER AND PHOTON DETECTORS MUST COPE WITH ROTATION (TELESCOPES, 4π UNIDIRECTIONAL READOUT..)

CARTOON

SHOWER FRONT (FLASH PHOTO BEFORE HITTING GROUND)

DETECTOR CONCEPTS



GROUND-BASED ARRAY DETECTORS

‘TAIL CHATCHER CALORIMETER’

- WERE ONCE THE MAIN DETECTORS FOR CR STUDIES, AIM TO FIND THE SOURCES
- OF CR AND THE CHEMICAL COMPOSITION OF HIGH ENERGY CRs

- MEASURE PARTICLES FROM THE SHOWER TAIL
- -> TAIL MUST REACH GROUND
- -> HIGH THRESHOLD
- -> TO LOWER THRESHOLD: GO TO HIGH MOUNTAINS

- CAN MONITOR ‘ALL SKY’ (GOOD FOR GRB OBSERVATIONS IF TeV PARTICLES
- 24 H UP-TIME

DETECTORS FOR CHARGED PARTICLES AT SHOWER END (TAIL CATCHER CALORIMETER I)

ONLY FOR SHOWERS THAT REACH TO GROUND
AT SEA LEVEL E > 10^{14} eV
AT HIGH MOUNTAINS E > 10^{11} eV

GENERAL PROBLEM: SHOWER TAIL PARTICLES SPREAD OVER LARGE AREAS
-> FOR COST REASONS ONLY SMALL COVERAGE (EX LAKE DETECTORS) -> SAMPLING OF SHOWER FRONT
ACTIVE DETECTOR FRACTION 0.1% - 100%

WHAT IS MEASURED :LOCAL PARTICLE DENSITY (-> SHOWER ENERGY) AND LOCAL ARRIVAL TIMES (-> SHOWER DIRECTION)

GEIGER COUNTERS(PROPORTIONAL COUNTERS)
WAS THE INITIAL TYPE OF PARTICLE DETECTOR
BUT MODERNIZED VARIANT (, DRIFT CHAMBERS, IAROCCI TUBES, RPCS) STILL IN USE

RELATIVELY CHEAP,
BIG SIGNALS -> EASY READOUT ELECTRONICS
ROBUST
NEED GAS SUPPLY
TIME RESPONSE 10-FEW 100 nsec, DEADTIME O μsec

CURRENTLY ONLY ONE DETECTOR USING MODERN VERSION OF G-TUBES, THE-SO-CALLED RPCS:
ARGO AT SINGAO (TIBET AT 4300 M ASL
NEARLY FULL AREA COVERED BY RPCS

SCINTILLATION COUNTERS

STANDARD TOOL FOR MANY PAST DETECTORS

PLASTIC SCINTILLATOR OR LIQUID SCINTILLATOR VIEWED BY FAST PHOTOMULTIPLIERS

PRICE FOR A 1m2 SCINTILLATION COUNTER, FULLY EQUIPPED, INC READOUT: 5-10 0000 €

MATRIX TYPE ARRANGEMENT WITH 10-20 mtr GRID SPACING

ONLY 1 DETECTOR IN OPERATION: TIBET AS AT 4300 m asl
THRESHOLD: FEW 100 GEV

WATER CHERENKOV DETECTORS

WATER IS A CHEAP DETECTOR MEDIUM
TYPICAL DETECTOR: WATER TANK (EXTREME A LAKE) LINED WITH REFLECTOR FOIL
VOLUME VIEWED BY LARGE PHOTOMULTIPLIERS

ONLY 1 DETECTOR IN OPERATION: MILAGRO AT NEW MEXICO, AT 2300m asl
70X80 M DECOMISSIONED WATER RESERVOIR
FULLY ACTIVE
MODEST MUON IDENTIFICATION CAPABILITIES
THRESHOLD: 100 GEV -1 TEV

PHYSICS GOALS OF THE CLASSICAL GROUND-BASED ARRAY DETECTORS WITH A THRESHOLD >1012-10^{14} TeV

D) FIND THE SOURCES OF THE CRs VIA γ ASTRONOMY (very meager results)
E) IDENTIFY THE CHEMICAL COMPOSITION OF THE CR AS FUNCTION OF ENERGY
F) (poor results)
G) MEASURE SPECTRAL SHAPE

+ LOTS OF PHYSICS GOALS IF CLEAR ANSWERS FROM a), b)

(see γ- astronomy)

FLUX MEASUREMENTS OF DIFFERENT CHEMICAL ELEMENTS IN CRs AS FUNCTION OF ENERGY, UP TO 1 TeV, I.E. BELOW ROI.

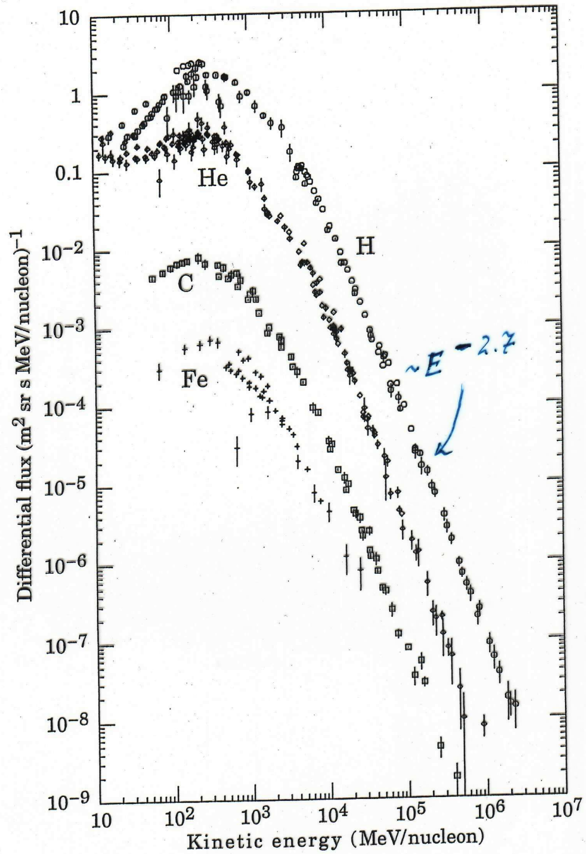
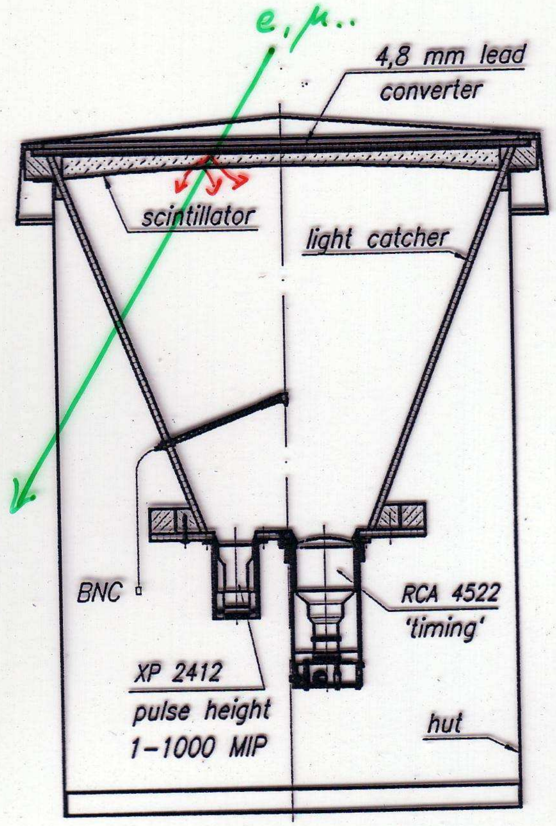


Figure B.1: The differential flux of cosmic rays (nuclei) in the energy range from 10^7 to 10^{13} eV/n (10MeV/n - 10TeV/n). The chemical composition is outlined. It is possible to see the peak of the spectrum and, above, the unbroken power law with the spectral index $\Gamma \approx 2.7$

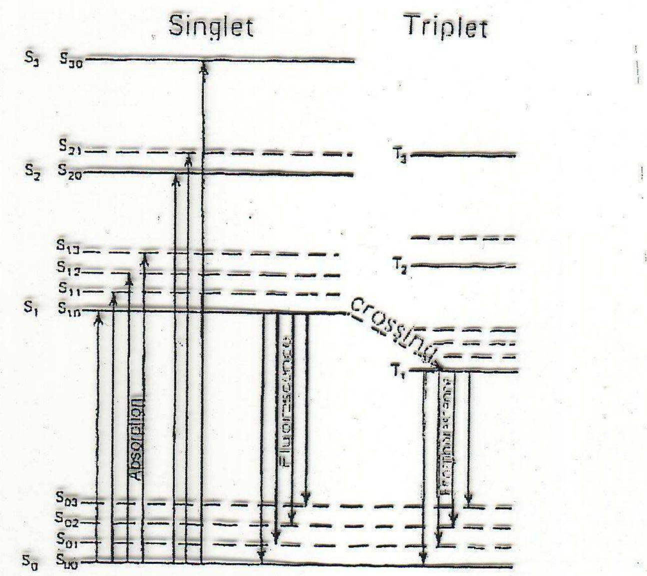
THE WORKHORSE FOR LARGE GROUND BASED ARRAYS



PLASTIC (LIQUID) SCINTILLATOR VIEWED BY
A PHOTOMULTIPLIER(S) IN A LIGHT-TIGHT BOX

MESURES TIME: -> for direction
MEASURES # PARTICLES -> for energy estimate

Plastic scintillator: transparent organic material with π electron configuration: polystyrene, polyvinyltoluene..
Low QE, light at 280 nm, near absorption>-needs wls shifters P-TP, POPOP..
τ 1-5 nsec. 10000 photons/MeV

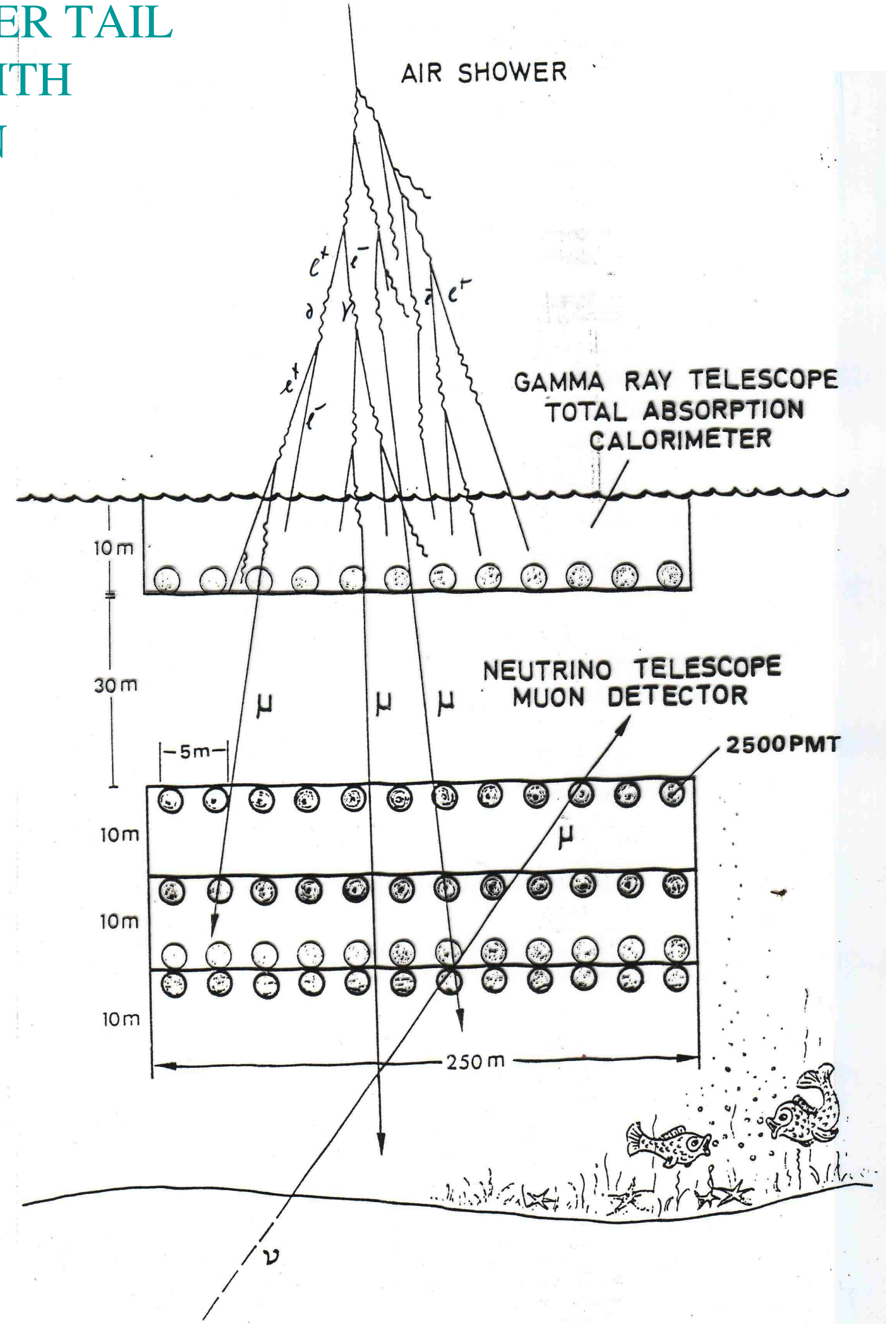


Energy levels of an organic molecule with π-structure

Tibet III Air Shower Array

CONCEPT OF A WATER TAIL CATCHER ARRAY WITH e-μ DISCRIMINATION

100% ACTIVE AREA

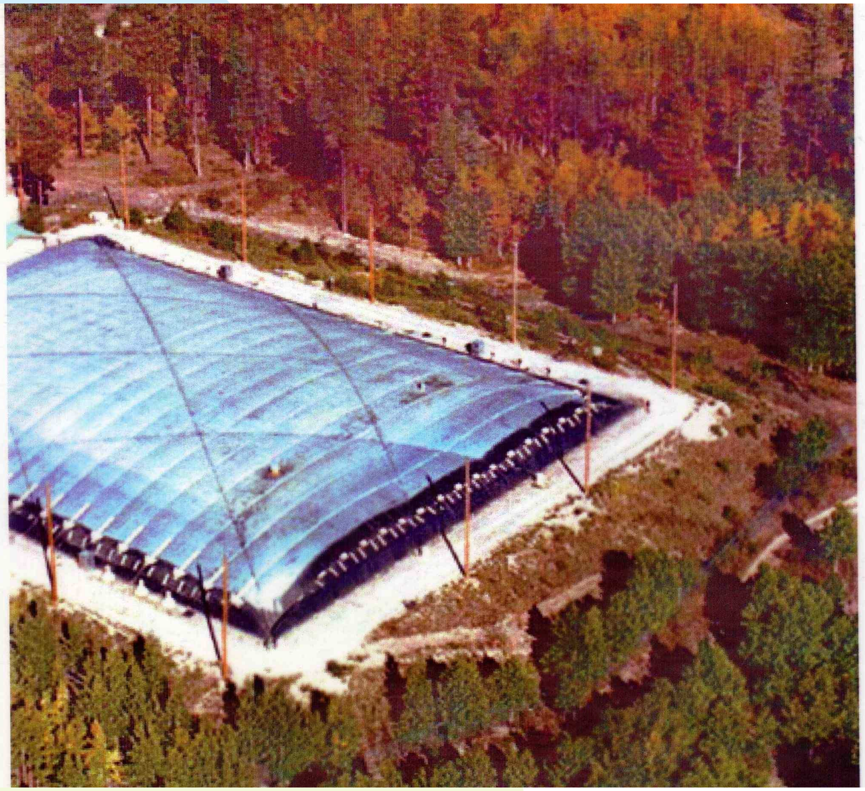


The Milagrito Detector

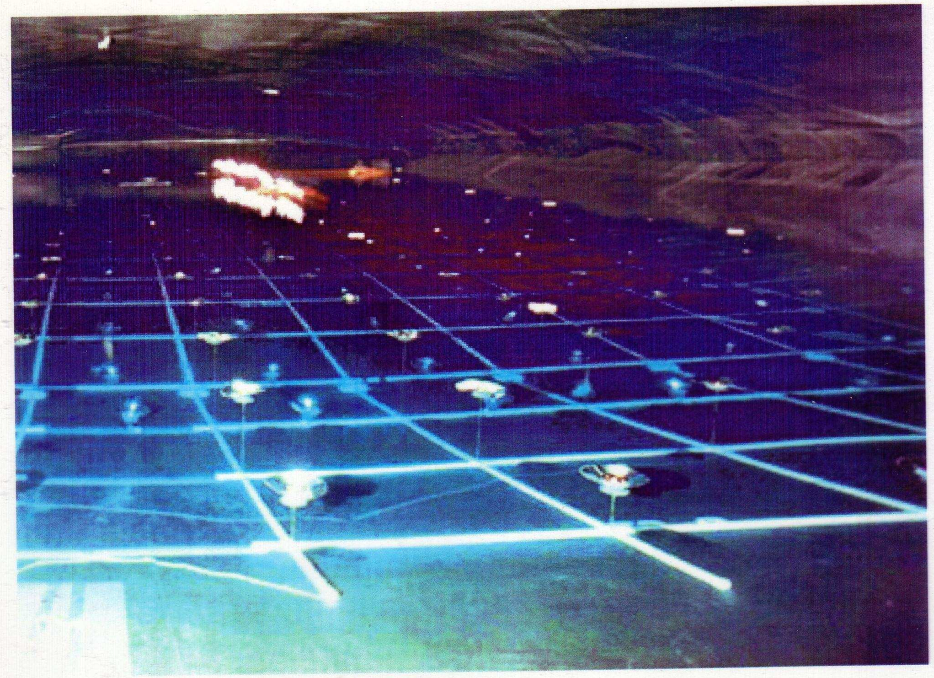
Jemez Mountains, NM
February 1997 to May 1998

- ground–based air shower array for detecting gamma rays in the energy regime ~100 GeV – ~20 TeV
- used water Cherenkov technique to detect air shower particles
- located 2650 m above sea level

THE MILAGRO TAIL CATCHER WATER'ARRAY'
100% ACTIVE COVERAGE AT SHOWER END



VIEW FROM OUTSIDE, LIGHT SEAL COVER

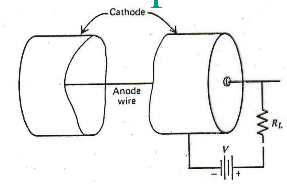


PM ARRANGEMENT

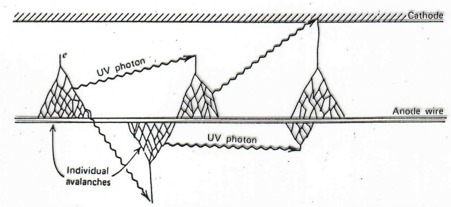
1. ARGO-YBJ [Girolamo[

4300m ASL
6,000 m² RPC detector
Scalers sensitive ~GeV energies.
95% active area coverage
Good for GRB detection
Threshold below 100 GeV
Near Tibet AS

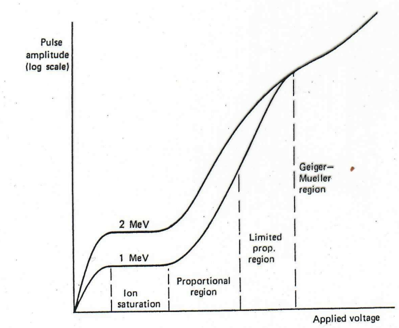
GEIGERTUBE (PARENT OF THE RPC (Resistive plate chamber)



Basic elements of a proportional counter. The outer cathode must also provide a vacuum-tight enclosure for the fill gas. The output pulse is developed across the load resistance R_L.



The mechanism by which additional avalanches are triggered in a Geiger discharge.



The different regions of operation of gas-filled detectors. The observed pulse amplitude is plotted for events depositing two different amounts of energy within the gas.

IN AN RPC ONE USES HIGH RESISTIVE OUTER WALLS, THAT LIMIT DISCHARGE AND CONFINE IT LOCALLY, OUTER PICK-UP ELECTRODES ALLOW 2-DIM READOUT FEW KHZ DEVICE

GENERAL ADVANTAGES AND DISATVANTAGES OF 'TAIL CATCHER ' CALORIMETERS

GROUND-BASED TAIL CATCHER ARRAYS HAVE 24 H UP-TIME,

ALL SKY DETECTION (E-DEPENDENT)

ROBUST

NEARLY NEVER MOVING MECHANICAL PARTS

HIGH THRESHOLD, STRONG ZENITH ANGLE DEPENDENCE

VERY MODEST ENERGY RESOLUTION

MODEST ANGULAR RESOLUTION.

PROBLEMS TO FIX ANGULAR REFERENCE POSITION (SHADOW OF THE MOON)

MAIN WEAKNESS: BASICALLY NO γ/HADRON SEPARATION