Azimuthal Alignment. (Pamir Results) 93.

- 60 cm. deep lead - emulsion Chamber. (XEC)

$\sum E_\gamma$ = 100 - 5000 TeV ⟵ 74 γ- families

- EDC = Energetically Distinguished Centre
  1. a halo or Separate Cores of a halo
  2. narrow group of γ-quanta - Specially Selected for high energy
  3. Single high energy hadron with $E_h = 3 E_h^{(\gamma)}$

     where $E_h^{(\gamma)}$ is the EM Component energy in XREC.

$$\lambda_N = \sum_{i \neq j \neq k} \cos 2 \phi_{ij}^k \Big/ N_c (N_c - 1)(N_c - 2)$$

ϕ_{ij}^k = angle between two Straight lines Connecting the k^{th}. Centre with i^{th} and j^{th}. Centres

N_c = Number of EDC's

$\lambda_N = 1$ for Cases when all Centres in question are aligned exactly along the Same Straight line

$\lambda_N \leq 0$ for isotropic distribution of EDC's

Working Definition of Aligned Events $\lambda > 0.6$ for $N = 3, 4$.

Conclusions:

① The alignment is practically absent at $\sum E_\gamma \simeq 100$ TeV

② The fraction rises significantly from 8% to 43 ± 17% at $\sum E_\gamma \simeq 1000$ TeV

③ The Simulations Showed that because of Spread of k_γ the fraction of alignment may be higher by a factor of 2 before detection

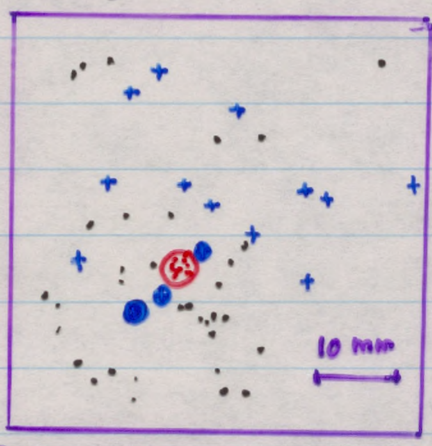
④ Aligned particles Stand out of a Coplanarity with $\langle p_t^\perp \rangle \simeq 0.1 \langle p_t \rangle$

AZIMATHAL ASYMMETRY:

Alignment of main energy flow in Gamma Hadron Families:

Pamir Collaboration noted in 1985, few events in EC having multiple halos aligned along a straight line in the target plane.

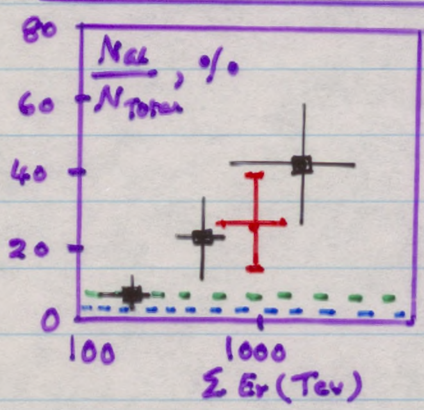
Typical Example.



⊙ Electromagnetic Halo – 700 TeV
● Hadron Halo 900 TeV
⊕ Hadrons 279 TeV and 180 TeV
. γ-quanta.
+ hadrons

• 74 Families have been analyzed.
with 60 cm. XEC. at Pamir.
ΣE_γ = 100 - 500 TeV. 14 > ΣE_γ = 500 TeV

(p84)
(p140)

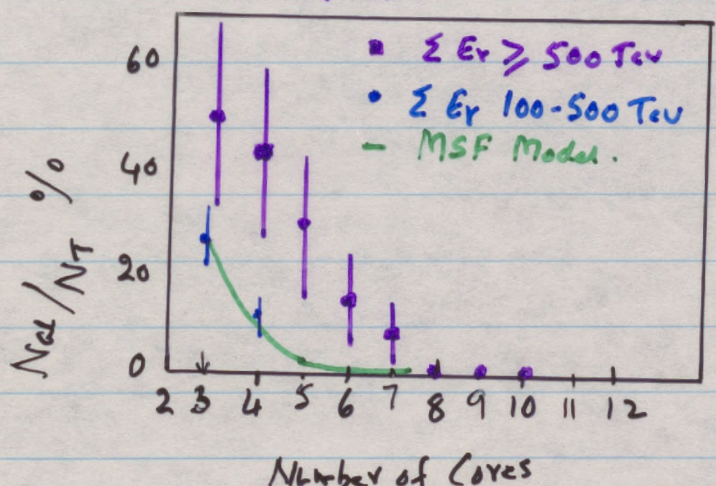


■ Experiment
--- Simulation MSF model
---- random
---- Pamir (Carbon Chamber data.)

Fraction of aligned events as a function of energy.

Selection $\lambda \geqslant 0.8$

Aligned Fraction (% of Total) Vs Selected Number of Cores in every family ($\lambda \geqslant 0.8$)



MSF = Quasi-Scaling Model (1981)
(17th. ICRC 11, 343)
1981

Effect of Electric Fields on Cascades

	Field →	Horizontal		Vertical	
	Particles →	Hadrons	γ-Quanta	Hadrons	γ-Quanta
4 Cores →	$\langle \lambda_4 \rangle$	0.24 ± 0.01	0.31 ± 0.02	0.28 ± 0.01	0.39 ± 0.02
	$W(\lambda_4 > 0.8)$	0.06 ± 0.01	0.09 ± 0.02	0.09 ± 0.01	0.16 ± 0.02
5 Cores →	$\langle \lambda_5 \rangle$	0.23 ± 0.01	0.32 ± 0.02	0.28 ± 0.01	0.41 ± 0.02
	$W(\lambda_5 > 0.8)$	0.015 ± 0.004	0.07 ± 0.03	0.033 ± 0.008	0.11 ± 0.02
6 Cores →	$\langle \lambda_6 \rangle$	0.24 ± 0.01	0.33 ± 0.02	0.29 ± .01	0.43 ± 0.02
	$W(\lambda_6 > 0.8)$	0.002 ± 0.002	0.045 ± 0.025	0.028 ± 0.009	0.09 ± 0.02

It is clear from this Table 3 that Atmospheric Electric Fields can cause alignment of the cascades, especially the vertical fields. The effect is less in the case of hadrons.

* Parameters For the Long Flying Component
  - Mean Free Path = $n \times 100$ gms/cm^2

In this case, hadron alignment has to be more than γ-quanta. Zenith Angle Distribution of aligned events flatter than usual families. 'n' – multiplicity of cores.

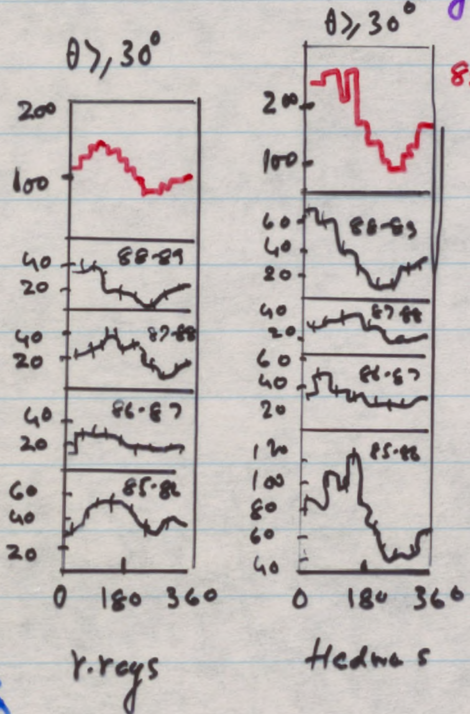
- The X-Component has to be about 1% in the Primary radiation — has to interact according to the special process proposed by 'Royzen' — (1993) QGS model

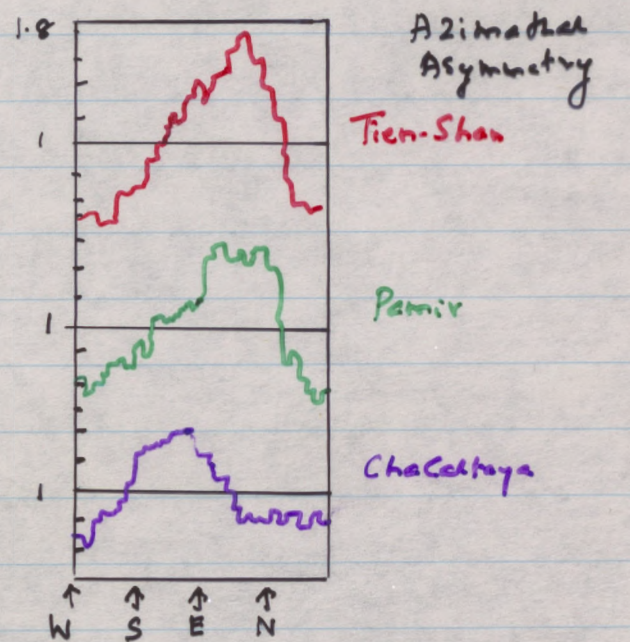
Does this indicate some anomalous component in the primary radiation?

AZIMATHAL ASYMMETRY

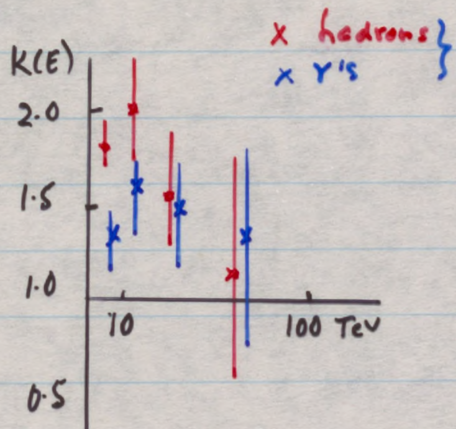
Experiment "HADRON" at TienShan (690 gms/cm²)
(Emulsion Chambers)
(1985-1991)

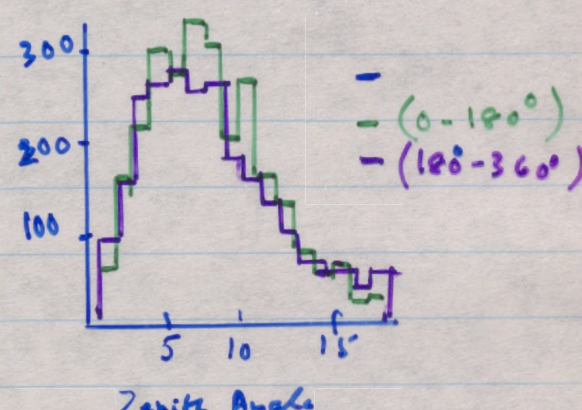
- This asymmetry is quite different from the Pamir Expt for Cosmic Ray Families. (600 gms/cm²)
- Energy of Hadrons and γ-families analysed at TienShan
  $\Sigma E_\gamma = 10\text{-}20$ TeV
- The Azimathal Asymmetry can be seen from the figure below.





Energy dependence of the asymmetry coefficient





$$K = \left\langle \frac{N_{0\text{-}180}}{N_{180\text{-}360}} \right\rangle$$

$K_{hadron} = 1.78 \pm 0.11$

$K_\gamma = 1.52 \pm 0.12$

Zenith Angle Distribution for different φ (0°-180°) and (180°-360°)

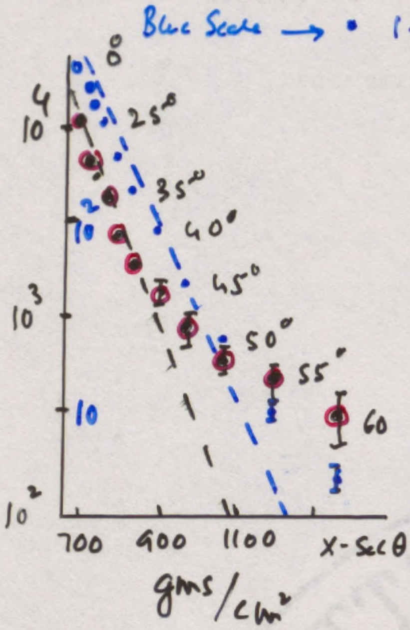
Systematic Effects have been ruled out.
Similar behaviour at TienShan, Pamir and Chacaltaya.

VAP
VAP387

* ZENITH ANGLE DISTRIBUTION OF EAS

TIENSHAN DATA.

Black Scale → • $2.5\times10^6 - 4\times10^6$
Blue Scale → • $1.6\times10^5 - 2.5\times10^5$



Integral Distribution.

The expected distributions Calculated on the basis:

$\gamma_1 = 1.66$ Knee at 3.10^{15} ev.

$\gamma_2 = 2.1$

$$n(\theta_i) = \frac{I_0 \sum_A H_A 2\pi \int_{\theta_i}^{\pi/2} \sin\theta \, d\theta \int_{Y_{min}(\theta,A)}^{Y_{max}(\theta,A)} e^{-\gamma \cdot Y} dy}{2\pi \cdot I_0}$$

H_A = Nuclei fraction with atomic number A

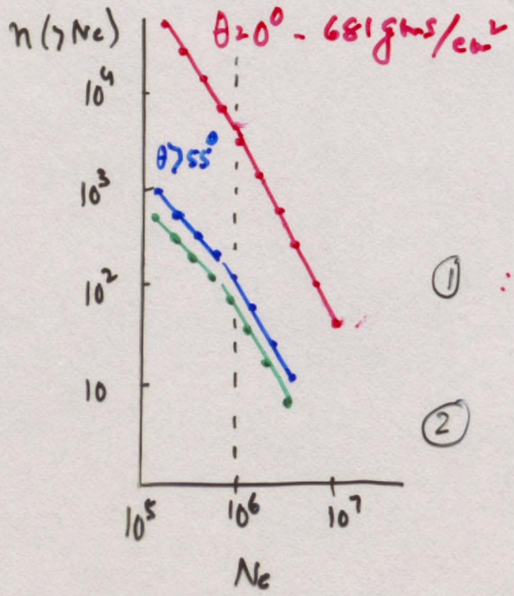
I_0 = Primary Flux

$Y = \ln\left(E / 3.16\times10^6 \text{ Gev}\right)$ –

Energy Threshold for Proton Showers.

It is Seen that the data clearly Shows Considerable excess at large zenith angles – beyond 50°.

* Size Spectrum of EAS at different Zenith Angles.



The bend Seems to occur at the Same Shower Size ($N_e \sim 10^6$) Irrespective of Zenith Angle –

① ∴ Is the bend Connected with the Primary Spectrum?

② The above two phenomena Connected with the Long Flying Component? (Increased Charm Production)

SCOPE FOR A WHOLE NEW CHAPTER OF CR RESEACH

Anomalies like

the leakage of electricity.

discharge of Counters in a horizontal plane through which a single particle could not go through

anomalous absorption of the penetrating component.

anomalous interacting property of the muon. . .

these laid the foundation of Cosmic ray studies — in the early part of this Century.

Now after 80 years — we are faced with more anomalies. new expectations

— AGN's — Source of High Energy CR.

Source of High Energy Neutrinos.

— Strange Matter — Quark Nuggets

— Cosmic Strings — Mag. Field of 10^{24} gauss —

Vacuum phase transitions.

— Primordial Black Holes —

— New type of installations —

AMANDA

DUMAND

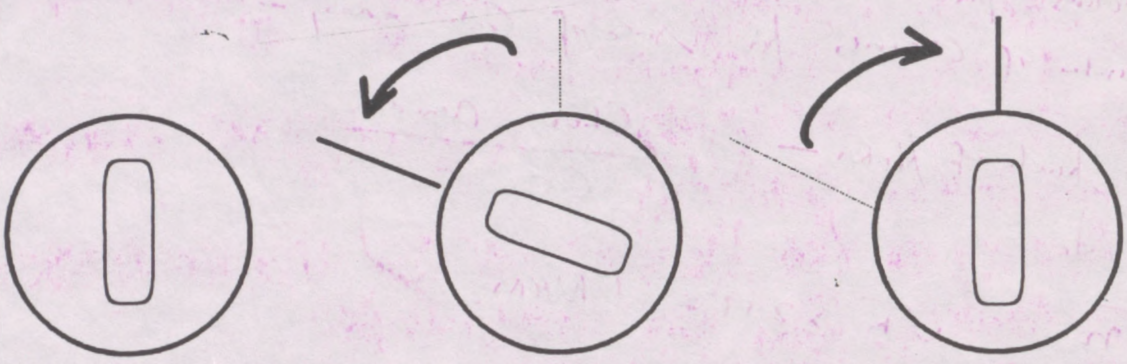
SUPER-KAMIOKANDE

TELESCOPE ARRAY.

LARGER EMULSION ARRAYS.

BALLOON FLIGHTS LASTING HUNDREDS OF HOURS.

SSC would have helped in the interpretation of Cosmic ray results.



TO OPEN DOOR AFTER HOURS AND ON WEEKENDS WHEN HANDLE IS LOCKED

1 INSERT KEY

2 ROTATE KEY COUNTERCLOCKWISE 90°(CLICK)

3 OPEN DOOR WITH KEY IN PLACE

4 HOLD DOOR OPEN

5 ROTATE KEY CLOCKWISE TO ORIGINAL VERTICAL POSITION (click)

6 REMOVE KEY

7 ENTER BUILDING

PLEASE DO NOT UNLOCK HANDLE.

{ G = photons per Channel.
{ C = number of Channels per Scale of Carbon energy –

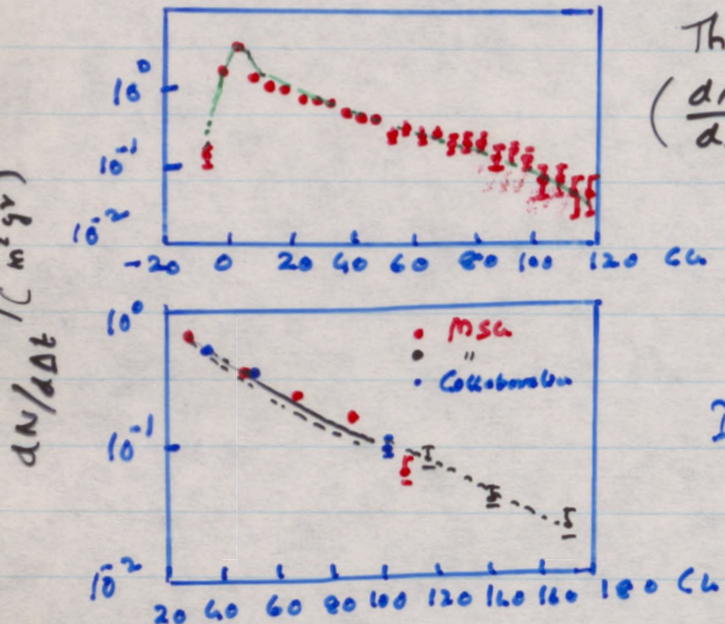
to get number of photons – $\frac{\text{Channels needed}}{GC}$

↓

$\sqrt{n}$ $\sqrt{n} \times 2.55 =$ FWHM.

- (•) Azimuthal asymmetry and strong alignment of cores in the observational plane.
- (•) EAST-WEST-NORTH-SOUTH asymmetry of arrival directions of families.
- (•) Anomaly in the behavior of the Hadron Spectrum at Tienshan from the Hybrid Expt.
- (•) The knee in the Size Spectrum - not at the same primary energy, but at the same Shower Size.
- (•) Excess of Showers at large Zenith angles.

Results from Pamir - Chacaltaya Collaboration



The distribution of observed hadrons $\left(\frac{dN}{d\Delta t}\right)$ as a function of depth (Δt) in Cascade Units. for $\theta < 50°$ $E(\gamma) > 63$ Tev

The Steep Rise is due to γ-rays long tail to hadron Component.

Distribution of $\frac{dN}{d(\Delta t)}$ for $\Delta t > 20$ Cascade Units (Comparison with MSU)

Attenuation Mean Free Path of Hadrons.

Chamber	range	$\lambda_{att}^{(Pb)}$ gms/cm²
Collaboration 60cms Pb.	ΔT ≥ 20 Cu $10 < \Delta t \leq 40$ Cu	237 ± 24 208 ± 15
MSU 120cm Pb.	$22 \leq \Delta t \leq 78$ $78 \leq \Delta t \leq 142$	209 ± 17 310 ± 36

Normal hadrons have an attenuation mean free path of ~ 230 gms/cm²

← This indicates that there is a mixture of another type of hadrons incident, which have a smaller m.f.

These attenuation m.f.s are than for normal hadrons which have a m.f. of gms/cm² indicating the presence of a new Component. – the penetrating Component that interacts weakly.

= The λ_{att}^{Pb} changes from around 209 gms/cm² at < 80 Cu to 310 gms/cm² for > 80 Cu. indicating the presence of a penetrating Component among the hadrons produced in the Chamber.

Λ = attenuation length

$$= \frac{\lambda}{\left\{1-(1-k)^{\gamma-1}\right\}}$$

λ = interaction length $= \frac{2.9 \times 10^4}{\sigma}$ (in air)

k = inelasticity.

$$\frac{dN}{dE} = E^{-\gamma}$$

$\rightarrow$ Attenuation $= e^{-h/\Lambda}$

—

accelerator experiments – translated to p-air collisions

$k_{p\text{-air}} \sim 0.7\, E^{-0.04}$

$\sigma \sim 25.4\, E^{0.074}$

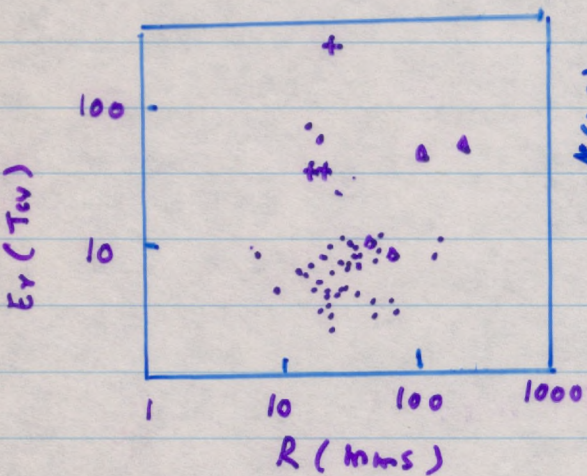
$$\Lambda = 100 \cdot \left\{\frac{E}{100\ \text{TeV}}\right\}^{-0.05} \text{gms cm}^{-2}.$$

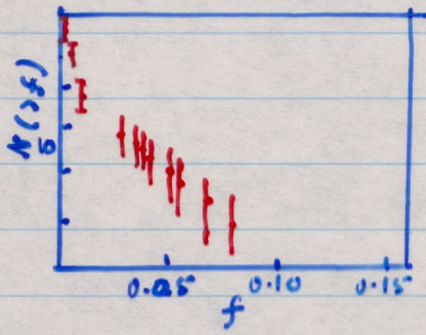
Λ = 100 gms cm^{-2} at 100 TeV.

Study of Extremely High Energy Interactions with Chacaltaya - Pamir Collaboration Chambers

Visible Energy > 500 Tev. Secondaries with E > ·04 of primary ∴ > 20 Tev.

1. Jets with large P_t particle production.





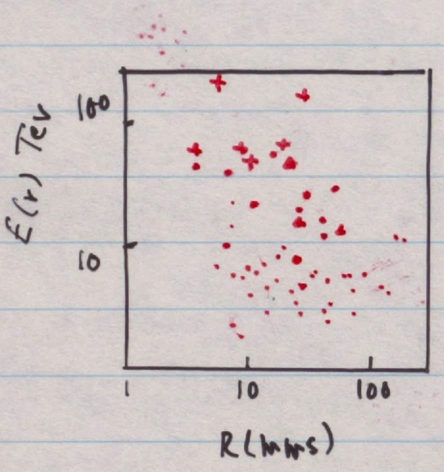
E-R diagram of the event P3C1Γ48H57

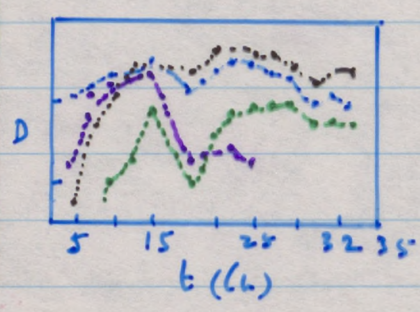
Family Energy = 794 Tev

+ Showers with penetrating character.

Fractional Energy Spectrum of P3C1Γ48H57

~~Average~~ P_t > 2 Gev/c or more.





Event C22 1135-871

+ penetrating Cascades

The fraction of Single hadrons is very much higher than what is expected according to model Calculations.

	Exposure m2yr		Singles	Total	Ratio S/T
Experiment →	16		858	938	0·92
UA-5	8·5	k = 0·15	558	763	0·73
		= 0·26	1082	1575	0·69
		= 30	1496	2145	0·70
MSF	8·5	k = 0·16	337	589	0·58
		= 0·26	576	1015	0·57

Start with the next transparency. ⇐ **Chirons:** Special type among Centauro events.

↓ unusual type (produced along with normal type. ?)

↓ Chief Characteristics:

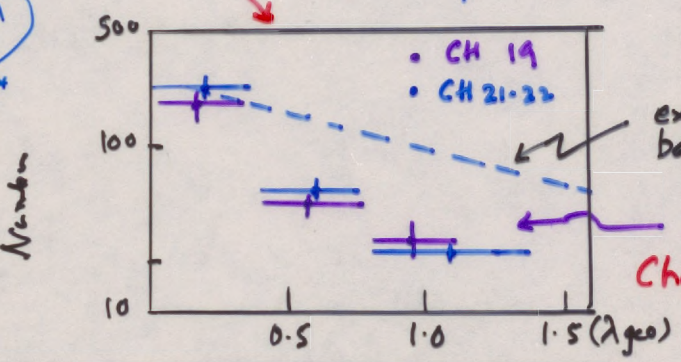
(i) At production the Chirons have large p_t ~ 2-3 GeV/c. One order of magnitude larger than p_t for pion production.

(ii) The Chirons have Short interaction mean free path. – 1/3 to 1/2 of geometric Collision m.f.

(iii) The Chirons give rise to "Mini-clusters" - produced by particles which have low p_t (~ 10 MeV/c) at production

Single Cored Showers in 82 families

p127

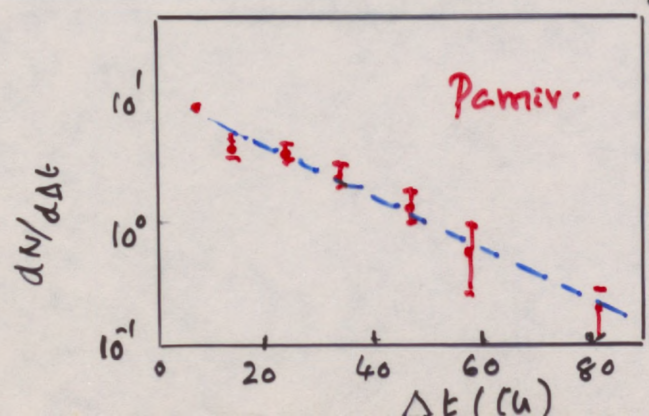


Depth dependence of Chiron type events

exponential attenuation expected on the basis of geometrical $\lambda_{Collision}$ mean free path. – (inside the Chamber)

Observed 1/3 - 1/2 λ_{geom}

Chacaltaya



depth distribution of 170 hadrons E^{γ} (≥ 10 TeV) in 16 high energy families ≥ 700 TeV in Pamir Expt.

λ_{pb} = 136 g/cm² [Value ~ half of λ for all hadron induced Showers E^{γ} > 6 TeV 230 gms/cm²]

↓ (Collision mf) – Shower Starting positions.

D0 Trailer City, 18-NOV-1993

Dear prof. Sreekantan,

I ahve been trying to send the following message to you at Prof. Yodh's address, as given by you. It bounced back. I tried others without success. I hope this will reach you. Please acknowledge so that I will know it reached you.

Rao

Dear Prof. Sreekantan,

You must have reached LA by now. I am giving below a copy of the transparenicies of my talk on CENTAURO events here. I am preparing a D0NOT on this subject. I will send you a copy as soon as it is ready. I will be here til the middle of January. The collider run, RUN 1b is scheduled to start in the beginning of next month. Good data may become available only after Christmas. Please acknowledge receipt of this mail, so that I know the address is ok.

Rao

Sept 2, 1993

CENTAURO EVENTS

M.V.S. Rao

- o INTRODUCTION
- o THE DETECTOR -- EMULSION CHAMBER
- o THE CENTAURO EVENT
- o INTERPRETATION
    - FIREBALL
    - FLUCTUATIONS ?
- o SEARCH AT ACCELERATORS
- o THEORETICAL MODELS
- o SEARCH WITH D0

Mukhamedshin's analysis of aligned events

Experimentally observed events. > 500 TeV 14 Lead Chamber.
95 Carbon Chamber

aligned events ↓

> 500 TeV. 43 ± 0.17 % – Lead Chamber }
20–25 %. – Carbon Chamber. }

Simulations:

- MCO – Quark-Gluon-String model of Mukhamedshin et al. (S$p\bar{p}$S results – jets, resonance, strange and charm particle production – taken into account)
- MF – Effect of Earth's Magnetic Field on alignment production.
- DDD – Double Diffraction Dissociation with large P_t
- ISD – Single Diffraction Dissociation with increased Cross-Section 1–10)
- EMD – Electro-magnetic Dissociation of the projectile nucleus by air nuclei field.
- ROT – High Spin Rotation of the non-interacting part of the projectile nucleus with following Co-planar emission of destruction products
- ALG – Total Co-planar generation of Secondaries by hadrons with resonance decay decreasing Co-planarity
- X – Unknown Long Flying Component – interacting through Coplanar hadron generation – long m.f.

(New primary component)

TABLE 1

Protons as Primaries.

Parameter	MCO	MF	DDD	ALG	ISD	ISD-ALG
$\langle\lambda_4\rangle$	0.23	0.22	0.21	0.27	0.21	0.28
$W(\lambda_4 > 0.8)$	0.06	0.05	0.05	0.09	0.06	0.10

→ perfect alignment

$\langle\lambda_4\rangle$ = Average value of λ

$W(\lambda_4 > 0.8)$: Fraction of events with $\lambda > 0.8$.

Parameter	~~0.21~~ MCO	MF	DDD	ALG	ISD	ISD-ALG
$\langle\lambda_4\rangle$	0.21	0.21	0.22	0.22		
$W(\lambda_4 > 0.8)$	0.05	0.04	0.05			

Long Flying Component

TABLE 2

α-particles and X-Component.

Parameters	MCO	MF	MF-EMD	ROT	X
$\langle \lambda_4 \rangle$	0.21	0.21	0.22	0.22	0.69
$W(\lambda_4 > 0.8)$	0.05	0.04	0.05	0.06	0.56

Errors < 0.01.

Vertical Electric Fields are taken into account.

* Tables I and II Show that none of the models except the one involving X-Component is able to account for either the extent of alignment seen or the fraction of Cases of full alignment of 4 Cores.

Effect of large Vertical Electric Fields:

Stormy Clouds Can produce large electric fields - Sometimes as high as 10^9 volts between the Clouds and the earth. The horizontal lightning lengths Can be ~ 20 kms. and Cloud height ~ 10 kms.

The following parameters have been used to see the effect of horizontal and Vertical electric fields on the alignment of Cascades.

Voltage across Vertical field ~ 10^9 V. 100 kV/m

Horizontal field 10^9 V. (1 GV)

Vertical field enclosed in air Cylinder of 10 kms dia.

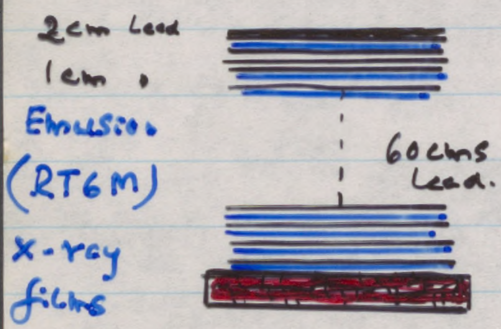
Height of Cylinder 10 kms

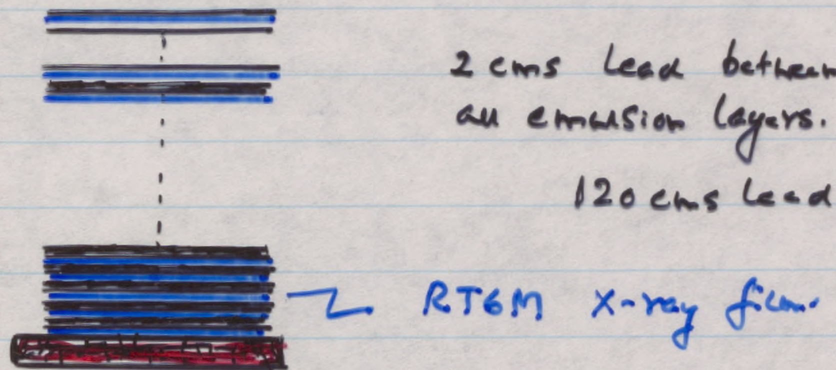
Table 3 gives results.

Vertical field is much more effective in bringing about alignment. The effect is ~~more~~ less on hadrons.

UNIFORM-TYPE LEAD-EMULSION CHAMBERS AT PAMIR.

(4300 m. alt)





Russia-Japan Collaboration

1 cm. Lead between all emulsion layers

58 photo-sensitive layers.

16 m². yr. exposure.

(Started in 1991)

Moscow State University.

7 photosensitive layers under 1 cm. Pb, the rest under 2 cms Pb.

26 m². yr exposure.

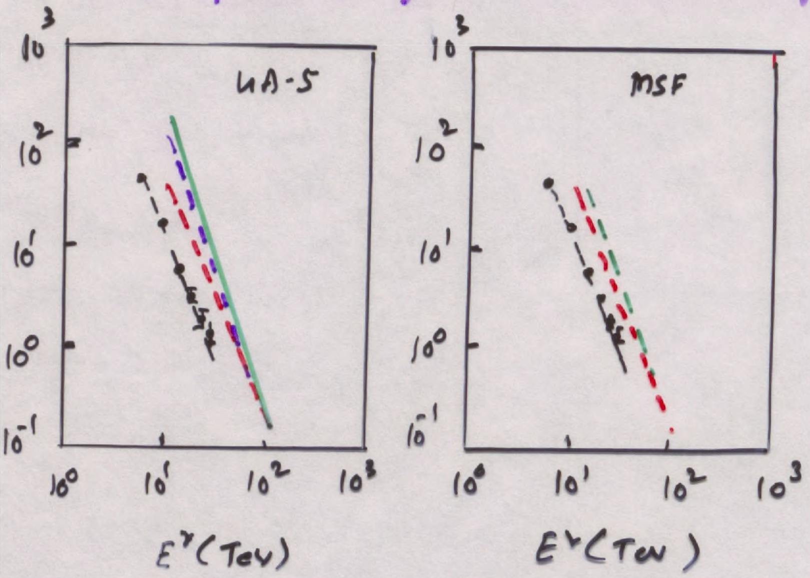
Chamber	MSU (120 cms Pb)	Pamir-Chacaltaya Collaboration (60cm Pb)	
Exposure	26 m². yr.	16 m² yr.	
Def of Hadron	Δt ≥ 14 Cu	Δt ≥ 14 Cu	Δt ≥ 6 Cu
* No. of γ-rays		594 (37.1/m² yr)	436 (27.3/m² yr)
No of hadrons	30 / m² yr.	565 (35.3/m² yr)	723 (45.2/m² yr)

* γ-ray : (γ's, e^+, e^-)

The rate of events observed by the two installations are consistent with each other.

Pamir. Chacaltaya Collaboration:

(*) At the observational level of Pamir (4300 m.s.l.) the high energy hadron flux as well as the cosmic ray family flux is much lower than expected on the basis of normal composition and interaction characteristics extrapolated from accelerator experiments.



The observed flux is very much lower than the calculated ones
↓ See Table Below.

Primary Flux $\sim E^{-1.7}$
Normalized at 10^{15} eV
$I(\geq E_0) = 50\left[E_0/10^{15}\,\text{eV}\right]^{-\gamma}/\text{m}^2\,\text{yr}$

Simulations on 80,000 primaries down to Pamir altitude done corresponding to $10\,\text{m}^2\,\text{yrs}$.

Comparison of the observed flux of $N_h(>\sum E_\gamma)$ with the model calculations (the red and green lines for two different models GA-5 and MSF for different values of inelasticity
↓ R.A. Mukhamedshin et al.

* Assumed Composition (%)

E_0	Protons	alphas	CNO	Heavy	Fe
10^{15} eV	42 (14)	17 (23)	14 (26)	14 (13)	13 (24)
10^{16} eV	42	13	14	15	16

The red values give the latest JACEE composition (93) at ≠ 370 TeV 3.70×10^{14}.

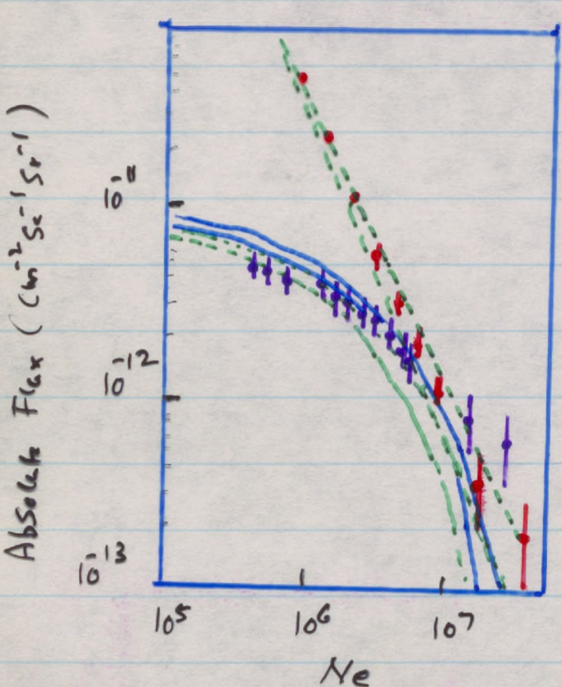
* Calculated Fluxes and Power Indices, compared with Expt.

		$I(E^\gamma \geq 10\,\text{TeV})$ $/\text{m}^2\,\text{yr}$	Power Index Integral
Experiment →		17	2.31
GA-5	$k_\gamma = 0.15$	38	2.09
	$= 0.26$	70	2.57
	$= 0.30$	110	2.48
MSF	$k_\gamma = 0.16$	40	2.27
	$= 0.26$	70	2.12

2780 m
735 gms/cm^2

NORIKURA HYBRID EXPERIMENT.

EAS + 20 m^2 Emulsion Chamber.



Air Shower Data.

Tagged Air Showers - EAS in which the Emulsion Chamber had $\Sigma E_\gamma > 10$ TeV.

Simulations — Proton Dominant — Heavy Dominant.

Proton Dominant.

PD model →

	10^{14}	10^{15}	10^{16} eV.
P	34	27	20
He	17	14	12
L-M	19	22	23
H	12	14	16
VH	4	5	6
Fe	14	18	23

Heavy Dominant

HD Model →

	10^{14}	10^{15}	10^{16} eV.	JACEE (93) $> 3.7 \times 10^{14}$
P	26	18	14	14
He	14	10	8	23
L-M	19	18	17	26
H	13	15	14	13
VH	5	6	7	
Fe	23	33	40	24

- No drastic changes in interaction characteristics required.
- However, the recent JACEE results on composition may have to be plugged into their calculations, since the interpretation depends on assumed composition.

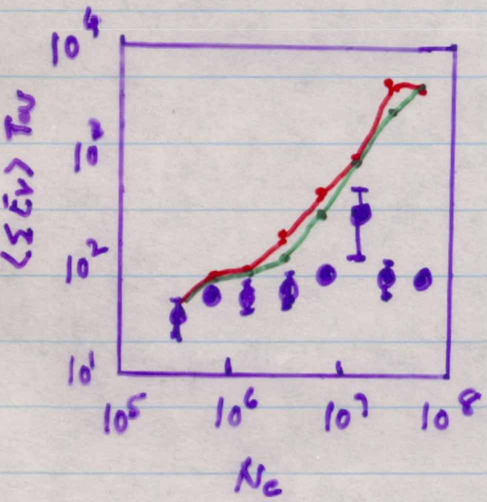
Results from Hybrid Installations

EMULSION CHAMBERS + Air Shower Arrays.

1. Chacaltaya : 40 scintillation detectors within 50 m.
   8 fast timing
   Emulsion Chamber 32 units each $0.25\,m^2$
   (32 Cascade units Lead)
   32 burst detectors – Plastic scintillators below EC.

46 Families with accompanying air showers registered.

Criteria for association: Arrival Direction + Burst size proportionality.



– heavy dominant → 18% P, 10% He, 18% CNO.
– normal Composition → 42% P, 17% He, 14% CNO
– Experimental

The experimentally observed ΣE_γ is significantly less than the expectations on the basis of normal and heavy dominant compositions and UAS simulations.

The CENTAURO

(First reported in 1973 at Denver ICRC)

Emulsion Chamber Detector at 540 gms/cm² (Chacaltaya)

- Big family of jets in the lower Chamber -- 43 hadrons
- Small family in upper Chamber .. 6 hadrons
- and only 1 gamma

Visible Energy 230 TeV 2.30×10^{14} ev

Estimated Energy of Interaction 1.5×10^{15} ev

$\langle P_T \rangle \sim 1.5$ to 2 Gev/c.

Interpretation:

Fireball of mass 200 Gev/c^2 created

which decays into $\sim$ 100 hadrons with no π^0

Other events 4 by the same group

(Mini Centauros) 0 by others – may be 1 by Pamir group.

Is it a case of extreme fluctuation?

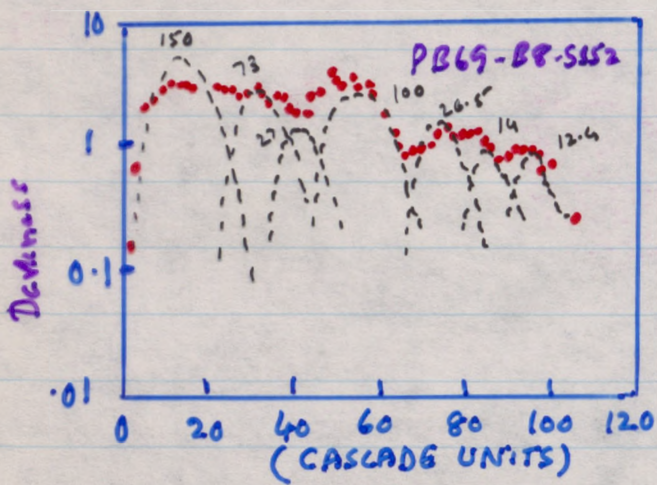
No evidence at accelerators so far.

CERN SPS Collider } upto 1.46×10^{14} ev.

CDF at FNAL 1.620×10^{15} ev.

Giant Mini Clusters

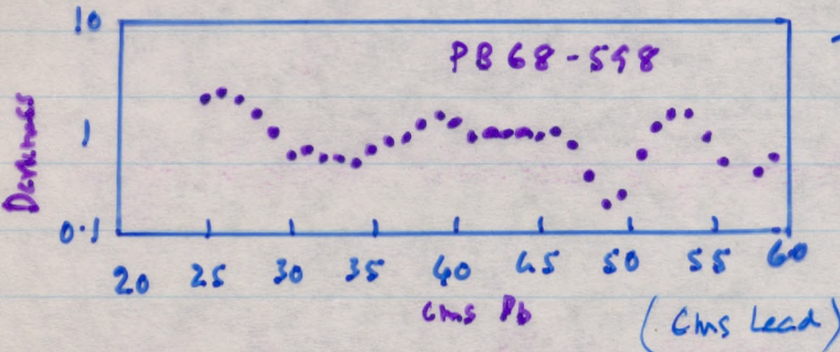
PENETRATING CASCADES
(Anomalous Transition Behavior)



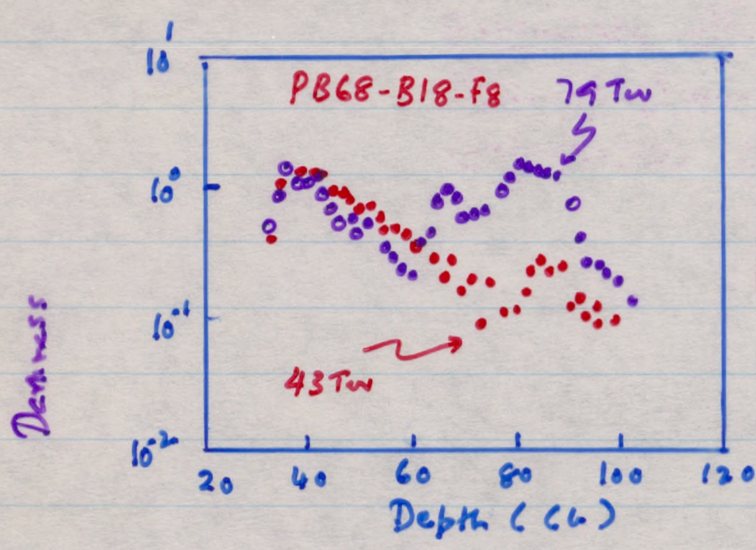
The dotted lines are trial fits to reproduce the transition curve by Tev Cascades starting at different depths.

Total Energy = 400 Tev.

[Darkness measured by a slit 200 μm x 200 μm]



The shower observed to start at 25 cms depth persists till the end of the chamber - 60 cms.



- A remarkable feature of this event is that it is composed of two very closely separated cascades with a separation ~ 1.3 mms

[The starting point at 32 C.U. is probably due to the event occurring when the chamber was under construction and the top layers not in position.]

- If the vertex is assumed to be 1 km. the angle between the two ~ 10^{-6} radian — p_t ~ 40 Mev/c.

⟨•⟩ Evidence for Change in interaction Characteristics.
↓
{ σ, K, n_s, Secondary Composition, p_t
Quark-Gluon plasma production.
Nucleus-Nucleus Collision features }

⟨•⟩ Ooty Cloud Chamber Experiment in EAS array in the 70's had shown two anomalies

(i) the Charge to neutral Ratio of hadrons – tens of GeV – TeV decreased with Energy to 1·5–1. All Simulations required this ratio be 10–30.

(ii) The hadron Spectrum Steepened beyond 100 GeV.

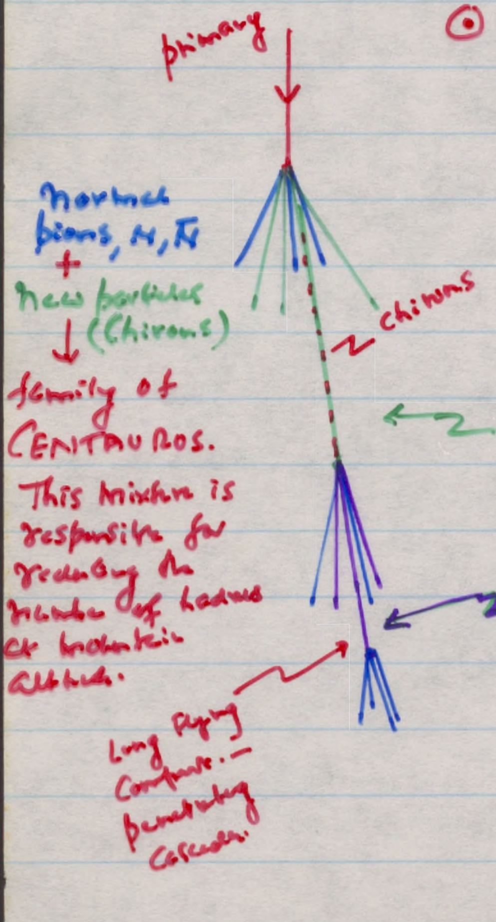
⟨•⟩ Large Emulsion Chamber Experiments : Pamir, Chacaltaya, Fuji, Kambala, Tienshan, Norikura.
+ Hybrid (with EAS)

Threshold greater than 1 TeV. in the Detectors.

<u>Main Results</u> : ⊙ Severe Paucity of High Energy Hadrons at mountain altitude

⊙ Flux of Gamma families much below expectation. (One order of magnitude)

The interpretation of the family events (lateral separation, penetration through lead, ...) suggest production of new types of particles with features shown in the figure



← large p_t, low interaction m.f. (2-3 GeV)

← large interaction m.f – give rise to very low p_t (10-20 MeV/c) in their interaction. responsible for penetrating Cascades – that do not spread out laterally.

The "HADRON" Expt at TIENSHAN.

HYBRID — EAS + EMULSIONS

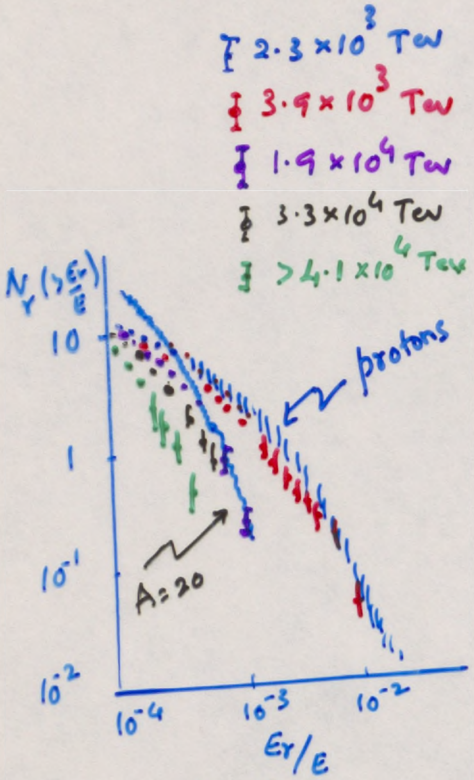


Fig 1

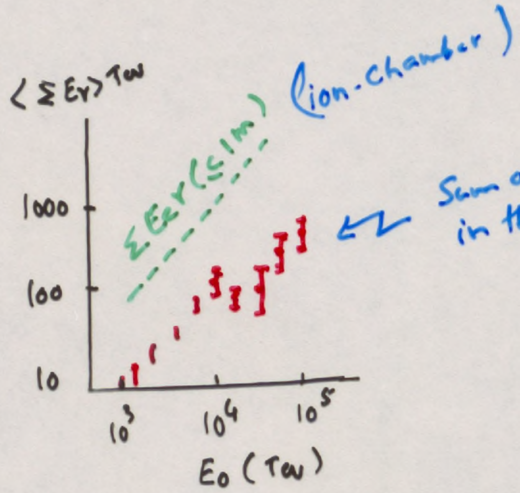


Fig 2.

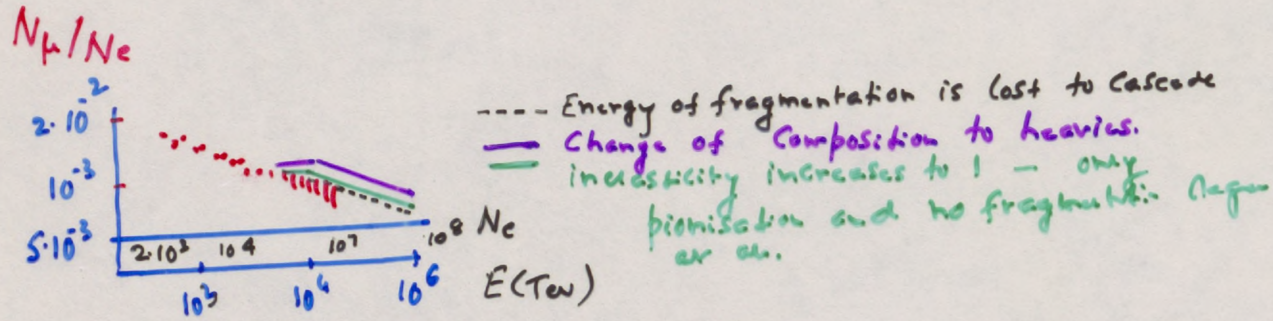


Fig 3.

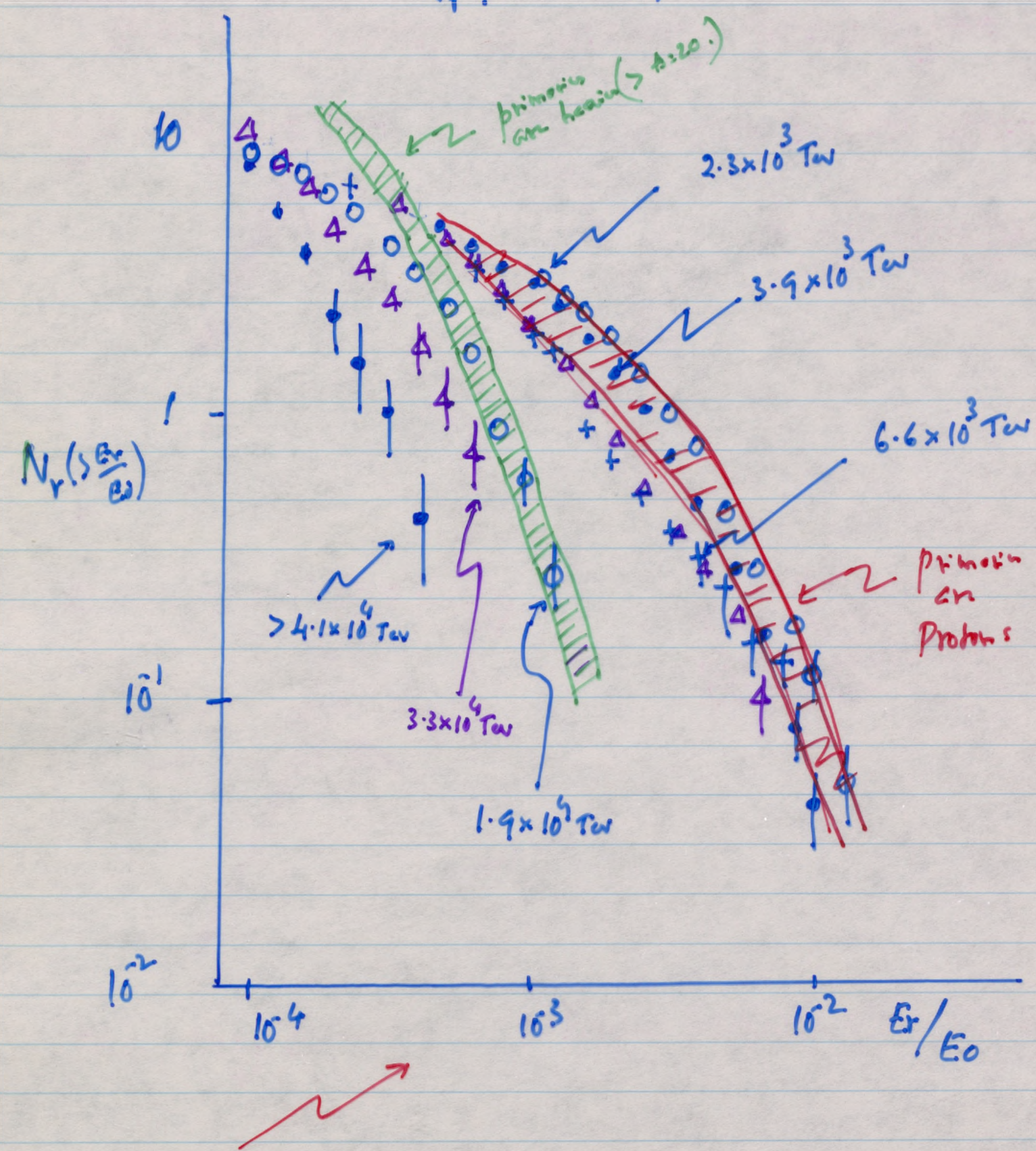
(1.) There is a marked Change in the behaviour of the hadron Spectrum $N_\gamma (> \frac{E_\gamma}{E})$ vs E_γ / E over the narrow

Fig 1 * primary energy range 5×10^3 Tev – 2×10^4 Tev. There is a Sudden depletion in the energy going to the Cascade – reflecting disappearance of the fragmentation region.

Fig 2 (2.) * Figure 2 Shows the discontinuity in the behaviour of the energy in high energy γ-rays as a function of primary energy.

Fig 3 (3) * There is no evidence for a Change in the primary Composition in the energy range $5 \cdot 10^3 - 2 \cdot 10^4$ Tev from the $N_\mu (> 5\,Gev) / N_e$ Curve

$N_r(> E_r/E_0)$ vs E_r/E_0.



Fraction of Primary Energy going into hadron + gamma at the observation level.

Nikolsky.

Japan-US-Polish Collaboration

v4. p29.

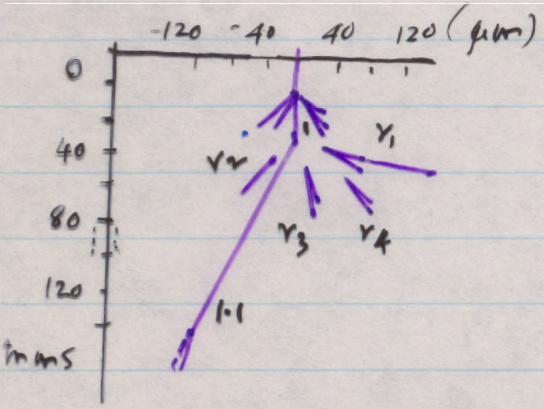
(DIRECT EXPERIMENTS)

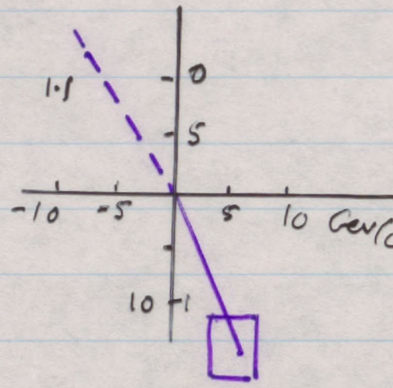
Rare Stamp Collisions

T, φ, e vs. T, θ, .. }

JACEE (1990)

– Cosmic Ray Interactions at energies > 1 TeV/n. at 3.5 gms/cm²



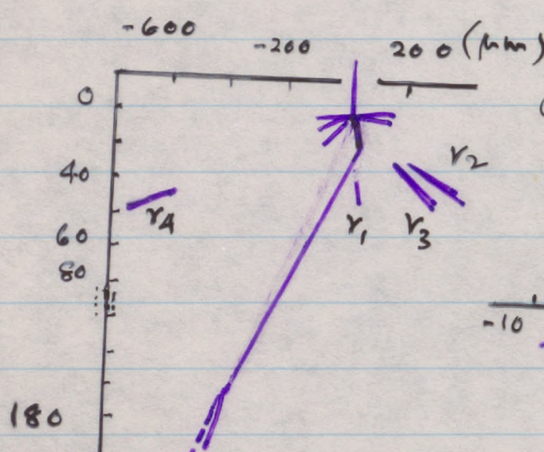


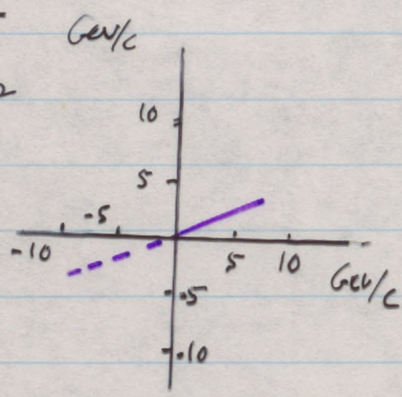
Four photons (Converted to e^+e^-) point to decay of a Charged particle identified as B-meson.

⇒ $He + C \to He + 38 n_s$

$E_0 = 50$ TeV/nucleon.

Transverse Momentum Balance. The dashed line Shows the direction of P_t of particle 1·1





Examples of Nucleus-Nucleus Collisions > (TeV/Nucleon)

⇒ $Be + Fe \to 2He + 8 n_s$

$E_0 = 4$ TeV/nucleon.

Examples of decays of Charged B-mesons into One Charged particle and four photons. The four photons all Convert early close to the Vertex – 0.4 and 0.6 Conversion lengths. –
This probability ~ 4×10^{-4}.
The data Suggests $N_\gamma = 20$ if all the 8 are to be Converted.
This would require high multiplicity (~10) of photons in each decay. What is happening?

Accelerator Experiments have provided information on Characteristics of Interactions p-p, p-nucleus, nucleus-nucleus
(~10^{15} eV) (~1 TeV) (200 GeV/nucleon)

1. Cosmic Ray Studies (1930-1955) launch the field of High Energy & Elementary Particle Physics.

• High Energy Processes.
- Bremstrahlung
- Pair Production
- Cascade Showers
- Meson production
- Extensive Air Showers
- Cerenkov Radiation.
- Decays of Fundamental Particles (μ, π, k, Λ, ...) — Time Dilation verified expt.

Missed opportunities: Anti-Proton, (Rossi) Charm (Niu)

• Elementary Particles discovered
- Positron
- Muon
- Pion (V^0, $V^{\pm}$) (Blackett) (1949)
- k, Λ^0, $\Sigma^{\pm}$, Ξ^-, .. Strangeness.
- τ-θ puzzle → Parity Breakdown.
- ⋮ Eightfold way - SU_3 . .
- upto Ω^- (first major accelerator discovery)

• Characteristics of High Energy Interactions:
- (•) Variation of σ_{in} with Energy
- (•) " n_s "
- (•) " $N\bar{N}$ production "
- (•) P_t distribution. log tan θ
- (•) Partial inelasticity - leading particle - fragmentation region
- (•) Fire Ball Production

} • Cloud Chambers at mountain altitudes.
• Emulsion Studies flown to Stratospheric altitudes.

(Ooty)

(•) Some early anomalies (Largest Multiplate Cloud Chamber Expt)
- • Steepening of the hadron Spectrum
- • Charge to neutral ratio of hadrons — tens of GeV - to hundreds of GeV. (10 → 1.5)

(KGF) → Behaviour of 220 GeV muons in air showers.

Recent Investigations :
- • Nuclear Emulsions - at Balloon Altitudes — JACEE
- • Emulsion Chambers at mountain altitudes
- • EAS, underground muons
- • 'hybrid' Systems - EAS + EC.