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VERY HIGH CENTRAL MULTIPLICITY 63 GeV - 63 GeV αα INTERACTIONS

The Axial Field Spectrometer Collaboration

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ABSTRACT

Calorimeters have been used to study the energy released in the fragmentation region of inelastic 15 GeV p - 15 GeV p and 63 GeV α - 63 GeV α collisions in correlation with high multiplicity in the central (pseudorapidity $|\eta| < 1.7$) region. Events with large central multiplicities (≥ 50 charged particles) may be simply interpreted as arising from independent inelastic collisions involving four nucleons in each α-particle.

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In high energy α-α collisions very high multiplicity events could arise from ordinary "central" collisions, four nucleons in each α-particle undergoing independent inelastic interactions. High multiplicity might also signal the onset of some new behaviour, or the presence of collective effects. We have devised an experiment to explore these possibilities at the CERN ISR where the energy is dramatically higher than that available at the LBL Bevalac or the Dubna Synchrophasotron.

A direct way to study the number of interacting nucleons which accompany high central multiplicities is to measure the associated fragmentation products near the downstream beam directions, and then compare them with pp data taken at the same cm energy per nucleon. It is necessary to use calorimeters rather than charged particle detectors for this task, since neutral as well as charged hadrons must be detected with high efficiency.

The experimental arrangement used in this study is shown in Fig. 1. Copper-scintillator calorimeters [1,2], positioned 4.5 m downstream of the ISR beam intersection and surrounding the evacuated beam pipes, detected the products of inelastic interactions. Each calorimeter consisted of eight modules, each containing two photomultipliers detecting the light collected by wavelength-shifter sheets. The difference in pulse heights between the two photomultipliers may be used to compute the centre of the energy distribution (in the x-direction) in each module. The individual pulse heights can give a crude measure of the lateral spread of the energy deposition, and the sums of the two pulse heights above a fixed threshold allow the use of the modules as a "module multiplicity" detector. Located in front of the calorimeters were beam scintillator hodoscopes consisting of four quadrants covering polar angle $1.2^\circ < \theta < 6^\circ$. Surrounding the intersection region were 44 scintillator strips comprising a "barrel" hodoscope, each strip viewed by two phototubes. Each scintillator strip subtended a laboratory angle $\Delta\phi = 8^\circ$, the complete barrel covering 352° of azimuth ϕ. Due to the c.m. motion the pseudorapidity range varied between $\pm$ 2.1 at $\phi = 0^\circ$ to $\pm$ 1.4 at $\phi = 180^\circ$.

The trigger requirement, defining a "minimum bias" event, was either a single beam-beam coincidence between any of the four scintillators located in front of each calorimeter, or at least one barrel scintillator hit. To minimize background events from beam-gas interactions we employed a beam-beam software requirement for the α-α data described in this paper. This sample contained approximately 40% of all inelastic interactions.

The idea of the measurement was to use the barrel counters to select events of very high multiplicity and to compare various calorimeter quantities, eg. the energy deposition and its lateral distribution, for both pp and $\alpha\alpha$ collisions of the same energy per nucleon.

Fig. 2 shows the measured barrel counter multiplicity distributions. They are, of course, not true charged particle multiplicities since the counters were not 100% efficient and since at high multiplicity there is a high probability for two or more particles to traverse the same scintillator. Furthermore a single particle can cause (through δ-ray production, decay etc.) more than one counter to be hit. The important point is that there is a strong correlation between true (charged) multiplicity and barrel multiplicity. In addition to minimum bias triggers we also took data with a hardware trigger on barrel multiplicity $\gtrsim 20$ to obtain a sample enriched in high multiplicity events. The squares in Fig. 2 show the data from this sample joining smoothly to the minimum bias data (circles).

It is important to be sure that the very high multiplicity events are not accidental coincidences between two (or more) events. On Fig. 2 we have superimposed the distribution predicted for accidental two-fold coincidences as calculated by convoluting $\alpha\alpha$ minimum bias events. This was done by OR-ing beam and barrel hodoscope hits for two events and then requiring that both beam hodoscopes contained hits. The magnitude was determined in two ways: from the measured interaction rate and resolving time, and from a direct measurement of the out-of-time events per nanosecond. Both gave the same result. At the luminosity present during the $\alpha\alpha$ run, $L = 2.8 \times 10^{28}\ cm^{-2}\ sec^{-1}$, there is no appreciable accidental rate. The pp multiplicity distribution is also shown in Fig. 2 .

Fig. 3 shows a plot of the mean pulse height in a calorimeter (summed over the eight modules) versus the barrel multiplicity. For the pp interactions there is a strong correlation between the mean pulse height and the central multiplicity. Furthermore the ratio of the mean $\alpha\alpha$ pulse height to the mean pp pulse height, at the highest multiplicities in each case, is approximately 4:1. This would be expected if four nucleons in each α-particle were interacting independently.

This hypothesis can be further investigated in the following way. Independent pp events can be combined, adding the pulse heights for each calorimeter phototube, ORing the hits in each hodoscope element, and then requiring both beam-beam hodoscopes to have hits as with the $\alpha\alpha$ data. If the very high multiplicity $\alpha\alpha$ events were indeed due to four independent nucleon-nucleon collisions these convoluted events would be similar in all respects to the $\alpha\alpha$ events, and we would observe similar distributions in the forward calorimeters. Exact agreement is not expected because of multiple scattering of the nucleons, final state interactions of the hadronization products and "Fermi motion" which should modify the transverse momentum of these products. However these nuclear effects are not likely to cause major losses in the acceptance of large angle fragments, as the calorimeters accept 15 GeV/c particles with transverse momenta up to 1.5 GeV/c at all azimuth.

Superimposed on Fig. 3a is our calculation corresponding to two, three and four-fold convolutions of the pp data at 15 GeV/nucleon. At large barrel multiplicity ($\gtrsim$ 24) the data agree well with the four-fold convolution, with little apparent contribution from three-fold convolutions. As the multiplicity is decreased the data deviate from the four-fold convolution, which we interpret as showing an increasing admixture of three-fold, two-fold and single collisions together with an increasing contribution from non-interacting spectators. The low multiplicity region is therefore rather complicated, in contrast with the high multiplicity events which appear to be entirely four-fold collisions.

We now proceed to study further the forward energy deposition pattern in the $\alpha\alpha$ events and the four-fold convoluted pp events, to see if other features are consistent with this interpretation. Fig. 4a shows the comparison of the summed pulse height distribution for αα events with barrel multiplicity > 24 and four-fold pp convolutions with the same requirement. On the same figure we show the single pp pulse height distribution for barrel multiplicity > 6, ie. approximately a quarter of the αα multiplicity cut. The αα distribution is unlike the single pp distribution but quite similar to the four-fold convoluted pp distribution. We can also compare how the energy in the high multiplicity αα collisions is distributed laterally in the calorimeter. The pulse heights in the upper and lower modules (at the same x) are summed and plotted versus lateral position in Fig. 4b. The energy spread is the same for the αα events and the four-fold convolution. From the lateral location x_i of the centre of energy deposition E_i in each module, determined to $\sigma_{x_i} \sim 3$ cm from pulse-height sharing, we then compute the centre of energy $x_{av} = \Sigma E_i x_i / \Sigma E_i$ for each event. Then for each event we calculate the rms spread of energy about x_{av}, namely:

$$x_{rms} = \sqrt{\frac{\Sigma E_i (x_i - x_{av})}{\Sigma E_i}}$$

This comparison is shown in Fig. 4c. We have also compared the rms spread about the centre of the calorimeter. Further, we show in Fig. 4d the multiplicity distribution of the number of modules recording more than 0.8 GeV energy. All comparisons show the same result: the character of the energy deposition in the calorimeters is the same for the αα and the four-fold pp convolution events.

In conclusion the calorimeter : multiplicity correlations that we have studied show that the majority of the very high multiplicity events in ultra-relativistic αα collisions can be simply understood as due to independent inelastic collisions of four nucleons in each α-particle.

We have carried out similar studies with 31 GeV p- 63 GeV α collisions (at the same cm energy per nucleon). The pα multiplicity distribution falls well below the $\alpha\alpha$ distribution at multiplicity > 24. Thus contributions from a single nucleon in one α-particle multiply scattering on four nucleons in the other cannot make appreciable contributions to the $\alpha\alpha$ pulse height at this high multiplicity. In Fig. 3b we show for $p\alpha$ the mean calorimeter pulse height in the α fragmentation region vs the barrel multiplicity. The pp data at 22 + 22 GeV (the same cm energy/nucleon) have been scaled down in pulse height by the ratio 15/22. The high multiplicity limit of the $p\alpha$ pulse height is close to four times the high multiplicity limit of the pp pulse height (see r.h. scale in Fig. 3b). Apparently high central multiplicity $p\alpha$ collisions arise from the inelastic scattering of the incoming proton off all four nucleons in the α-particle, each struck nucleon contributing independently to the calorimeter pulse height. Finally we point out that events in $\alpha\alpha$ collisions with barrel multiplicities greater than 34 are quite rare, representing $< 5 \times 10^{-5}$ of all the events (see fig. 2), so that the agreement between the data and the four-fold convolution prediction (see Fig. 3a) is quite good even at this high sensitivity.

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REFERENCES

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FIGURE CAPTIONS

Fig. 1 The apparatus on the downstream side of one beam showing the eight module calorimeter surrounding the vacuum pipe, the four quadrant beam hodoscope, and the 44 element "barrel" hodoscope used for a multiplicity trigger. The distance from the centre of the intersection to the front face of the calorimeter is 4.5 m. The calorimeter modules above and below the beam pipe are separated by 0.1 m in y.

Fig. 2 Relative number of events vs. barrel multiplicity. (diamond: p-p; circle: minimum bias α-α ; square BM > 20 $\alpha\alpha$ trigger; triangle: calculated accidental coincidences.

Fig. 3a Mean calorimeter pulse height vs. barrel multiplicity for p-p and α-α data. Superimposed are the predicted values for 2,3, and 4-fold convolutions of the p-p data. The mean calorimeter pulse height for an elastically scattered proton of 15 GeV entering the calorimeter is 190 units.

Fig. 3b Mean calorimeter pulse height vs barrel multiplicity on the α side of 31 GeV p - 63 GeV α collisions compared with scaled 22 GeV p-22 GeV p pulse heights.

Fig. 4a Calorimeter pulse height distribution. In this and succeeding figures comparison is made between alpha-alpha (squares) and four-fold p-p convolutions of p-p data (diamonds) for BM > 24 and single p-p interactions (circles) for BM > 6.

Fig. 4b Lateral energy spread in the calorimeter. Vertical dashes indicate the edges of the modules. Each plotted point is the mean pulse height recorded in the photomultiplier tubes. The upper and lower modules have been averaged to obtain the x energy projection.

Fig. 4c rms spread of the energy deposition, x_{rms}, in each event about the mean position.

Fig. 4d Module multiplicity distribution. The energy threshold in each module is set at .8 GeV.

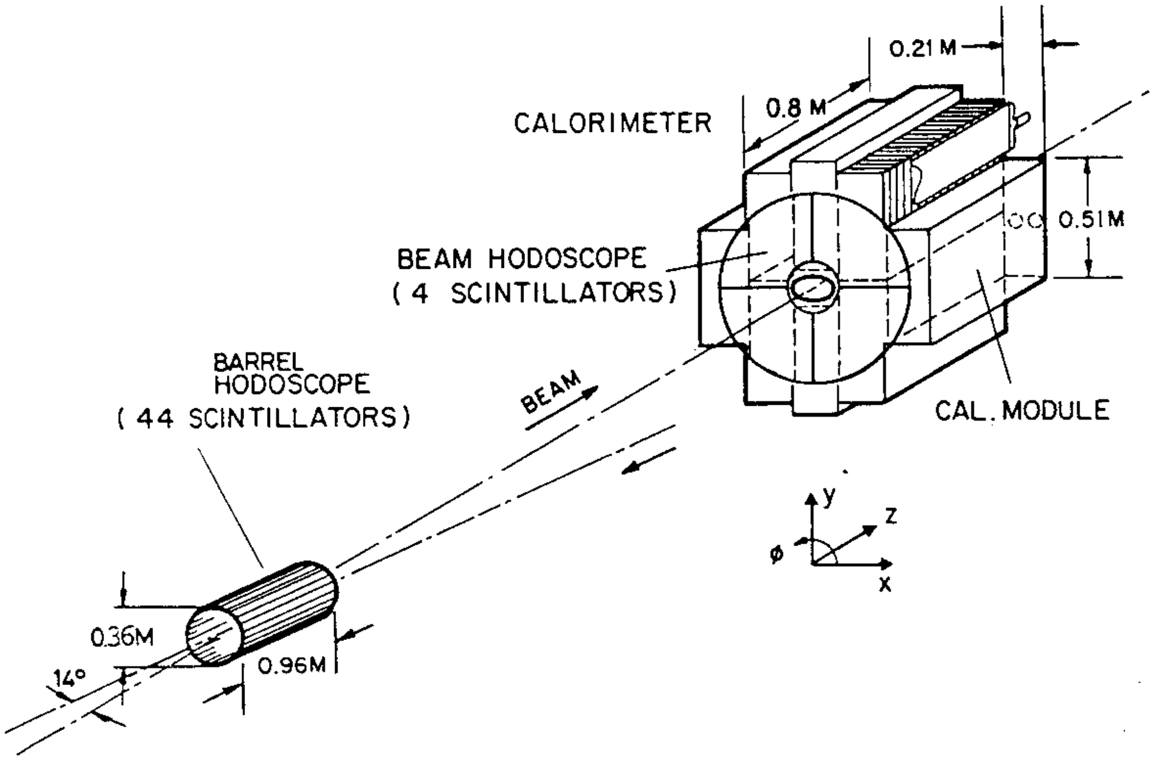
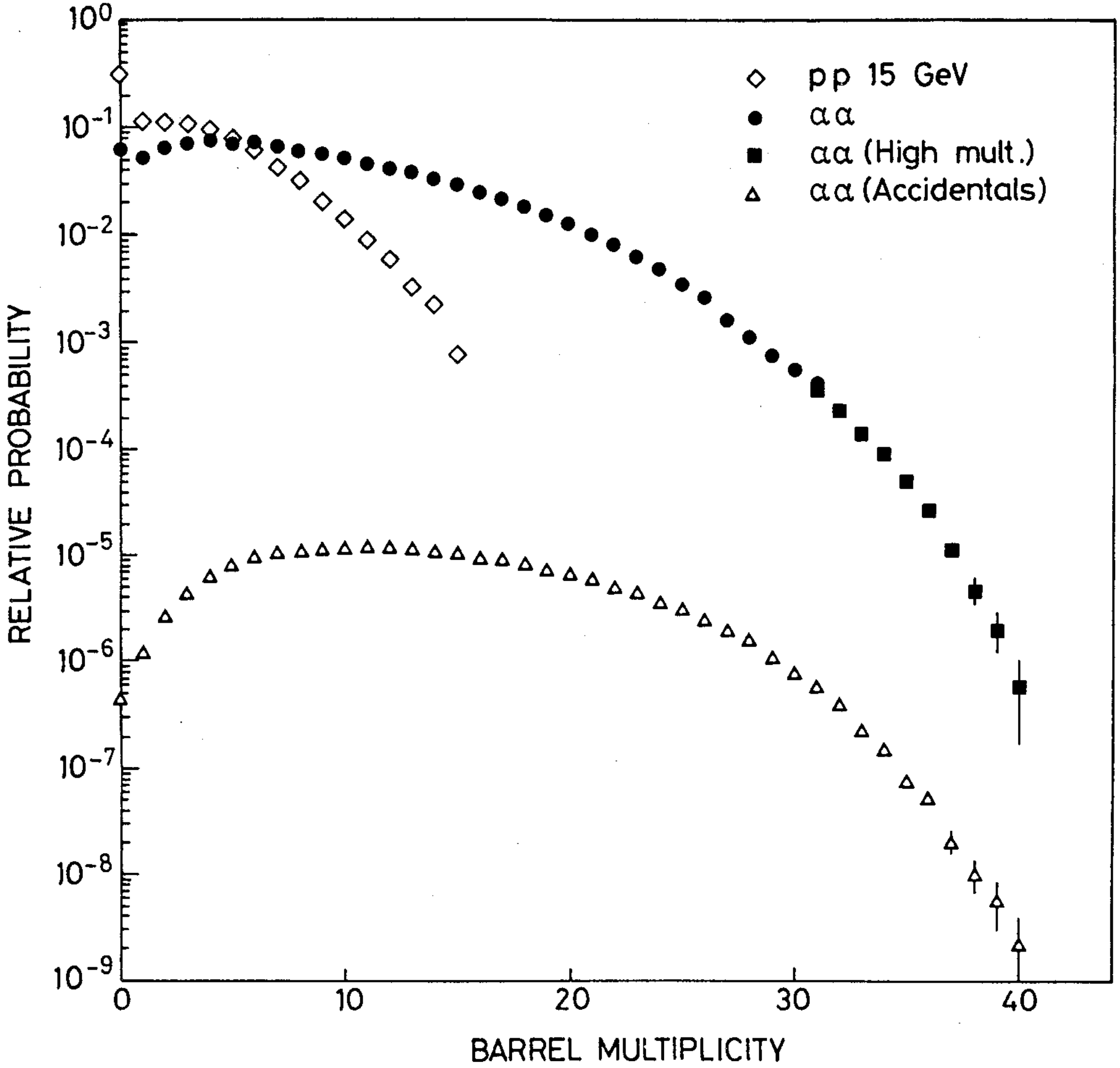

0.21 M
0.8 M
CALORIMETER
0.51M
BEAM HODOSCOPE
(4 SCINTILLATORS)
BARREL
HODOSCOPE
(44 SCINTILLATORS)
BEAM
CAL. MODULE
y
z
ø
x
0.36M
14°
0.96M

Fig. 1



pp 15 GeV
αα
αα (High mult.)
αα (Accidentals)
RELATIVE PROBABILITY
BARREL MULTIPLICITY

Fig. 2

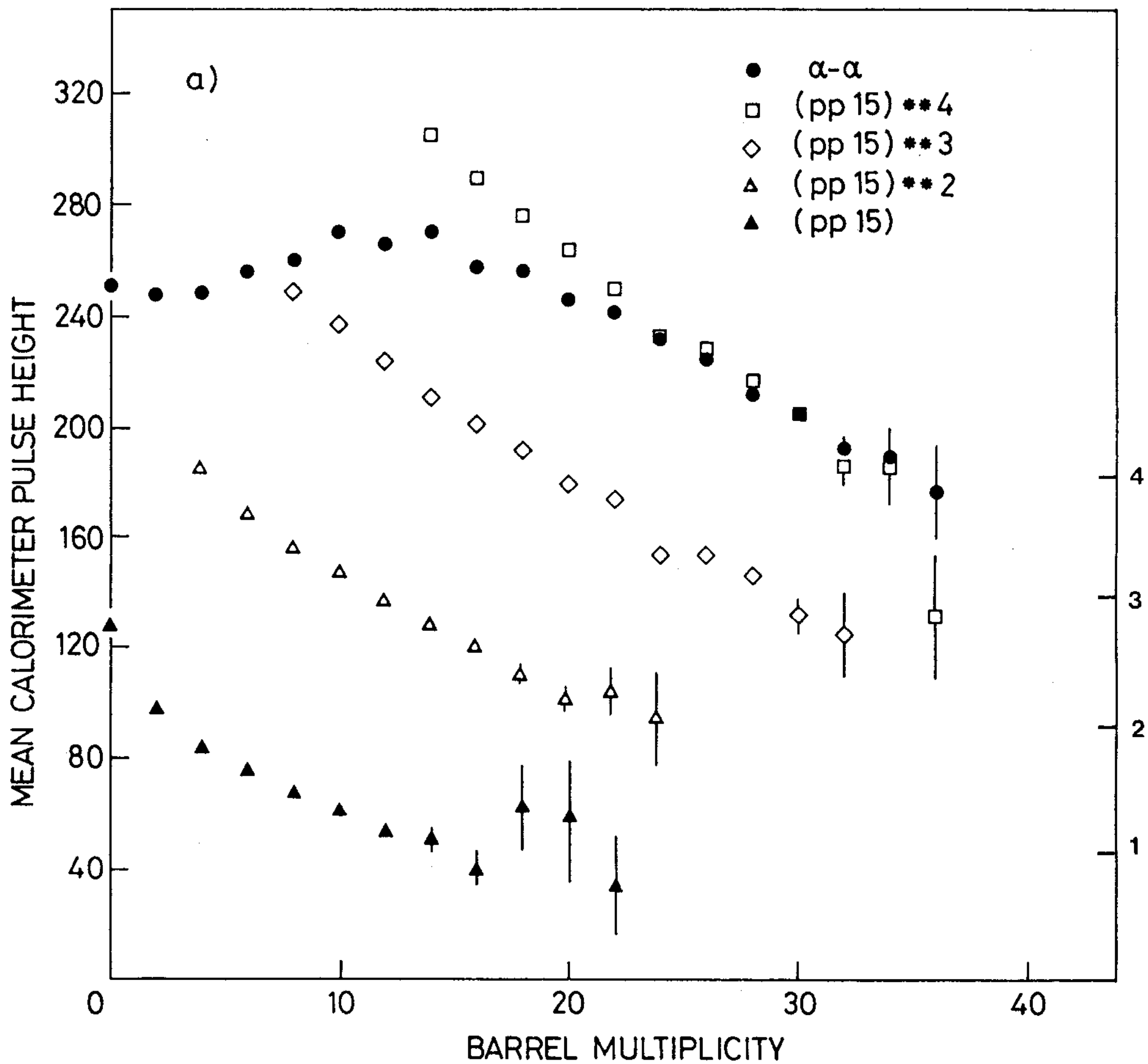

a)
α-α
(pp 15) **4
(pp 15) **3
(pp 15) **2
(pp 15)
MEAN CALORIMETER PULSE HEIGHT
BARREL MULTIPLICITY
320
280
240
200
160
120
80
40
0
10
20
30
40
4
3
2
1

Fig. 3a

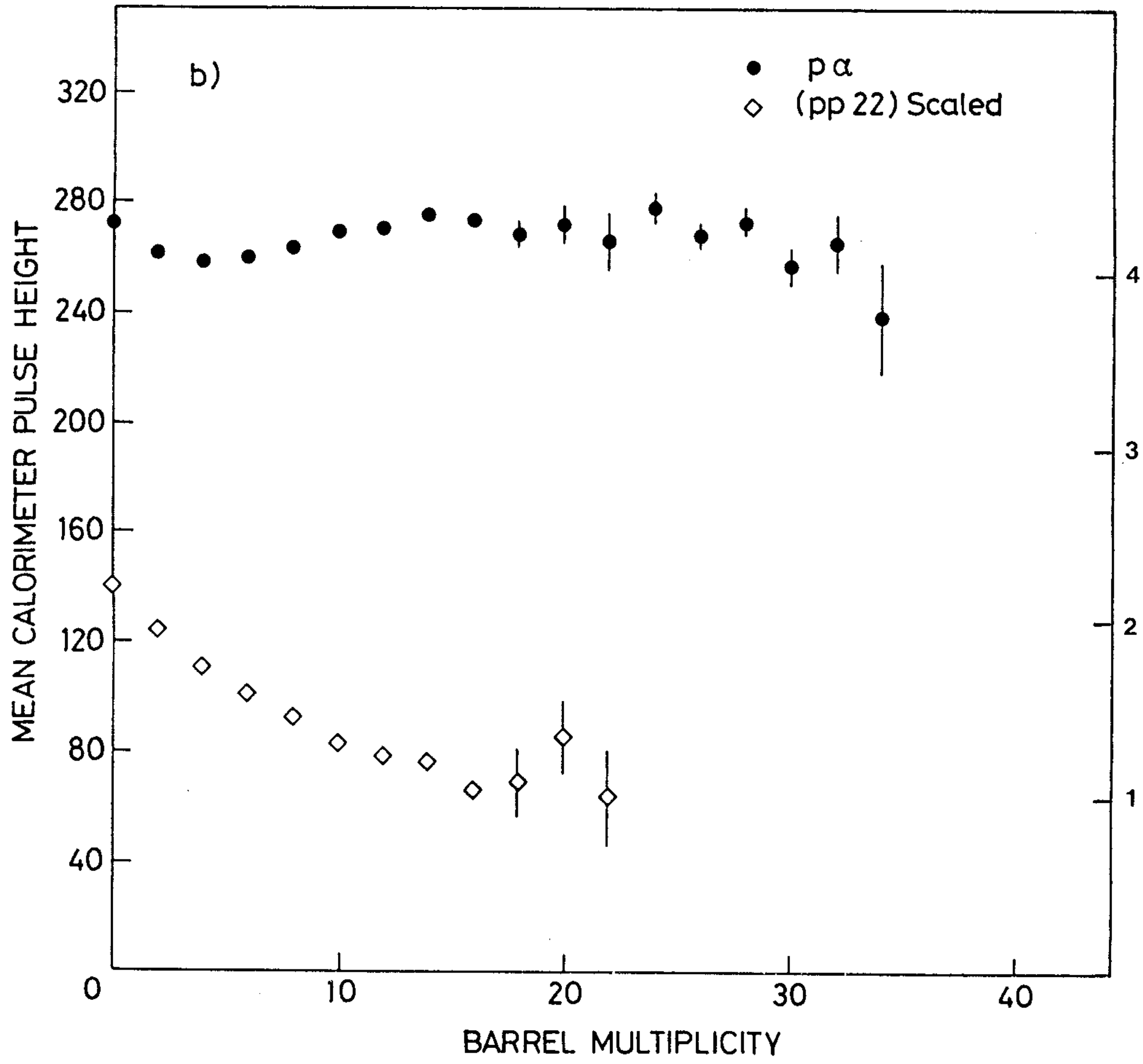

b)
p α
(pp 22) Scaled
MEAN CALORIMETER PULSE HEIGHT
BARREL MULTIPLICITY
0
40
80
120
160
200
240
280
320
10
20
30
40
1
2
3
4

Fig. 3b

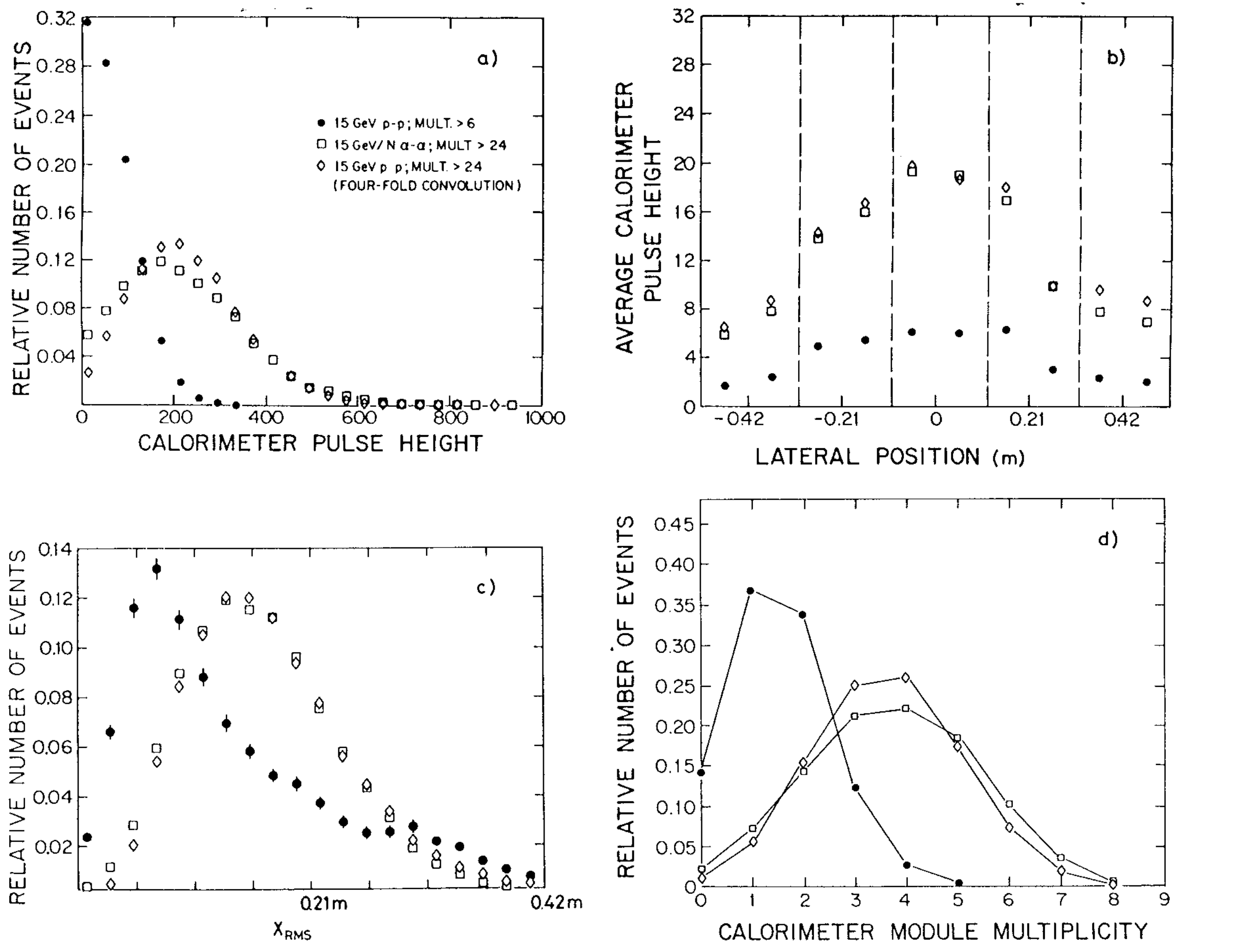

a)
15 GeV p-p; MULT. > 6
15 GeV/N α-α; MULT > 24
15 GeV p p; MULT. > 24
(FOUR-FOLD CONVOLUTION)
RELATIVE NUMBER OF EVENTS
CALORIMETER PULSE HEIGHT
b)
AVERAGE CALORIMETER PULSE HEIGHT
LATERAL POSITION (m)
c)
RELATIVE NUMBER OF EVENTS
0.21m
0.42m
X_RMS
d)
RELATIVE NUMBER OF EVENTS
CALORIMETER MODULE MULTIPLICITY

Fig. 4