IC/76/78
INTERNAL REPORT
(Limited distribution)

International Atomic Energy Agency

and

United Nations Educational Scientific and Cultural Organization

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

T O P I C A L   M E E T I N G

ON LEPTON INTERACTIONS AND NEW PARTICLES

6 - 9 July 1976

P A R T   I

(Contributions)

MIRAMARE - TRIESTE

July 1976

PRODUCTION OF NEW PARTICLES BY STRONG INTERACTIONS - A REVIEW OF THE LATEST DEVELOPMENTS

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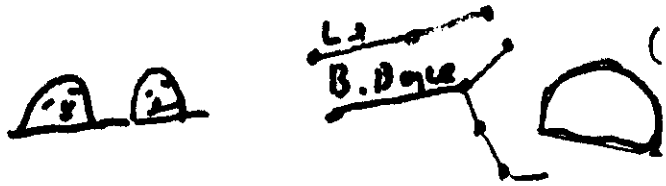
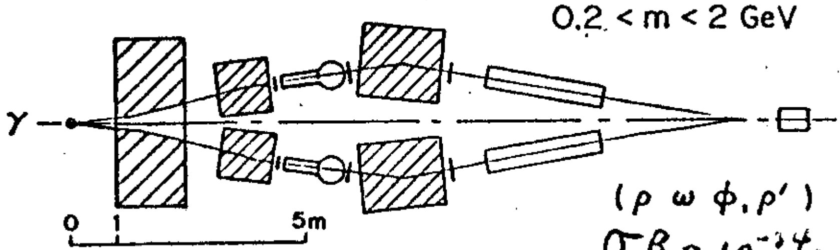
Cambridge, Mass. 02139, USA.



1965 - 1972
(DESY)

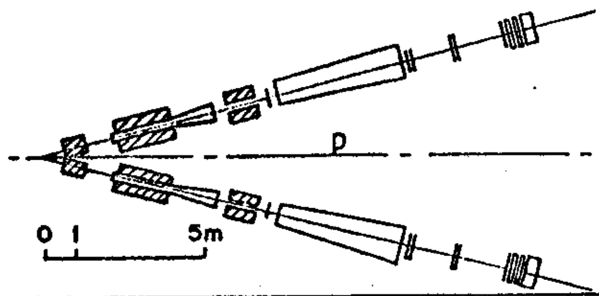
$\gamma + p \rightarrow e^- e^+ + x$
$0.2 < m < 2$ GeV



(ρ ω ϕ, ρ')
$\sigma B \sim 10^{-34}$ cm^2

1972 - 1976
(BNL)

$p + p \rightarrow e^- e^+ + x$
$1.5 < m < 5.5$ GeV

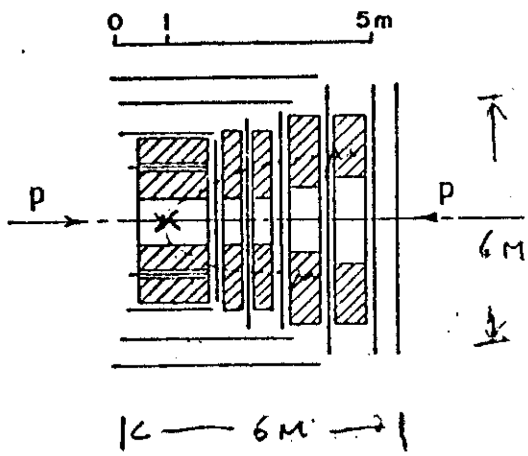


(J)

$\sigma B = 10^{-36}$ cm^2

1976 - 1978
(ISR)

$p + p \rightarrow \mu\mu + x$
$4 < m < 60$ GeV



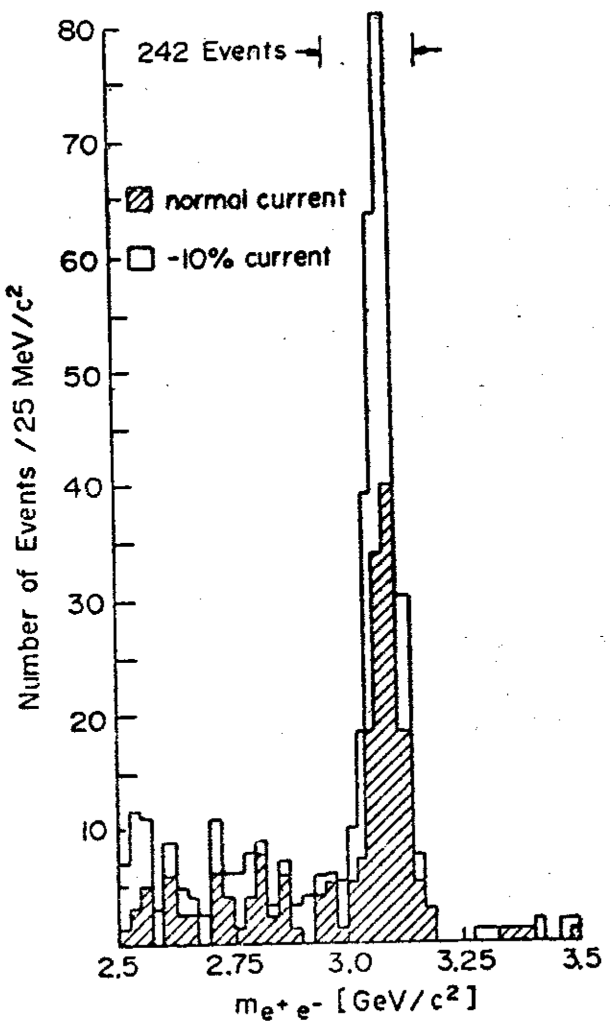
(Z°, W°)

$\sigma_B = 10^{-38}$ cm^2

J.J. AUBERT, U. BECKER, P.J. BIGGS, J. BURGER, M. CHEN
G. EVERHART, P. GOLDHAGEN, J. LEONG, P. MANTSCH, T. McCORRISTON
T.G. RHOADES, M. ROHDE, T. SANFORD, SAMUEL C.C. TING
AND SAU LAN WU
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
J.W. GLENN III AND Y.Y. LEE
BROOKHAVEN NATIONAL LABORATORY

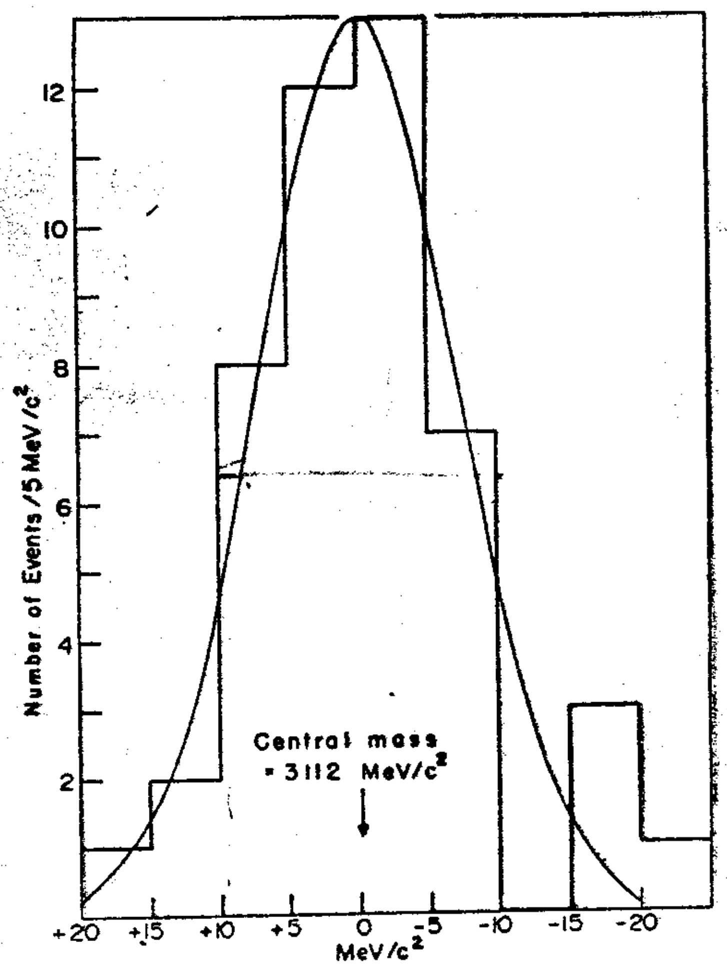
Unique Features

1. Can stand incident flux of 2×10^{12} protons/pulse.
   or 20 MC single rates.
   σ B $\Longrightarrow 10^{-36}$ cm^2.
2. Sort out 8 tracks per arm.
3. Rejection $\frac{e^- e^+}{h^- h^+} << 10^{-8}$.
4. Mass resolution ± 5 MeV.
5. Mass acceptance 2 BeV.



Mass spectrum for events in the mass range $2.5 < m_{ee} < 3.5$ GeV/c^2. The shaded events correspond to those taken at the normal momentum setting, while the unshaded ones correspond to a momentum setting 10% below normal. The acceptance is a smooth function of m.

Fig. 3a



The width of J

Fig. 3b

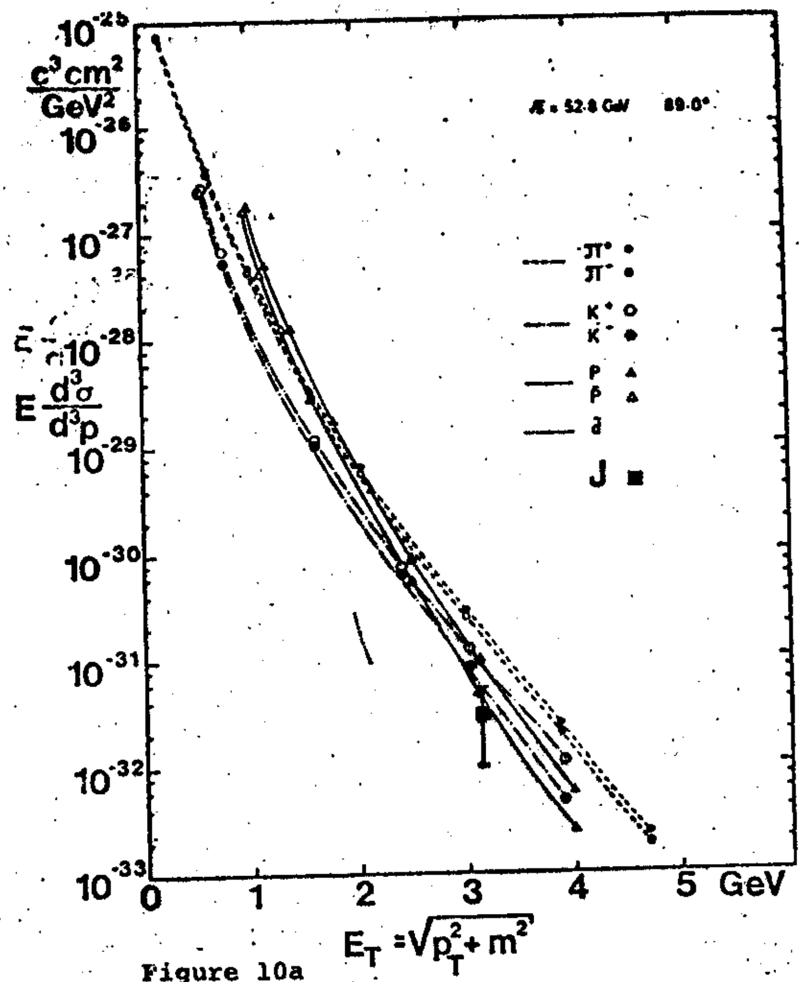


Figure 10a

Comparison of the J production cross section at $y = 1.6$ and $P_\perp = 0.5$ GeV/c with pion, kaon and proton data.

$p + p \to \pi^{\pm} + X$
$\to K^{\pm} + X$
$\to p^{\mp} + X$
$\to \bar{d} + X$
$\to J + X$
3000 BeV.

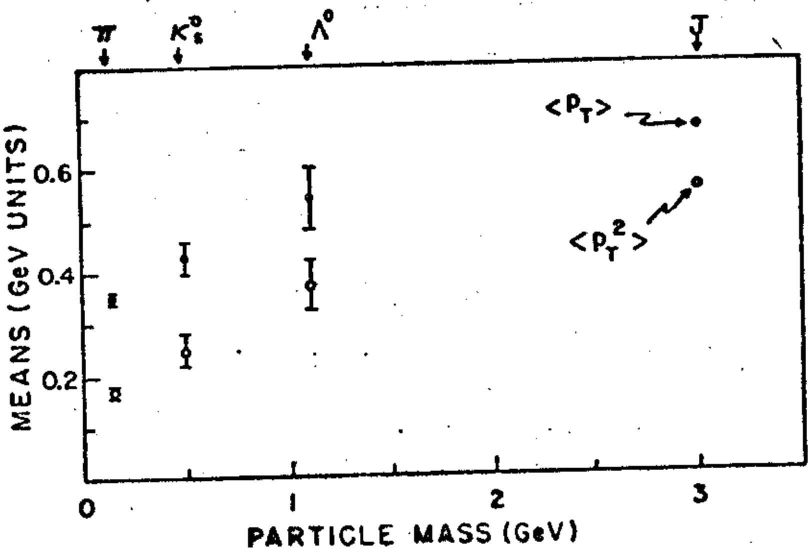


Fig. 10b

$\langle p_T \rangle$ and $\langle p_T^2 \rangle$ for particles produced in pp collisions ≥ 100 GeV (except for J)

$\gamma + p \to J + p$

$t_{min} = \frac{m_J^4}{4k^2}$

$\frac{d\sigma}{dt}\Big|_{\theta=0} = e^{b\,t_{min}} \frac{d\sigma}{dt}\Big|_{t_{min}}$

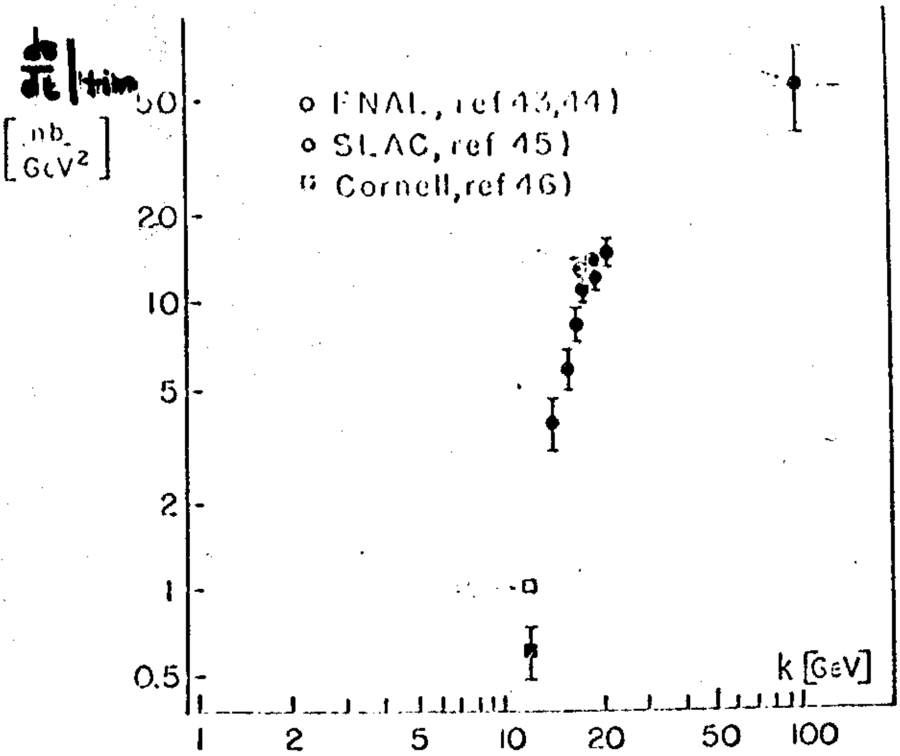


Fig. 14a)

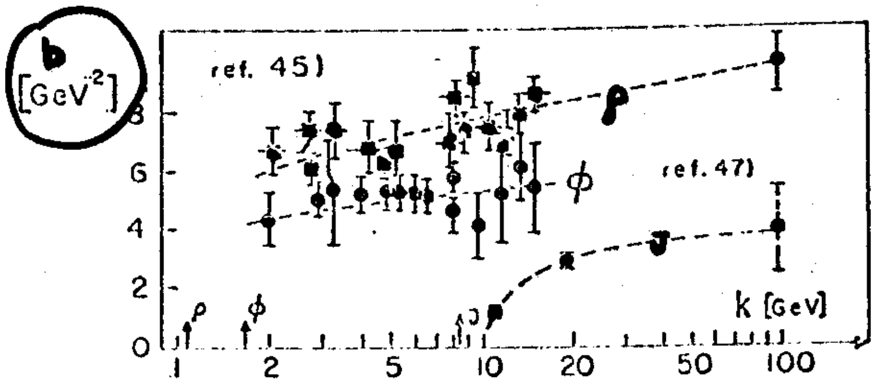


Fig. 14b)

$\frac{d\sigma}{dt}\Big|_{t=0}(\gamma p \to J p) =$

$\frac{\alpha}{4}\left(\frac{\gamma_J^2}{4\pi}\right)^{-1} \frac{d\sigma}{dt}\Big|_{t=0}(Jp \to Jp)$

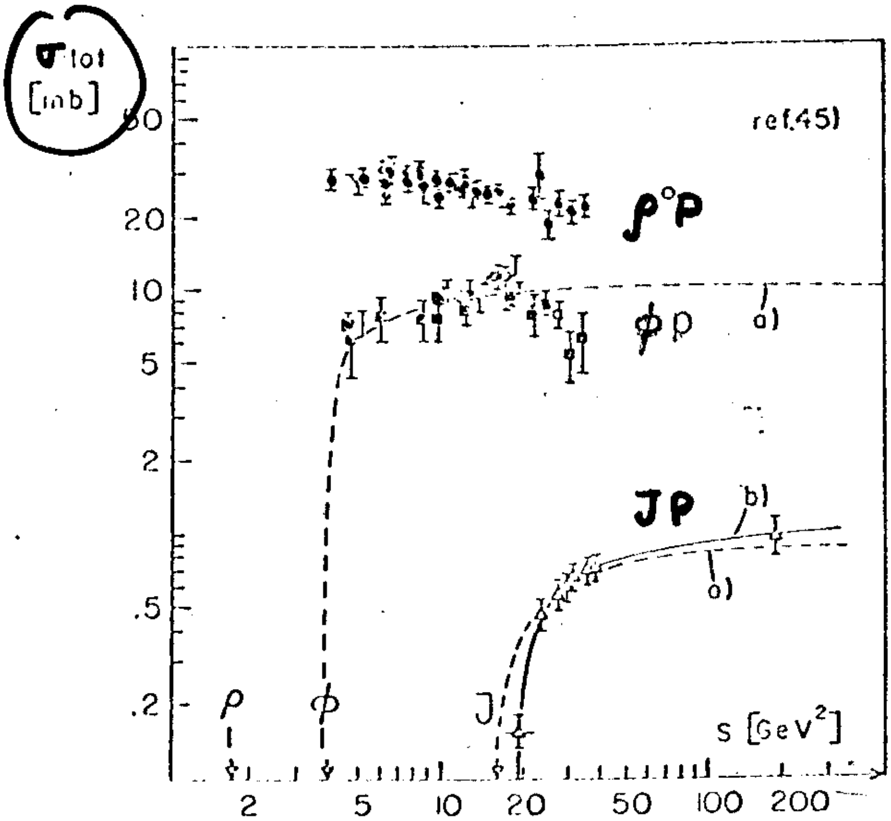
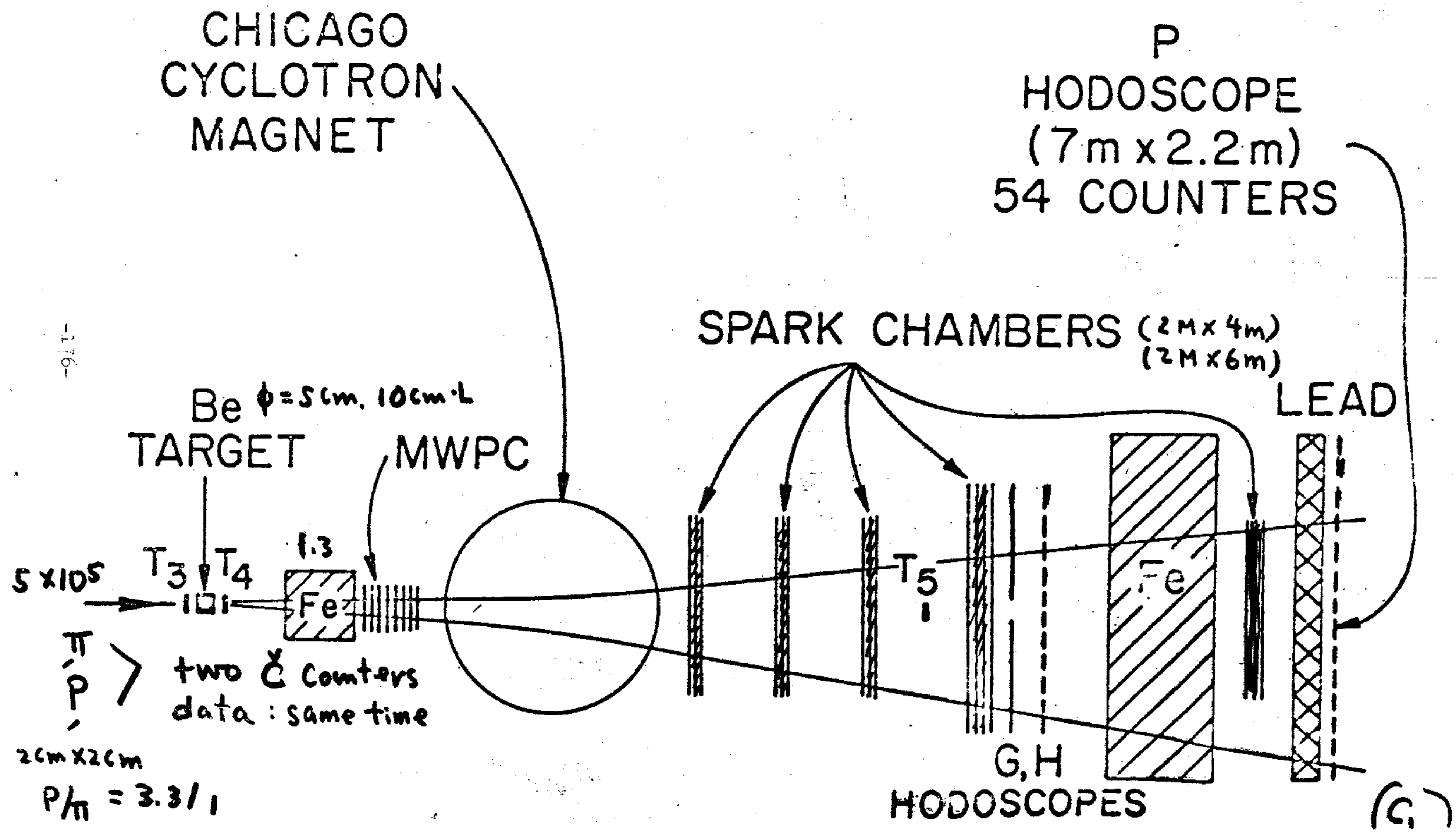


Fig. 14c)

B2

J. E pilcher and A.J.S. Smith. Chicago + Princeton.



Chicago - princeton.
150 GeV.

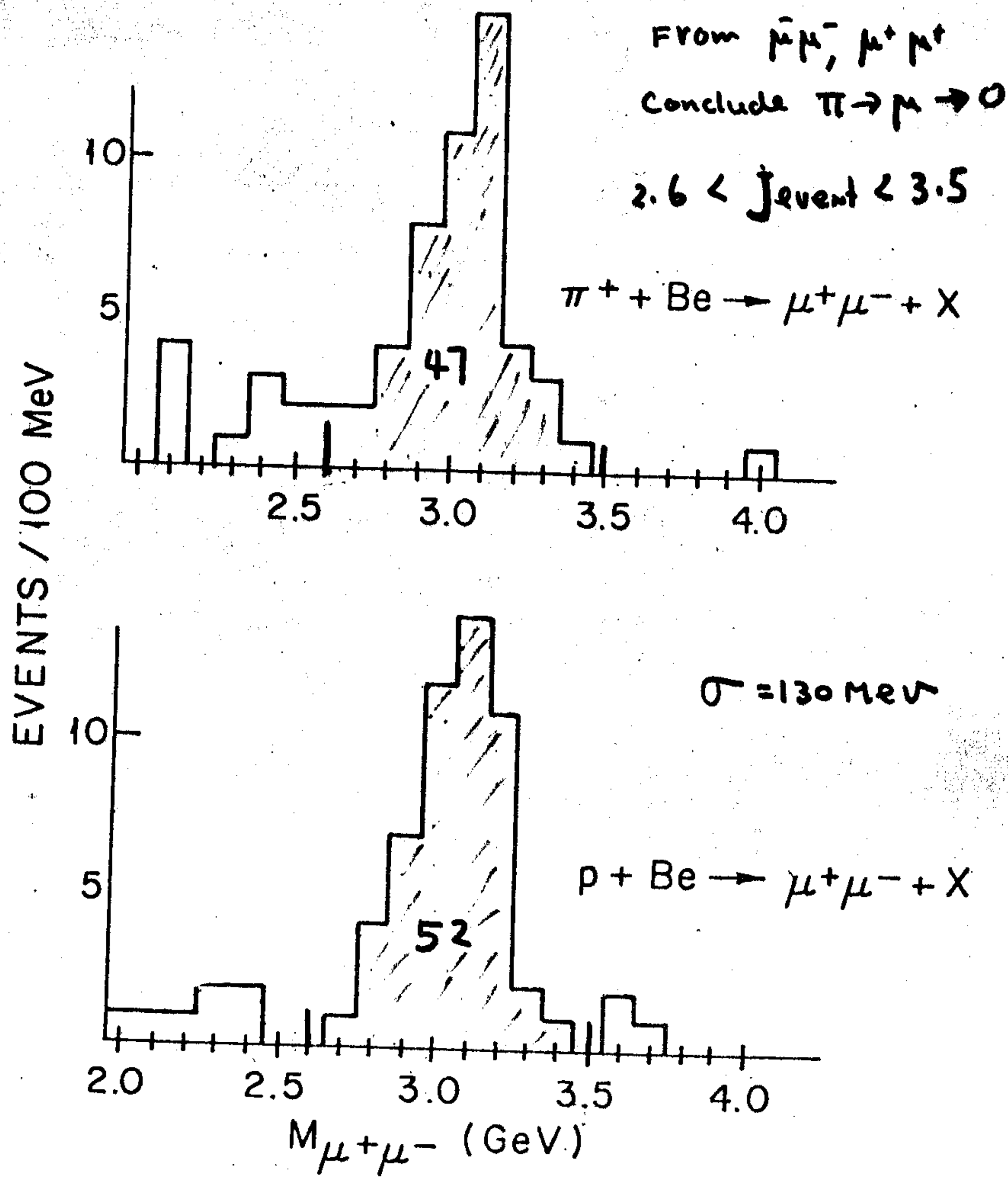


FIG. 2

C2

Chicago - Princeton.

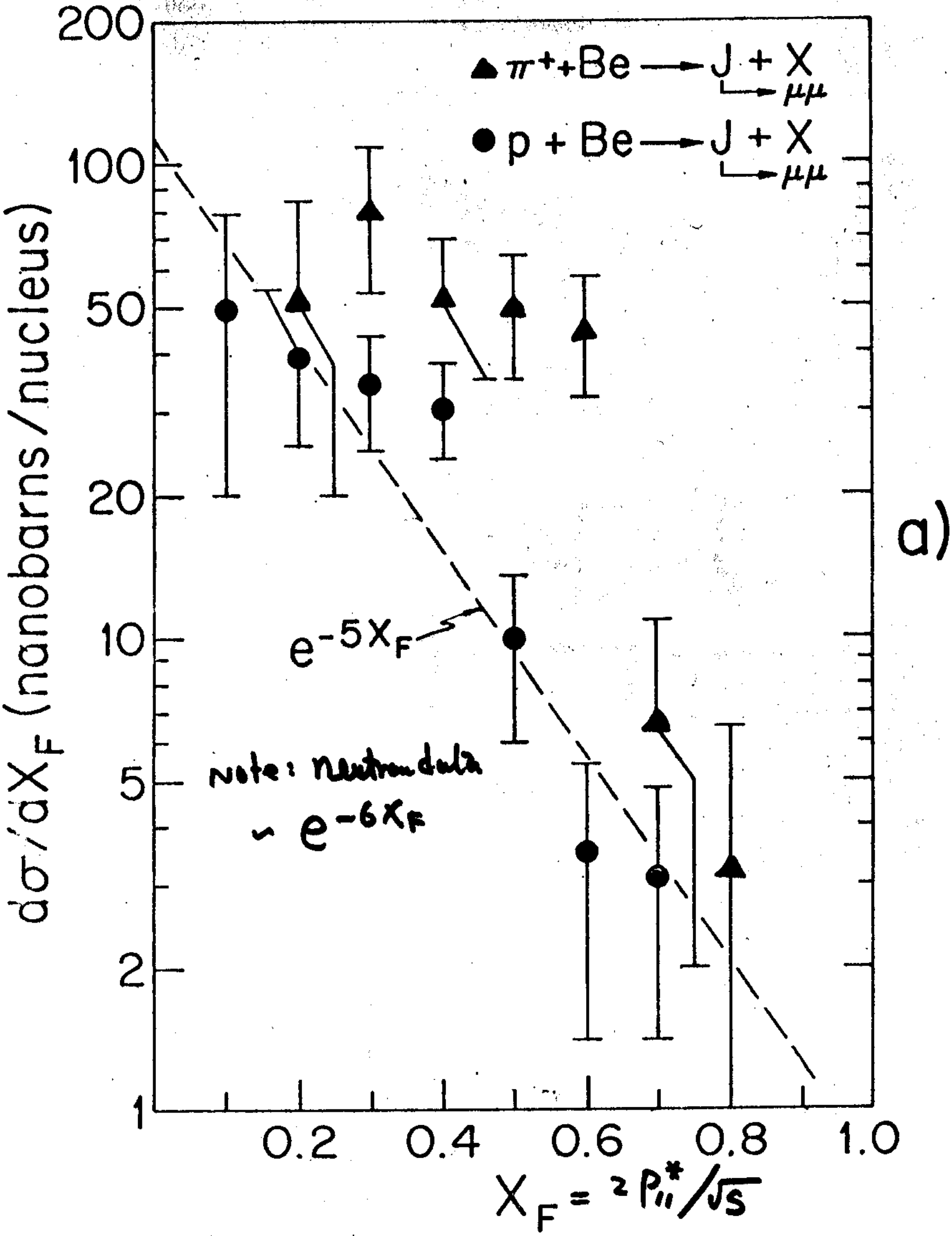


FIG. 3

C3

Chicago - Princeton

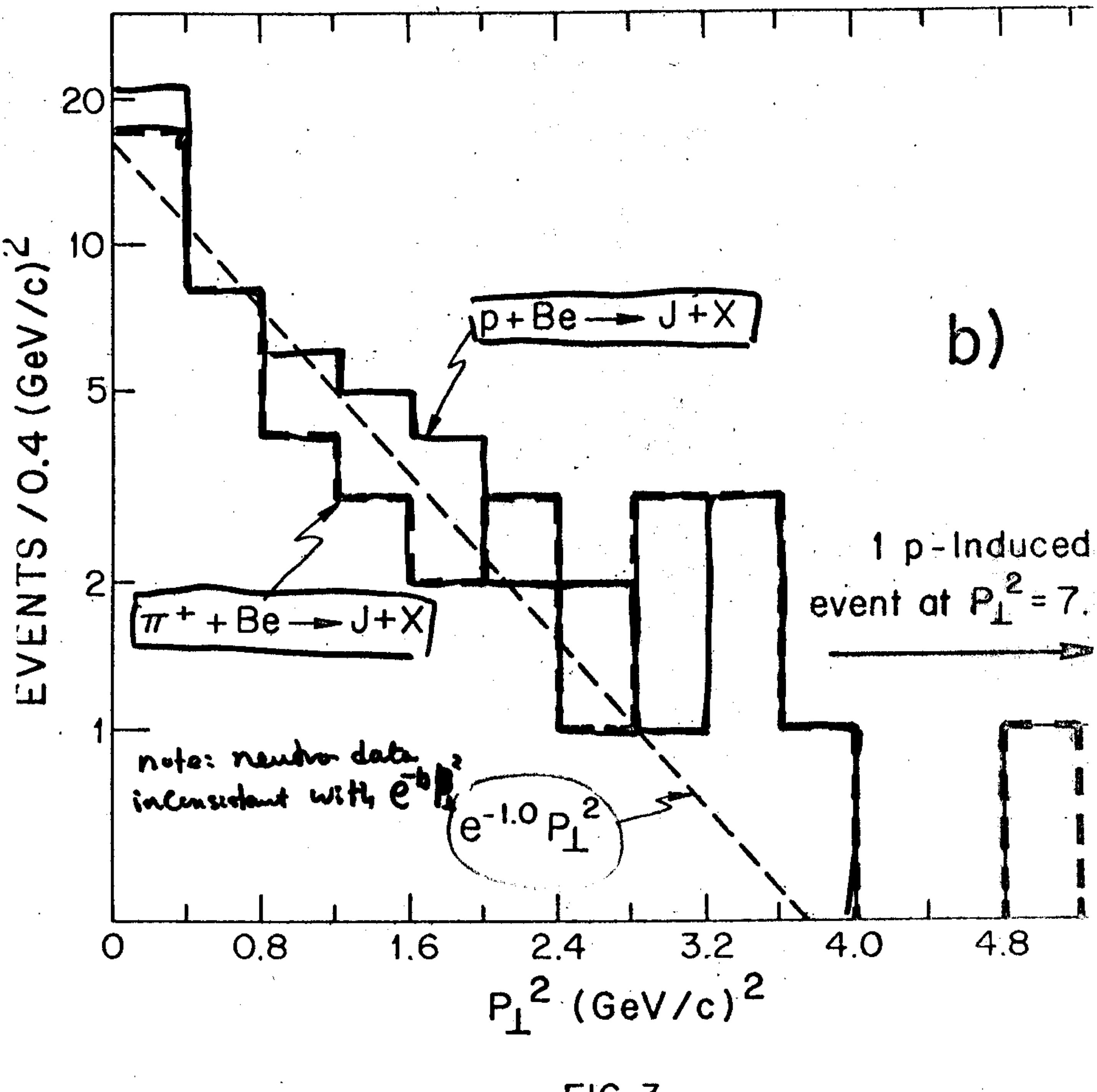


FIG. 3

C4

Chicago - Princeton:

J production: $2.6 < M_{\mu\mu} < 3.5$ GeV

$$\frac{\sigma(p + Be \to J + X)}{\sigma(\pi^{+} + Be \to J + X)} = \begin{array}{lll} 0.59 \pm 0.15 & & X_F > 0.05 \\ 0.16 & \pm 0.05 & X_F > 0.45 \end{array}$$

Continuum $2.0 < M_{\mu\mu} < 2.6$ GeV

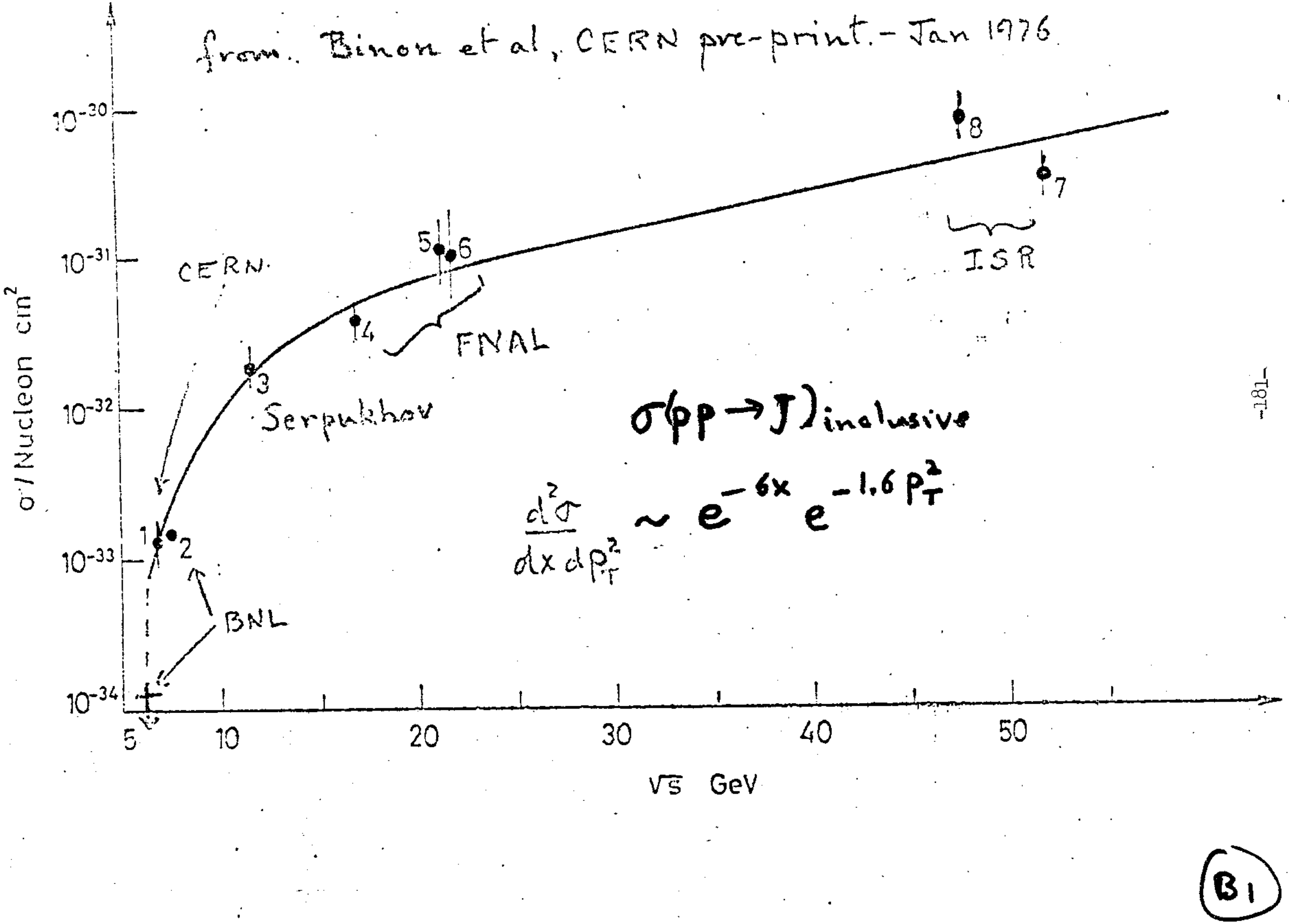
$$\frac{\sigma(p + Be \to \mu^+\mu^- + X)}{\sigma(\pi^+ + Be \to \mu^+\mu^- + X)} = 0.21 \pm 0.11 \quad X_F > 0.5$$

At low X_F: π, p data comparable.

$X_F > 0.45$ π dominate over p.

Both: data agrees with $e^{-1.0 p_\perp^2}$.

C5

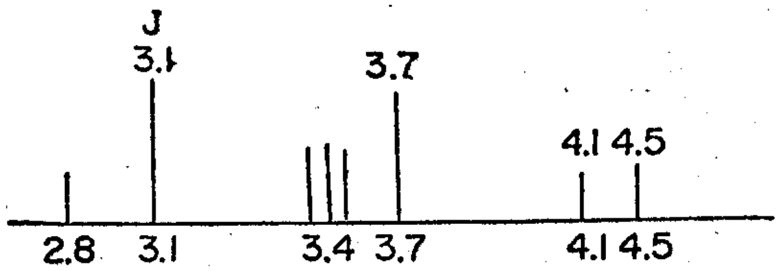

from. Binon et al, CERN pre-print. - Jan 1976
σ/Nucleon cm²
10⁻³⁰
10⁻³¹
10⁻³²
10⁻³³
10⁻³⁴
5
10
20
30
40
50
√s GeV
CERN
BNL
Serpukhov
FNAL
ISR
1
2
3
4
5
6
7
8
σ(pp → J) inclusive
d²σ/dx dp_T² ~ e^{-6x} e^{-1.6 p_T²}
B1

New Particles

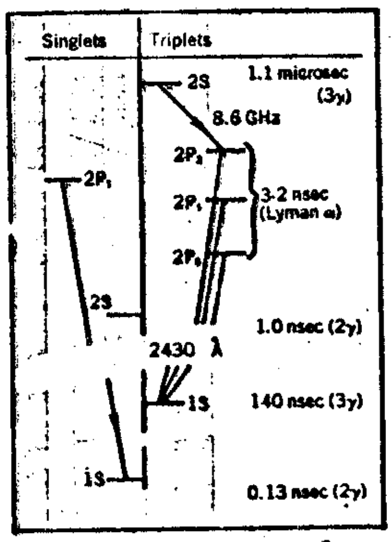
1. long live time $\sim 10^{-18}$ sec

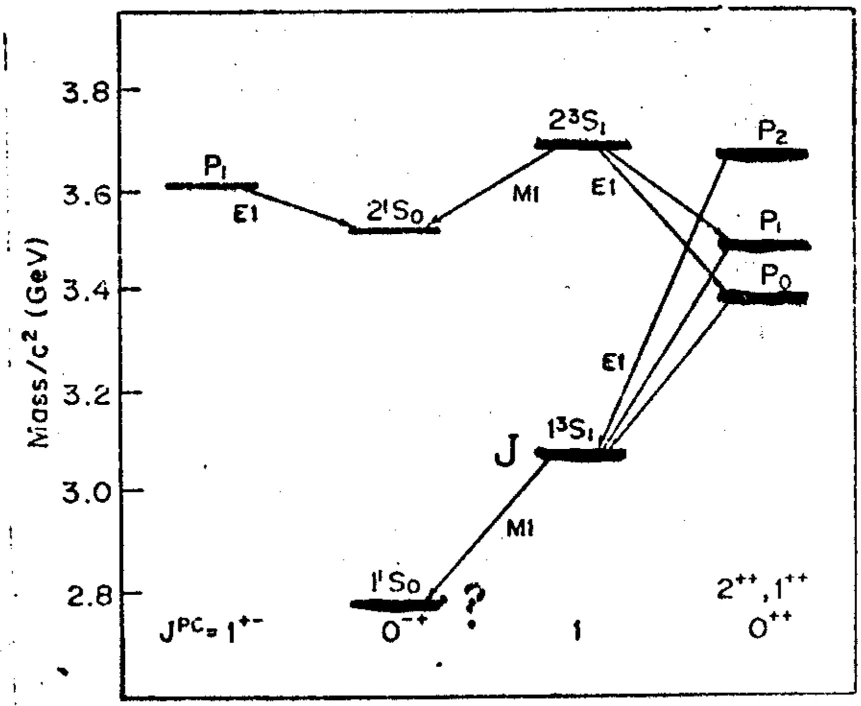
2. massive (3 - 5 BeV)

DESY — SLAC — ADONE



(e⁺e⁻) Atom





e spin $\quad$ orbital

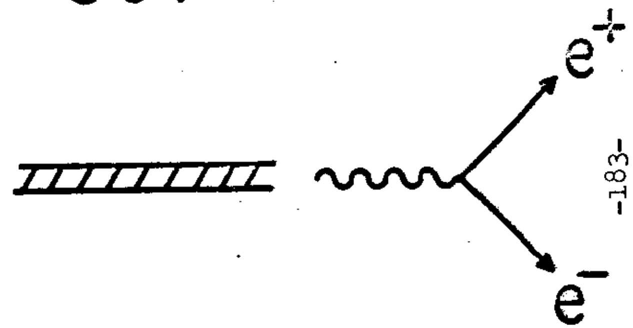
$n^{2s+1}\, l\, (J) \rightarrow$ Total

principal

$p + p \longrightarrow e + x$

$p + p \longrightarrow \pi + x$

$\underline{\frac{e}{\pi} = 10^{-4}}$; at 30, 300, 3000 GeV

Normaly we have $\rho\, \omega\, \phi\, \rho'$; 

But, this yield $\frac{e}{\pi} \approx 10^{-5}$

Something New must be there!

SEARCH for more new particles if J is bound state of $(C\bar{C})$ then Charm Quark bound with Ordinary Quark to form new states.

MIT/BNL

$D \to K^+\pi^-, Ke\nu, K\mu\nu$, etc. (cq)

$B \to p+K, pe\nu$, etc (cqq)

This can be detected by

$$P + Be \to D + \bar{D} + X \qquad (1)$$

$$\quad D \to K\pi,\ eh\nu, \cdots$$

or

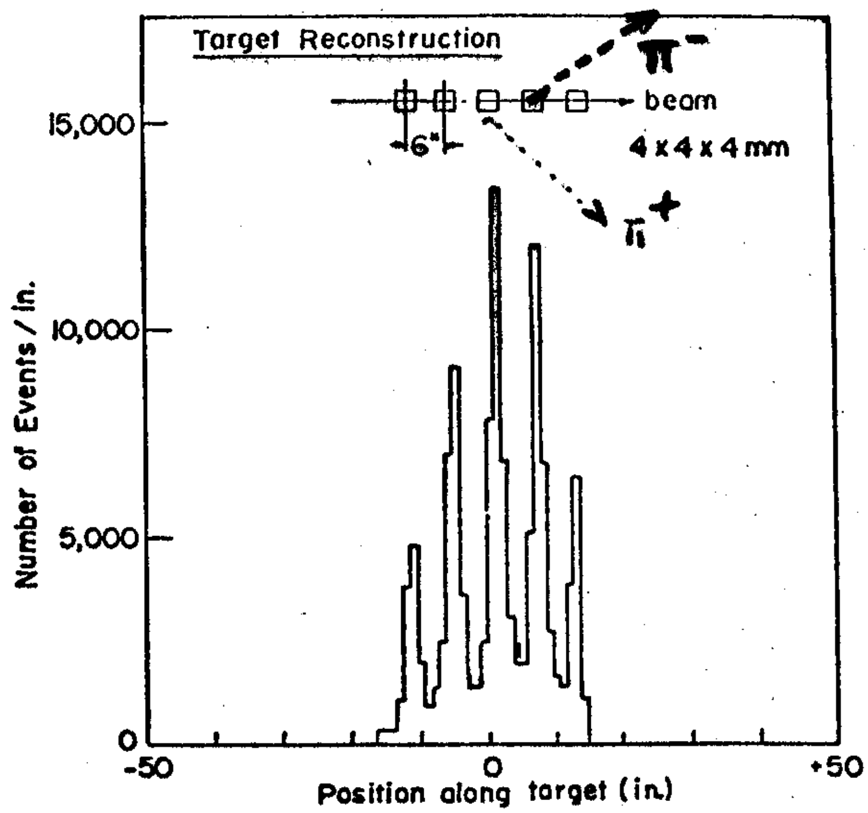
$$P + Be \to \bar{D} + B + X \qquad (2)$$

$$\quad B \to p + K,\ eh\nu + \cdots$$

or

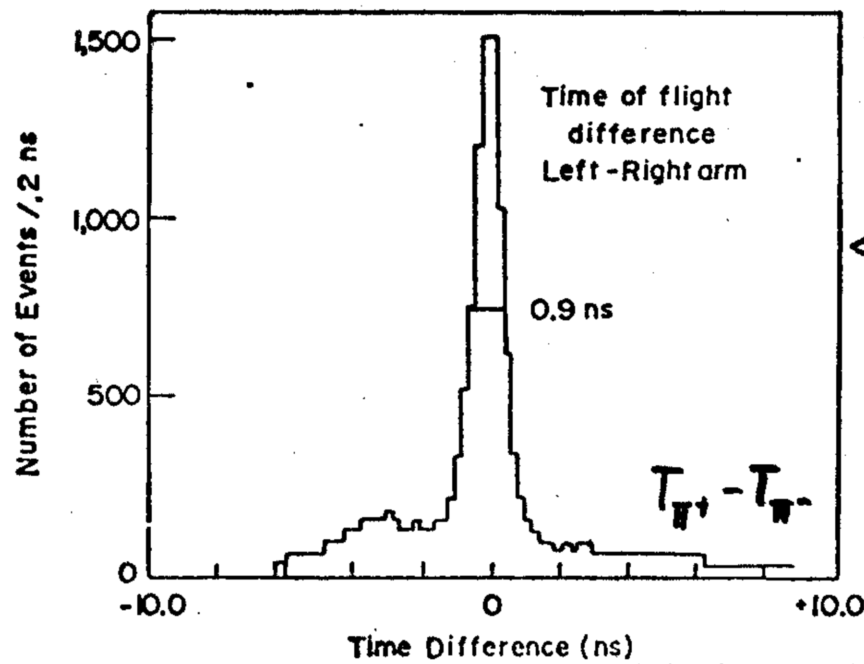
$$P + Be \to D + \bar{D} + X \qquad (3)$$

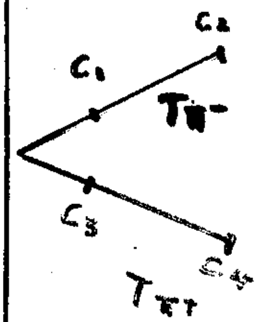
$$\quad D \to \mu h\nu,\quad \bar{D} \to k\pi$$



Al_2O_3

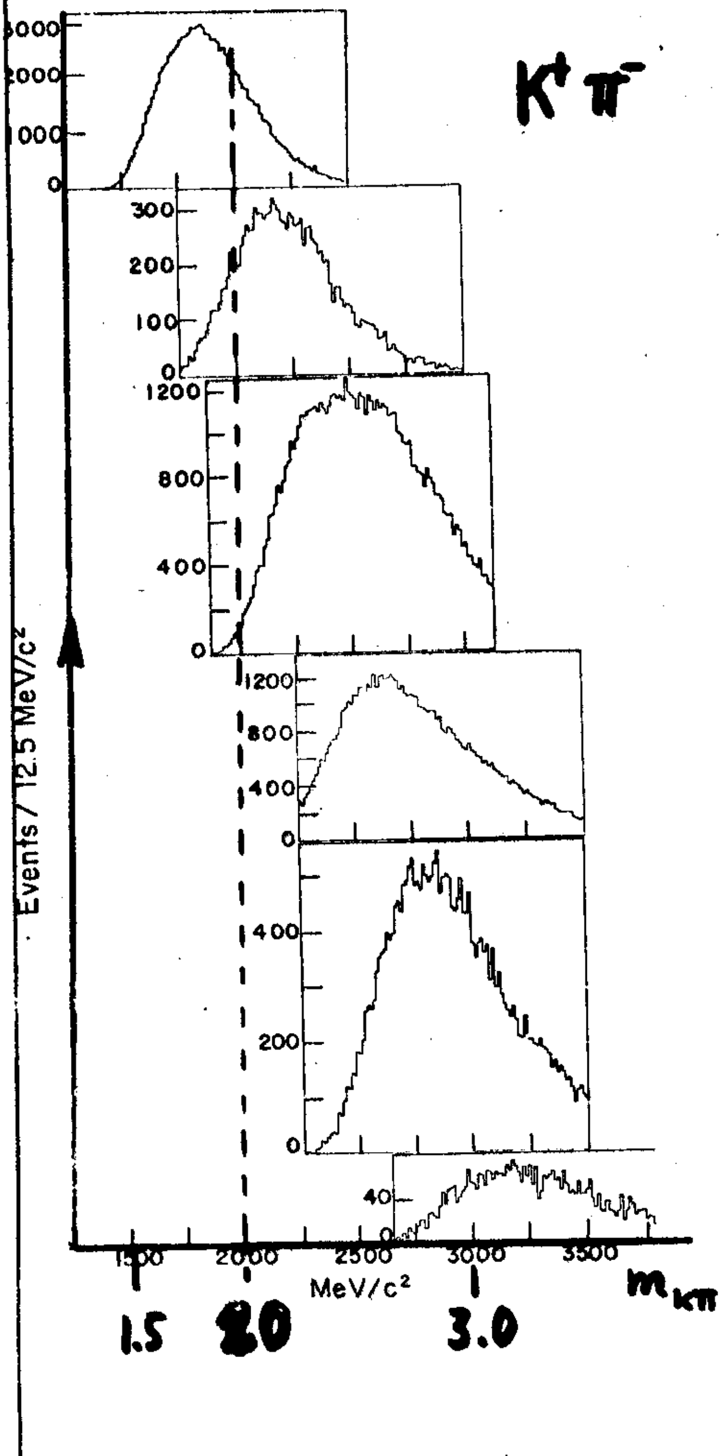
a. Reconstruction of the pair vertex at the target; using information from the proportional chambers. The five pieces of beryllium are seen clearly.

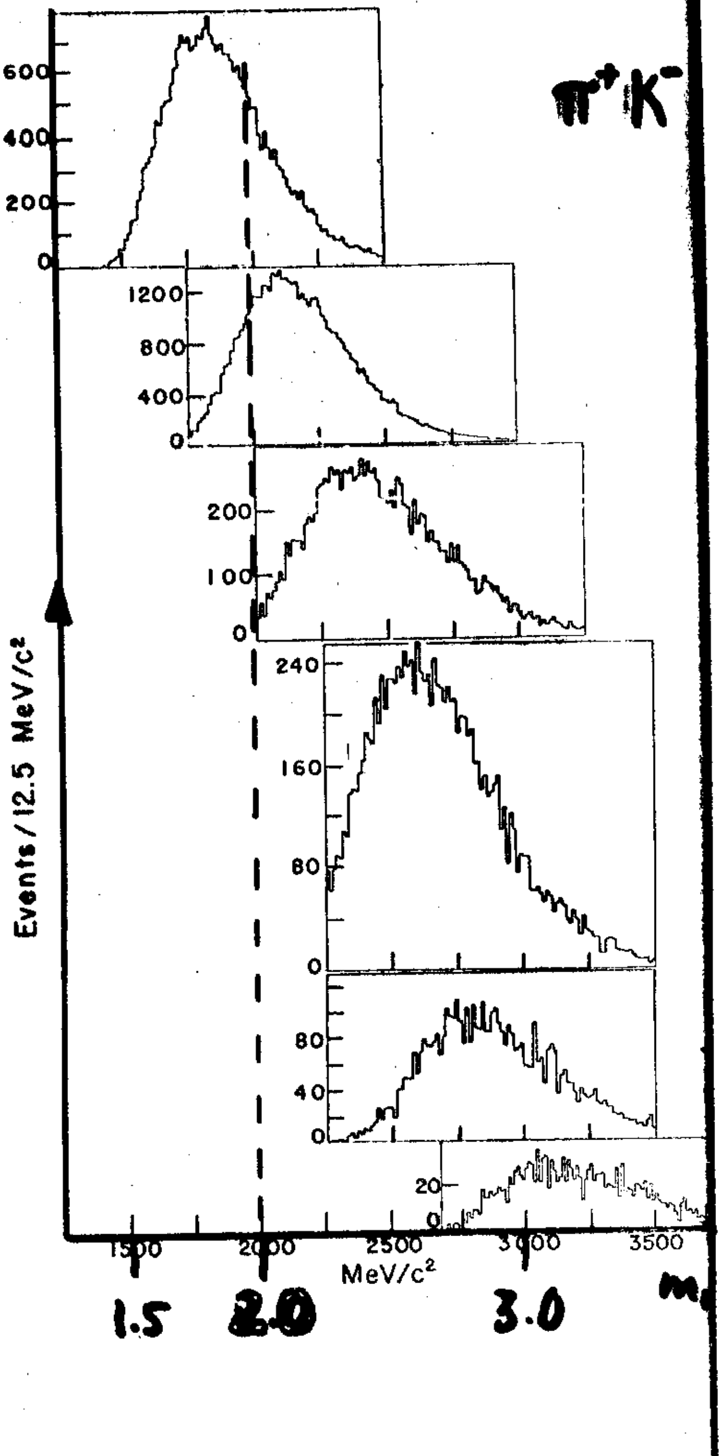


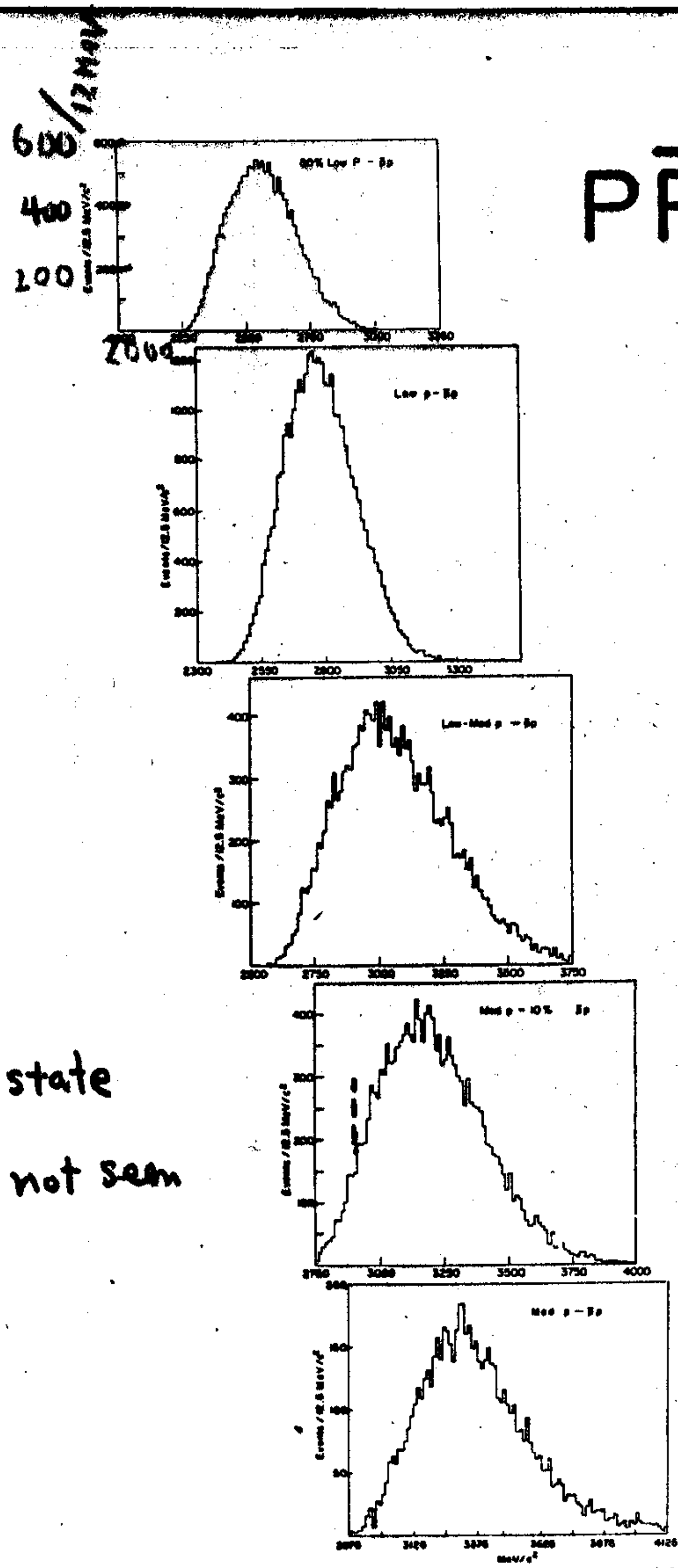


b. Time difference between additional scintillation counters in the left and right arms. The resolution obtained is 0.9ns and little background is present.

Fig. 7


K+ π-
Events / 12.5 MeV/c²
3000
2000
1000
0
300
200
100
1200
800
400
40
1500
2000
2500
3000
3500
MeV/c²
m Kπ
1.5
2.0
3.0


π+ K-
Events / 12.5 MeV/c²
600
400
200
0
1200
800
240
160
80
40
20
1500
2000
2500
3000
3500
MeV/c²
1.5
2.0
3.0



4125 MeV

$P\bar{P}$

2.8 GeV state
$\rightarrow \bar{P}P$; not seen
by us.

$p\,Be \to J + X$

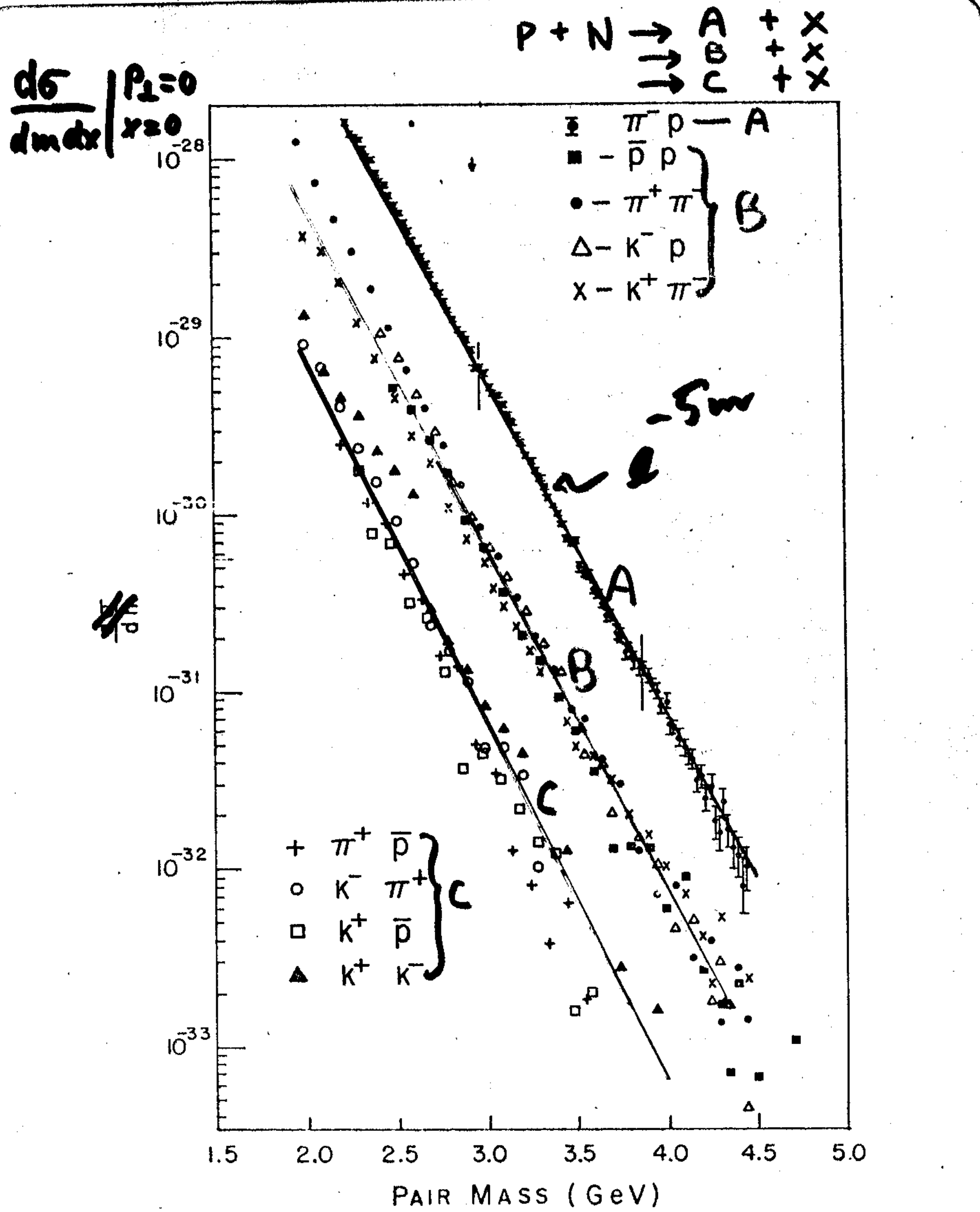
$\sigma \sim 10^{-32}\,cm^2$

SENSITIVITY (cm^2)
FOR NARROW RESONANCES

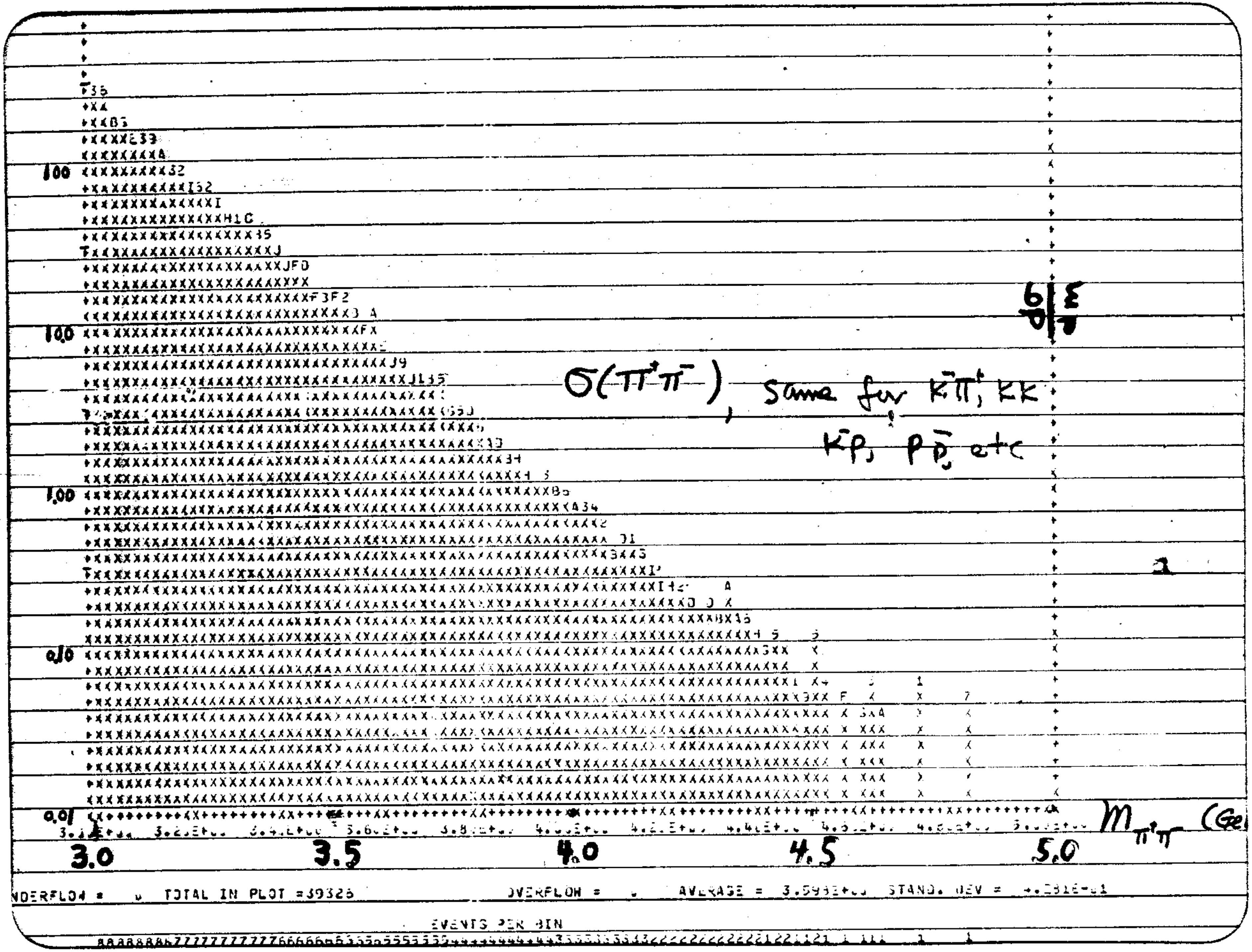
h^+X^- \ m	2.25 GeV	3.1 GeV	3.7 GeV
$\pi^+\pi^-$	8×10^{-33}	5×10^{-34}	3×10^{-35}
π^+K^-	$\boxed{1 \times 10^{-33}}$	4×10^{-35}	1×10^{-35}
$\pi^+\bar{p}$	2×10^{-33}	4×10^{-35}	7×10^{-36}
$K^+\pi^-$	4×10^{-33}	8×10^{-35}	4×10^{-35}
K^+K^-	1×10^{-33}	5×10^{-35}	1×10^{-35}
$K^+\bar{p}$	$\boxed{2 \times 10^{-33}}$	4×10^{-35}	8×10^{-36}
$p\,\pi^-$	4×10^{-32}	4×10^{-33}	5×10^{-34}
$p\,K^-$	7×10^{-33}	4×10^{-34}	3×10^{-35}
$p\,\bar{p}$	—	$\boxed{4 \times 10^{-34}}$	2×10^{-35}

50 million events

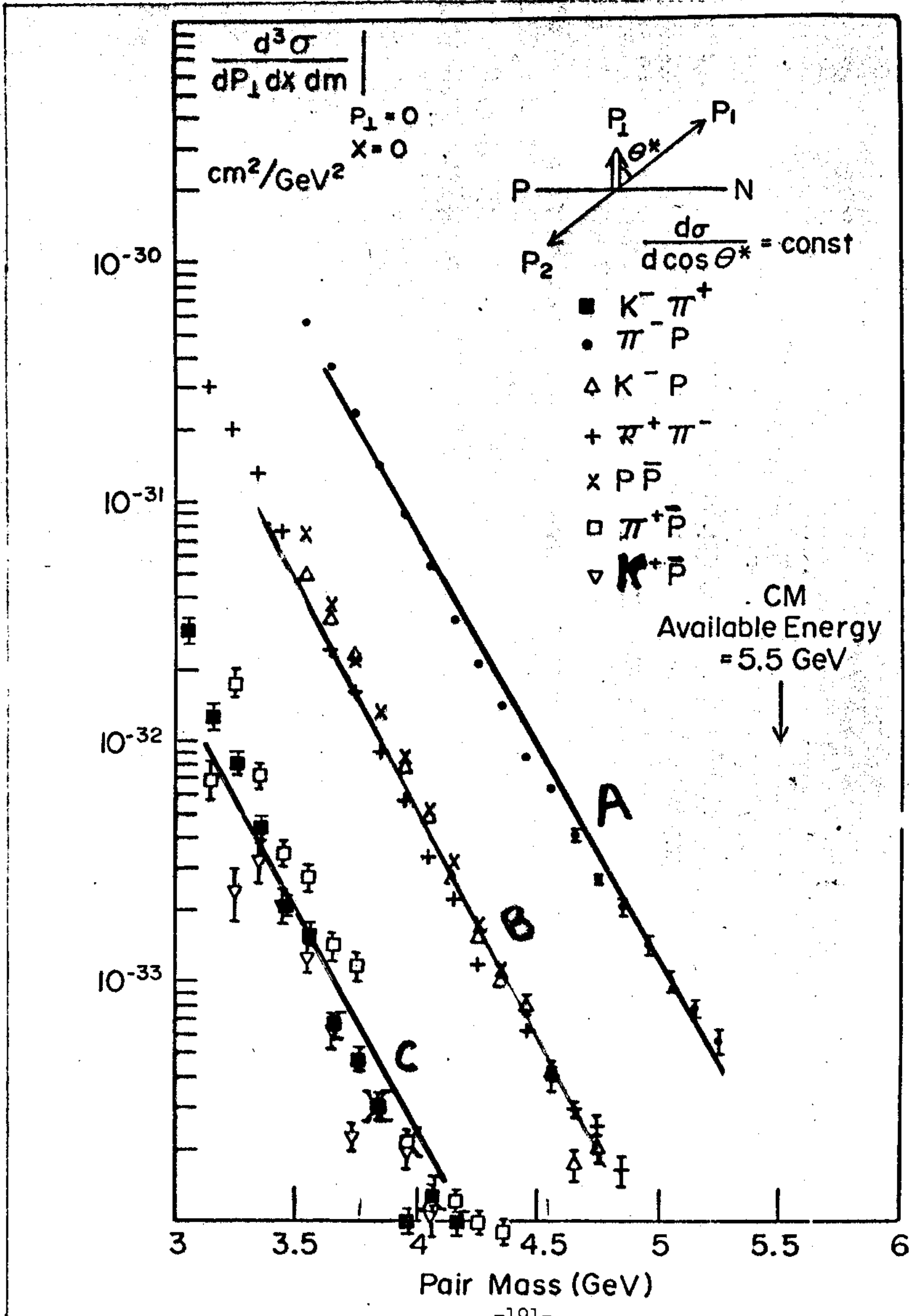
20 Mio



P + N → A + X
→ B + X
→ C + X
dσ/dmdx | p⊥=0, x=0
π⁻ p — A
■ – p̄ p
● – π⁺ π⁻
△ – K⁻ p
x – K⁺ π⁻
B
~ e^{-5m}
A
B
C
+ π⁺ p̄
○ K⁻ π⁺
□ K⁺ p̄
▲ K⁺ K⁻
C
10⁻²⁸
10⁻²⁹
10⁻³⁰
10⁻³¹
10⁻³²
10⁻³³
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
PAIR MASS (GeV)



100
10.0
1.00
0.10
0.01
3.0
3.5
4.0
4.5
5.0
$\frac{d\sigma}{dM}$
$\sigma(\pi^+\pi^-)$, same for $K^-\pi^+$, $K\bar{K}$
K^-p, $p\bar{p}$ etc
$M_{\pi^+\pi^-}$ (Ge
UNDERFLOW = 0 TOTAL IN PLOT =39326
OVERFLOW = 0
EVENTS PER BIN



$\frac{d^3\sigma}{dP_\perp dx\, dm}\Big|_{P_\perp=0,\ x=0}$
cm²/GeV²
P
N
P_1
P_2
$P_\perp$
θ^*
$\frac{d\sigma}{d\cos\theta^*}$ = const
■ $K^-\pi^+$
● $\pi^- P$
△ $K^- P$
+ $\pi^+\pi^-$
× $P\bar{P}$
□ $\pi^+\bar{P}$
▽ $K^+\bar{P}$
CM
Available Energy
= 5.5 GeV
A
B
C
10^{-30}
10^{-31}
10^{-32}
10^{-33}
3
3.5
4
4.5
5
5.5
6
Pair Mass (GeV)

$$e^{-6p_\perp} \text{ or } e^{-bp_\perp^2} \; ?$$

→ slope is mass dependent!

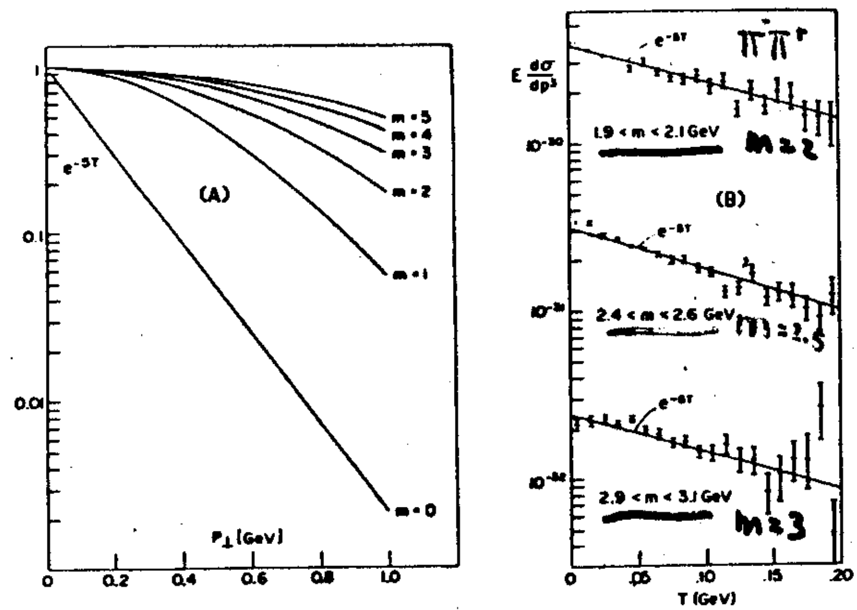


FIG. 2. (a) The $P_\perp$ behavior of e^{-5T} as a function of m [see Eq. (2)]. (b) The T dependence of the invariant cross section (in units of cm²/GeV²) for $\pi^+ + \pi^-$ at three narrow mass bands. The e^{-5T} line is a visual fit to the data.

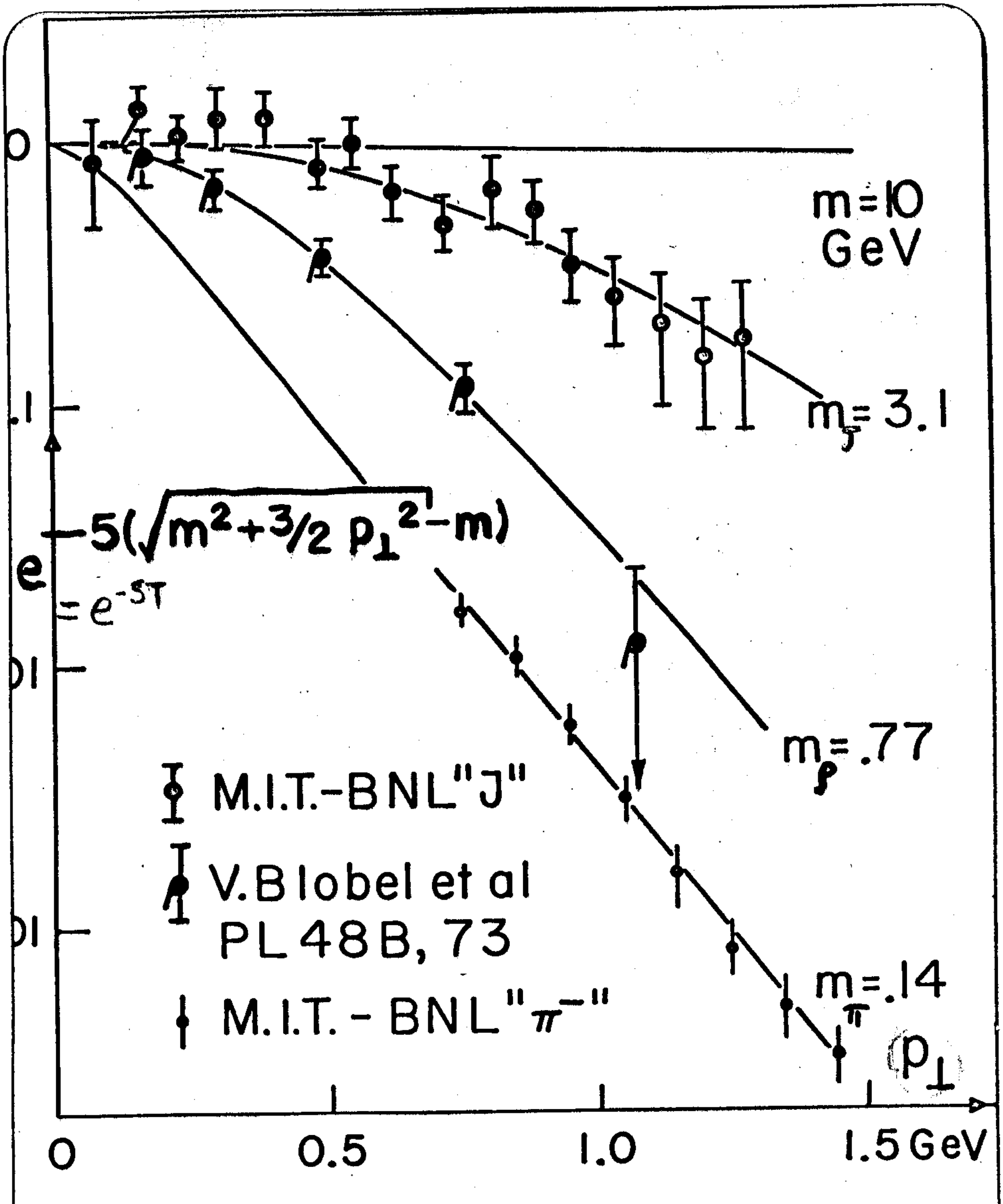
$$E\frac{d^3\sigma}{dp^3} \sim e^{-5E} = \underbrace{e^{-5m}} \cdot e^{-5(\sqrt{m^2+p^2}-m)}$$

if ↓ isotrop

$$= \tfrac{3}{2}\langle p_\perp^2\rangle$$

$$= e^{-5m}\, e^{-5T}$$

$$= e^{-5m}\, e^{-5(\sqrt{m^2+3/2\,p_\perp^2}-m)}$$



m = 10 GeV
$m_J = 3.1$
$m_\rho = .77$
$m_\pi = .14$
$e^{-5(\sqrt{m^2+3/2\, p_\perp^2}-m)}$
$= e^{-5T}$
M.I.T.-BNL "J"
V. Blobel et al
PL 48B, 73
M.I.T. - BNL "π^-"
$p_\perp$
0
0.5
1.0
1.5 GeV

SEARCH for more new particles
if J is bound state of $(C\bar{C})$
then Charm Quark bound with
Ordinary Quark to form new states.

$D \rightarrow K^{+}\pi^{-}, Ke\nu, K\mu\nu$, etc.

$B \rightarrow p + K, pe\nu$, etc

This can be detected by

$$P + Be \rightarrow D + \bar{D} + X \qquad ①$$

$\hookrightarrow \cancel{K\pi}, eh\nu \ldots$ mostly eK, ep.

or

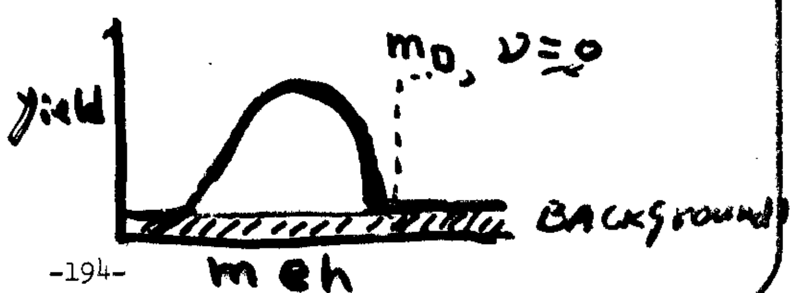
$$P + Be \rightarrow \bar{D} + B + X \qquad ②$$

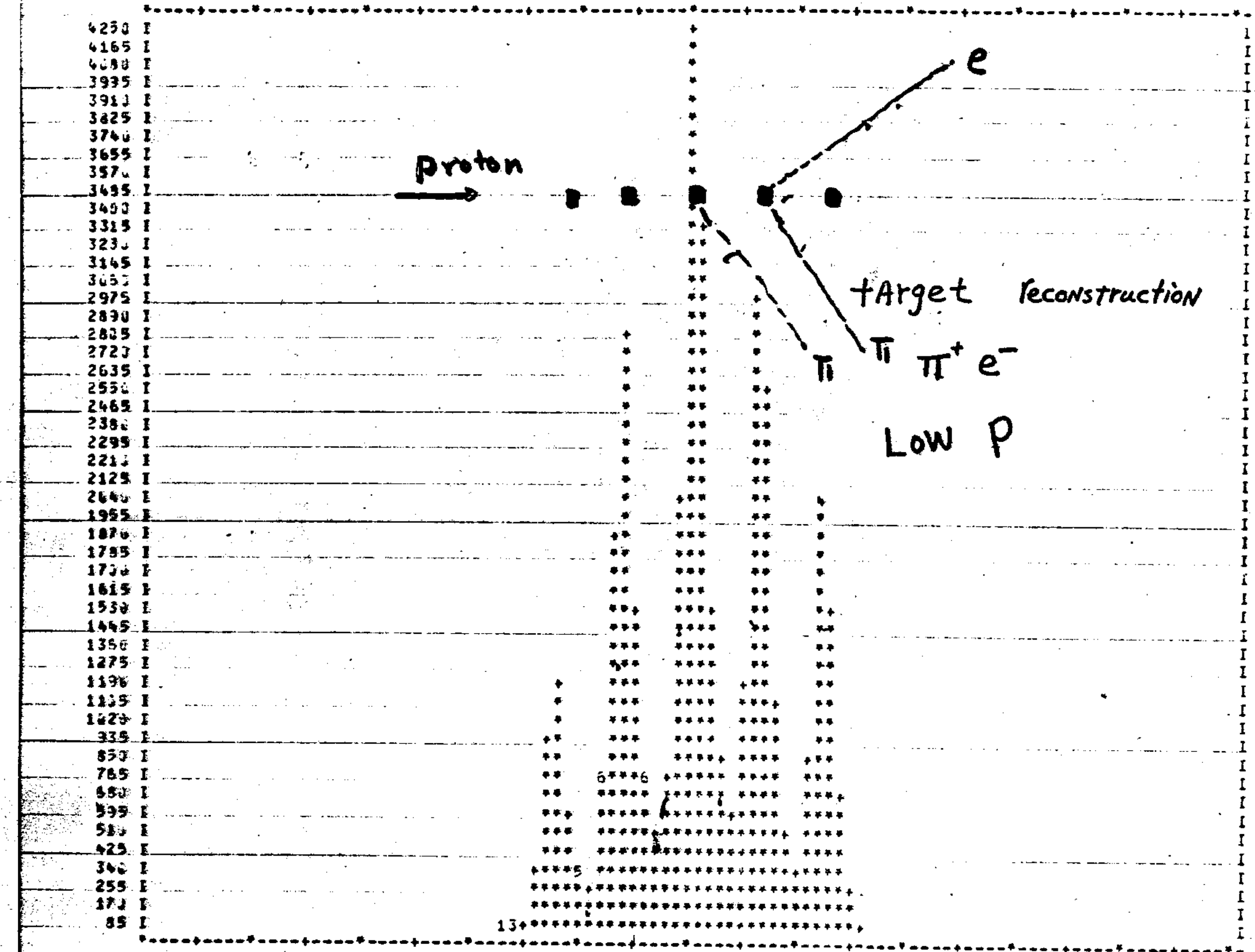
$B \rightarrow \cancel{p + K}, eh\nu + \ldots$

or

$$P + Be \rightarrow D + \bar{D} + X \qquad ③$$

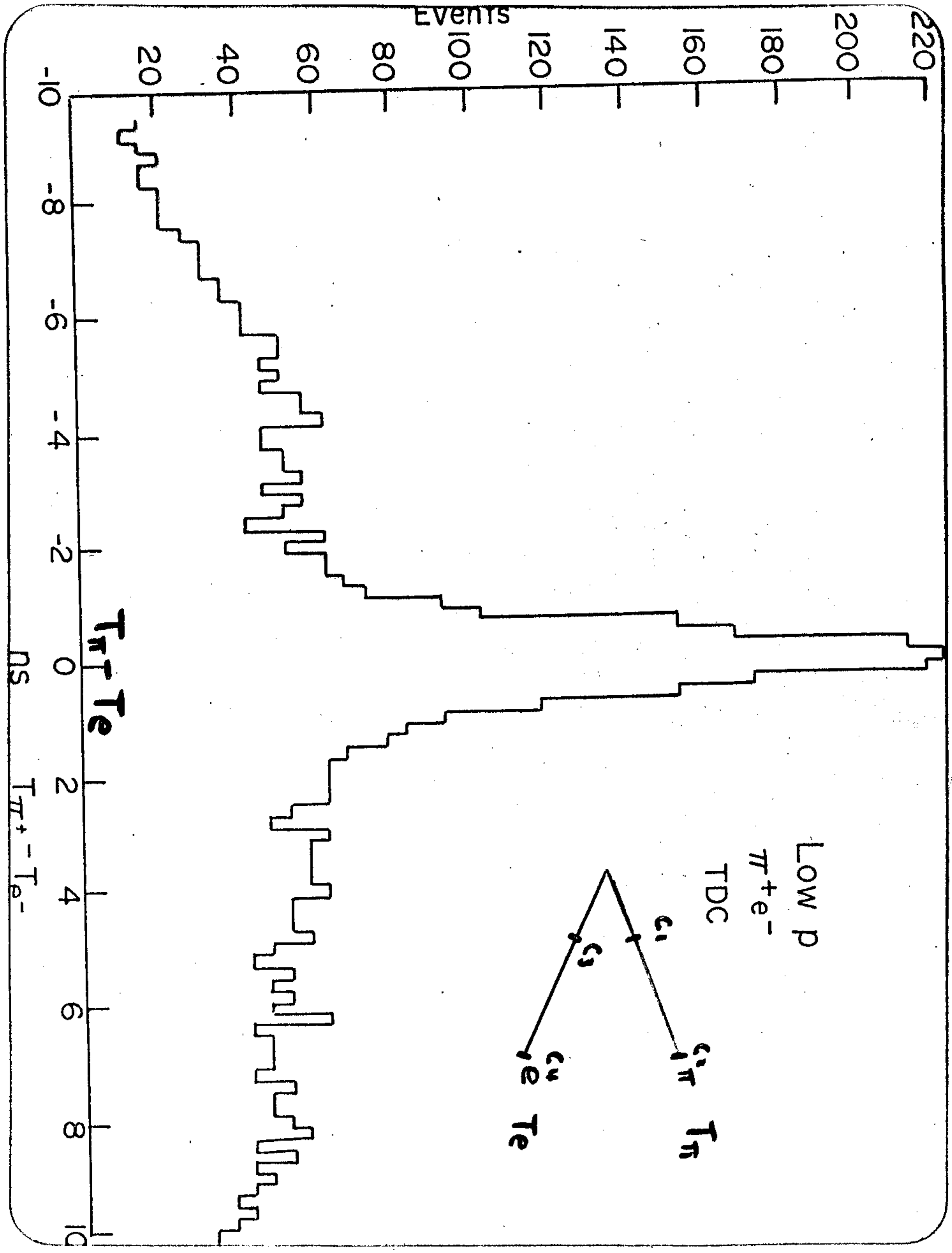
$D \hookrightarrow \mu h\nu$, $\bar{D} \hookrightarrow K\pi$

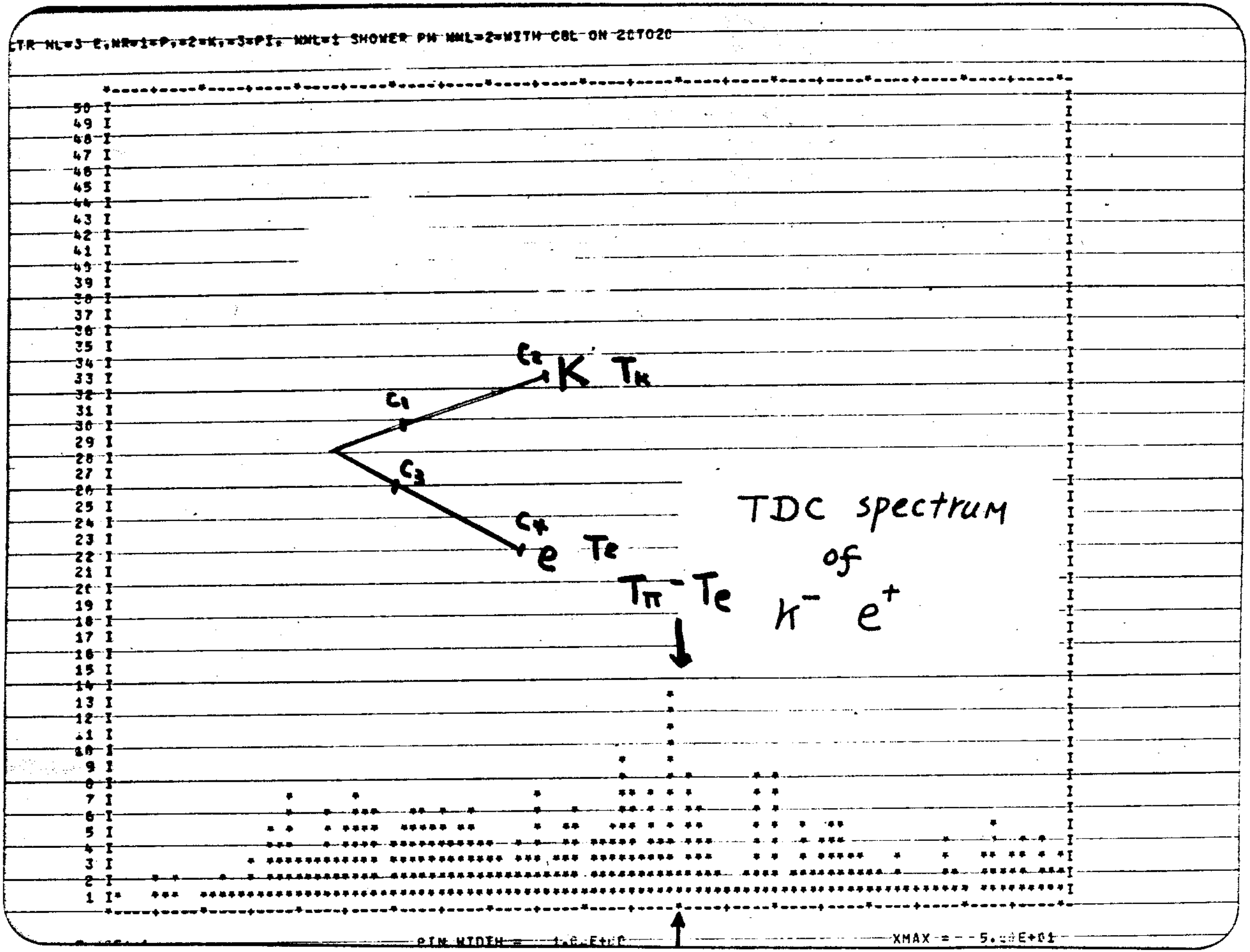




MIN = -5.[illegible]E+01 BIN WIDTH = 1.[illegible]E+[illegible] INCH XMAX = 5.[illegible]E+[illegible]

AL = 3.835E+04 PLOTTED = 3.835E+04 UNDERFLOWS = [illegible] OVERFLOWS = [illegible]


Events
20
40
60
80
100
120
140
160
180
200
220
-10
-8
-6
-4
-2
0
2
4
6
8
10
ns
$T_{\pi^+} - T_{e^-}$
$T_\pi T_e$
Low p
π^+e^-
TDC
T_π
T_e


TDC spectrum of K⁻ e⁺
K T_K
e T_e
T_π - T_e
C1
C2
C3
C4
XMAX

In $3 < p < 6$ GeV

$$\begin{array}{l} \pi^- + e^+ \\ K^- + e^+ \\ \bar{p} + e^+ \end{array} \quad \text{pairs}$$

We found

$$\frac{\int_2^3 \frac{d\sigma}{dm}(K^-e^+)\,dm}{\int \frac{d\sigma}{dm}(\,)\,dm} = \frac{7}{1} \qquad \sim 10^{-33}\ \text{cm}^2$$

but experimental:

$$\frac{\sigma(K^-e^+)}{\sigma(\pi^-e^+)} < 1\%$$

$$\frac{\sigma(\bar{p}\,e^+)}{\sigma(\pi^-e^+)} < 1\%$$

[illegible] charm one expects $K^-e^+ > \pi^-e^+$

SEARCH for more new particles
if J is bound state of $(C\bar{C})$
then Charm Quark bound with
Ordinary Quark to form new states.

$D \rightarrow K^{+}\pi^{-}, Ke\nu, K\mu\nu$, etc.

$B \rightarrow p + K, pe\nu$, etc

This can be detected by

$$P + Be \rightarrow D + \bar{D} + X \qquad (1)$$

$$\quad \hookrightarrow \cancel{K\pi}, \cancel{e\mu\nu}, \ldots$$

or

$$P + Be \rightarrow \bar{D} + B + X \qquad (2)$$

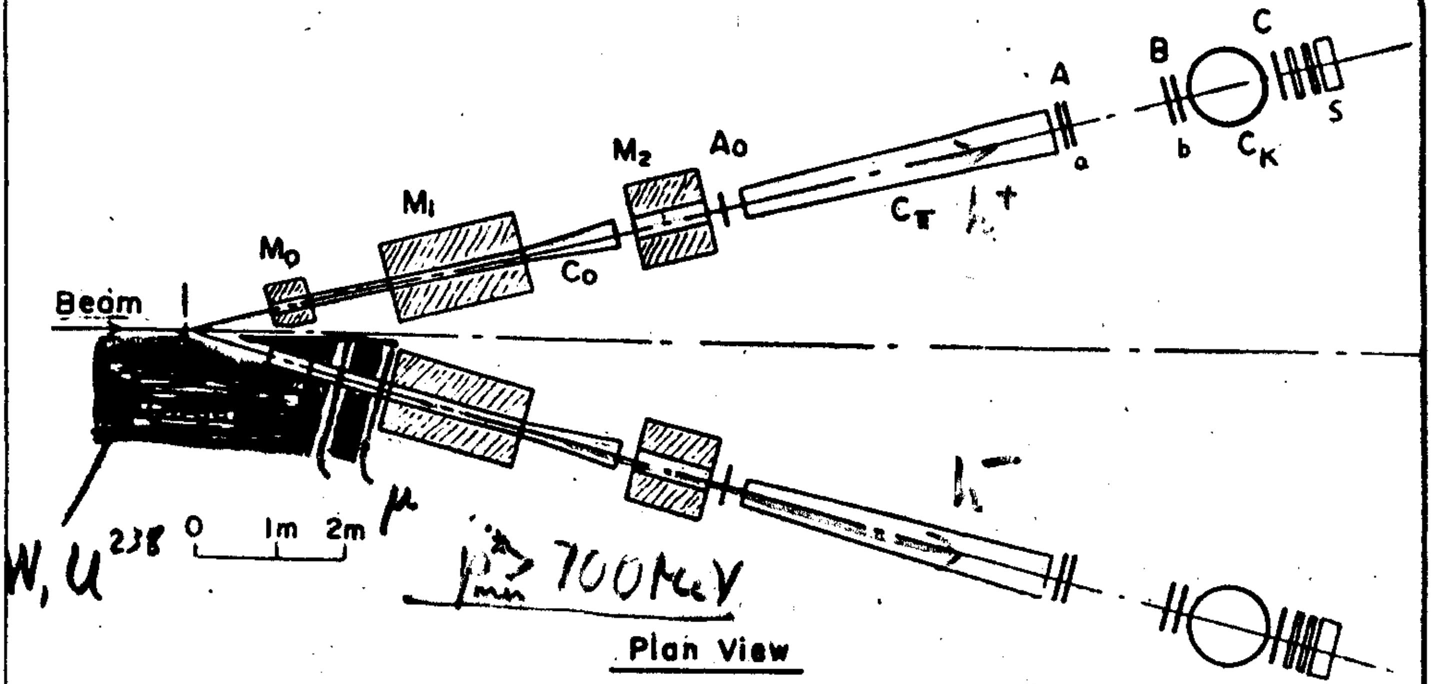
$$\quad \hookrightarrow \cancel{p + K}, \cancel{e\mu\nu} + \ldots$$

or

$$P + Be \rightarrow D + \bar{D} + X \qquad (3)$$

$$\quad \hookrightarrow \mu\nu \qquad \hookrightarrow K\pi$$

$\frac{\mu}{\pi} = 10^{-4}$ More Sensitive by $10^{3} - 10^{4}$



Plan View

M_1, M_2 — dipole magnets

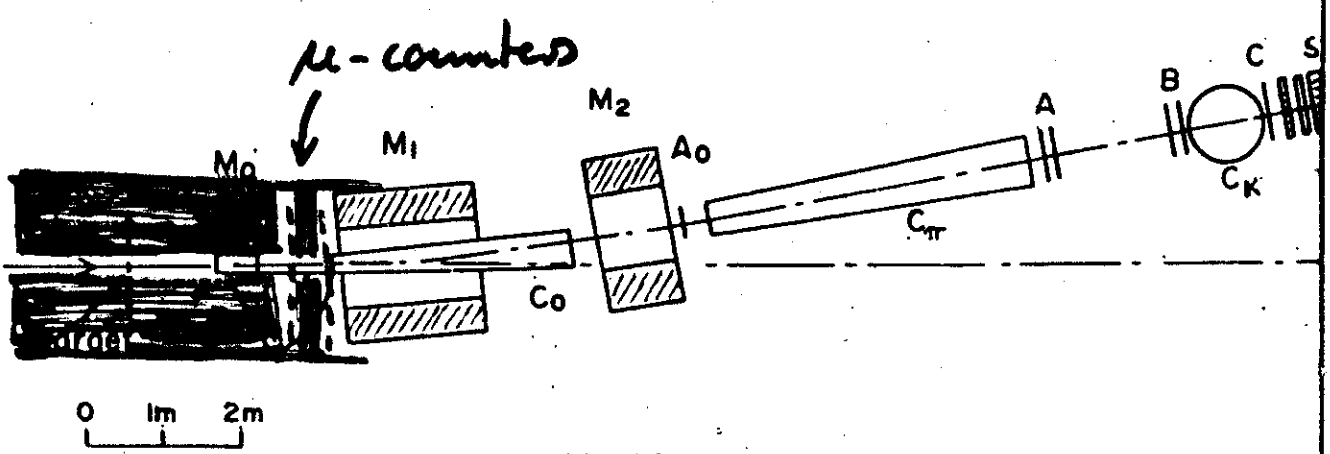
A, B, C— 8000 proportional wire chambers

a, b — 8x8 hodoscopes

S:— 3 banks of pb-glass shower counters

C_0, C_π, C_K — gas cerenkov counter

2sτ



Side View

$$\pi \to \mu\nu \quad < \quad 5 \cdot 10^{-4}$$

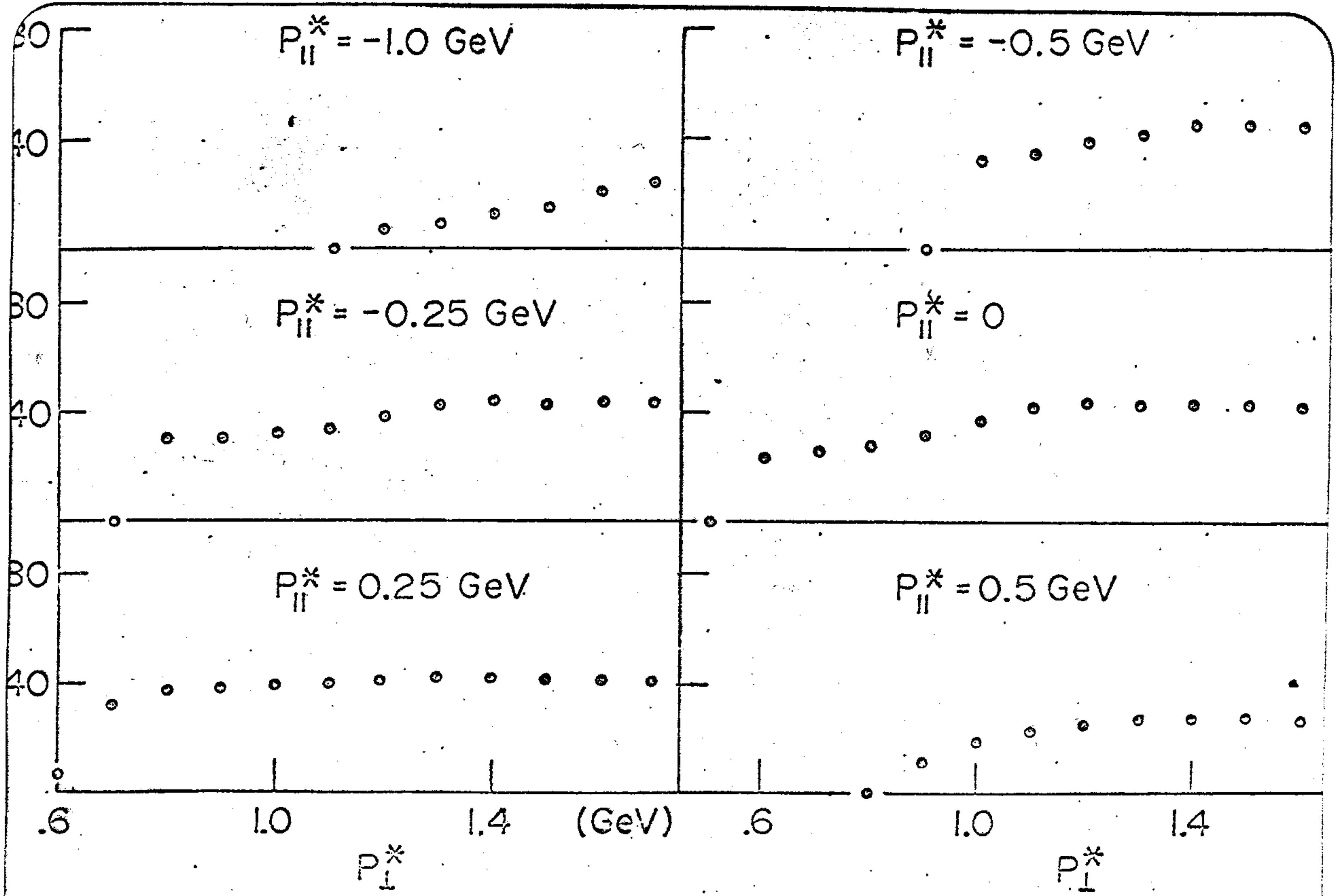
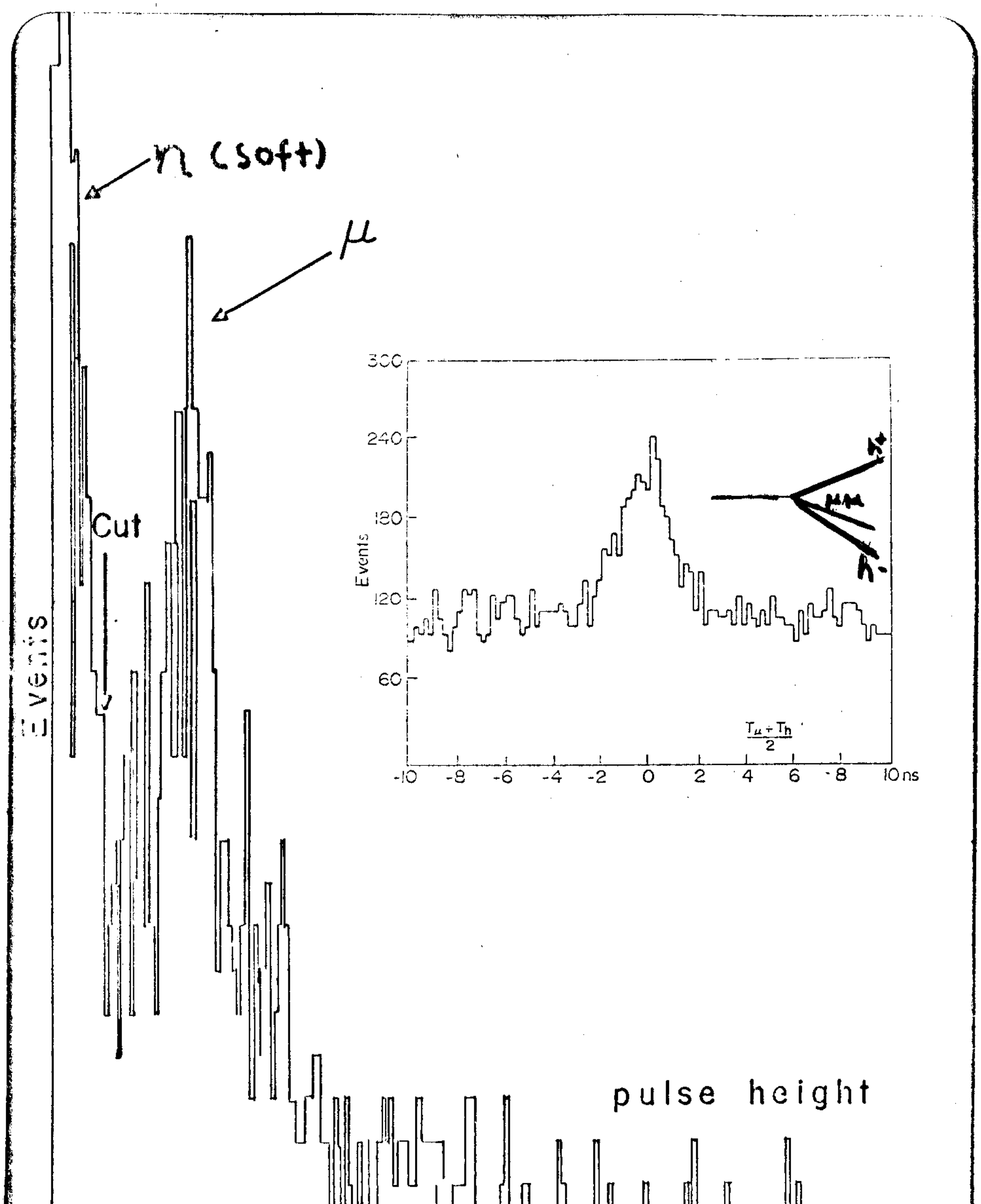
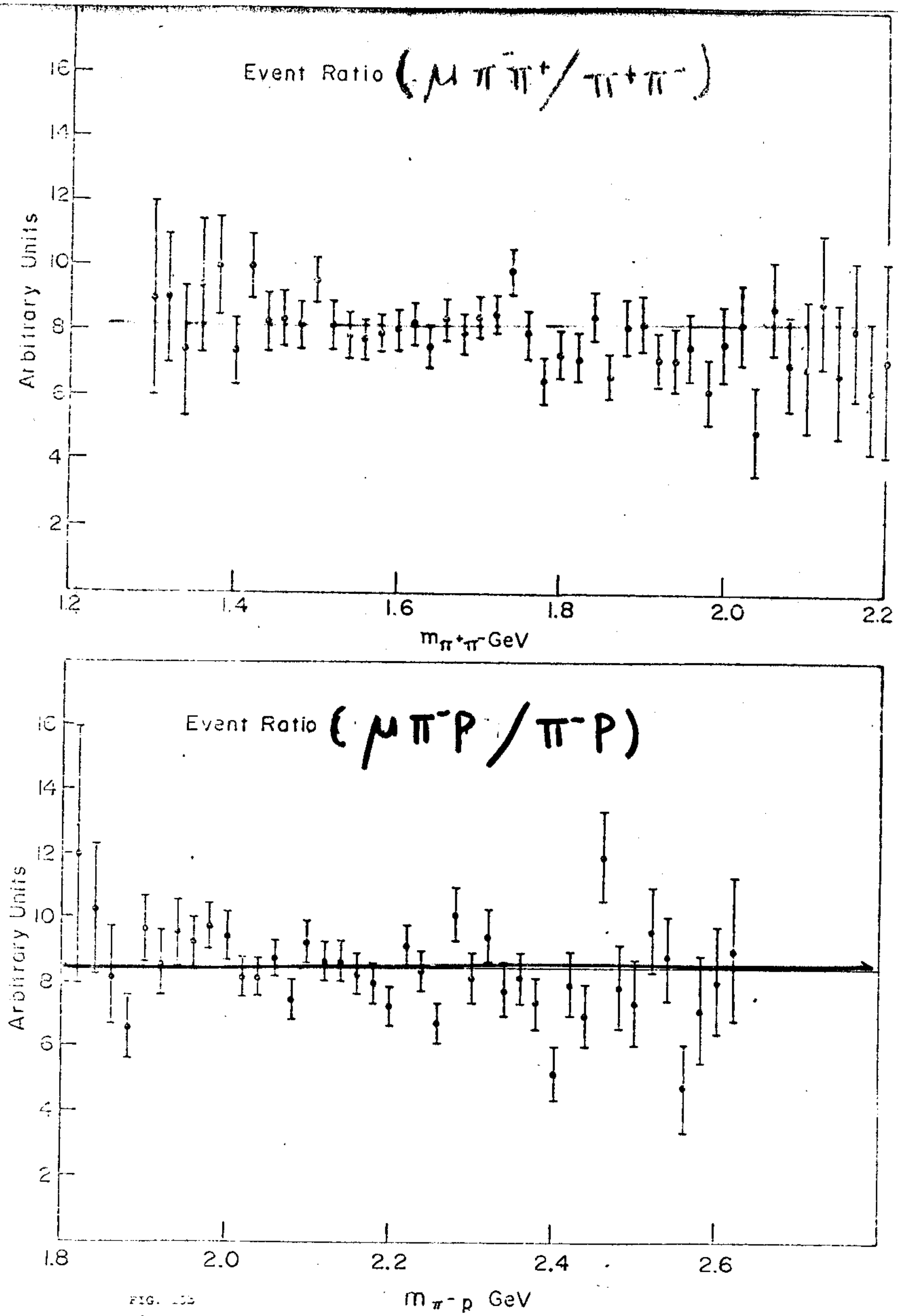


Fig. 15

ACCEPTANCE OF MUONS AS FUNCTION OF THE MUON MOMENTUM IN CM SYSTEM

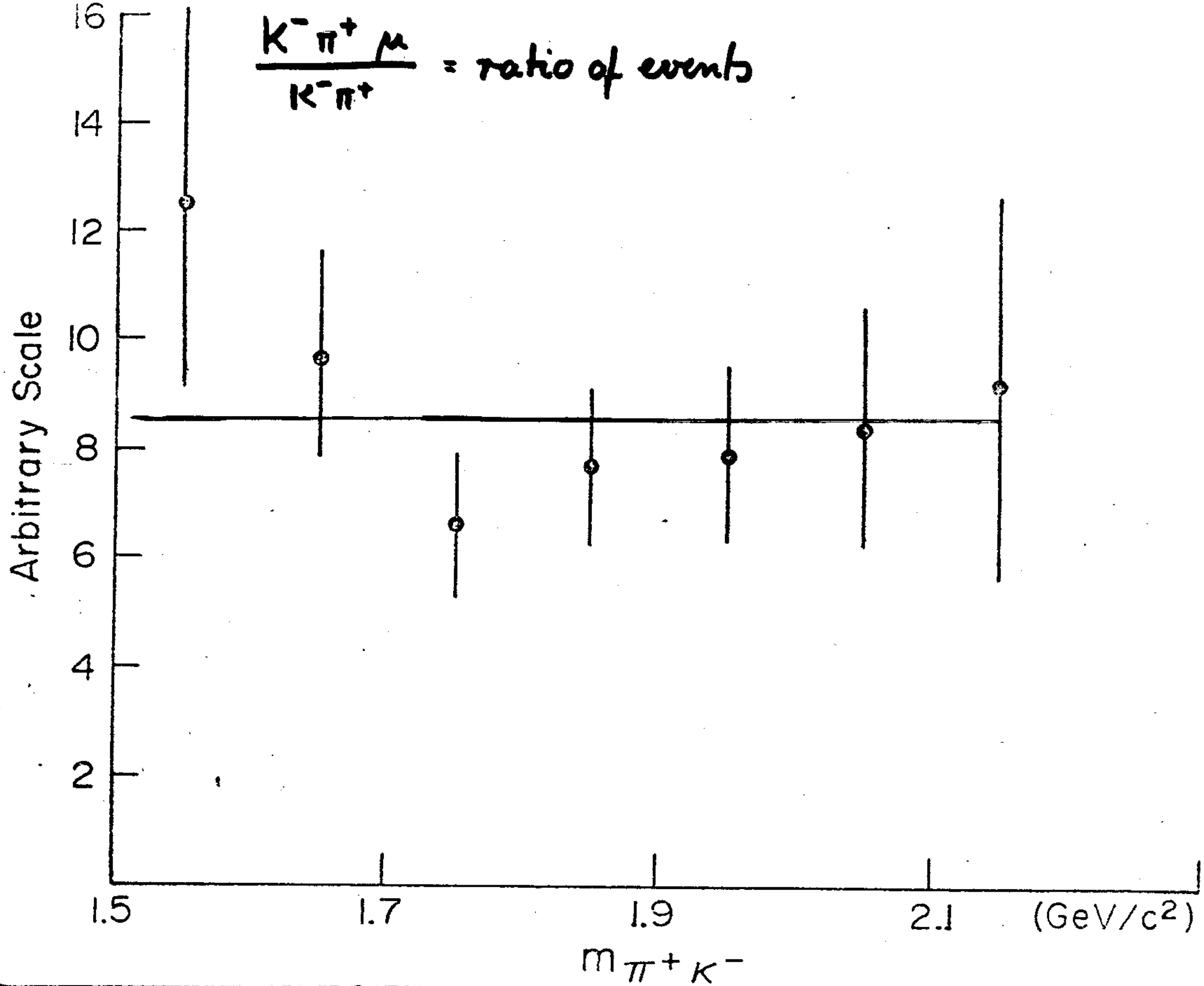


η (soft)
μ
Cut
Events
pulse height
300
240
180
120
60
Events
μμ
$\frac{T_\mu + T_h}{2}$
-10
-8
-6
-4
-2
0
2
4
6
8
10 ns



Event Ratio ($\mu\pi^-\pi^+/\pi^+\pi^-$)
Arbitrary Units
$m_{\pi^+\pi^-}$ GeV
Event Ratio ($\mu\pi^-p/\pi^-p$)
Arbitrary Units
m_{π^-p} GeV

FIG. [illegible]



$\frac{K^- \pi^+ \mu}{K^- \pi^+}$ = ratio of events
Arbitrary Scale
16
14
12
10
8
6
4
2
1.5
1.7
1.9
2.1
(GeV/c²)
$m_{\pi^+ K^-}$

① $p\,Be \to K^- \pi^+ \; X$

$$\left.\frac{d^3\sigma}{dm\,dp_\perp dx}\right| \simeq \underbrace{10^{-29}\frac{cm^2}{GeV^2\,nucl}}_{\text{measured}} \cdot \underbrace{e^{-2p_\perp} \cdot e^{-5x}}_{\text{assumed}} \quad \text{at } 2\,GeV$$

$\frac{d\sigma}{dm} = 10^{-30}\frac{cm^2}{GeV\,nucl}$ and $\sigma \approx 10^{-32}\,cm^2$ in one bin

statistics ~ 2000 ev $\to 5\sigma = 10\%$ $\longrightarrow$ $\underline{B_{K\pi}\sigma_D \leq 10^{-33}\,cm^2}$

② $p\,Be \to K^- e^+ \,(\nu X)$

Since 3 body "washed out"
8 "J" observed : $\rightarrow B_e\,\sigma_D \leq 10^{-33}\,cm^2$

important: $\frac{K^-e^+}{\pi^-e^+} = 1\% \neq \frac{D\to Ke\nu}{D\to\pi e\nu}$

③ $p\,Be \to K^-\pi^+\mu + X$

Observed: $K\pi\mu\,/\,K\pi \simeq 10^{-3}$
~5 events / 12.5 MeV at ~ 1.8 - 2.0 GeV

$$\frac{d\sigma}{dm} = 10^{-30}\frac{cm^2}{GeV\,nucl} \cdot 10^{-3} \cdot \underset{\mu\text{-acc}}{10^{-1}} \cdot \underset{5\sigma}{200\%} = 2\cdot 10^{-34}\frac{cm^2}{GeV}$$

If $0 \leq \eta \leq 1$ is the fraction of $D\bar{D}$-events $\to (K\pi)\mu$

$$\sigma \Longrightarrow \underline{\eta\cdot B_\mu \cdot B_{K\pi}\cdot\sigma_D \leq 2\cdot 10^{-34}\,cm^2}$$

From $\mu = 10^{-4}\pi$, $\sigma_\pi = 100\,mb$, we expect $10^{-4}\cdot 100\cdot 10^{-27} = 10^{-29}\,cm^2$
if all μ from D

$$\Longrightarrow \underline{\eta\cdot B_\mu \cdot B_{K\pi} \leq 2\cdot 10^{-5}}$$

ISR. Sens. at ω
P.G. Murphy

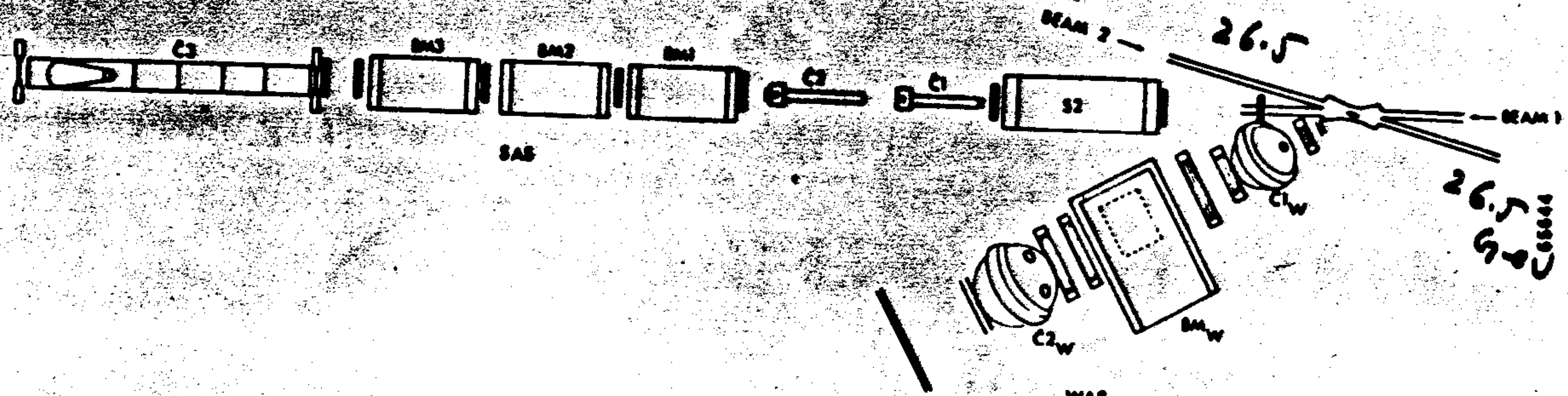
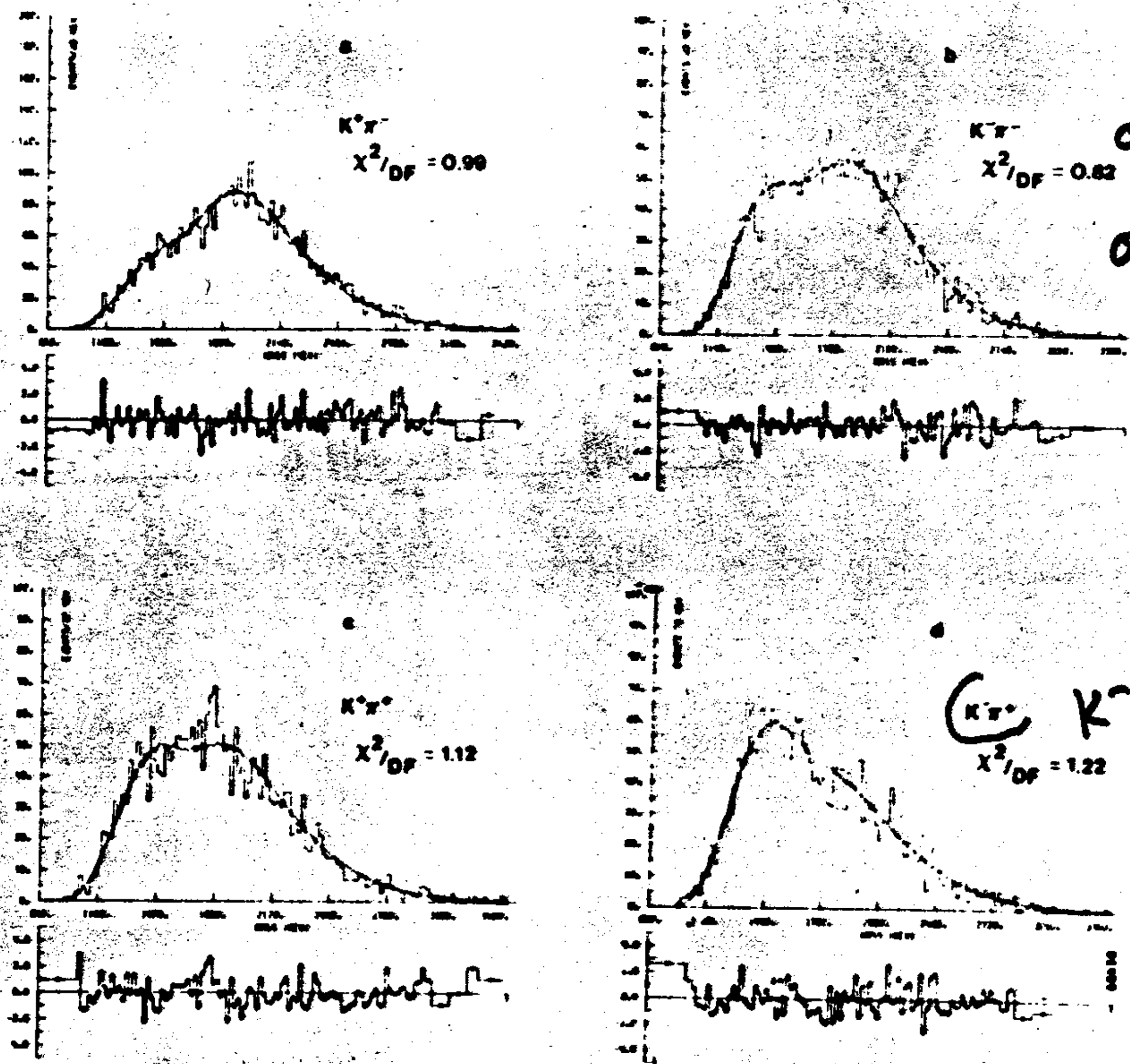


Fig.1

ISR results

P. G. Murphy



$0.15 \leq X < 0.6$

$0.3 < P_\perp \leq 2.0$

$S = 2760\ GeV^2$

2×10^5 events

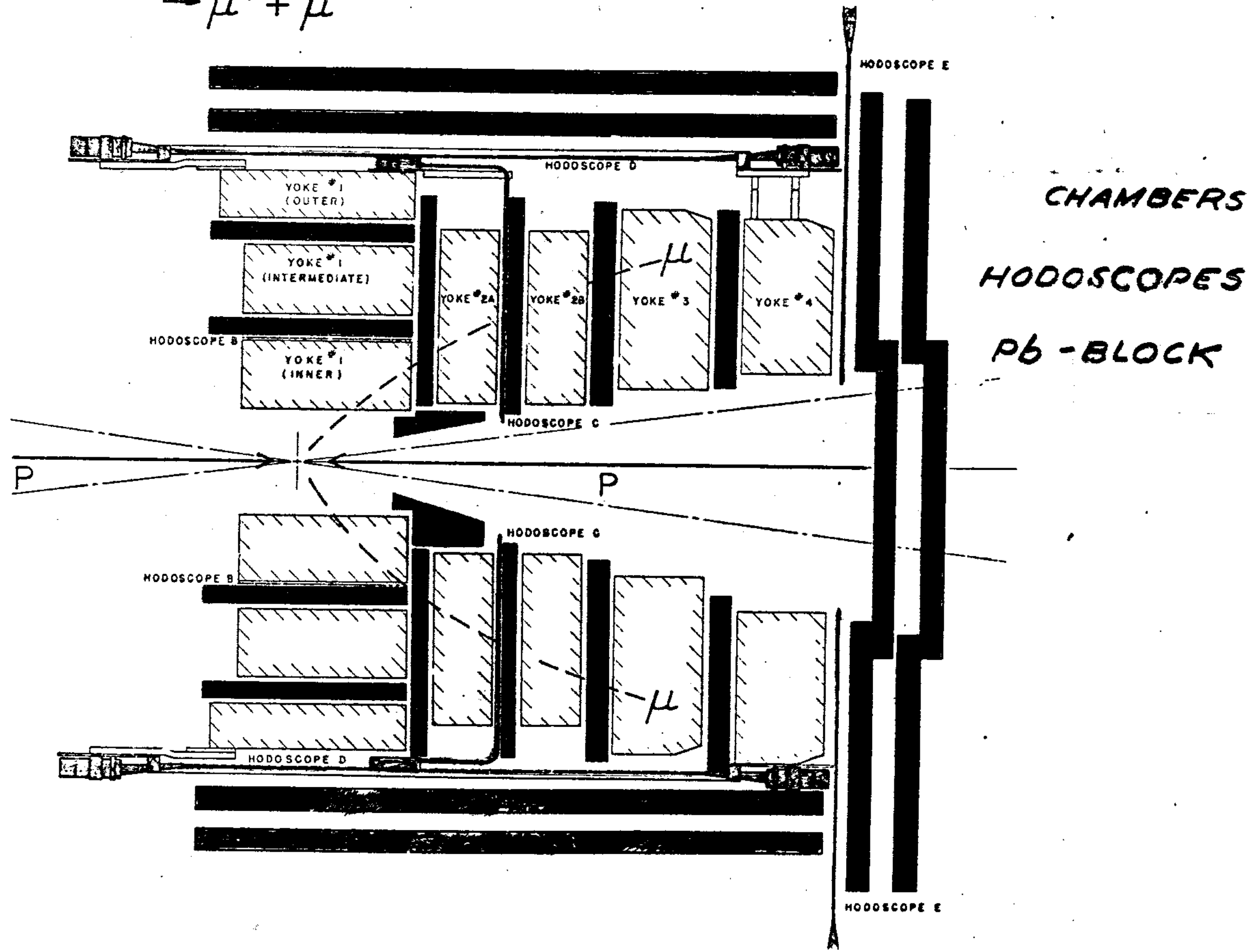
$K^-\pi^+$

Fig.2 a)

$P + P \rightarrow W + X$

$\quad \hookrightarrow \mu^+ + \mu^-$

$m_J < \text{Mass} < 60 \text{ BeV}$



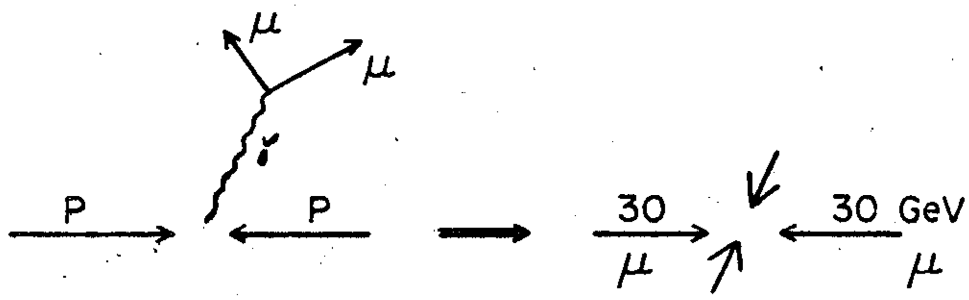
FRASCATI - GENOA - HARVARD - MIT

- NAPLES - PISA

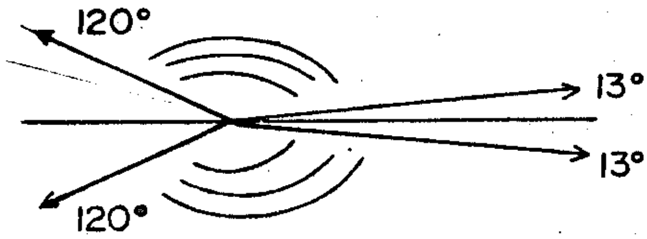
P.L. Braccini

Physics :

$P + P \longrightarrow \mu^+ \mu^- + X \qquad M_s < M_{\mu\mu} < 60$



Unique features ① Angle range $120° > \theta_\mu > 13°$



All other exp (eq. CCR)

$135° > \theta_e > 45°$

Neutrino data $\Longrightarrow M_J = 12$ GeV

$\theta_\mu \sim 20°$

② All detectors behind iron $\Longrightarrow 10^{32}\ cm^2/sec$

Sensitivity $\approx 10^{-38}\ cm^2$

③ A particle with Quantum number 0^+

$\rightarrow \mu^- \mu^+$ not to $e^- e^+$

④ Can study $\mu^- \mu^+$ hadron correlations

⑤ The most sensitive experiment to search for new particles before large $e^- e^+$ rings (50 on 50 are build)