IC/76/79
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 II

(Contributions)

MIRAMARE - TRIESTE
July 1976

e^+e^- PHYSICS AT SPEAR

R.F. Schwitters

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Schwitters

e^+e^- Physics at SPEAR
(West side)

I.) NON PARTICLES

II.) NEW PARTICLES

III.) NEWER PARTICLES

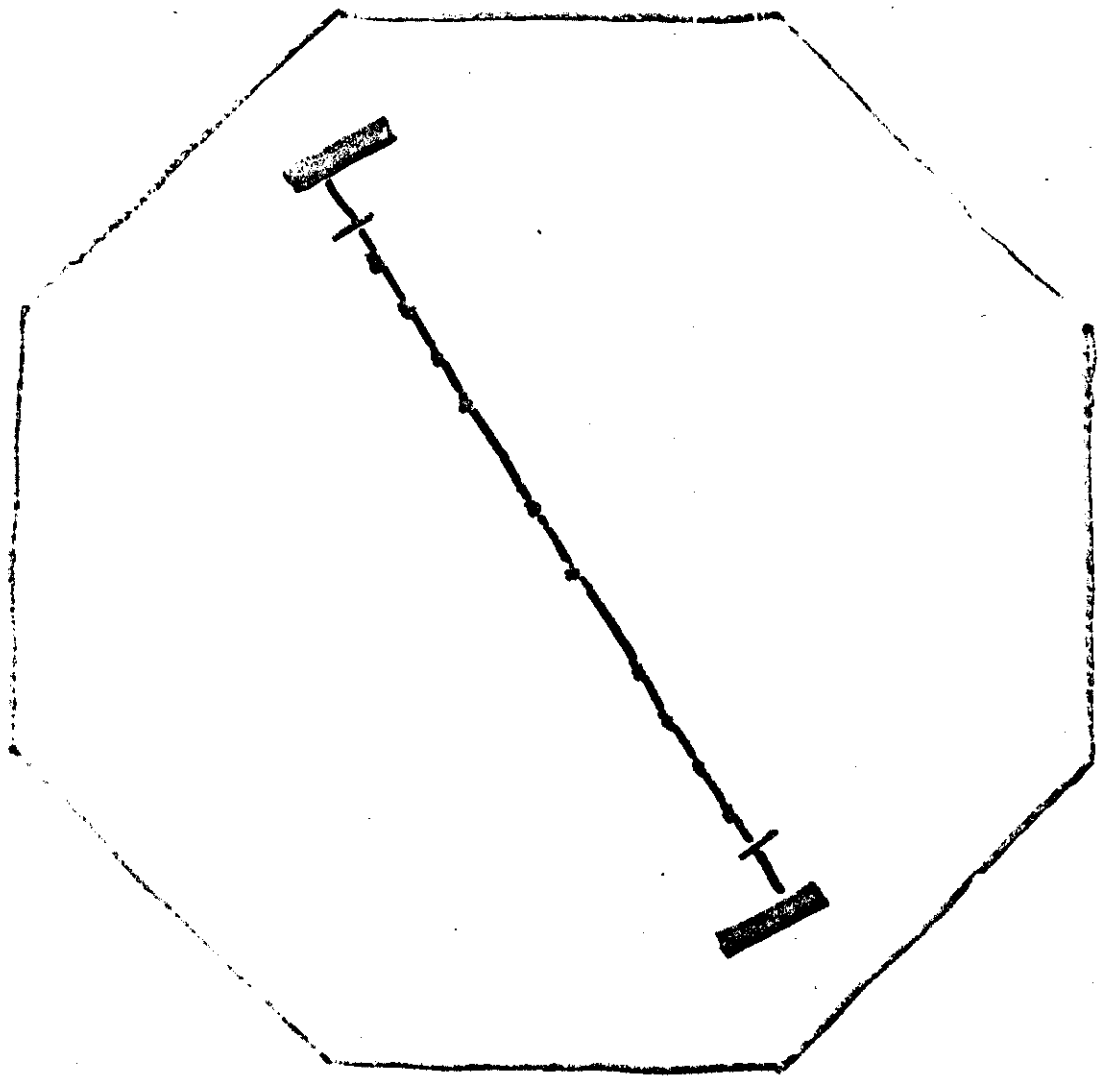
IV.) NEWEST PARTICLES

SLAC - LBL COLLABORATION
(CLASS of '76)

G.S. Abrams
M.S. Alam
A.M. Boyarski
M. Breidenbach
W.C. Carithers
W. Chinowsky
S.C. Cooper
R.G. DeVoe
J.M. Dorfan
G.J. Feldman
C.E. Friedberg
D. Fryberger
G. Goldhaber
G. Hanson
J. Jaros
A.D. Johnson
J.A. Kadyk
R.R. Larsen
D. Lüke
V. Lüth
H.L. Lynch
R.J. Madaras
C.C. Morehouse
H.K. Nguyen
J.M. Paterson
M.L. Perl
I. Peruzzi
M. Piccolo
F.M. Pierre
T.P. Pun
P. Rapidis
B. Richter
B. Sadoulet
R.H. Schindler
J. Siegrist
W. Tanenbaum
G.H. Trilling
F. Vannucci
J.S. Whitaker
J.E. Wiss

INTERNATIONAL CENTRE FOR THE NEW PARTICLE PHYSICS

LEPTON PAIRS



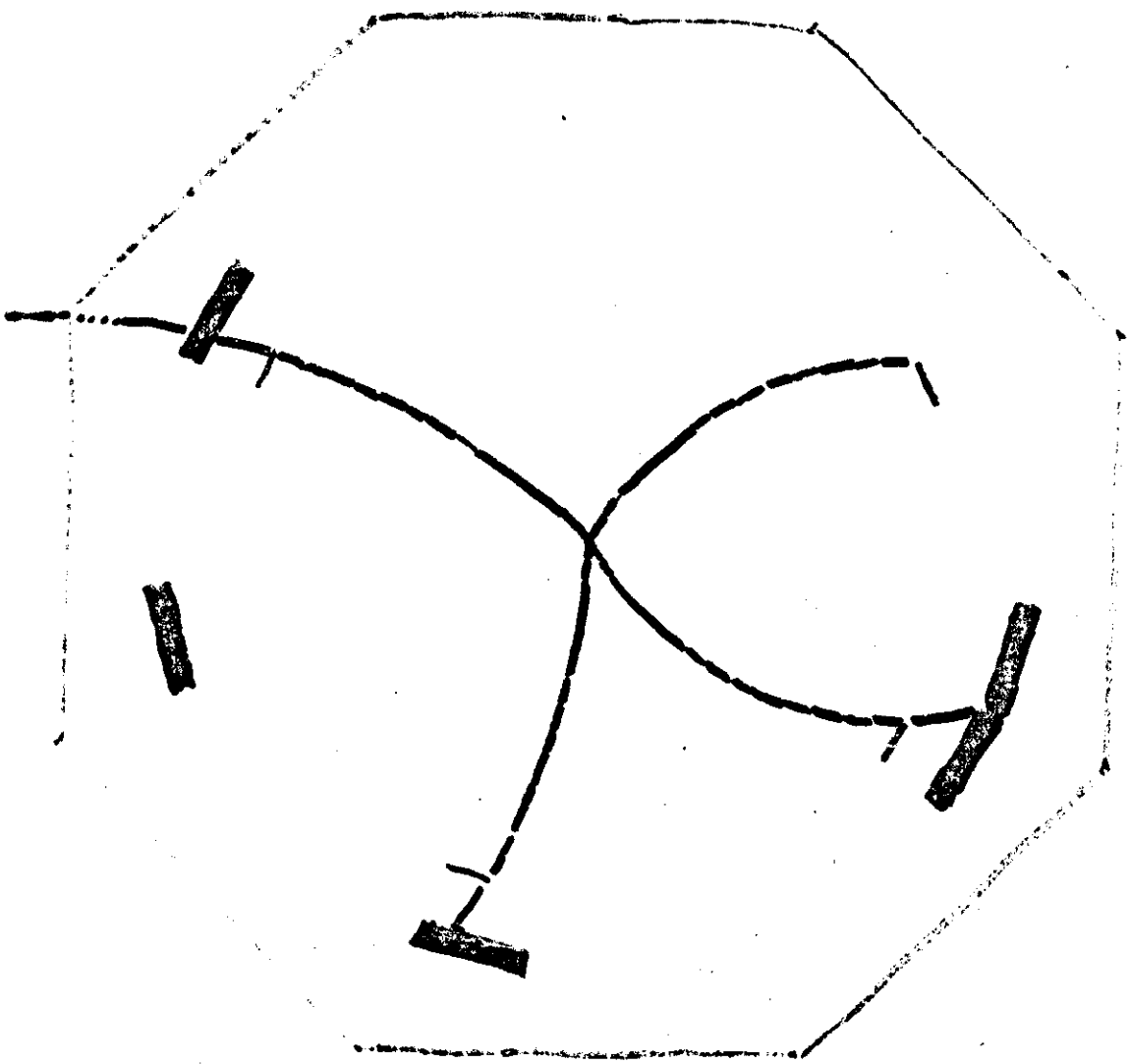
COLLINEARITY $\leq 10°$

MOMENTUM $> 1/2$ BEAM ENERGY

"ELECTRON" LARGE SHOWER COUNTER PH

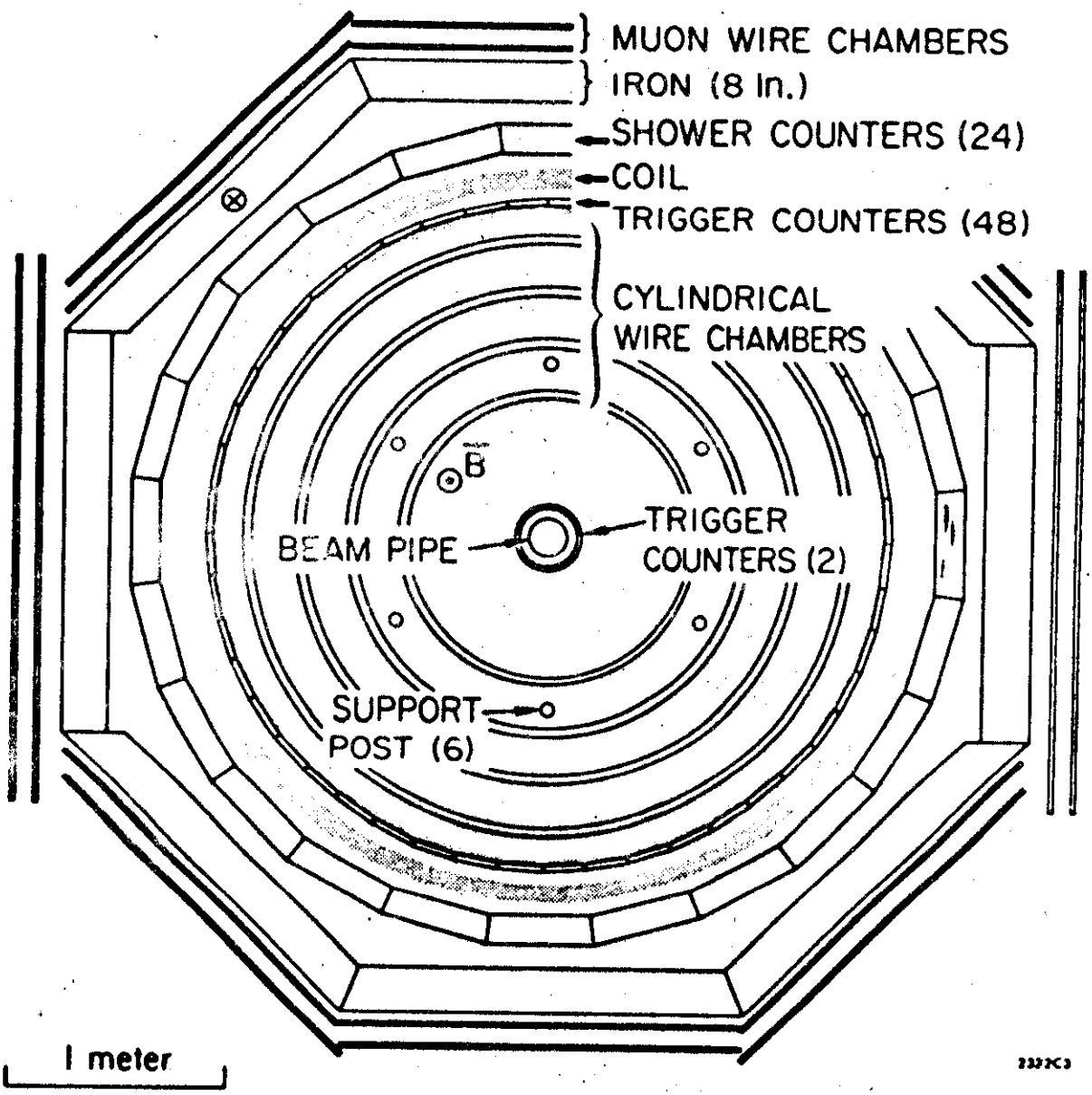
"MUON" SMALL " " "

MULTI-HADRON EVENT

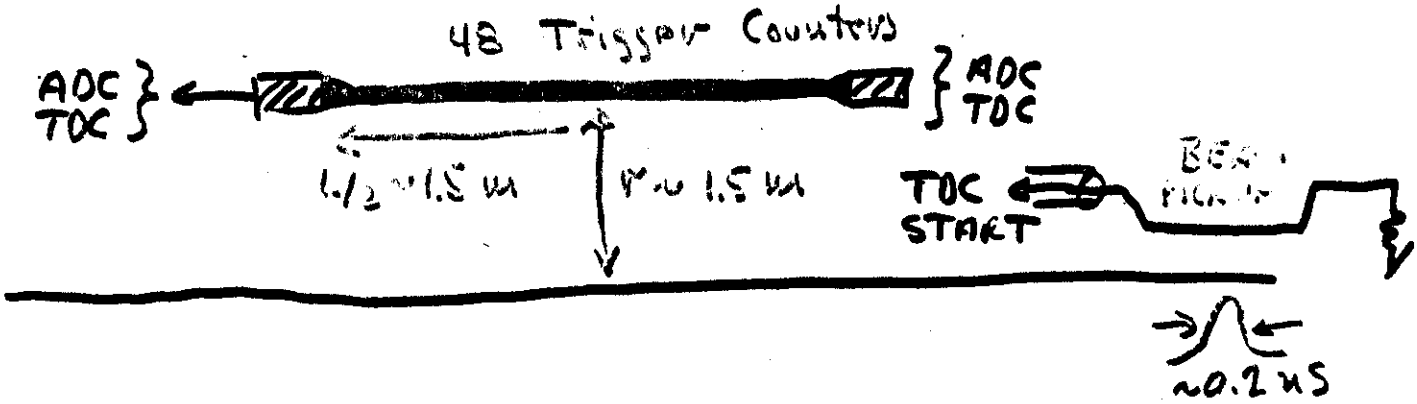


≥ 3 PRONGS

or 2 PRONGS WITH $p >$ [illegible] GeV/c
and $\theta_{opl} > 20°$

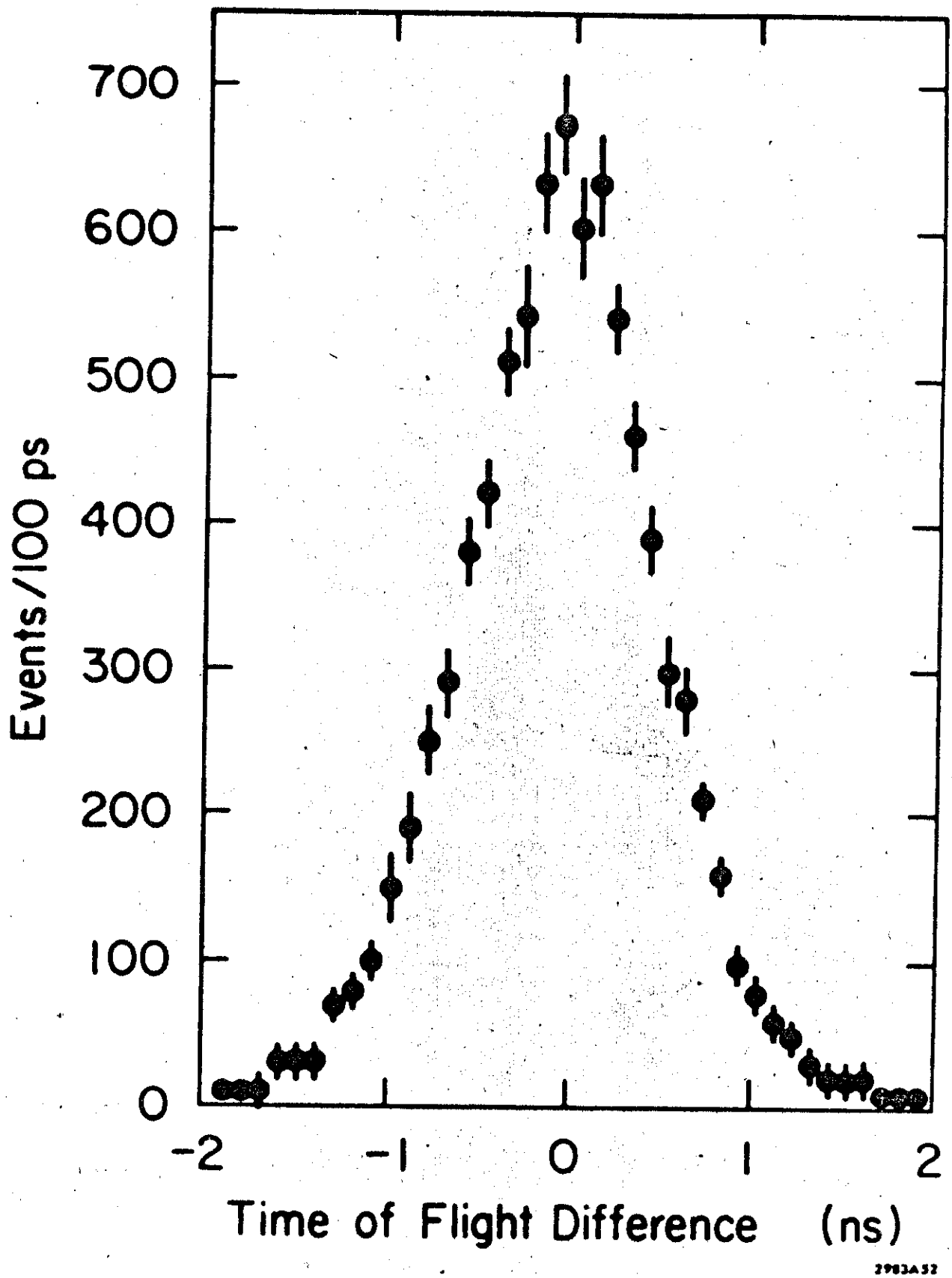

MUON WIRE CHAMBERS
IRON (8 In.)
SHOWER COUNTERS (24)
COIL
TRIGGER COUNTERS (48)
CYLINDRICAL
WIRE CHAMBERS
B
BEAM PIPE
TRIGGER
COUNTERS (2)
SUPPORT
POST (6)
1 meter

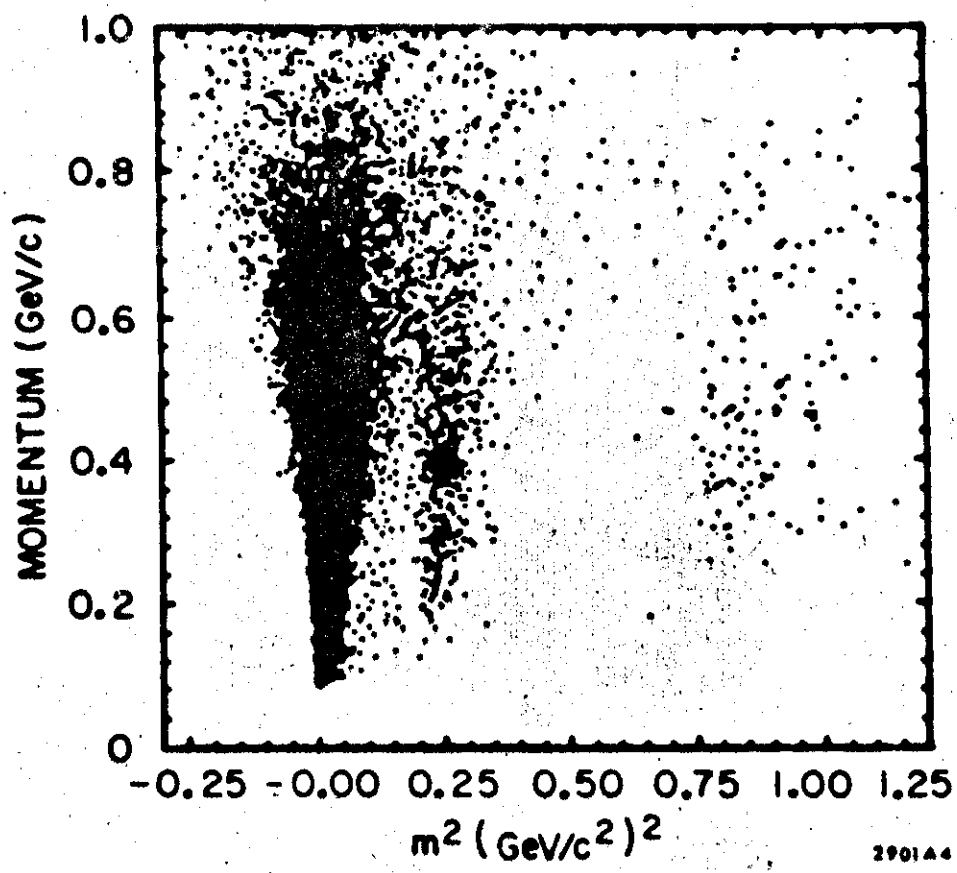
Time of Flight Analysis

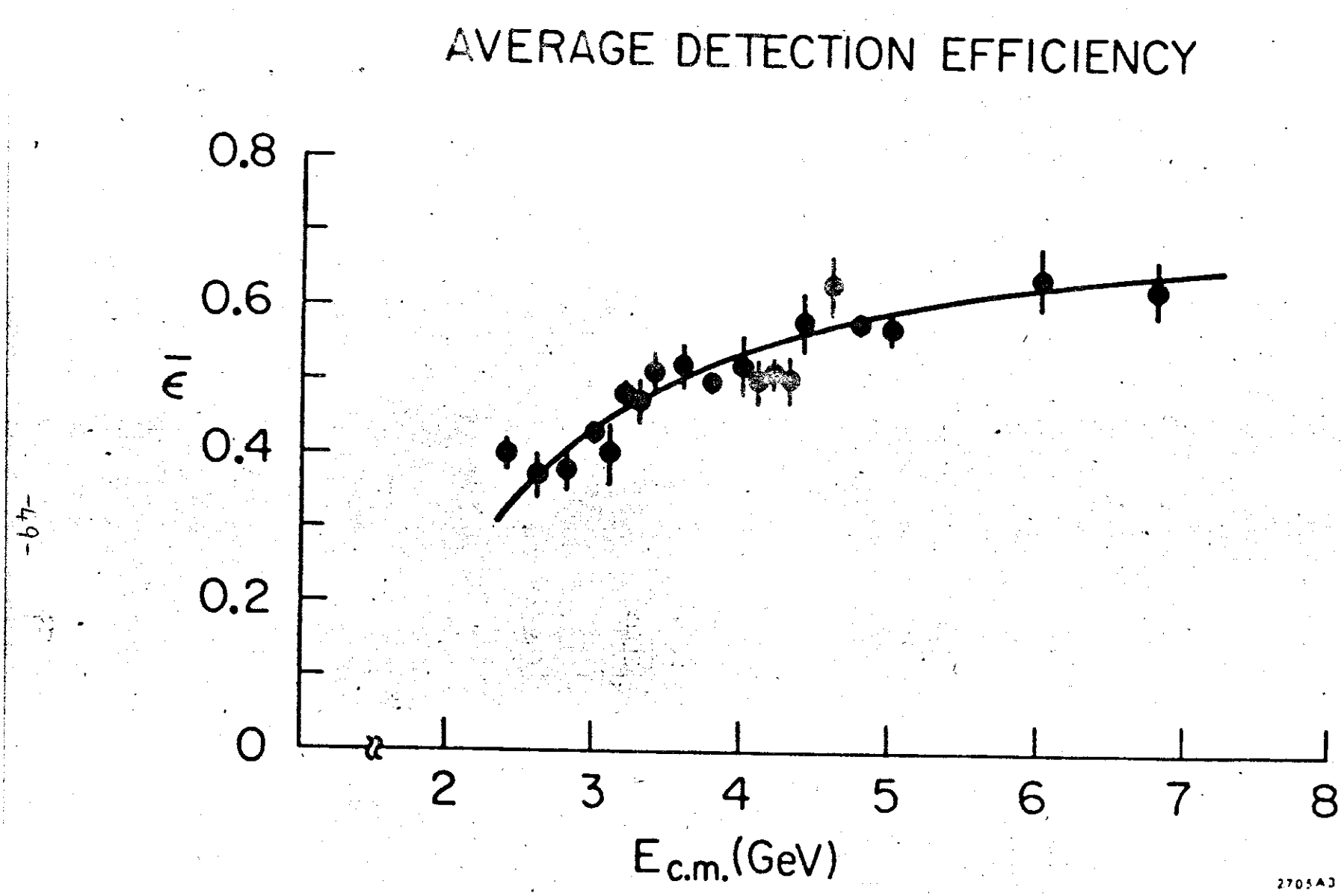


$\sigma \sim$ 350 - 400 ps $\Rightarrow$ $\frac{\Delta t_{\pi K}}{\sigma} \simeq$ 1 - 1½ s.d. @ 1 GeV/c

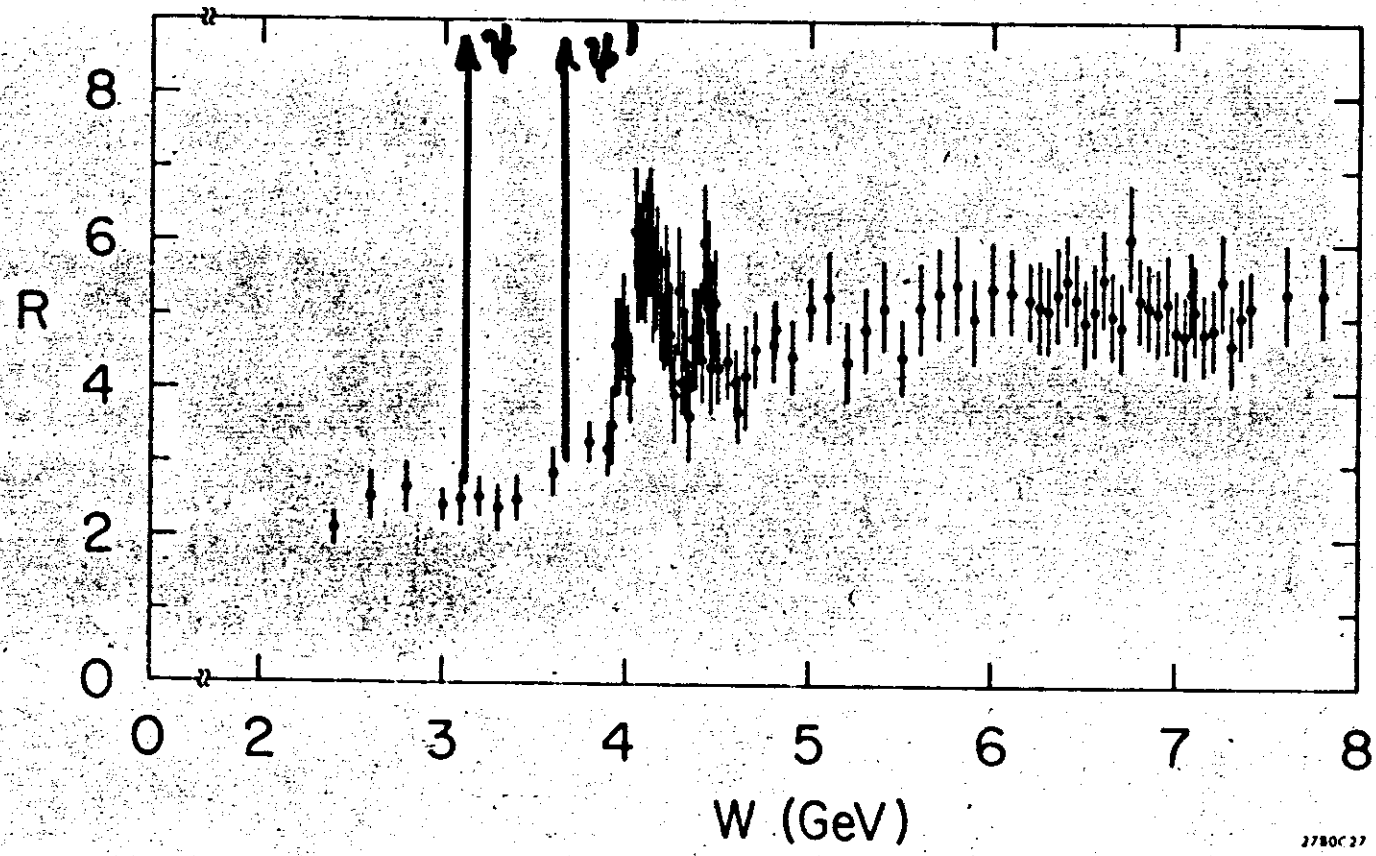
$\frac{\Delta t_{\pi K}}{\sigma} \geq$ 3 s.d. @ 0.5 GeV/c

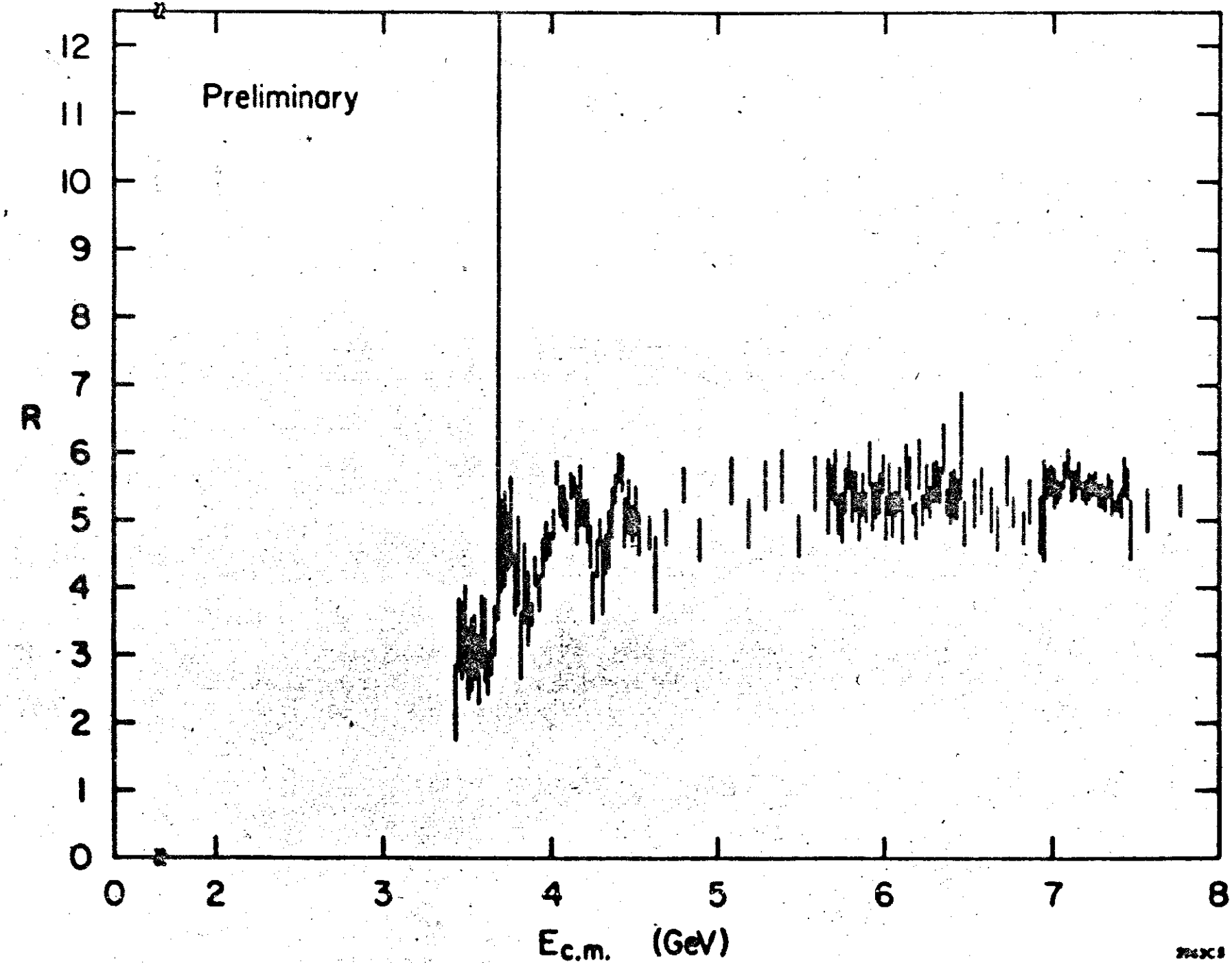

700
600
500
400
300
200
100
0
Events/100 ps
-2
-1
0
1
2
Time of Flight Difference (ns)
2983A52

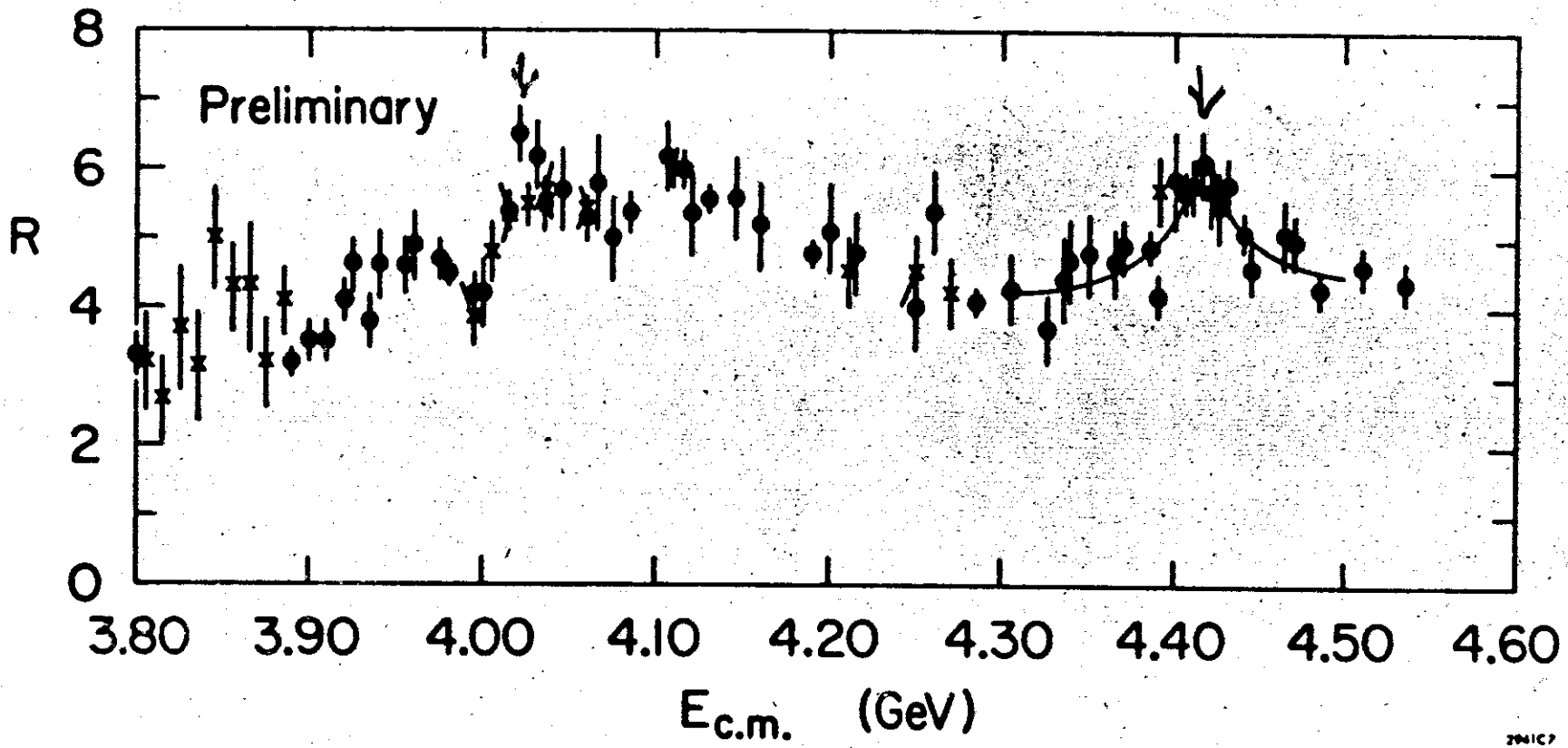

1.0
0.8
0.6
0.4
0.2
0
MOMENTUM (GeV/c)
-0.25 -0.00 0.25 0.50 0.75 1.00 1.25
m² (GeV/c²)²
2901A4

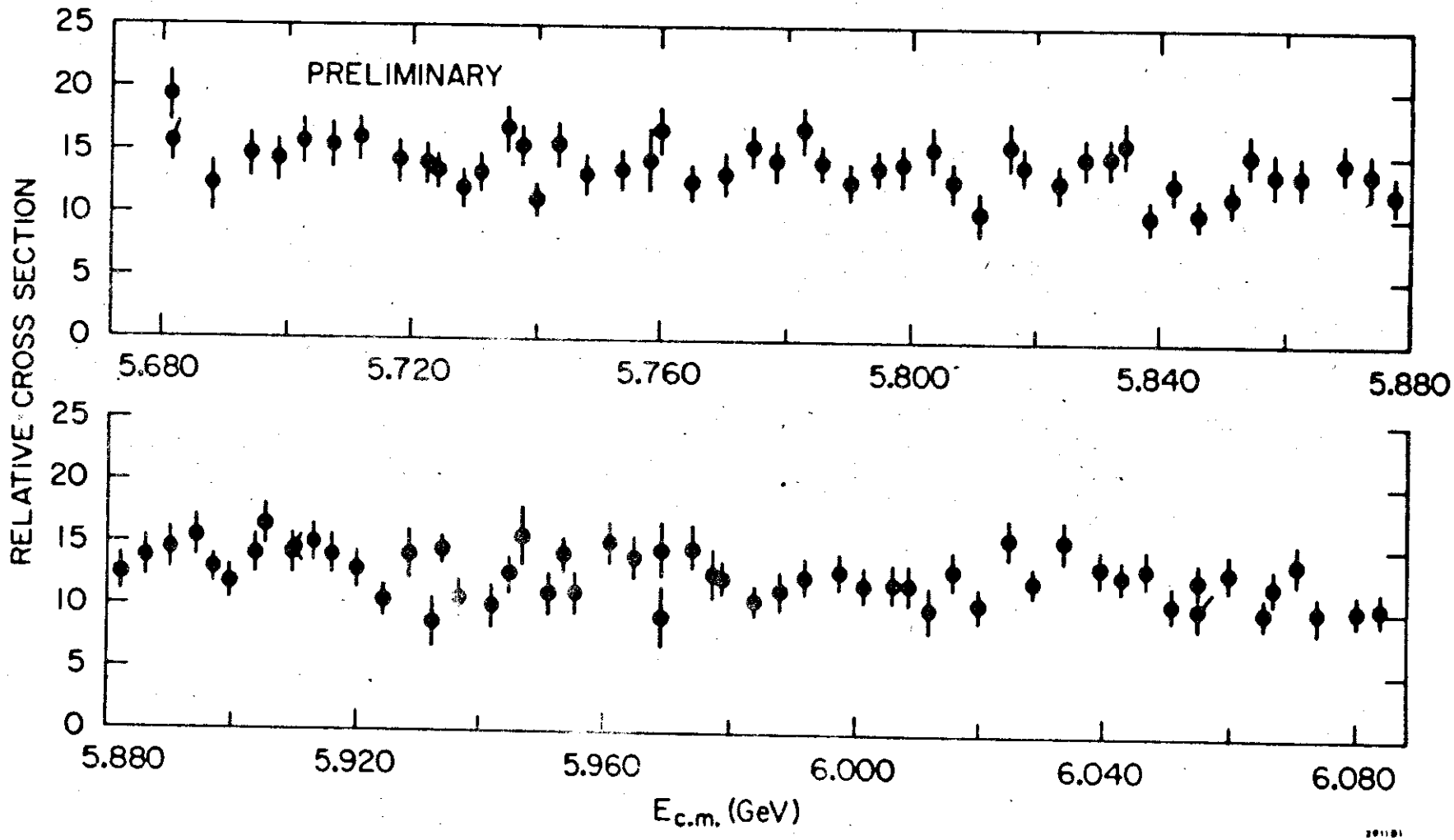

AVERAGE DETECTION EFFICIENCY
0.8
0.6
0.4
0.2
0
$\bar{\epsilon}$
2
3
4
5
6
7
8
$E_{c.m.}$(GeV)
2705A3

$$R = \frac{\sigma_t}{\sigma_{\mu\mu}}$$




Preliminary
R
0
1
2
3
4
5
6
7
8
9
10
11
12
0
2
3
4
5
6
7
8
$E_{c.m.}$ (GeV)


Preliminary
R
8
6
4
2
0
3.80
3.90
4.00
4.10
4.20
4.30
4.40
4.50
4.60
$E_{c.m.}$ (GeV)


PRELIMINARY
RELATIVE CROSS SECTION
25
20
15
10
5
0
5.680
5.720
5.760
5.800
5.840
5.880
5.880
5.920
5.960
6.000
6.040
6.080
$E_{c.m.}$ (GeV)

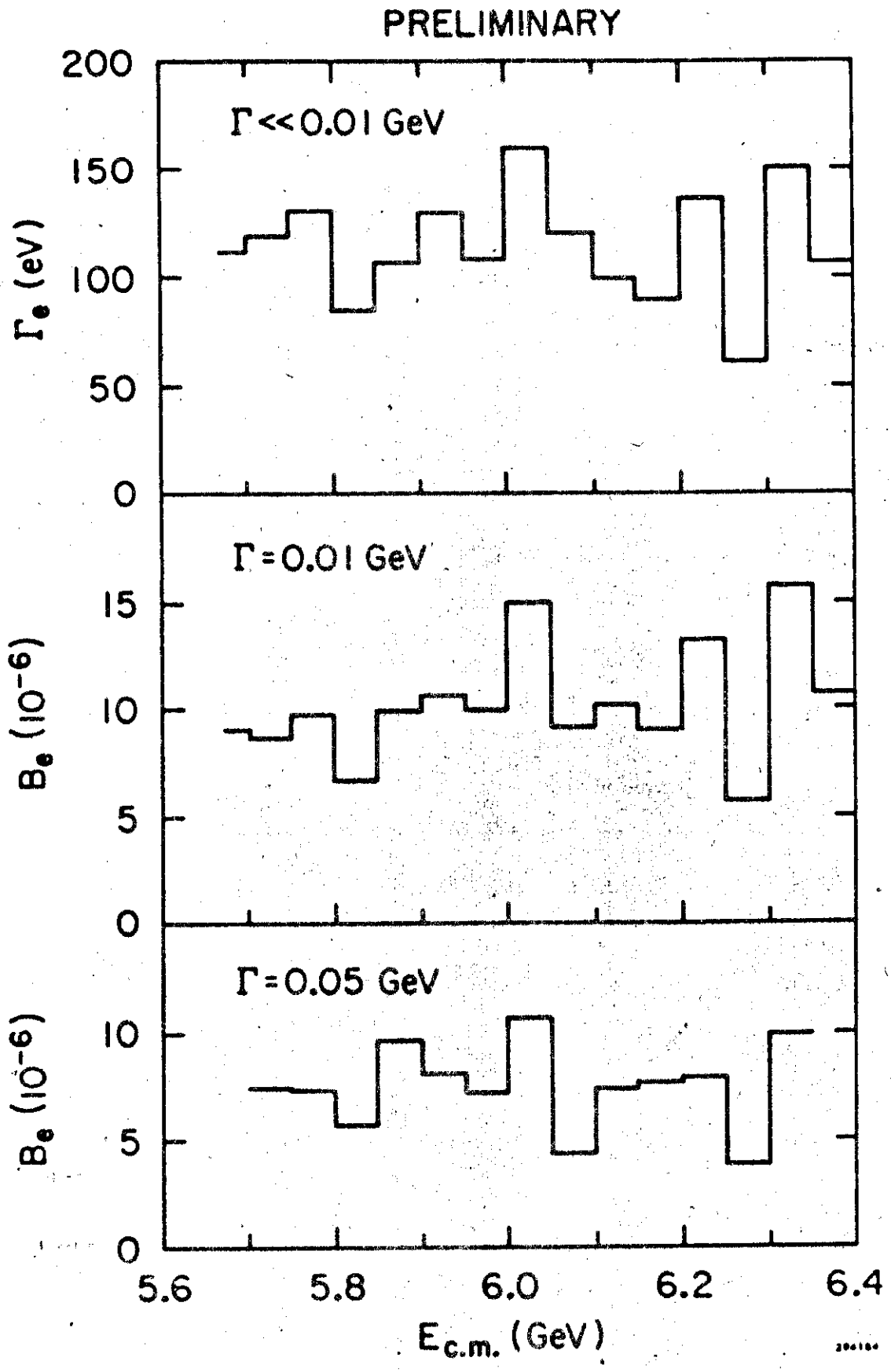
FOR NARROW RESONANCES ($\Gamma \lesssim 10$ MeV),

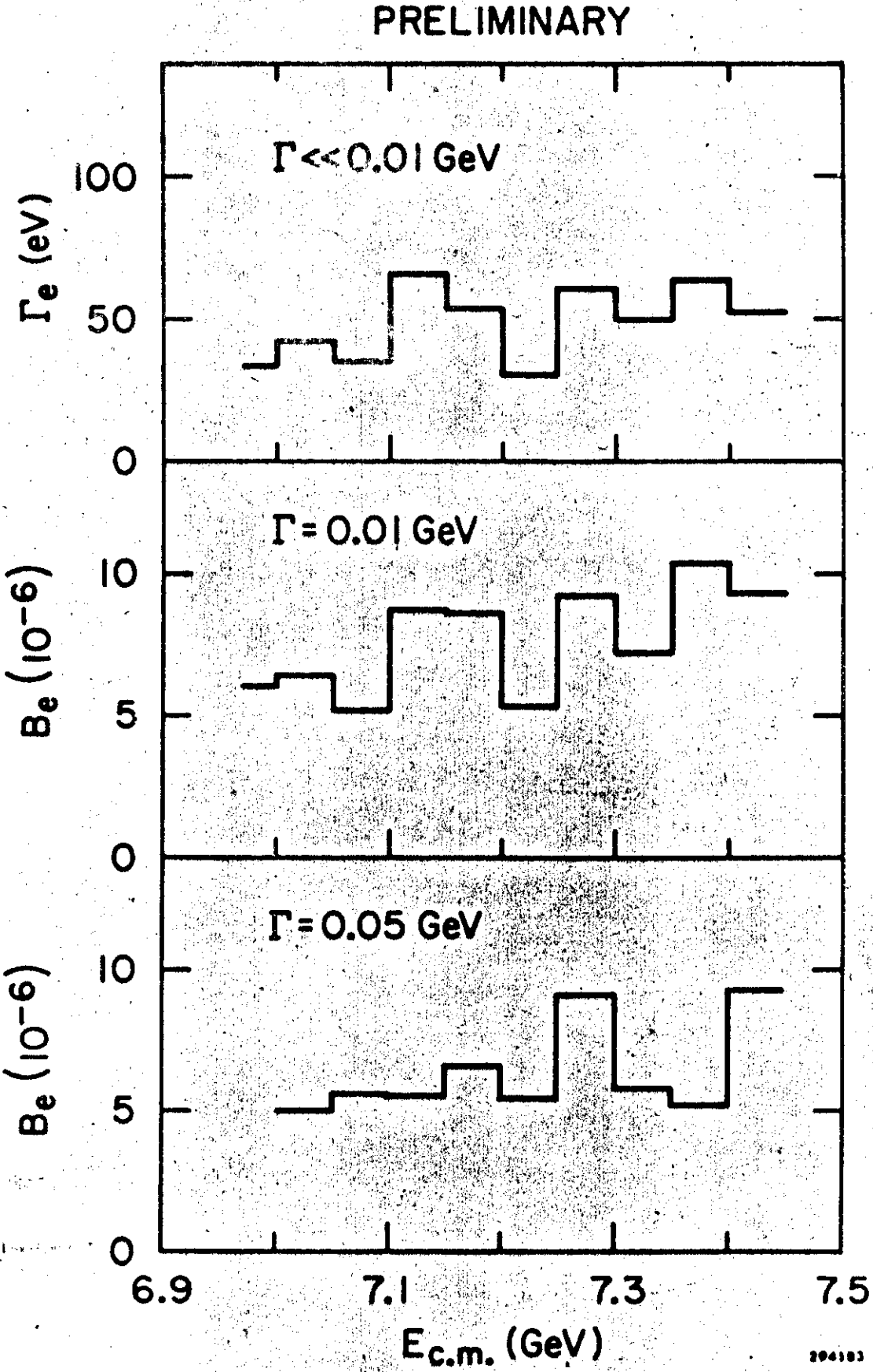
WE MEASURE:

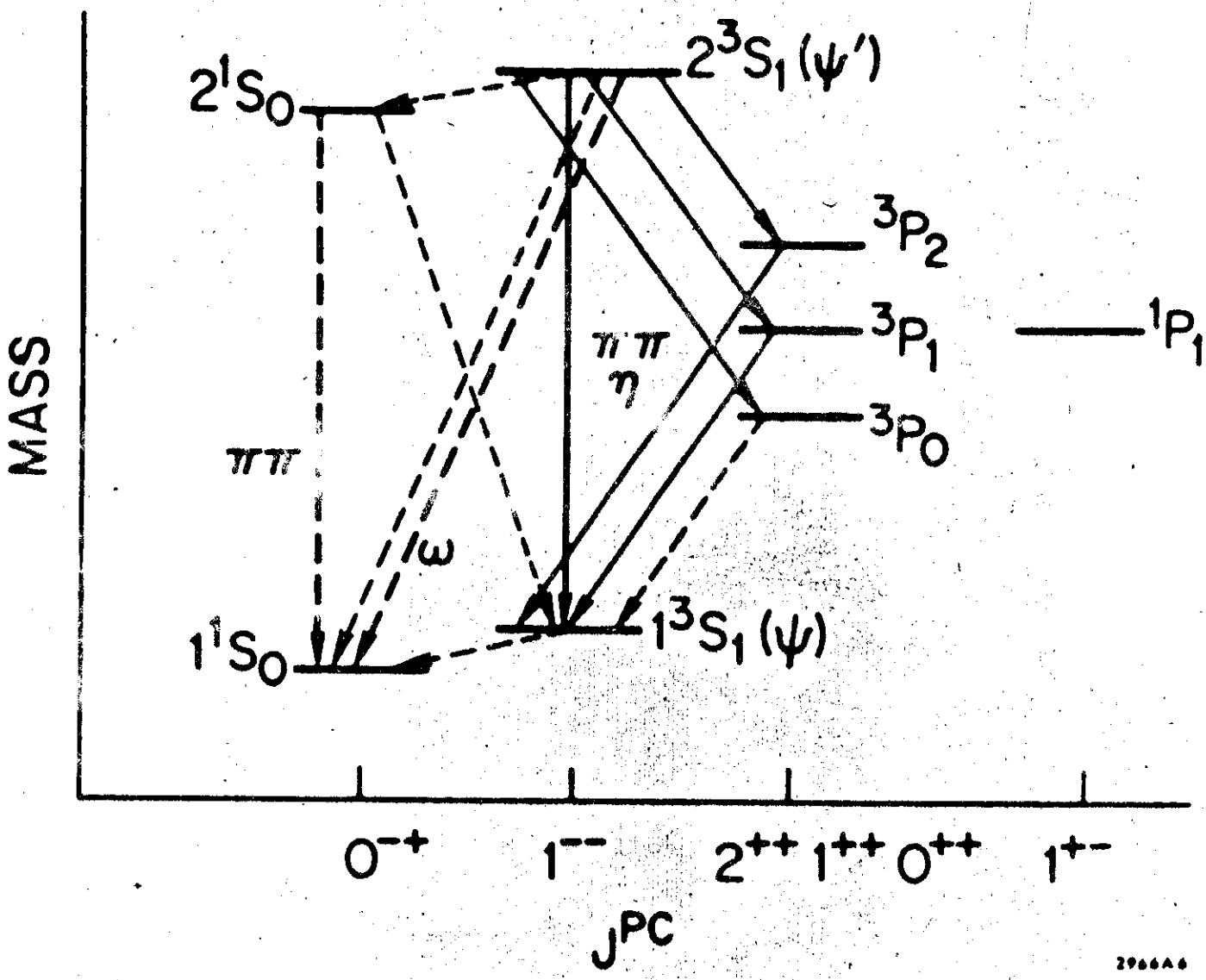
$$\int R \, dW = \frac{9\pi}{2\alpha^2} \Gamma_{ee} \qquad (J = 1)$$

FOR WIDE RESONANCES,

$$\Delta R = \frac{9}{\alpha^2} B_{ee}$$


PRELIMINARY
200
150
100
50
0
Γ<<0.01 GeV
Γe (eV)
Γ=0.01 GeV
15
10
5
0
Be (10-6)
Γ=0.05 GeV
10
5
0
Be (10-6)
5.6
5.8
6.0
6.2
6.4
Ec.m. (GeV)


PRELIMINARY
Γ≪0.01 GeV
Γ = 0.01 GeV
Γ = 0.05 GeV
Γe (eV)
Be (10−6)
Be (10−6)
100
50
0
10
5
0
10
5
0
6.9
7.1
7.3
7.5
Ec.m. (GeV)
204183

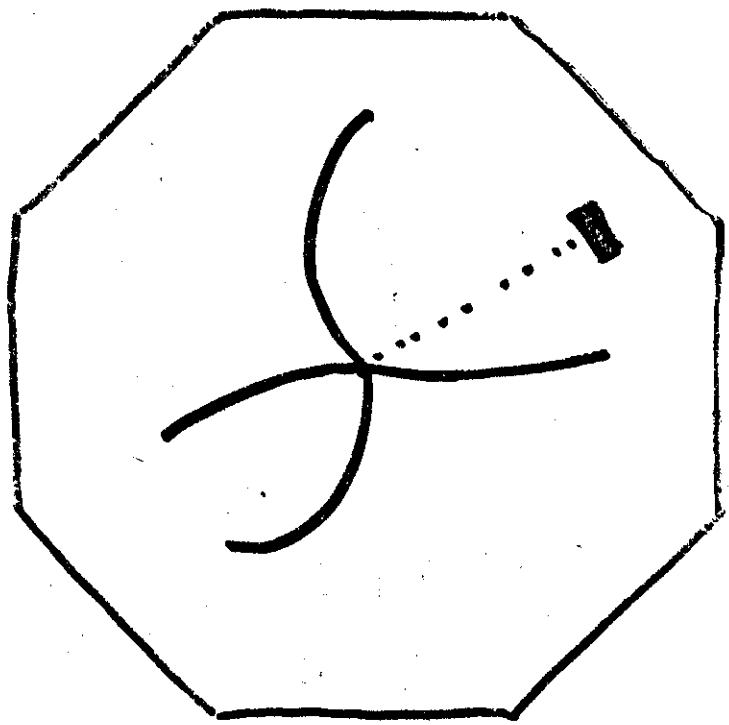

MASS
2^1S_0
$2^3S_1(\psi')$
$^3P_2$
$^3P_1$
$^1P_1$
$^3P_0$
$\pi\pi$
η
$\pi\pi$
ω
1^1S_0
$1^3S_1(\psi)$
0^{-+}
1^{--}
2^{++}
1^{++}
0^{++}
1^{+-}
J^{PC}
2966A6

GAMMA RAY ANALYSIS

1.) $\Sigma Q = 0$

$\Sigma \vec{P} \neq 0$

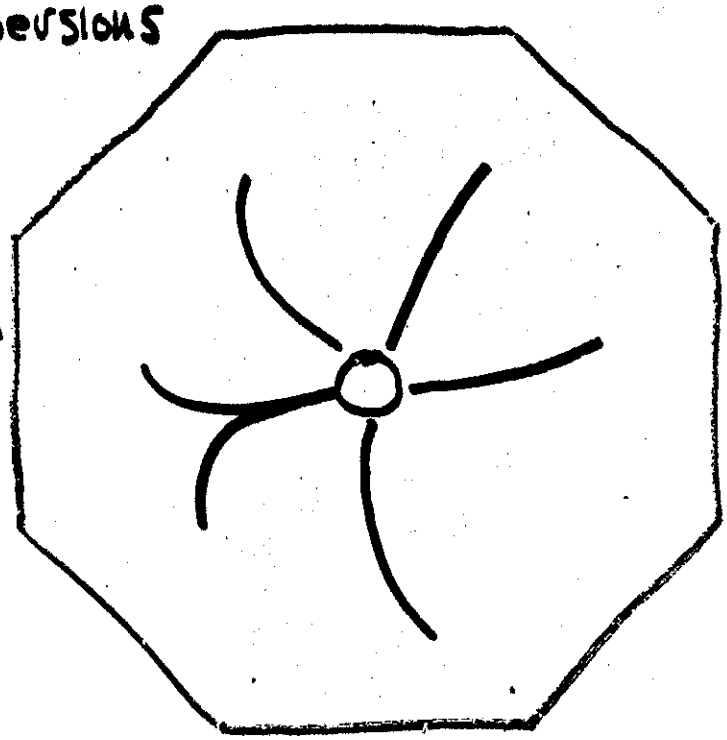
$MM^2 \simeq 0$



2.) Pair Conversions

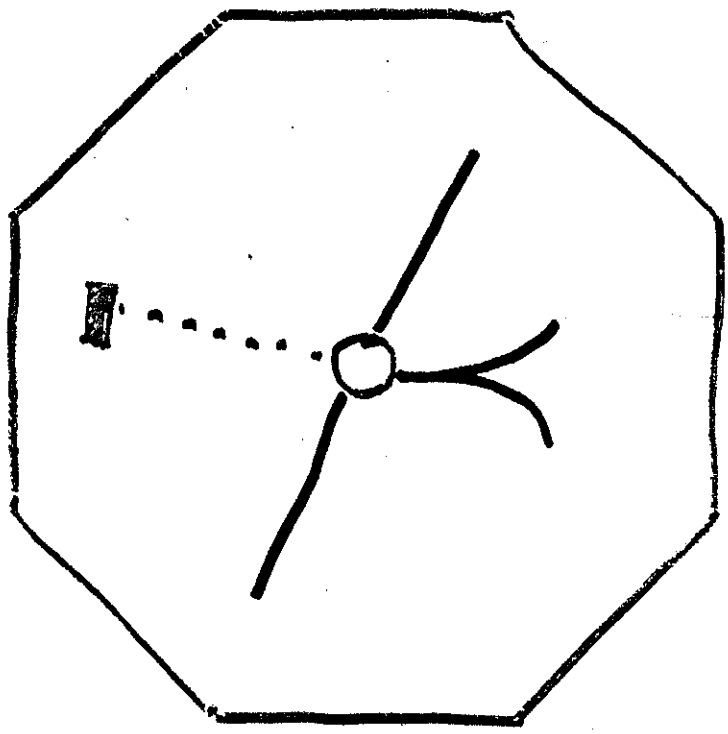
$t \approx 5\% X_0$

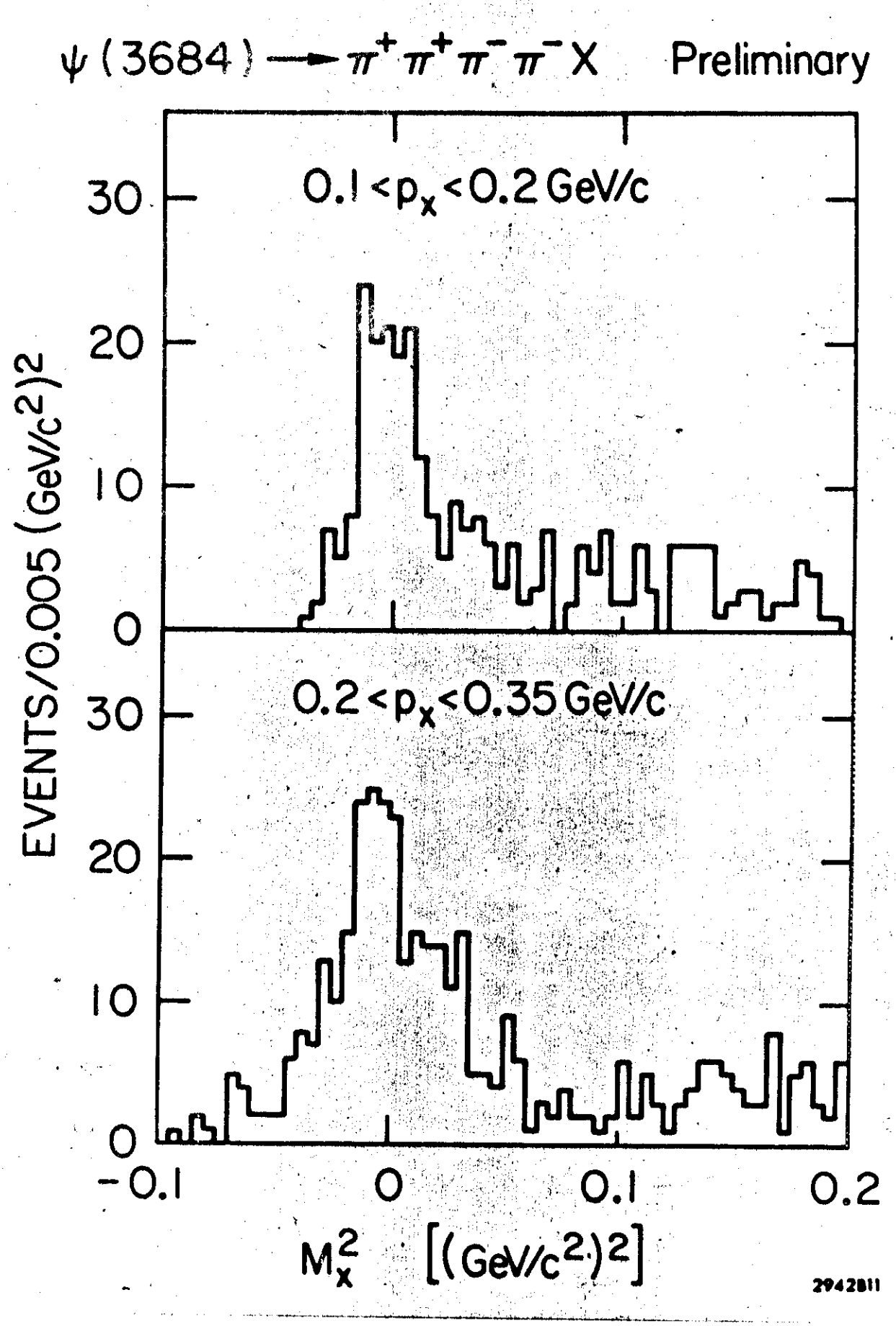
Measure γ-ray energy spectrum

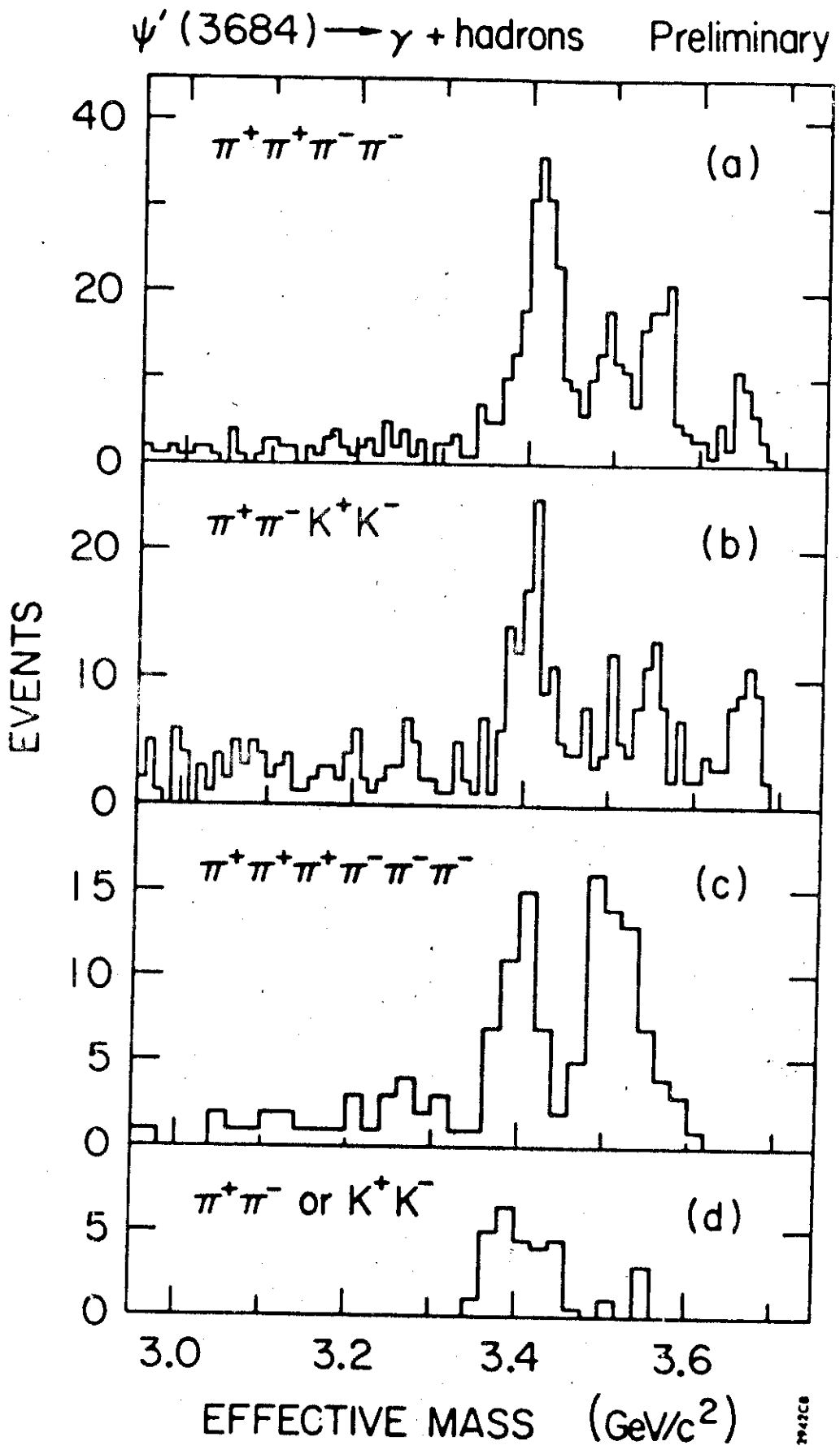


3. $\psi' \to \psi + \gamma + \gamma$

$\hookrightarrow \mu\mu$, ee $\quad \hookrightarrow e^+e^-$




ψ(3684) → π⁺π⁺π⁻π⁻X Preliminary
0.1 < p_x < 0.2 GeV/c
0.2 < p_x < 0.35 GeV/c
EVENTS/0.005 (GeV/c²)²
30
20
10
0
-0.1
0
0.1
0.2
M_x² [(GeV/c²)²]
2942B11


ψ′ (3684) → γ + hadrons
Preliminary
π⁺π⁺π⁻π⁻
(a)
π⁺π⁻K⁺K⁻
(b)
π⁺π⁺π⁺π⁻π⁻π⁻
(c)
π⁺π⁻ or K⁺K⁻
(d)
EVENTS
EFFECTIVE MASS (GeV/c²)
3.0
3.2
3.4
3.6
40
20
0
20
10
0
15
10
5
0
5
0

Cuts for χ analysis (1c)

All cases : $(\text{MISSING MASS})^2 \leq 0.05\ (\text{GeV}/c^2)^2$

$\pi^+\pi^-\pi^+\pi^-$

i) $\Delta E - |\Delta \vec{p}| \leq 0.1$ GeV

ii) $MM(\pi^+\pi^-) \leq 3.05$ GeV/c^2

$\pi^+\pi^- K^+K^-$

i) $\Delta E(\pi's) - |\Delta \vec{p}| > 0.1$ GeV

ii) $MM(\pi^+\pi^-) \leq 3.05$ GeV/c^2

iii) $\chi^2_{TOF}(\pi\pi KK) < \chi^2_{TOF}(4\pi)$

$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$

i) $\Delta E - |\Delta \vec{p}| \leq 0.1$ GeV

ii) $MM(\pi^+\pi^-) \leq 3.05$ GeV/c^2
≥ 3.20 GeV/c^2

$\pi^+\pi^-$, K^+K^-

i) e, μ cuts

ii) $\Delta\phi < 160^\circ$

iii) $p > 1$ GeV/c

iv) $p_{\perp}$ miss > 50 MeV/c

v) $M(\pi\pi) \leq 3.02$, ≥ 3.19

χ Branching Ratios

$$BR = \frac{\Gamma(\psi' \to \gamma\chi)}{\Gamma(\psi' \to all)} \cdot \frac{\Gamma(\chi \to f)}{\Gamma(\chi \to all)} \quad (\%)$$

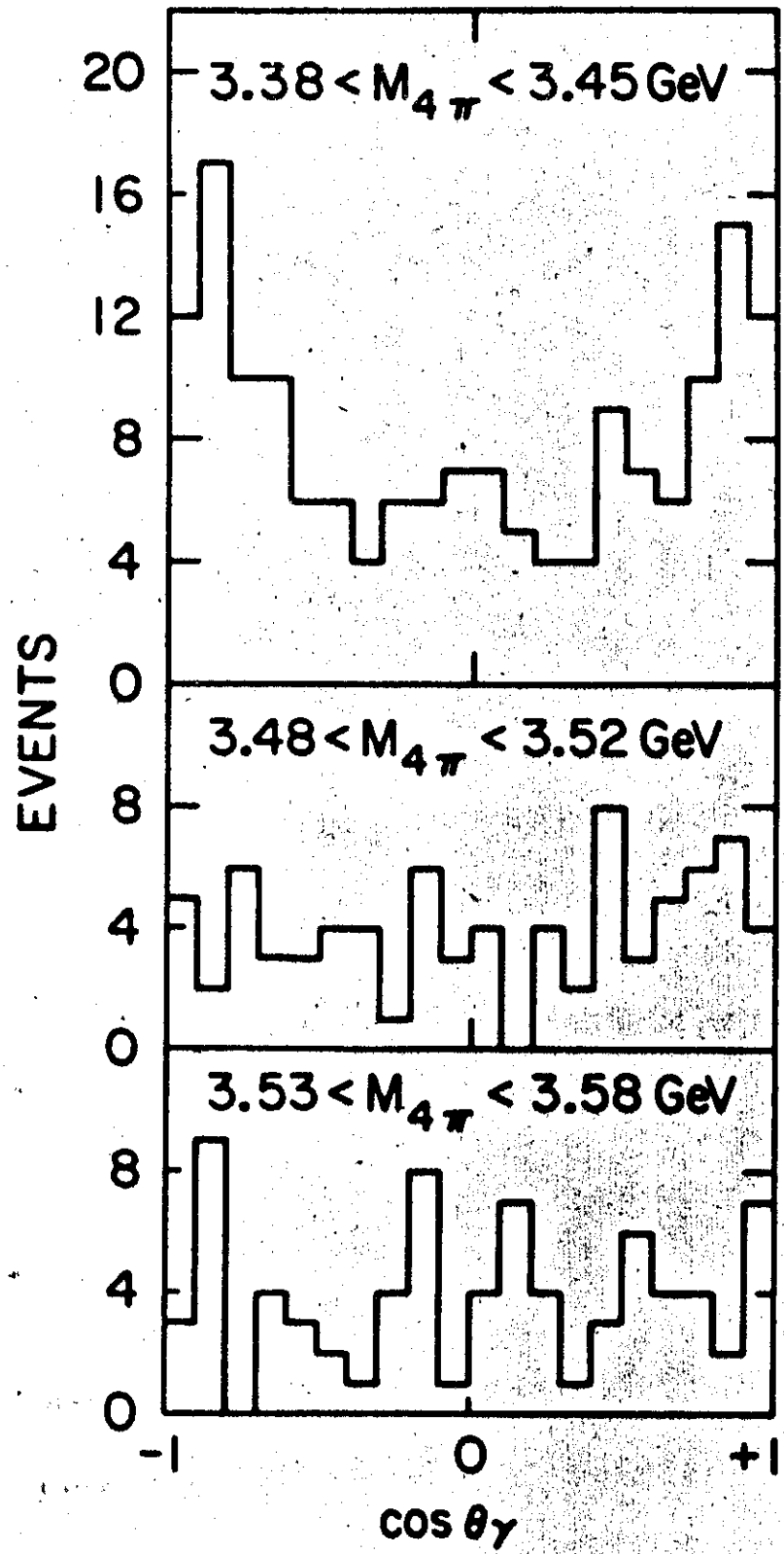
MODE \ MASS	3415	3500	3550
$\pi^+\pi^-\pi^+\pi^-$	0.32 ± 0.06	0.11 ± 0.04	0.16 ± 0.04
$K^+K^-\pi^+\pi^-$	0.27 ± 0.07	0.06 ± 0.03	0.11 ± 0.04
$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$	0.14 ± 0.05	[0.25 ± 0.08]	
$\pi^+\pi^- + K^+K^-$	0.14 ± 0.03	< 0.015	0.023 ± 0.012

$\chi(3415)$ Branching Ratios (%)

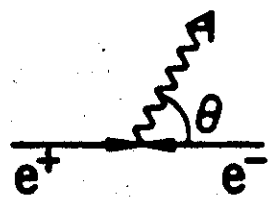
$$BR(\psi' \to \gamma\chi(3415)) = 6.5 \pm 2.2\%$$

$\pi^+\pi^-\pi^+\pi^-$	4.9 ± 2.0
$K^+K^-\pi^+\pi^-$	4.1 ± 2.0
$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$	2.1 ± 1.0
$\pi^+\pi^- + K^+K^-$	2 ± 1

$\psi'(3684) \longrightarrow \pi^+\pi^+\pi^-\pi^-\gamma$ Preliminary



$\frac{d\sigma}{d\cos\theta} \propto 1 + a\cos^2\theta$



$a = 1.4 \pm 0.4$

$a = 0.3 \pm 0.5$

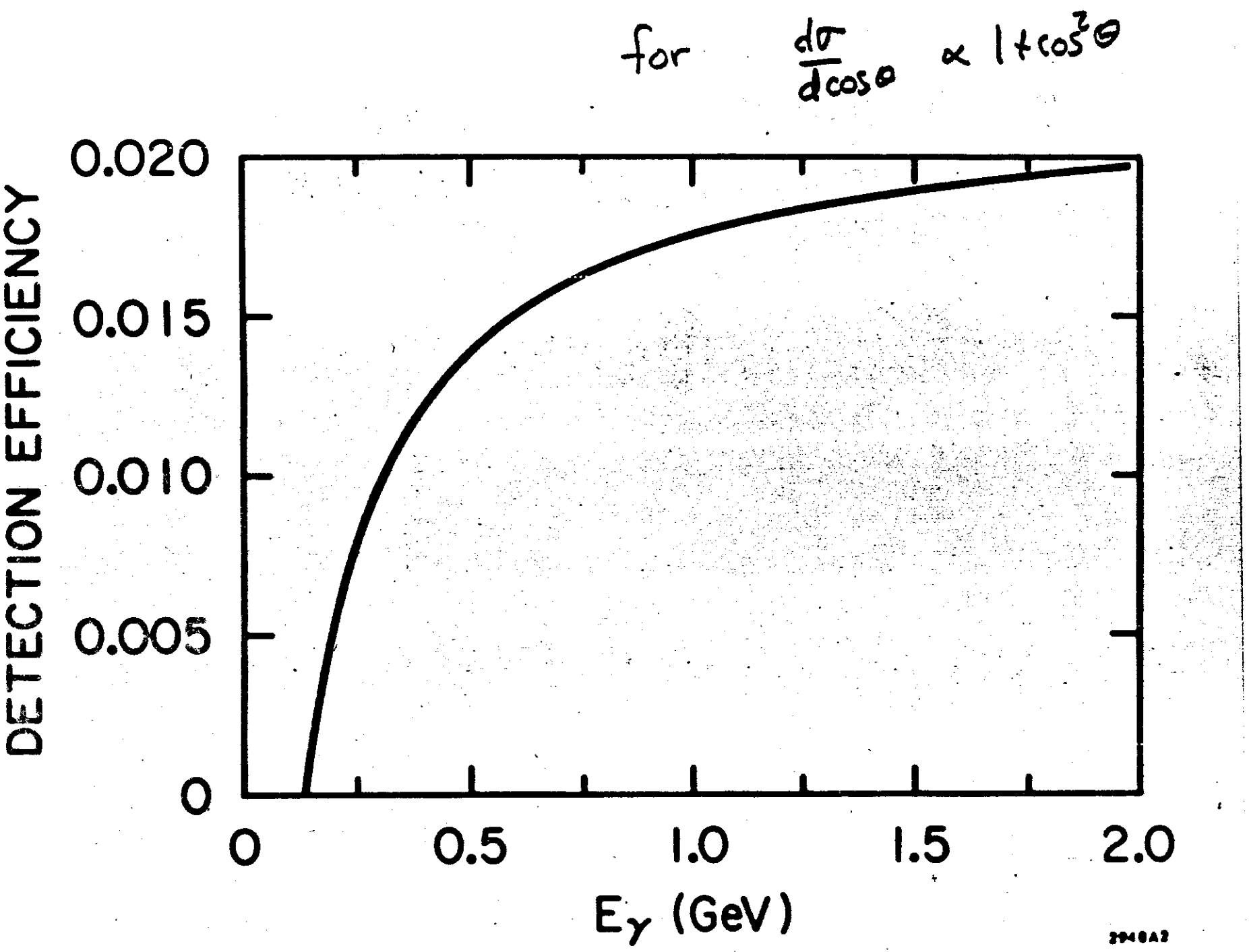
$a = 0.2 \pm 0.4$

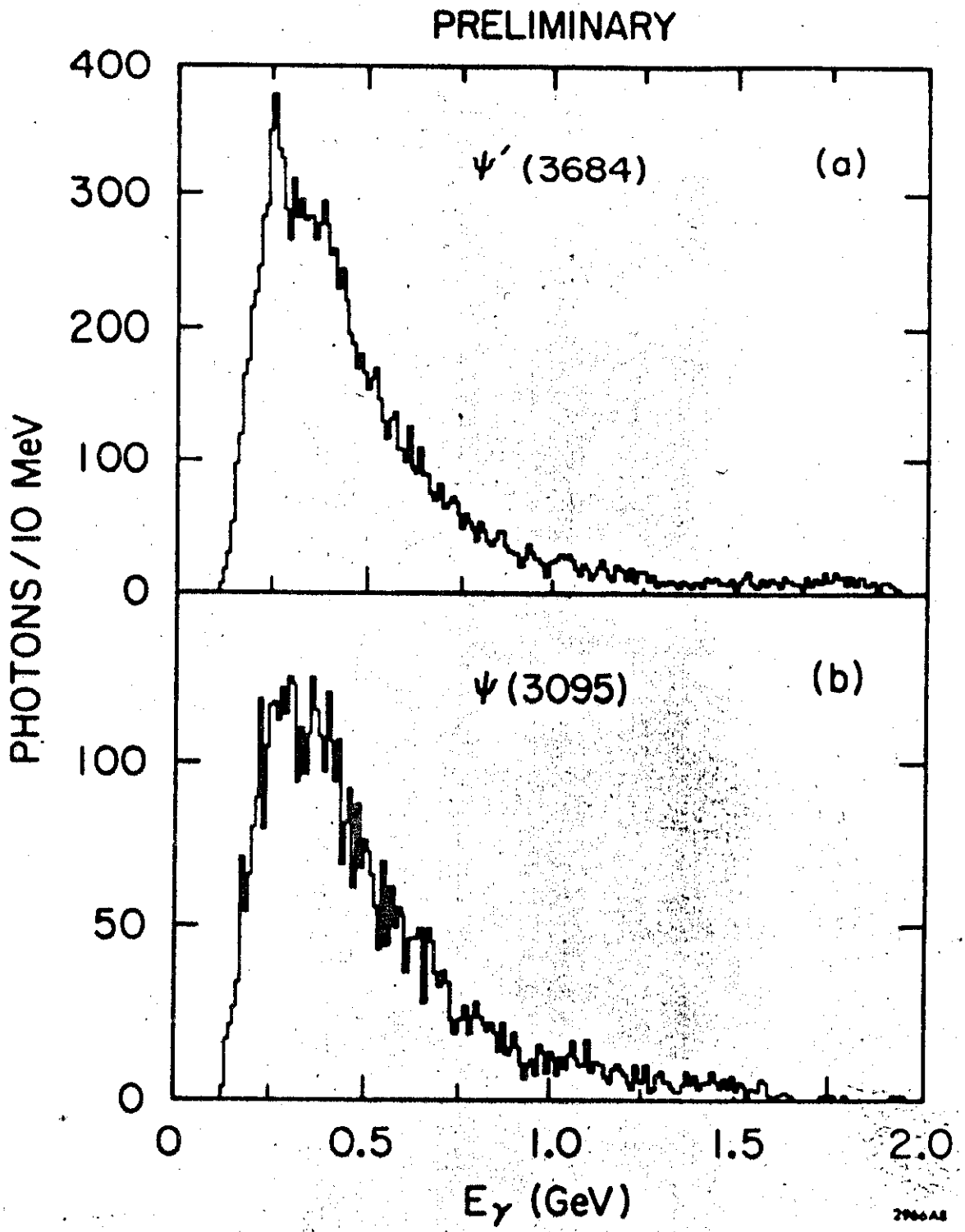
Conclusions from hadronic χ decays

- There exist at least 3 states

  3415 MeV/c^2
  3500 MeV/c^2 } $\pm$ w/o MeV/c^2
  3550 MeV/c^2

- J^{PC} for $\chi(3415)$ most likely $\underline{\underline{0^{++}}}$
- J, P even for $\chi(3550)$, probably 2^{++}
- $\chi(3415)$ BR similar to $\psi\omega\pi^0$
- K^* & ρ's seen in decays — consistent with SU(3) singlet for χ

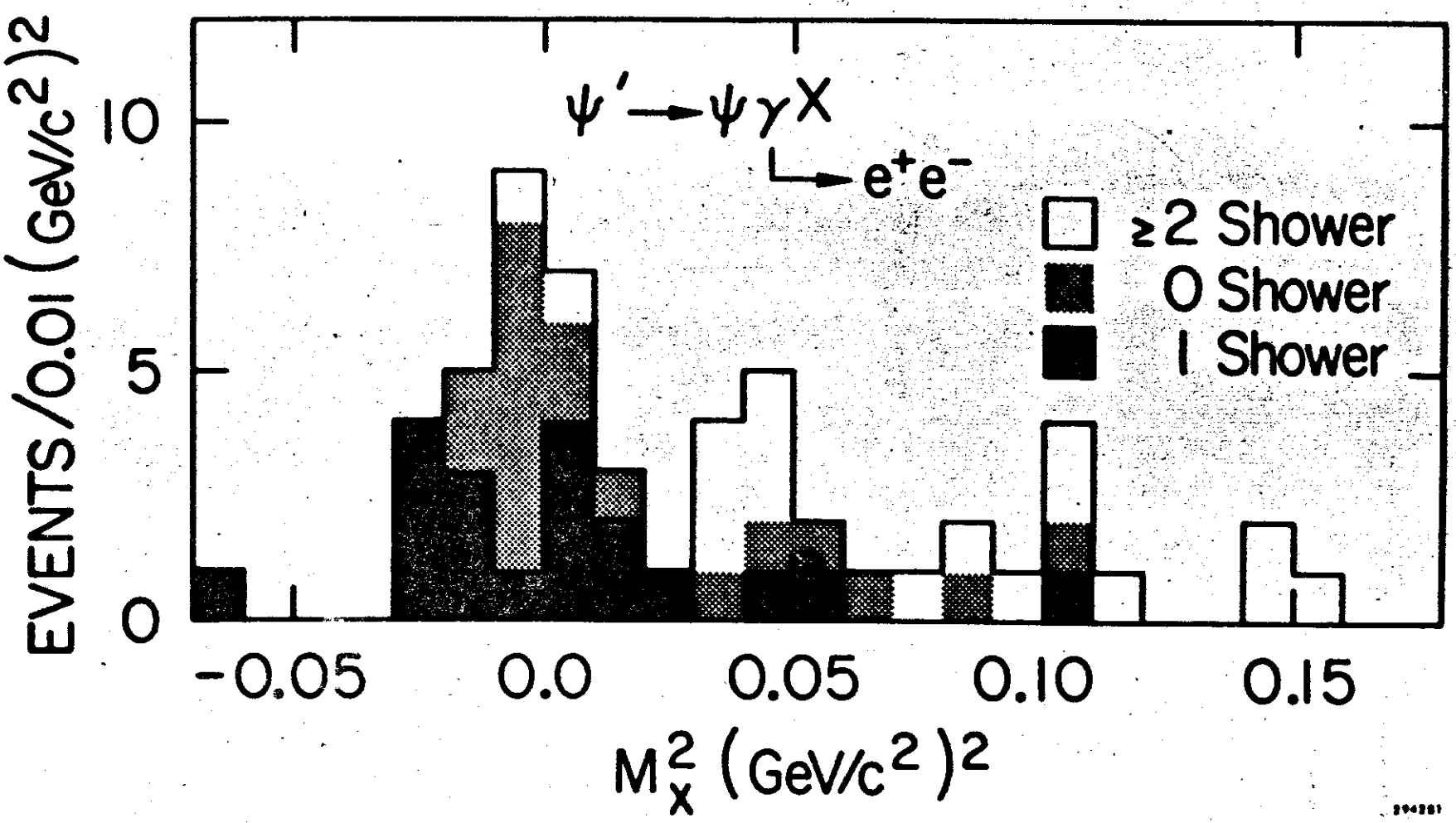

for $\frac{d\sigma}{d\cos\theta} \propto 1+\cos^2\theta$
DETECTION EFFICIENCY
0.020
0.015
0.010
0.005
0
0
0.5
1.0
1.5
2.0
E_γ (GeV)

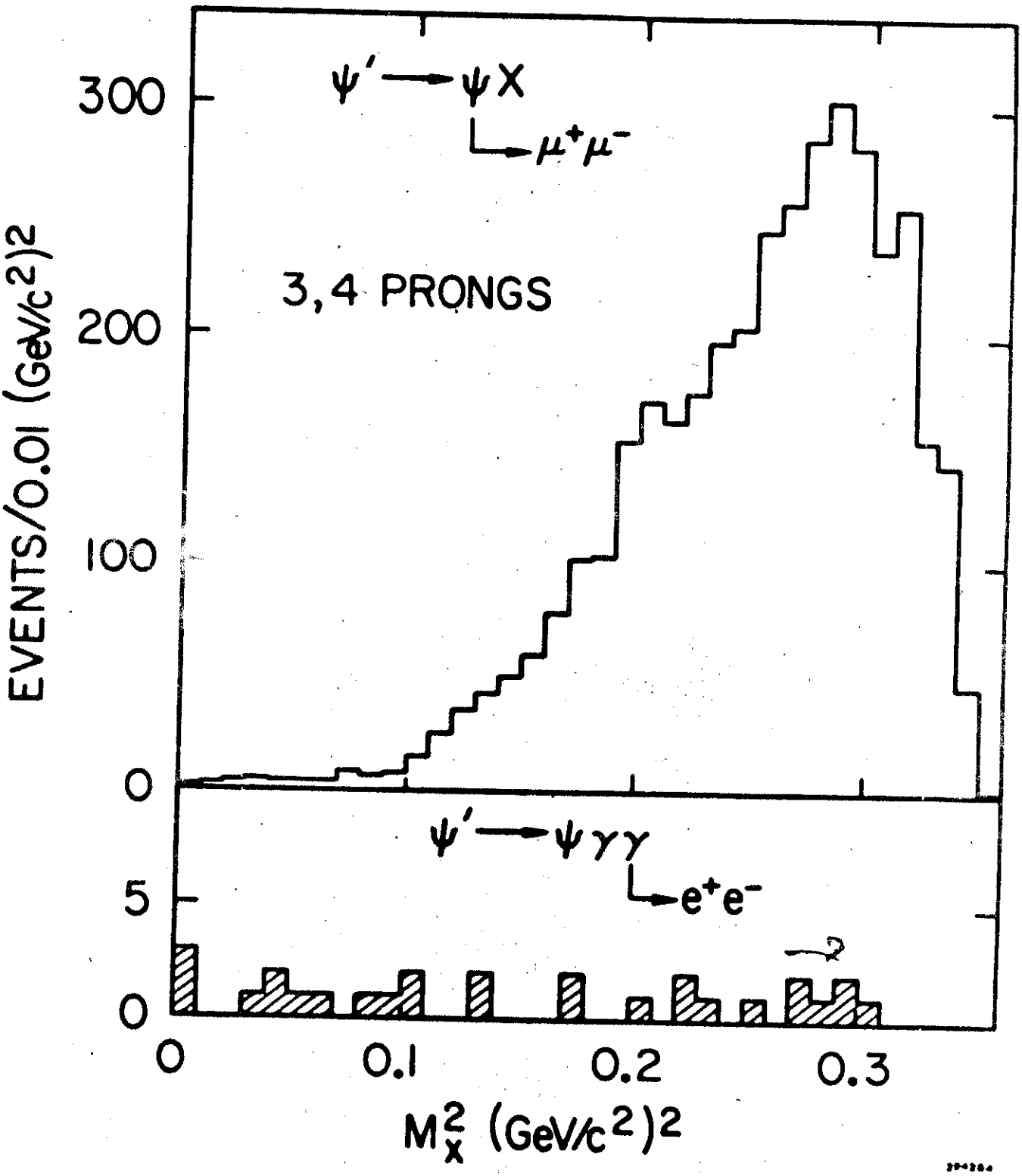


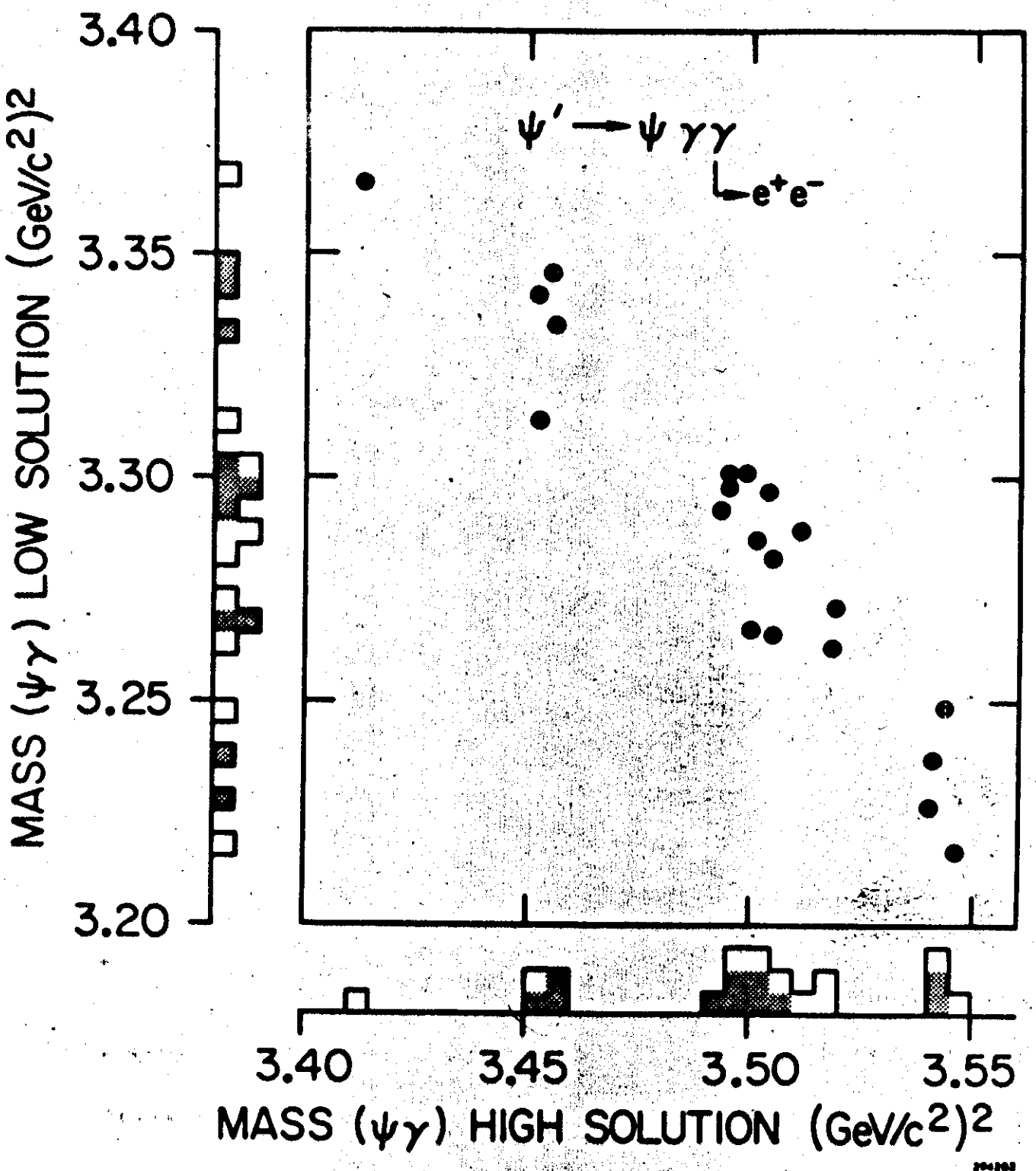
$E_\gamma = 261 \pm 10$ MeV

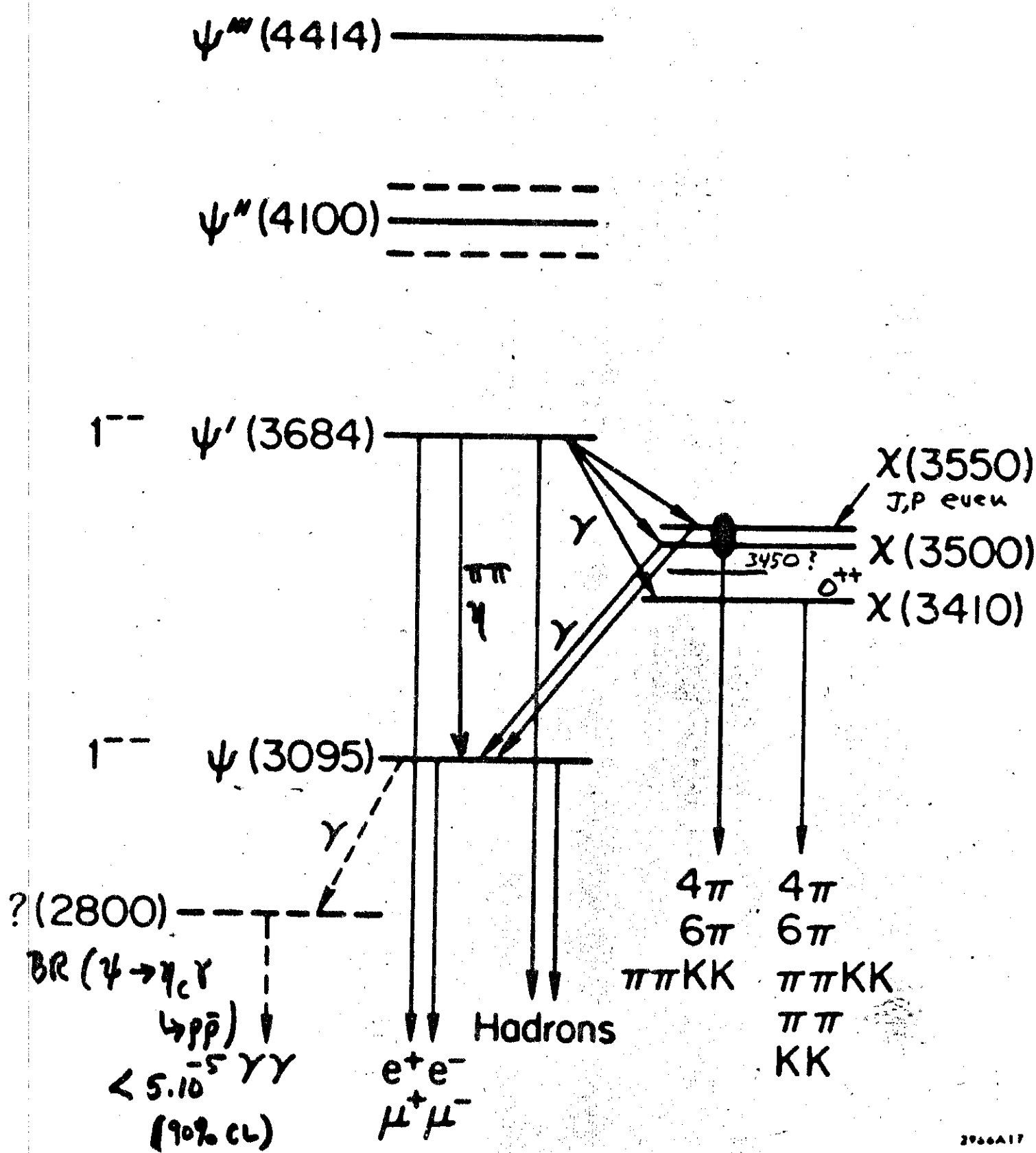
$BR(\psi' \to \gamma\, K(3410)) = (6.5 \pm 2.2)\%$ $\quad 1+\cos^2\theta$

$(5.5 \pm 1.9)\%$ $\quad$ isotropic


EVENTS/0.01 (GeV/c²)²
10
5
0
ψ′→ψγX
↳e⁺e⁻
≥2 Shower
0 Shower
1 Shower
-0.05
0.0
0.05
0.10
0.15
M²x (GeV/c²)²


300
200
100
0
5
0
EVENTS/0.01 (GeV/c²)²
ψ′ → ψX
└→ μ⁺μ⁻
3,4 PRONGS
ψ′ → ψγγ
└→ e⁺e⁻
0
0.1
0.2
0.3
M²x (GeV/c²)²


3.40
3.35
3.30
3.25
3.20
MASS (ψγ) LOW SOLUTION (GeV/c²)²
ψ′ → ψ γγ
└e⁺e⁻
3.40
3.45
3.50
3.55
MASS (ψγ) HIGH SOLUTION (GeV/c²)²

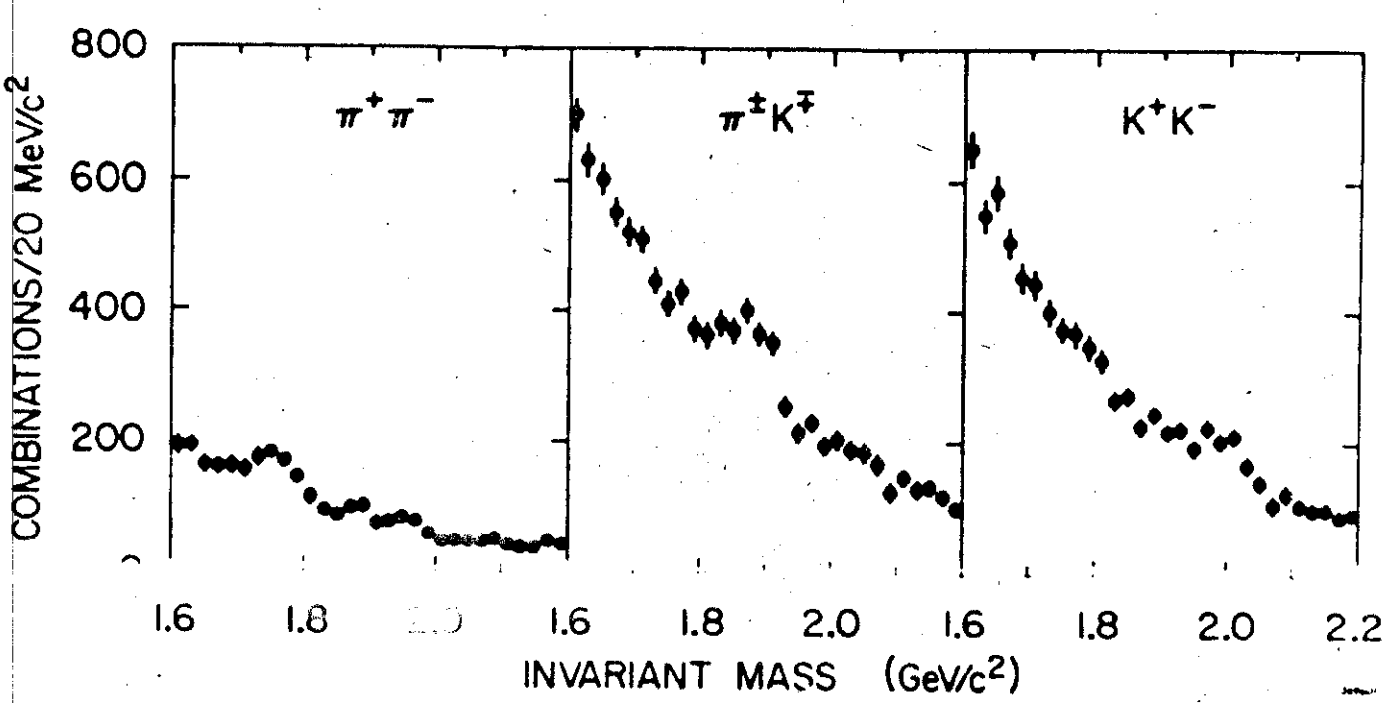

ψ‴(4414)
ψ″(4100)
1⁻⁻ ψ′(3684)
χ(3550)
J,P even
χ(3500)
3450 ?
0⁺⁺
χ(3410)
ππ
η
γ
γ
γ
1⁻⁻ ψ(3095)
?(2800)
BR(ψ→η_c γ
↳pp̄)
< 5.10⁻⁵ γγ
(90% CL)
e⁺e⁻
μ⁺μ⁻
Hadrons
4π
6π
ππKK
4π
6π
ππKK
ππ
KK

$e\mu$ Events

110 events above bkgnd

Summary of study of events with $e^{\pm}\mu^{\mp}$ + γ's + K^0's + tracks

Undetected Particle	Upper Limit (90% CL) for fraction of $e\mu$ + undetected (%)
K^0	< 9 %
π^0 or γ	< 18 %
charged particle	< 9 %
charged particle + π^0, γ	< 11 %
TOTAL	< 39 %


800
600
400
200
COMBINATIONS/20 MeV/c²
π⁺π⁻
π±K∓
K⁺K⁻
1.6
1.8
2.0
1.6
1.8
2.0
1.6
1.8
2.0
2.2
INVARIANT MASS (GeV/c²)

EVENT WEIGHTING

1) Select tracks with "good" TOF:

ie $z_{TOF} = z_{TRACK}$

2) Calculate relative probability

track is $\pi, K, (p)$

$$P_i = e^{-\frac{(t-t_i)^2}{2\sigma^2}} \qquad i = \pi, K, (p)$$

3) Require $\sum_i P_i > 1\%$

4) Normalize P_i such that $\sum_i P_i = 1$

5) Weight event by total track p for given hypothesis

$$\omega_j = \prod_i P_i$$

eg. $\omega_{\pi K^2} = P_\pi \cdot P_K^2$

Number of Events

$3.9 \leq E_{cm} \leq 4.6$ GeV

	Events weight	$K\pi$ MonteCarlo Fraction	$K\bar{K}$ M.C Fraction
$K\pi$	67.4 ± 12.2	0.55	0.46
$K\bar{K}$	28.4 ± 6.0	0.21	0.44
$\pi\pi$	14.7 ± 7.1	0.24	0.10

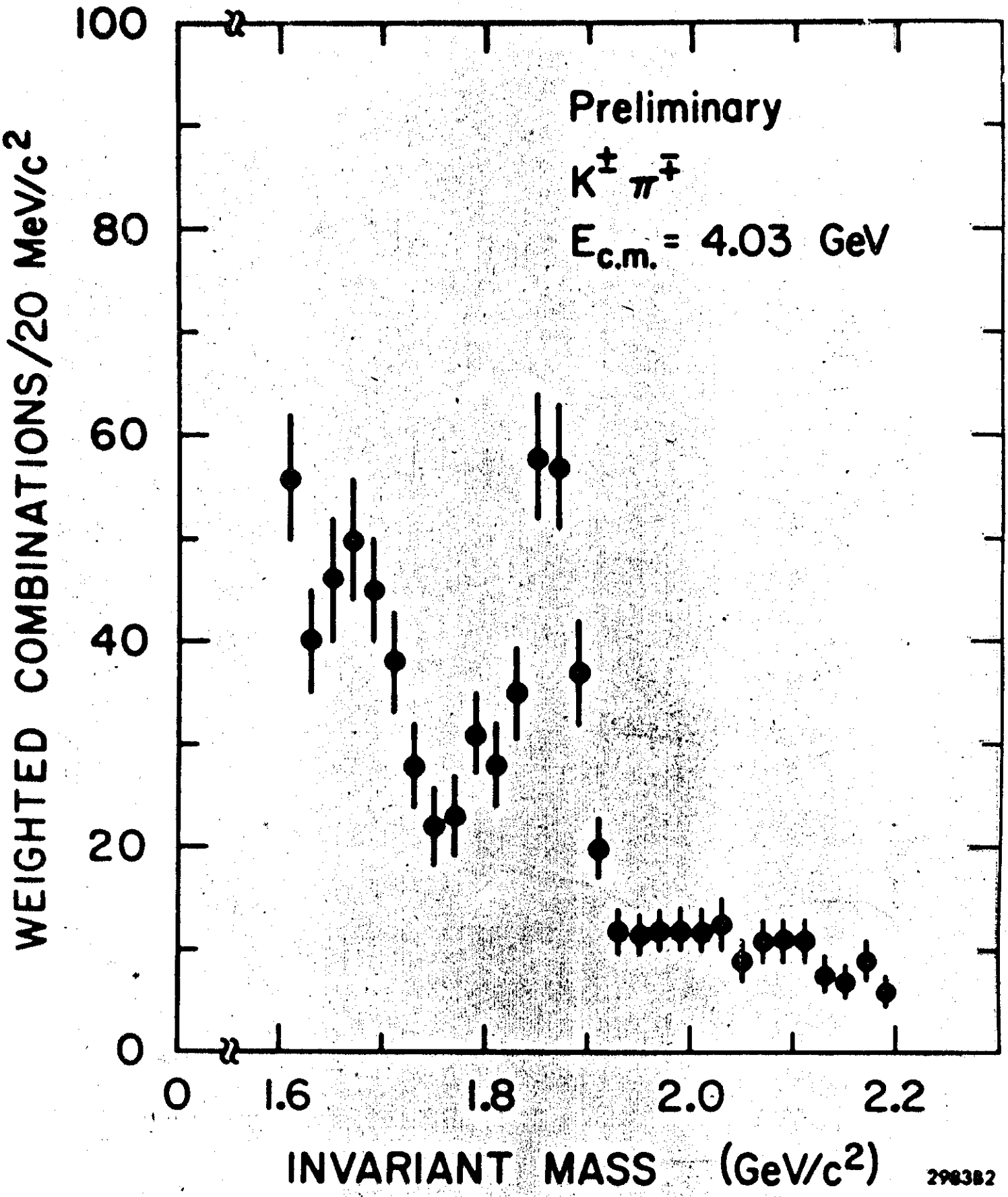
$\therefore \quad \# \pi K = 110 \pm 24$

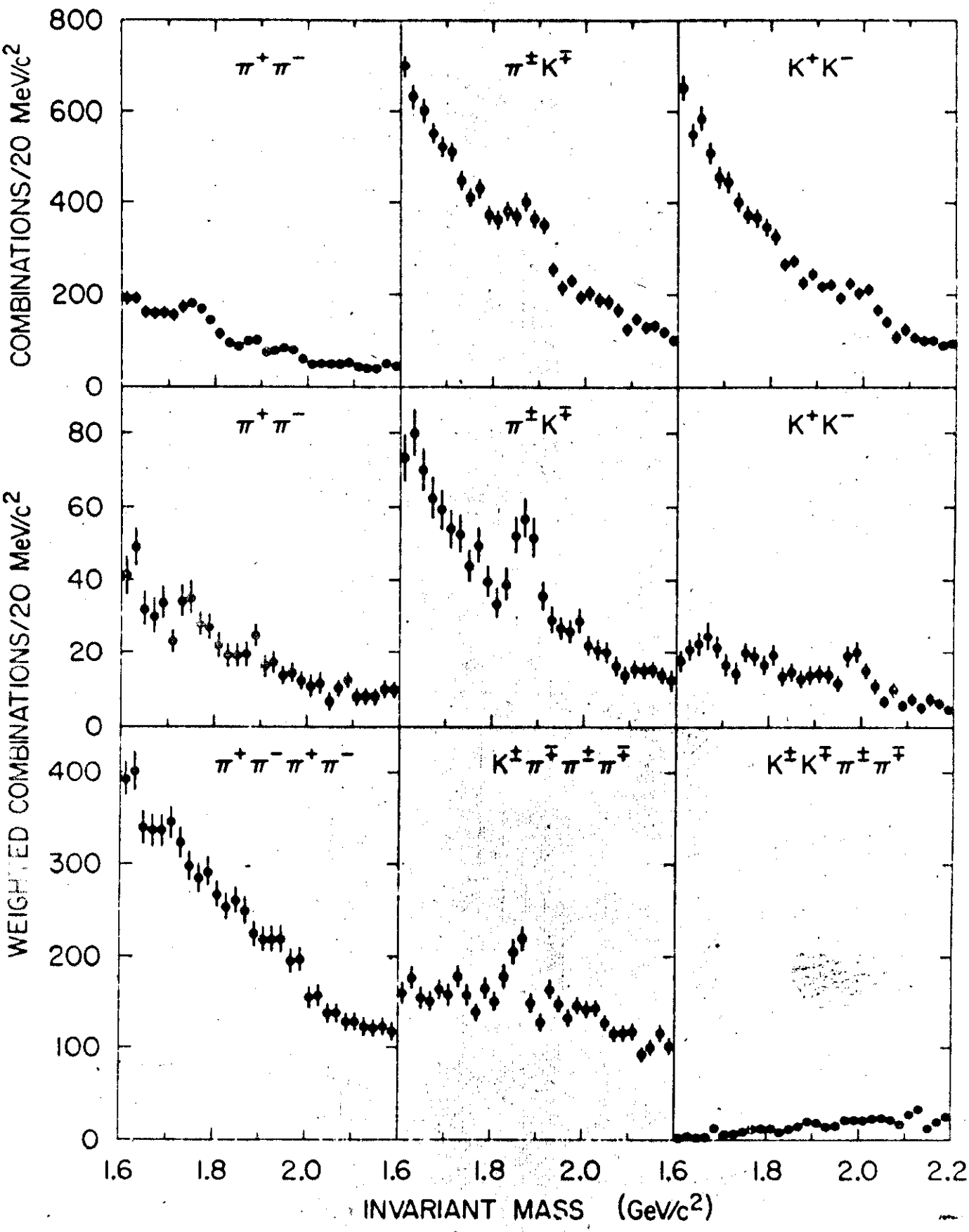
$\Rightarrow \sigma \cdot Br = 0.20 \pm 0.05$

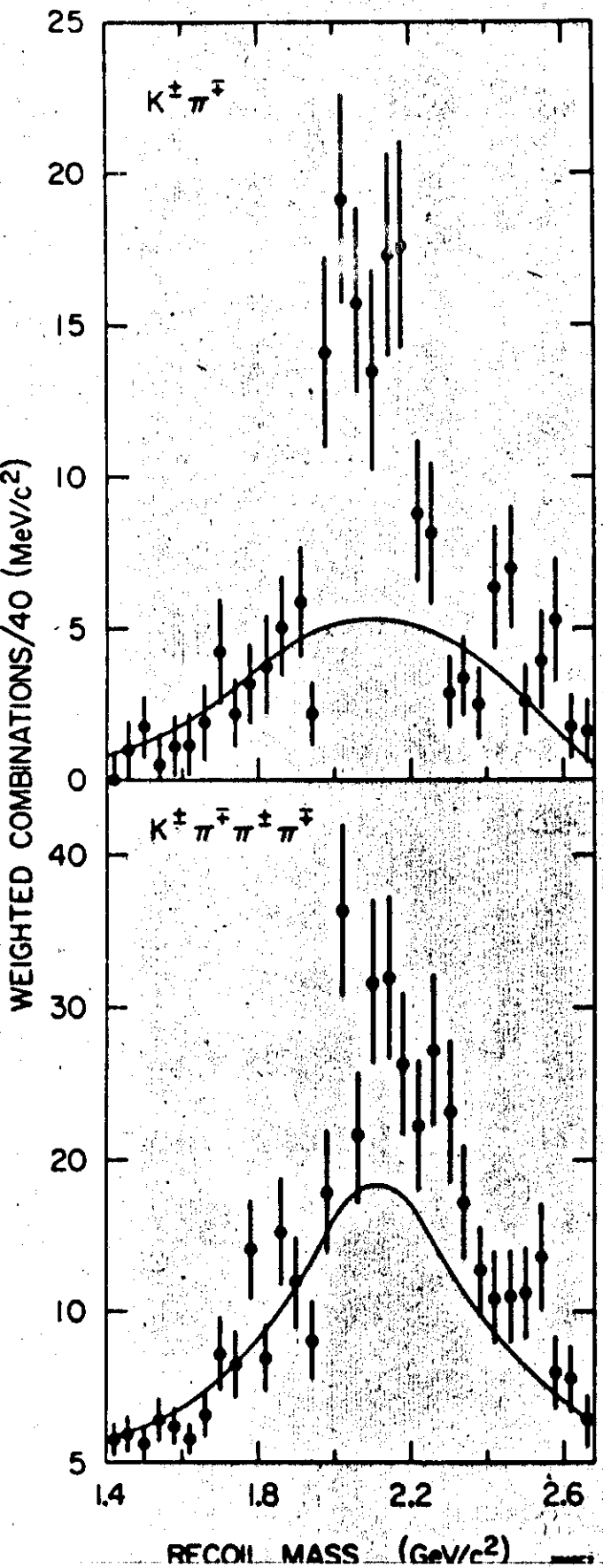
$\sigma_{TOT} = 27 \pm 3$ nb

$\# \quad K3\pi = 124 \pm 21$

$\Rightarrow \quad \sigma \cdot Br = 0.67 \pm 0.11$ nb


Preliminary
$K^{\pm}\pi^{\mp}$
$E_{c.m.}$ = 4.03 GeV
WEIGHTED COMBINATIONS/20 MeV/c^2
INVARIANT MASS (GeV/c^2)
0
20
40
60
80
100
1.6
1.8
2.0
2.2
298382


$\pi^+\pi^-$
$\pi^\pm K^\mp$
K^+K^-
$\pi^+\pi^-$
$\pi^\pm K^\mp$
K^+K^-
$\pi^+\pi^-\pi^+\pi^-$
$K^\pm\pi^\mp\pi^\pm\pi^\mp$
$K^\pm K^\mp\pi^\pm\pi^\mp$
COMBINATIONS/20 MeV/c^2
WEIGHTED COMBINATIONS/20 MeV/c^2
INVARIANT MASS (GeV/c^2)
0
200
400
600
800
20
40
60
80
100
300
1.6
1.8
2.0
2.2



$D^0, \bar{D}^0$

$D^0, \bar{D}^0$

Mass & Width

Fit for various bin sizes, cuts, bkgnd terms

$M_{K\pi} = 1870 \pm 5$ MeV/c^2

$M_{K3\pi} = 1860 \pm 5$ MeV/c^2

$\sigma_{K\pi} \simeq 25 \pm 4$ MeV/c^2 M.C. $\Rightarrow$ 25 MeV

$\sigma_{K3\pi} \simeq 10\text{-}15 \pm 3$ MeV/c^2 M.C. $\Rightarrow$ 13 MeV

Conclude:

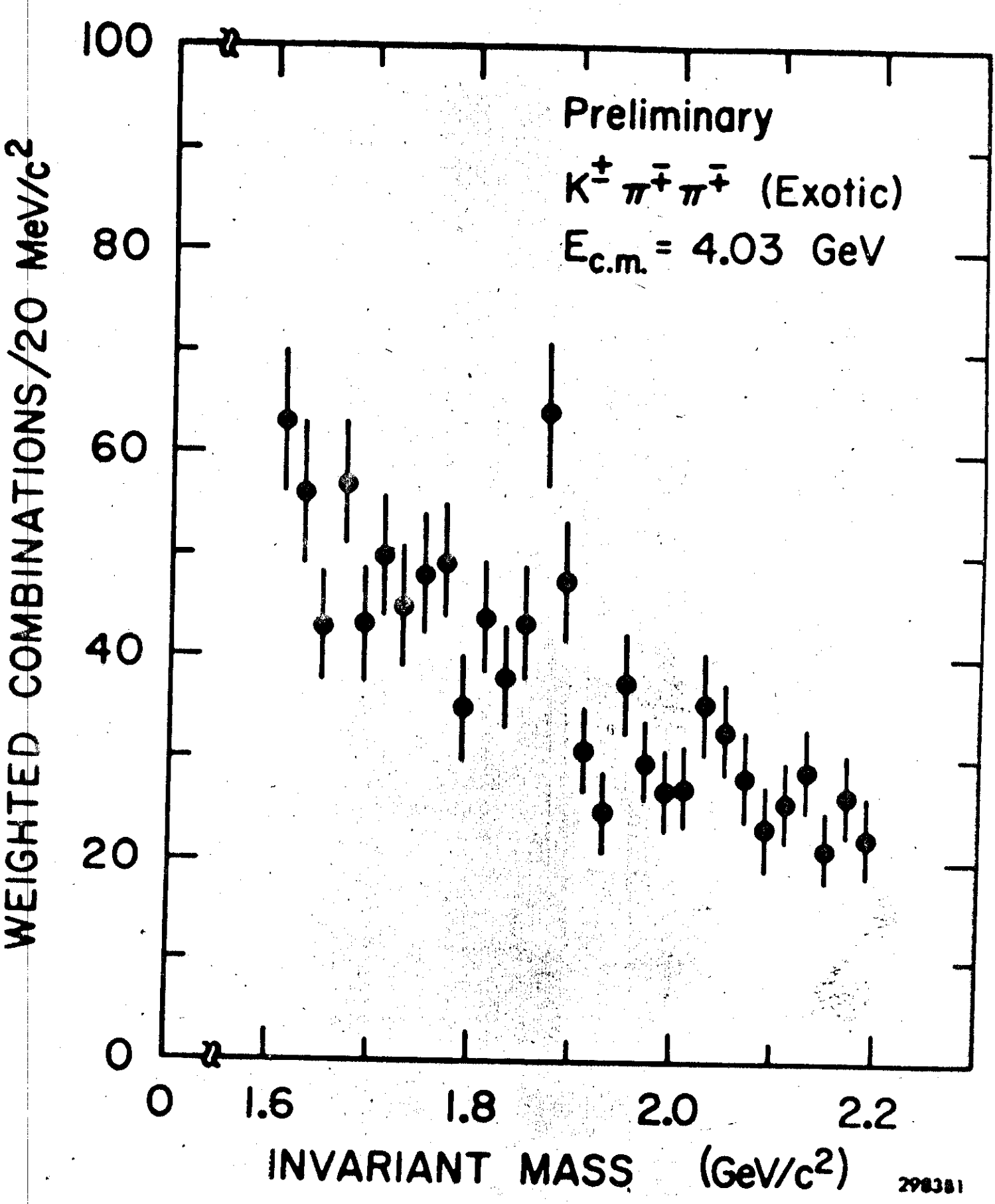
$K\pi$, $K3\pi$ Represent different decay modes of the same object

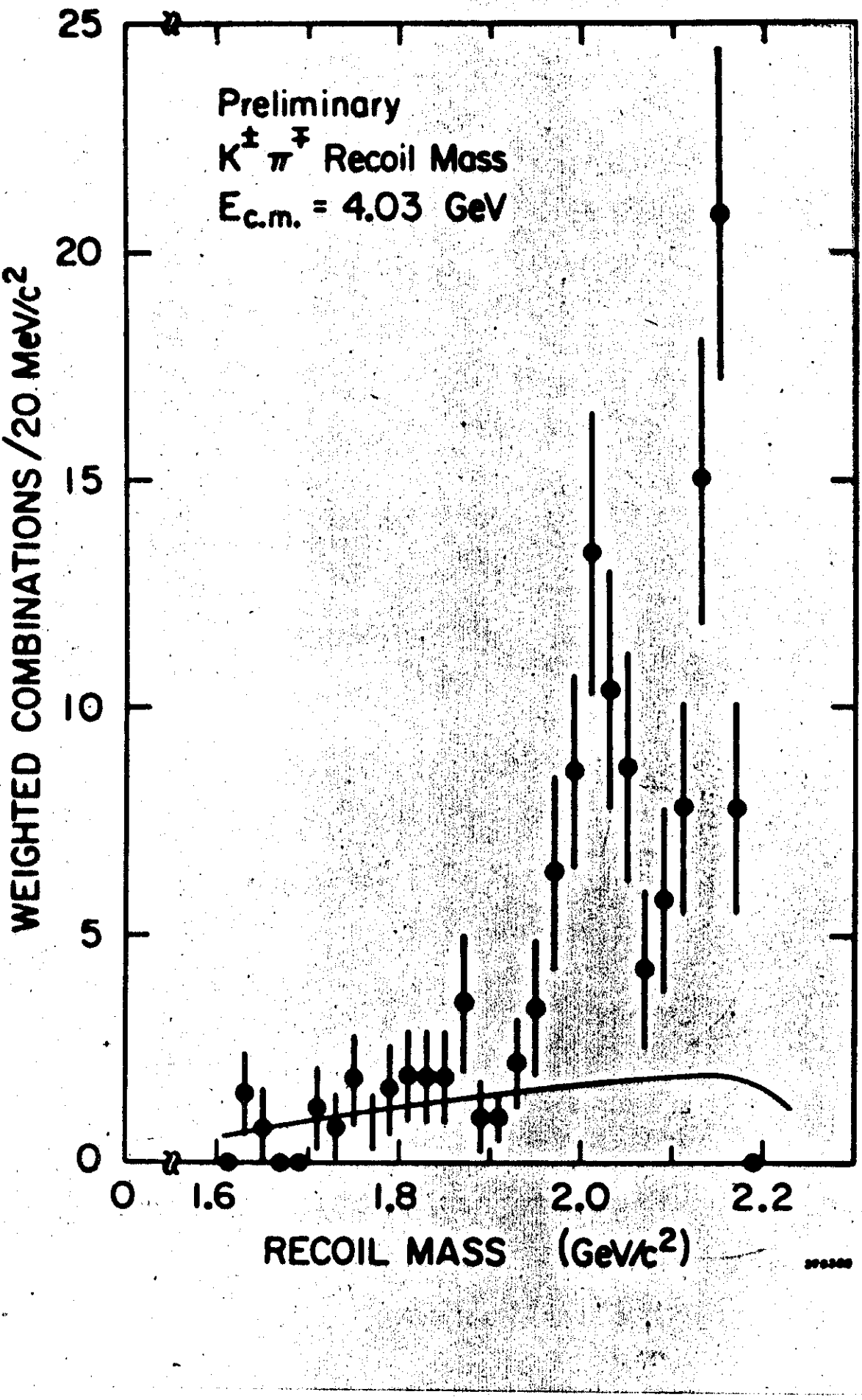
$M = 1865 \pm 15$ MeV/c^2

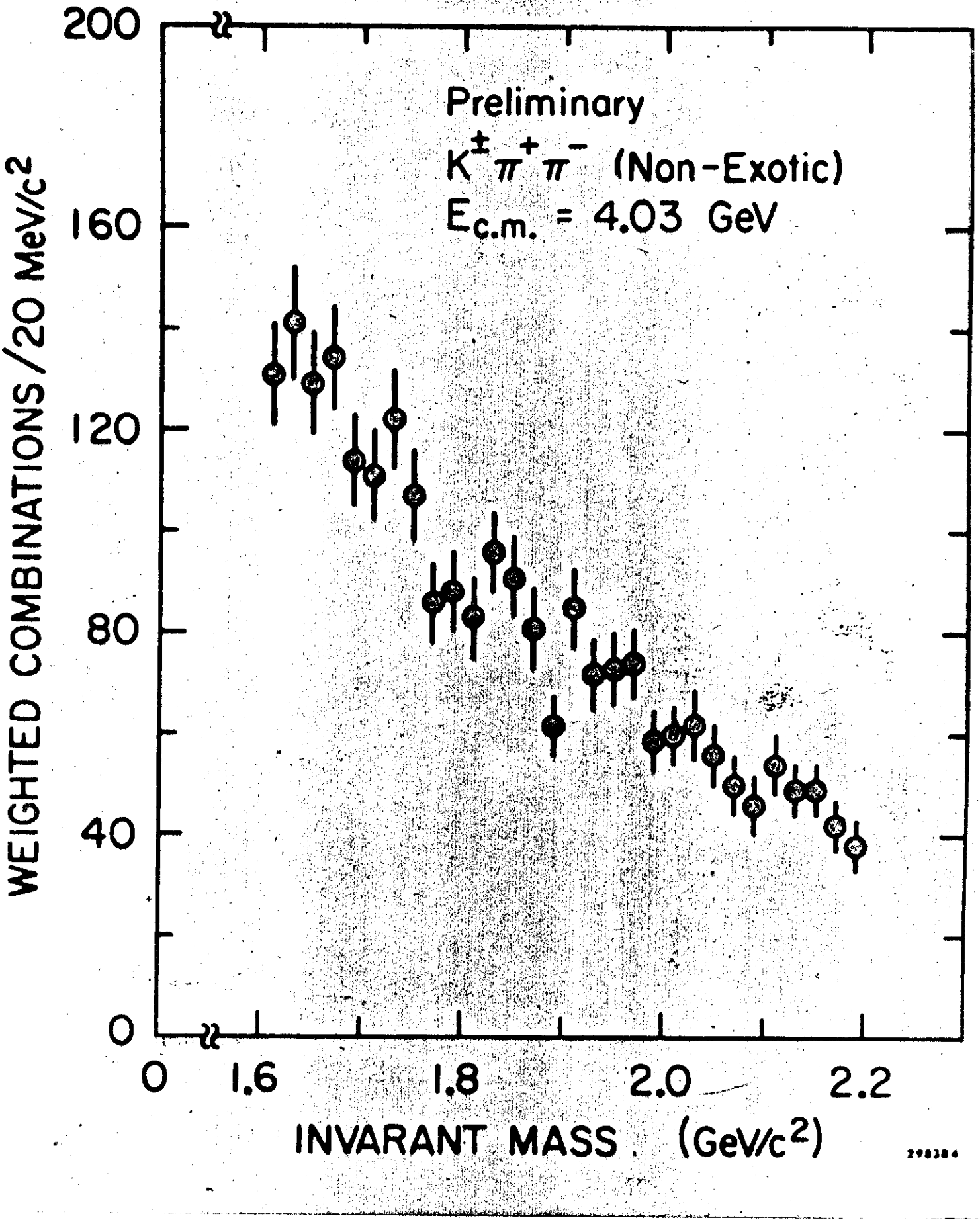
$\Gamma < 40$ MeV/c^2 (90%

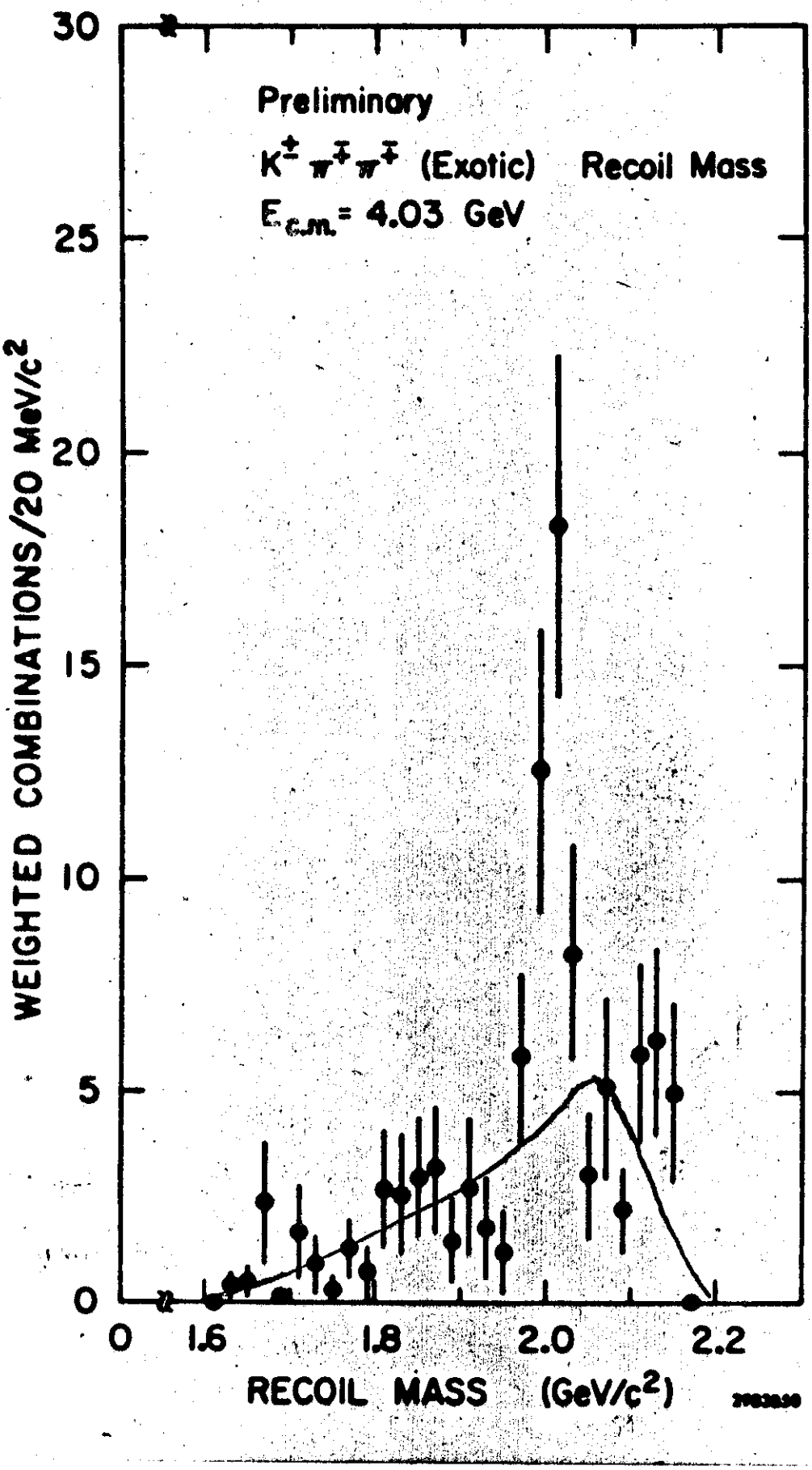
Event Sample

"old"	3.9 – 4.6 GeV		29 K events
4.03 GeV		June '76	19 K
4.4 GeV		"	~25 K


Preliminary
$K^{\pm}\pi^{\mp}\pi^{\mp}$ (Exotic)
$E_{c.m.}$ = 4.03 GeV
WEIGHTED COMBINATIONS/20 MeV/c^2
INVARIANT MASS (GeV/c^2)
0
20
40
60
80
100
1.6
1.8
2.0
2.2
298381


Preliminary
$K^{\pm}\pi^{\mp}$ Recoil Mass
$E_{c.m.}$ = 4.03 GeV
WEIGHTED COMBINATIONS/20 MeV/c²
RECOIL MASS (GeV/c²)
0
5
10
15
20
25
1.6
1.8
2.0
2.2


Preliminary
$K^{\pm}\pi^{+}\pi^{-}$ (Non-Exotic)
$E_{c.m.}$ = 4.03 GeV
WEIGHTED COMBINATIONS/20 MeV/c^2
INVARANT MASS (GeV/c^2)
200
160
120
80
40
0
0
1.6
1.8
2.0
2.2
298384


Preliminary
$K^{\pm}\pi^{\mp}\pi^{\mp}$ (Exotic) Recoil Mass
$E_{c.m.}$ = 4.03 GeV
WEIGHTED COMBINATIONS/20 MeV/c²
RECOIL MASS (GeV/c²)
0
5
10
15
20
25
30
1.6
1.8
2.0
2.2

Some Conclusions

- There exist narrow peaks in the invariant mass spectra for $K\pi$, $K\pi\pi$, $K\pi\pi\pi$ (charged prongs) near 1.86 - 1.87 GeV/c^2
- Recoil mass spectra and threshold behavior suggest they producted only in association with states of $\geq$ mass
- $K\pi\pi$ occurs only in exotic charge-strangeness combinations
- At $W = 4.03$ GeV,
  - $K^{\pm}\pi^{\mp}$ is greatly enhanced
  - $K\pi$ and $K\pi\pi$ recoil mass spectra have sharp peaks @ 2.02 GeV
  - $K\pi$ recoil mass peaks @ 2.15 GeV while $K\pi\pi$ does not.