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

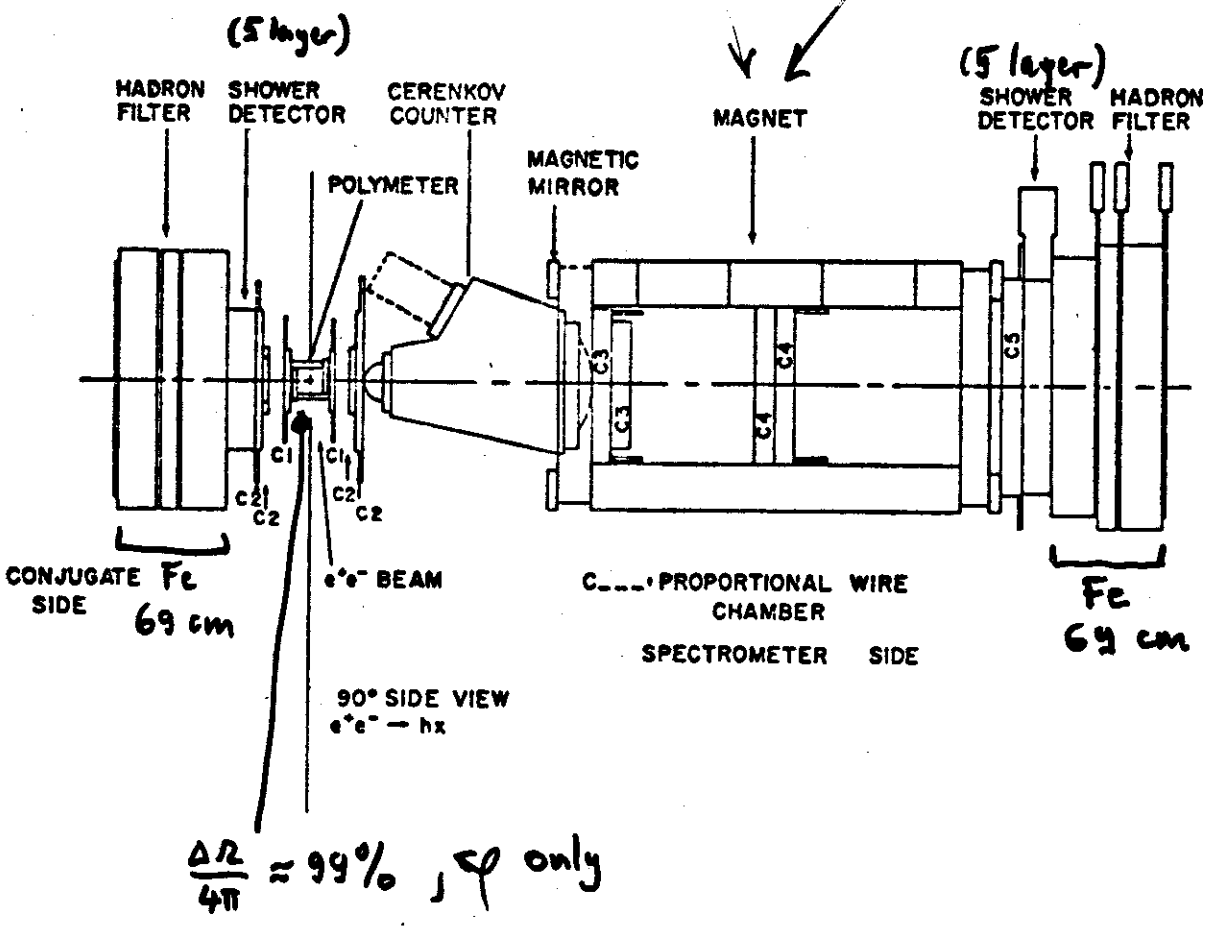
M. Cavalli Sforza

Istituto di Fisica Nucleare, Via Bassi 6, Pavia, Italy.

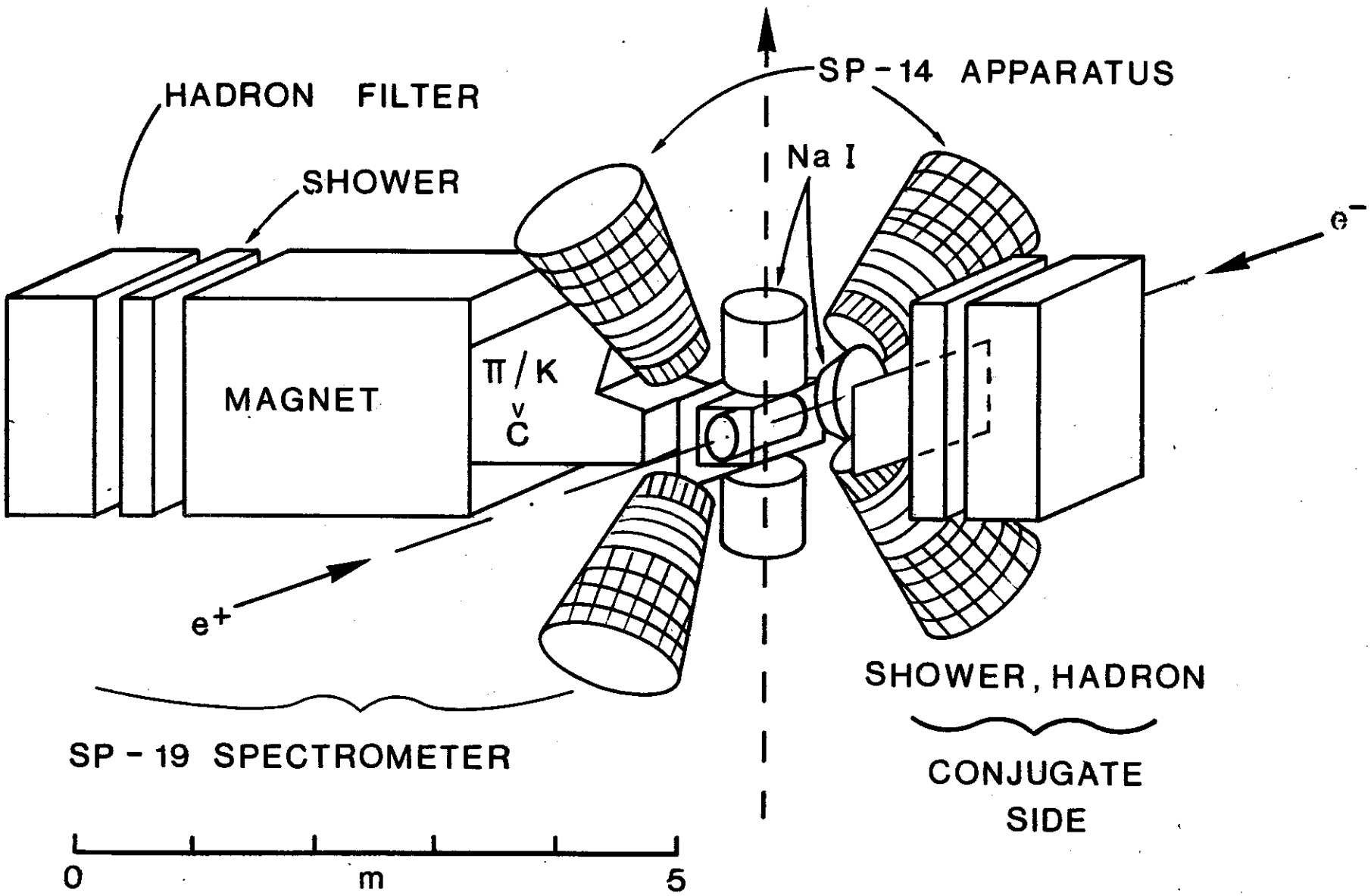
SP-8

(end '73-74)

$\frac{\Delta\Omega}{4\pi} \approx .01$ $\frac{\Delta p}{p} \approx .01$ @ 2.4 GeV/c



$\frac{\Delta\Omega}{4\pi} \approx 99\%$, φ only



SP - 27 APPARATUS FOR $e^+ e^-$ ⟶ HADRONS + γ's

New Results :

SP-8 : anomalous muon production at $W = 4.8$ GeV and $W = 3.8$ GeV

SP-14/19 : search for narrow resonances in σ_{had} and σ_{ee} for $5.6 \leq W \leq 6.4$ GeV

SP-27 : ψ', ψ radiative decays (inclusive γ-ray spectra) | PRELIMINARY

MP²

(INCLUSIVE PARTICLE SPECTRA AT 90°)

Maryland:

T.L. ATWOOD
D.H. BADTKE
B.A. BARNETT
L.V. TRASATTI
G.T. ZORN

Pavia

M. CAVALLI-SFORZA
G. GOGGI
G.C. MANTOVANI
A. PIAZZOLI
B. ROSSINI
D. SCANNICCHIO

Princeton

D.G. COYNE
G.K. O'NEILL
H.F.W. SADROZINSKI
K.A. SHINSKY

INCLUSIVE MUON PRODUCTION

$W = 4.8$ GeV:

→ $\mu +$ ≥ 2 prongs:

2 events observed (hadron + ≥ 2pr. = 71 evts.)
Expected events are 5.3

∴ No signal seen, $\left.\frac{d\sigma}{d\Omega}\right|_{90^\circ} < 7.5$ pb/st, 95% cl.
($p_\mu \geq 1.05$ GeV/c)

→ $\mu + 1$ prong, $\Phi_{ACOP} > 20^\circ$

13 events observed (hadron + 1 pr. = 18 evts)
Expected events are 4 (mainly QED)
Probability of stat. fluctuation very small

∴ $\left.\frac{d\sigma}{d\Omega}\right|_{90^\circ} = 23^{+12}_{-9}$ pb/sr ($\Phi > 20^\circ$, $p_\mu \geq 1.05$ GeV/c)

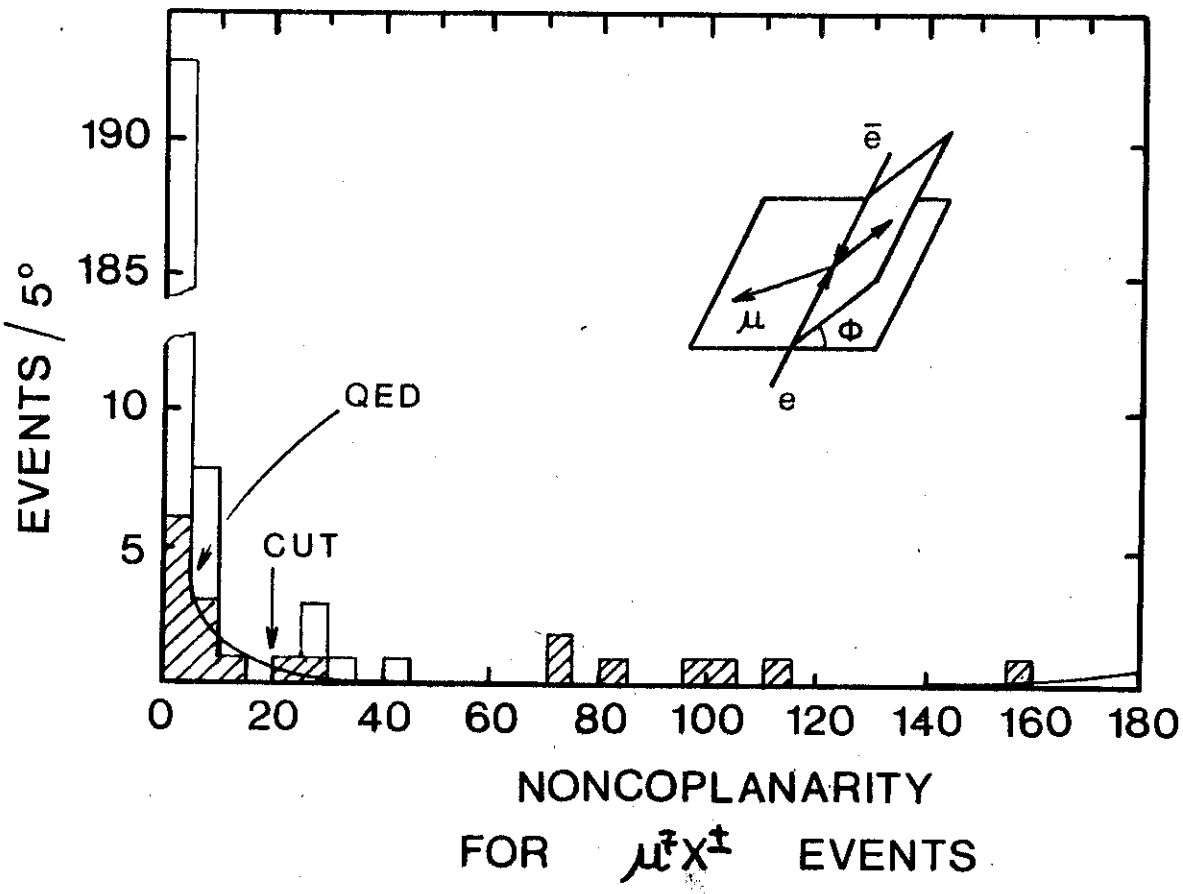
$W = 3.8$ GeV:

→ $\mu +$ ≥ 2 prongs: 4 events observed, 2.4 " expected

$\mu + 1$ prong: 3 events observed, 1.3 " expected

NO SIGNIFICANT SIGNALS

∴ ONLY SIGNIFICANT EFFECT IS $\mu + 1$ prong at 4.8 GeV


190
185
10
5
EVENTS / 5°
QED
CUT
ē
μ
Φ
e
0
20
40
60
80
100
120
140
160
180
NONCOPLANARITY
FOR $\mu^{\mp}X^{\pm}$ EVENTS

CAN CHARM BE THE SOURCE OF OUR ANOMALOUS MUONS ?

If $e^+e^- \to U^\pm U^\mp \to$ charged particles
$\hookrightarrow \mu^\pm$ + neutrals

$$\frac{d\sigma/d\Omega(\mu + \geq 2\,pr.)}{d\sigma/d\Omega(\mu + 1\,pr.)} = \frac{\Gamma(U^\pm \to 3\,ch.\,part.)}{\Gamma(U^\pm \to 1\,ch.\,part.)} \leq .33$$

(G.A. Snow, PRL 36, 766)

Models:

→ Charm: $\frac{\Gamma(D^\pm, F^\pm \to \geq 3\,ch.)}{\Gamma(D^\pm, F^\pm \to 1\,ch.)} \gtrsim 2$ NO

(Einhorn + Quigg, PR D12, 2015)

→ Heavy Leptons: $\frac{\Gamma(L^\pm \to \geq 3\,ch.)}{\Gamma(L^\pm \to 1\,ch.)} \approx .18$ OK

(Tsai, PR D4, 2821)

→ Quark/Gluon: $\frac{\Gamma(V, Q \to \geq 3\,ch.)}{\Gamma(V, Q \to 1\,ch.)} \approx .20$ OK

(Pati, Salam + Sakakibara, PRL 37, 229)

∴ CHARM CANNOT BE THE ONLY SOURCE OF ANOMALOUS MUONS.

IS THE LIMIT ON $\mu + \geq 3$ prongs COMPATIBLE WITH CHARM ?

Assume that:

→ $\sigma(e^+e^- \to c\bar{c}) \approx$ 5.2 nb @ 4.8 GeV ($\Delta R = 1.5$)

→ prob. of $c \to \geq 3$ chgd. part $\approx .7$

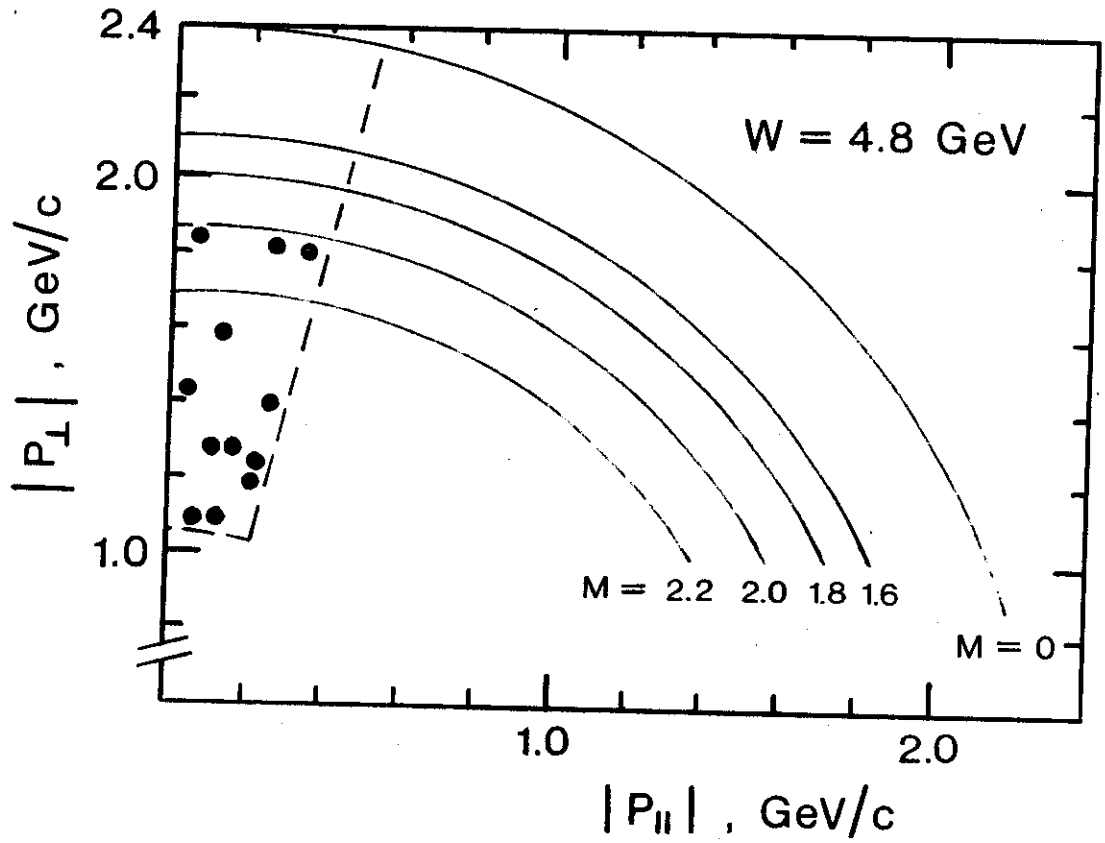
(Einhorn + Quigg)

from limit on $\mu + \geq 3$ pr.

$$\frac{\Gamma(c \to K\mu\nu)}{\Gamma(c \to \text{all})} \lesssim .12$$

NOT A STRINGENT LIMIT

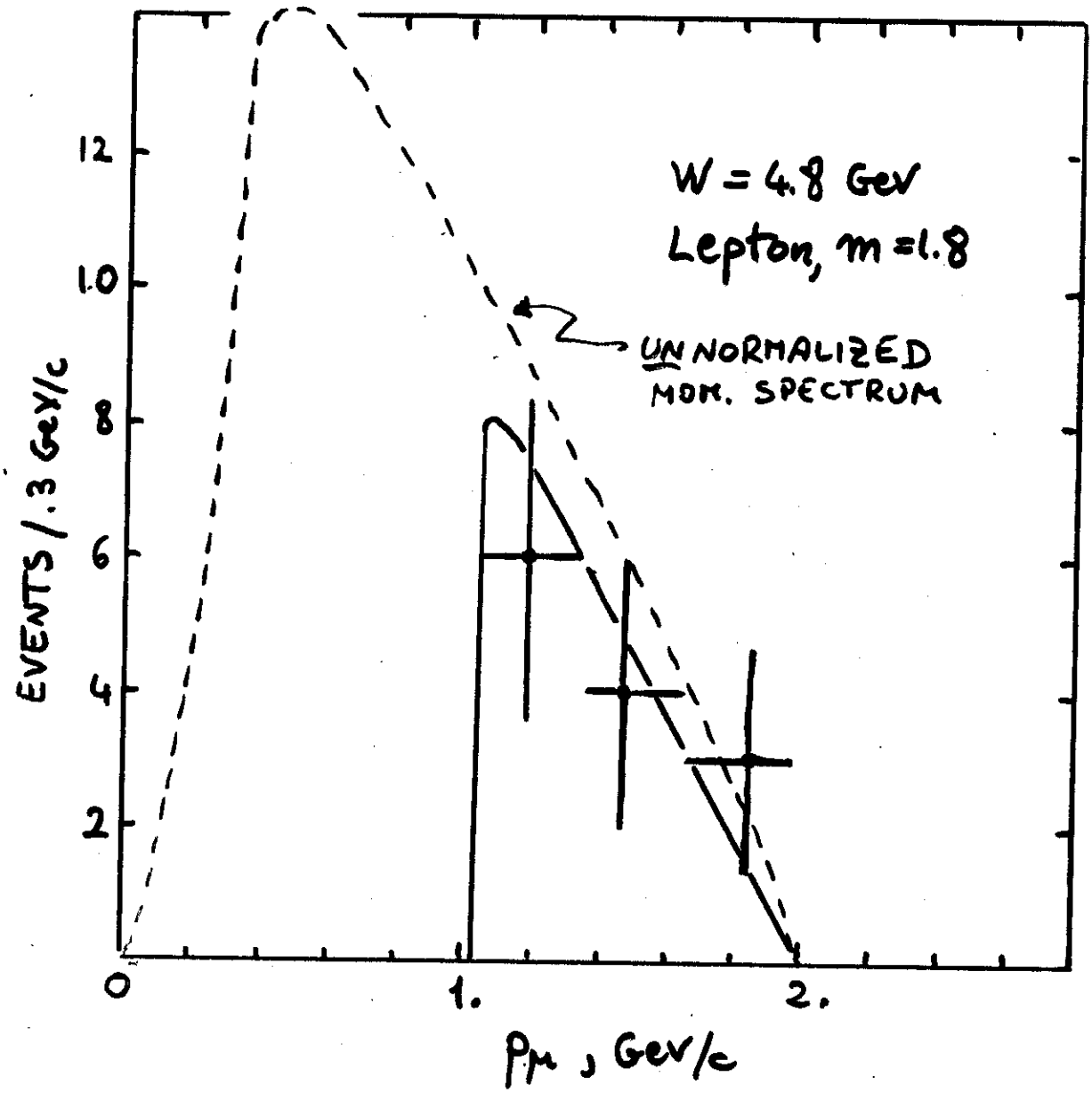
∴ NO INCONSISTENCY BETWEEN CHARM IN e^+e^- AND LIMIT ON σ ($\mu + \geq 2$ pr.)

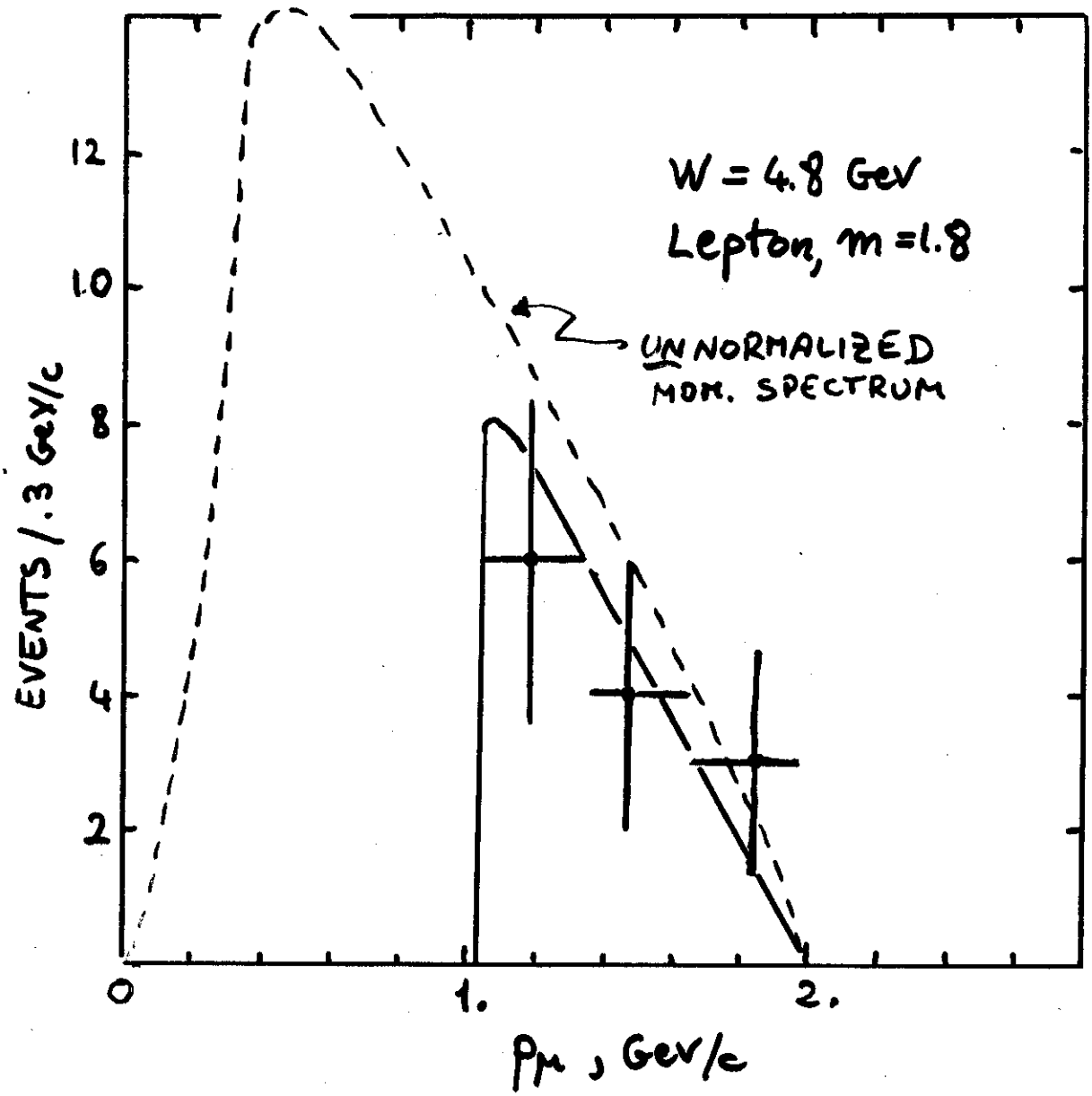

2.4
2.0
1.0
W = 4.8 GeV
M = 2.2 2.0 1.8 1.6
M = 0
1.0
2.0
|P⊥| , GeV/c
|P∥| , GeV/c

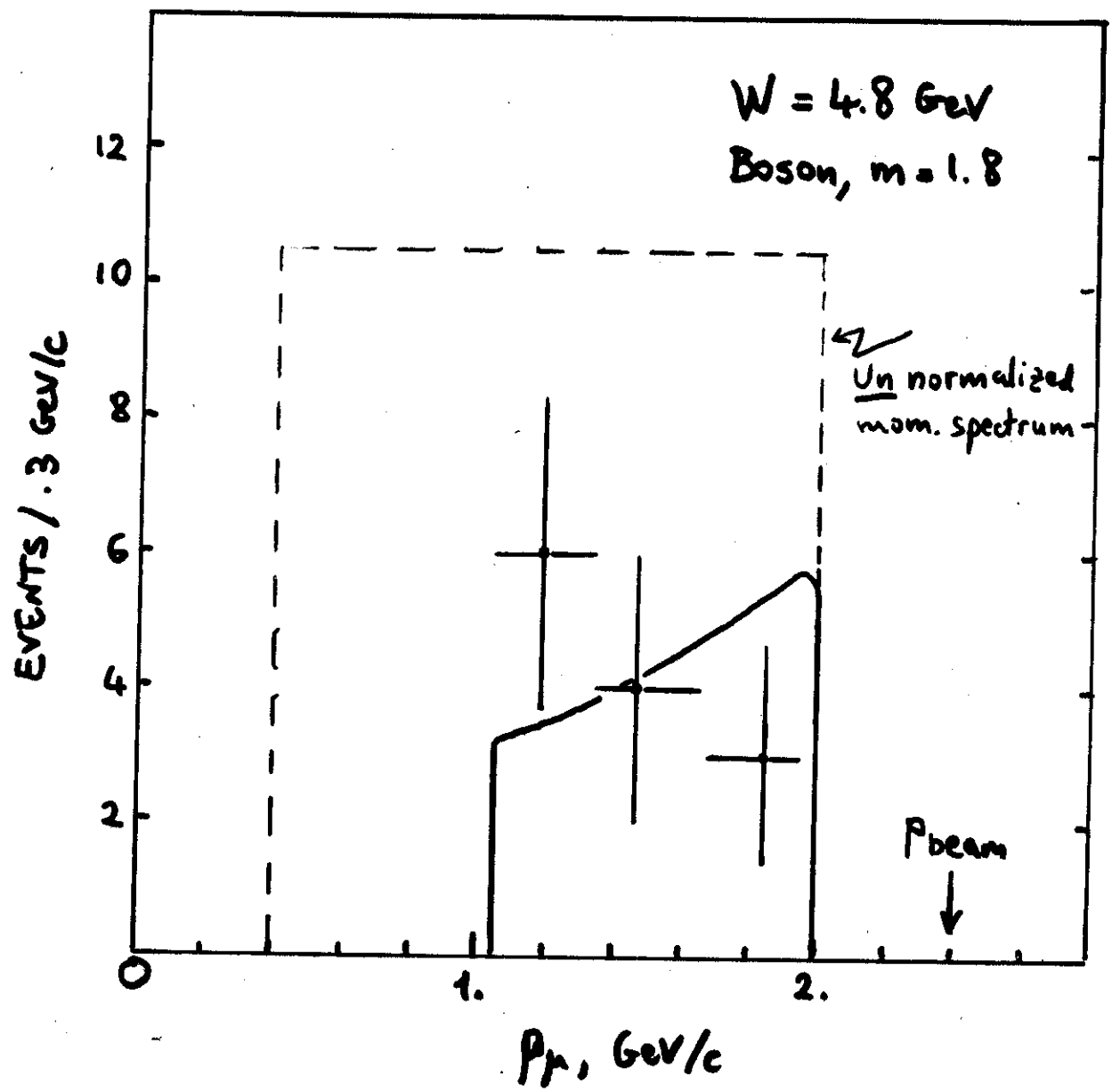
μ + 1 pr. : MOMENTUM SPECTRA

Mass = 1.8 GeV

THREE-BODY DECAYS	TWO-BODY DECAYS
→ Take heavy lepton $L \to \mu \nu_L \bar{\nu}_\mu$	→ Take heavy boson $B \to \mu \nu$
→ Decay like $\mu \to e \nu \nu$	→ (p^*_μ monochromatic)
→ $f(p^*_\mu) = \frac{p^*_\mu}{p^*_{\mu max}} \left(3 - 2 \frac{p^*_\mu}{p^*_{\mu max}}\right)$	


W = 4.8 GeV
Lepton, m = 1.8
UNNORMALIZED
MOM. SPECTRUM
EVENTS / .3 GeV/c
12
10
8
6
4
2
0
1.
2.
Pm , GeV/c


W = 4.8 GeV
Lepton, m = 1.8
UNNORMALIZED
MOM. SPECTRUM
EVENTS / .3 GeV/c
0
2
4
6
8
10
12
1.
2.
Pμ , GeV/c


W = 4.8 GeV
Boson, m = 1.8
Un normalized
mom. spectrum
P beam
EVENTS / .3 GeV/c
P_μ, GeV/c
0
2
4
6
8
10
12
1.
2.

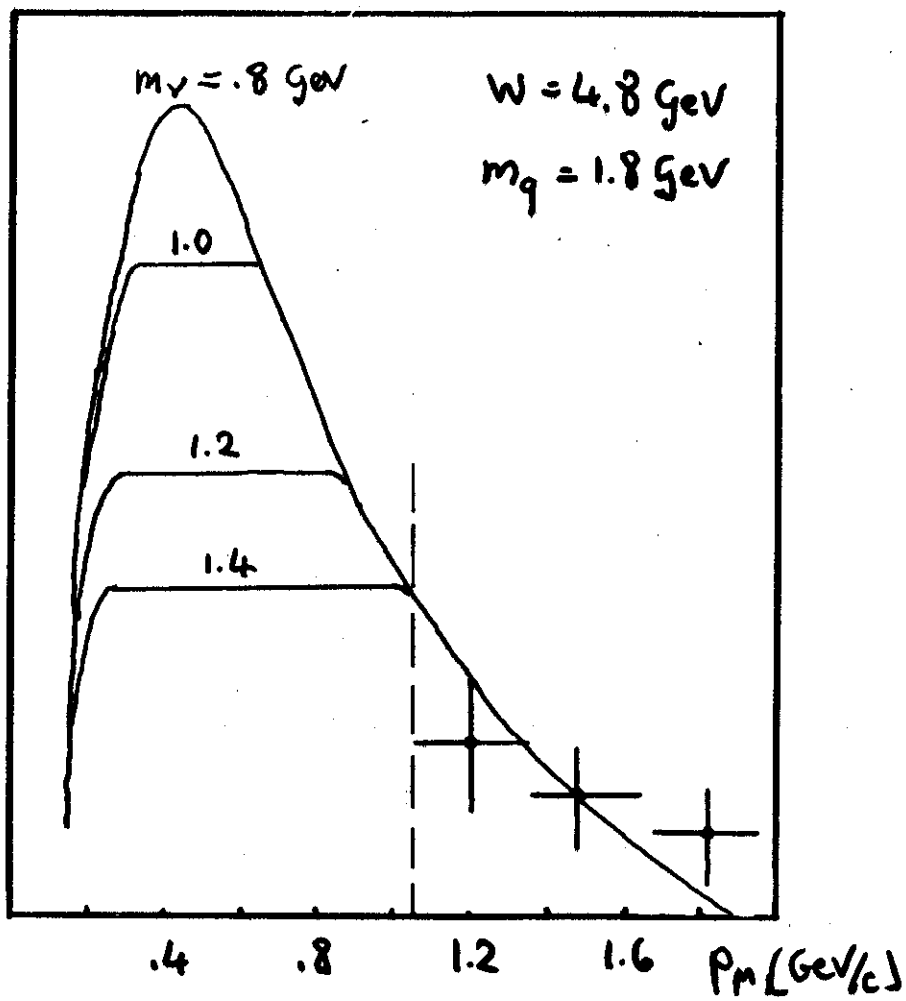
QUARK → GLUON DECAY

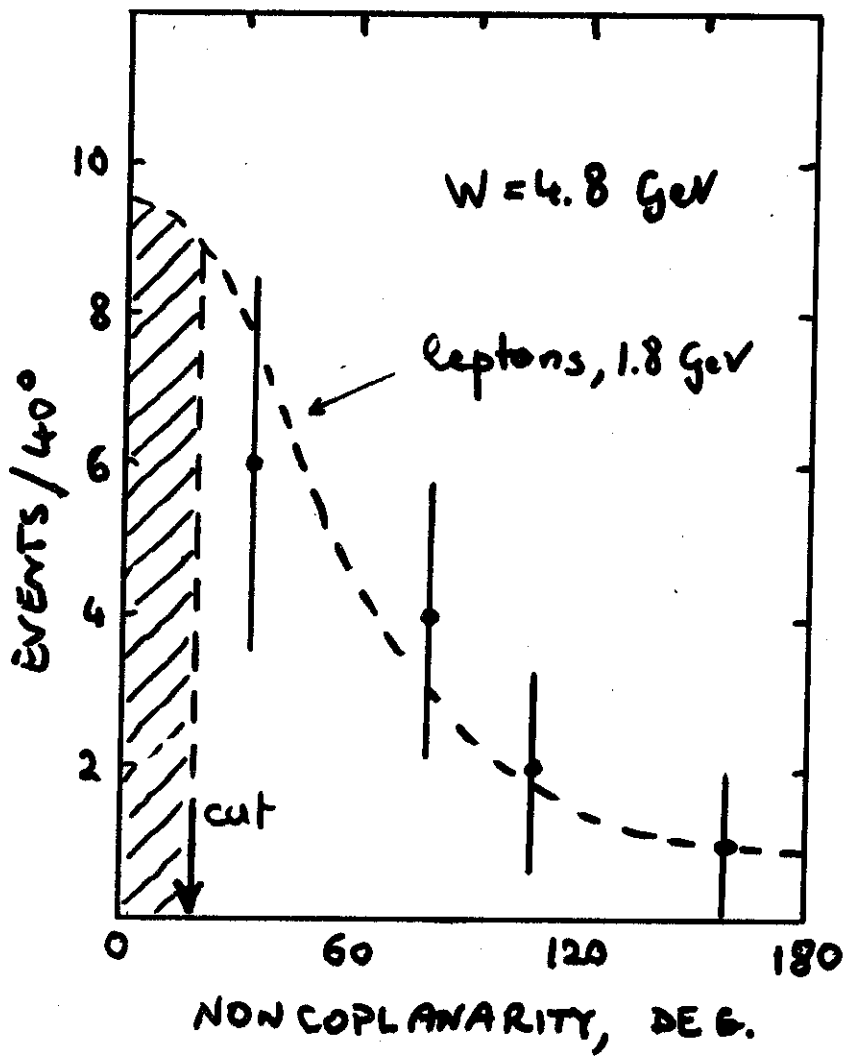
→ $e^+e^- \rightarrow q\bar{q}$

$\hookrightarrow \nu_e^- + \nu_e$

$\hookrightarrow \mu^- + \nu_\mu$

→ Spectrum computed by
Sakurai bara, Kayser, Pati', Zorn



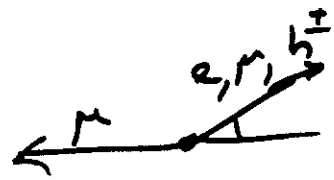

W = 4.8 GeV
leptons, 1.8 GeV
cut
EVENTS / 40°
10
8
6
4
2
0
60
120
180
NON COPLANARITY, DEG.

HEAVY LEPTON HYPOTHESIS

(1) MUONIC BRANCHING RATIO

→ for $m_L = 1.8$ GeV, $\sigma_{\mu x} = 1.5^{+.8}_{-.6}$ nb

$$\frac{\sigma_{\mu x}}{\sigma_{LL}} = .41 \pm^{.21}_{.16}$$



$$\rightarrow \frac{\sigma_{\mu x}}{\sigma_{LL}} = 2B_\mu(B_\mu + B_e + B_h)$$

but since $B_\mu + B_e + B_h + B_{multih} \equiv 1$

and we see $B_{multih} \simeq 0$

$$\frac{\sigma_{\mu x}}{\sigma_{LL}} \simeq 2B_\mu \rightarrow \boxed{B_\mu = .2^{+.10}_{-.08}}$$

(H.L., Tsai: $B_\mu = .18$)

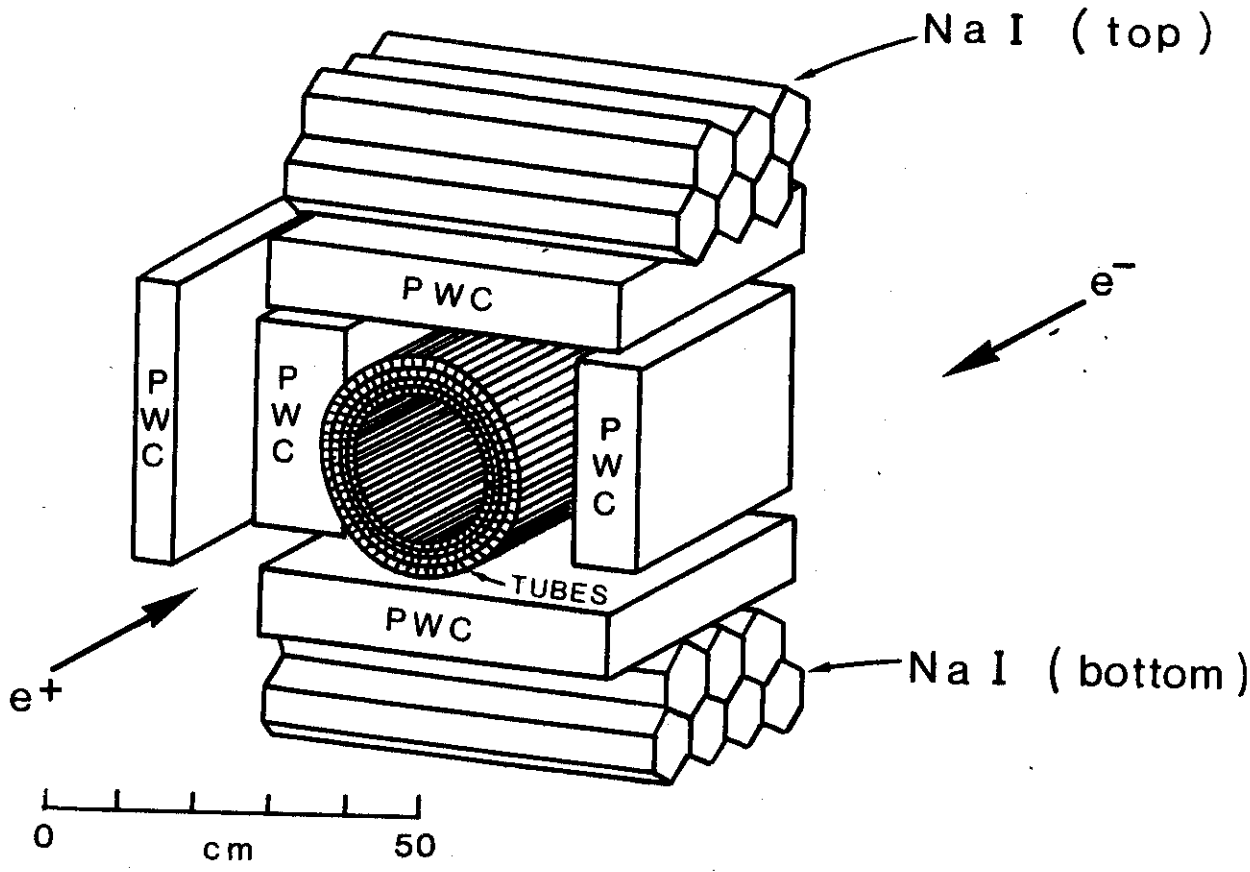
(2) COMPARISON WITH $e\mu$ EVENTS (SLAC-LBL)

$$\sigma_{e\mu} = \sigma_{\mu x} B_e = .27^{+.14}_{-.10} \text{ nb}$$

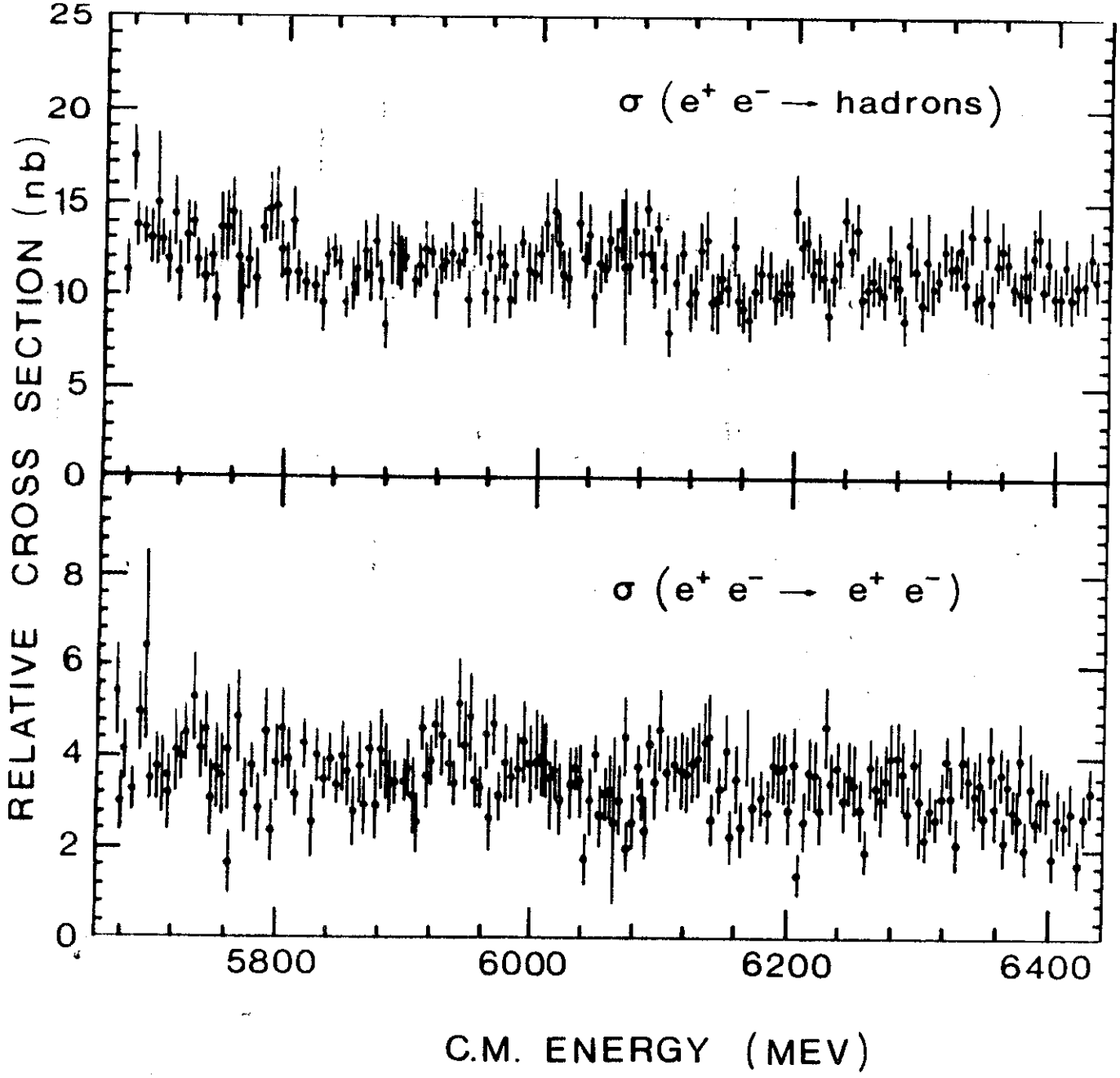
SLAC-LBL: $\sigma_{e\mu}(\text{H.L. decay}) = .32 \pm .08$ nb

CONCLUSIONS ON OBSERVED ANOMALOUS MUON PRODUCTION

1. Cannot be explained by charm only
2. Limit on $\mu+ \geq 2$ prong OK with charm
3. Multiplicity ratios consistent with heavy lepton and quark/gluon decays
4. Mom. spectrum prefers 3-body decays
5. B_μ agrees with H.L.
6. If heavy lepton decay, consistent with $e\mu$ events.



CENTRAL DETECTOR
FOR 6 GeV ENERGY SCAN


σ (e⁺ e⁻ → hadrons)
σ (e⁺ e⁻ → e⁺ e⁻)
RELATIVE CROSS SECTION (nb)
C.M. ENERGY (MEV)
25
20
15
10
5
0
8
6
4
2
0
5800
6000
6200
6400

Limits on narrow-resonance widths from 6 GeV scan

→ $e^+e^- \to$ hadrons: (95% c.l.)

$\Gamma \sim 0$: $\int \sigma_{had}\, dE < 90$ nb-MeV

$\Gamma = 70$ MeV: $\int \sigma_{had}\, dE < 240$ nb-MeV

→ $e^+e^- \to e^+e^-$ (95% c.l.)

$\Gamma \sim 0$: $\int \sigma_{ee}\, dE < 140$ nb-MeV

$\Gamma = 70$ MeV: $\Gamma_{ee}/\Gamma < 6 \times 10^{-6}$

SP-27 : MP^2S^3D

(Inclusive γ-spectroscopy of ψ', ψ)

MARYLAND
- D.H. Badtke
- B.A. Barnett
- L.H. Jones
- G.T. Zorn

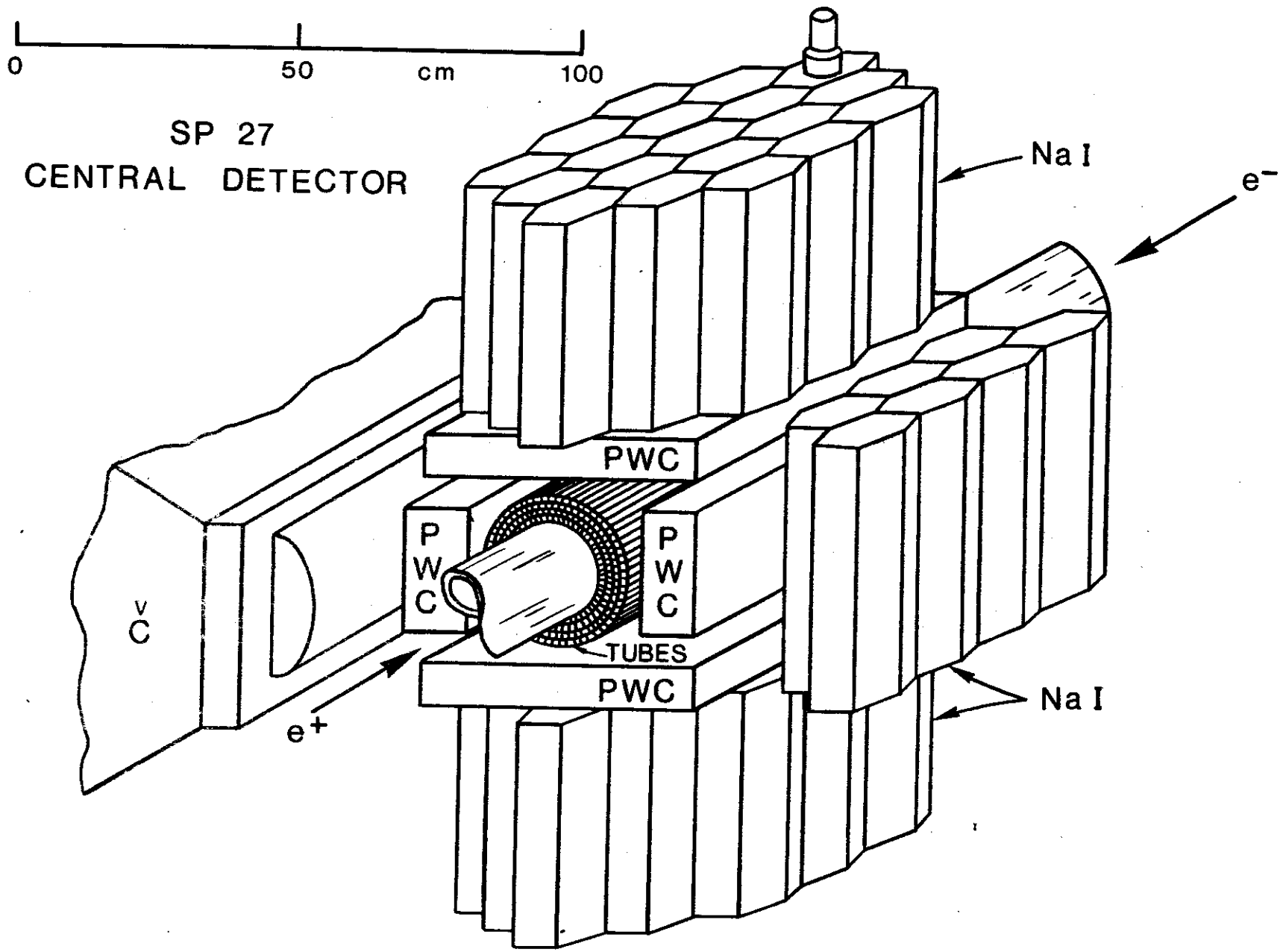
PAVIA
- M. Cavalli-Sforza
- G. Goggi
- F. Iu[illegible]zzeri
- M. Livan
- F. Pastore
- B. Rossini

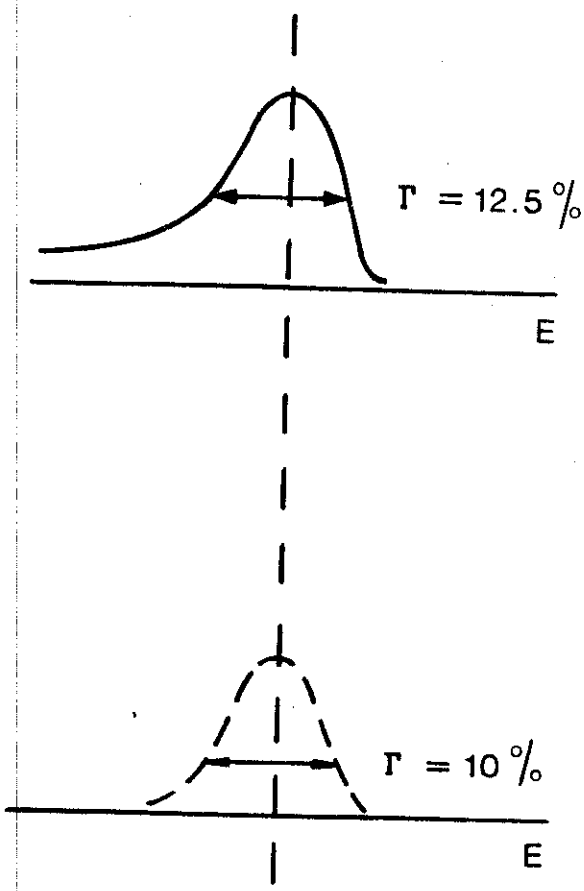
PRINCETON
- D.G. Aschman
- D. Groom
- D.G. Coyne
- G.K. O'Neill
- H.F.W. Sadrozinski
- K.A. Shinsky

SAN DIEGO
- C. Biddick
- C. Burnett
- G. Masek
- E. Miller
- J. Smith
- J. Stronsky
- M. Sullivan
- W. Vernon

STANFORD
- R.L. Ford
- E. Hilger
- R. Hofstadter
- E. Hughes
- L.A. O'Neill
- J.W. Simpson

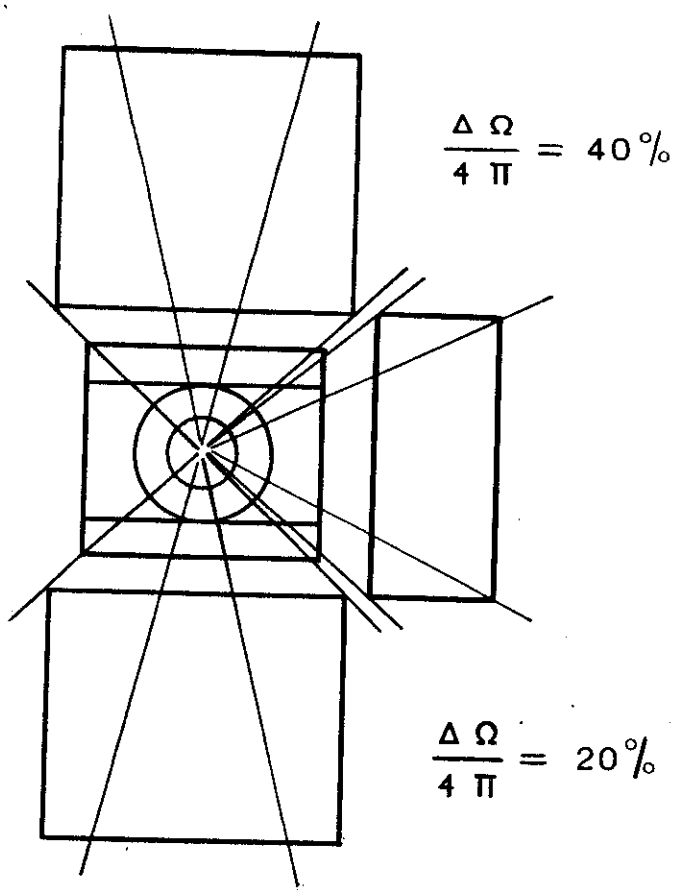
SLAC
- L. Keller
- D. Lyon

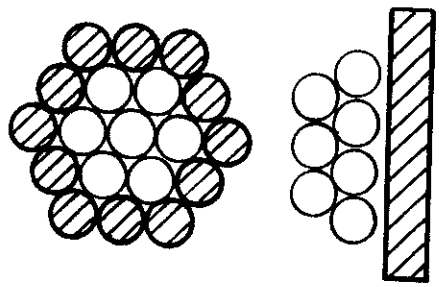

0
50
cm
100
SP 27
CENTRAL DETECTOR
Na I
e⁻
PWC
P
W
C
P
W
C
V
C
TUBES
PWC
e+
Na I



RESOLUTION FUNCTION FROM HEPL CALIBRATION

VIEW ALONG BEAMS





TOP VIEW

SP-27 TRIGGERS :

#1 : ≥ 2 charged part. in prop. tubes
≥ 70 MeV in NaI crystals

#2 : ≥ 2 NaI stacks
≥ 250 MeV in NaI crystals

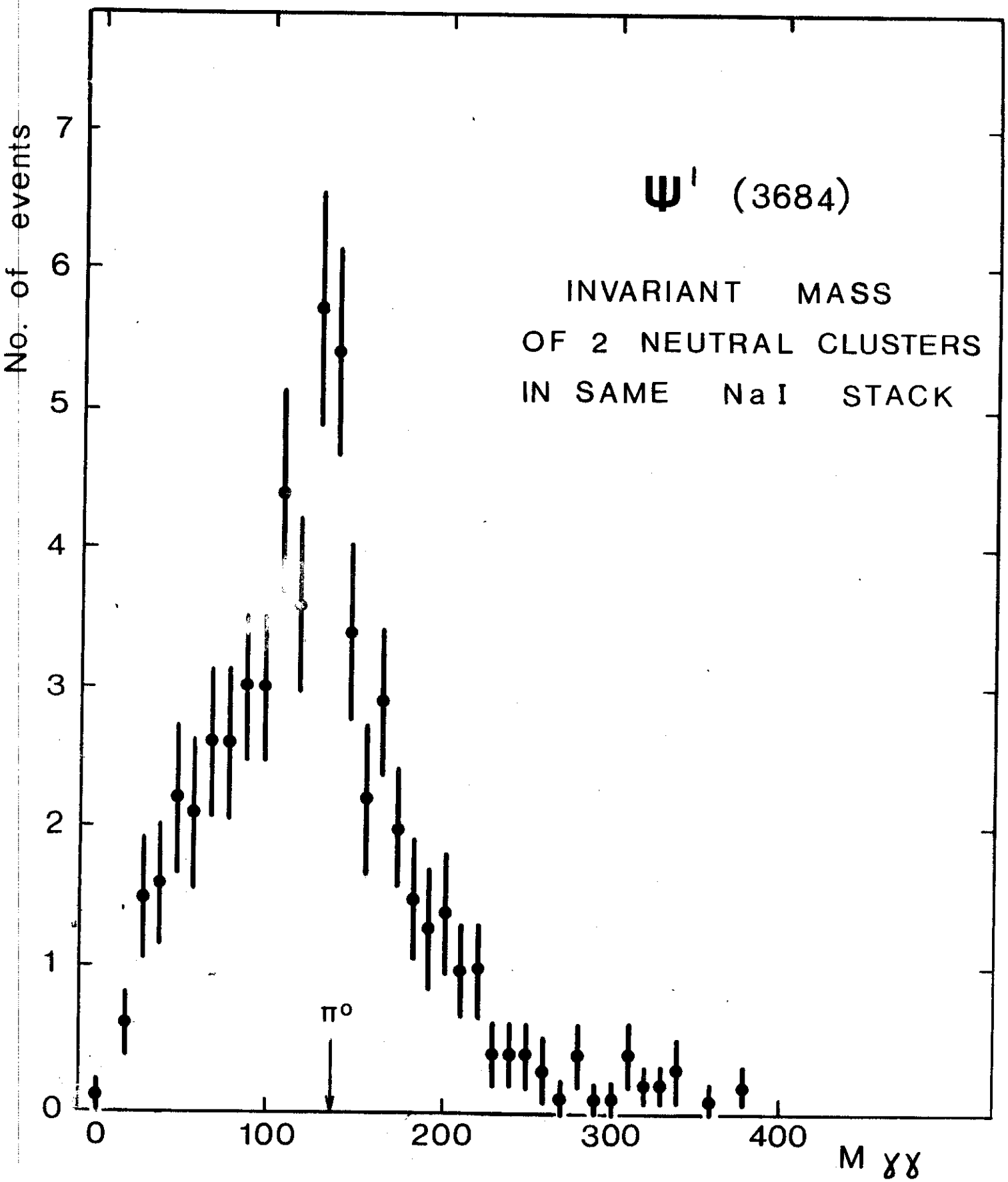
BACKGROUNDS :

1. Machine junk (vetos at small angle + veto large clusters in tubes)
2. Cosmic rays (TOF gate, int. region)
3. "Physics" : π^0's, η from ψ', ψ decays

CUTS: (after reconstruction)

1. ≥ 2 clean tracks in tubes, pointing to I.R.
2. Fiducial cut on origin along beam line
3. TOF gate (± 25 ns)
4. NaI (inner energy/outer energy) $\geq .9$
5. "Cosmic ray" cut
6. Neglect NaI stack containing :
   ≥ 2 chgd. particle clusters
   or ≥ 2 neutral clusters

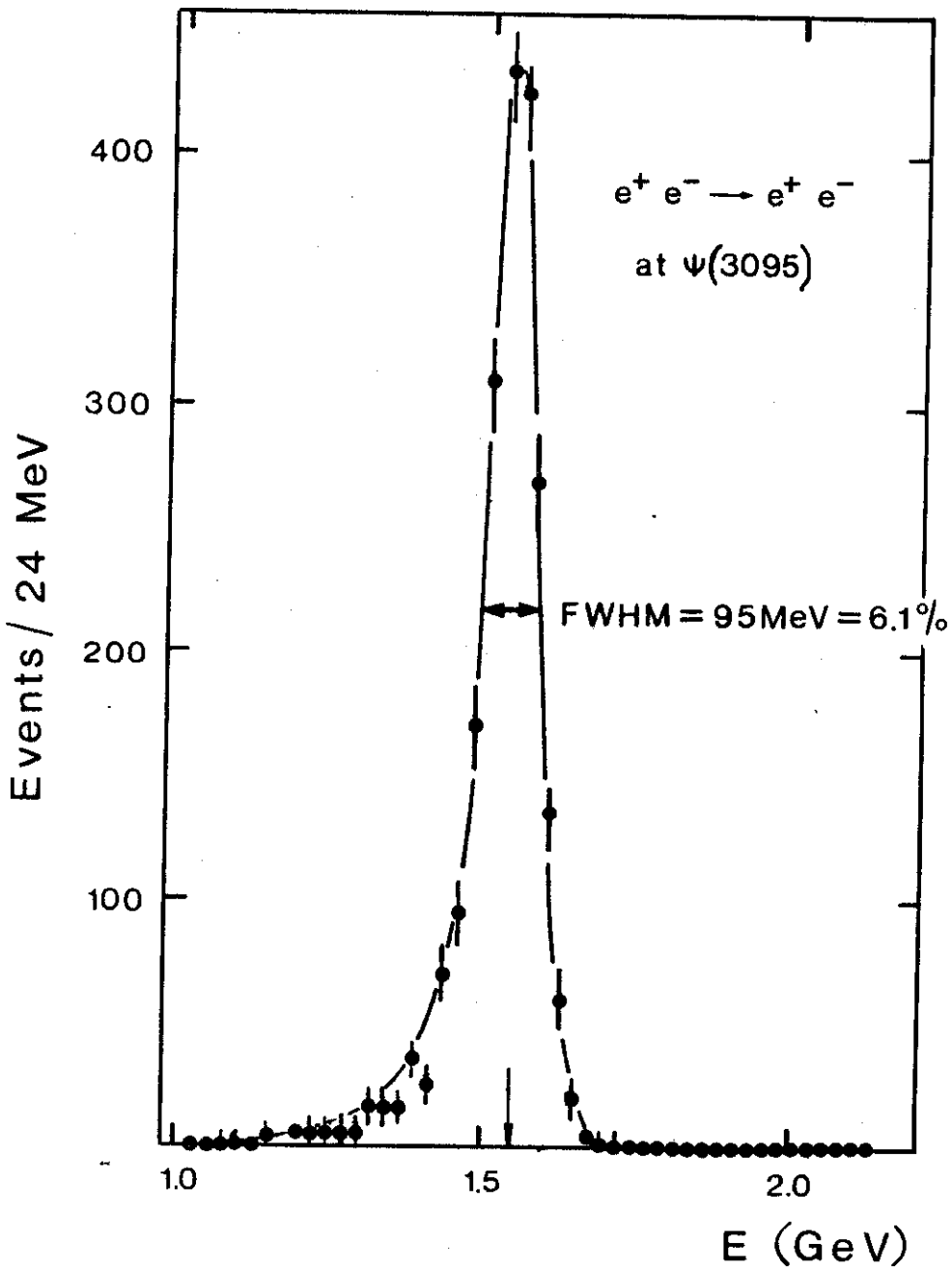
Residual cosmic ray contam $\approx 1.5\%$

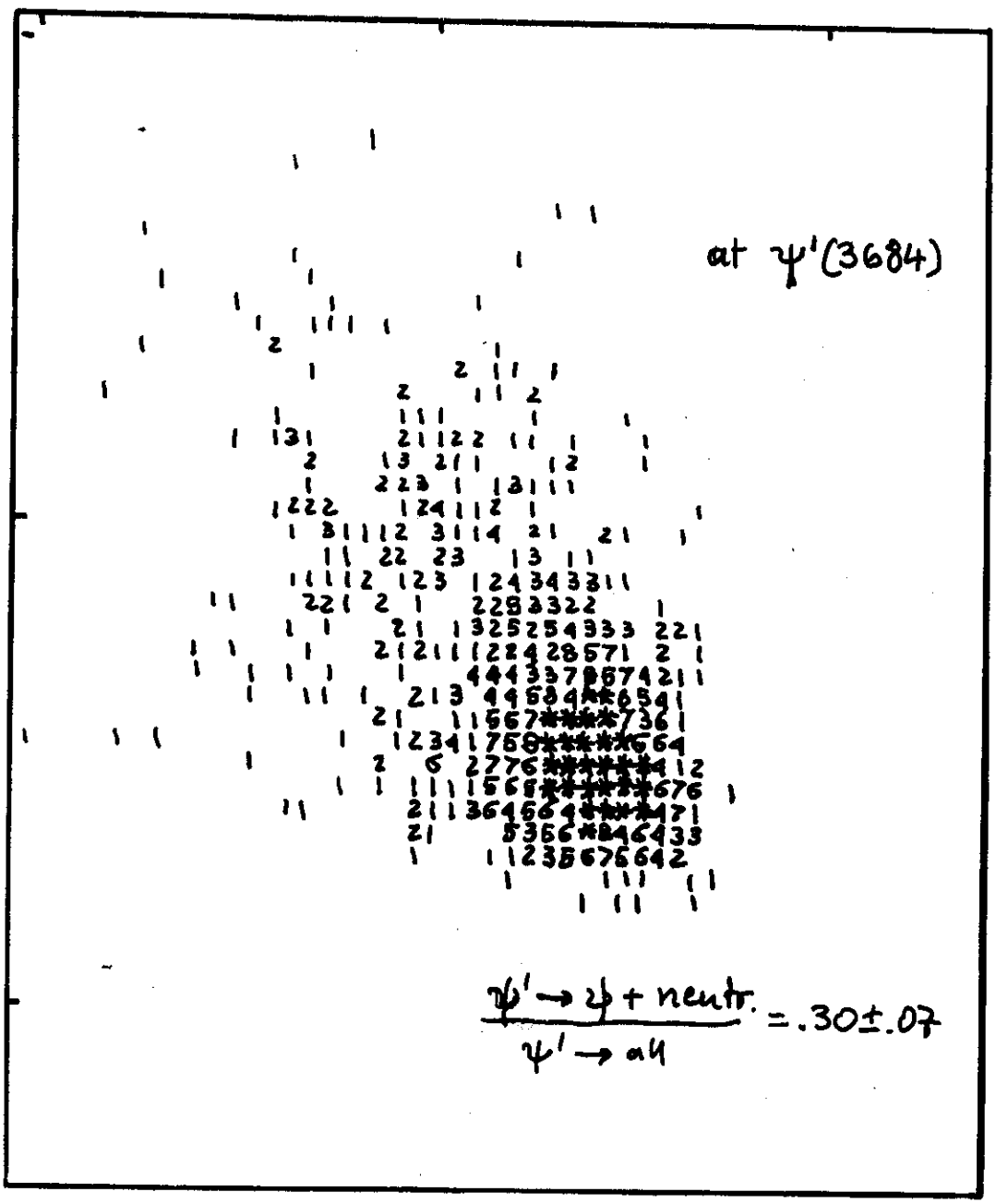

No. of events
0
1
2
3
4
5
6
7
0
100
200
300
400
M γγ
π°
Ψ' (3684)
INVARIANT MASS
OF 2 NEUTRAL CLUSTERS
IN SAME NaI STACK

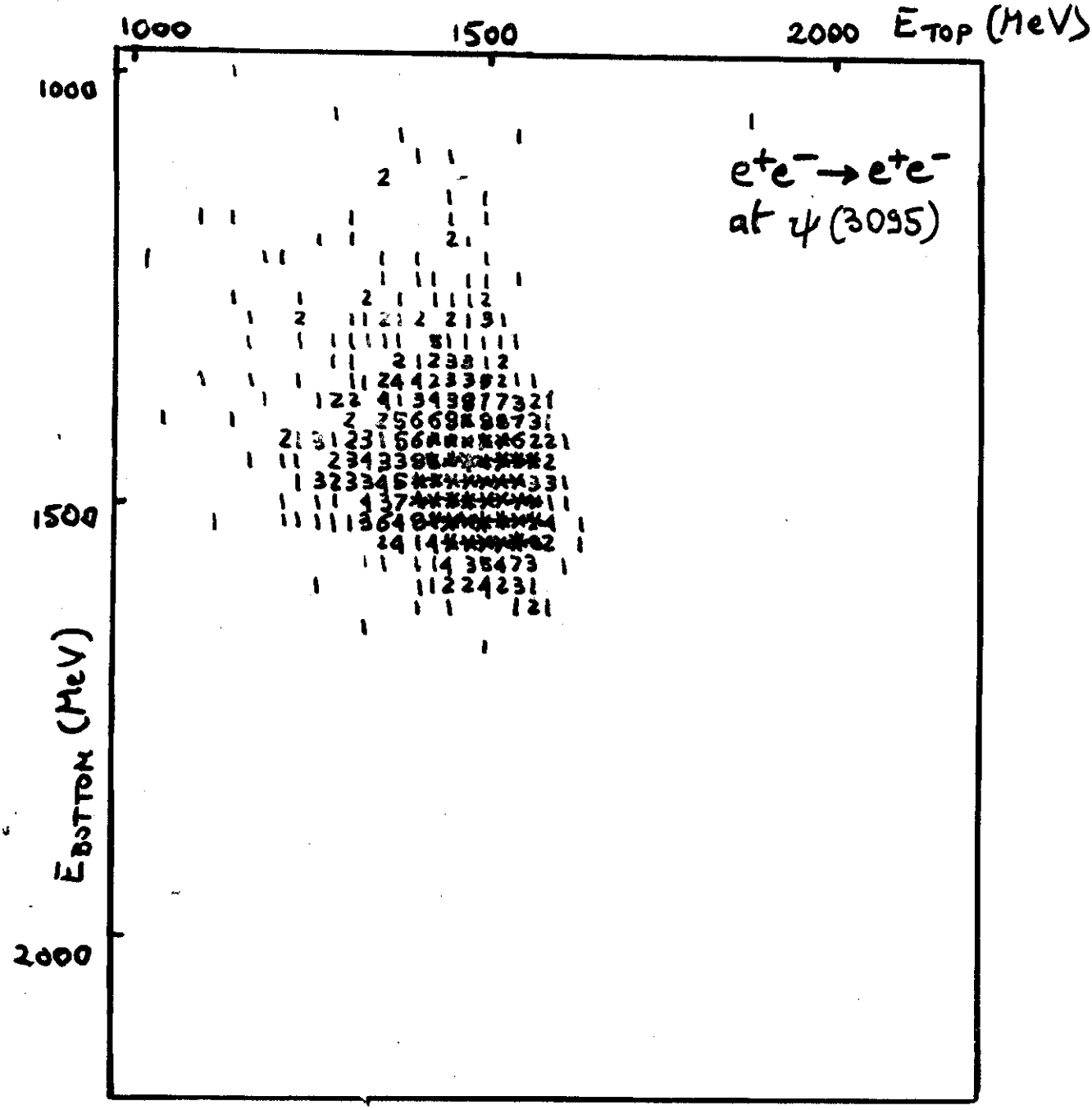
SP-27 DATA SUMMARY

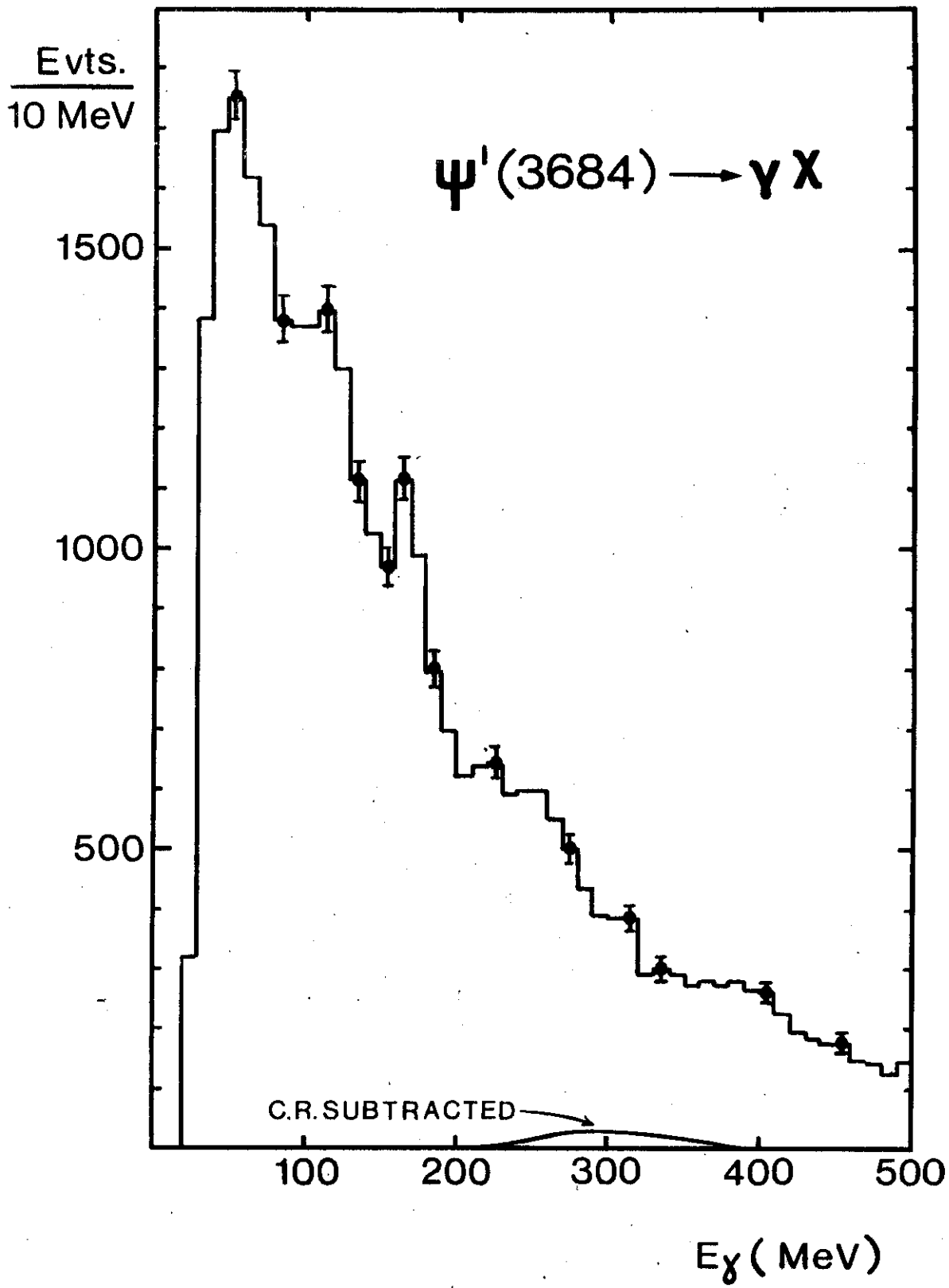
	$\psi'(3684)$	$\psi(3095)$
$\int \mathcal{L}\, dt$	550 nb^{-1}	104 nb^{-1}
Physics triggers	360 K evts	230 K evts
e^+e^- pairs in NaI	3.5K evts	2K evts
≥ 2 chgd. + $\geq 1\gamma$	35 K evts	27 K evts

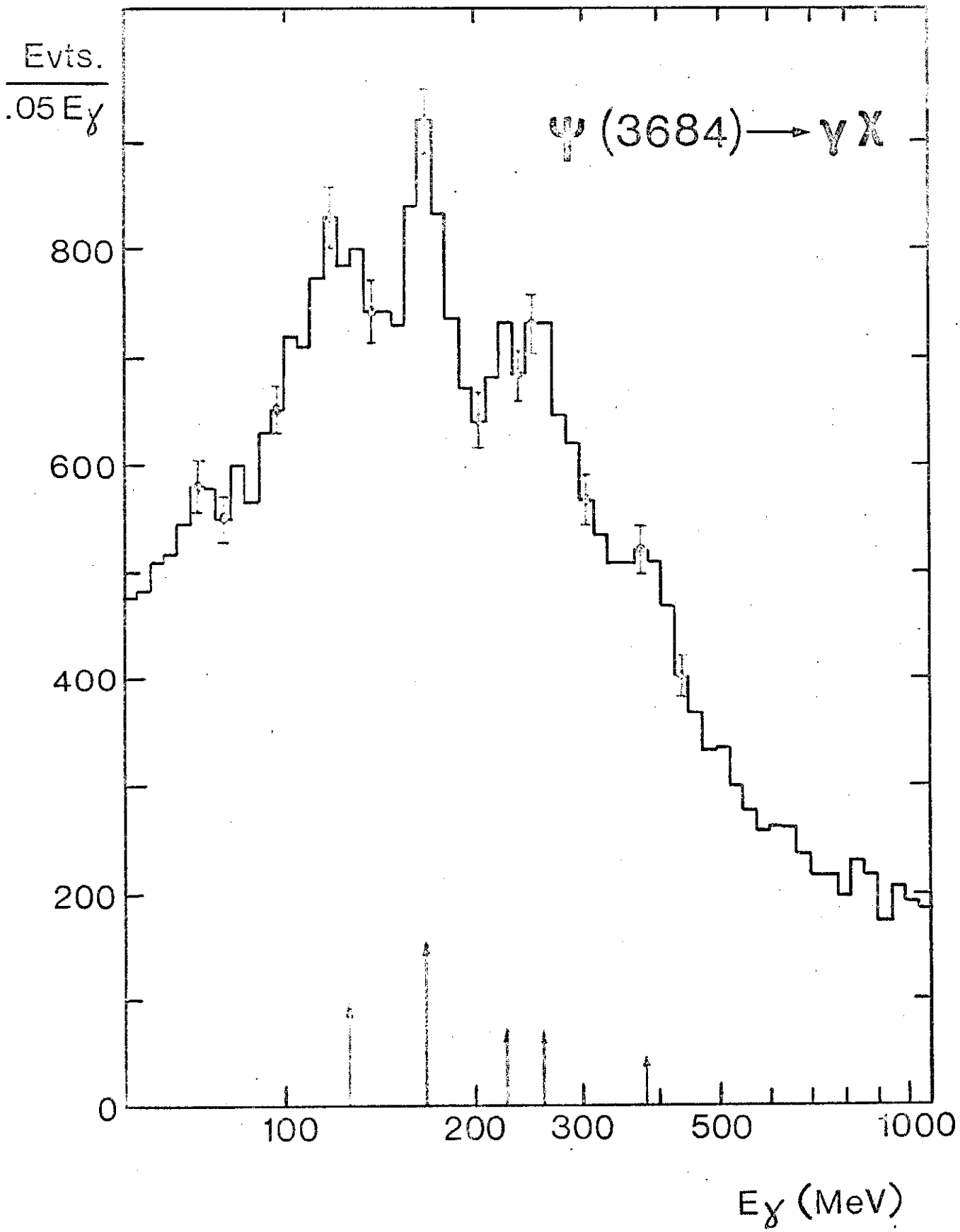
No neutral triggers yet

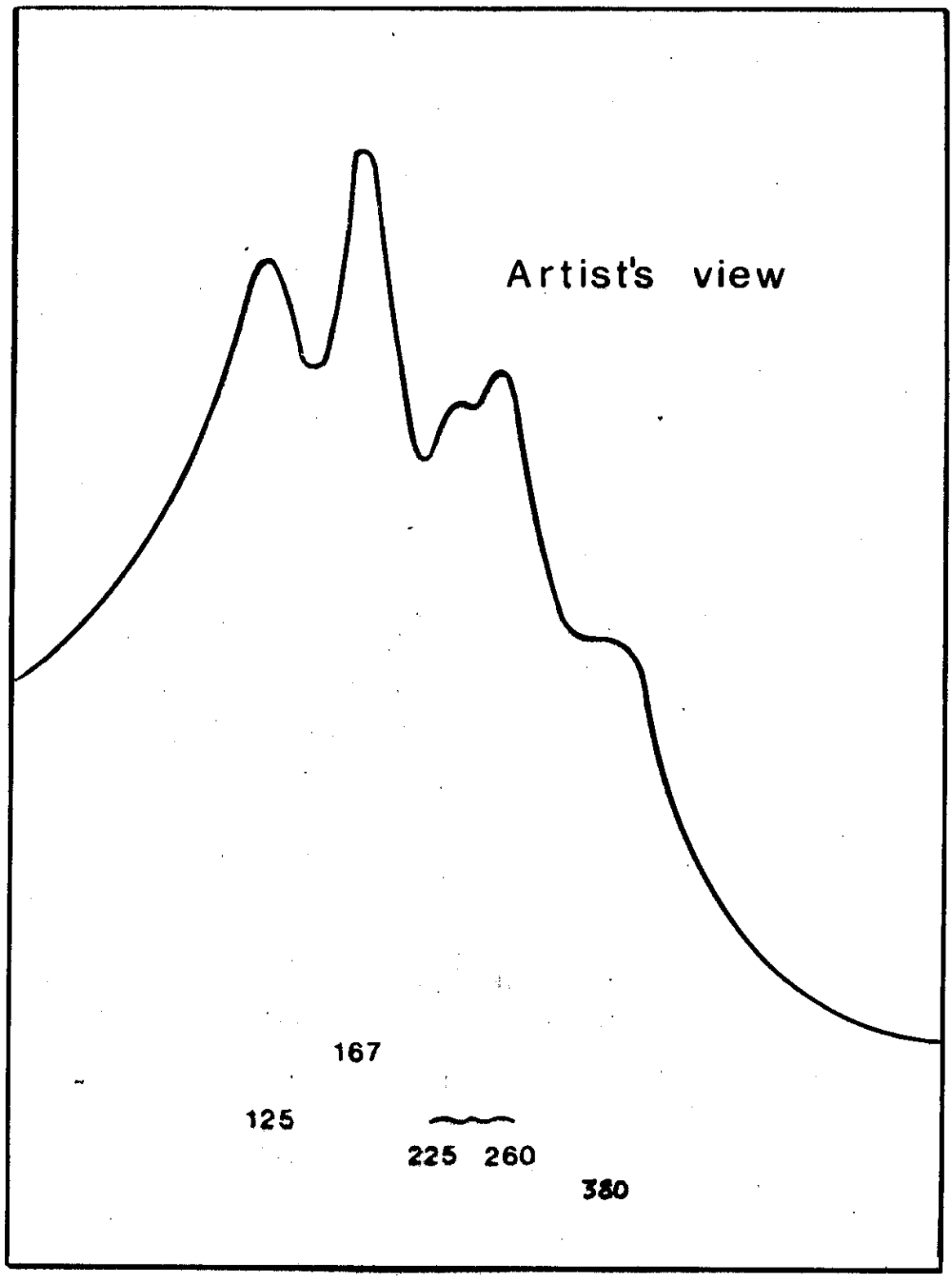

400
300
200
100
Events / 24 MeV
$e^+ e^- \rightarrow e^+ e^-$
at ψ(3095)
FWHM = 95MeV = 6.1%
1.0
1.5
2.0
E (GeV)

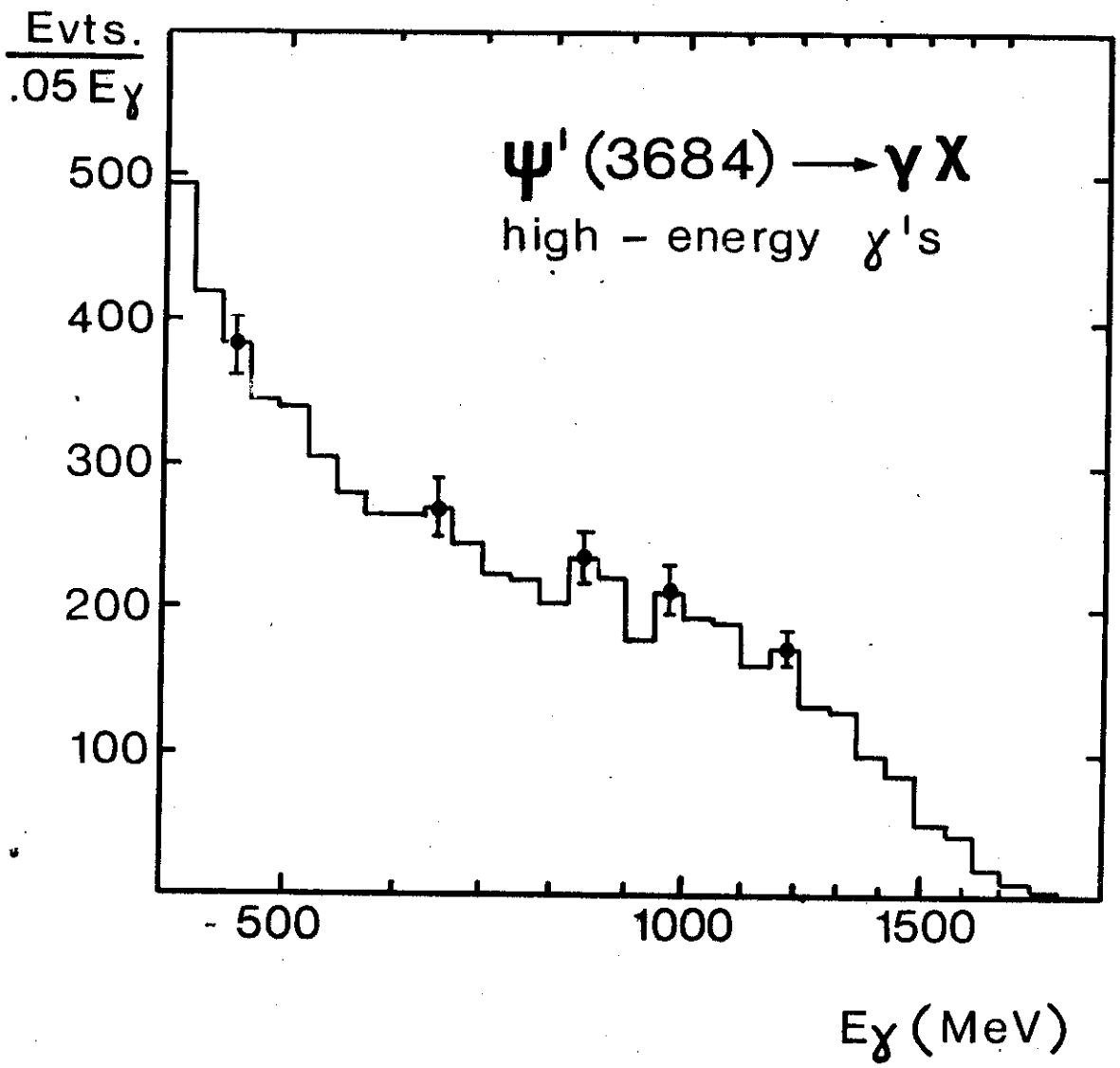

at ψ'(3684)
ψ' → ψ + neutr. / ψ' → all = .30±.07


1000
1500
2000
E_TOP (MeV)
1000
1500
2000
E_BOTTOM (MeV)
e+e− → e+e−
at ψ(3095)

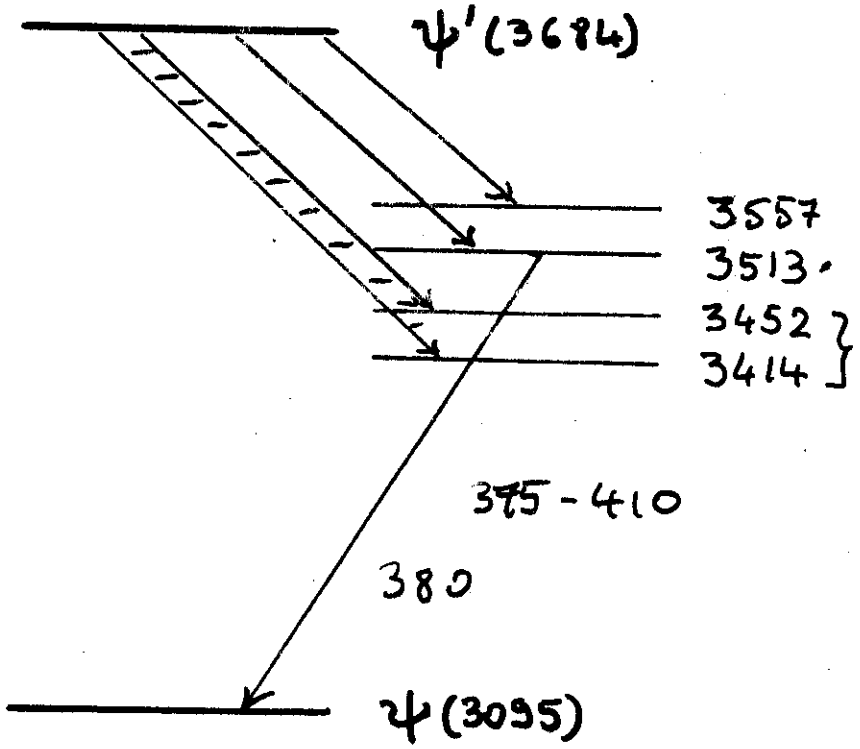

Evts.
10 MeV
ψ'(3684) → γ X
1500
1000
500
C.R. SUBTRACTED
100
200
300
400
500
Eγ (MeV)


Evts.
.05 Eγ
ψ (3684) → γ X
800
600
400
200
0
100
200
300
500
1000
Eγ (MeV)

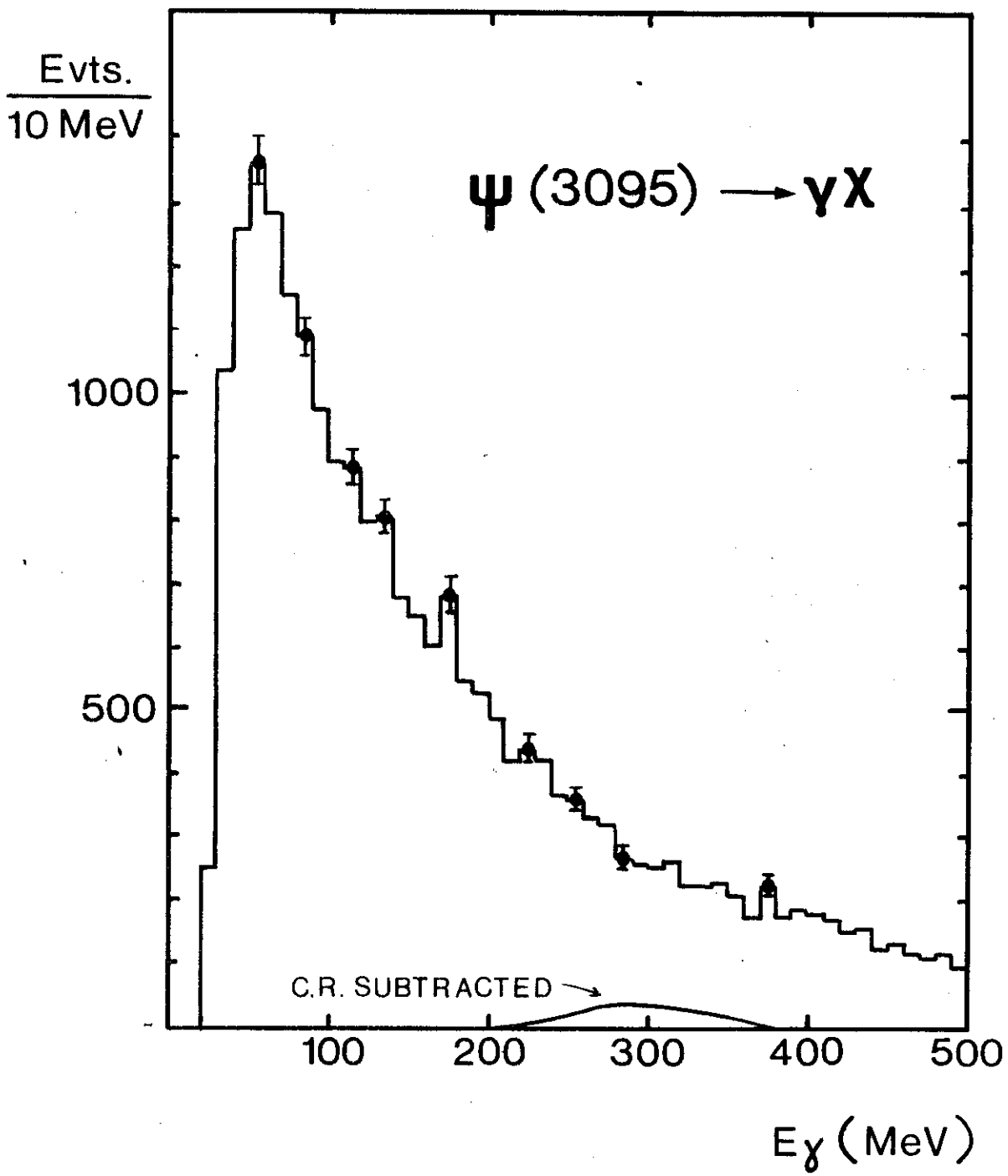

Artist's view
167
125
225 260
380

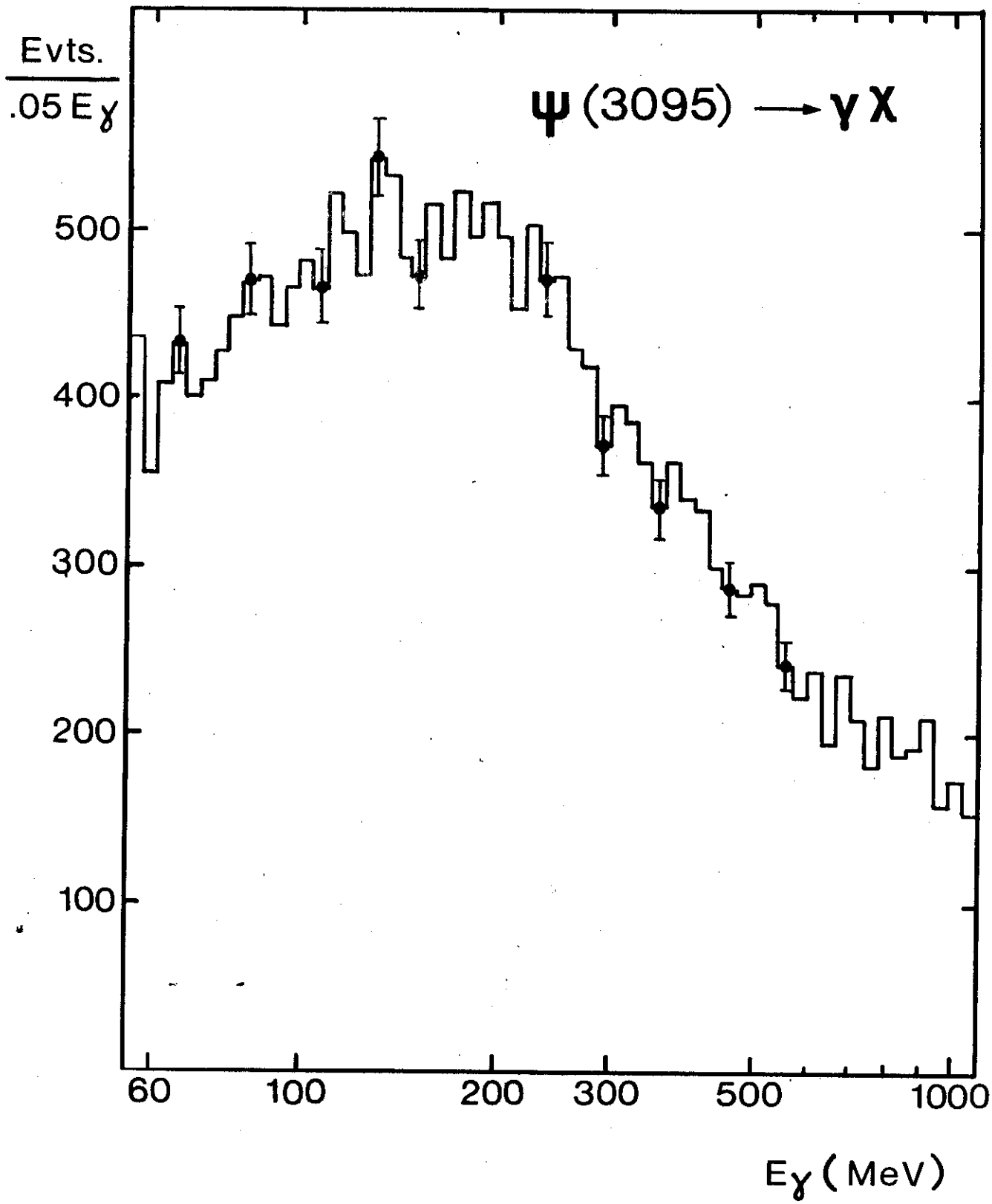

Evts.
.05 Eγ
500
400
300
200
100
ψ' (3684) → γ X
high - energy γ's
- 500
1000
1500
Eγ (MeV)

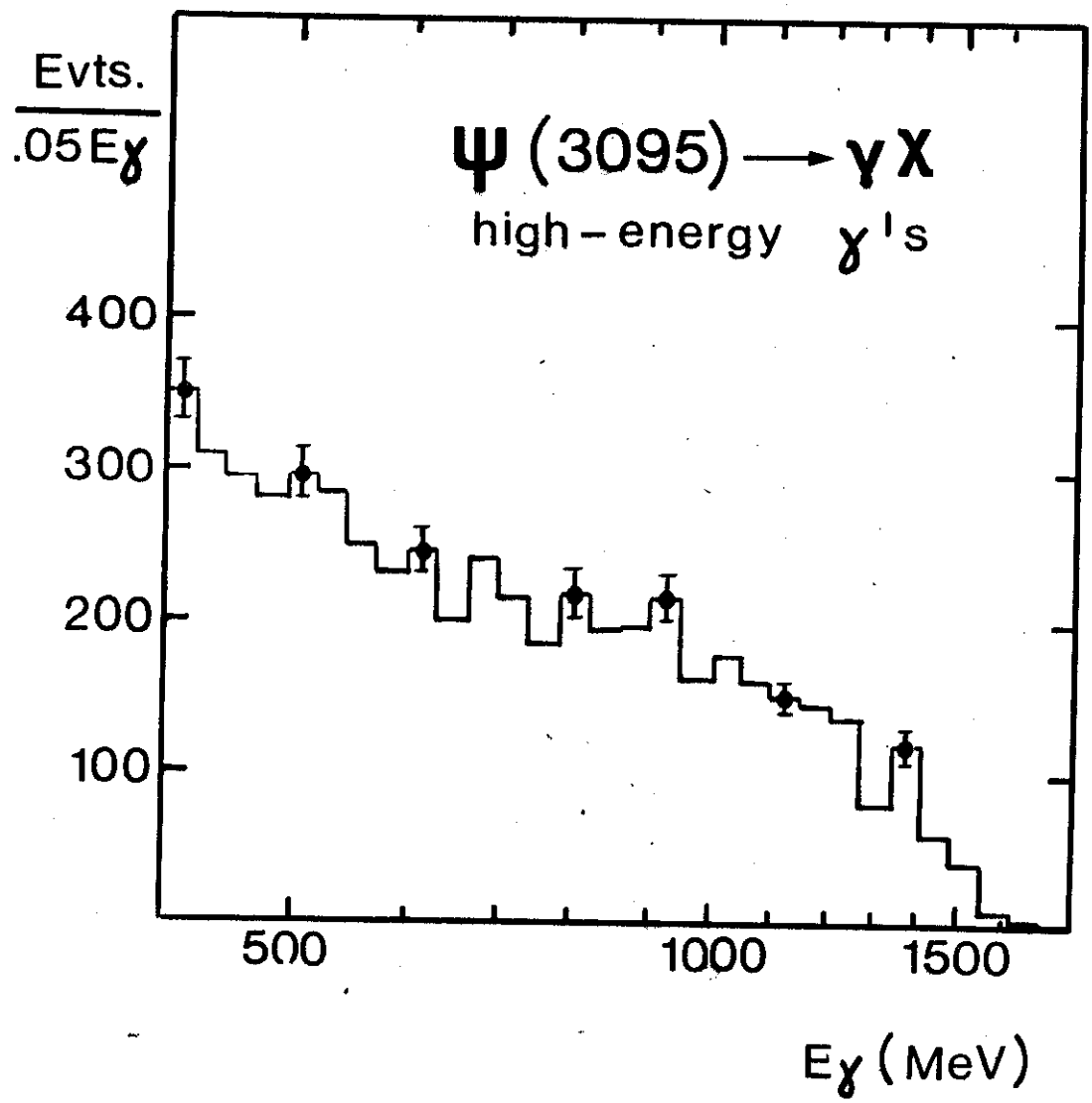
ψ' RADIATIVE DECAYS



E_γ (MeV)	Decay	VERY ROUGH BR RATIO	Previously seen
125	$\psi' \to \gamma + 3557$	3-7%	$\chi(3530)$ SLAC-LBL
167	$\psi' \to \gamma + 3513$	6-9%	$P_c(3510)$ DASP, SLAC-LBL
225 }	$\psi' \to \gamma + 3452$	} 3-6%	Nwr, SLAC-LBL
260 }	$\psi' \to \gamma + 3414$	} 3-6%	$\chi(3410)$, SLAC-LBL
380	$3513 \to \gamma + \psi$	(broad)	DASP, SLAC-LBL


Evts.
10 MeV
ψ (3095) → γX
1000
500
C.R. SUBTRACTED
100
200
300
400
500
Eγ (MeV)


Evts.
.05 Eγ
ψ (3095) → γ X
500
400
300
200
100
60
100
200
300
500
1000
Eγ (MeV)


Evts.
.05Eγ
ψ (3095) → γ X
high-energy γ's
400
300
200
100
500
1000
1500
Eγ (MeV)