The RadPhi Experiment at Jefferson Lab

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Abstract

The scalar mesons, the $f_0(980)$ and the $a_0(980)$, have been receiving much attention of late. The low values of their masses and widths bring into question their assignment to the $^3P_0$ $\overline{q}q$ scalar nonet and recent Crystal Barrel results have uncovered scalar states with more appropriate masses and widths. It has been suggested that the $f_0(980)$ and the $a_0(980)$ are molecules or 4-quark states. This talk will review recent results from BNL (Brookhaven AGS) experiment E852 in which the $f_0(980)$ and the $a_0(980)$ are produced in the $\pi^0\pi^0$ and $\pi^0\eta$ channels, respectively, in π-induced reactions. Hadroproduction characteristics of these states may reveal their nature. The $a_0(980)$ is also observed in $f_1(1285) \rightarrow \eta\pi\pi$. At JLAB (formerly CEBAF), an experiment is under construction to look for the rare radiative decays $\phi \rightarrow f_0(980)\gamma$ and $\phi \rightarrow a_0(980)\gamma$. The ratio of these branching ratios is also expected to provide information on the substructure of these scalars. These measurements are feasible since intense photon beams will yield a high rate of ϕ's. The possibility also exists of studying low-mass $\pi^0\pi^0$ and $\pi^0\eta$ scattering in $\eta' \rightarrow \eta\pi^0\pi^0$ at BNL and JLAB.

Hadron 97
BNL
Aug. 25-29

Rad Phi

An Experiment to Measure Radiative Decays of the ϕ meson

E 94 - 16

Catholic U., U. Connecticut, *Indiana U., Notre Dame,
*Rensselaer, U. Richmond, U. Virginia, William & Mary,
and Jefferson Lab

R.T. Jones

1. Primary physics issue: radiative couplings of $a_0/f_0(980)$
2. Technique: photoproduction as a source of boosted ϕ's
3. Apparatus: rates, acceptance, yields
4. Other physics issues
5. Present status

* A. Dzierba, spokesman
* J. Napolitano, cospokesman

1. Primary Physics Issue: the nature of the $a_0/f_0(980)$

$f_0(980)$ PDG: Γ = 40 - 100 MeV

- major decay $\pi\pi$ (S-wave) 0^{++} $(I=0^{G=+1})$
- large threshold enhancement in $\bar{K}K$ s-wave $\Rightarrow$ strong coupling to $\bar{K}K$

  $$\frac{g_{KK}}{g_{\pi\pi}} \simeq 4$$

- observed in its interference with broad $\pi\pi$ s-wave structure(s)

  $\Rightarrow$ width depends on how structures are put into the fit.

M. BUTTRAM *et al.* 1976

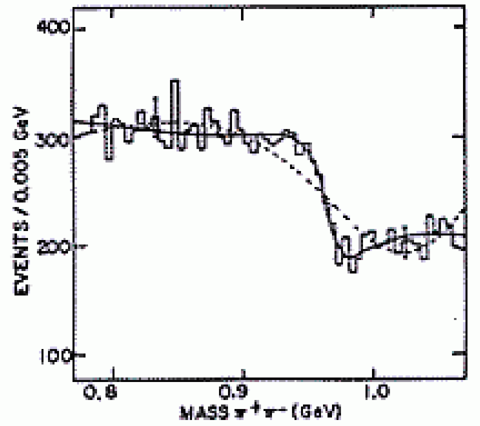


FIG. 6. The MM spectrum for events from the reaction $\pi^-p \to \pi^+\pi^-n$ where only one pion reaches the spectrometer. The solid curve is the best S^* fit to the data as described in the text. The dashed curve is the best fit if the nonresonant s-wave phase is held at 90°.

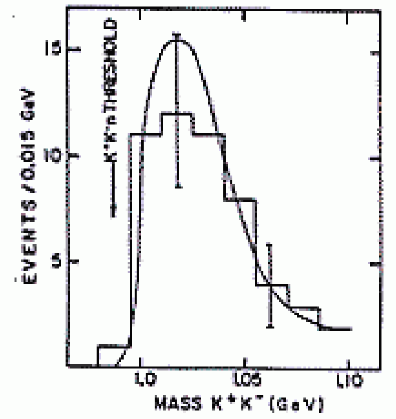


FIG. 7. The MM spectrum for $\pi^-p \to K^+K^-n$ with both kaons momentum analyzed in the spectrometer. The curve is a one-parameter (g_K) fit to the data with the S^* pole held at the $\pi^+\pi^-n$ best value.

$a_0(980)$ PDG: $\Gamma = 50 - 100$

- major decay $\eta\pi$ (s-wave) 0^{++} $(I = 1^{G=-1})$
- copiously produced in $f_1(1285)$ decays
  $f_1(1285) \to \underbrace{(\eta\pi)}_{\sim 80\%\ a_0(980)}\pi$ 50% branch
- also seen in $f_1(1285) \to (\bar{K}K)\pi$ 10% branch
  $\Rightarrow$ strong coupling to $\bar{K}K$: $\frac{g_{KK}}{g_{\pi\pi}} \sim 1$
- large $a_0^{\pm}$ signal seen in photoproduction

Crystal Barrel 1994
$\bar{p}p \to \pi^0\pi^0\eta$

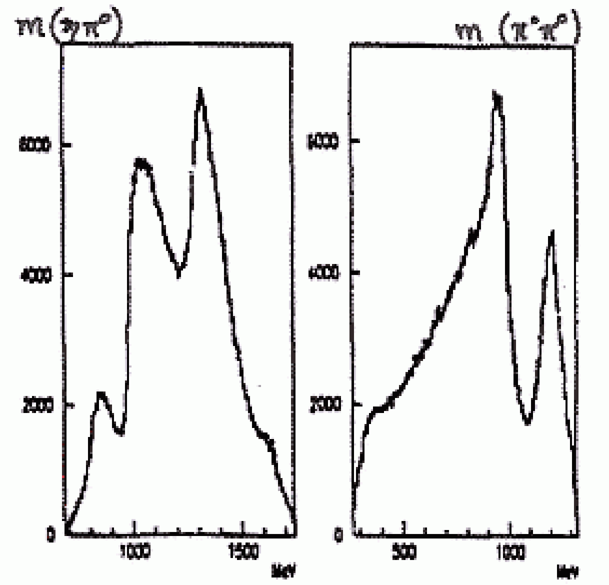
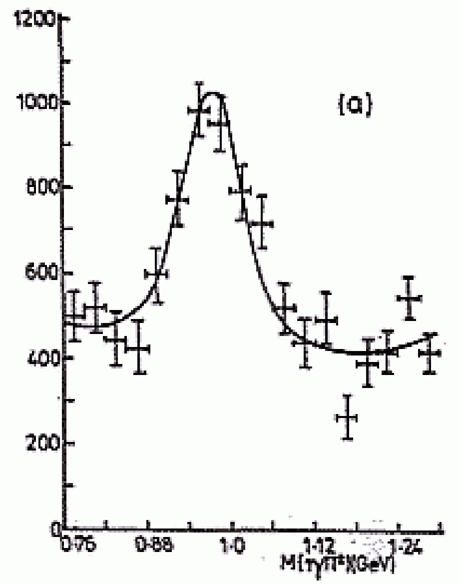


Fig. 2. Dalitz plot projections: $m(\pi\eta)$ distribution (left) and $m(\pi\pi)$ distribution (right). The dots are data and the full lines the results of the fits discussed in the text.

CERN Ω 1984
$\gamma p \to \eta\pi X$

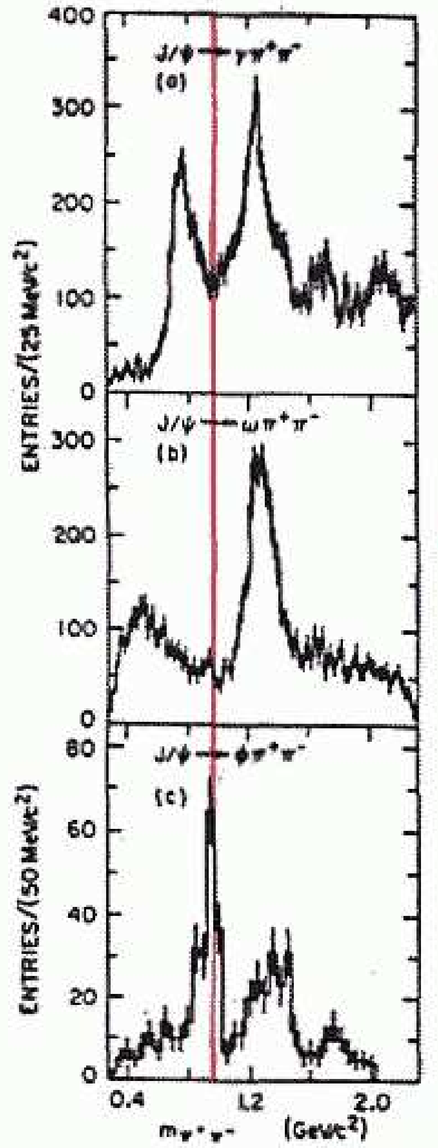


favours $n\bar{n}$ interpretation

Important clue concerning flavour content of f_0

$$J/\psi \to V \begin{cases} \pi\pi \\ \bar{K}K \end{cases}$$

Mark III 1987 (review by Eigen)



$V = \gamma$

$V = \omega$

$V = \varphi$

Fig.15. A comparison of the Mark III invariant mass spectra observed in the processes: a) $J/\psi \to \gamma\pi^+\pi^-$, b) $J/\psi \to \omega\pi^+\pi^-$, and c) $J/\psi \to \phi\pi^+\pi^-$.

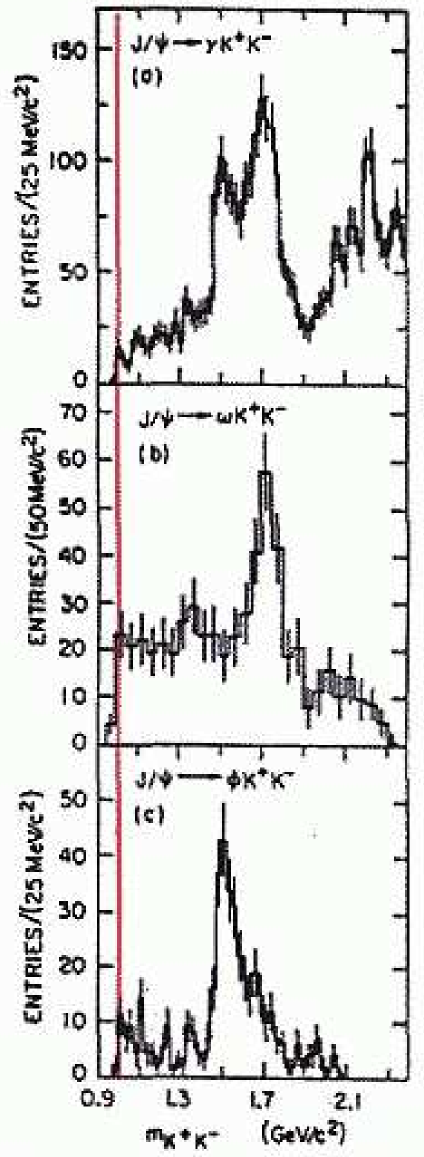


Fig.14. A comparison of the Mark III invariant mass spectra observed in the processes: a) $J/\psi \to \gamma K^+K^-$, b) $J/\psi \to \omega K^+K^-$, and c) $J/\psi \to \phi K^+K^-$.

Where do these states fit in the $^3P_0$ nonet?

	Γ
$a_2(1320)$	107 MeV
$a_1(1260)$	400 MeV
$a_0(1280?)$	$\gtrsim$ 400 MeV
$a_0(980)$	50 MeV

With difficulty ...

✓ too light

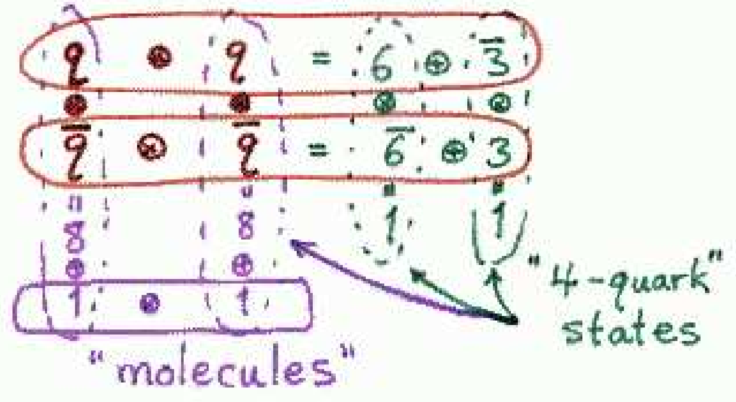
✓ too narrow

For comparison: $K_0^*(1430)$: $\Gamma = 290$ MeV

Jaffe '77:

confine SU(3) singlets in a bag

$\Rightarrow qq\bar{q}\bar{q}$ 4-quark states



Weinstein, Isgur '83

In general 4-quark states $\underset{\bar{3},6}{(qq)}\underset{3,\bar{6}}{(\bar{q}\bar{q})}$ overlap with "molecular" colour config. $\underset{1}{(q\bar{q})}\underset{1}{(q\bar{q})}$ so that they "fall apart" into 2 mesons <u>if possible</u>

exceptional case: $K\bar{K}$ is bound (weakly)

Neat solution: 1) $a_0/f_0(980)$ sit near $\bar{K}K$ threshold because they are (largely) $4q$ states in 1×1 configurations $\Longrightarrow K\bar{K}$ "molecules"

2) $f_0(1370)$, $a_0(1450)$ are "ordinary" $^3P_0$ nonet members.

3) excess of f_0 states below $1.7\,\mathrm{GeV}/c^2$ agrees with expectations for 0^{++} glueball.

4) "unitarized" quark models predict (fit) states near $K\bar{K}$ threshold with large continuum components

Present experimental data inspire this picture.

We need new data to test its predictions.

example: f_0 or a_0 production in Z^0 decays

Close, Isgur, Kumano: new input needed

Important constraint on models would come from a measurement of

$$\varphi \to \gamma \begin{cases} a_0 \\ f_0 \end{cases}$$

1) φ is narrow $\Rightarrow$ clean selection of initial state
2) simple $s\bar{s}$ configuration
3) radiative decays are calculable
4) low B.R. expected, difficult measurement

B.R. × 10^6	B.R. $(\varphi \to \gamma a_0 \to \gamma \pi^0 \eta)$	$3 \cdot$ B.R. $(\varphi \to \gamma f_0 \to \gamma \pi^0 \pi^0)$	$\frac{B.R(\varphi \to \gamma a_0)}{B.R(\varphi \to \gamma f_0)}$
$^3P_0$ state	$\lesssim 0.1$	10 $(s\bar{s})$ small $(u\bar{u}+d\bar{d})$	0 9
$K\bar{K}$ molecule			
(naive)	40	40	1
(Achasov'97)	10 - 20	10 - 20	
Bag $qq\bar{q}\bar{q}$ $(us)(\bar{u}\bar{s}) \mp (ds)(\bar{d}\bar{s})$	1 − 100 (?)	1 − 100 (?)	(any) 9
Present limits			
PDG	< 5000	< 1000	
Novirsibirsk'97	< 200	< 700	SND preliminary
NEW:	130 ± 50	470 ± 100	SND Hadron '97

2. Technique: photoproduction of (boosted) φ's

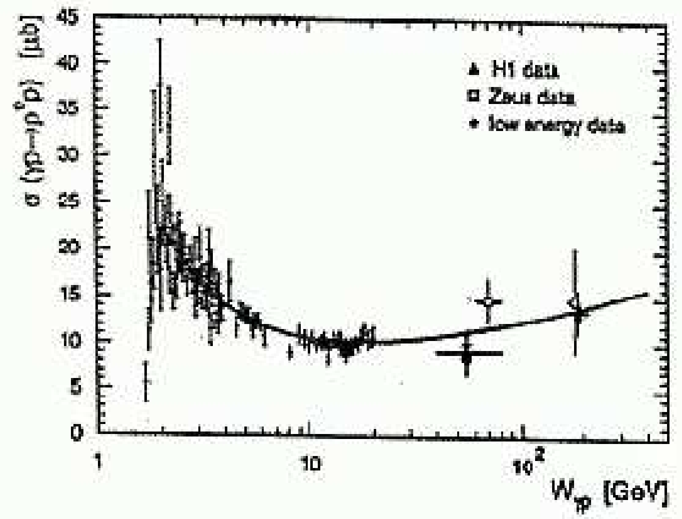
a. alternative to e^+e^- collider "φ-factories"

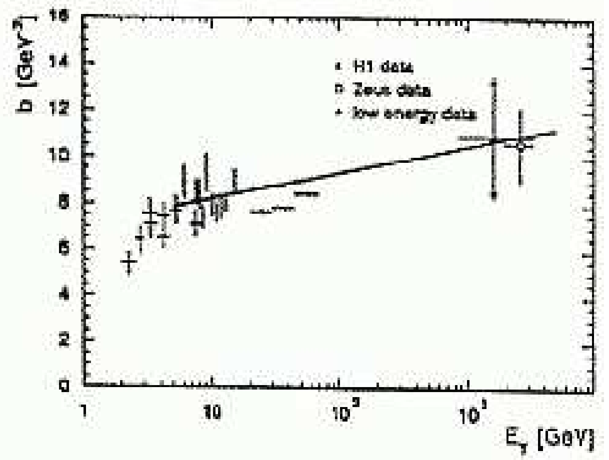
VEPP-2M, DAΦNE

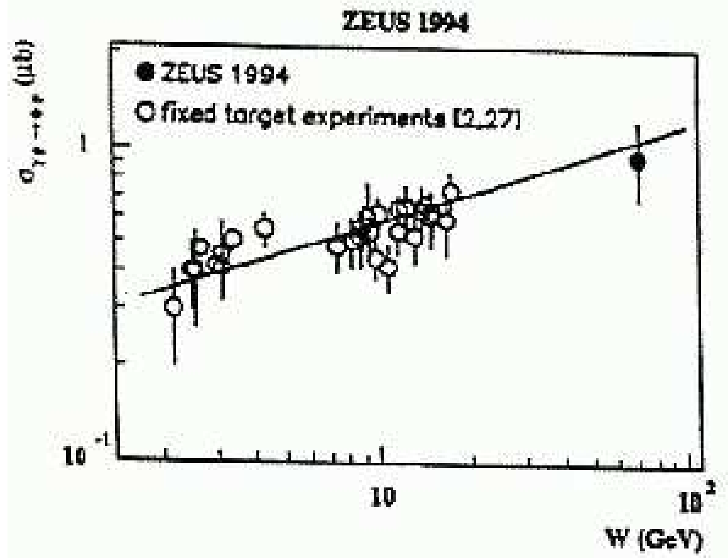
b. large (diffractive) $\sigma_{\gamma p \to \varphi p}$

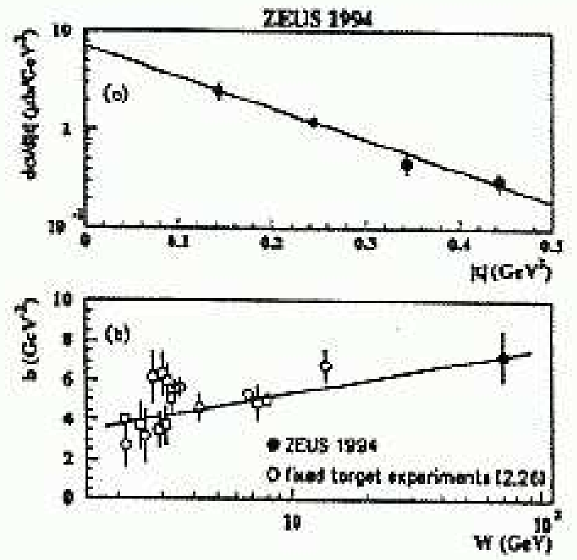
	f_ρ^2	:	f_ω^2	:	f_φ^2
ideal	9	:	1	:	2
@5GeV	12μb		2μb		0.5μb

(VMD)

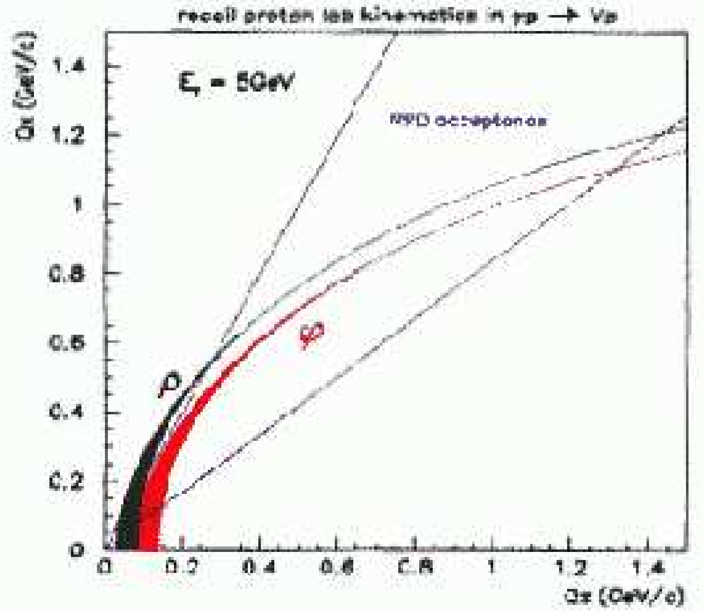




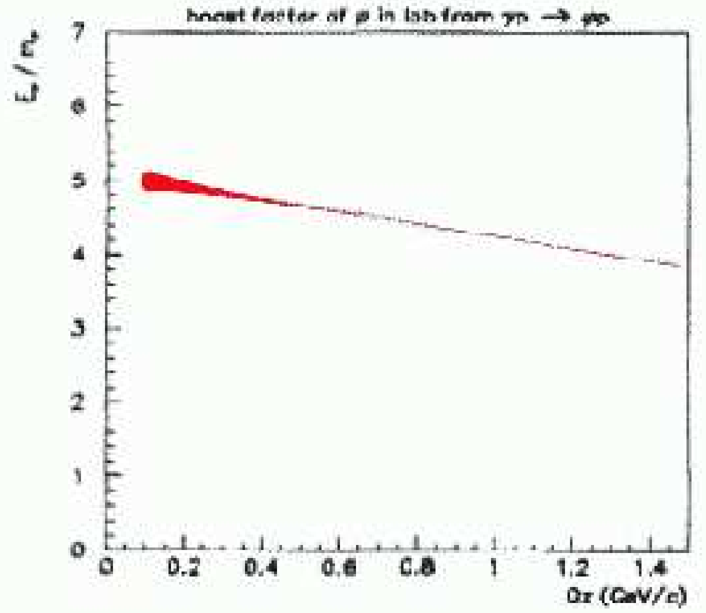




* φ signal enhanced by triggering on recoil proton



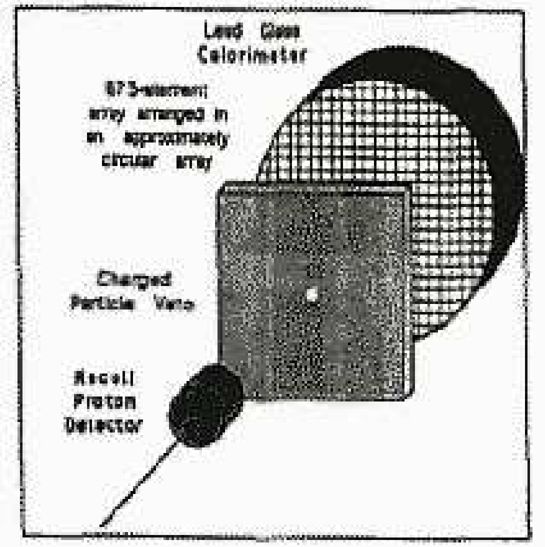
* detection enhanced by large "boost" of φ in lab

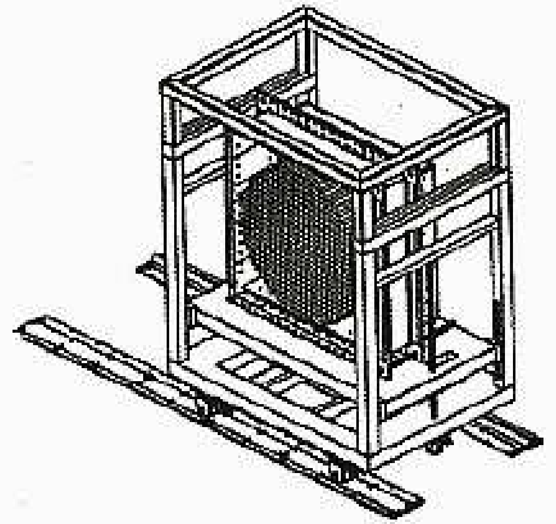


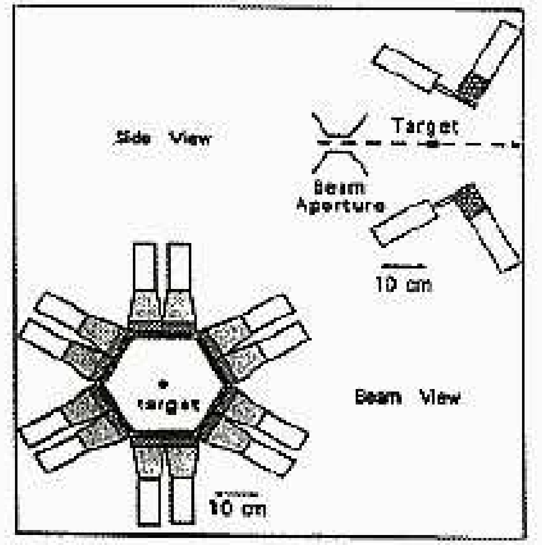
Calorimeter

Pb-glass towers

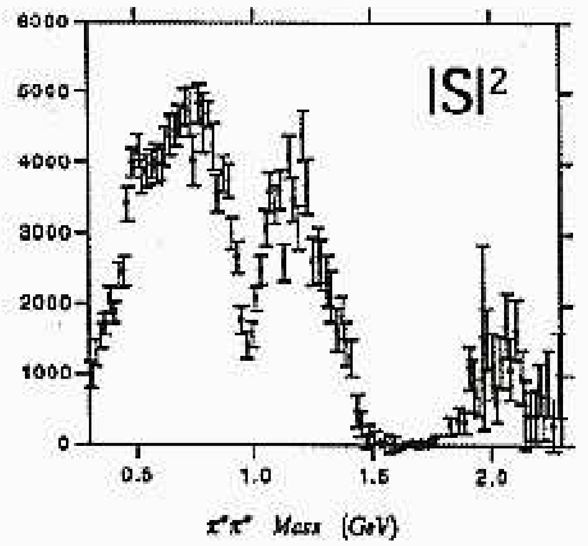
- 4cm × 4cm × 45cm
  (14.5 rad. len.)
- resolution $\frac{5\%}{\sqrt{E}}$

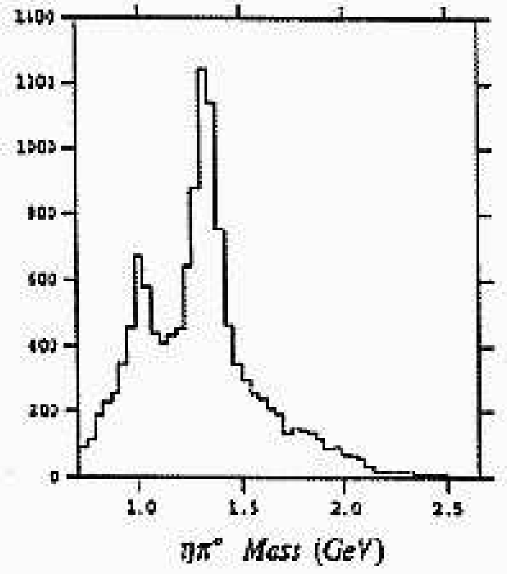






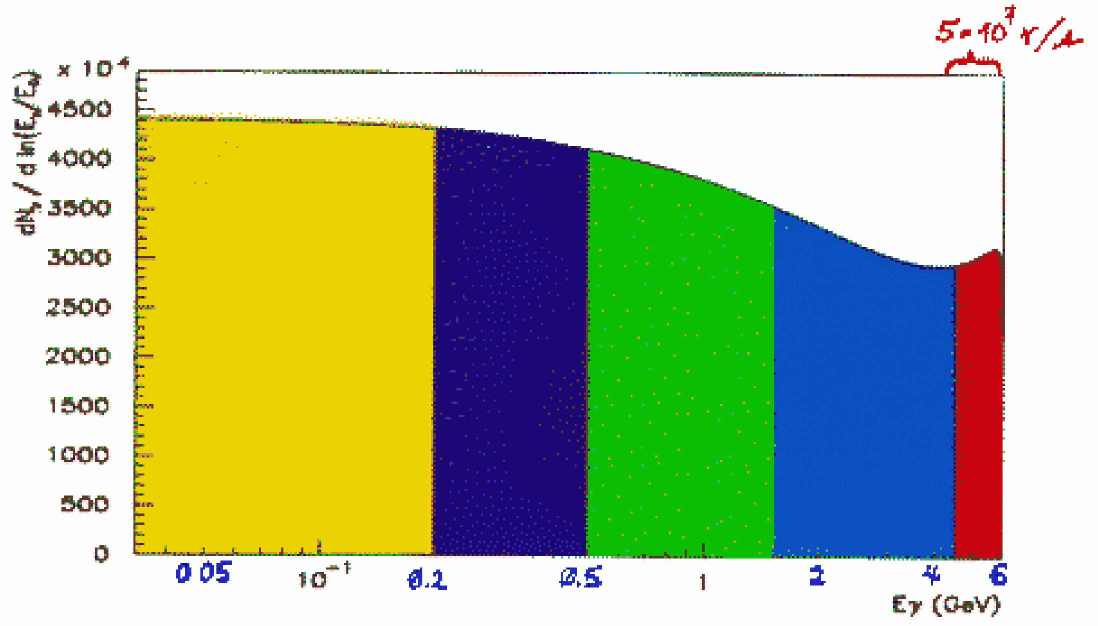
E852 (AGS)





Beam:

tagged bremsstrahlung in Hall B at CEBAF



range	process	RPD · $\overline{\text{VETO}}$
50 - 200 MeV	giant resonances photodisintegration	20 kHz (50 - 500 MeV)
200 - 500 MeV	$\gamma p \to \Delta^+ \to p\pi^0$ $\quad\hookrightarrow n\pi^+$	
		10 kHz
500 - 1500 MeV	$\gamma p \to N^* \to pX$ $\quad\hookrightarrow \pi^+ X$	10 kHz 10 kHz
1.5 - 4 GeV	$\gamma p \to p$ + neutrals	6 kHz
		56 kHz
tagged 4.5 - 6 GeV	$\gamma p \to p$ + neutrals	4 kHz

Acceptance estimates from Monte Carlo

1. input bremsstrahlung photon spectrum
2. $\sigma_{\gamma p \to \phi p} = 0.5\,\mu b$, $\frac{d\sigma}{dt} \sim e^{-4|t|}$
3. s-channel helicity conservation
4. minimum E_γ 100 GeV, 6 cm between clusters

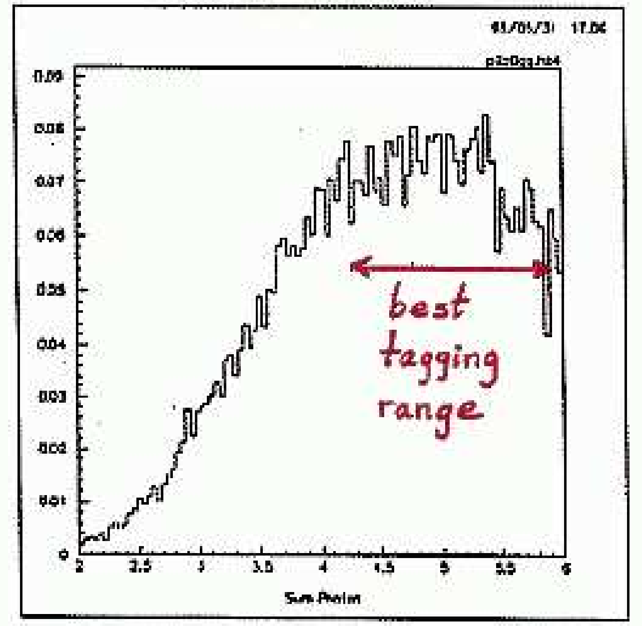


Figure 3: Acceptance for $\gamma p \to \phi p$ followed by $\phi \to a_0(980)\gamma \to 5$ photons. The incident photons are generated by bremsstrahlung from a 6 GeV primary electron beam.

Expected yields for 1000 h experiment (30 ϕ/s)

$\phi \to$	B.R. $\cdot 10^6$	(all photons)	# γ	A%	yield
$\gamma\pi^0$	1300	1300	3	35	45000
$\gamma\eta$	13000	5000	3	35	175000
$\gamma\eta'$	60	~ 1	3	30	40
γa_0	10	4	5	7	30
γf_0	10	3	5	10	30

4. Other physics issues

$\phi \to \eta'\gamma$ (Rosner)

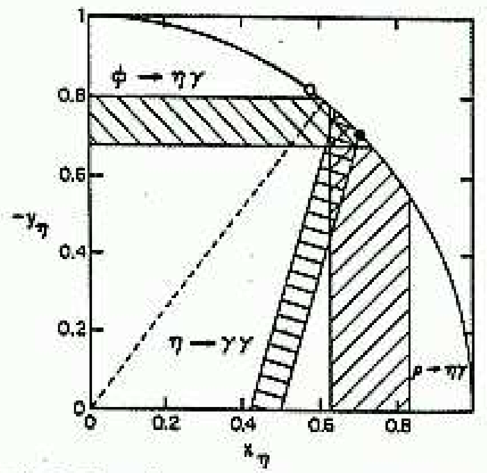


FIG. 1. Constraints on nonstrange- (x_η) and strange- (y_η) quarkonium mixing coefficients in the η, as defined in Eq. (6). The circular boundary denotes the constraint $x_\eta^2+y_\eta^2 \le 1$. Only the quadrant containing a pure octet η [open circle, with $x_\eta=(\frac{1}{3})^{1/2}$, $y_\eta=-(\frac{2}{3})^{1/2}$] is shown. The mixing solution of Ref. 19, $x_\eta=(\frac{1}{2})^{1/2}=-y_\eta$, is shown as a closed circle. The mixing scheme of Ref. 12, to be discussed in Sec. V, implies a ratio of y_η/x_η shown as the dashed straight line. The vertical, horizontal, and inclined bands are the regions allowed by Eqs. (12), (14), and (16), respectively.

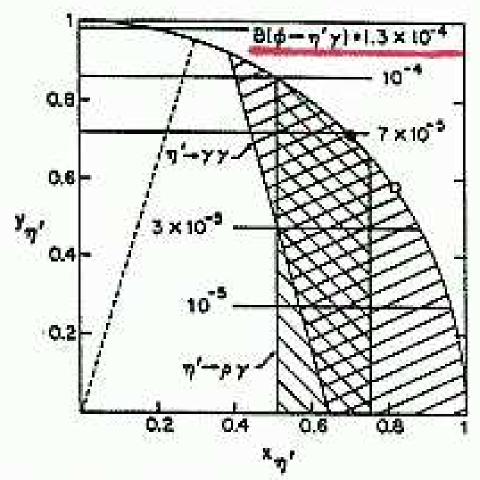


FIG. 2. Constraints on nonstrange- ($x_{\eta'}$) and strange- ($y_{\eta'}$) quarkonium mixing coefficients in the η'. The open circle denotes a pure quarkonium singlet η', $x_{\eta'}=(\frac{2}{3})^{1/2}$, $y_{\eta'}=(\frac{1}{3})^{1/2}$. Closed circle denotes mixing solution of Ref. 19, $x_{\eta'}=(\frac{1}{2})^{1/2}=y_{\eta'}$. Dashed straight line: mixing scheme of Ref. 12 (Sec. V). Vertical and inclined bands are regions allowed by Eqs. (18) and (23), respectively. Horizontal lines are labeled by predicted values of $B(\phi \to \eta'\gamma)$.

$\phi(1020)$ DECAY MODES

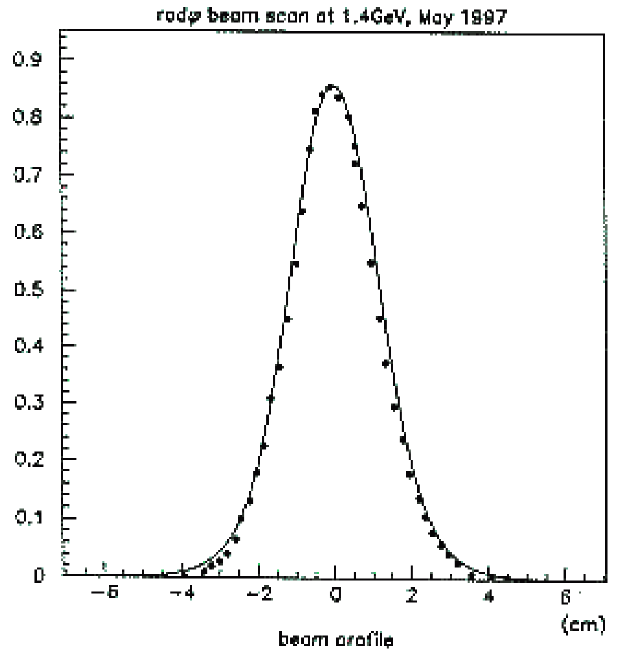
	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	K^+K^-	(49.1 ± 0.6) %	S=1.2
Γ_2	$K_L^0 K_S^0$	(34.1 ± 0.5) %	S=1.1
Γ_3	$\rho\pi$	(12.9 ± 0.7) %	
Γ_4	$\pi^+\pi^-\pi^0$	(2.7 ± 0.9) %	S=1.1
Γ_5	$\eta\gamma$	(1.26 ± 0.06) %	S=1.1
Γ_6	$\pi^0\gamma$	$(1.31 \pm 0.13) \times 10^{-3}$	
Γ_7	e^+e^-	$(3.00 \pm 0.06) \times 10^{-4}$	S=1.1
Γ_8	$\mu^+\mu^-$	$(2.48 \pm 0.34) \times 10^{-4}$	
Γ_9	ηe^+e^-	$(1.3\ ^{+0.8}_{-0.6}) \times 10^{-4}$	
Γ_{10}	$\pi^+\pi^-$	$(8\ ^{+5}_{-4}) \times 10^{-5}$	S=1.5
Γ_{11}	$\omega\gamma$	< 5 %	CL=84%
Γ_{12}	$\rho\gamma$	< 2 %	CL=84%
Γ_{13}	$\pi^+\pi^-\gamma$	$< 7 \times 10^{-3}$	CL=90%
Γ_{14}	$f_0(980)\gamma$		
Γ_{15}	$\pi^0\pi^0\gamma$	$< 1 \times 10^{-3}$	CL=90%
Γ_{16}	$\pi^+\pi^-\pi^+\pi^-$	$< 8.7 \times 10^{-4}$	CL=90%
Γ_{17}	$\eta'(958)\gamma$	$< 4.1 \times 10^{-4}$	CL=90%
Γ_{18}	$\pi^+\pi^+\pi^-\pi^-\pi^0$	$< 1.5 \times 10^{-4}$	CL=95%
Γ_{19}	$\pi^0 e^+e^-$	$< 1.2 \times 10^{-4}$	CL=90%
Γ_{20}	$\pi^0\eta\gamma$		
Γ_{21}	$a_0(980)\gamma$	$< 5 \times 10^{-3}$	CL=90%

5. Present status:

★ Installed in Hall B alcove 4/97

- ✓ 1" Be target (to begin with)
- ✓ 18-element target-region hodoscope (RPD)
- ✓ veto wall in place, upgrade underway
- ✓ 320 instrumented Pb-glass blocks ($\theta_{lab} < 20^\circ$) (625 when fully instrumented)

★ first tagged photons 5/97



★ first π^0 in calorimeter