Analysis of $p\bar{p} \longrightarrow \phi f_0$ in the JETSET Experiment

for the GlueX Graduate Student Workshop

Igor Senderovich

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X(3872)

$X(3872) : \{M, \Gamma\}(\pi^+\pi^- J/\psi) = \{3871.4 \pm 0.6, 2.3\}$ in $B^- \to K^- X$.

- Decay analysis: $\gamma \to \rho \to \pi^+\pi^-$
- PWA suggests $J^{PC} = 1^{++}$ and $J^{PC} = 2^{-+}$
- $\therefore$ charmonium states χ_{c1} and η_{c2} would be poor choices due to isospin violation necessary for decay to $\rho J/\psi$

  (evidence of a competing decay to $\pi^+\pi^-\pi^0 J/\psi$, e.g. via a virtual ω may confirm isostate mixing)

Speculations:

- $X(3872)$ is a $D^0 D^{*0}$ molecule! The mass is nearly equal to the sum of D^0 and D^{*0} masses.
- Tetraquark proposed with the prediction of strong "X" production from B^0 decays to $K^0\pi^+\pi^- J/\psi$

States near predicted η_c''

Two states found around the predicted $\eta_c''(3^1S_1) : \{M, \Gamma\} = \{3943, 50\}$

1. $X(3940) : \{M, \Gamma\}(D\bar{D}^*) = \{3942 \pm 8, 52\}$ in $e^+e^- \to J/\psi\ X$
   - Not found in $D\bar{D}$ or $\omega J/\psi$ - taken to be 0^{-+} given the production mechanism.
   - Reasonable agreement to theory but below potential model estimate.
2. $X(4160) : \{M, \Gamma\}(D^*\bar{D}^*) = \{4156 \pm 29, 139\}$ in $e^+e^- \to J/\psi\ X$
   - For analogous reasons, 3^1S_1 assignment makes sense
   - Mass is perhaps too high.

So, which is the expected charmonium state, and what to do with with the other one?

Also $Y(3940) : \{M, \Gamma\}(\omega J/\psi) = \{3943 \pm 17, 87 \pm 34\}$ in $B \to KX$

- not yet clear if distinct from $X(3940)$
- large branching fraction inconsistent with P-wave charmonium, but may be plausible if it decays via $D\bar{D}^*$ or mixes with $X(3872)$

Other interesting findings

$Z(3930) : \{M, \Gamma\}(D\bar{D}) = \{3929 \pm 6, 29 \pm 10\}$ in $\gamma\gamma \to Z$.

- $\gamma\gamma$ allows 0^{++} and 2^{++}; PWA favors the latter.
- Consistent with predicted: $\{M, \Gamma\}(\chi_{c2}(2P)) = \{3972, 28.6\}$
- The production rate is also thought consistent

Some broad resonances in ISR production of $\pi^+\pi^-\psi'$ found that are inconsistent with the established charmonium states:

- $Y(4360) : \{M, \Gamma\} = \{4361 \pm 13, 74 \pm 18\}$
- $Y(4660) : \{M, \Gamma\} = \{4664 \pm 12, 48 \pm 15\}$

$Z^+(4430) : \{M, \Gamma\}(\pi^+\psi') = \{4433 \pm 5, 45^{+35}_{-18}\}$ in $B \to KZ^+$
Non-zero charge suggests that this may be a molecule or tetraquark.

Y(4260) and Y(2175)

$Y(4260) : \{M, \Gamma\}(\pi^+\pi^- J/\psi) = \{4259 \pm 10, 88 \pm 24\}$ in ISR events

- values do not match those of established charmonium states
- no evidence of the expected D meson pair decay channels

Candidates: **charmonium hybrid**, given the broad hadronic transitions found in bottomonium hybrids by LQCD.

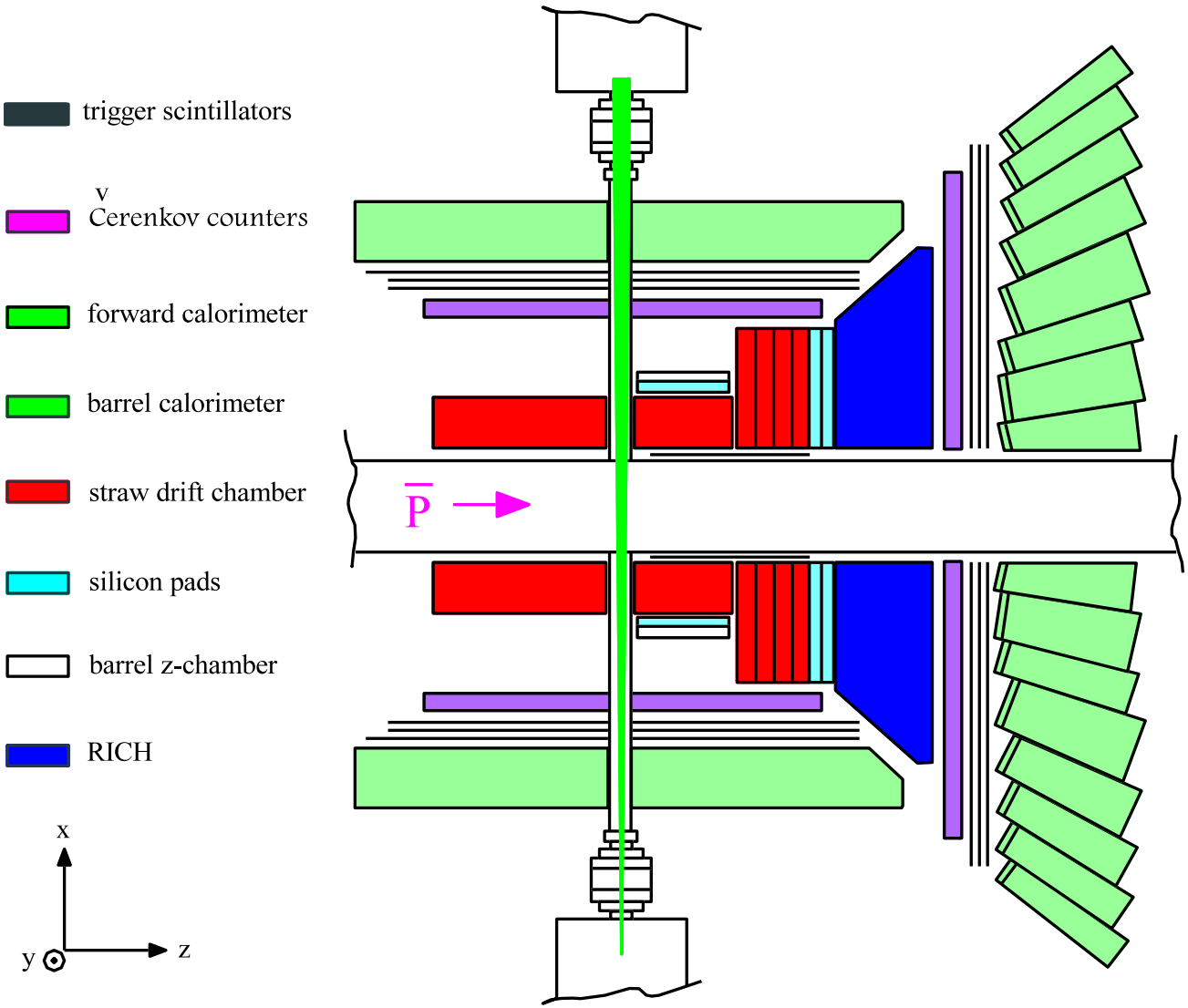
Possible counterpart in the strange sector?

$Y(2175)$ in $\phi f_0(980)$: consider ϕ as an analog of J/ψ

- BaBar observed: $e^+e^- \to \gamma_{ISR}\phi f_0(980)$
  $\{M, \Gamma\} = \{2175 \pm 18, 58 \pm 26\}$
- BES confirmed: $J/\psi \to \phi f_0(980)\eta$ with
  $\{M, \Gamma\} = \{2186 \pm 10 \pm 6, 65 \pm 23 \pm 7\}$

In these analyses, decay products interpreted from:
$\phi \to K^+K^-, f_0(980) \to \pi^+\pi^-$

The JETSET detector



JETSET data

Realities of the data triggered at JETSET:

1. Detector acceptance for $KK\pi\pi$ was not very good. Events satisfying this hypothesis: **1051**
2. Set of 4K events: **22384**

However, $f_0(980) \rightarrow KK$ has been seen.
Let's look for interference between

$$\begin{aligned} \phi\phi &\rightarrow 4K \\ \phi f_0 &\rightarrow 4K \\ f_0 f_0 &\rightarrow 4K \end{aligned}$$

Hints in JETSET data

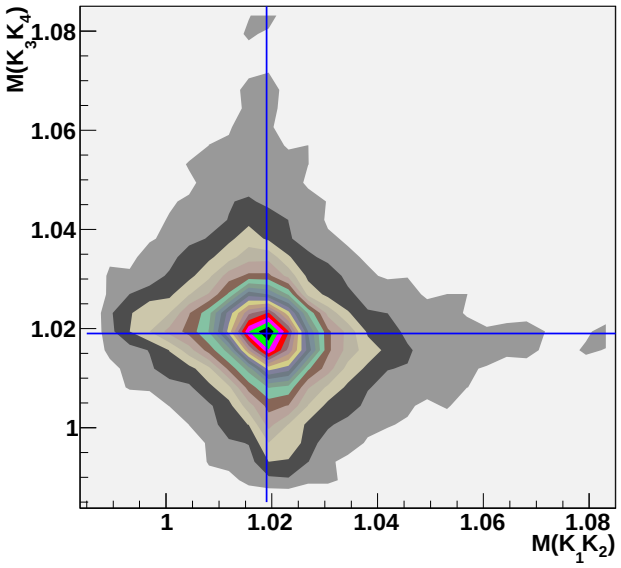


Figure: 4K dalitz plot in the vicinity of $M(\phi)$. Note the skew in the $\phi\phi$ peak.

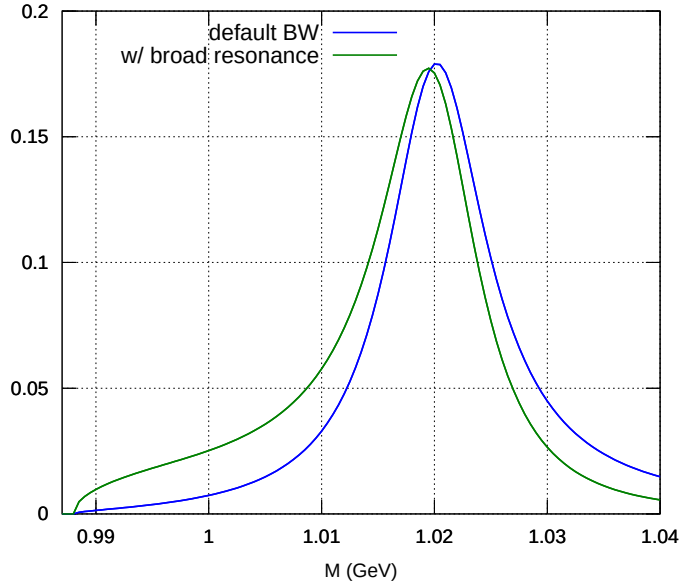


Figure: Example of a Breit-Wigner line shape shifted in the presence of an $f_0(980)$-like resonance (below threshold.)

The skew in the tails of the enhancement corresponding to the ϕ is suggestive of an interference. An example of an interference shifting a peak is shown on the right.

Outlook

This is just the beginning - plenty of work ahead:

1. Understand precisely what type of interference will cause the kind of skew in the Dalitz plot
2. Make some rough fits of the appropriate waves and line shapes to this pattern
3. Do a proper fit and try to extract properties of the anomalous waves. Is there significant ϕf_0 in there? What is it like?