Onia Hadronic Transitions at CLEO

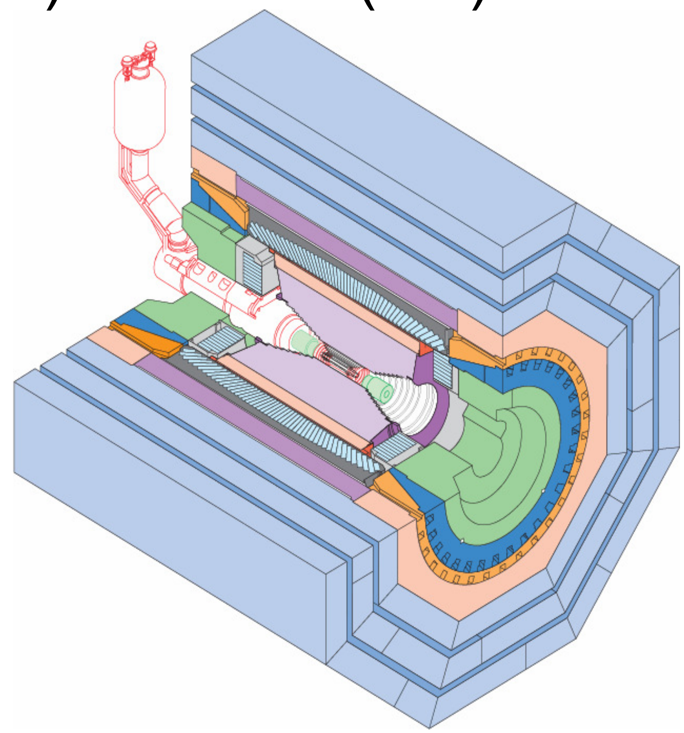
D. Kreinick – Cornell University

$\psi(3770) \rightarrow \pi\,\pi\,J/\psi$

$\Upsilon(mS) \rightarrow \pi\,\pi\,\Upsilon(nS)$ m=2,3; n=1,2

New approach for analyzing $\Upsilon(mS) \rightarrow \pi\,\pi\,\Upsilon(nS)$

$\psi(2S) \rightarrow \pi^+\,\pi^-\,\pi^0\,\eta_c$



Will not have time to present

$\psi(3770) \rightarrow \pi^0/\eta\ \ J/\psi$ (PRL 96, 082004 (2006))

$\chi_b' \rightarrow \pi\,\pi\,\chi_b$ (hep-ex/0511019, accepted PRD)

$\chi_b \rightarrow\ \omega\,\Upsilon(1S)$ (PRL 92, 222002 (2004))

$\psi(3770)$ to light hadrons

$\psi(3770) \to \pi\,\pi\,J/\psi$

Observe $\ell^+\ell^-$ from the J/ψ and $\pi^+\pi^-$ or $\pi^0\pi^0$ in 281/pb of $\psi(3770)$ data

Major backgrounds

- Radiative return to $\psi(2S)$ with ~87 MeV ISR photon
- Direct production of $\psi(2S)$ on tail of Breit-Wigner
- small linear background

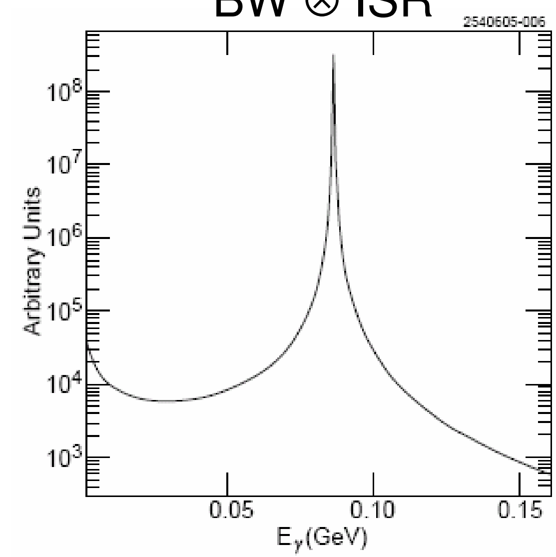
$\vec{k} = \vec{0} - \vec{p}_{\ell+} - \vec{p}_{\ell-} - \vec{p}_\pi - \vec{p}_\pi$ poor resolution

Better if you calculate k more carefully:

$$|\vec{k}| = k = \frac{s - M_J^2 + m_X^2 - 2\sqrt{s(p_x^2 + m_X^2)}}{2(\sqrt{p_J^2 + M_J^2} - p_J\cos\phi)}$$

M_J = PDG mass of J/ψ
m_X, p_X = measured $\pi\pi$ mass and momentum
p_J = momentum of $\ell^+\ell^-$
ϕ = angle between J/ψ momentum and $\vec{k}$

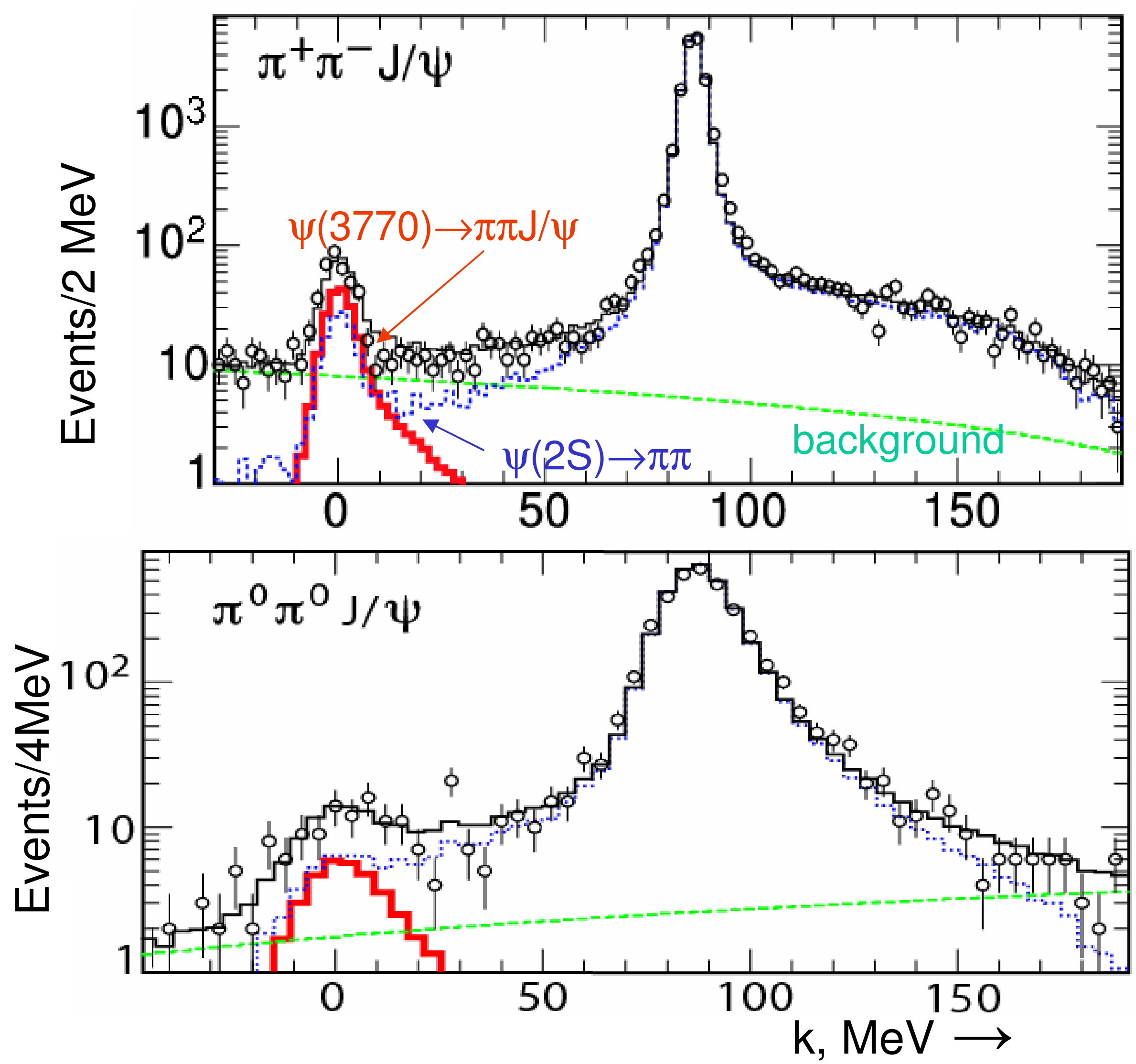
BW ⊗ ISR



Expected yield from $\psi(2S)$

(2 MeV γ cutoff)

k Distribution $\psi(3770) \to \pi\,\pi\, J/\psi$



Branching ratios

$\psi(3770) \to \pi^+\pi^- J/\psi$

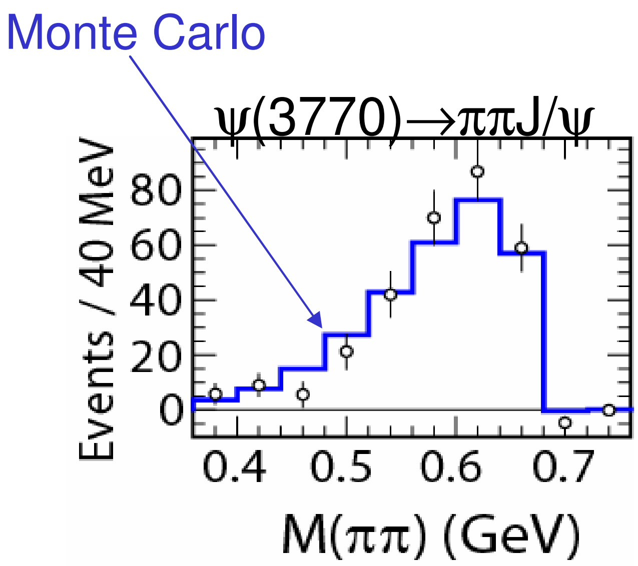
$(189\pm20\pm20)\times10^{-5}$

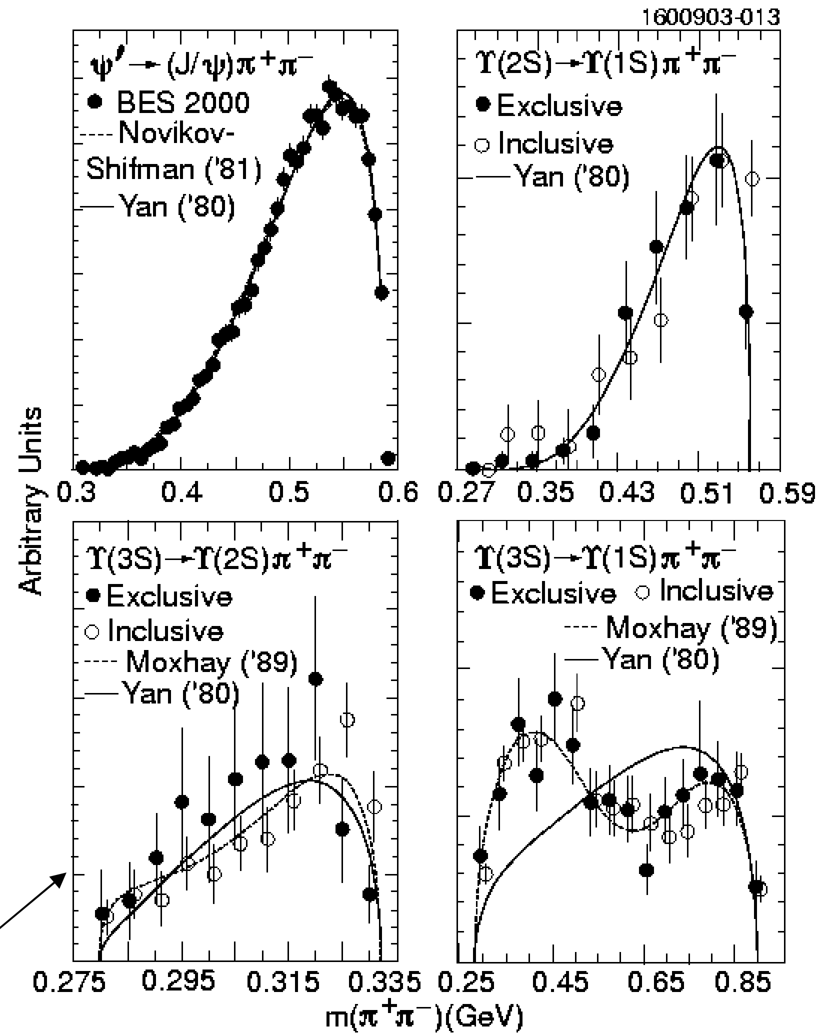
$\psi(3770) \to \pi^0\pi^0 J/\psi$

$(80\pm25\pm16)\times10^{-5}$

PRL 96, 082004 (2006)

$\pi\pi$ Mass Distribution





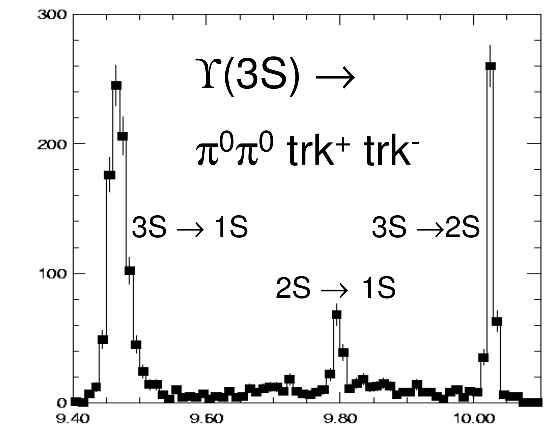
$\pi\pi$ mass distribution looks like the others (except the strange $\Upsilon(3S) \rightarrow \pi\pi\Upsilon(1S)$)

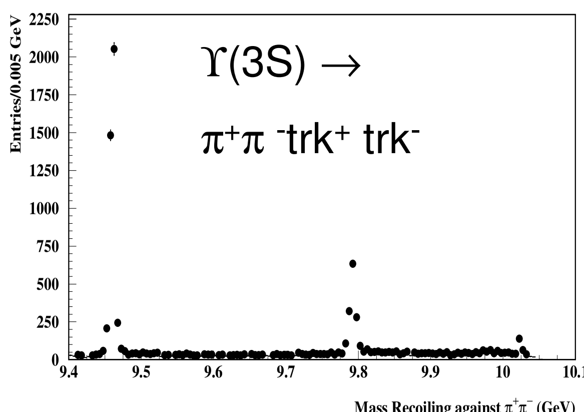
Υ data from 1994

$\Upsilon(mS) \rightarrow \pi\ \pi\ \Upsilon(nS)$

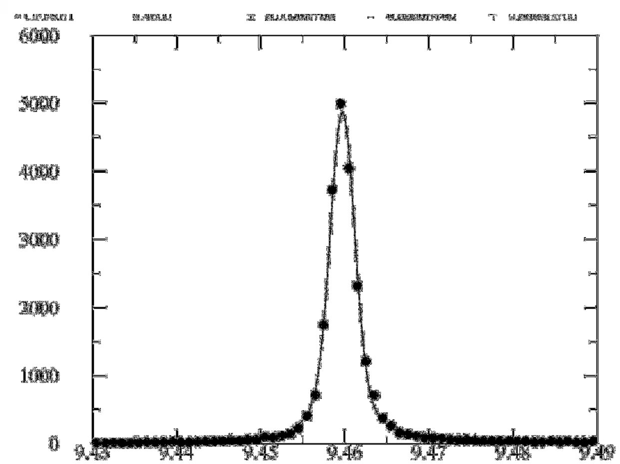
Exclusive: Observe

$\pi^+\pi^-$ or $\pi^0\pi^0$ and $\ell^+\ell^-$ from $\Upsilon(nS)$



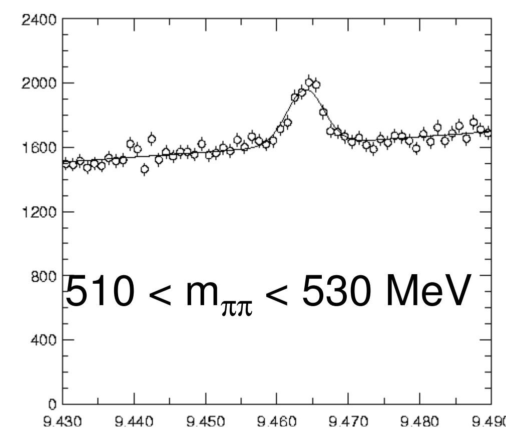


$\Upsilon(2S) \rightarrow \pi^+\pi^-\Upsilon(1S)$



Inclusive: Observe only the $\pi^+\ \pi^-$

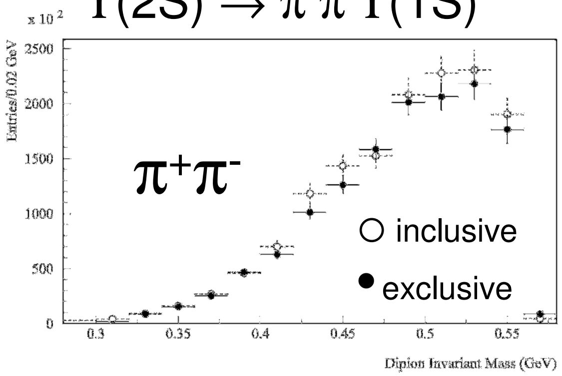
$\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$



Mass recoiling against $\pi\pi$, GeV→

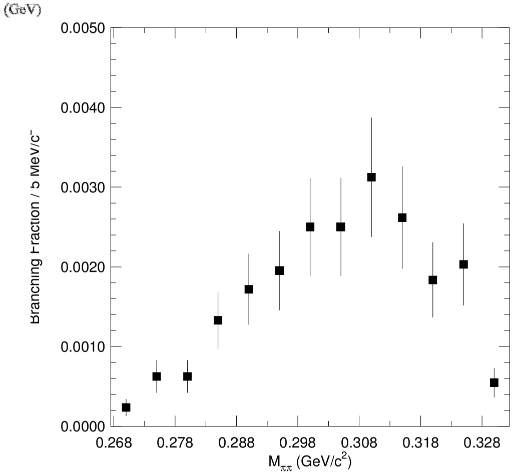
$M_{\pi\pi}$ distributions

$\Upsilon(2S) \rightarrow \pi\, \pi\, \Upsilon(1S)$

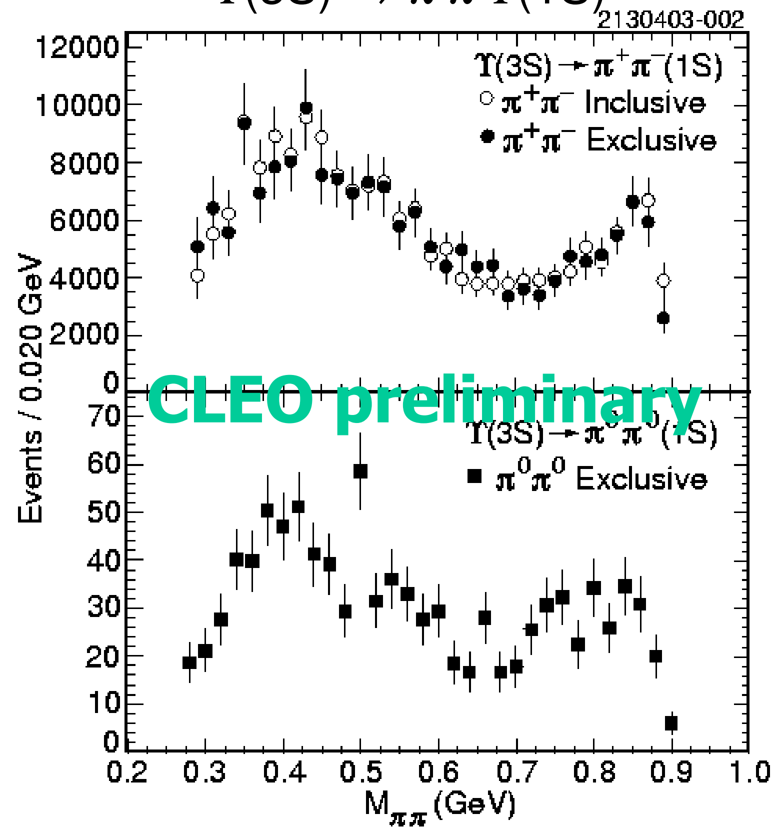


$\Upsilon(3S) \rightarrow \pi\, \pi\, \Upsilon(2S)$

Charged pions range out



$\Upsilon(3S) \rightarrow \pi\, \pi\, \Upsilon(1S)$



$\pi^0\pi^0$

Not done yet

$BR(\Upsilon(2S)\rightarrow\pi^+\pi^-\Upsilon(1S))$ ~18%

$2 \times BR(\Upsilon(3S)\rightarrow\pi^0\pi^0\Upsilon(2S))$ ~4%

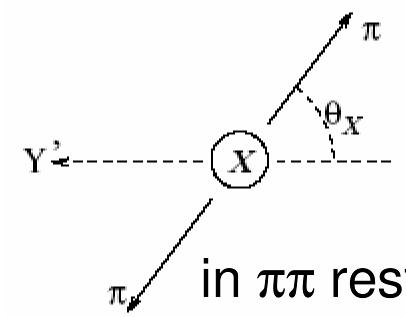
$BR(\Upsilon(3S)\rightarrow\pi^+\pi^-\Upsilon(1S))$ ~4%

Matrix Element Analysis for $\Upsilon(mS) \to \pi\,\pi\,\Upsilon(nS)$

3 body final state $\Rightarrow$ 2 Dalitz variables, traditionally $M_{\pi\pi}^2$ and $M_{\Upsilon\pi}^2$

Here, we prefer $M_{\pi\pi}^2$ and $\cos\theta_x$

($\cos\theta_x$ is linear in $M_{\Upsilon\pi}^2$)



in $\pi\pi$ rest frame

PCAC + Lorentz invariance (Brown and Cahn, PRL 35, 1 (1975))

$\mathcal{M} = A\times(\varepsilon'\bullet\varepsilon)\times(q^2 - 2m_\pi^2) +$ (Yan form; Moxhay adds constant for B*B*)

$B\times(\varepsilon'\bullet\varepsilon)\times(E_1 * E_2) +$ (Traditionally neglected)

~~$C\times[(\varepsilon'\bullet q_1)(\varepsilon\bullet q_2) + (\varepsilon'\bullet q_1)(\varepsilon\bullet q_1)]$~~ (spin flip, neglect)

where q_i are the pion momenta, E_i their energies

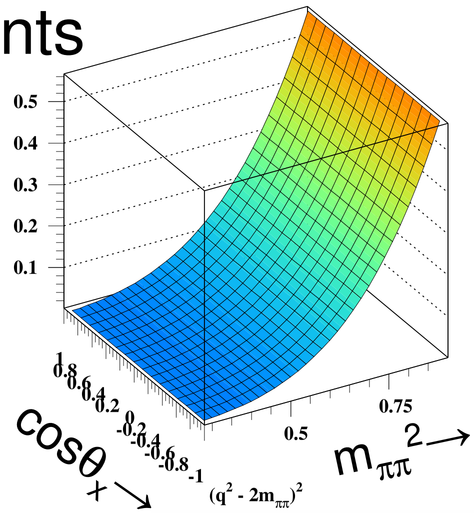
$q^2 = (q_1 + q_2)^2 = M_{\pi\pi}^2$ ε', ε polarization vectors of Υ', Υ

A $\cos\theta_x$ dependence indicates the presence of a B term

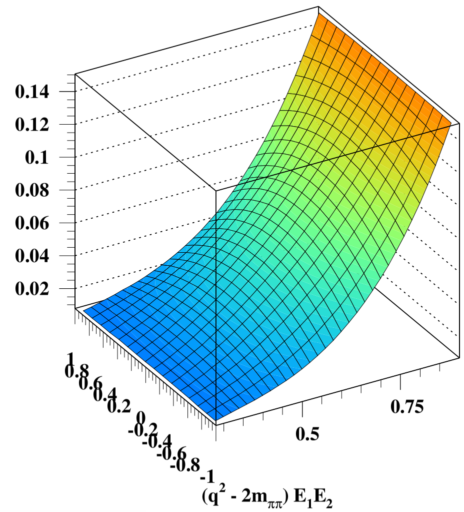
2-D distributions (all MC)

Matrix Elements

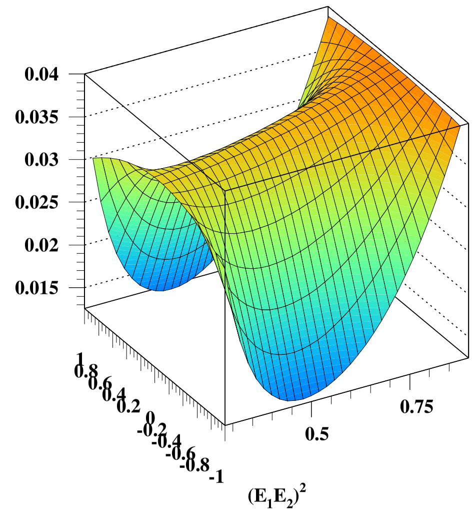
$A^2(q^2-2m_\pi^2)^2$



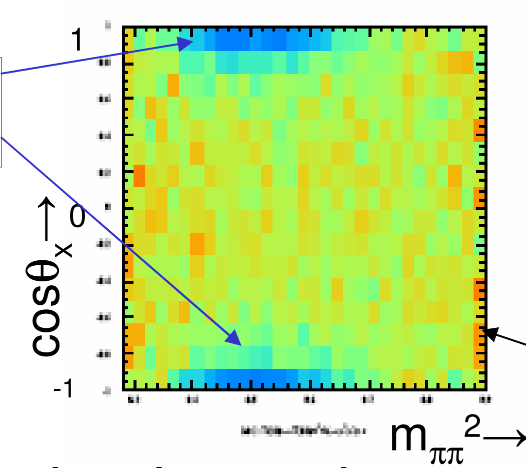
$2AB(q^2-2m_\pi^2)E_1E_2$



$B^2E_1^2E_2^2$

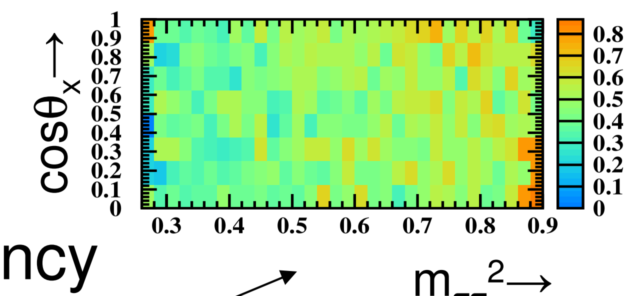


small π momentum



Efficiency

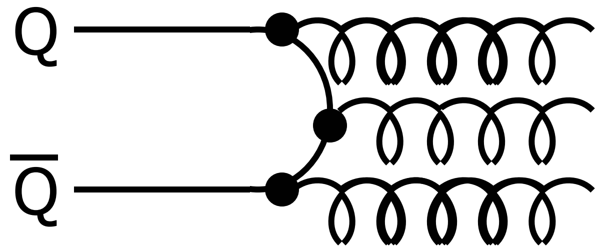
$\pi^+\pi^-$ $\pi^0\pi^0$



Tricky business, but we hope to have results soon

$\psi(2S)\to\pi\pi\pi\eta_c$ and the $\rho\pi$ puzzle

Annihilation into 3g:



expect transition probability

~ $|\psi(0)|^2$, so that

$$Q_h = \frac{B(\psi(2S)\to h)}{B(J/\psi\to h)} \approx \frac{B(\psi(2S)\to \ell^+\ell^-)}{B(J/\psi\to \ell^+\ell^-)} \approx 12\%$$

"12% rule"

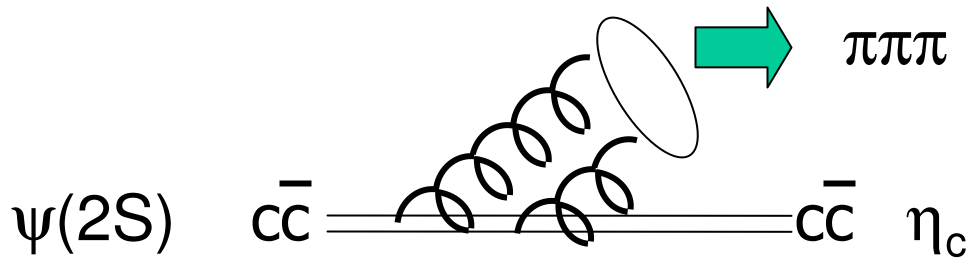
Naively anticipate this to hold for individual hadronic channels, but it doesn't:

- $(\psi(2S)\to\pi\rho)/(J/\psi\to\pi\rho) = 1.4\times10^{-3}$, off a factor ~100
  PRL 94, 012005 (2005)
- Many individual hadronic modes deviate above or below the predicted 12%

Survival before Annihilation

Artoisenet, et al. Phys.Lett.B 628(2005)211

"… The cc pair in the ψ' does not annihilate directly into three gluons, but rather survives before annihilating. An interesting prediction is that a large fraction of all ψ' decays could originate from the $\psi' \rightarrow \eta_c(3\pi)$ channel which we urge experimentalists to identify. Our model solves the problem of the apparent hadronic excess in ψ' decays as well as the $\rho\pi$ puzzle…"



This decay mechanism is postulated to dominate $\psi(2S)$ decays.

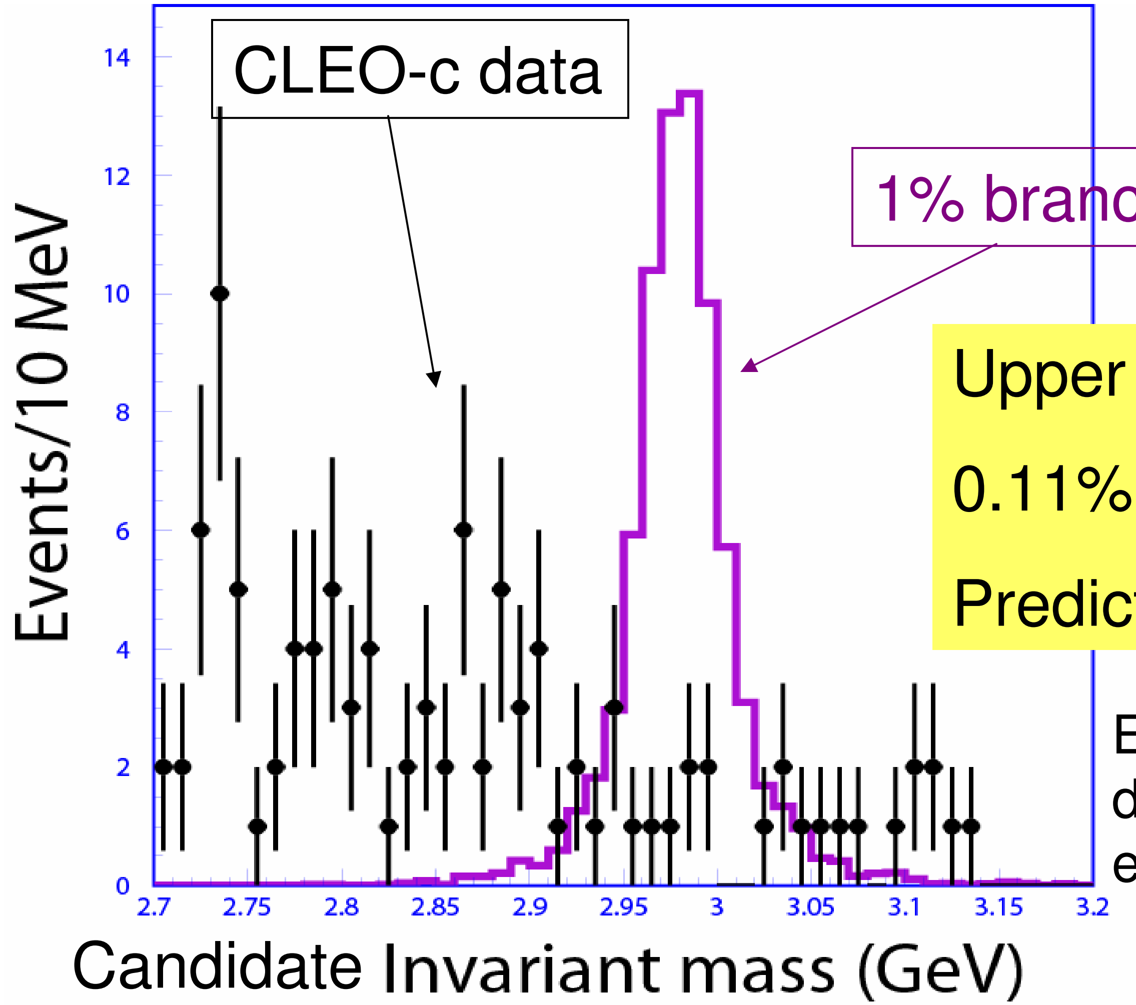
Predict $\psi(2S) \rightarrow \pi\pi\pi\eta_c$ as much as 1% or more

η_c Decay Channels used

5.6 pb^{-1} of data, 3.1M $\psi(2S)$ events

Mode	Br Rate, (%)	%error in BR	effic, %	Syst Error (%)	Sig-nal evts	Side Band
$\eta_c \to K^+K^-\pi^0$	0.95	28	3.1	30	1	1
$\eta_c \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$	1.3	37	2.8	38	0	1
$\eta_c \to \eta\pi^+\pi^-$, $\eta \to \pi^+\pi^-\pi^0$	0.7	37	0.8	39	0	0
$\eta_c \to K^+K^-\pi^+\pi^-$	1.5	40	3.1	41	7	8
$\eta_c \to \pi^+\pi^-\pi^+\pi^-$	1.2	25	4.1	26	6	19
$\eta_c \to K^-\pi^+K^0$	3.8	28	1.6	30	4	4
all six modes	9.5			15	18	33

Spectrum of η_c Candidates



Upper Limit

0.11% @ 90% C.L.

Predicted ~ 1%

Expect 10× the data by summer's end

Summary

$\pi\pi$ transitions:

CLEO sees $\psi(3770) \rightarrow \pi\pi\, J/\psi$ at the $\sim 10^{-3}$ level

$\pi\pi$ mass plots for $\Upsilon(nS) \rightarrow \pi\pi\Upsilon(mS)$

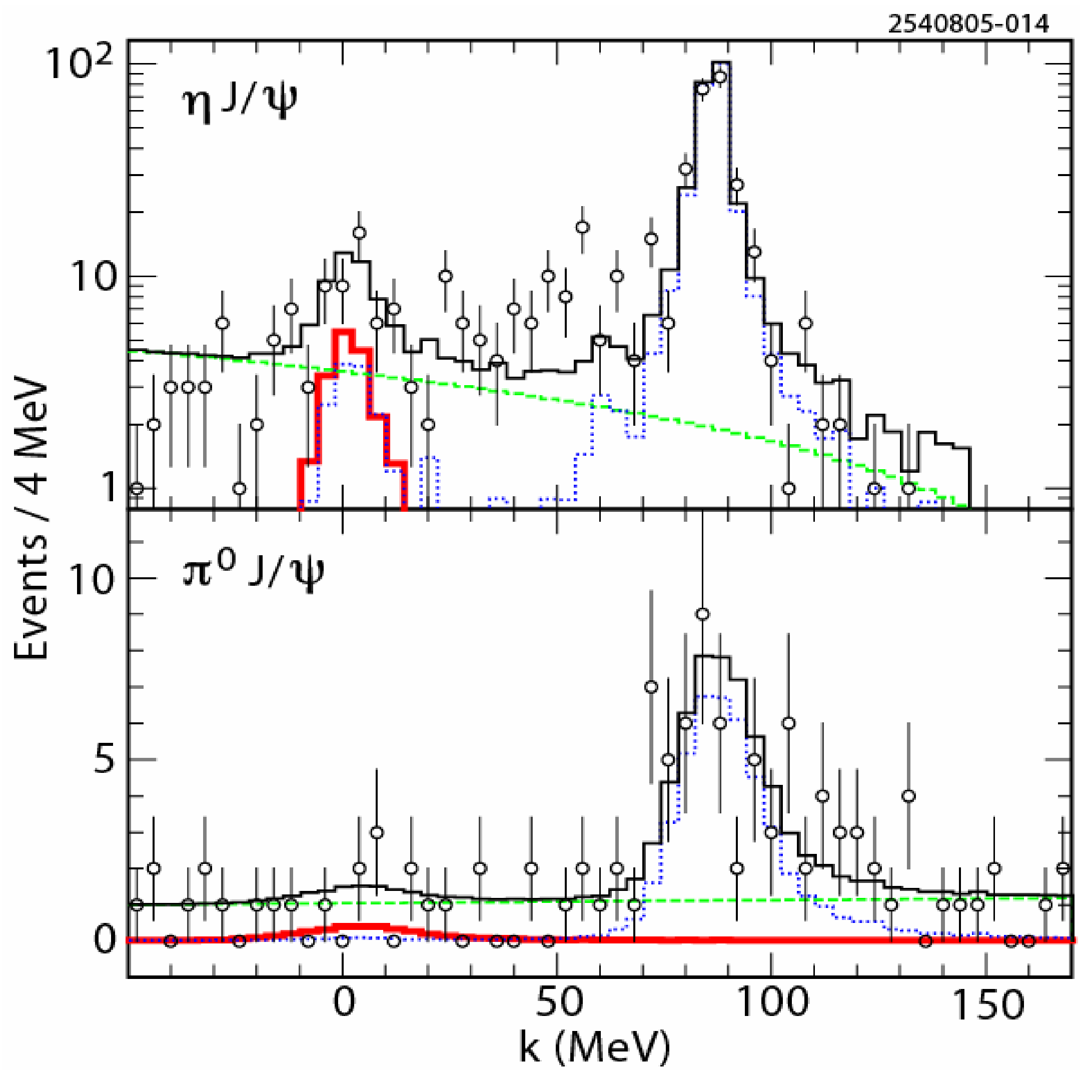
All the dipion mass distributions look like the Yan form, except $\Upsilon(3S) \rightarrow \pi\pi\Upsilon(1S)$

Described technique for extracting matrix element by fitting in q^2-$\cos\theta_x$ space

A possible explanation for the $\rho\pi$ puzzle predicts a large $\psi(2S)\rightarrow\pi\pi\pi\eta_c$. We don't see it.

Backup Slides

k Distribution $\psi(3770) \to \pi^0/\eta\ J/\psi$



Branching ratio

$\psi(3770) \to \eta\ J/\psi$

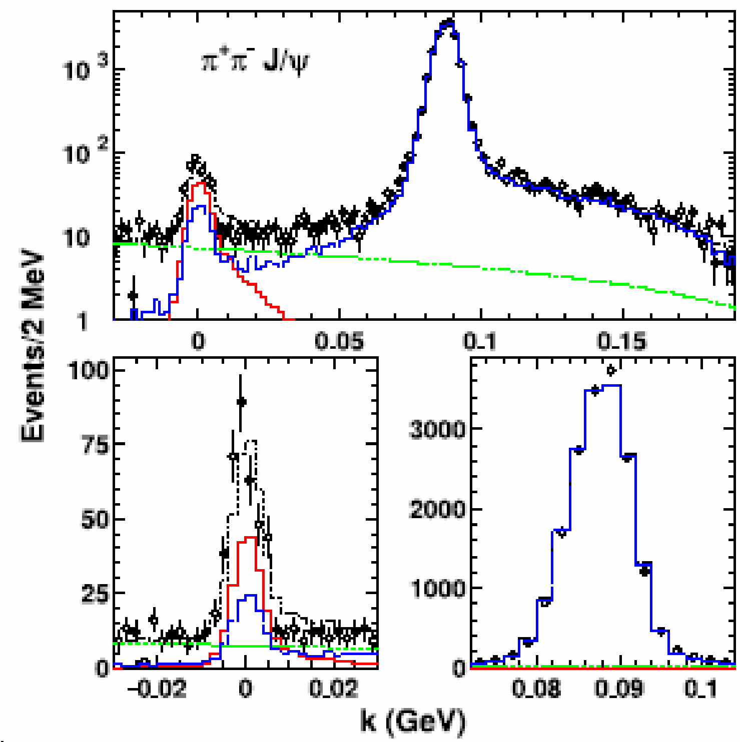
$(87\pm33\pm22\ )\times10^{-5}$

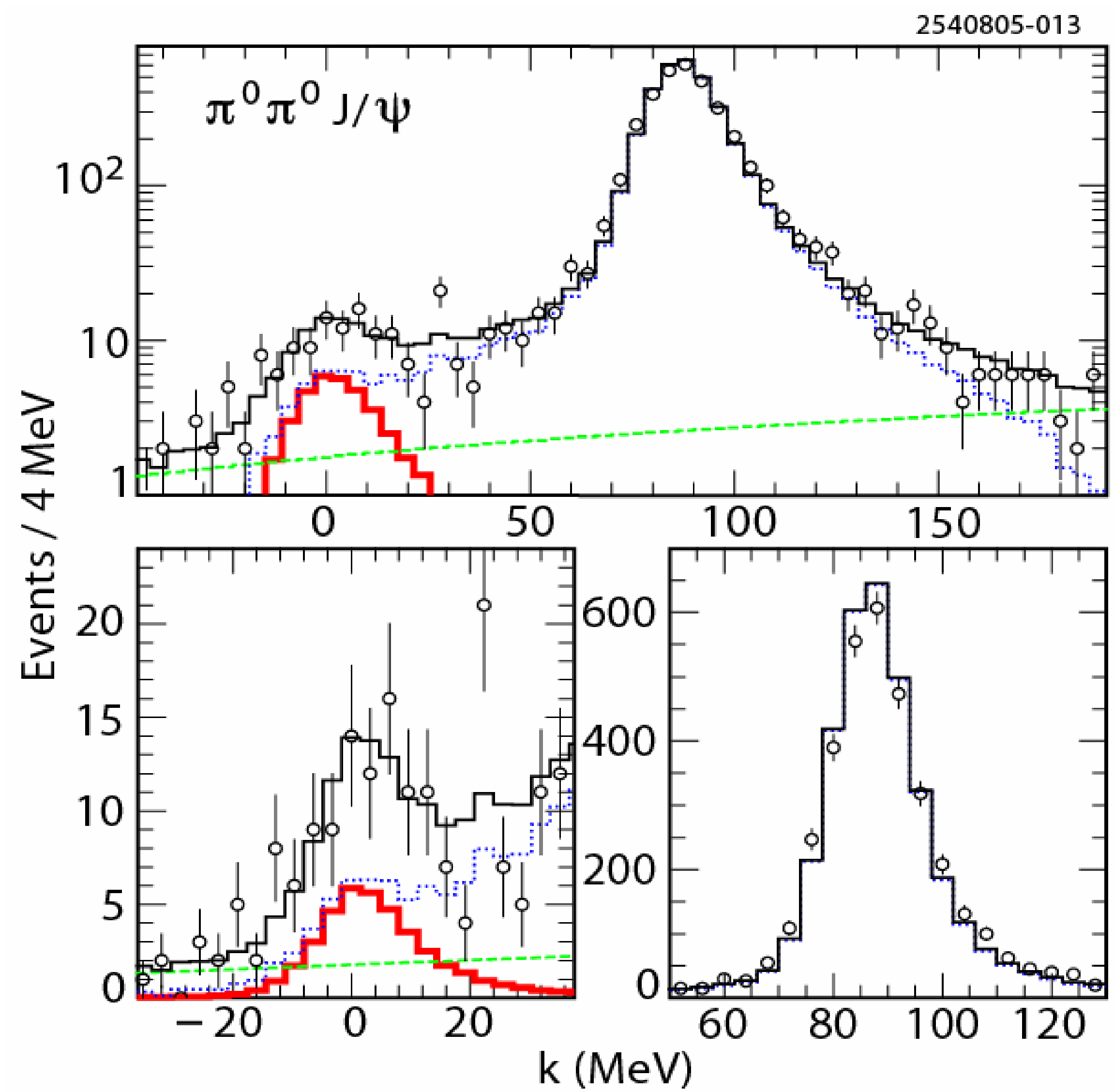
$\psi(3770) \to \pi^0\ J/\psi$

$<28\times10^{-5}$ (90% CL)

k-distribution: $J/\psi\pi^+\pi^-$

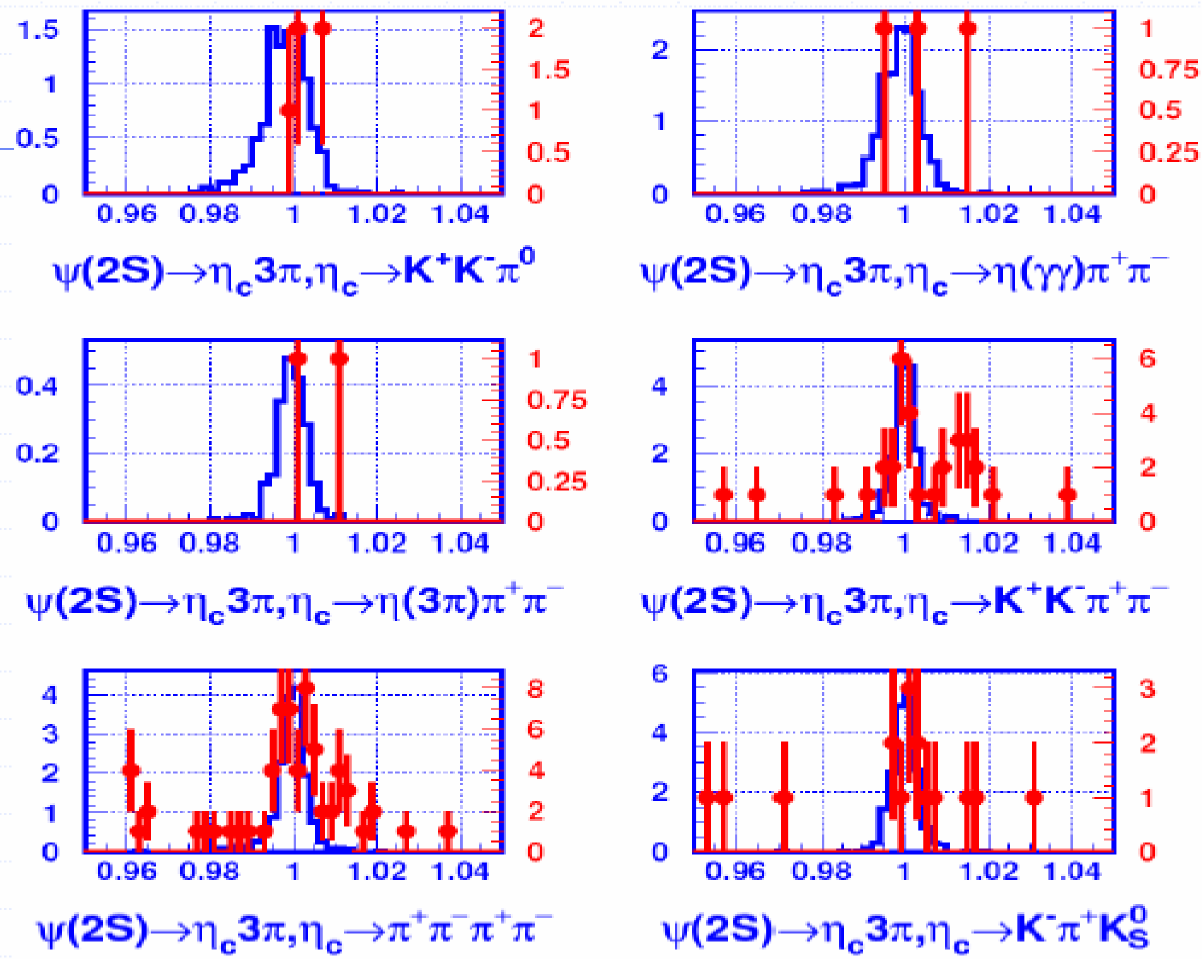
Direct
$\psi(3770)$
RR$\rightarrow\psi(2S)$
Bkg



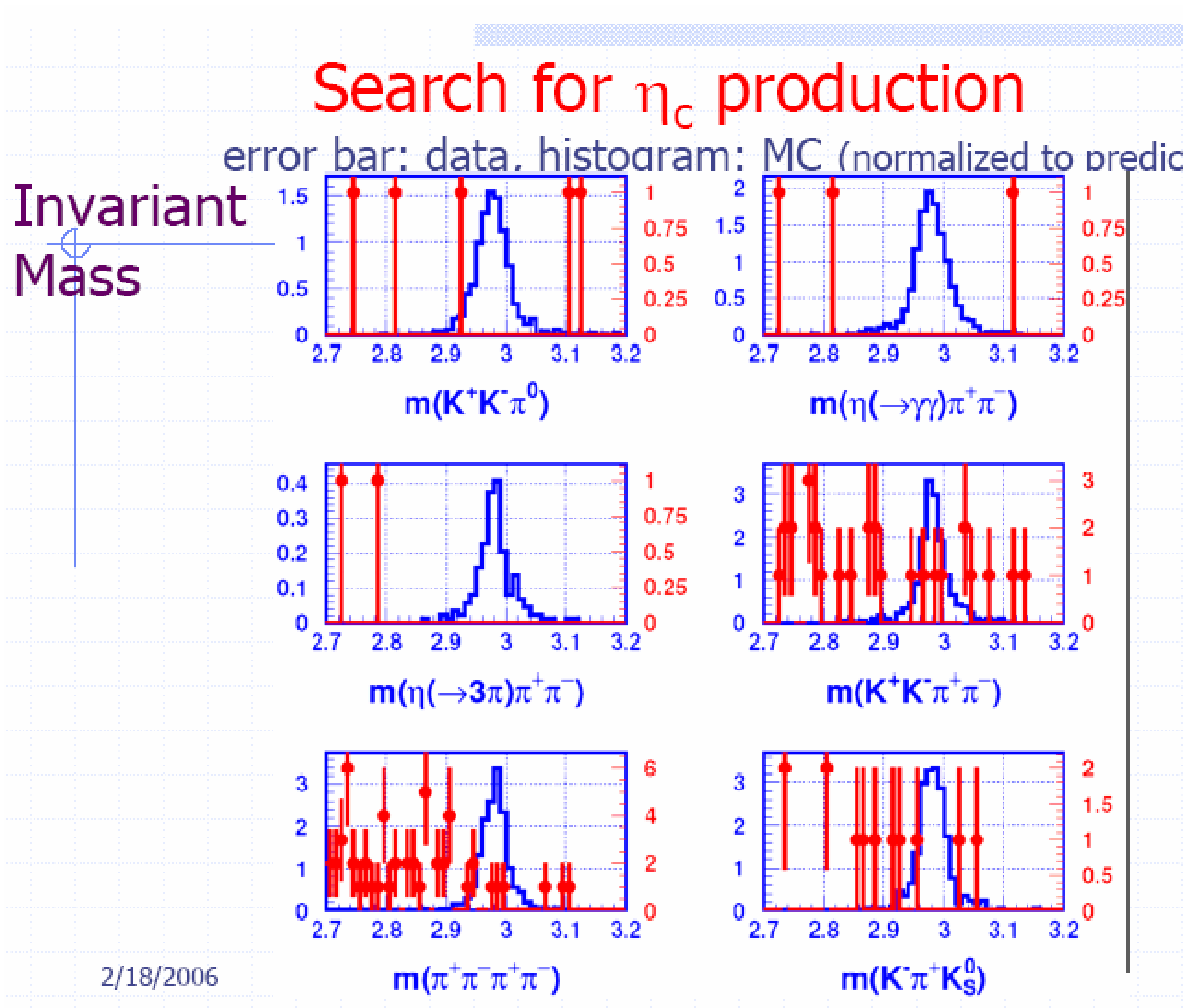

2540805-013
$\pi^0\pi^0 J/\psi$
Events / 4 MeV
k (MeV)

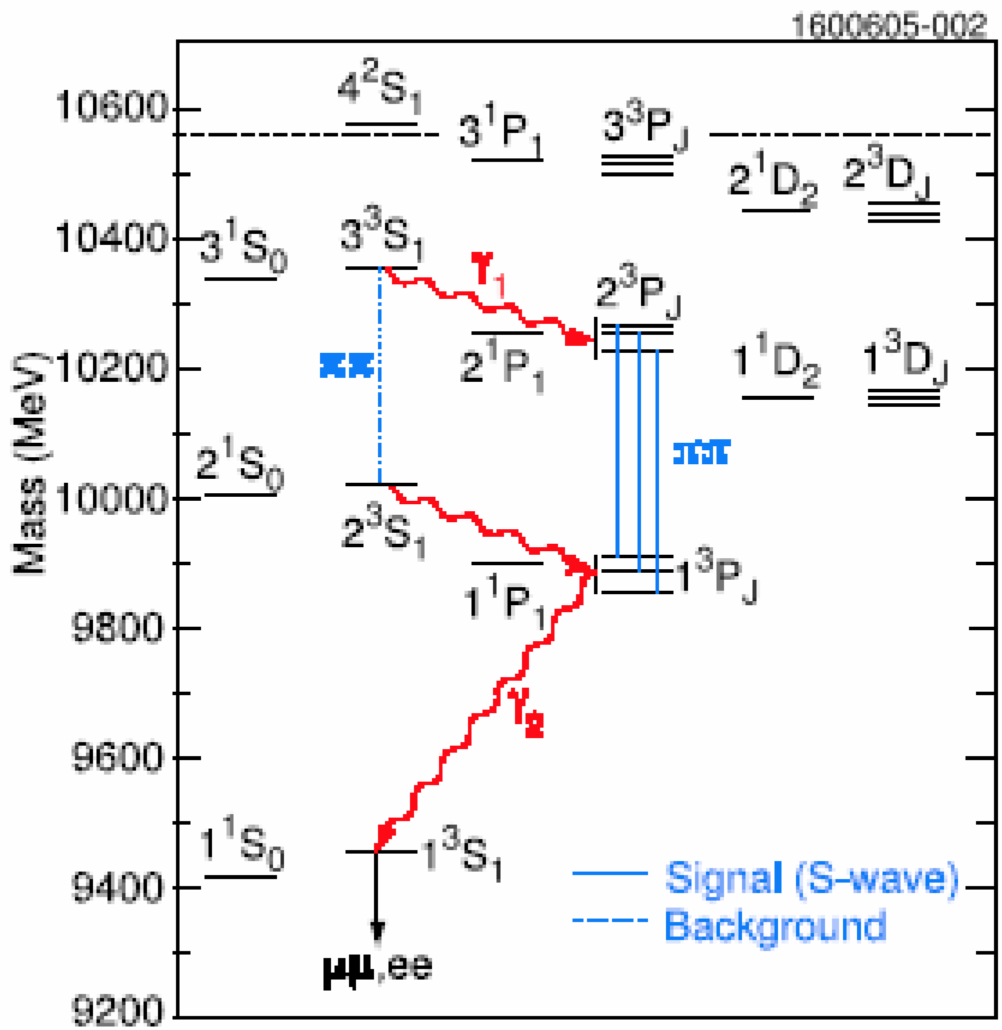
Scaled energy

error bar: data, histogram: MC (normalized to predictior



2/18/2006 8


Search for ηc production
error bar: data, histogram: MC (normalized to predic
Invariant Mass
m(K+K-π0)
m(η(→γγ)π+π-)
m(η(→3π)π+π-)
m(K+K-π+π-)
m(π+π-π+π-)
m(K-π+K0S)
2.7 2.8 2.9 3 3.1 3.2
2/18/2006


1600605-002
Mass (MeV)
10600
10400
10200
10000
9800
9600
9400
9200
4^2S_1
3^1P_1
3^3P_J
2^1D_2
2^3D_J
3^1S_0
3^3S_1
γ_1
2^3P_J
2^1P_1
1^1D_2
1^3D_J
2^1S_0
2^3S_1
1^3P_J
1^1P_1
γ_2
1^1S_0
1^3S_1
$\mu\mu$,ee
Signal (S-wave)
Background

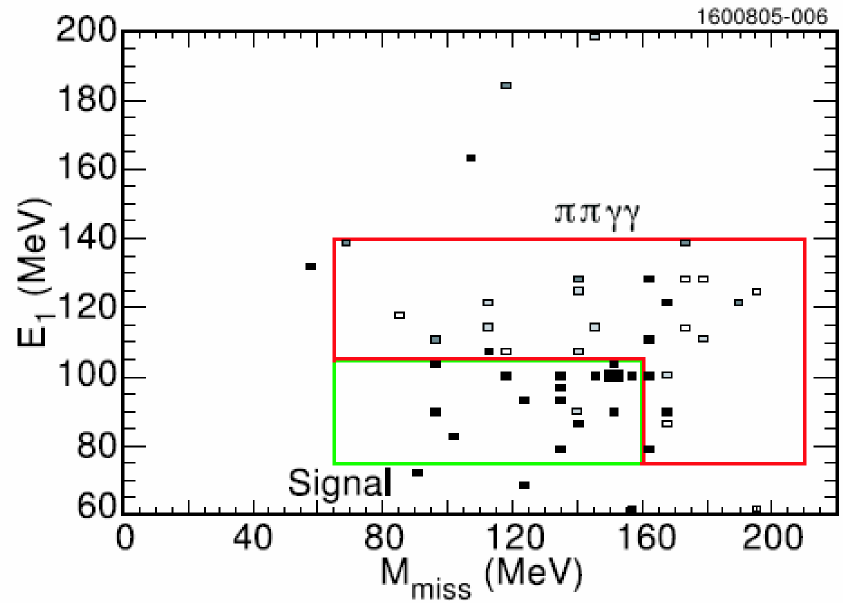
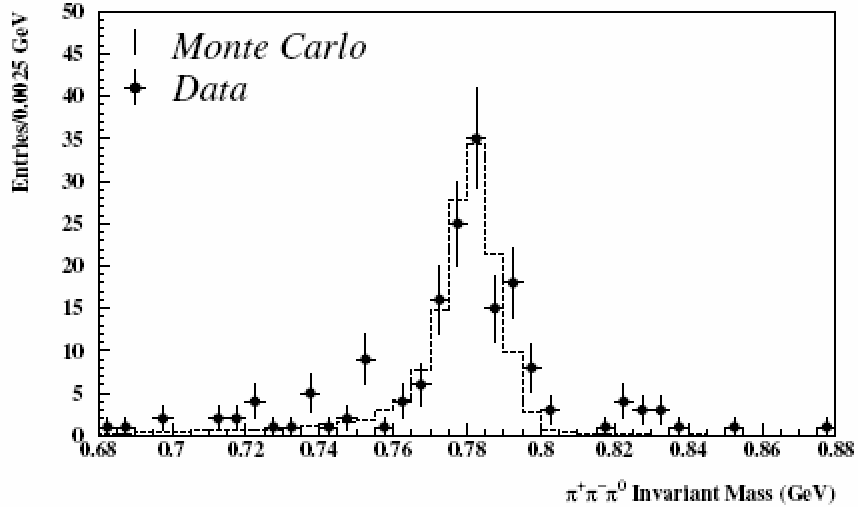


FIG. 4: The data events falling into our three defined regions for the *charged one-pion* analysis, shaded according to their $\chi^2_{\gamma\gamma}$ value. The darkest boxes are for events with $\chi^2_{\gamma\gamma}$ values between 0 and 1 and the lightest for those with $\chi^2_{\gamma\gamma}$ values between 3 and 4. Most of the events in the small signal region (the smaller rectangle) show low values for $\chi^2_{\gamma\gamma}$, indicating excellent fits of the photon energy sum to that expected for signal events.

Channel	N_{obs}	N_{bck}	$\epsilon_{1\to1}$ (%)	$\epsilon_{2\to2}$ (%)	$\Gamma_{\pi\pi}$ (keV)
Charged one-pion	17	2.4 ± 0.7	$(1 \pm 0.07)(10.6 \pm 0.8)$	$(1 \pm 0.07)(9.6 \pm 0.3)$	$1.24 \pm 0.35 \pm 0.12$
Neutral one-pion	35	26.7 ± 5.8	$(1 \pm 0.10)(13.4 \pm 1.7)$	$(1 \pm 0.10)(12.3 \pm 1.0)$	$1.12 \pm 0.80\ ^{+0.82}_{-0.78}$
Charged two-pion	–	–	$(1 \pm 0.10) \cdot 5.1$	$(1 \pm 0.10) \cdot 4.3$	
Neutral two-pion	–	–	$(1 \pm 0.11) \cdot 7.2$	$(1 \pm 0.11) \cdot 6.4$	
Combined two-pion	8	3.1 ± 0.6	–	–	$0.52 \pm 0.30 \pm 0.08$

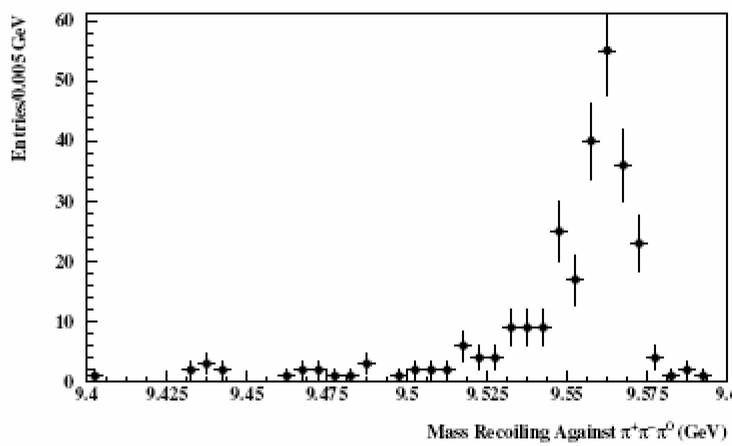
TABLE IV: The various contributions to the calculation of the partial width from sources in this experiment. The two two-pion analyses have been combined for the width determination. Of the two quoted uncertainties, the first is statistical and the second is from the uncertainties in N_{bck} and the efficiencies. An additional systematic uncertainty of $\sim 22\%$ comes from branching fractions, estimates of the total widths, and the number of $\Upsilon(3S)$.

$\Upsilon(3S) \rightarrow \Upsilon(1S)\, \omega\, X$



ASSUME $\pi^+\pi^-\pi^0$ form an ω

$$M_{recoil}^2 = \{(M_{\Upsilon(3S)},0,0,0) - (p_{\pi^+}+p_{\pi^-}+p_{\pi^0})\}^2$$



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APS April 2003

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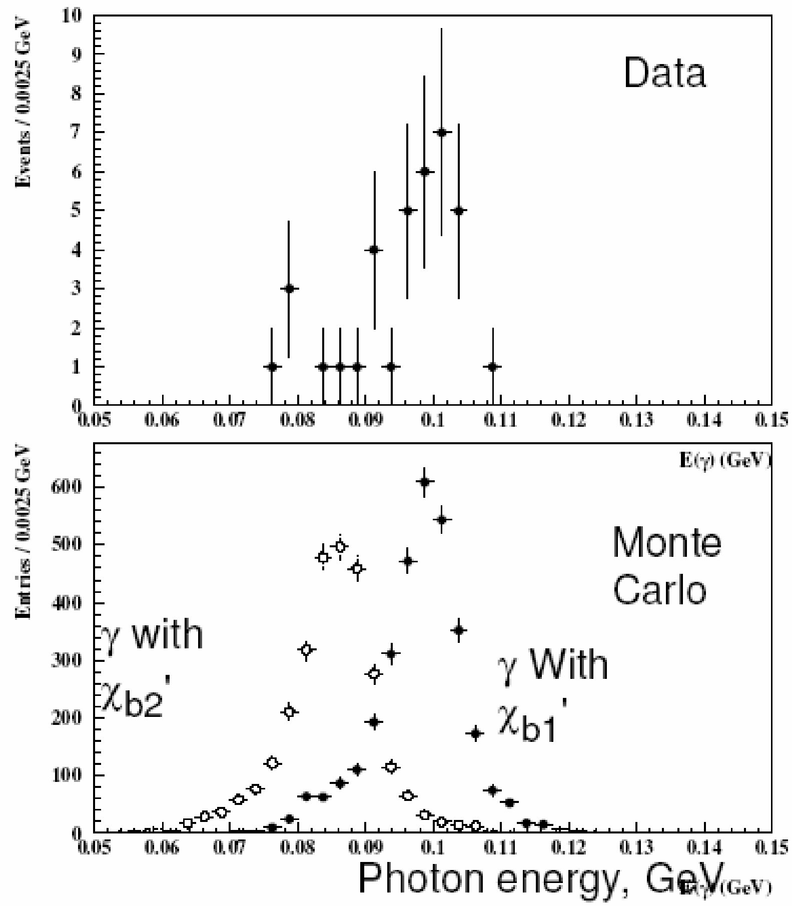
Photon Spectrum



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