Observation of double cc̄ production in e⁺e⁻ annihilation at ≈10.6 GeV

Henryk Palka
## (INP Cracow)

on behalf of the Belle Collaboration

Outline:

> Scope and motivation
> Inclusive prompt charmonia: momentum distr. and cross-sections
> J/ψ recoil mass spectrum analysis
> Associated J/ψD*+,D⁰ production
> Determination of σ(e⁺e⁻→ J/ψ cc̄)
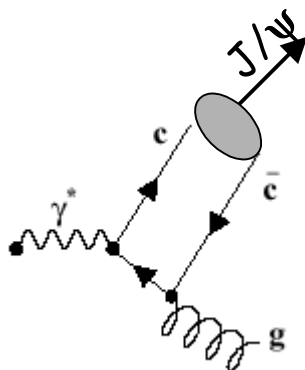> Conclusions

PRL 88, 052001 (2002) (32.4 fb⁻¹)

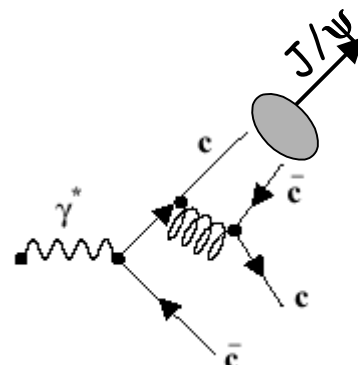ABS746, hep-ex/0205104, submitted to PRL (46.2 fb⁻¹)

Scope and Motivation

➢ $(Q\bar{Q})$ production : interplay of QCD and non-pert. effects

➢ J/ψ(ψ(2S)) production excess at CDF explained by NRQCD, validity of the framework still has to be verified

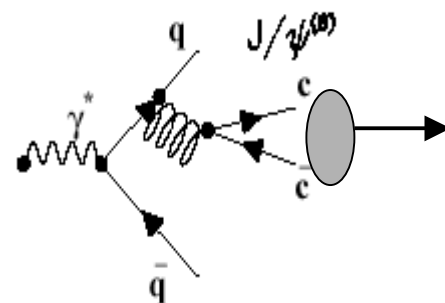➢ NRQCD predictions for $e^+e^- \to J/\psi X$ at $\sqrt{s} \approx 10$ GeV:
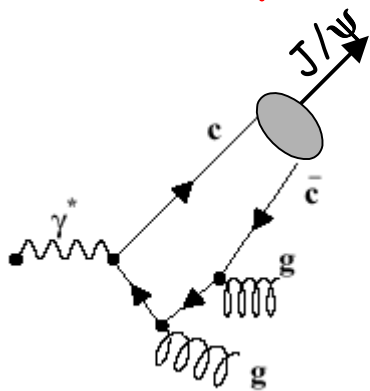
$(c\bar{c})[^3S_1]^{(1)} + gg$

dominant

$(c\bar{c})[^3S_0, {}^3P_J]^{(8)} + g$

dominant at $p^* = p_{max}$

$(c\bar{c})[^3S_1]^{(1)} + c\bar{c}$

O(10%)

$(c\bar{c})[^3S_1]^{(8)} + q\bar{q}$

smaller

Inclusive prompt charmonia

> $J/\psi \to e^+e^-, \mu^+\mu^-$,
> $\psi(2S) \to J/\psi \pi^+\pi^-$:

> Two data sets @ $\sqrt{s}$:
>   10.58 GeV ('on-resonance')
>   10.52 GeV ('off-resonance')($\sim$10%)

> 'on-resonance': p*>2GeV/c
>   to eliminate   secondary
> $B \to J/\psi$ ($\psi(2S)$) X

> N_{ch} > 4 to suppress QED J/ψ 's
>   and backgrounds

32.4fb^{-1}

Inclusive prompt charmonia

off-res.   **on & off-res.**
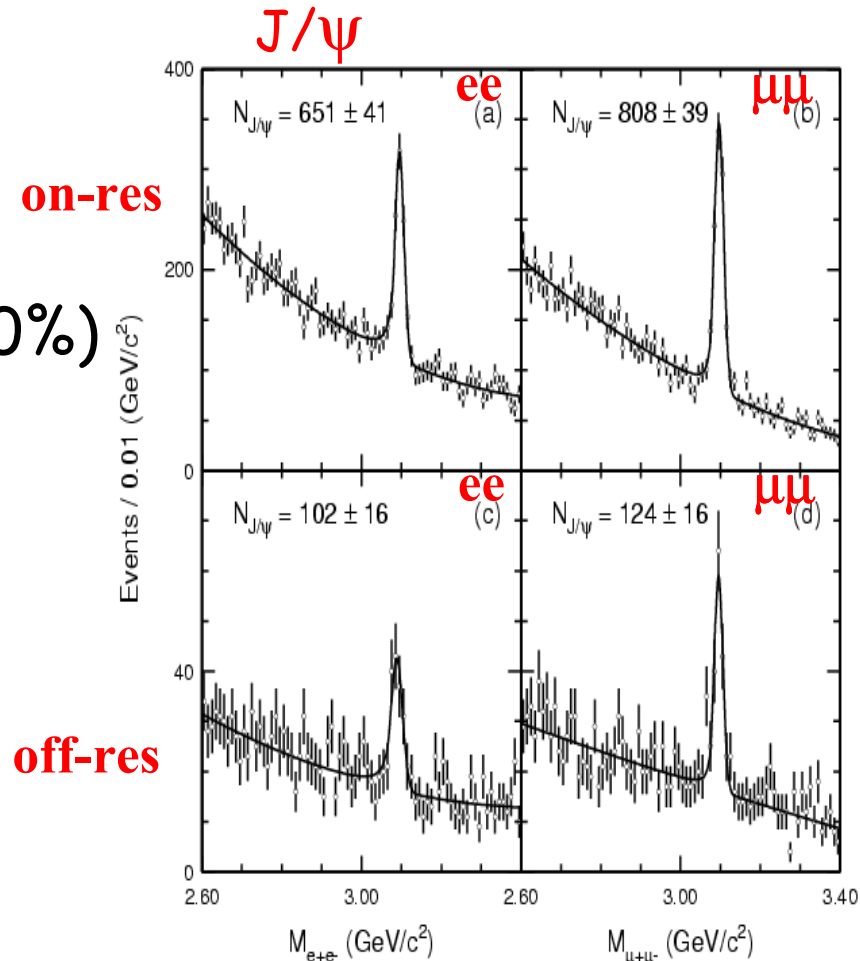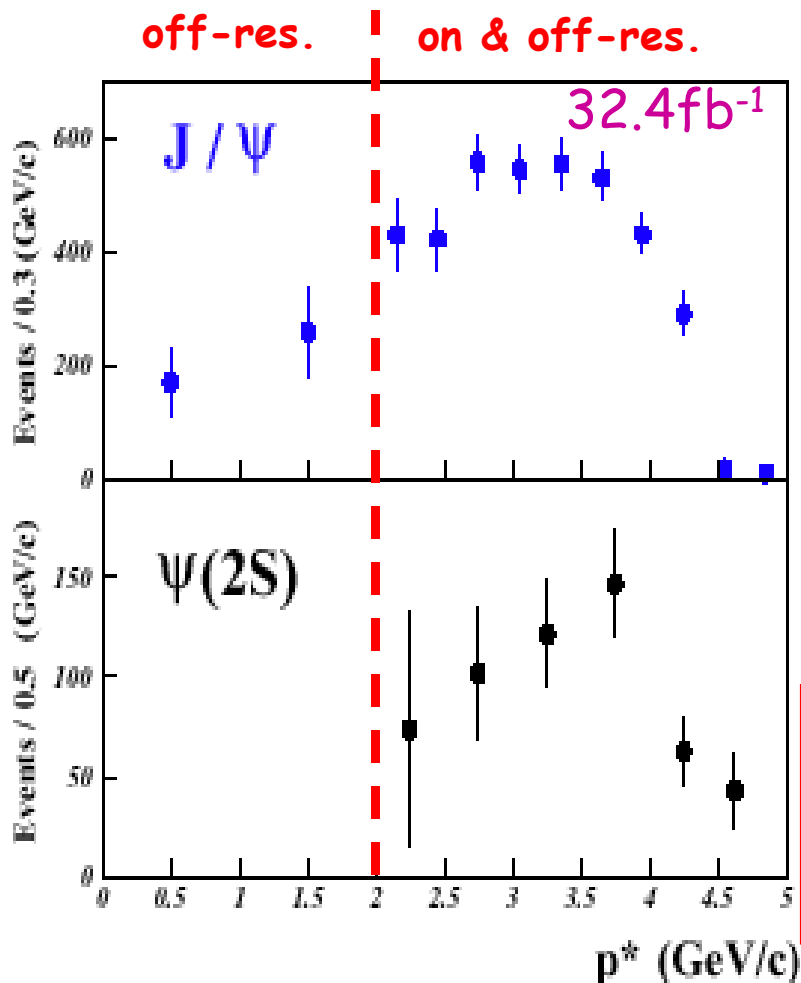
> No evidence for $e^+e^- \to J/\psi\, g$ at the p^* endpoint

(as predicted in some NRQCD calcul^s)

$\sigma(e^+e^- \to J/\psi X) = 1.47 \pm 0.10 \pm 0.11$ pb

For $2.0 < p^* < p^*_{max}$:

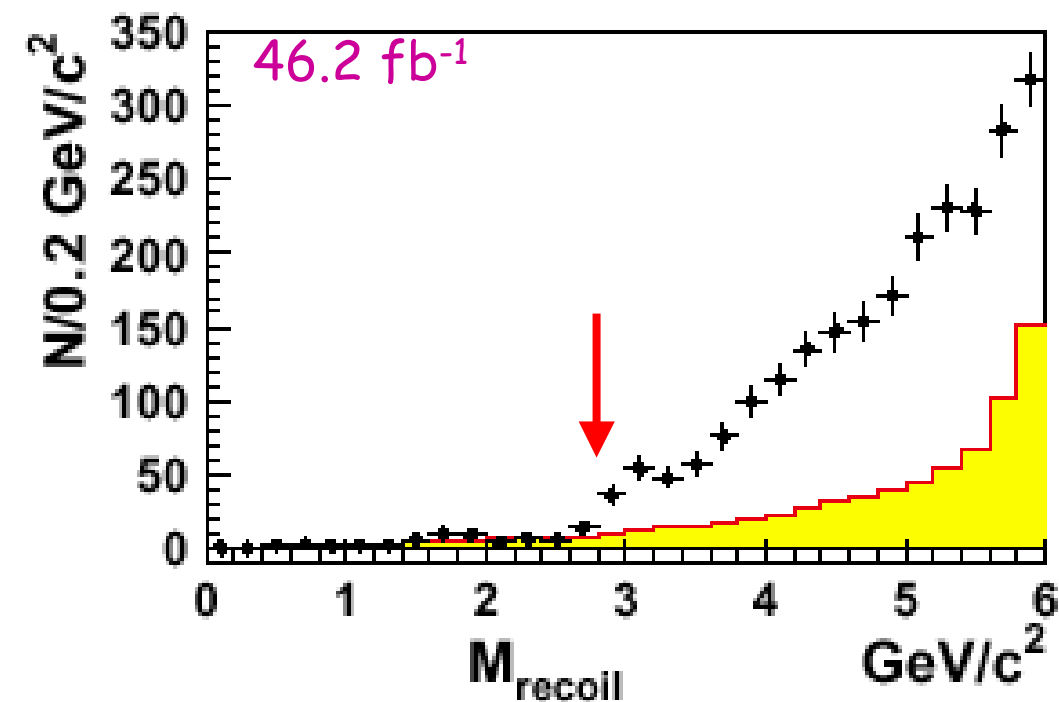$\sigma(e^+e^- \to J/\psi X) = 1.05 \pm 0.04 \pm 0.09$ pb

$\sigma(e^+e^- \to J/\psi_{dir} X) = 0.72 \pm 0.08\, ^{+0.13}_{-0.17}$ pb

$\sigma(e^+e^- \to \psi(2S) X) = 0.67 \pm 0.09\, ^{+0.09}_{-0.11}$ pb

> No clear picture/correspondence to NRQCD calculations

Recoil mass spectrum to the J/ψ

$$M_{recoil} = \sqrt{\left(\sqrt{s} - E^*_{J/\psi}\right)^2 - p^{*\,2}_{J/\psi}}$$

46.2 fb^{-1}

➢ clear threshold at $\approx 2m_c$
   for J/ψ candidates

➢ J/ψ mass sidebands

➢ threshold pronounced after background subtraction
   (scaled sidebands):
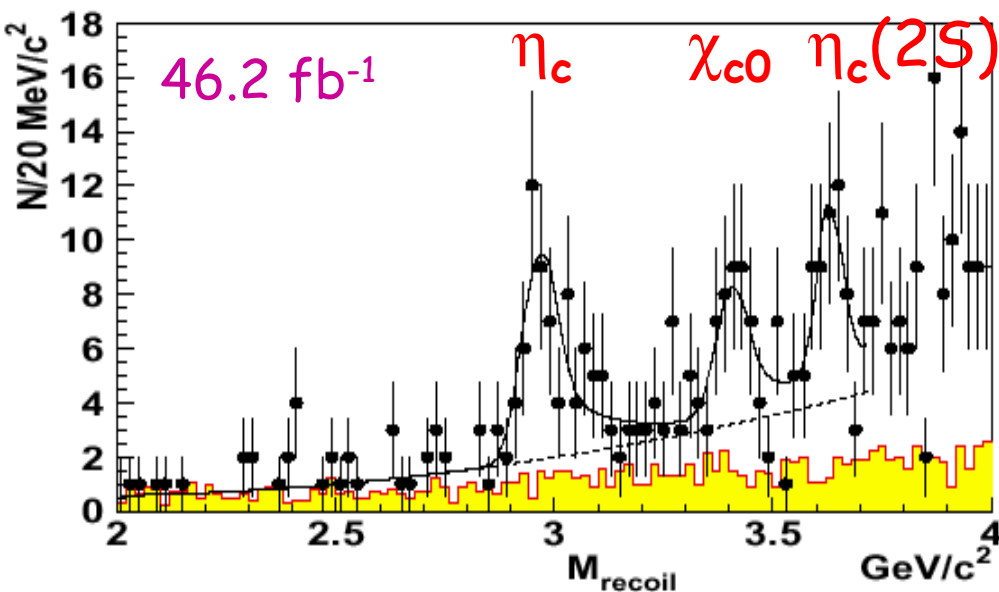
Recoil mass spectrum to the J/ψ

46.2 fb^{-1}
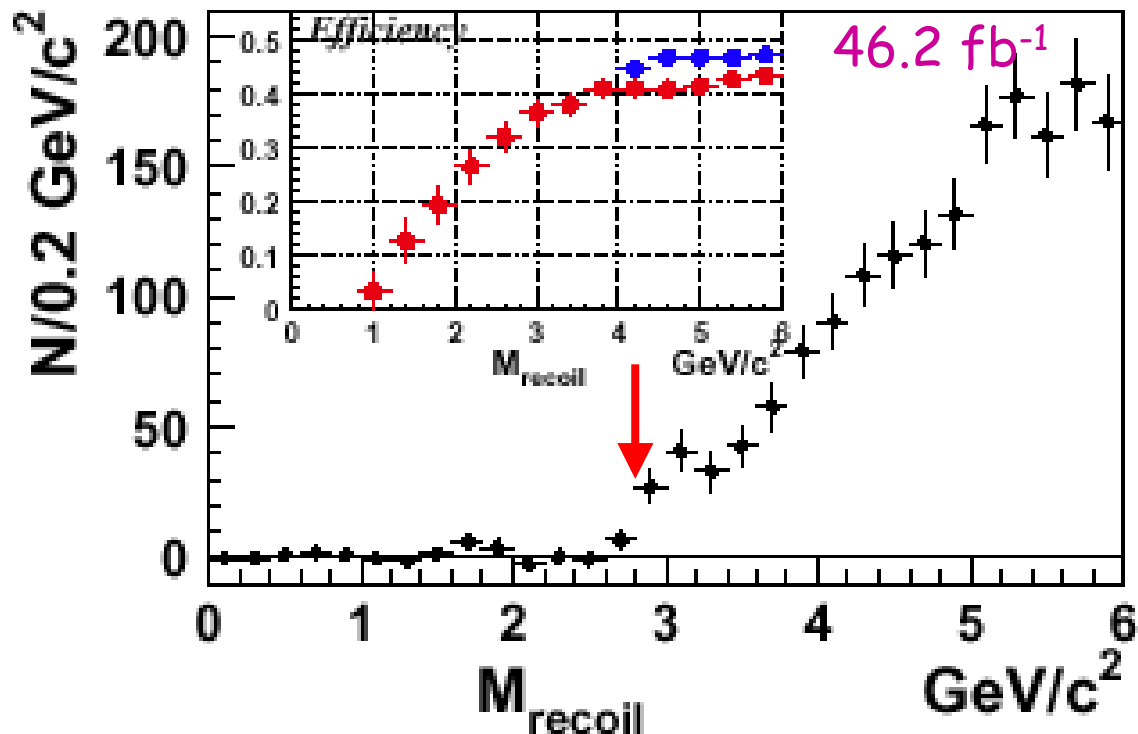
> efficiency high and smoothly varying near threshold
> (MC: $e^+e^- \rightarrow J/\psi\ \bar{q}q$
> $e^+e^- \rightarrow J/\psi\ c\bar{c}$)

> $N_{ch} > 4$ cut is safe

> Improve resolution (x2) by constraining $m_{l^+l^-}$ to the $m_{J/\psi}$

Recoil mass spectrum to the J/ψ

η_c χ_{c0} $\eta_c(2S)$

46.2 fb^{-1}

> a clear peak at $\approx$ 3 GeV
> not $\gamma^* \to J/\psi \, J/\psi$ (C-parity)

> consistent with η_c (0^{-+})
> 2nd & 3rd : χ_{c0} (0^{++}), η_c(2S)

> fit M$_{recoil}$ with:
> $\eta_c + \chi_{c0} + \eta_c(2S)$

	N$_s$	M	$\sqrt{-2\ln(L_0/L_{max})}$
η_c	67^{+13}_{-12}	2.962 ± 0.013	6.7
χ_{c0}	39^{+14}_{-13}	3.403 ± 0.014	3.3
η_c(2S)	42^{+15}_{-13}	3.622 ± 0.012	3.4

Signals: BW + ISR tail
           J/ψ η$_c$(η$_c^{'}$): p-wave
           J/ψ χ$_{c0}$: s-wave

Backgd: 2nd degree polynomial

Associated charm $e^+e^- \to J/\psi\, D^{*+}X$

> $D^{*+}(2010) \to D^0\pi^+$

> $K^-\pi+(\pi^0), K^+K^-, K^-(3\pi)^+, K_s^0\pi^+\pi^-$

> $2\sigma\ m_D$ window, vertexing and m_D constraint for $m_{D\pi}$ calculation

> remove $B\bar{B} \to (D^{(*)}l^-\bar{\nu})(Xl^+\nu)$ by $p^*(D^*) > 2.6$ GeV or $p^*(l) > 2.6$ GeV
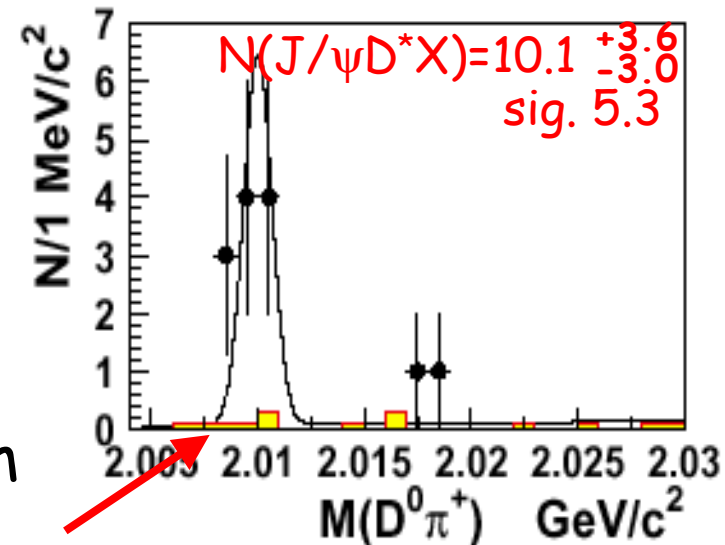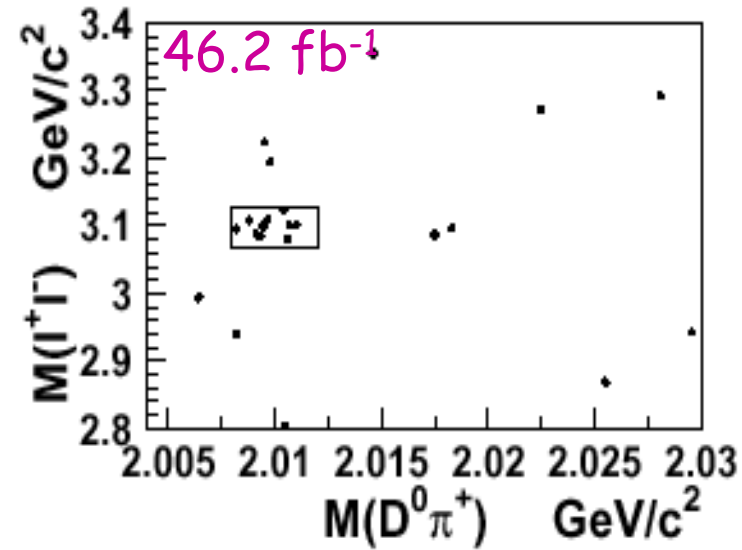
> simultaneous $m_{D\pi}$ fit to J/ψ signal window and sidebands:
> $N = 10.5^{+3.6}_{-3.0}$ $N_b = 0.4\pm0.3$

> Cross-check: dilepton mass spectrum fit: $N = 9.6^{+3.6}_{-2.9}$

46.2 fb^{-1}

$M(l^+l^-)$ GeV/c^2 vs $M(D^0\pi^+)$ GeV/c^2

$N(J/\psi D^* X) = 10.1^{+3.6}_{-3.0}$
sig. 5.3

$N/1$ MeV/c^2 vs $M(D^0\pi^+)$ GeV/c^2

bkgd predicted from J/ψ sidebands

Associated charm $e^+e^- \to J/\psi \, D^0 X$

➤ Use $D^0 \to K^-\pi^+, K^+K^-$ (the cleanest)

➤ remove $B\bar{B} \to (D^{(*)}l^-\bar{\nu})(Xl^+\nu)$ by
   $p^*(D) > 2.6$ GeV or $p^*(l) > 2.6$ GeV

➤ simultaneous fit to evts from the
   J/ψ signal window and sidebands:
   $N = 15.9 \, ^{+5.4}_{-4.7}$ $N_b = 1.0 \pm 0.8$

➤ Cross-check: dilepton mass spectrum
   fit: $N = 17.7 \, ^{+5.3}_{-4.6}$ $N_b = 4.3 \pm 0.8$

46.2 fb^{-1}

$N(J/\psi D^0 X) = 14.9 \, ^{+5.4}_{-4.7}$
sig. 3.7

bkgd predicted from J/ψ sidebands
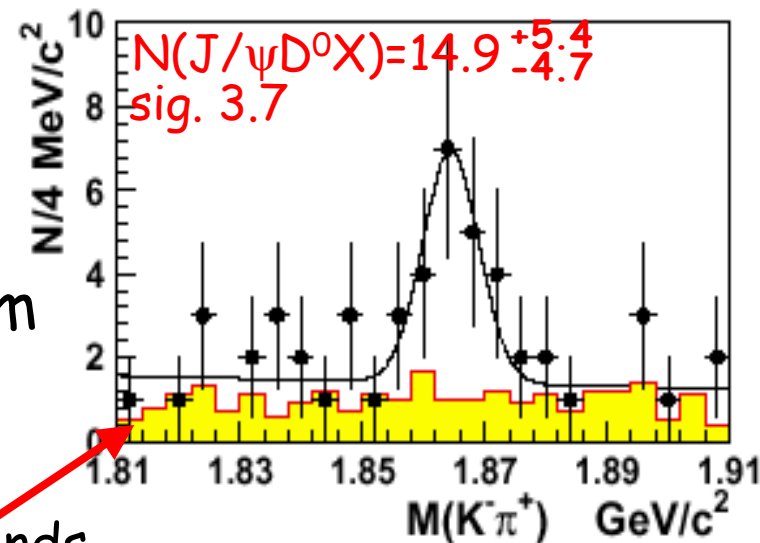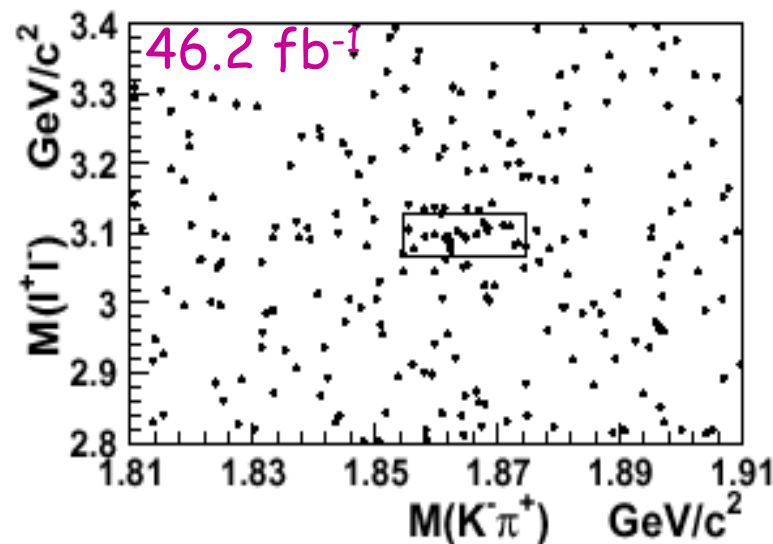
$e^+e^- \rightarrow J/\psi \, c\bar{c}$ cross-section

$\sigma(e^+e^- \rightarrow J/\psi D^{*+}X) = 0.53^{+0.19}_{-0.15} \pm 0.14$ pb

$\sigma(e^+e^- \rightarrow J/\psi D^0 X) = 0.87^{+0.32}_{-0.28} \pm 0.20$ pb

0.53/evt

LUND model
$c\bar{c} \rightarrow D^{*+} (D^0)$ rates

1.18/evt

$\sigma(e^+e^- \rightarrow J/\psi c\bar{c}X) = 1.01^{+0.36}_{-0.30} \pm 0.26$ pb

$\sigma(e^+e^- \rightarrow J/\psi c\bar{c}X) = 0.74^{+0.28}_{-0.24} \pm 0.19$ pb

$\sigma(e^+e^- \rightarrow J/\psi c\bar{c}X) = 0.87^{+0.21}_{-0.19} \pm 0.17$ pb

$\sigma(e^+e^- \rightarrow J/\psi c\bar{c}X)/\sigma(e^+e^- \rightarrow J/\psi X) = 0.59^{+0.15}_{-0.13} \pm 0.12$

Conclusions

➢ $e^+e^- \rightarrow J/\psi(\psi(2S))X$ has been observed ; cross-sections, momentum and angular distributions measured

■ No sign of color octet process $e^+e^- \rightarrow J/\psi g$ observed

➢ $e^+e^- \rightarrow c\bar{c}c\bar{c}$ has been observed for the first time:

■ $e^+e^- \rightarrow J/\psi\eta_c$ observed, evidence for $J/\psi\chi_{c0}$ and $J/\psi\eta_c(2S)$

■ $e^+e^- \rightarrow J/\psi D^{*+}X$ and $J/\psi D^0 X$ observed

■ Large fraction of the $e^+e^- \rightarrow J/\psi X$ is due to double $c\bar{c}$:

$$\sigma(e^+e^- \rightarrow J/\psi c\bar{c}X)/\sigma(e^+e^- \rightarrow J/\psi X) = 0.59^{+0.15}_{-0.13} \pm 0.12$$

Backup slides

Recoil mass fit to η_c alone
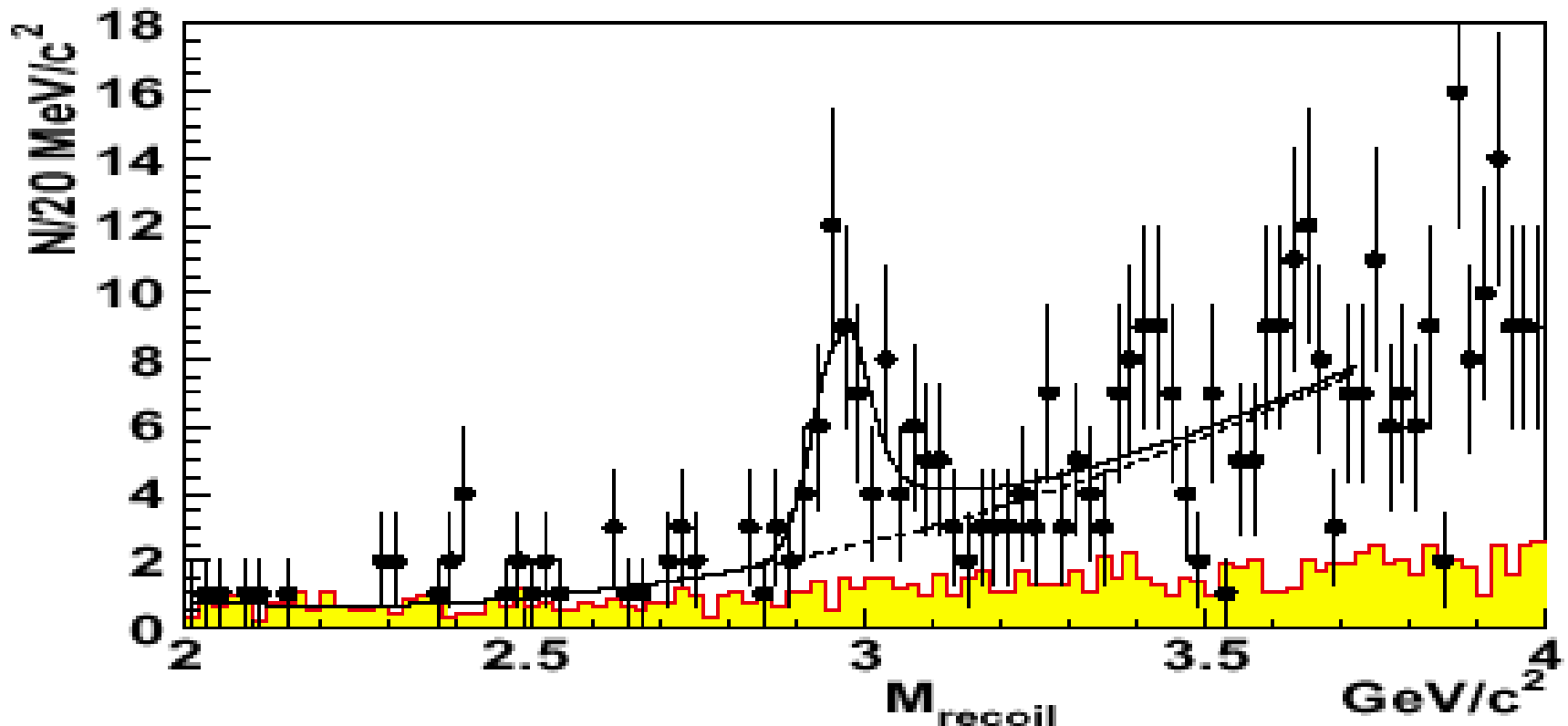
Yields: $N(\eta_c) = 56 \pm 13$ with significance 5.9

$e^+e^- \to J/\psi \, c\bar{c}$ cross-section (1) : $e^+e^- \to J/\psi \eta_c$

Source	Systematic error (%)
ISR correction	± 19
Fitting procedure	± 16
J/ψ polarization	± 11
Track reconstruction	± 5
Lepton identification	± 4
Total	± 28

➤ selection cuts remove 0 and 2 prong η_c decays

➤ η_c branching fractions poorly known

➤ we quote:

$$\sigma(e^+e^- \to J/\psi \eta_c(\gamma)) \times \mathcal{B}(\eta_c \to \geq 4\,\text{charged}) = (0.033^{+0.007}_{-0.006} \pm 0.009)\,\text{pb}$$

➤efficiencies: $\varepsilon_{J/\psi D^*} = (4.1 \pm 1.0) \times 10^{-4}$, $\varepsilon_{J/\psi D^*} = (3.7 \pm 0.8) \times 10^{-4}$

	Systematic error (%)	
Source	$J/\psi\, D^0$	$J/\psi\, D^*$
MC kinematics correction	± 11 (± 8)	± 10 (± 8)
$c\bar{c}$ fragmentation function	± 8 (± 8)	$\pm 15\,(\pm 15)$
Fitting procedure	$\pm 10\,(\pm 10)$	± 5 (± 5)
Efficiency of $p^*_{J/\psi}$ cut	± 11 (0)	± 11 (0)
Track reconstruction	± 8 (± 4)	± 12 (± 8)
Lepton and K identification	± 6 (± 3)	± 6 (± 3)
Total	23 (16)	26 (20)