# Status of the Charmonium (Exotic) Analyses for the Physics Book

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Mar 06, 2007

Overview

- **charmonium spectroscopy**

  ▸ $J/\Psi\eta$ at $\eta(2S)$ / $\Psi(2S)$ / $X(3872)$ / $Y(4260)$

- **exotics**

  ▸ $Y(3940) \rightarrow J/\Psi\omega$

  ▸ hybrid charmonium: $pp \rightarrow \Psi\eta$ with

    – $\Psi \rightarrow \chi_{c1}\pi^0\pi^0$

    – $\Psi \rightarrow DD^*$

  ▸ $Y(4320) \rightarrow \Psi(2S)\pi^+\pi^-$

J/Ψη selection

- 40k J/Ψη events at η(2S),Ψ(2S), X(387...
  and Y(4260) each

  ▸ J/Ψ→e⁺e⁻ / μ⁺μ⁻ and η→γγ

- selection criteria

  ▸ PID: $p(l^+)>0.2$, $p(l^-)>0.85$

  ▸ kinematic fit w/ beam, J/Ψ and

    η mass constraint (6C)

  ▸ invariant mass

    – $m(\gamma\gamma)\in[0.535;0.565]$ GeV

    – $m(l^+l^-)\in[3.07;3.12]$ GeV

  ▸ accept only candidate w/ biggest
    confidence level CL>0.1% per event

$\Psi(2S)\to J/\Psi\eta$
$\Gamma=4.96$ MeV

- reconstruction efficiencies ~28-33%

	Eff. [%]	BR[%]	X sec.	reco. evt/day
η(2S)	28	4.67x$BR(\eta(2S)\to J/\Psi\eta$)	10nb?	1050x$BR(\eta(2S)\to J/\Psi\eta$)
Ψ(2S)	31	1.5	10nb	350
X(3872)	33	4.67x$BR(X\to J/\Psi\eta$)	10nb?	1230x$BR(X\to J/\Psi\eta$)
Y(4260)	33	4.67x$BR(Y\to J/\Psi\eta$)	10nb?	1230x$BR(Y\to J/\Psi\eta$)
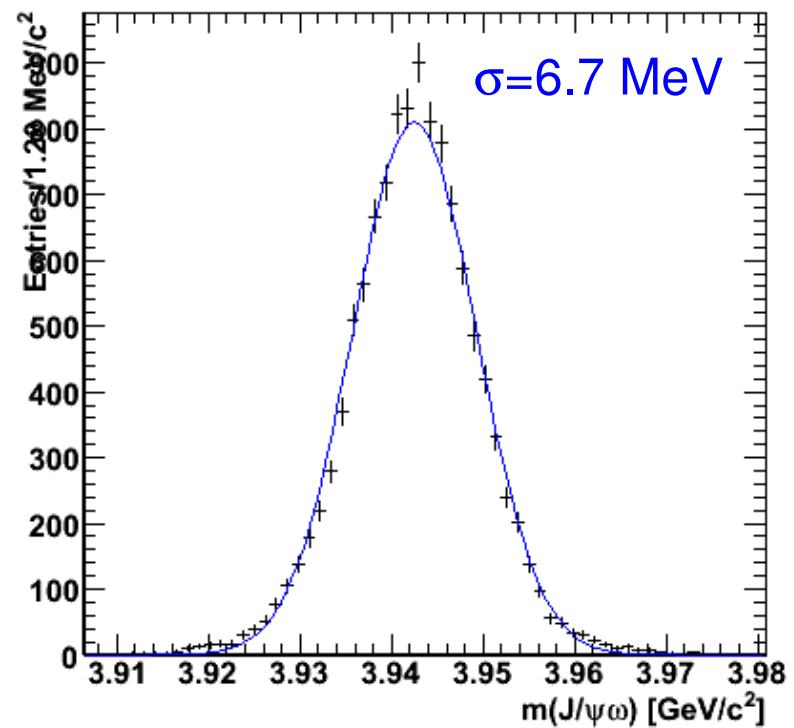
includes $BR(\Psi(2S)\to J/\Psi\eta$)
assume int.luminosity of 8pb-1/day

- background suppression at Y(4260)

  ‣ $J/\Psi\eta\eta$ ($\eta\to\gamma\gamma$): $<1.3\cdot10^{-6}$

  ‣ $J/\Psi\eta\pi^0$ ($\eta\to\gamma\gamma$, $\pi^0\to\gamma\gamma$): $<2.7\cdot10^{-6}$

  ‣ $J/\Psi\pi^0\pi^0$ ($\pi^0\to\gamma\gamma$): $<5.0\cdot10^{-5}$

  ‣ $J/\Psi\eta\gamma$ ($\eta\to\gamma\gamma$): $3.9\cdot10^{-4}$

  ‣ $J/\Psi\pi^0\gamma$ ($\pi^0\to\gamma\gamma$): $3.7\cdot10^{-4}$

J/Ψω selection

- 40k J/Ψω events at Y(3940)

  ▸ J/Ψ→l⁺l⁻, ω→π⁺π⁻π⁰

- selection

  ▸ PID: $p(l^+)>0.2$, $p(l^-)>0.85$

  ▸ PID: $p(\pi^+)>0.2$, $m(\gamma\gamma)\in[115;150]$ MeV

  ▸ 6C fit: beam, J/Ψ and π^0 mass constraint

  ▸ mass windows

    – $m(e^+e^-)\in[3.07;3.12]$ GeV

    – $m(\pi^+\pi^-\pi^0)\in[750;810]$ MeV

  ▸ J/Ψω cand. w/ biggest CL>0.1%

  ▸ veto on Ψ(2S)→J/Ψπ⁺π⁻

    – $m(J/\Psi\pi^+\pi^-)\in[3.6725;3.7]$GeV

σ=6.7 MeV
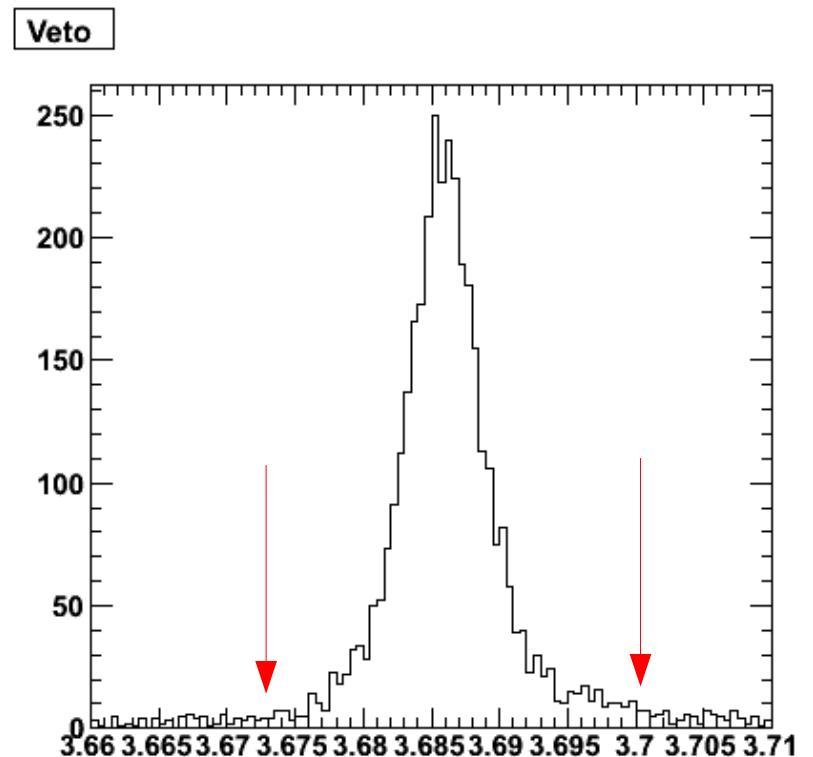
Reconstruction efficiency: 16.5%
Product of branching ratios:
BR(Y(3940)→J/Ψω)x10.7%
Assume: int. lum. 8pb-1/day
         cross sec. of 1nb
Expect BR(Y(3940)→J/Ψω)x140 evts/day

J/Ψω background

- **investigated background**

  ▸ pp→Ψ(2S)π⁰→J/Ψπ⁺π⁻π⁰

    – BR=0.32xBR(J/Ψω)

  ▸ suppression: $5\cdot10^{-5}$

  (without veto: $5\cdot10^{-2}$)
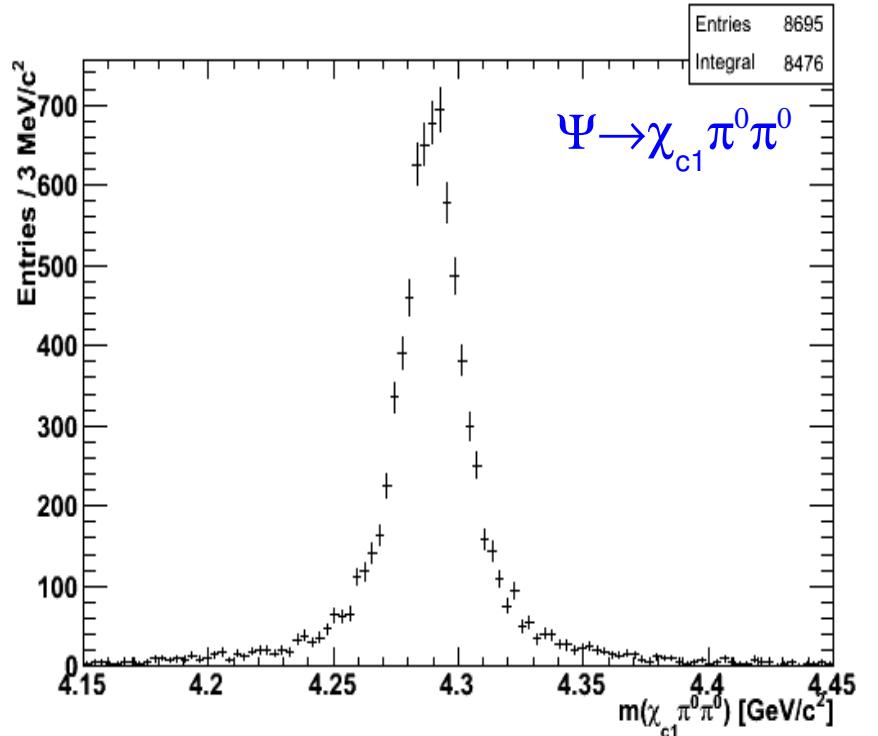
Charmonium hybrid

- hypothetical $J^{PC}=1^{-+}$ charmonium hybrid state Ψ

  - ▸ m=4290 MeV; Γ=20 MeV

  - ▸ production: pp$\rightarrow\Psi\eta$ at 15 GeV/c

  - ▸ decay modes: $\Psi\rightarrow\chi_{c1}\pi^0\pi^0$ and $\Psi\rightarrow D^0D^{0*}$

$\Psi \to \chi_{c1}\pi^0\pi^0$: Selection

- 100k $\Psi\eta$ events at 15 GeV/c

  ▸ $\Psi \to \chi_{c1}\pi^0\pi^0$, $\chi_{c1} \to J/\Psi\gamma$, $J/\Psi \to e^+e^-$, $\mu^+\mu^-$

- $J/\Psi \to e^+e^-$, $\mu^+\mu^-$ selection

  ▸ electron PID: $p(e^+)>0.2$, $p(e^-)>0.2$

  ▸ muon PID: $p(\mu^+)>0.2$, $p(\mu^-)>0.2$

  ▸ $m(l^+l^-) \in [2.98;3.16]$ GeV

- $\chi_{c1} \to J/\Psi\gamma$ selection

  ▸ $m(J/\Psi\gamma) \in [3.48;3.54]$ GeV

- π^0/η mass windows

  ▸ $m(\gamma\gamma) \in [115;150]$ and $m(\gamma\gamma) \in [530;565]$ MeV

- 9C fit: beam, η, χ_{c1}, J/Ψ and π^0 mass constraint

  ▸ $(\chi_{c1}\pi^0\pi^0)\eta$ cand. w/ biggest CL>0.1%

Entries 8695
Integral 8476

$\Psi \to \chi_{c1}\pi^0\pi^0$

Reconstruction efficiency: 5.05%
Product of branching ratios:
BR($\Psi \to \chi_{c1}\pi^0\pi^0$)x1.6%
Assume: int. lum. 8pb-1/day
cross sec. of 0.1nb
Expect BR($\Psi \to \chi_{c1}\pi^0\pi^0$)x0.6 evts/day

$\Psi \rightarrow \chi_{c1}\pi^0\pi^0$: Background studies
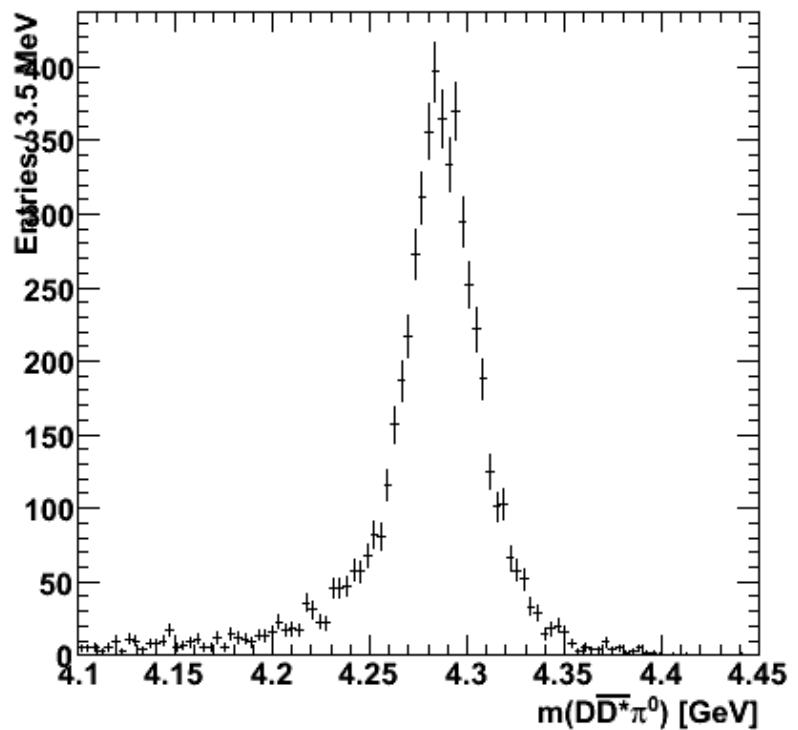
- background suppression

  ▶ $\chi_{c1}\pi^0\pi^0\pi^0\eta$: BR=0.99xBR($\chi_{c1}\pi^0\pi^0\eta$) $7\cdot10^{-6}$

  ▶ $\chi_{c0}\pi^0\pi^0\eta$: BR=0.037xBR($\chi_{c1}\pi^0\pi^0\eta$) $0.3\cdot10^{-6}$

  ▶ $\chi_{c1}\pi^0\eta\eta$: BR=0.4xBR($\chi_{c1}\pi^0\pi^0\eta$) $4\cdot10^{-6}$

Charmonium hybrid: $(D^0 D^{0*})\eta$

- 100k $\Psi\eta$ events at 15 GeV/c
  - $\Psi\to D^0 D^{0*}$, $D^{0*}\to D^0\pi^0$, $D^0\to K^-\pi^+\pi^0$, $\eta\to\gamma\gamma$
- $D^0\to K^-\pi^+\pi^0$ selection
  - PID: $p(K^+)>0.2$, $p(\pi^+)>0.2$
  - kin. fit w/ π^0 mass constraint, CL>0.1%
  - $m(K^-\pi^+\pi^0)\in[1.79;1.93]$ GeV
- $D^{0*}\to D^0\pi^0$ selection
  - kin. fit w/ D^0 and π^0 mass constr., CL>0.1%
  - $m(D^0\pi^0)\in[1.95;2.05]$ GeV
- 11C fit: beam, D^0,D^{0*},π^0 and η mass constr.
  - $(D^0 D^{0*})\eta$ cand. w/ biggest CL>0.1%

Reconstruction efficiency: 5.3%
Product of branching ratios:
BR($\Psi\to D^0 D^{0*}$)x0.3%
Assume: int. lum. 8pb-1/day
        cross sec. of 0.1nb
Expect BR($\Psi\to D^0 D^{0*}$)x0.1evts/day

Summary / Outlook

- **charmonium spectroscopy**

  - $J/\Psi\eta$ at $\eta(2S)$ / $\Psi(2S)$ / X(3872) / Y(4260)

    - efficiencies ~28-33%
    - background studies for Y(4260) [extend to other states]

- **exotics**

  - $Y(3940) \to J/\Psi\omega$

    - efficiency 16%
    - $\Psi(2S)\pi^0$ suppression ok [more problematic $J/\Psi\rho\pi$]

  - hybrid charmonium: $pp \to \Psi\eta$ with

    - $\Psi \to \chi_{c1}\pi^0\pi^0$ and $\Psi \to DD^*$ [efficieincy ~5%]
    - $\chi_{c1}\pi^0\pi^0\pi^0\eta$, $\chi_{c0}\pi^0\pi^0\eta$, $\chi_{c1}\pi^0\eta\eta$ suppression ok

- **investigate photon efficiency loss due to**

  - DIRC pre-shower / EMC overlap regions (barrel/FW cap)