Recent results from CLEO

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for CLEO collaboration

Outline

- Introduction
- Measurement of the branching ratio $J/\psi \to \ell^+\ell^-$
- Measurement of the branching ratios $\Upsilon(1,2,3S) \to \mu^+\mu^-$
- Search for $D^0 - \bar{D}^0$ mixing in $D^0 \to K^0_S\pi^+\pi^-$
- Search for $e^+e^- \to \Lambda^0_b\bar{\Lambda}^0_b$ near threshold
- Summary

Introduction

CLEO Collaboration continues to produce results using e^+e^- collision statistics accumulated at Cornell Electron-Positron Storage Ring (CESR):

Detector config.	CLEO II.V	CLEO III	CLEO-c
Years of operation	Nov.1995 - - Feb.1999	Jul.1999 - - Mar.2003	Oct.2003 - - till now
Energy, $\sqrt{s}$ Resonances	most data @ $\sim$ **10** GeV $\Upsilon(nS)$, n=1,2,...,5; test $\psi(2S)$		$\sim$ **3.8** GeV $\psi(2S)$, $\psi(3770)$
Luminosity, $\int Ldt$	9 fb^{-1}	16 fb^{-1}	60 pb^{-1} by Apr.2004 $\sim$ $\times$ 4 now

Results covered in 2 other CLEO talks:

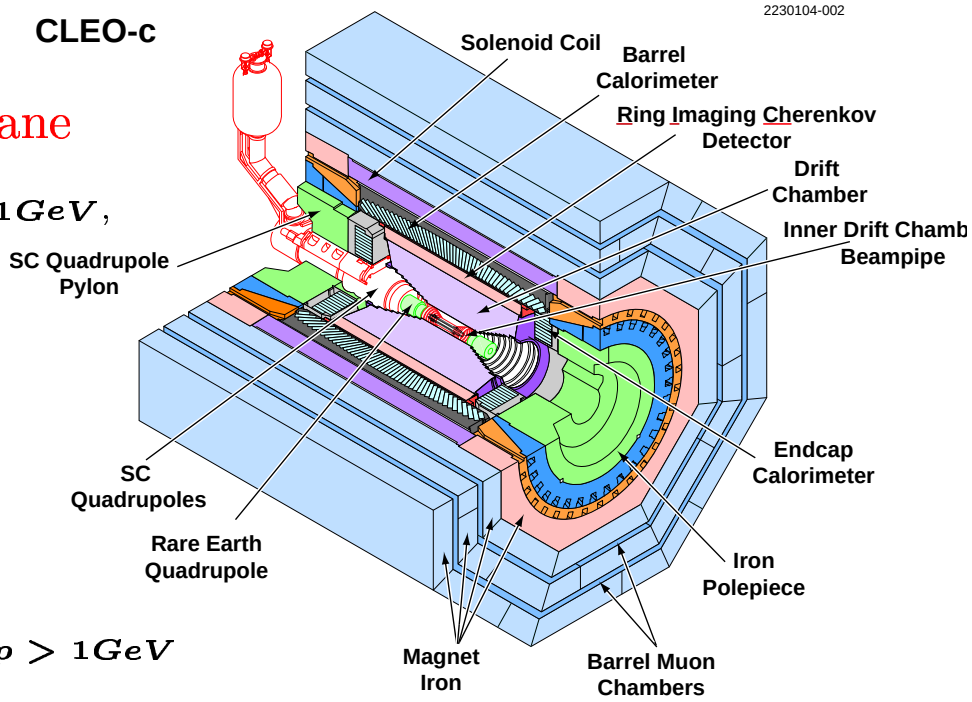
- ✓ Tomasz Skwarnicki, CLEO results on transitions in heavy quarkonia
- ✓ Steven Blusk, Measurements of Hadronic, Semileptonic and Leptonic decays of D mesons @ $E_{cm} = 3.77$ GeV in CLEO

Recent ($\sim$ half of year) CLEO publications

- $\surd$ $J/\psi \to \ell^+\ell^-$, To be submitted to Phys. Rev. Lett.
- $\surd$ Measurement of the Muonic Branching Fractions of the Narrow Upsilon Resonances, G. Adams et al. Phys. Rev. Lett. 94:012001,2005 (hep-ex/0409027)
- $\surd$ Search for $D^0 - \bar{D}^0$ Mixing in the Dalitz Plot Analysis of $D^0 \to K^0_S\pi^+\pi^-$, To be submitted to Phys. Rev. Lett.
- $\surd$ Search for $e^+e^- \to \Lambda^0_b\bar{\Lambda}^0_b$ Near Threshold, D. Besson et al., Phys. Rev. D 71, 012004 (2005) (hep-ex/0411078)
- Search for X(3872) in $\gamma\gamma$ Fusion and ISR at CLEO, S. Dobbs et al. Phys. Rev. Lett. 94:0032004,2005 (hep-ex/0410038)
- The Search for $\eta(1440) \to K^0_S K^\pm\pi^\mp$ in Two-Photon Fusion at CLEO, R. Ahohe, et al. Submitted to Phys. Rev. D (hep-ex/0501026)
- A New Measurement of the Masses and Widths of the Σ_c^{*++} and Σ_c^{*0} Charmed Baryons, S. B. Athar et al. Submitted to Phys. Rev. D (hep-ex/0410088)
- Study of Tau Decays to Four-Hadron Final States with Kaons, K. Arms et al. Submitted to Phys. Rev. Lett. (hep-ex/0501042)
- Observation of 1^-0^- Final States from $\psi(2S)$ Decays and e^+e^- Annihilation, N.E. Adam et al. Phys. Rev. Lett. 94:012005,2005 (hep-ex/0407028)

CLEO-c at CESR-c

- Tracker:
  - ▷ Inner Drift Chamber
  - ▷ Drift Chamber / He–Propane
  - ▷ 93% of 4π, $\sigma_p/p = 0.35\%$ @ $1GeV$,
    dE/dx: 5.7% π @ $min\ I$
- CsI Calorimeter: 93% of 4π,
  $\sigma_E/E = 2\%$ @ $1GeV$, 4% @ $100MeV$
- RICH: 83% of 4π,
  87% Kaon ID with 0.2% fake @0.9GeV
- Muon Chambers: 85% of 4π @ $p > 1GeV$
- Super-conducting Solenoid: 1T
- Trigger: Tracks & Showers,
  Pipelined, Latency=$2.5\mu s$
- DAQ: Event size=25kB, Thruput<6MB/s



$J/\psi \to \ell^+\ell^-$

- **Importance of $B(J/\psi \to \ell^+\ell^-)$:**
- Normalization of all J/Ψ BR
- Measurement of $\Gamma_{total}(J/\Psi)$
- Input to test potential models
- PDG average unc. $\pm 1.7\%$, from
  - ▷ BES'98 : $\pm 2\%$
  - ▷ MARK3'92 : $\pm 4\%$

- **Method:** 3M: $\Psi(2S) \to \pi^+\pi^- J/\Psi$

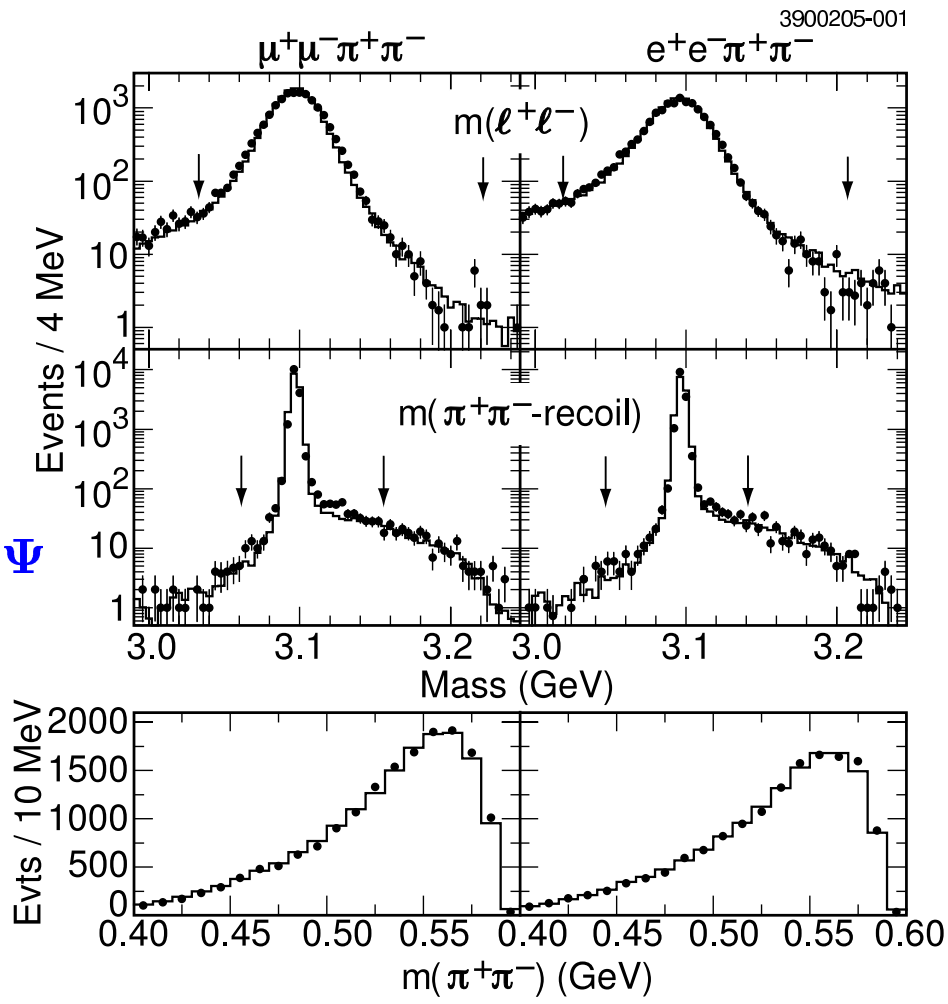
$$B = \frac{\pi^+\pi^- J/\Psi,\ J/\Psi \to \ell^+\ell^-}{\pi^+\pi^- J/\Psi,\ J/\Psi \to X} = \frac{N_{\ell\ell}/\varepsilon_{\ell\ell}}{N_X/\varepsilon_{Any}}$$

▷ Denominator: $\pi^+\pi^-$ tag,
Fit $m(\pi^+\pi^- - recoil)$ for N_X

▷ Numerator: Add $J/\Psi \to \ell^+\ell^-$ sel.
$m(\pi^+\pi^- - recoil)$ count for $N_{\ell\ell}$

▷ $\pi^+\pi^-$ systematics is mostly canceled !

▷ The only systematics from leptonic ID

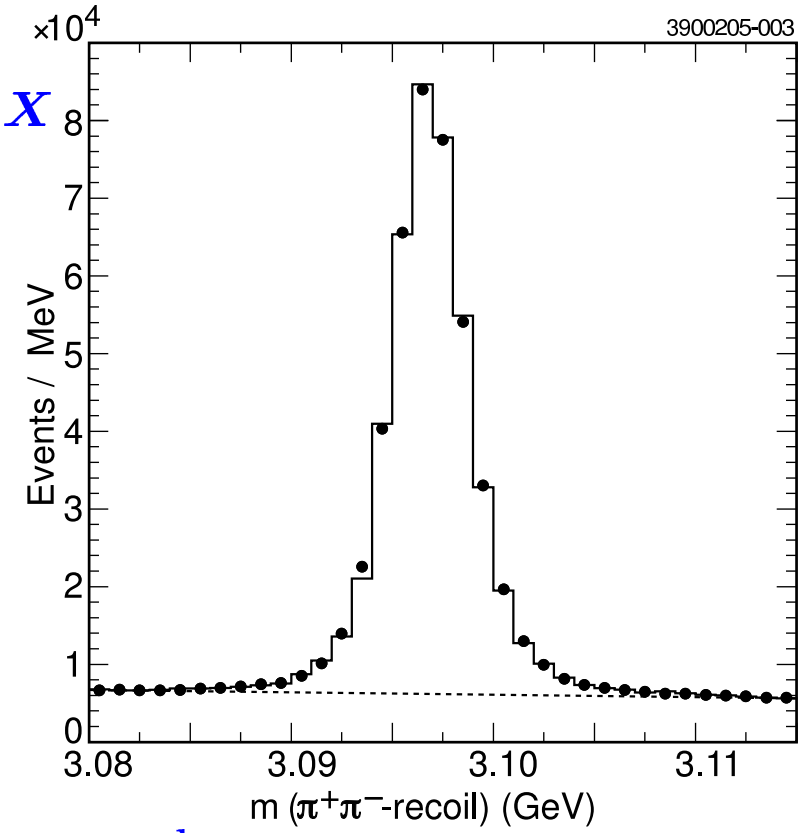


$N_{\mu\mu} = 16697, \quad N_{ee} = 14830$

$\varepsilon_{\mu\mu} = 28\%, \quad \varepsilon_{ee} = 25\%$

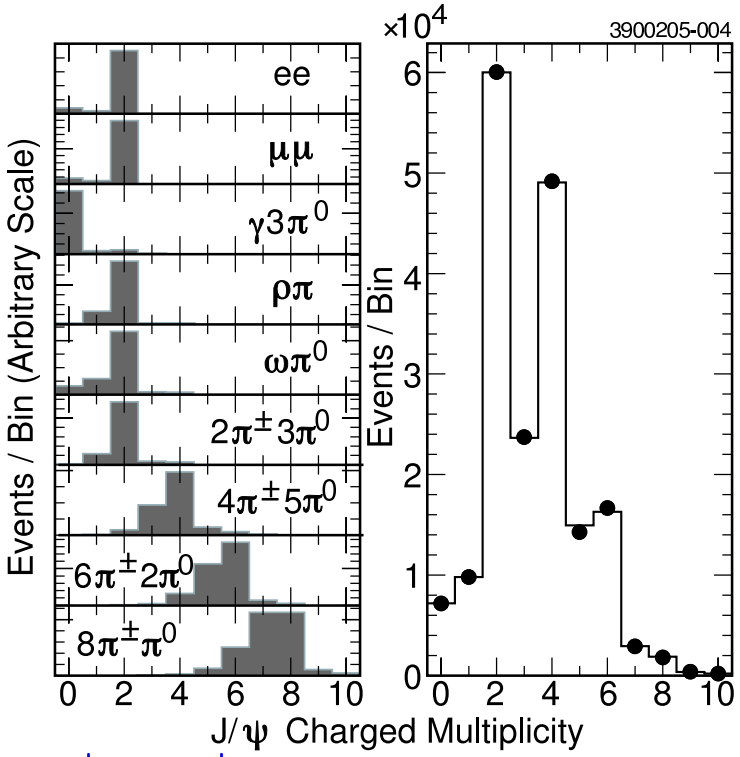
$J/\psi \to \ell^+\ell^-$ (cont.)

- $m(\pi^+\pi^- - recoil)$ fit:
- $\pi^+\pi^-\ell^+\ell^-$ shape is used to fit $\pi^+\pi^- X$
  Data shape is used for data
  MC shape is used for MC
- 2^{nd} order poly. for comb. background
- Same fit technique applied to get
  $N_{\mu\mu}$, N_{ee}, N_X, $\varepsilon_{\mu\mu}$, ε_{ee}, ε_{Any}
- How does ε_{Any} depend on
  J/ψ decay mode?
- Check it for variety of final states
- $\varepsilon_{Any} \simeq 40\%$
- $1-2\%$ relative variation with J/ψ decay mode
- More &/or softer tracks $\to$ lower ε_{Any}
- What is the N_{trk} composition of J/ψ decays ?



$J/\psi \to \ell^+\ell^-$ (summary)

- e^+e^-, $\mu^+\mu^-$, $\rho\pi$ -fixed BR
- Other BR float to get good charged multiplicity representation
- Result: BR Weights to produce $J/\Psi \to Xmix$
- Generate MC with new weights, get $\varepsilon_{Any} = 40\%$
- **Syst. uncertainties:**
  - ▷ Lepton ID (E/P): 0.2%;
  - ▷ Tracks $e^{\pm}$:0.2%, $\mu^{\pm}$:0.5%;
  - ▷ $J/\Psi \to Xmix$ weights set: 0.1%;
  - ▷ $m(\pi^+\pi^- - recoil)$ fit:0.5%;



- **Stat. uncertainties:** exclusive $\pi^+\pi^-e^+e^-$, $\pi^+\pi^-\mu^+\mu^-$ statistics : 1.1% for CLEO III and CLEO-c separately
- **Results:**
  - ✓ $BR(J/\Psi \to e^+e^-) = (5.945 \pm 0.059 \pm 0.042)\%$, PDG: $(5.93 \pm 0.10)\%$
  - ✓ $BR(J/\Psi \to \mu^+\mu^-) = (5.960 \pm 0.059 \pm 0.049)\%$, PDG: $(5.88 \pm 0.10)\%$
  - ✓ Ratio = $(99.7 \pm 1.1 \pm 0.7)\%$, confirms lepton universality,
  - ✓ $BR(J/\Psi \to \ell^+\ell^-) = (5.953 \pm 0.042 \pm 0.043)\%$,

$\Upsilon(1,2,3S) \to \mu^+\mu^-$

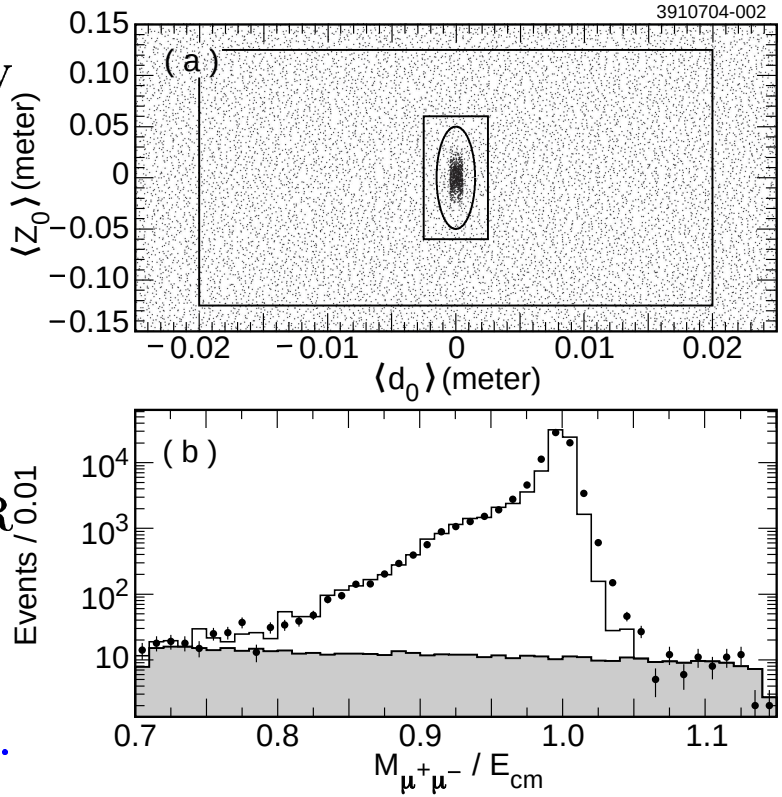
- **Importance of $B_{\mu\mu}$ for $\Gamma_{tot}(\Upsilon(nS))$:**

▷ $\Gamma_{tot}(\Upsilon(nS))$ can not be measured directly $\simeq \times 10^{-2}$ of e^+e^- beam energy spread

▷ $\Gamma_{tot}(\Upsilon(nS))$ is determined indirectly: from $\int \sigma(e^+e^- \to hadrons)d\sqrt{s} \to \Gamma_{ee}\Gamma_{had}/\Gamma_{tot}$

▷ $\Gamma_{tot} = \Gamma_{ee}/B_{\mu\mu} = \frac{\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}}{B_{\mu\mu}(1-3B_{\mu\mu})}$

- $B_{\mu\mu}$ is used for normalization of BR hadronic decays as well as Γ_{tot}



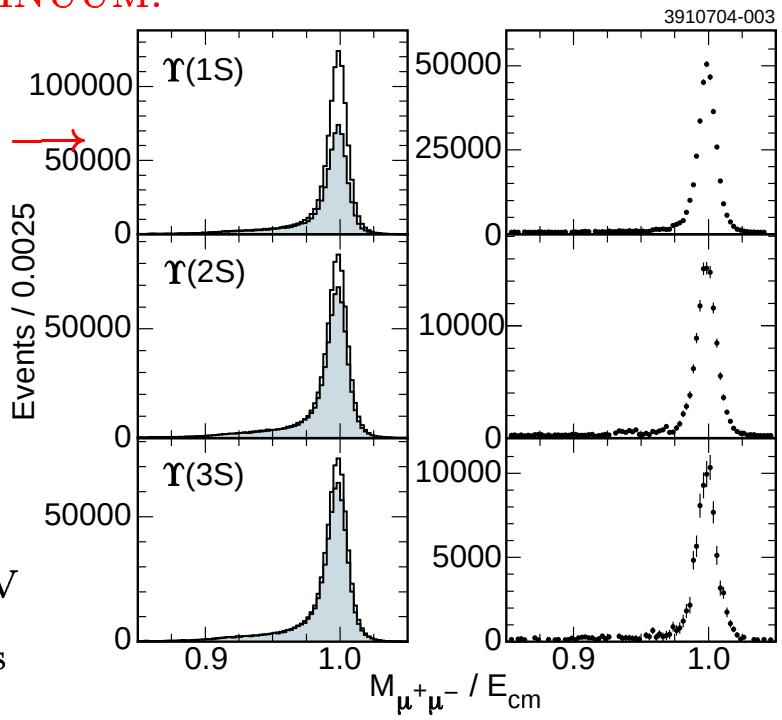
- **Method:**

▷ $B'_{\mu\mu} = \frac{N(\Upsilon(nS)\to\mu\mu)\ /\ \varepsilon_{\mu\mu}}{N(\Upsilon(nS)\to hadrons)\ /\ \varepsilon_{had}}$, ←had.
$B_{\mu\mu} = B'_{\mu\mu}/(1+3B'_{\mu\mu})$ ← total

- **Select:** 2 tracks, back-to-back within 10^o, $\mathbf{0.7 < P/E_{beam} < 1.15}$; $|\cos\theta| < 0.8$; μ ID: $\mathbf{0.1 < E_{matched} < 0.6}$ GeV, ≥ 1 track with expected range in Muon Chamb.
- **Background:** COSMIC: use track impact parameter to I.P., Z_0, d_0; subtract 0.3-0.6% depending on sample.

$\Upsilon(1,2,3S) \to \mu^+\mu^-$ (cont.)

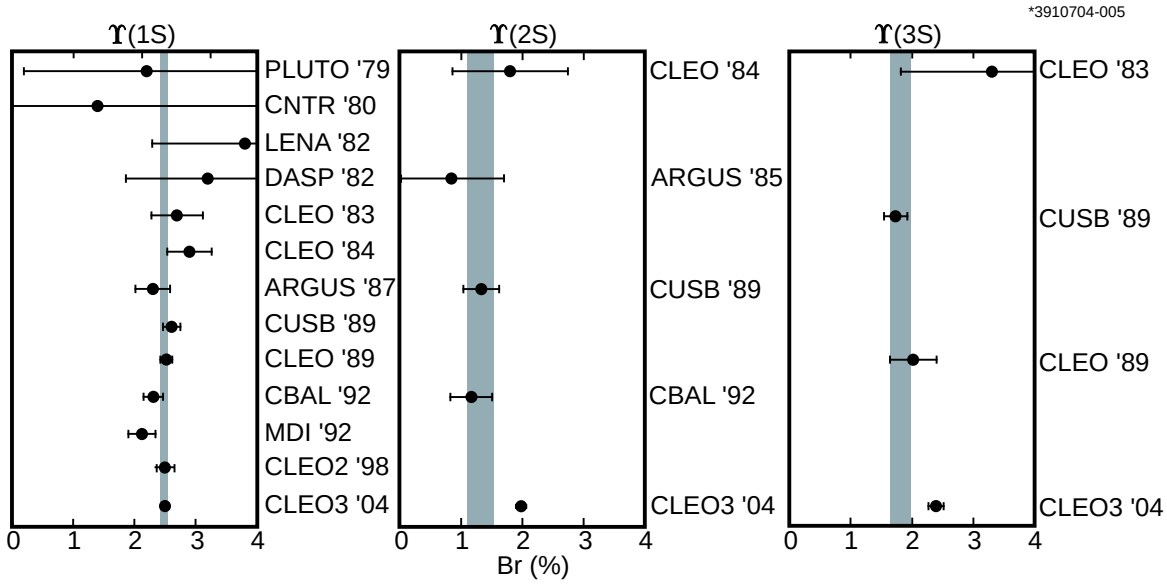
- **Main background:** $ee \to \mu\mu$ QED CONTINUUM:
  $\sigma(ee \to \mu\mu) \sim 1.2$nb,
  $\sigma(\Upsilon \to \mu\mu) \sim 0.5/0.16/0.10$nb for 1S/2S/3S
  - use scaled OFF resonance data to subtract bkg. →
  - dedicated OFF resonance statistics:
    $L_{off}/L_{on} = 0.19/1.1,\ 0.44/1.2,\ 0.16/1.2\text{fb}^{-1}$
    for 1S, 2S, 3S
  - 2-4% correction for resonance-cont. interference



- **Cascade background:**
  $\Upsilon(nS) \to (\gamma\gamma, \pi^+\pi^-)\Upsilon(n'S)$
  - Give additional peaks in $M_{\mu^+\mu^-}/E_{cm}$ plot
  - Suppress: discard events with 2sh. $E_\gamma > 50$MeV
  - Residual $\Upsilon(nS) \to (\gamma\gamma, \pi^+\pi^-)\Upsilon(n'S)$ events are subtracted using MC:
    $(2.9 \pm 1.5)\%$, $(2.2 \pm 0.7)\%$ for 2S,3S
- **Hadronic event selection:**
  $N_{tr} \geq 3$; $0.15 < E_{calorim}/E_{cm} < 0.75$; $E_\gamma < 0.75 E_{beam}$; Z_0, d_0 constrain;
  - Efficiency $\Upsilon(nS) \to hadrons$: MC, Jetset 7.3 and 7.4: $\varepsilon_{hadronic} \sim 96 - 98\%$
  - Background: from $\Upsilon(nS) \to \tau\tau$, MC:0.4-0.7%;
    from beam-gas, beam-walls, cosmic rays: 1-2%(OFF RES), <1%(ON RES);

$\Upsilon(1,2,3S) \to \mu^+\mu^-$ (summary)

$$BR(\Upsilon(1S) \to \mu^+\mu^-) = (2.49 \pm 0.02 \pm 0.07)\%$$
$$BR(\Upsilon(2S) \to \mu^+\mu^-) = (2.03 \pm 0.03 \pm 0.08)\%$$
$$BR(\Upsilon(3S) \to \mu^+\mu^-) = (2.39 \pm 0.07 \pm 0.10)\%$$



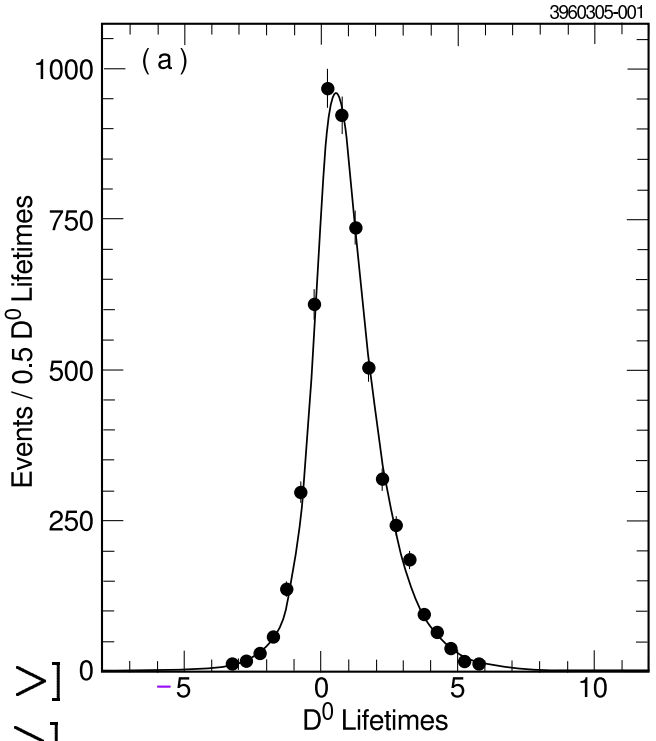
- Combining with hadronic cross section measurement:

  $\Gamma(1S) = (52.8 \pm 1.8)$ keV, $\Gamma(2S) = (29.0 \pm 1.6)$ keV, $\Gamma(3S) = (20.3 \pm 2.1)$ keV

- $\Upsilon(1,2,3S) \to e^+e^-, \tau^+\tau^-$ coming soon (summer?)

Search for $D^0 - \bar{D}^0$ Mixing in $D^0 \to K^0_S\pi^+\pi^-$

- Published:
  - ✓ $D^0 \to K^0_S\pi^+\pi^-$ Dalitz analysis,
    PRL 89,251802,2002 (hep-ex/0207067)
  - ✓ Search for CP Violation,
    PR D70:091101,2004 (hep-ex/0311033)

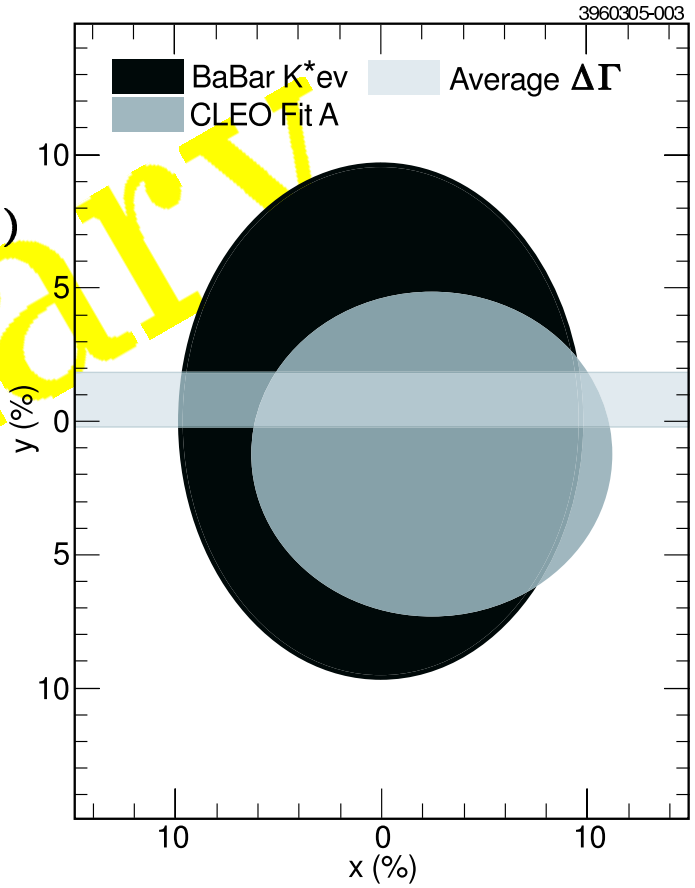


- Now: $D^{*+} \to D^0\pi^+$ tags D^0 flavor @$t = 0$
- $D^0 - \bar{D}^0$ time evolution, Schrödinger Eqn:
  $i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix} = \left(M - \frac{i}{2}\Gamma\right)\begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix}$
- Substituting $e_{1,2} = exp\left[-i(m_{1,2} - \frac{i\Gamma_{1,2}}{2})t\right]$:
  $|D^0(t)>= \frac{1}{2p}[p(e_1 + e2)|D^0> + q(e_1 - e_2)|\bar{D}^0>]$
  $|\bar{D^0}(t)>= \frac{1}{2q}[p(e_1 - e2)|D^0> + q(e_1 + e_2)|\bar{D}^0>]$
- $d\Gamma \propto |\mathcal{M}(m_{K\pi}, m_{\pi\pi}, t)|^2 dm^2_{K\pi} dm^2_{\pi\pi}$, now depends on proper time t ↑ ,
- sensitive to the mixing parameters, $x = \frac{m_1 - m_2}{\Gamma}$, $y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$, which can be extracted from the time dependent fit to Dalitz plot.
- t is measured using vertical distance from beam center to D^0 decay vertex, $\sigma_\tau \simeq \tau_{D^0}$,
- We get $\tau_{SIG} = 402 \pm 8$ fs (PDG: $\tau_{D^0} = 411$ fs)

Search for $D^0 - \bar{D}^0$ Mixing in $D^0 \to K^0_S\pi^+\pi^-$ (summary)

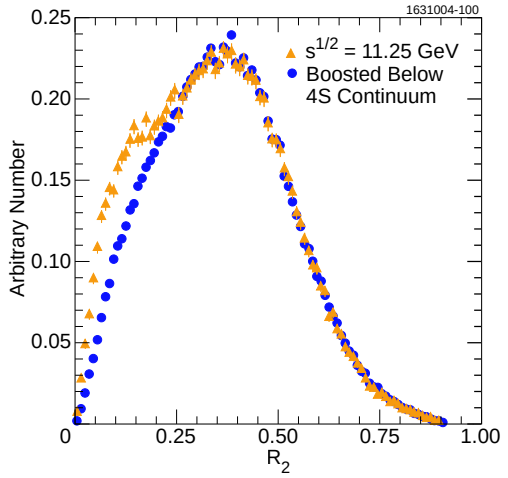
- CLEO II.V statistics:
  9.0 fb^{-1}, $\sim$ **5300** tagged events.
- fit to 10 known intermediate states:
  - CP+: $\boldsymbol{K^0_S f_0(980)}$, $\boldsymbol{K^0_S f_2(1270)}$, $\boldsymbol{K^0_S f_0(1680)}$
  - CP-: $\boldsymbol{K^0_S \rho^0}$, $\boldsymbol{K^0_S \omega}$
  - CF NON-CP: $\boldsymbol{K^{*-}(890)\pi^+}$, $\boldsymbol{K^{*-}_0(1430)\pi^+}$, $\boldsymbol{K^{*-}_0(1430)\pi^+}$, $\boldsymbol{K^{*-}(1680)\pi^+}$
  - DCS NON-CP: $\boldsymbol{K^{*+}(890)\pi^-}$,
- fit uses 35 free parameters =
  20 amplitude and phases of resonances/N.R.,
  4 signal decay time parameters,
  5 background decay time parameters,
  2 mixing amplitudes,
  2 CP violating parameters

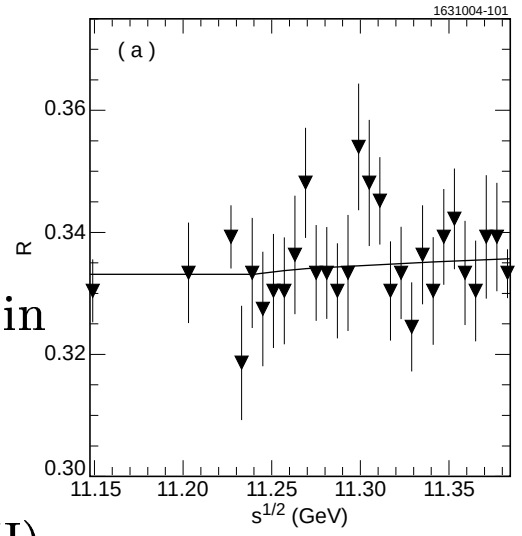
Parameter	fitted value	95% C.L. interval
x	$\boldsymbol{(2.3^{+3.5}_{-3.4} \pm 1.0)\%}$	(-4.5:9.3)
y	$\boldsymbol{(-1.5^{+2.5+1.5}_{-2.4-0.8})\%}$	(-6.2:3.4)



Search for $e^+e^- \to \Lambda_b\bar{\Lambda}_b$ near threshold

- $\Lambda_b = |bud>$
- $m(\Lambda_b) = 5620.4 \pm 1.6 \pm 1.2$ MeV, CDF(2004)
- $e^+e^- \to \Lambda_b\bar{\Lambda}_b$ is not observed yet, interesting for absolute BR measurements
- CLEO III dedicated statistics:
  - ✓ 710pb^{-1} @ $11.227 < \sqrt{s} < 11.383$ GeV
  - ✓ 270pb^{-1} below $\Upsilon(4S)$ to measure $\sigma_{b\bar{b}}$
- Main background: $\gamma^*\gamma^*$ and $\tau^+\tau^-$
- Selection: ≥ 5 tracks, $E_{vis} > E_{beam}$, Wolfram-Fox moment ratio $R_2 < 0.25$, accounts for boost, $R_2(E)$
- Search for "narrow"(20MeV) and "broad"thr. enh. in
  1. $b\bar{b}$ cross-section
  2. inclusive Λ production
  3. inclusive $\bar{p}$ production (using dE/dx and RICH)

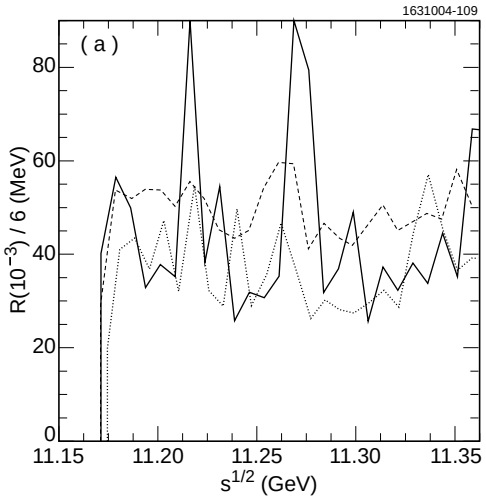




Search for $e^+e^- \to \Lambda_b\bar{\Lambda}_b$ near threshold (summary)

- Systematic uncertainties:

Source of uncertainties	± Error in %
Λ_b BR in MC decay table	31
$\bar{p}$ BR in MC decay table	20
$\bar{p}$ ID efficiency	4
Hadron efficiency	3
Total background of hadronic events	2
Luminosity	1



- Results depend on assuming BR in MC
- $\sigma(s) = A \times (\sqrt{s} - m(\Lambda_b^0))^{0.62} + R_0$
- Upper limits in units of R statistical & systematic:

Method	Upper Limit, @ 95% C.L.
$b\bar{b}$ cross-section	6.1%
Λ production	11.3%
$\bar{p}$ production	21%

Summary

- **CLEO Collaboration continues to produce results using CLEO II.V/III/c statistics**
- **Most interesting recent results are presented at this conference**
- **Universal CLEO detector allows to deal with various physics processes**
- **CLEO-c continues to accumulate statistics of e^+e^- collisions at $\sqrt{s} \simeq$ mass of $\psi(3770)$**
- **We plan to work on $D^{(*)}_{(s)}\overline{D^{(*)}_{(s)}}$ thresholds, $\psi(2S)(3686)$, $J/\psi(3100)$**
- **More results from CLEO-c are expected by summer conferences**