# First Results of E835 2000 Data Run

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## The E835 Collaboration

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Northwestern University
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# E835 is the Continuation of Charmonium Studies in the Antiproton Accumulator.

## E760 (1990-1991 Run):

$\eta_c$: M, $\Gamma$, $\Gamma_{\gamma\gamma}$ {$\bar{p}p \rightarrow \eta_c \rightarrow \gamma\gamma$}

J/$\psi$: M, $\Gamma$ {$\bar{p}p \rightarrow J/\psi \rightarrow e^+e^-$}

$\chi_1$: M, $\Gamma$, $\Gamma_{\bar{p}p}$ {$\bar{p}p \rightarrow \chi_1 \rightarrow \gamma J/\psi \rightarrow e^+e^-$}

$\chi_2$: M, $\Gamma$, $\Gamma_{\bar{p}p}$, $\Gamma_{\gamma\gamma}$ {$\bar{p}p \rightarrow \chi_2 \rightarrow \gamma J/\psi \rightarrow e^+e^-$; $\bar{p}p \rightarrow \chi_2 \rightarrow \gamma\gamma$}

$^1P_1$: M, $\Gamma$(90%CL) {$\bar{p}p \rightarrow hc \rightarrow J/\psi\pi^0 \rightarrow e^+e^-\gamma\gamma$}

$\eta_c'$ search via $\bar{p}p \rightarrow \eta_c' \rightarrow \gamma\gamma$

$\psi'$: $\Gamma$ {$\bar{p}p \rightarrow \psi' \rightarrow e^+e^-$, J/$\psi$ X}

## E835 (1996-1997 Run)

Remeasure/Search $\eta_c$, $^1P_1$, $\chi_2$, $\eta_c'$, $\psi'$ and added capability of searching for final states of $\phi\phi(\gamma) \rightarrow K^+K^-K^+K^-(\gamma)$

Measurement of $\chi_0$: M, $\Gamma$, $\Gamma_{\bar{p}p}$, $\Gamma_{\gamma\gamma}$

Also visited J/$\psi$, $\chi_1$ for checks

## E835 (2000 Run)

Remeasure $\chi_0$ and $^1P_1$ with the added capability of searching for $\bar{p}p \rightarrow \bar{c}c \rightarrow \bar{p}p$

Also visiting $\chi_1$, $\chi_2$, $\psi'$ for checks

# Why $\bar{p}p$ annihilations?

Early experiments: produced $\psi$ and $\psi'$ directly in $e^+e^-$ collisions; non $1^{--}$ states were observed via radiative decays where detector resolution limits measurement precision.

All of the charmonium states can be formed directly with $\bar{p}p$ annihilation, for the price of a large hadronic background. (~mb compared to $\bar{c}c$ signals ~nb). The solution is to look only for the **electromagnetic decays** of the charmonium states.

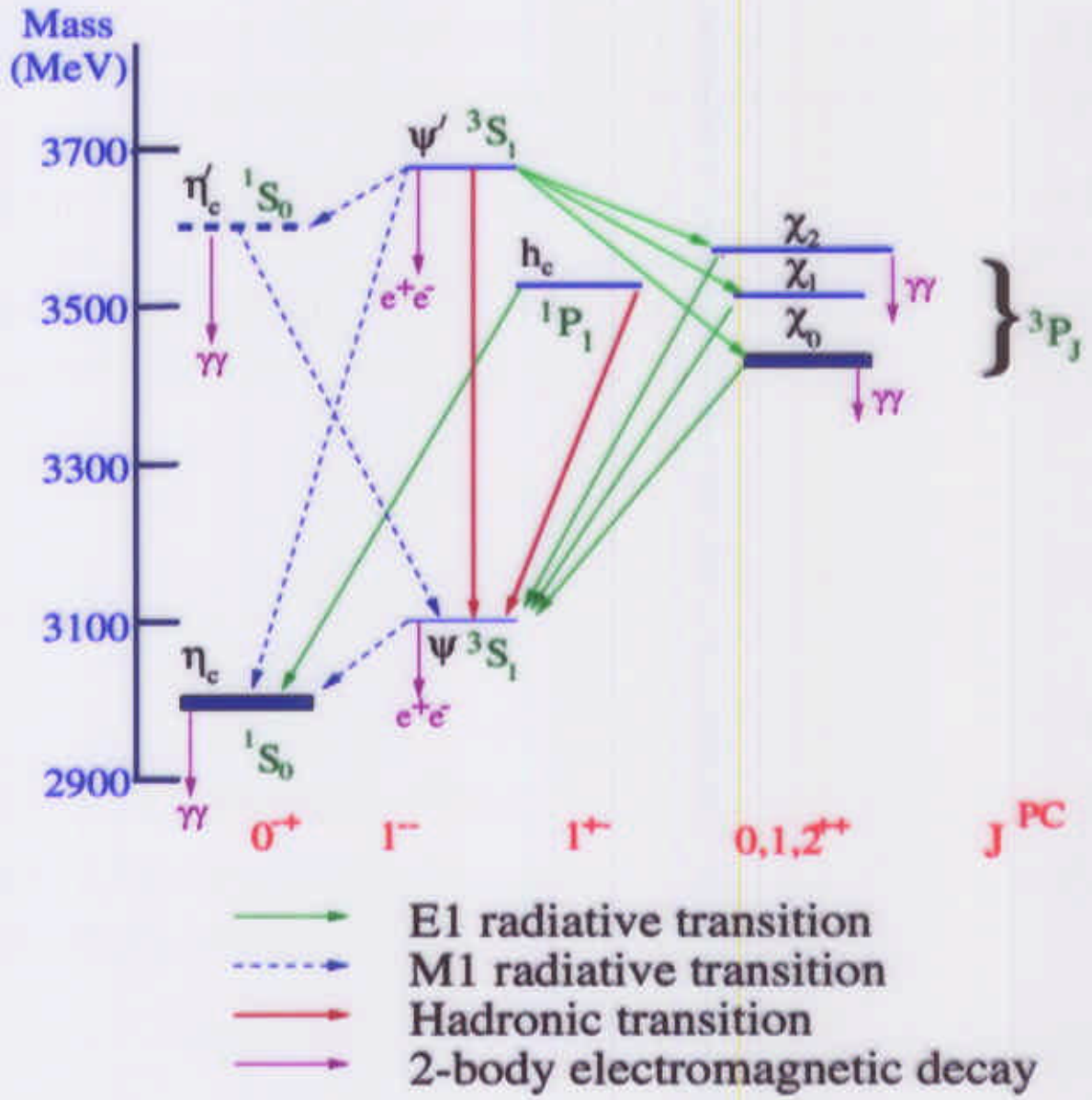
## E835 technique

Stochastically cooled circulating $\bar{p}$ beam intersecting a hydrogen gas-jet target

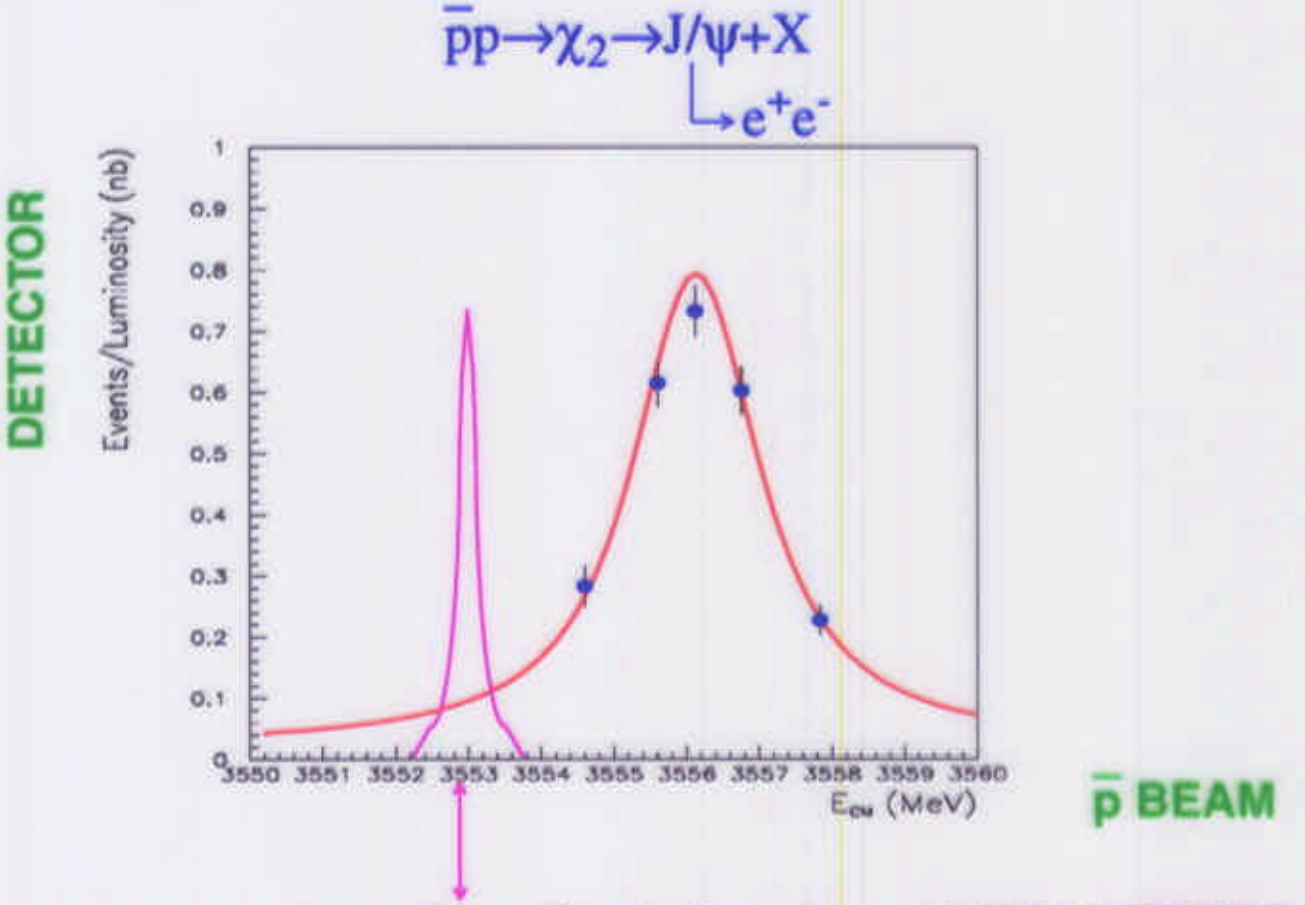
- Beam momentum spread : $\Delta p/p \sim 10^{-4}$
- Beam orbital frequency: ~0.63 MHz, measured to ±0.2 Hz
- Data collection cycle ~ 3-4 days [stack ~40-80 mA at a rate of 2-4 mA/hr; beam lifetime ~50 hrs]; $\int Ldt \sim 4\ pb^{-1}$
- Variable density of jet: 0.5-2.5 $\times 10^{14}$ atoms/cm$^3$
- Interaction volume ~ 5 mm x 5 mm x 7mm
- Luminosity ~2-3 x $10^{31}$ cm$^{-2}$s$^{-1}$
- Orbit length = 474.045 ± 0.0007 m, calibrated at the $\psi'$ mass
  Deviations from calibration orbit measured to ±1 mm

$\sigma_{Ecm}$ ~ 400 keV (FWHM) $\quad\quad$ $\langle E_{cm} \rangle$ to ±100 keV

# E835's view of the Charmonium Spectrum



E835 maps out a resonance by decelerating the antiproton beam in small energy steps, and measuring the event rate at each energy.




## Parameters of a resonance curve:

- Mass $M_R = E_{CM}/c^2$ of peak, Total Width $\Gamma_{tot}$, and $B_{in} \times B_{out}$ come from a convolution of a Breit-Wigner and the beam shape.

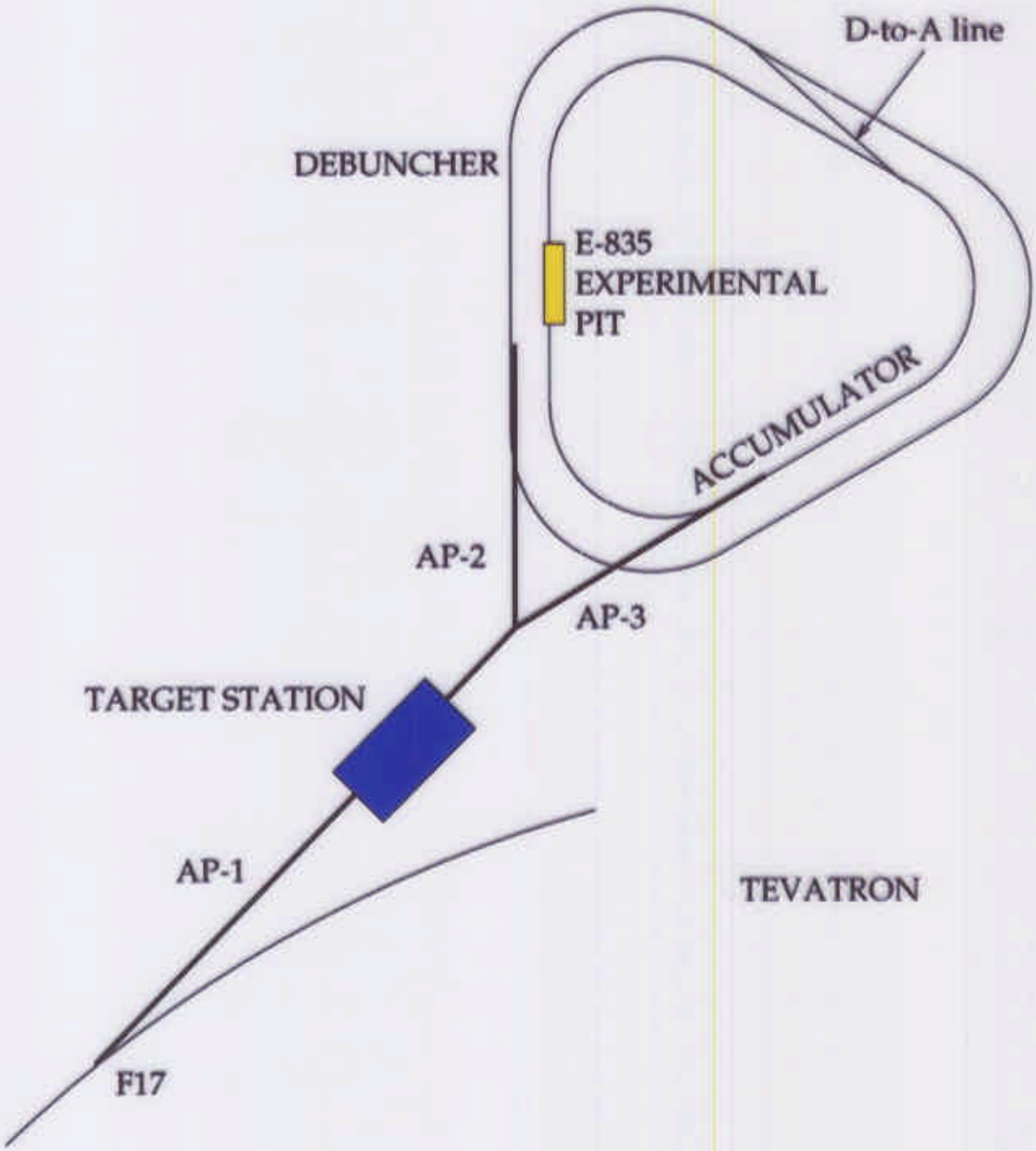
# Source and Target

- **Antiproton Accumulator** - Provides a stochastically cooled $\bar{p}$ beam with a momentum range 3.4 to 8.9 GeV/c ($E_{cm}$ 2.9 to 4.3 GeV)
- **Hydrogen Gas Jet** - Target with diameter~7mm and density $(0.5 - 2.5)*10^{14}$ atoms/cm$^2$
- **Luminosity** - Measured with $\bar{p}p$ elastic scattering rate

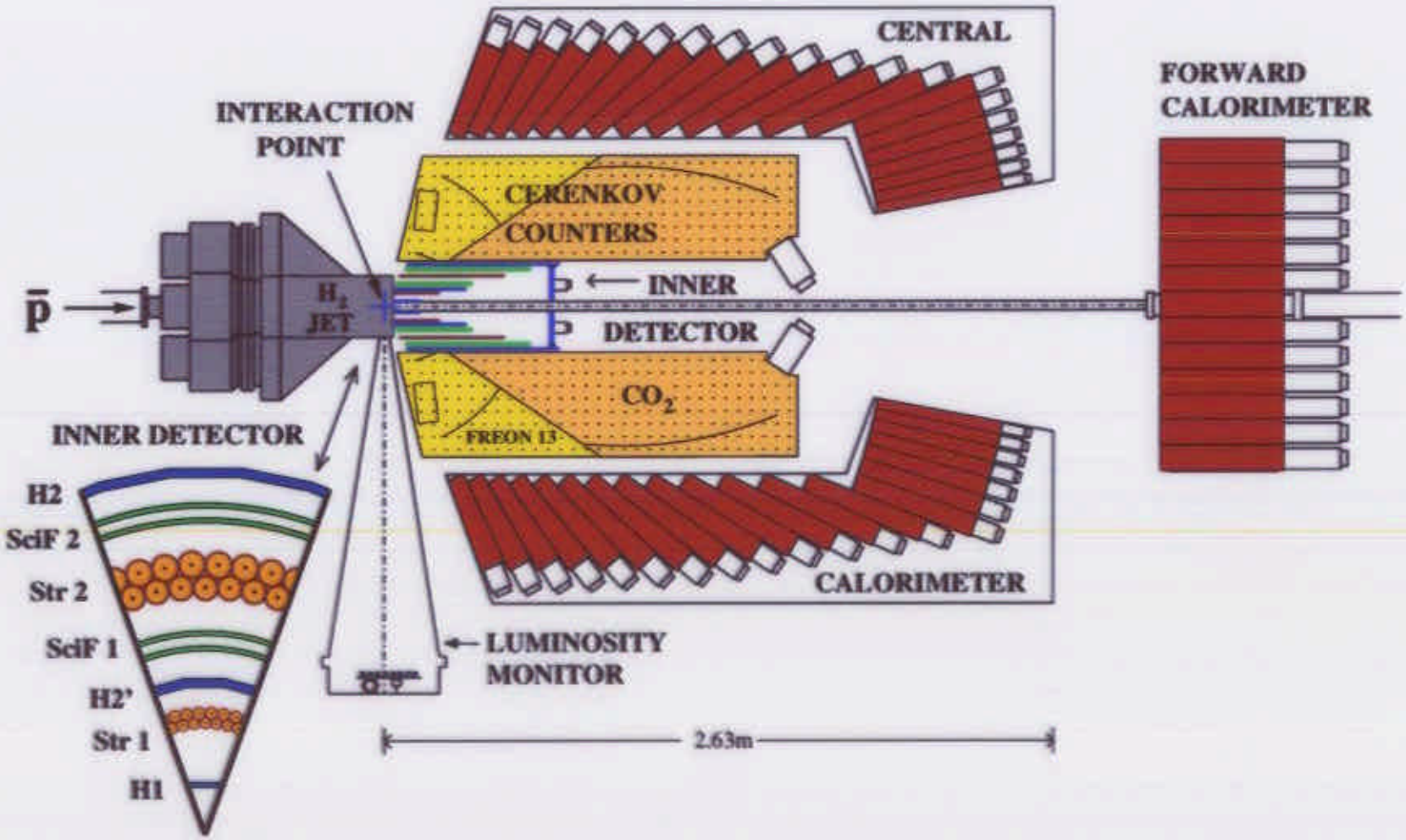
# Detector Components

- **Hodoscopes** - The four hodoscopes identify charged particles, covering 2° to 65° in $\theta$
- **Charged Tracking** - Straw chambers measure $\phi$ of the charged particles and scintillating fibers measure $\theta$
- **Gas Threshold Cherenkov Counter** - identifies $e^+$, $e^-$ from heavier charged particles
- **Central Calorimeter** - Array of 1280 lead glass counters, segmented in $\theta$ and $\phi$ that measures the energy and position of $e^+$, $e^-$, $\gamma$ covering 10° to 70° in $\theta$
- **Forward Calorimeter** - Array of lead glass counters covering from 2° to 10° in $\theta$

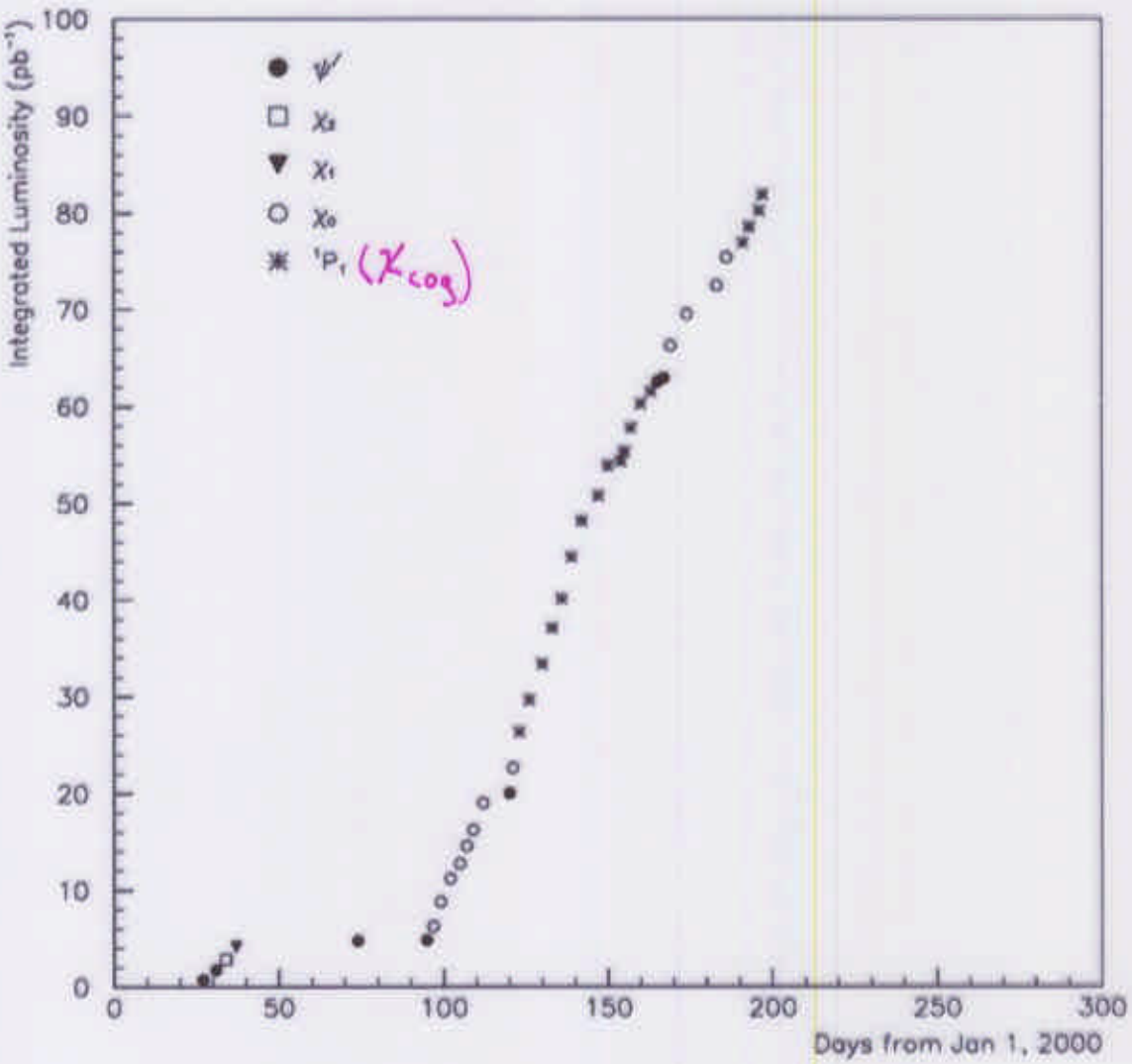
# Antiproton Source



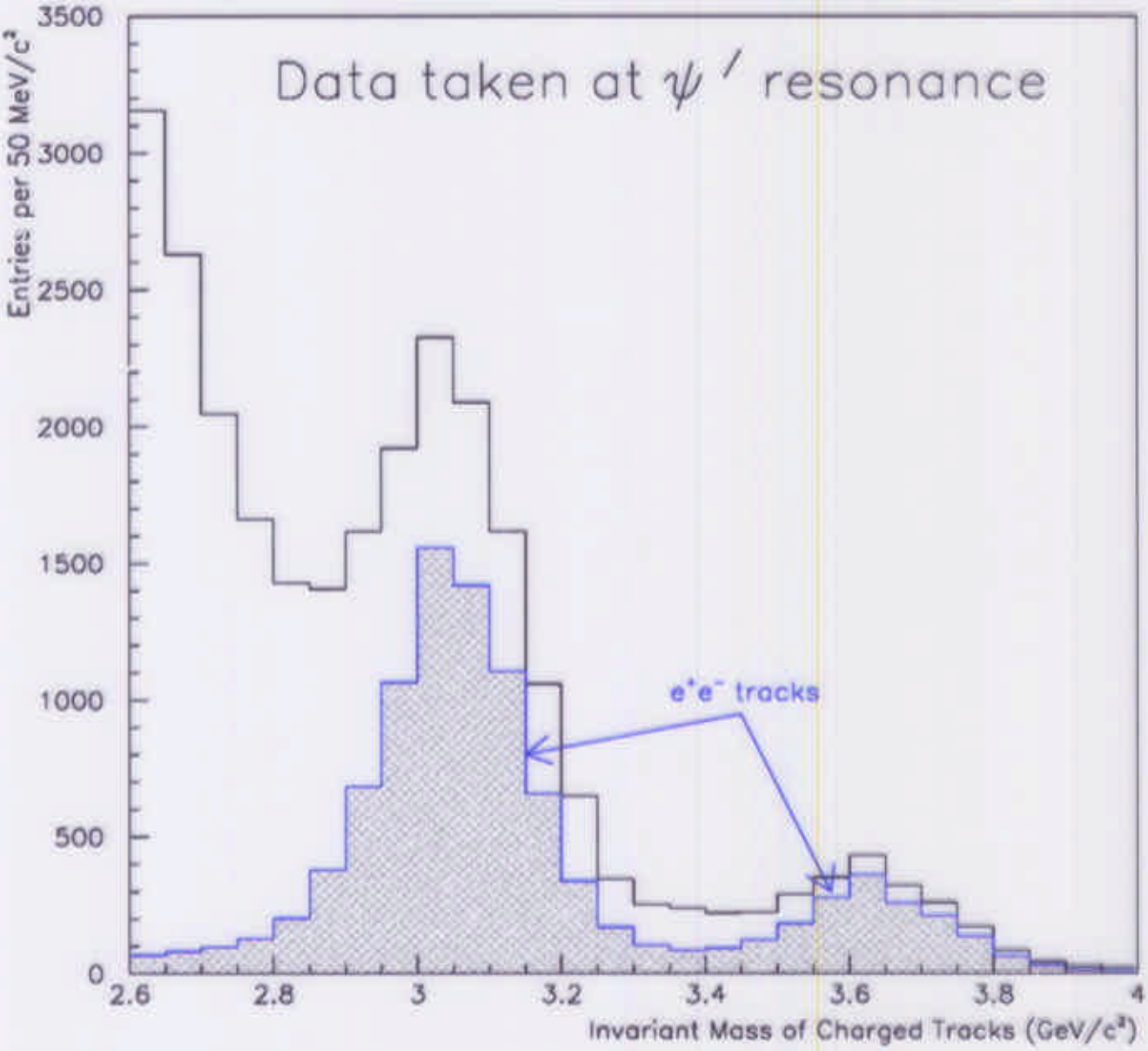
# E835 EQUIPMENT LAYOUT (Y2K)



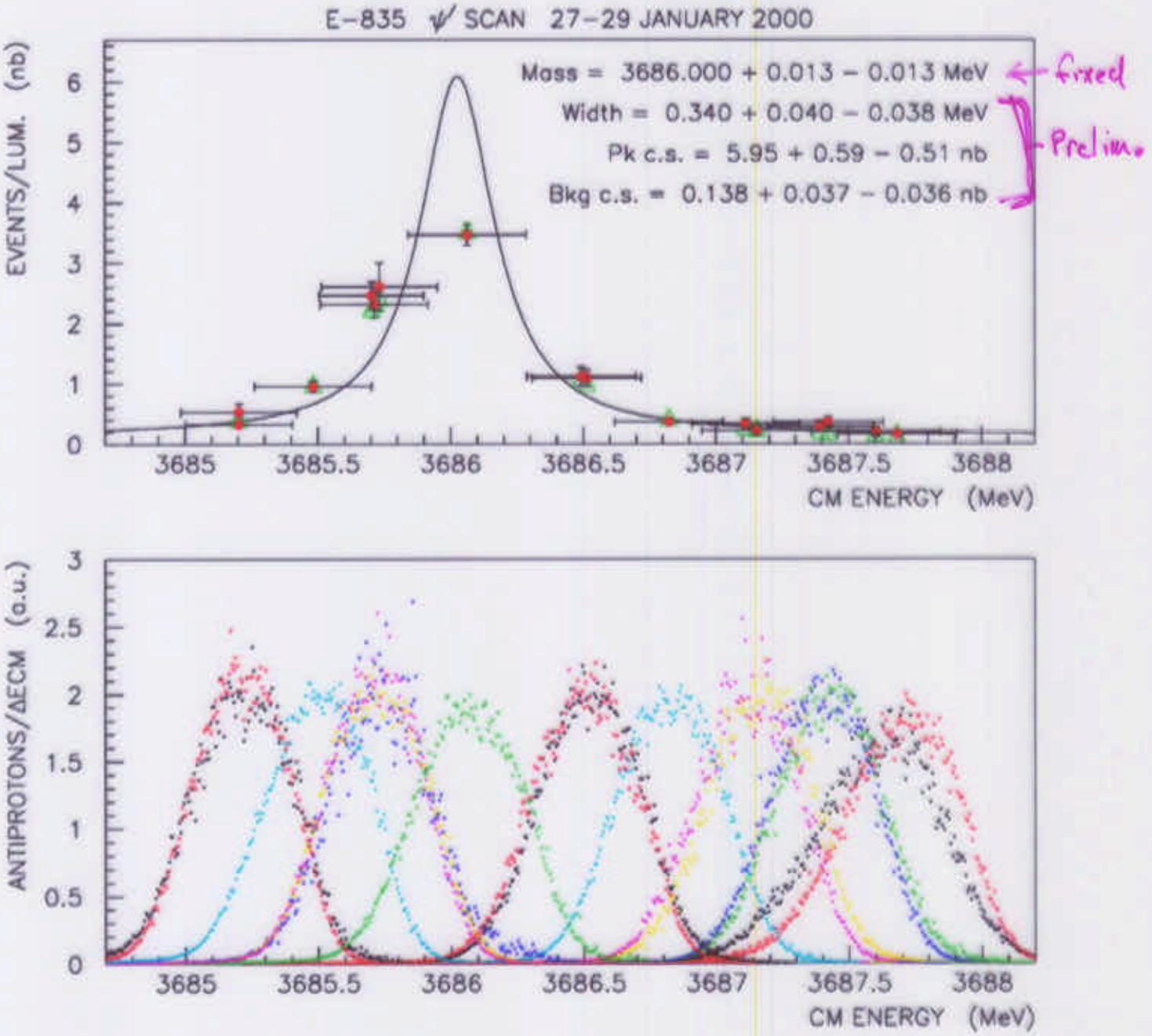
# E835 Integrated Luminosity

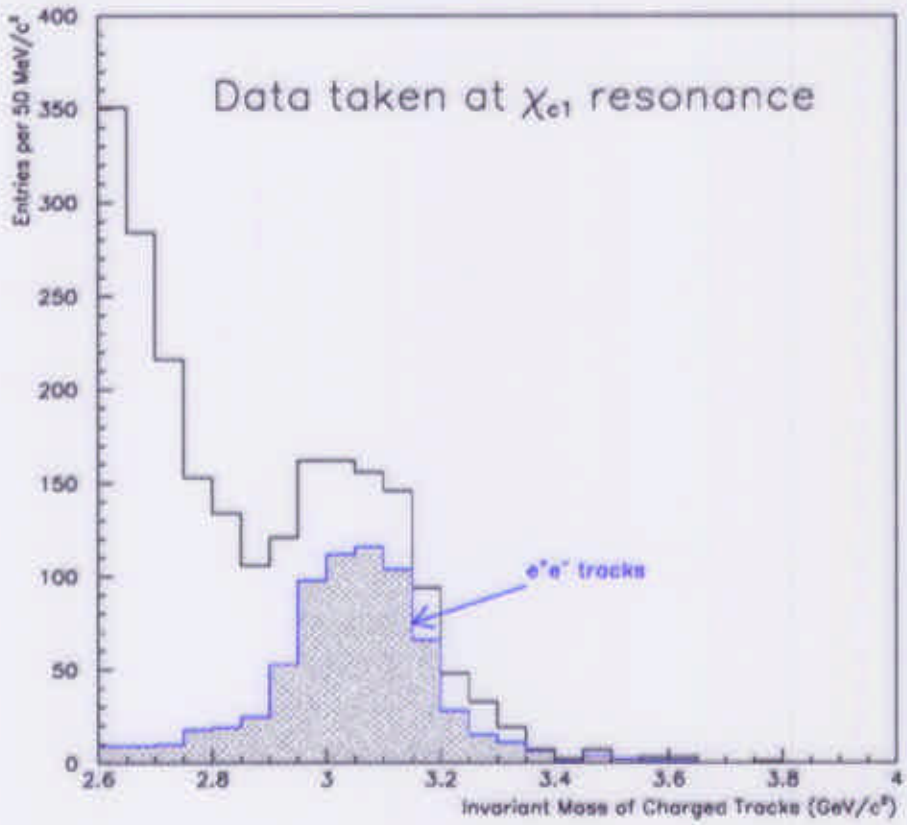



$\chi_{cog}$ : Spin Weighted Average of $\chi_{0,1,2}$




**Use the pulse heights in the Hodoscopes and Cherenkov Counters to select electron/positron tracks**


E-835 ψ' SCAN 27-29 JANUARY 2000
Mass = 3686.000 + 0.013 − 0.013 MeV
Width = 0.340 + 0.040 − 0.038 MeV
Pk c.s. = 5.95 + 0.59 − 0.51 nb
Bkg c.s. = 0.138 + 0.037 − 0.036 nb
fixed
Prelim.
EVENTS/LUM. (nb)
ANTIPROTONS/ΔECM (a.u.)
CM ENERGY (MeV)
3685
3685.5
3686
3686.5
3687
3687.5
3688




**E835 2000 Preliminary**

$M = 3510.64 \pm 0.03$ MeV/$c^2$

$\Gamma = 0.94 \pm 0.08$ MeV

$BR(\chi_1 \to \bar{p}p) = (0.87 \pm 0.08) \times 10^{-4}$

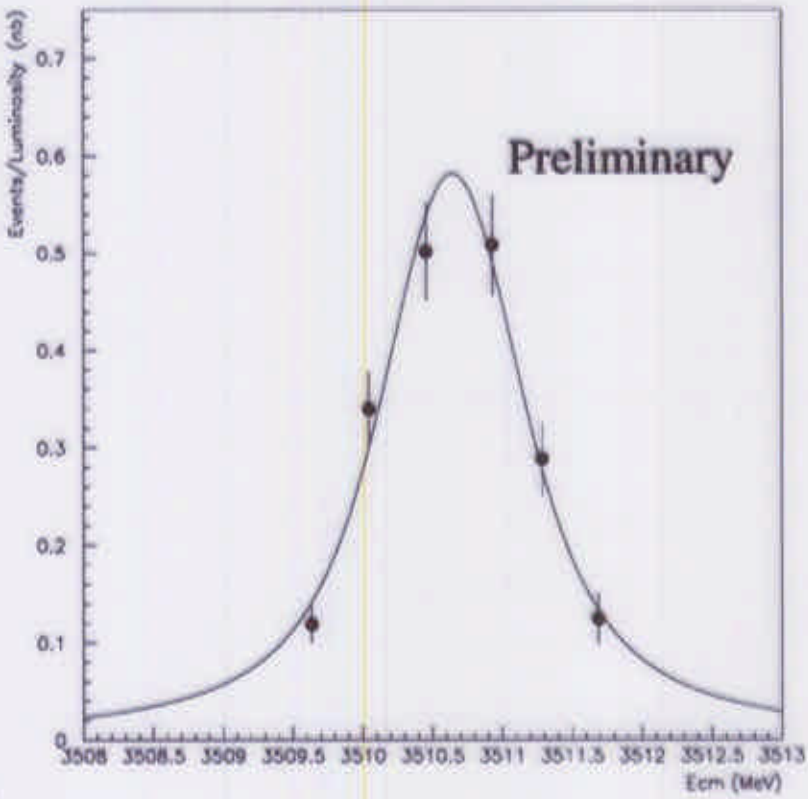
**E760 1991**

$M = 3510.53 \pm 0.04$ MeV/$c^2$

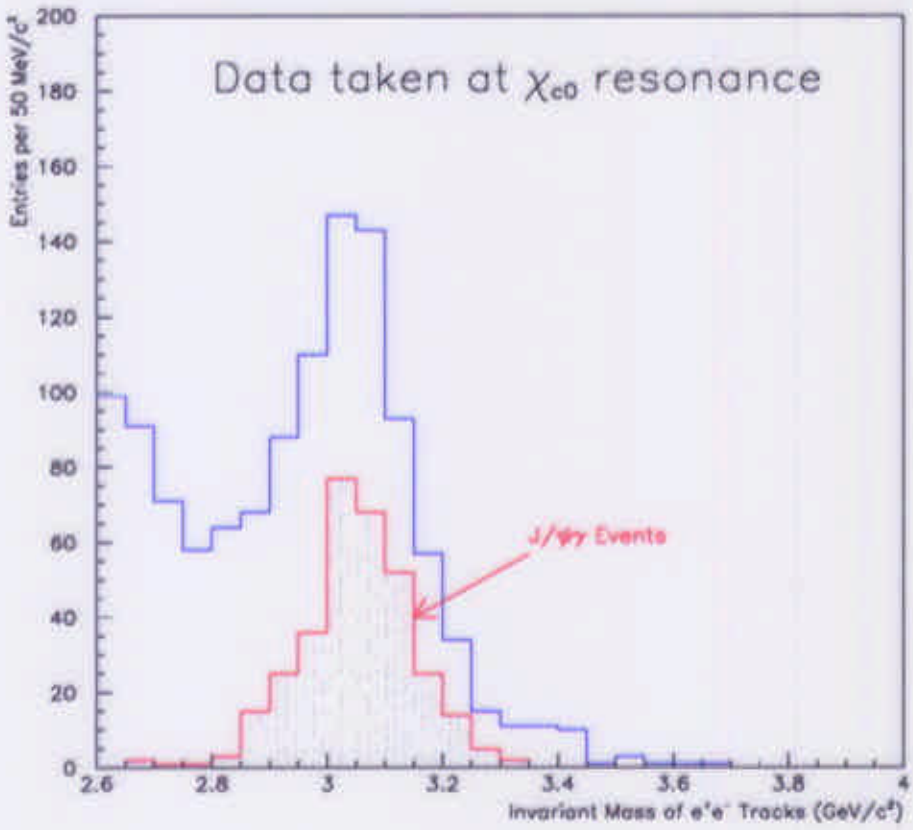
$\Gamma = 0.88 \pm 0.11$ MeV

$BR(\chi_1 \to \bar{p}p) = (0.86 \pm 0.10) \times 10^{-4}$

All errors for E760 and E835 are statistical



Requiring the photon to be observed, removes background and a clear J/ψ signal is observed.




Note that the radiative decay branching fraction, $\chi_0 \to \gamma J/\psi$, is a factor of 40 and 20 smaller than the corresponding branching fractions of $\chi_1$ and $\chi_2$.

**E835 2000 Preliminary**

$M = 3415.2 \pm 0.4$ MeV/c²

$\Gamma = 9.4 \pm 1.1$ MeV

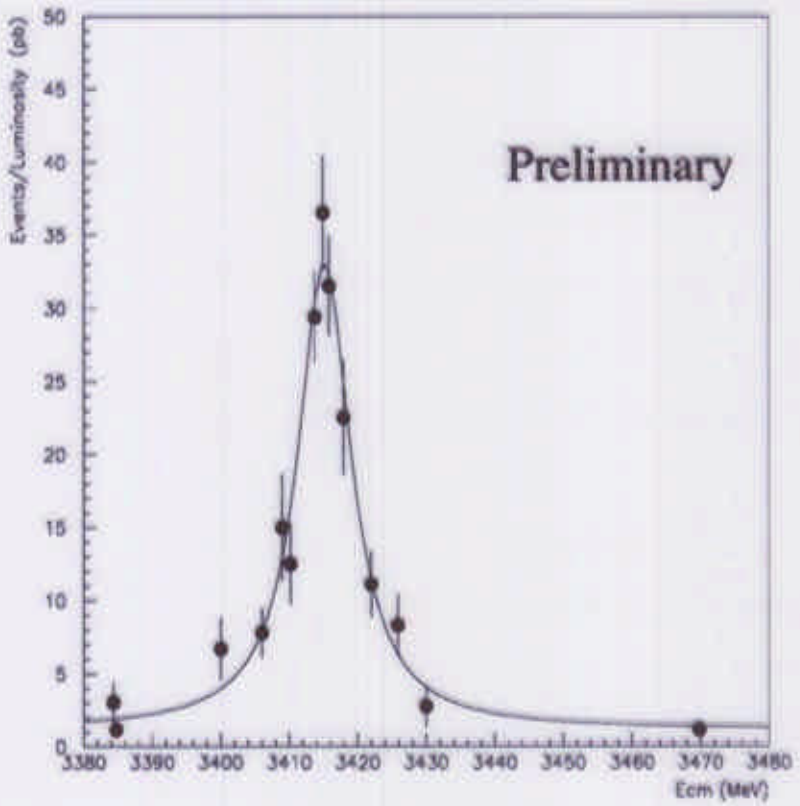
$BR(\chi_0 \to \bar{p}p) = (5.5 \pm 0.4) \times 10^{-4}$

**E835 1999**

$M = 3417.4 \pm 1.9$ MeV/c²

$\Gamma = 16.6 \pm 5.2$ MeV

$BR(\chi_0 \to \bar{p}p) = (4.8 \pm 0.9) \times 10^{-4}$




All errors are statistical

# Comment on BR($\chi_{0,1,2}$ -> $\bar{p}p$)

E760 and E835 measurements rely upon the previous measurements for BR($\chi_{0,1,2}$ -> $\gamma J/\psi$)

From PDG2000:

$$BR(\chi_0 \to \gamma J/\psi) = (6.6 \pm 1.8) \times 10^{-3}$$

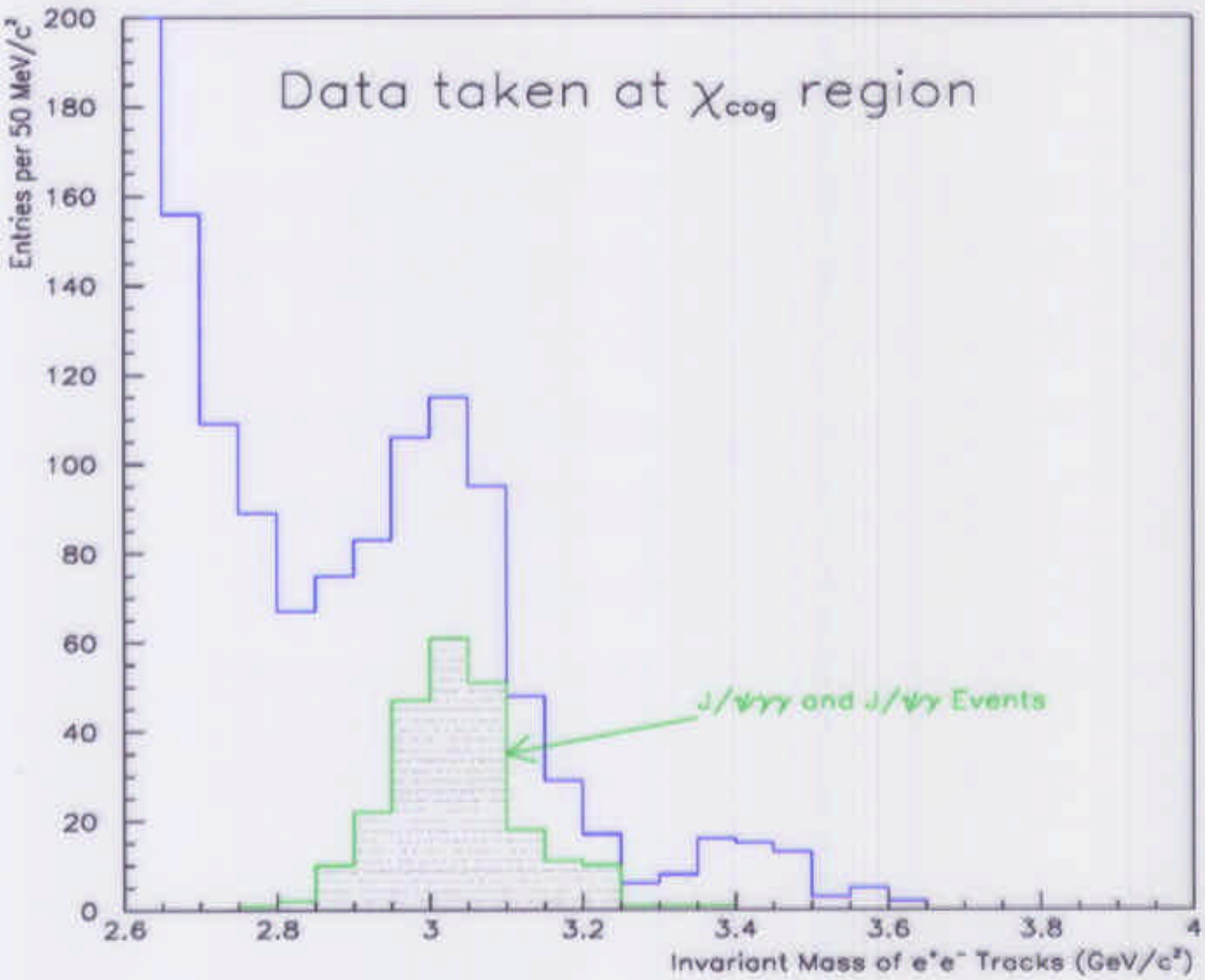
$$BR(\chi_1 \to \gamma J/\psi) = (27.3 \pm 1.6)\%$$

$$BR(\chi_2 \to \gamma J/\psi) = (13.5 \pm 1.1)\%$$

*It would help to have a new measurement for $\chi_0$*

Comparison of measurements:

| BR($\chi_0$ -> $\bar{p}p$) [$10^{-4}$] | BR($\chi_1$ -> $\bar{p}p$) [$10^{-4}$] | BR($\chi_2$ -> $\bar{p}p$) [$10^{-4}$] |
|---|---|---|
| $5.5 \pm 0.4 \pm ?$ E835 2000 Prelim | $0.87 \pm 0.08 \pm ?$ E835 2000 Prelim | $0.89 \pm 0.08 \pm ?$ E835 2000 Prelim |
| $4.8 \pm 0.9 \pm 0.2$ E835 99 | $0.86 \pm 0.10 \pm 0.11$ E760 92 | $1.00 \pm 0.08 \pm 0.04$ E760 92 |
| $1.59 \pm 0.43 \pm 0.53$ BES 98 | $0.42 \pm 0.22 \pm 0.28$ BES 98 | $0.58 \pm 0.31 \pm 0.32$ BES 98 |



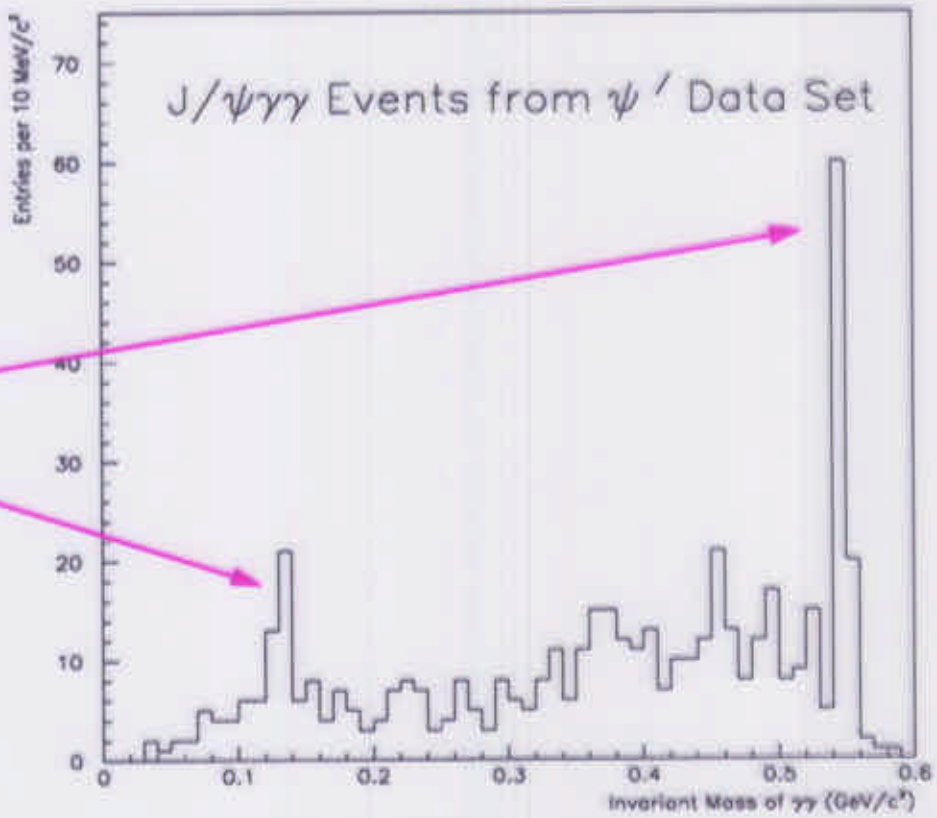

**The data are very preliminary.**

**The "Events/Luminosity" of the combined selected $\gamma J/\psi$ and $J/\psi\pi^0$ events is a factor of 5 smaller than the $\gamma J/\psi$ of $\chi_0$.**

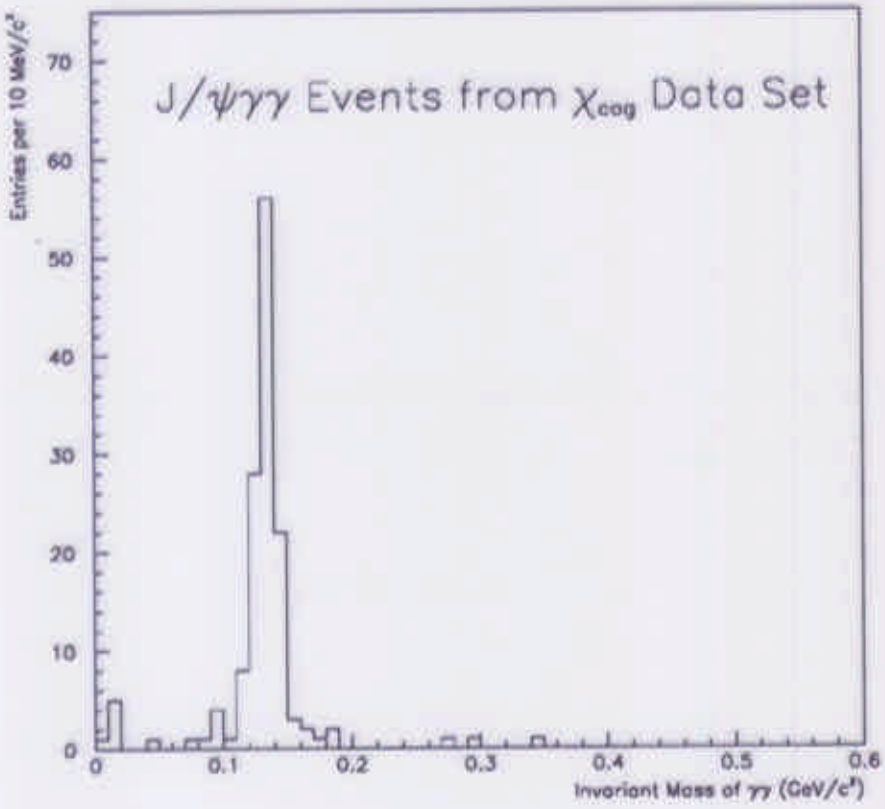
The $^1P_1$ ($h_c$) is not allowed to radiatively decay to J/ψ; these events come from the tails of the $\chi_1$ and $\chi_2$.

**The $J/\psi\pi^0$ rate is compatible with the E760 discovery of the $^1P_1$**

# $\psi'$ Data




$\psi'$ hadronic decays to J/$\psi$ include both $\pi^0$ and $\eta$




The continuum reaction $\bar{p}p \rightarrow J/\psi\,\pi^0$, contributes ~2.5 events per $pb^{-1}$ to the observed Events/Luminosity in the region of the $\chi_{cog}$

# $\chi_{cog}$ Data

# E835 2000 Analyses

$\bar{p}p \rightarrow \chi_0 \rightarrow \gamma J/\psi \rightarrow e^+e^-$

$\gamma\gamma$

$\pi^0\pi^0 \rightarrow \gamma\gamma\,\gamma\gamma$

$\eta\eta \rightarrow \gamma\gamma\,\gamma\gamma$

$\phi\phi \rightarrow K^+K^-\,K^+K^-$

$\bar{p}p$

. . .

$\bar{p}p \rightarrow {}^1P_1 \rightarrow J/\psi\pi^0 \rightarrow e^+e^-\,\gamma\gamma$

$J/\psi\pi^0\pi^0 \rightarrow e^+e^-\,\gamma\gamma\,\gamma\gamma$

$J/\psi\pi^+\pi^- \rightarrow e^+e^-\,\pi^+\pi^-$

$\gamma\eta_c \rightarrow \gamma\,\gamma\gamma$

$\gamma\eta_c \rightarrow \gamma\,\phi\phi \rightarrow \gamma\ K^+K^-\,K^+K^-$

$\bar{p}p$

. . .

More Data to be collected