IV International Conference on Hyperons, Charm and Beauty Hadrons
Valencia (Spain), 27-30 June 2000

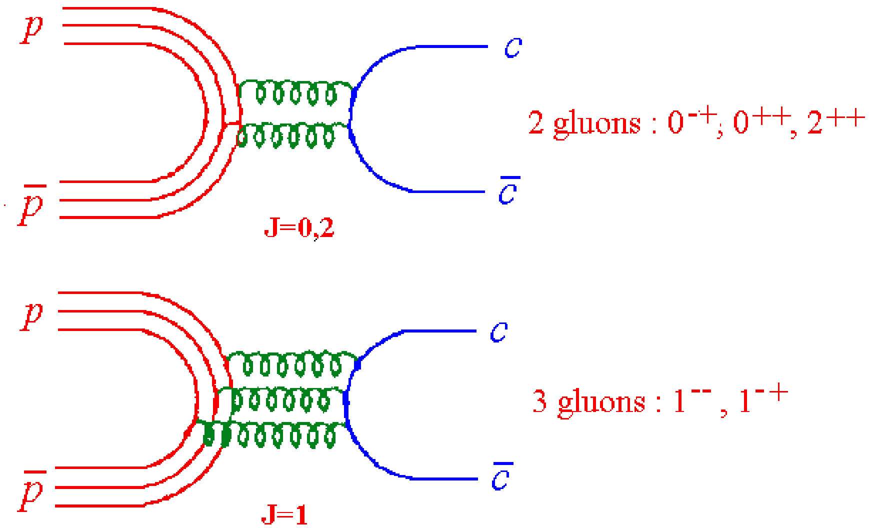
STUDY OF CHARMONIUM STATES IN ANTIPROTON-PROTON ANNIHILATIONS: RESULTS FROM FERMILAB E-835

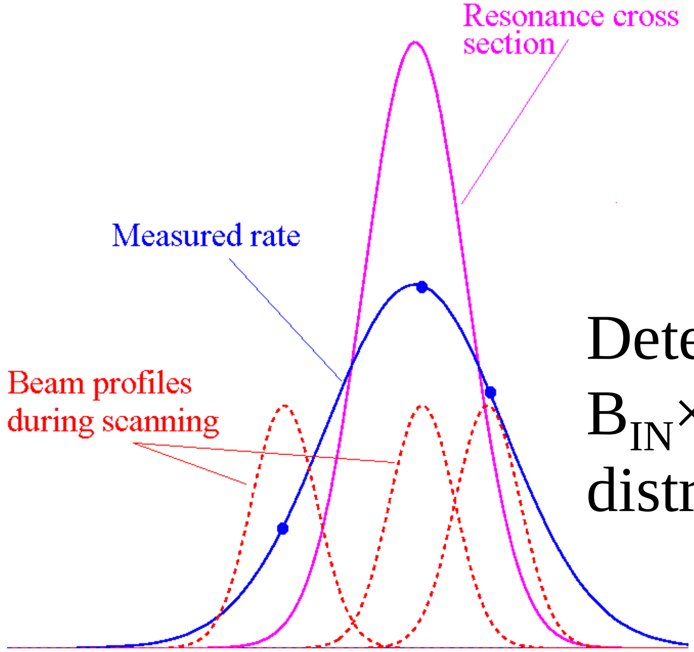
Giulio Stancari
Fermi National Accelerator Laboratory

for the E-835 Collaboration:
Fermilab (USA)
INFN and University of Ferrara (Italy)
INFN and University of Genoa (Italy)
University of California at Irvine (USA)
University of Minnesota (USA)
Northwestern University (USA)
INFN and University of Turin (Italy)

EXPERIMENTAL TECHNIQUE

All charmonium states can be directly formed in $\bar{p}p$ annihilations

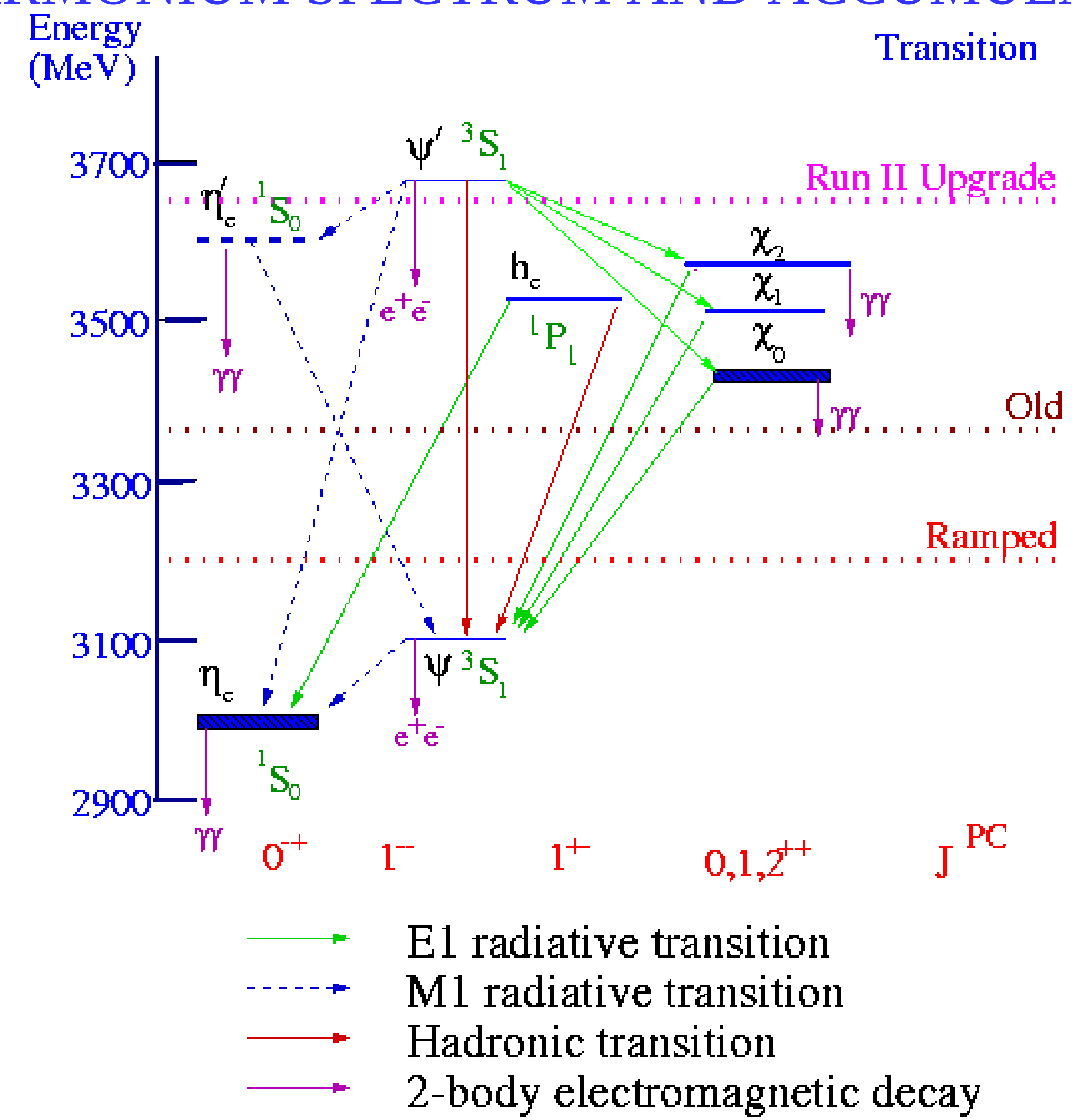




Determination of resonance parameters M, Γ and $B_{IN} \times B_{OUT}$ depends on knowledge of beam energy distribution and NOT on detector resolution

To overcome large hadronic background ($\sigma_{TOT} \approx 70$ mb), e.m. final states are used as signature of charmonium formation ($\sigma_{OBS} \approx$ pb-nb)

CHARMONIUM SPECTRUM AND ACCUMULATOR



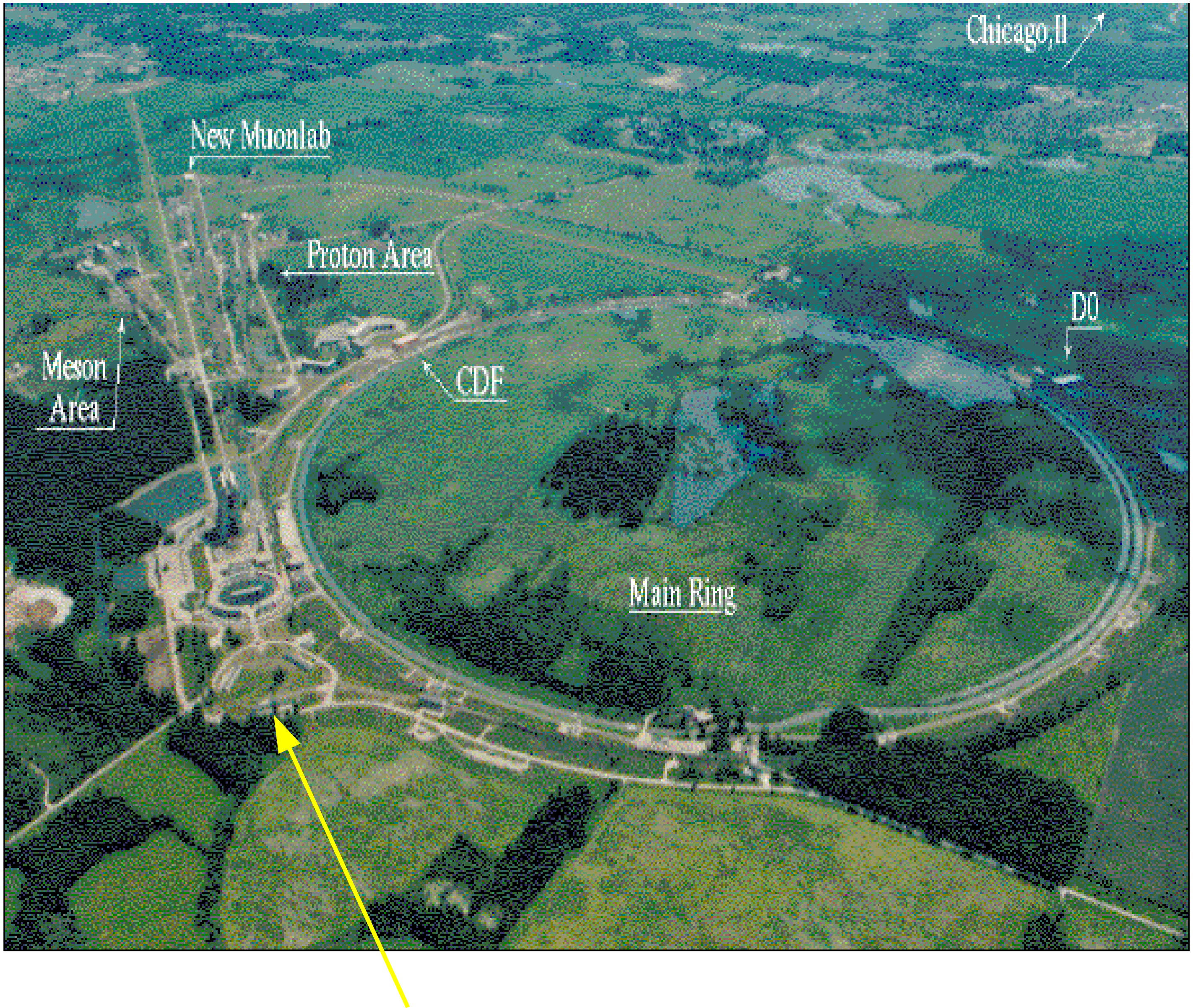
THE $\bar{p}p \to (c\bar{c})$ EXPERIMENTAL TRADITION

CERN experiment R704 at the ISR (mid 1980s) proved the feasibility of the technique. Study of the χ_{c1} and χ_{c2} states...

Fermilab E-760 took data in 1990 and 1991. Precise measurements of χ_{c1} and χ_{c2} parameters, J/ψ and ψ' widths. Observation of the $h_c(1^1P_1)$ state...

Fermilab E-835 (1996/97) was a continuation of E-760. Several detector upgrades (CCAL signal shapers, scintillating-fiber tracker, additional hodoscope…). Some results presented here

E-835 (2000) started data taking last January (till August?). New FCAL, additional fiber tracker, new Accumulator lattice (no transition crossing)… Present status of χ_{c0} study shown here



E-835 @ FERMILAB

E-835 DETECTOR

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

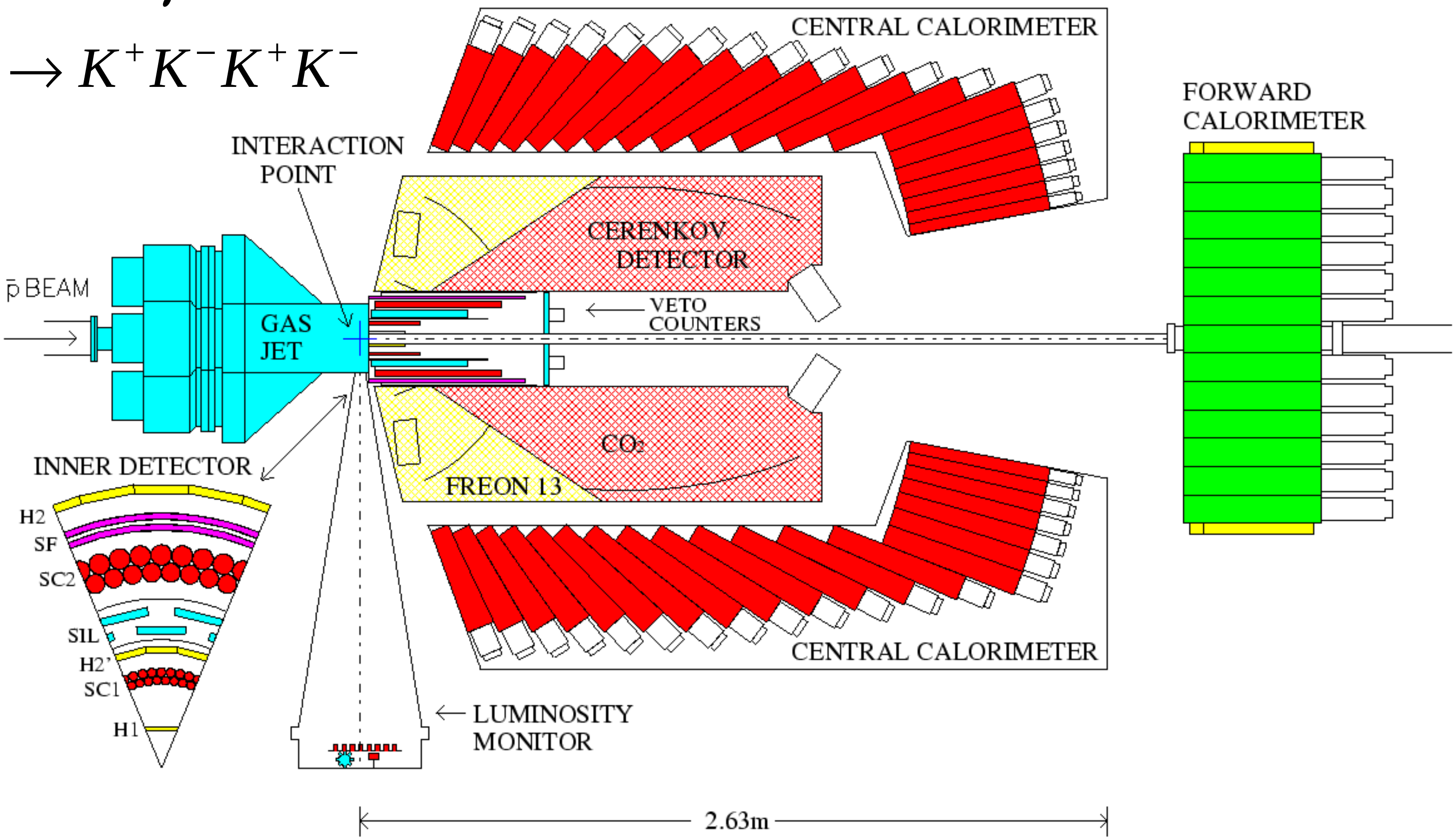
$$\bar{p}p \rightarrow e^+e^-$$

$$\bar{p}p \rightarrow 2 \text{ or more } \gamma s$$

$$\bar{p}p \rightarrow \phi\phi \rightarrow K^+K^-K^+K^-$$

$$\bar{p}p \rightarrow \bar{p}p$$

…



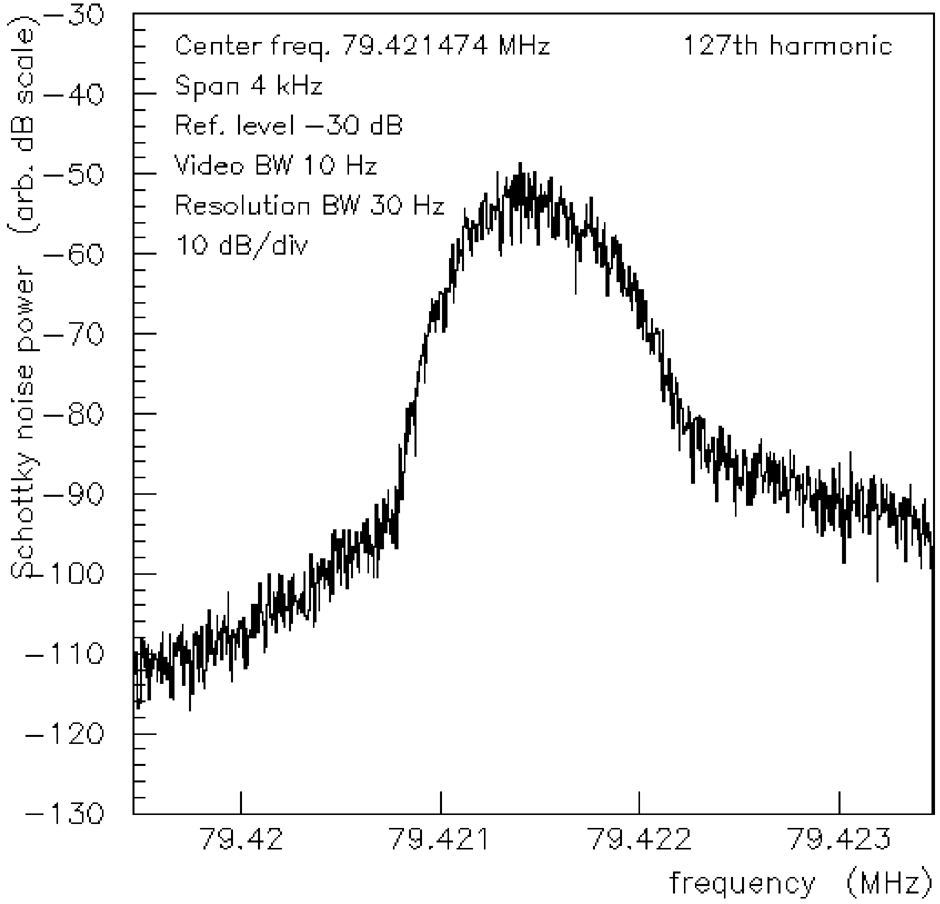
BEAM, TARGET, LUMINOSITY

Energy distribution of stochastically cooled antiprotons measured from Schottky noise spectrum ($\Delta f/f \sim 10^{-7}$) and closed-orbit length ($\Delta L/L_0 \cong$ 1mm / 474m):

$$\beta c = f \times (L_0 + \Delta L)$$

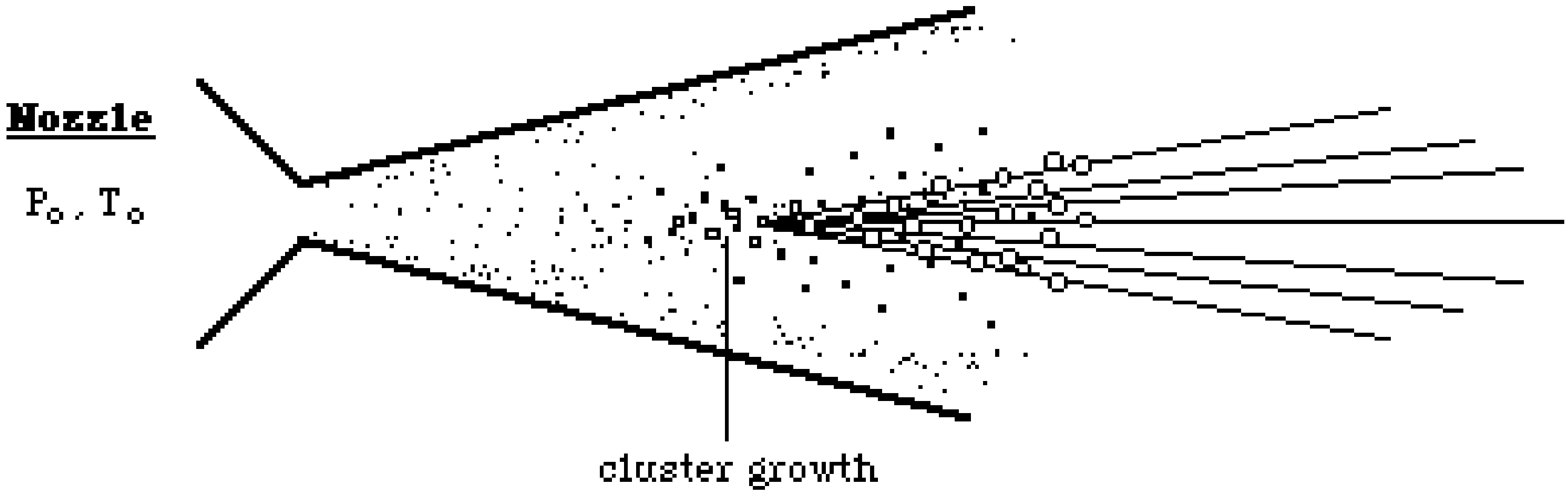
L_0 calibrated at ψ'

Typical CM energy spread (FWHM) is 500-900 keV



BEAM, TARGET, LUMINOSITY

The variable-density hydrogen-gas jet target allows efficient use of antiprotons and typical instantaneous luminosities of 2.5×10^{31} cm^{-2} s^{-1} (=90 events/nb/hour)



Interaction region, as defined by beam and jet target, is 5×5×7 mm

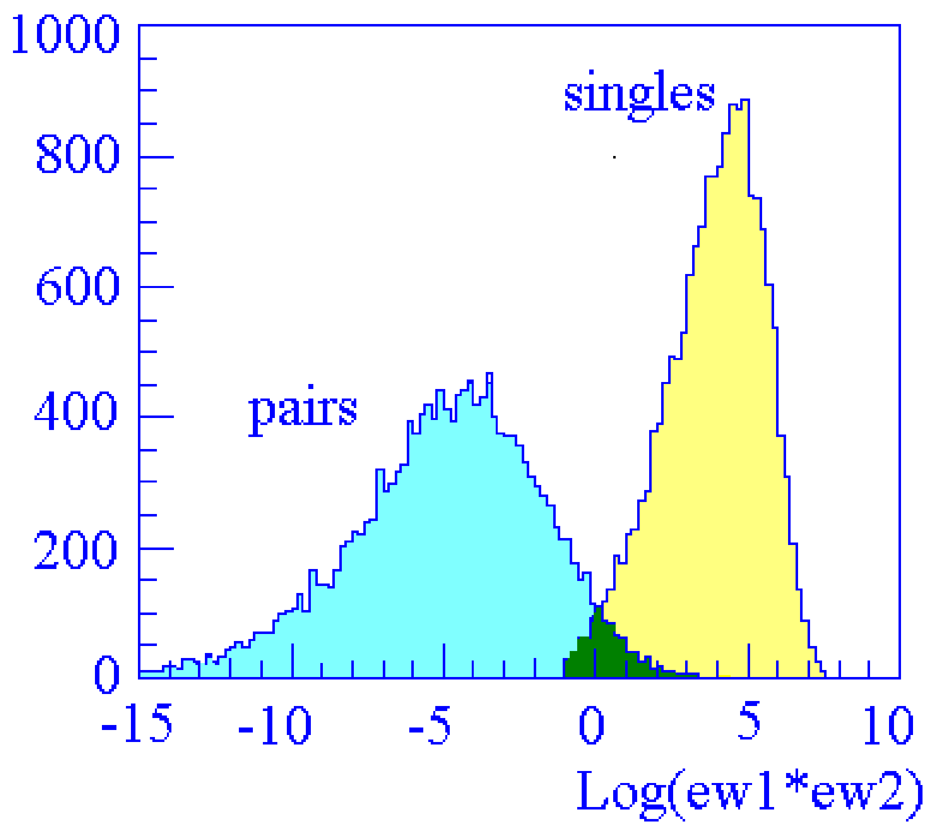
Luminosity is measured to 3% from pbar-p elastic recoil near 90°

ELECTRON IDENTIFICATION

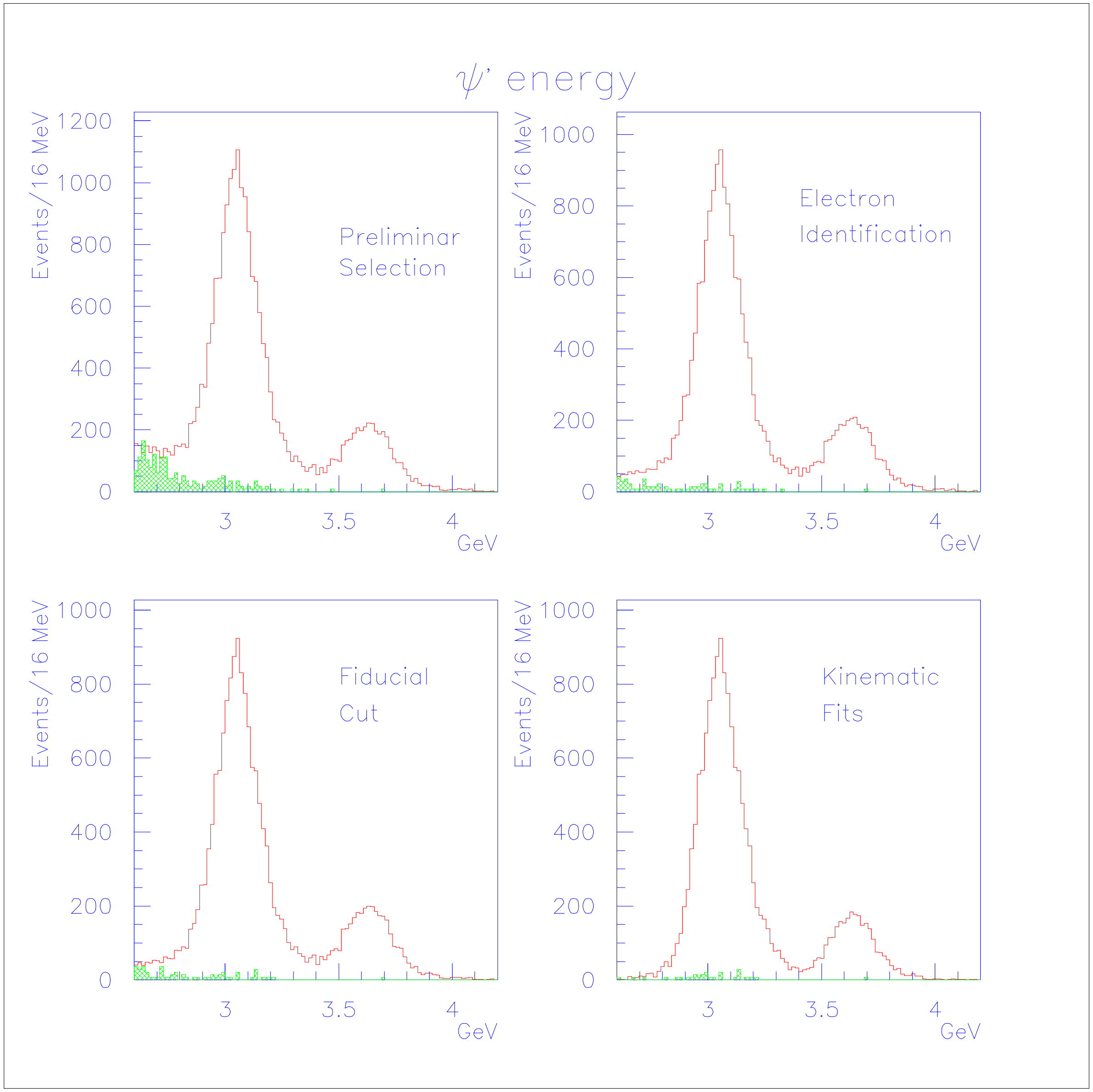
On-line: two back-to-back charged tracks associated with Cherenkov signal; two back-to-back energy deposits in CCAL with invariant mass > 2.4 GeV

Off-line: Neyman-Pearson test statistic (“Electron Weight”) based upon hodoscope dE/dx, Cherenkov npe and CCAL shower shape

Background mostly due to π^0s: photon conversions and Dalitz decays



ELECTRON IDENTIFICATION



STUDY OF THE $\chi_{c0}(1^3P_0)$ RESONANCE

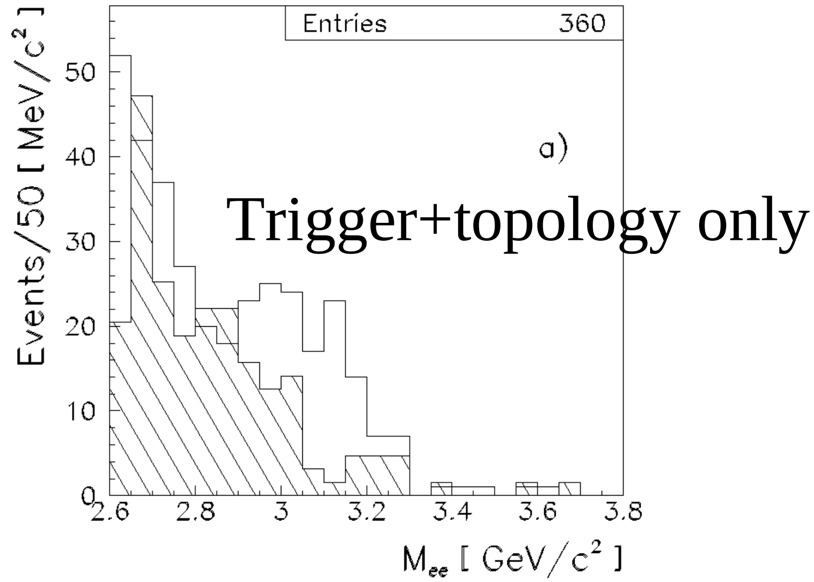
$$\bar{p}p \rightarrow J/\psi\,\gamma \rightarrow e^+e^-\gamma$$

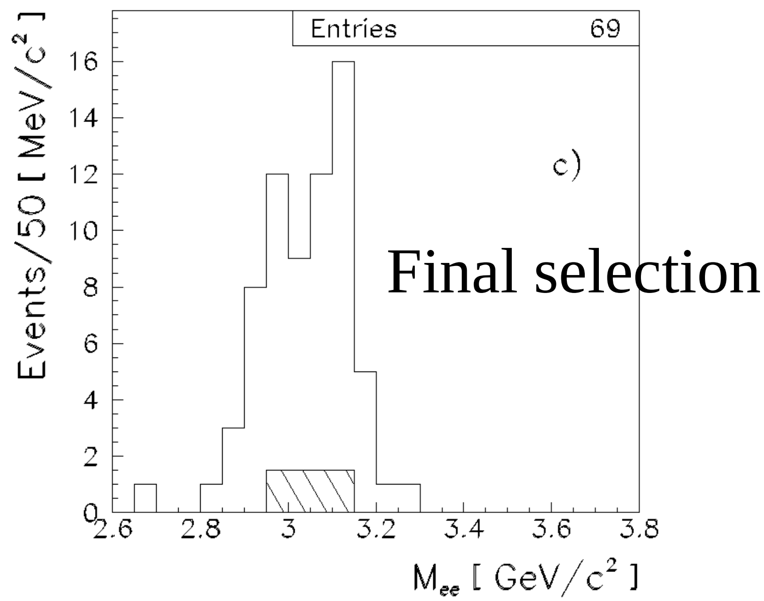
Off-line event selection :

- 3 (or 4) in-time CCAL clusters;
- $15° < \theta_{e^+,e^-} < 60°$ (Cherenkov);
- $12° < \theta_\gamma < 68°$ (CCAL);
- Electron Weight > 1.5;
- Kinematic fit probability $> 10^{-4}$

$$\text{Efficiency} = \varepsilon_{\text{trigger}} \times \alpha_{\text{geom}} \times \varepsilon_{\text{selection}}$$

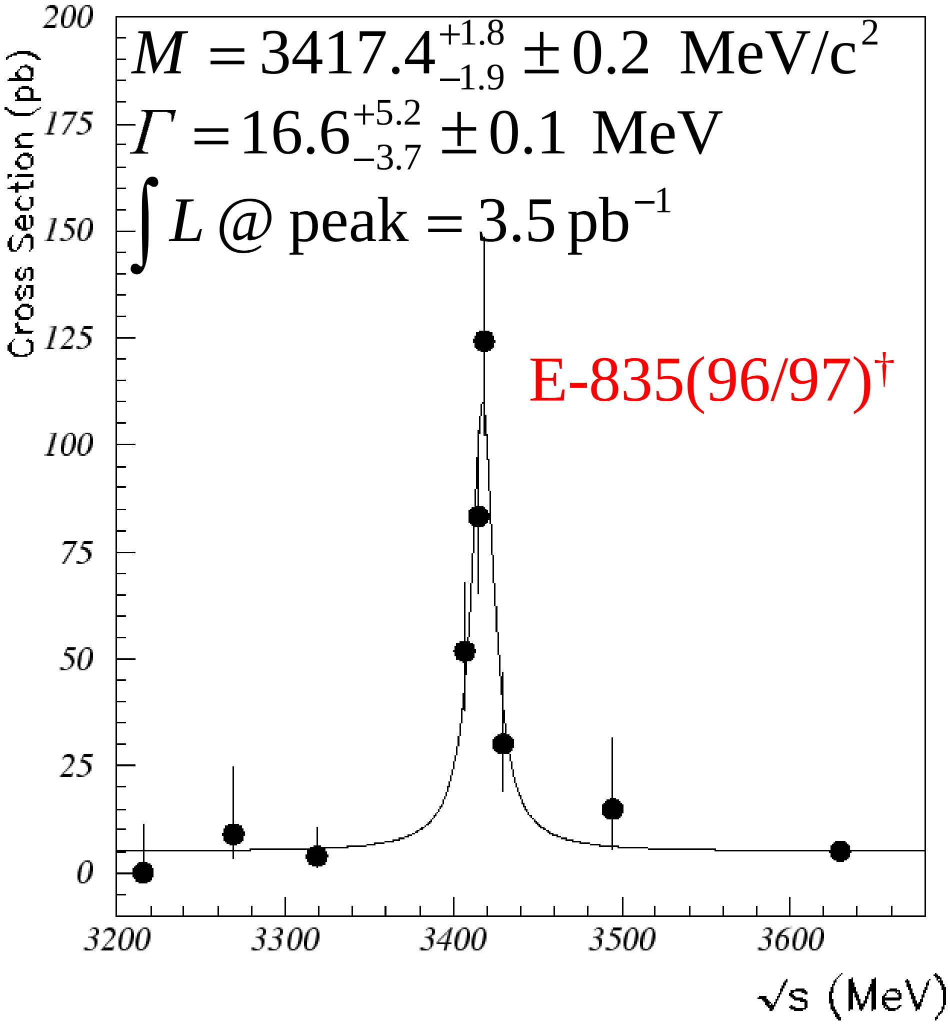
$$= 0.90 \times 0.35 \times 0.85 = (27 \pm 1)\%$$





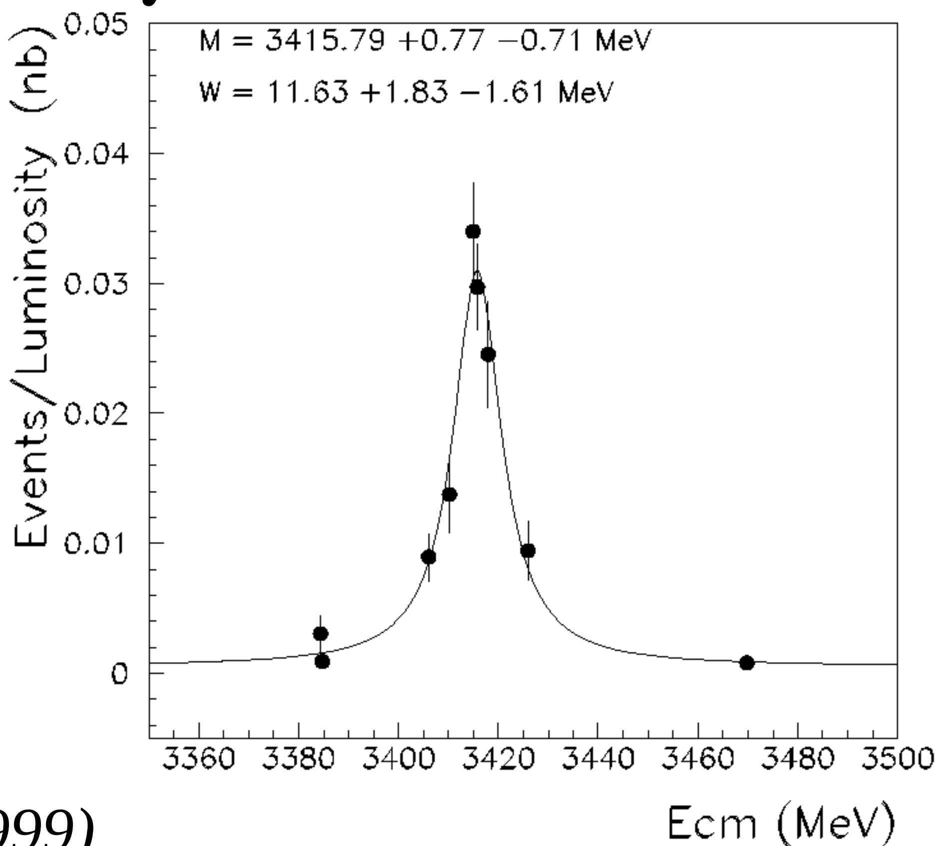
STUDY OF THE $\chi_{c0}(1^3P_0)$ RESONANCE

$$\bar{p}p \to J/\psi\,\gamma \to e^+e^-\gamma$$



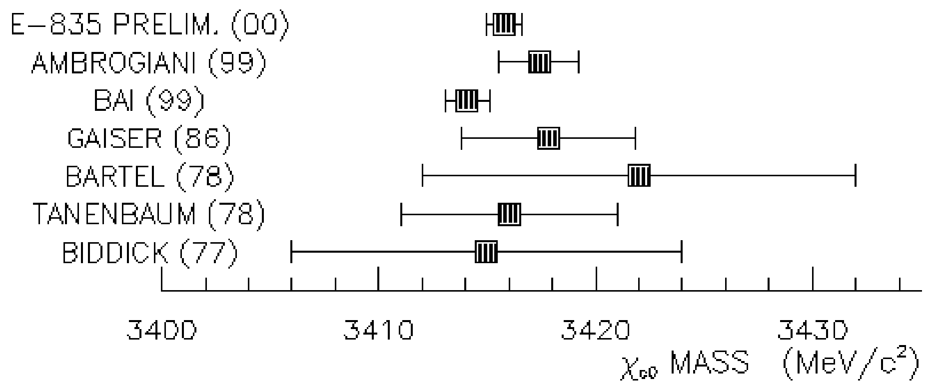
E-835(2000) PRELIMINARY

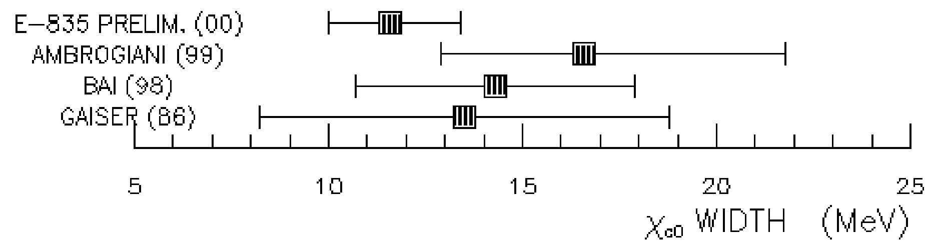
$\int L$ @ peak $= 12.6\ \mathrm{pb}^{-1}$ (so far)



†*Ambrogiani et al., PRL 83, 2902 (1999)*

STUDY OF THE $\chi_{c0}(1^3P_0)$ RESONANCE



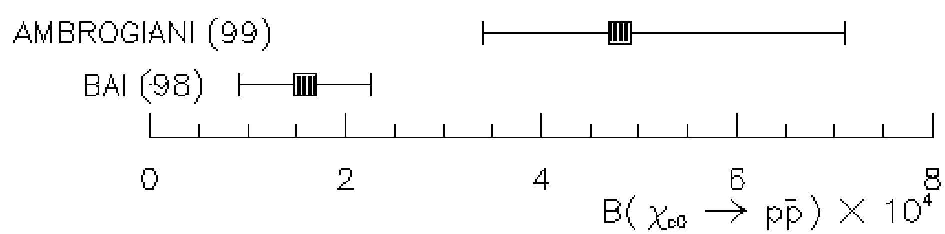


$$B_{\mathrm{in}} B_{\mathrm{out}} = 1.74^{+0.34}_{-0.28} \pm 0.09 \times 10^{-7}$$

Using $B(\chi_{c0} \rightarrow J/\psi\ \gamma)$ and

$B(J/\psi \rightarrow e^+ e^-)$ from literature

$$\Rightarrow B_{\bar{p}p} = 4.8^{+0.9+2.1}_{-0.8-1.1} \times 10^{-4}$$



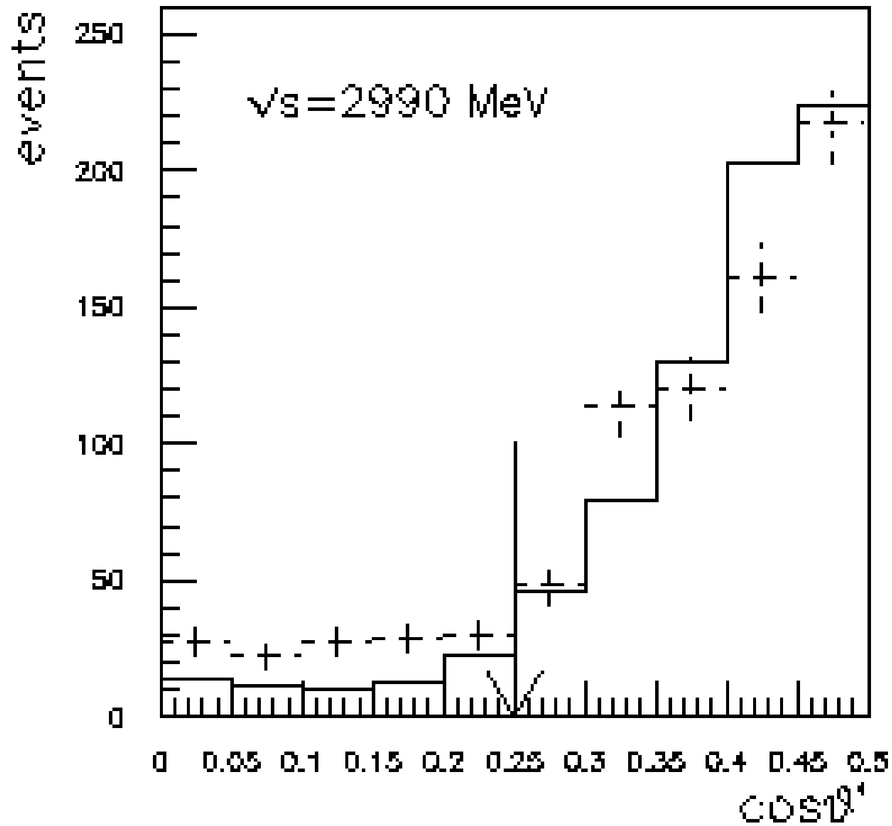
strong coupling to $\bar{p}p$:

$(c\bar{c}, J=0) \rightarrow \bar{p}p$ forbidden in massless QCD

$B(\chi_{c1,2} \rightarrow \bar{p}p) \approx 1 \times 10^{-4}$

SELECTION OF $\gamma\gamma$ FINAL STATES

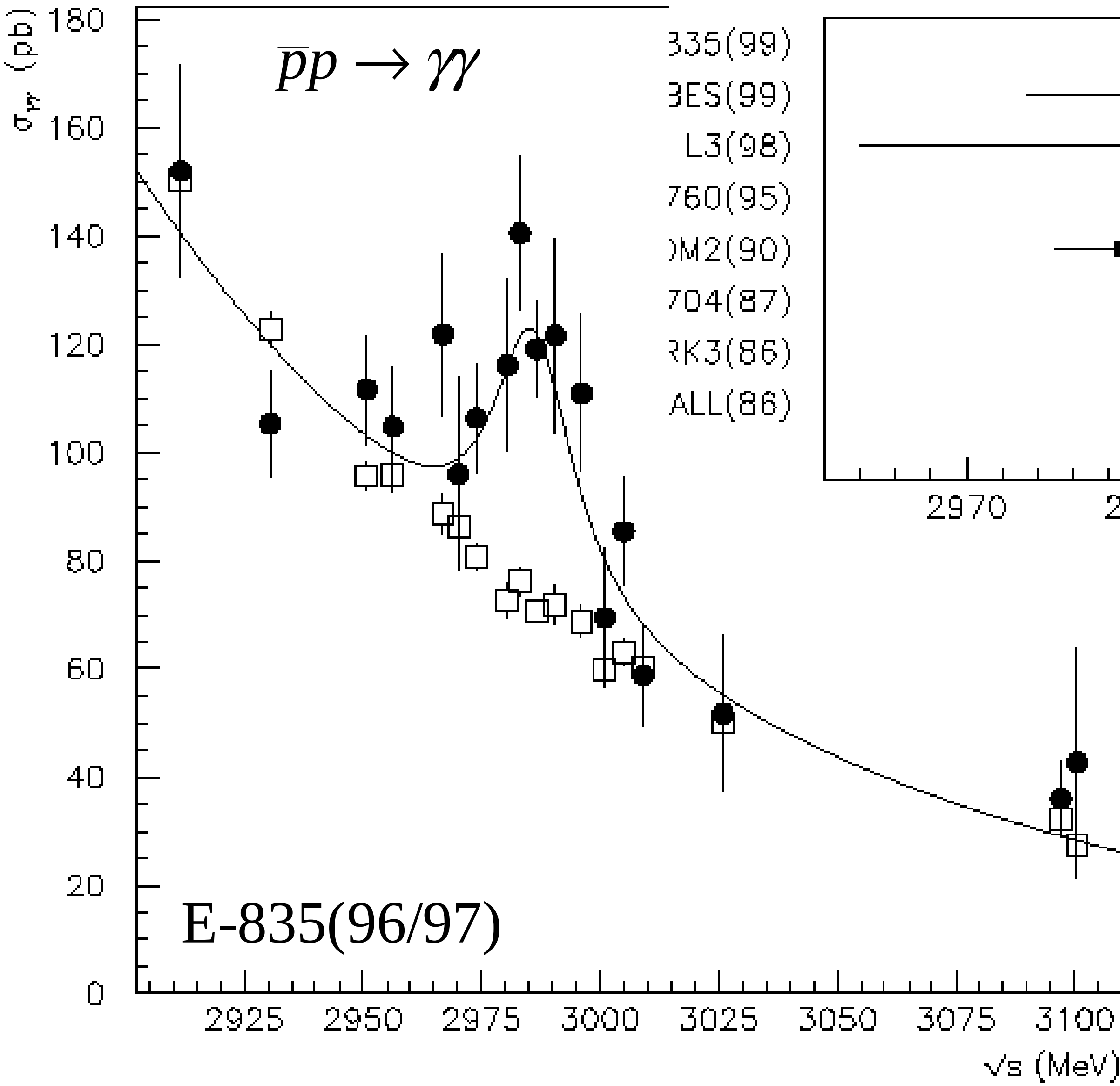
- No in-time extra clusters in CCAL
- No undetermined extra clusters forming invariant mass within 35 MeV of π^0 mass when paired with γ candidates
- Kinematic fit probability > 5%
- Electron Weight < 10^{-4}

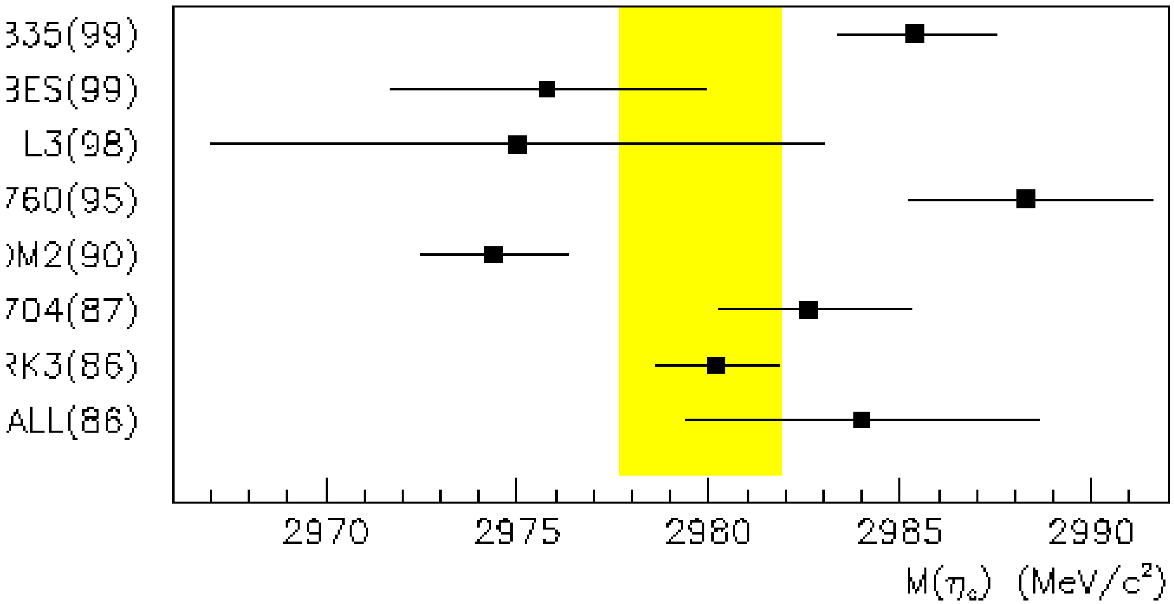


Efficiency (~75%) estimated for each run

Background comes from $\pi^0\pi^0$ and $\pi^0\gamma$ final states with photon(s) outside acceptance or below CCAL energy threshold ("feeddown"). $\gamma\gamma$ continuum is negligible

STUDY OF THE $\eta_c(1^1S_0)$ RESONANCE





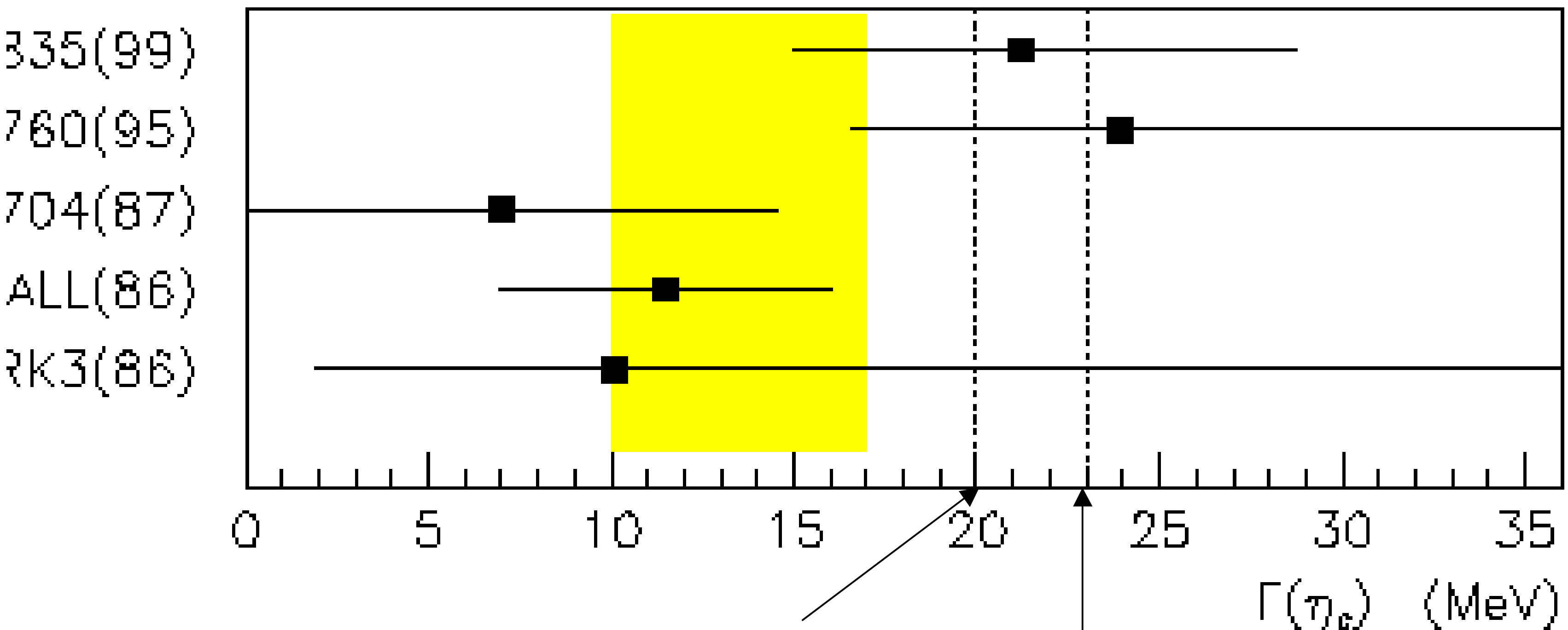
$$M = 2985.4 \pm 2.1\,\mathrm{MeV}$$

E-835 PRELIMINARY

STUDY OF THE $\eta_c(1^1S_0)$ RESONANCE

$$\Gamma = 21.1^{+7.5}_{-6.2}\ \text{MeV}$$

E-835 PRELIMINARY



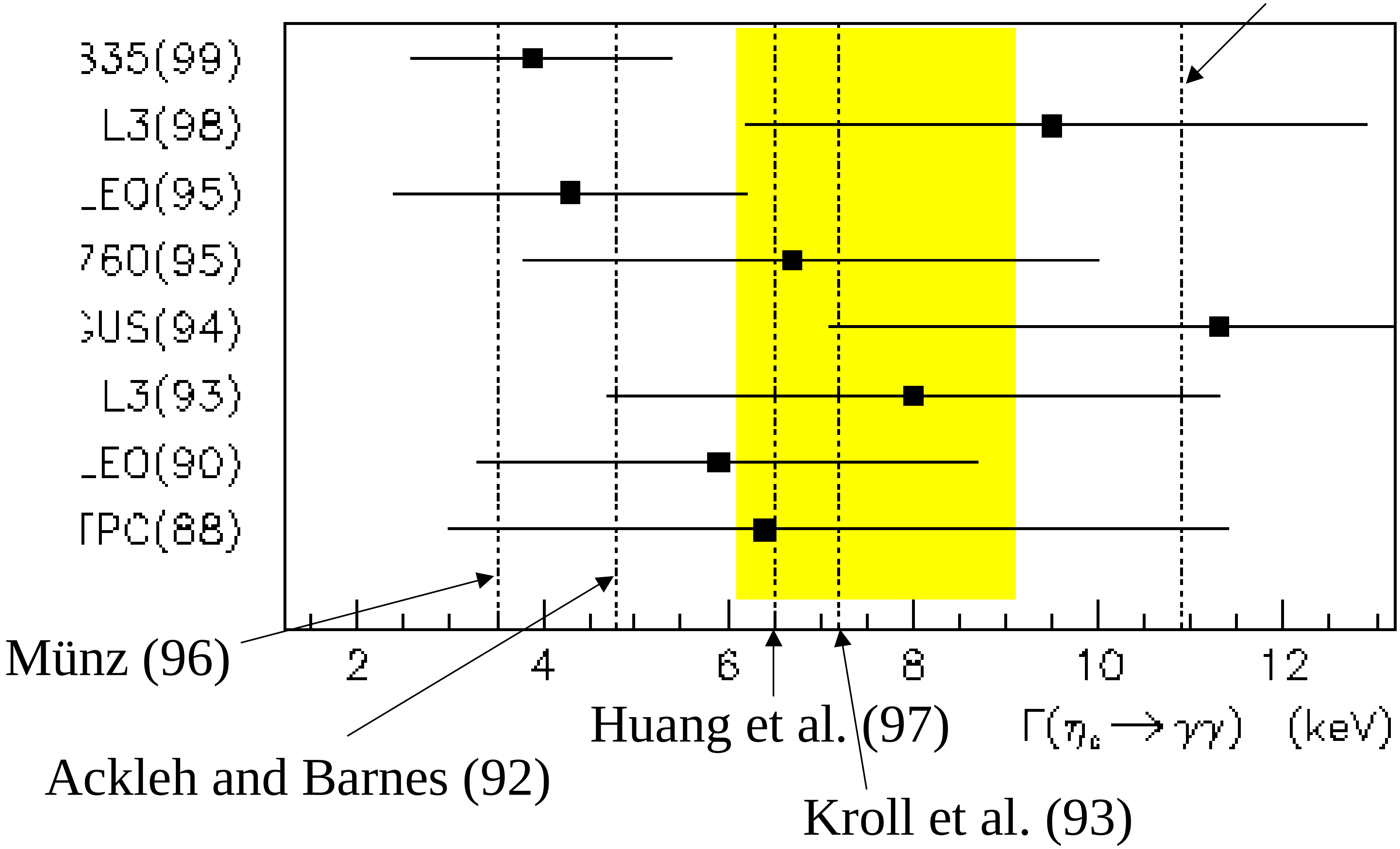
Huang et al. (97)

Gupta et al. (96)

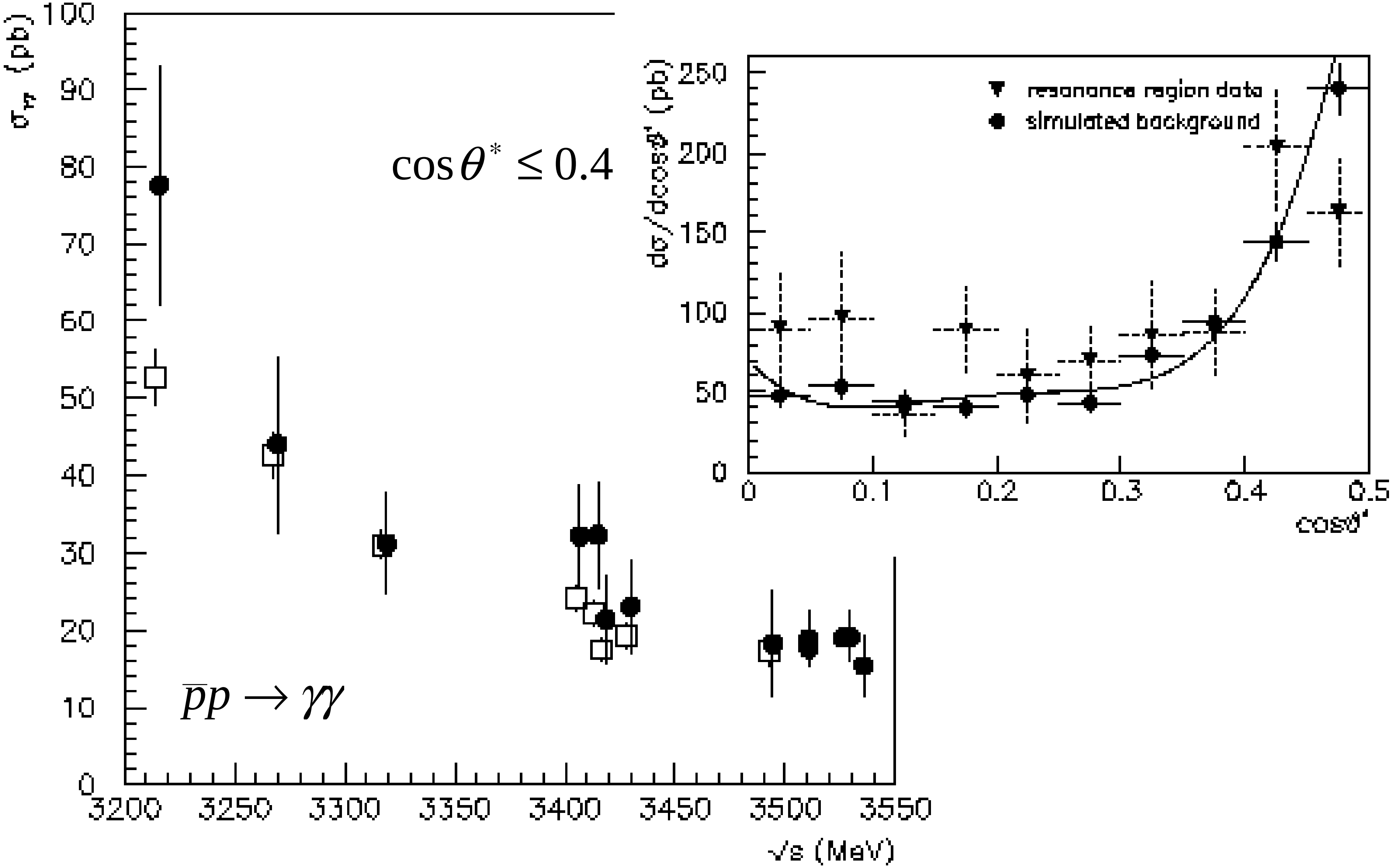
STUDY OF THE $\eta_c(1^1S_0)$ RESONANCE

E-835 PRELIMINARY

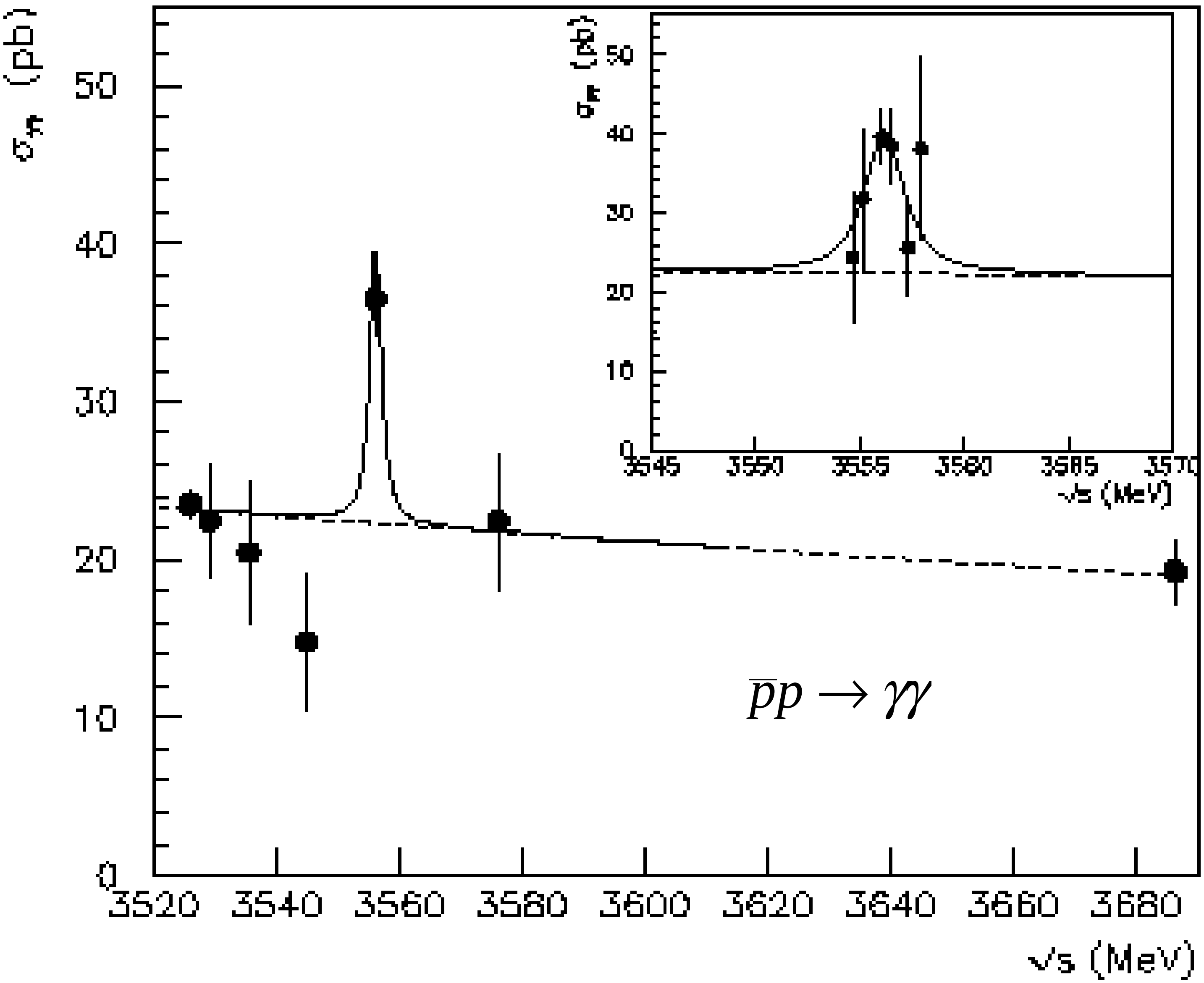
$$\Gamma(\eta_c \to \gamma\gamma) = 3.9^{+1.5+1.8}_{-1.3-1.1}\ \text{keV}$$



$\gamma\gamma$ DECAYS OF $\chi_{c0}(1^3P_0)$ AND $\chi_{c2}(1^3P_2)$



$\gamma\gamma$ DECAYS OF $\chi_{c0}(1^3P_0)$ AND $\chi_{c2}(1^3P_2)$



$\gamma\gamma$ DECAYS OF $\chi_{c0}(1^3P_0)$ AND $\chi_{c2}(1^3P_2)$

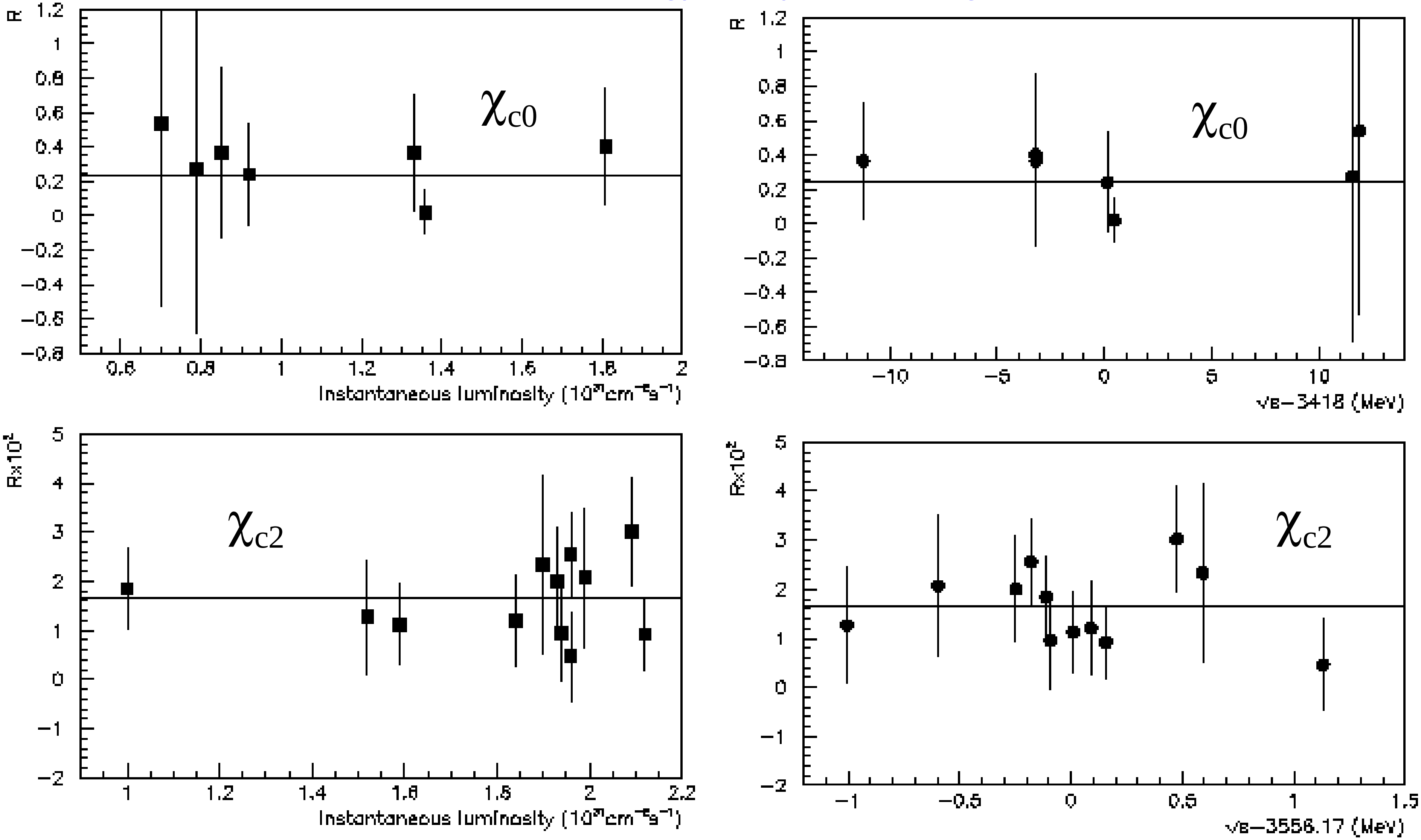
Decay rates to $\gamma\gamma$ are measured from the ratio of $\gamma\gamma$ and $J/\psi\,\gamma$ cross sections:

$$R \equiv \frac{B(\chi_{0,2} \to \gamma\gamma)}{B(\chi_{0,2} \to J/\psi\,\gamma)} = \frac{\left(N^t_{\gamma\gamma} - N^b_{\gamma\gamma}\right)/\varepsilon_{\gamma\gamma}}{\left(N^t_{J/\psi\,\gamma} - N^b_{J/\psi\,\gamma}\right)/\varepsilon_{J/\psi\,\gamma}}$$

$B(\chi_{0,2} \to J/\psi\,\gamma)$ is relatively well known, compared to statistical error.

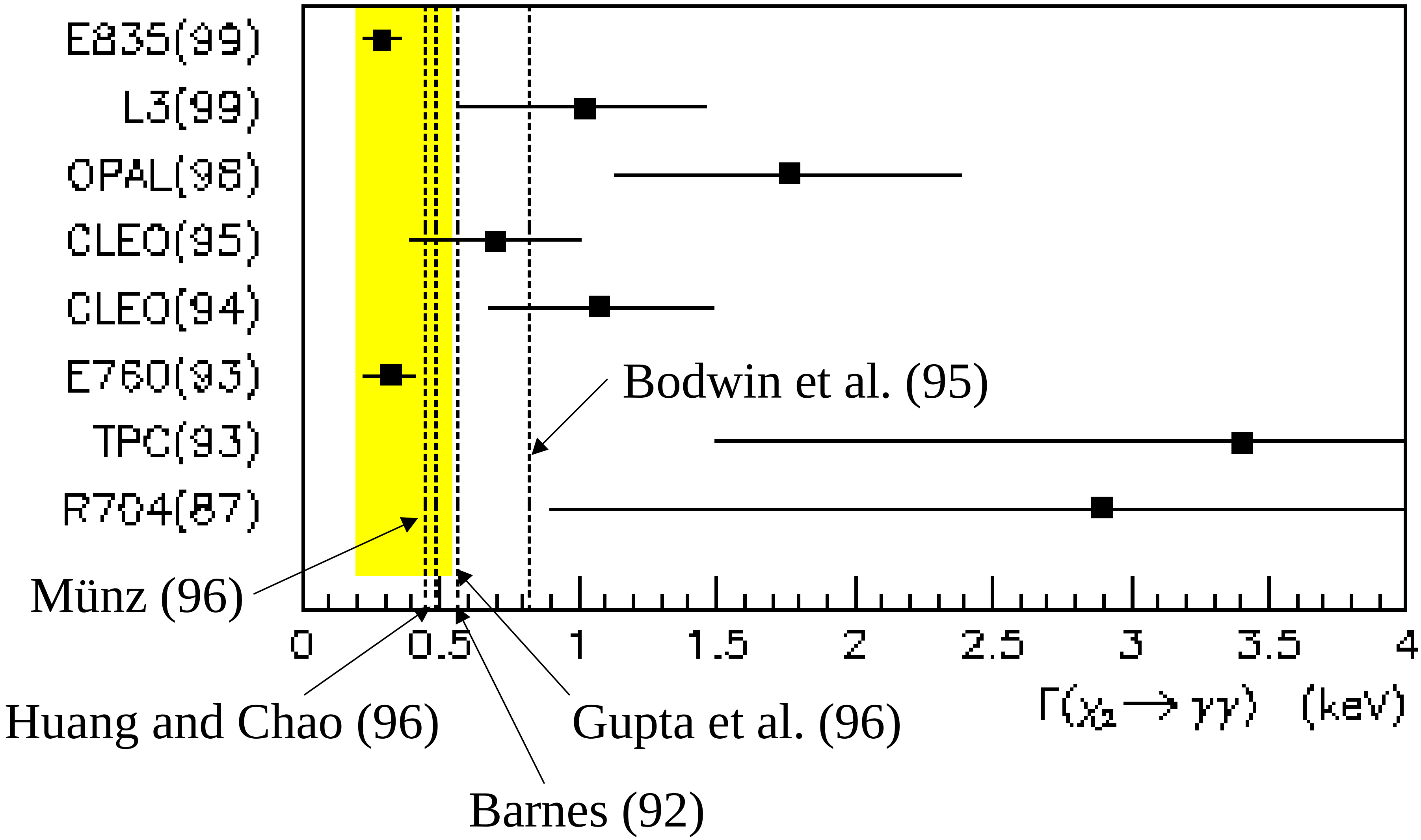
Possible systematics from CM energy or luminosity cancel out.

γγ DECAYS OF $\chi_{c0}(1^3P_0)$ AND $\chi_{c2}(1^3P_2)$



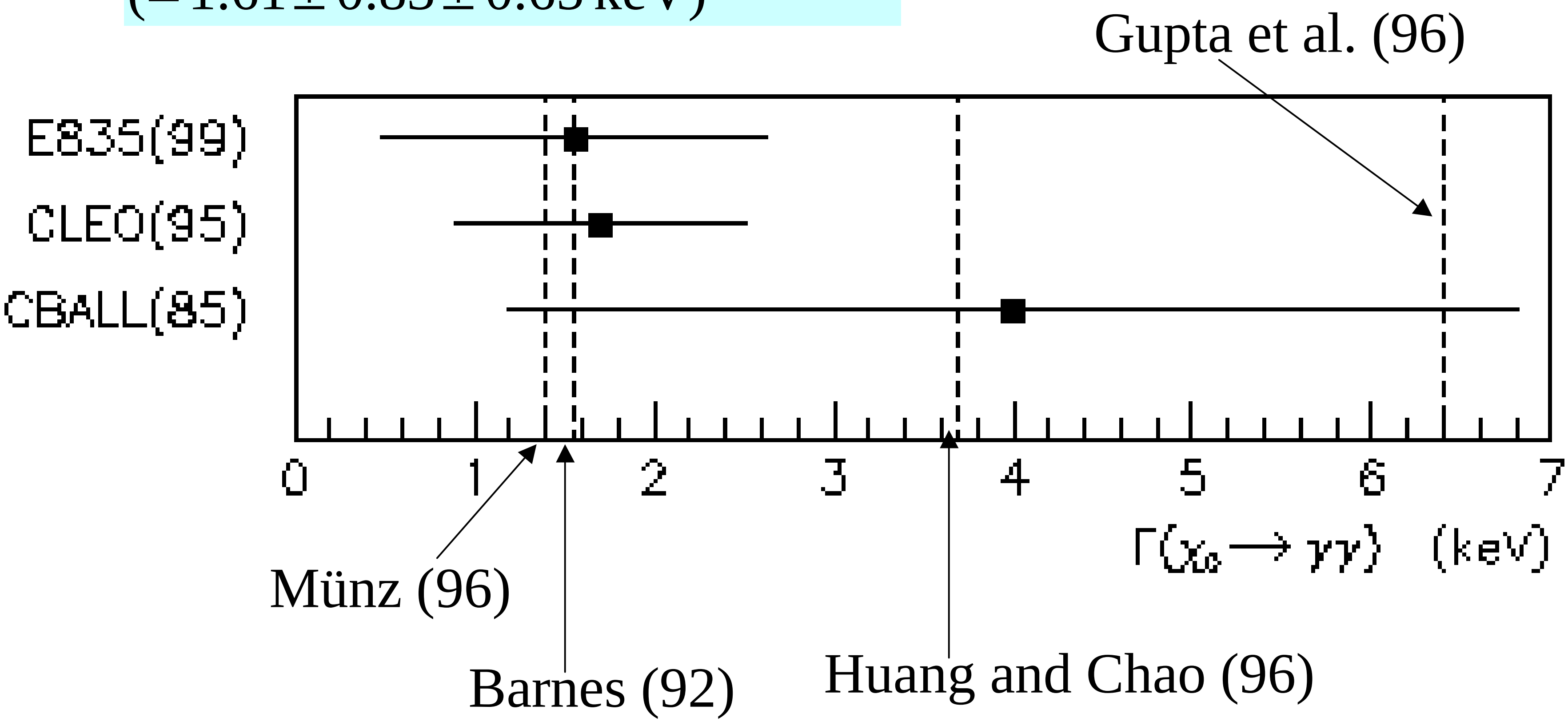
$\gamma\gamma$ DECAYS OF $\chi_{c0}(1^3P_0)$ AND $\chi_{c2}(1^3P_2)$

$$\Gamma(\chi_2 \to \gamma\gamma) = 0.270 \pm 0.049 \pm 0.033\,\mathrm{keV}$$



$\gamma\gamma$ DECAYS OF $\chi_{c0}(1^3P_0)$ AND $\chi_{c2}(1^3P_2)$

$$\Gamma(\chi_0 \to \gamma\gamma) < 3.47\ \mathrm{keV}\ (95\%\ \mathrm{CL})$$
$$(= 1.61 \pm 0.83 \pm 0.65\ \mathrm{keV})$$



$\chi_{c1}(1^3P_1)$ AND $\chi_{c2}(1^3P_2)$ ANGULAR DISTRIBUTIONS

$$\bar{p}p \to \chi_{c2} \to J/\psi\,\gamma \to e^+e^-\gamma$$

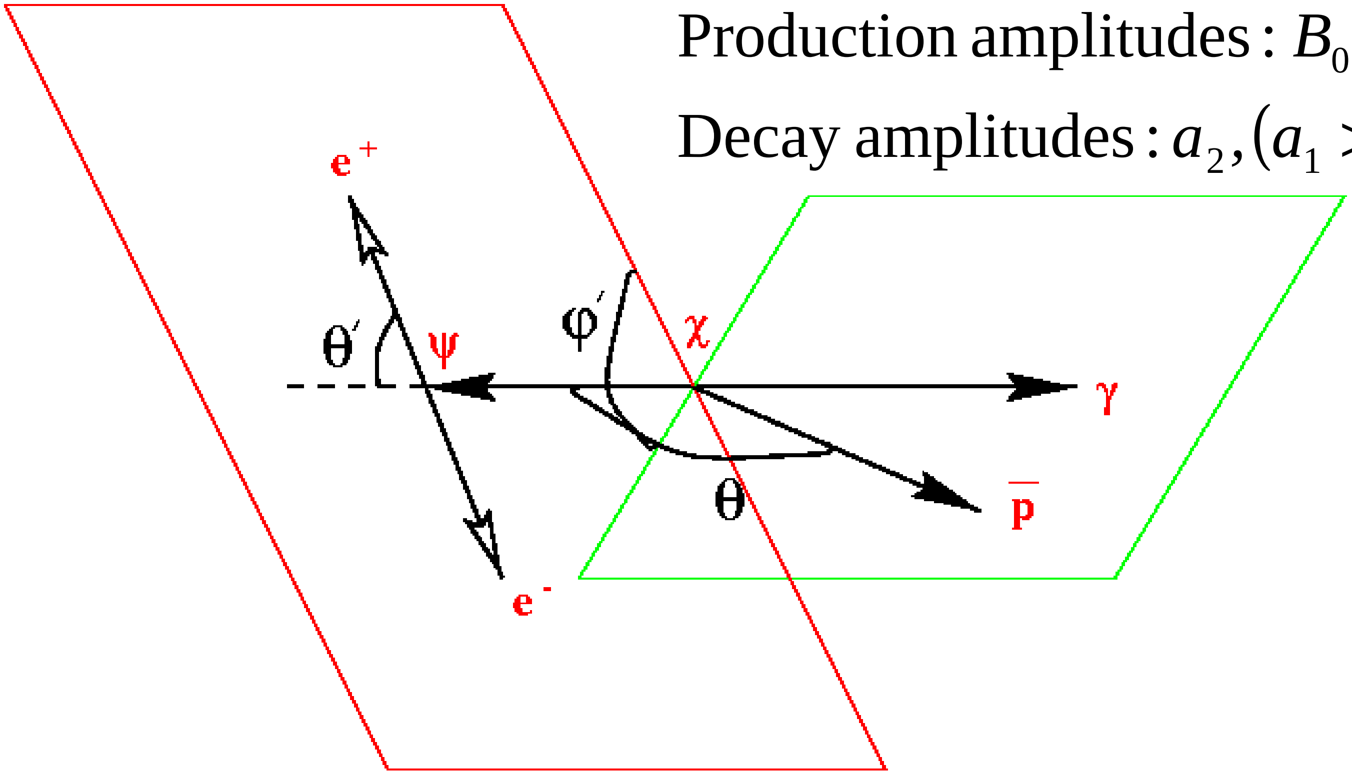
Production amplitudes: B_0^2 ($\Rightarrow B_1$ and B_{-1})

Decay amplitudes: $a_2, a_3, (a_1 > 0)$ (or A_0, A_1 and A_2)

$$\bar{p}p \to \chi_{c1} \to J/\psi\,\gamma \to e^+e^-\gamma$$

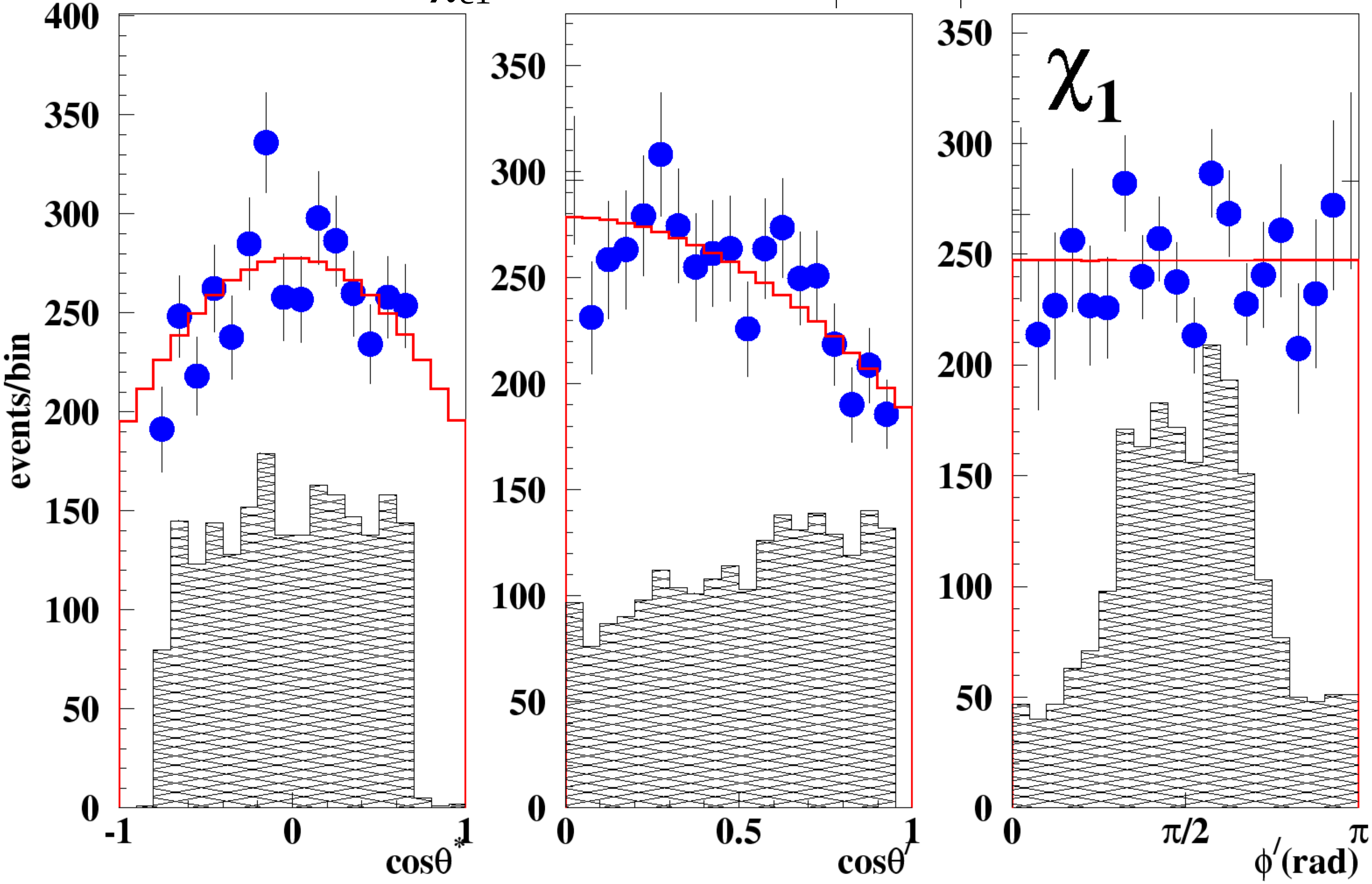
Production amplitudes: $B_0 = 0, |B_1| = |B_{-1}| = 1/\sqrt{2}$

Decay amplitudes: $a_2, (a_1 > 0)$ (or A_0 and A_1)



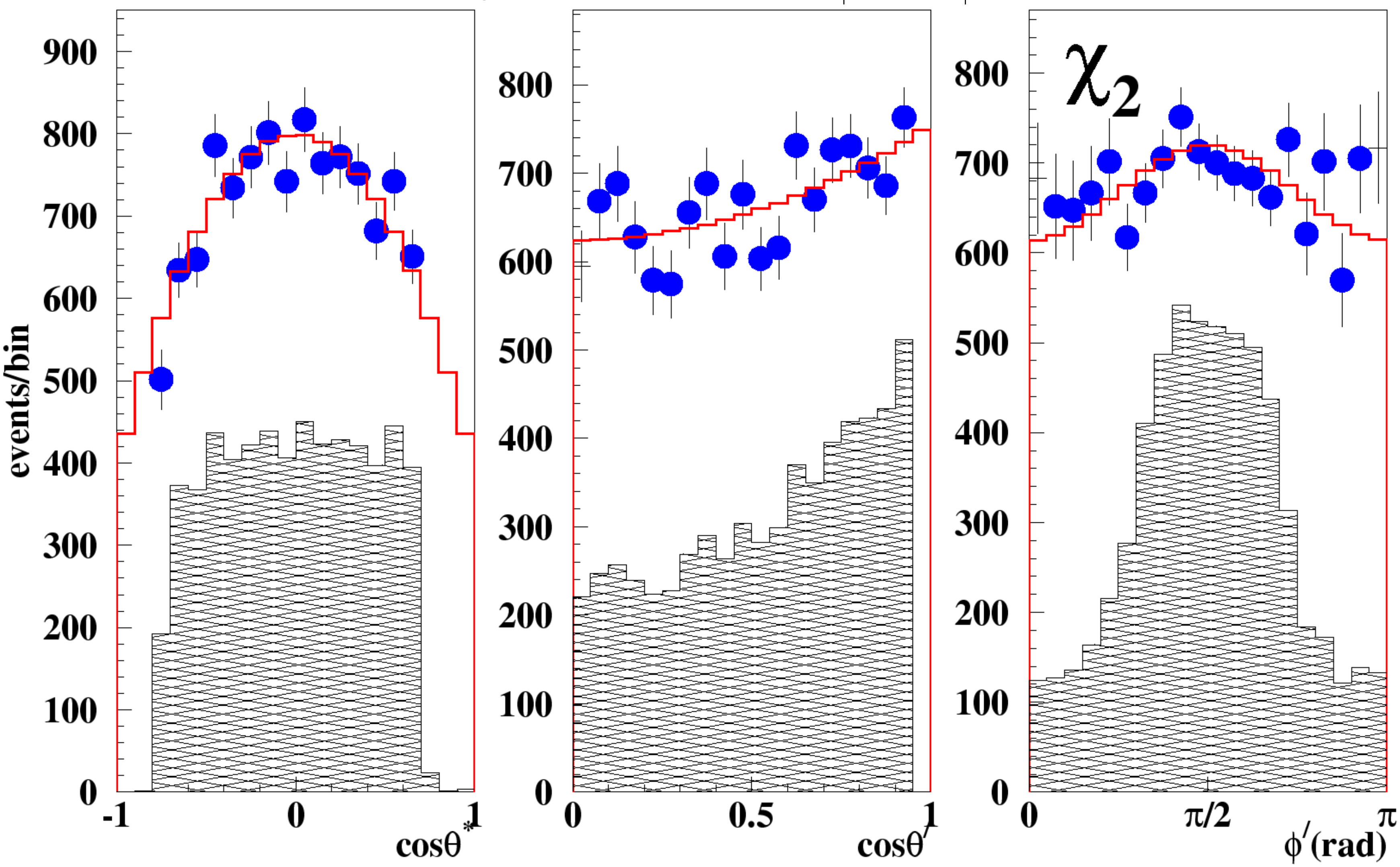
$\chi_{c1}(1^3P_1)$ AND $\chi_{c2}(1^3P_2)$ ANGULAR DISTRIBUTIONS

2144 χ_{c1} events $\quad |\cos\theta'| < 0.95$



$\chi_{c1}(1^3P_1)$ AND $\chi_{c2}(1^3P_2)$ ANGULAR DISTRIBUTIONS

6028 χ_{c2} events $\quad |\cos\theta'| < 0.95$



$\chi_{c1}(1^3P_1)$ AND $\chi_{c2}(1^3P_2)$ ANGULAR DISTRIBUTIONS

$$B_0^2 = \frac{B(\chi_{c2} \to \bar{p}p, J_z = 0)}{B(\chi_{c2} \to \bar{p}p)} = 0.097^{+0.090}_{-0.093}$$

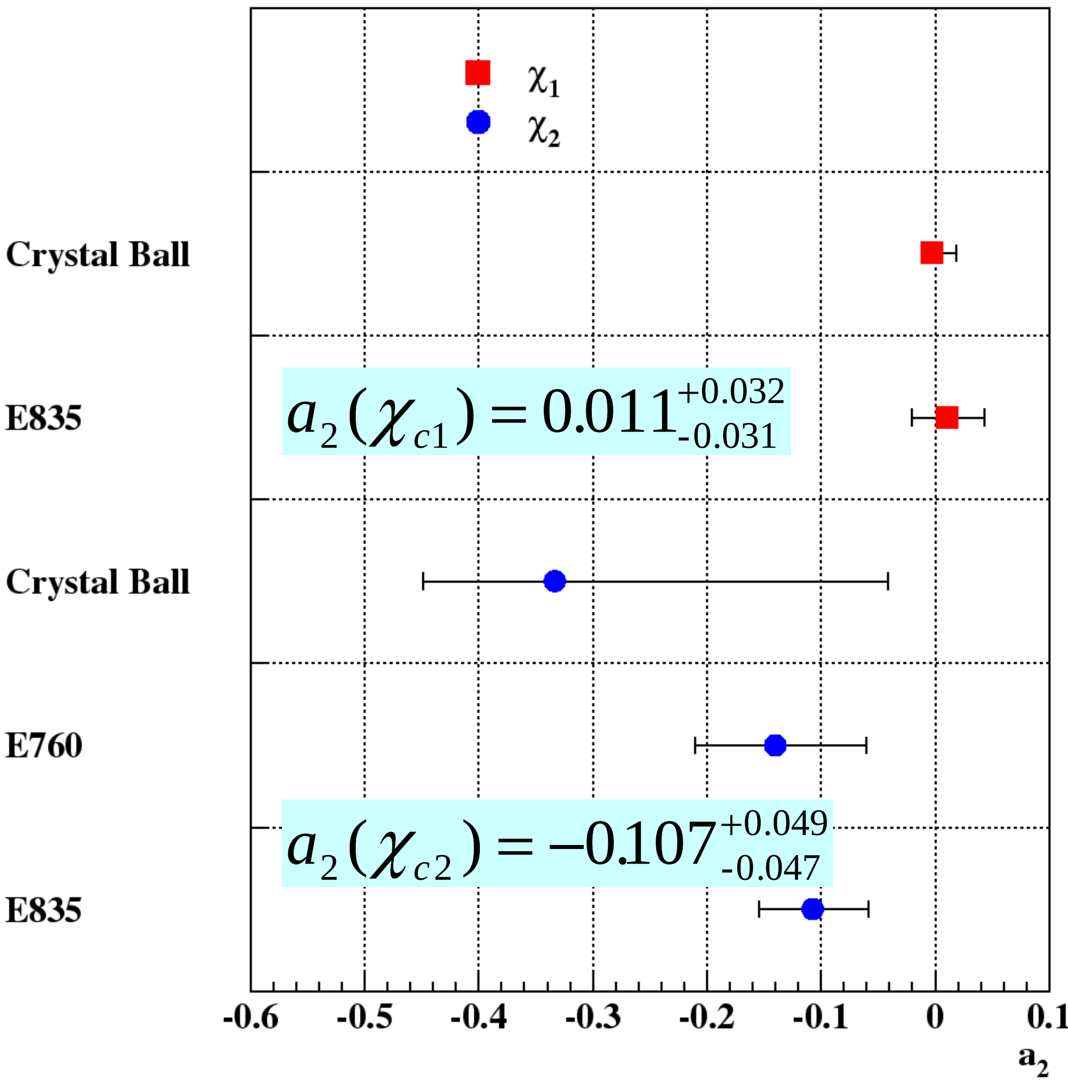
$$\left(\text{therefore } \frac{B(\chi_0 \to \bar{p}p)}{B(\chi_2 \to \bar{p}p, J_z = 0)} \approx 50 \right)$$

Interesting physics. Good test for models

$$a_3 = 0.014^{+0.046}_{-0.038}$$

Predicted to be 0 or negligibly small (Olsson et al. 1985, Sebastian et al. 1992, Grotch et al. 1984)

$\chi_{c1}(1^3P_1)$ AND $\chi_{c2}(1^3P_2)$ ANGULAR DISTRIBUTIONS



$$a_2(\chi_{c1}) = 0.011^{+0.032}_{-0.031}$$

$$a_2(\chi_{c2}) = -0.107^{+0.049}_{-0.047}$$

$$\left(\frac{a_2(\chi_{c1})}{a_2(\chi_{c2})}\right)_{E-835} = -0.10 \pm 0.31$$

McClary and Byers (1983) predict that ratio is independent of c-quark mass and anomalous magnetic moment

$$\left(\frac{a_2(\chi_{c1})}{a_2(\chi_{c2})}\right)_{\text{theory}} =$$

$$\frac{\sqrt{5}}{3}\frac{E_\gamma(\chi_{c1} \to J/\psi\ \gamma)}{E_\gamma(\chi_{c2} \to J/\psi\ \gamma)} = 0.676$$

CONCLUSIONS

An interesting physics program is being carried out by Fermilab experiment E-835. Some results have been presented here:

- χ_{c0} resonance parameters (and more data is being taken as we speak) $\Rightarrow$ intriguing coupling to pbar-p

- η_c resonance parameters

- χ_{c0}, χ_{c2} and η_c decay rates to two photons

- angular distribution of χ_{c1} and χ_{c2} radiative decays

  $\Rightarrow$ χ_{c2} magnetic quadrupole component higher than χ_{c1}

  $\Rightarrow$ χ_{c0} coupling to pbar-p much higher than χ_{c2} with J_z=0

Thanks for your attention!