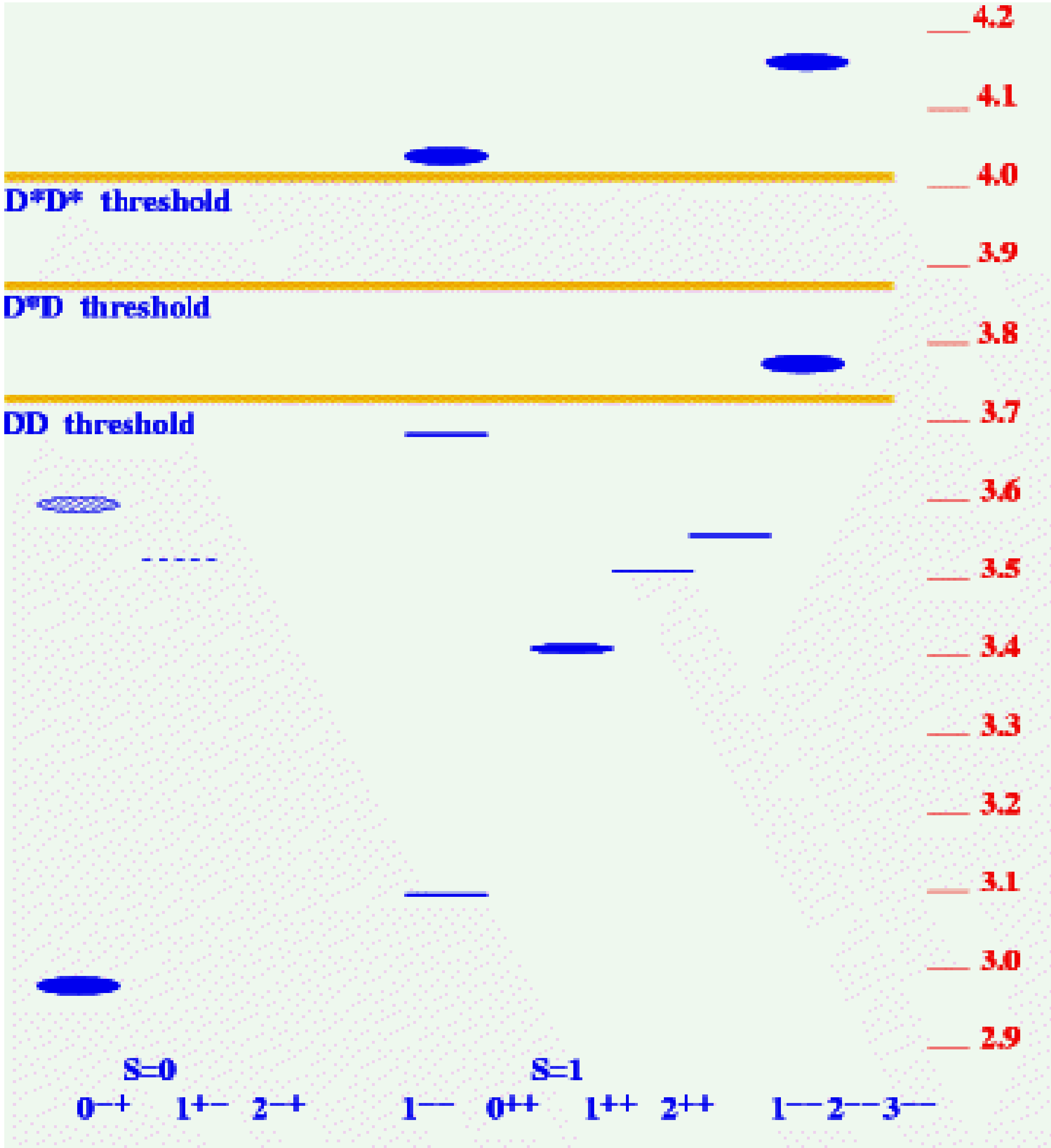
# CHARM SPECTROSCOPY

- Mass splittings
- Total Widths
- Hadronic and EM transitions between states
- EM widths: $e^+e^-$, $\gamma\gamma$
- No weak decays.
- No glueballs.

- Charmonium
- D-mesons
- C-Baryons

# Charmonium spectrum

- 8 states below D$\mathbb{D}$ threshold
- 2 still need confirmation
- S−D mixing on $1^{--}$ states
- Narrow states above D$\mathbb{D}$: $^1D_2$, $^3D_2$



# Charmonium sources

1) $e^+e^-$ annihilations (Mark−III, Crystal Ball, DM2, BES):

- directly only $J^{PC}=1^{--}$;
- access to hadronic and EM decay modes ;
- initial state radiation

2) $\bar{p}p$ annihilations (R704,E760,E835)

- direct on all $J^{PC}$ ;
- only EM decay modes (huge hadronic background)
- Very good $\delta p/p$ (stochastic cooling)

3) $\gamma\gamma,\gamma\gamma^*$ scattering, from $e^+e^- \rightarrow e^+e^-\gamma\gamma$ (CLEO,LEP)

- only on states with positive C

4) Hadronic production, via gluon−gluon fusion (E705,E771,Hera−B)

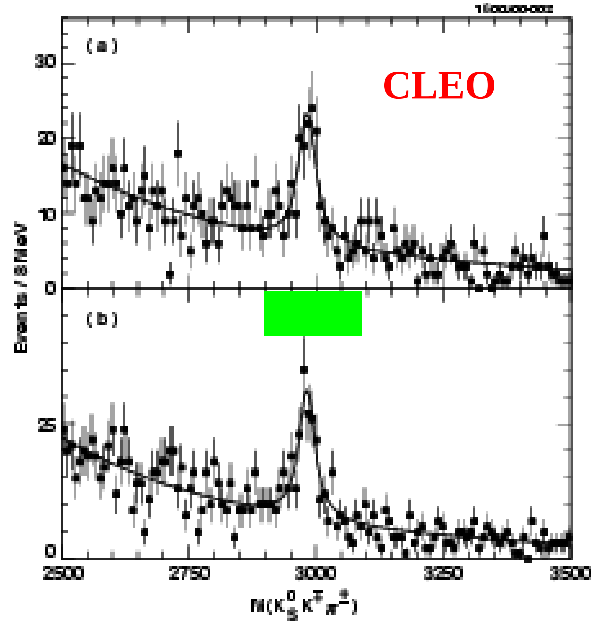
- Good for discovery in EM final states

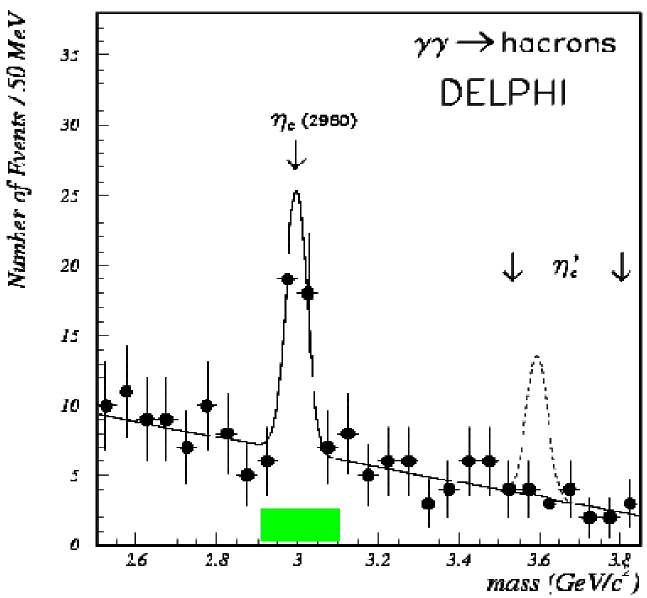
5) B decays, via b−>ccs (B factories)

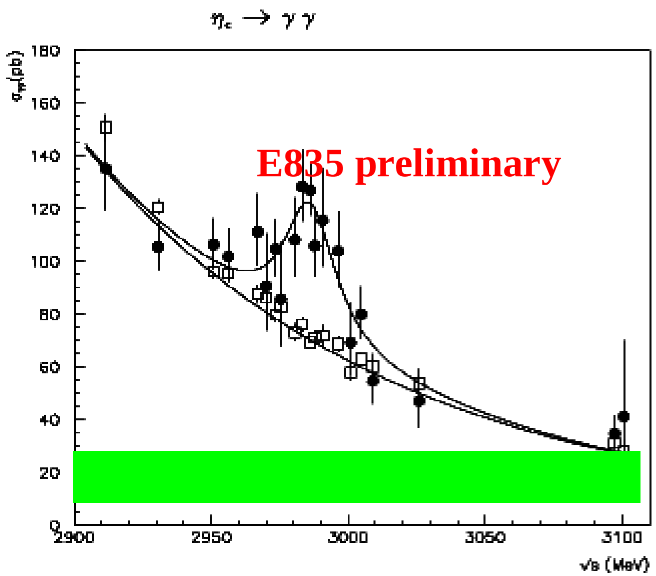
# $\eta_c$ mass and width

- Recent data from:
  - *CLEO: Brandenburg et al. Phys.RevLett. 85 (2000) 3095*
  - *BES: Bai et al. Phys.Rev.D60(1999) 072001*
  - *DELPHI: Abreu et al., Phys.Lett. B441(1998) 479*
- Preliminary data from E835

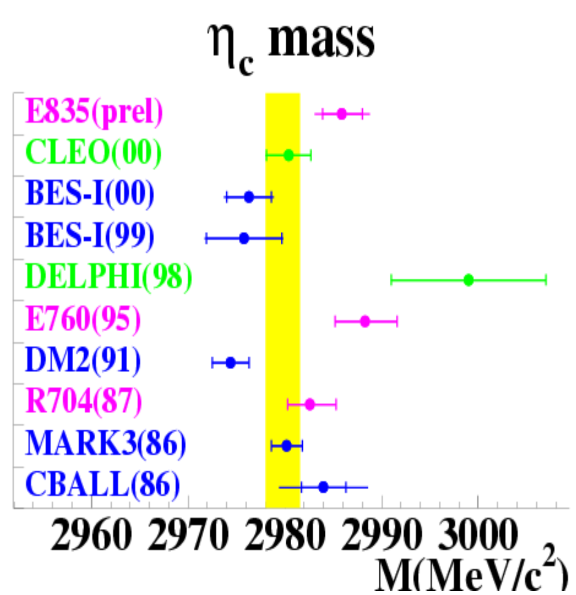
Studying syst errors from energy dependence of $p\bar{p} \to \pi^0\pi^0 + \pi^0\gamma$ feeddown .



# $\eta_c$ mass and width




Recent data from: E835,BES,CLEO, LEP

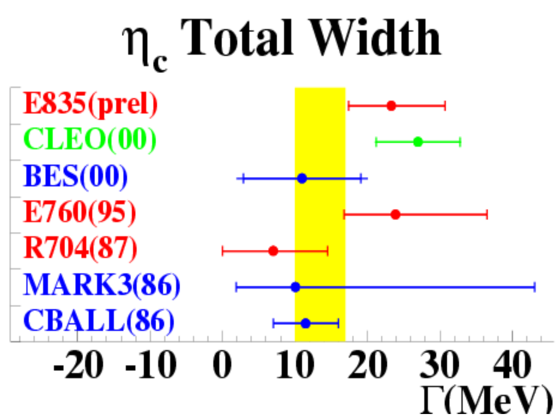
- MASS:

Hyperfine splitting:

$M(J/\psi)-M(\eta_c) = 117\pm2$ MeV/c$^2$

Bad overall $\chi^2$ on PDG:

$M(p\bar{p})>M(e^+e^-)$?




- TOTAL WIDTH=$\Gamma(\eta_c\rightarrow gg)$

BES−I data from $\psi$ and $\psi'$ sample

$\delta\Gamma/\Gamma$~25% ?? Bad $\chi^2$ casts doubts on PDG2000

Waiting for results from the 50M$\psi$ BESII sample.

CLEO−c

# Masses of $\chi_{cJ}$ states

$$M\begin{Bmatrix}\chi_{c0}\\ \chi_{c1}\\ \chi_{c2}\end{Bmatrix} = M_{cog} + h_{LS}\begin{Bmatrix}-2\\ -1\\ 1\end{Bmatrix} + h_T\begin{Bmatrix}-2\\ 1\\ -1/5\end{Bmatrix}$$

- New averages:

  $M(\chi_{c0})_{new} = 3415.2 \pm 0.4$ MeV/$c^2$

- Mass splittings:

  $M(\chi_{c1})_{E760} - M(\chi_{c0})_{new} = 95.3 \pm 0.4$ MeV/$c^2$

  $M(\chi_{c2})_{E760} - M(\chi_{c1})_{E760} = 45.6 \pm 0.2$ MeV/$c^2$

| | cc(n=1) | | bb(n=1) | |
|---|---|---|---|---|
| M2−M1 | 45.6 | 0.2 | 19.9 | 0.9 |
| M1−M0 | 95.3 | 0.4 | 32.8 | 1.1 |
| HT | 12.9 | 0.1 | 4.1 | 0.2 |
| HLS | 30.6 | 0.1 | 12.4 | 0.4 |

- $M_{cog} = [M(\chi_{c0})_{new} + 3M(\chi_{c2})_{E760} + 5M(\chi_{c1})_{E760}]/9$

  $= 3525.3 \pm 0.1$ MeV/$c^2$

- $M_{cog} - M(J/\psi) = 428.4 \pm 0.1$ MeV/$c^2$
- Triplet P − S splitting known at 0.2 ‰ level.

- Lattice predictions still not satisfactory *(e.g.: CPPACS, hep−lat/0011005, see plot)* ....even after unquenching (*Stewart−Koniuk, hep−lat/0010015)*

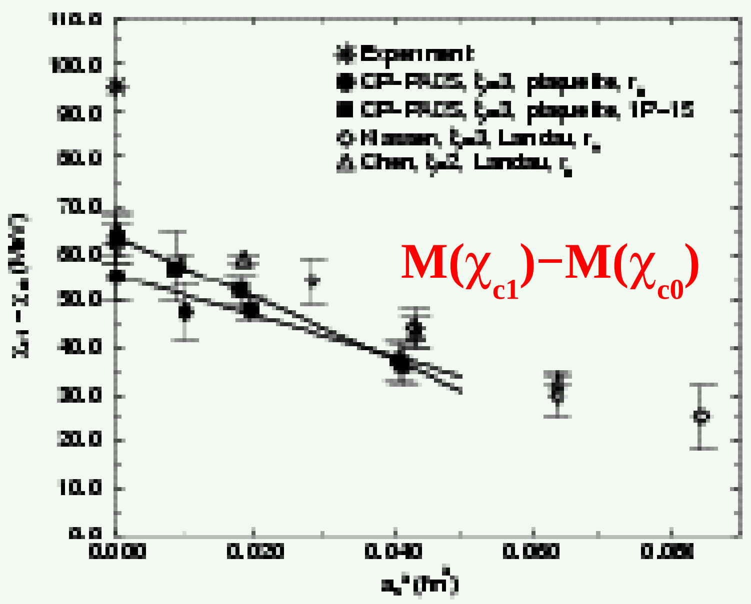



Figure 4. The scaling behavior of $\Delta M_{\chi_{c1}-\chi_{c0}}$.

# Widths of $\chi_{cJ}$ states

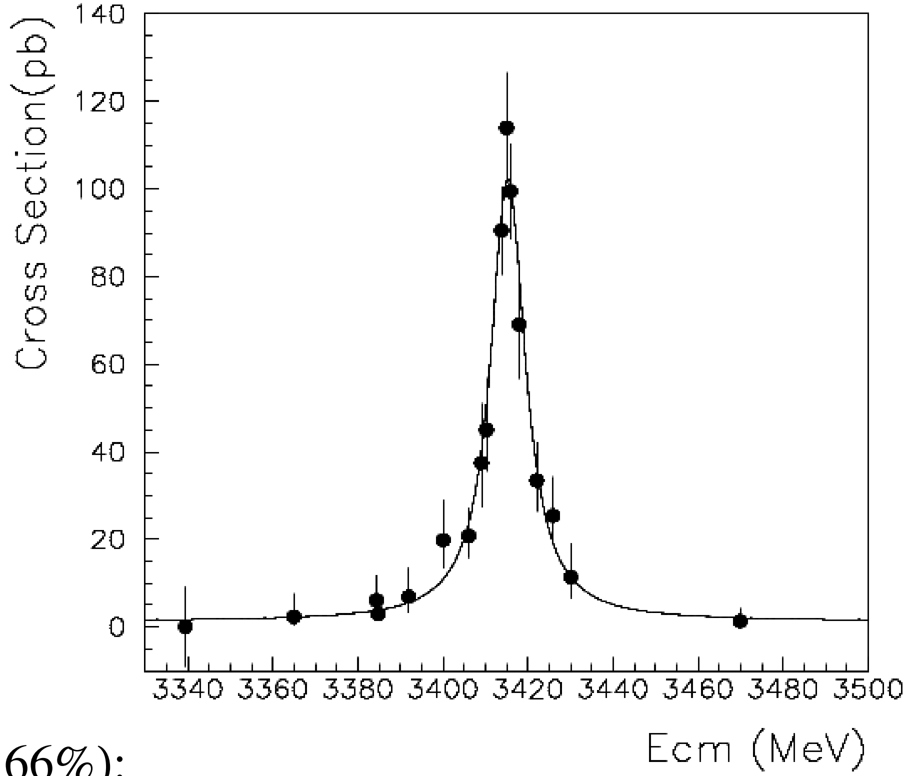
- Recent Results at $\chi_{c0}$: BES and E835

*Bai et al., Phys.Rev.Lett.81(1998),3091*

- From $e^+e^- \to \psi' \to \gamma\,\pi^+\pi^-, \gamma\,K^+K^-$
  - 1.5 k reconstructed events total
  - $\Gamma_{BES}(\chi_{c0}) = 14.3 \pm 2.0 \pm 3.0$ MeV
  - PDG(2000): $\Gamma = 14.9^{+2.6}_{-2.3}$ MeV
- E835(00) vs E835(97) result:

*Ambrogiani et al., Phys.Rev.Lett., in preparation*

  - Increased statistics (x 6)




- $\Gamma(\chi_{c0} \to LH) \simeq \Gamma_{E835}(\chi_{c0})$ $(BR_{CB}(\chi_{c0} \to \gamma J/\psi) = 0.66\%)$:

- $\chi_{c0}$: 9.8±1.0±0.1 MeV (*10% error*)

- $\Gamma(\chi_{\chi1,2} \to LH) \simeq \Gamma_{E760}(\chi_{c1,2})*\{1 - BR_{CB}(\chi_{c1,2} \to \gamma J/\psi)\}$:

- $\chi_{c1}$:(0.88±0.11±0.08 MeV)*(72.7±1.6%) = 0.64±0.09 MeV (*14% error*)

- $\chi_{c2}$:(2.00±0.17±0.07 MeV)*(86.5±1.1%) = 1.73±0.16 MeV (*10% error*)

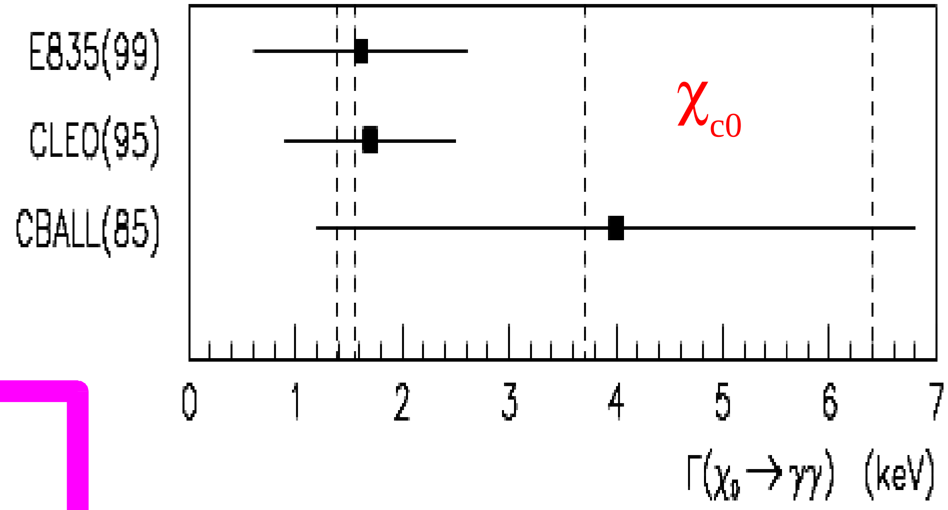
- E835(97+00) : 2k+2k $\chi_{c1}$ and 6k $\chi_{c2}$ .Analysis of syst errors in progress.

# $\Gamma(\chi_{cJ} \to \gamma\gamma)$

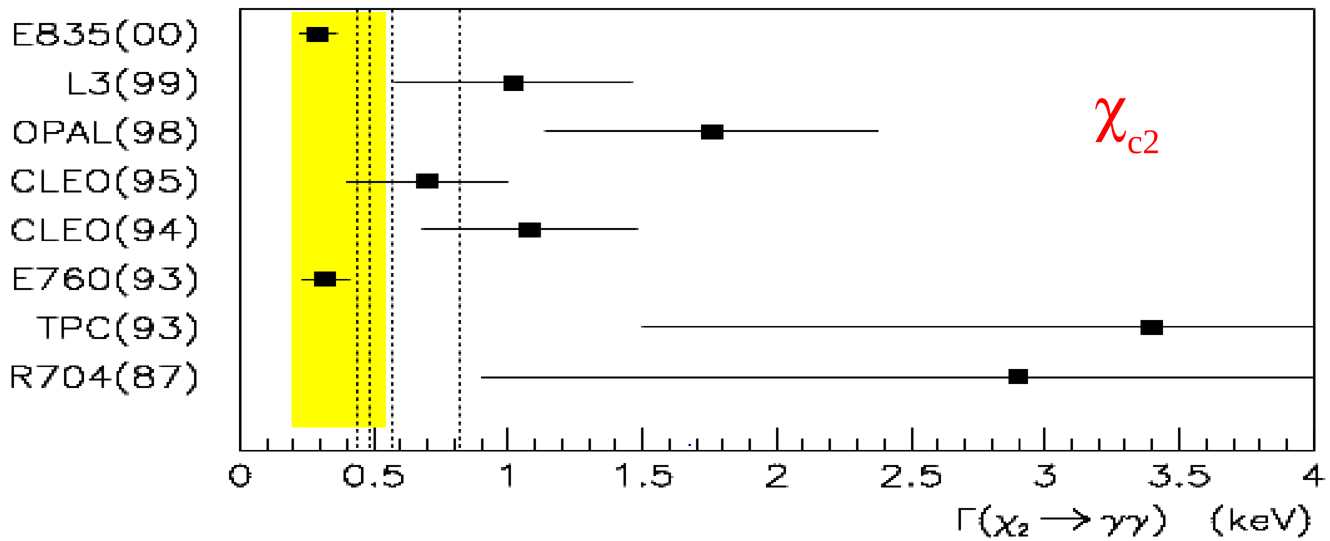
- Recent Results at $\chi_{c0,2}$: E835(97)

*Ambrogiani et al., Phys.Rev.D62(2000):052002*

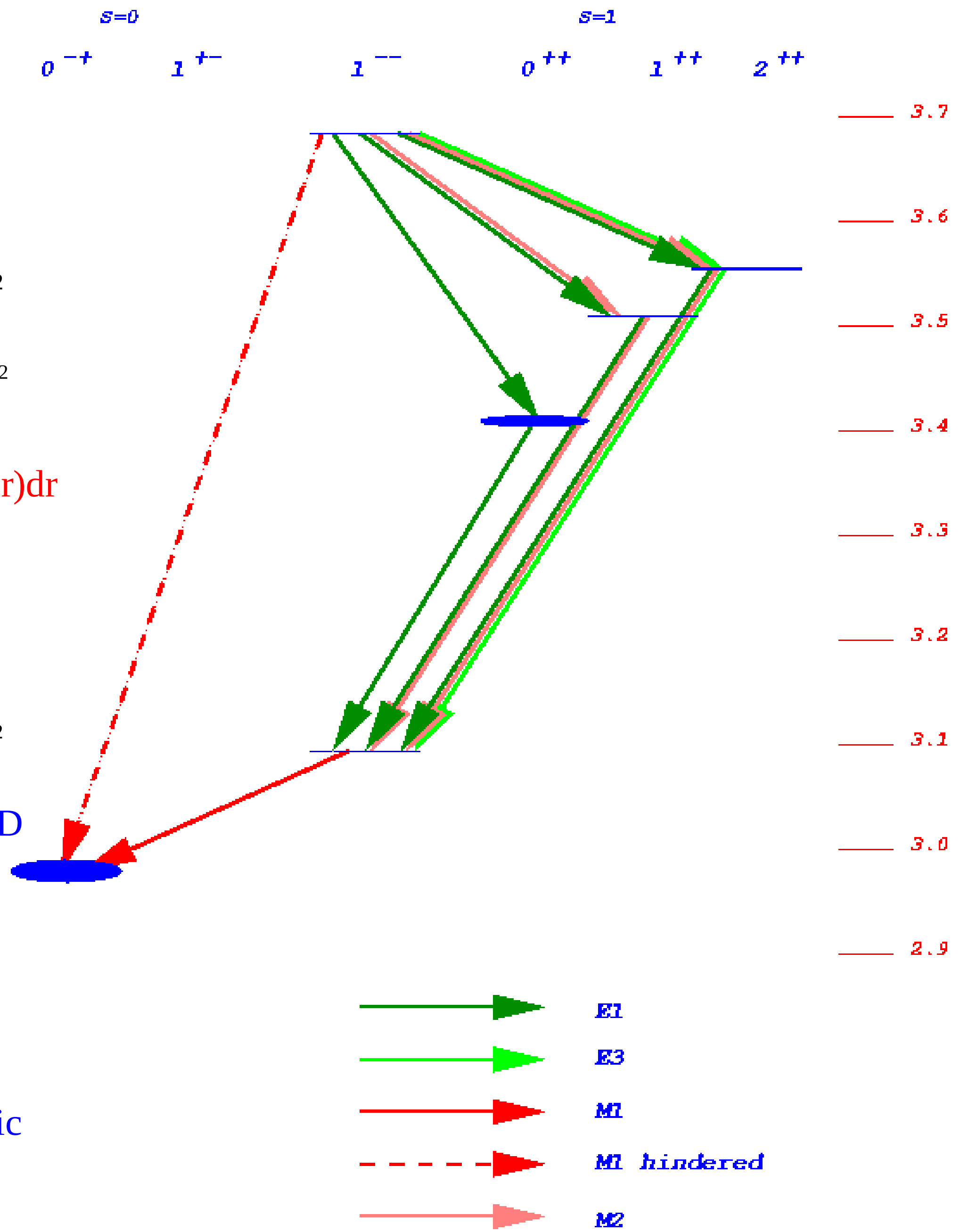
  - $\chi_{c0}$:1.61± 0.83± 0.65 keV
  - $\chi_{c2}$:270± 49± 33 eV




- Analysis of the 2000 $\chi_{c0}$ data set is in progress(> 6x more statistics).



# Radiative transitions




- Electric dipole transitions

$$\Gamma(\chi_c \to \gamma J/\psi) = |E1|^2 (1+O(\beta^2)) = \frac{4}{9} e_c^2 \alpha E_\gamma^3 \langle r_{if} \rangle^2$$

$$\Gamma(\psi' \to \gamma \chi_{cJ}) = |E1|^2 (1+O(\beta^2)) = \frac{2J+1}{3} \frac{4}{9} e_c^2 \alpha E_\gamma^3 \langle r_{if} \rangle^2$$

  - Sensitive to overlap integral $r_{if} = \int r\psi_i(r)\psi_f(r)dr$

- Magnetic dipole transitions

$$\Gamma(J/\psi \to \gamma \eta_c) = |M1|^2 = \frac{4}{9} e_c^2 \alpha \frac{E_\gamma^3}{m_c^2} \frac{1}{1+E_\gamma/\sqrt{M_f^2+E_\gamma^2}} |I_{if}|^2$$

  - Sensitive to charm magnetic moment AND $I_{if} = \int j_0(kr)\psi(r)^2 dr$

- Higher order terms: M2/E1,E3/E1

  Accessible thru angular distributions

  Sensitive to charm magnetic moment, relativstic corrections, ...

# Radiative Widths of $\chi_{cJ}$ states

- All current values are obtained combining $e^+e^-$ and $p\bar{p}$ data as follows:

$$\Gamma_{rad}(\Psi_i \to \gamma \Psi_f) = \Gamma_{tot}(\Psi_i) * BR(\Psi_i \to \gamma \Psi_f)$$

- The fractional error is given by:

$$\frac{\delta \Gamma_{tot}}{\Gamma_{tot}} \oplus \frac{\delta BR}{BR} = \frac{\delta \Gamma_{rad}}{\Gamma_{rad}}$$

- Current values are summarized below:

| | Transition | Rad.Width (keV) | | Error |
|---|---|---|---|---|
| E1 | PSIP to CHI2 | 22 | 11% ⊕ 10% = | 15% |
| | PSIP to CHI1 | 24 | 11% ⊕ 9% = | 14% |
| | PSIP to CHI0 | 26 | 11% ⊕ 10% = | 15% |
| | CHI2 to JPSI | 270 | 9% ⊕ 8% = | 12% |
| | CHI1 to JPSI | 240 | 16% ⊕ 6% = | 17% |
| | CHI0 to JPSI | 98 | 17% ⊕ 27% = | 32% |
| M1 | **PSIP to ETAC** | **0.78** | **11% ⊕ 21% =** | **24%** |
| | **JPSI to ETAC** | **1.13** | **6% ⊕ 31% =** | **31%** |
| M2/E1 | | Amplitude ratio | | Error |
| | PSIP to CHI2 | 8% | | 5% |
| | PSIP to CHI1 | 13% | | 9% |
| | CHI2 to JPSI | –9% | | 4% |
| | CHI1 to JPSI | 0% | | 2% |

E835

# Syst errors from inclusive photon spectra

- *All* BR($\eta_c,\chi_c \rightarrow$hadrons) measured from e+e− annihilations *depend* on BR($J/\psi,\psi' \rightarrow \gamma$+...), measured by Crystal Ball. *Gaiser et al. Ph. Rev. D34,711 (1986)*
- Crystal Ball's charged tracking inefficiency: 20% syst error on BR($\psi' \rightarrow \gamma\chi_c$)?
- Low statistics of M1 transitions: 30% stat error on BR($J/\psi,\psi' \rightarrow \gamma\eta_c$)

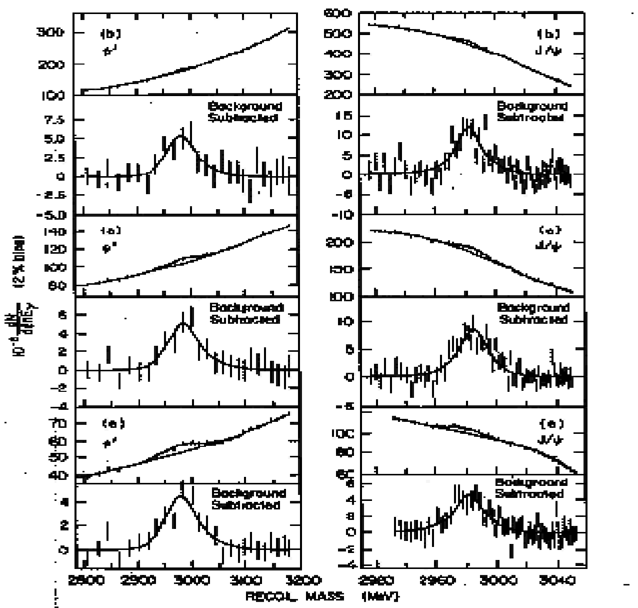
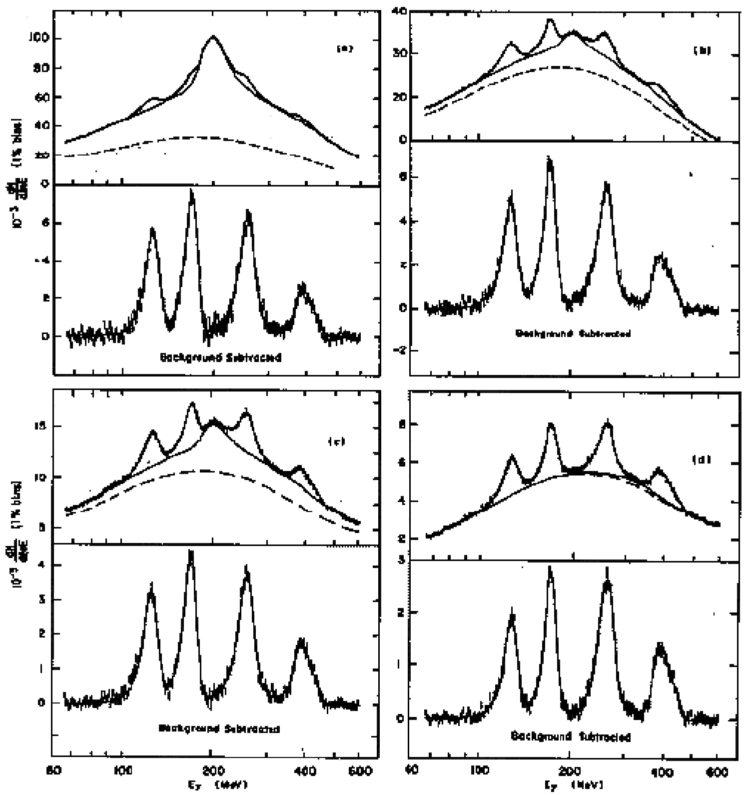



FIG. 8. Simultaneous fits to the $\eta_c$ mass in the $\psi'$ and $J/\psi$ inclusive photon spectra. The data are plotted in 2% bins in the photon energy. The preferred resolution value of $\sigma_0$=2.7% is used in the fit. The spectra labeled (b) and (c) correspond to the photon selection criteria of the $\chi$ analysis. The spectra labeled (e) employ a modified cut on the lateral photon energy pattern as described in the text.



# Complementarity between $e^+e^-$ and $p\bar{p}$ data

- A more rigorous approach to the calculation of radiative widths accounts for the correlation between different measurements. A global fit of all experimental data can be found in *C.Patrignani,Phys. Rev. D 64(2001) 034017*

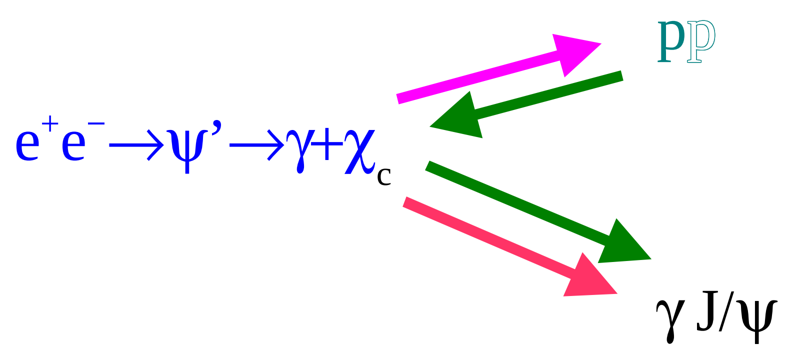
- From e+e−machines:

  Nevents($\longrightarrow$) $\propto$ $\Gamma(\psi')BR(\psi'\to\gamma+\chi_c)*BR(\chi_c\to p\bar{p})$

  Nevents($\longrightarrow$) $\propto$ $\Gamma(\psi')BR(\psi'\to\gamma+\chi_c)*BR(\chi_c\to\gamma\, J/\psi)$

- From $p\bar{p}$ machines:

  Nevents($\longrightarrow$) $\propto$ $\Gamma(\chi_c)BR(\chi_c\to p\bar{p})*BR(\chi_c\to\gamma\, J/\psi)$



# $\psi' \rightarrow J/\psi\ \gamma\gamma$

Crystal Ball and E835 samples are numerically compatible.
Access to $\gamma\chi_c$, $\psi\pi^o$, $\psi\eta$.

ECAL:NaI much better than PbG $\Rightarrow$ $\chi_{c2}$ and $\chi_{c1}$ merge.

Analysis under way: $\chi_{c0}$, angular distributions

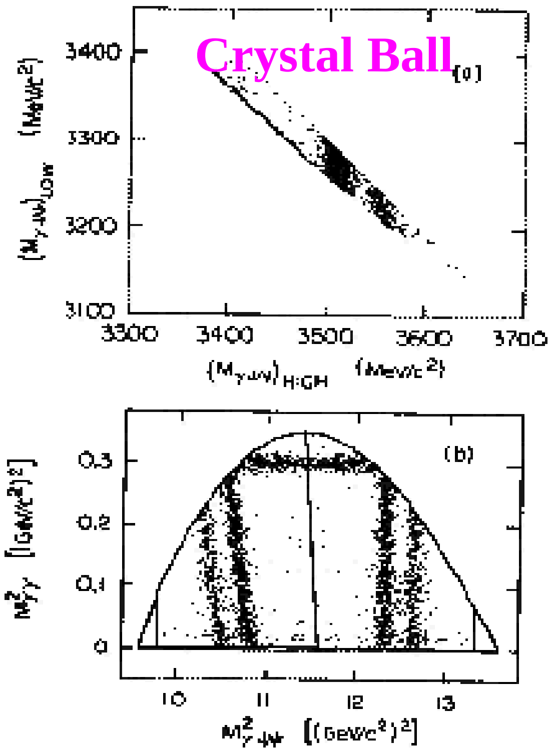
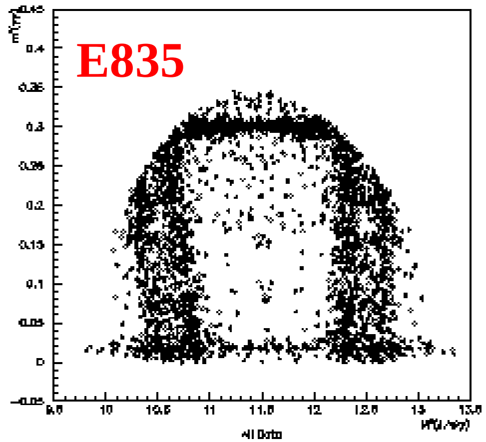
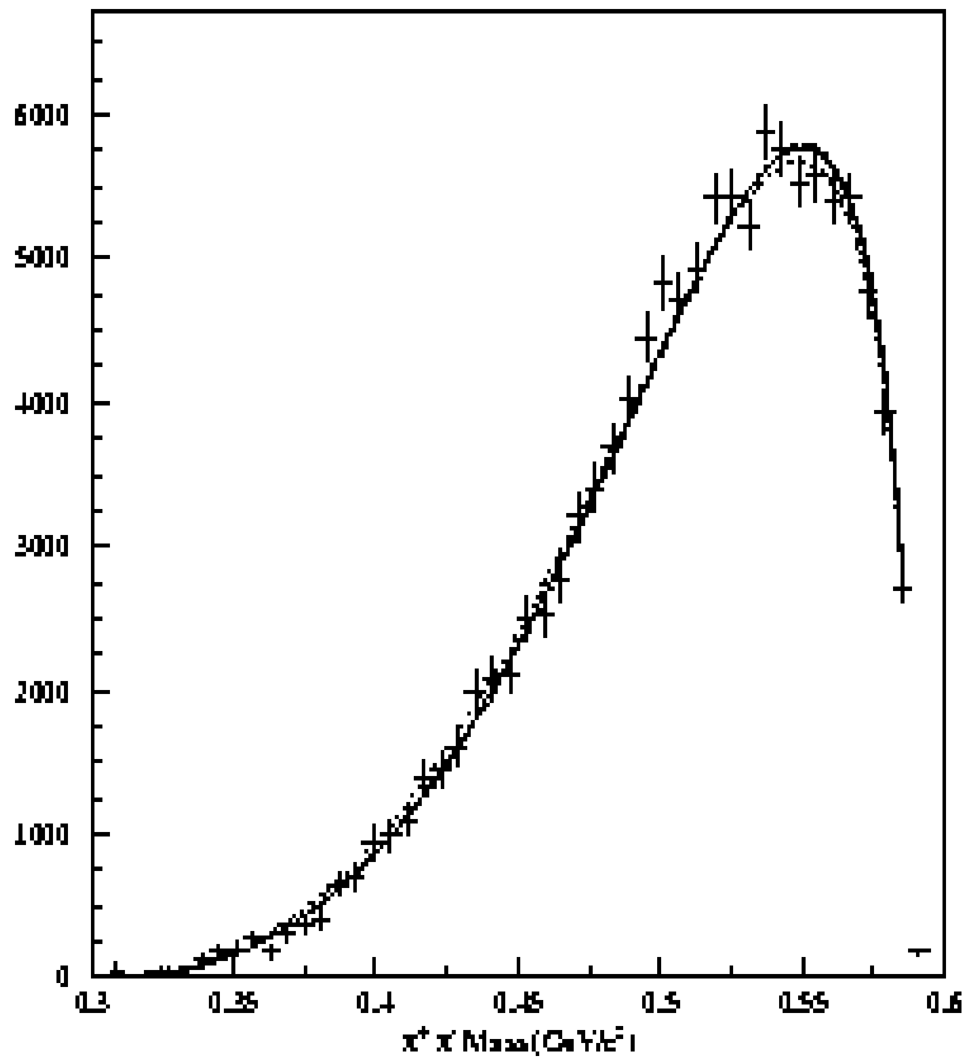



FIG. 11. Events after kinematic fitting in the (a) mass scatter plot and (b) Dalitz plot.




# $\psi' \to J/\psi\, \pi^+ \pi^-$

- BES results in
  *Bai et al,Phys.Rev.D62(2000)032002*
- From a 3.8M $\psi'$ sample.
- $M_{\pi\pi}$ peaked at high values.
- S wave between $\psi$ and $\pi\pi$
- D wave content in the dipion: ~15%



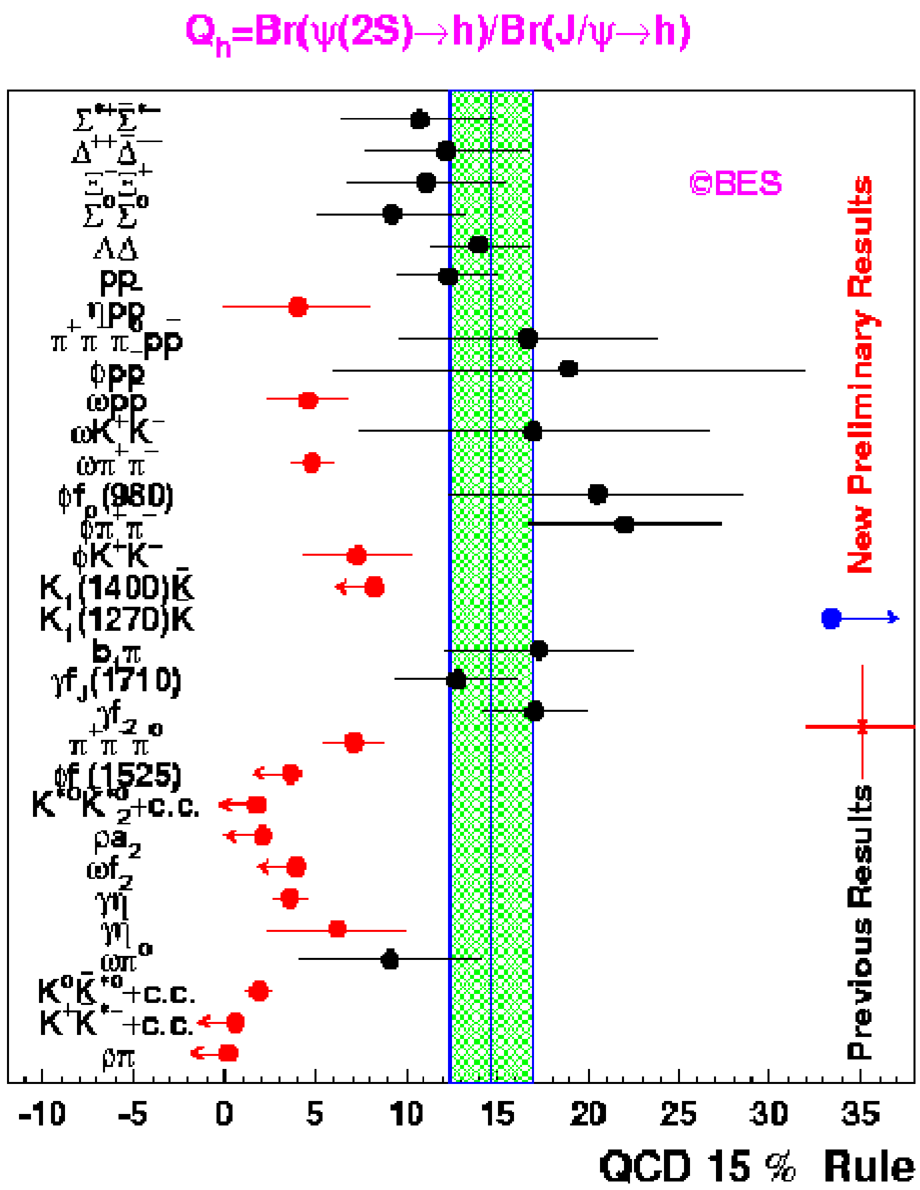
# $\psi'$ vs J/$\psi$ decays: the 15% rule

•BES−I results (preliminary)

•From a 4M $\psi'$ ans 7.8M J/$\psi$ sample.

•Works for AP and B$\mathbb{B}$ modes, not for others.

•

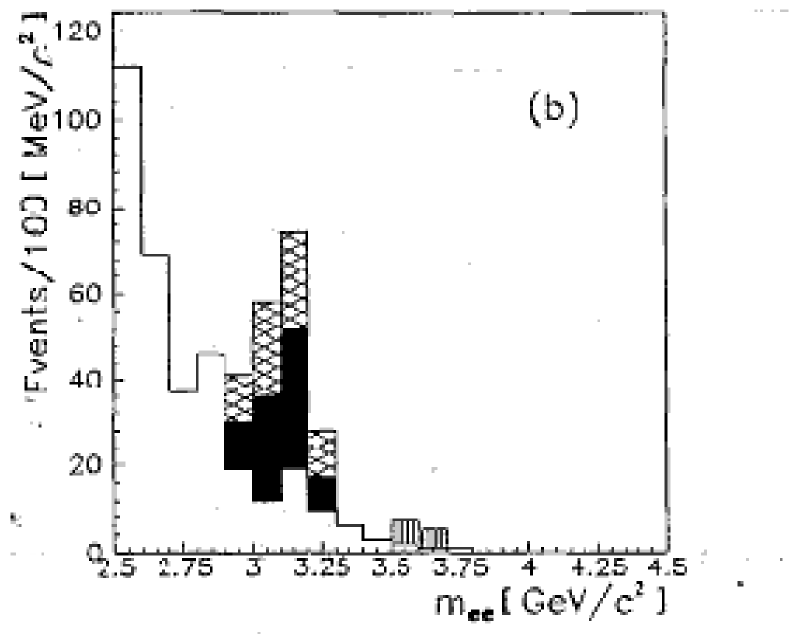


# $^1P_1$ (*a.k.a. $h_c$*) search

- E760 data: 16 $pb^{-1}$ in the $M_{cog}$ region
  - Observed a state at M=3526.2±0.15±0.20

    in $p\bar{p} \to h_c \to J/\psi\, \pi^0$
    - Not seen in $p\bar{p} \to h_c \to J/\psi\, \pi\pi$ , and

      $p\bar{p} \to h_c \to \gamma\eta_c \to \gamma\gamma\gamma$
    - Large amount of cross−calibration data: $\chi_{c1,2}$ scans, J/ψ,ψ' double scans.
- E835 data: 47$pb^{-1}$ (in 96−97) and 50 $pb^{-1}$ (in 2000) in the $M_{cog}$ region
  - Careful study on the stability of $E_{beam}$ measurements (at a level of few hundred keV) under way .



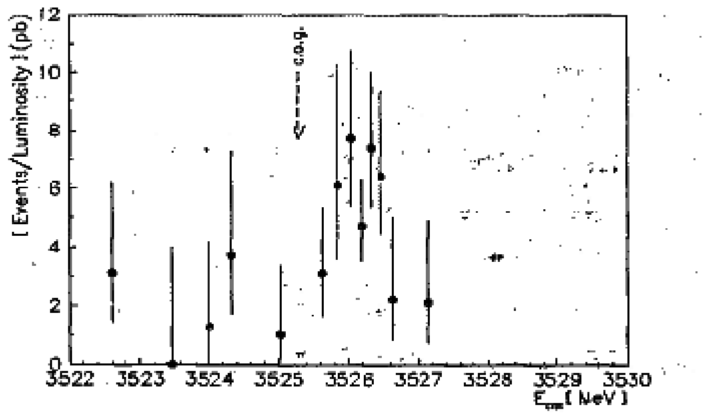




FIG. 2. Number of events per integrated luminosity vs center-of-mass energy; data are binned in 150-keV intervals in the average center-of-mass energy.

# $\eta_c$' searches

- A $^1S_0(n=2)$ candidate at $3594\pm5$ MeV/$c^2$ wasobserved by Crystal Ball in

  $e^+e^- \rightarrow \gamma+X$

  *Edwards et al., Phys.Rev.Lett.48(1982),70*

  ... but never confirmed

- DELPHI: did not find it in

  $\gamma\gamma \rightarrow \eta_c' \rightarrow$ hadrons

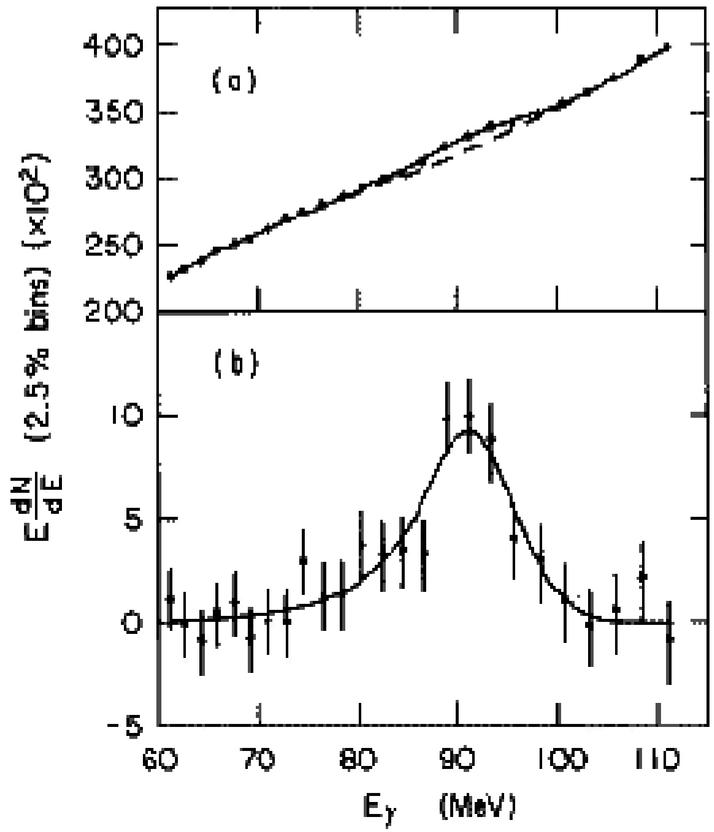
  *Abreu et al., Phys.Lett.B441(1998),479*

- E760−E835: did not find it in

  $p\bar{p} \rightarrow \eta_c' \rightarrow \gamma\gamma$ (3576<Ecm<3660 MeV)

  *Ambrogiani et al.,Phys.Rev.D64(2001),052003*

  Upper limits at 90%CL on BR($p\bar{p}$)*BR($\gamma\gamma$) with $\Gamma$=5,10,15 MeV are given.



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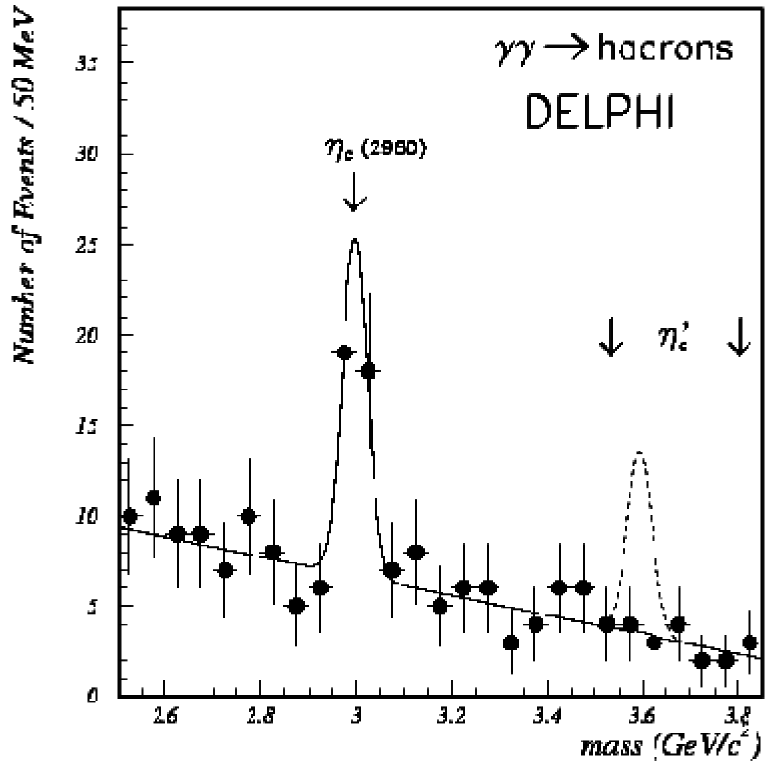

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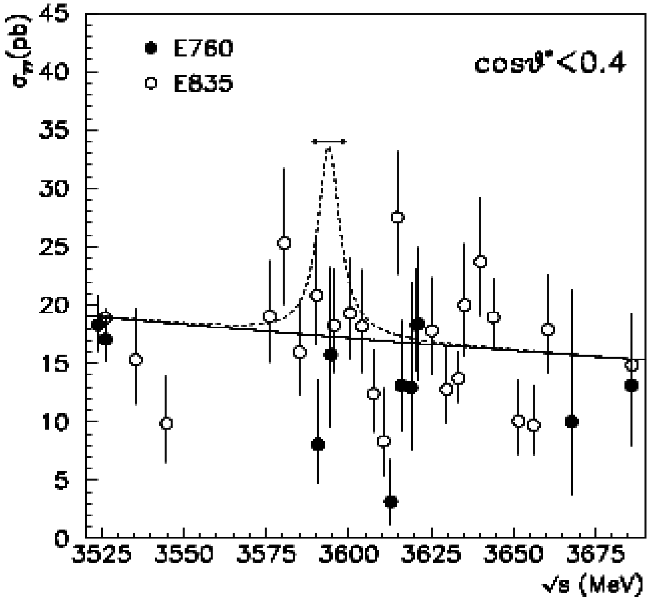

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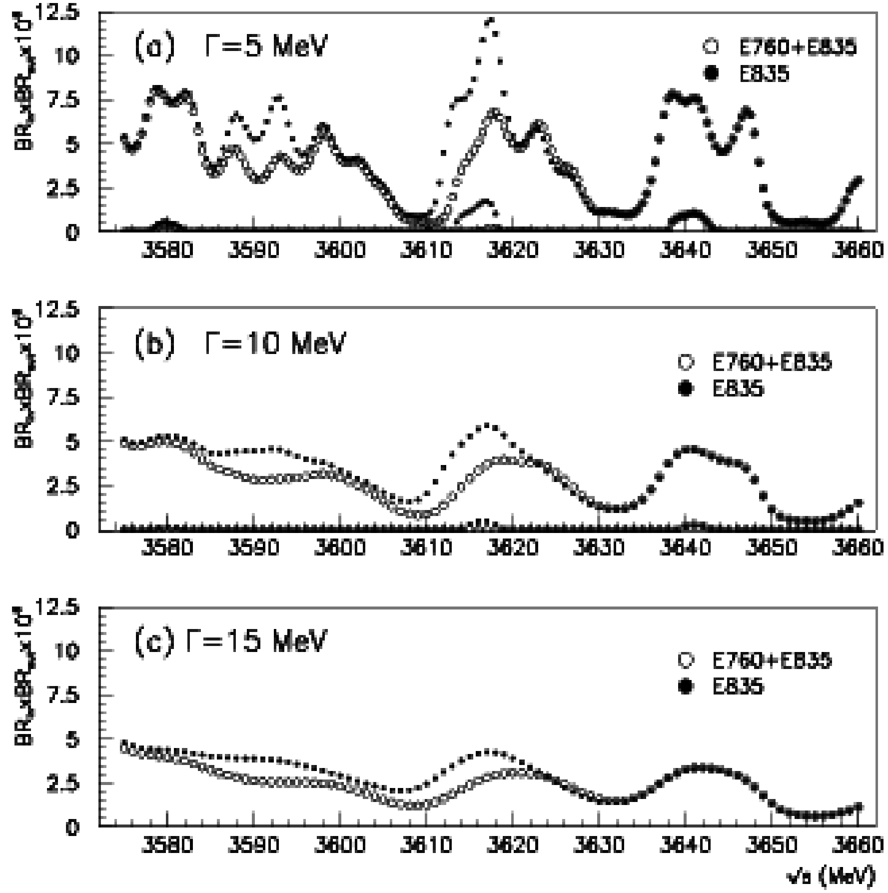



CLEO−c

BR($p\bar{p}$)*BR($\gamma\gamma$)*$10^8$

# $^1D_2, ^3D_2$ searches

One singlet ($^1D_2$) and 3 Triplet ($^3D_{1,2,3}$) D−wave state are expected in the region between $D\bar{D}$ and $D\bar{D}^*$ threshold (3729−3871 MeV/$c^2$) .

S−D wave relativistic mixing in vector states:

$\psi(3770) = |\,^3D_1> - \varepsilon\,|\,^3S_1>$ ($\Gamma$=23.6±2.7 MeV)

$\psi'(3686) = |\,^3S_1> + \varepsilon\,|\,^3D_1>$ ($\Gamma$=277±31 keV)

The $^3D_2$ and $^1D_2$ can't decay to $D\bar{D}$, and are narrow.

⇒*High BR(ψ+X) is possible*.

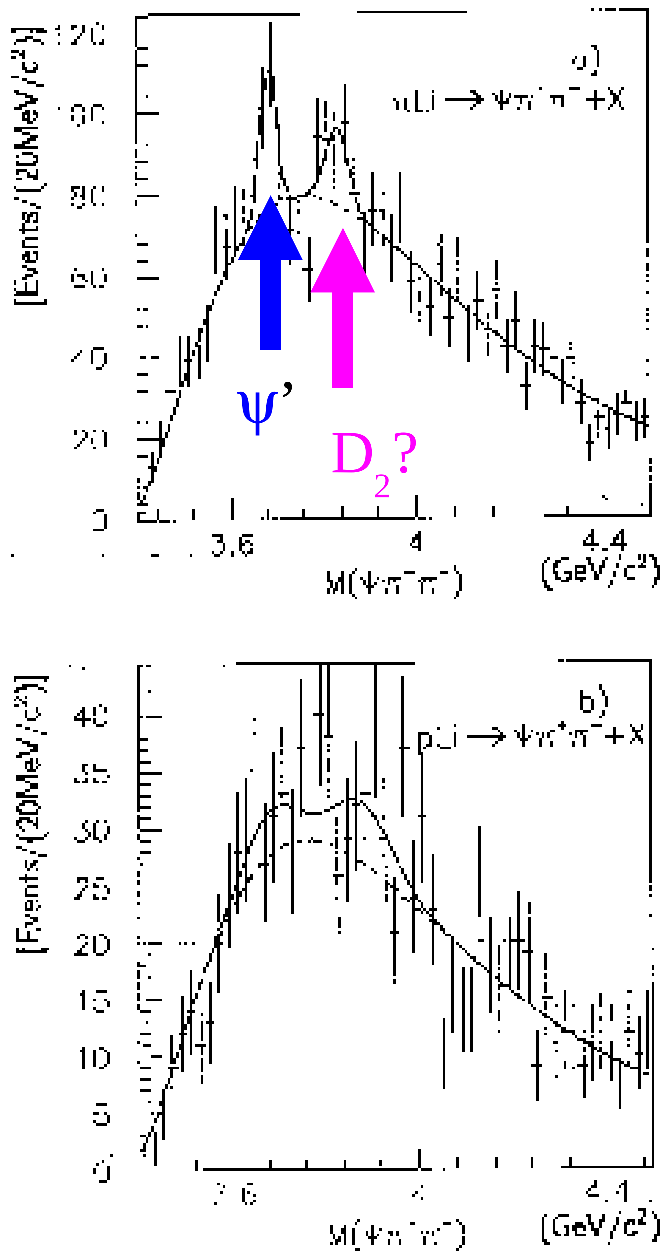
E771 observed a signal at M=3836±13 MeV/$c^2$ in

$\pi Li \rightarrow \psi\pi^+\pi^- + X$

*Antoniazzi et al.,Phys.Rev.D50(1994),4258*

BES search from $e^+e^-$ @$E_{cm}$=4.03 GeV, exploiting ISR (*but what quantum numbers are accessible?*)

*Bai et al.,Phys.Rev.D57(1998),3854*



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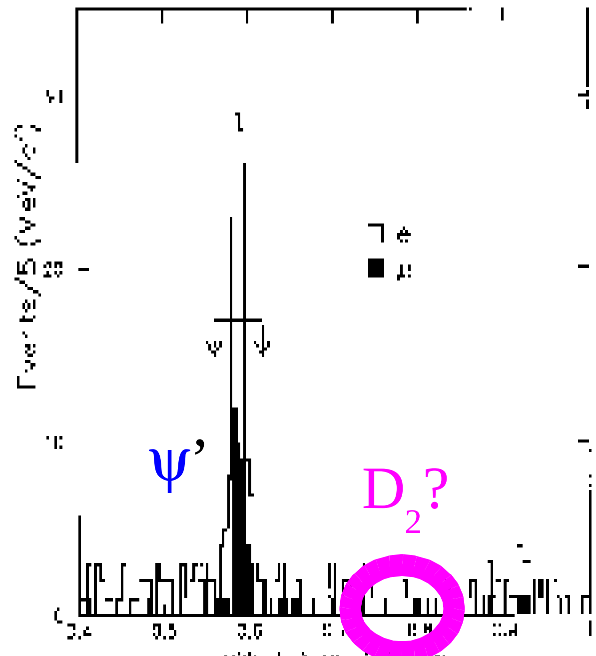
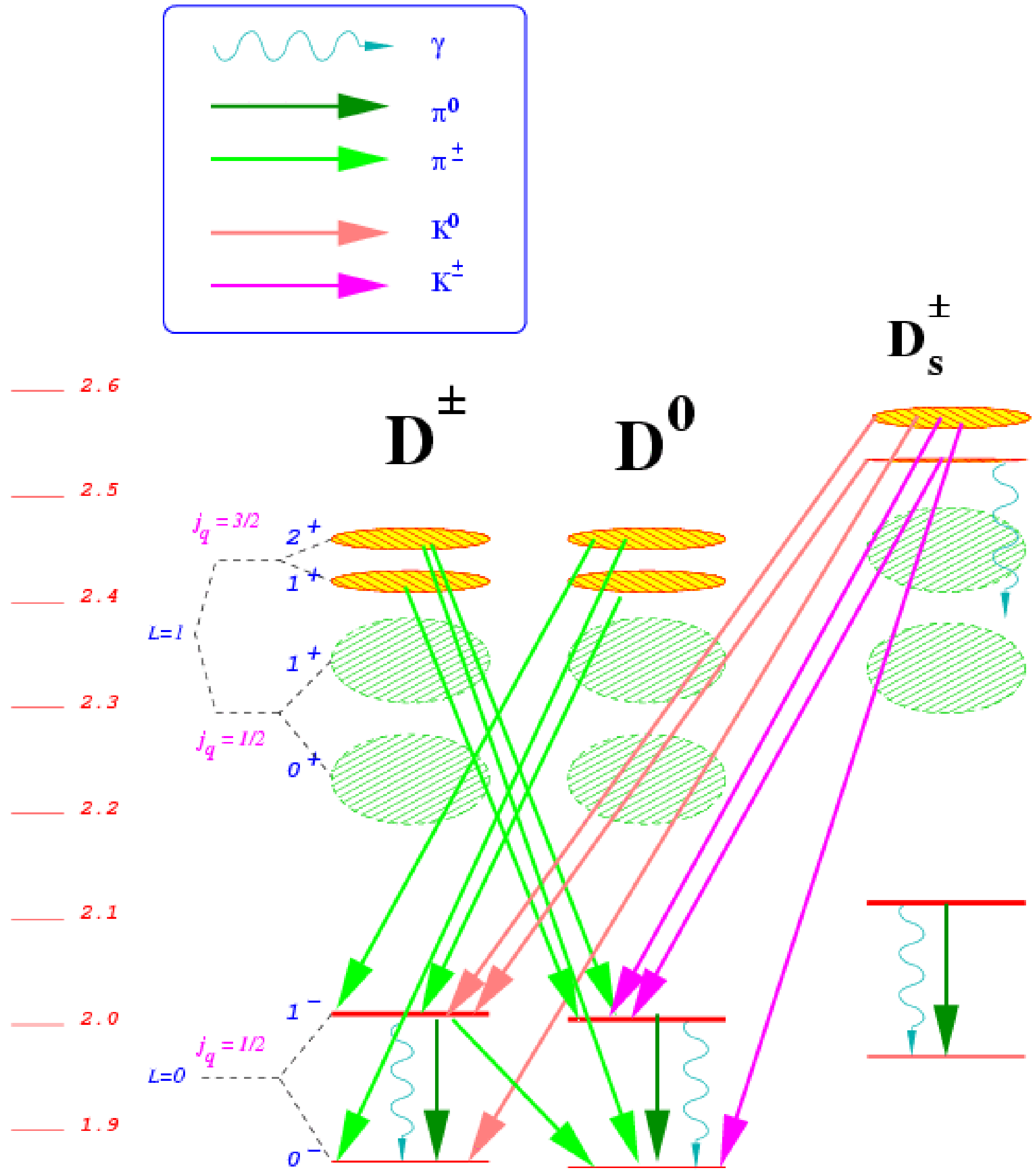


# $D^0, D^{\pm}, D_s^{\pm}$ meson spectrum




•P arity cons. forbids
$D^{**}(1^+) \to D\pi$, and
$D^{**}(0^+) \to D^*\pi$

# $D^{*\pm}$−meson width

CLEO : first measurement of the narrow width of the $D^{*\pm}$ meson, from the exact determination of the Q of the reaction:

$D^{*\pm} \to \pi^{\pm} D^0$

*hep−ex/0108043 , to be published on Phys.Rev.D*

Key factor:10μm transverse size of interaction region.

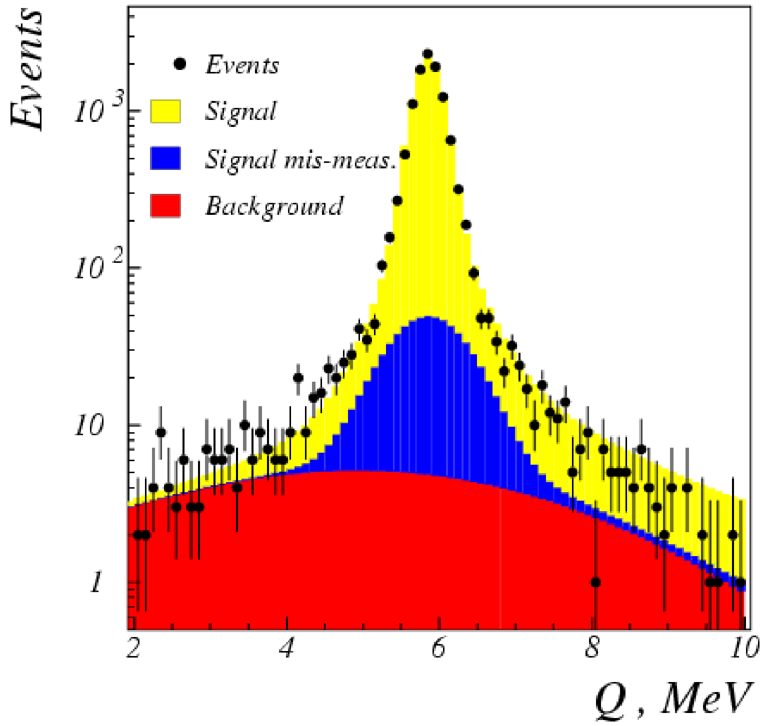
$\Gamma(D^{*\pm}) = 96 \pm 4(stat) \pm 22(syst)$ keV

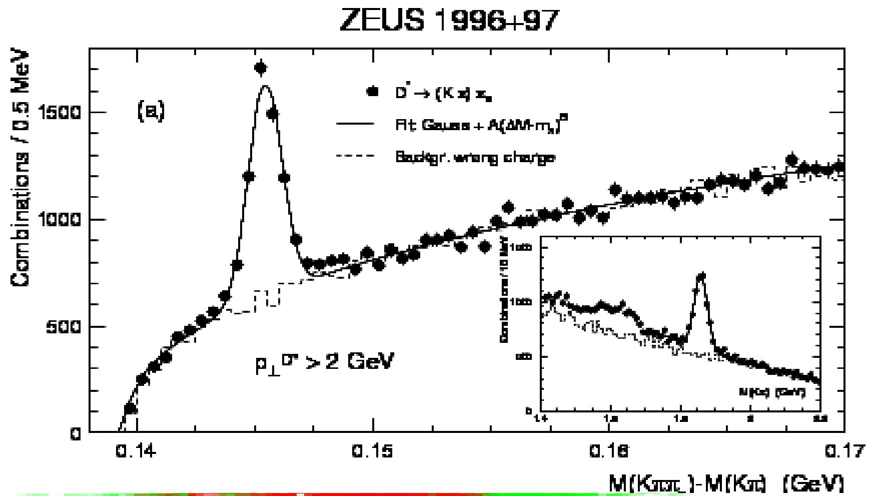
PDG(2000): > 132 keV(90% CL)

Mass splitting, from the Q value:
$M(D^{*\pm}) - M(D^0) = 145.412 \pm 0.002 \pm 0.012(syst)$ MeV/$c^2$

to be compared with the ZEUS result(1999):
$M(D^{*\pm}) - M(D^0) = 145.45 \pm 0.02$ MeV/$c^2$

*Breitweg et al., Eur.Phys.J.C6(1999),67−83*



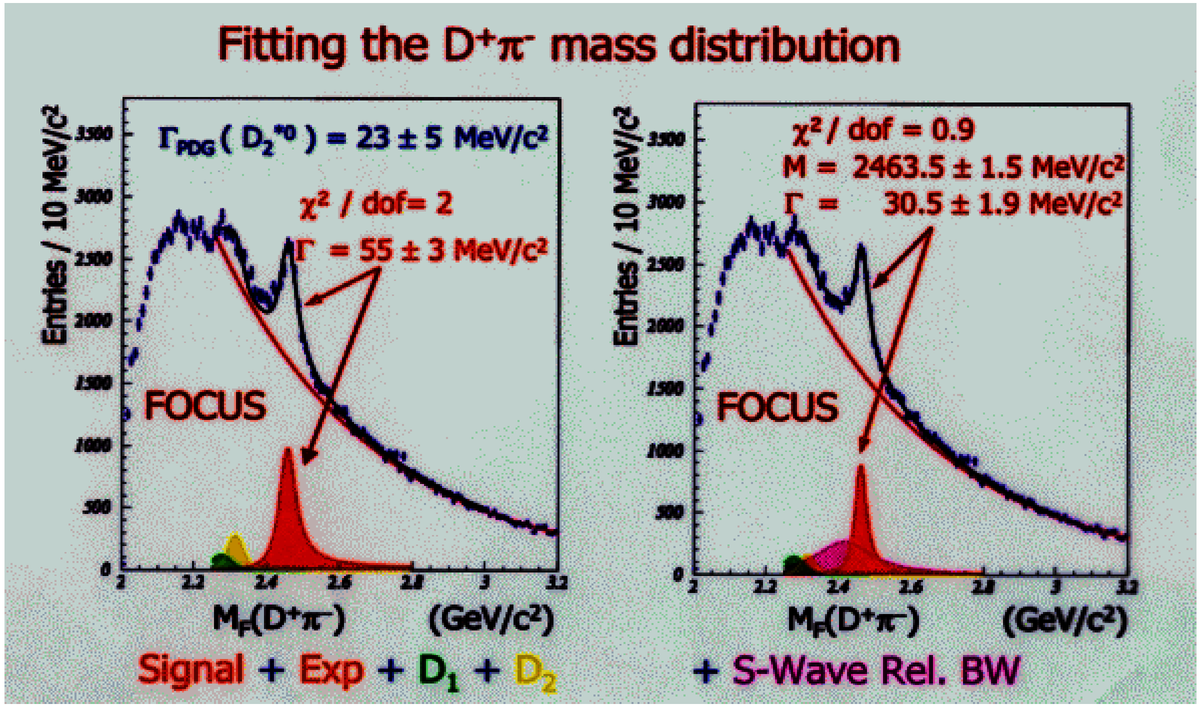



# P−wave D−mesons

Preliminary Results from E831: 330k D, 70 k D* from $\gamma$+BeO$\rightarrow$D+X

Spectra of P−wave $2^+$ states detected in reactions: $D^0{**} \rightarrow D^{\mp}\pi^{\pm}$ (see slide) and $D^{\pm}{**} \rightarrow D^0\pi^{\pm}$
(P arity cons. forbids $D^{**}(1^+) \rightarrow D\pi$, and $D^{**}(0^+) \rightarrow D^*\pi$)

Need to include broad S−wave states in the fits in order to obtain decent $\chi^2$ values: evidence of $D^{**}(0^+)$ ?

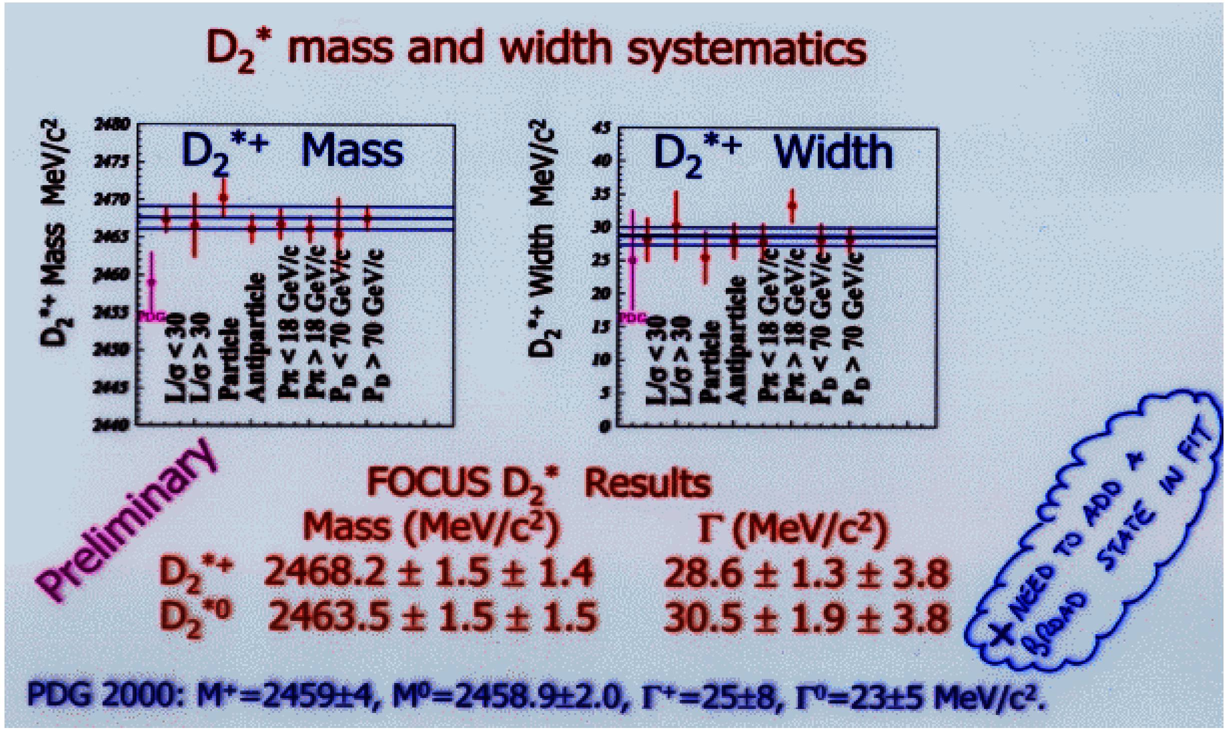


# P−wave D−mesons

•Preliminary Results from E831(upgraded E687): 330k D, 70 k D* from $\gamma$+BeO$\rightarrow$D+X

•Spectra of P−wave $2^+$ states detected in reactions: $D^0{**} \rightarrow D^{\mp}\pi^{\pm}$ (see slide) and $D^{\pm}{**} \rightarrow D^0\pi^{\pm}$
(P arity cons. forbids $D^{**}(1^+) \rightarrow D\pi$ , and $D^{**}(0^+) \rightarrow D^*\pi$)

•Need to include broad S−wave states in the fits in order to obtain decent $\chi^2$ values: evidence of $D^{**}(0^+)$ ?
•Study of systematic effects is in progress.

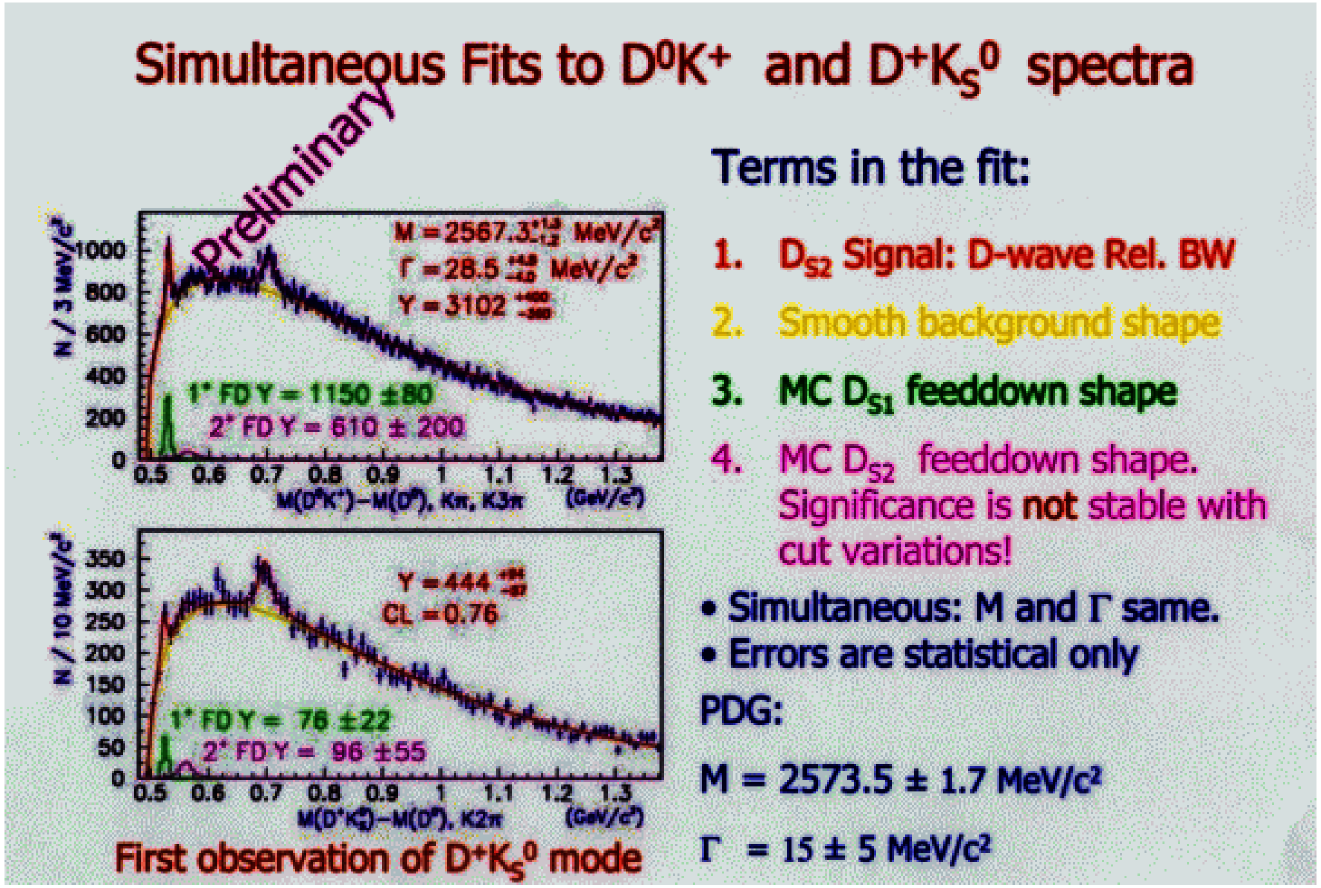


# P–wave $D_s$–mesons

Preliminary Results from E831(upgraded E687)

Samples: 330k D, 70 k D* from $\gamma$+BeO $\rightarrow$ D+X

First observation of $D_s^{**} \rightarrow DK^0_s$



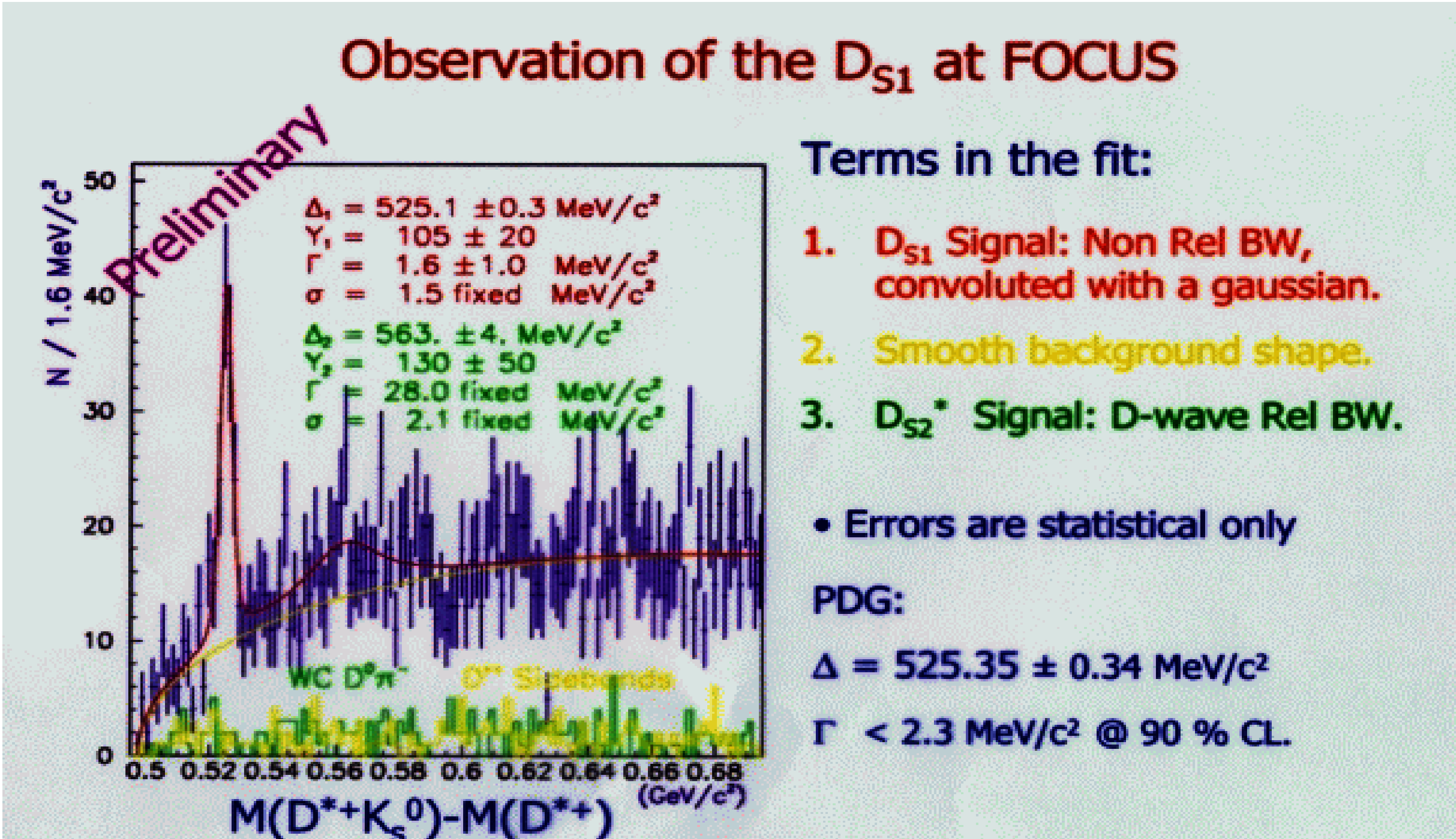
# P–wave $D_s$–mesons

Preliminary Results from E831(upgraded E687)

Samples: 330k D, 70 k D* from $\gamma$+BeO $\rightarrow$ D+X

First observation of $D_s^{**} \rightarrow DK^0_s$

Width of $D_s(1+)$?



# D*'−mesons

First evidence of an orbital excitation at DELPHI, in the channel:

$D^{*'+} \rightarrow D^{*+}\pi^+\pi^-$

at M = 2637± 2± 6 MeV/$c^2$

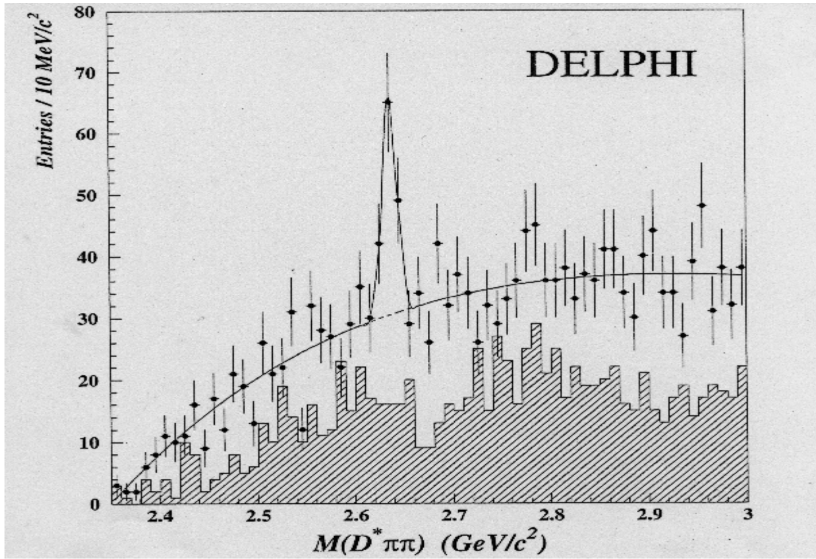
*Abreu at al., Phys.Lett.B426(98),231*

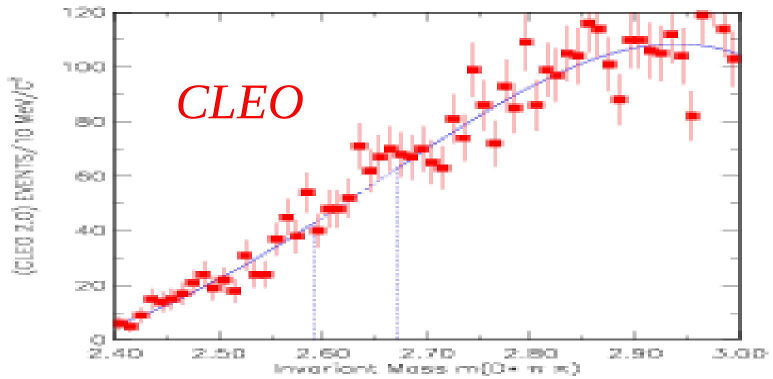
⇒Vector $D^{*+}$−meson mass splitting:
M(D*')−M(D*) = 627± 6 MeV/$c^2$

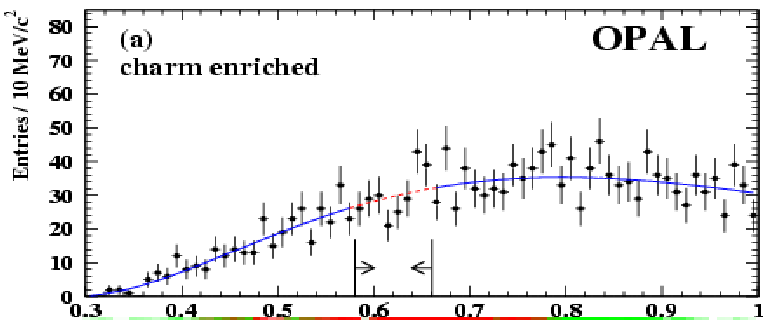
- CLEO did not see it
  *hep−ex/9901008*

- OPAL did not see it
  *G. Abbiendi et al.Eur.Phys.J.C20(2001):445*

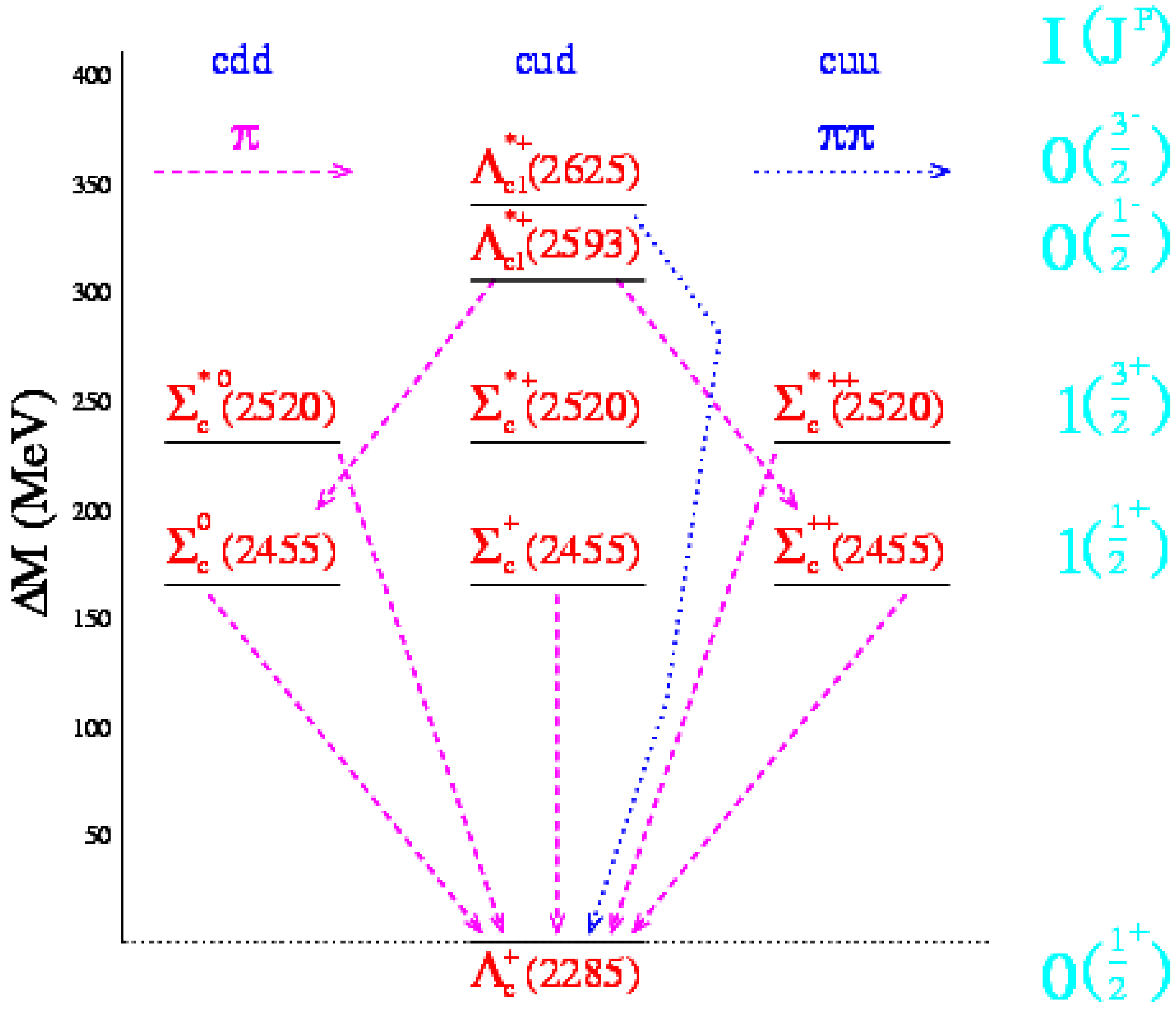
- Waiting for E831 analysis



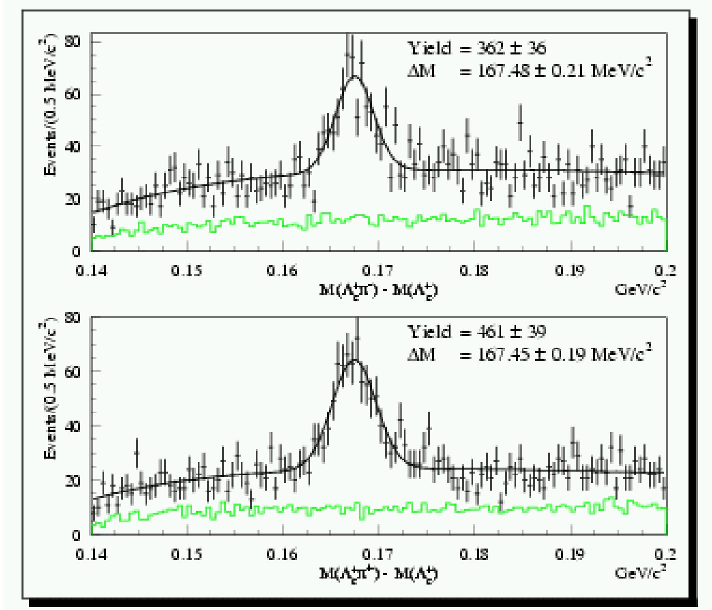



# Charmed Baryons: spectrum



# $\Sigma_c$ masses

Most recent data from E831:
*J.M. Link et al.,Phys.Lett.B488(2000),224*
and CLEO:
*Ammar et al.,PRL 86 (2001),1167*
Errors on mass splittings at about 1−2‰ level.




M(cuu) > M(cdd)??

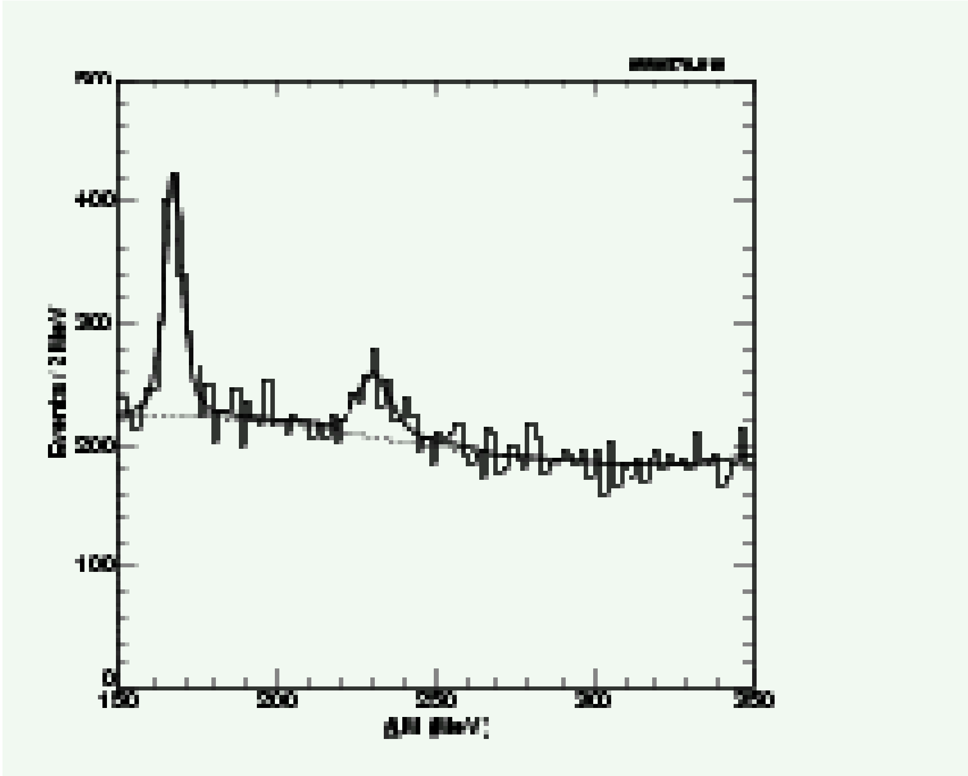
$M(\Sigma_c)-M(\Lambda_c)$:

| | PDG2000 | E831(00) | CLEO(01) | "PDG2001" |
|---|---|---|---|---|
| Σ0 | 167.30±0.20 | 167.38±0.21±0.13 | 167.2±0.1±0.2 | 167.32±0.15 |
| Σ+ | 168.7±0.6 | | 166.4±0.2±0.3 | 166.4±0.4 |
| Σ++ | 167.87±0.19 | 167.35±0.19±0.12 | 167.4±0.1±0.2 | 167.67±0.15 |
| Σ0* | 232.6±1.3 | | 232.6±1.0±0.8 | 232.6±1.3 |
| Σ+* | | | 231.0±1.1±2.0 | 231.0±2.3 |
| Σ++* | 234.5±1.4 | | 234.5±1.1±0.8 | 234.5±1.4 |

# $\Sigma_c$ masses

Most recent data from E831:
*J.M. Link et al.,Phys.Lett.B488(2000),224*
and CLEO:
*Ammar et al.,PRL 86 (2001),1167*
Errors on mass splittings at about 1−2‰ level.

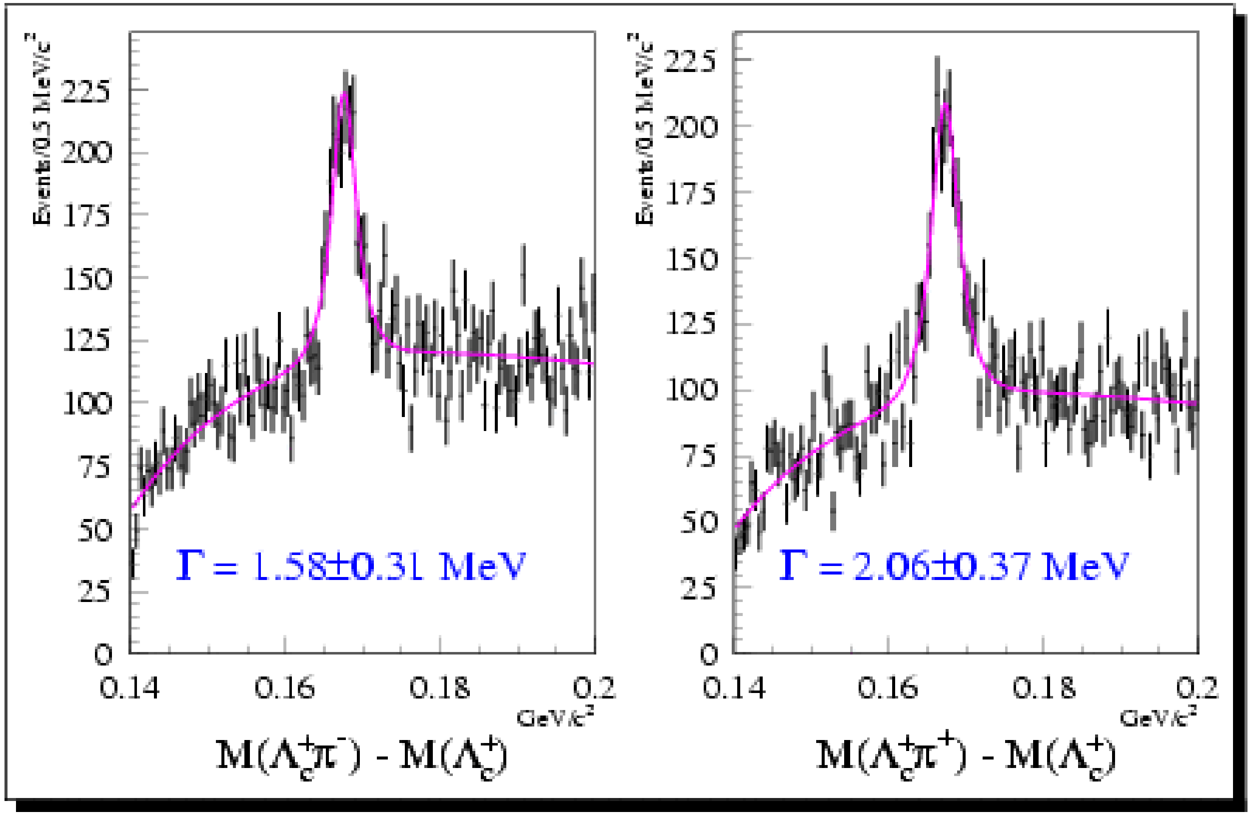
M(cuu) > M(cdd)??




$M(\Sigma_c)-M(\Lambda_c)$:

| | PDG2000 | E831(00) | CLEO(01) | "PDG2001" |
|---|---|---|---|---|
| Σ0 | 167.30±0.20 | 167.38±0.21±0.13 | 167.2±0.1±0.2 | 167.32±0.15 |
| Σ+ | 168.7±0.6 | | 166.4±0.2±0.3 | 166.4±0.4 |
| Σ++ | 167.87±0.19 | 167.35±0.19±0.12 | 167.4±0.1±0.2 | 167.67±0.15 |
| Σ0* | 232.6±1.3 | | 232.6±1.0±0.8 | 232.6±1.3 |
| Σ+* | | | 231.0±1.1±2.0 | 231.0±2.3 |
| Σ++* | 234.5±1.4 | | 234.5±1.1±0.8 | 234.5±1.4 |

# $\Sigma_c$ widths




$\Gamma(\Sigma)$/MeV:

| | PDG2000 | E831(prel) | CLEO(01) |
|---|---|---|---|
| Σ0 | | 1.58±0.31±.... | 2.4±0.2±0.4 |
| Σ+ | | | <4.6 (90% CL) |
| Σ++ | | 2.06±0.37±..... | 2.5±0.2±0.4 |
| Σ0* | 17.9±3.5±4.0 | | |
| Σ+* | | <17 (90% CL) | |
| Σ++* | 13.0±3.3±4.0 | | |

# Conclusions

Oops ... I didn’t think to make it in time..

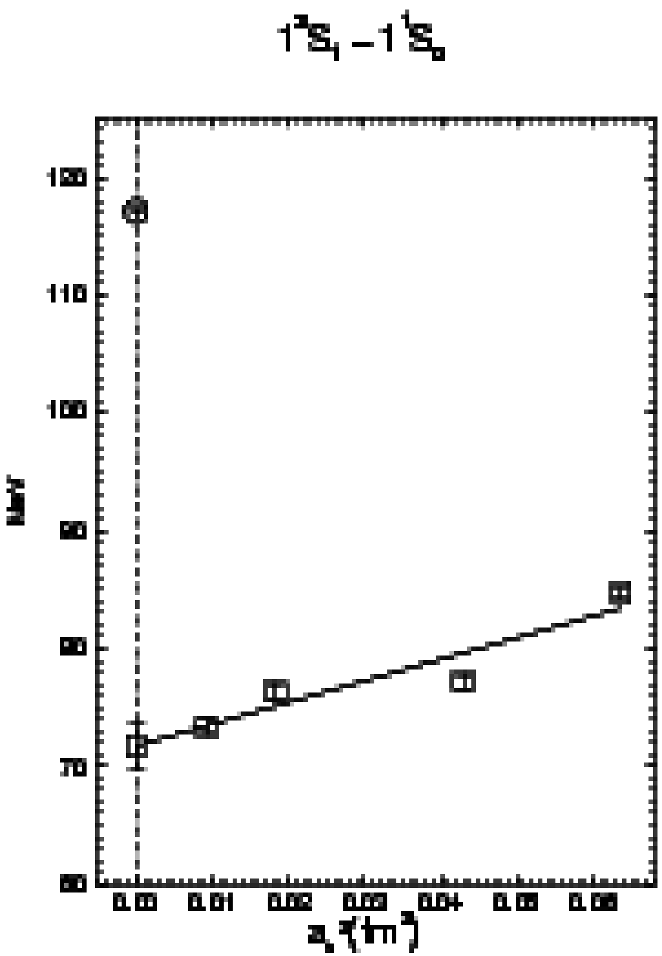
# Radiative Widths of $\chi_{cJ}$ states

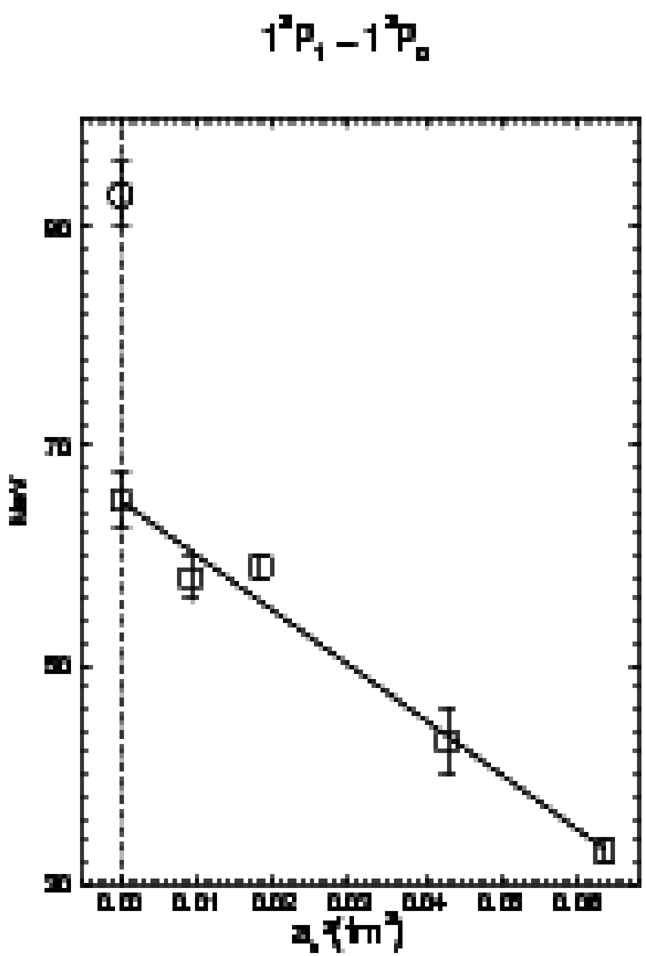
- 
  - The refitted values (*C.Patrignani,hep−ex/0104003*) are compared with these theory predictions:
    - ref.A: Fayyazuddin and Mobarek, Phys.Rev.D48, 1220(1983)
    - ref.B:Gupta et al., Phys.Rev.D39, 974 (1989)
    - ref.C:Resag and Munz, Nucl.Phys. A590,735 (1995)
    - ref.D:McClary and Byers, Phys.Rev. D28,1692 (1985)
  - The errors on P→S widths include the syst errors on BR(S→P)

| *Transition* | *Rad.Width (keV)* | *Error* | **ref.A** | **ref.B** | **ref.C** | **ref.C2** | **ref.D** | **ref.D2** |
|---|---|---|---|---|---|---|---|---|
| *PSIP to CHI2* | *19* | *16%* | **14** | **25** | **60** | **35** | **27** | **22** |
| *PSIP to CHI1* | *23* | *15%* | **20** | **29** | **36** | **48** | **31** | **23** |
| *PSIP to CHI0* | *20* | *20%* | **21** | **20** | **31** | **32** | **19** | **16** |
| *CHI2 to JPSI* | *374* | *17%* | **347** | **326** | **270** | **347** | **347** | **305** |
| *CHI1 to JPSI* | *281* | *19%* | **273** | **250** | **250** | **230** | **270** | **240** |
| *CHI0 to JPSI* | *119* | *23%* | **141** | **117** | **140** | **119** | **128** | **117** |
| ***PSIP to ETAC*** | ***0.78*** | ***24%*** | **4.39** | **8.77** | **206.83** | **90.9** | **12.61** | **3.74** |
| ***JPSI to ETAC*** | ***1.13*** | ***31%*** | | | | | | |

# Lattice predictions

Anisotropic lattice (from hep−lat/



# $J/\psi$ Width (E760)

- The accuracy of the $J/\psi$ Width was obtained by an improved scanning technique (double scan): by measuring the excitation curve on 2 orbits during the same run, syst errors were kept down to 6 keV

- The same technique was used at the $\psi'$: syst=16 keV

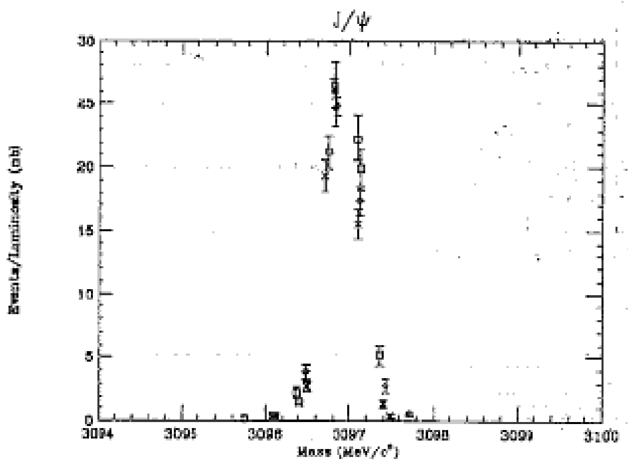



FIG. 7. Excitation curves for $J/\psi$. Data from the first 1990 single scan are shown as crosses, from the second 1990 single scan as diamonds, and from the 1990 double scan as squares.

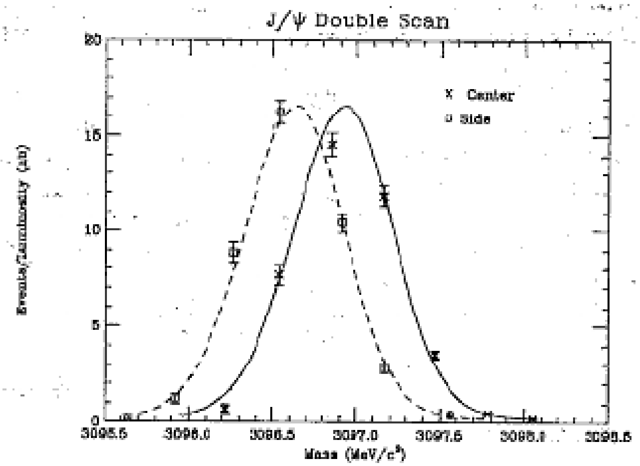



FIG. 9. 1991 $J/\psi$ double scan. The horizontal axis is the invariant mass of the *central orbit*. The lines are theoretical excitation curves calculated using the best fit parameters.

# Intro: QED vs QCD bound states

- Systems: $\left\{\begin{matrix} Hydrogen\ Atom \\ Positronium \end{matrix}\right\}_{QED} \Leftrightarrow \left\{\begin{matrix} D,B-mesons \\ Charmonium,Bottomonium \end{matrix}\right\}_{QCD}$

- Similarities: $\gamma^\mu\gamma_\mu$ coupling, $V(r) \sim 1/r$

- Differences:
  - QCD non **perturbative** when $Q^2 \to 0$
  - Free quarks not directly observable
  - Large Relativistic effects: $\beta \sim \alpha_s$

# Two approaches to QCD

- Weak approach: "knowledge of hadron dynamics at few % level is fundamental for precise measurements of CKM parameters"
- Strong approach: "heavy hadrons are the best available systems to achieve the deepest possible understanding of strong interactions".

# Theoretical Progress in the 90's

- Potential models
- Lattice
- HQET
- NRQCD
- pNRQCD
- Heavy meson chiral lagrangians

# Widths of $\chi_{cJ}$ states

- Recent Results at $\chi_{c0}$: BES

*Bai et al., Phys.Rev.Lett.81(1998),3091*

- From $e^+e^- \rightarrow \psi' \rightarrow \gamma\, \pi^+\pi^-, \gamma\, K^+K^-$
  - 1.5 k reconstructed events total
  - $\Gamma_{BES}(\chi_{c0}) = 14.3 \pm 2.0 \pm 3.0$ MeV

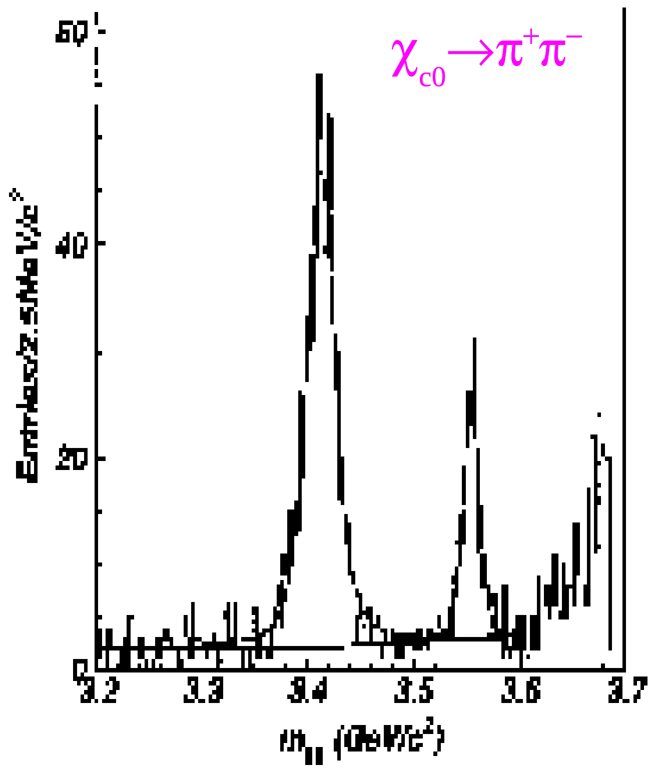



FIG. 1. The $\pi^+\pi^-$ mass distribution for selected $\psi(2S) \rightarrow \gamma\pi^+\pi^-$ events.