
# Hadronic Physics and Exotics

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EPS/HEP2007
July 19-25, 2007
Manchester, England

European Physical Society
HEP 2007

Insight into what holds hadrons together
$\Rightarrow$ access to the strong force

Hadrons come in many different shapes and sizes
$\Rightarrow$ access to different manifestations of the strong force

# Hadron spectroscopy and decay as a study ground for QCD

Compare expected system of states (mesons, baryons, glueballs, …) against observations

Observables: masses, widths, decay dynamics

New observations just as important as comprehensive surveys – and planning for the unexpected, too!

Unless a heavy-system decay, this is non-perturbative QCD.

# 3-step program to make headway on Route QCD

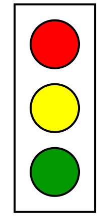
| | | |
|---|---|---|
| (1) FIND | Search for the expected<br>Observe the unexpected | Example:<br>A new state is seen |
| (2) SORT | Systematically probe properties:<br>Confirmation<br>Cross-check<br>Anti-checks | Study production and decay in different and in similar production and decay scenarios |
| (3) ✓ | Categorize within the framework<br>Perform precision studies<br>Deviations from expectation?<br>Back to (1)! | Assign a place in the system of states<br>Leaving out (2) gets you a ticket! |

This talk: Examples from all three categories.

Q=c,b

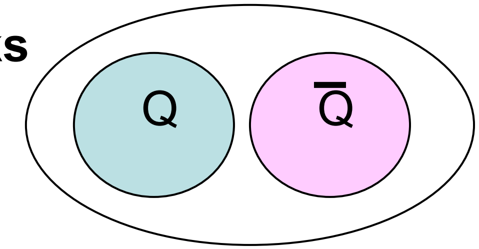
q=u,d,s

# Overview



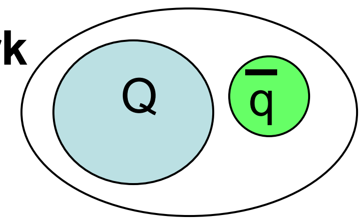
General goal:
Explore QCD phenomena at different scales

**Two heavy quarks**

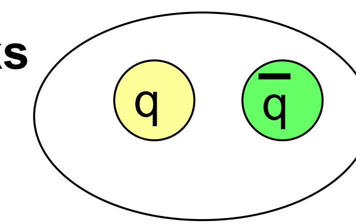



**$\psi$(2S) width**
**J/$\psi$, $\chi_{cJ}$ decay to light q**
**B decay to charmonium**
**States above DD threshold**
**Charmonium-like states**

**One heavy quark**




**Zero heavy quarks**



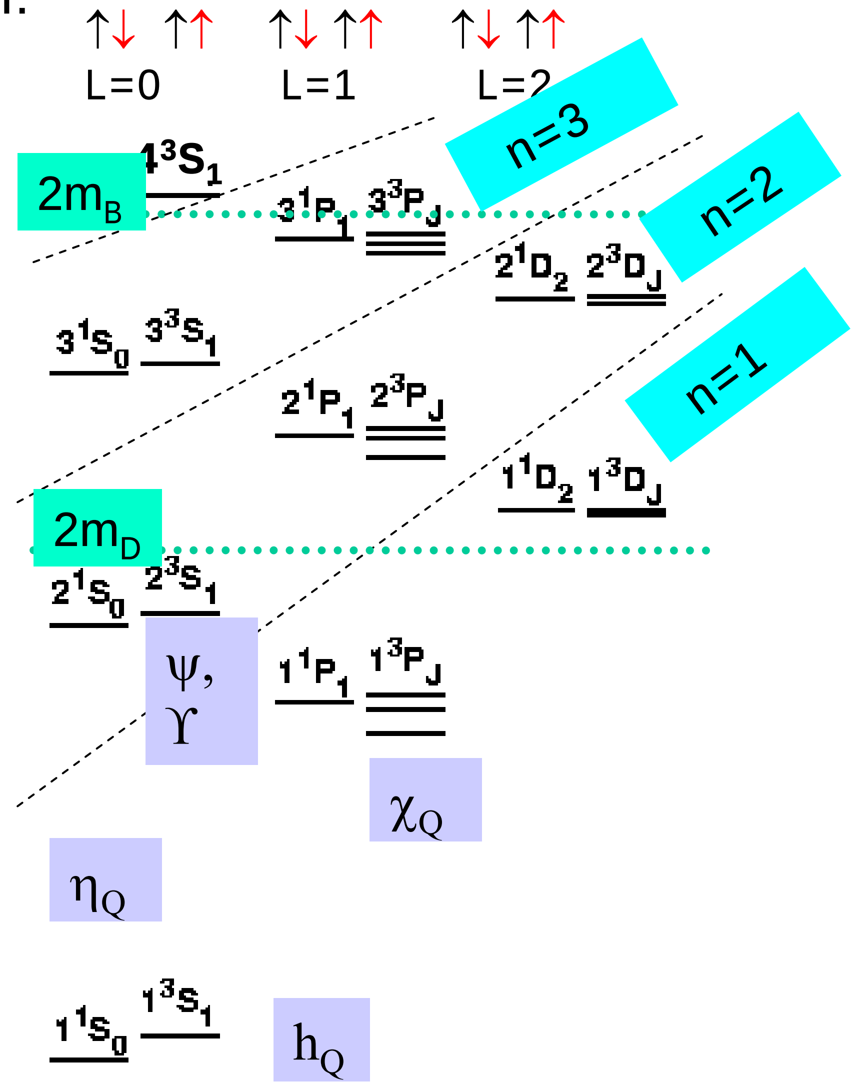

This talk: mostly mesons, but many new results on baryons as well. See list of topics at the end.

# $(Q\bar{Q})$ States

Notation:
$n^{2S+1}L_J$
$\vec{J} = \vec{L} + \vec{S}$

Study system of states, governed by underlying binding force: strong force.

**Charmonium and bottomonium very similar.**
**$(b\bar{b})$: less relativistic**
**$(c\bar{c})$: more data available**




J/ψ: 3.10 GeV
ϒ(1S): 9.46 GeV
$\Delta\,(1^3S_1, 2^3S_1) \sim 600$ MeV

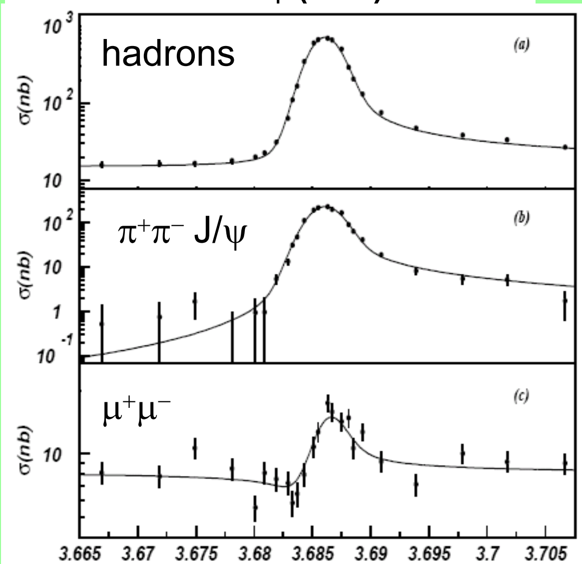
? Masses
? Widths
? Production and decay dynamics

**Partly discovery, partly precision measurements**

This summer – mostly charmonium results.

# ψ(2S) width measurements

BES scan: ψ(2S)→…




4MeV

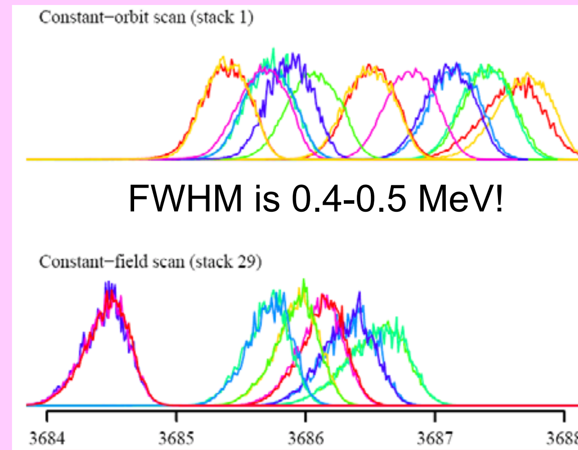
$E_{CM}$ (GeV)

BES, PLB 550, 24 (2002)

**E835 ($p\bar{p}$):**
beam energy spread is ~ψ(2S) width, can directly observe the line shape

**BES ($e^+e^-$):**
beam energy spread is O(MeV), can measure width through effect on observed cross-sections

E835



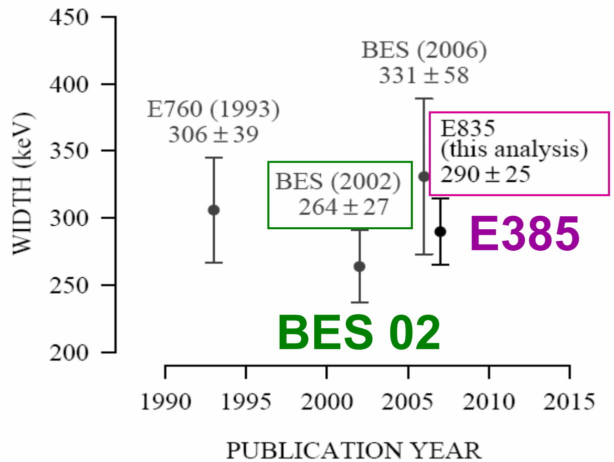

FWHM is 0.4-0.5 MeV!

$E_{CM}$ (GeV)

4MeV

E835, hep-ex/0703012

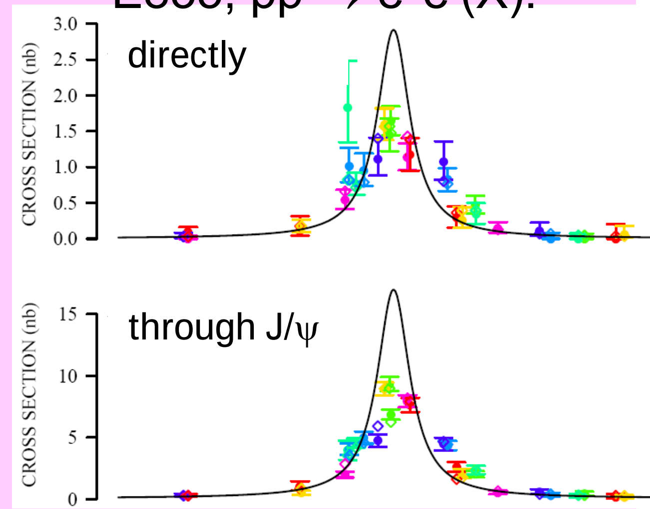
$\Gamma_{total}$:
Different methods, different channels, consistent results



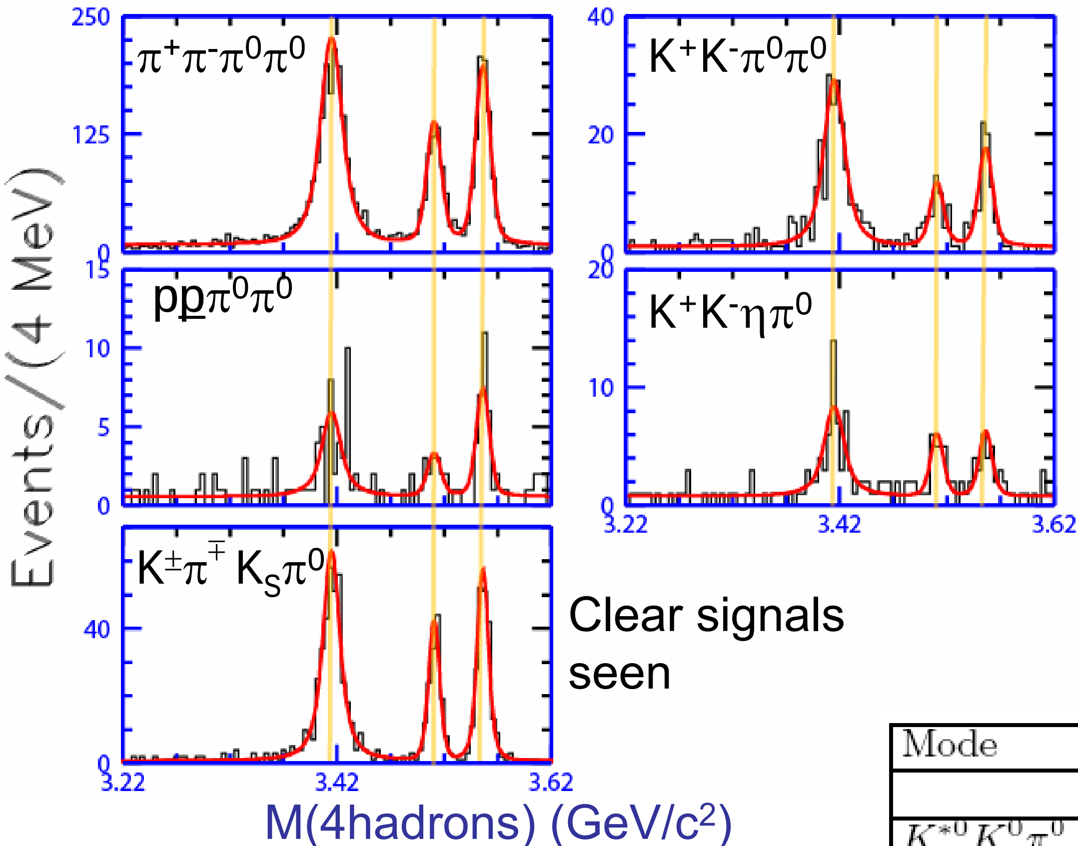

**E385**

**BES 02**

E835, $p\bar{p} \rightarrow e^+e^-(X)$:



# $\chi_{cJ} \rightarrow h^+h^-h^0\pi^0$




Clear signals seen

Survey of four-body decays

Resonant substructure is important for 4π and KKππ, (ρππ or K*Kπ or KKρ or ...)

Branching fractions and contributions from intermediate resonances determined

Isospin relations:

$\rho^+\pi^-\pi^0 = \rho^0\pi^+\pi^-$ ? ✓

K*Kπ modes: ✓

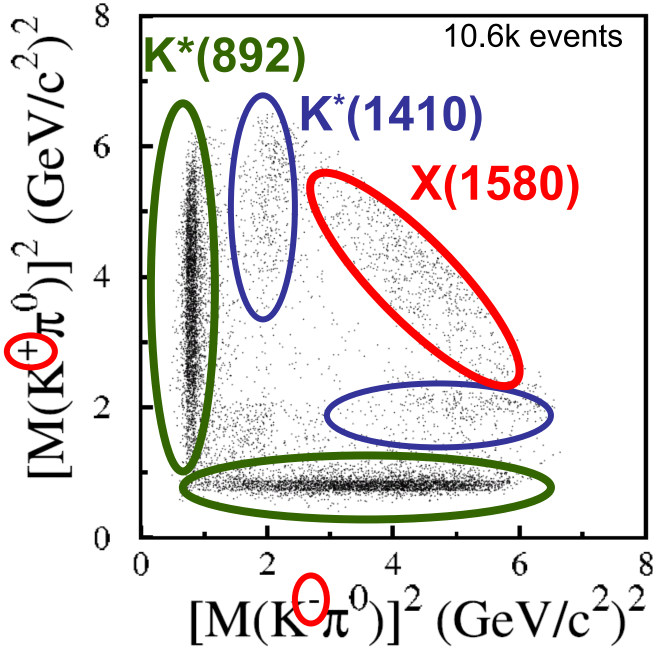
Expect 1:2

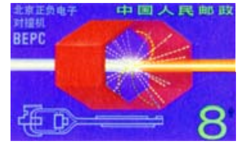
| Mode | $\chi_{c0}$ | $\chi_{c1}$ | $\chi_{c2}$ |
|---|---|---|---|
| | B.F. (%) | B.F. (%) | B.F. (%) |
| $K^{*0}K^0\pi^0$ | 0.56±0.15 | 0.38±0.11 | 0.59±0.14 |
| $K^{*0}K^\pm\pi^\mp$ | - | - | 0.90±0.25 |
| $K^{*\pm}K^\mp\pi^0$ | 0.74±0.18 | - | 0.57±0.13 |
| $K^{*\pm}\pi^\mp K^0$ | 0.96±0.25 | - | 0.90±0.25 |

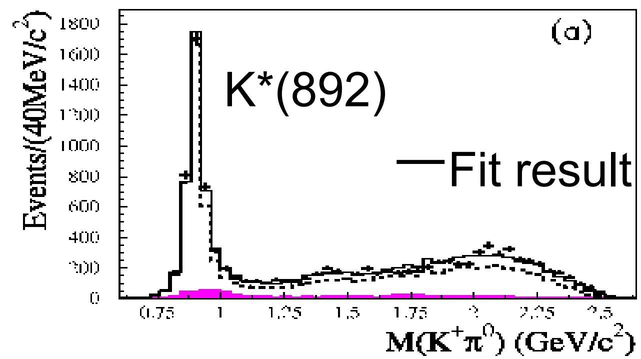
see talk by D. Cassel at this conference

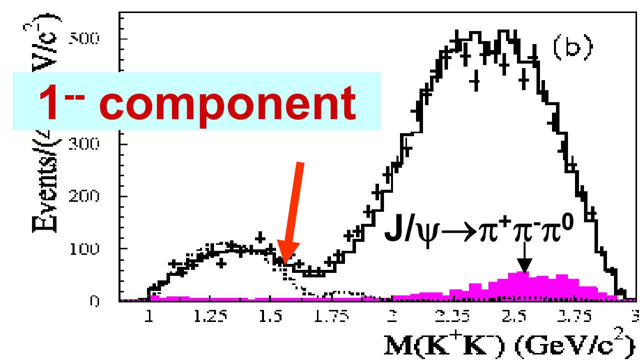
# Observation of a broad $1^-$ resonance in $J/\psi \to K^+K^-\pi^0$

Phys. Rev. Lett. 97 (2006) 142002 and talk by J. Chen at this conference




C-parity cons: X should have $J^{PC} = 1^{--}, 3^{--}, \ldots$

PWA results:

- Need $K^*(892)$, $K^*(1410)$, $\rho(1700)$, X, non-res.
  - using rho excitations to describe signal doesn't work
- Big destructive interference among X, $\rho(1700)$ and phase space
  - ("hole" in the middle of the Dalitz plot)
- $1^-$ is much better than $3^-$
- Pole position of X $(1576^{+49}_{-55}{}^{+98}_{-91}) - i(409^{+11}_{-12}{}^{+32}_{-67})\ \mathrm{MeV}/c^2$
- Br $(J/\psi \to X\pi^0, X \to K^+K^-) = (8.5 \pm 0.6^{+2.7}_{-3.6}) \times 10^{-4}$

Further check: $K_S K^{+/-}\pi^{-/+}$

Width(X) » width($\rho(1450)$, $\rho(1700)$):

4-quark state?

BABAR-CONF-07/001, SLAC-PUB-12665
S. Tosi, talk at this conference

# Production: $B \to \eta_c K(*)$, $h_c K(*)$

($\eta_c$: $K_S K^+ \pi^-$, $K^+ K^- \pi^0$; $h_c$: $\gamma \eta_c$)

Goal: insight into production mechanisms of $B \Rightarrow c\bar{c}$, comparison btw different $c\bar{c}$

$b \to c\underline{c}s$ produces
- $\eta_c$, $J/\psi$ ($B \sim 0.1\%$)
- and $\chi_{c1}$ $B \sim 0.03\text{-}0.05\%$ (and excitations)
- but not $h_c, \chi_{c0}, \chi_{c2}$, need other mechanism

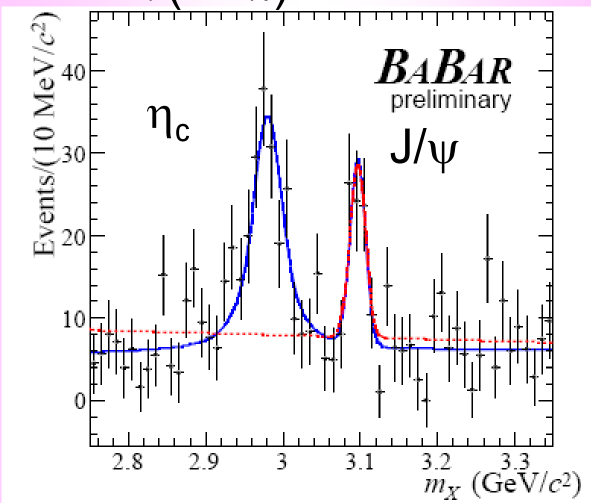
Prediction: $h_c, \chi_{c0}, \chi_{c2}$ + K(*) as copious as $\chi_{c1}$ + K(*)

$\chi_{c0}$ + K(*) ~ $10^{-4}$ ✓

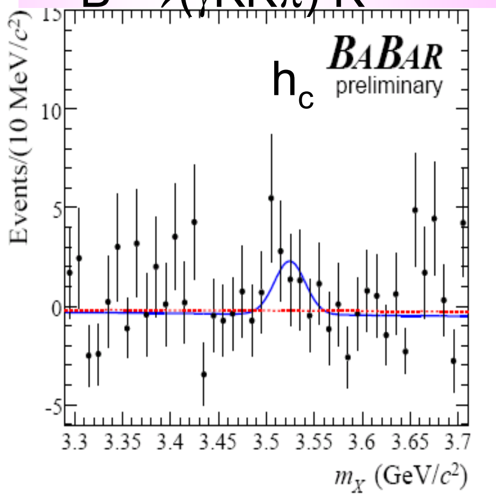
Godwin et al., PRD 51, 1125 (1995)

$\chi_{c2}$, $h_c$ + K(*): UL ~ $10^{-5}$ ✗

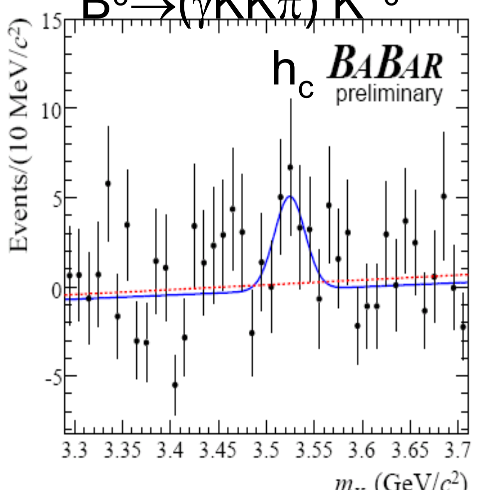
$B^0 \to (KK\pi)\, K^{*0}$




$B^+ \to (\gamma KK\pi)\, K^+$




$B^0 \to (\gamma KK\pi)\, K^{*0}$



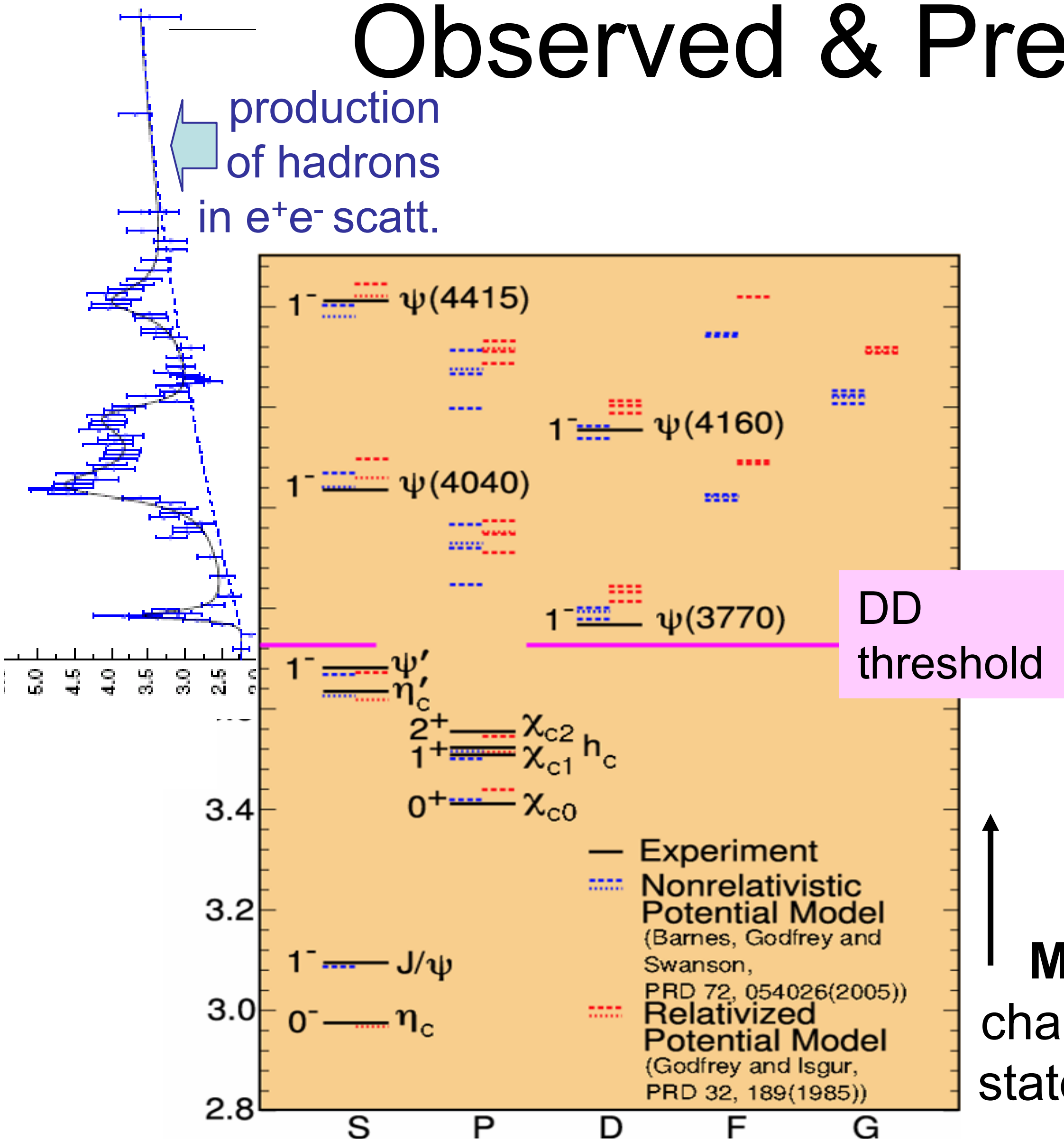

m(KKπ(γ)) spectra after subtraction of background

BaBar preliminary

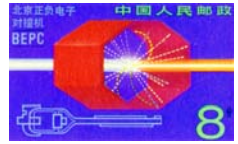
| | | | |
|---|---|---|---|
| Uncertainty reduced by 50% | $\eta_c K^{*0}$ | $(6.1 \pm 0.8 \pm 0.8 \pm 0.9)$ | $\times 10^{-4}$ |
| confirms Belle | $h_c K^+ \times h_c \to \eta_c \gamma$ | <5.2 | $\times 10^{-5}$ |
| First limit | $h_c K^{*0} \times h_c \to \eta_c \gamma$ | <2.41 | $\times 10^{-4}$ |

Confirms $h_c$ suppression in B decays

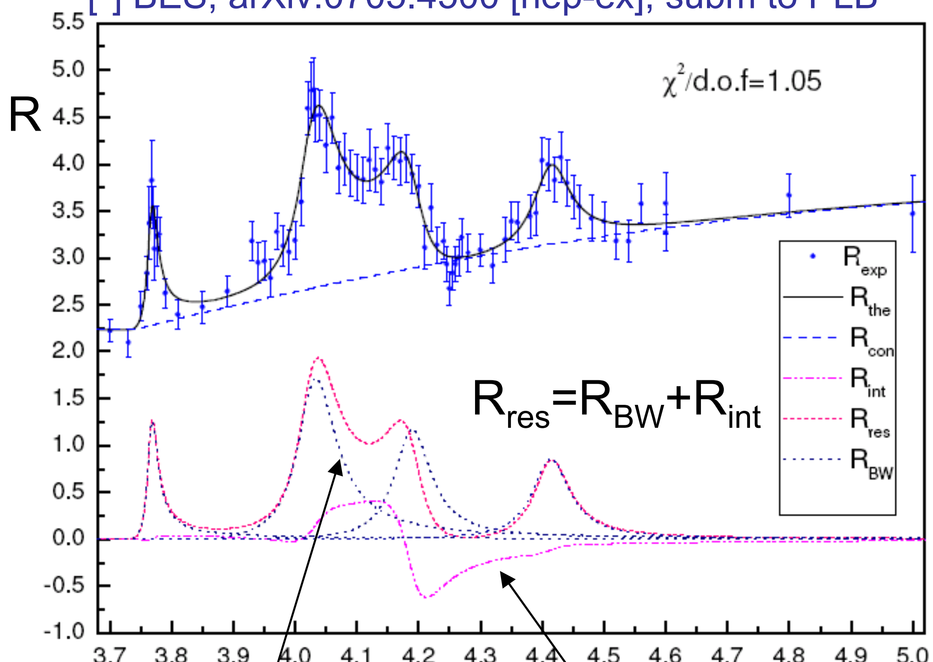
# Observed & Predicted States




States not accessible in $e^+e^-$ can be reached through transitions, in $p\bar{p}$, or in $\gamma\gamma$ production – a systematic approach to identify the missing states is needed.

# Re-analysis of  R data and extraction of charmonium resonance parameters

[*] BES, arXiv:0705.4500 [hep-ex], subm to PLB




Resonance shapes

Interference term

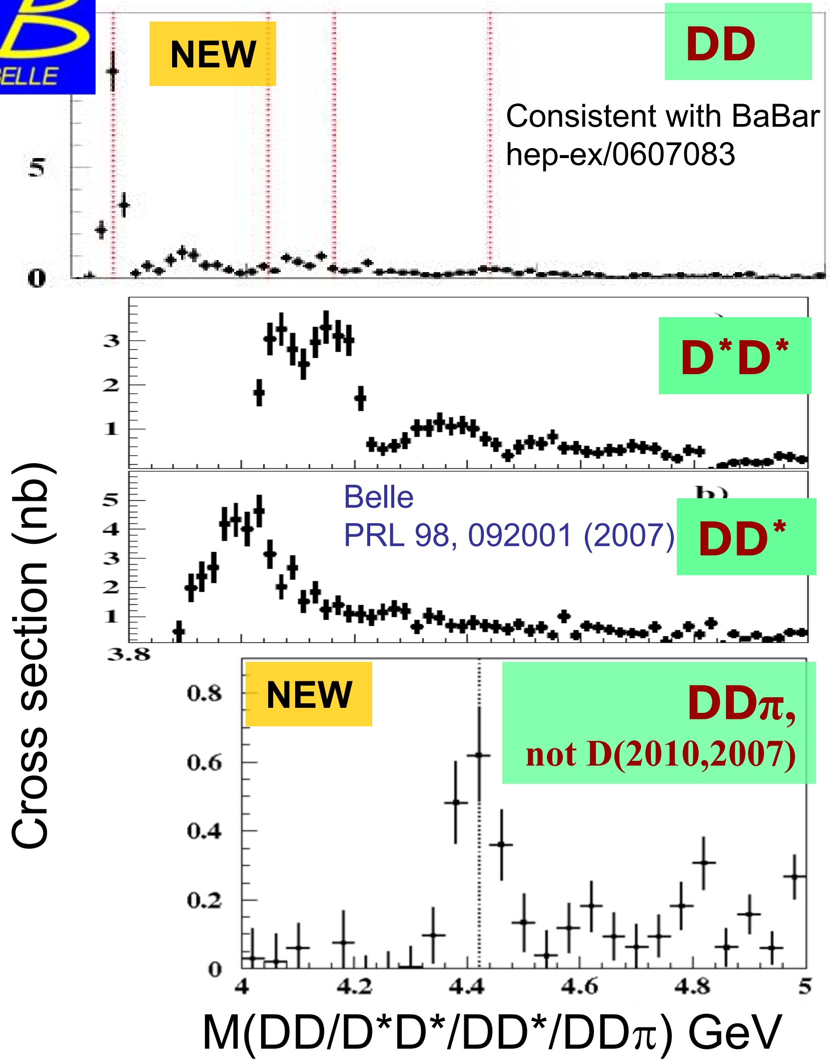
Resonance properties:

| | | $\psi(3770)$ | $\psi(4040)$ | $\psi(4160)$ | $\psi(4415)$ |
|---|---|---|---|---|---|
| $M$ (MeV/$c^2$) | PDG2004 | 3769.9±2.5 | 4040±10 | 4159±20 | 4415±6 |
| | PDG2006 | 3771.1±2.4 | 4039±1.0 | 4153±3 | 4421±4 |
| | CB (Seth) | - | 4037±2 | 4151±4 | 4425±6 |
| | BES (Seth) | - | 4040±1 | 4155±5 | 4455±6 |
| | BES (this work) | 3771.4±1.8 | 4038.5±4.6 | 4191.6±6.0 | 4415.2±7.5 |
| $\Gamma_{tot}$ (MeV) | PDG2004 | 23.6±2.7 | 52±10 | 78±20 | 43±15 |
| | PDG2006 | 23.0±2.7 | 80±10 | 103±8 | 62±20 |
| | CB (Seth) | - | 85±10 | 107±10 | 119±16 |
| | BES (Seth) | - | 89±6 | 107±16 | 118±35 |
| | BES (this work) | 25.4±6.5 | 81.2±14.4 | 72.7±15.1 | 73.3±21.2 |
| $\Gamma_{ee}$ (keV) | PDG2004 | 0.26±0.04 | 0.75±0.15 | 0.77±0.23 | 0.47±0.10 |
| | PDG2006 | 0.24±0.03 | 0.86±0.08 | 0.83±0.07 | 0.58±0.07 |
| | CB (Seth) | - | 0.88±0.11 | 0.83±0.08 | 0.72±0.11 |
| | BES (Seth) | - | 0.91±0.13 | 0.84±0.13 | 0.64±0.23 |
| | BES (this work) | 0.18±0.04 | 0.81±0.20 | 0.50±0.27 | 0.37±0.14 |
| $\delta$ (degree) | BES (this work) | 0 | 133±68 | 301±61 | 246±86 |

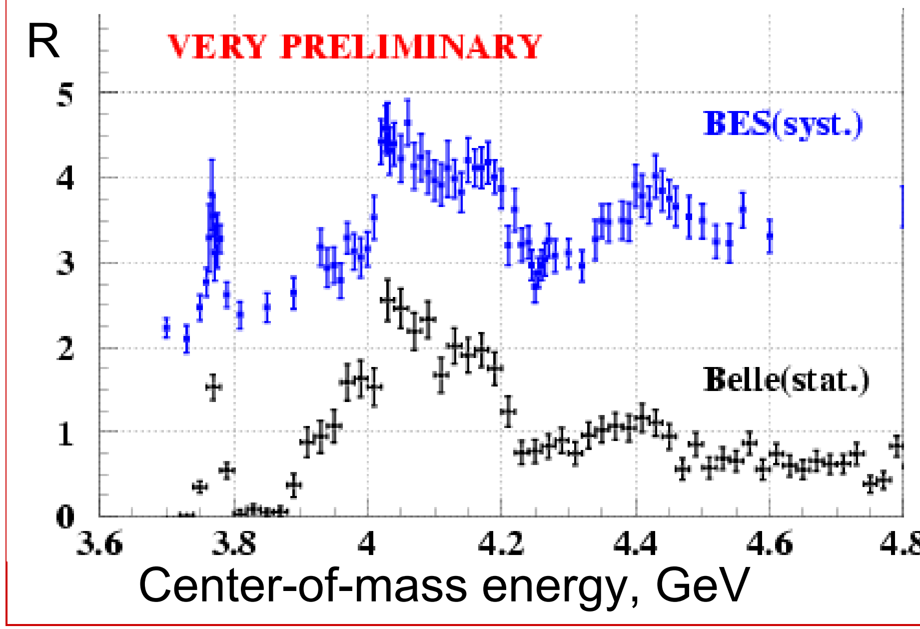
Substantial difference between fits with or without interference!

# Contributions to the inclusive hadronic cross-section at 4-5GeV

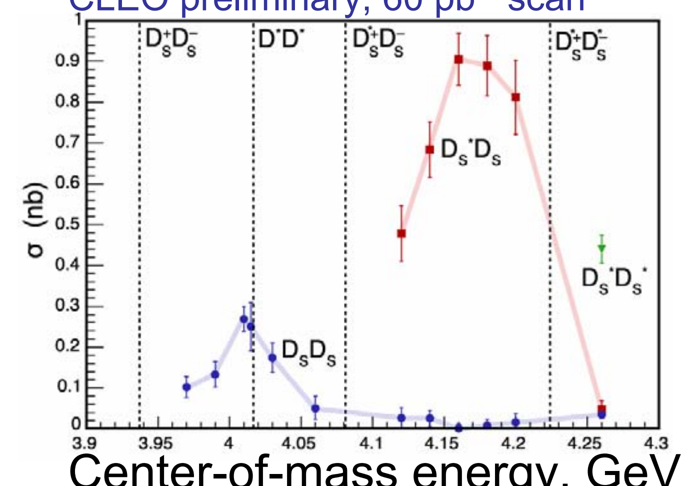
P. Pakhlov, talk at this conference




DD + 2× D*D* + 2× DD* + 2× DDπ =




CLEO preliminary, 60 pb-1 scan

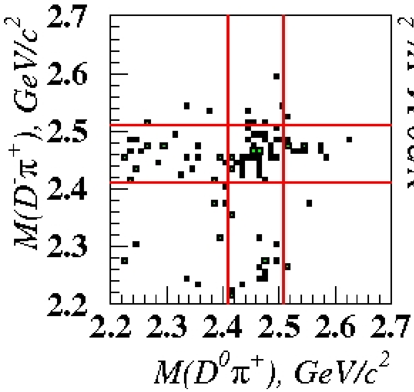


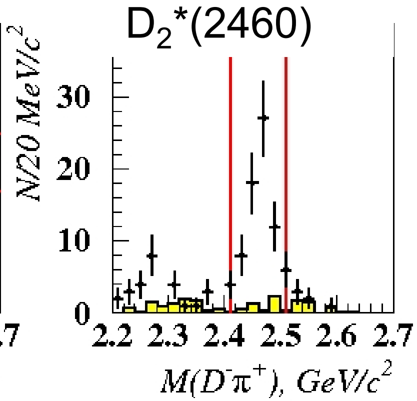

What else is there:

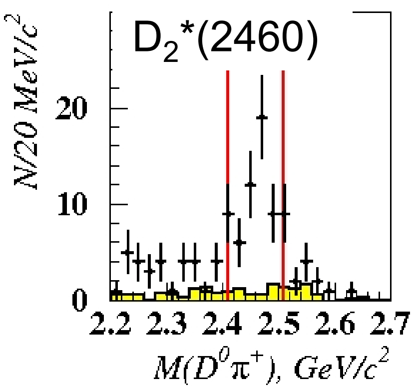
- * charmonium production in the continuum, $O$(pb)
- * $D_s$ production ··········►
- * other DDnπ rates (non-resonant)
- * Charm baryons

P. Pakhlov, talk at this conference

# Resonant structure in $\psi(4415) \to DD\pi$



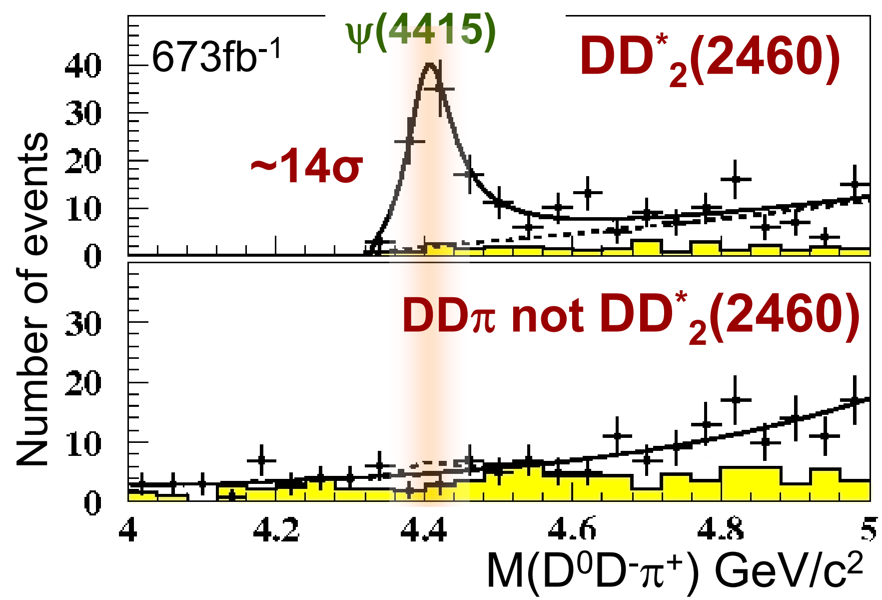

**$M(D^0\pi^+)$ vs $M(D^-\pi^+)$** from **$\psi(4415)$** region

(D(2010,2007) vetoed)

- Clear **$D^*_2(2460)$** signals
- Positive interference
- **Non $D^*_2(2460)$** contribution **smooth**
- **$1^{st}$ exclusive decay mode of $\psi(4415)$**

M =4411± 7± 3 MeV
$\Gamma_{tot}$= 77±20±12 MeV
$N_{ev}$= 109±25±11

Consistent with
BES, hep-ex/0705.4500,
PDG06,
Barnes at.al
PRD72,054026 (2005)




**$\sigma(e^+e^- \to \psi(4415)) \times Br(\psi(4415) \to DD^*_2(2460)) \times Br(D^*_2(2460) \to D\pi) = (0.74 \pm 0.17 \pm 0.07)nb$**

**$Br(\psi(4415) \to D(D\pi)_{non\ D2(2460)}) / Br(\psi(4415) \to DD^*_2(2460)) < 0.2$**

Above DD threshold:

# Observed & Predicted States

X(4350)

Y(4260) in ISR and $e^+e^-$

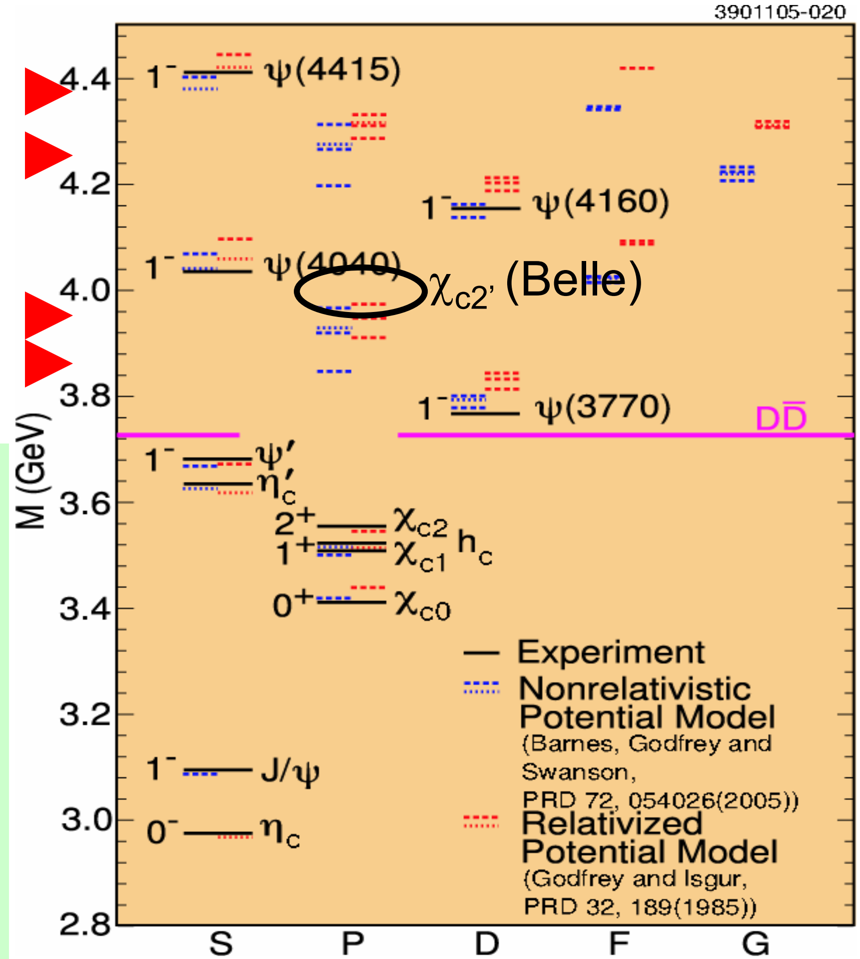
X(3940)→D*D in $c\bar{c}$ J/ψ,

Y(3940) in B→ ωJ/ψ

BaBar: Talk by G. Cibinetto

CLEO: PRL 98, 092002 (2007)

X(3872)




Many charmonium-like states found, most could not be identified with a charmonium state (or have been ruled out as conventional $c\bar{c}$ state)

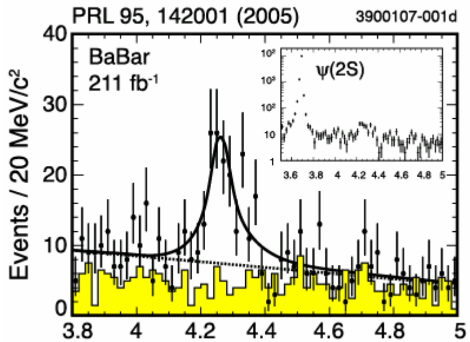
in order to claim new $c\bar{c}$ state, need to "prove" quantum numbers – angular distributions, decay modes, …

Need systematic approach from several fronts

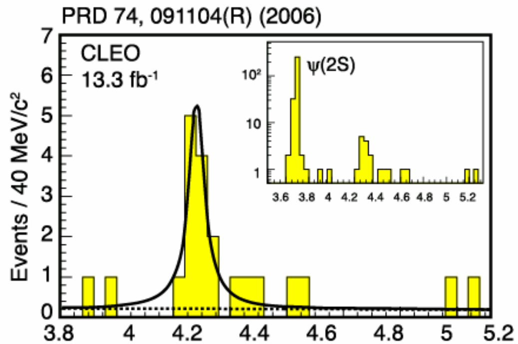
# $J/\psi,\psi(2S)\pi^+\pi^-$ States

Reminder:

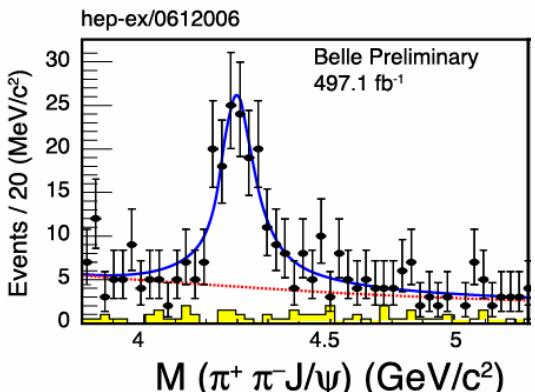
$Y(4260)\rightarrow J/\psi\ \pi^+\pi^-$ seen in ISR by BaBar,




CLEO,

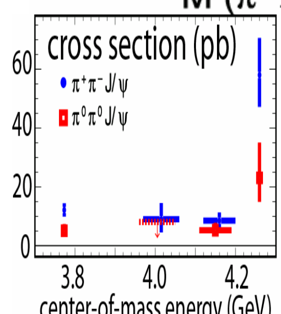



Belle:



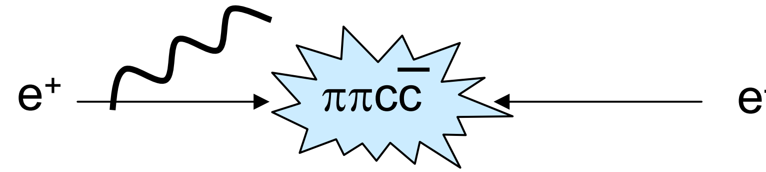

Simplest fit to peak uses single Breit-Wigner shape, multiple reonances possible

$J/\psi\ \pi^+\pi^-$, $J/\psi\ \pi^0\pi^0$, $J/\psi\ K^+K^-$, and more CLEO PRL 96, 162003 (2006)




2005/2006

Initial state radiation:




Quantities of interest:

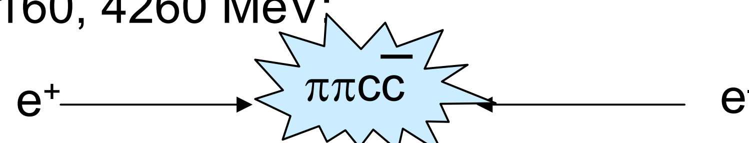
Mass

Width

Decay BR's to different final states and ratios

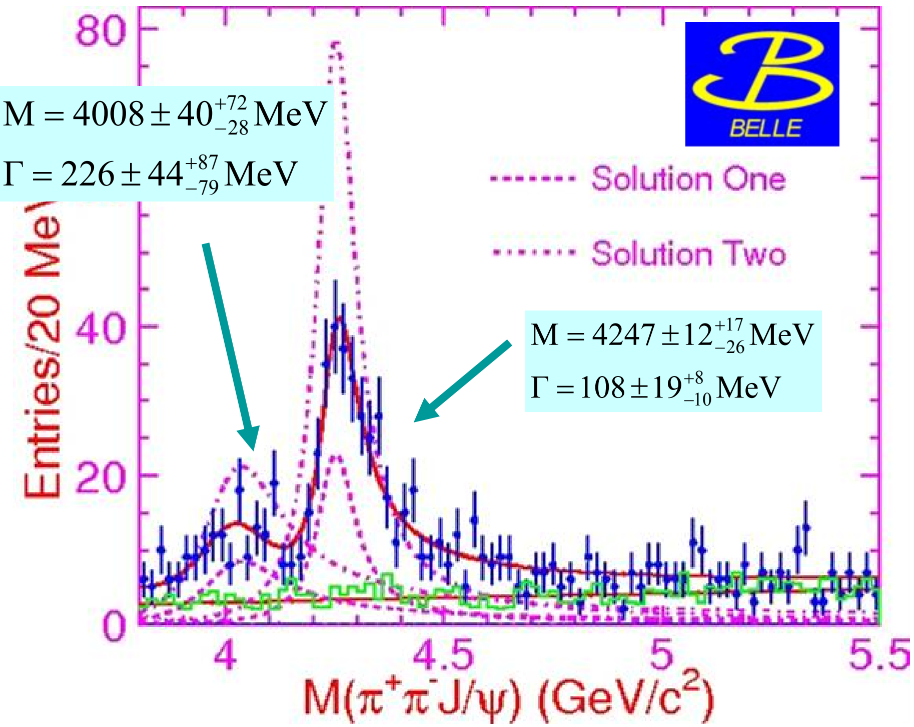
$M(\pi\pi)$ distribution

Direct production at 3770, 4040, 4160, 4260 MeV:



# $J/\psi+\pi^+\pi^-$ in Initial State Radiation

550/fb




Quantities of interest:
mass, width, coupling

New fit to improve low-side description:
two overlapping resonances and
constructive / destructive interference

| Parameters | Solution One | Solution Two |
|---|---|---|
| $M(R1)$ | $4008 \pm 40^{+72}_{-28}$ | |
| $\Gamma_{tot}(R1)$ | $226 \pm 44^{+87}_{-79}$ | |
| $\mathcal{B}\cdot\Gamma_{e^+e^-}(R1)$ | $5.0 \pm 1.4^{+5.6}_{-0.9}$ | $12.4 \pm 2.4^{+11.9}_{-1.1}$ |
| $M(R2)$ | $4247 \pm 12^{+17}_{-26}$ | |
| $\Gamma_{tot}(R2)$ | $108 \pm 19^{+8}_{-10}$ | |
| $\mathcal{B}\cdot\Gamma_{e^+e^-}(R2)$ | $6.0 \pm 1.2^{+1.7}_{-0.5}$ | $20.6 \pm 2.3^{+4.9}_{-1.7}$ |
| $\phi$ | $12 \pm 29^{+7}_{-66}$ | $-111 \pm 7^{+28}_{-29}$ |

Earlier results, single BW fit:

Refs see end of talk

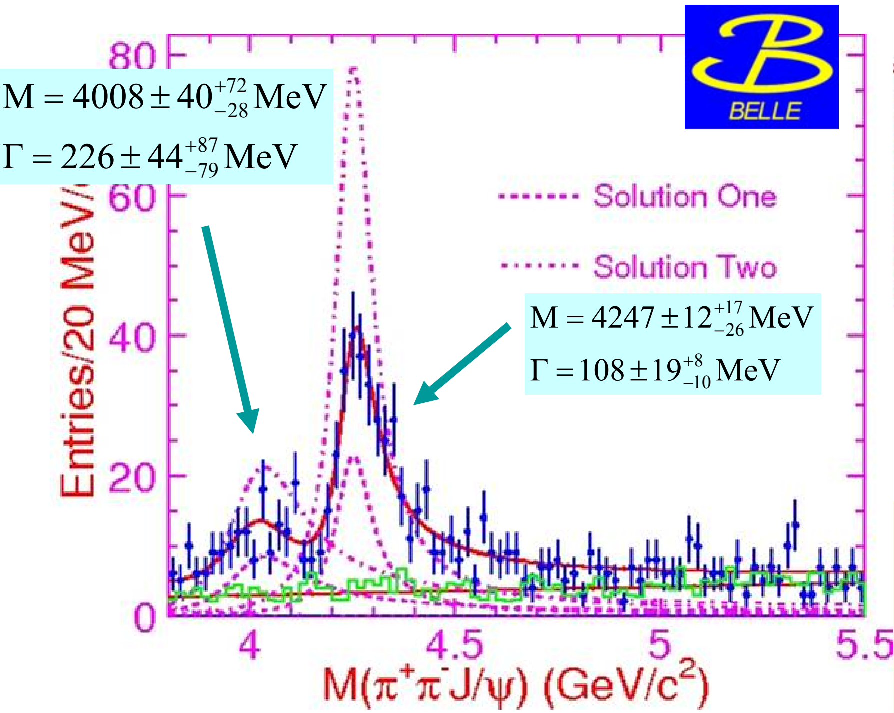
| | Mass, MeV | Width, MeV |
|---|---|---|
| BaBar | $4259^{+8}_{-10}$ | $88\pm23$ |
| CLEO | $4284\pm17$ | $73^{+39}_{-25}$ |
| Belle old | $4295\ ^{+14}_{-10}$ | $133\pm26$ |
| Belle new | $4263\pm6$(st) | $126\pm18$(st) |

2 solutions reproduce the data (same m,$\Gamma$), but $B(Y(4260)\to\pi\pi J/\psi)\times\Gamma_{ee}$ a factor of 3.5 apart!

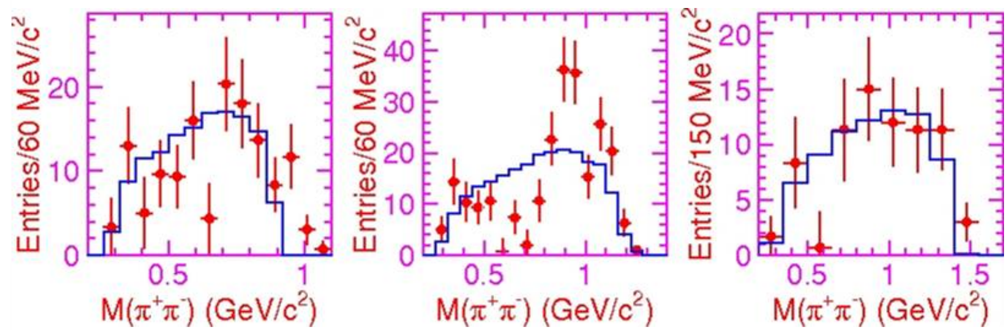
Belle arXiv:0707.2541v1, subm to PRL

# (cont'd) $J/\psi+\pi^+\pi^-$ in Initial State Radiation

Fit input: assume two overlapping resonances
$\Rightarrow$ 2 solutions reproduce the data (same m,$\Gamma$)
$B(Y(4260)\to\pi\pi J/\psi)\times\Gamma_{ee}$ a factor of 3.5 apart!




below | 4.2-4.4 GeV | above

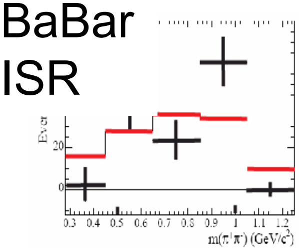



MC:

Belle, BaBar: 3body phase space

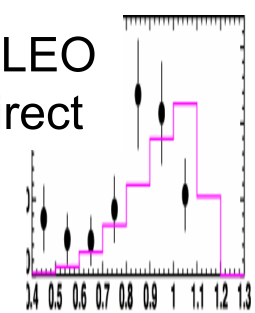
CLEO: like $\psi(2S)\to\pi\pi J/\psi$

BaBar ISR



PRL 95, 142001 (2005)

CLEO direct

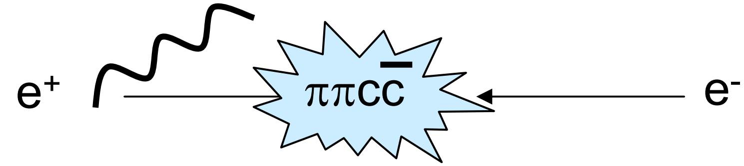


PRL 96, 162003 (2006)

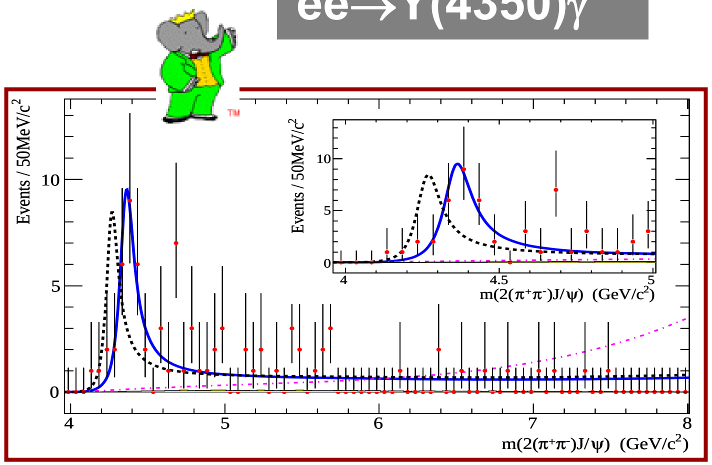
$M(\pi\pi)$ (GeV)

$M(\pi\pi)$ distribution distinctly different for Y(4260) signal region than for sidebands

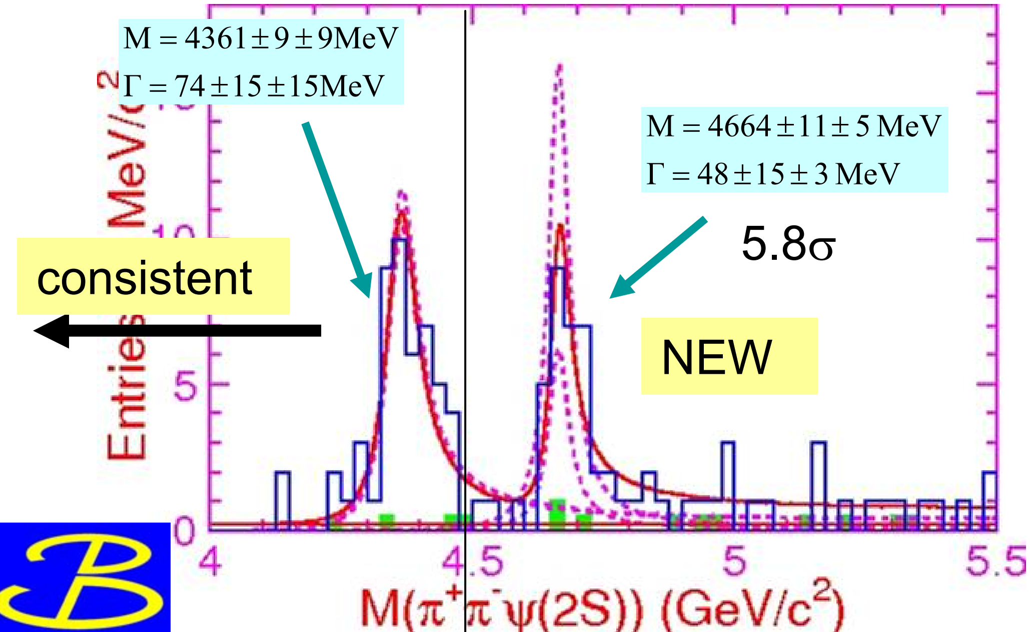
# $\psi(2S)+\pi^+\pi^-$ in Initial State Radiation



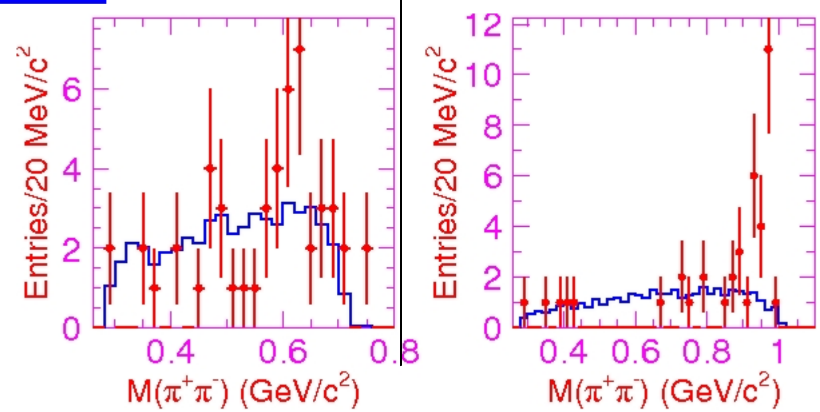

**ee→Y(4350)γ**




Phys. Rev. Lett. 98, 212001 (2007)



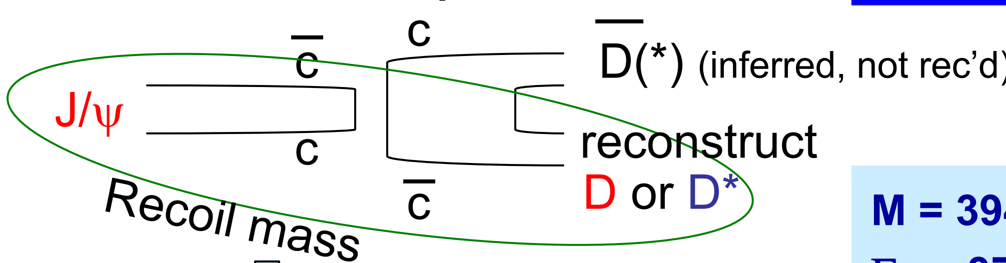

| Parameters | Solution one | Solution two |
|---|---|---|
| $M(Y(4360))$ | $4361 \pm 9 \pm 9$ | |
| $\Gamma_{tot}(Y(4360))$ | $74 \pm 15 \pm 10$ | |
| $\mathcal{B} \cdot \Gamma_{e^+e^-}(Y(4360))$ | $10.4 \pm 1.7 \pm 1.5$ | $11.8 \pm 1.8 \pm 1.4$ |
| $M(Y(4660))$ | $4664 \pm 11 \pm 5$ | |
| $\Gamma_{tot}(Y(4660))$ | $48 \pm 15 \pm 3$ | |
| $\mathcal{B} \cdot \Gamma_{e^+e^-}(Y(4660))$ | $3.0 \pm 0.9 \pm 0.3$ | $7.6 \pm 1.8 \pm 0.8$ |
| $\phi$ | $39 \pm 30 \pm 22$ | $-79 \pm 17 \pm 20$ |



Obtain J/ψ+D(*)D(*) samples through kinematic separation, look at m(D(*)D(*)) after background subtraction:

# $e^+e^- \rightarrow J/\psi\ D^{(*)}D^{(*)}$

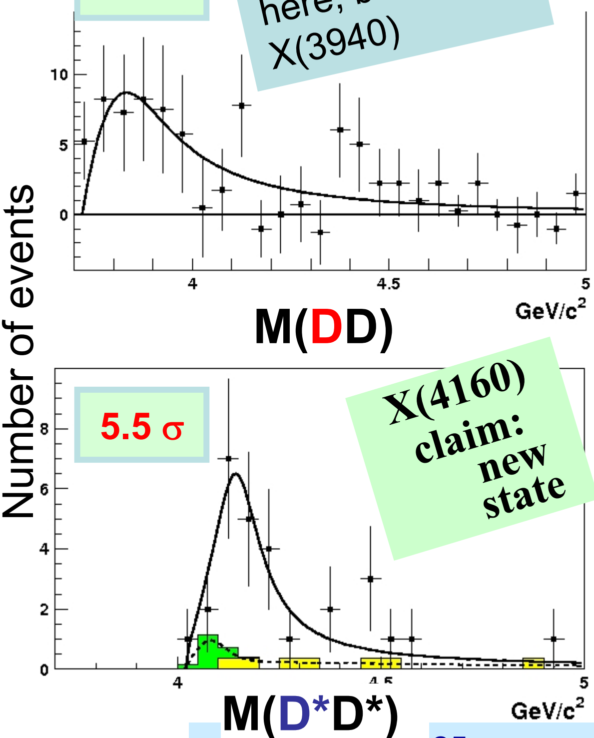
BELLE




$M = 3942 \quad \pm 6$ MeV
$\Gamma_{tot} = 37 \quad \pm 12$ MeV
$N_{ev} = 52 \quad \pm 11$

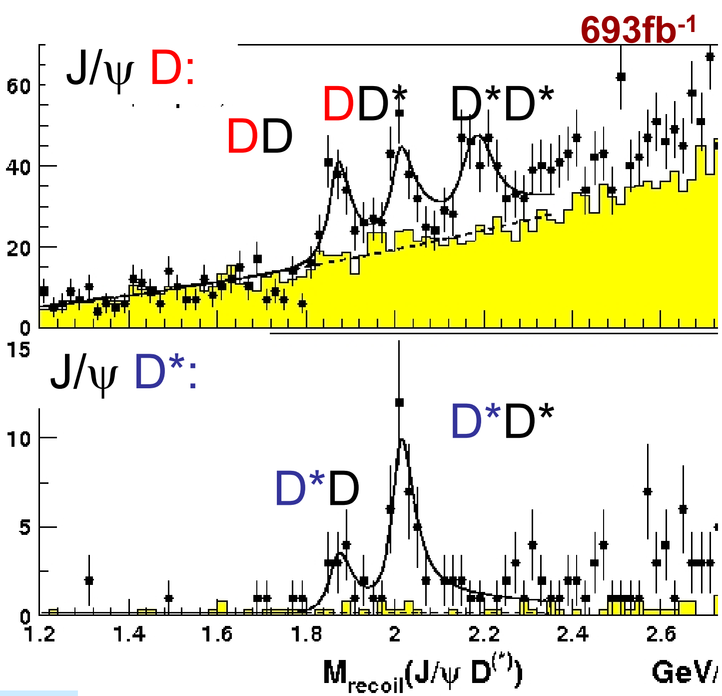
3.8 σ

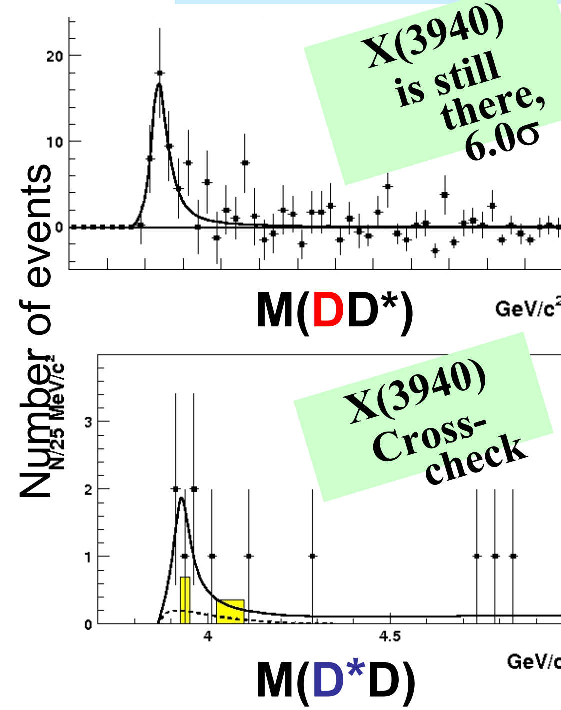
Something's here, but it's not X(3940)




5.5 σ

X(4160) claim: new state




X(3940) is still there, 6.0σ

X(3940) Cross-check

$M = 4156 \ {}^{+25}_{-20} \pm 15$ MeV
$\Gamma_{tot} = 37 \ {}^{+111}_{-61} \pm 21$ MeV
$N_{ev} = 24 \ {}^{+12}_{-8}$

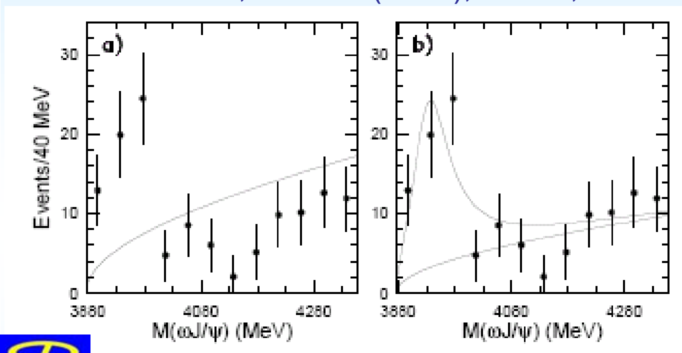
P. Pakhlov,
talk at this conference,

G. Cibinetto, talk at this conference

# Confirmation of Y(3940) ($B \to K\omega J/\psi$)

$\omega \to \pi^+\pi^-\pi^0$

Belle PRL 94, 182002 (2005), 253/fb, >8$\sigma$

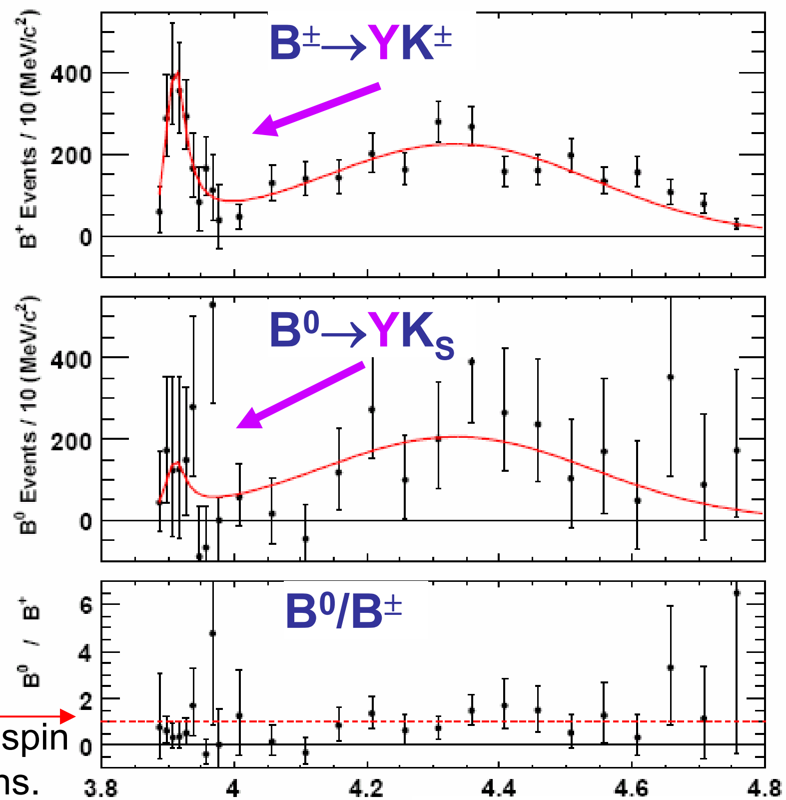



M=3943±11±13 MeV

$\Gamma$=87±22±26 MeV

Unexplained state; mass and width compatible with radially excited P-wave cc state, but decay to hidden charm


preliminary




New result, based on 350 fb$^{-1}$:

$$M(Y) = (3914.3^{+3.8}_{-3.4}(stat)^{+1.6}_{-1.6}(syst))\ \mathrm{MeV}/c^2\,,$$
$$\Gamma(Y) = (33^{+12}_{-8}(stat)^{+0.6}_{-0.6}(syst))\ \mathrm{MeV}\,.$$

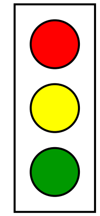
Belle's evidence for $B \to YK$, $Y \to J/\psi\omega$ confirmed

- ~30MeV lower mass than Belle's
- Narrower width
- Preliminary BF estimate similar to Belle's (~10$^{-5}$)

Q=c,b

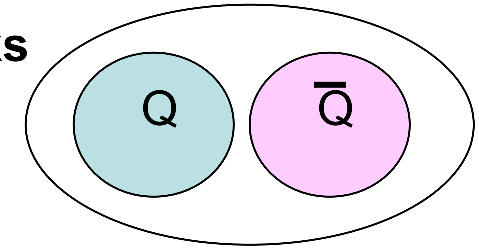
q=u,d,s

# Overview



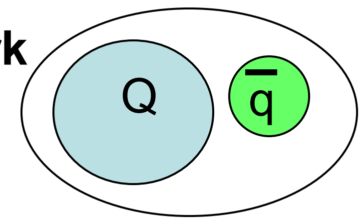
General goal:
Explore QCD phenomena
at different scales

**Two heavy quarks**



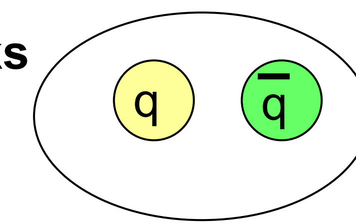

$\psi$(2S) width
J/$\psi$, $\chi_{cJ}$ decay to light q
B decay to charmonium
States above DD threshold
Charmonium-like states

**One heavy quark**




**$D_{s1}(2536)^+ \rightarrow D^{*+}K^0_S$**
**$\Xi_c(3077)$, $\Xi_c(3123)$**

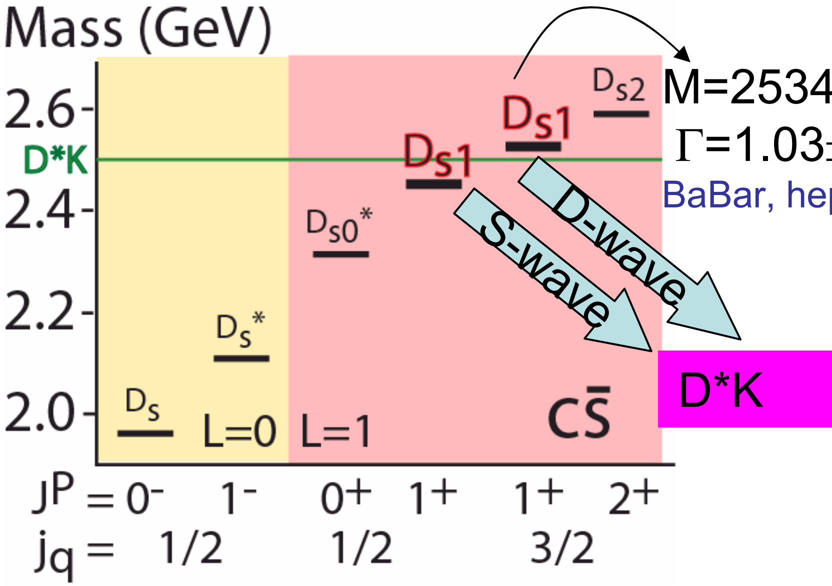
**Zero heavy quarks**




This talk: mostly mesons, but many new results on baryons as well. See list of topics at the end.

# Partial Wave Analysis of $D_{s1}(2536)^+ \to D^{*+}K^0_S$

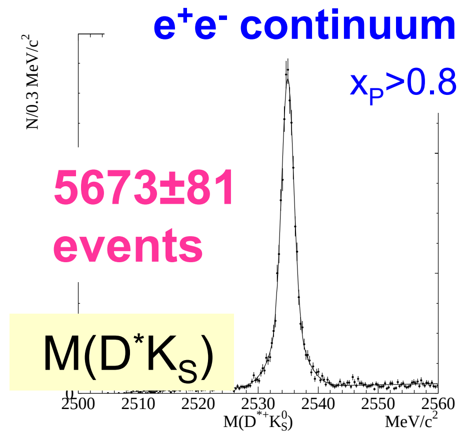
V. Balagura, this conference

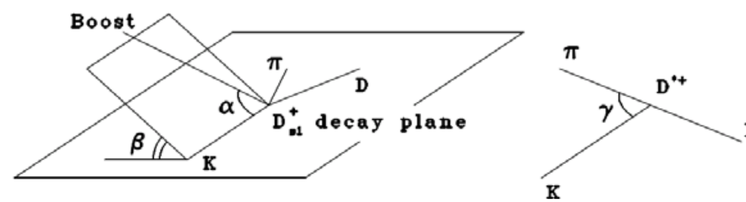



$M = 2534.85 \pm 0.02 \pm 0.40$ MeV

$\Gamma = 1.03 \pm 0.05 \pm 0.12$ MeV

BaBar, hep-ex/0607084



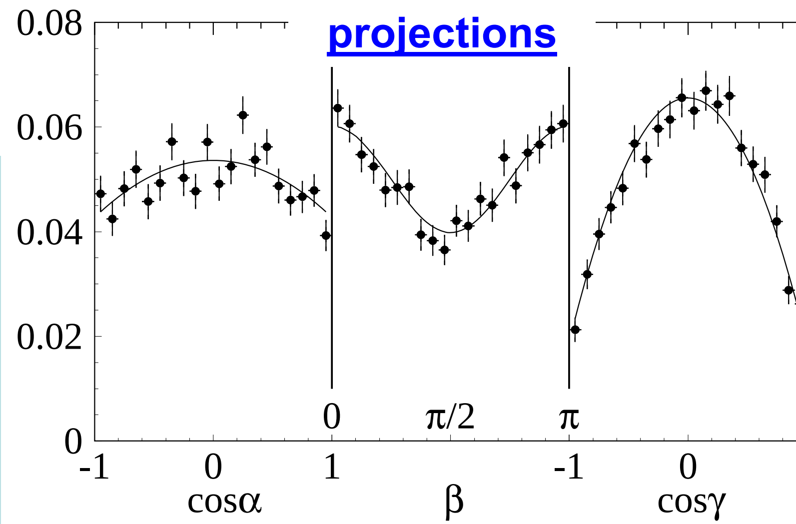




*$D_{s1}(2536)^+$: j=3/2 with small admixture of j=1/2*

**Energy release is small**

**→ D-wave decay to $D^*K_S$ is suppressed**

**→ j=1/2 can be visible**




## 3-D fit results

$$D/S = (0.63 \pm 0.07) \cdot \exp(\pm i \cdot (0.77 \pm 0.03))$$

$$\Gamma_S/\Gamma_{total} = 0.72 \pm 0.05$$

→ **S-wave dominates**

$$\rho_{00} = 0.490 \pm 0.013$$

$\rho_{00}$ – longitudinal polarization

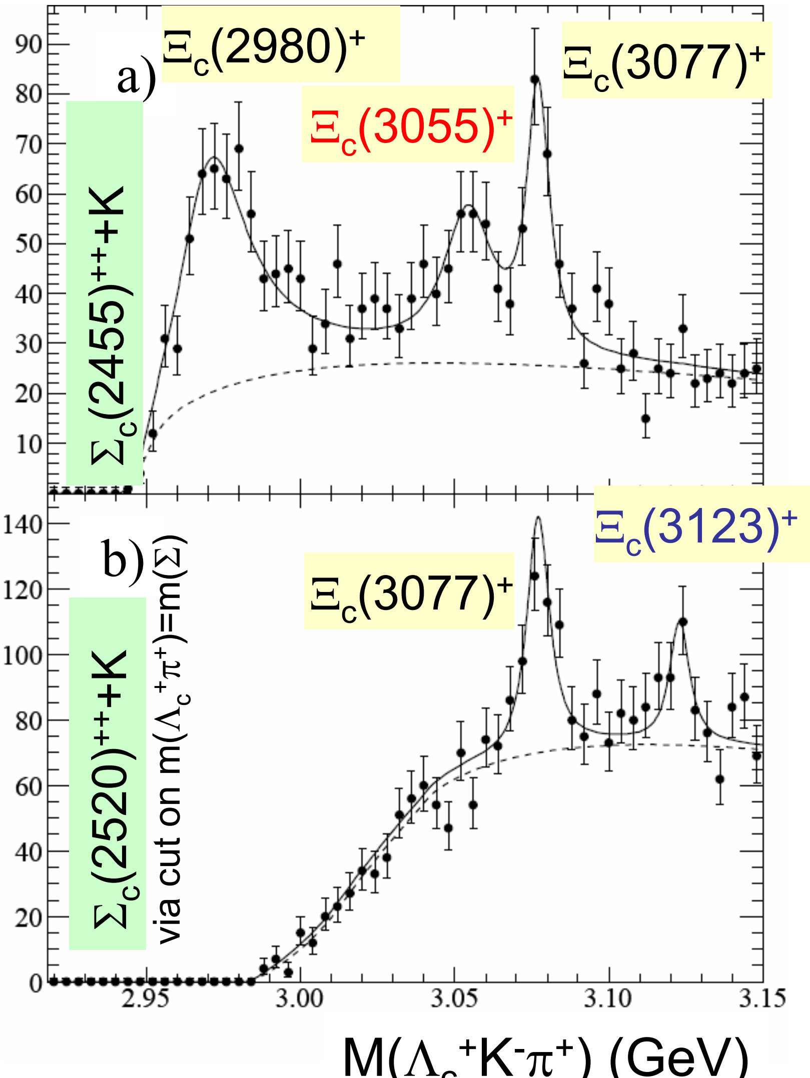
**$\chi^2$ difference between points and projected fit results corresponds to prob. 60%**

T. Schroeder, talk at this conference

# Excited charm-strange baryons

Search: cs baryons → $\Lambda_c^+ + K_S$, $K^-$, $K^-\pi^+$, $K_S\pi^-$, $K_S\pi^-\pi^+$, $K^-\pi^-\pi^+$

preliminary




| $\Xi_c(3055)^+$ | |
|---|---|
| Mass ( $MeV/c^2$ ) | $3054.2 \pm 1.2 \pm 0.5$ |
| Width ( $MeV/c^2$ ) | $17 \pm 6 \pm 11$ |
| Yield | $218 \pm 53 \pm 79$ |
| Significance | $6.4\sigma$ |

| $\Xi_c(3123)^+$ | |
|---|---|
| Mass ( $MeV/c^2$ ) | $3122.9 \pm 1.3 \pm 0.3$ |
| Width ( $MeV/c^2$ ) | $4.4 \pm 3.4 \pm 1.7$ |
| Yield | $101 \pm 34 \pm 9$ |
| Significance | $3.6\sigma$ |

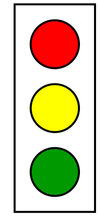
only observed in $\Sigma_c^{++}$ K intermediate decays – c and s split up.

Further results:
confirmation of $\Xi_c(2980)^+$, $\Xi_c(3077)^{+,0}$
$\Xi_c(2980)^+$ mass and width measurements improved

Q=c,b

q=u,d,s

# Overview



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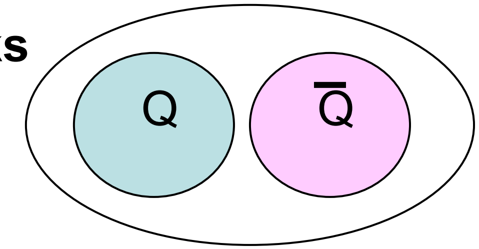


$\psi(2S)$ width
$J/\psi$, $\chi_{cJ}$ decay to light q
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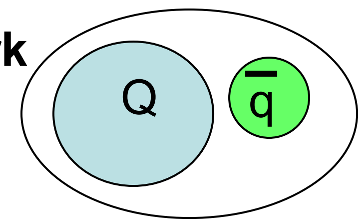
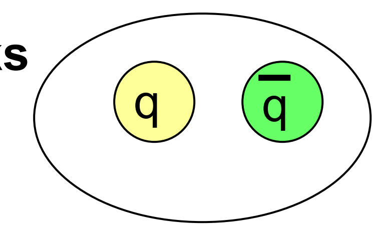



$D_{s1}(2536)^+ \to D^{*+} K^0_S$
$\Xi_c(3077)$, $\Xi_c(3123)$

Non-perturbative QCD

$a_0, f_0(980)$
$\eta, \eta'$ mixing and glue in $\eta'$
$\eta$ mass
$\eta(')$ decay
$K^{+-} \to \pi^+\pi^- e^{+-}\nu$, $\pi^{+-}\pi^0\pi^0$, $\pi^\pm\pi^0\gamma$

**Zero heavy quarks**




This talk: mostly mesons, but many new results on baryons as well. See list of topics at the end.

KLOE

# $\phi \to \pi^0\pi^0\gamma$

Goal: Understand low-mass dimeson behavior; here: $\pi\pi$,KK.

EPJ C49 (2007) 473

<u>Context:</u> Low-mass broad $\pi\pi$, $K\pi$ systems are "everywhere": $\pi$+K/$\pi$ scattering, K decay, D decay, ...

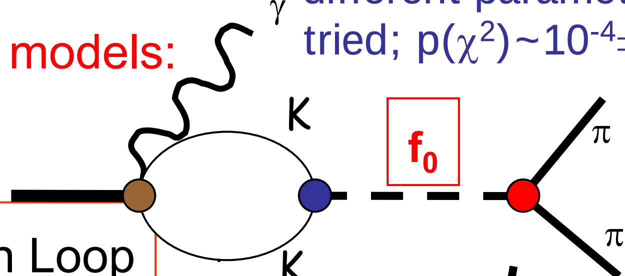
"$\sigma,\kappa$" (low-mass $\pi\pi$/$K\pi$ S-wave), $a_0(980)\to\eta\pi^0$, **$f_0(980)$**$\to\pi^+\pi^-$,$\pi^0\pi^0$, $K^+K^-$, $K^0K^{0bar}$

Parameters? Nature?

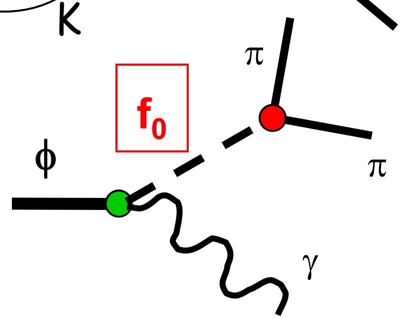
Fit needs $\phi \to \sigma(500)\gamma$, different parametrizations tried; $p(\chi^2)$~$10^{-4}\Rightarrow$14%

Two fit models:

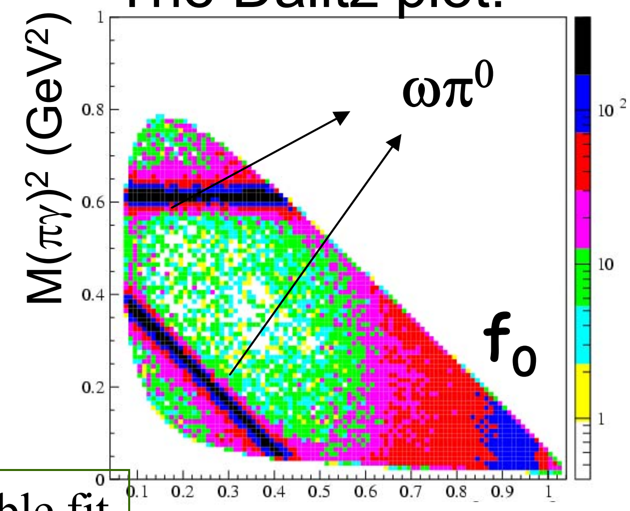
Kaon Loop




No Structure




The Dalitz plot:




**Result 1:**

An acceptable fit is obtained with both models:
$P(\chi^2)$(KL)=14%
$P(\chi^2)$(NS)= 4%

**Result 2:**

List of couplings for both models

**Result 3:**

$$\mathrm{BR}(\ \phi \to \gamma f_0 \to \pi^0\pi^0\gamma\ )$$

$$\left[1.07^{+0.01}_{-0.04}(fit)^{+0.04}_{-0.02}(syst)^{+0.06}_{-0.05}(mod)\right]\times 10^{-4}$$

-- Also see $\phi\to\gamma f_0(980)\to\gamma\pi^+\pi^-$ and $\phi\to\gamma a_0(980)\to\gamma\eta\pi^0$ KLOE results

# $\eta/\eta'$ mixing; gluon content in the $\eta'$

$B(\phi \to \eta'\gamma) / B(\phi \to \eta\gamma) =$

$$(4.77 \pm 0.09_{stat.} \pm 0.19_{syst}) \times 10^{-3}$$

Gives insight into $\eta/\eta'$ mixing.

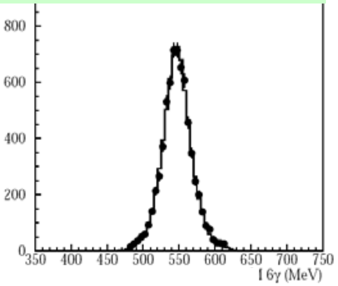
Assuming $\eta'$=uds only, no |gg>:

$\varphi_P = (41.4 \pm 0.3 \pm 0.7 \pm 0.6)^o$

$B(\phi \to \eta\gamma) = (1.301 \pm 0.024)\%$ from PDG

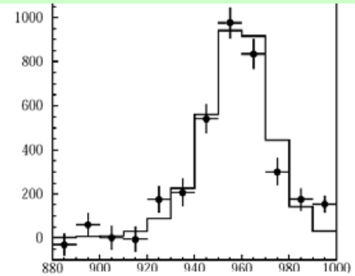
$B(\phi \to \eta'\gamma) = (6.20 \pm 0.09_{stat.} \pm 0.25_{syst.}) \times 10^{-5}$

$\eta$ signal (no bgd)




$M(6\gamma)$

$\eta'$ signal (~10% bgd)




$M(6\gamma + \pi^+\pi^-)$

KLOE
PLB648 (2007) 267

Now allow $\eta'$ to have |gg>:

$$|\eta> \;=\; cos(\varphi_p)|q\bar{q}> - sin(\varphi_p)|s\bar{s}>$$

$$|\eta'> = X_{\eta'}|q\bar{q}> + Y_{\eta'}|s\bar{s}> + Z_{\eta'}|gluon>$$

$$X_{\eta'} = \cos\phi_G \sin\varphi_P$$
$$Y_{\eta'} = \cos\phi_G \cos\varphi_P$$
$$Z_{\eta'} = \sin\phi_G$$

Mixes $\eta,\eta'$

Mixes gluonium into $\eta'$

Use SU(3) relations between modes involving $\pi^0,\omega,\rho,\eta,\eta'$ and measured branching ratios to obtain X,Y,Z($\eta'$) $\Rightarrow \phi_G,\ \varphi_P$

# η’ gluonium content

PLB648 (2007) 267

KLOE

Fit results

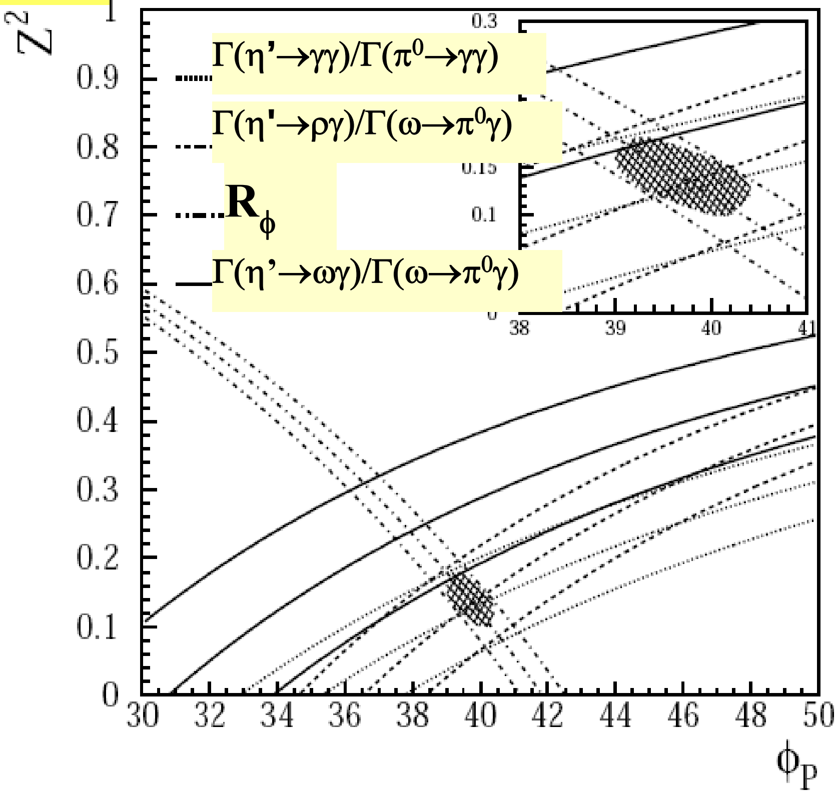
$\phi_P = (39.7 \pm 0.7_{tot})^\circ$
$|\phi_G| = (22 \pm 3)^\circ$

Gluonium coefficient:

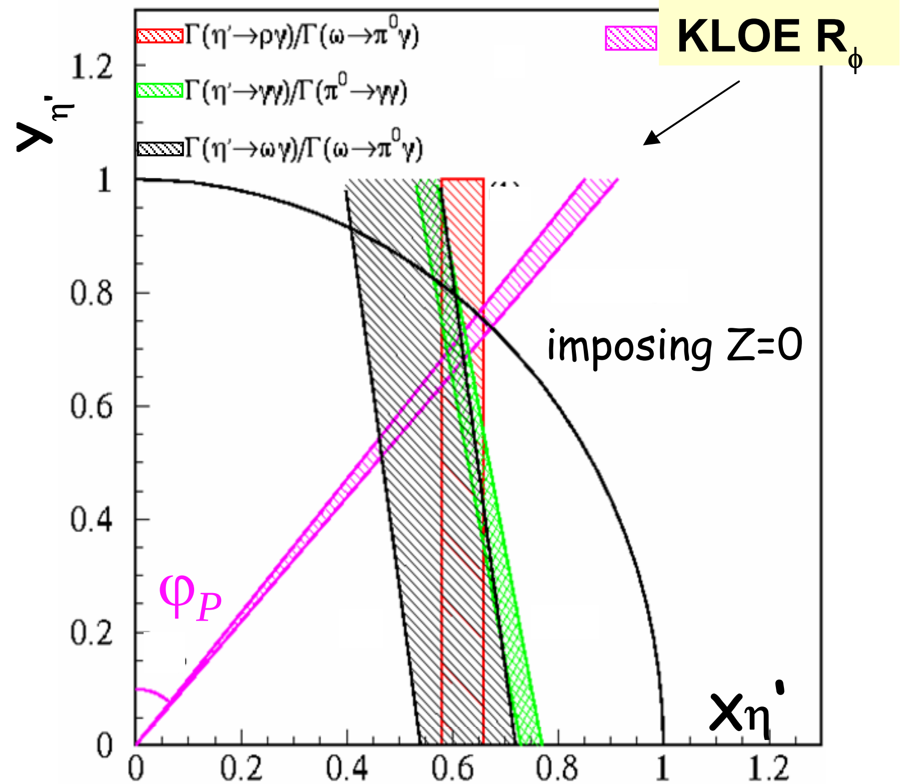
$\sin^2\phi_G = Z^2 = 0.14 \pm 0.04$

Sin $\phi_G$

**49 % $\chi^2$ probability**

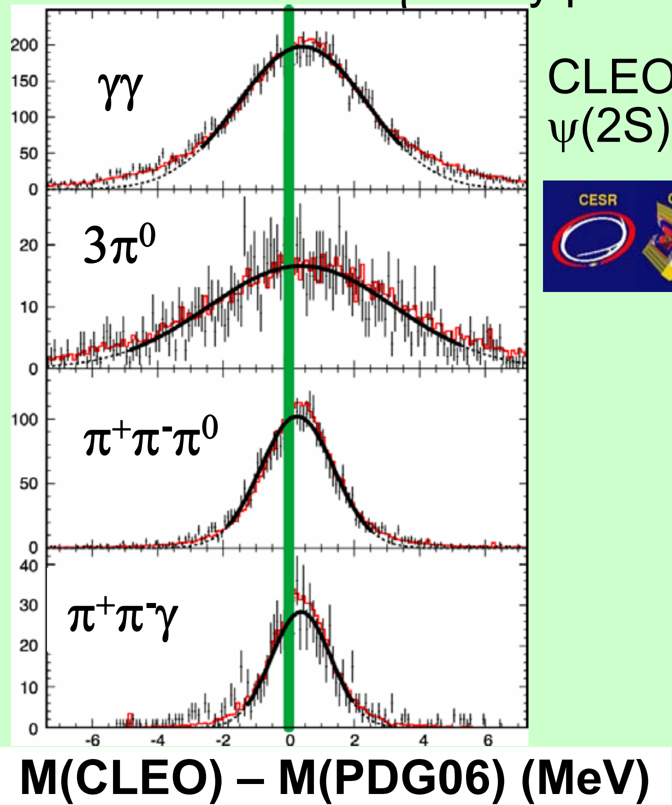



**1 % $\chi^2$ probability**

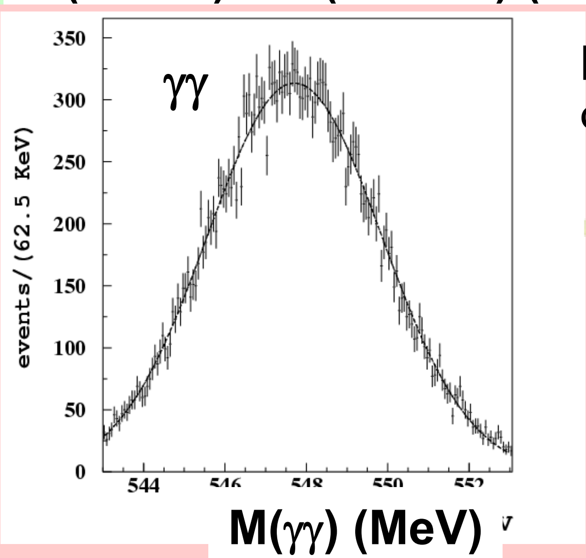



Bands – constraints from input branching fractions (depend on X,Y,Z(η’) ⇒ $\phi_G$, $\varphi_P$)

Invariant mass of η decay products:




CLEO
$\psi(2S) \to \eta J/\psi$

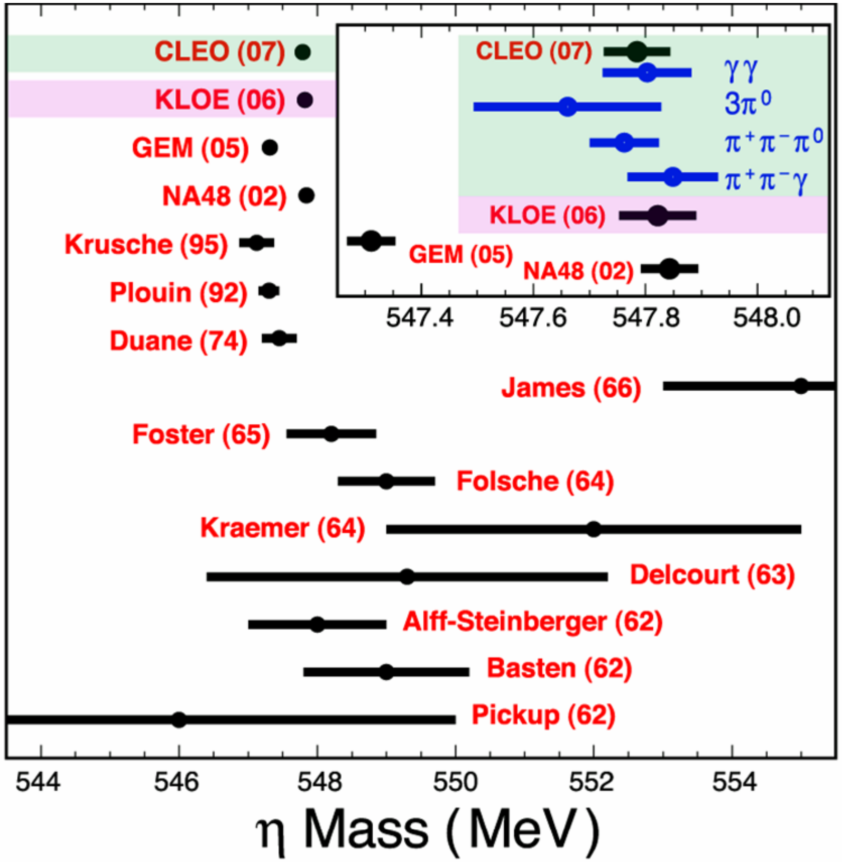


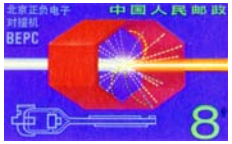

KLOE
$\phi \to \gamma\eta$

# η Mass

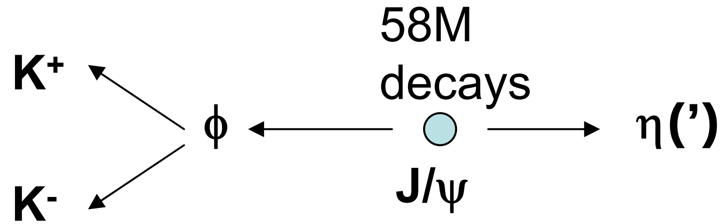
CLEO: $M(\eta) = 547.785 \pm 0.017 \pm 0.057$ MeV
arXiv:0707.1810

KLOE: $M(\eta) = 547.822 \pm 0.005 \pm 0.069$ MeV
preliminary

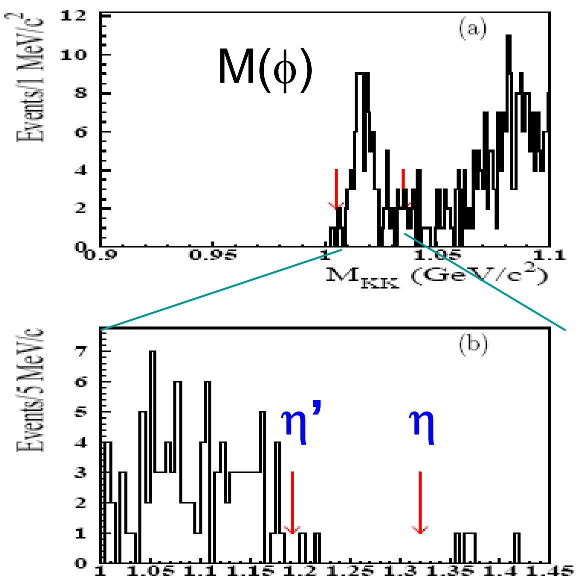




# η(’) Branching Ratios (1)

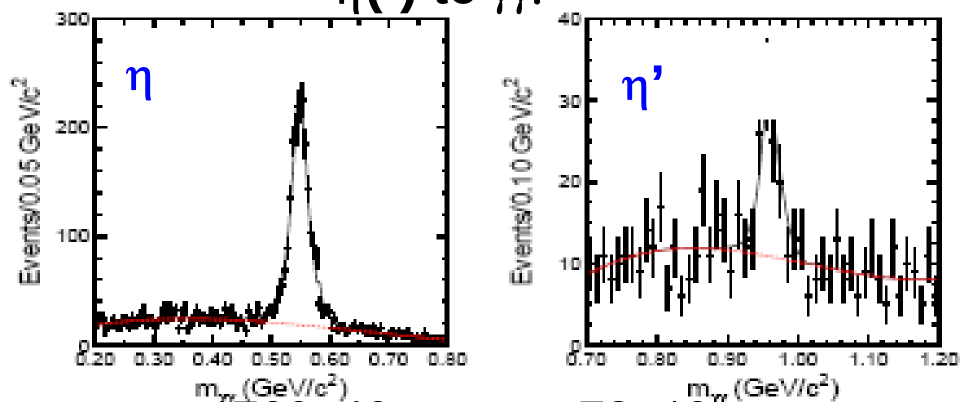



**η to undetectable final states:**




Missing momentum

**η(’) to γγ:**




1760±49 72±13

UL, absolute:

$$\frac{B(\eta \to \text{invisible})}{B(\eta \to \gamma\gamma)} < 1.65 \times 10^{-3}$$ ~0.1%)

$$\frac{B(\eta' \to \text{invisible})}{B(\eta' \to \gamma\gamma)} < 6.69 \times 10^{-3}$$ ~0.01%

58M J/ψ,
B(J/ψ→η(’)ϕ) = 7.4 (4.0) $\times 10^{-4}$
B(ϕ→K⁺K⁻) = 50%

BES PRL 97, 202002 (2006)

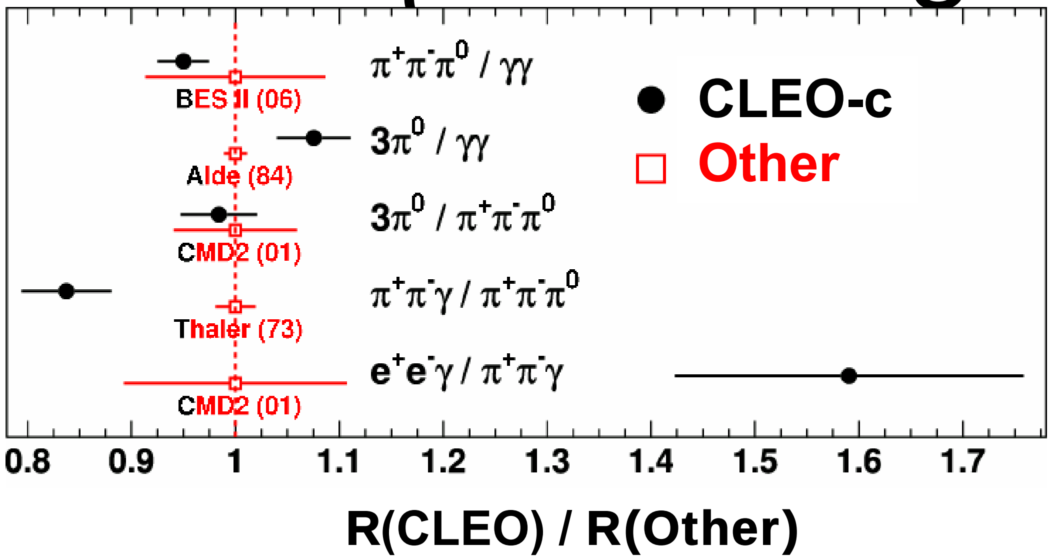
Other “invisible” BR measurements:

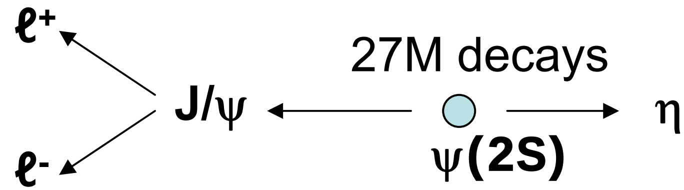
**ϒ(1S): <0.39%** (CLEO) PRD 75, 031104 (2007)

**<0.29%** (Belle) PRL 98, 132001 (2007)

Important as an input to total width measurements!

# η branching fractions (2)

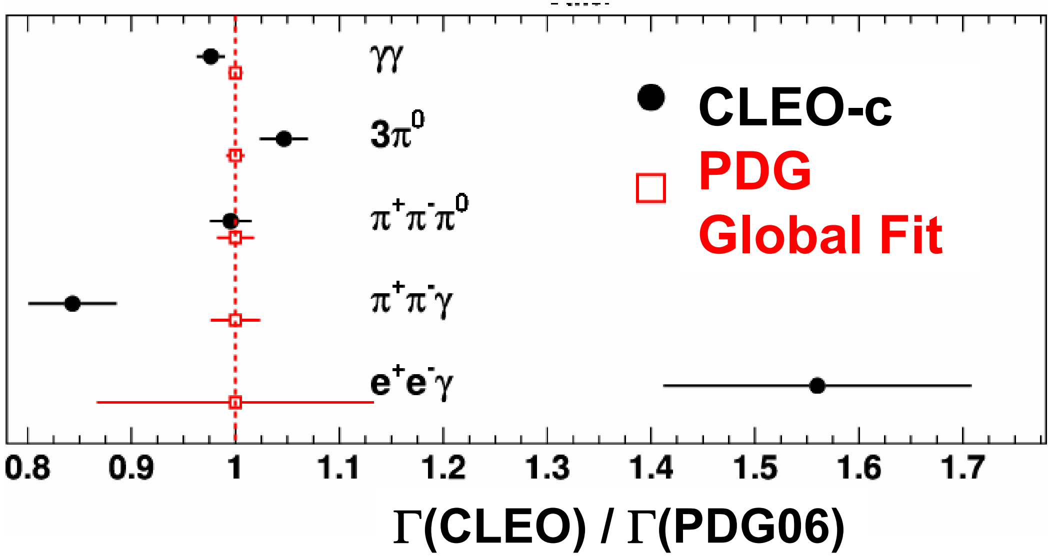



Fully reconstruct five final states:

$\gamma\gamma$ + $3\pi^0$ + $\pi^+\pi^-\pi^0$ + $\pi^+\pi^-\gamma$ + $e^+e^-\gamma$

38.5 34.0 22.6 4.0 0.9%




Follow PDG procedure: sum of the above five modes is ~ 100%
⇒ build absolute Br's from ratios

CLEO, arXiv:0707.1601

KLOE

arXiv:0707.2355v1

# $\eta\to\pi^+\pi^-\pi^0$ decay dynamics

B. V. Martemyanov, V. S. Sopov, PRD 71 (2005) 017501

A good understanding of $\eta\to 3\pi$ dynamics can in principle lead to a very accurate determination of quark masses:

$$\Gamma(\eta\to 3\pi)\propto |A|^2$$

$$\mathbf{Amplitude(s,t,u)}\propto\frac{1}{Q^2}\times \mathbf{M(s,t,u)}$$

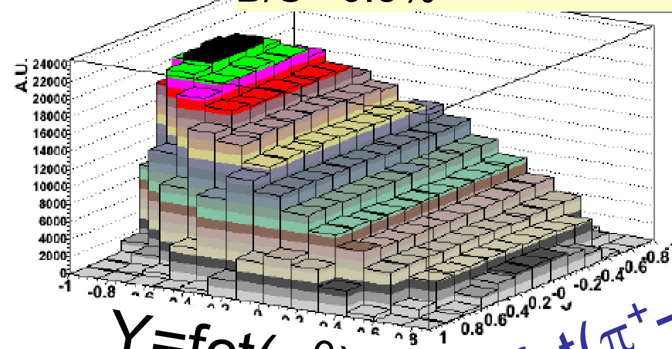
$$Q^2=\frac{m_s^2-\hat{m}^2}{m_d^2-m_u^2},\quad M(s,t,u)\overset{(*)}{=}\frac{3s-4m_\pi^2}{m_\eta^2-m_\pi^2}$$

(*) lowest order Current Algebra

Measured matrix element:

$N_{obs}=(1.377\pm 0.001)\times 10^6$

B/S ≈0.3%




Fit parameters:

$|A(X,Y)|^2=$
$1+aY+bY^2+cX+dX^2+eXY+fY^3$
with X=fct($\pi^+$-$\pi^-$), Y=fct($\pi^0$)

Fit result:

$$a=-1.090\pm 0.005(stat)^{+0.008}_{-0.019}(syst)$$
$$b=0.124\pm 0.006(stat)\pm 0.010(syst)$$
$$d=0.057\pm 0.006(stat)^{+0.007}_{-0.016}(syst)$$
$$f=0.14\pm 0.01(stat)\pm 0.02(syst)$$

$$c=0.002\pm 0.003(stat)\pm 0.001(syst)$$
$$e=-0.006\pm 0.007(stat)^{+0.005}_{-0.003}(syst)$$

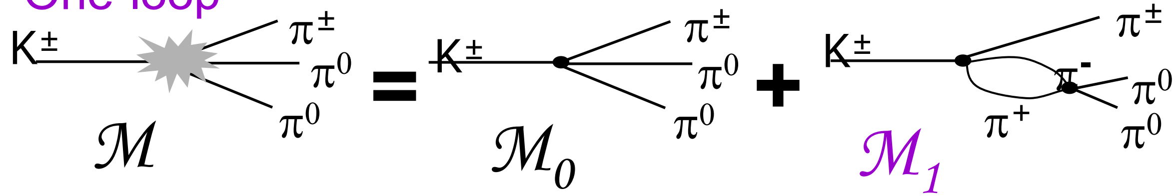
**LOCA: $b = a^2/4$**

⇒ Indicates need for higher order corrections compared to (*)

# $K^{+/-} \to \pi^{+/-}\pi^0\pi^0$

Final state interactions

"One-loop"




$\mathcal{M} = \mathcal{M}_0 + \mathcal{M}_1$

Prop. to $\mathbf{a_0}$-$\mathbf{a_2}$

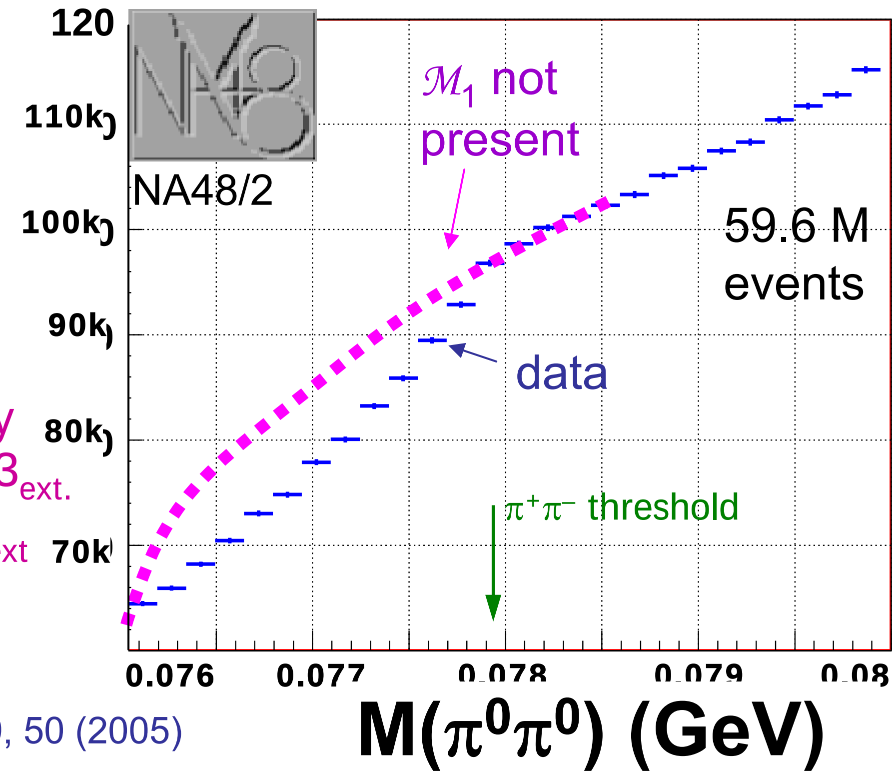
"Two-loop" introduces dependence on $\mathbf{a_2}$ in ampl.

<u>Dalitz plot analysis. Look at $M(\pi^0\pi^0)$:</u>
"cusp" structure at $\pi^+\pi^-$ threshold
(due to $\pi^+\pi^- \to \pi^0\pi^0$ rescattering)
provides a new method to measure the $\pi\pi$ scattering lengths: $a_0$ and $a_2$
($\chi$PT predictions exist)

preliminary

$(a_0 - a_2)m_+ = 0.261 \pm 0.006_{stat.} \pm 0.003_{syst.} \pm 0.0013_{ext.}$

$a_2 m_+ = -0.037 \pm 0.013_{stat.} \pm 0.009_{syst.} \pm 0.0018_{ext}$



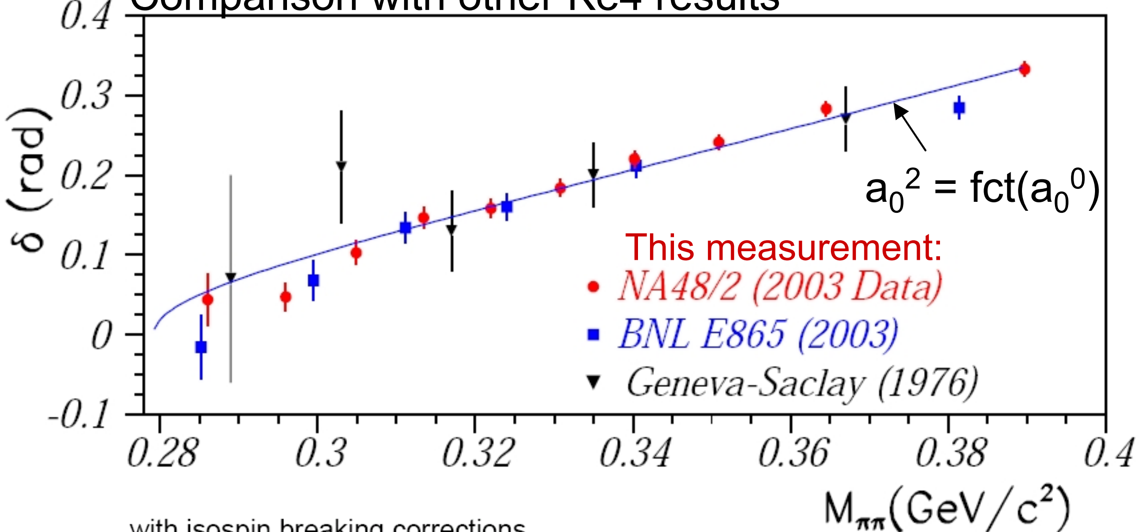

Dominated by the theoretical uncertainties, consistent with Ke4 measurement and with $|a_2 - a_0|$ from DIRAC (pionium lifetime). PLB 619, 50 (2005)

Experimentally sensitive to higher-order terms in matrix element expansion

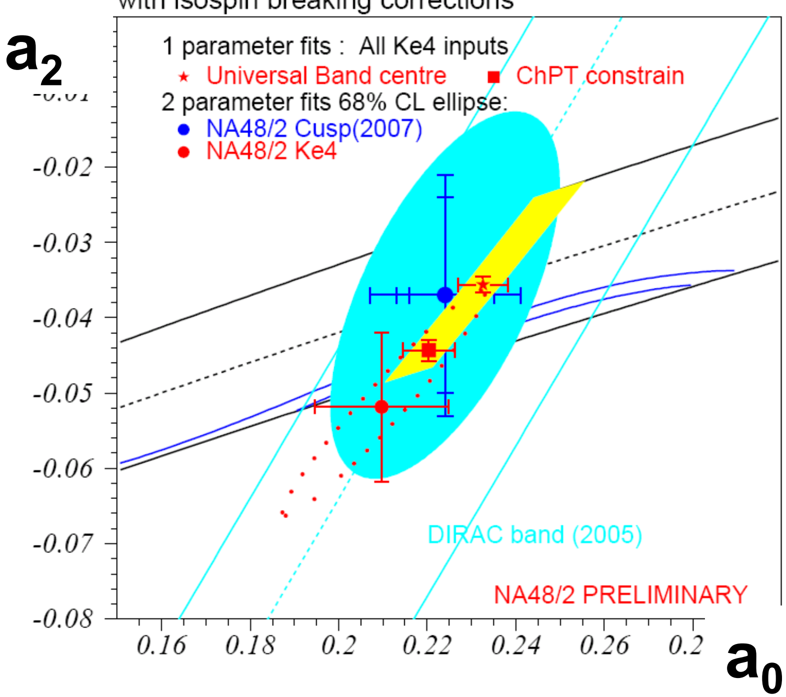
G. Lamanna, talk at this conference

# $K^{+-} \rightarrow \pi^+\pi^- e^{+-}\nu$ (Ke4) results

Comparison with other Ke4 results




with isospin breaking corrections




NA48/2

Five independent kinematic variables, expansion in form factors with spin-dependent coefficients, model-independent determination of coefficients and phase shift btw L=0 and L=1, δ.

$\delta \Rightarrow a_0$ and $a_2$ via theory

- 677500 $K^+$ and $K^-$ Ke4 decays (preliminary results on partial statistics)
- Ke4 Form factors measured with a precision within 5% to 15%

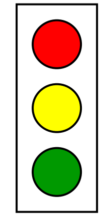
A new level of sensitivity

G. Lamanna, talk at this conference

Q=c,b

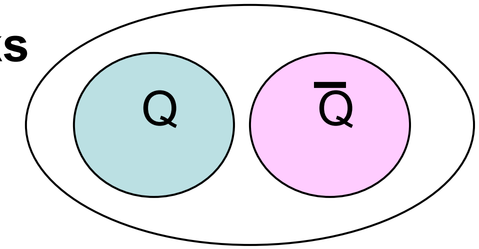
q=u,d,s

# Summary



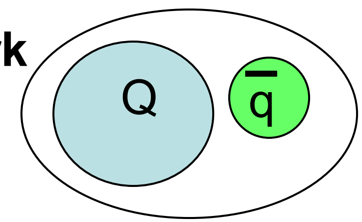
General goal:
Explore QCD phenomena
at different scales

**Two heavy quarks**




$\psi(2S)$ width
$J/\psi$, $\chi_{cJ}$ decay to light q
B decay to charmonium
States above DD threshold
Charmonium-like states

**One heavy quark**

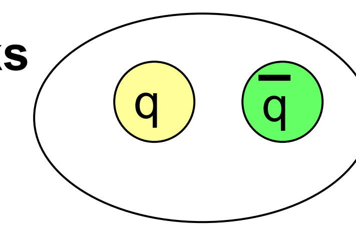



$D_{s1}(2536)^{+} \to D^{*+}K^{0}_{S}$
$\Xi_c(3077)$, $\Xi_c(3123)$

Non-perturbative QCD

**$a_0, f_0(980)$**
**$\eta,\eta'$ mixing and glue in $\eta'$**
**$\eta$ mass**
**$\eta(')$ decay**
**$K^{+-} \to \pi^{+}\pi^{-}e^{+-}\nu$, $\pi^{+-}\pi^{0}\pi^{0}$, $\pi^{\pm}\pi^{0}\gamma$**

**Zero heavy quarks**

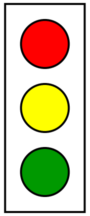



This talk: mostly mesons, but many new results on baryons as well. See list of topics at the end.

# Conclusion

Many measurements on hadron spectroscopy and decay are arriving

- Examples shown of new phenomena, systematic surveys, and precision studies
- Especially overwhelming the amount of new unclassified states: Organize!!



Many thanks to my colleagues on BaBar, Belle, BES, CLEO, KLOE, NA48, …

# Many more results

Bottomonium:

- CLEO bottomonium results: talk by H. Vogel at this conference
- CDF $h_b$ search: talk by A. Gessler at this conference

Charmonium:

- psi(2S) to gamma+light survey: BES, PRL99, 011802 (2007)
- psi(2S) multibody survey: CLEO: PRL 95, 062001 (2005)
- psi(3770) non-DDbar: CLEO, PRL 96, 032003 (2006), PRD 73, 012002 (2006)
  BES, C. Jiangchuan, talk at this conference
- J/psi to light: BES, Phys. Rev. Lett. 97 (2006) 142002: gamma pipi PWA

Y(4260):

- BaBar: PRL 95, 142001 (2005),
  CLEO: PRD 74, 091104(R),
  Belle "old" prelim: hep-ex/0612006

X(3872):

- X(3872) mass: BaBar, G. Cibinetto, talk at this conference
- D0 mass: CLEO, PRL 98, 092002 (2007)

Charm mesons:

- BaBar: T. Schroeder, talk at this conference
- Belle: B0bar -> D**+ pi-; (observation of D_0*) hep-ex/0611054 (acc by PRD)

Open charm production:

- Belle: e+e- -> D(*)D* cross-section (at sqrt(s) from threshold to ~5 GeV), PRL98, 092001 (2007)

Baryons:

- Belle, $\Lambda_c$(2880) J^P and $\Lambda_c$(2940) -> $\Sigma_c$ $\pi$; PRL 98, 262001 (2007)
- Belle, Observation of $\Xi_c$(2980), $\Xi_c$(3077); PRL 97, 162001 (2006)
- BaBar: T. Schroeder, talk at this conference
- D0: $\Lambda_b$ lifetime, $\Xi_b$ discovery: E. De La Cruz Burelo, talk at this conference

Light scalars:

- KLOE: $a_0$ → eta $pi^0$, $f_0$ → $pi^0 pi^0$ shown at winter conferences

Light resonances:

- E. Fadeeva, talk at this conference

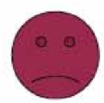
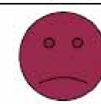
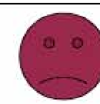
NA48

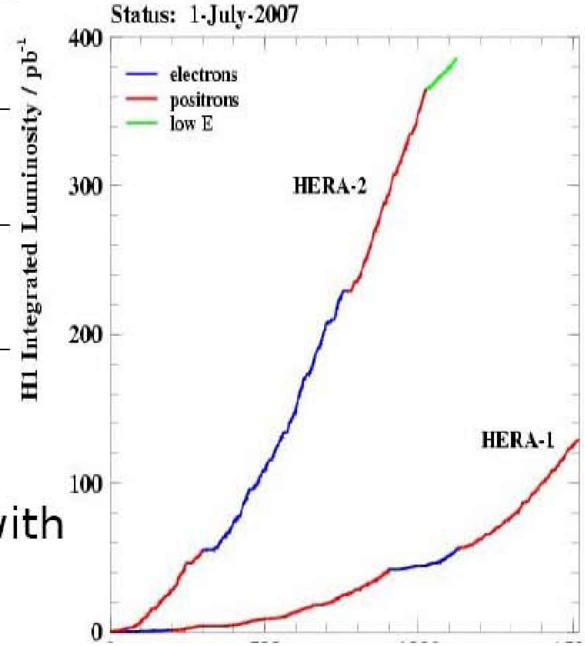
- Radiative decays: M. Piccini, talk at this conference

D. Ozerov, talk at this conference

# Pentaquarks Summary

• Complete HERA I data was analysed with the following results from H1 & ZEUS:

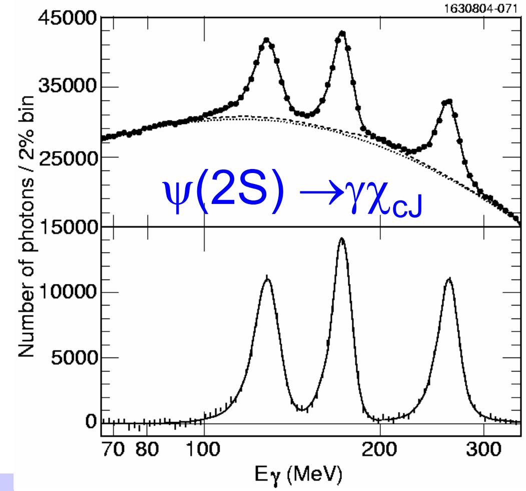
| | H1 | ZEUS |
|---|---|---|
| strange pentaquark ($K^0_s p$) |  |  |
| double strange pentaquark ($\Xi\,\pi$) |  |  |
| charm pentaquark ($D^* p$) |  |  |




This controversial situation will be possible to resolve with high statistics HERA II data

# Charmonium States

$\chi_{cJ}$: masses, width, dominant decay modes reasonably well measured. Beginning to study substructure.

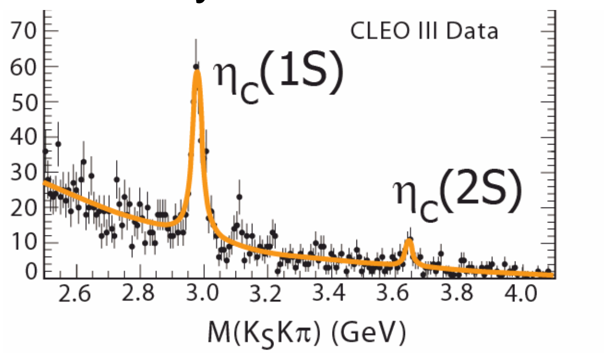



$\eta_c(2S)$:
mass recently remeasured,
width a moving target,
M1 rates not measured,
only one decay mode seen

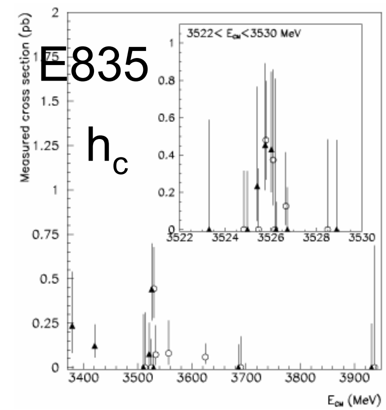
$2^1S_0$ $2^3S_1$

$1^1P_1$ $1^3P_J$

$h_c$ $\chi_c$




$h_c$: Newest member of the family, seen in $\psi(2S) \to \pi^0 h_c \to \gamma\eta_c$ and in $p\bar{p}$ production, product BR measured. That's it!




$\eta_c(1S)$: mass and width known to MeV's, most urgent project: M1 transition rate $J/\psi \to \gamma\eta_c$

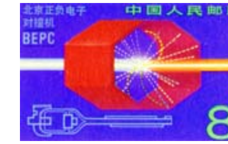
$1^1S_0$ $1^3S_1$

$\eta_c$ $\psi$

$\psi(2S), J/\psi$: accessible in $e^+e^-$. Masses, total width, dominant decay modes well measured. Studying BR's in the range of <0.01%, and substructure.

PRL99, 011802 (2007)

# $\psi(2S) \to \gamma$ + light hadrons




$\psi(2S)$ to light hadrons, PDG07:

$\gamma\pi^0$
$\gamma\eta'(958)$
$\gamma f_2(1270)$
$\gamma f_0(1710)$
  $\gamma f_0(1710) \to \gamma\pi\pi$
  $\gamma f_0(1710) \to \gamma K\overline{K}$
$\gamma\gamma$
$\gamma\eta$
$\gamma\eta\pi^+\pi^-$
$\gamma\eta(1405)$
  $\gamma\eta(1405) \to \gamma K\overline{K}\pi$
  $\gamma\eta(1405) \to \eta\pi^+\pi^-$
$\gamma\eta(1475)$
  $\gamma\eta(1475) \to K\overline{K}\pi$
  $\gamma\eta(1475) \to \eta\pi^+\pi^-$

All limits or meas'ts at $10^{-4..5}$

The corresponding list for the $J/\psi$ is almost 50 entries long…

BR($\psi(2S) \to ggg + \gamma gg$)
= $1 - \pi\pi, \eta, \pi^0 J/\psi - \Sigma M1, E1$ = ~ 20%

$J/\psi$: $\gamma gg$/ $ggg$ ~6%

BR($\psi(2S) \to \gamma gg$) ~ 1%
Where are they?

BES: survey of $\gamma + n(\pi^+\pi^-) + m(K^+K^-)$

| Mode | $N^{Tot}$ | $N^{Bg}$ | $N^{Sig}$ | $\epsilon(\%)$ | $\mathcal{B}(\times 10^{-5})$ |
|---|---|---|---|---|---|
| $\gamma p\bar{p}$ | 329 | 187 | $142 \pm 18$ | 35.3 | $2.9 \pm 0.4 \pm 0.4$ |
| $\gamma 2(\pi^+\pi^-)$ | 1697 | 1114 | $583 \pm 41$ | 10.4 | $39.6 \pm 2.8 \pm 5.0$ |
| $\gamma K^0_S K^+\pi^- + c.c.$ | – | – | $115 \pm 16$ | 4.83 | $25.6 \pm 3.6 \pm 3.6$ |
| $\gamma K^+K^-\pi^+\pi^-$ | 361 | 229 | $132 \pm 19$ | 4.94 | $19.1 \pm 2.7 \pm 4.3$ |
| $\gamma K^{*0} K^+\pi^- + c.c.$ | – | – | $237 \pm 39$ | 6.86 | $37.0 \pm 6.1 \pm 7.2$ |
| $\gamma K^{*0}\bar{K}^{*0}$ | 58 | 17 | $41 \pm 8$ | 2.75 | $24.0 \pm 4.5 \pm 5.0$ |
| $\gamma\pi^+\pi^- p\bar{p}$ | 55 | 38 | $17 \pm 7$ | 4.47 | $2.8 \pm 1.2 \pm 0.5$ |
| $\gamma K^+K^-K^+K^-$ | 15 | 8 | $< 14$ | 2.93 | $< 4.0$ |
| $\gamma 3(\pi^+\pi^-)$ | 118 | 95 | $< 45$ | 1.97 | $< 17$ |
| $\gamma 2(\pi^+\pi^-)K^+K^-$ | 17 | 13 | $< 15.5$ | 0.69 | $< 22$ |

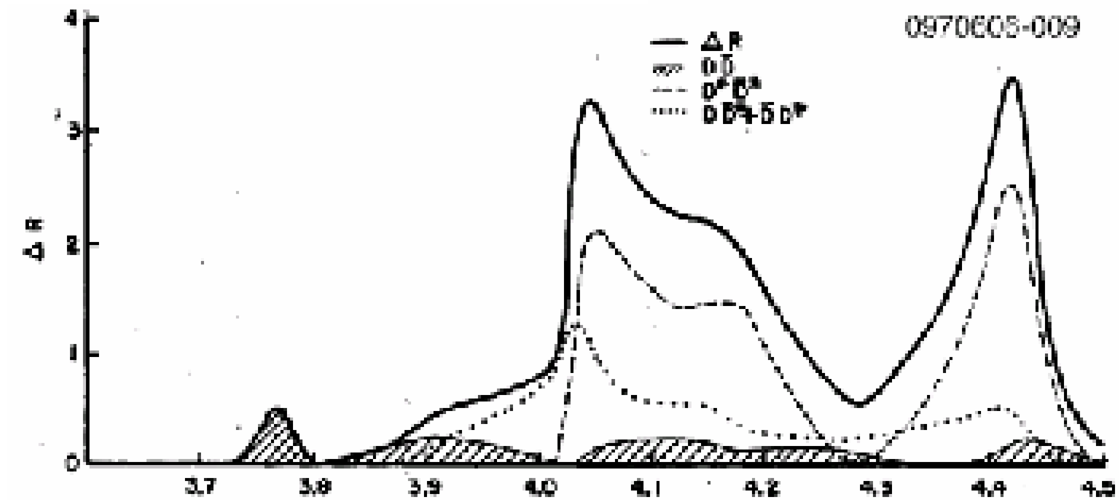
Sum nowhere near 1%…

Also included $\pi^0 + 2(\pi^+\pi^-)$[and $K^+K^-$], rich resonant substructure

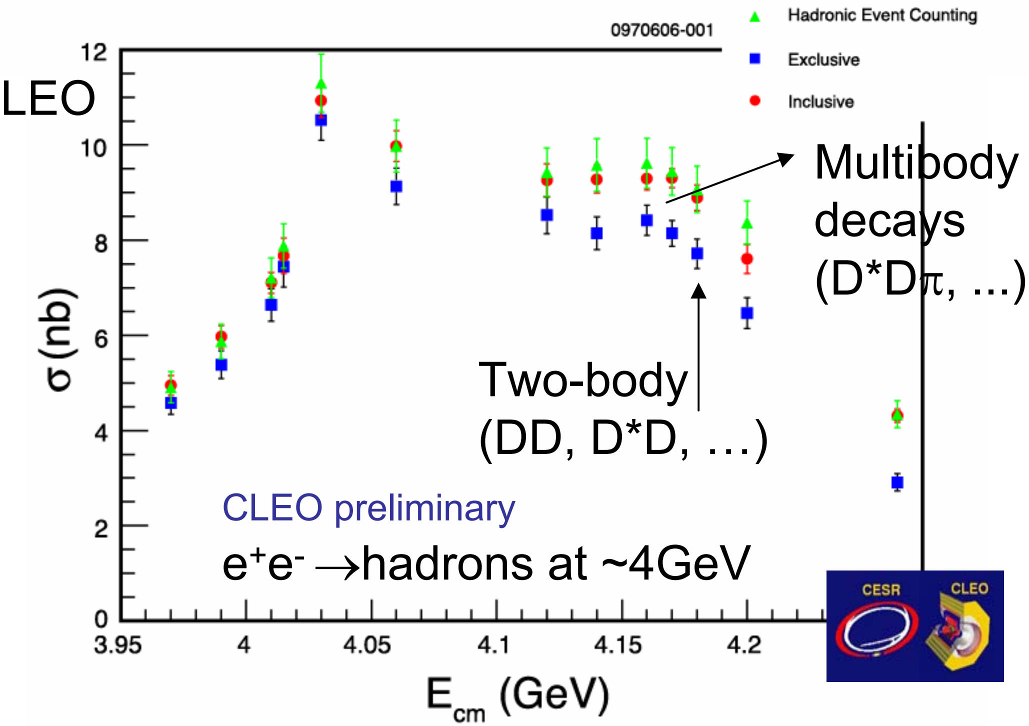
# Open charm production in $e^+e^-$

Study dependence of production rate on center-of-mass energy

Eichten et al, PRD 21, 208 (1980)




CLEO inclusive:



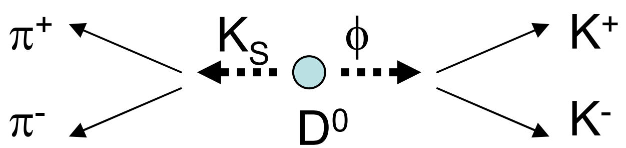

Decomposition of this cross-section?

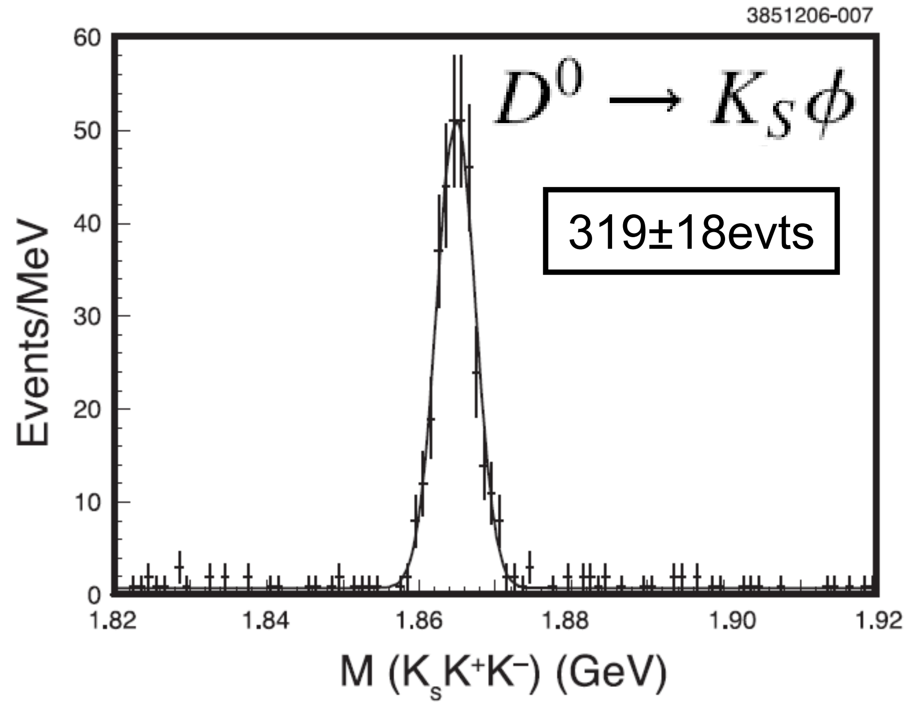
Measure yield of $D/D^*/D_S/\ldots$ combinations as function of $E_{cm}$

# $D^0$ mass measurement

PDG: $M(D^0)=1864.5\pm0.4$MeV
- average of LGW, MARK II, NA32
- Measured in $D^0\to K\pi$, $K\pi\pi\pi$

CLEO-c, 281pb$^{-1}$, use $D^0\to K_S\varphi$:
- $M(D^0)-M(\varphi)-M(K_S)=347$MeV
- $p(K)$, $p(\pi)$ <600MeV range
- Cross-check: $M(\psi(2S)\to\pi^+\pi^-J/\psi)$




$$M(D^0) = 1864.847 \pm 0.150(\text{stat}) \pm 0.095(\text{syst})\ \text{MeV}$$

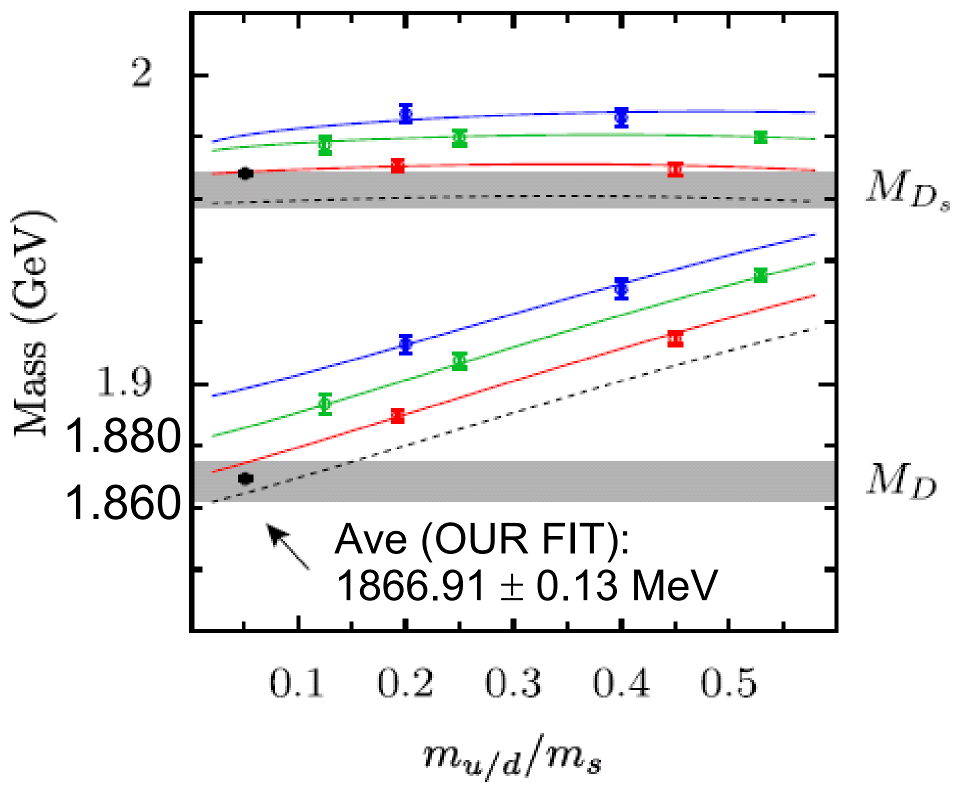
# LQCD D mass calculation

$D^+$

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **1869.62 ± 0.20 OUR FIT** | Error includes scale factor of 1.1. | | | | | | |
| **1869.5 ± 0.5 OUR AVERAGE** | | | | | | | |
| 1870.0 ± 0.5 ±1.0 | 317 | | BARLAG | 90C | ACCM | $\pi^-$ Cu 230 GeV |
| 1869.4 ± 0.6 | | [1] | TRILLING | 81 | RVUE | $e^+e^-$ 3.77 GeV |

$D^0$

| | | | | |
|---|---|---|---|---|
| **1864.84 ± 0.17 OUR FIT** | Error includes scale factor of 1.1. | | | |
| **1864.84 ± 0.18 OUR AVERAGE** | | | | |
| 1864.847 ± 0.150 ± 0.095 | 319 ± 18 | CAWLFIELD | 07 | |




LQCD arXiv:0706.1726 (hep-lat)

# $\eta,\eta'$: mixing and gluonium

**The η , η' mesons wave function can be decomposed in the strangeness non strangeness base.**

$$|\eta'>= X_{\eta'}|q\bar{q}> +Y_{\eta'}|s\bar{s}> +Z_{\eta'}|gluon>$$
$$|\eta> \;=\; cos(\varphi_p)|q\bar{q}> -sin(\varphi_p)|s\bar{s}>$$

$$X_{\eta'} = \cos\phi_G \sin\varphi_P$$
$$Y_{\eta'} = \cos\phi_G \cos\varphi_P$$
$$Z_{\eta'} = \sin\phi_G$$

$$\frac{Br(\phi\to\eta'\gamma)}{Br(\phi\to\eta\gamma)} = R_\phi = \cot^2\phi_P\cdot\cos^2\phi_G\left(1-\frac{m_s}{\bar{m}}\cdot\tan\frac{\phi_V}{\sin 2\phi_P}\right)^2\cdot\left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

**Comparing with other decay rates using SU(3) relations:**

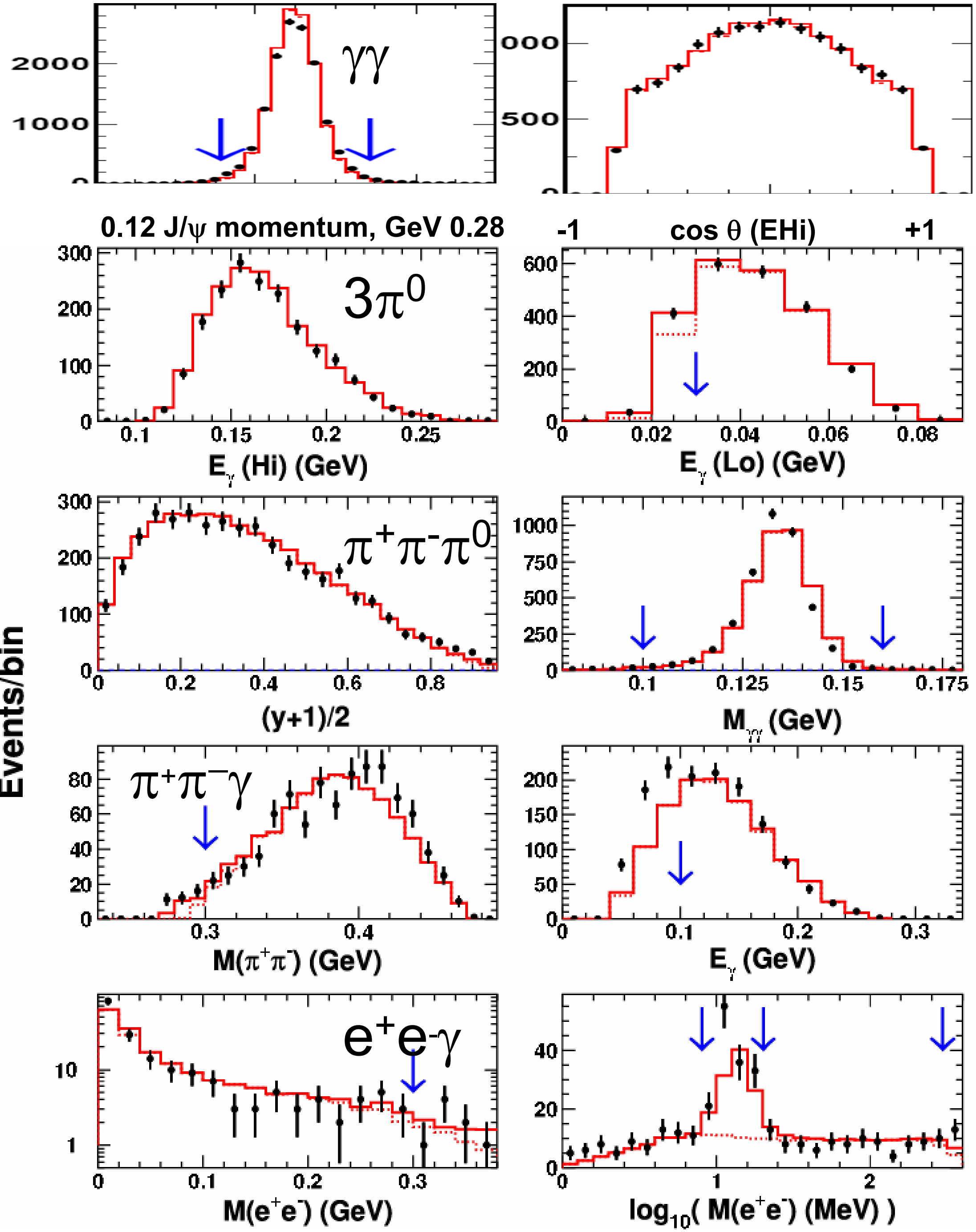
$$\Gamma(\eta'\to\gamma\gamma)/\Gamma(\pi^0\to\gamma\gamma) = \frac{1}{9}\left(\frac{m_{\eta'}}{m_\pi}\right)^3\left(5\cos\phi_G\sin\varphi_P + \sqrt{2}\frac{f_q}{f_s}\cos\phi_G\cos\varphi_P\right)^2$$

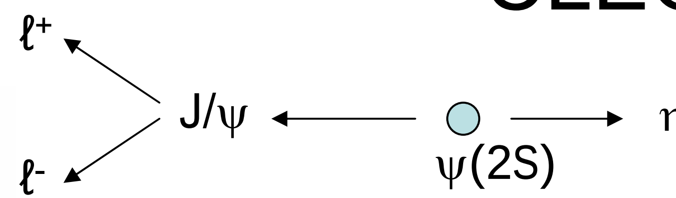
$$\Gamma(\eta'\to\rho\gamma)/\Gamma(\omega\to\pi^0\gamma) = \frac{C_{NS}}{\cos\varphi_V}\cdot 3\left(\frac{m^2_{\eta'}-m^2_\rho}{m^2_\omega-m^2_\pi}\frac{m_\omega}{m_{\eta'}}\right)^3\cos^2\phi_G\sin^2\varphi_P$$

$$\Gamma(\eta'\to\omega\gamma)/\Gamma(\omega\to\pi^0\gamma) = \frac{1}{3}\left(\frac{m^2_{\eta'}-m^2_\omega}{m^2_\omega-m^2_\pi}\frac{m_\omega}{m_{\eta'}}\right)^3 [C_{NS}\cdot\cos\phi_G\sin\varphi_P + 2\frac{m_s}{\bar{m}}C_S\cdot\tan\varphi_V\cdot\cos\phi_G\cos\varphi_P]^2$$

The gluonium coupling is neglected.

# η branching ratios, CLEO




27M ψ(2S),
$B(\psi(2S)\to\eta J/\psi)$ = 3.1%,
$B(J/\psi\to l^+l^-)$ = 12%,

Fully reconstruct five final states:
$\gamma\gamma + 3\pi^0 + \pi^+\pi^-\pi^0 + \pi^+\pi^-\gamma + e^+e^-\gamma$

Constrain $\ell^+$, $\ell^-$ ⇒J/ψ,
constrain J/ψ, η products ⇒ ψ(2S)

Excellent data/MC agreement

Measurement of ratios allow cancellation of systematics

Follow PDG procedure: sum of the above five modes is ~ 100%
⇒ build absolute Br's from ratios

# *Results and systematics*

KLOE

The result is dependent from the knowledge of the sqrt(s). It is calibrated using the resonance curve of the $\phi \to K_S K_L$.

$m(\phi) = 1019.483 \pm 0.011 \pm 0.025$ MeV/c$^2$

CMD-2 Phys. Lett. B578, 285

**$M(\pi^0) = ( 134990 \pm 6_{stat} \pm 30_{syst} )$ keV**

**$M(\pi^0)_{\Pi\Delta\Gamma} = ( 134976.6 \pm 0.6 )$ keV**

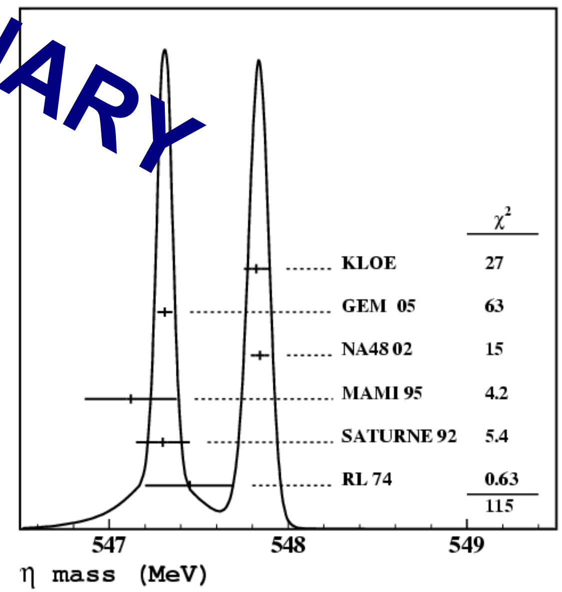
**$M(\eta) = ( 547822 \pm 5_{stat} \pm 69_{syst} )$ keV**

PRELIMINARY

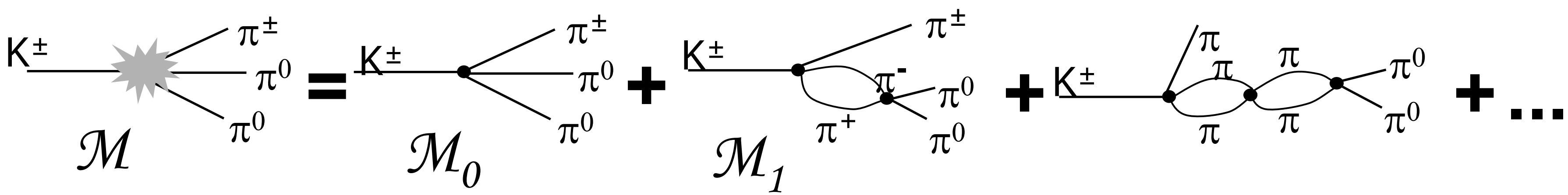
- NA48 compatibility: 0.24 $\sigma$
- Independent measurement with the $\eta \to \pi^+\pi^-\pi^0$ decay mode in progress: $m_\eta = 547.95 \pm 0.15$ MeV/c$^2$ (very preliminary fully in agreement with the $\gamma\gamma$ channel)

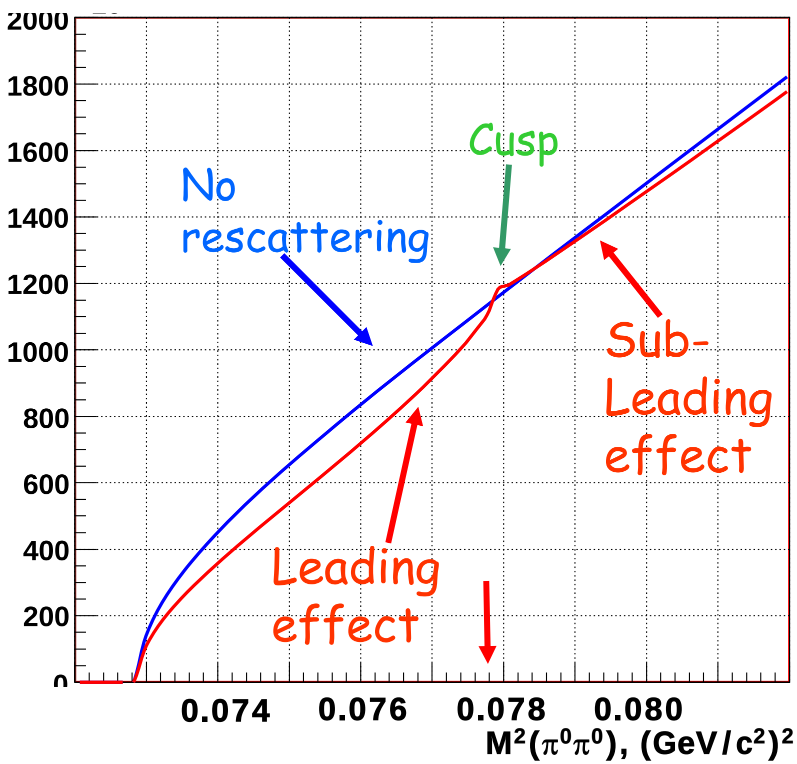
Systematic table

| | err./(tot. err) |
|---|---|
| **Calorimeter calibration** | **1%** |
| **Calorimeter linearity** | **1 %** |
| **Vertex position** | **1 %** |
| **Azimuthal dependence** | **18 %** |
| **Polar dependence** | **8 %** |
| **Dalitz plot cut + corr.** | **67 %** |



# Cusp: two loops




Cabibbo, Isidori JHEP 0503 (2005) 21

- Including 2-loops diagrams other terms appear in the amplitude
- All the S-wave amplitudes (5 terms) can be expressed as linear combination of a0 and a2
- The isosping breaking effect is taking in to account
- The radiative correction (most relevant near threshold) are still missing
- A deviation from the no rescattering amplitude behaviour appears also above threshold

# $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$: First measurement of direct emission contribution

NA48/2

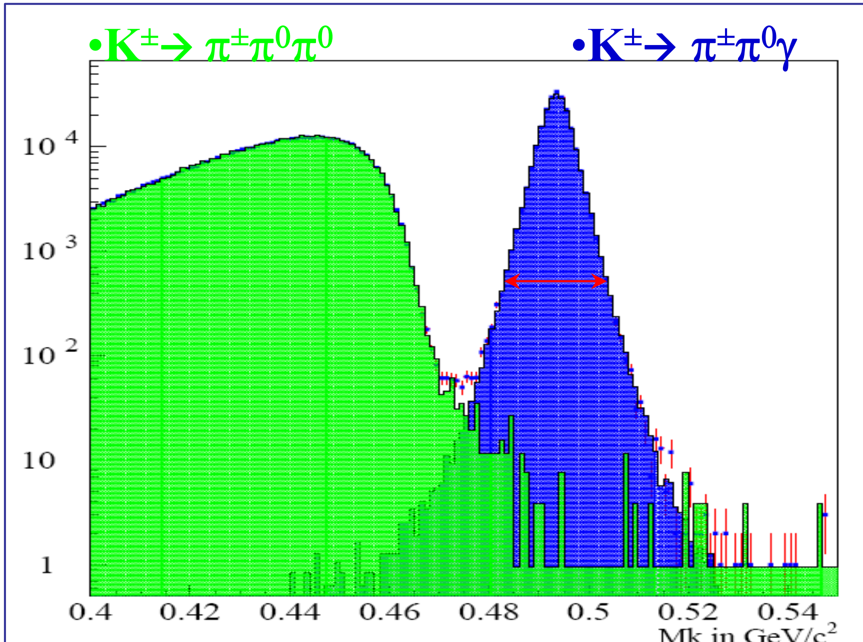
$$\frac{d\Gamma^{\pm}}{dW} \simeq \underbrace{\left(\frac{d\Gamma^{\pm}}{dW}\right)_{IB}}_{\text{IB}} \left[1 + \underbrace{2\left(\frac{m_\pi}{m_K}\right)^2 W^2 |E| cos((\delta_1 - \delta_0) \pm \phi)}_{\text{INT}} + \underbrace{\left(\frac{m_\pi}{m_K}\right)^4 W^4 (|E|^2 + |M|^2)}_{\text{DE}}\right]$$

Sensitive variable:

$$W^2 = \frac{(P_K^* \cdot P_\gamma^*)(P_\pi^* \cdot P_\gamma^*)}{(m_k m_\pi)^2}$$

$P^*_K$ = 4-momentum of the $K^{\pm}$
$P^*_\pi$ = 4-momentum of the $\pi^{\pm}$
$P^*_\gamma$ = 4-momentum of the $\gamma$

~124K events from 2003 data




Preliminary result:

$\text{Frac(DE)}_{0<T^*_\pi<80\text{ MeV}} = (3.35 \pm 0.35 \pm 0.25)\%$

$\text{Frac(INT)}_{0<T^*_\pi<80\text{ MeV}} = (-2.67 \pm 0.81 \pm 0.73)\%$

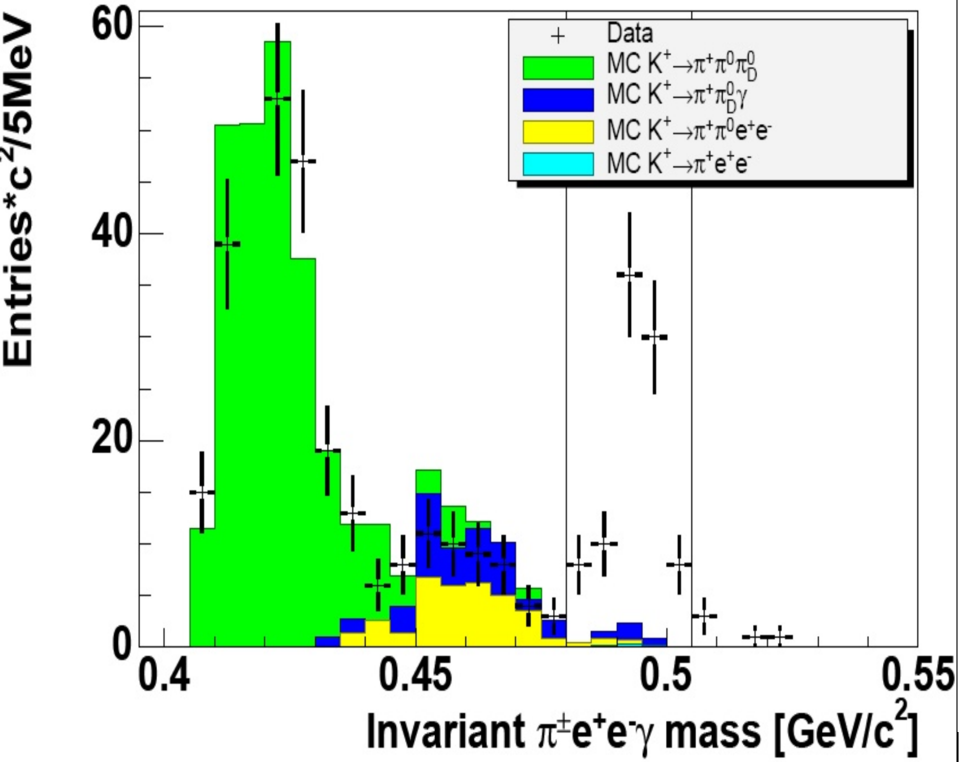
Correlation=-92%

2004 data set: x4 # events and lower systematic due to trigger (analysis ongoing)

Weak radiative decay
NA48/2

## $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma$

First evidence from 2003 data

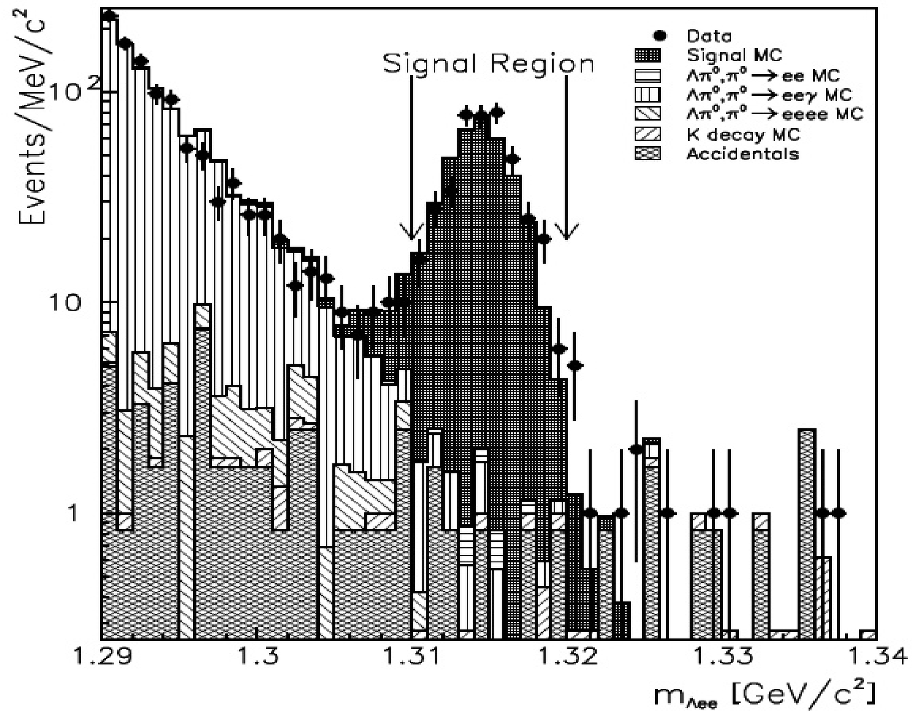



Preliminary result:

$BR=(1.27\pm0.14_{stat}\pm0.05_{sys})\cdot10^{-8}$

## $\Xi^{0}\rightarrow\Lambda^{0}e^{+}e^{-}$

First evidence from 2002 data




Final result (**Phys.Lett.B650:1-8,2007**):

$BR(\Xi\rightarrow\Lambda ee)$ =
$7.7\pm0.5stat\pm0.4syst\cdot10^{-6}$
$\alpha(\Xi\rightarrow\Lambda ee)= -0.8 \pm 0.2$