

Light Meson Spectroscopy at CLEO-c

Matthew Shepherd
Indiana University

(for the CLEO Collaboration)

April 9, 2008

International Workshop on e^+e^- Collisions from Φ to ψ

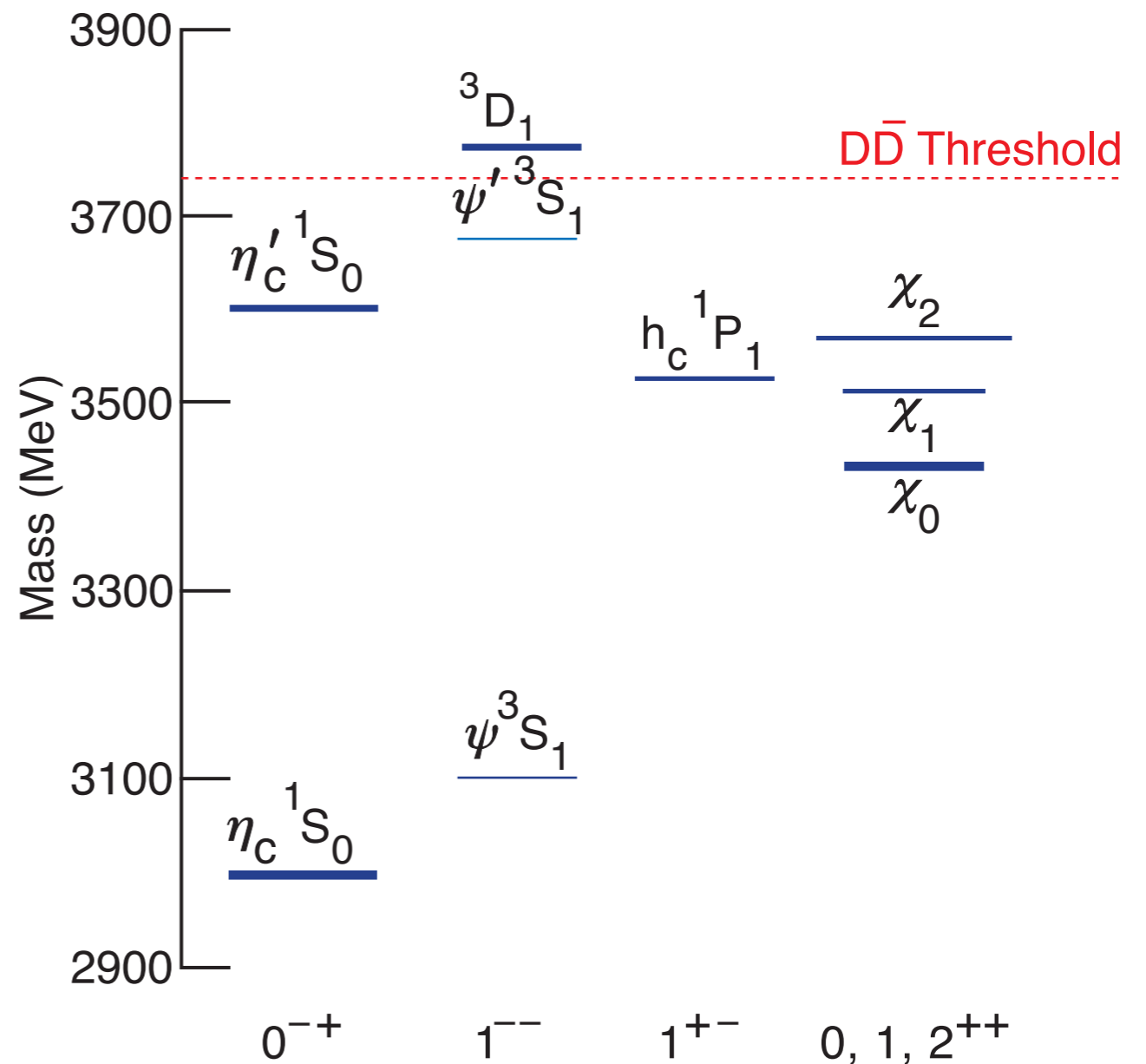
The CLEO-c Physics Program

- Three major data sets:
 - 818 pb⁻¹ sample taken at $\psi(3770)$ which will yield over 5 million DD events
 - studies of quantum correlated decays, mixing, precision flavor physics (J. Libby - Monday)
 - light meson spectroscopy in multi-body D decays
 - ~600 pb⁻¹ taken at $E_{CM} = 4170$ MeV where D_s production is enhanced
 - D_s leptonic and semileptonic form factors
 - 58 pb⁻¹ at ψ' → 27 million ψ' decays, clean source of “tagged” J/ψ and χ_c
 - QCD in the charmonium system *tomorrow!*
 - production and properties of light mesons in decay of charmonia
- Scan of open charm cross sections from 3.97 - 4.26 GeV (J. Libby - yesterday)



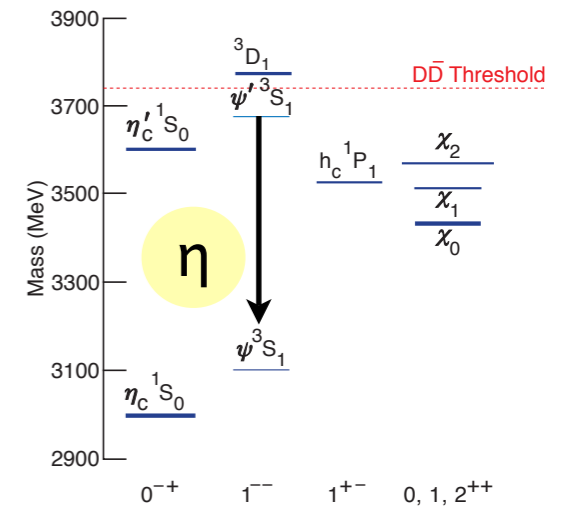
The Charmonium System: An Outline

- Studies of light meson properties in transitions and decay of charmonia
- Results:
 - η mass and branching fraction measurements in $\psi' \rightarrow \eta J/\psi$
 - spectroscopy in decays of the χ_c
 - light meson interactions on the $D^+ \rightarrow K^- \pi^+ \pi^+$ Dalitz plot

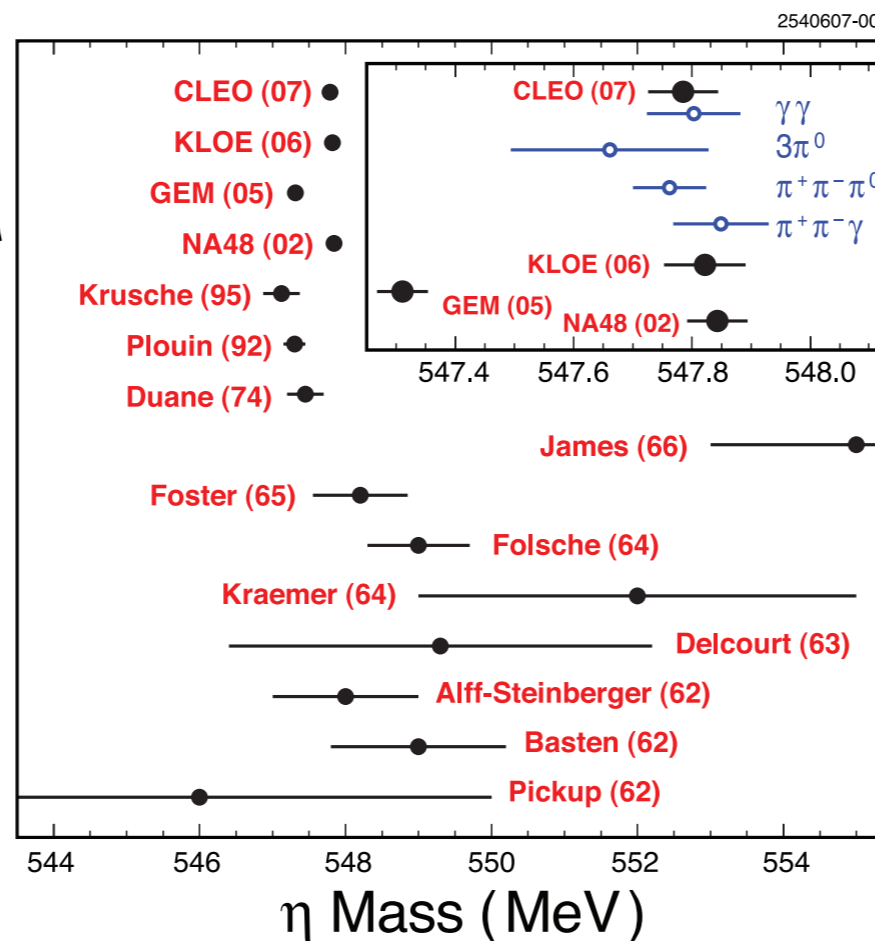


η Mass

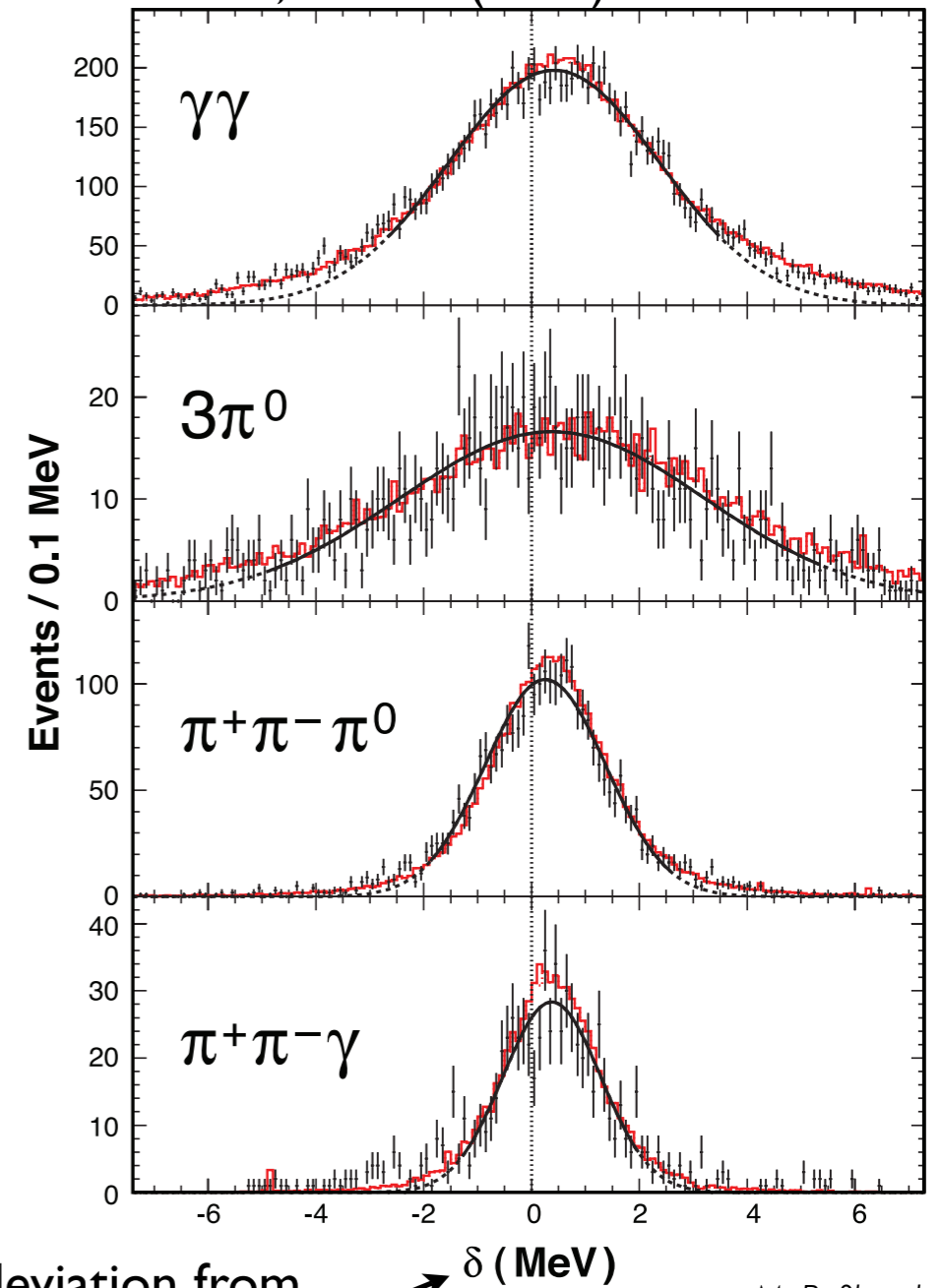
- Use the transition $\psi' \rightarrow \eta J/\psi$, with $J/\psi \rightarrow l^+l^-$, to study the properties of the η
- Kinematic fitting of both J/ψ and ψ' to known masses improves η mass resolution (test technique on π^0):
 $M_\eta = 547.785 \pm 0.017 \pm 0.057$ MeV



Compare w/KLOE Update
 JHEP 0712, 073 (2007):
 $M_\eta = 547.873 \pm 0.007 \pm 0.029$ MeV
 Good agreement!



PRL 99, 122002 (2007)

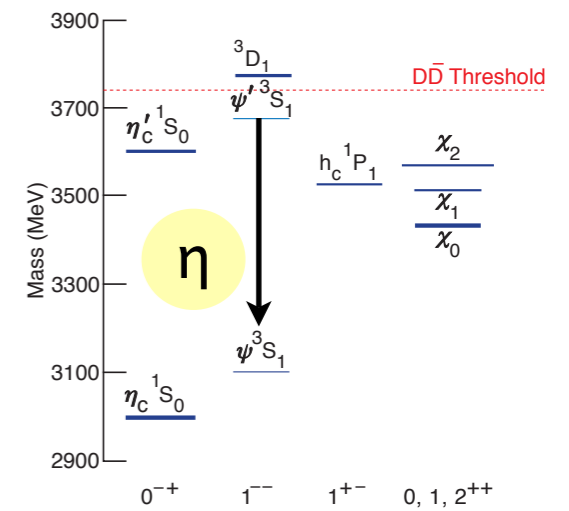


deviation from
 PDG07 Avg.

M. R. Shepherd
 PHPSI 08, INFN Frascati
 April 9, 2008



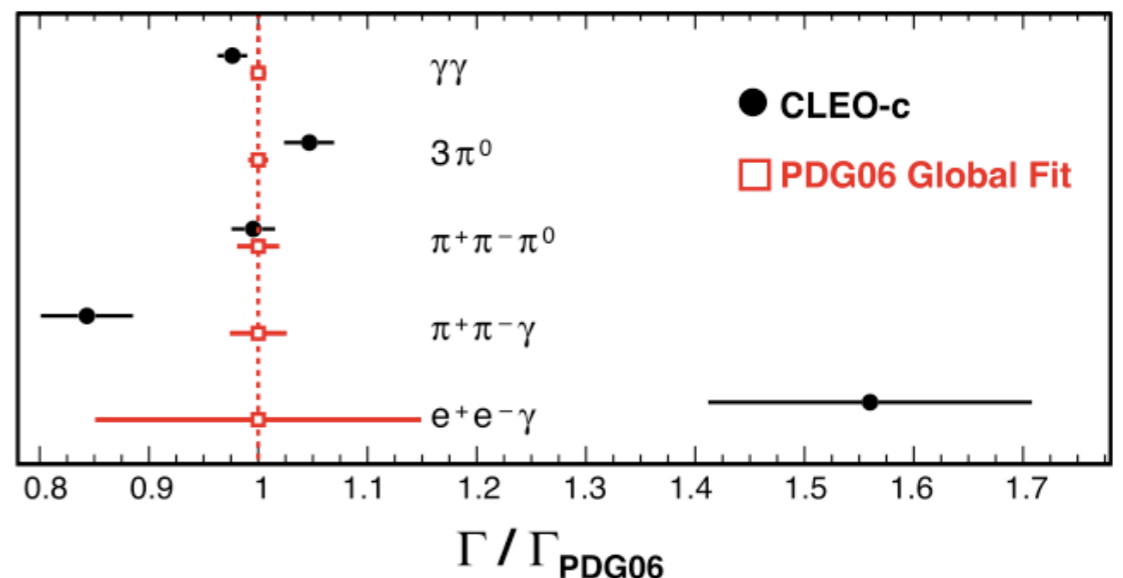
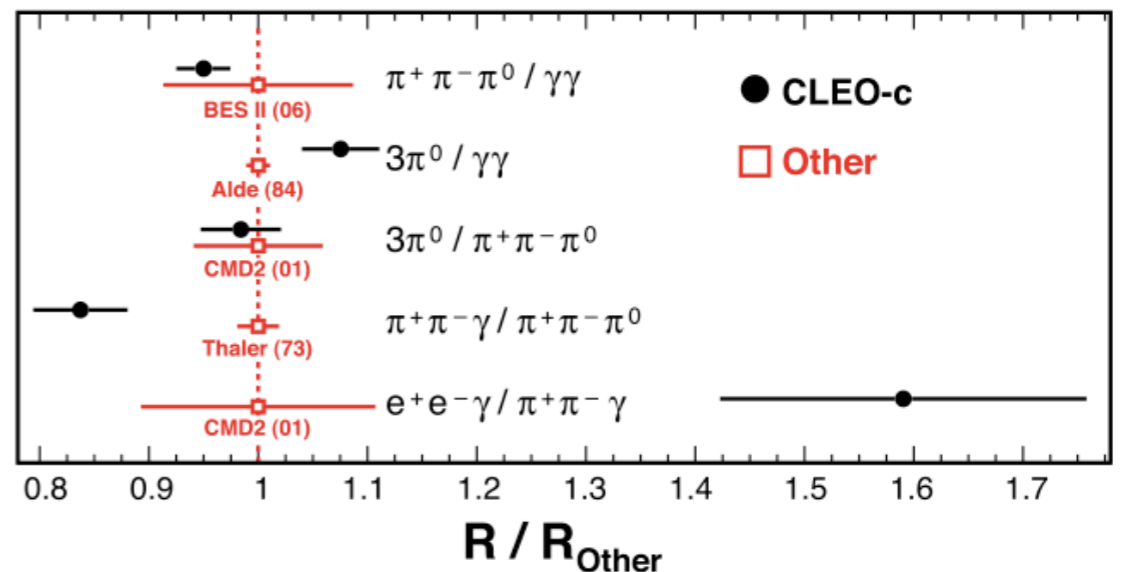
η Branching Fractions



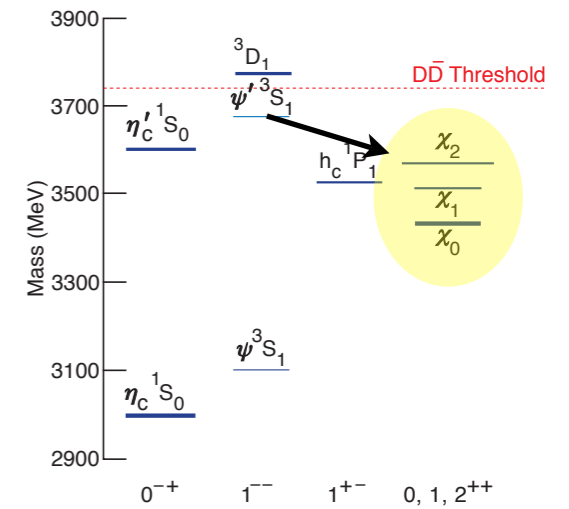
- Apply similar technique to simultaneously measure all allowed branching fractions of η
- Construct absolute branching fractions by measuring all possible branching fraction ratios
- Assume measured modes comprise all modes (limit on “other” < 0.2%)
- Systematics are well under control since all measurements are made with the same experiment

PRL 99, 122001 (2007)

2540607-004

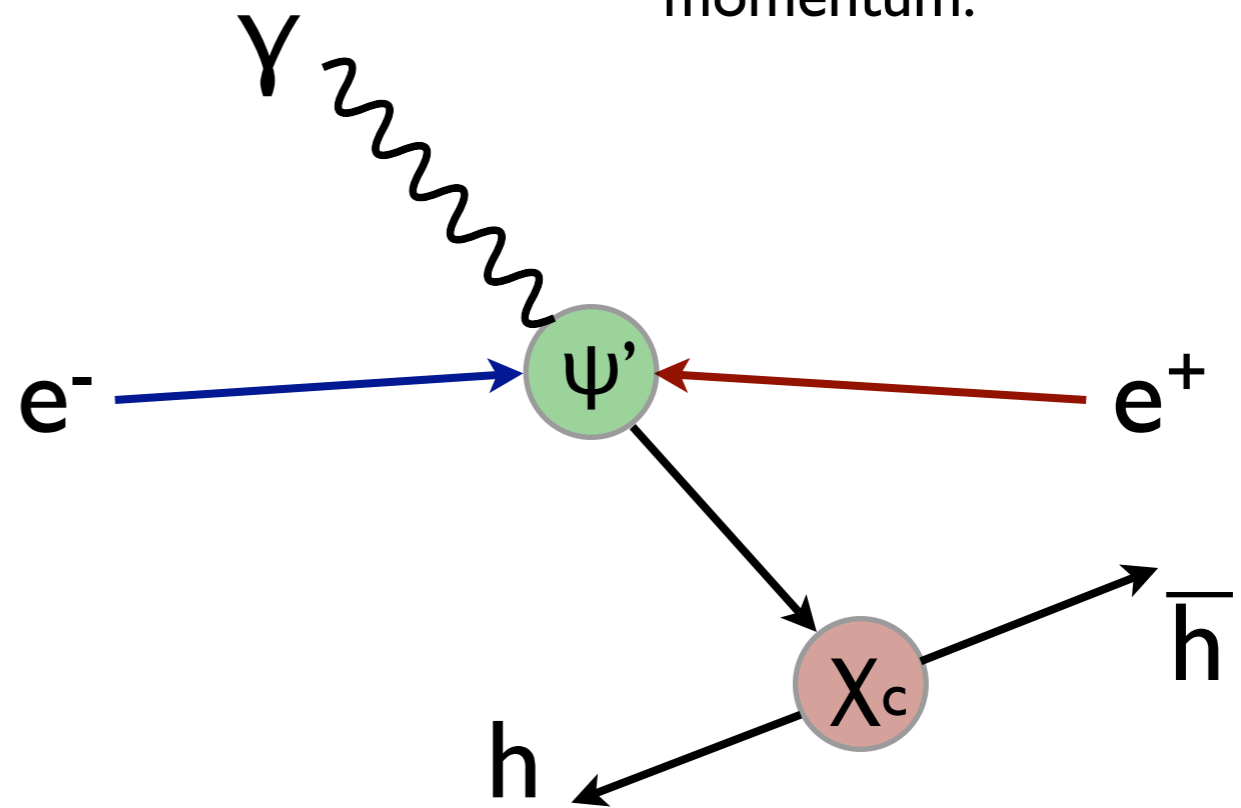


Hadronic χ_{cJ} Decays



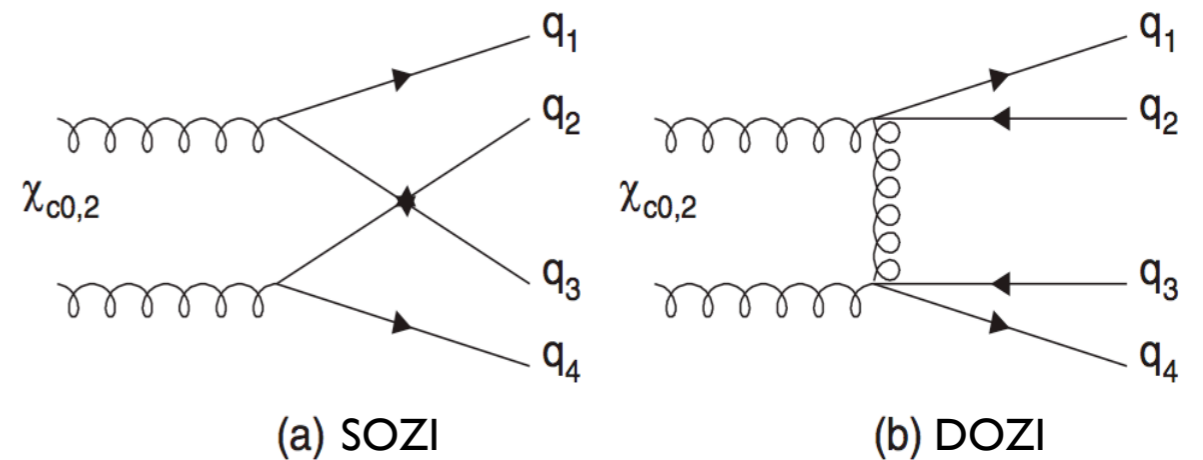
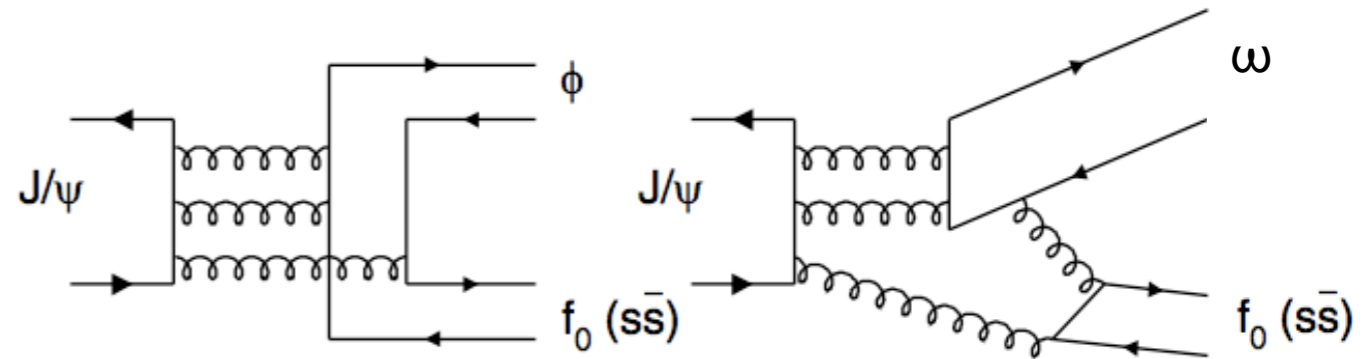
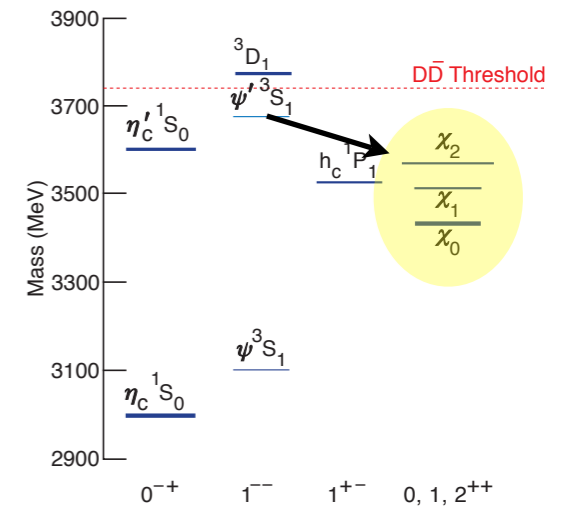
- Decays of χ_c proceed by annihilation into light quarks -- patterns of decays may provide insight on light meson and glueball structure
- χ_c produced in electromagnetic transitions from the ψ'
 - BF ~8-10% provides high statistics χ_c sample
- Search for various hadronic multi-body decay modes of χ_c

Analysis relies on identification of all decay products and kinematic fit to initial ψ' four-momentum.



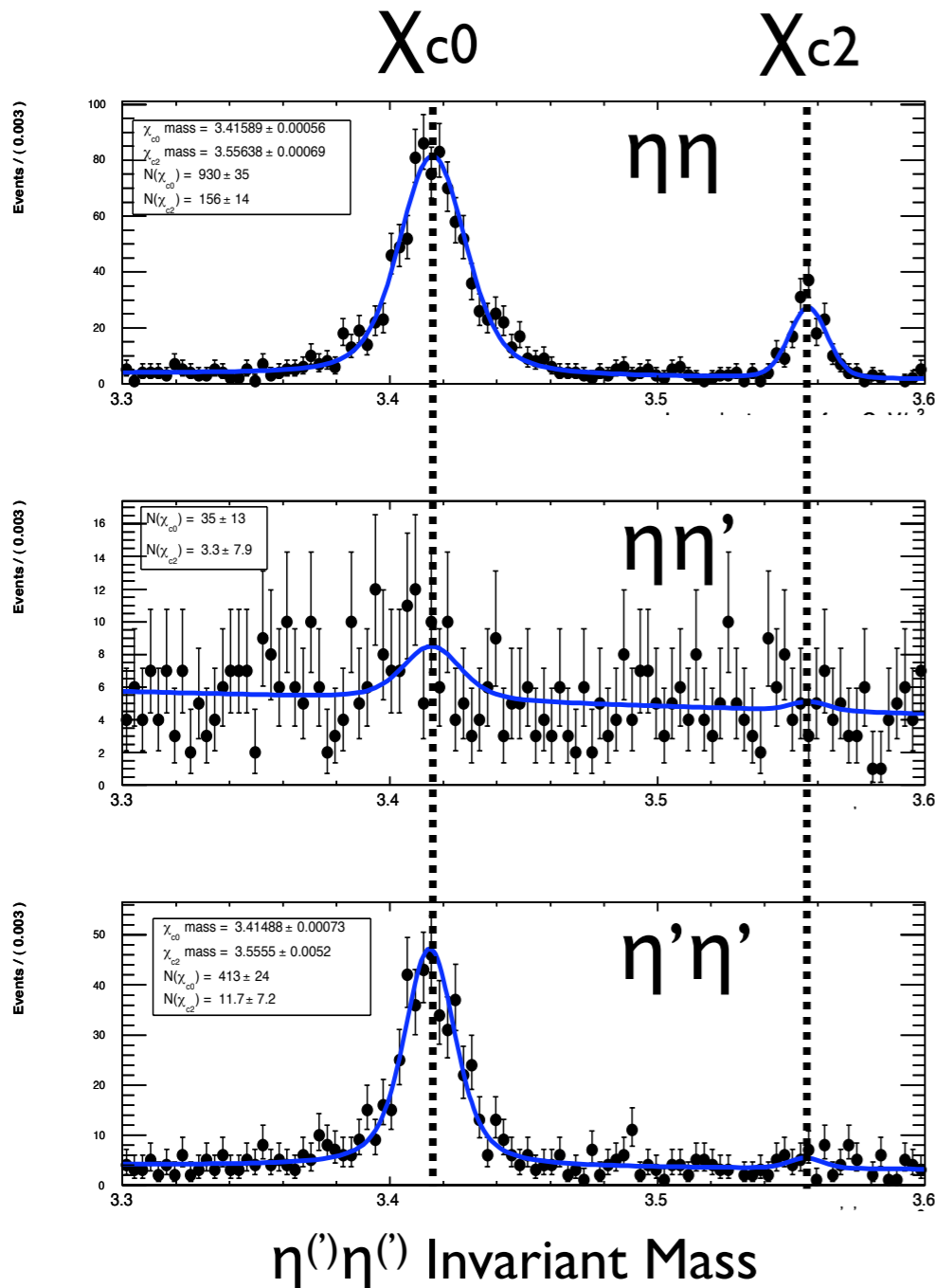
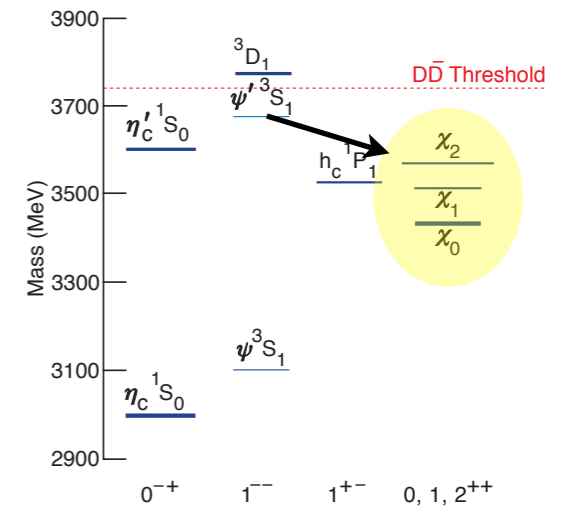
$\chi_{cJ} \rightarrow \eta^{(\prime)} \eta^{(\prime)}$

- It is interesting that $B(J/\psi \rightarrow \omega f_0(1710))$ is greater than $B(J/\psi \rightarrow \phi f_0(1710))$ given $f_0(1710)$ is thought to be largely strange.
- Suggestive of large OZI violating effects in J/ψ decay? ...glueball mixing? (F. Close and Q. Zhao, PRD 71, 094022)
- Look for similar effects in χ_c decays to the pseudoscalar isoscalars
 - connected to η -glueball mixing
- Use the factorization scheme proposed by Q. Zhao (PRD 72, 074001; PLB 659, 221)



$r =$ relative strength between singly-OZI and doubly-OZI suppressed transition amplitudes

$\chi_{cJ} \rightarrow \eta^{(\prime)}\eta^{(\prime)}$



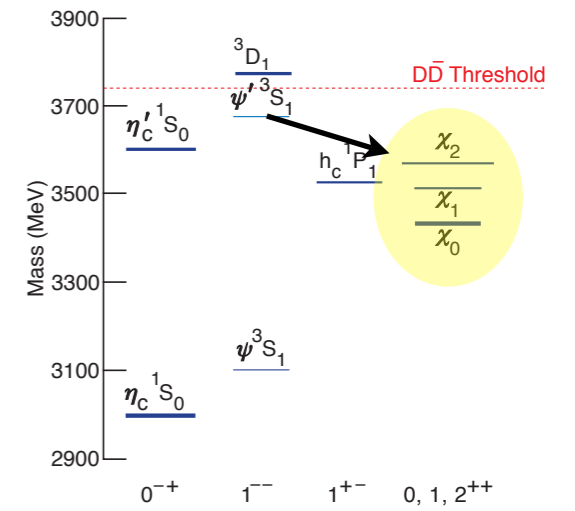
- Analysis utilizes the large 25M ψ' sample
- Supersedes previous CLEO analysis on 3M ψ' (PRD 75, 071101(R)(2007))

CLEO Preliminary

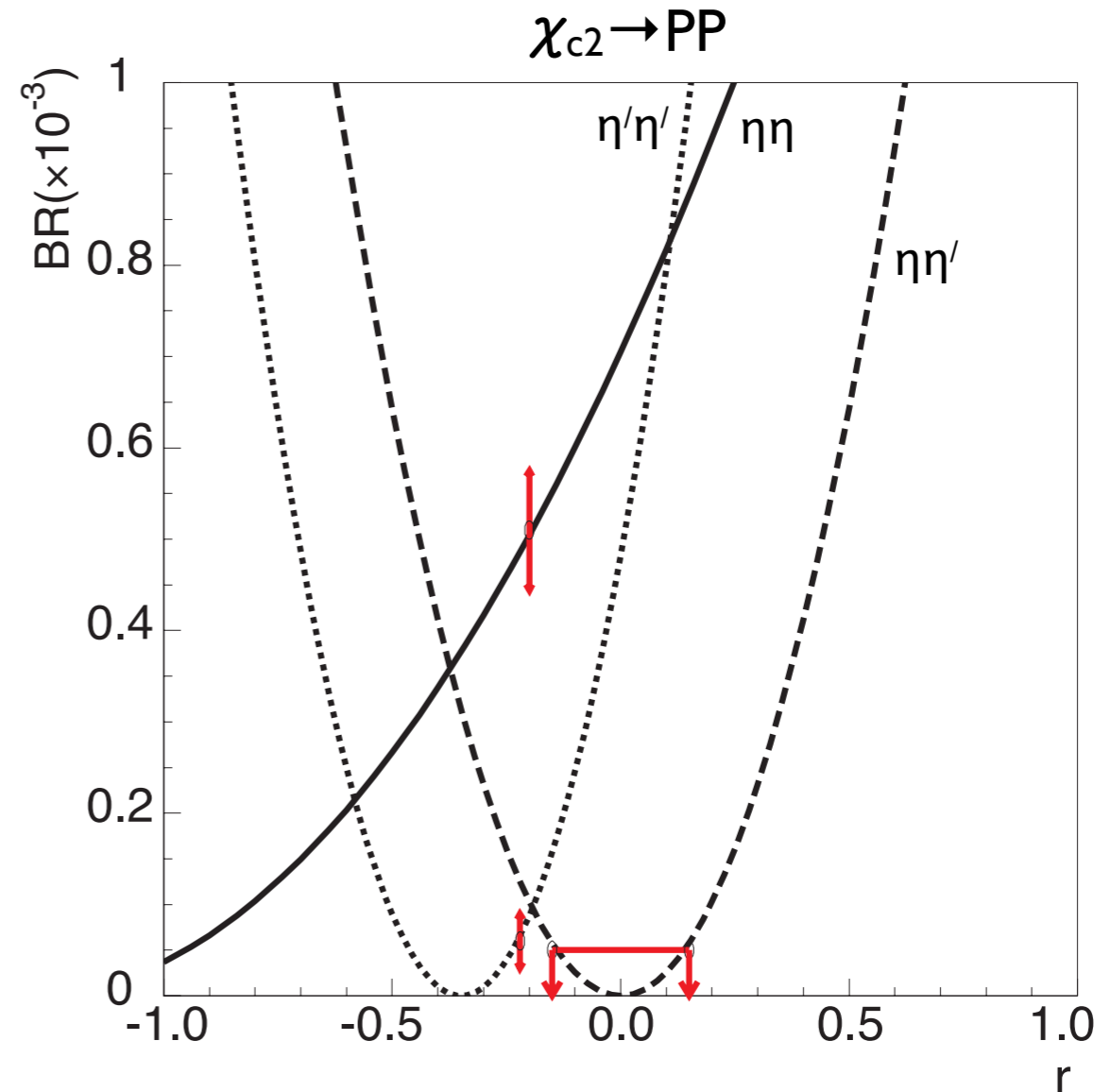
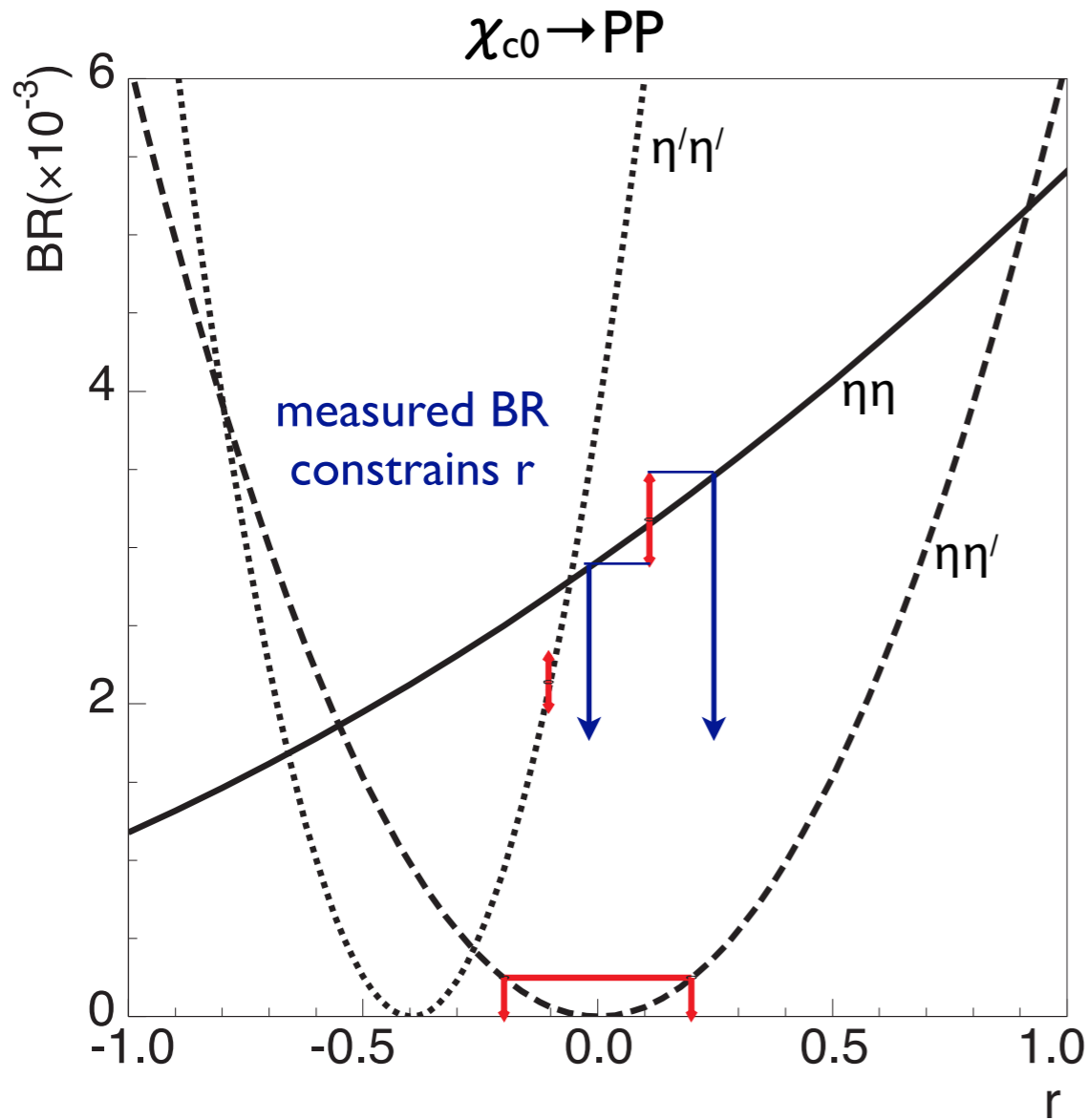
B.F. ($\times 10^{-3}$)	χ_{c0}	χ_{c2}
$\eta\eta$	$3.18 \pm 0.13 \pm 0.18 \pm 0.16$	$0.51 \pm 0.05 \pm 0.03 \pm 0.03$
$\eta'\eta$	< 0.25 (90% CL)	< 0.05 (90% CL)
$\eta'\eta'$	$2.12 \pm 0.13 \pm 0.11 \pm 0.11$	$0.06 \pm 0.03 \pm 0.004 \pm 0.004$ < 0.10 (90%CL)

Errors: (stat.) \pm (syst.) \pm (B($\psi' \rightarrow Y\chi_{cJ}$))

$\chi_{cJ} \rightarrow \eta^{(\prime)}\eta^{(\prime)}$



Predicted dependence of BR on r (DOZI/SOZI)
(from Q. Zhao (PRD 72, 074001))



CLEO Preliminary Results

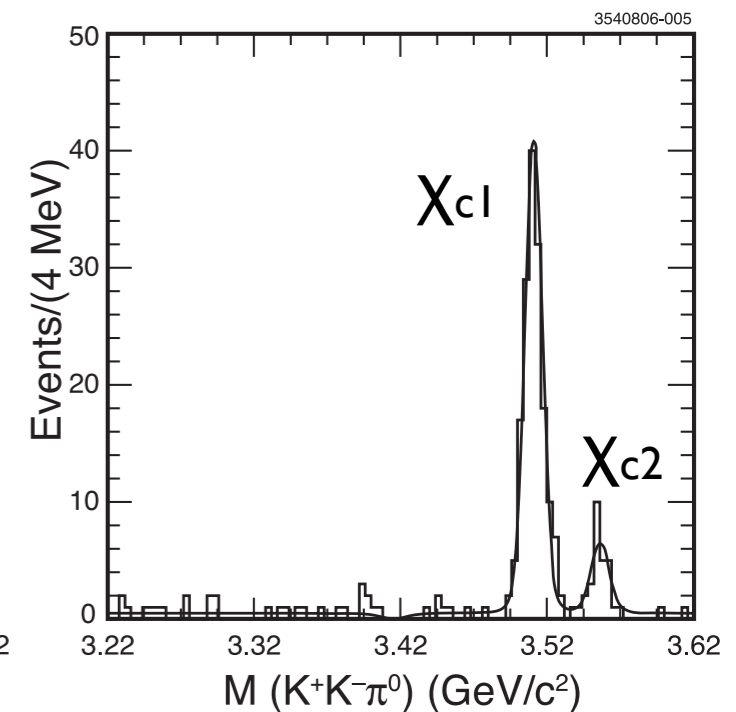
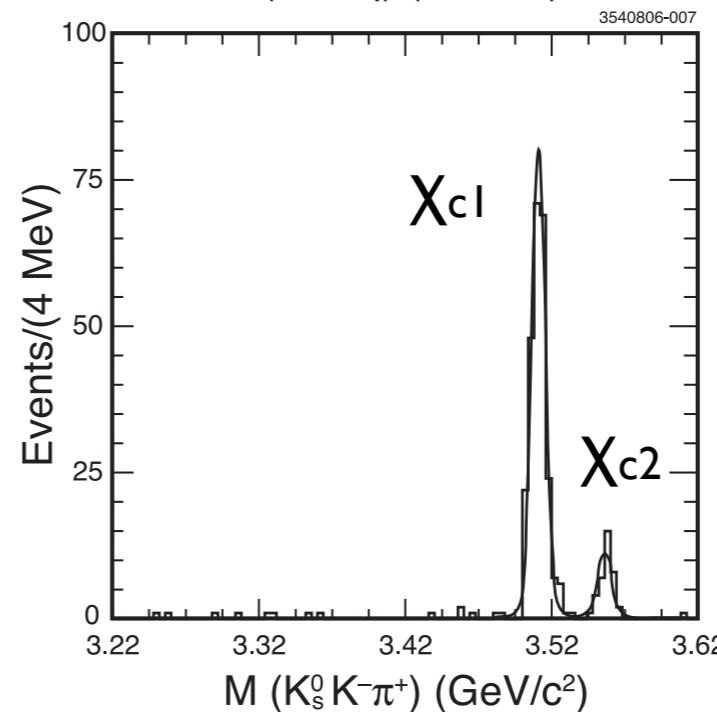
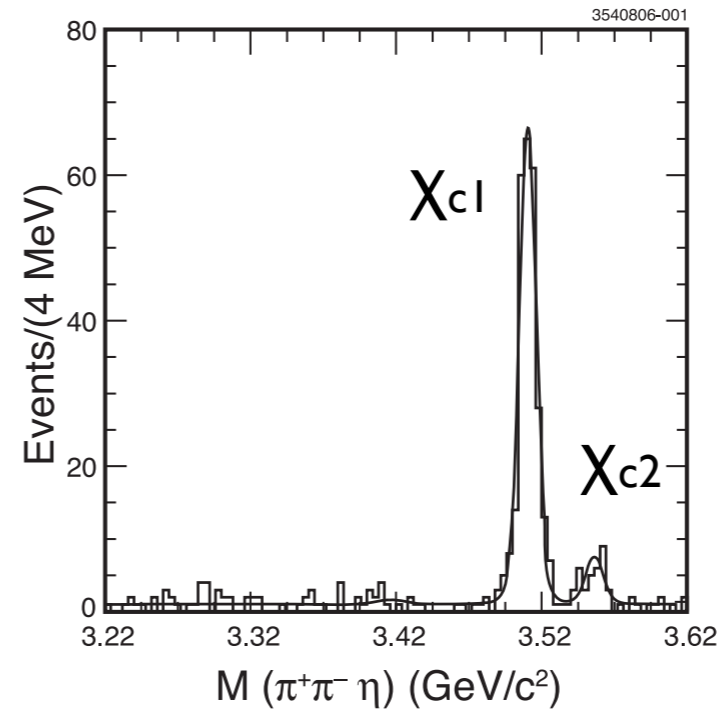
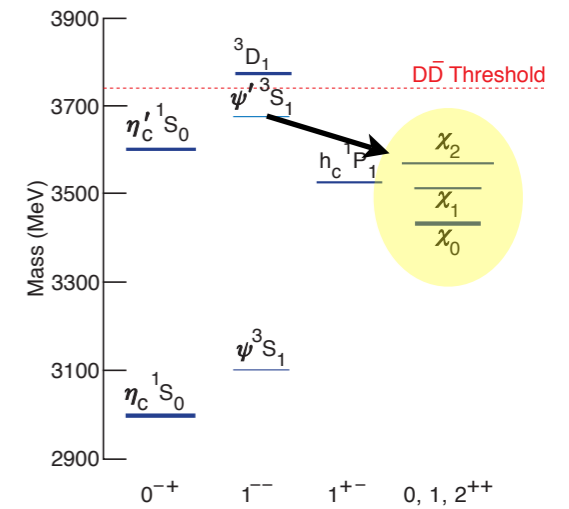
Data suggest small if any contribution for DOZI decays in 0^+ channel.

Similar analysis for scalars (0^{++}) can be carried out.



$\chi_{c1} \rightarrow h^+ h^- h^0$

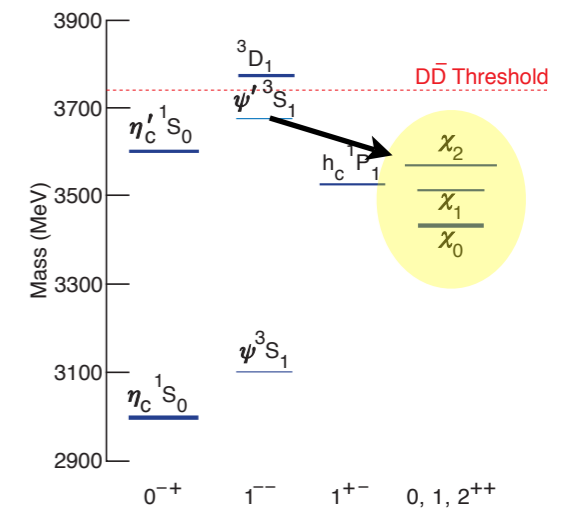
- Three body decays of χ_c states provide an opportunity to explore light quark mesons through Dalitz plot structure
- Kinematic fit provides nearly background free sample
- Heavy χ_c provides large phase space for light meson production
- Low multiplicity decay modes are relatively easy to reconstruct and analyze
- Results use pilot sample of 3M ψ' PRD 75, 032002 (2007)



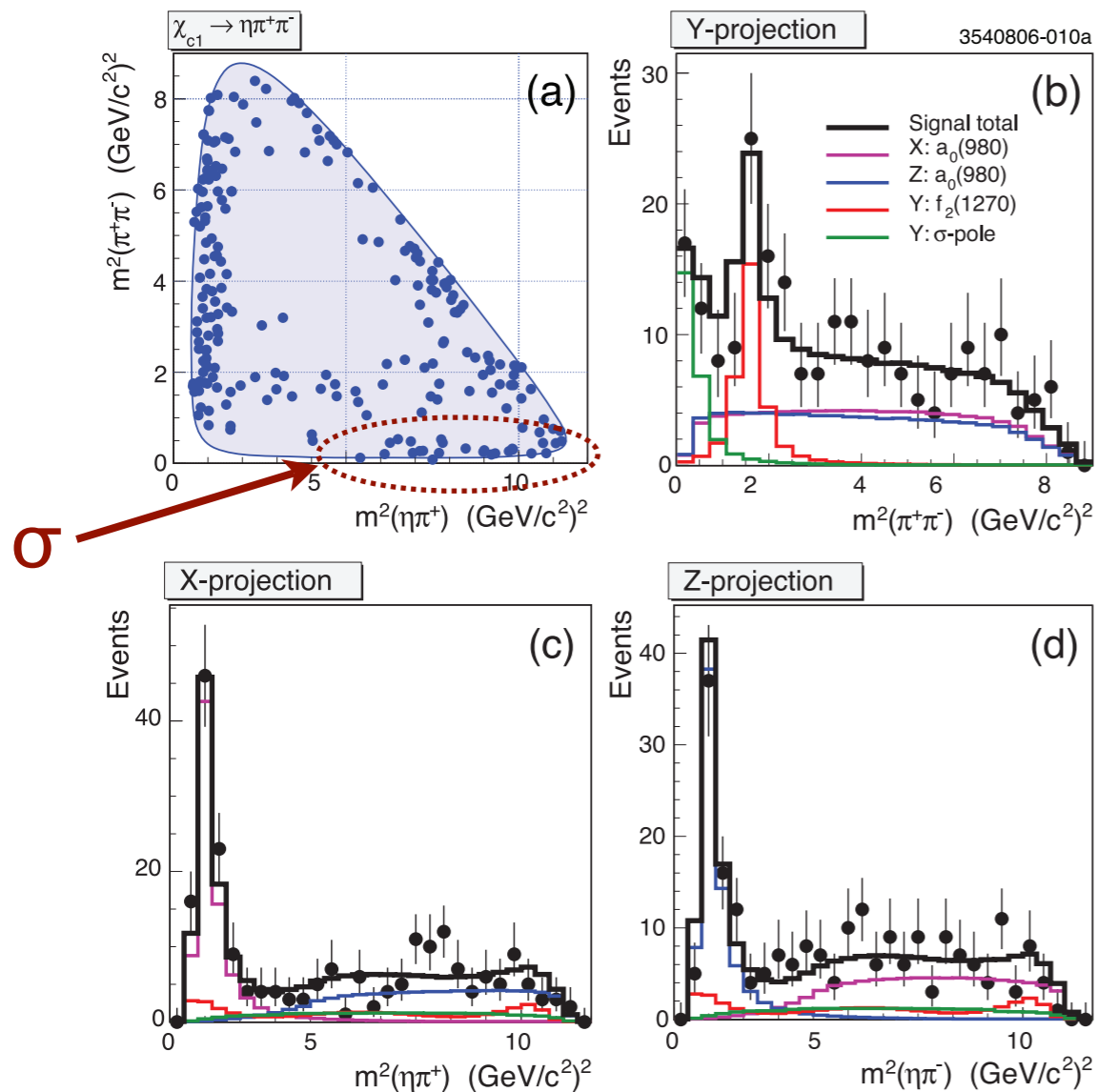
isospin related

$\chi_{c1} \rightarrow h^+ h^- h^0$

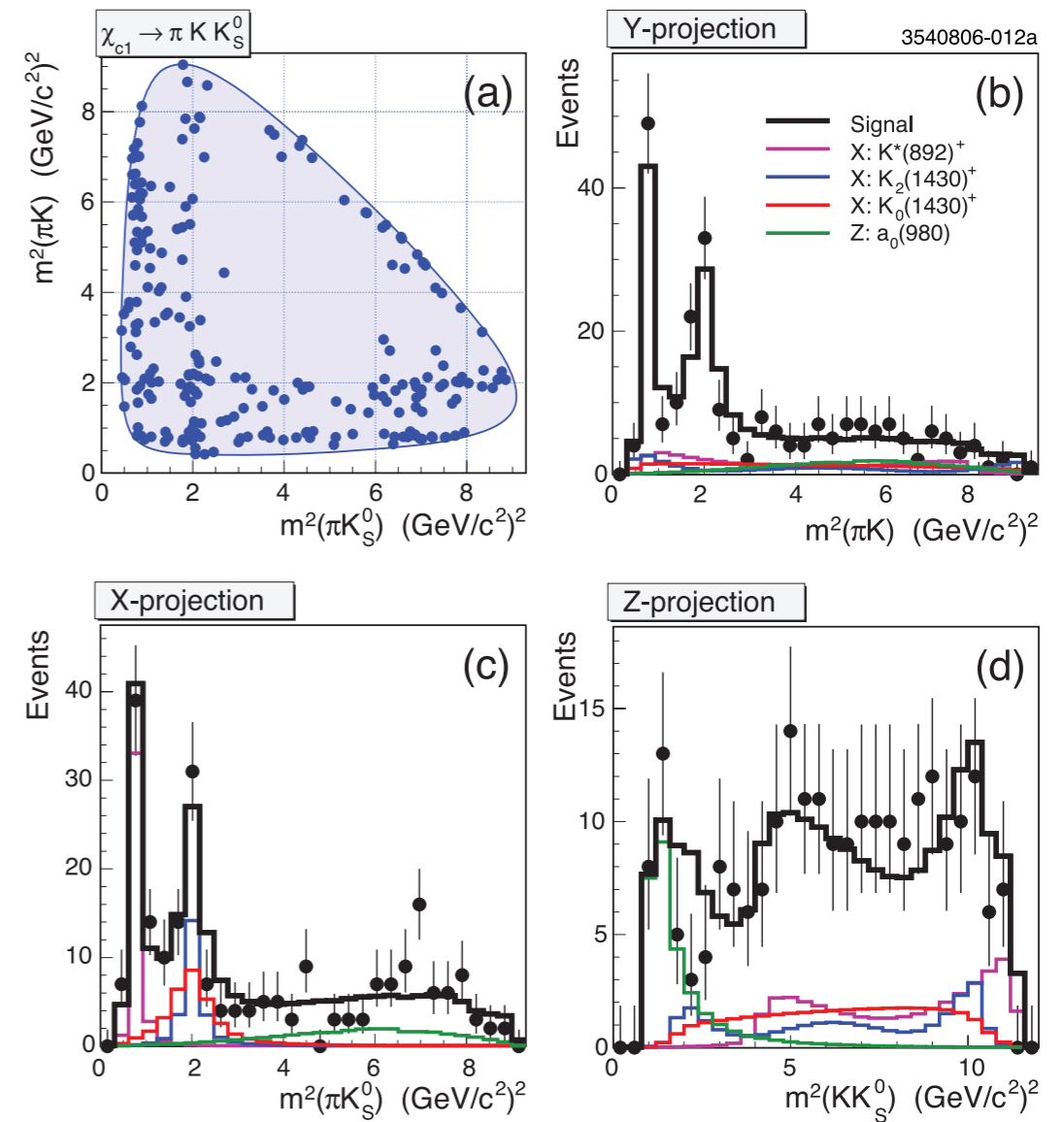
rudimentary Dalitz fit neglects χ_{c1} polarization and interference
see PRD 75, 032002 (2007) for fit fractions



$\chi_{c1} \rightarrow \pi^+ \pi^- \eta$



$\chi_{c1} \rightarrow \pi^+ K^- K_S^0$



*CLEO now has an order of magnitude more statistics:
a couple thousand events on the Dalitz plot*

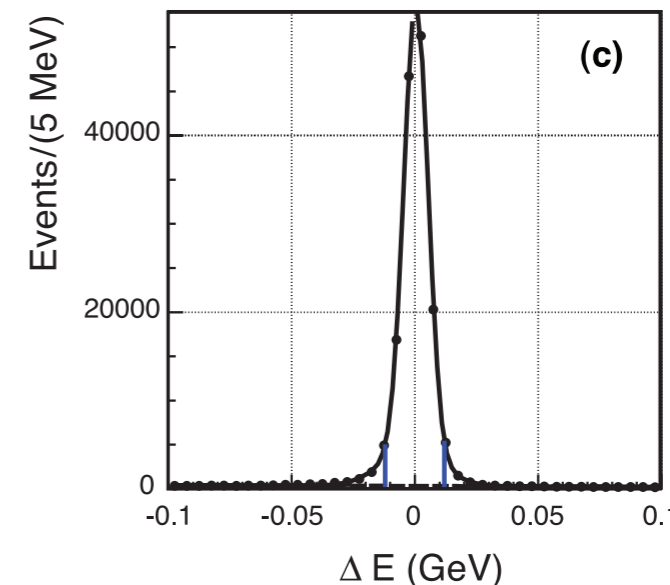
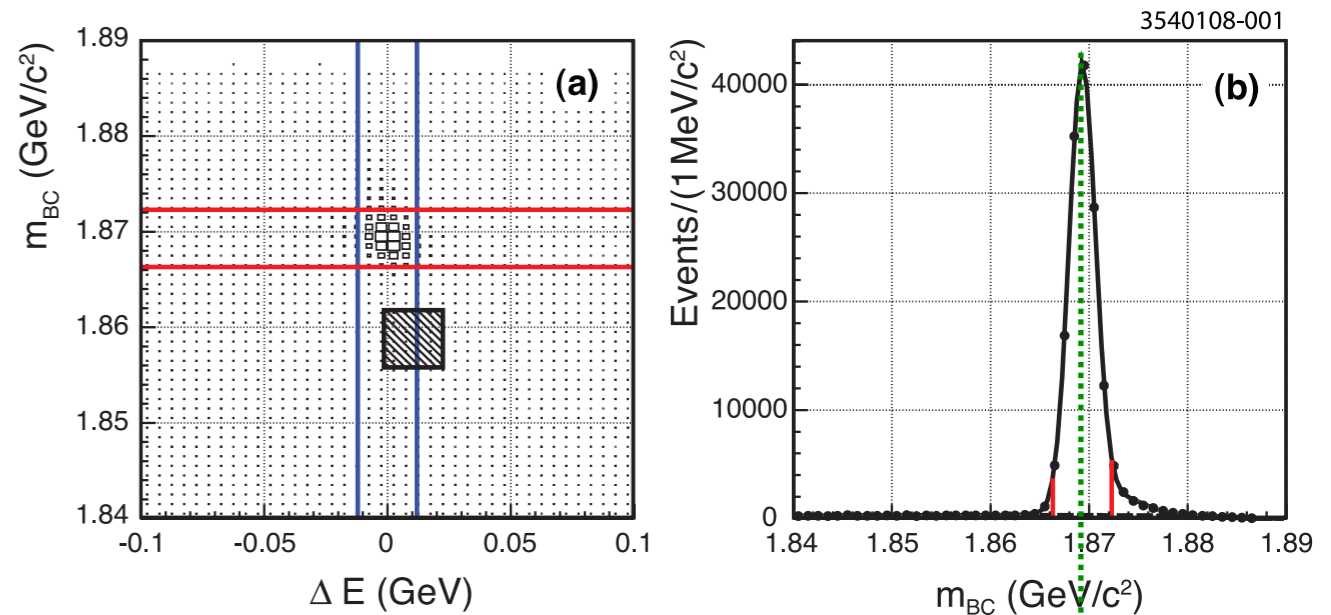
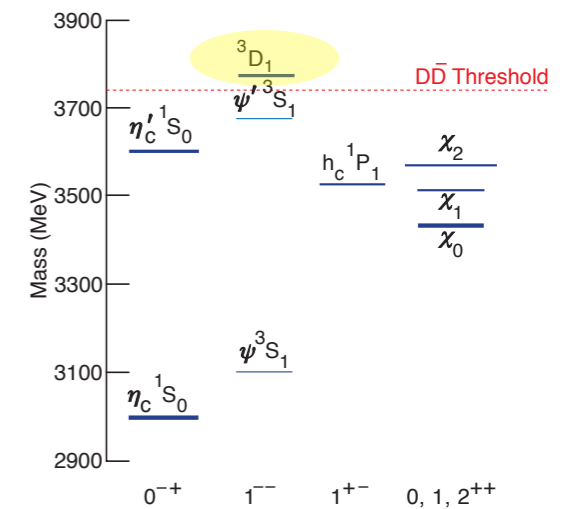
$D^+ \rightarrow K^- \pi^+ \pi^+$

- Use 572 pb^{-1} $\psi(3770)$ decays to open charm as a clean source of D decays
- Select candidates using energy and momentum conservation

$$\Delta E = E_D - E_{\text{beam}},$$

$$m_{\text{BC}} = \sqrt{E_{\text{beam}}^2 - P_D^2},$$

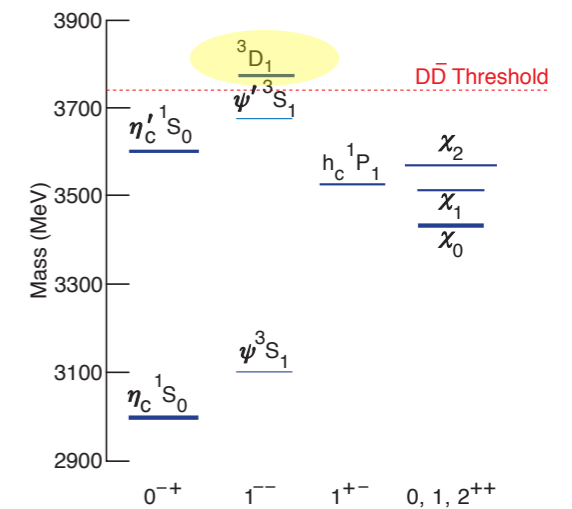
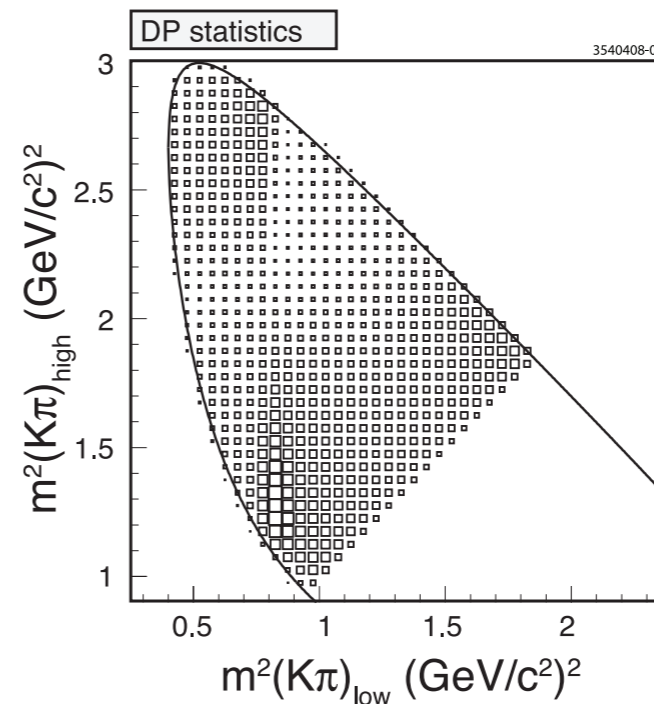
- Very clean sample: 140793 signal candidates with only 1.1% background
- Study light hadron substructure



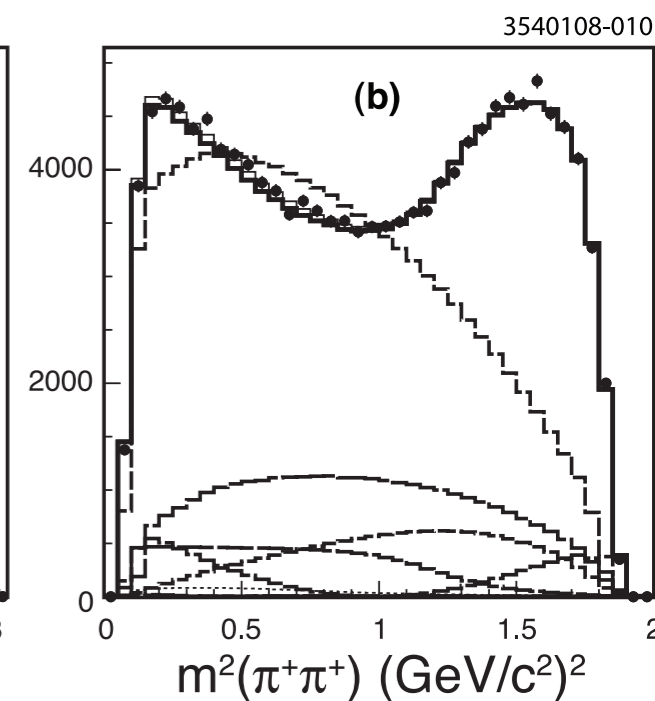
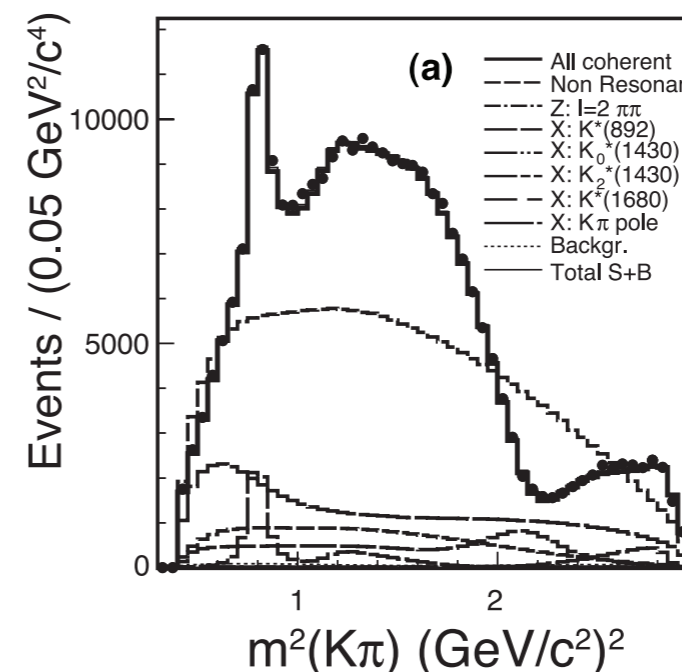
$m(D)$

$D^+ \rightarrow K^- \pi^+ \pi^+$

- Perform a fit to the Dalitz plot, including contributions from K , $K^*(892)$, $K_0^*(1430)$, $K_2^*(1430)$, and $K^*(1680)$
- Asymmetry in $K^*(892)$ peak is a indicates interference with a scalar $K\pi$ component
- Additional $I=2$ $\pi^+\pi^+$ S wave is needed to achieve an adequate fit to the data
- Isobar model description not sufficient for high precision analysis

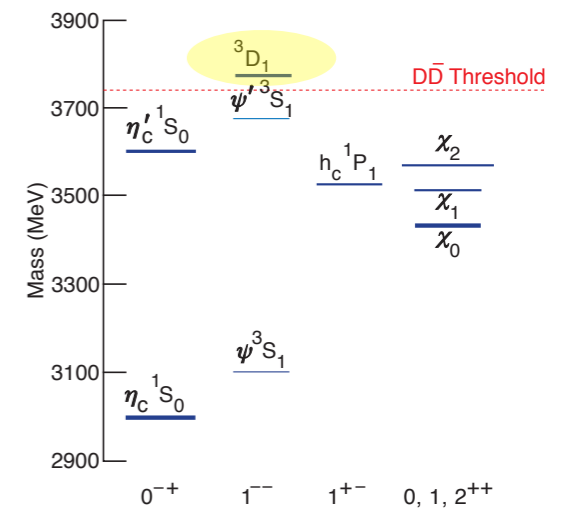


arXiv:0802:4214
submitted to
Phys. Rev. D

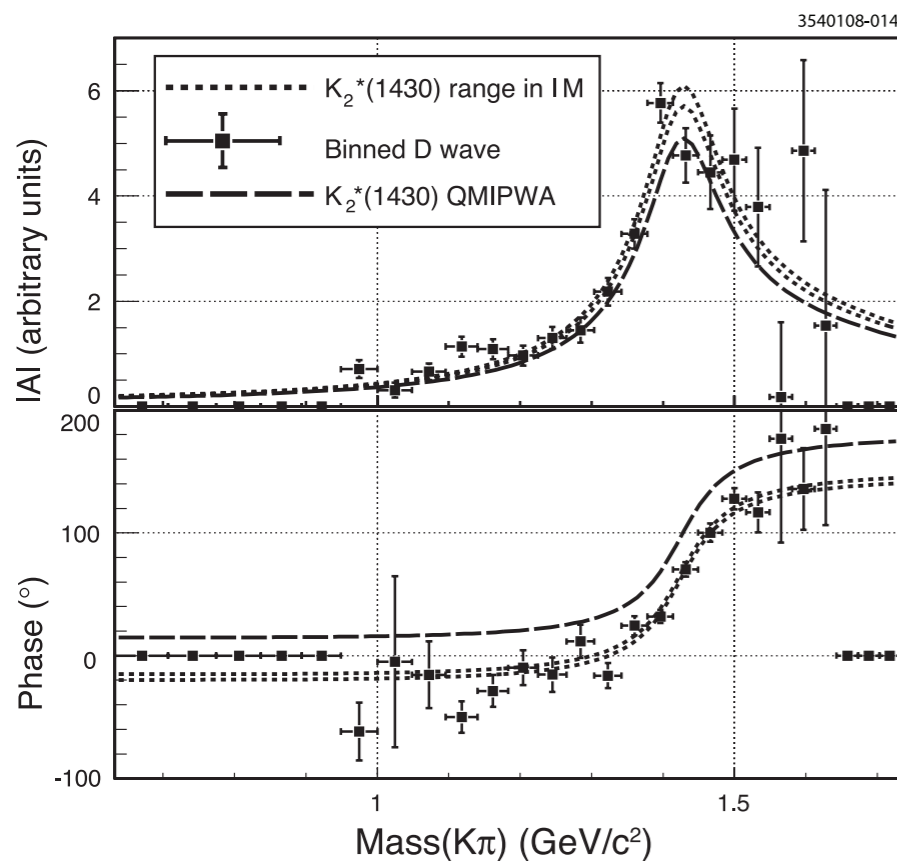


$D^+ \rightarrow K^- \pi^+ \pi^+$

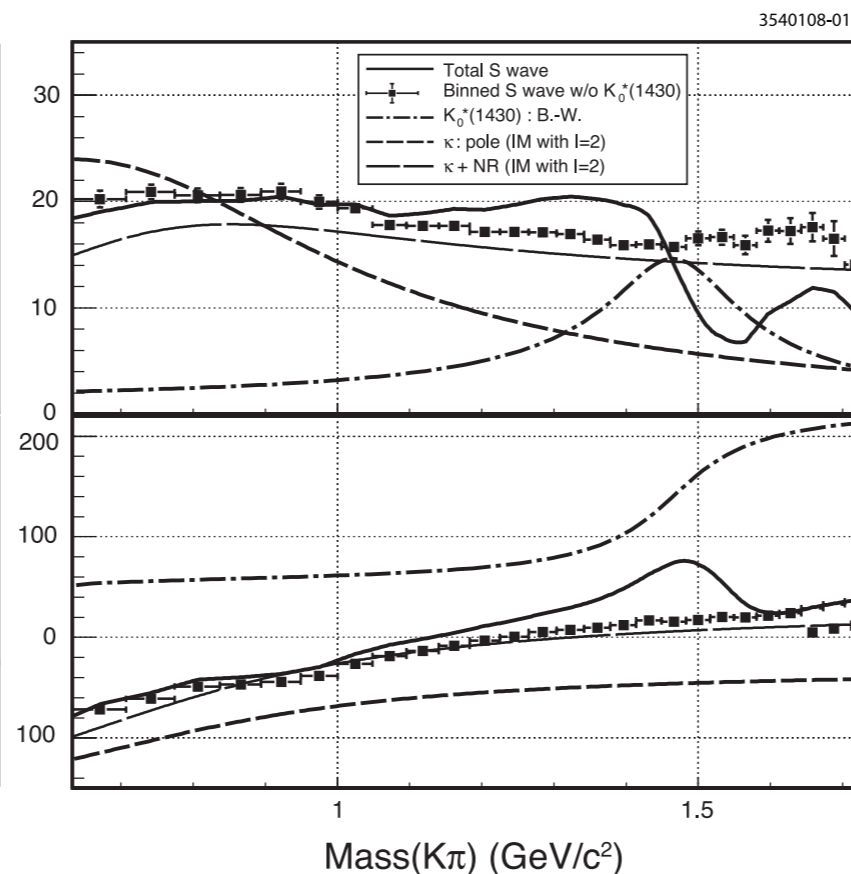
- Fit for amplitude and phase in bins of $K\pi$ or $\pi\pi$ mass (quasi-model-independent PWA) [E791: PRD 73, 32004]
- $K\pi$ S wave does not look like a Breit-Wigner resonance
- $I=2$ $\pi\pi$ S wave consistent with $\pi\pi$ scattering data



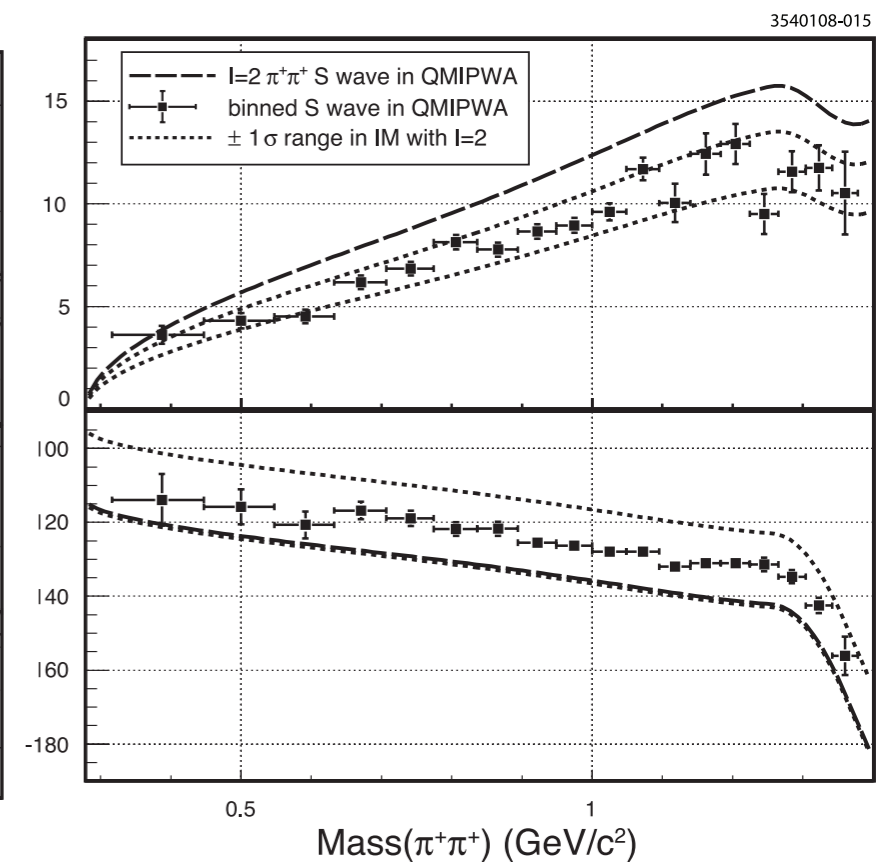
arXiv:0802:4214
submitted to
Phys. Rev. D



Example: $K^- \pi^+$ D wave



$K^- \pi^+$ S wave



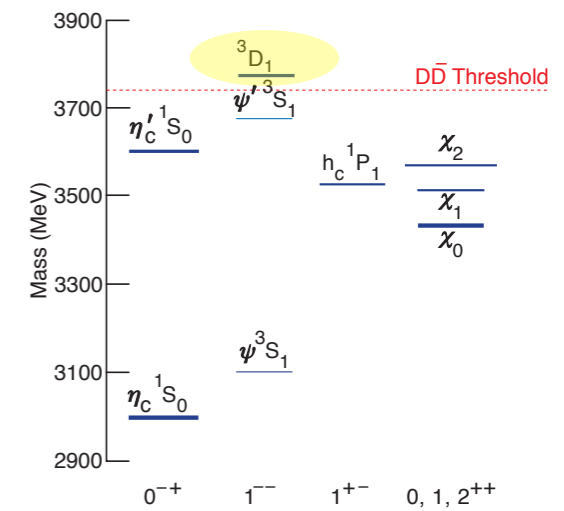
$I=2$ $\pi^+ \pi^+$ S wave



Summary

- Decays of charmonia and charm mesons provide nice opportunity to study light meson properties
- With large, clean open charm and ψ' samples CLEO-c continues to make excellent contributions in this area:
 - precision measurements of η mass and branching fractions
 - formation of light hadrons in two-body χ_c decays and implications on meson structure
 - study of properties of light hadrons with the substructure of multibody χ_c and D decays
- *Data taking has now been completed – expect many more results this summer!*





Breit-Wigner, Flatte, complex pole, $l=2$ $\pi^+\pi^+$ wave, binned

$$\mathcal{W}_R(m) = \frac{1}{m_R^2 - m^2 - im_R\Gamma_{R,total}(m)}$$

$$\Gamma_{R,total}(m) = \Gamma_R \frac{m_R}{m} \left(\frac{p}{p_R}\right)^{2L+1} \left[\frac{\mathcal{F}_R^L(p \cdot r_R)}{\mathcal{F}_R^L(p_R \cdot r_R)} \right]^2$$

$$\mathcal{W}_R(m) = \frac{1}{m_R^2 - m^2 - i \sum_{ab} g_{Rab}^2 \rho_{ab}(m)}$$

$$\mathcal{W}_R(m) = \frac{1}{s_R - m^2} \quad s_\kappa = (0.71 - i0.31)^2 \text{ GeV}^2$$

$$\mathcal{W}_{L=0}^{I=2}(m) = \frac{\eta_0^2(m) e^{i\delta_0^2(m)} - 1}{2i} \quad \eta, \delta \text{ parametrized vs } m$$

$$W_L \text{ binned}(s) = a_{Lk}(s) \cdot e^{i\phi_{Lk}(s)}$$