Light Meson Spectroscopy at CLEO-c

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(for the CLEO Collaboration)

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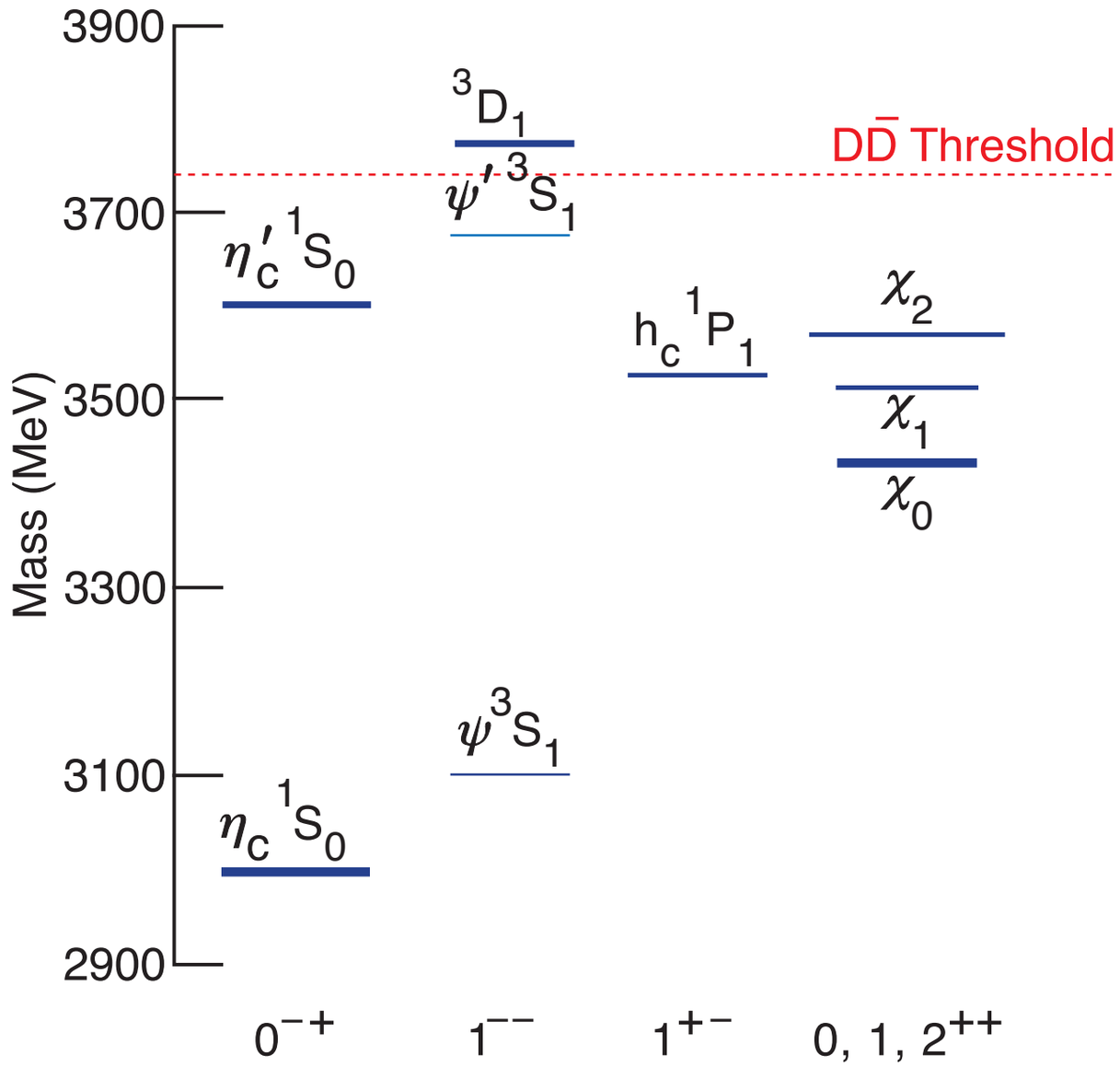
International Workshop on e^+e^- Collisions from Φ to ψ

The CLEO-c Physics Program

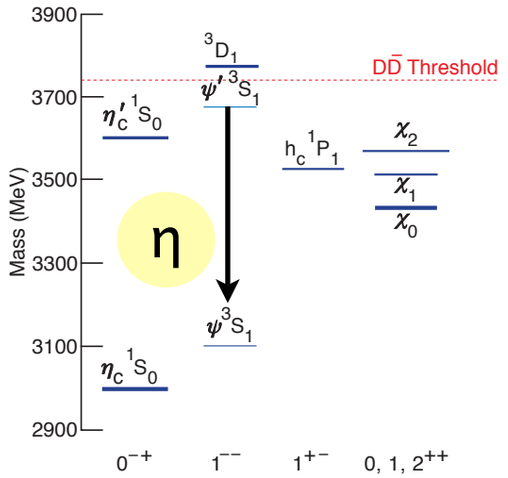
- Three major data sets:
  - 818 pb^{-1} sample taken at $\psi(3770)$ which will yield over 5 million DD events
    - studies of quantum correlated decays, mixing, precision flavor physics (J. Libby - Monday)
    - light meson spectroscopy in multi-body D decays
  - ~600 pb^{-1} taken at E_{CM} = 4170 MeV where D_s production is enhanced
    - D_s leptonic and semileptonic form factors
  - 58 pb^{-1} at $\psi' \rightarrow$ 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 ψ'→η J/ψ
  - spectroscopy in decays of the χ_c
  - light meson interactions on the $D^+ \to K^-\pi^+\pi^+$ Dalitz plot

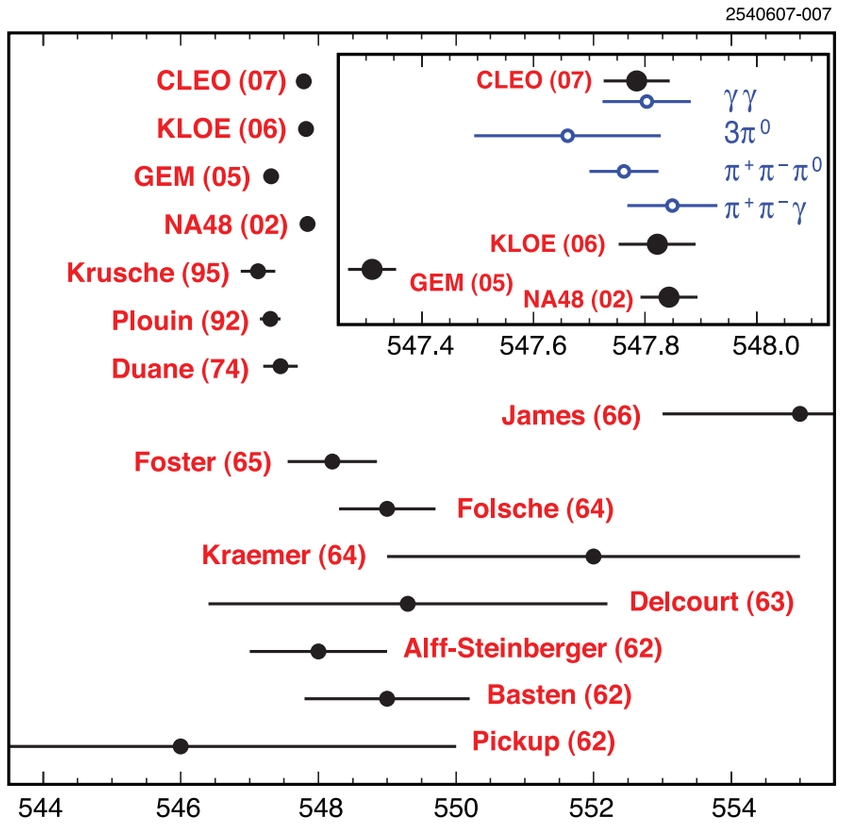


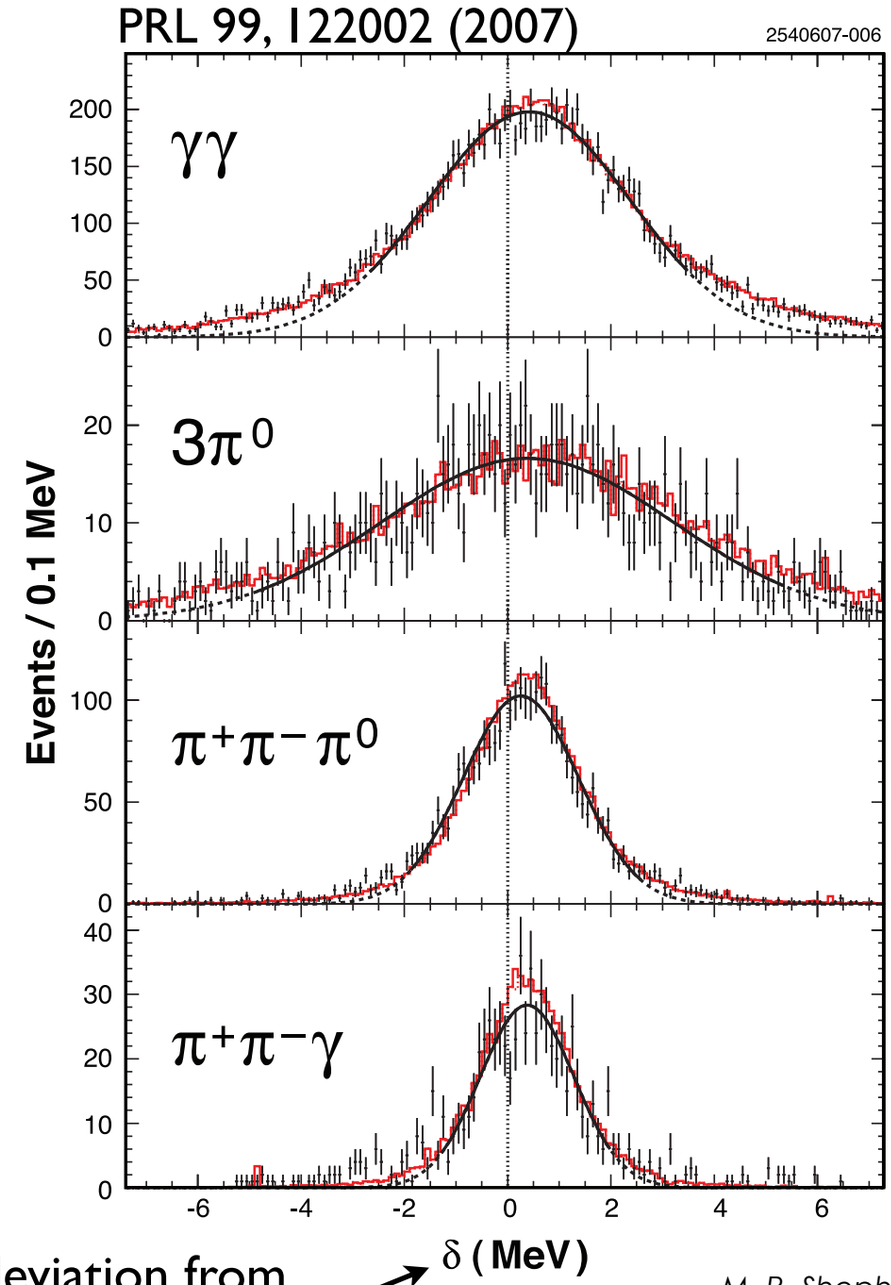
η Mass



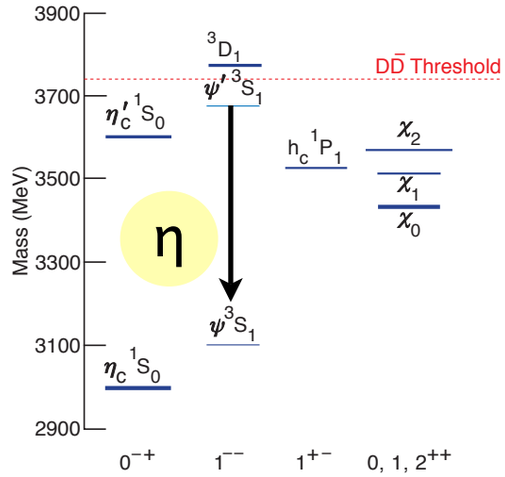
- Use the transition $\psi' \to \eta\, J/\psi$, with $J/\psi \to l^+l^-$, to study the properties of the η
- Kinematic fitting of both J/ψ and ψ' to known masses improves η mass resolution (test technique on π^0): $M_\eta = 547.785 \pm 0.017 \pm 0.057$ MeV

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



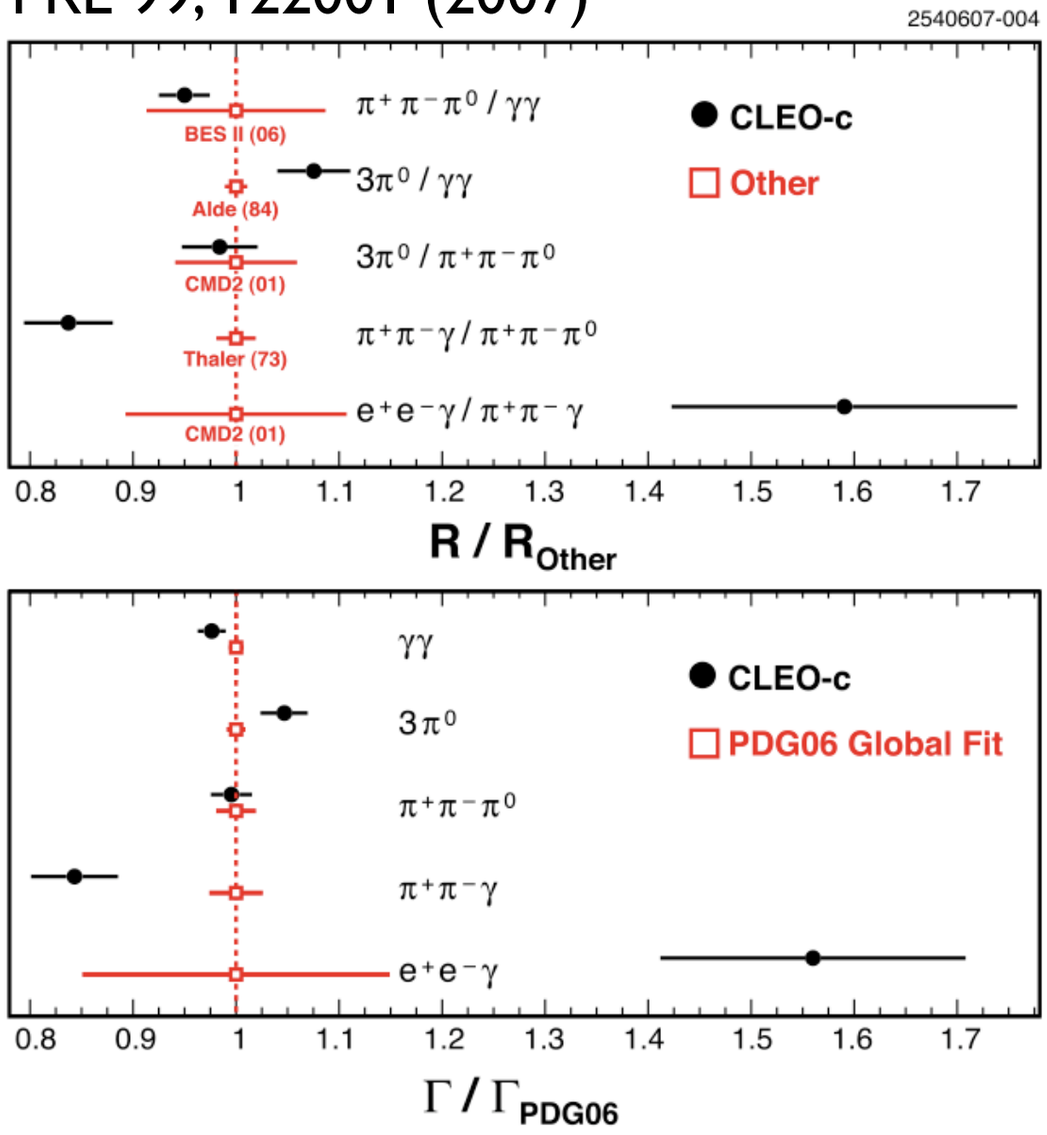


η Branching Fractions

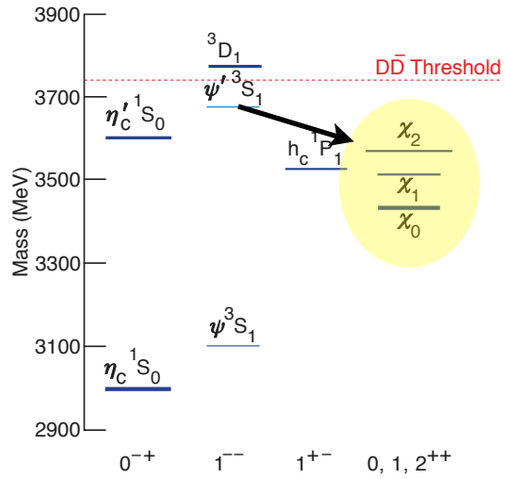


- Apply similar technique to simultaneously measure all allowed branching fractions of η
- Construct absolute branching fractions by measuring all possible branching fraction ratios
- Assume measured modes comprise all modes (limit on "other" < 0.2%)
- Systematics are well under control since all measurements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

PRL 99, 122001 (2007)



Hadronic χ_{cJ} Decays

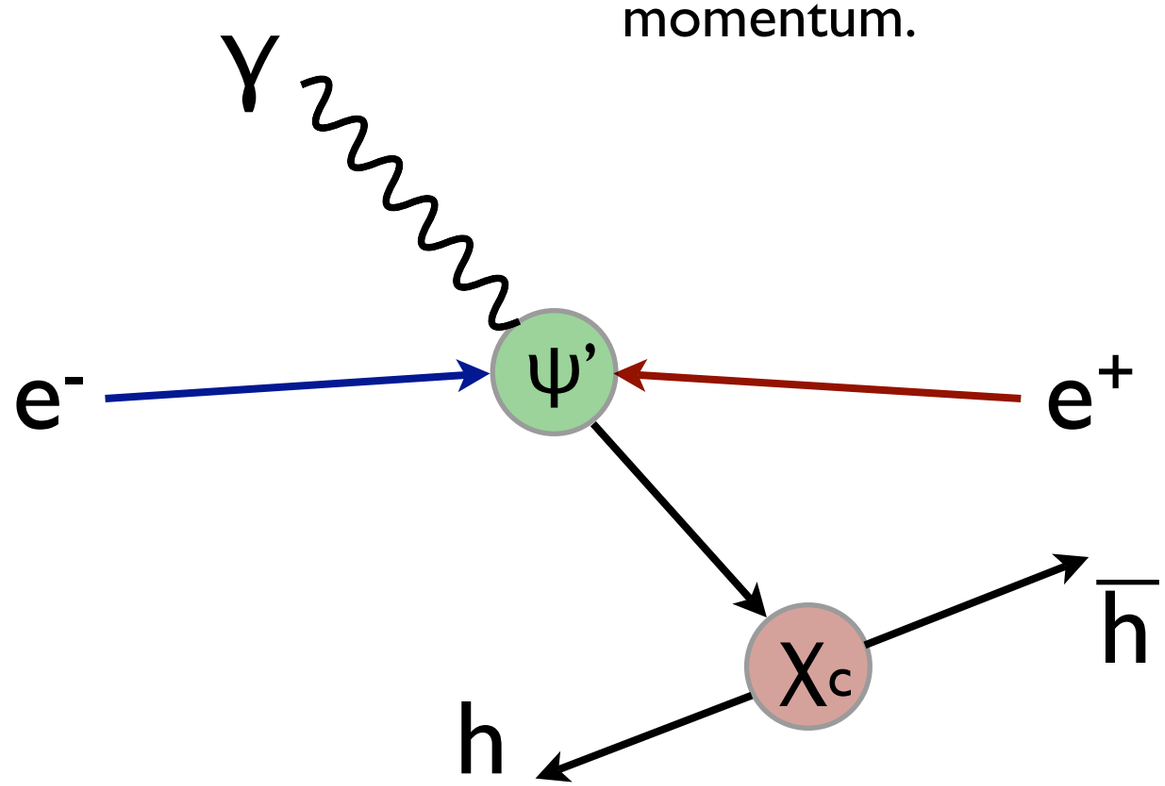


- Decays of χ_c proceed by annihilation into light quarks -- patterns of decays may provide insight on light meson and glueball structure

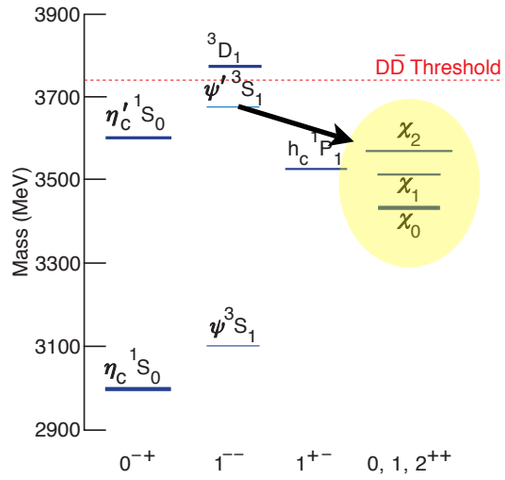
- χ_c produced in electromagnetic transitions from the ψ'
  - BF ~8-10% provides high statistics χ_c sample

- Search for various hadronic multi-body decay modes of χ_c

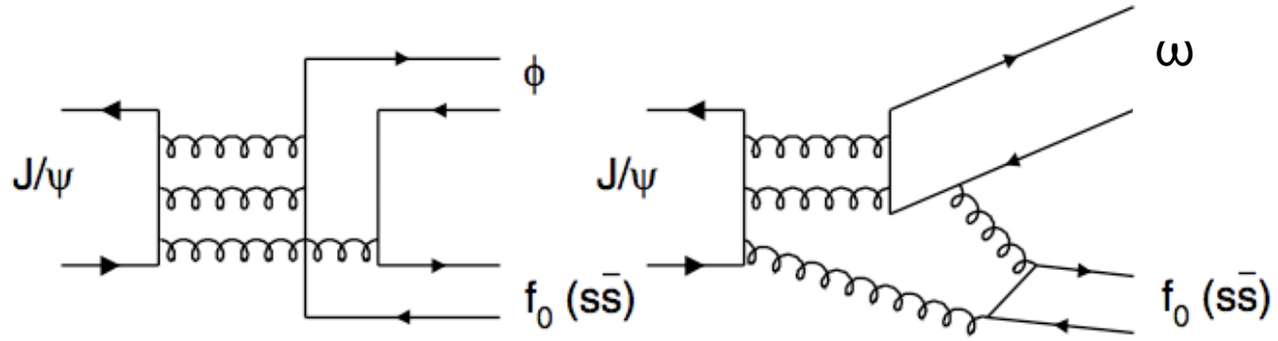
Analysis relies on identification of all decay products and kinematic fit to initial ψ' four-momentum.

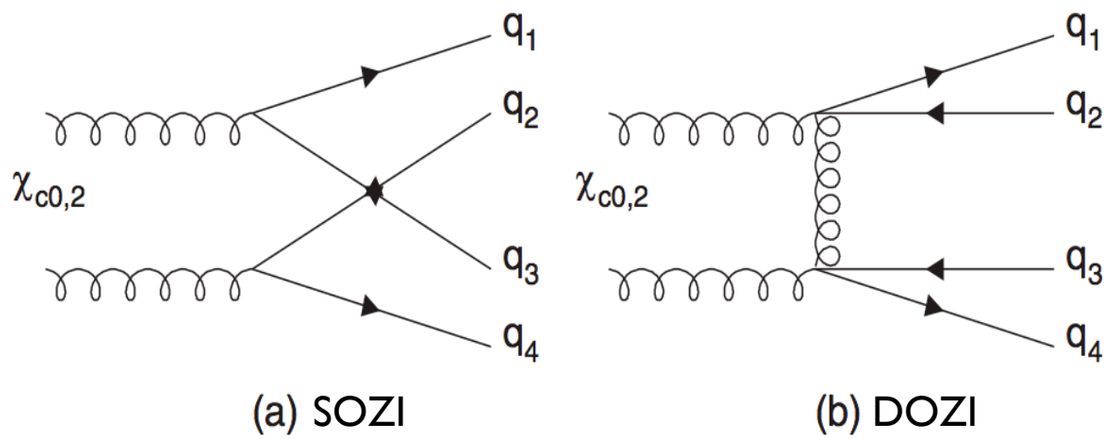


$\chi_{cJ} \rightarrow \eta^{(\prime)}\eta^{(\prime)}$



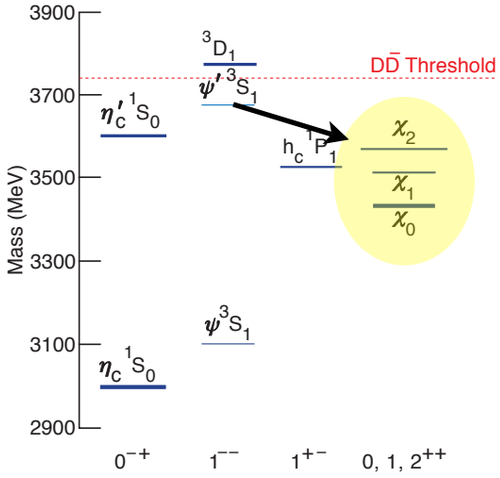
- It is interesting that $B(J/\psi \rightarrow \omega f_0(1710))$ is greater than $B(J/\psi \rightarrow \phi f_0(1710))$ given $f_0(1710)$ is thought to be largely strange.
- Suggestive of large OZI violating effects in J/ψ decay? ....glueball mixing? (F. Close and Q. Zhao, PRD 71, 094022)
- Look for 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)

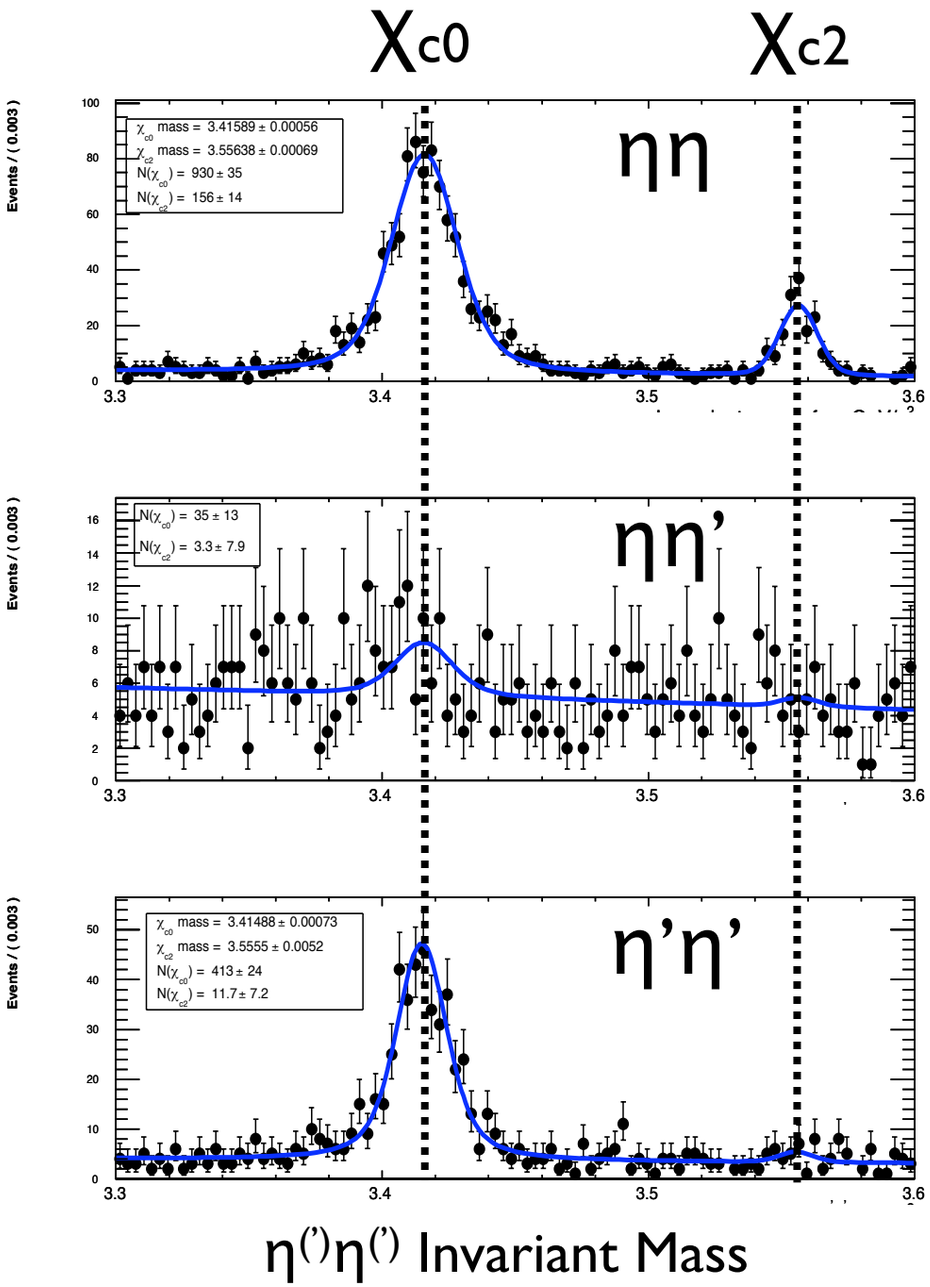




r = relative strength between singly-OZI and doubly-OZI suppressed transition amplitudes

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





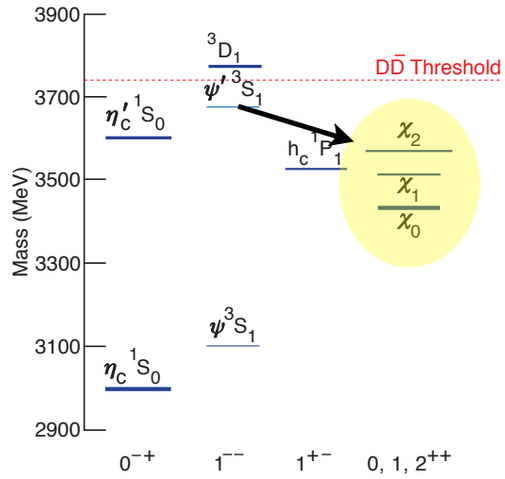
- Analysis utilizes the large 25M ψ' sample
- Supersedes previous CLEO analysis on 3M ψ' (PRD 75, 071101(R)(2007))

CLEO Preliminary

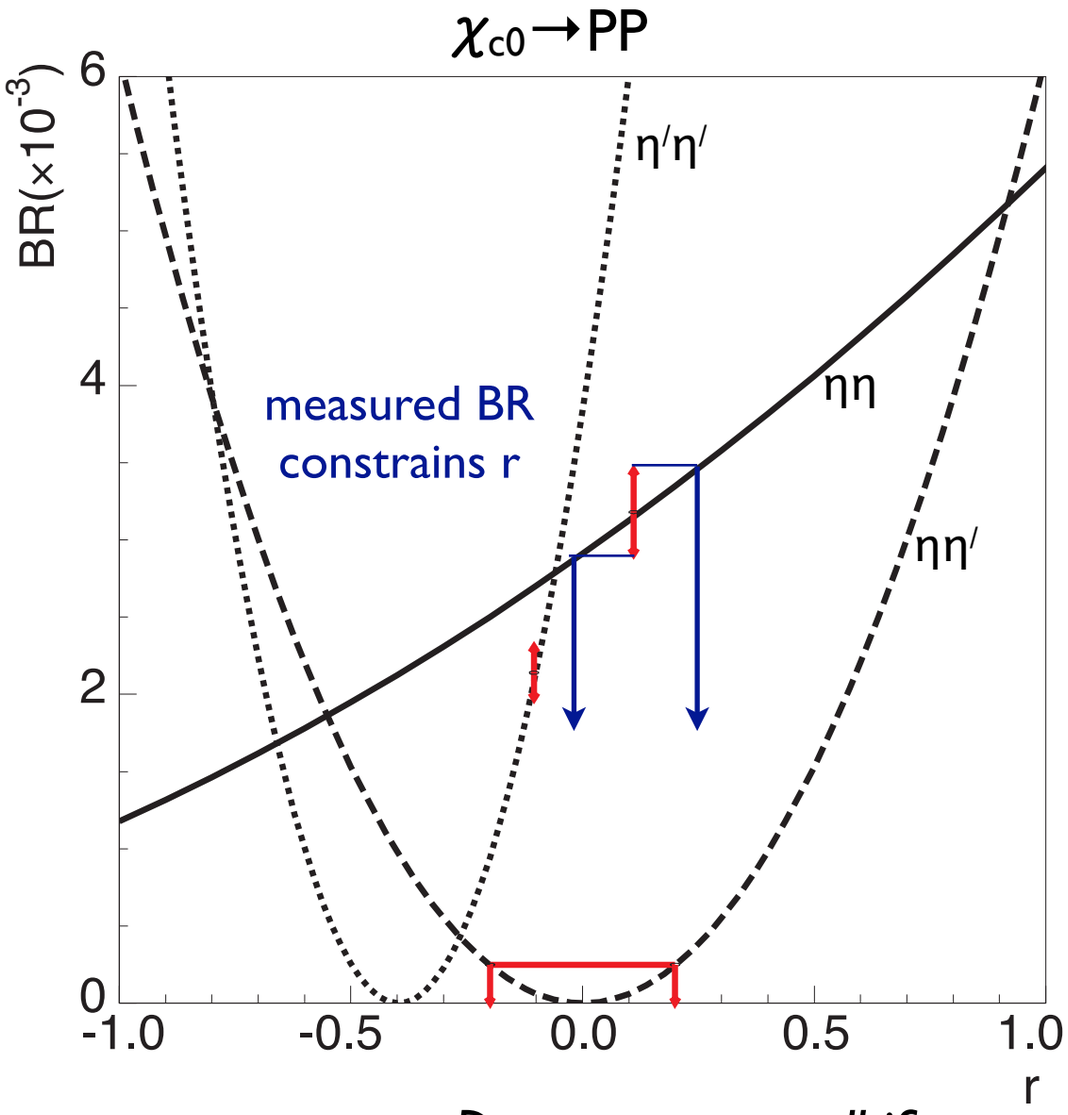
B.F. ($\times 10^{-3}$)	χ_{c0}	χ_{c2}
$\eta\eta$	3.18±0.13±0.18±0.16	0.51±0.05±0.03±0.03
$\eta'\eta$	<0.25 (90% CL)	<0.05 (90% CL)
$\eta'\eta'$	2.12±0.13±0.11±0.11	0.06±0.03±0.004±0.004 < 0.10 (90%CL)

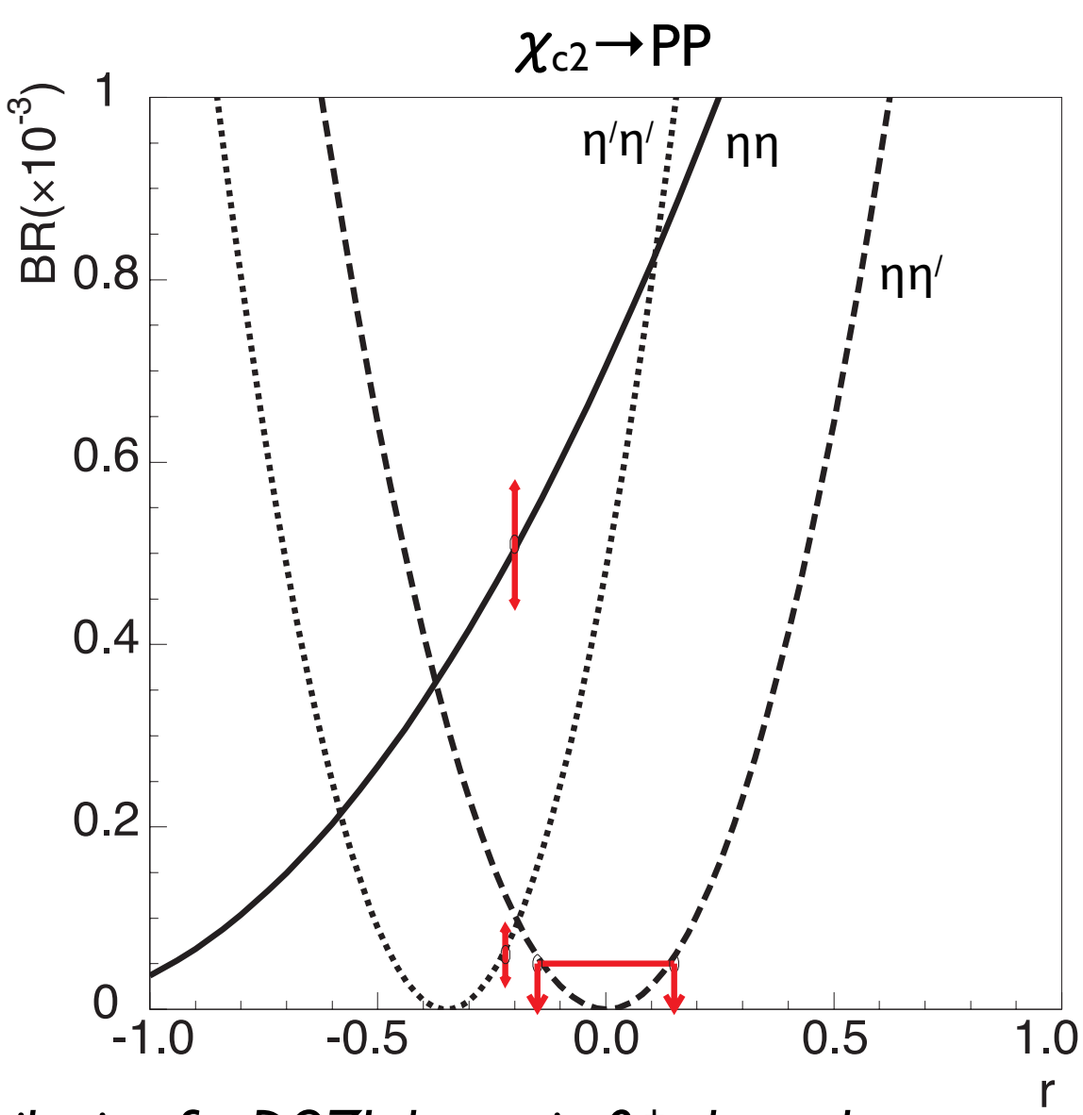
Errors: (stat.) ± (syst.) ± ($B(\psi' \rightarrow \gamma X_{cJ})$)

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



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

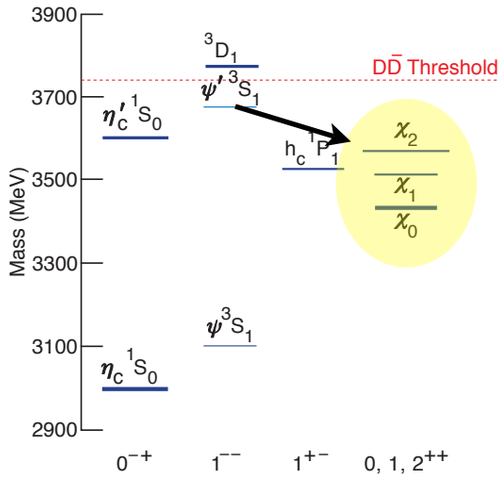




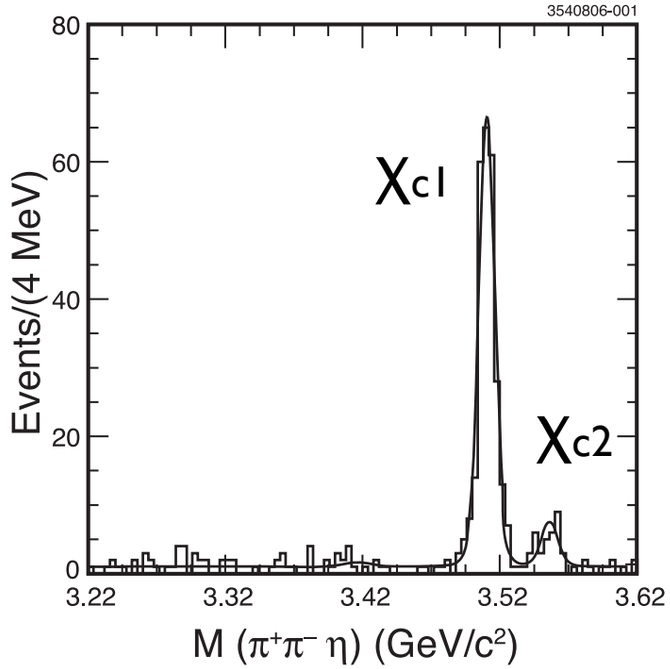
Data suggest small if any contribution for DOZI decays in 0^{-+} channel.

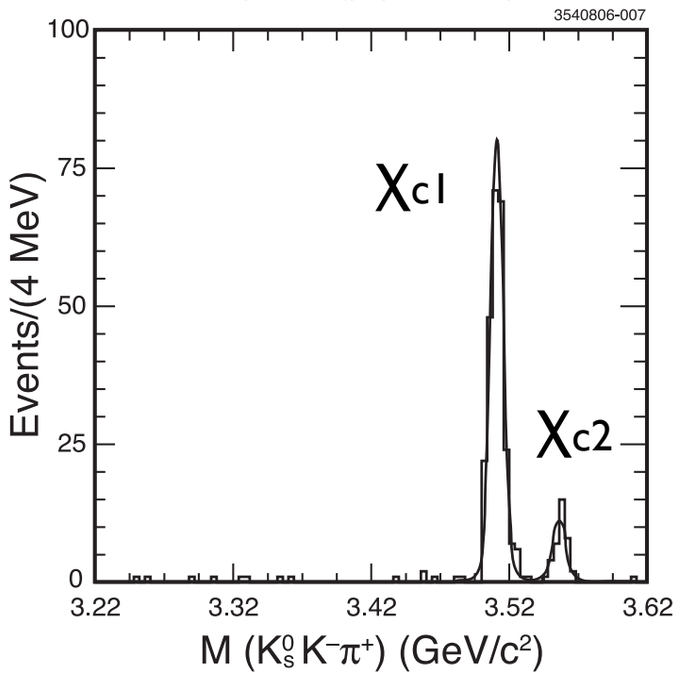
Similar analysis for scalars (0^{++}) can be carried out.

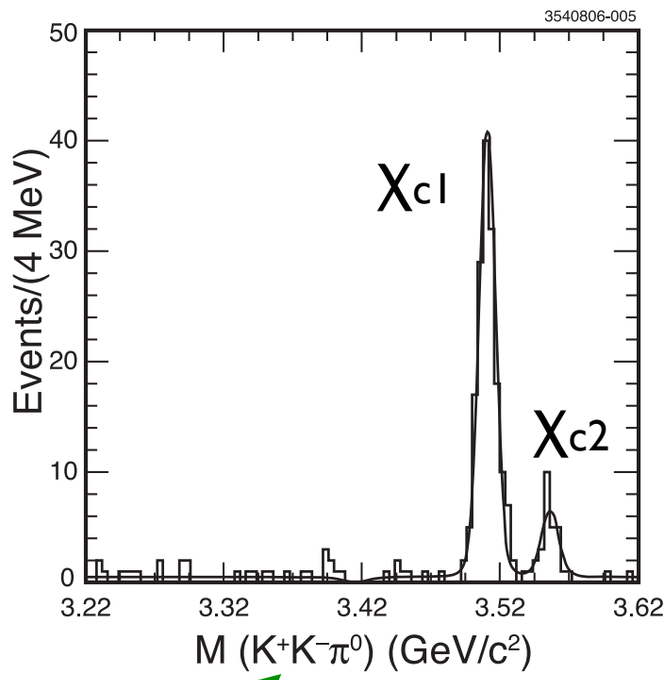
$\chi_{c1} \rightarrow h^+h^-h^0$



- 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)

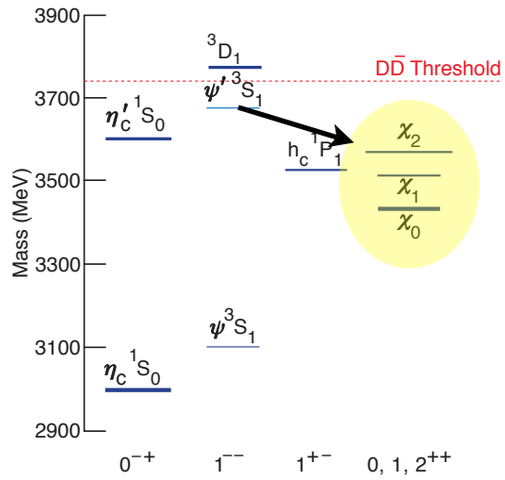






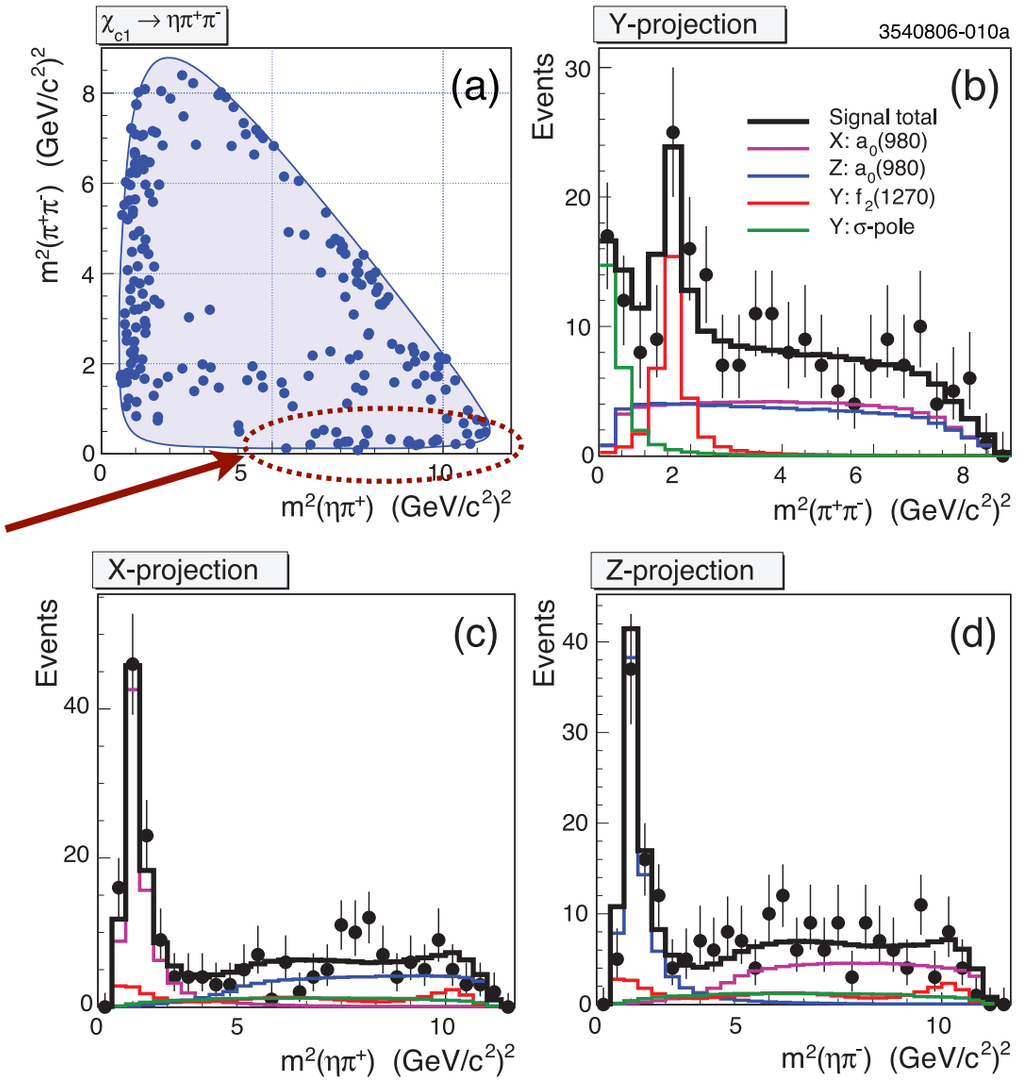
isospin related

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

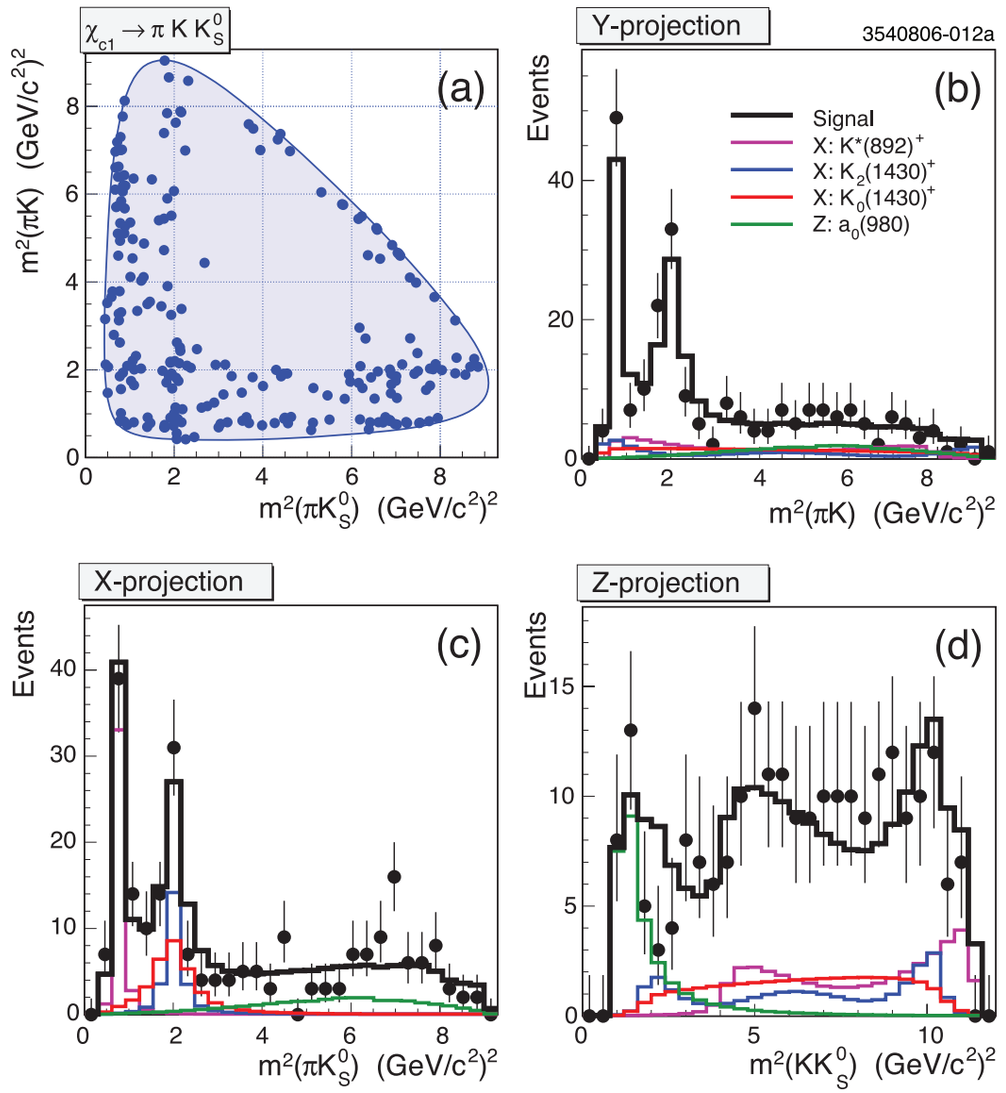


rudimentary Dalitz fit neglects χ_{c1} polarization and interference
see PRD 75, 032002 (2007) for fit fractions

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

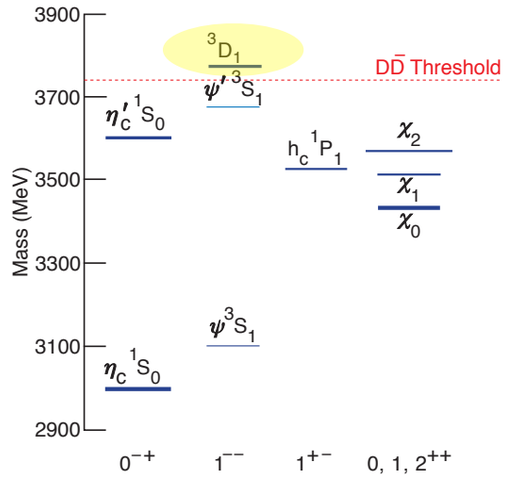


$\chi_{c1} \rightarrow \pi^+K^-K_S^0$



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

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

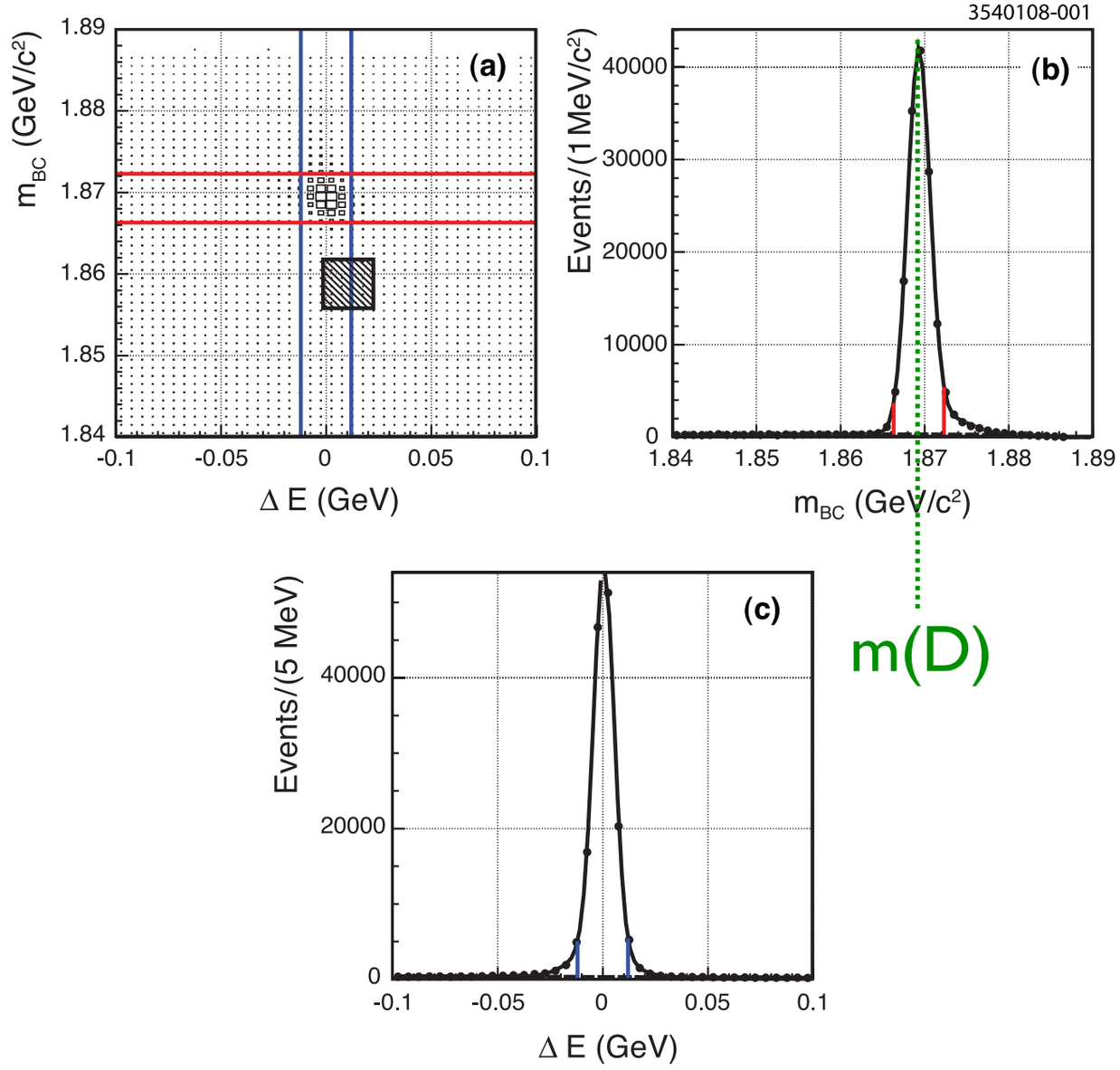


- Use 572 pb^{-1} ψ(3770) decays to open charm as a clean source of D decays
- Select candidates using energy and momentum conservation

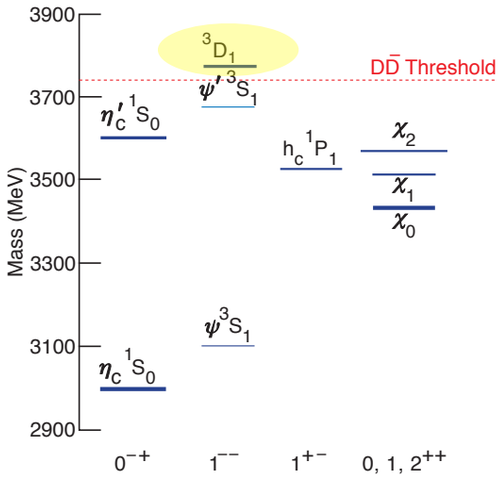
$$\Delta E = E_D - E_{\rm beam},$$

$$m_{\rm BC} = \sqrt{E^2_{\rm beam} - {\rm P}^2_D},$$

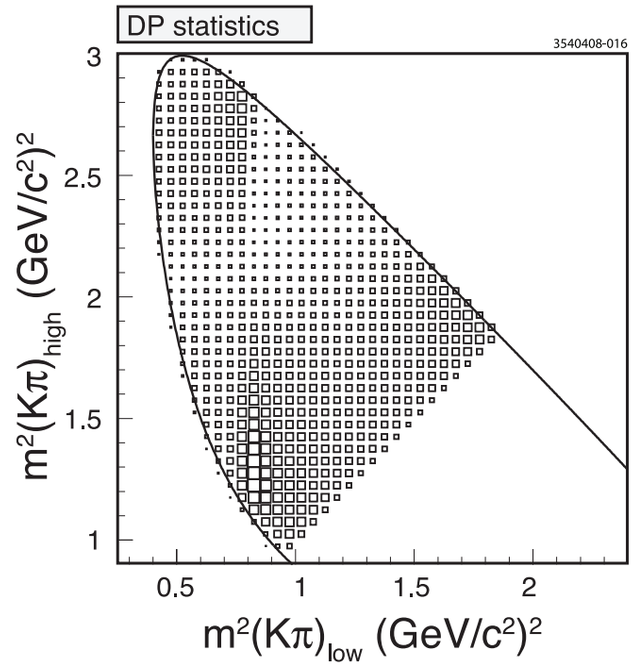
- Very clean sample: 140793 signal candidates with only 1.1% background
- Study light hadron substructure



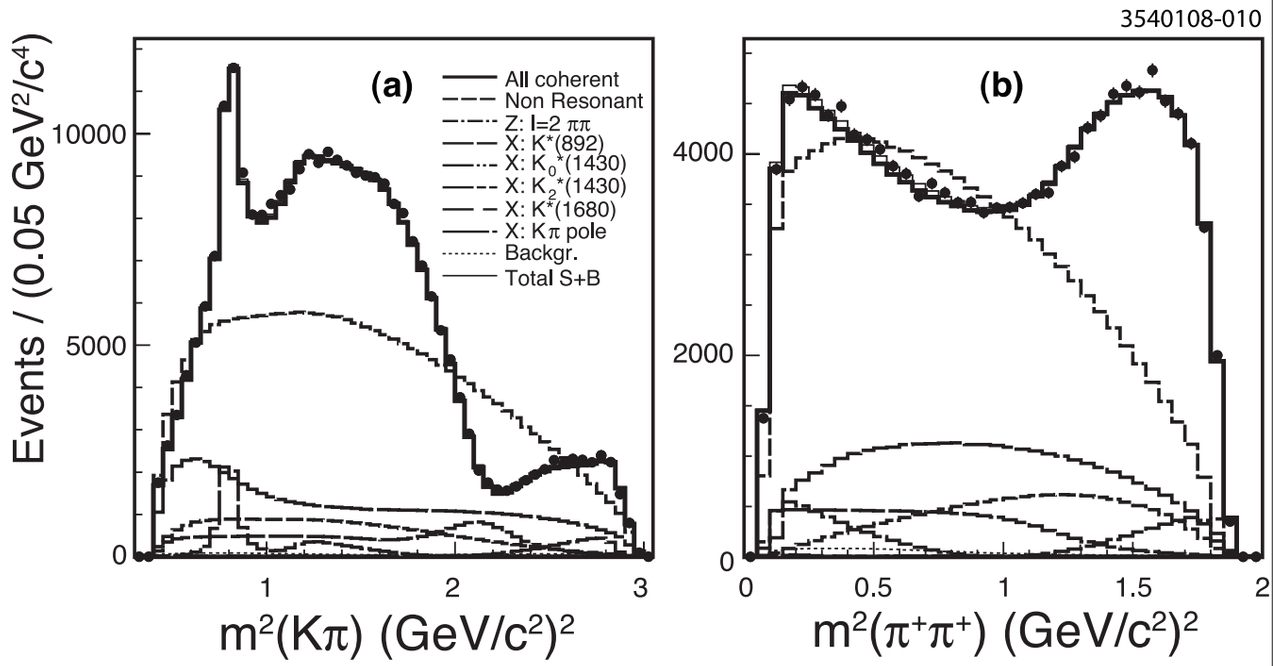
$D^+ \to K^-\pi^+\pi^+$



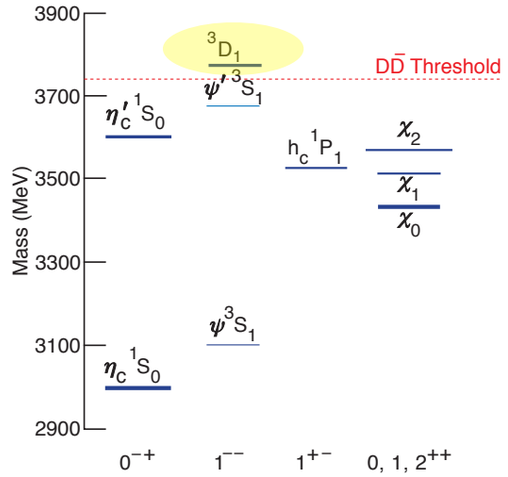
- Perform a fit to the Dalitz plot, including contributions from κ, K*(892), K_0*(1430), K_2*(1430), and K*(1680)
- Asymmetry in K*(892) peak is a indicates interference with a scalar Kπ component
- Additional I=2 $\pi^+\pi^+$ S wave is needed to achieve an adequate fit to the data
- Isobar model description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



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



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



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

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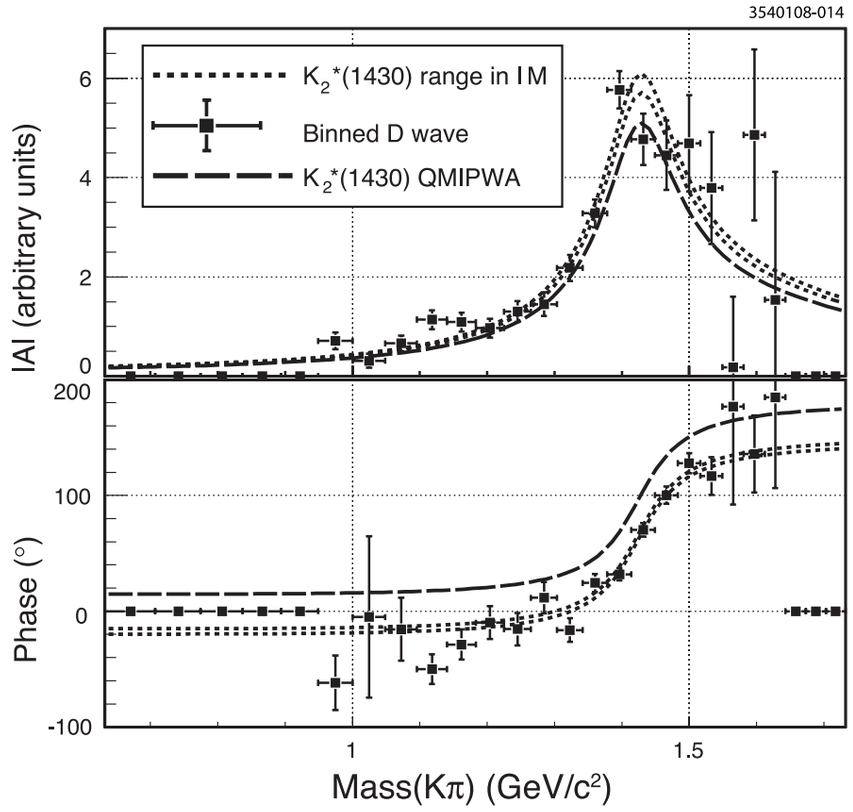
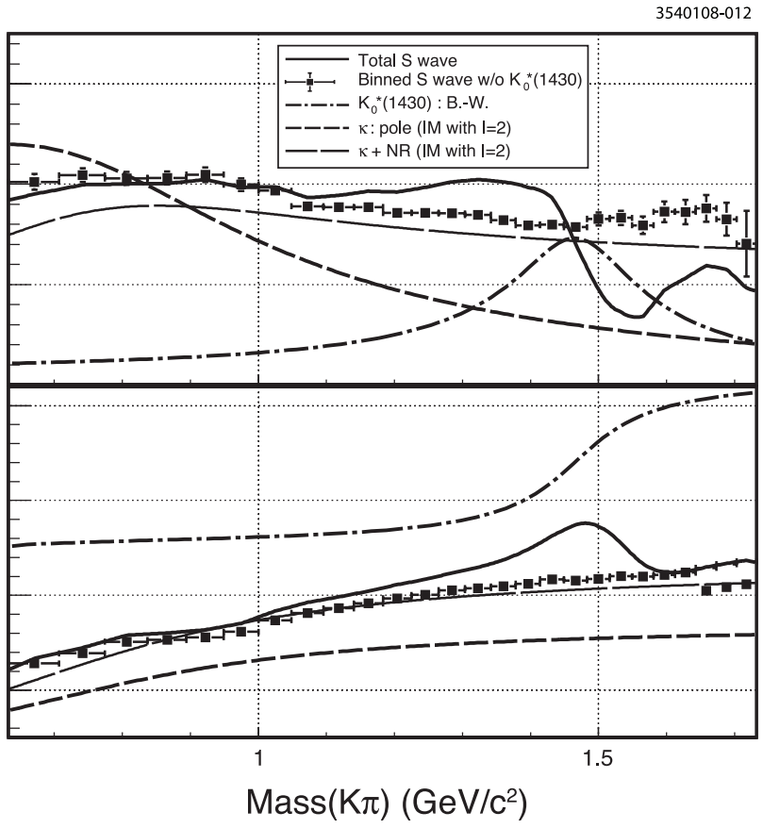
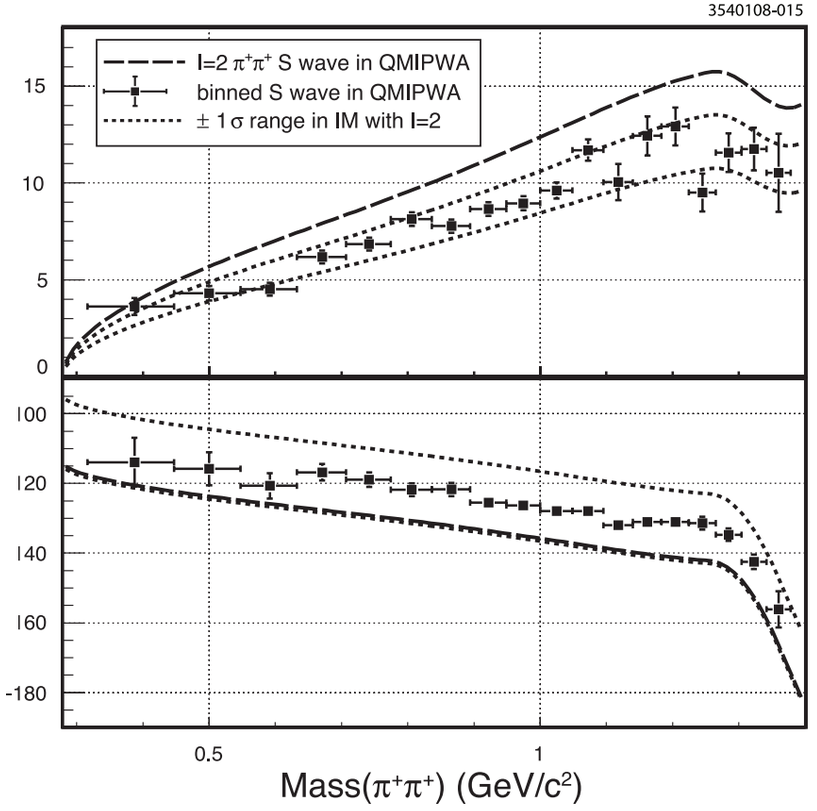


Example: $K^-\pi^+$ D wave



$K^-\pi^+$ S wave

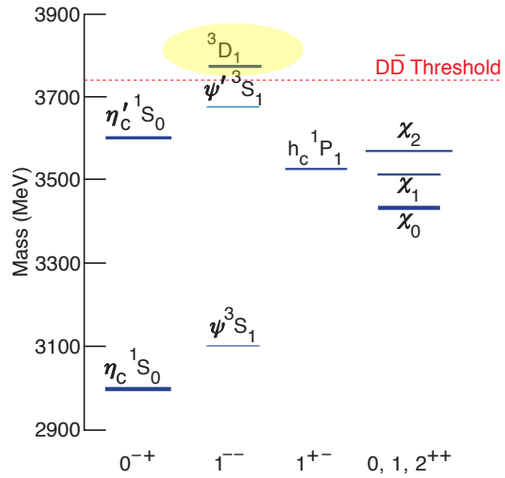


I= 2 $\pi^+\pi^+$ S wave

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!*

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



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

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

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

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

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

$$\mathcal{W}_{L=0}^{I=2}(m) = \frac{\eta_0^2(m)e^{i\delta_0^2(m)} - 1}{2i}$$

η,δ parametrized vs m

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