Electromagnetic transitions in charmonium
$h_c \longrightarrow \eta_c$ as an example

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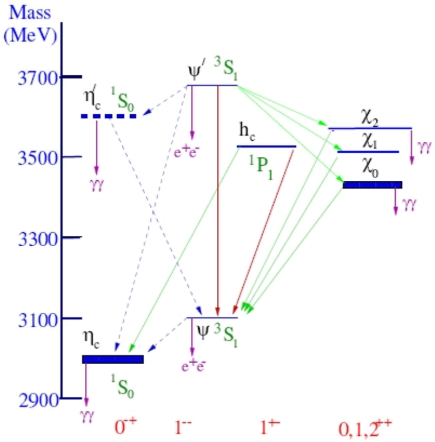
Outline

The cc spectrum and EM transition



EM transition in charmonium. Theoretical description

- For charmonium states below threshold for strong decay to $D\overline{D}$ pair EM transitions are significant decay modes.
- It is described theoretically in the framework of effective field theory
- Leading order therm for NRQCD for EM interaction

$$j \cdot A_{em} = e_Q \Psi^\dagger \{ \frac{\{\overrightarrow{D}, \overrightarrow{A_{em}}\}}{2m} + (1 + k_Q) \frac{\overrightarrow{\sigma} \cdot \overrightarrow{B_{em}}}{2m} + \ldots \} \Psi$$

where first term produces electric, second magnetic transitions, k_Q - anomalous magnetic moment of heavy quark.

Transition amplitudes

Electromagnetic transition amplitude for charmonium is determined by the matrix element of the EM current $\langle f|j^{\mu}_{em}|i\rangle$
The general for for transition amplitude is:

$$M(i \to f) = [M^{(1)}(i \to f) + M^{(2)}(i \to f)] \cdot \varepsilon_{\gamma}(k)$$

where

$$M^{(1)}(i \to f) = \frac{e}{2m} \int d^3x \langle i|Q^{+}(x)(\overrightarrow{D}, exp(i\overrightarrow{k} \cdot \overrightarrow{x}) + (1 + k_Q)\overrightarrow{\sigma} \times \overrightarrow{k} exp(i\overrightarrow{k} \cdot \overrightarrow{x}))|f\rangle$$

is a term for c quark and $M^{(2)}$ is a term for antiquark $\overline{c}$.
Expanding this in power of photon momentum generates electric and magnetic multipole moments.
Although EM transition amplitude can be calculated from the first principles using Lattice QCD, only potential model approach provides the detailed prediction for strength of individual transition amplitudes.

Helicity amplitude formalism

There are two equivalent description for transition between states: via multipole transition amplitude and via helicity amplitude.
Helicity formalism have several advantages:

- Sates are labeled by the component of the total angular momentum along the direction of particle motion, which avoid relativistic complication inherent in breaking up the angular momentum operator into a spin- and orbital- part
- For two-particle states within the centre-of-mass frame orbital momentum is perpendicular to relative motion. $\Rightarrow$ The component of spin along the direction of motion is a component of total angular momentum along this direction.

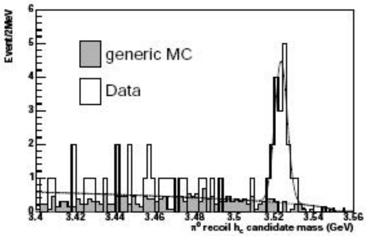
Helicity amplitude squared gives probability that a given eigen value of J_z along the axis formed by decay products is observed.

What can be learnt from angular distribution?

- Determine to high accuracy the electromagnetic radiation multipole structure for transition between charmonium states. $\Rightarrow$ These multipoles probe the electromagnetic structure of the heavy quark and test quark model including wave functions.
- Measurement annihilation through possible helicity states.
- Measurement of the angular distribution will serve to verify the correct J^P assignment for a newly detected states such as the $^1P_1$.

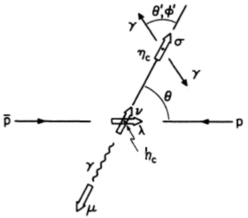
h_c discovery

- h_c is a singlet P-state
- It was firstly claimed by E760 experiment
- E835 has failed to confirm results
- CLEO has observed h_c in inclusive and exclusive measurements of Ψ' decay



h_c angular distributions

$$p\bar{p} \rightarrow h_c \rightarrow \gamma_1 \eta_c \rightarrow \gamma_1 \gamma\gamma$$



The joint angular distribution for this process:

$$W(\theta;\theta';\phi') = \sum_{\lambda} B^2_{|\lambda|} \sum_{\mu,\mu'=\pm 1} d^1_{\lambda\mu}(\theta) d^1_{\lambda\mu'}(\theta) A^2_0$$

h_c angular distribution

Some information can be obtained from integrated distribution:

$$W(\theta) = \int d\Omega' W(\theta; \theta'; \phi')$$

For $h_c \to \gamma\eta_c$ and E1 transition

$$W(\theta) = W(\pi/2)(1 + \alpha \cos^2 \theta)$$

where

$$\alpha = \frac{3R - 2}{2 - R}$$

$$R \equiv \frac{2B_1^2}{B_0^2 + 2B_1^2}$$

measures the fractional distribution of the helicity-one production process

h_c angular distribution

Due to C-parity conservation the B_1 helicity state does not enter into $^1P_1$ production.
Since the $^1P_1$ state is formed by pure R=0, the angular distribution is

$$W(\theta) = W(\pi/2)\sin^2(\theta)$$

On the other hand if angular distribution has such a shape we can confirm J^P assignment.

$$P = (-1)^{L+1} \quad C = (-1)^{L+S}$$

Results on h_c γ angular distribution from CLEO-C

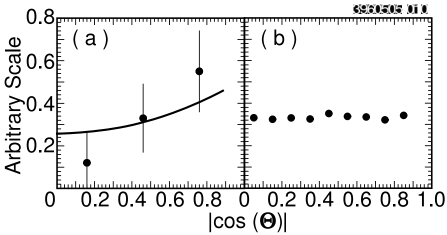


FIG. 3. Inclusive analysis: Efficiency-corrected fit yields versus $|\cos\theta|$ for data with $E_\gamma = 503 \pm 35$ MeV; (a) for h_c yield, the curve corresponds to the best fit $\propto (1 + \cos^2\theta)$ and (b) for the nearly isotropic background yield.

h_c. Channels under study

Exclusive process

$$\overline{p}p \rightarrow h_c \rightarrow \gamma + \eta_c$$

Neutral channel

$$h_c \rightarrow \gamma + \eta_c \rightarrow \gamma + \gamma + \gamma \quad (BR = 4.3 \cdot 10^{-4})$$

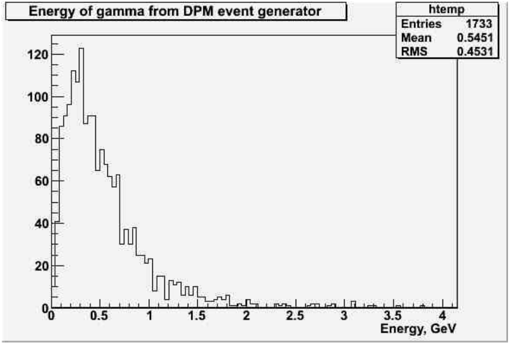
Channels with charged particles

$$h_c \rightarrow \gamma + \eta_c \rightarrow \gamma + \phi\phi \rightarrow \gamma + 2K^+ + 2K^- \quad (BR = 2.6 \cdot 10^{-3})$$

$$h_c \rightarrow \gamma + \eta_c \rightarrow \gamma + K_s^0 K^{\pm}\pi^{\pm} \quad (BR = 1.9 \cdot 10^{-2})$$

MC simulations

E_γ distribution from the DPM event generator at the energy corresponding to h_c production



In the range $530 \pm 35 MeV$ which correspond to $h_c \rightarrow \eta_c + \gamma$ transition there are $\gamma's$ for 1% of events

Summary

- Studying angular distribution in charmonium EM transitions we can not only check predictions of the theory but also determine quantum number for newly detected states
- Preliminary results are positive about possibility to study electromagnetic decay of h_c in PANDA experiment.
- Detailed Monte-Carlo studies for presented processes are planned