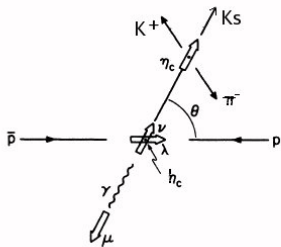


# Status of $\bar{p}p \rightarrow h_c \rightarrow \eta_c + \gamma$ analysis

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# Reaction for study



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

$$E_\gamma = 503 \text{ MeV}$$

$$E_{CM} = 3526 \text{ MeV}, p_z = 5609 \text{ MeV}$$

$$\sigma_{p\bar{p} \rightarrow h_c \rightarrow \eta_c + \gamma} = 40 \text{ nb} \text{ (E835)}$$

## Decay modes of $\eta_c$

- $\eta_c \rightarrow K_S^0 K^\pm \pi^\mp$ ,  $BR = 1.9 \cdot 10^{-2}$ ,  
 $K_S \rightarrow \pi^+ \pi^-$ , 69%
- $\eta_c \rightarrow K^{0*} \bar{K}^{0*}$ ,  $BR = 0.46 \cdot 10^{-2}$ ,  
 $K^{0*} \rightarrow K^+ \pi^-$ , 67%
- $\eta_c \rightarrow \gamma\gamma$ ,  $BR = 4.3 \cdot 10^{-4}$

## Angular distribution

Due to C-parity conservation the helicity-1 state does not enter into  $h_c$  production.

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

## Background channels

- $p\bar{p} \rightarrow K_S K^\pm \pi^\mp \pi^0$
- $p\bar{p} \rightarrow K^+ K^- \pi^+ \pi^- \pi^0$
- $p\bar{p} \rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^0$

## Cross-section estimation

- **Extrapolation from lower energy.**

Measurements in 1966 at Brookhaven gives

$\sigma_{p\bar{p} \rightarrow K_S K^\pm \pi^\mp \pi^0} = 74 \mu b$  at beam momentum 3.66 GeV.

Scaling down according to inelastic cross-section gives

$\sigma = 60 \mu b$  at 5.6 GeV beam momentum.

- **Estimation from DPM.**

2000000 events were generated with DPM and number of

$K_S K^\pm \pi^\mp \pi^0$  events were count (96). It corresponds to

$\sigma = 3 \mu b$ .

Analysed events:

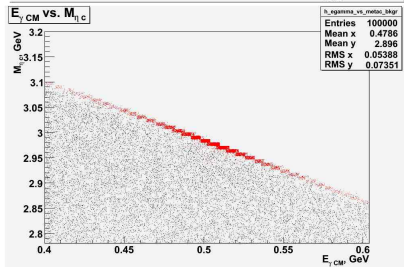
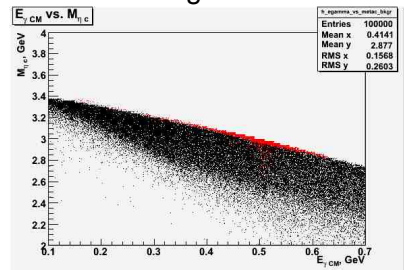
- 78 k -  $p\bar{p} \rightarrow h_c \rightarrow K_S^0 K^\pm \pi^\mp \gamma$
- 100 k -  $p\bar{p} \rightarrow K_S K^\pm \pi^\mp \pi^0$

Selection:

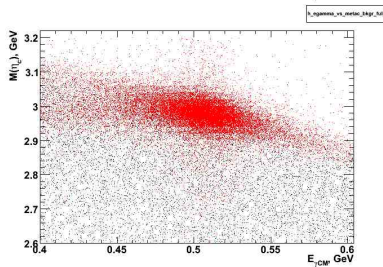
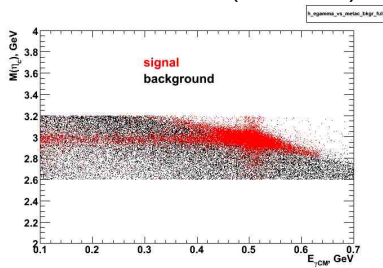
- 4C-fit to beam energy and momentum + additional constraint on  $K_S$  mass,  $CL > 0.05$
- $\eta_c$  pre-fit selection [2.6:3.2] GeV
- $\eta_c$  post-fit selection [2.93:3.03] GeV
- $K_S$  common vertex constraint, with pre-fit mass selection [0.3:0.8] GeV
- $E_\gamma$  within [0.4:0.6] GeV
- no  $\pi^0$  candidates in event

# Analysis of $h_c \rightarrow K_S K^+ \pi^-$

## Event generator

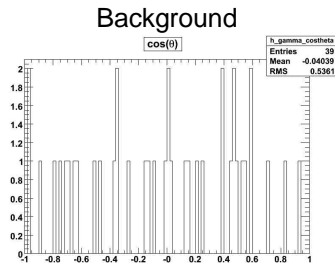
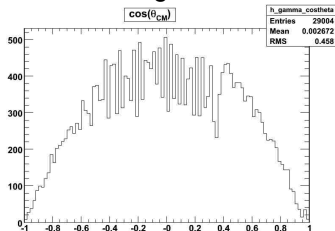


## Full simulation (no 4C-fit)



- Background/signal ratio from 180:1 (extrapolation of the cross-section) to 9:1 (cross-section from DPM).
- Using 10 MeV gamma threshold vs. 30 MeV gamma threshold gives 20% improvement in signal/background ratio.
- Estimated event rate - 2200 events/day.

## Angular distribution of $\gamma$



## Background channels

- $p\bar{p} \rightarrow K^{0*} K^- \pi^+ \pi^0$
- $p\bar{p} \rightarrow K^+ K^- \pi^+ \pi^- \pi^0$
- **Extrapolation from lower energy.** Measurements in 1966 at Brookhaven gives  $\sigma_{p\bar{p} \rightarrow K^+ K^- \pi^+ \pi^- \pi^0} = 34 \mu b$  at beam momentum 3.66 GeV. Scaling down according to inelastic cross-section gives  $\sigma = 28 \mu b$  at 5.6 GeV beam momentum. 30% of events go via  $K^{0*}$  resonance. Assuming the same fraction at momentum 5.6 GeV -  $\sigma_{p\bar{p} \rightarrow K^{0*} K^- \pi^+ \pi^0} = 8.4 \mu b$ . No evidence for  $K^{0*} \overline{K^{0*}}$  was observed in this channel.
- **Estimation from DPM.** 2000000 events were generated with DPM and number of  $K^+ K^- \pi^+ \pi^- \pi^0$  and  $K^{0*} K^- \pi^+ \pi^0$  events were count (758 and 15). It corresponds to  $\sigma = 22 \mu b$  and  $\sigma = 0.4 \mu b$ .

Analysed events:

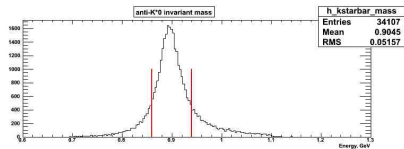
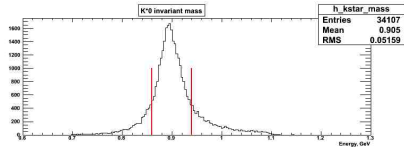
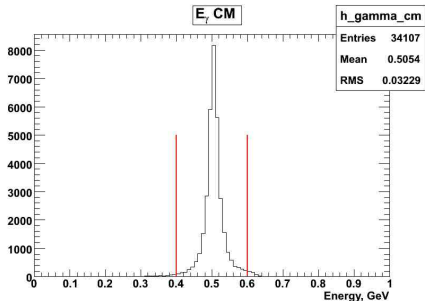
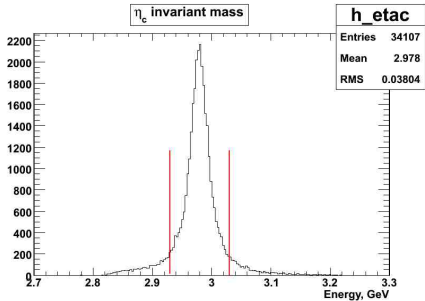
- 80 k -  $p\bar{p} \rightarrow h_c \rightarrow K^{0*}\overline{K^{0*}}\gamma$
- 1.128.000 -  $p\bar{p} \rightarrow K^{0*}K^-\pi^+\pi^0$
- 200 k -  $p\bar{p} \rightarrow K^+K^-\pi^+\pi^-\pi^0$

Selection:

- 4C-fit to beam energy and momentum,  $CL > 0.1$
- $\eta_c$  pre-fit selection [2.6:3.2] GeV
- $\eta_c$  post-fit selection [2.93:3.03] GeV
- $K^{0*}, \overline{K^{0*}}$  common vertex constraint, with pre-fit mass selection [0.7:1.1] GeV
- $K^{0*}, \overline{K^{0*}}$  post-fit selection [0.86:0.94] GeV
- $E_\gamma$  within [0.4:0.6] GeV
- no  $\pi^0$  candidates in event, i.e no 2  $\gamma$  invariant mass in the range [0.115:0.15] GeV



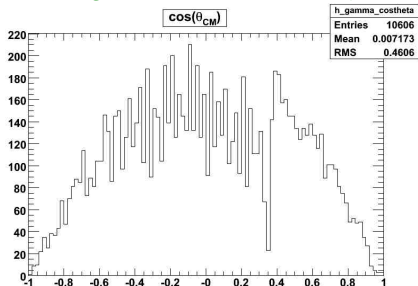
# Analysis of $h_c \rightarrow K^{0*} K^{0*} \gamma$



# Results on $h_c \rightarrow K^{0*} \overline{K^{0*}} \gamma$

- Background/signal ratio from 10:1 (extrapolation of the cross-section) to 1:2 (cross-section from DPM) for  $p\bar{p} \rightarrow K^{0*} K^- \pi^+ \pi^0$  background channel and  $<15:1$  for  $p\bar{p} \rightarrow K^+ K^- \pi^+ \pi^- \pi^0$  background channel (no events passed the cuts).
- Using 10 MeV gamma threshold vs. 30 MeV gamma threshold gives 50% improvement in signal/background ratio.
- Estimated event rate - 400 events/day.

## Angular distribution of $\gamma$



# Background for $h_c \rightarrow 3\gamma$

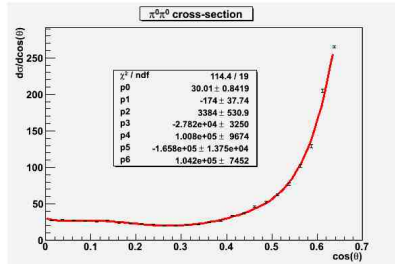
## Background channels

- $p\bar{p} \rightarrow \pi^0\pi^0$ ,  $\sigma = 31.4 \text{ nb}$ ,  
( $|\cos(\theta)| < 0.6$ )
- $p\bar{p} \rightarrow \pi^0\gamma$ ,  $\sigma = 1.4 \text{ nb}$
- $p\bar{p} \rightarrow \pi^0\eta$ ,  $\sigma = 33.6 \text{ nb}$
- $p\bar{p} \rightarrow \eta\eta$ ,  $\sigma = 34.04 \text{ nb}$

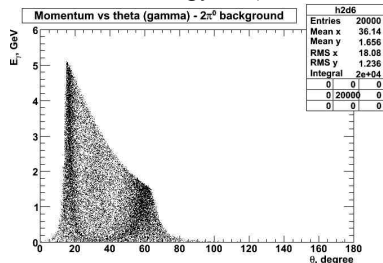
Several EMC options were studied with this channel:

- Possible low energy thresholds - 10, 30, 50 MeV.
- With/without backward endcap.

## Parametrization of cross-section



## Energy of $\gamma$



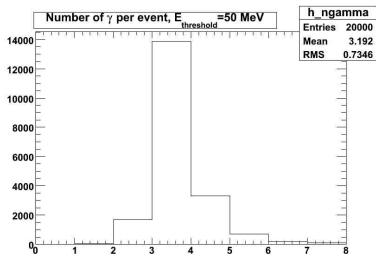
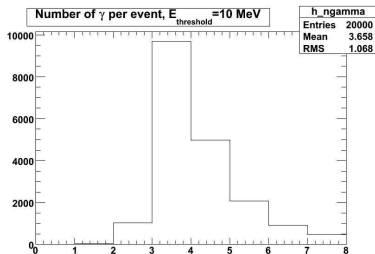
## Analysed events:

- 20 k -  $p\bar{p} \rightarrow h_c \rightarrow \eta_c + \gamma$
- 100 k -  $p\bar{p} \rightarrow \pi^0\pi^0$
- 100 k -  $p\bar{p} \rightarrow \pi^0\gamma$
- 100 k -  $p\bar{p} \rightarrow \pi^0\eta$
- 100 k -  $p\bar{p} \rightarrow \eta\eta$

## Selection:

- 4C-fit to beam momentum,  $CL > 10^{-4}$
- $E_{\gamma_3}$  within [0.4:0.6] GeV
- $|\cos(\theta_{\gamma_{1,2}}^*)| < 0.6$
- $M(\gamma_1 + \gamma_3), M(\gamma_2 + \gamma_3) > 1.0\text{GeV}$

## Number of $\gamma$ in event



## Conclusions

- All the background is suppressed with signal efficiency 10% at the level of signal/background ratio 10:1.
- No difference between different threshold options
- Requirement on 3  $\gamma$  in event make signal efficiency relatively lower for 10 MeV threshold in comparison with 30 or 50 MeV thresholds.

# Summary

The following signal/background ratios have been obtained for the studied  $h_c$  decay modes with correspondent event rates at  $L = 2 \cdot 10^{32}$ :

## Summary

decay mode	S:B ratio	Event rate (events/day)
$p\bar{p} \rightarrow h_c \rightarrow K_S^0 K^\pm \pi^\mp \gamma$	1:180-1:9	2200
$p\bar{p} \rightarrow h_c \rightarrow K^{0*} \overline{K^{0*}} \gamma$	1:10-2:1	400
$p\bar{p} \rightarrow h_c \rightarrow 3\gamma$	>10:1	30