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

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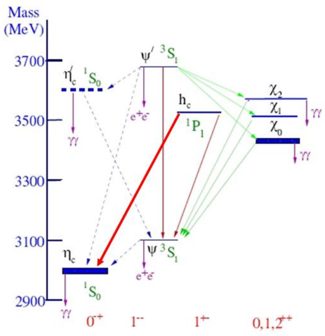
Reaction for study



$$p\bar{p} \to h_c \to \eta_c + \gamma \to \phi\phi\gamma \to K^+K^-K^+K^-\gamma$$

Decay mode of η_c

$\eta_c \to \phi\phi,\ BR = 2.6 \cdot 10^{-3}$,
$\phi \to K^+K^-, BR = 0.49$

Advantages of decay mode

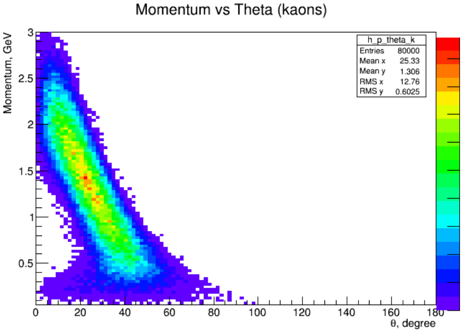
- Narrow ϕ resonance (Γ = 4 MeV) in the final state allows tight constraint on its invariant mass.
- Relatively low background due to the fact that $K^+K^-K^+K^-$ final state have 4 s quarks.

Signal cross-section

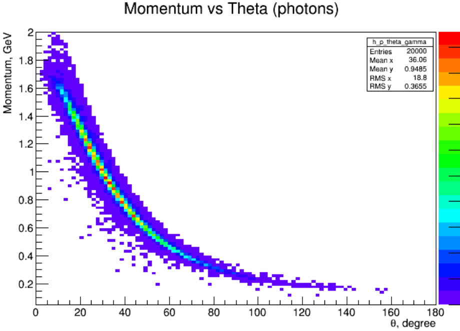
E835: $\Gamma_{p\bar{p}} B_{\eta_c\gamma}$ = 12 eV
$\sigma_{p\bar{p}\to h_c \to \eta_c+\gamma} = 40nb$

Reaction kinematics

Kaons



Photons



Width measurement

E835 experiment gave an upper limit on the h_c width $\Gamma_{h_c} < 1 MeV$.
However BES3 experiment in 2012 measured h_c width
$\Gamma_{h_c} = 0.7 \pm 0.4 MeV$
Phys.Rev. D86 (2012) 092009 ($\psi(3686) \to \pi^0 h_c, h_c \to \gamma \eta_c$ via η_c exclusive decays.)

Can PANDA measure it better in a reasonable time?

Background

DPM event generator was used to estimate cross-section for background channels with 10^7 generated events for first 3 channels. For last reaction background cross-section is an extrapolation from lower energy according to total cross-section.

Background cross-section

decay mode	σ
$p\bar{p} \rightarrow K^+K^-K^+K^-\pi^0$	360 nb
$p\bar{p} \rightarrow K^+K^-\phi\pi^0$	37 nb
$p\bar{p} \rightarrow \phi\phi\pi^0$	<6 nb
$p\bar{p} \rightarrow K^+K^-\pi^+\pi^-\pi^0$	30 μb

Analised events

Analised events:

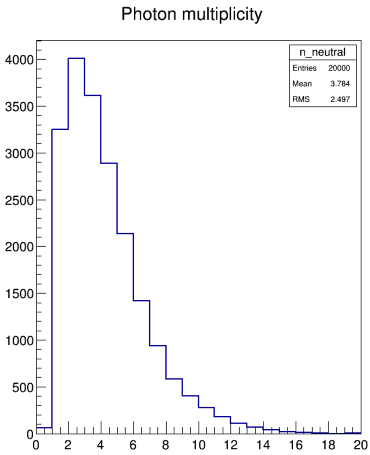
- 20 k - $p\bar{p} \rightarrow h_c \rightarrow \phi\phi\gamma$ (Full simulation)
- 20 k - $p\bar{p} \rightarrow h_c \rightarrow \phi\phi\gamma$ (Fast simulation: full detector, NoMvdGem, NoFwdSpec, NoEmcBarrel)
- 1 M - $p\bar{p} \rightarrow K^+K^-K^+K^-\pi^0$ (full detector, NoMvdGem, NoFwdSpec, NoEmcBarrel)
- 1 M - $p\bar{p} \rightarrow K^+K^-\phi\pi^0$
- 1 M - $p\bar{p} \rightarrow \phi\phi\pi^0$
- 20 M - $p\bar{p} \rightarrow K^+K^-K^+K^-\pi^0$

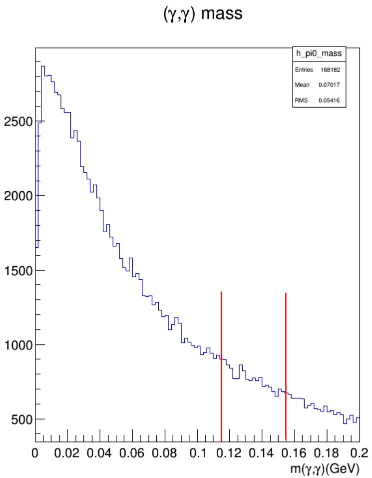
Event selection

Selection:

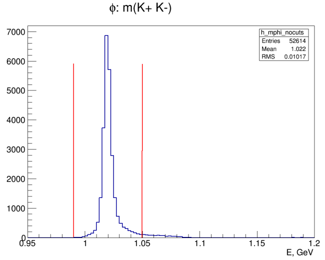
- 4C-fit to beam energy and momentum, CL> 0.05
- η_c mass selection [2.9:3.06] GeV
- $m(\phi)$ within [0.99;1.05] GeV
- no π^0 candidates in event (no $\gamma\gamma$ invariant mass in the range $135 \pm 20\ MeV$)

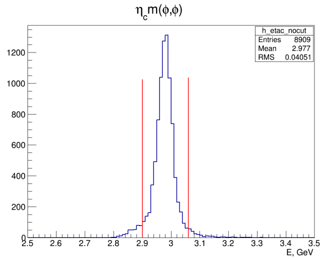
Hadronic split-off



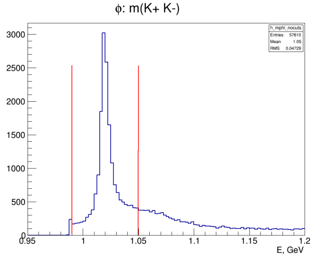


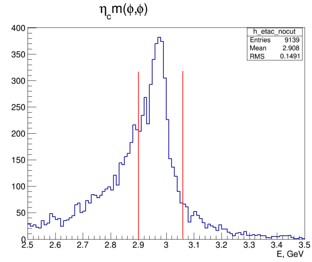
Fast simulation





Full simulation





Background suppression

Signal to background ratio

decay mode	S/B
$p\bar{p} \to K^+K^-K^+K^-\pi^0$	3.3
$p\bar{p} \to K^+K^-\phi\pi^0$	30
$p\bar{p} \to \phi\phi\pi^0$	>7
$p\bar{p} \to K^+K^-\pi^+\pi^-\pi^0$	>5

- In the analysis no PID information was used. In the $p\bar{p} \to K^+K^-\pi^+\pi^-\pi^0$ background channel no event was reconstructed from 20 M with only 4C Kinematic fit.
- For Physics Book studies the signal to background ratio 8:1 was achieved. The difference comes from the hadronic split-off suppression based on the cluster shape analysis implemented in the software used for Physics Book.

Results

- Signal reconstruction efficiency in fast simmulation 28.8%.
- With full simulation signal reconstruction efficiency - 11.8%
- For physics book analysis reconstruction efficiency was 26%.
- With 28.8 % reconstruction efficiency and luminocity $L = 10^{31}\ s^{-1} cm^{-2}$ 6 reconstructed h_c per day is expected.

Minimal setup

- Using detector setup without Forward spectrometer reduce signal reconstruction efficiency to 25.9% and S/B ratio for $p\bar{p} \rightarrow K^+K^-K^+K^-\pi^0$ is the same.
- Detector setup without Mvd and GEM. Signal reconstruction efficiency 5.9%. S/B ratio for $p\bar{p} \rightarrow K^+K^-K^+K^-\pi^0$ is the same within statistical uncertanity.
- Without Barrel EMC still 6.7% h_c are reconstructed with S/B 1.5 for $p\bar{p} \rightarrow K^+K^-K^+K^-\pi^0$ channel.

Width reconstruction

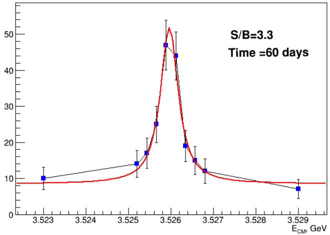
The expected shape of measured resonance in $\bar{p}p \to h_c \to \eta_c\gamma$ is the convolution of the Breit-Wigner resonance curve with the normalised beam energy distribution and an added background term. The expected number of events at the *i*-th data point is:

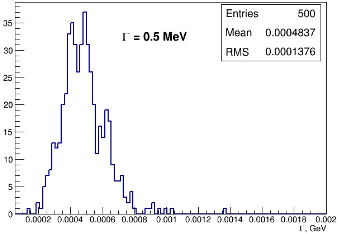
$$\nu_i = [\varepsilon \times \int L dt]_i \times [\sigma_{bkgd}(E) + \frac{\sigma_p \Gamma_R^2/4}{(2\pi)^{1/2}\sigma_i} \times \int \frac{e^{-(E-E')^2/2\sigma_i^2}}{(E'-M_R)^2 + \Gamma_R^2/4} dE']$$

where σ_i is the beam energy resolution at the *i*-th data point, Γ_R and M_R the resonance width and mass, σ_p incorporates branching ratios for the formation and decay, the factor in square brackets is the product of ε, an overall efficiency and acceptance factor and the integrated luminosity at the *i*-th point of measurements.

Width reconstruction

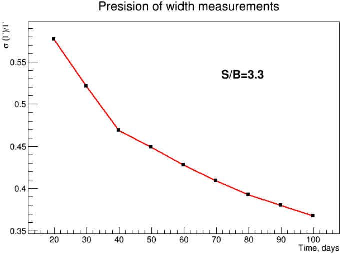
- Number of reconstructed events were generated at 10 E_{CM} points around h_c mass smeared with poissonian distribution for given resonance width Γ, time of measurements and S/B ratio.
- Obtained points are fitted and Γ is extracted.
- The procedure is repeated to obtain the distribution of the reconstructed width.
- The RMS of this distribution is considered as an error of the width.

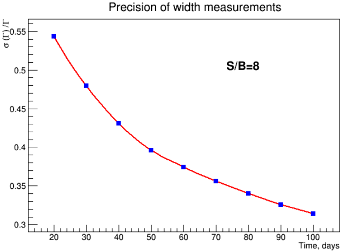




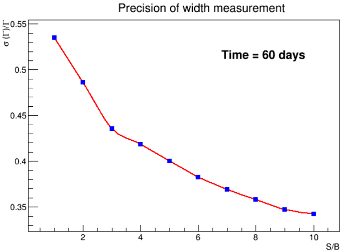
Width reconstruction

Dependence on time





Dependence on S/B ratio



Conclusion

- Minimal setup includes Central tracker with MvD and GEM and Barrel EMC.
- Reasonable time for h_c width measurements is around 60 days with $L = 10^{31}\ s^{-1} cm^{-2}$. No resonable results are expected with 0.1 or 0.01 of design luminosity.
- Number of point for resonsnce scan and step between them can be optimized to minimize time for the width measurements.