$p\bar{p} \to h_c \to 5\pi$

Anastasia Karavdina

Motivation

$$\frac{h_c \to \gamma \eta_c}{h_c \to hadrons} \sim 1$$

Not much information about $h_c \to hadrons$ channels:

- $h_c \to \pi^+\pi^-\pi^0 < 2.2 \cdot 10^{-3}$
- $h_c \to 2(\pi^+\pi^-)\pi^0$ $(2.2^{+0.8}_{-0.7})$ %
- $h_c \to 3(\pi^+\pi^-)\pi^0 < 2.9$ %

NB: $p\bar{p} \to 2(\pi^+\pi^-)\pi^0$ highest inelastic channel for $p\bar{p}$

+ high statistic
– significant background

Model $h_c \to 1 + 2$

$$h_c : I^G(J^{PC}) = 0^-(1^{+-})$$

S = Scalar, P = Pseudoscalar
V = Vector, V_p = pseudoVector (* skipped in this study)
angular momentum and parity conservation:

$$(-1)^{J_c} P_c = (-1)^{J_1+J_2} P_1 P_2$$

PP [1]	PV [1]	VV [1]	PS	SS	SV	V_pS	V_pV	V_pP	V_pV_p
−	+	ϵ	+	−	−	+	+	−	−

+ - allowed
− - forbidden by angular momentum and parity conservation
ϵ - forbidden to leading-twist accuracy
G parity $\to$ odd number of pions

QWG report "Heavy quarkonium physics" arXiv:hep-ph/0412158

Model $h_c \to$ PV, PS

Vectors (ω, ϕ, $J/\psi(1S)$, $\rho(I{=}1)$)

- $\omega[0^-(1^{--})] \to$
  $\pi^+\pi^-\pi^0$ (89.2 ± 0.7) %
  $\pi^+\pi^-$ $(1.53^{+0.11}_{-0.13})$ %
- $\rho[1^+(1^{--})] \to$
  $\pi^+\pi^-$ (~ 100) %

Scalars (f_0, $\chi_{c0}(1P)$)

- $f_0(600, 980)[0^+(0^{++})] \to$
  $\pi\pi$ (dominant)
- $f_0(1500)[0^+(0^{++})] \to$
  $\pi\pi$ (34.9 ± 2.3) %
- $\chi_{c0}(1P)[0^+(0^{++})] \to$
  $\pi\pi$ $(8.4 \pm 0.4) \times 10^{-3}$

Pseudoscalars (η, η', $\eta_c(1S)$)

- $\eta[0^+(0^{-+})] \to$
  $3\pi^0$ (32.57 ± 0.23) %
  $\pi^+\pi^-\pi^0$ (28.1 ± 0.34) %

$h_c \to 2(\pi^+\pi^-)\pi^0$

- $\eta\omega$ (+)
  $\mathrm{Br}(hc \to \eta\omega) \times 0.0043 \sim 0.0043$
- $\eta\rho$ (violate I)
  $\mathrm{Br}(h_c \to \eta\rho) \times 0.28 \sim (\alpha^2 \times 0.28)$
- $\eta f_0(980)$ (violate G)
  $\mathrm{Br}(h_c \to \eta f_0) \times 0.28 \sim$ (???)

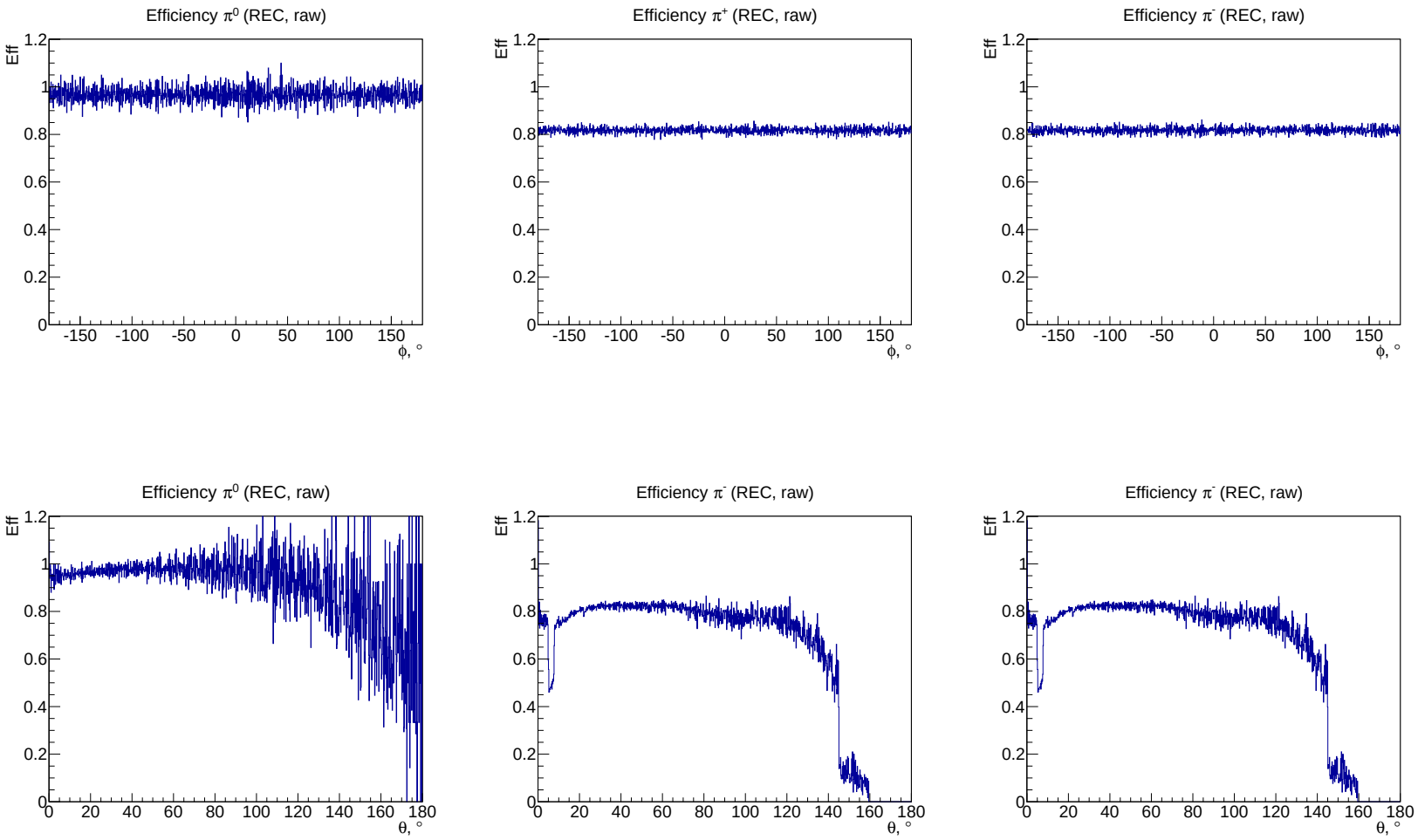
NB: $h_c \to \pi^+\pi^-3\pi^0$ via $\eta \to 3\pi^0$

Simulation details

- ⋆ standard decay and particles files in EvtGen
- ⋆ Only width of h_c changed $0 \rightarrow 0.7$ MeV
  (default mass of h_c is 3.52593 GeV)
- ⋆ noPhotos
- ⋆ standard FastSim (full and reduced) set-up
- ⋆ *MergeNeutralClusters()* switched on (more realistic π^0)
- ⋆ PionAllPlus, PionAllMinus ("PidChargedProbability")

P_{beam} = 5.61 GeV/c
(E_{CM} = 3.52593 GeV $\rightarrow$ P_{beam} = 5.60883 GeV/c in LAB)

Reconstruction efficiency
Finale state particles



Event selection
$h_c \to 2(\pi^+\pi^-)\pi^0$

$\pi^0 \to \gamma\gamma$

- π^0 mass window cut ($\pm$50 MeV)
- N_{π^0}=1, N_{π^+}=2, N_{π^-}=2

$h_c \to 2(\pi^+\pi^-)\pi^0$

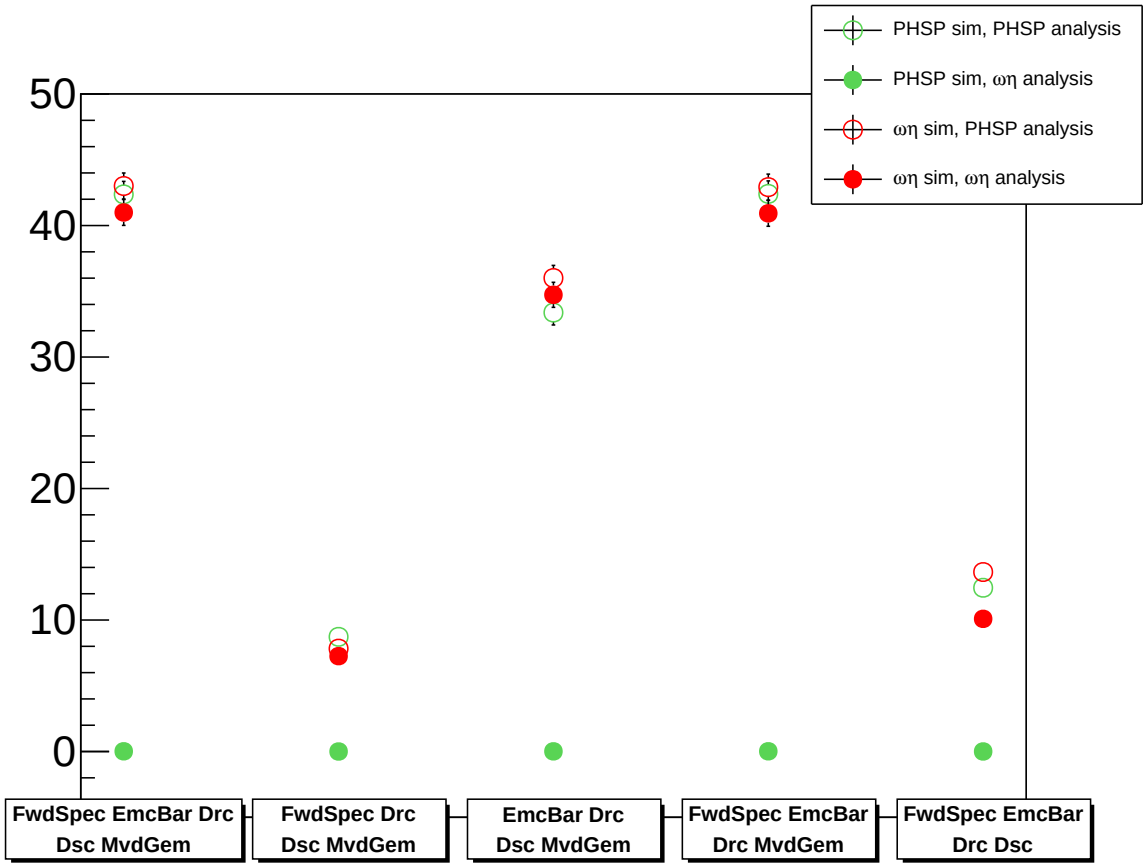
$\omega\eta$ analysis model:

- $\omega \to \pi^+\pi^- \to p_\perp(p_z)$ check
- $\eta \to \pi^+\pi^-\pi^0 \to p_\perp(p_z)$ check
- if both OK for diff $\pi^+\pi^-$ pairs $\to$ ω and η mass cuts

4C fit $\to$ cut on χ^2

Reconstruction efficiency

Signal, $\eta\omega$ cut



FwdSpec = complete Forward Spectrometer (Fwd Spec. EMC, Fwd Tracking, RICH, Fwd MUO)

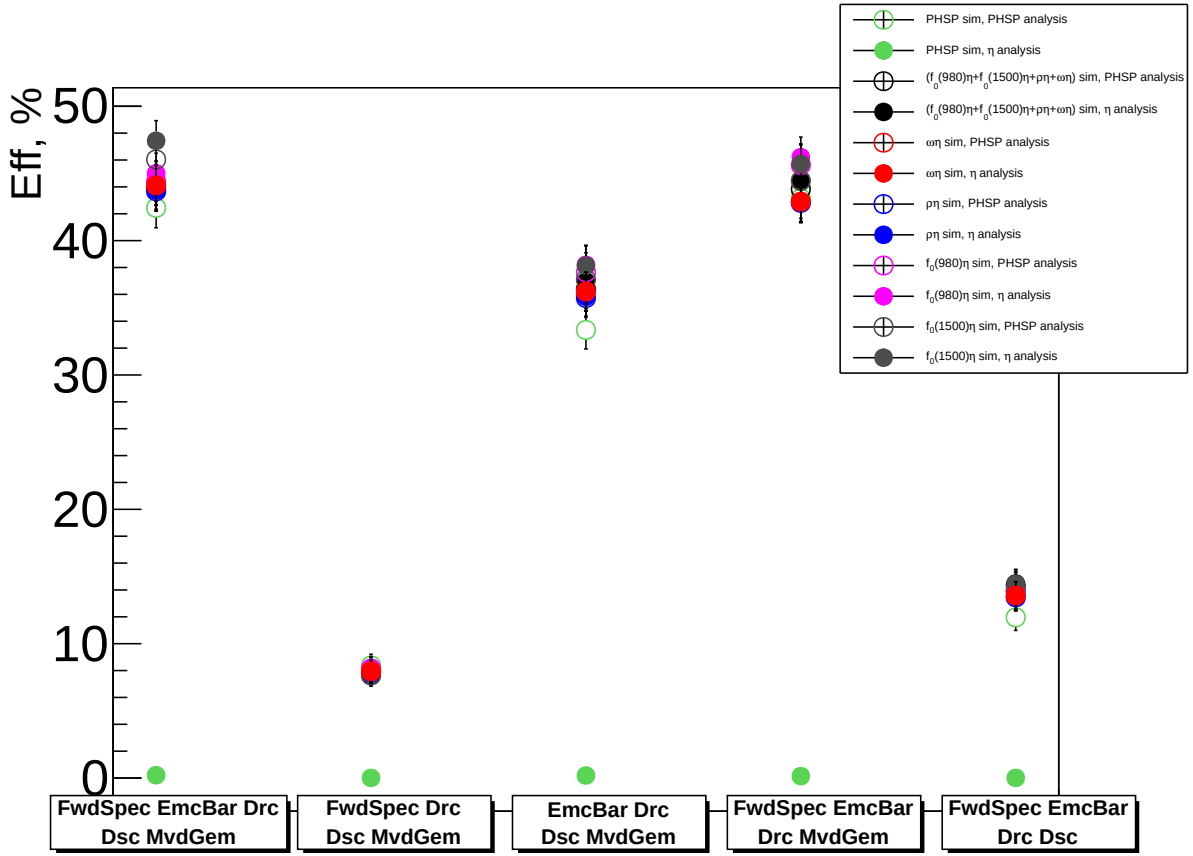
EmcBarrel = EMC barrel for calorimetry (neutral detection and PID component)

Drc = Barrel DIRC for PID, **Dsc** = Disc DIRC for PID

MvdGem = MVD and GEM for central tracking in addition to STT

Reconstruction efficiency

Signal, only η mass cut



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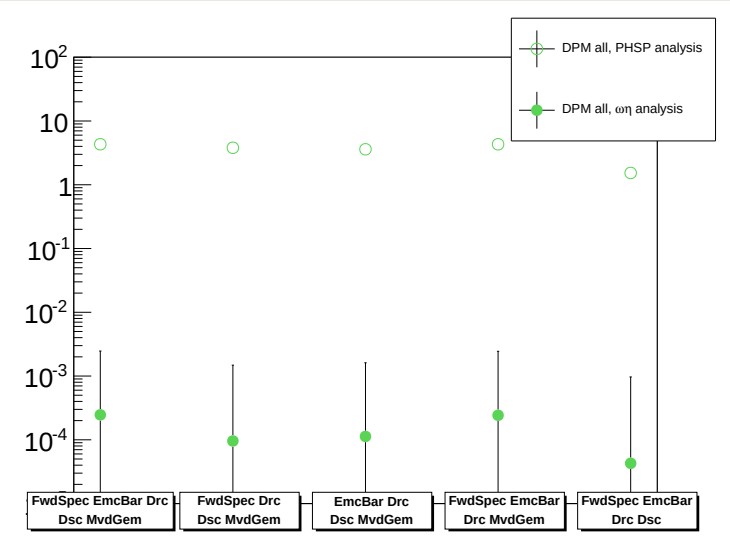
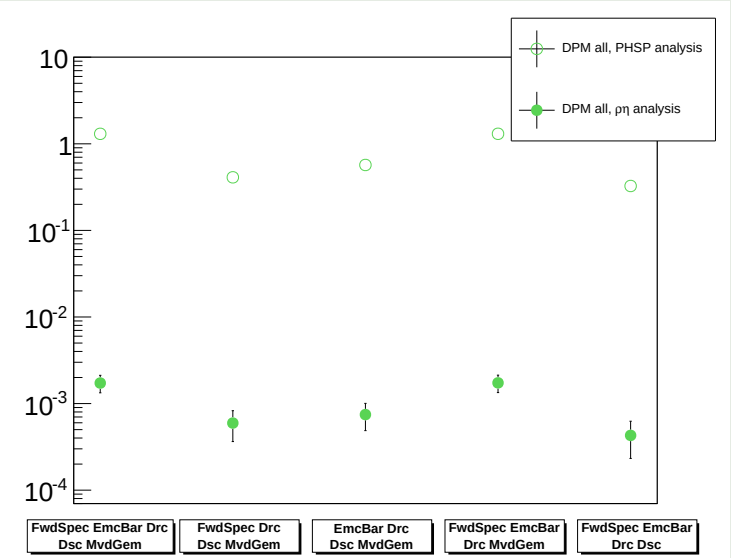
Reconstruction efficiency
Background

$\eta\omega$ cut



only η mass cut



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Significance
$h_c \to 2(\pi^+\pi^-)\pi^0$

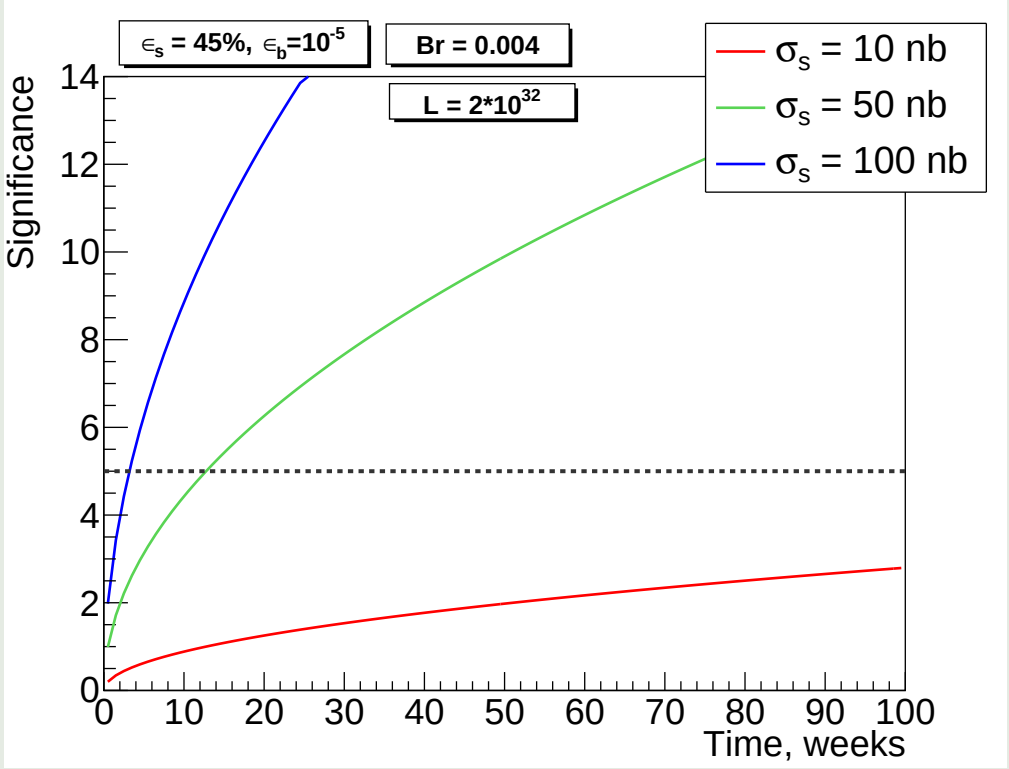
$$\text{Significance}(t) = \sqrt{L \cdot t}\,\frac{\sigma_s \cdot \epsilon_s \cdot f_{BR}}{\sqrt{\sigma_s \cdot \epsilon_s \cdot f_{BR} + \sigma_b \cdot \epsilon_b}}$$

"known":

- σ_s – signal cross-section (10-100 nb)
- σ_b – bkg cross-section (50 mb)
- f_{BR} – BR factor for given decay (0.004)
- L – luminosity ($2 \cdot 10^{32}$)

"input":

- ϵ_s – rec. efficiency for signal
- ϵ_b – rec. efficiency for bkg



Event selection
$h_c \to \pi^+\pi^-3\pi^0$

$\pi^0 \to \gamma\gamma$

- π^0 mass window cut ($\pm$50 MeV)
- $N_{\pi^0}=3$, $N_{\pi^+}=1$, $N_{\pi^-}=1$

$h_c \to \pi^+\pi^-3\pi^0$

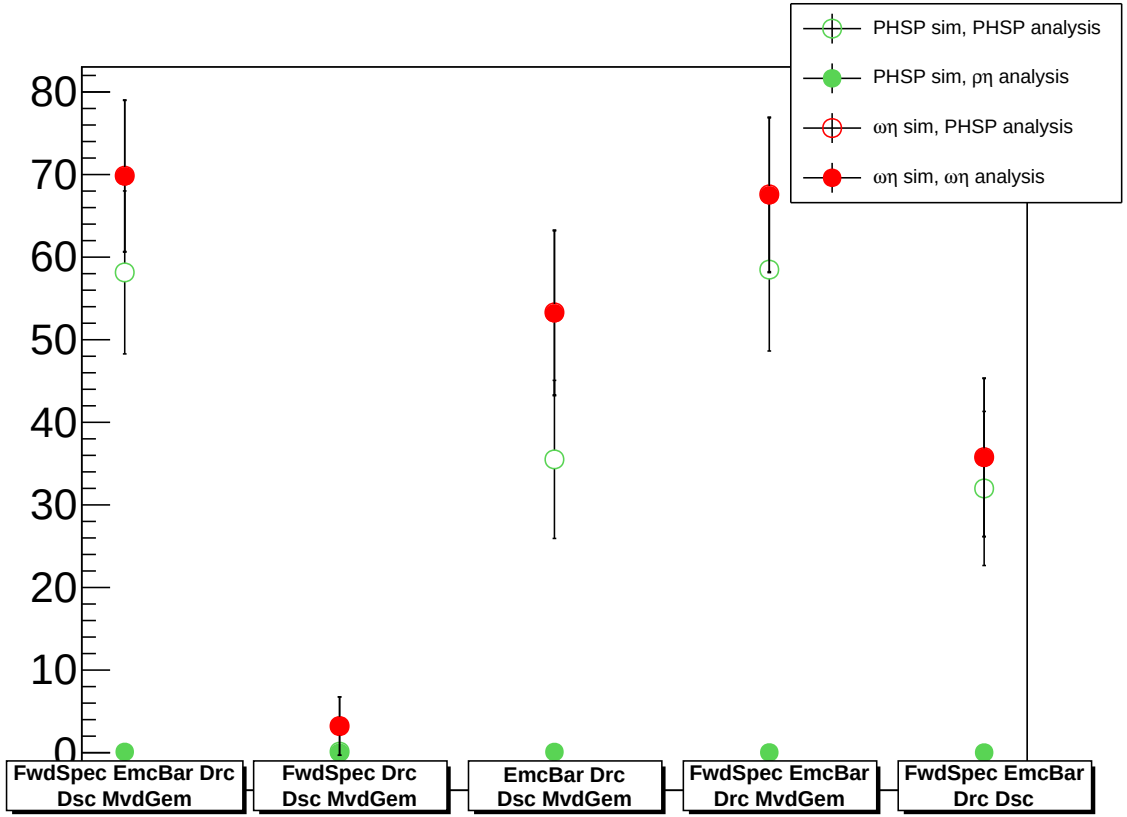
η analysis model:

- $0.25<M^2_{3\pi^0}<0.35$

4C fit $\to$ cut on χ^2

Reconstruction efficiency

Signal, η mass cut



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Reconstruction efficiency
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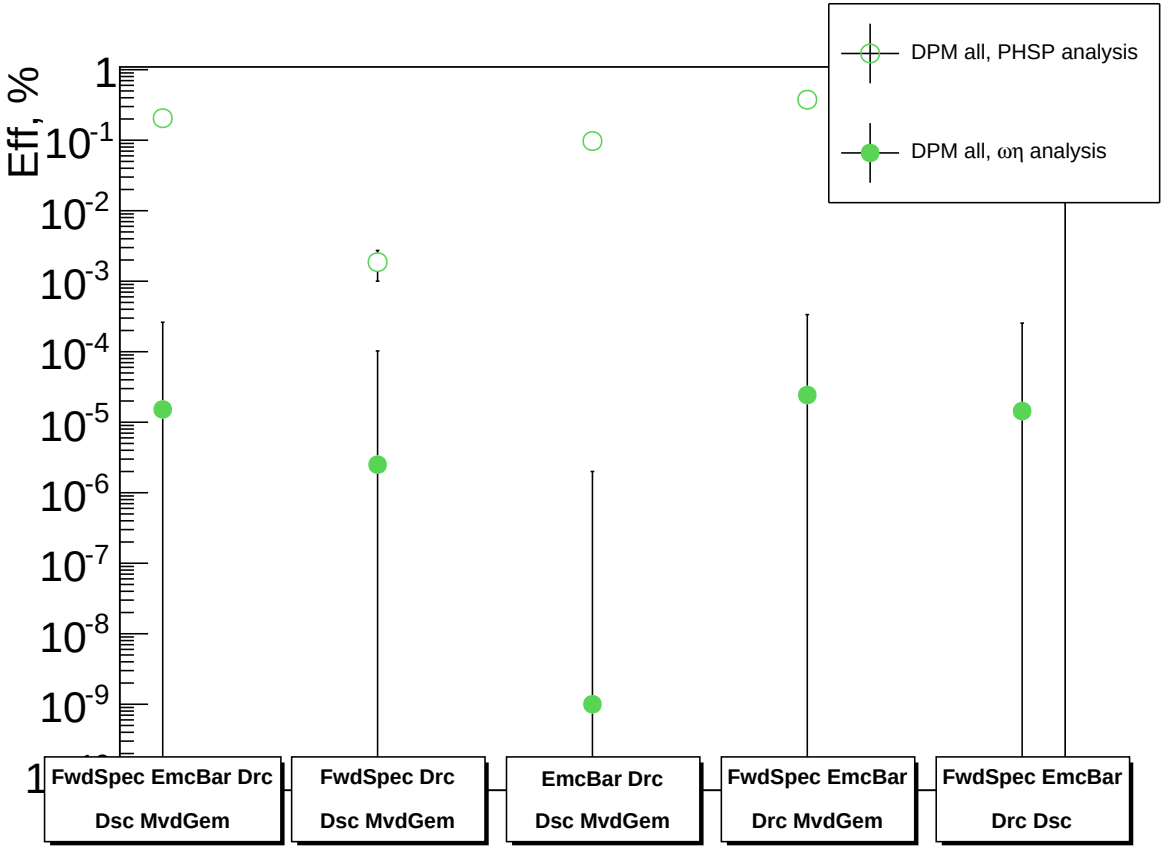

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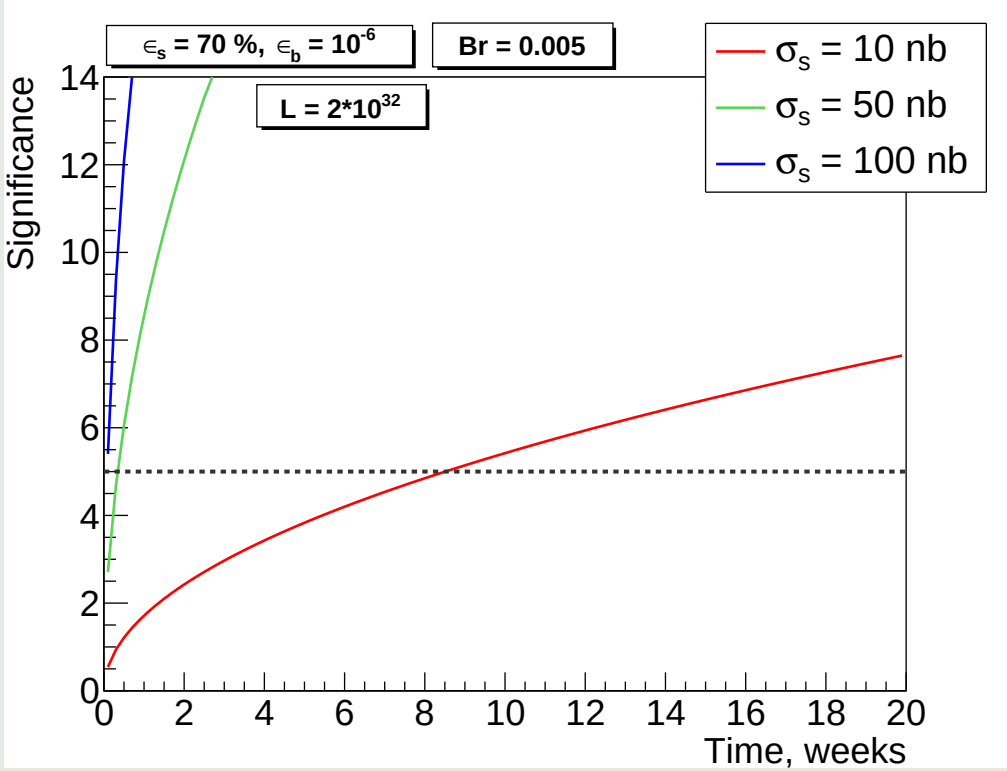

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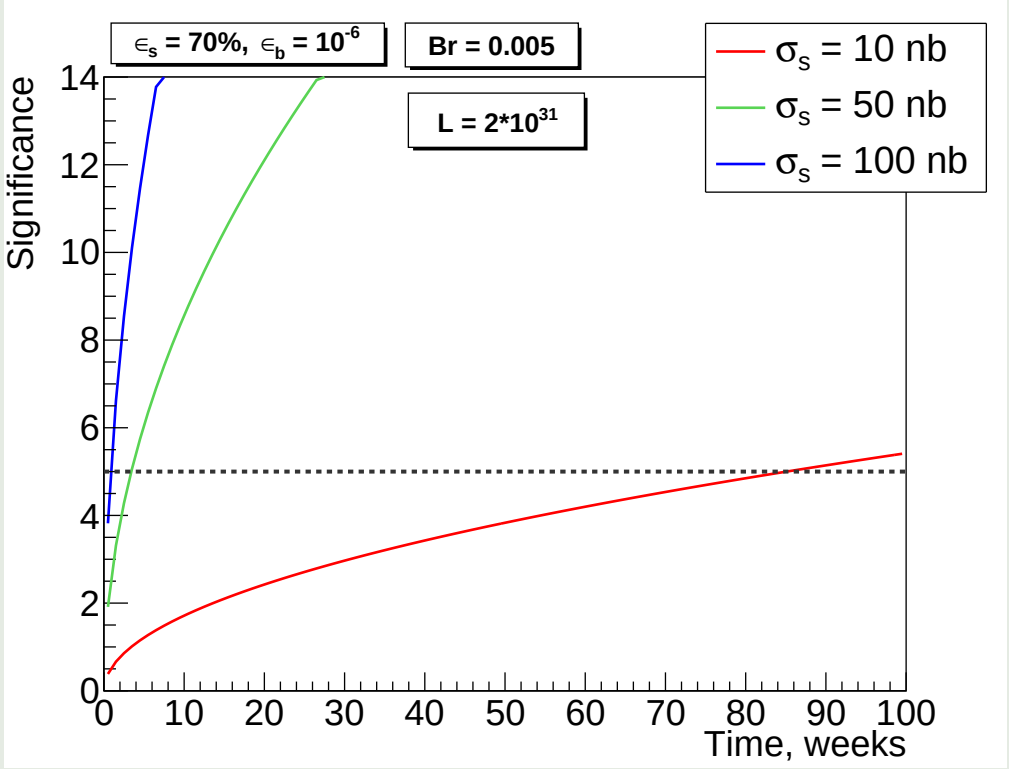


Results (P_{beam} = 5.61 GeV/c)

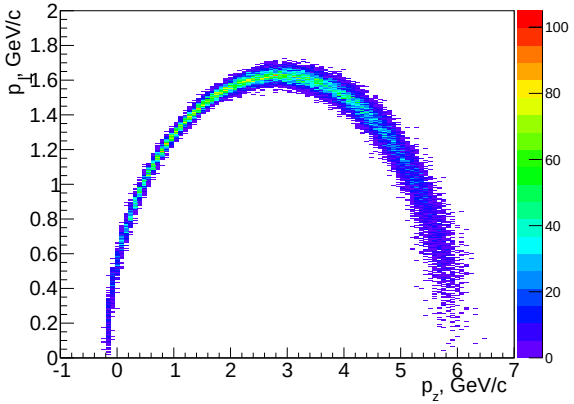
$p\bar{p} \rightarrow h_c \rightarrow 2(\pi^+\pi^-)\pi^0$

- PHSP and PV, PS models were checked
- $\epsilon_{sig} \sim 45$ %, $\epsilon_{bkg} \sim 10^{-5}$
- $\sim$ 2-10 weeks to achieve 5σ significance (σ_s=50-100 nb, L=2·10^{32} $cm^{-2}s^{-1}$)
- different detector set-up scenarios checked
  $\rightarrow$ without EmcBarrel or MvdGem $\epsilon_{sig} \sim 10$ %

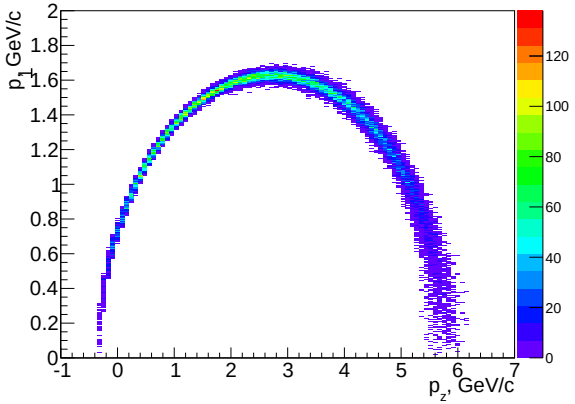
$p\bar{p} \rightarrow h_c \rightarrow \pi^+\pi^- 3\pi^0$

- PHSP and PV models were checked
- $\epsilon_{sig} \sim 70$ %, $\epsilon_{bkg} \sim 10^{-7}$
- $\sim$ 1 week to achieve 5σ significance
- different detector set-up scenarios checked
  $\rightarrow$ without EmcBarrel $\epsilon_{sig} \sim 2$ %

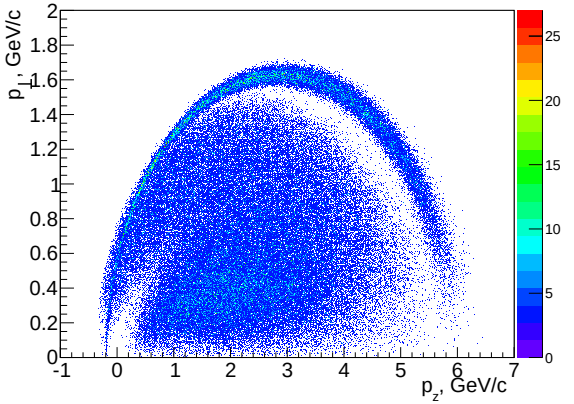
Event selection with $p_\perp(p_z)$ [Peyrou]



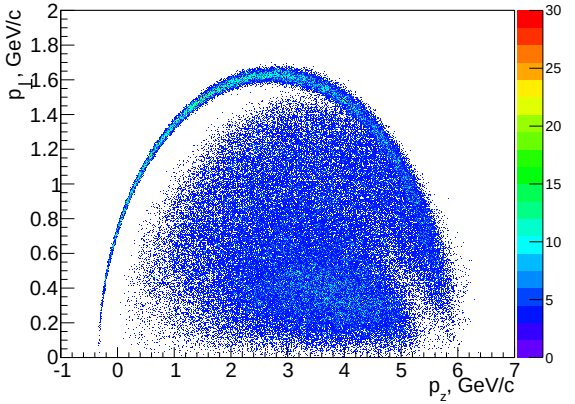
ω (MC)



η (MC)



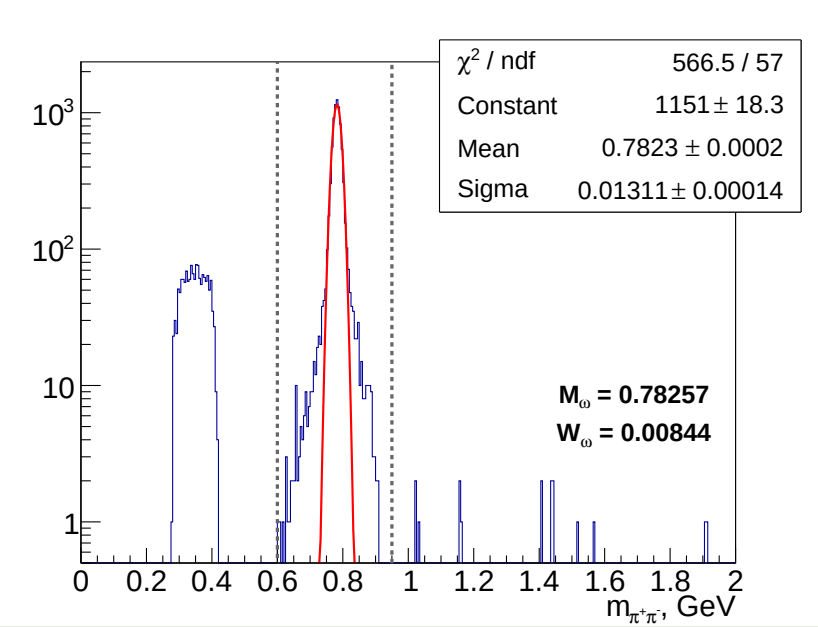
ω (all candidates)

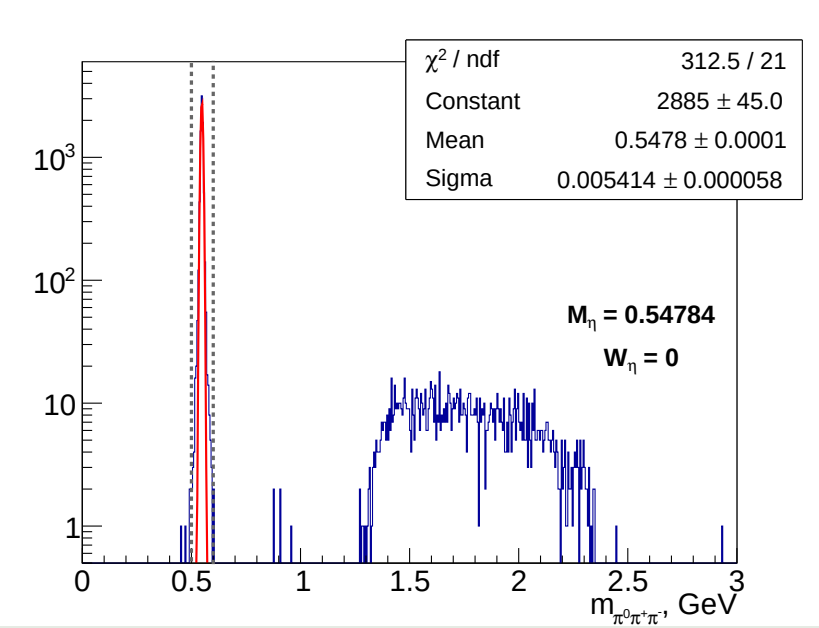


η (all candidates)

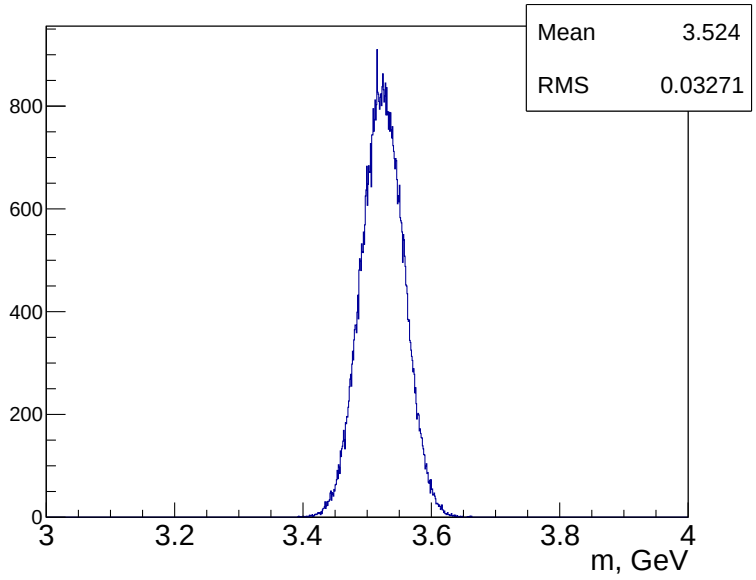
Event selection
Mass window cut

ω (left) and η (right)

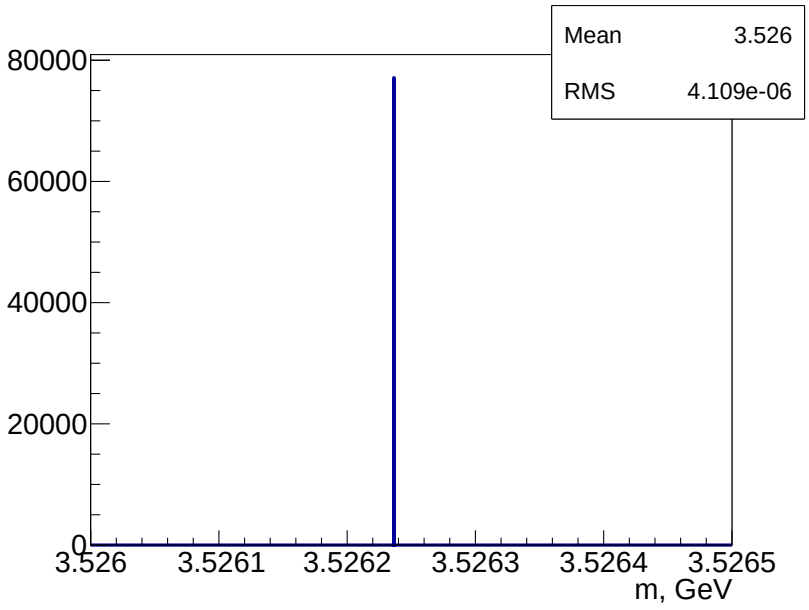




Reconstructed h_c mass



after all cuts



after 4C fit