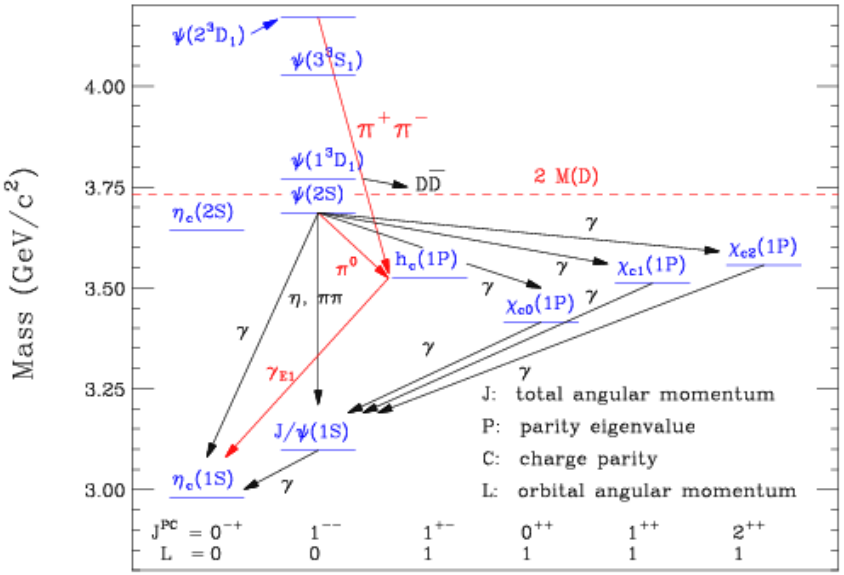
$p\bar{p} \to h_c \to 5\pi$

Anastasia Karavdina

Motivation



arXiv:1107.2023

h_c

- Not well established charmonium state
- Mass: 3525.38 ± 0.11 MeV
  Singlet partner for χ_{cJ} triplet spin–spin interaction → hyperfine mass splitting
- Width: 0.7 ± 0.4 MeV simply aren't measured precise

Decay modes

Radiative transitions: $h_c \to \gamma\eta_c$ (Br $\sim$ 50%)

Hadronic transitions: $h_c \to J/\Psi\pi\pi$ (not seen)

Hadronic decay: $h_c \to \pi\pi\pi$

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

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

G parity $\to$ odd number of pions

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

$p\bar{p} \to 2(\pi^+\pi^-)\pi^0$ the largest inelastic channel for $p\bar{p}$

\+ high statistic

\- significant background

Model $h_c \longrightarrow 1 + 2$

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

S = Scalar, P = pseudoScalar, V = Vector,
V_p = pseudoVector *
angular momentum and parity conservation:

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

PP	PV	VV	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 [1]

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

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* skipped in this study

Model $h_c \to$ PV, PS

Vectors

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

Scalars

- $f_0(600, 980)[0^+(0^{++})] \to$
  $\pi\pi$ (dominant)
- $f_0(1500)[0^+(0^{++})] \to$
  $\pi\pi$ (34.9 ± 2.3) %
- $\chi_{c0}(1P)[0^+(0^{++})] \to$
  $\pi\pi$ $(8.4\pm0.4) \times 10^{-3}$

Pseudoscalars

- $\eta[0^+(0^{-+})] \to$
  $3\pi^0$ (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

EvtGen for signal

PHSP Model

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

Doesn't have a signature $\Rightarrow$ model is needed!

$\eta\omega$ Model

- $p\bar{p} \rightarrow h_c \rightarrow P_{seudoscalar} + V_{ector}$

  $h_c \rightarrow \eta\omega$ (HELAMP)

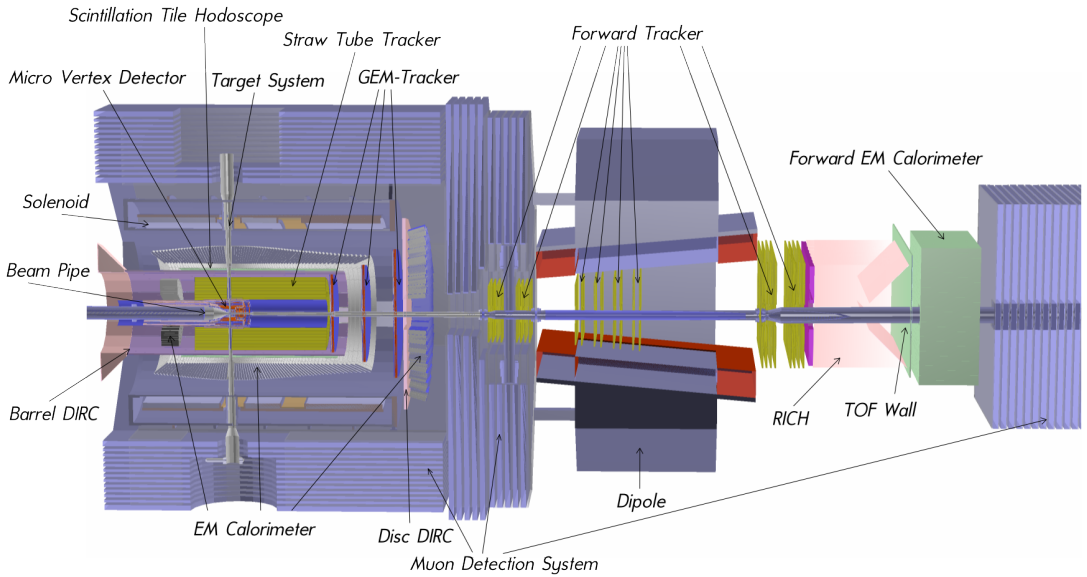
  $\eta \rightarrow \pi^+\pi^-\pi^0$ (PTO3P)

  $\omega \rightarrow \pi^+\pi^-$ (VSS)

DPM for background

- ⋆ FastSim (full and reduced set-ups)
- ⋆ P_{beam} = 5.61 GeV/c

Detector scenarios



Proposed scenarios

I MvdGem, EmcBarrel, Drc, Dsc, FwdSpec

II MvdGem, Drc, Dsc , FwdSpec (w/o barrel EMC)

III MvdGem, EmcBarrel, Drc, Dsc (w/o FwdSpec)

IV MvdGem, EmcBarrel, Drc, FwdSpec (w/o Disc DIRC)

V EmcBarrel, Drc, Dsc, FwdSpec (STT only)

EmcFwd, EmcBw, STT, Barrel MUO are always enabled

+ several very restricted set-ups

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

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

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

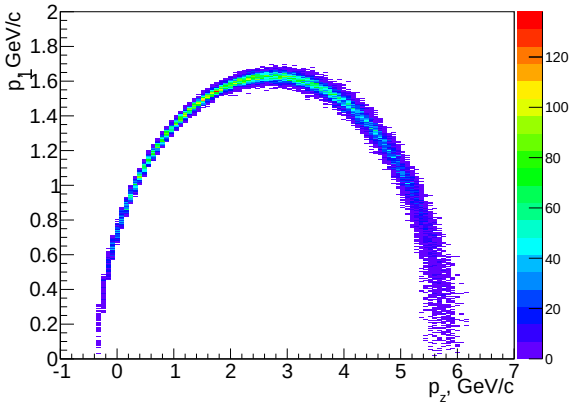
$h_c \to 2(\pi^+\pi^-)\pi^0$

$\omega\eta$ analysis model:

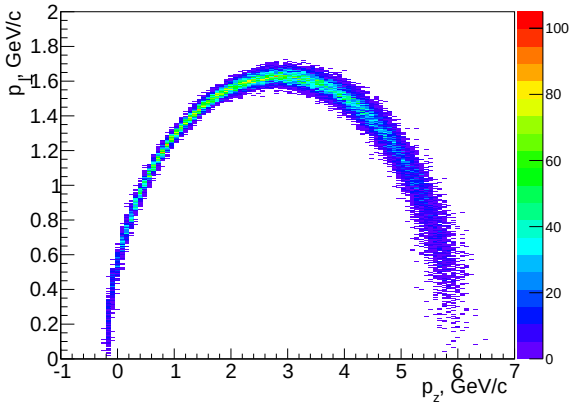
- $\omega \to \pi^+\pi^- \to p_\perp(p_z)$ check
- $\eta \to \pi^+\pi^-\pi^0 \to p_\perp(p_z)$ check
- if both OK for diff $\pi^+\pi^-$ pairs $\to$ ω and η mass cuts

4C fit $\to$ cut on χ^2, best candidate

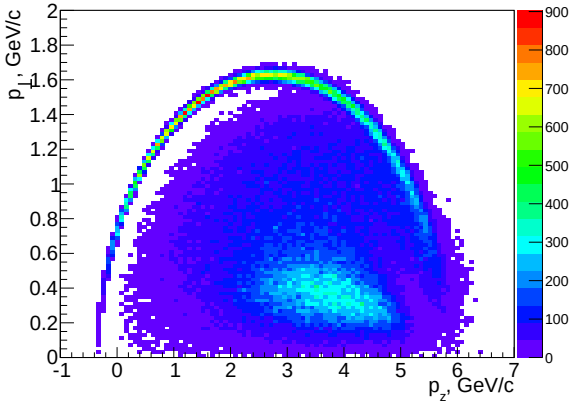
Event selection with $p_\perp(p_z)$ [Peyrou]



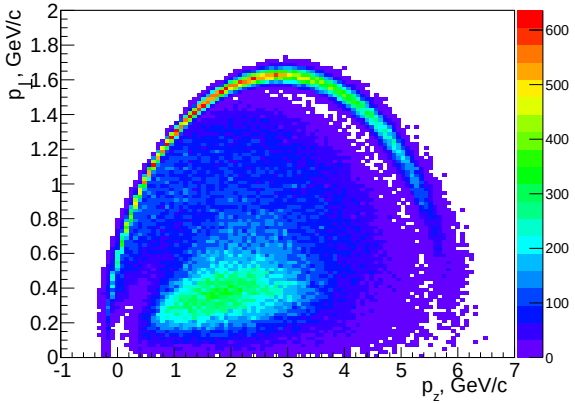
η (MC)



ω (MC)



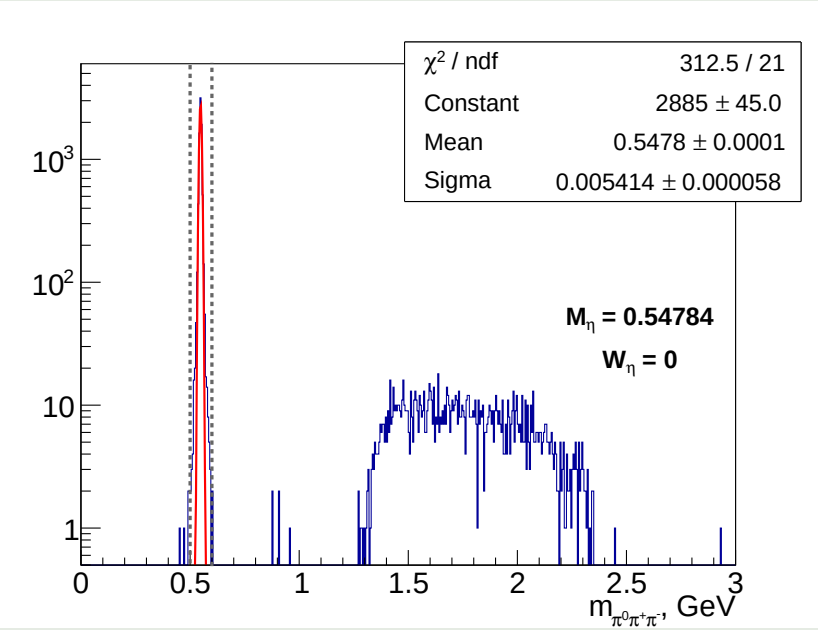
η (all candidates)

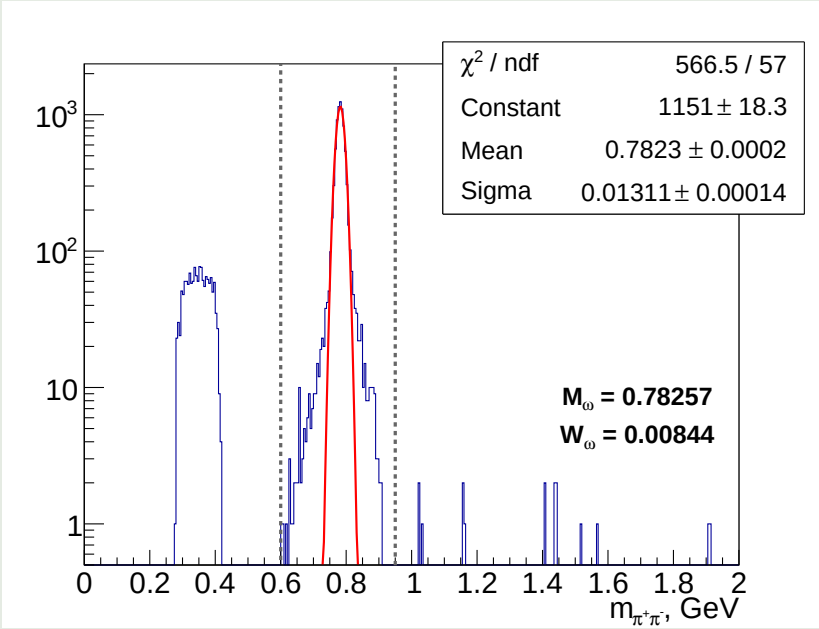


ω (all candidates)

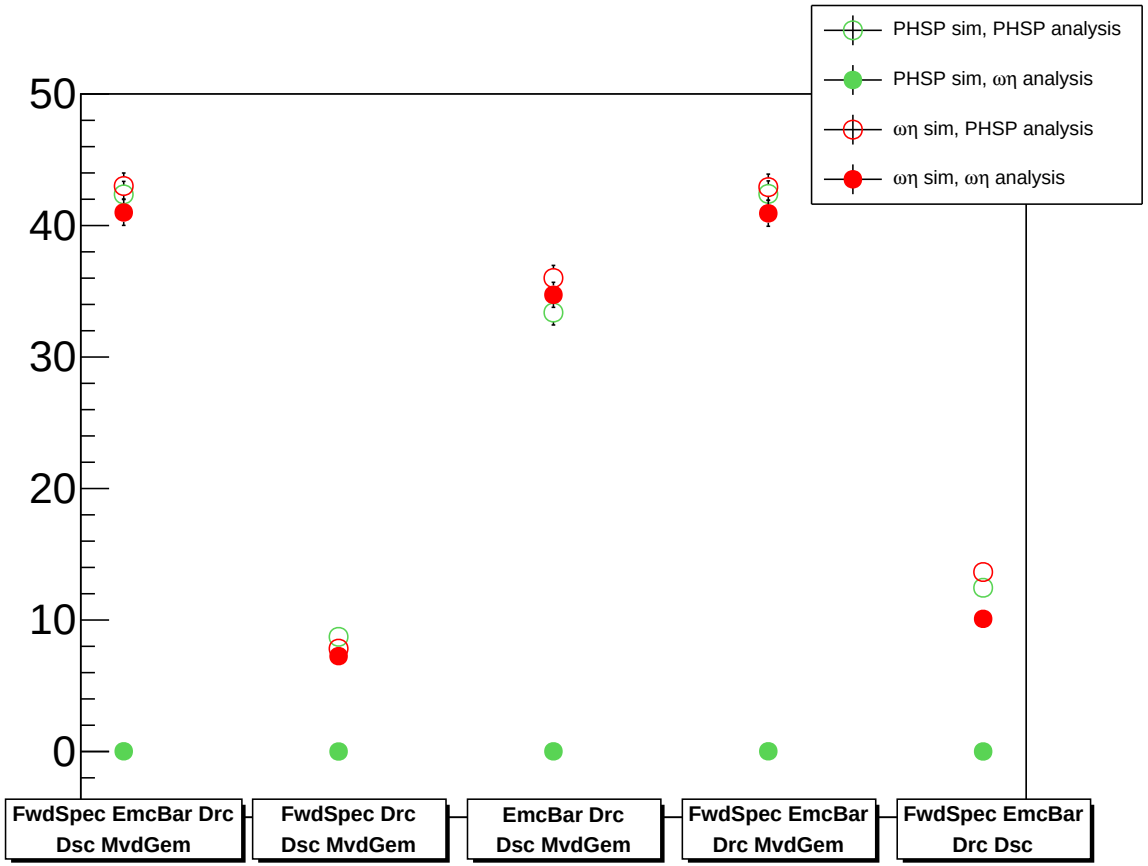
Event selection
Mass window cut

η (right) and ω (left)





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)

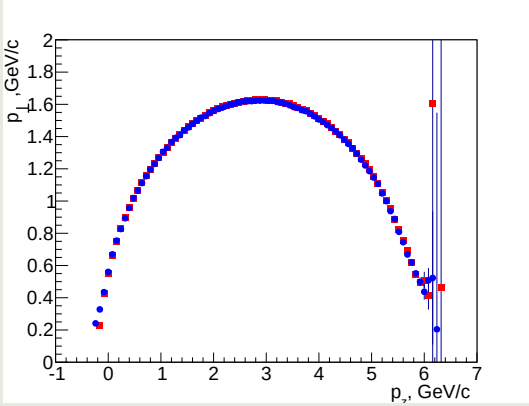
Drc = Barrel DIRC for PID, **Dsc** = Disc DIRC for PID

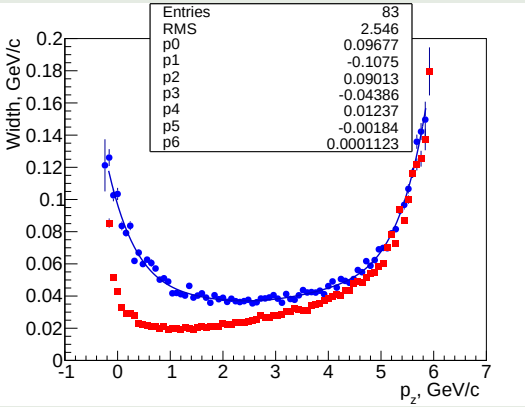
MvdGem = MVD and GEM for central tracking in addition to STT

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

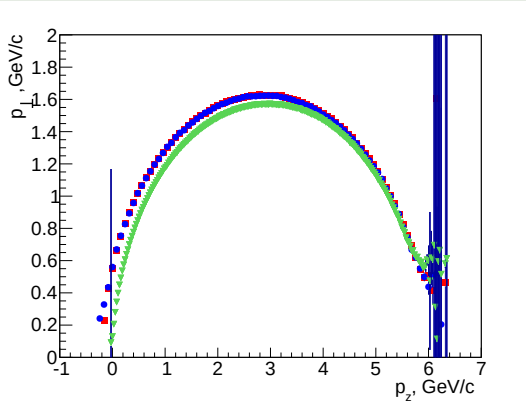
$h_c \to \eta\omega$, $h_c \to \eta\rho$ and $h_c \to \eta f_0(1500)$

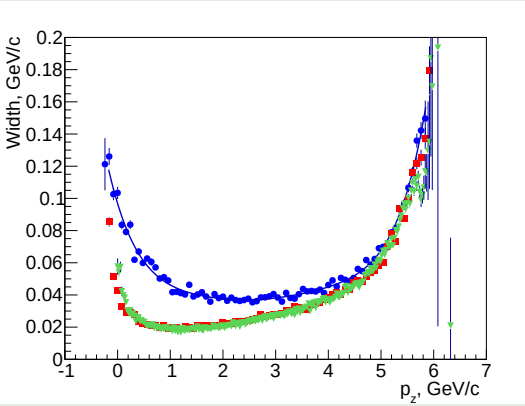
$p_\perp(p_z)$ for ω(red) and ρ(blue)





$p_\perp(p_z)$ for ω(red), ρ(blue) and f_0(green)

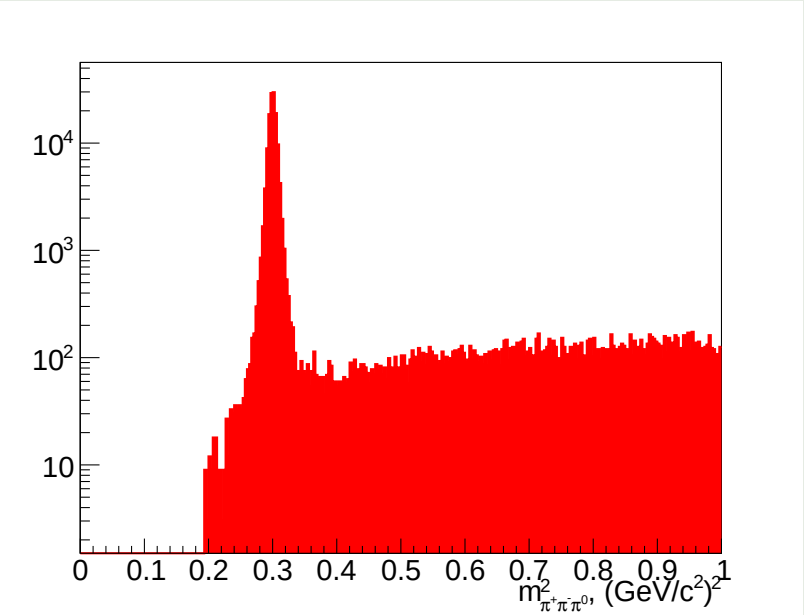




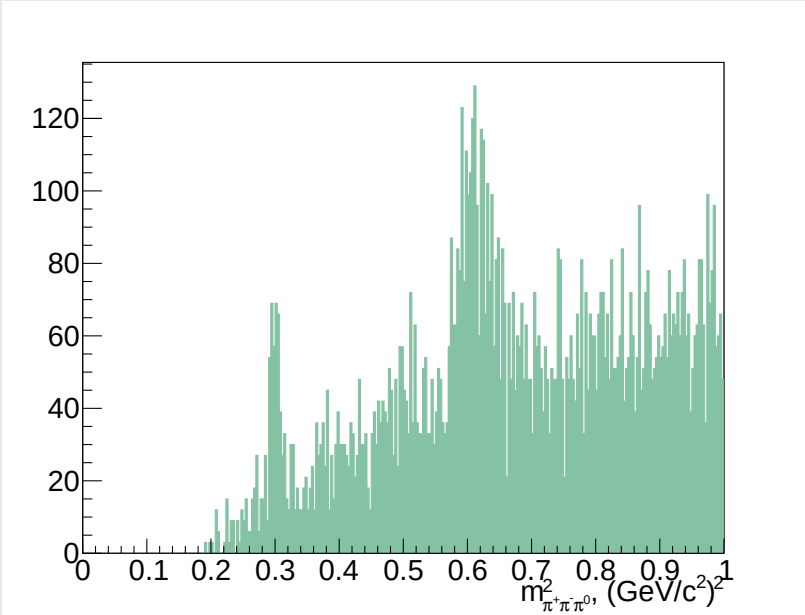
due to different mass and widths

η mass cut

$m^2_{\pi^+\pi^-\pi^0}$



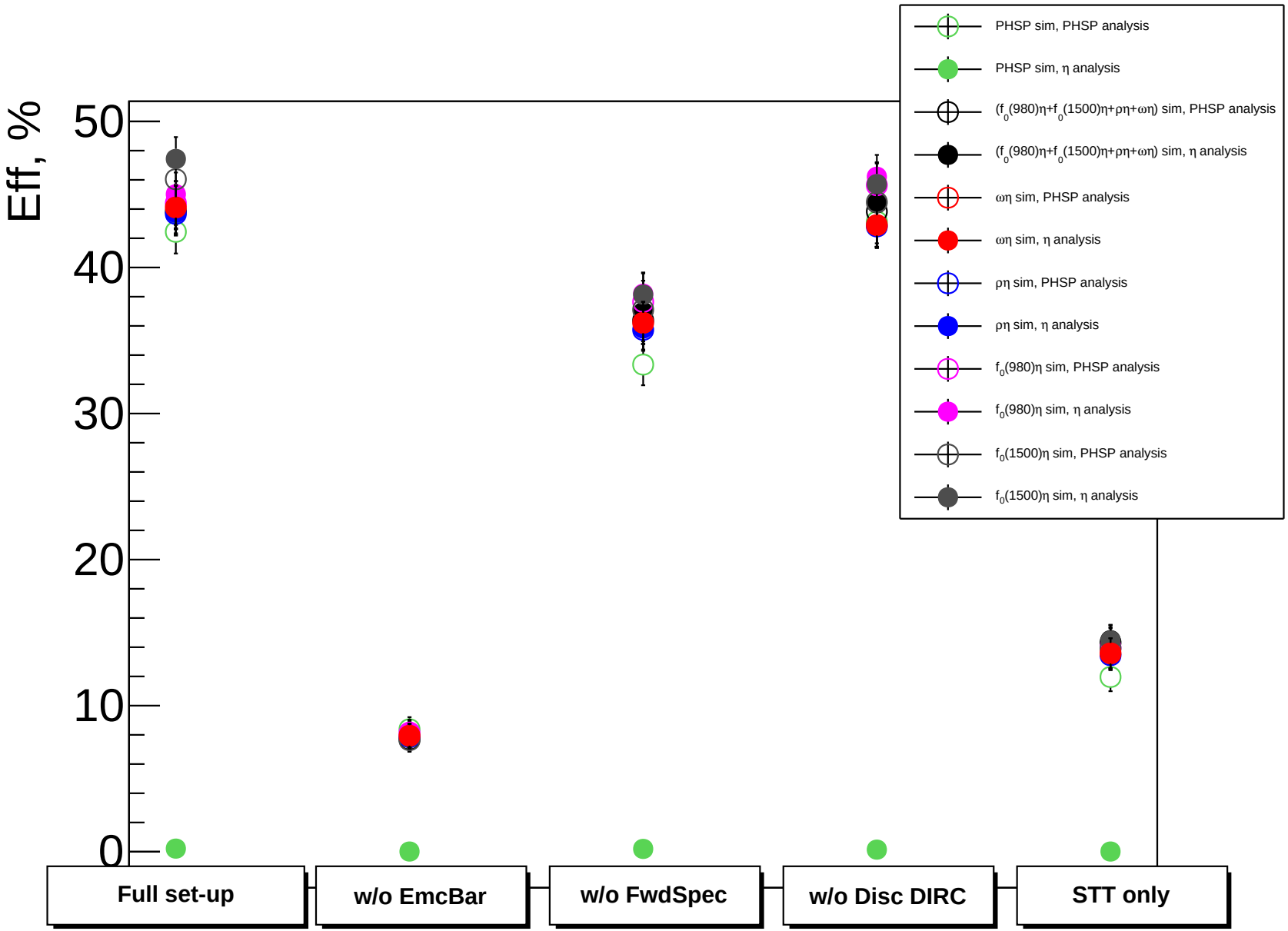
Signal



DPM background

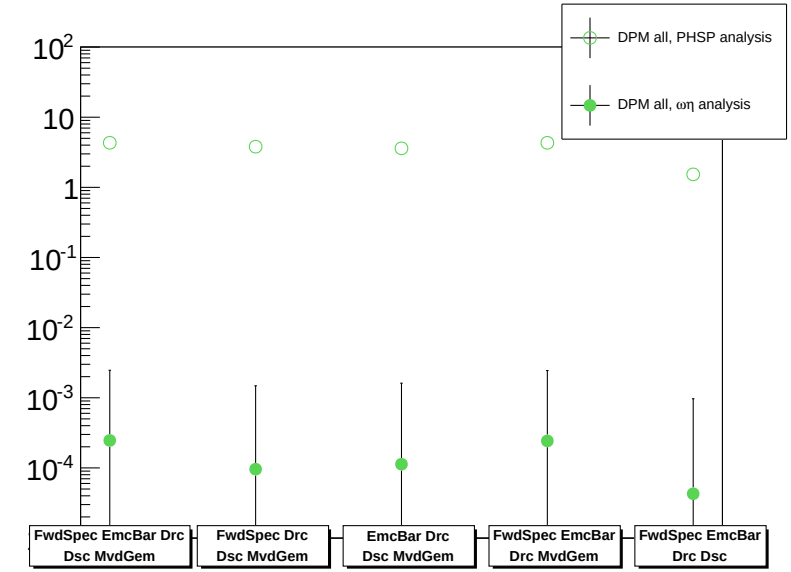
Reconstruction efficiency

Signal, only η mass cut

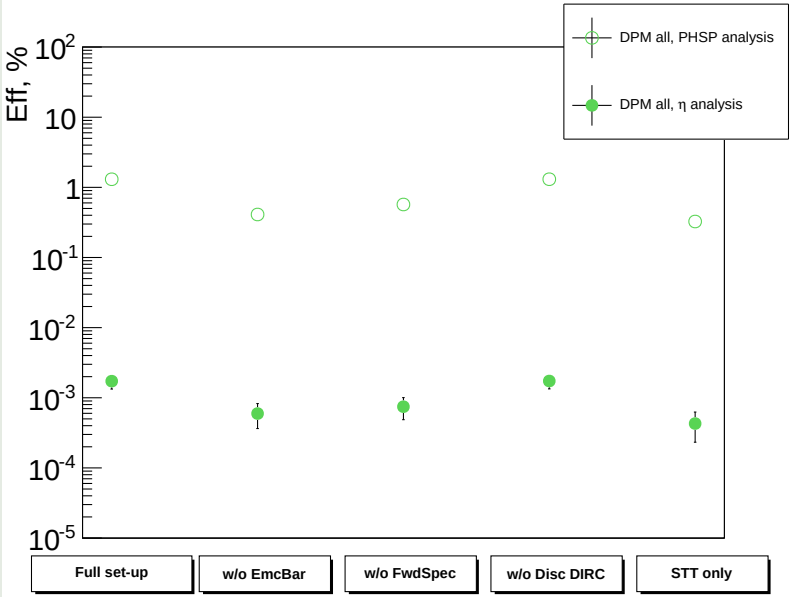


Reconstruction efficiency
Background

$\eta\omega$ cut



only η mass cut



More strict model helps to suppress background better

Significance

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

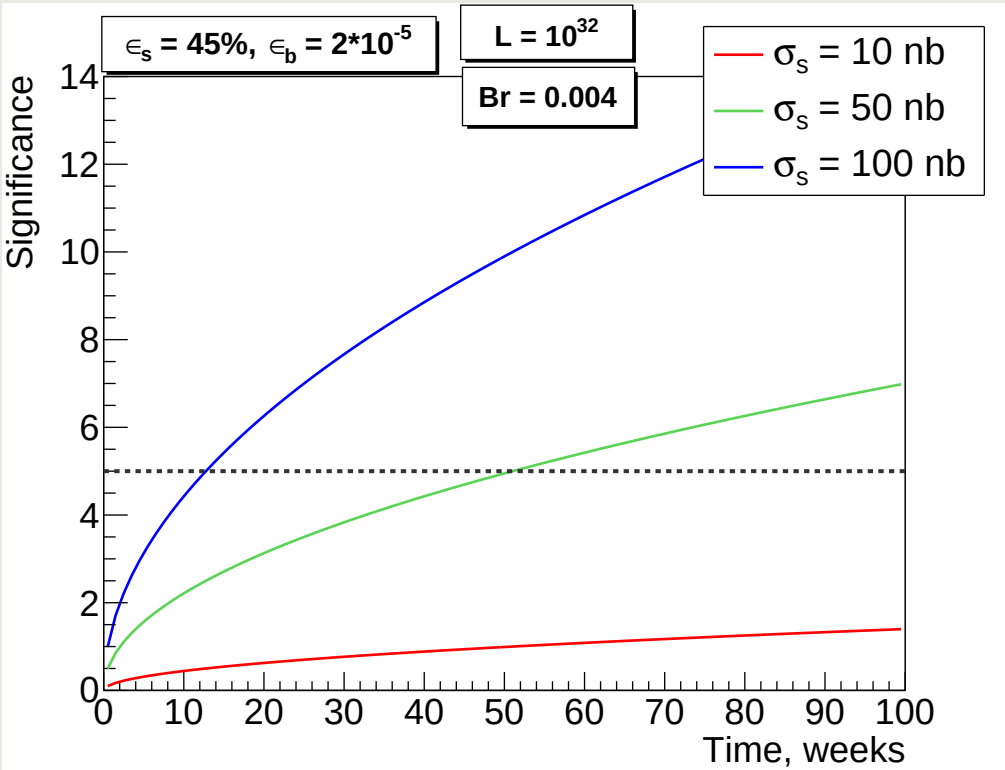
$$\text{Significance}(t) = \sqrt{L \cdot t}\,\frac{\sigma_s \cdot \epsilon_s \cdot f_{BR}}{\sqrt{\sigma_s \cdot \epsilon_s \cdot f_{BR} + \sigma_b \cdot \epsilon_b}}$$

"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 (10^{32} or 10^{31})

"input":

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



Time for 10^4 events with L=10^{32}

64, 13 or 7 days respectively for σ_s 10nb, 50 nb or 100 nb

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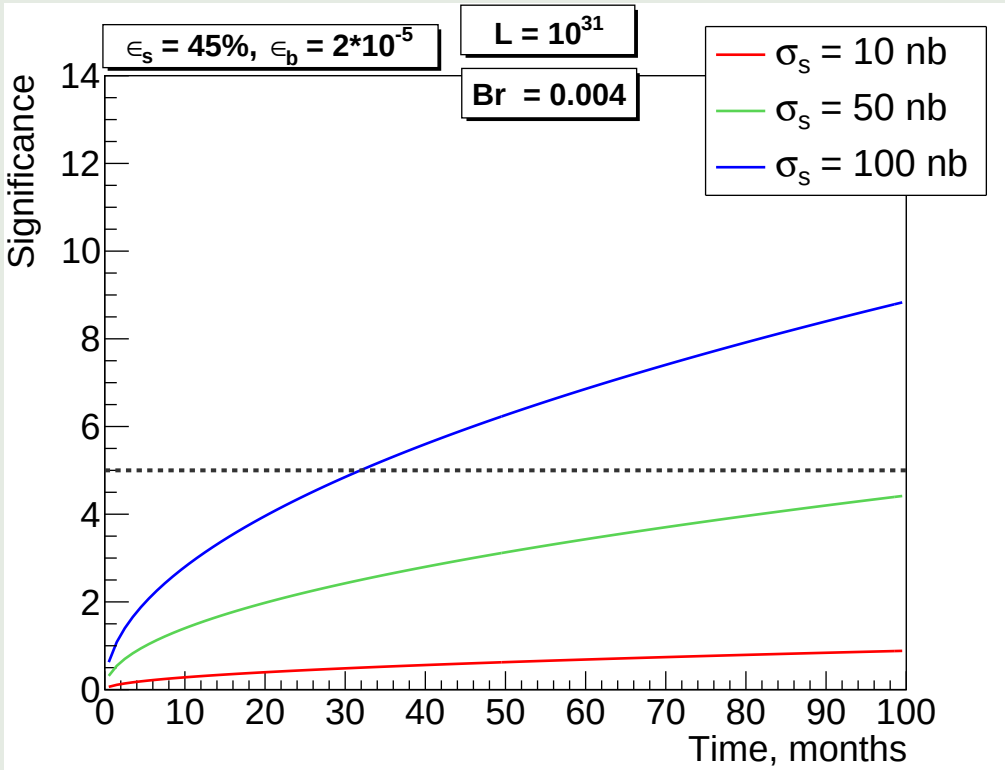


Time for 10^4 events with L=10^{32}

64, 13 or 7 days respectively for σ_s 10nb, 50 nb or 100 nb

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

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

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

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

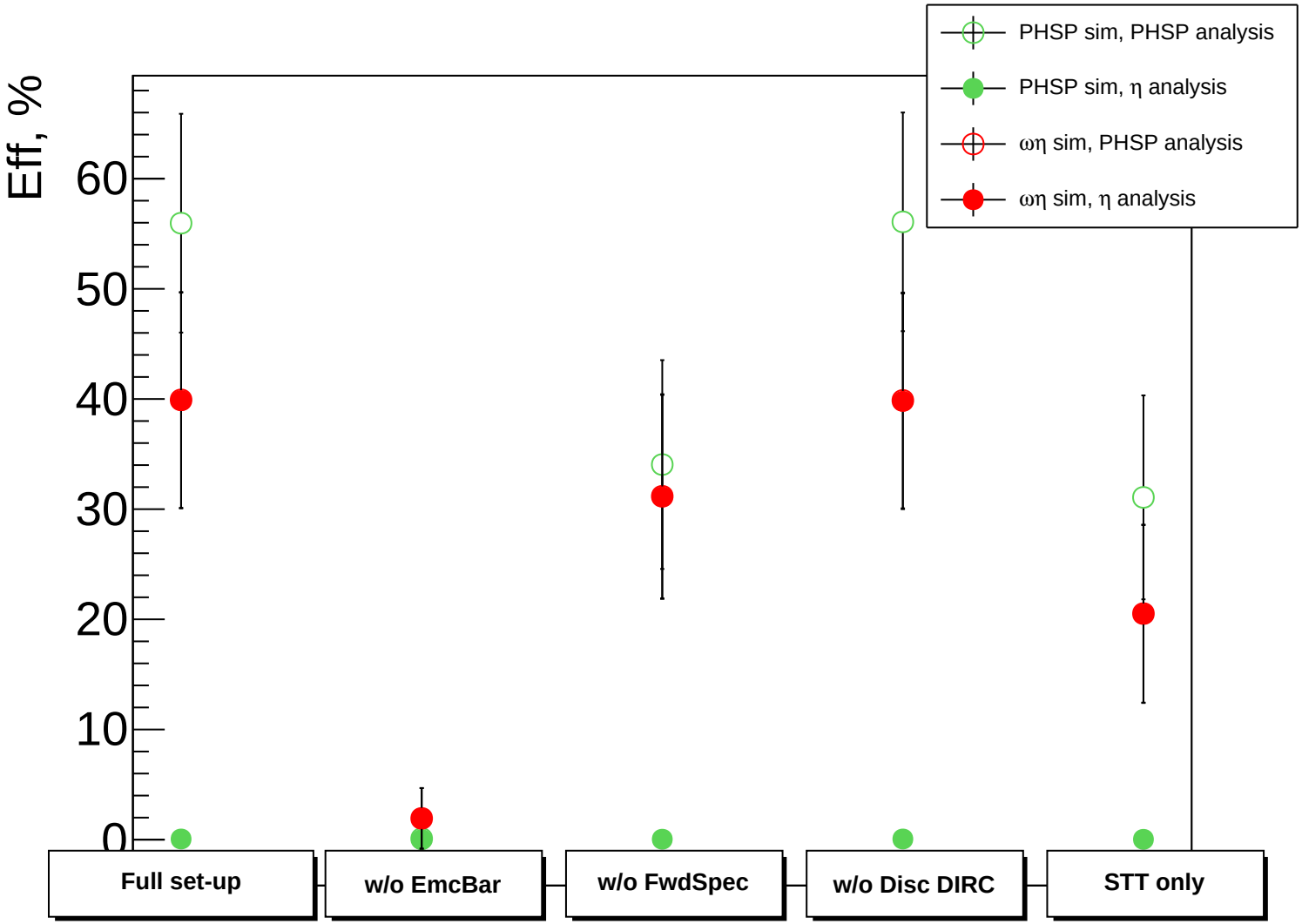
η analysis model:

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

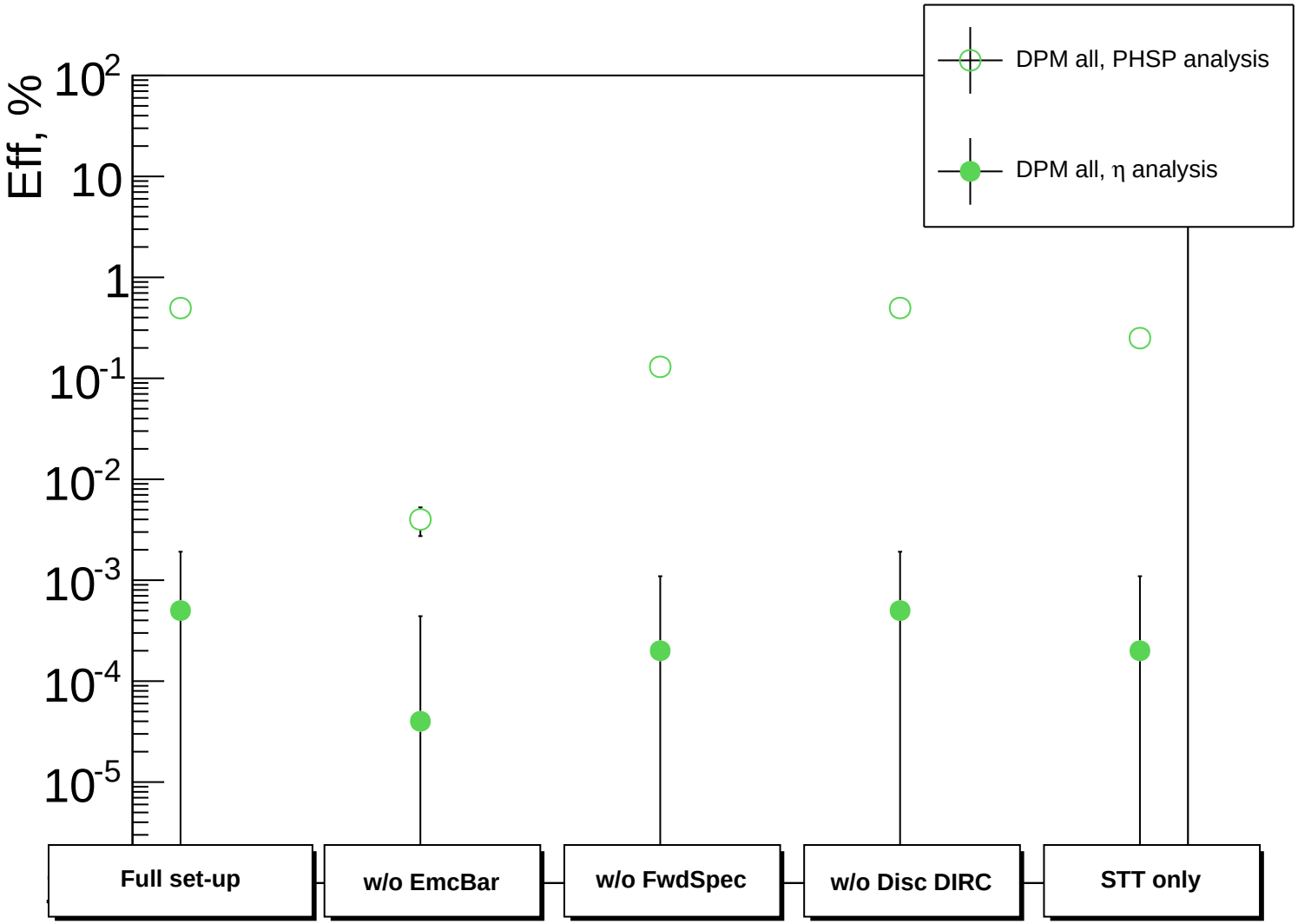
4C fit $\to$ cut on χ^2, best candidate

Reconstruction efficiency

Signal, η mass cut



Reconstruction efficiency
Background



Significance

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

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

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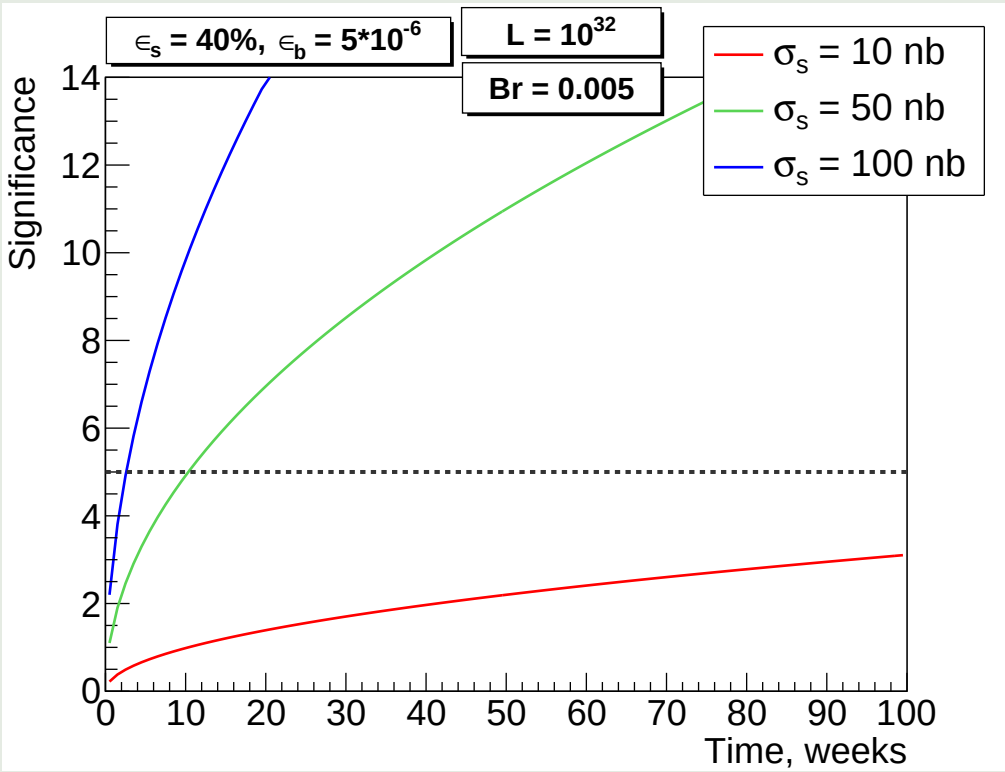

Time for 10^4 events with L=10^{32}

58, 12 or 6 days respectively for σ_s 10nb, 50 nb or 100 nb

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

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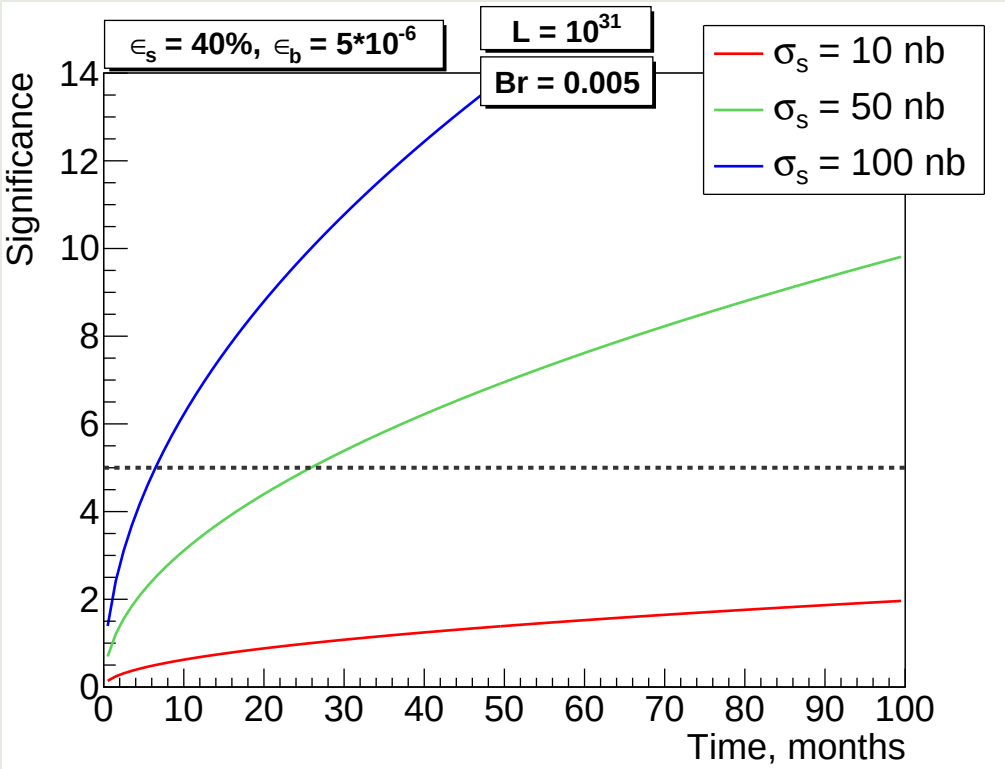


Time for 10^4 events with L=10^{32}

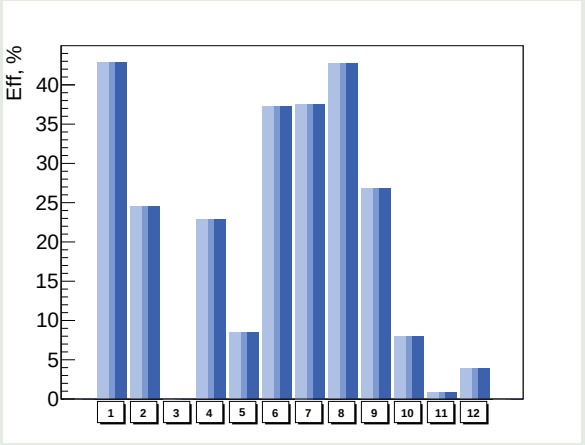
58, 12 or 6 days respectively for σ_s 10nb, 50 nb or 100 nb

Minimal set-up

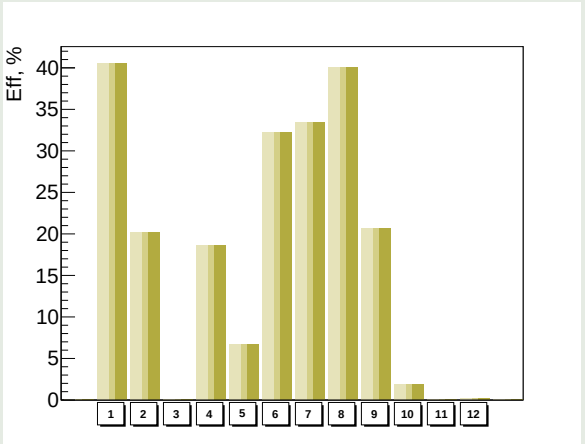
1. Full detector
2. EmcBar FwdTrk STT MvdGem
3. EmcBar FwdTrk
4. EmcBar STT MvdGem
5. EmcBar FwdTrk STT
6. EmcBar EmcFwCap FwdTrk STT MvdGem
7. EmcBar EmcFwCap EmcBwCap FwdTrk STT MvdGem
8. EmcBar EmcFwCap EmcBwCap EmcFwd FwdTrk STT MvdGem
9. EmcBar EmcFwd FwdTrk STT MvdGem
10. EmcFwCap EmcBwCap EmcFwd FwdTrk STT MvdGem
11. EmcFwd FwdTrk STT MvdGem
12. EmcFwCap EmcBwCap FwdTrk STT MvdGem

Essential: EmcBar, STT+MvdGem (4)
Helpful: EmcFwCap and FwdTrk (6)
+ EmcFwd (8)

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



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



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
- $\epsilon_{sig} \sim 45$ %, $\epsilon_{bkg} \sim 2 \cdot 10^{-5}$
- $\sim$ 10–50 weeks to achieve 5σ significance

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

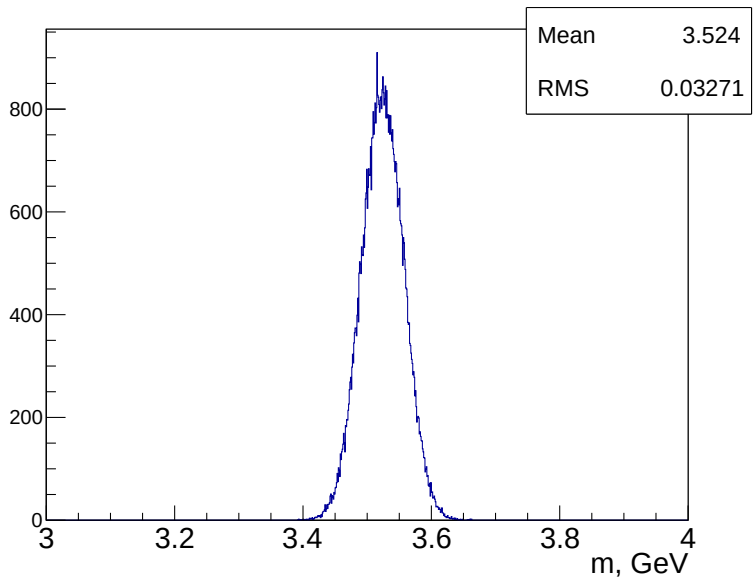
- PHSP and PV models were checked
- $\epsilon_{sig} \sim 40$ %, $\epsilon_{bkg} \sim 5 \cdot 10^{-6}$
- $\sim$ 2–10 weeks to achieve 5σ significance

Set-up

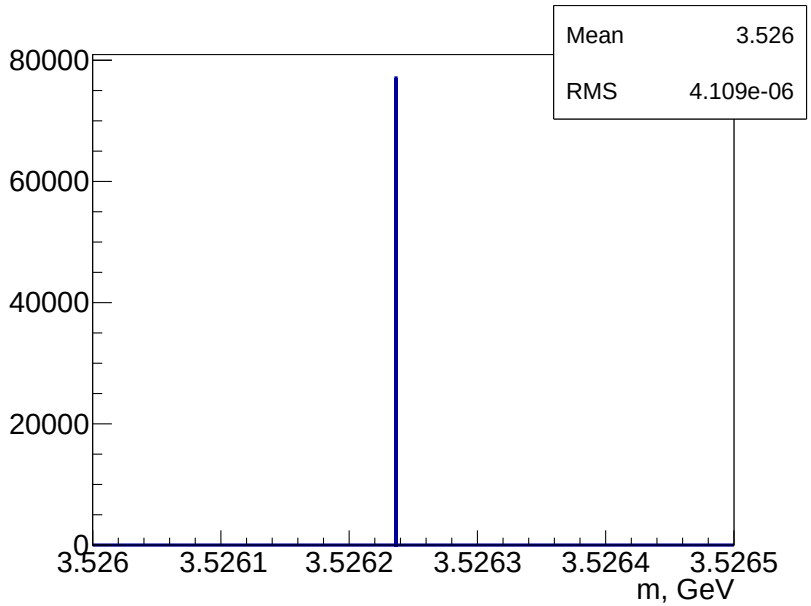
Min: EmcBar, STT+MvdGem
Max: EmcBar(+FwCap+BwCap), EmcFwd, FwdTrk, STT+MvdGem

NB: production mechanism was not simulated $\rightarrow$ impotance of Forward Spectrometer could be underestimated

Reconstructed h_c mass



after all cuts



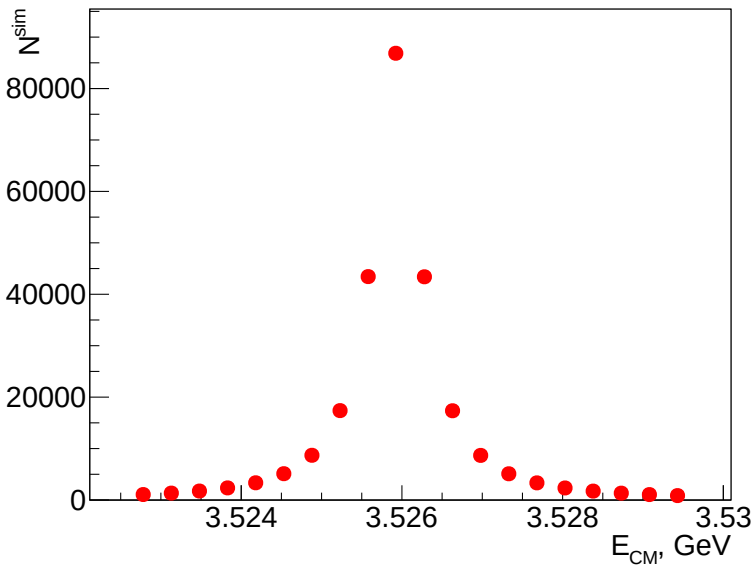
after 4C fit

Production cross-section

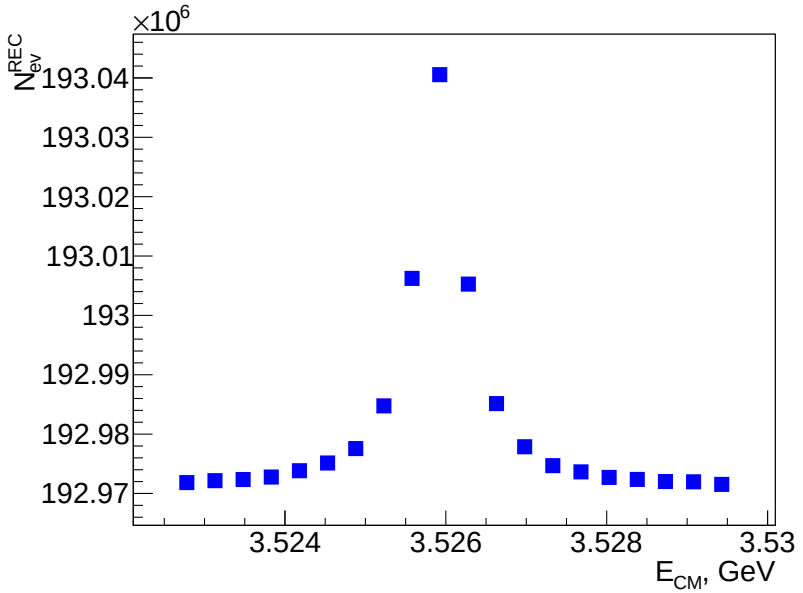
Breit-Wiegner Production cross-section:

$$\sigma_{BW}(\sqrt{s}) = \frac{(2J+1)\cdot 4\pi}{s-4m_p^2}\,\frac{BR(h_c \to p\bar{p})\Gamma_{h_c}^2}{4(\sqrt{s}-m_{h_c})^2+\Gamma_{h_c}^2} \qquad (1)$$

Measured rates (red: true distribution, blue: reconstructed signal+DPM bkg)



Simulated shape



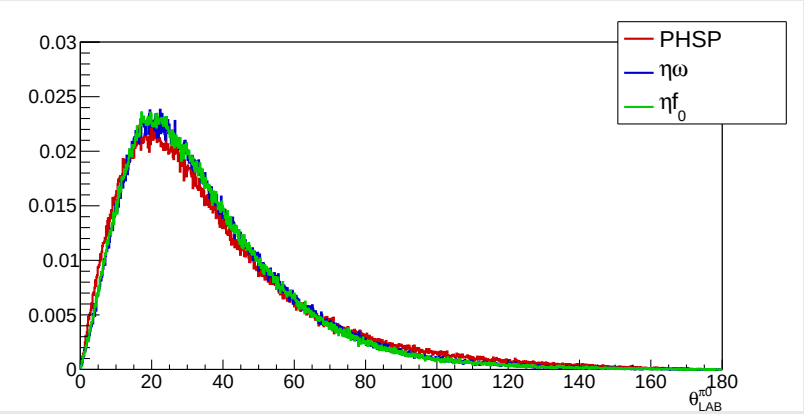
$h_c \to 2(\pi^+\pi^-)\pi^0$

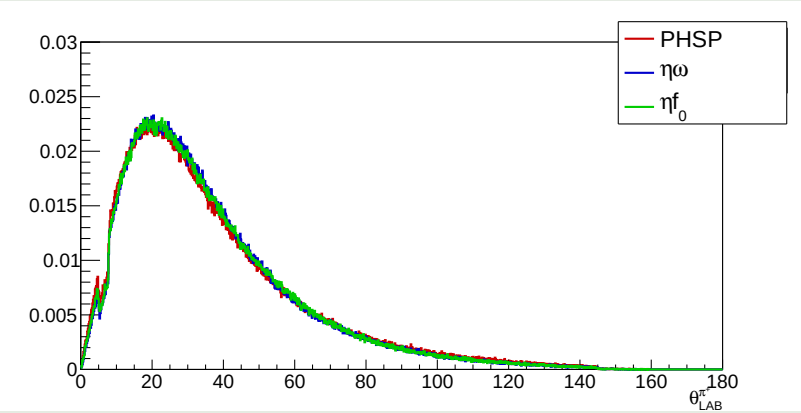
NB: no efficiency correction

Angular distributions of final particles

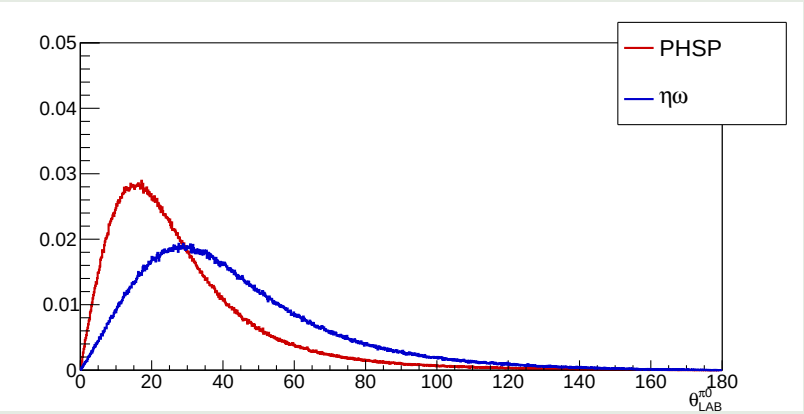
LAB frame

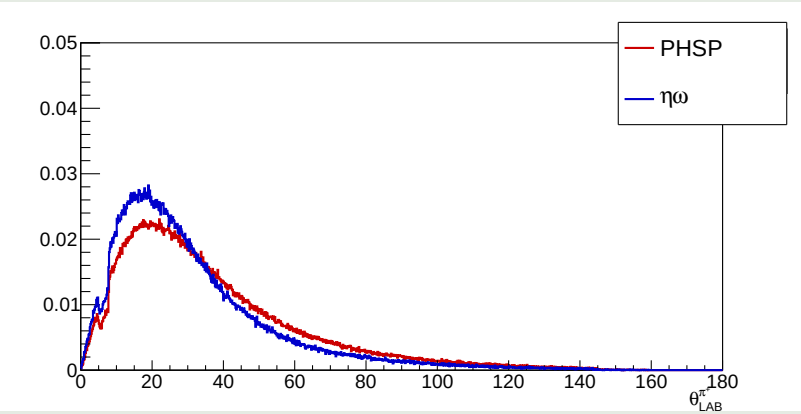
$h_c \to 2(\pi^+\pi^-)\pi^0$





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

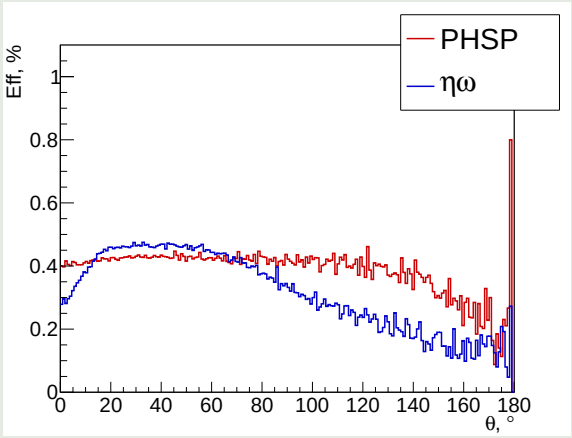


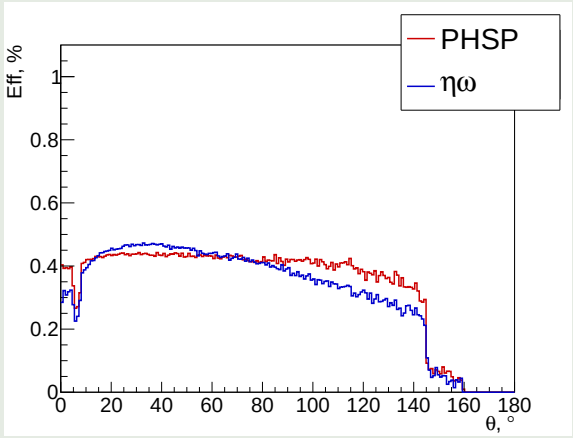


Efficiency of reconstruction for final state particles

LAB frame

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





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