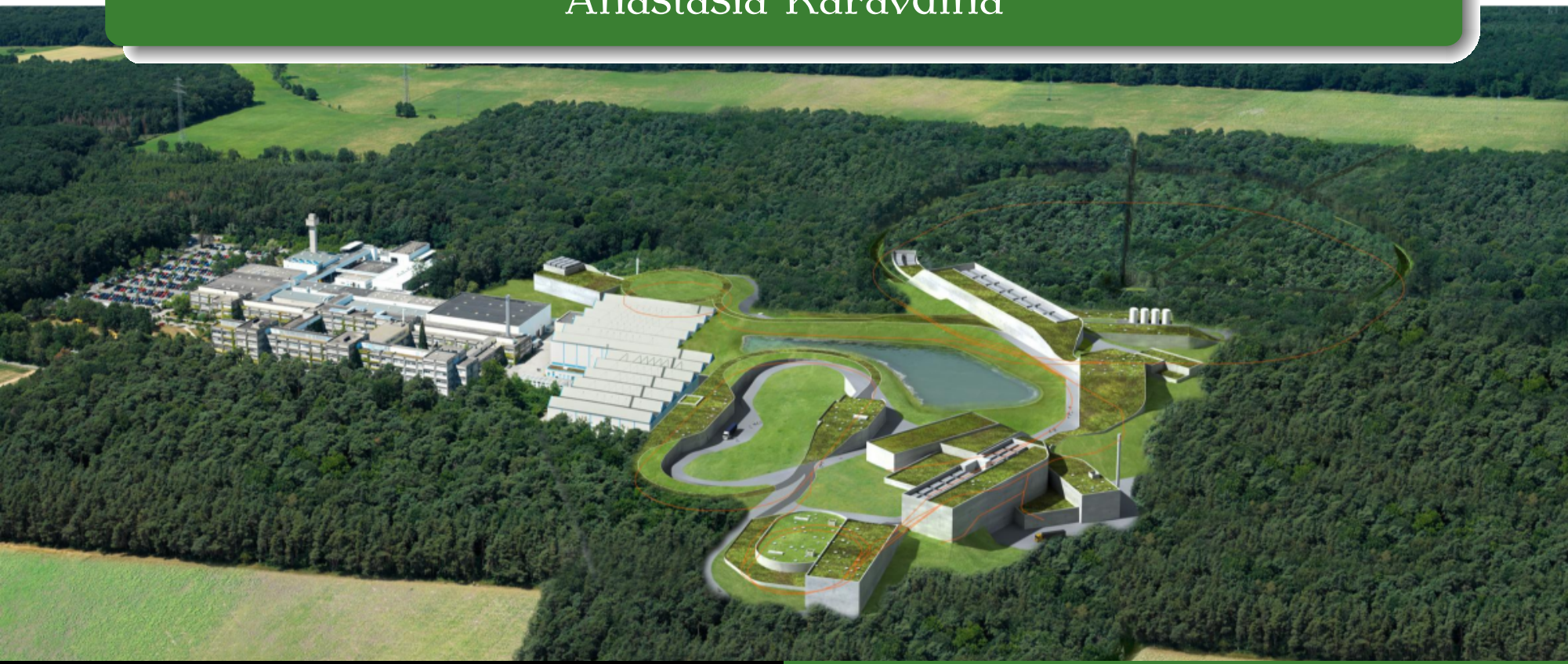
$p\bar{p} \to h_c \to 2(\pi^+\pi^-)\pi^0$

Anastasia Karavdina



$h_c(1P)$ $I^G(J^{PC})=?^?(1^{+-})$

Mass = 3525.38 ± 0.11 MeV, Width = 0.7 ± 0.4 MeV

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

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

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

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

+ high statistic
– significant background

Simulation approach

PHSP Model

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

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

$\omega\eta$ Model

- $p\bar{p} \to h_c \to$ Vector + Pseudoscalar

  $h_c \to \omega\eta$ (PHSP, 100%)

  $\omega \to \pi^+\pi^-$ (PHSP, 100%)

  $\eta \to \pi^+\pi^-\pi^0$ (PHSP, 100%)

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

Background estimation

$p\bar{p} \to 2(\pi^+\pi^-)\pi^0$ with DPM

- σ_{sig} ~10-50 nb
- σ_{bkg} ~ 1 mb

$\Rightarrow$ signal/bkg ~ 10^{-5}-10^{-4}

e.g for 10^4 signal events $\to 10^9$ DPM filtered events

- σ_{sig} ~10-100 nb
- σ_{inel}^{tot} ~ 50 mb

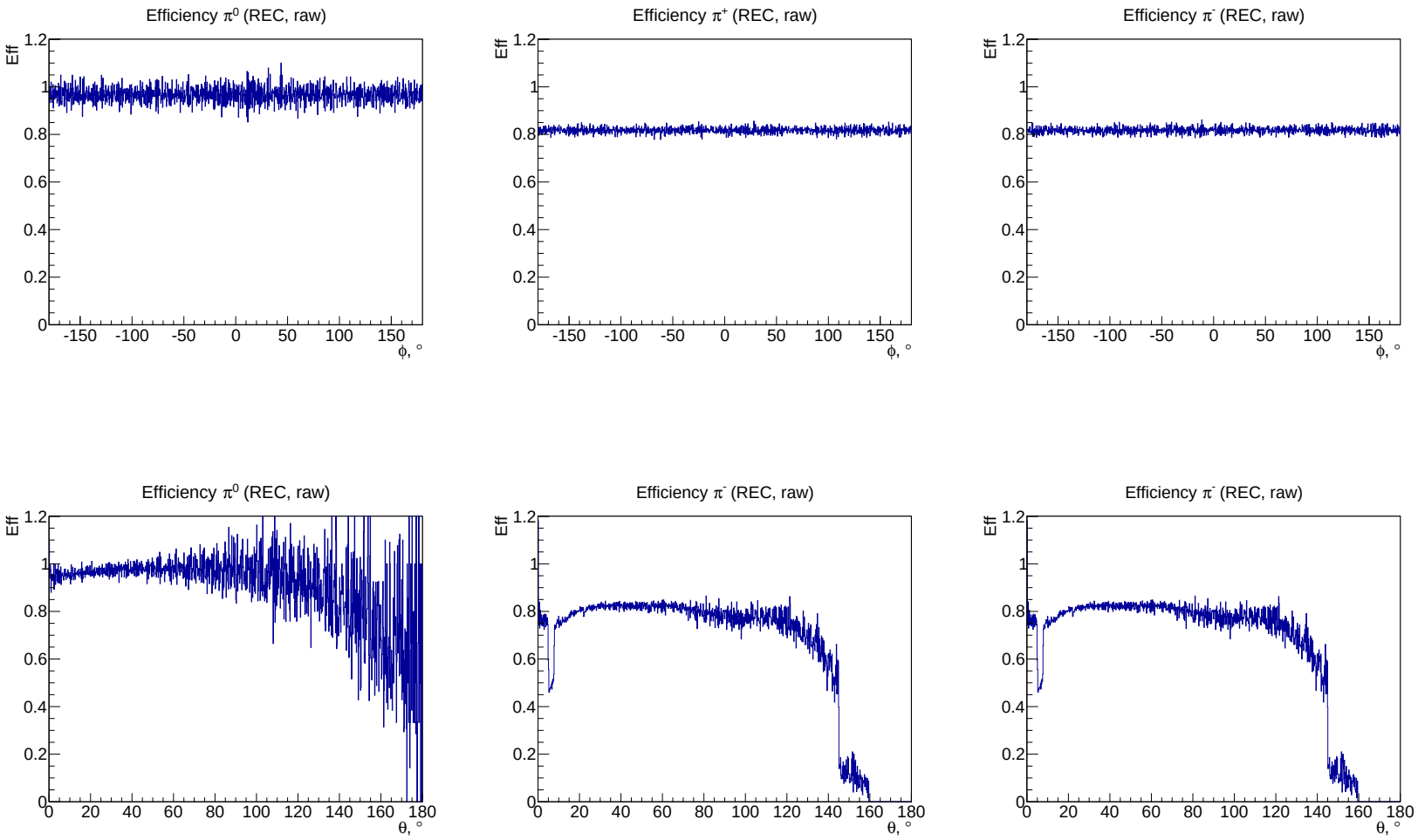
$\Rightarrow$ signal/bkg ~ $2{\cdot}10^{-7}$-$2{\cdot}10^{-6}$

e.g for 10^4 signal events $\to 5{\cdot}10^{10}$ DPM events

- DPM inelastic
  - ⋆ contains $2(\pi^+\pi^-)\pi^0$ final state
  - ⋆ adds background due to misidentification (e.g $\pi^+\pi^-K^+K^-\pi^0$)

Due to lack of time only supression power was checked ($2{\cdot}10^7$ simulated events)

Reconstruction efficiency
Finale state particles



Event selection
General strategy

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

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

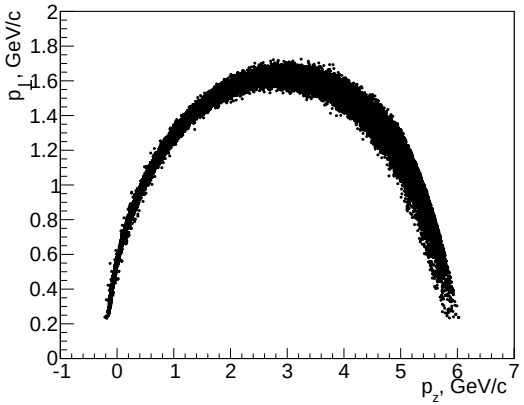
$h_c \to 2(\pi^+\pi^-)\pi^0$

$\omega\eta$ analysis model:

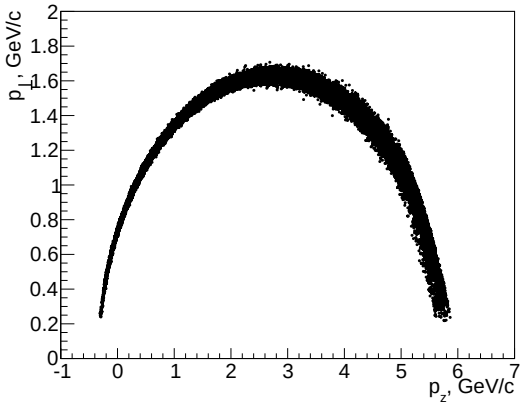
- $\omega \to \pi^+\pi^- \to p_\perp(p_z)$ check
- $\eta \to \pi^+\pi^-\pi^0 \to p_\perp(p_z)$ check
- if both OK for diff $\pi^+\pi^-$ pairs $\to$ ω and η mass cuts

4C fit $\to$ cut on χ^2

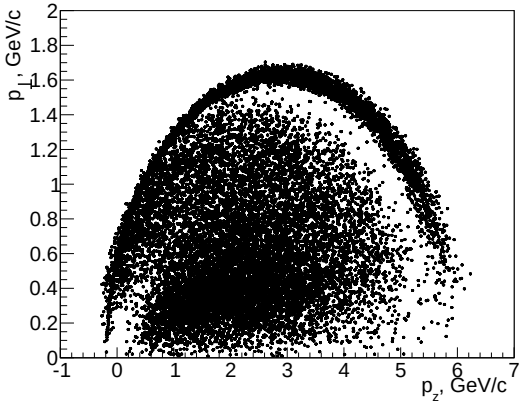
Event selection
$p_\perp(p_z)$ [Peyrou]



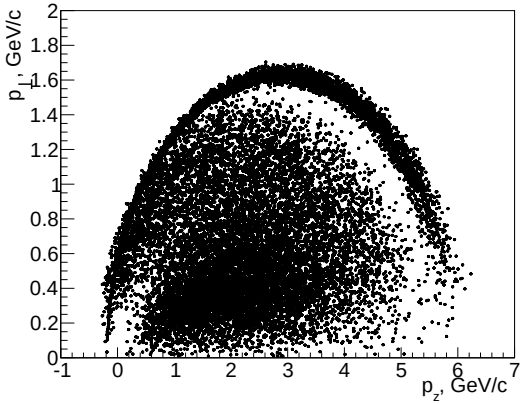
ω (MC)



η (MC)



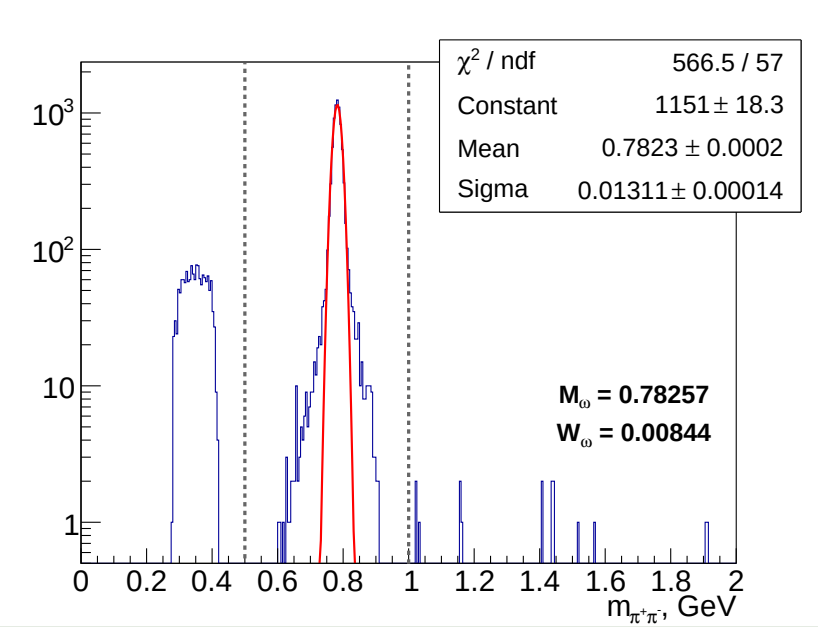
ω (all candidates)

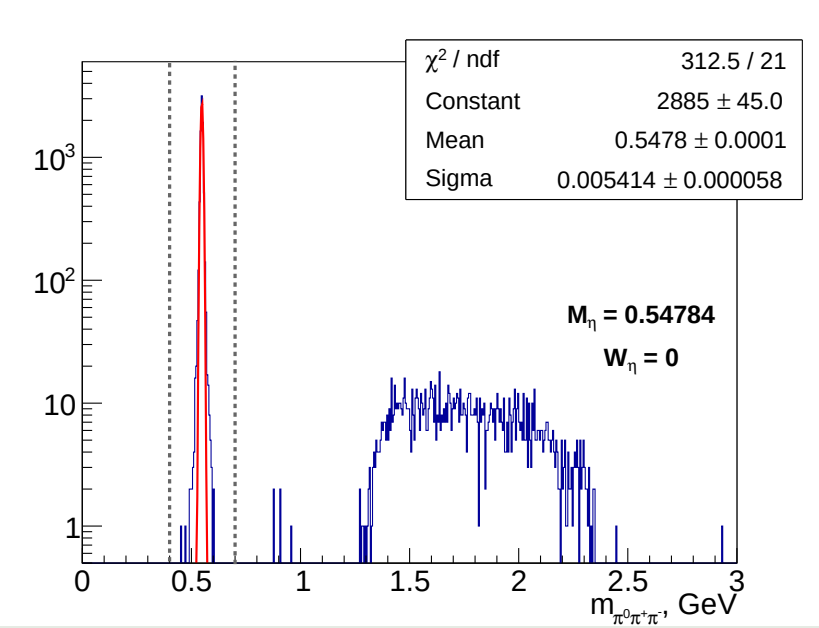


η (all candidates)

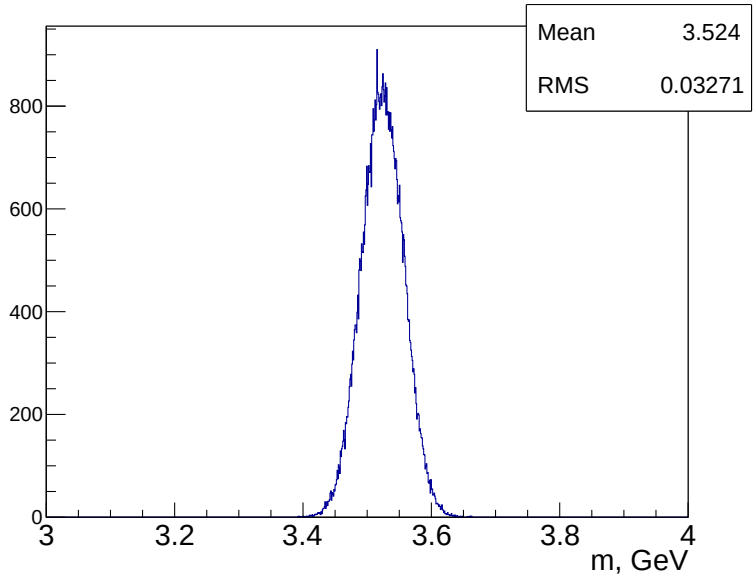
Event selection
Mass window cut

ω (left) and η (right)

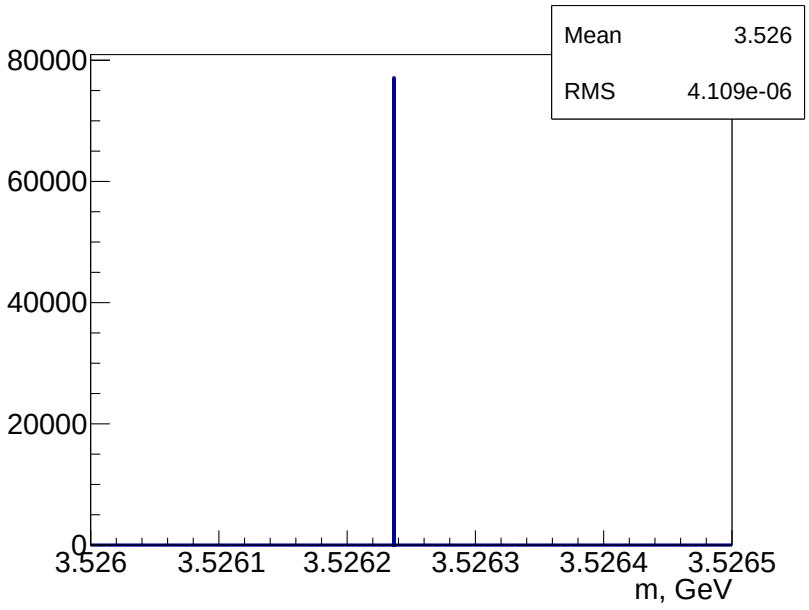




Reconstructed h_c mass



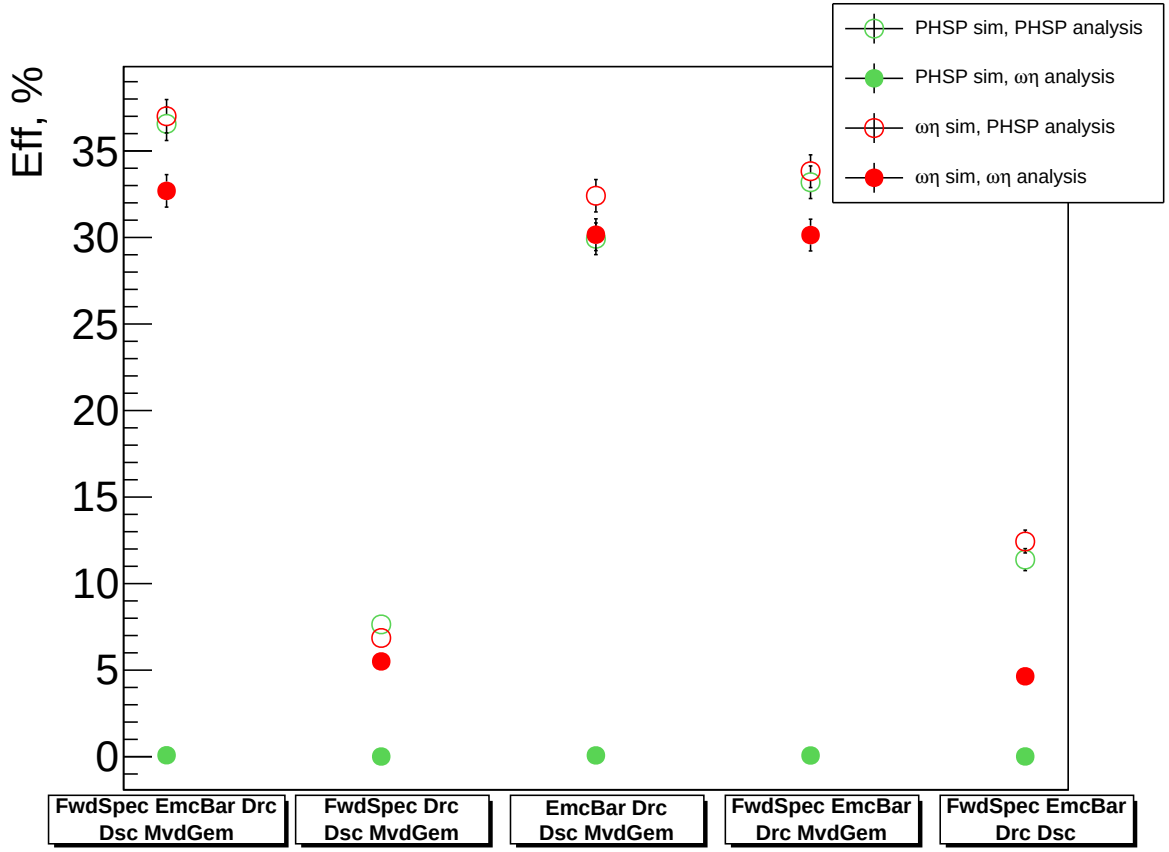
after all cuts



after 4C fit

Reconstruction efficiency

Signal (NB: efficiency ~ 10% higher if *PionLoosePlus* → *PionAllPlus*)



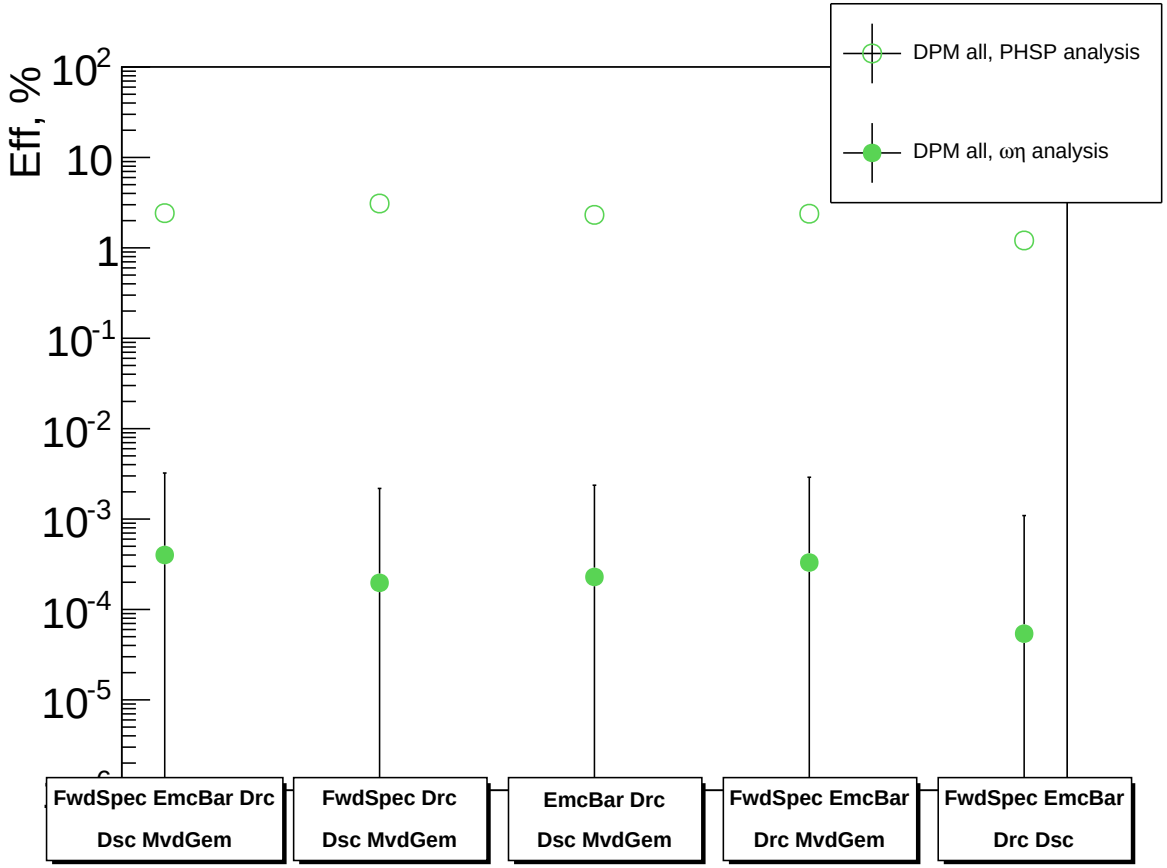
FwdSpec = complete Forward Spectrometer (Fwd Spec. EMC, Fwd Tracking, RICH, Fwd MUO)

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
Background



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Significance
full set-up

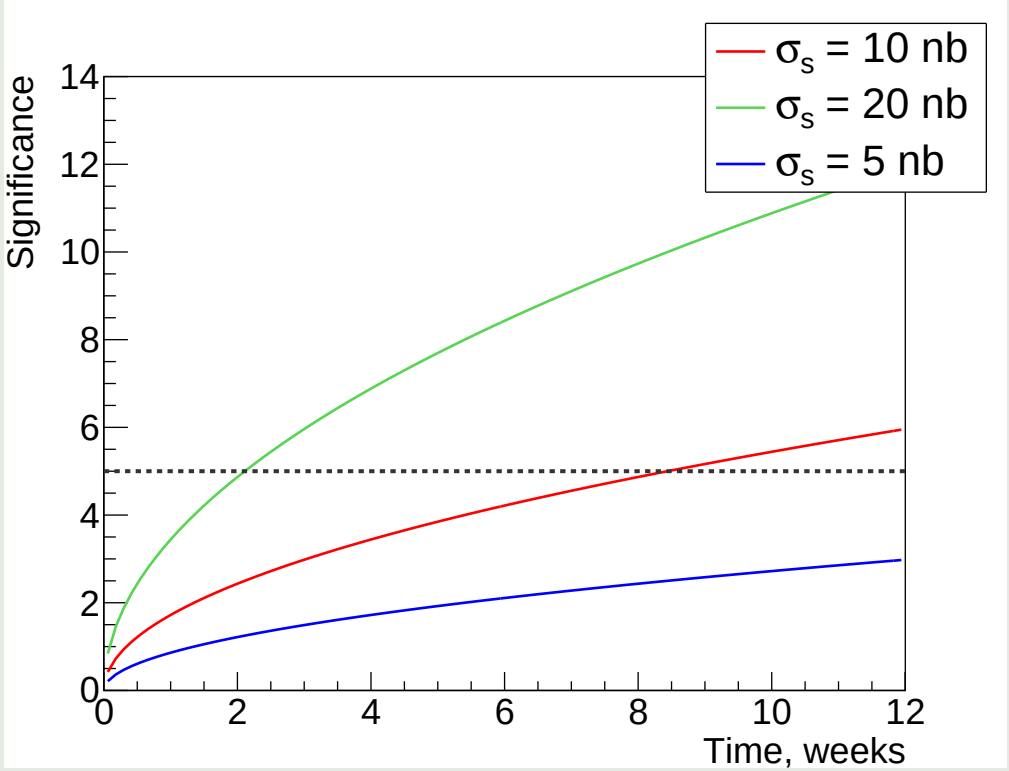
$$\text{Significance(t)} = \sqrt{L \cdot t}\,\frac{\sigma_s \cdot \epsilon_s \cdot f_{BR}}{\sqrt{\sigma_s \cdot \epsilon_s \cdot f_{BR} + \sigma_b \cdot \epsilon_b}}$$

"known":

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

"input":

- ϵ_s – rec. efficiency for signal (35%)
- ϵ_b – rec. efficiency for bkg ($4 \cdot 10^{-6}$)



Significance
without EMC or MvdGem

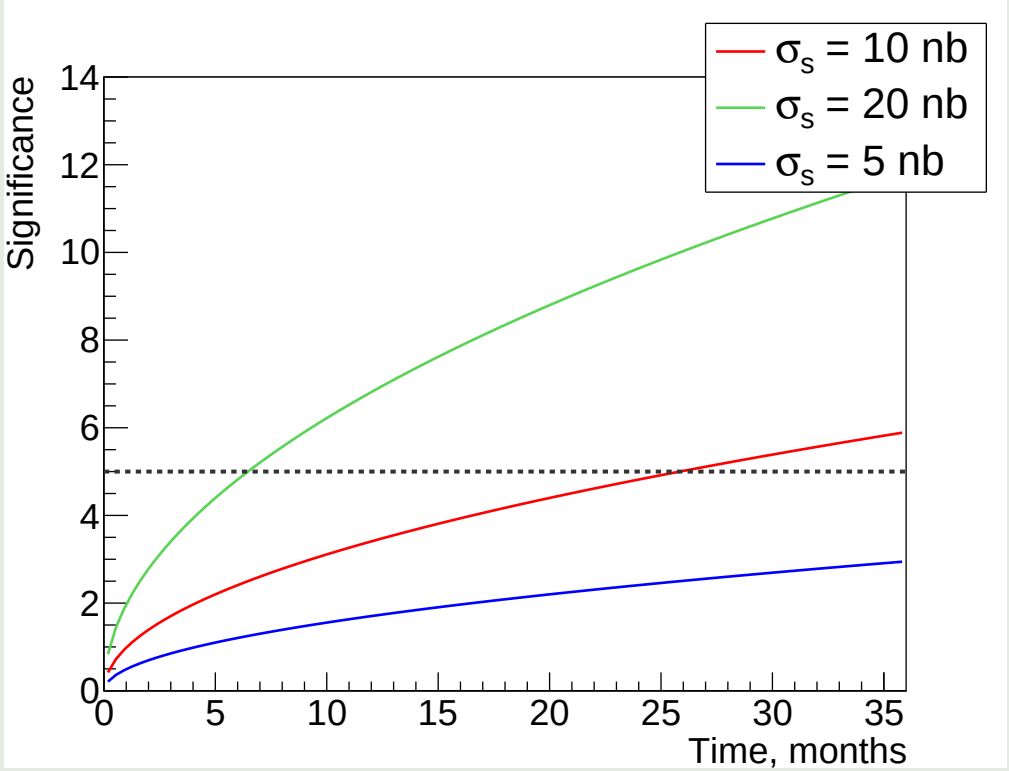
$$\text{Significance(t)} = \sqrt{L \cdot t}\,\frac{\sigma_s \cdot \epsilon_s \cdot f_{BR}}{\sqrt{\sigma_s \cdot \epsilon_s \cdot f_{BR} + \sigma_b \cdot \epsilon_b}}$$

"known":

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

"input":

- ϵ_s – rec. efficiency for signal (5%)
- ϵ_b – rec. efficiency for bkg (10^{-6})



Summary

Results

$p\bar{p} \rightarrow h_c \rightarrow 2(\pi^+\pi^-)\pi^0$ (P_{beam} = 5.61 GeV/c)

- with PHSP and VP($\omega\eta$) model
- $\epsilon_{sig} \sim 35$ %
- background suppression $4{\cdot}10^{-6}$ achieved
- $\sim$ 2-8 weeks needed to achieved 5σ significance (σ_s=20-10 nb, L=$2{\cdot}10^{32}$ cm^{-2}s^{-1})
- different detector set-up scenarios checked
  $\rightarrow$ without EmcBarrel or MvdGem $\epsilon_{sig} \sim 5$ %

Outlook

- accurate significance calculation for different scenarios

? Scan "'measurement"

(more points, at least for background)

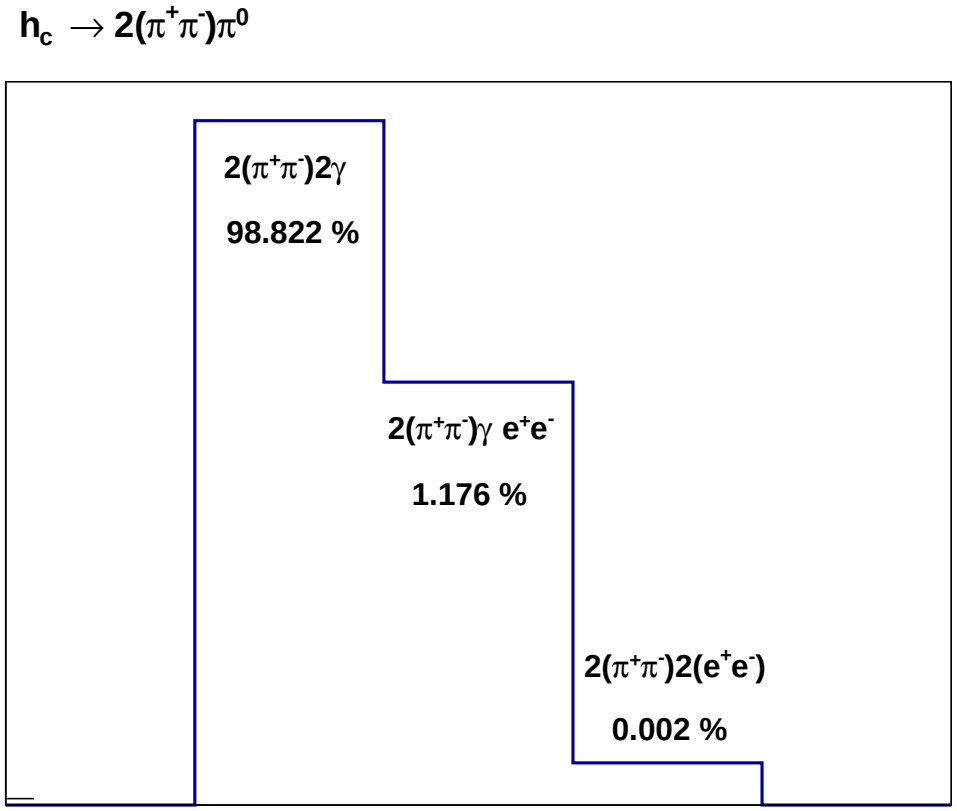
Simulation approach details

- ⋆ 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)
- ⋆ PionLoosePlus, PionLooseMinus
  ("PidChargedProbability")

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

Event selection

$N_{\pi^0}=1$, $N_{\pi^+}=2$, $N_{\pi^-}=2$

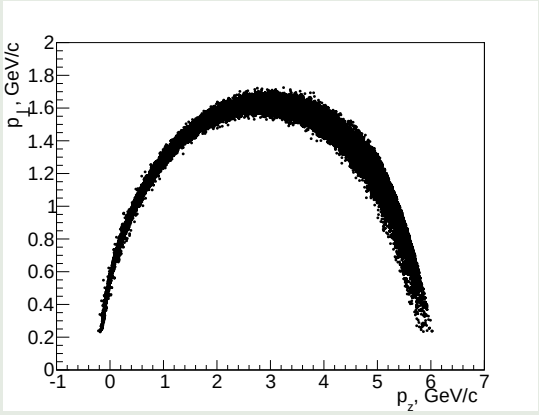


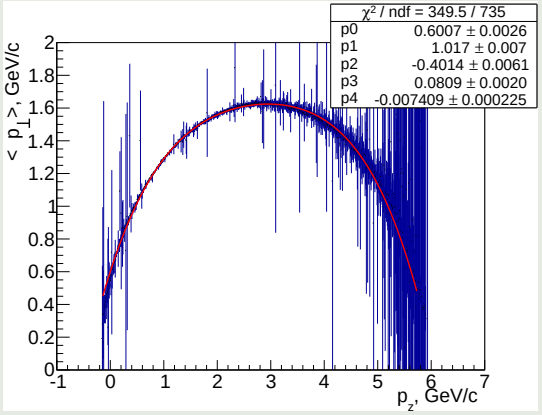
Efficiency loss due to diffirent final state $< 2\%$

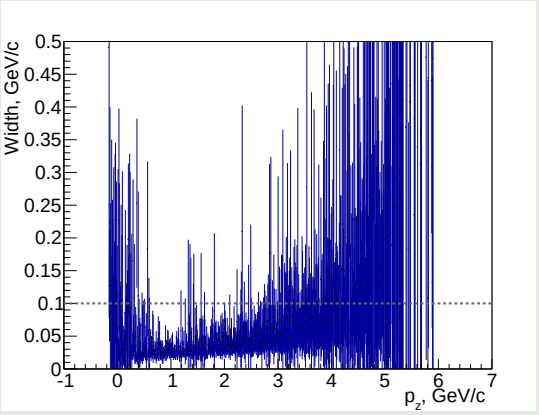
Event selection

$p_\perp(p_z)$ [Peyrou]

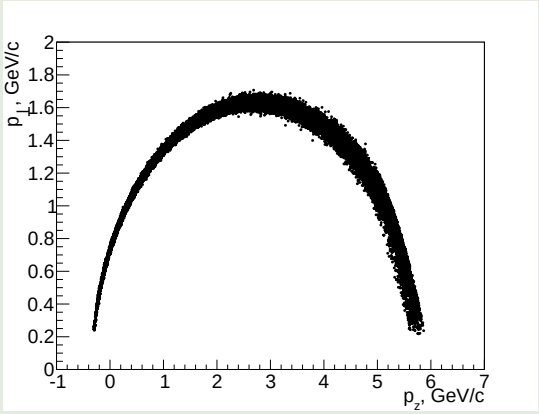
Cut $p_\perp(p_z)$ for ω

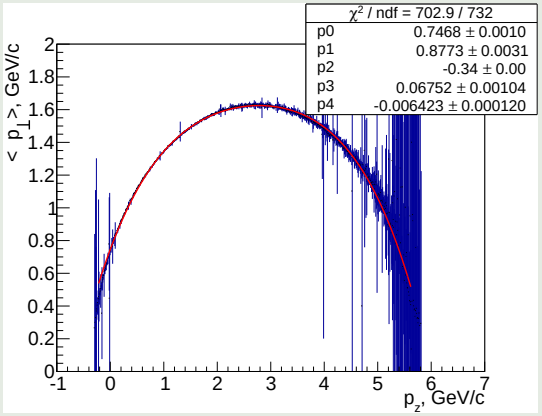


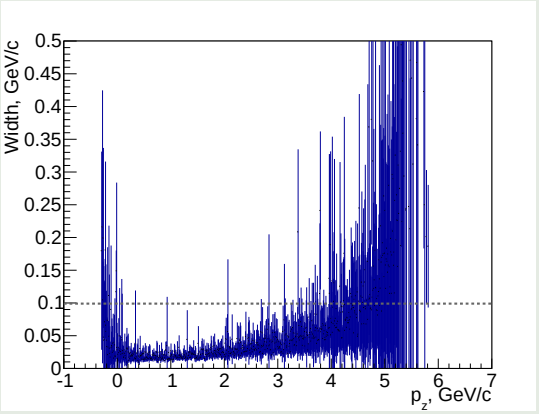




Cut $p_\perp(p_z)$ for η







Ideas for background study

$p\bar{p} \to 2(\pi^+\pi^-)\pi^0$ with DPM

- σ_{sig} ~10-100 nb
- σ_{bkg} ~ 1 mb

$\Rightarrow$ signal/bkg ~ 10^{-5}

e.g for 10^4 signal events $\to$ 10^9 DPM events

- DPM with filter on $2(\pi^+\pi^-)\pi^0$ final state

  (σ^{tot}_{inel} ~ 50 mb $\Rightarrow$ gain 50 times with filter, but takes some CPU time to filter interesting events)

  - ⋆ suppression with [close to] perfect PID
  - ⋆ check signal vs. bkg shape, angular distributions, etc
- DPM inelastic (done in this study)
  - ⋆ contains $2(\pi^+\pi^-)\pi^0$ final state
  - ⋆ adds background channels due to misidentification (e.g $\pi^+\pi^-K^+K^-\pi^0$)