

# Spin alignment measurement of inclusive $\phi(1020)$ at BESIII

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# Outline

1 Data sets and event selection

2 Spin alignment of  $\phi$

3  $\rho_{00}$  result

4 BACKUP

- fit result

# Data sets

- Boss version: 703
- Data sets: chic1 scan.

$\sqrt{s}$ (GeV)	Run number	$\mathcal{L}$ ( $\text{pb}^{-1}$ )
3.4900	47467 – 47493	12.11
3.5080	51657 – 51893	181.79
3.5097	51584 – 51656	39.29
3.5104	51894 – 52090	183.64
3.5146	52298 – 52332	40.92

- Hadronic MC samples:
  - LUARLW**, 10M events each point.
  - HYBRID**, 10M events each point.

# Hadronic event selection

- Same as R-value analysis published in PRL 128, 062004 (2022)

## Track Level

- **Veto Bhabha and Di-gamma events**
  - $N_{\text{shower}} \geq 2$
  - $E_1 \geq E_2 \geq 0.65E_{\text{beam}}$
  - $|\Delta\theta| = |\theta_1 + \theta_2 - 180^\circ| < 10^\circ$
- **Isolated photon**
  - Energy deposition should be larger than 0.1 GeV
  - Angle from the nearest charged track should be larger than  $20^\circ$
  - $0 < T_{\text{EMC}} < 700$  ns
- **Good charged hadronic tracks**
  - $|V_x| < 0.5$  cm,  $|V_z| < 5.0$  cm,  $|\cos\theta| < 0.93$
  - $p_{\text{track}} < 0.94p_{\text{beam}}$ , where  $p_{\text{beam}} \approx E_{\text{beam}}$
  - $\chi_{\text{prob.}} = (dE/dx_{\text{measure}} - dE/dx_{\text{proton}}) / \sigma_{\text{proton}} > 10$
  - Remove charged tracks when  $E/p > 0.8$  and  $p > 0.65p_{\text{beam}}$
  - Veto  $\gamma$ -conversions when  $M(e^+e^-) < 0.1$  GeV and  $\theta_{ee} < 15^\circ$

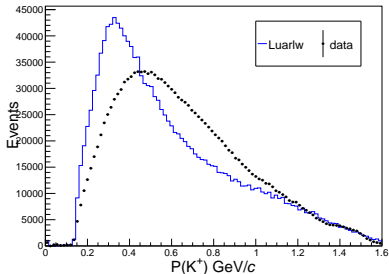
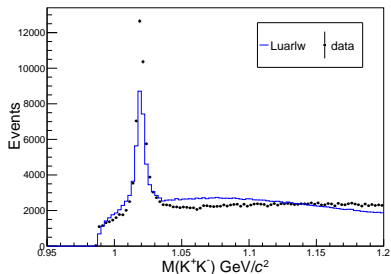
## Event Level

At least 2 good charged hadronic tracks

- **Number of good charged hadronic tracks = 2:**
  - $|\Delta\theta| = |\theta_1 + \theta_2 - 180^\circ| > 10^\circ$  or  $|\Delta\phi| = ||\phi_1 - \phi_2| - 180^\circ| > 15^\circ$
  - At least 2 isolated photons
- **Number of good charged hadronic tracks = 3:**
  - The two highest momentum tracks are required not back-to-back:  $|\Delta\theta| = |\theta_1 + \theta_2 - 180^\circ| < 10^\circ$  or  $|\Delta\phi| = ||\phi_1 - \phi_2| - 180^\circ| < 15^\circ$
  - (number of track with  $E/p > 0.8$ )  $\leq 1$
  - (number of track with PID ratio  $> 0.25$ )  $\leq 1$ , where the PID ratio is defined as  $r_{\text{PID}} = \frac{\text{Prob.}(e)}{\text{Prob.}(p)+\text{Prob.}(K)+\text{Prob.}(\pi)+\text{Prob.}(e)}$
- **Number of good charged hadronic tracks  $\geq 4$ :**  
No additional requirements

# Reconstruction of $\phi(1020)$ via $\phi(1020) \rightarrow K^+K^-$

- 1 PID (dE/dx + ToF)
  - Prob.(K) $>$ Prob.( $\pi$ ), Prob.(K) $>$ Prob.(p) and Prob(K) $>$ 0.001
- 2  $N(K^+) \geq 1$  and  $N(K^-) \geq 1$
- 3  $P(\phi) \geq 0.2$  GeV



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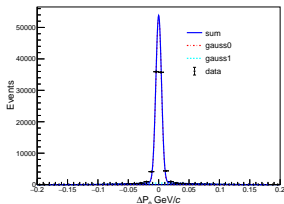
3  $\rho_{00}$  result

4 BACKUP

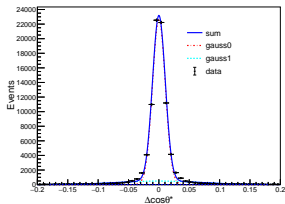
- fit result

# Binning determination

- 1 the **resolution** of  $\cos \theta^*$  and  $P_\phi$ :
  - Obtained by **LUARLW MC**, and fitted with **double Gaussian function**
- 2 The candidate events are divided into **10 intervals** of  $\cos \theta^*$ 
  - $\Delta \cos \theta^* = 0.2 > 5\sigma_{\cos \theta^*}$
- 3 The momentum intervals is set at 0.1 GeV, ranging from 0.4 to 1.6 GeV.
  - Dropped 0-0.4 GeV because of the **low reconstruction efficiency** of  $\phi$
  - $\Delta P_\phi = 0.1 > 5\sigma_{P_\phi}$



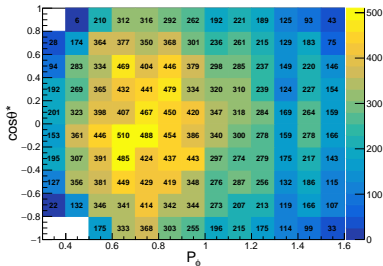
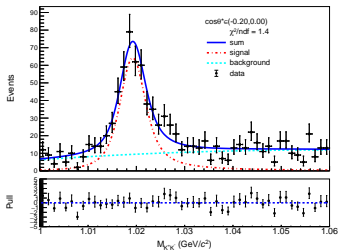
$$\sigma_{P_\phi} = 0.0158$$



$$\sigma_{\cos \theta^*} = 0.0257$$

# Extract $\phi$ signals

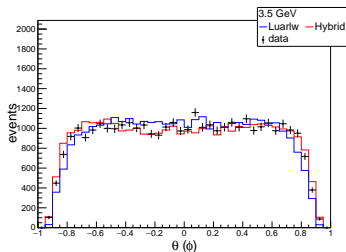
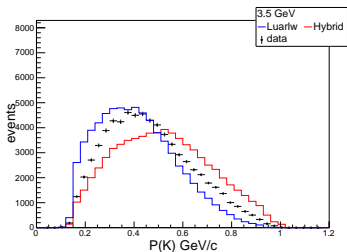
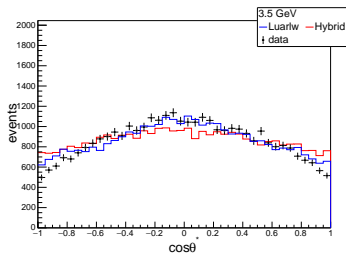
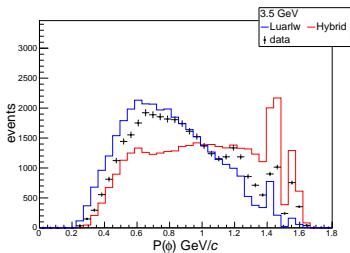
- Unbinned maximum likelihood fit method is used to extract signals from  $M(K^+K^-)$  in each ( $p$  vs.  $\cos\theta^*$ ) bin.
- Signal:** Breit-Wigner  $\otimes$  Gaussian
- Background:** 3<sup>th</sup>-order Chebyshev polynomial
- The parameter of the Breit-Wigner function is fixed to the  $\phi$ 's PDG values.





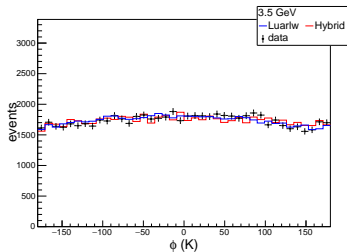
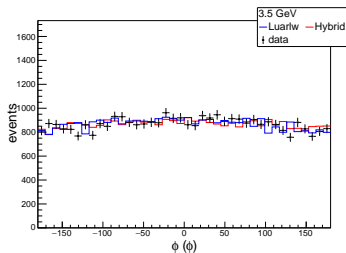
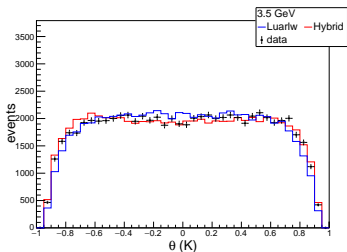
# The difference between data and MC

- 1 SPlot method for data to extract  $\phi$  signal distribution
- 2 MCtruth match for MC to extract  $\phi$  signal distribution



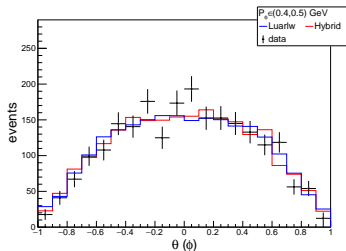
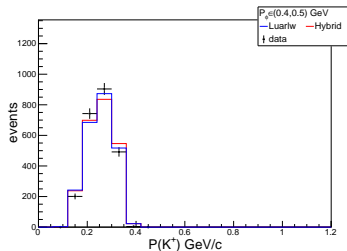
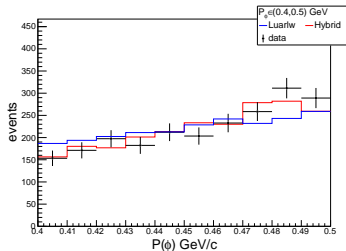
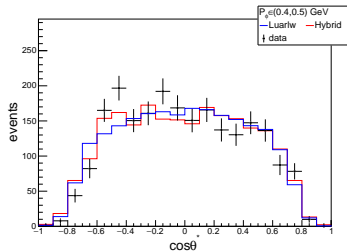
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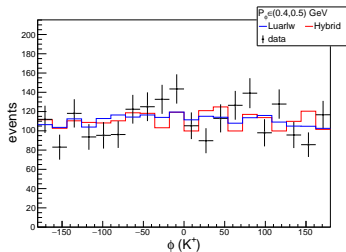
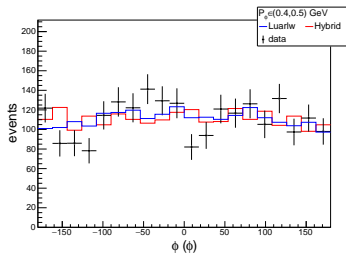
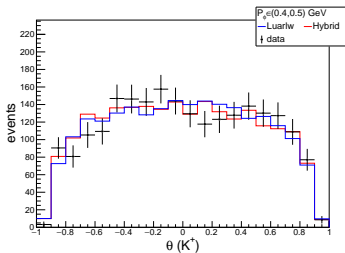
# The signal distribution of $\phi$

$0.4 < P_\phi < 0.5$  GeV/c



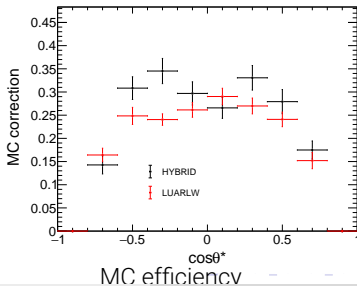
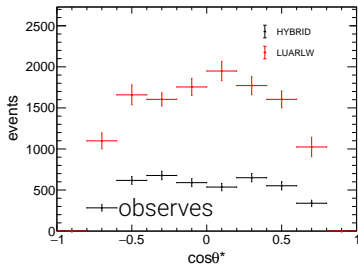
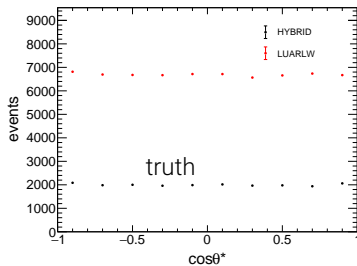
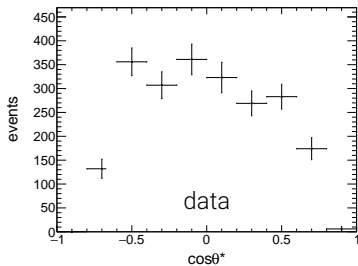
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# $\rho_{00}$ result

$0.4 < P_\phi < 0.5 \text{ GeV}/c$

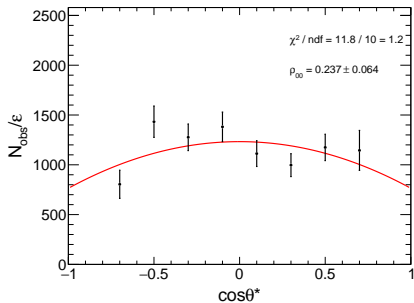


MC efficiency

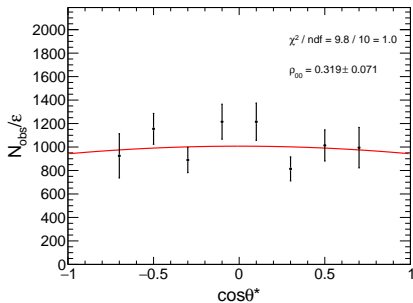


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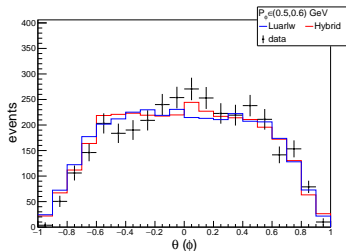
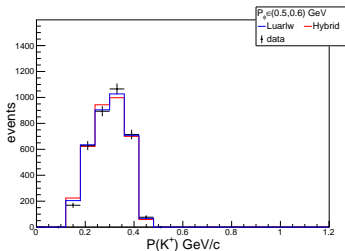
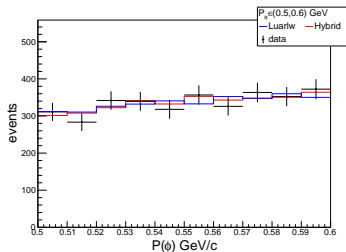
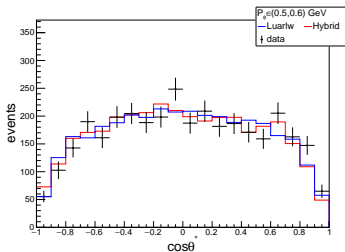
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

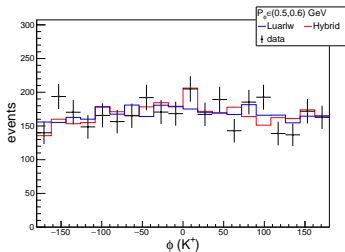
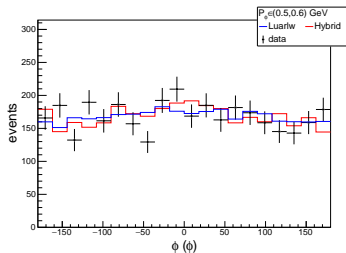
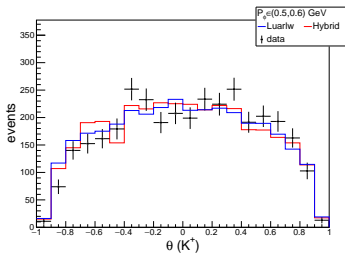
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$0.5 < P_\phi < 0.6 \text{ GeV}/c$



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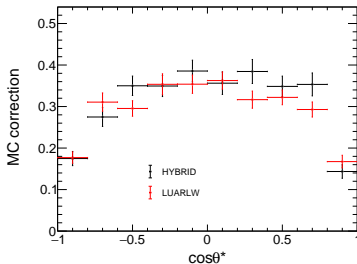
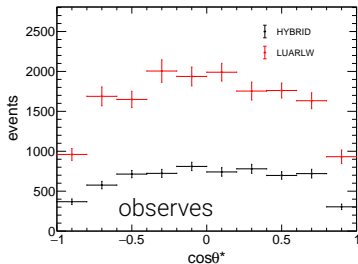
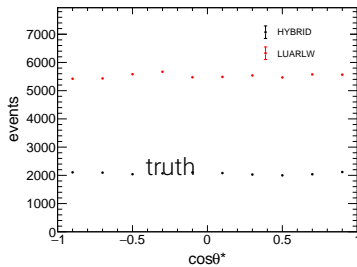
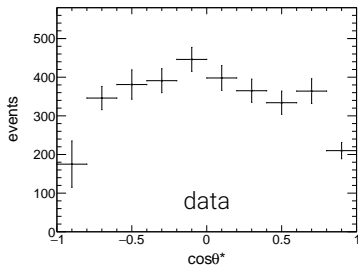
$0.5 < P_\phi < 0.6 \text{ GeV}/c$





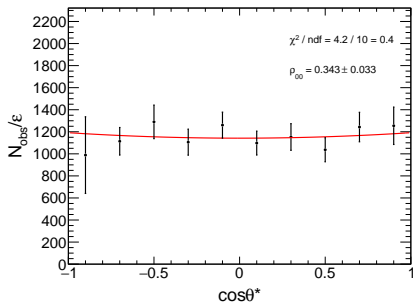
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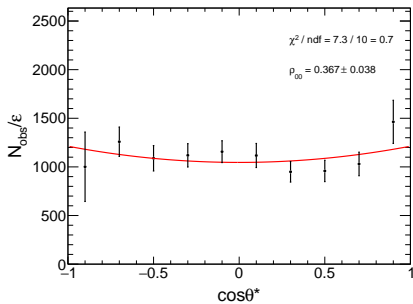


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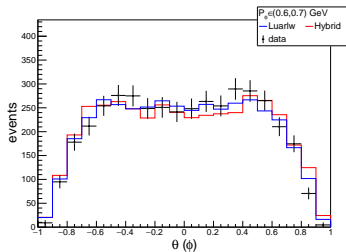
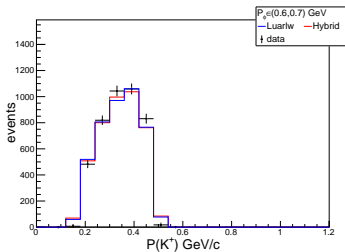
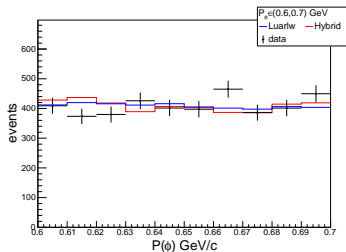
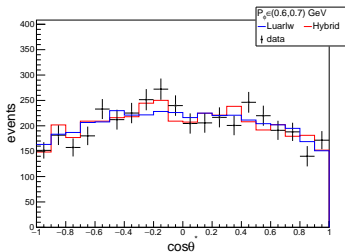
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

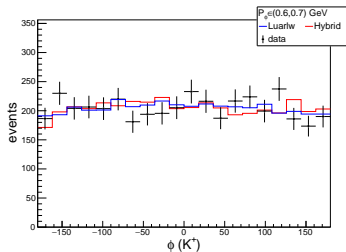
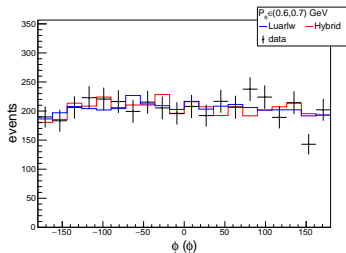
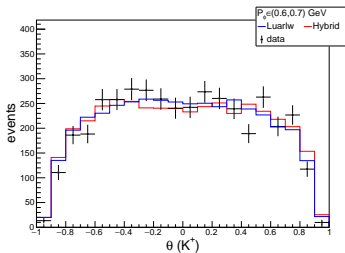
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$0.6 < P_\phi < 0.7$  GeV/c



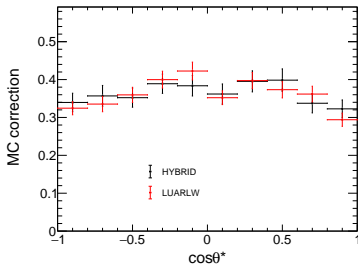
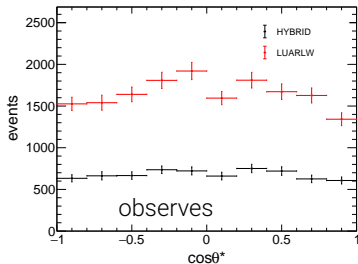
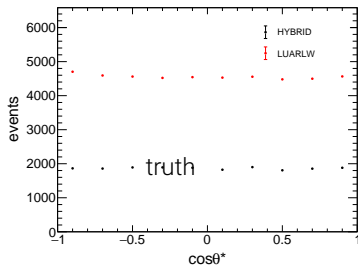
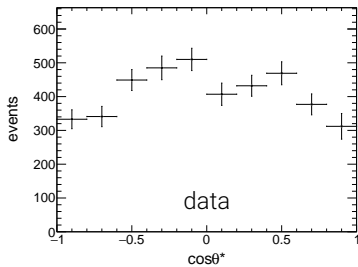
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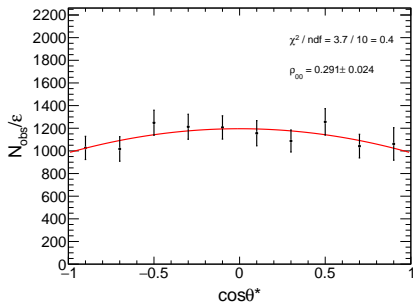
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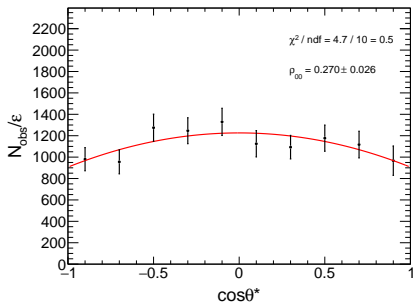


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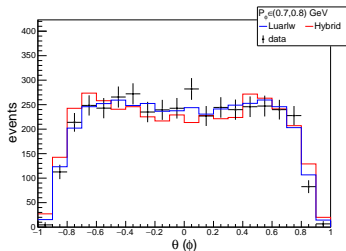
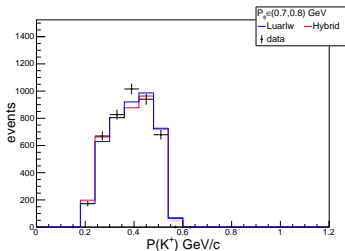
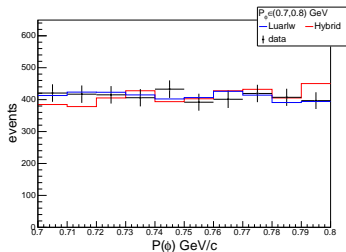
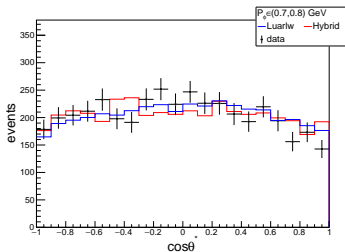
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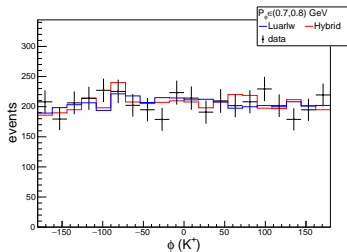
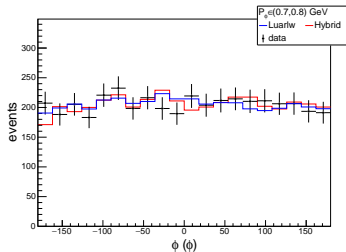
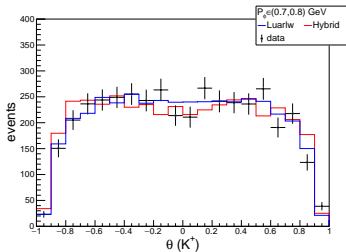
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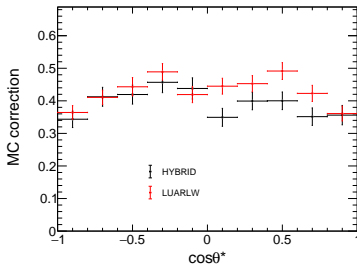
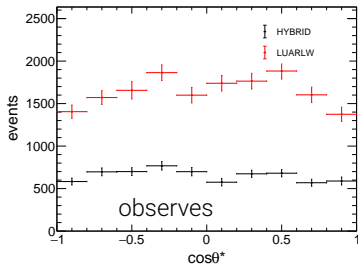
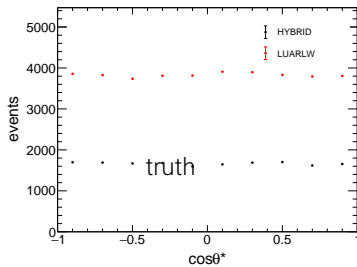
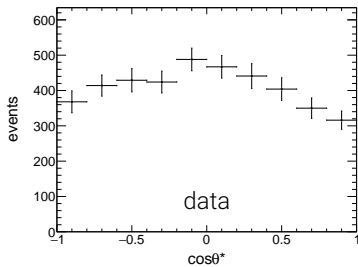
$0.7 < P_\phi < 0.8 \text{ GeV}/c$





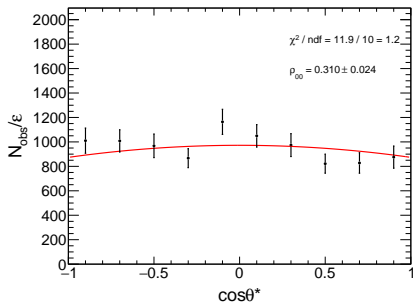
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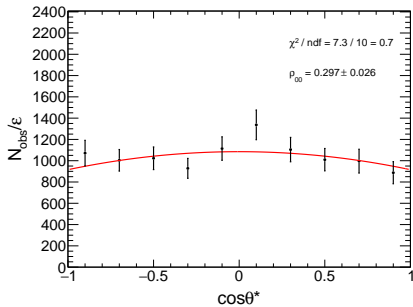


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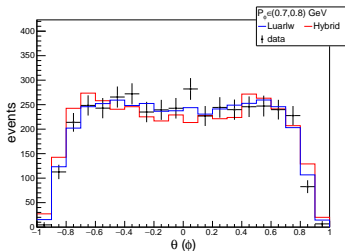
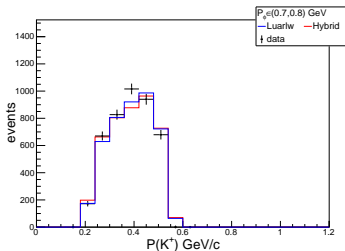
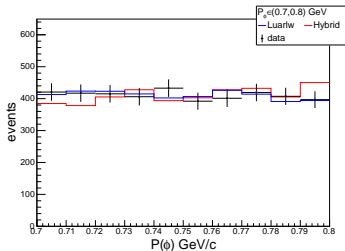
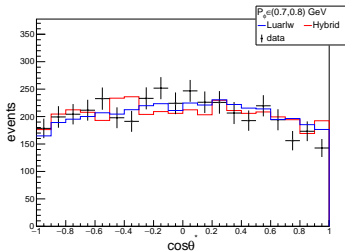
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

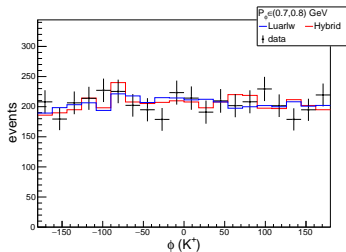
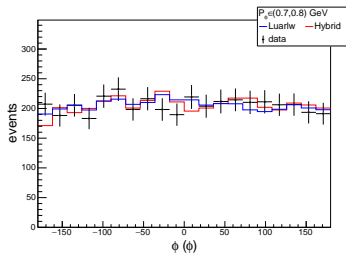
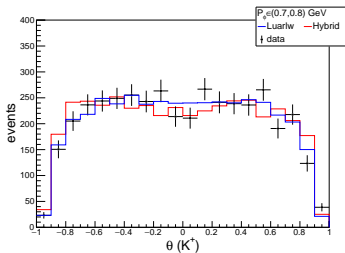
# The signal distribution of $\phi$

$0.8 < P_\phi < 0.9$  GeV/c



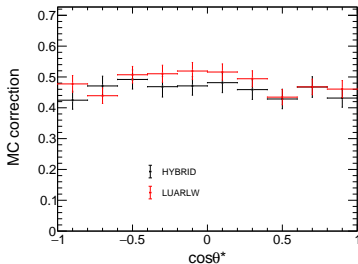
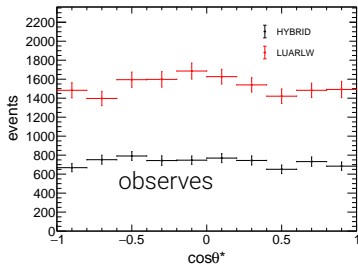
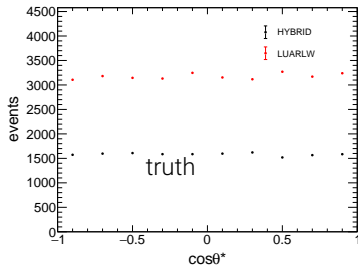
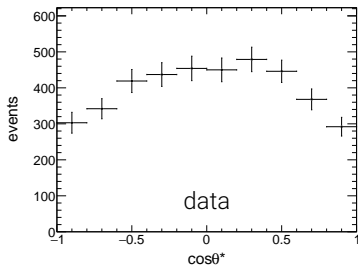
# The signal distribution of $\phi$

$0.8 < P_\phi < 0.9 \text{ GeV}/c$



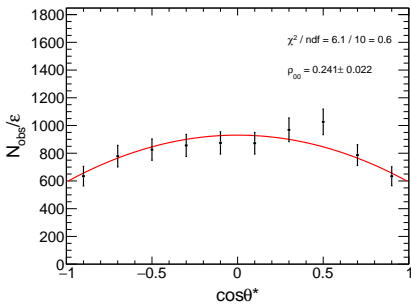
# $\rho_{00}$ result

$0.8 < P_\phi < 0.9 \text{ GeV}/c$

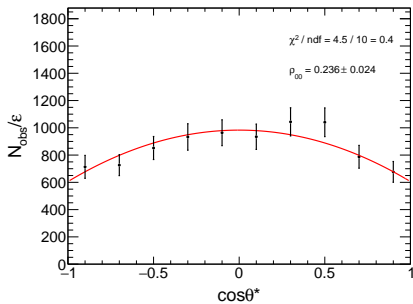


# $\rho_{00}$ result

$0.8 < P_\phi < 0.9 \text{ GeV}/c$



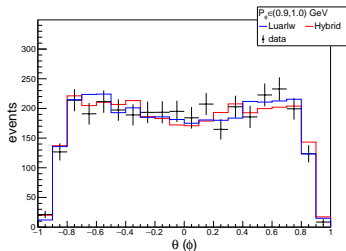
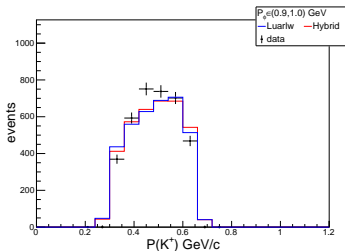
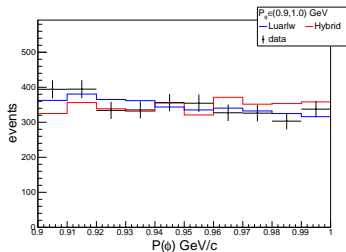
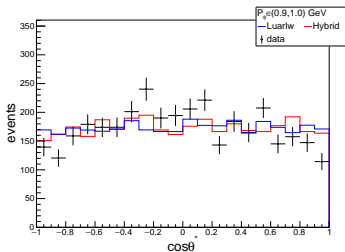
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

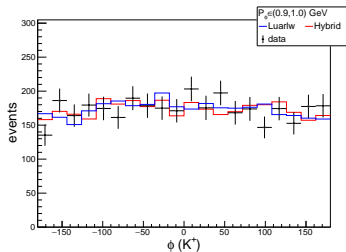
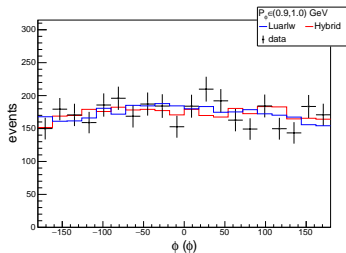
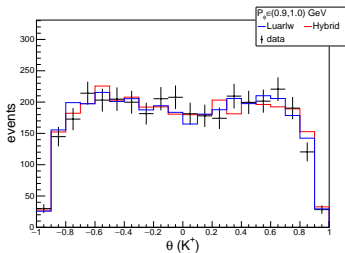
# The signal distribution of $\phi$

$0.9 < P_\phi < 1.0$  GeV/c



# The signal distribution of $\phi$

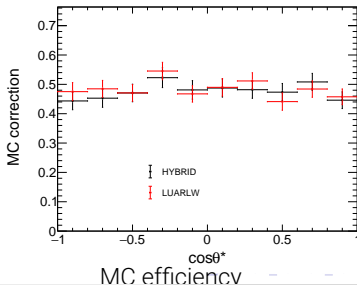
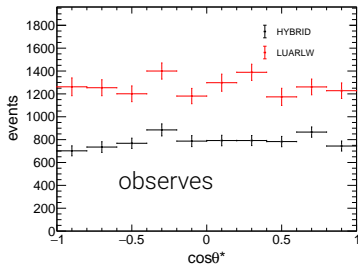
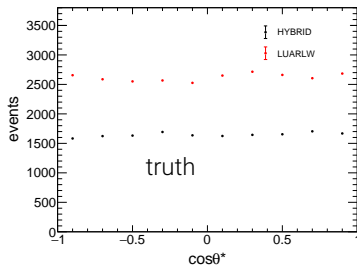
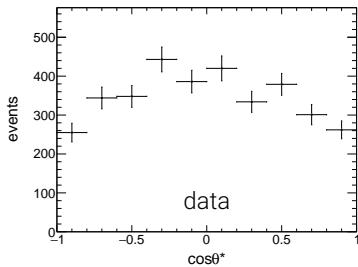
$0.9 < P_\phi < 1.0$  GeV/c





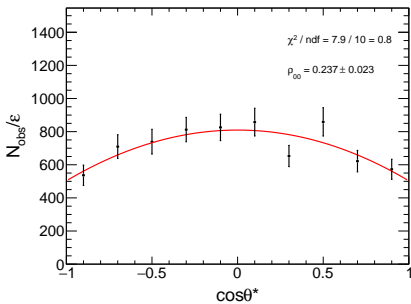
# $\rho_{00}$ result

$0.9 < P_\phi < 1.0$  GeV/c

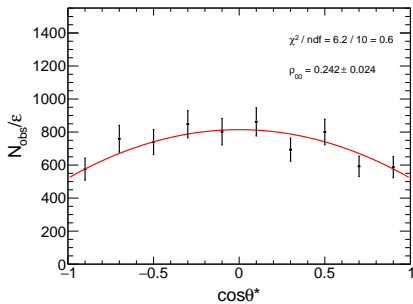


# $\rho_{00}$ result

$0.9 < P_\phi < 1.0 \text{ GeV}/c$



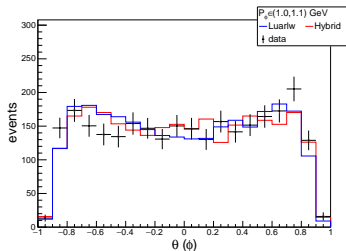
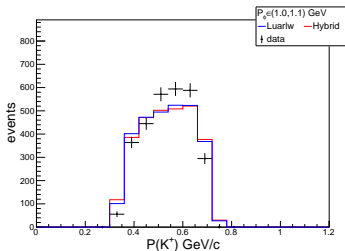
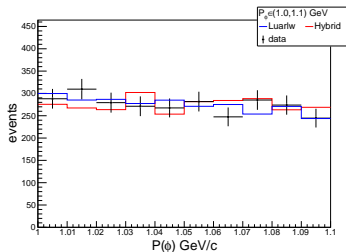
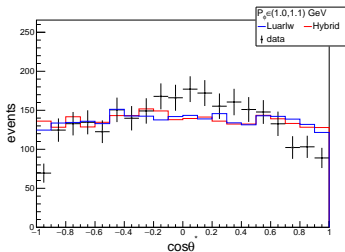
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

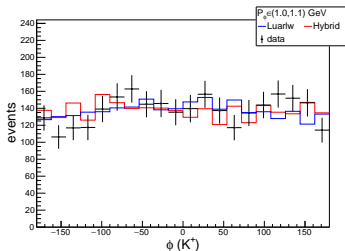
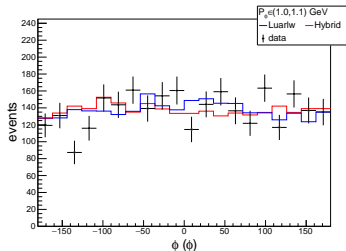
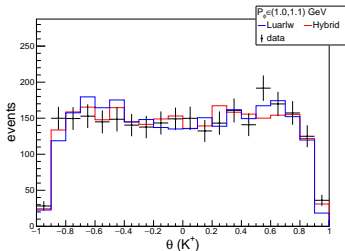
# The signal distribution of $\phi$

$1.0 < P_\phi < 1.1$  GeV/c



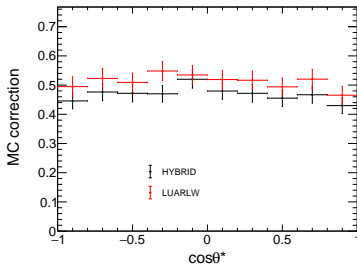
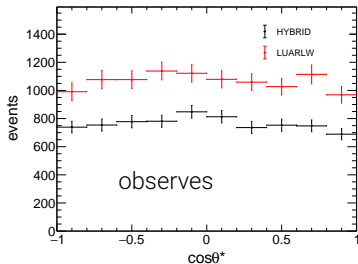
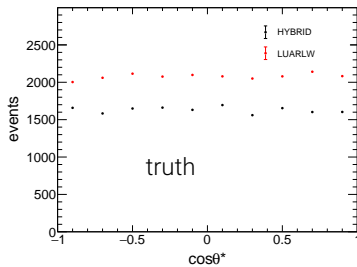
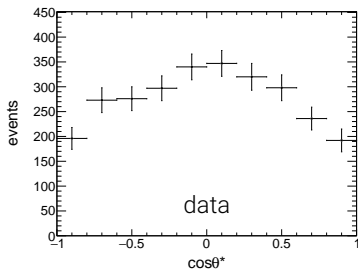
# The signal distribution of $\phi$

$1.0 < P_\phi < 1.1$  GeV/c



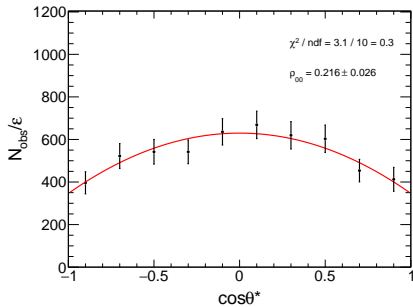
# $\rho_{00}$ result

$1.0 < P_\phi < 1.1 \text{ GeV}/c$

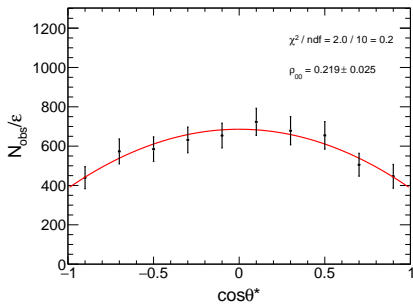


# $\rho_{00}$ result

$1.0 < P_\phi < 1.1 \text{ GeV}/c$



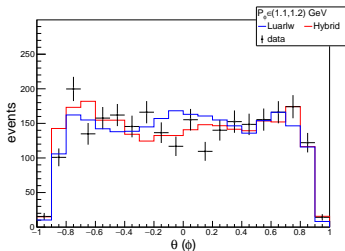
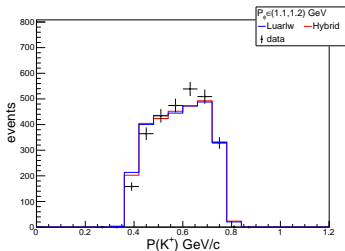
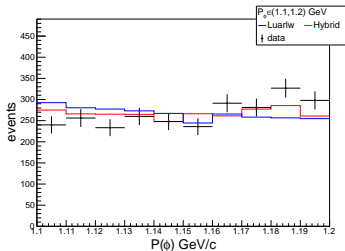
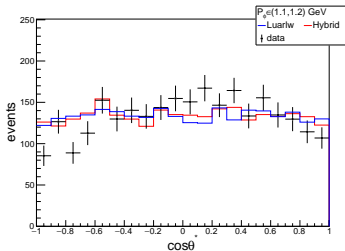
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

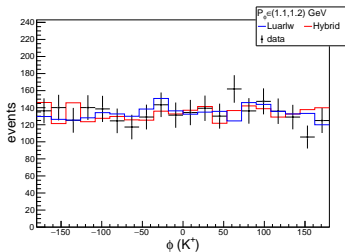
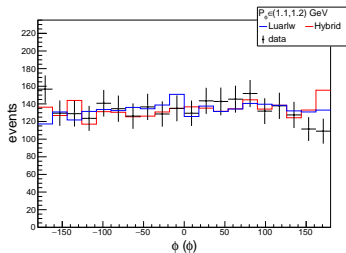
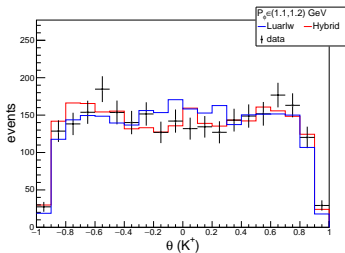
# The signal distribution of $\phi$

$1.1 < P_\phi < 1.2$  GeV/c



# The signal distribution of $\phi$

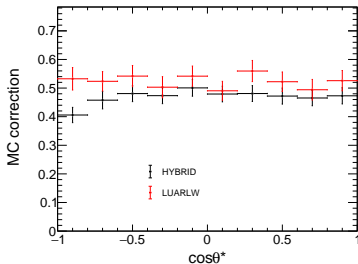
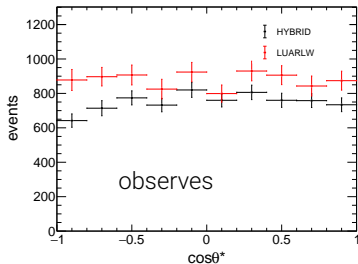
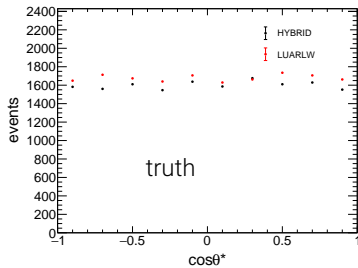
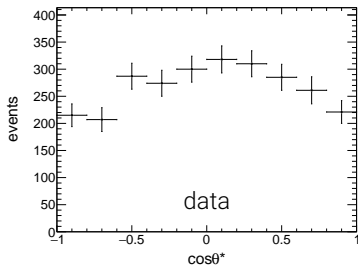
$1.1 < P_{\phi} < 1.2 \text{ GeV}/c$





# $\rho_{00}$ result

$1.1 < P_\phi < 1.2 \text{ GeV}/c$

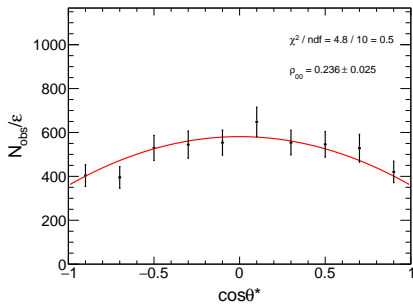


MC efficiency

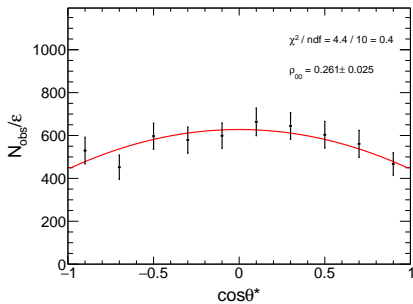


# $\rho_{00}$ result

$1.1 < P_\phi < 1.2 \text{ GeV}/c$



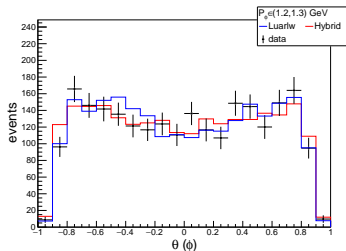
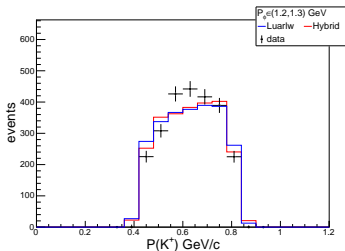
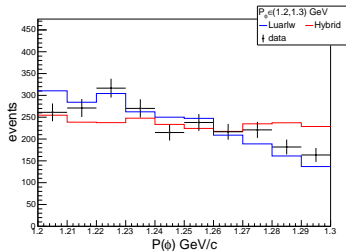
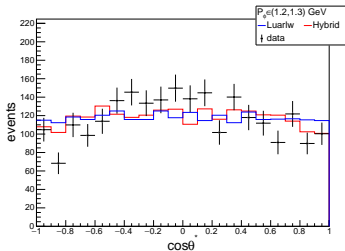
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

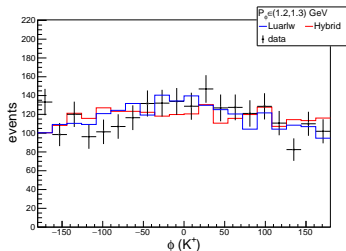
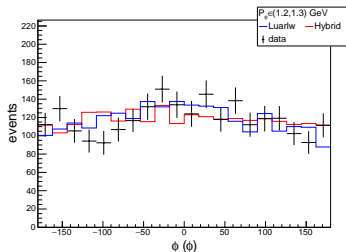
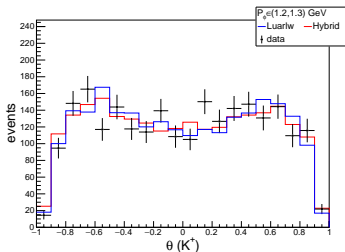
# The signal distribution of $\phi$

$1.2 < P_\phi < 1.3$  GeV/c



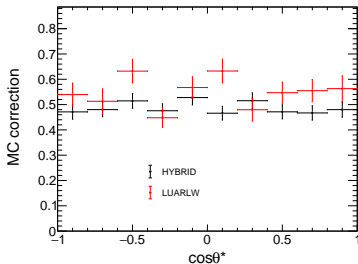
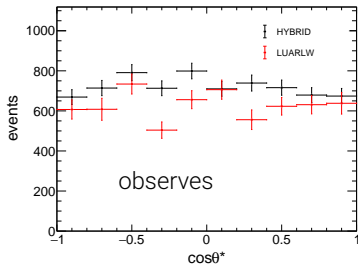
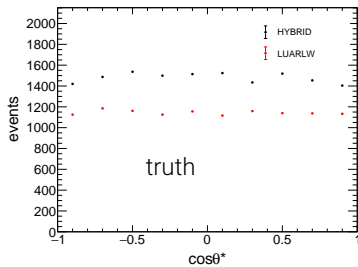
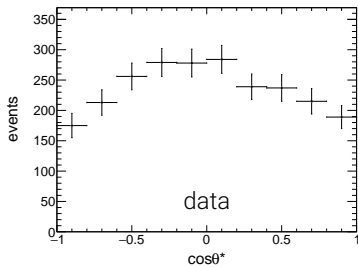
# The signal distribution of $\phi$

$1.2 < P_\phi < 1.3$  GeV/c



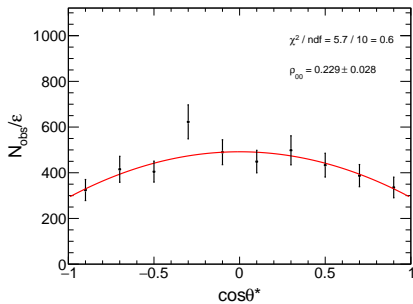
# $\rho_{00}$ result

$1.2 < P_\phi < 1.3 \text{ GeV}/c$

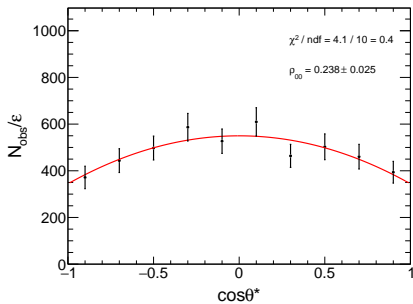


# $\rho_{00}$ result

$1.2 < P_\phi < 1.3 \text{ GeV}/c$



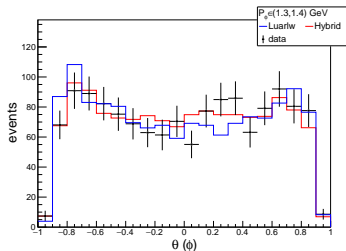
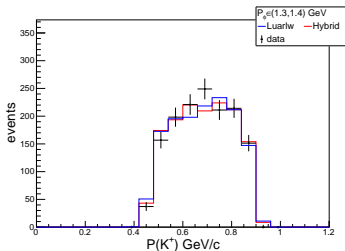
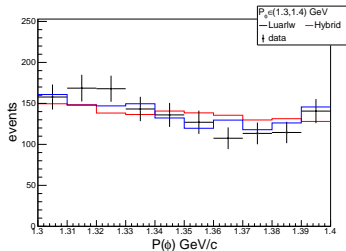
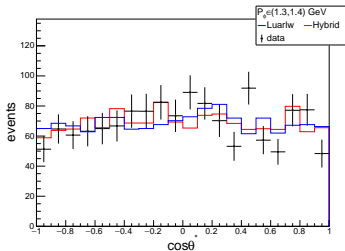
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

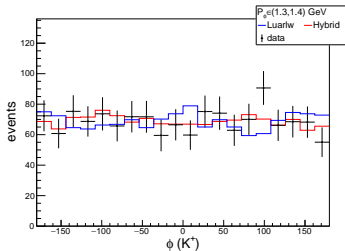
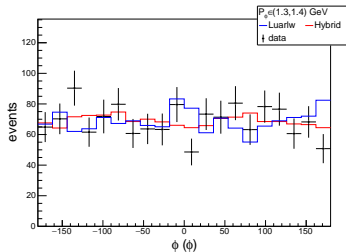
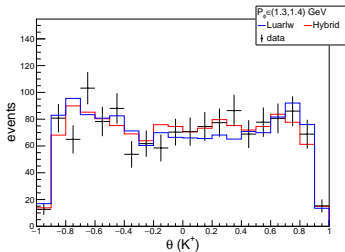
# The signal distribution of $\phi$

$1.3 < P_\phi < 1.4$  GeV/c



# The signal distribution of $\phi$

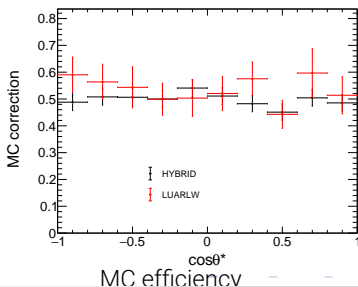
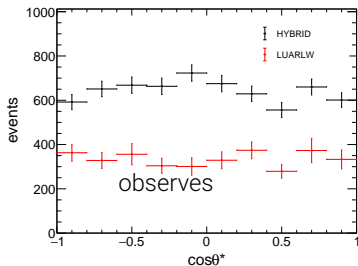
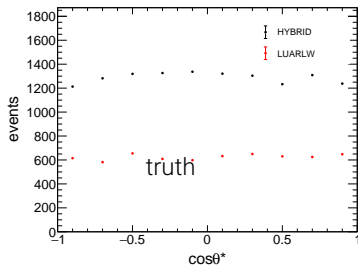
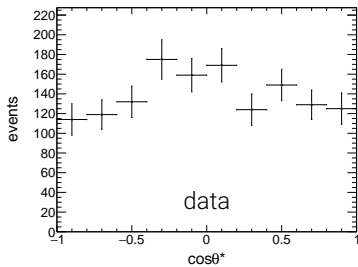
$1.3 < P_\phi < 1.4 \text{ GeV}/c$





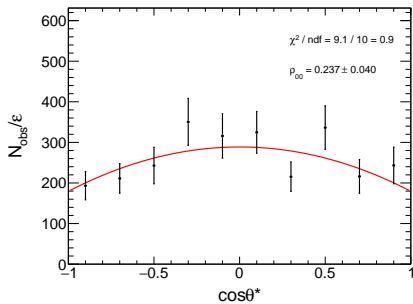
# $\rho_{00}$ result

$1.3 < P_\phi < 1.4 \text{ GeV}/c$

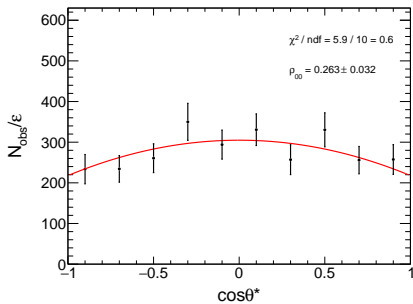


# $\rho_{00}$ result

$1.3 < P_\phi < 1.4 \text{ GeV}/c$



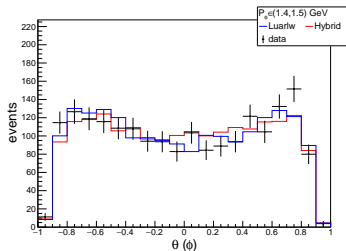
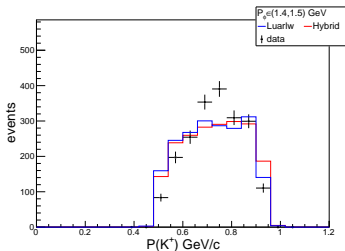
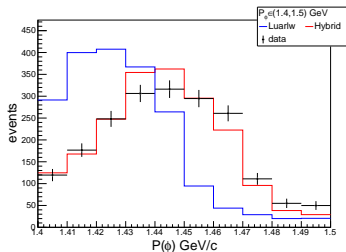
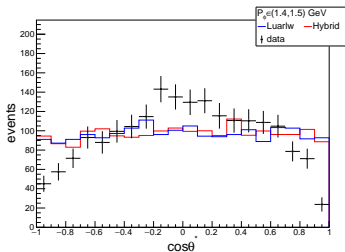
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

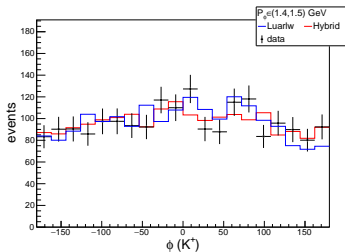
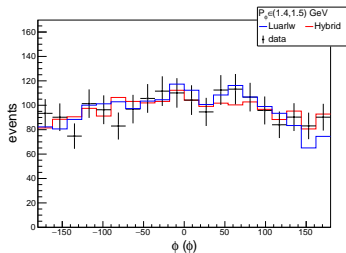
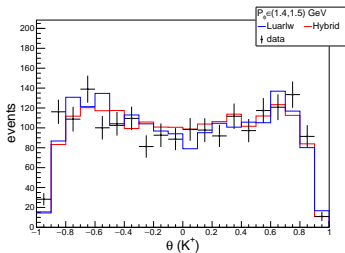
# The signal distribution of $\phi$

$1.4 < P_\phi < 1.5$  GeV/c



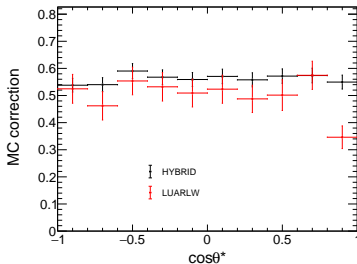
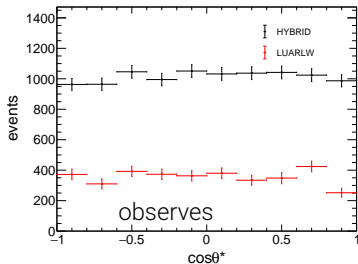
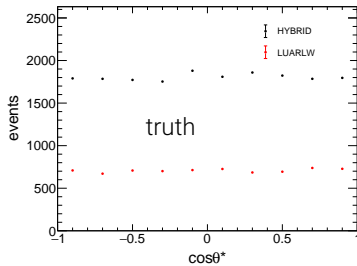
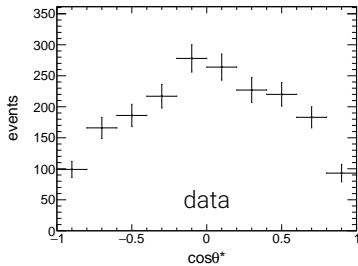
# The signal distribution of $\phi$

$1.4 < P_\phi < 1.5 \text{ GeV}/c$



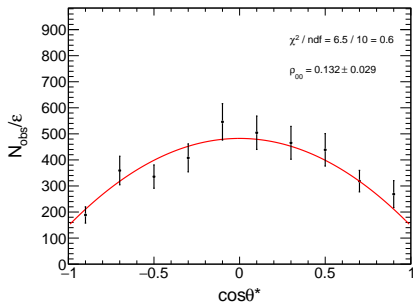
# $\rho_{00}$ result

$1.4 < P_\phi < 1.5 \text{ GeV}/c$

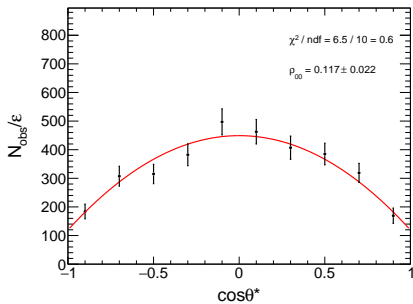


# $\rho_{00}$ result

$1.4 < P_\phi < 1.5 \text{ GeV}/c$



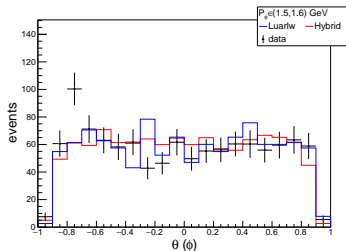
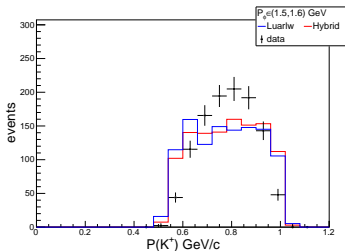
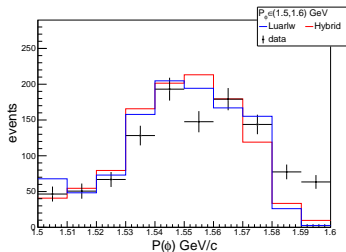
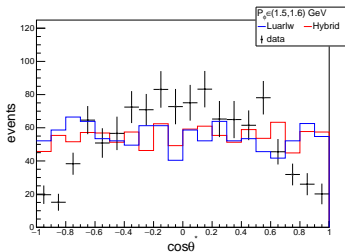
$\rho_{00}$  of LUALRW



$\rho_{00}$  of HYBRID

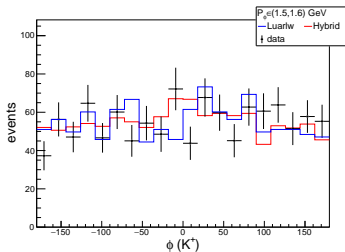
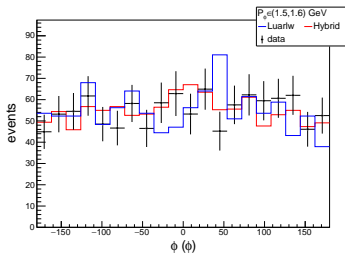
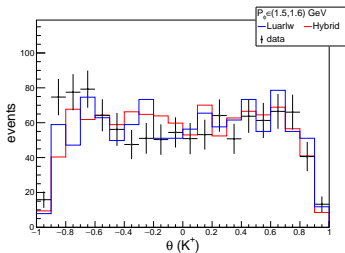
# The signal distribution of $\phi$

$1.5 < P_\phi < 1.6$  GeV/c



# The signal distribution of $\phi$

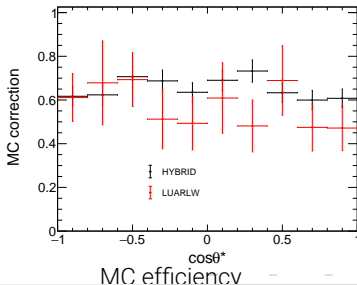
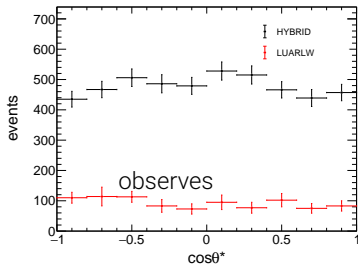
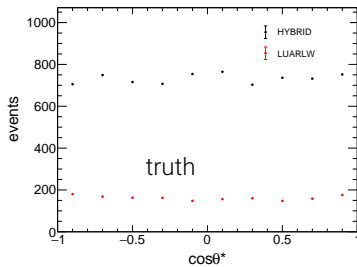
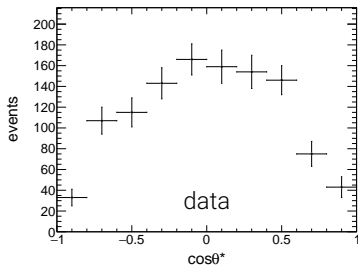
$1.5 < P_\phi < 1.6$  GeV/c





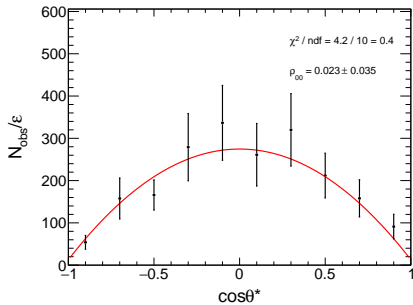
# $\rho_{00}$ result

$1.5 < P_\phi < 1.6 \text{ GeV}/c$

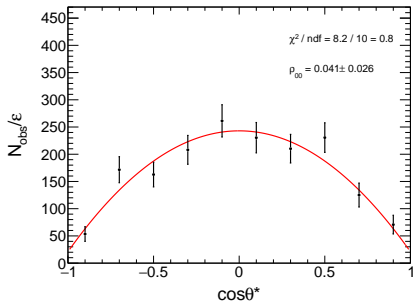


# $\rho_{00}$ result

$1.5 < P_\phi < 1.6 \text{ GeV}/c$



$\rho_{00}$  of LUALRW

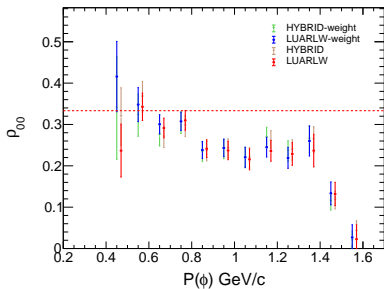
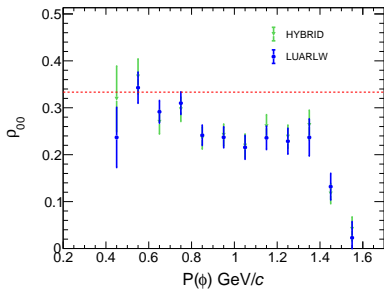


$\rho_{00}$  of HYBRID

# Outline

- 1 Data sets and event selection
- 2 Spin alignment of  $\phi$
- 3  $\rho_{00}$  result
- 4 BACKUP
  - fit result

# $\rho_{00}$ result

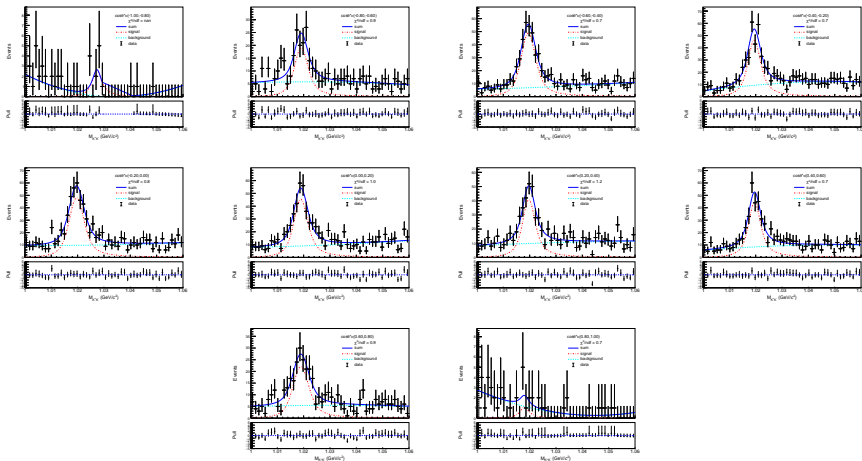


# Outline

- 1 Data sets and event selection
- 2 Spin alignment of  $\phi$
- 3  $\rho_{00}$  result
- 4 **BACKUP**
  - fit result

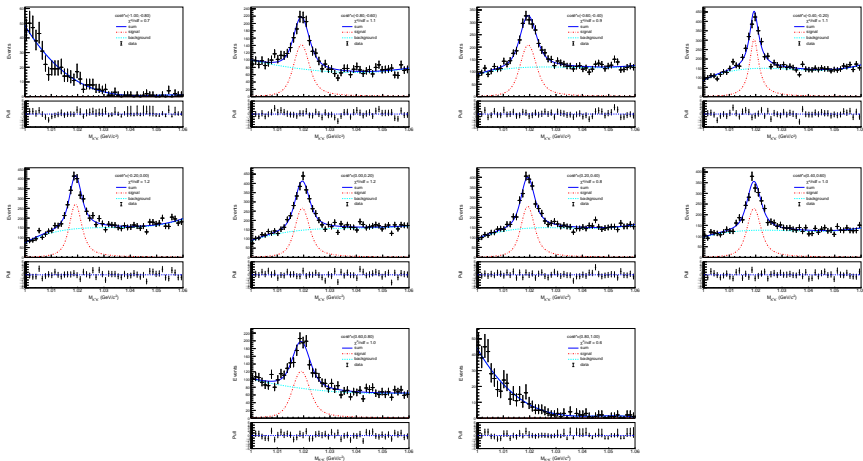
# fit result (data)

$0.4 < P_\phi < 0.5 \text{ GeV}/c$



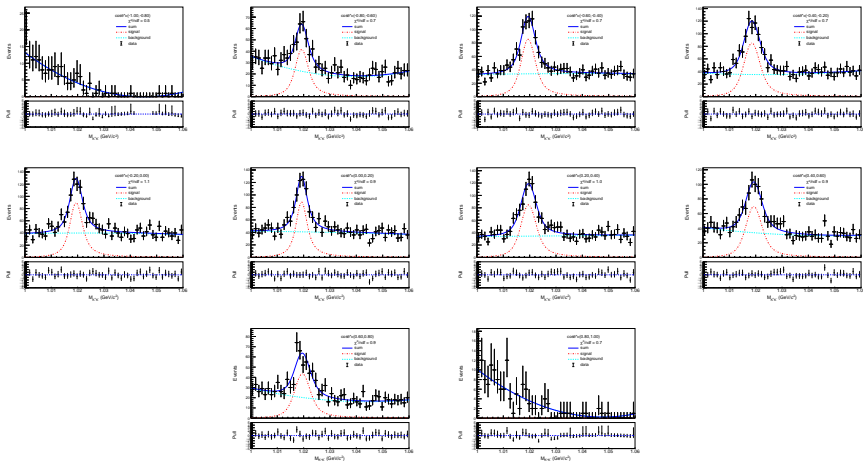
# fit result (LUARLW MC)

$0.4 < P_\phi < 0.5 \text{ GeV}/c$



# fit result (HYBRID MC)

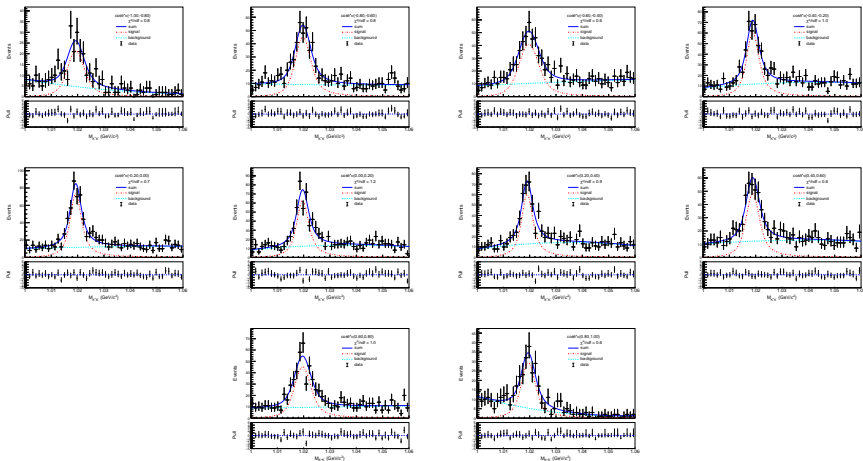
$0.4 < P_\phi < 0.5 \text{ GeV}/c$





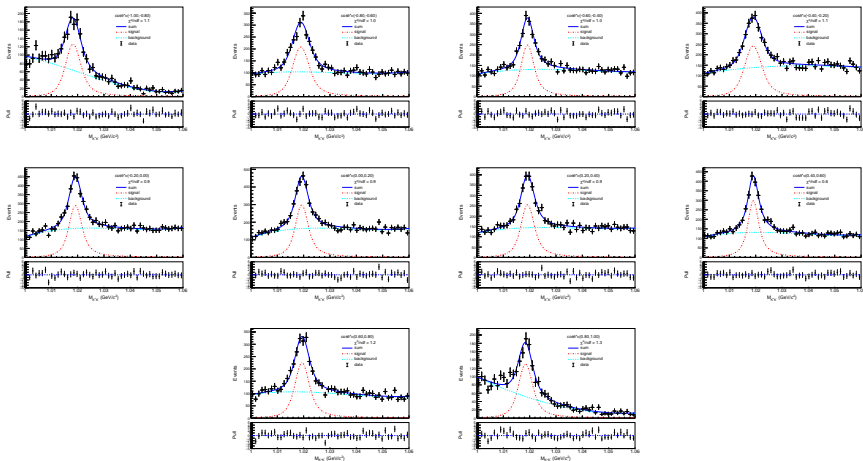
# fit result (data)

$0.5 < P_\phi < 0.6 \text{ GeV}/c$



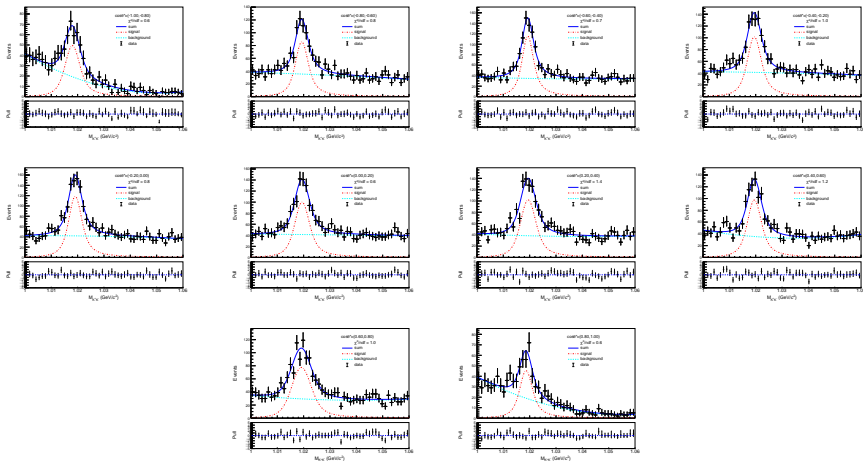
# fit result (LUARLW MC)

$0.5 < P_\phi < 0.6 \text{ GeV}/c$



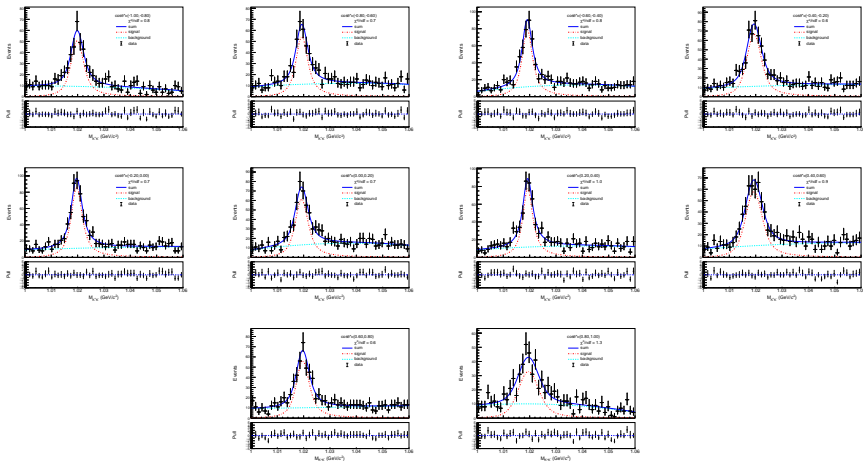
# fit result (HYBRID MC)

$0.5 < P_\phi < 0.6 \text{ GeV}/c$



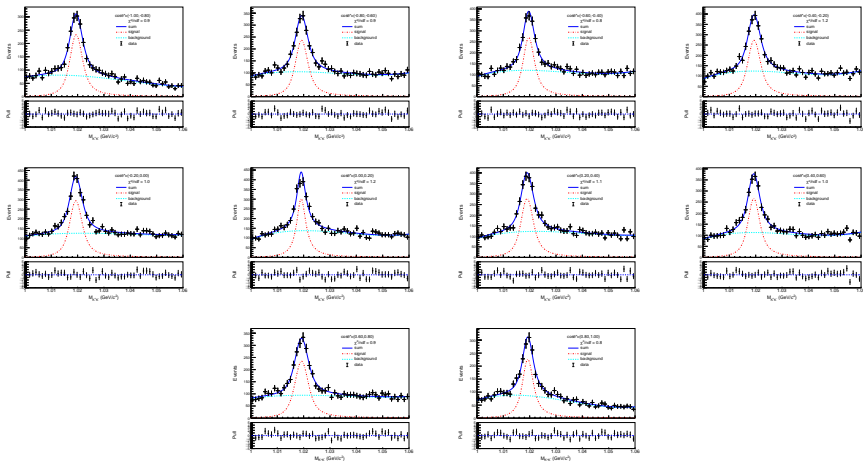
# fit result (data)

$0.6 < P_\phi < 0.7 \text{ GeV}/c$



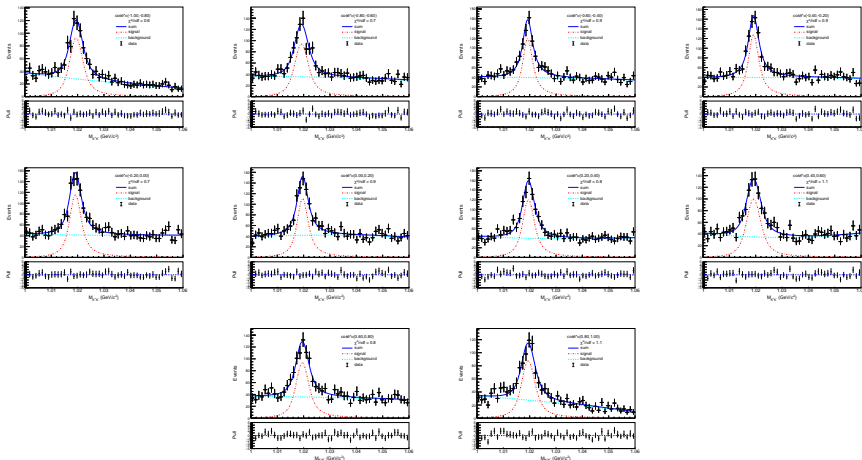
# fit result (LUARLW MC)

$0.6 < P_\phi < 0.7 \text{ GeV}/c$



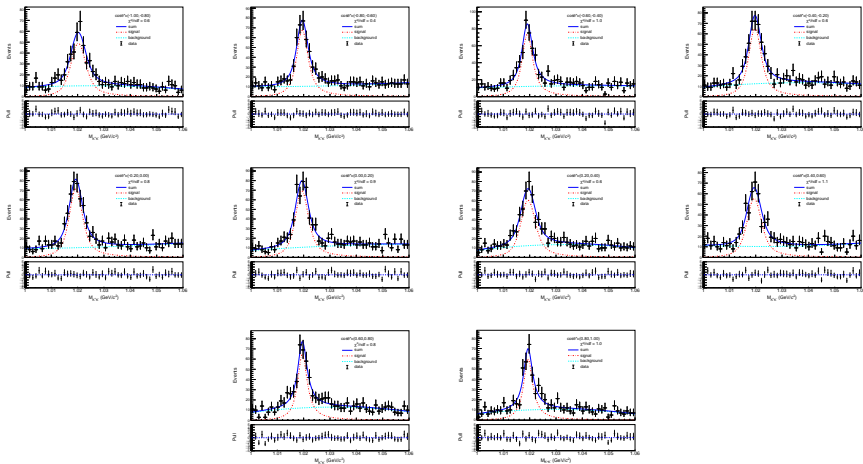
# fit result (HYBRID MC)

$0.6 < P_\phi < 0.7 \text{ GeV}/c$



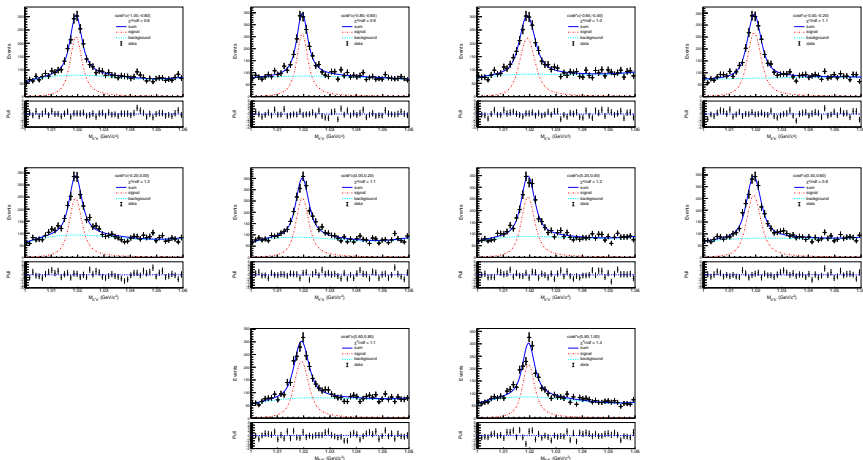
# fit result (data)

$0.7 < P_\phi < 0.8 \text{ GeV}/c$



# fit result (LUARLW MC)

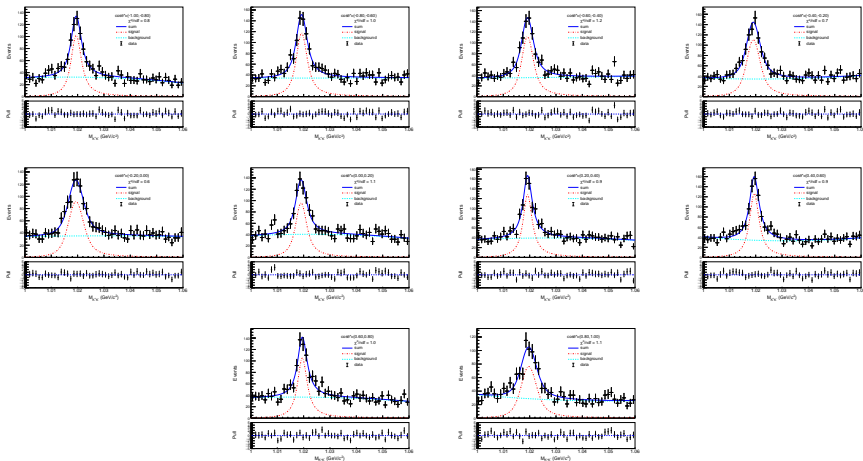
$0.7 < P_\phi < 0.8 \text{ GeV}/c$





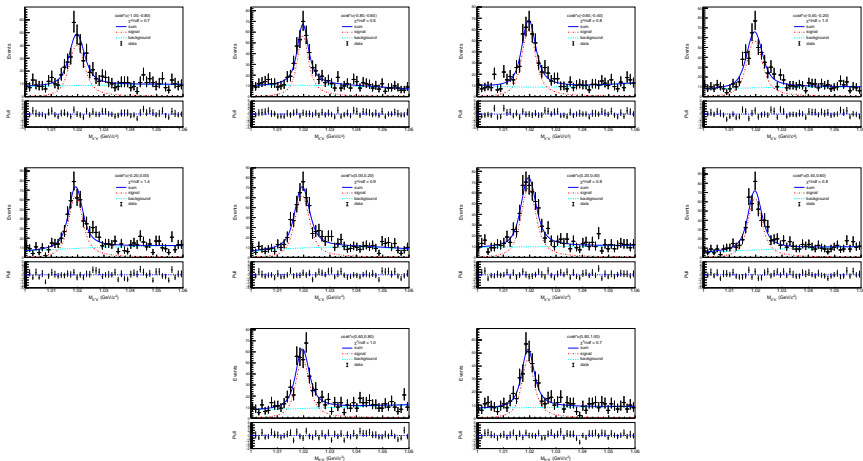
# fit result (HYBRID MC)

$0.7 < P_\phi < 0.8 \text{ GeV}/c$



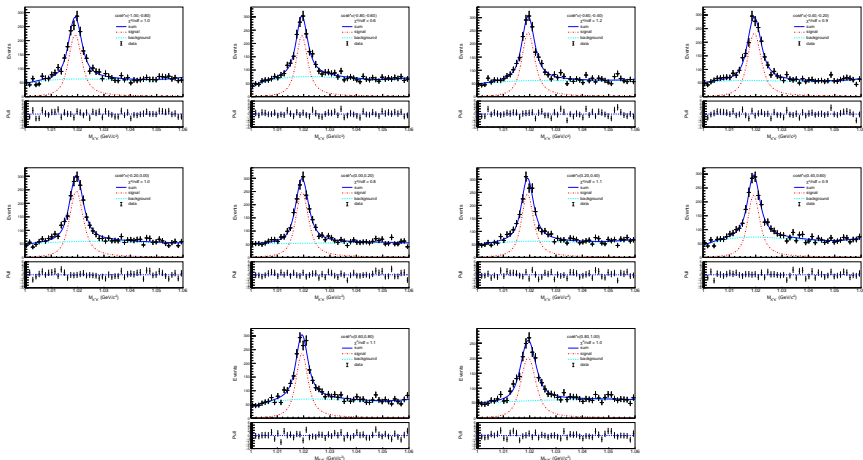
# fit result (data)

$0.8 < P_\phi < 0.9 \text{ GeV}/c$



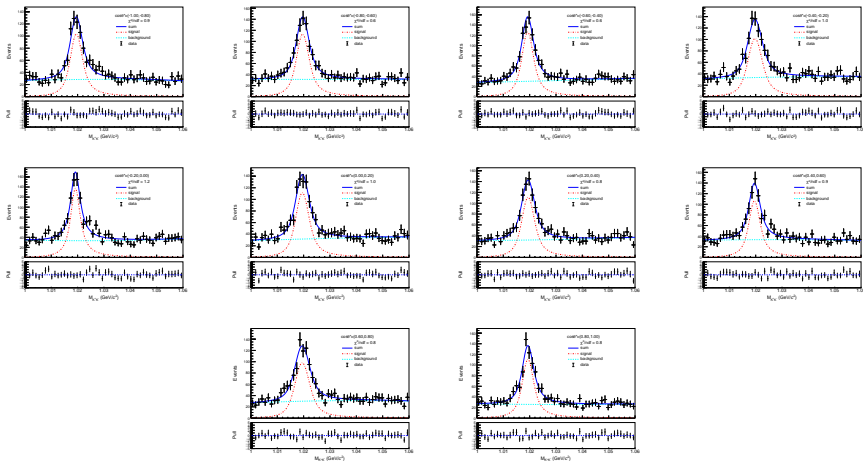
# fit result (LUARLW MC)

$0.8 < P_\phi < 0.9 \text{ GeV}/c$



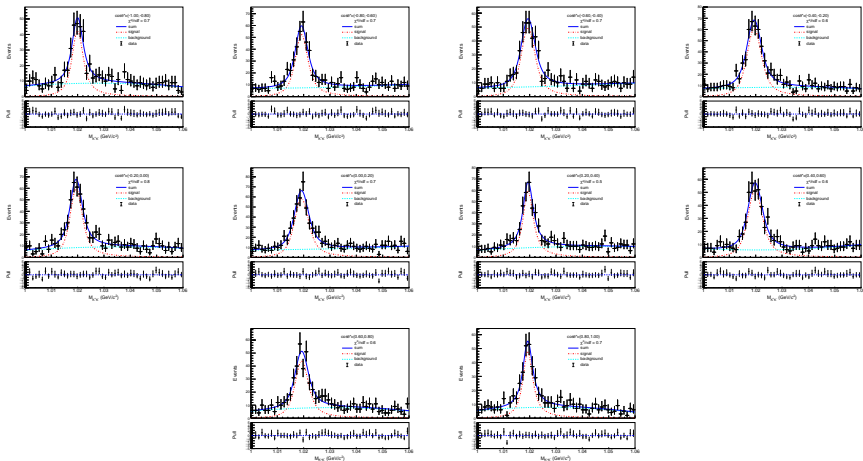
# fit result (HYBRID MC)

$0.8 < P_\phi < 0.9 \text{ GeV}/c$



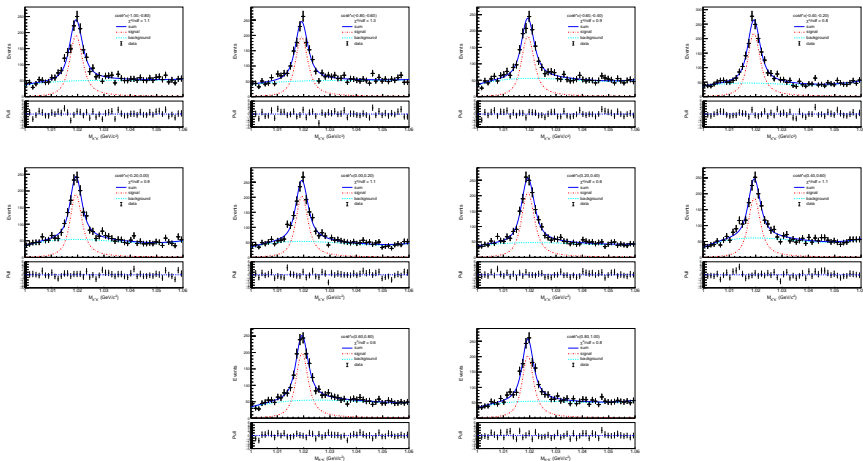
# fit result (data)

$0.9 < P_\phi < 1.0 \text{ GeV}/c$



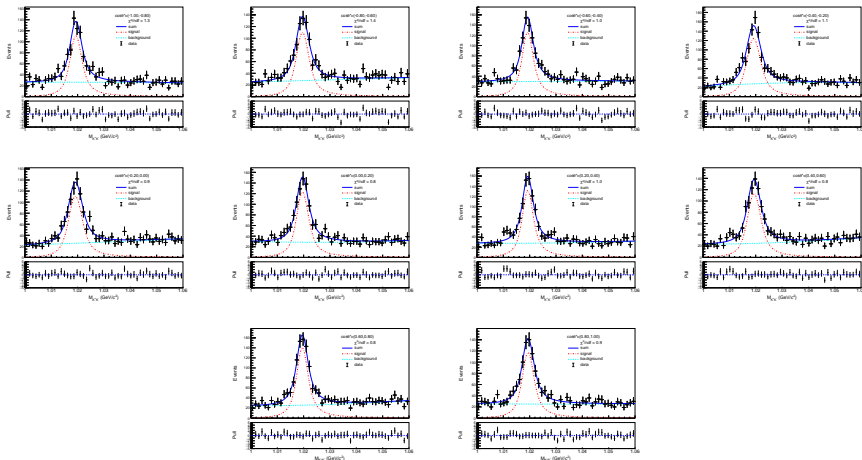
# fit result (LUARLW MC)

$0.9 < P_\phi < 1.0 \text{ GeV}/c$



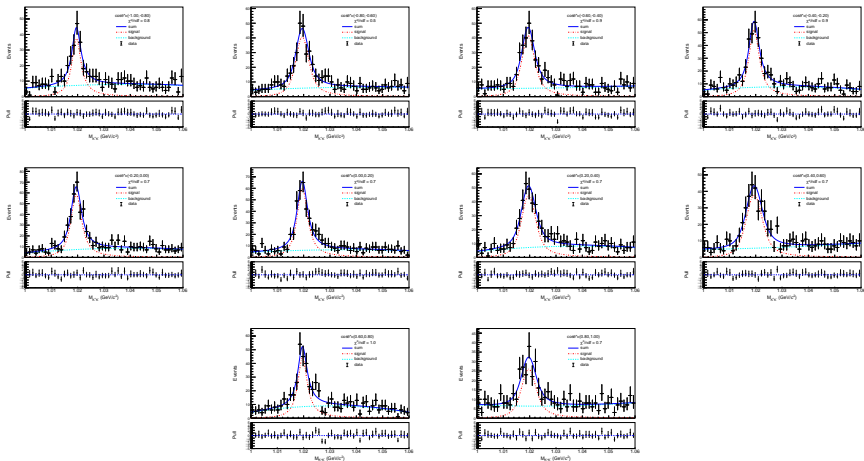
# fit result (HYBRID MC)

$0.9 < P_\phi < 1.0 \text{ GeV}/c$



# fit result (data)

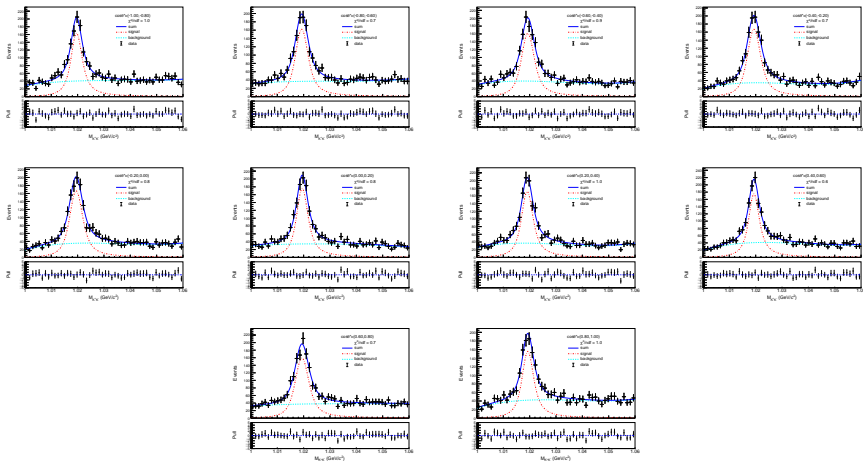
$1.0 < P_\phi < 1.1 \text{ GeV}/c$





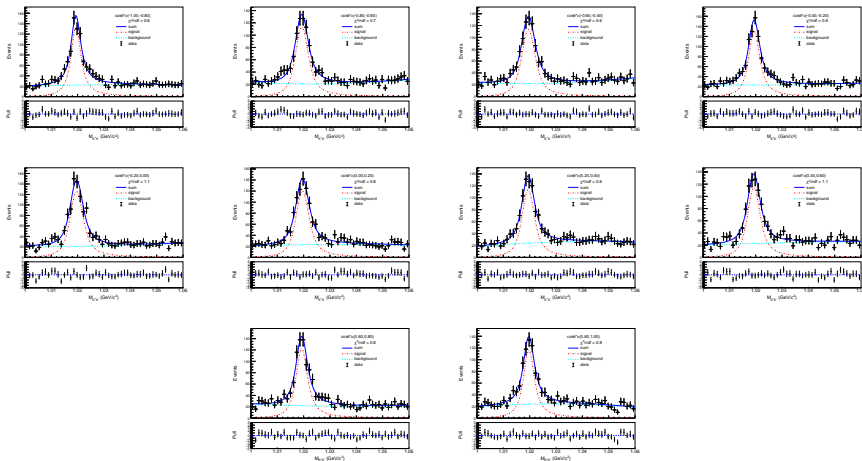
# fit result (LUARLW MC)

$1.0 < P_\phi < 1.1 \text{ GeV}/c$



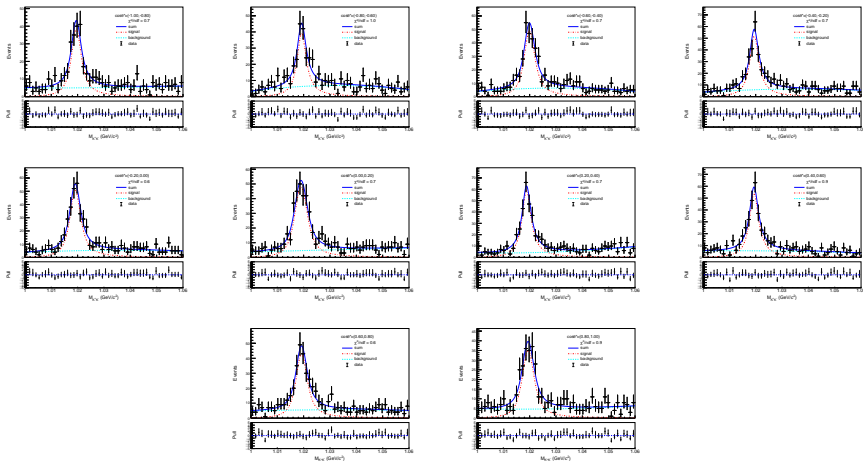
# fit result (HYBRID MC)

$1.0 < P_\phi < 1.1 \text{ GeV}/c$



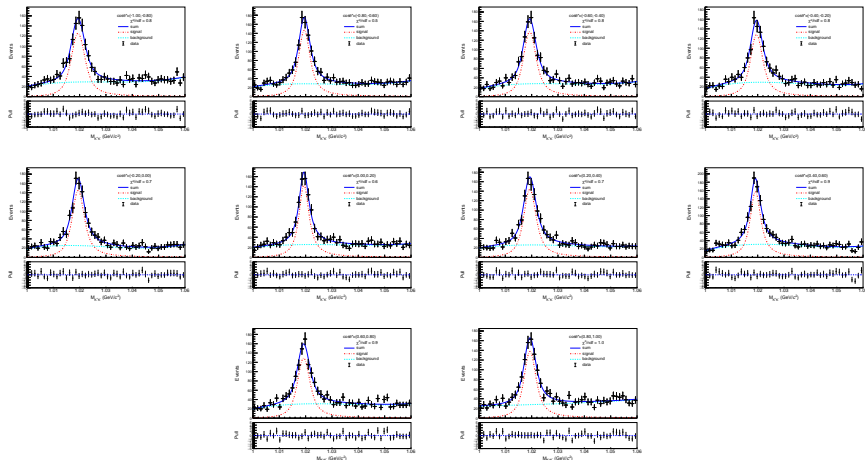
# fit result (data)

$1.1 < P_\phi < 1.2 \text{ GeV}/c$



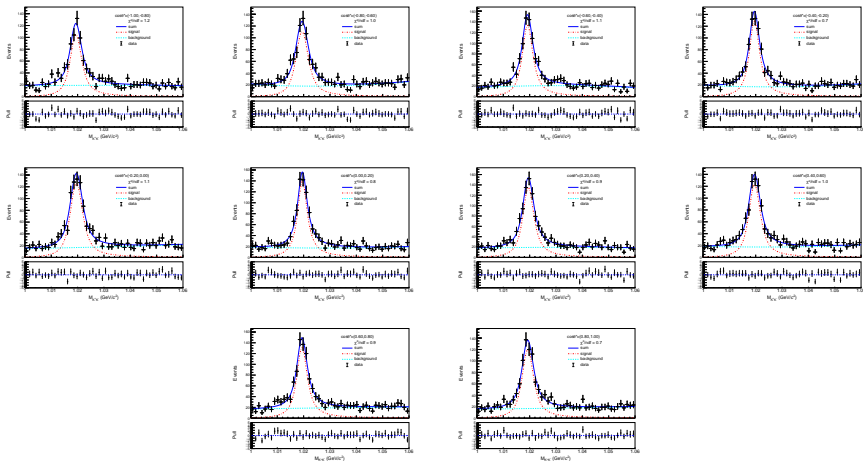
# fit result (LUARLW MC)

$1.1 < P_\phi < 1.2 \text{ GeV}/c$



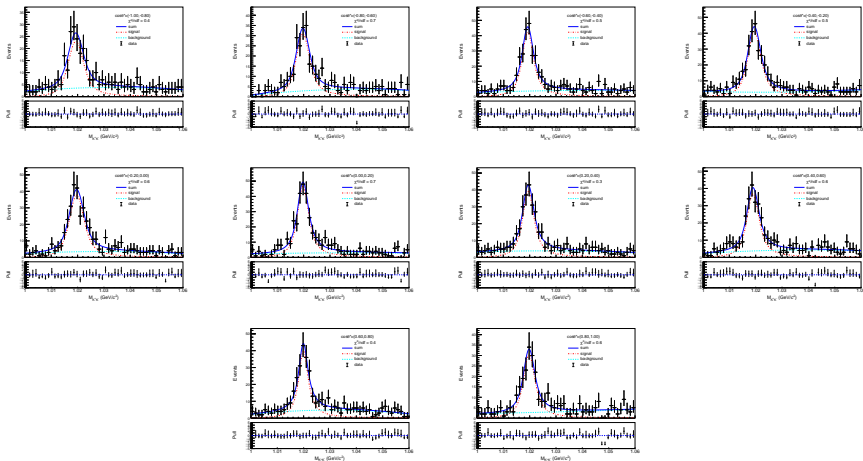
# fit result (HYBRID MC)

$1.1 < P_\phi < 1.2 \text{ GeV}/c$



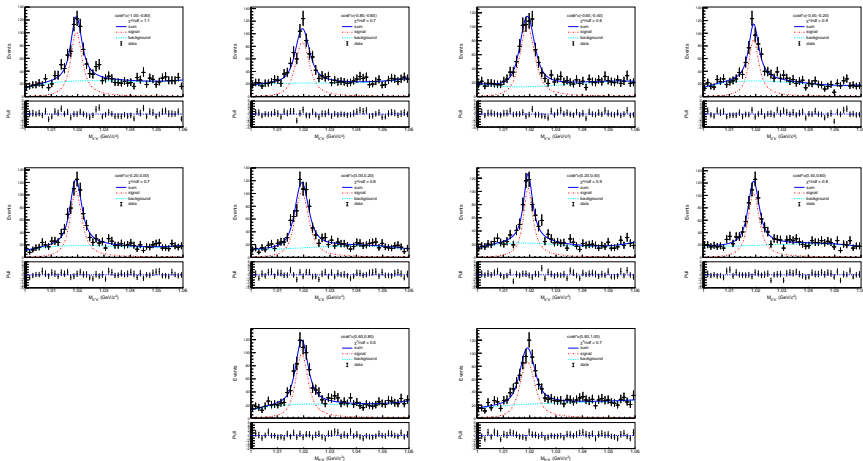
# fit result (data)

$1.2 < P_\phi < 1.3 \text{ GeV}/c$



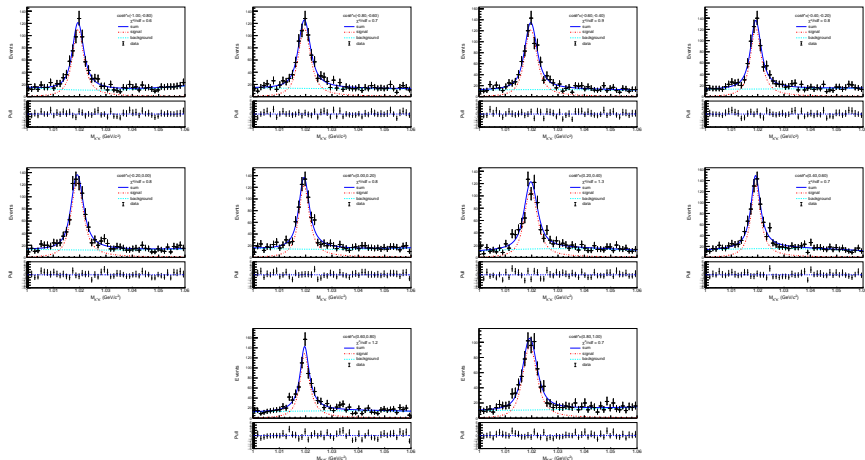
# fit result (LUARLW MC)

$1.2 < P_\phi < 1.3 \text{ GeV}/c$



# fit result (HYBRID MC)

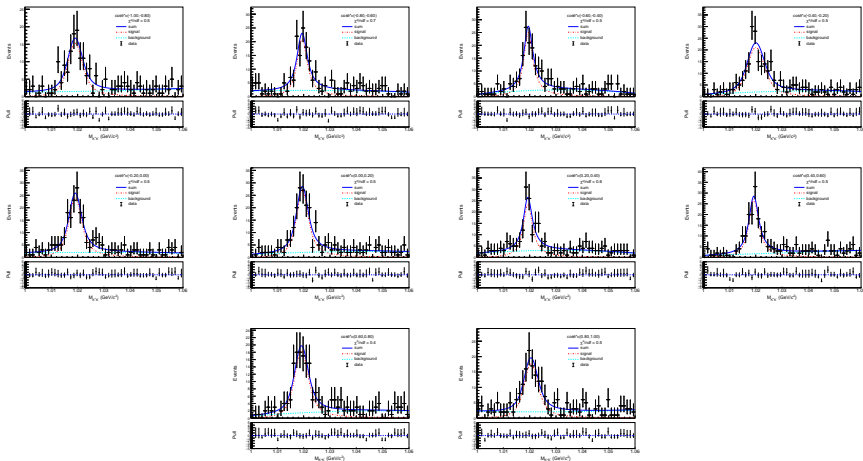
$1.2 < P_\phi < 1.3 \text{ GeV}/c$





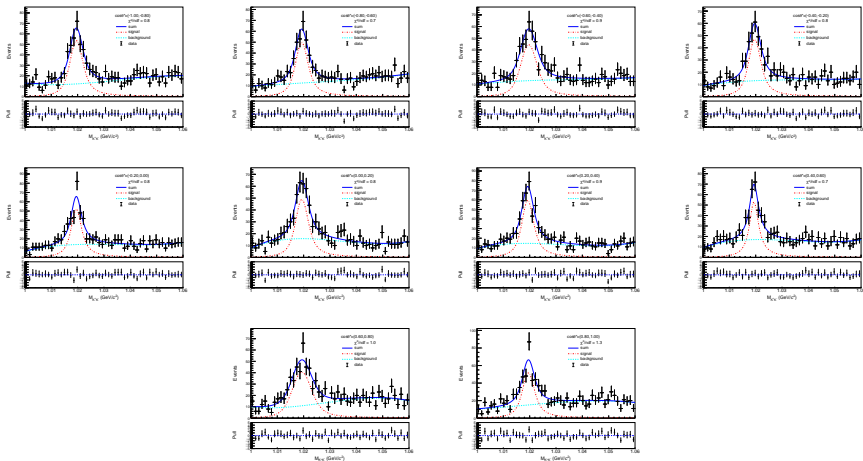
# fit result (data)

$1.3 < P_\phi < 1.4 \text{ GeV}/c$



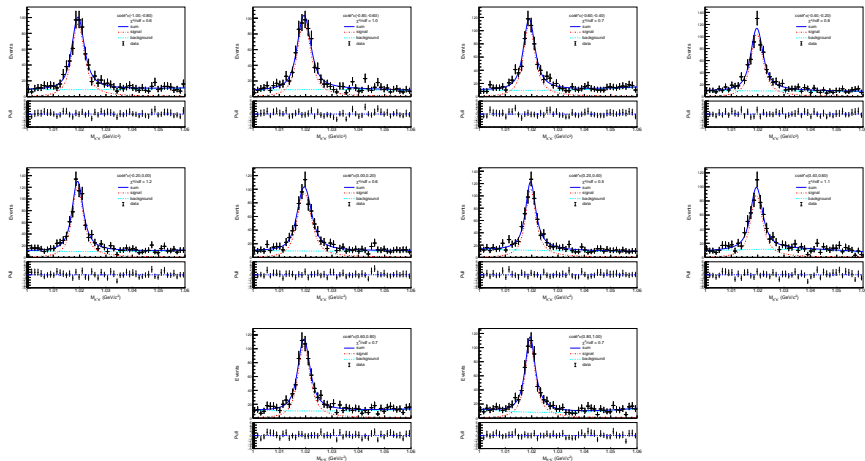
# fit result (LUARLW MC)

$1.3 < P_\phi < 1.4 \text{ GeV}/c$



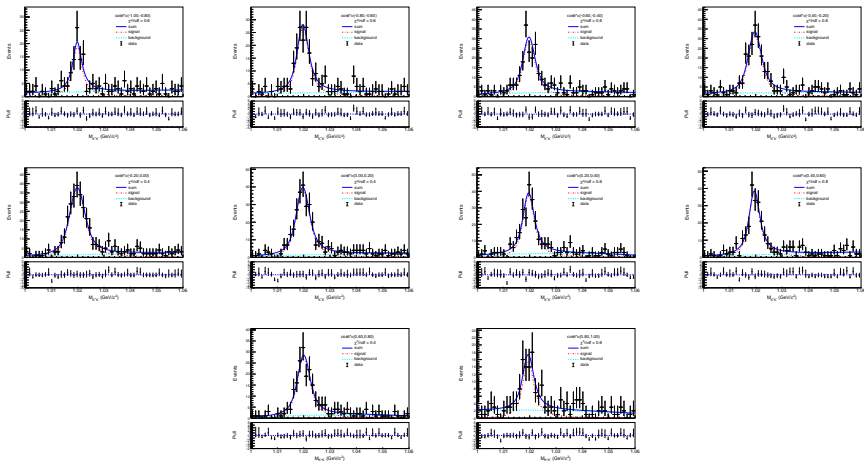
# fit result (HYBRID MC)

$1.3 < P_\phi < 1.4 \text{ GeV}/c$



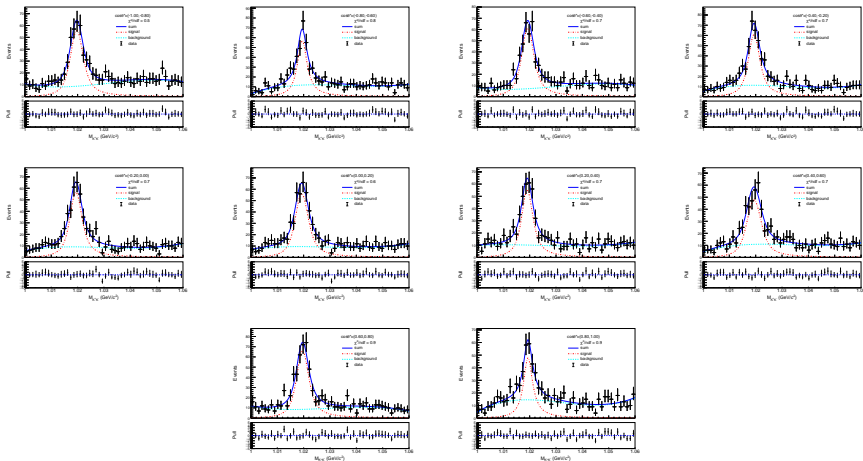
# fit result (data)

$1.4 < P_\phi < 1.5 \text{ GeV}/c$



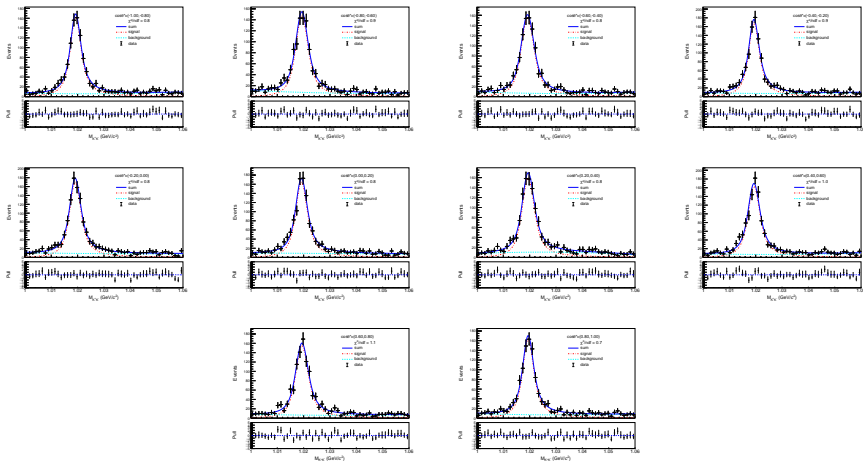
# fit result (LUARLW MC)

$1.4 < P_\phi < 1.5 \text{ GeV}/c$



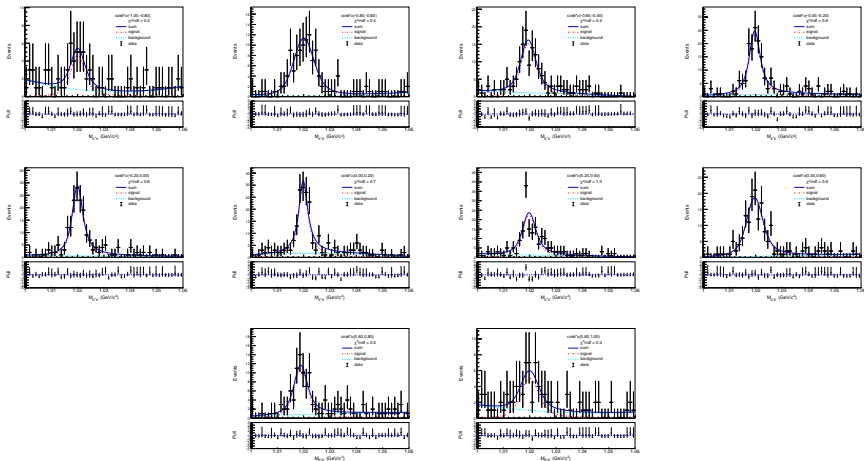
# fit result (HYBRID MC)

$1.4 < P_\phi < 1.5 \text{ GeV}/c$



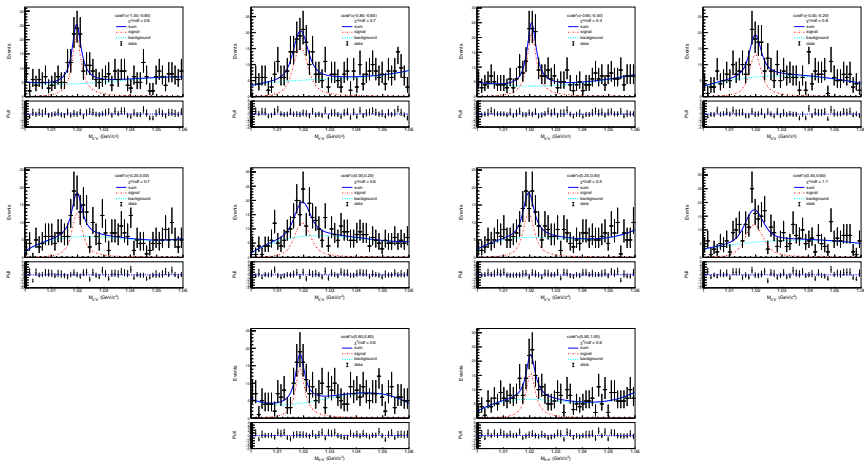
# fit result (data)

$1.5 < P_\phi < 1.6 \text{ GeV}/c$



# fit result (LUARLW MC)

$1.5 < P_\phi < 1.6 \text{ GeV}/c$





# fit result (HYBRID MC)

$1.5 < P_\phi < 1.6 \text{ GeV}/c$

