momentum dependence of $K^*(892)$'s ρ_{00} at BESIII

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Outline

1. Motivation
2. Data sets and event selection
3. Spin alignment of $K^*(892)$
4. Systematic uncertainty
5. Summary
6. BACKUP
   - fit for data
   - fit for luarlw

Spin density matrix of vector meson

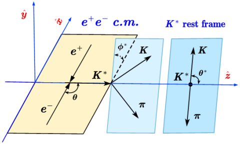
1. The spin state of a vector state is described by 3×3 spin density matrix
   - ρ_{mm}: probability to be in $|s; s_z = m\rangle$ state

$$\begin{pmatrix} \rho_{-1,-1} & \rho_{-1,0} & \rho_{-1,1} \\ \rho^*_{-1,0} & \rho_{00} & \rho_{01} \\ \rho^*_{-1,1} & \rho^*_{01} & \rho_{11} \end{pmatrix}$$

2. The polarization vector is related to some elements of spin density matrix

$$\vec{\mathcal{P}} = [\mathcal{P}_1, \mathcal{P}_2, \mathcal{P}_3] = [\sqrt{2}\mathrm{Re}(\rho_{-1,0}+\rho_{01}), \sqrt{2}\mathrm{Im}(\rho_{-1,0}+\rho_{01}), (\rho_{11}-\rho_{-1,-1})]$$

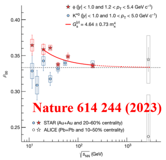
3. Angular of decay particle (kaon) at K^{*0} helicity frame
   - extract some elements, e.g. ρ_{00}

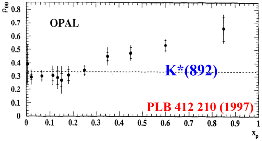


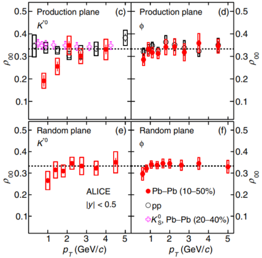
4. Vector meson are polarized or not by comparing of ρ_{00} and 1/3
   - $\rho_{00} \neq 1/3$: **spin alignment**
5. **The angle distribution for the decay particle in the rest frame:**

$$W(\theta^*, \phi^*) = \boxed{\frac{3}{4\pi}[\frac{1}{2}(1-\rho_{00}) + \frac{1}{2}(3\rho_{00}-1)\cos^2\theta^*}$$
$$-\mathrm{Re}\rho_{1,-1}\sin^2\phi^*\cos 2\phi^* - \frac{1}{\sqrt{2}}\mathrm{Re}(\rho_{10}-\rho_{0,-1})\sin 2\theta^*\cos\phi^*$$
$$+\mathrm{Im}\rho_{1,-1}\sin^2\theta^*\sin 2\phi^* + \frac{1}{\sqrt{2}}\mathrm{Im}(\rho_{10}-\rho_{0,-1})\sin 2\theta^*\sin\phi^*]$$

ρ_{00} of vector meson





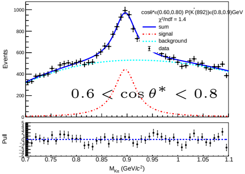


PRL 125, 012301 (2020)

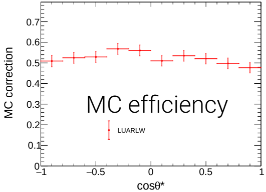
1. Heavy ion collision: contribution from **QGP(Quark-Gluon Plasma) & fragmentation**
   - STAR:for ϕ **unexpectedly large** than 1/3 (with respect to reaction plane)
2. e^+e^- collision:contribution from **fragmentation, Z^0 energy**
   - $x_p < 0.3$, consistent with 1/3;$x_p > 0.3$, larger than 1/3
3. pp collision:contribution from PDF fucntion & fragmentation.
   - ALICE: ρ_{00} for ϕ and K^* are consistant with 1/3.
4. BESIII: e^+e^- collision: **fragmentation, γ^* dominant**
   - **BAM-00884, unbinned ρ_{00} @ $\sqrt{s}$=3.5 GeV.**
   - **How about momentum dependence of ρ_{00}?**

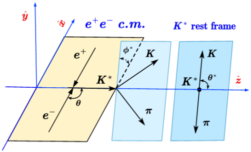
How to determine ρ_{00} at BESIII

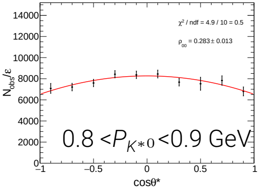
1. **Hadronic selection** to select hadrons
2. Extract K^{*0} signals from hadrons
   - fit to the spectrum of $M_{K^{\pm}\pi^{\mp}}$



$0.8 < P_{K^{*0}} < 0.9$ GeV







3. MC for the correction efficiency.
4. Get ρ_{00} component from fitting the **efficiency corrected signal events.**

$$W(\theta^*) = \frac{3}{4}\left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$

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Data sets

- Boss version: 703
- Data sets:

	$\sqrt{s}$ (GeV)	Run number	$\mathcal{L}$ (pb^{-1})
chic1 scan	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.(nominal)
  HYBRID, 10M events each point.

- QED MC:

  $e^+e^- \to e^+e^- / \mu^+\mu^- / \gamma\gamma$: **Babayaga3.5**
  $e^+e^- \to e^+e^- + X$(X:leptons and hadrons): **DIAG36,EKHARA,GALUGA2.0**

Hadronic event selection

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

Track Level

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

Event Level

At least 2 good charged hadronic tracks

- **Number of good charged hadronic tracks = 2:**
  - $|\Delta\theta| = |\theta_1 + \theta_2 - 180°| > 10°$ or $|\Delta\phi| = ||\phi_1 - \phi_2| - 180°| > 15°$
  - At least 2 isolated photons
- **Number of good charged hadronic tracks = 3:**
  - The two highest momentum tracks are required not back-to-back: $|\Delta\theta| = |\theta_1 + \theta_2 - 180°| < 10°$ or $|\Delta\phi| = ||\phi_1 - \phi_2| - 180°| < 15°$
  - (number of track with $E/p > 0.8$) ≤ 1
  - (number of track with PID ratio > 0.25) ≤ 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 ≥ 4:**
  No additional requirements

Reconstruction of $K^*(892)$ via $K^*(892) \to K\pi$

1. PID (dE/dx + ToF)
   - Prob.(K)>Prob.(π),Prob.(K)>Prob.(p) and Prob(K)>0.001
   - Prob.(π)>Prob.(K),Prob.(π)>Prob.(p) and Prob(π)>0.001
2. combinate all $K^{\pm}\pi^{\mp}$

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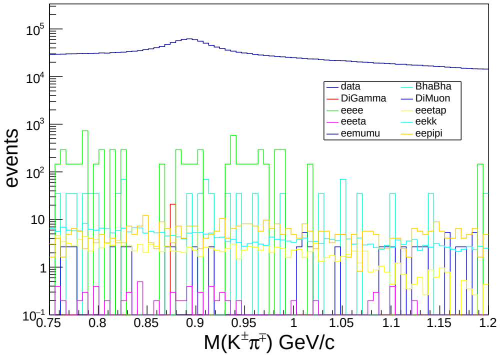
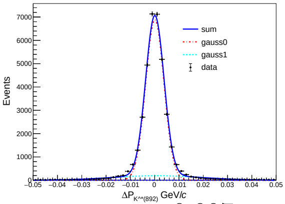
QED Background MC



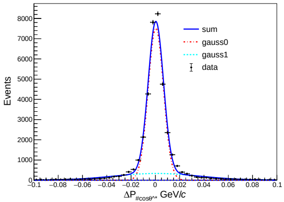
1. QED background: Bhabha, di-gamma, di-muon, and two-photon events.
2. All QED process can be well described by **polynomial function**.

Binning determination

1. The **resolution** of $\cos\theta^*$ and $P_{K^{*0}}$:
   - Obtained by **LUARLW MC**, and fited 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.
   - $\Delta P_{K^{*0}} = 0.1 > 5\sigma_{P_{K^{*0}}}$

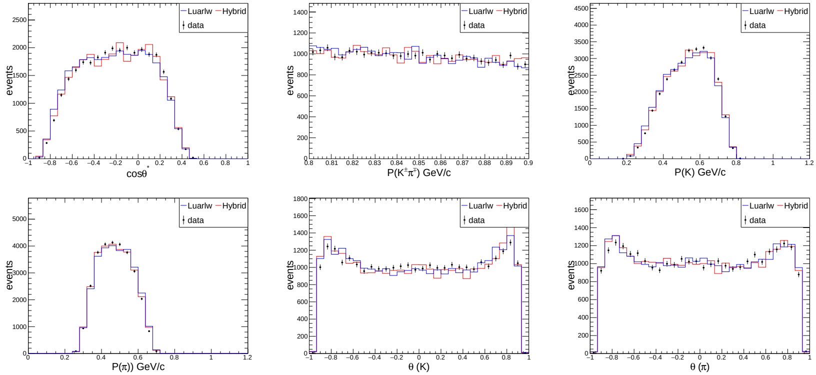


$\sigma_{P_{K^{*0}}} = 0.007$



$\sigma_{\cos\theta^*} = 0.009$

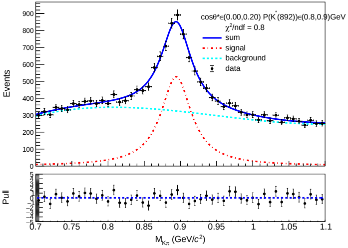
The difference between data and MC

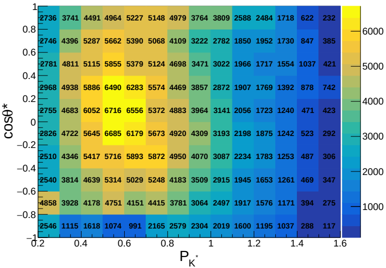


The MC fits with the data well.

Extract $K^{*0}(892)$ signals

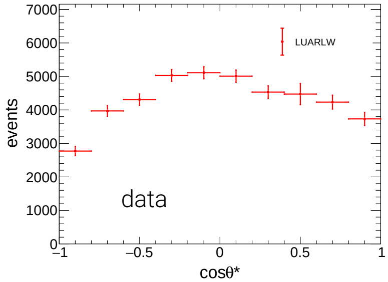
1. Unbinned maximum likelihood fit method is used to extract signals from $M(K^{\pm}\pi^{\mp})$ in each (p vs. $\cos\theta^{*}$) bin.
   - **Signal**: Breit-Wigner $\otimes$ Gaussian
   - **Background**: 3^{th}-order Chebyshev polynomial
   - The parameter of the breit-Wigner function is fixed to the $K^{*}(892)$'s PDG values.

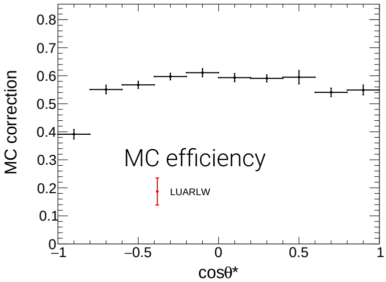




The fit result and MC efficiency

$0.8 < P_{K^*} < 0.9$ GeV/c

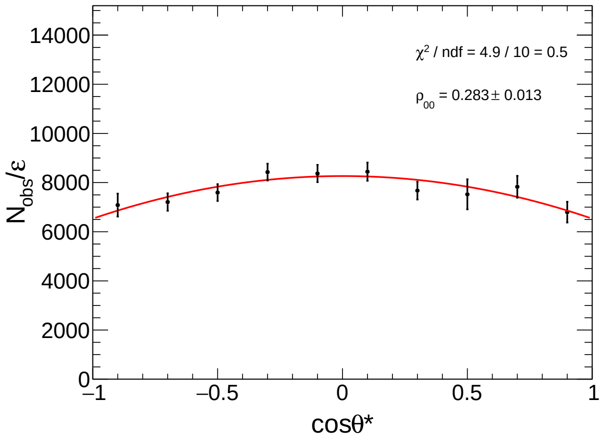




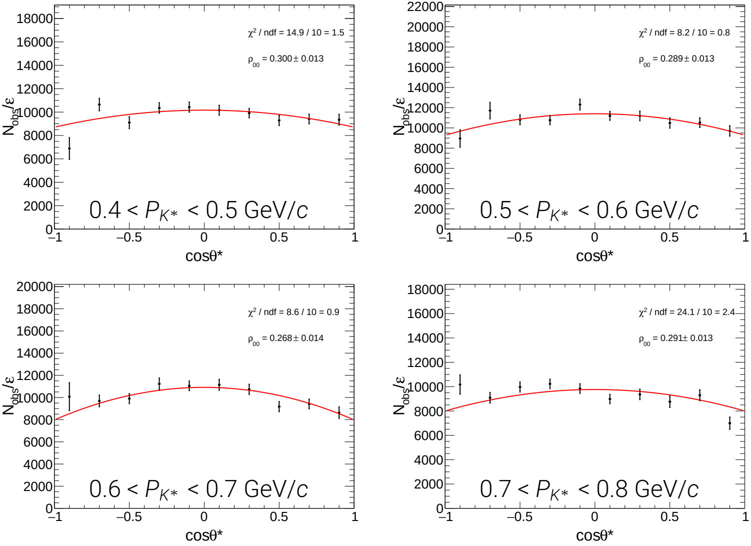
- The signal yields of data is shown in left figure.

ρ_{00} result while $P_\phi \in (0.8, 0.9)$ GeV/c

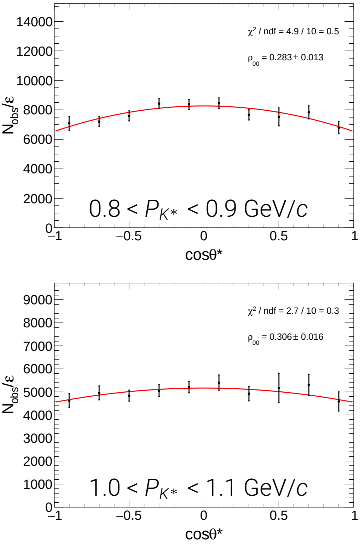
$$W(\theta^*)=\frac{3}{4}[(1-\rho_{00})+(3\rho_{00}-1)\cos^2\theta^*]$$



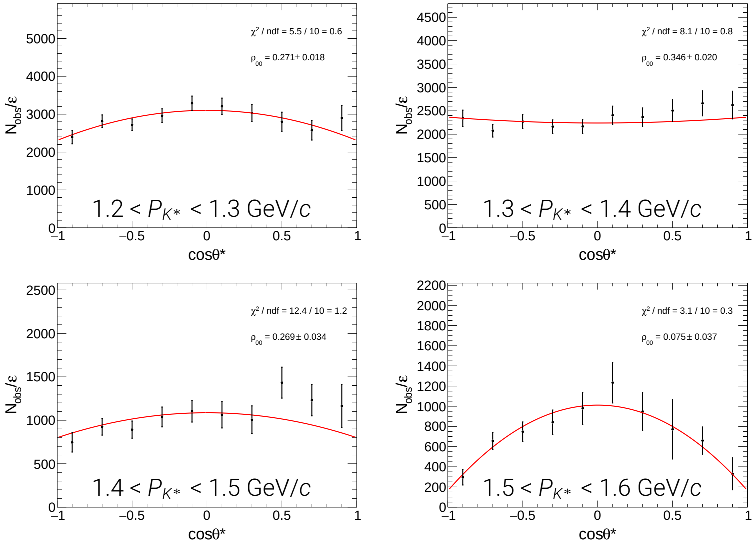
ρ_{00} result in each momentum bin



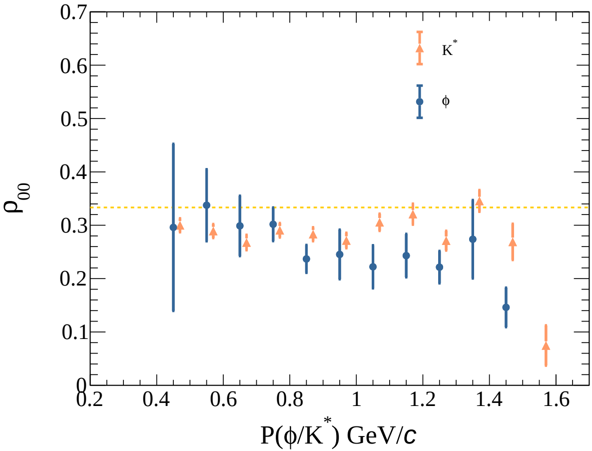
ρ_{00} result in each momentum bin



ρ_{00} result in each momentum bin



ρ_{00} result at $\sqrt{s} = 3.5$ GeV/c^2



K^{*0} come from resonance decay

1. At BESIII, K^{*0} may come from **fragmentation** or by **resonance decay.**
   - The helicity distribution of the resonance decay to K^{*0} may **influence** the decay angle of K^{*0}
2. List table show that the number of K^{*0} decayed by **resonance**(by topology)

source	percent(%)
$K_2^{*+}(1430)$	1.74
$K_1^0(1400)$	1.46
$K_1^+(1400)$	0.75
$K_2^{*0}(1430)$	0.61
$K_1^+(1270)$	0.31

- Generate MC to consider the effect from those resonances.(ongoing)

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Systematic uncertainty (still ongoing)

1. **MC model**: LUARLW $\rightarrow$ HYBRID.
   - The difference between two MC model results.
2. **Event selection**
   - Same as **R-value analysis**.
3. **Fit method**
   - **Signal** pdf & **background** pdf
4. **Beam associated background**
   - N_{beam} is estimate by sideband method.

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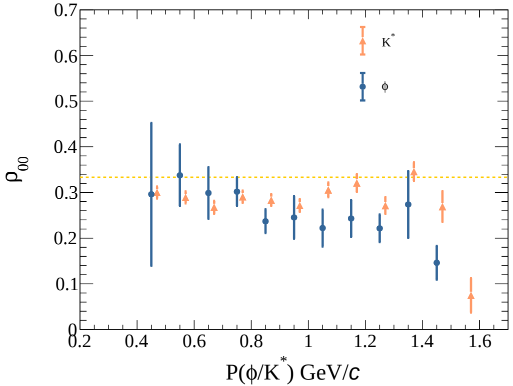
Summary and outlook

1. **Spin alignment** of inclusive K^* is studied with $\mathcal{L} = 457.75$ pb^{-1} at $\sqrt{s} = 3.5$ GeV.
2. ρ_{00} for K^* deviates from 1/3, ϕ is more polarized than K^* does.



3. **Next to do**:
   - Finish **systematic uncertainty** for $\sqrt{s} = 3.5$ GeV.
   - Other energy points(3.65 GeV and 3.08 GeV).

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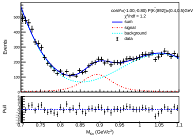
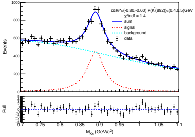
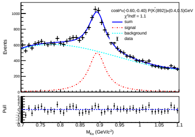
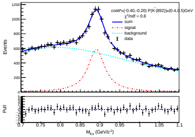
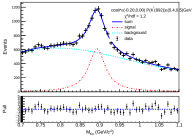
data result on 0.4<P_{K*}<0.5 GeV

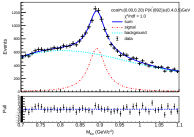


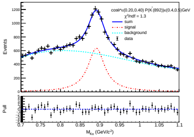


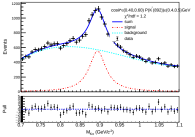


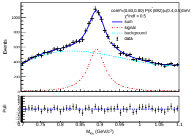


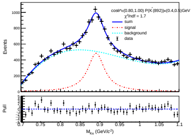




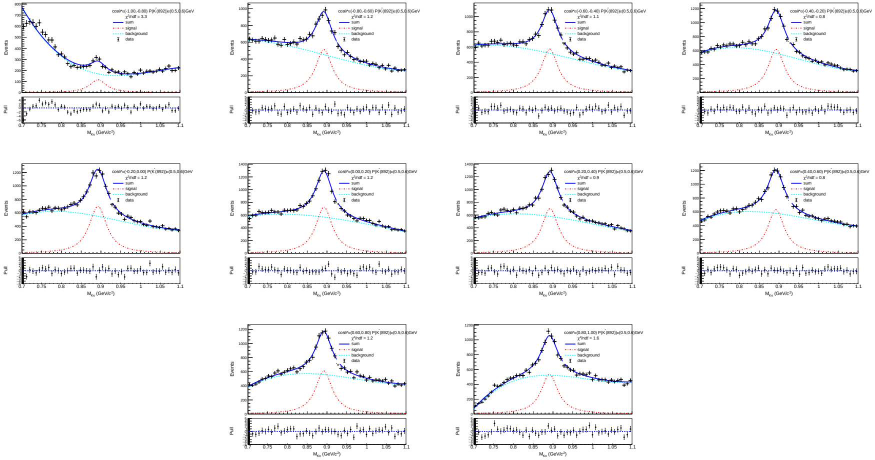




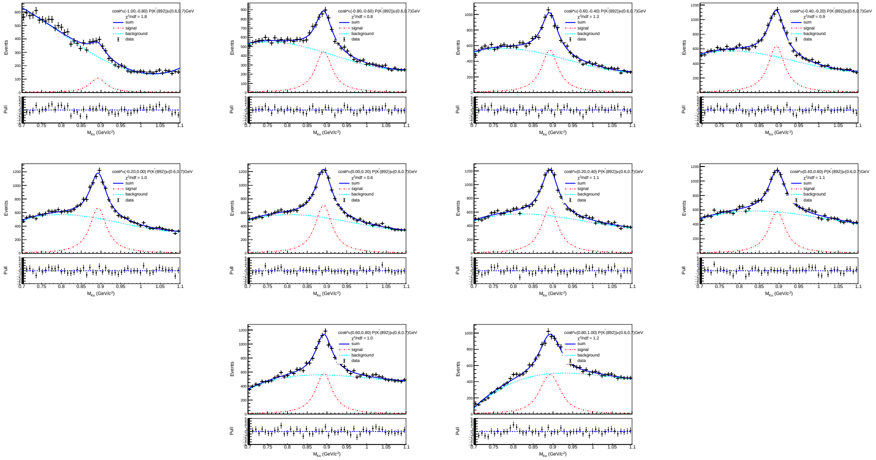




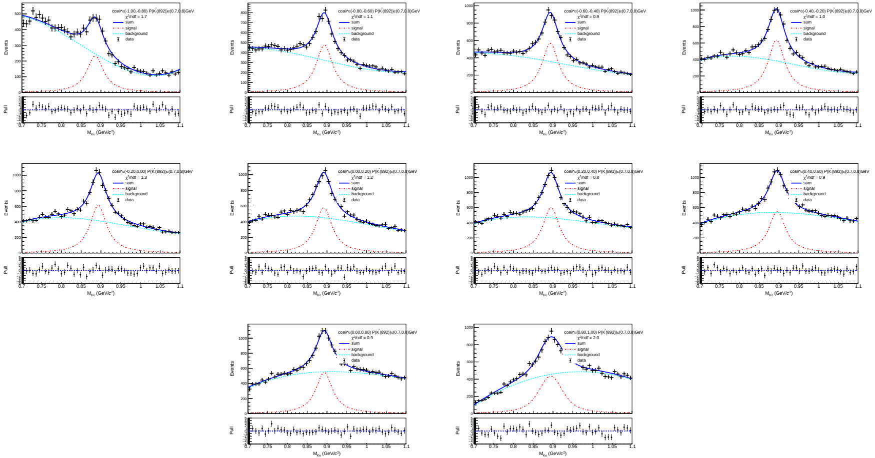
data result on 0.5<P_{K^*}<0.6 GeV



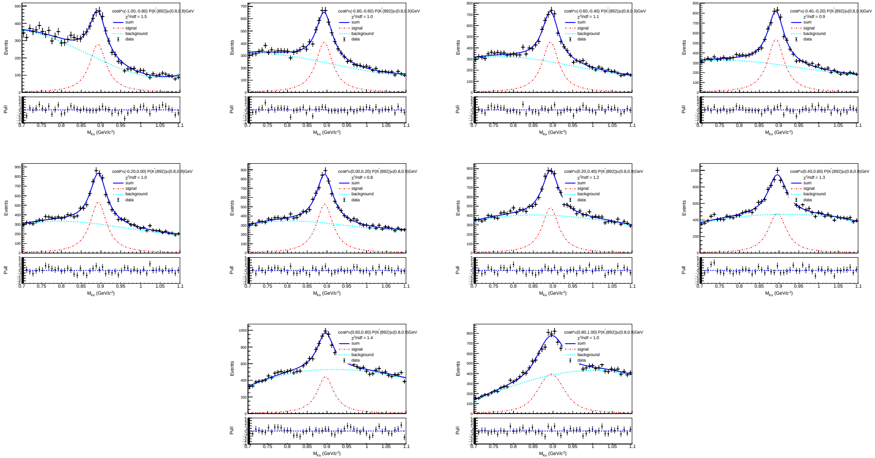
data result on $0.6<P_{K^*}<0.7$ GeV



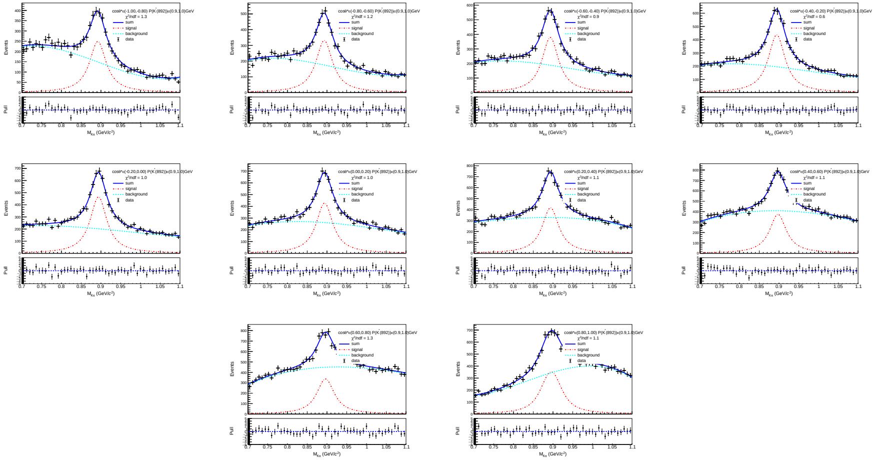
data result on 0.7<P_{K^*}<0.8 GeV



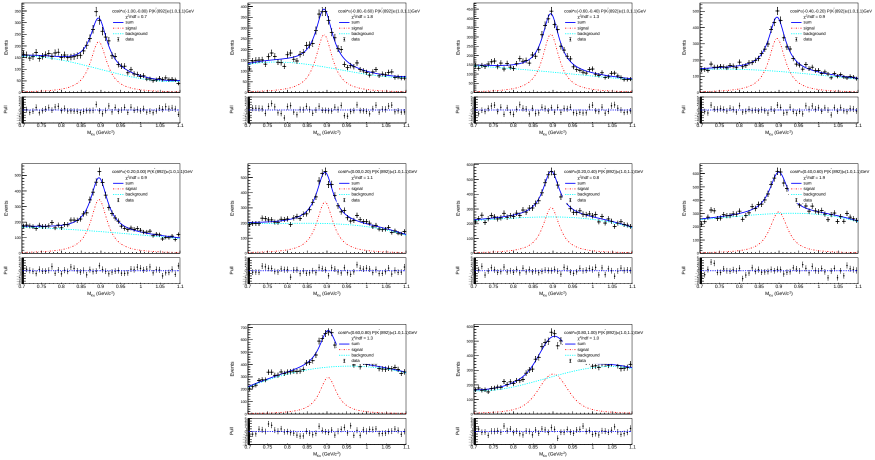
data result on 0.8<P_{K^*}<0.9 GeV



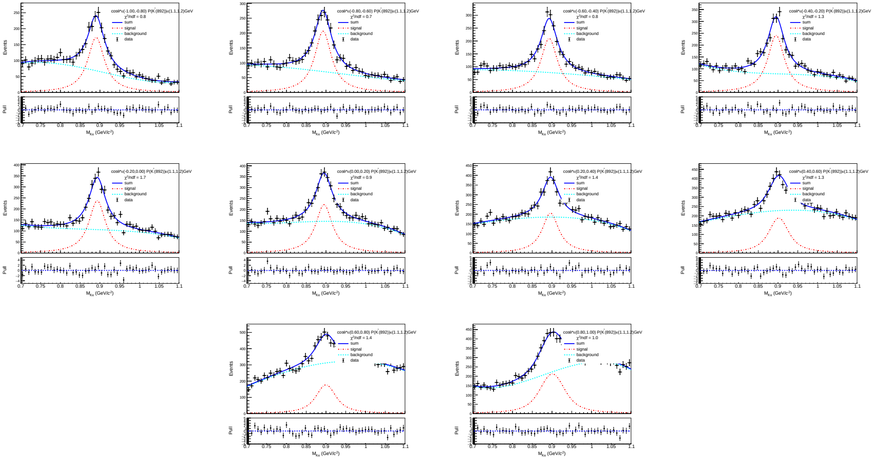
data result on 0.9<P_{K*}<1.0 GeV



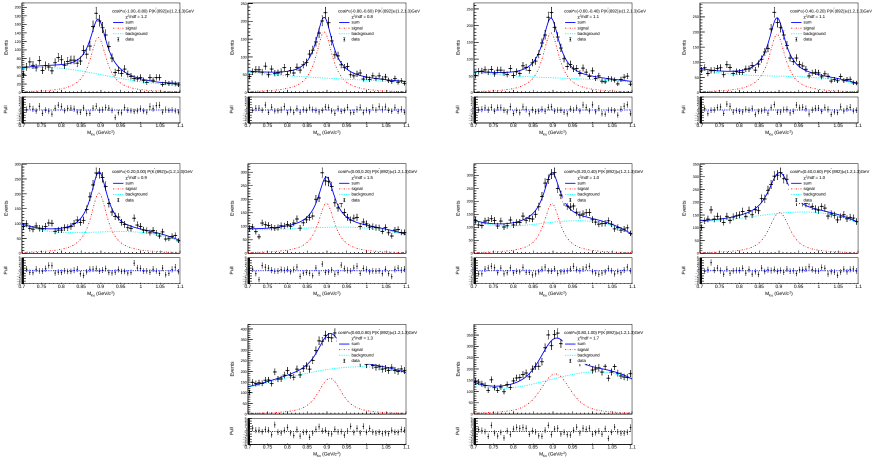
data result on 1.0<P_{K*}<1.1 GeV



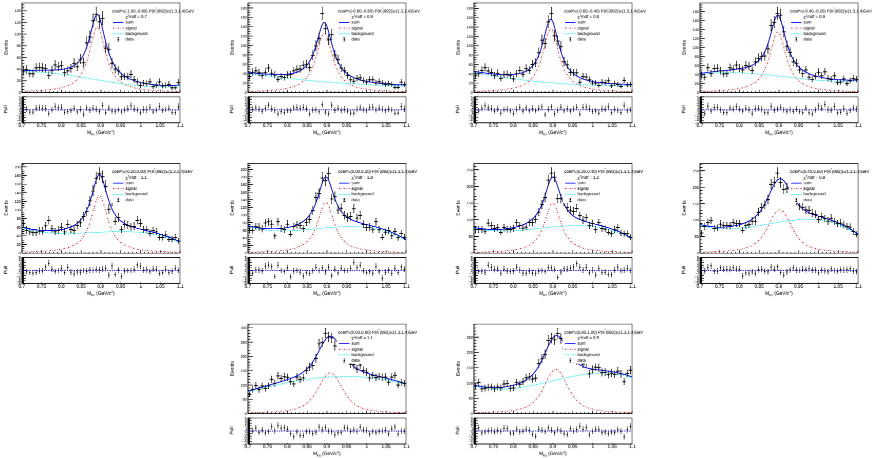
data result on 1.1<P_{K*}<1.2 GeV



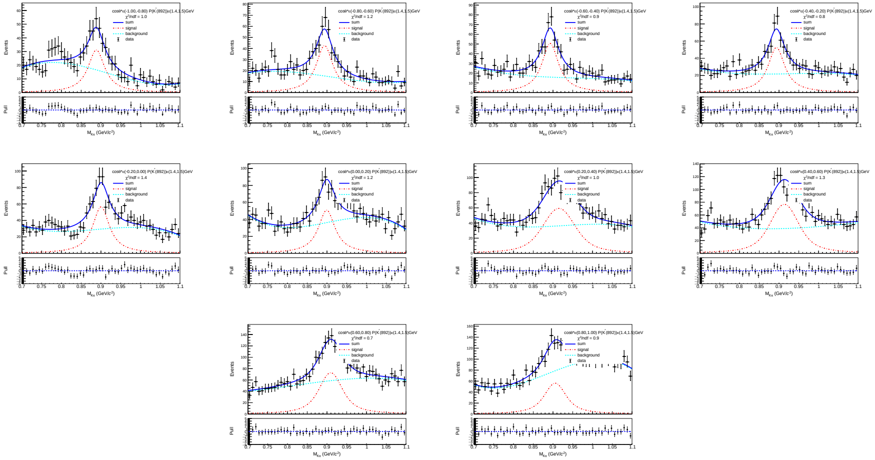
data result on 1.2<P_{K^*}<1.3 GeV



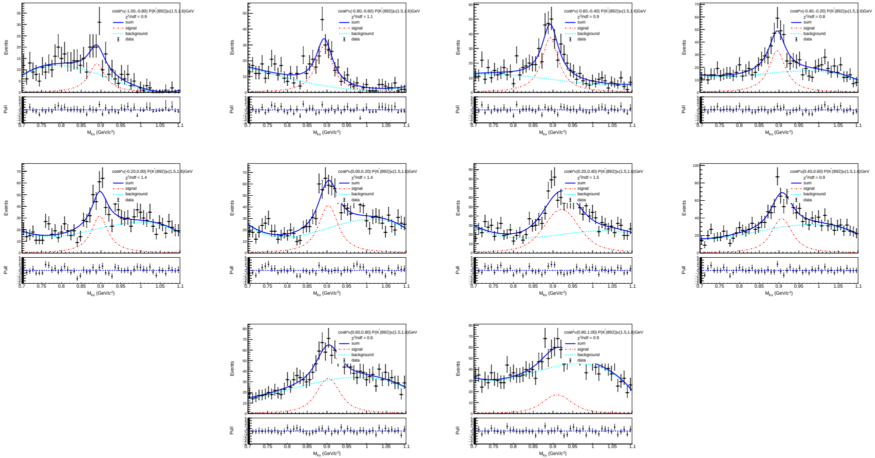
data result on 1.3<P_{K^*}<1.4 GeV



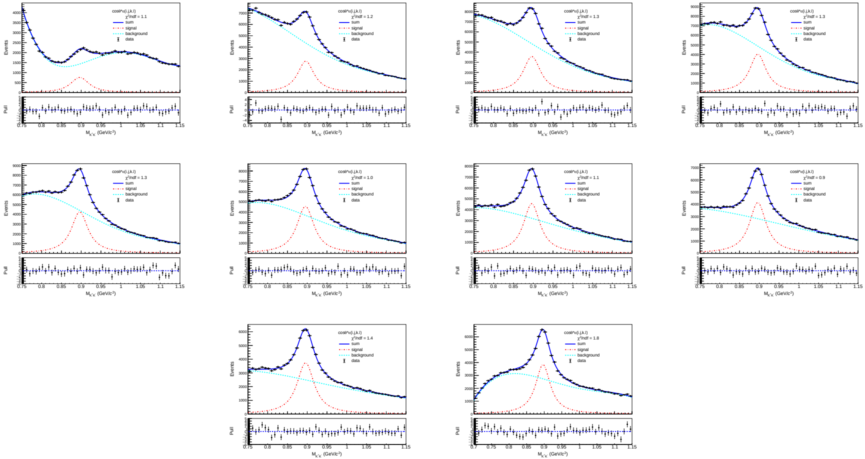
data result on 1.4<P_{K^*}<1.5 GeV



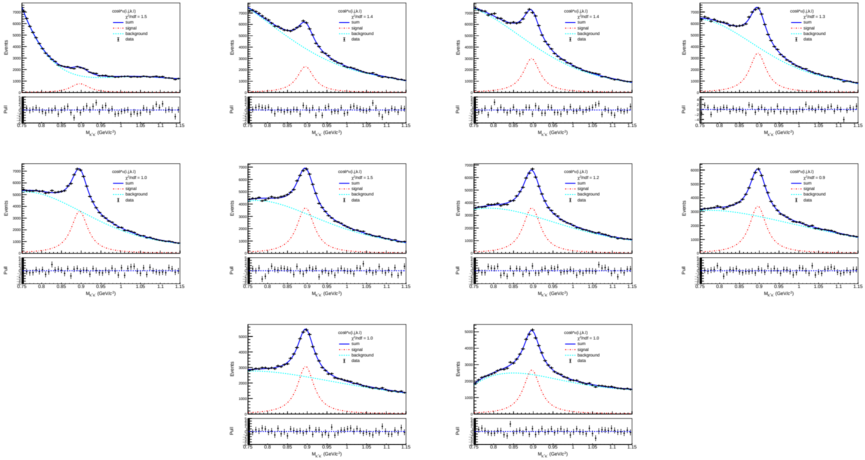
data result on 1.5<P_{K^*}<1.6 GeV



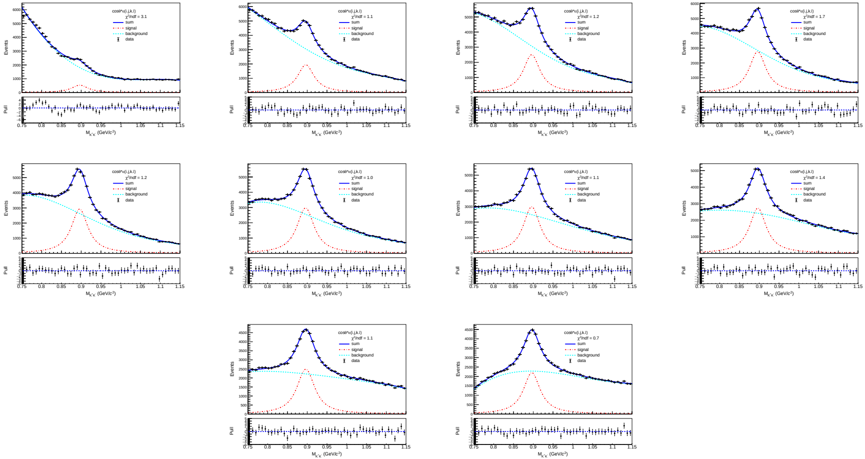
Ion result on 0.4<P_{K^*}<0.5 GeV



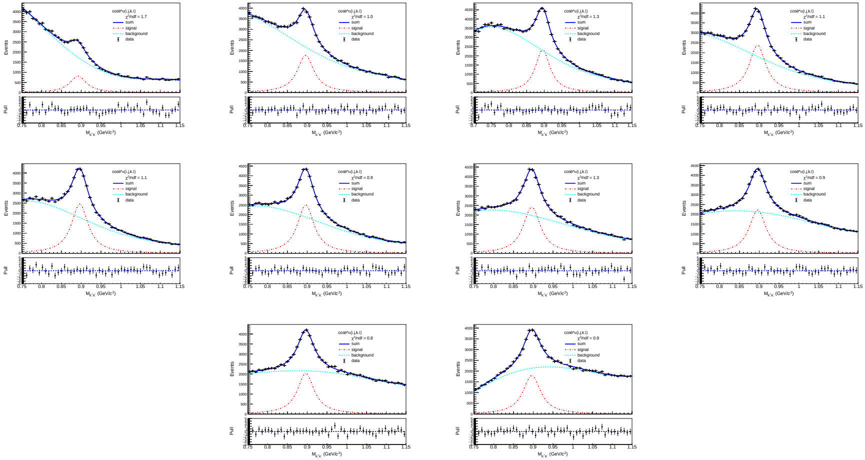
Ion result on 0.5<P_{K*}<0.6 GeV



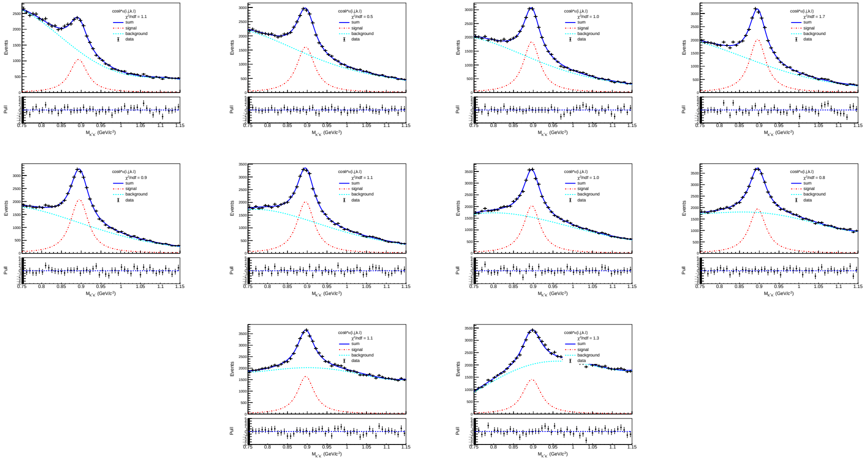
Ion result on 0.6<P_{K*}<0.7 GeV



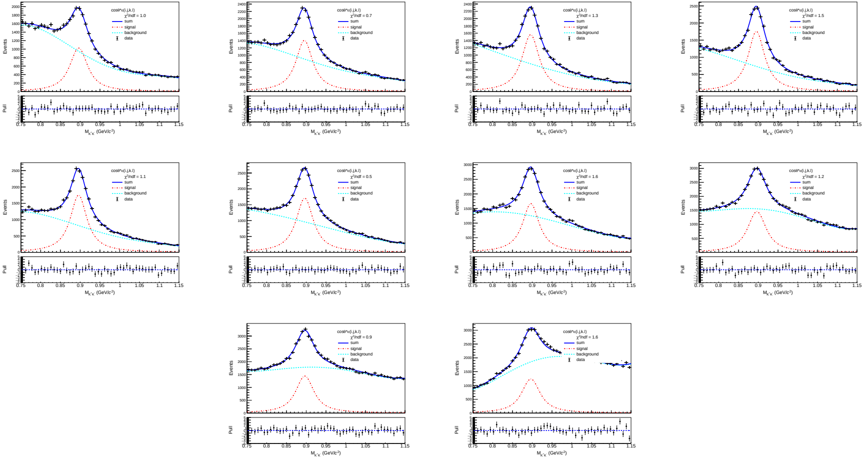
Ion result on 0.7<P_{K*}<0.8 GeV



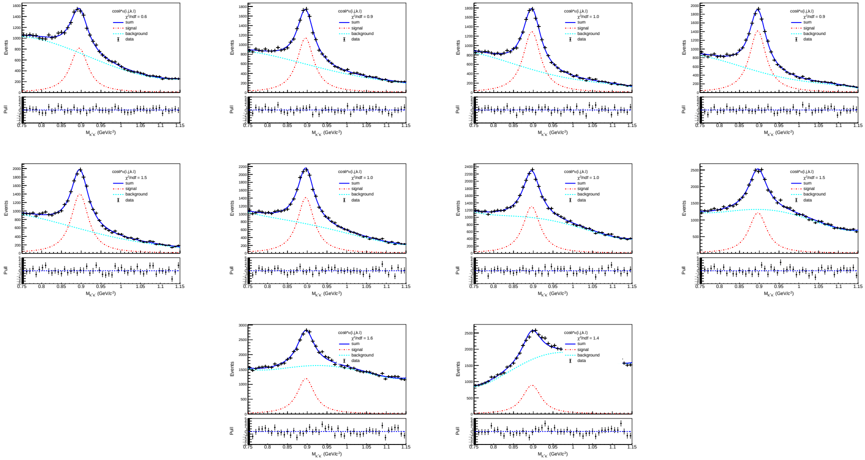
Ion result on 0.8<P_{K*}<0.9 GeV



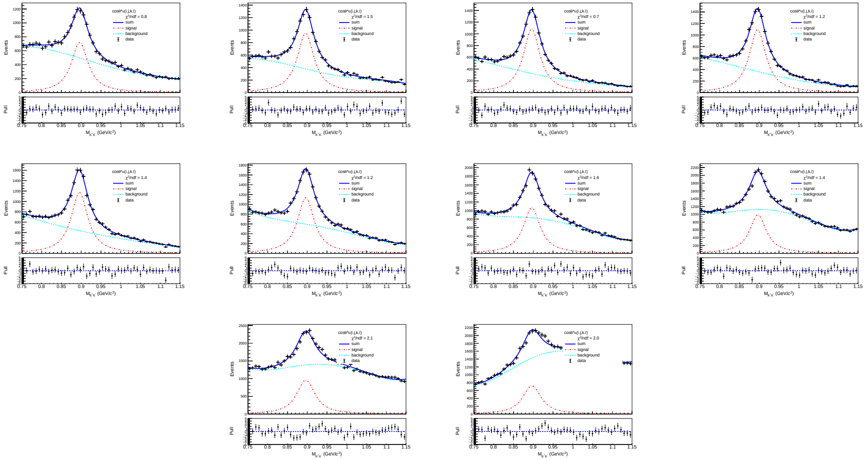
Ion result on $0.9 < P_{K^*} < 1.0$ GeV



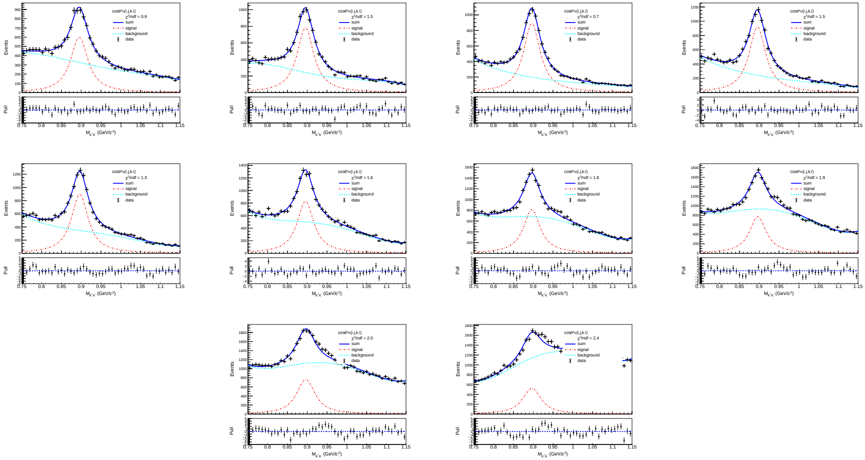
Ion result on 1.0<P_{K*}<1.1 GeV



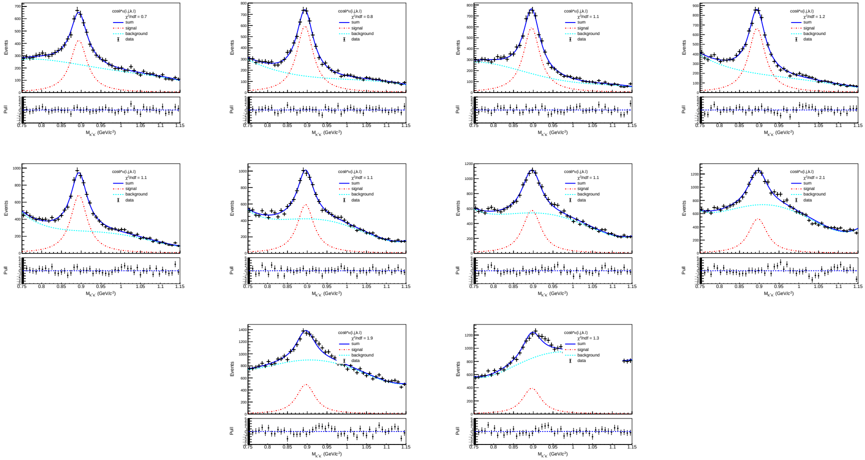
Ion result on $1.1<P_{K*}<1.2$ GeV



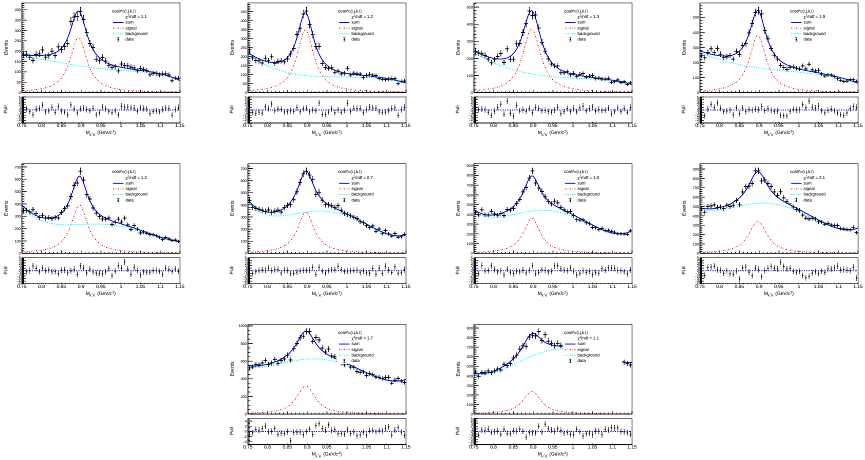
Ion result on 1.2<P_{K*}<1.3 GeV



Ion result on 1.3<P_{K*}<1.4 GeV



Ion result on 1.4<P_{K*}<1.5 GeV



Ion result on 1.5<P_{K^*}<1.6 GeV