Cross sections for $e^+e^-\rightarrow K^+K^-\pi^+\pi^-(\pi^0)$, $K^+K^-K^+K^-(\pi^0)$, $\pi^+\pi^-\pi^+\pi^-(\pi^0)$, $p\bar{p}\pi^+\pi^-(\pi^0)$ in energy region between 3.8 and 4.6 GeV

Jingyi Zhao, Ryan Mitchell, Xinchou Lou

2019/6/3

Charmonium Group Meeting

Outline

- Motivation
- Data and software
- Measurement of cross sections
  - Event selection
  - Background analysis and subtraction
  - Reconstruction efficiency
  - Calculation of cross sections
- Analysis of cross sections
- Summary

Introduction

- The region at center-of-mass energies above the open-charm threshold is of great interest due to its richness of cc-bar states.
- In particular, many charmonium-like (XYZ) states were observed in the past decade, which provide new opportunities in the study of QCD at the charmonium spectrum.
- Up to now, no light hadronic decays of the Y states or conventional charmonium resonances above 4 GeV are observed yet. Searching for light hadronic decays of charmonium and XYZ states enables a beneficial understanding of the nature of those resonances or structures.
- In this analysis, we report the cross section of $e^+e^- \to K^+K^-\pi^+\pi^-(\pi^0)$, $K^+K^-K^+K^-(\pi^0)$, $\pi^+\pi^-\pi^+\pi^-(\pi^0)$, $pp\pi^+\pi^-(\pi^0)$ and search for possible structures such as charmonium or Y states in the e^+e^- line shape at center-of-mass energies between 3.8 and 4.6 GeV.

Data and software

- Data:
  - 28 XYZ data samples.
- Software:
  - BOSS version 7.0.3
  - Monte Carlo events are generated with KKMC+BesEvtGen.
- Channels analyzed:
  - $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-\pi^0$, $K^+K^-K^+K^-$, $K^+K^-K^+K^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0$, $pp\pi^+\pi^-$, $pp\pi^+\pi^-\pi^0$

E_{cm} (GeV)	Luminosity (pb^{-1})	Year
4.00762	481.96	2009
3.80765	50.54	2013
3.89624	52.61	2013
4.08545	52.86	2013
4.18859	43.33	2013
4.20773	54.95	2013
4.21713	54.60	2013
4.22626	44.54	2013
4.22626	1056.37	2013
4.24166	55.88	2013
4.25797	828.36	2013
4.30789	45.08	2013
4.35826	543.94	2013
4.38740	55.57	2013
4.41558	46.80	2013
4.41558	1043.86	2014
4.46706	111.09	2014
4.52714	112.12	2014
4.57450	48.93	2014
4.59953	586.89	2014
4.18899	524.60	2017
4.19903	526.00	2017
4.20925	518.00	2017
4.21884	514.60	2017
4.23582	530.30	2017
4.24393	538.10	2017
4.26680	531.10	2017
4.27774	175.70	2017

Method

- Measurements of the cross sections for $e^+e^- \to K^+K^-\pi^+\pi^-(\pi^0)$, $K^+K^-K^+K^-(\pi^0)$, $\pi^+\pi^-\pi^+\pi^-(\pi^0)$, $pp\pi^+\pi^-(\pi^0)$ are made based on the numbers of events observed from the data collected at different energy points , the luminosities of the data samples, reconstruction efficiency and radiative correction factor.

$$\sigma = \frac{N^{\rm obs}(E_{{\rm cm},i}) - N^{\rm bkg}(E_{{\rm cm},i})}{L(E_{{\rm cm},i}) \times \epsilon^0(E_{{\rm cm},i}) \times \kappa(E_{{\rm cm},i})},$$

$E_{cm,i}$: center-of-mass energy

$N^{obs}(E_{cm,i})$: number of the observed events

$N^{bkg}(E_{cm,i})$: number of background events

$L(E_{cm,i})$: integrated luminosity

$\varepsilon^0(E_{cm,i})$: reconstruction efficiency without considering ISR

$\kappa(E_{cm,i})$ is the correction factor

$$\kappa = \int \frac{\sigma(x)}{\sigma^0}\frac{\epsilon(x)}{\epsilon^0}W(x)dx.$$

x is the ratio of E_γ/E_{beam},

E_γ : energy of ISR photon

E_{beam} : beam energy,

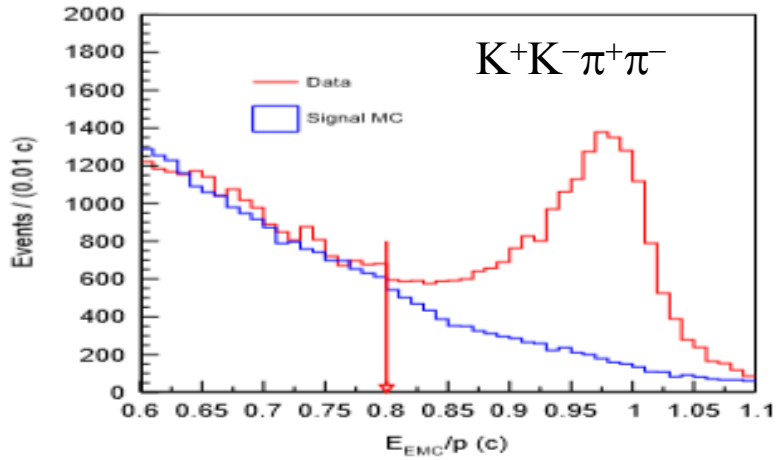
W(x) is the radiator function

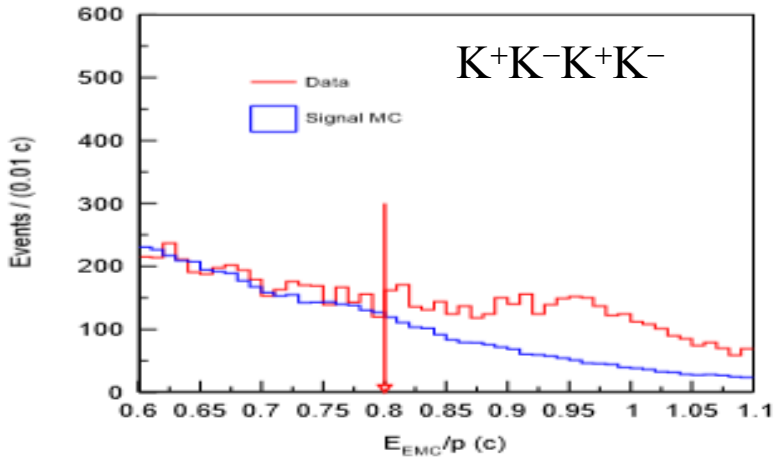
Event selection

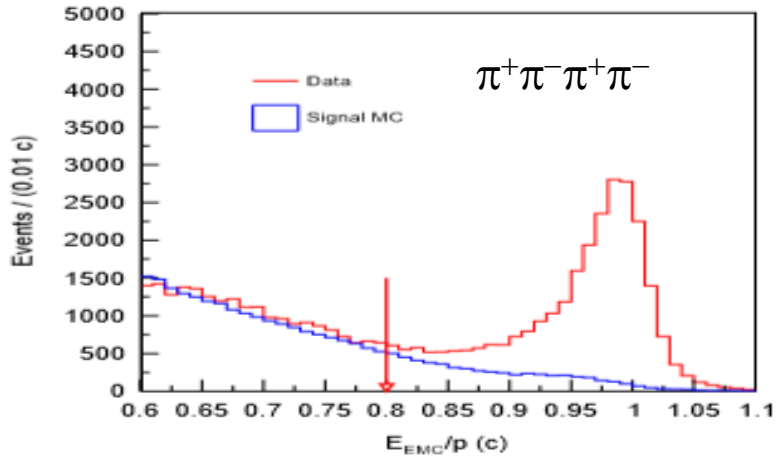
- Charged track selection:
  - $|R_{xy}|<1.0$ cm, $|R_z|<10.0$ cm, $|\cos\theta|<0.93$
- Photon selection:
  - $0<TDC<14$;
  - $E_\gamma>25/50$ MeV for the barrel/endcap EMC.
- Kinematic fit:
  - For final states without (with) a π^0, 4-C (5-C) kinematic fit is performed;
  - $\chi^2<50$.

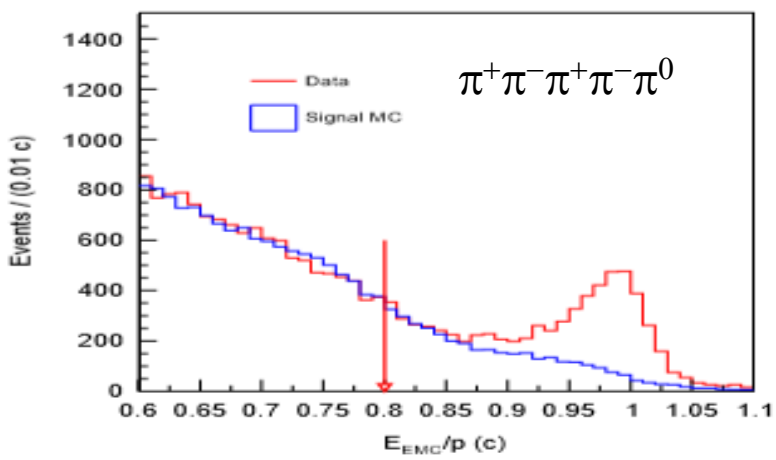
Event selection

- For $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$, $K^+K^-K^+K^-$, $\pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0$, to reject $e^+e^- \rightarrow (\gamma)e^+e^-$ background, it is required $E_{EMC}/p<0.8$.



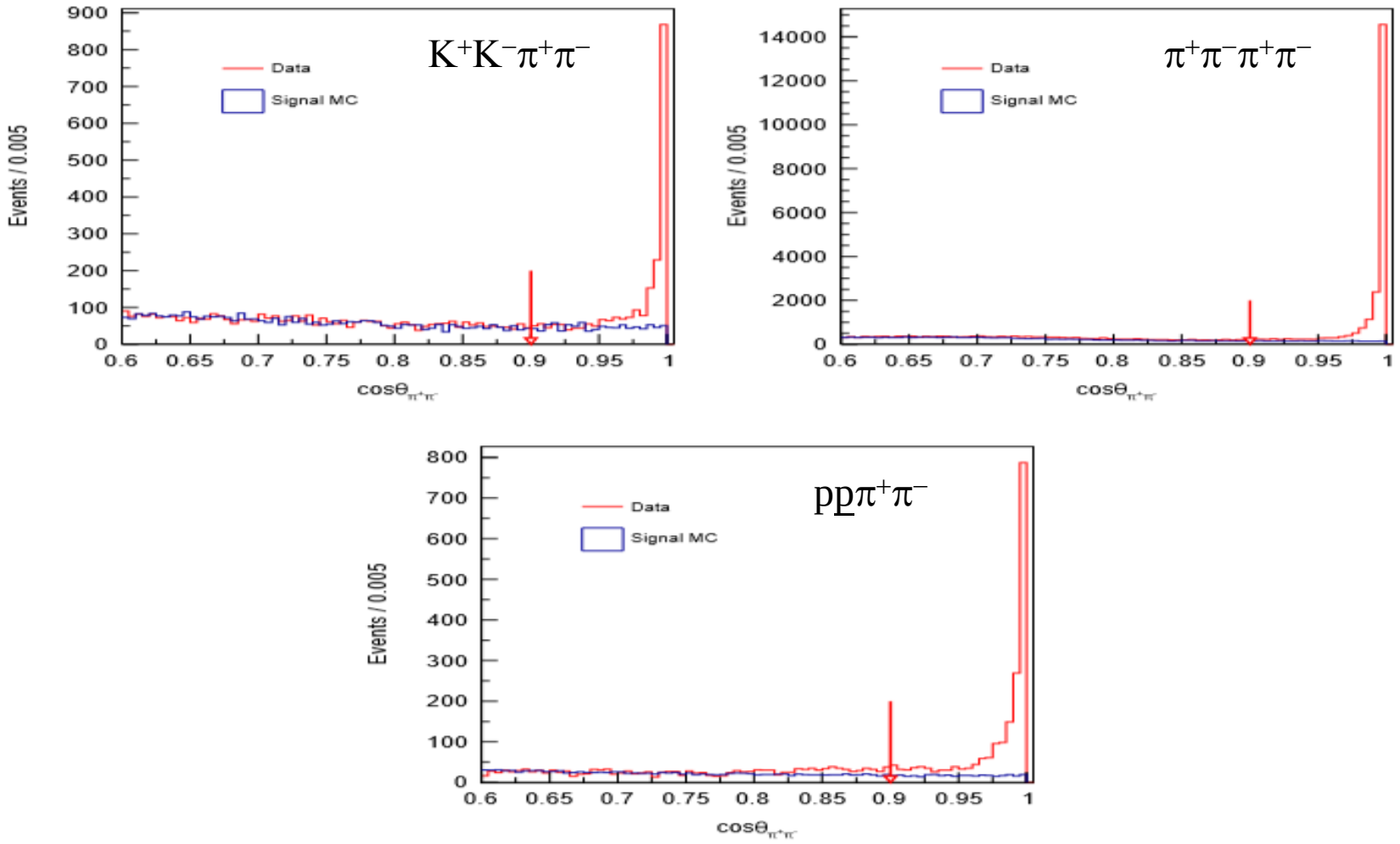






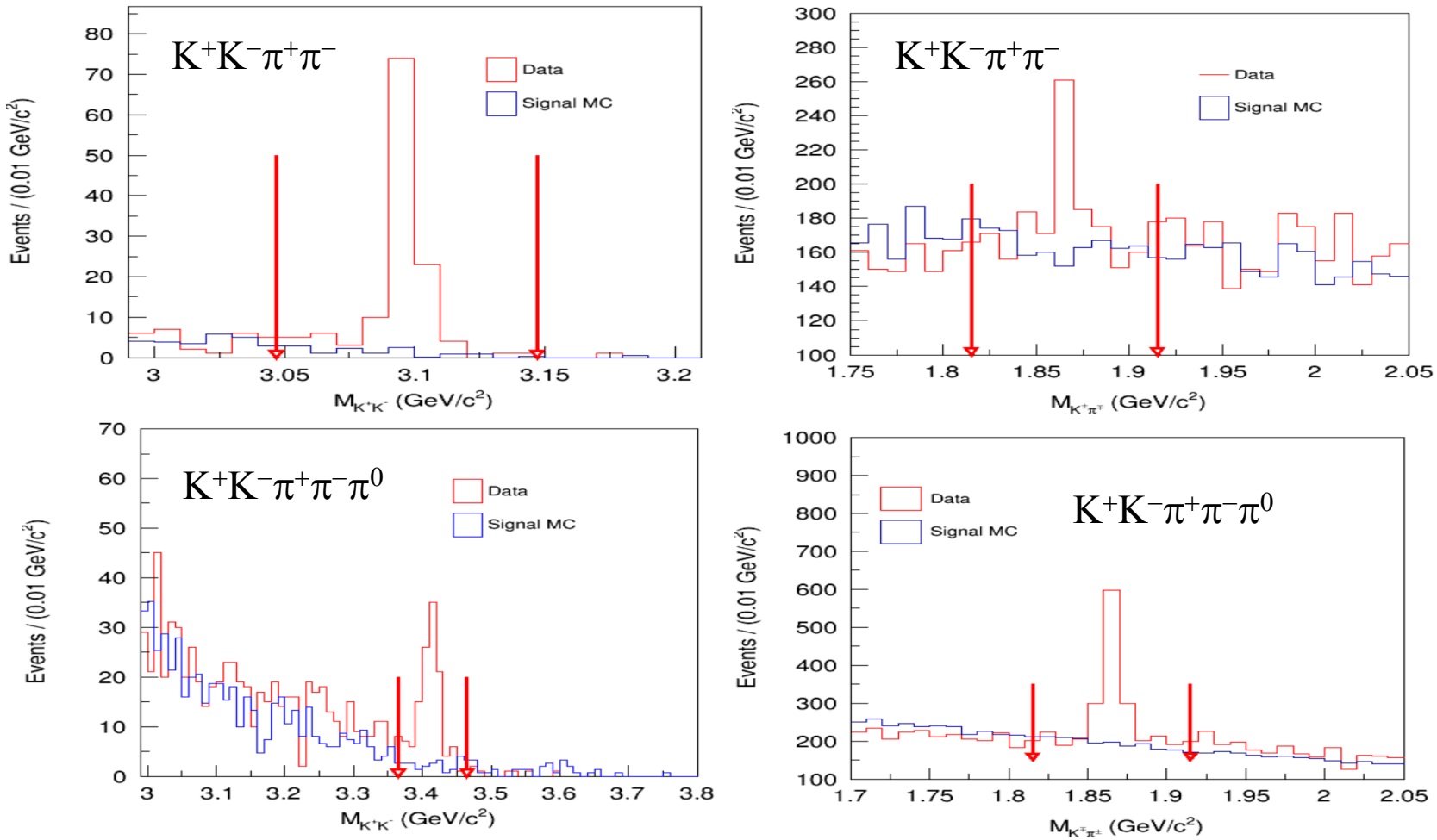
Event selection

- For $e^+e^- \rightarrow K^+K^-\pi^+\pi^-$, $p\bar{p}\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-$, to reject gamma conversion background, it is required $\cos\theta_{\pi^+\pi^-} < 0.9$.



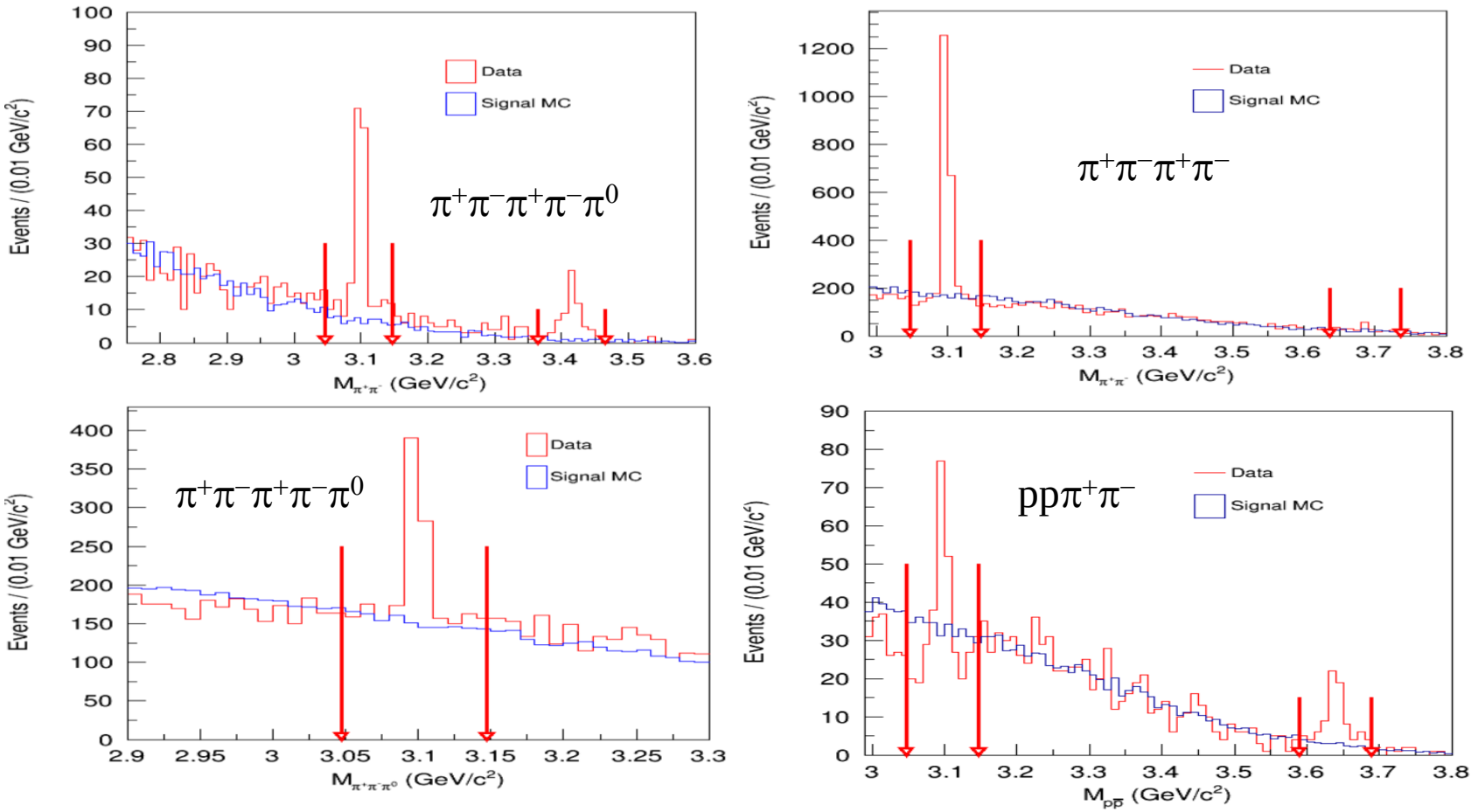
Event selection

- Obvious J/ψ, ψ', χ_c, D backgrounds are removed by requiring $|M_{\text{possible combination}} - M_{J/\psi,\ \psi',\ \chi c,\ D}|>50$ MeV.



Event selection

- Obvious J/ψ, ψ', χ_c, D backgrounds are removed by requiring $|M_{\text{possible combination}} - M_{J/\psi,\ \psi',\ \chi c,\ D}|>50$ MeV.



- After applying the above selection requirements, we count the number of signal events at every energy point for every signal channel.

Background study

- In the selected candidate events, there may be some backgrounds. To study backgrounds, I analyzed Inclusive MC samples generated at 4.230 GeV.

MC samples	Number
$e^+e^- \to e^+e^-$	45.35×10^6
$e^+e^- \to \mu^+\mu^-$	5.65×10^6
$e^+e^- \to \tau^+\tau^-$	53.82×10^6
$e^+e^- \to \gamma\gamma$	21.55×10^6
$e^+e^- \to$ hadrons	110.9×10^6

- Study shows that there are two types of backgrounds:
  - The first type of backgrounds are from D and J/ψ decays, and the final states of those backgrounds are the same as the signal channel. Although we have applied selection requirements to veto those backgrounds, there are still some residue events from those processes. ("peaking backgrounds")

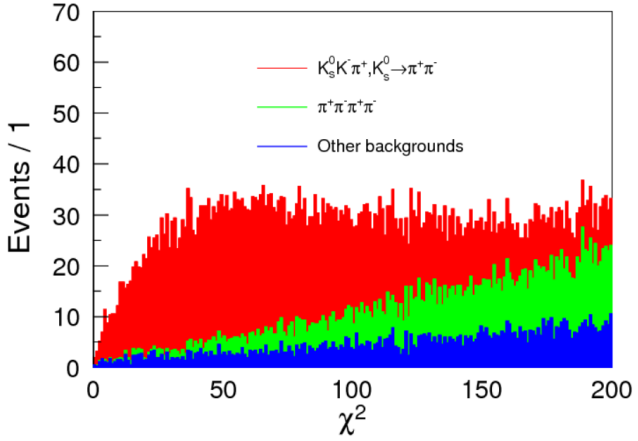
Signal	Peaking Backgrounds
$e^+e^- \to K^+K^-\pi^+\pi^-$	$e^+e^- \to D^0\bar{D}^0, D^0 \to K^-\pi^+, \bar{D}^0 \to K^+\pi^-$
$e^+e^- \to K^+K^-\pi^+\pi^-\pi^0$	$e^+e^- \to D^0\bar{D}^0, D^0 \to K^-\pi^+, \bar{D}^0 \to K^+\pi^-\pi^0$(and c.c.). $e^+e^- \to J/\psi\pi^+\pi^-, J/\psi \to K^+K^-\pi^0$
$e^+e^- \to p\bar{p}\pi^+\pi^-\pi^0$	$e^+e^- \to J/\psi\pi^+\pi^-, J/\psi \to p\bar{p}\pi^0$

  - The second type of backgrounds are from particle mis-identification. ("non-peaking backgrounds")

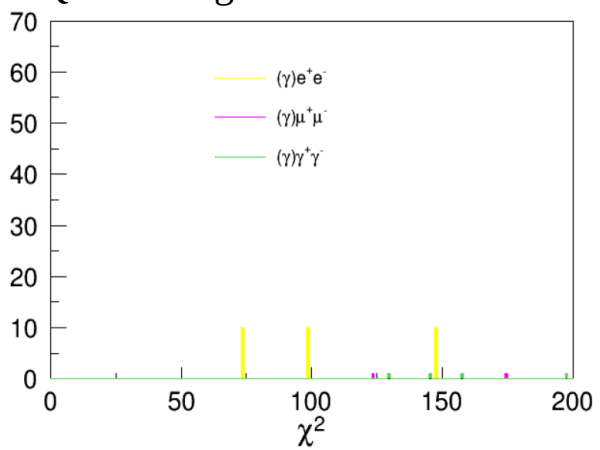
Background study

- By analyzing Inclusive MC samples generated at 4.230 GeV. distributions of χ^2 of kinematic fit from non-peaking backgrounds for every signal channel.

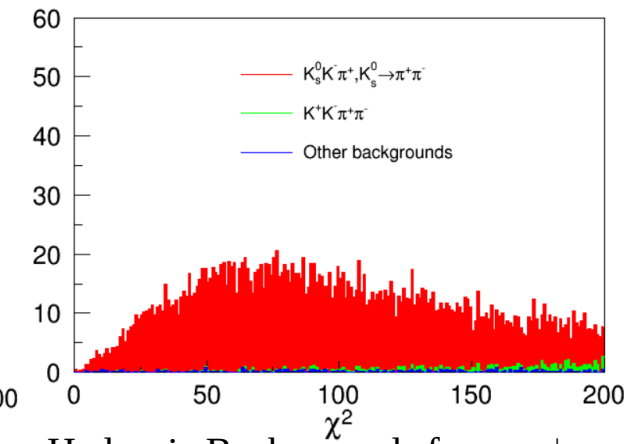
Hadronic Backgrounds for $K^+K^-\pi^+\pi^-$



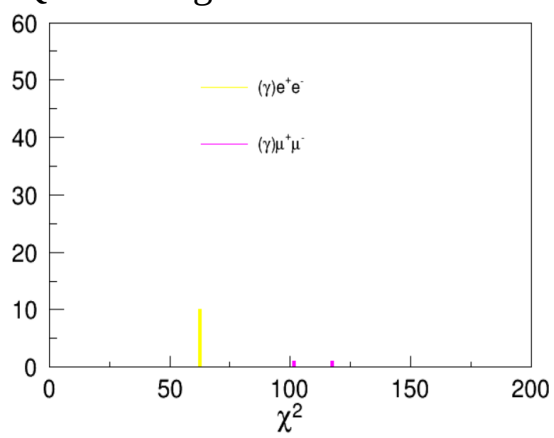
QED Backgrounds for $K^+K^-\pi^+\pi^-$



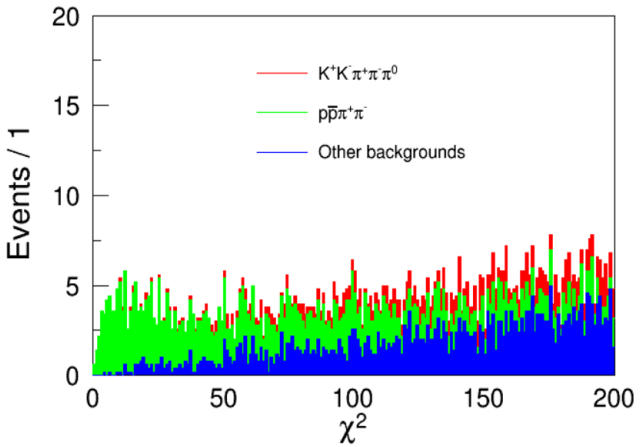
Hadronic Backgrounds for $\pi^+\pi^-\pi^+\pi^-$



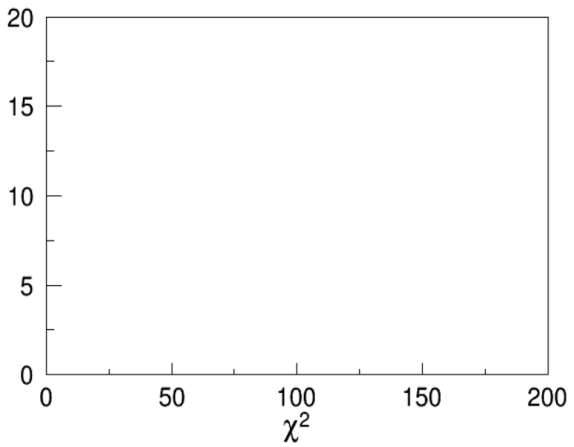
QED Backgrounds for $\pi^+\pi^-\pi^+\pi^-$



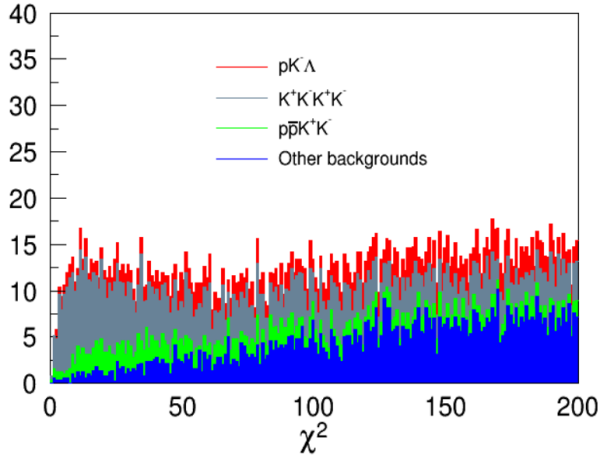
Hadronic Backgrounds for $K^+K^-K^+K^-$



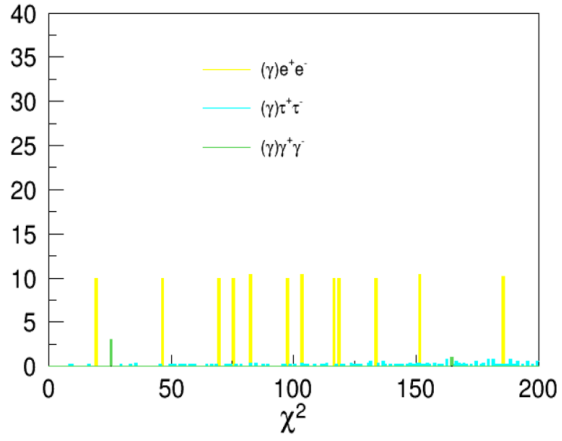
QED Backgrounds for $K^+K^-K^+K^-$



Hadronic Backgrounds for $pp\pi^+\pi^-$



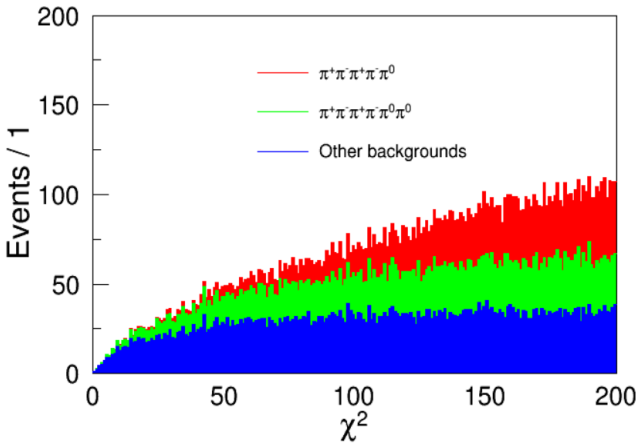
QED Backgrounds for $pp\pi^+\pi^-$



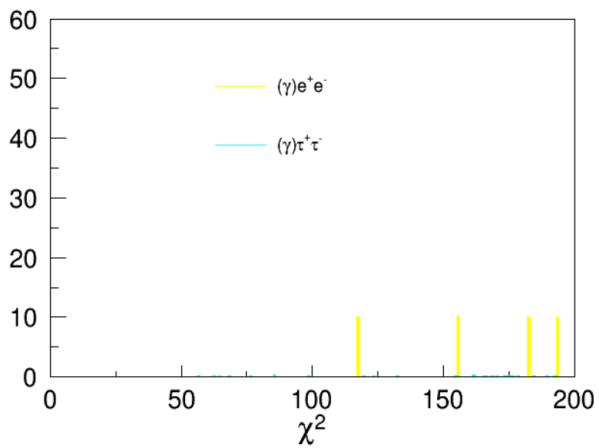
Background study

- By analyzing Inclusive MC samples generated at 4.230 GeV. distributions of χ^2 of kinematic fit from non-peaking backgrounds for every signal channel.

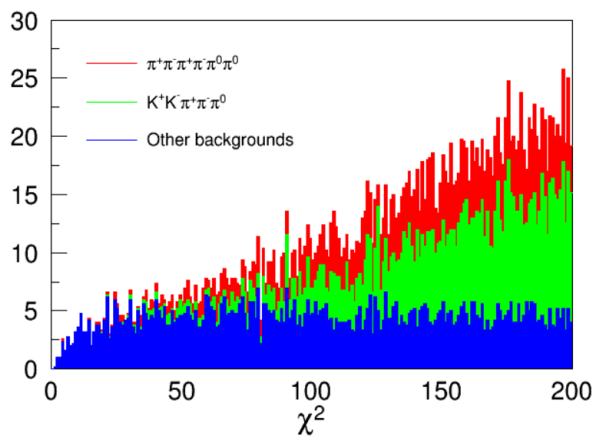
Hadronic Backgrounds for $K^+K^-\pi^+\pi^-\pi^0$



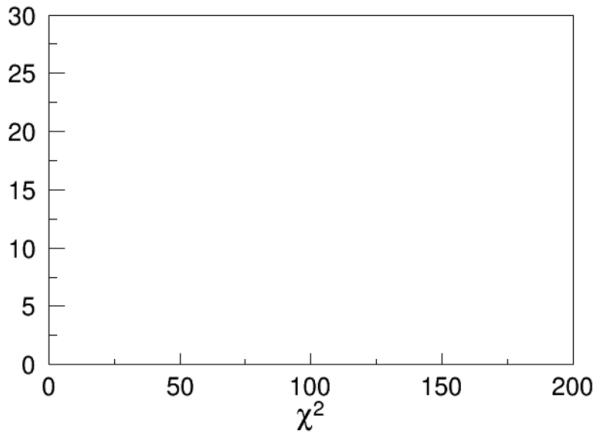
QED Backgrounds for $K^+K^-\pi^+\pi^-\pi^0$



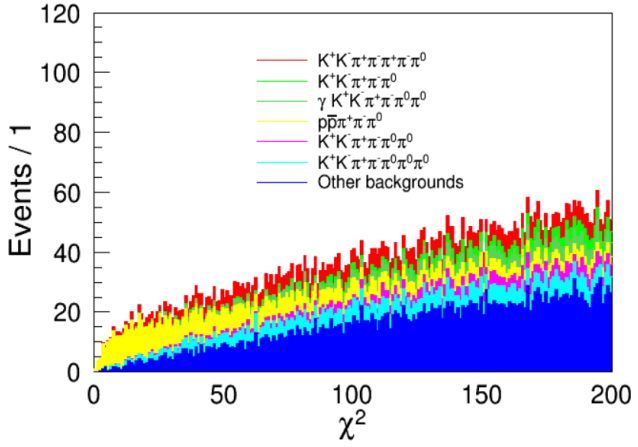
Hadronic Backgrounds for $\pi^+\pi^-\pi^+\pi^-\pi^0$



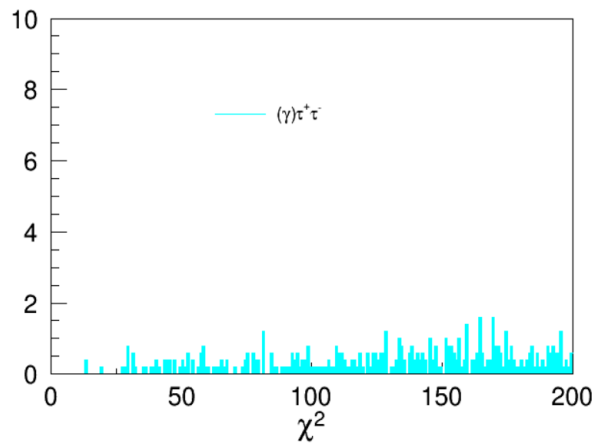
QED Backgrounds for $\pi^+\pi^-\pi^+\pi^-\pi^0$



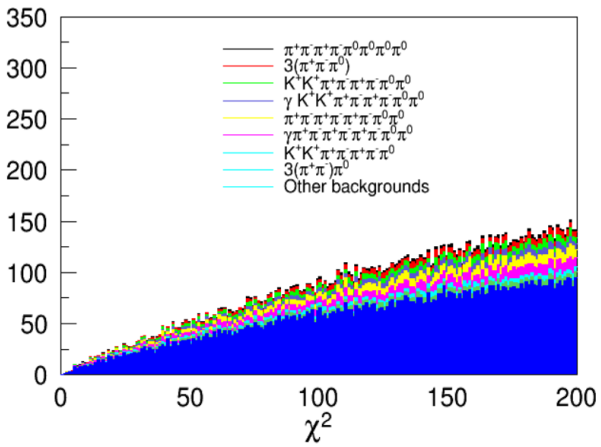
Hadronic Backgrounds for $K^+K^-K^+K^-\pi^0$



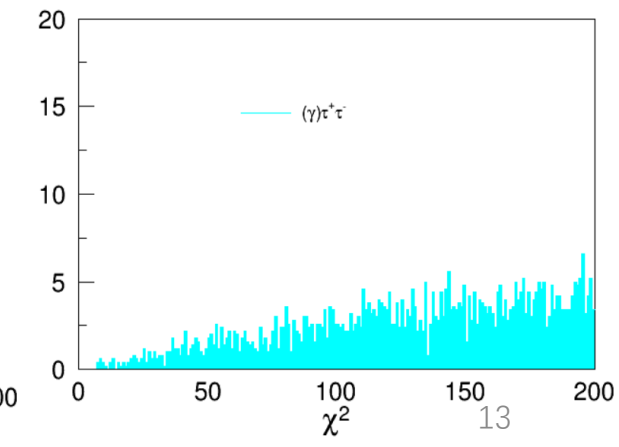
QED Backgrounds for $K^+K^-K^+K^-\pi^0$



Hadronic Backgrounds for $pp\pi^+\pi^-\pi^0$



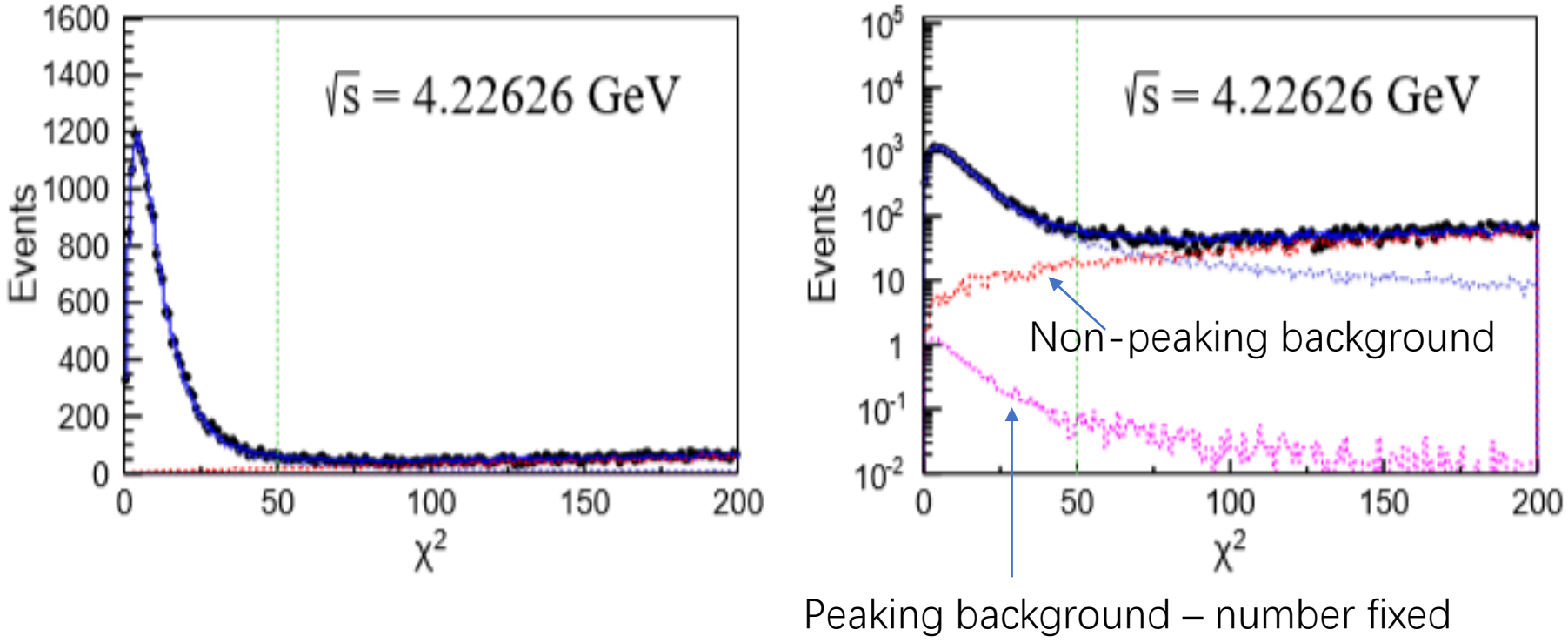
QED Backgrounds for $pp\pi^+\pi^-\pi^0$



Subtraction of backgrounds

- Number of backgrounds are estimated from the fit to $\chi^2_{4C/5C.}$

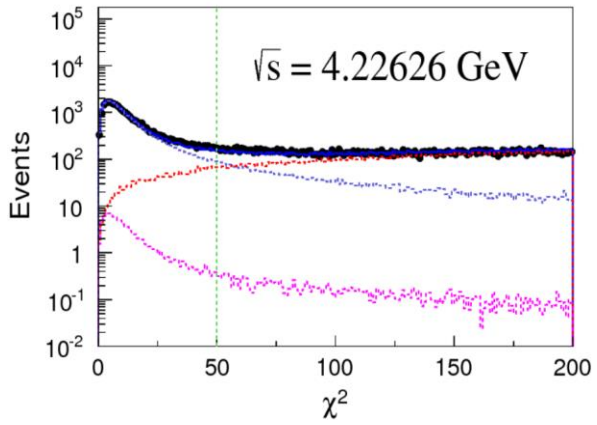
$e^+e^- \rightarrow K^+K^-\pi^+\pi^-$



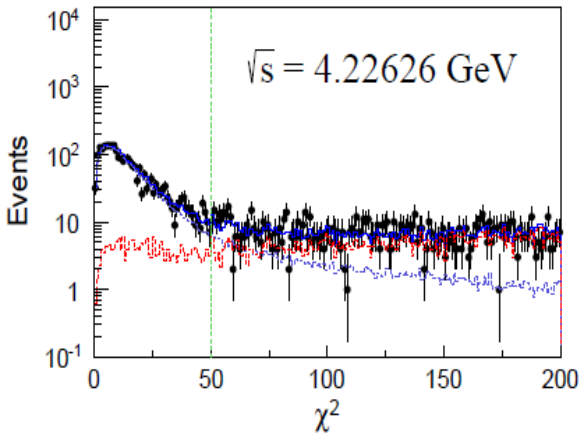
Subtraction of backgrounds

- Number of backgrounds are estimated from the fit to $\chi^2_{4C/5C}$.

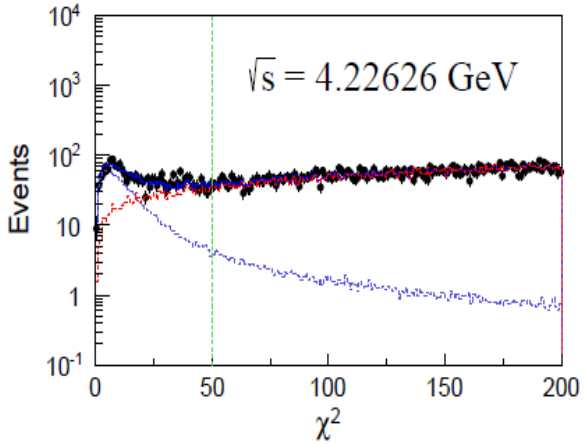
$K^+K^-\pi^+\pi^-\pi^0$



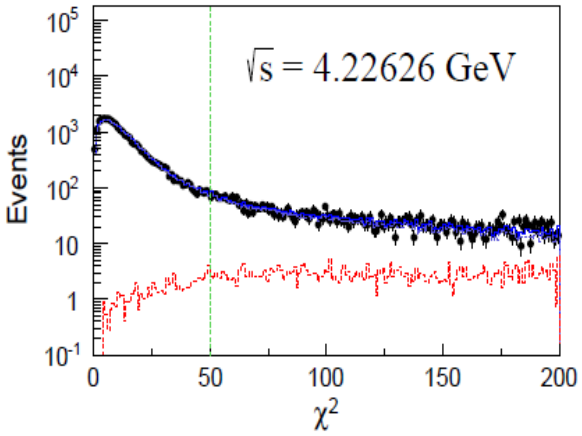
$K^+K^-K^+K^-$



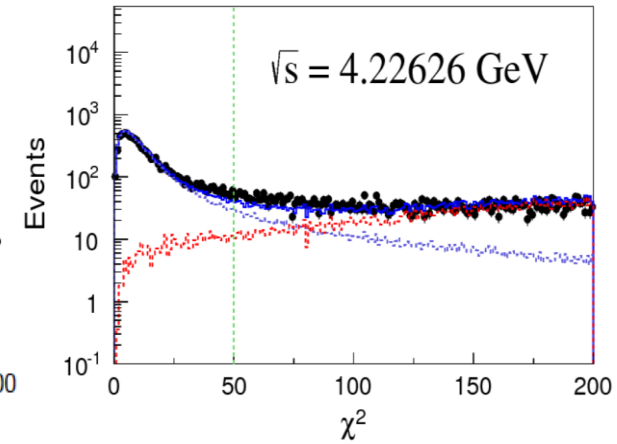
$K^+K^-K^+K^-\pi^0$



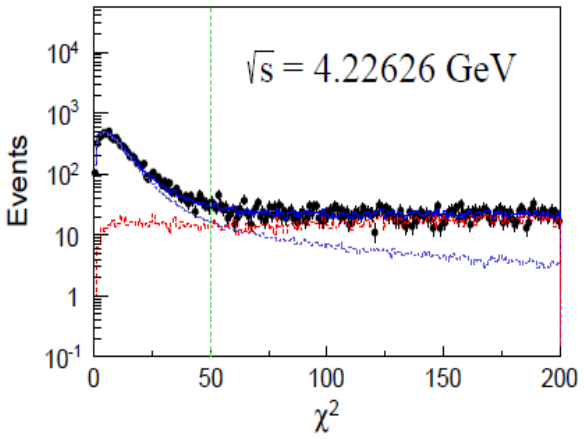
$\pi^+\pi^-\pi^+\pi^-$



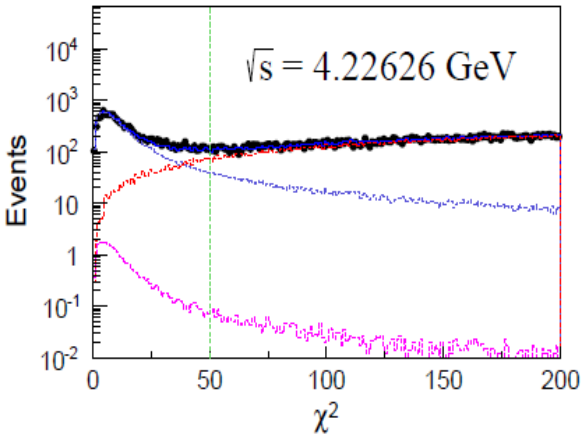
$\pi^+\pi^-\pi^+\pi^-\pi^0$



$pp\pi^+\pi^-$



$pp\pi^+\pi^-\pi^0$

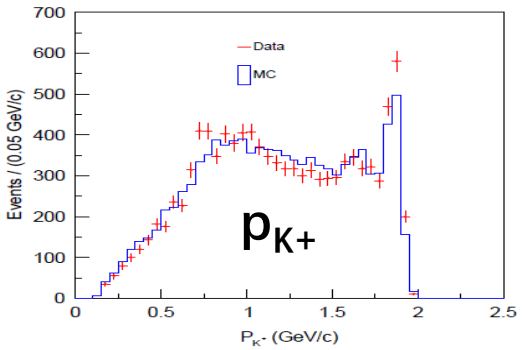


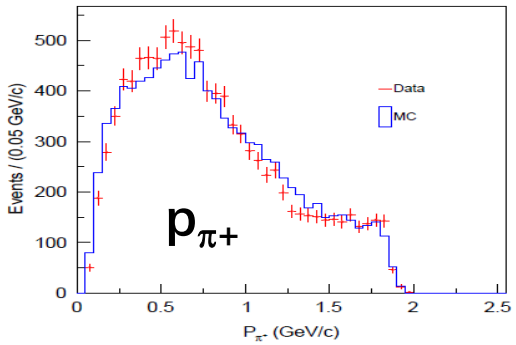
Efficiency

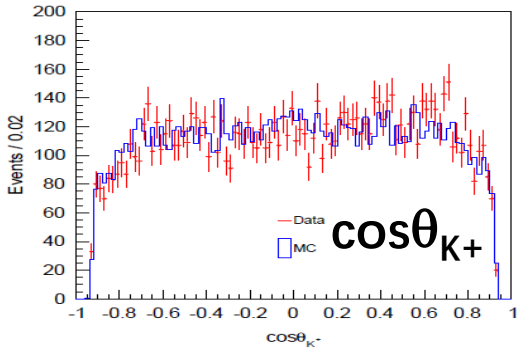
- From the two body and three body invariant mass distributions, we can see there are obvious intermediate states, such as ρ, ω, ϕ and so on.
- To take those intermediate stated into account, an amplitude analysis is performed to data and PHSP signal MC using the AmpTools package developed by Indiana University.
- To select a clean sample to do the amplitude analysis, particle identification requirements are also applied to charged tracks in addition to selection requirements mentioned before.
  - π selection: Prob(π)>Prob(K).
  - K selection: Prob(K)>Prob(π).
  - p selection: Prob(p)>Prob(π), and Prob(p)>Prob(K).
- The amplitude analyses are based on data and MC samples at 4.22626 GeV. From the amplitude analyses, we obtain the ratios of different amplitudes, which are used in efficiency determination.
- Applying the same selection requirements as that in data analysis, ε^0 at every energy point for every final state is determined by analyzing signal MC samples without ISR.

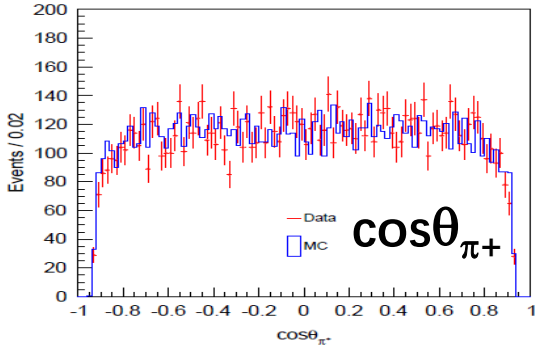
Comparison between data & MC

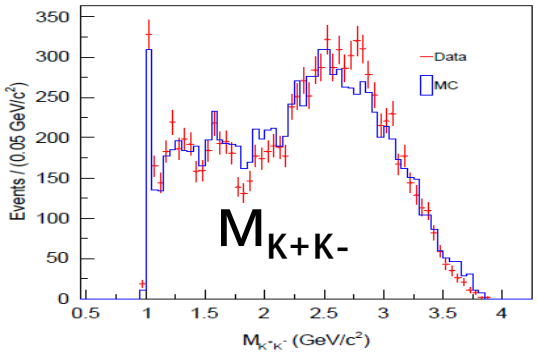
$K^+K^-\pi^+\pi^-$

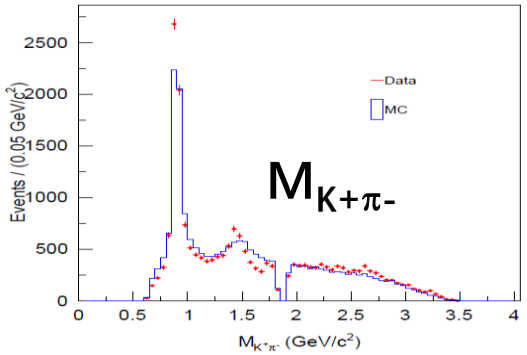


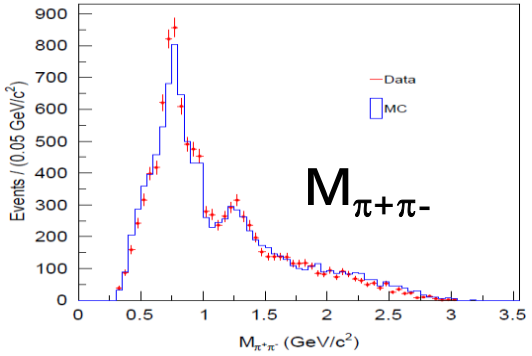


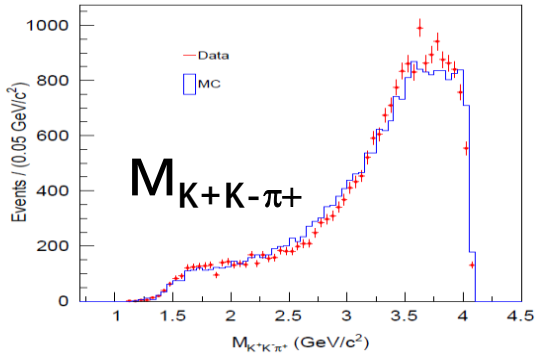




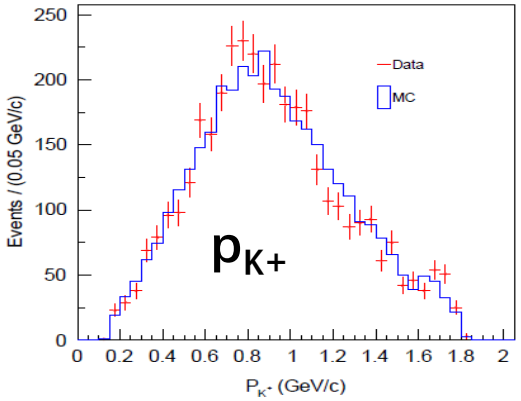


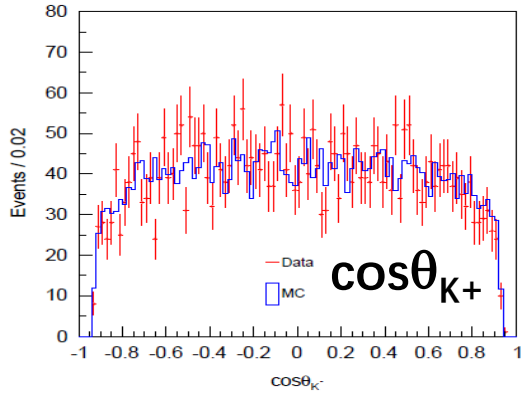


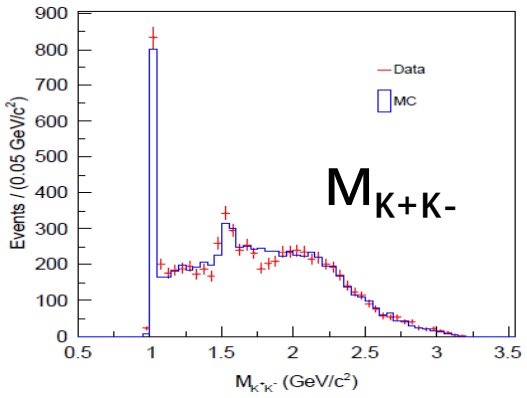


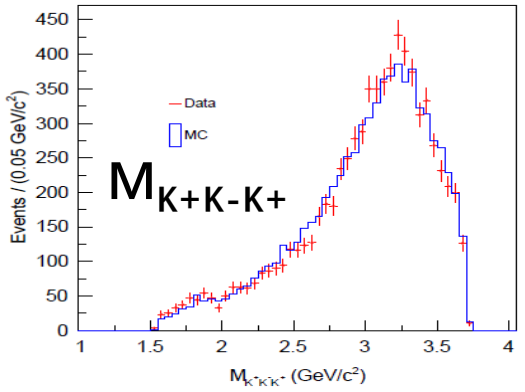


$K^+K^-K^+K^-$



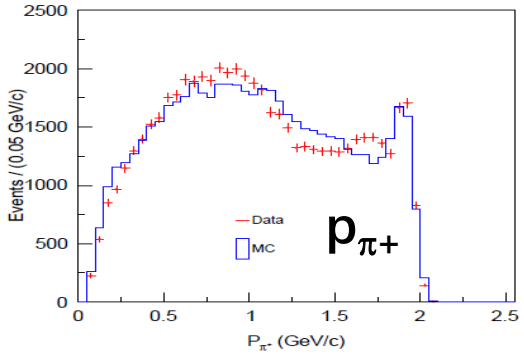


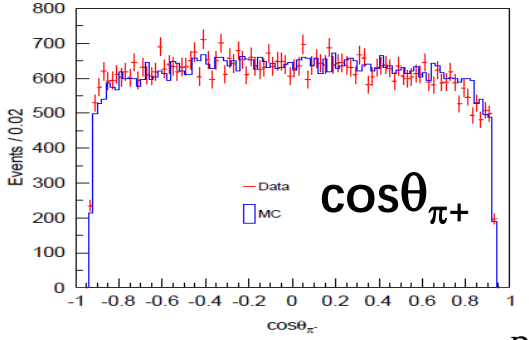


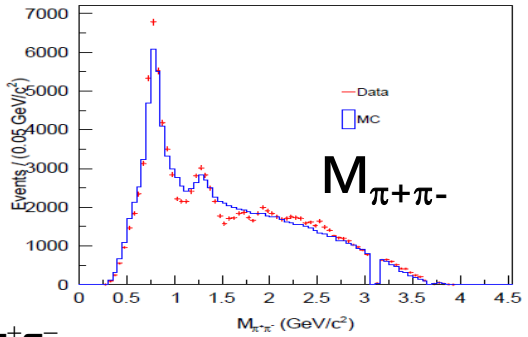


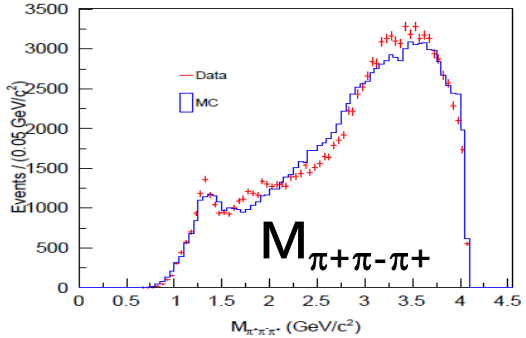
Comparison between data & MC

$\pi^+\pi^-\pi^+\pi^-$

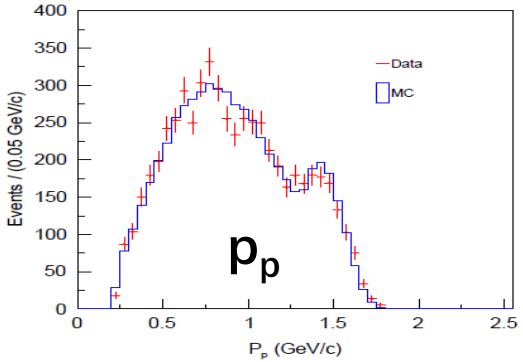


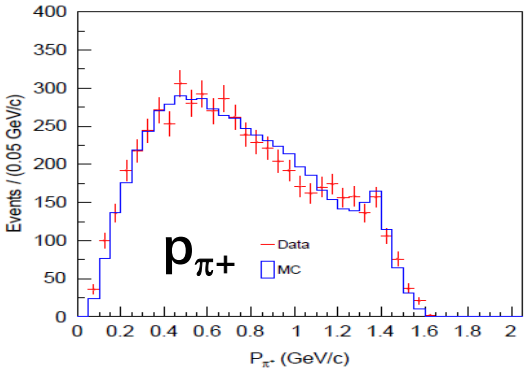


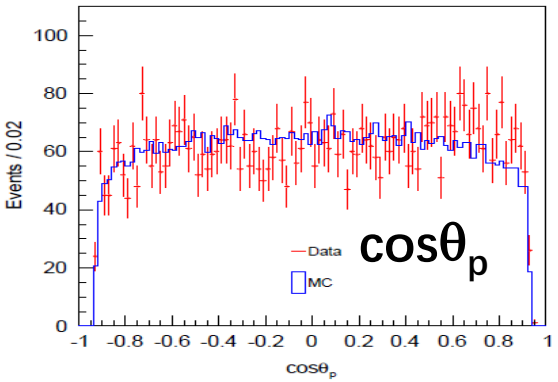


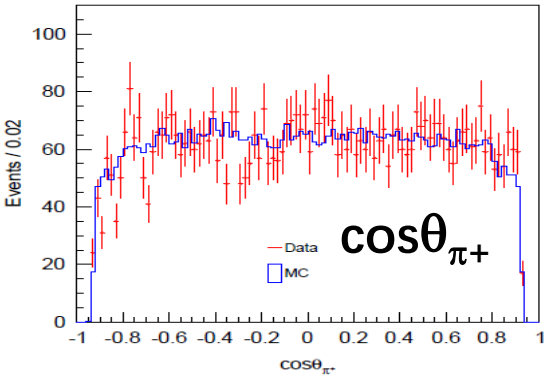


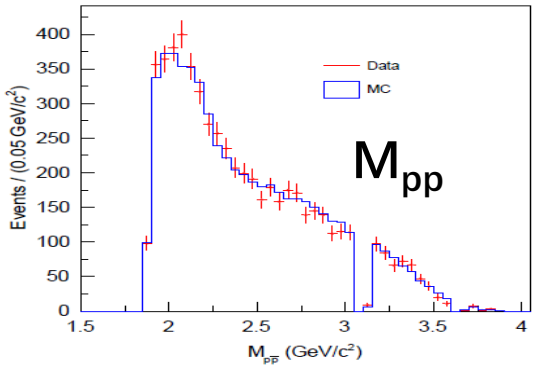
$pp\pi^+\pi^-$

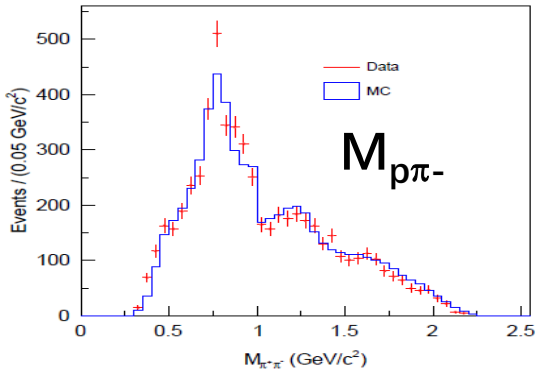


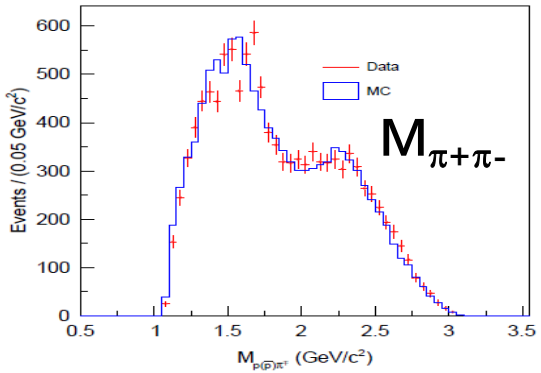


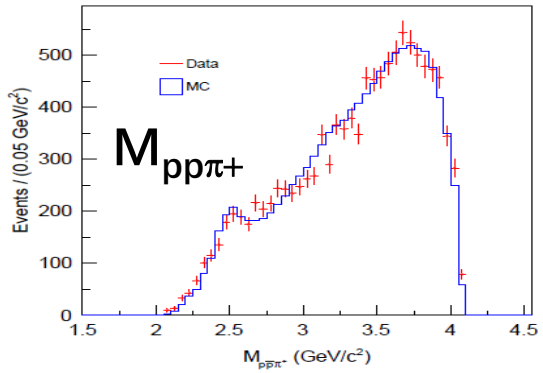






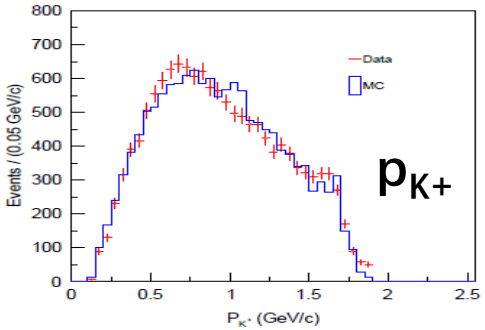


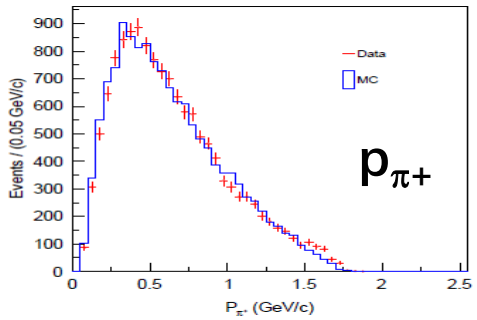


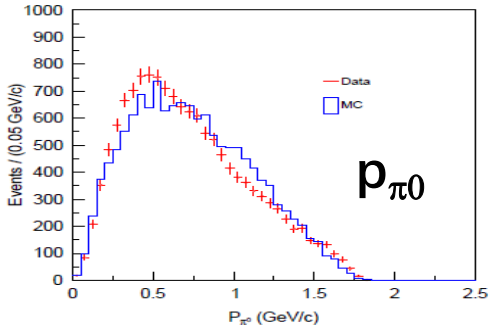


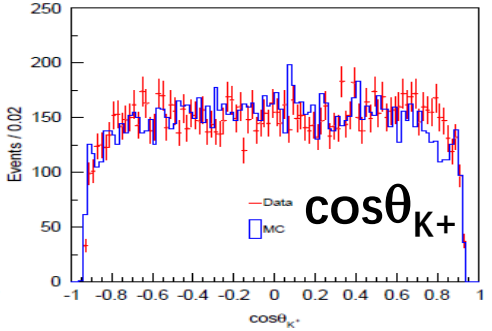
Comparison between data & MC

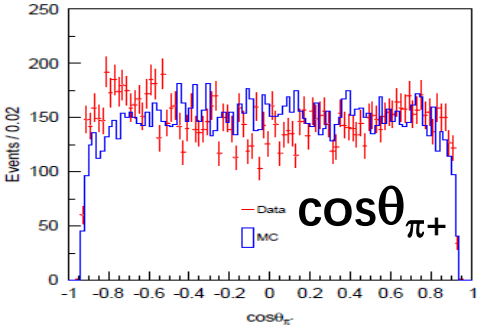
$K^+K^-\pi^+\pi^-\pi^0$

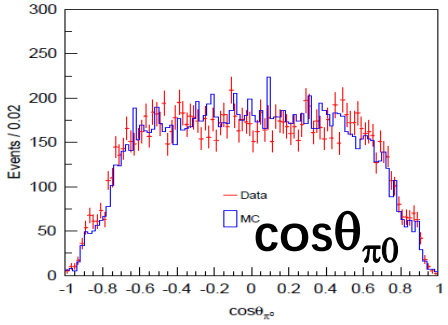


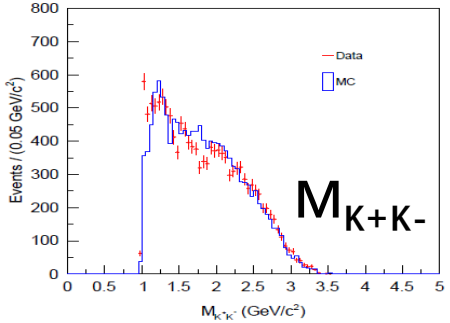


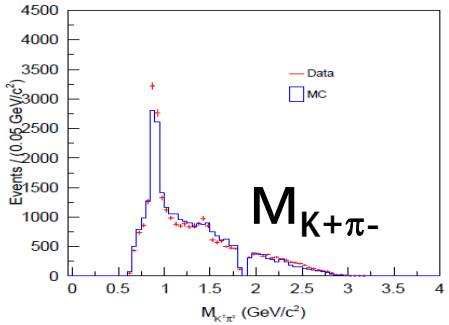


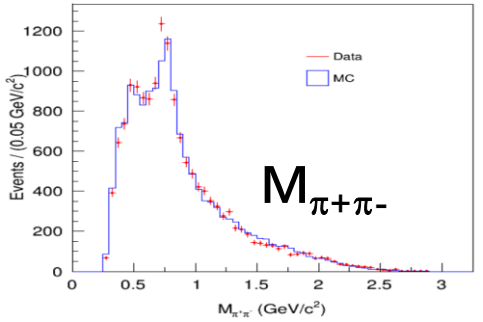


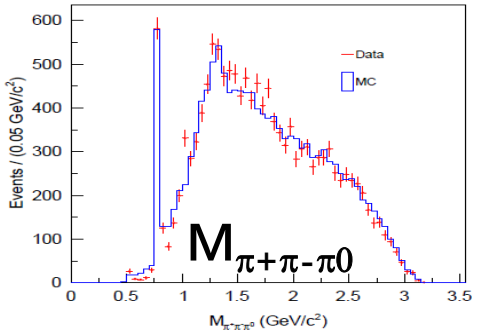




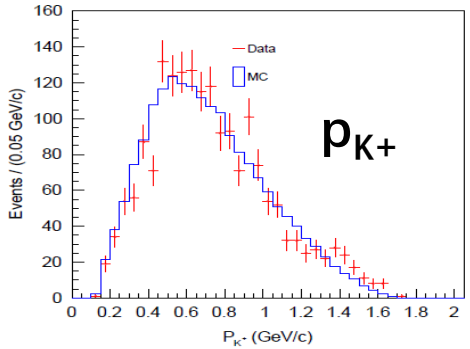


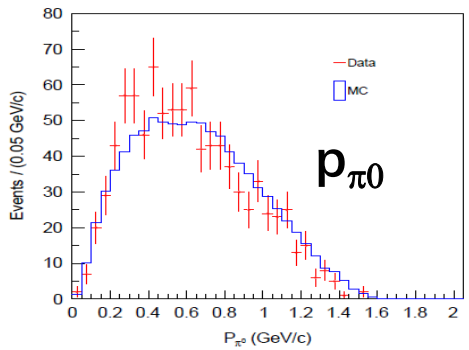


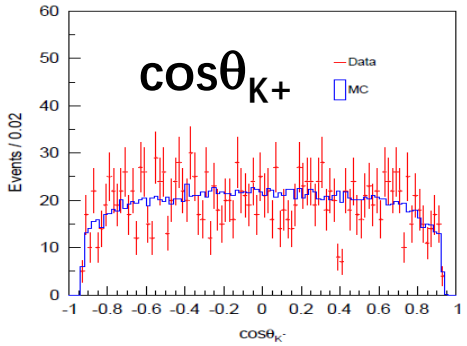


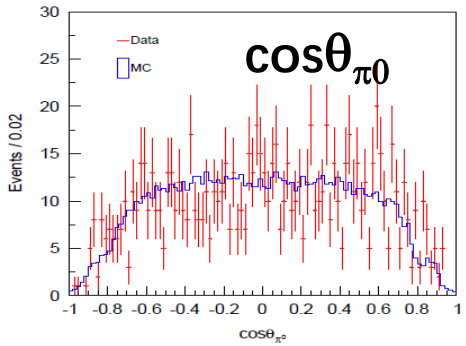


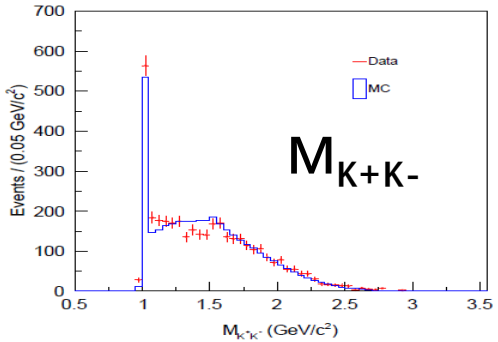
$K^+K^-K^+K^-\pi^0$





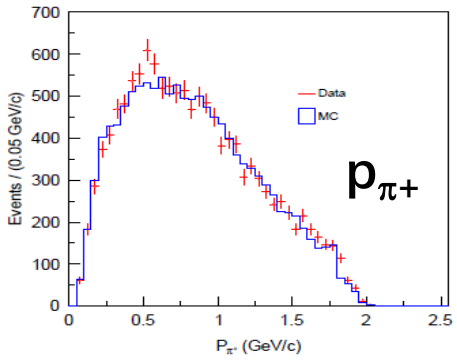


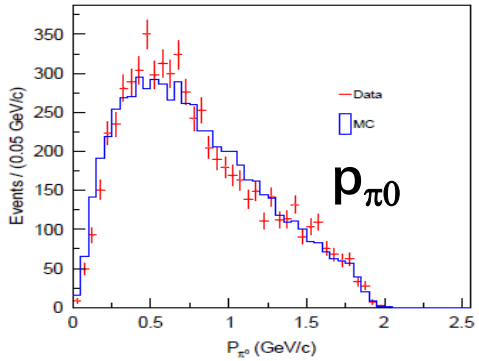


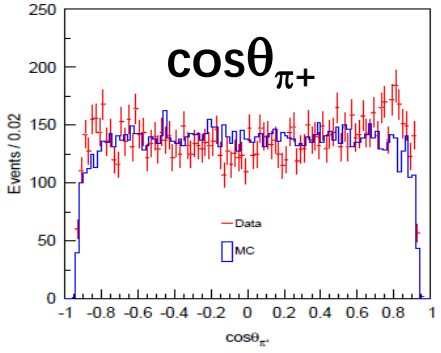


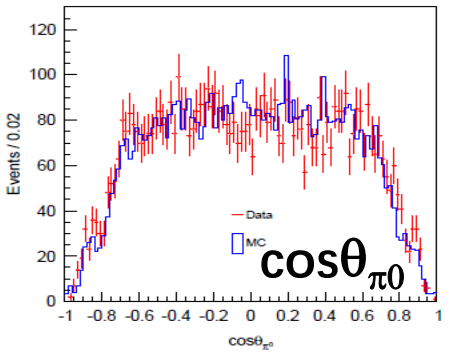
Comparison between data & MC

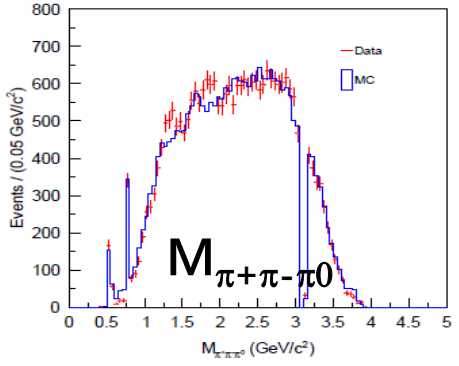
$\pi^+\pi^-\pi^+\pi^-\pi^0$



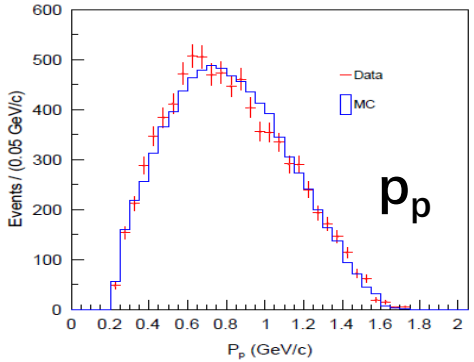


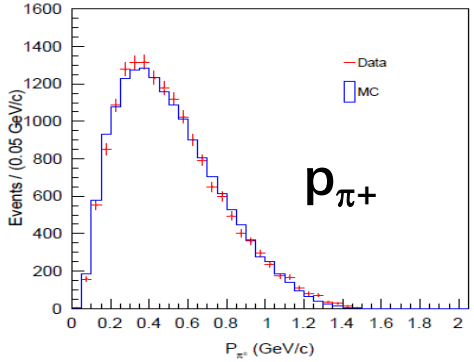


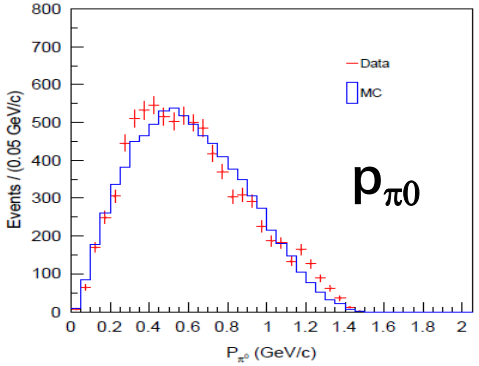


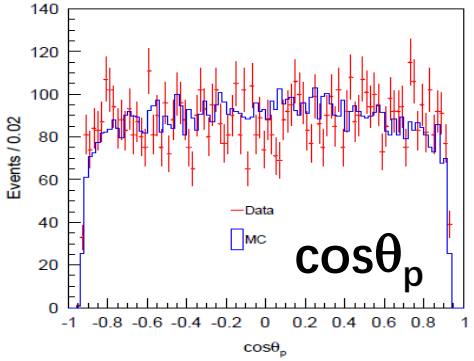


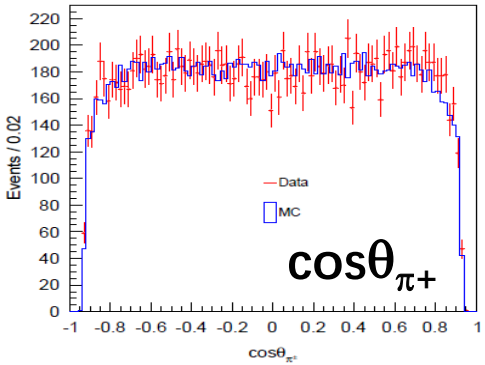
$pp\pi^+\pi^-\pi^0$

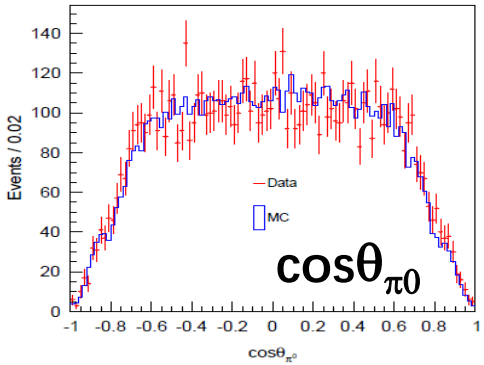


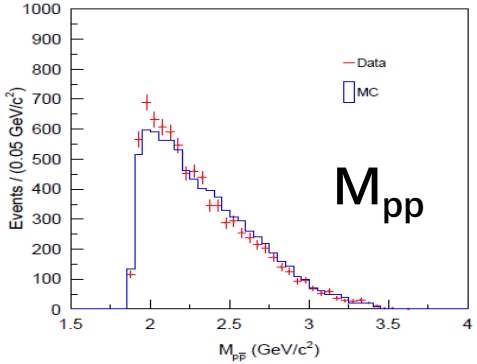


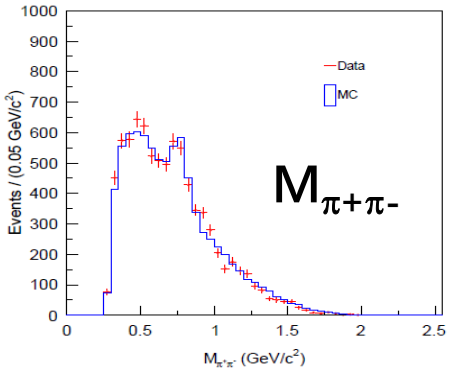


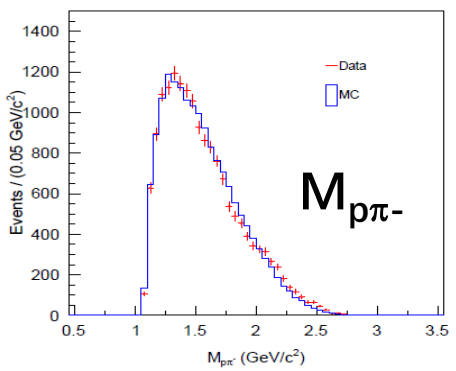


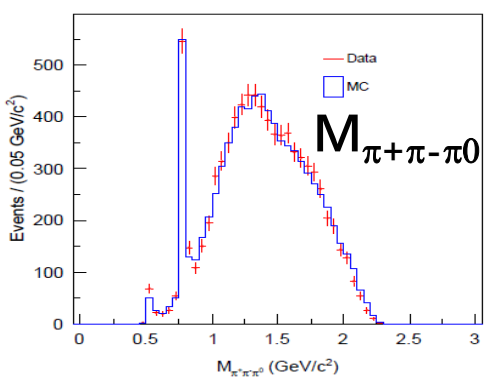








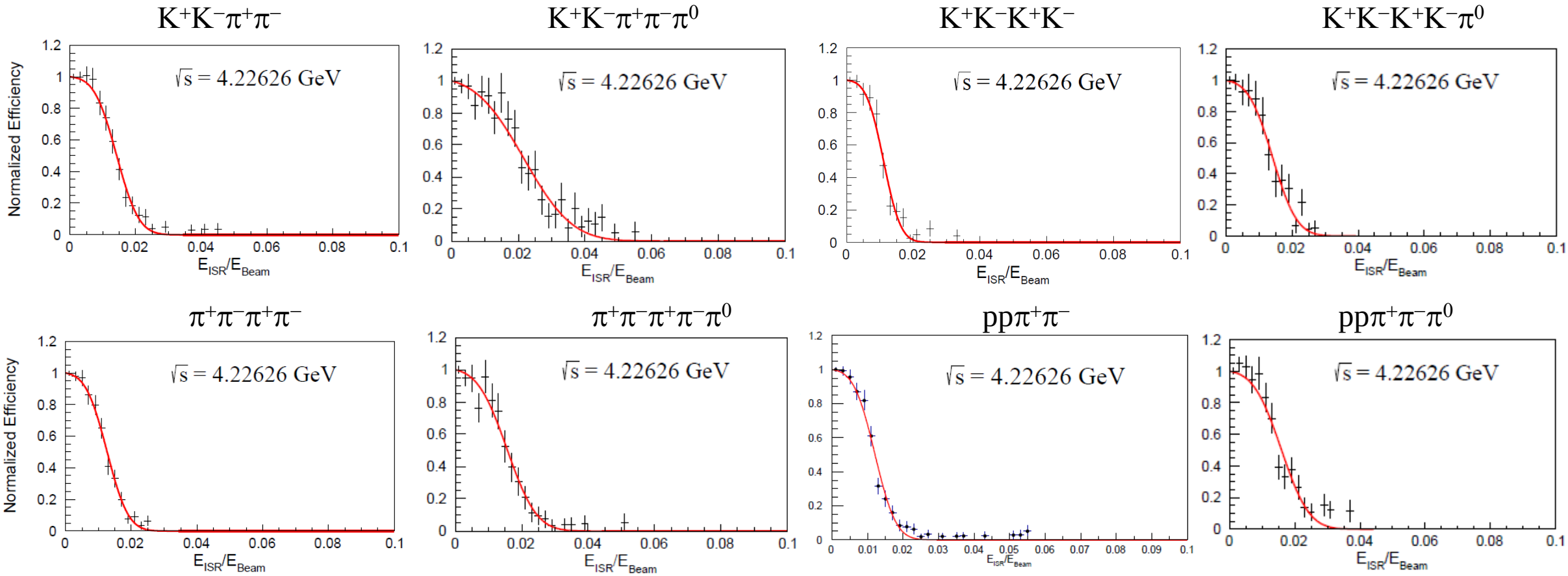




Radiative correction

- The function of ε(x) at every energy point for every final state is determined by analyzing signal MC samples with ISR.

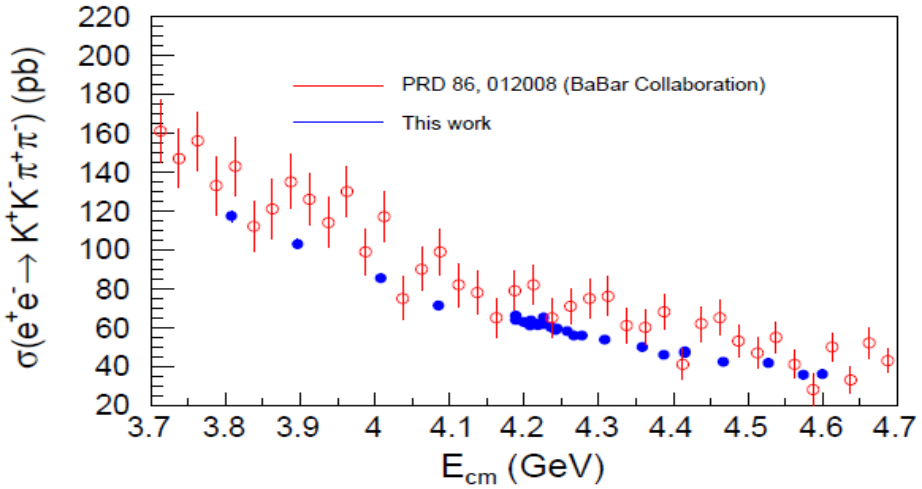
$$\kappa = \int \frac{\sigma(x)}{\sigma^0}\frac{\epsilon(x)}{\epsilon^0}W(x)dx.$$

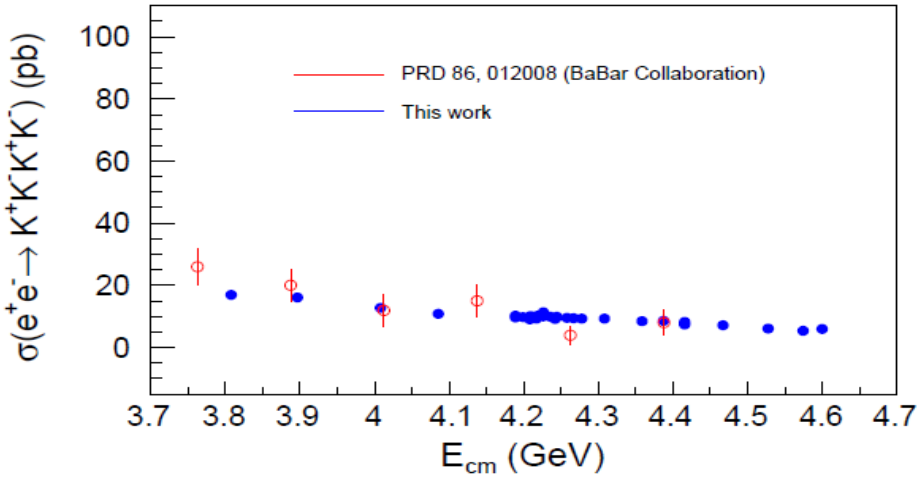


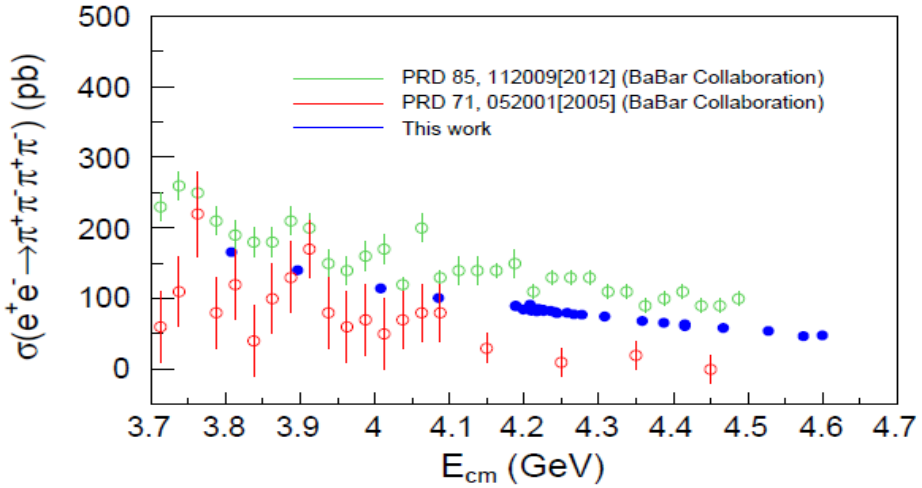
Calculation of cross section

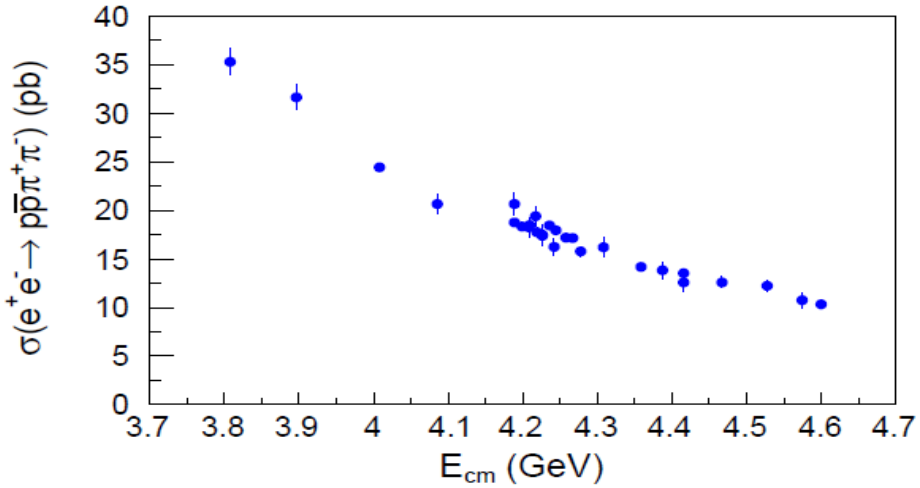
- Having obtained the number of observed events, number of backgrounds events, the luminosity of the data sample, the reconstruction efficiency, radiative correction factor, we could calculate the dressed cross section at every energy point.

$$\sigma = \frac{N^{\rm obs}(E_{{\rm cm},i}) - N^{\rm bkg}(E_{{\rm cm},i})}{L(E_{{\rm cm},i}) \times \epsilon^0(E_{{\rm cm},i}) \times \kappa(E_{{\rm cm},i})},$$





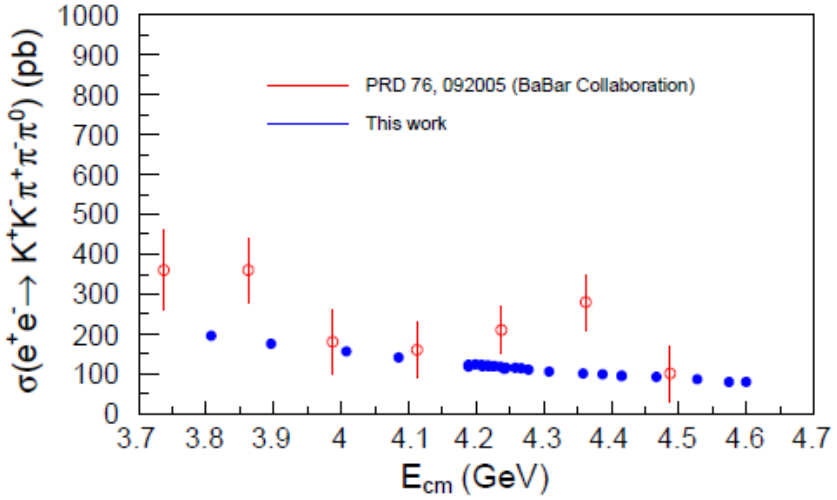


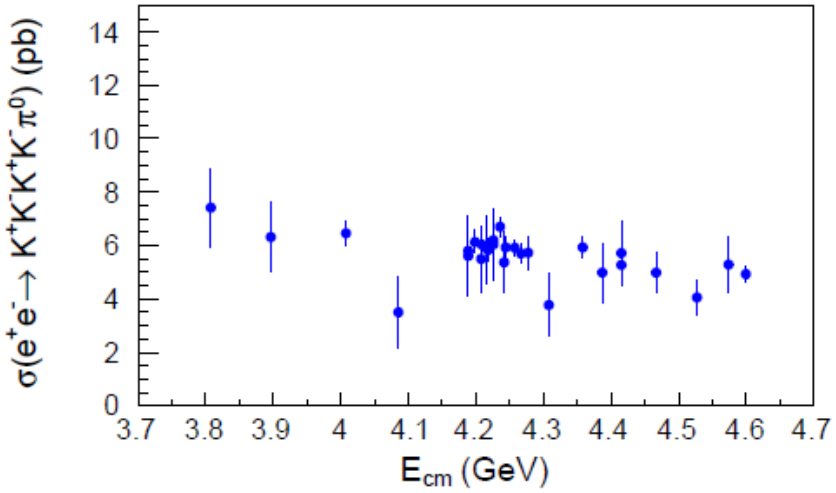


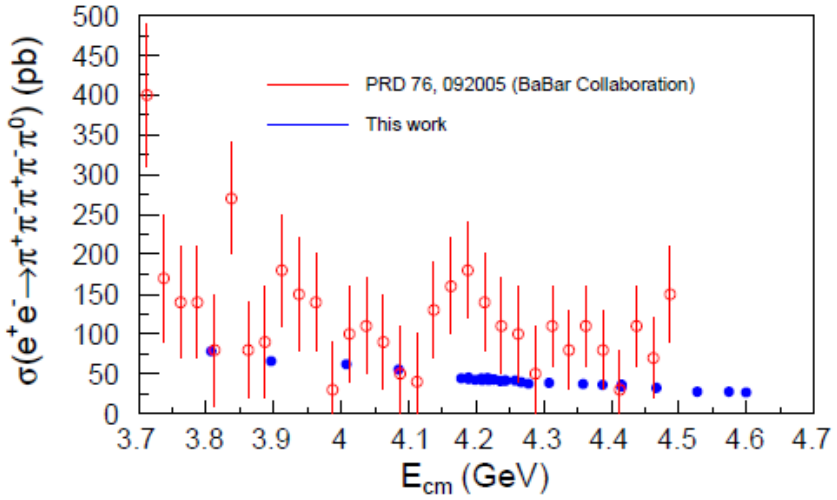
Calculation of cross section

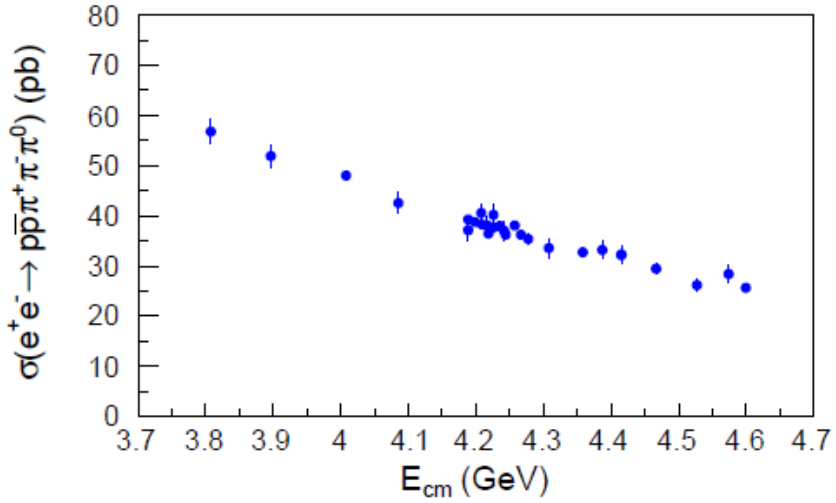
- Having obtained the number of observed events, number of backgrounds events, the luminosity of the data sample, the reconstruction efficiency, radiative correction factor, we could calculate the dressed cross section at every energy point.

$$\sigma = \frac{N^{\rm obs}(E_{{\rm cm},i}) - N^{\rm bkg}(E_{{\rm cm},i})}{L(E_{{\rm cm},i}) \times \epsilon^0(E_{{\rm cm},i}) \times \kappa(E_{{\rm cm},i})},$$









Analysis of dressed cross sections

- A least χ2 fit is applied to those dressed cross sections.

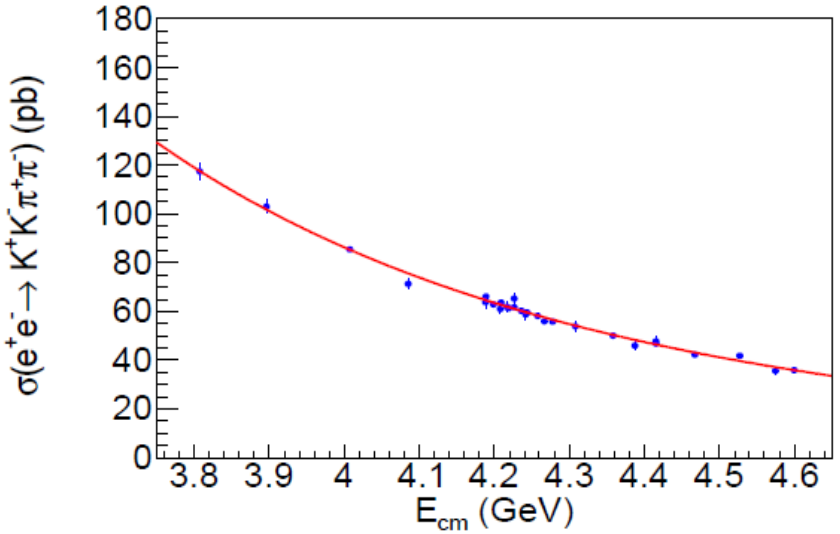
$$\chi^2 = \sum_{i=1}^{N} \left(\frac{\sigma^{\text{dressed}}(E_{\text{cm,i}}) - \sigma^{\text{expected}}(E_{\text{cm,i}})}{\Delta_{\sigma^{\text{dressed}}(E_{\text{cm,i)}}}} \right)^2$$

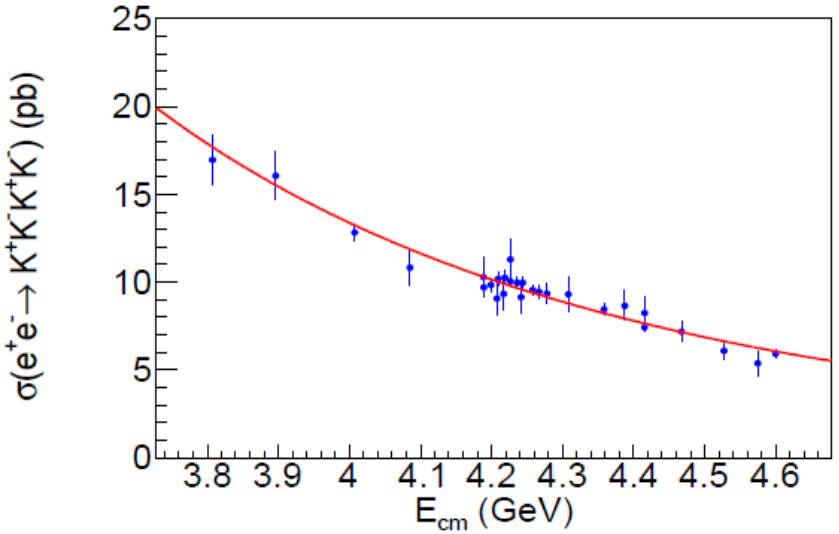
$\sigma^{\text{dressed}}(E_{\text{cm,i}})$: measured value of dressed cross section
$\sigma^{\text{expected}}(E_{\text{cm,i}})$: expected value of dressed cross section
$\Delta_{\sigma^{\text{dressed}}(E_{\text{cm,i}})}$: combined statistical and uncorrelated systematic error

- Firstly, we construct the expected dressed cross section of continuum process.

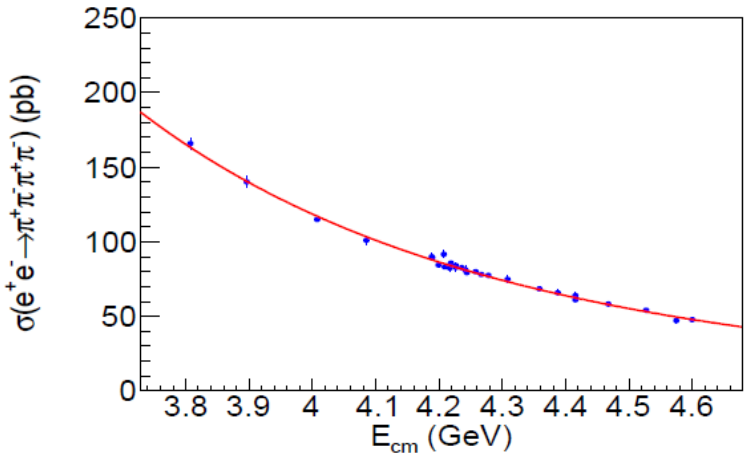
$$\sigma_{\text{cont}}^{\text{expected}} = |A_{\text{cont}}|^2, \qquad A_{\text{cont}} = \sqrt{\frac{f_{\text{cont}}}{E_{\text{cm}}^n}}$$

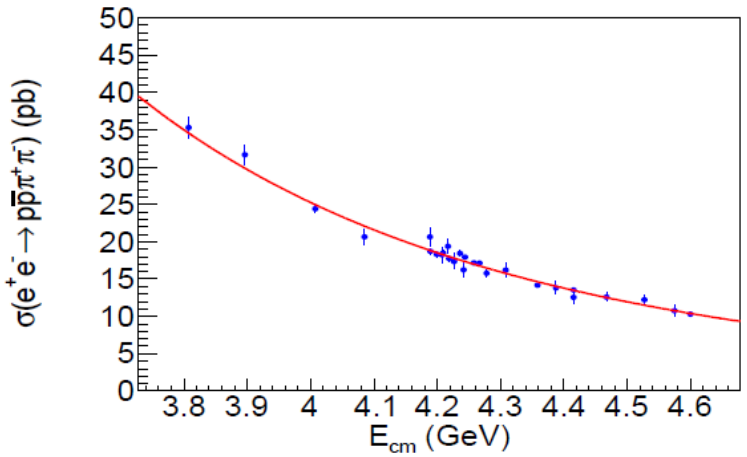
E_{cm} : center-of-mass energy
f_{cont}, n : float parameters

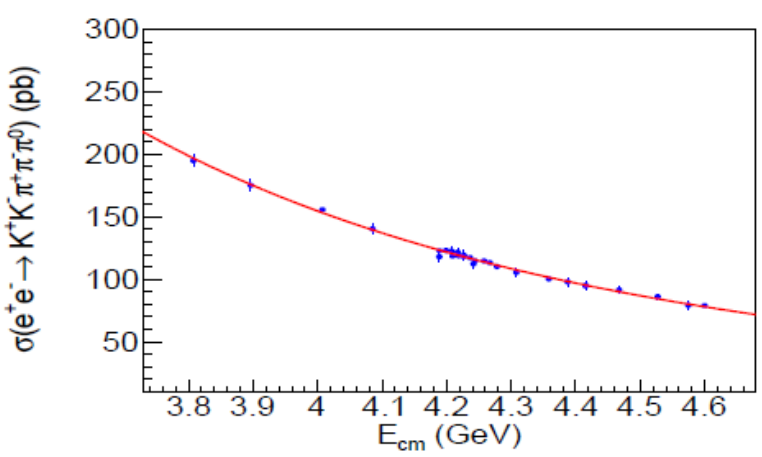


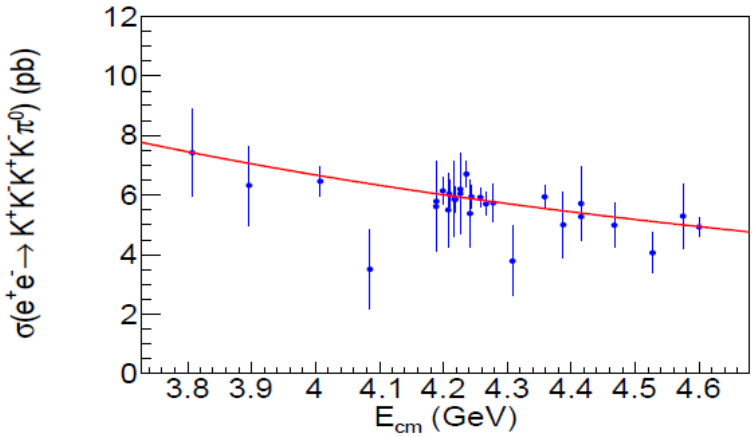


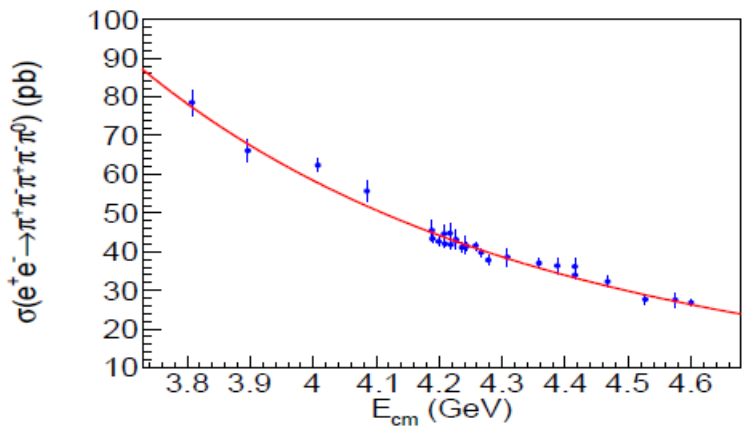
Analysis of dressed cross sections

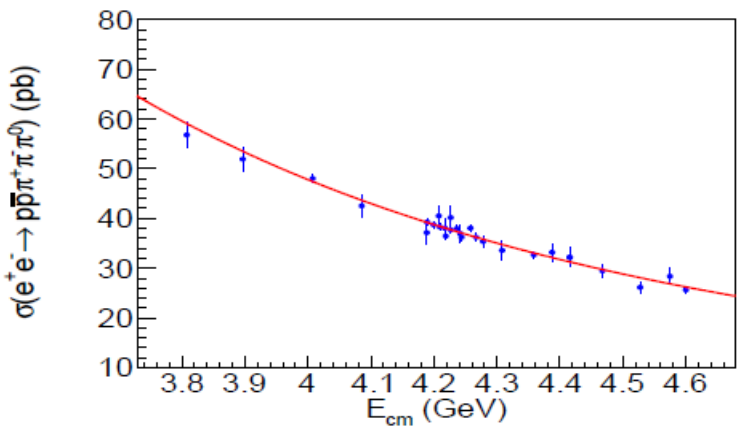












Parameter	$K^+K^-\pi^+\pi^-$	$K^+K^-K^+K^-$	$\pi^+\pi^-\pi^+\pi^-$	$p\bar{p}\pi^+\pi^-$	$K^+K^-\pi^+\pi^-\pi^0$	$K^+K^-K^+K^-\pi^0$	$\pi^+\pi^-\pi^+\pi^-\pi^0$	$p\bar{p}\pi^+\pi^-\pi^0$
χ^2	31.3	19.6	26.4	34.7	13.8	17.3	28.7	31.7
χ^2/ndf	1.2	0.8	1.0	1.3	0.5	0.7	1.1	1.2
n	$6.27 \pm 0.09 \pm 0.02$	$5.66 \pm 0.23 \pm 0.01$	$6.48 \pm 0.10 \pm 0.01$	$6.35 \pm 0.15 \pm 0.02$	$4.90 \pm 0.09 \pm 0.01$	$2.16 \pm 0.49 \pm 0.01$	$5.71 \pm 0.18 \pm 0.01$	$4.29 \pm 0.14 \pm 0.01$

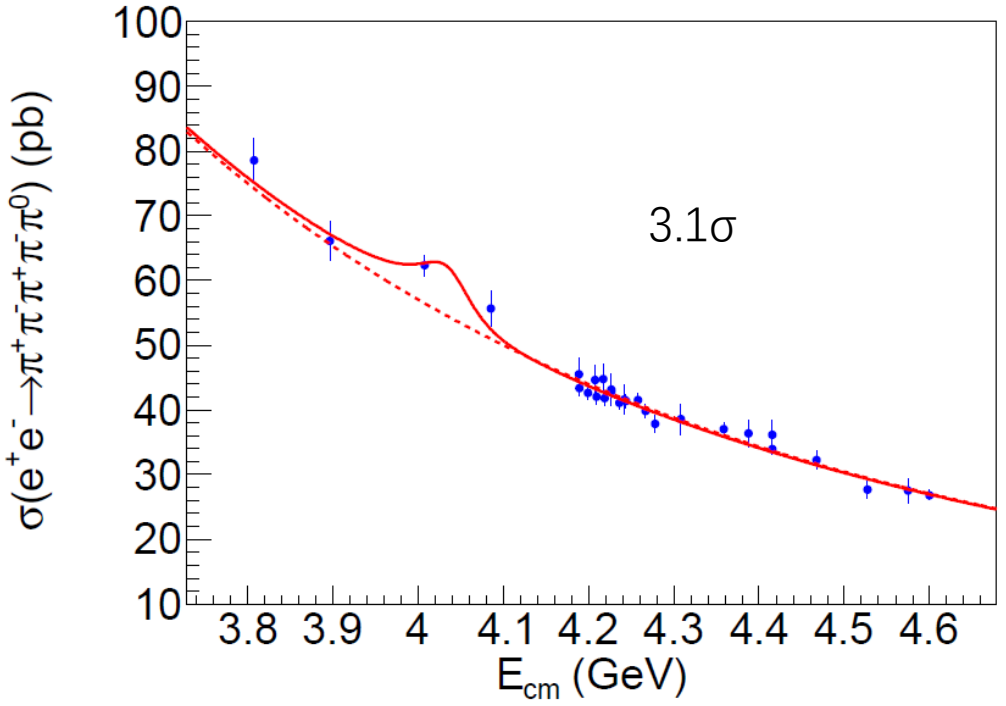
Analysis of dressed cross sections

- For the cross section of $e^+e^-\rightarrow\pi^+\pi^-\pi^+\pi^-\pi^0$, we also constructed fit amplitude considering contribution from ψ(4040) decay.

$$\sigma^{\text{expected}}_{\text{cont}+\psi(4040)} = |A_{\text{cont}} + A_{\psi(4040)}e^{i\phi}|^2$$

$$A_{\psi(4040)} = \frac{\sqrt{12\pi\Gamma^{ee}_{\psi(4040)}\Gamma^{\text{total}}_{\psi(4040)}\text{Br}(\psi(4040)\rightarrow\pi^+\pi^-\pi^+\pi^-\pi^0)}}{(E^2_{\text{cm}} - M^2_{\psi(4040)}) + i\Gamma^{\text{total}}_{\psi(4040)}M_{\psi(4040)}}$$

ϕ	: phase angle
$M_{\psi(4040)}$	: mass of ψ(4040)
$\Gamma^{\text{total}}_{\psi(4040)}$	: total width of ψ(4040)
$\Gamma^{ee}_{\psi(4040)}$	: leptonic width of ψ(4040)



Parameter	$\pi^+\pi^-\pi^+\pi^-\pi^0$
χ^2	15.9
χ^2/ndf	0.6
n	$5.35 \pm 0.21 \pm 0.02$
$\text{Br}(\psi(4040)\rightarrow\pi^+\pi^-\pi^+\pi^-\pi^0)$	$(2.79 \pm 1.99 \pm 0.92) \times 10^{-5}$
ϕ	$(113.51 \pm 25.25 \pm 4.04)^\circ$

Analysis of dressed cross sections

- Furthermore, we search for the charmonium-like resonance Y (4260) decays into those final state, and corresponding upper limits are provided since no clear signal is observed.
- The expected cross sections are constructed as

$$\sigma^{\text{expected}}_{\text{cont}(+\psi(4040))+\text{Y}(4260)} = c_0\sigma^{\text{expected}}_{\text{cont}(+\psi(4040))} + \sigma_{Y(4260)},$$

$$\sigma_{Y(4260)} = \frac{12\pi\Gamma^{ee}_{Y(4260)}\Gamma^{\text{total}}_{Y(4260)}\text{Br}(\text{Y}(4260) \to \text{Light Hadrons})}{(E^2_{\text{cm}} - M^2_{Y(4260)})^2 + (\Gamma^{\text{total}}_{Y(4260)}M_{Y(4260)})^2}$$

c_0	: float parameter
$\sigma^{\text{expected}}_{\text{cont}(+\psi(4040))}$	: fixed to the shape determined without considering Y(4260)
$M_{Y(4260)}$	: mass of Y(4260)
$\Gamma^{\text{total}}_{Y(4260)}$	: total width of Y(4260)
$\Gamma^{ee}_{Y(4260)}$	: leptonic width of Y(4260)

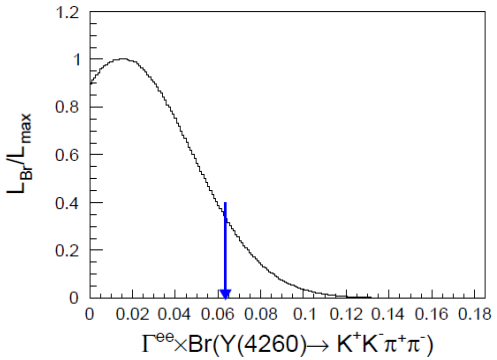
- Then the likelihood is constructed as

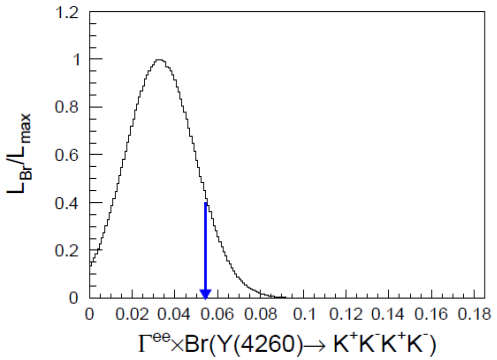
$$L_{\text{Br}} = e^{-0.5\chi^2}$$

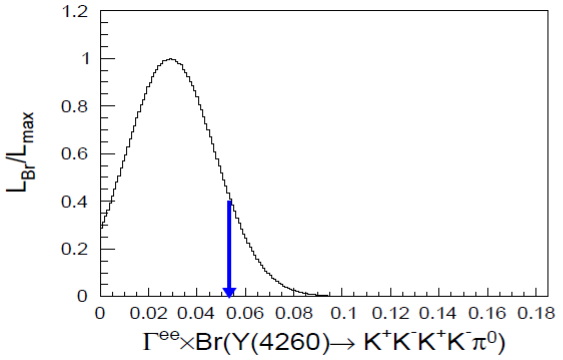
- The normalized value of L_{Br}/L_0 is used to get the upper limits at 90% confidence level for Y(4260)→Light Hadrons.

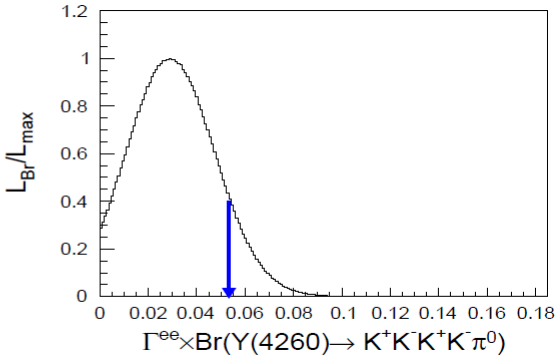
Analysis of dressed cross sections

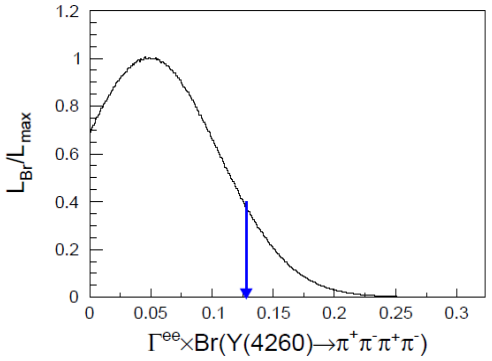
- Distributions of L_{Br}/L_0

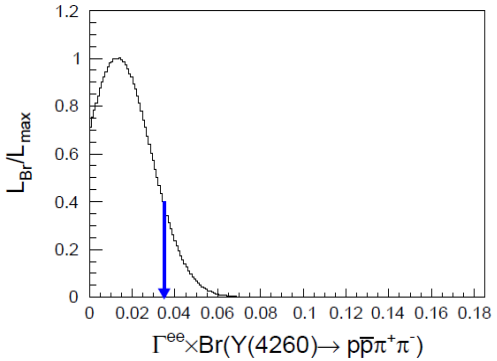


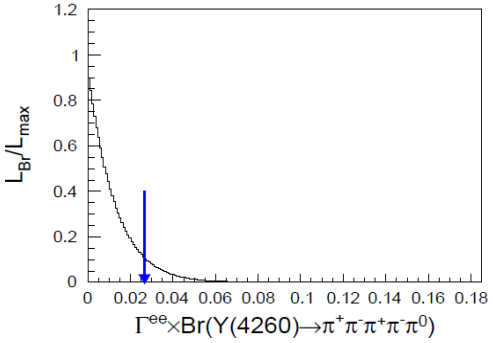


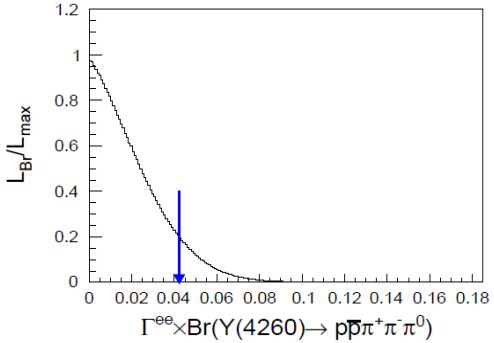








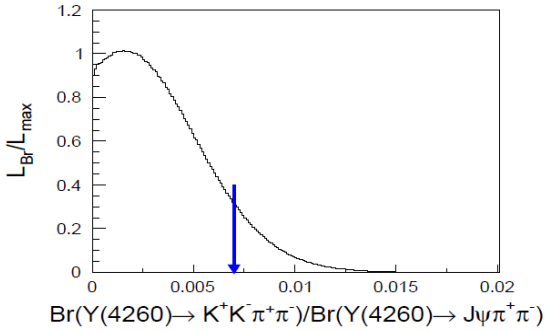


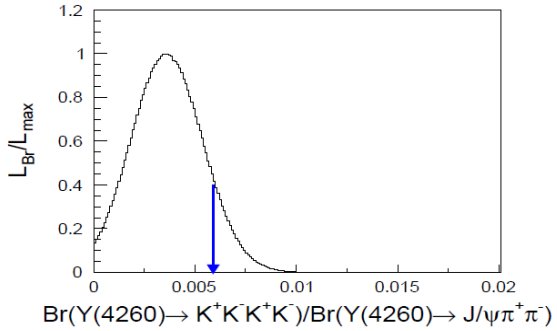


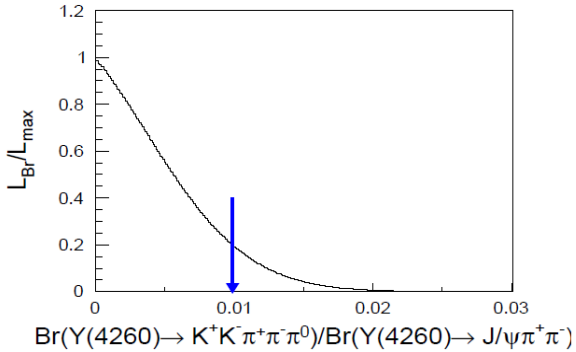
Final state	$\Gamma^{ee}_{Y(4260)} \times$ Br(Y(4260) $\to$ Light Hadrons)(eV)
$K^+K^-\pi^+\pi^-$	< 0.06
$K^+K^-K^+K^-$	< 0.05
$\pi^+\pi^-\pi^+\pi^-$	< 0.13
$p\bar{p}\pi^+\pi^-$	< 0.03
$K^+K^-\pi^+\pi^-\pi^0$	< 0.09
$K^+K^-K^+K^-\pi^0$	< 0.05
$\pi^+\pi^-\pi^+\pi^-\pi^0$	< 0.03
$p\bar{p}\pi^+\pi^-\pi^0$	< 0.04

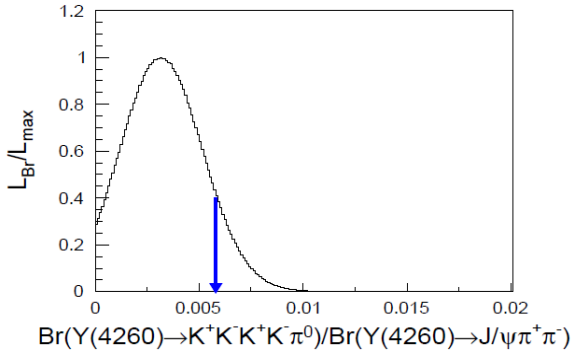
Analysis of dressed cross sections

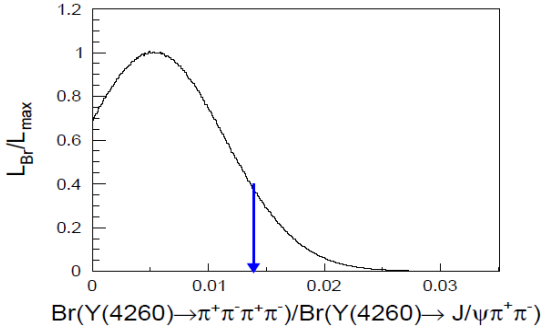
- Distributions of L_{Br}/L_0

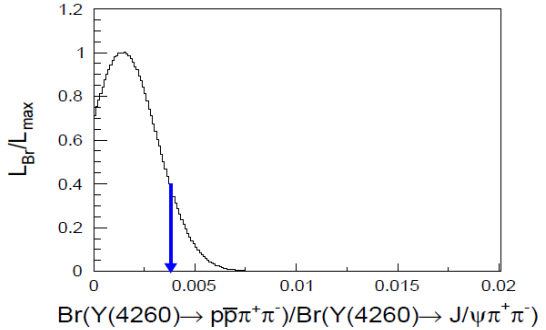


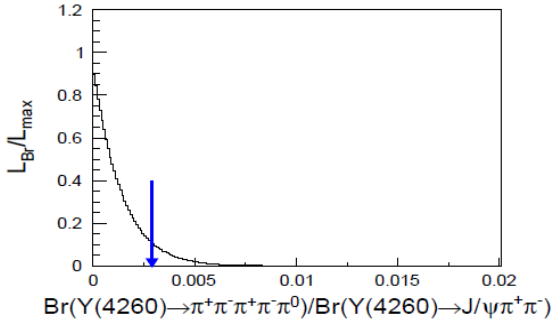


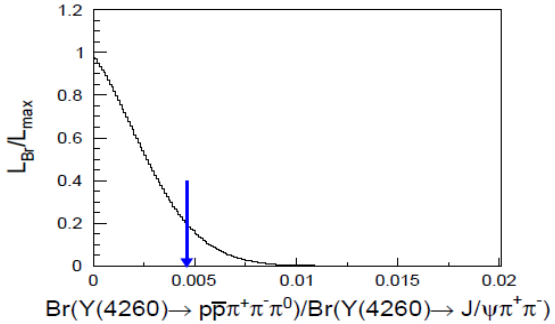












Final state	Br(Y(4260) → Light Hadrons)/Br(Y(4260) → $J/\psi\pi^+\pi^-$)
$K^+K^-\pi^+\pi^-$	$< 0.70\%$
$K^+K^-K^+K^-$	$< 0.59\%$
$\pi^+\pi^-\pi^+\pi^-$	$< 1.39\%$
$p\bar{p}\pi^+\pi^-$	$< 0.38\%$
$K^+K^-\pi^+\pi^-\pi^0$	$< 0.99\%$
$K^+K^-K^+K^-\pi^0$	$< 0.58\%$
$\pi^+\pi^-\pi^+\pi^-\pi^0$	$< 0.29\%$
$p\bar{p}\pi^+\pi^-\pi^0$	$< 0.46\%$

Systematic uncertainties – cross section

- Kinematic fit: comparing efficiency before/after helix correction.
- Selection requirements: varying selection requirements.
  - E_{EMC}/p ➔ $E_{EMC}/p < 0.7$, $E_{EMC}/p < 0.75$, $E_{EMC}/p < 0.85$ or $E_{EMC}/p < 0.9$.
  - Opening angle ➔ $\cos\theta_{\pi+\pi-} < 0.75$, $\cos\theta_{\pi+\pi-} < 0.8$, $\cos\theta_{\pi+\pi-} < 0.85$ or $\cos\theta_{\pi+\pi-} < 0.95$.
  - J/ψ, $\psi(2S)$, D, χ_c, K_s^0 veto ➔ 40 MeV, 45 MeV, 55 MeV or 60 MeV.
- Background: refit χ^2 distribution by varying bin size and fit range.
- Efficiency: varying AmpTools parameters determined by data at other energy points (4.00762/4.25797/4.35826/4.41558/4.59953 GeV).

Quoted

Source	$K^+K^-\pi^+\pi^-$	$K^+K^-K^+K^-$	$\pi^+\pi^-\pi^+\pi^-$	$p\bar{p}\pi^+\pi^-$	$K^+K^-\pi^+\pi^-\pi^0$	$K^+K^-K^+K^-\pi^0$	$\pi^+\pi^-\pi^+\pi^-\pi^0$	$p\bar{p}\pi^+\pi^-\pi^0$
Tracking	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
π^0 reconstruction	—	—	—	—	2.0%	2.0%	2.0%	2.0%
Luminosity	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Kinematic fit	0.2%	0.6%	0.7%	0.1%	0.1%	0.8%	0.8%	0.2%
$E_{\rm EMC}/p < 0.8$	2.2%	2.5%	2.8%	—	—	—	2.8%	—
$\cos\theta_{\pi^+\pi^-} < 0.9$	1.2%	—	0.8%	1.5%	—	—	—	—
J/ψ veto	0.5%	—	0.2%	0.1%	—	—	0.4%	—
$\psi(2S)$ veto	—	—	0.05%	0.04%	—	—	—	—
D veto	0.4%	—	—	—	0.01%	—	—	—
χ_c veto	—	—	—	—	0.08%	—	0.4%	—
K_S^0 veto	—	—	—	—	0.4%	—	0.6%	—
Background	0.4%	0.4%	0.1%	0.6%	1.1%	4.3%	1.1%	0.9%
Efficiency	0.5%	2.0%	1.3%	0.9%	0.8%	2.6%	2.1%	0.8%
Total	4.9%	5.3%	5.3%	4.5%	4.8%	6.8%	6.0%	4.7%

Systematic uncertainties – fit parameter

- The systematic uncertainty for fit parameters originates from the uncertainty of center-of-mass energies (E_{cm}), the uncertainty of cross sections and the uncertainty of ψ(4040) resonance parameters.
  - E_{cm} : changing center-of-mass energies with a standard deviation of 0.8 MeV.
  - cross sections: changing the value of cross sections by ±1σ.
  - ψ(4040) resonance parameters: changing the value ψ(4040) resonance parameters by ±1σ.
- The total systematic uncertainty is assigned by adding these values in quadrature.

Summary

- The cross sections of $e^+e^- \rightarrow K^+K^-\pi^+\pi^-(\pi^0)$, $K^+K^-K^+K^-(\pi^0)$, $\pi^+\pi^-\pi^+\pi^-(\pi^0)$, $pp\pi^+\pi^-(\pi^0)$ are obtained with data samples collected at 28 energy points from 3.8 to 4.6 GeV.
- Those cross sections are analyzed to obtained the relationship between cross sections and center-of-mass energy.
- We observe the $\psi(4040)$ decays to $\pi^+\pi^-\pi^+\pi^-\pi^0$ with a statistical significance of 3.1σ.
- No obvious Y (4260) signal is observed, so we provide the upper limits for $\Gamma^{ee} \times$ Br(Y(4260)→Light Hadrons) and Br(Y(4260)→Light Hadrons)/Br(Y(4260)→$J/\psi\pi^+\pi^-$) for those final states at 90% confidence level.

Thank you !

Back Up

Calculating ISR Corrections

Use a customized approach to the ISR corrections.

Ryan Mitchell
BESIII Collaboration Meeting
June 14, 2016

The number of observed events is, as usual:

$$N = \mathcal{L} \int \sigma(x)\varepsilon(x)W(x)dx \qquad \text{where} \qquad x = \frac{E_\gamma}{E_{\text{beam}}}$$

Factor out the Born cross section and the efficiency at $x = 0$:

$$N = \mathcal{L}\sigma_0\varepsilon_0 \int \frac{\sigma(x)}{\sigma_0}\frac{\varepsilon(x)}{\varepsilon_0}W(x)dx$$

Define the correction factor to be:

$$\kappa \equiv \int \frac{\sigma(x)}{\sigma_0}\frac{\varepsilon(x)}{\varepsilon_0}W(x)dx \qquad \text{so that} \qquad N = \mathcal{L}\sigma_0\varepsilon_0\kappa$$

Use MC to determine $\varepsilon(x)/\varepsilon_0$; take $W(x)$ from the ConExc note; determine kappa using numerical integration.

Table 4: Summary of the dressed cross sections for $e^+e^- \to K^+K^-\pi^+\pi^-$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm peaking}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	11502.0 ± 107.2	3.9	264.8	0.3621	0.7539	85.3840 ± 0.8152
3.80765	50.54	1614.0 ± 40.2	0.0	26.3	0.3544	0.7551	117.3875 ± 2.9703
3.89624	52.61	1498.0 ± 38.7	2.0	21.4	0.3634	0.7493	102.9306 ± 2.7016
4.08545	52.86	1075.0 ± 32.8	2.3	28.1	0.3697	0.7493	71.3399 ± 2.2392
4.18859	43.33	810.0 ± 28.5	1.0	22.3	0.3788	0.7507	63.8516 ± 2.3100
4.20773	54.95	989.0 ± 31.4	1.4	29.6	0.3814	0.7489	61.0347 ± 2.0036
4.21713	54.60	999.0 ± 31.6	1.2	27.7	0.3802	0.7555	61.8575 ± 2.0154
4.22626	44.54	850.0 ± 29.2	0.8	21.7	0.3793	0.7511	65.2170 ± 2.2977
4.22626	1056.37	19005.0 ± 137.9	19.3	567.3	0.3759	0.7511	61.7500 ± 0.4622
4.24166	55.88	971.0 ± 31.2	0.7	32.0	0.3789	0.7538	58.7923 ± 1.9525
4.25797	828.36	14153.0 ± 119.0	9.8	466.3	0.3790	0.7489	58.1723 ± 0.5060
4.30789	45.08	720.0 ± 26.8	0.4	27.9	0.3810	0.7480	53.8439 ± 2.0887
4.35826	543.94	8188.0 ± 90.5	5.9	316.6	0.3865	0.7480	50.0204 ± 0.5755
4.38740	55.57	785.0 ± 28.0	0.7	35.7	0.3902	0.7500	46.0333 ± 1.7229
4.41558	46.80	680.0 ± 26.1	0.6	28.2	0.3888	0.7507	47.6764 ± 1.9092
4.41558	1043.86	14816.0 ± 121.7	13.3	542.1	0.3896	0.7487	46.8357 ± 0.3998
4.46706	111.09	1433.0 ± 37.9	1.4	69.6	0.3900	0.7437	42.2689 ± 1.1748
4.52714	112.12	1436.0 ± 37.9	1.2	71.8	0.3902	0.7456	41.7857 ± 1.1617
4.57450	48.93	548.0 ± 23.4	0.4	32.5	0.3986	0.7397	35.7052 ± 1.6227
4.59953	586.89	6619.0 ± 81.4	4.5	348.5	0.3973	0.7461	36.0189 ± 0.4677
4.18899	524.60	9834.0 ± 99.2	12.4	251.4	0.3695	0.7459	66.1926 ± 0.6859
4.19903	526.00	9497.0 ± 97.5	13.5	248.7	0.3721	0.7507	62.8538 ± 0.6633
4.20925	518.00	9363.0 ± 96.8	12.9	251.8	0.3693	0.7473	63.6455 ± 0.6769
4.21884	514.60	9050.0 ± 95.1	11.1	271.7	0.3729	0.7460	61.2459 ± 0.6646
4.23582	530.30	9279.0 ± 96.3	7.7	272.2	0.3767	0.7471	60.2981 ± 0.6454
4.24393	538.10	9340.0 ± 96.6	6.8	280.1	0.3772	0.7489	59.5554 ± 0.6358
4.26680	531.10	8830.0 ± 94.0	6.1	282.6	0.3839	0.7492	55.9184 ± 0.6152
4.27774	175.70	2841.0 ± 53.3	1.8	98.5	0.3737	0.7472	55.8674 ± 1.0865

Table 5: Summary of the dressed cross sections for $e^+e^- \to K^+K^-K^+K^-$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	1400.0 ± 37.4	127.7	0.2777	0.7416	12.8177 ± 0.3770
3.80765	50.54	172.0 ± 13.1	10.6	0.2551	0.7386	16.9492 ± 1.3772
3.89624	52.61	179.0 ± 13.4	11.8	0.2680	0.7383	16.0612 ± 1.2852
4.08545	52.86	137.0 ± 11.7	14.8	0.2886	0.7397	10.8294 ± 1.0373
4.18859	43.33	113.0 ± 10.6	13.4	0.3028	0.7377	10.2901 ± 1.0982
4.20773	54.95	128.0 ± 11.3	15.0	0.3075	0.7374	9.0694 ± 0.9080
4.21713	54.60	130.0 ± 11.4	14.6	0.3068	0.7382	9.3319 ± 0.9220
4.22626	44.54	124.0 ± 11.1	10.6	0.3057	0.7372	11.2967 ± 1.1093
4.22626	1056.37	2580.0 ± 50.8	187.9	0.3058	0.7375	10.0404 ± 0.2132
4.24166	55.88	125.0 ± 11.2	7.5	0.3105	0.7398	9.1538 ± 0.8710
4.25797	828.36	1955.0 ± 44.2	153.3	0.3083	0.7377	9.5635 ± 0.2347
4.30789	45.08	105.0 ± 10.2	7.7	0.3159	0.7338	9.3117 ± 0.9806
4.35826	543.94	1192.0 ± 34.5	101.5	0.3228	0.7342	8.4588 ± 0.2678
4.38740	55.57	125.0 ± 11.2	8.7	0.3262	0.7412	8.6565 ± 0.8322
4.41558	46.80	102.0 ± 10.1	8.2	0.3282	0.7407	8.2444 ± 0.8877
4.41558	1043.86	2045.0 ± 45.2	169.0	0.3278	0.7382	7.4270 ± 0.1790
4.46706	111.09	212.0 ± 14.6	17.5	0.3304	0.7374	7.1860 ± 0.5379
4.52714	112.12	186.0 ± 13.6	16.5	0.3390	0.7308	6.1021 ± 0.4910
4.57450	48.93	74.0 ± 8.6	7.5	0.3437	0.7335	5.3910 ± 0.6974
4.59953	586.89	970.0 ± 31.1	80.4	0.3469	0.7365	5.9330 ± 0.2077
4.18899	524.60	1223.0 ± 35.0	119.7	0.2964	0.7324	9.6884 ± 0.3071
4.19903	526.00	1265.0 ± 35.6	124.1	0.2991	0.7361	9.8510 ± 0.3071
4.20925	518.00	1263.0 ± 35.5	114.5	0.2967	0.7339	10.1830 ± 0.3151
4.21884	514.60	1246.0 ± 35.3	92.8	0.2967	0.7362	10.2588 ± 0.3140
4.23582	530.30	1278.0 ± 35.7	95.0	0.3063	0.7303	9.9725 ± 0.3014
4.24393	538.10	1300.0 ± 36.1	97.5	0.3069	0.7302	9.9725 ± 0.2990
4.26680	531.10	1222.0 ± 35.0	76.1	0.3111	0.7333	9.4578 ± 0.2885
4.27774	175.70	406.0 ± 20.1	37.2	0.3075	0.7300	9.3514 ± 0.5109

Table 6: Summary of the dressed cross sections for $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	18237.0 ± 135.0	64.2	0.4386	0.7482	114.9006 ± 0.8538
3.80765	50.54	2774.0 ± 52.7	9.8	0.4421	0.7459	165.8527 ± 3.1601
3.89624	52.61	2435.0 ± 49.3	5.1	0.4408	0.7472	140.2237 ± 2.8476
4.08545	52.86	1757.0 ± 41.9	9.8	0.4365	0.7492	101.0761 ± 2.4249
4.18859	43.33	1261.0 ± 35.5	4.3	0.4350	0.7399	90.1130 ± 2.5463
4.20773	54.95	1624.0 ± 40.3	11.3	0.4321	0.7407	91.6999 ± 2.2914
4.21713	54.60	1462.0 ± 38.2	7.7	0.4361	0.7412	82.4065 ± 2.1666
4.22626	44.54	1195.0 ± 34.6	8.0	0.4344	0.7403	82.8739 ± 2.4135
4.22626	1056.37	28689.0 ± 169.4	71.7	0.4332	0.7438	84.0723 ± 0.4976
4.24166	55.88	1471.0 ± 38.4	10.5	0.4331	0.7423	81.2961 ± 2.1349
4.25797	828.36	21310.0 ± 146.0	97.9	0.4323	0.7409	79.9467 ± 0.5502
4.30789	45.08	1081.0 ± 32.9	7.9	0.4286	0.7422	74.8322 ± 2.2928
4.35826	543.94	11935.0 ± 109.2	63.7	0.4293	0.7414	68.5721 ± 0.6310
4.38740	55.57	1180.0 ± 34.4	8.7	0.4299	0.7443	65.8766 ± 1.9320
4.41558	46.80	965.0 ± 31.1	6.7	0.4308	0.7429	63.9851 ± 2.0742
4.41558	1043.86	20305.0 ± 142.5	102.1	0.4291	0.7383	61.0951 ± 0.4309
4.46706	111.09	2065.0 ± 45.4	23.0	0.4272	0.7376	58.3389 ± 1.2983
4.52714	112.12	1907.0 ± 43.7	21.9	0.4238	0.7321	54.1868 ± 1.2553
4.57450	48.93	733.0 ± 27.1	7.0	0.4248	0.7396	47.2273 ± 1.7612
4.59953	586.89	8874.0 ± 94.2	77.0	0.4236	0.7389	47.8889 ± 0.5128
4.18899	524.60	14930.0 ± 122.2	67.2	0.4278	0.7415	89.3154 ± 0.7343
4.19903	526.00	14405.0 ± 120.0	78.5	0.4325	0.7444	84.5939 ± 0.7087
4.20925	518.00	13812.0 ± 117.5	102.9	0.4258	0.7457	83.3477 ± 0.7145
4.21884	514.60	13954.0 ± 118.1	70.7	0.4238	0.7420	85.7886 ± 0.7299
4.23582	530.30	14014.0 ± 118.4	62.4	0.4300	0.7407	82.6020 ± 0.7009
4.24393	538.10	13738.0 ± 117.2	69.8	0.4335	0.7388	79.3104 ± 0.6801
4.26680	531.10	13309.0 ± 115.4	56.4	0.4315	0.7408	78.0670 ± 0.6796
4.27774	175.70	4318.0 ± 65.7	30.7	0.4251	0.7410	77.4667 ± 1.1873

Table 7: Summary of the dressed cross sections for $e^+e^- \to p\bar{p}\pi^+\pi^-$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	5061.0 ± 71.1	426.3	0.5277	0.7459	24.4305 ± 0.3750
3.80765	50.54	736.0 ± 27.1	44.1	0.5228	0.7415	35.3129 ± 1.3846
3.89624	52.61	682.0 ± 26.1	35.9	0.5250	0.7391	31.6516 ± 1.2793
4.08545	52.86	472.0 ± 21.7	42.1	0.5323	0.7401	20.6451 ± 1.0433
4.18859	43.33	387.0 ± 19.7	31.7	0.5369	0.7390	20.6658 ± 1.1442
4.20773	54.95	447.0 ± 21.1	46.6	0.5377	0.7426	18.2483 ± 0.9636
4.21713	54.60	461.0 ± 21.5	37.7	0.5391	0.7415	19.3935 ± 0.9837
4.22626	44.54	346.0 ± 18.6	36.1	0.5361	0.7417	17.4981 ± 1.0503
4.22626	1056.37	8036.0 ± 89.6	729.2	0.5370	0.7416	17.3685 ± 0.2131
4.24166	55.88	399.0 ± 20.0	35.1	0.5398	0.7431	16.2339 ± 0.8911
4.25797	828.36	6229.0 ± 78.9	553.4	0.5384	0.7403	17.1909 ± 0.2391
4.30789	45.08	322.0 ± 17.9	29.4	0.5400	0.7416	16.2075 ± 0.9940
4.35826	543.94	3499.0 ± 59.2	388.5	0.5429	0.7417	14.2020 ± 0.2701
4.38740	55.57	351.0 ± 18.7	38.8	0.5458	0.7444	13.8286 ± 0.8299
4.41558	46.80	268.0 ± 16.4	29.8	0.5439	0.7441	12.5757 ± 0.8643
4.41558	1043.86	6356.0 ± 79.7	688.9	0.5398	0.7423	13.5495 ± 0.1906
4.46706	111.09	632.0 ± 25.1	69.0	0.5433	0.7410	12.5878 ± 0.5621
4.52714	112.12	624.0 ± 25.0	73.4	0.5432	0.7384	12.2441 ± 0.5555
4.57450	48.93	240.0 ± 15.5	27.3	0.5441	0.7421	10.7665 ± 0.7842
4.59953	586.89	2786.0 ± 52.8	362.5	0.5442	0.7353	10.3195 ± 0.2248
4.18899	524.60	4254.0 ± 65.2	389.6	0.5293	0.7425	18.7428 ± 0.3163
4.19903	526.00	4174.0 ± 64.6	364.4	0.5322	0.7415	18.3519 ± 0.3112
4.20925	518.00	4080.0 ± 63.9	364.7	0.5268	0.7362	18.4929 ± 0.3179
4.21884	514.60	3907.0 ± 62.5	350.4	0.5260	0.7396	17.7664 ± 0.3122
4.23582	530.30	4216.0 ± 64.9	342.3	0.5344	0.7402	18.4676 ± 0.3096
4.24393	538.10	4163.0 ± 64.5	342.6	0.5348	0.7393	17.9572 ± 0.3033
4.26680	531.10	3923.0 ± 62.6	335.8	0.5340	0.7371	17.1608 ± 0.2996
4.27774	175.70	1195.0 ± 34.6	110.0	0.5281	0.7405	15.7923 ± 0.5032

Table 8: Summary of the dressed cross sections for $e^+e^- \to K^+K^-\pi^+\pi^-\pi^0$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm peaking}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	16536.0 ± 128.6	17.0	1276.7	0.2655	0.7737	155.8014 ± 1.3144
3.80765	50.54	2089.0 ± 45.7	0.4	116.2	0.2630	0.7706	194.8696 ± 4.5156
3.89624	52.61	1958.0 ± 44.2	7.1	113.4	0.2617	0.7711	175.1364 ± 4.2175
4.08545	52.86	1638.0 ± 40.5	7.8	119.9	0.2667	0.7723	140.3648 ± 3.7614
4.18859	43.33	1157.0 ± 34.0	3.7	92.0	0.2719	0.7733	117.8717 ± 3.7778
4.20773	54.95	1530.0 ± 39.1	5.6	108.5	0.2743	0.7762	122.4708 ± 3.3833
4.21713	54.60	1502.0 ± 38.8	5.4	109.9	0.2725	0.7761	121.5137 ± 3.3961
4.22626	44.54	1215.0 ± 34.9	4.3	87.4	0.2761	0.7764	119.0587 ± 3.6945
4.22626	1056.37	28265.0 ± 168.1	102.7	1970.9	0.2741	0.7747	118.1582 ± 0.7585
4.24166	55.88	1416.0 ± 37.6	4.6	104.9	0.2728	0.7727	112.2448 ± 3.2329
4.25797	828.36	21428.0 ± 146.4	57.5	1583.4	0.2725	0.7737	114.6415 ± 0.8481
4.30789	45.08	1109.0 ± 33.3	2.5	88.5	0.2807	0.7727	105.3595 ± 3.4466
4.35826	543.94	12564.0 ± 112.1	27.4	971.0	0.2789	0.7692	100.2975 ± 0.9720
4.38740	55.57	1265.0 ± 35.6	2.8	97.7	0.2803	0.7725	97.9245 ± 2.9909
4.41558	46.80	1036.0 ± 32.2	2.4	81.1	0.2828	0.7689	94.7162 ± 3.2007
4.41558	1043.86	22949.0 ± 151.5	53.3	1728.7	0.2794	0.7742	94.8571 ± 0.6789
4.46706	111.09	2379.0 ± 48.8	5.4	182.7	0.2814	0.7756	91.4427 ± 2.0357
4.52714	112.12	2235.0 ± 47.3	4.7	178.4	0.2794	0.7718	85.8823 ± 1.9787
4.57450	48.93	902.0 ± 30.0	1.7	65.7	0.2824	0.7740	78.9691 ± 2.8417
4.59953	586.89	10880.0 ± 104.3	18.1	884.7	0.2840	0.7687	78.8000 ± 0.8238
4.18899	524.60	14311.0 ± 119.6	45.1	1036.7	0.2679	0.7764	122.6805 ± 1.1094
4.19903	526.00	14454.0 ± 120.2	51.0	1035.1	0.2704	0.7735	122.9494 ± 1.1058
4.20925	518.00	13632.0 ± 116.8	52.6	998.0	0.2677	0.7749	118.4772 ± 1.0995
4.21884	514.60	13494.0 ± 116.2	51.0	957.5	0.2689	0.7698	118.6034 ± 1.1035
4.23582	530.30	13930.0 ± 118.0	48.0	952.0	0.2738	0.7689	117.1939 ± 1.0697
4.24393	538.10	13844.0 ± 117.7	42.8	982.8	0.2709	0.7760	114.6702 ± 1.0526
4.26680	531.10	13443.0 ± 115.9	35.3	941.2	0.2733	0.7669	113.3263 ± 1.0540
4.27774	175.70	4327.0 ± 65.8	10.7	307.8	0.2714	0.7718	110.2080 ± 1.8085

Table 9: Summary of the dressed cross sections for $e^+e^- \to K^+K^-K^+K^-\pi^0$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	1160.0 ± 34.1	674.3	0.2097	0.7530	6.4582 ± 0.4529
3.80765	50.54	114.0 ± 10.7	59.7	0.1962	0.7468	7.4204 ± 1.4591
3.89624	52.61	108.0 ± 10.4	58.2	0.2020	0.7504	6.3193 ± 1.3187
4.08545	52.86	124.0 ± 11.1	94.5	0.2159	0.7451	3.5103 ± 1.3251
4.18859	43.33	115.0 ± 10.7	74.7	0.2238	0.7484	5.6193 ± 1.4953
4.20773	54.95	127.0 ± 11.3	76.3	0.2258	0.7514	5.5025 ± 1.2231
4.21713	54.60	130.0 ± 11.4	76.5	0.2264	0.7474	5.8595 ± 1.2488
4.22626	44.54	100.0 ± 10.0	54.8	0.2276	0.7459	6.0492 ± 1.3383
4.22626	1056.37	2335.0 ± 48.3	1230.0	0.2271	0.7517	6.2005 ± 0.2711
4.24166	55.88	111.0 ± 10.5	60.2	0.2280	0.7495	5.3830 ± 1.1164
4.25797	828.36	1705.0 ± 41.3	871.7	0.2292	0.7500	5.9217 ± 0.2934
4.30789	45.08	80.0 ± 8.9	50.9	0.2319	0.7450	3.7810 ± 1.1622
4.35826	543.94	1191.0 ± 34.5	631.6	0.2357	0.7436	5.9377 ± 0.3663
4.38740	55.57	115.0 ± 10.7	66.3	0.2365	0.7507	4.9949 ± 1.0999
4.41558	46.80	102.0 ± 10.1	54.7	0.2402	0.7448	5.7165 ± 1.2206
4.41558	1043.86	2122.0 ± 46.1	1145.5	0.2381	0.7538	5.2740 ± 0.2488
4.46706	111.09	206.0 ± 14.4	107.5	0.2396	0.7510	4.9862 ± 0.7266
4.52714	112.12	180.0 ± 13.4	98.7	0.2404	0.7519	4.0595 ± 0.6699
4.57450	48.93	90.0 ± 9.5	42.8	0.2449	0.7527	5.2954 ± 1.0643
4.59953	586.89	1027.0 ± 32.0	500.7	0.2458	0.7485	4.9322 ± 0.3003
4.18899	524.60	1323.0 ± 36.4	830.7	0.2197	0.7454	5.7986 ± 0.4284
4.19903	526.00	1309.0 ± 36.2	779.8	0.2214	0.7492	6.1376 ± 0.4196
4.20925	518.00	1200.0 ± 34.6	697.6	0.2186	0.7435	6.0382 ± 0.4163
4.21884	514.60	1136.0 ± 33.7	643.8	0.2203	0.7510	5.8502 ± 0.4006
4.23582	530.30	1153.0 ± 34.0	555.1	0.2258	0.7538	6.7028 ± 0.3807
4.24393	538.10	1066.0 ± 32.6	532.6	0.2254	0.7495	5.9375 ± 0.3634
4.26680	531.10	1023.0 ± 32.0	513.0	0.2274	0.7484	5.7096 ± 0.3581
4.27774	175.70	344.0 ± 18.5	175.1	0.2260	0.7502	5.7372 ± 0.6300

Table 10: Summary of the dressed cross sections for $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	5882.0 ± 76.7	210.8	0.2494	0.7685	62.1280 ± 0.8402
3.80765	50.54	798.0 ± 28.2	28.3	0.2563	0.7684	78.2545 ± 2.8720
3.89624	52.61	677.0 ± 26.0	18.3	0.2515	0.7622	66.0904 ± 2.6106
4.08545	52.86	568.0 ± 23.8	20.2	0.2458	0.7687	55.5015 ± 2.4147
4.18859	43.33	383.0 ± 19.6	11.7	0.2487	0.7649	45.5842 ± 2.4026
4.20773	54.95	483.0 ± 22.0	20.9	0.2492	0.7675	44.4918 ± 2.1160
4.21713	54.60	478.0 ± 21.9	21.7	0.2481	0.7663	44.4797 ± 2.1312
4.22626	44.54	371.0 ± 19.3	15.7	0.2473	0.7618	42.8490 ± 2.3229
4.22626	1056.37	8726.0 ± 93.4	387.1	0.2455	0.7641	42.5823 ± 0.4770
4.24166	55.88	458.0 ± 21.4	19.5	0.2471	0.7739	41.5214 ± 2.0264
4.25797	828.36	6687.0 ± 81.8	295.1	0.2468	0.7624	41.4988 ± 0.5309
4.30789	45.08	344.0 ± 18.5	17.4	0.2475	0.7686	38.5399 ± 2.1886
4.35826	543.94	3958.0 ± 62.9	189.1	0.2505	0.7550	37.0734 ± 0.6189
4.38740	55.57	398.0 ± 19.9	22.0	0.2472	0.7679	36.0677 ± 1.9137
4.41558	46.80	332.0 ± 18.2	17.6	0.2460	0.7652	36.1144 ± 2.0930
4.41558	1043.86	6989.0 ± 83.6	347.8	0.2489	0.7664	33.7496 ± 0.4248
4.46706	111.09	707.0 ± 26.6	36.4	0.2471	0.7672	32.2237 ± 1.2777
4.52714	112.12	630.0 ± 25.1	42.4	0.2495	0.7683	27.6672 ± 1.1818
4.57450	48.93	274.0 ± 16.6	18.3	0.2505	0.7658	27.5660 ± 1.7845
4.59953	586.89	3129.0 ± 55.9	191.5	0.2500	0.7596	26.6715 ± 0.5079
4.18899	524.60	4416.0 ± 66.5	190.9	0.2445	0.7667	43.4749 ± 0.6838
4.19903	526.00	4381.0 ± 66.2	193.6	0.2481	0.7644	42.4775 ± 0.6714
4.20925	518.00	4210.0 ± 64.9	185.6	0.2441	0.7674	41.9660 ± 0.6766
4.21884	514.60	4120.0 ± 64.2	184.7	0.2433	0.7629	41.6920 ± 0.6800
4.23582	530.30	4269.0 ± 65.3	180.0	0.2489	0.7622	41.1296 ± 0.6572
4.24393	538.10	4365.0 ± 66.1	174.7	0.2488	0.7663	41.3306 ± 0.6517
4.26680	531.10	4107.0 ± 64.1	174.4	0.2455	0.7668	39.8035 ± 0.6486
4.27774	175.70	1299.0 ± 36.0	64.8	0.2453	0.7685	37.7068 ± 1.1011

Table 11: Summary of the dressed cross sections for $e^+e^- \to p\bar{p}\pi^+\pi^-\pi^0$. Errors are statistical only.

$E_{\rm cm}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	$N^{\rm bkg}_{\rm peaking}$	$N^{\rm bkg}_{\rm non-peaking}$	ϵ_0	κ	$\sigma^{\rm Dressed}$ (pb)
4.00762	481.96	6600.0 ± 81.2	2.7	1227.0	0.3106	0.7559	48.0268 ± 0.7265
3.80765	50.54	738.0 ± 27.2	0.2	113.9	0.2926	0.7517	56.7967 ± 2.4731
3.89624	52.61	718.0 ± 26.8	0.3	107.5	0.2993	0.7550	51.9380 ± 2.2807
4.08545	52.86	653.0 ± 25.6	0.3	130.0	0.3111	0.7561	42.5386 ± 2.0796
4.18859	43.33	492.0 ± 22.2	0.2	105.0	0.3229	0.7534	37.1331 ± 2.1294
4.20773	54.95	648.0 ± 25.5	0.7	112.1	0.3232	0.7522	40.5403 ± 1.9282
4.21713	54.60	608.0 ± 24.7	1.0	107.1	0.3226	0.7549	38.0424 ± 1.8764
4.22626	44.54	520.0 ± 22.8	1.1	85.9	0.3249	0.7531	40.2040 ± 2.1173
4.22626	1056.37	11623.0 ± 107.8	25.7	1936.4	0.3241	0.7573	37.7067 ± 0.4208
4.24166	55.88	593.0 ± 24.4	1.5	95.2	0.3234	0.7517	36.9675 ± 1.8139
4.25797	828.36	9118.0 ± 95.5	16.5	1444.6	0.3240	0.7584	38.0642 ± 0.4747
4.30789	45.08	454.0 ± 21.3	0.8	79.5	0.3293	0.7585	33.5825 ± 1.9148
4.35826	543.94	5312.0 ± 72.9	5.3	935.8	0.3293	0.7556	32.6817 ± 0.5450
4.38740	55.57	555.0 ± 23.6	0.4	96.8	0.3331	0.7538	33.1990 ± 1.7084
4.41558	46.80	455.0 ± 21.3	0.3	78.5	0.3333	0.7570	32.2371 ± 1.8279
4.41558	1043.86	10025.0 ± 100.1	6.3	1729.2	0.3299	0.7569	32.1800 ± 0.3887
4.46706	111.09	988.0 ± 31.4	0.5	175.0	0.3346	0.7507	29.4662 ± 1.1399
4.52714	112.12	906.0 ± 30.1	0.5	165.5	0.3382	0.7555	26.1402 ± 1.0633
4.57450	48.93	418.0 ± 20.4	0.2	65.3	0.3419	0.7507	28.4032 ± 1.6474
4.59953	586.89	4628.0 ± 68.0	2.1	778.8	0.3426	0.7558	25.6182 ± 0.4530
4.18899	524.60	5946.0 ± 77.1	2.9	1144.1	0.3139	0.7512	39.2564 ± 0.6308
4.19903	526.00	5965.0 ± 77.2	4.6	1119.0	0.3169	0.7581	38.7688 ± 0.6185
4.20925	518.00	5738.0 ± 75.7	6.9	1052.0	0.3157	0.7557	38.3140 ± 0.6203
4.21884	514.60	5414.0 ± 73.6	9.6	991.6	0.3152	0.7551	36.4598 ± 0.6079
4.23582	530.30	5749.0 ± 75.8	14.7	923.2	0.3217	0.7522	37.9378 ± 0.5979
4.24393	538.10	5644.0 ± 75.1	13.4	916.4	0.3221	0.7591	36.2551 ± 0.5778
4.26680	531.10	5511.0 ± 74.2	10.0	867.4	0.3220	0.7563	36.2525 ± 0.5808
4.27774	175.70	1786.0 ± 42.3	3.2	293.6	0.3204	0.7572	35.3507 ± 1.0032