Search for BNV process $J/\psi \to pe^-(\bar{p}e^+)$ via $\psi(2S) \to \pi^+\pi^- J/\psi$,

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BESIII Physics and Software meeting

Outline

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2. Data Samples, Monte Carlo simulation and software
3. Event Selection
4. Cut Flow
5. Systematic Uncertainty
6. Upper Limit of Signal
7. IO check results
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Motivation

- If baryon number is conserved, in the process of baryon generation and annihilation of baryon-antibaryon pairs, the baryon number should always be 0, which means there should not be more matter than antimatter. But it is observed to depart from the fact. So, Sakharov put forward three rules:
  (1) Baryon number violating (BNV).
  (2) C violation and CP violation.
  (3) Out of thermal equilibrium.
- As many theories have suggested, even a small amount of BNV processes can cause great influence on the universe and its evolution. Searching for BNV processes can help to learn the origin of matter and expend the standard model.
- $J/\psi \to pe^-/\bar{p}e^+$ is a baryon number violating process with $\Delta(B-L)=0$.

Data Samples

- Data samples： NPG semi-blind data
- Inclusive MC: 2748M $\psi(2S)$ MC samples (2009, 2012, 2021)
- BOSS version: 7.0.9
- Generator:

```
Decay psi(2S)
1.0 J/psi  pi+ pi-                 JPIPI;
Enddecay

Decay J/psi
1.0   anti-p-   e+                PHSP;
Enddecay


End
```

```
Decay psi(2S)
1.0 J/psi  pi+ pi-                 JPIPI;
Enddecay

Decay J/psi
1.0   p+   e-                PHSP;
Enddecay


End
```

Event Selection

- 1. Total tracks ≥ 4
- 2. 4 good charged tracks, Total charge = 0

  $|V_z|$ < 10 cm

  V_r < 1 cm

  $|\cos\theta|$ < 0.93
- 3. PID (Combine dE/dx and TOF)

  pion: $|p_\pi| < 0.45\ \mathrm{GeV}/c^2$

  electron: $\frac{CL_e}{CL_e+CL_\pi+CL_K} > 0.8$, $CL_e > 0.001$, $0.8 < E/p$

  proton: $CL_p > CL_K, CL_p > CL_\pi, CL_p > CL_e, CL_p > 0.001$
- 4. 4c kinematic fit: $\chi^2(\pi^+\pi^-pe^-) < \chi^2(\pi^+\pi^-e^+e^-)$,

  $\chi^2(\pi^+\pi^-pe^-) < \chi^2(\pi^+\pi^-\pi^+\pi^-)$,

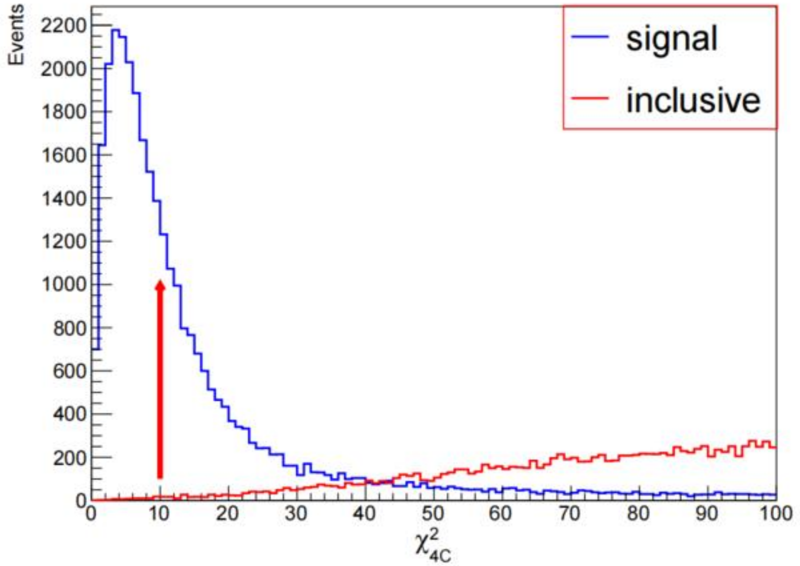
  $\chi^2(\pi^+\pi^-pe^-) < \chi^2(\pi^+\pi^-\mu^+\mu^-)$,

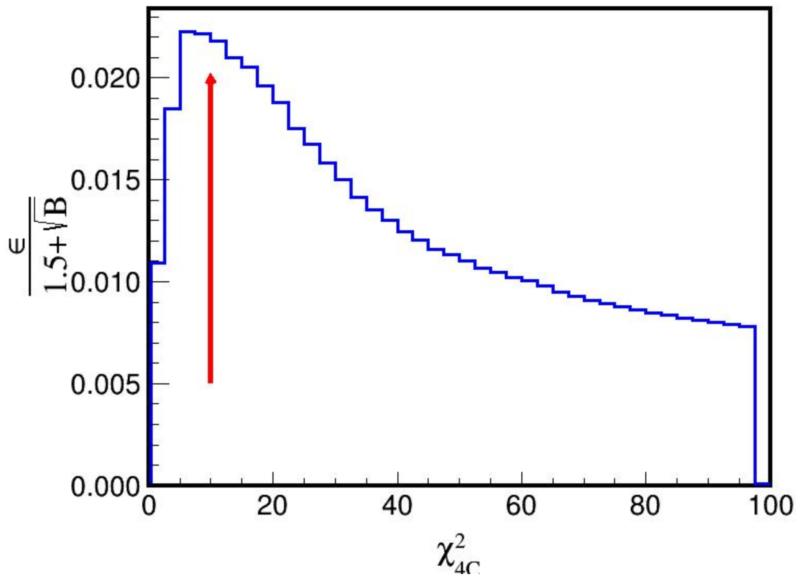
  $\chi^2(\pi^+\pi^-pe^-) < \chi^2(\pi^+\pi^-K^+K^-)$,

  $\chi^2(\pi^+\pi^-pe^-) < \chi^2(\pi^+\pi^-p\,\bar{p})$;

Event Selection

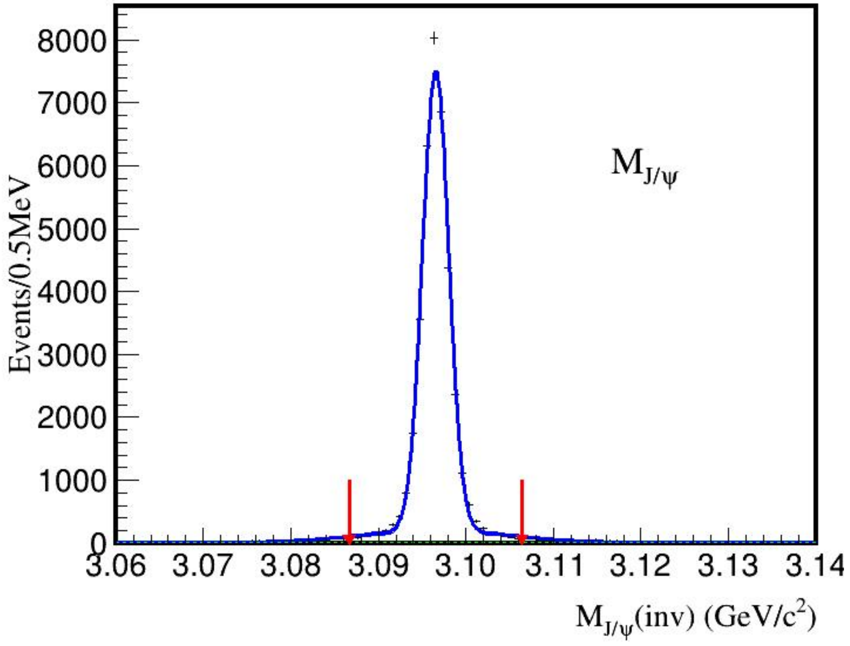
- $5.\ \chi^2(\pi^+\pi^-\bar{p}e^+) \leq 10$ (determined by Punzi significance method)

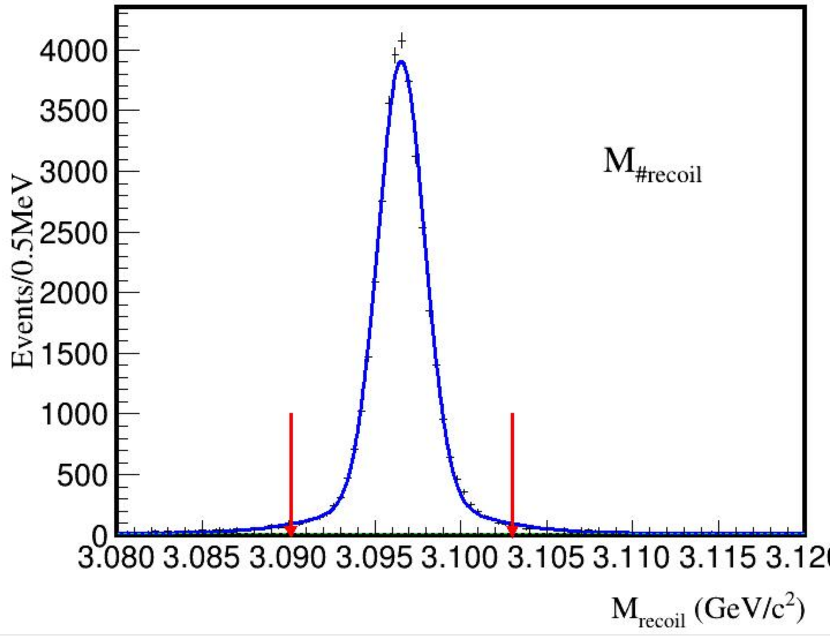




Signal region

Signal shape model:
Double Gaussian function
Background shape model:
second-order Chebychev function





μ = 3.097 GeV
σ = 0.002GeV
[μ -3σ,μ +3σ] = [3.091, 3.102]

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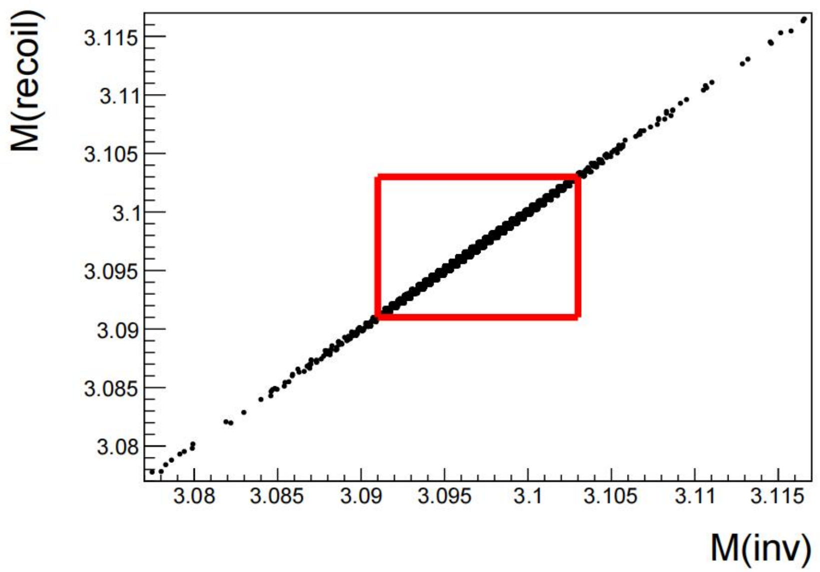
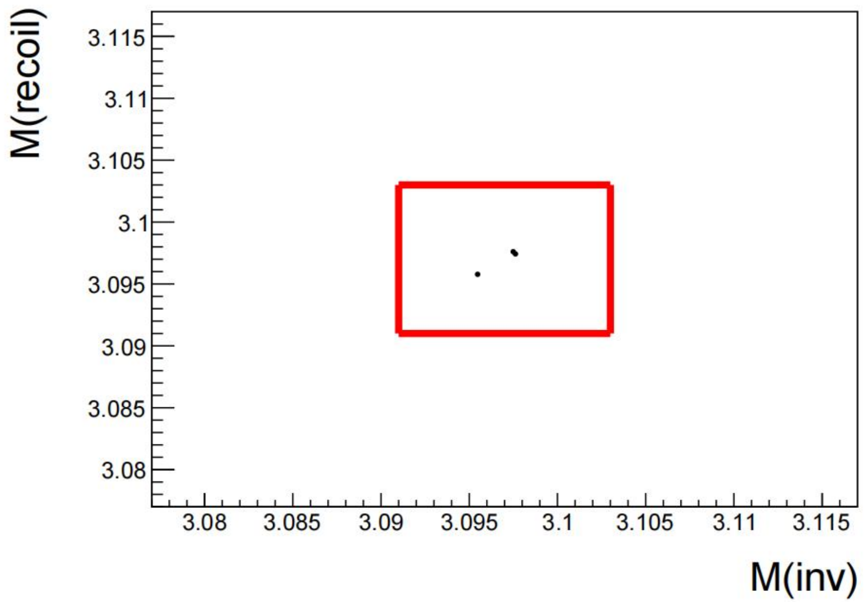
σ = 0.002 GeV
[μ -3σ,μ +3σ] = [3.091, 3.102]

2D distribution



signal MC



inclusive MC

signal region = $[\mu -3\sigma, \mu +3\sigma]$
x-axis region = $[\mu -10\sigma, \mu +10\sigma]$
y-axis region = $[\mu -10\sigma, \mu +10\sigma]$

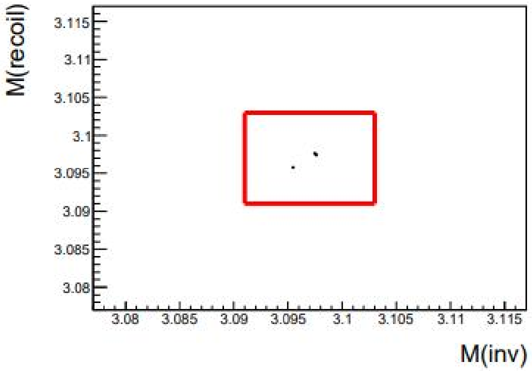
Cut flow

	pe^-efficiency (%)	$\bar{p}e^+$ efficiency (%)	inclusiveMC Absolute efficiency (%)
Total number	100000 (100, 100)	100000 (100, 100)	2748000000 (100, 100)
Charged tracks >= 4	77603 (77.60, 77.60)	78602 (78.60, 78.60)	1918480114 (69.81, 69.81)
Good charged tracks = 4	63859 (63.86, 82.29)	63543 (63.54, 80.84)	670439126 (24.40, 34.95)
After particle ID	52828 (52.83, 82.73)	51658 (51.66, 81.30)	2623404 (0.10, 0.39)
After 4c kinematic fit	42102 (42.10, 79.70)	40422 (40.42, 78.25)	89949 (3.27E-03, 3.43)
χ^2min	41803 (41.80, 99.29)	40132 (40.13, 99.28)	9994 (3.64e-04, 11.11)
χ^2<10	22011 (22.01, 52.65)	21051 (21.1, 52.45)	8 (2.91e-07, 0.08)
signal region	20431 (20.43, 98.71)	19539 (19.53, 98.81)	3 (1.09e-07, 37.5)

Background Study

- After applying all cuts to inclusive MC (2748M from 2009, 2012 and 2021), there are 3 events left in the signal region (red box).

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-\gamma^f\gamma^f$	$e^+e^-\pi^+\pi^-\gamma^f\gamma^f$	0	2	2
2	$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to e^+e^-\gamma^f$	$e^+e^-\pi^+\pi^-\gamma^f$	1	1	3



Continue background

At 3.650GeV and 3.680GeV, 0 events survived from data sample.

Events selection	3650	3680
Total events	1995337496	1205457414
nCharged ≥ 4	17599575	16962236
nGood Charge Tracks =4	2629392	4228460
After particle ID	35873	37079
Kinematic fit	1006	810
χ^2min	137	106
$\chi^2 < 10$	9	2
Signal window cut	0	0

Systematic Uncertainty

- Total Number of $\psi(3686)$
  We quote the BESIII measurement of $N_{\psi(3686)} = (2704 \pm 101)\times 10^{6}$, where the uncertainty is the systematic and the statistical one is negligible. Here we take 0.6% as the systematic uncertainty[1].

- Br ($\psi(3686) \to \pi^{+}\pi^{-} J/\psi$)
  The input $\mathrm{Br}\left(\psi(3686) \to \pi^{+}\pi^{-} \mathrm{J}/\psi\right) = (34.68 \pm 0.02 \pm 0.45)\%$ is cited from Ref[2]. The uncertainty of the input Br should be considered in the systematic errors, which is 1.3%.

[1] C. liu et al. (BESIII Collaboration), Report on Collaboration Meeting in Summer 2022
[2] M. Ablikim er al., Phys. Rev. D 88(2013) 3, 032007
[3] M. Ablikim er al., Phys. Rev. D 99 (2019) , 112010

Systematic Uncertainty

- Tracking Efficiency and Particle Identification Efficiency

The uncertainties on the tracking efficiency and particle identificancation efficiency are estimated with control sample $J/\psi -> \pi^+\pi^-\pi^0$, $J/\psi -> e^+e^-\gamma_{FSR}$, $J/\psi -> \pi^+\pi^- p\,\bar{p}$ and $J/\psi -> \pi^0 K^+ K^-$[2].

	MDC tracking	PID
pion	0.3%	1.0%
electron	0.7%	1.1%
proton	1.0%	2.8%

[1] C.liu et al. (BESIII Collaboration), Report on Collaboration Meeting in Summer 2022
[2] M.Ablikim et al., Phys.Rev. D 105, 032006, (2022).
[3] M.Ablikim er al.,Phys.Rev. D 99 (2019) , 112010

Systematic Uncertainty

- For $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to pe$, the final state is $\pi^+\pi^- pe$. The systematic error introduced by the 4C kinematic fit can be studied by the Helix correction .

	pe^-		$\bar{p}e^+$	
Requirement	before	after	before	after
Selection Efficiency	22.01%	19.36%	21.1%	17.11%
Error from 4C Kinematic Fit	12.04%		18.91%	

Uncertainty in Mass Window（pe）

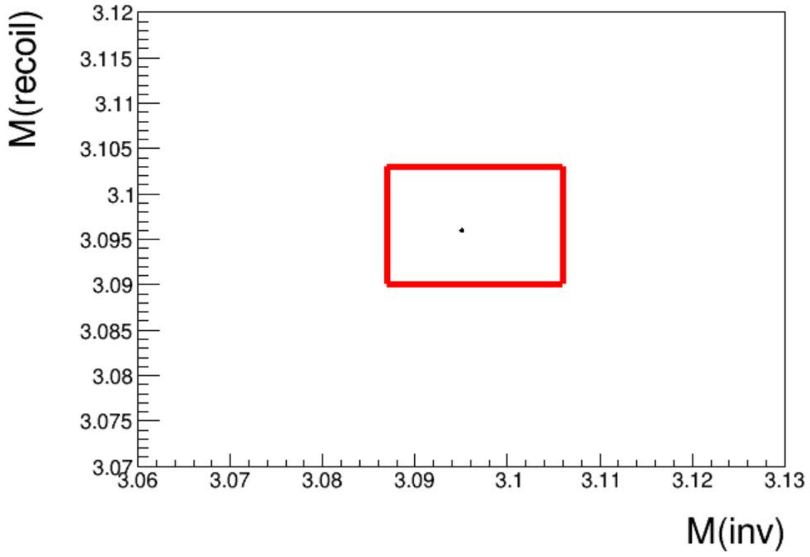
Signal window	Detection Efficiency(%)	
	pe^-	$\bar{p}e^+$
$\mu - 2.7\sigma, \mu + 2,7\sigma$	20.34	19.46
$\mu - 2.8\sigma, \mu + 2.8\sigma$	20.38	19.49
$\mu - 2.9\sigma, \mu + 2.9\sigma$	20.40	19.51
$\mu - 3.1\sigma, \mu + 3.1\sigma$	20.45	19.56
$\mu - 3.2\sigma, \mu + 3.2\sigma$	20.48	19.58
$\mu - 3.3\sigma, \mu + 3.3\sigma$	20.50	19.60
Diffrence	0.4%	0.3%

Summary of Systematic uncertainties

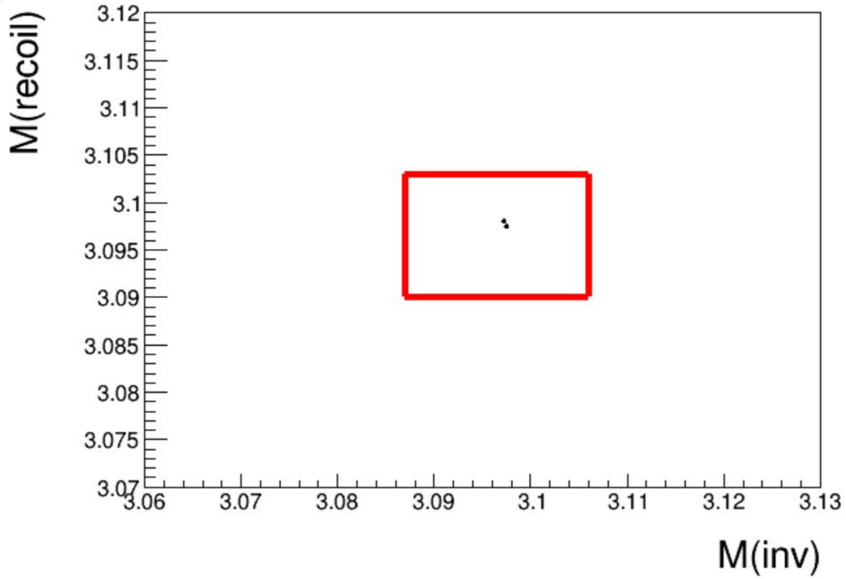
Source	pe^-	$\bar{p}e^+$
$N_{J/\psi}$	0.6	0.6
$\mathrm{Br}(\psi(3686) \to \pi^+\pi^- J/\psi)$	1.3	1.3
MDC tracking	2.3	2.3
PID	5.9	5.9
4C kinematic fit	12.04	18.91
Signal window	0.3	0.4
Total	13.68	20.0

[1] C.liu et al. (BESIII Collaboration), Report on Collaboration Meeting in Summer 2022
[2] M.Ablikim er al.,Phys.Rev. D 88(2013) 3, 032007
[3] M.Ablikim er al.,Phys.Rev. D 105 (2022) , 032006
[4]https://docbes3.ihep.ac.cn/DocDB/0009/000988/020/diff_SP2.pdf

The Upper Limit $N^{up}_{J/\psi \to pe}$ with Full blind data



$N_{sig} = 1, N_{bkg} = 0$
$em = 20.43\%, \Delta sys = 13.68\%$
$N^{up}_{sig} = 18.31$
$Br_{J/\psi -> pe^-} < 1.92 \times 10^{-8}$

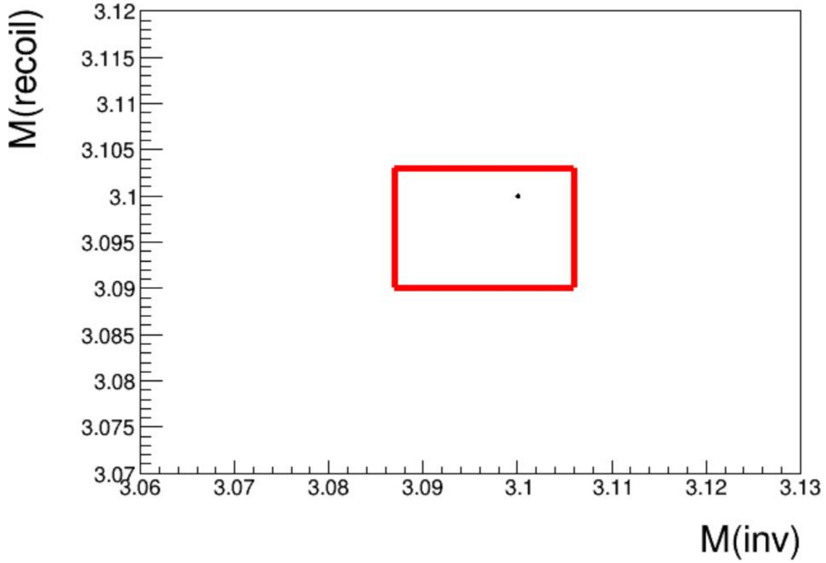


$N_{sig} = 2, N_{bkg} = 0$
$em = 19.53\%, \Delta sys = 20.0\%$
$N^{up}_{sig} = 29.18$
$Br_{J/\psi -> \bar{p}e^+} < 3.06 \times 10^{-8}$

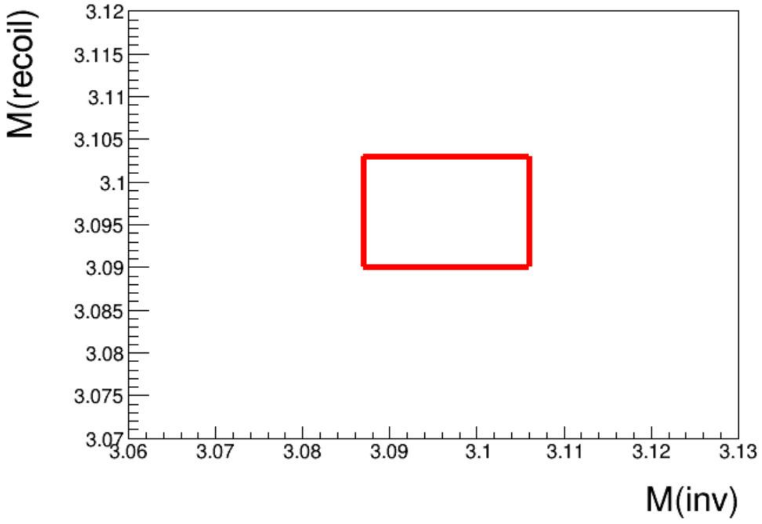
- N^{up} 90% C.L. is estimated by using the TROLKE program, where the number of the signal and background events are assumed to follow a Poisson distribution, the detection efficiency is assumed to follow a Gaussian distribution.

The Upper Limit $N^{up}_{J/\psi\to pe}$ with semi-blind data

- In semi-blind analysis, the Nsig is obtained from semi-blind data, the Nbkg is estimated from inclusive MC sample whose size if 10 times of semi-blind data.



$N_{sig} = 1, N_{bkg} = 1/10$
$em = 20.43\%, \Delta sys = 13.68\%$
$N^{up}_{sig} = 18.31$
$Br_{J/\psi->pe^-} < 1.92 \times 10^{-7}$



$N_{sig} = 0, N_{bkg} = 2/10$
$em = 19.53\%, \Delta sys = 20.0\%$
$N^{up}_{sig} = 10.36$
$Br_{J/\psi->\bar{p}e^+} < 1.08 \times 10^{-7}$

IO check results

The results show the output values of the fractions are consistent with those of input values.

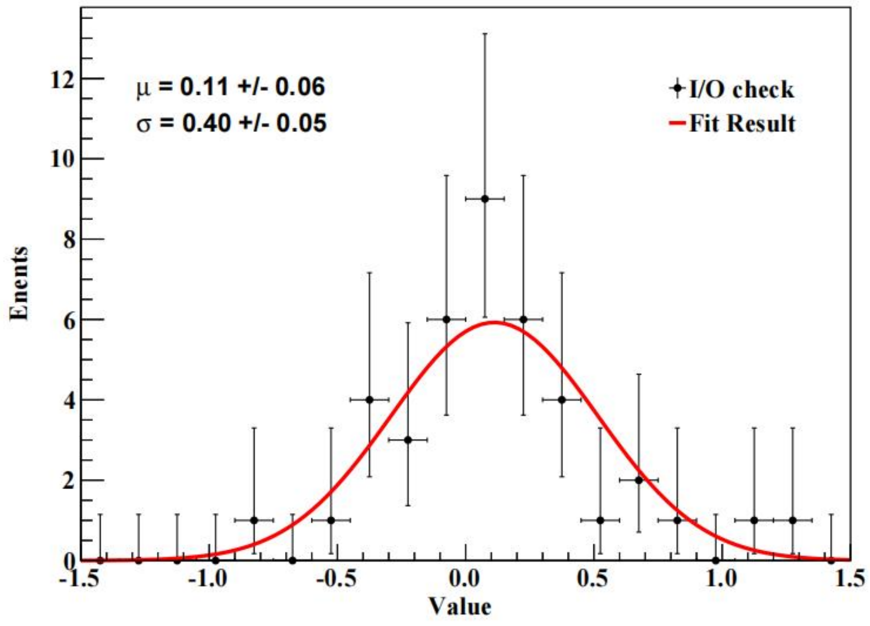


Figure 7: The pull distributions of $J/\psi \to pe^-$

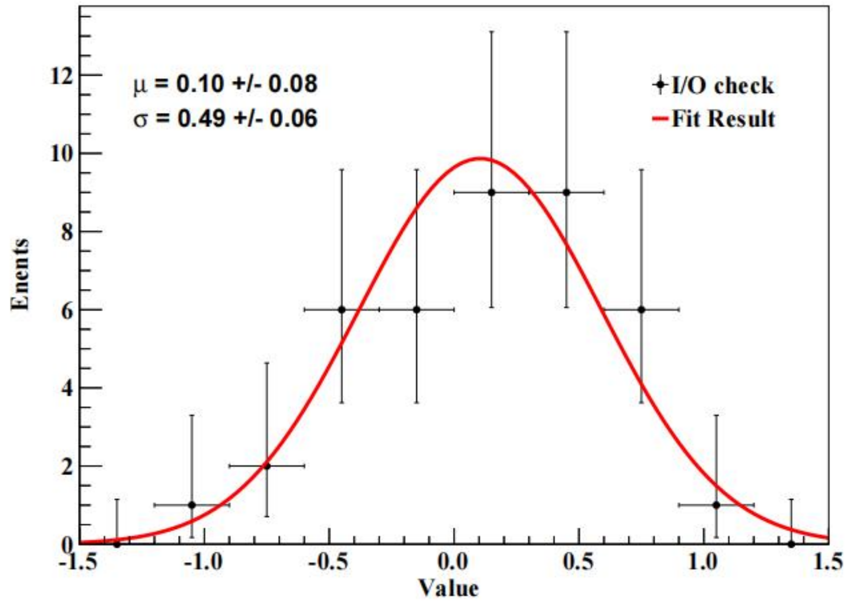


Figure 9: The pull distributions of $J/\psi \to \bar{p}e^+$

Summery

- Full blind analysis: based on inclusive MC of 2748M J/ψ events, 1/2 events left in the $J/\psi \to pe/\bar{p}e^{+}$ signal region, leading to the upper limit at 90% C.L. $B(J/\psi \to pe^{-}/\bar{p}e^{+})$<$1.92 \times 10^{-8}/3.06 \times 10^{-8}$.
- Semi blind analysis: the signal is obtained from data while background is estimated from inclusive MC sample, the upper limit at 90% C.L. is set to be $B(J/\psi \to pe^{-}/\bar{p}e^{+})$<$1.03 \times 10^{-7}/2.07 \times 10^{-7}$.

THANKS

Helix correction parameters of electron and muon

the 2012 psi(2S)

Table 8: Correction factors from process of $e^+e^- \to \pi^+\pi^-e^+e^-$ ($\sqrt{s}$ = 3.686GeV).

	ϕ_0		κ		tgλ	
	$m^{data} - m^{MC}$	$\sigma^{data}/\sigma^{MC}$	$m^{data} - m^{MC}$	$\sigma^{data}/\sigma^{MC}$	$m^{data} - m^{MC}$	$\sigma^{data}/\sigma^{MC}$
π^+	-0.042	1.145	0.146	1.118	-0.119	1.055
π^-	0.025	1.155	-0.134	1.156	-0.124	1.099
e^+	-0.079	1.236	0.308	1.001	-0.152	1.045
e^-	0.067	1.235	-0.334	1.036	-0.130	1.039

Table 9: Correction factors from process of $e^+e^- \to \pi^+\pi^-\mu^+\mu^-$ ($\sqrt{s}$ = 3.686GeV).

	ϕ_0		κ		tgλ	
	$m^{data} - m^{MC}$	$\sigma^{data}/\sigma^{MC}$	$m^{data} - m^{MC}$	$\sigma^{data}/\sigma^{MC}$	$m^{data} - m^{MC}$	$\sigma^{data}/\sigma^{MC}$
π^+	-0.047	1.246	0.144	1.207	0.124	1.177
π^-	-0.037	1.257	-0.118	1.195	-0.153	1.152
μ^+	-0.088	1.301	0.249	1.114	-0.199	1.133
μ^-	0.056	1.306	-0.267	1.132	-0.169	1.091

https://docbes3.ihep.ac.cn/charmoniumgroup/images/c/c4/Helix_Correction.pdf

Helix correction parameters of pion

BOSS 709, including 2009, 2012,2021 psi(2S)

2009	ϕ_0		κ		$tg\lambda$	
	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$
π^+	0.087	1.164	0.186	1.171	0.470	1.169
π^-	0.100	1.165	-0.036	1.207	0.456	1.166

2012	ϕ_0		κ		$tg\lambda$	
	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$
π^+	0.082	1.211	0.284	1.164	-0.0537	1.180
π^-	0.105	1.206	-0.122	1.199	-0.064	1.119

2021	ϕ_0		κ		$tg\lambda$	
	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{MC}$
π^+	0.094	1.167	0.206	1.169	0.109	1.185
π^-	0.102	1.171	-0.060	1.178	0.097	1.165

https://docbes3.ihep.ac.cn/charmoniumgroup/images/e/ec/Pi_helix.pdf

Helix correction parameters of kaon

BOSS 709, including 2009, 2012,2021 psi(2S)

09	Parameter	ϕ_0		κ		$\mathrm{tg}\lambda$	
		$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$
Web page	K^+	0.01	1.17	0.12	1.18	0.53	1.14
	K^-	0.06	1.18	-0.07	1.18	0.53	1.12
Our result	K^+	0.10	1.10	0.13	1.17	0.48	1.18
	K^-	0.09	1.13	0.06	1.18	0.47	1.26

12	Parameter	ϕ_0		κ		$\mathrm{tg}\lambda$	
		$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$
Web page	K^+	-0.05	1.20	0.31	1.21	-0.07	1.14
	K^-	0.05	1.20	-0.30	1.21	-0.06	1.14
Our result	K^+	0.08	1.23	0.31	1.19	-0.03	1.08
	K^-	0.12	1.18	-0.14	1.18	-0.04	1.07

21	Parameter	ϕ_0		κ		$\mathrm{tg}\lambda$	
		$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$	$m_{data}-m_{MC}$	$\sigma_{data}/\sigma_{(MC)}$
Our result	K^+	0.11	1.15	0.17	1.17	0.23	1.14
	K^-	0.11	1.15	0.003	1.16	0.21	1.15

https://docbes3.ihep.ac.cn/charmoniumgroup/images/9/92/K_helix.pdf

Helix correction parameters of protron

BOSS 709, including 2009, 2012,2021 psi(2S)

2009	ϕ_0		κ		tgλ	
	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$
p	0.063	1.051	0.154	1.076	0.987	1.001
$\bar{p}$	0.204	1.059	0.007	1.092	0.973	1.010

2012	ϕ_0		κ		tgλ	
	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$
p	0.025	1.056	0.342	1.098	0.061	1.002
$\bar{p}$	0.193	1.055	-0.095	1.107	0.025	1.001

2021	ϕ_0		κ		tgλ	
	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$	$m_{data} - m_{MC}$	$\sigma_{data}/\sigma_{MC}$
p	0.123	1.049	0.133	1.077	0.212	1.020
$\bar{p}$	0.123	1.053	0.072	1.076	0.219	1.025

https://docbes3.ihep.ac.cn/charmoniumgroup/images/7/79/Ppbar_helix.pdf