南華大學
UNIVERSITY OF SOUTH CHINA

Prospects CPV of Λ decay in $J/\psi \to \Lambda\bar{\Lambda}$ with polarized beam at STCF

Zengsheng
University of South China
December 2,2022

Outline

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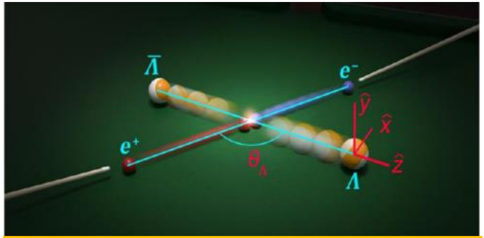
PART 01

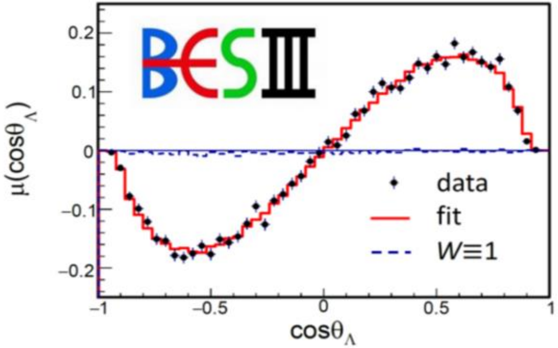
Motivation

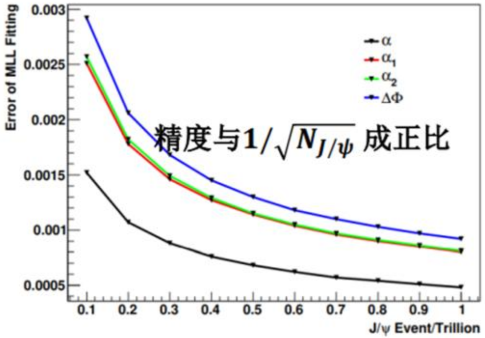
Motivation

- There is still much work to be done to test the CP violation and discover new CP violation sources because the CP violation predicted by the Standard Model is insufficient to explain the matter-antimatter asymmetry in the cosmos.
- The SM predicts that the CP violation of -hyperon decay can approach 10^{-5}, but the experimental results fail to reach the order of CP violation expected by the theory due to data statistical limitations.
- To offer feedback for detector design, investigate the influence of beam polarization on detection efficiency.



Exp： $A_{CP} = -0.0025 \pm 0.0046 \pm 0.0012$
SM： $-3 \times 10^{-5} < A_{CP} < 4 \times 10^{-5}$





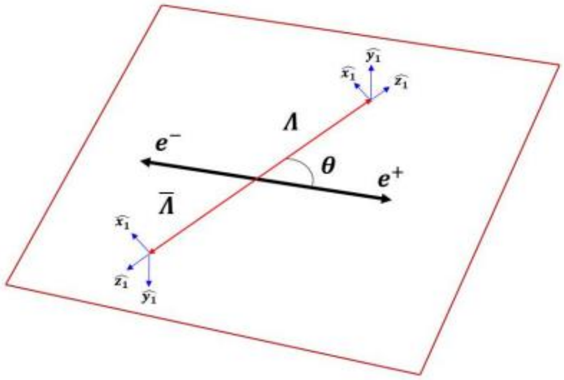
PART 02

Formulas

Formulas

- **Production process:**

$$n_R = n_{tot} \cdot \frac{1+P_e}{2},\ n_L = n_{tot} \cdot \frac{1-P_e}{2}$$



$J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$helicty coordinate

✓ **The joint density :**

$$\rho_{\Lambda\bar{\Lambda}} = \sum_{u,v=0}^{3} C_{u\bar{\bar{v}}} \sigma_u^{\Lambda} \otimes \sigma_v^{\bar{\Lambda}}$$

$$C_{u\bar{\bar{v}}} = \begin{bmatrix} 1+\alpha_\varphi cos^2\theta & \gamma_\varphi P_e sin\theta & \beta_\varphi sin\theta cos\theta & (1+\alpha_\varphi)P_e cos\theta \\ \gamma_\varphi P_e sin\theta & sin^2\theta & 0 & \gamma_\varphi sin\theta cos\theta \\ -\beta_\varphi sin\theta cos\theta & 0 & \alpha_\varphi sin^2\theta & -\beta_\varphi P_e sin\theta \\ -(1+\alpha_\varphi)P_e cos\theta & -\gamma_\varphi sin\theta cos\theta & -\beta_\varphi P_e sin\theta & -\alpha_\varphi - cos^2\theta \end{bmatrix}$$

$$\beta_\varphi = \sqrt{1-\alpha_\varphi{}^2} sin\Delta\Phi \qquad \gamma_\varphi = \sqrt{1-\alpha_\varphi{}^2} cos\Delta\Phi$$

Formulas

$$W(\varepsilon)=\boxed{T_0}+\sqrt{1-\alpha_\varphi^2}\sin(\Delta\Phi)\boxed{(\alpha_2.T_3-\alpha_1.T_4)}+\alpha_1\ \alpha_2\boxed{\left(T_1+\sqrt{1-\alpha_\varphi^2}\cos(\Delta\Phi)\ .T_2+\alpha_\varphi.\,T_5\right)}$$

describes the Λ angular distribution

account for the transverse polarization effects of Λ and $\overline{\Lambda}$

account for the spin correlations between two hyperons

$$\boxed{+\alpha_1.T_6+\alpha_2.T_7-\alpha_1\ \alpha_2\ T_8}$$

describe polarizability

$T_0=1+\alpha_\varphi cos^2\theta$

$T_1=sin^2\theta sin\theta_1\cos\varphi_1\sin\theta_2\cos\varphi_2-cos^2\theta\cos\theta_1\cos\theta_2$

$T_2=\sin\theta\cos\theta(sin\theta_1\cos\theta_2\cos\varphi_1-\cos\theta_1\sin\theta_2\cos\varphi_2)$

$T_3=\sin\theta\cos\theta\sin\theta_2\sin\varphi_2$

$T_4=\sin\theta\cos\theta sin\theta_1\sin\varphi_1$

$T_5=sin^2\theta sin\theta_1\sin\varphi_1\sin\theta_2\sin\varphi_2-\cos\theta_1\cos\theta_2$

$T_6=p_e(\gamma_\varphi\sin\theta sin\theta_1\cos\varphi_1-(1+\alpha_\varphi)\cos\theta\cos\theta_1)$

$T_7=p_e(\gamma_\varphi\sin\theta sin\theta_2\cos\varphi_2+(1+\alpha_\varphi)\cos\theta\cos\theta_2)$

$T_8=p_e\ \beta_\varphi\sin\theta(\cos\theta_1 sin\theta_2\sin\varphi_2+sin\theta_1\sin\varphi_1\cos\theta_2)$

$\boldsymbol{\alpha_\varphi=0.471}$

$\boldsymbol{\Delta\Phi=0.752}$

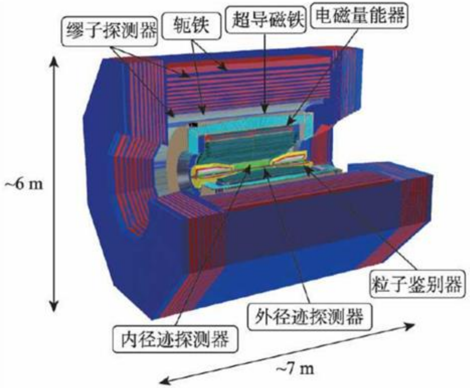
$\boldsymbol{\alpha_1=0.743}$

$\boldsymbol{\alpha_2=-0.745}$

PART 03

Events selections

STCF



- At a center of mass energy of 4 GeV, it reaches a peaking luminosity of up to $0.5 \times 10^{35} \mathrm{cm}^{-2} \mathrm{s}^{-1}$.
- The collision's center of mass energy ranges from 2 to 7 GeV.
- Potential to continue to increase brightness and achieve beam polarization

- It needs to have a very strong anti-radiation ability, especially in the collision area;
- Good momentum resolution for low momentum (<1GeV) tracks, and high detection efficiency for extremely low momentum (<100 MeV) tracks;
- The design concept is to apply the most advanced technical solutions, optimize the sub-detectors for physical targets, and the expected performance can meet the needs of future particle physics exploration.

Data sets and tool

- **Signal MC:**

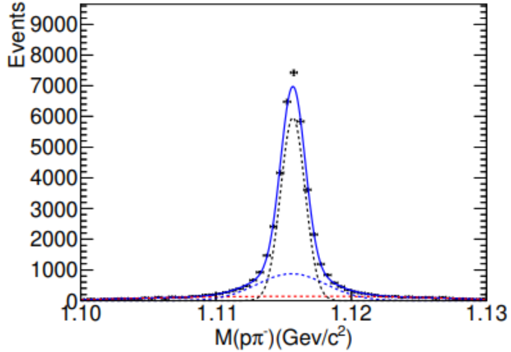
0.8 billion signal MC($J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$),mDIY

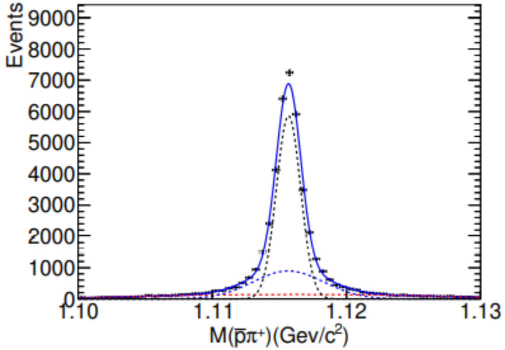
- **Fast simulation**
  - ✓ At the very beginning status of STCF, the design of all detectors are not settled. To investigate the sensitivity of physics results on detector performance, a fast simulation tool is needed.
  - ✓ It takes the most common event generator as input to perform a realistic simulation.
  - ✓ The fast simulation package can flexibly change the corresponding efficiency value or resolution value

Event selections

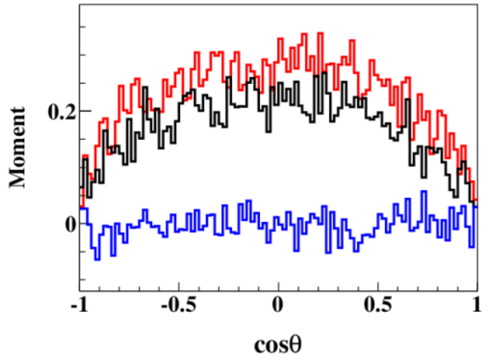
- **Good Charged Tracks**
  - ✓ $V_r \leq 10cm, V_z \leq 30cm, |\cos\theta| < 0.93$
  - ✓ nGood≥4, nCharge_poz ≥ 2 , nCharge_neg ≥ 2
- **Distinguish p and π**
  - ✓ Charged tracks >0
    - $P_{trk} > 0.5Gev \rightarrow$ Proton
    - $P_{trk} < 0.5Gev \rightarrow$ Pion(+)
  - ✓ Charged tracks <0
    - $P_{trk} > 0.5Gev \rightarrow$ anti-Proton
    - $P_{trk} < 0.5Gev \rightarrow$ Pion(-)
  - ✓ npip≥1,npim≥ 1,np≥ 1,npm≥ 1
- **Λ and Λ^{-} Reconstruction**
  - ✓ Second vertex
  - ✓ Select the minimum value of chi-square
- **4C-fit**
  - ✓ The total 4-momentum

- **The invariant mass spectrum of Λ and $\bar{\Lambda}$**

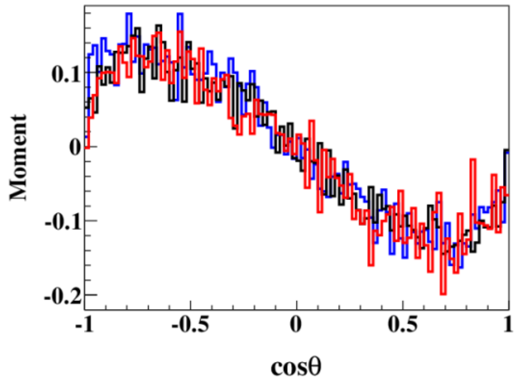




Truth Moment



X direction

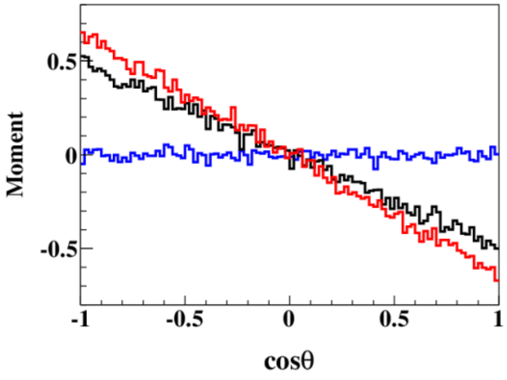


Y direction

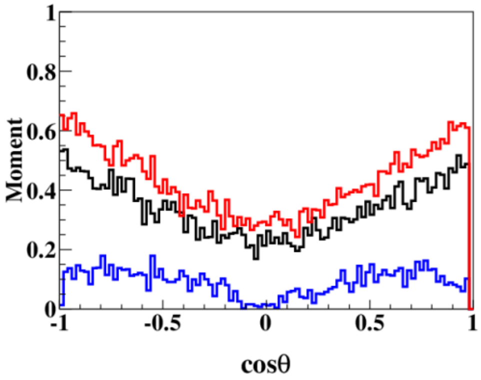
Blue： $P_e = 0$

Black:$P_e = 0.8$

Red:$P_e = 1$



Z direction



total

Cut flow and efficiency comparison

	Events	Efficiency(%)	Relative efficiency
Total number	100000	100	
Good trk	60010/59758/59524	60.0/59.8/59.5	60.0/59.8/59.5
Reconstruct lambda	55877/55707/55442	55.9/55.7/55.4	93.2/93.1/93.1
Reconstruct lambdabar	53496/53365/53064	53.5/53.4/53.1	95.7/95.9/95.8
4c fit	48114/47944/47621	48.1/47.9/47.6	89.9/89.7/89.6
Chi-square<60	43844//43353/43325	43.8/43.4/43.3	91.1/90.6/91.0
$\Lambda\bar{\Lambda}$ mass window	40460/41544/41530	40.5/41.5/41.5	92.5/95.6/95.8

Red:$P_e = 0$

Green:$P_e = 0.8$

Blue:$P_e = 1$

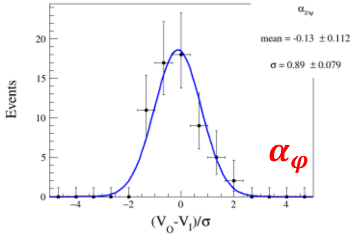
PART 04

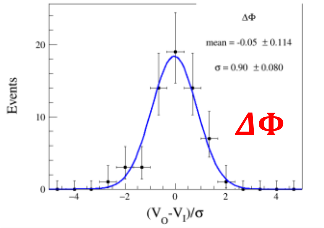
Angular fit

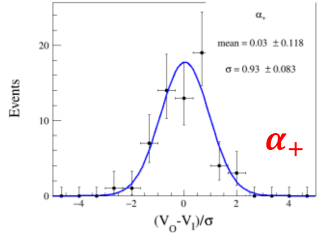
I/O check

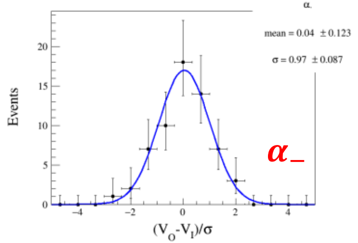
- 67 groups 400w mDIY MC and a 4000w mDIY MC(MC integral) with 0 polarization

✓ Pure Truth

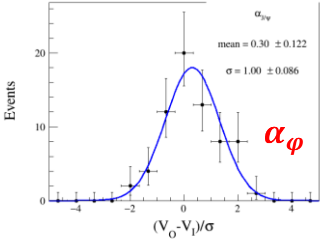


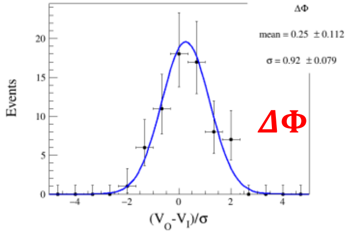


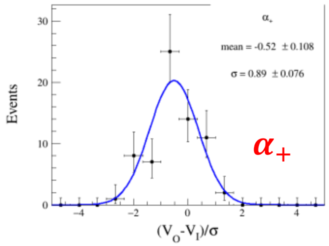


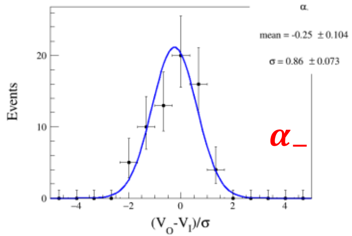


✓ Truth with fficiency

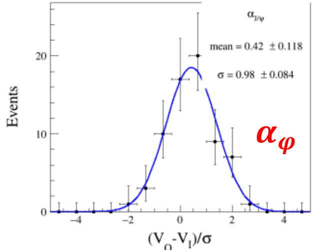


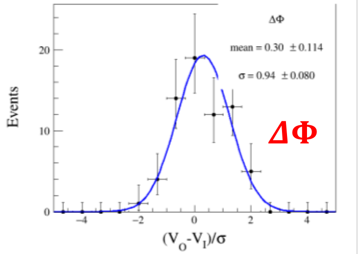


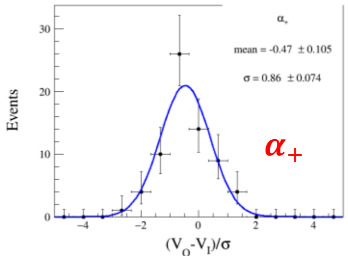


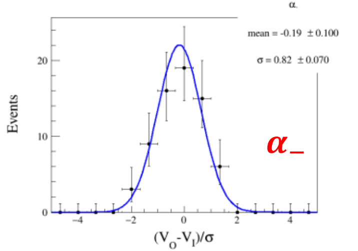


✓ Full reconstruction





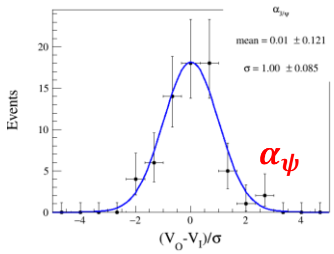


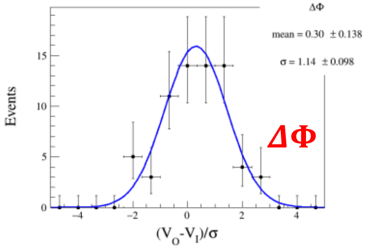


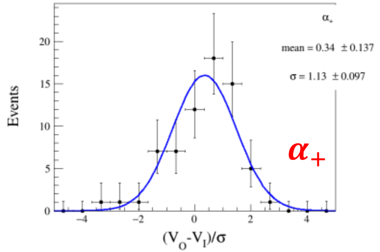
I/O check

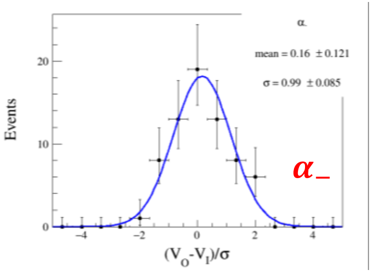
- 67 groups 400w mDIY MC and a 4000w mDIY MC(MC integral) with 80% polarization

✓ Pure Truth

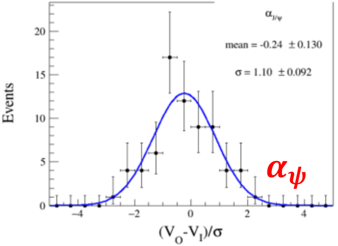


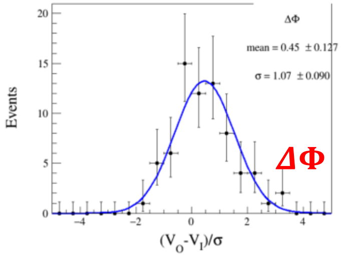


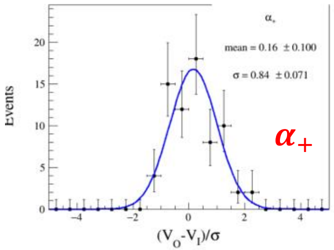


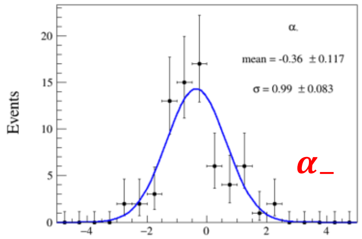


✓ Truth with fficiency

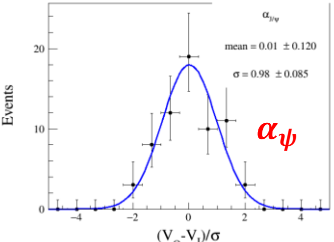


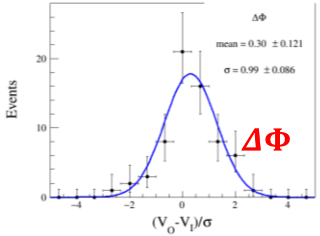


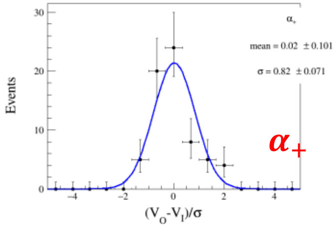


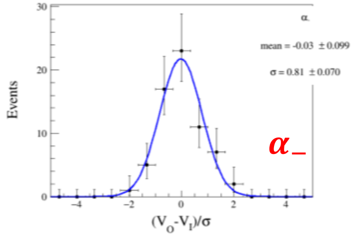


✓ Full reconstruction









Angular fit result

Parameters	Intput	Output	
		$p_e = 0$	$p_e = 0.8$
α_φ	0.471	0.471±0.00187	0.471±0.00136
$\Delta\Phi$	0.752	0.755±0.00369	0.752±0.00158
α_1	0.743	0.740±0.00314	0.743±0.00086
α_2	-0.745	-0.747±0.00317	-0.743±0.00087

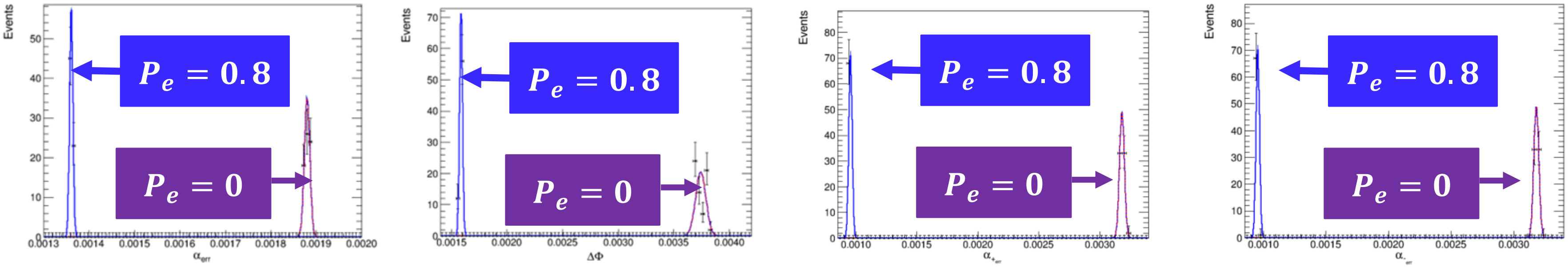
Increased accuracy:

$\alpha_\varphi = 27.1\%$

$\Delta\Phi = 57.0\%$

$\alpha_1 = 69.9\%$

$\alpha_2 = 69.9\%$



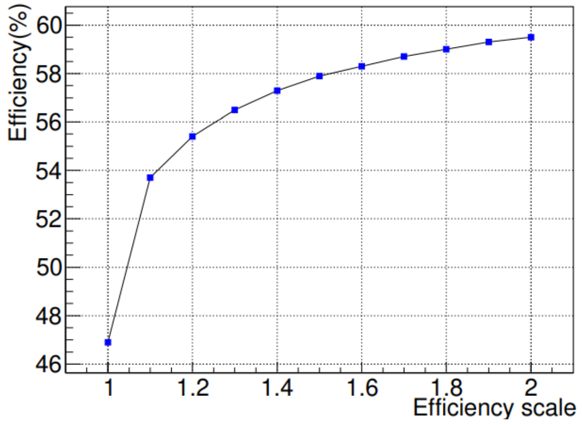
- We are able to have a higher sensitivity at $P_e = 0.8$ than at $P_e = 0$.

PART 05

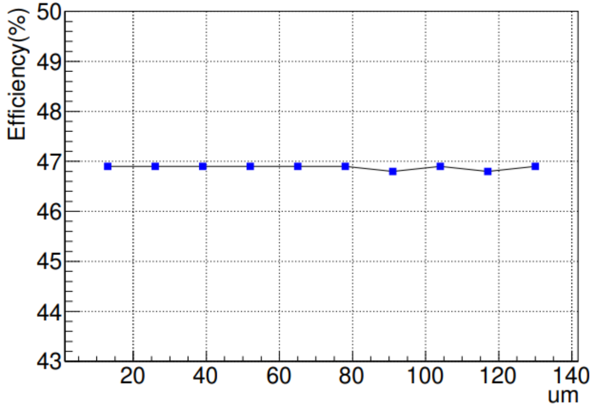
Check detector performance

Check detector performance

◆ Tracking efficiency scale



◆ Momentum resolution of tracking



- ✓ The final selection efficiency has greatly improved between 1.0 and 1.1, and that the selection efficiency will rise from 46.8% to 53.70%.
- ✓ The related σ_z is optimized from 0 um to 2480 um, and σ_{xy} is optimized from 0 um to 130 um. Efficiency hasn't changed much.

PART 06

Summary and prospect

Summary and prospect

- We demonstrate that the polarization and nonpolarization of the electron beam have no discernible effects on the detection efficiency of $J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$.
- We show that by using a longitudinally-polarized electron beam, the statistical precision of the CP tests can be significantly improved compared to the experiments without polarized beams.
- We verified the an electron beam polarization of 80–90% at J/ψ energies can be obtained with the same beam current.