CP-violating phase ϕ_s measurement

$B_s^0 \to J/\psi\, \phi$ potential at CEPC

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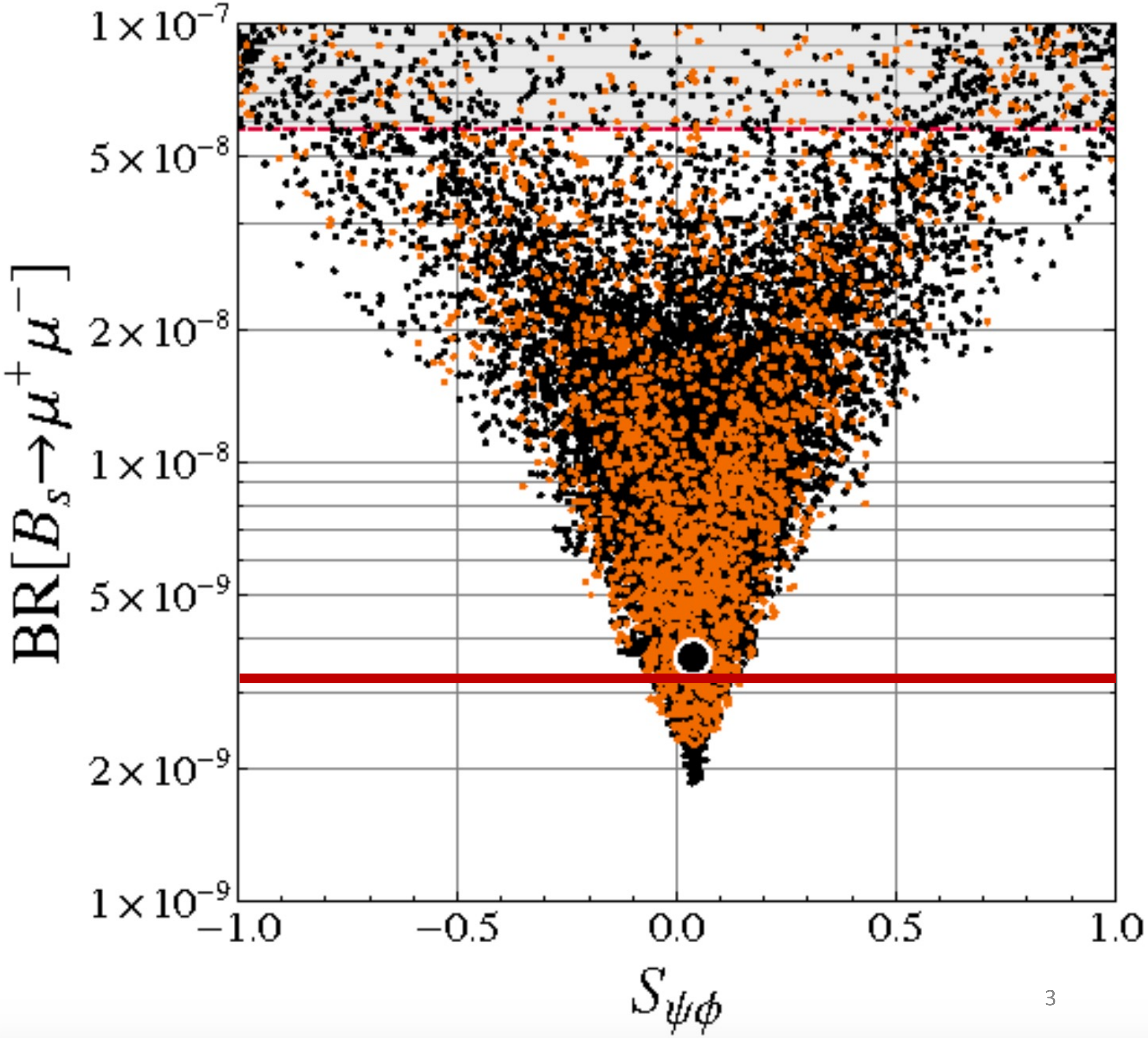
Introduction

- CP violation arises through a single phase in the CKM quark mixing matrix.
- In neutral B meson decays to a final state the interference between the amplitude for the direct decay and the amplitude for decay after oscillation, leads to a time-dependent CP-violating asymmetry between the decay time distributions of B and anti-B mesons.
- $\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H, \phi_s = -2\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$
- SM: small CPV phase ϕ_s
- Contributions from physics beyond the SM could lead to much larger values of ϕ_s.

NP prediction

- AC model (0910.1032)
- Red line: measurement
- Large black dot: SM
- Small dots: NP model predictions
- Deviation ~ 0.1



Analysis strategy for real analysis

$$B_s^0 \to J/\psi\,\phi \to \mu^+\mu^- K^+ K^- \quad (e^+e^-K^+K^-)$$

Disentangle the CP -even and CP -odd components.

$$\frac{\mathrm{d}^4\Gamma(B_s^0 \to J/\psi\,\phi)}{\mathrm{d}t\;\mathrm{d}\Omega} \;\propto\; \sum_{k=1}^{10} h_k(t)\, f_k(\Omega)\,.$$

$$\begin{aligned} h_k(t) \;=\; N_k e^{-\Gamma_s t}\; & [c_k \cos(\Delta m_s t) \,+\, d_k \sin(\Delta m_s t) \\ & + a_k \cosh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + b_k \sinh\left(\tfrac{1}{2}\Delta\Gamma_s t\right)]\,. \end{aligned}$$

- Distinguish B, anti-B: Flavour tagging(tagging power)
- Time resolution

CEPC benchmark detector

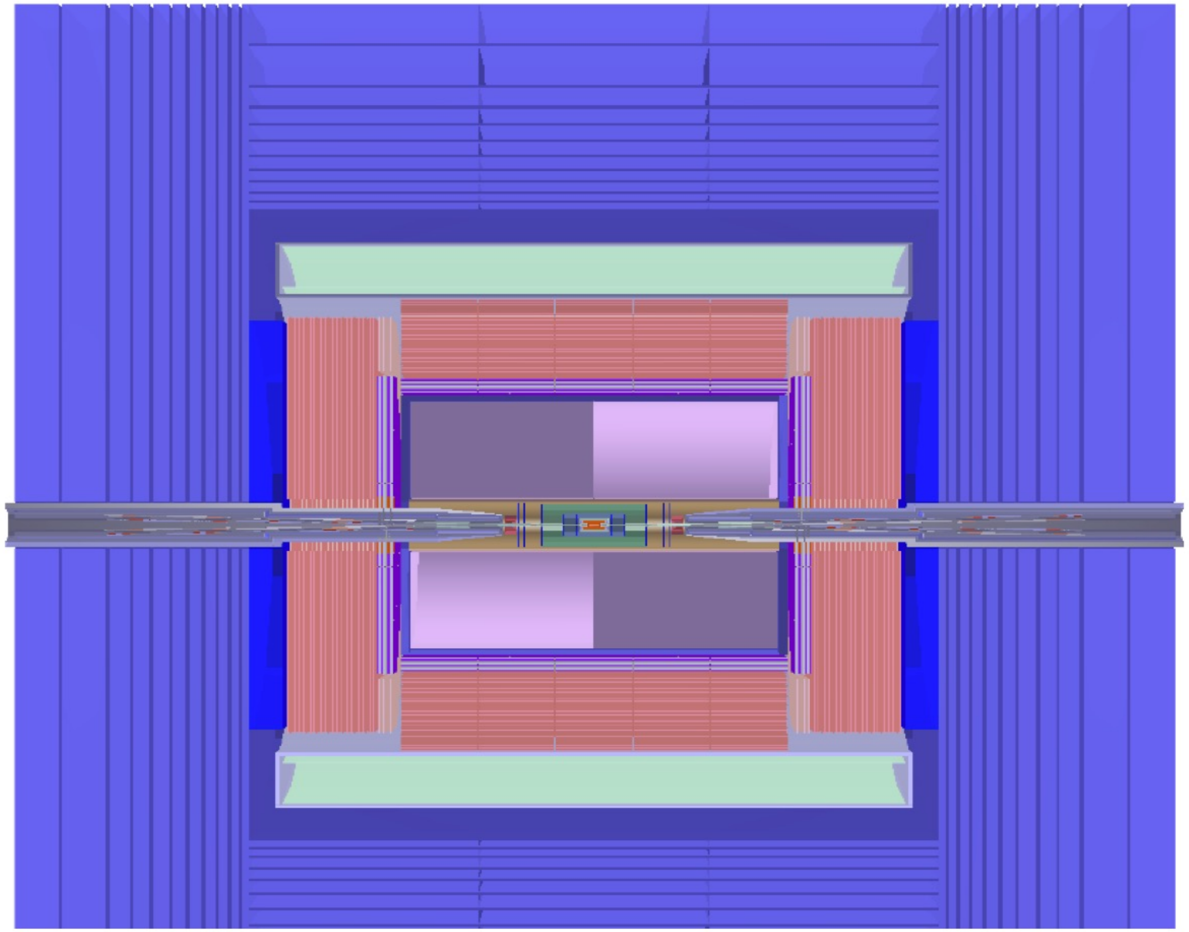
CEPC:

circular electron-position collider

Higgs factory/Z factory

- Excellent vertex reconstruction.
- Good PID!
- Clean environment.

- Huge B production in Z pole run



Estimation of $\sigma(\phi_s)$ at CEPC

- $\sigma(\phi_s) \propto 1/\sqrt{N_{\mathrm{Eff}}}$

- $N_{\mathrm{Eff}} \propto N_{b\bar{b}}$
- $N_{\mathrm{Eff}} \propto$ Efficiency
- $N_{\mathrm{Eff}} \propto$ Tagging power

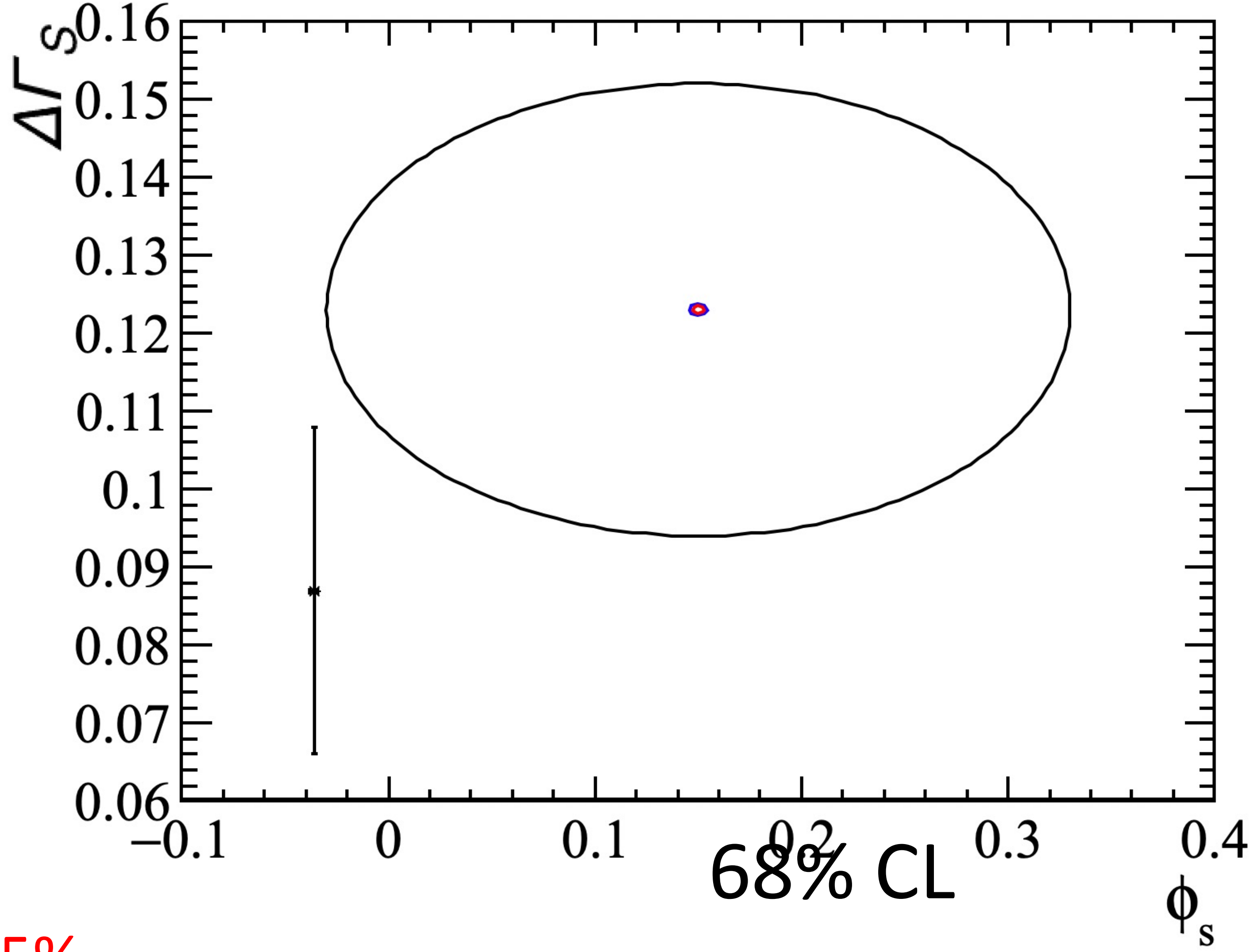
- $\sigma(\phi_s) \propto 1/e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2}$

Scaling from LHCb measurement

$\phi_s \sim \Delta\Gamma_s$

- Dot: SM prediction
- Black: LHCb(Run 1)
- Blue: LHCb(HL-LHC)
- Red: CEPC

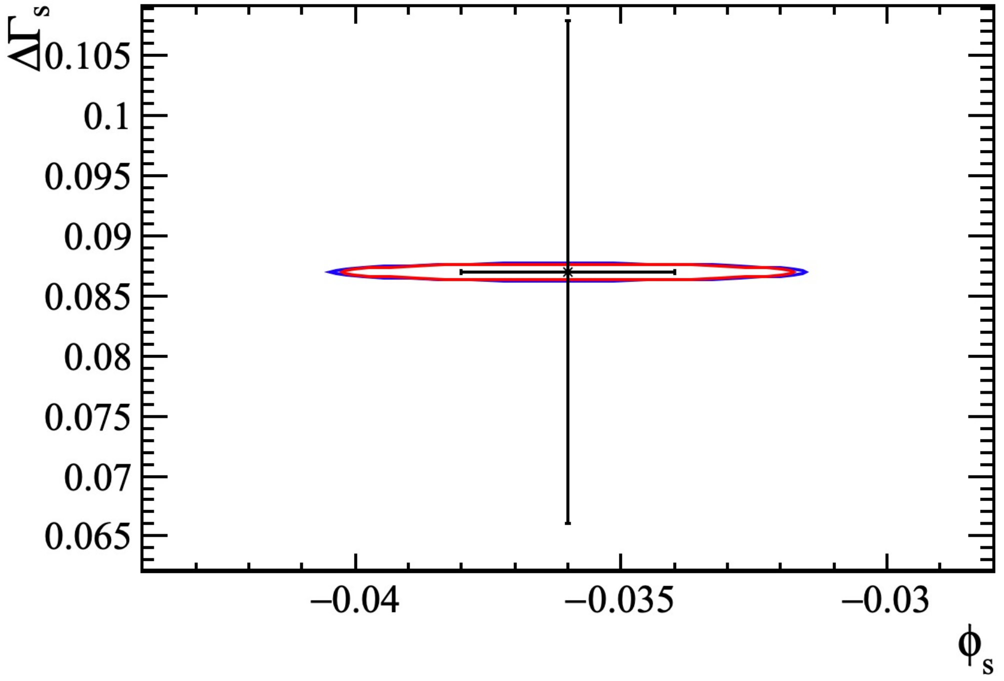
- $N_{\rm Eff} \propto N_{b\bar{b}}$ ~ Tera-Z
- $N_{\rm Eff} \propto$ Efficiency ~ 100%
- $N_{\rm Eff} \propto$ Tagging power ~ 15%
- $\sigma(\phi_s) \propto 1/e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2}$ σ_t^2 ~ 10 fs

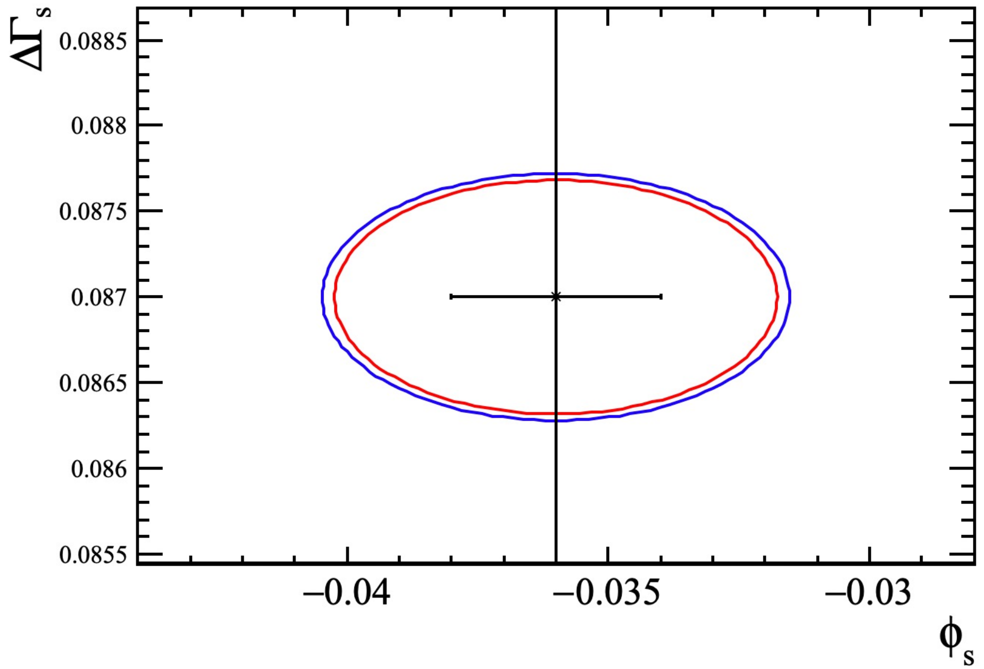


$\phi_s \sim \Delta\Gamma_s$

- Dot: SM prediction
- Black: LHCb(Run 1)
- Blue: LHCb(HL-LHC)
- Red: CEPC

- Zoomed and move the central value to SM prediction

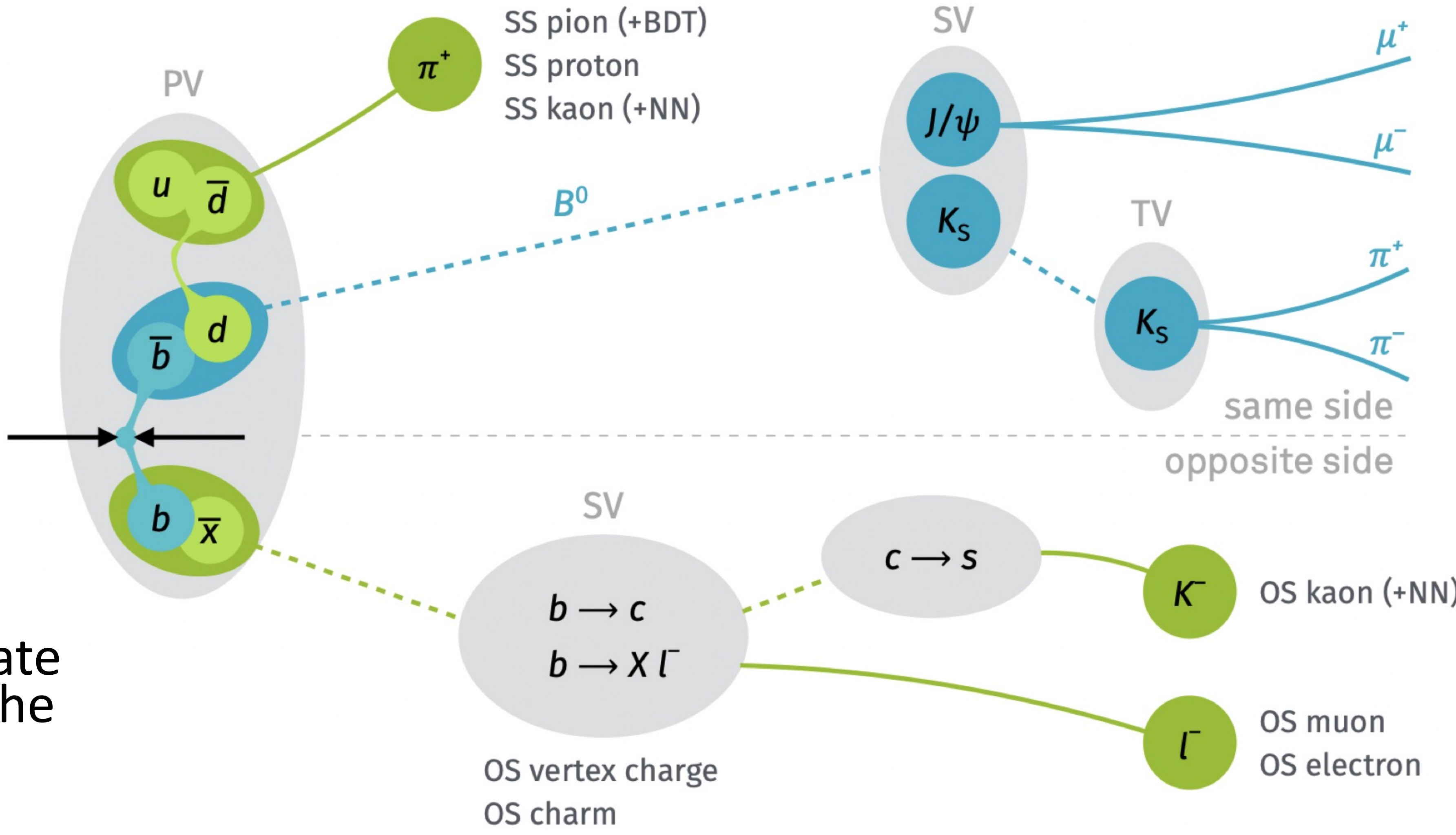




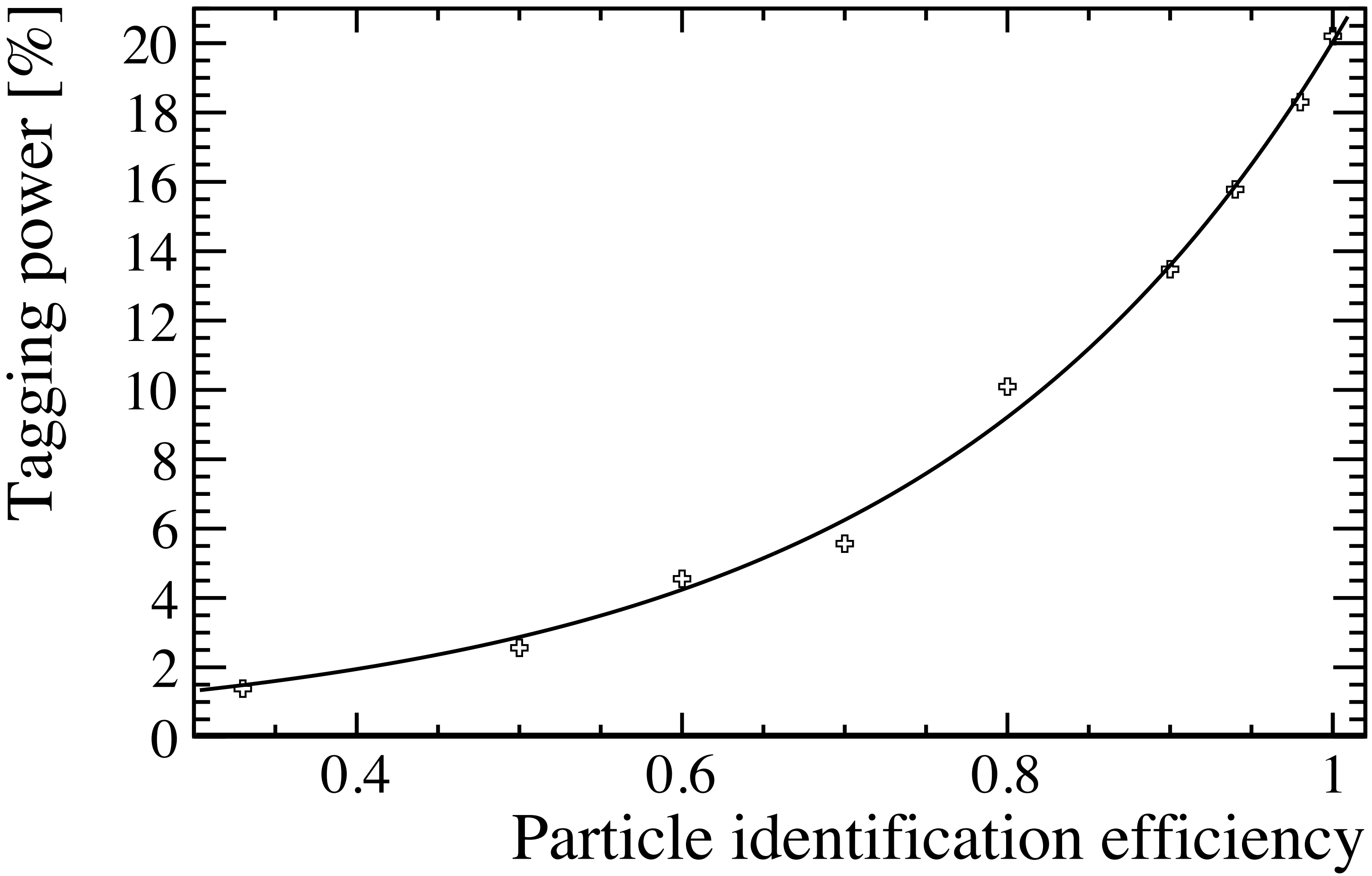
Flavour tagging power

- LHCb: 3~4%
- CEPC: 15%
- B factory: ~30%

- For Bs:
  - OS lepton
  - OS kaon
  - SS kaon
- A naïve algorithm developed to validate the robustness of the estimation



Flavour tagging power

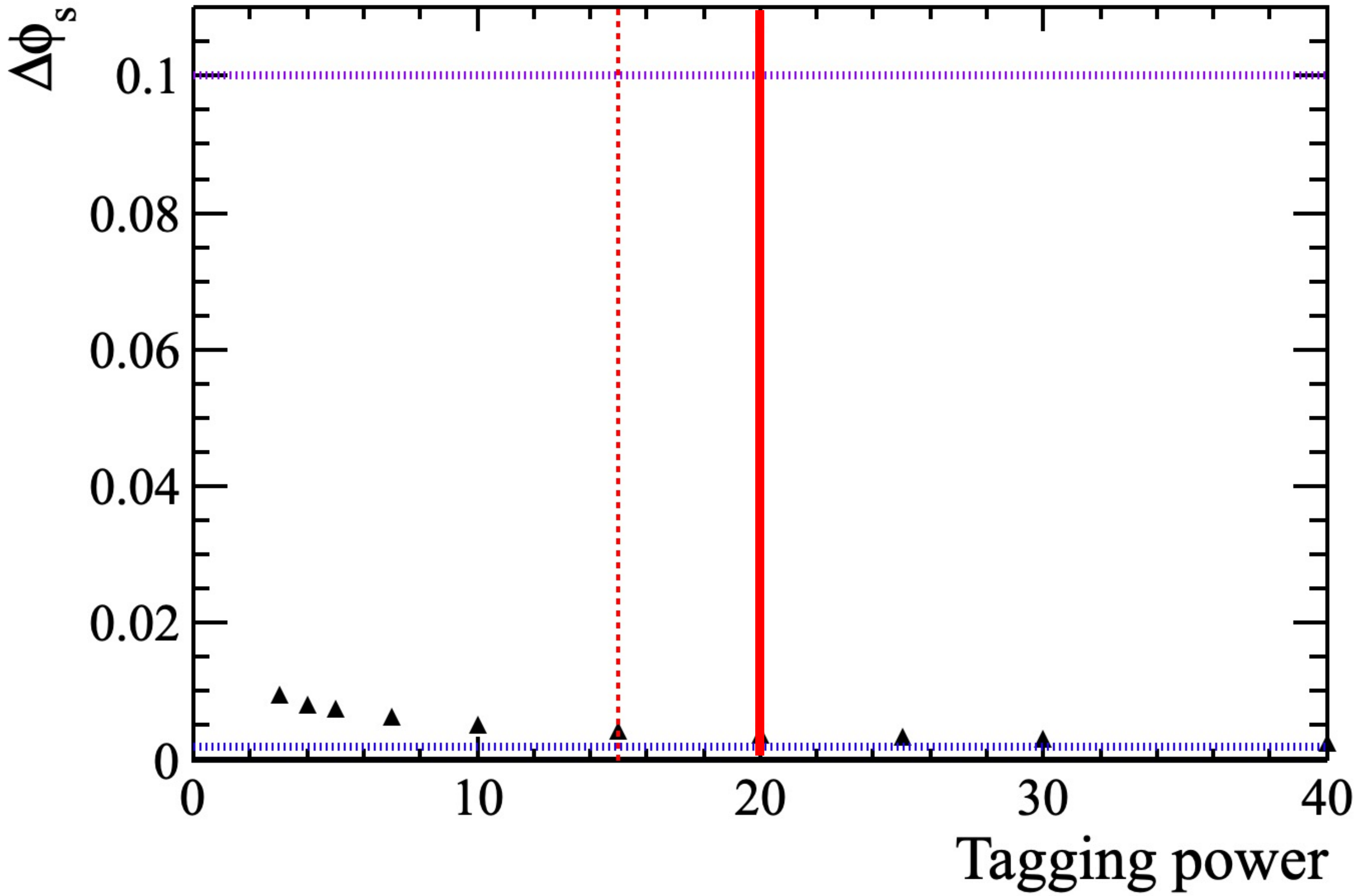


The PID effect to Tagging power:

- The misidentification of p/K/pi is considered.
- PID efficiency = a:
  - The probability of p/K/pi identified correctly = a
  - The probability of p/K/pi identified incorrectly as other particle = (1-a)/2.

Flavour tagging effect

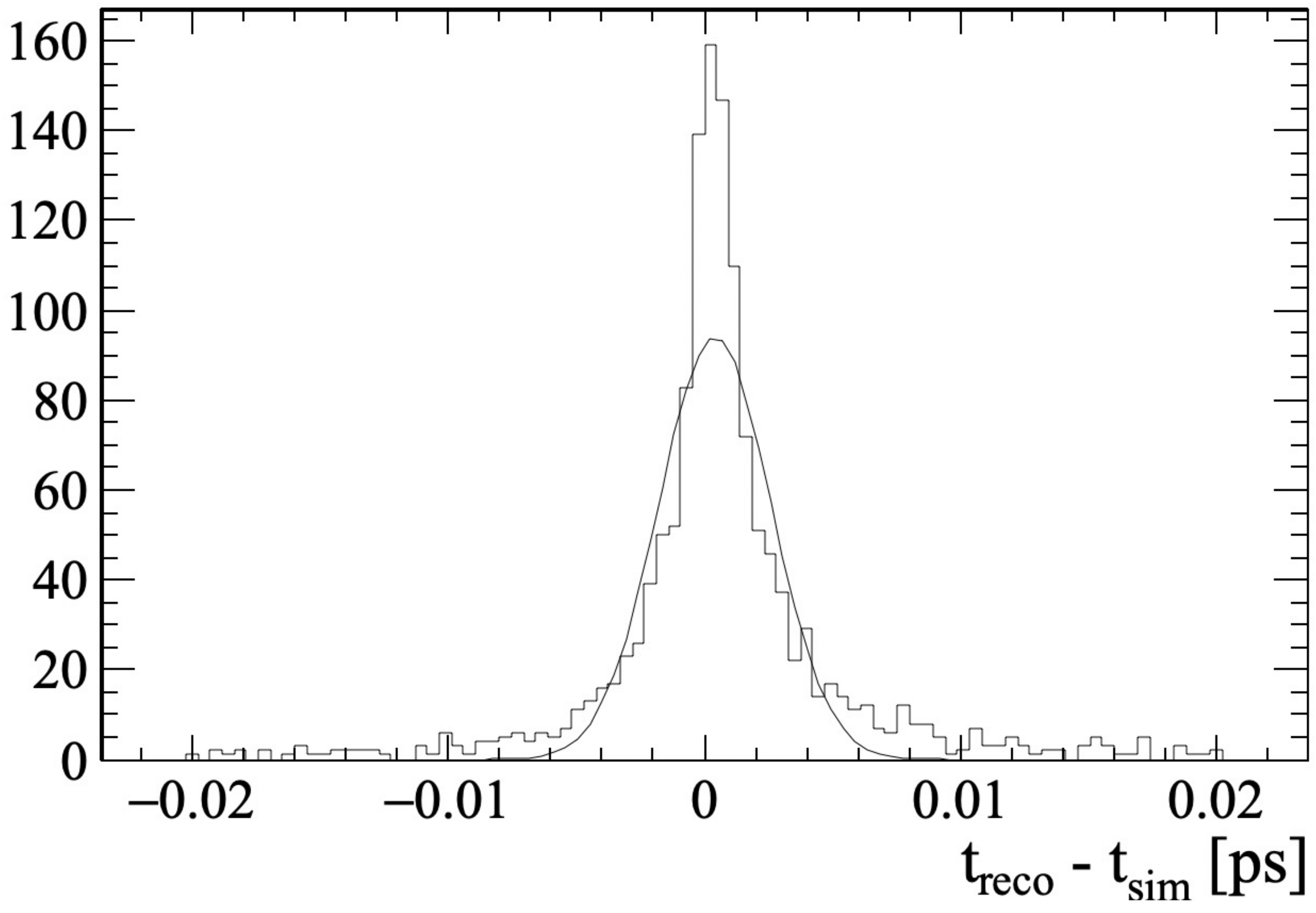
- Red: 15/20%(CEPC)
- Blue: SM resolution
- Purple: NP deviation



Time resolution

- Vertex reconstruction:
  - find the MC vertex
  - Find the neareast points of the MC vertex on the four track
  - Take the averaged position of the four points
  - To be replaced by a chi2 vertex fit

- Time resolution ~ a few fs

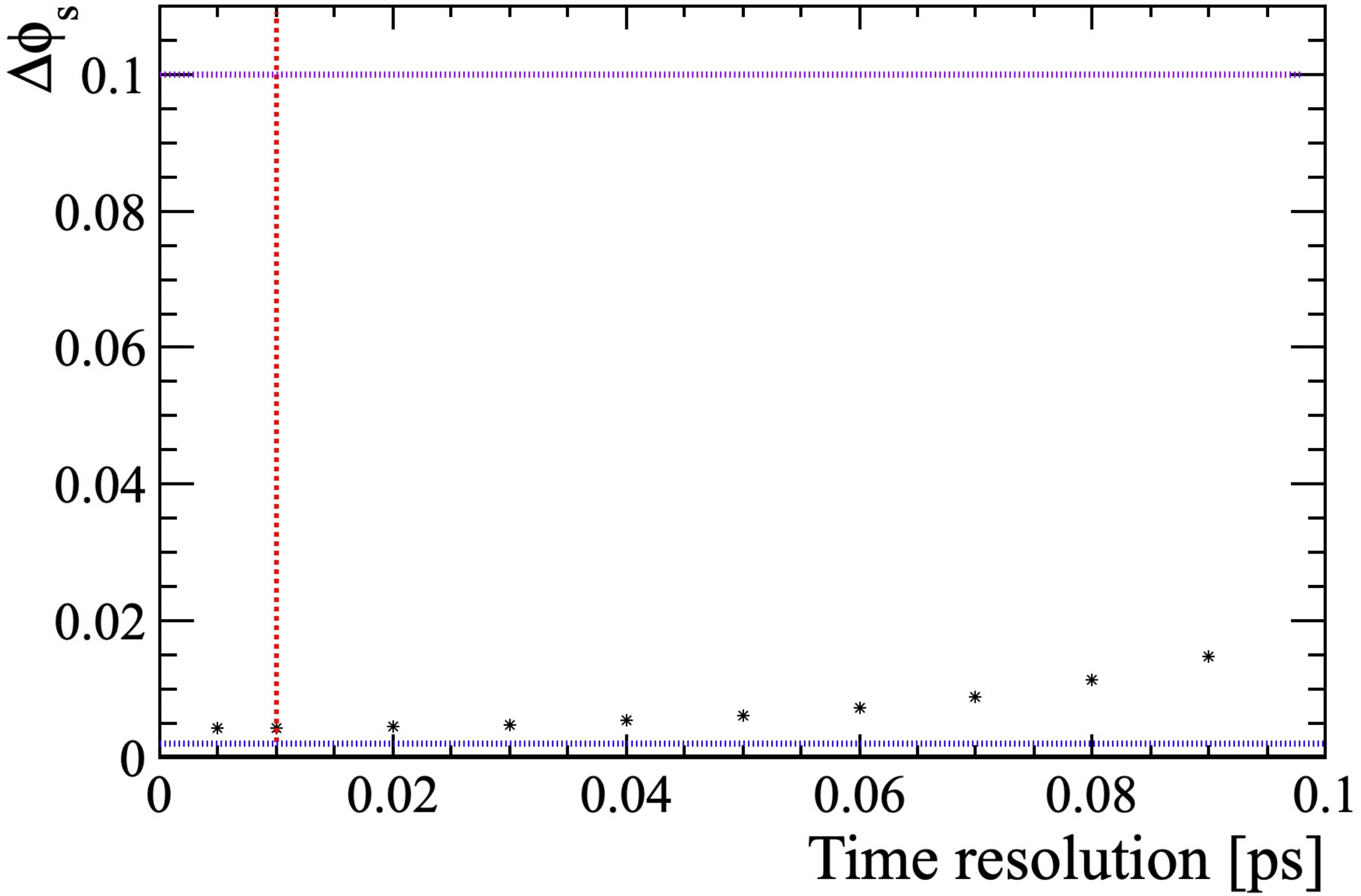


Time resolution effect

- Red: 10fs(CEPC)
- Blue: SM resolution
- Purple: NP deviation

$$\sigma(\phi_s) \propto 1/e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2}$$

- $\Delta m_s = 17.8 \times 10^{12}\ \hbar s^{-1}$
- LHCb: $\sigma_t = 50$ fs -> 0.67
- CEPC: $\sigma_t = 10$ fs -> 1

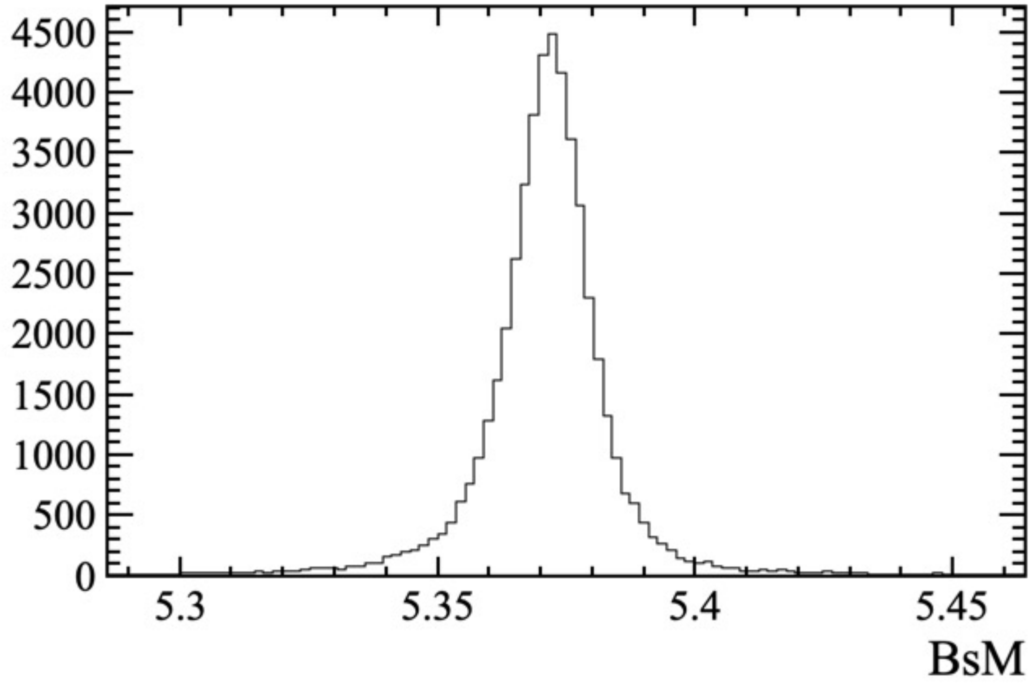


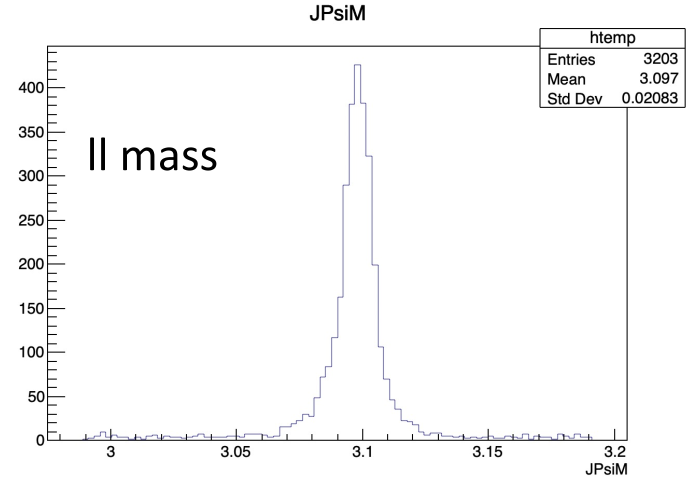
Efficiency:

- Signal Bs reconstruction:
- Four tracks with correct final state PID

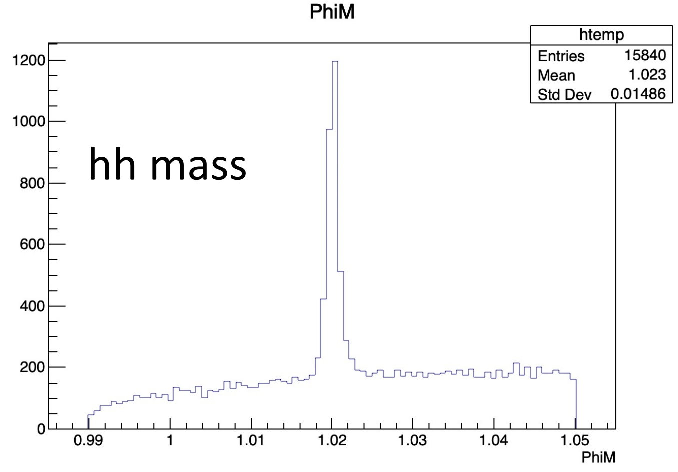
- JPsi mass: 3.09 +- 0.1 GeV
- Phi mass: 1.02 +- 0.03 GeV
- Bs mass: 5.3-5.45 GeV

- Acceptance * Reconstruction = 84%





PID not required



PID not required

Background level

- Backgrounds in Z->bb: 1.7×10^5 times higher than the Bs signal
- How many events will be incorrectly reconstructed?
  - ll invariant mass in [3.07,3.14]GeV (Jpsi window) : 1.3%
  - hh invariant mass in [1.017,1.023]GeV (phi window) : 67%
  - Reconstructed Bs in [5.3-5.45]GeV (Bs window) : 4.5%

  - Background: 1.7×10^5 × 1.3% × 67% $\times 4.5\% \sim 70$
- The reconstructed background is 70 times higher than the signal.

Background

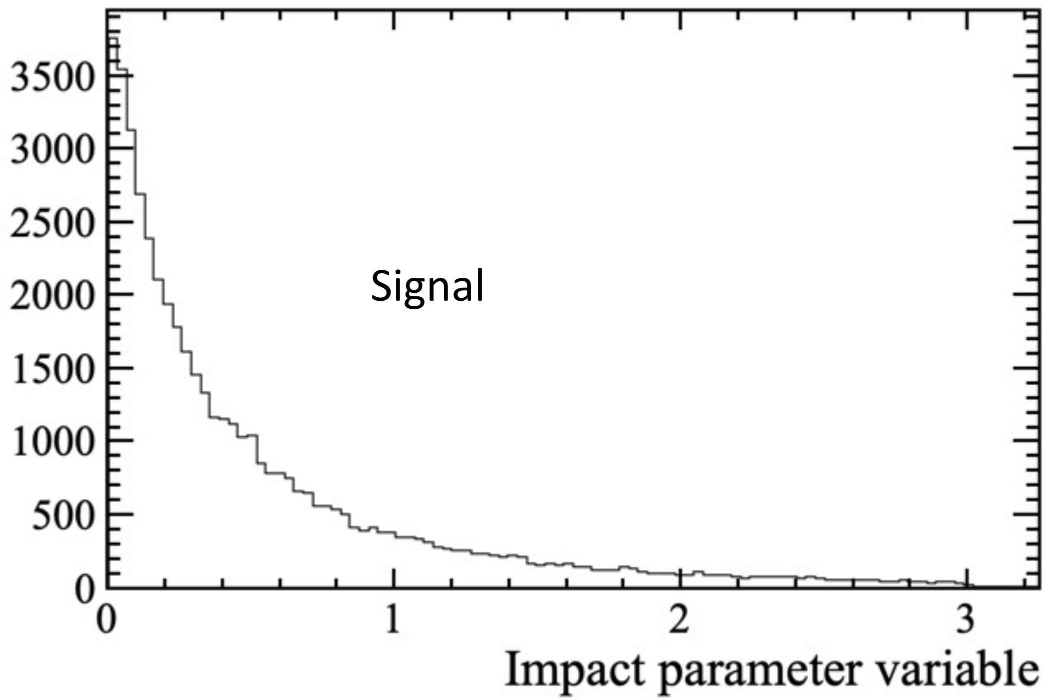
- With perfect PID:
  - ll invariant mass in [3.07,3.14]GeV (Jpsi window) : 0.4%
  - hh invariant mass in [1.017,1.023]GeV (phi window) : 3.6%
  - Reconstructed Bs in [5.3-5.45]GeV (Bs window) : 4.5%

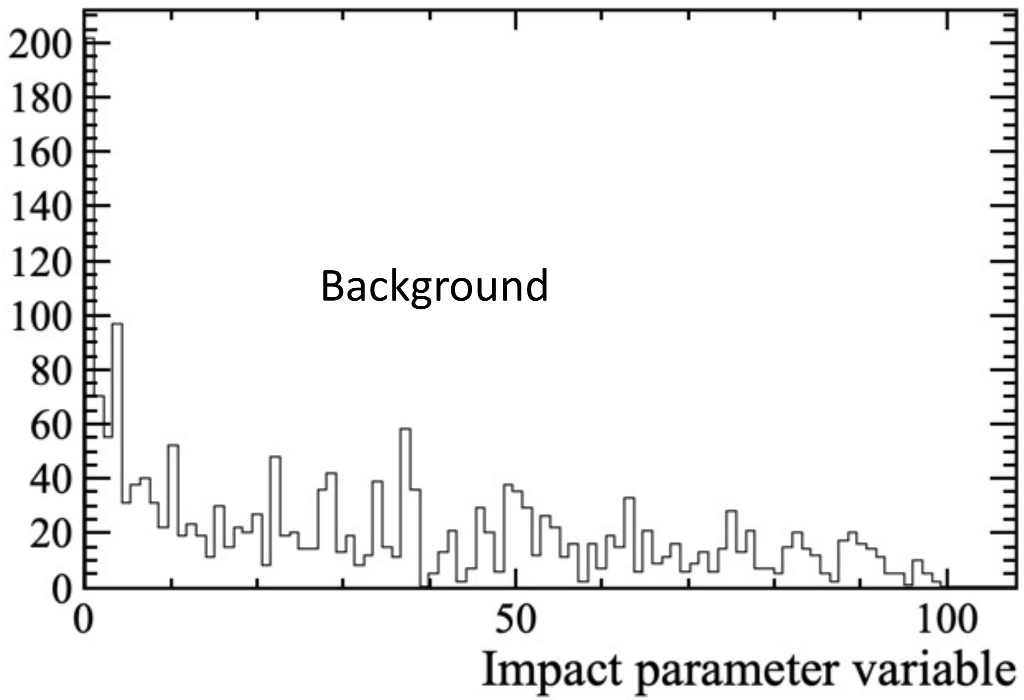
  - Background: $1.7\times10^5 \times 0.4\% \times 3.6\% \times 4.5\% \sim 1.1$

- The background level is supressed significantly with PID.

Impact parameter information

- Variable:
  - Max(Four track impact parameter) – Min(Four track impact parameter)
  - If the four track are not from the same vertex, this variable should be large.
  - Could supress the background. This vertex cut could be replaced by vertex chi2.





Conclusion

- Study of CPV-phase is promising at CEPC.
- Competitive with LHCb(HL-LHC).
- Powerful to test new physics model.
- Promising to reach SM accuracy.

- The PID dependent of tagging power is studied.
- Time resolution is studied with full simulation, a vertex reconstruction algorithm is needed (Will have it soon).
- Acceptance * efficiency ~ 84% is studied with full simulation. The background level could be suppressed significantly with PID and vertex cut. The dependence will be studied.

References

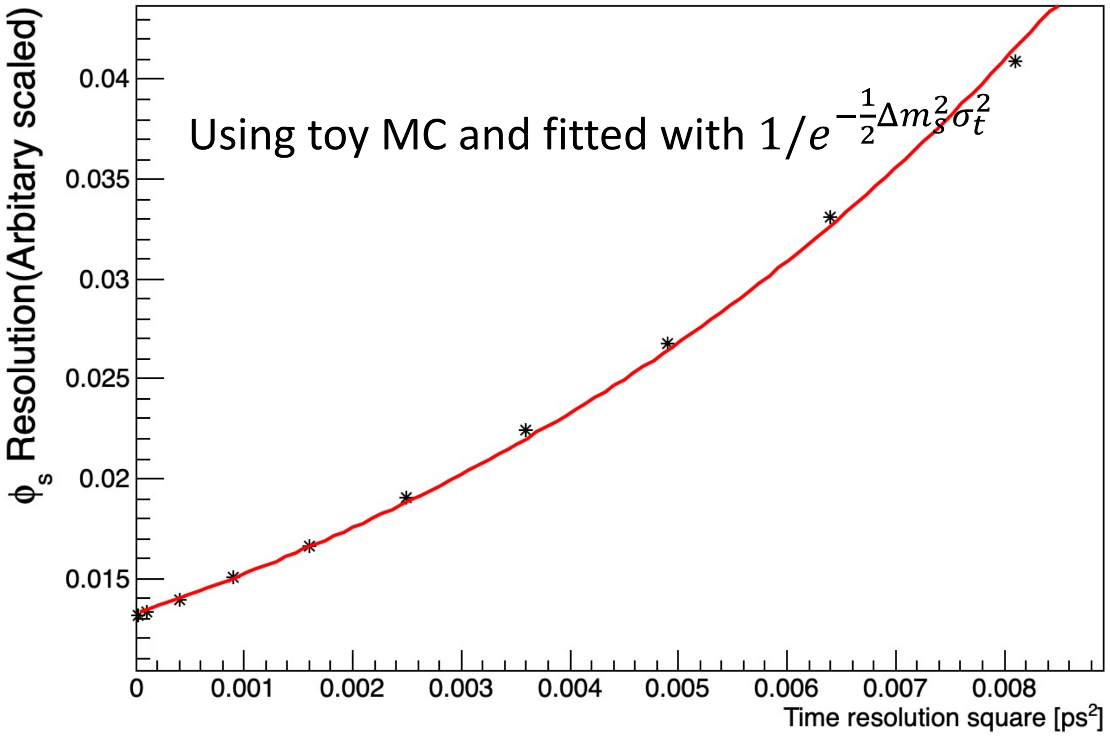
- [1]https://cds.cern.ch/record/2630496/files/Parkes_ICHEP_U2_070718_vFinal.pdf
- [2] https://arxiv.org/pdf/1612.05140.pdf
- [3] CEPC CDR

  https://arxiv.org/abs/1811.10545

  https://arxiv.org/abs/1809.00285
- [4] PDG

Backups

- Validation of $\sigma(\phi_s) \propto 1/e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2}$



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$b\bar{b}$ statistics at LHCb and CEPC

- **LHCb**
- Luminosity at HL-LHC: $300\ \mathrm{fb}^{-1}$ [1]
- $b\bar{b}$ cross-section at LHCb at 13 TeV: $144\mu\mathrm{b}$[2]
- Total statics: 43.2×10^{12}

- **CEPC**
- Z production at Z pole: 10^{12} Z[3]
- $b\bar{b}$ branching fraction: 15.2%[4]
- Total statics: 0.152×10^{12}

$b\bar{b}$ statistics at LHCb(run 1) for cross check

- **LHCb**
- Luminosity at LHC: $0.37\ \text{fb}^{-1}$
- $b\bar{b}$ cross-section at LHCb at 7 TeV: 72 μb
- Total statics: 26.64×10^9

- **CEPC**
- Z production at Z pole: 10^{12} Z[3]
- $b\bar{b}$ branching fraction: 15.2%[4]
- Total statics: 0.152×10^{12}

Reconstruction efficiency

- Acceptance * Reconstruction * Trigger

- LHCb: 20%
- CEPC: 100%
- Full-simulation is needed for more detailed study. (on going)

Reconstruction for efficiency and tagging study

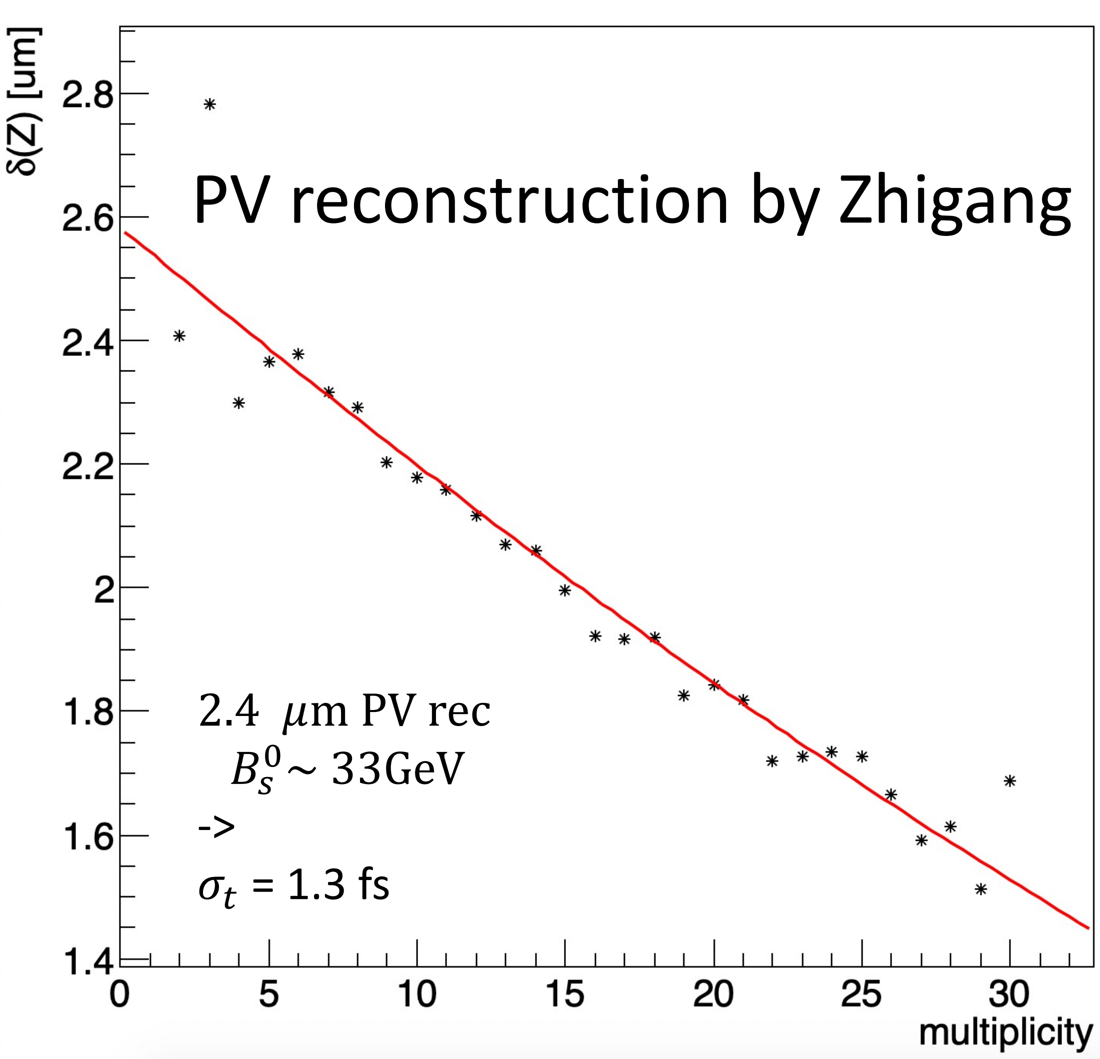
- A fast reconstruction processor is developed
  - Choose a B_s^0 in the event and force it to decay as: $B_s^0 \to J/\psi(\to \mu^+\mu^-)\,\phi(\to K^+K^-)$ using Pythia.
  - Read all the long-lived charge particle p, K, pi, mu, e in the MCParticles.
  - Smear the momentum of the MCParticles, randomly let the particles to get wrong pid, and create reconstructed particle.

Time resolution effect

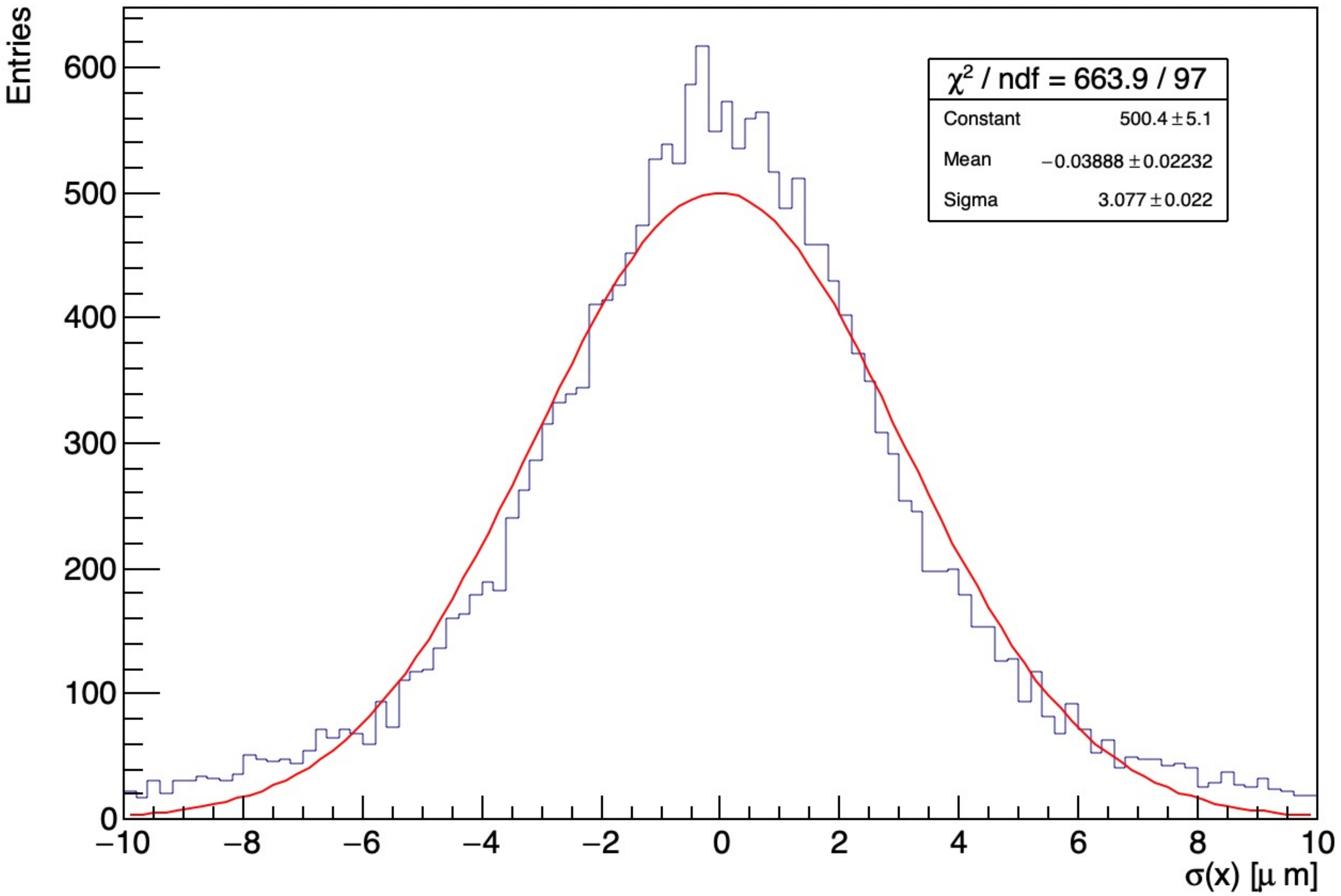
$$\sigma(\phi_s) \propto 1/e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2}$$ (see backup)

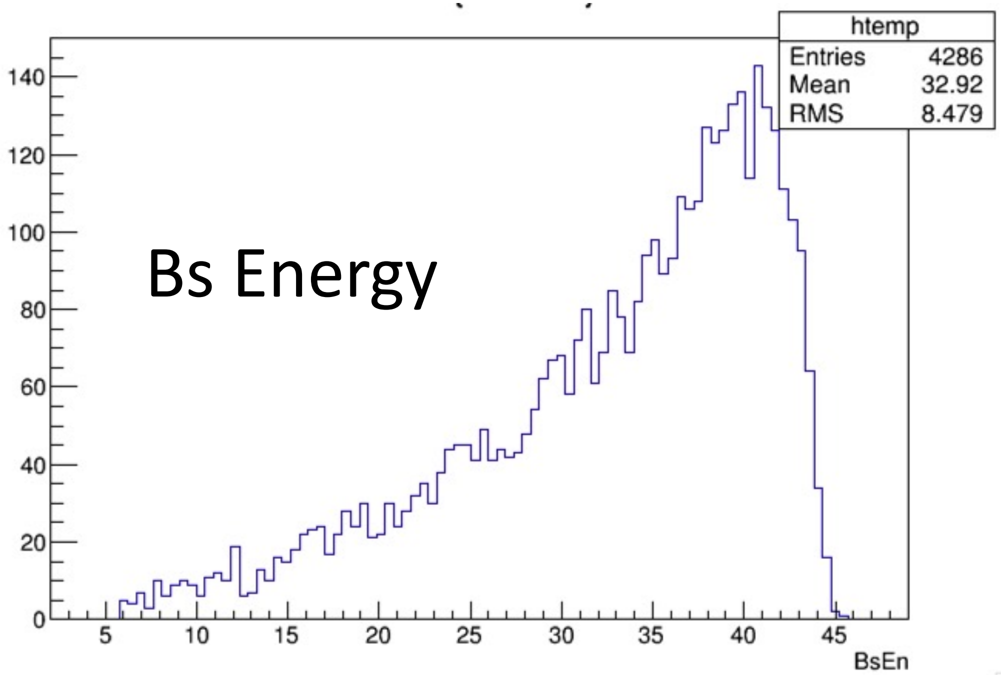
- $\Delta m_s = 17.8 \times 10^{12}\ \hbar s^{-1}$
- LHCb: $\sigma_t = 50$ fs -> 0.67
- CEPC: $\sigma_t = 10$ fs -> 1

- Conservative assumption that the SV reconstruction is 10 times worth than PV reconstruction.



SV reconstruction by Yongfeng





Summary on effecitive stat

	LHCb	CEPC	LHCb(Run 1)
$b\bar{b}$ statics	43.2 * 10^12	0.152 * 10^12	26.64 * 10^9
Acceptance * trigger * Reconstruction	5%	100%	5%
Br($b\bar{b}$ -> Bs)	10% * 2(b and anti-b)	10% * 2	10% * 2
Br(Bs->Jpsi Phi) *Br(Jpsi->ll) *Br(Phi->KK)	0.001 * 0.06 * 0.5	0.001 * 0.12 (ee channel) * 0.5	0.001 * 0.06 * 0.5
Bs->Jpsi(->ll)Phi(->KK) stat			8000 consist with paper
Flavour tagging	4%	15%	4%
Time resolution	0.67	1	0.67
Total effective statics	0.23 * 10^6	0.27 * 10^6	144