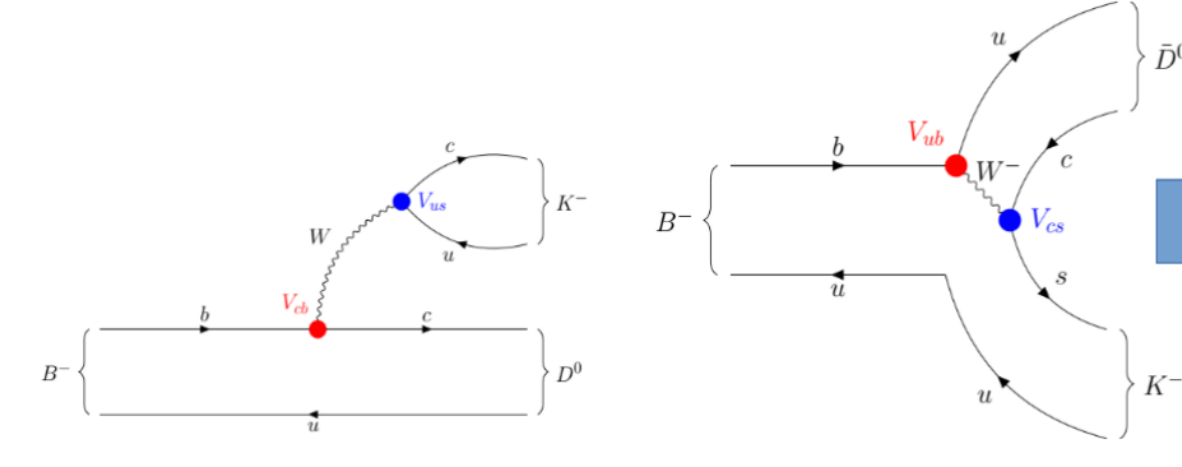


A novel method to measure the relative strong phase between D^0 and \bar{D}^0 in $D \rightarrow K_S^0 \pi^+ \pi^-$ and its application to measurements of the CKM angle γ in $B^\pm \rightarrow D^0(\bar{D}^0) K^\pm$ decays.

Jake Lane [1], Evelina Gersabeck [2], Jonas Rademacker [3]
[1] Monash University (Aus), [2] University of Manchester (UK), [3] University of Bristol (UK)

1. Measuring γ from $B \rightarrow DK$

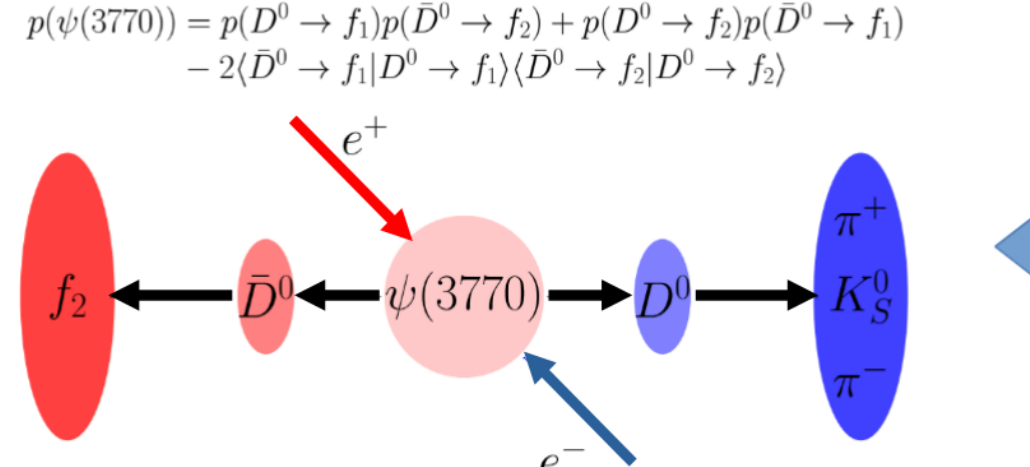
- Produce B hadrons from $pp \rightarrow BX$ collisions of LHCb (or from $e^+e^- \rightarrow BX$ at Belle II), which decay to states with the charm quark ($b \rightarrow c$)
- $B^- \rightarrow DK^-$ decays are essentially interference between $b \rightarrow csu$ and $b \rightarrow csd$ tree diagrams



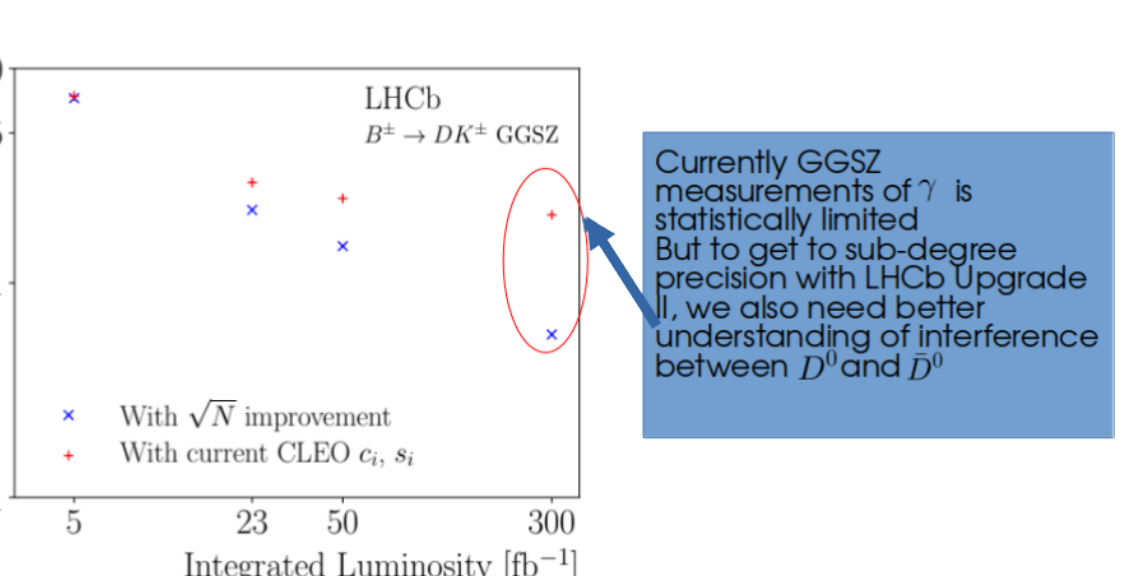
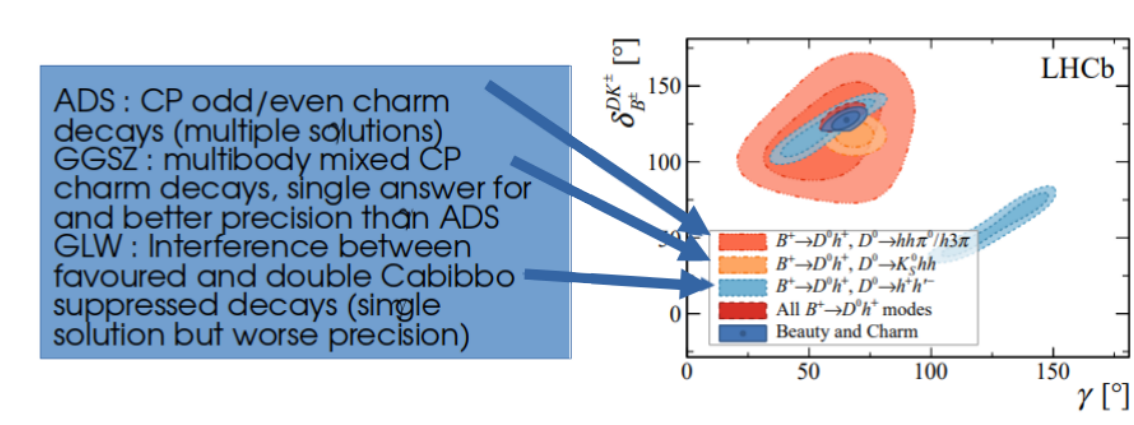
$$M(B^- \rightarrow D^0 K^-) \sim V_{cb} V_{cs} M_{D^0} \\ M(B^- \rightarrow \bar{D}^0 K^-) \sim V_{cb} V_{cs} M_{\bar{D}^0}$$

- Amplitude for $B^- \rightarrow DK^-$ decays is a coherent sum:
 $p(B^- \rightarrow D(\rightarrow f)K^-) = p(D^0 \rightarrow f) + r_{D^0} p(\bar{D}^0 \rightarrow f) + 2(D^0 \rightarrow f_1) p(D^0 \rightarrow f_1) \times r_{B^0} e^{i(\delta_B - \gamma)}$

- e^+e^- collide at $\sqrt{s} = 3.773$ GeV at the $\psi(3770)$ resonance at BESIII (2020 measurement of $\Delta\delta_D$: <https://arxiv.org/abs/2002.12791>)
- $\psi(3770)$ decays to two charm mesons, $D D \rightarrow f_1 f_2$ pairs, which are quantum correlated.



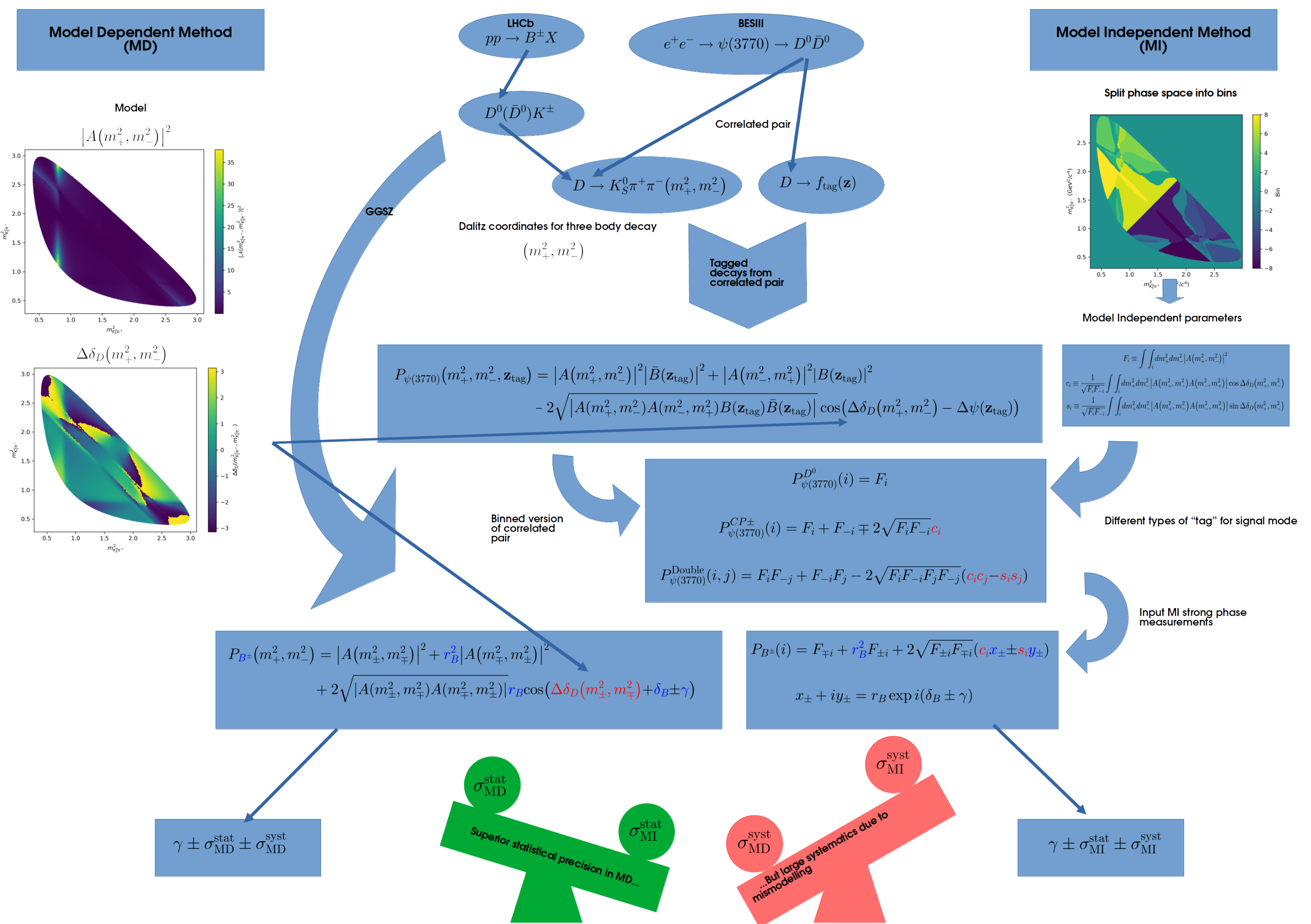
- $\Delta\delta_D$ obtained if $f_{12} = K_S^0 \pi^+ \pi^-$
 $(D^0 \rightarrow K_S^0 \pi^+ \pi^- | \bar{D}^0 \rightarrow K_S^0 \pi^+ \pi^-) = |A(m_+^2, m_-^2)| A(m_+^2, m_-^2) \exp i \Delta\delta_D(m_+^2, m_-^2)$



Golden mode for three body decays (GGSZ)
 $K_S^0 \pi^+ \pi^-$

- $N = 3$ body final state, $3N - 7 = 2$ dimensional phase-space:
 $m_{K_S^0 \pi^+ \pi^-}^2 = (E_{K_S^0} + E_{\pi^+})^2 - |p_{K_S^0} + p_{\pi^+}|^2$
- From CP conservation:
 $A_{D^0}(m_+^2, m_-^2) = A_{\bar{D}^0}(m_+^2, m_-^2)$
- The relative strong phase is the only phase difference:
 $\Delta\delta_D(m_+^2, m_-^2) = \text{Arg}(A_{D^0}) - \text{Arg}(A_{\bar{D}^0}) = -\Delta\delta_D(m_+^2, m_-^2)$
- Amplitude for $D^0 \rightarrow K_S^0 \pi^+ \pi^-$, fitted to $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ events from $e^+e^- \rightarrow D^0 X$ at B-Factories (BaBar and Belle) ($\sim 10^6$ events) (<https://arxiv.org/abs/1804.06153v1>).

2. Existing methods (MD and MI)



3. Our method (Quasi Model Independent - QMI)



Our Paper on ArXiv: <https://arxiv.org/abs/2305.10787>

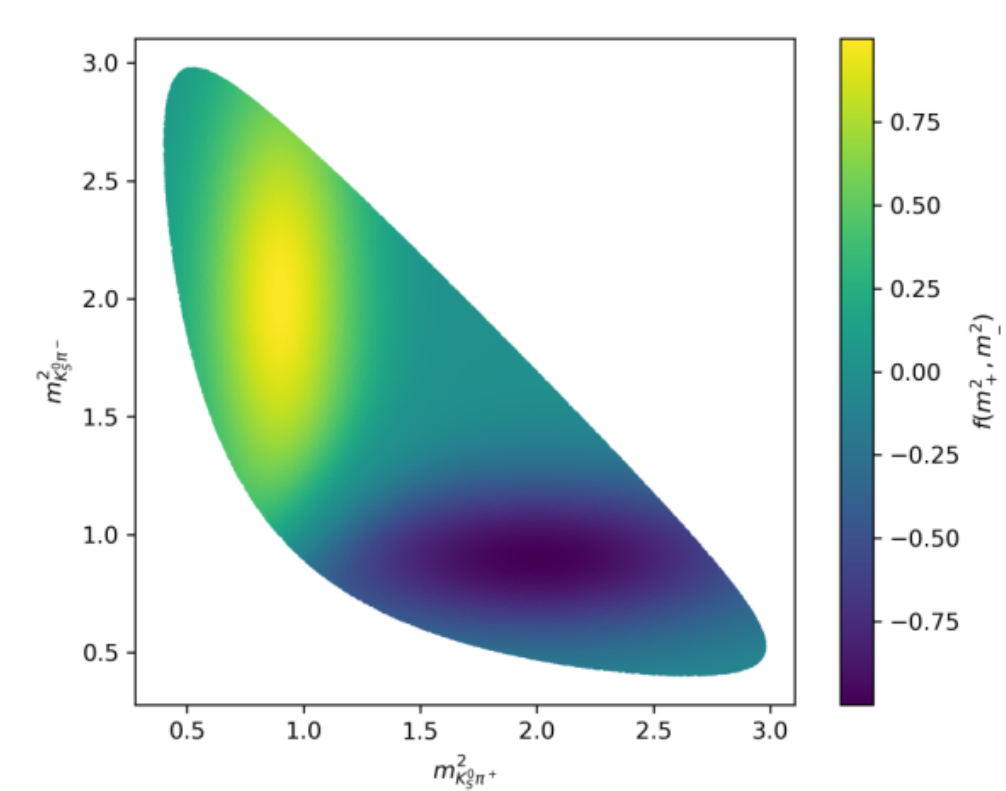
Add a "correction" to a given model: $\Delta\delta_D(m_+^2, m_-^2) \rightarrow \Delta\delta_D(m_+^2, m_-^2) + f(m_+^2, m_-^2 | C)$

Two dimensional polynomial of order O : $f(z_+, z_- | C) = \sum_{i=0}^O \sum_{j=0}^{O-i} C_{i,j} P_i(z_+) P_j(z_-)$

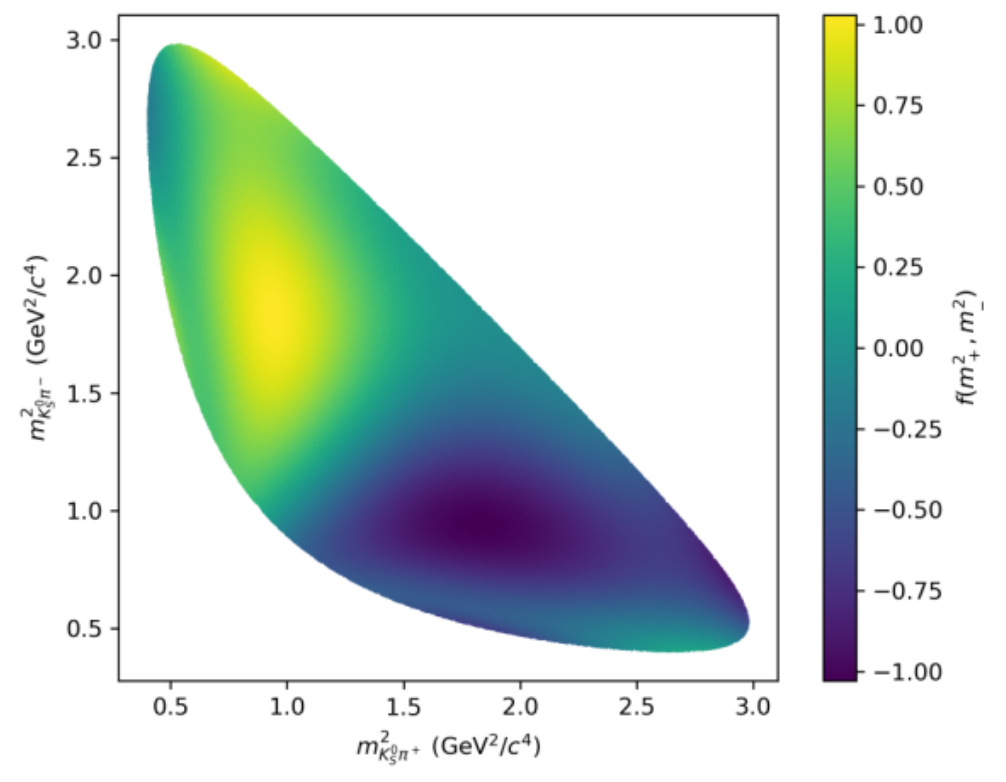
Ensure: $|P_i(z_\pm)| \leq 1$ $z_+ = 2.234(m_-^2 + m_+^2) - 3.116$ $z_- = \frac{1.556(m_-^2 - m_+^2)}{z_+ + 2}$

Simultaneously fit C and $r_B \exp i(\delta_B \pm \gamma)$
From simulated $e^+e^- \rightarrow \psi(3770) \rightarrow D^0 \bar{D}^0$ and $pp \rightarrow B^\pm X$

Generate a bias in $\Delta\delta_D(m_+^2, m_-^2)$



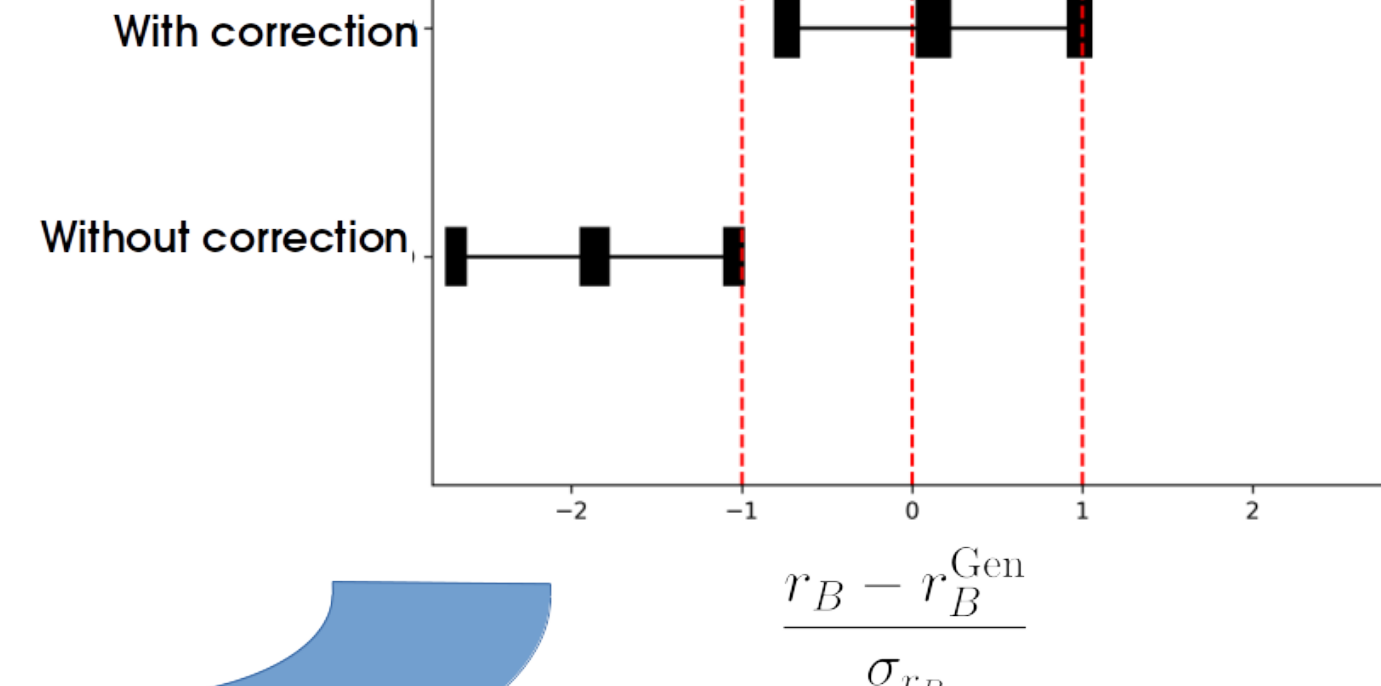
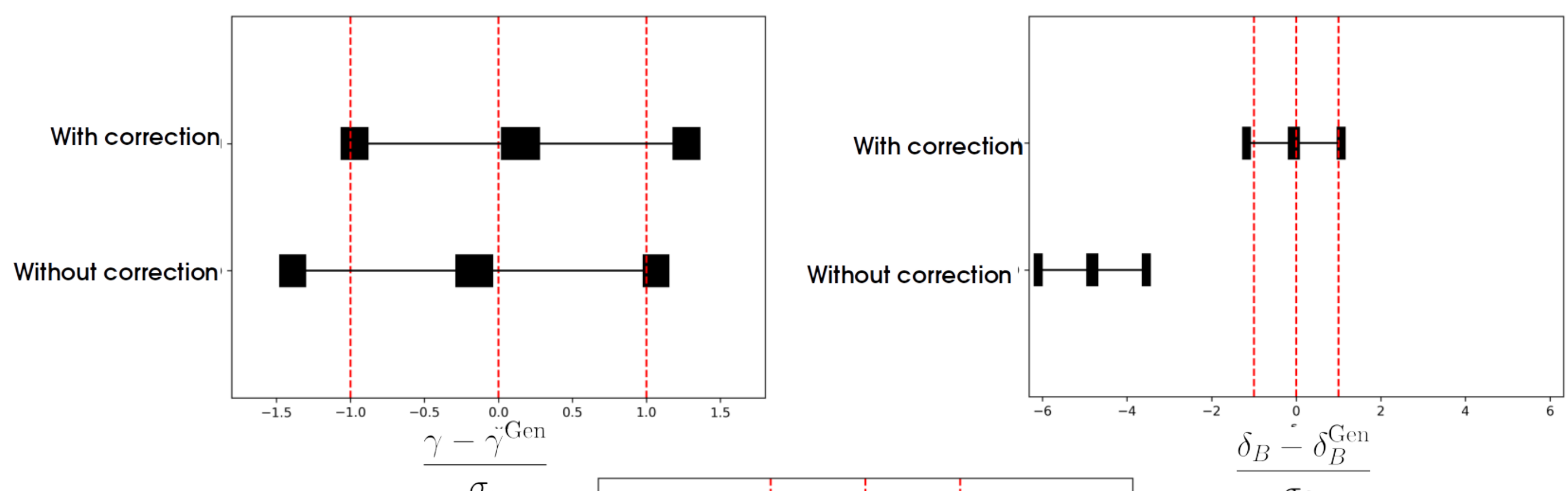
Add correction $f(z_+, z_- | C)$



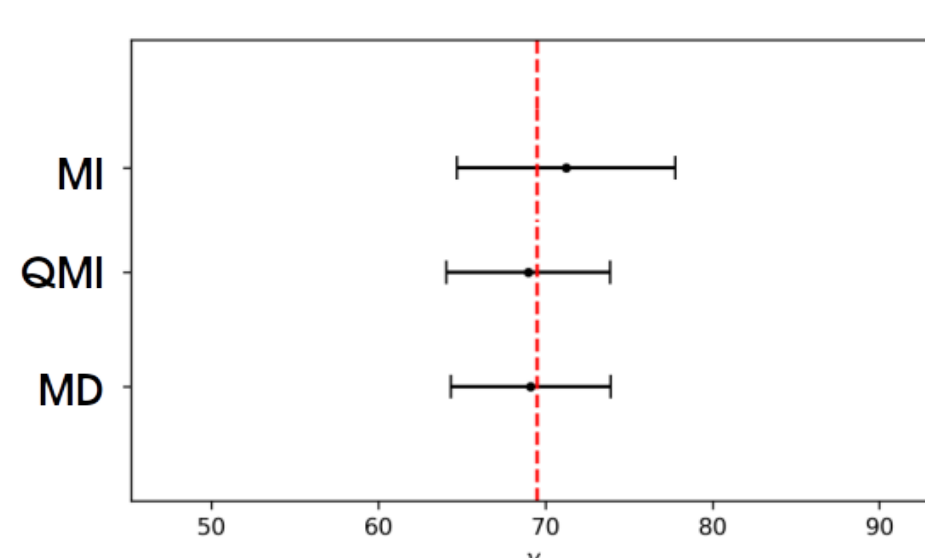
Fit CKM parameters with a correction to $\Delta\delta_D(m_+^2, m_-^2)$

$$\text{pull}(x) \equiv \frac{x - x^{\text{Gen}}}{\sigma_x}$$

$\langle \text{pull}(x) \rangle = 0 \Rightarrow$ No bias in x
 $s(\text{pull}(x)) = 1 \Rightarrow \sigma_x = \sigma_x^{\text{stat}}$



Comparison of precision, simulate pure signal, fit to same data with different methods



4. Conclusion

- Shown our novel method measures γ with similar statistical precision to the optimal unbinned method (MD)
- QMI method compensates for mismodelling $\Delta\delta_D$ without losing precision due to binning

5. References/Further reading

- Our method paper: <https://arxiv.org/abs/2305.10787>
- Belle-BaBar model for $D^0 \rightarrow K_S^0 \pi^+ \pi^-$: <https://arxiv.org/abs/1804.06153v1>
- AmpGen (by Dr. Timothy Evans) (applications and libraries used to develop the method, simulate $D \rightarrow K_S^0 \pi^+ \pi^-$ and fit γ): <https://github.com/goofit/ampgen>