

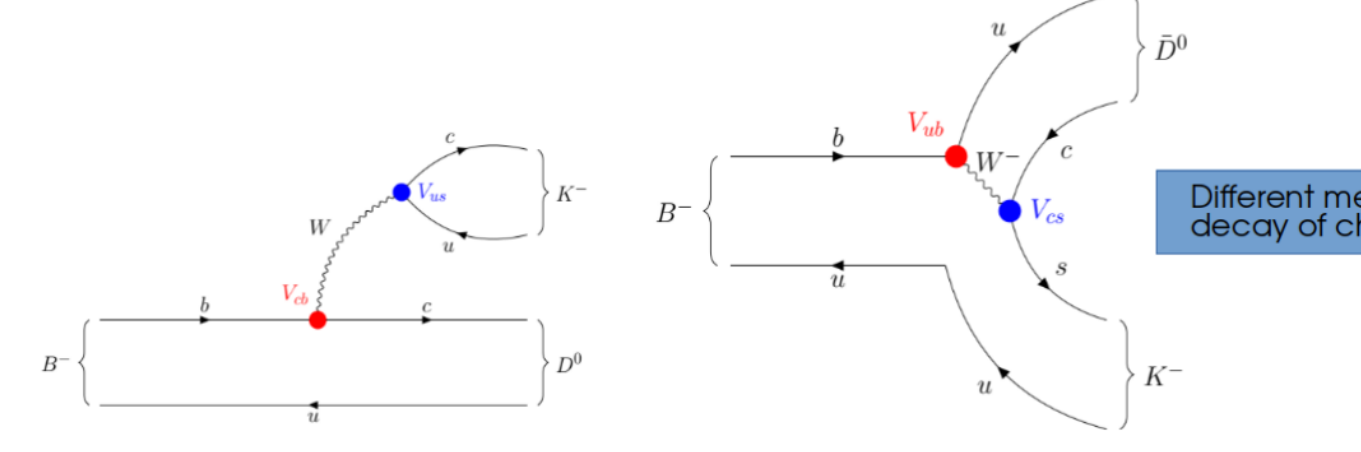
# A novel method to measure the relative strong phase between $D^0$ and $\bar{D}^0$ in $D \rightarrow K_S^0 \pi^+ \pi^-$ and its application to measurements of the CKM angle $\gamma$ in $B^\pm \rightarrow D^0(\bar{D}^0) K^\pm$ decays.

Jake Lane [1], Evelina Gersabeck [2], Jonas Rademacker [3]

[1] Monash University (Aus), [2] University of Manchester (UK), [3] University of Bristol (UK)

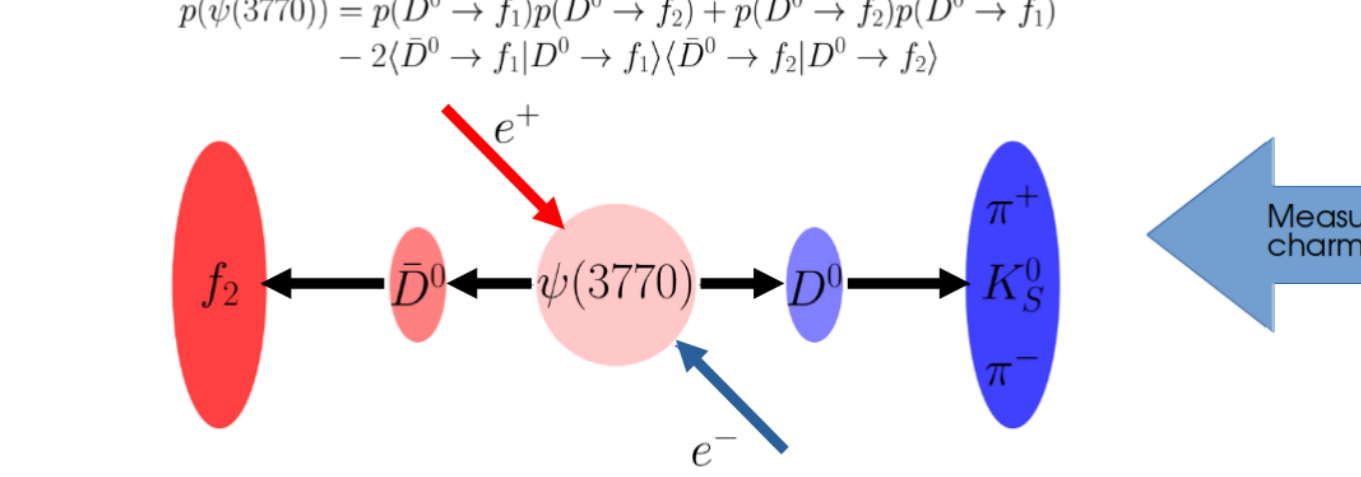
## 1. Measuring $\gamma$ from $B \rightarrow DK$

- Produce  $B$  hadrons from  $pp \rightarrow BX$  collisions at 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  $b \rightarrow csu$  tree diagrams

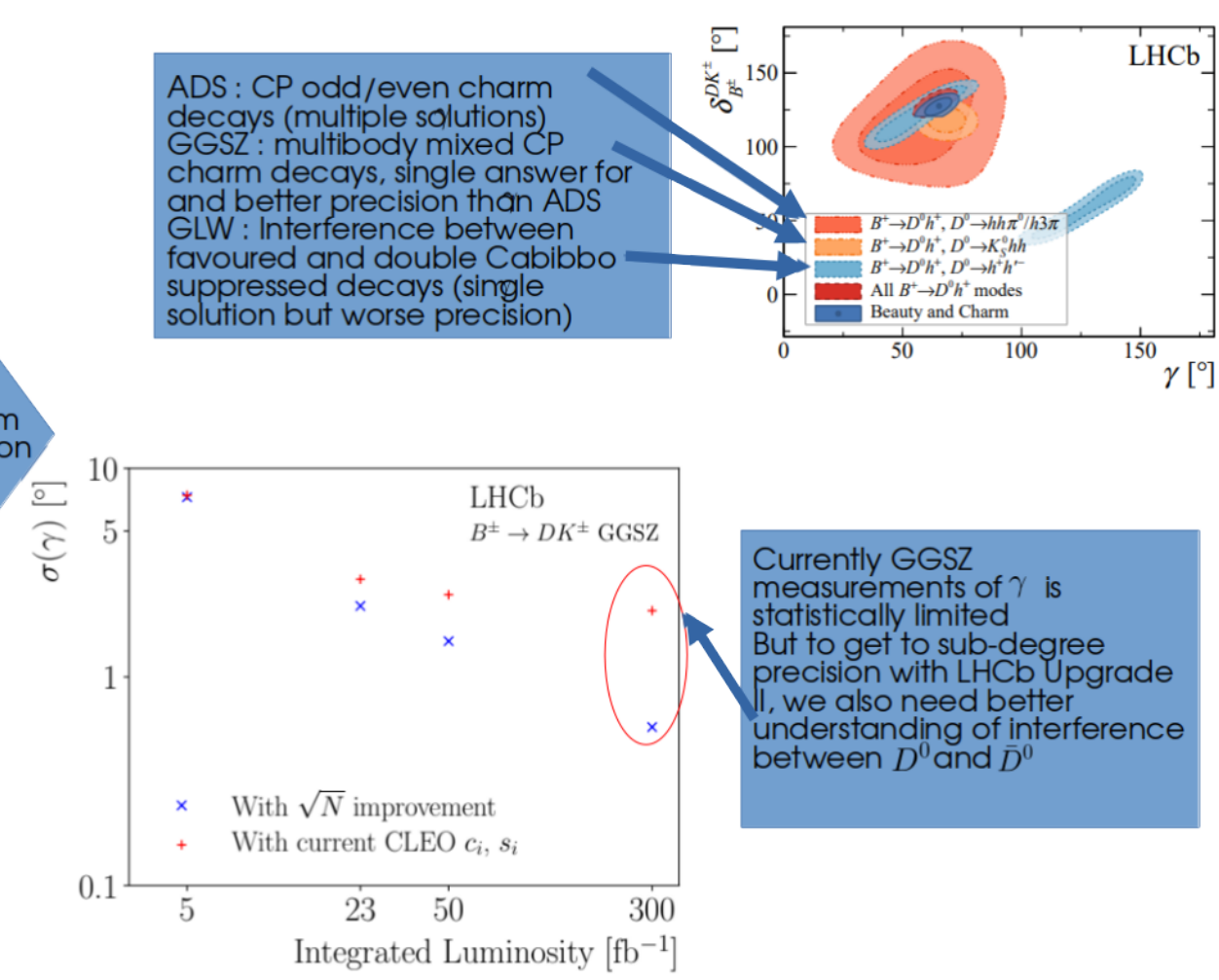


Amplitude for  $B^- \rightarrow DK^-$  decays is a coherent sum:  
 $p(B^- \rightarrow D(\rightarrow f) K^-) = p(D^0 \rightarrow f) + r_B p(D^0 \rightarrow f)$   
 $+ 2(D^0 \rightarrow f) D^0 \rightarrow f \times r_B e^{i(\delta_B - \gamma)}$

- $e^+e^-$  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,  $D\bar{D}$  to  $f_1 f_2$  pairs, which are quantum correlated.



$\Delta\delta_D$  obtained if  $f_{1,2} = K_S^0 \pi^\pm \pi^\mp$   
 $\langle D^0 \rightarrow K_S^0 \pi^+ \pi^- | D^0 \rightarrow K_S^0 \pi^+ \pi^- \rangle = |A(m_+^2, m_-^2) A(m_-^2, m_+^2)| \exp i \Delta\delta_D(m_+^2, m_-^2)$



- $N = 3$  body final state,  $3N - 7 = 2$  dimensional phase-space:

$$m_{K_S^0 \pi^\pm}^2 = (E_{K_S^0} + E_{\pi^\pm})^2 - |\mathbf{p}_{K_S^0} + \mathbf{p}_{\pi^\pm}|^2$$

- From CP conservation:

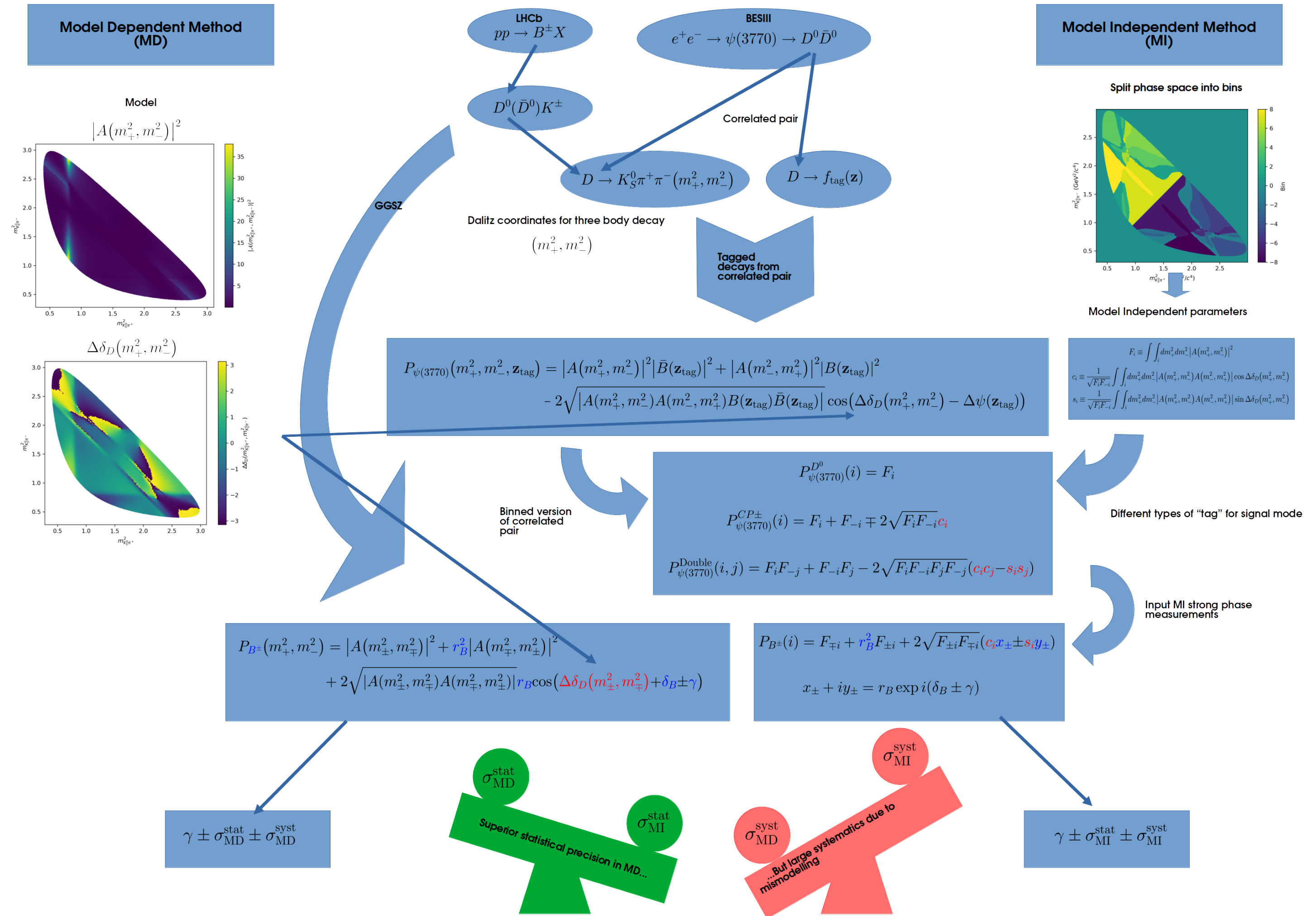
$$A_{D^0}(m_+^2, m_-^2) = A_{D^0}(m_-^2, m_+^2)$$

- The relative strong phase is the only phase difference:

$$\Delta\delta_D(m_+^2, m_-^2) = \Delta\delta_D(A_{D^0}) - \Delta\delta_D(A_{\bar{D}^0}) = -\Delta\delta_D(m_+^2, m_-^2)$$

- 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) ( $\sim 10^7$  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:  $\Delta\delta_D(m_+^2, m_-^2) \rightarrow \Delta\delta_D(m_+^2, m_-^2) + f(m_+^2, m_-^2 | \mathbf{C})$

Two dimensional polynomial of order  $O$ :  $f(z_+, z_- | \mathbf{C}) = \sum_{i=0}^O \sum_{j=0}^{O+1} C_{i,2j+1} P_i(z_+) P_{2j+1}(z_-)$

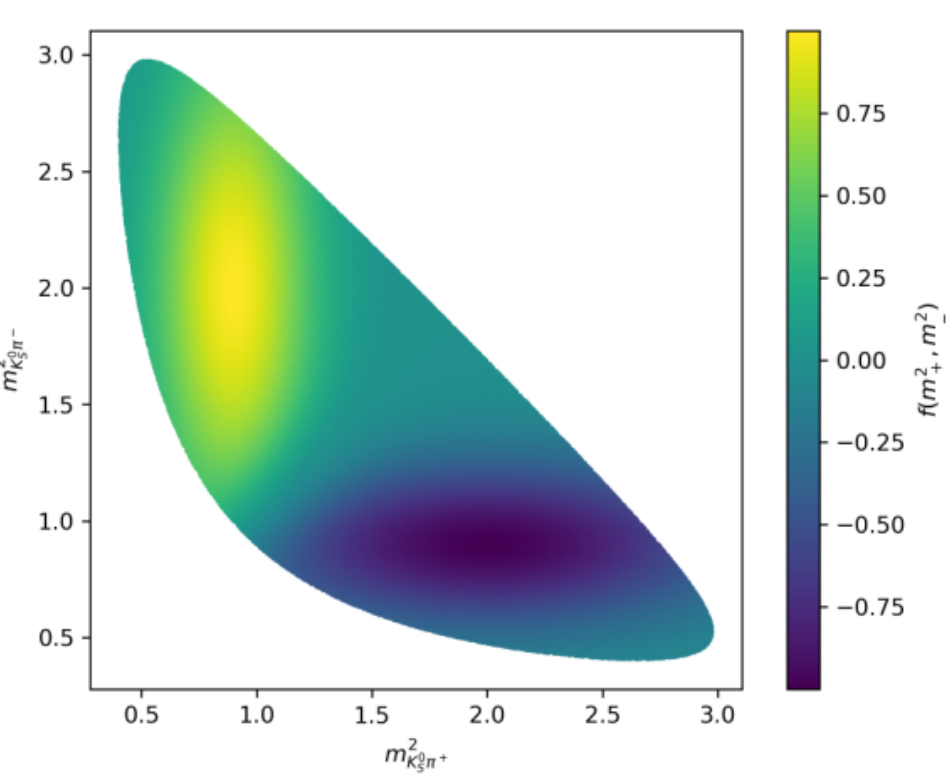
Ensure:  $|P_i(z_\pm)| \leq 1$

$z_+ = \frac{2.234(m_+^2 + m_-^2)}{2} - 3.116$

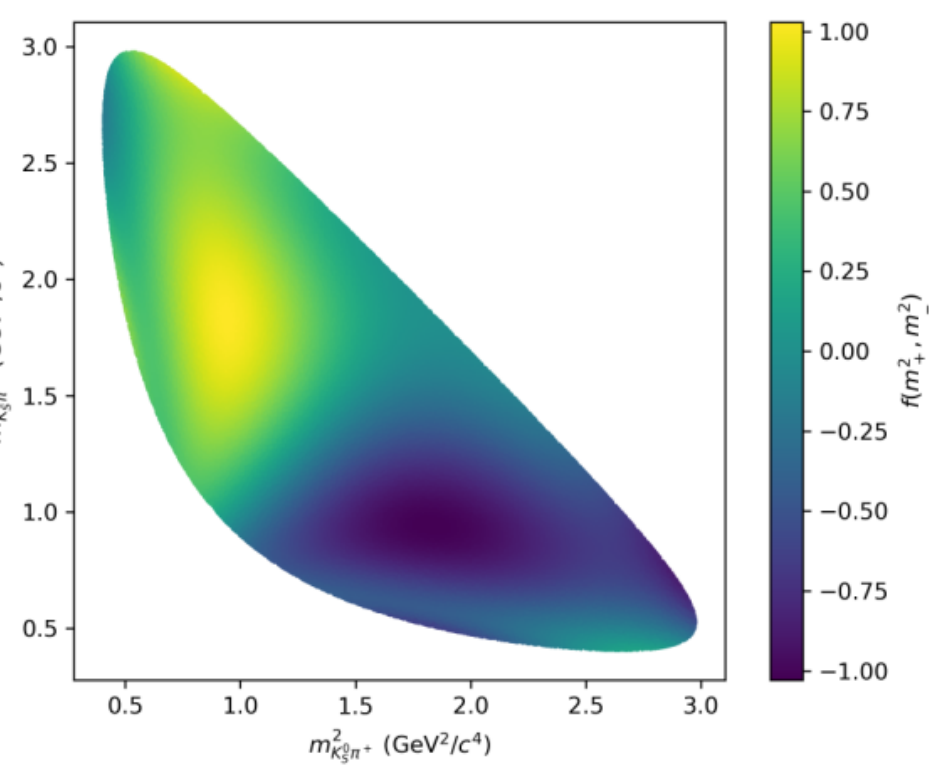
$z_- = \frac{0.805(m_+^2 - m_-^2)}{2(z_+ + 2)}$

Simultaneously fit  $\mathbf{C}$  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 with bias in  $\Delta\delta_D(m_+^2, m_-^2)$



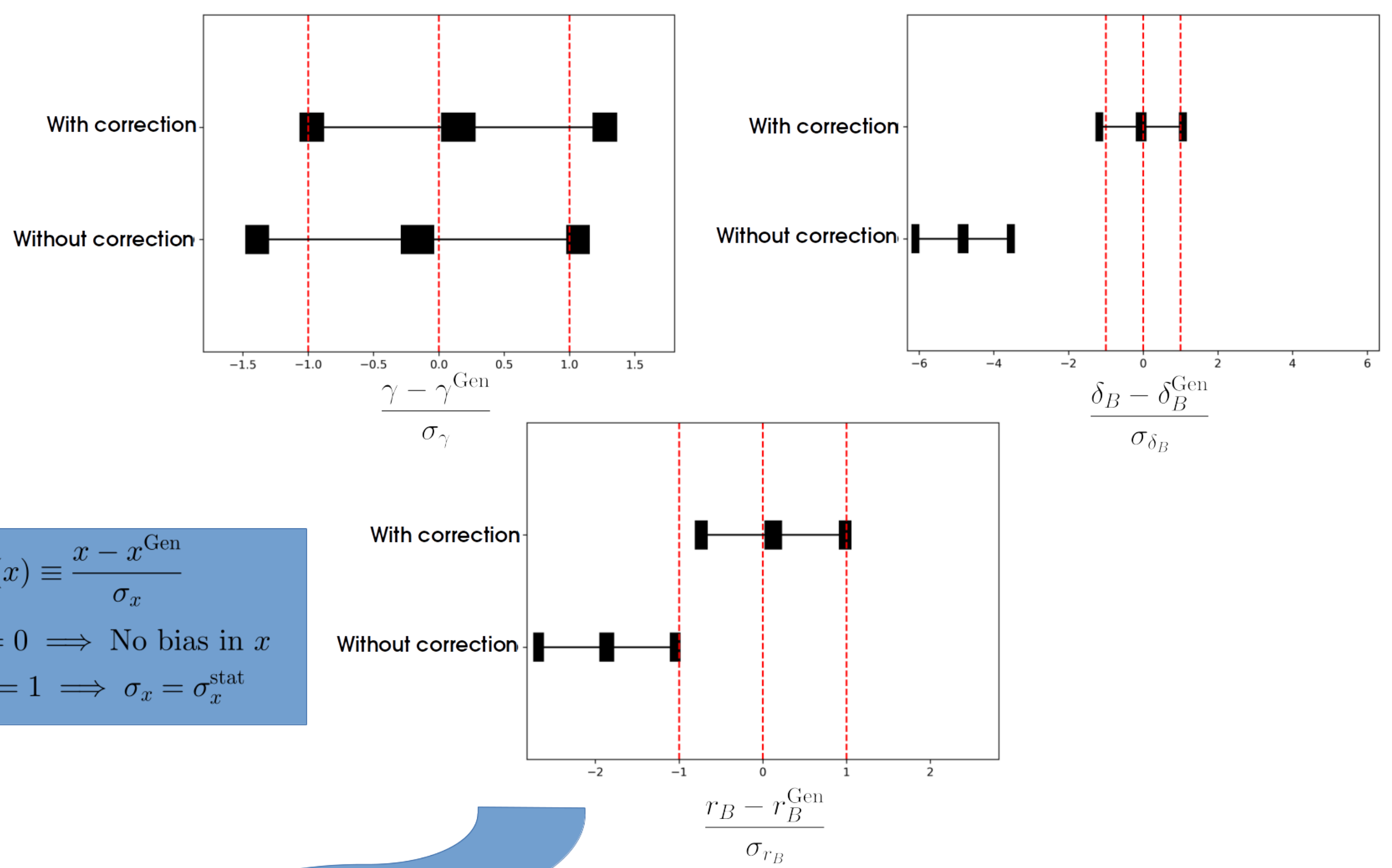
Fit with correction  $f(z_+, z_- | \mathbf{C})$



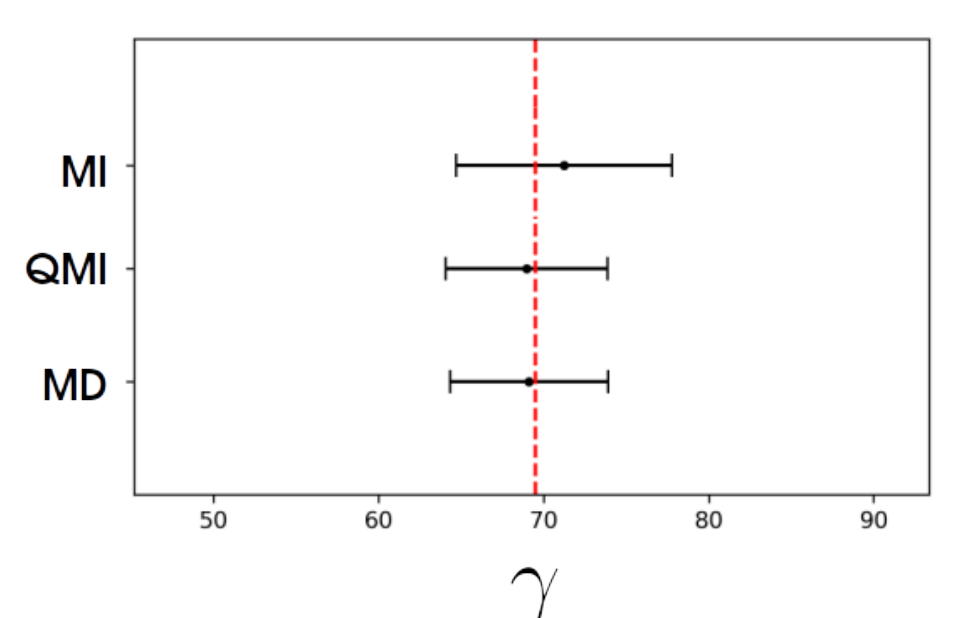
Fit CKM parameters with a correction to  $\Delta\delta_D(m_+^2, m_-^2)$

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

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



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



## Conclusions

- Shown our novel method measures gamma with similar statistical precision to the optimal unbinned method (MD)
- QMI method compensates for mismodelling strong phase without losing precision due to binning

## References

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  $\gamma$ ) : <https://github.com/goofit/ampgen>