Dalitz analysis of $B^0 \to D^-\pi^+\pi^0$ and $B^+ \to D^-\pi^+\pi^+$

Belle II Germany Meeting

Melisa Akdag, Agrim Aggarwal, Valerio Bertacchi, Markus Prim 09.09.2025

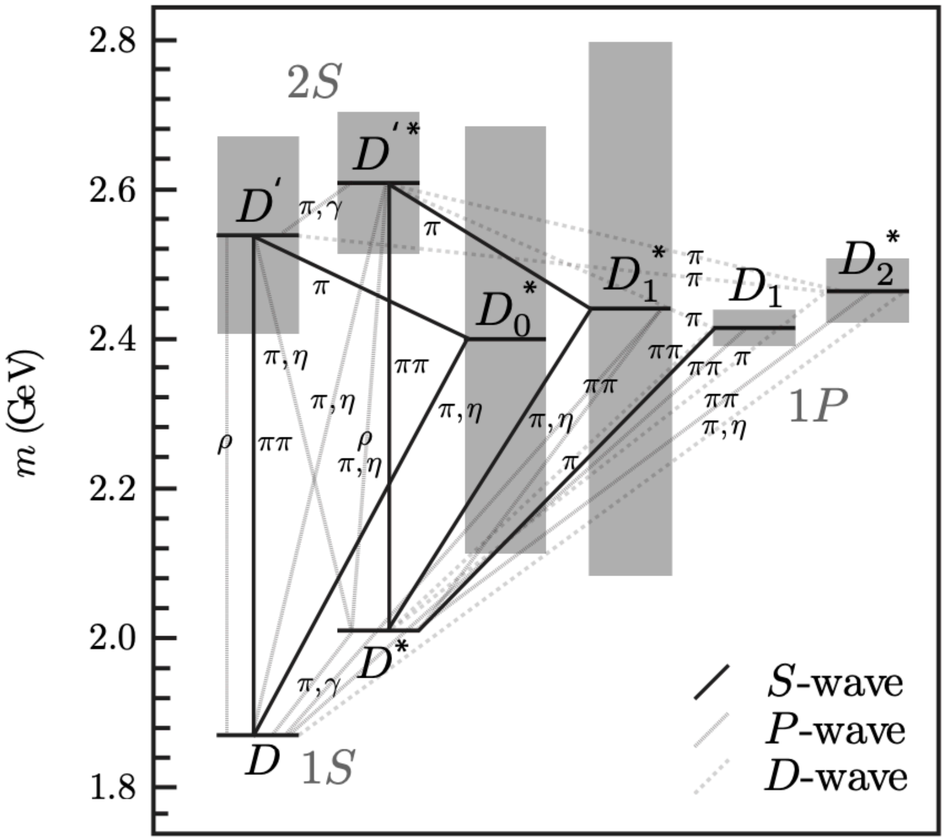
makdag@uni-bonn.de

Introduction

- Study of orbitally excited charmed mesons

Current questions

- Width D_0^* and D_1^* broad compared to others
- Comparison of $D_{s0}^*(2317)$ and $D_0^*(2300)$
  $\rightarrow D_{s0}^*(2317)$ should be about m_s (100 MeV) heavier
- $D_{s0}^*(2317)$ about 150MeV below the prediction of quark model

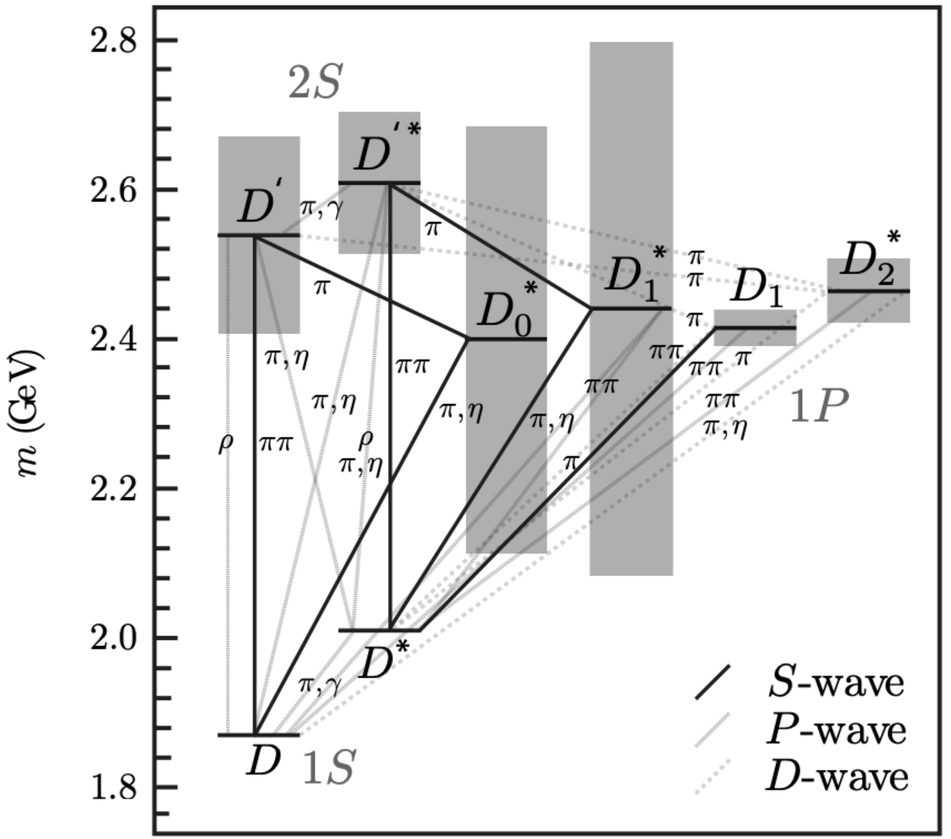


[Bernlochner, Ligeti, Turczyk, 2012]

makdag@uni-bonn.de

Introduction

- Importance of $B \to D^{(*)}\pi\pi$ measurements:
  1. $B \to D\pi\pi$: access to D_0^* and D_2^*
  2. $B \to D^*\pi\pi$: access to D_1, D_1' and D_2^*
- Analysis of different $B \to D\pi\pi$ final states gives access to 3-body final-state dynamics
- Comparison of D and D^* final states gives access to spin symmetry



[Bernlochner, Ligeti, Turczyk, 2012]

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Recent findings

- Strong evidence that D_0^* is not described by a Breit-Wigner but is a dynamically generated state described by UChPT
- partial wave amplitudes $\mathscr{A}_L(s)$ and Legendre polynomials P_L with helicity angle θ

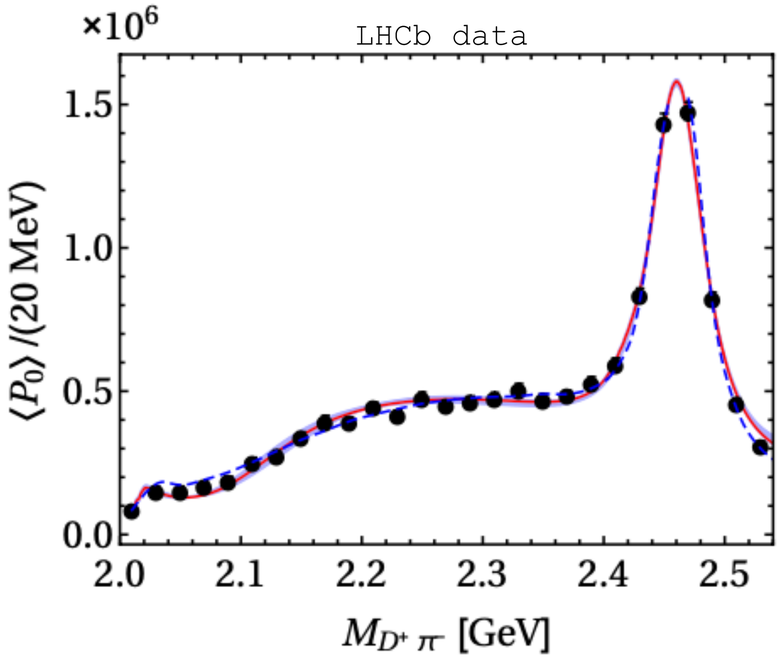
$$\mathscr{A}(B^- \to D^+\pi^-\pi^-) = \sum_{L=0}^{2} \sqrt{2L+1}\,\mathscr{A}_L(s) P_L(\cos\theta(D^+\pi^-))$$

Angular moments

$$\langle P_0 \rangle \propto |A_0|^2 + |A_1|^2 + |A_2|^2$$

$$\langle P_2 \rangle \propto \frac{2}{5}|A_1|^2 + \frac{2}{7}|A_2|^2 + \frac{2}{\sqrt{5}}|A_0||A_2|\cos(\delta_2 - \delta_0)$$

$$\langle P_{13} \rangle = \langle P_1 \rangle - \frac{14}{9}\langle P_3 \rangle \propto \frac{2}{\sqrt{3}}|A_0||A_1|\cos(\delta_1 - \delta_0)$$



[Meißner, 2020]

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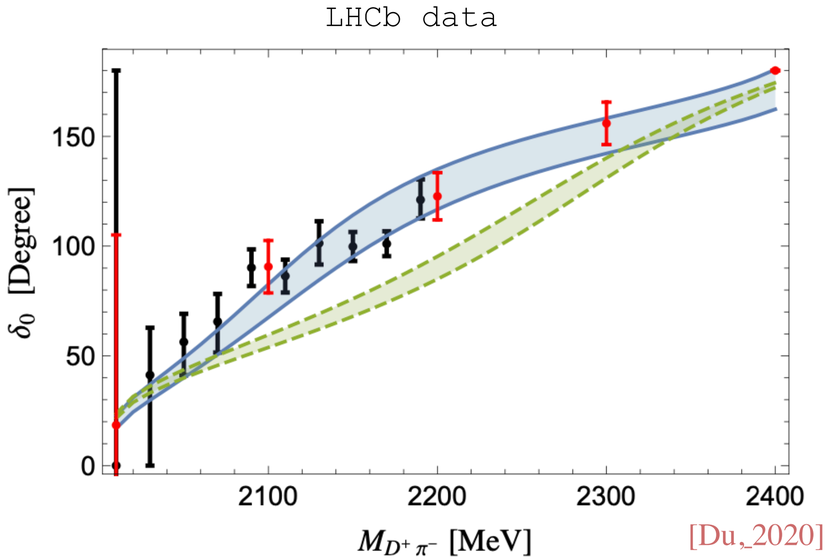
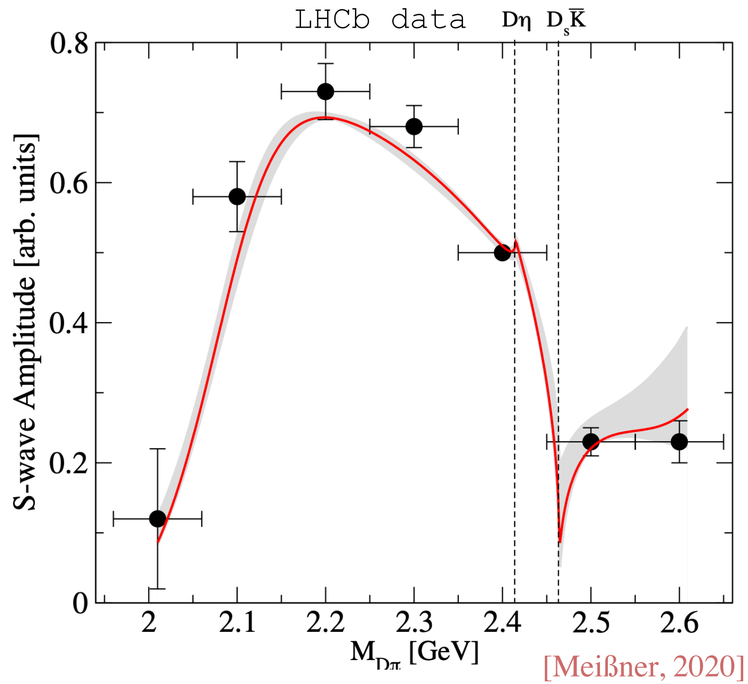


[Du,_2020]



[Meißner, 2020]

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Decays of interest

Signal decays

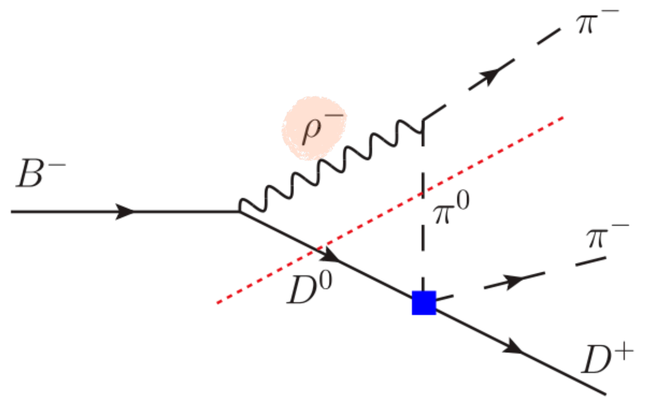
$$B^- \to D_0^{*0}\pi^- \to (D^+\pi^-)\pi^-$$
$$\to (D^0\pi^0)\pi^0$$
$$\not\to (D_s^+K^-)\pi^-$$
$$\overline{B}^0 \to D_0^{*+}\pi^- \to (D^+\pi^0)\pi^-$$
$$\to (D^0\pi^+)\pi^-$$
$$\not\to (D_s^+\overline{K}^0)\pi^-$$
$$\overline{B}^0 \to D_0^{*0}\pi^0 \to (D^+\pi^-)\pi^0$$
$$\to (D^0\pi^0)\pi^0$$
$$\not\to (D_s^+K^-)\pi^0$$
$$\overline{B}^0 \to D^+\rho^- \to D^+(\pi^-\pi^0)$$

LHCb → can measure charged final states very precisely

Belle II ↔ same final state

$D^+\pi^-\pi^-$	$D^+\pi^-\pi^0$	D_s
LHCb	Belle II	need more statistics for full Dalitz analysis
D*	D*	
dominated by loop diagram with ρ	access ρ directly in the measurement instead of indirectly in a loop	still worth to study projections

- $D^+\pi^-\pi^-$ process dominated by loop with ρ contribution, precise measurement by LHCb available, but large theory uncertainty from ρ contribution
- we can measure the ρ contribution by studying $D^+\pi^-\pi^0$
- all resonances contributing to $D^+\pi^-\pi^-$ also occur in $D^+\pi^-\pi^0$
  → cross check for amplitude modelling in $D^+\pi^-\pi^0$



[Du, Guo, Hanhart, Kubis, Meißner, 2021]

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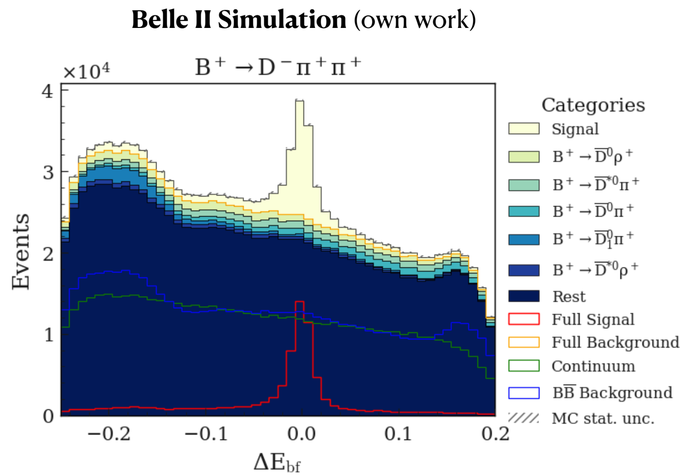
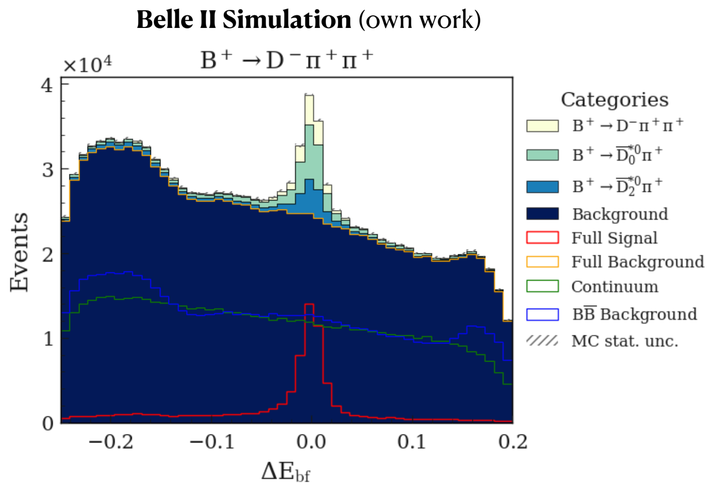
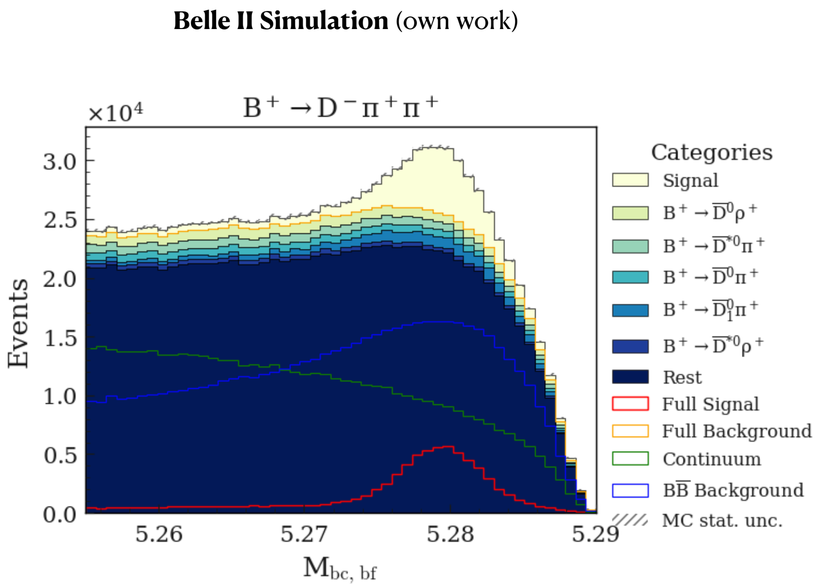
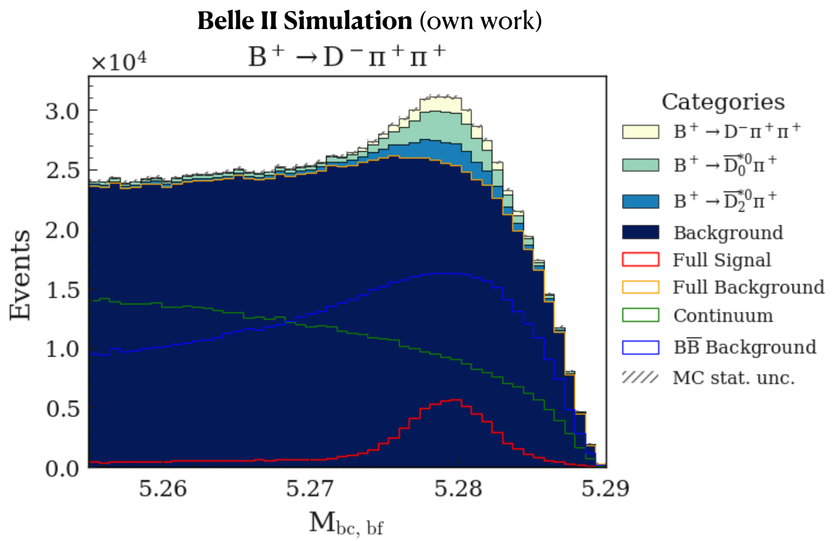
Reconstruction of $B^- \to D^+\pi^-\pi^-$

Before tighter selections









Selections on e.g.

$$\Delta E = E_{\mathrm{CMS}}/2 - E_B$$

$$M_{bc} = \sqrt{E^2_{\mathrm{beam}} - \mathbf{p}^2_B}$$

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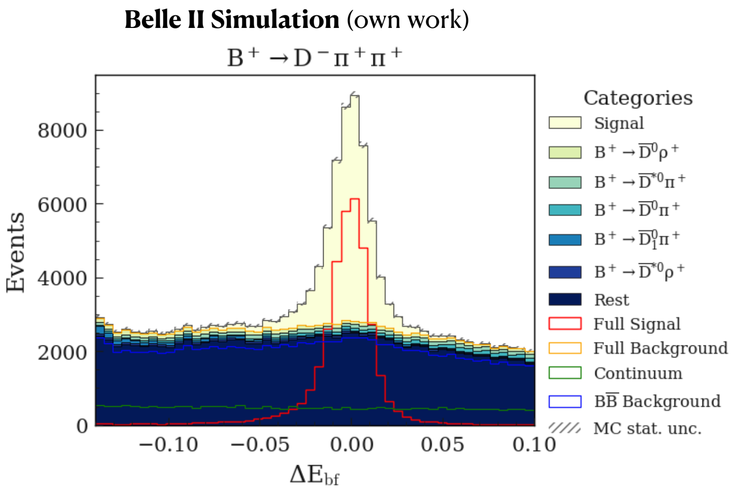
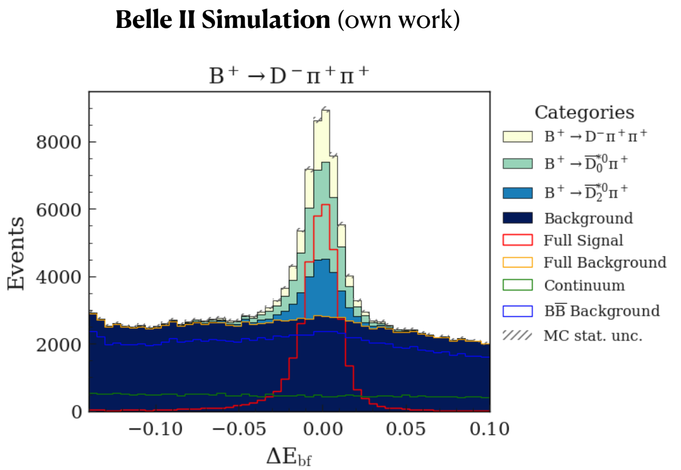
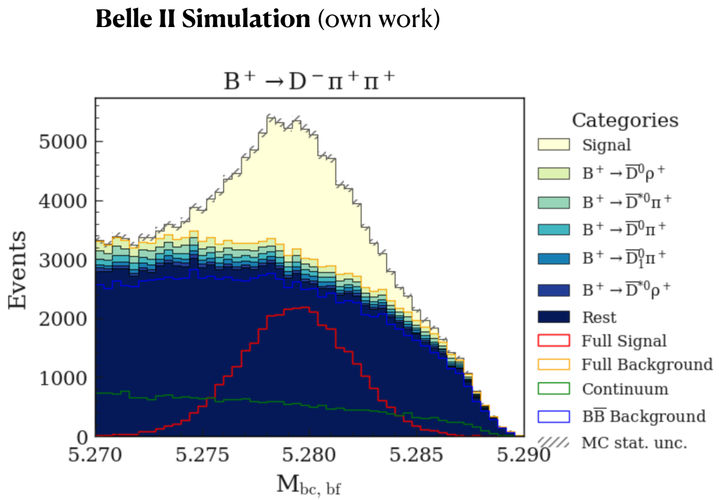
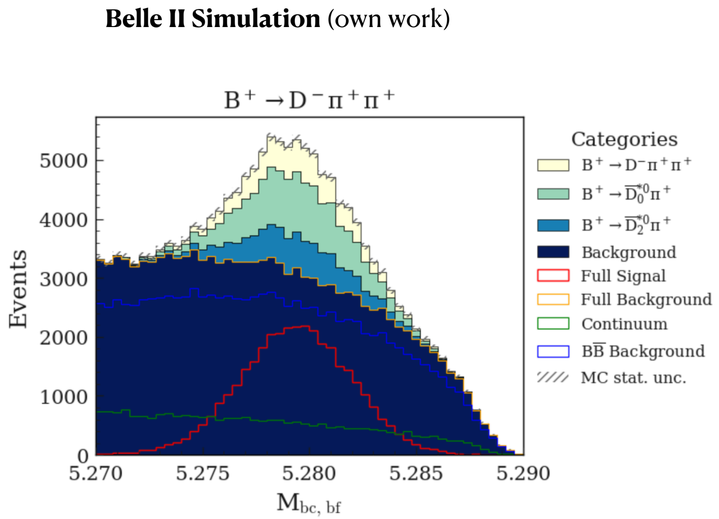
Reconstruction of $B^- \to D^+\pi^-\pi^-$ and selections

After tighter selections









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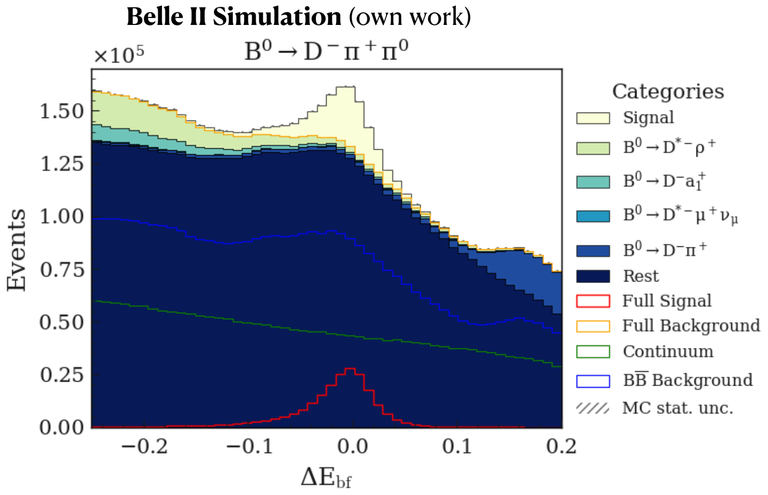
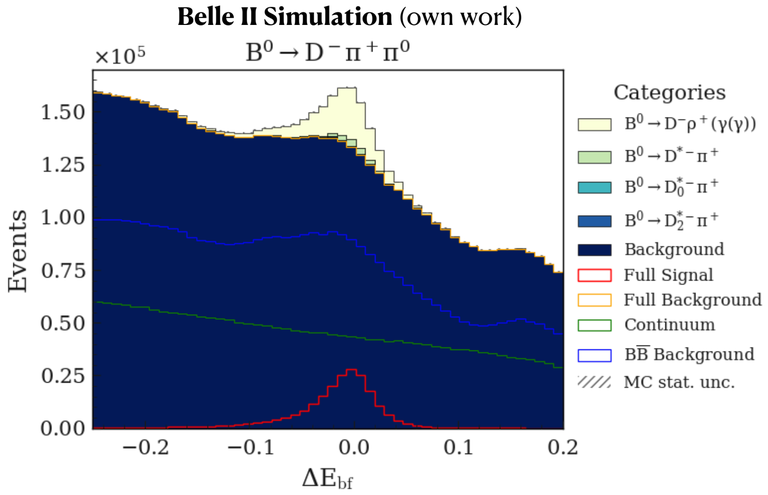
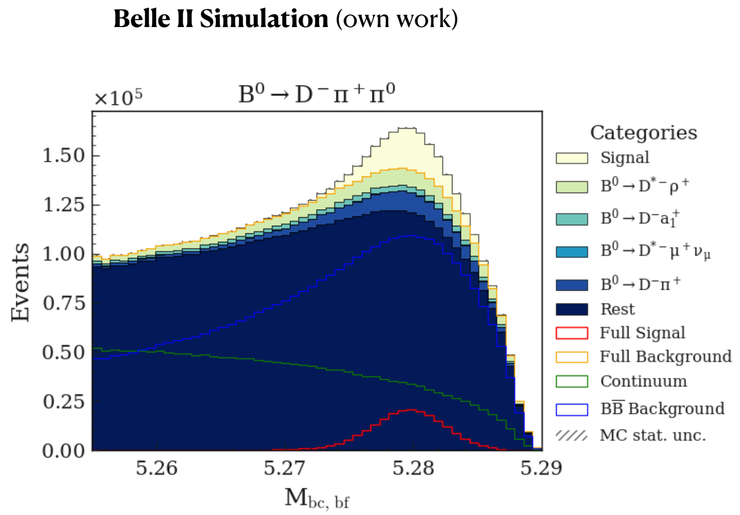
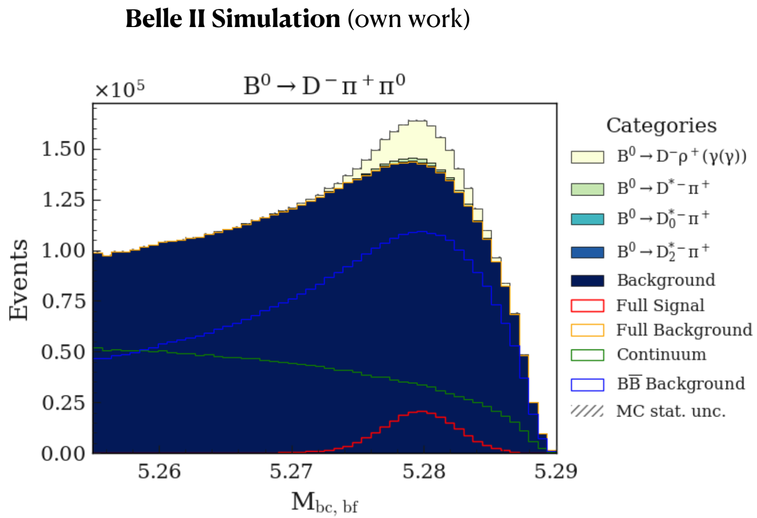
Reconstruction of $B^0 \to D^+\pi^-\pi^0$

Before tighter selections









Selections on e.g.

$$\Delta E = E_{\text{CMS}}/2 - E_B$$

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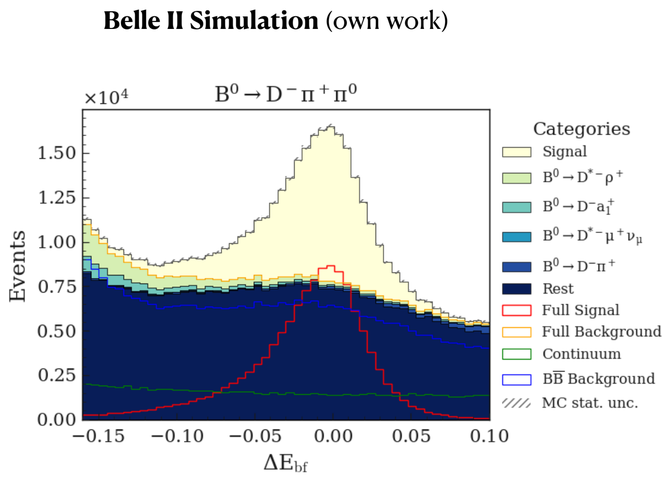
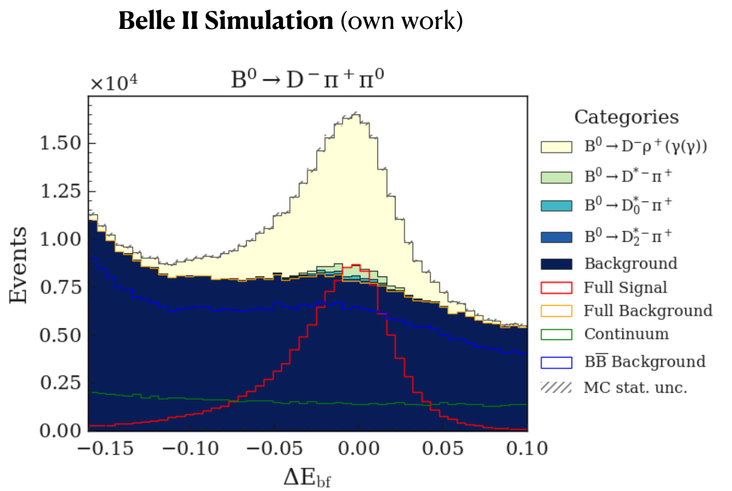
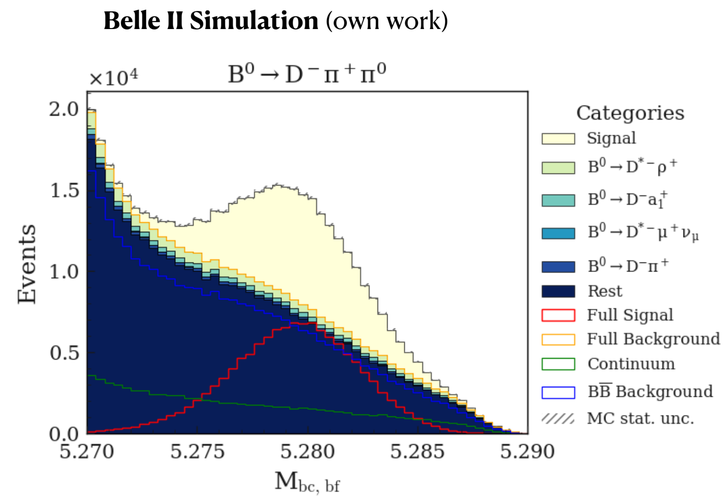
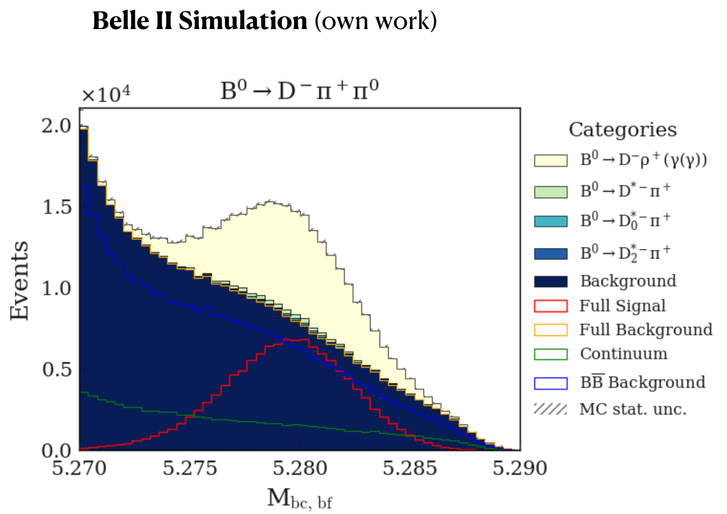
Reconstruction of $B^0 \to D^+\pi^-\pi^0$ and selections

After tighter selections









Selections on e.g.

$$\Delta E = E_{\mathrm{CMS}}/2 - E_B$$

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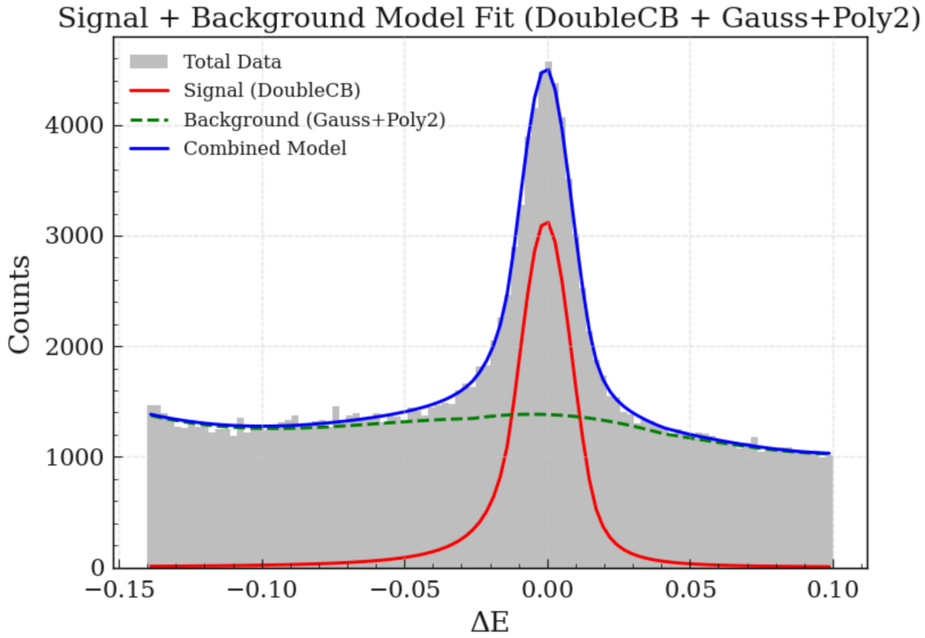
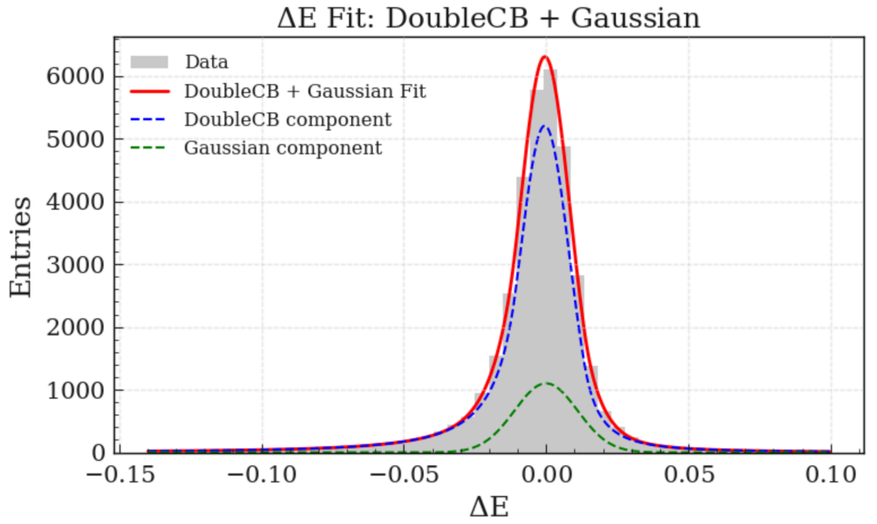
Fit results: $B^- \to D^+\pi^-\pi^-$



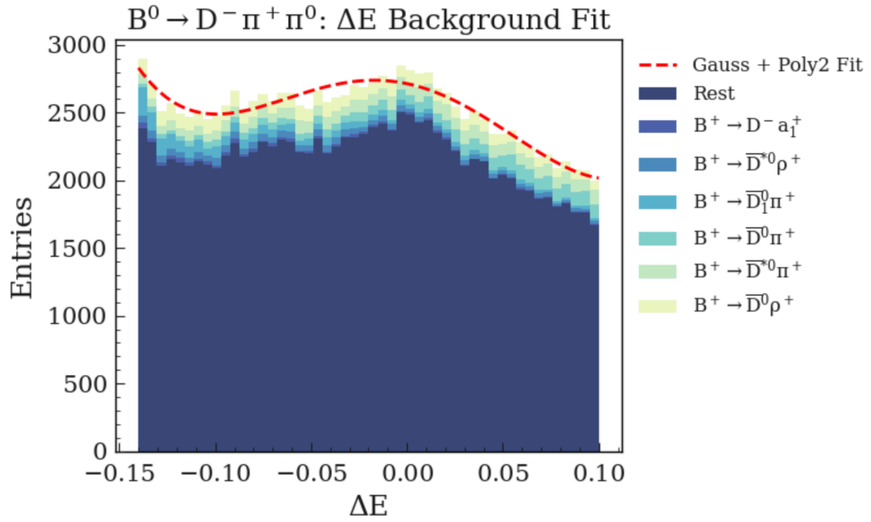
Chi² = 136.21, dof = 94, reduced = 1.45, p-value = 0.003

Raw signal yields from df: 35313

Integrated signal yields from fit: 35307.7

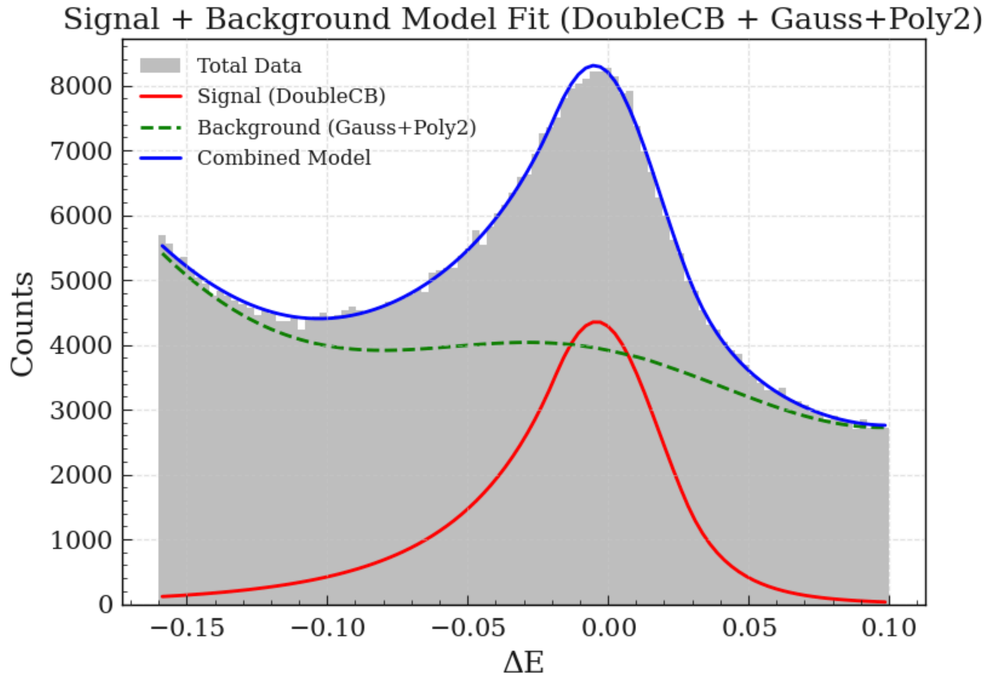


Chi² = 51.26, dof = 40, Reduced χ^2 = 1.28, p-value = 0.109



Chi² = 86.54, dof = 44, Reduced χ^2 = 1.97, p-value = 0.000

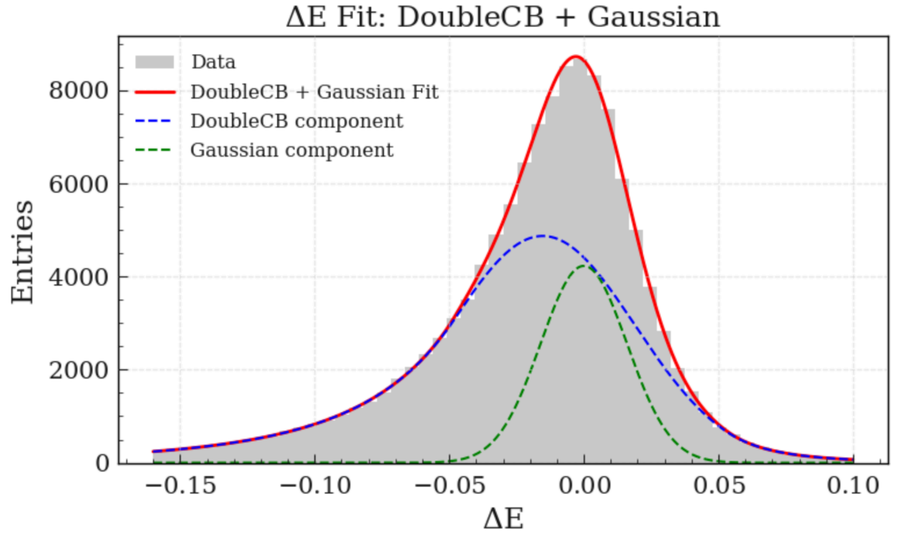
Fit results: $B^0 \to D^+\pi^-\pi^0$



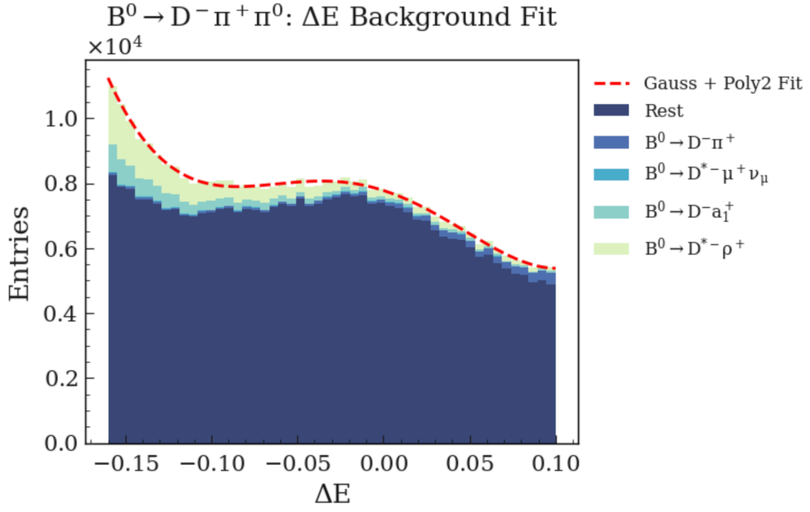
Chi² = 119.43, dof = 94, reduced = 1.27, p-value = 0.039

Raw signal yields from df: 122047

Integrated signal yields from fit: 122026.5



Chi² = 46.86, dof = 40, Reduced χ^2 = 1.17, p-value = 0.212



Chi² = 54.55, dof = 44, Reduced χ^2 = 1.24, p-value = 0.132

Dalitz plot of $B^- \to D^+\pi^-\pi^-$

- Resonances

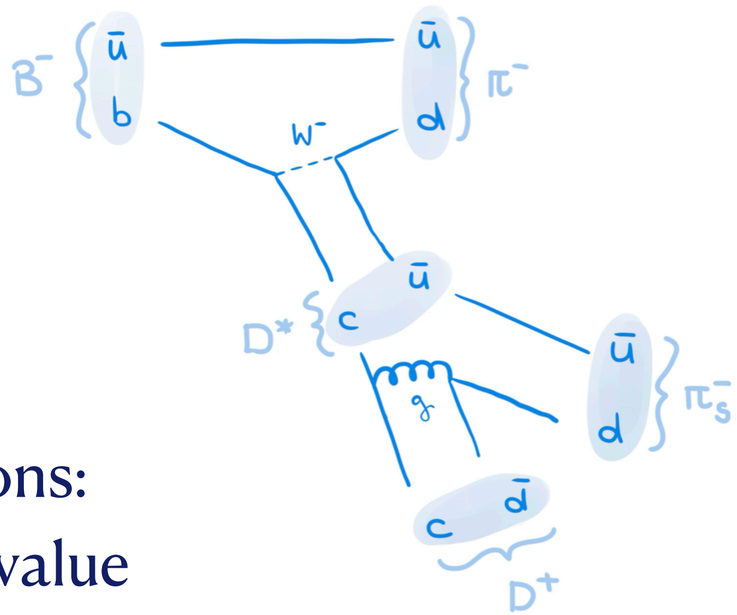
  $B \to D_0^*\pi$

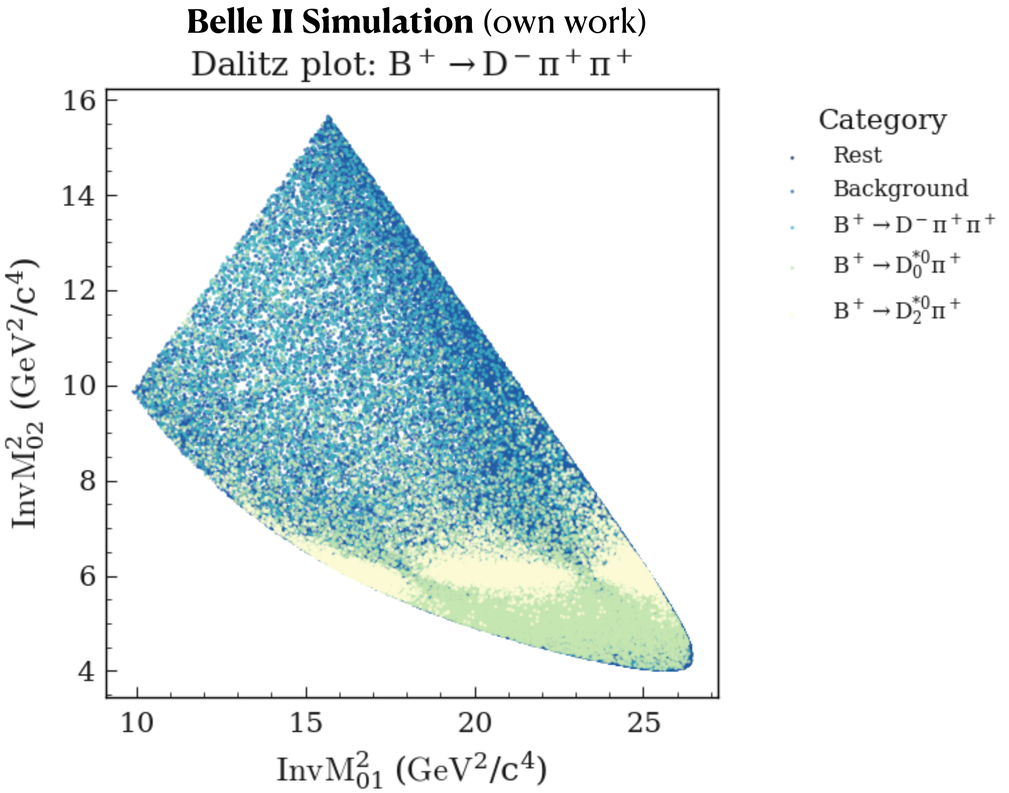
  $B \to D_2^*\pi$

- Two identical pions:
  order masses by value
  (higher and lower mass)

  → causes folding of Dalitz plot

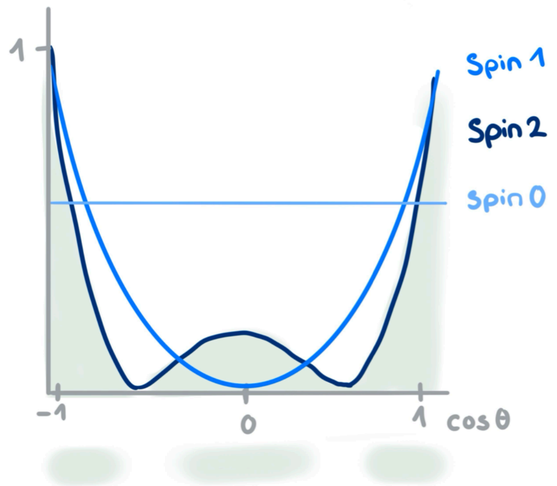
  → else: would be symmetrical

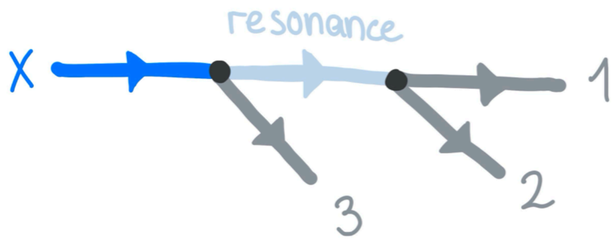




makdag@uni-bonn.de

Dalitz plot



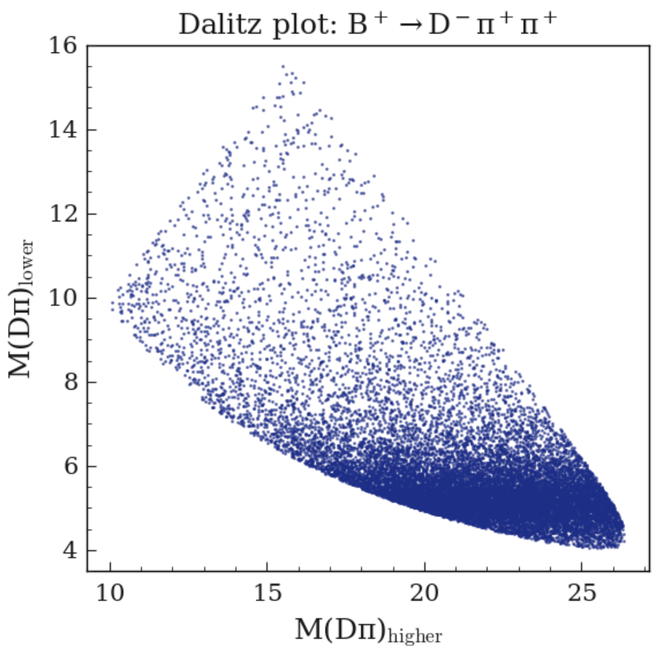


Legendre polynomials

Angular distribution

- Scalar: $\propto 1$
- Vector: $\propto \cos(\theta)$
- Tensor: $\propto (3\cos^2(\theta) - 1)$

Belle II Simulation (own work)



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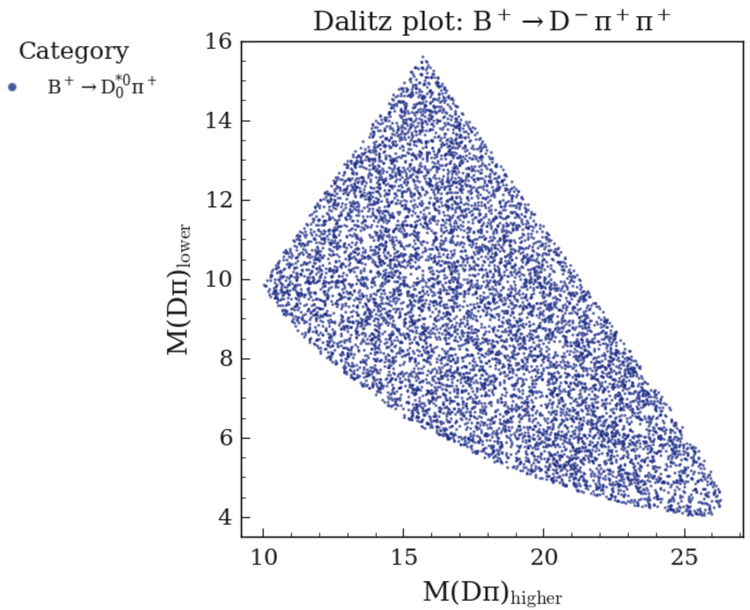
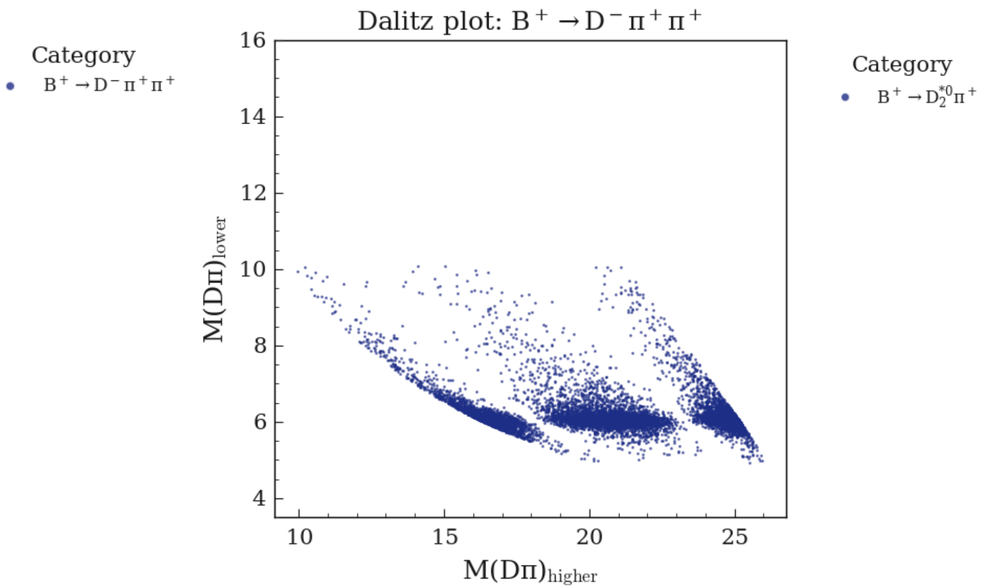


Belle II Simulation (own work)



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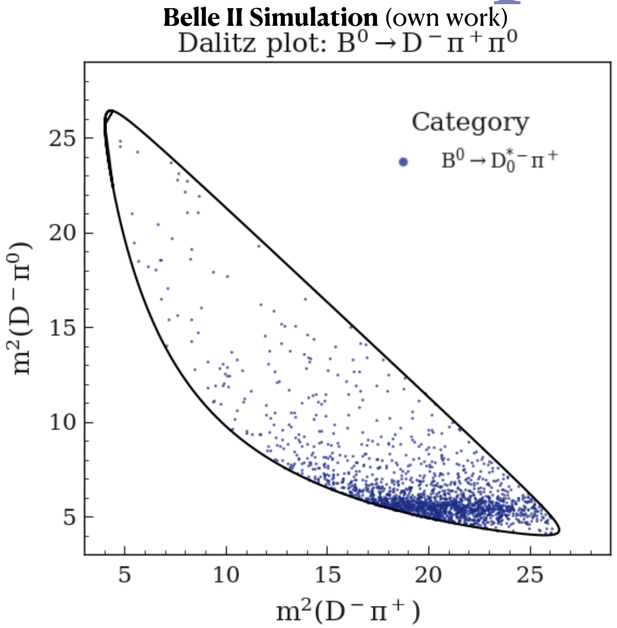
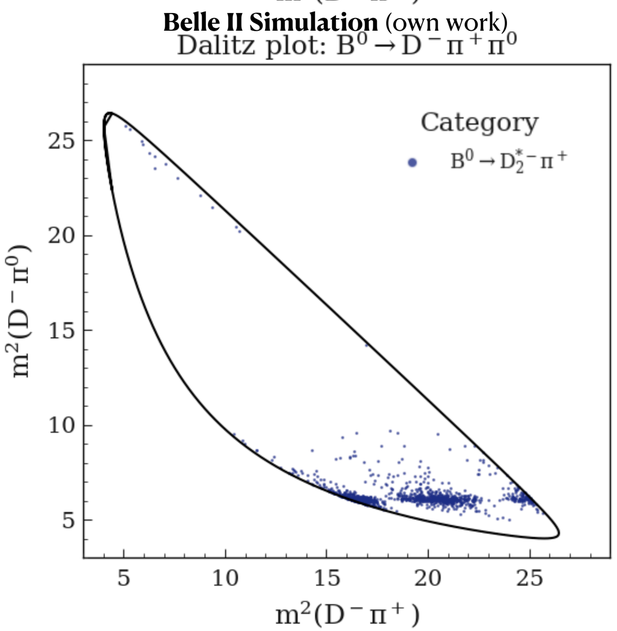
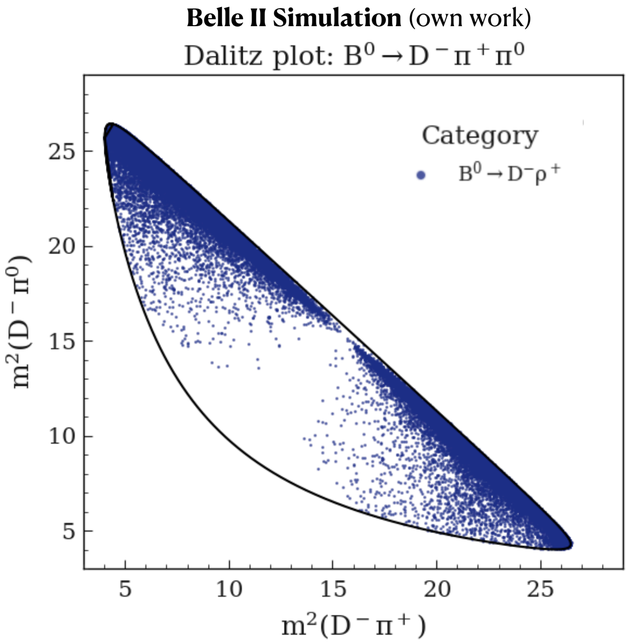
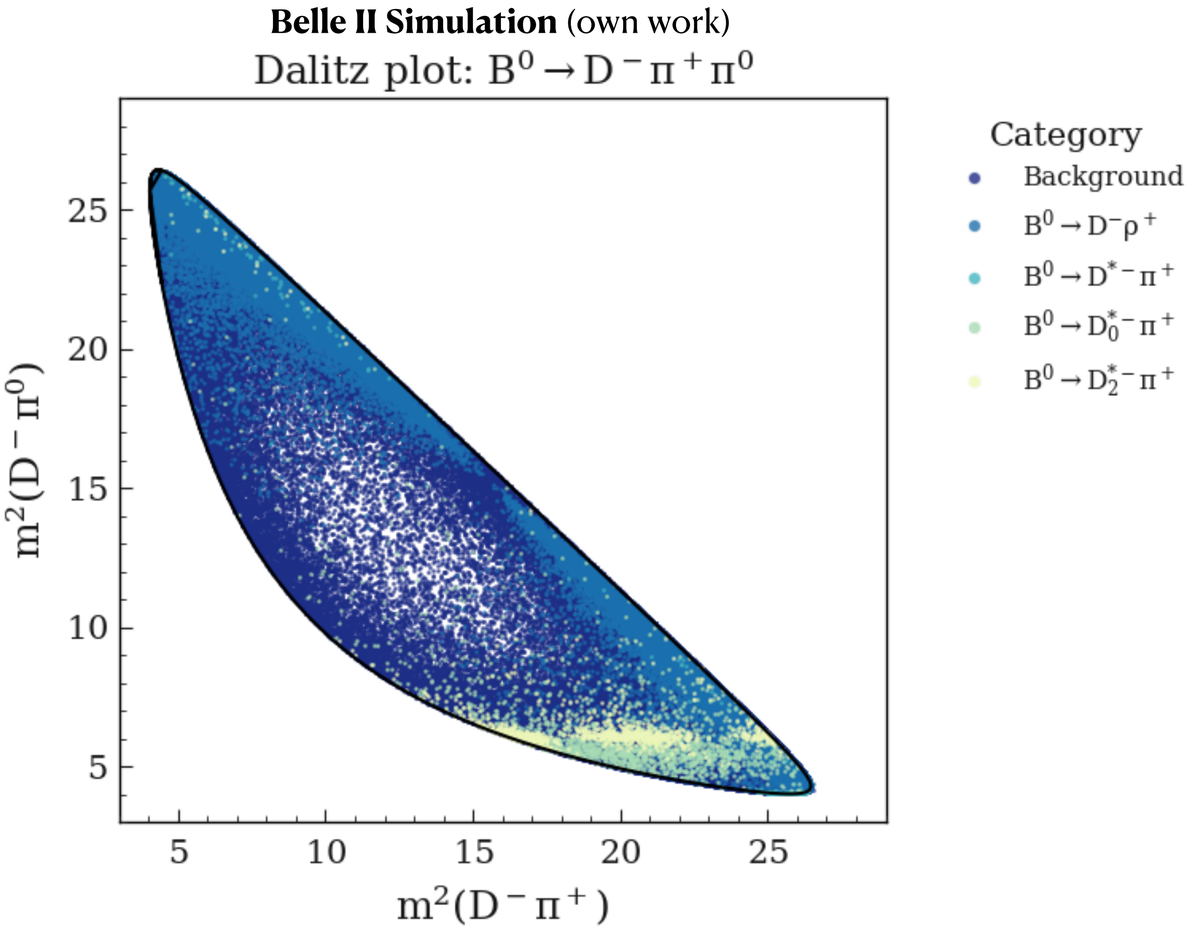
Dalitz plot of $B^0 \to D^+\pi^-\pi^0$









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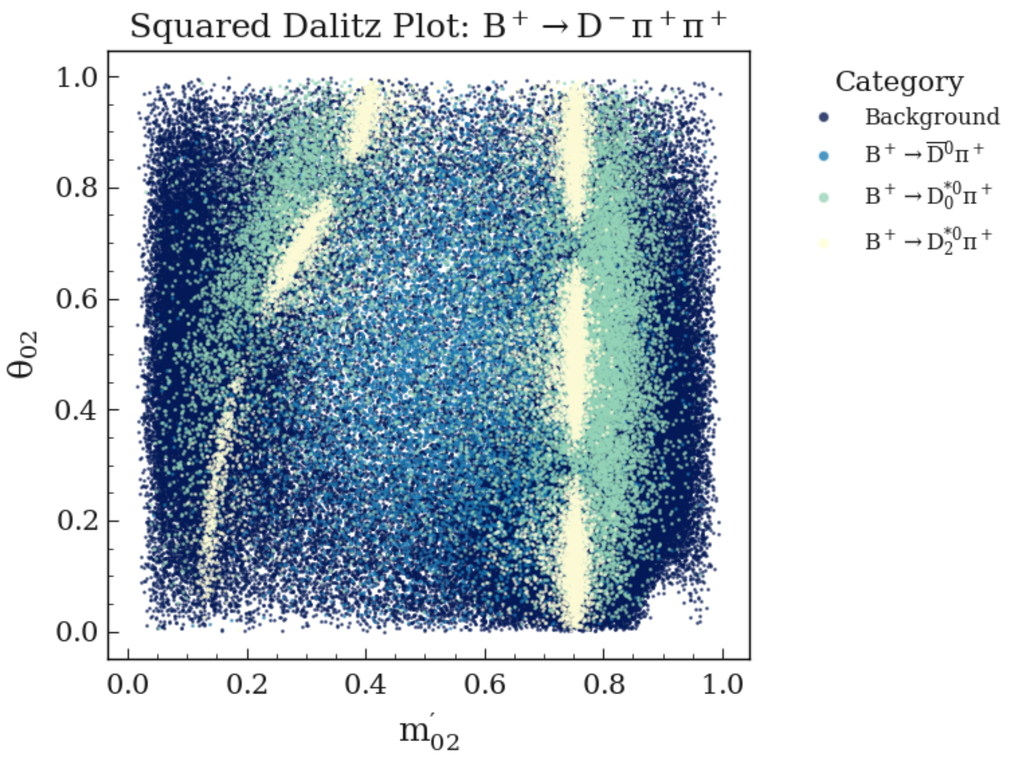
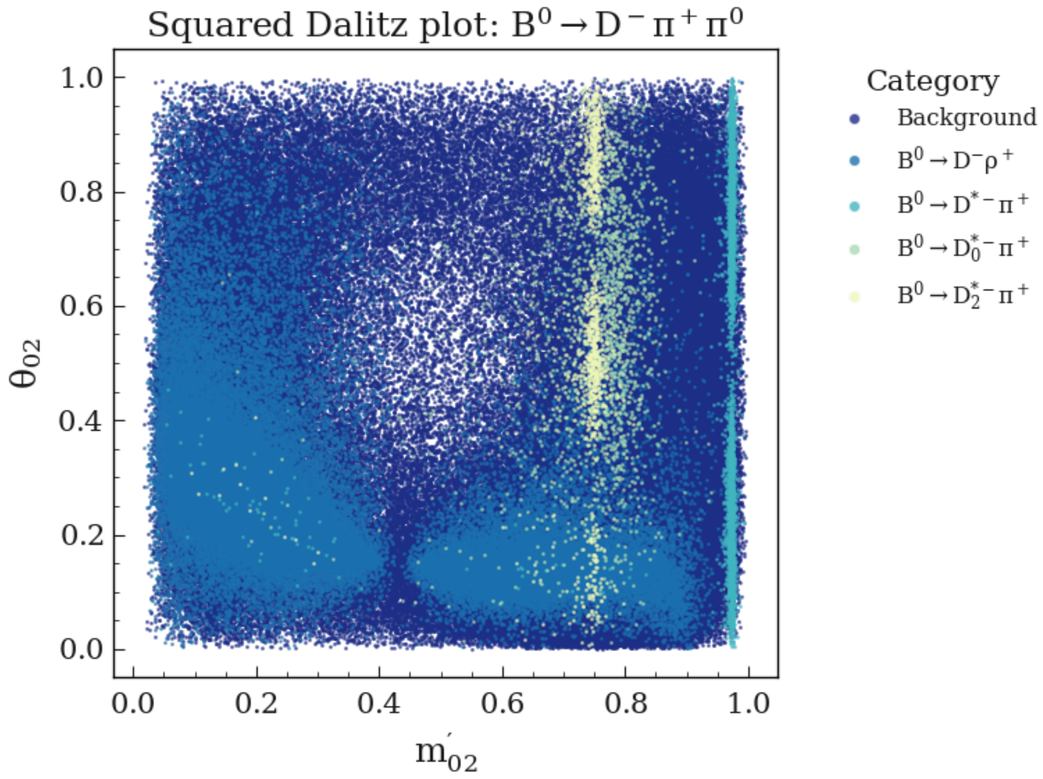
Squared Dalitz plot

- Variable transformation $m' = \frac{1}{\pi} \arccos\left(\frac{2m_{\mathrm{ab}} - m^{ac}_{\mathrm{min}}}{m^{ac}_{\mathrm{max}} - m^{ac}_{\mathrm{min}}} - 1\right)$ and $\theta' = \frac{\theta_{\mathrm{ac}}}{\pi}$
- Used for Dalitz plot fit





Next steps

- Apply the efficiency correction to obtain the efficiency corrected Dalitz plot
- Build and test amplitude model on MC using AmpGen
- Perform amplitude analysis/fit

makdag@uni-bonn.de

Thank you very much for your attention

Backup: s-wave amplitude

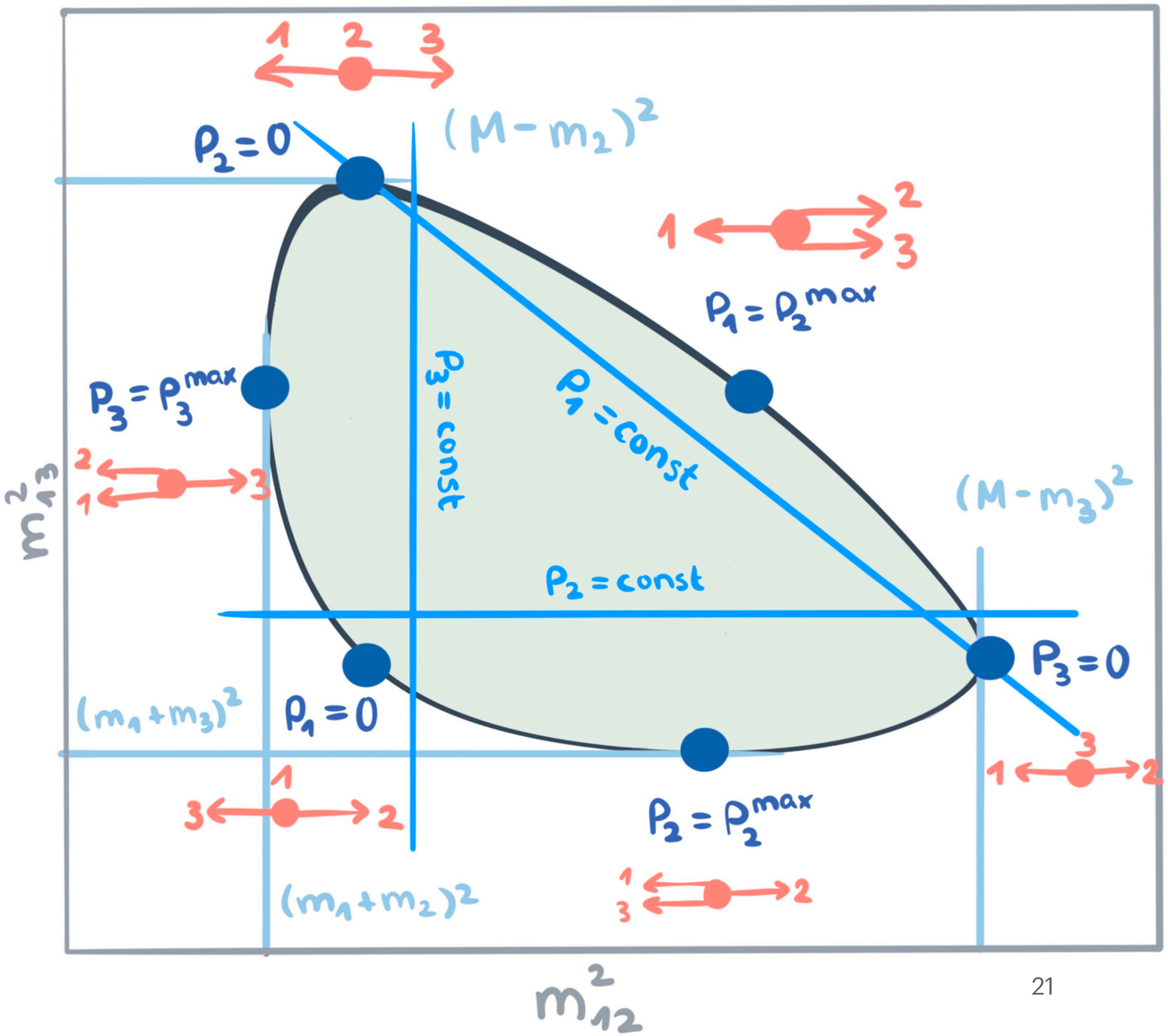
Obtaining s-wave amplitude

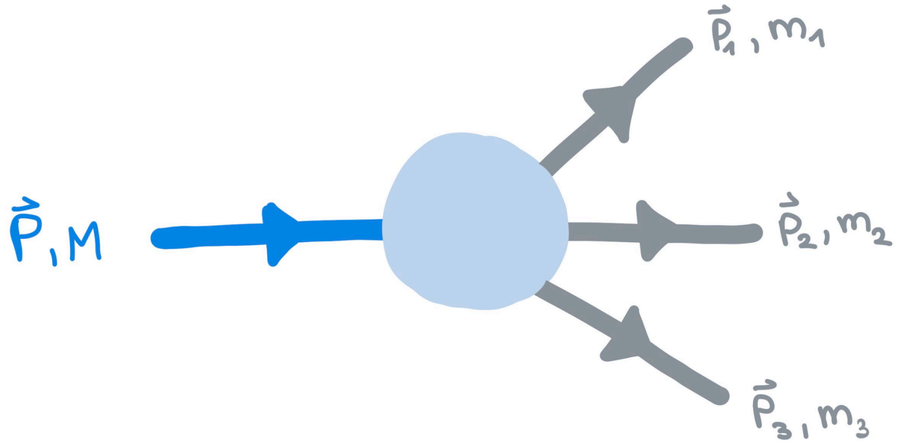
- mass distribution of $D^+\pi^-$ system with weight $w_i = 1$
- Calculate Legendre polynomials P_L
- New weight $w_i = P_L(\cos\theta_i)$
- mass distribution with new weights
- obtain angular moments $\langle P_L \rangle$ wrt phase shift δ_L and $|A_L|^2$ via fit

Backup: Dalitz plot

- Invariant mass of particles i and j $m_{ij}^2 = (p_i + p_j)^2$
- Kinematic boundaries $m_{12}^2 + m_{23}^2 + m_{13}^2 = M^2 + m_1^2 + m_2^2 + m_3^2$
- Invariant mass$m_{12}^2 = (P - p_3)^2 = M^2 + m_3^2 - 2ME_3$
- Reduce dynamics only two variables

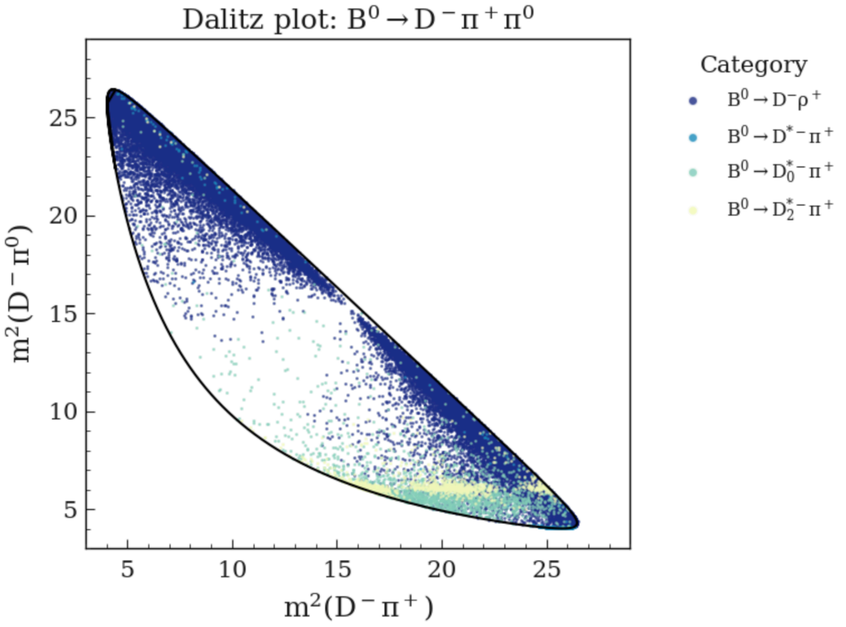
Backup: Dalitz plot

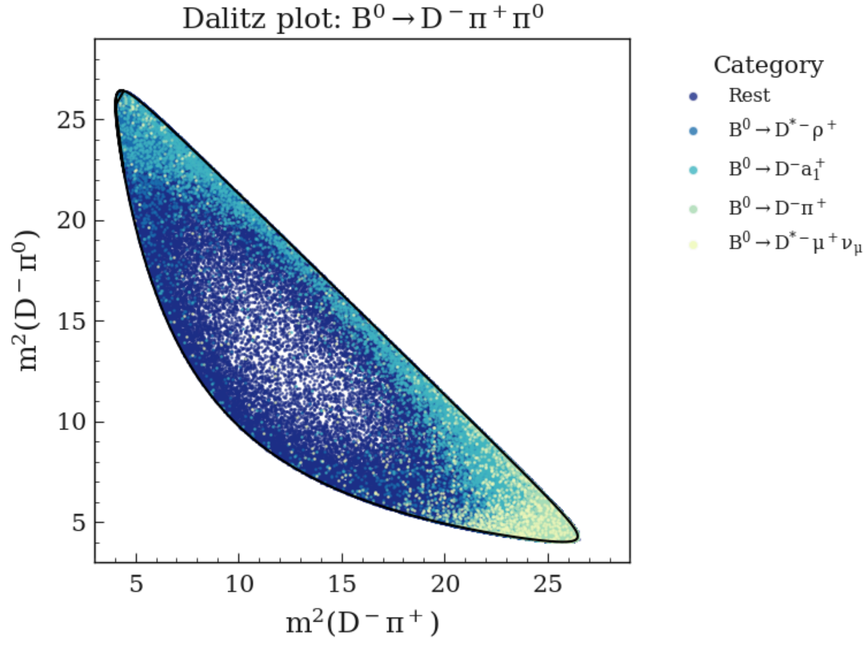


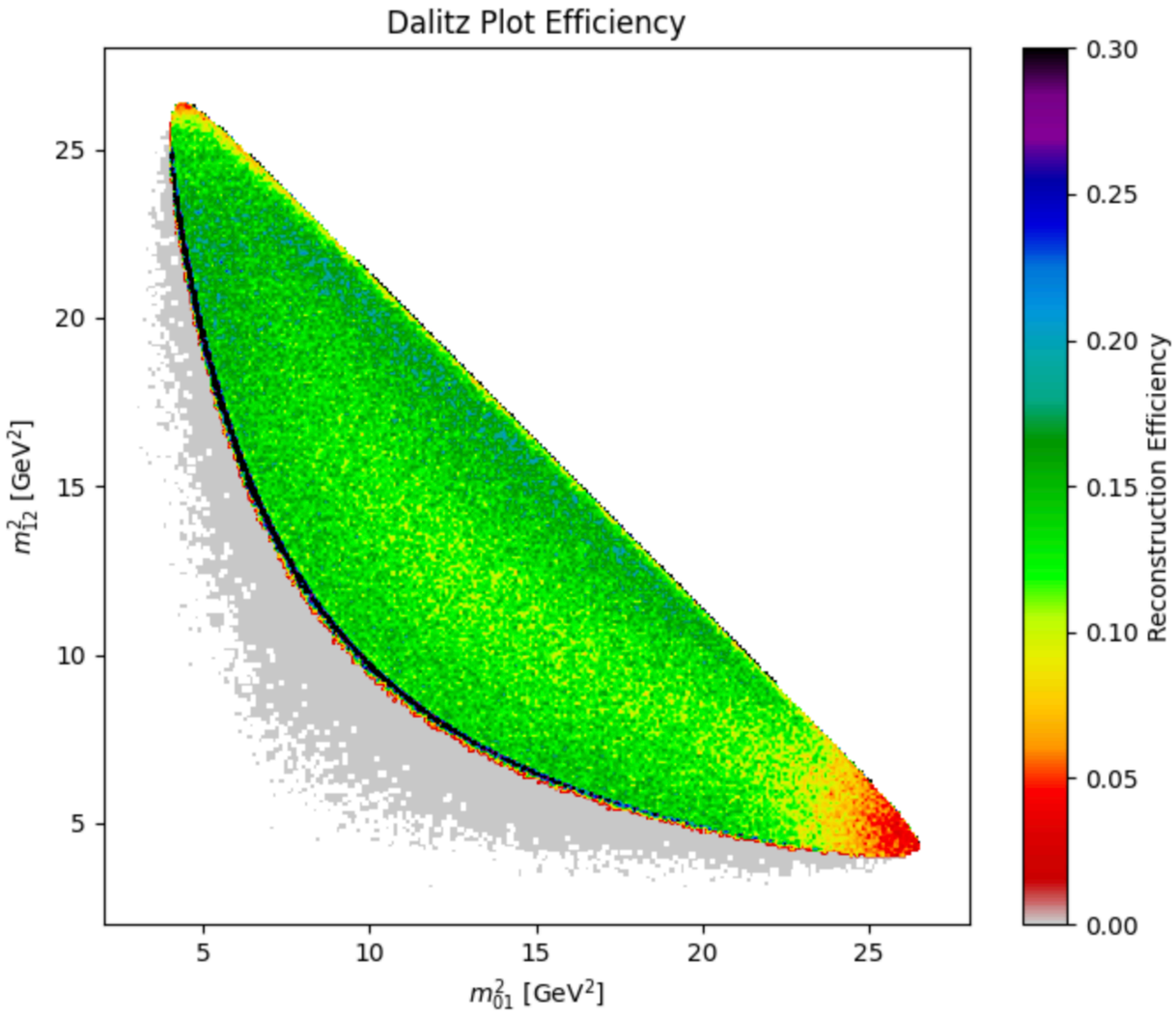


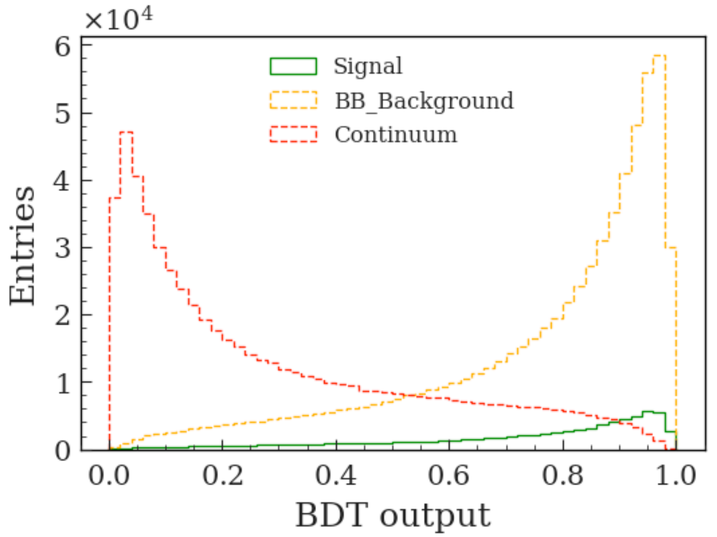
- Two dimensional representation of phase space for three body decays
- Reduce dynamics only two variables

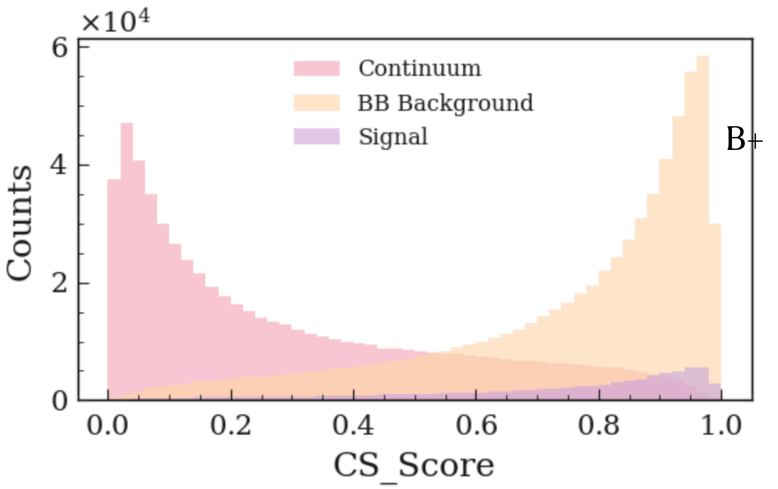
makdag@uni-bonn.de


Dalitz plot: $B^0 \to D^- \pi^+ \pi^0$
$m^2(D^- \pi^0)$
$m^2(D^- \pi^+)$
Category
$B^0 \to D^- \rho^+$
$B^0 \to D^{*-} \pi^+$
$B^0 \to D_0^{*-} \pi^+$
$B^0 \to D_2^{*-} \pi^+$

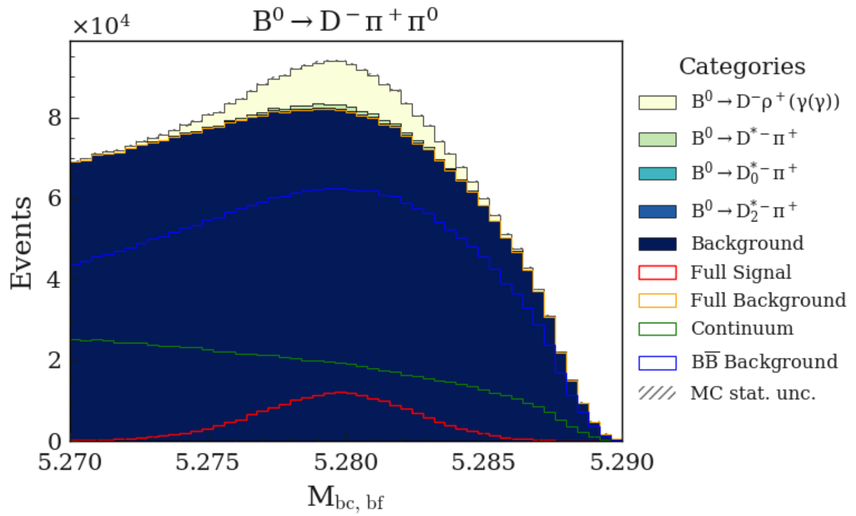

Dalitz plot: $B^0 \to D^- \pi^+ \pi^0$
$m^2(D^- \pi^0)$
$m^2(D^- \pi^+)$
Category
Rest
$B^0 \to D^{*-} \rho^+$
$B^0 \to D^- a_1^+$
$B^0 \to D^- \pi^+$
$B^0 \to D^{*-} \mu^+ \nu_\mu$

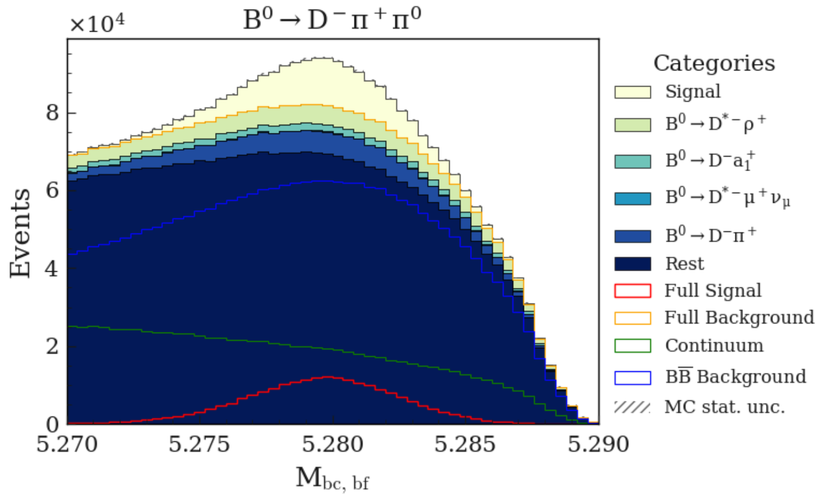

Dalitz Plot Efficiency
m_{12}^2 [GeV^2]
m_{01}^2 [GeV^2]
Reconstruction Efficiency





B+





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