Study of $B^+ \rightarrow \overline{D}^0 (K^0_s \pi^0)\pi^+$ decay at Belle II

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Motivation

Signal: $B^0 \to K_S^0 \pi^0$

Control: $B^+ \to \bar{D}^0 (K_S^0 \pi^0) \pi^+$

Why $B^0 \to K_S^0 \pi^0$ is significant?

- Key to CP Violation measurements
- Isospin sum rule relation test

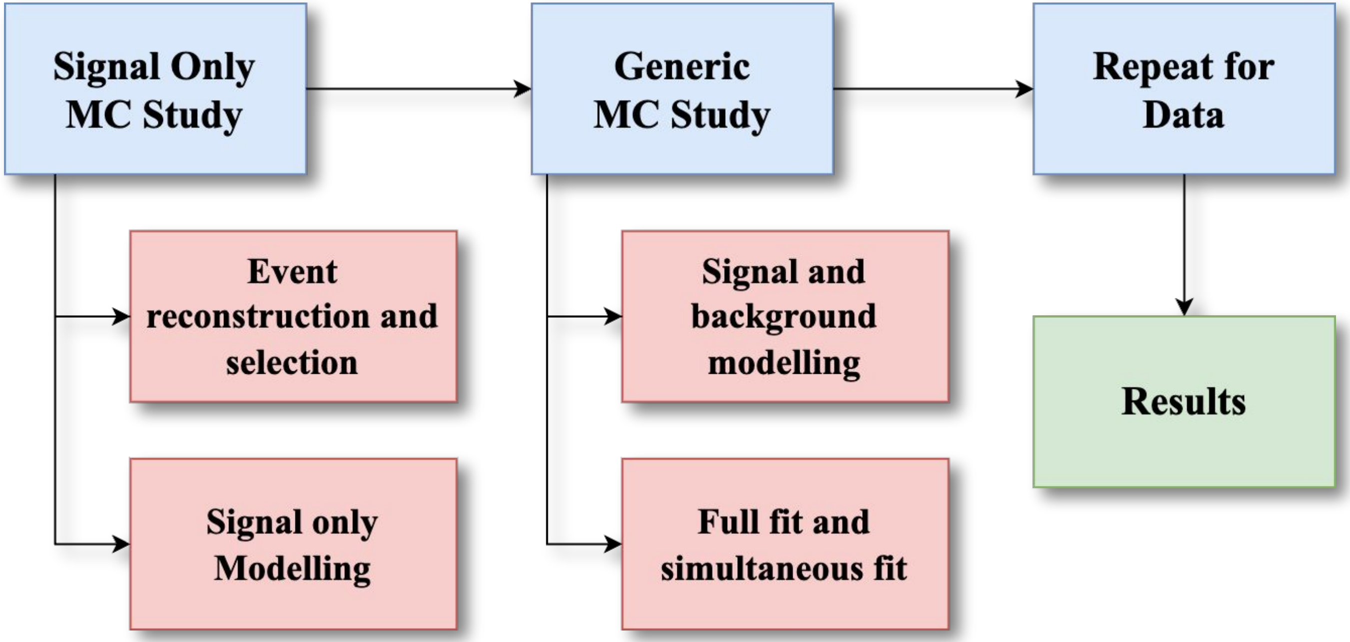
Why $B^+ \to \bar{D}^0 (K_S^0 \pi^0) \pi^+$ as Control channel?

- Similarity in Event topology
- Branching fraction greater than $B^0 \to K_S^0 \pi^0 \sim 10^2$ order

Main focus:

- Study of possible Data - Monte Carlo difference
- Correction for Continuum suppression
- Branching fraction as Consistency check

Analysis Procedure and Data Sample



Signal events : 10^6

Generic MC : 400 fb^{-1}

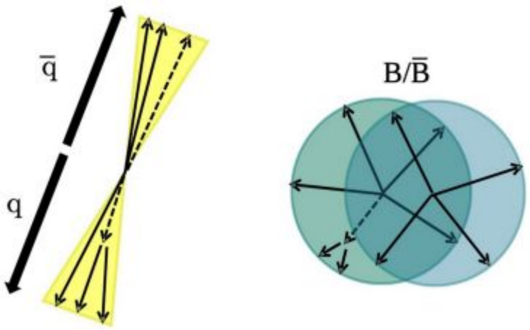
Detector Data : 361.5 fb^{-1}

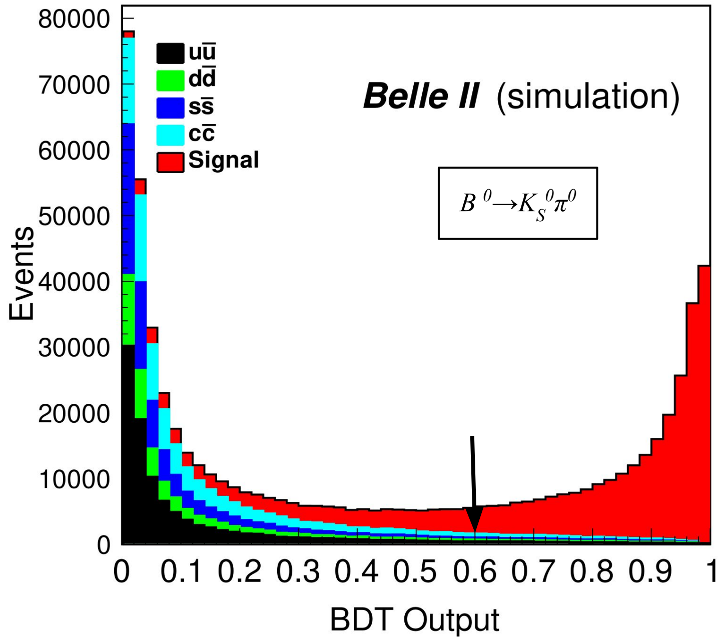
Selection Criteria

Particle	Selection criterion	Description
$B^+ \to \bar{D}^0(K_S{}^0\boldsymbol{\pi^0})\pi^+$	• $0.116 < M_\pi < 0.150$ GeV/c^2 • $p_\pi > 1.5$ GeV/c	• $\pi^0 \to \gamma\gamma$ • Invariant Mass(±3σ) and Momentum
$B^+ \to \bar{D}^0(\boldsymbol{K_S{}^0}\pi^0)\pi^+$	• $0.489 < M_K < 0.507$ GeV/c^2	• $K_S{}^0 \to \pi^+\pi^-$ • Invariant Mass (±3σ)
$B^+ \to \bar{D}^0(K_S{}^0\pi^0)\boldsymbol{\pi^+}$	• $\lvert dr \rvert < 0.5$ cm and $\lvert dz \rvert < 2.0$ cm • PID (K/π) > 0.5	• Transverse and Longitudinal Impact parameters • Binary Particle ID
$B^+ \to \boldsymbol{\bar{D}^0}(K_S{}^0\pi^0)\pi^+$	• $1.82 < M_D < 1.9$ GeV/c^2	• Invariant mass (±3σ)
$\boldsymbol{B^+} \to \bar{D}^0(K_S{}^0\pi^0)\pi^+$	• $-0.2 < \Delta E < 0.3$ GeV • $5.25 < M_{bc} < 5.29$ GeV/c^2	• $\Delta E = E^*_B - E^*_{beam}$ • $M_{bc} = (E^{*2}_{beam} - p^{*}_{B}{}^2)^{1/2}$

Background

- **Continuum Background:** $e^+e^- \rightarrow q\bar{q}$
- Continuum Suppression: Boosted Decision Trees (BDT)
- The BDT distribution output: One more variable to the fit model
- $\boldsymbol{B\bar{B}}$ **background:** Mis-reconstructed B events





$$C'_{out} = \ln\left(\frac{C_{out} - C_{out,min}}{C_{out,max} - C_{out}}\right)$$

Max = 1.0
Min = 0.6

PDF Models and Components

- Three variables: ΔE, M_{bc}, C'_{out}
- For fitting: Probability Density Functions (PDF) are used
- Final fit model: 3D PDF with 4 components

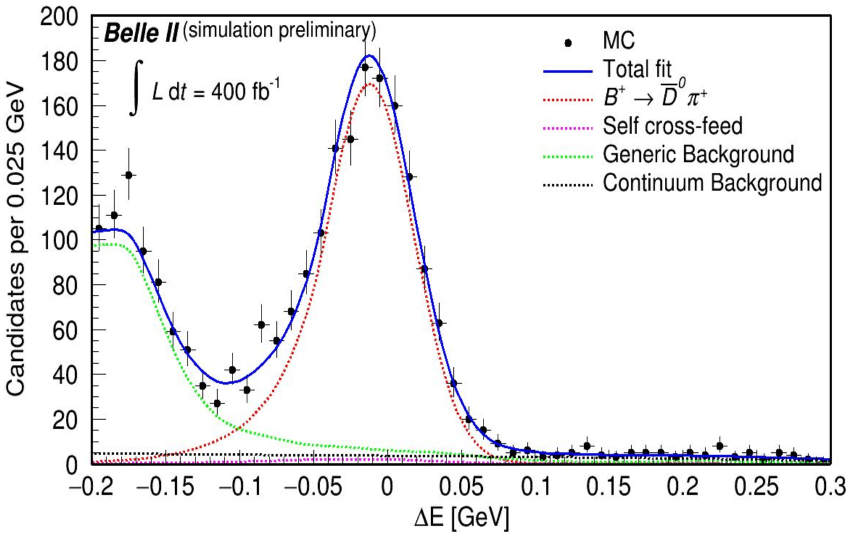
- G: Gaussian
- 2G: Double Gaussian
- AG: Asymmetric Gaussian
- CB: Crystal Ball
- Poly(n): Polynomial
- A: Argus
- KDE:Kernel Density Estimation

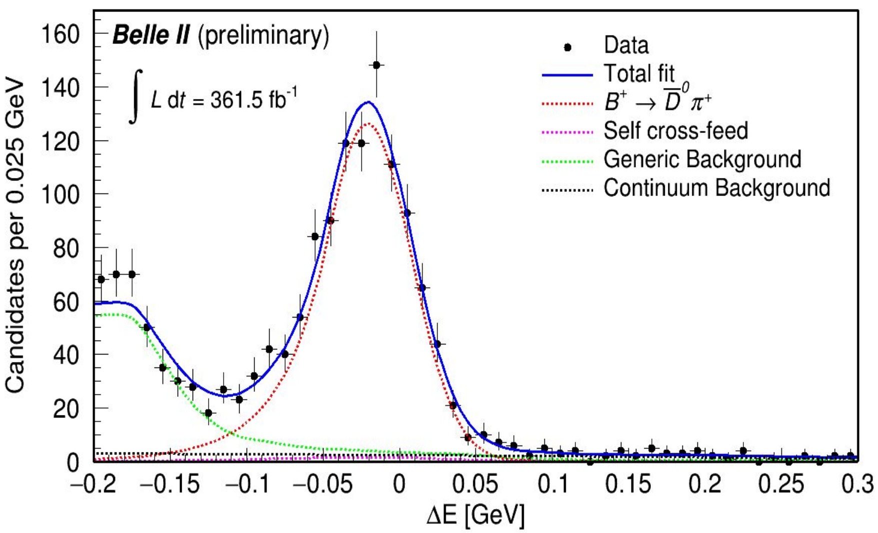
Self Cross-Feed :

- Mis-reconstructed signal events
- SCF/Signal = 3 %

Components	ΔE	M_{bc}	C'_{out}
Signal	CB+G	2G	AG+G+G
SCF	AG+ Poly1	A+G	AG+G+G
Continuum	Poly3	A	AG+G+G
BB	KDE	KDE	AG+G

Complete Model for ΔE

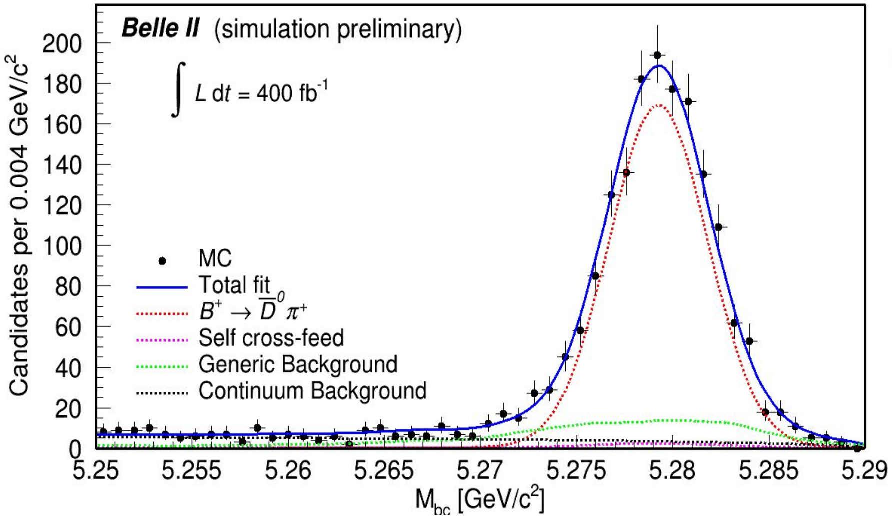


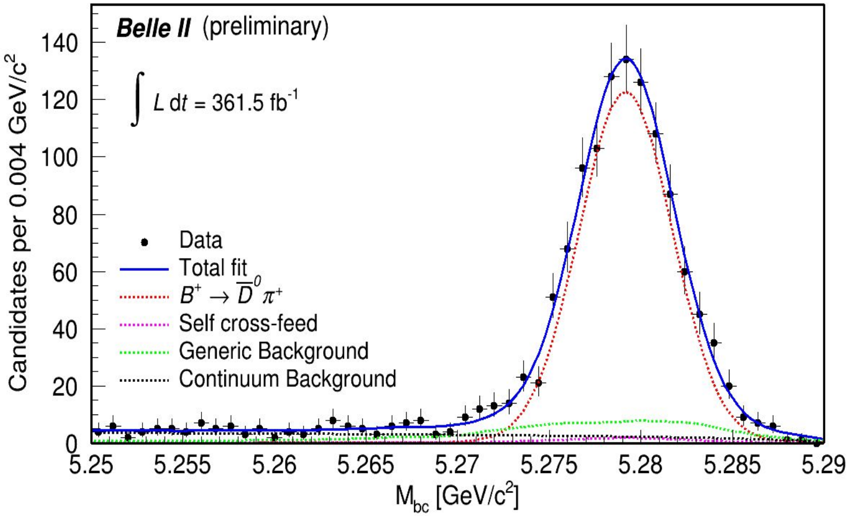


⇧ **MC**

⇧ **DATA**

Complete Model of M_{bc}

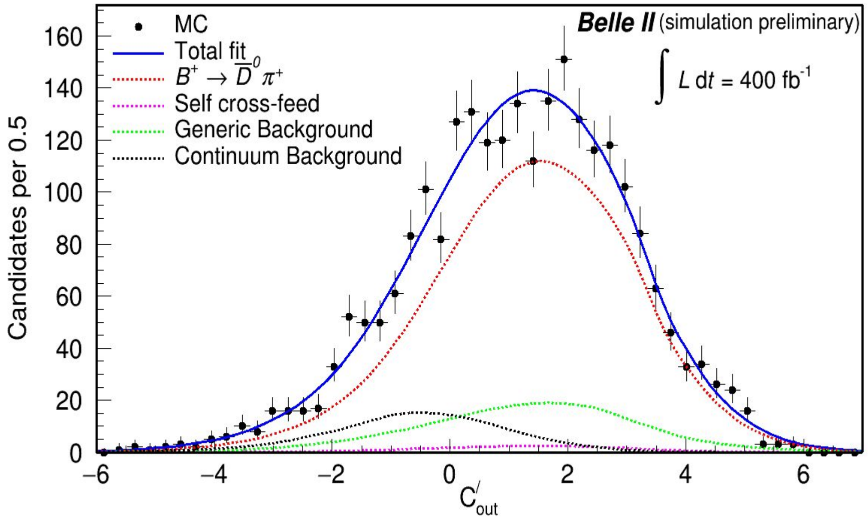


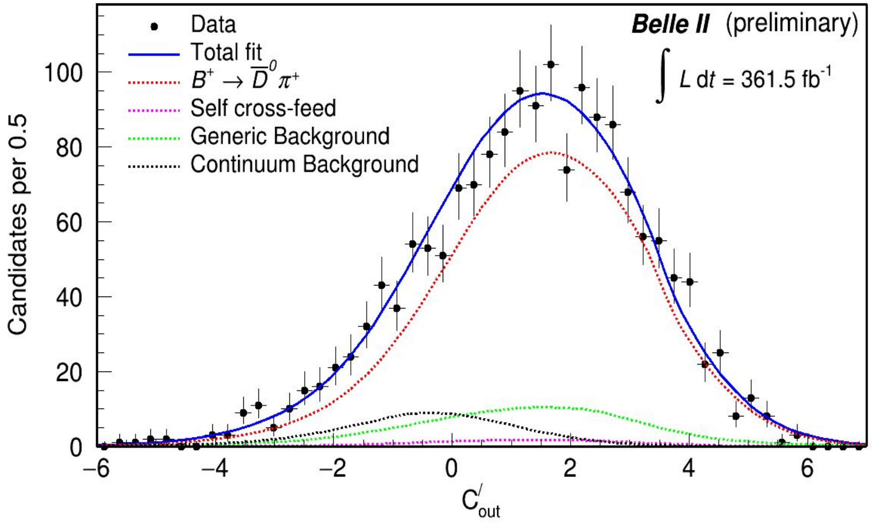


⇧ **MC**

⇧ **DATA**

Complete Model for C'_{out}





⇧

MC

⇧

DATA

Results: Data - MC Correction factors

Parameters	Data	Monte Carlo	Correction factor
ΔE mean (GeV)	-0.0185±0.0017	-0.0163±0.0015	-0.0022±0.0023
ΔE width (GeV)	0.0327±0.0013	0.0334±0.0013	0.9790±0.0545
M_{bc} mean (GeV/c^2)	5.2790±0.0001	5.2792±0.0001	-0.0002±0.0001
M_{bc} width (GeV/c^2)	0.0101±0.0003	0.0098±0.0003	1.0306±0.0440
C'_{out} mean	1.6469±0.0731	1.6591±0.0612	-0.0122±0.0953
C'_{out} width	1.6794±0.0593	1.5694±0.0482	1.0701±0.0501

Correction for Continuum Suppression

$$R = \frac{\text{signal events pass the selection}}{\text{Total signal events (pass + fail the selection)}}$$

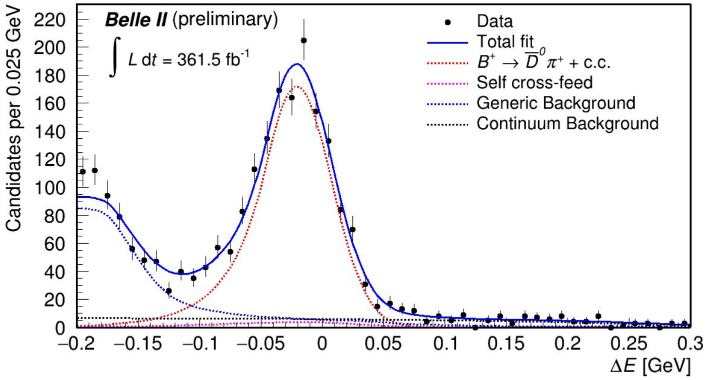
	Data	***MC***
Signal	732 ± 28	922 ± 31
Continuum bkg	240 ± 19	284 ± 22
BB bkg	374 ± 24	532 ± 29
R	0.7513 ± 0.0139	0.7531 ± 0.0133

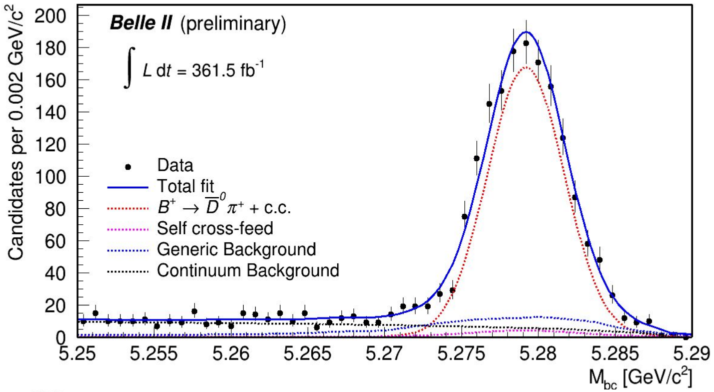
- Data-MC correction for the continuum suppression cut efficiency
- Table lists the number of signal and background events obtained
- SCF/Signal ratio fixed → SCF yield can be calculated from signal yield

$$\epsilon_{(Data/MC)} = 0.9976 \pm 0.0254$$

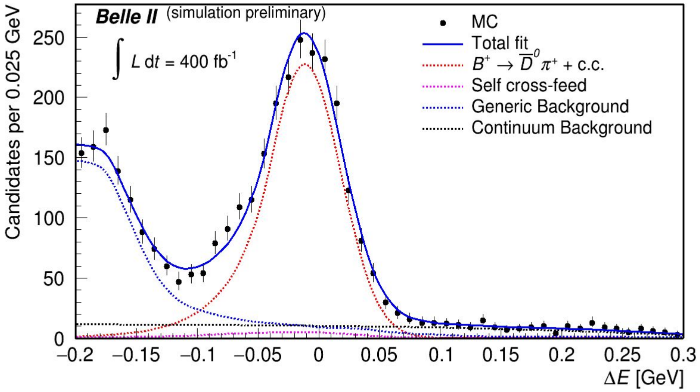
The simultaneous fit for BDT > 0.6

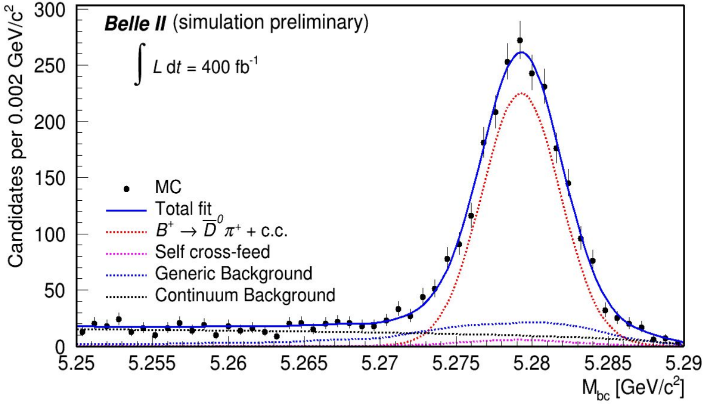
DATA ⇨





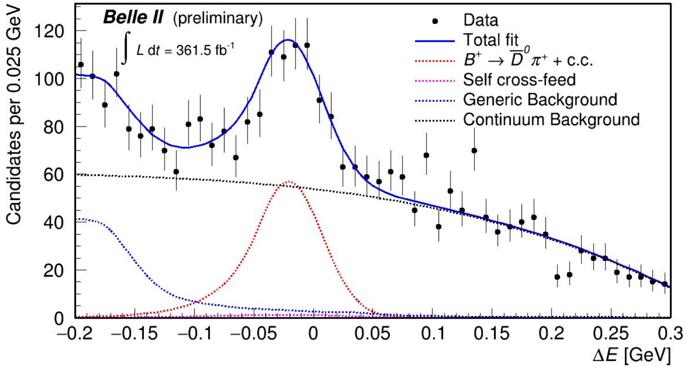
MC ⇨

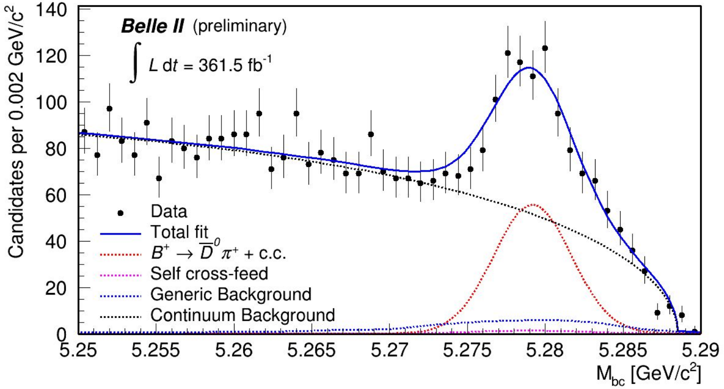




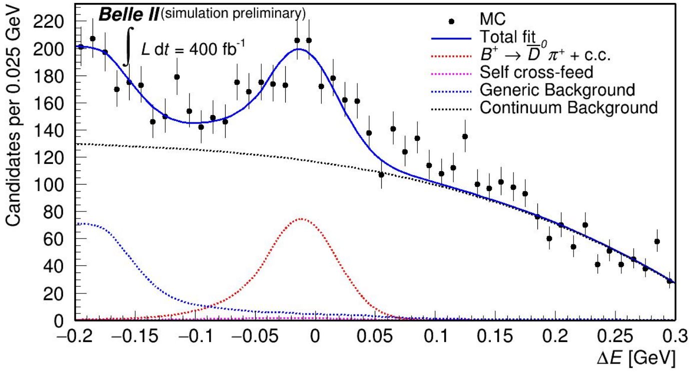
The simultaneous fit for BDT < 0.6

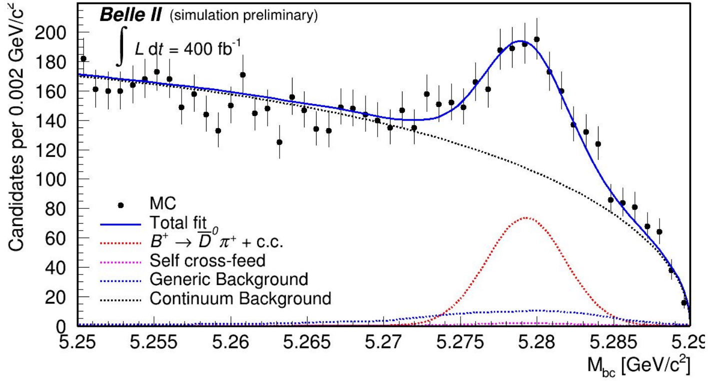
DATA ⇨





MC ⇨





Branching Fraction

Data

$BF\,(B^+ \to D^0\pi^+) = (\mathbf{4.17 \pm 0.16}) \times 10^{-3}$

- N_{sig} = 732 (Expected = 833)
- N_{BB} = Number of BB events = 387.5 $\times 10^6$

Correction factors for BF_{data}:

- For π^0: 1.016
- For K_S^0: 0.963
- For π^+: 0.981

$$\mathcal{B}(B^+ \to \bar{D}^0\pi^+) = \frac{N_{\rm sig}}{2f_{+-} \times N_{B\bar{B}} \times \varepsilon \times \mathcal{B}(\bar{D}^0 \to K_S^0\pi^0)}$$

MC

$BF\,(B^+ \to D^0\pi^+) = (\mathbf{4.65 \pm 0.17}) \times 10^{-3}$

- N_{sig} = 922 (Expected = 929)
- N_{BB} = Number of BB events = 420 $\times 10^6$

- $BF_{\rm PDG} = (4.68 \pm 0.15) \times 10^{-3} \to N_{sig} = 929$
- Scaling 400 to 361.5 gives N_{sig} = 833

- $f_{+-} = BF\,(\Upsilon(4S) \to B^+B^-) = 0.513$
- ε = MC signal efficiency = 0.074295
- $BF\,(D^0 \to K_S^0\pi^0) = 0.0124$

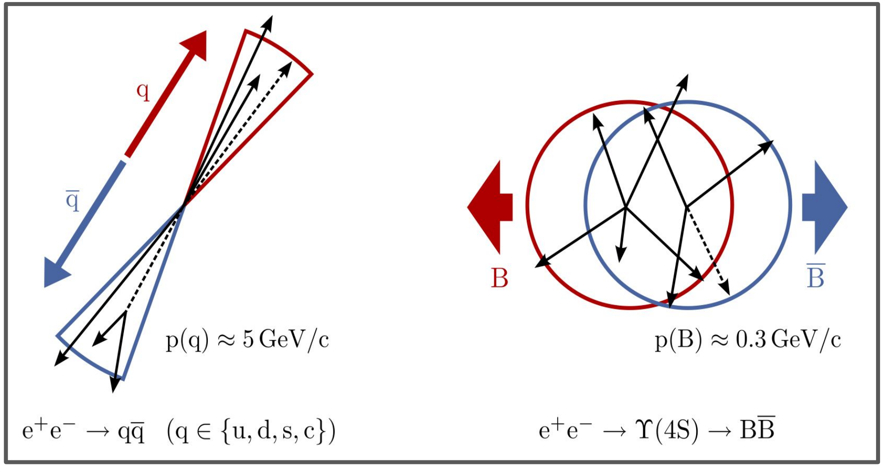
Summary

- The study was performed on 361.5 fb^{-1} Data
- Possible Data-MC differences were evaluated for $B^+ \to \bar{D}^0(K_S^0\pi^0)\pi^+$
- Correction to the Continuum Suppression efficiency was done
- The Branching fraction of the $B^+ \to \bar{D}^0(K_S^0\pi^0)\pi^+$ decay was calculated

Thank You!

Background

- Two background sources: Continuum and generic *BB*
- Continuum background: Dominant source that comes from e^-e^+ to *qq*
- *BB* background: Generic background from mis-reconstructed *B* events



- It is difficult to model the BDT distribution output analytically
- Logarithmic transformation → Can be modelled with one or more Gaussian functions

C'_{out} : -6.0 - 7.0

PDF functions

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot \left(B - \frac{x-\bar{x}}{\sigma}\right)^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

⇒ **Crystal-Ball**

$$f(x) = \mathcal{N} \cdot \sum_i a_i * x^i$$

⇒ **Polynomial**

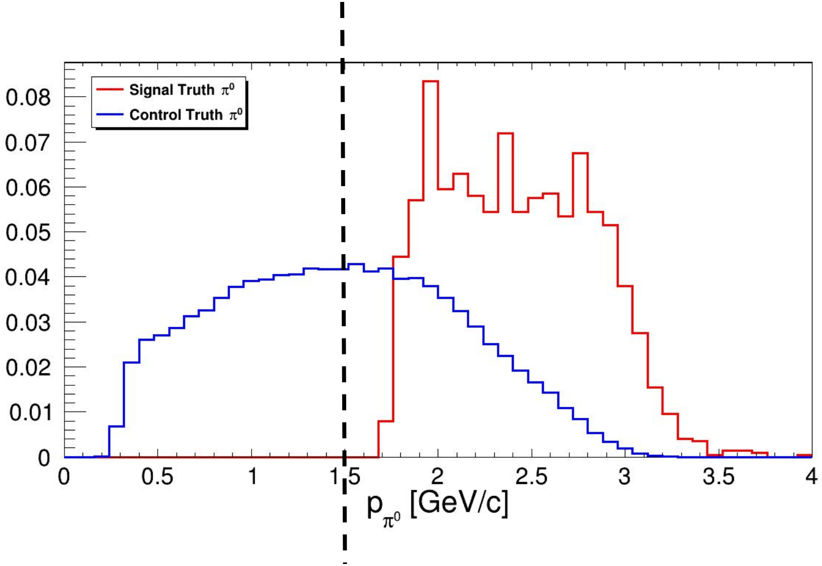
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

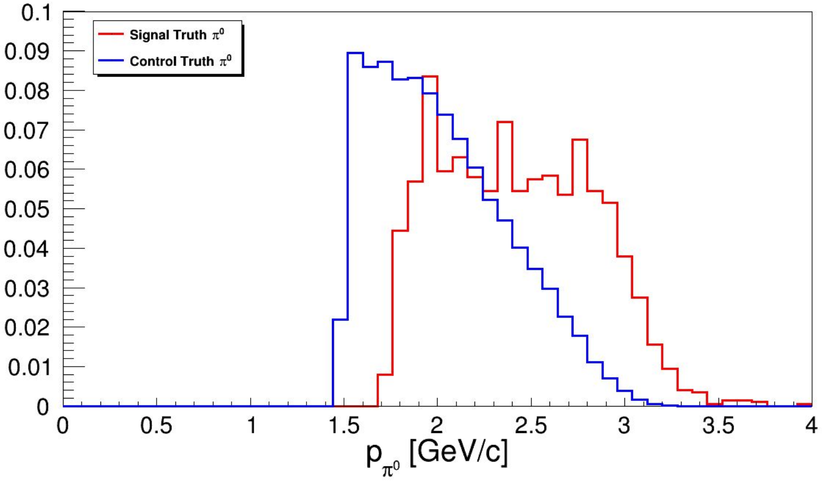
⇒ **Gaussian**

$$f(x;\chi,c) = \frac{\chi^3}{\sqrt{2\pi}\,\Psi(\chi)} \cdot \frac{x}{c^2}\sqrt{1-\frac{x^2}{c^2}}\exp\left\{-\frac{1}{2}\chi^2\left(1-\frac{x^2}{c^2}\right)\right\}$$

⇒ **Argus**

π^0 momentum systematics





π^0 momentum > 1.5 GeV/c

Other Projects: Summer Project 2021

Summer Project (2021):

- The Vertex detector upgrade of Belle II from Belle → Improvement of K_S^0 reconstruction
- Signal reconstruction efficiency calculation
- Improvement in efficiency is related to K_S^0 reconstruction
- Signal decay for the analysis: $\mathbf{B^+ \rightarrow K_S^0 \pi^+}$

	Belle II	Belle
Efficiency (%)	**59.3**	**49.7**

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