Branching Fractions : $B^{\pm} \rightarrow D^0 h^{\pm}\ (h = K\ or\ \pi)$

Tia Crane

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Branching Fractions

- Branching Fraction: the fraction of the time a particle decays to a certain signature (final state) [7]

$$\mathcal{B} = \frac{signal\ yield}{(total\ B\ mesons)(\mathcal{B}_{fixed})(\mathcal{E}_{signal})} = \frac{\Gamma_{bc}}{\Gamma}$$

- Given $a \rightarrow b + c$, integration over all possible kinematic configurations of the final states yields the partial decay width, Γ_{bc}. The total decay width, $\Gamma = 1/\tau$, of particle a is the sum of all the corresponding partial decay widths. [2] [7]
  - Decay width: probability of a decay channel occurring within a specified time interval
- Large statistics permit for precision measurements of absolute branching fractions [3]
- Units: mass (energy)

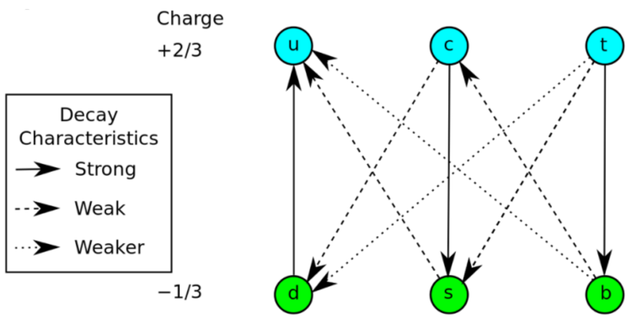
Ratios of Branching Fractions

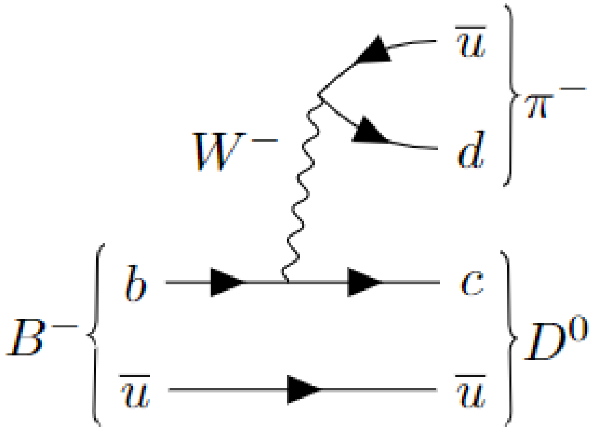
- The ratio of branching fractions is typically measured instead of the individual absolute branching fractions in order to reduce systematic experimental and theoretical uncertainties. [1]
- Relative branching fractions are measured with respect to a decay channel which has similar topology. [3]

$$\mathcal{R} = \frac{\mathcal{B}(signal)}{\mathcal{B}(normalization)}$$

Why are These Measurements Important?

- Obtaining the measurements of the ratios of branching fractions is key to many analysis as it sheds light on the properties of the corresponding particles.
- The physical behaviors of tricky decay channels (i.e. missing energy) may be investigated to a high degree of precision.
- This permits for a comparison between decay percentages of channel with similar properties. The results may in turn lead to new physics!

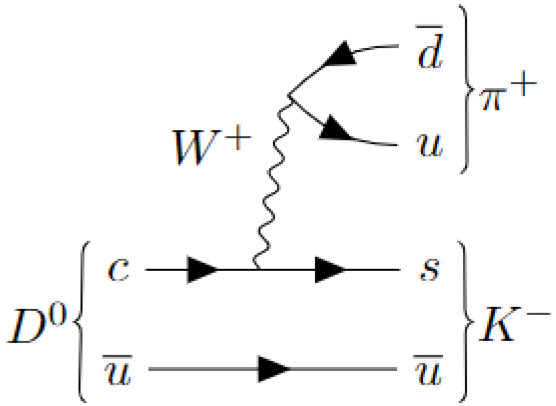




Not a rare decay as $b \rightarrow c$ is the dominant transition (i.e. no jump in generations compared to $b \rightarrow u$) [4]

Example 1

$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]\pi^{\pm}$



Cabibbo favored decay. The charge conjugate with π^- and K^+ is doubly Cabibbo suppressed [4]

Signal Selection

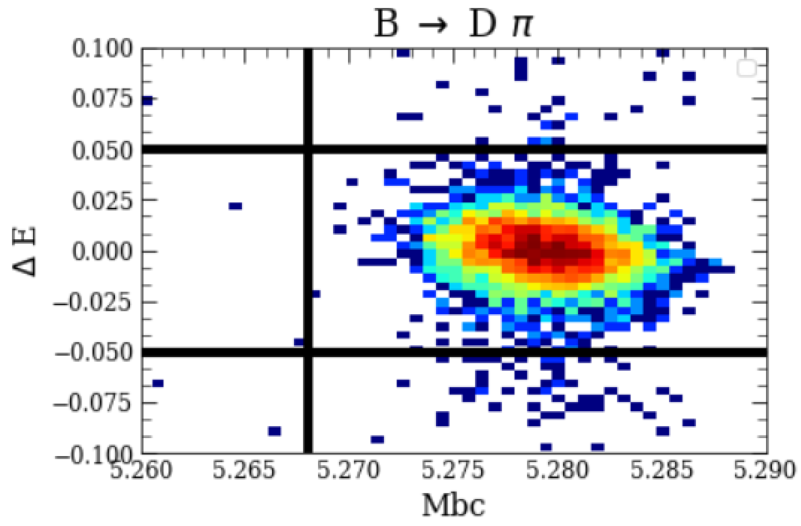
$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]\pi^{\pm}$

- Selection criteria (cuts) based on the signal MC sample in order to increase sample purity through background rejection.

	Selection Cut
Track cuts	$\lvert dz \rvert < 2.0$ [cm], $dr < 0.5$ [cm], $pt > 0.1$ [GeV/c], $E < 5.5$ [GeV], $\theta \in$ CDC ($17° < \theta < 150°$)
$\pi_{B^{\pm}}$, (fast)	PID > 0.1
binary K_{D^0}, (slow)	PID > 0.6
binary π_{D^0}, (slow)	PID > 0.1
D^0	$1.850 < \text{InvM [GeV/c}^2] < 1.879$
B_{sig}	Mbc > 5.268 [GeV/c^2] $\lvert\Delta E\rvert < 0.5$ [GeV] R2 < 0.4
*ΔE signal range	$-0.05 < \Delta E \text{ [GeV]} < 0.05$

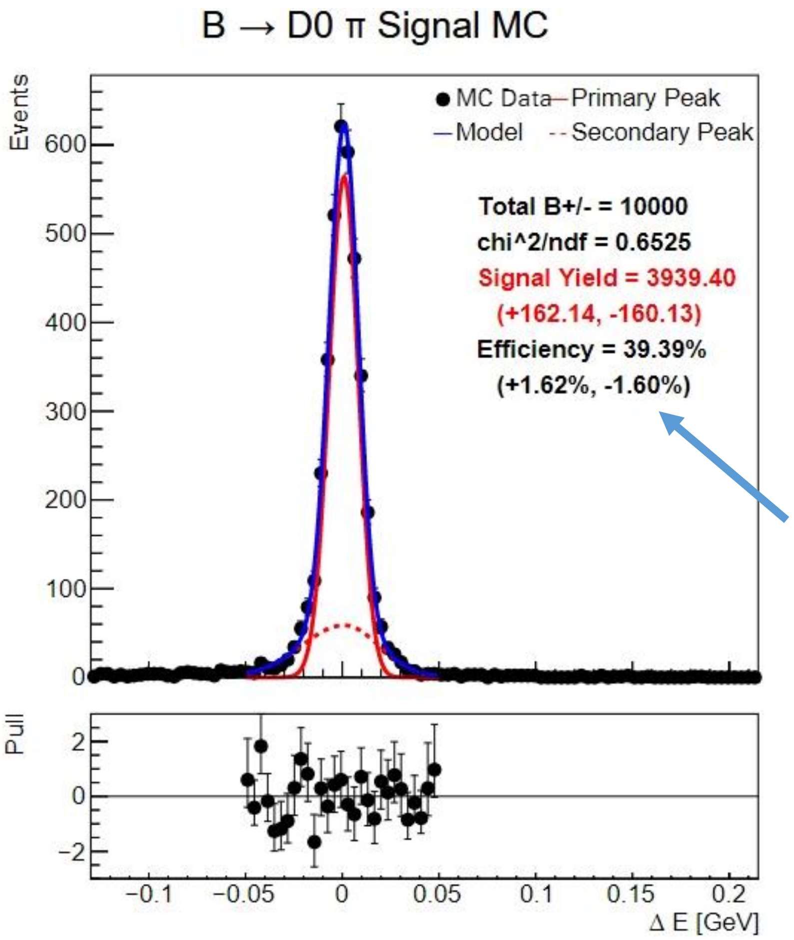
3σ cut based off double gaussian fit to signal

Cut and signal range based off two-dimensional histogram of signal



Fit to Signal and Efficiency

$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]\pi^{\pm}$

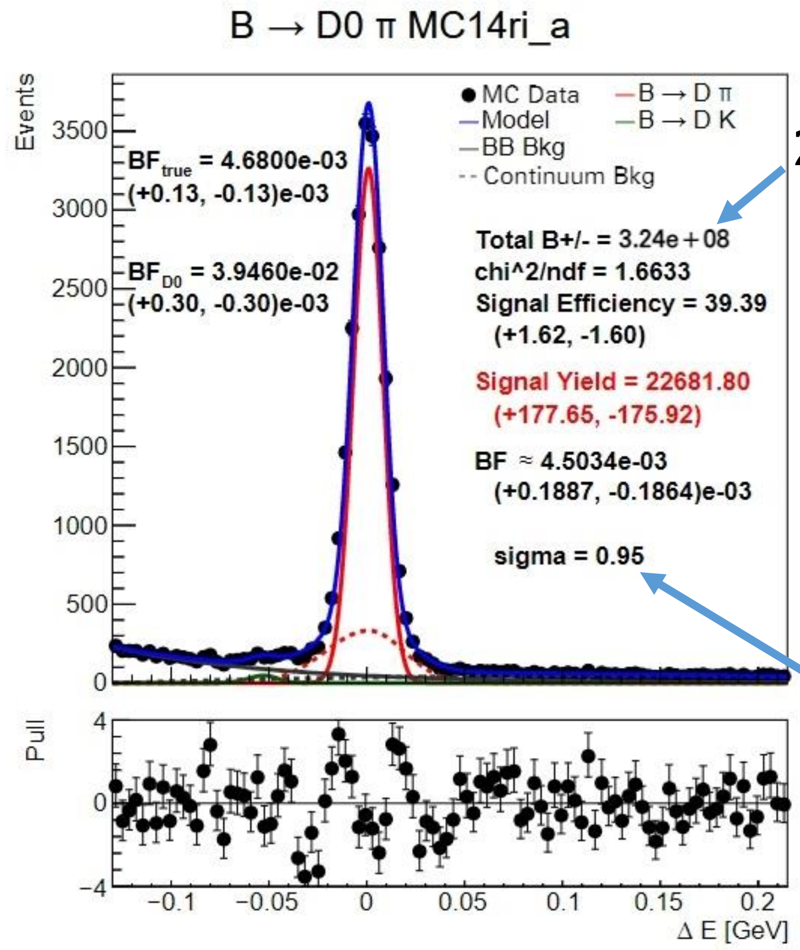


Uncertainties determined through asymmetric errors of fit and error propagation

- Signal region set to -50 MeV to +50 MeV
- Signal PDF defined as two bifurcated gaussians with the same mean
- Goodness of fit seen through χ^2/ndf
- When fitting the generic MC data, the signal PDF parameters of μ and σ are held fixed.

Fit to MC Data and Branching Fraction

$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]\pi^{\pm}$



$2(Run\ Events)$ [9]

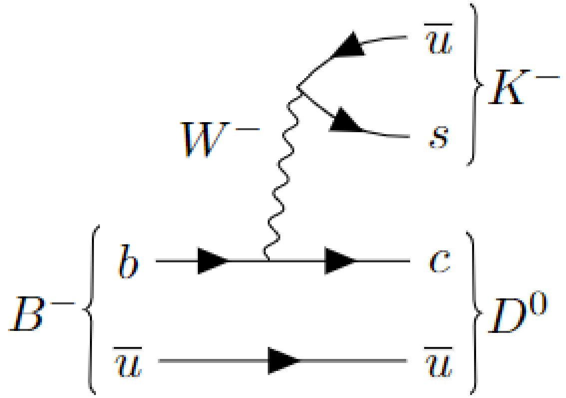
$$\frac{\mathcal{B}(true) - \mathcal{B}(estimated)}{\sigma(estimated)}$$

$$\mathcal{B} = \frac{signal\ yield}{\#\ B^{\pm}\ total\ *\ \mathcal{B}_{D^0 \rightarrow K\pi}\ *\ \mathcal{E}_{signal}}$$

$$= \frac{2.27 * 10^4}{(3.24 * 10^8)(3.95 * 10^{-2})(0.39)}$$

$$\approx 4.50 * 10^{-3}$$

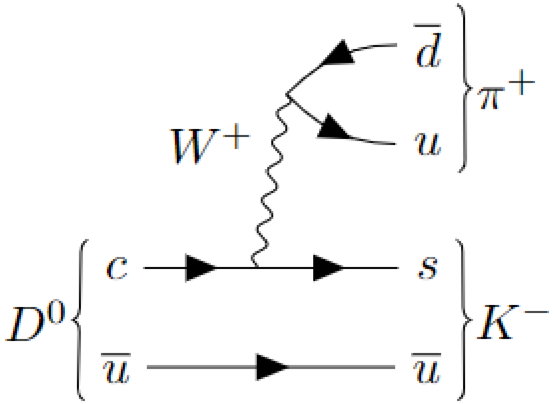
- Signal yield estimation completed through integration of signal PDF (two bifurcated gaussians)



Cabibbo suppressed compared to $B^{\pm} \rightarrow D^0\pi^{\pm}$ due to V_{us} vertex instead of V_{ud} vertex [4]

Example 2

$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]K^{\pm}$



Signal Selection

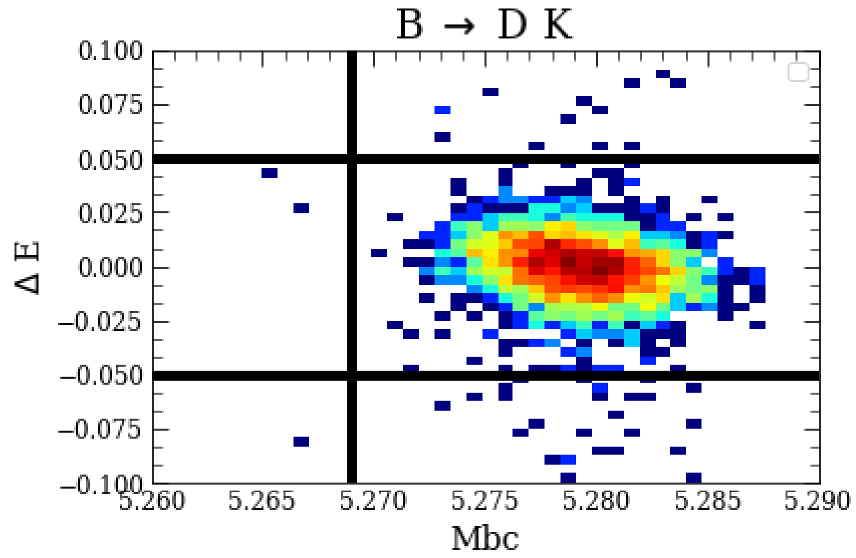
$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]K^{\pm}$

- Selection criteria (cuts) based on the signal MC sample in order to increase sample purity through background rejection.

	Selection Cut
Track cuts	$\lvert dz \rvert < 2.0$ [cm], $dr < 0.5$ [cm], $pt > 0.1$ [GeV/c], $E < 5.5$ [GeV], $\theta \in$ CDC ($17^\circ < \theta < 150^\circ$)
$K_{B^{\pm}, \text{(fast)}}$	PID > 0.6
binary $K_{D^0, \text{(slow)}}$ binary $\pi_{D^0, \text{(slow)}}$	PID > 0.6 PID > 0.1
D^0	$1.850 < \text{InvM [GeV/}c^2] < 1.880$
B_{sig}	Mbc > 5.269 [GeV/c^2] $\lvert \Delta E \rvert < 0.5$ [GeV] R2 < 0.4
*ΔE signal range	$-0.05 < \Delta E \text{ [GeV]} < 0.05$

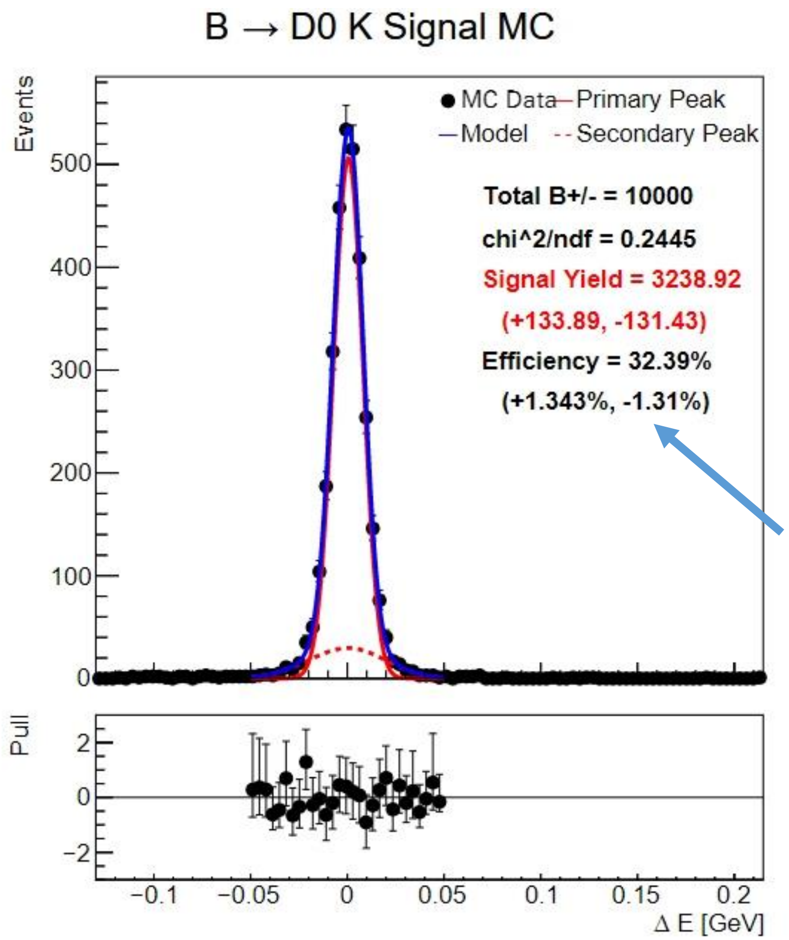
3σ cut based off double gaussian fit to signal

Cut and signal range based off two-dimensional histogram of signal



Fit to Signal and Efficiency

$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]K^{\pm}$



Uncertainties determined through asymmetric errors of fit and error propagation

- Signal region set to -50 MeV to +50 MeV
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- Goodness of fit seen through χ^2/ndf
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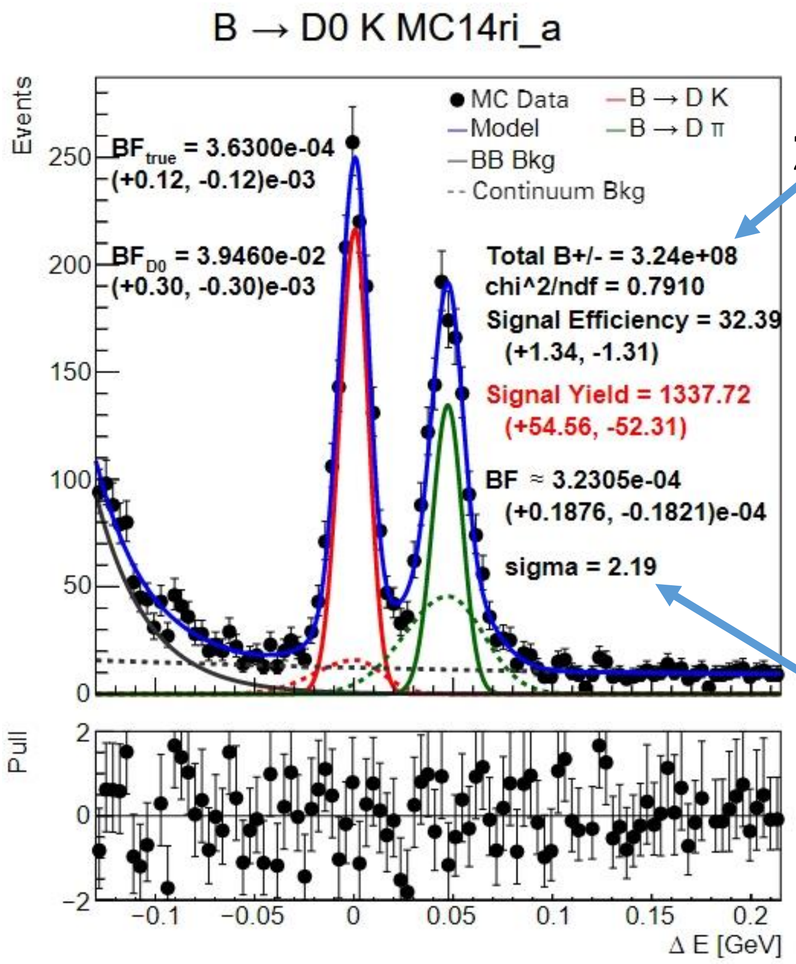
Fit to MC Data and Branching Fraction

$$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]K^{\pm}$$



2(*Run Events*)
[9]

$$\frac{\mathcal{B}(true) - \mathcal{B}(estimated)}{\sigma(estimated)}$$

$$\mathcal{B} = \frac{signal\ yield}{\#B^{\pm}\ total\ *\ \mathcal{B}_{D^0 \rightarrow K\pi}\ *\ \mathcal{E}_{signal}}$$

$$= \frac{1.34 * 10^{-3}}{(3.24 * 10^{8})(3.95 * 10^{-2})(0.32)}$$

$$\approx 3.23 * 10^{-4}$$

- Signal yield estimation completed through integration of signal PDF (two bifurcated gaussians)

- Note: smaller amplitude due to Cabibbo suppression

Resulting Ratio of Branching Fractions

- In this example, the kaon mode is generally the signal mode as it is an excellent probe to the ϕ_3 angle of the unitary triangle for the CKM matrix. The pion mode has a very similar topology and a very clear signal, so it is an excellent normalization mode.

$$\mathcal{R} = \frac{\mathcal{B}(B^- \to [K^+\pi^-]_{D^0}K^-) + \mathcal{B}(B^+ \to [K^+\pi^-]_{D^0}K^+)}{\mathcal{B}(B^- \to [K^+\pi^-]_{D^0}\pi^-) + \mathcal{B}(B^+ \to [K^+\pi^-]_{D^0}\pi^+)}$$

$$true = (7.756 \pm 0.335)\%$$

$$estimated \approx (7.1 \pm 0.5)\% \quad \leftarrow 1.2\sigma$$

Summary

- Ratios of branching fractions are excellent tools for probing physics phenomena.
- An example of a further analysis that utilize branching ratios is the investigation of R(D) in semi-leptonic decays probing lepton universality, as mentioned by Tom, Leo, and Swagato.

Citations

[1] Abdesselam, et al. (2019, April 29). *Measurement of $\mathcal{R}(d)$ and $\mathcal{R}(d^{\ast})$ with a semileptonic tagging method*. arXiv.org. Retrieved August 3, 2022, from https://arxiv.org/abs/1904.08794

[2] Bettini, A. (2008). Preliminary notions : Collisions and decays. In *Introduction to elementary particle physics* (p. 13). Cambridge University Press.

[3] Bevan, A. J. (2015, October 31). The Physics of B Factories (p. 520). Retrieved August 3, 2022, from https://arxiv.org/abs/1406.6311

[4] Browder, T. (2021). *Rare Decay*. Indinco Belle II 2021 Summer Workshop. Retrieved August 3, 2022, from https://indico.belle2.org/event/3812/contributions/23417/attachments/12097/18447/BelleII_Rare_teb.pdf

[5] Chakraborty, D. (n.d.). *Chapter 4 - Process rates*. Retrieved August 3, 2022, from http://nicadd.niu.edu/~dhiman/courses/phys684_10/lectures/process_rates.pdf

Citations

[6] Gershon, T., Kenzie, M., & Trabelsi, K. (2019, August). *determination of CKM angles from B hadrons - particle data group*. pdg.lbl.gov. Retrieved August 3, 2022, from https://pdg.lbl.gov/2019/reviews/rpp2019-rev-ckm-angles.pdf

[7] Martin, V. J. (2010). *Subatomic physics: Particle physics lecture 3*. Retrieved August 3, 2022, from https://www2.ph.ed.ac.uk/~vjm/Lectures/ParticlePhysics2010_files/Particle3-2Nov.pdf

[8] Nave, R. (n.d.). Transition probabilities and Fermi's golden rule. Retrieved August 3, 2022, from http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/fermi.html

[9] seddonr. (2018, October). *How to find integrated luminosity/B-count numbers*. Confluence. Retrieved August 3, 2022, from https://confluence.desy.de/pages/viewpage.action?pageId=107054222

Backup Slides

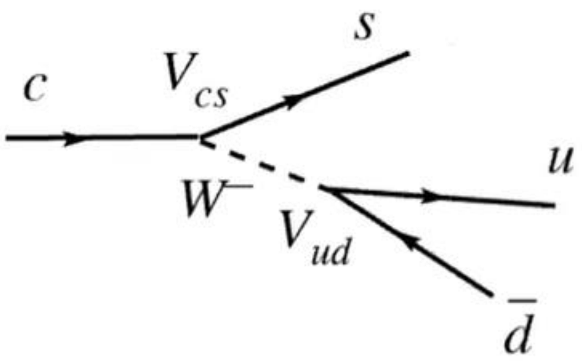
General

Cabibbo Matrix

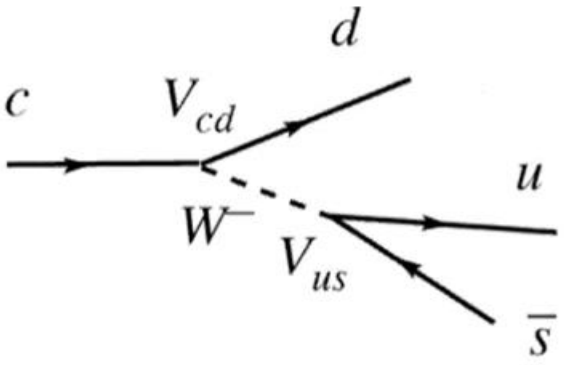
- Cabibo matrix - rotate mass eigenstates to weak interaction states [4]

$$\begin{pmatrix} d' \\ s' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} \\ V_{cd} & V_{cs} \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix} = \begin{pmatrix} \cos\theta_c & sin\theta_c \\ -sin\theta_c & cos\theta_c \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}$$

Cabibbo angle
($sin\theta_c \approx 0.22$)



$V_{cs}V_{ud} = \cos^2\theta_c \approx 1$
→Cabibbo favored



$V_{cd}V_{us} = \sin^2\theta_c$
→double Cabibbo suppression

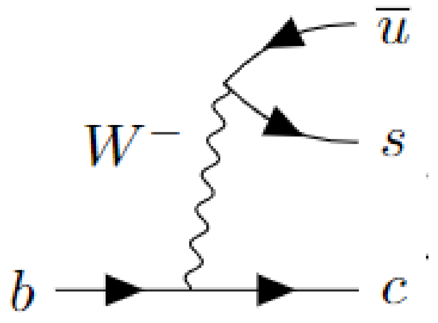
CKM Matrix

- Cabibo-Kobayahi-Maskawa (CKM) matrix [6], [4]

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{tb} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

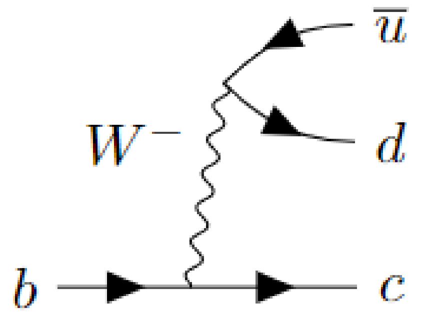
$$\begin{pmatrix} 0.9739 \text{ to } 0.9751 & 0.221 \text{ to } 0.227 & 0.0029 \text{ to } 0.0045 \\ 0.221 \text{ to } 0.227 & 0.9730 \text{ to } 0.9744 & 0.039 \text{ to } 0.044 \\ 0.0048 \text{ to } 0.014 & 0.037 \text{ to } 0.043 & 0.9990 \text{ to } 0.9992 \end{pmatrix}$$

90% confidence limits



$B^- \rightarrow D^0 K^-$

$V_{cb}V_{us} \approx (0.039)(0.221)$
$\approx 8.619 * 10^{-3}$



$B^- \rightarrow D^0 \pi^-$

$V_{cb}V_{ud} \approx (0.039)(0.974)$
$\approx 3.799 * 10^{-2}$

Decay Widths

- Measure of the probability of a decay channel occurring in a specified time interval in the parent (composite) particle rest frame
- When a particle's mass is measured, the total rate shows up as an irreducible width [5]
- Obtained through calculating the amplitude then integrating the amplitude over all space through use of the matrix element in Fermi's golden rule [8]:

$$\Gamma = \frac{2\pi}{\hbar}\left|M_{if}\right|^2 \rho_f \text{ where } |M| = \int \psi_f^* V \psi_i$$

Transition probability / decay width

Interaction matrix element

Density of final states

Final state wavefunction

Potential

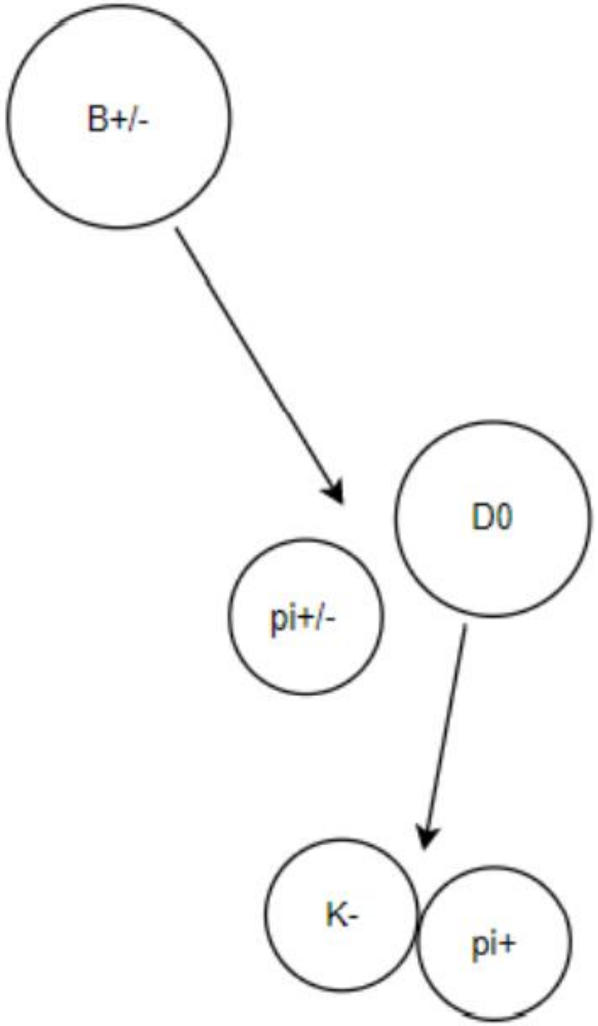
Initial state wavefunction

Metadata

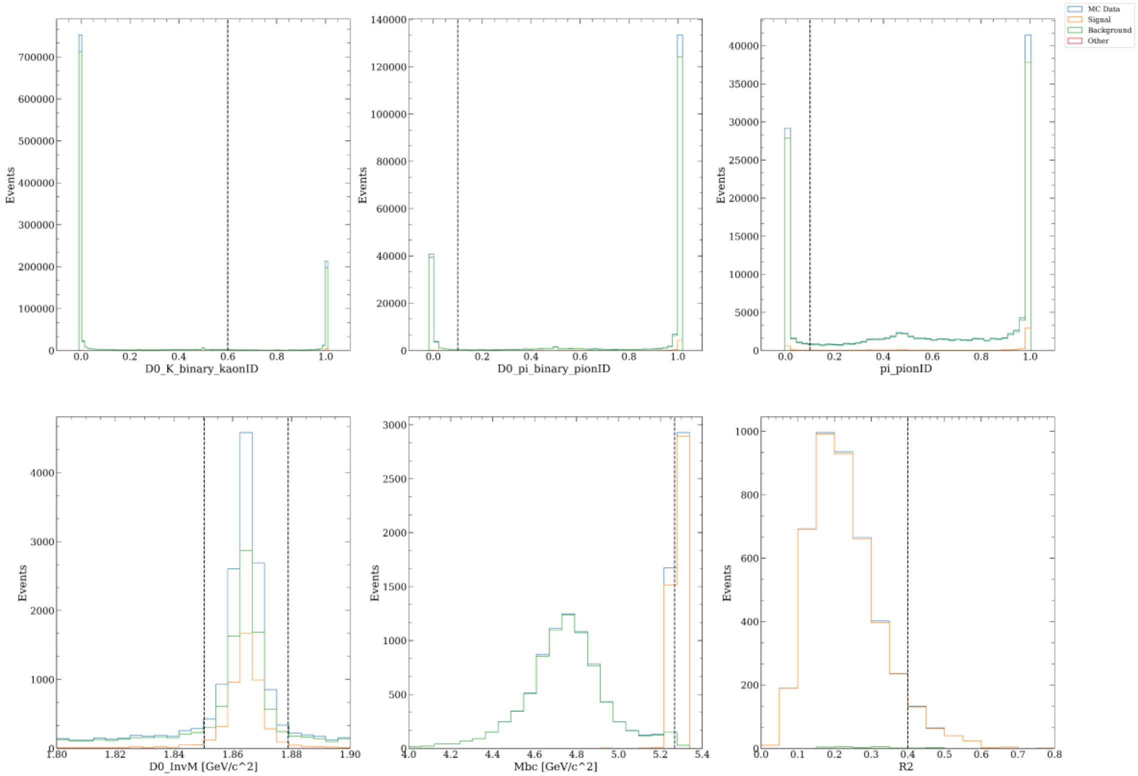
- Reconstruction Release: light-2201-venus
- MC Generation Release: release-05-00-02
- Campaigns: MC14ri_a (experimental MC data), MC14ri_d (confirmation MC data)
- Experiment Number: 1003
- MC Event Types: charged, mixed, ccbar, uubar, ddbar, ssbar, taupair
- Total $B^{\pm}$
  - per file: $1.08 * 10^8$ mesons (100 fb^{-1})
  - overall: $3.24 * 10^8$ mesons

Backup Slides

$B^{\pm} \rightarrow [D^0 \rightarrow K^{+}\pi^{-}]\pi^{\pm}$



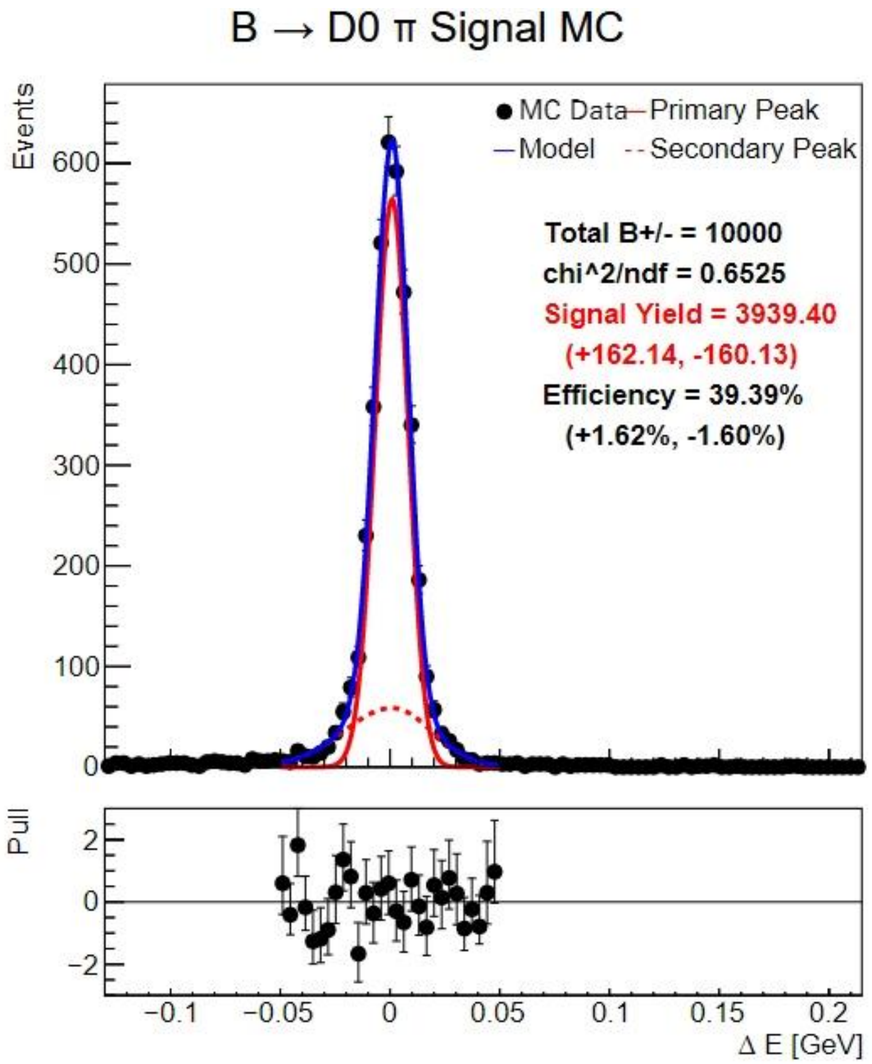
Selection Plots: : $B \rightarrow D\pi$ $Final\ States$



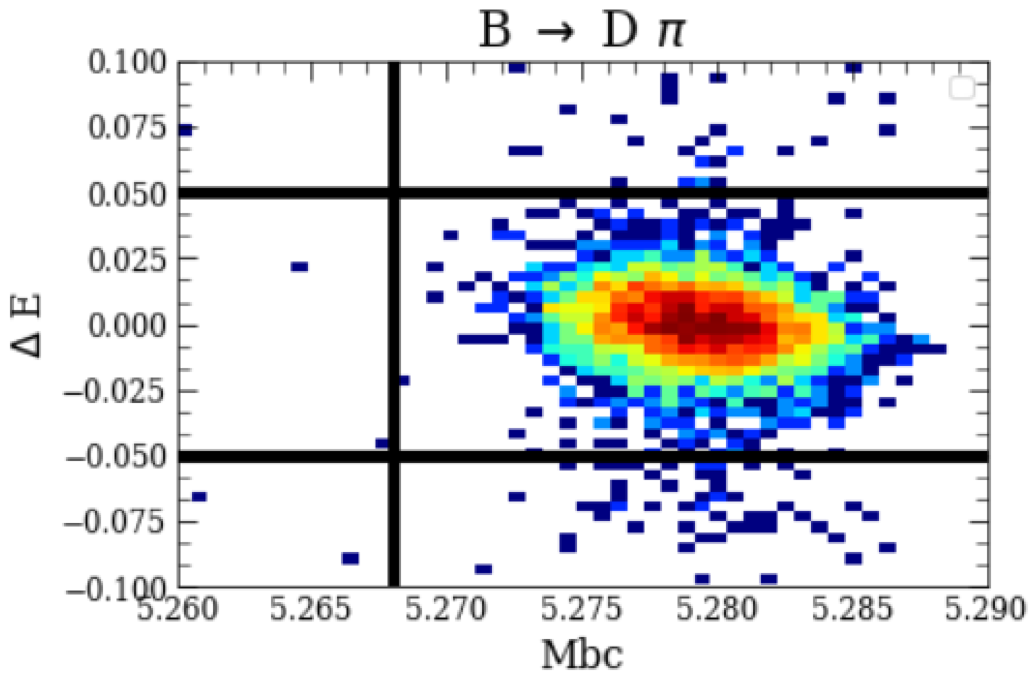
$B^{\pm}$ Signal : no cuts		
NA	Reconstruction	1569120 potential candidates
$B^{\pm}$ Signal : $K^{\pm}_{slow}$		
Classification	**Variable and Cut**	**Relative Efficiency**
goodTrack kinematics	$\lvert dz\rvert < 2.0$ [cm], $dr < 0.5$ [cm] $pt > 0.1$ [GeV/c], $E < 5.5$ [GeV] thetaInCDCAcceptance	1.0
PID	kaonID_binary_noSVD > 0.6	0.229
$B^{\pm}$ Signal : $\pi^{\pm}_{slow}$		
goodTrack kinematics	$\lvert dz\rvert < 2.0$ [cm], $dr < 0.5$ [cm] $pt > 0.1$ [GeV/c], $E < 5.5$ [GeV] thetaInCDCAcceptance	0.796
PID	pionID_binary_noSVD > 0.1	0.766
$B^{\pm}$ Signal : $\pi^{\pm}_{fast}$		
goodTrack kinematics	$\lvert dz\rvert < 2.0$ [cm], $dr < 0.5$ [cm] $pt > 0.1$ [GeV/c], $E < 5.5$ [GeV] thetaInCDCAcceptance	0.782
PID	pionID > 0.1	0.748
$B^{\pm}$ Signal : D^0		
kinematics	$1.85031 < InvM < 1.87885$	0.126
$B^{\pm}$ Signal : $B^{\pm}$		
kinematics	$Mbc > 5.268$	0.358
kinematics	abs(deltaE) < 0.5	0.992
$B^{\pm}$ tree fit	conf_level=0.0, D^0 mass constraint	1.0
continuum suppression	$R2 < 0.4$	0.939
Classification	**Variable and Cut**	**Candidate Efficiency with respect to Generated Events**
NA	Final Candidate (via BCS on ChiProb)	0.4117

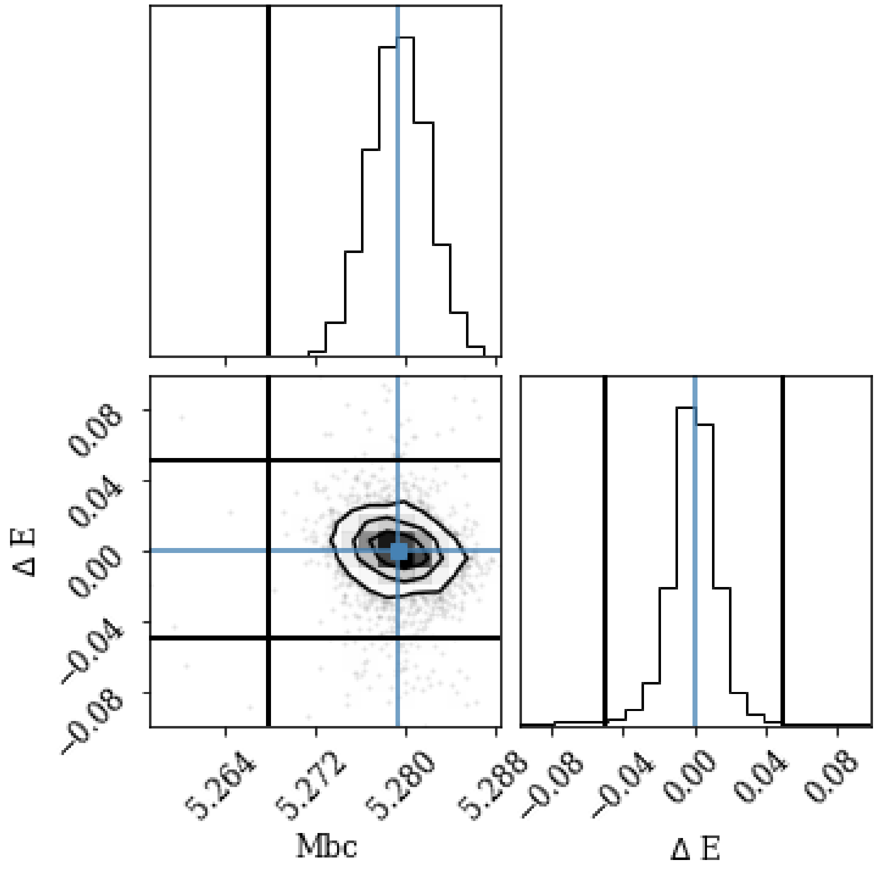
Fit Parameters: $B \to D\pi \quad D^0\ InvM$

```
FCN=-40925.7 FROM MINOS     STATUS=SUCCESSFUL    245 CALLS        1305 TOTAL
                     EDM=5.59178e-06    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                 PARABOLIC         MINOS ERRORS
  NO.   NAME      VALUE           ERROR      NEGATIVE      POSITIVE
   1  mean        9.63965e-04   4.74351e-04  -4.74324e-04   4.74823e-04
   2  no_sig1     3.08339e+03   1.20009e+02  -1.22482e+02   1.17684e+02
   3  no_sig2     8.56003e+02   1.07342e+02  -1.03147e+02   1.11532e+02
   4  sigma1L     7.76232e-03   4.18129e-04  -4.21870e-04   4.14609e-04
   5  sigma1R     7.28696e-03   3.76608e-04  -3.78789e-04   3.74976e-04
   6  sigma2L     2.20395e-02   1.63044e-03  -1.47698e-03   1.83260e-03
   7  sigma2R     1.81322e-02   1.13014e-03  -1.04196e-03   1.24157e-03
                              ERR DEF= 0.5
```



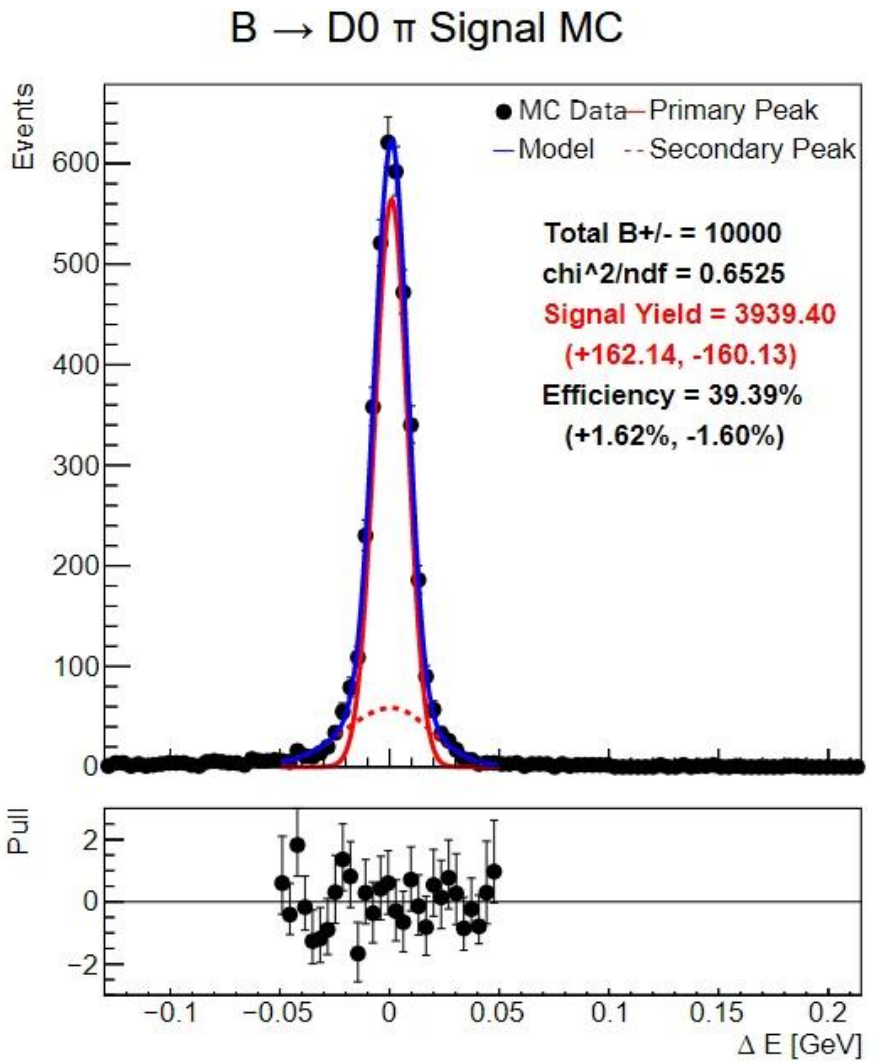
Selection Plots : $B \rightarrow D\pi\ Mbc\ vs.\Delta E$





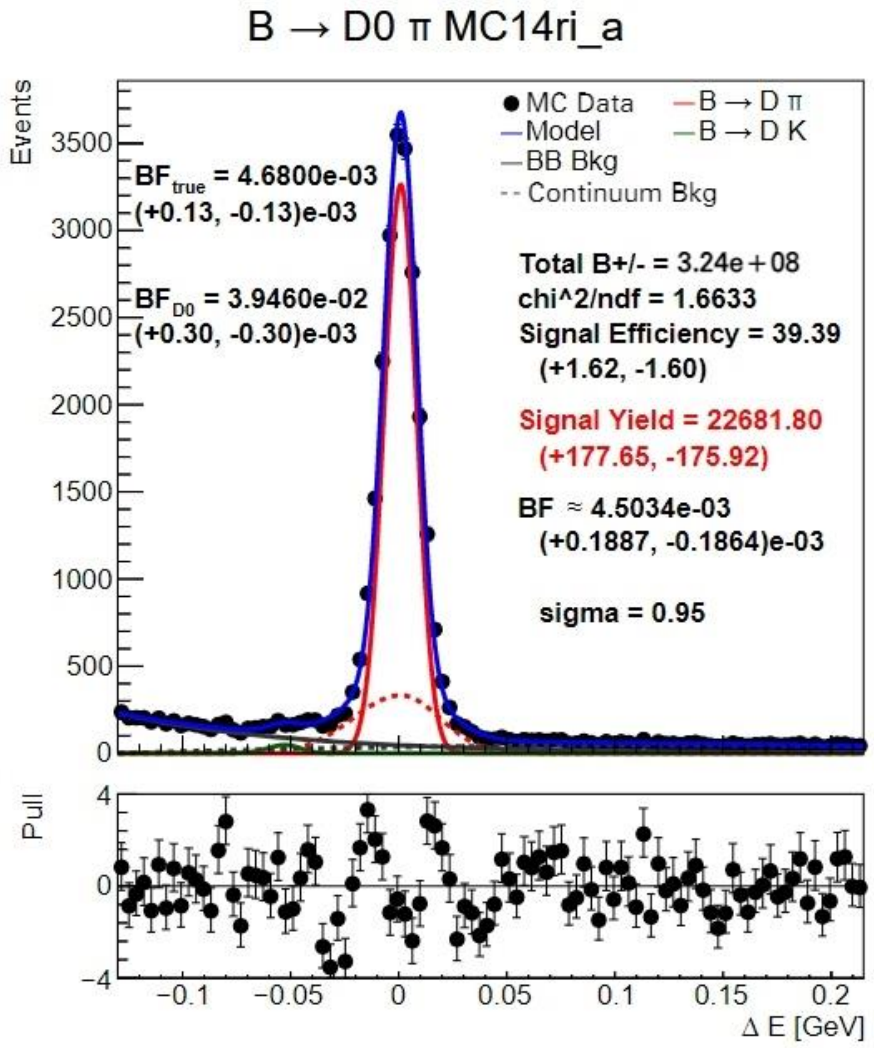
Fit Parameters: $B \to D\pi\ \ Signal\ \Delta E$

```
FCN=-40925.7 FROM MINOS      STATUS=SUCCESSFUL     245 CALLS         1305 TOTAL
                     EDM=5.59178e-06    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                  PARABOLIC         MINOS ERRORS
  NO.   NAME      VALUE            ERROR      NEGATIVE      POSITIVE
   1  mean         9.63965e-04   4.74351e-04  -4.74324e-04   4.74823e-04
   2  no_sig1      3.08339e+03   1.20009e+02  -1.22482e+02   1.17684e+02
   3  no_sig2      8.56003e+02   1.07342e+02  -1.03147e+02   1.11532e+02
   4  sigma1L      7.76232e-03   4.18129e-04  -4.21870e-04   4.14609e-04
   5  sigma1R      7.28696e-03   3.76608e-04  -3.78789e-04   3.74976e-04
   6  sigma2L      2.20395e-02   1.63044e-03  -1.47698e-03   1.83260e-03
   7  sigma2R      1.81322e-02   1.13014e-03  -1.04196e-03   1.24157e-03
                               ERR DEF= 0.5
```



Fit Parameters: $B \to D\pi$ ΔE MC14ri_a

```
FCN=-365721 FROM MINOS     STATUS=SUCCESSFUL    338 CALLS        3377 TOTAL
                     EDM=6.2448e-06    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                        PARABOLIC         MINOS ERRORS
 NO.   NAME       VALUE                 ERROR       NEGATIVE       POSITIVE
  1  cb          -1.22514e+01   1.06596e+00  -1.11517e+00   9.25547e-01
  2  fracK        7.60110e-02   6.82435e-01   at limit      4.08268e-01
  3  fracpi       2.13778e-01   7.87214e-03  -7.81961e-03   7.87201e-03
  4  meanK       -5.25191e-02   1.69257e-03  -1.73229e-03   1.68614e-03
  5  no_BBbkg     5.33092e+03   3.58734e+02  -3.49744e+02   3.02179e+02
  6  no_cbkg      3.46790e+03   2.13181e+02  -2.03076e+02   2.01945e+02
  7  no_sigK      2.61420e+02   9.69255e+01  -5.35048e+01   9.84948e+01
  8  no_sigpi     2.26818e+04   1.77569e+02  -1.75923e+02   1.77652e+02
                                 ERR DEF= 0.5
```



Fit Parameters: $B \rightarrow D\pi$ ΔE MC14ri_d

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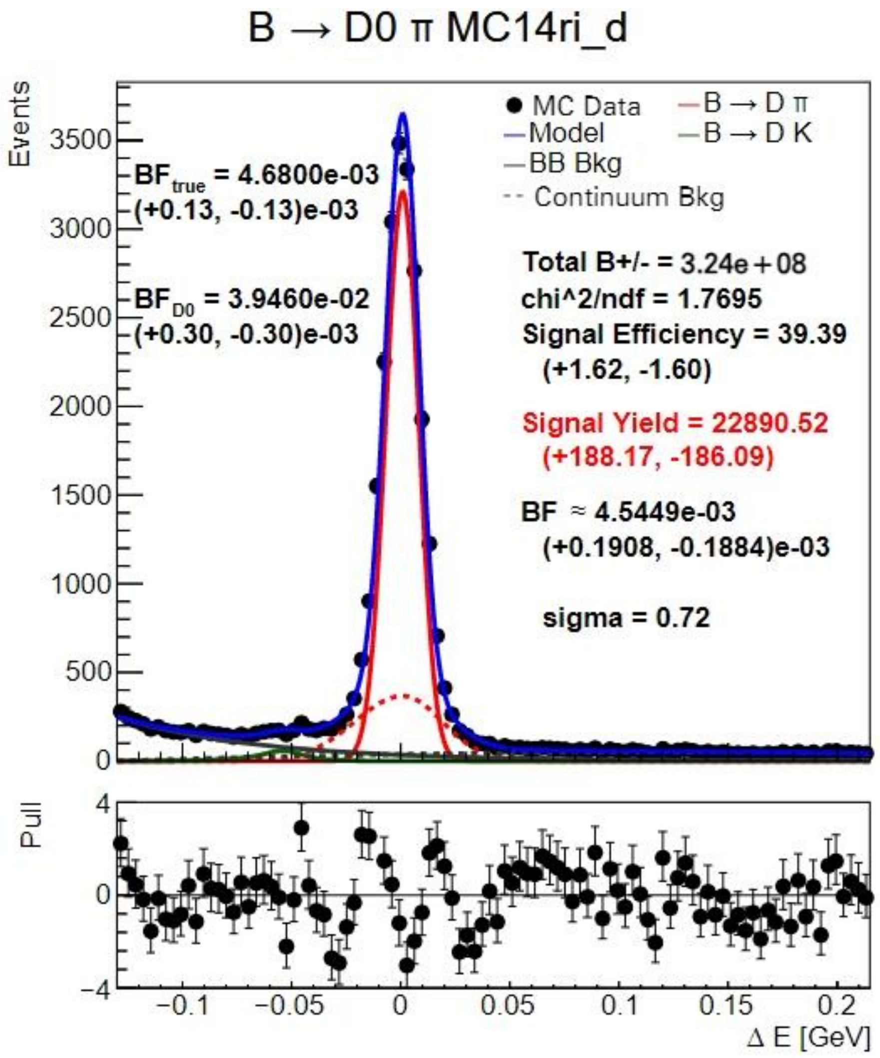
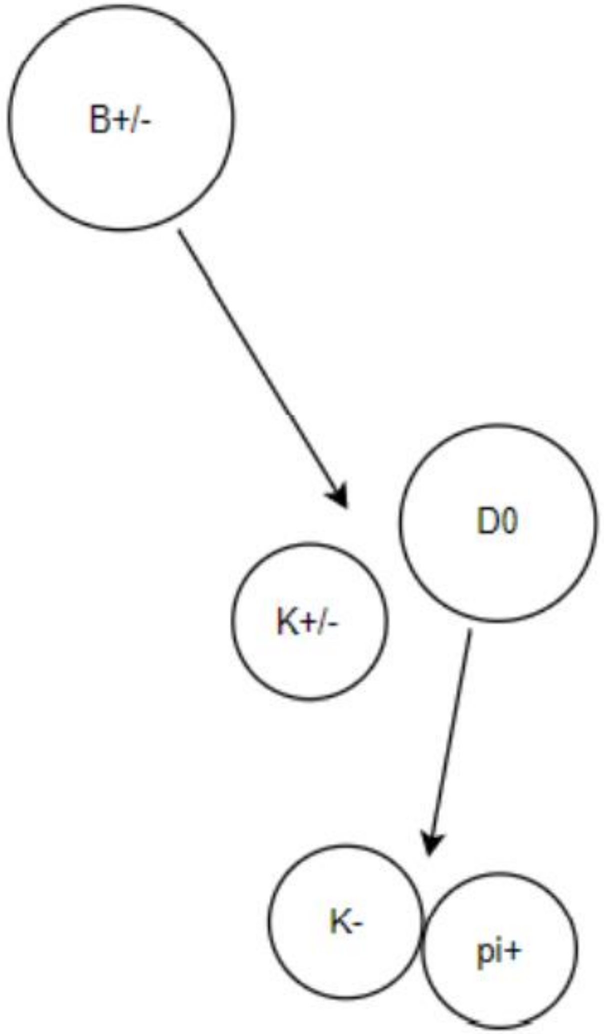
 EXT PARAMETER                  PARABOLIC         MINOS ERRORS
 NO.   NAME      VALUE            ERROR      NEGATIVE      POSITIVE
  1  cb         -1.52004e+01   1.46636e+00  -1.67495e+00   1.40935e+00
  2  fracK       6.45964e-01   1.98389e-01  -2.59296e-01   1.83457e-01
  3  fracpi      2.33685e-01   8.38430e-03  -8.43482e-03   8.52179e-03
  4  meanK      -5.34821e-02   1.89766e-03  -1.90421e-03   1.94133e-03
  5  no_BBbkg    4.71064e+03   3.46561e+02  -3.61502e+02   3.64922e+02
  6  no_cbkg     3.67490e+03   1.69756e+02  -1.84305e+02   1.66953e+02
  7  no_sigK     4.84943e+02   1.12323e+02  -1.13744e+02   1.23885e+02
  8  no_sigpi    2.28905e+04   1.85293e+02  -1.86094e+02   1.88167e+02
                               ERR DEF= 0.5
```

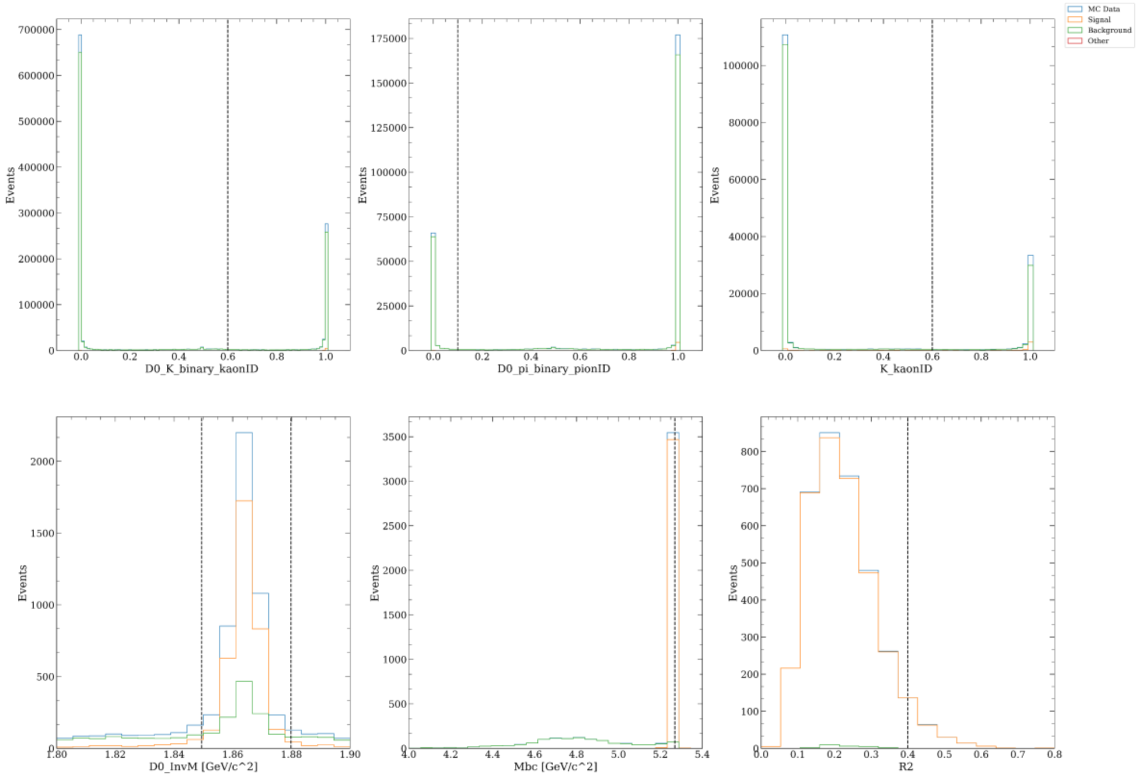


Backup Slides

$B^{\pm} \rightarrow [D^0 \rightarrow K^+\pi^-]K^{\pm}$



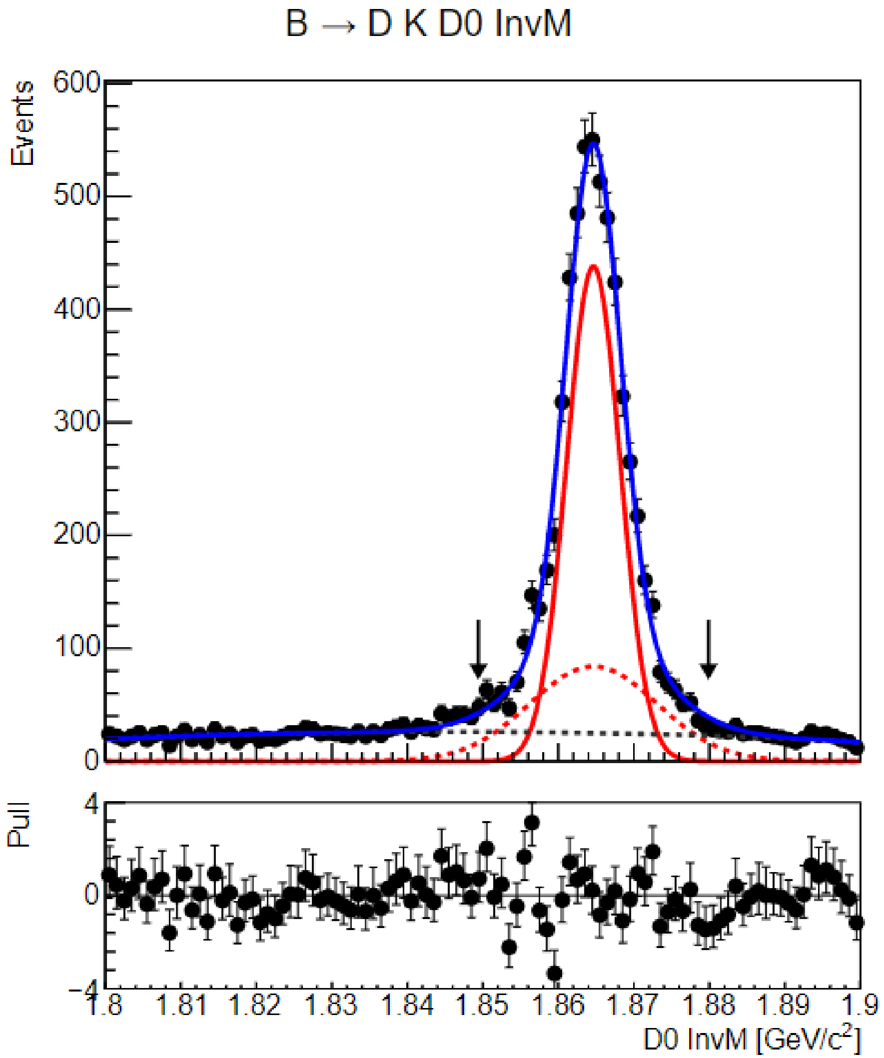
Selection Plots: : $B \to DK\ Final\ States$



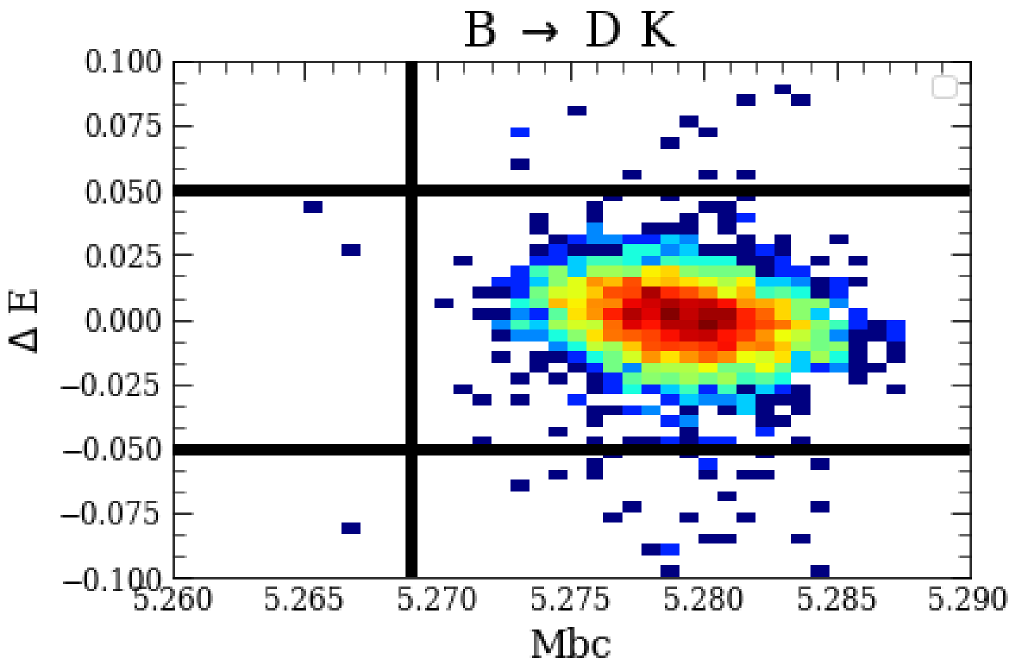
$B^{\pm}$ Signal : no cuts		
NA	Reconstruction	1603616 potential candidates
$B^{\pm}$ Signal : $K^{\pm}_{slow}$		
Classification	**Variable and Cut**	**Relative Efficiency**
goodTrack kinematics	|dz| < 2.0 [cm], dr < 0.5 [cm] pt > 0.1 [GeV/c], E < 5.5 [GeV] thetaInCDCAcceptance	1.0
PID	kaonID_binary_noSVD > 0.6	0.3101
$B^{\pm}$ Signal : $\pi^{\pm}_{slow}$		
goodTrack kinematics	|dz| < 2.0 [cm], dr < 0.5 [cm] pt > 0.1 [GeV/c], E < 5.5 [GeV] thetaInCDCAcceptance	0.794
PID	pionID_binary_noSVD > 0.1	0.733
$B^{\pm}$ Signal : $K^{\pm}_{fast}$		
goodTrack kinematics	|dz| < 2.0 [cm], dr < 0.5 [cm] pt > 0.1 [GeV/c], E < 5.5 [GeV] thetaInCDCAcceptance	0.790
PID	kaonID > 0.6	0.253
$B^{\pm}$ Signal : D^0		
kinematics	1.8494 < InvM < 1.87989	0.110
$B^{\pm}$ Signal : $B^{\pm}$		
kinematics	Mbc > 5.269	0.747
kinematics	abs(deltaE) < 0.5	0.998
$B^{\pm}$ tree fit	conf_level=0.0, D^0 mass constraint	1.0
continuum suppression	R2 < 0.4	0.952
Classification	**Variable and Cut**	**Candidate Efficiency with respect to Generated Events**
NA	Final Candidate (via BCS on ChiProb)	0.3308

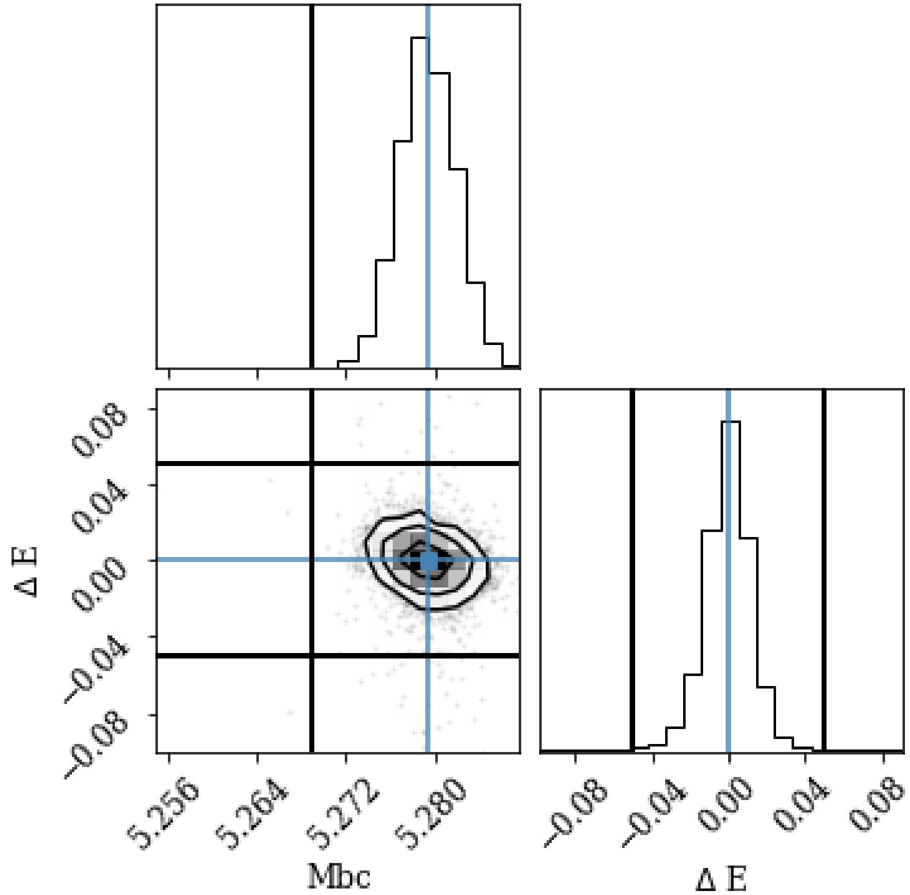
Fit Parameters: $B \to DK \quad D^0 \; InvM$

```
FCN=-88579.7 FROM MINOS      STATUS=SUCCESSFUL     294 CALLS         2221 TOTAL
                            EDM=4.8318e-05     STRATEGY= 1       ERROR MATRIX ACCURATE
 EXT PARAMETER                            PARABOLIC           MINOS ERRORS
 NO.    NAME       VALUE                    ERROR        NEGATIVE        POSITIVE
  1  c0           -5.46929e-02   4.83246e-02  -5.08308e-02   4.68448e-02
  2  c1           -1.74867e-01   5.00287e-02  -4.92451e-02   5.12145e-02
  3  mean          1.86464e+00   6.96046e-05  -6.95835e-05   6.96418e-05
  4  no_cbkg       2.34749e+03   1.02992e+02  -1.08253e+02   1.00364e+02
  5  no_sig1       3.89362e+03   3.64139e+02  -4.15874e+02   3.30225e+02
  6  no_sig2       1.77581e+03   3.13261e+02  -2.81209e+02   3.62754e+02
  7  sigma1        3.54594e-03   1.75309e-04  -1.92769e-04   1.65133e-04
  8  sigma2        8.44525e-03   1.05437e-03  -9.74661e-04   1.18375e-03
                                 ERR DEF= 0.5
```



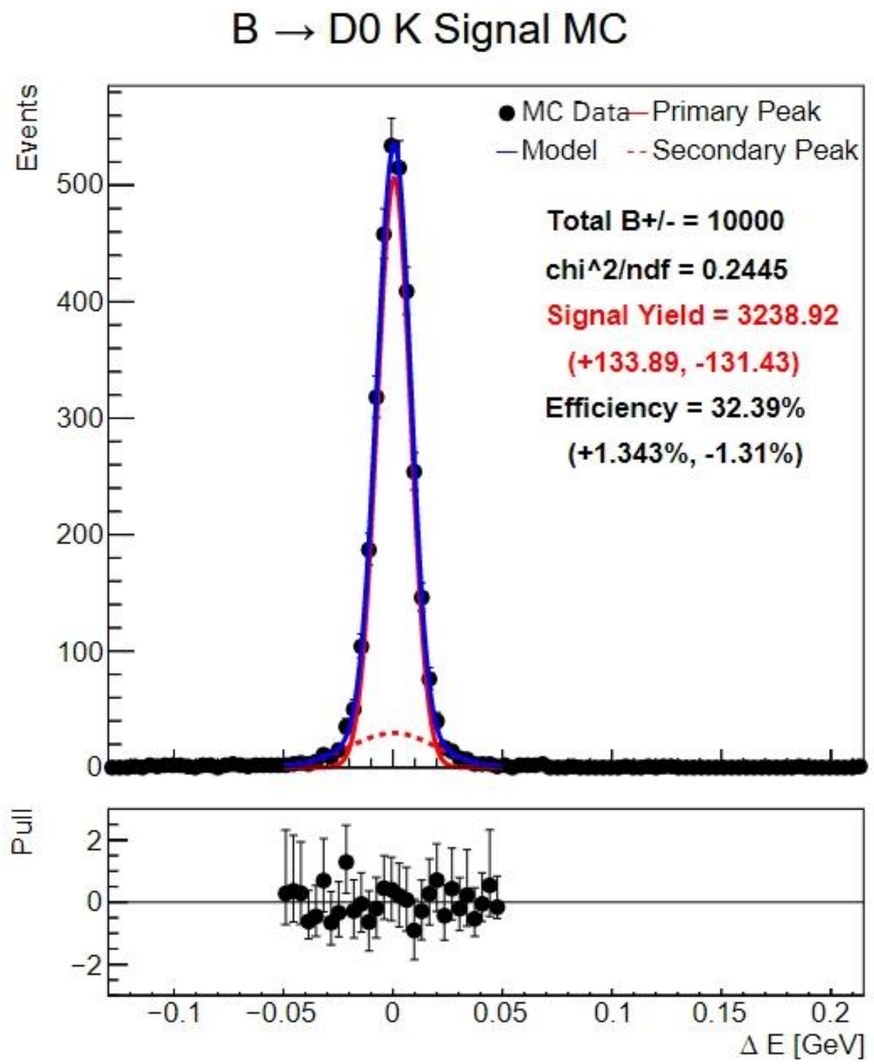
Selection Plots : $B \rightarrow DK\ Mbc\ vs.\Delta E$





Fit Parameters: $B \rightarrow DK\ \ Signal\ \Delta E$

```
FCN=-33403.6 FROM MINOS     STATUS=SUCCESSFUL     247 CALLS        1430 TOTAL
                     EDM=2.63456e-05    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                PARABOLIC         MINOS ERRORS
 NO.   NAME      VALUE           ERROR       NEGATIVE      POSITIVE
  1  mean         6.52712e-04   4.50363e-04  -4.52369e-04   4.50533e-04
  2  no_sig1      2.81440e+03   1.00356e+02  -1.05291e+02   9.60517e+01
  3  no_sig2      4.24515e+02   8.57857e+01  -7.86571e+01   9.32815e+01
  4  sigma1L      7.84985e-03   3.69911e-04  -3.75851e-04   3.65418e-04
  5  sigma1R      7.45648e-03   3.53221e-04  -3.57721e-04   3.50673e-04
  6  sigma2L      2.05633e-02   2.10082e-03  -1.84297e-03   2.46416e-03
  7  sigma2R      1.89443e-02   1.84125e-03  -1.62807e-03   2.13491e-03
                          ERR DEF= 0.5
```

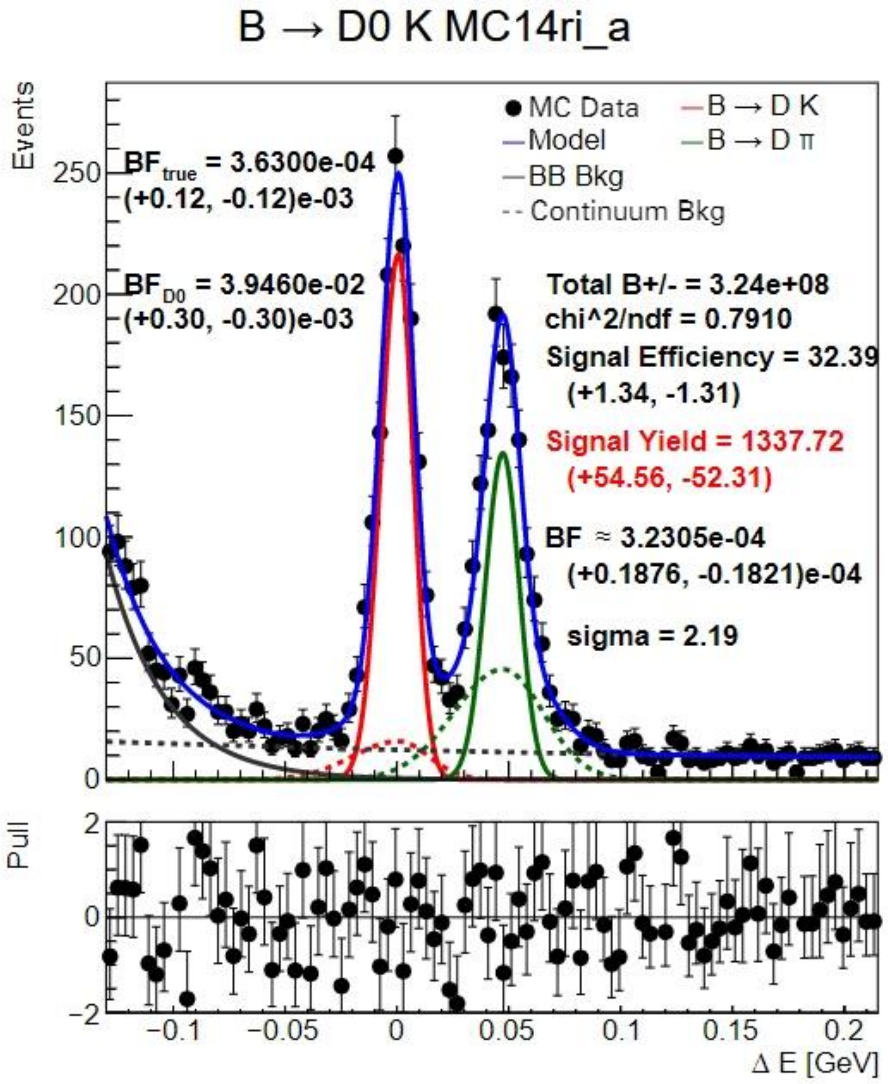


Fit Parameters: $B \rightarrow DK\ \ \Delta E$ MC14ri_a

FCN=-41662.2 FROM MINOS   STATUS=SUCCESSFUL   295 CALLS   4430 TOTAL
EDM=2.48458e-05   STRATEGY= 1   ERROR MATRIX ACCURATE

EXT NO.	PARAMETER NAME	VALUE	PARABOLIC ERROR	MINOS ERRORS NEGATIVE	MINOS ERRORS POSITIVE
1	c0	-2.65352e-01	2.67991e-01	-1.96899e-01	4.82569e-01
2	c1	4.42295e-02	1.49592e-01	-2.35702e-01	1.20951e-01
3	cb	-3.85058e+01	7.99036e+00	-8.43629e+00	7.81776e+00
4	fracK	1.46611e-01	5.01341e-02	-5.04100e-02	5.06638e-02
5	fracpi	4.74355e-01	3.74962e-02	-3.77867e-02	3.72912e-02
6	meanpi	4.73746e-02	3.72655e-04	-3.72634e-04	3.72713e-04
7	no_BBbkg	6.99666e+02	1.69704e+02	-1.39352e+02	2.28145e+02
8	no_cbkg	1.18082e+03	2.11235e+02	-2.74306e+02	1.79844e+02
9	no_sigK	1.33772e+03	5.31767e+01	-5.23133e+01	5.45589e+01
10	no_sigpi	1.39878e+03	4.83393e+01	-4.79337e+01	4.88370e+01

ERR DEF= 0.5



Fit Parameters: $B \rightarrow DK$ ΔE MC14ri_d

```
FCN=-40621.5 FROM MINOS     STATUS=SUCCESSFUL     239 CALLS        3965 TOTAL
                     EDM=8.56386e-06     STRATEGY= 1       ERROR MATRIX ACCURATE
 EXT PARAMETER                    PARABOLIC         MINOS ERRORS
 NO.   NAME       VALUE             ERROR       NEGATIVE       POSITIVE
  1  c0          -2.98930e-01   2.55594e-01  -1.91698e-01   4.26781e-01
  2  c1          -1.01073e-01   1.71124e-01  -2.61647e-01   1.37147e-01
  3  cb          -3.84136e+01   7.00524e+00  -7.28062e+00   6.85812e+00
  4  fracK        1.45014e-01   4.76518e-02  -4.78993e-02   4.78726e-02
  5  fracpi       4.26218e-01   4.17913e-02  -4.21730e-02   4.15293e-02
  6  meanpi       4.85578e-02   3.80517e-04  -3.80650e-04   3.80817e-04
  7  no_BBbkg     7.31857e+02   1.55352e+02  -1.30242e+02   1.98630e+02
  8  no_cbkg      1.16608e+03   1.94709e+02  -2.41069e+02   1.68979e+02
  9  no_sigK      1.37450e+03   5.21127e+01  -5.13876e+01   5.30596e+01
 10  no_sigpi     1.23757e+03   4.63635e+01  -4.59807e+01   4.67959e+01
                              ERR DEF= 0.5
```