SEARCH FOR CP VIOLATION IN $B^{\pm} \rightarrow D^{(*)}D^{\pm}$ DECAYS IN THE BELLE II EXPERIMENT

Bartek Pierzchala and Silje Øino

Supervisor: Olga Werbycka

OUTLINE

Introduction

Data simulation and analysis

Results

Summary

PROJECT AIMS

LEARN HOW TO:

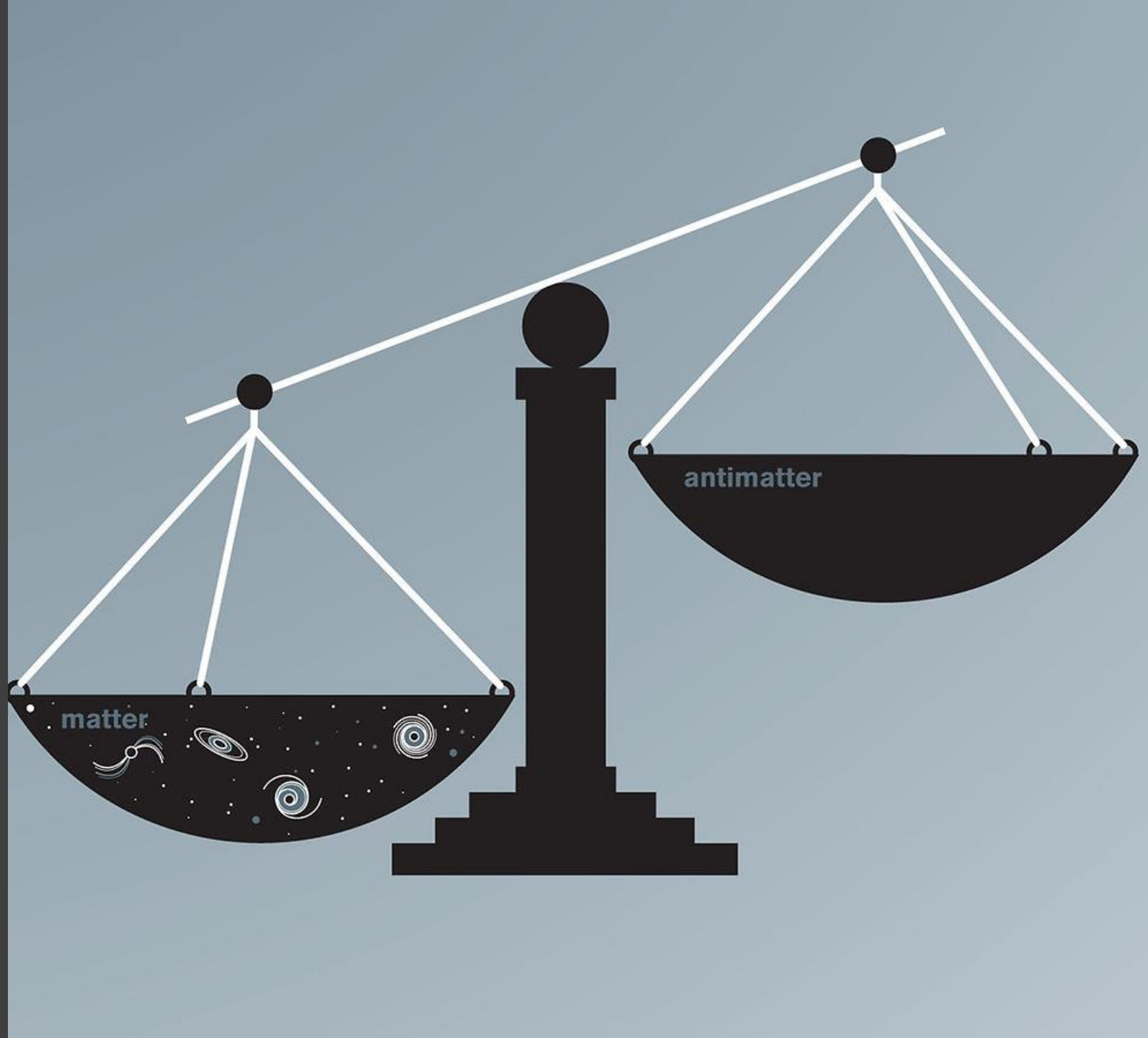
- Use **basf2** (Belle II analysis software framework) to
  - perform signal Monte Carlo simulation of real physical process
  - reconstruct B-mesons and daughter particles
- Use **RooFit** to
  - fit PDFs to relevant variable plots

ULTIMATE GOAL:

Verify **direct violation** of CP symmetry by comparing the reconstructed signal yields of four B-meson decay chains and their charge conjugate.

THE ISSUE OF ASYMMETRY

- Asymmetry of matter and antimatter shortly after the big bang
- - otherwise, nothing would exist!
- Matter and antimatter must somehow have different properties
- Partially explained by small CP violation in weak decays within SM (discovered 1964 [1])
- Search for CPV beyond SM continues



[1] A. D. Sakharov. «Violation of CP in variance, C asymmetry, and baryon asymmetry of the universe.” American Institute of Physics, 1991

CHARGE AND PARITY (CP) SYMMETRY:

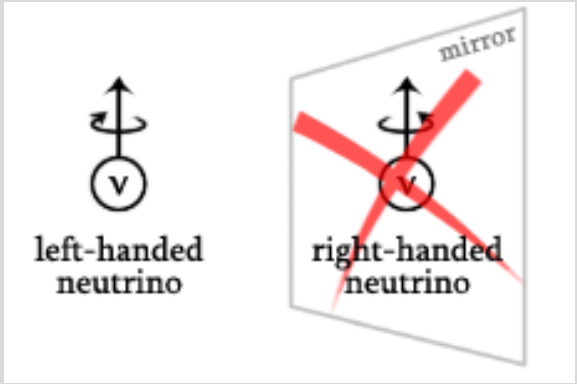
- **Charge-symmetry:**

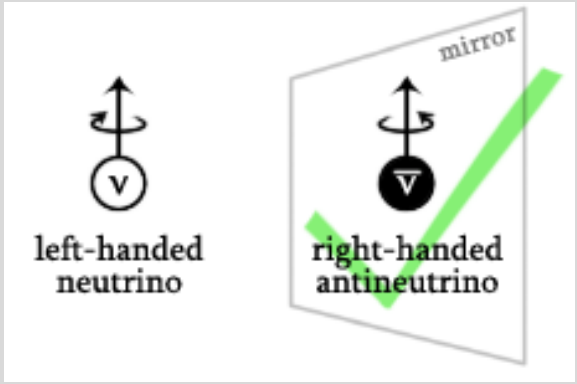
  «Particle interactions are unaffected when taking the conjugate of charge and magnetic moment.»

- **Parity-symmetry:**

  «The laws of physics are unconcerned with left- or right-handedness.»

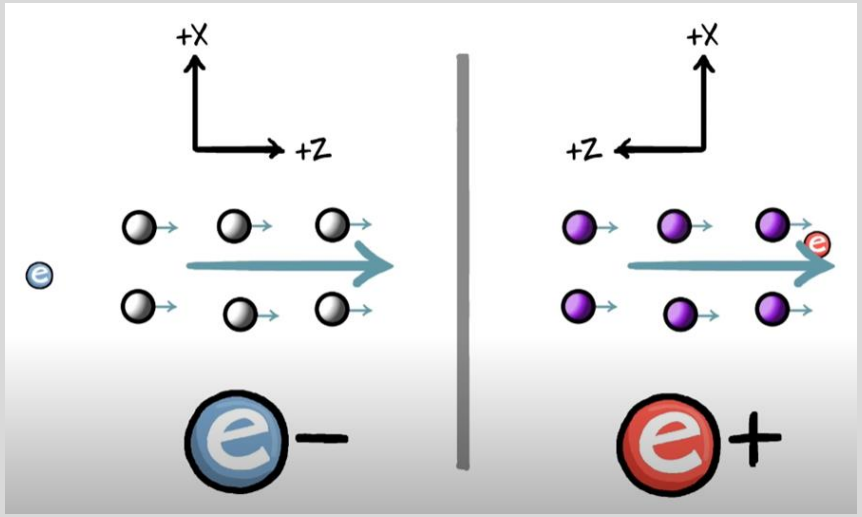
- Holds for strong and EM interactions.





CP VIOLATION

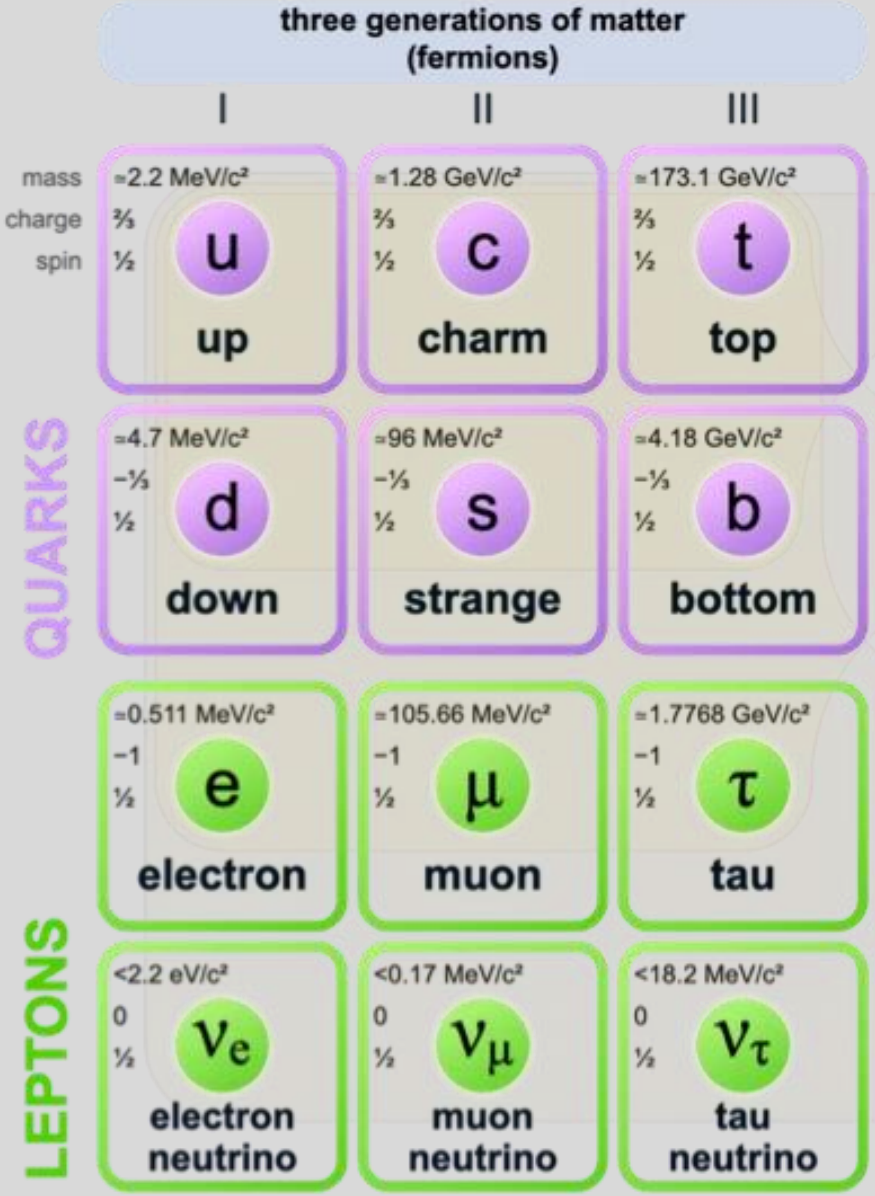
- Some **weak** decays display **abnormal behaviour:**
  - Mirror image of physical process ≠ mirror image of outcome
    - even when mirror particle is replaced by self-conjugate (antiparticle)
  - → violation of CP symmetry
  - Type: **Direct** CP violation
  - Mothers → daughter particles without transforming into self-conjugate first



[2] Fry, J. R. "Cp Violation and the Standard Model." Reports on Progress in Physics 63, no. 2 (2000/01/27 2000): 117-69.

B-MESONS

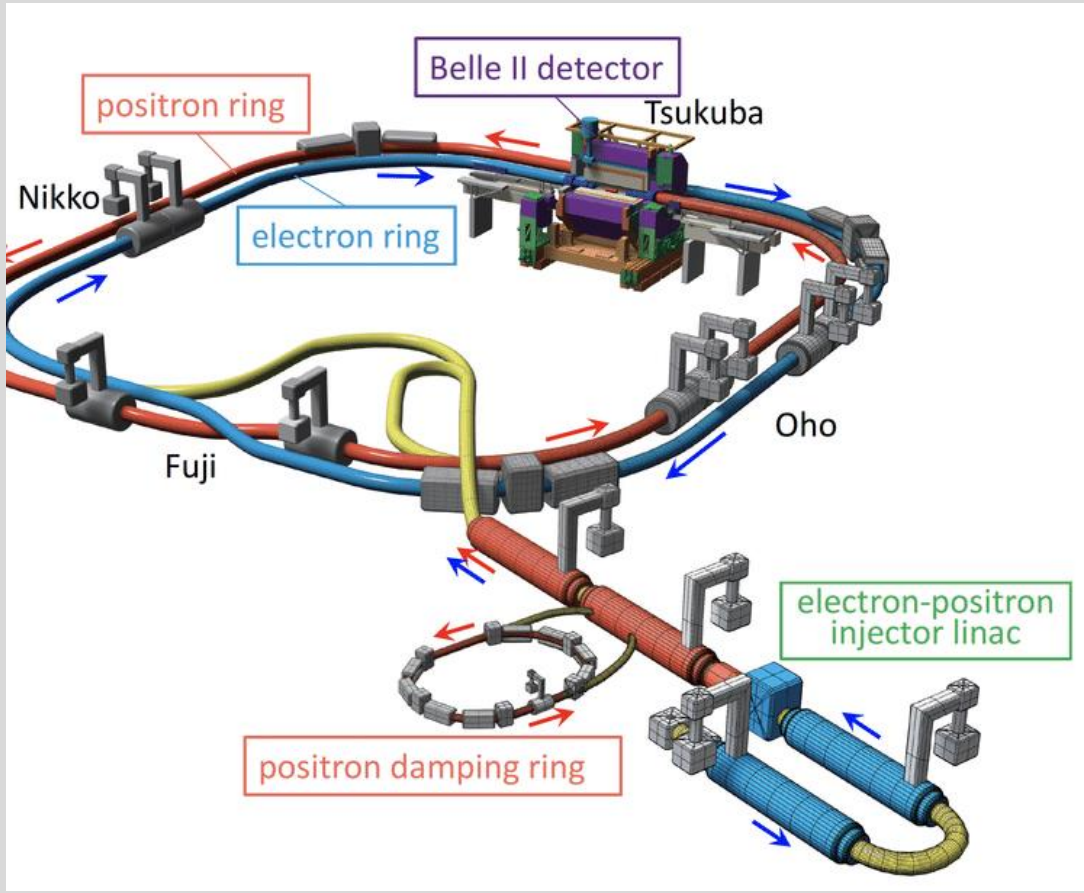
- SM: matter = **quarks** and **leptons**
- Mesons are a quark-antiquark pair
- B-mesons have **one bottom-quark** (**3rd** generation)
- Large initial mass → many possible decay paths & end particles
- Subject to **flavour mixing**
- Expect presence of direct CP violation as difference in decay rates



[3] Fry, J. R. "Cp Violation and the Standard Model." Reports on Progress in Physics 63, no. 2 (2000/01/27 2000): 117-69.
[4] Takasaki F. The discovery of CP violation in B-meson decays. Proc Jpn Acad Ser B Phys Biol Sci. 2012;88(7):283-298. doi:10.2183/pjab.88.283

THE BELLE II EXPERIMENT

- SuperKEKB factory in Japan accelerates and collides electron-positron pairs
- Cleaner than LHC (protons are complex) → less background noise
- World record: highest instantaneous luminosity of $2.80 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ [5]
- Centre-of-momentum at mass of $\Upsilon(4s)$ resonance $(10.57\ GeVc^{-2})$
- $\Upsilon(4s) \rightarrow B\bar{B}$ > **96%**



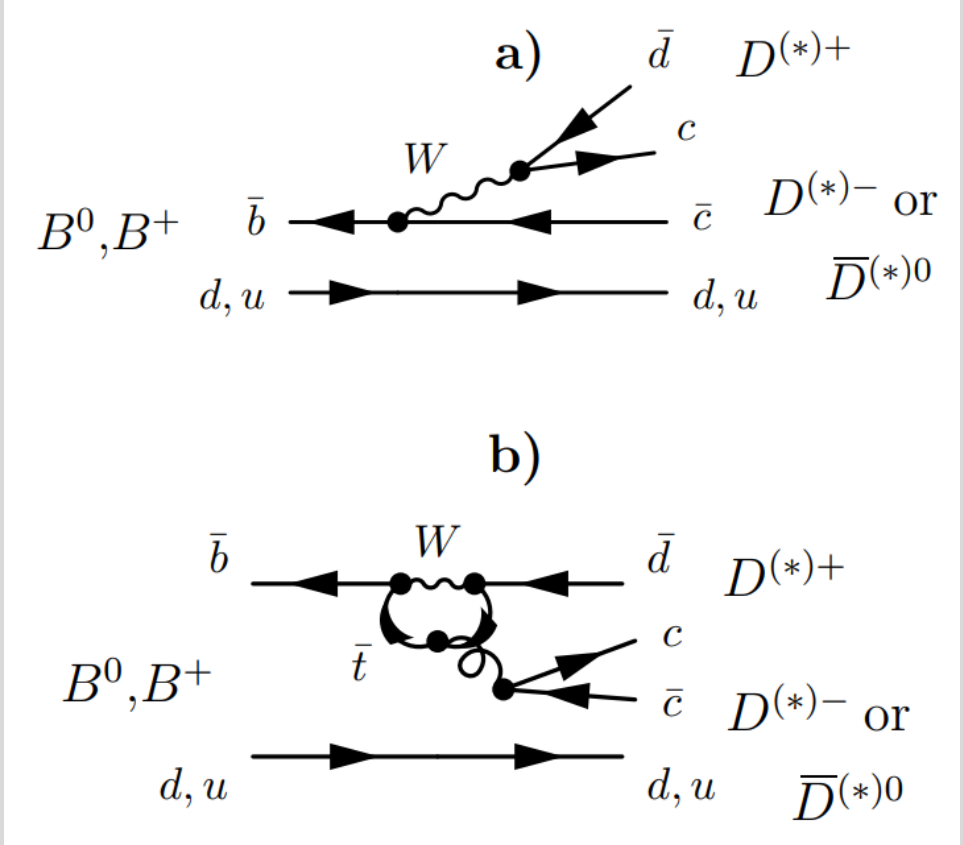
[5] Akai, Kazunori, Kazuro Furukawa, and Haruyo Koiso. "Superkekb Collider." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 907 (08/01 2018).

DECAY CHAINS

Four B meson decay chains and their charge conjugate:

$$B^{\pm} \rightarrow D^{*\pm}\overline{D}^{*0}$$
$$B^{\pm} \rightarrow D^{*\pm}\overline{D}^{0}$$
$$B^{\pm} \rightarrow D^{\pm}\overline{D}^{*0}$$
$$B^{\pm} \rightarrow D^{\pm}\overline{D}^{0}$$

$$\Upsilon(4s) \rightarrow B^{+}B^{-}$$
$$\downarrow$$
$$D^{*+}\ \overline{D}^{0}$$
$$\downarrow \qquad \downarrow$$
$$D^{+}\ \pi^{-} \qquad K^{+}\ \pi^{-}$$
$$\downarrow$$
$$K^{-}\ \pi^{+}\ \pi^{+}$$



Tree (a) and penguin (b) Feynman diagrams of $B^{\pm} \rightarrow D^{(*)\pm}\overline{D}^{(*)0}$

DATA SIMULATION & ANALYSIS

BASIC IDEA OF THE PROJECT

- We are interested in $A_{CP} \equiv \frac{\Gamma(\bar{X}\to\bar{Y})-\Gamma(X\to Y)}{\Gamma(X\to Y)+\Gamma(\bar{X}\to\bar{Y})}$[1],[2]
- Generate events
- M_{bc} and ΔE are ‚historically'[2] the basic variables in B physics:[3]
  - $\Delta E \equiv E_{Bs} - E_{beam}.$
  - $M_{bc}^2 = E_{beam}^2 - \boldsymbol{P}_{Bs}^2$
- Obtain number of events from 2D fits to M_{bc} and $\Delta E \Rightarrow A_{CP}$

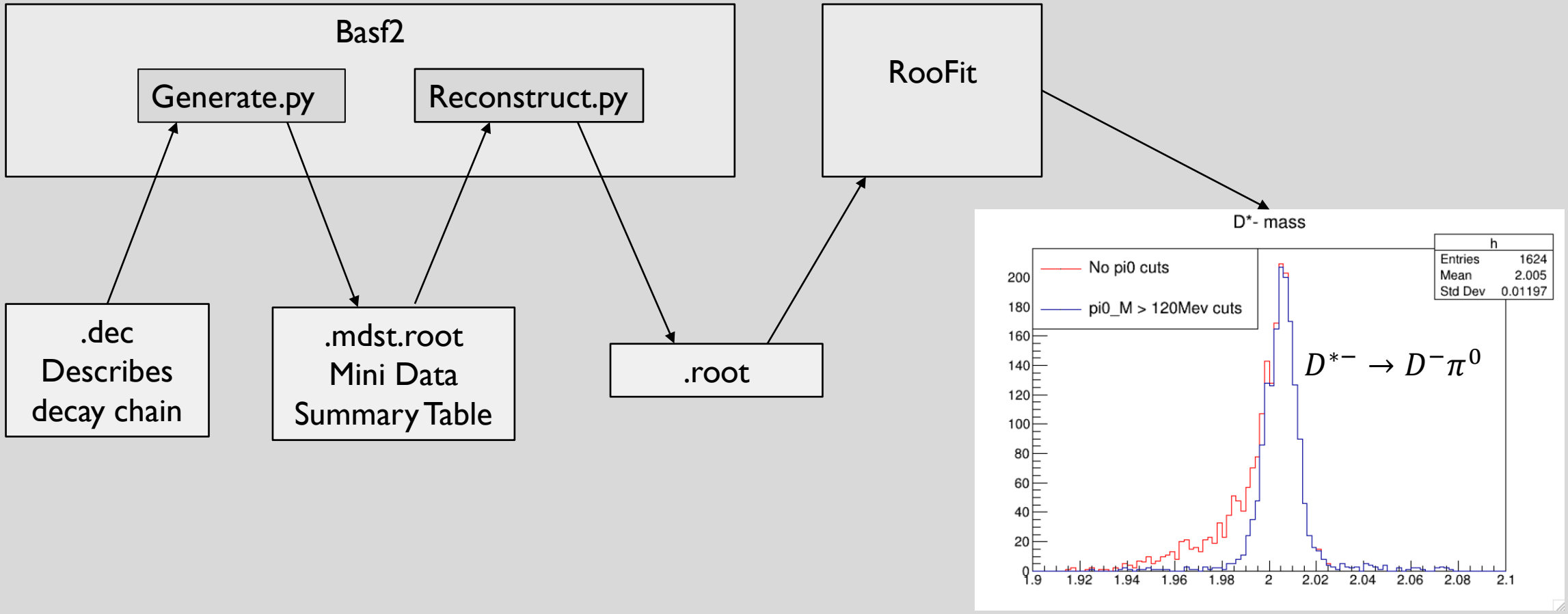
[1] Measurements of CP asymmetry in $D^0 \to K^-K^+$, the LHCb collaboration, 2016
[2] Measurements of direct CP violation, M. S. Sozzi and I. Mannelli, 2003
[3] Physics and Techniques of B-factories, Hitoshi Yamamoto, University of Hawaii, 1999, KIAS
[4] Study of doubly-charmed B→$\bar{D}^*\ \bar{D}^*K$ decays at Belle, Jolanta Brodzicka, Polish Academy of Sciences, Kraków, Poland, 2005

BELLE ANALYSIS SOFTWARE FRAMEWORK

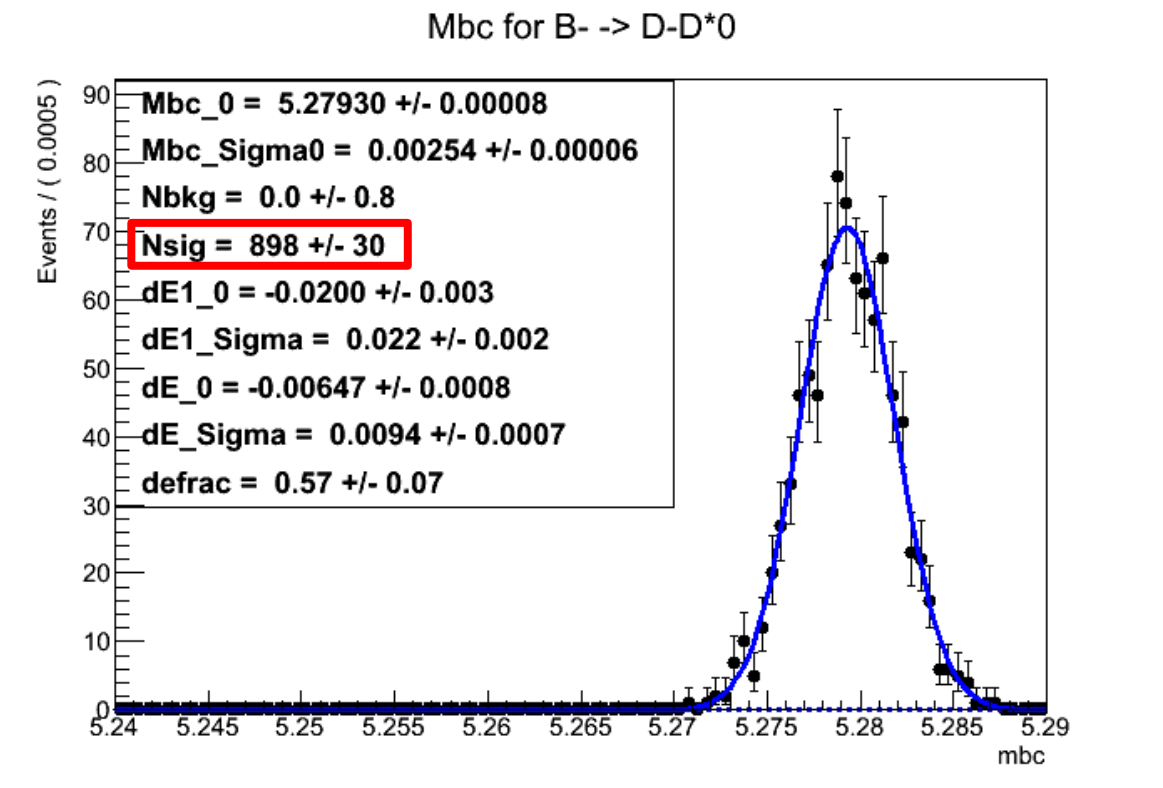
- Program to reconstruct decays, generate and analyse data…
- Broad physics: B, charm and Tau
- C++ wrapped in Python
- Basf2 is upgraded and further developed basf, more documentation, flexibility etc.
- Allows for collecting a lot of information about particles, with cross checks e.g. isSignal
- Powerful tool, struggles with neutral particles e.g. π^0

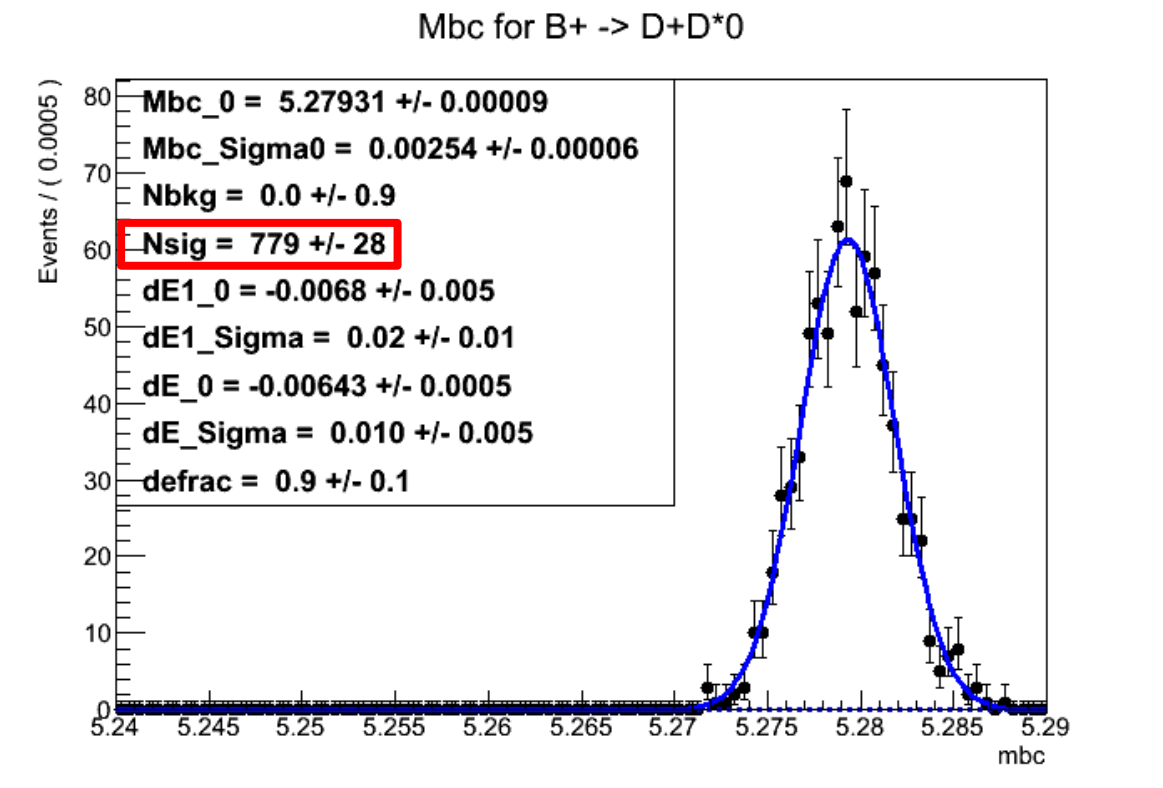
Basf2 logo from Belle II collaboration's Facebook

EVENTS GENERATION AND ANALYSIS



SOME RESULTS: $B^- \rightarrow D^- D^{*0}$

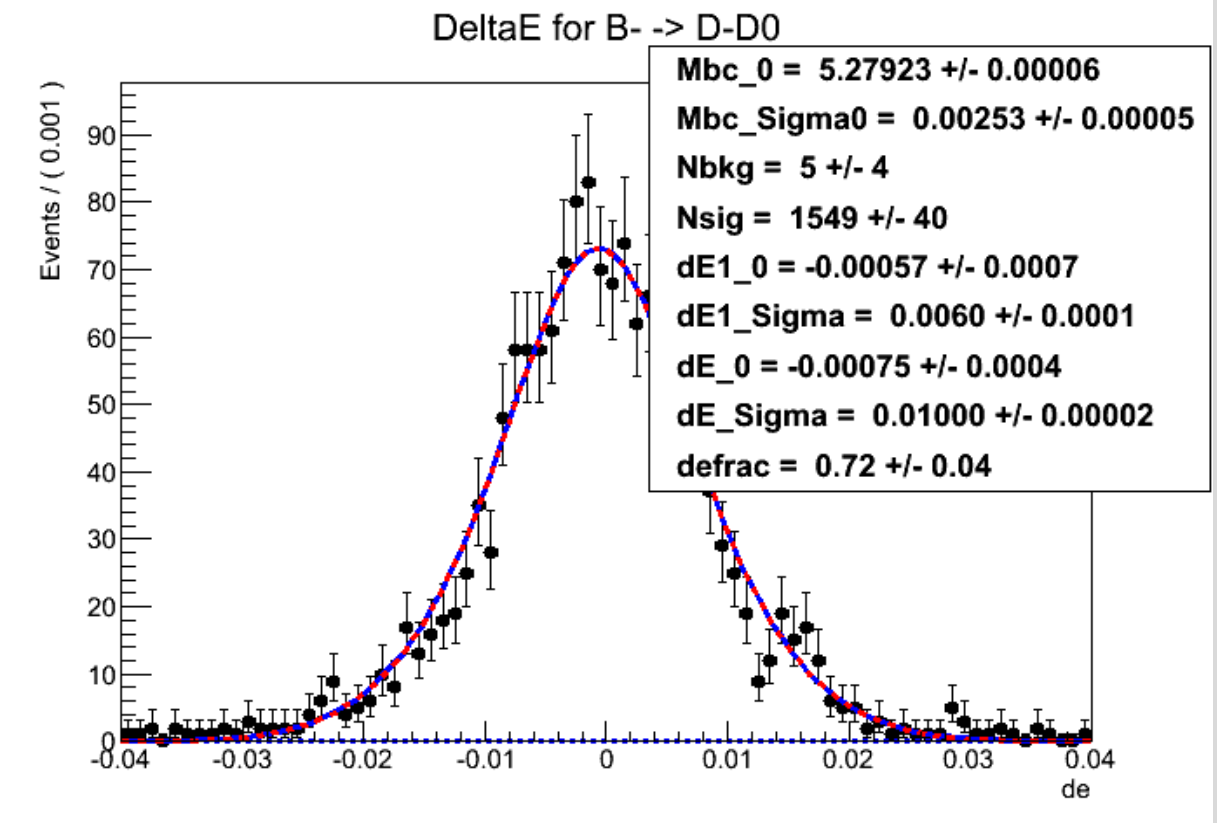


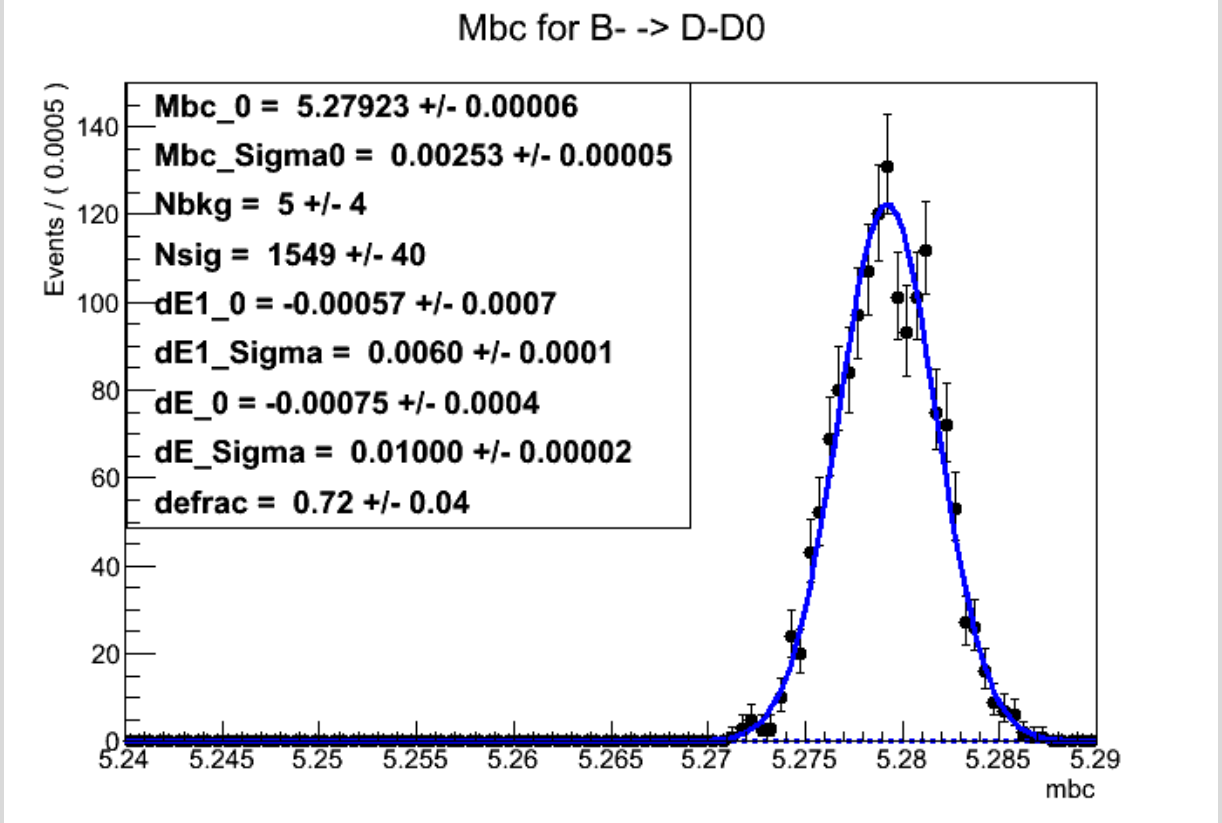


Mass of $B^{\pm} = 5.27932 \pm 0.00014$ GeV[1]

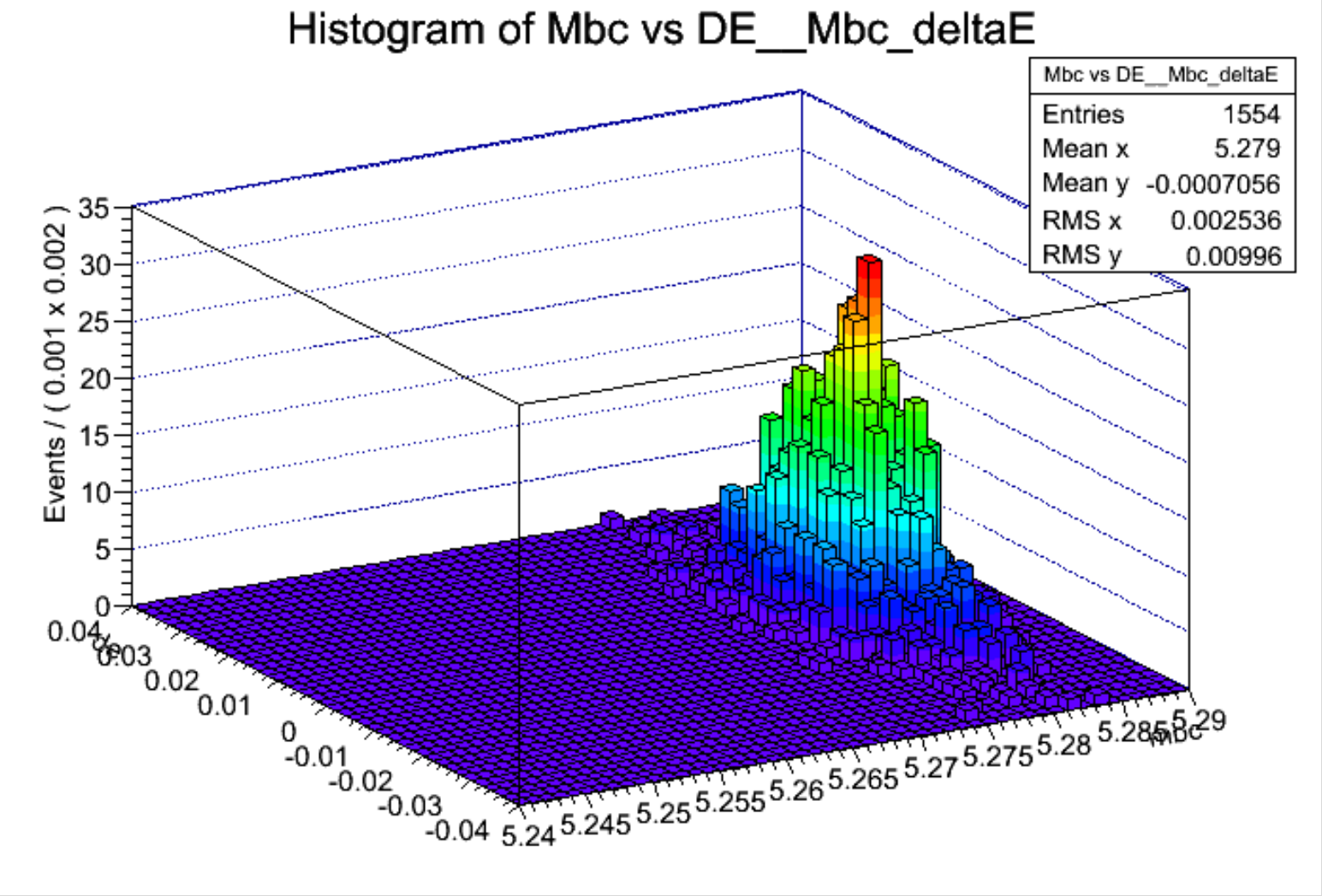
[1] M. Tanabashi et al.(Particle Data Group), Phys. Rev. D98, 030001 (2018)

SOME RESULTS: $B^- \to D^- D^0$





SOME RESULTS: $B^- \rightarrow D^- D^0$



RESULTS

SIMULATED

- $A_{CP}(B^+ \to D^{*+}\overline{D}^{*0}) = -0.15 \pm 0.03$
- $A_{CP}(B^+ \to D^{*+}\overline{D}^{0}) = -0.005 \pm 0.019$
- $A_{CP}(B^+ \to D^{+}\overline{D}^{*0}) = 0.07 \pm 0.02$
- $A_{CP}(B^+ \to D^{*+}\overline{D}^{*0}) = -0.01 \pm 0.02$

WORLD AVERAGE[I]

$A_{CP}(B^+ \to D^{*+}\overline{D}^{*0}) = -0.15 \pm 0.11$
$A_{CP}(B^+ \to D^{*+}\overline{D}^{0}) = -0.06 \pm 0.13$
$A_{CP}(B^+ \to D^{+}\overline{D}^{*0}) = 0.13 \pm 0.18$
$A_{CP}(B^+ \to D^{+}\overline{D}^{0}) = -0.03 \pm 0.07$

[I] M. Tanabashi et al.(Particle Data Group), Phys. Rev. D98, 030001 (2018)

THANK YOU FOR YOUR ATTENTION. ANY QUESTIONS?