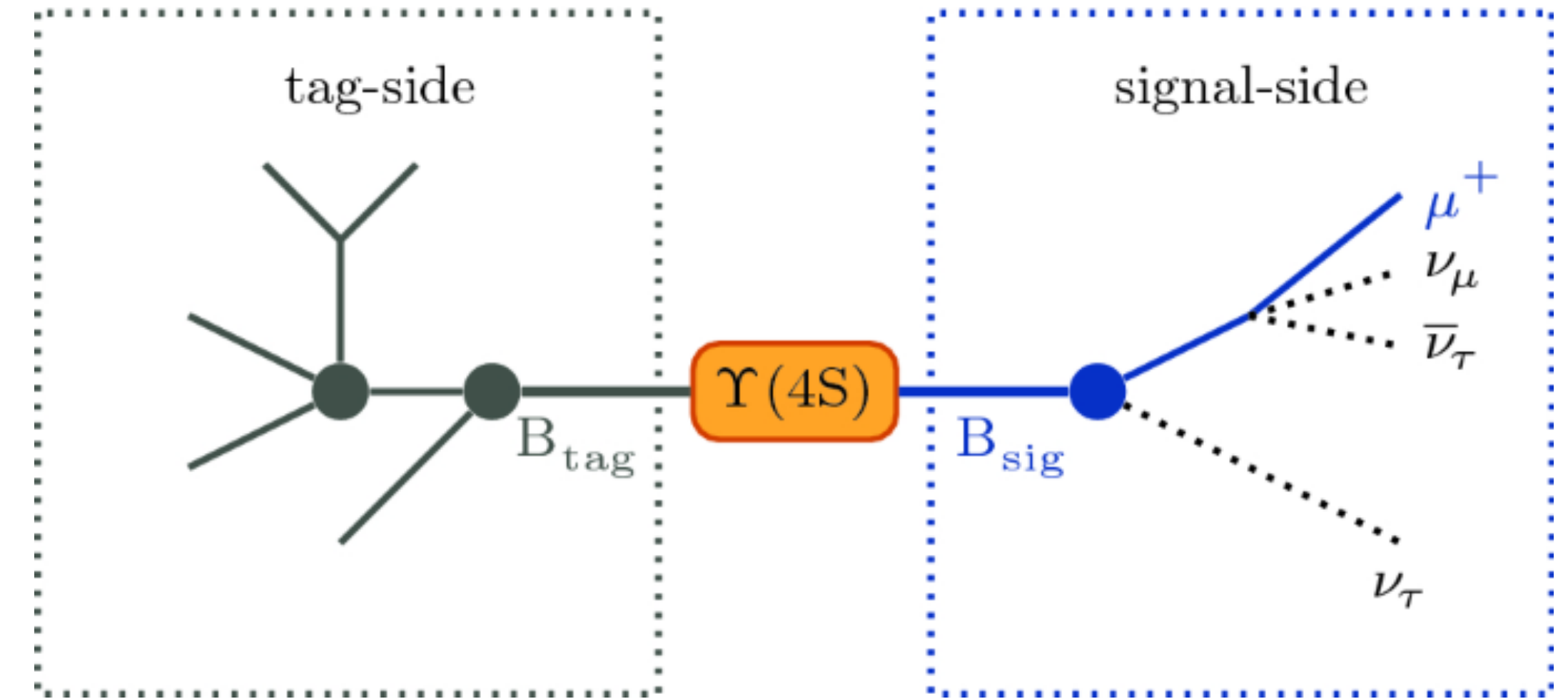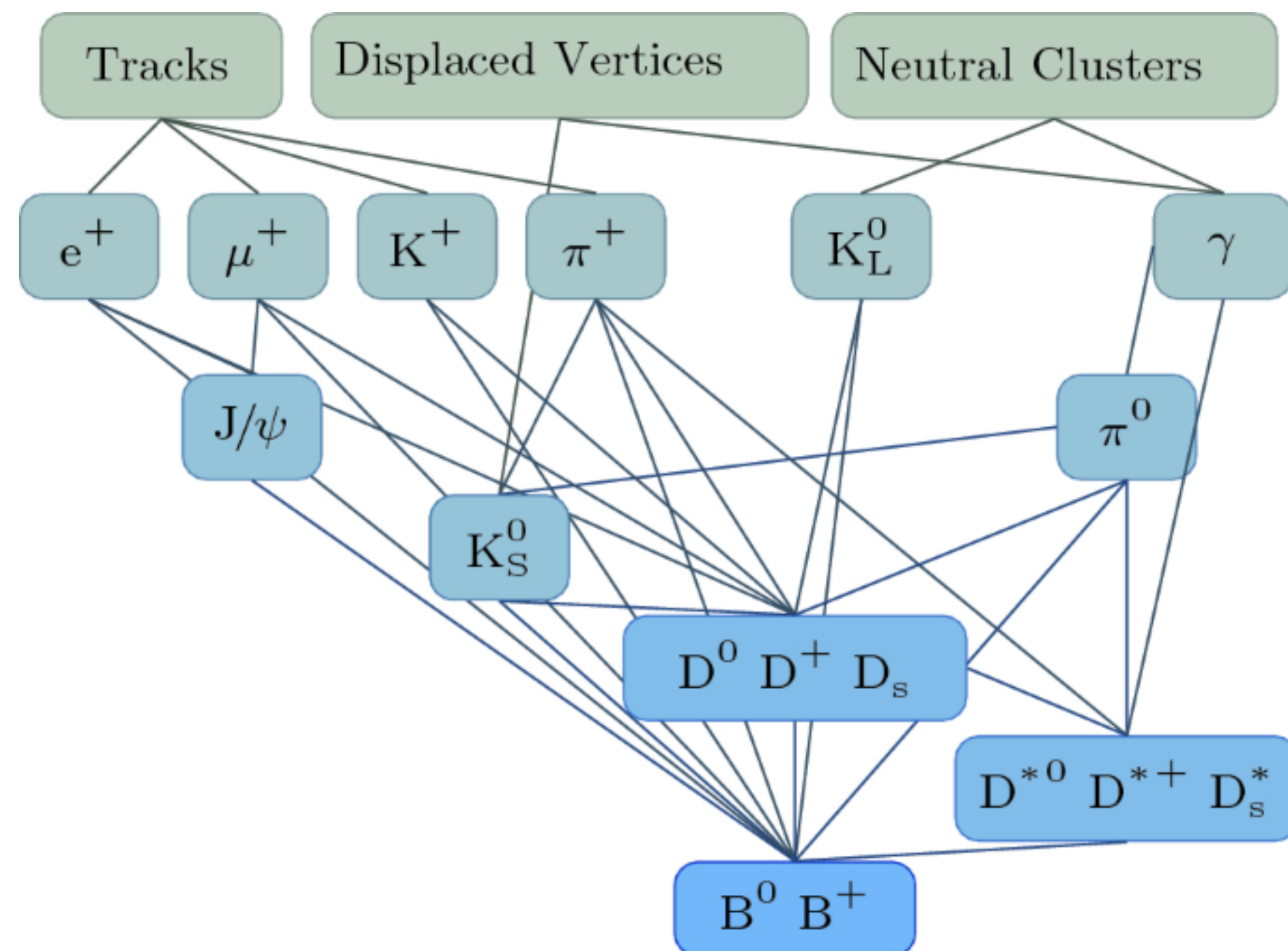# FEI Calibration study at Belle II

Niharika Rout

Motivation

- Many interesting missing energy analyses

- Relies on the tagging tools

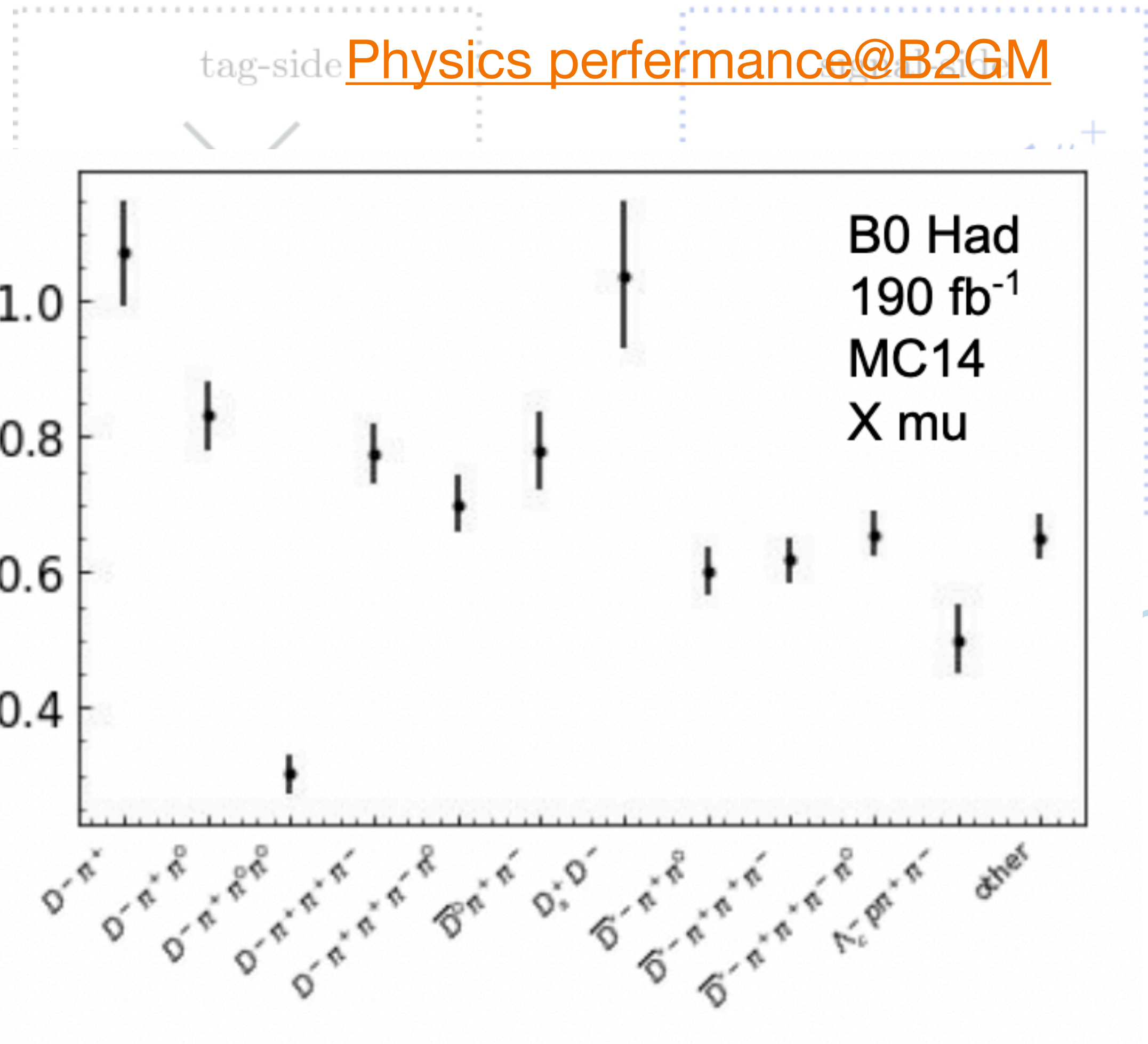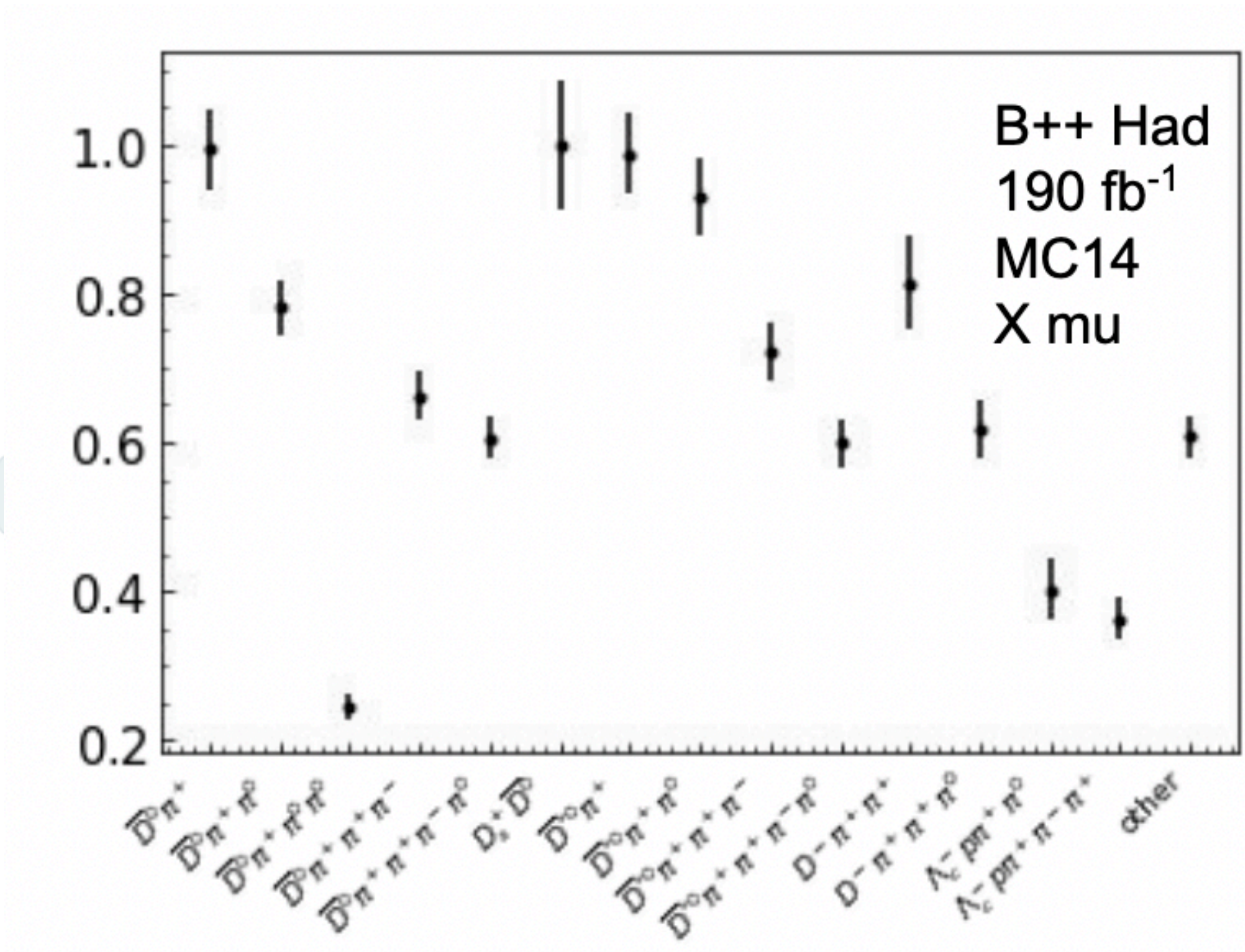- FEI: heavily used tagging tool at Belle II

Employs over 200 BDTs to reconstruct over 10000 B decay chain

Depends on MC samples for the training of the BDT

Incorrect MC description gives large FEI calibration/correction factor

Hadronic FEI

- Many interesting missing energy analyses

-

-

B++ Had
190 fb⁻¹
MC14
X mu

B0 Had
190 fb⁻¹
MC14
X mu

Incorrect MC description gives large FEI calibration factor

B^0 B^+

3

Hadronic FEI

- Many interesting missing energy analyses

- Relie

- FEI:

Limiting factor : $\epsilon_{tag} < 1\%$ **!**

over 200 BDTs to reconstruct over
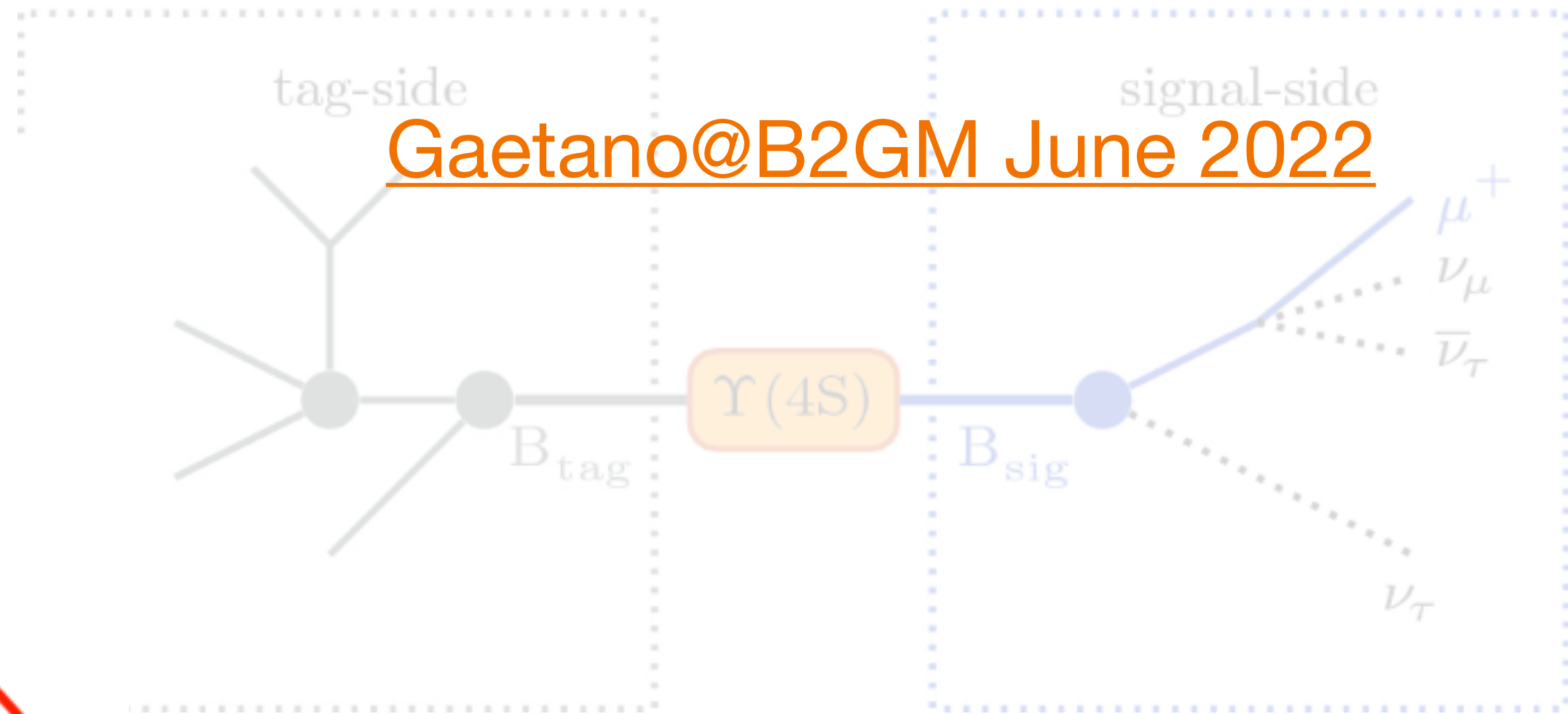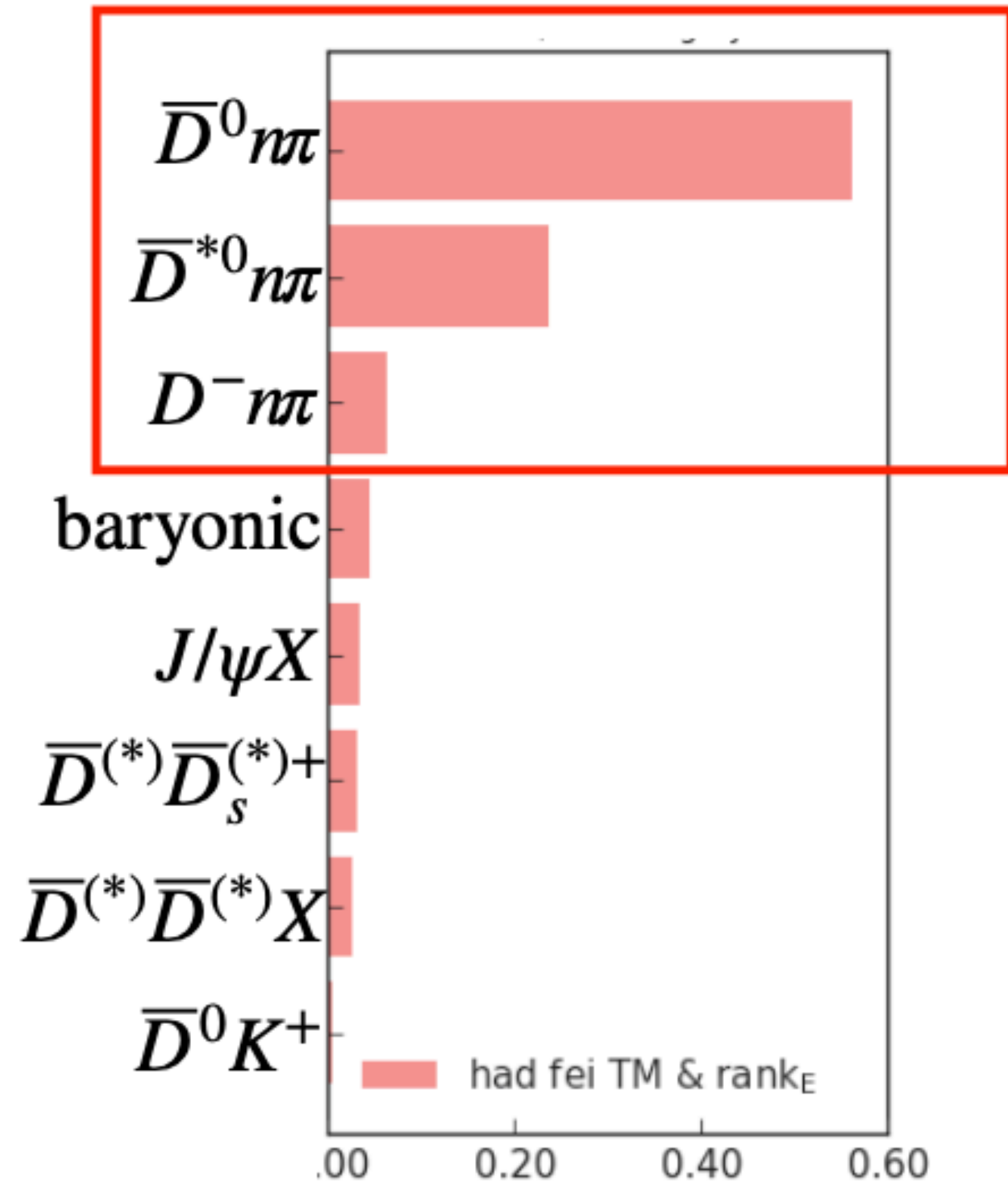
12 modes out of 36 makes 90% of the total efficiency $D^{(*)}n\pi$

on MC samples for the training of

The results shown later are based on these modes only!

4

Method

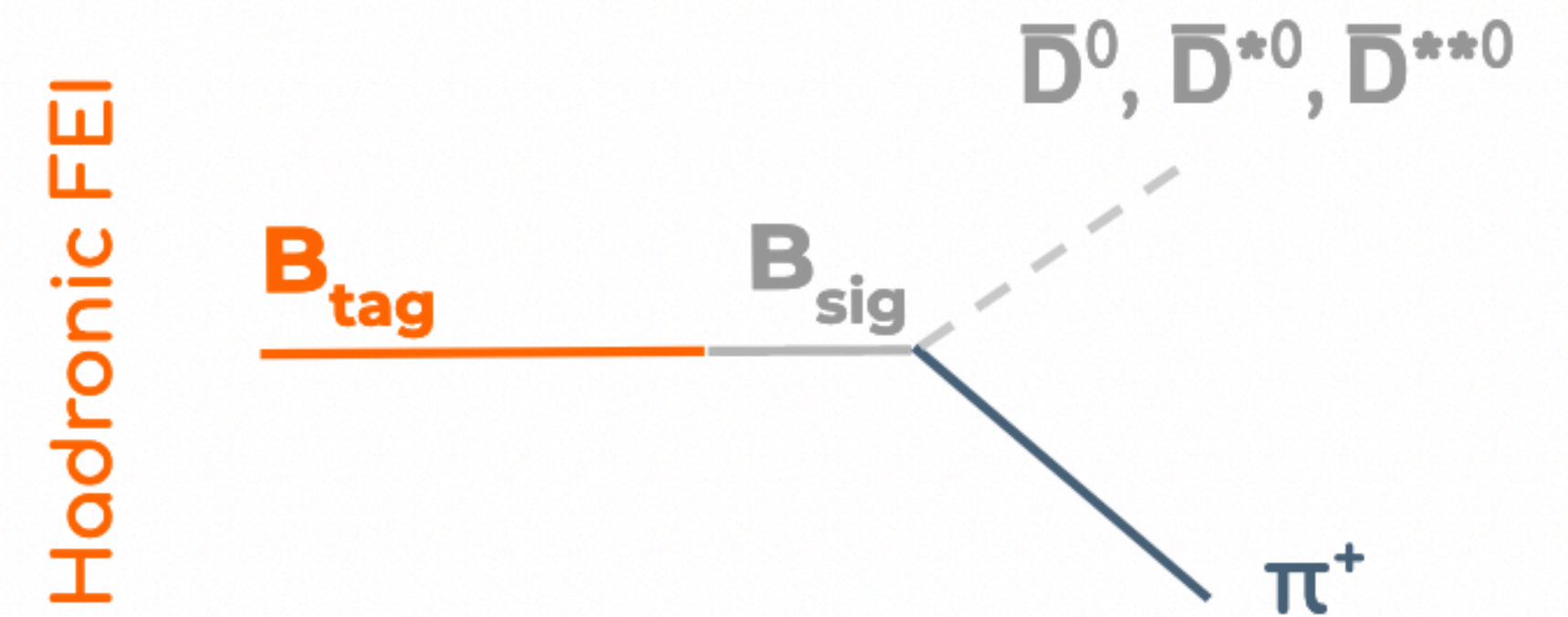Partial reconstruction for more statistics!

In CM frame of $\Upsilon(4S)$:

$$\vec{p}_{B_{sig}} = -\vec{p}_{B_{tag}}$$

$$\vec{p}_X = \vec{p}_{B_{sig}} - \vec{p}_{\pi^+}$$

$$E_X = E_{beam} - E_{\pi^+}$$

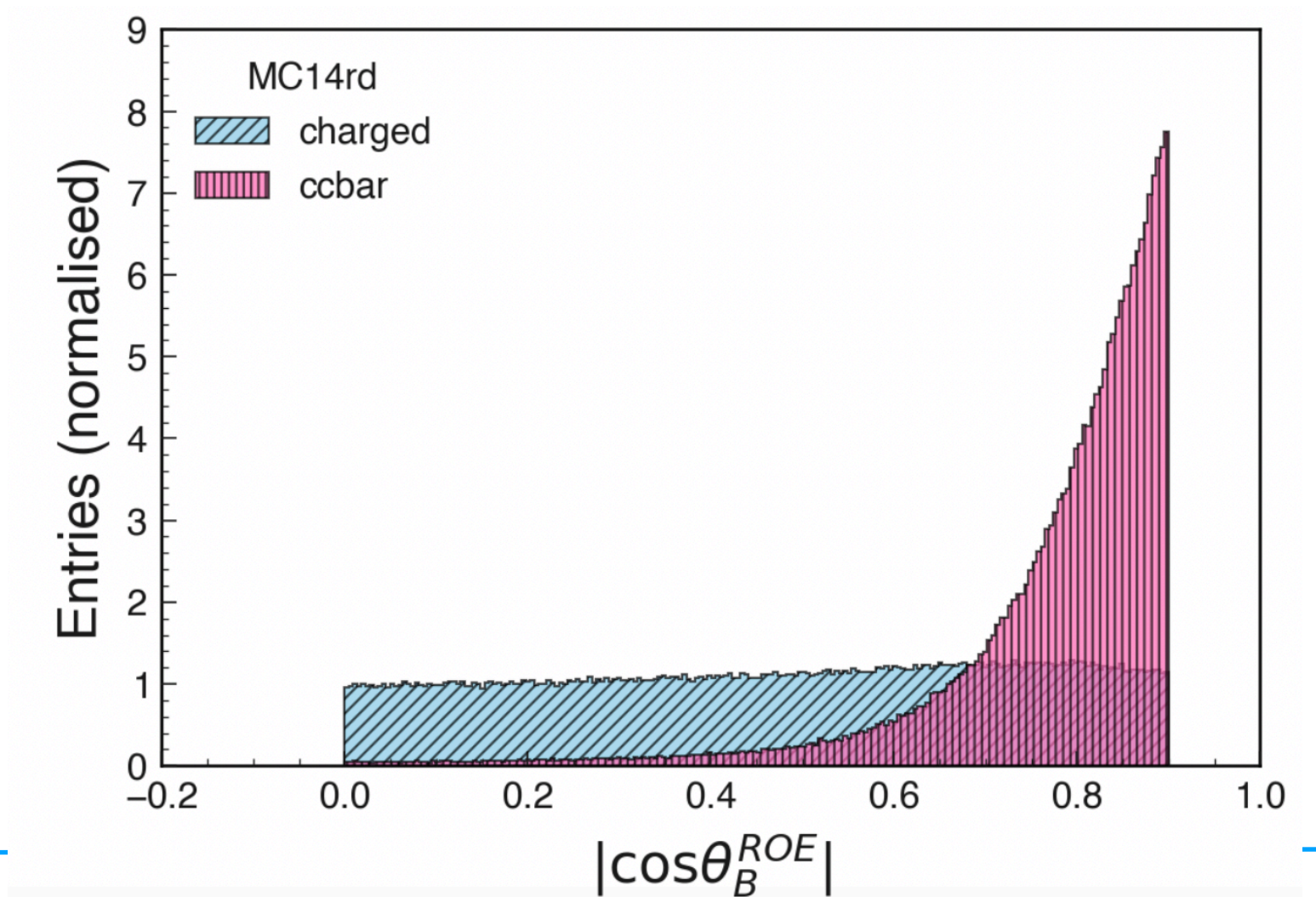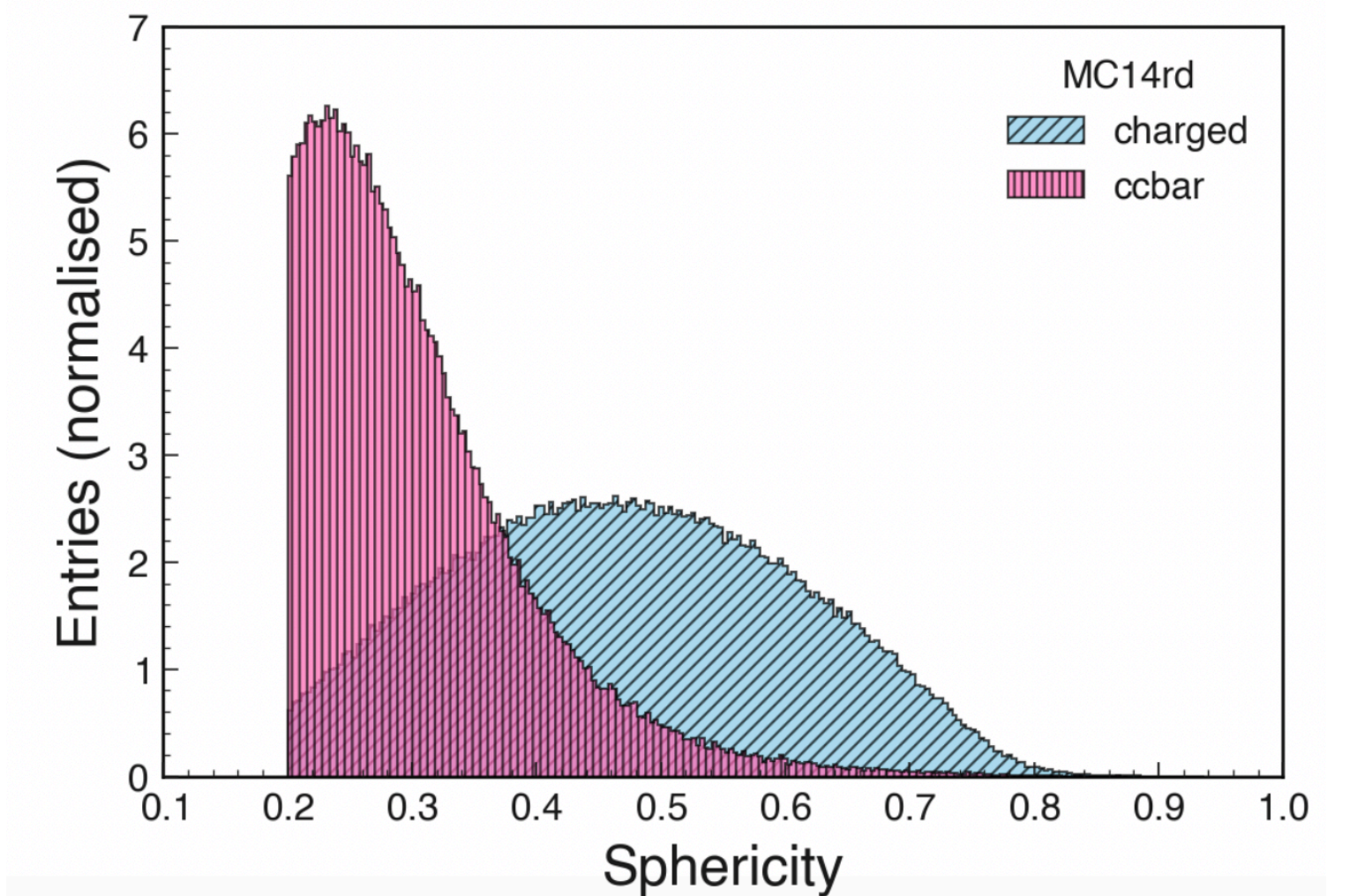$$M_{recoil} = M_X = \sqrt{E_X^2 - \vec{p}_x^2}$$

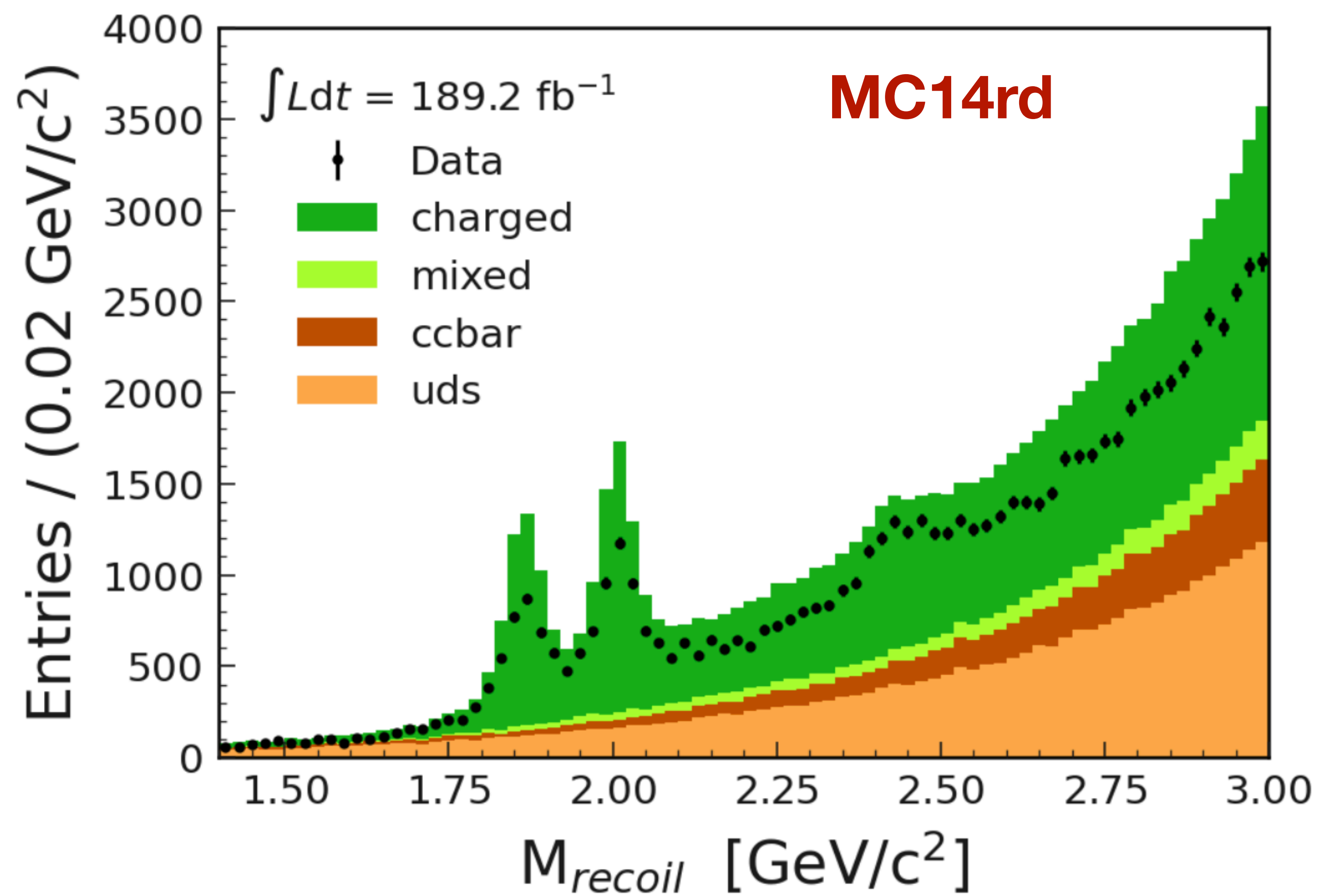We can look for D^0, D^{*0} and even D^{**0} in the recoil mass of a fully reconstructed B and a $\pi^{\pm}$

Event selection

- **Event**: sphericity > 0.2

- **Tracks**: abs(d0) < 1 and abs(z0) < 3 and thetaInCDCAcceptance

- **Kinematics**: mbc > 5.27 and abs(deltaE) < 0.05 and signalProbability > 0.001

- **Continuum suppression**: costheta < 0.9

- **π tracks**: track selection + kid < 0.9 and muid < 0.9 and eid < 0.9

- **BCS selection**: max of (pi_CMS_p) and (FEI_sig_prob)

M_{recoil}

$\int L dt = 189.2 \text{ fb}^{-1}$

MC14rd

Data
charged
mixed
ccbar
uds

Overall calibration factor obtained using this method ~ 0.65

Signal window of $D^{(*)}$

D^0

M_{recoil}	Data/MC
[1.84, 1.88]	0.64
[1.82, 1.90]	0.66
[1.80, 1.92]	0.70

D^{*0}

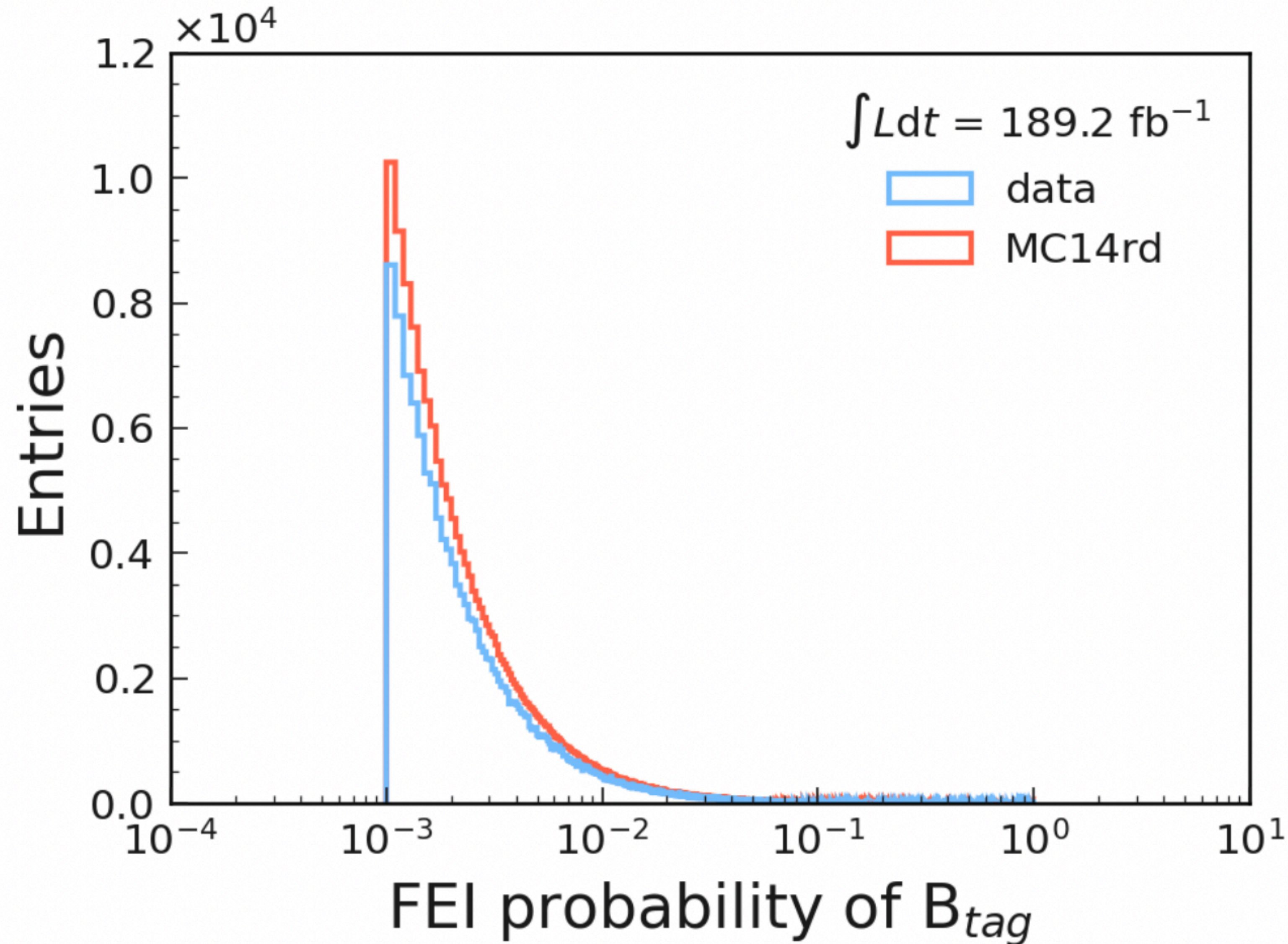| M_{recoil}	Data/MC
[1.98, 2.02]	0.66
[1.95, 2.05]	0.71
[1.92, 2.10]	0.73

FEI: mode by mode
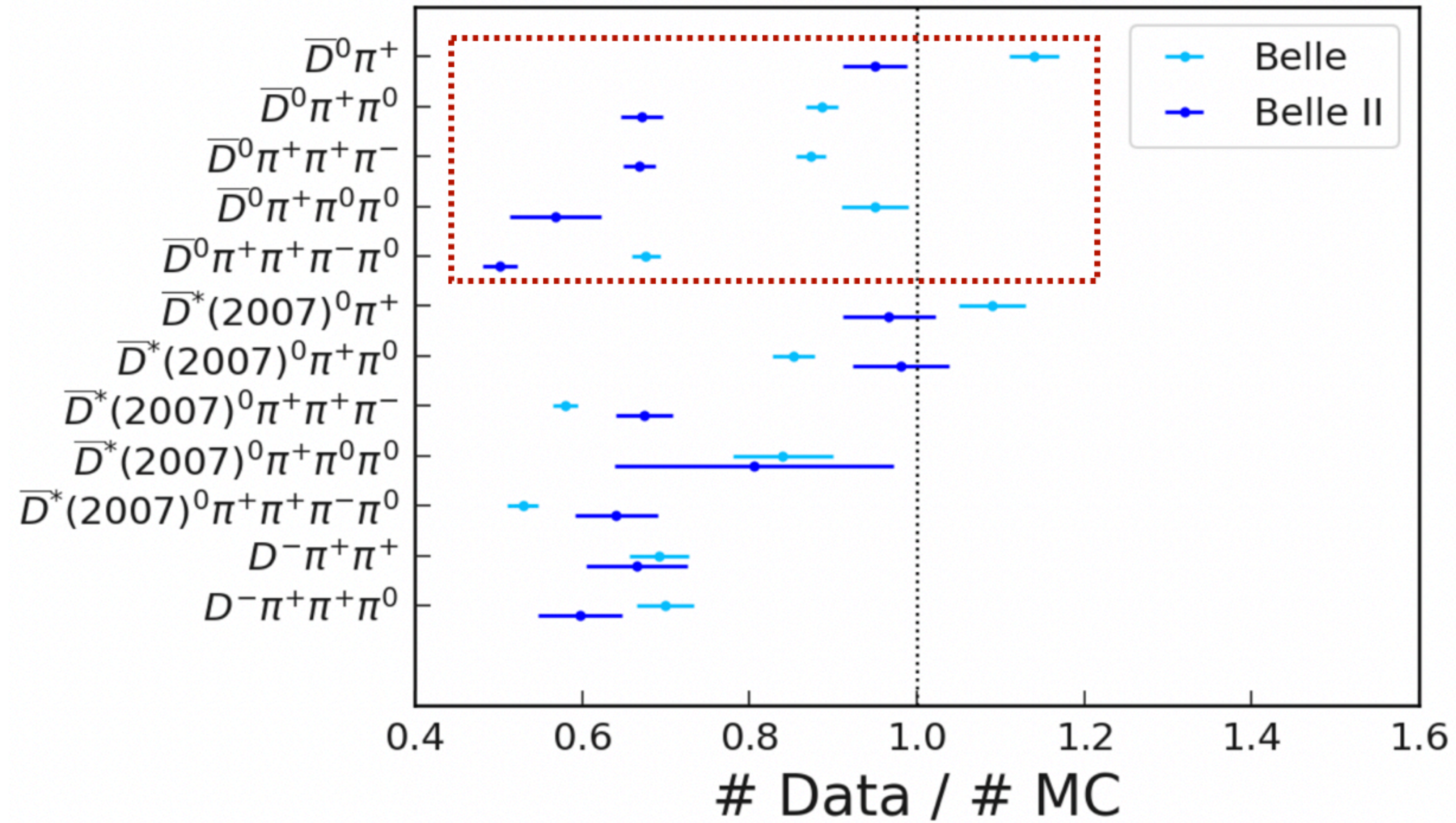
- Belle calibration factor is ~ 0.8

- **Belle II: 0.65; why so low at Belle II?**

- Most of the differences are in $D^0 n\pi$ channels

Further investigations
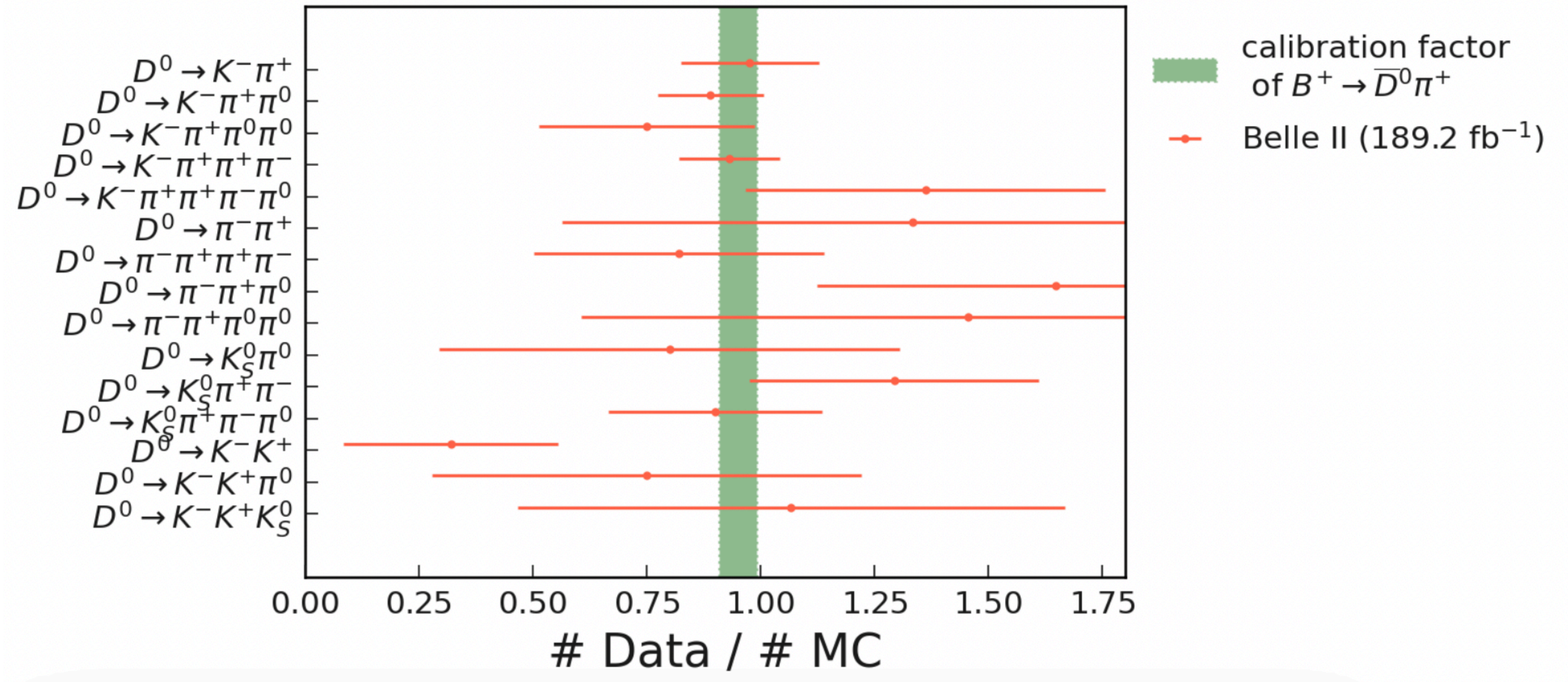
Looked at calibration factors at D-level; nothing suspicious!

Further investigations

- FEI probability is used in the BCS selection along with pion momentum
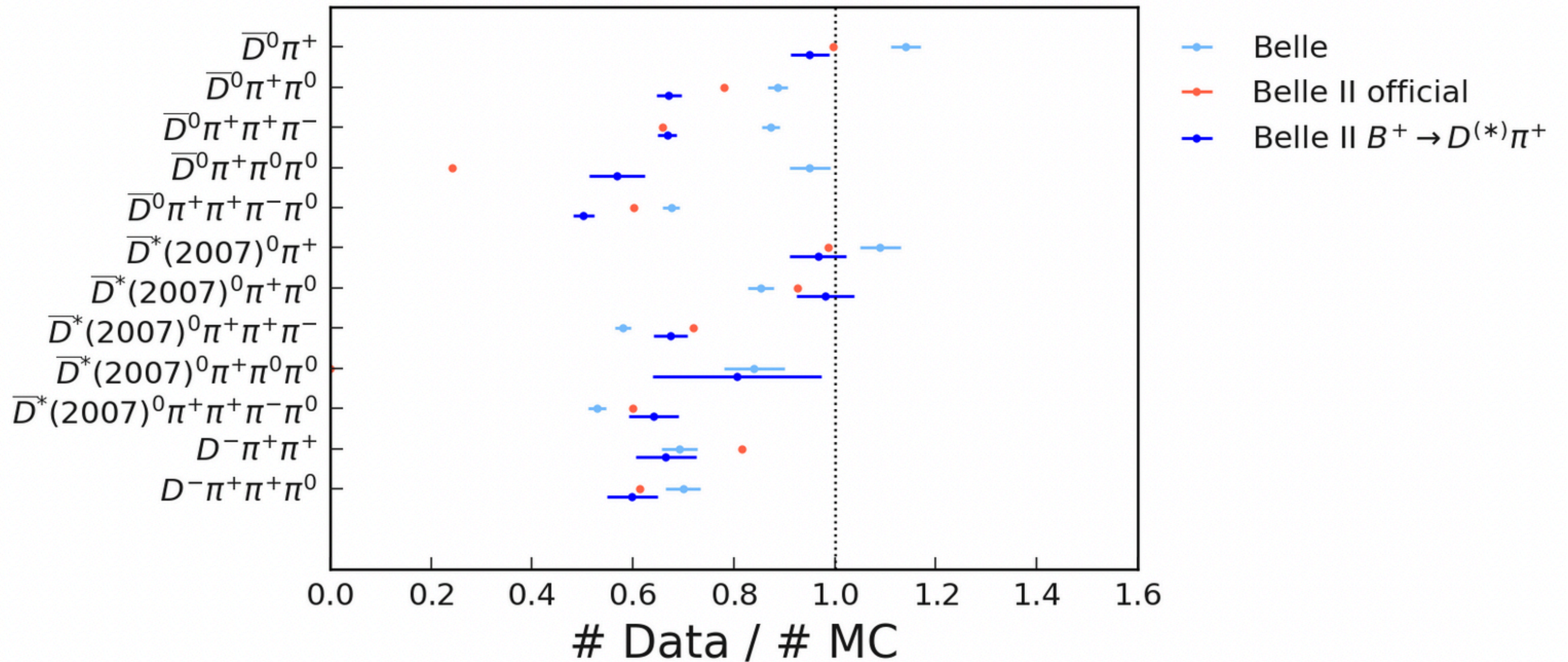
- Data-MC comparison looks fine

Branching ratio check

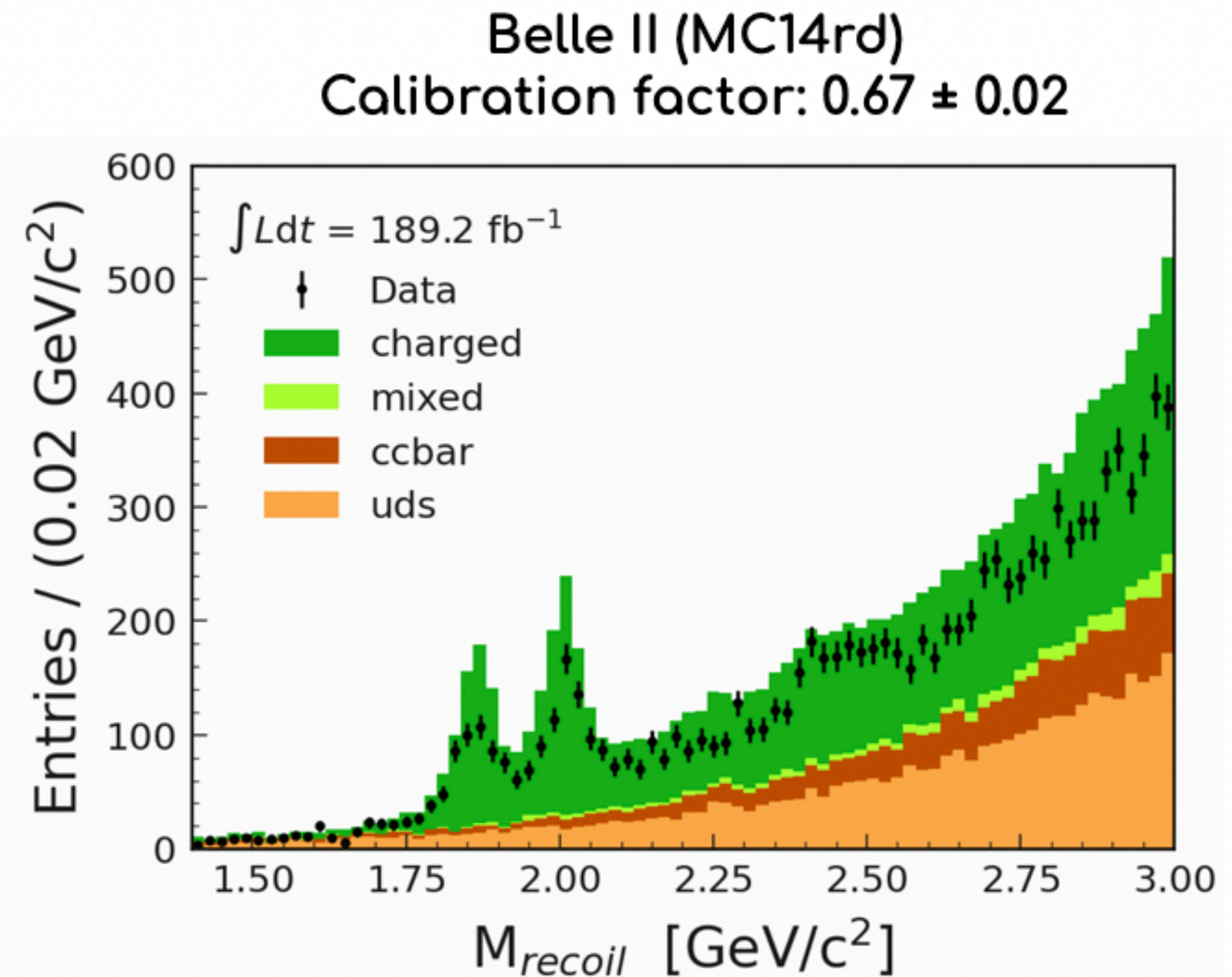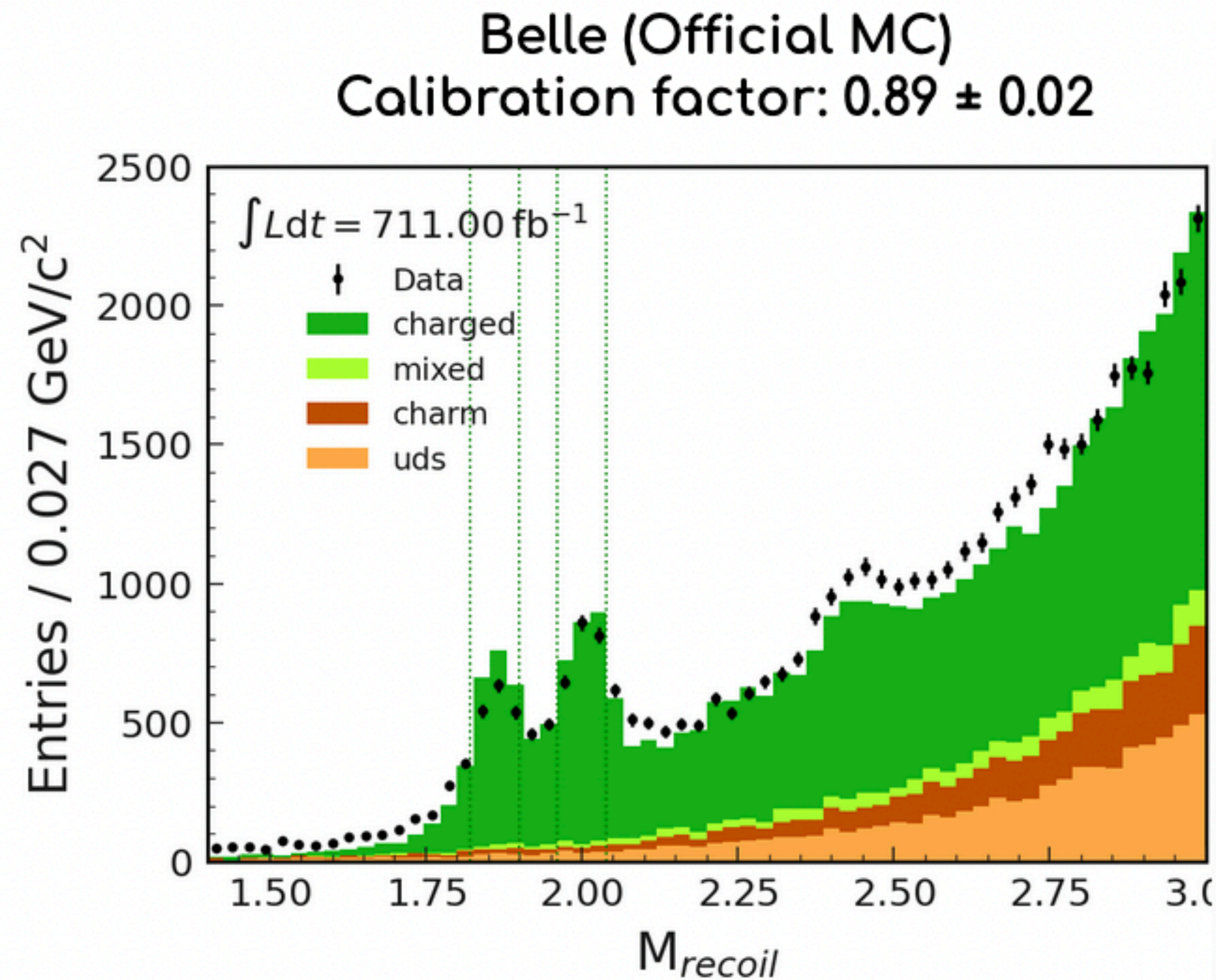| Mode	Belle (%)	Belle II (%)
$D\pi\pi^0$	1.76	1.74
$D\pi\pi^0\pi^0$	1.69	1.56
$D\pi\pi\pi$	1.12	1.38
$D\pi\pi\pi\pi^0$	3.54	3.42

- The difference in the calibration factor for $D\pi\pi\pi$ makes sense (~30% difference in BR between Belle and Belle II)

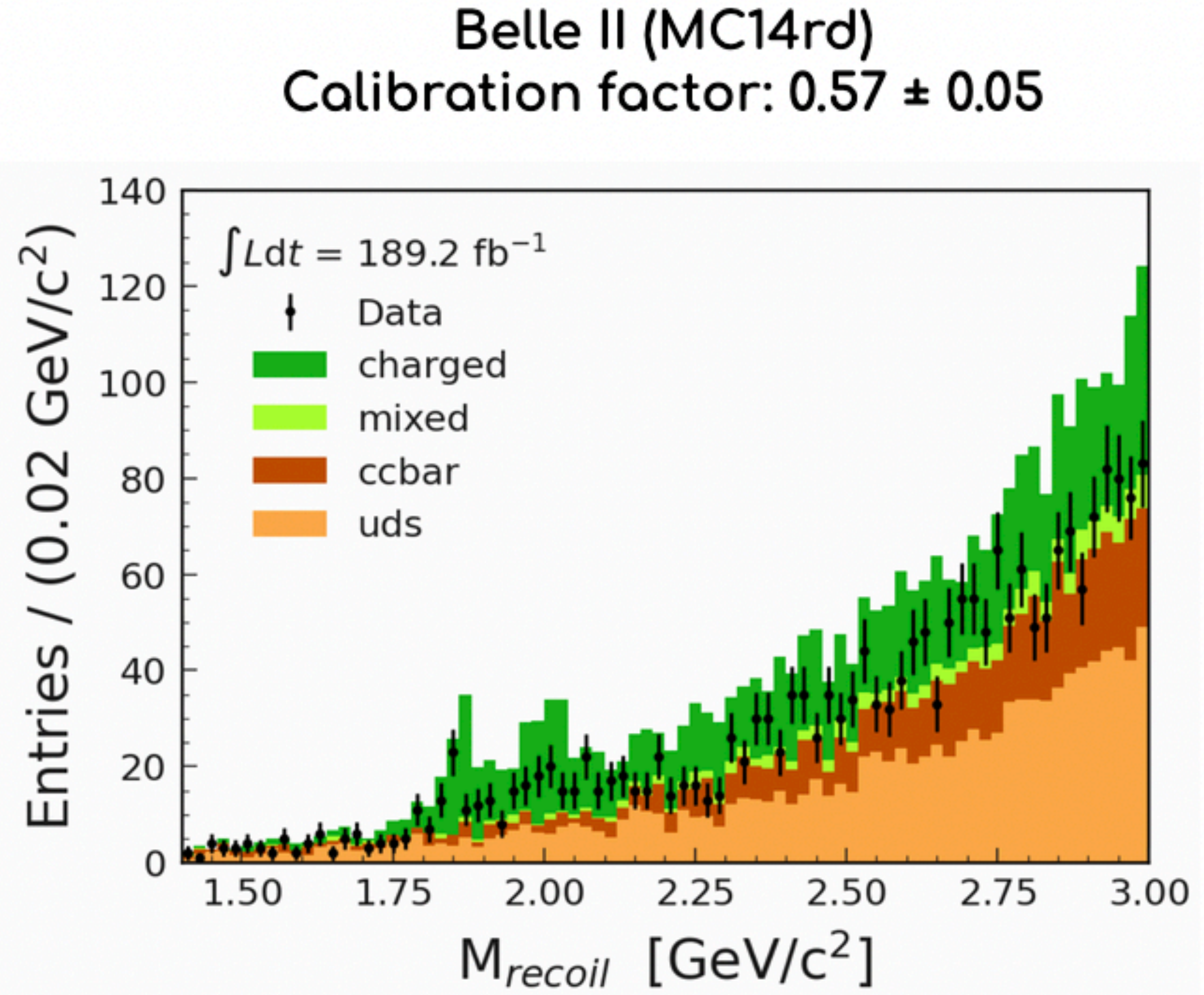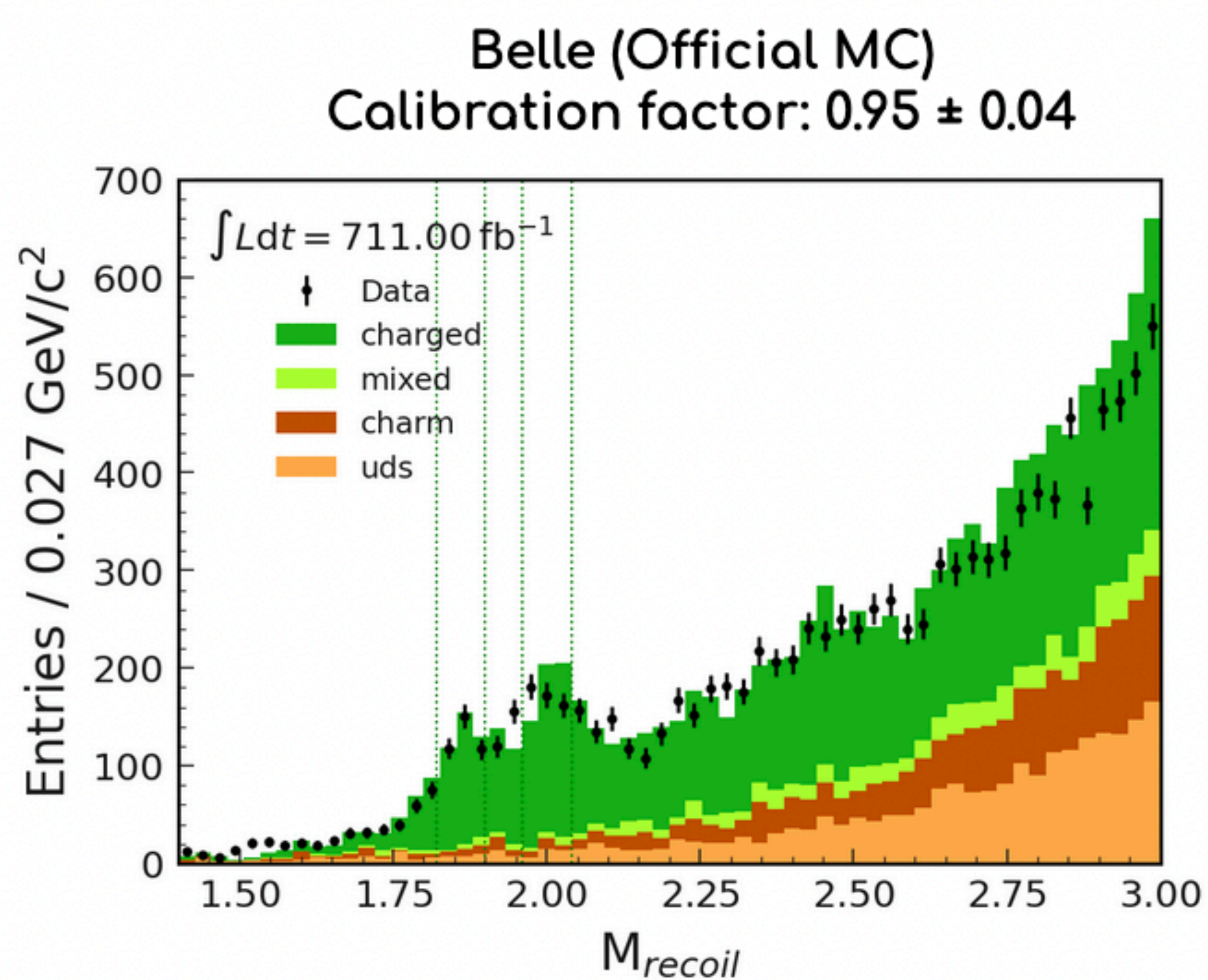- Need to study other 3 modes!

Comparison with official values

Comparison with Belle: M_{recoil}

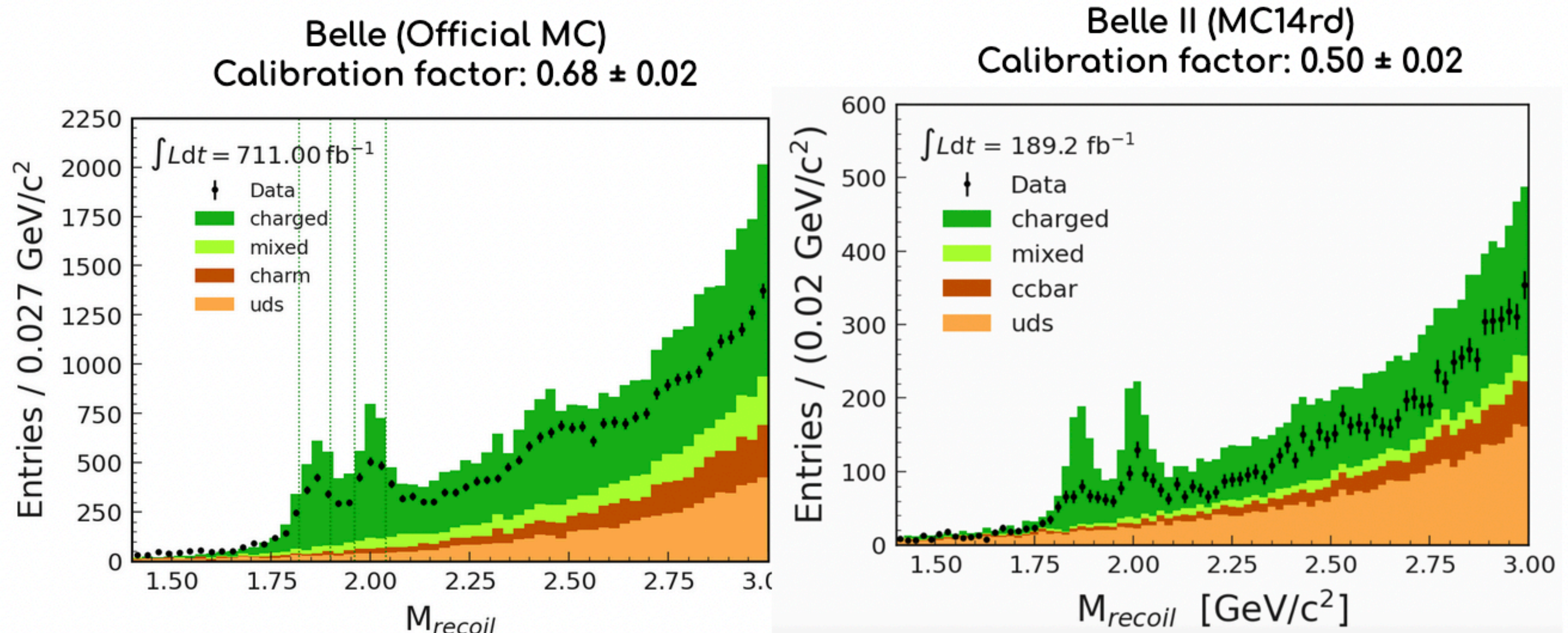# FEI mode: $B^+ \rightarrow \overline{D}^0 \pi^+ \pi^0$

- Resolution is better at Belle II

- uds background level is very high!

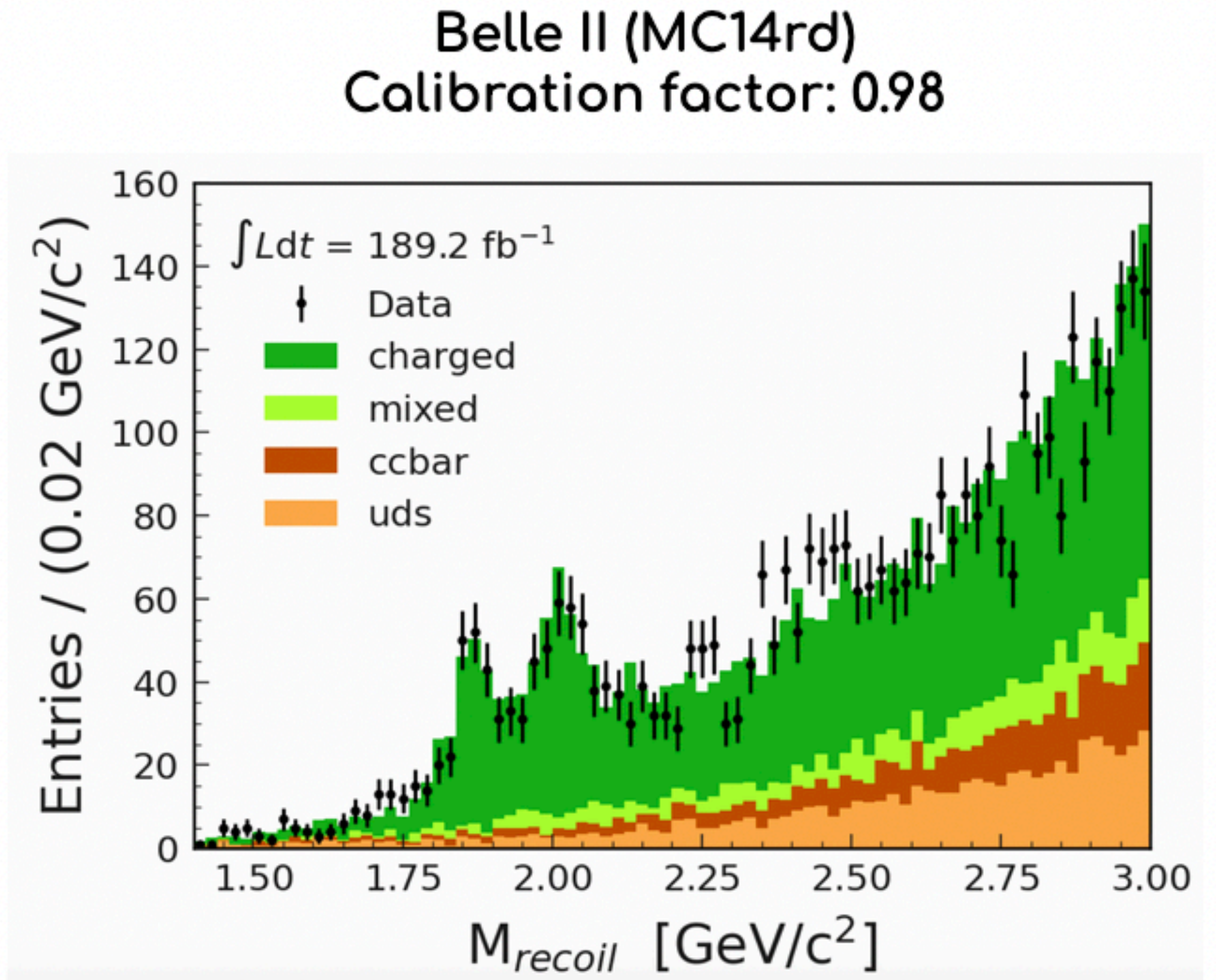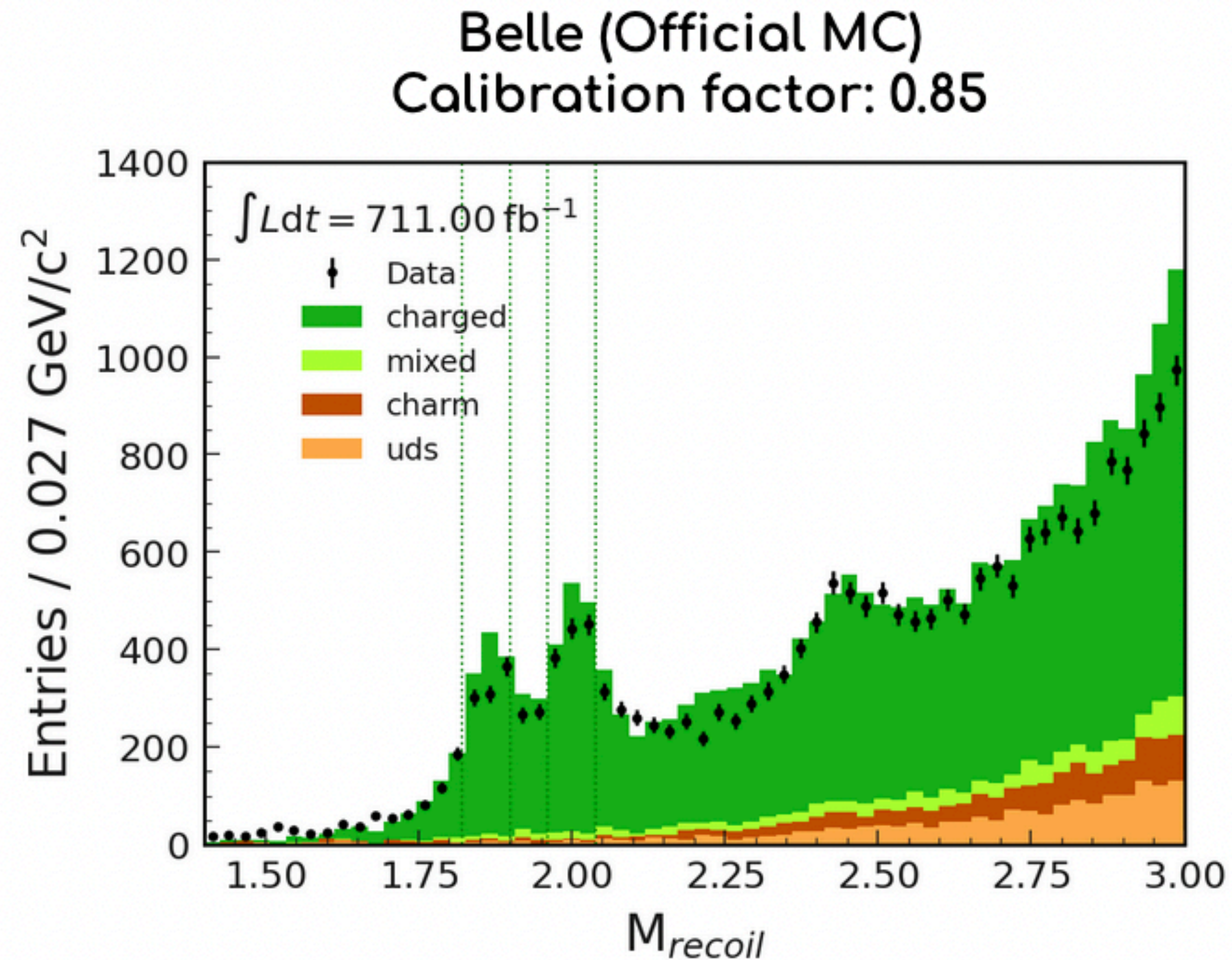# FEI mode: $B^+ \to \overline{D}^0 \pi^+ \pi^0 \pi^0$

- Low statistics!

- uds background level is very high!

FEI mode: $B^+ \to \overline{D}^0 \pi^+ \pi^- \pi^+ \pi^0$

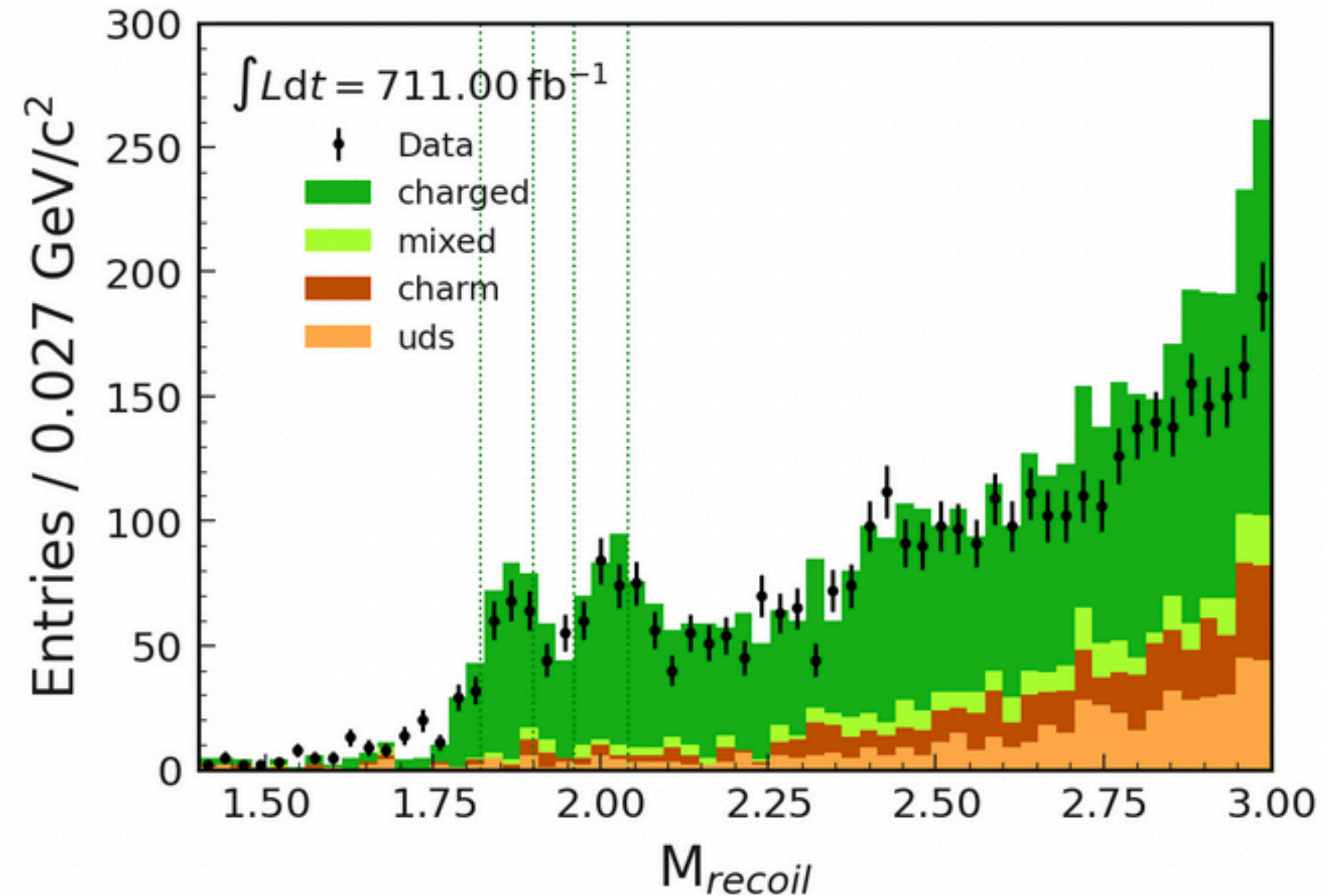- Resolution is better at Belle II

- uds background level is very high!
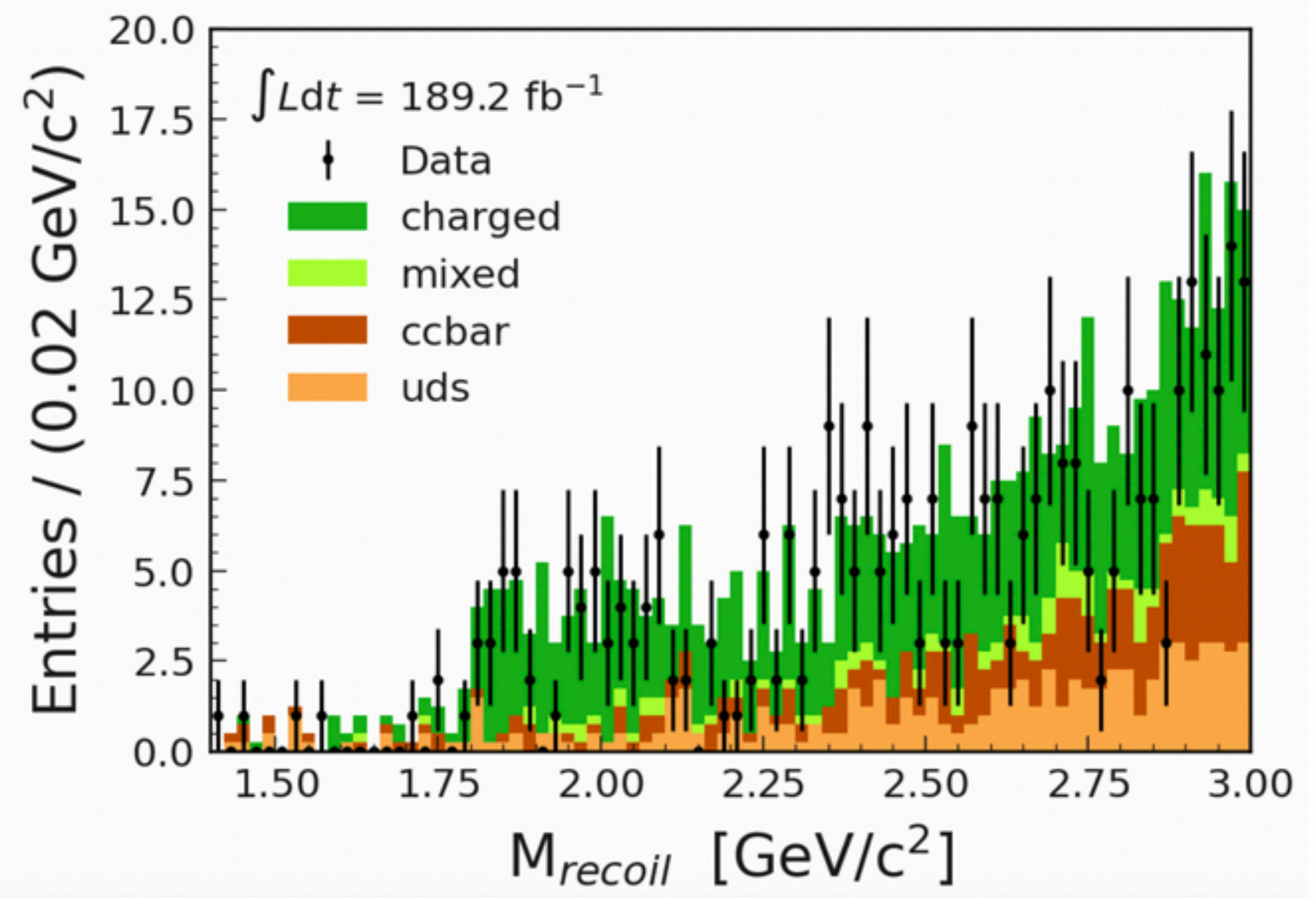
FEI mode: $B^+ \to \overline{D}^{*0}\pi^+\pi^0$

- Resolution is better at Belle II

- Background level is low as compared to D modes

FEI mode: $B^+ \to \overline{D}^{*0}\pi^+\pi^0\pi^0$
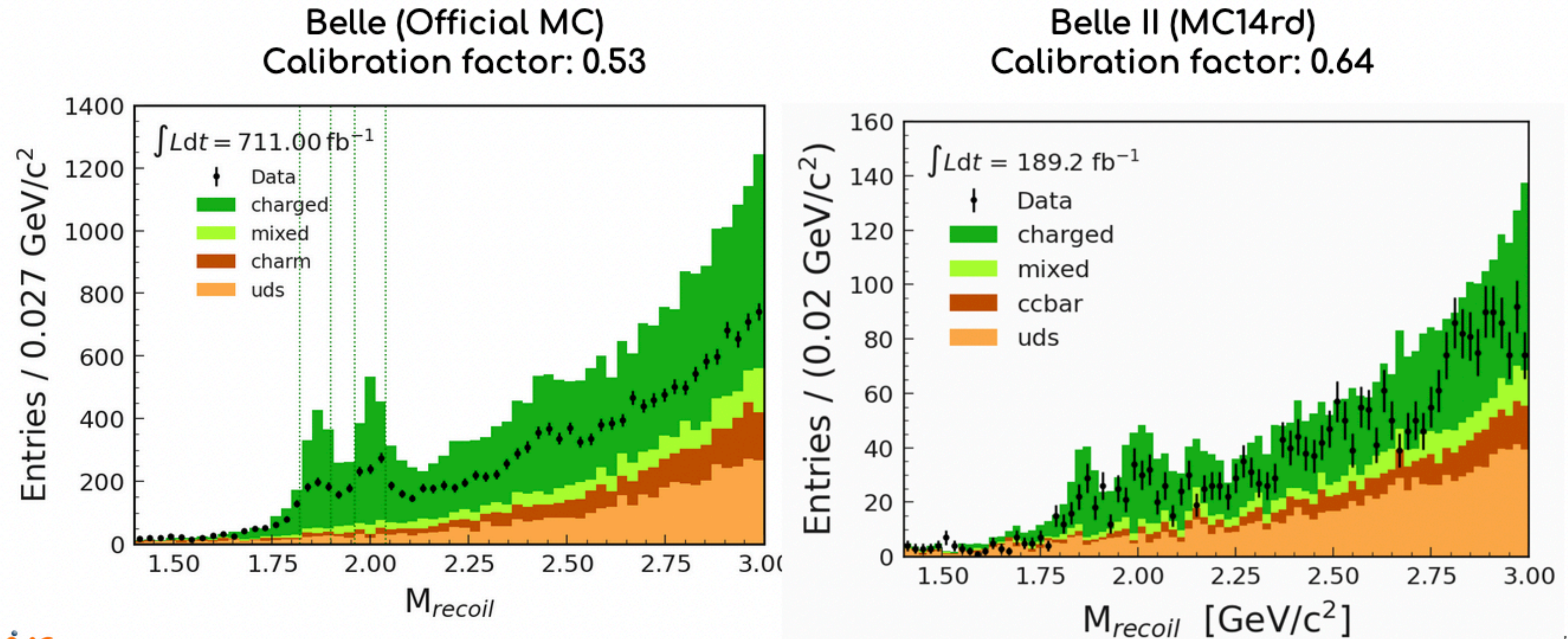

Belle (Official MC)
Calibration factor: 0.84

Belle II (MC14rd)
Calibration factor: 0.81

- Low statistics: no conclusion!

FEI mode: $B^+ \to \overline{D}^{*0}\pi^+\pi^-\pi^+\pi^0$

Belle (Official MC)
Calibration factor: 0.53

Belle II (MC14rd)
Calibration factor: 0.64
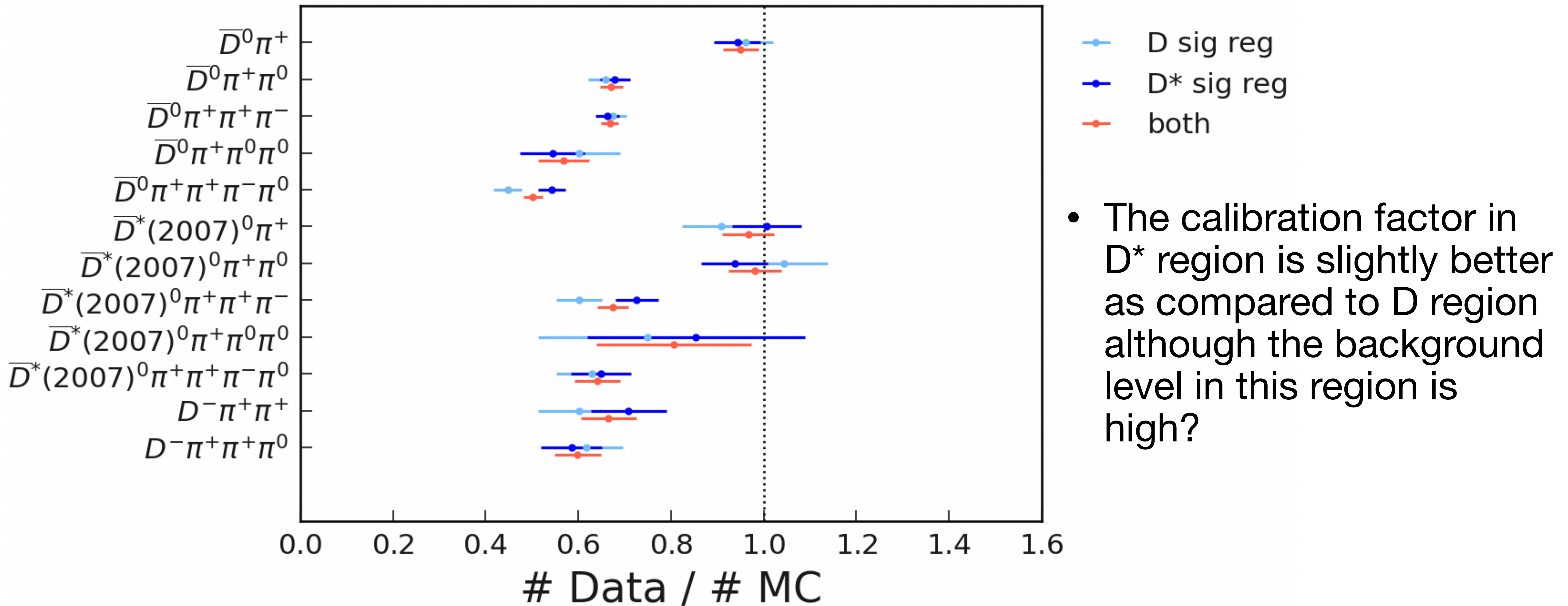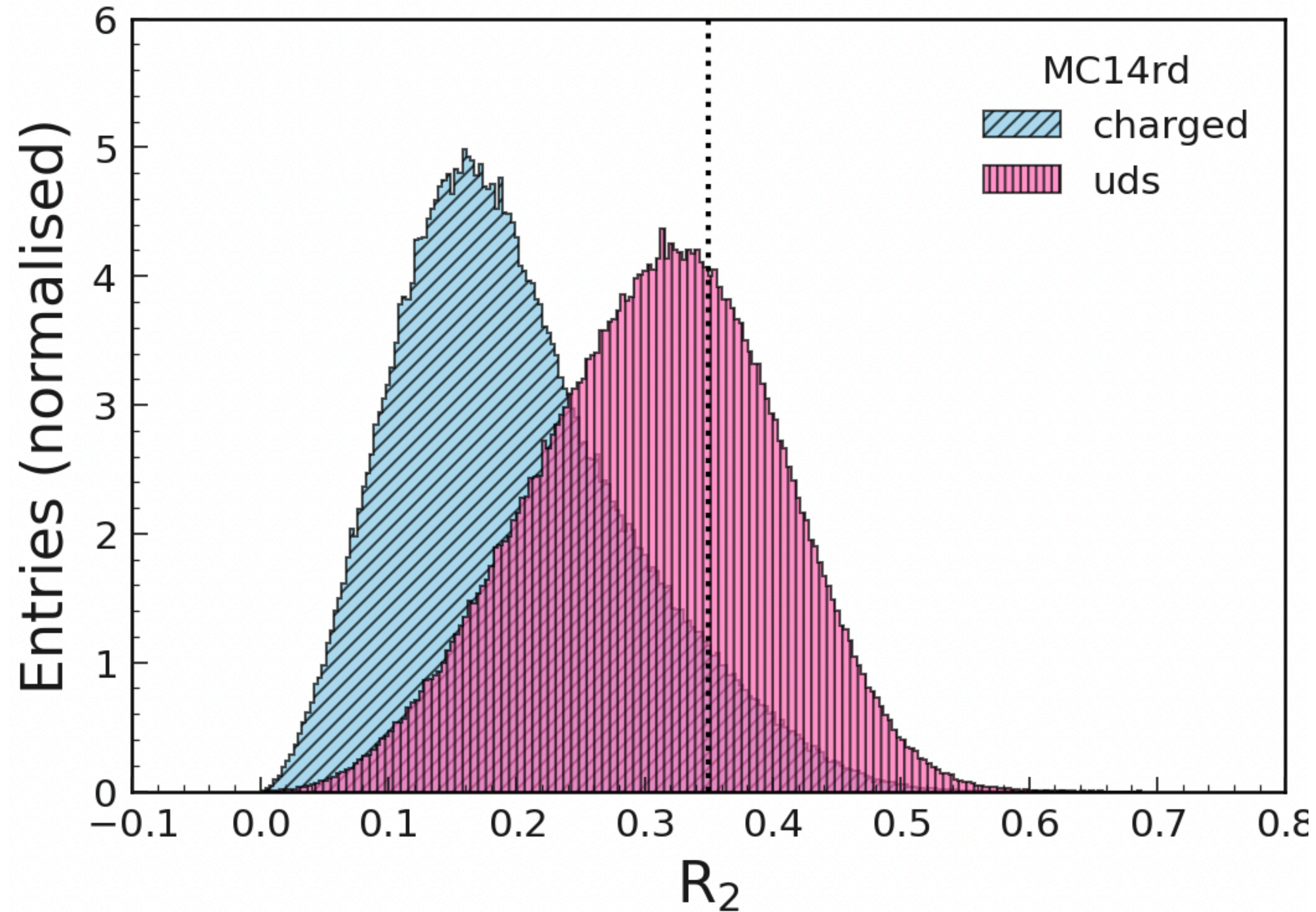
- High multiplicity mode

- Background level is low as compared to D modes, but still high

Check in different signal region of D and D*

- The calibration factor in D* region is slightly better as compared to D region although the background level in this region is high?

Further optimisation of continuum at Belle II

R2 < 0.35

Further optimisation of continuum at Belle II

$\int L\ dt = 189.2\ fb^{-1}$

— without R2 cut

— with R2 cut
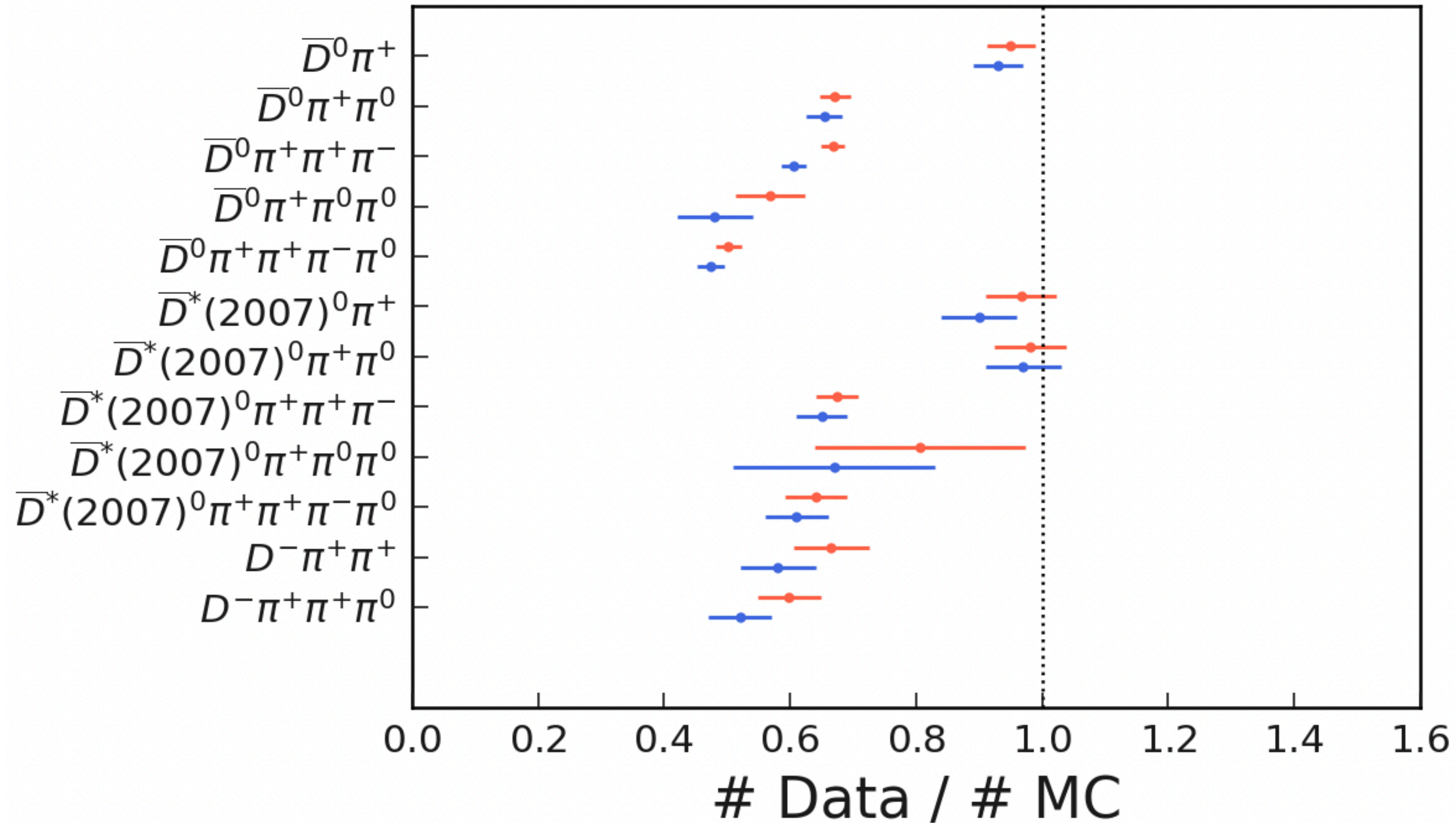
- With R2 selection the factors get worse!

- Any suggestion what to check next?

Study with new MC

New MC

- The changes are made only to the charged MC

- The changes are taken from the <u>BELLE2-NOTE-PH-2022-002</u> [<u>Vidya sagar @ BHadronicMeeting</u>]

- Generated signal MC of $B \to D\pi$ and $B \to D^{*0}\pi$: one side decays to signal and other side decays generically (new MC)

- The number of events generated are equivalent to luminosity of the MC14rd MC used for studying (753.64 fb-1) times the BR of the decay.

  - $B \to D\pi$: 3542108 events

  - $B \to D^{*0}\pi$: 3692836 events
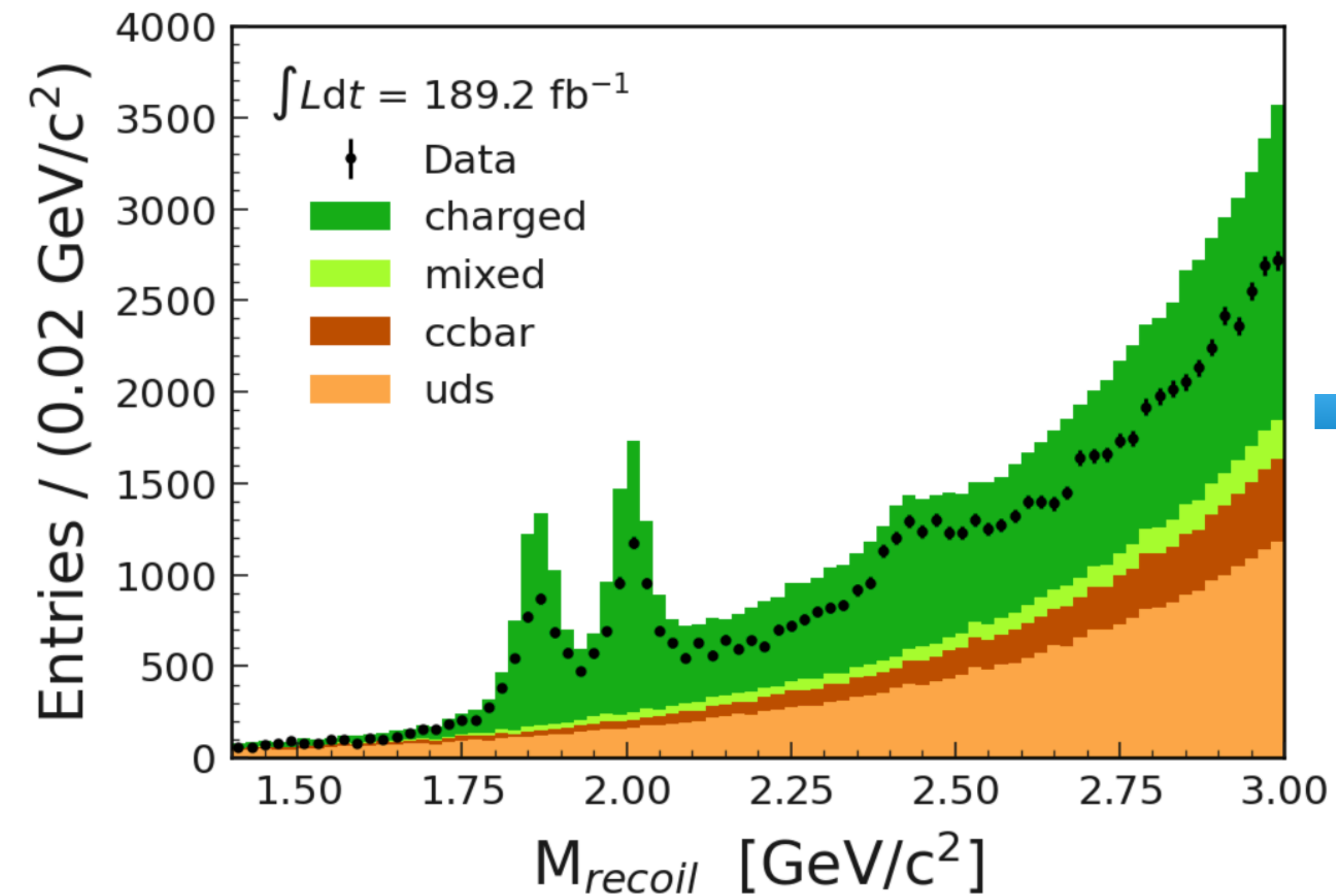
$\mathrm{M_{recoil}}$ in signal MC

- Removed events: combinations of one side $D^{(*0)}\pi$ and other side $D^{(*0)}\pi$

- Kept these events as it is in the generic MC as no there is no corrections applied to the BRs of these final states
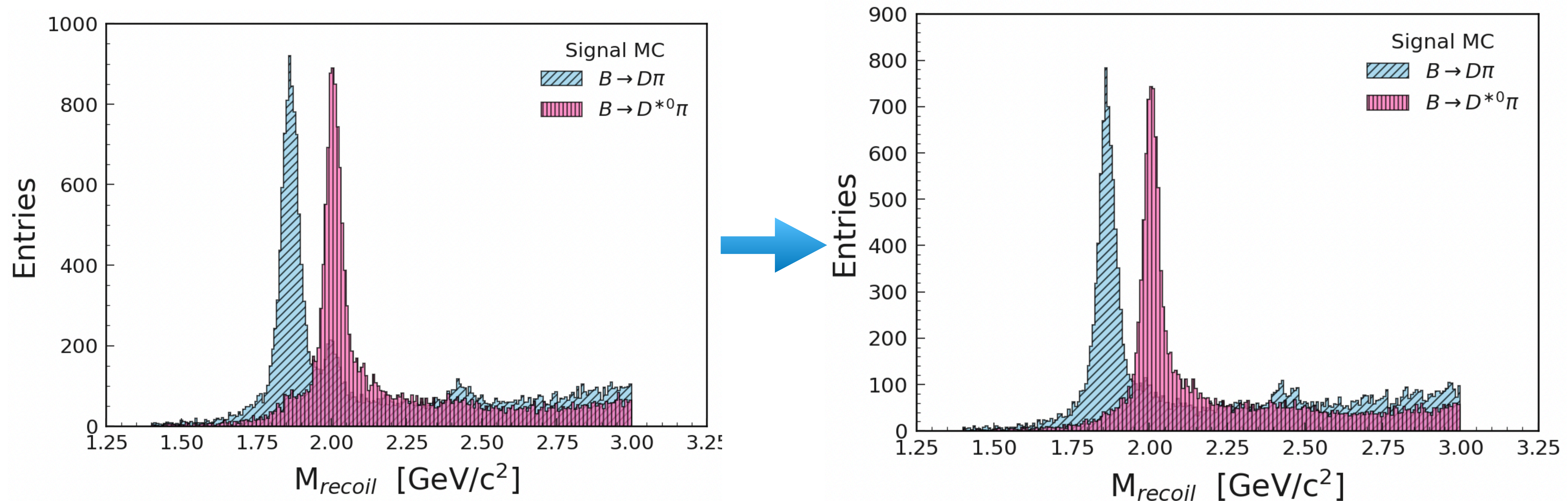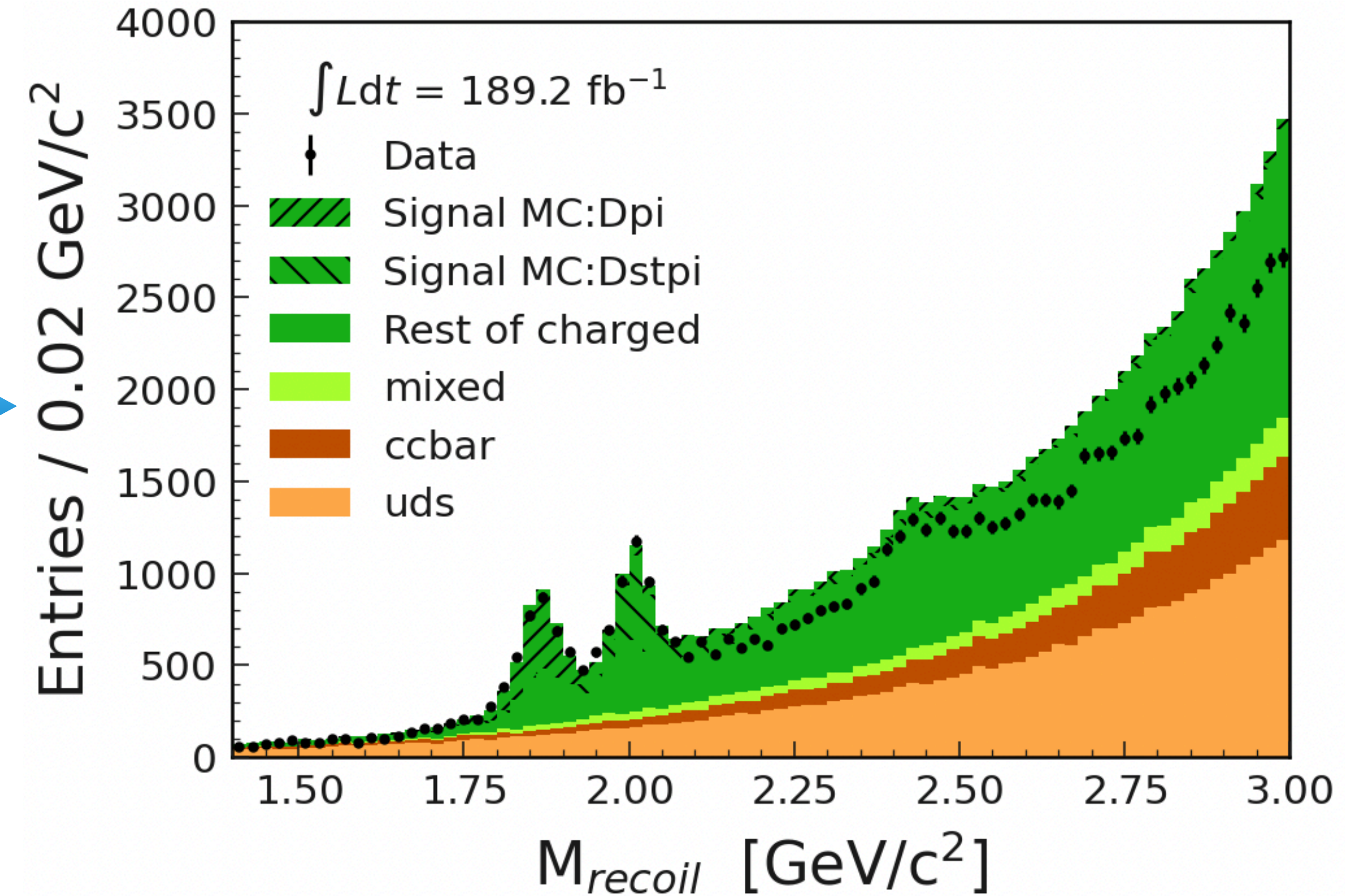
M_{recoil}

- Removed $D\pi$ and $D^{*0}\pi$ events from MC14rd sample and embedded events from signal MC sample
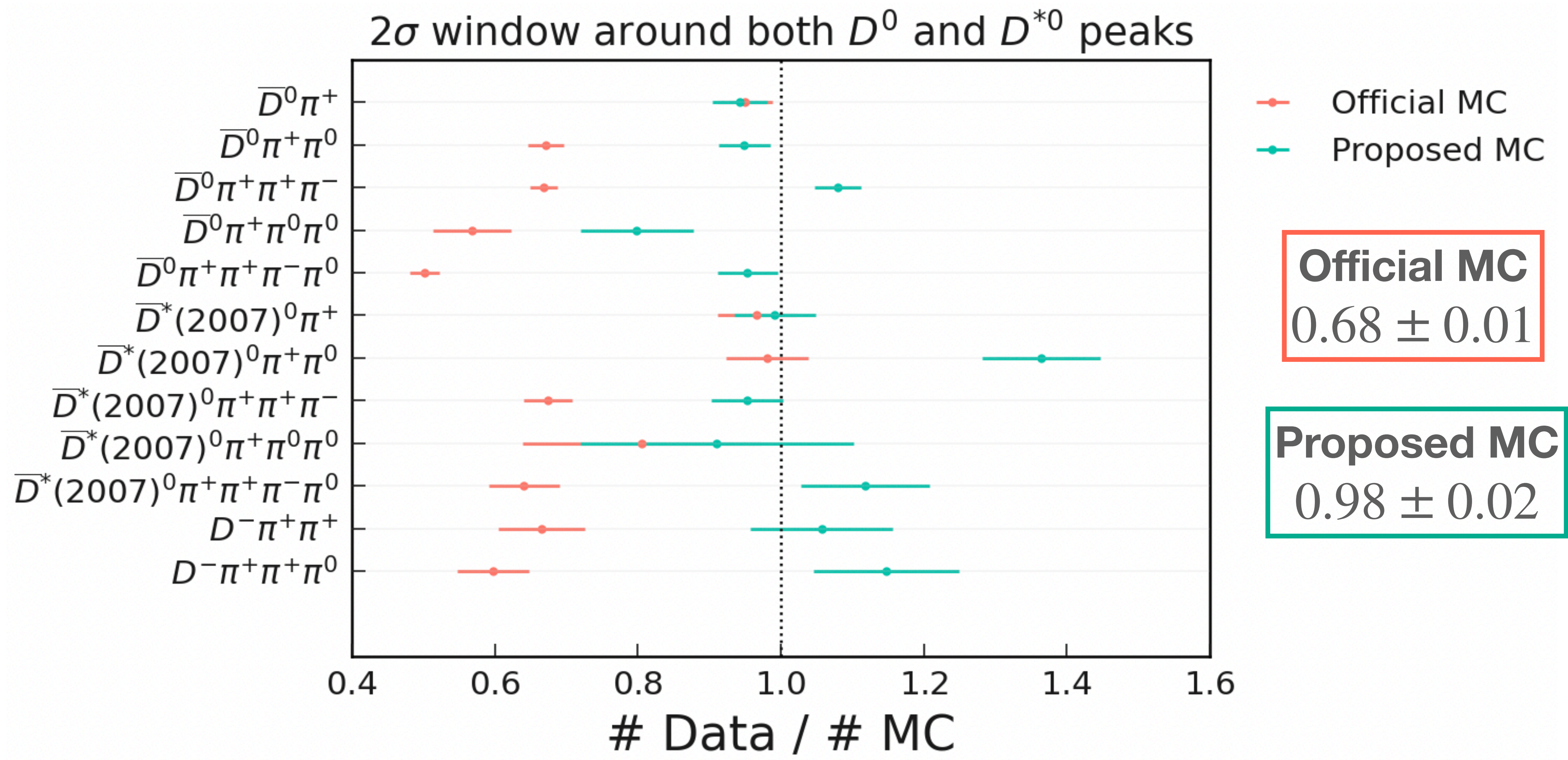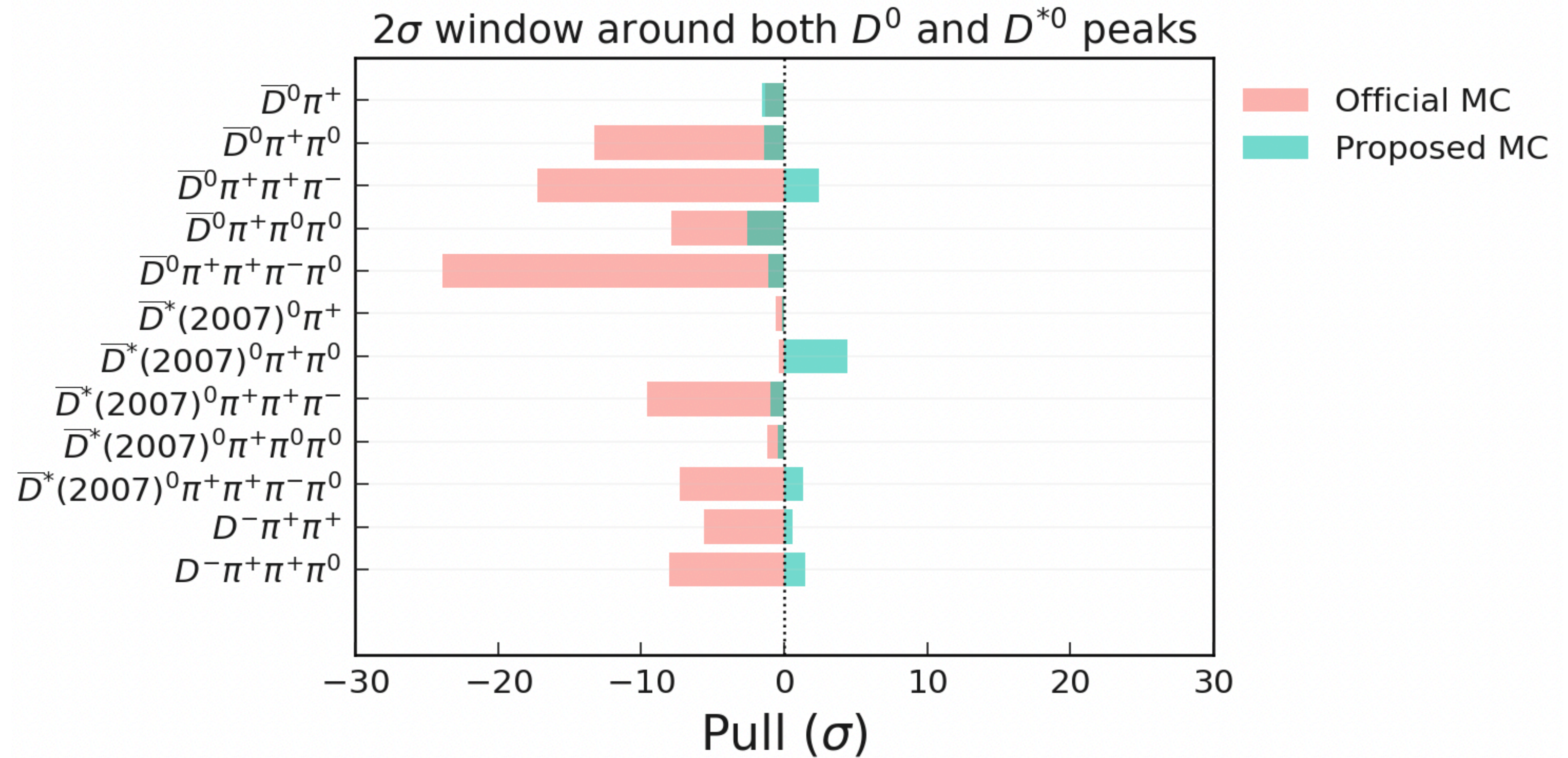
Calibration factors
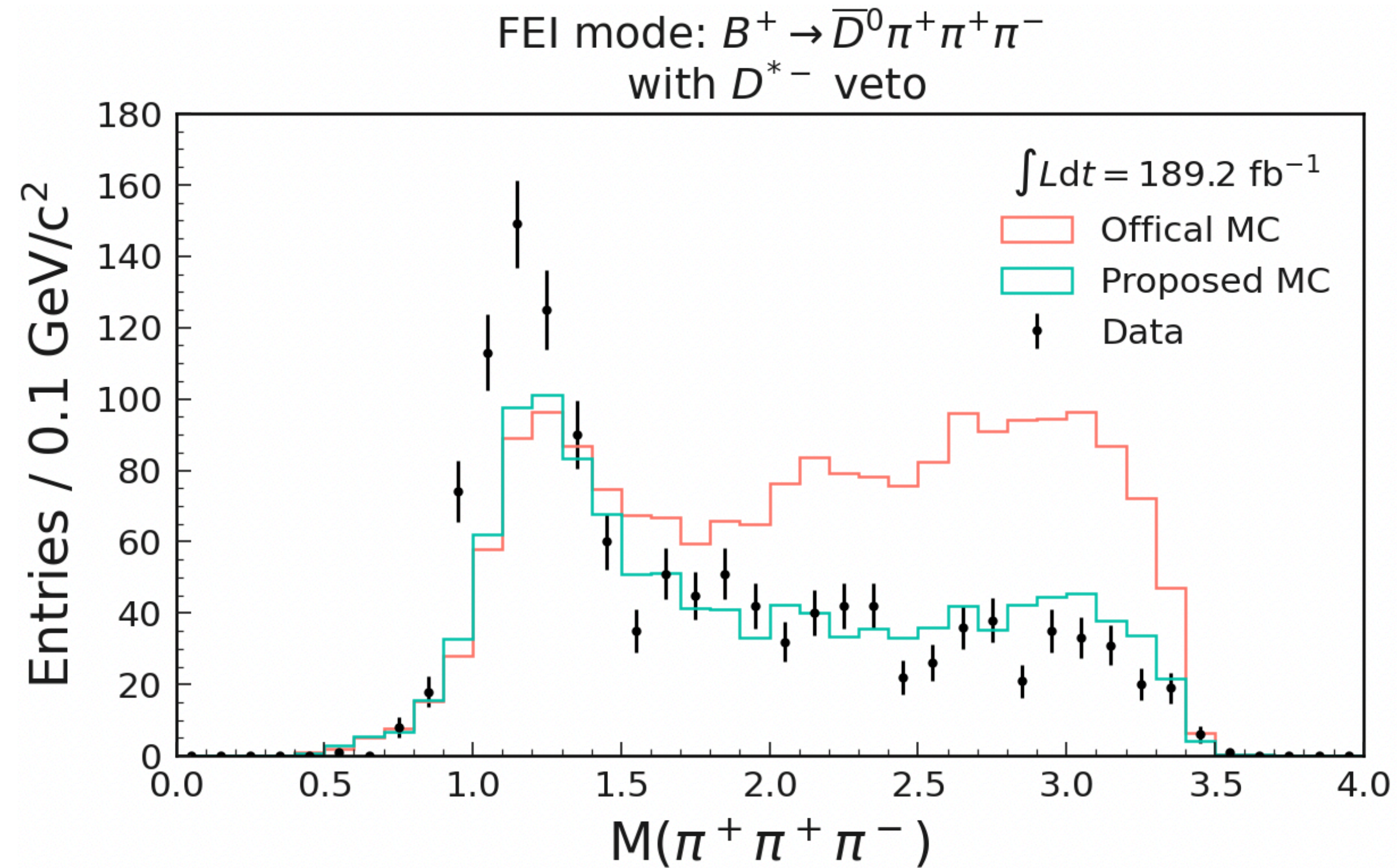

2σ window around both D^0 and D^{*0} peaks

Official MC
0.68 ± 0.01

Proposed MC
0.98 ± 0.02

Pull

2σ window around both D^0 and D^{*0} peaks

Intermediate resonances: tag side

FEI mode: $B^+ \to \overline{D}^0 \pi^+ \pi^+ \pi^-$ with D^{*-} veto

$\int L dt = 189.2 \text{ fb}^{-1}$

Offical MC

Proposed MC

Data

FEI mode: $B^+ \to \overline{D}^0 \pi^+ \pi^+ \pi^-$ with D^{*-} veto

$\int L dt = 189.2 \text{ fb}^{-1}$

Offical MC

Proposed MC

Data
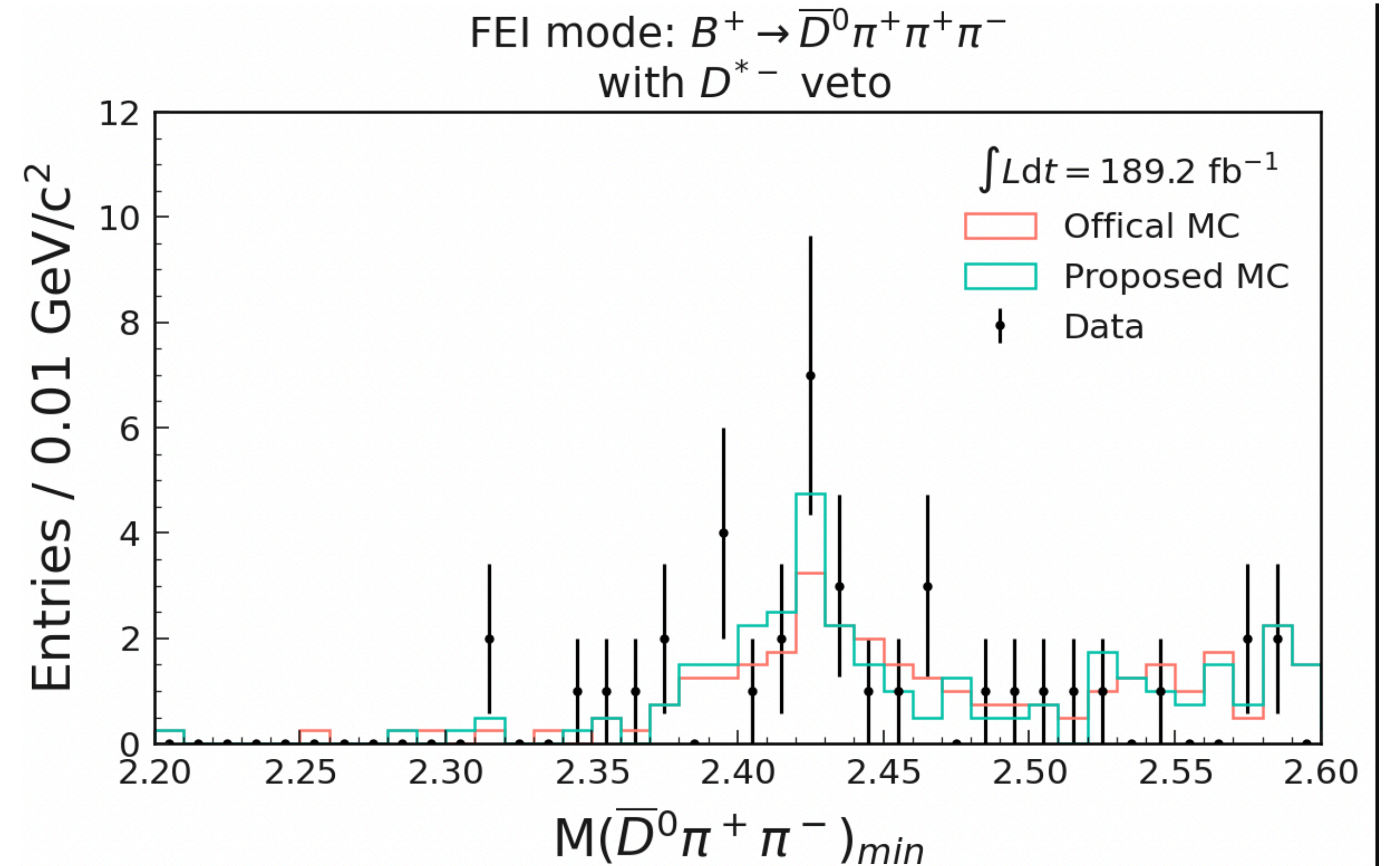
Intermediate resonances: tag side

Intermediate resonances: tag side

FEI mode: $B^+ \to \overline{D}^*(2007)^0 \pi^+ \pi^+ \pi^- \pi^0$

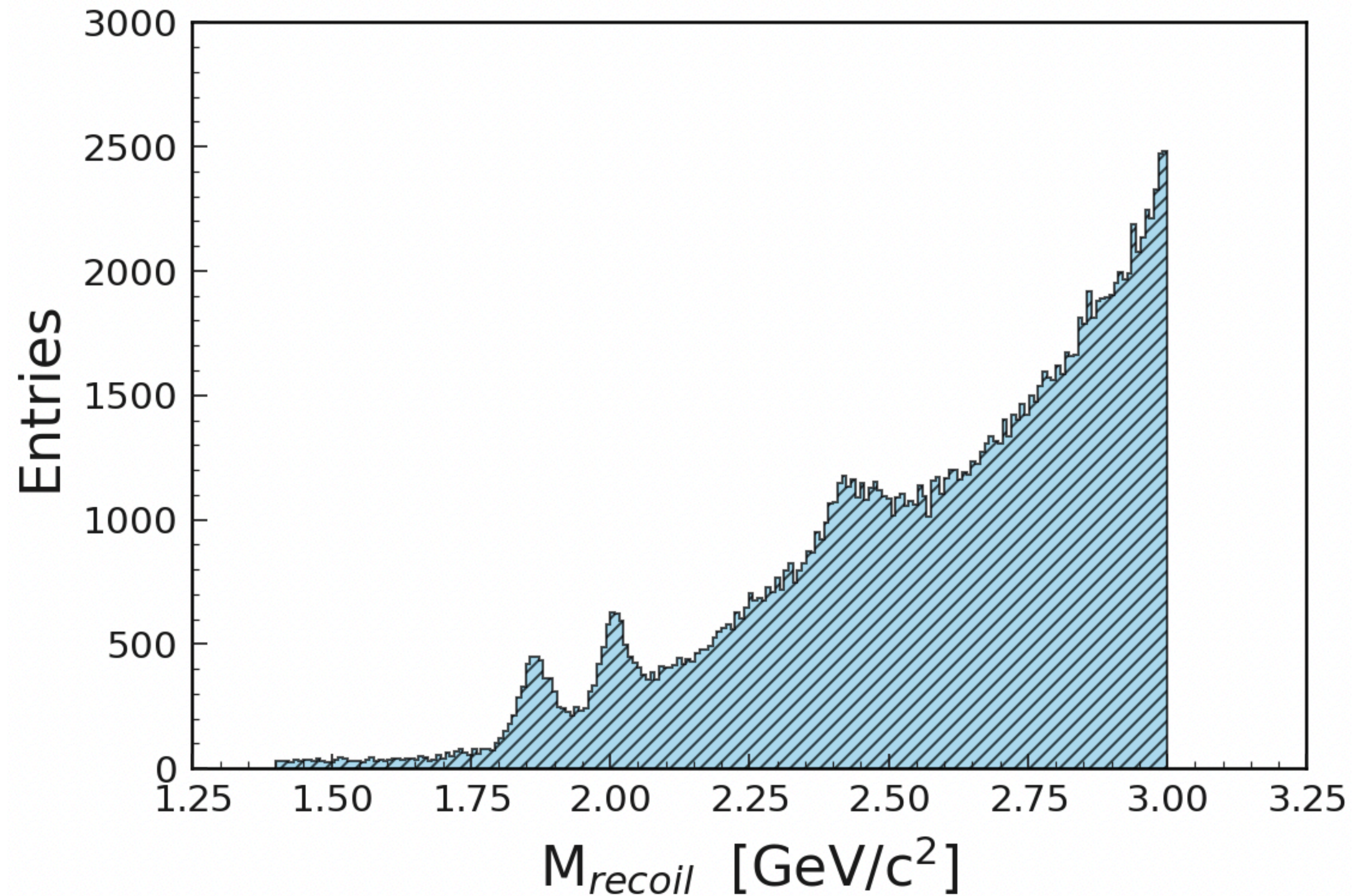$\int L dt = 189.2 \text{ fb}^{-1}$

Offical MC

Proposed MC

Data

Entries / 0.1 GeV/c^2

$M(\pi^+ \pi^+ \pi^- \pi^0)$
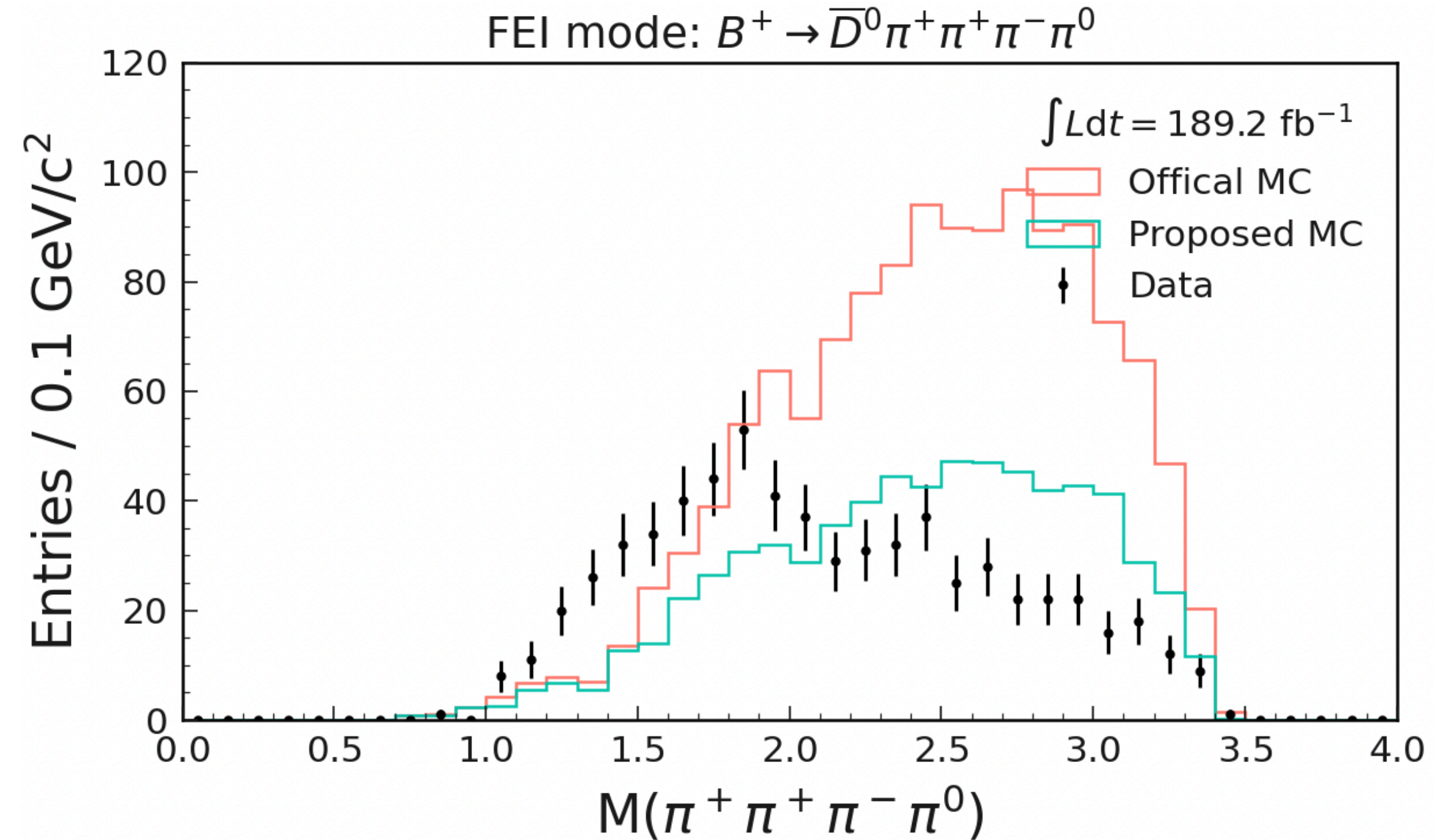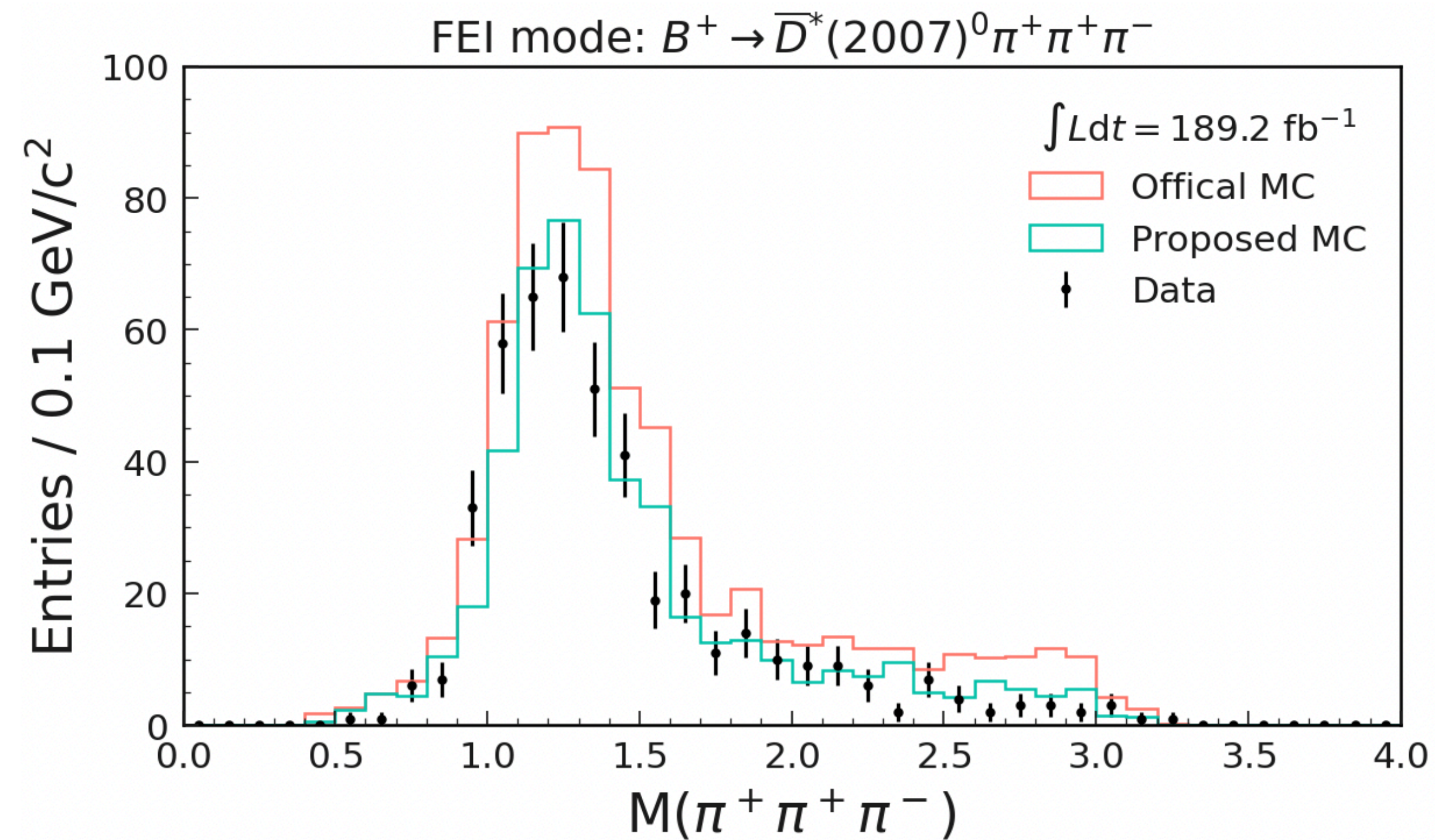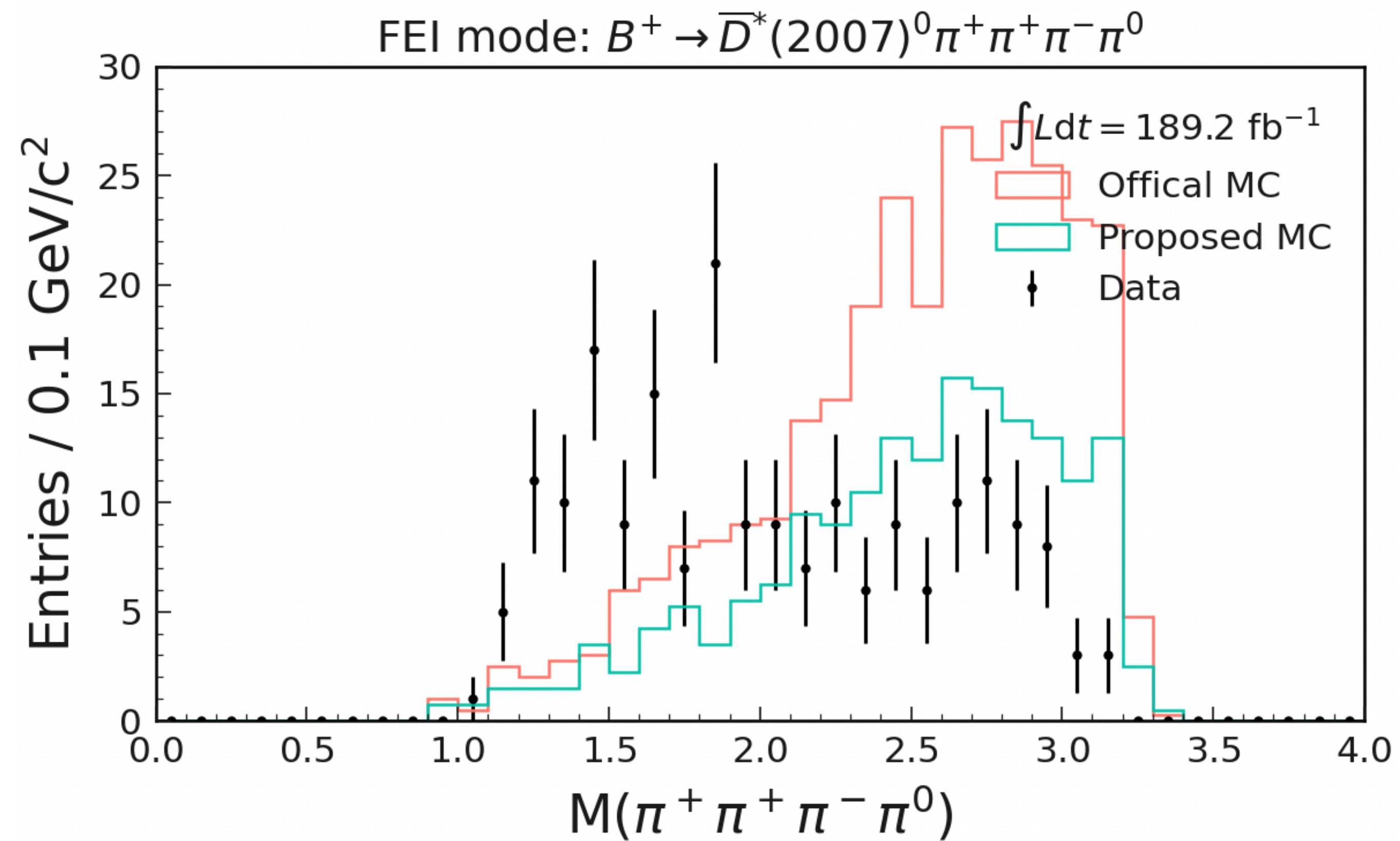
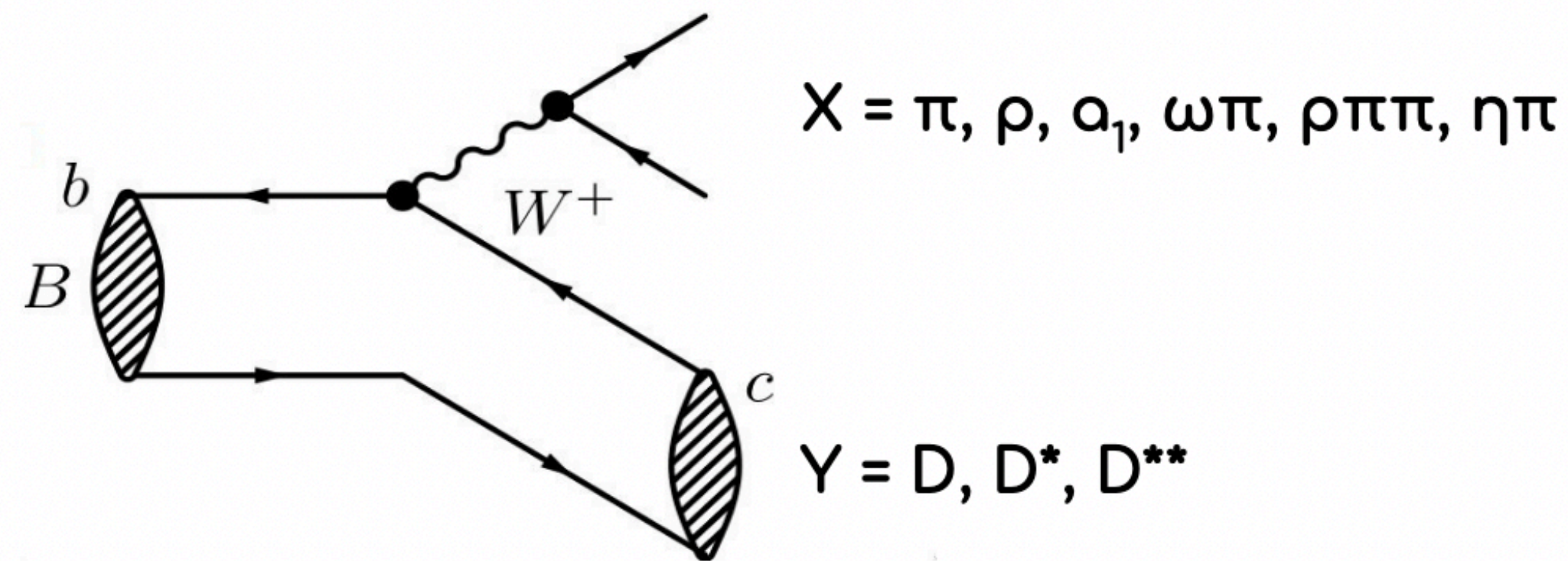# Backup

- M_recoil after removing the Dpi and D*0pi events: old MC14rd

Corrections to decay file

Model for B → D$^{(*,**)}$ nπ mπ^0 decays

X = π, ρ, a$_1$, ωπ, ρππ, ηπ

Y = D, D*, D**

Happens through 2 channels, one with spectator quarks (call Y) and one from the W (call X).

2 primary rules:
- D^0 X: D^{*0} X : D^{**0} X ~= 1 : 1 : 1
 (based on observation from D π$^-$: D* π$^-$: D** π$^-$ and D ρ$^-$: D* ρ$^-$)
- Y π$^-$: Y ρ$^-$: Y a$_1^-$ ~= 1 : 2.5 : 2.5
  (based on predictions and confirmed with τ → h ν decays)

We want to <u>modify</u> the DECAY table to latest PDG/paper interpretations and this model to see the impact.

Additional information:
- 3π π^0 is hard to model without some sort of ρ' resonance
  - For ωπ and ηπ we fix from measurements/observations.
  - For ρππ we let PYTHIA generate it.
- Decays of D** particles is synchronized with Belle II
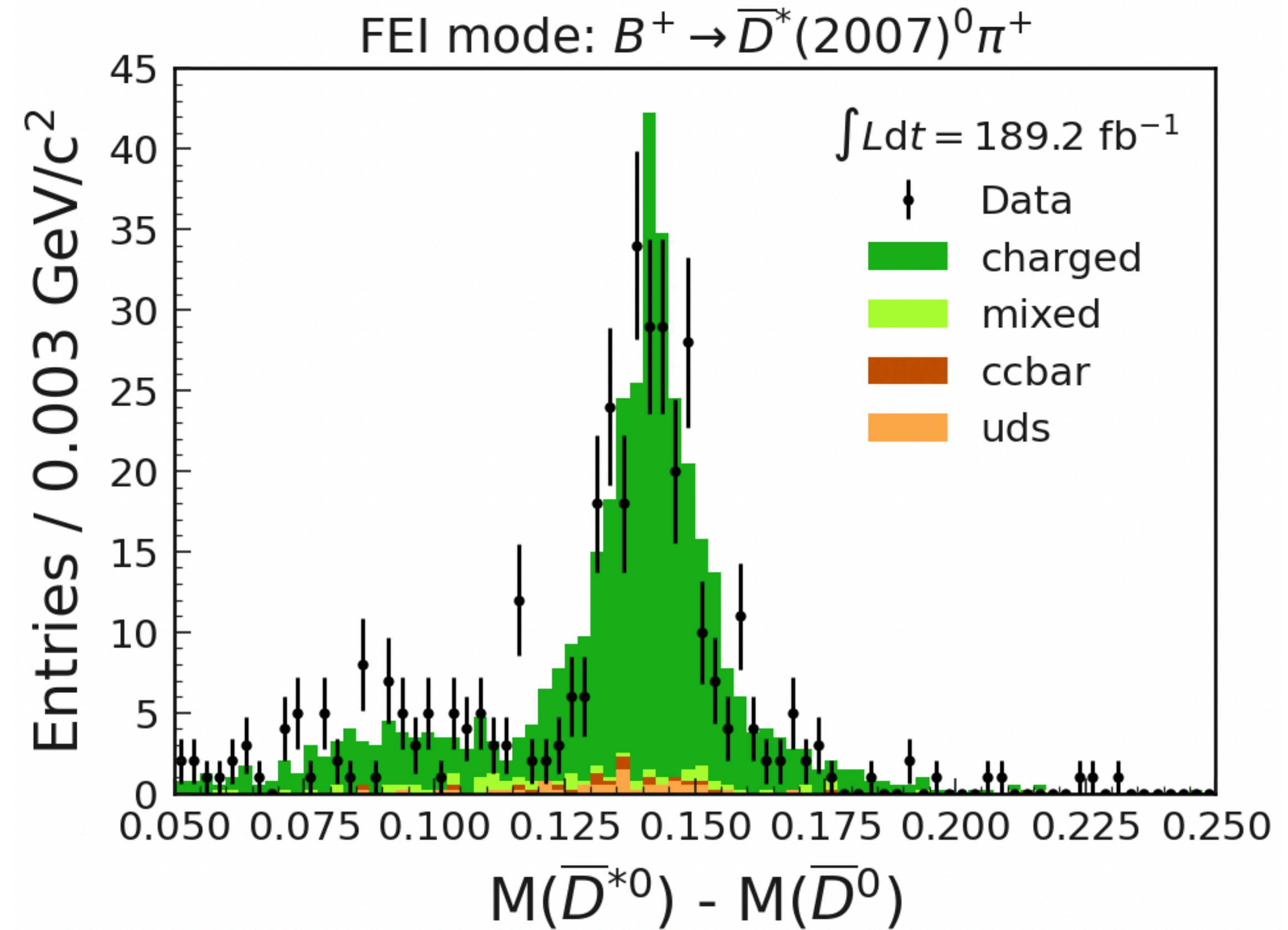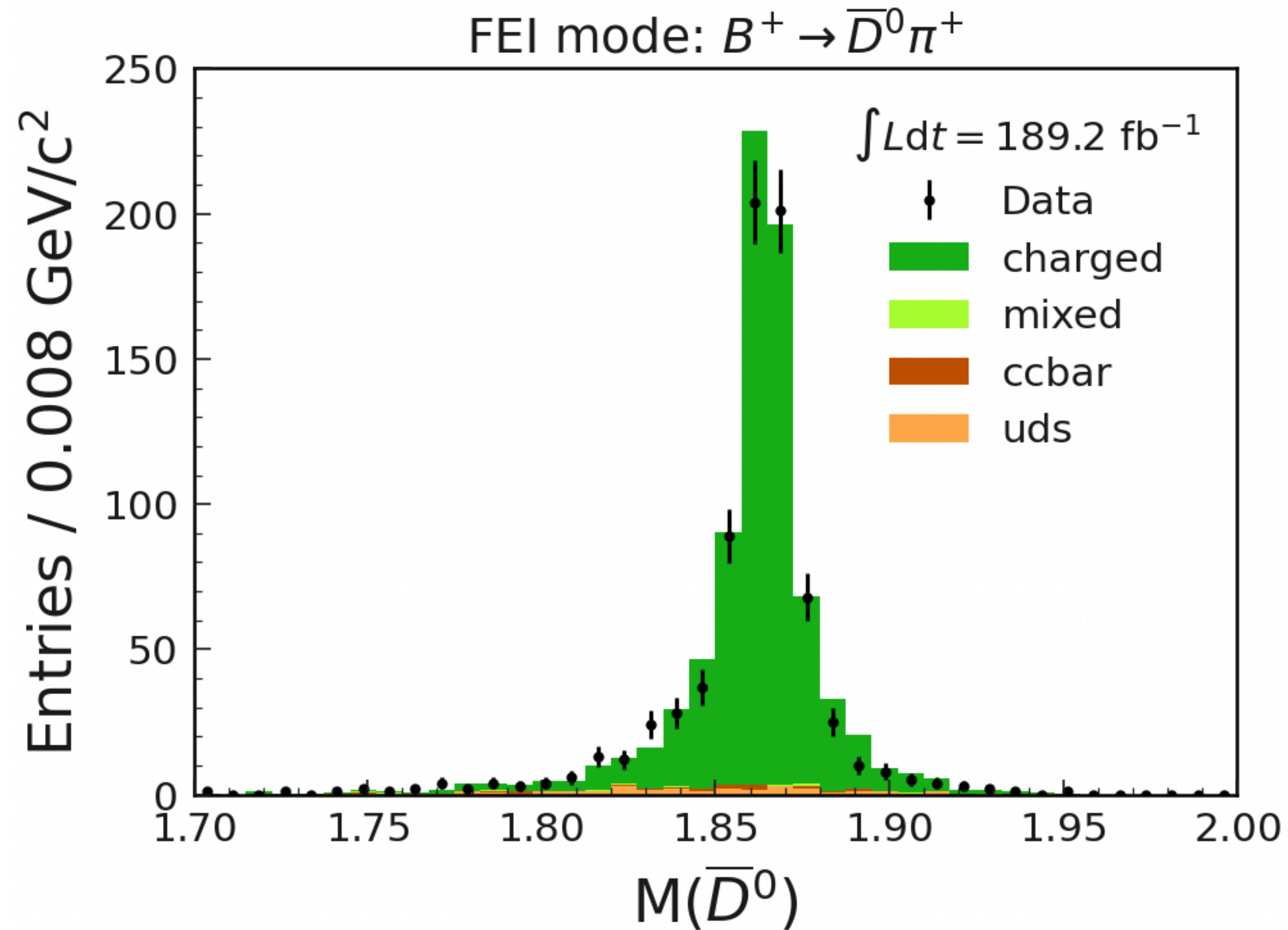- The fraction of 4 different D** is fixed based on observations.

9

Calibration factors
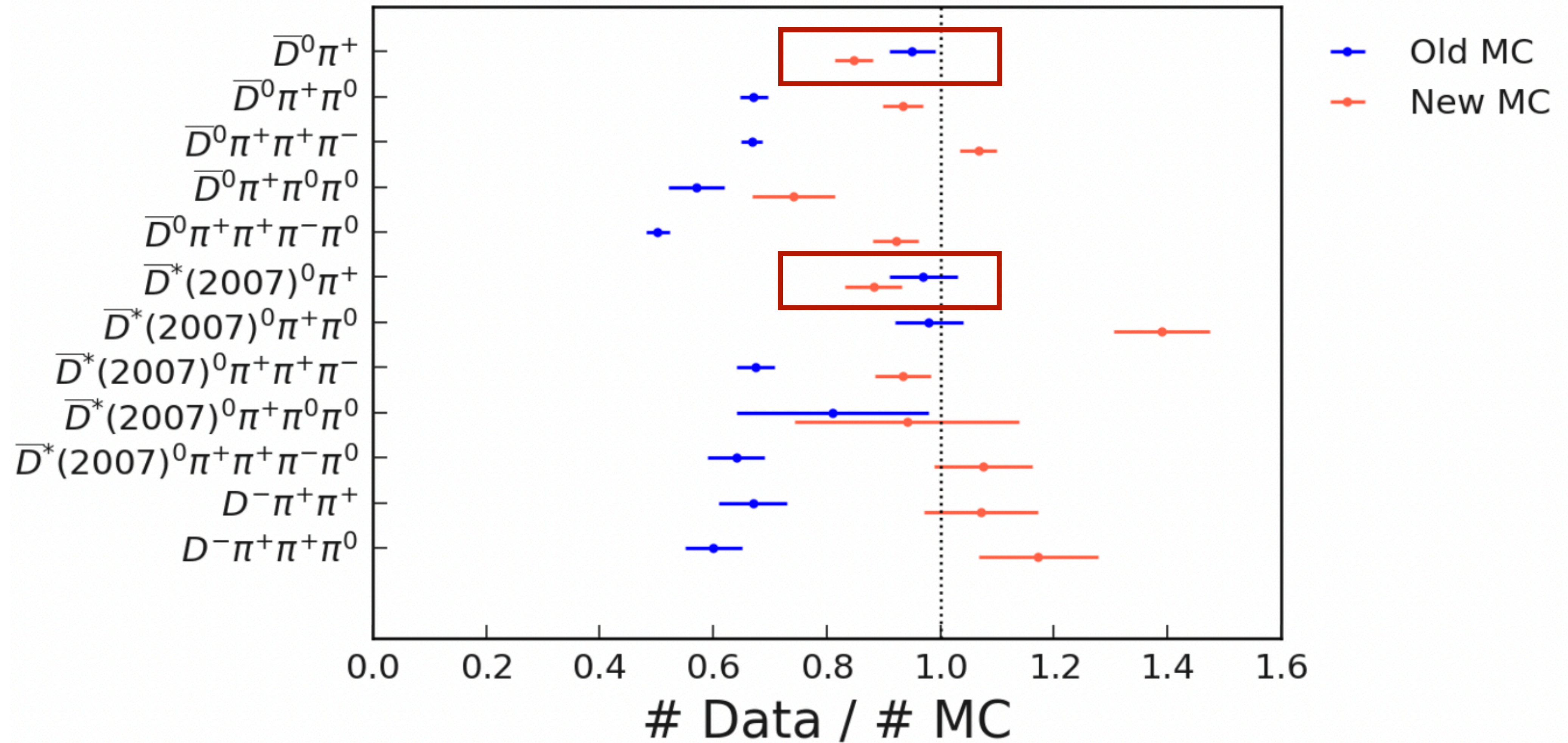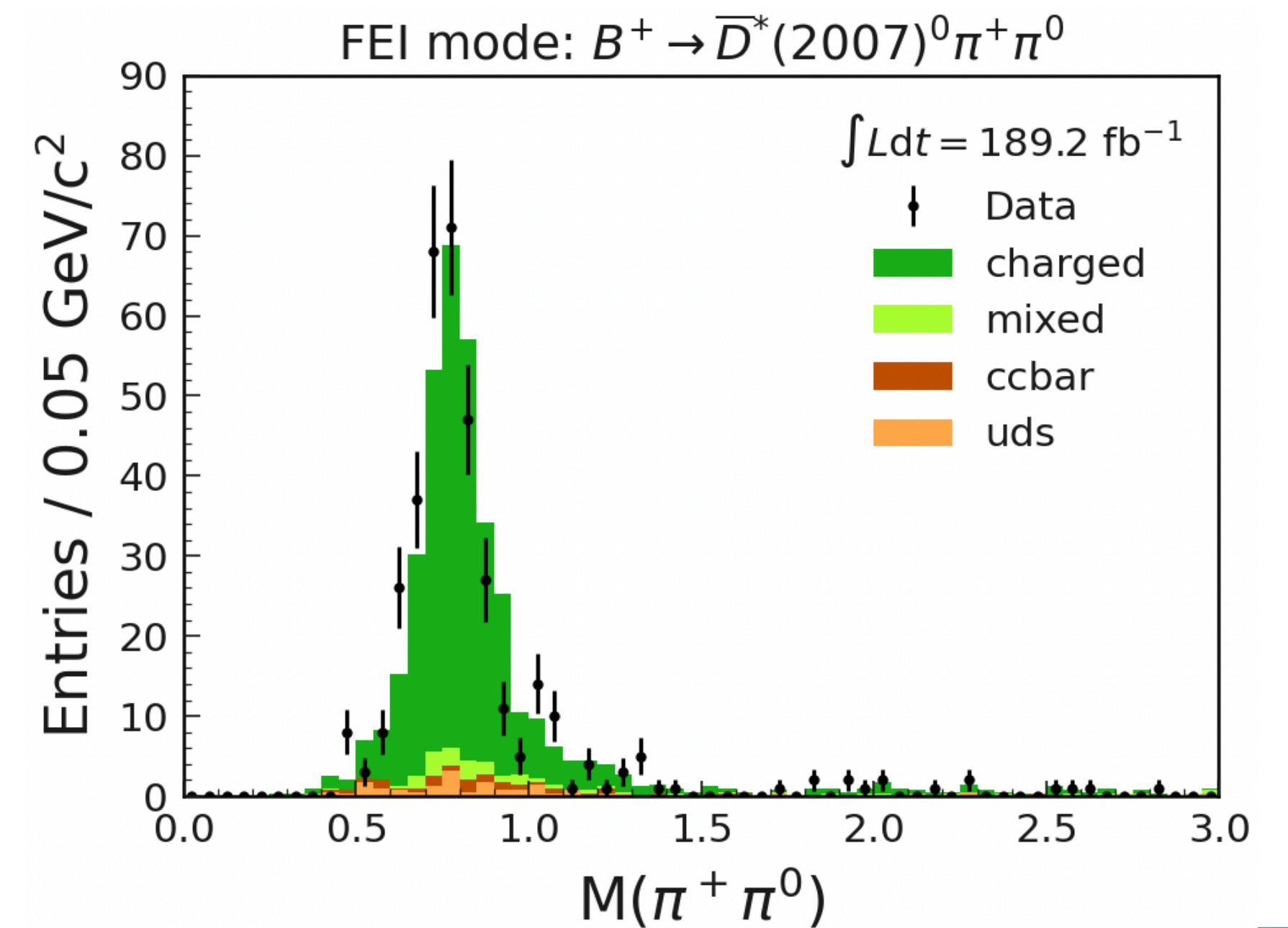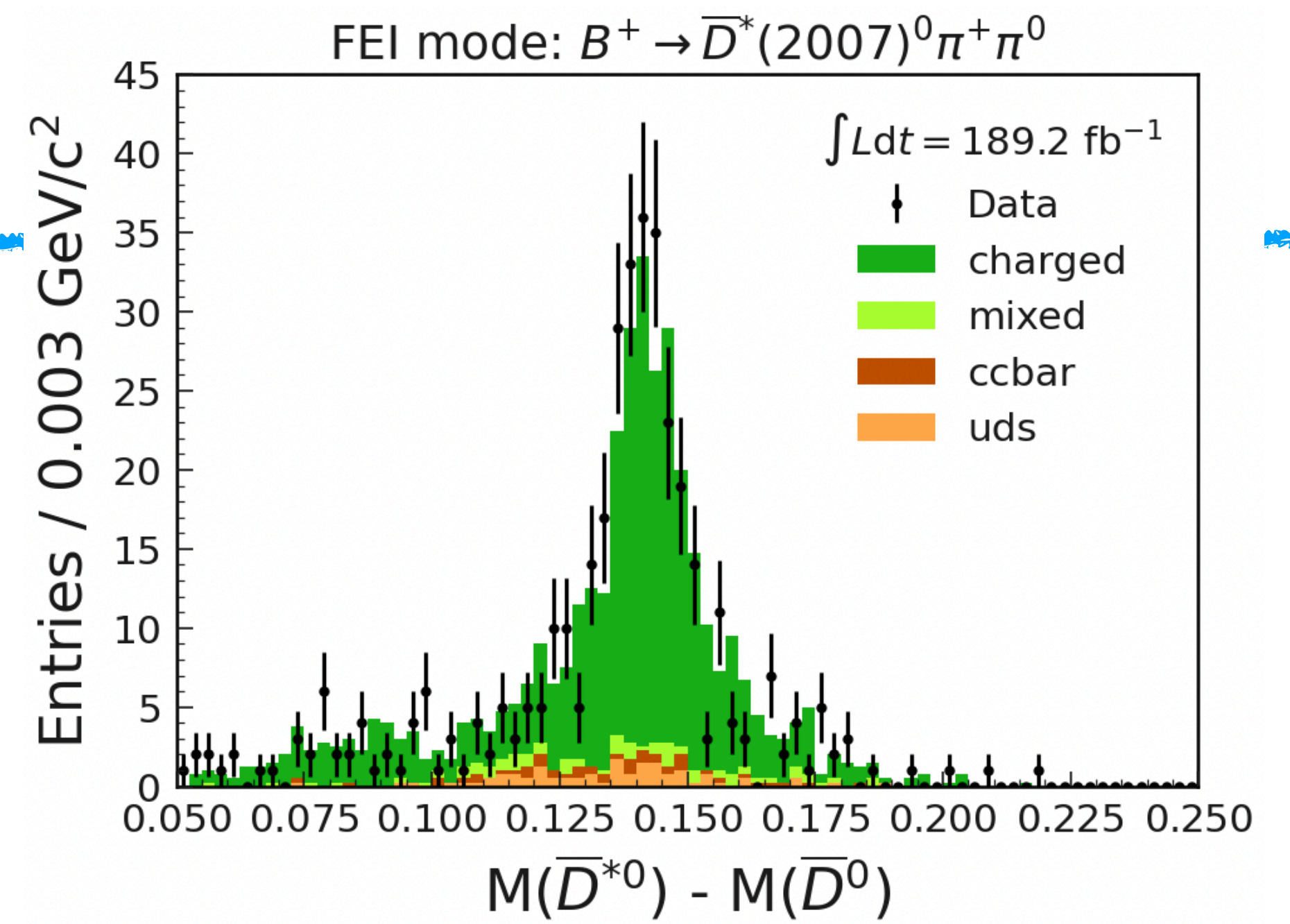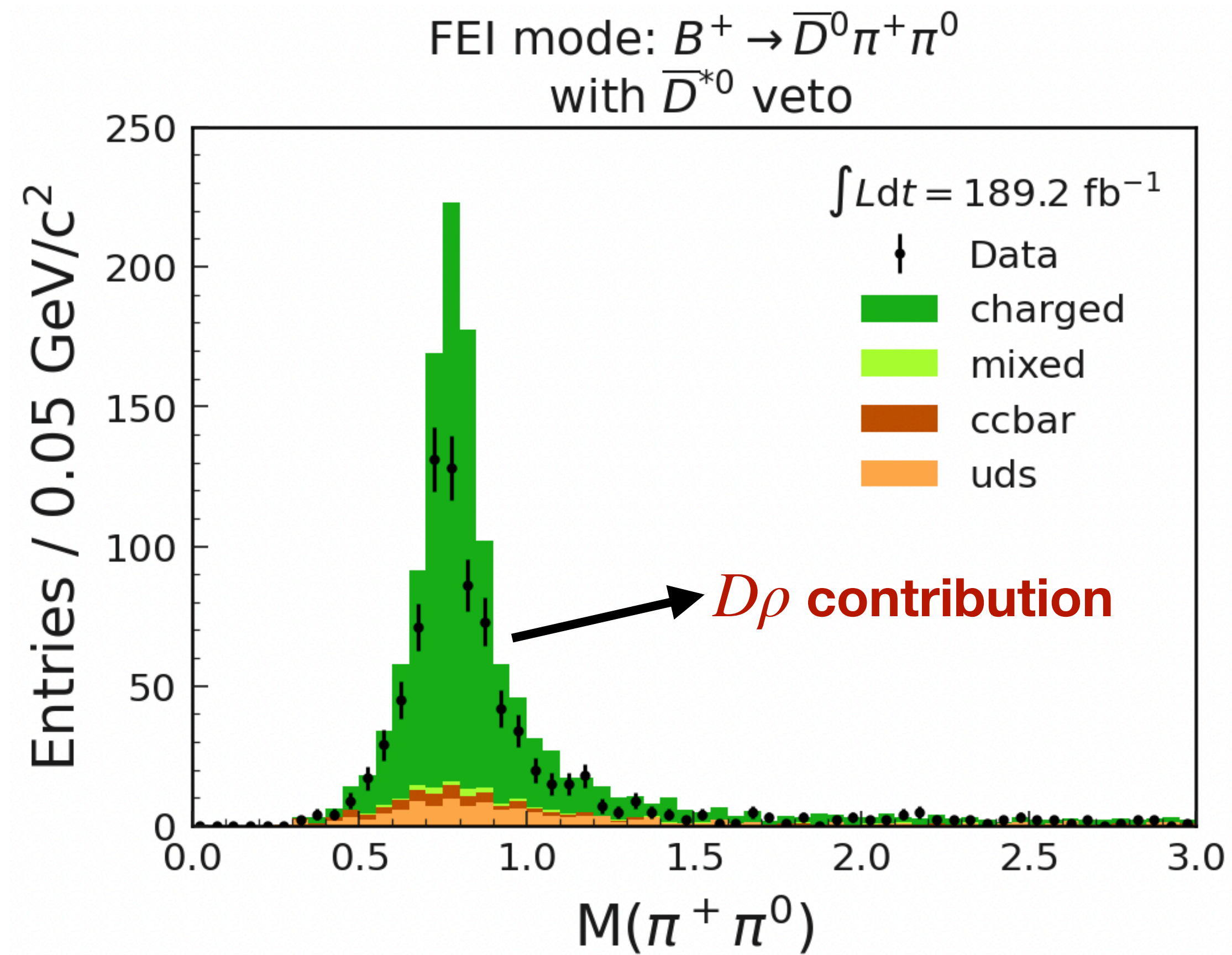
Calibration factors: new MC
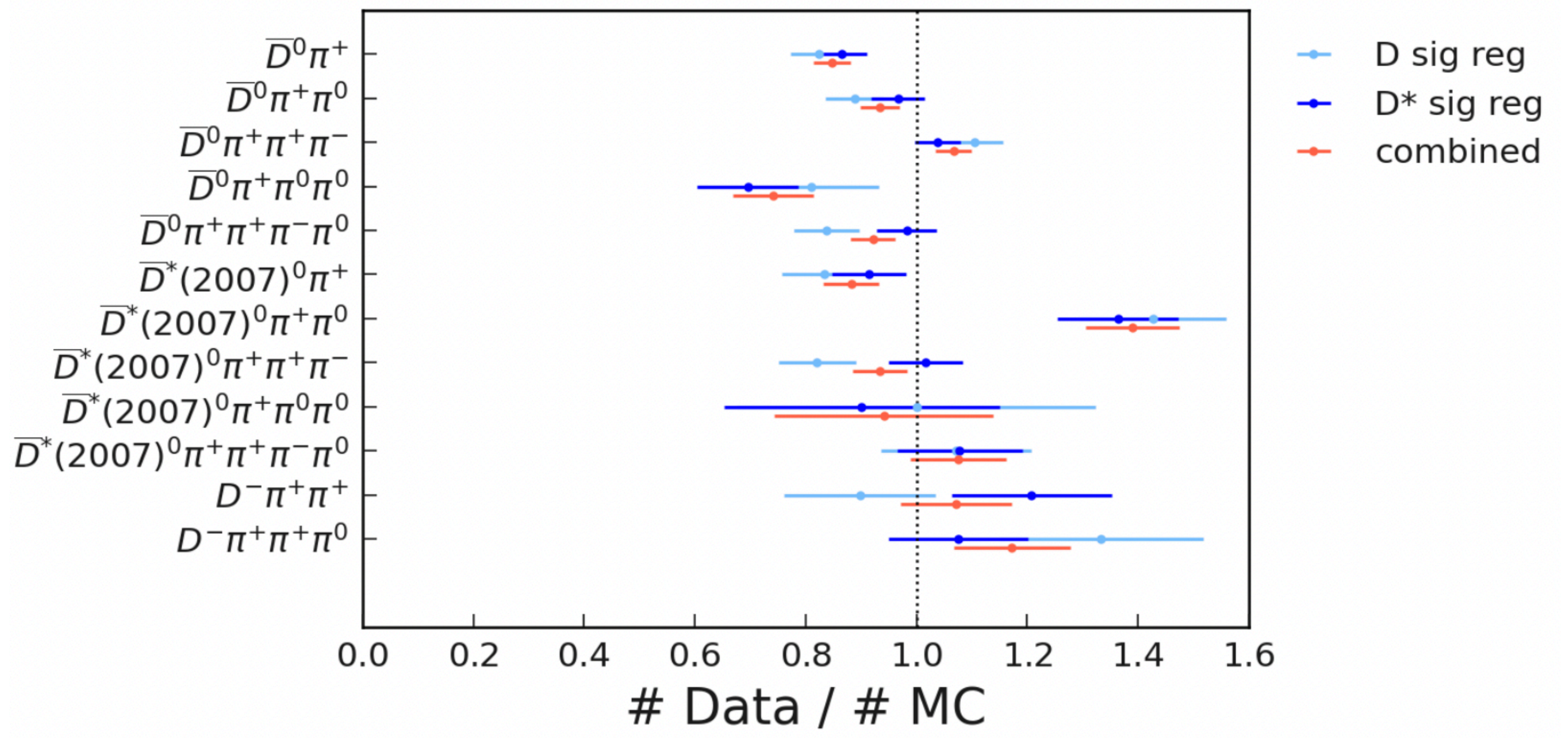
FEI: mode by mode study

$B^+ \to \overline{D}^{0(*)}\pi^+$

- The ΔM resolution is very bad!

- And there are lots of background events! → Not sure if the obtained calibration factors are correct.

$\mathbf{B^+ \to \overline{D}^{0(*)} \pi^+ \pi^0}$

FEI mode: $B^+ \to \overline{D}^0 \pi^+ \pi^0$
with $\overline{D}^{*0}$ veto

$D\rho$ **contribution**

FEI mode: $B^+ \to \overline{D}^*(2007)^0 \pi^+ \pi^0$

FEI mode: $B^+ \to \overline{D}^*(2007)^0 \pi^+ \pi^0$

Next steps

- Look at other FEI modes

- Apply the proposed corrections to Belle II MC and see if the calibration factors are close to one.