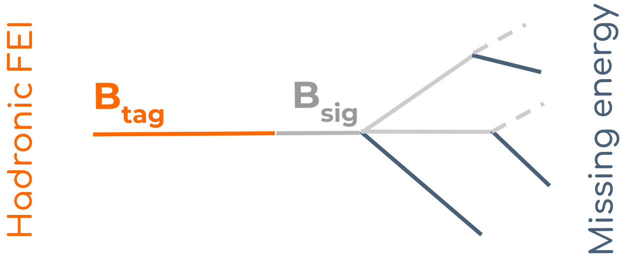
# Digging into hadronic B decays

BAW India 2022 @ IISER Mohali

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IJCLab
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# Motivation for studying B-tagging

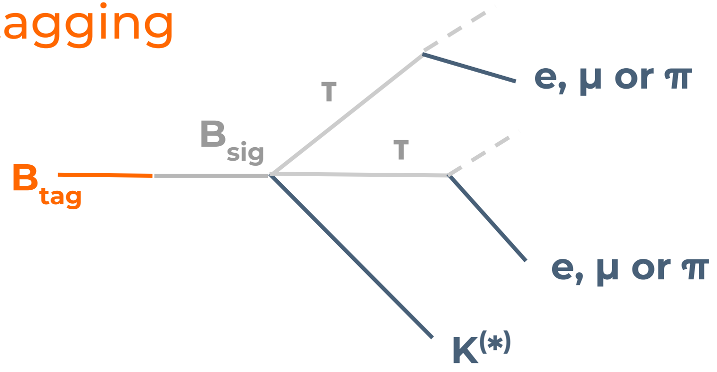
## B → K τ l/τ searches rely on the purity of B-tagging

$B^+ \rightarrow K^+\tau l$ has 1 - 2 neutrinos in the final state
$B^+ \rightarrow K^+\tau\tau$ has 2 - 4 neutrinos in the final state

⇒ Huge background

⇒ Requires high purity in the tag-side

For hadronic $B_{tag}$: $\epsilon_{tag}$ (<1%) is a limiting factor.

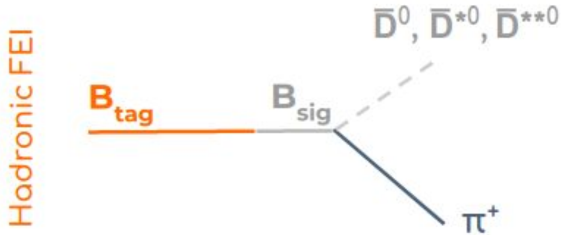




Many interesting B-physics studies involve missing energy: $D^{(*)}\tau\nu$, $K^{(*)}\tau l$, $K^{(*)}\tau\tau$, $K^{(*)}\nu\nu$, $\pi l\nu$, $\tau l$, $\tau\nu$, $\mu\nu$... which require B-tagging.

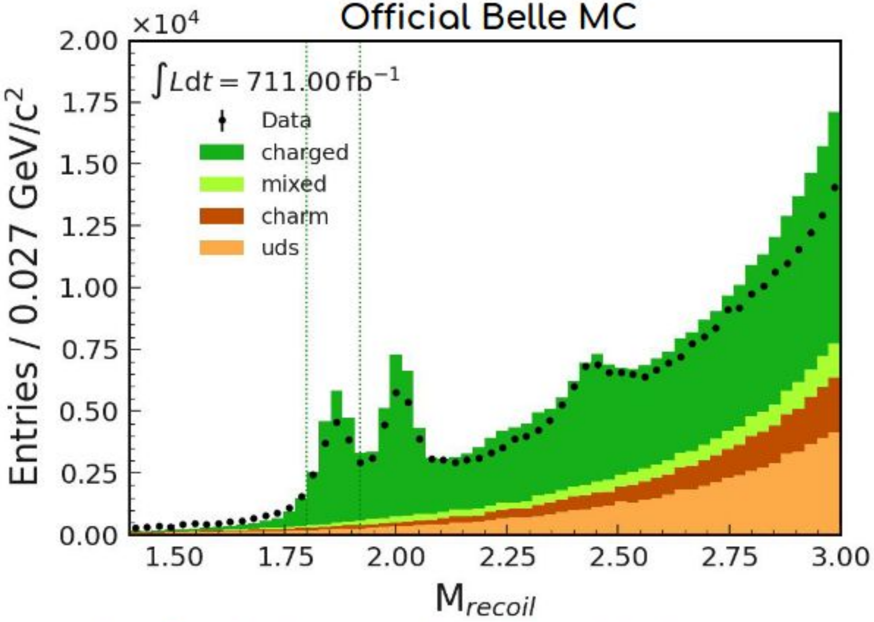
Irrespective of tagging strategy, optimal MC modeling is essential for good performance of ML techniques (NN/BDT).

# Partial reconstruction for more statistics!




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

Within a narrow region around the peak, we know that one B decays to $D^0\pi^+$ and we can study the other B (decaying hadronically)

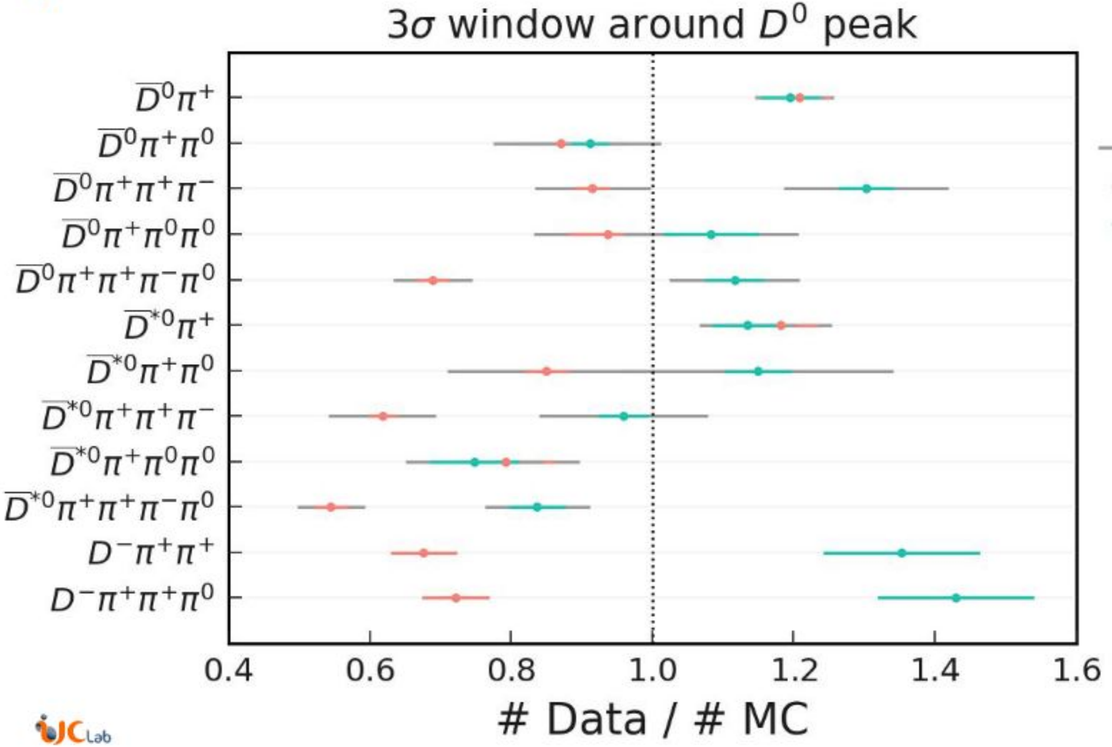



~16k events in a 3σ window around each peak in data.
Roughly ⅓ statistics of $X_c l\nu$ sample, but much smaller systematic.
[BELLE2-NOTE-PH-2021-029, Belle note bn1615]

[See B2GM slides]

# Updated calibration factors

## per mode




Overall calibration factor:

(82.6 ± 0.9)%

↓

(104.2 ± 1.2)%

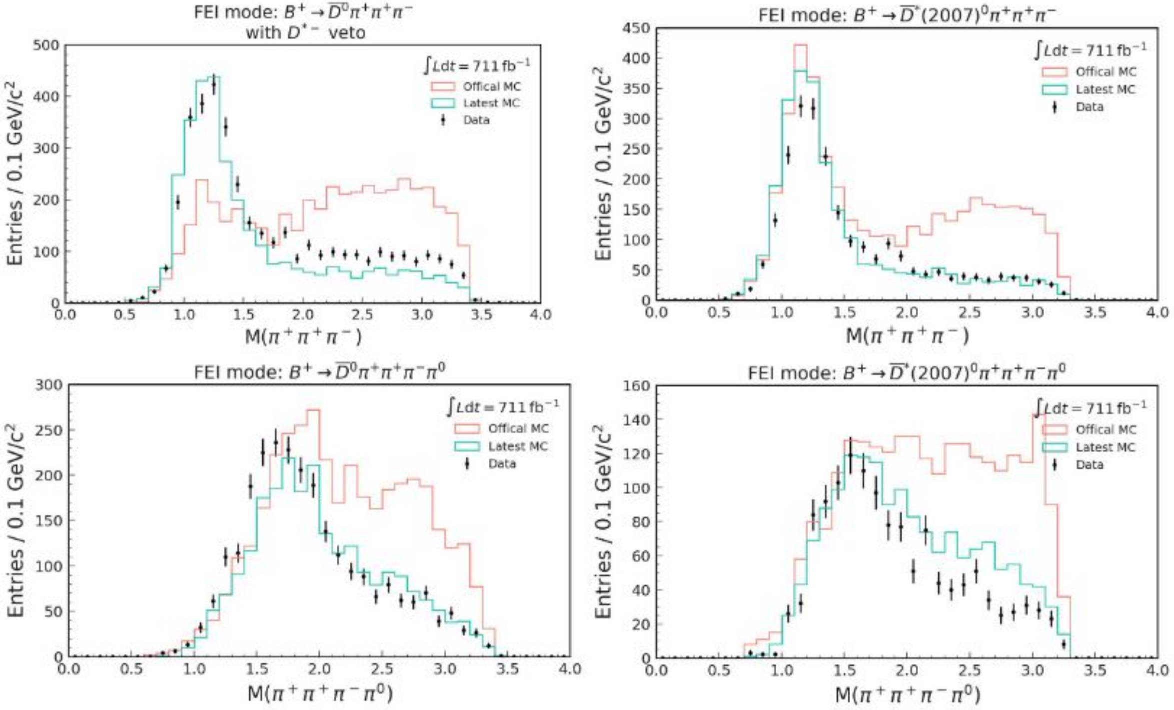
[See B2GM slides]

# Decay description is improved!

The improvement is not limited to calibration factors, but more importantly in the invariant masses (of intermediate particles), which are used as training variables in FEI

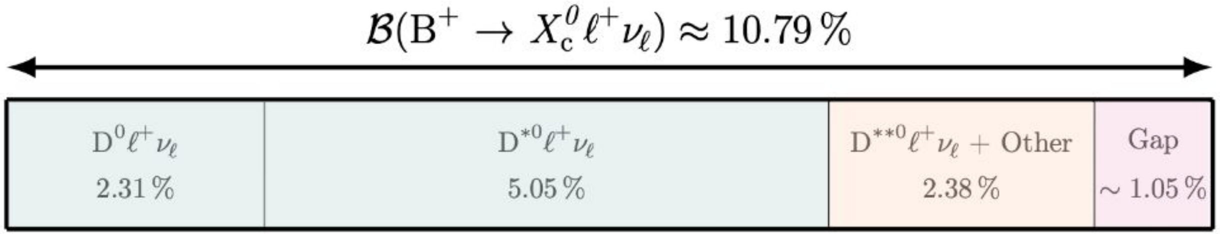
3π± case:

3π± π⁰ case:



# Semi-Leptonic gap

[Raynette van Tonder]




This gap leads to up to 3σ difference in $V_{cb}$ measured from inclusive vs exclusive.

| Decay | $\mathcal{B}(B^+)$ | $\mathcal{B}(B^0)$ |
|---|---|---|
| $B \to D\,\ell^+\,\nu_\ell$ | $(2.4 \pm 0.1) \times 10^{-2}$ | $(2.2 \pm 0.1) \times 10^{-2}$ |
| $B \to D^*\,\ell^+\,\nu_\ell$ | $(5.5 \pm 0.1) \times 10^{-2}$ | $(5.1 \pm 0.1) \times 10^{-2}$ |
| $B \to D_1\,\ell^+\,\nu_\ell$ | $(6.6 \pm 0.1) \times 10^{-3}$ | $(6.2 \pm 0.1) \times 10^{-3}$ |
| $B \to D_2^*\,\ell^+\,\nu_\ell$ | $(2.9 \pm 0.3) \times 10^{-3}$ | $(2.7 \pm 0.3) \times 10^{-3}$ |
| $B \to D_0^*\,\ell^+\,\nu_\ell$ | $(4.2 \pm 0.8) \times 10^{-3}$ | $(3.9 \pm 0.7) \times 10^{-3}$ |
| $B \to D_1'\,\ell^+\,\nu_\ell$ | $(4.2 \pm 0.9) \times 10^{-3}$ | $(3.9 \pm 0.8) \times 10^{-3}$ |
| $B \to D\pi\pi\,\ell^+\,\nu_\ell$ | $(0.6 \pm 0.9) \times 10^{-3}$ | $(0.6 \pm 0.9) \times 10^{-3}$ |
| $B \to D^*\pi\pi\,\ell^+\,\nu_\ell$ | $(2.2 \pm 1.0) \times 10^{-3}$ | $(2.0 \pm 1.0) \times 10^{-3}$ |
| $B \to X_c \ell \nu_\ell$ | $(10.8 \pm 0.4) \times 10^{-2}$ | $(10.1 \pm 0.4) \times 10^{-2}$ |

→ Fairly well known. Some iso-spin tension.

→ Broad states based on 3 measurements. (BaBar, Belle, DELPHI)

→ Some hints from the BaBar result. [1507.08303]

Image credit: F. Metzner

# Semi-Leptonic gap: Filled with η?

[Raynette van Tonder]

**Model 1:**
Equidistribution of all final state particles in phase space

| Decay | $\mathcal{B}(B^+)$ | $\mathcal{B}(B^0)$ |
|---|---|---|
| $B \to D\,\ell^+\,\nu_\ell$ | $(2.4 \pm 0.1) \times 10^{-2}$ | $(2.2 \pm 0.1) \times 10^{-2}$ |
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| $B \to D\eta\,\ell^+\,\nu_\ell$ | $(4.0 \pm 4.0) \times 10^{-3}$ | $(4.0 \pm 4.0) \times 10^{-3}$ |
| $B \to D^*\eta\,\ell^+\,\nu_\ell$ | $(4.0 \pm 4.0) \times 10^{-3}$ | $(4.0 \pm 4.0) \times 10^{-3}$ |
| $B \to X_c \ell \nu_\ell$ | $(10.8 \pm 0.4) \times 10^{-2}$ | $(10.1 \pm 0.4) \times 10^{-2}$ |

→

**Model 2:**
Decay via intermediate broad $D^{**}$ state

| Decay | $\mathcal{B}(B^+)$ | $\mathcal{B}(B^0)$ |
|---|---|---|
| $B \to D_0^*\,\ell^+\,\nu_\ell$ ($\hookrightarrow D\pi\pi$) | $(0.03 \pm 0.03) \times 10^{-2}$ | $(0.03 \pm 0.03) \times 10^{-2}$ |
| $B \to D_1^*\,\ell^+\,\nu_\ell$ ($\hookrightarrow D\pi\pi$) | $(0.03 \pm 0.03) \times 10^{-2}$ | $(0.03 \pm 0.03) \times 10^{-2}$ |
| $B \to D_0^*\pi\pi\,\ell^+\,\nu_\ell$ ($\hookrightarrow D^*\pi\pi$) | $(0.108 \pm 0.051) \times 10^{-2}$ | $(0.101 \pm 0.048) \times 10^{-2}$ |
| $B \to D_1^*\pi\pi\,\ell^+\,\nu_\ell$ ($\hookrightarrow D^*\pi\pi$) | $(0.108 \pm 0.051) \times 10^{-2}$ | $(0.101 \pm 0.048) \times 10^{-2}$ |
| $B \to D_0^*\,\ell^+\,\nu_\ell$ ($\hookrightarrow D\eta$) | $(0.396 \pm 0.396) \times 10^{-2}$ | $(0.399 \pm 0.399) \times 10^{-2}$ |
| $B \to D_1^*\,\ell^+\,\nu_\ell$ ($\hookrightarrow D^*\eta$) | $(0.396 \pm 0.396) \times 10^{-2}$ | $(0.399 \pm 0.399) \times 10^{-2}$ |

The current workaround to explain the SL gap is to fill it with $D^{(*)}\eta l\nu$, either as a non-resonant state or through $(D^{(*)}\eta)$ resonance.
**But never seen.**

# Source of η: D**?

| $D^{**}$ | decay channel | branching ratio |
|---|---|---|
| $D_0(2300)^0$ | $D^0\pi^0$ | 0.3333 |
| | $D^+\pi^-$ | 0.6667 |
| $D_1(2420)^0$ | $D^{*0}\pi^0$ | 0.1997 |
| | $D^{*+}\pi^-$ | 0.3994 |
| | $D^0\pi^+\pi^-$ | 0.1719 |
| | $D^0\pi^0\pi^0$ | 0.1145 |
| | $D^+\pi^-\pi^0$ | 0.1145 |
| $D_1(2430)^0$ | $D^{*+}\pi^-$ | 0.6667 |
| | $D^{*0}\pi^0$ | 0.3333 |
| $D_2^*(2460)^0$ | $D^{*0}\pi^0$ | 0.1334 |
| | $D^{*+}\pi^-$ | 0.2669 |
| | $D^0\pi^0$ | 0.1999 |
| | $D^+\pi^-$ | 0.3998 |

TABLE XIX: Decay channels of $D^{**}$

**Model 2:**
Decay via intermediate broad $D^{**}$ state

| Decay | $\mathcal{B}(B^+)$ | $\mathcal{B}(B^0)$ |
|---|---|---|
| $B \to D_0^* \ell^+ \nu_\ell$ $(\hookrightarrow D\pi\pi)$ | $(0.03 \pm 0.03) \times 10^{-2}$ | $(0.03 \pm 0.03) \times 10^{-2}$ |
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| $B \to D_0^*\pi\pi \ell^+ \nu_\ell$ $(\hookrightarrow D^*\pi\pi)$ | $(0.108 \pm 0.051) \times 10^{-2}$ | $(0.101 \pm 0.048) \times 10^{-2}$ |
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| $B \to D_1^* \ell^+ \nu_\ell$ $(\hookrightarrow D^*\eta)$ | $(0.396 \pm 0.396) \times 10^{-2}$ | $(0.399 \pm 0.399) \times 10^{-2}$ |

The decays of D** are not well measured, and the Belle II model does not consider η.

D** decays and B → D** X decays needs further studies.

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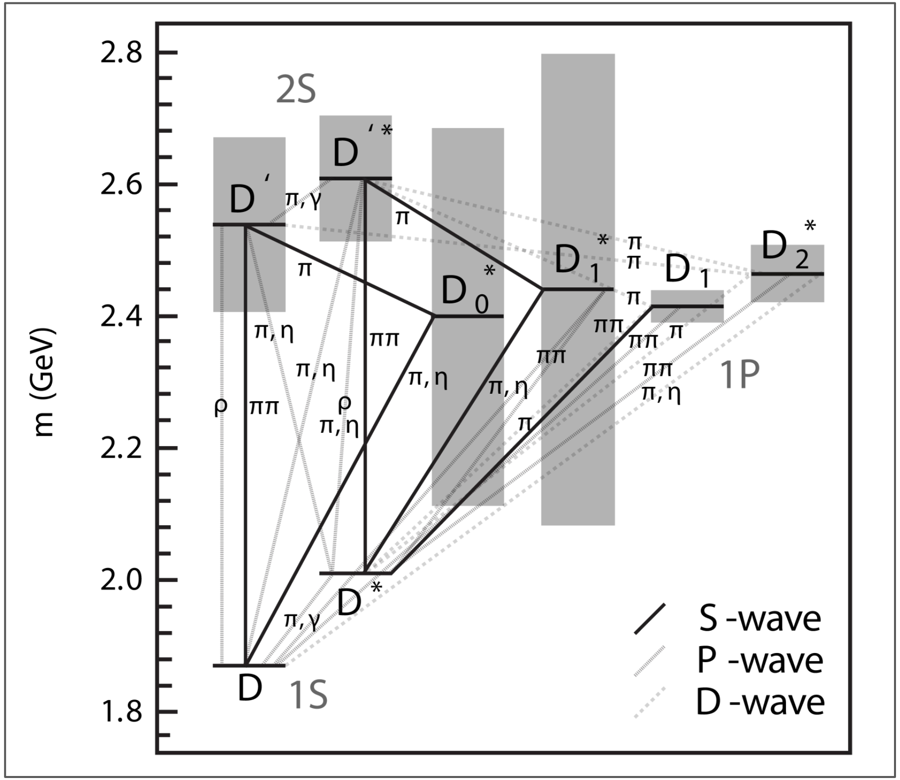
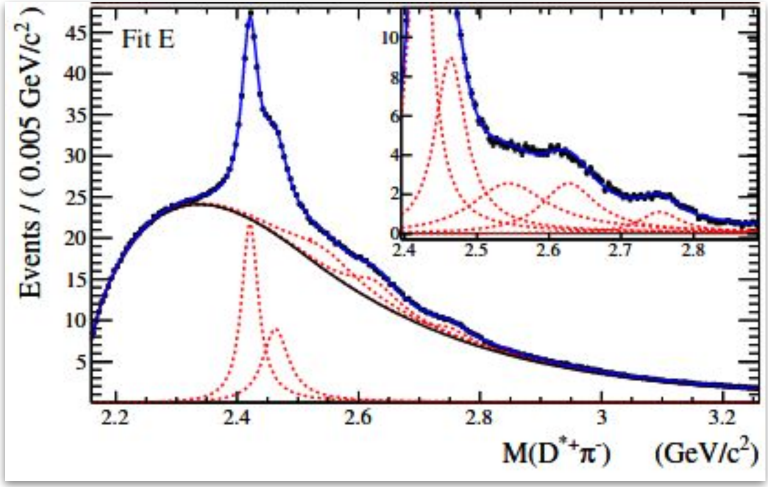
# Source of η: D(2S)?




[arXiv:1202.1834]

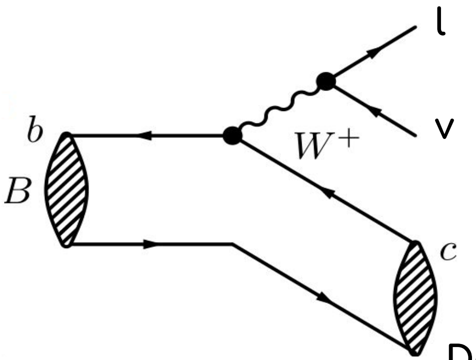
In 2010, BaBar observed even higher D resonances, consistent with L=2.

[1009.2076]




These D(2S) resonances have higher mass, and are potential candidates for sources of η filling the SL gap.

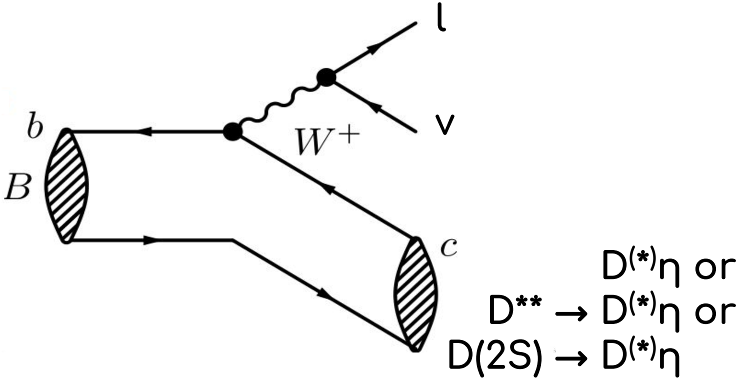
# SL $D^{(*)}\eta l\nu$

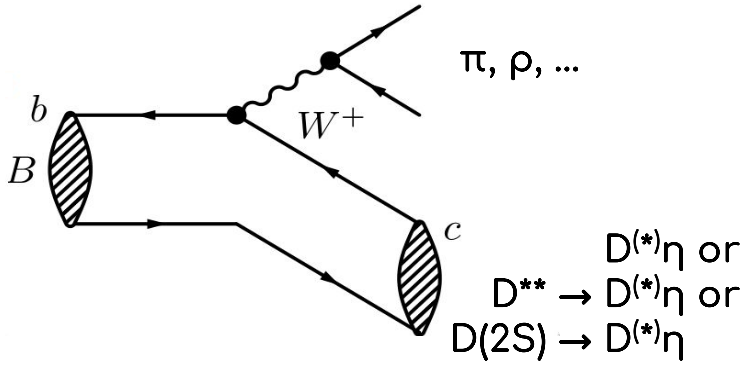



$D^{(*)}\eta$ or
$D^{**} \to D^{(*)}\eta$ or
$D(2S) \to D^{(*)}\eta$

Signals of these SL decays are difficult to search for.

# SL $D^{(*)}\eta l\nu \Rightarrow$ Hadronic $D^{(*)}\eta\pi$, $D^{(*)}\eta\rho$



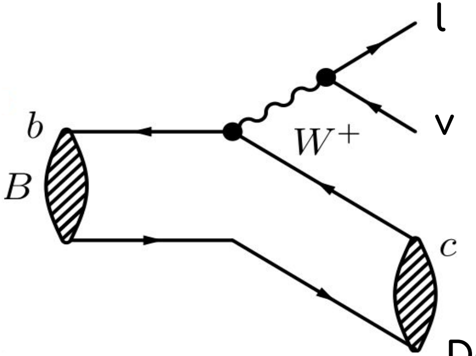

Signals of these SL decays are difficult to search for.

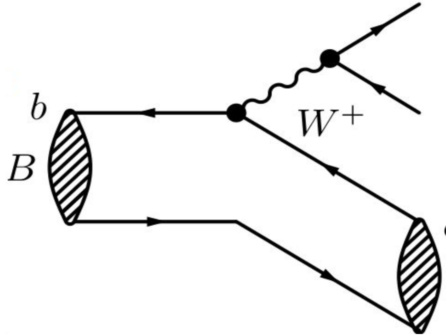
But the hadronic counterparts (changing lν with π/ρ) are easier to search.

The presence of $D(^*)\eta\pi$ can validate the assumption of η filling the SL-gap and can also describe the source of η.

Vismaya will talk more about the status.

# SL $D^{(*)}\eta l\nu \Rightarrow$ Hadronic $D^{(*)}\eta\pi$, $D^{(*)}\eta\rho$




Signals of these SL decays are difficult to search for.

B → D*π is 1/10 of B → D*lν.

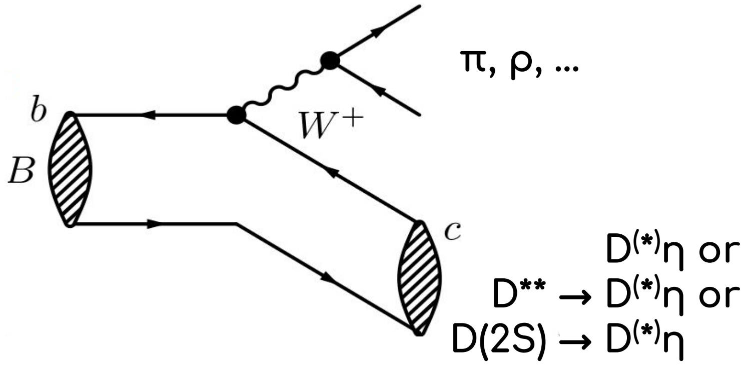
⇒ A limit of BF(B → D*ηπ) < $4 \times 10^{-4}$ is enough to invalidate η as a candidate for SL gap.

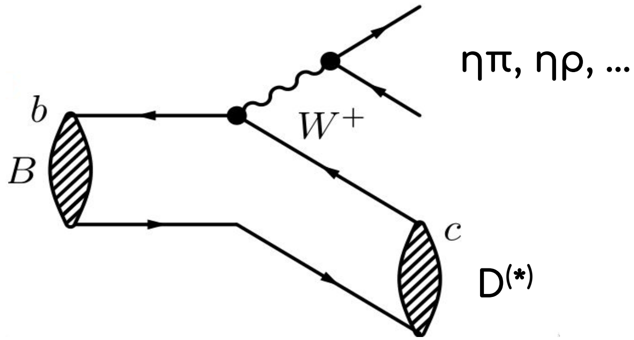
But the hadronic counterparts (changing lν with π/ρ) are easier to search.

The presence of D(*)ηπ can validate the assumption of η filling the SL-gap and can also describe the source of η.

Vismaya will talk more about the status.

# Hadronic $D^{(*)}\eta\pi$ vs $D^{(*)}\eta\rho$



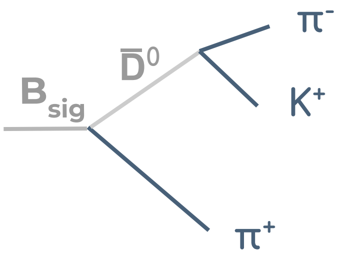




In the alternative way of producing η through W, the ηπ contribution is suppressed.
G-parity violation ⇒ Second class current.
(also seen in τ decays)

But ηρ is still possible.

So, studying both $D^{(*)}\eta\pi$ vs $D^{(*)}\eta\rho$ simultaneously can also shed light on the source of η.

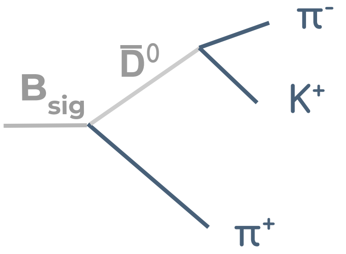
# Exclusive reconstruction




Reconstruct all the final state particles from the B
⇒ Calculate the 4-momentum of B.
And apply selection using ΔE (and $M_{bc}$)

Efficiency =
$BR_{\bar{D}0 \to K\pi} \times \epsilon_K \times \epsilon_\pi \times \epsilon_\pi$

# Exclusive vs Partial reconstruction




Reconstruct all the final state particles from the B
⇒ Calculate the 4-momentum of B. And apply selection using ΔE (and $M_{bc}$)

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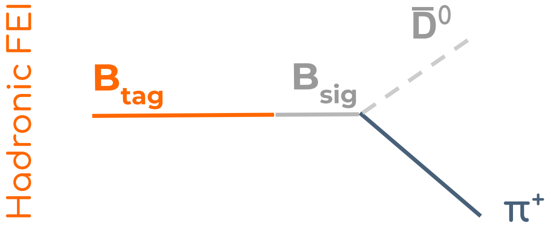



Popular when there are neutrinos which cannot be reconstructed, like in B → K τ l

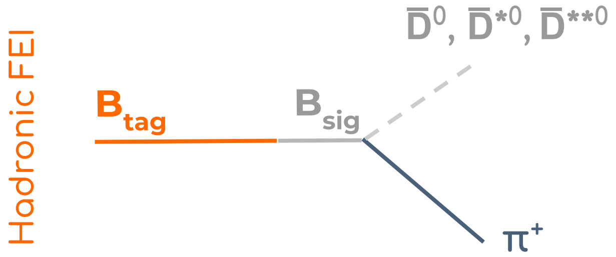
Instead of reconstructing the D exclusively, one could reconstruct the other B in the event fully. And look for the D in the recoil mass.

In CM frame of ϒ(4S):

$$\vec{p}_{B_{sig}} = -\vec{p}_{B_{tag}}$$
$$\vec{p_X} = \vec{p}_{B_{sig}} - \vec{p}_{\pi^+}$$
$$E_X = E_{beam} - E_{\pi^+}$$
$$M_X = \sqrt{E_X^2 - \vec{p}_X^2}$$

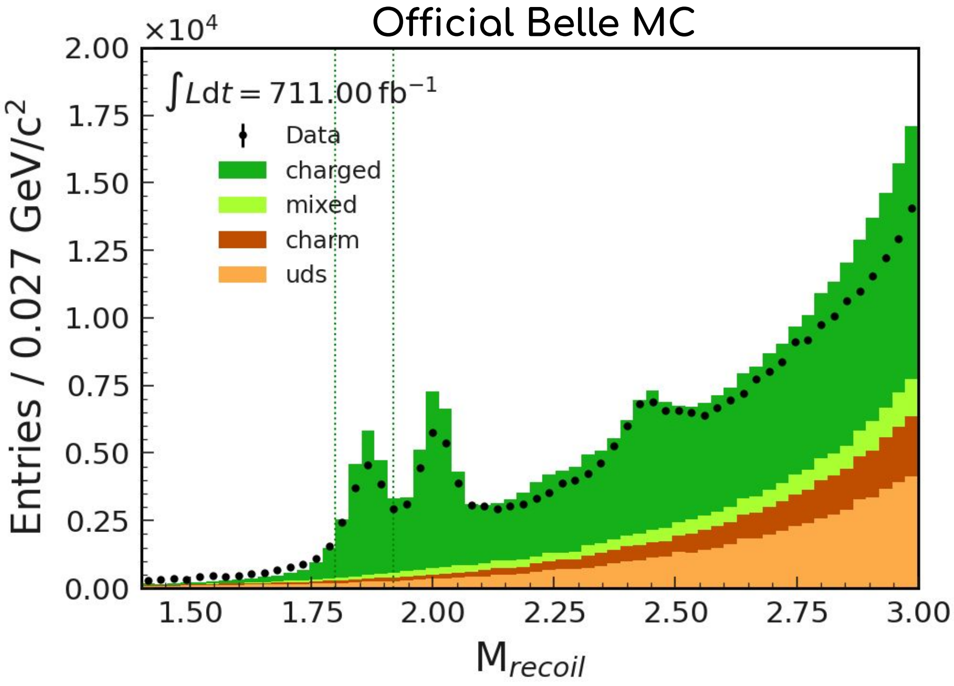
Here, efficiency =
$\epsilon_{B\text{-}tag} \times \epsilon_\pi$

# Recoil with π

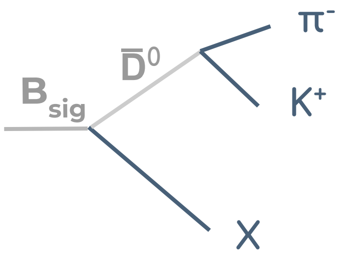


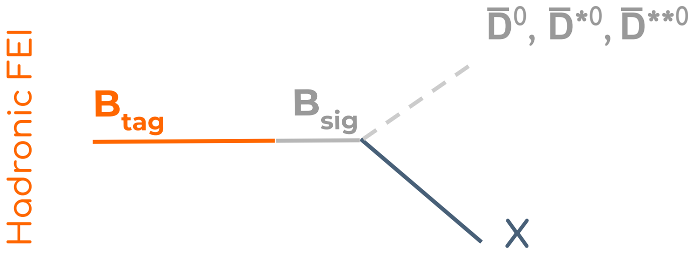

We can look for $D^0$, $D^{*0}$ and even $D^{**0}$ in the recoil mass of a fully reconstructed B and a π±

Within a narrow region around the peak, we know that one B decays to $D^0\pi^+$ and we can study the other B (decaying hadronically)



# Exclusive vs Partial reconstruction




Efficiency =

for $D^0$: $(BR_{\bar{D}0 \to K\pi} \times \epsilon_K \times \epsilon_\pi) \times \epsilon_X$

for $D^{*0}$: $(BR_{\bar{D}^*0 \to \bar{D}0\,\pi0} \times \epsilon_{\pi0} \times BR_{\bar{D}0 \to K\pi} \times \epsilon_K \times \epsilon_\pi) \times \epsilon_X$

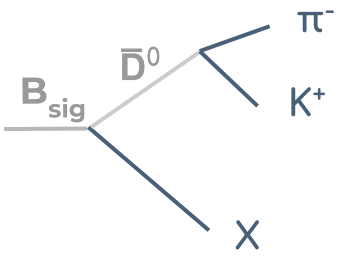
Here, D* has lower efficiency than D.

Efficiency =

$\epsilon_{B\text{-}tag} \times \epsilon_X$

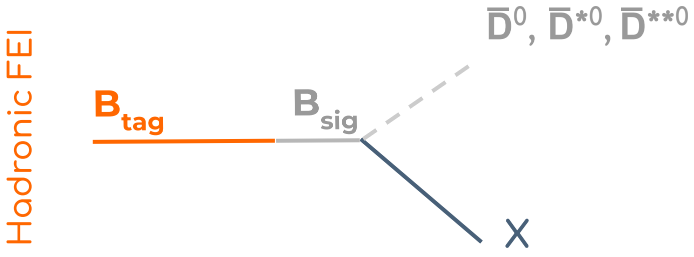
Here D* and D have same efficiency!

# Exclusive vs Partial reconstruction




To extend on this idea, we are not limited to π.

X can be anything like $\pi\pi^0$ (ρ), πππ ($a_1$), ηπ, ηρ, ωπ, $KK_S$, KK*.....?!




Efficiency =
for $D^0$: $(BR_{\bar{D}0 \to K\pi} \times \epsilon_K \times \epsilon_\pi) \times \epsilon_X$

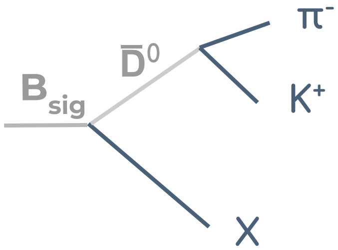
for $D^{*0}$: $(BR_{\bar{D}^{*}0 \to \bar{D}0\,\pi 0} \times \epsilon_{\pi 0} \times BR_{\bar{D}0 \to K\pi} \times \epsilon_K \times \epsilon_\pi) \times \epsilon_X$

Here, D* has lower efficiency than D.

Efficiency =
$\epsilon_{B\text{-}tag} \times \epsilon_X$

Here D* and D have same efficiency!

# Exclusive vs Partial reconstruction




To extend on this idea, we are not limited to π.

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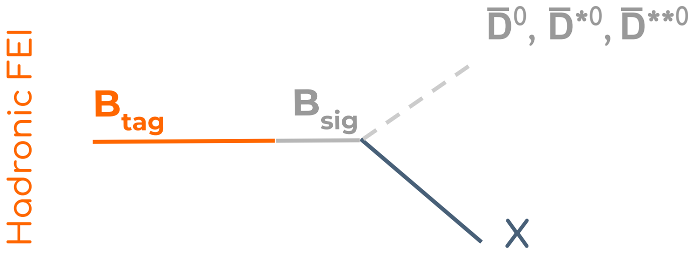
$\pi\pi^0$ (ρ), $\pi\pi\pi$ ($a_1$),
ηπ, ηρ, ωπ, $KK_S$, $KK^*$.....?!




Here, D* has lower efficiency than D.

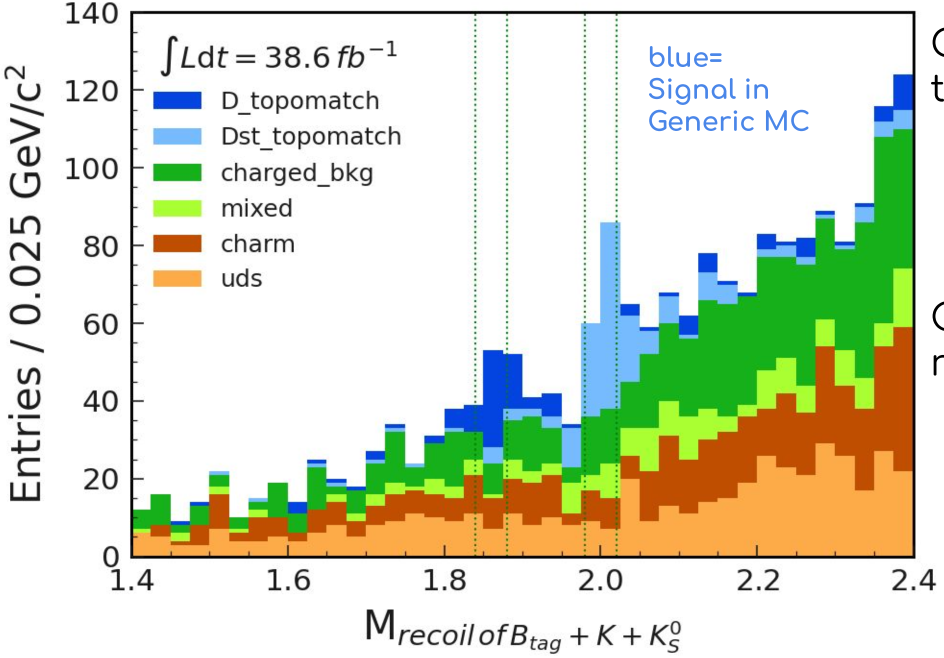
Here D* and D have same efficiency!

Both procedure look at different events:

Events with $B \to D^{(*(*))} X$ where the other $B \to$ Had B-tag

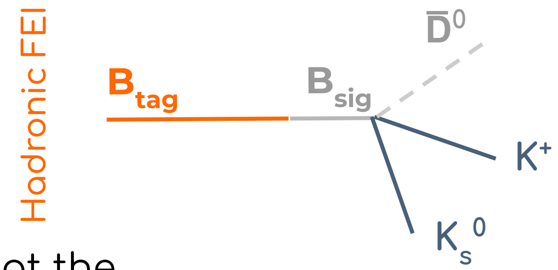
Events with $B \to DX$ where $D \to K\pi$

# Example: DKK partial reconstruction

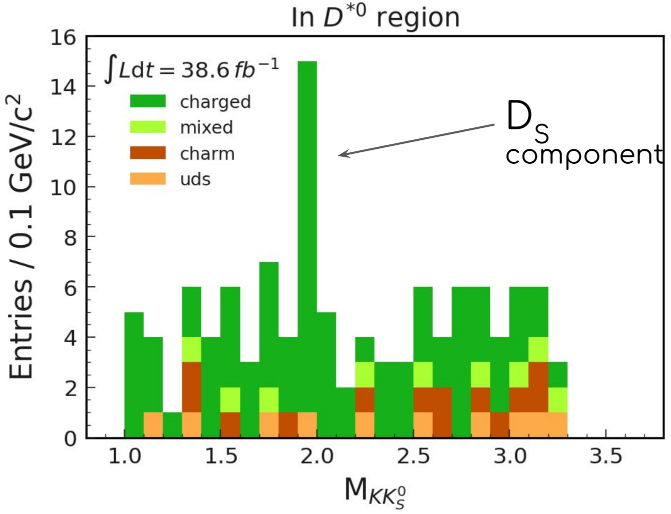



[Valerio Bertacchi is working on exclusive approach]

One can fit to get the BR




Can also look at the resonant contributions:




| Efficiency (%) | Exclusive* | Partial |
|---|---|---|
| D | ~0.3 | ~0.3 |
| D* | ~0.1 | ~0.3 |

*hep-ex/0207041

Same efficiency!

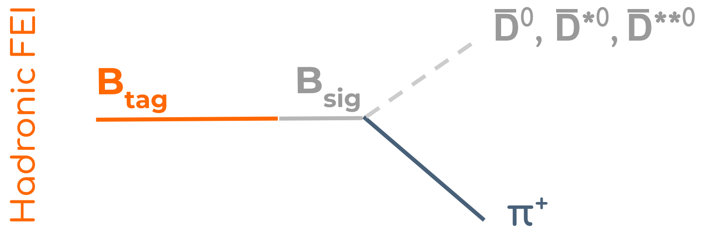
# Baryonic decays with recoil?

$B \to D^{(*)} p\bar{p}\pi$
$\to D^{(*)} p\bar{p}\pi\pi$
$B \to \Lambda_c p\pi$
$\to \Lambda_c p\pi\pi^0$
$\to \Lambda_c p\pi\pi\pi$

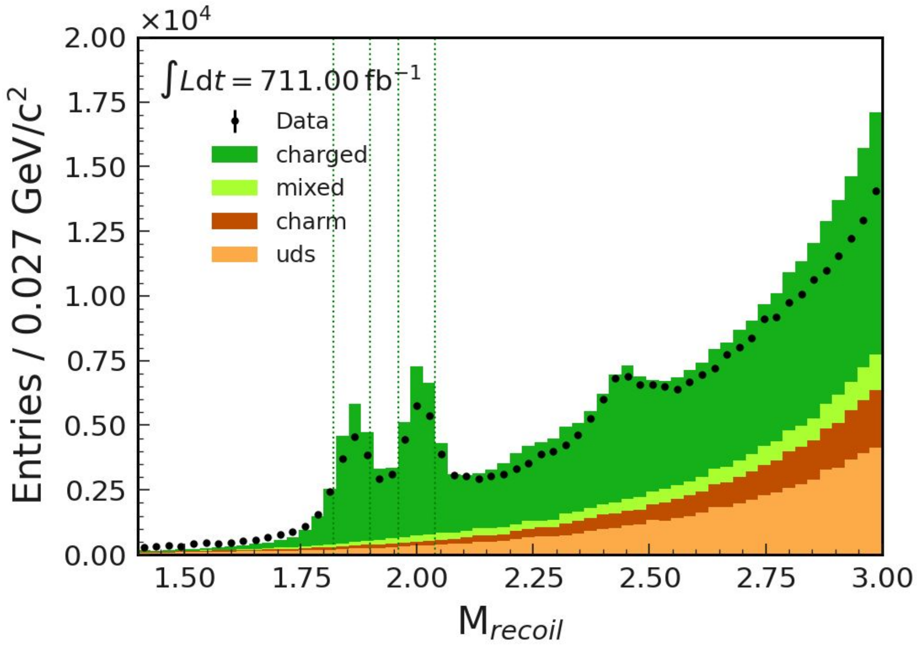
are the baryonic decays of B with the largest branching fractions
(some based on 20 year old CLEO measurements).

Clean enough to study using recoil method i.e., without reconstructing $D^{(*)}$ and $\Lambda_c$.

# D** is more difficult

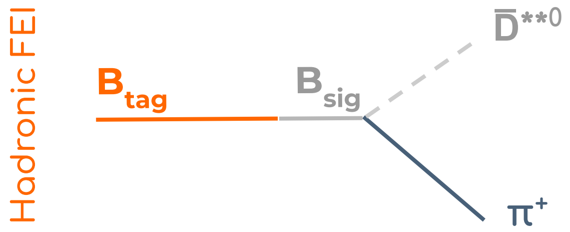


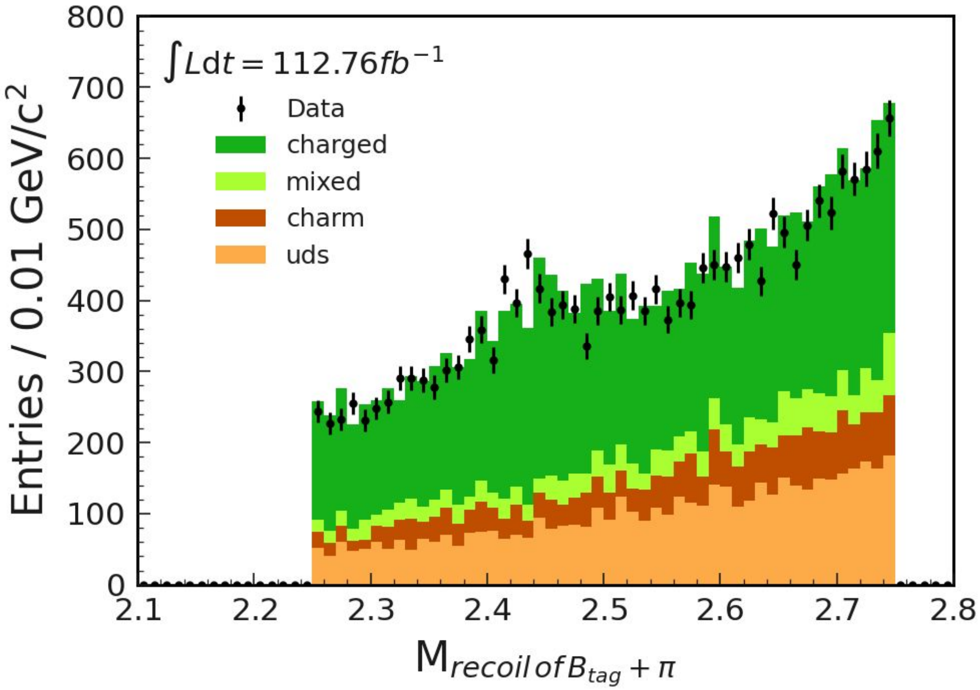

Official Belle MC




The D and D* peaks are narrow and at the low-background region, but D** is more difficult to study here.

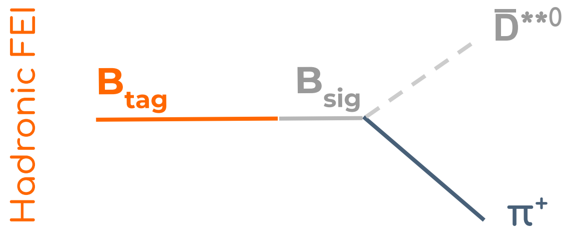
# D** in recoil

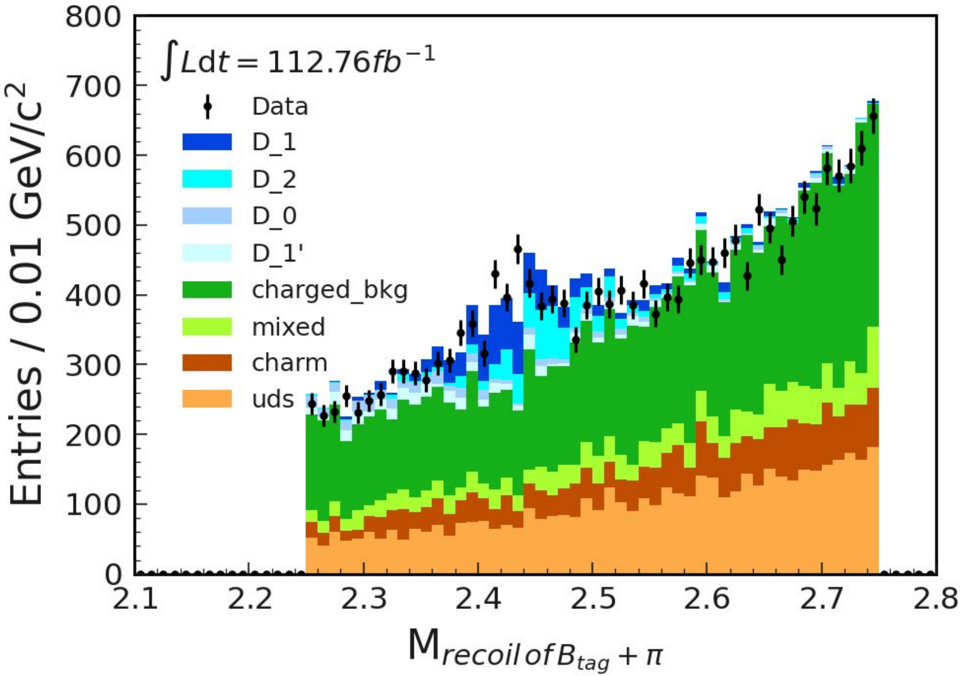



We can first zoom into the D** region.

# D** in recoil

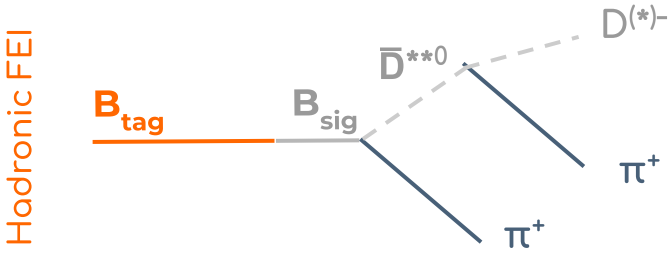



We can first zoom into the D** region.
And focus on the “narrow” D**s: $D_1$ and $D_2$

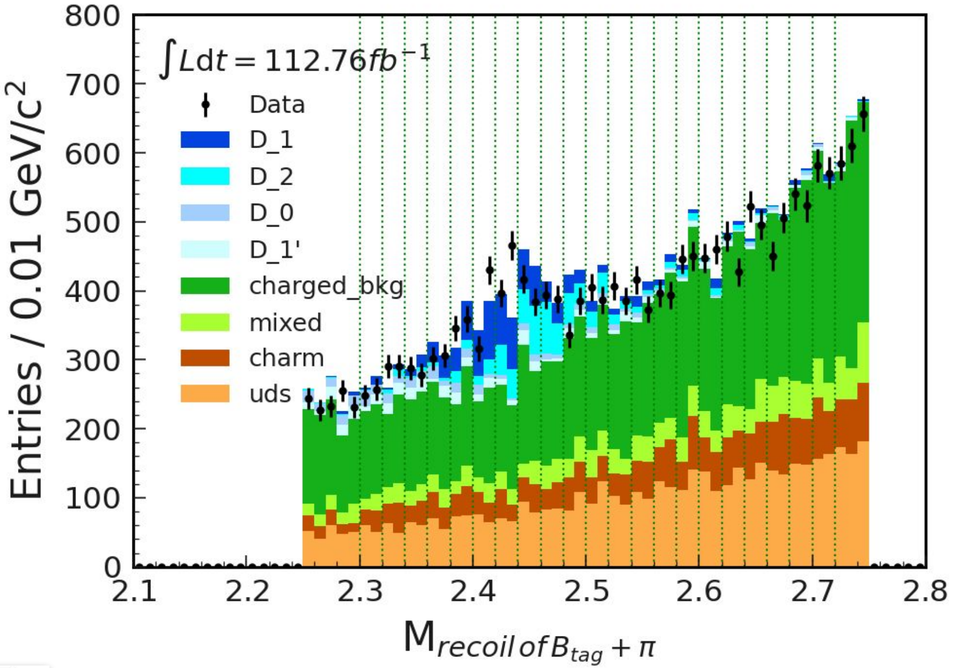
Only 1/10th of data; not optimized, just a demonstration.

# Double-recoil with D** sample




In these events, we can do a "double-recoil" by adding another $\pi^+$

$D_1$ can only decay to $D^{*-}\pi^+$, but
$D_2$ can decay to both $D^-\pi^+$ and $D^{*-}\pi^+$




| | | |
|---|---|---|
| $D_1(2420)^0$ | $D^{*0}\pi^0$ | 0.1997 |
| | $D^{*+}\pi^-$ | 0.3994 |
| | $D^0\pi^+\pi^-$ | 0.1719 |
| | $D^0\pi^0\pi^0$ | 0.1145 |
| | $D^+\pi^-\pi^0$ | 0.1145 |

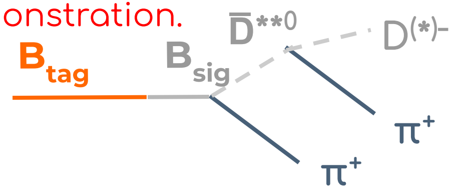
| | | |
|---|---|---|
| $D_2^*(2460)^0$ | $D^{*0}\pi^0$ | 0.1334 |
| | $D^{*+}\pi^-$ | 0.2669 |
| | $D^0\pi^0$ | 0.1999 |
| | $D^+\pi^-$ | 0.3998 |

Only 1/10th of data; not optimized, just a demonstration.

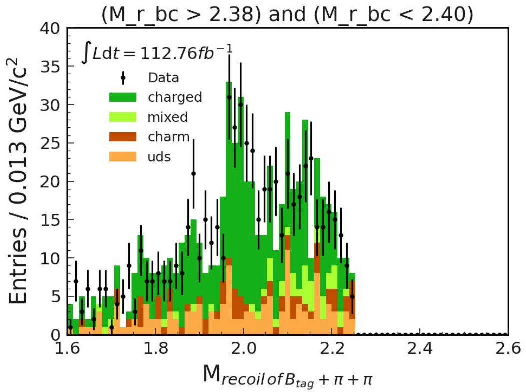
IJCLab

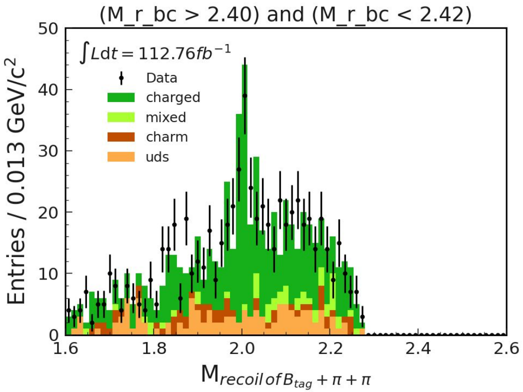
Only 1/10th of data; not optimized, just a demonstration.

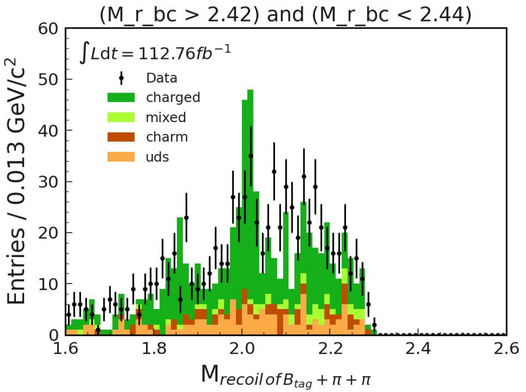
# Double-recoil with D** sample



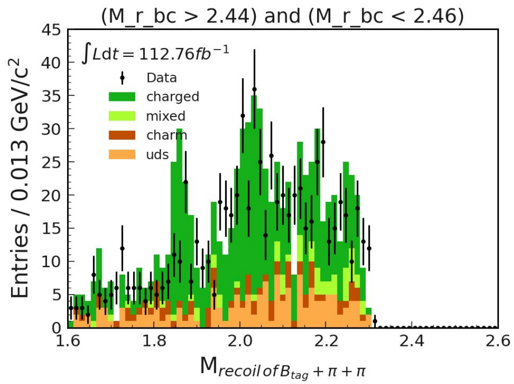

As expected, in the region of $D_1$, we see mostly $D^{*-}$:

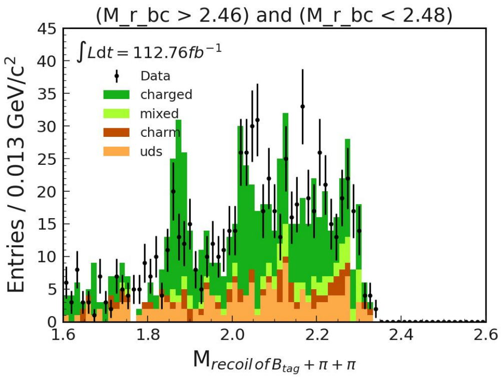


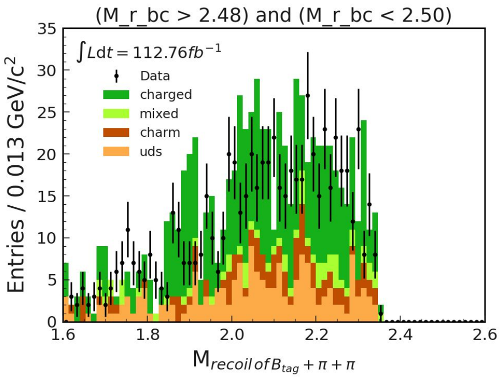



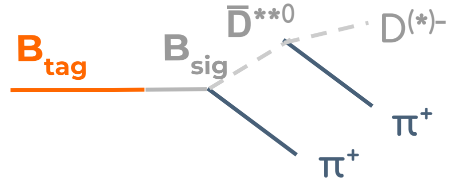

And in the region of $D_2$, we see both $D^-$ and $D^{*-}$:



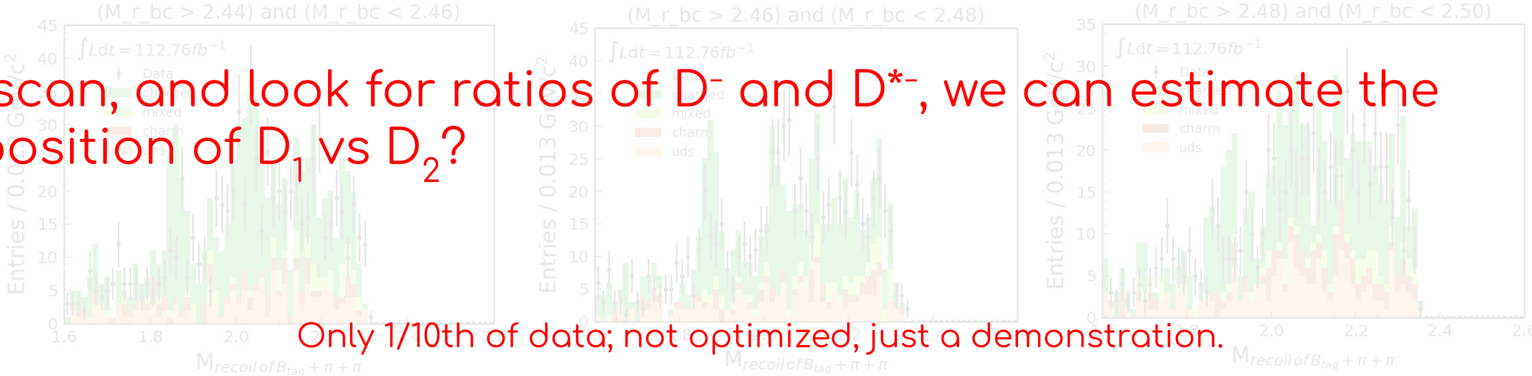
# Double-recoil with D** sample




As expected, in the region of $D_1$, we see mostly $D^{*-}$:




And in the region of $D_2$, we see both $D^-$ and $D^{*-}$:




If we scan, and look for ratios of $D^-$ and $D^{*-}$, we can estimate the composition of $D_1$ vs $D_2$?

Only 1/10th of data; not optimized, just a demonstration.

# Summary We don't need to reconstruct the $D^{(*)}$ or $\Lambda_c$ exclusively.

- There are many problems other than anomalies.

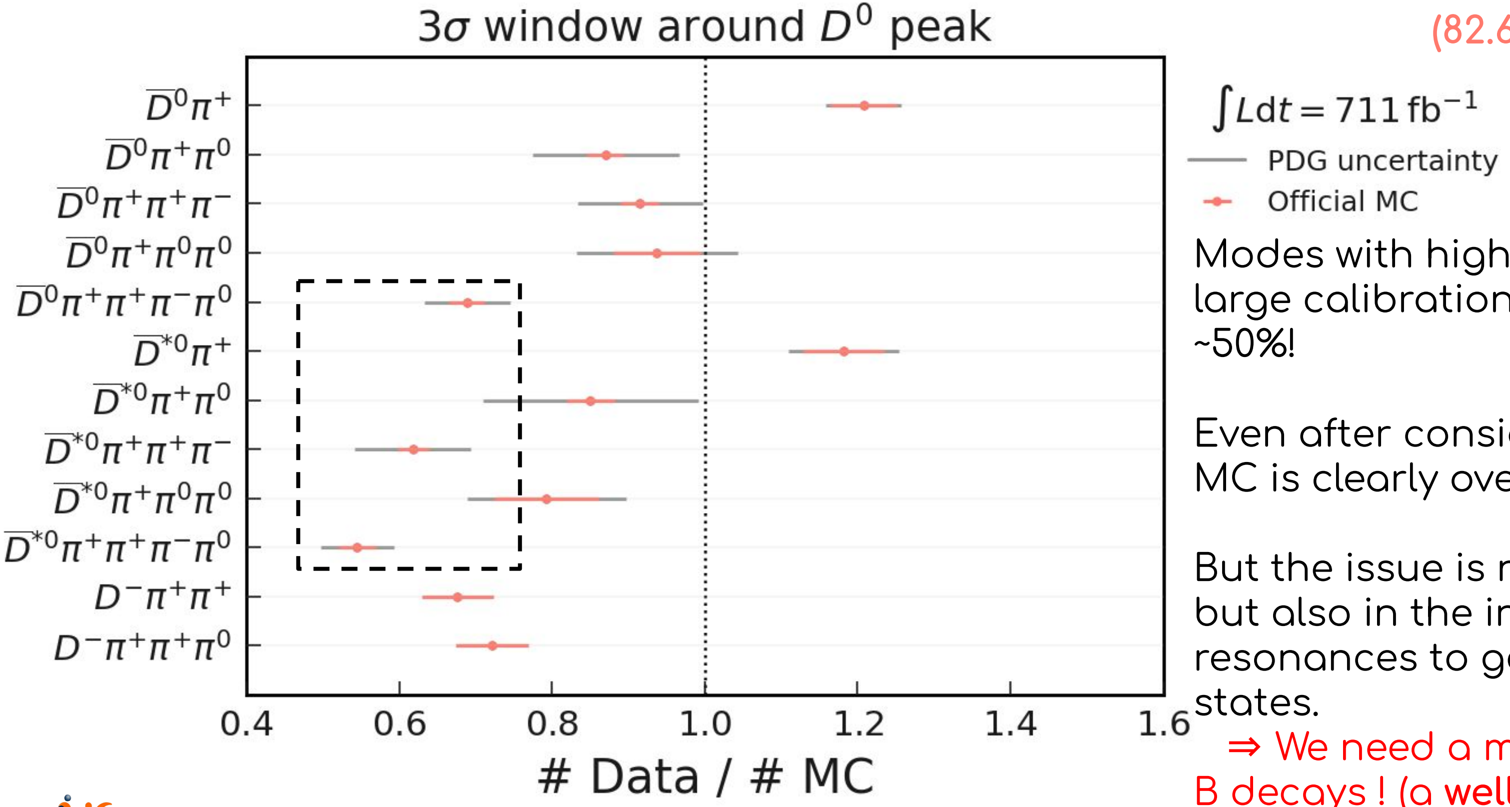
- Studying $B \to D^{(*)}\eta\pi$ and $B \to D^{(*)}\eta\rho$ along with possible intermediate resonances like $D^{**}$ or D(2S) will be a crucial input for understanding SL-gap and $V_{cb}$.
- Studying the decays of $D^{**}$ and D(2S) is also essential (charm physics)

- Demonstrated the performance of reconstruction $B \to D^{(*)}\pi$ with recoil-mass method.
- Many more exciting possibilities with recoil:
  - $B \to D^{(*)}\,\pi\pi^0\,(\rho)$, $B \to D^{(*)}\,\pi\pi\pi\,(a_1)$,
  - $B \to D^{(*)}\,\eta\pi$, $B \to D^{(*)}\,\eta\rho$, $B \to D^{(*)}\,\omega\pi$,
  - $B \to D^{(*)}\,KK_S$, $B \to D^{(*)}\,KK^*$
  - $B \to D^{(*)}p\bar{p}\pi$, $B \to D^{(*)}p\bar{p}\pi\pi$
  - $B \to \Lambda_c p\pi$, $B \to \Lambda_c p\pi\pi^0$, $B \to \Lambda_c p\pi\pi\pi$

# Backup

# Calibration factors per mode

## with PDG uncertainties




Overall calibration factor:
(82.6 ± 0.9)%

Modes with high multiplicity have large calibration factors! Even ~50%!

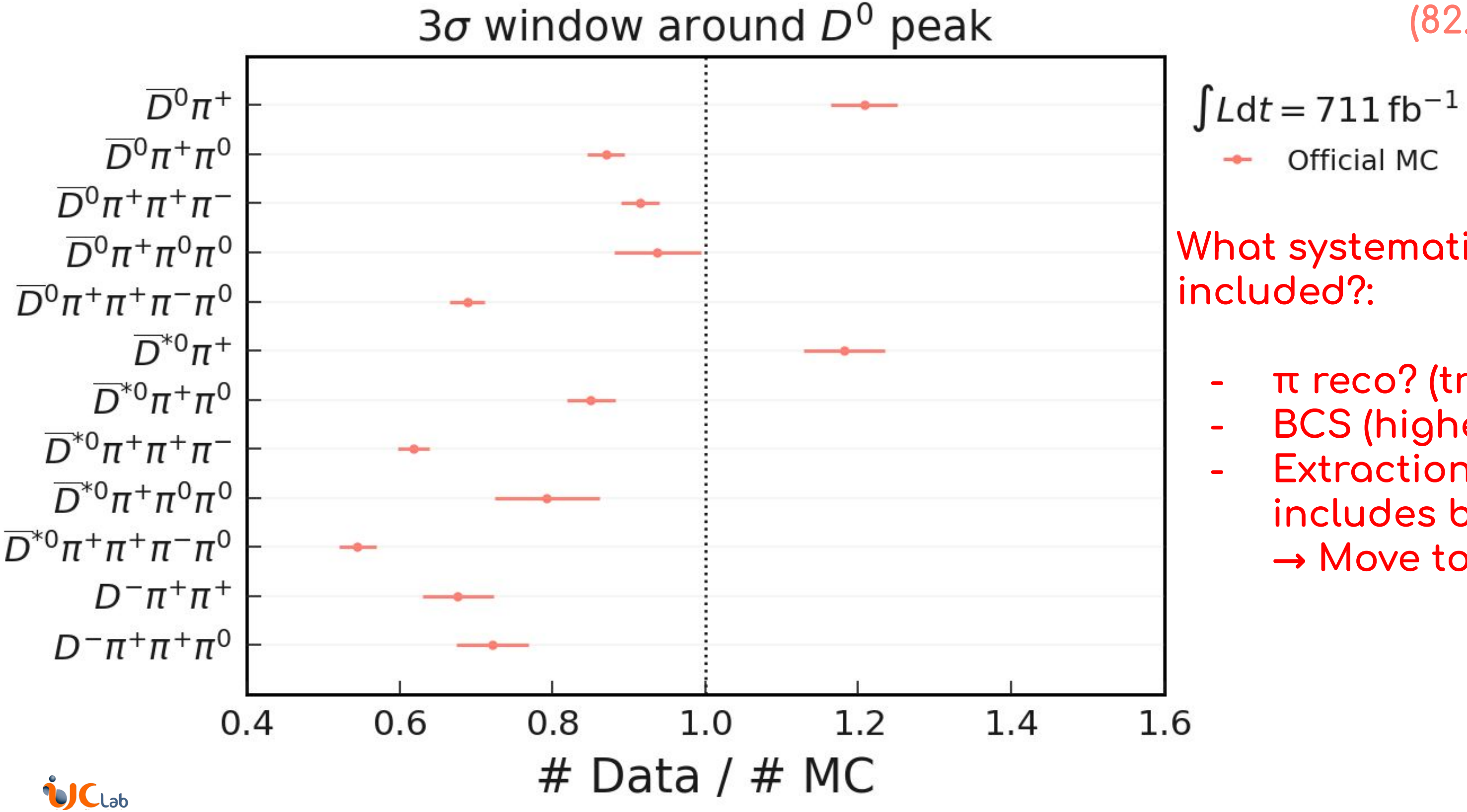
Even after considering PDG uncert, MC is clearly overestimating.

But the issue is not just in scaling, but also in the intermediate resonances to get to these final states.

⇒ We need a model for Hadronic B decays ! (a **well educated and coherent** update of DECAY table)

# Systematics on calibration factors?

By counting the number of events per FEI mode:




Overall calibration factor:

(82.6 ± 0.9)%

What systematics should be included?:

- π reco? (tracking, PID)
- BCS (highest $p_\pi$ in CMS)
- Extraction method (Counting; includes background events) → Move to fitting?

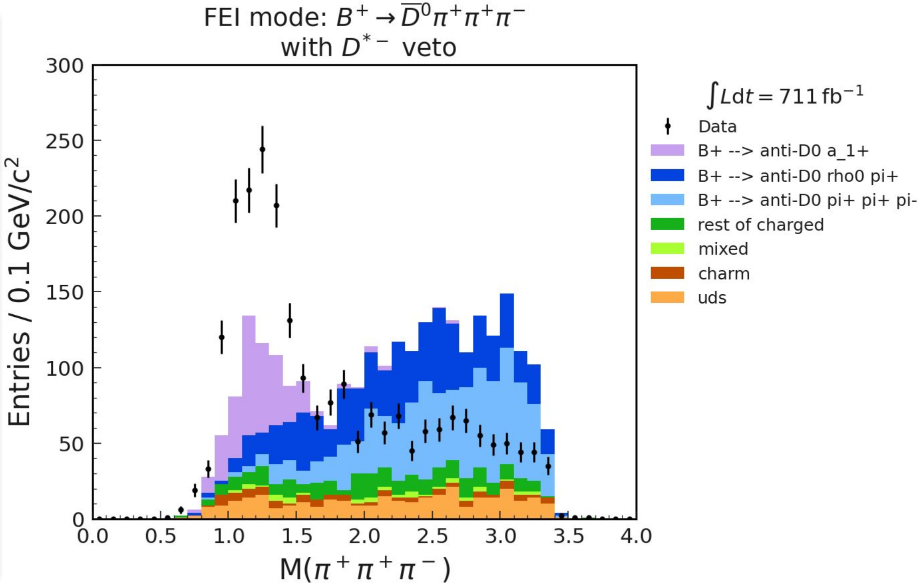
# Case study: $B^+ \to \overline{D}^0 \pi^+\pi^+\pi^-$

Improving calibration factors is not our primary target, instead improving the invariant masses (of intermediate particles), which are used as training variables in FEI will impact efficiency and purity

TABLE VI: Contents of the DECAY file concerning the $B^+ \to \overline{D}^0\pi^+\pi^+\pi^-$ final state and corresponding measurements in PDG [in %].

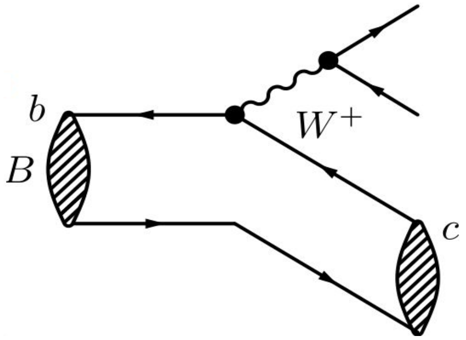
| Decay | Belle | Belle II | Marker | Ref |
|---|---|---|---|---|
| $B^+ \to \overline{D}^0\pi^-\pi^+\pi^+$ | 0.46 | 0.51 | ■ | [8] |
| $B^+ \to \overline{D}^0\rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$ | 0.39 | 0.42 | ★ | [8] |
| $B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$ | 0.13 | 0.14 | ★ | [8] |
| $B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(500)\pi^+; f_0(500) \to \pi^+\pi^-$ | 0.05 | 0.05 | ★ | [8] |
| $B^+ \to \overline{D}_1(2420)^0\pi^+; \overline{D}_1(2420)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$ | 0.04 | 0.02 | | [10], [9] |
| $B^+ \to \overline{D}_1(2430)^0\pi^+; \overline{D}_1(2430)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$ | 0.03 | 0.02 | | [10], [9] |
| $B^+ \to \overline{D}_2^*(2460)^0\pi^+; \overline{D}_2^*(2460)^0 \to D^*(2010)^-\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$ | 0.01 | 0.01 | | [10], [9] |
| $B^+ \to D^*(2010)^-\pi^+\pi^+; D^*(2010)^- \to \overline{D}^0\pi^-$ | - | 0.09 | ■ | [10] |
| $B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \pi^+\pi^+\pi^-$ | - | 0.07 | ★ | [8] |
| $B^+ \to \overline{D}_1(2420)^0\pi^+; \overline{D}_1(2420)^0 \to \overline{D}^0\pi^-\pi^+$ | - | 0.02 | | [10], [9] |
| $B^+ \to \overline{D}^0 K^*(892)^+; K^*(892)^+ \to K^0\pi^+; K^0 \to K^0_S; K^0_S \to \pi^+\pi^-$ | - | 0.01 | | |
| Rest of Exclusive | 0.03 | 0.03 | | |
| Sum of Exclusive | 1.12 | 1.38 | | |
| Sum of PYTHIA | 0 | 0 | | |
| Total Sum | 1.12 | 1.38 | | |

[BELLE2-NOTE-PH-2022-002]




By restudying the CLEO and LHCb measurements for this mode, we realized that the NR and ρ components should be almost 0 and should be dominated by $a_1^+$

# Model for $B \to D^{(*,**)}\, n\pi\, m\pi^0$ decays




$X = \pi, \rho, a_1, \omega\pi, \rho\pi\pi, \eta\pi$

$Y = D, D^*, D^{**}$

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

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

Essentially validation, we do not want to fine-tune (except set 0 there is no signal*).

2 primary rules:

- $D^0 X : D^{*0} X : D^{**0} X$ ~= 1 : 1 : 1
  (based on observation from $D\pi^- : D^*\pi^- : D^{**}\pi^-$ and $D\rho^- : D^*\rho^-$)
- $Y\pi^- : Y\rho^- : Y a_1^-$ ~= 1 : 2.5 : 2.5
  (based on predictions and confirmed with $\tau \to h\,\nu$ decays)

Additional information:

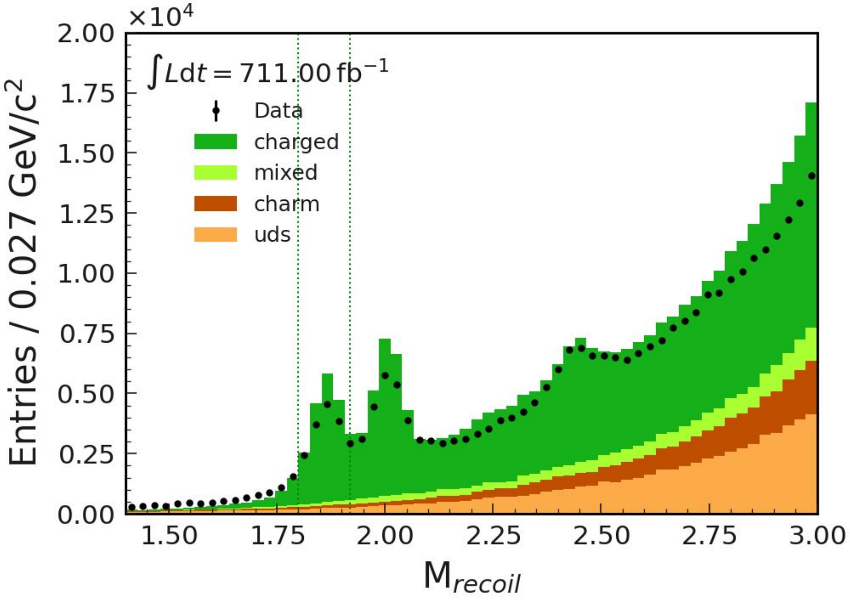
- $3\pi\,\pi^0$ is hard to model without some sort of ρ' resonance
  - For **ωπ** we fix from measurements.
  - For **ρππ** and **ηπ**, we let PYTHIA generate it.
- Decays of D** particles is synchronized with Belle II
- The fraction of 4 different D** is fixed based on observations.

*See backup

# Validation by embedding signal MC

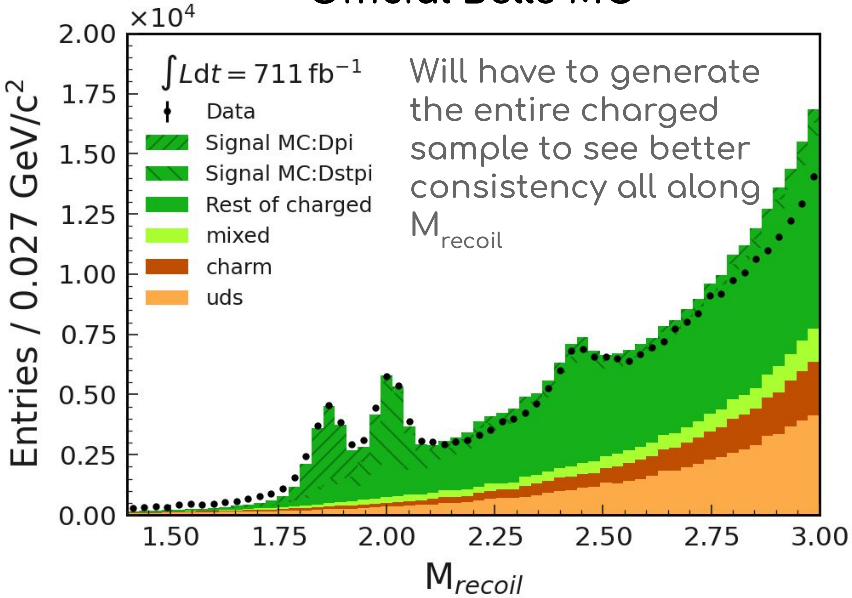
To **quickly study the impact of the modified DECAY.DEC** file, generated Signal MC of $B \to D^{(*)}\pi$ (other B decays updated) and replaced corresponding events in the generic Charged MC:

**Official Belle MC**



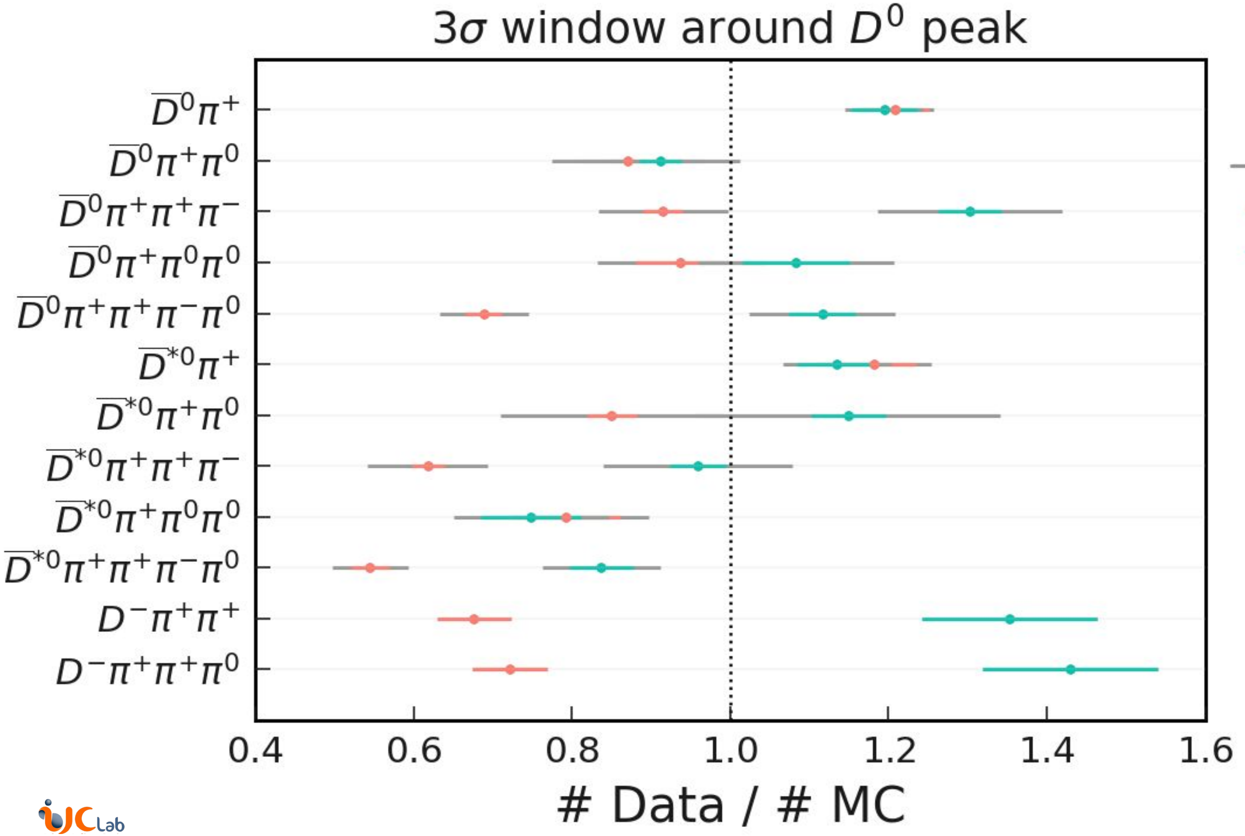

→

**Modified Signal MC embedded in Official Belle MC**



# Updated calibration factors

## per mode




Overall calibration factor:

(82.6 ± 0.9)%

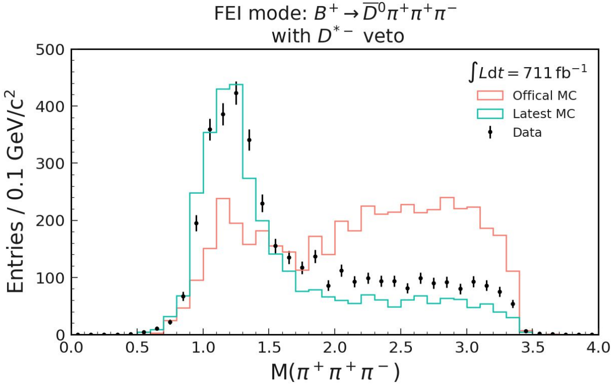
↓

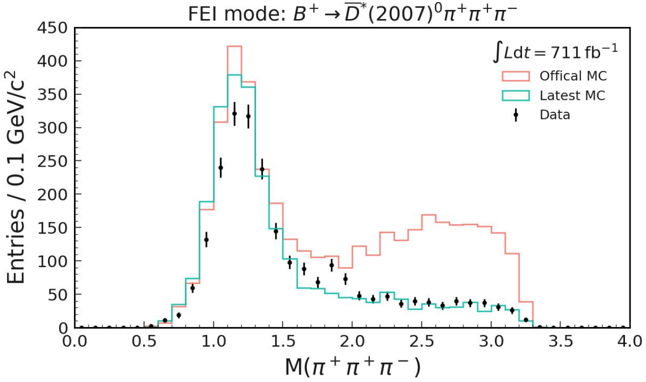
(104.2 ± 1.2)%

# Decay description is improved!

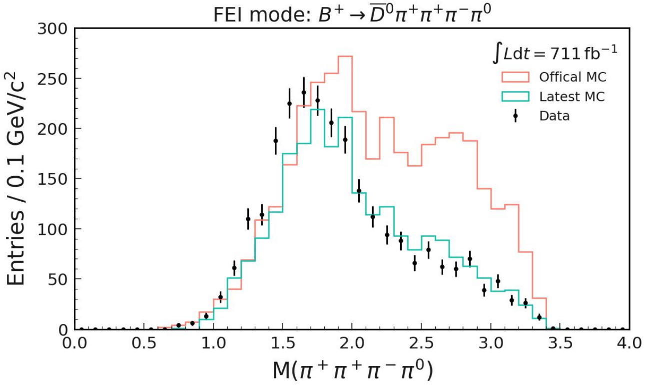
The improvement is not limited to calibration factors, but more importantly in the invariant masses (of intermediate particles), which are used as training variables in FEI

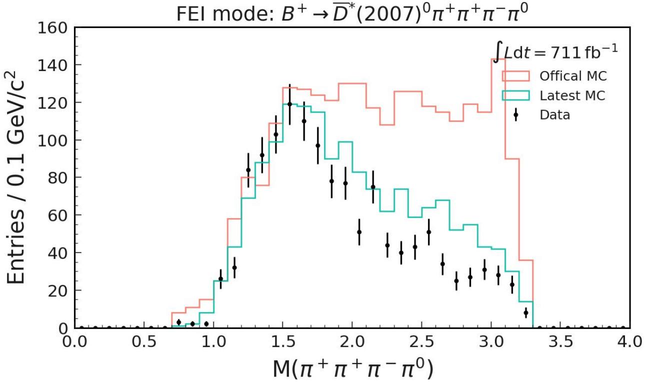
3π± case:



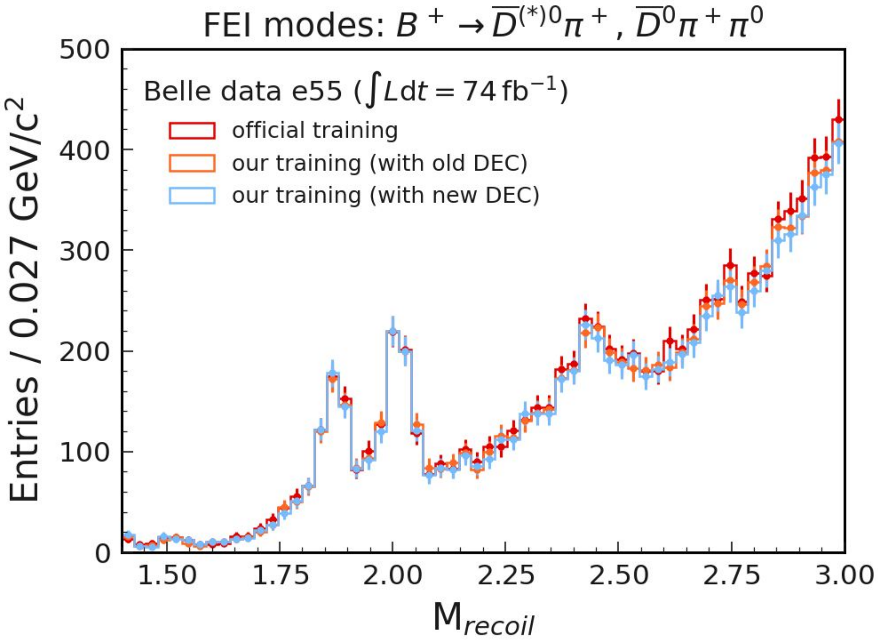



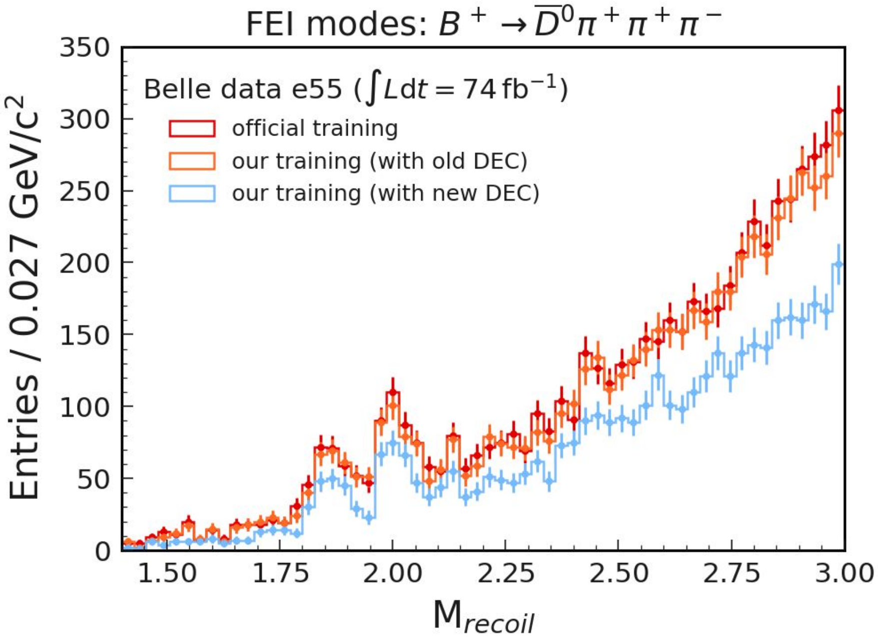

3π± π⁰ case:



# Retraining FEI: Validation



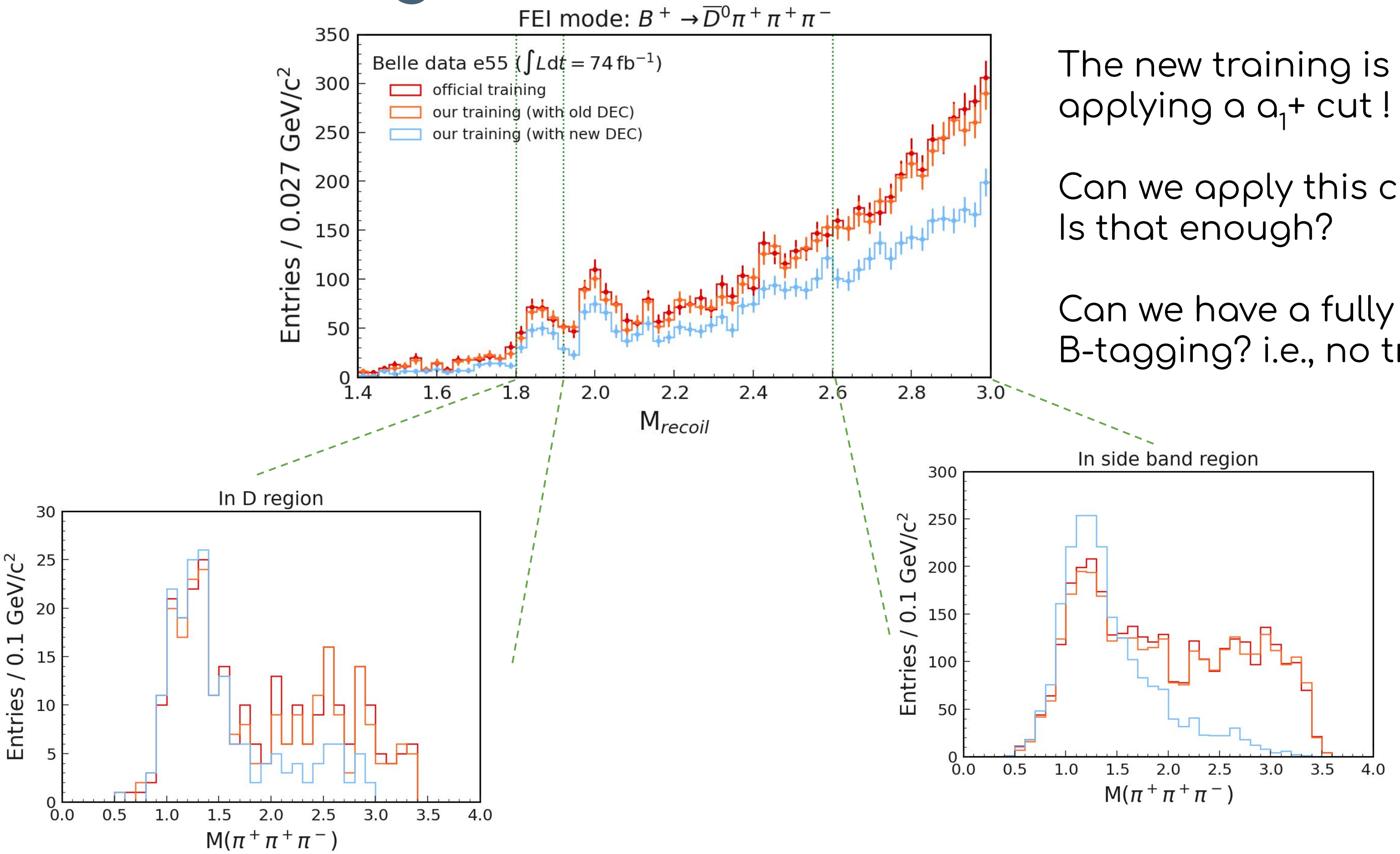




Nothing changes in the FEI modes where we did not change anything.

There is a significant background reduction in FEI modes where MC model is improved.

Our training has some issues while reconstructing modes with $\pi^0$, under investigation… (see backup)

# Retraining FEI: Effective cuts

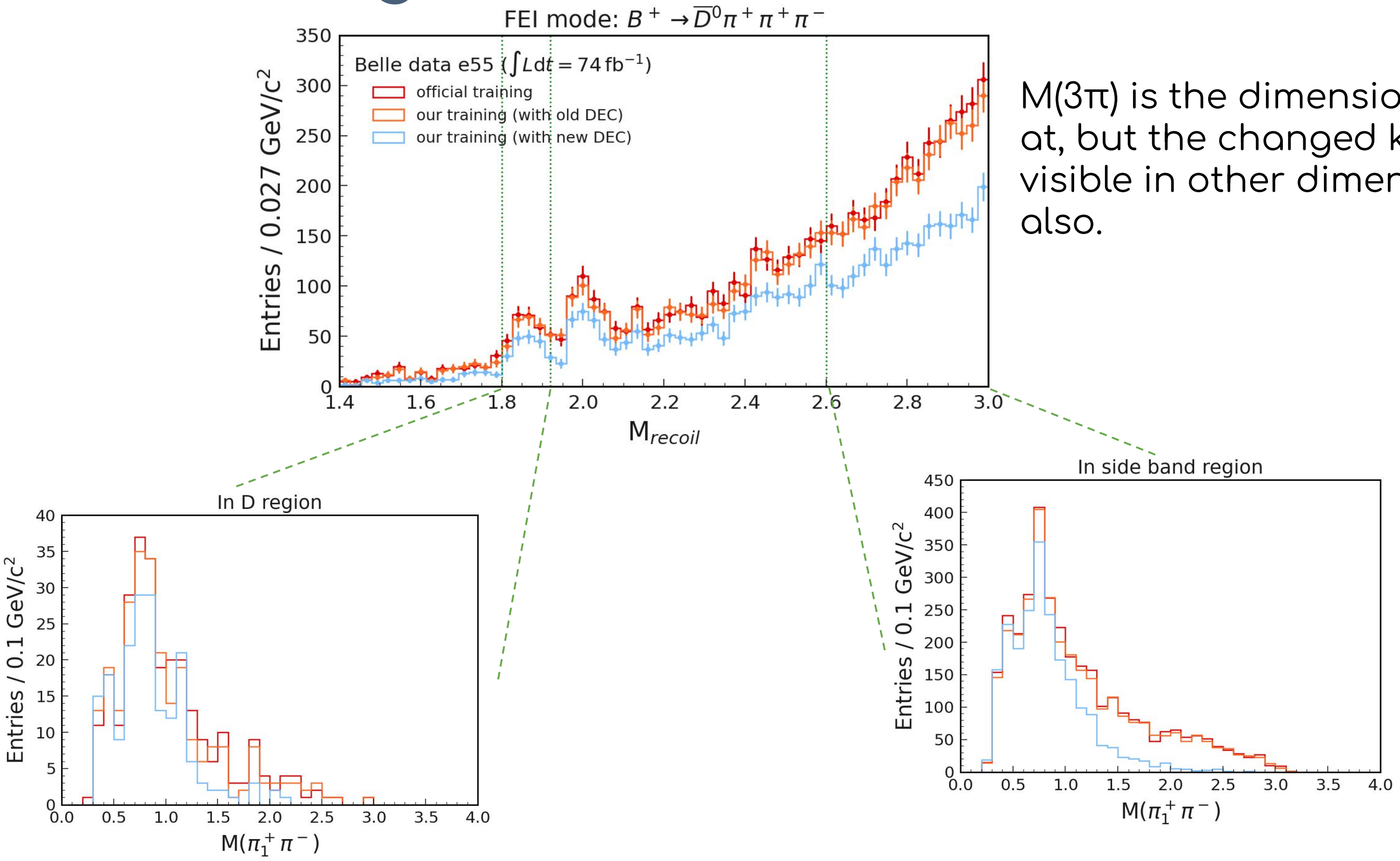



The new training is effectively applying a $a_1$+ cut !

Can we apply this cut manually? Is that enough?

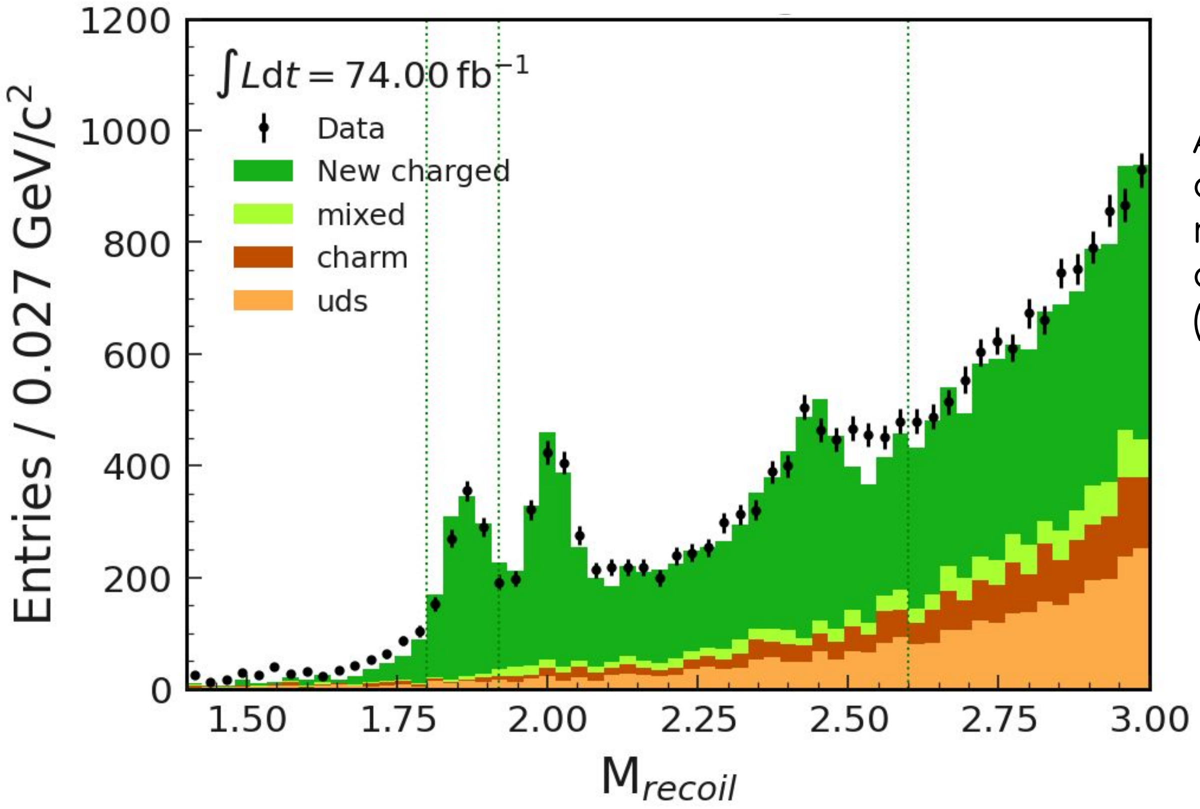
Can we have a fully cut-based B-tagging? i.e., no training?

# Retraining FEI: Effective cuts




M(3π) is the dimension we usually look at, but the changed kinematics is visible in other dimensions like M(2π) also.

# Retraining FEI: Data-MC agreement




After reconstructing all MC and data with the training based on new DEC, the Data - MC agreement improves too! (even at higher $M_{recoil}$ !)

# $B^+ \to D\pi$ selection procedure

These cuts could be further optimized, but seem good enough for preliminary studies.

The code is present [here]

We start by reconstructing a FEI-Hadronic B with cuts:

- $M_{bc} > 5.27$ GeV/$c^2$
- $|\Delta E| < 0.05$ GeV
- FEI Signal Probability > 0.01

Select a π with:

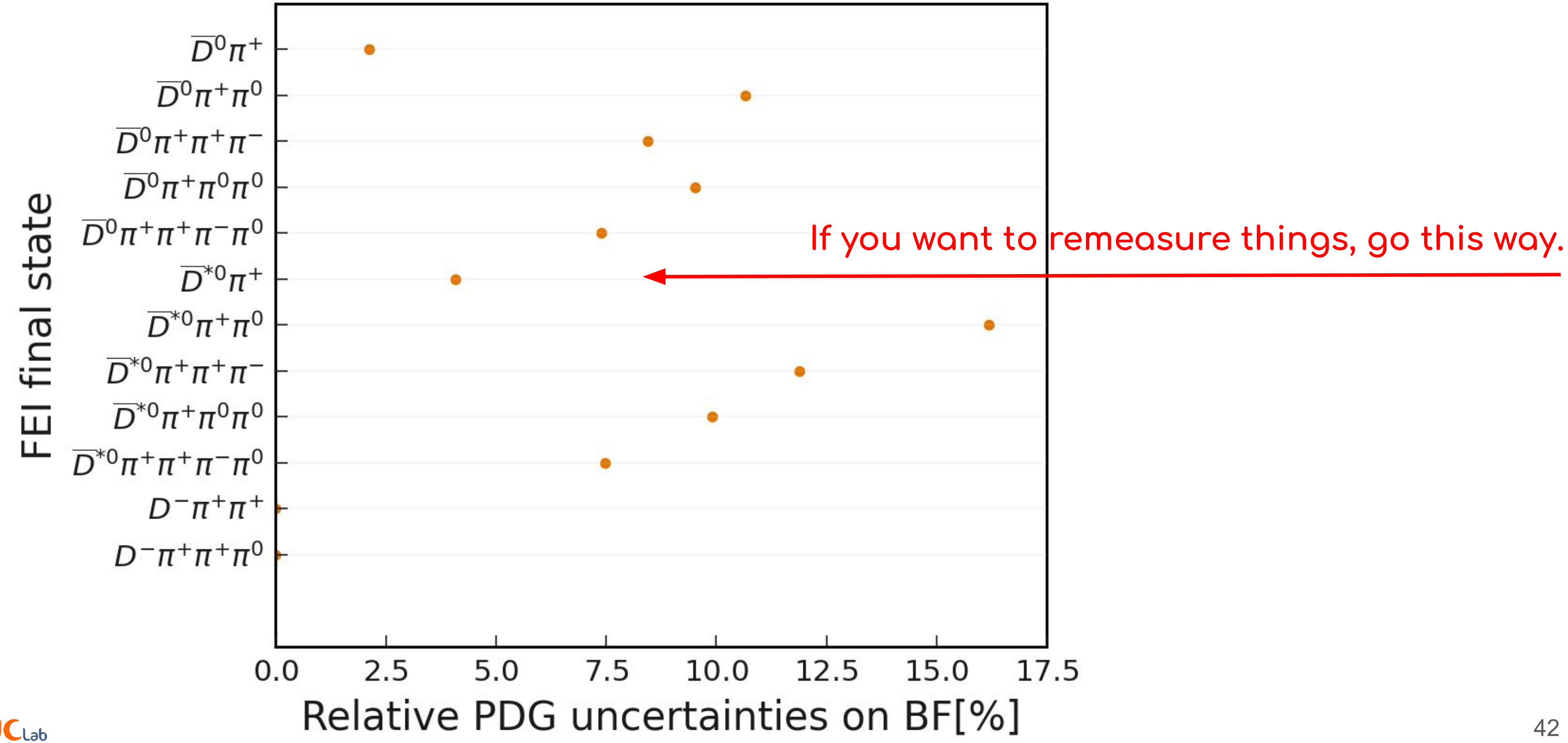
- $|d0| < 1$ and $|z0| < 3$
- $L_{K/\pi} < 0.9$ and μ-id < 0.9 and e-id < 0.9

Simple continuum suppression:

- Event sphericity > 0.2
- $B_{tag}$'s cosTBTO < 0.9

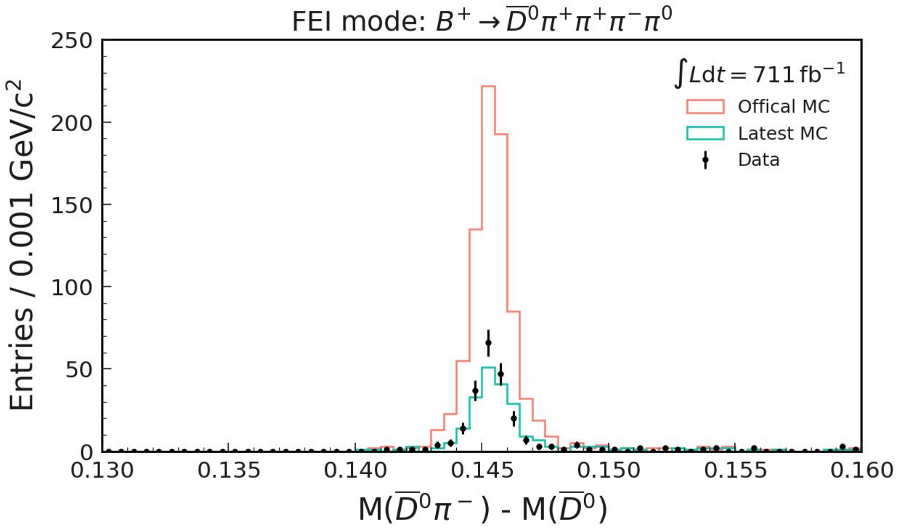
After all this, if there are multiple candidates, we select the one with highest FEI signal probability and highest π momentum in CMS

# Relative PDG uncertainties



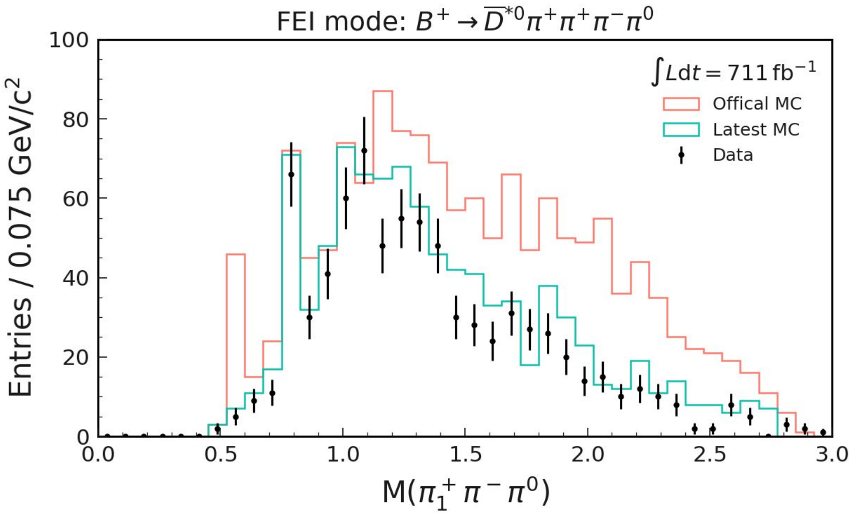
# Changes in DEC not based on measurements: 1/2

## $B^+ \to D^{*-} \pi^+\pi^+\pi^0$




ARGUS measured it to be (1.5 ± 0.7)%
But we see that the contribution coming from D** is enough

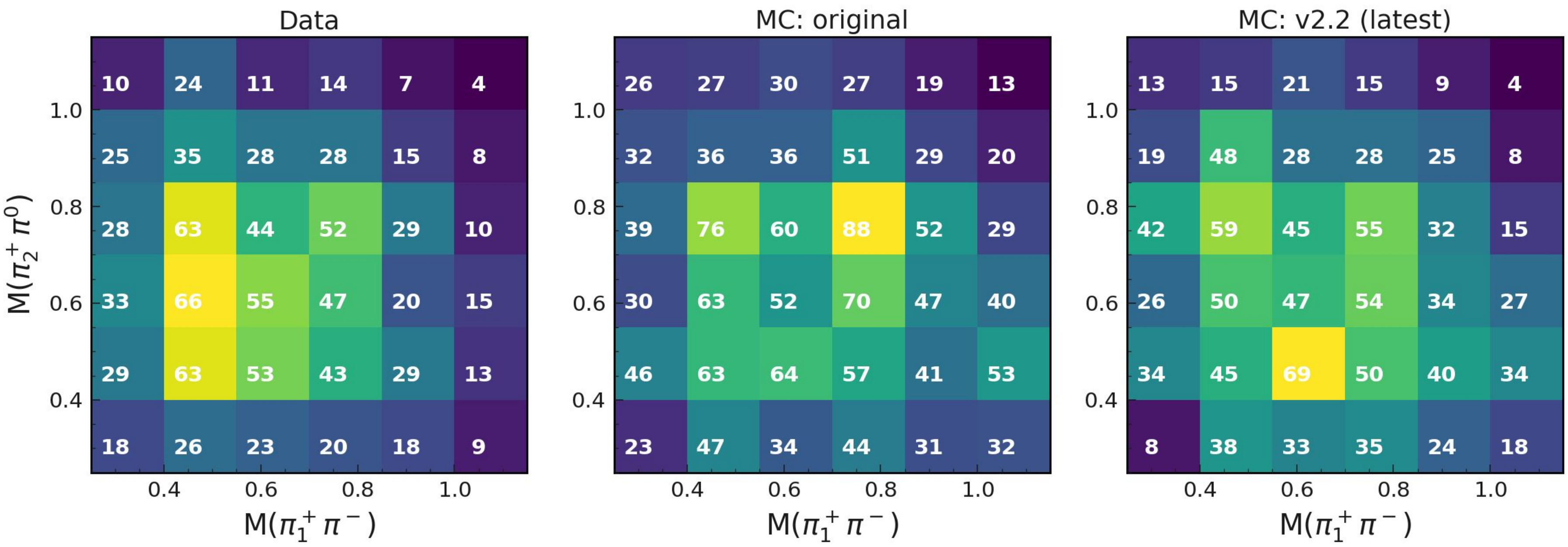
## $B^+ \to \bar{D}^{(*)0} \eta\pi^+$




No measurement, but overestimated by PYTHIA.

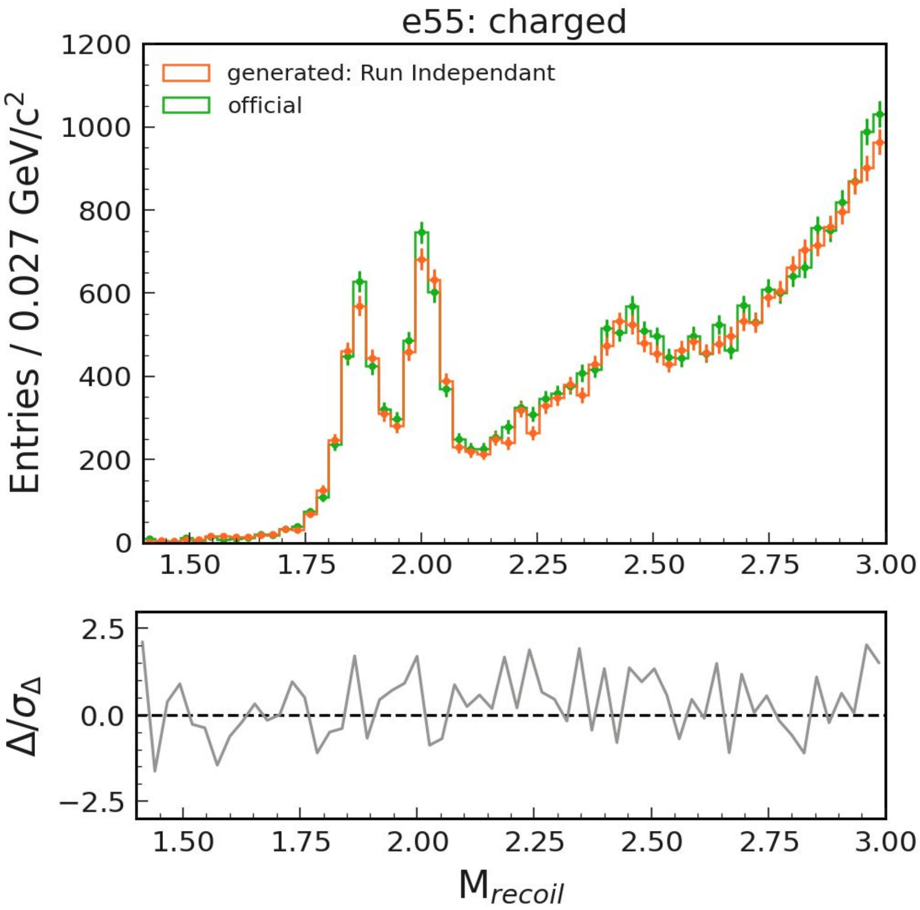
# Changes in DEC not based on measurements: 2/2

$B^+ \to \bar{D}^{(*)} \rho^+ \rho^0$



# Regenerating run-independent* samples

*still exp-dependent BG




Run-Independent sample of 10% seems good enough for comparison?

# Regenerating run-independent* samples

*still exp-dependent BG

With new DEC file: