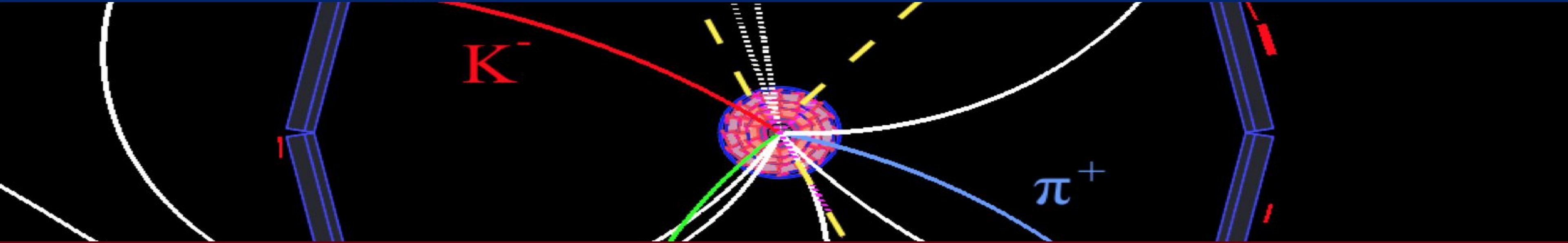
FEI Brainstorm



Belle II Physics Week December 1st, 2022

William Sutcliffe

University of Bonn

Program

- FEI Task Force, performance and calibrations - Will
- B → D pi calibration and more immediate potential improvements - Vidya
- More on potential FEI improvements for the longer term - Will
- A couple of slides on the FEI training - Will

10 mins discussion after each subsection, feel free to ask questions through out.

FEI Task Force, FEI Performance, Calibrations

FEI Task Force

- Confluence: https://confluence.desy.de/display/BI/FEI+Task+Force
- Mailing List: task-fei@belle2.org
- First meeting: Indico 16 Nov and in a person meeting here.
- **Aims:**
  - **Immediate: Robust calibration factors for the LS dataset and MC15ri**
  - Key improvements to be discussed later.

- Time frame
  - next 1-2 months for Moriond 2023, 5-6 months for EPS 2023

- Samples:
  - FEI skims MC15ri_b

FEI skims: currently FEI skims exist for $0.8ab^{-1}$ of generic MC15ri_b, $1ab^{-1}$ of continuum MC15ri_b + the LS1 dataset.

FEI modes	Skim Code
Hadronic B0/B+	11180500
Semileptonic B0/B+	11180600

- Future aims (3-9 months)
  - Improved MC15 (rd) training with improved simulation.
  - Tuning of particle selections and BDTs
  - Extra B modes.
  - Improved vertex fitting (decay tree fitting)

FEI Task Force

https://confluence.desy.de/display/BI/FEI+Task+Force

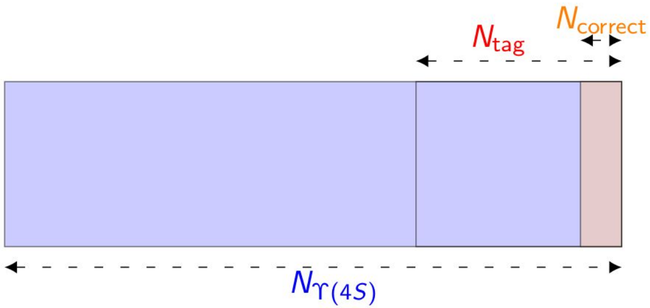
Calibration and FEI performance efforts

The table below gives a list of people expressed their interest to actively participate in sub-group's activities. Please feel free to modify or add information if needed.

Responsible / interested parties	Tag-side modes	Calibration channel / Performance study	Reference
@William Sutcliffe	Hadronic FEI (B+, B0)	B→Xlnu (inclusive, pl fit)	BELLE2-NOTE-PH-2019-031
@Taichiro Koga @Qidong Zhou @Michele Aversano @William Sutcliffe	Hadronic FEI (B+, B0)	B->D(*)lnu	
@Niharika Rout @Vidya Vobbilisetti @Trabelsi Karim	Hadronic FEI (B+)	B+ → D(*)pi+ (partial reco)	BELLE2-NOTE-PH-2022-002
@Meihong Liu @Trabelsi Karim @Vidya Sagar Vobbilisetti	Hadronic FEI (B0)	B0 → D(*)pi+ (partial reco)	BELLE2-NOTE-PH-2022-046
@William Sutcliffe	Hadronic FEI (B+, B0)	Mbc fitting in Data (ROC curves)	
@Andre Hao Yuan Huang @Kevin Varvell	Semileptonic FEI (B+, B0)	B→D(*) l nu	
	Semileptonic FEI (B+, B0)	B → X l nu (inclusive)	
	Semileptonic FEI (B+, B0)	cos theta BY fits in Data (ROC curves)	

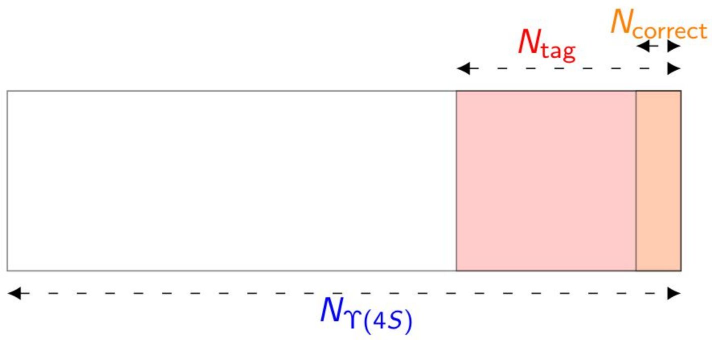
Lacking still some person power for the SL FEI - especially we need cos theta BY fits perhaps also Sydney group (Andre, Kevin et al.) or Markus Roerken

FEI Performance



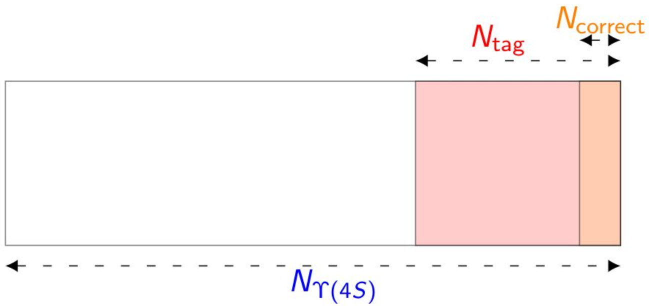
- **tagging efficiency** $= N_{\text{tag}} / N_{\Upsilon(4S)}$
- **tag-side efficiency** $= N_{\text{correct}} / N_{\Upsilon(4S)}$

FEI Performance metrics

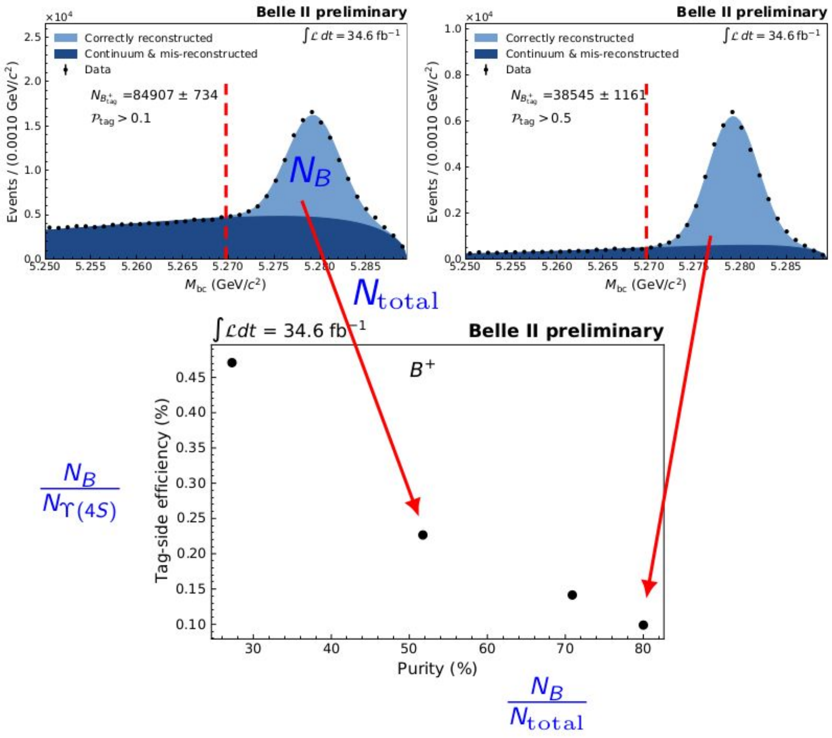


- **tagging efficiency** $= N_{\text{tag}} / N_{\Upsilon(4S)}$
- **tag-side efficiency** $= N_{\text{correct}} / N_{\Upsilon(4S)}$
- **purity** $= N_{\text{correct}} / N_{\text{tag}}$

FEI Performance metrics



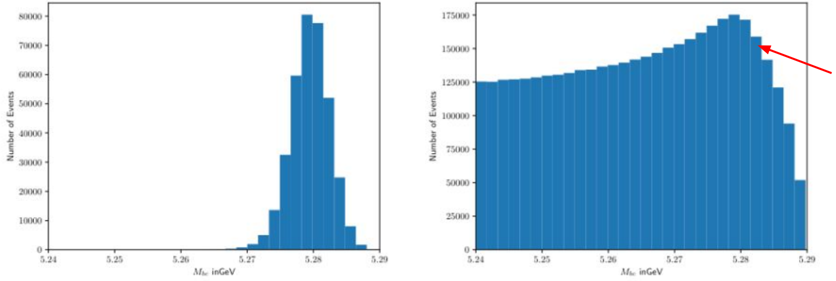
- **tagging efficiency** $= N_{\text{tag}} / N_{\Upsilon(4S)}$
- **tag-side efficiency** $= N_{\text{correct}} / N_{\Upsilon(4S)}$
- **purity** $= N_{\text{correct}} / N_{\text{tag}}$



- Aim: Tag-side efficiency vs purity for both hadronic and semileptonic tag-sides.
- High priority of Moriond 2023 and EPS 2023 but not critical like calibrations.

Big Issue: How is a correct tag-side defined?

- Issues arise regarding the definition of a correct tag.
- Good example of this from Noreen Rauls below.
- She implemented basf2 variables for the % of wrong and missing tag-sides.

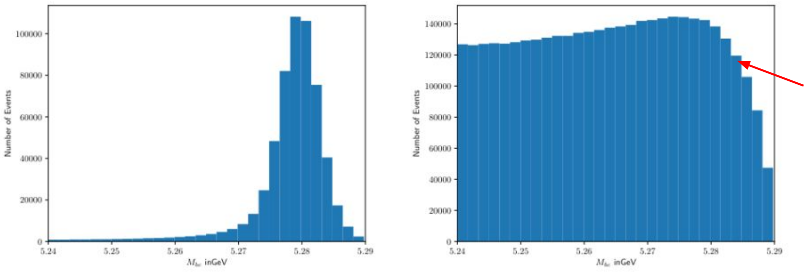


$isSignal == 1$ $isSignal != 1$

FIG. 13: M_{bc} distribution for all B^0 FEI decay modes by applying the provided cut.

"Bad tags" peak

Note: Noreen, Ariane, Racha and Will [BELLE2-NOTE-TE-2021-026]



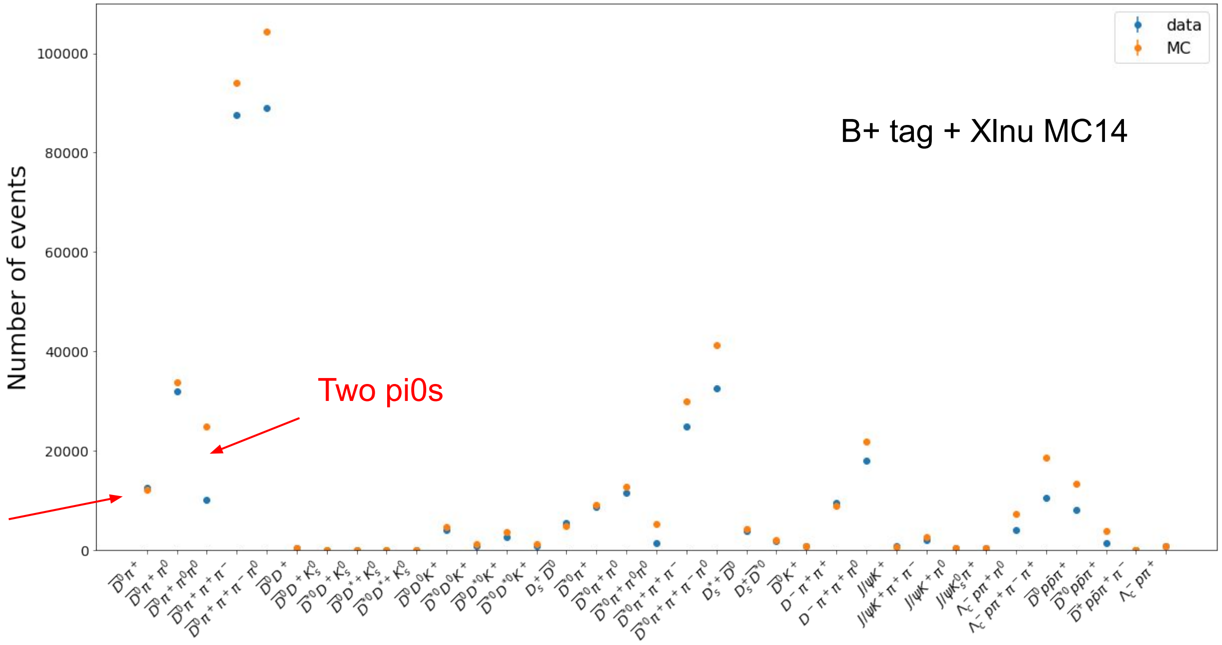
$percentage_{missing} \leq 25$ % and $percentage_{wrong} < 10$ % $percentage_{missing} > 25$ % and $percentage_{wrong} \geq 10$ %

FIG. 17: M_{bc} distribution for all B^0 FEI decay modes by applying the provided cut.

"Bad tags" peak better using new variables:
percentageMissingParticlesBTag
percentageWrongParticlesBTag

One can also use mcErrors as done for Xs gamma [BELLE2-NOTE-PH-2022-021]

The need for calibrations



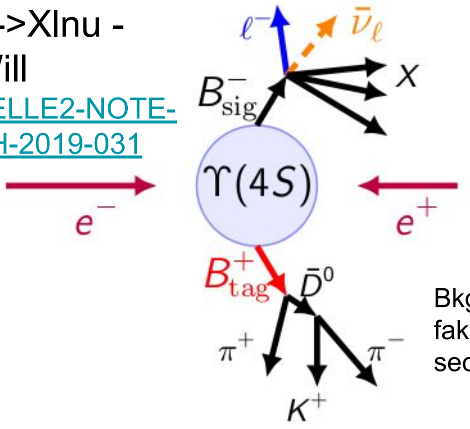
Some tag-sides agree well (less pi0s)

- The algorithm requires independent calibrations for SL and hadronic tag-sides due to the data-MC efficiency mismatch.
- **$\varepsilon = N^{Data}_{cal\ channel}$ (sig prob bin, tag decay mode) / $N^{MC}_{cal\ channel}$ (sig prob bin, tag decay mode)**
- Several calibration channels -> need for combination and application framework eventually.

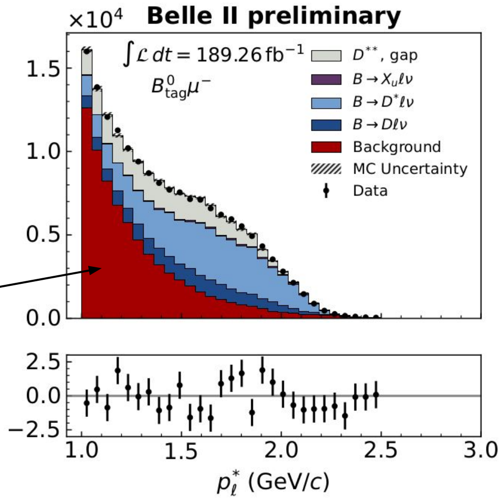
Current Calibration Channels

https://confluence.desy.de/display/BI/FEI+Task+Force

B->Xlnu - Will
BELLE2-NOTE-PH-2019-031

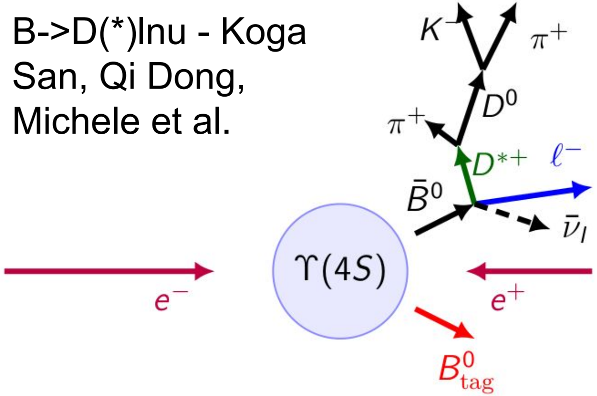


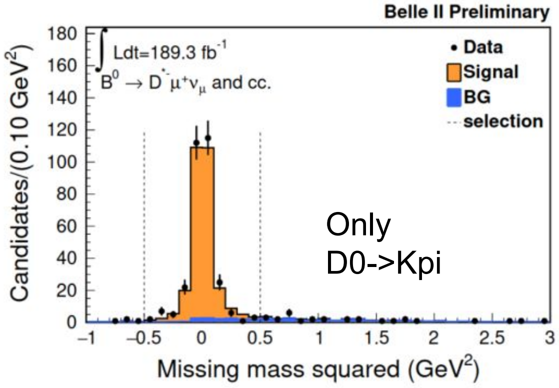
Bkg from cont., fake lep and secondary lep



- High BF (~20%) + single lepton -> lots of Stats
- Only a single lepton so B0 / B+ cross feed issues
- Dominating systematic from the B-> Xlnu BF 3%
- Discrepancy seen between e and mu

B->D(*)lnu - Koga San, Qi Dong, Michele et al.

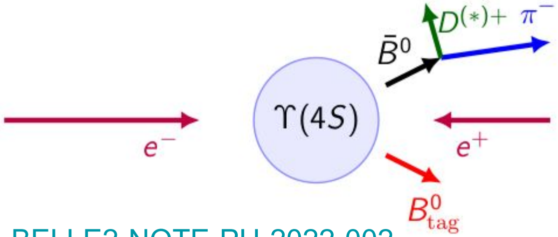




- Very pure but lower stats due to D BF coverage.
- Reconstructed D*+ l nu constrains B+ / B0
- Discrepancy seen between e and mu
- slow pions for D*

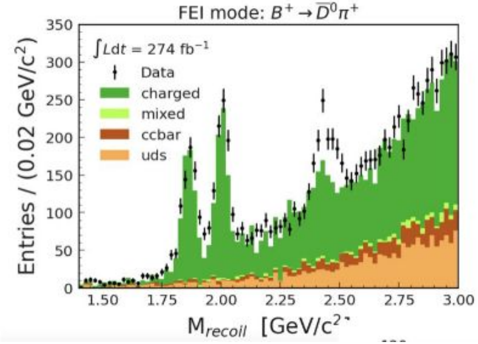
Current Calibration Channels

Partial reco D pi / D* pi - Vidya, Niharika, Karim et al.



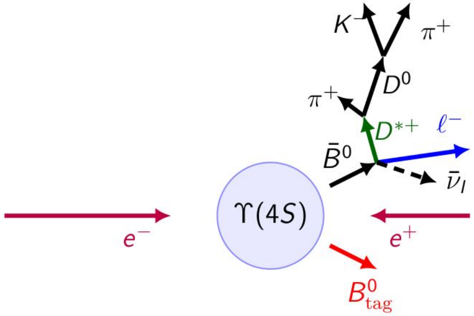
[BELLE2-NOTE-PH-2022-002](#)

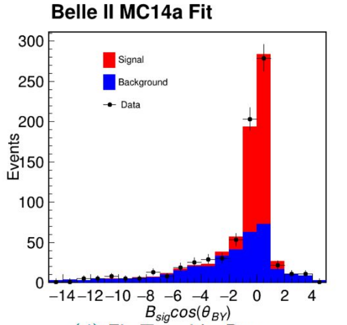
[BELLE2-NOTE-PH-2022-046](#)



- Lower had. branching fraction however partial reconstruction helps boost efficiency -> Moderate stats
- Orthogonal dominating systematic effects (e.g no LID)
- Potential cross feedfeed between tag-side and the signal side. E.g swapped pi+
- B+ (B0)->D pi BF uncertainty ~ 3% (5%) similar for D* pi

SL Tagging + B->D(*) l nu- Andre, Chia-Ling and Kevin



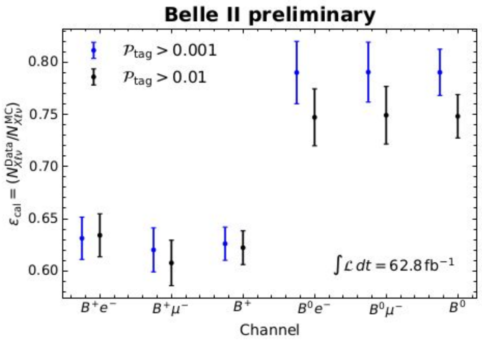


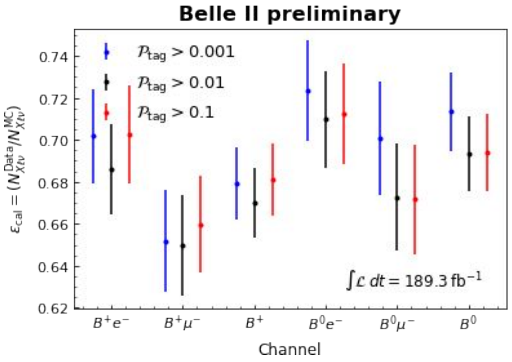
(d) Fit Tag-side $D\mu\nu$

- Low - moderate stats
- Issues with peaking background however reasonable purity.
- Could be signal - calibration correlations as both are semileptonic.

Example of hadronic tag-side cal. factors

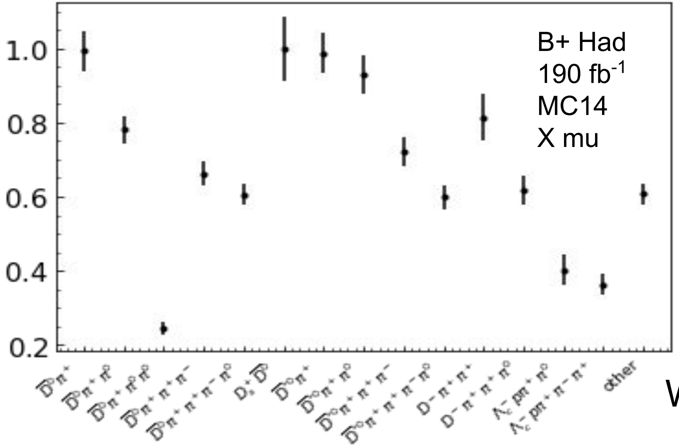
Old format: average cal. factor across tag-side modes



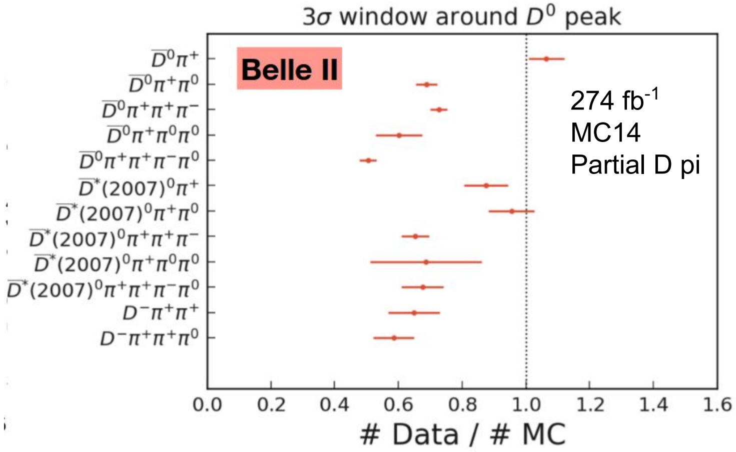


Will

Future format: calibration factors for decay modes, some grouping required



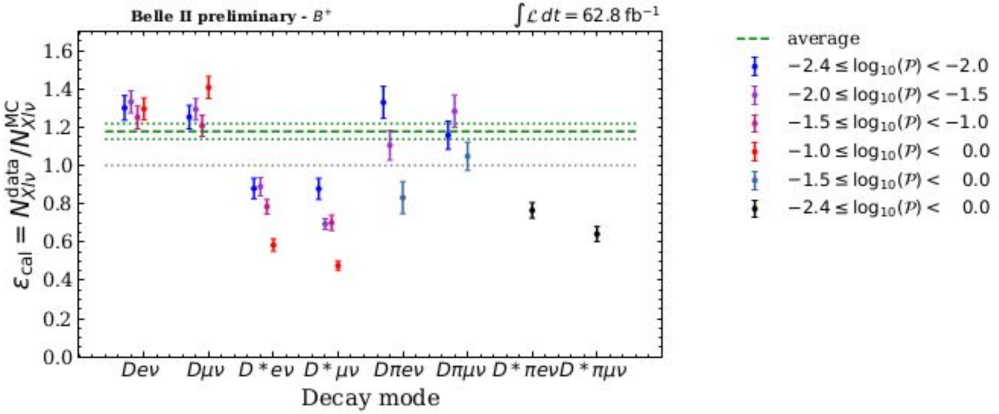
Will

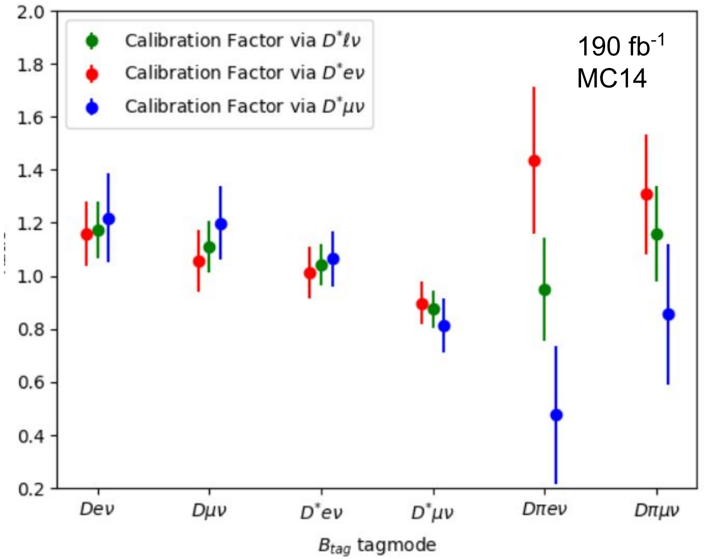


Vidya,
Niharika,
Karim et al.

Example of SL tag-side cal. factors

Old format: split by SL tag-side decay mode





Alina Mantei, Will, Peter et al.
- no more person power

Andre, Kevin and Chia-Ling

New format: split by SL tag-side decay mode, Sig prob cuts 0.001, 0.01, 0.1

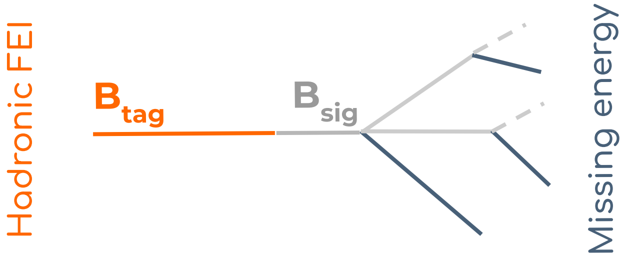
Key Calibration questions

As Peter said users must follow the same key tag-side selection choices of calibrations

- **Which tag-side cuts ?**
  - Had: M_{bc} > 5.27, -0.15 < delta E < 0.1
  - SL: p^*_l > 1 GeV/c , X < cos theta BY < Y
- **Tagside Best Candidate selection**
  - Highest sig prob. (Caveats which will be explained later)
- **Continuum suppression?**
  - cos θ_{TBO} < 0.9 (in the past Fox Wolfram R2 however this is poorly modelled)
- **Granularity of the calibration?**
  - In bins of decay mode for high stat. Modes.
  - Various sig. Prob cuts or bins? At least 0.001, 0.01 and 0.1. (Again caveats later)
- **Other Ideas?**
  - Simultaneous fitting of good and bad tags in the calibration.
  - Double tagging, SL + had. Signal side

Break for discussion (~10 mins)

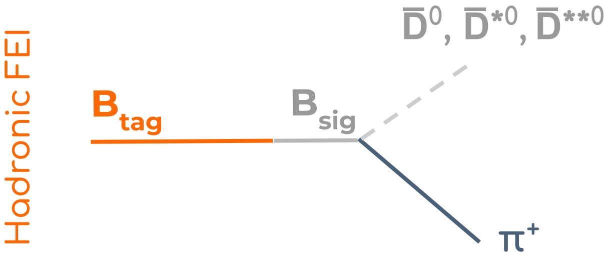
Calibration and first round of improvements with $B \to D\pi$ samples



Gaetano de Marino, Meihong Liu (Fudan), Niharika Rout (Trieste), Karim Trabelsi, Vidya Sagar Vobbilisetti

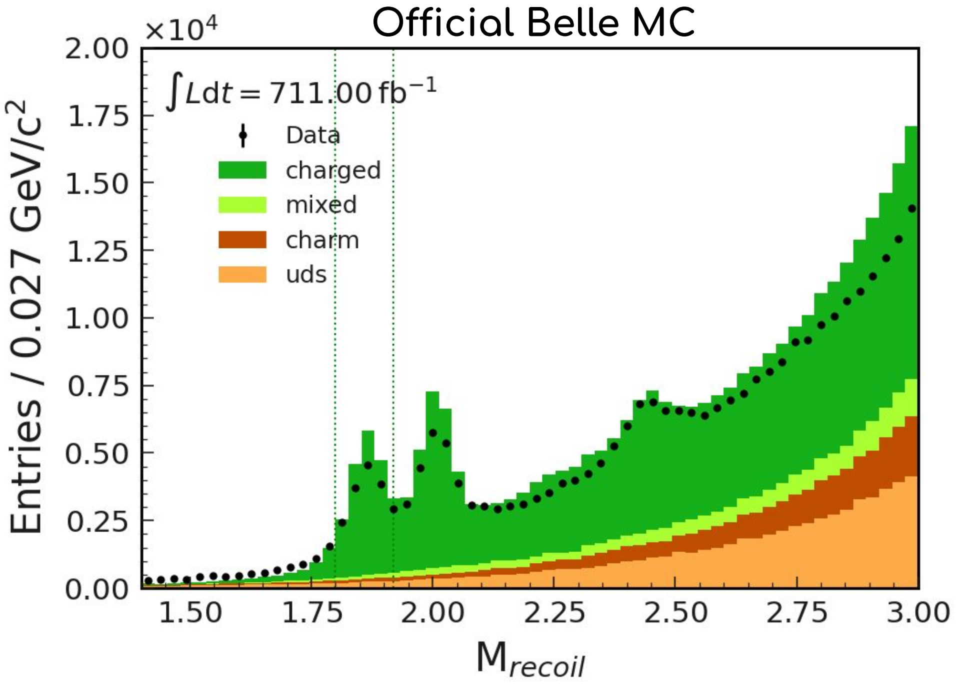
IJCLab Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

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 $\pi^\pm$

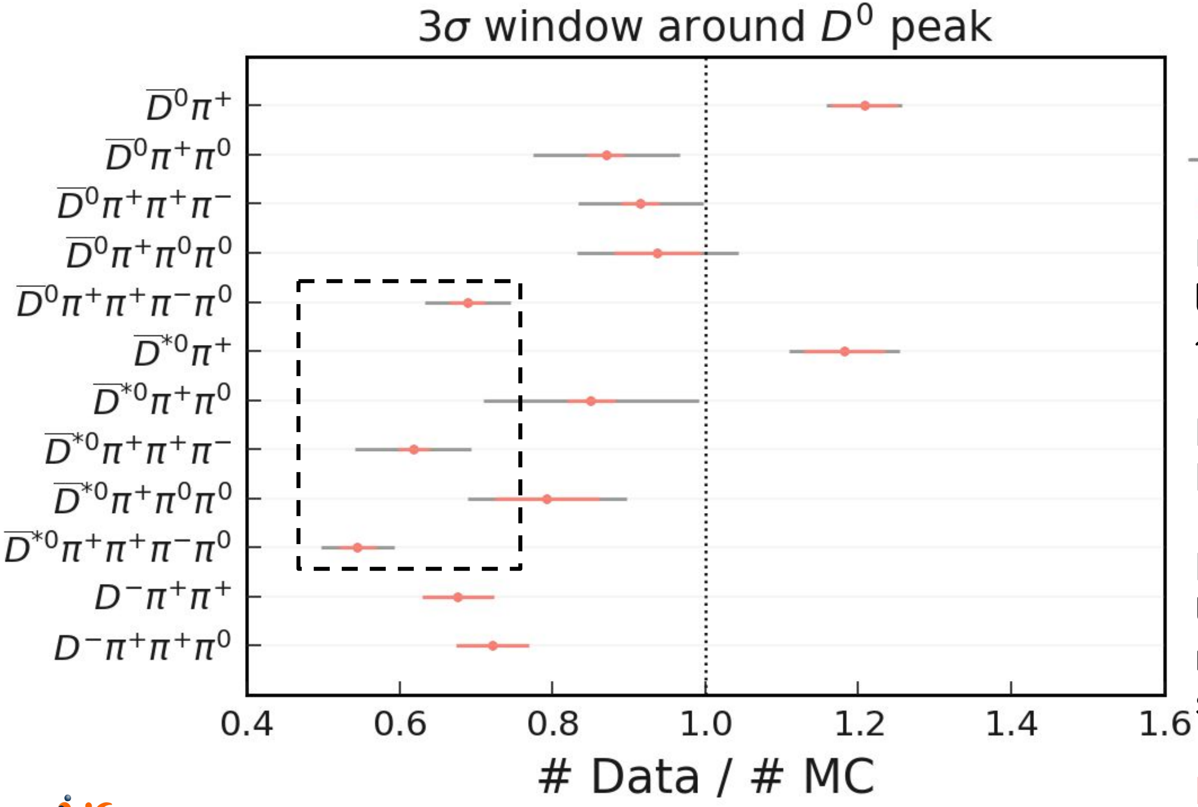
Within a narrow region around the peak, we know that one B decays to $D^0\pi^+$ and we can study the other B (decaying hadronically)



~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]

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)

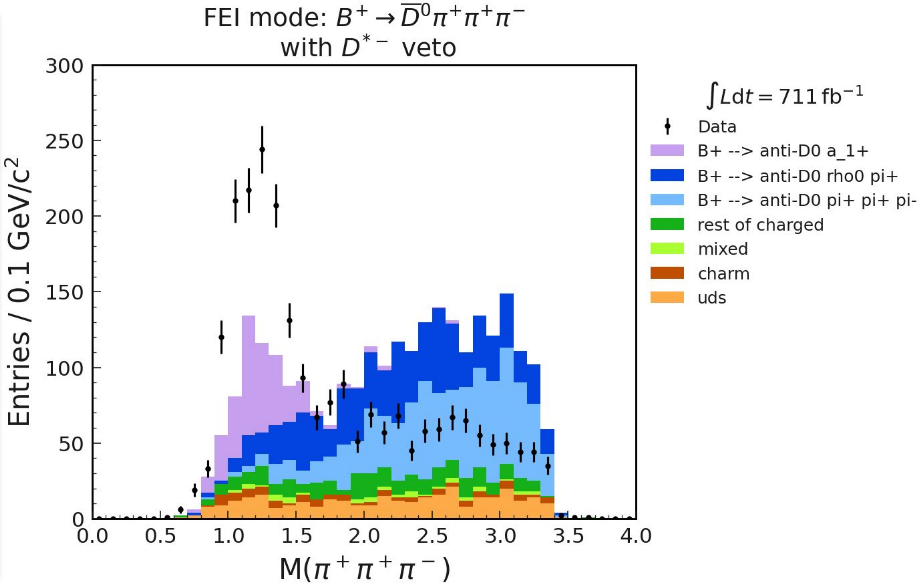
Case study: $B^+ \to \bar{D}^0 \pi^+\pi^+\pi^-$

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 %].

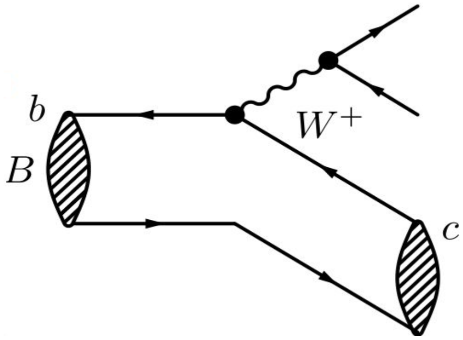
Decay	Belle	Belle II	Marker	Ref
$B^+ \to \overline{D}^0\pi^-\pi^+\pi^+$	0.46	0.51	■	[8]
$B^+ \to \overline{D}^0\rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$	0.39	0.42	★	[8]
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to \rho(770)^0\pi^+; \rho(770)^0 \to \pi^+\pi^-$	0.13	0.14	★	[8]
$B^+ \to \overline{D}^0 a_1(1260)^+; a_1(1260)^+ \to f_0(500)\pi^+; f_0(500) \to \pi^+\pi^-$	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]
$B^+ \to \overline{D}^0 K^*(892)^+; K^*(892)^+ \to K^0\pi^+; K^0 \to K_S^0; K_S^0 \to \pi^+\pi^-$	-	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

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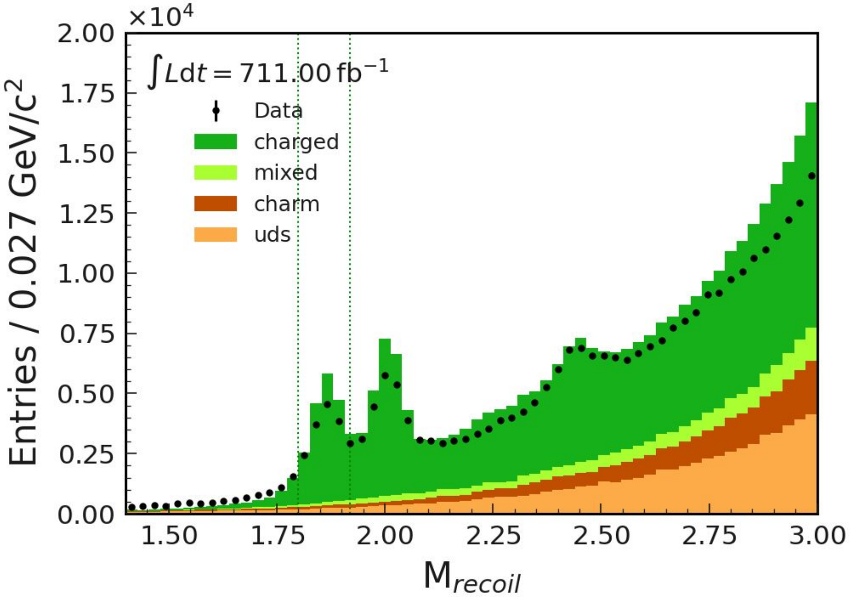
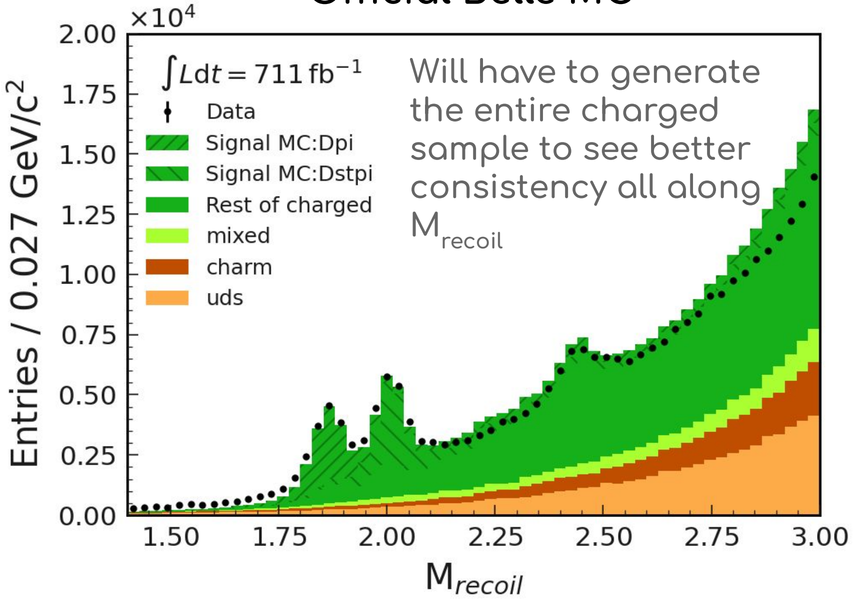
Validation by embedding signal MC

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

Official Belle MC

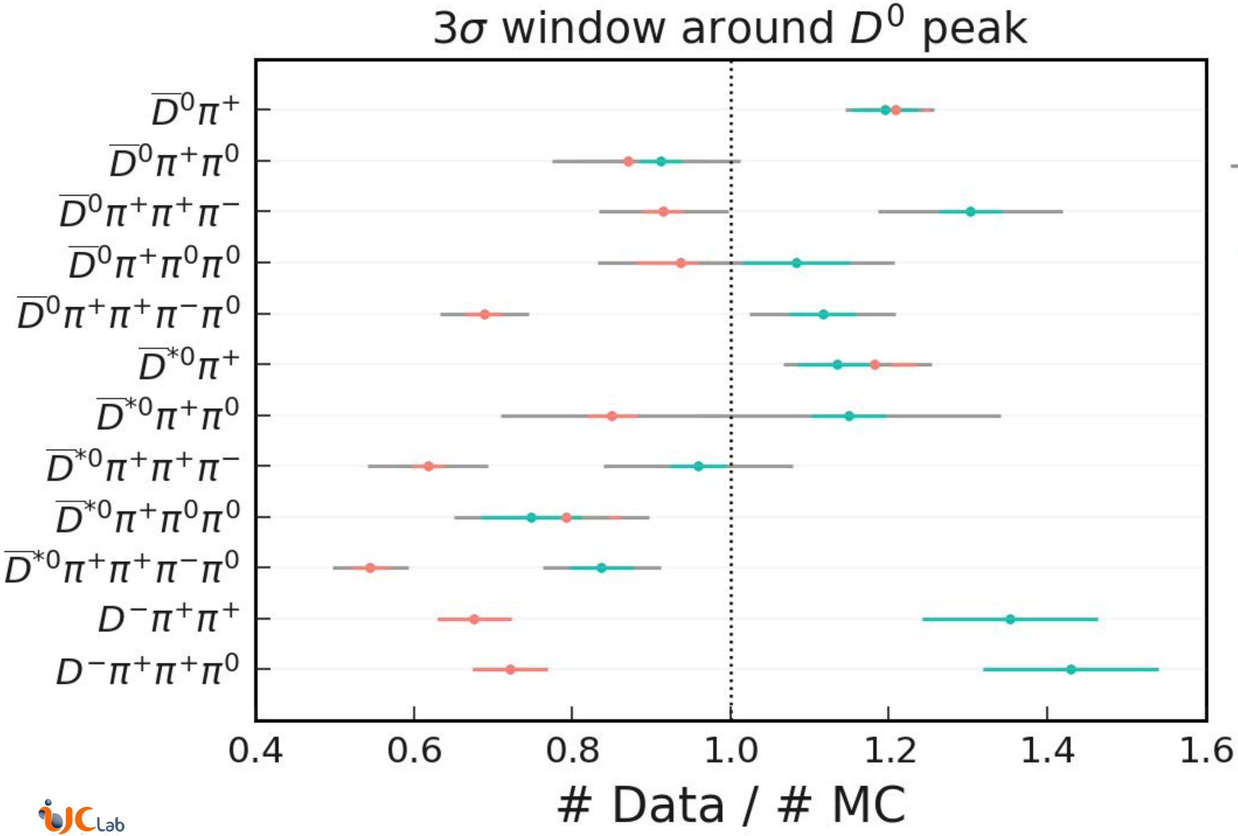


Modified Signal MC embedded in Official Belle MC



Updated calibration factors

per mode

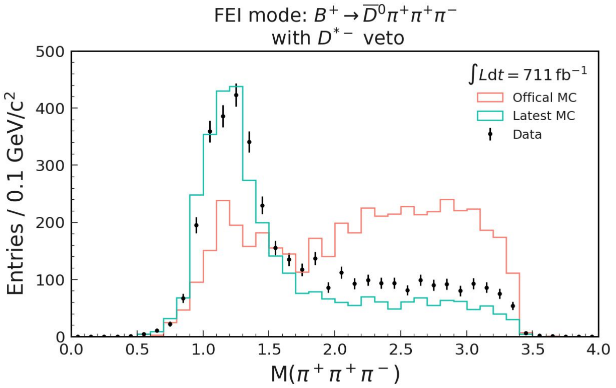


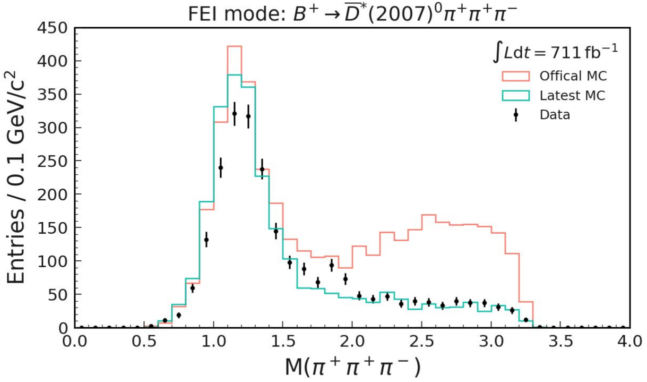
Overall calibration factor:
(82.6 ± 0.9)%
↓
(104.2 ± 1.2)%

Decay description is improved!

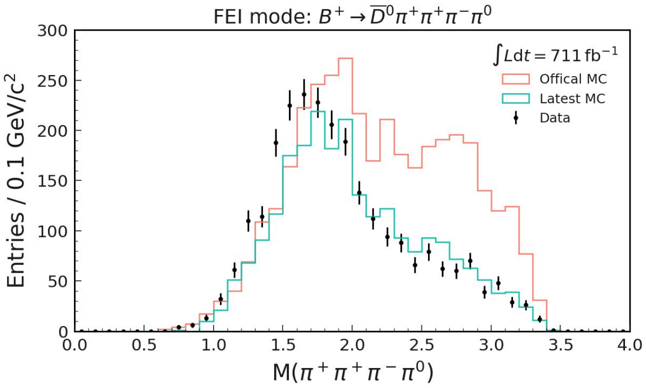
The improvement is not limited to calibration factors, but more importantly in the invariant masses (of intermediate particles), which are used as training variables in FEI

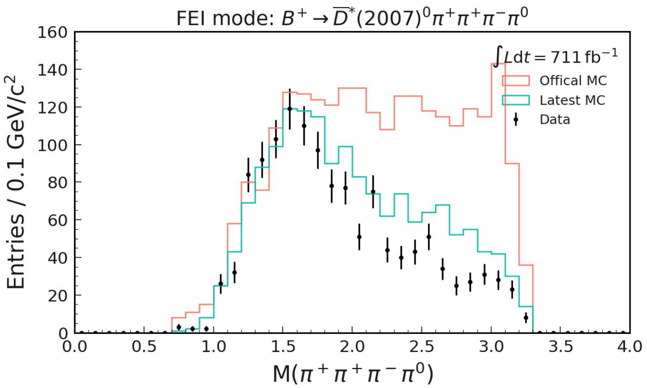
3π± case:



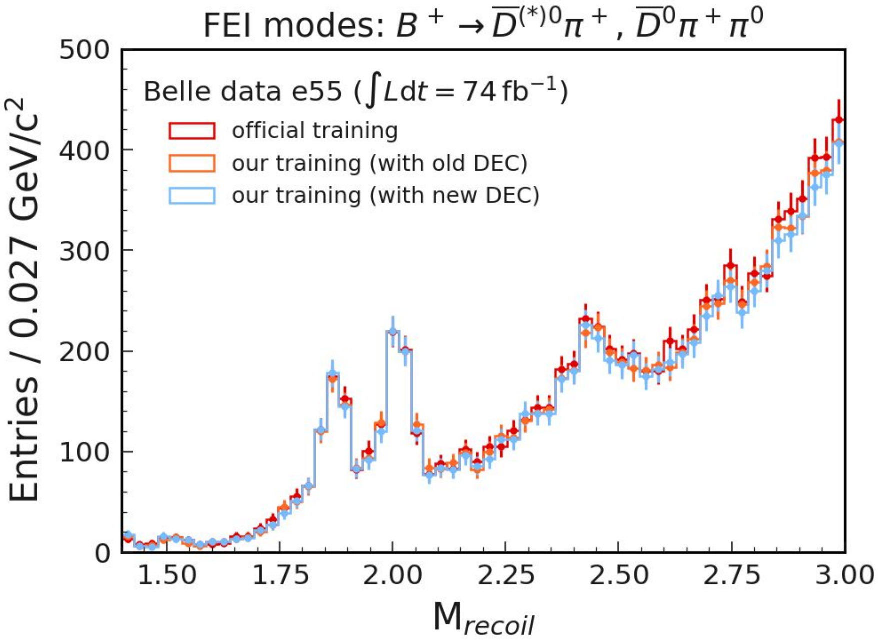


3π± π⁰ case:

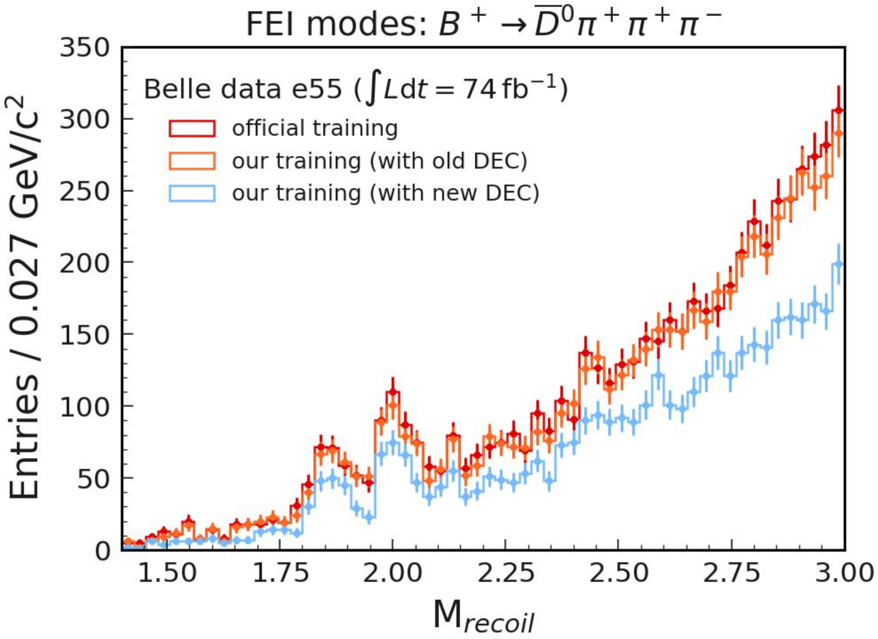




Retraining FEI: Validation



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 π^0, under investigation… (see backup)

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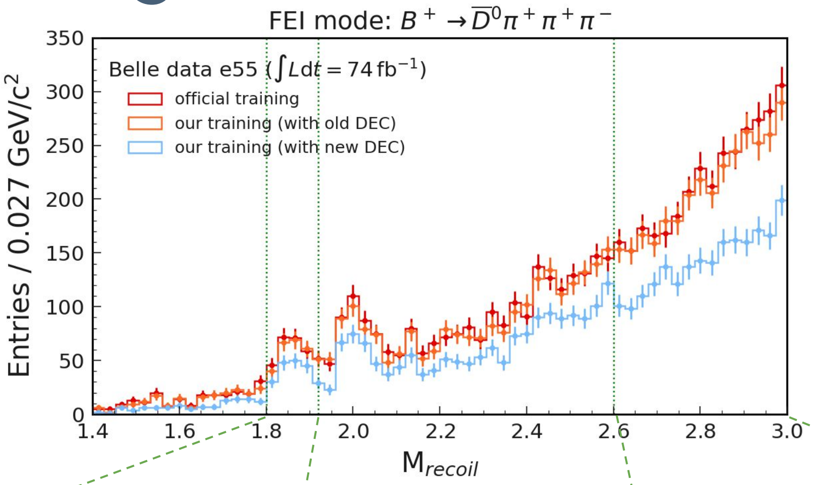
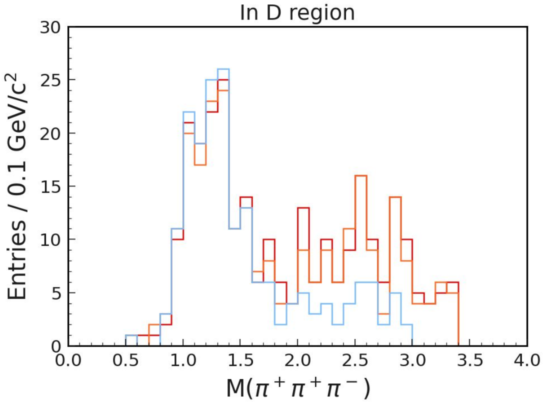
Retraining FEI: Effective cuts

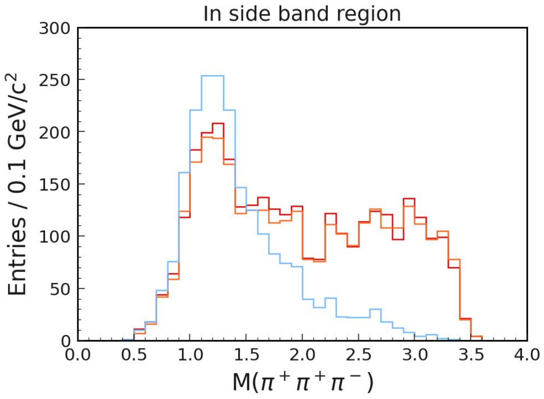


The new training is effectively applying a a_1+ cut !

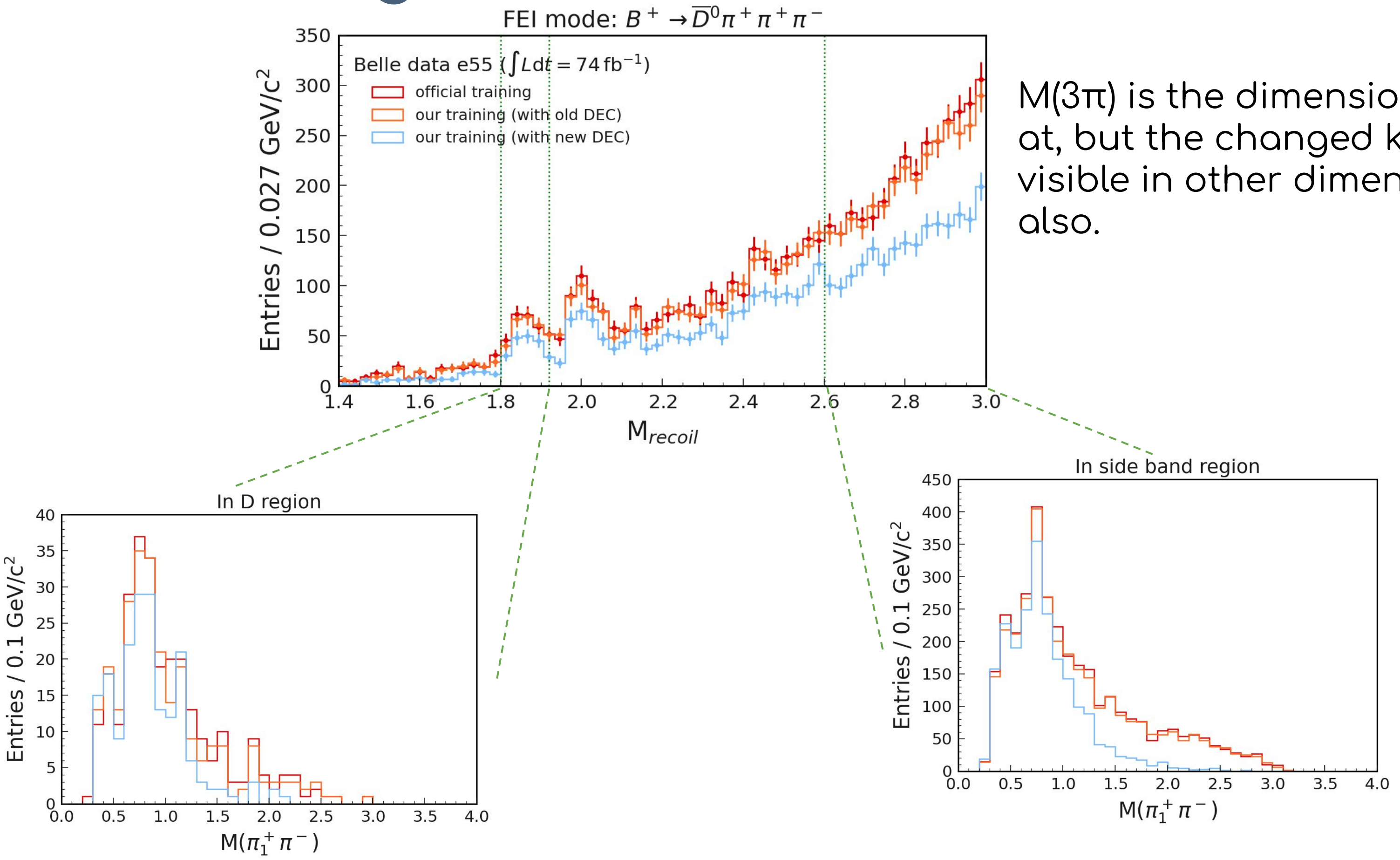
Can we apply this cut manually? Is that enough?

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



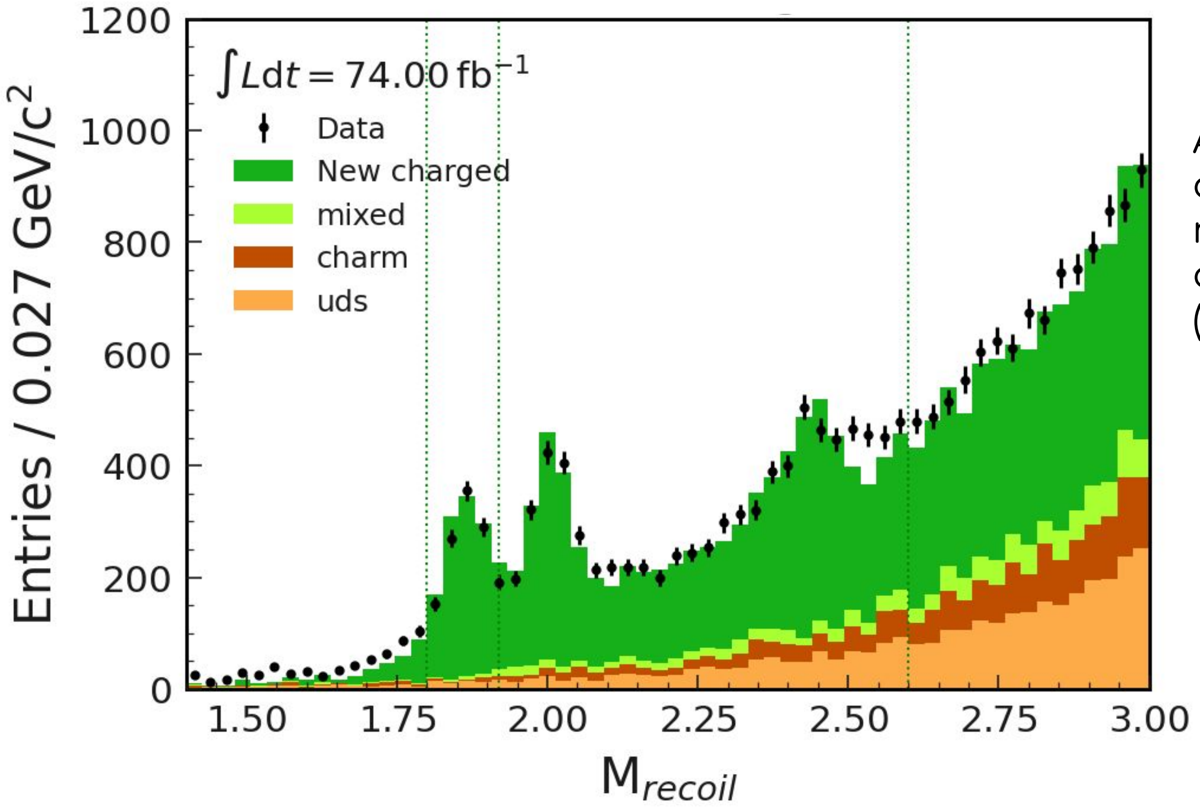


Retraining FEI: Effective cuts



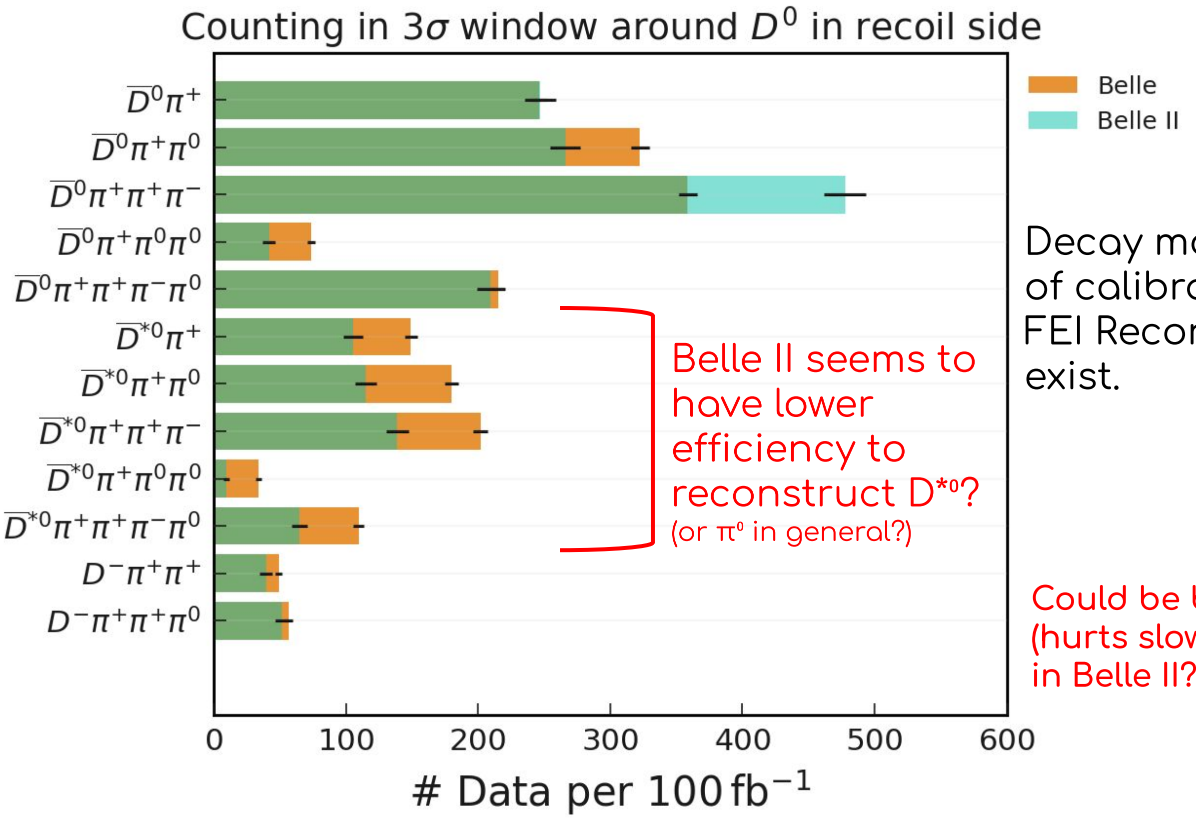
M(3π) is the dimension we usually look at, but the changed kinematics is visible in other dimensions like M(2π) also.

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} !)

What can we learn by comparing Belle and Belle II?



Decay model may not be the only source of calibration factor?
FEI Reconstruction effects certainly also exist.

Could be because of tighter γ cuts (hurts slow π^0) in Belle II?

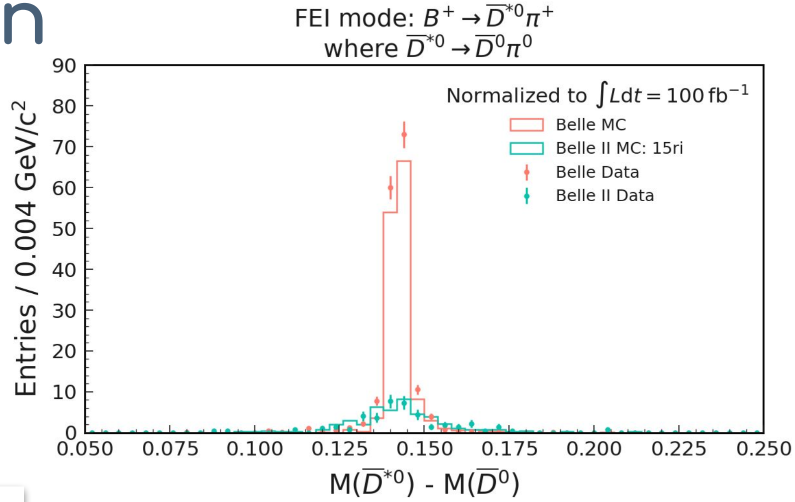
$D^{*0} \rightarrow D^0 \pi^0$ reconstruction

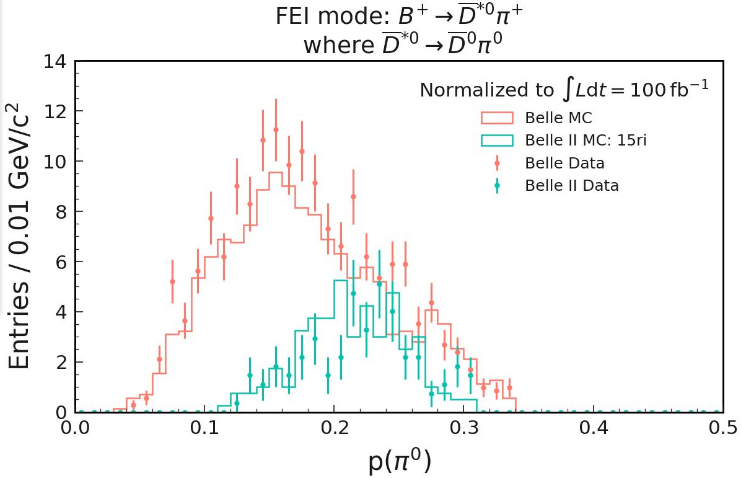
In Belle II, the yield of $D^{*0} \rightarrow D^0 \pi^0$ is much worse than Belle.

E > 0.09 GeV cut for γ is too tight for slow π^0
Should be loosened.

```
if convertedFromBelle:
    gamma_cut = 'goodBelleGamma == 1 and clusterBelleQuality == 0'
else:
    gamma_cut = '[[clusterReg == 1 and E > 0.10] or [clusterReg == 2 and E > 0.09] or [clusterReg == 3 and E > 0.16]]'
if specific:
    gamma_cut += ' and isInRestOfEvent > 0.5'

gamma = Particle('gamma',
                 MVAConfiguration(variables=['clusterReg', 'clusterNHits', 'clusterTiming', 'extraInfo(preCut_rank)',
                                             'clusterE9E25', 'pt', 'E', 'pz'],
                                  target='isPrimarySignal'),
                 PreCutConfiguration(userCut=gamma_cut,
                                     bestCandidateMode='highest',
                                     bestCandidateVariable='E',
                                     bestCandidateCut=40),
                 PostCutConfiguration(bestCandidateCut=20, value=0.01))
gamma.addChannel(['gamma:FSP'])
```





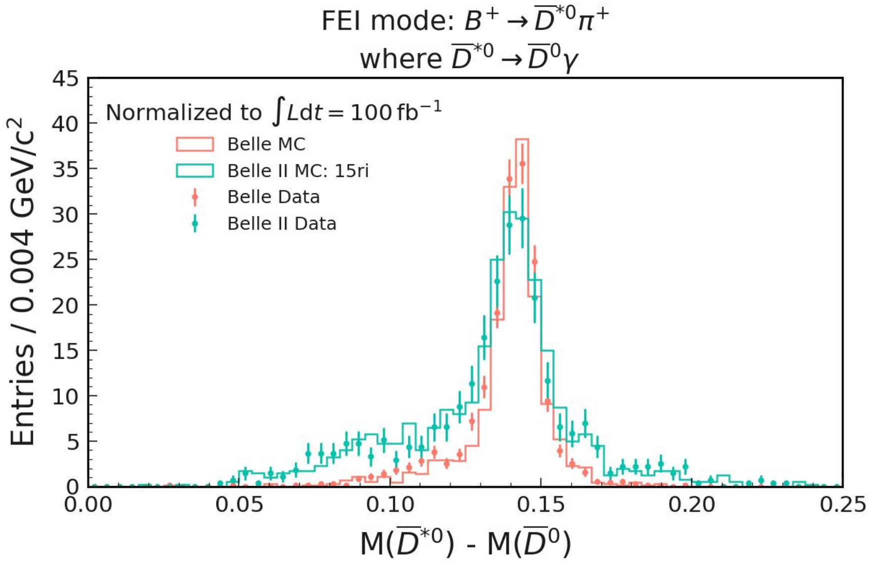
$D^{*0} \rightarrow D^0 \gamma$ reconstruction

In Belle II, the yield of $D^{*0} \rightarrow D^0 \pi^0$ is much worse than Belle, because the tighter pre-cuts on γ hurts slow π^0 reconstruction.

A part of it is recovered in the tail of $D^{*0} \rightarrow D^0 \gamma$, but not ideal.

This also shows that a tight ΔM constraint, which could bring high purity is not effectively utilized.

Should tighten the ΔM pre-BDT cut?



“Light” plans before summer

- **Provide calibration factors for Moriond:** Fitting, systematics and ROC with Dπ sample
- **First round of improvements:**
  - **Retraining with updated MC model (DEC files):**
    - Generate (2 streams of) run-dependant charged MC with proposed DEC file for:
      - for Belle and,
      - MC15rd with rel-06 for Belle II.
  - **Debug slow-π^0 reconstruction to fix D^{*0} yield in Belle II**
  - **Remove ΔE from Hadronic B-training,** which is being sculpted by BDTs (This is essential to recover some broken Bs from shifted ΔE bin.)

Other potential FEI algorithm improvements in the longer term

Improving the FEI - Particle selections, features

- The bases selections of the FEI could do with tuning
  - Charged tracks: [dr < 2] and [abs(dz) < 4]
  - Gammas: [[clusterReg == 1 and E > 0.10] or [clusterReg == 2 and E > 0.09] or [clusterReg == 3 and E > 0.16]]
  - Pi0s: 0.08 < InvM < 0.18
  - Jpsi: 2.6 < M < 3.7
  - Kshorts: 0.4 < M < 0.6, Lamdas: 0.9 < M < 1.3
  - D and D+: 1.7 < M < 1.95, Ds+ 1.68 < M < 2.1 , Lc: 2.2 < M < 2.4
  - D*0, D*+, Ds* :0 < Q < 0.3
  - B+ and B0: Mbc > 5.2 and abs(deltaE) < 0.5
- Possible improvements could be:
  - Tuning the simple gamma preselection
  - Multiple types of particles e.g new fei lists for charged and neutral slow pions including gammas for slow pi0s

Q. Do the various particle experts have recommendations?

Improving the FEI - Particle selections, features

- Charged particles:

```
chargedVariables = ['electronID', 'kaonID', 'protonID', 'muonID',
                    'p', 'pt', 'pz', 'dr', 'dz', 'chiProb', 'extraInfo(preCut_rank)']
```

Introduction of new lepton / hadron ID MVAs ?

- Gammas

```
variables=['clusterReg', 'clusterNHits', 'clusterTiming', 'extraInfo(preCut_rank)',
           'clusterE9E25', 'pt', 'E', 'pz'],
```

Here we should we consider adding beam background and hadronic splitoff MVAs ?

- Pi0s

```
variables=['InvM', 'extraInfo(preCut_rank)', 'chiProb', 'abs(BellePi0SigM)',
           'daughterAngle(0,1)', 'pt', 'pz', 'E'],
```

Separate BDT for slow pions

- Ks0 and Lambdas

```
variables=['dr', 'dz', 'distance', 'significanceOfDistance', 'chiProb', 'M', 'abs(dM)',
           'useCMSFrame(E)', 'daughterAngle(0,1)',
           'cosAngleBetweenMomentumAndVertexVector',
           'extraInfo(preCut_rank)', 'extraInfo(goodKs)', 'extraInfo(ksnbVLike)',
           'extraInfo(ksnbNoLam)', 'extraInfo(ksnbStandard)'],
```

Improving the FEI - Particle selections, features

- Intermediates:

```
# variables for D mesons and J/Psi
intermediate_vars = ['daughterProductOf(extraInfo(SignalProbability))', 'daughter({},extraInfo(SignalProbability))',
                     'chiProb', 'daughter({}, chiProb)', 'extraInfo(preCut_rank)', 'abs(dM)',
                     'useRestFrame(daughter({}, p))',
                     'useRestFrame(daughter({}, distance))',
                     'decayAngle({})', 'daughterAngle({},{})', 'cosAngleBetweenMomentumAndVertexVector',
                     'daughterInvariantMass({},{})', 'daughterInvariantMass({},{},{})', 'daughterInvariantMass({},{},{},{})',
                     'daughterInvariantMass({},{},{},{},{})', 'dQ', 'Q', 'dM', 'daughter({},extraInfo(decayModeID))']
```

- Had Bs:

```
# note: these should not be correlated to Mbc (weak correlation of deltaE is OK)
B_vars = ['daughterProductOf(extraInfo(SignalProbability))', 'daughter({},extraInfo(SignalProbability))',
          'chiProb', 'daughter({}, chiProb)', 'extraInfo(preCut_rank)',
          'useRestFrame(daughter({}, p))',
          'useRestFrame(daughter({}, distance))',
          'decayAngle({})', 'daughterAngle({},{})', 'cosAngleBetweenMomentumAndVertexVector',
          'dr', 'dz', 'dx', 'dy', 'distance', 'significanceOfDistance', 'deltaE', 'daughter({},extraInfo(decayModeID))']
```

As Vidya mentioned immediate plan to remove deltaE as loosely correlated to sig. prob.

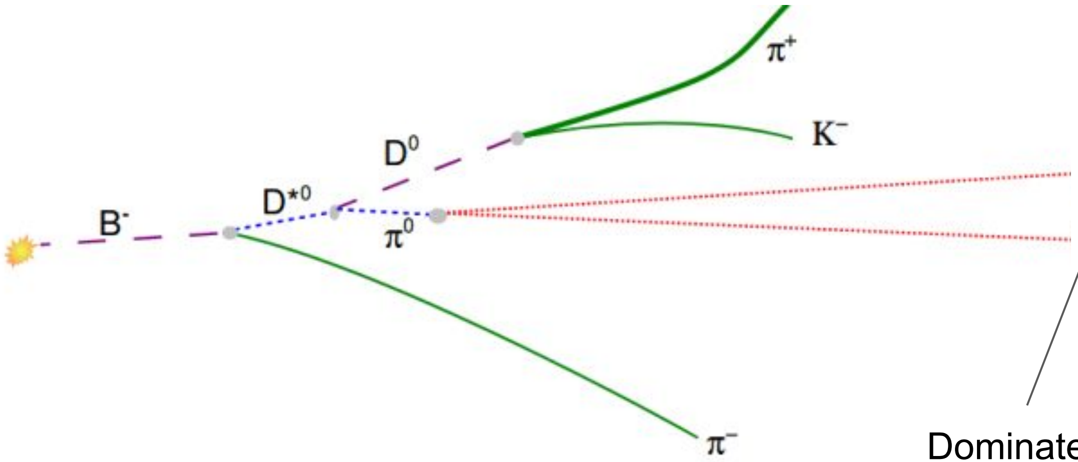
- SL Bs

```
#MR20210301 B_vars_SL original (remove DeltaE, decayAngle and daughterAngle)
    B_vars_SL = ['daughterProductOf(extraInfo(SignalProbability))', 'daughter({},extraInfo(SignalProbability))',
                 'chiProb', 'daughter({}, chiProb)', 'extraInfo(preCut_rank)',
                 'useRestFrame(daughter({}, p))',
                 'useRestFrame(daughter({}, distance))',
                 'cosAngleBetweenMomentumAndVertexVector',
                 'dr', 'dz', 'dx', 'dy', 'distance', 'significanceOfDistance', 'daughter({},extraInfo(decayModeID))']
```

Markus Roerken already removed some biasing variables already for the SL case.

Vertex Fitting

- Vertex fitting dominates reconstruction time of FEI decay chains.
- Decay tree fitting with suitable constraints could help better reconstruct decay chains with neutrals.
- Current kFit does not work when two pi0s are present.

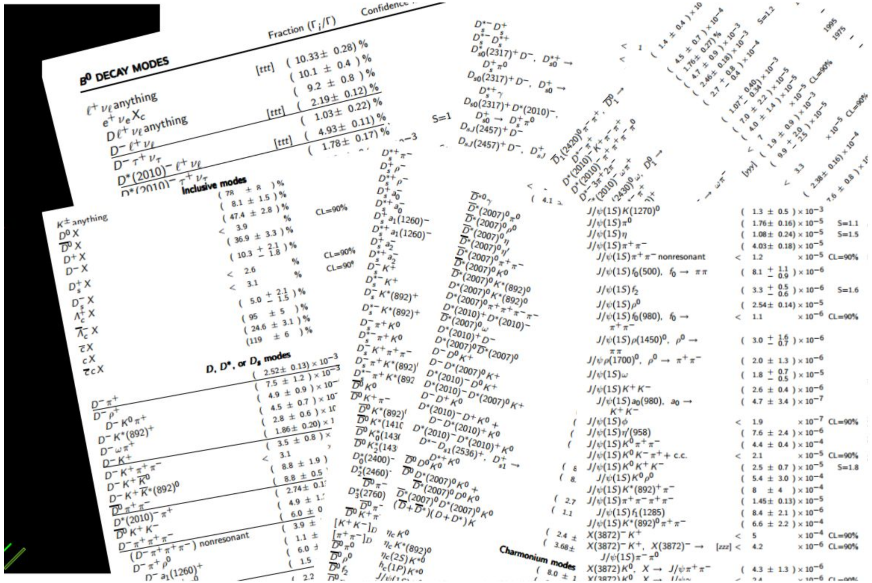


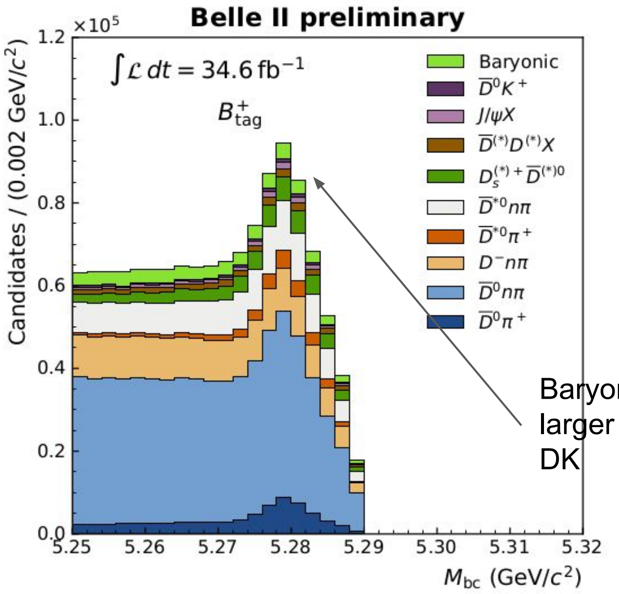
Task	Training	Application
read/write DataStore	30	0
vertex fitting	26	38
particle combination	19	27
classifier inference	11	15
training data & monitoring	6	0
best candidate selection	3	6
other	5	14

Dominate time on vertex fitting in application (during skims)

Adding more decay modes

- Naturally the higher the branching fraction covered the higher the tag-side efficiency.
- An example of this was adding B decay modes with Baryons.
- Suggested by Vidya et al.: - B+ → D*- (4π)++ , B+ → D*0 (5π)+, B+ → D(*)0 K+ K0(*) (an easy change)





Baryons were added, larger than XJpsi and DK

An aside on an earlier caveat: FEI confusion

- Noreen also looked into a FEI confusion matrix

Perhaps alternative classifiers / BCSs could improve this

Here Best cand. Selection on Sig Prob > 0.001 (?)

- **People forget that the FEI has a unique BDT for each B mode. A single overall BCS + global cut is not optimal.**
- BCS per mode? Different cuts for each mode. Applies also to delta E and Mbc

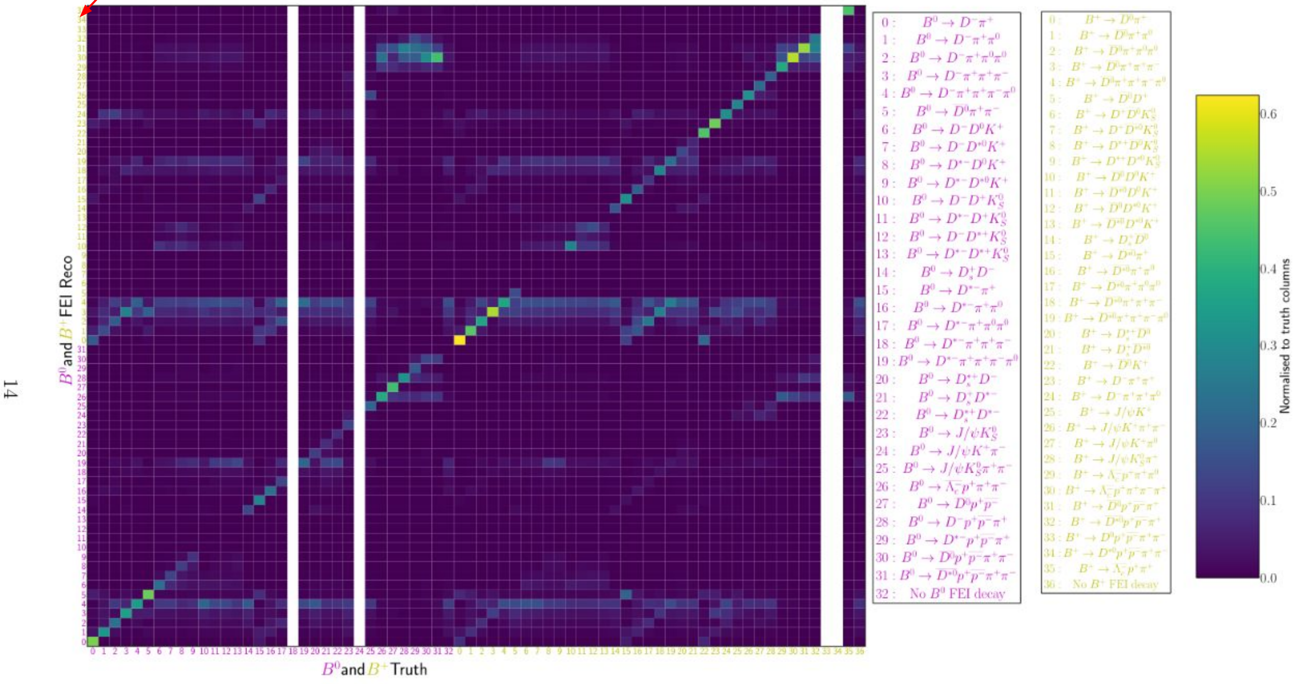


FIG. 22: Correlation between the hadronic B^0 and B^+ FEI. On the x axis the truth decays are given by TopoAna. On the y axis the reconstructed mode used by the FEI is provided. All B^0 decays are coloured in purple and the charged decays are greenish. All the decay modes are also written out in the boxes next to the plot on the right hand side. The plot is normalised to the truth columns, thus to the x axis.

Classifiers of the FEI

- One could also aim to improve the classifier (ROC curve + confusion matrix) of the FEI (new architectures)
- This can not increase the maximum tag-side efficiency. However it can improve the ROC curve (a better background rejection for a given tag-side efficiency).
- Here one can explore hyperparameter optimizations or more sophisticated architectures such as graph convolutional networks for graph classifications.

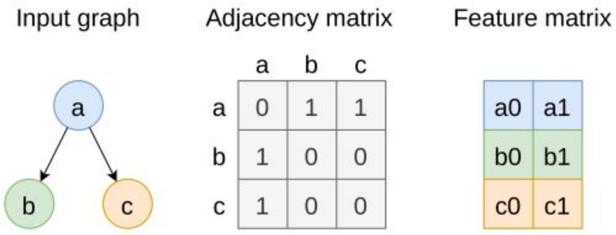
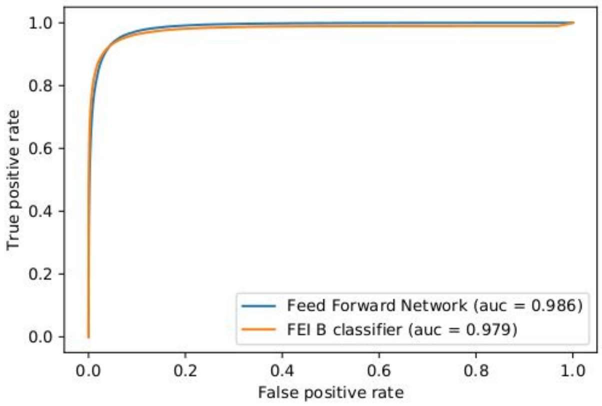
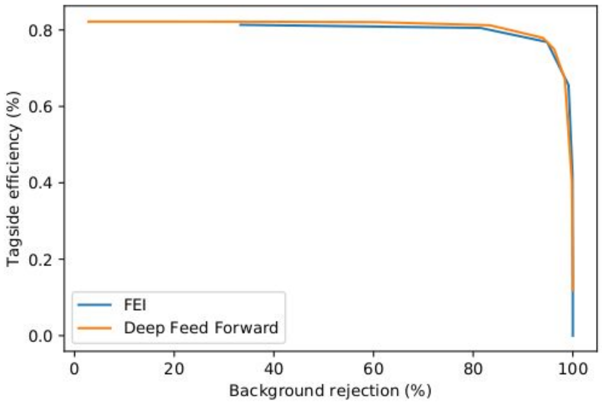


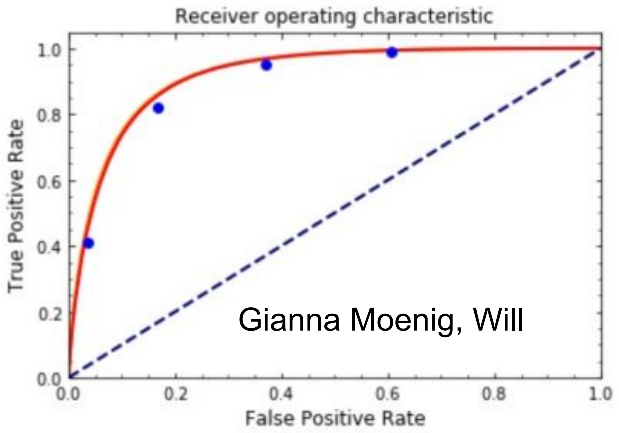
Figure: Example of matrices fully defining a graph.





Other possible developments

- A built in continuum classifier trained specifically on the ROEs of FEI candidates.



- Investigating training with K_Ls (already implemented but not run in trainings)

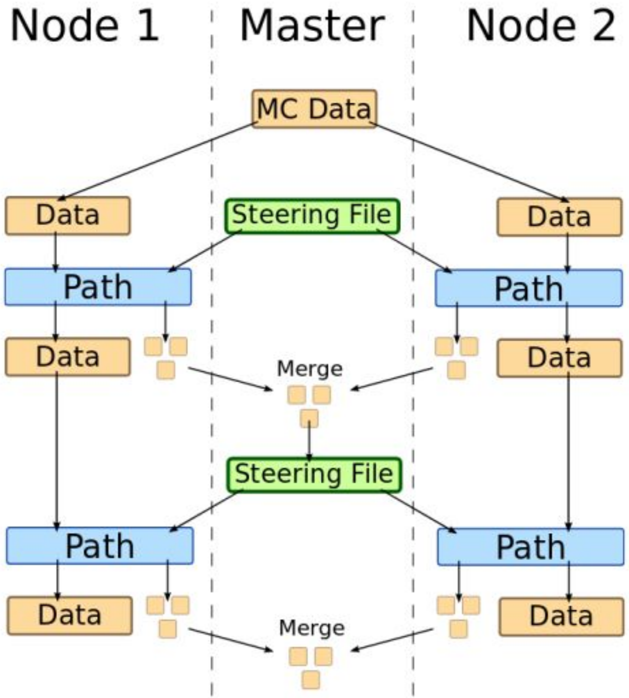
- No one uses semileptonic D decays (tag-side efficiency small ~0.1%)

- **Other ideas?**

Improving FEI Trainings

FEI - Training

- Both training and application phases can be distributed via a map reduce approach.
- For training:
  - O(100M) simulated $\Upsilon(4S) \rightarrow B\bar{B}$ events
  - Monte carlo is partitioned and processed at different nodes.
  - At each of the reconstruction phases training data is generated.
  - Training data of each stage is subsquently merged and classifiers trained.



Training is offline in between each distributed reconstruction stage

FEI - Training

- Locally:
  - 100 fb^-1 MC required.
  - Space requirements large O(10TB)

- Technically FEI can be trained on the grid (Artur Gottman, sphinx) but it is error prone and longer than local trainings.
  - All prior reconstruction stages must be rerun at each stage of training -> 2x training time without failed jobs

- However the GRID would allow for greater automation and a training + skimming workflow

- As discussed training assistance would be welcome. Many hurdles to overcome for better automation.

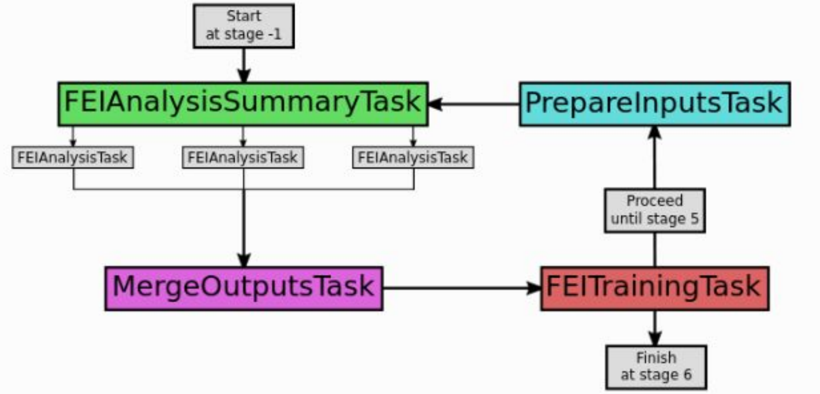
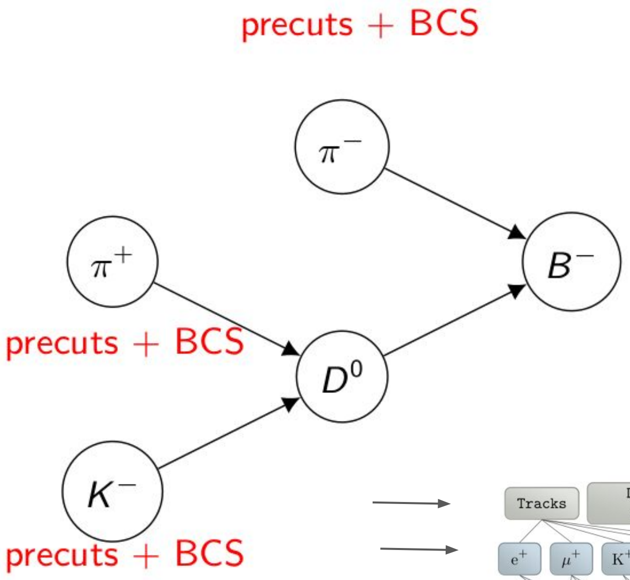


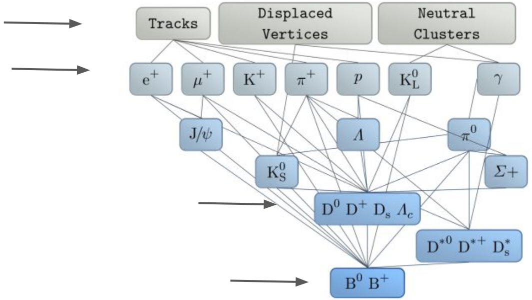
Fig. 7.10 Visualization of the workflow concept of FEI training running on the grid.

Backup

FEI - Algorithm in greater depth

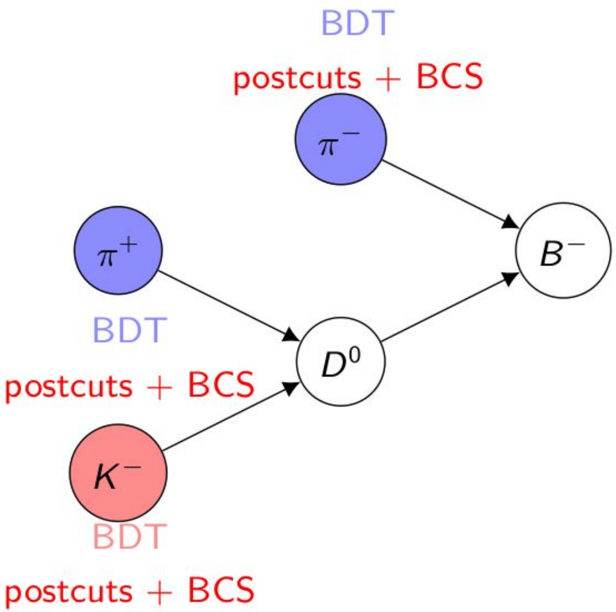
- Particle candidates assigned from tracks and clusters after a precuts + Best Candidate Selection (BCS).





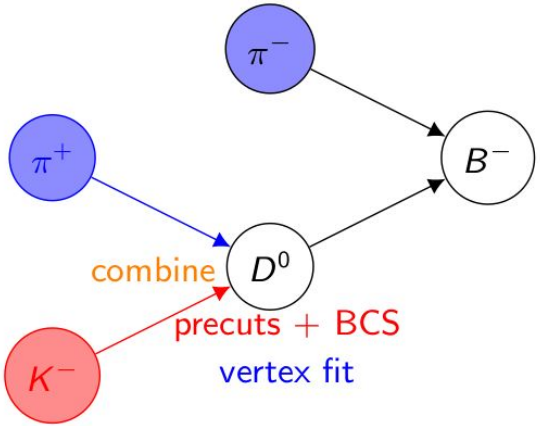
FEI - Algorithm in greater depth

- Particle candidates assigned from tracks and clusters after a precuts + Best Candidate Selection (BCS).
- For each particle a pre-trained BDT is applied and post cuts + BCS are made.



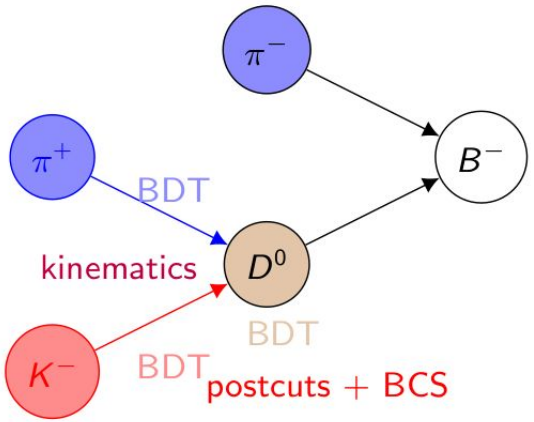
FEI - Algorithm in greater depth

- Particle candidates assigned from tracks and clusters after a precuts + Best Candidate Selection (BCS).
- For each particle a pre-trained BDT is applied and post cuts + BCS are made.
- Stable particles are combined to reconstruct decays of intermediate particles. After precuts + BCS a vertex fit is performed.



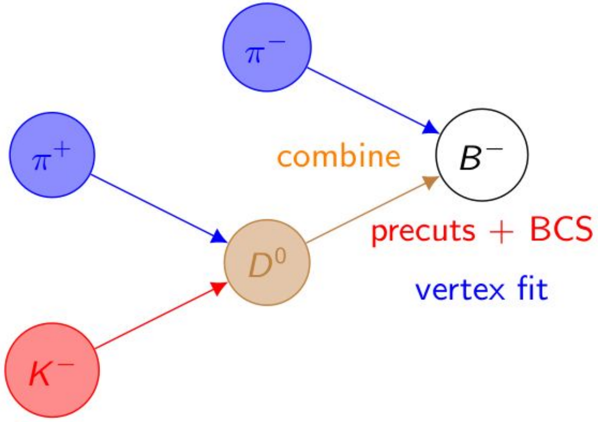
FEI - Algorithm in greater depth

- Particle candidates assigned from tracks and clusters after a precuts + Best Candidate Selection (BCS).
- For each particle a pre-trained BDT is applied and post cuts + BCS are made.
- Stable particles are combined to reconstruct decays of intermediate particles. After precuts + BCS a vertex fit is performed.
- Intermediate classifiers use daughter kinematics and classifiers.

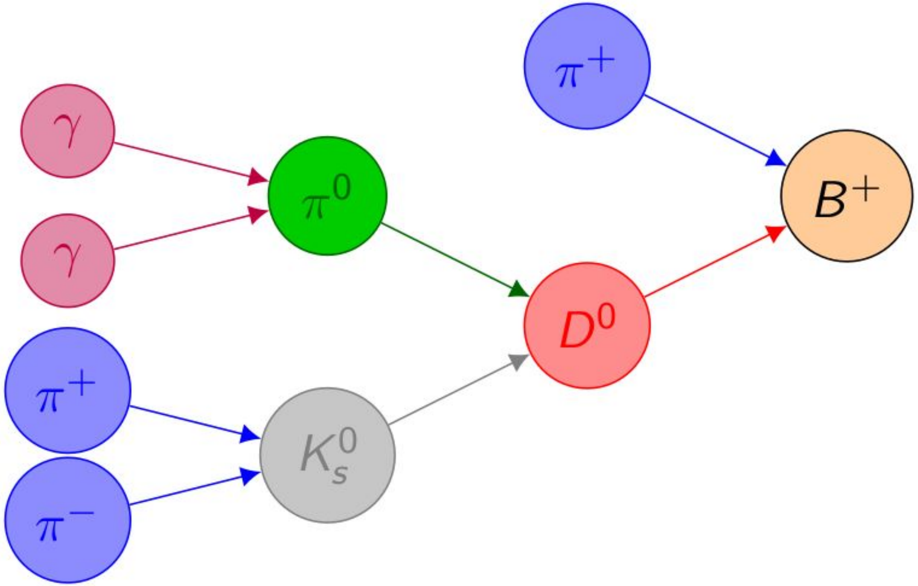


FEI - Algorithm in greater depth

- Particle candidates assigned from tracks and clusters after a precuts + Best Candidate Selection (BCS).
- For each particle a pre-trained BDT is applied and post cuts + BCS are made.
- Stable particles are combined to reconstruct decays of intermediate particles. After precuts + BCS a vertex fit is performed.
- Intermediate classifiers use daughter kinematics and classifiers.
- Intermediates and stable particles are combined into a B candidate.



FEI - Algorithm in greater depth - another decay



- Same $B^+ \to D^0\pi^+$ classifier.
- Different decay chain as $D^0 \to K_s^0\pi^0$.
- $D^0 \to K_s^0\pi^0$ has its own classifier.

Improving the FEI - Best Candidate Selections

- Major challenge of the FEI is to reduce combinatorics
- Therefore there are best candidate selections
  - Generally 20 candidates kept for precuts and 10 for postcuts
  - Exceptions e and mu (10 pre. 5 post), Gammas (40 pre. 20 post), Bs (20 pre., 20 post)
  - Precuts based on particle ID for charged particles (electronID, pionID etc), E for gammas, Mreco - Mtrue for most intermediate particles, abs(dQ) for D*s, Sig Prob. for Bs
- Here we could explore retuning these hyperparameters

Backup

$B^+ \to D\pi$ 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:

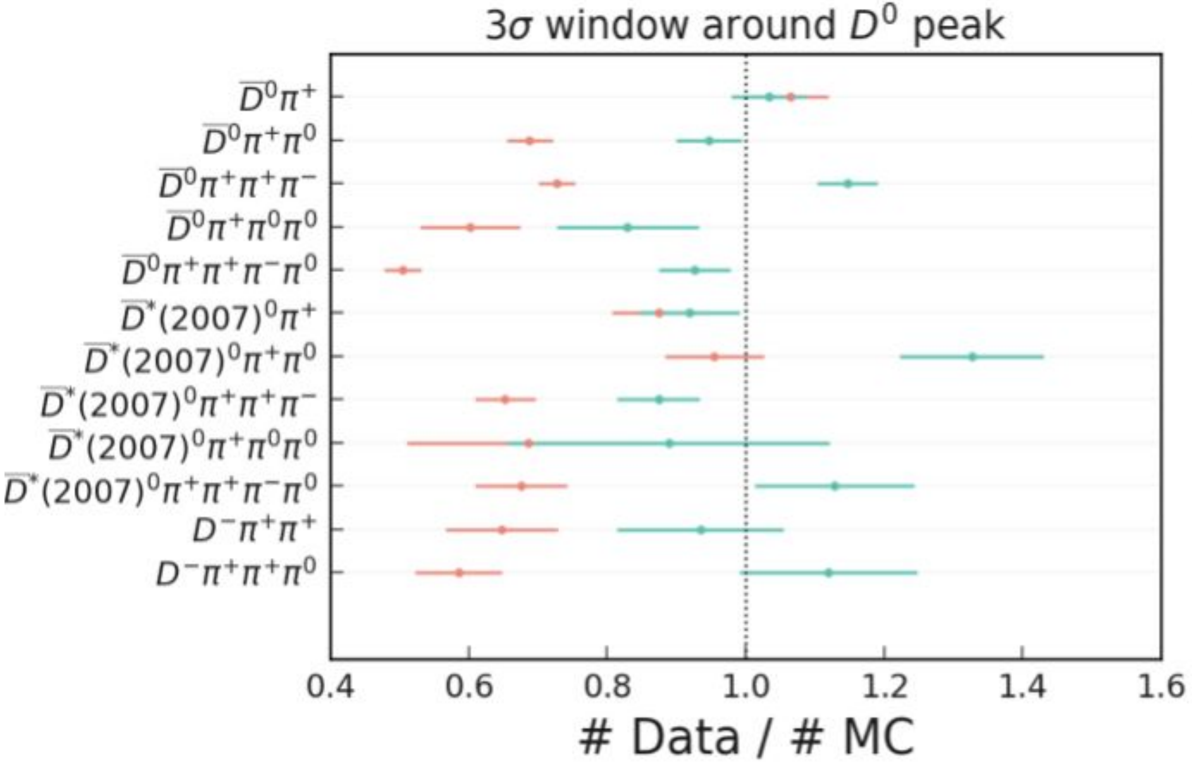
- Event sphericity > 0.2
- B_{tag}'s cosTBTO < 0.9

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

IJCLab

Similarly, in Belle II with MC14rd + rel5

[Niharika Rout]



Even lower than Belle !

Overall:

(70 ± 1)%

↓

(98 ± 2)%

MC15rd looks essentially the same.
Except for $\pi^0\pi^0$ modes, where official MC is very low, still investigating...(see backup)

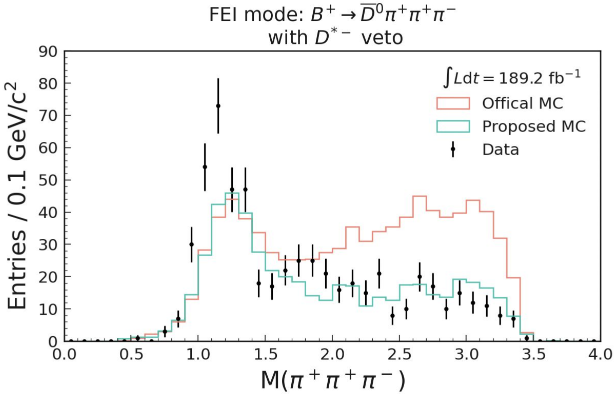
Belle II: Decay description is improved!

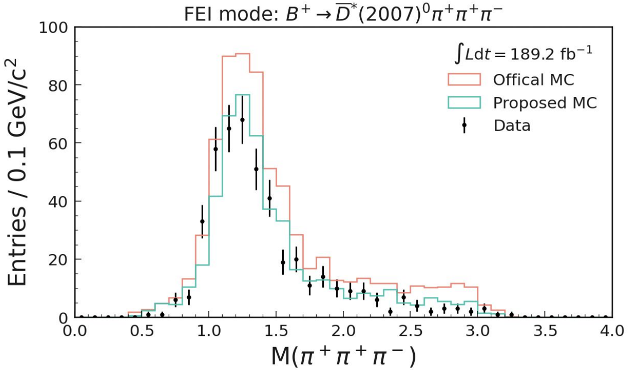
with MC14rd + rel5

[Niharika Rout]

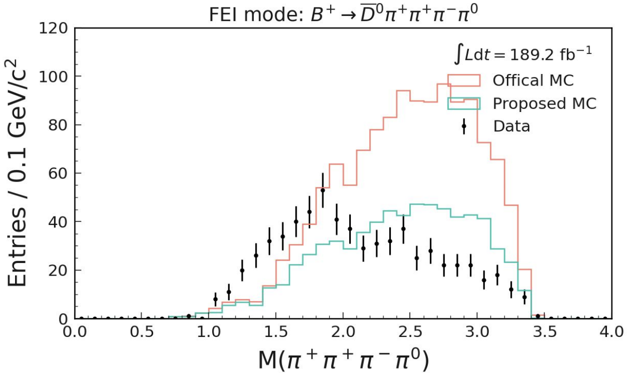
The improvement is not limited to calibration factors, but more importantly in the invariant masses (of intermediate particles):

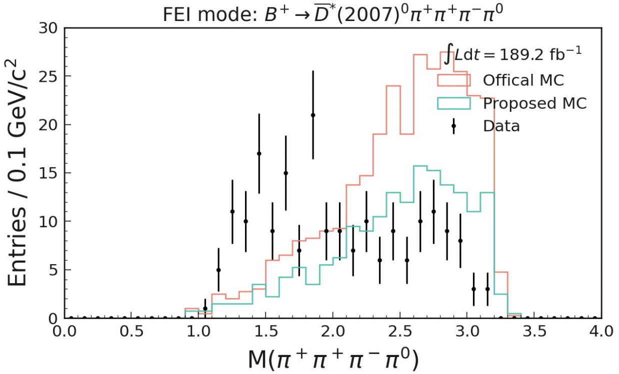
3π± case:





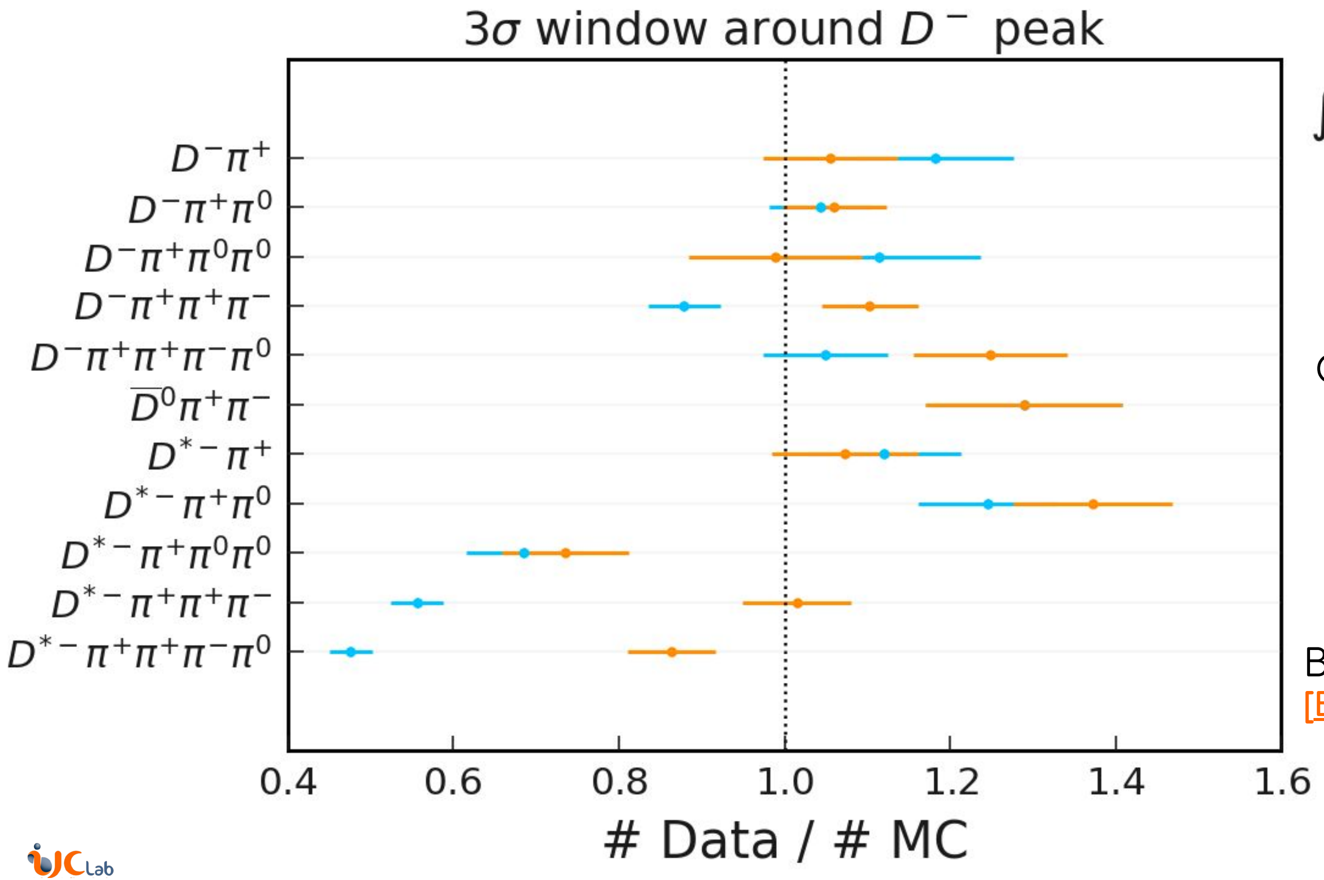
3π± π⁰ case:





Similarly, with $B^0 \to D^- \pi^+$ in recoil @ Belle

[Meihong Liu]



Overall calibration factor:
(84.8 ± 1.6)%
↓
(103.7 ± 2.0)%

Belle II note in progress:
[BELLE2-NOTE-PH-2022-046]

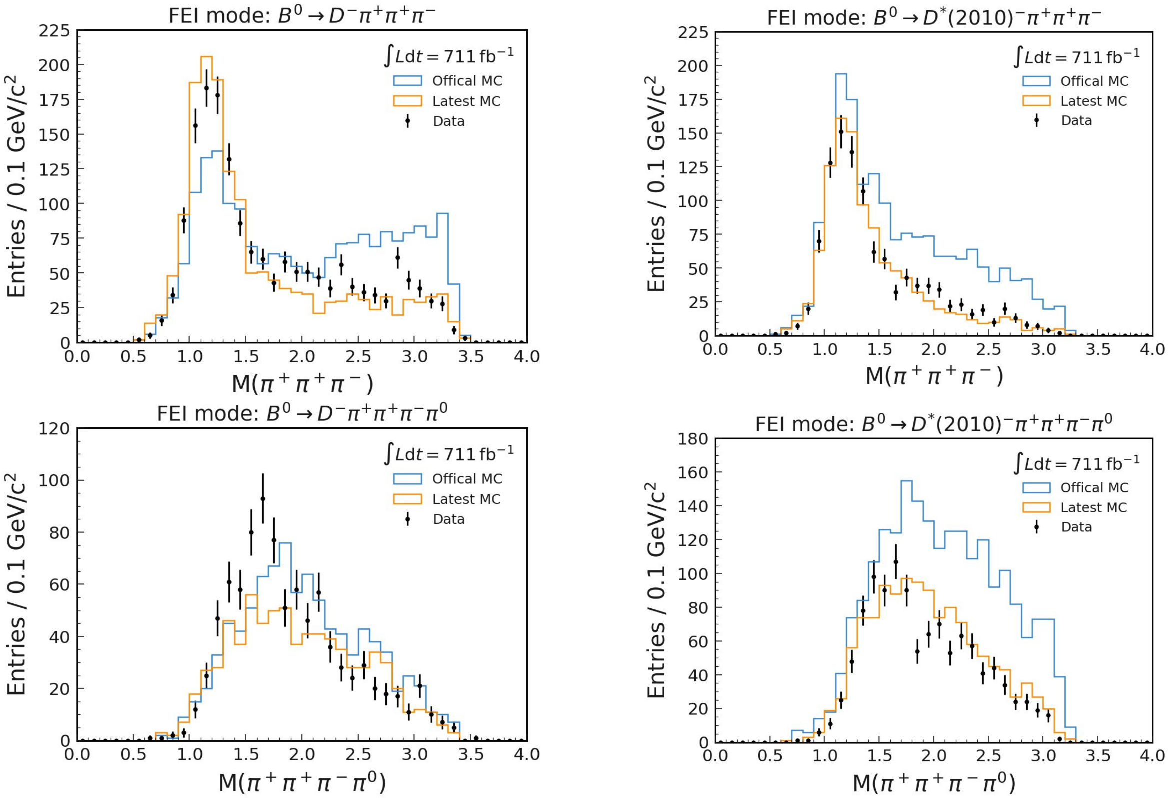
Decay description is improved in B^0!

[Meihong Liu]

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:



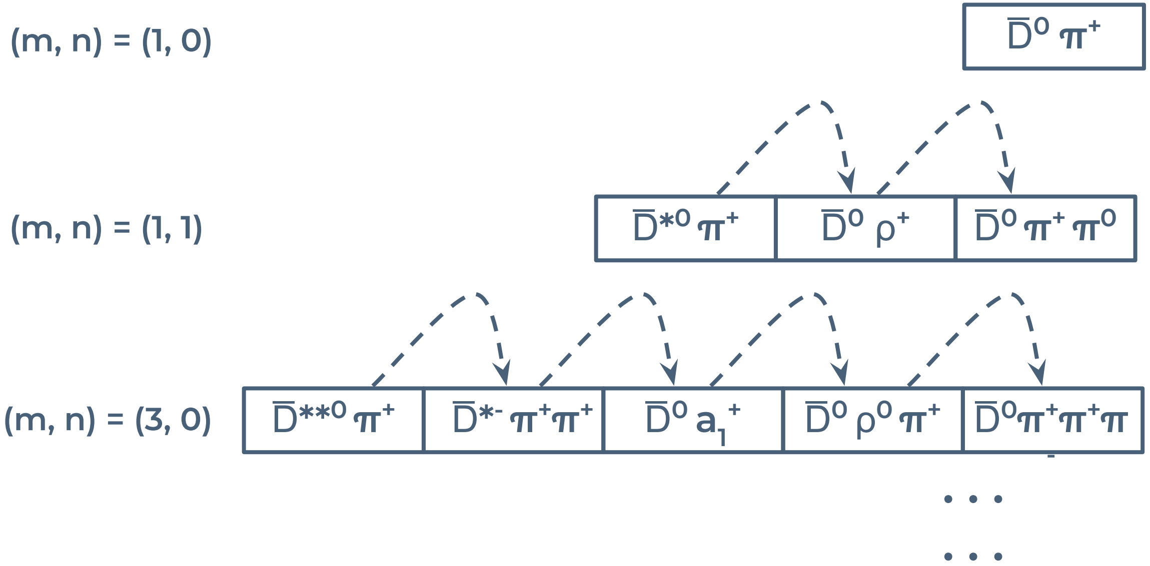
Plans (for the task-force?)

- **Calibration and modeling efforts:**
  - Study the issue in MC for modes with $\pi^0\pi^0$ in MC15rd
  - Fitting, systematics and ROC with $D\pi$ sample
  - Monitor the changes in $B \rightarrow D\, n\pi$ modes decay tables over time. Promote (re-)measurement of these modes (including intermediate states)?
- **Retraining efforts:**
  - Understand the impact of retraining on π^0
  - Generate (2 streams of) run-dependant charged MC with proposed DEC file for retraining:
    - for Belle and,
    - MC15rd with rel-06 for Belle II.
- **Modifying FEI reconstruction:**
  - Reconsider the pre-BDT cuts: like loosen the E cut on γ; tighten the ΔM cut for D^{*0}
  - Apply cuts on $n\pi$-system invariant masses as pre-cuts or add as intermediate particles?
  - Reconsider variables used for BDT: Like removing ΔE (in Hadronic FEI also) which is being sculpted by BDTs? (This is essential to recover some broken Bs from shifted ΔE bin.)
  - Applying the right kind of fit among (mass constrained, mass-vertex constrained or vertex) for different intermediate states instead of vertex fit for all.
    [Roman Mizuk: BELLE2-NOTE-PH-2022-015]
  - Add a couple of B modes?

Alternative FEI algorithm

Alternatively, using FEI particle list of $\bar{D}^0$, we want to reconstruct B^+ particle list manually

in orders of $\bar{D}^0$ **($m\ \pi^+$) ($n\ \pi^0$)**:

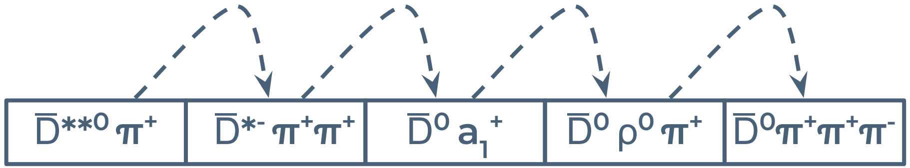


Reconstructing in this order,
going to the next step only if it fails, ⇒ Simpler best candidate selection
using the constraints of intermediate resonances when possible ⇒ Higher purity

Let's call this algorithm " FREE "

Multiplicity in FREE: BCS

(m, n) = (3, 0)
⇒ FREE line 30



FREE Stop: 301 302 303 304 305

- Level 1 (among FREE lines):
  - Like an event having a $\bar{D}^0\,\pi^+$ candidate and a $\bar{D}^0\,\pi^+\,\pi^0$ candidate
  - Tight tag-side selection (Mbc and deltaE cuts) should make this negligible.
- Level 2 (among FREE stops):
  - Like a 301 candidate and a 303 candidate.
  - Lowest stop is the best.
- Level 3 (among the same FREE stop):
  - Like 2 candidates in 303.
  - Not worrying about this right now and see how many survive till the end.