Progress on the A_{FB}^{b} feasibility study at FCCee

Marina Cobal, Giovanni Guerrieri, Hamzeh Khanpour,
Giancarlo Panizzo, Michele Pinamonti, **Leonardo Toffolin**

INFN Trieste – Gruppo collegato di Udine & ICTP Trieste

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- Details of the FCCAnalysis framework that have been used (configurations, option, ...)
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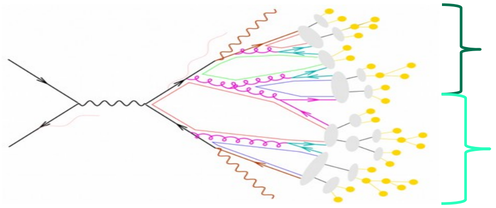
Overview and motivation

- **The goal:** precise measurement of **forward-backward asymmetry** of *b* in $e^+e^- \rightarrow Z \rightarrow b\bar{b}$ events

$$\frac{d\sigma_{b\bar{b}}}{d\cos\theta_b} = \sigma_{b\bar{b}} \frac{3}{8}\left(1+\cos^2\theta_b + \frac{8}{3}A^b_{\mathrm{FB}}\cos\theta_b\right)$$

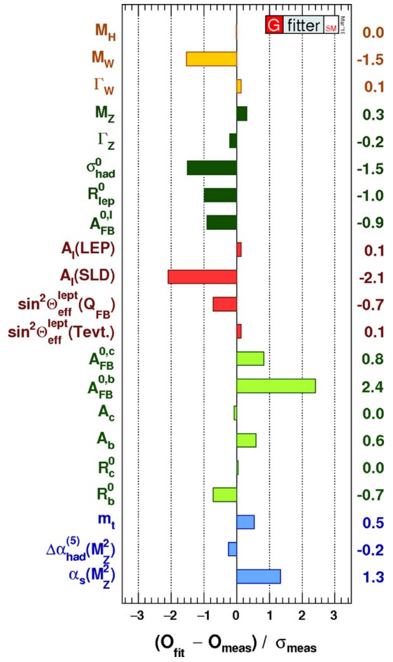
- *b*-quark charge determination:



*: many possible variations exist, e.g. based on exclusive final states, secondary vertex reconstruction, etc...

1. **Jet charge**:
   - charge of jet obtained as weighted **sum** of charges of constituent **tracks**
   - can be applied to all jets ⇒ maximal efficiency
   - relatively low purity
   - strong dependence on jet shape and hadronization

2. **Leading (soft) lepton tagging**:
   - charge of *b* inferred from charge of e or μ in ***B*-hadron semileptonic decay**
   - relatively low efficiency (restricted to semileptonic decays)
   - better purity
   - highly sensitive to *B*-hadron decay modelling



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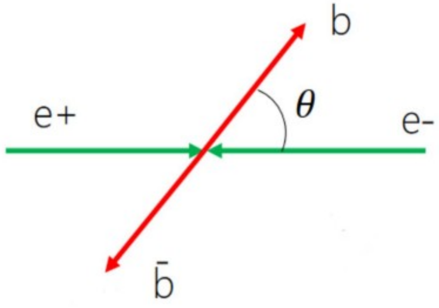
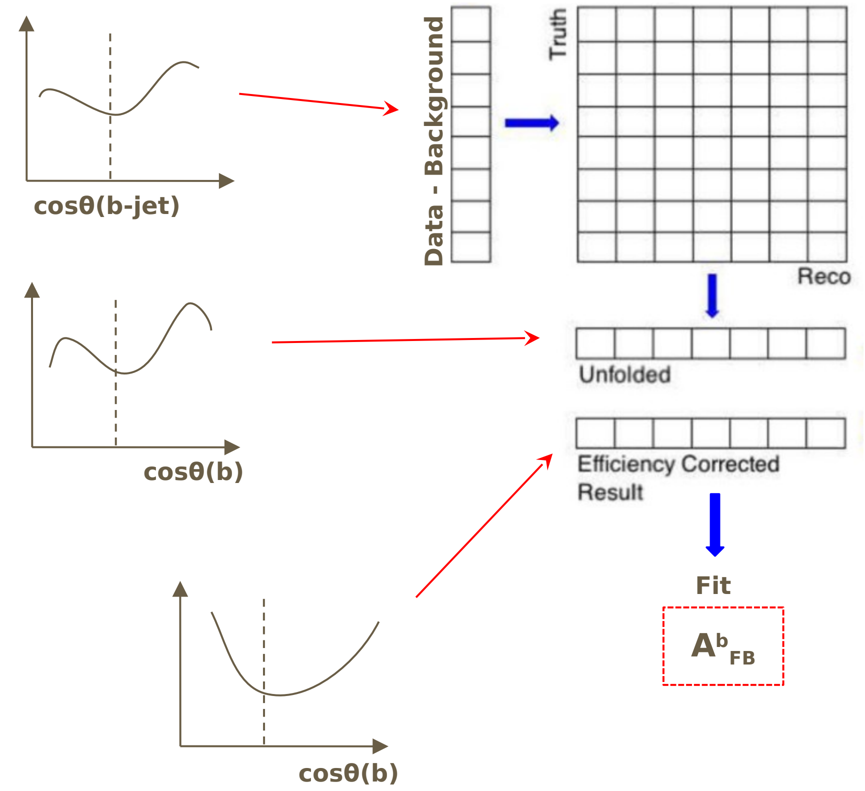


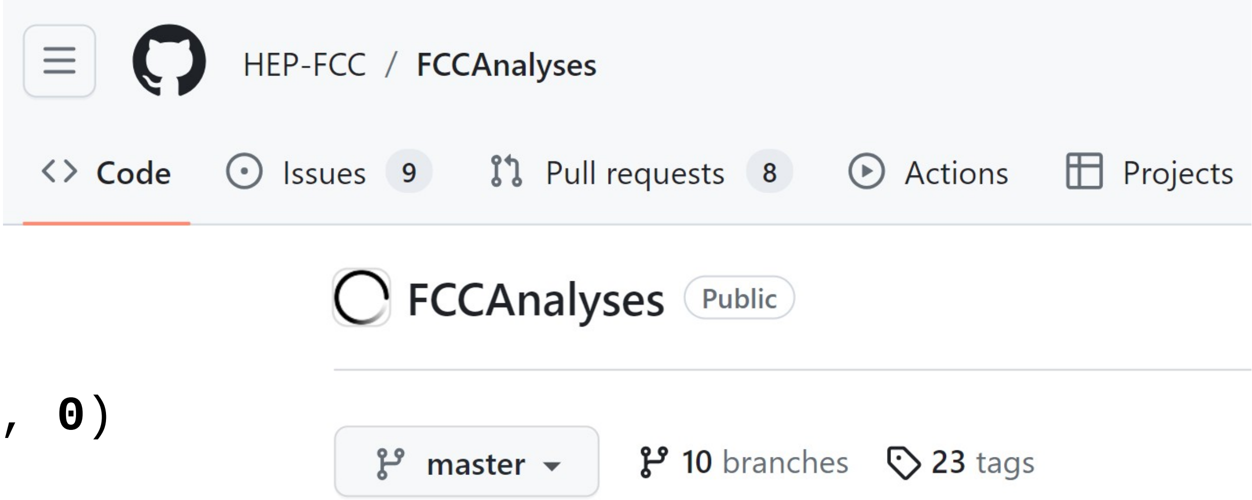
Analysis strategy

- **Investigated workflow:**
  1) build **reco-level *cosθ* observable** exploiting:
     - jet direction
     - charge reconstruction
  2) perform **unfolding** from reco-level to parton-level
  3) Extract A_{FB}^{b} from **fit** to unfolded distribution
- **HEP-FCC/FCCAnalyses framework**
  - Preliminary study with stand-alone Madgraph+Delphes already performed
  - EDM4HEP for event generation
  - Investigating usage of thrust axis, jets with different algorithms, leptons...



Framework: main features

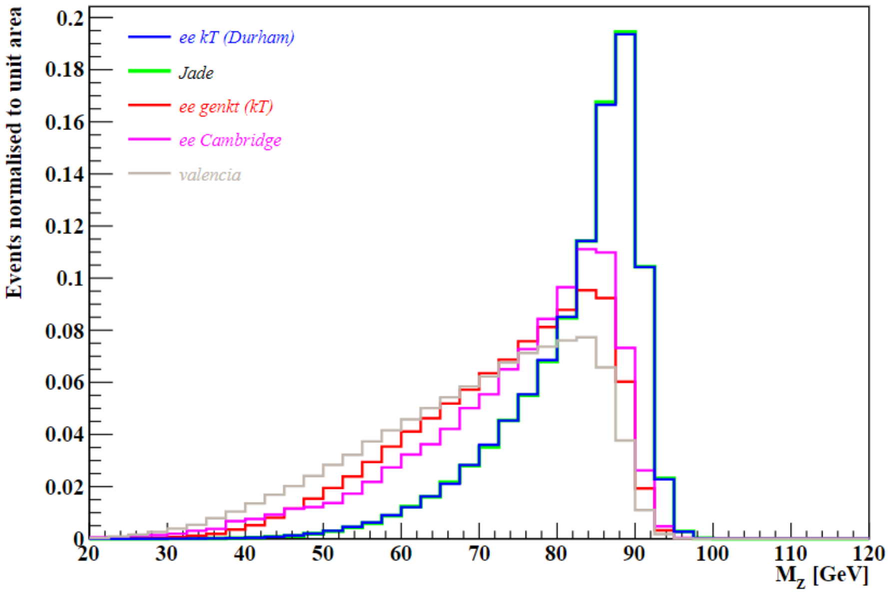
- Both methods based on official FCCAnalysis framework & official spring_2021 samples
- Centre-of-mass energy: 91.2 GeV
- Signal: **p8_ee_Zbb_ecm91**
- Backgrounds: **p8_ee_Zcc_ecm91** & **p8_ee_Zuds_ecm91** & **p8_ee_Zmumu_ecm91**
- Configuration and Object selection:
  - ee-KT Durham jet algorithm
  - Exclusive process
  - Exactly two jets
  - ES recombination scheme

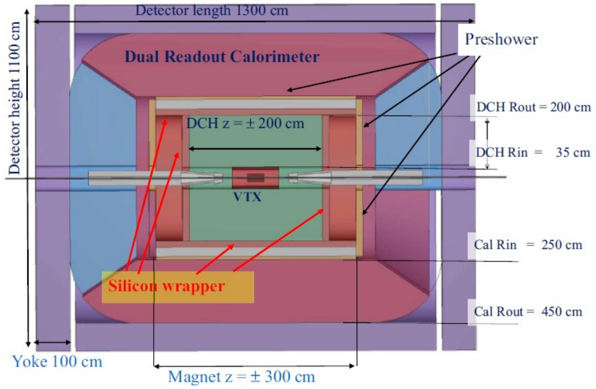



```
JetClustering::clustering_ee_kt(2, 2, 1, 0)
```

Preselection cuts and jet clustering algorithm

- Set of preselection cuts applied for both methods:
  - Jets to satisfy p_T > 10 GeV
  - Polar angle of jets required to be θ^{jets} > 0.226 rad
- For the jet selection, we require to have exactly 2 jets, which need to be considered as *b*-tagged jets as well
  - Flat *b*-tag efficiency of 80%
  - Mis-tag rate for *c*-quark jets of 10%
- Study on the jet clustering algorithm to find the optimal one
  - Choice: **ee-kT Durham** clustering algorithm
- **Pythia8** for parton shower simulation
- Delphes **IDEA** card for detector fast-simulation





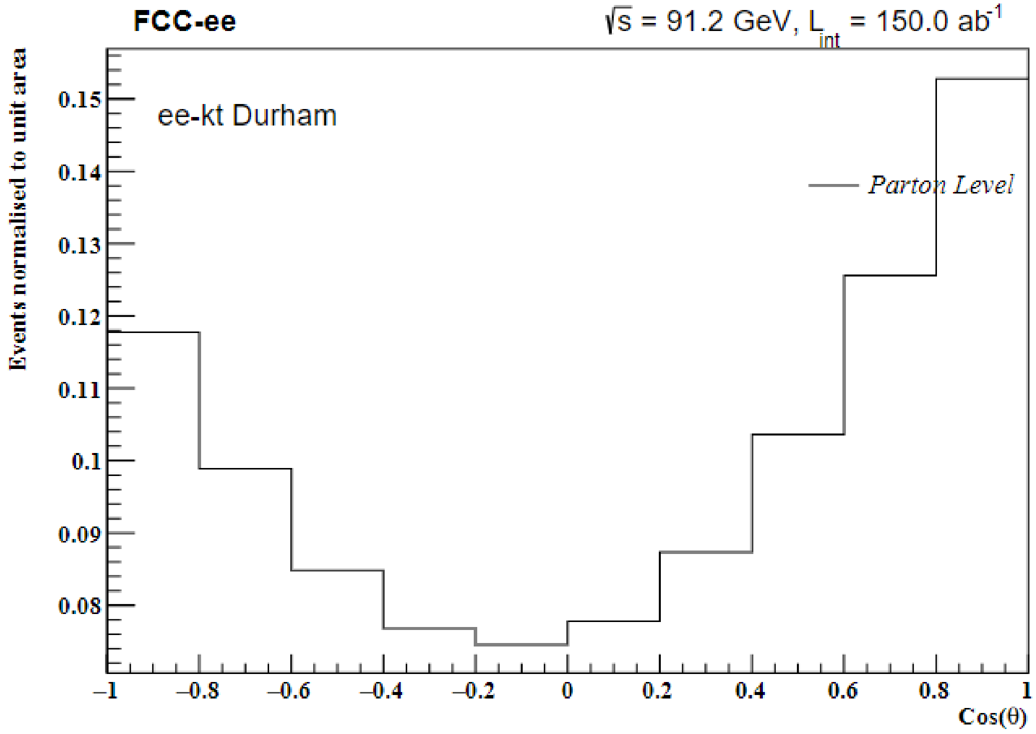
Soft-lepton and jet-charge methods

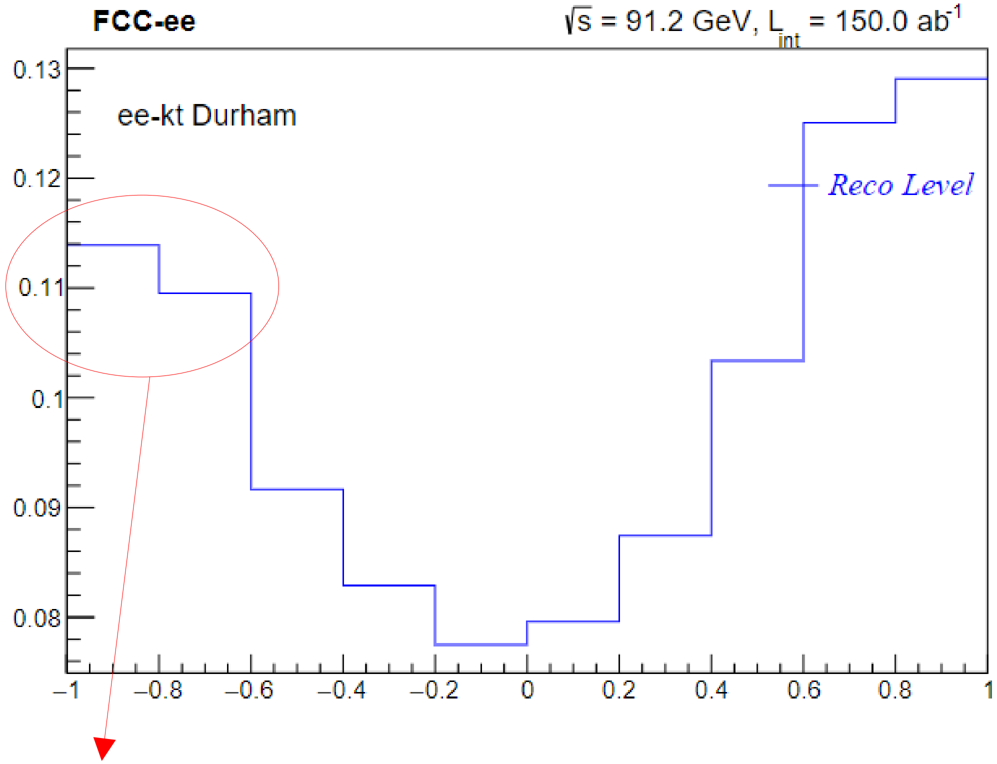
- Leading lepton selection
  - Have exactly one lepton in the final state
- For the case of two leptons, we considered those with the highest energy
  - Aim: to suppress the contribution from the $b \to c \to \mu$
- Requirement of at least one leading lepton (muon) with $p_T > 10$ GeV
  - Could suppress the backgrounds as well

- For the jet-charge method
  - Two hemispheres in forward and backward directions
    - Jets clustered with ee-kT (Durham)
    - Original $\Delta R < 0.4$ cut on tracks has been removed
  - Consider the reconstructed particles (RPs) branch for tracks
  - Weighted charge:
    - Weights are the longitudinal momenta of the tracks
    - “Longitudinal” wrt to jet direction

Distributions and unfolding

- Distributions for the **cosθ** observable at parton/reco level for the jet-charge method

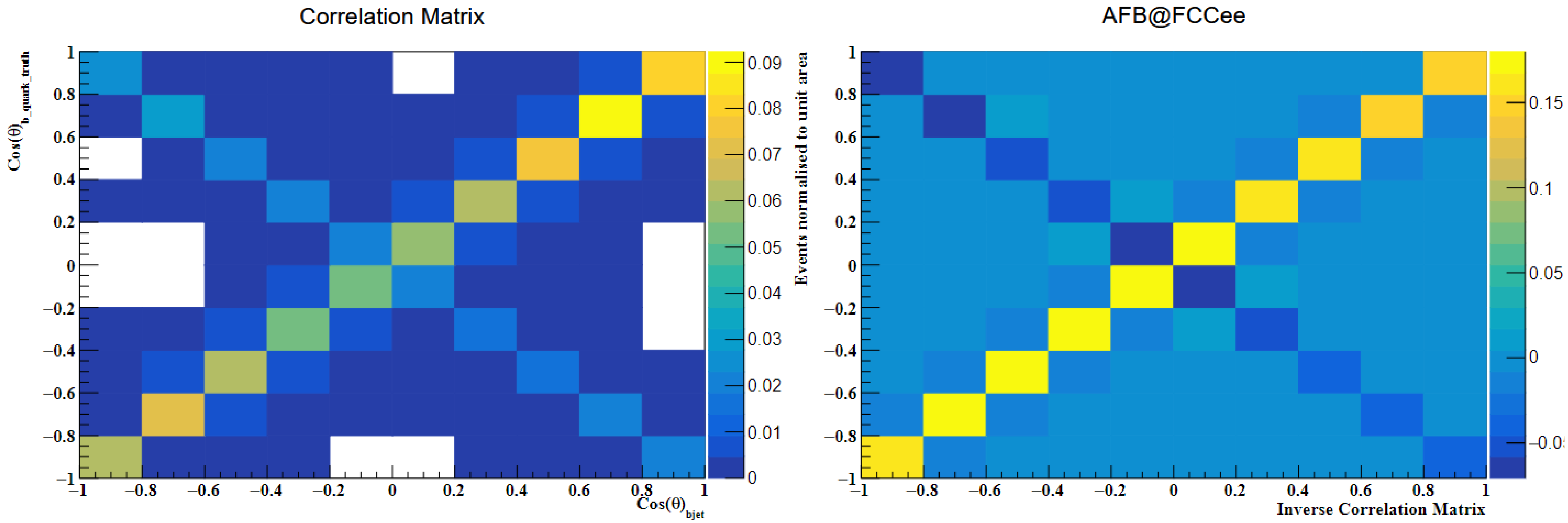




No drop at high |cosθ|

Correlation matrices

- Correlation matrix and unfolding matrix for *b*-quark-jets
  - Reco-level on x-axis
  - Truth-level on y-axis



Systematic uncertainties – *b*-fragmentation

- Modelling of *b*-quark fragmentation
- Lund-Bowler fragmentation function parametrization:

$$f_z = \frac{1}{z^{1+br_b m_b^2}}(1-z)^a e^{\frac{-bm_T^2}{z}}$$

- `Tstring:rFactB`
  - Besides the standard value is **0.855**, some other values of **0.875** and **0.835** are investigated in both methods
  - New official samples are generated with r_b = **0.875**, **0.835**
  - Unfolding procedure is repeated for those samples

Systematic uncertainties – FSR

- Emission of final state QCD radiation
- The following numbers are considered accordingly, and new official samples are generated and analyzed:
    - `TimeShower:renormMultFac=`**`0.707`**`; TimeShower:factorMultFac=`**`0.707`**`;`
    - `TimeShower:renormMultFac=`**`1.414`**`; TimeShower:factorMultFac=`**`1.414`**`;`

Next-to-leading order (NLO) DGLAP corrections

- Dire ("Dipole Resummation") parton shower serves as a comprehensive replacement for the default parton showers in Pythia
- Dire incorporates inclusive next-to-leading order (NLO) DGLAP corrections into the shower evolution
- Consider `PartonShowers:model = 3`, to select the Dire showering
- Consider `DireTimes:kernelOrder = 3` and `DireSpace:kernelOrder = 3` to define the higher-order corrections to the parton shower splitting functions used for time-like (i.e. final state) and space-like (i.e. initial state) evolution
- Considering the Dire parton shower, new official samples are generated using Pythia and Delphes (IDEA card) is used for the detector simulation, and finally the EDM4HEP format is produced

Results – *b*-fragmentation uncertainty

- The *b*-quark fragmentation uncertainty on the A_{FB}^{b} measurement for the **lepton-based study** considering two different values of `Tstring:rFactB=0.835; 0.875`, is found to be **0.00037 and 0.00091**, respectively
- In the case of the **jet-charge method**, the *b*-fragmentation uncertainty is calculated considering considering two different values of `Tstring:rFactB=0.835; 0.875`, is symmetric and is **0.00252**

Results – FSR uncertainty

The systematic uncertainty related to the emission of the FSR in the b-quark FB asymmetry measurement is estimated to be of the order of 10^{-3}.

- Symmetric systematic uncertainty of **0.0034**, for two different values of TimeShower:renormMultFac and TimeShower:factorMultFac = 0.707; 1.414, for the **lepton-based** method
- In the case of the **jet-charge method**, the uncertainty regarding the final state QCD radiation is calculated to be symmetric and equal to **0.00152**

Results – uncertainty and *b*,*c* efficiencies

- Assuming an uncertainty of 5% on the b-tagging and c-mistagging efficiencies
- New official samples generated by scaling up and down the *b*, *c* efficiencies:
  - $\varepsilon_b = 0.84,\ \varepsilon_c = 0.05;$
  - $\varepsilon_b = 0.76,\ \varepsilon_c = 0.15$
- For the **jet-charge method**, systematic uncertainty equal to **0.00035**

Dire parton shower and final state QCD radiation

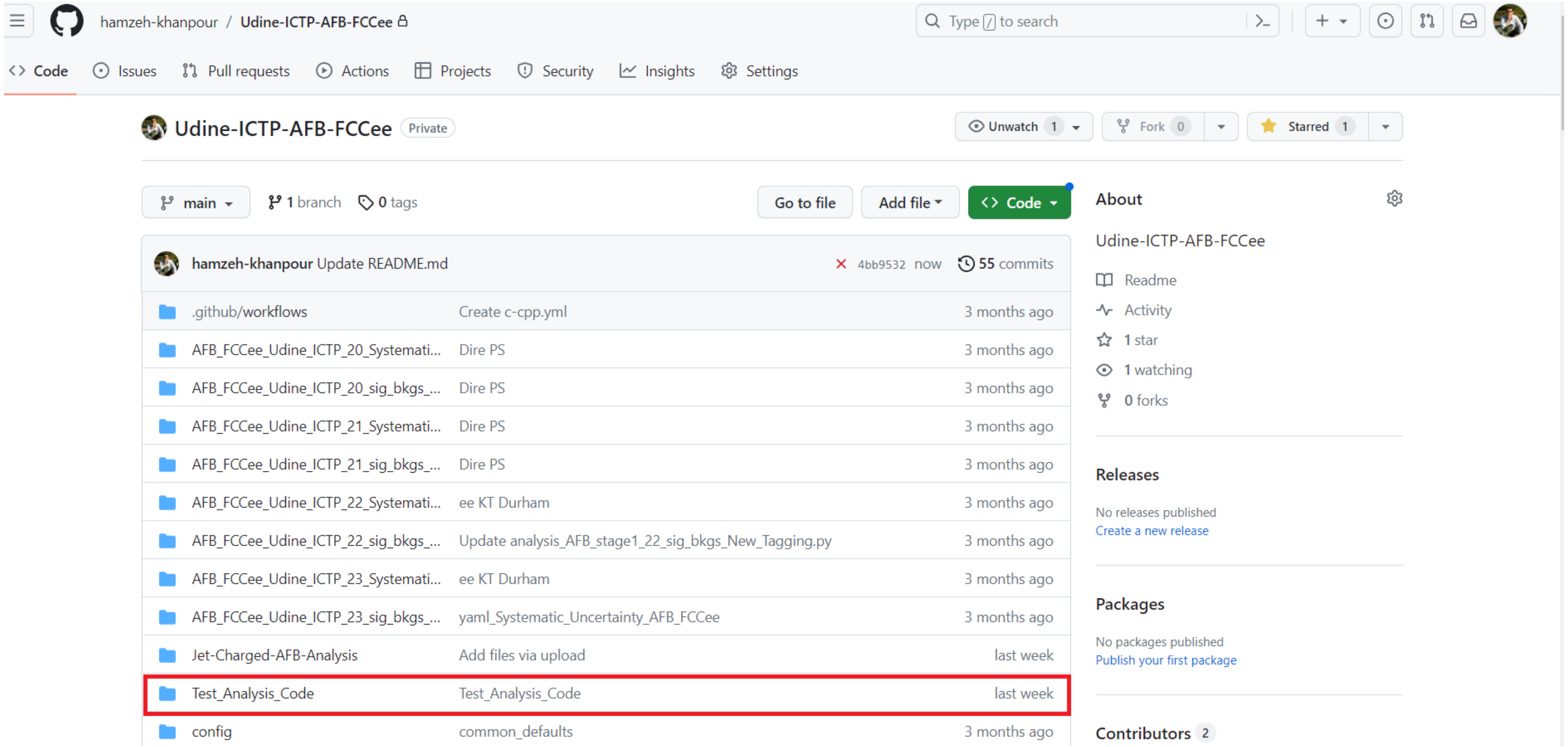
- Considering the usage of Dire parton showering, we extracted the central value and investigated the most significant source of systematic uncertainty, namely the final state QCD radiation
- Applying the same methodology (unfolding procedure), we calculated the associated uncertainty for the QCD radiation

A_{FB} = 0.0927 +/- 0.0012 → Dire, soft lepton method

A_{FB} = 0.0960 +/- 0.0003 → Dire, jet-charge method

→ Improvement with respect to +/- 0.00152 with Pythia

Private GitHub repository



we will make it public

To test and reproduce the framework

1- FCCAnalyses framework

2- Generating the ntuples for the jet-charge method study

3- Running the main analysis code: Leonardo.C (Jet-charge analysis)

4- Doing the Unfolding and Fit to extract the AFB value (Jet-charge analysis)

5- Running analysis_AFB_stage1_FCCee.py (Soft-muon analysis)

6- Running the main analysis code: AFB_FCCee_Udine_ICTP.C (Soft-muon analysis)

Reproducibility: README file

README.md

Udine-ICTP-AFB-FCCee

Udine-ICTP-AFB-FCCee

This repository contains the files and codes that have been used to study the heavy flavor forward-backward asymmetry (AFb) at the future electron-positron collider FCCee. This study has been done at the **Udine/ICTP FCC group** using the official FCCAnalysis framework.

In the following, we present the instructions to read the official samples (Abb signal, and related SM backgrounds). Then we present the main code which read the Ntuples, does the selection, and finally stores some selected distributions that need to extract the AFb from fit to the cos(theta) and do the uncertainty studies as well.

All the necessary files to test and check the analysis code and to do the whole procedure can be found in the folder: **Test_Analysis_Code**

1- FCCAnalyses framework

The FCCAnalyses is a CMake-based project and any customizations can be provided in classic CMake style. In order to install and setup the FCCAnalysis framework, one needs to follow the instructions that appeared on the FCCAnalysis official GitHub repository:

https://github.com/HEP-FCC/FCCAnalyses

We first need to

```
git clone https://github.com/HEP-FCC/FCCAnalyses.git
```

Languages

- C 56.5%
- Python 23.0%
- C++ 20.5%

Independently tested by Nitika Sangwan (ICTP/Udine group) as a new user

Status of the note and contacts

- Whole text revised to add new results for the jet-charge method in the official framework

CONTENTS

Contacts

For additional information or questions, contact us using the email adresses below:

- Marina Cobal (Marina.Cobal@cern.ch)
- Giovanni Guerrieri (Giovanni.Guerrieri@cern.ch)
- Hamzeh Khanpour (Hamzeh.Khanpour@cern.ch)
- Giancarlo Panizzo (Giancarlo.Panizzo@cern.ch)
- Michele Pinamonti (Michele.Pinamonti@cern.ch)
- Leonardo Toffolin (Leonardo.Toffolin@cern.ch)

Future steps and acknowledgements

In the near future:

- To finalize definitely the note
- Structure is fine, adding much more details
- Check the reproducibility of the analysis/code with the official FCC software
  - To exploit the jet-charge method using suggestions from the CEPC and FCC community
    - ✔ Currently looking into https://arxiv.org/pdf/2306.14089.pdf
  - To put all the instructions on our GitLab page
  - To test them from scretch with new users

In the far future:

- Use inputs from detector **FullSim** for feasibility studies

Many thanks to Patrizia, Emmanuel and the whole FCC comunity for the inputs to our Udine/ICTP group

Keep pushing on the FS → still lot of work to do!