Update of A^{b}_{FB} @FCC-ee

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

(Udine-ICTP)

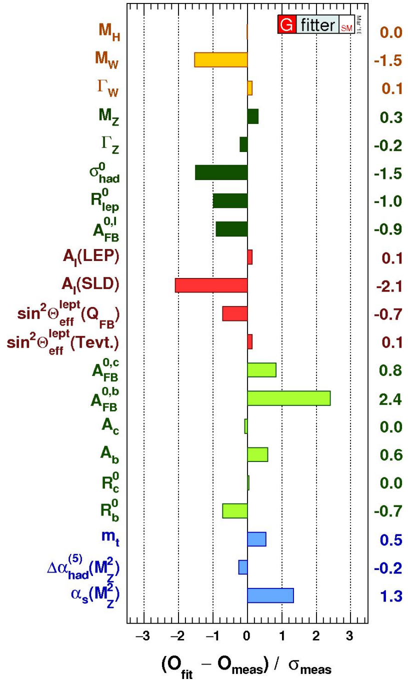
8 November 2022

FCC-ee Electroweak Precision -- Progress Meeting

https://indico.cern.ch/event/1216069/

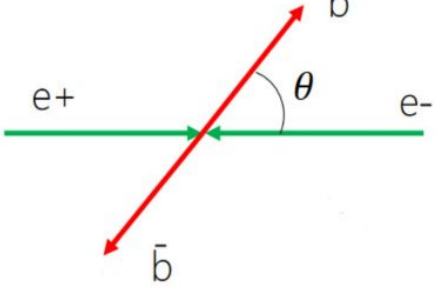
Introduction

- **The goal**:
  - precise measurement of **forward-backward asymmetry** of $b\bar{b}$ in $e^+e^- \to Z \to b\bar{b}$ events
  - **>2σ deviation** btw. LEP combination and EW fits
  - ideal **benchmark** measurement for FCC-ee @m_Z

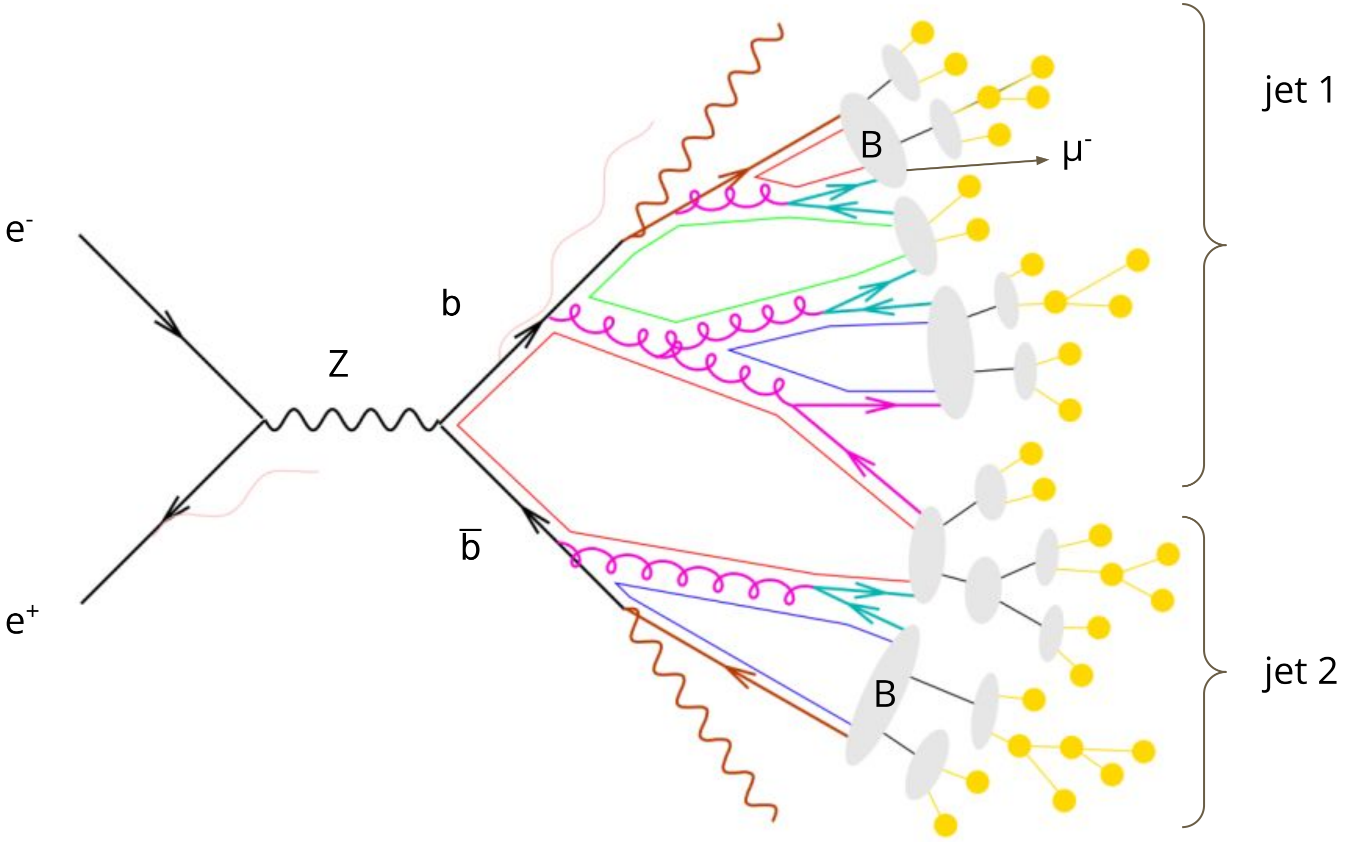


$$\frac{d\sigma_{b\bar{b}}}{d\cos\theta_b} = \sigma_{b\bar{b}}\,\frac{3}{8}\left(1+\cos^2\theta_b+\frac{8}{3}A^b_{\mathrm{FB}}\cos\theta_b\right)$$

- **The measurement**:
  - A^b_{FB} can be extracted from ***cosθ(b)*** distribution
  - experimental distinction between b and $\bar{b}$ needed
    ⇒ quark **charge** determination



Experimental challenges



b-quark charge determination

- Two classes of **methods**:

**: 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. **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

LEP measurements

Reference	Measurement: Experiment	$(A_{FB}^{0,b}) \pm \delta(stat) \pm \delta(syst)$	relative uncertainties stat.	QCD syst.	total syst.
	Lepton-charge based:				
Eur.Phys.J.C24	ALEPH (2002)	$0.1003 \pm 0.0038 \pm 0.0017$	3.8%	0.7%	1.7%
Eur.Phys.J.C34	DELPHI (2004–05)	$0.1025 \pm 0.0051 \pm 0.0024$	5.0%	1.2%	2.3%
Phys.Lett.B448	L3 (1992–99)	$0.1001 \pm 0.0060 \pm 0.0035$	6.0%	1.8%	3.5%
Phys.Lett.B577	OPAL (2003)	$0.0977 \pm 0.0038 \pm 0.0018$	3.9%	1.1%	1.8%
	Jet-charge based:				
Eur.Phys.J.C22	ALEPH (2001)	$0.1010 \pm 0.0025 \pm 0.0012$	2.5%	0.7%	1.2%
Eur.Phys.J.C40	DELPHI (2005)	$0.0978 \pm 0.0030 \pm 0.0015$	3.1%	0.7%	1.5%
Phys.Lett.B439	L3 (1998)	$0.0948 \pm 0.0101 \pm 0.0056$	10.6%	4.3%	5.9%
Phys.Lett.B546	OPAL (1997,2002)	$0.0994 \pm 0.0034 \pm 0.0018$	3.4%	0.7%	1.8%
	Combination	$0.0992 \pm 0.0015 \pm 0.0007$	1.5%	0.5%	0.7%

stat syst

Effort and tools

- **Person-power**:
  - Master thesis / PhD student *(Leonardo, graduated 2 weeks ago, starting PhD now)*
  - Dedicated post-doc *(Hamzeh)*
  - part-time 2nd year PhD student *(Giovanni)*
  - Supervision and help by seniors *(Marina, Giancarlo, Michele)*

- **Analysis framework**:
  - using both **HEP-FCC/FCCAnalyses framework** and stand-alone Madgraph+Delphes
  - investigating usage of thrust axis, jets with different algorithms, soft muons… *(considering for the future: secondary vertex reconstruction, exclusive B-hadron decays, interplay with b-tagging…)*

Analysis strategy

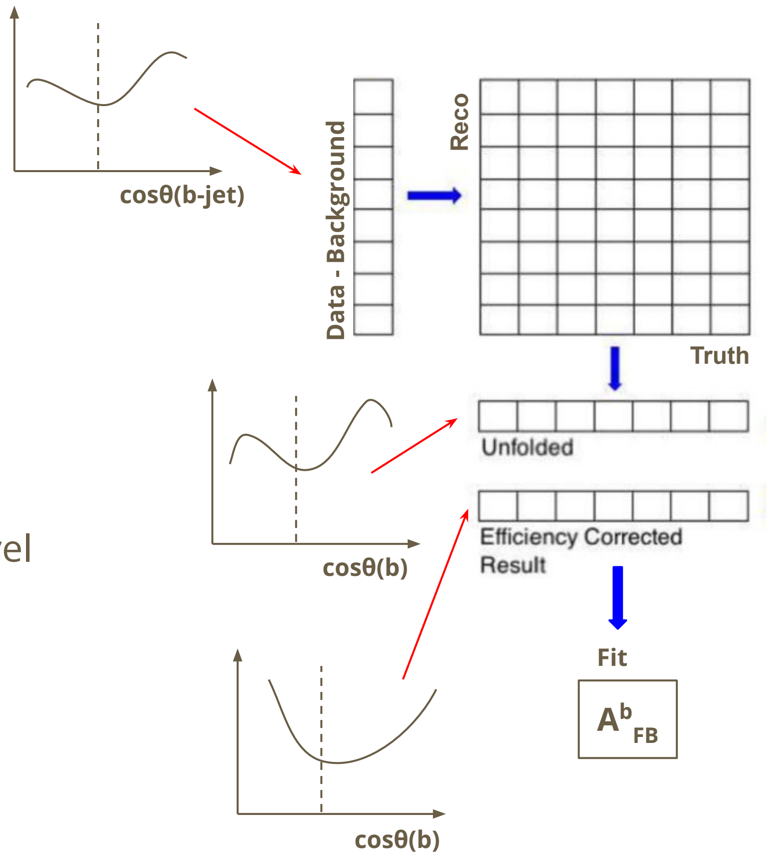
- **Investigated workflow**:

  1. build **reco-level observable** using:
     - jet direction
     - charge determined with one of the two methods (studies in parallel)

  2. perform **unfolding** from reco-level to parton-level

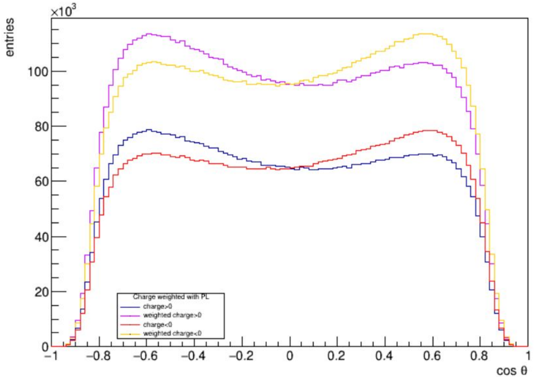
  3. extract A^b_{FB} from **fit** to unfolded distribution

Alternative workflow:
starting to consider also template fit at reco-level (with templates obtained via "folding" or reweighting)

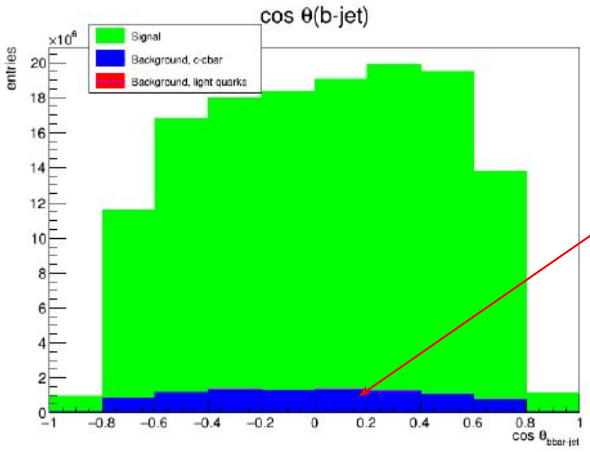


Jet-charge based studies

- Mostly carried on in the context of **Leonardo's master thesis**
- Based on private MadGraph+Delphes simulation (with IDEA card)
- Anti-kt 0.5 jets used
- Simplified *b*-tagging (flat 80% eff., 10%/1% c/light-mis-tagging)
- **Jet charge** built with weighted sum of charges of tracks (as saved by Delphes) within $\Delta R < 0.4$ from jet axis, with weight = p_L(track) w.r.t. jet axis



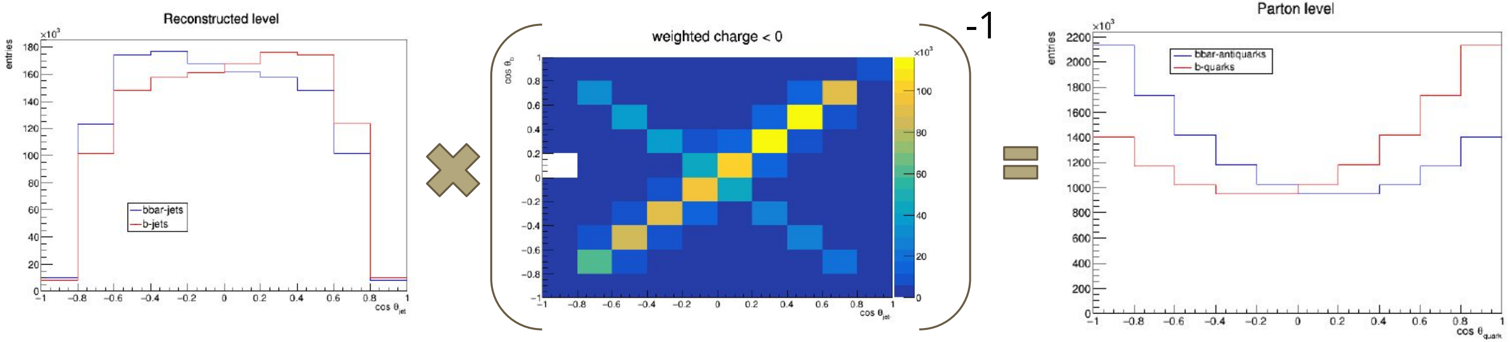
- Event selection:
    - ≥ 2 b-tagged jets
    - ≥ 1 jet with charge > 0, ≥ 1 jet with charge < 0



background from $c\bar{c}$

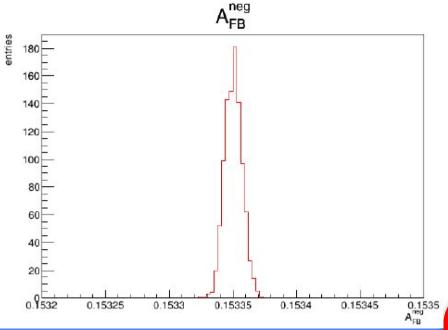
Jet-charge based studies - II

- **Response matrix** and **efficiency correction vector** built from 13 M $b\bar{b}$ events
- **Unfolding** with simple Matrix inversion, 10x10 matrix used



- **Statistical uncertainty** obtained from pseudo-experiments:

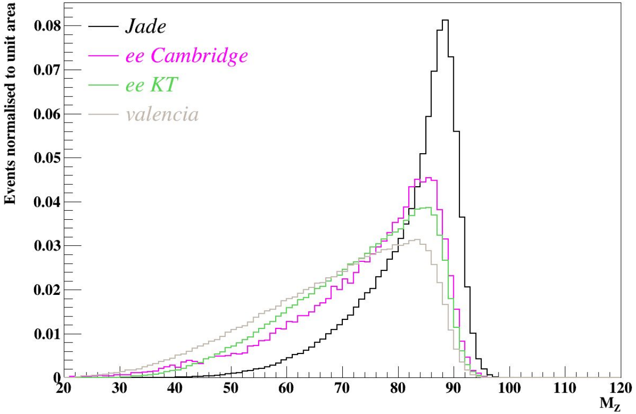
1.4 fb^{-1} ± 0.0001
150 ab^{-1} ± 0.00001

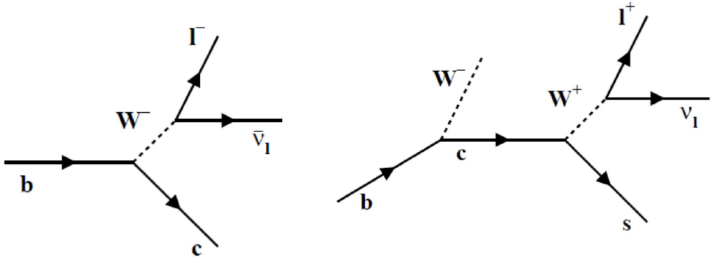


Soft muon based studies

- Work started by **Hamzeh**
- Using **central FCC analysis software** and centrally produced samples
- **Jets** reconstructed by **JADE** algorithm
- Focusing on **soft muon tagging** method

- Investigating optimal **selection** to minimize contribution from "charge flips" due to ***b*** → ***c*** → ***μ*** decays:
  - *μ* with ΔR(jet) < 0.4 (non-isolate) used to *tag* jets
  - *p*(*μ*) > 10 GeV cut applied
  - investigating cuts on other quantities (*e.g.* $p_T^{rel}(\mu, jet)$)



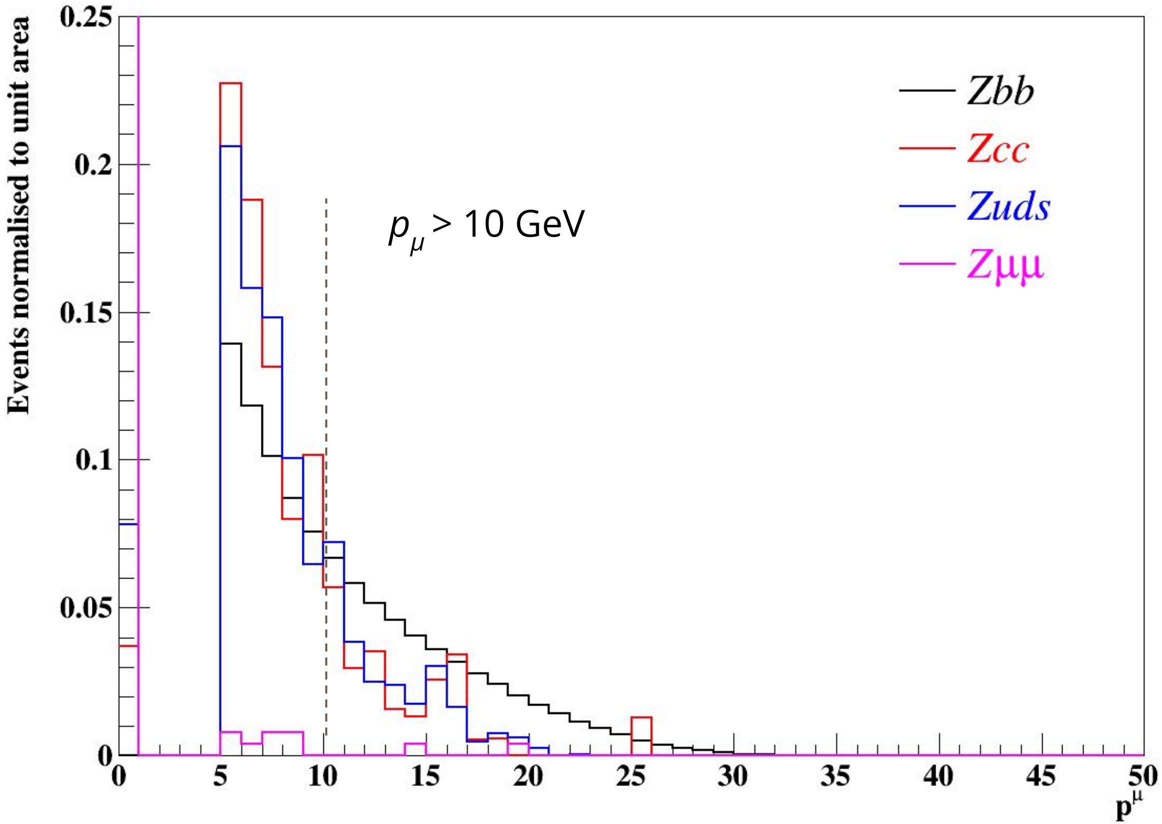


Branching ratios (in %)	
$BR(b \to \ell^-)$	10.90 ± 0.32 ($\mp$ 0.21)
$BR(b \to c \to \ell^+)$	8.30 ± 0.47 ($\pm$ 0.19)
$BR(b \to \bar{c} \to \ell^-)$	1.30 ± 0.50
$BR(b \to \tau \to \ell^-)$	0.70 ± 0.20
$BR(c \to \ell^+)$	9.80 ± 0.50

Soft muon based studies - II

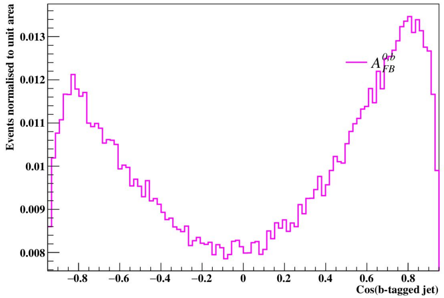
- Background studies in progress:
  - $Z \rightarrow c\bar{c}$
  - $Z \rightarrow$ light
  - $Z \rightarrow \mu\mu$

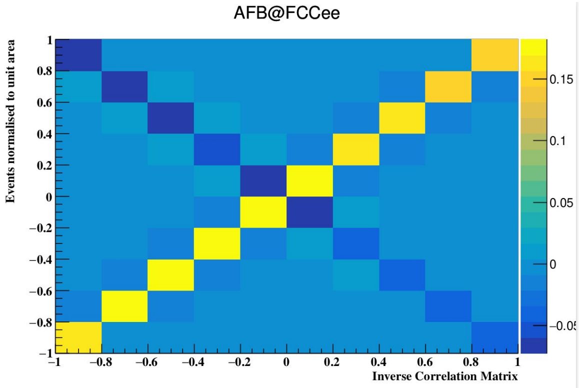
- Jet selection should reject most of $Z \rightarrow \mu\mu$
- *b*-tagging cut will reduce the rest
  - cut on $p_\mu > 10$ GeV will further reduce them

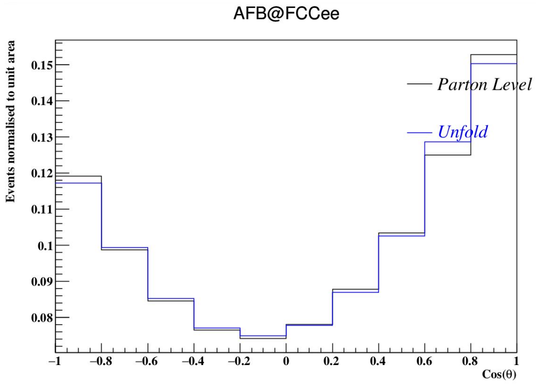


Soft muon based studies - III

- Unfolding implemented in the same way:







- Extraction of statistical & systematic uncertainty under way

Systematic uncertainties

- **We know statistical uncertainty will not be an issue**:
  - LEP combination has ~equal stat and syst contributions
  - we expect ~10^5 times more statistics at FCC-ee ⇒ ~300 times smaller stat. uncertainty

- **Systematic uncertainties expected to be dominant**:
  - modelling ***b*-fragmentation**
    - affecting B-hadron kinematics
  - **final-state QCD radiation** effects
    - affecting jet shapes, distribution of charge, B-hadron kinematics...
  - ***B*-hadron decay** modelling:
    - mostly BRs, in particular for $b \to c \to \mu$ decays
  - ***b*-tagging** efficiency:
    - uncertainty on mis-tag rate affecting background prediction
    - p_T and η dependency of *b*-tagging eff. for signal

Systematic uncertainties - II

- **First numbers** - for **jet-charge** based analysis:
  - b-fragmentation: ± 0.008
  - α_S^{FSR} : ± 0.007
  - background rate: ± 0.0003

changing r_b value in Lund-Bowler fragmentation function in Pythia

changing α_S^{FSR} value in Pythia

varying Z → cc according to estimated b-tagging mis-identification uncertainty (±10%)

- **Total systematic** already at the **level of 0.01**
  - w.r.t. to stat uncertainty ~10^{-5}

    … and **LEP** systematics ~ **0.001 – 0.006** (depending on measurement)

    ⇒ somehow ***overestimating*** systematics?

    … or need to consider ways to ***reduce*** them (e.g. in-situ calibration methods)?

Future Studies and Plans

- Would like to **complete** the two studies based on simple methods for *b*-quark charge determination, before investigating ***more complex methods***
  - re-implementing jet charge study with HEP-FCC/FCCAnalyses framework
  - finalizing systematic uncertainty evaluation for the soft-muon based study

- **Systematic uncertainties**:
  - tested production of alternative samples with varied Pythia parameters within HEP-FCC/FCCAnalyses framework
  - need to start thinking about additional systematic uncertainties to consider:
    - **tracking** efficiency & resolution?
    - **jet energy** uncertainties expected to be negligible (?)

- **Collecting information and making plans on more sophisticated techniques**:
  - thinking about a **general machine-learning technique** for *b*-quark charge determination
  - possibly in a **joint effort with *b*-tagging** algorithm development studies

Conclusions

- **Analysis workflow in place**:
  - able to get results within **FCC framework** and with **stand-alone MG5+Delphes**
  - unfolding and pseudo-experiment **machinery** in place

- **Carrying on two strategies in parallel**:
  - will need to ***converge*** on a few details after completion of master thesis

- **Started studying systematics**:
  - already clear that **parton shower and hadronization modelling systematics** can kill the precision
    - if no ad-hoc calibrations / auxiliary measurements are considered

- **Plan to have simple studies ready be the end of the year**