Update of A^b_FB @FCC-ee

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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

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

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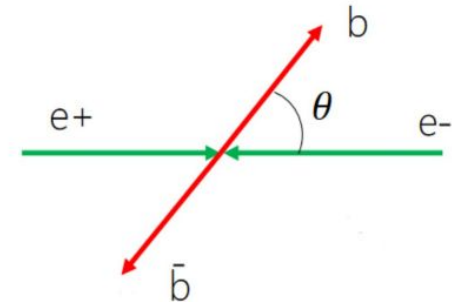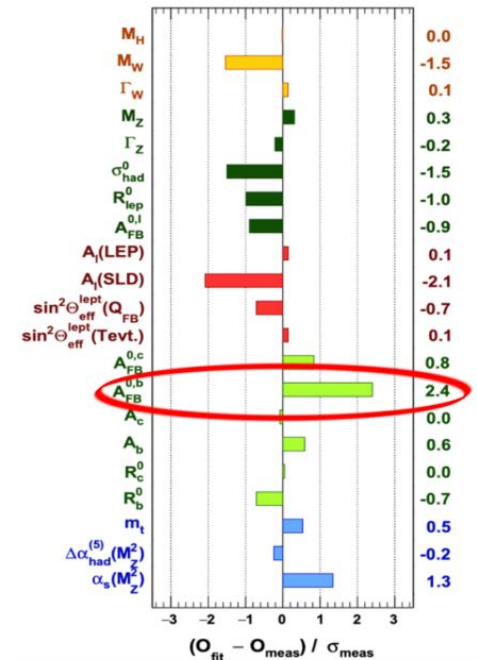
b-quark charge determination

- Two classes of **methods**:

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

| Measurement: | $(A_{FB}^{0,b}) \pm \delta(stat) \pm \delta(syst)$ | relative uncertainties | | |
Experiment		stat.	QCD syst.	total syst.
Lepton-charge based:				
ALEPH (2002)	$0.1003 \pm 0.0038 \pm 0.0017$	3.8%	0.7%	1.7%
DELPHI (2004–05)	$0.1025 \pm 0.0051 \pm 0.0024$	5.0%	1.2%	2.3%
L3 (1992–99)	$0.1001 \pm 0.0060 \pm 0.0035$	6.0%	1.8%	3.5%
OPAL (2003)	$0.0977 \pm 0.0038 \pm 0.0018$	3.9%	1.1%	1.8%
Jet-charge based:				
ALEPH (2001)	$0.1010 \pm 0.0025 \pm 0.0012$	2.5%	0.7%	1.2%
DELPHI (2005)	$0.0978 \pm 0.0030 \pm 0.0015$	3.1%	0.7%	1.5%
L3 (1998)	$0.0948 \pm 0.0101 \pm 0.0056$	10.6%	4.3%	5.9%
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

Eur.Phys.J.C22
Eur.Phys.J.C40
Phys.Lett.B439
Phys.Lett.B546

Eur.Phys.J.C24
Eur.Phys.J.C34
Phys.Lett.B448
Phys.Lett.B577

Effort and tools

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

- **Analysis framework**:
  - using both central FCC software and stand-alone Madgraph+Delphes
  - investigating usage of thrust axis, jets with different algorithms, soft muons...

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
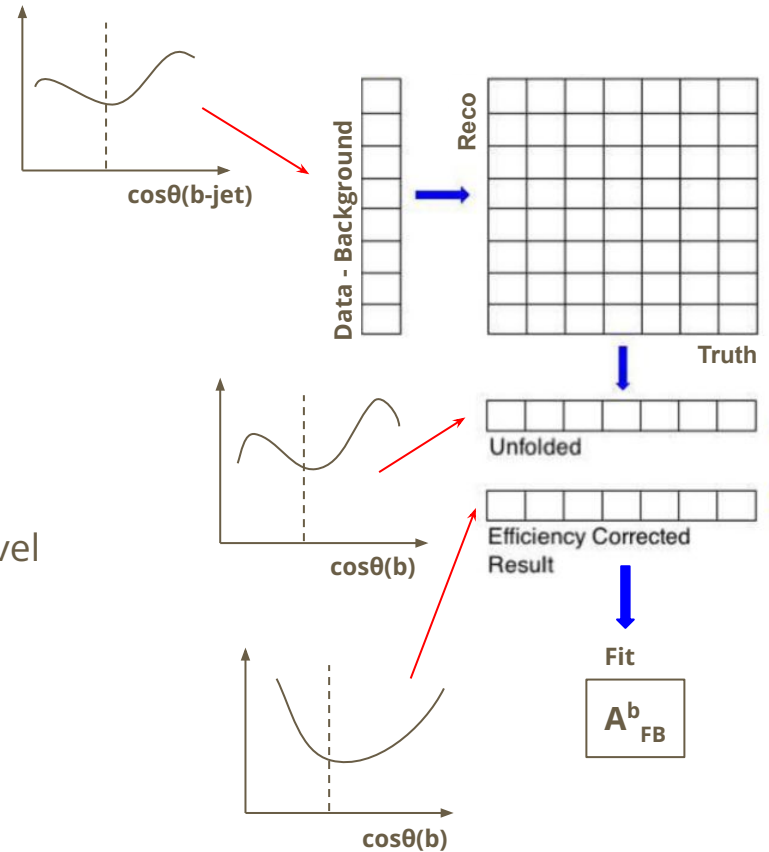
Jet-charge based studies

- 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 ΔR < 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
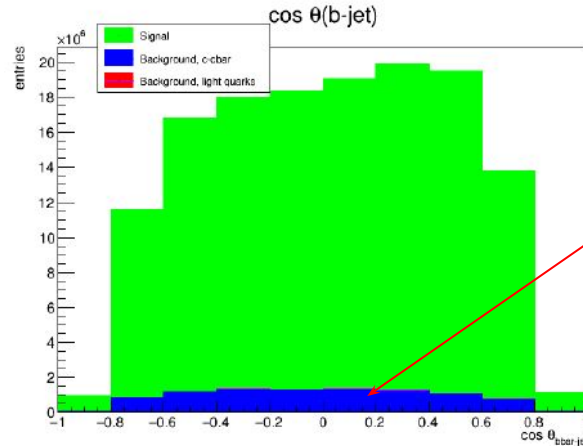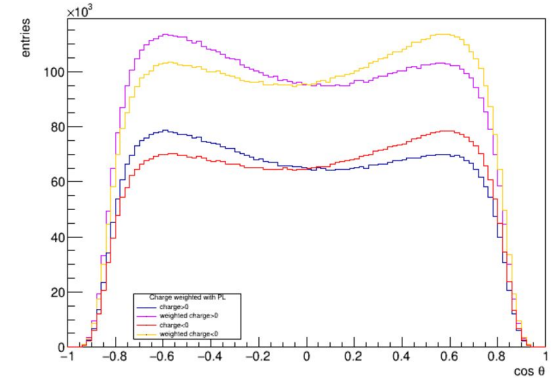
background from c$\bar{c}$
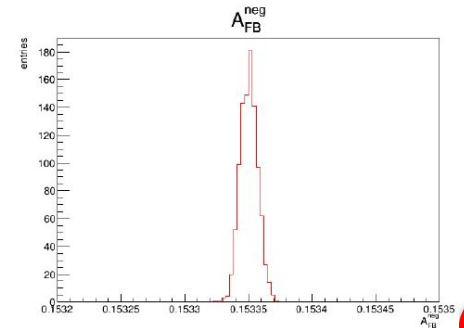
Jet-charge based studies - II

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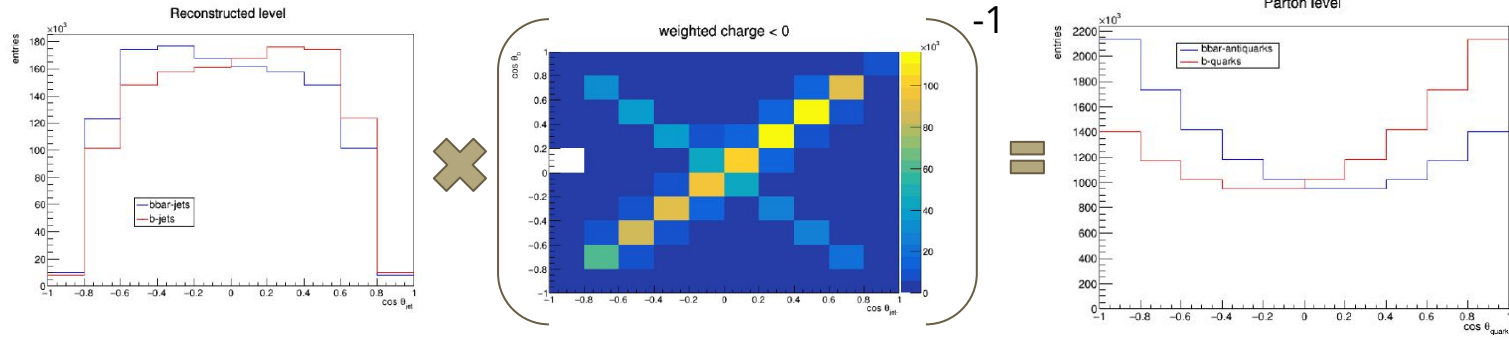
- **Statistical uncertainty** obtained from pseudo-experiments:

  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 $b \rightarrow c \rightarrow \mu$ decays:
  - μ with $\Delta R(jet) < 0.4$ (non-isolate) used to *tag* jets
  - $p_T(\mu) > 10$ GeV cut applied
  - investigating cuts on other quantities (*e.g.* $p_T^{rel}(\mu, jet)$)
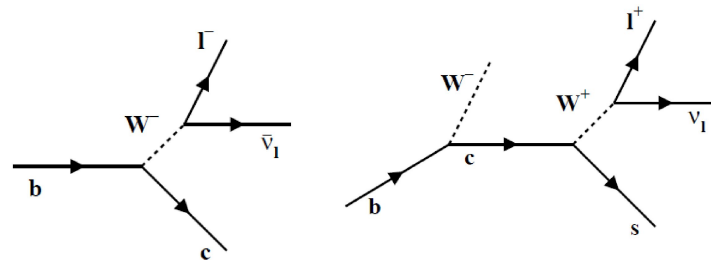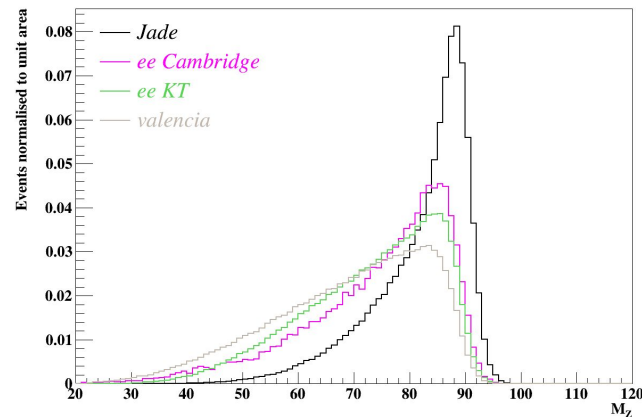
Branching ratios (in %)	
BR(b→ℓ⁻)	$10.90 \pm 0.32 \ (\mp 0.21)$
BR(b→c→ℓ⁺)	$8.30 \pm 0.47 \ (\pm 0.19)$
BR(b→c→ℓ⁻)	1.30 ± 0.50
BR(b→τ→ℓ⁻)	0.70 ± 0.20
BR(c→ℓ⁺)	9.80 ± 0.50

Soft muon based studies - II
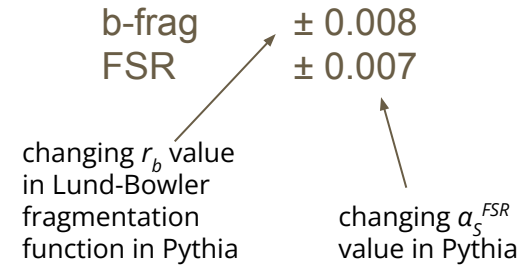
- Unfolding implemented in the same way:
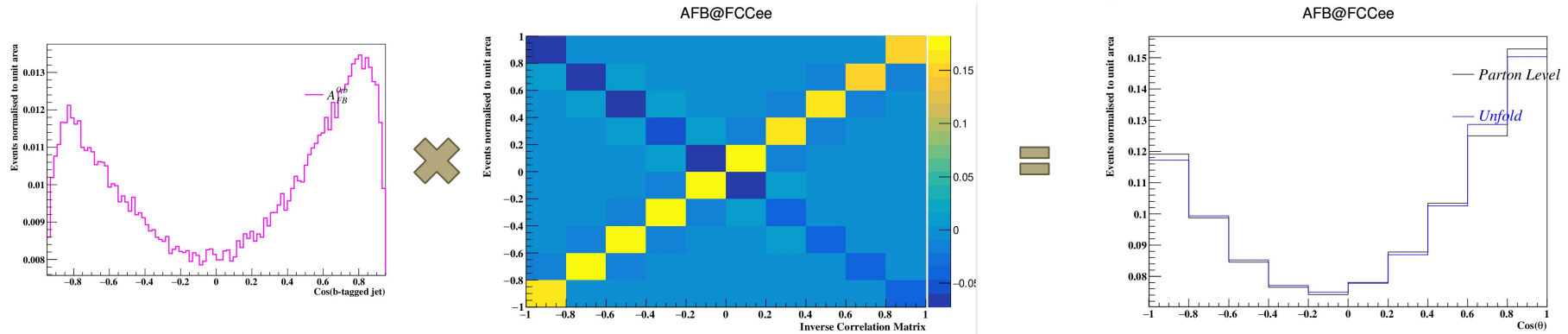
- Extraction of statistical uncertainty under way

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 $b \rightarrow c \rightarrow \mu$ decays
  - **b-tagging** efficiency:
    - uncertainty on mis-tag rate affecting background prediction
    - p_T and η dependency of b-tagging eff. for signal

First numbers
(for jet-charge based analysis)

b-frag	± 0.008
FSR	± 0.007

changing r_b value in Lund-Bowler fragmentation function in Pythia

changing α_S^{FSR} value in Pythia

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 studies ready be the end of the year**