Forward-backward asymmetries at FCC-ee

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

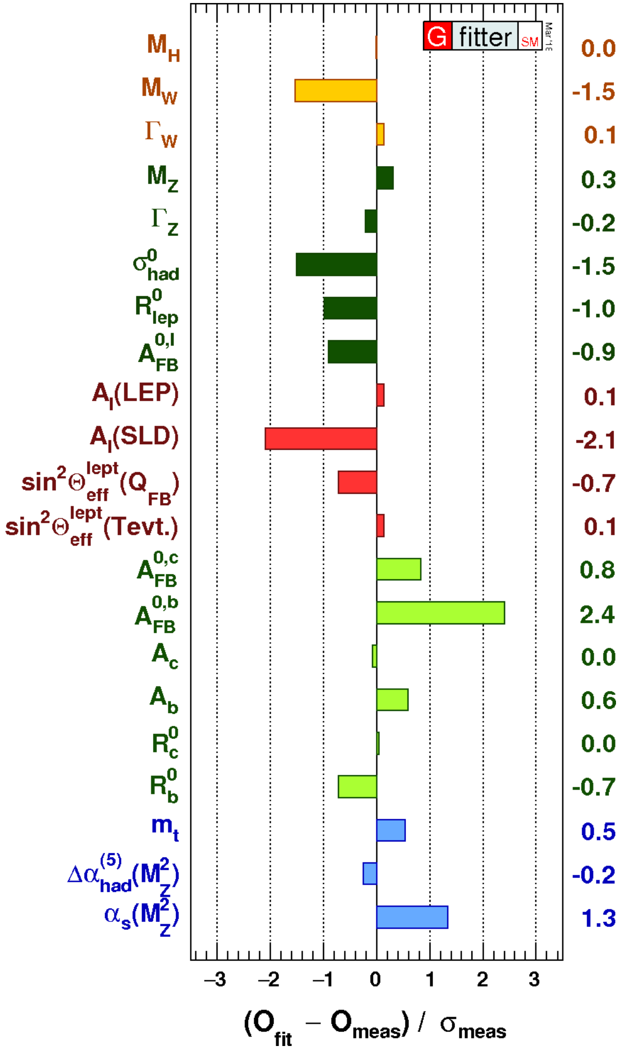
Outline

- Short introduction: $A^{0,b}_{FB}$, motivations
- Route to follow
- Status and plans
- Conclusions

$A^{0,b}_{FB}$: the EW fit

- *b*-quark observables → Largest discrepancies!
- Indirect $A_b(A^{0,b}_{FB}\,;\,A_e(SLD)) > 2\sigma$
- Ideal benchmark measurement for FCC-ee @m_Z

$$A^{0,f}_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4} A_e A_f, \quad A_f = \frac{2 a_f v_f}{a_f^2 + v_f^2}$$



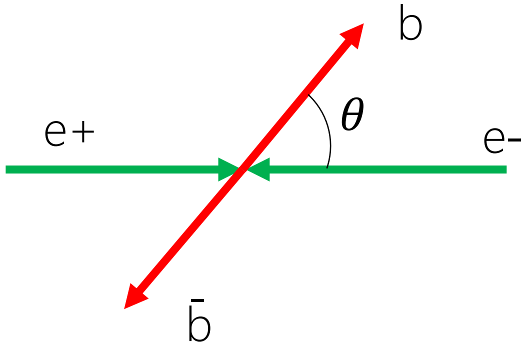
Eur.Phys.J.C 78 (2018) 8, 675

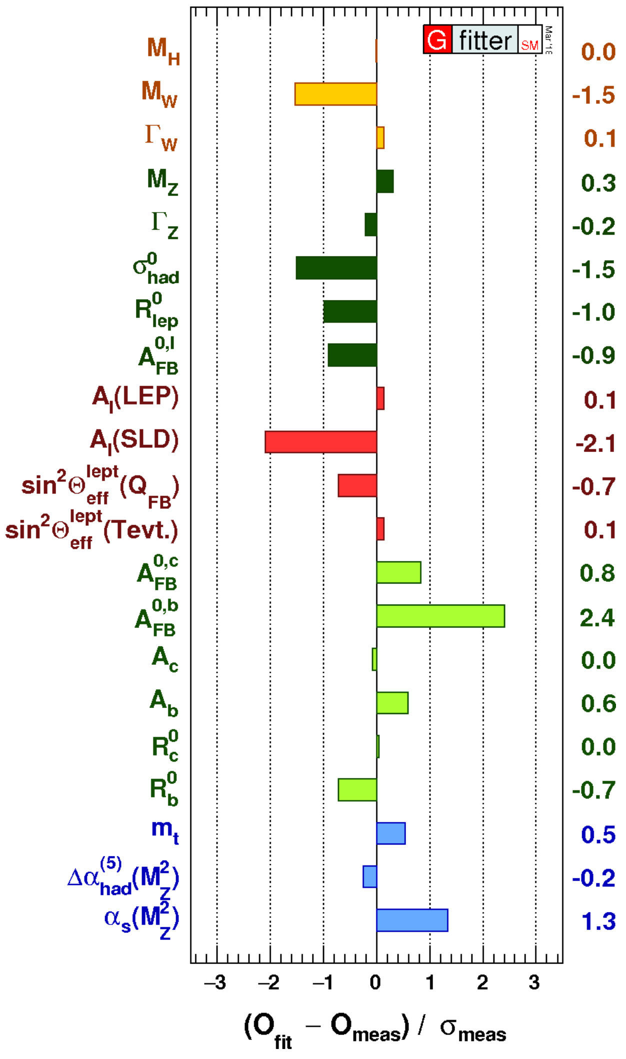
$A^{0,b}_{FB}$: the measurement

- $A^{0,b}_{FB}$ can be extracted from the distribution of $\cos\theta(b)$
- experimental distinction between b and $\bar{b}$ needed

  ⇒ quark charge determination

$$\frac{d\sigma}{d\cos\theta} = \sigma^{\rm tot}_{b\bar{b}}\left(\frac{3}{8}(1+\cos^2\theta) + (A^b_{\rm FB})_{\rm obs}(1-2\chi_B)\cos\theta\right)$$





Eur.Phys.J.C 78 (2018) 8, 675

$A^{0,b}_{FB}$: b-jet charge

Two classes of methods:

- 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

- Decay channels with leptons (e or μ) (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

$A^{0,b}_{FB}$: LEP measurements

	Measurement: Experiment	$(A^{0,b}_{FB}) \pm \delta(\text{stat}) \pm \delta(\text{syst})$	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%

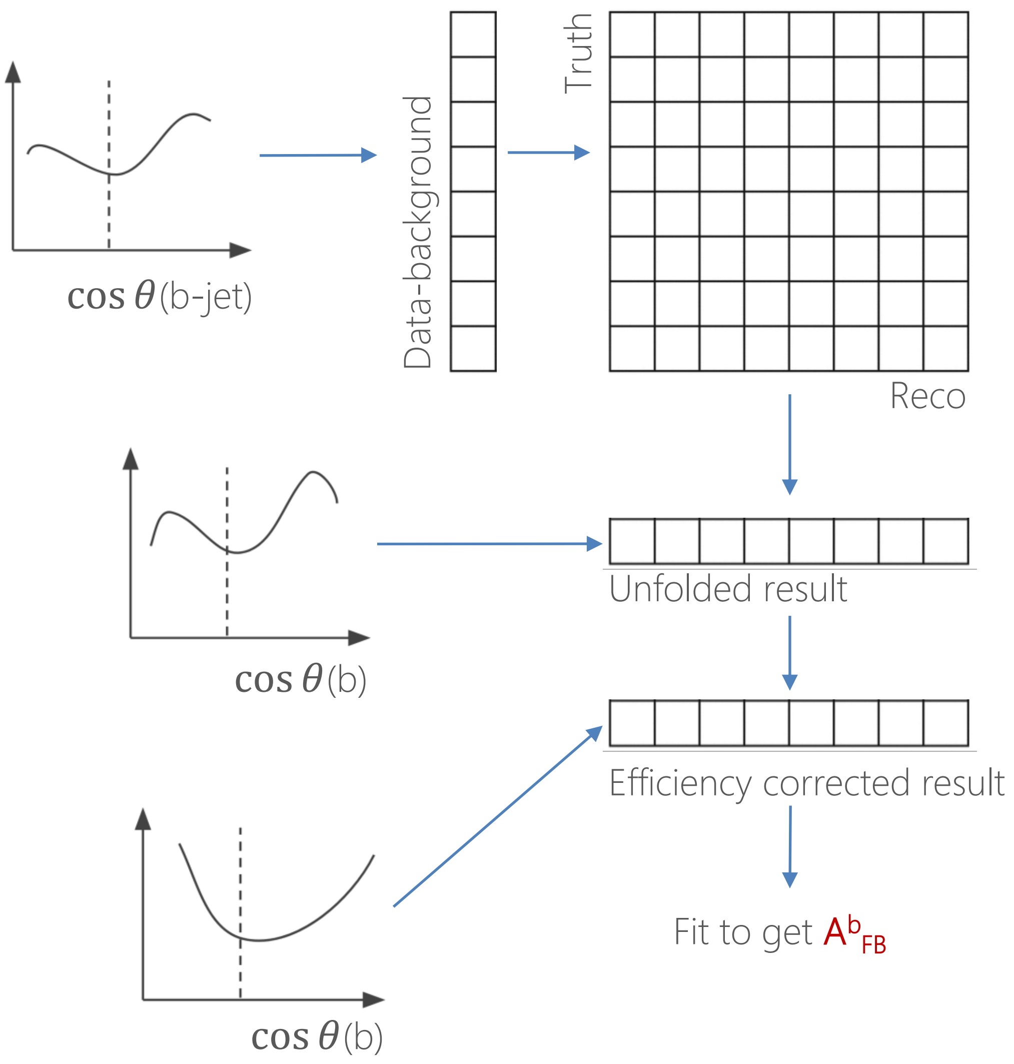
stat. syst.

Analysis strategy

Workflow

1. Build reco-level observable exploiting:
   - Jet direction
   - Jet-charge (determined with one of the two methods)
2. Perform unfolding from reco-level to parton-level
3. Extract $A^{0,b}_{FB}$ from the unfolded distribution

Alternative: template fit at reco-level (with templates obtained via "folding" or reweighting)



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…

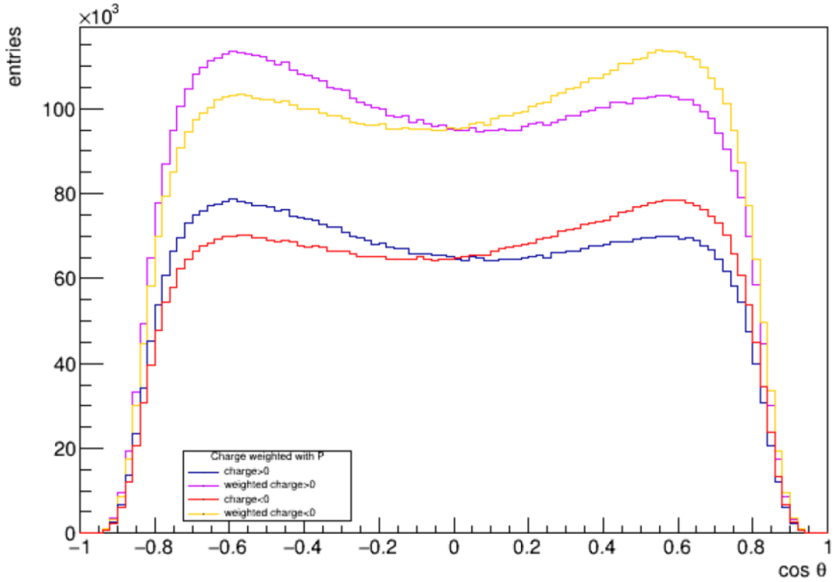
Jet charge study

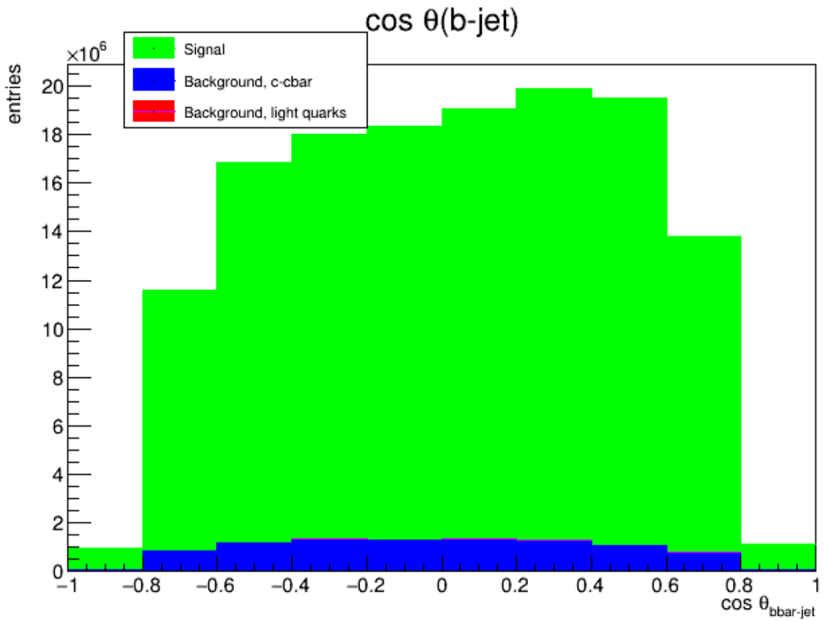
Leonardo Toffolin

- Based on private MadGraph+Delphes simulation (with IDEA card)
- Anti-kt 0.5 jets used *(not optimal, will switch to Durham)*
- 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)
  - ΔR<0.4 from jet axis
  - weight = p_L (track) w.r.t. jet axis

Event Selection

- ≥ 2 b-tagged jets
- ≥ 1 jet with opposite charge > 0
- ≥ 1 jet with charge < 0

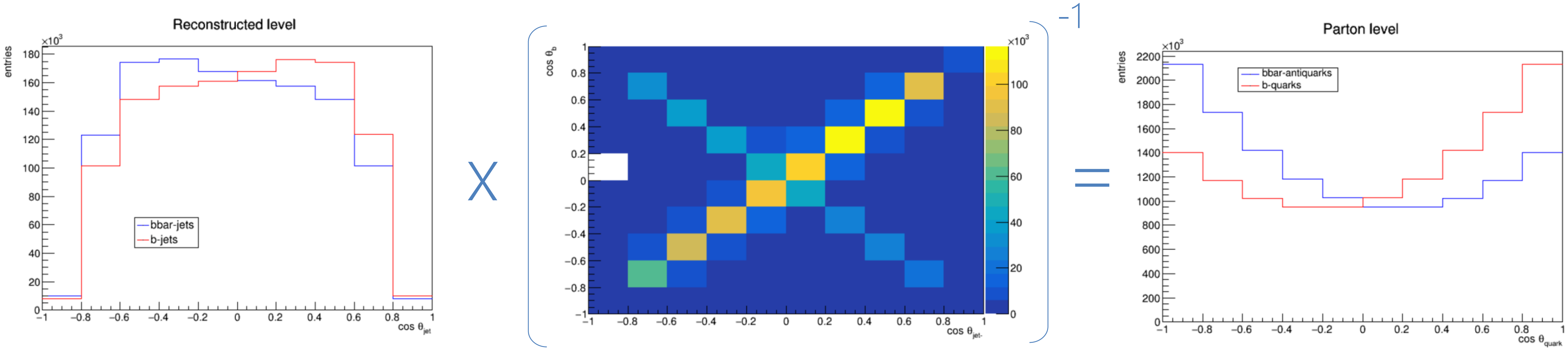




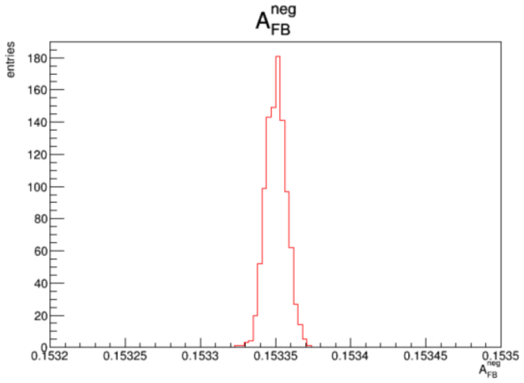
Jet charge study

Leonardo Toffolin

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



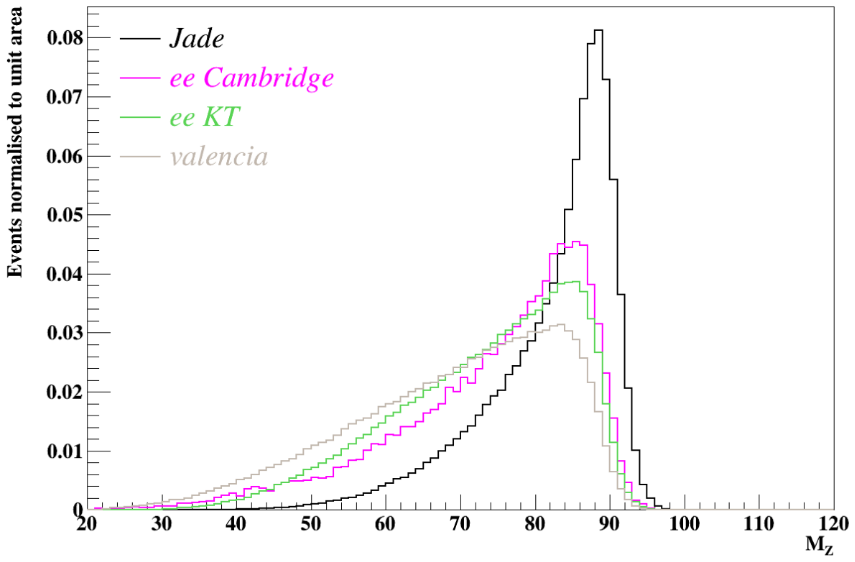
- Statistical uncertainty obtained from pseudo-experiments
  - 1.4 fb^{-1}: ± 0.1%
  - 150 ab^{-1}: ± 0. 01%



Soft muon study

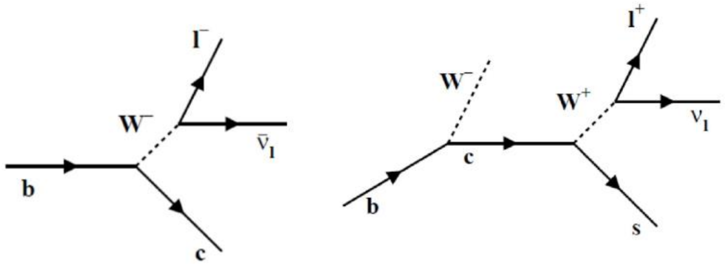
Hamzeh Khanpour

- Based on private HEP-FCC/FCCAnalyses (with centrally produced samples)
- Jets reconstructed by JADE algorithm



Event Selection

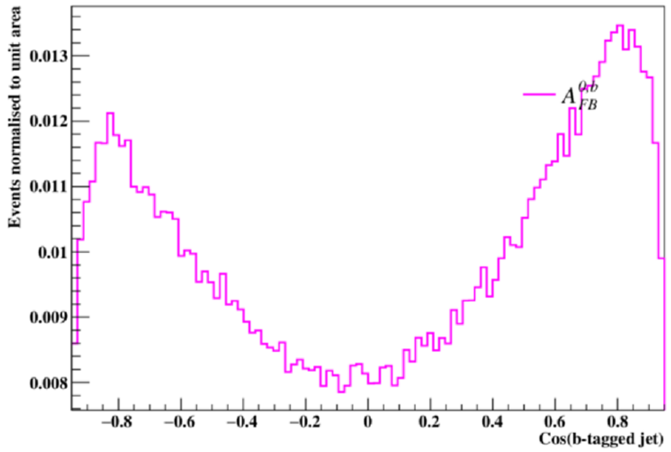
- Investigating optimal selection to minimize contribution from "charge flips" due to $b \to c \to \mu$ decays:
  - μ with ΔR(jet) < 0.4 (non-isolate) used to tag jets
  - $p(\mu)$ > 10 GeV cut applied
  - Investigating cuts on other quantities (*e.g.* $p_T^{rel}(\mu, jet)$)



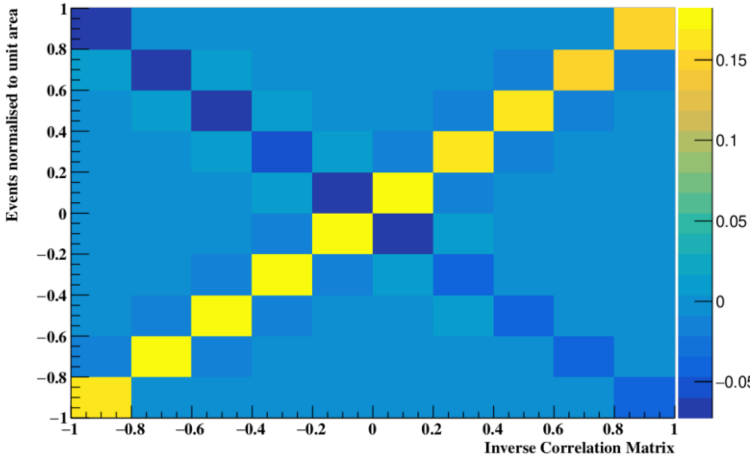
Branching ratios (in %)	
$BR(b \to \ell^-)$	10.90 ± 0.32 ($\mp$ 0.21)
$BR(b \to c \to \ell^+)$	8.30 ± 0.47 ($\pm$ 0.19)
$BR(b \to c \to \ell^-)$	1.30 ± 0.50
$BR(b \to \tau \to \ell^-)$	0.70 ± 0.20
$BR(c \to \ell^+)$	9.80 ± 0.50

Soft muon study

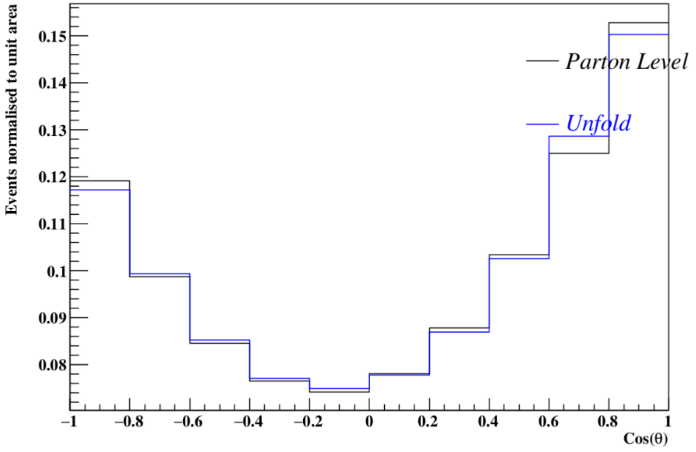
Hamzeh Khanpour



X



=



- As before, statistical uncertainty of the order of:
  - 1.4 fb^{-1}: ± 0.1%
  - 150 ab^{-1}: ± 0. 01%

$$A_{FB}^{0,b} = 0.09410 \pm 0.00001(\text{stat}) \pm 0.00450(\text{syst})$$

Systematic uncertainties

We know that 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

Jet-charge based analysis

- b-fragmentation: ± 5.2% — changing r_b value in Lund-Bowler fragmentation function in Pythia
- α_S^{FSR}: ± 4.3 — changing α_S^{FSR} value in Pythia
- Background rate: ± 0.2% — varying Z → cc according to estimated b-tagging mis-identification uncertainty (±10%)

$$f(z) = \frac{1}{z^{1+br_b m_b^2}}(1-z)^a \exp(-bm_T^2/z)$$

Soft lepton tagging analysis *(ongoing)*

- b-fragmentation: ± 4.4%
- α_S^{FSR}: ± 2.4

Are we somehow overestimating systematics?

Need to consider ways to reduce them (e.g. in-situ calibration methods)?

$$A^b_{FB} = 0.09410 \pm 0.00001(\text{stat}) \pm 0.00450(\text{syst})$$

Ongoing studies and future plans

- Need 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.
  - Have a detailed comparison with one/more of the LEP results.

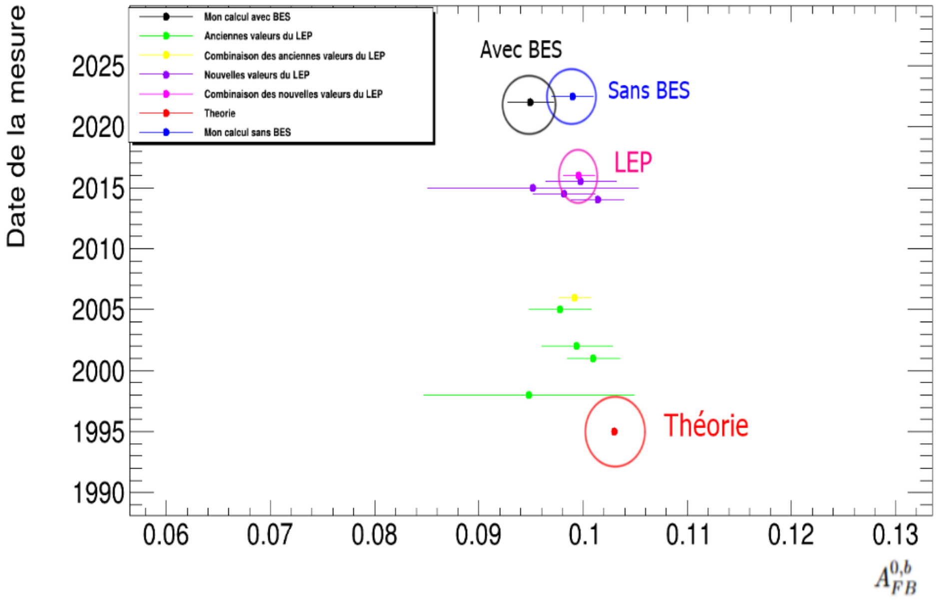
Systematic uncertainties

- Tested production of alternative samples with varied Pythia parameters within HEP-FCC/FCCAnalyses framework
- Additional systematic uncertainties to consider:
  - Tracking efficiency & resolution?
  - Jet energy uncertainties expected to be negligible (?)

Planning usage of advanced techniques

- General machine-learning method for b-quark charge determination
- Possibly in a joint effort with flavour-tagging algorithm development studies

Fairouz Malek, Mathis Granjon



Cooperating across working groups

- Provide additional studies (*e.g. Beam Energy Shape*)
- Provide detector requirements
- Benchmark software and simulations

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

- Already starting to converge on a combined result

Started studying systematics

- Already clear that parton shower and hadronization modelling systematics can kill the precision

  ⇒ ad-hoc calibrations / auxiliary measurements needed

Plan to have simple studies ready by the end of the year

Thank you!