

# STUDY OF THE Z-BOSON COUPLINGS TO HEAVY FERMIONS AT THE FCC-ee

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## THEORETICAL FRAMEWORK

### $A_{FB}^b @ LEP$

Inclusive production cross section:

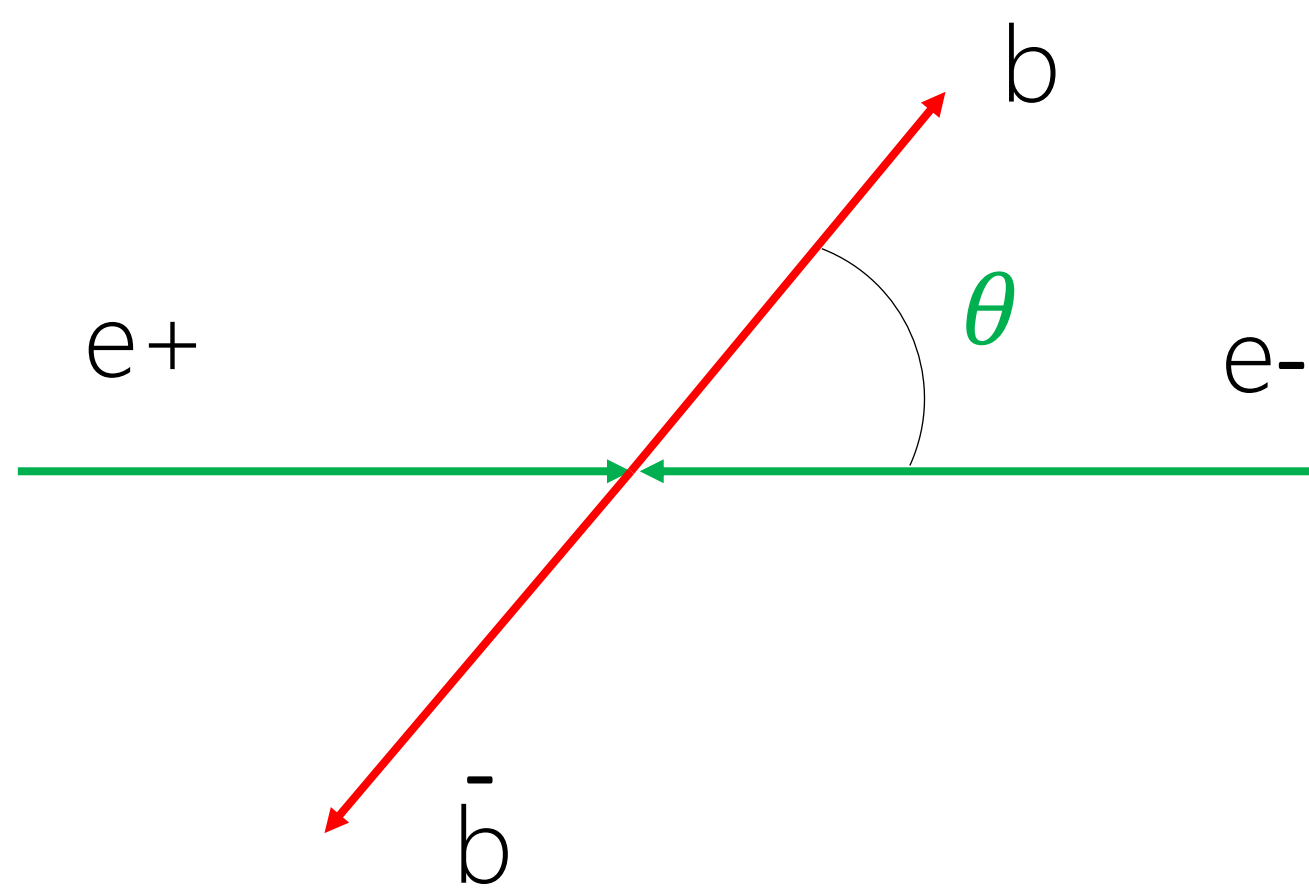
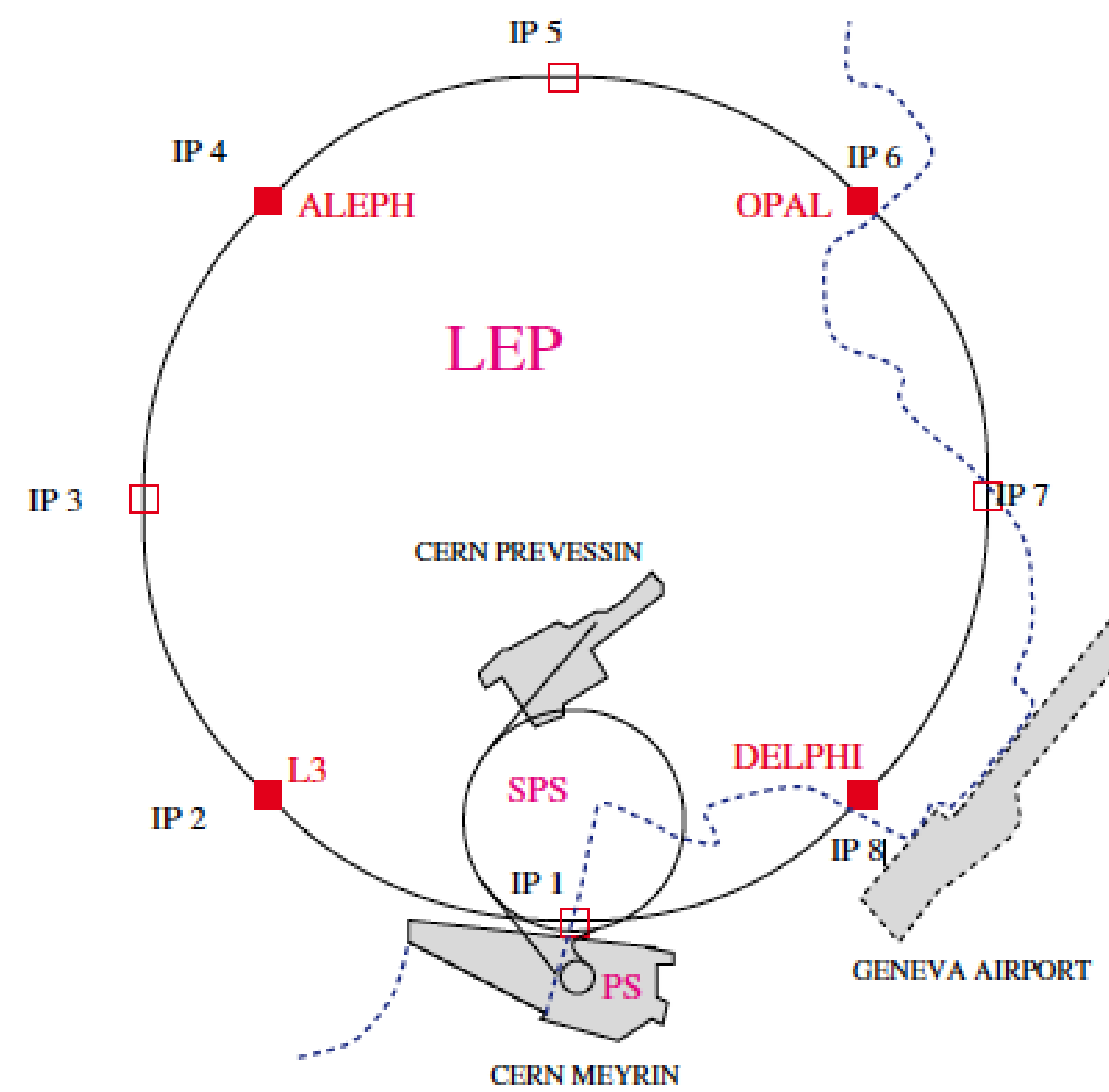
$$\frac{d\sigma}{d\Omega} = N_c \frac{\alpha^2}{4s} \{ (1 + \cos^2\theta) [Q_f^2 - 2\chi_1 v_e v_f Q_f + \chi_2 (a_e^2 + v_e^2)(a_f^2 + v_f^2)] + 2 \cos\theta [-2\chi_1 a_e a_f Q_f + 4\chi_2 a_3 a_f v_e v_f] \}$$

$$a_f = T_3^f, \quad v_f = T_3^f - 2 \sin^2 \theta_w Q_f$$

$T_3^f$  = fermion isospin  
 $Q_f$  = fermion charge

$$\sigma_B = \int_{-1}^0 \frac{d\sigma}{d\Omega} d\cos\theta, \quad \sigma_F = \int_0^1 \frac{d\sigma}{d\Omega} d\cos\theta$$

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



### THE ELECTROWEAK FIT

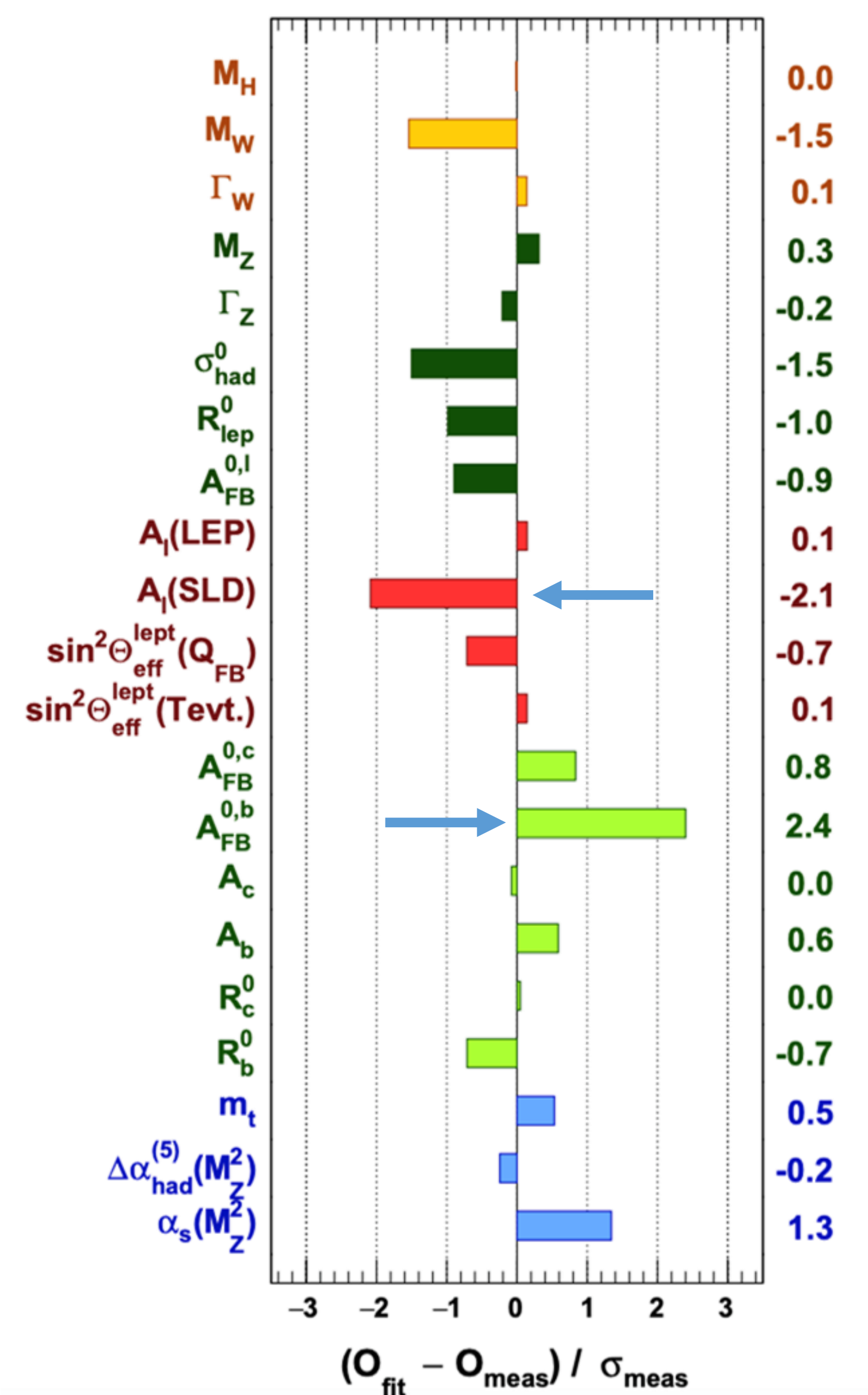
- Experimental b-quark asymmetry has a  $\sim 2.8$  pull w.r.t. theoretical prediction (QED/EWK, NNLO QCD, b-quark mass, jet/thrust axis corrections)

Pull value:

$$\frac{O_{fit} - O_{meas}}{\sigma_{meas}}$$

- The absence of strong disagreements in other variables related to b-quarks, but also the potential for this to be a signal of new physics makes this tension a puzzle to be solved with dedicated experimental and theoretical studies at a future electron circular collider.

- Include not only b-quarks, but c-quarks as well

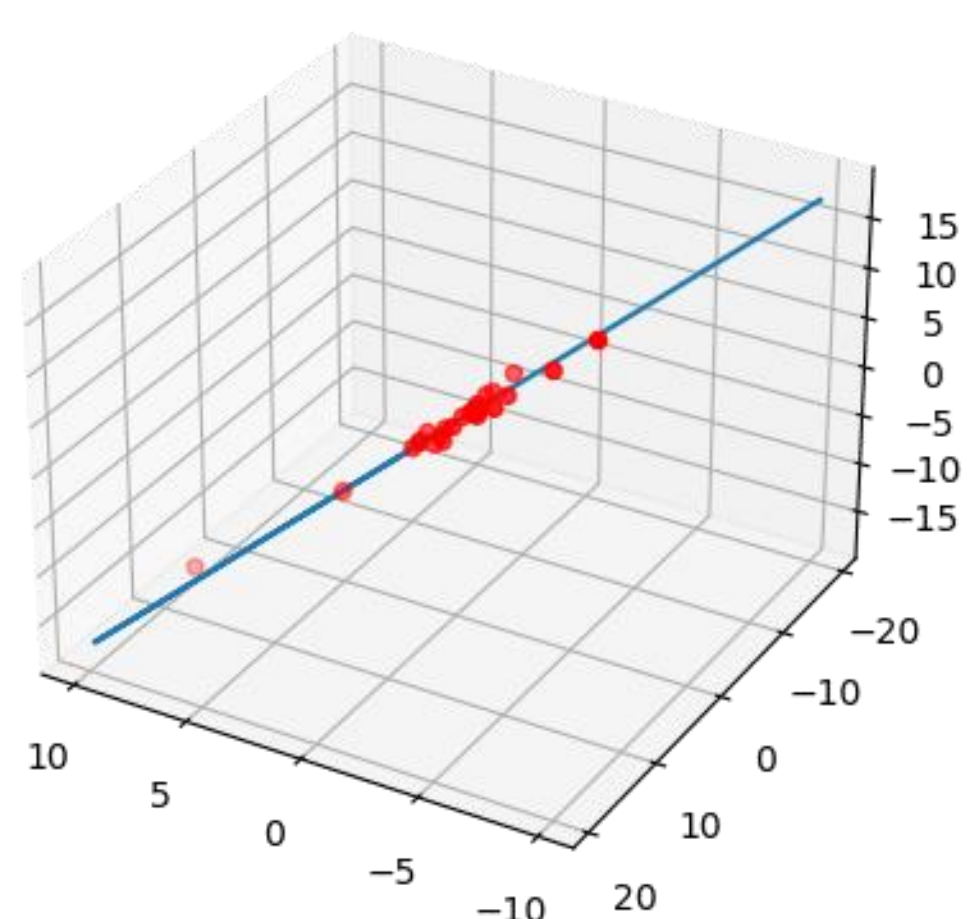


## ANALYSIS STRATEGY

### THRUST AXIS

- Thrust axis can be used to estimate the direction of the original quark. For a given event defined as:

$$T = \max_{\hat{n}} \frac{\sum_i |p_i \cdot \hat{n}|}{\sum_i |p_i|}$$



### B-QUARK CHARGE

- Jet charge can be measured with two classes of methods:

- $Q_{jet}$  variable (with > 6 charged tracks sum, each weighted)

$$Q_{jet} \equiv \sum q_{tr} w_{tr}, \quad w_{tr} \equiv \frac{(p_{tr}^{\parallel})^r}{\sum (p_{tr}^{\parallel})^r}$$

- Soft  $\mu$  charge (here in a simplified variant "Qjet")

$$p_{T\mu}^{lab} > 4\text{GeV}, \quad p_{T\mu}^{rel} > 0.8\text{GeV},$$

$$Q_{\mu,jet} \equiv q_{\mu} \left( \frac{p_{T\mu}^{rel}}{m_b} \right)^r$$

### B-QUARK IDENTIFICATION

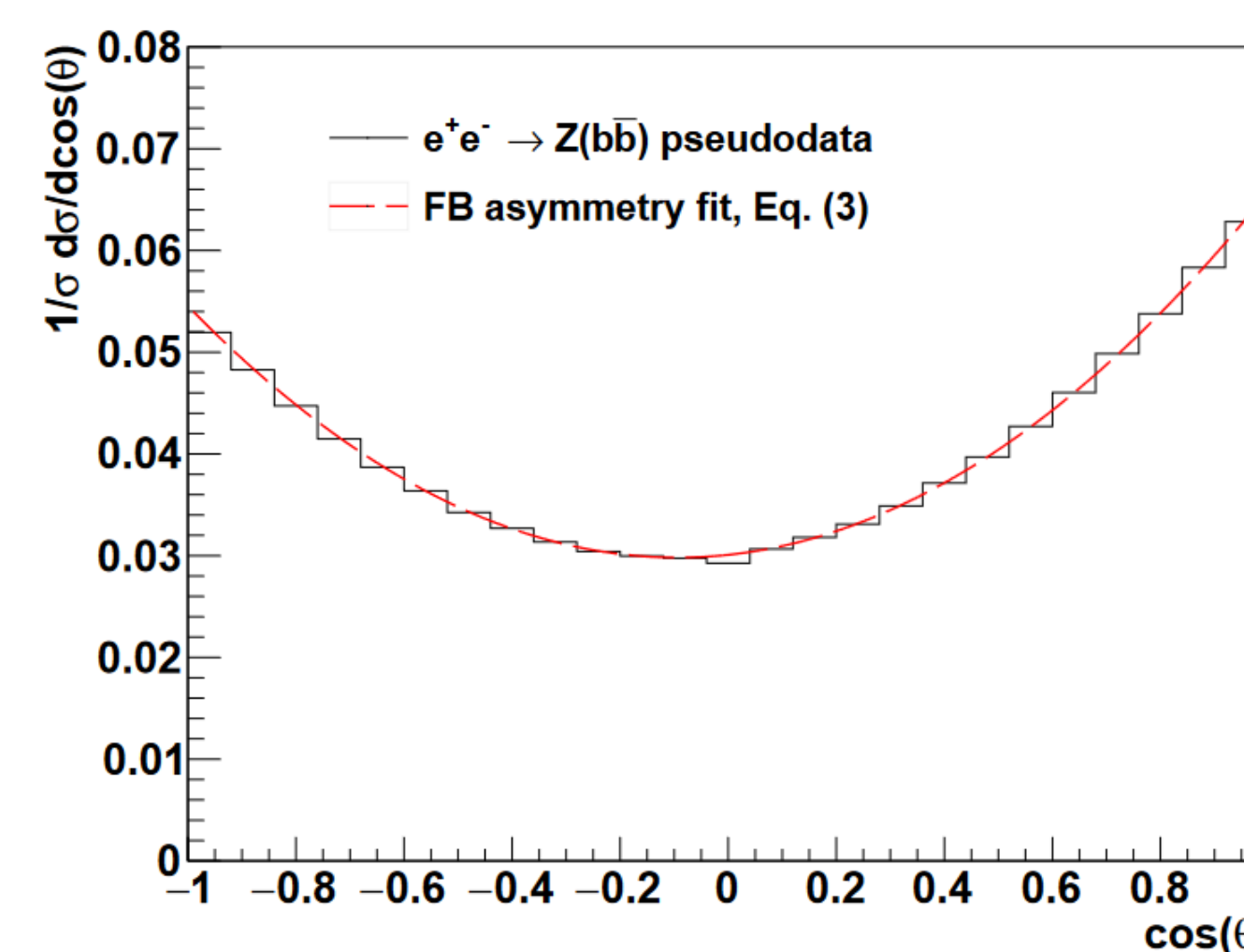
- Decay channels with leptons (e or  $\mu$ ) (Soft lepton tagging)
- Non-zero lifetime of heavy flavoured particles  $\langle L \rangle \sim 2.7\text{mm}$ 
  - Hard fragmentation and large mass of the b-quark  $\rightarrow$  leptons from b-quark decay with large transverse momentum,  $P_T$ , with respect to the quark direction.
  - c-quark: lower mass and softer fragmentation, produces leptons with lower  $P_T$ , but nevertheless still higher than that of leptons from the decays of the  $\rightarrow$  lighter q
- Ingredients for machine learning algorithms

## ESTIMATION METHOD

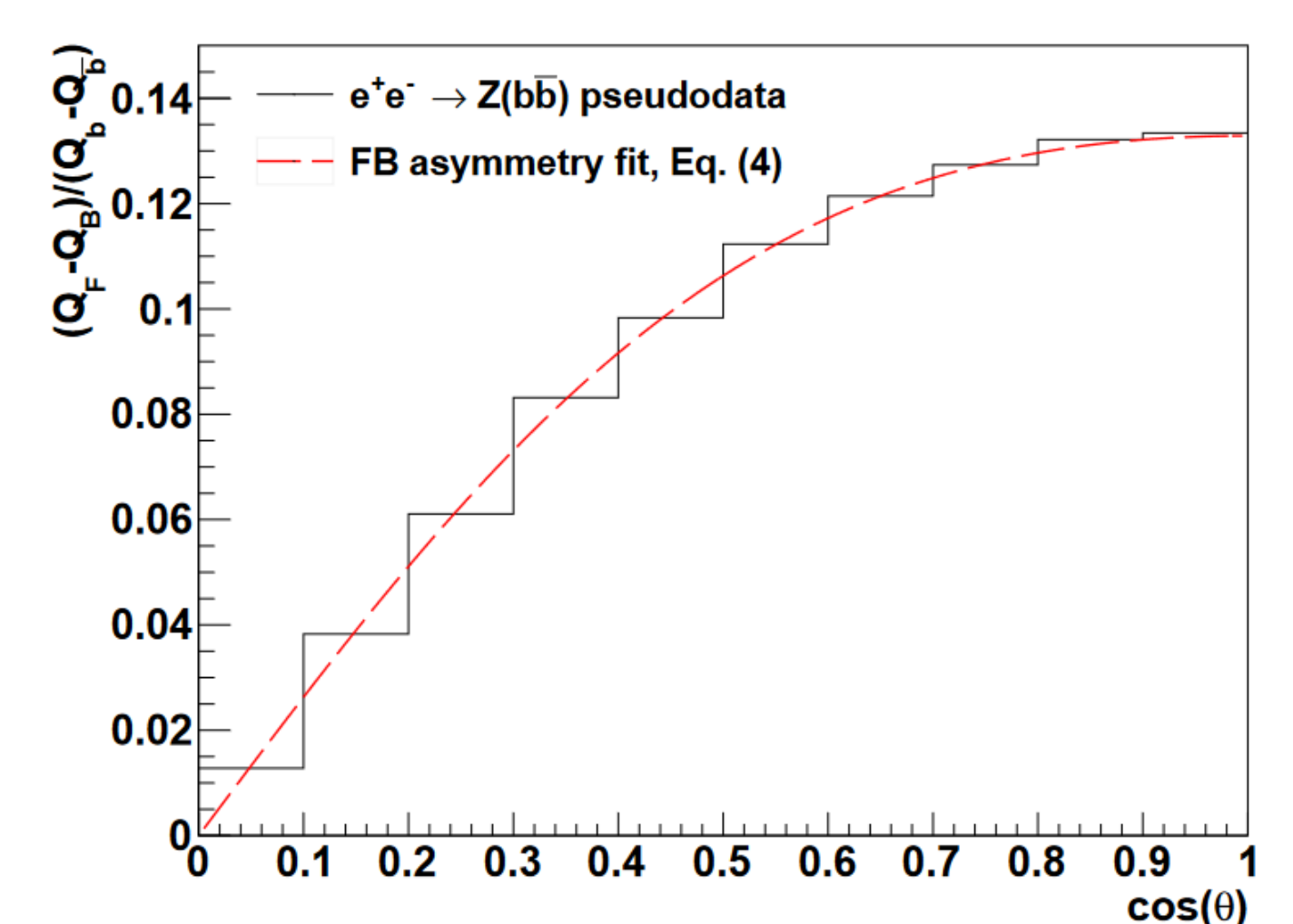
### THRUST AXIS vs CHARGE FLOW

Revised QCD effects on the  $Z \rightarrow b\bar{b}$  forward-backward asymmetry, D. d'Enterria and C. Yan, e-Print: 2011.00530, 2020

Fitting the distribution of polar angles  $\theta$  between the  $e^-$  and the thrust axis.



Fitting the charge flow distribution wrt  $\cos\theta$ .



## SUMMARY AND PLANS

- Collaborative development of with Key4HEP and the EDM4HEP event data model frameworks
- Ongoing and planned studies:
  - Truth level analyses on thrust axis and  $A_{FB}^b$  estimation
  - Jet charge, soft muon methods for charge reconstruction
  - Machine Learning driven approach to event reconstruction
- Signal+background studies (c,light jets)

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