$$e^+e^- \rightarrow b\bar{b}$$

b charge measurement

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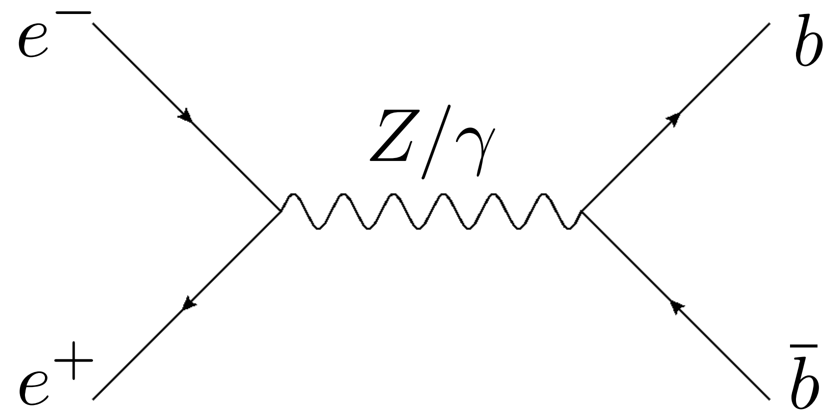
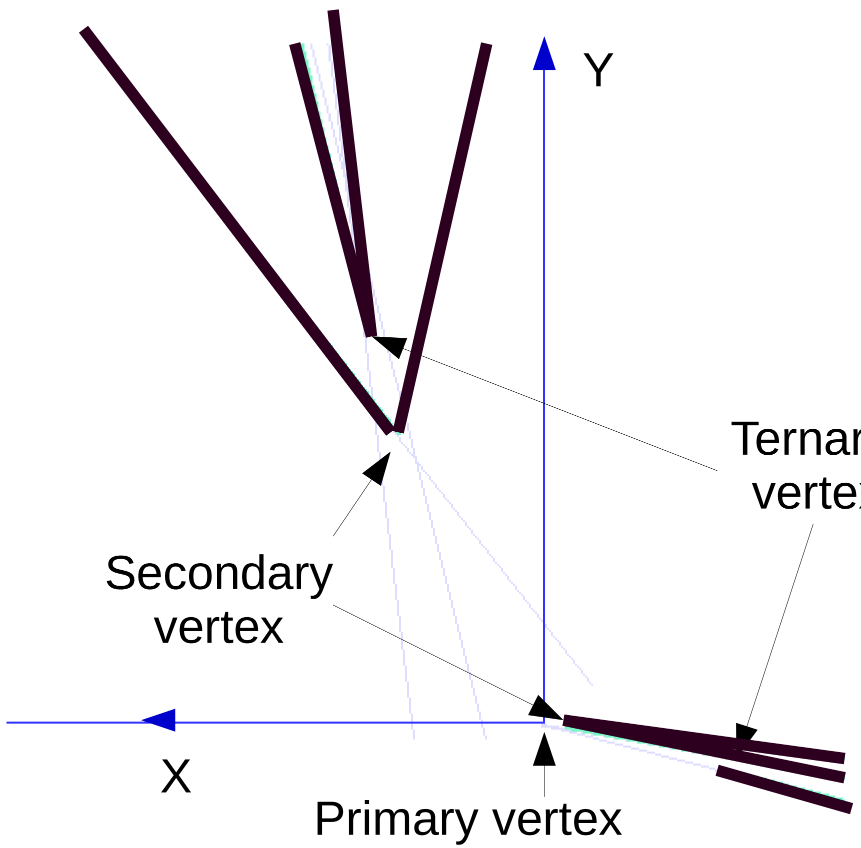
ILD Software and Analysis meeting

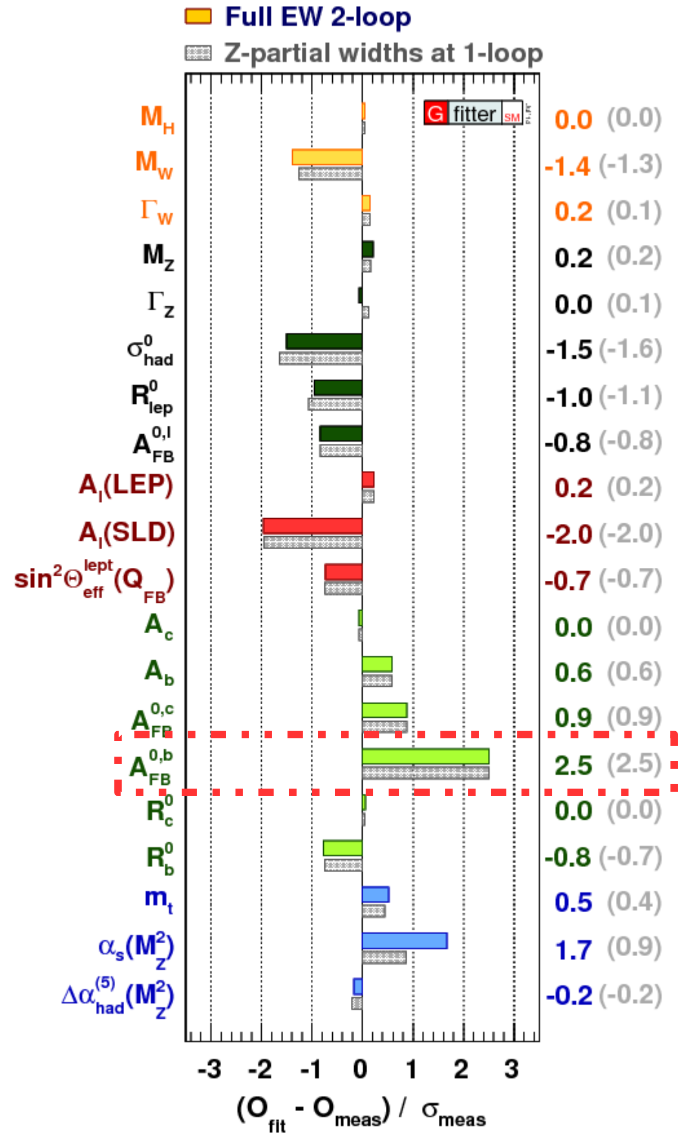
Objective

- Main purpose of this work is to define the electroweak couplings of the bottom quark using the b-quark polar angle measurement of the $e^+e^- \to b\bar{b}$ process
- Properties of decay products from the b-hadrons are used to determine the charge of initial b-quark
- Charge of the b-quark is calculated as a sum of the charges of secondary and ternary vertex particles
- The charge of K-mesons from reconstructed vertices is directly connected to the initial quark charge





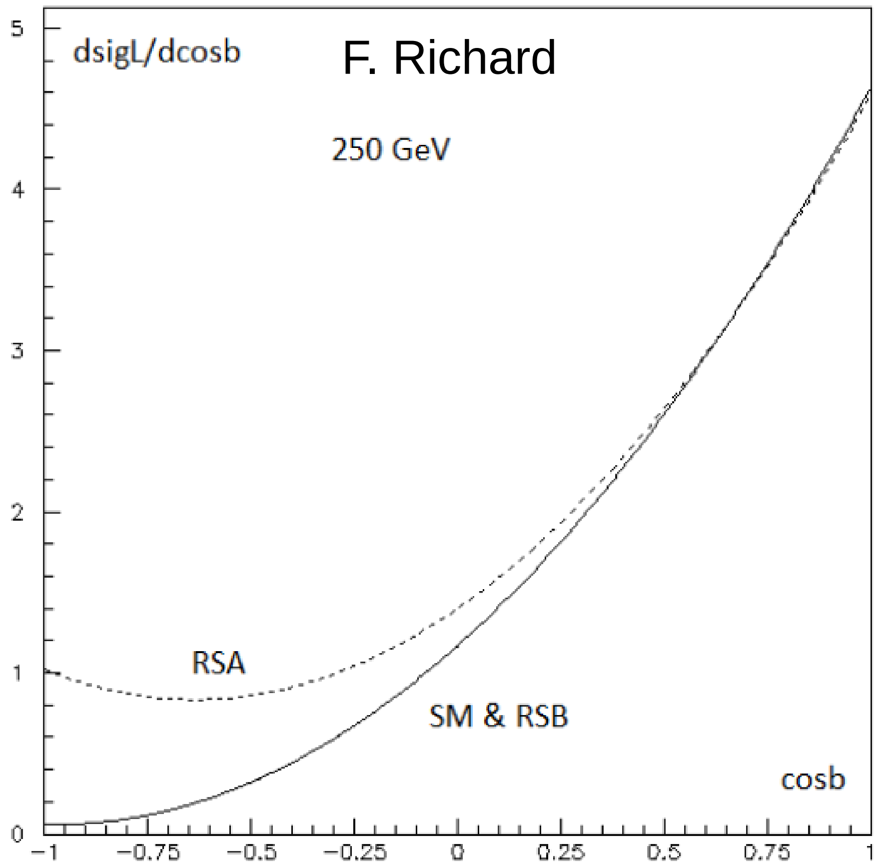
Motivation

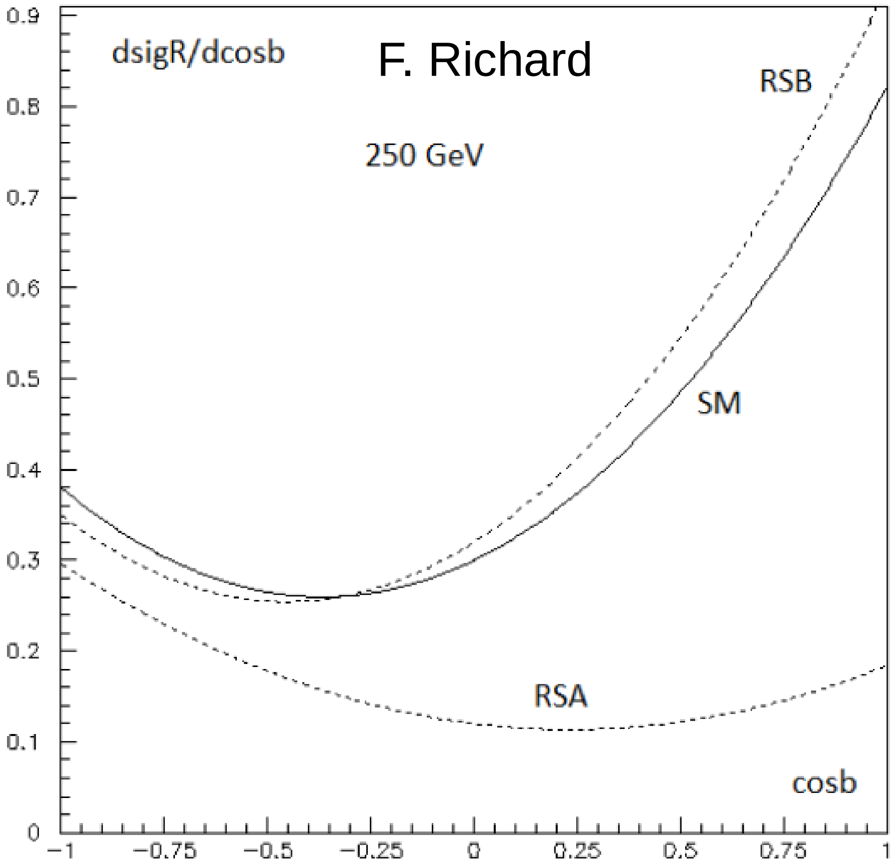


- The measured value of Afb for b-quarks has the highest tension with Standard Model expectation

arxiv: 1407.3792v1

Motivation





- Asymmetry is extremely strong for left-handed case
- Different Randall-Sundrum scenarios can affect SM polar angle spectrum

arxiv:1105.3158

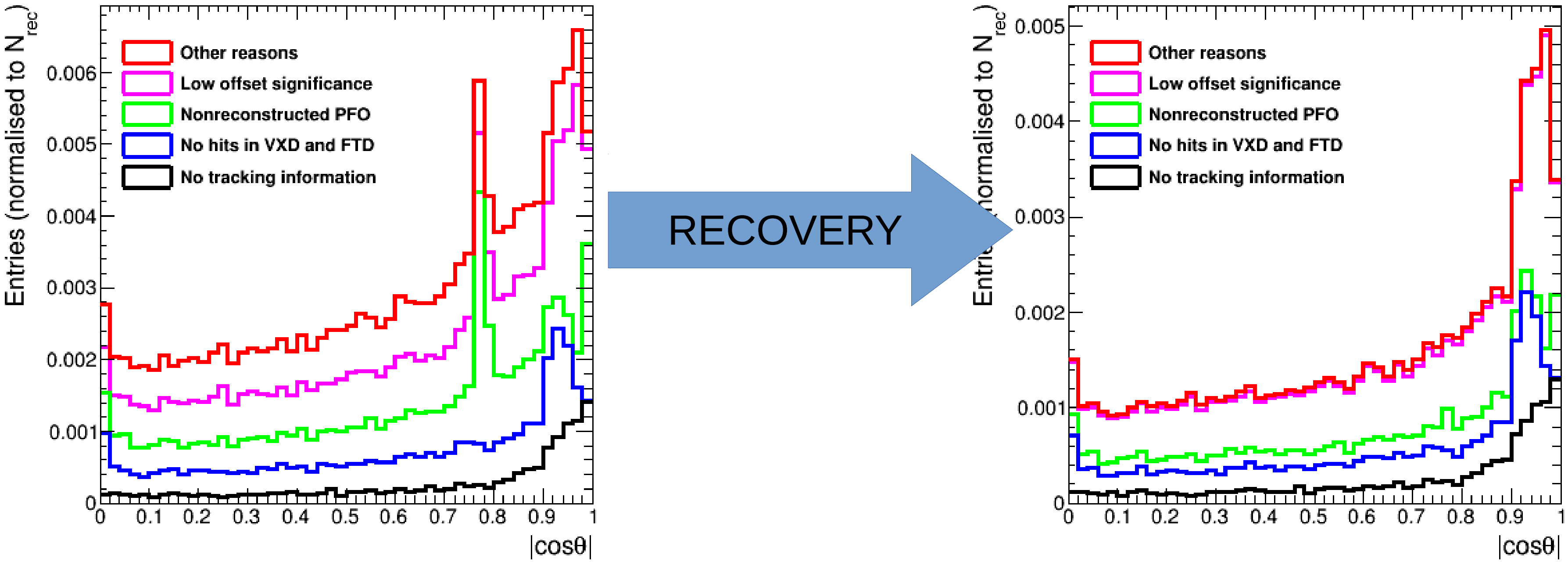
Research setup

- We are using 250 GeV q qbar sample with pair background v01-16-05 (DBD) for each polarization
- To estimate the background we use ZZ HZ WW samples with the same version of ilcsoft
- Modified version of VertexChargeRecovery from MarlinReco/Analysis (Recovery)

- We are using the new 250 fb^{-1} production thanks to Hiroaki Ono and Akiya Miyamoto

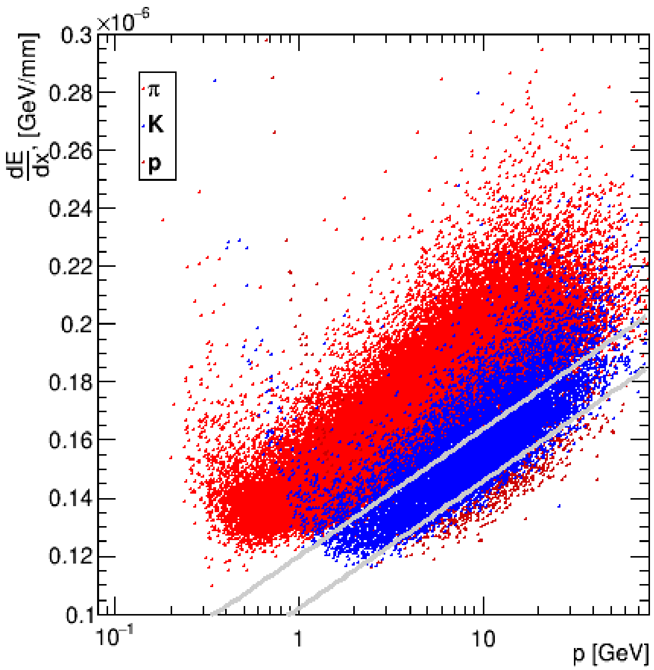
Technical side: Vertex

- The central problem of the vertex charge measurement is the missing particles from the reconstructed vertices
  - We have identified the sources:
    - No reconstructed tracks
    - Particle has no hits in VXD
    - No reconstructed PFO by Pandora
    - Low offset\low momentum
  - This study resulted in VertexChargeRecovery algorithm, which enhances the charge purity by adding the missing particles back

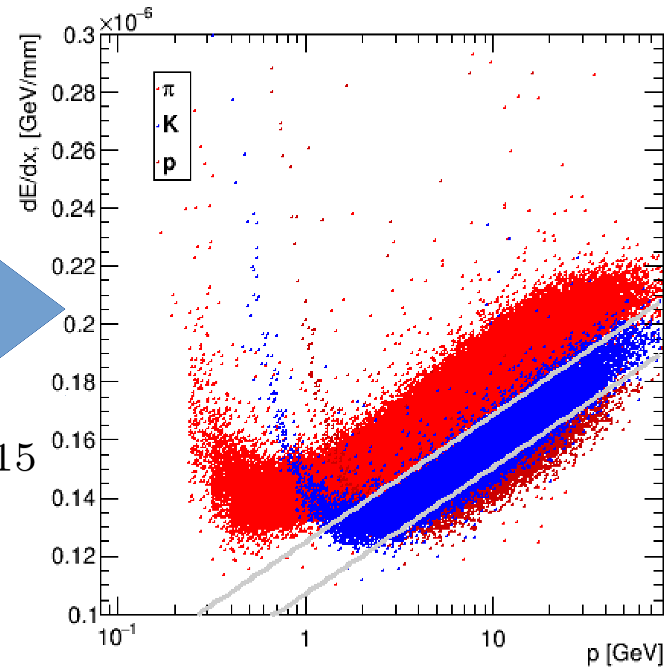


Technical side: Kaons

- The kaons are identified by the dE/dx measurement of the TPC tracks
- The main background particles for Kaons are
  - Pions
  - Protons
- The developed angular correction compensates the increased dE/dx for longer TPC tracks, which increases purity and efficiency of the kaon selection



$$\frac{dE'}{dx} = \frac{dE}{dx}\theta^{0.15}$$



Event preselection

1) Sort jets by b-tag

2) B-tag cuts: 0.8 for a high-tagged jet and 0.3 for a low-tagged jet

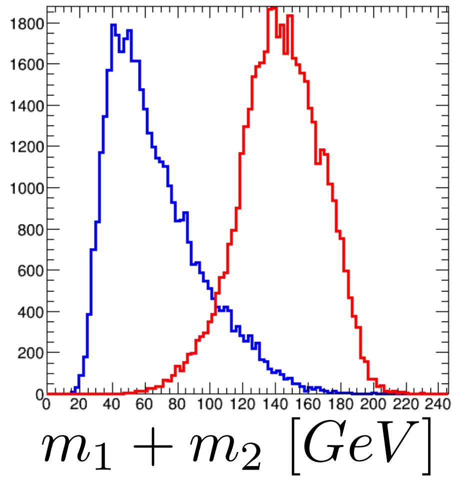
3) For Z return rejection:

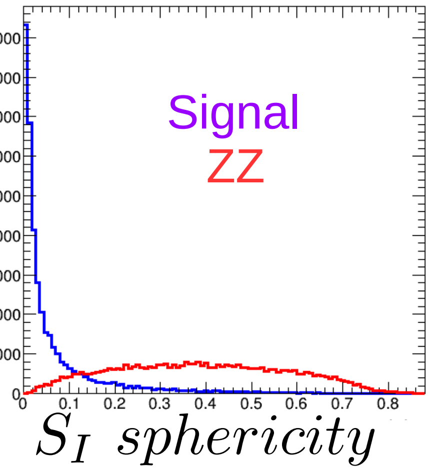
   – Invariant mass > 180 GeV and maximum photon energy < 40 GeV

4) For diboson background rejection

   – Sum of jet masses < 120 GeV and event sphericity < 0.2

- Efficiency of the preselection is **~49%** for both polarizations





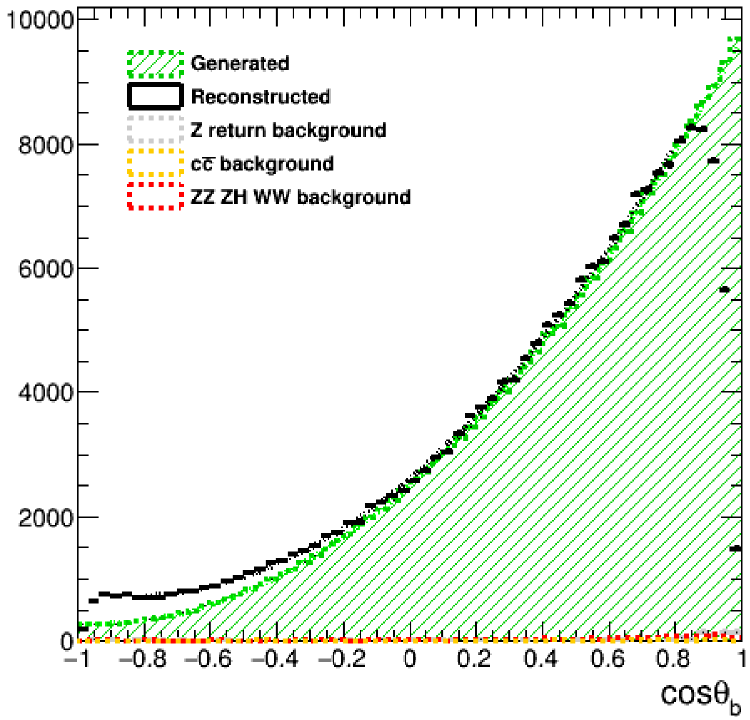
Event selection

- We are using kaon charge and vertex charge combination to define a charge of a bjet
- Kaons are identified using generator information on each particle in a reconstructed secondary or ternary vertex
  - but we introduce ~94% purity and 88% efficiency, according to our previous PID studies
- Kaon charge is a sum of charges of all kaons found in jet vertices, zero sum is rejected
- Vertex charge is the sum of all secondary and ternary track charges in a jet, zero sum is rejected
- Only independent combinations are used to avoid charge correlations in the final result:
  - Vertex charge from one jet, vertex charge from another jet
  - Kaon charge from one jet, kaon charge from another jet
  - Event is accepted if charges are opposite

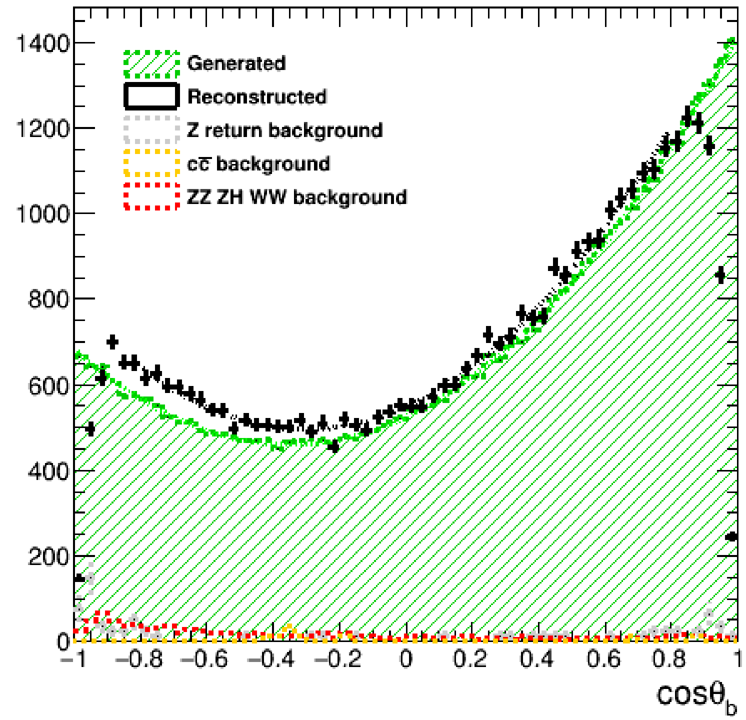
Polar angle reconstruction+bkg

$$L = 250\,\mathrm{fb}^{-1}$$

$$e^-_L e^+_R \to b\bar{b}$$



$$e^-_R e^+_L \to b\bar{b}$$

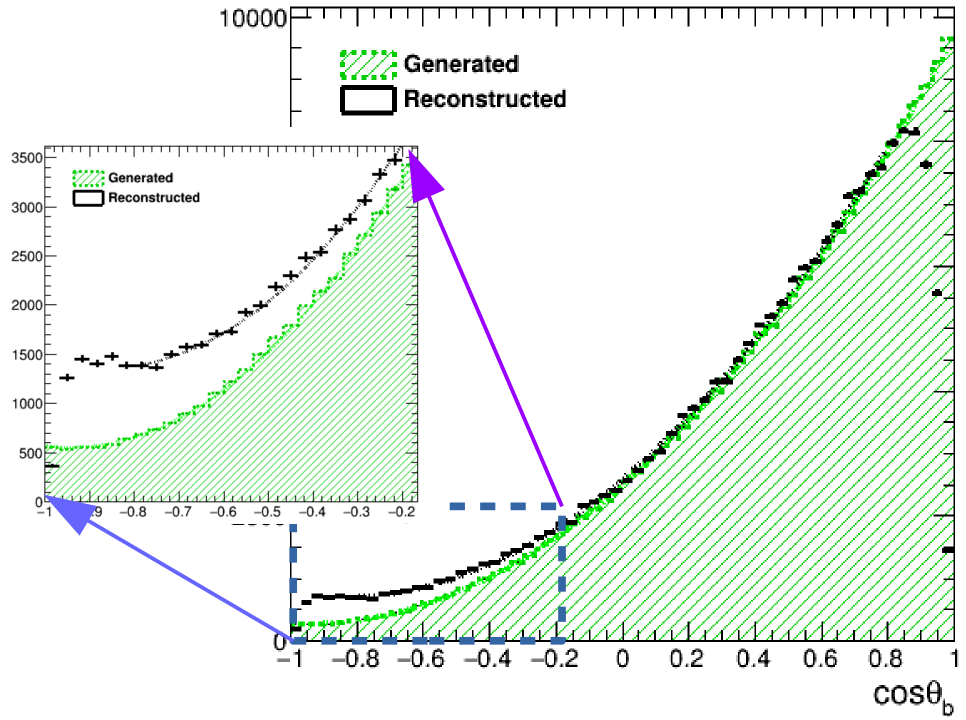


- The background is small due to the preselection cuts and the high signal cross section
- Further plots for signal only

Bottom polar angle reconstruction

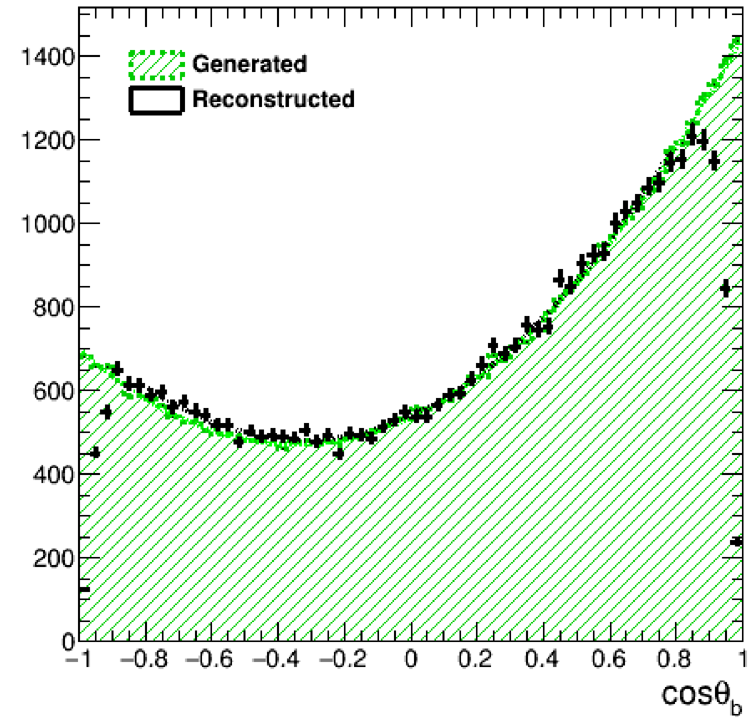
$$L = 250\,\mathrm{fb}^{-1}$$

$$e^-_L e^+_R \to b\bar{b}$$



$$A^{rec}_{fb}/A^{gen}_{fb} = 91.5\% \pm 0.44\%$$

$$e^-_R e^+_L \to b\bar{b}$$



$$A^{rec}_{fb}/A^{gen}_{fb} = 95.2\% \pm 1.8\%$$

- Forward region inefficiency is seen in both figures
- The residual charge misreconstruction contaminates completely the backward region in the left-handed case

Charge purity and polar angle correction

- We can use refused events with contradictory charges as a measure of our charge purity and calculate correction factors
- Let p be a probability of a correct charge measurement of a jet
- Then q = *1 – p* is an incorrect charge probability
- We can compute it from the following equations:

$$N = N_a + N_r$$

\# of refused events (N_r); # of accepted events (N_a)

$$N_a = N_a^+ + N_a^- = p^2 N + q^2 N \qquad N_r = 2pqN$$

- We define a number of true events:

$$\begin{cases} N_a^+ = p^2 N_{true}^+ + q^2 N_{true}^- \\ N_a^- = p^2 N_{true}^- + q^2 N_{true}^+ \end{cases}$$

Migration terms: $q^2 N_{true}^-$, $q^2 N_{true}^+$

- Corrected values:

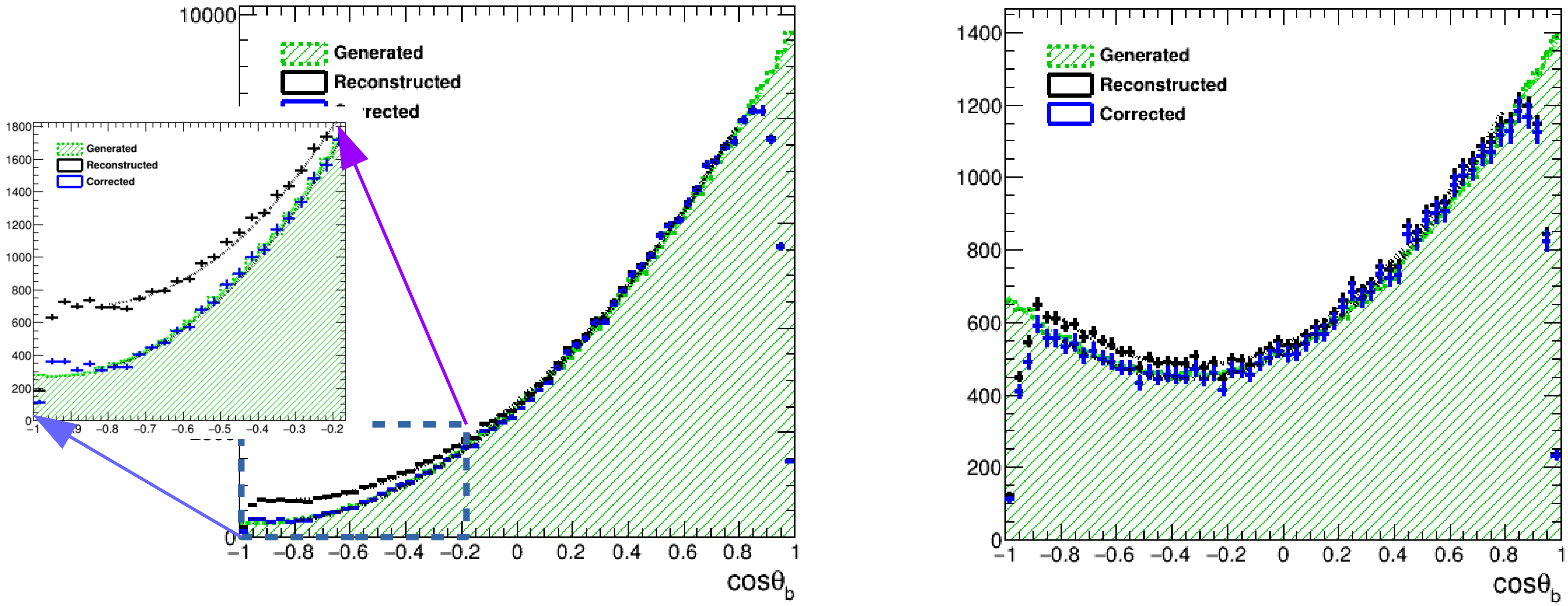
$$\begin{cases} N_a^{+\prime} = p^2 N_{true}^+ \\ N_a^{-\prime} = p^2 N_{true}^- \end{cases}$$

- We do not use generator information for correction

Polar angle reconstruction

$$L = 250\,\mathrm{fb}^{-1}$$

$e_L^- e_R^+ \to b\bar{b}$ $\qquad$ $e_R^- e_L^+ \to b\bar{b}$



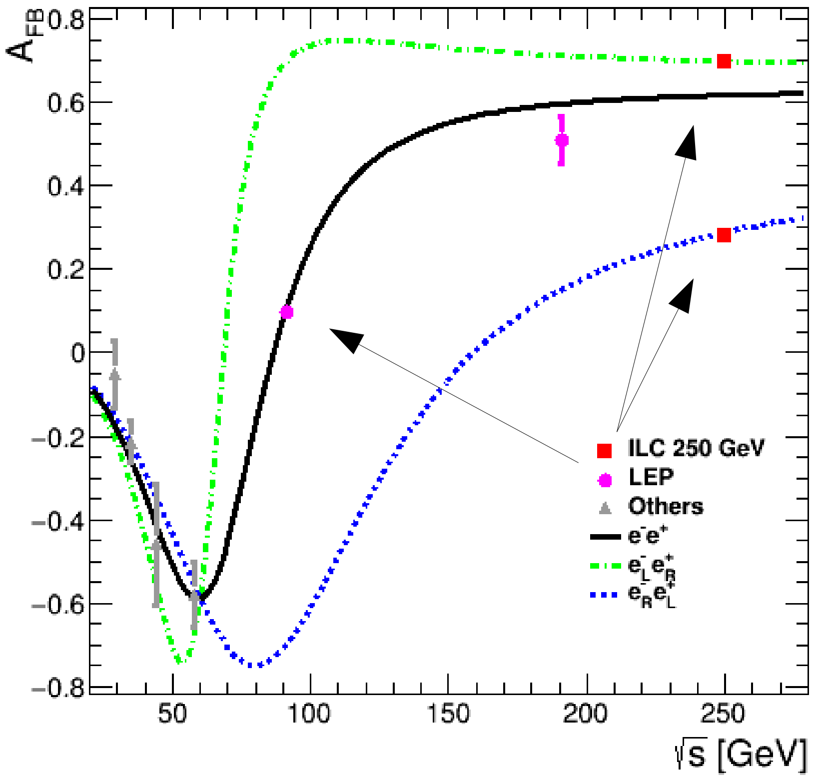
$A_{fb}^{rec}/A_{fb}^{gen} = 100.7\% \pm 0.62\%$ $\qquad$ $A_{fb}^{rec}/A_{fb}^{gen} = 104.9\% \pm 1.9\%$

- The computed corrected distributions are much closer to the generated ones

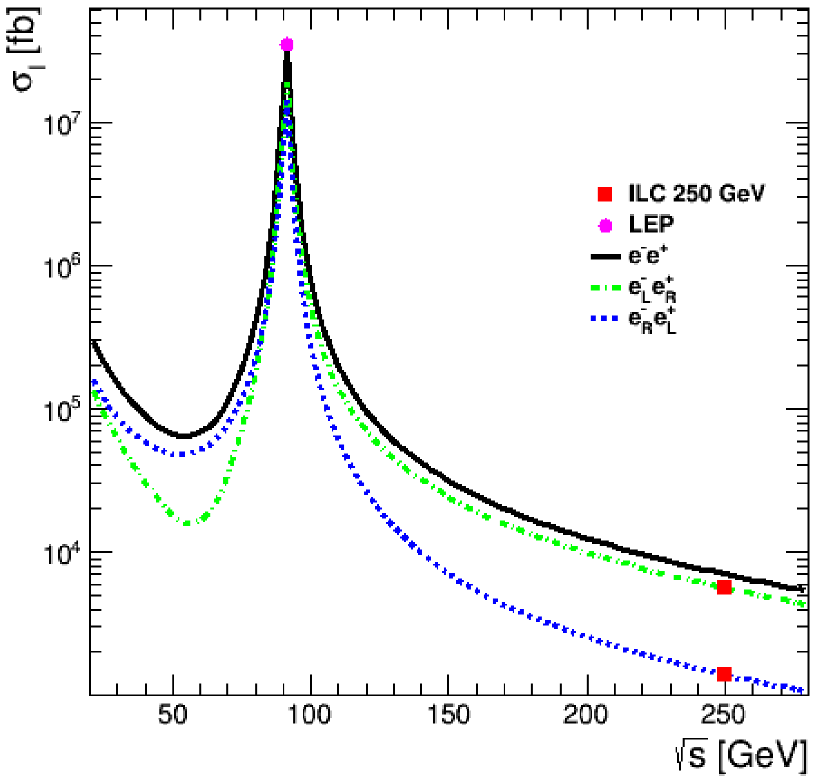
Asymmetry and cross section

PRELIMINARY | WORK IN PROGRESS

Forward-backward asymmetry



Cross section



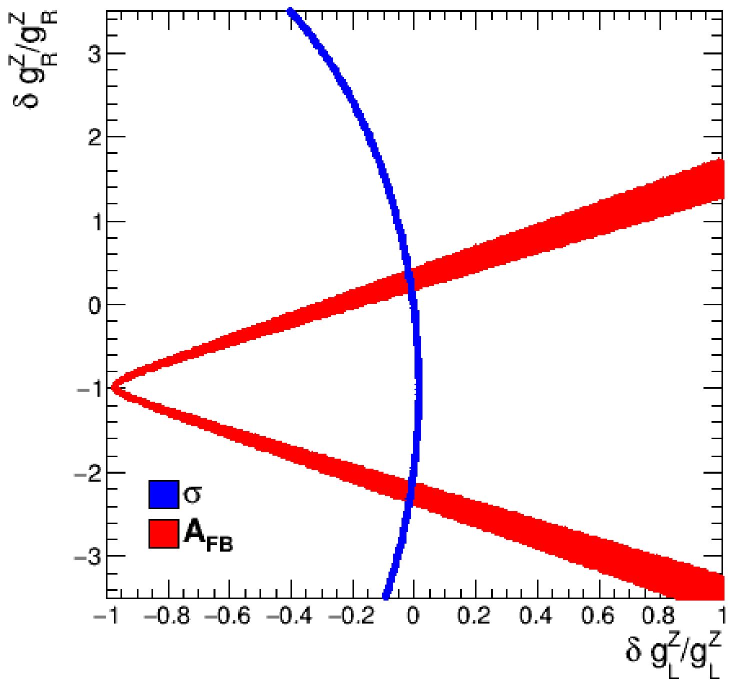
- The Afb value and precision is determined from the fit to the reconstructed curve
- The precision on the ILC cross section measurement to be determined

Precision on b-quark couplings

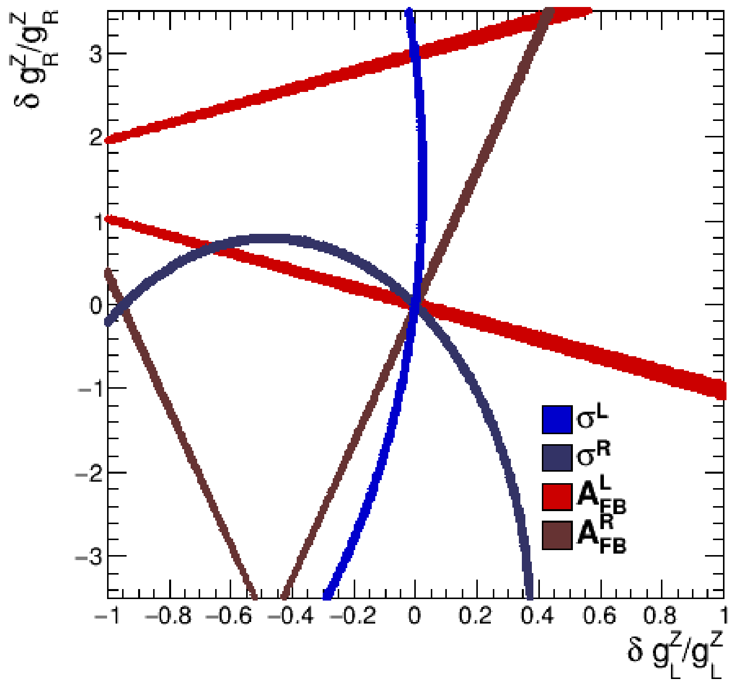
PRELIMINARY | WORK IN PROGRESS

Allowed 1σ regions for the tree level predictions

LEP



ILC



- gL is well defined
- gR sign flip is possible
- Allows for 20% gR variation

- Only one precise solution

- Assume only the Zbb coupling varies

Determination of the Form Factors

- We are measuring the differential cross section

$$\frac{d\sigma^I}{d\cos\theta} = A^I(1+\cos^2\theta) + B^I\cos\theta + C^I\sin^2\theta \qquad I = L, R$$

where the $A\ B\ C$ are

$$A^I \text{ cross section magnitude } \propto F^I_{1V}, F^I_{2V}, F^I_{1A}$$

$$B^I \text{ asymmetry magnitude } \propto F^I_{1A}, F^I_{1V}, F^I_{2V}$$

$$C^I \text{ spin flip } \propto \gamma^{-1} F^I_{1V}, \gamma F^I_{2V}$$

- We have 6 observables and 6 form factors to estimate
- Therefore, we can independently extract the form factors directly from the polar angle histograms
- One can extract $A\ B\ C$ factors from the fit

Determination of the Form Factors

PRELIMINARY | WORK IN PROGRESS

$$\frac{d\sigma^I}{d\cos\theta} = A(1+\cos^2\theta) + B\cos\theta + C\sin^2\theta$$

$$e_L^- e_R^+ \longrightarrow b\bar{b}$$

Reconstructed

Factor	Value	Error
A	2514	15.18
B	4730.6	19.29
C	-34.84	20.48

Generated

Factor	Value	Error
A	2486.32	2.04
B	4689.86	3.43
C	12.88	3.00

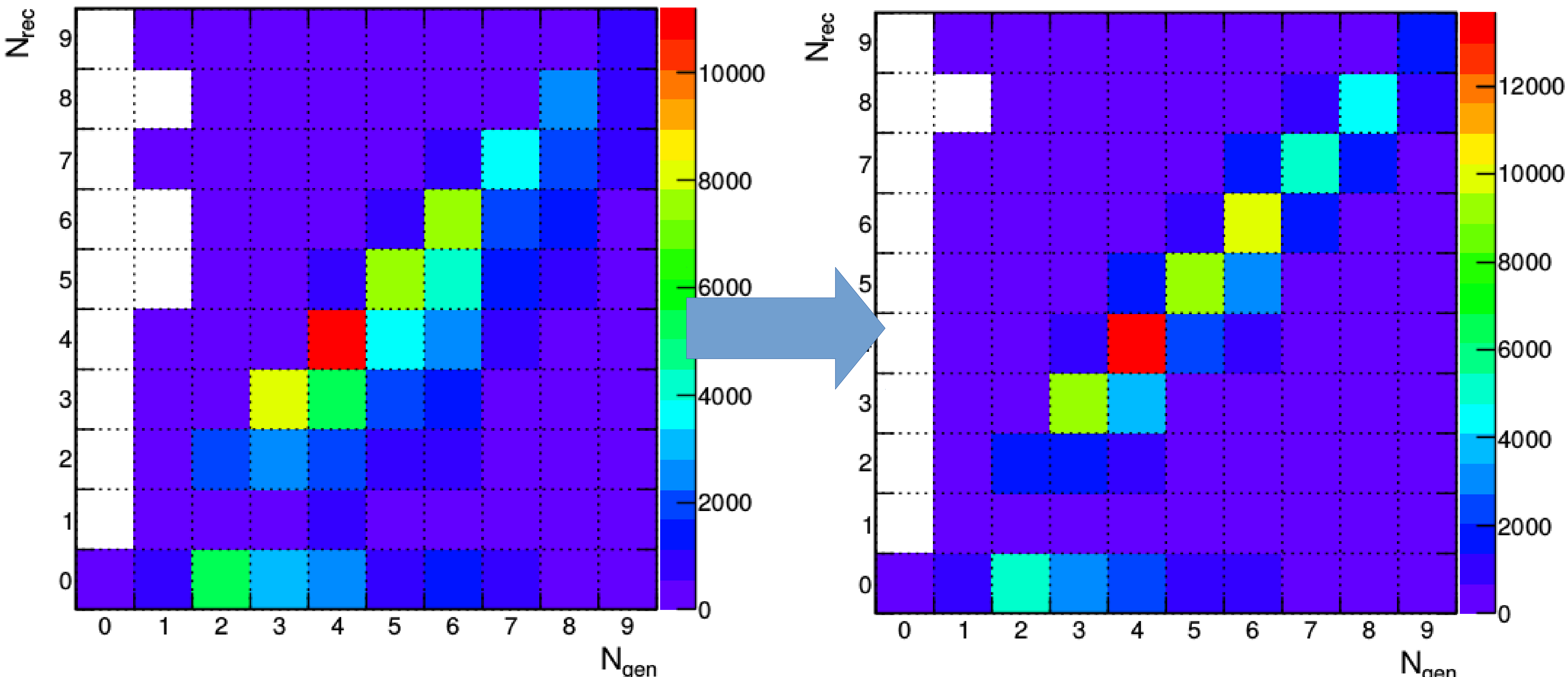
- Results depend on the number of events used – to be fixed
- There are 1-2% percent difference between the reconstructed and generated A and B values
- We get small C value as compared to A and B values as expected
- Errors on the A and C values are correlated
- Results and conclusions are similar for the right-handed polarization

Conclusions

- The b-quark polar angle is well reconstructed in the ILD environment
- The ILC will provide precise and unambiguous solution to the LEP tension
- At the ILC it will be possible to extract the b-quark form factors independently using the differential cross section
- Future work:
  - Rescale to 1st 250 GeV run and the beam polarization
  - Define the final uncertainties
  - Define the final precision on the LEP tension

Thank you!

Vertex charge recovery improvement



49.0% on diagonal

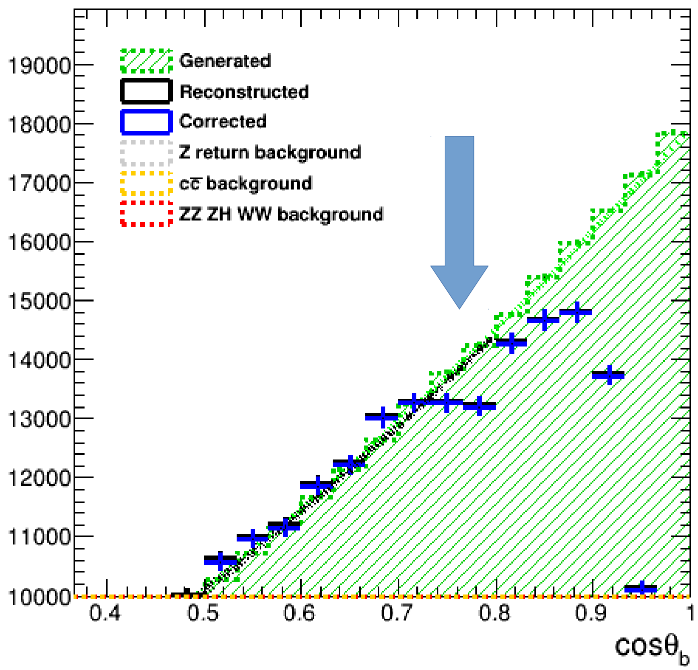
62.0% on diagonal

- The b-jet charge measurement requires very precise vertex reconstruction

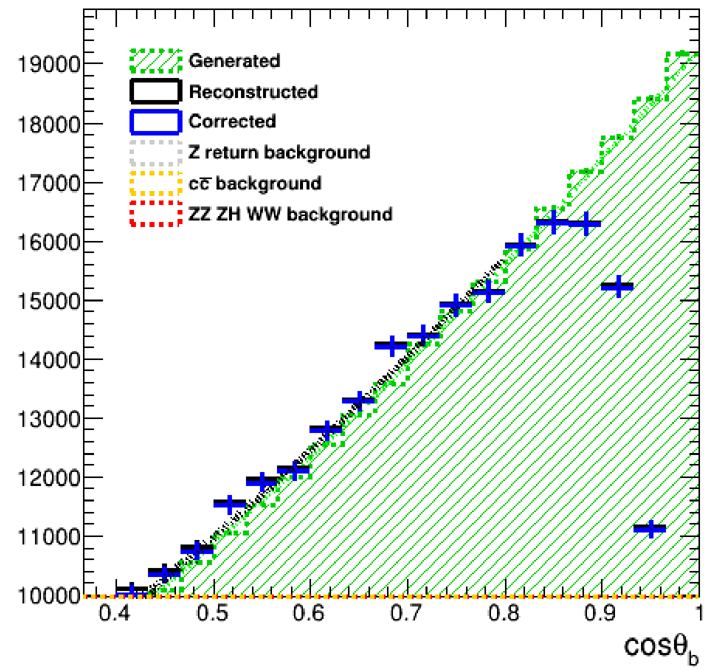
Recovery effects

$$e^-_L e^+_R \rightarrow b\bar{b}$$

Before charge recovery



After charge recovery

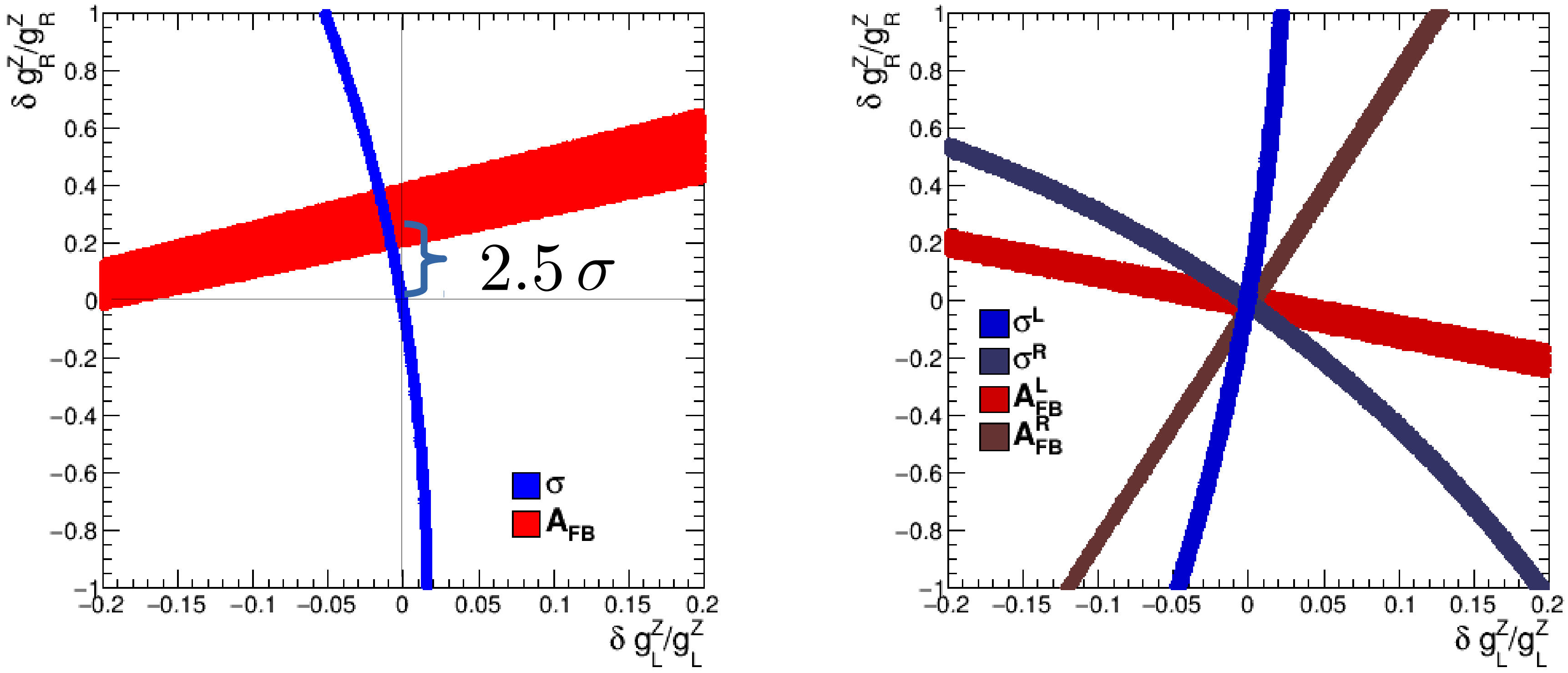


- +7% of statistics
- +4% of vertex purity
- More kaons with the same purity
- Constant charge purity in the barrel

Precision on bottom couplings

PRELIMINARY | WORK IN PROGRESS

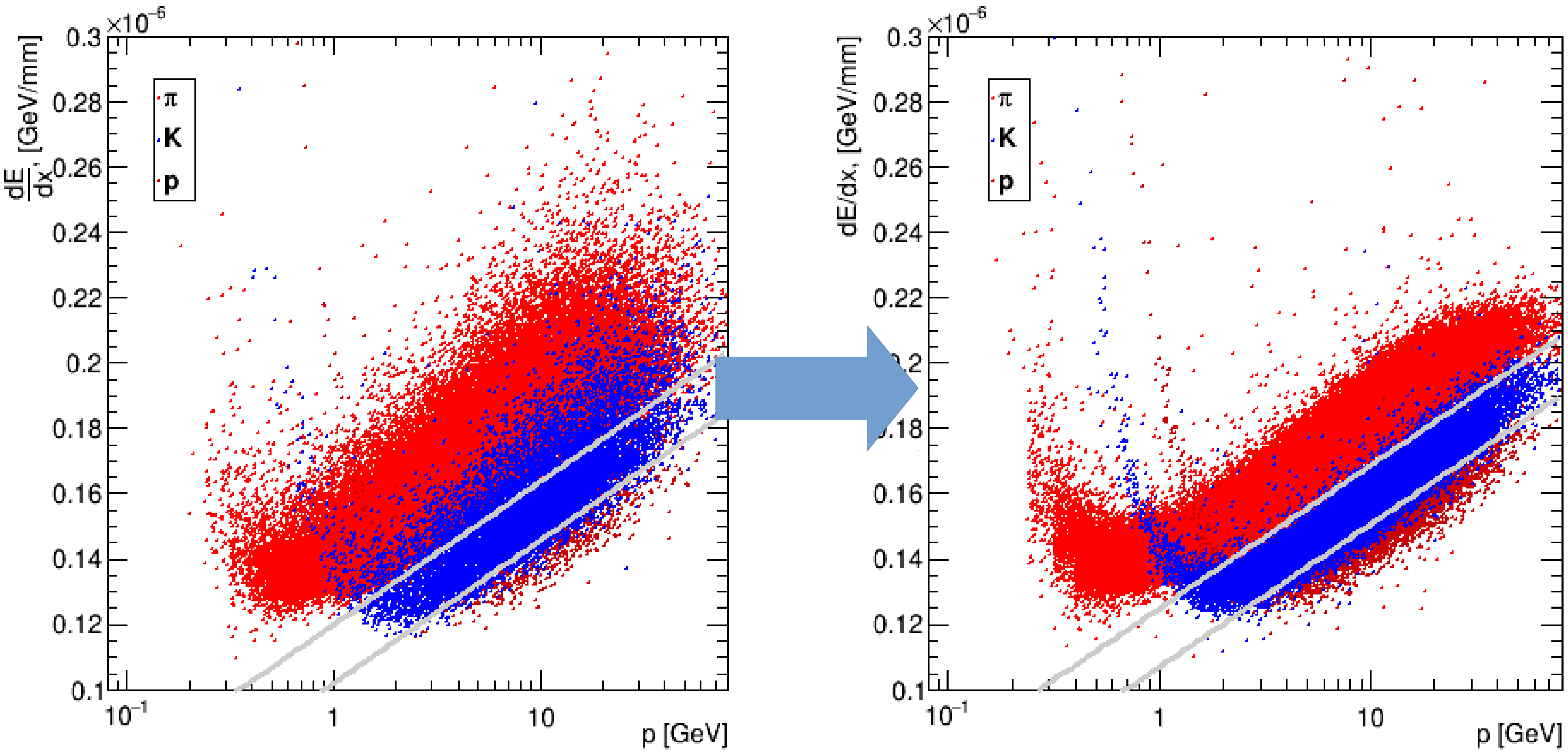
LEP ILC



- The ILC can resolve the LEP Afb anomaly

Reducing angular dependence

Particle separation after reducing the dE/dx angular dependence

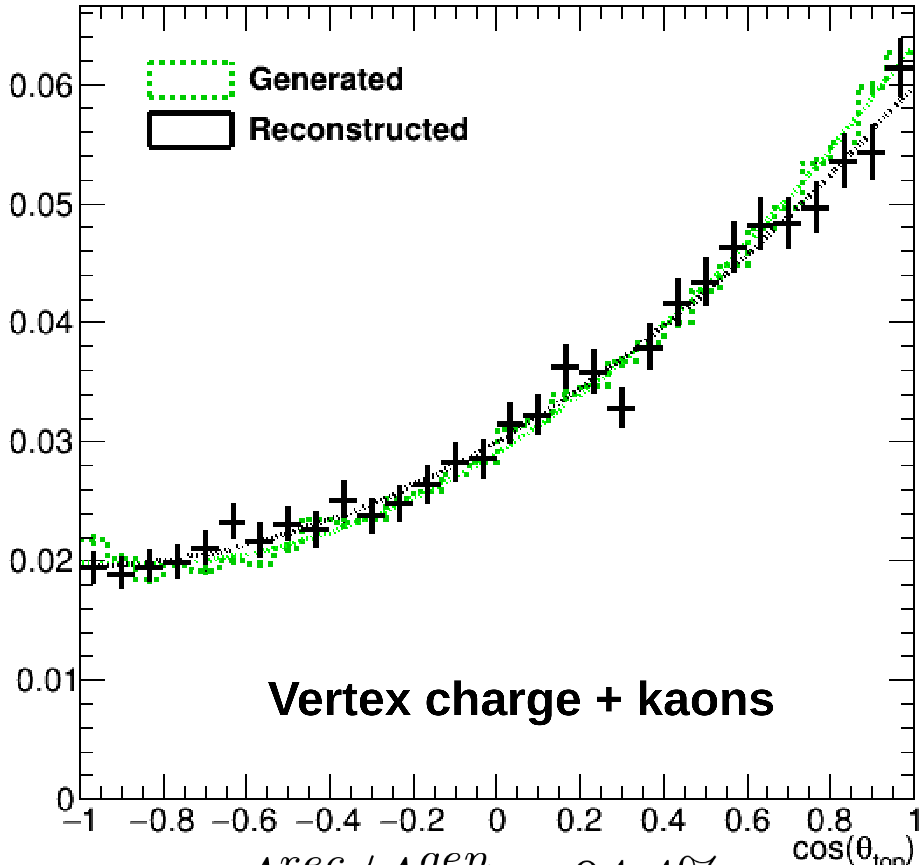


$$\frac{dE'}{dx} = \frac{dE}{dx}\theta^{0.15}$$

- After correction dE/dx does have a better kaon separation properties
- Selection cuts are optimized for dE/dx'

Top polar angle reconstruction

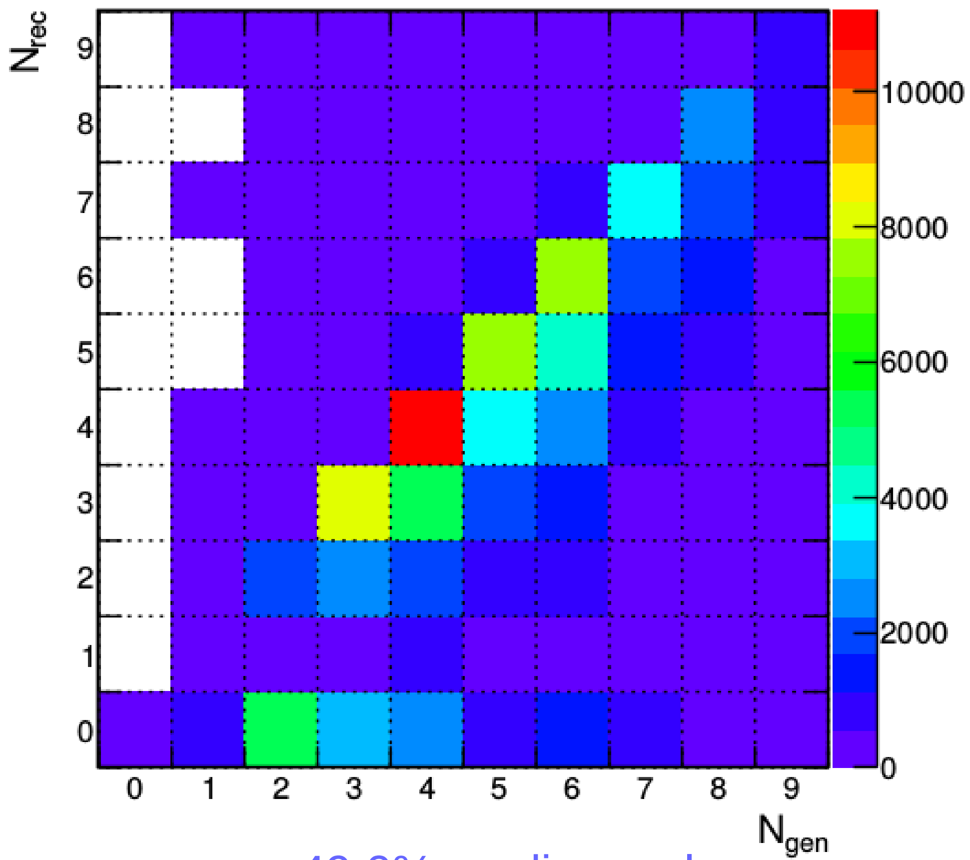
$$e_R^+ e_L^- \rightarrow t\bar{t}$$



$$A_{fb}^{rec}/A_{fb}^{gen} = 94.4\%$$

- Top polar angle reconstruction using kaons and vertex charge combination. **B-jet information only.**

Vertex reconstruction quality

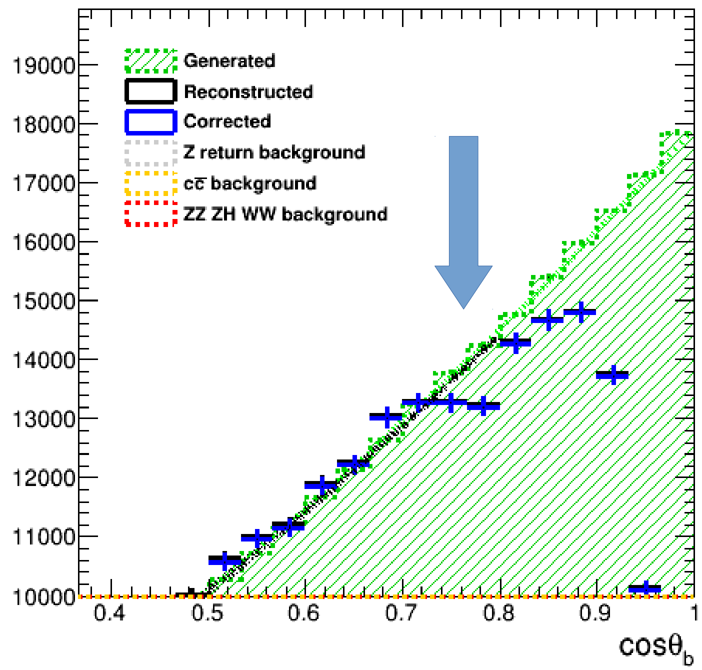


49.0% on diagonal

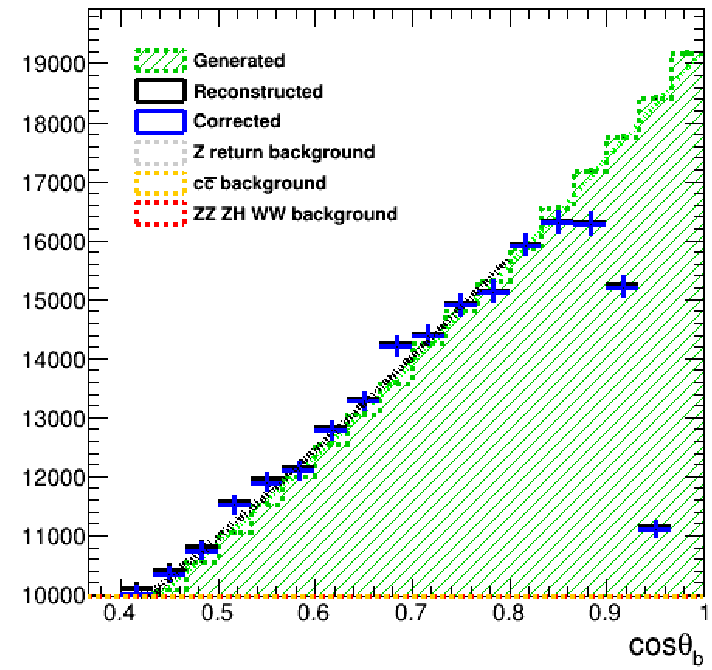
- The b-jet charge measurement requires very precise vertex reconstruction.

Recovery effects

Before charge recovery



After charge recovery



- +7% of statistics
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- More kaons with the same purity
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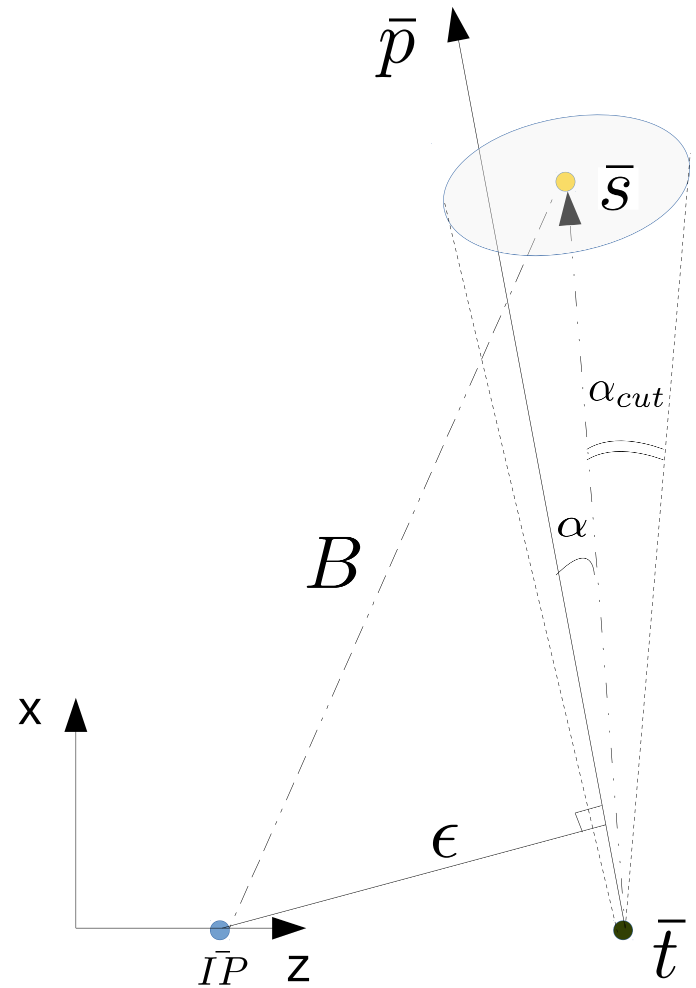
Recovery of vertices



- **IP** – interaction point (primary vertex) , **s** – secondary vertex, **t** – point of closest approach of a track, **p** – reconstructed momentum, ϵ - offset of a track from primary vertex