Third Generation Quark and Electroweak Boson Couplings at the 250 GeV stage of the ILC

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on behalf of ILD concept group

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

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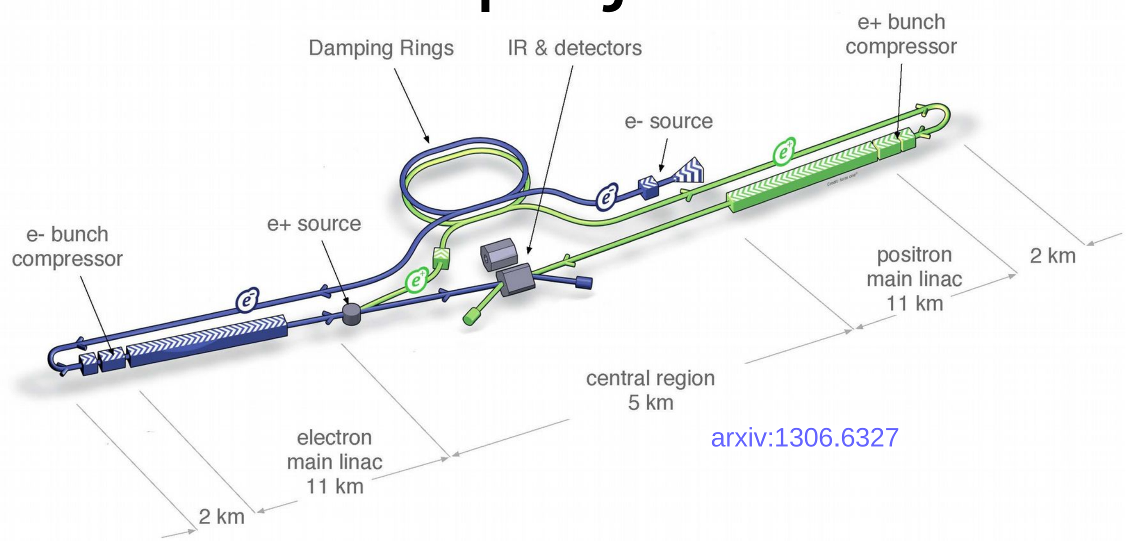
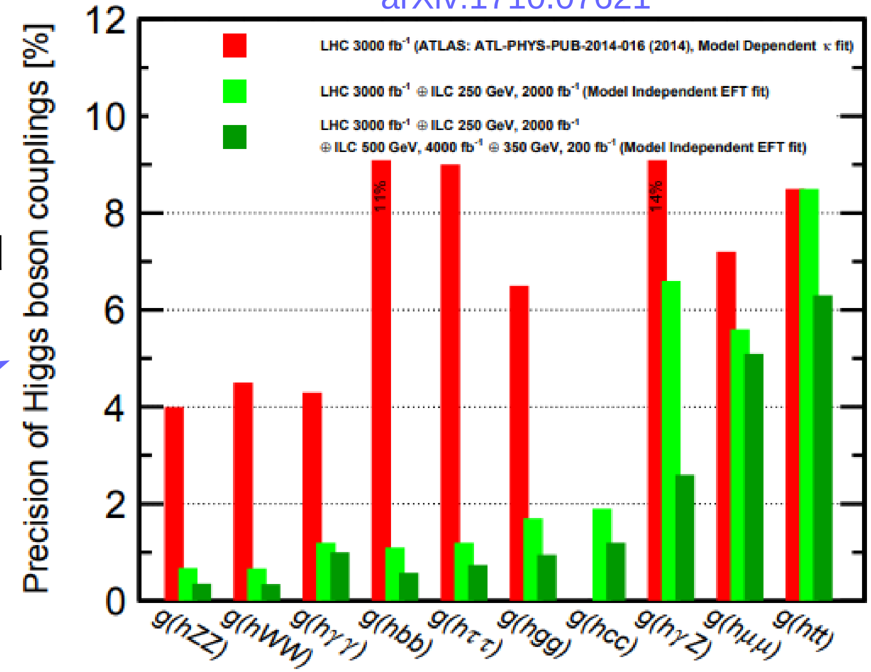
ILC project



arxiv:1306.6327

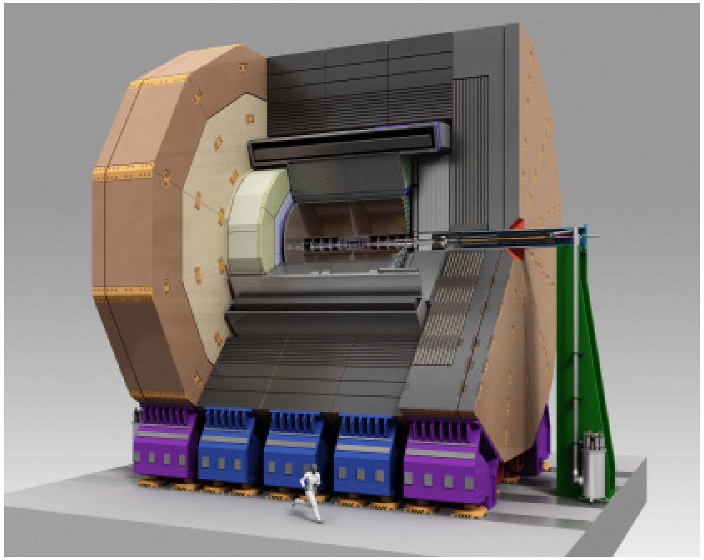
- A new Higgs factory with $\sqrt{s} = 250\,\mathrm{GeV}$
- Upgradable to higher energies
- Highly granular general purpose detectors
- Well known initial state, low machine background
- **Polarized electron and positron beams**
- Main goals:
  - Precision measurement of Higgs couplings and Standard Model parameters
  - Direct search of BSM particles

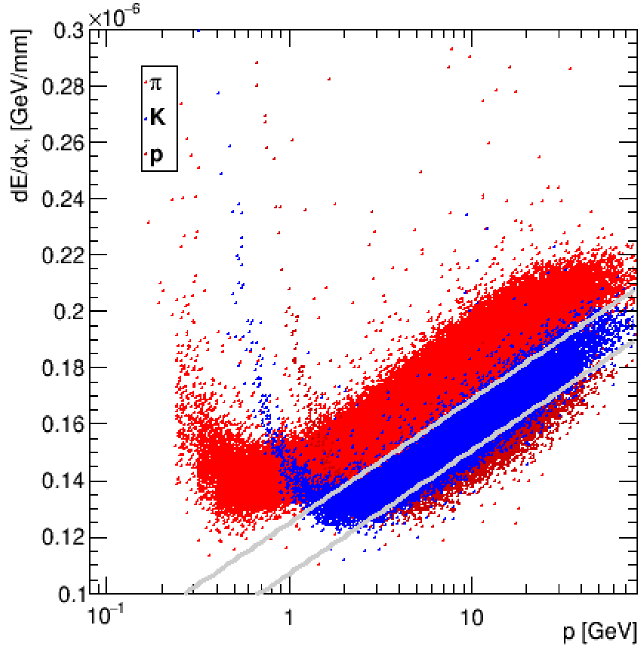
arXiv:1710.07621



ILD project

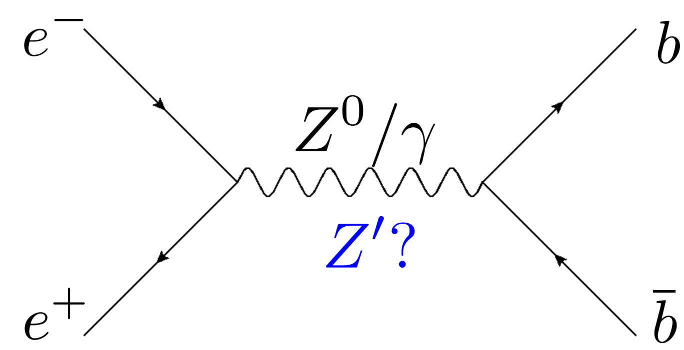
- Designed for Particle Flow algorithms, aimed at 3-4% jet energy resolution
  - Full GEANT4 simulation and event reconstruction
- Hybrid tracking system: gas and silicon devices
  - Vertex Detector - 3 double layers of silicon
    - 5 μm impact parameter resolution
  - Time Projection Chamber with particle identification capabilities (PID)
  - Other devices
- Highly granular hadronic and EM calorimeters
- 3.5T Solenoid
- Muon trackers

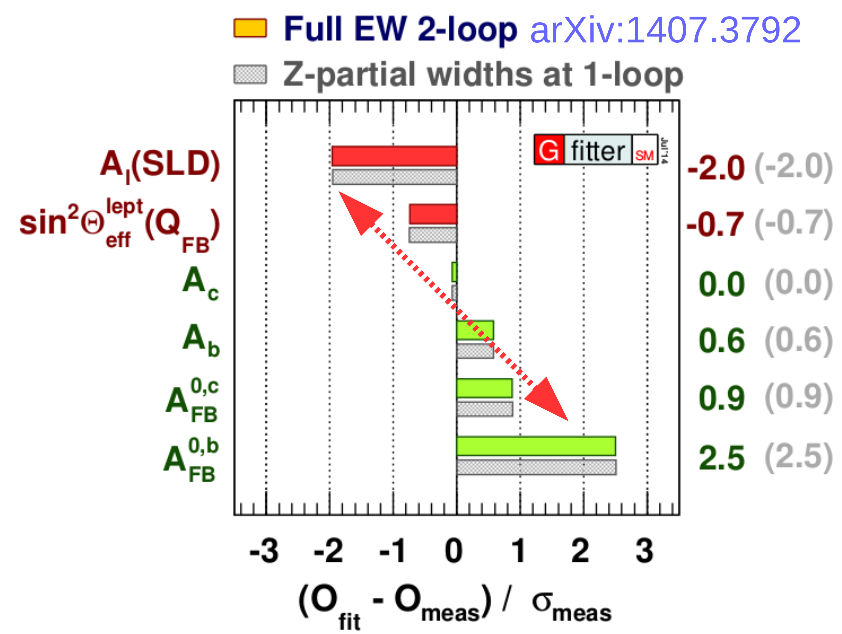




Motivation of measurements

- Top quark is the heaviest elementary particle in the SM
  - carries imprint of the Higgs mechanism
- BSM theories (i.e. Randall-Sundrum) predict deviations for the EW couplings of the 3rd generation quarks
- The top and bottom quarks belong to one doublet $\begin{pmatrix} t \\ b \end{pmatrix}_L$
- LEP has 2.5σ tension in A^b_{FB} incompatible with SLC measurements
- We have to measure precisely the heavy quark EW couplings

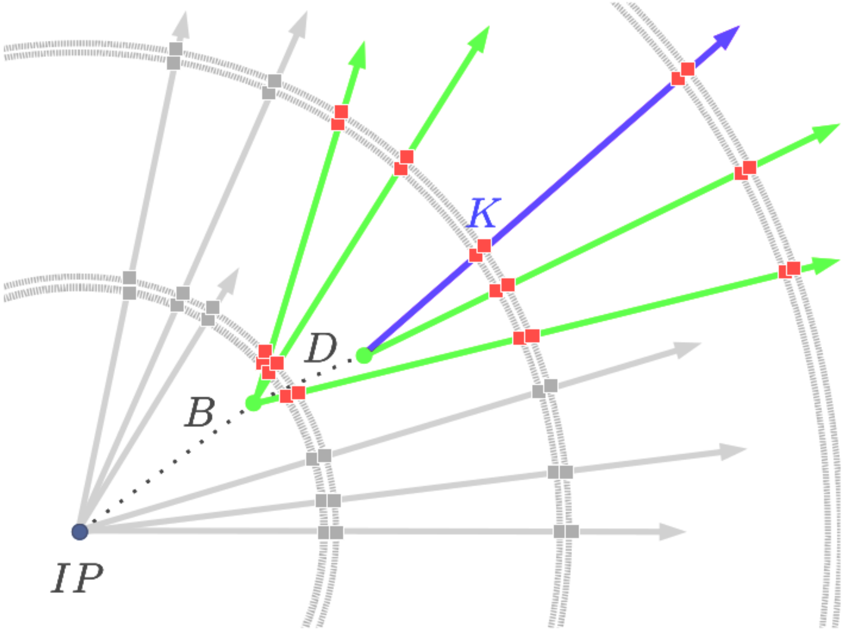




EW t-quark couplings at ILC are discussed in Eur. Phys. J. C (2015) 75: 512.

Event selection

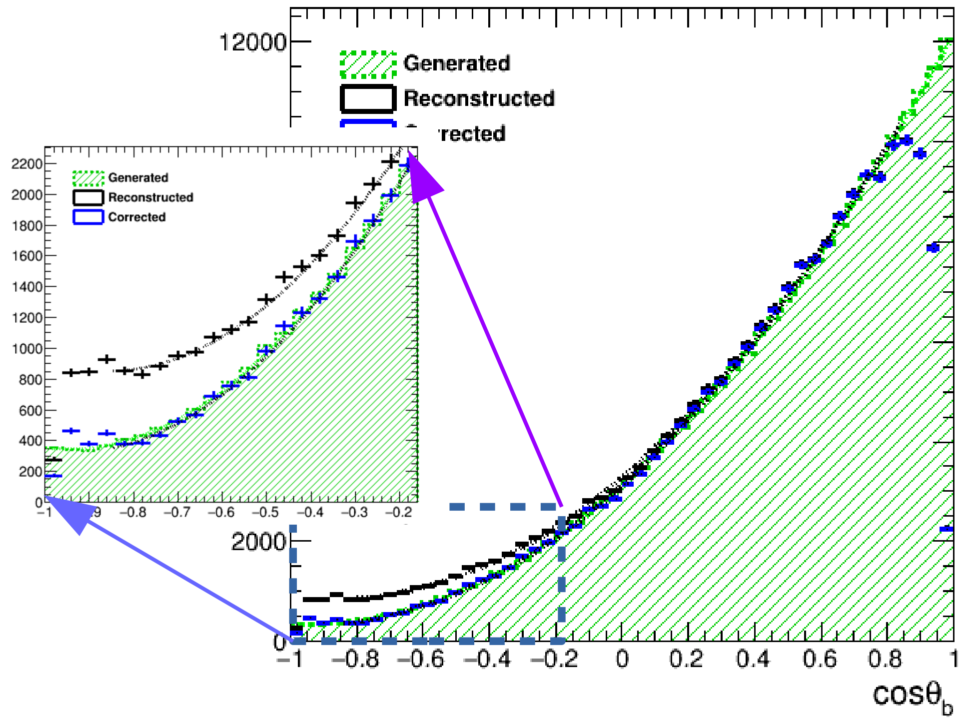
- The $e^+e^- \to b\bar{b}$ process is studied at $\sqrt{s} = 250\,\mathrm{GeV}$ using full simulation of the ILD experiment
- Challenge: reconstruct the b-quark differential cross section
  - requires b-quark charge measurement
- Two methods:
  - Kaon charge
  - Vertex charge
- Event is accepted if b-quark charges are opposite
- Event is discarded if the b-quark charges are the same,
  - Used for b-quark charge impurity corrections

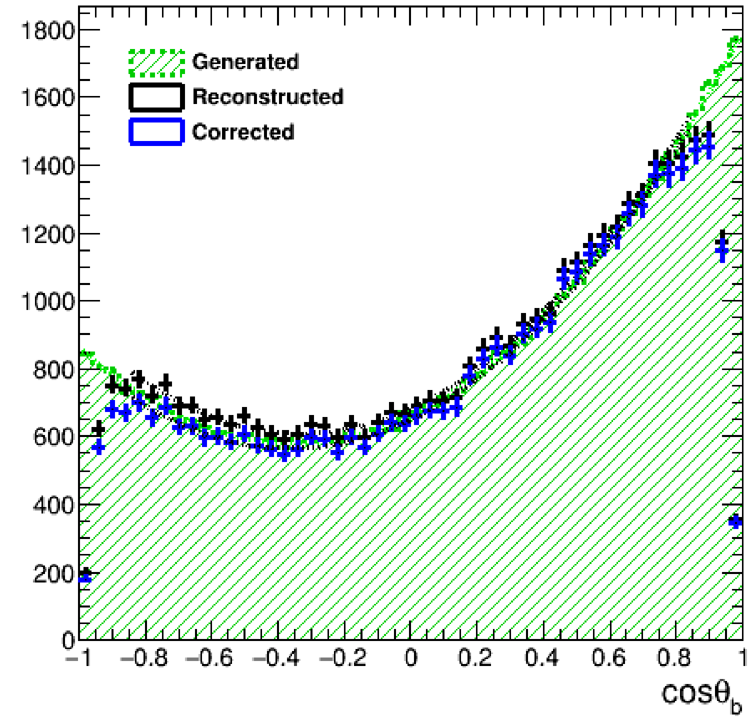


Polar angle reconstruction

$\mathcal{L} = 250\,\mathrm{fb}^{-1}$ for each polarization

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

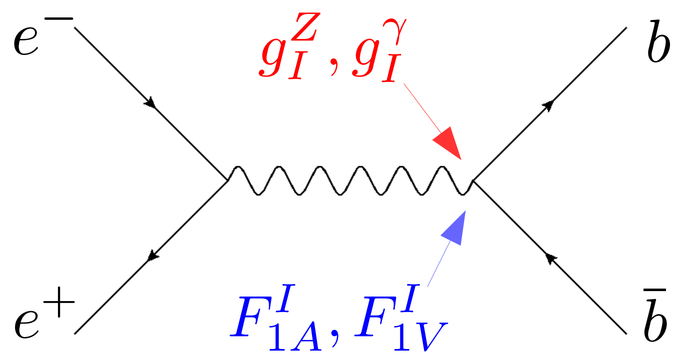




- Final efficiency ~13%
- Well matched to generated distributions:

$A^{rec}_{FB}/A^{gen}_{FB} = 100.7\% \pm 0.2\%$ $A^{rec}_{FB}/A^{gen}_{FB} = 103.8\% \pm 2.1\%$

Determination of the Form Factors



- We are measuring the differential cross section

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

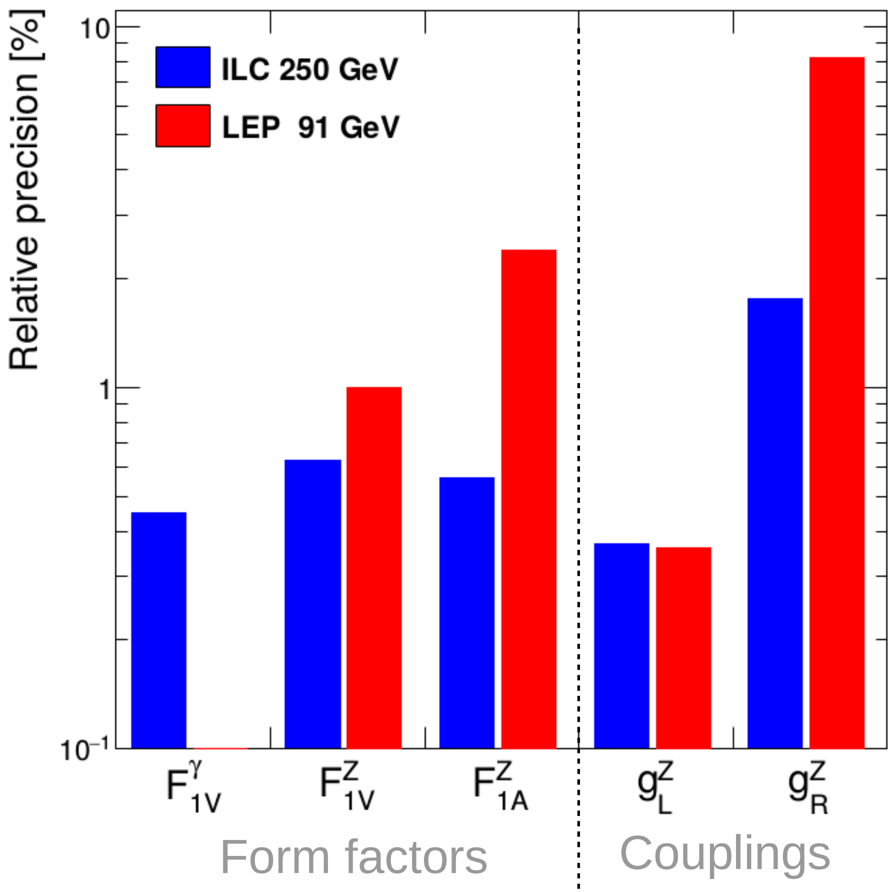
- where the $S\,A$ are

$$S^I \text{ cross section magnitude } \propto F_{1V}^I, F_{1A}^I, g_I^Z, g_I^\gamma$$
$$A^I \text{ asymmetry magnitude } \propto F_{1V}^I, F_{1A}^I, g_I^Z, g_I^\gamma$$

- Independent estimation of 4 observables and 4 EW form factors using beam polarization

Reachable accuracies at the ILC

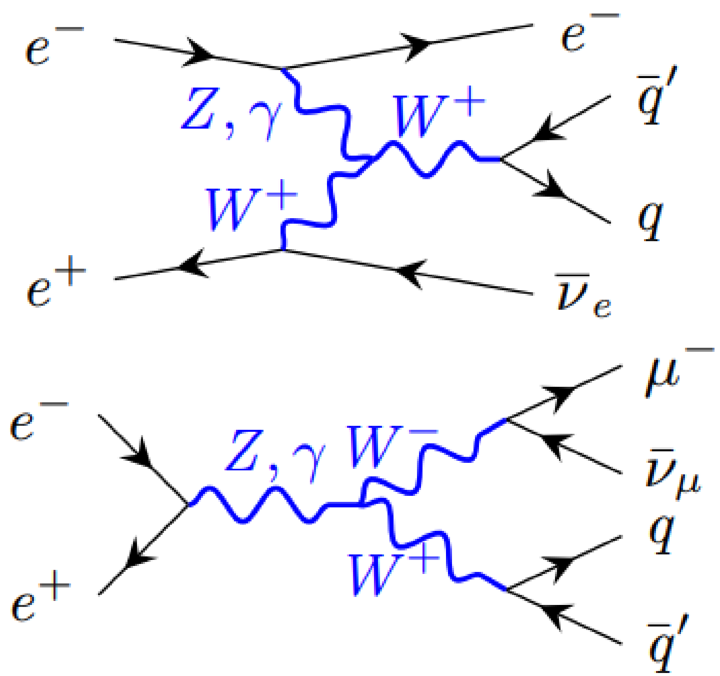
- The accuracies reachable after the first 500 fb^{-1} at 250 GeV:



- The ILC precision for the right handed coupling of the b-quark is 5 times better then at LEP

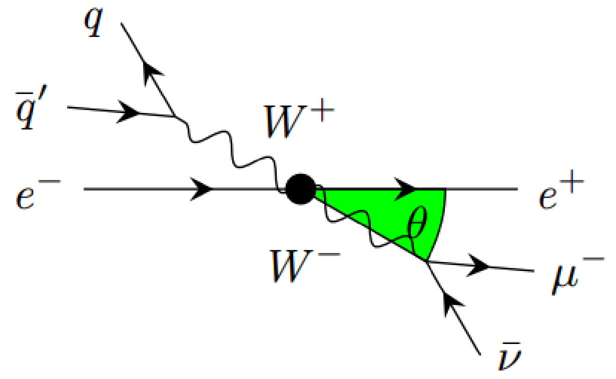
Motivation for TGC measurements

- The constraint of Triple Gauge Couplings (TGCs) and their precision of ≈ 10^{-3} is necessary for the distinction of different Higgs-models beyond the SM
- Additional bosons (e.g. Z' or W') will affect TGCs
- This measurement relies on beam polarization knowledge
  - At the ILC TGC and beam polarization can be measured simultaneously!
- We have to measure precisely the TGC and beam polarization!

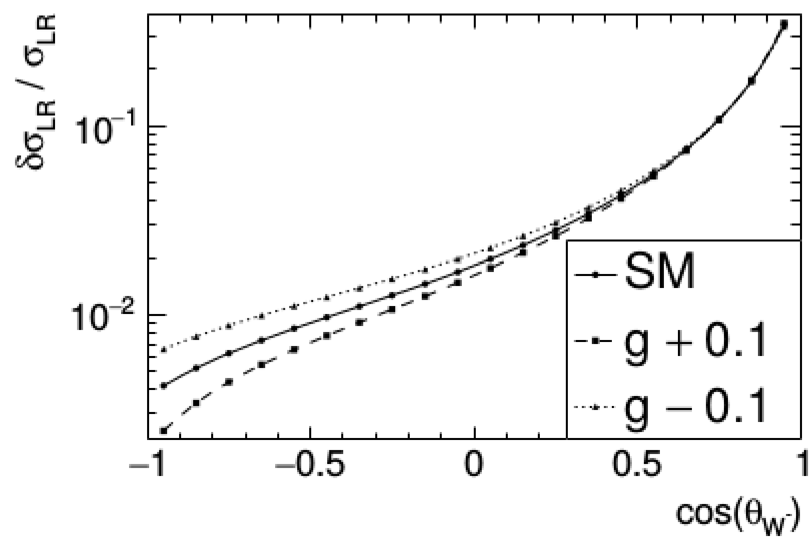


TGC measurements

- This study uses all four possible combinations of polarized beams at ILC:
  - $$\sigma_{--} := \sigma\left(P^-_{e^-}, P^-_{e^+}\right) \quad \sigma_{++} := \sigma\left(P^+_{e^-}, P^+_{e^+}\right)$$
    $$\sigma_{-+} := \sigma\left(P^-_{e^-}, P^+_{e^+}\right) \quad \sigma_{+-} := \sigma\left(P^+_{e^-}, P^-_{e^+}\right)$$



- To measure:
  - $g_1^Z, \lambda_\gamma, \kappa_\gamma$ + 4 beam polarizations
- Using differential cross sections of WW and single W processes:
  - Cross section calculated for each bin
  - Sensitive to New physics effects
  - Toy MC is used, inputs taken from full ILD simulation



Results of TGC and polarization measurements

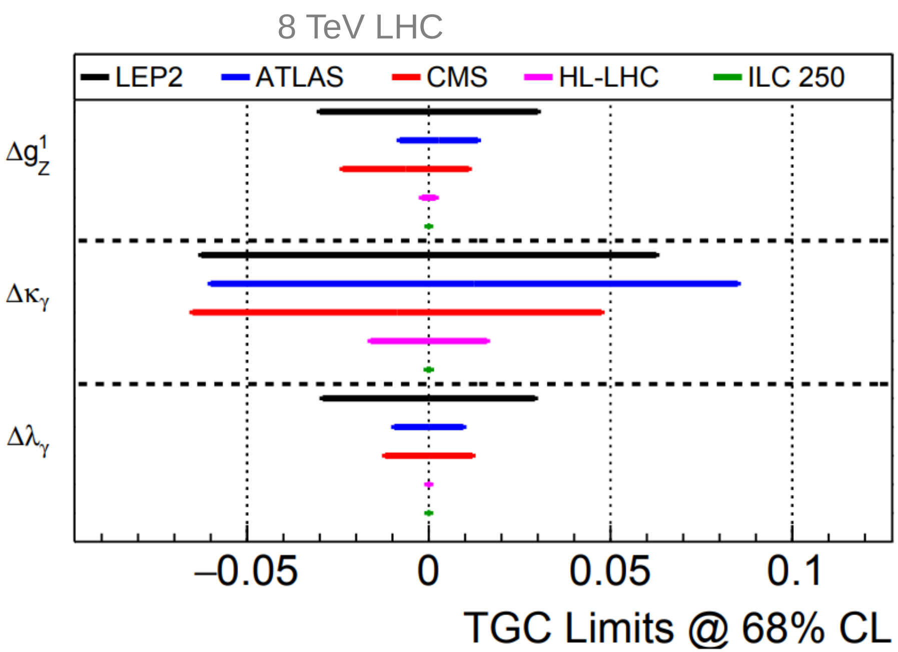
- The accuracies reachable at 250 GeV ILC:

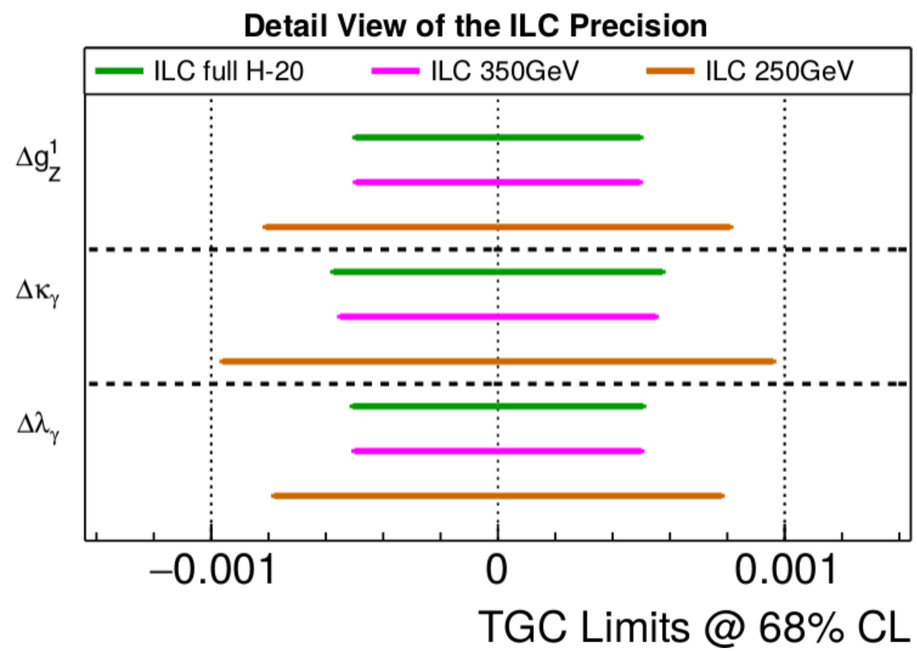
Input from full simulation:

Efficiency $\varepsilon = 0.6$

Purity $\pi = \frac{D - \mathfrak{B}}{D} = 0.8$

Int. Luminosity $\mathcal{L} = 2\,\text{ab}^{-1}$





- The ILC at 250 GeV precision is close to ILC 500 GeV
- More than 2 orders of magnitude better than LEP

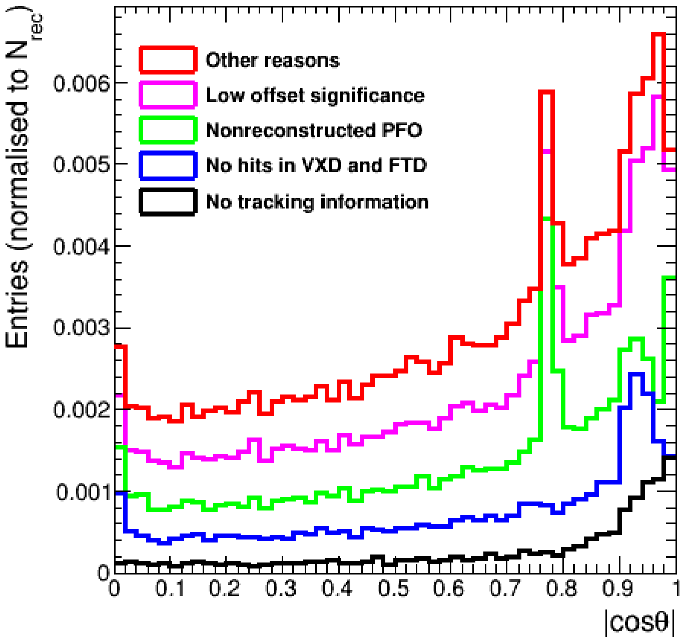
Conclusions

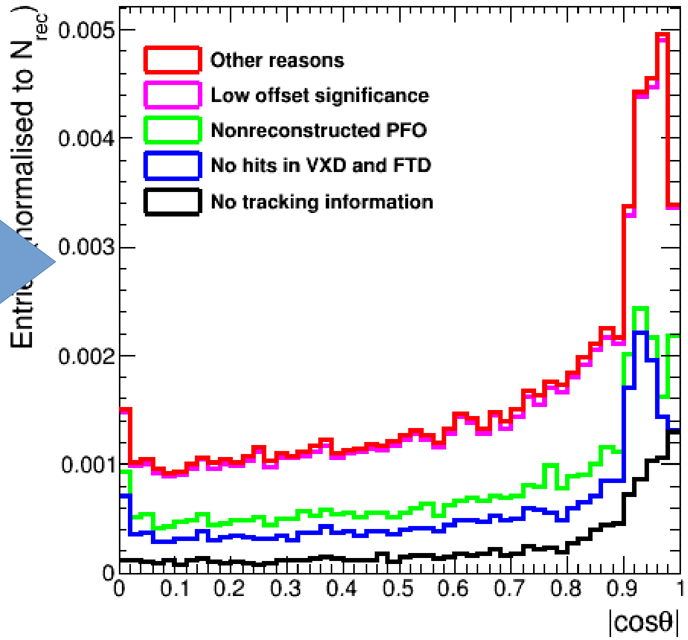
- ILC is a high-luminosity Higgs factory, aimed at precision measurements of the SM parameters
- The ILC precision on right-handed b-quark coupling will be 5 times better than at LEP
- This measurement is used as the detector benchmark process to reoptimize the ILD layout
- The Triple Gauge Couplings will be measured simultaneously with the beam polarization
- The ILC precision on TGC will be an order of magnitude better than at LEP
- Beam polarization is essential for all presented measurements!

Thank you!

Elements of vertex charge measurement

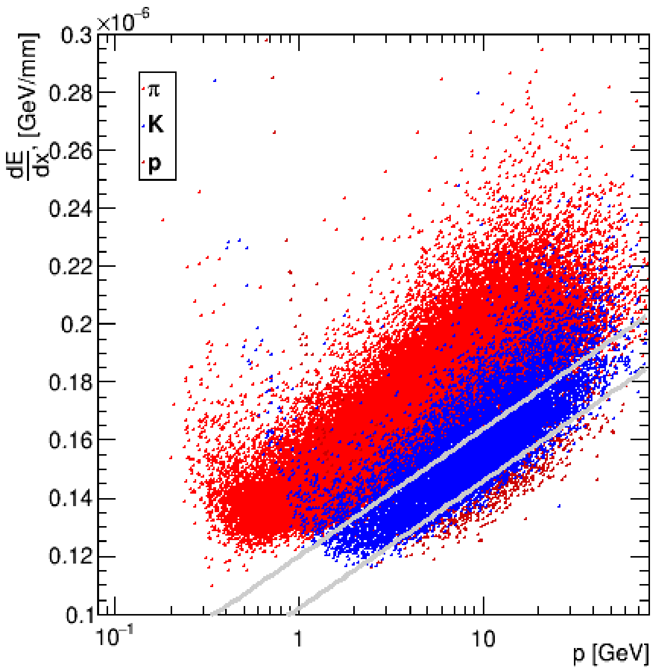
- The central problem of the vertex charge measurement is the missing particles from the reconstructed vertices
  - We have identified the sources:
    - No reconstructed tracks
    - Particle has no hits in VXD
    - No reconstructed PFO by Pandora
    - Low offset\low momentum
  - This study resulted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





Elements of vertex charge measurement: 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



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

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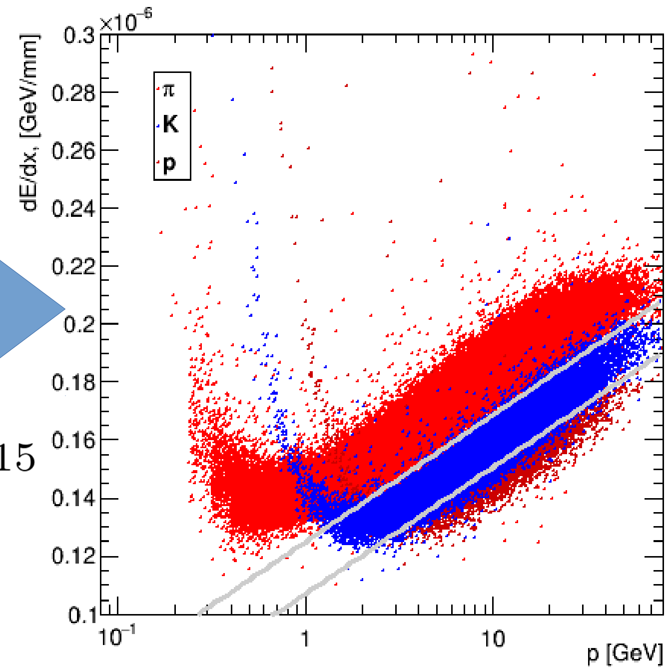
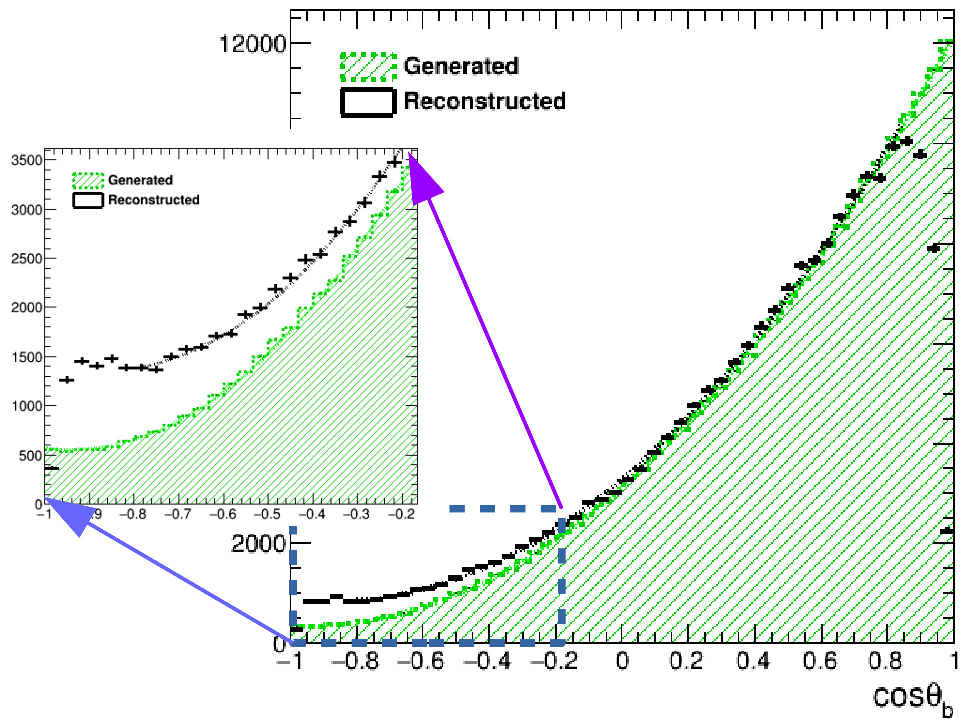


Bottom polar angle reconstruction

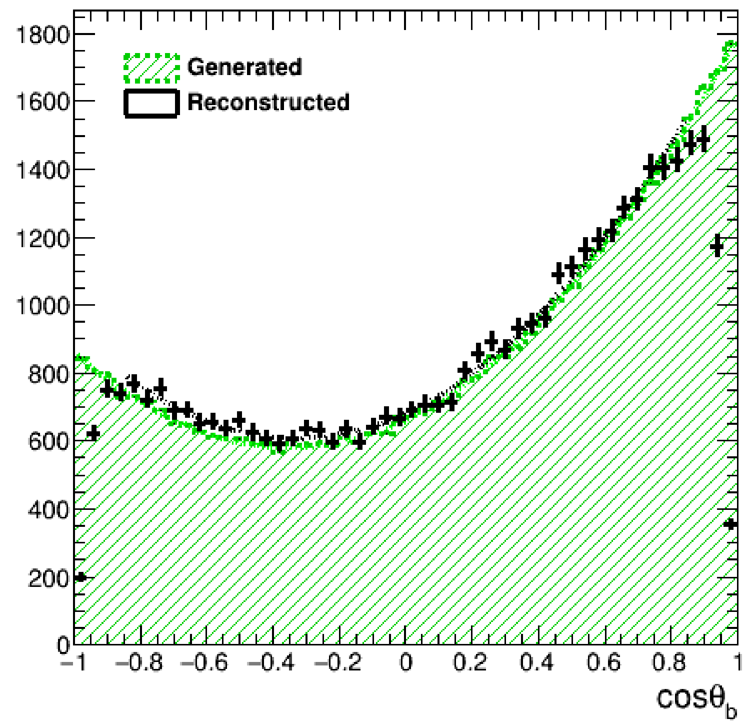
$$\mathcal{L} = 250\,\mathrm{fb}^{-1}$$

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



$$A_{fb}^{rec}/A_{fb}^{gen} = 90.5\% \pm 0.44\%$$

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



$$A_{fb}^{rec}/A_{fb}^{gen} = 93.2\% \pm 2.4\%$$

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

Event preselection for polar angle

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

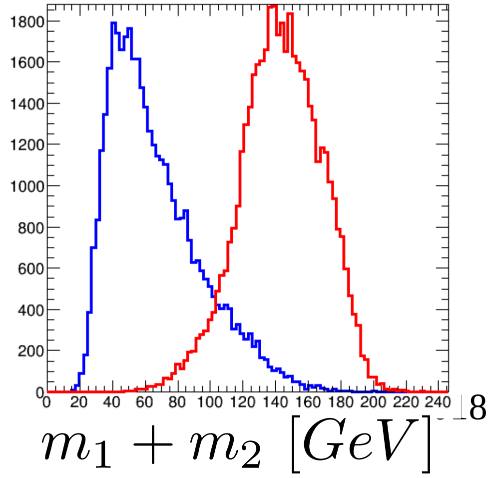
3) For Z return rejection:

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

4) For diboson background rejection

   – Sum of jet masses < 120 GeV

- Efficiency of the preselection is **55%** for both polarizations



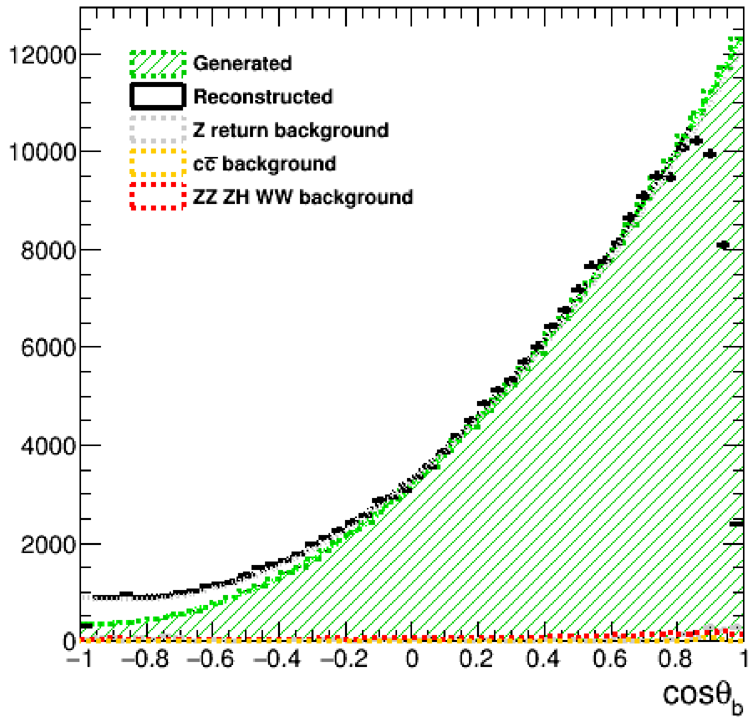
Opportunities for direct discoveries

- 250 GeV only marginally more than 209 GeV, but:
  - ~1000x more integrated luminosity
  - polarised beams
  - can suppress SM backgrounds by 1-2 orders of magnitude
  - tremendous advances in detector technology,
- Examples:
  - searches for additional light (Higgs) bosons with reduced couplings to the Z
  - MSSM: most general limit (any mixing, any mass difference to LSP) on staus is as low as 26.3 GeV
  - sterile neutrinos with m>45 GeV from WW cross section: expect 1-2 orders of magnitude improvement on mixing parameter
- … and WIMPs!
- Any search channel limited by rate at LEP2 will explore new territory at ILC250 !

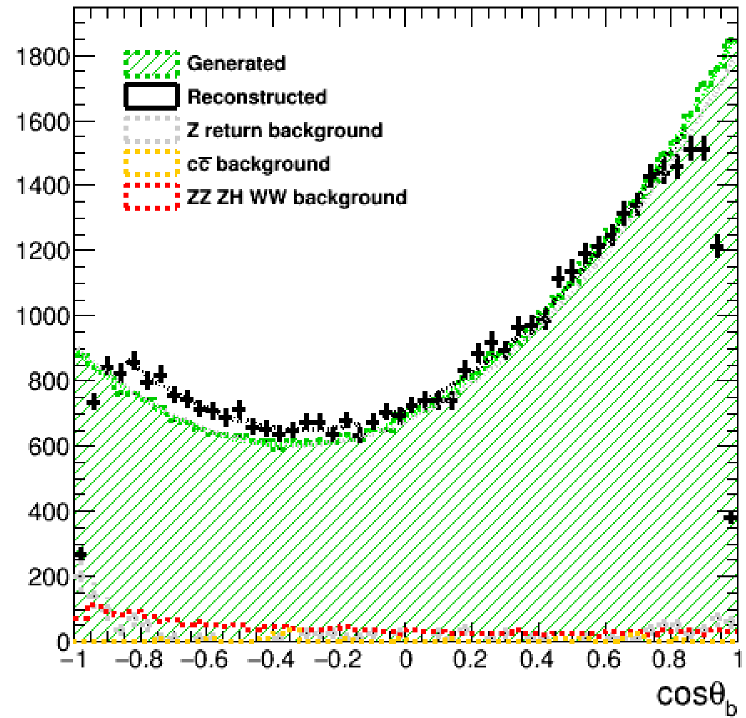
Polar angle reconstruction+bkg

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

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



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



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

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:

# of refused events

$$N = N_a + N_r$$

# of accepted events

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

- We define a number of original events:

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

$N_{orig}^{\pm}$ Original number of non-migrated events in the forward/backward bins

Migration terms

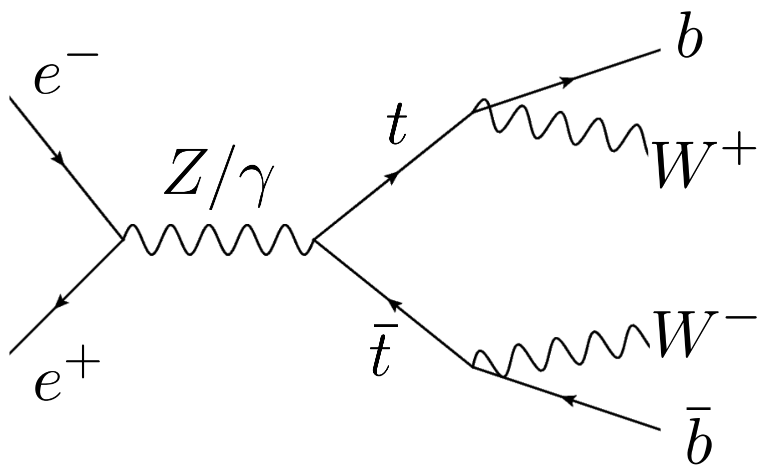
- Corrected values:

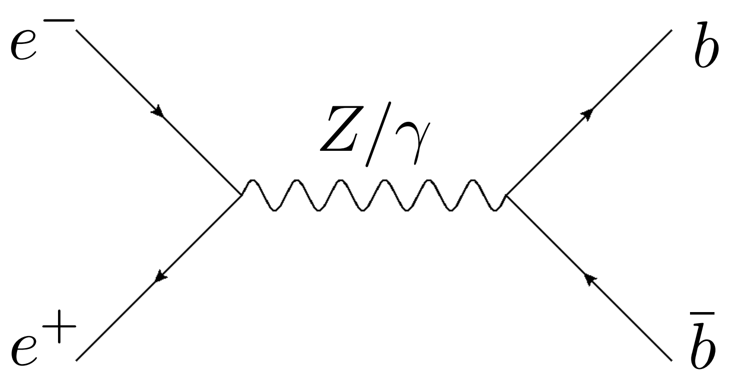
$$\begin{cases} N_a^{+\prime} = p^2 N_{orig}^+ \\ N_a^{-\prime} = p^2 N_{orig}^- \end{cases}$$

- We do not use generator information for correction

Heavy flavour at ILC

- Measurement of the heavy flavour quarks at the electron-positron machines:
  - Direct EW production
  - No competing QCD production
- Advantages of the ILC:
  - Operating at $\sqrt{s} = 500\,\mathrm{GeV}$ increases the sensitivity to top axial form factors, minimizes the QCD uncertainties
  - Polarized beams allow independent determination of the b-quark form factors
  - Highly granular 4π detectors allow for precise final state reconstruction using PFA





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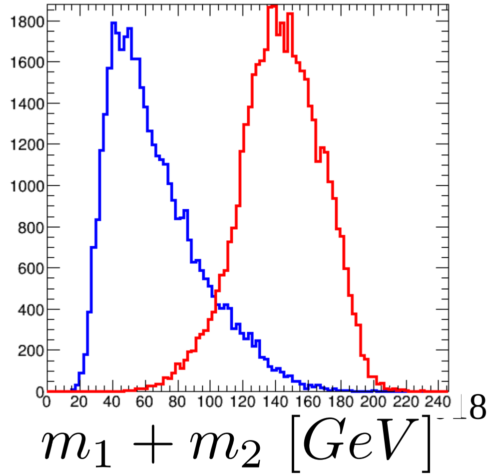
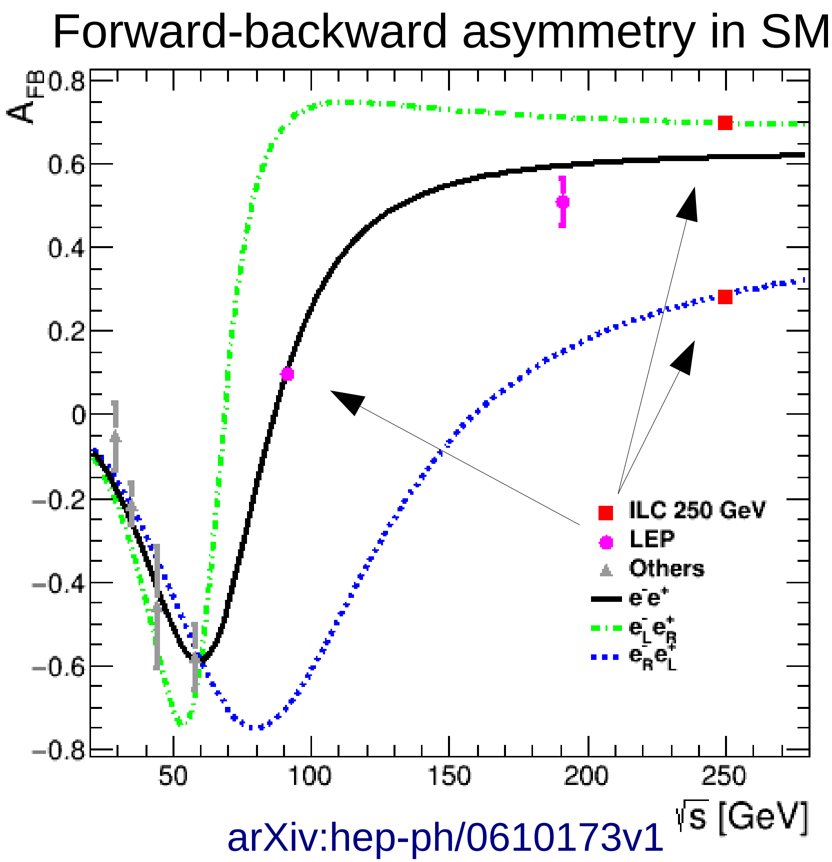
- Efficiency of the preselection is **55%** for both polarizations
- Final efficiency for the polar angle plots is **13%**

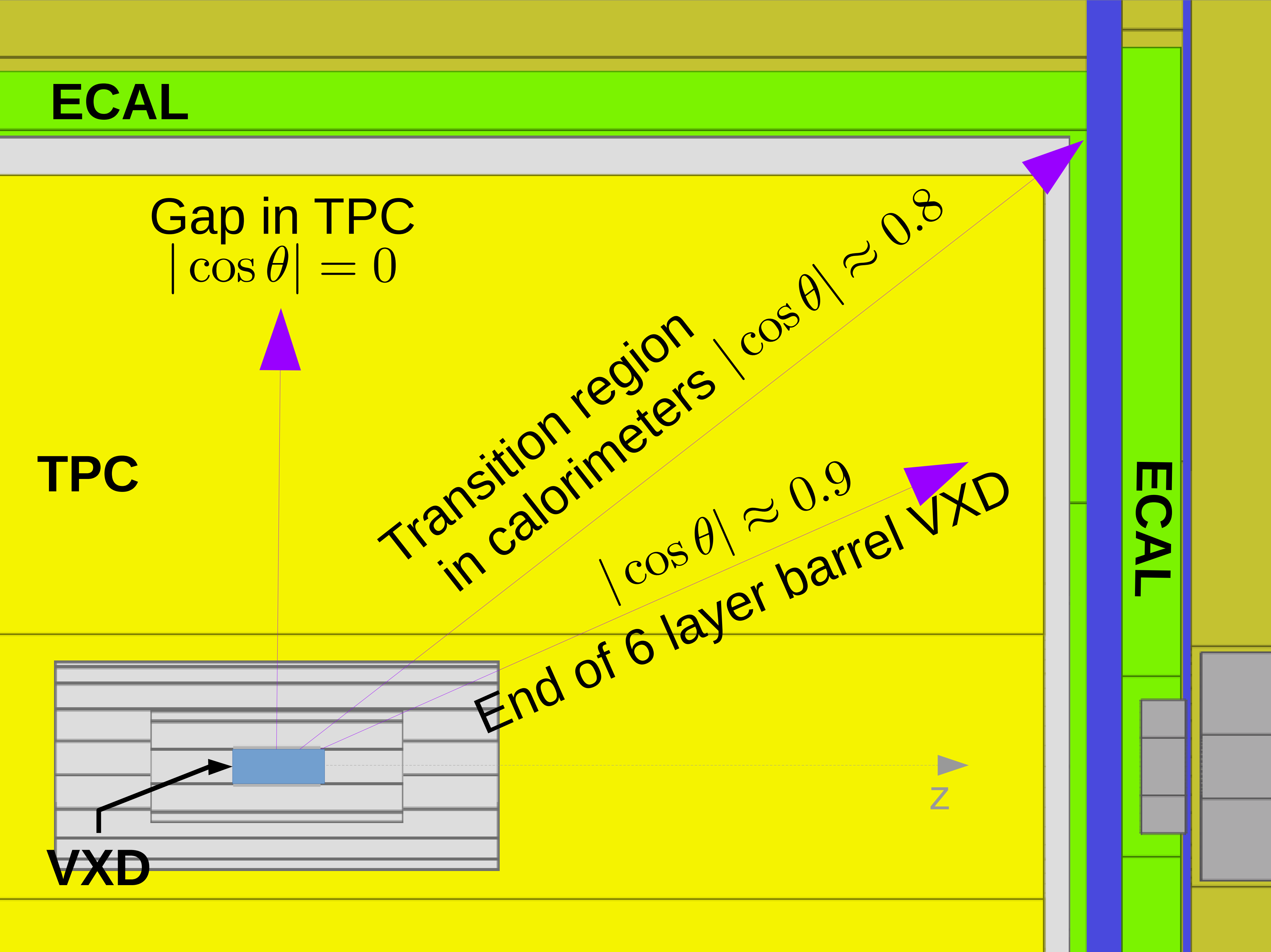


Overview of A_{FB} measurements



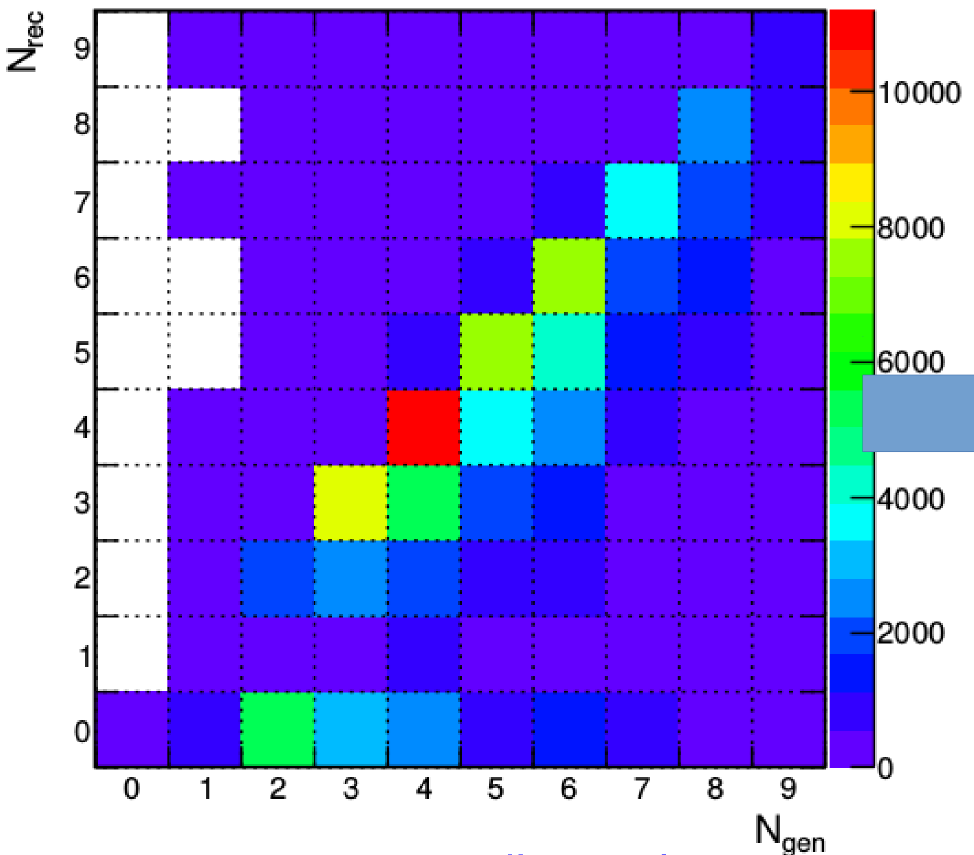
arXiv:hep-ph/0610173v1

- The A_{FB} value and the uncertainty is determined from the fit to the reconstructed curve
- The measurements at Z pole are the most precise

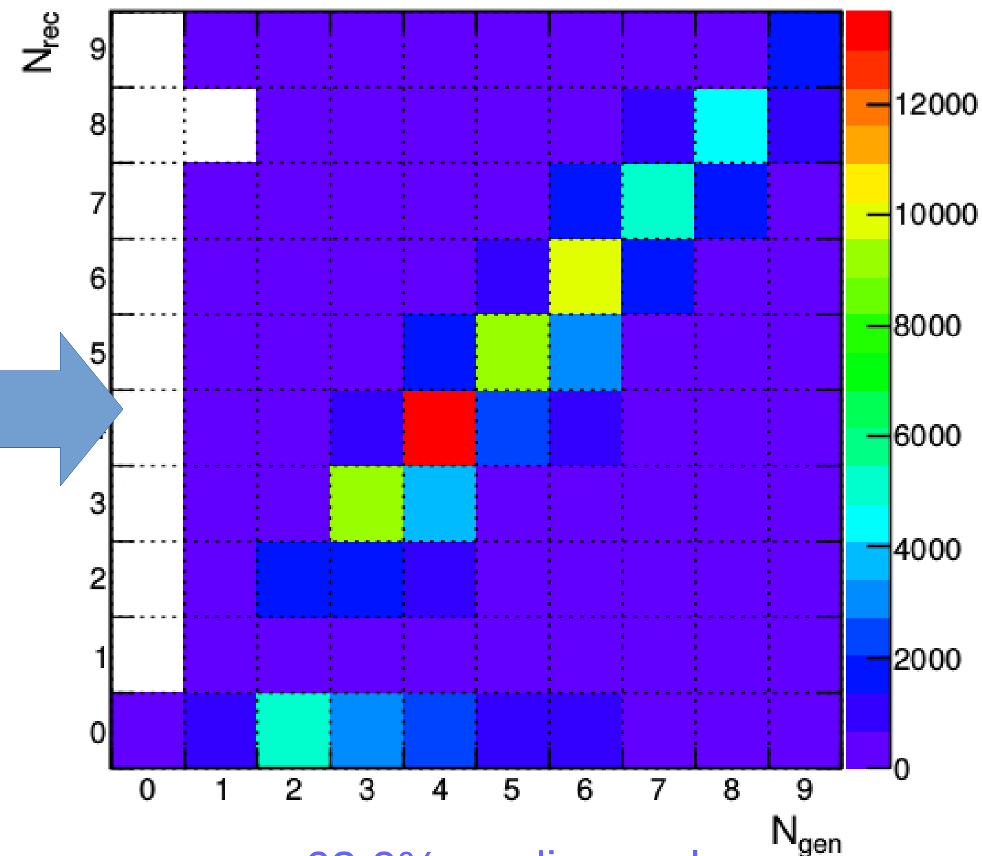


ECAL
Gap in TPC
$|\cos\theta| = 0$
Transition region
in calorimeters $|\cos\theta| \approx 0.8$
TPC
$|\cos\theta| \approx 0.9$
End of 6 layer barrel VXD
ECAL
VXD
z

Vertex charge recovery improvement



49.0% on diagonal

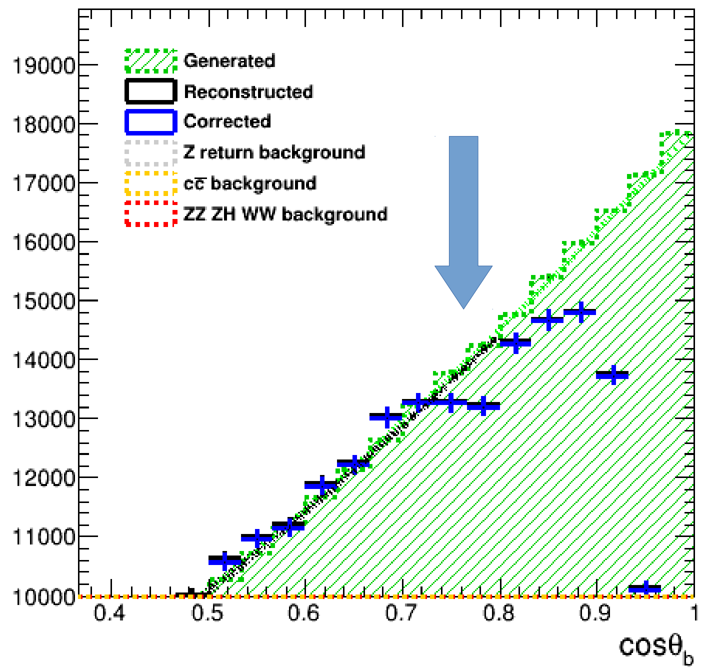


62.0% on diagonal

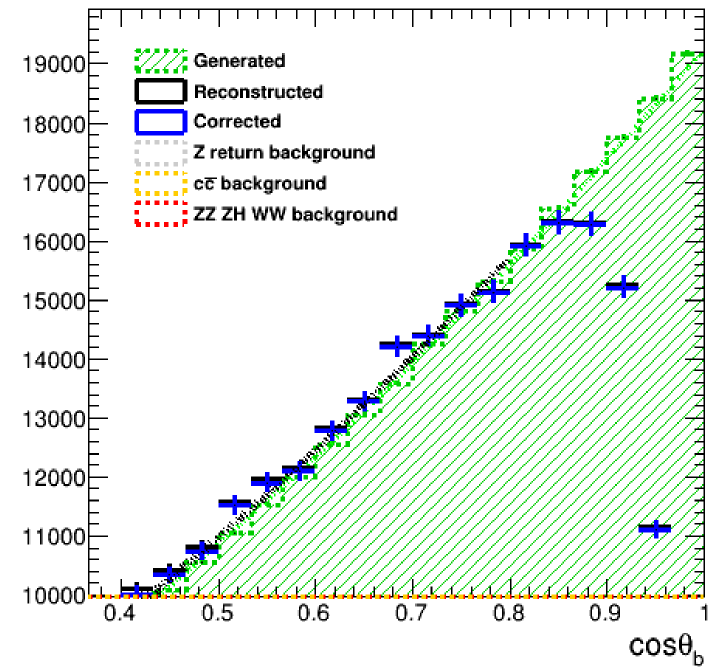
- The b-jet charge measurement requires very precise vertex reconstruction

Recovery effects

Before charge recovery

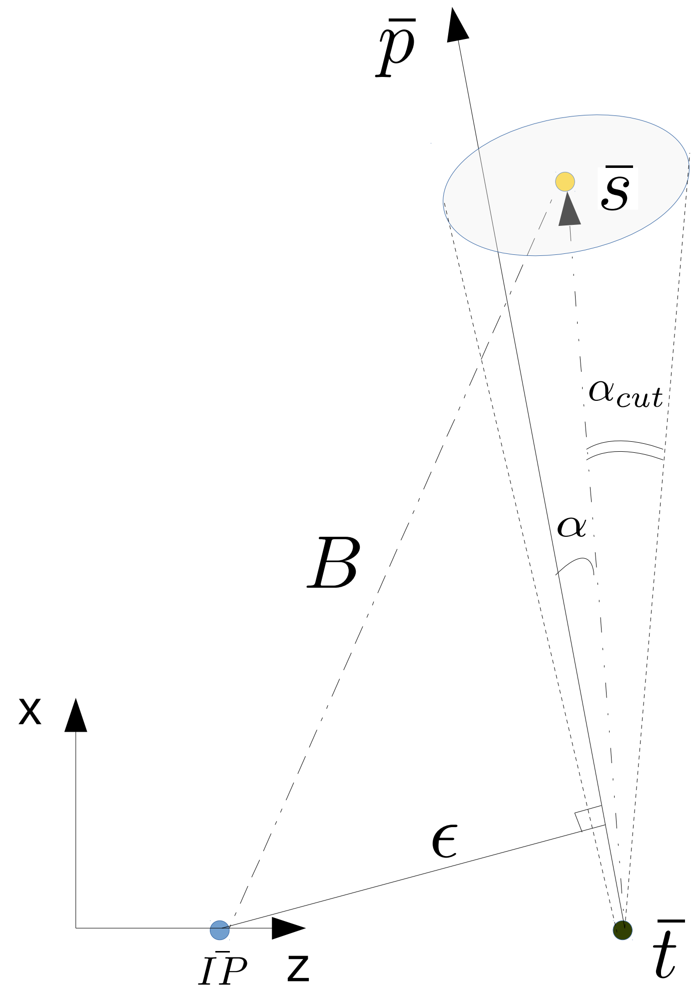


After charge recovery



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

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