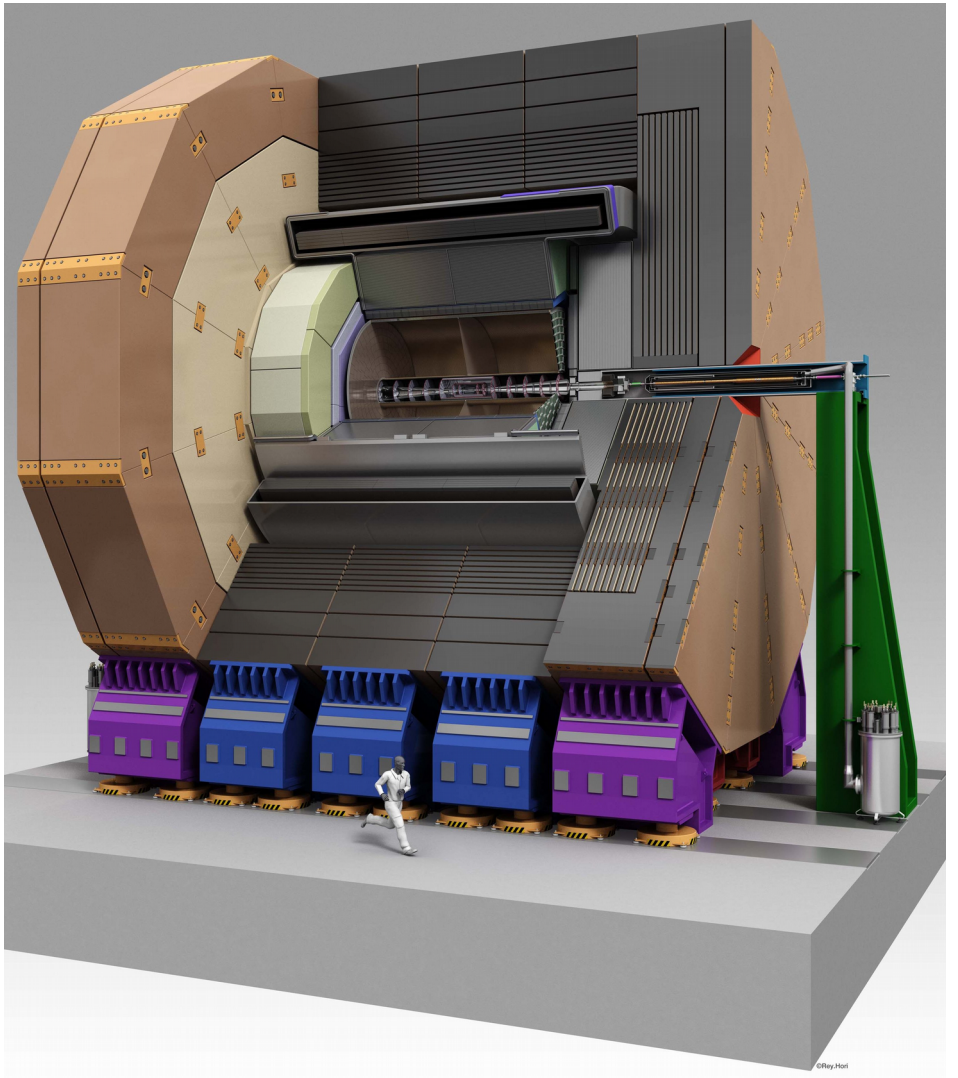
High precision forward backward asymmetry measurements in $e\text{-}e^{+} \rightarrow b\bar{b}$ at ILC@250GeV

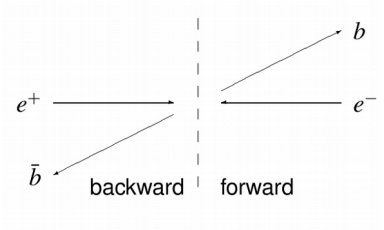
S. Bilokin, R. Poeschl, F. Richard, A. Irles

ILD group meeting, 5th Feb. 2019



Motivation

- **B-quark electroweak couplings** can be inferred from cross section and forward backward asymmetry (Afb) observables.



$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

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

where the $A\ B\ C$ are

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

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

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

The b-quark polar angle is defined as a polar angle of the vector

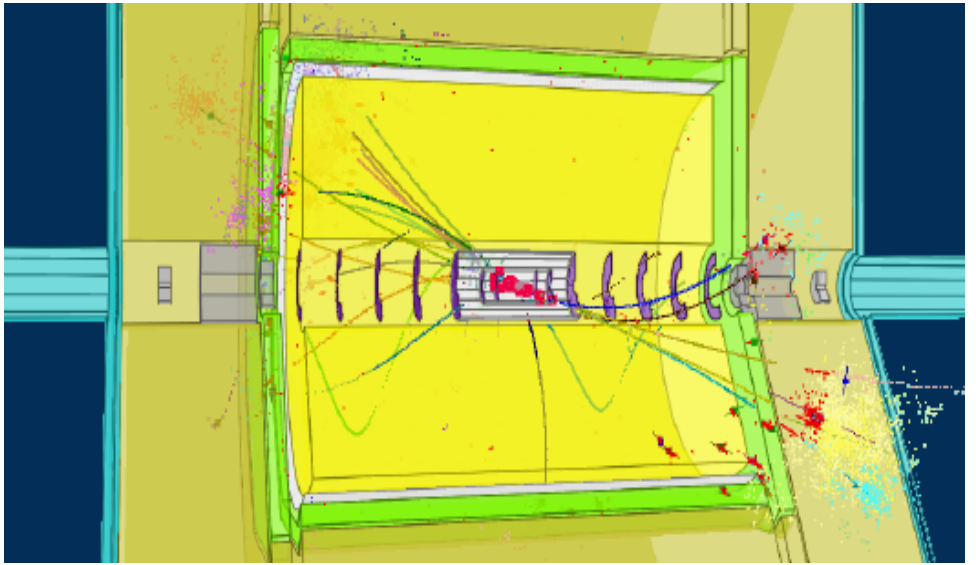
$$\vec{p}_{b\bar{b}} = \vec{p}_b - \vec{p}_{\bar{b}},$$

- Afb has been measured in SLC and LEP at the Z-pole (showing some tension between both measurements)
- **ILC provides polarized beams that allow already at 250 GeV for a large disentangling of elw. couplings and a final word on the LEP1 anomaly**
  - A running at the Z pole is highly desirable to complete the physics picture
- **ILC aims to precision of the ‰ in these measurements.**

$b\bar{b}$-asymmetry measurement

- All results shown here are for the bb asymmetry measurement (cosθ) using $e^+e^- \rightarrow b\bar{b}$, 250 GeV, for pure left and right handed polarizations.
  - /ilc/prod/ilc/mc-dbd/ild/dst-merged/250-TDR_ws/2f-highM_Z_hadronic + ILCsoft v01-17-06
  - Each sample has~250 fb^{-1}
- Preselection
  - e^-e^+ kT jet algorithm with 2 exclusive jets
  - Btag(j1)>0.9 && btag(j2)>0.2 (against qq)
  - events with a photon with E>40GeV or m(j1j2)<180GeV are rejected (Cut against Radiative return)
  - m(j1)+m(j2)<120

This is a DBD analysis



Simulation of a $b\bar{b}$ event at ILD (S. Bilokin)

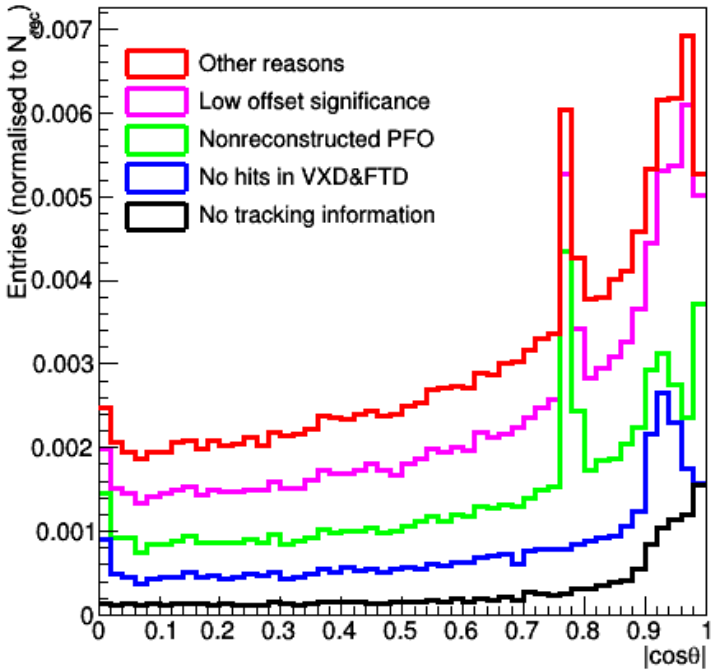
b-asymmetry measurement

- The goal is to measure the asymmetry basically by measuring the **direction and charge** of the two final state jets and their charge. **How?**
- We have two methods to identify b-jet charge, called **Bc and Kc methods**
  - **Bc:** With the full vertex charge measurement (associated to the b-hadrons decays) (~5 tracks per jet)
  - **Kc:** With the charge of K-mesons (identified by the TPC), from B-decays. (~1 track per event)
- The observable measurement relies on the efficiency of **reconstruction of tracks.**
- The track reconstruction **efficiency is not 100%,** therefore the **purity** of Bc and Kc methods is not 100%: it is **~80-85%** for both.
- To correct for charge calculation mistakes **we use double tagged events:**
  - We keep only events that have compatible charges in both jets or in the same jet.
  - In the first study from S. Bilokin, only pure Bc-Bc or Kc-Kc categories were used. Including crossed categories (Bc-Kc between different and/or the same jet) **we increase the statistics** of the sample **by a factor 2.5**

See back-up slides for more details.

Track/Vertex Recovery

- The jet charge measurement relies on the track and vertex reconstruction efficiency
- **~10% of the tracks/vertexes are lost.**



Lost tracks/vertexes

in **Z→ $b\bar{b}$** events at 250GeV

- **No tracking information:**
  - These track left 0 hits in the full detector.
  - This is only happening ~1% of the times.
- But **we need fully reconstructed tracks** i.e.: were TPC segment is associated to the micro-vertexes and the tracks are associated to the right calorimeter cluster.
  - In this case, we have a factor ~10 more lost tracks than the "no tracking info" case

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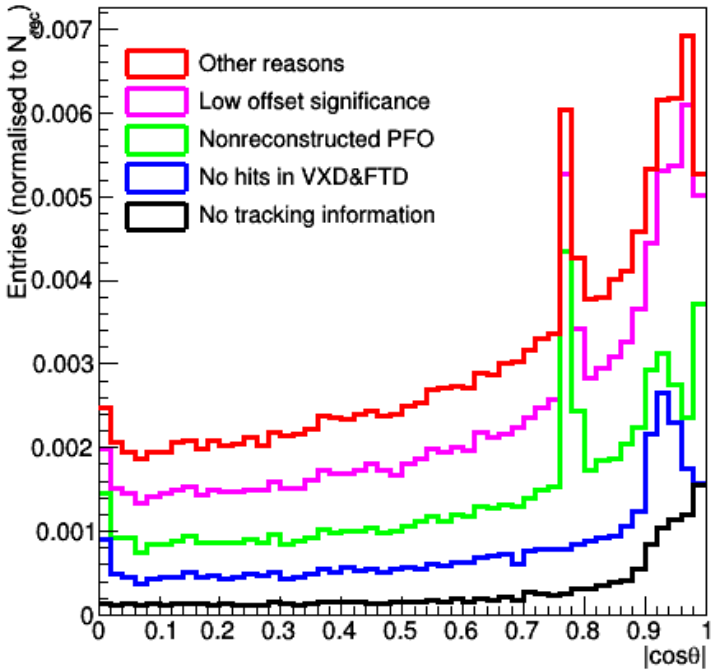
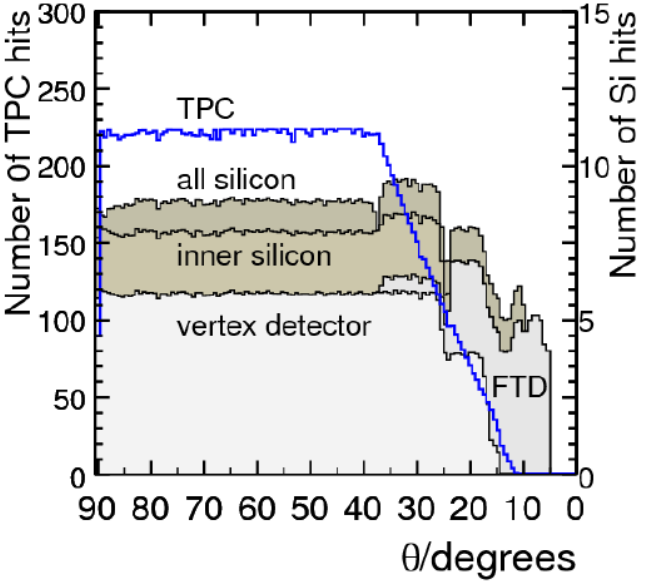


Lost tracks/vertexes

in **Z→ b$\bar{b}$** events at 250GeV

- **No hits in VXD/FTD →** recoverable
  - The track segment from the Vertex Detector or the Forward Tracking Disks was not connected to the long TPC segment.
  - These particles have large uncertainties on the impact parameters, which make them not suitable for vertexing algorithms.



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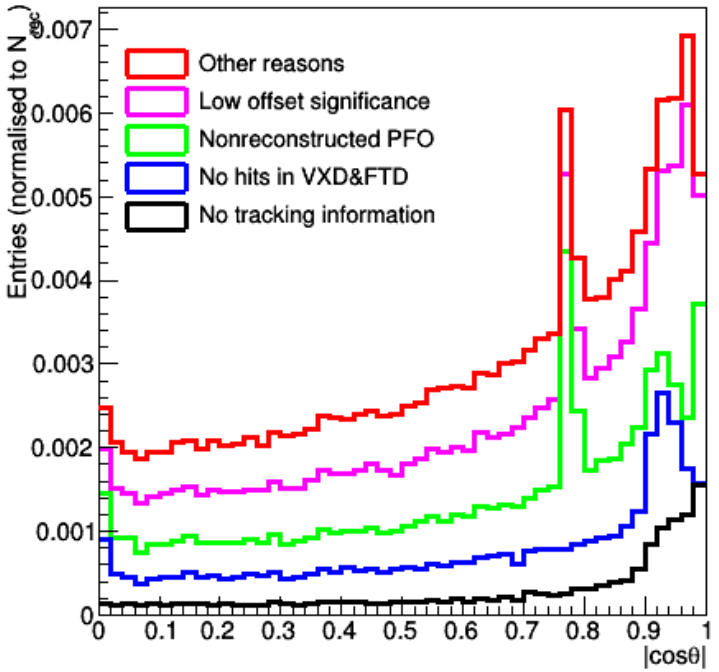
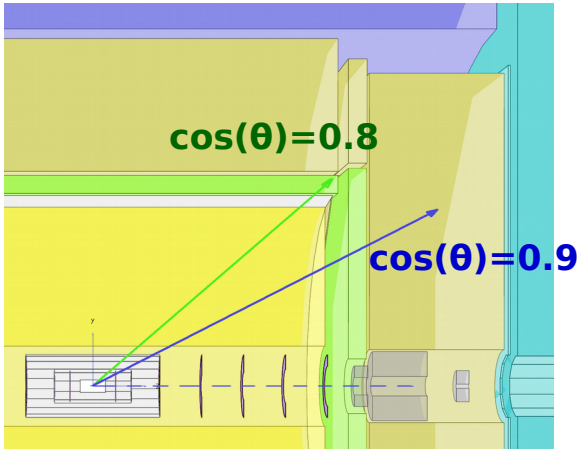


Lost tracks/vertexes

in **Z→ $b\bar{b}$** events at 250GeV

- **Non reconstructed PFO** → recoverable
  - Pandora fails to reconstruct PFO from tracks.
  - Dramatic effect at the transition between barrel and endcap calorimeters (mostly fixed with the new reconstruction, IDR)



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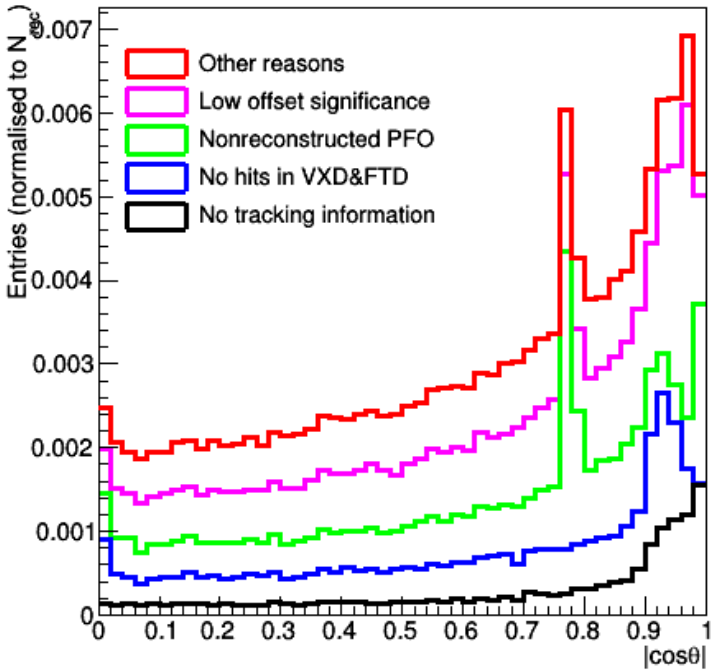


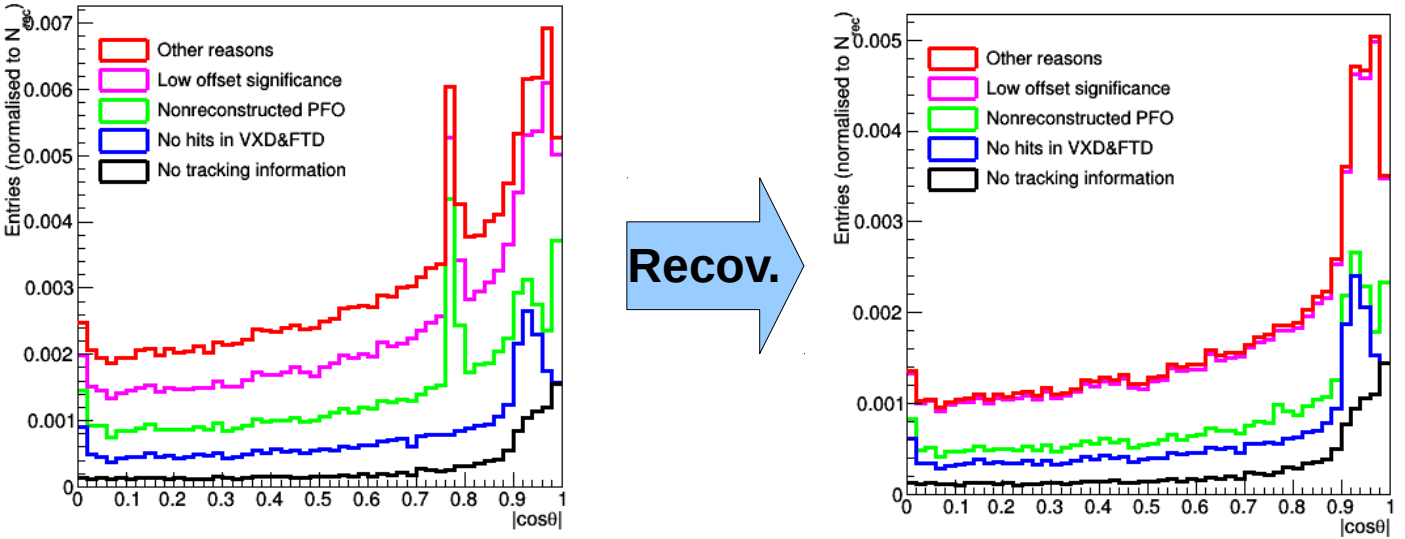
Lost tracks/vertexes

in **Z→ b$\bar{b}$** events at 250GeV

- **Other reasons** → recoverable
  - Vertex fitting problems.
- **Low offset significance** (not recoverable ~1/3 of the lost tracks)
  - The reconstructed particle was produced with impact parameters bellow the detector resolution.

Track/Vertex Recovery

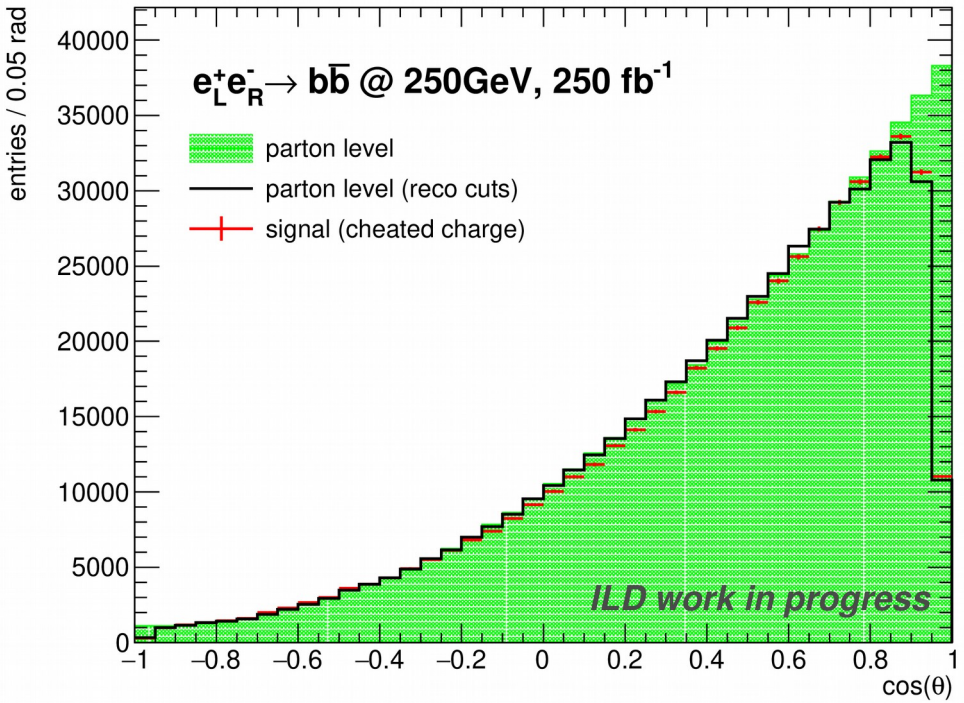
- Result of the recovery *à la* S. Bilokin (see more details in the back-up)



- **~50%** of the lost tracks **are recovered**. Good improvement do the PFO assignment and solved fitting issues.
- **Still improvable**: large amount of lost tracks on the forward regions and only partial restoring at cos(θ)=0

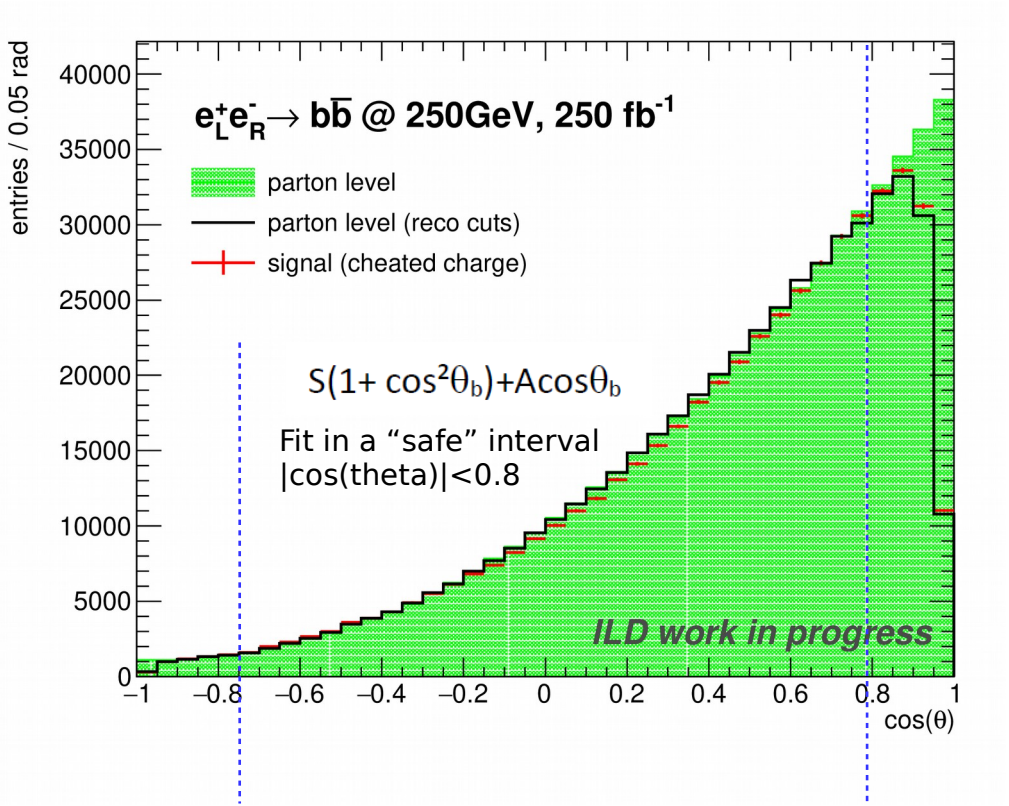
- **The recovery is applied after jet reconstruction and b-tagging → recovered tracks are only "linked" to already existing jets.**

Detector Correction issue: Intro



- The track restoring, as it is now implemented at already final jets, helps in the improvement of the charge measurement.
  - The jet kinematics is not recalculated.
- The charge measurement is still not perfect (purities of 0.8-0.85) but we know how to correct the mistakes using a data-driven correction (see back-up)
- Let's focus now in the "ideal" distributions

Detector Correction issue: Intro



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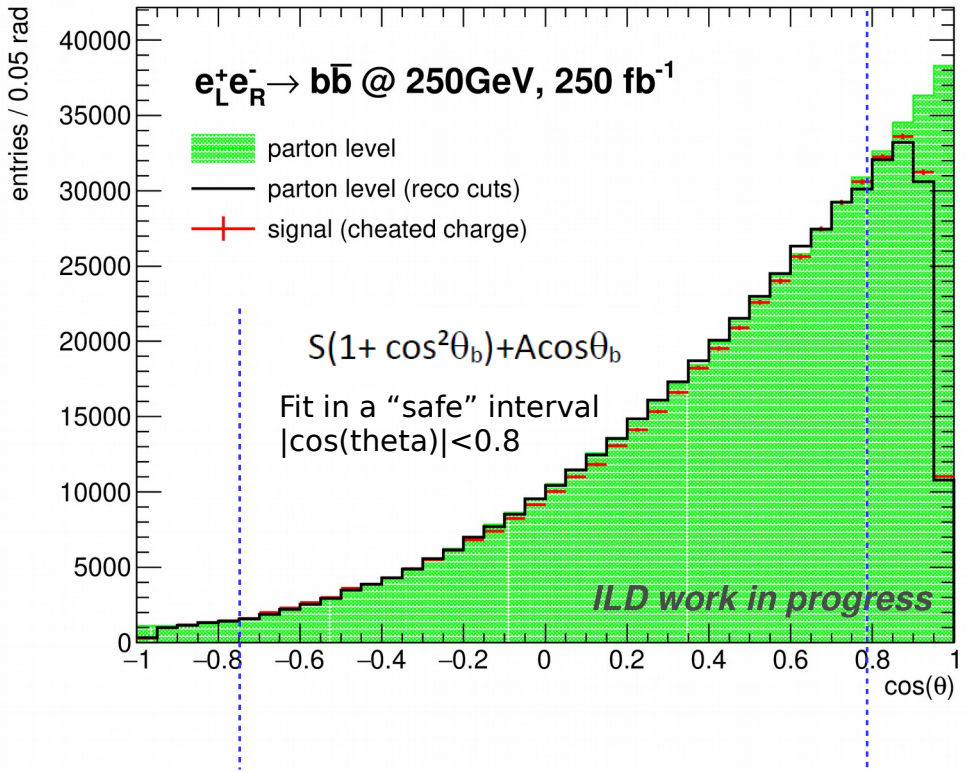

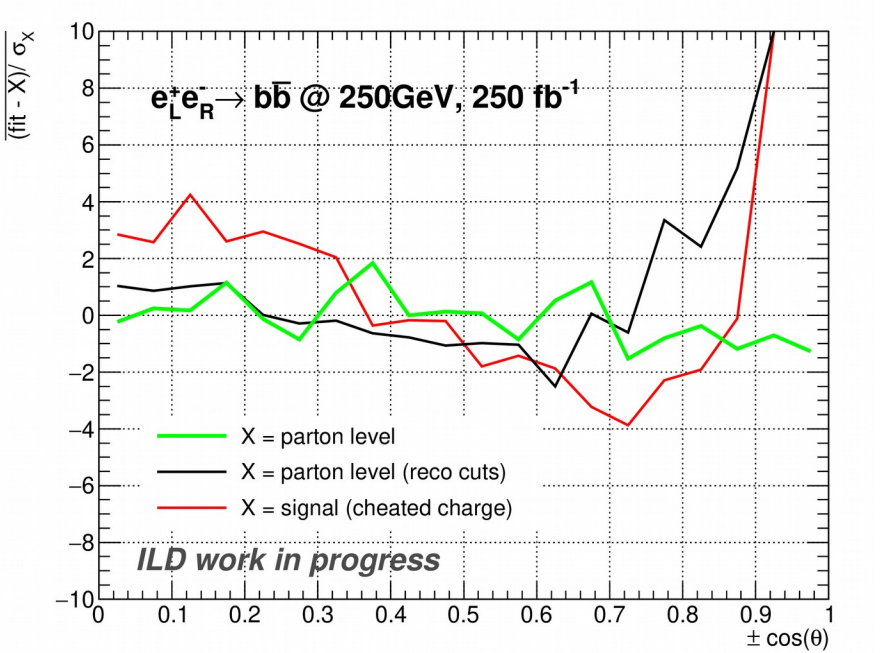

- **Pull** values averaged for positive and negative cos(θ)

- The acceptance issue is already visible at cos(θ) ~0.75 **(black curve)**
- The chi2 of the signal **(red curve)** it is already bad in the barrel → **this is clear now thanks to the enhanced efficiency**

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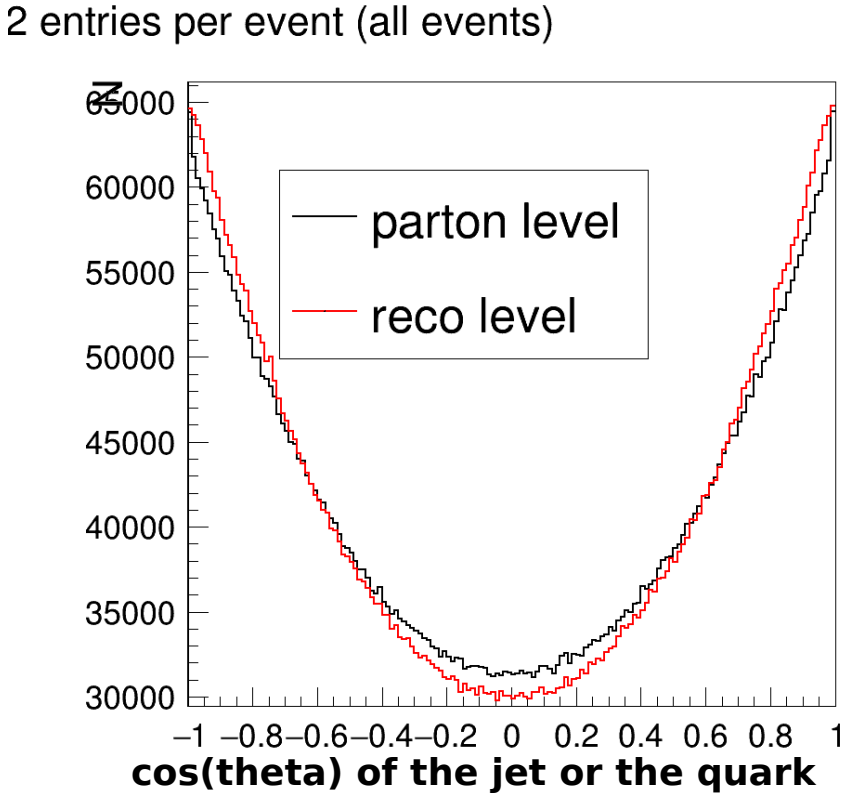
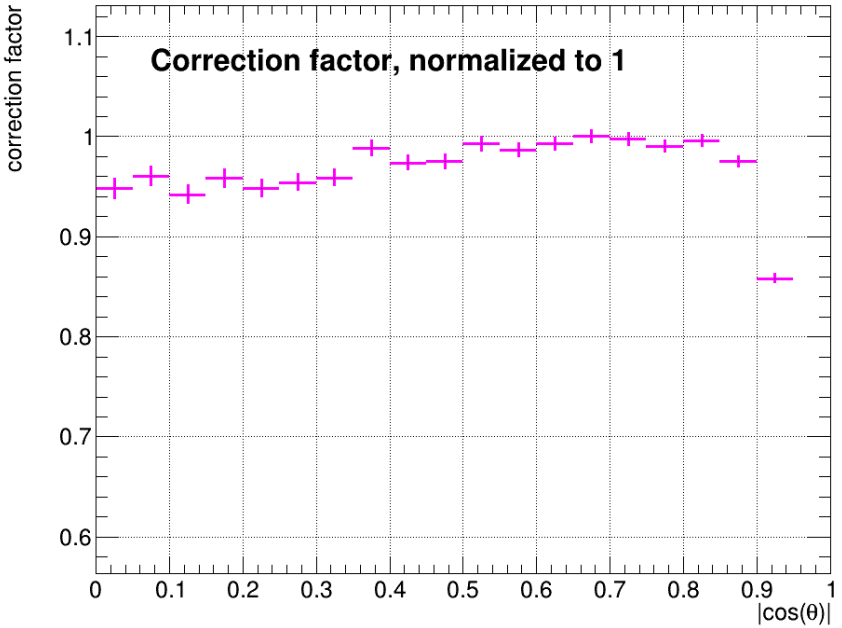


- **What is the origin of the discrepancy in the barrel?**
- Let's go back to the jet level
- Look to the Jet/quark angular distribution for ALL simulated EVENTS.
  - There is a tendency to reconstruct larger angles (in abs. value) angles than the generated.
  - Compromised angular reconstruction.

Resolution effects are seen as a few percent level acceptance issue in the barrel region.

How to correct for detector effects?

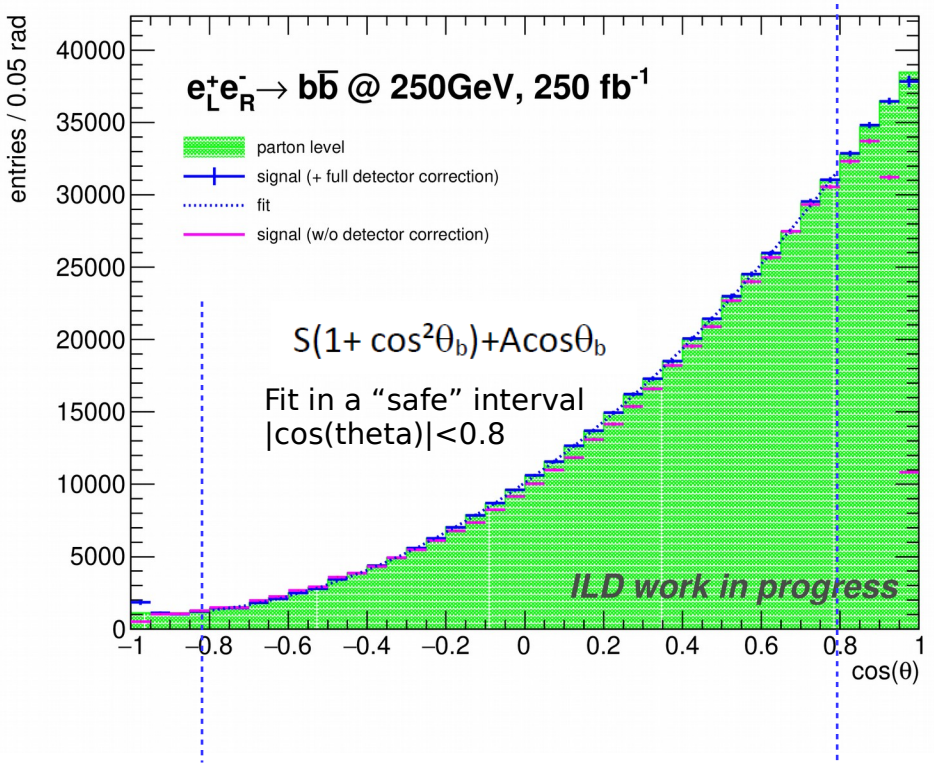
- **Resolution + acceptance issues.** How can we fix them?
- **Naive approach:** apply a correction fudge factor and avoid the forward region
  - Correction factor = (truthreco_level / parton_level)$^{-1}$
  - This factor includes correction for acceptance and resolution effects.

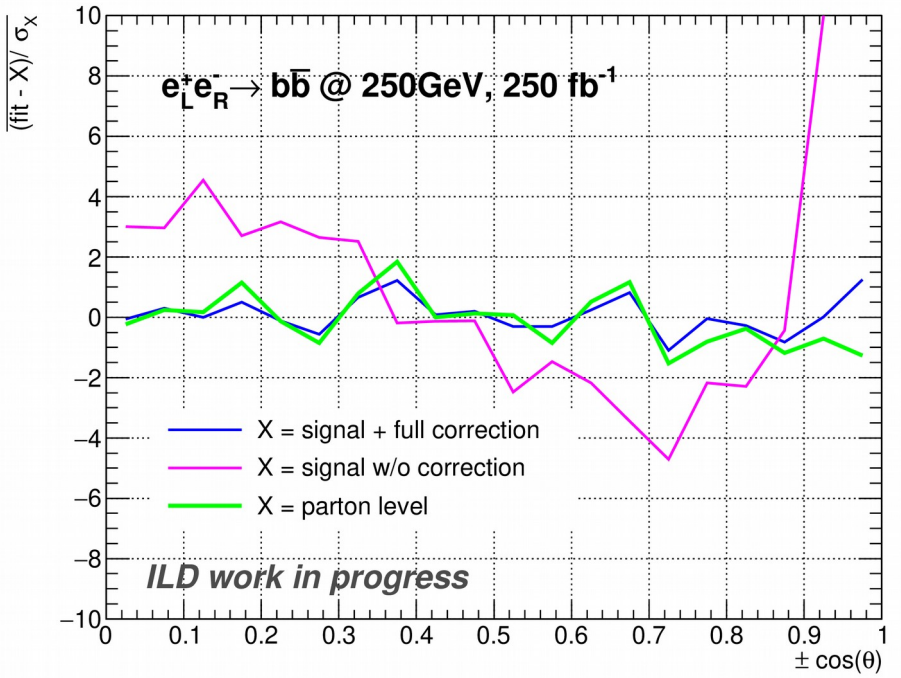


Correction factor of ~5% in the barrel region

(and it would be larger than 15% in the forward region but this is excluded from the fit)

Fits at parton level: eL (250 fb^{-1})





- A good chi-square is recovered after applying the detector corrections.

Prospects for 250 fb^{-1} (left polarization)

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B} \qquad A_{fb}^{parton} = 0.7078 \pm 0.0014 \,(0.20\,\%)$$

Achievable stat. precision after applying selection efficiency:

$$A_{fb}^{parton}(selection\ \ eff) = 0.7078 \pm 0.0023 \,(0.33\,\%)$$

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→ if we don't use kaon ID

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Preliminary results:

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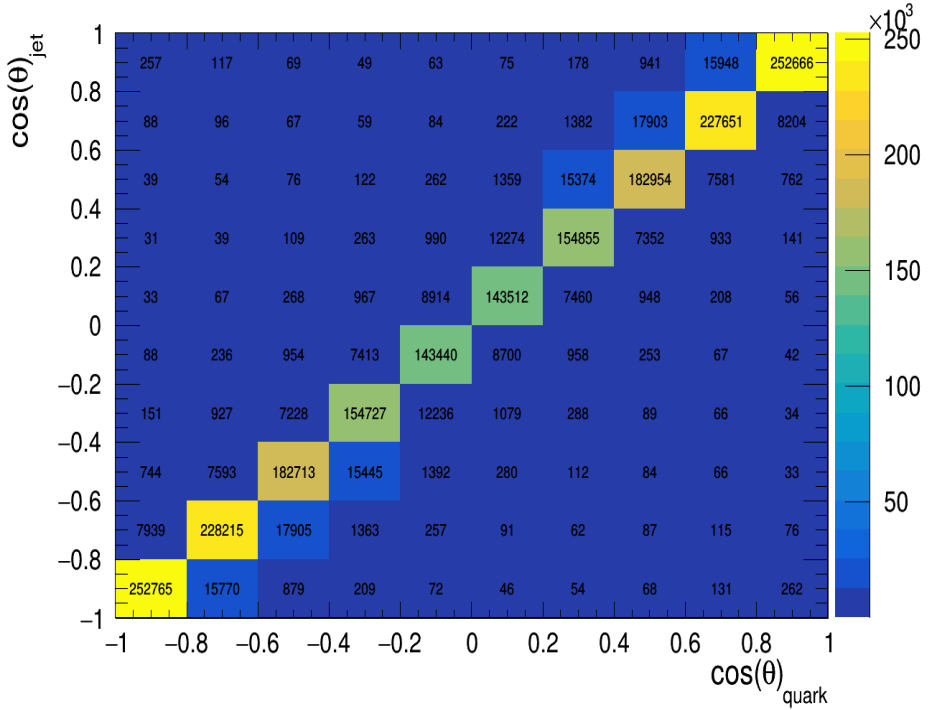
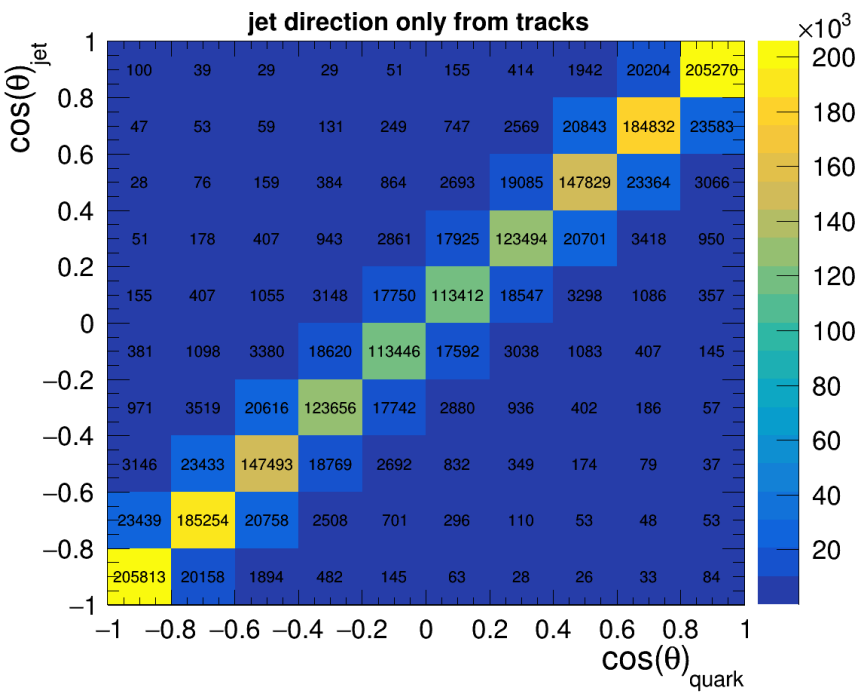
$$dA_{fb}^{reco,\,non\,corr.} = 0.34\,\%, \qquad \frac{A_{fb}^{reco,\,non\,corr.}}{A_{fb}^{parton}} = 99.4\,\%$$

The impact of the correction is already larger than the statistical uncertainties for a luminosity scenario of 250fb^{-1}

Can we reduce the size of the correction?

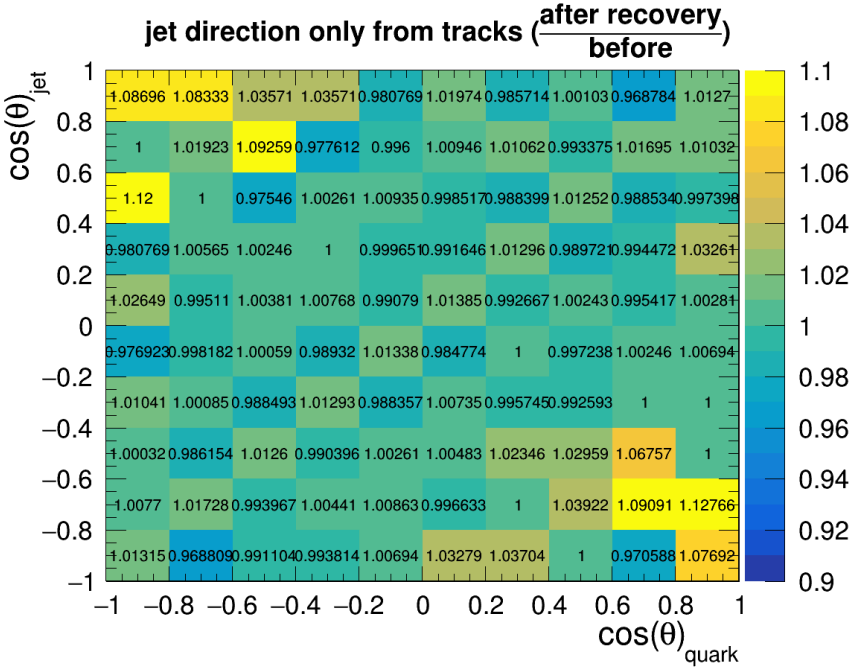
- Would the resolution improve if we use the restored tracks for the reclustering of the jets ?
- **Exercise 1**, try to **compare** the **jet direction calculated with all PFOs** with the direction using **only** tracks from **secondary vertexes**.
  - The matrix is more diagonal, although the migrations are larger.





Can we reduce the correction?

- **Exercise 2**, compare the resolution matrix made using only tracks before and after the restoring of tracks.
  - There is a global improvement of in the diagonal and nearest bins.



- **The main issue is that the recovery process is applied with already reconstructed objects**

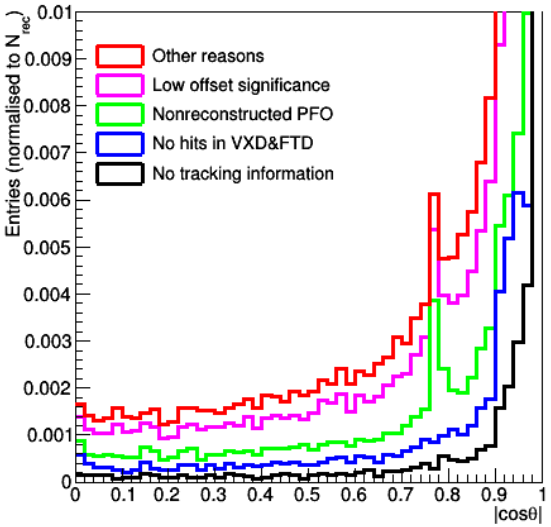
→ we need a reprocessing of the samples with the restoring done at the beginning to measure the real impact of the lost tracks in the resolution.

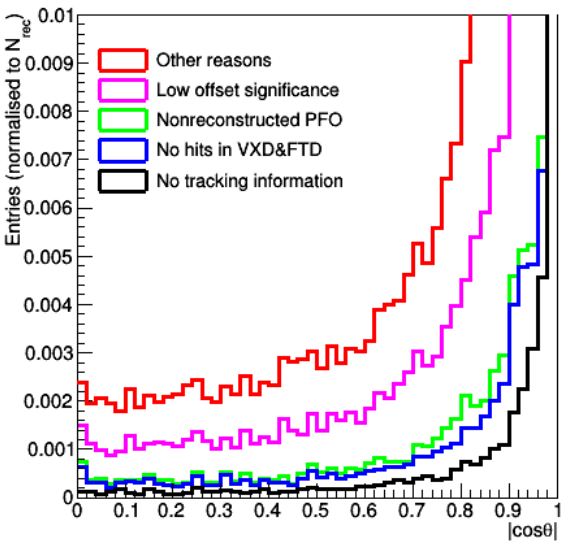
New Tracking / Reconstruction Improvements ($b\bar{b}$, 500GeV, left pol.)

- DBD

Before Recovery

- IDR, large model





- The new reconstruction solves the “horn” issue in the transition of barrel/endcap calo.|
- The “other reasons” case (vertex fitting problems) is worst but we expect that will be solved after reprocessing the vertexing taking into account the IP smearing.
- The issue in the nearby of the TPC cathode is still present, although it is smaller at 500GeV.
- Is the 500 GeV $b\bar{b}$ case extrapolable to the 250 GeV? The differences look substantial.

Summary/Conclusions

- With increased statistics we get sensitive to subtle detector and reconstruction effects. This observation will most likely be amplified one we would have 2ab-1.
  - i.e. acceptance and resolution issues.

If these effects are not corrected, we need:

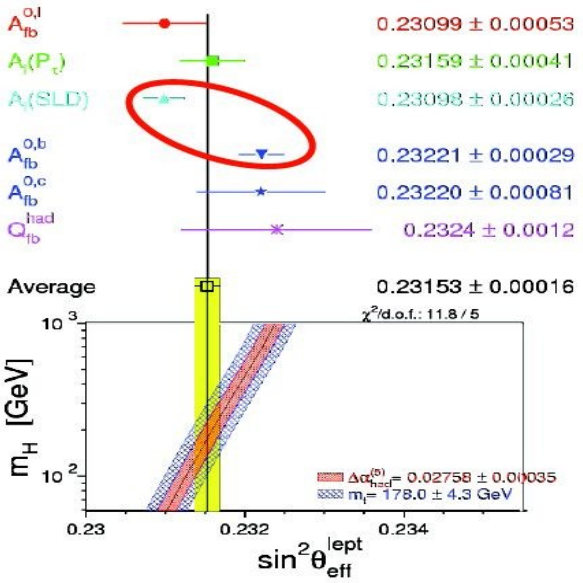
- To apply a MC fudge factor to the data
  - This factor sizes 5-6% in the barrel region.
- Exclude the forward region from the fit

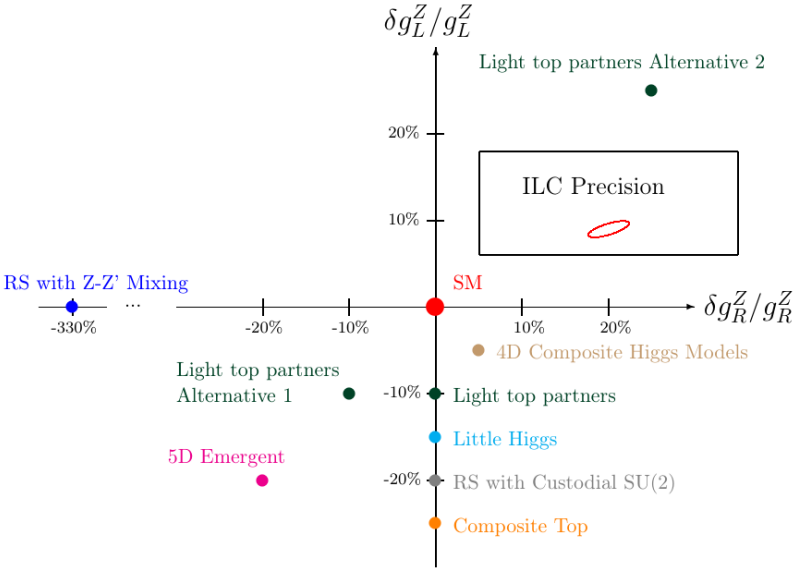
To continue making progresses in the understanding of this issue we would need to:

- Study the impact of the new reconstruction algorithms at 250 GeV
- Reprocess the samples to recover at an early stage of the reconstruction the lost information (*i.e.* lost tracks because the hits in the micro vertex are not associated to a TPC segment) that may spoil the angular resolution of the reconstructed jets.

Back-up slides

Such differential cross section and Afb measurements are excellent probes for new physics searches **if measured at the ‰ level**

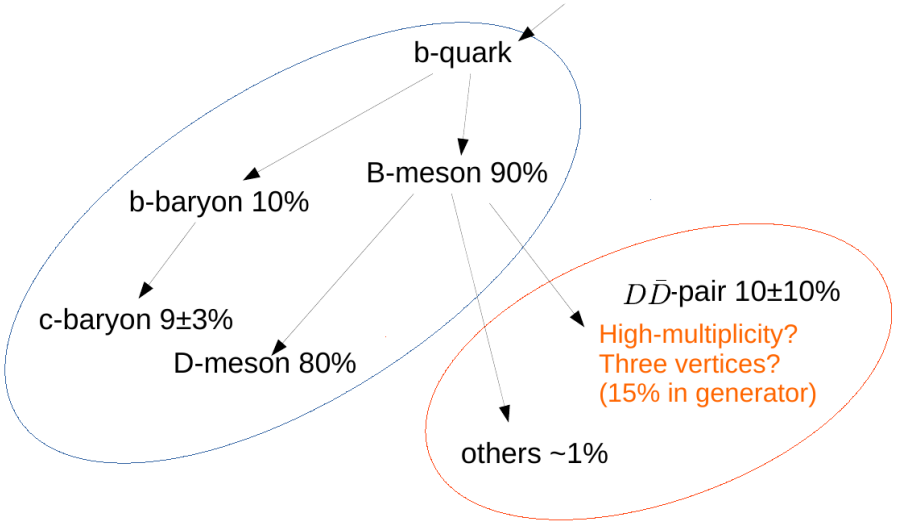




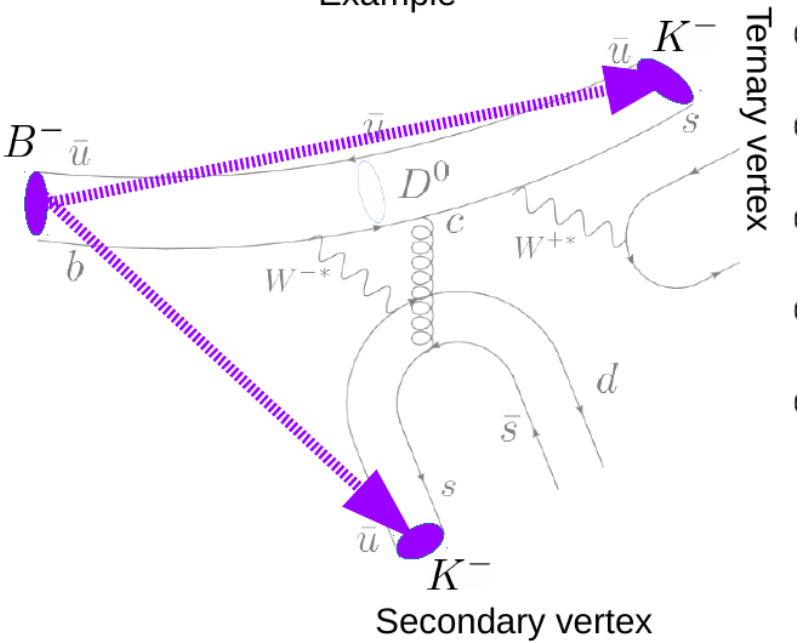
- The goal is to measure the asymmetry basically by measuring the **direction and charge** of the two final state jets. **How do we measure the charge?**

Process overview

- Hadronization and decay modes of b-quark:



Example



Bilokin S.

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Track/Vertex Recovery

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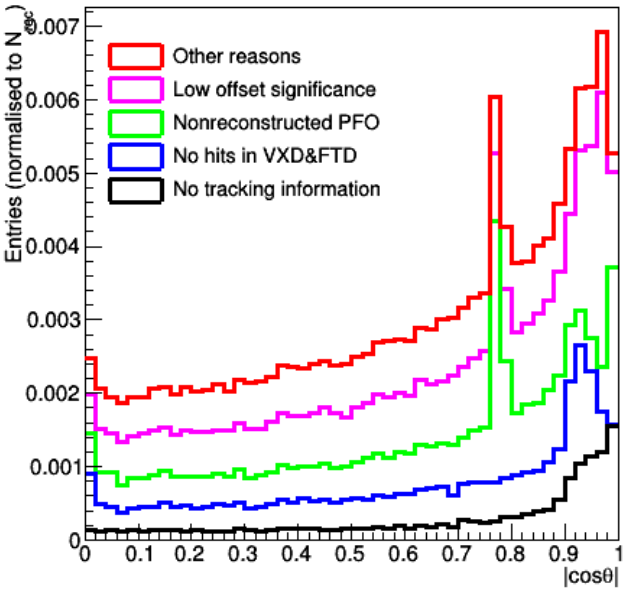
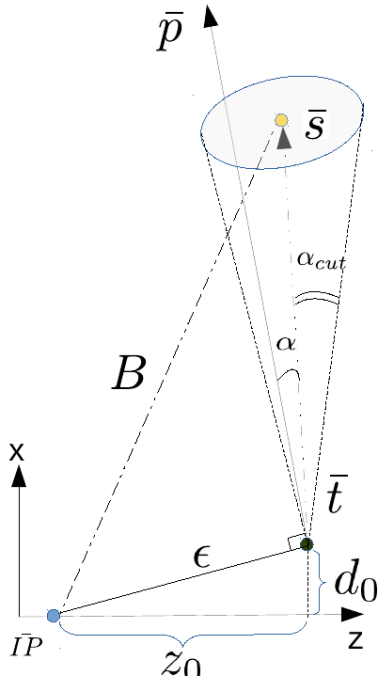
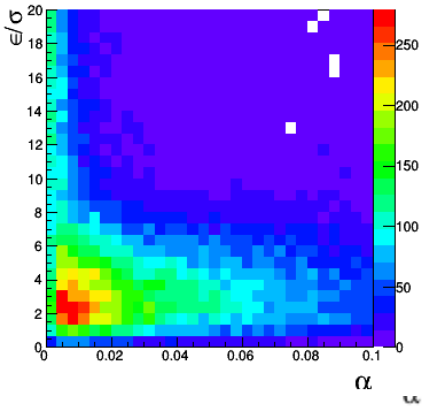


- No tracking information - the MarlinTrk algorithms fails to reconstruct the track. This category is tiny - only 0.93% of the generated prongs;
- No associated hits in the VXD or FTD - the track segment from the Vertex Detector or Forward Tracking Disks was not connected to the long TPC track segment. These reconstructed particles have large uncertainties on the impact parameters, which makes them not suitable for vertexing algorithms. They constitute 2.% of the generated prongs;
- No reconstructed PFO - the PandoraPFA fails to create the PFO from a reconstructed track. These tracks are discarded by the LCFI+ algorithms - 3.2% of the generated prongs;
- Low generated momentum or offset - the reconstructed particle was produced with impact parameters below the detector resolution - 3.1% of the generated prongs;
- Other reasons connected to vertex fitting problems - 1.7% of the generated prongs.

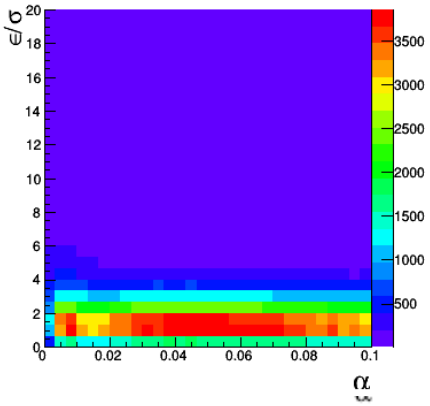
- Recovering the lost tracks/vertexes



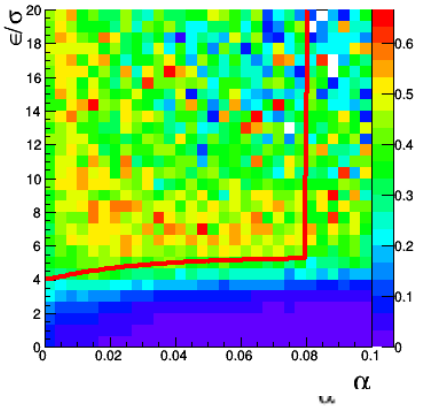
IP – interaction point (primary vertex) , **s** – secondary vertex, **t** – point of closest approach of a track, **p** – reconstructed momentum, ϵ - offset of a track from primary vertex $\epsilon/\sigma = d_0/\sigma_{d_0} + z_0/\sigma_{z_0}$



(a) Missing particles



(b) Background

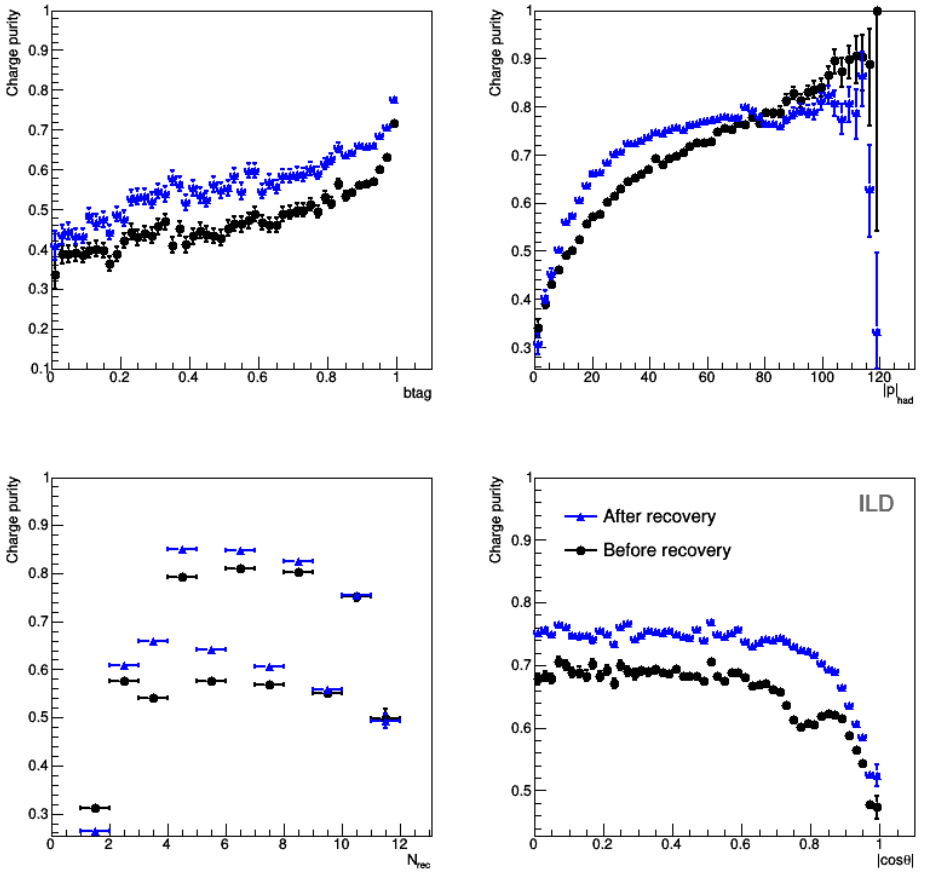


(c) Purity map

- This process is run over reconstructed and b-tagged jets. The recovered tracks/vtx are linked back to the jet but no reprocessing of the reconstruction/clustering is done.

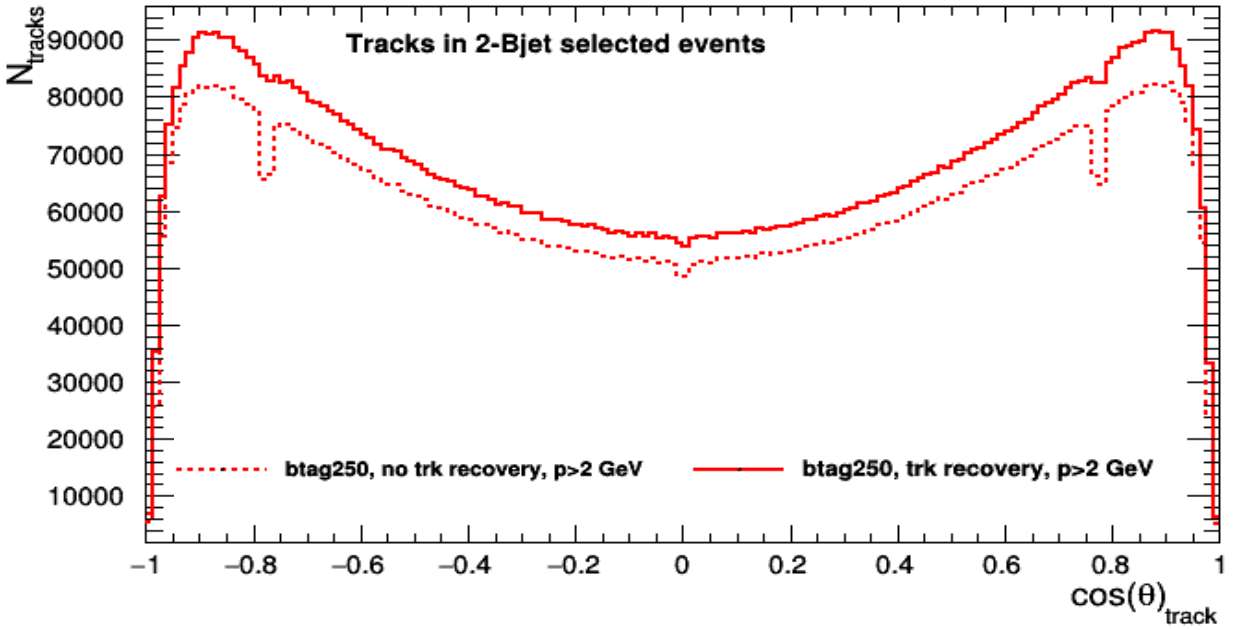
Track/Vertex Recovery

- **A. Irles (bbbar 250GeV, DBD)**



Track/Vertex Recovery

- **Result of the recovery**



- The recovery of tracks has a large impact but:
  - Still there is a **big drop** of **acceptance of b-jets** in the **calorimeter transitions** and in the **forward** regions.
  - Also a small **efficiency drop** is still seen in the **center** of the **detector**.
  - **What is the impact of these inefficiencies?**

B-jet charge measurement: double tagging

- The method relies on the jet-charge measurement, which has a given purity.
- Errors in the charge measurement will migrate events from +cos(theta) to -cos(theta) and viceversa.
- The migrations are fixed by determining the purity of the charge calculation using double tagged events with compatible and uncompatible charges
  - $N_{accepted} = N^{+}_{accepted} + N^{-}_{accepted} = p^2 N_{total} + q^2 N_{total}$
  - $N_{rejected} = 2pqN_{total}$
  - p=purity, q=1-q; "+" means positive angle
- Six double tagged categories are defined (as a function of the different charge measurement methods applied to the two or only one jet)
- The use of TPC for kaon identification (Kc method) enhances the statistics by a factor ~2.5

Charge measurement methods

- To be done

Charge calculation categories

- 2016 approach, only two categories are defined
  - BcBc opposite jets and at least one of the jet without Kaons.
  - KcKc opposite jets, and at least one jet without measured charge with the vertex
- Total eff ~ 12-13%

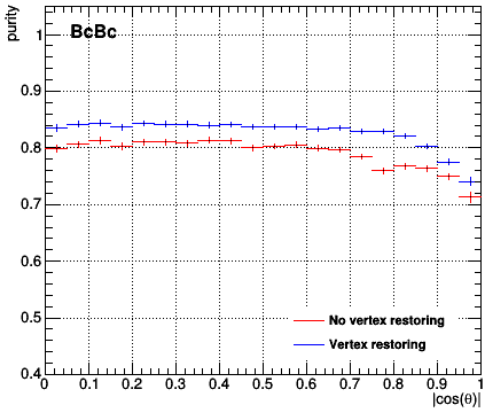
- New approach: 6 categories are defined.
  - BcBc opposite jets and I do not care about Kc. Category 1 (non exclusive)
  - KcKc opposite jets, and again I don not care about Bc, Category 2 (non exclusive but not category 1)
  - BcKc_same1 in the same jet (the one with higher b-tag) with the other jet Kc and Bc =0. Category 3 (& not category 1-2)
  - BcKc_same2 the same than above, but in the jet with smaller btag. Category 4 (& not category 1-3)
  - BcKc, opposite jets, with the other Kc and Bc =0. Category 5 (& not category 1-4)
  - KcBc, opposite jets, with the other Bc and Kc =0. Category 6 (& not category 1-5)
- Total eff ~ 31-32%

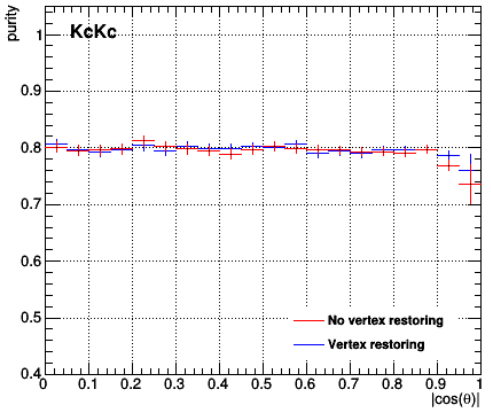
Charge calculation categories

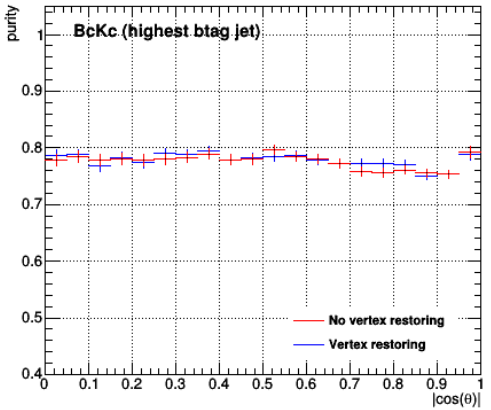
250GeV, eL, DBD	
Step	**Eff**
Preselection:	67.2 %
BcBc:	12.8 %
KcKc:	5.3 %
BcKc(jet1):	6.8 %
BcKc(jet2):	2.7 %
BcKc:	1.6 %
KcBc:	1.5 %
total	**30.7 %**

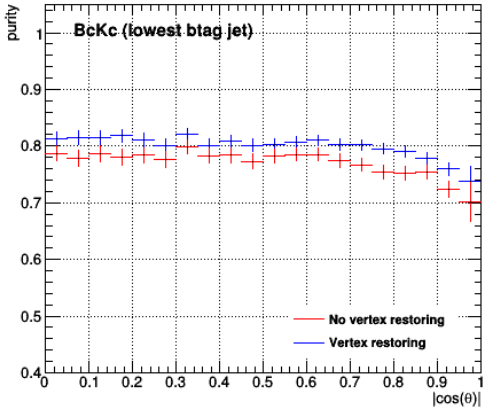
250GeV, eR, DBD	
Step	**Eff**
Preselection:	68.0 %
BcBc:	12.9 %
KcKc:	5.3 %
BcKc(jet1):	6.9 %
BcKc(jet2):	2.7 %
BcKc:	1.7 %
KcBc:	2.5 %
total	**32.0 %**

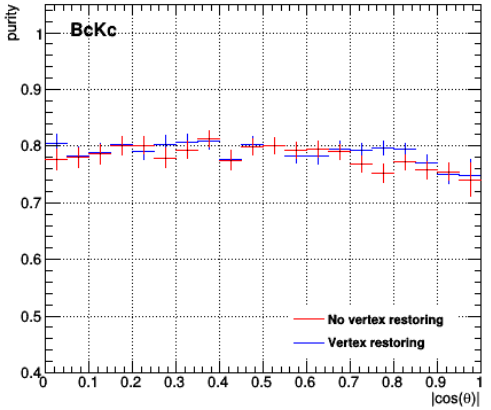
Track/Vertex Recovery: impact on the measured purity

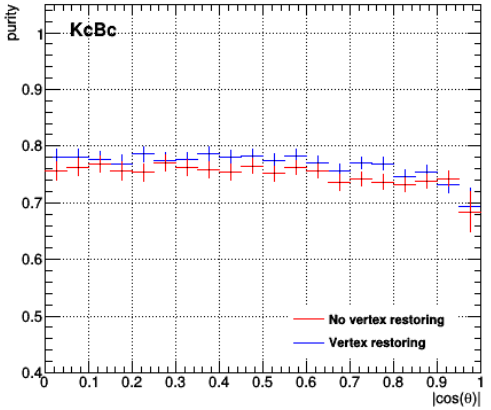




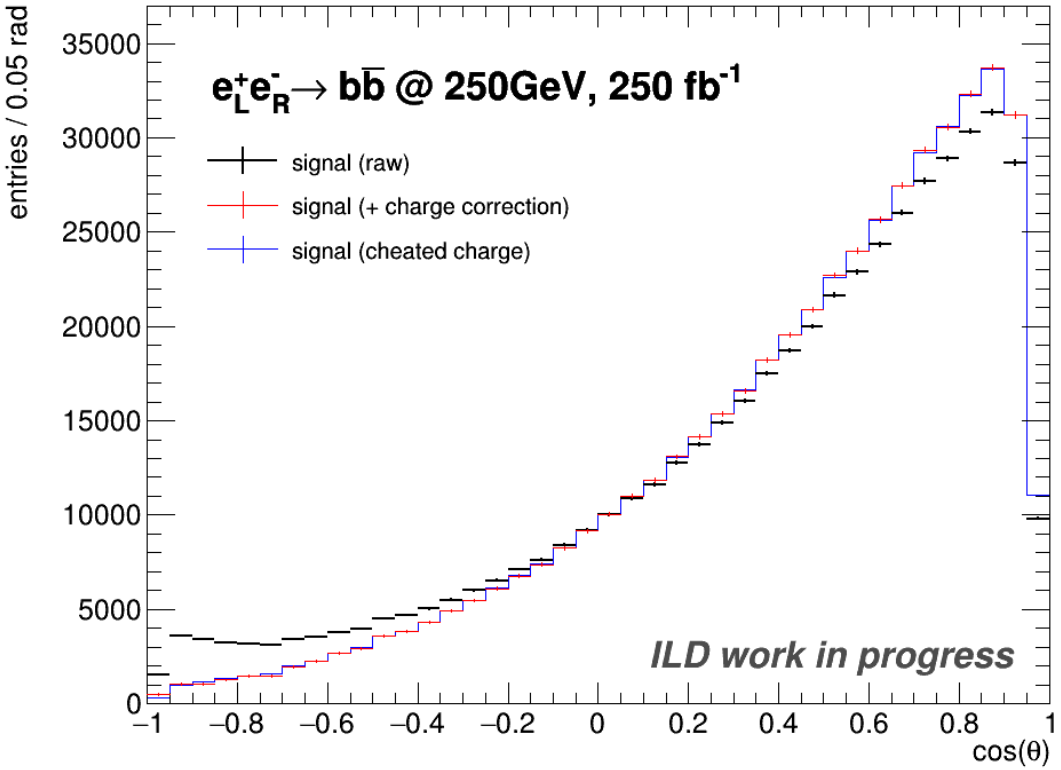






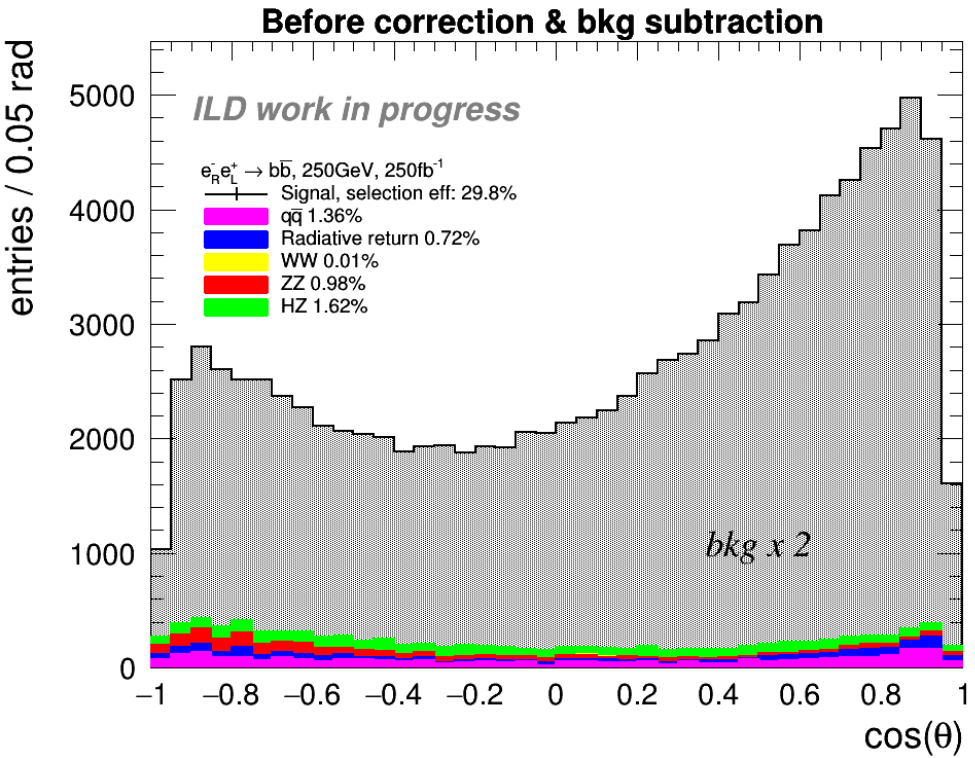


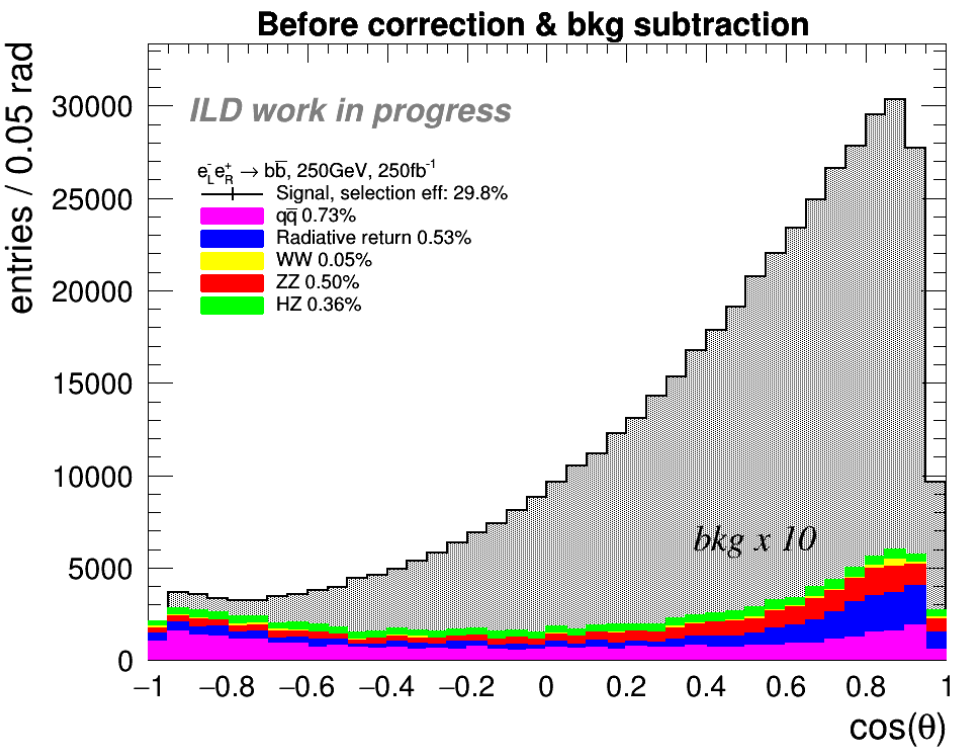
Performance of the charge correction based on data



- Left plot: comparison of the result of the p-q method (red) and the reconstructed distribution with cheated charge (blue)
- **The p-q method works perfectly**

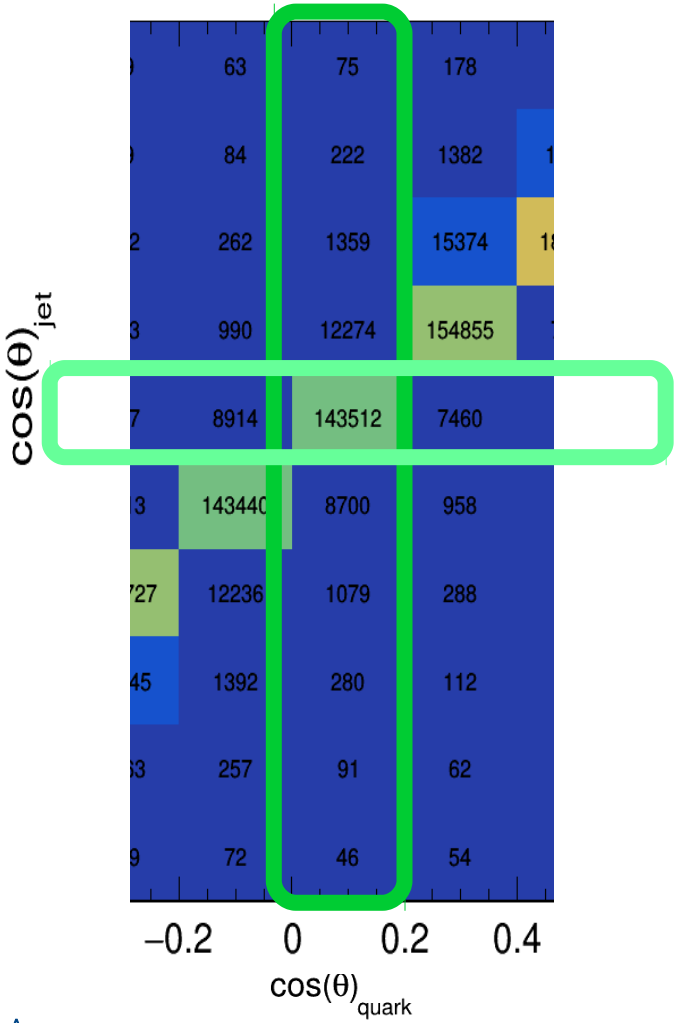
Results





- Reconstructed distributions before any correction.

Detector Correction issue: going back to the jet level



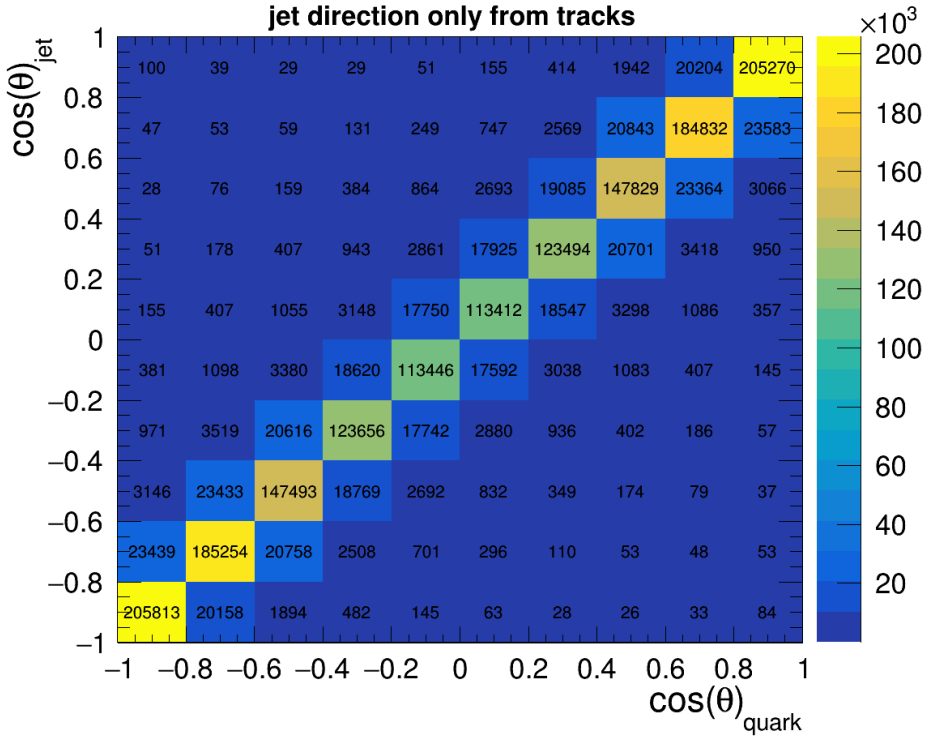
- Lets look at only a couple of bins.
- For the 0-0.1
  - 167638 events are generated
  - 143512 (85.6%) are reconstructed in the correct bin.
  - 24126 go to different bins.
  - Only 18921 events are migrated in from different bins.
- **This will be seen as a 3% of acceptance loss !!**

- Recovering tracks can slightly improve the selection after btagging but the impact of the migrations is still large.
- If the tracks would have been added to the jet… would the resolution matrix improve?

Detector Correction issue: going back to the jet level

- **Exercise**, try to define the jet direction using only tracks from secondary vertexes. **AFTER VERTEX RECOVERY.**
- The matrix is more diagonal, although the migrations are larger.

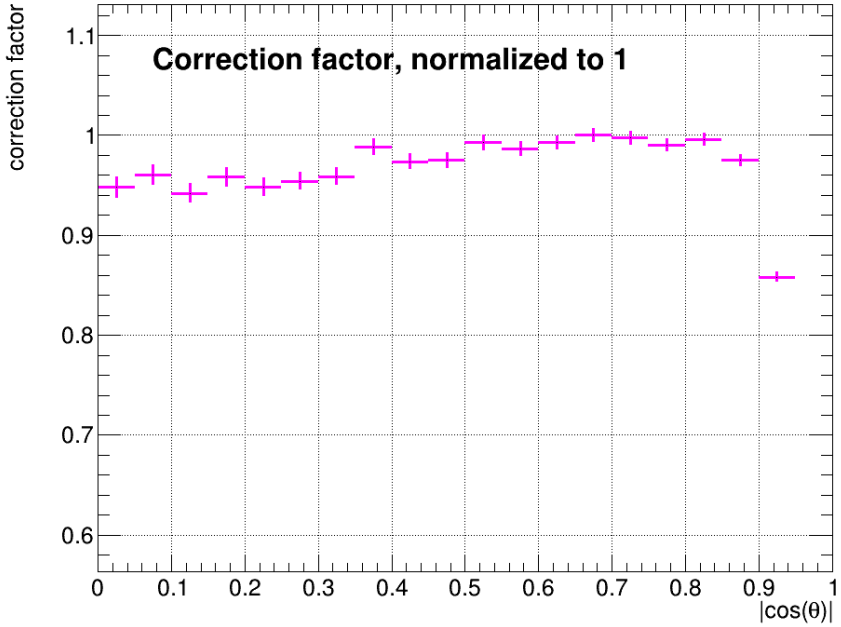
- Repeat the same exercise for the bin 0-0.1
  - 156595 events are generated
  - 113412 (72,4%) are reconstructed in the correct bin.
  - 43183 go to different bins.
  - and 45803 events are migrated in from different bins.
  - → **Acceptance loss of 1.6%**



How to correct for detector effects?

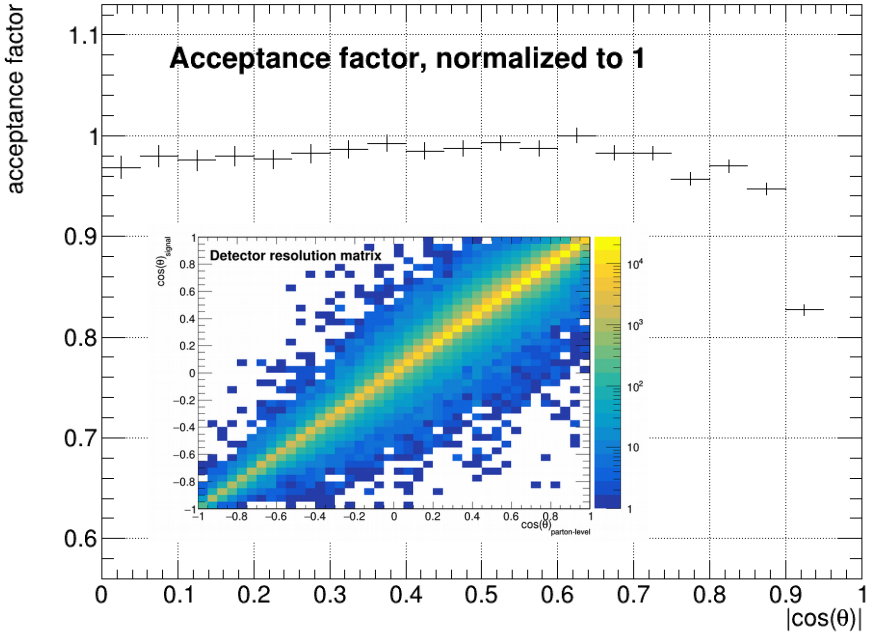
Option a)

- Correction factor = (truthreco_level / parton_level)$^{-1}$



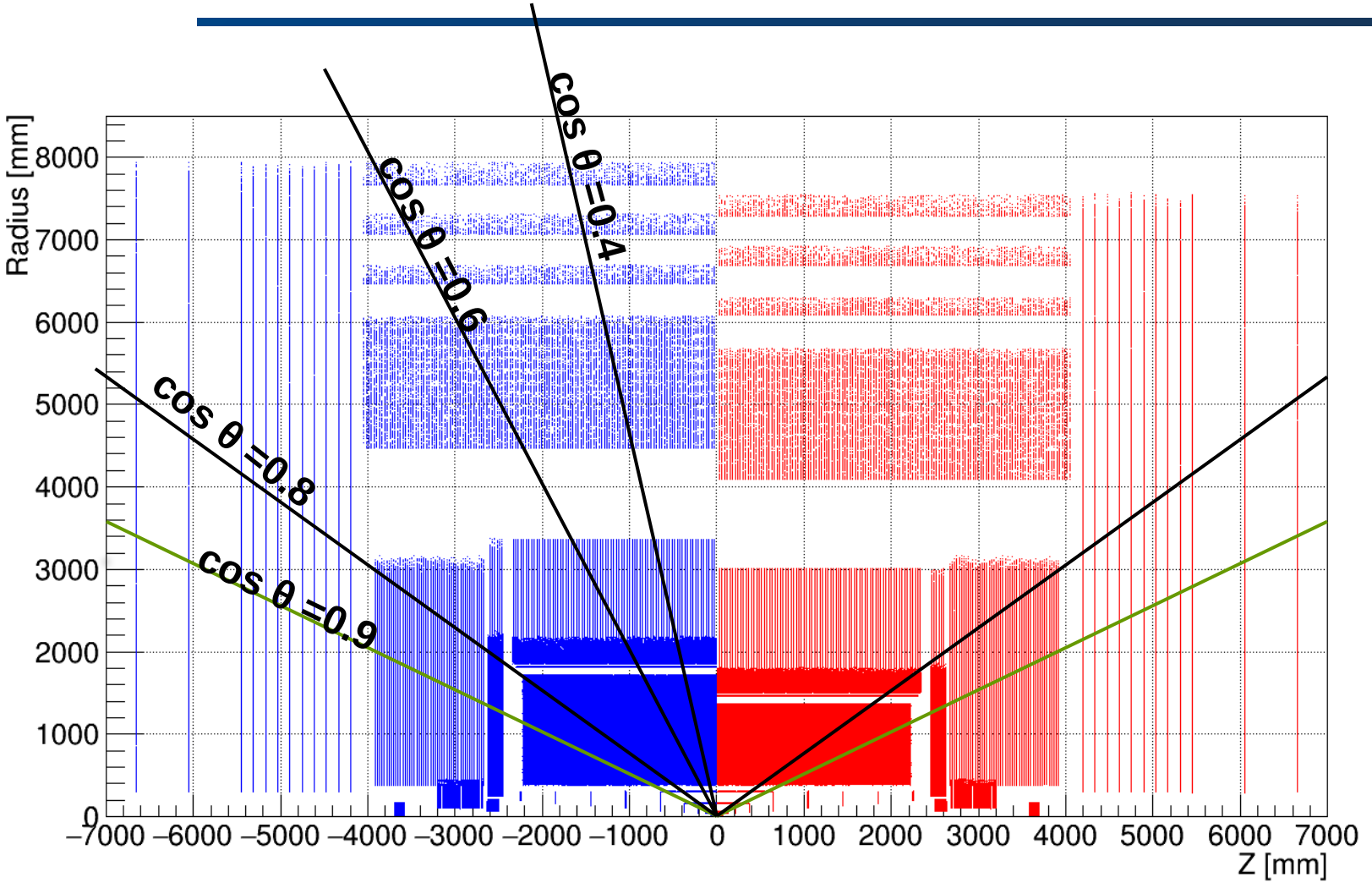
Option b)

- Corrected = M^{-1} x Reco x (Acceptance)$^{-1}$ (atPartonLevel)



This factor includes correction for acceptance and resolution effects.

Impact of using the vertex restorer: efficiency



ILD geometry