ILC Heavy Flavours

1. **Flavour identification tool at ILC (LCFIPlus)**

   for the LCFIPlus developers

2. **Study on the 3rd generation quarks (top quark only)**

   for the ILD heavy flavour working subgroup

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2019 Joint workshop of FKPPL and TYL/FJPPL @ Jeju Island, 8-10 May 2019

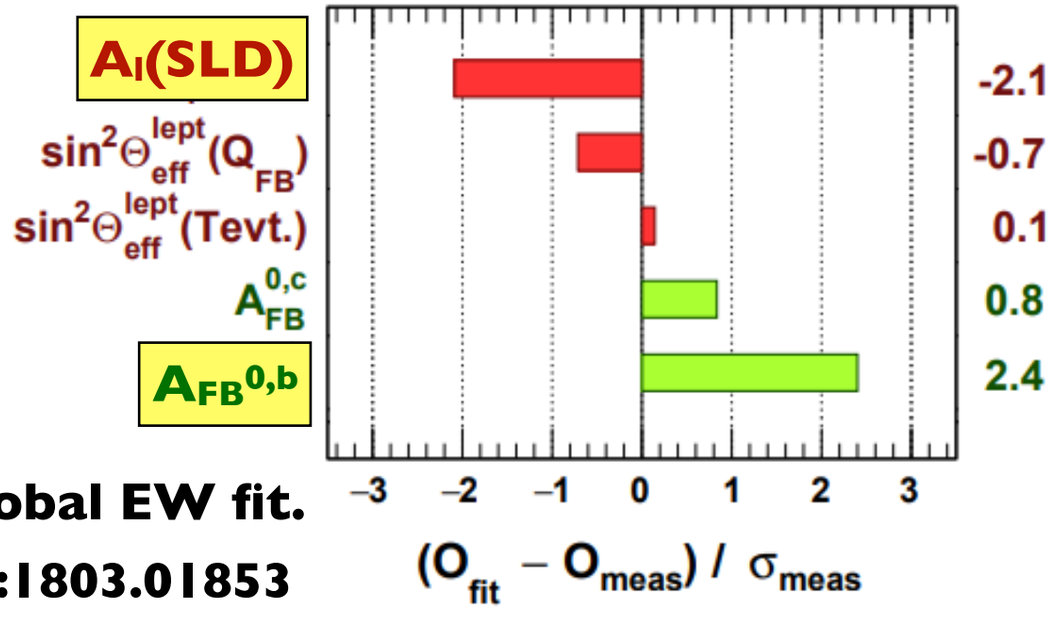
Why heavy flavours?

- **Top quark is the heaviest elementary particle in the SM.**
  - Expected to be strongly connected to EWSB mechanism.

- **Bottom quark is also heavy in the sense that the left bottom quark is the same SU(2)×U(1) multiplet as top quark. b-quark pair can be produced at 250GeV, while top quark can not.**

- **Right bottom quark is not well constrained by earlier experiments compared to left-handed one.**
  —> it must be tested precisely whether there is non-standard behaviour or not.
  - Beam polarization and higher statistics are essential for this test.
  - 3σ discrepancy between the value of $\sin^2\Theta_w$ from A^b_{FB} at LEP and the value from A_l at SLC.

$$g^Z := T_3 - Q\sin^2\theta_W$$



the global EW fit.

arXiv:1803.01853

B quark tagging is the key!

ILC and ILD

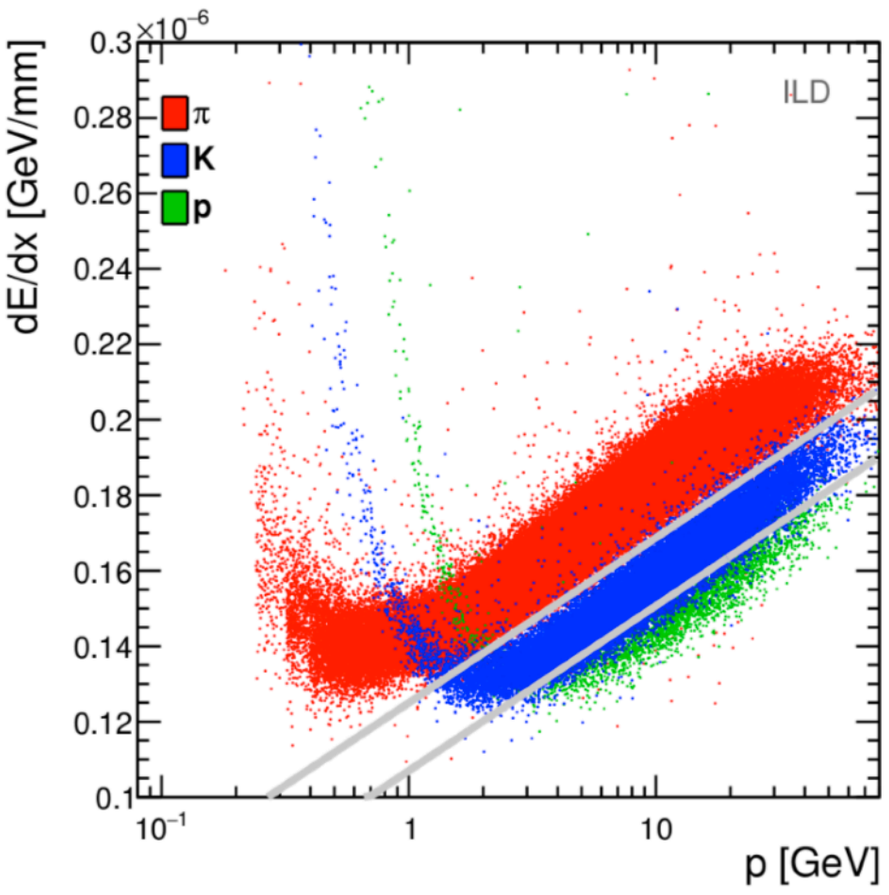
- **ILC : e+ e- collider**
  - Provides controllable initial states (initial particle energy, **beam polarization**)
  - Precision measurements of BEH boson couplings and SM parameters.

- **ILD : One of detector concepts proposed for ILC**

- Design philosophy : Reconstruct individual particle with **Particle Flow approach** to achieve ideal jet energy resolution.

- Example sub-detectors (relevant to this report)
  - TPC : Continuous tracking (V0, kink tracks)
    dEdx measurement > PID > Flavour tagging
  - Vertex detector :

    Precise position measurement around IP.
    Essential for b-jet, c-jet identification by secondary vertex finding.

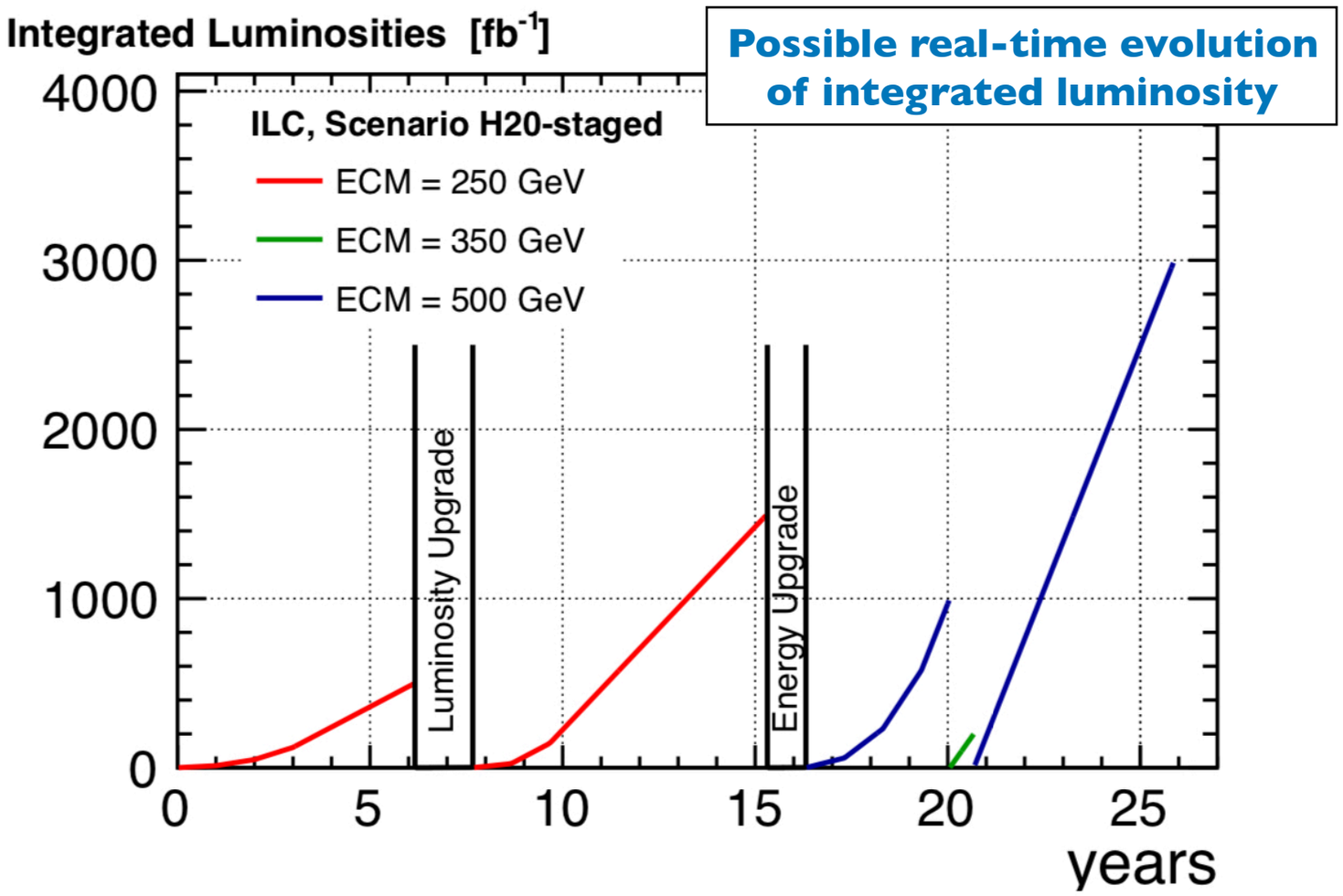


ILC Running scenario

(https://arxiv.org/pdf/1710.07621.pdf)

- **Ecm = 250GeV**
  - 15 years running ($L=2ab^{-1}$) together with LHC results and EFT framework will give powerful and model-independent constraints on the Higgs properties!

- **Energy upgrade**
  - Higgs self coupling, **Top EW couplings**
  - New particle searches



- There is a cost-neutral possibility to increase the instantaneous luminosity by focussing the beam more strongly at the IP. This option can reduce 15 year-operation to 11.

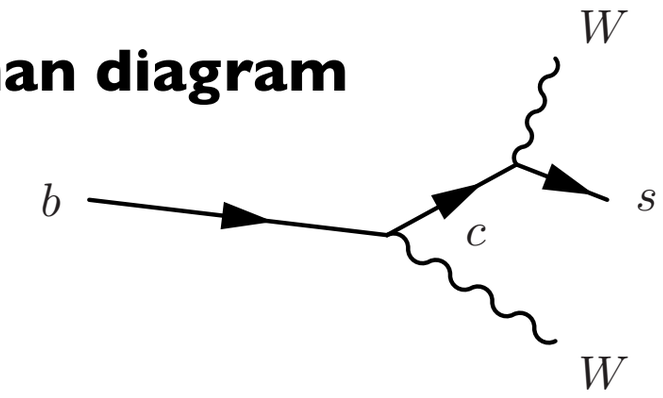
1. Flavour identification tool

LCIFPlus

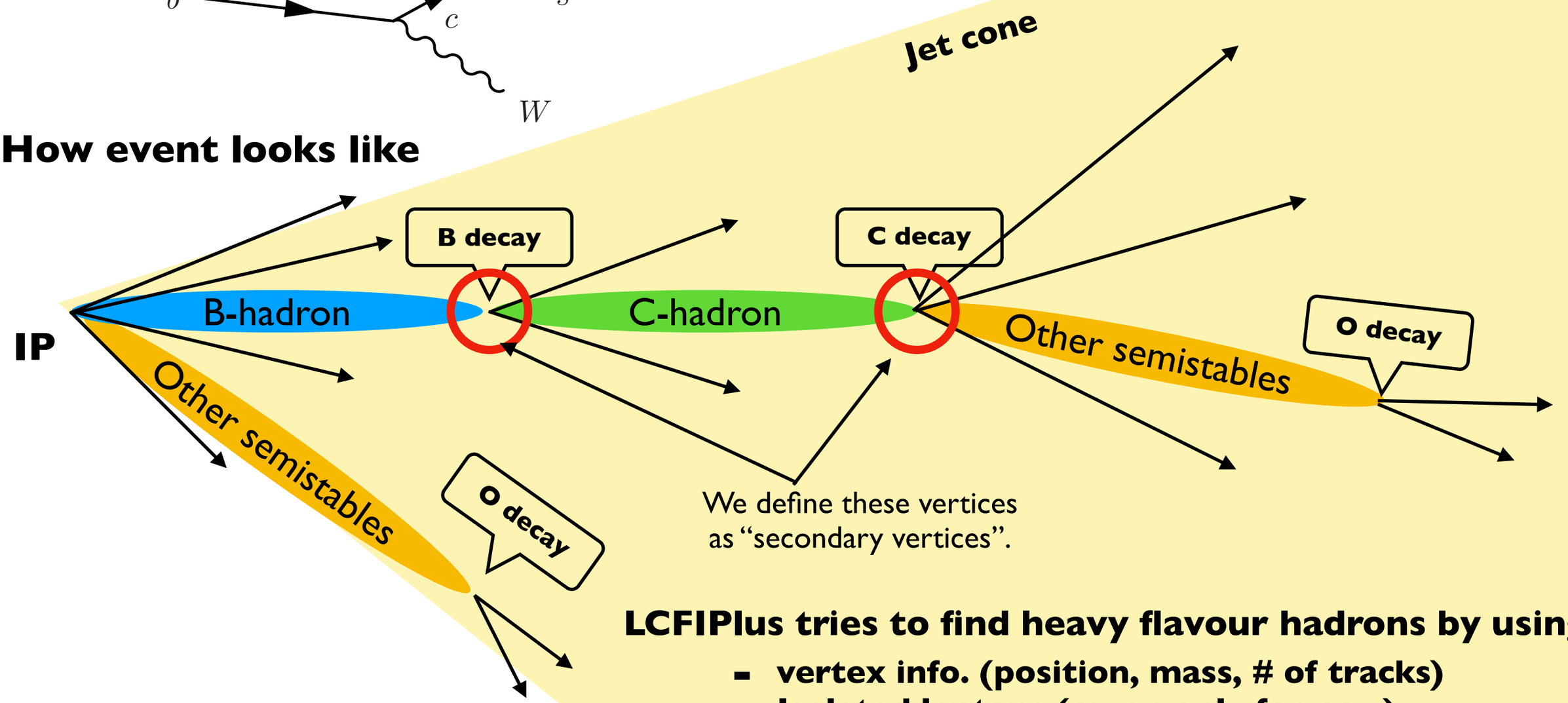
Brief introduction and Recent updates

Our goal : b-tagging and c-tagging

Feynman diagram



How event looks like



LCFIPlus tries to find heavy flavour hadrons by using:

- **vertex info. (position, mass, # of tracks)**
- **Isolated leptons (muon only for now)**

Splitting secondary vertex tracks (e.g. by jet mis-clustering) would easily lose the signatures, especially in "jetty" environment.

—> Search secondary vertices first, then construct jets keeping the vertex structures.

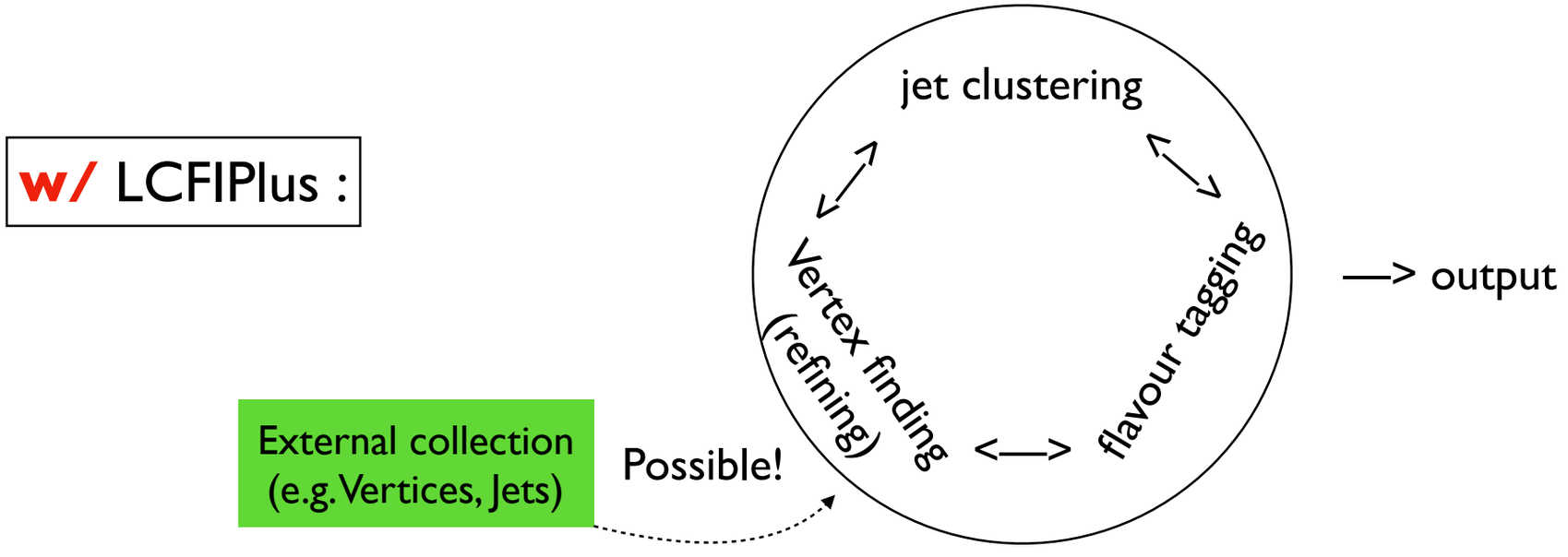
LCFIPlus for the best b/c tagging

Reference paper : Nucl.Instrum.Meth. A808 (2016) 109-116

- **A framework for jet flavour identification.**
  - Integrates **Vertex finding**, **Jet clustering**, and **flavour tagging**.
  - Originated from LCFIVertex (https://arxiv.org/abs/0908.3019).
  - Composed of modular algorithms.
    - Gives flexibility to iterate or reverse the processes.

w/o LCFIPlus : jet clustering —> vertex finding —> flavour tagging —> output

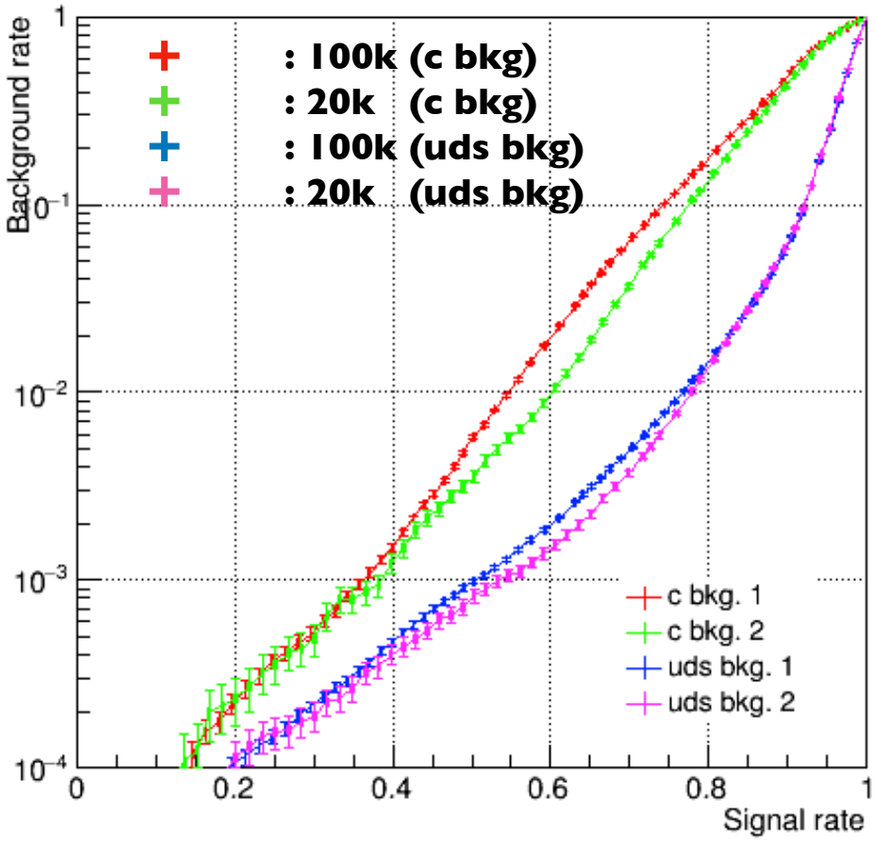
w/ LCFIPlus :

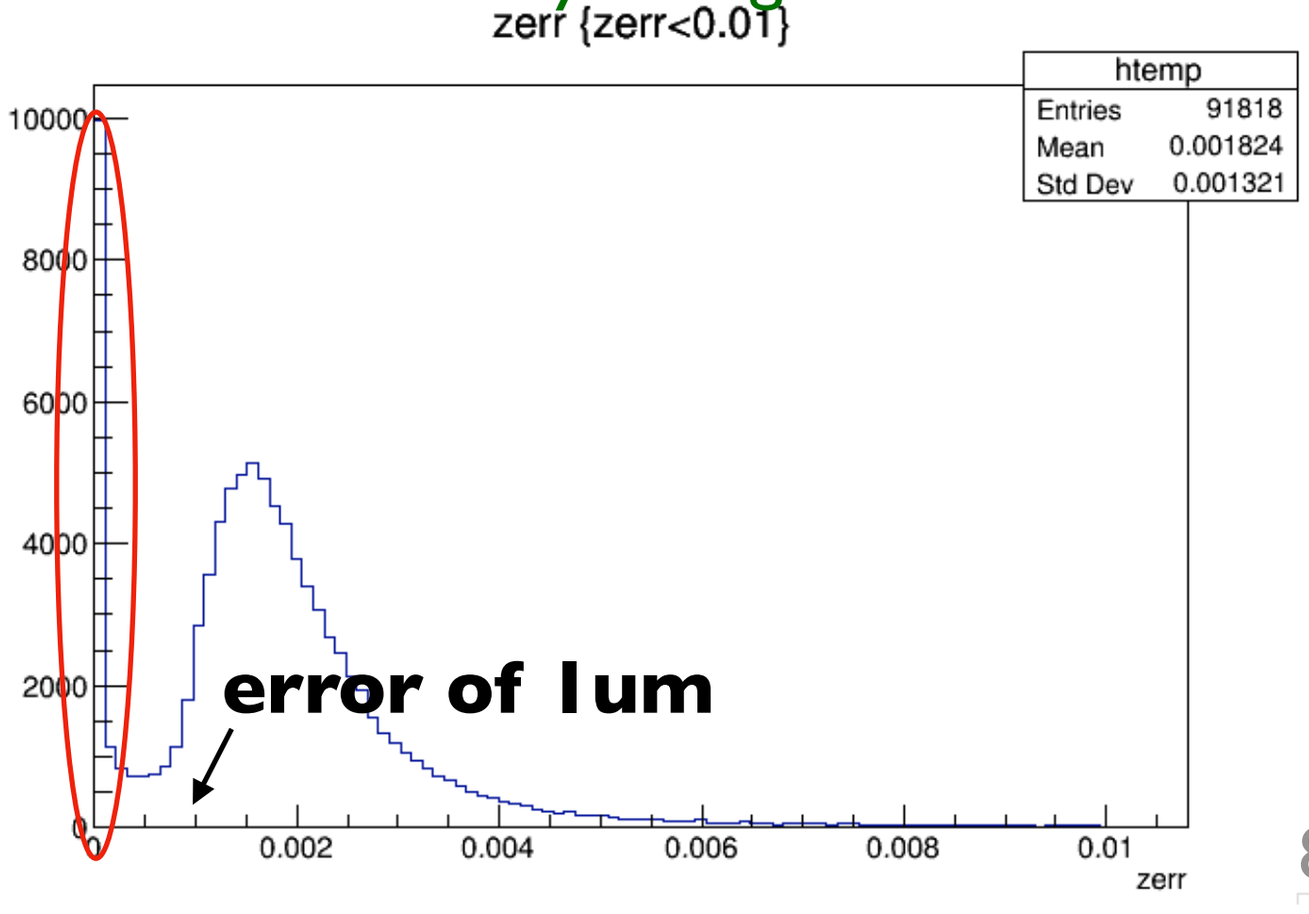


- Typical flow with LCFIPlus (Vertexing first!) :
  "vertex finding —> (built-in) jet clustering
  —> vertex refining —>flavour tagging"

Issues in 2018

- **Strange dependency on statistics of training data: Large statistics gives worse performance.**
  - This was finally turned out that the problem came from a bug where IP=(0,0,0) was assumed, while IP smearing has been newly introduced in the ILD simulation.
- **Failures on primary vertex fitting**
  - Originally primary vertex fitting was not well cared about (The highest priority was the secondary vertex finding!)
  - We got a feedback from a user that the error on primary vertex position was sometimes too small. —> Caused by fitting failures





ToDo/Ideas

Our plans to improve the performance in 2019!

- **Try additional information into MVA**
  - dEdx, TOF, etc

- **Try NN in flavour tagging**
  - BDT has been used because it decently works without much effort.
  - We have just started working with TMVA Keras interface.
  - Keras is a interface which supports several backends of the machine learning framework (Tensorflow, CNTK, Theano).

- **Optimization for vertex charge measurement (connected to the next topic.)**
  - Loosen the vertex quality cut would improve the performance.
  - Comprehensive study done by S. Bilokin (PhD thesis:https://tel.archives-ouvertes.fr/tel-01826535/document)

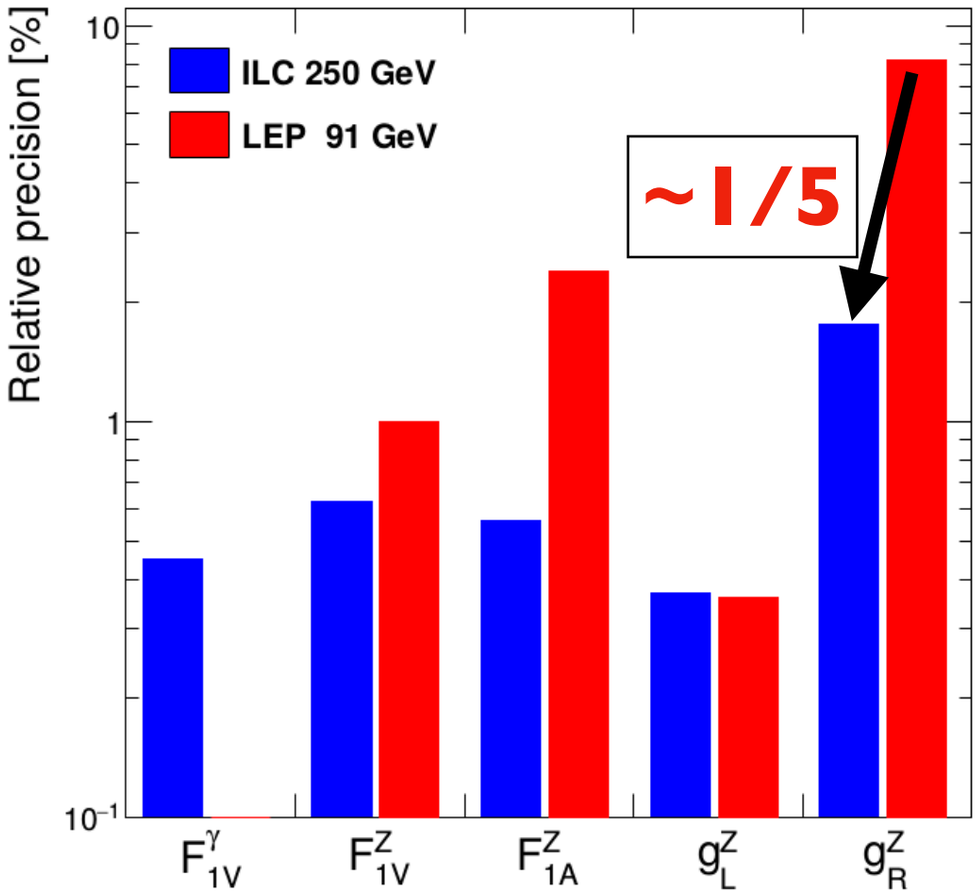
2. Study on the 3rd generation quarks (Top quark part only)

Earlier study compared to LEP

Right-handed b-quark coupling to Z

- **BSM models can explain the LEP anomaly on $\sin\Theta_w$. It predicts a large correction for g_R^Z while Δg_L^Z remains small.**
  - e.g. A. Djouadi et. al., https://arxiv.org/pdf/hep-ph/0610173.pdf
  - ~25±10% shift from SM expected on g_R^Z.

(L250+R250) fb^{-1} **S. Bilokin**



- **The result shows potential capability of 250 GeV ILC to constrain models by measuring right-handed coupling to Z thanks to**
  - beam polarization
  - high luminosity
- **This can be extended to the other two fermion pairs.**

Other earlier studies : M.S. Amjad (ttbar semi-leptonic), Y. Sato (ttbar leptonic)

The following study benefits significantly from this study by S.Bilokin.

Recent activities

Nice collaboration between LAL and Tohoku U.!

Heavy Quark Pair Production in $ee \to ff$ at ILD

Y. Okugawa[1] A. Irles[2] S. Amjad[3] R. Yonamine[1] F. Richard[2]
R. Pöschl[2]

[1]Tohoku University

[2]Laboratoire de l'Accélérateur Linéaire

[3]University College London

Feburary 27, 2019

Original version :

https://agenda.linearcollider.org/event/8122/contributions/43463/attachments/34355/52958/ILD_meeting.pdf

iLCSoft has been renewed (there are non-negligible changes).

Our first priority:

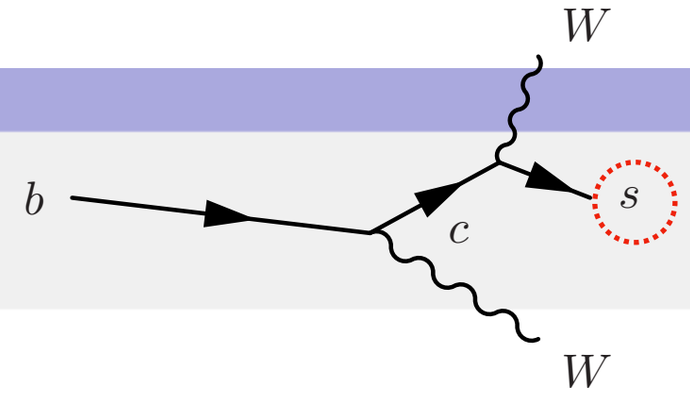
- migrate to the latest software (and MC samples),

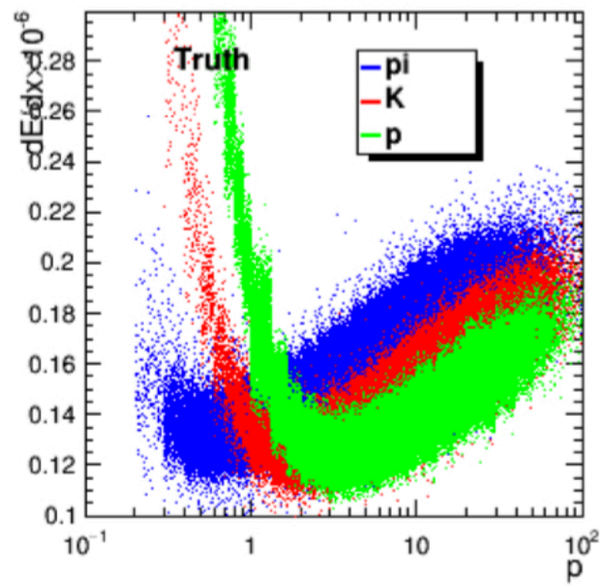
- check the consistency with the previous studies.

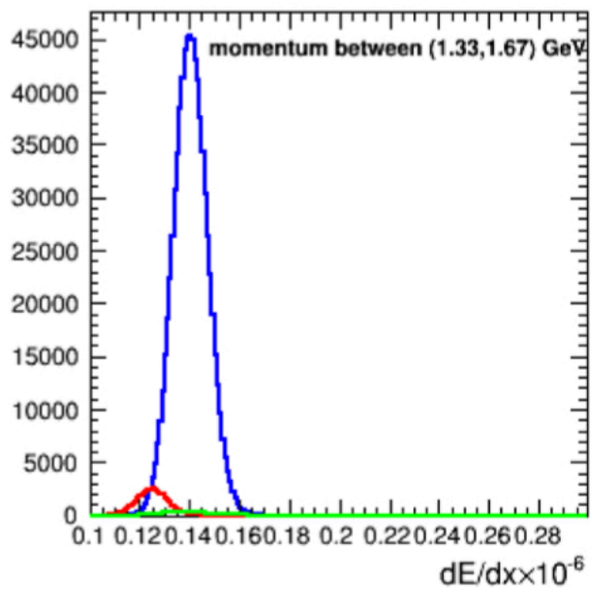
- check any difference between two benchmark det. models.

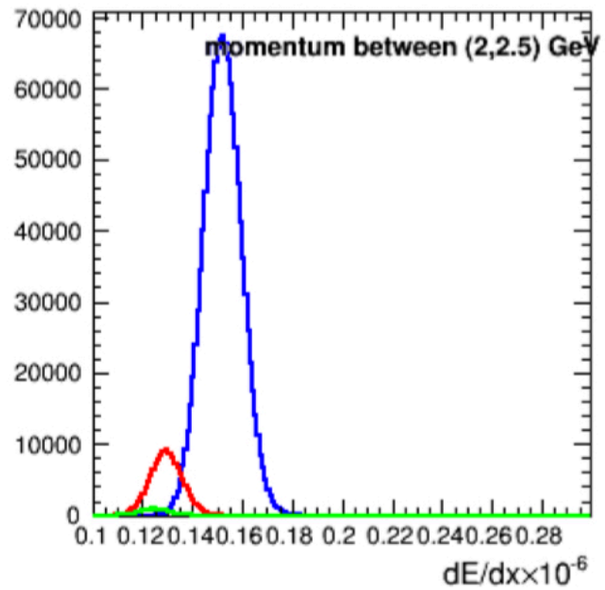
We must distinguish b and bbar.

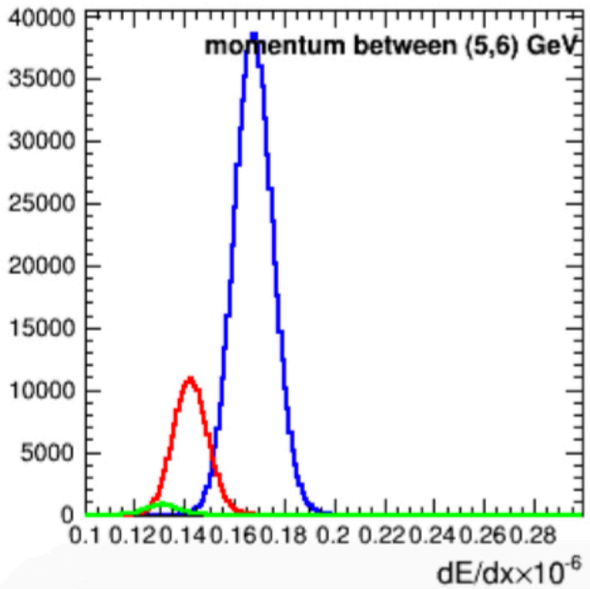
dEdx Distribution

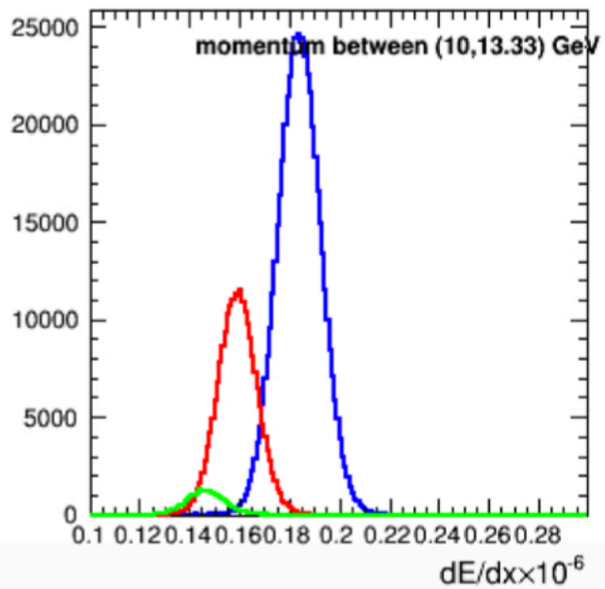


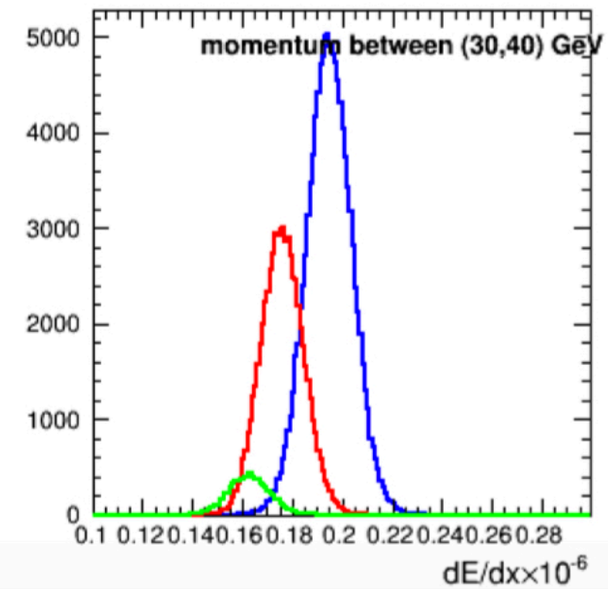












Top polar angle distribution
(left-handed, semi-leptonic)

$t\bar{t}$ Result

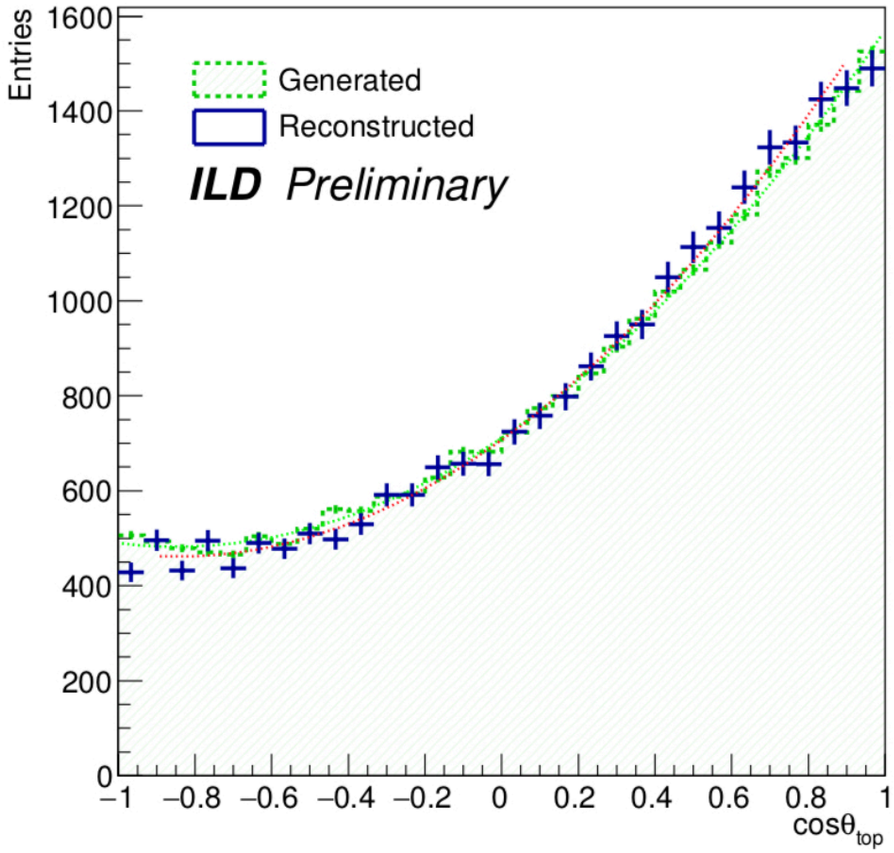


Figure: Top polar angle (small)

Afb gen	0.32973	N: 164292
Afb reco	0.352793	N: 24530
Final efficiency	29.8615%	

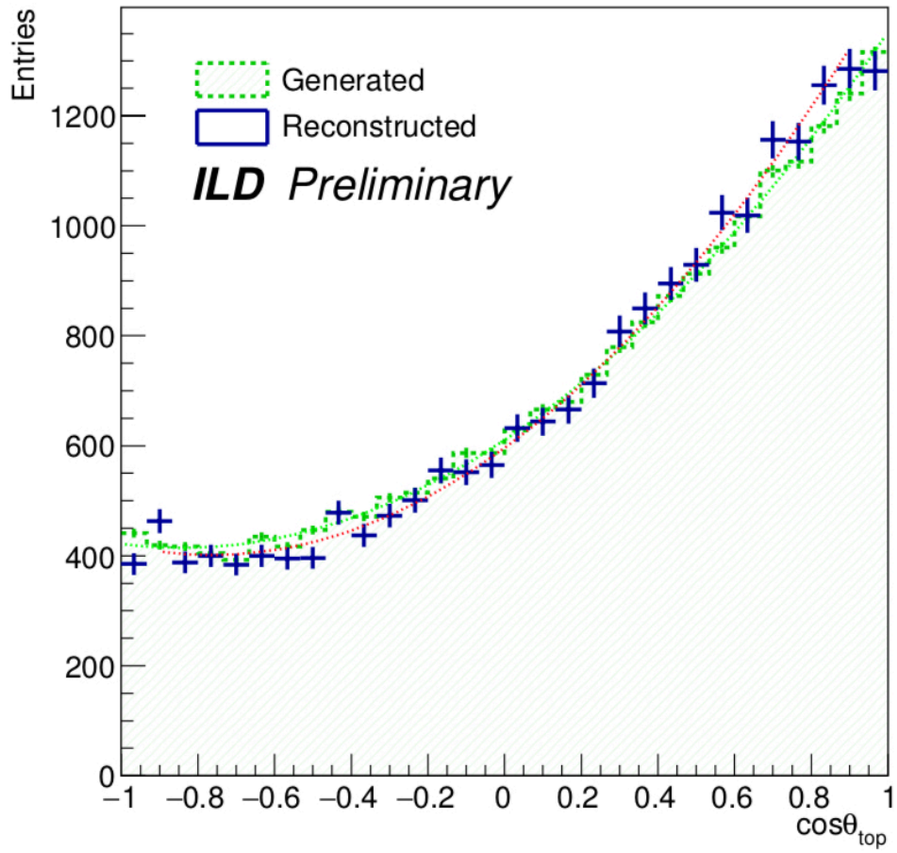


Figure: Top polar angle (large)

Afb gen	0.330374	N: 142148
Afb reco	0.357678	N: 21086
Final efficiency	29.6677%	

Bottom (in ttbar events) polar angle distribution
(left-handed, semi-leptonic)

b Polar Angle

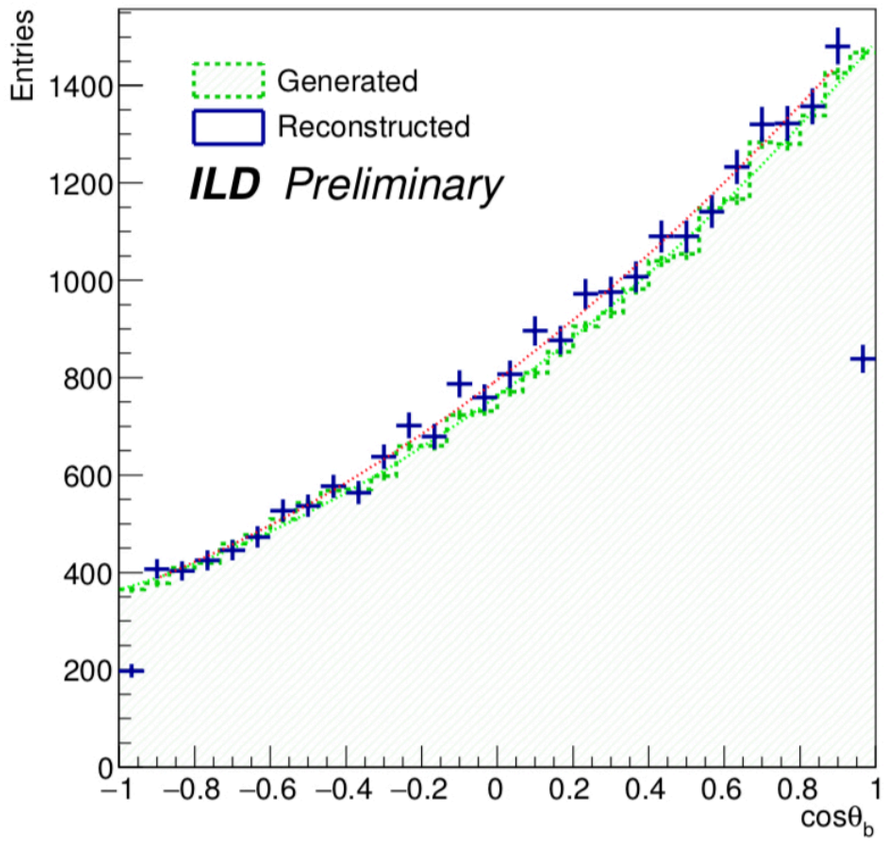


Figure: b polar angle (small)

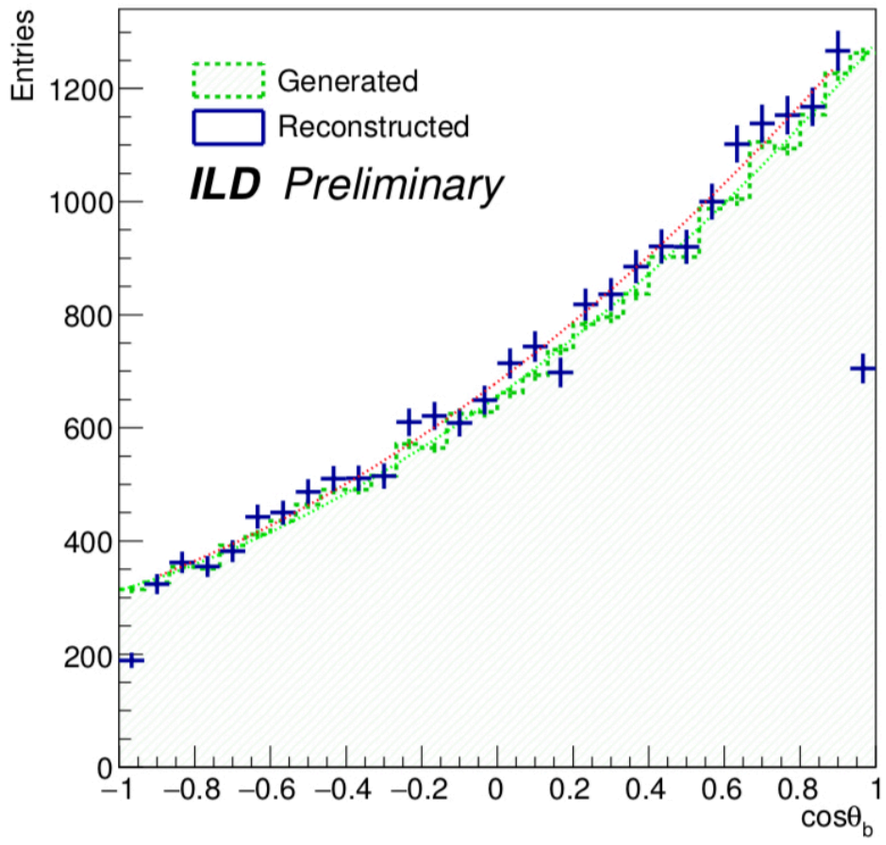


Figure: b polar angle (large)

We do see inefficiency at forward region due to acceptance drop, which we didn't see in $t\bar{t}$ distribution.

Summary

- **LCFIPlus**
  - Two issues (IP smearing, Position error on Primary vertex) have been solved.
  - Started working on TMVA Keras interface to use the Machine Learning for flavour identification.
  - Will take some additional variables into account (e.g. dEdx, TOF)

- **Heavy flavour studies (reported Top quark part only)**
  - Migrated to the latest ILC software (iLCSoft).
  - Confirmed the results of the earlier study with the new software.
  - Plan : ttbar hadronic mode (This would be a part of Y. Okugawa's master thesis.)

Backup

Predicted deviations of top-Z coupling

François Richard

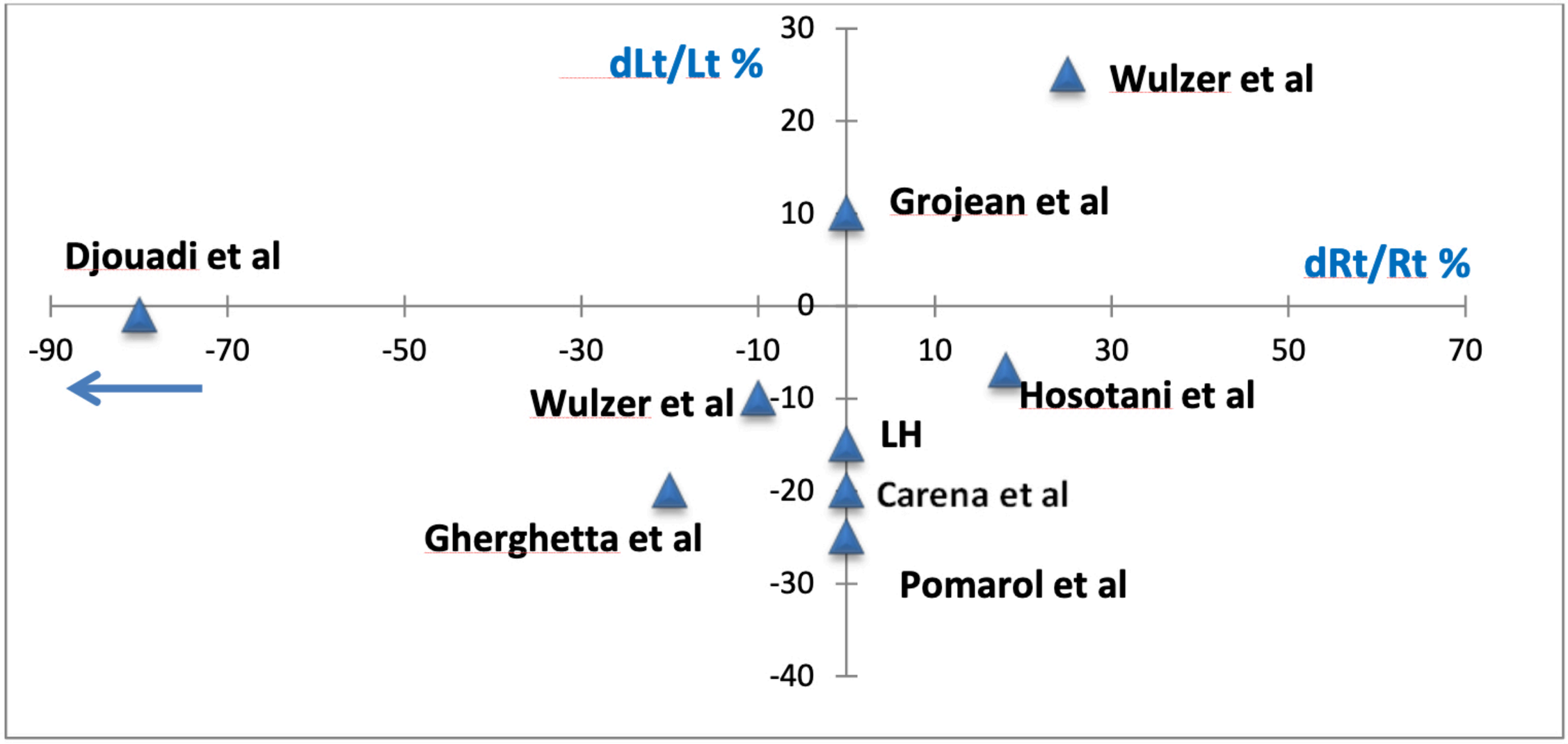


Figure 2: Plot showing the predicted deviations of Z couplings to tL and tR in %. The Djouadi et al prediction falls outside of the scale.

https://arxiv.org/ftp/arxiv/papers/1403/1403.2893.pdf