FCC-ee: Analysis of $ee \to t\bar{t}$ and first jet studies

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March 22, 2021

Keywords of the project

The focus of this project is analysing **top-quark electroweak couplings** in pair produced events. An **optimal observables analysis** is planned to be performed in order to gauge the sensitivity to **anomalous couplings of the top quark to the photon and the Z**. MC data is simulated using FCCSW where an **event selection and event reconstruction** is being developed with plans of performing a **kinematic fit**.

Optimal Observables (OO)

For a single coupling parameter C which is zero at Born level in SM

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right|_{SM} = 1 + \frac{OO_C^{(1)}}{SM}\cdot C + \frac{OO_C^{(2)}}{SM}\cdot C^2 \Rightarrow$$

$$\left\langle\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right\rangle = \langle SM\rangle + \langle OO^{(1)c}\rangle\cdot C + \langle OO_C^{(2)}\rangle\cdot C^2$$

– same statistical sensitivity as a maximum likelihood fit
– requires matrix elements from **MadGraph** $\leftrightarrow$ **Feynrules** $\leftrightarrow$ **SMEFT**

Signal:

Semileptonic channel

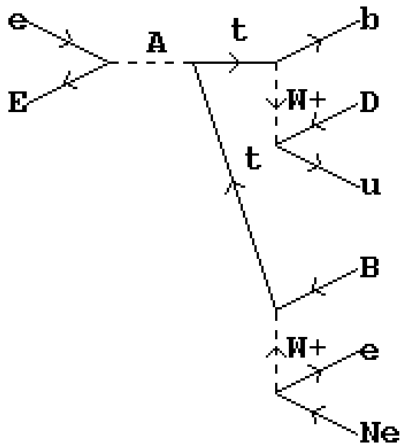
$$t\bar{t} \rightarrow b\bar{b}W^+W^- \rightarrow b\bar{b}q\bar{q}\ell\nu_\ell$$

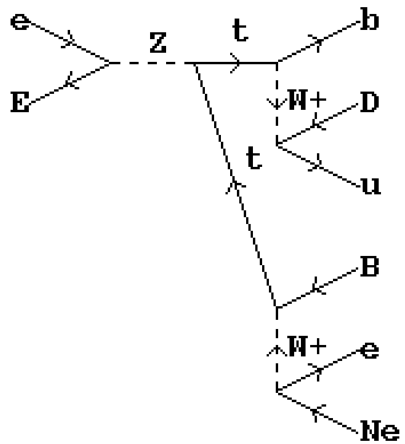
Planned phase of FCC-ee @ $\sqrt{s} = 365\,GeV$

Signature: 1 lepton + $\not{E}$ + 4 jets

Backgrounds:

$\mu\mu$	γZ	ZW^+W^-
$b\bar{b}$	W^+W^-	ZZZ
$\sum q\bar{q}$	ZZ	single top
$q = u, d, c, s$		LHE files from MadGraph





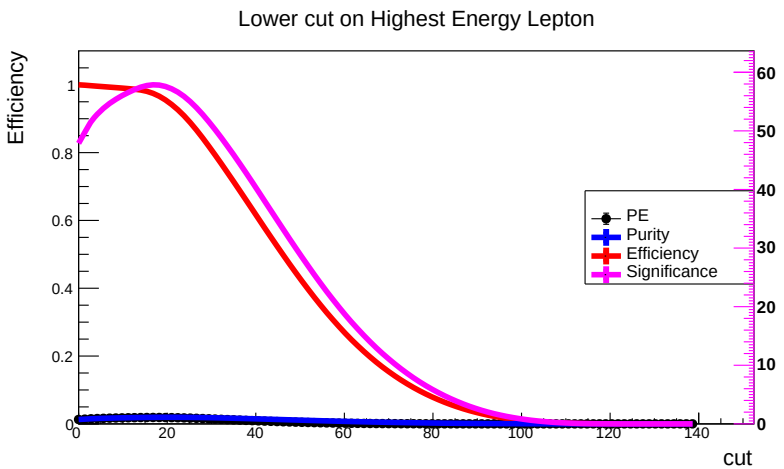
- All MC files are generated in the FCCSW framework with DelphesPythia8_EDM4HEP and ILD Delphes Card
  - Plan to switch to IDEA Delphes Card to fit common baseline detector for Physics Performance studies

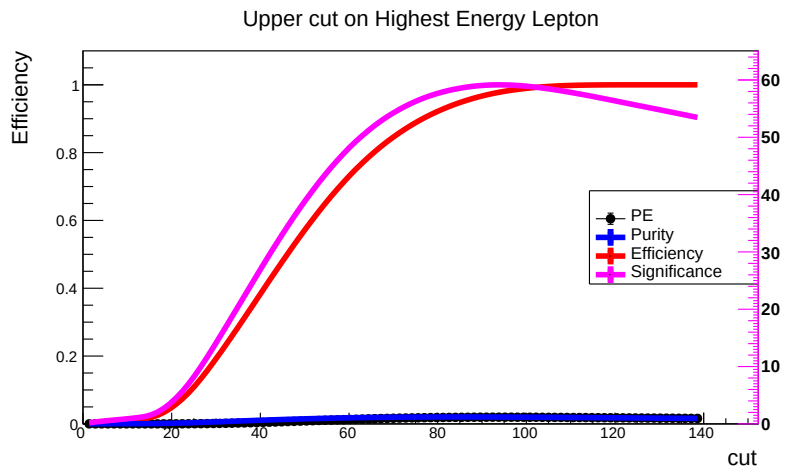
Significance-Optimised Selection Cut Strategy:

Iterative procedure based on maximum significance on a set of variables

→ choose variable with highest maximum significance

→ make cut and reiterate on remaining set





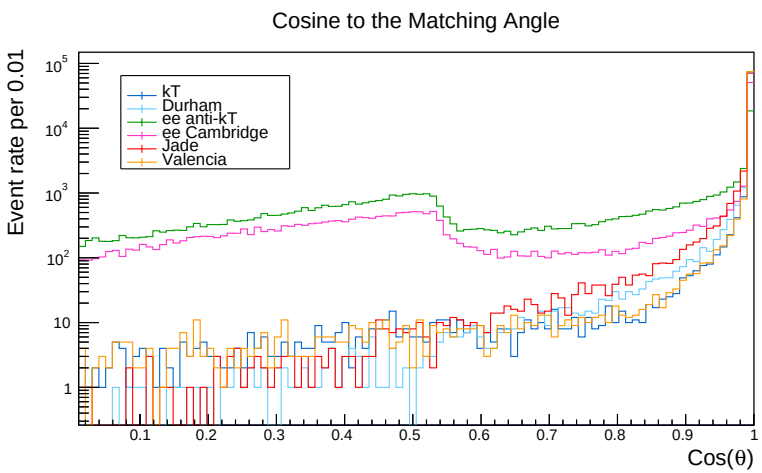
Pre-selection cuts

- Exclude events with zero leptons
- Thrust for entire event < 0.85
- 15 GeV $<$Highest energy lepton $<$ 100 GeV
- 160 GeV $<$ Invariant mass of event excluding highest energy lepton $<$ 300 GeV
- 2nd highest energy lepton $<$ 40 GeV
- Jet specific cuts to be determined

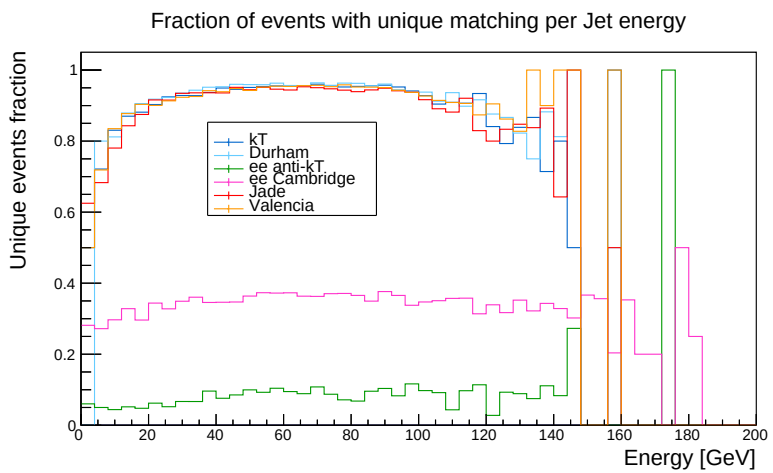
Jet reconstruction:

- Jet clustering interface in FCCAnalyses using FastJet
  - Recent developments where plugins have been added
- **Jet Algorithms:** k_t, anti-k_t, Cambridge, and their as e^+e^- versions, Jade Plugin, Valencia Plugin
- Jet reconstruction with exclusive clustering up to **exactly 4 jets**. Highest energy lepton is excluded from the clustering.

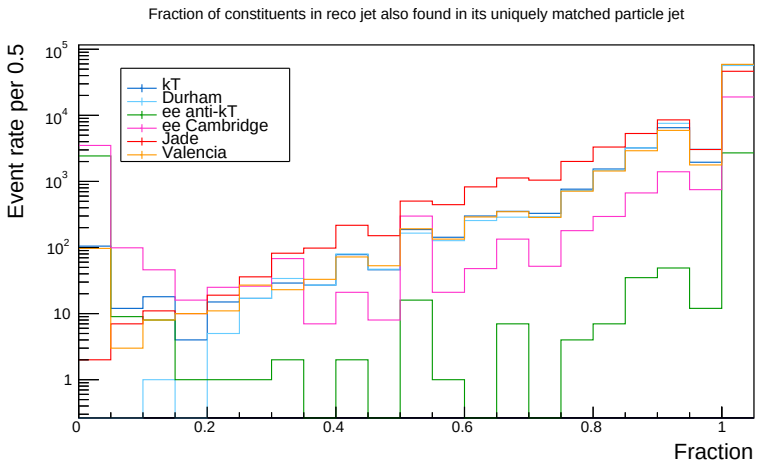
Matching angle between reco and particle jets



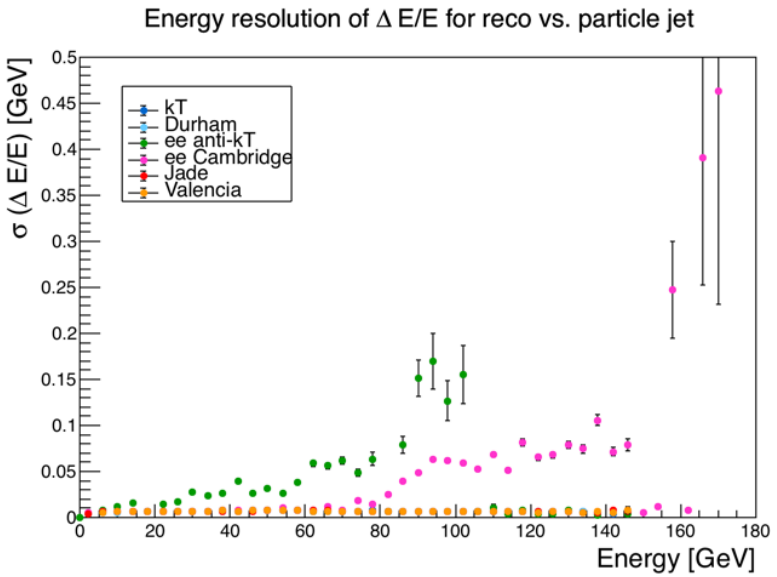
Unique matching between reco and particle jets



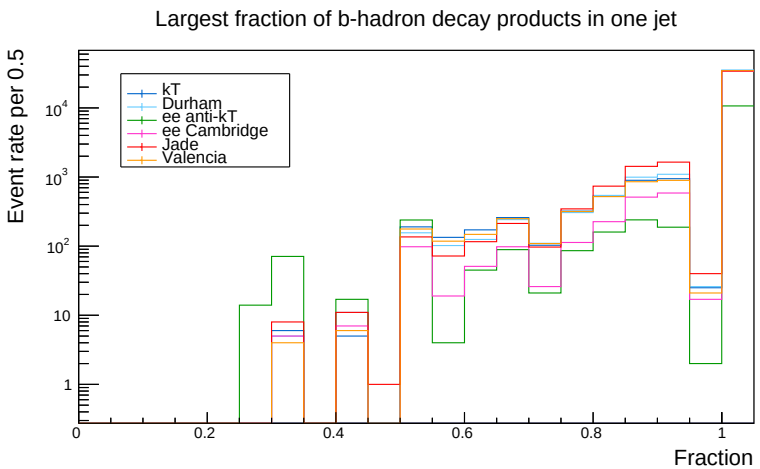
Matching constituents in events with unique matching



Energy resolution of jets



b-hadron distribution in reco jets



Events with full separation of b-hadron decay products:

- k_T: 76.3 %
- Durham: 79.2 %
- ee anti-k_T: 12.3 %
- ee Cambridge: 61.7 %
- Jade: 73.8 %
- Valencia: 76.9 %

Continuing Jet Studies

- Add b-tagging to Jet clustering interface in FCCAnalyses
- Energy normalisation methods provided by FastJet
- Merging schemes (default is E-scheme)
- Additional ideas?
- Jet Specific Selection Cuts
  - Thrust to test distribution of jets in event shape, invariant mass, etc.

Kinematic Fit

- Imposing constraints to improve resolution and reduce background for event selection and reconstruction of ttbar events
- Semileptonic $\rightarrow$ maximum kinematic information
- Complete reconstruction
  - Develop software inspired by ABC-fit compatible with FCCSW

Backup

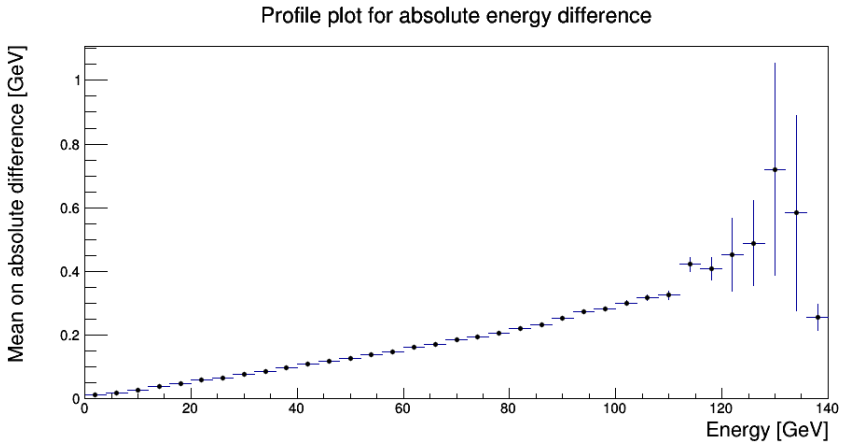
Highest energy lepton:

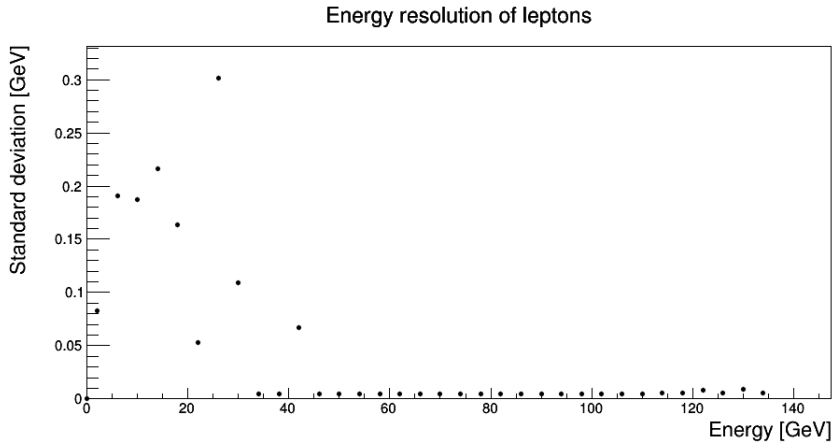
Assuming that the lepton from the W-decay will have the highest energy, it can be used as a selector. This selector has an acceptance of

$$\mathbf{96.6 \pm 0.7\ \%}$$

→ Find RP highest energy lepton
→ Match to MC particle
→ Parent history (EDM4Hep gives parent and daughter history for MCParticleData)
→ Stopping criteria with PDG and status code

The majority of the highest energy leptons are originating from a W-boson with the same charge. 0.02% are originating from an opposite charge W-boson indicating a decay from a lighter-flavour non-b-quark. The remaining leptons are originating from a b-quark.





List of variables:

- Highest energy lepton
- 2nd highest energy lepton
- Lepton momentum
- Lepton momentum excluding highest energy lepton
- Momentum difference between highest and second highest energy lepton
- Missing momentum
- Invariant mass of lepton-neutrino pair
- Invariant mass of 1st and 2nd highest energy leptons
- Invariant mass of event excluding highest energy lepton
- Thrust of event excluding highest energy lepton
- Thrust of entire event

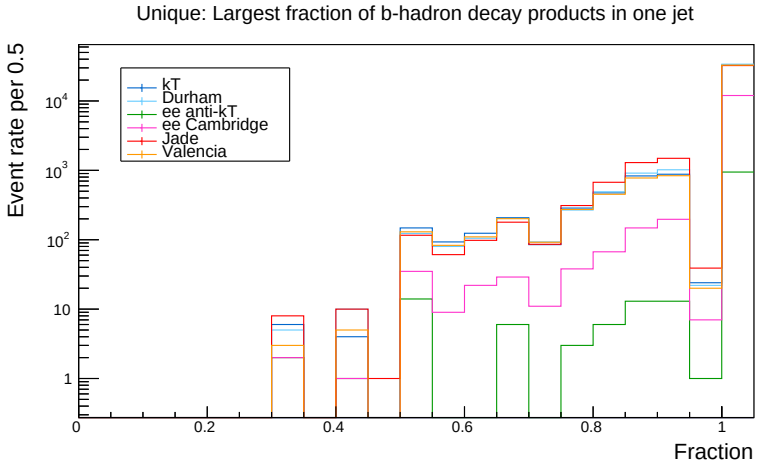
Significance of signal for each background before and after Pre-Selection

Background	Sanity check	Pre-Selection
Total	48	192
$\mu\mu$	162	402
$\sum q\bar{q}$	169	400
$b\bar{b}$	198	400
γZ	152	399
WW	61	326
ZZ	234	392
ZWW	405	400
ZZZ	421	405
single top	157	211

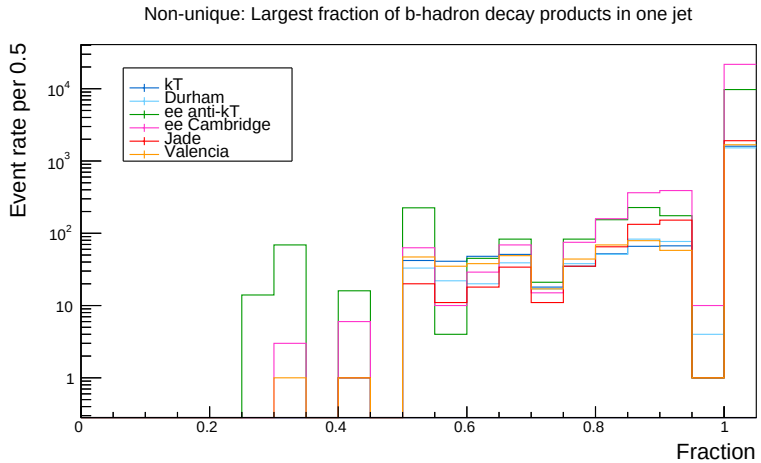
$$\textbf{Significance} = \frac{sig}{\sqrt{sig + bkg}} \quad , \quad \textbf{Efficiency} = \frac{sig}{sig_{\text{tot}}} \quad , \quad \textbf{Purity} = \frac{sig}{sig + bkg}$$

b-hadron distribution in reco jets

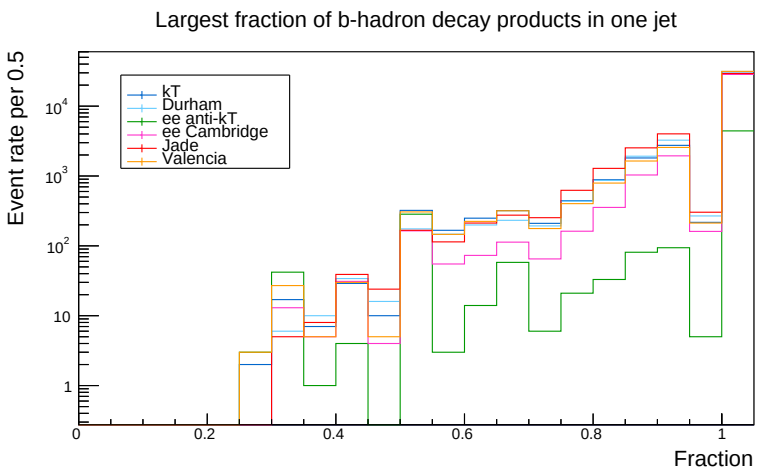
Events with unique matching



Events with non-unique matching



b-hadron distribution in particle jets



Events with full separation of b-hadron decay products:

- k_T: 62.2 %
- Durham: 62.8 %
- ee anti-k_T: 3.7 %
- ee Cambridge: 42.5 %
- Jade: 54.3 %
- Valencia: 64.1 %