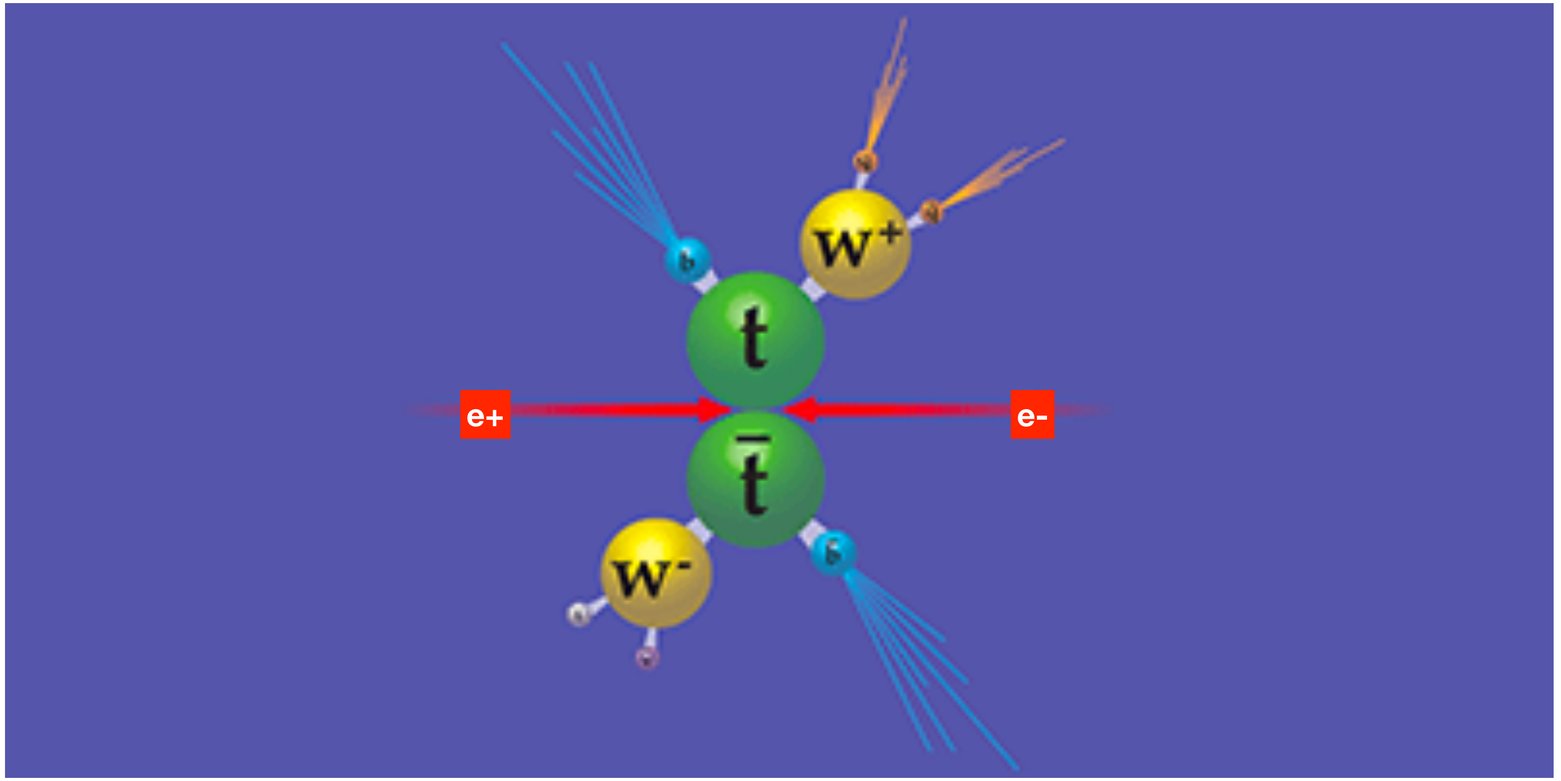
Tools for top analysis
in the FCC software framework

P. Azzi - INFN/CERN



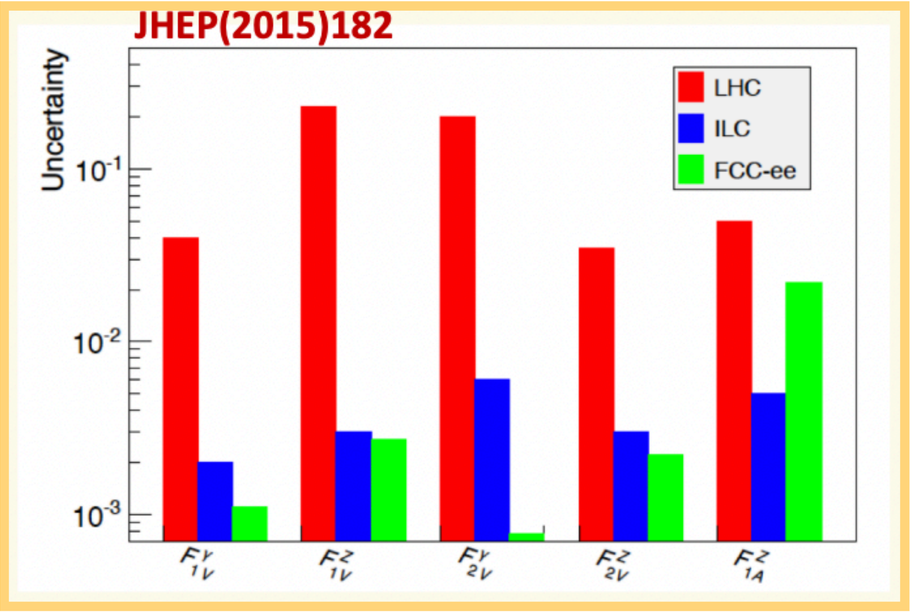
Many thanks to Julie Munch-Torndal (NBI) who is the author of most of the material presented

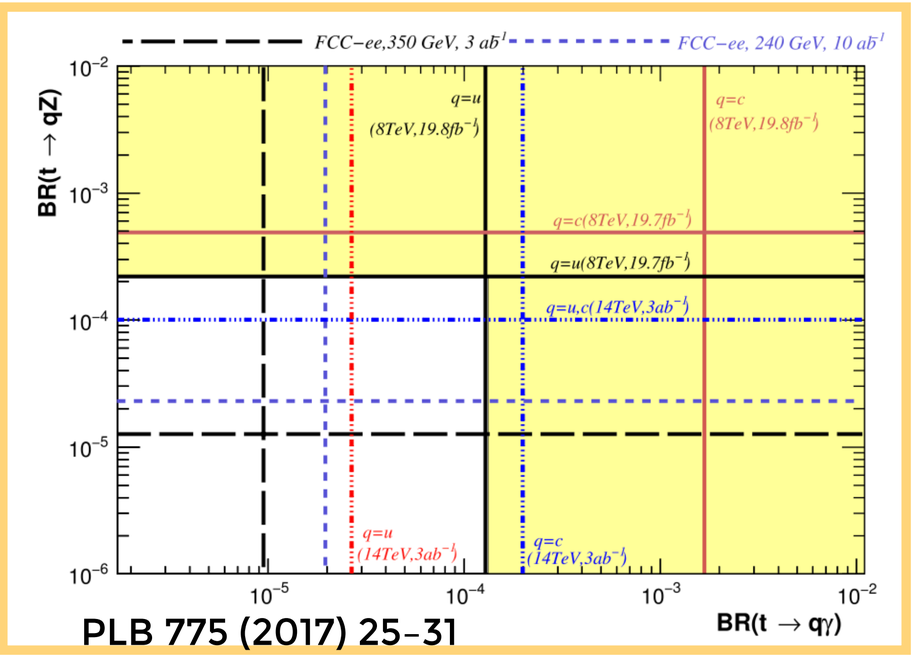
3rd FCC-France Higgs&EWK Factory Workshop
Annecy, Nov30-Dec2, 2021

Top physics case studies

See also Snowmass LOI

- **Measurements at threshold**: precision top mass, width, (indirect) Yt. But also, differential distributions, Afb, top polarisation important for EFT fits need to be explored.
  - To fully profit of the hadronic channel statistics will help set requirements on jet reconstruction and kinematical fits
- **EWK couplings:** √s=365GeV optimal to extract sensitivity on (anomalous) EWK couplings below the % using optimal variables (lepton energy and polar angle). Need to extend the analysis to more variables and extract detector requirements.
- **FCNC:** preliminary results at 240GeV and 365GeV show sensitivity 10^{-5}-10^{-6}. Need to fully optimise the analysis, combine the energies and extract the requirements on jet flavour tagging.

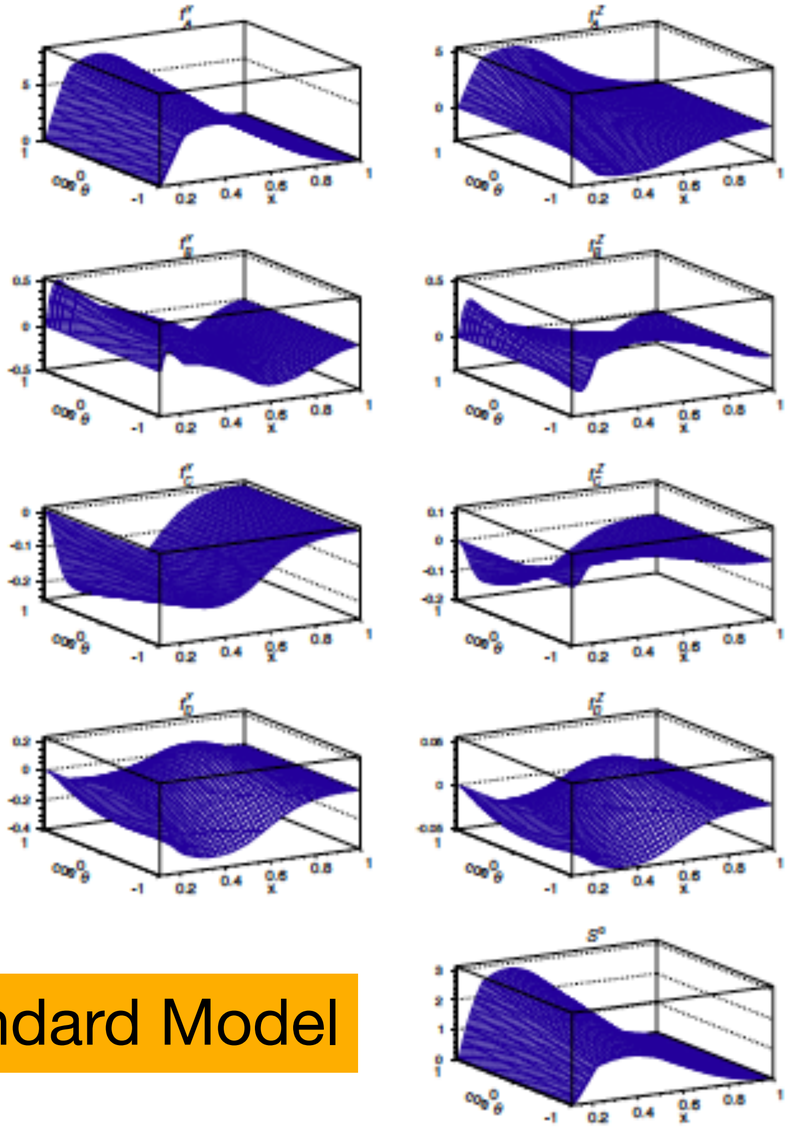




EWK couplings of the top quark in CDR

Reminder from P. Janot JHEP(2015)182

- ttZ, ttγ couplings can be enhanced in extra dimensions and (particularly) composite Higgs models
- Directly probed in the tt production process at FCC-ee as **top polarization information is maximally transferred** to its final state particles via the weak decay
- Use **lepton energy and angular distributions** in top decay to disentangle ttZ from ttγ in l+jets. Sensitivity investigated in optimal observable analysis (confirmed by full simulation analysis)



Standard Model

New top EWK couplings analysis

Authors: Julie Much Torndal, Jørgen Beck Hansen

- Project for Master Thesis
- First use of FCCAnalysis framework for top study
- Important contribution to set the basis for further code development

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{SM} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \sum_j \frac{C_j^{(8)}}{\Lambda^4} O_j^{(8)} + \dots$$

- 7 independent dim-6 operators contributing to top couplings
  → 10 anomalous couplings which depend on 7 operator coefficients

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}} \bar{b}\gamma^\mu (V_L P_L + V_R P_R) t W_\mu^- - \frac{g}{\sqrt{2}} \bar{b} \frac{i\sigma^{\mu\nu} q\nu}{M_W} (g_L P_L + g_R P_R) t W_\mu^- + H.c.$$

$$\mathcal{L}_{Ztt} = -\frac{g}{2c_W} \bar{t}\gamma^\mu (X_{tt}^L P_L + X_{tt}^R P_R - 2s_W^2 Q_t) t Z_\mu - \frac{g}{2c_W} \bar{t} \frac{i\sigma^{\mu\nu} q\nu}{M_Z} (d_V^Z + i d_A^Z \gamma_5) t Z_\mu$$

$$\mathcal{L}_{\gamma tt} = -eQ_t \bar{t}\gamma^\mu A_\mu - e\bar{t} \frac{i\sigma^{\mu\nu} q\nu}{m_t} (d_V^\gamma + i d_A^\gamma \gamma_5) t A_\mu$$

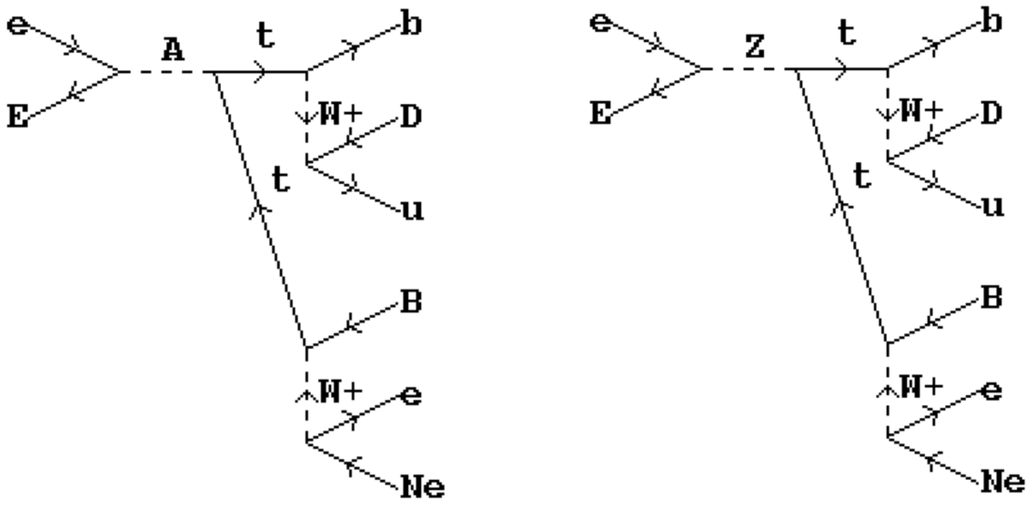
Strategy

Signal:

Semileptonic channel

$$e^+e^- \to t\bar{t} \to bW^+\bar{b}W^- \to b\bar{b}q\bar{q}\ell\nu_\ell$$

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



Backgrounds:

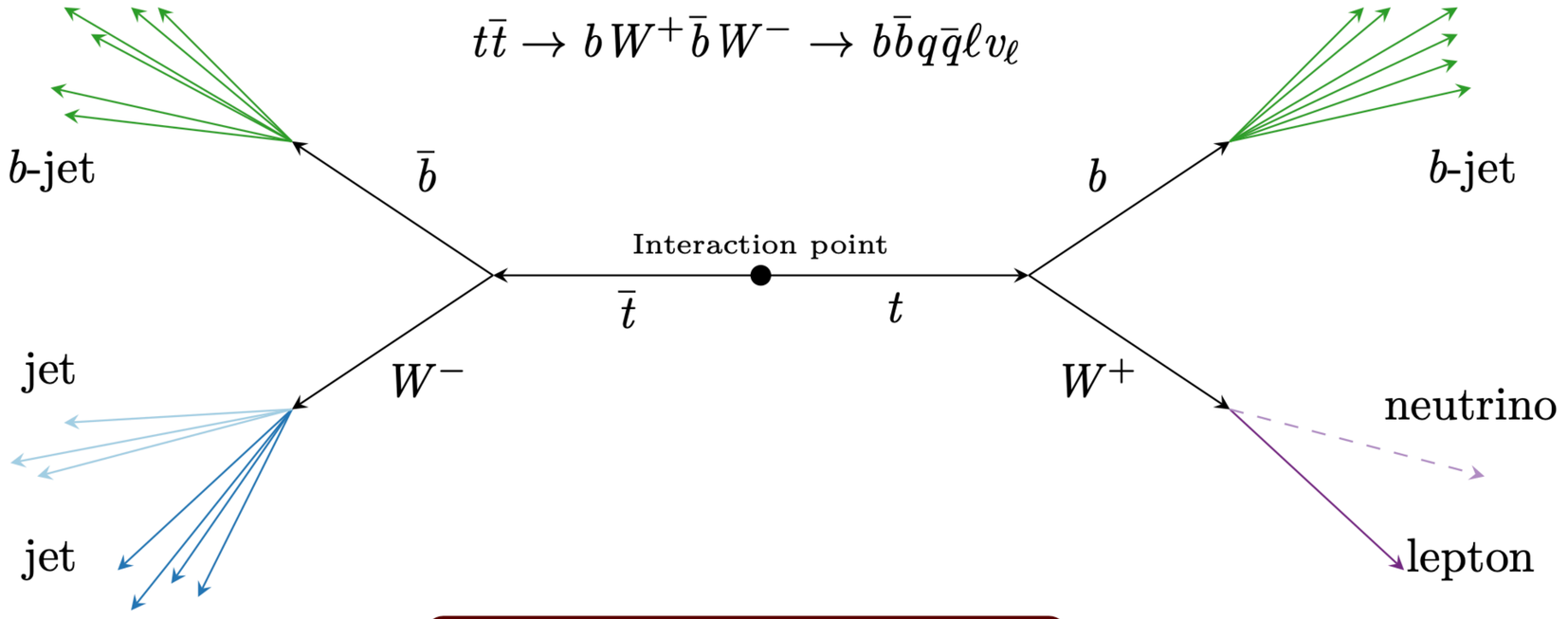
Process	σ [pb]
$t\bar{t} \to b\bar{b}q\bar{q}\ell\nu_\ell$	0.1933
$\mu\mu$	0.7942
$\tau\tau$	0.7937
$\sum_{b\bar{b}} q\bar{q}$	4.143
γZ	0.7448
WW	3.386
ZZ	10.72
ZH	0.6428
ZWW	0.1173
ZZZ	$15.91 \cdot 10^{-3}$
Single top	$0.7633 \cdot 10^{-3}$
	$3.337 \cdot 10^{-3}$

- All MC files are generated in the FCCSW framework with DelphesPythia8_EDM4HEP and IDEA Delphes Card
- Anomalous couplings available with Whizard

Typical signature: semi-leptonic decay

- When one of the two W's decays leptonically
- For lepton selection: highest momentum & matched to the MC truth

Signature of semileptonic channel:



Signature objects:

- 1 lepton
- 1 neutrino
- 4 jets
- (2 b-tags)

Jet reconstruction

- Delphes jets in centrally produced samples not usable. (Next version of Delphes will fix the problem)

- Development of a new interface between Fastjet and Delphes to be able to rerun jet reconstruction on the Delphes particle candidates collection. Now added in FCCAnalyses/JetClustering *(link to example in backup)*

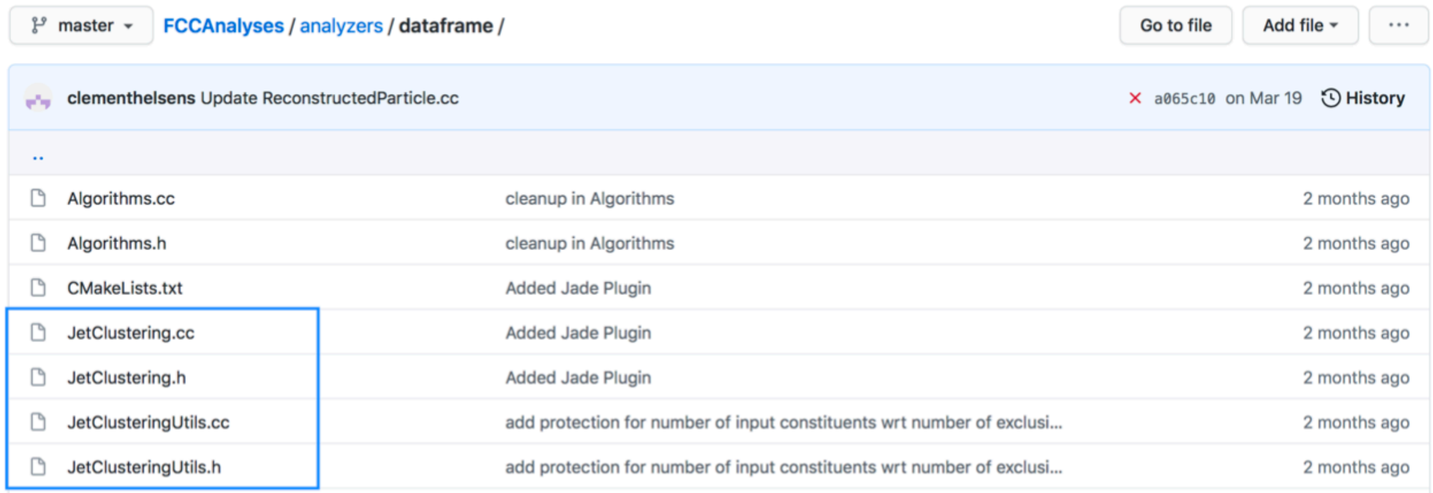
Jet Algorithms		
k_t	`clustering_kt`	suitable for *pp* collisions
Anti-k_t	`clustering_antikt`	
Cambridge/Aachen	`clustering_cambridge`	
Generalised-k_t	`clustering_genkt`	
Durham	`clustering_ee_kt`	suitable for e^+e^- collisions
Generalised-k_t for e^+e^-	`clustering_ee_genkt`	
Valencia	`clustering_Valencia`	
Jade	`clustering_Jade`	

Plugins

Fastjet interface

FastJet very much focused on hadron collider environment

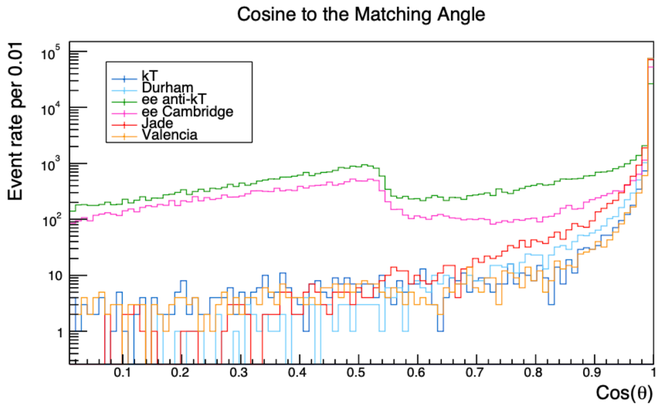
At FCCee it's important to optimise jet reco as part of the analysis



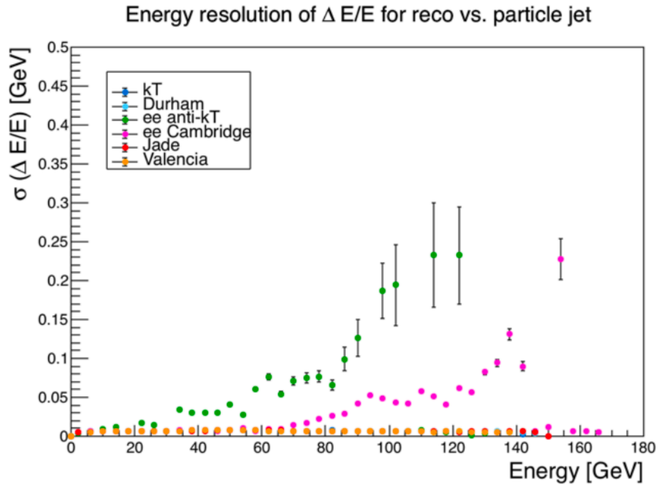
- Several algorithms available. And recombination schemes
- Can choose which particles to cluster and how
- "Plugins" allow to add new algorithms
- Can perform inclusive or exclusive reconstruction

Jet performance studies

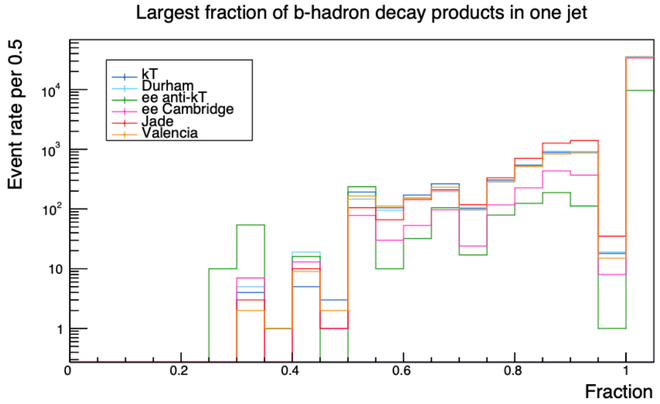
Matching angle between reco and particle jets



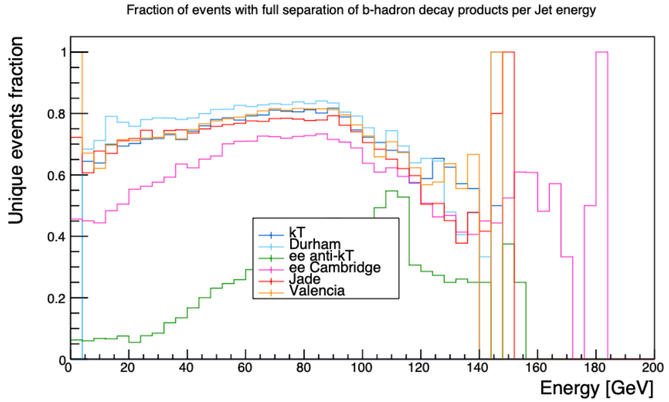
Energy resolution of jets



Largest fraction of b-hadron decay products in one jet



Fraction of events with full separation of b-hadron decay products



- Possible to compare the different reconstructions algorithms with the MC truth information and choose the most appropriate
- Clearly each analysis might have different needs
- In this case we see that with exclusive clustering with N(jet)=4 the ee-antikt and ee-Cambridge have a worse performance

B-tagging

- In Delphes, a jet is b-tagged if a b-parton lies within a cone radius of ΔR < 0.5. An efficiency formula is applied e.g. in delphes/cards/delphes card IDEA.tcl:

```
# efficiency formula for b-jets
add EfficiencyFormula {5} {0.80}
```

- Once the jets are reclustered in Delphes the b-tagging needs to be re-run as well on the new collection.
- Julie provided also an interface for a parameterised b-tagging routine with the same characteristics as in the original Delphes card.

Jet Tagging Interface

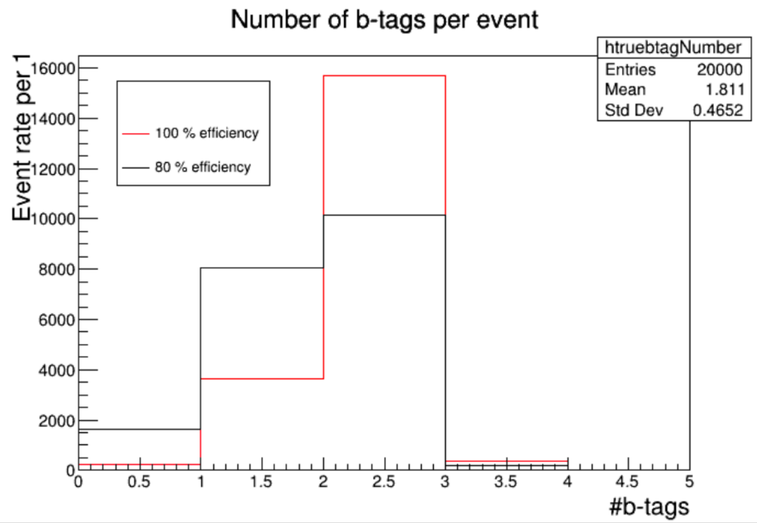
- Jet is matched to parton by

  $Angle(\text{jet,parton}) < 0.3$ rad
- Flavour priority: $b > c >$light flavour
- Flat efficiency for individual flavours

FCCAnalyses / JetTagging

analyzers/dataframe/**JetTagging**Utils.h

analyzers/dataframe/**JetTagging**Utils.cc

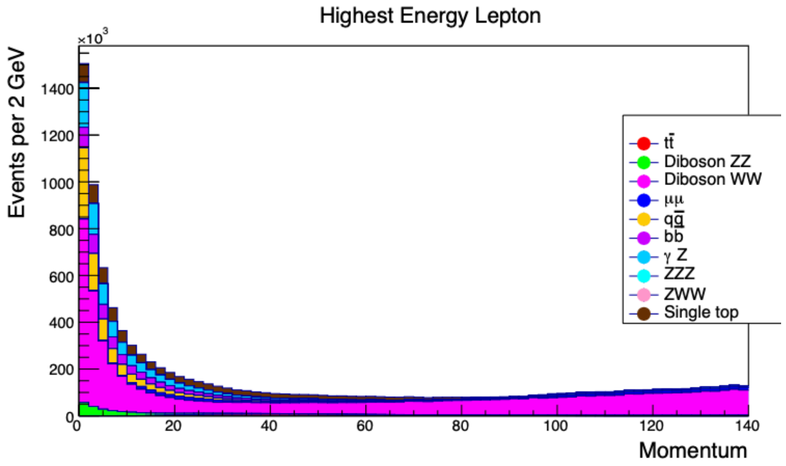


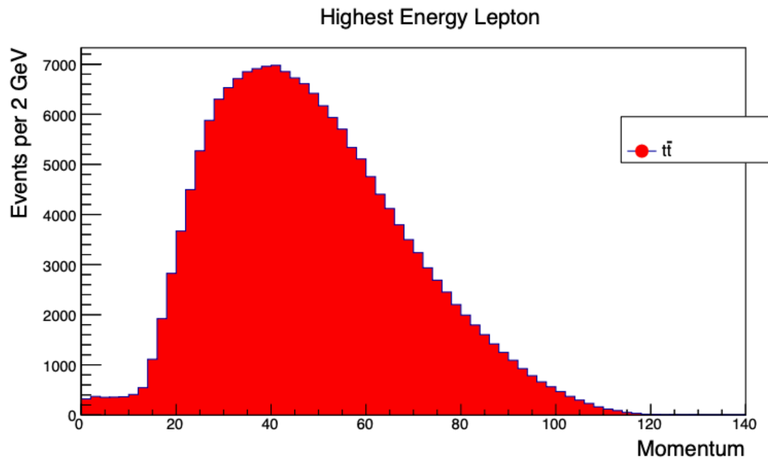
- In the future we plan to add algorithms for secondary vertex reconstruction as well, profiting of the more sophisticated track information present in the Delphes for FCC (full covariance matrix)

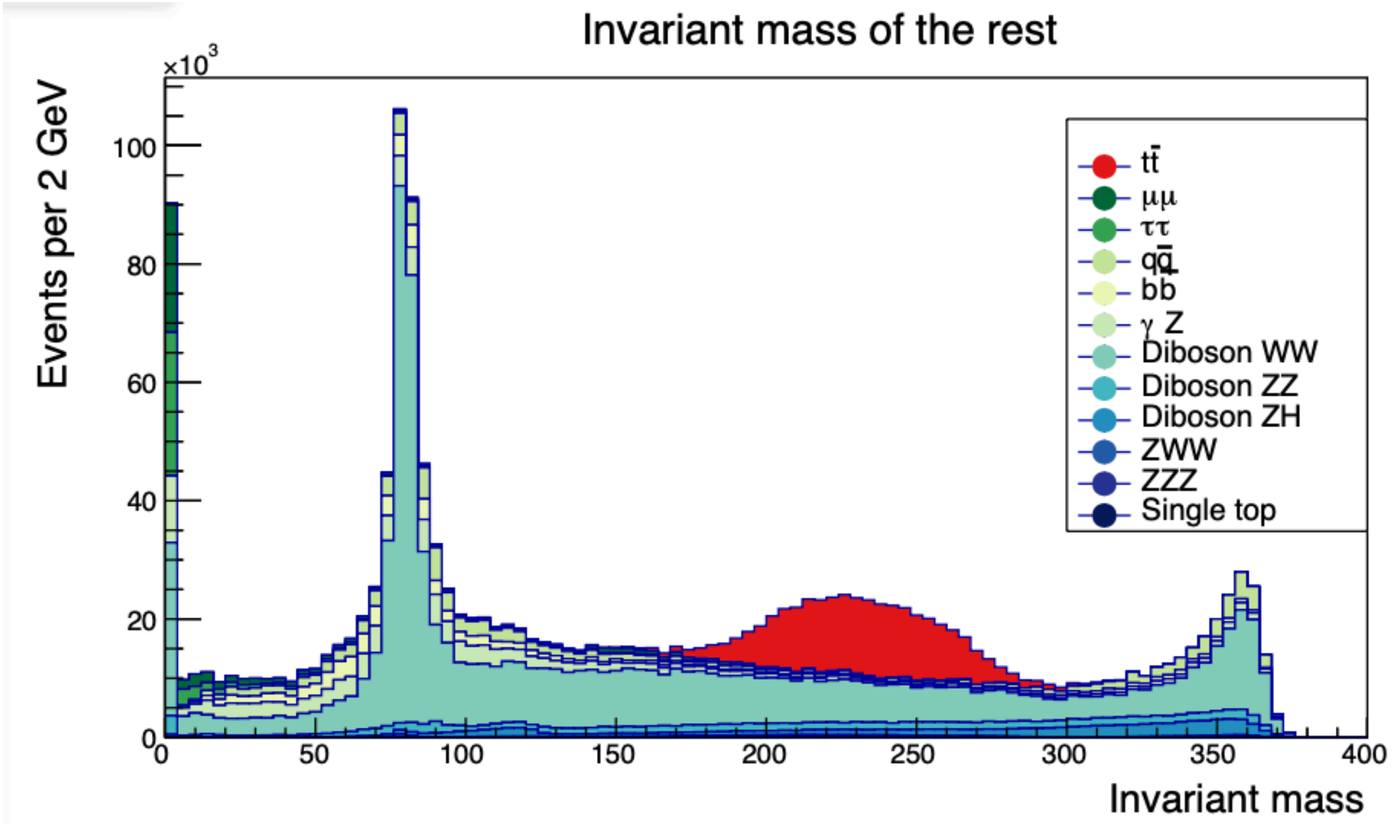
Signal selection

Signal region cuts

- At least 1 lepton
- Thrust < 0.85
- $M(rest) > 160$ GeV
- $M(\ell_{HE}, \not{E}) > 50$ GeV
- $p_{\ell_{HE}} < 100$ GeV
- $p_{\ell_{HE}} > 15$ GeV
- $p_{\ell_{2nd\,HE}} < 40$ GeV
- Exactly 4 jets
- At least 1 b-tag

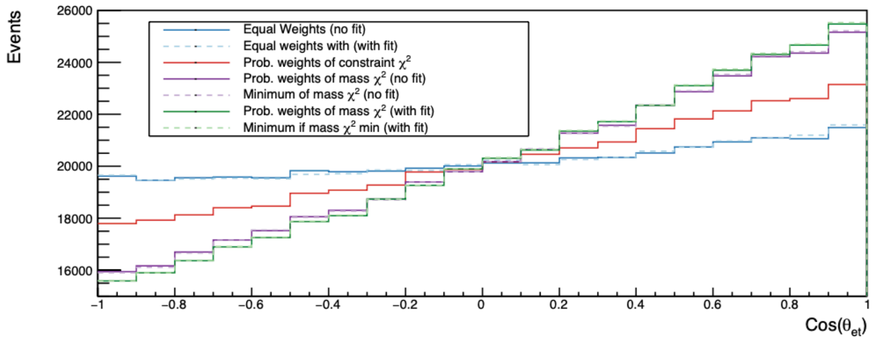


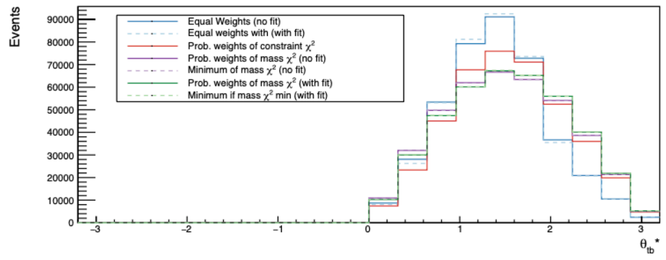


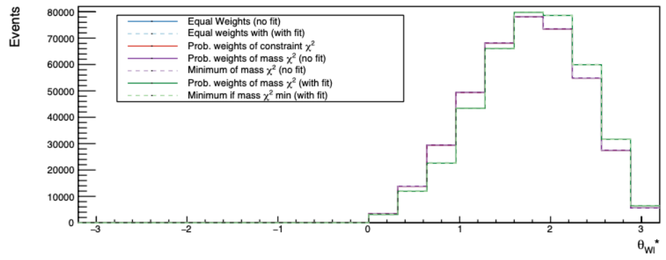


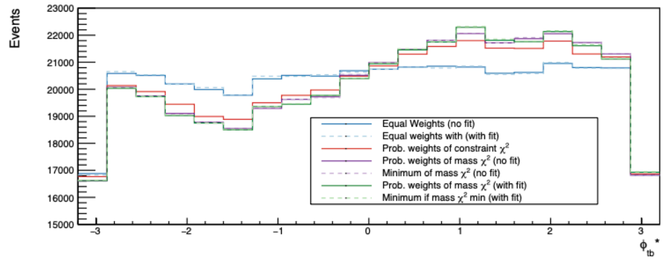
Event reconstruction & preliminary results

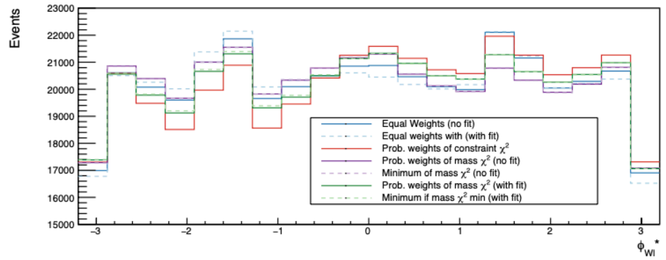
- Written a kinematical fit ABCfit++(ported from a LEP algorithm) as a general package to perform kinematical fits.
  - *Used also by the WW analysis (see talk by J.L. Raymond)*
- Preliminary 1σ sensitivities extracted. Can add energy information to improve.
  - *More work needed to extract requirements (student graduated)*

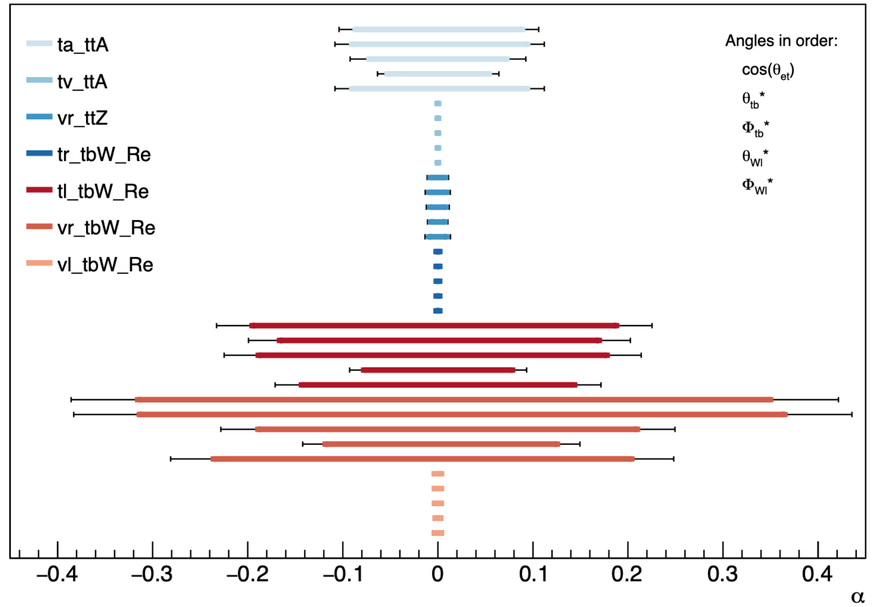












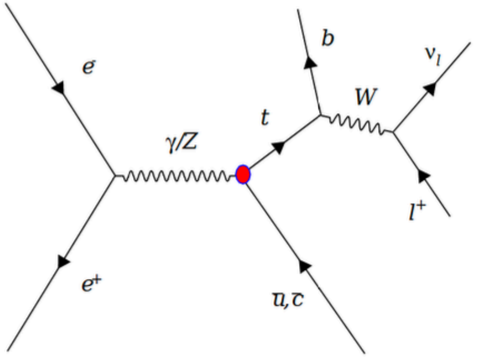
FCNC in single top production

Hamzeh Khanpour, Mojtaba Mohamadi Najafabadi, Seddigheh Tizchang - IPN Teheran

- Anomalous single top production can be studied at $\sqrt{s}$= 240GeV and 365GeV
- In parallel, need to study also the pair production case with the anomalous coupling in the decay.
- Final result will be a combination also of different final states.

SIGNAL

Final state: *charged lepton, a b-jet, a light-jet and missing energy*

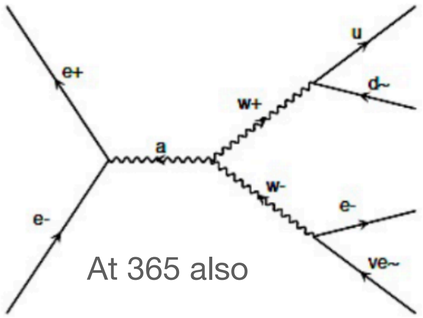


Background

$e^-e^+ \to W^-W^+ \to l\nu_l jj$

$e^-e^+ \to ZZ \to l^-l^+jj$

$e^-e^+ \to ZH \to l^-l^+jj$



$e^-e^+ \to t\bar{t} \to \ell\nu b(jj)b$

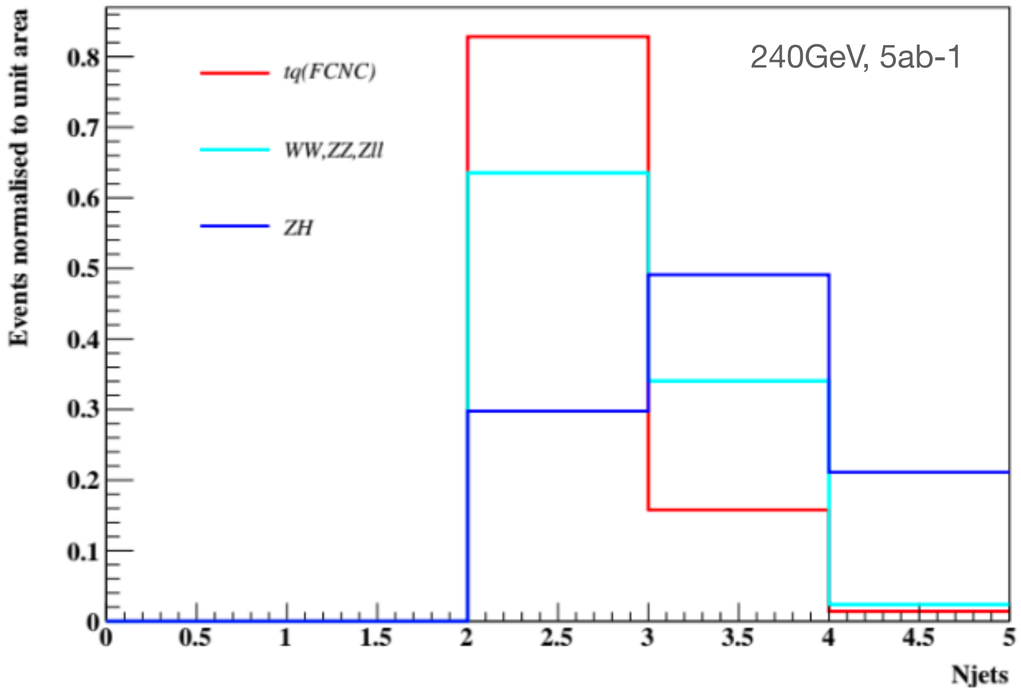
Datasets & setup

Very preliminary

- Signal samples prepared in Madgraph and processed with Delphes centrally with EDM4HEP output (Spring21 production)
- Analysis being setup in FCCAnalysis
- Using Fastjet interface to test various jet reconstruction options.
- Using b-tag interface to apply selection cuts

Work just starting. Stay tuned

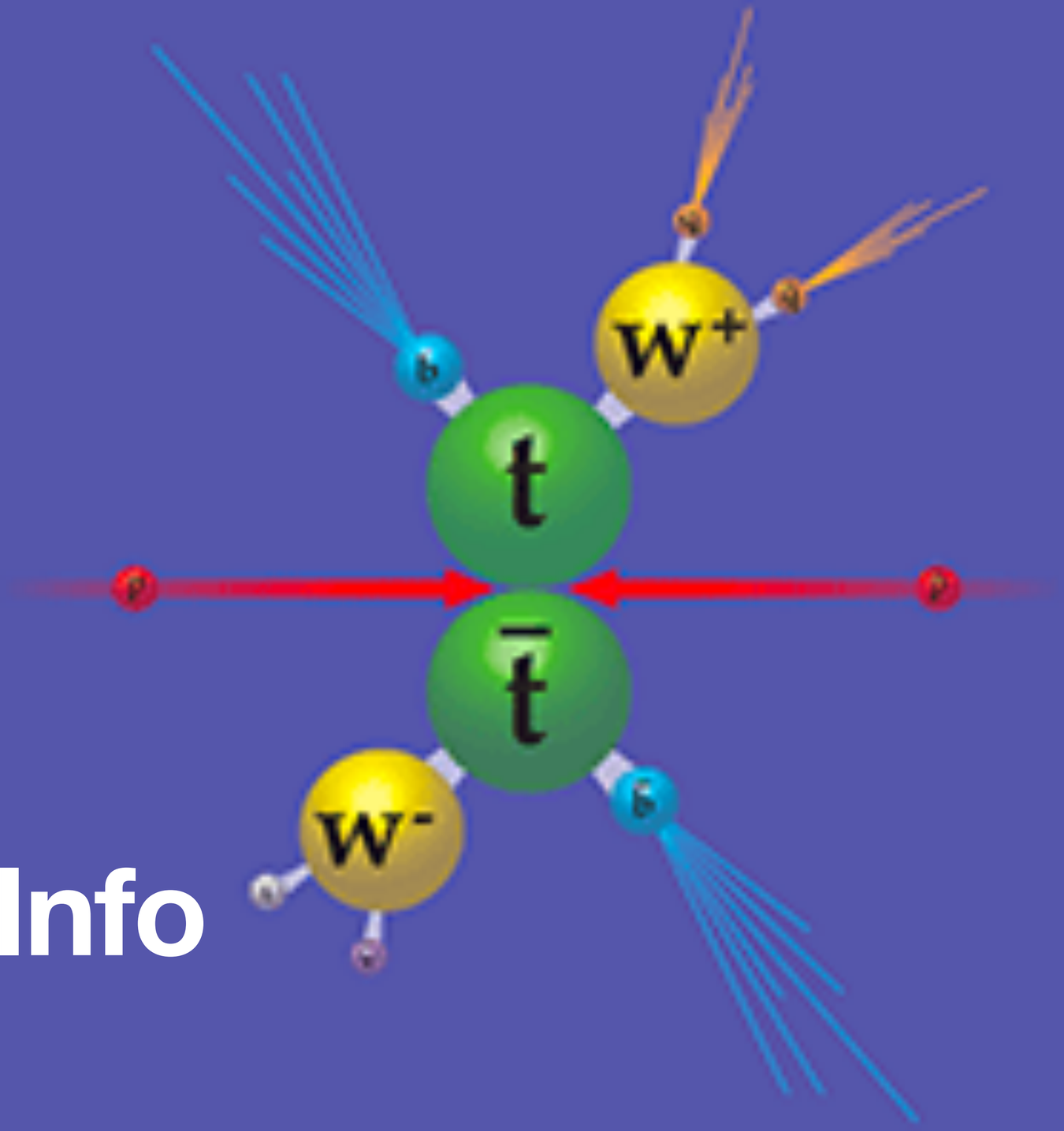
mgp8_ee_tbw_FCNC_tuz_ecm365
mgp8_ee_tbw_FCNC_tuz_ecm240
mgp8_ee_tbw_FCNC_tua_ecm240
mgp8_ee_tbw_FCNC_tcz_ecm240
mgp8_ee_tbw_FCNC_tca_ecm365
mgp8_ee_tbw_FCNC_tca_ecm240



Next steps

- Top physics case studies are very important for FCC-ee and it's detector requirements. They allow to study effects on jets and fits and complicated final states.
- A first set of tools to interface jet algorithms, tagging and a LEP kinematical fit have been developed in FCCAnalysis and are available to all users.
- Hoping to find new interest to pick up more top analyses!
- We (Physics Performance) are here to help out in getting started, sample productions, practical suggestions for those coming from LHC not used to the lepton collider specifics.
- Entry point for info: **https://hep-fcc.github.io/FCCeePhysicsPerformance/**

Backup Info



Issues with the jets in the Delphes card

For Spring21 production

```
#####################################################
# Find uniquely identified photons/electrons/tau/jets
#####################################################

module UniqueObjectFinder UniqueObjectFinder {
# earlier arrays take precedence over later ones
# add InputArray InputArray OutputArray
  add InputArray PhotonIsolation/photons photons
  add InputArray ElectronIsolation/electrons electrons
  add InputArray MuonIsolation/muons muons
  add InputArray JetEnergyScale/jets jets
}
```

Overlap removal procedure: if an "isolated photon" is among the jet components, the jet is removed from the list (it is said to be a photon)

Problem: the 'PhotonIsolation" module actually applies no isolation cut at all.
The overlap removal basically kills jets if there was a pi0 in the shower..

```
module Isolation PhotonIsolation {
  set CandidateInputArray PhotonEfficiency/photons
  set IsolationInputArray EFlowMerger/eflow

  set OutputArray photons

  set DeltaRMax 0.5

  set PTMin 0.5

  set PTRatioMax 999.
}
```

To get the jets right

What you should do is re-cluster the jets, as explained here: https://github.com/HEP-FCC/FCCeePhysicsPerformance/tree/master/General#example-analyses (5th bullet).

Look at the example here: https://github.com/HEP-FCC/FCCAnalyses/blob/master/examples/FCCee/top/hadronic/analysis.py that shows how to re-do the jets (using JetClusteringUtils) (and how to 'tag" them (see JetTaggingUtils), if you are interested in that part).

That should be quite straightforward, but let me know in case of any problem. This re-clustering was set up by Julie, there is some information in her talk in our September meeting.