Laboratoire d'Annecy de Physique des Particules

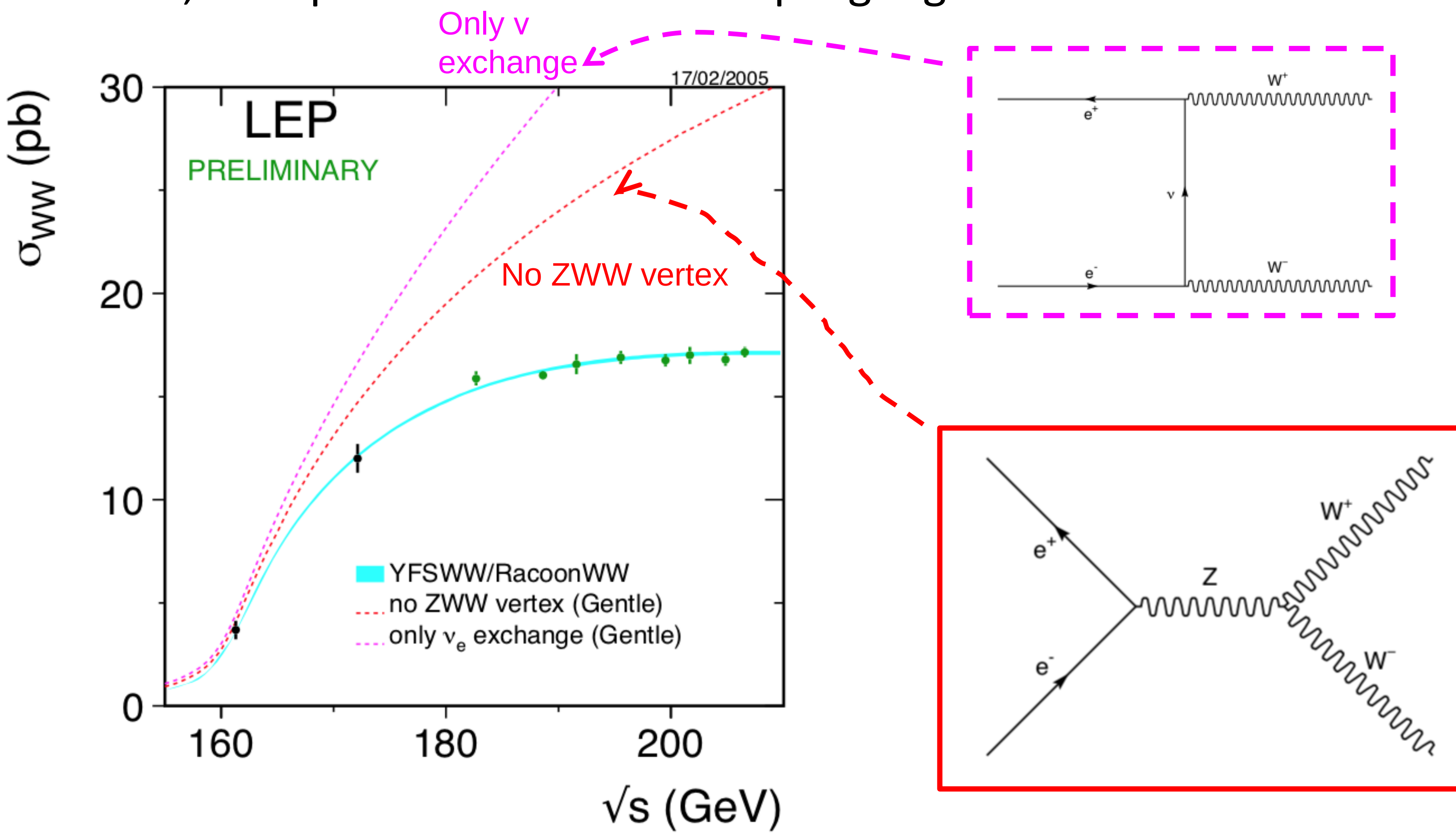
Angular analysis for $e^+e^- \longrightarrow W^+W^-$ final states at $\sqrt{s} = 240\mathrm{GeV}$

20 Septembre 2021

Jean-Loup Raymond, Lucia di Ciaccio

UNIVERSITÉ SAVOIE MONT BLANC

In SM, WW production involves triple gauge boson vertices = TGC



Search for new physics in the gauge boson sector

➔ Anomalous TGC (aTGC). Studied at previous machines and @LHC

Anomalous TGC may give different contributions to different helicity states of the W bosons (wrt SM)

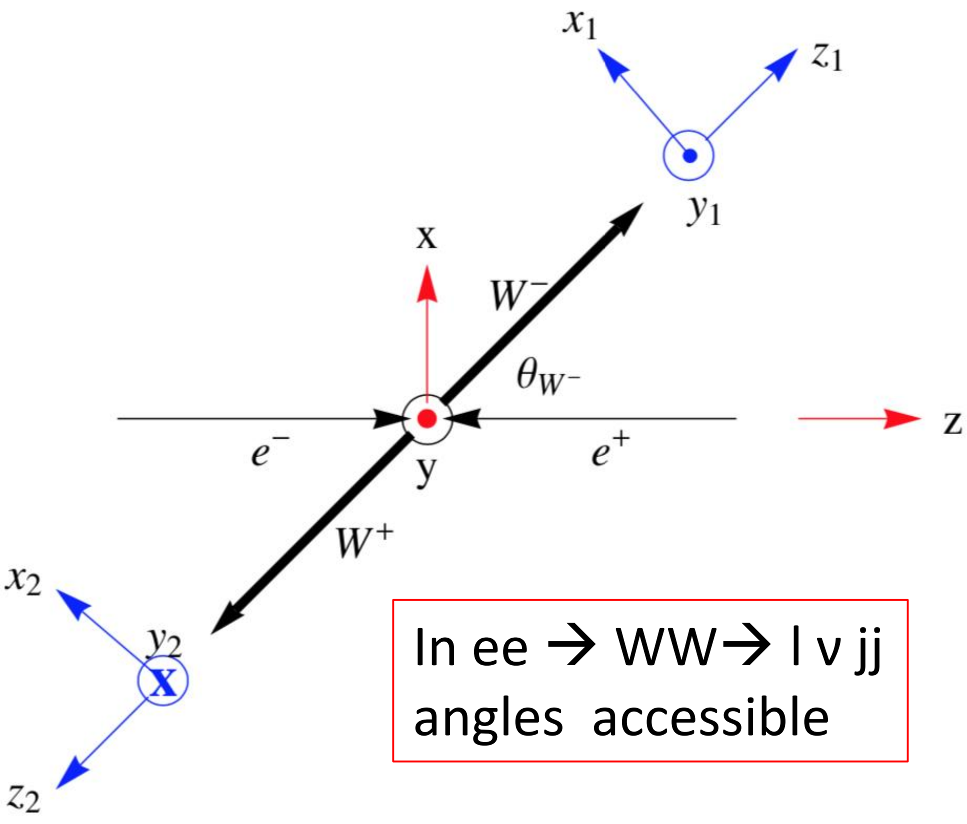
→ W production and decay angles may give access to BSM effects

W production and decay defined by 5 angles (neglecting ISR):

θ_{W^-}

θ^*_1, ϕ^*_1 — angles of the fermion in the W^- rest frame

θ^*_2, ϕ^*_2 — angles of the antifermion in the W^+ rest frame



In ee → WW→ l ν jj angles accessible

The aim is to study the possibility to measure:

- Spin Density Matrix (SDM) elements ($\rho_{\tau\tau}$) of an ensemble of W

SDM = composition of average spin state

$$\rho^{W^-}_{\tau\tau'}(s, \cos\theta_W) = \frac{\sum_{\lambda,\lambda'} F_\tau^{(\lambda,\lambda')} (F_{\tau'}^{(\lambda,\lambda')})^*}{\sum_{\lambda,\lambda',\tau} \left| F_\tau^{(\lambda,\lambda')} \right|^2}$$

Amplitude to produce a W^- with helicity **τ** from an electron with helicity **λ** and a positron with helicity **λ'** (a)

- Fraction of W bosons which are longitudinally polarised

$$\frac{d\sigma_L}{d\cos\theta_W} = \rho_{00} \cdot \frac{d\sigma}{d\cos\theta_W}$$

W longitudinal component arises from Electroweak Symmetry Breaking !

- CP violation :

$$\Delta^{CP}_{+-} = \sigma^{W^-}_{+-} - \sigma^{W^+}_{-+}$$
$$\Delta^{CP}_{+0} = \sigma^{W^-}_{+0} - \sigma^{W^+}_{-0}$$
$$\Delta^{CP}_{-0} = \sigma^{W^-}_{-0} - \sigma^{W^+}_{+0}$$

Cross section $\sigma_{\tau\tau}$ defined in terms of $\rho_{\tau\tau}$

(a) single W SDM - 3x3 Hermitian, unit trace → 8 free parameters

Using projection operators:

G. Gounaris et al:
Int. J. Mod. Phys. A8(1993)

$$\rho^{W^-}_{\tau\tau'}(s, \cos\theta_W) = \frac{\int \frac{d^3\sigma}{d\cos\theta_W d\cos\theta^*_f d\phi^*_f} \cdot \Lambda_{\tau\tau'} d\cos\theta^*_f d\phi^*_f}{\frac{d\sigma}{d\cos\theta_W}}$$

$$\Lambda_{--} = \tfrac{1}{2}(5\cos^2\theta^*_f + 2\cos\theta^*_f - 1)$$
$$\Lambda_{00} = 2 - 5\cos^2\theta^*_f$$
$$\Lambda_{++} = \tfrac{1}{2}(5\cos^2\theta^*_f - 2\cos\theta^*_f - 1)$$

$$\Lambda_{+-} = 2e^{2i\phi^*_f}$$
$$\Lambda_{+0} = \frac{-8}{3\pi\sqrt{2}} \cdot \left(1 - 4\cos\theta^*_f\right) e^{-i\phi^*_f}$$
$$\Lambda_{-0} = \frac{-8}{3\pi\sqrt{2}} \cdot \left(1 + 4\cos\theta^*_f\right) e^{i\phi^*_f}$$

- No assumption about the form of the TGC vertex is necessary
  → model independent
- So far @LHC measured only Λ_{++}, Λ_{--}, Λ_{00}

- Measurement already done at LEP

- Aim here: build the distribution of
  * $\rho_{\tau\tau}$,
  * $d\sigma/d\cos\theta_W$
  * Δ^{CP}

as function of $\cos\theta_W$ and estimate the statistical uncertainty taking into account (part of) the background

gives an idea of the level of systematic uncertainty needed

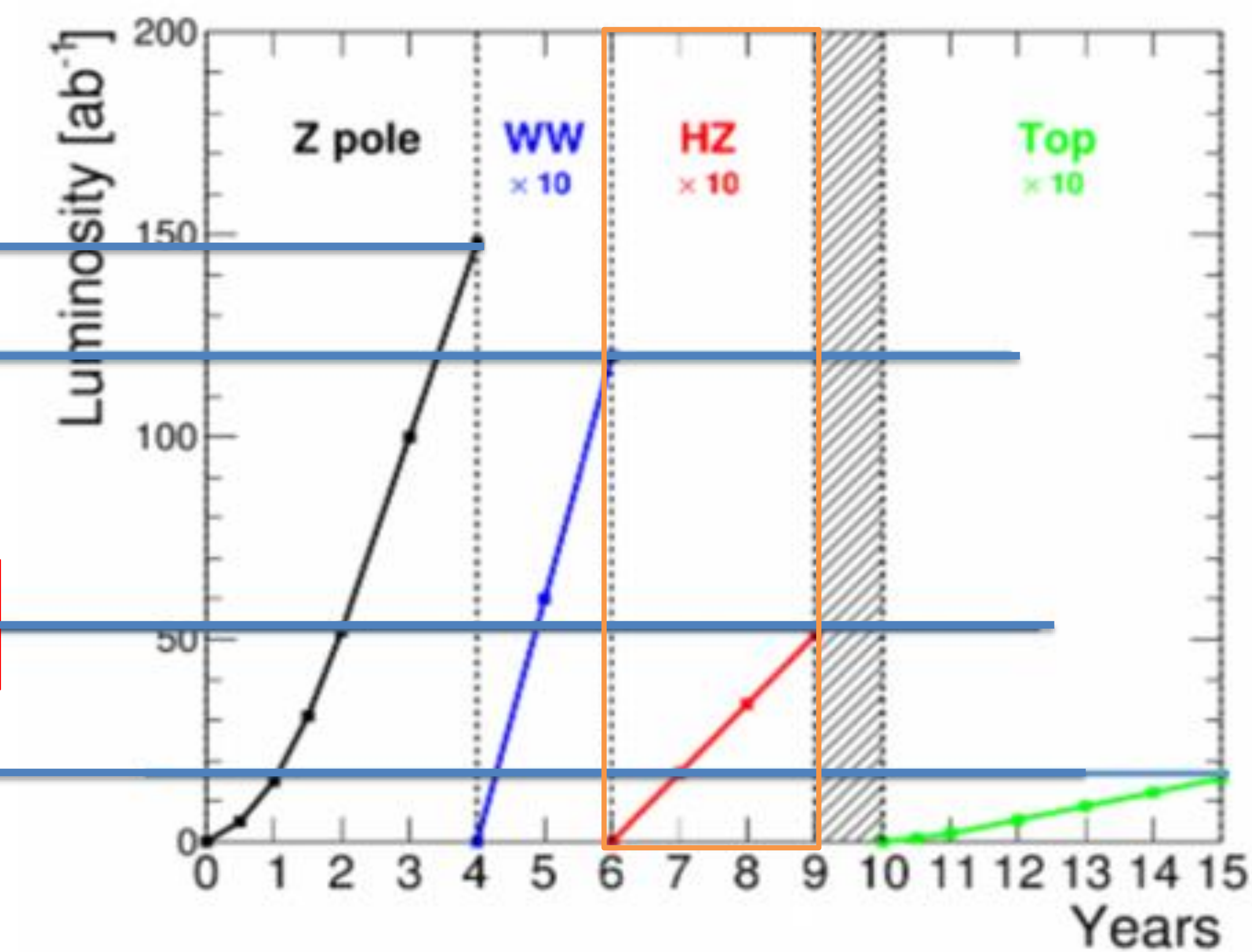
if time : compare to the extrapolation to HL-LHC

$\sqrt{s}$ ~91GeV / 150 ab^{-1}

$\sqrt{s}$ ~161 GeV / 12 ab^{-1}

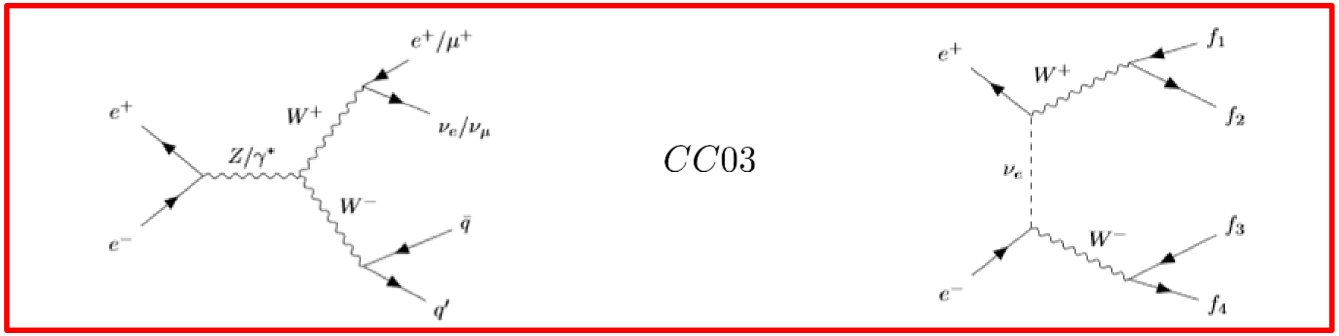
$\sqrt{s}$ =240 GeV / 5 ab^{-1} /
~80.10^6 WW

$\sqrt{s}$ =350 GeV / 1,8 ab^{-1}

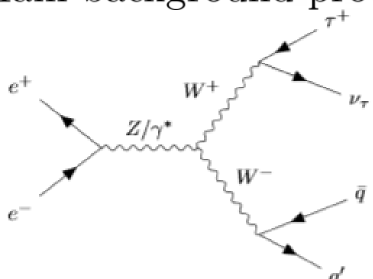


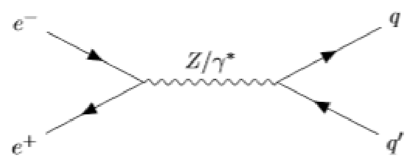
Signal & Main backgrounds

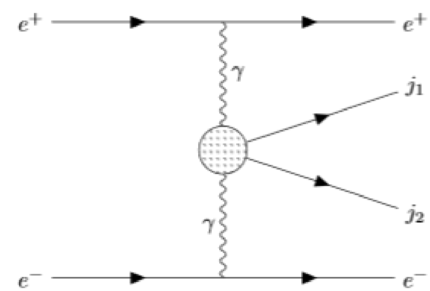
Signal = WW semi-leptonic e, μ



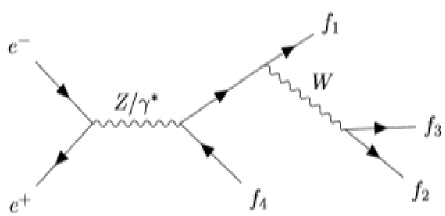
Main background processes

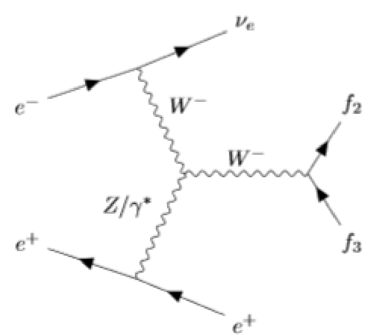






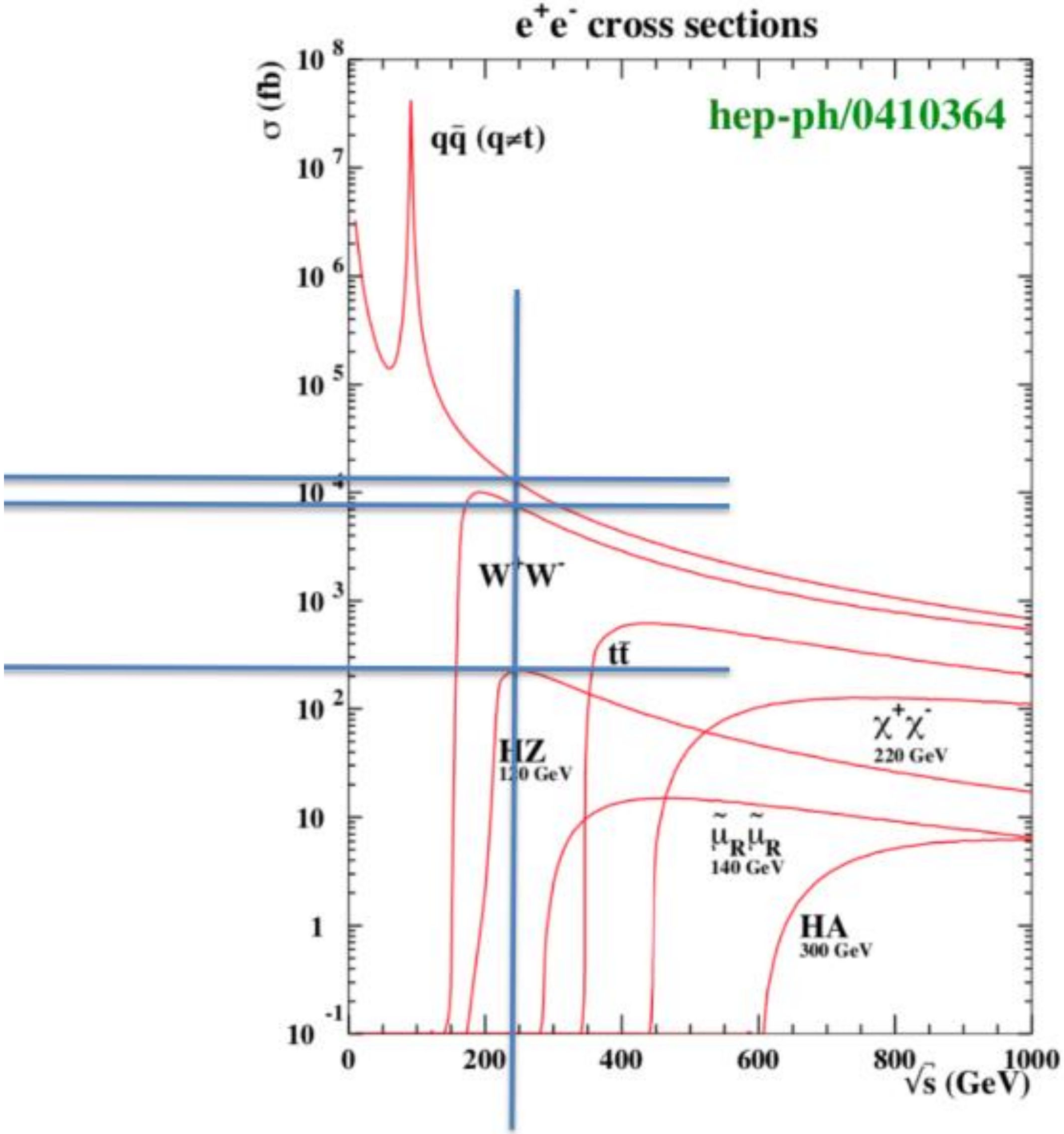
Non-CC03 4-fermion processes





Part of the background interferes with signal

Signal & Main backgrounds



- Pythia 8 samples available @240 GeV:

Events : WW – Zqq – Zll – ZH

- Spring 2021 latest samples

with IDEA detector

- Data format : EDM4HEP

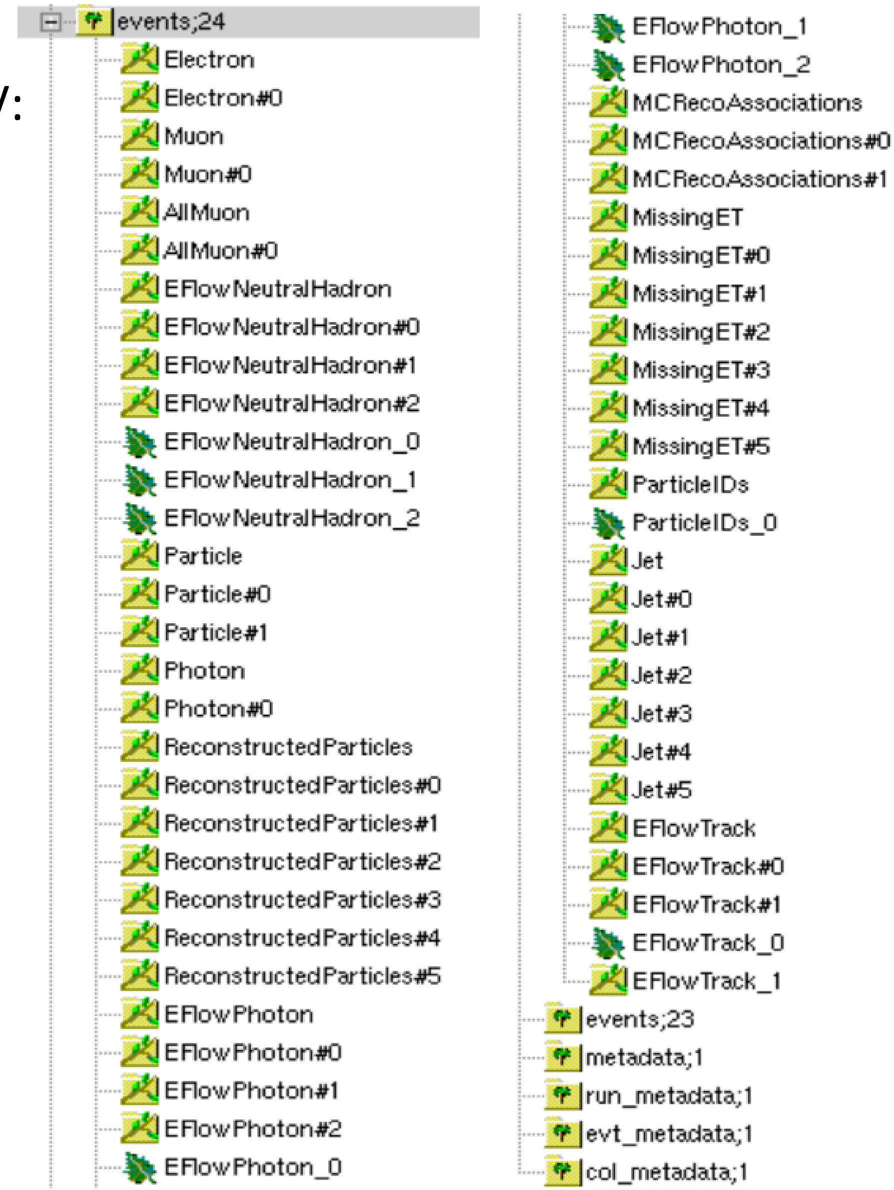
TTree : Events

Branches : Collections & Index

Leaves : Particles data

Exhaustive but costly in space

WW : ~600MB / 100000 events



- FCCAnalyses Package :
  - RootDataFrame based (easy manipulation of data, multithreading)
  - Steered by python scripts
  - Analyzers C++
  - Preselection (which we use to create custom N-tuples)
  - Final Selection
  - Plotting

- Custom N-tuples structure :

Event quantities

Ex : charged multiplicity, transverse energy, …

Particle quantities

Particle : Jets, Charged Leptons, Missing momentum

WW : ~600MB / 100000 events ➔ ~25MB / 100000 events

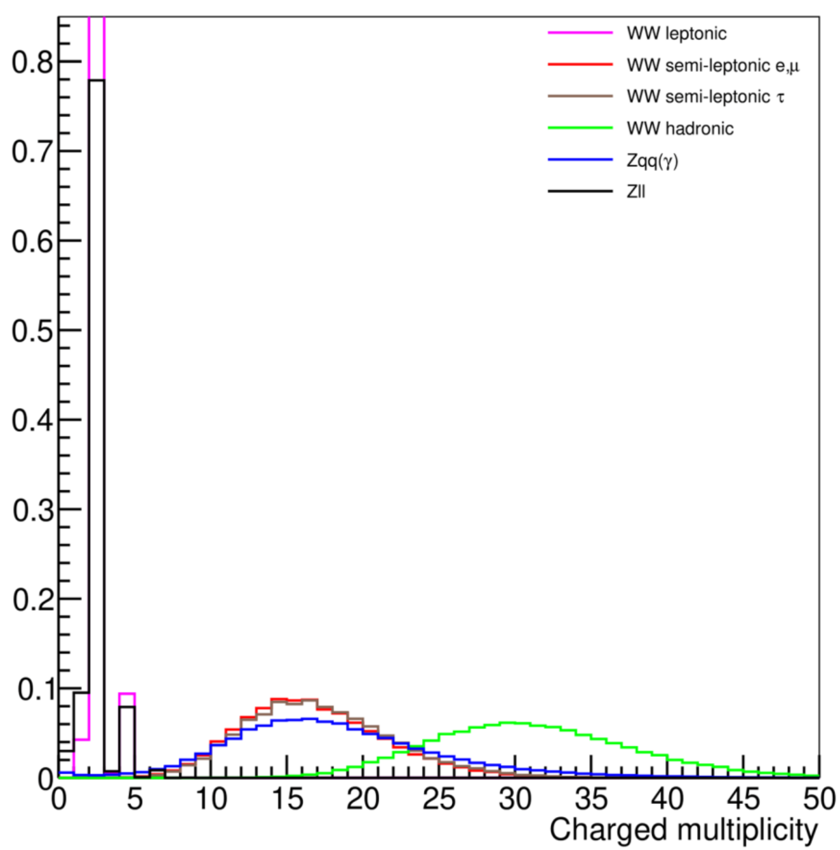
Preselection to isolate signal from background :

- Cutflow on reco level
- Mainly cuts on events quantities
- Normalization factor: $\frac{\mathcal{L}_{expected}}{N_{generated}\ \sigma}$ $\mathcal{L}_{expected} = 5ab^{-1}$

	Signal WW sl e, μ	BKG 1 WW sl τ	BKG 2 WW lep	BKG 3 WW had	BKG 4 Zqq(γ)	BKG 5 Zll
σ(pb)	4.729	2.522	1.744	7.470	52.65	13.78
Normalization factor	411.0				1316	344.0

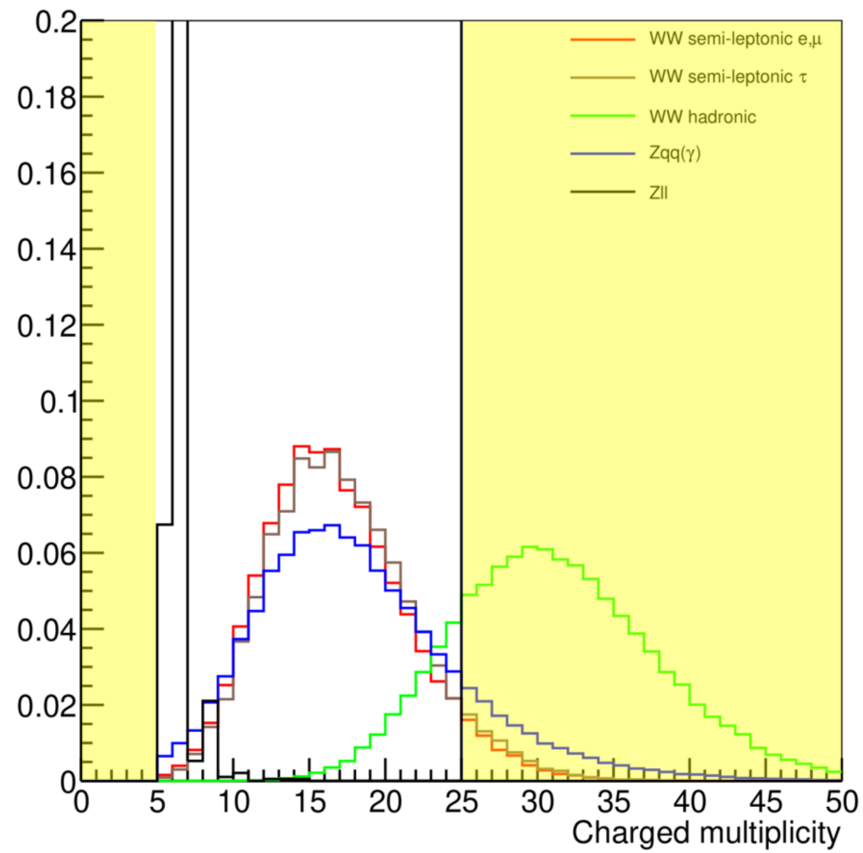
Cuts on charged multiplicity (Normalized to the same area) :

Before all cuts



Remove WW leptonic decays and Zll

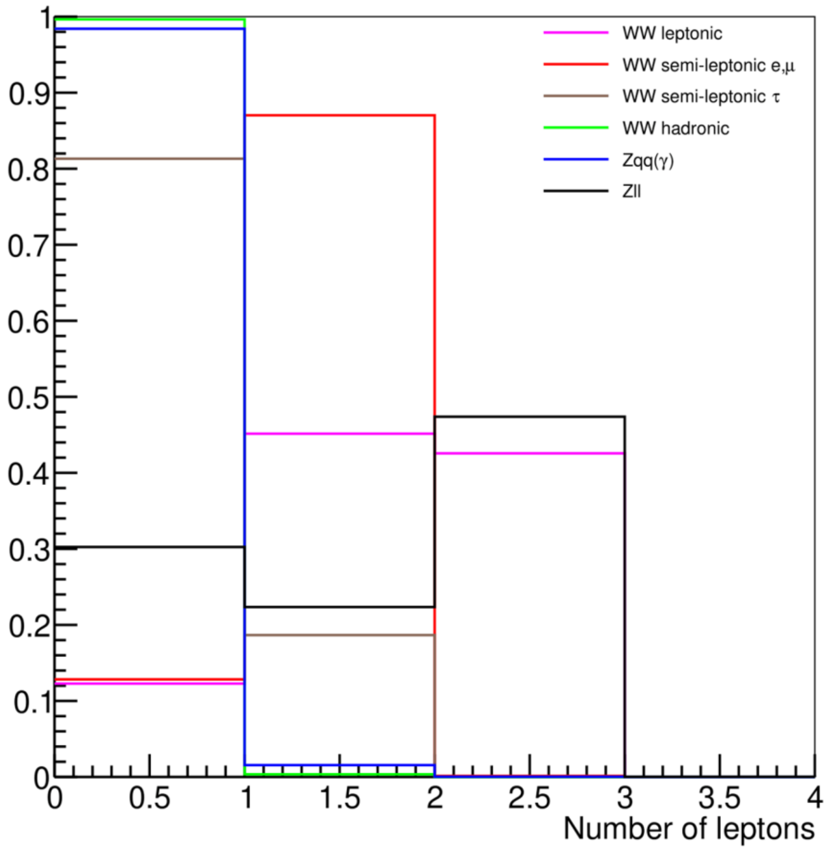
After first cut



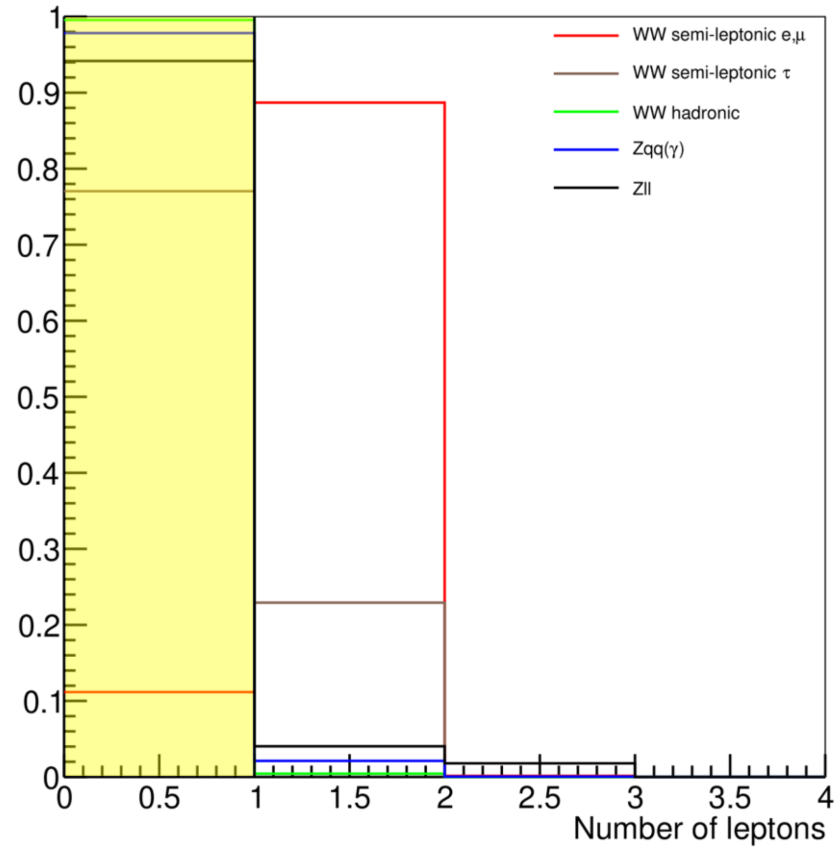
Remove WW hadronic decays

Cuts on number of leptons (>20 GeV, Normalized to the same area) :

Before all cuts



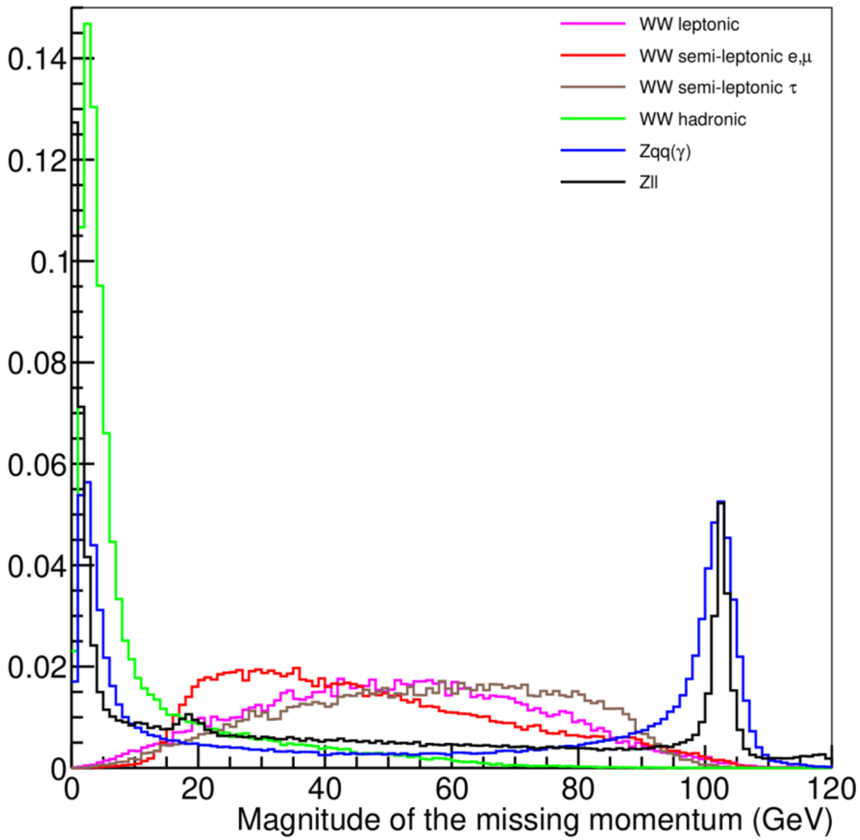
After previous cuts



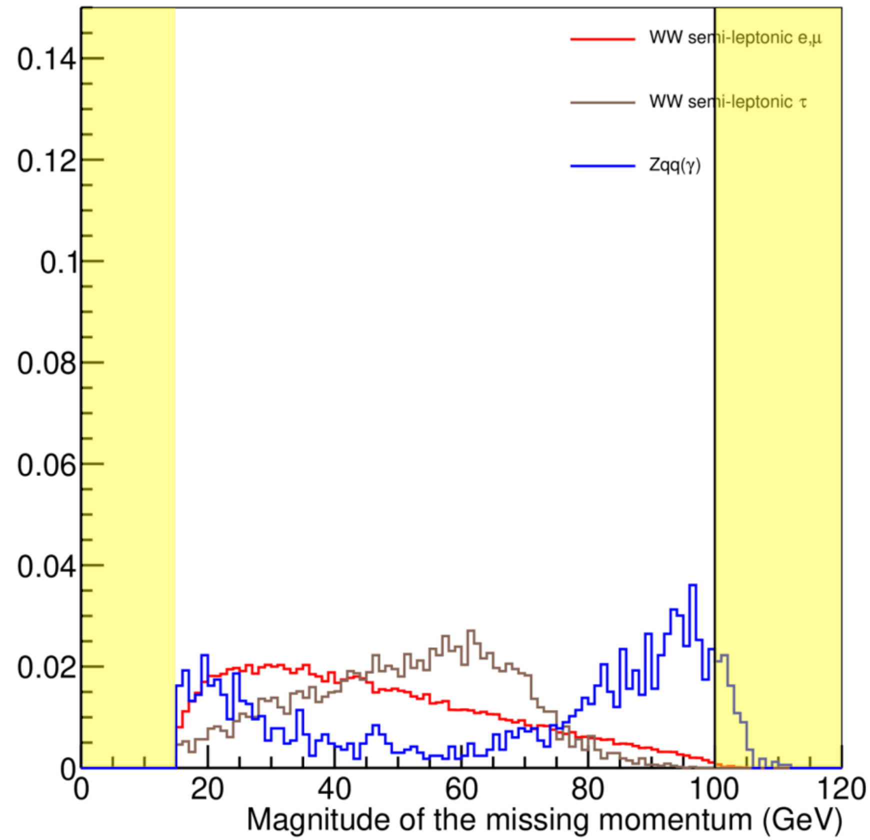
Remove mainly WW -> τ & hadronic decays, Zqq(γ)

Cuts on missing momentum (Normalized to the same area) :

Before all cuts

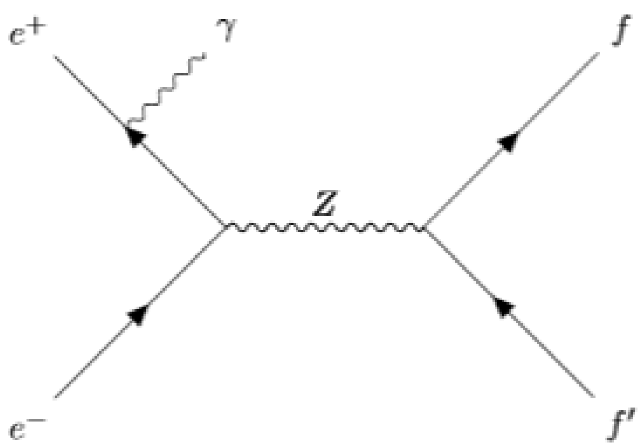


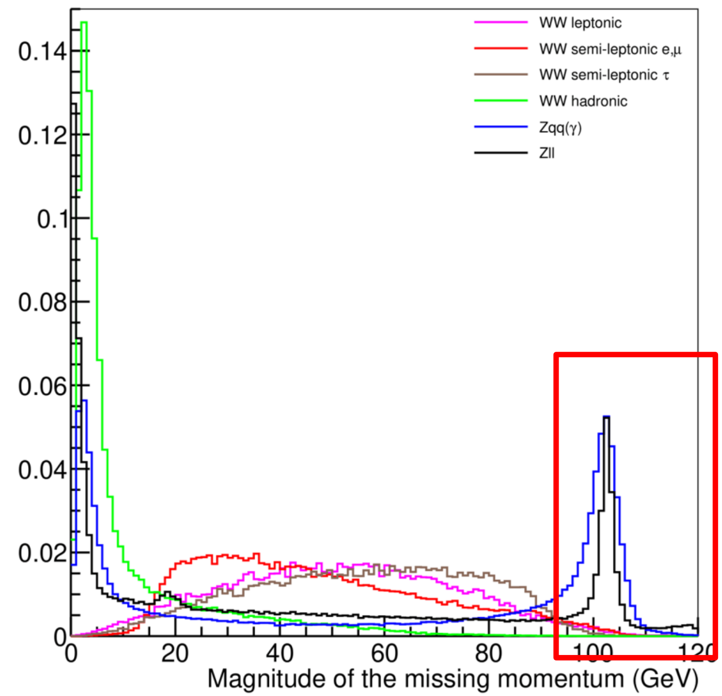
After previous cuts



Remove Zqq(γ)

- Radiative return (Z produced on-shell)
- Expected photon energy : 102 GeV
- Photon is lost in the beam pipe





Objective : maximise final purity with at least 80% signal efficiency

→ Each cut > 97% efficiency

Cut defintion :

- C1 : Charged multiplicity > 5
- C2 : Charged multiplicity < 25
- C3 : Charged energy > 72 GeV
- C4 : 1 Lepton with 20 GeV
- C5 : Missing momentum > 15 GeV
- C6 : Missing momentum < 100 GeV
- C7 : Transverse energy > 72 GeV

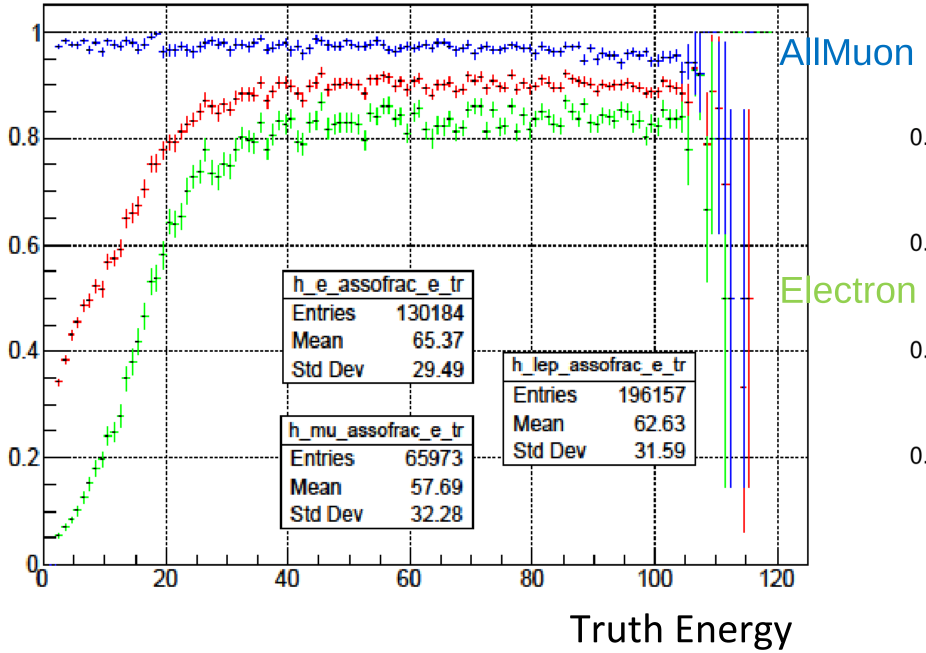
Cut	Signal WW sl e, μ		BKG 1 WW sl τ		BKG 2 WW lep	BKG 3 WW had	BKG 4 Zqq(γ)	BKG 5 Zll	$\frac{S}{S+B}$ %
No	23932530		11994624		8666757	37606089	263200000	68800000	5.778 ± 0.001
C1	23916090	0.999	11987637	0.999	32880	37606089	257843880	652912	7.203 ± 0.001
C2	22975311	0.961	11429088	0.953	32880	8554143	225733480	652912	8.529 ± 0.002
C3	22143036	0.964	8711556	0.762	25071	8100399	137943120	536984	12.478 ± 0.002
C4	19670460	0.888	1999926	0.230	10275	35757	2982056	31304	79.542 ± 0.008
C5	19361799	0.984	1958415	0.979	9864	15207	2188508	20640	82.200 ± 0.008
C6	19331796	0.998	1958415	1	9864	15207	1997688	19952	82.852 ± 0.008
C7	19006695	0.983	1841280	0.940	7809	15207	1179136	14792	86.140 ± 0.007
ε	79.4 ± 0.5		15.4 ± 0.2		0.09 ± 0.02	0.040 ± 0.007	0.45 ± 0.02	0.022 ± 0.003	

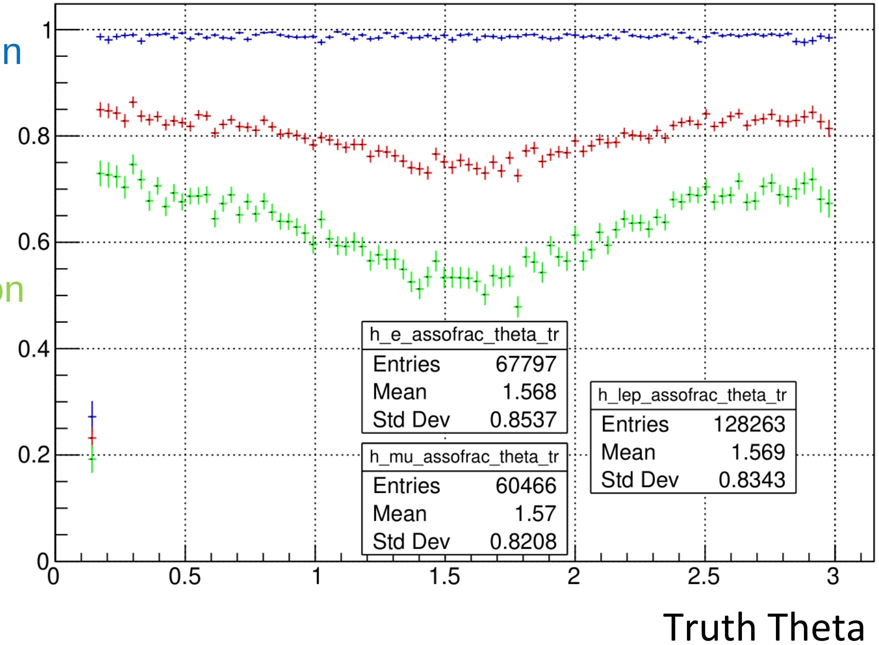
Zqq & $WW \rightarrow jj\ \tau\upsilon$ remain the main background but they are very much suppressed

➔ Signal efficiency of C4 is too low

Signal efficiency of C4 is too low because electron efficiency is low

Cut on E > 2GeV

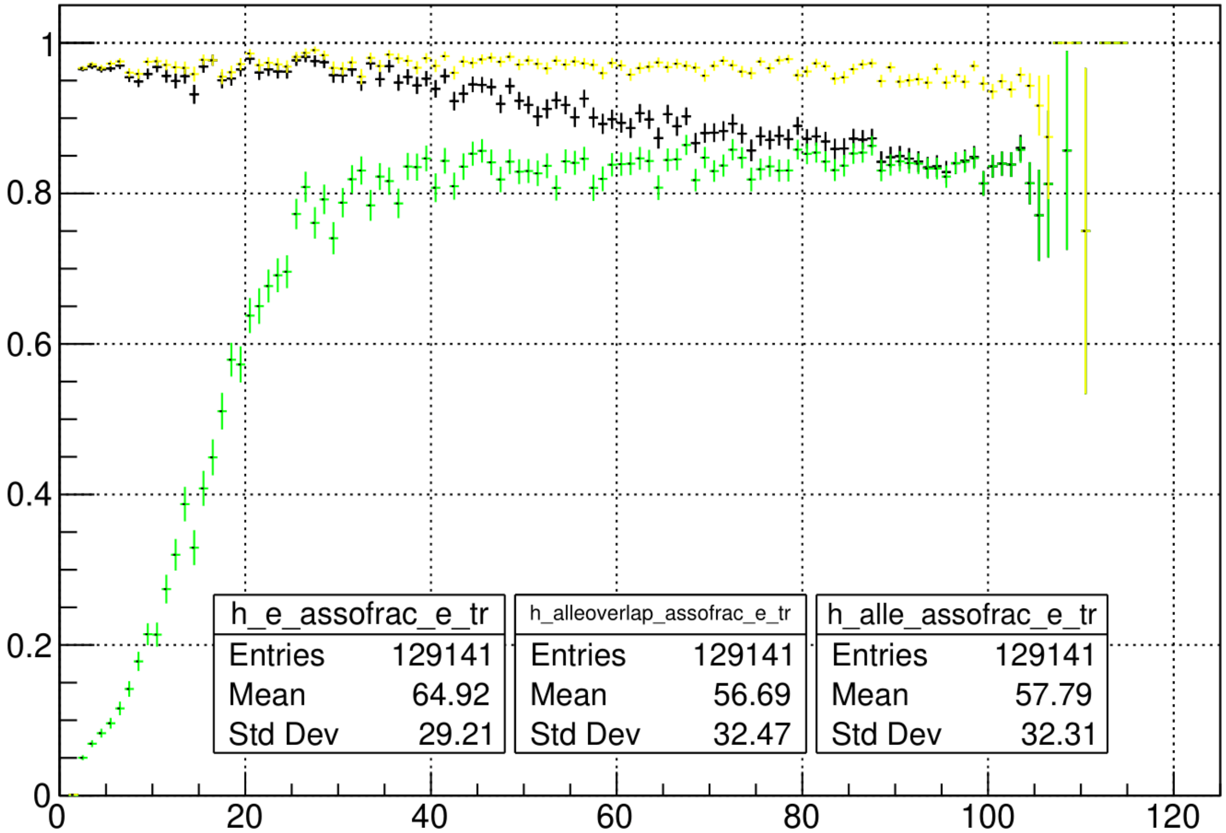




Fraction of truth final state charged leptons that are associated with a reconstructed particle identified as a muon or associated electron

Detector & association efficiency

Electron efficiency is too low because isolation requirement is too tight
(Thanks to Emmanuel) Two new containers are implemented

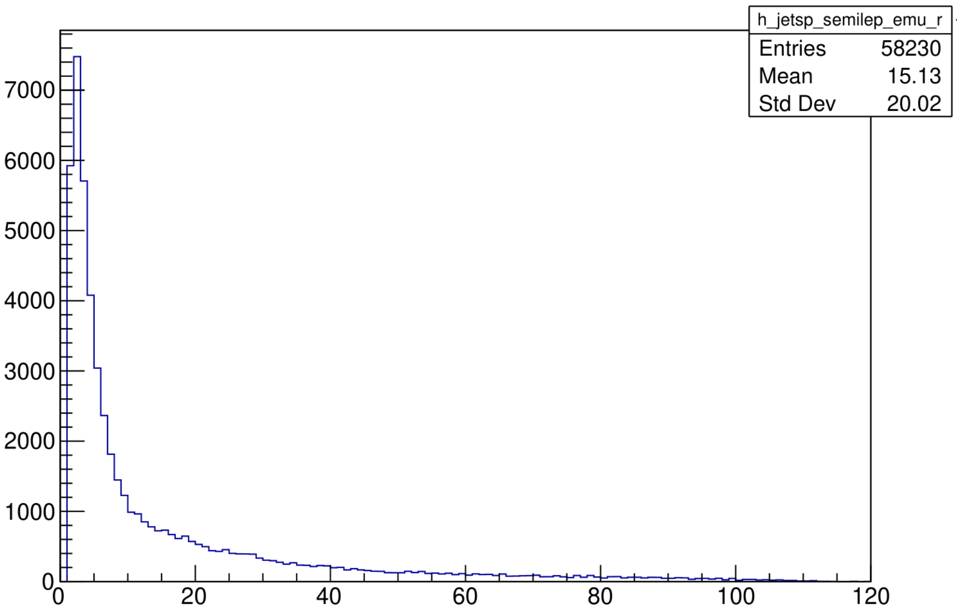


Fraction of truth final state electrons that are associated with a reconstructed particle in the collection Electron (Green), AllElectron (Yellow) and AllElectronOverlapRemoval (Black)

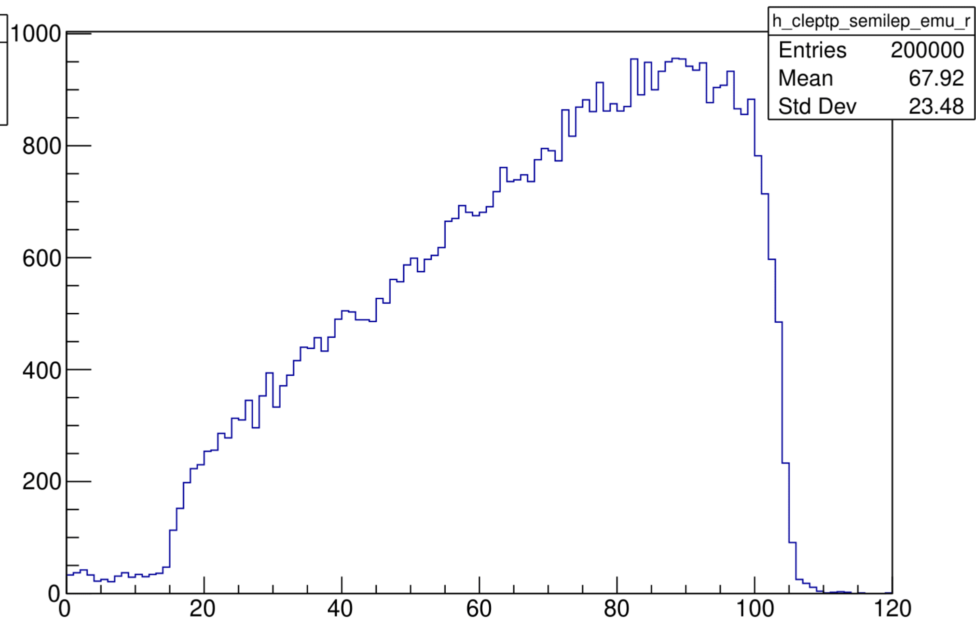
But the overlap applied to AllElectron removes good electrons
(electrons with a close by radiated photon)

Jets study – Jets too soft

Momentum distribution in signal events $WW \rightarrow jj\, e\nu$ & $WW \rightarrow jj\, \mu\nu$



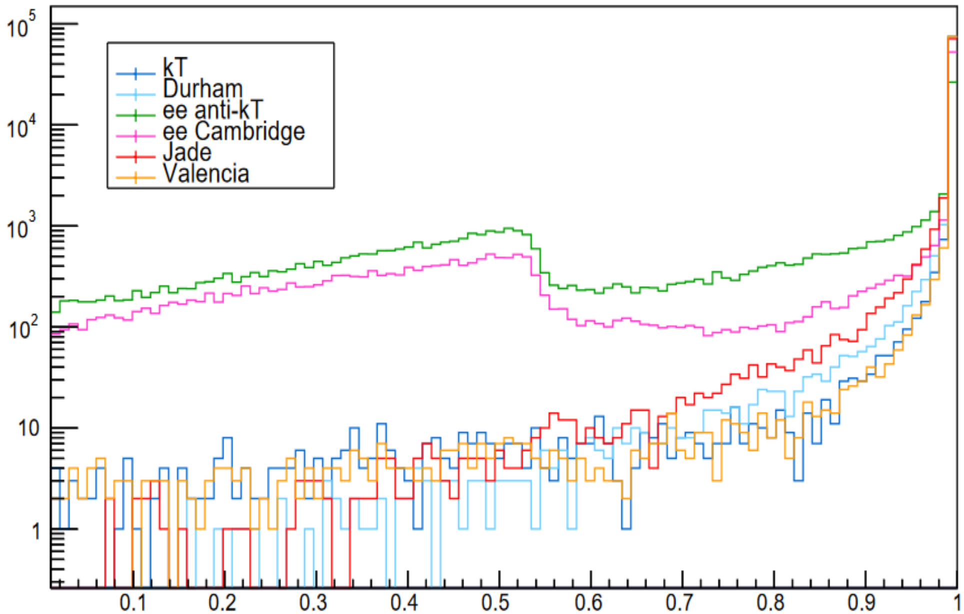
Highest jet momentum in the Jet collection



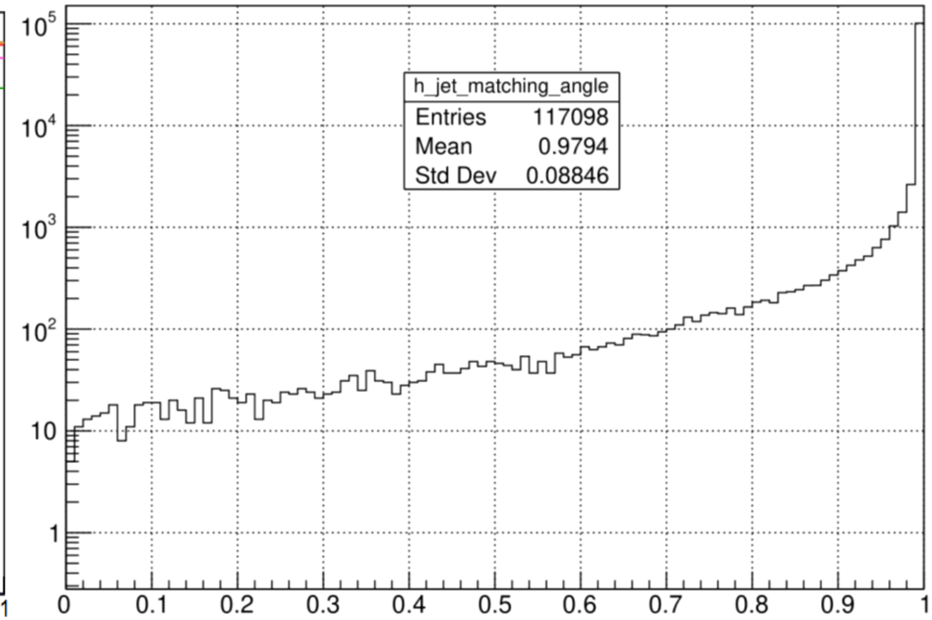
Highest charged lepton momentum

Jets in the File are too soft

Cosine of the minimum angle between a truth and reco jet



Plot by Julie Munch Torndal

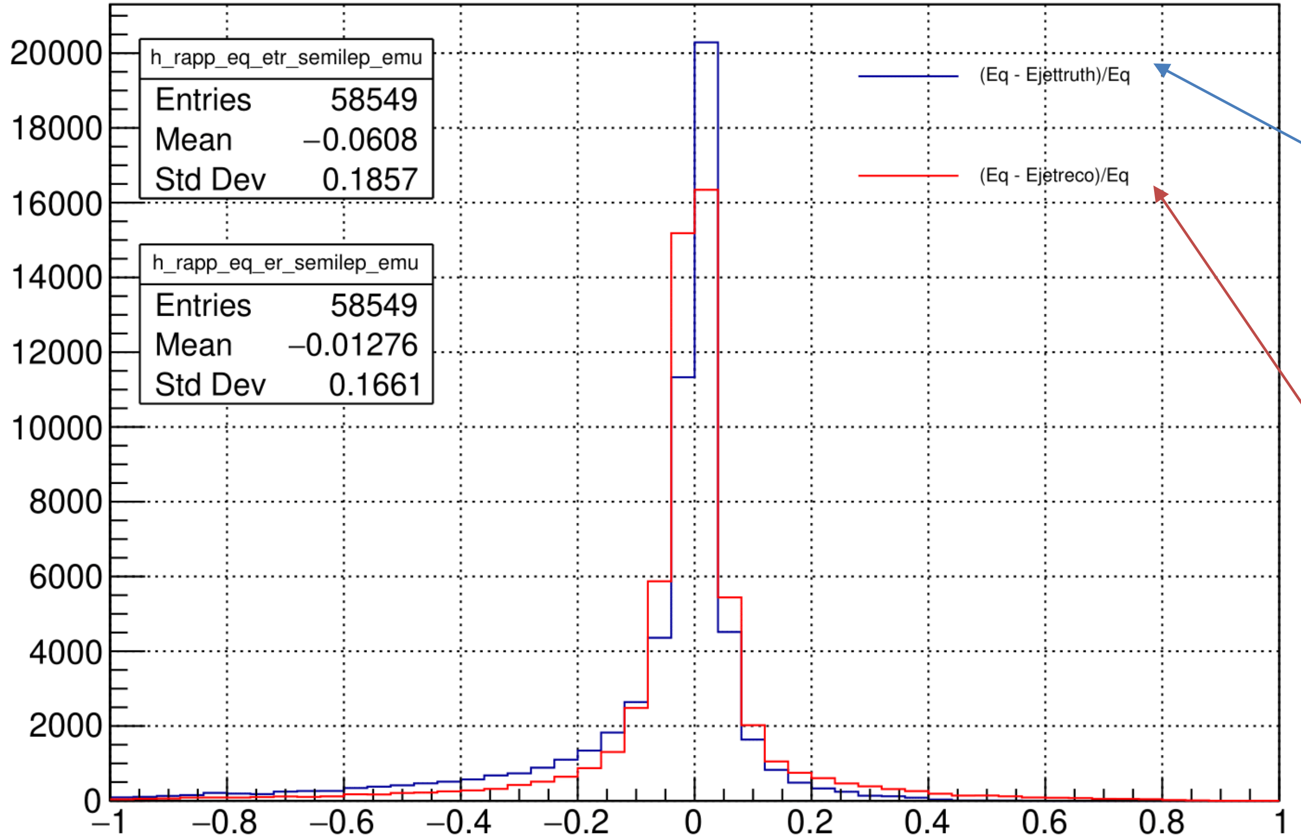


Durham algorithm, forcing 2 jets

- Keep the Durham algorithm
- Forcing 2 jets
- Input Particles
  - Reco : All particles > 500MeV except highest energy lepton
  - Truth : All particles > 500MeV Status = 1, except highest energy lepton & neutrinos

Quark energy reconstruction

Reco & truth jets clustering done with Durham algorithm
Eq found with quark from W energy (truth)
Relative difference between leading quark and leading jet

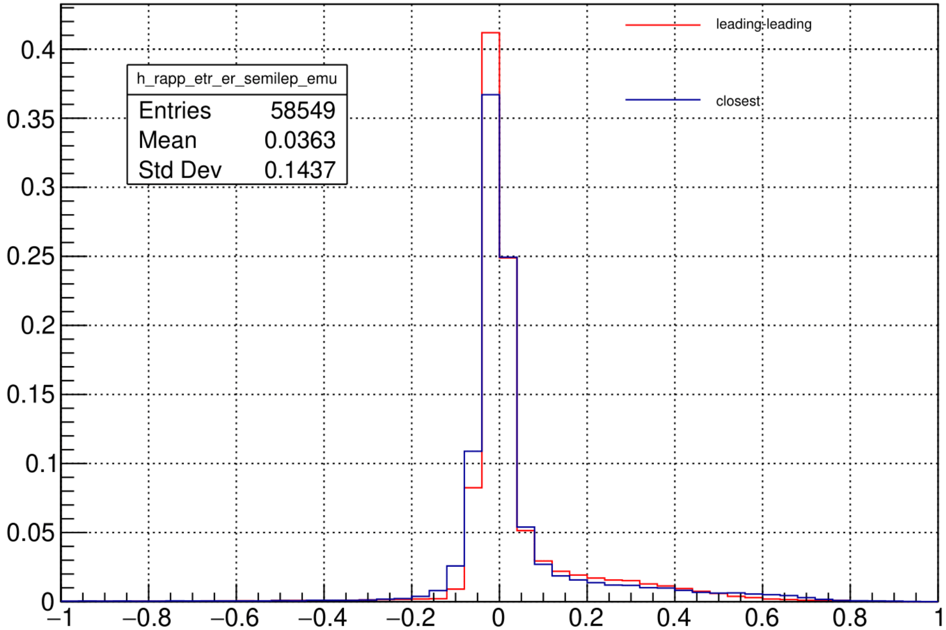


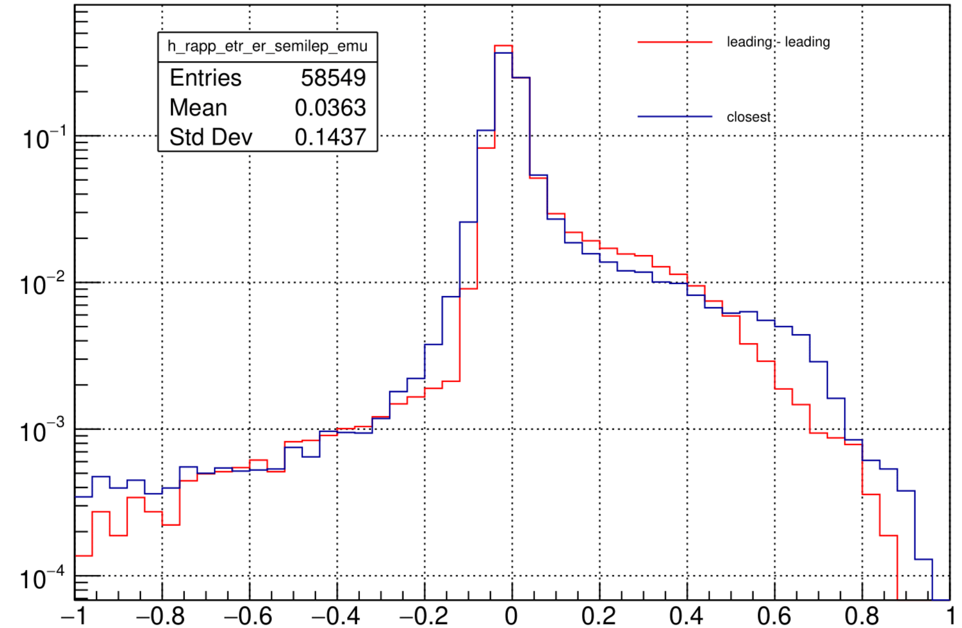
$$\frac{E_{quark} - E_{jet\ truth}}{E_{quark}}$$

$$\frac{E_{quark} - E_{jet\ reco}}{E_{quark}}$$

Jets study – Leading association vs Angle association

Jet study matching truth-reco with closest angle

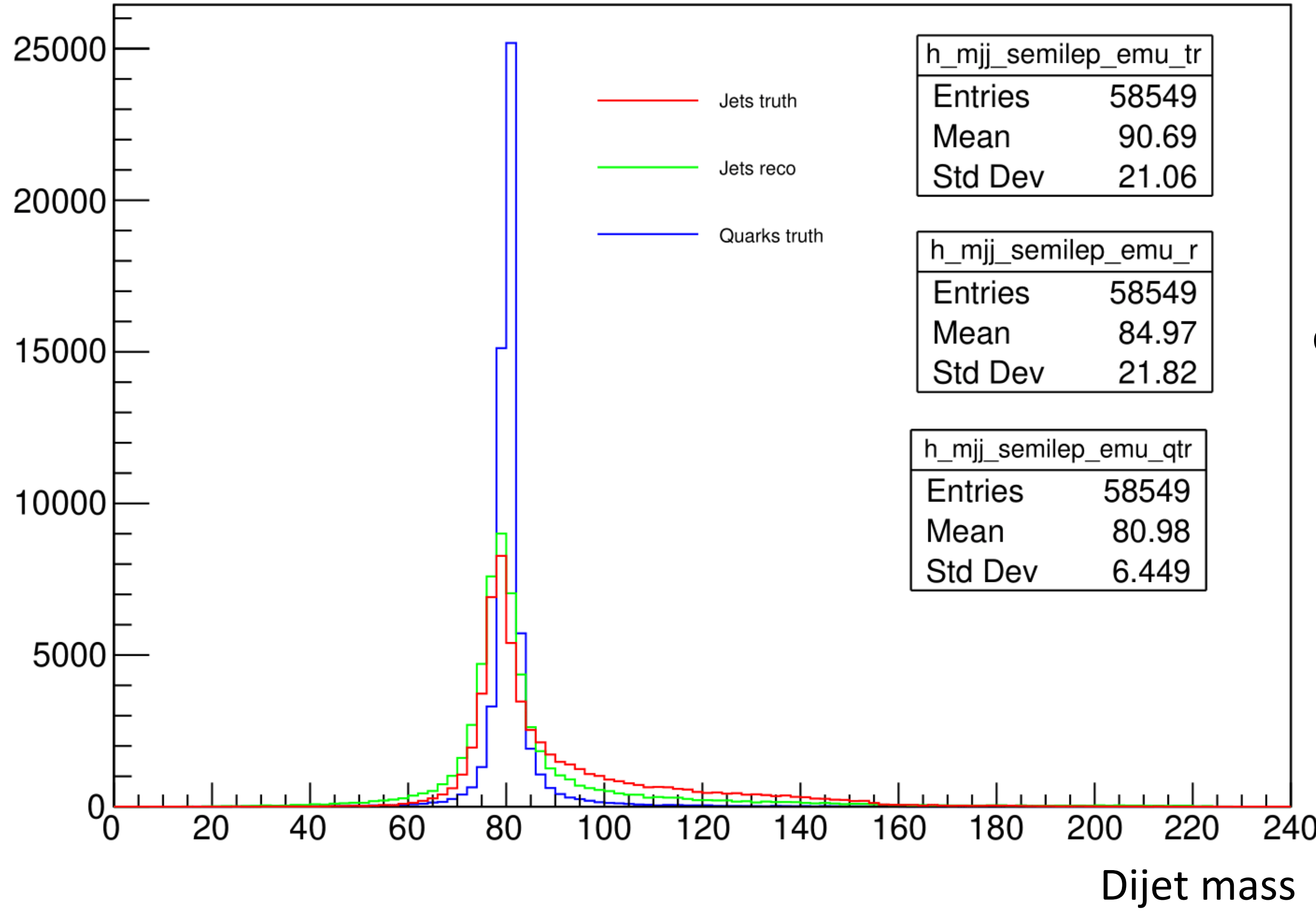




$$\frac{E_{jet\ truth} - E_{jet\ reco}}{E_{jet\ truth}}$$

$$\frac{E_{jet\ truth} - E_{jet\ reco}}{E_{jet\ truth}}$$

Jets study – Reconstructed W mass

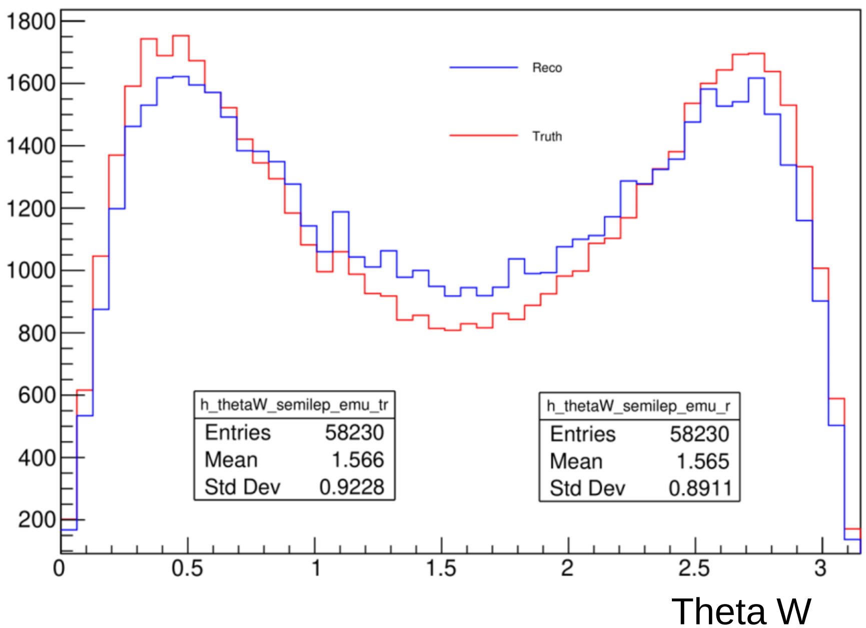


Comparison :

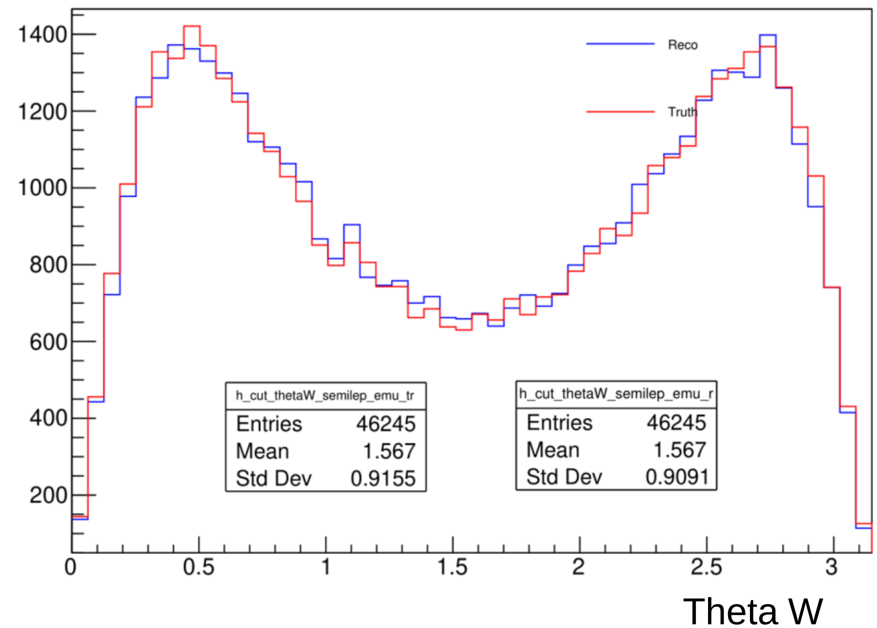
- W mass from quarks (blue)
- W mass from truth jets (red)
- W mass from reco jets (green)

Variable of interest : Theta distribution of the W boson

Before all cuts

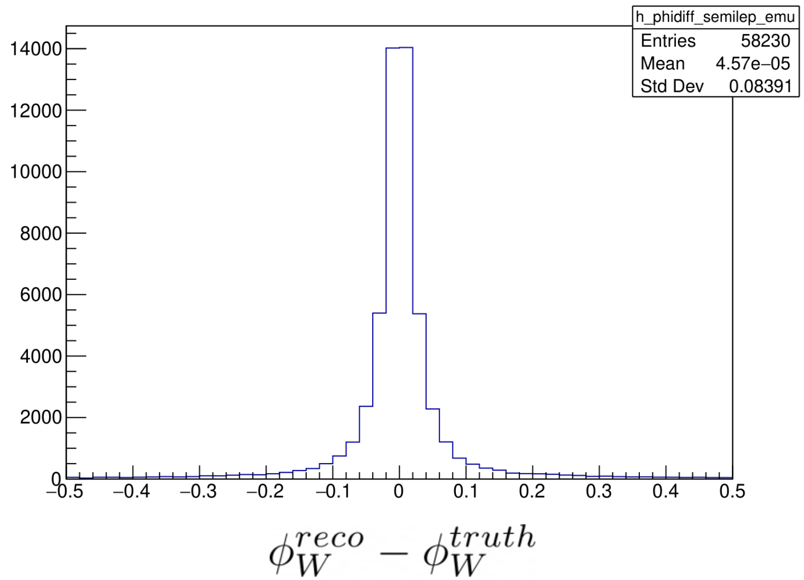


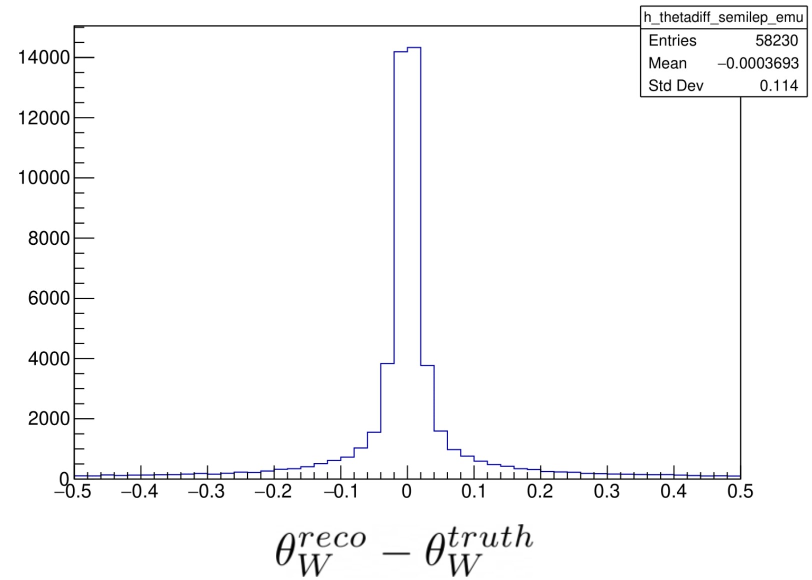
After all cuts

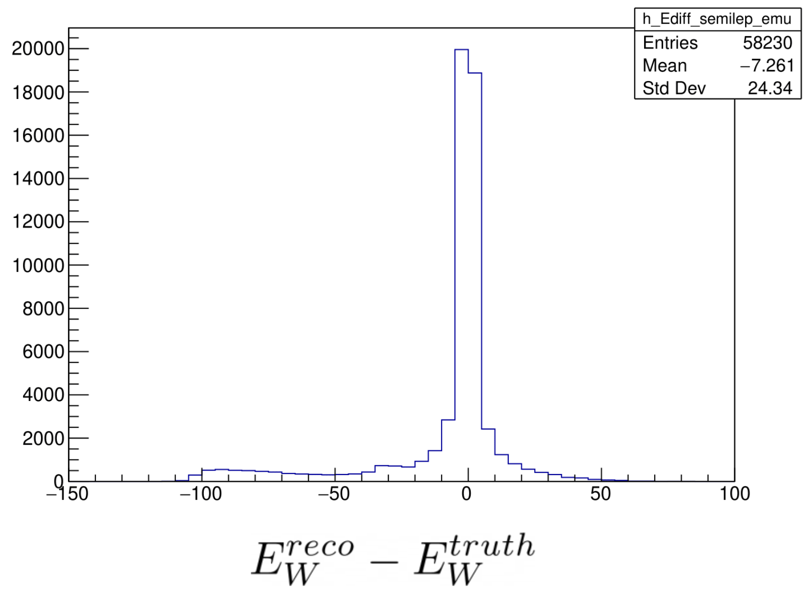


$$\tilde{p}_W^{reco} = \tilde{p}_{\text{missing momentum}}^{reco} + \tilde{p}_{\text{highest energy lepton}}^{reco}$$

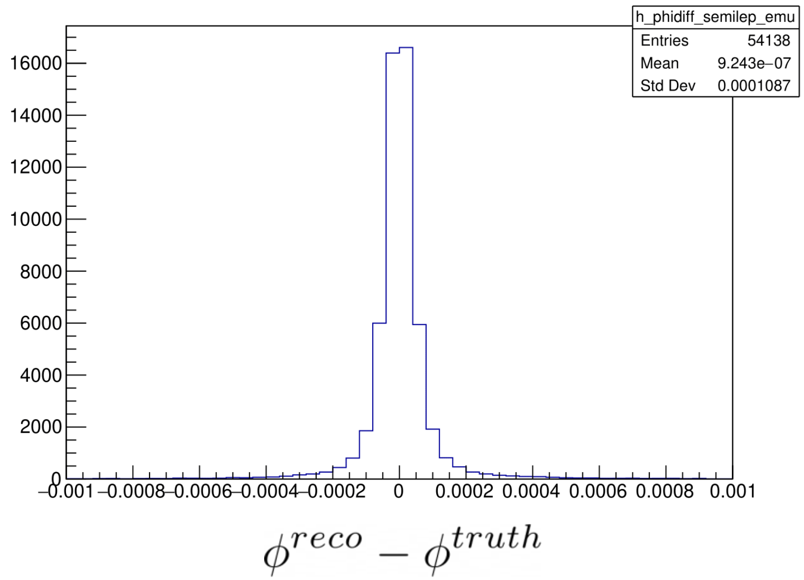
W resolution before kinematic fit

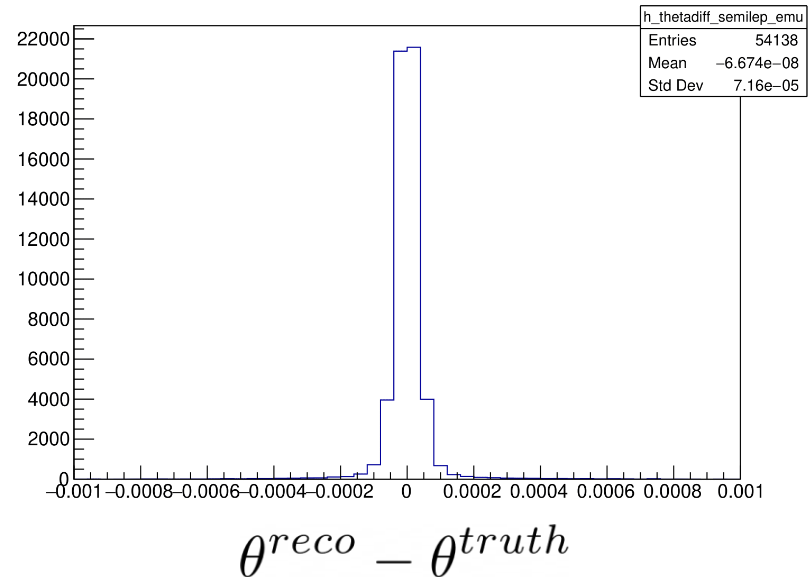


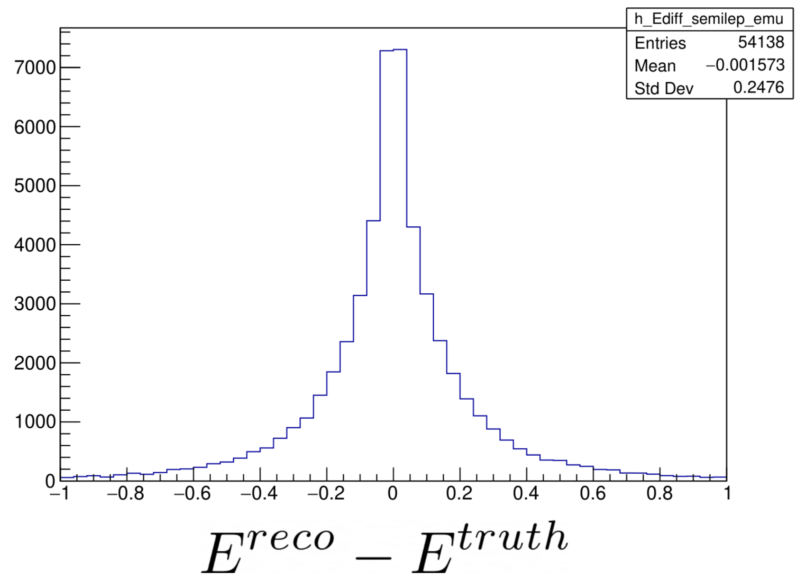




Lepton resolution







Conclusion :

- All elements in place to start a kinematic fit
- Electrons to be used is AllElectron (removing non isolated but without including the photons in the isolation cone)
  - It should improve a bit the signal efficiency
- Found too soft jets in the samples
  - Use custom made jets (Durham – investigate different parameters)
- Verified that missing momentum in the file is computed as expected (not shown)

Next steps :

- Implement a kinematic fit
- Study the $WW \rightarrow jj\ \tau\upsilon$ contribution and evaluate it with a BDT
- Extract the reconstructed angular variables