Higgs mass measurement with Z recoil analysis

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Context

Hi, there !

- ATLAS physicist
  - Expertise in Higgs physics (VH, $H \to b\bar{b}$; combination)
  - Expertise in statistical analyses
- FCC Noble Liquid Calorimetry project
  - Main FCC involvement
  - Project with CERN (Martin Aleksa), Prague, Edinburgh
  - Work on electrodes and readout electronics

FCC Physics

- 6-weeks internship of Olivier Salin
- Good excuse to do a bit of FCC physics analysis
- Picked Higgs mass measurement from recoil as an easy topic for a young student, and with already existing software base

Software

- No prior experience with FCC software at all
- Followed the tutorials and asked questions
  - Overall very pleasant journey
  - Managed to run on a machine with cvmfs access at IJCLab
  - Copied MC samples locally
  - Managed to run new MC samples (Pythia+DELPHES) easily ($Z\gamma^*$)
- Selections and plots using the FCCAnalyses
  - Using mHrecoil-mumu code
  - And updating to status of Ang's studies as of end of May
  - Made contribution to FCC software (!) by improving runDataFrameFinal to make use of full power of RDataFrame
- mrecoil fits using Ang's fitting code

Huge thanks to Clément !

Recoil analysis with $Z \to \mu\mu$

- Started from Ang's preselection
- Tried several kinematic variables, some of them found in ILC theses on the subject (H. Li, M. Ruan)
- Included Z/γ^* background (private sample, as official one was not yet available)
- Signal/backgrounds always evaluated in mrecoil window around 125 GeV
- Tried several types of selections

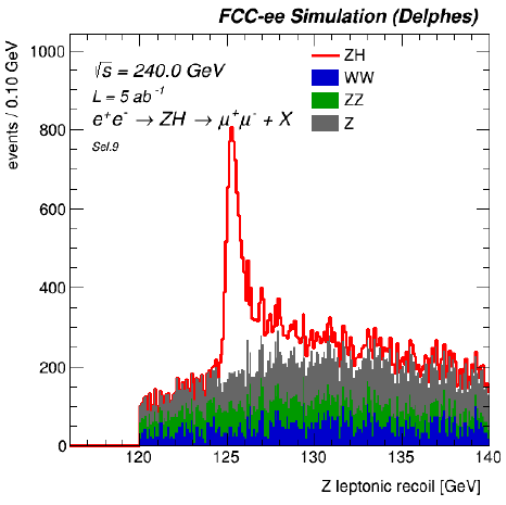
Basic selection	$M_{rec} \in [120.140]$ GeV $M_z \in [86.96]$ GeV $p_T^Z > 20\ GeV$
Kinematic selection Aim : use only Z decay in selection	Basic selection $\lvert p_z^Z \rvert < 40$ GeV $\theta \in [0.5, 2.5]$ rad cos(acol) ∈ [-0.9, -0.48] $\lvert\Delta\varphi\rvert < 2.7$ rad
Leading photon selection	Basic selection $p_T^\gamma < 20$ GeV
Missing energy selection	Basic selection $p_T^\gamma < 20$ GeV $\lvert$Missing_$p_z\rvert < 10$ GeV Missing_$p_T < 20$ GeV

Recoil analysis with $Z \to \mu\mu$ II

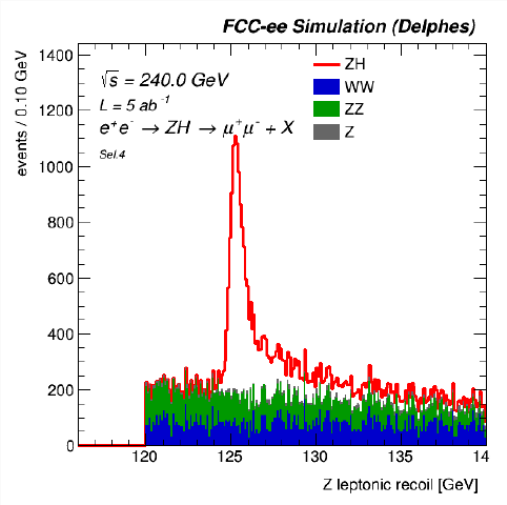
Z->μ+μ-, Lumi = 5 /ab , simulated:10^7	ZH	ZZ	WW	Zγ	Signal/Bruit	Significance
					rapport	S/√(S+B)
Section efficace (pb)	0.201037	1,35899	16,4385	4,6		
Total number of events	1005185	6794950	82192500	23000000		
# of mu+mu-	30084	434051	1044740	18295492	**0%**	7
Sel Basique: Mrec ∈ [120,140]GeV , pt>20 GeV, mz	18484	19612	16512	39288	**25%**	60
Sel cinematique: (Mrec,pt,mz, θ,Δφ,pz,acol,kin)	11815	9896	9674	18696	**31%**	53
Sel photon : pt_γ<20 GeV ,Mrec,pt,mz	17350	17265	15879	2139	**49%**	76
Sel énergie manquante (|Missing_pz|, Missing_pt,photon)	12133	4168	8,2	719	**248%**	93

- Cutflows are as expected:
  - Photon selection kills Z with ISR
  - MET/Mpz selections kill bkgs with neutrinos (and ISR in beam pipe)

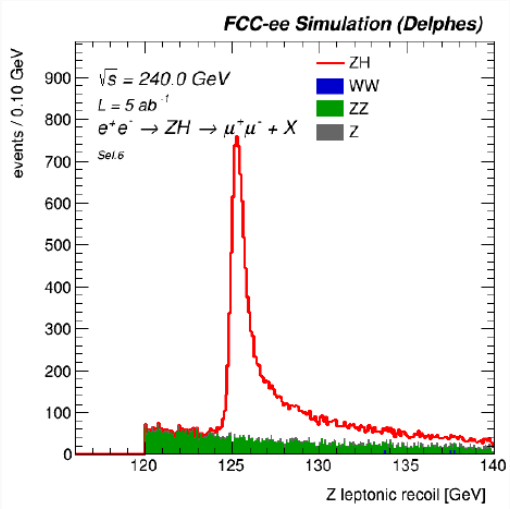
Pretty plots



Z-only selection



Selection on photons



Selection with MET/MPz

Consequences on Higgs decays

Désintégration	Prédiction	Sel Basique	Sel Cinematique	Sel Photon	Sel Energie manquante
cc	2,9%	2,90%	3,01%	2,78%	3,48%
bb	58,20%	57,04%	59,91%	57,89%	66,24%
μμ	0,02%	0,02%	0,00%	0,02%	0,02%
ττ	6,30%	6,56%	5,24%	5,69%	1,49%
gg	8,20%	8,23%	8,38%	8,40%	11,36%
γγ	0,23%	0,22%	0,00%	0,00%	0,00%
Zγ	0,15%	0,24%	0,06%	0,07%	0,07%
ZZ	2,60%	3,75%	3,53%	3,76%	2,99%
WW	21,40%	21,06%	19,88%	21,38%	14,36%

- Selections using event info beyond Z kinematics bias Higgs decays
- Best S/B may not be suitable for inclusive ZH cross-section measurement
  - As it requires same efficiency for all decay modes

Mass measurement

	Sel Basique	Sel Cinematique	Sel Photon	Sel Energie manquante
estimateur de masse (GeV)	125,303	125,307	125,296	125,314
incertitude (MeV)	6,6	10,1	6,2	4,9
S/B	25%	31%	49%	248%
Signal ZH	18484	11815	17350	12133

- Best mass resolution obtained from combination of high S/B and large signal statistics
  - MET/MPz selection works remarkably well
- Issues with fitting code found along the way
  - Too many parameters: fit with all parameters free tends to be unstable
  - Also quite large (anti-)correlations between params
  - Performed Toy study to estimate the precision of the mass measurement over 1000 toys (RMS of gaussian fit to the postfit values of the mass parameter), but results also unstable there.

Cutflow with the same cut

30084 in the $\mu^+\mu^-$ channel

Z->e+e-, Lumi = 5 /ab , simulated:10^7	ZH	ZZ	WW	Zμ+μ-	Signal/Bkg rapport	Significance S/sqrt(S+B)
Cross section (pb)	0.201037	1,35899	16,4385	4,6		
Total number of events	1005185	6794950	82192500	23000000		
Number of e+e-	23915	344811	827193	13169358	**0%**	6
Basic selection	14629	15832	14005	33189	**23%**	52
Kinematic selection	9413	8134	7841	15584	**30%**	47
Leading photon selection	13718	13844	13471	2168	**47%**	66
Missing energy	9503	3306	8	634	**241%**	82

Attempted same analysis in electron channel

- Consciously leaving aside the missing backgrounds specific to this channel
- Much lower signal yield found
  - Traced back to a too tight isolation in DELPHES card
  - Checked by reproducing few signal samples with varying isolation cone and isolation cut
- Too good electron resolution
  - i.e resolution as good as pions/muons
  - No Bremstrahlung effect in DELPHES as far as I understand
  - Smeared manually electrons to $1\% + 3|7|10|15\%/\sqrt{(E)}$
  - Unfortunately end results not very reliable because of fit instabilities (still all in 5-20 MeV range)

Conclusions

- Very pleasant journey through FCC analysis
- Some interesting findings along the way
  - Physics lessons
  - Limitations of current fastsim
- I now know I can easily perform physics benchmarks when we reach a reasonable fullsim description of the LAr calo
  - Provided there is adequate description of electrons by a combined tracking/calo code