Overlay events in Delphes simulation at high energy CLIC

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Motivations: Inert Doublet Model

SM-like Higgs:

$$\phi_{SM} = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(v + h + i\xi) \end{pmatrix}$$

„Higgs boson”: h

IDM Higgs:

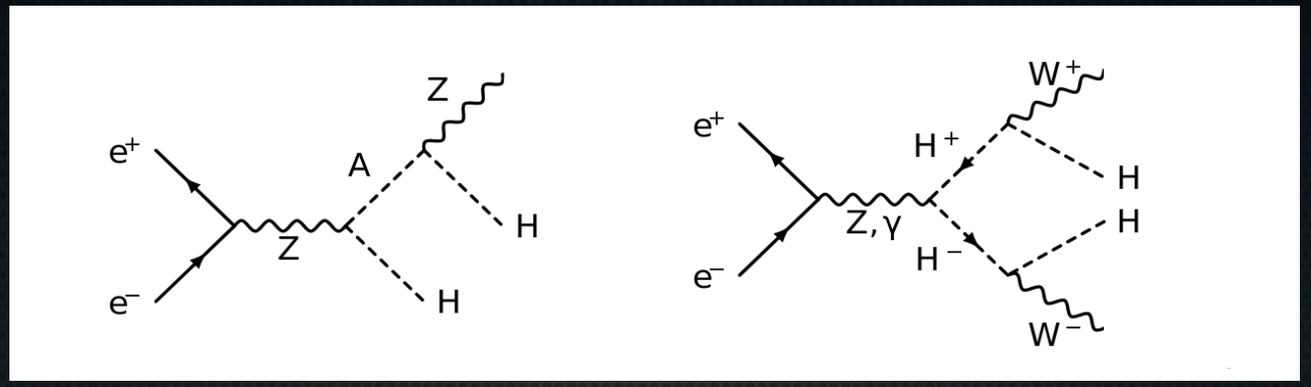
$$\phi_D = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(H + iA) \end{pmatrix}$$

New particles: $H^\pm, H, A$

- Additional scalars does not couple to fermions on tree level
- Lightest of the new particles is stable
- 5 free parameters in the model with existing constraints

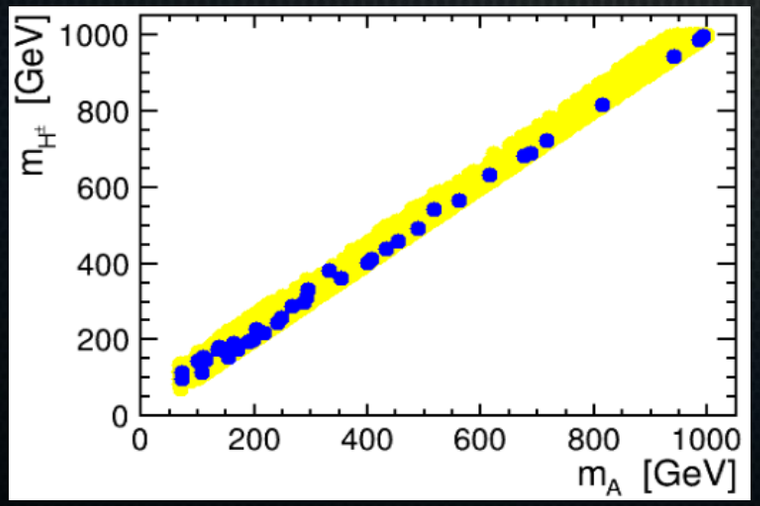
Motivations: Benchmark points

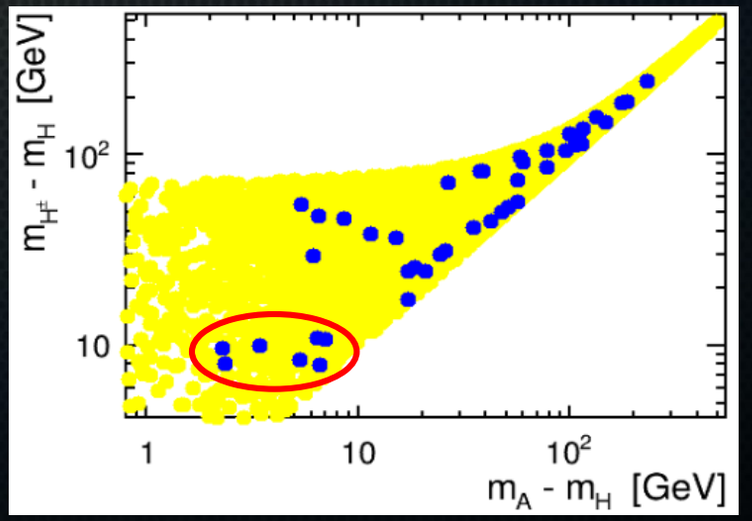
Considered 23 benchmark points from **JHEP 1812 (2018) 081, arXiv:1809.07712** for two production scenarios:



Mass difference affects virtuality of W boson!

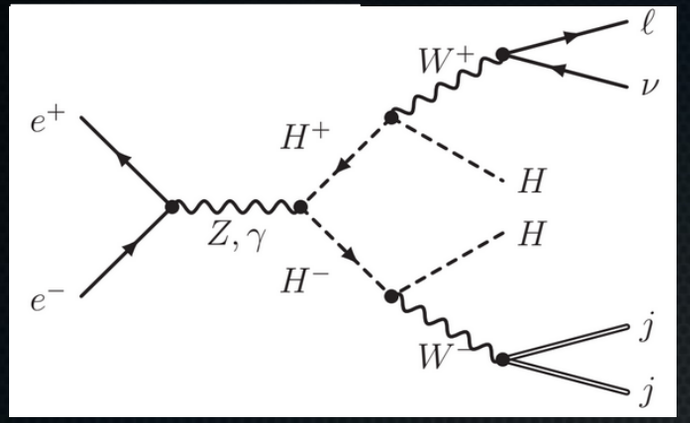
A.F. Żarnecki, ALPS2019





Motivations: Strategy

Semi-leptonic channel



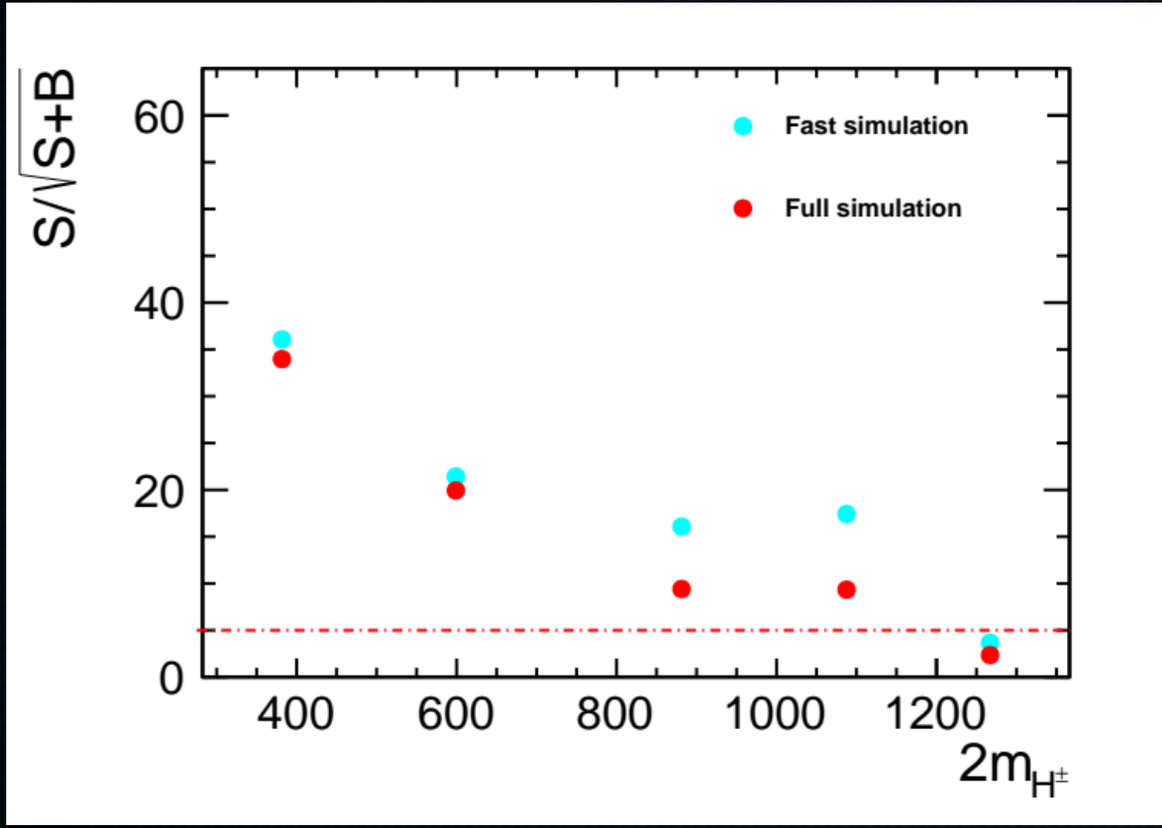
Expected **signature** of the final state:
One lepton: e or μ, and a **pair of jets**

- Use CLIC beam spectra for **1.5 TeV (2000 fb^{-1})** and **3 TeV (4000 fb^{-1})**
- Generate samples with **Whizard 2.7.0**
- Use **Delphes** fast simulation to simulate detector response

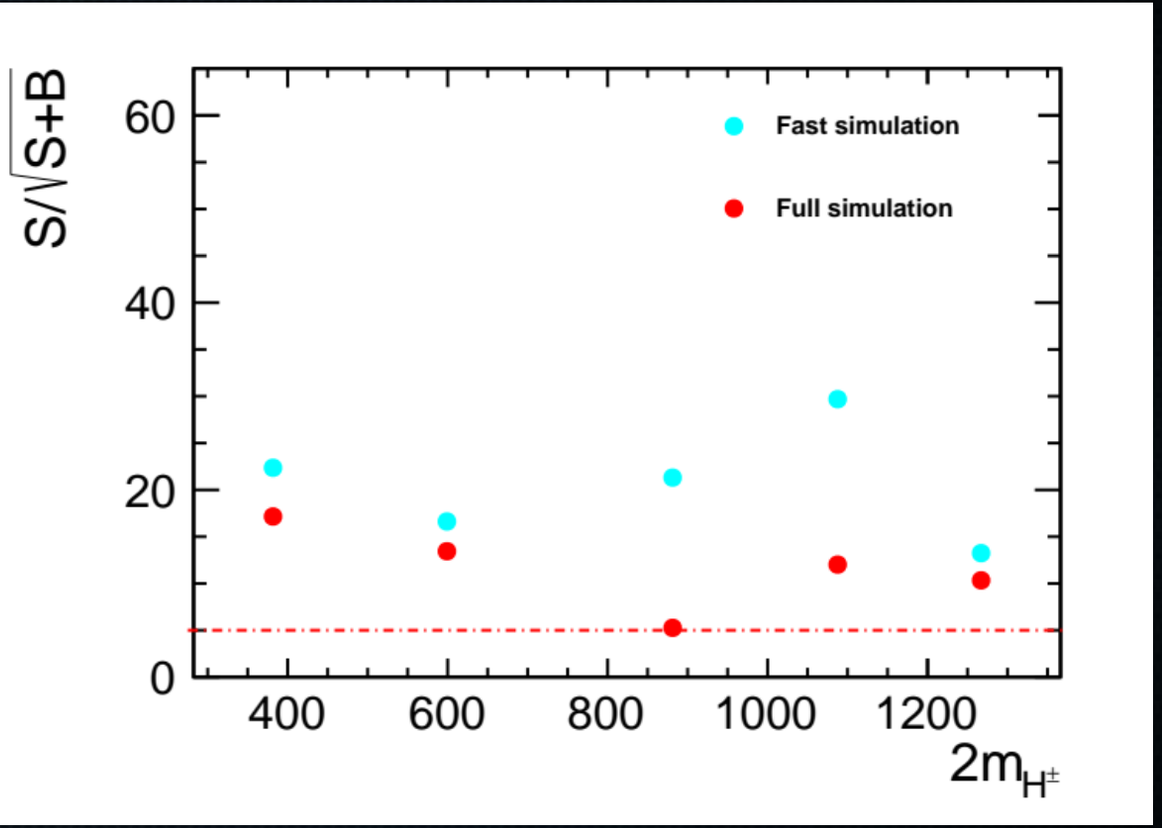
Make validation for 5 benchmarks using full simulation study

Motivations: Results

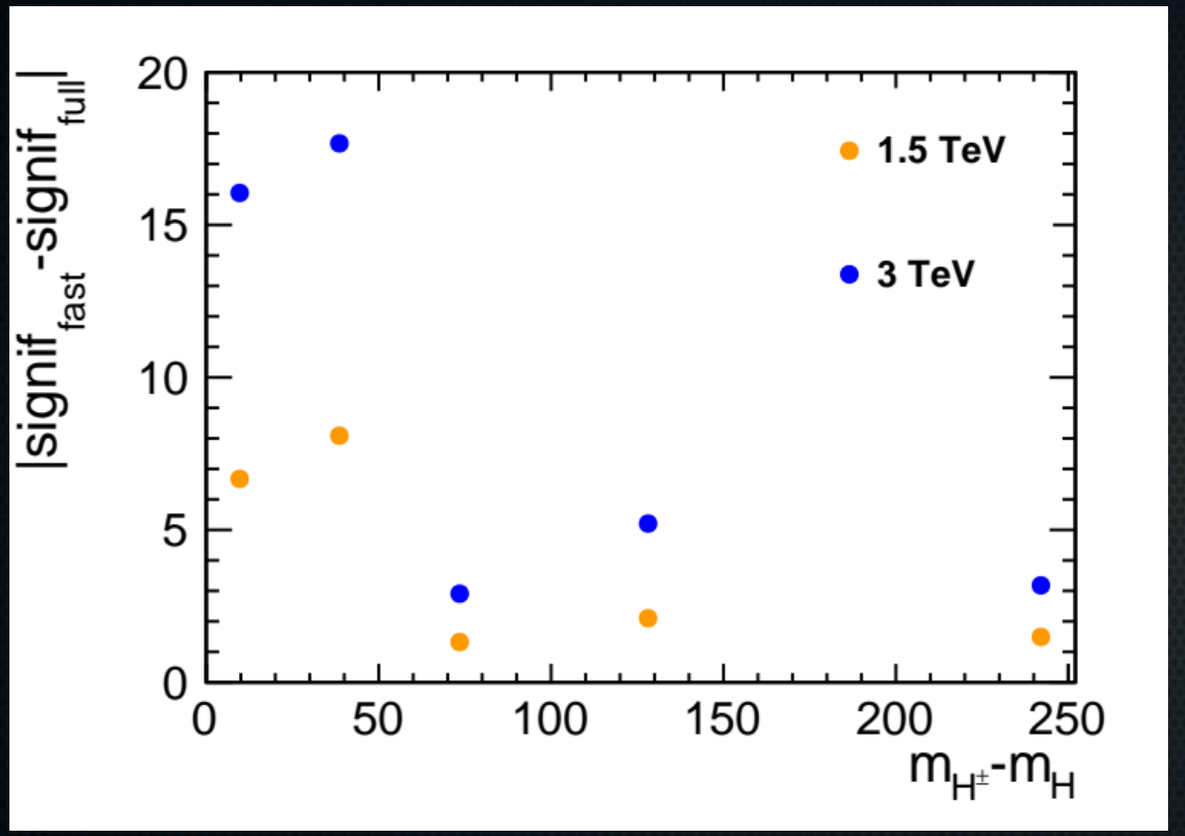
1.5 TeV



3 TeV



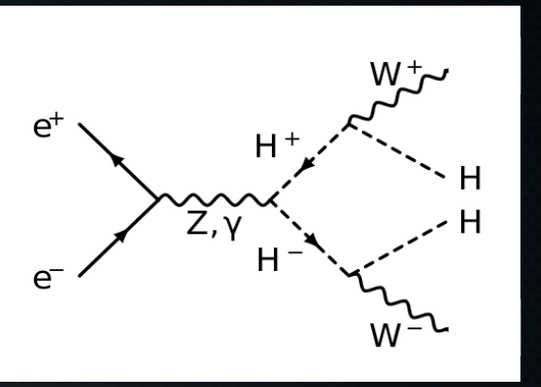
Motivations: Results

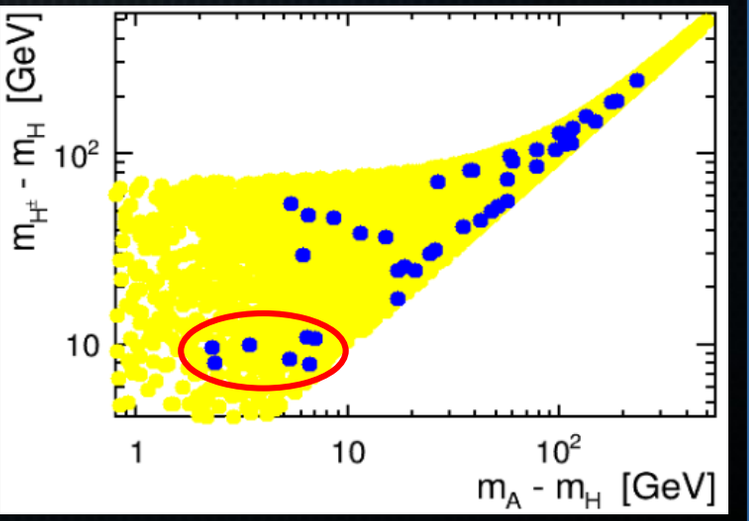


Huge influence of $\gamma\gamma \to \mathrm{had.}$ background!

It would be useful to implement it in Delphes

Mass difference affects virtuality of W boson!





Pile-up in full simulation

- $\gamma\gamma \to \mathrm{had.}$ events overlaid on „hard“ events

Generator files on grid:

/ilc/prod/clic/1.4tev/gghad/...

/ilc/prod/clic/3tev/gghad/...

- Timing cuts applied on reconstructed PFOs to reduce background contribution

Pile-up in Delphes

- It is possible to add pile-up events in Delphes (designed for LHC) ⟶ (binary .pileup file)

- Random events from binary file merged with sample

- Number of overlaid events drawn from selected (Poisson, Uniform) distribution with given mean

<u>However</u>:

- No possibility for CLICdet to apply timing cuts on PFOs

CLIC $\gamma\gamma \to \mathrm{had.}$ generator files used to produce PileUp file

Timing cuts

DefaultSelectedPFOs from CLIC CDR, arXiv:1202.5940

Region	p_T range	time cut
Photons		
central	$0.75\ \text{GeV} \leq p_T < 4.0\ \text{GeV}$	$t < 2.0$ ns
$\cos\theta \leq 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	$t < 1.0$ ns
forward	$0.75\ \text{GeV} \leq p_T < 4.0\ \text{GeV}$	$t < 2.0$ ns
$\cos\theta > 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	$t < 1.0$ ns
neutral hadrons		
central	$0.75\ \text{GeV} \leq p_T < 8.0\ \text{GeV}$	$t < 2.5$ ns
$\cos\theta \leq 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	$t < 1.5$ ns
forward	$0.75\ \text{GeV} \leq p_T < 8.0\ \text{GeV}$	$t < 2.0$ ns
$\cos\theta > 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	$t < 1.0$ ns
charged particles		
all	$0.75\ \text{GeV} \leq p_T < 4.0\ \text{GeV}$	$t < 3.0$ ns
	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	$t < 1.5$ ns

+ $|t| < 5$ ns for higher pT (assuming 10 ns window)

Approximate timing cuts

- **1 bunch crossing every 0.5 ns**
- Widest cut |t| < 5 ns for high pT corresponds to accepting 20 bunch crossings
- Tighter cuts accept respectively less particles
  e.g. |t| < 2 ns corresponds to 8 bunch crossings

Approximate timing cuts

- **1 bunch crossing every 0.5 ns**
- Widest cut |t| < 5 ns for high pT corresponds to accepting 20 bunch crossings
- Tighter cuts accept respectively less particles
  e.g. |t| < 2 ns corresponds to 8 bunch crossings

1. Overlay 20 bg. events per hard event ← (20 on average, Poisson)
2. Accept low-pT particles with probabilities based on cuts in CDR
3. Probability = t_{cut} / 5 ns

Region	p_T range	time cut
neutral hadrons		
central	0.75 GeV $\leq p_T <$ 8.0 GeV	t < 2.5 ns
$\cos\theta \leq 0.975$	0 GeV $\leq p_T <$ 0.75 GeV	t < 1.5 ns
forward	0.75 GeV $\leq p_T <$ 8.0 GeV	t < 2.0 ns
$\cos\theta > 0.975$	0 GeV $\leq p_T <$ 0.75 GeV	t < 1.0 ns

+ |t| < 5 ns for higher pT

Region	p_T range	Acceptance prob.
neutral hadrons		
central	0.75 GeV $\leq p_T <$ 8.0 GeV	$1/2$
$\cos\theta \leq 0.975$	0 GeV $\leq p_T <$ 0.75 GeV	$3/10$
forward	0.75 GeV $\leq p_T <$ 8.0 GeV	$2/5$
$\cos\theta > 0.975$	0 GeV $\leq p_T <$ 0.75 GeV	$1/5$

...but it neglects time correlation!

Approximate timing cuts

Solution:

~~Probability = t_{cut} / 5 ns~~

Every 20 overlay events accept particles from first **N events**,

where N = buch crossings number corresponding to cut

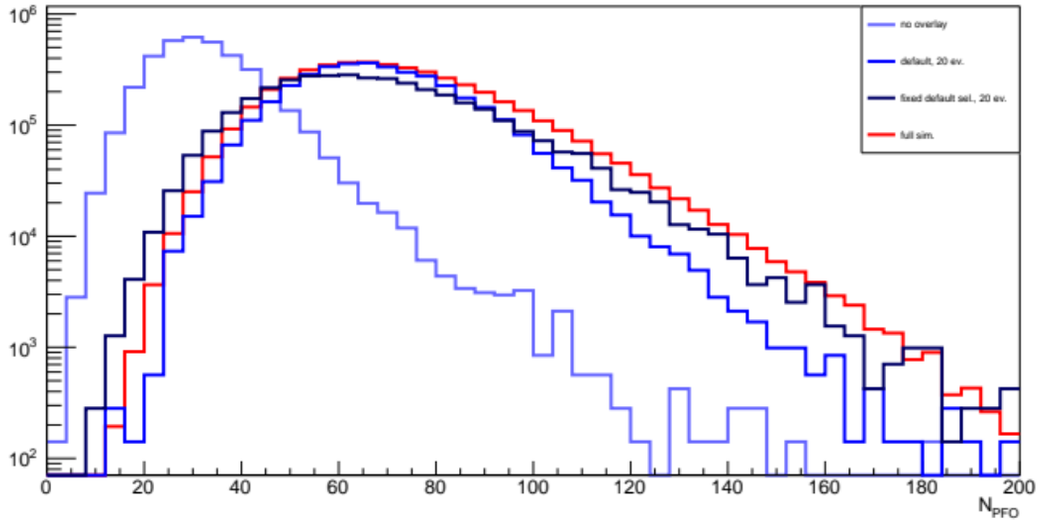
Region	p_T range	time cut
neutral hadrons		
central	$0.75\ \text{GeV} \leq p_T < 8.0\ \text{GeV}$	$t < 2.5$ ns
$\cos\theta \leq 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	$t < 1.5$ ns
forward	$0.75\ \text{GeV} \leq p_T < 8.0\ \text{GeV}$	$t < 2.0$ ns
$\cos\theta > 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	$t < 1.0$ ns

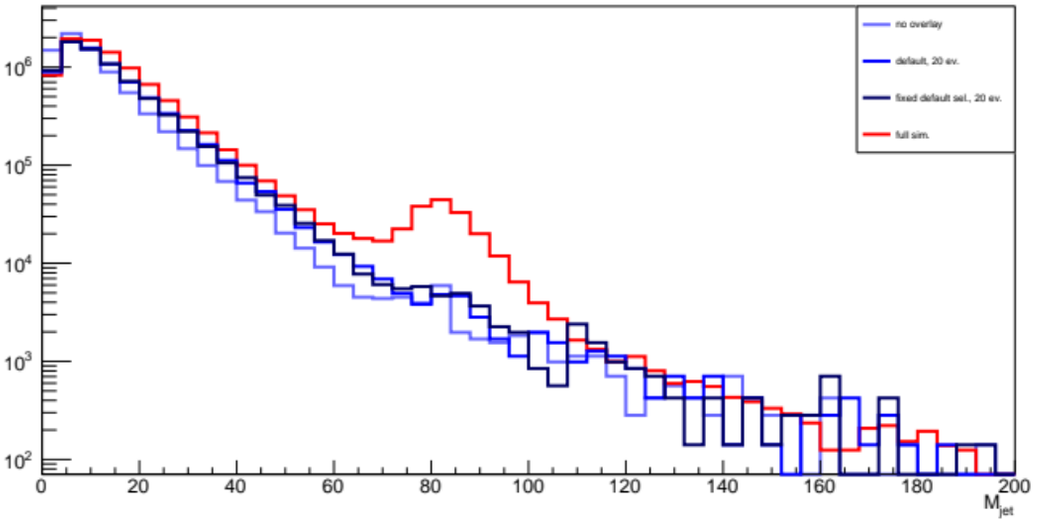
+ |t| < 5 ns for higher pT

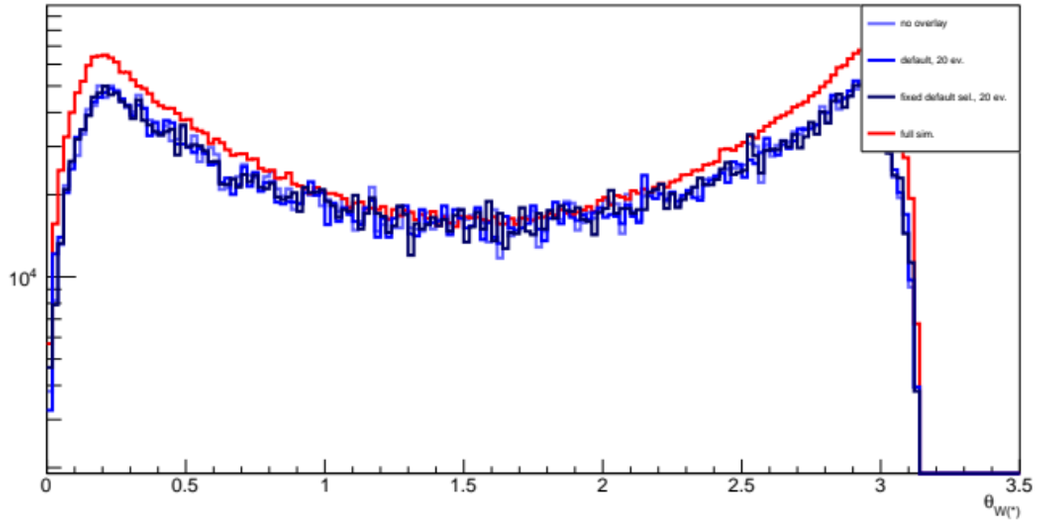
Region	p_T range	N
neutral hadrons		
central	$0.75\ \text{GeV} \leq p_T < 8.0\ \text{GeV}$	10
$\cos\theta \leq 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	6
forward	$0.75\ \text{GeV} \leq p_T < 8.0\ \text{GeV}$	8
$\cos\theta > 0.975$	$0\ \text{GeV} \leq p_T < 0.75\ \text{GeV}$	4

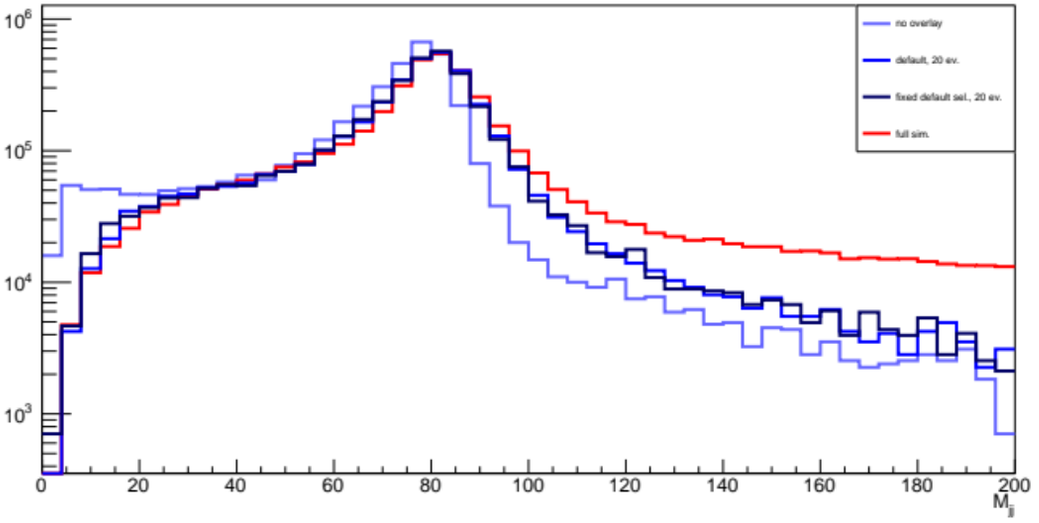
This should include the correlation

Results (qqlv background, 1.5 TeV), different approaches

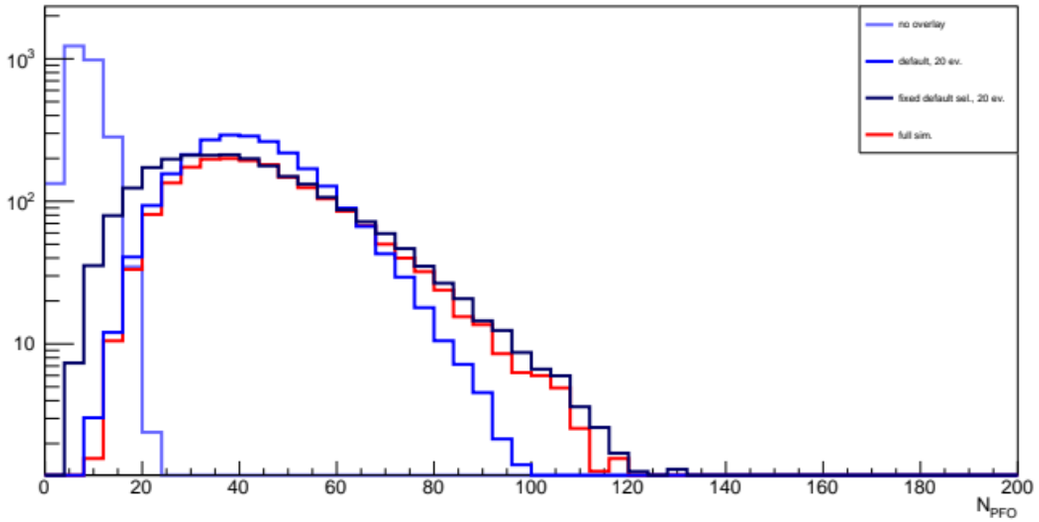


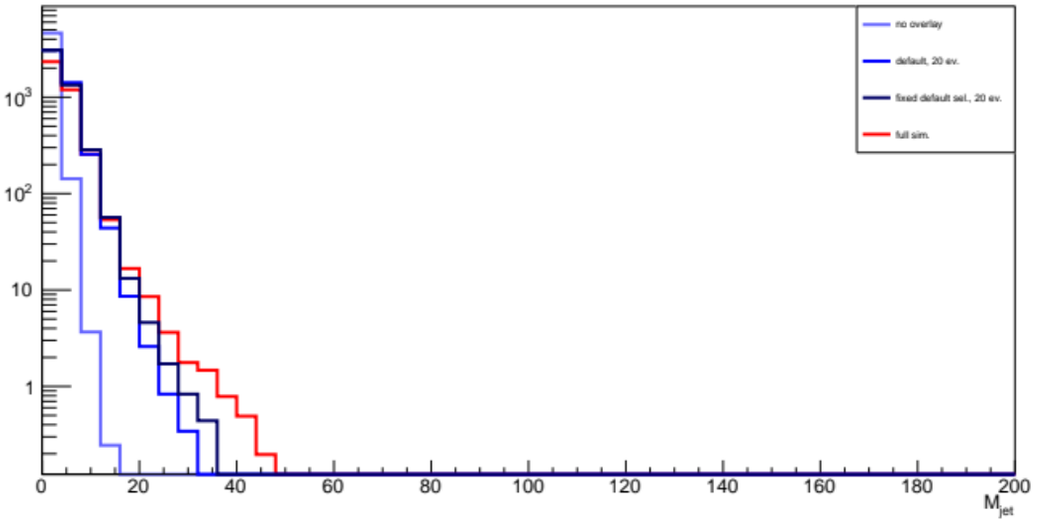


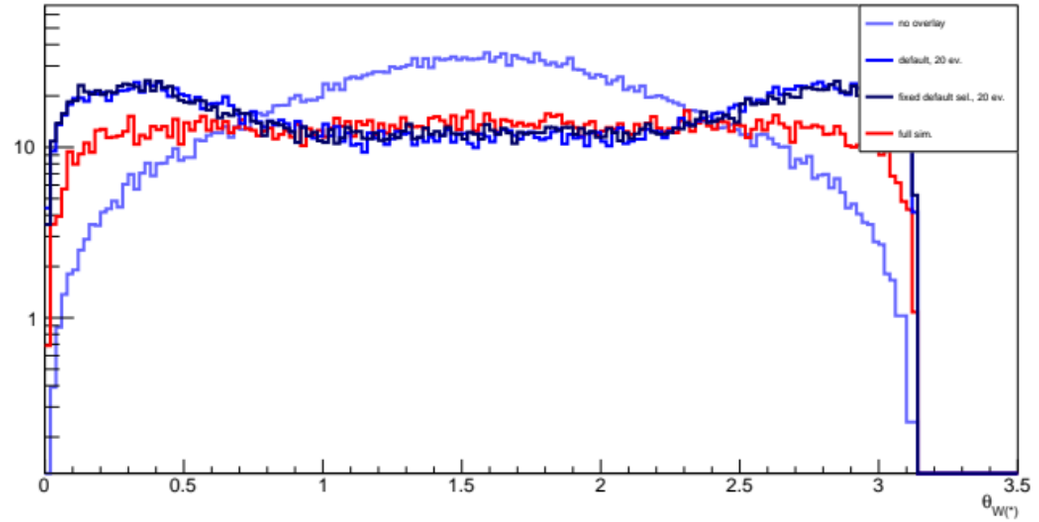


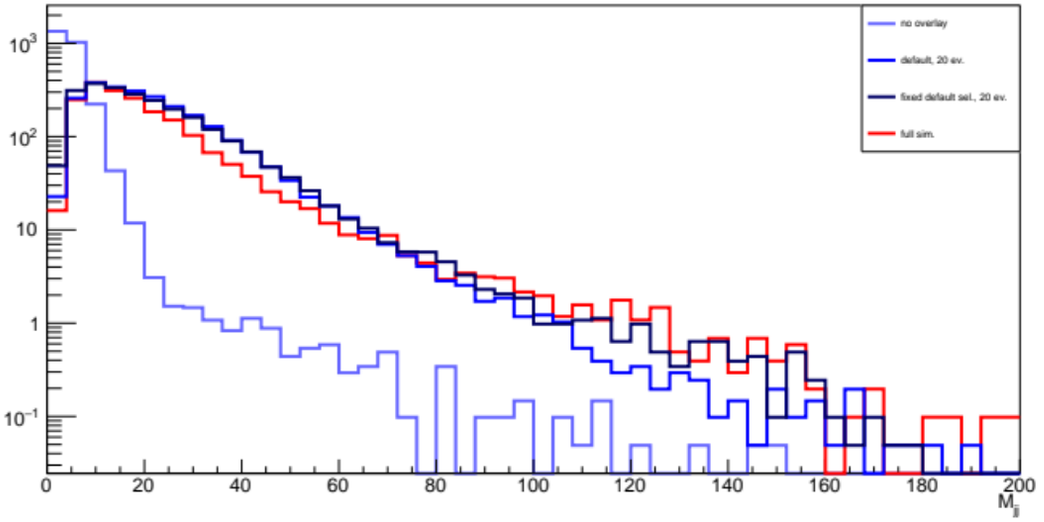


Results (HP17 signal, 1.5 TeV), different approaches

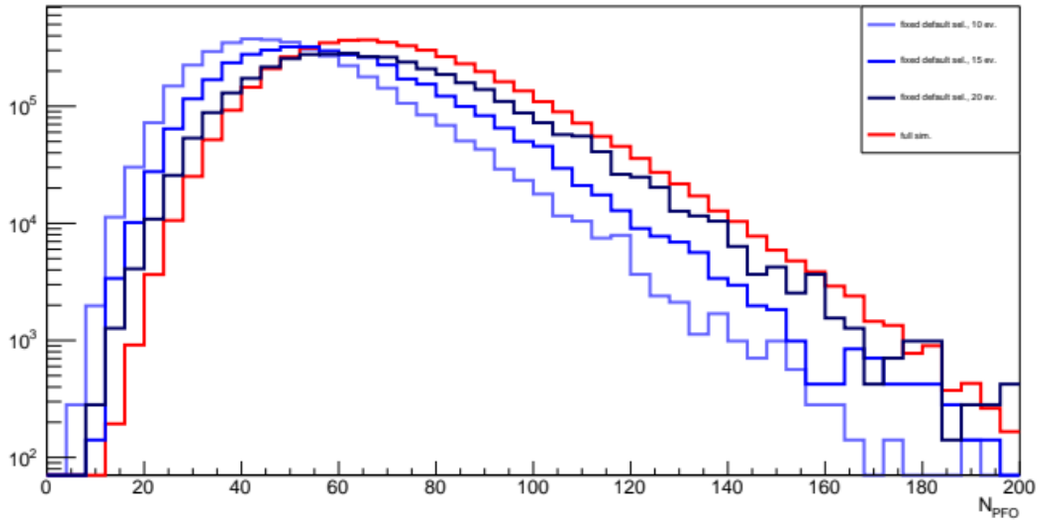


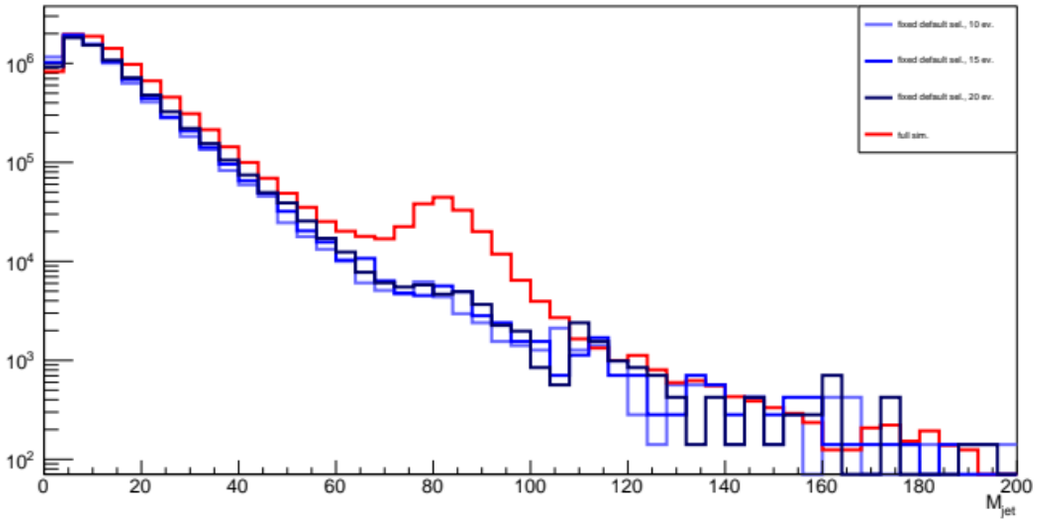


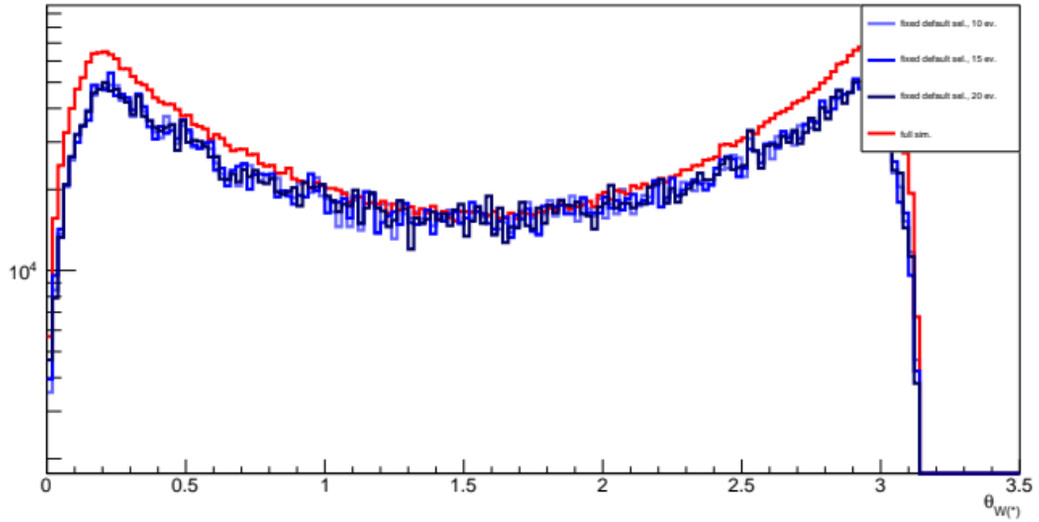


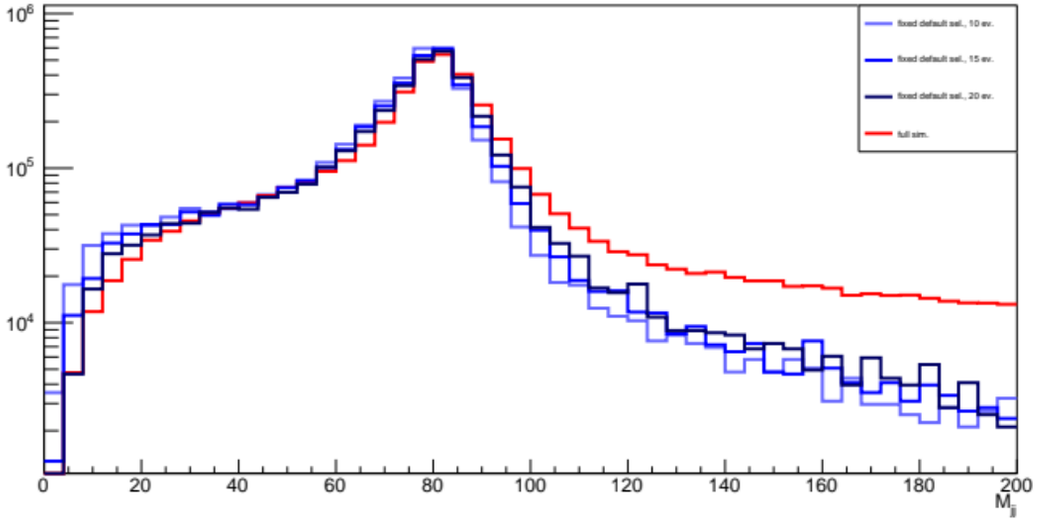


Number of overlaid events (qqlv, 1.5 TeV), second approach

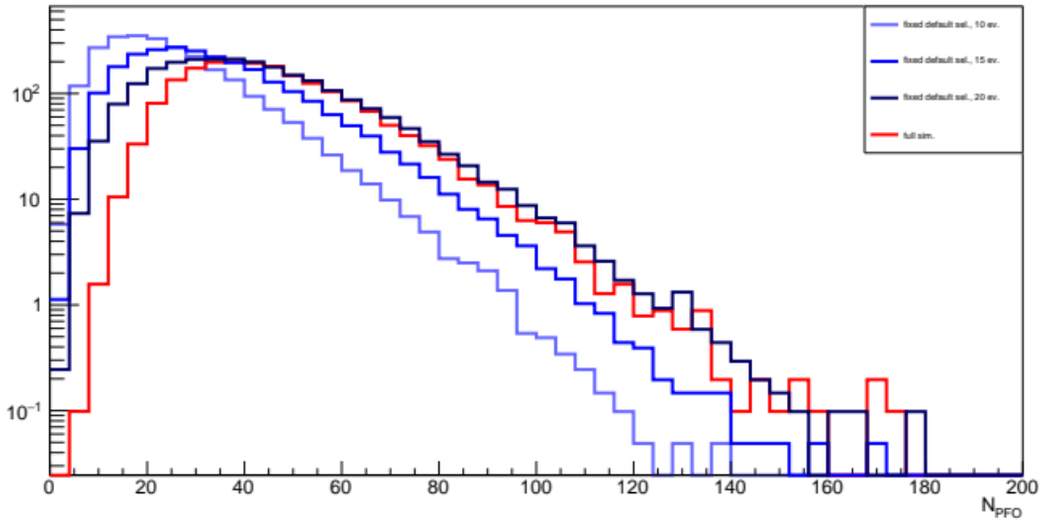


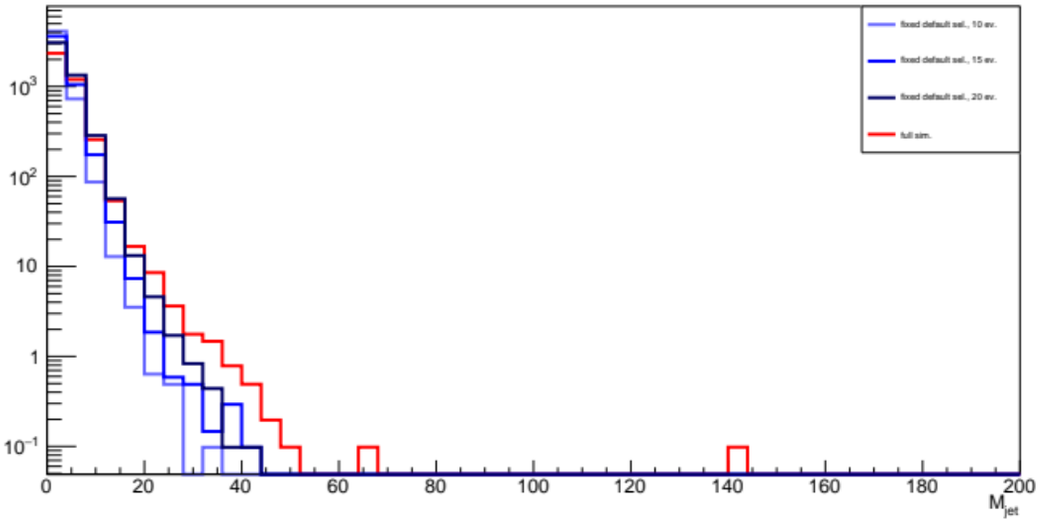


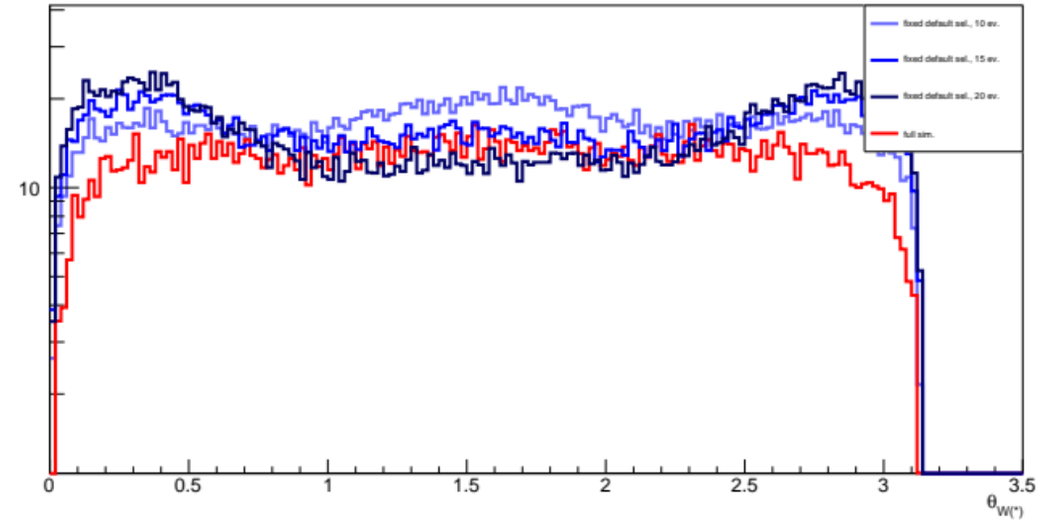


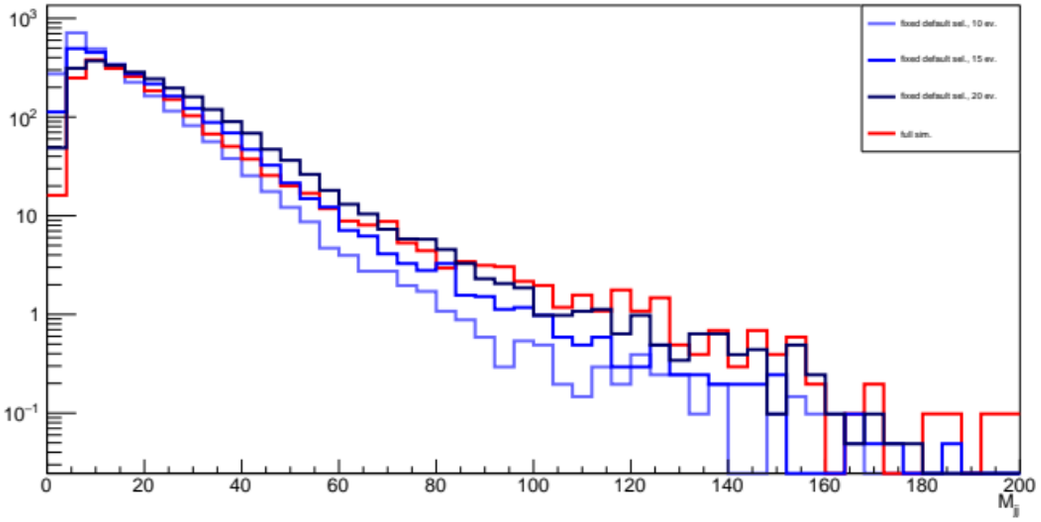


Number of overlaid events (HP17, 1.5 TeV), second approach









Summary

- First attempt made to include overlay $\gamma\gamma \to \mathrm{had.}$ background at high energy CLIC in Delphes

- „Approximate“ approach for timing cuts

- Big improvement in agreement between fast and full simulation

Next:

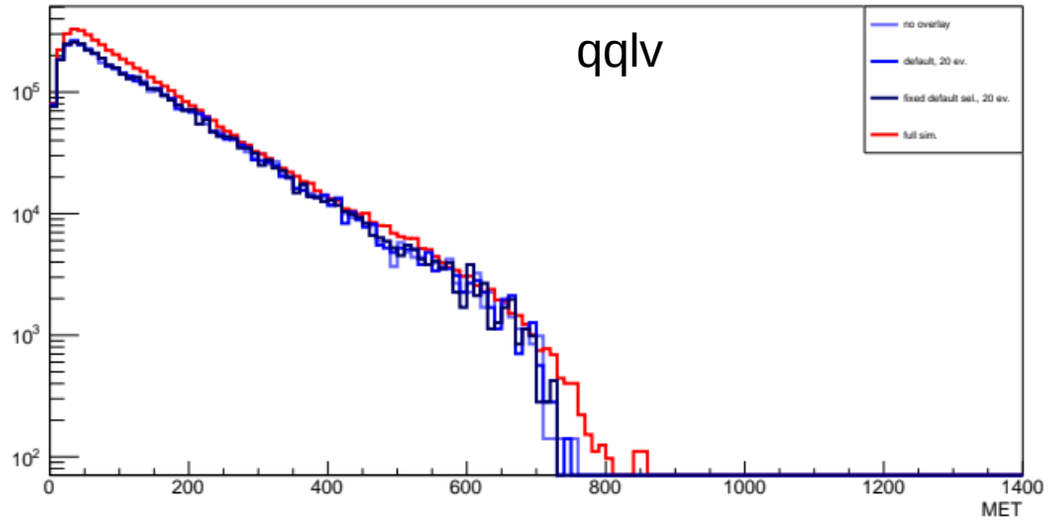
- Extend to 3 TeV

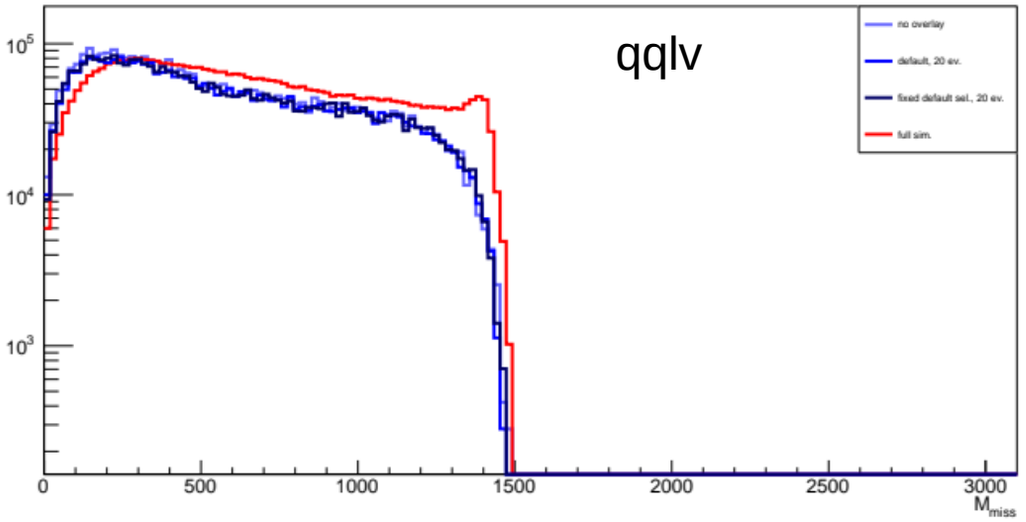
- More improvements?

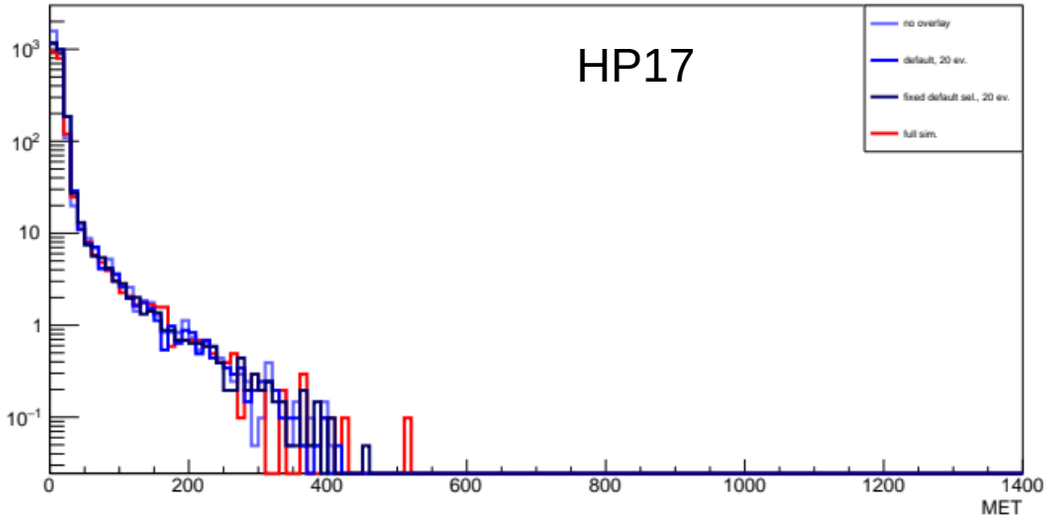
- Investigate influence on the analysis results

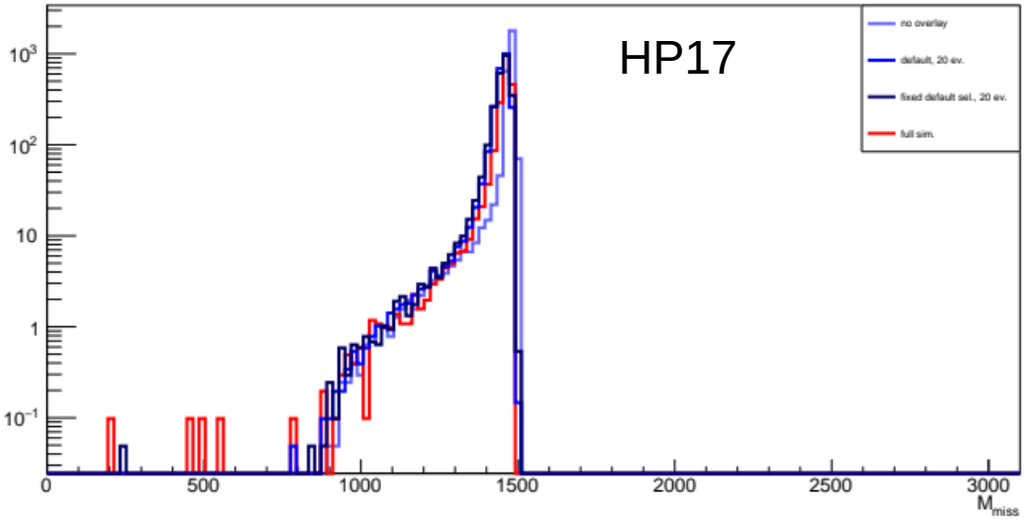
BACKUP

Results, other plots









Results (qqlv background, 1.5 TeV), different jet R