Update of WW-diff ECFA study

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ILD Analysis/Software Meeting
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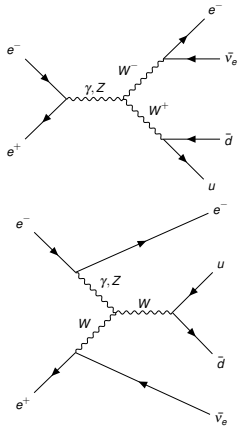
WWdiff?

- One of the ECFA Higgs/Top/EW focus topics
- “[...] [T]he main objective of this focus topic is to understand the full potential of e^+e^- colliders with respect to gauge boson interactions, using the full differential information from W-pair and single-W events to extract CP-even and CP-odd couplings, based on detailed detector simulation with assessments of systematic uncertainties, at all centre-of-mass energies”

WWdiff

- Look at all 4-fermion final states that look like a W-pair
- hadronic: $qqqq$, semi-leptonic: $\ell\nu qq$, leptonic: $\ell\nu\ell\nu$
- $\ell = e, \mu, \tau$
- Special case: semi-leptonic $e\nu qq$ final state: ‘single-W’ (also contains W-pairs)
- This work: focus on $e\nu qq$



WW kinematics

- 8 degrees of freedom
- W^- production angles:
  - $\cos\theta_{W^-}$
  - ϕ_{W^-} (isotropic, irrelevant)
- $W^\pm$ decay angles:
  - In $W^\pm$ rest frames
  - $\cos\theta_{f/\bar{f}}$
  - $\phi_{f/\bar{f}}$
- $\left(M_{W^-} = M_{W^+} = M_{W,\mathrm{SM}}\right)$
- Hadronic decay angles need to be folded or jet-charge distinction

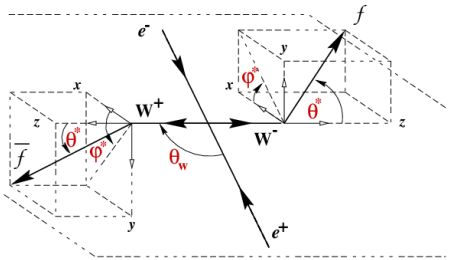
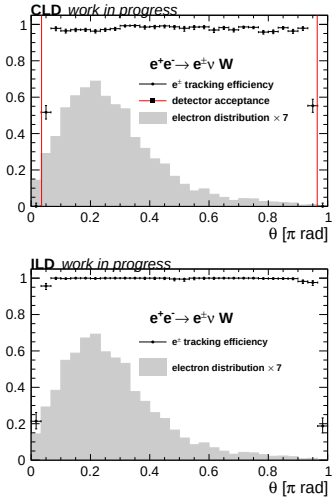


Figure 3.9: *Production and decay angles of W bosons.*

Our study

Motivation:

- Provide input for fits
- Study detector and software performance
- Figure out what works and what needs improvement
  - Detector layout?
  - Reconstruction algorithms?
  - Analysis framework?
- Investigate differences between detectors/colliders



CLD/ILD electron tracking efficiencies

Analyis status (Paris)

- Event categorization ✅
- Event selection ⏳ (waiting for stable release)
- Selection of isolated electron 🚧
- Overlay removal 🚧
- Kinematic fit 🚧
- Reconstruct production and decay angles ✅
- Figure out result format/binning ❓

Analyis status (now)

- Event categorization✅
- Event selection🚧 (started)
- Selection of isolated electron🚧
- Overlay removal🚧
- Kinematic fit🚧
- Reconstruct production and decay angles✅
- Figure out result format/binning✅ ❓

Analyis status (BTS)

- Event selection: mini-DSTs produced by Andre Silva at DESY and first look at selection. Files still not on the grid but I will upload them soon.
- Definitions of reconstructed objects: so far electron FSR+brems identification, jet clustering, overlay removal cheated.
- Kinematic fit: the tooling is there but not investigated in detail yet...
- Result format: Optimal Observables implementation up and running.

Optimal Observables: Idea

We want to measure some small coupling(deviations)s g_i. Expand differential cross-section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Phi} = S_0 + g_i S_{1,i} \left(+ g_i g_j S_{2,i,j} + \ldots\right)$$

Build observables:

$$\mathscr{O}_i = \frac{S_{1,i}}{S_0}$$

Extract g_i by solving

$$c_{ij} g_i = E[\mathscr{O}_j] - E_0[\mathscr{O}_j]$$

with $c_{ij} = \mathrm{Cov}(\mathscr{O}_i, \mathscr{O}_j)$

Optimal Observables: Implementation

- Original Fortran code provided by M. Diehl used in **M. Diehl, O. Nachtmann Z.Phys.C 62 (1994) 397-412**
- Interfaced to C++ and Python using ROOT, validated against published coefficient matrix using a custom Whizard sample.
- Provides the SM differential cross-section (S_0) in the double pole approximation without ISR.
- Provides the $S_{1,i}$ for the 14 complex form factors $f_i^{\gamma/Z}$ of the $\gamma WW/ZWW$ vertex parametrisation of **Hagiwara et al. Nucl.Phys.B 282 (1987) 253-307**

Optimal Observables: Further validation

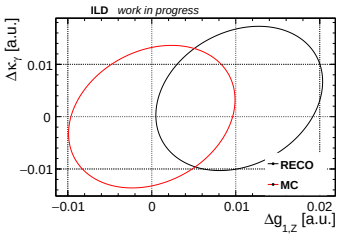
- We convert the f_i OOs to ones based on the 'standard' LEP parametrisation i.e. $\Delta g_1^Z, \Delta\kappa_\gamma, \lambda_Z$ and compare the correlations of the estimators (c_{ij}^{-1}) with some previous results

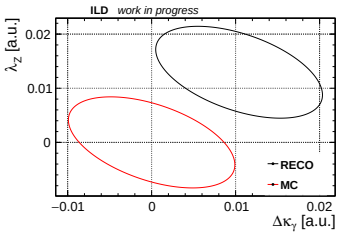
	$\Delta g_1^Z/\Delta\kappa_\gamma$	$\Delta g_1^Z/\lambda_Z$	$\Delta\kappa_\gamma/\lambda_Z$
ALEPH 3D fit	-0.17	-0.62	-0.15
Hepfit FCCee OO full*	-0.17	-0.58	-0.10
Hepfit FCCee OO aTGC only	-0.27	-0.52	-0.04
My MC**	-0.26	-0.54	-0.04
ILD MC2020	**0.23**	-0.49	-0.14

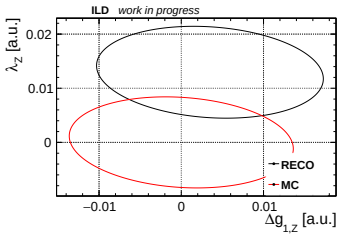
*: extracted by me naively from 7×7 covariance matrix

**: Whizard 3.1.4 $e^+e^- \to e^-\bar{\nu}_e u\bar{d}$+ISR @250 GeV

Optimal Observables: Results







- Numbers on the axes have no meaning as is, need full analysis first
- Correlation and absolute error size seem unimpressed by the detector resolution

Outlook and summary

- Many parts of the analysis are still under active development
- Need the full event selection before quantitative statements about the errors are possible
- It looks like our detector is good enough, but more realistic reconstruction might still cause some degradation
- Need to understand the sign switch in the correlations for the MC2020 data... (ongoing)

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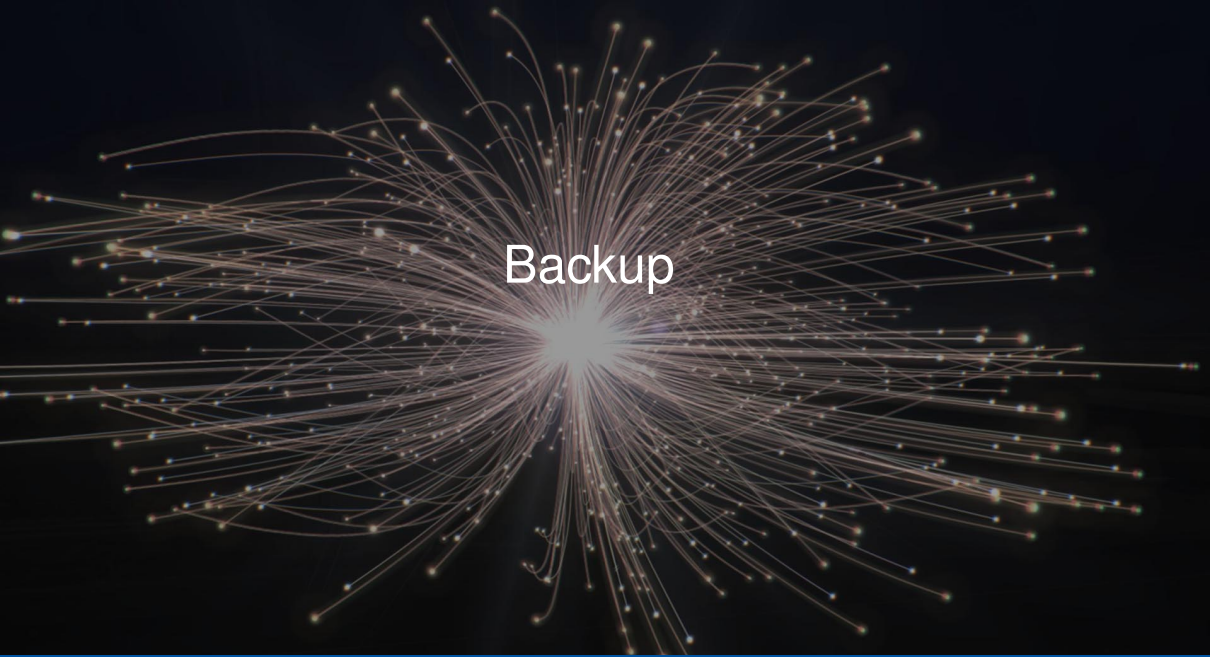
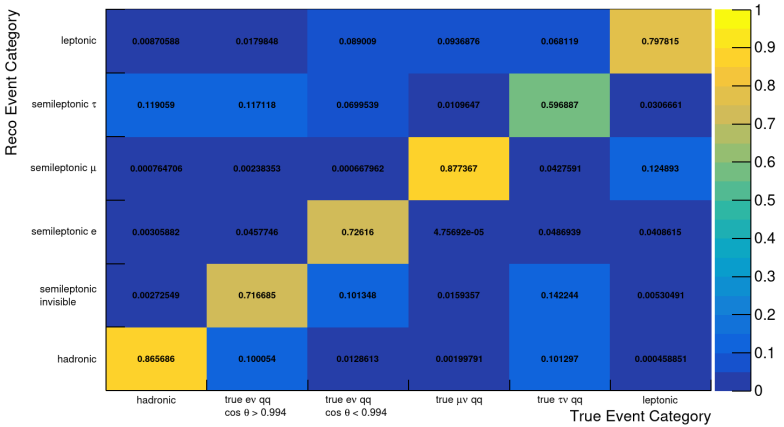

Backup

Event categorization

- Work performed by Andre Silva from DESY
- Splits 4 fermion events into the mentioned categories
- Based on ILD mini-DST format information content



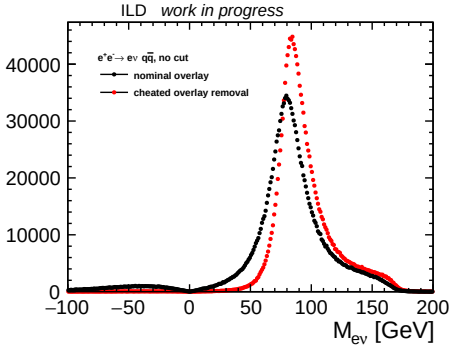
Reconstruction definitions

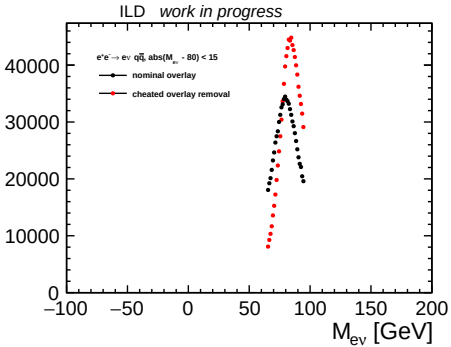
- Every event is treated like a W-pair event
- Reco electron is selected from truth and FSR+brems photons are added back to it
- Hadronic W is defined as the sum of all visible PFOs minus the electron and identified overlay
- Neutrino is defined as initial state minus the electron and minus the hadronic W
- Leptonic W is electron + neutrino
- N.B.: neither W needs to be an actual W

Used data

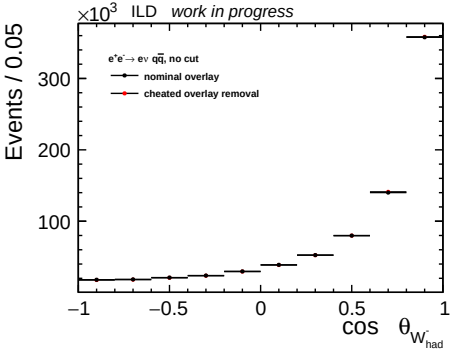
- A small subset of ILD mc-2020 `4f_sw_sl` DST files with beam background events (overlay) at 250 GeV
- Converted to edm4hep format and processed with ‘bleeding-edge’ Key4hep tools, to also use this for other detectors later
- Only looking at unpolarized data for easier comparison to LEP and FCC-ee for now, but output of polarized differential cross-sections can be added easily
- Current focus: detector resolution, beam background effects
- Two sets of results, one arbitrarily restricts M_{ev} to be compatible with M_W within 15 GeV

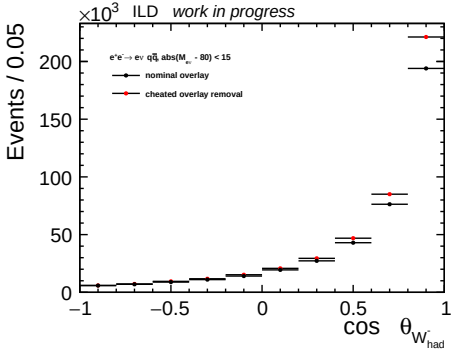
Cut


ILD work in progress
e⁺e⁻→ eν qq̄, no cut
nominal overlay
cheated overlay removal
40000
30000
20000
10000
0
−100
−50
0
50
100
150
200
M_eν [GeV]


ILD work in progress
e⁺e⁻→ eν qq̄, abs(M_eν - 80) < 15
nominal overlay
cheated overlay removal
40000
30000
20000
10000
0
−100
−50
0
50
100
150
200
M_eν [GeV]

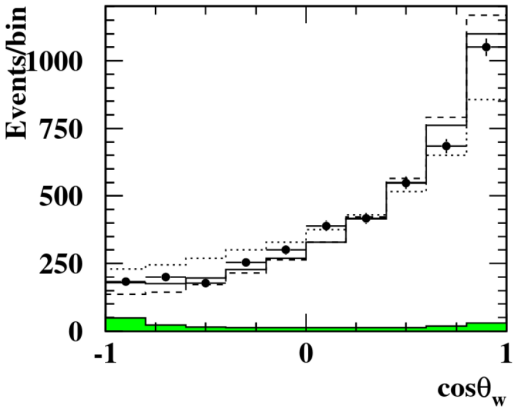
Results



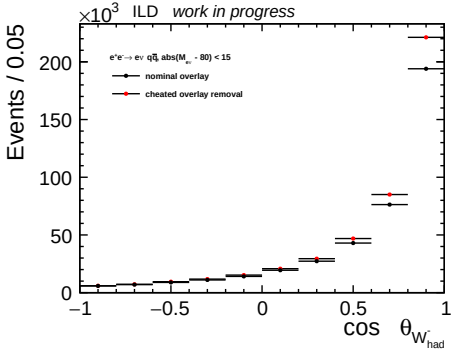


- Overlay removed region contains more W-pair after cut →more t-channel →more forward

Results

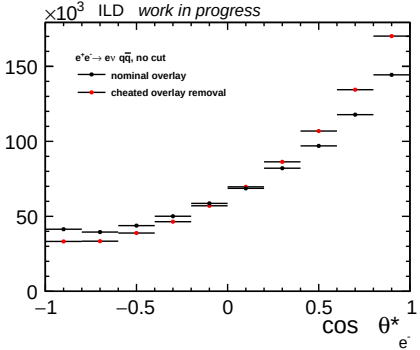


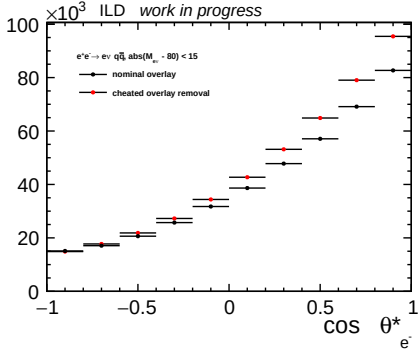
OPAL Eur. Phys. J. C 33, 463-476 (2004)



- More boost →more forward

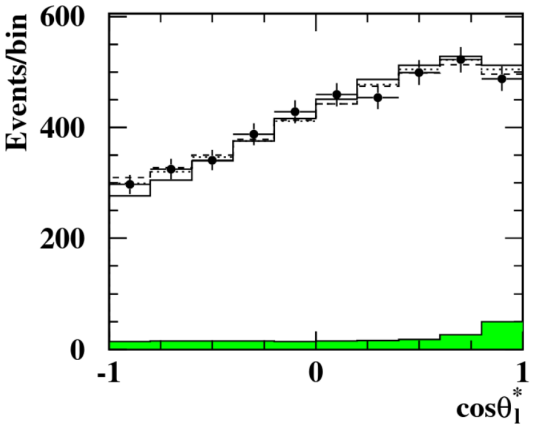
Results





- Overlay removed region contains more W-pair after cut →more t-channel →more forward

Results



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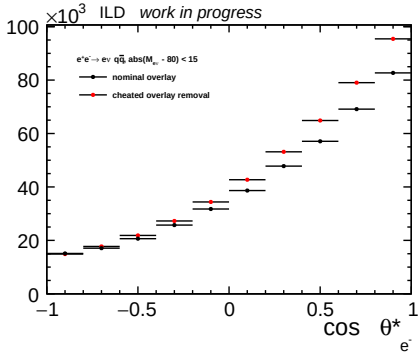
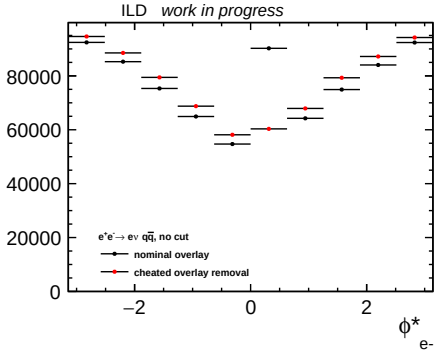
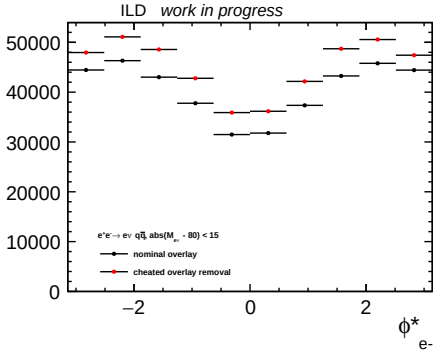


- More boost →more forward

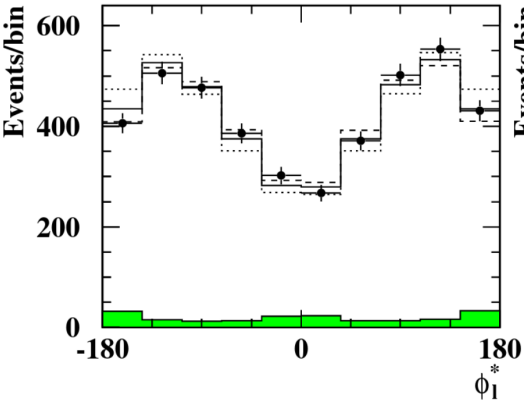
Results

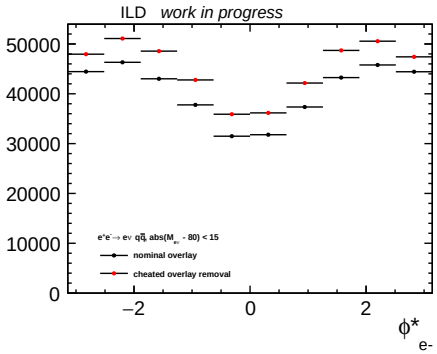




- Very sensitive to neutrino mis-reconstruction without the cut (‘off-peak’)

Results

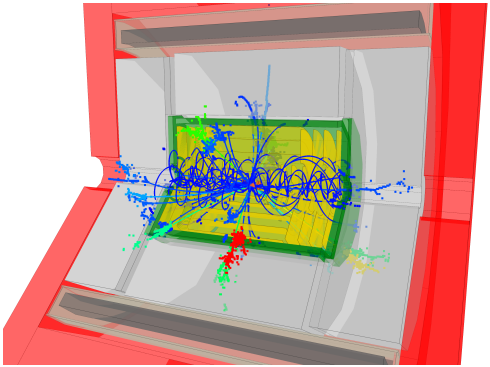




OPAL Eur. Phys. J. C 33, 463-476 (2004)

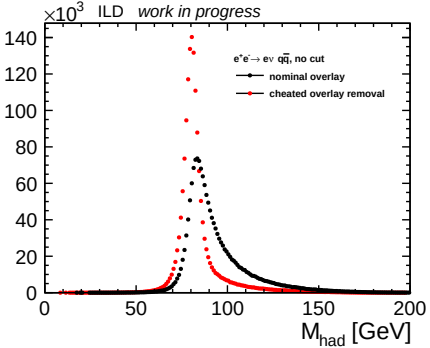
Interlude: Overlay? Beam backgrounds!

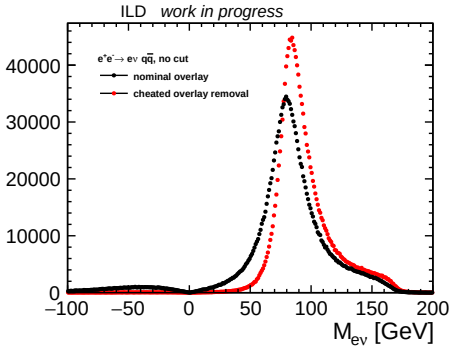
- Coherent pairs, incoherent pairs, low-p_T hadrons
- Simulated separately from the ‘physics’ events for performance reasons
- Are overlaid on top of the events
- Need to be removed by reconstruction cuts to determine quantities like missing Energy correctly!
- Can also be removed by ‘cheating’ using the `isOverlay` flag (done here)



Beam backgrounds (blue) in the CLIC detector at 380 GeV

Results (no cut)





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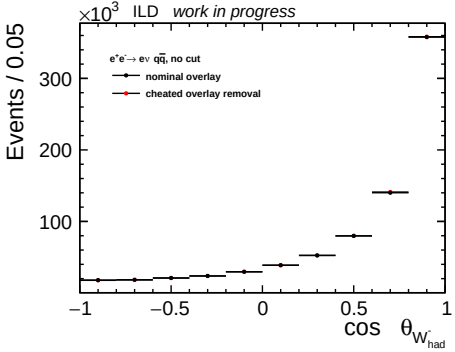
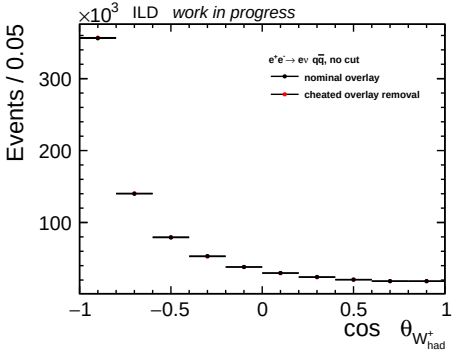
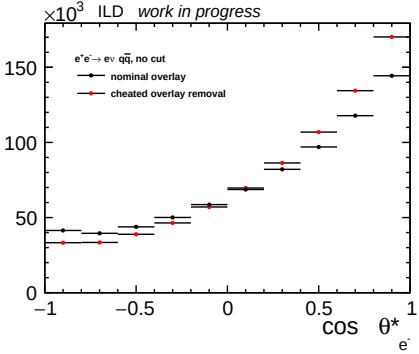
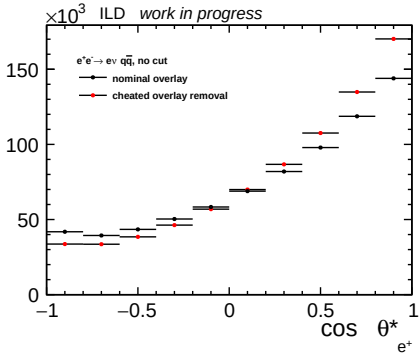


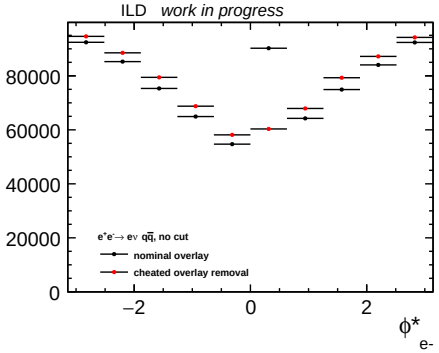


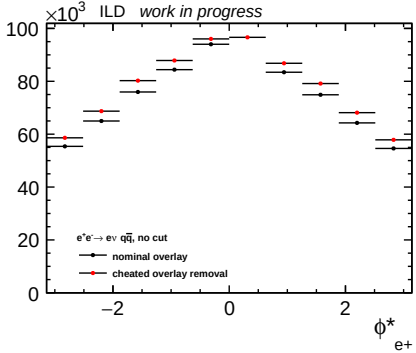
Results (no cut)





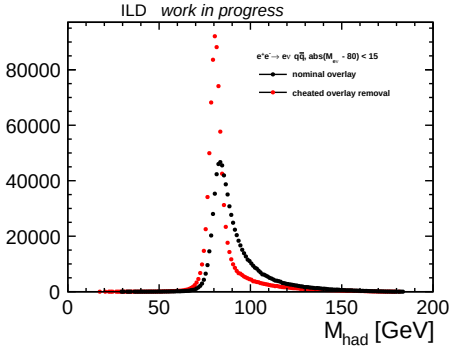
Results (no cut)

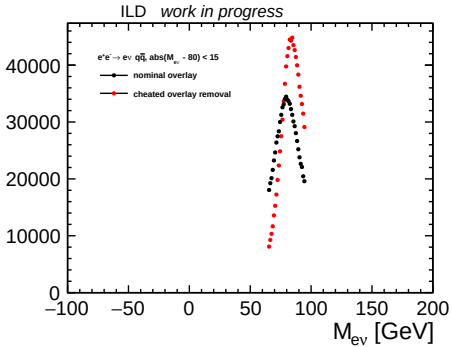




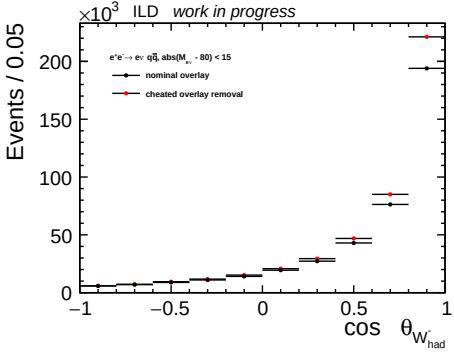
- Note the degradation in the 0th bin

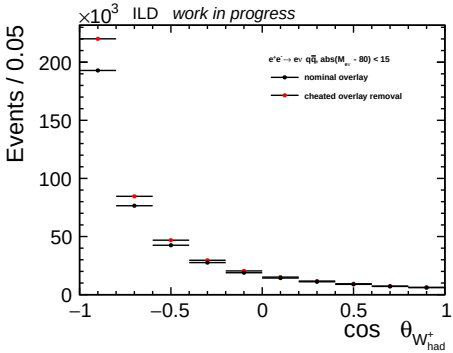
Results (with cut)



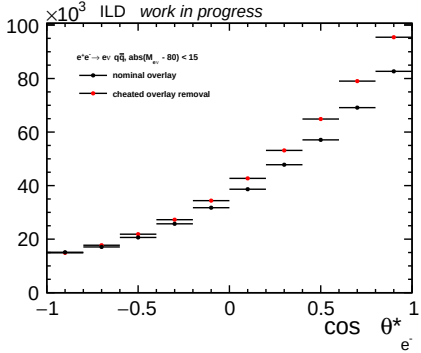


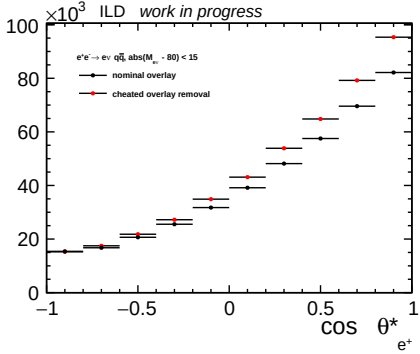
Results (with cut)



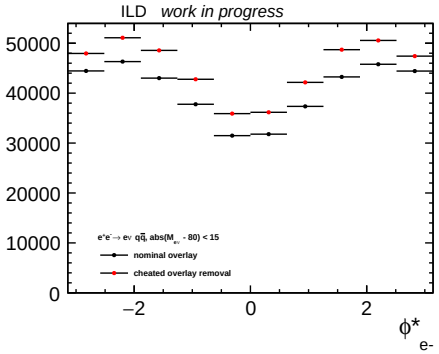


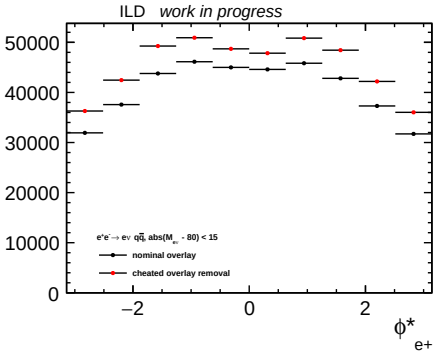
Results (with cut)





Results (with cut)





- Degradation in 0th bin mostly disappears