First WWdiff results from full simulation studies of WW and single-W production

Leonhard Reichenbach (CERN, U. Bonn),
Andre Silva (U. Coimbra, DESY), Andre Sailer (CERN), Jenny List (DESY)

Third ECFA Workshop on e+e- Higgs/EW/Top Factories
Paris, October 9, 2024

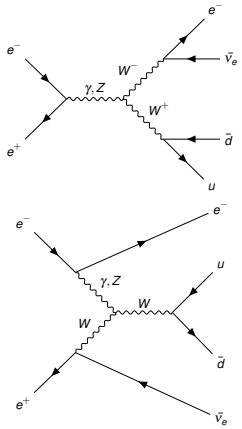
SPONSORED BY THE
Federal Ministry of Education and Research

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”
- This work: produce (nD-)differential cross-sections from full sim data
- Later: use them in SMEFT fits and to extract couplings

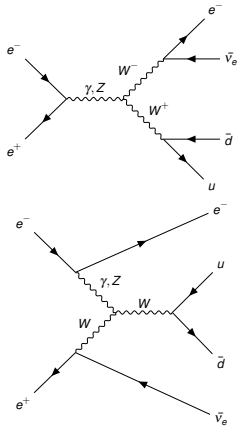
WWdiff

- 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 $e\nu qq$



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 jet-charge, not further investigated here
- Focus on production and leptonic decay angles

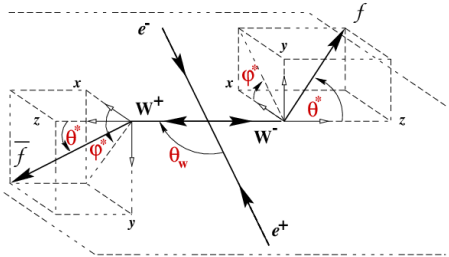
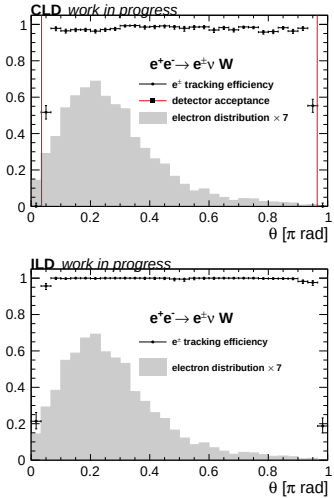


Figure 3.9: *Production and decay angles of W bosons.*

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



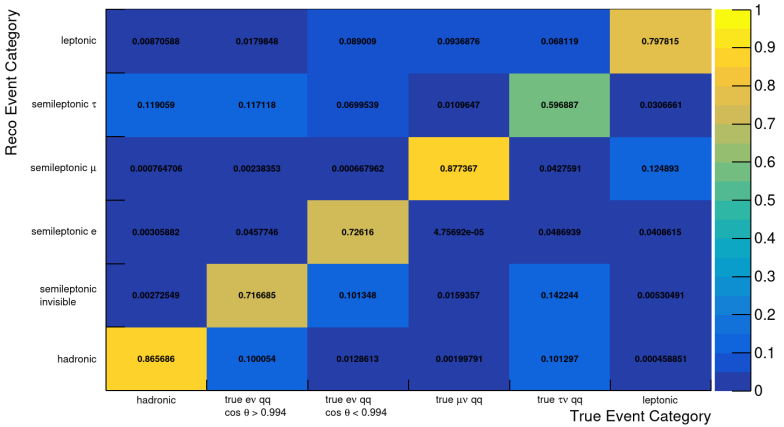
CLD/ILD electron tracking efficiencies

Analyis structure

- 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 ❓

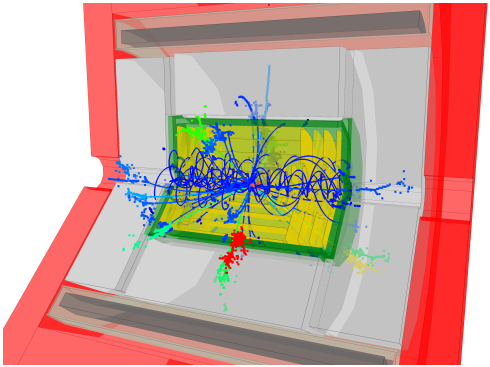
Event categorization

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



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

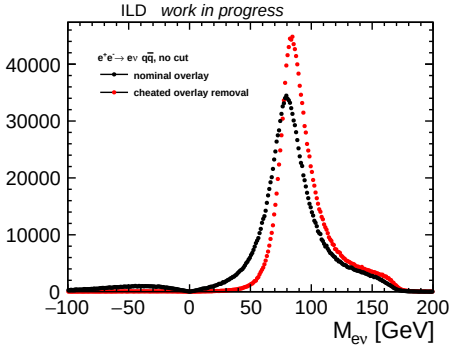
Used data

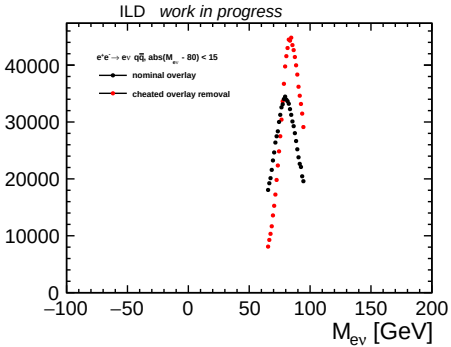
- A small subset of ILD mc-2020 `4f_sw_sl` DST files with beam background events (overlay) at 250 GeV
- Converted to edm4hep format and processed with ‘bleeding-edge’ Key4hep tools, to also use this for other detectors later
- Only looking at unpolarized data for easier comparison to LEP and FCC-ee for 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

Reconstruction definitions

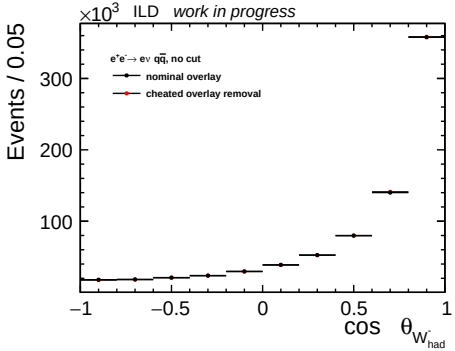
- Every event is treated like a W-pair event
- Reco electron is selected from truth and FSR+brems photons are added back to it
- Hadronic W is defined as the sum of all visible PFOs minus the electron and identified overlay
- Neutrino is defined as initial state minus the electron and minus the hadronic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

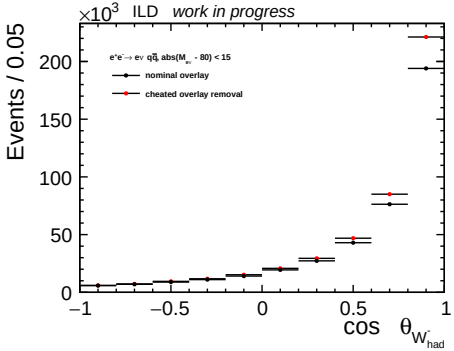
Cut


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]

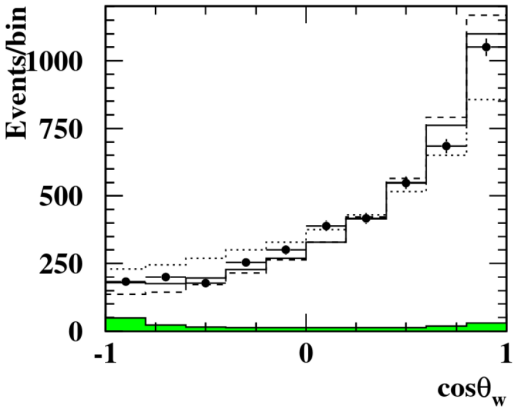
Results



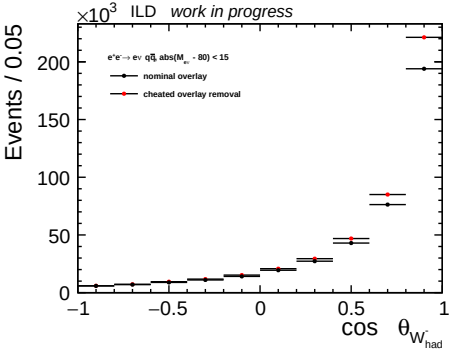


- Overlay removed region contains more W-pair after cut →more t-channel →more forward

Results

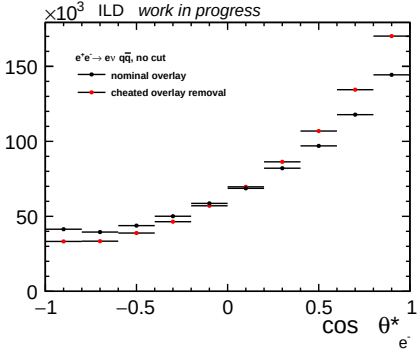


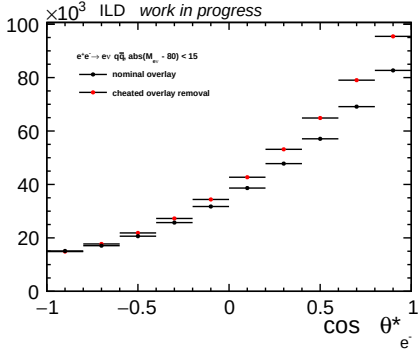
OPAL Eur. Phys. J. C 33, 463-476 (2004)



- More boost →more forward

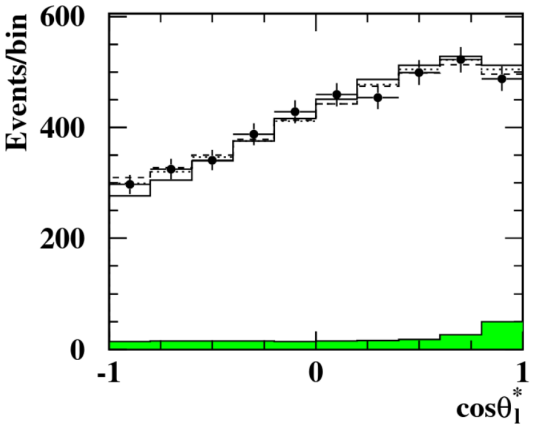
Results



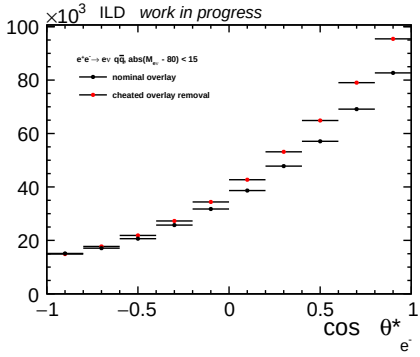


- Overlay removed region contains more W-pair after cut →more t-channel →more forward

Results

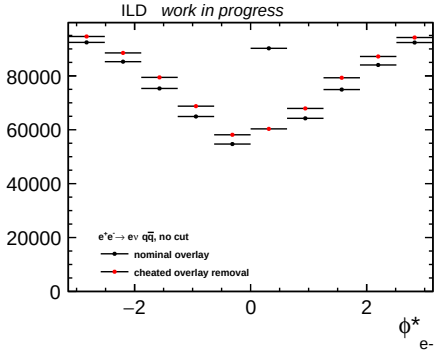


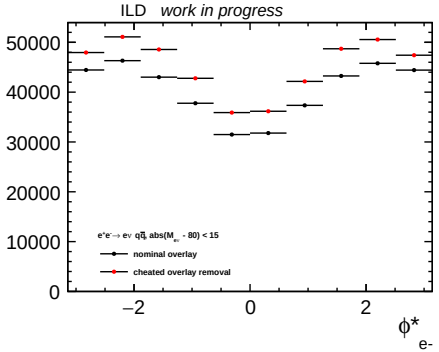
OPAL Eur. Phys. J. C 33, 463-476 (2004)



- More boost →more forward

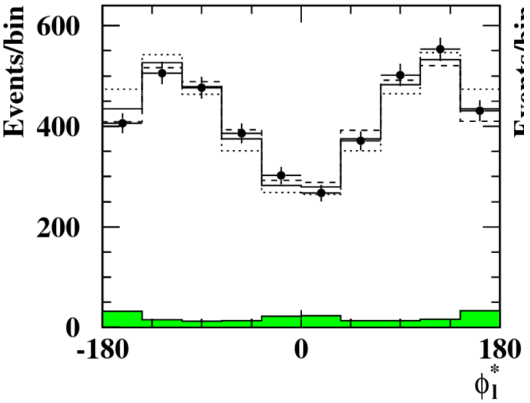
Results

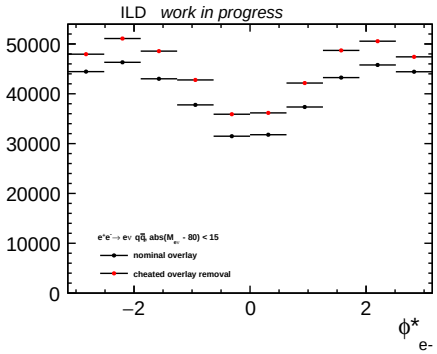




- Very sensitive to neutrino mis-reconstruction without the cut (‘off-peak’)

Results





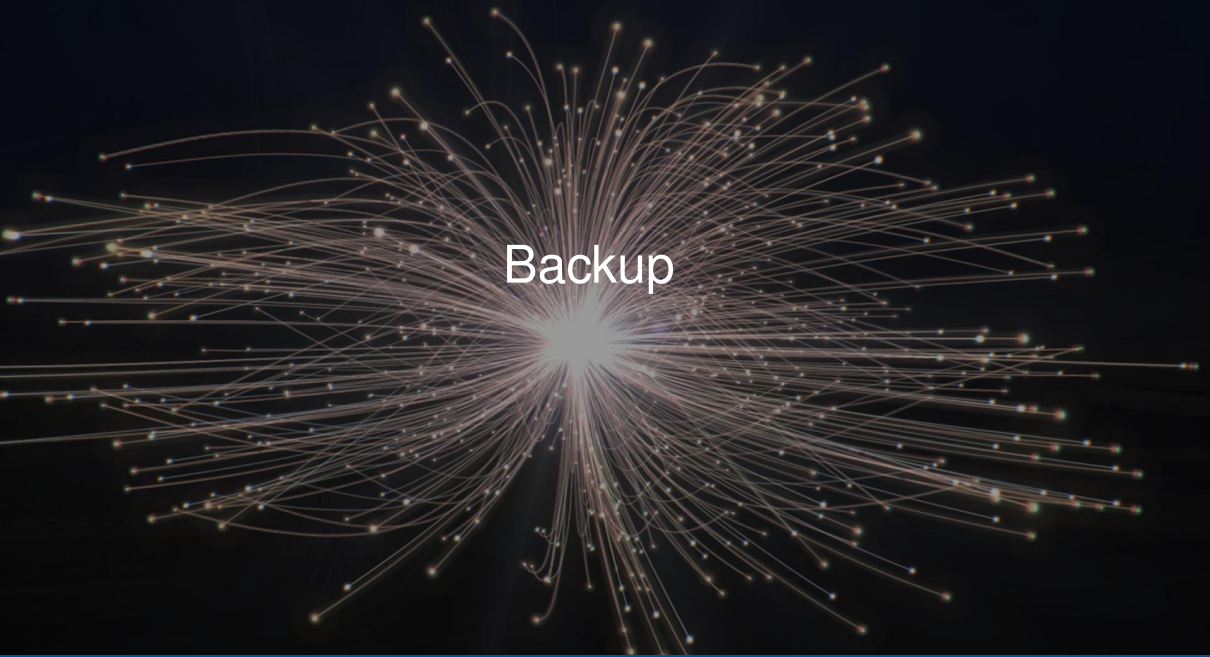
OPAL Eur. Phys. J. C 33, 463-476 (2004)

Outlook and summary

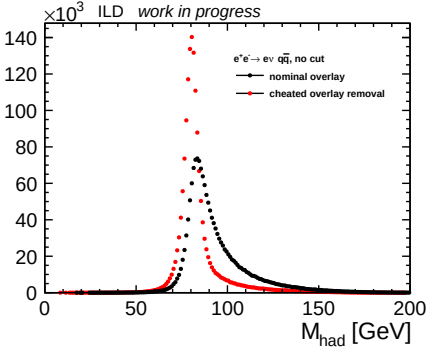
- Beam background removal at ILC will be crucial, needs to be studied for FCC
- Many parts of the analysis are under active development
- Most technical hurdles are disappearing
- Comparisons between detector concepts possible (if they have working reconstruction)

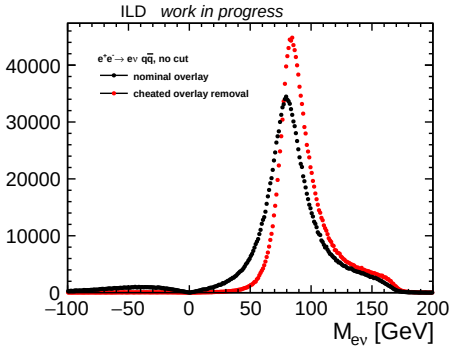
This work has been sponsored by the Wolfgang Gentner Programme of the German Federal Ministry of Education and Research (grant no. 13E18CHA).

SPONSORED BY THE
Federal Ministry of Education and Research

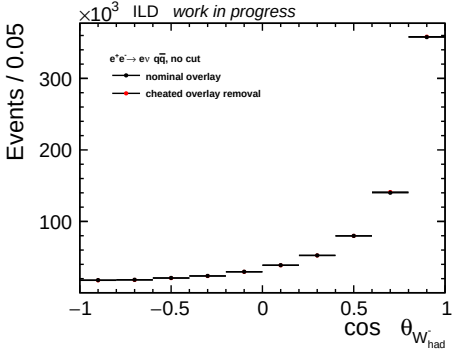

Backup

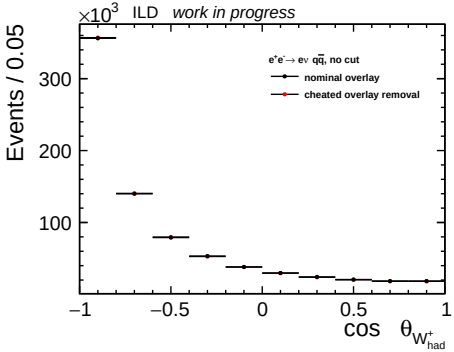
Results (no cut)



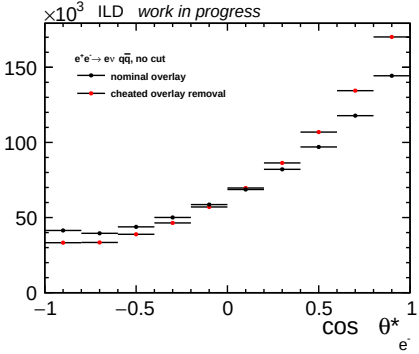


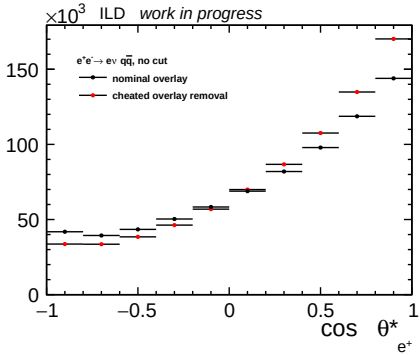
Results (no cut)



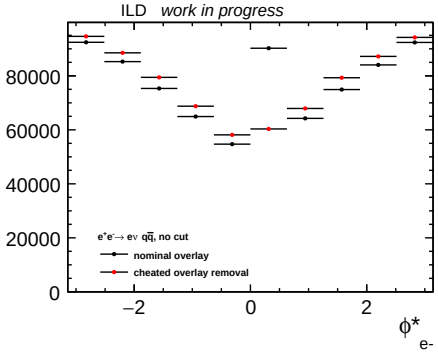


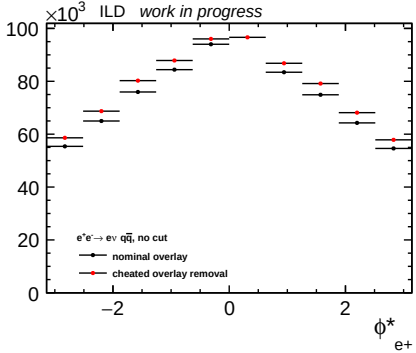
Results (no cut)





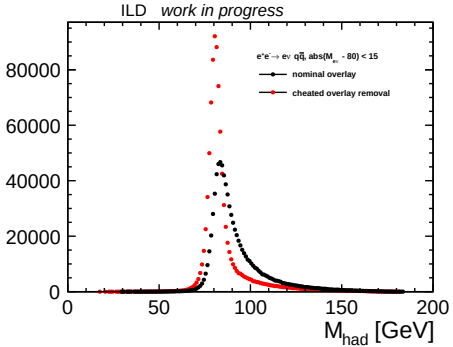
Results (no cut)

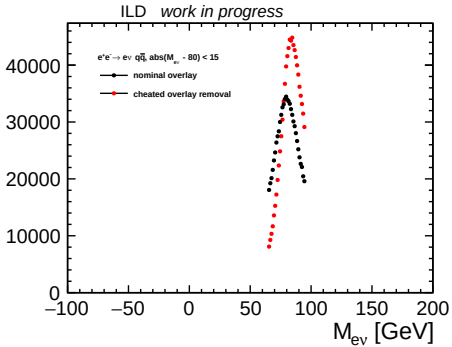




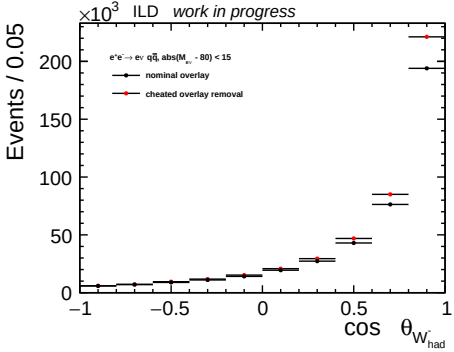
- Note the degradation in the 0th bin

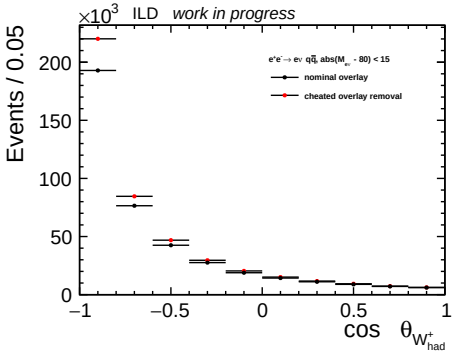
Results (with cut)



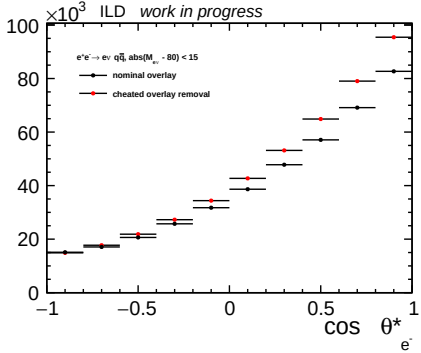


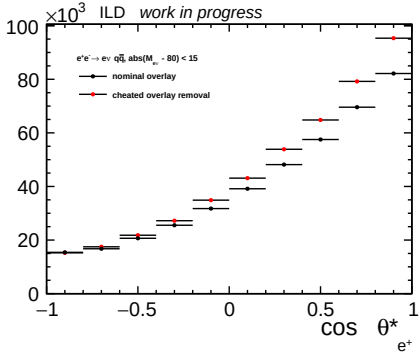
Results (with cut)



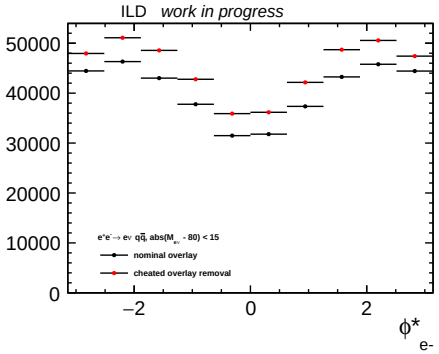


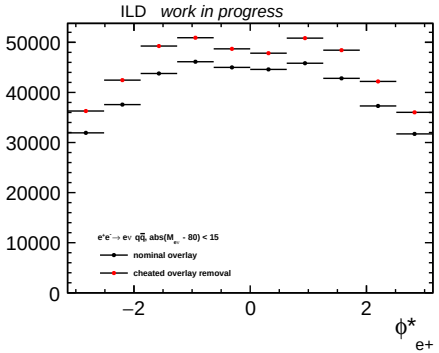
Results (with cut)





Results (with cut)





- Degradation in 0th bin mostly disappears