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

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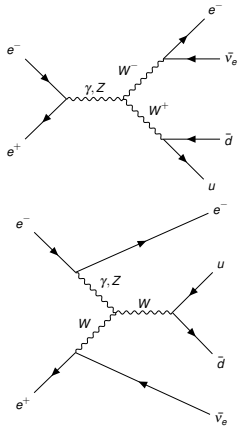
WWdiff?

- 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”
- 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 $e\nu qq$



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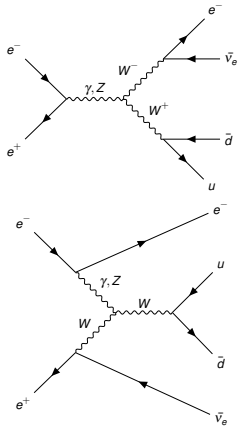


WW kinematics

- 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

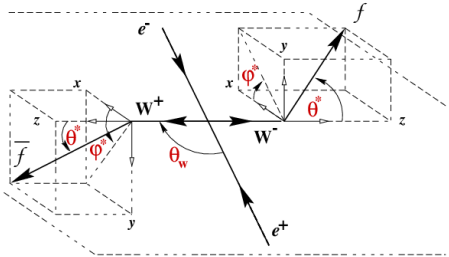
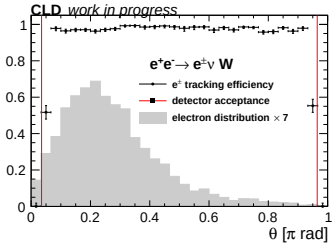


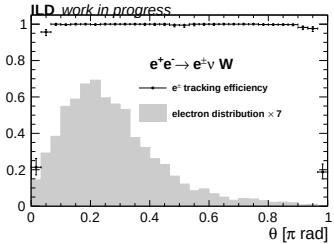
Figure 3.9: *Production and decay angles of W bosons.*

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



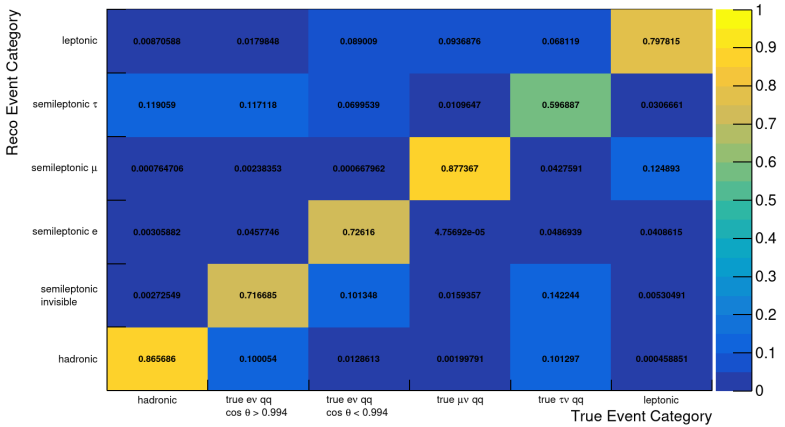


Analyis structure

- 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

- Splits 4 fermion events into the mentioned categories
- Based on ILD mini-DST format information content



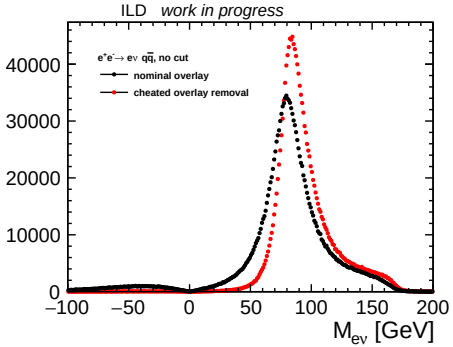
Used data

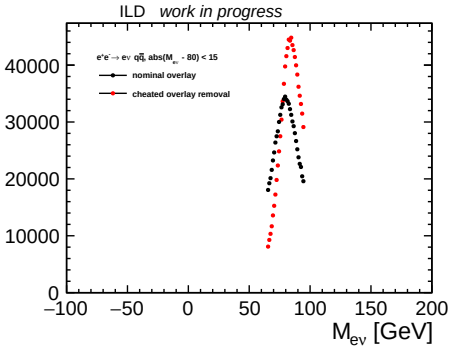
- A small subset of ILD mc-2020 `4f_sw_sl` DST files with beam background events (overlay)
- Converted to edm4hep format and processed with ‘bleeding-edge’ Key4hep tools, to also use this for other detectors later
- Only looking at unpolarized data for easier comparison to LEP and FCC-ee for now, but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

Reconstruction definitions

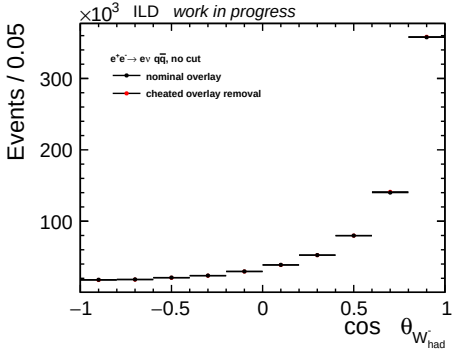
- Every event is treated like a W-pair event
- Reco electron is selected from truth and FSR+brems photons are added back to it
- Hadronic W is defined as the sum of all visible PFOs minus the electron and identified overlay
- Neutrino is defined as initial state minus the electron and minus the hadronic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

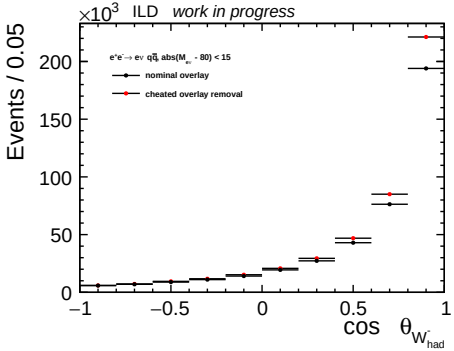
Cut


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]

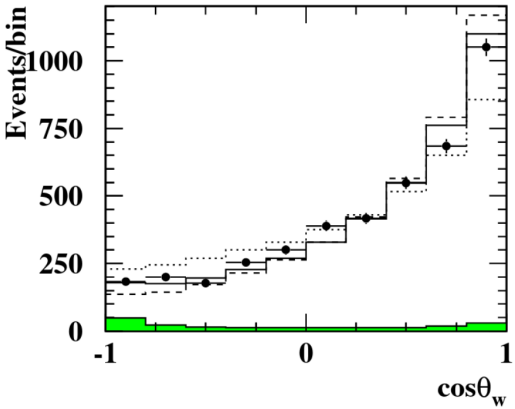
Results



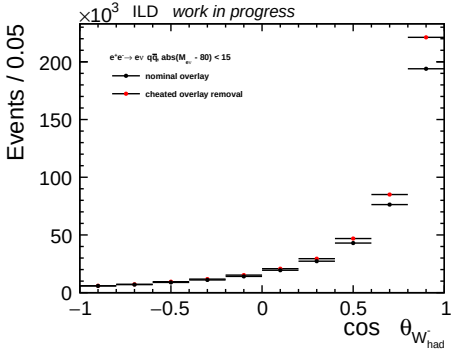


- Overlay removed region contains more W-pair after cut →more t-channel →more forward

Results

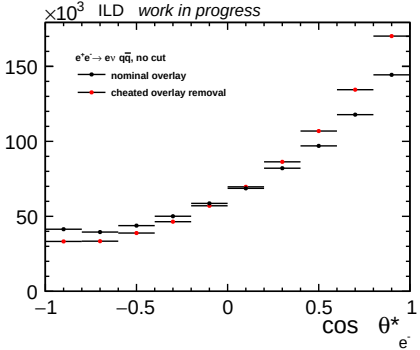


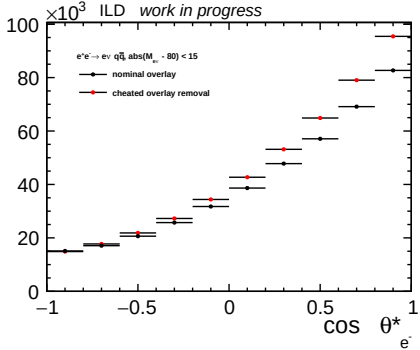
OPAL Eur. Phys. J. C 33, 463-476 (2004)



- More boost →more forward

Results





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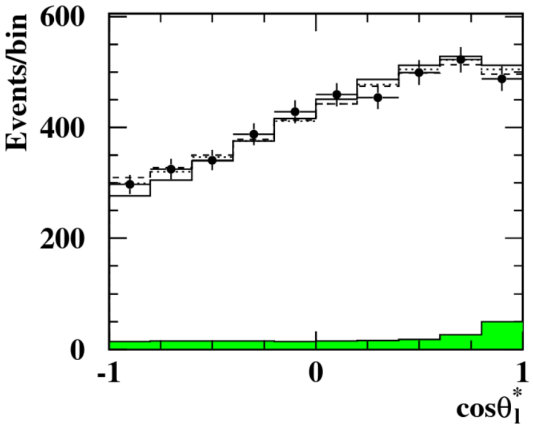

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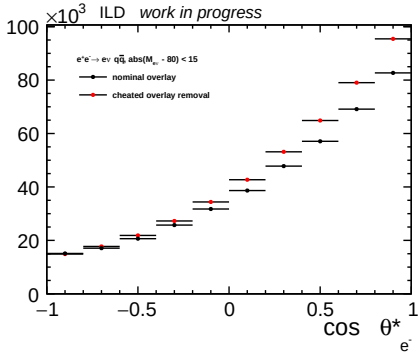

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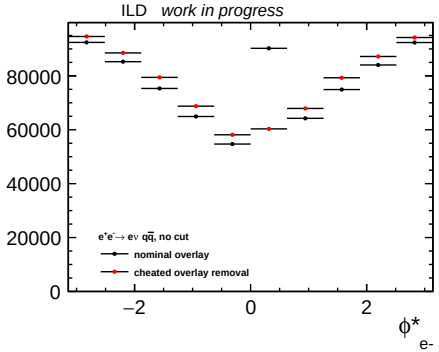
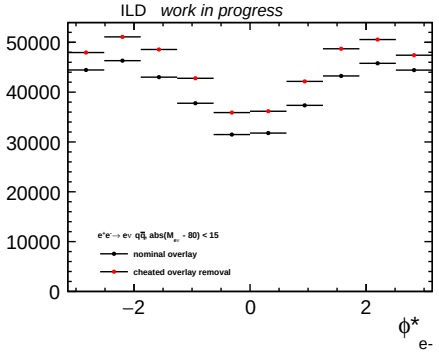
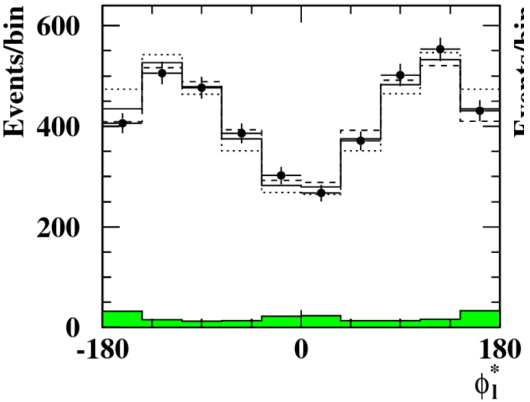
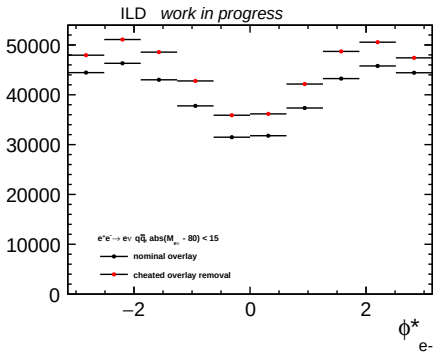




- Very sensitive to neutrino mis-reconstruction without the cut (‘off-peak’)

Results





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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)

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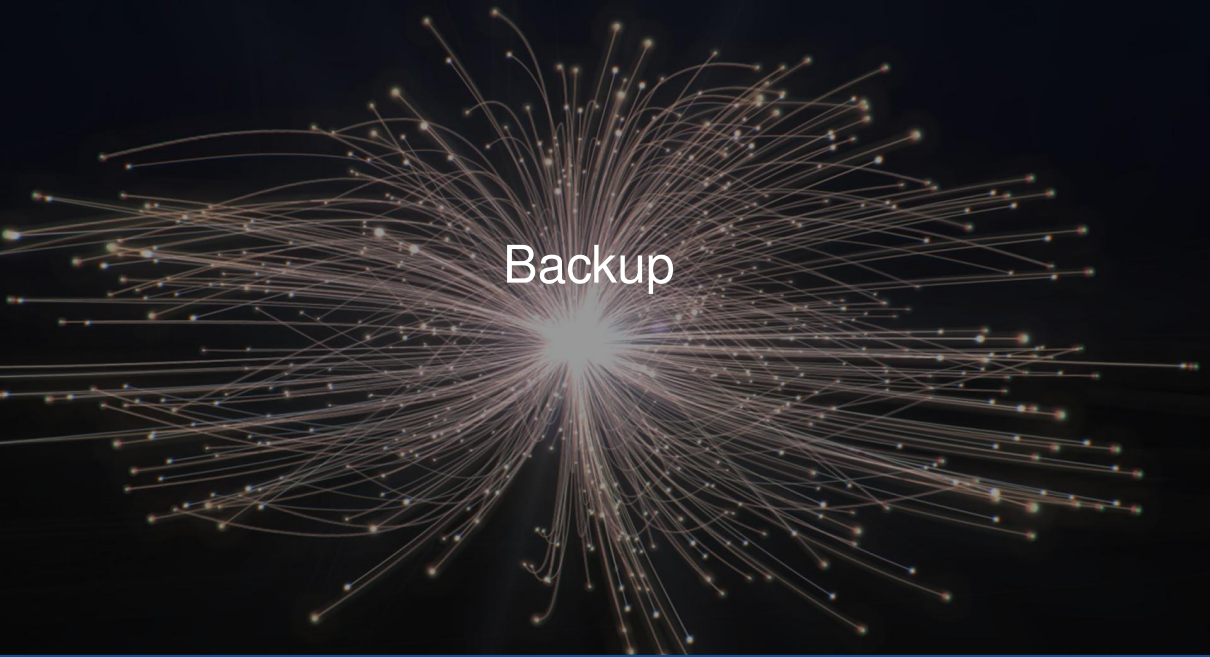
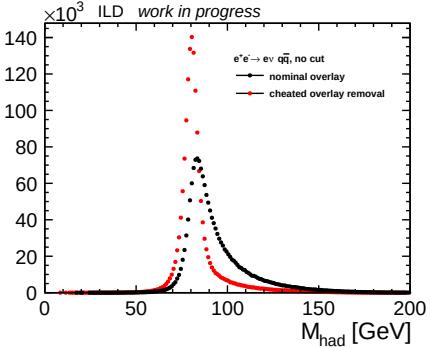
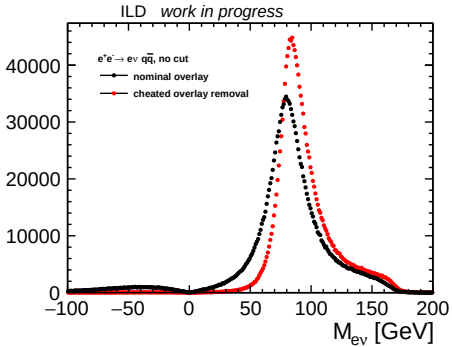

Backup

Results (no cut)





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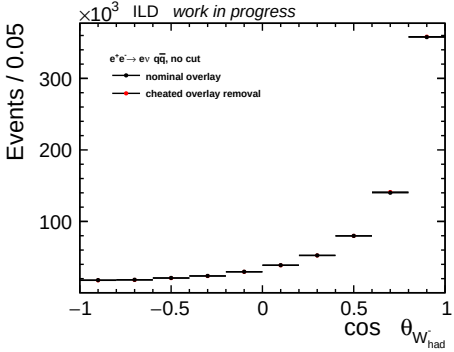

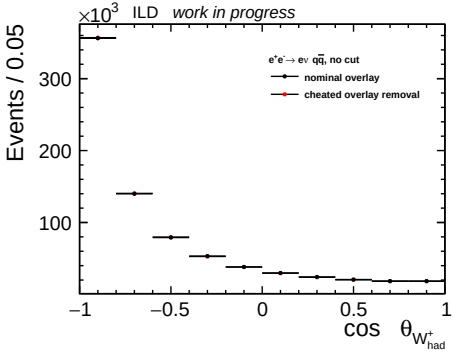

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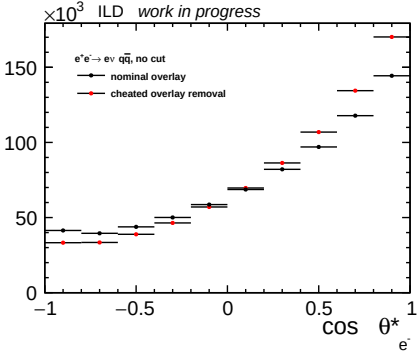

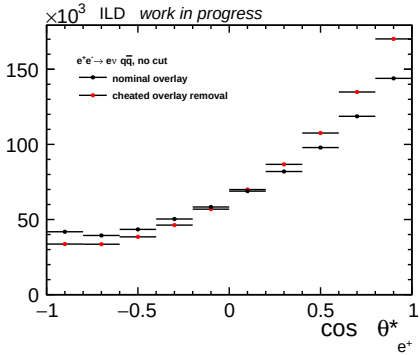

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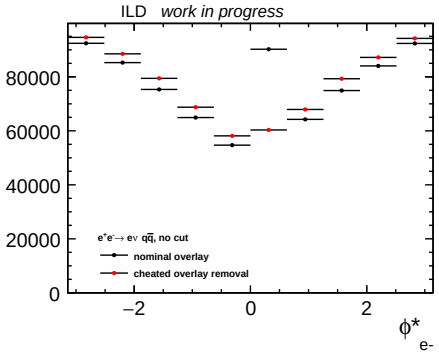
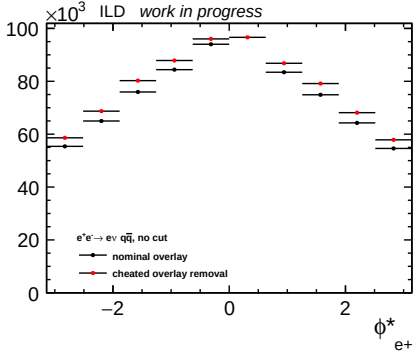
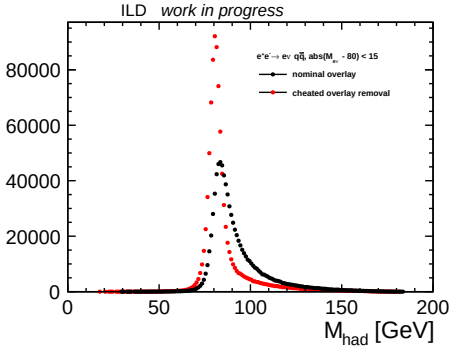
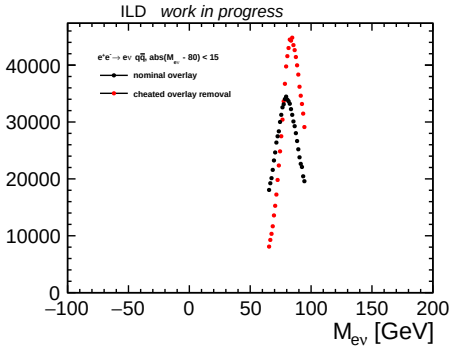




- Note the degradation in the 0th bin

Results (with cut)





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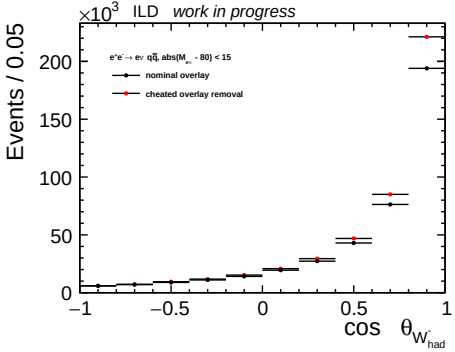

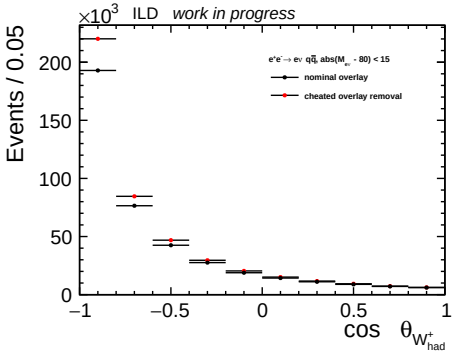

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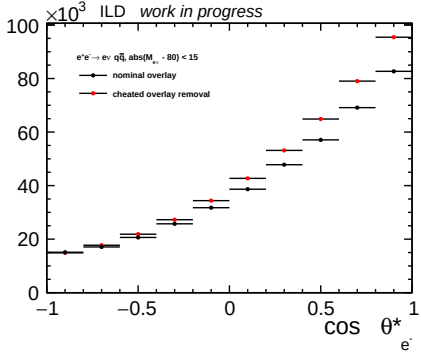

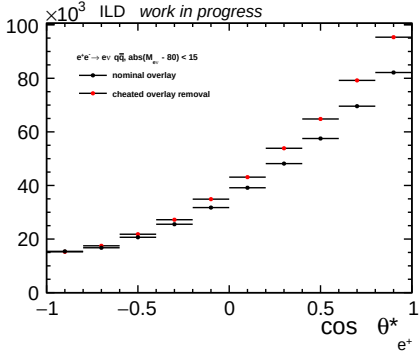

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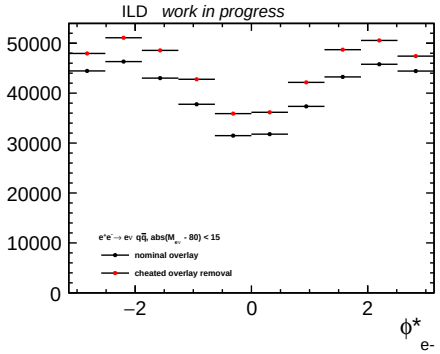
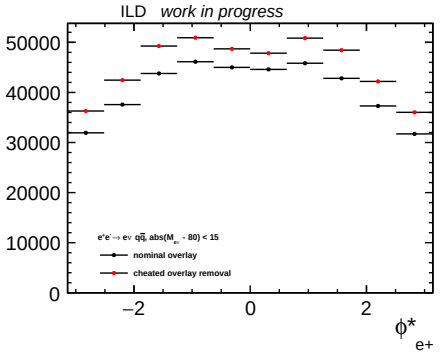


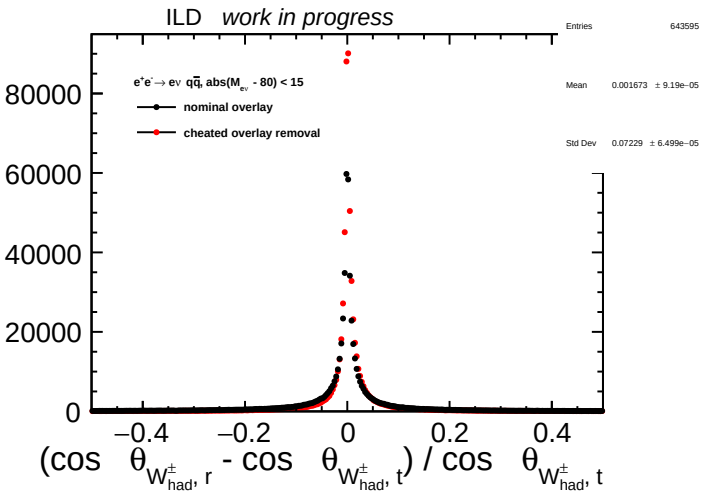


- Degradation in 0th bin mostly disappears

Results (with cut)

remove normalization again

- Attempt to plot resolutions for the angles



Results (with cut)