WW/ZZ separation and timing cut comparison for old and new CLIC detector model

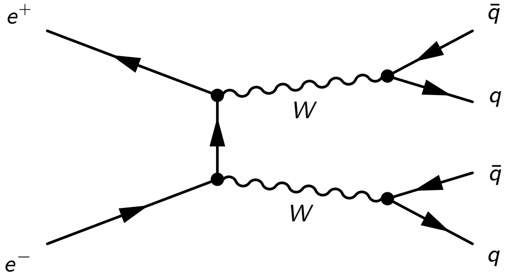
Sascha Dreyer
Supervisors: Lars Rickard Strom, Matthias Weber

CLICdp collaboration meeting

August 29, 2017

Motivation

- Study the $ee \to qqqq$ process
- Idea: Measure WW cross-section as input parameter to EFT studies
- First view on new detector model $\to$ WW/ZZ separation to evaluate performance
- SM: mainly WW, ten times less ZZ, different scenarios possible in BSM



Technical introduction

- Compare CLIC_ILD with CLIC_o3_v12, use Pandora PFA for particle reconstruction
- Study different timing cuts to reduce contribution from $\gamma\gamma \rightarrow$hadrons (overlay):
  - Loose selected (considered use at 380 GeV)
  - Selected (1.4 TeV)
  - Tight selected (3 TeV)
- Compare CLIC_o3_v12 without overlay (reference) and with overlay
- Study WW/ZZ separation in new and old detector model

- Use MC quarks to:
  - tag events
  - cut on invariant mass: 1.2 for 1.4 TeV and 2.8 for 3 TeV
  - cut on $|\cos\theta|$ of all quarks
- Mainly use VLC jet clustering algorithm:
  - radius: jet size
  - β: "control clustering order"
  - γ: "beam jet size"
  - use 2 exclusive jets

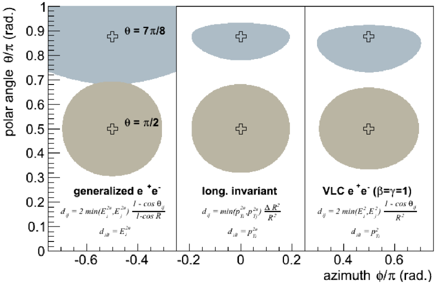


Figure: arXiv:1607.05039v1

Timing cuts at 1.4 TeV: comparison of CLIC_ILD and CLIC_o3_v12

Compare old and new detector model: 1.4 TeV

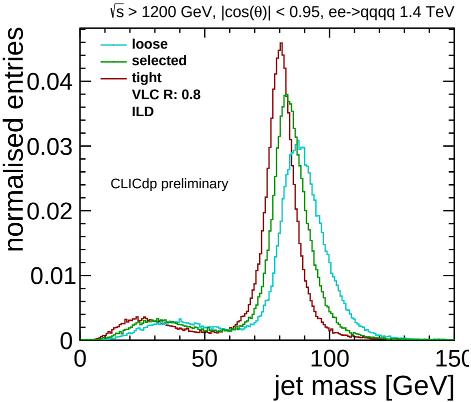


Figure: CLIC_ILD

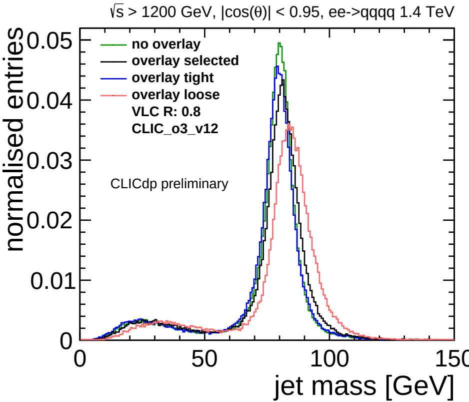


Figure: CLIC_o3_v12

- Large differences in loose selections, new model performs better (changed also calo barrel timings)
- Smaller differences in selected collection: mass lower, closer to W
- No significant differences in tight
- Comparison with reference (no overlay): use tight selection for W jet mass

Timing cuts at 3 TeV: comparison of CLIC_ILD and CLIC_o3_v12

Compare old and new detector model: 3 TeV

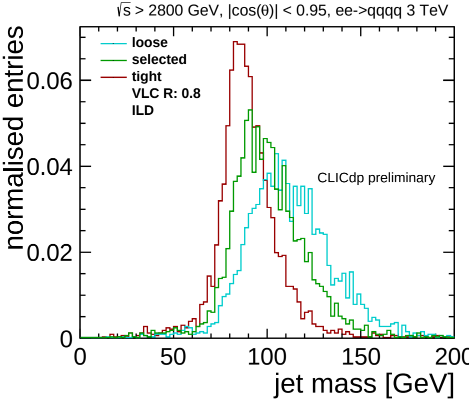


Figure: CLIC_ILD

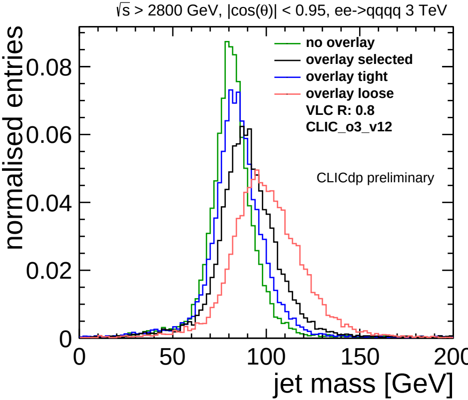


Figure: CLIC_o3_v12

- Again largest differences in loose collection: now much closer to W mass
- For selected and tight selection only small shifts to lower masses
- Comparison with reference (no overlay): use tight selection for W jet mass

WW/ZZ separation with CLIC_ILD

WW/ZZ separation with CLIC_ILD

- Studied different jet clustering algorithms: VLC, kT, ee-genkT
  - Median of W and Z jet mass distributions
  - Separation of medians
  - IQR_{34}

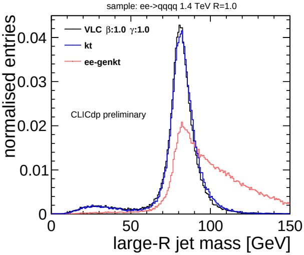


Figure: Different algorithms

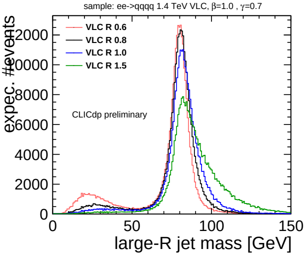


Figure: Different jet radii

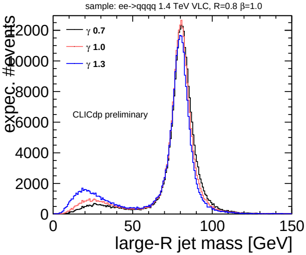
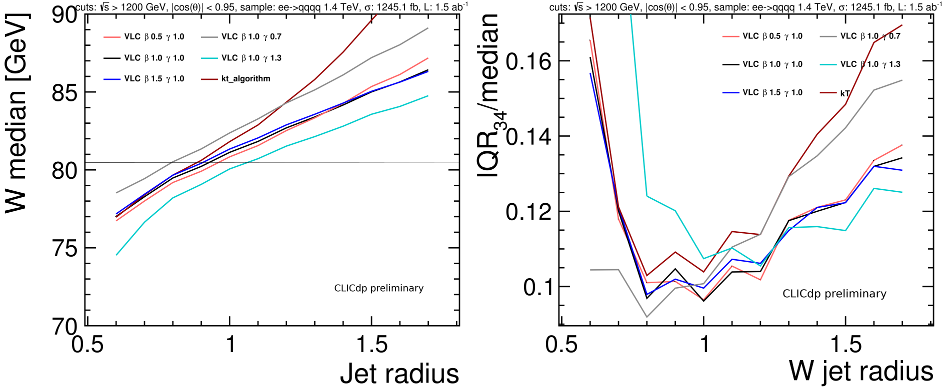


Figure: Different VLC γ values

Jet clustering optimisation

- IQR_{34}: half width of interval around median containing 68% of the distribution, as used in arXiv:1607.05039v1
- resulting settings: VLC with $R = 0.8$, $\beta = 1.0$, $\gamma = 0.7$



Separation with VLC $r = 0.8\ \beta = 1.0\ \gamma = 0.7$: two exclusive jets

- Jet mass distributions clearly separated for same amount of WW and ZZ events: separation of medians around 8 GeV
- For SM conditions, we expect around ten times less ZZ events (right plot) $\rightarrow$ Z lies in W shoulder

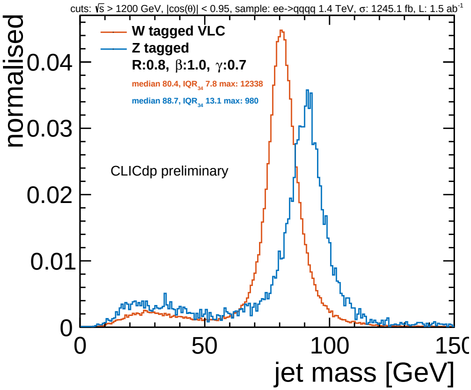


Figure: scaled to same #events

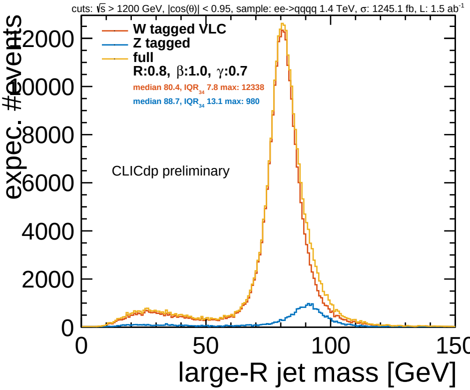


Figure: at expected SM ratio with combination

Separation with VLC $r = 0.8$ $\beta = 1.0$ $\gamma = 0.7$: four exclusive jets

- 4 exclusive jets: combine by $\chi^2_{W/Z} = ((m_{ij} - m_{W/Z})^2 + (m_{kl} - m_{W/Z})^2)$
- decreases the low mass tail $\rightarrow$ improves separation: here around 15% higher
- scatter plot shows the separation for the same amount of WW and ZZ events

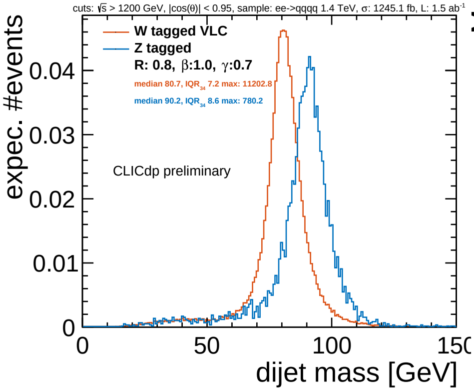


Figure: Using 4 exclusive jets

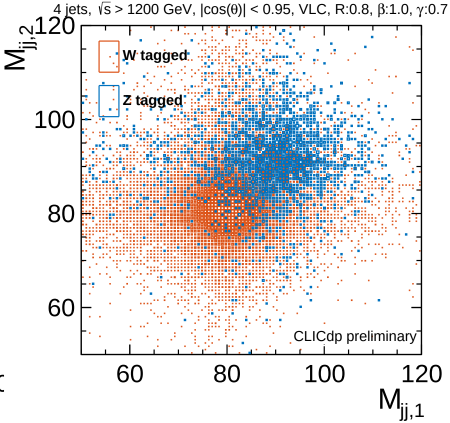


Figure: mass jet1 vs mass jet2, same amount of WW and ZZ

WW/ZZ separation with CLIC_o3_v12

WW/ZZ separation with CLIC_o3_v12

- Use optimisation results from old model to study separation in new model
- generally slightly lower jet masses
- overall separation similar to CLIC_ILD: around 8 GeV between medians

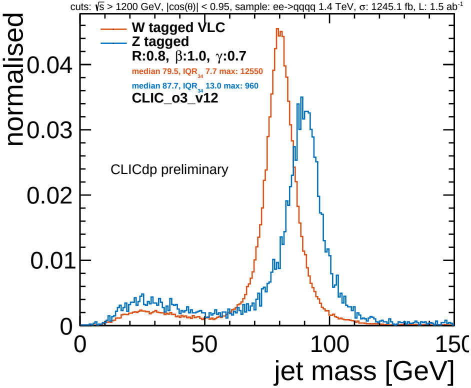


Figure: two excl. jets

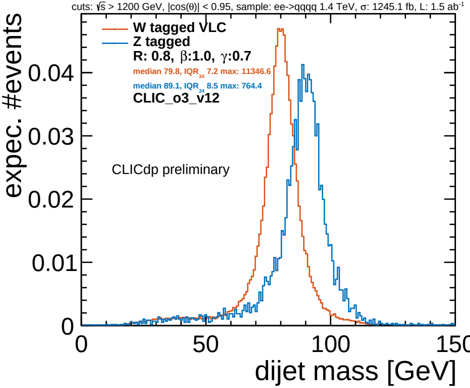
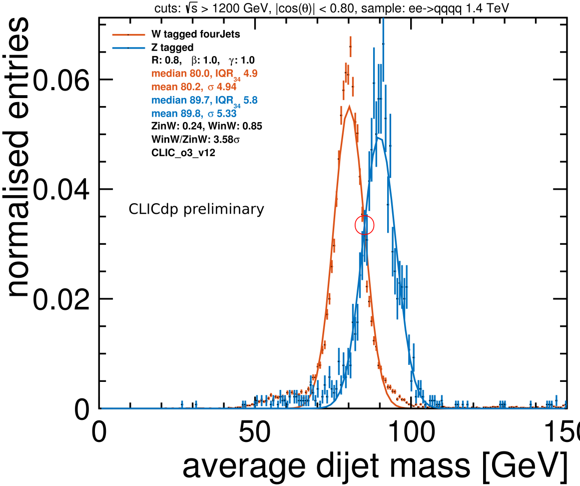


Figure: four excl. jets

Outlook

- Study separation with new detector further
- Use average jet mass to reduce tails
- Gaussian fit + cut at intersection
- maximise significance
- currently: 85% of WW and 24% of ZZ events in signal region
- caveat for detector performance: Z decay to c and b quarks included
- furthermore: evaluate missing p_T distributions for new detector model
- use jet trimming on selected timing cut collection



Summary

- Compared timing cuts for new and old CLIC detector model:
  - timing cuts work out of the box for CLIC_o3_v12 (closer to W mass)
  - loose PFO selection gives better jet mass than before, but tight selection is still to be preferred
- Looked at WW/ZZ separation in ee $\rightarrow$ qqqq events:
  - optimised jet clustering algorithm and parameters
  - looks hard to separate according to SM cross-sections
  - for same amount of WW and ZZ events: good separation achieveable
  - ongoing work: separation with same amount of WW/ZZ

Backup

Backup

Compare old and new detector model: 1.4 TeV

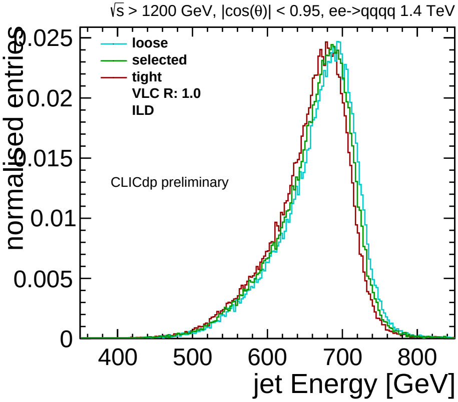


Figure: CLIC_ILD

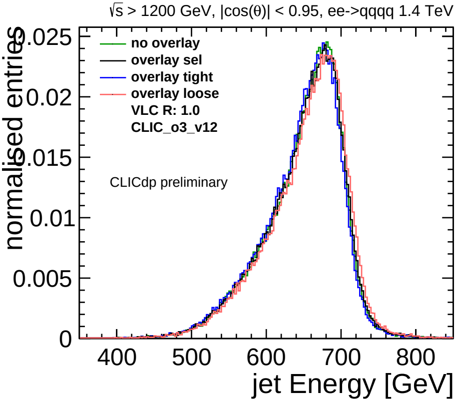


Figure: CLIC_o3_v12

- Small differences in compared from old to new detector: now slightly lower energies
- Barely any differences in jet energy between timing cut collections in CLIC_o3_v12

Compare old and new detector model: 3 TeV

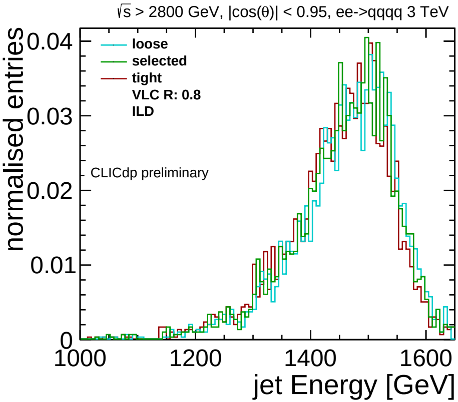


Figure: CLIC_ILD

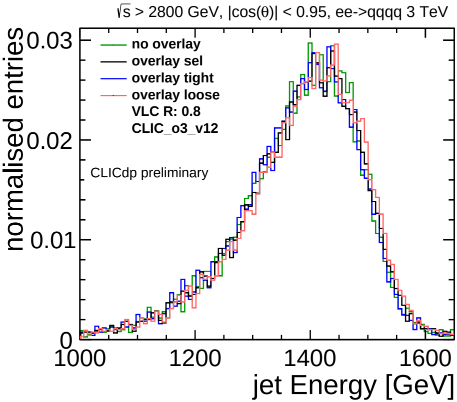


Figure: CLIC_o3_v12

- More sizeable differences between old and new model in jet energy compared to the 1.4 TeV case
- No distinct differences in jet energy between timing cut collections in CLIC_o3_v12 or CLIC_ILD

Jet mass and energy: loose selected

- Compare collection for CLIC_ILD and CLIC_o3_v12 with overlay
- Loosely selected PFOs, CLIC_o3_v12, CLIC_ILD

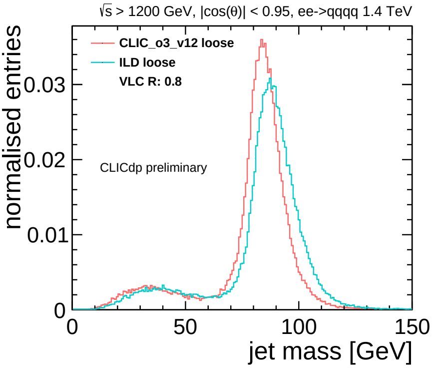


Figure: W jet mass

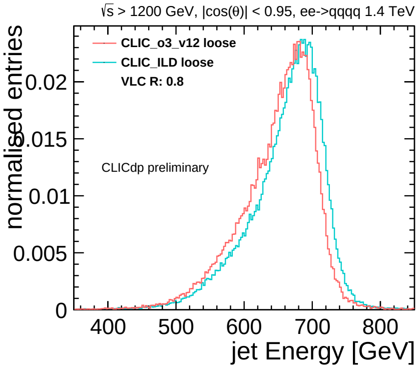


Figure: W jet energy

- Loose collection usually not considered at 1.4 TeV but considerably better now
  - narrower distribution and peak closer to W mass

Jet mass and energy: selected

- Selected PFOs compared, CLIC_o3_v12, CLIC_ILD

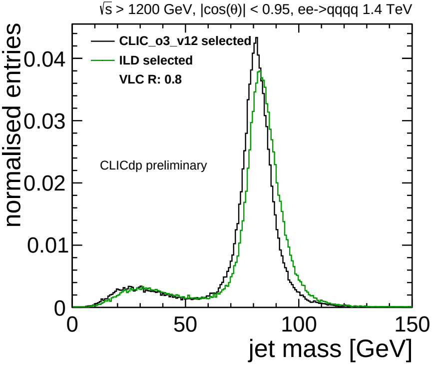


Figure: W jet mass

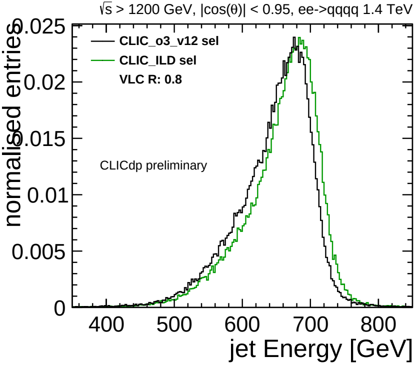


Figure: W jet energy

- Smaller difference in selected collection, shift to slightly lower masses
  - closer to W mass

Jet mass and energy: tight selected

- Tight selected PFOs compared, CLIC_o3_v12, CLIC_ILD

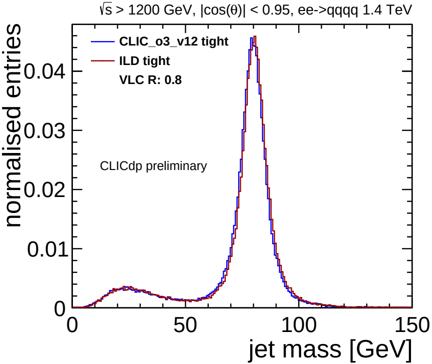


Figure: W jet mass

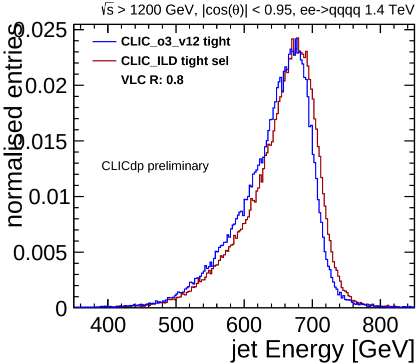


Figure: W jet energy

- Tight selected PFOs show very similar W jet mass distributions

Jet mass and energy: loose

- Selected PFOs compared, CLIC_o3_v12, CLIC_ILD

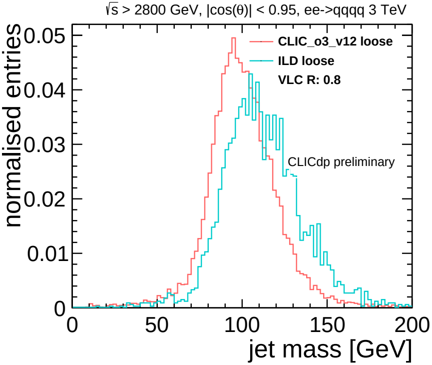


Figure: W jet mass

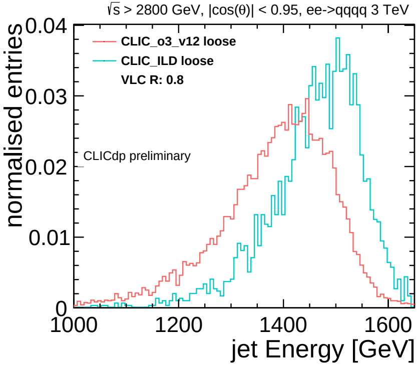


Figure: W jet energy

- W mass peak a lot more pronounced for new model

W mass Peak height

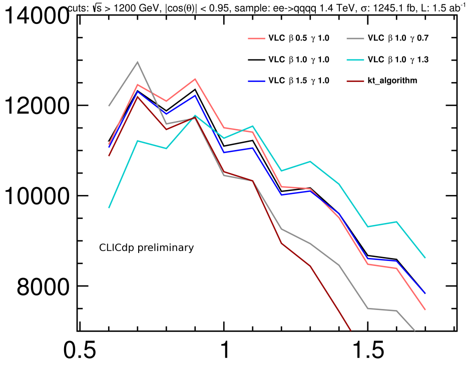


Figure: Separation of W and Z median

- medium peak height for VLC with $\beta = 1.0$ and $\gamma = 0.7$
- settings with higher peak height lead to worse IQR_{34}/median or median

Median

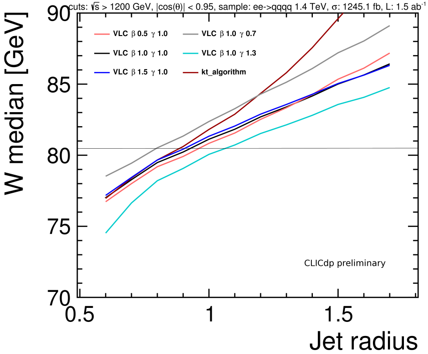


Figure: Median of W jet mass distribution

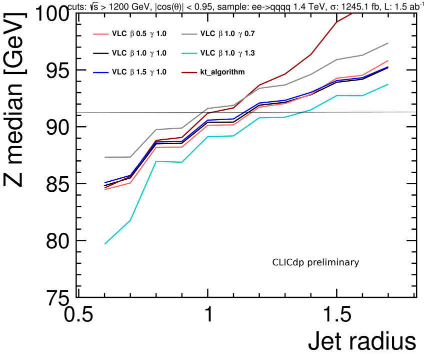


Figure: Median of Z jet mass distribution

- As expected, median of jet mass rises with jet radius: picking up more PFOs
- difficult to get W and Z median right with same setting
- VLC with $\beta = 1.0$ and $\gamma = 0.7$, median around the W mass for $r = 0.8$

Median separation

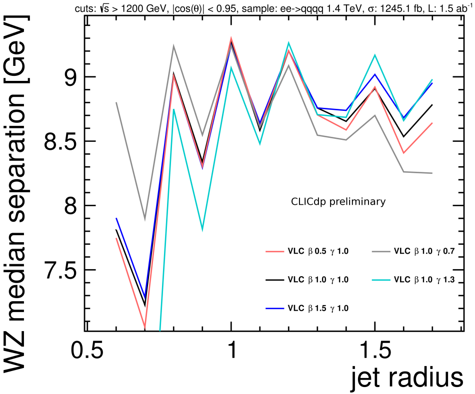


Figure: Separation of W and Z median

- Flatness at high radii expected, W and Z jets both pick up more mass
- VLC with $\beta = 1.0$ and $\gamma = 0.7$ achieves high separation around 9 GeV

Detailed comparison: Change in $\sqrt{s}$ cut

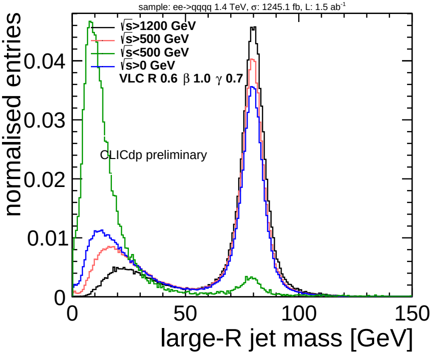


Figure: $r = 0.6$ Figure: $r = 1.5$

- $\sqrt{s} > 1200\,\text{GeV}$, $\sqrt{s} > 500\,\text{GeV}$, $\sqrt{s} < 500\,\text{GeV}$, $\sqrt{s} > 0\,\text{GeV}$
- low boost $\rightarrow$ not the whole W captured in one jet
- for high radii (here 1.5) low mass bump vanishes already for $\sqrt{s} > 500\,\text{GeV}$, but high mass tail

Detailed comparison: Change in $|\cos(\theta)|$ cut

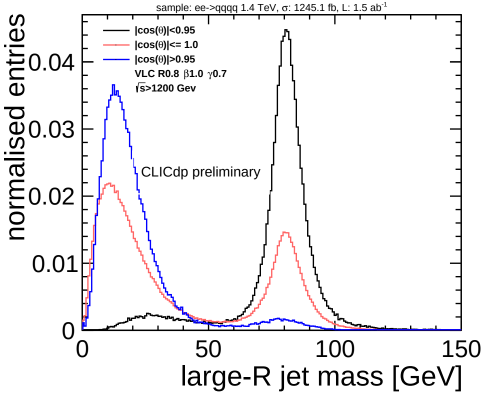


Figure: $|\cos\theta| < 0.95$, all, $|\cos\theta| > 0.95$

- $\cos\theta$ cut on quarks
- forward region: part of the jet not captured

Detailed comparison: Change in VLC β

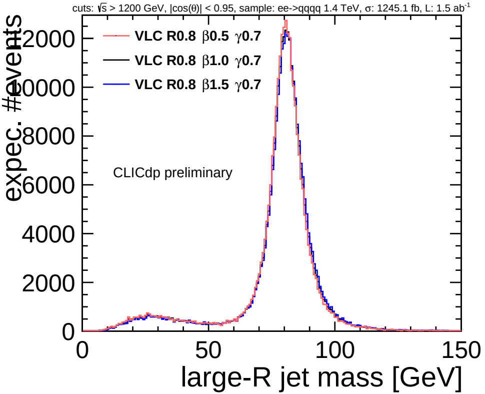


Figure: $\beta = 0.5$,$\beta = 1.0$,$\beta = 1.5$

- For boosted events not important (clustering order) ?
  - will check influence of β for 4 excl. jets at lower energies