Jet Performance and Validation at CLIC

LCWS 2018

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Jet Reconstruction and Physics

Good jet energy reconstruction essential in many measurements
→ Larger cross-section in hadronic signatures, more challenging to reconstruct with high precision

Accurate jet energy measurement key point in distinguishing signatures → test case W and Z mass separation

Excellent Particle Flow identification (both type and energy) required for good jet performance
→good track reconstruction essential
→requires fine grained calorimeter for good cluster separation between close-by particles and matching of clusters and tracks

Jet Energy Resolution

Jet Energy resolution (JER): total Energy vs Jets

SO FAR: compare **total reconstructed energy** with **total energy sum of MC truth particle energies** in dijet events to quantify jet energy resolution → assumes energy distributed evenly in two jets, jet energy resolution related to total energy resolution by

$\Delta E_{jet}/E_{jet} = \sqrt{2}*\Delta E_{tot}/E_{tot}$

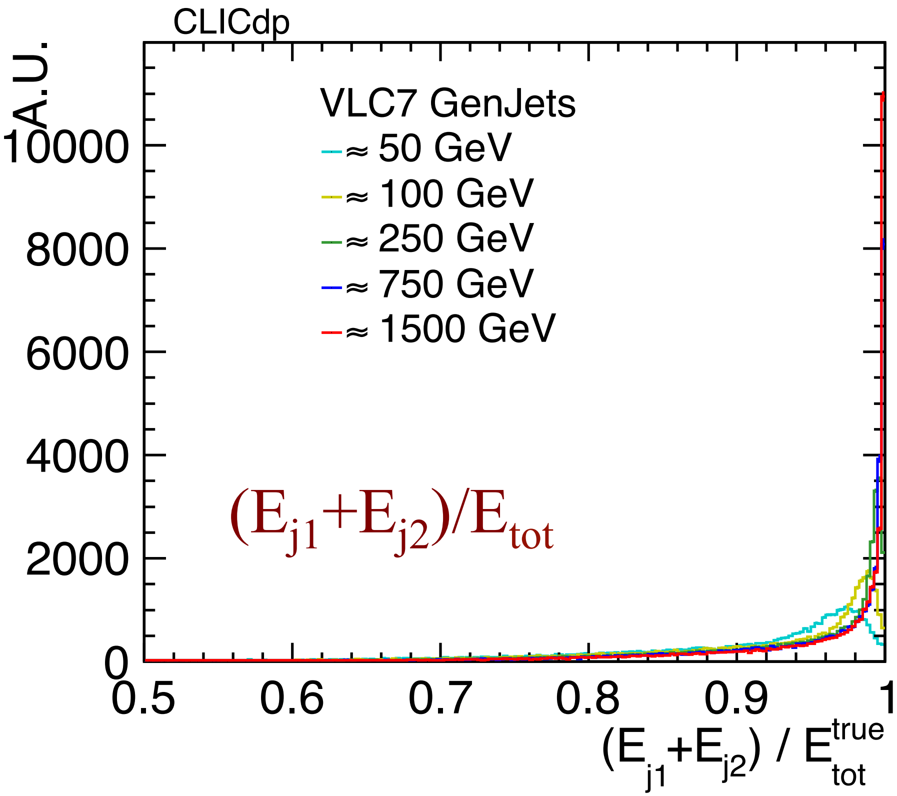
NOW: compare quantities of **reconstructed jets** with quantities of **MC truth jets clustering stable particles**

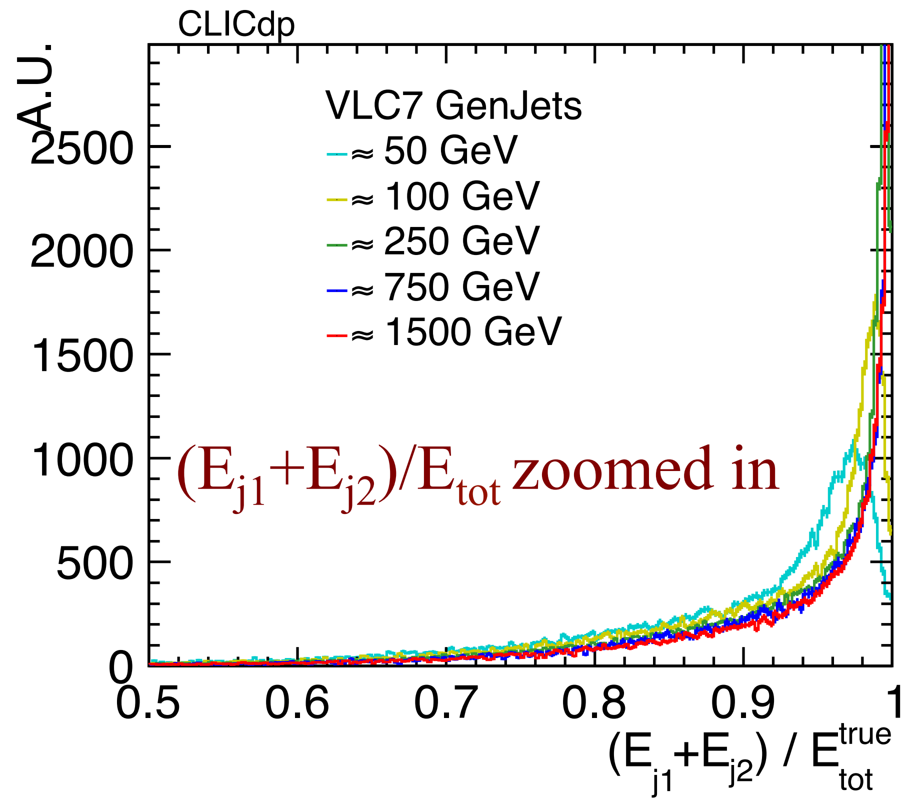
- Ignore neutrinos for MC particle jets
- Define reconstructed jets using as input
  - PandoraPFOs in events without background
  - TightSelectedPandoraPFOs in events with 3 TeV $\gamma\gamma$→hadrons background
  - LE_LooseSelectedPandoraPFOs for 380 GeV $\gamma\gamma$→hadrons
- Studied in Z→qq events, with q=u,d,s
- Jet algorithm: Valencia algorithm (VLC) $\gamma=\beta=1.0$, radius R=0.7, exclusive jet clustering of event in exactly two jets

Jet energies vs total event energy

MC truth jets, events with $\Delta\varphi(j1,j2)>2.8$

Compare energy sum of both jets vs total energy in event



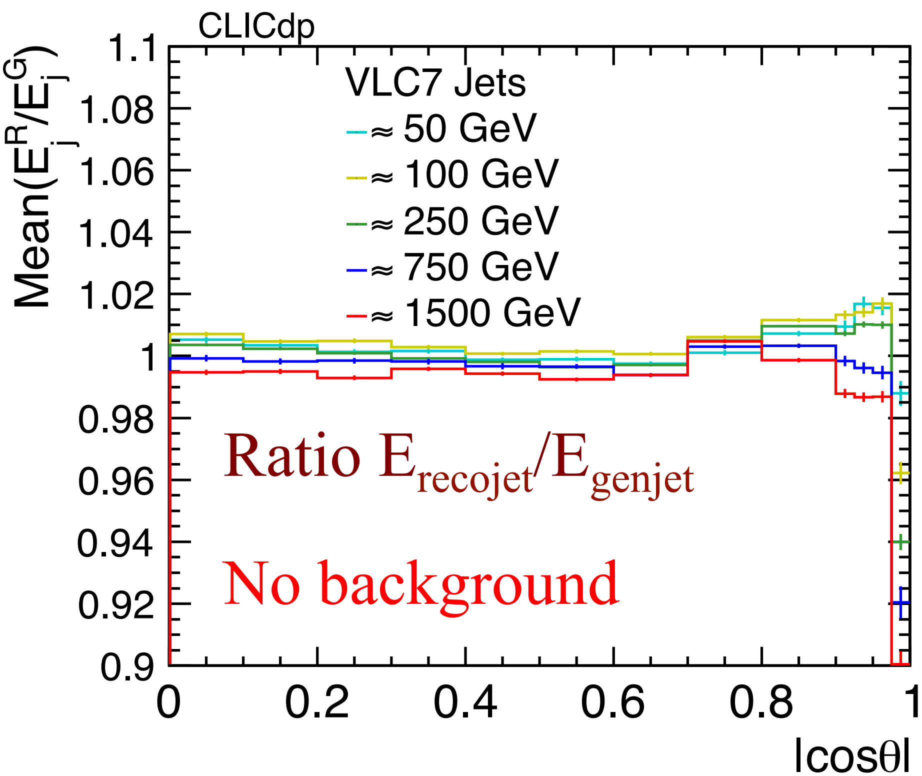


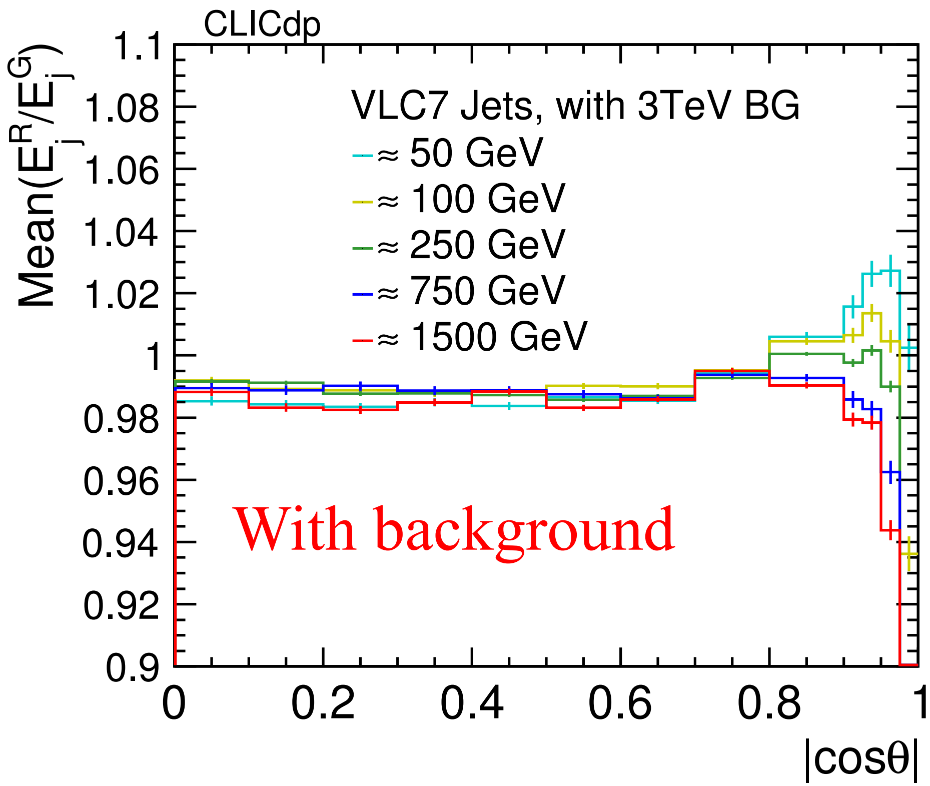
For most events in this preselection vast majority of total event energy contained in both jets, slightly larger tail to lower values for low energetic jets at 50 GeV → jet cone of R=0.7 well suited for study

Jet energy: particle level vs detector level

PandoraPFOs calibrated, no further calibration on jet energy

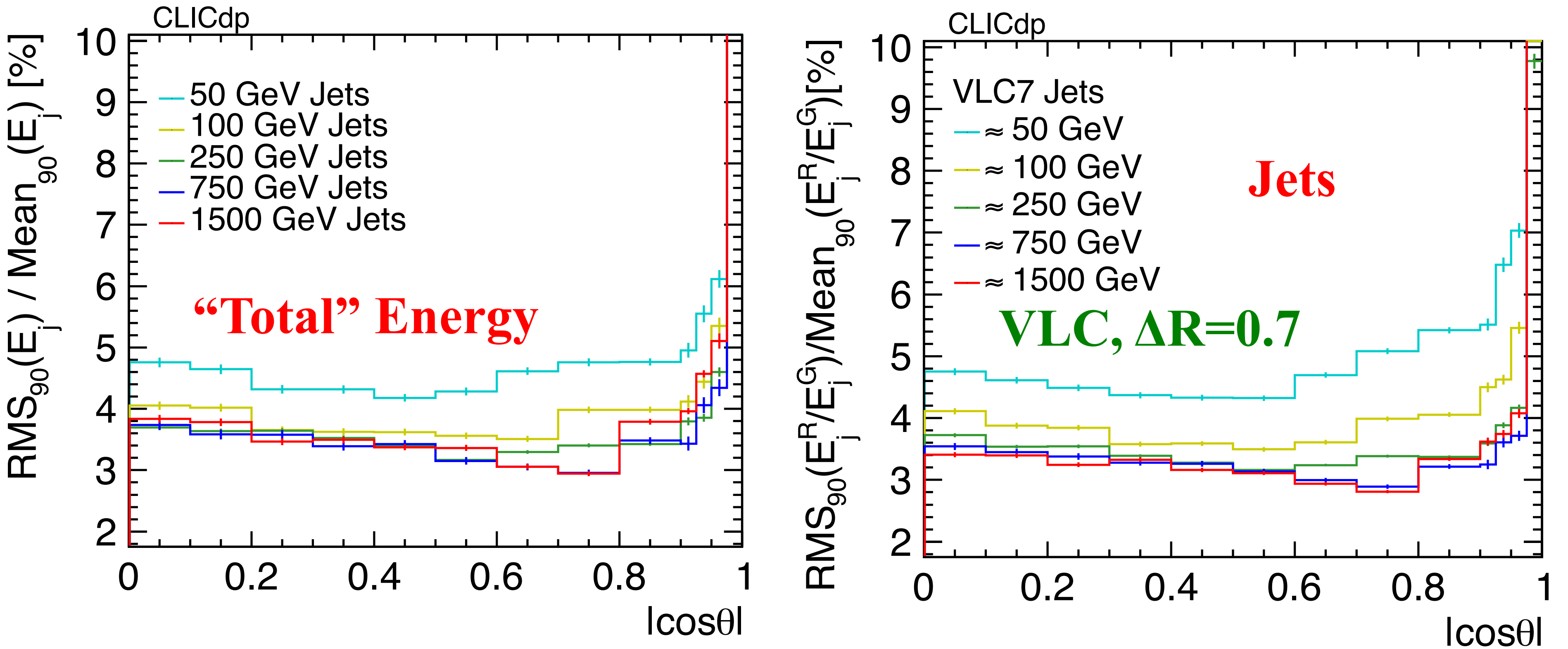
Check if $\gamma\gamma \rightarrow$ hadrons background has large impact on energy collected in jet





Angular matching requirement between detector level recojet and particle level genjet within 10° $\rightarrow$ raw jet energy response close to unity for both cases, no large impact of background within jet cone

Jet Energy resolution (JER): total Energy vs Jets



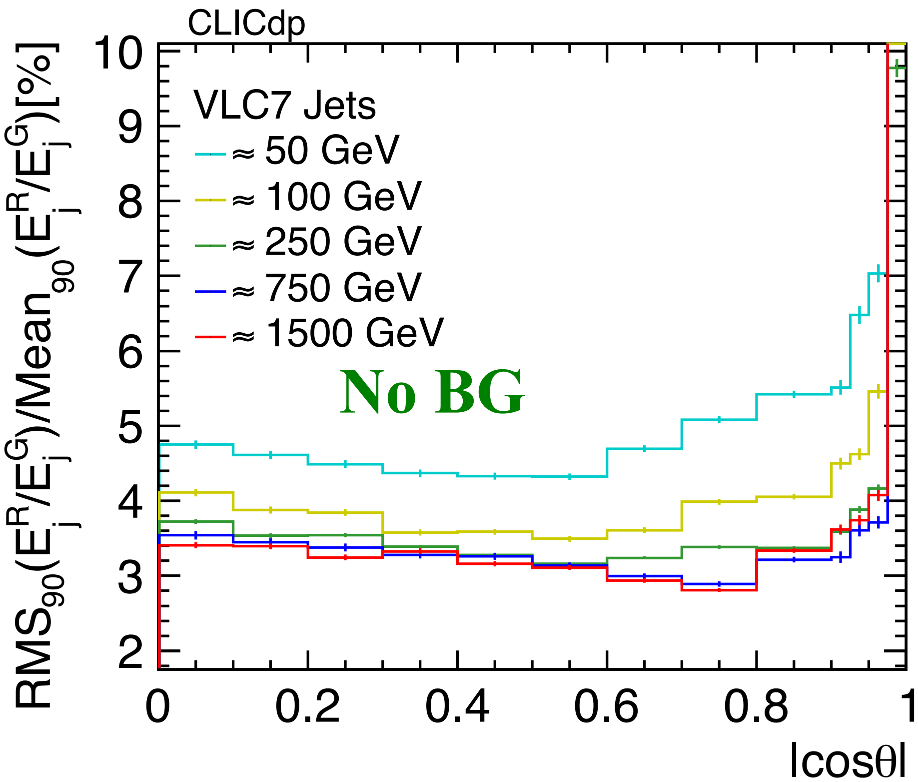
Jet Energy Resolution for several jet energies, as function of |cos θ| of quark

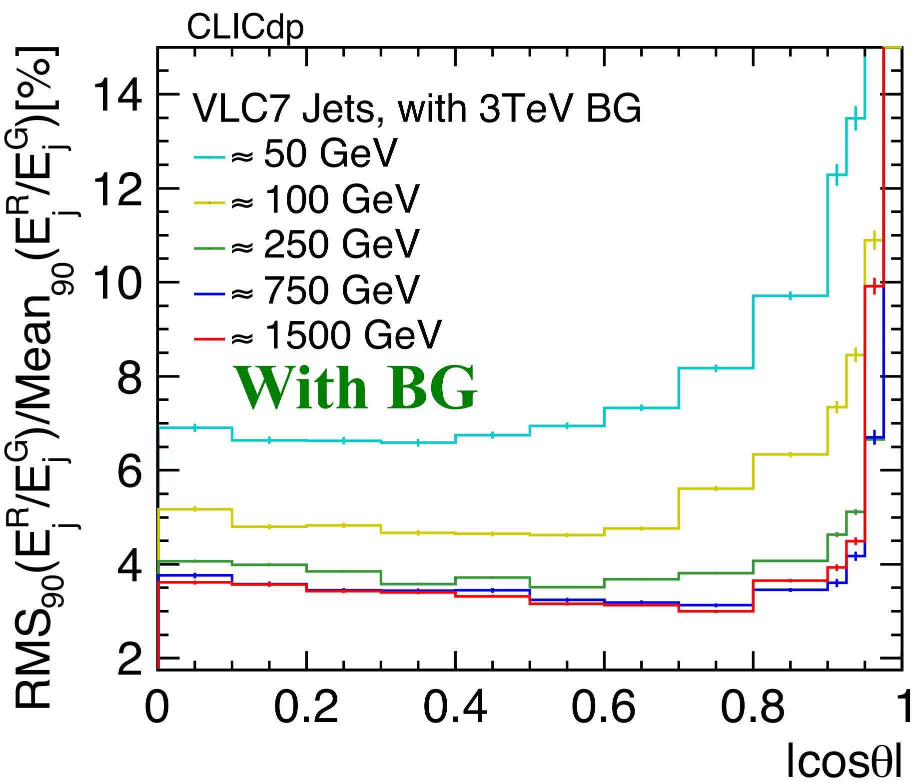
Compare reconstructed jets and particle jets, $\Delta R = 0.7$

Angular matching between reconstructed and particle jet (<10 °)

→ Similar resolution values after jet clustering

JER vs cosTheta: with and without BG





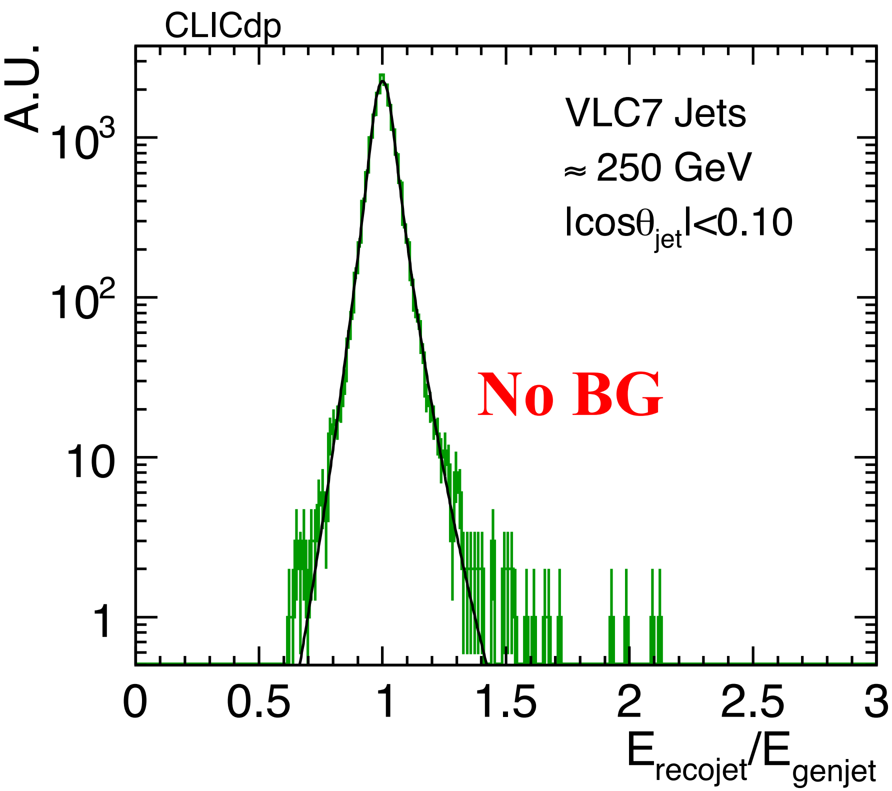
Compare resolution of reconstructed jets →3TeV conditions for overlay

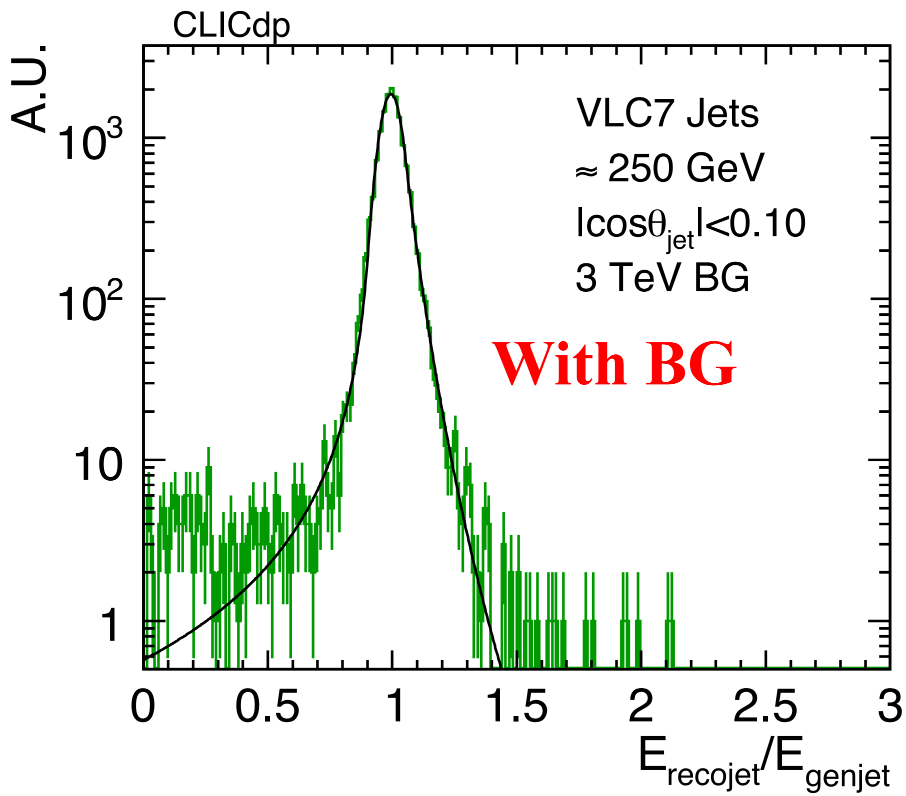
→for 50 GeV jets increase from 4.5/5 % to 7 % in barrel

→for 100 GeV jets increase from 4 % from 5% in barrel, 6.5 % in endcap

At high jet energies mild increase, except for very forward jets

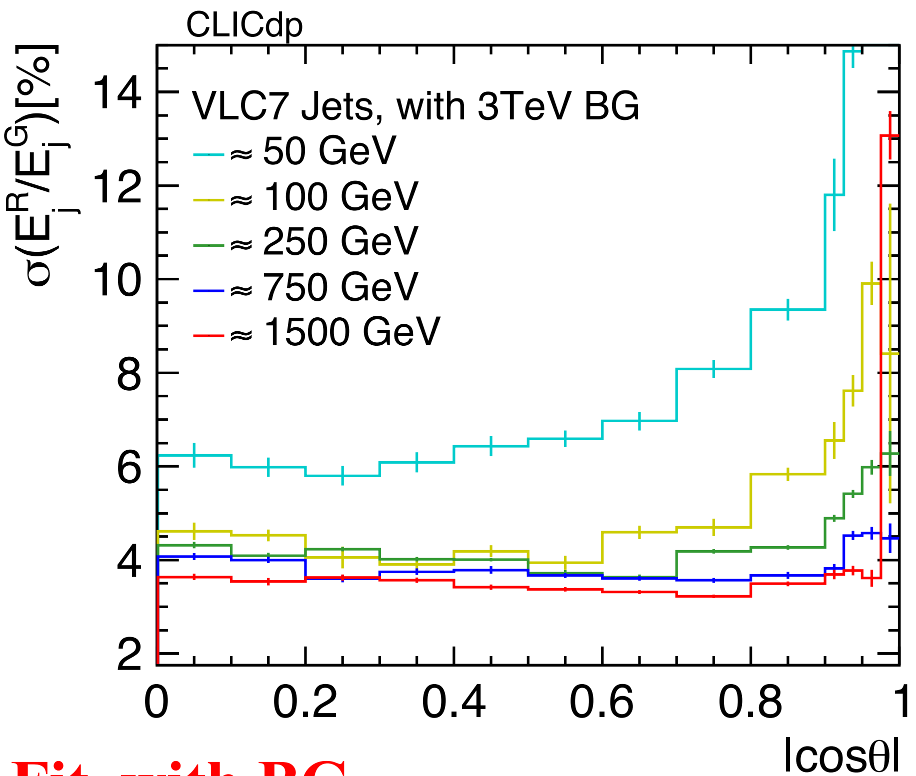
Jet Energy Resolution: Fit resolution curves



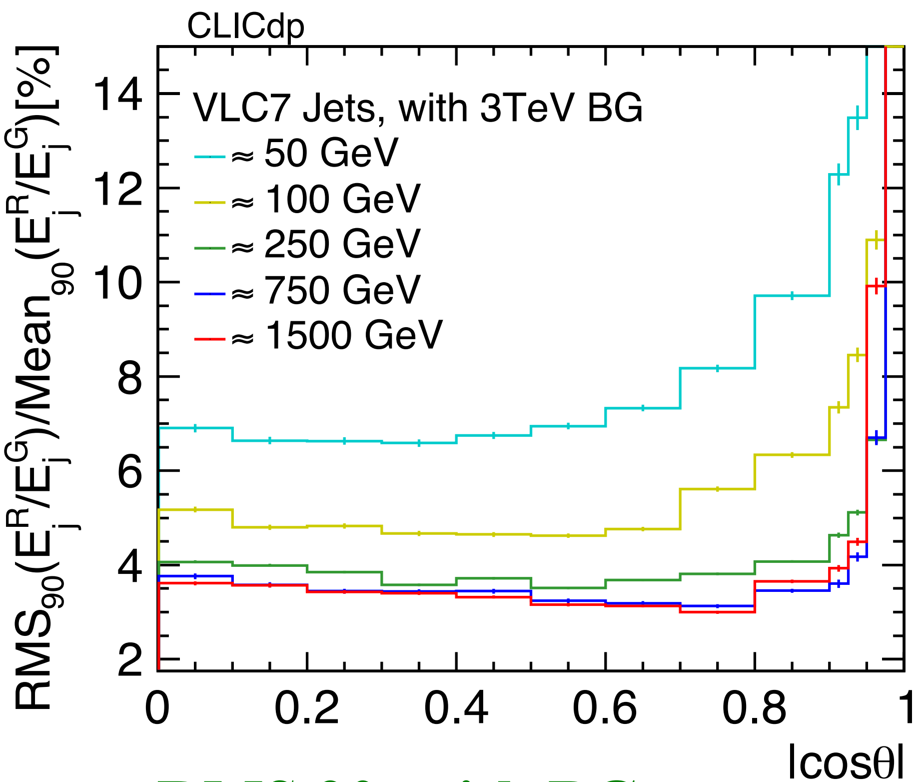


γγ → hadrons background leads to significant non gaussian tails in the jet energy resolution distribution, double sided crystal ball function (gaussian core and power law tails) fits most of the distribution for all detector regions

- Double sided crystal ball used by CMS
- Background creates a larger tail to lower resolution values



Fit, with BG

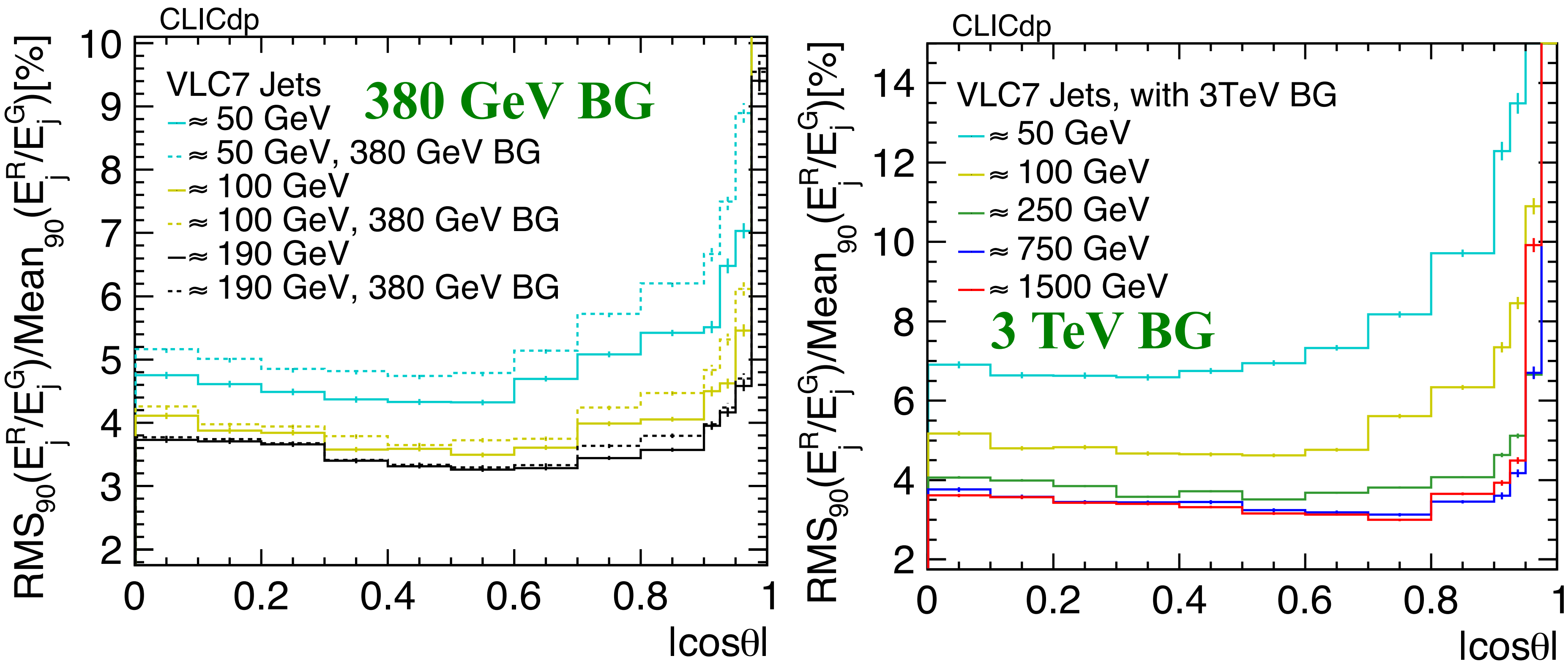


RMS 90, with BG

Fit jet energy response by double sided Crystal Ball function, use sigma of the Gaussian core as measure for jet energy resolution

For most energies resolution values of fit close to the RMS90 resolution measure, for high energies within 10-15 %

JER vs cosTheta: 380 and 3 TeV BG

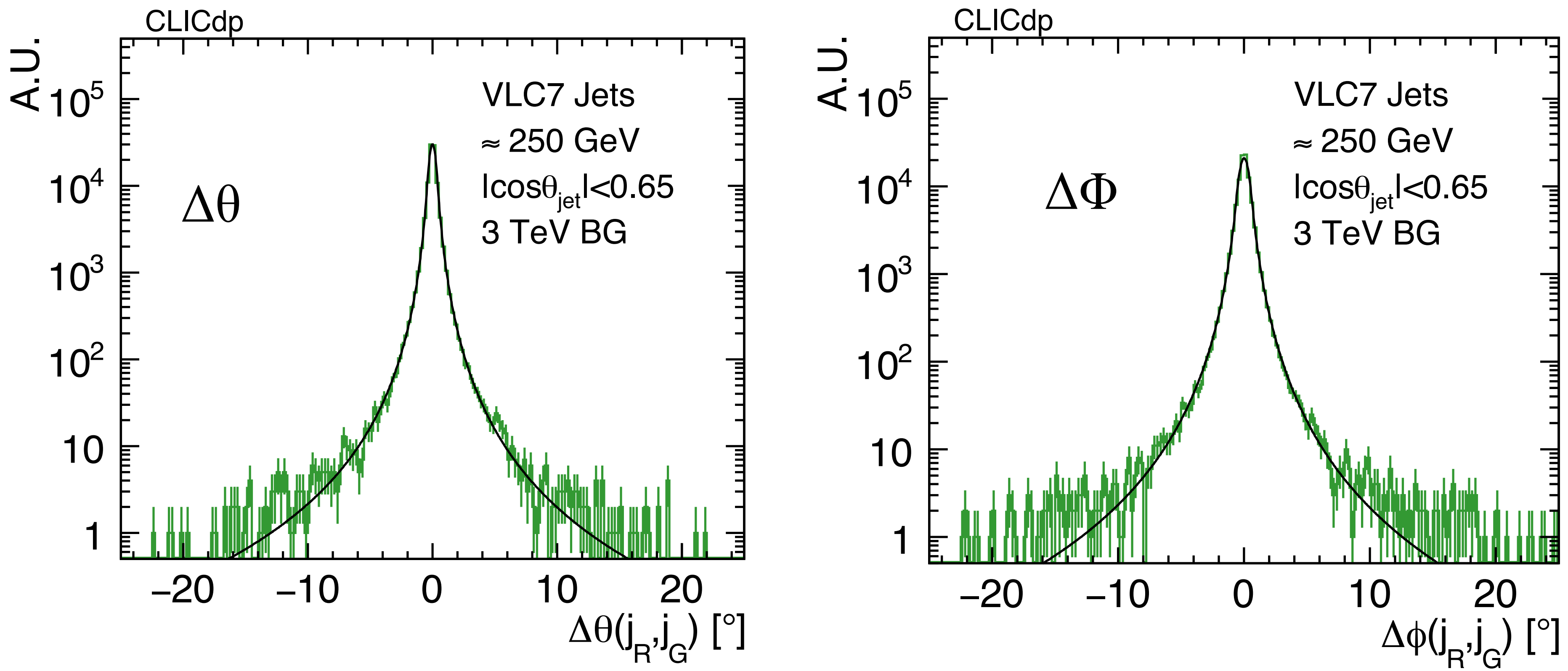


Compare background levels from γγ→hadrons of the 380 GeV machine to the 3 TeV machine

- Moderate increase in jet energy resolution for barrel jets even for 50 GeV jets, at 3 TeV machine increase from 5→7 %
- Almost no effect of background for barrel jets for energies >100 GeV

Jet Phi and Theta Resolution

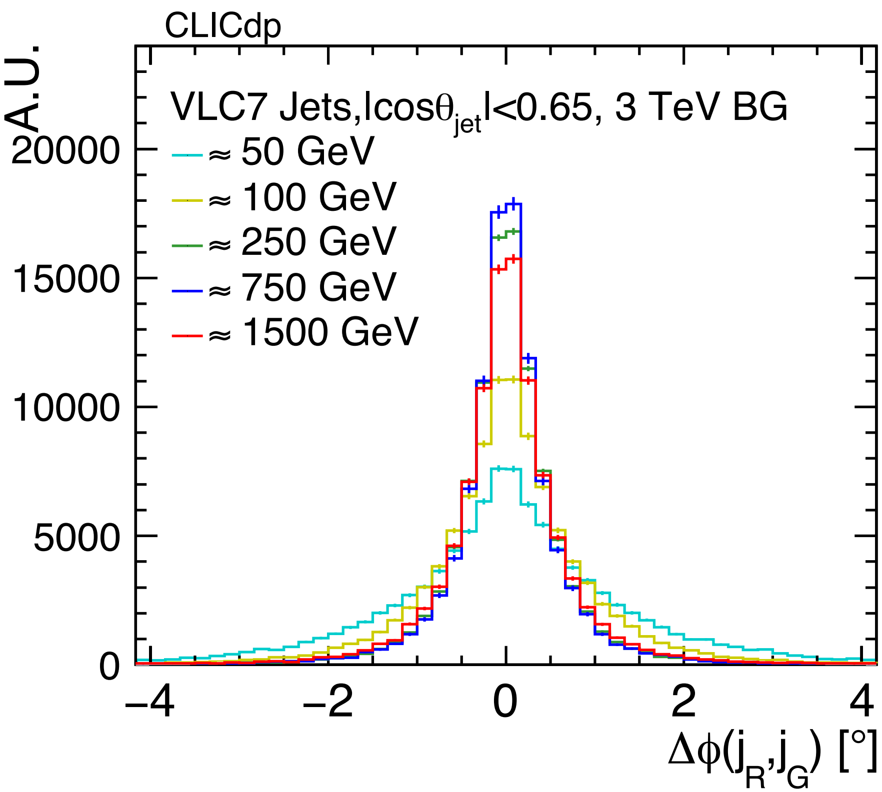
Position Resolution: Fit resolution curves

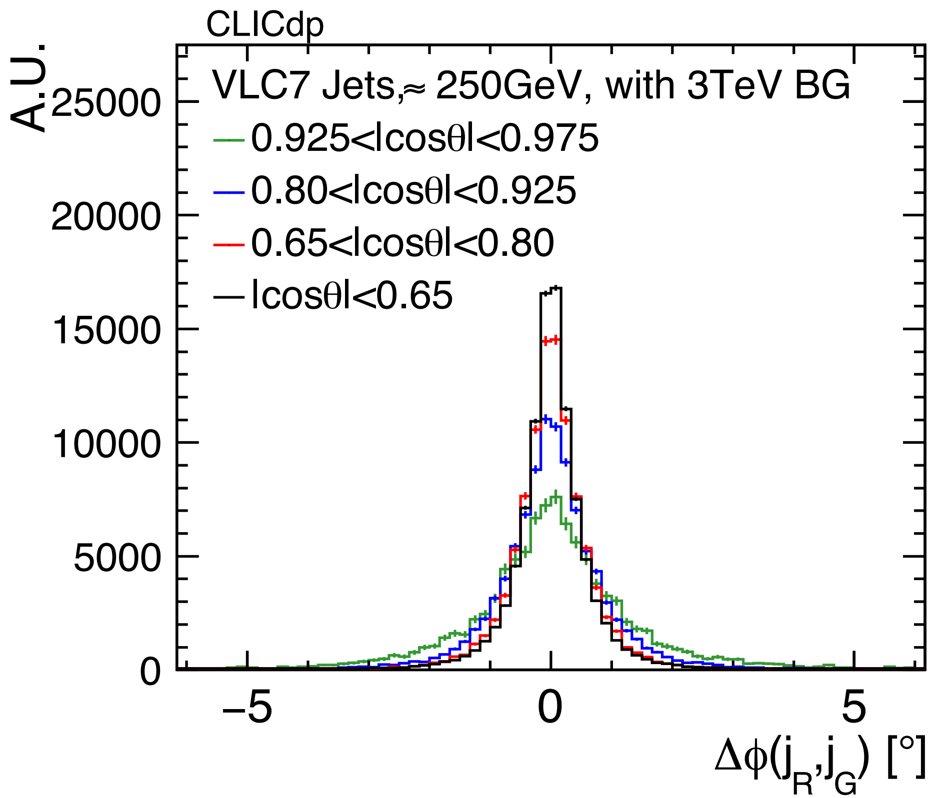


$\Delta\theta$ and $\Delta\Phi$ distributions between reconstructed and closest MC truth jet

Fit with a double sided Crystal Ball function with a Gaussian core and two exponentials, fits most of the distribution well

ΔΦ Resolution vs jet Energy and polar angle

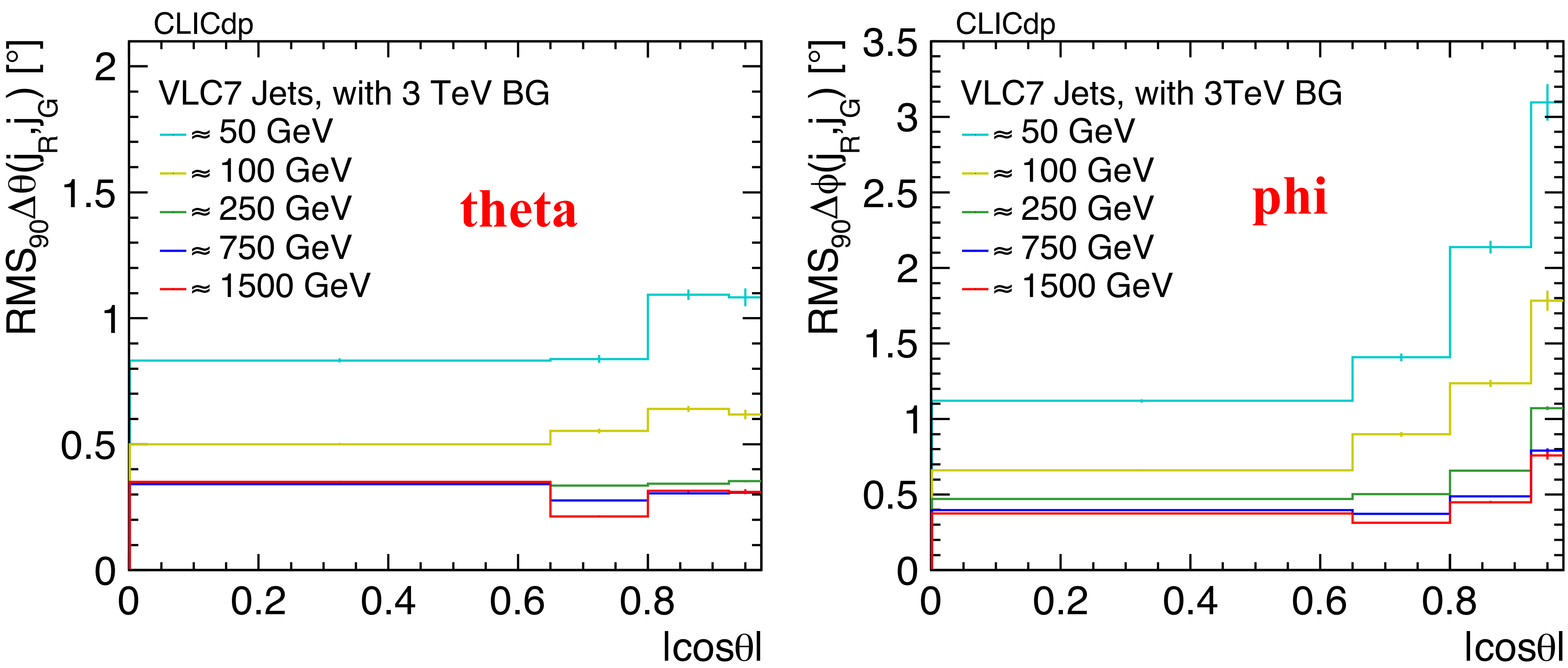




Phi Resolution increases for polar angles closer to the beamline

As function of jet energy with higher energies, jets are more collimated and jet phi resolution curve is less wide

Jet Phi and Theta Resolution with 3 TeV BG



Theta/Phi resolutions below 1/1.5 degree for most detector regions for all jet energies, for forward region phi resolutions a bit larger for low energetic jets

W and Z mass separation

W and Z mass with overlay

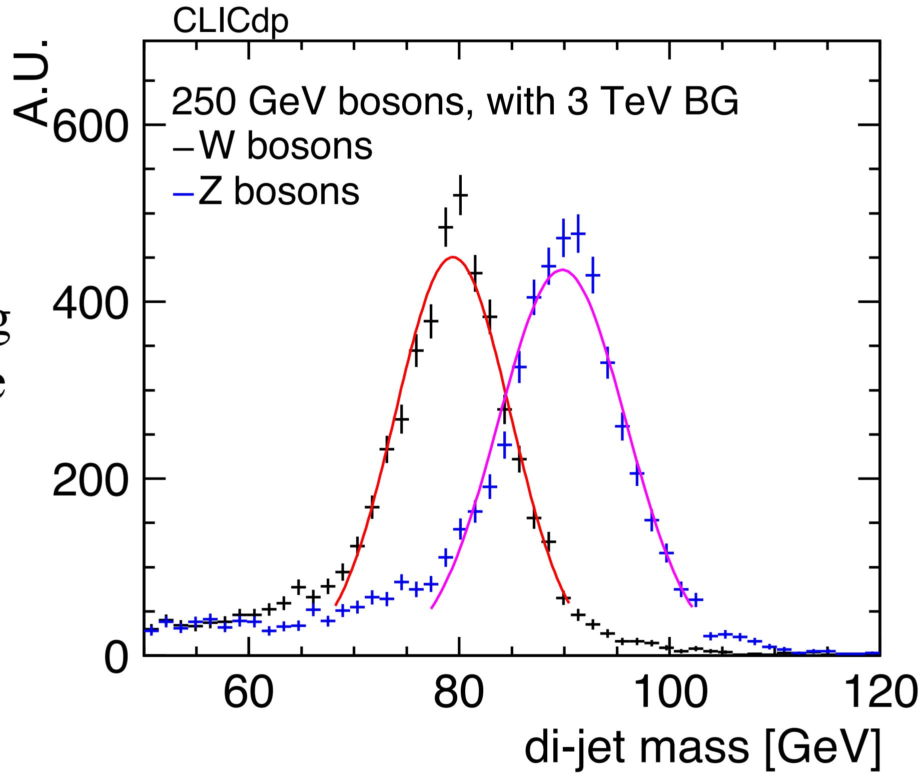
Study dijet mass reconstruction in WW→qq lν and ZZ→qq νν events

Impact of γγ→hadrons studied using 3 TeV beam conditions

Dijet mass peak separation quantified using the overlap fraction A_O and the corresponding selection efficiency ε (=1-A_O), defined by the gaussian fits

$$A_O = \left(\int_{-500}^{X_{int}} gaussZ(x)\,dx + \int_{X_{int}}^{500} gaussW(x)\,dx \right) / 2$$

500 GeV c.m. WW and ZZ events, dijet mass



W and Z mass separation results

Background	$E_{W,Z}$ [GeV]	$\sigma_{m(W)}/m(W)$ [%]	$\sigma_{m(Z)}/m(Z)$ [%]	ε [%]	Separation [σ]
no BG	125	5.5	5.3	88	2.3
	250	5.3	5.4	88	2.3
	500	5.1	4.9	90	2.5
	1000	6.6	6.2	84	2.0
3TeV BG	125	7.8	7.1	80	1.7
	250	6.9	6.8	82	1.8
	500	6.2	6.1	85	2.0
	1000	7.9	7.2	80	1.7
380 GeV BG	125	6.0	5.5	87	2.2

Without background overlap fraction between 10-16 %
Increase of overlap fraction to 15-20 % due to beam background effects (13% for 380 GeV backgrounds)

Conclusion

Jet energy resolution around 3-5% for all energies and all detector regions, up to 10 % for very forward jets
→RMS90 and sigma of double sided Crystal Ball fits lead to similar JER values

Beam backgrounds lead to an increase of the Jet Energy resolution to 7 % for 50 GeV jets, values below 5 % reached for jets energies above 100 GeV

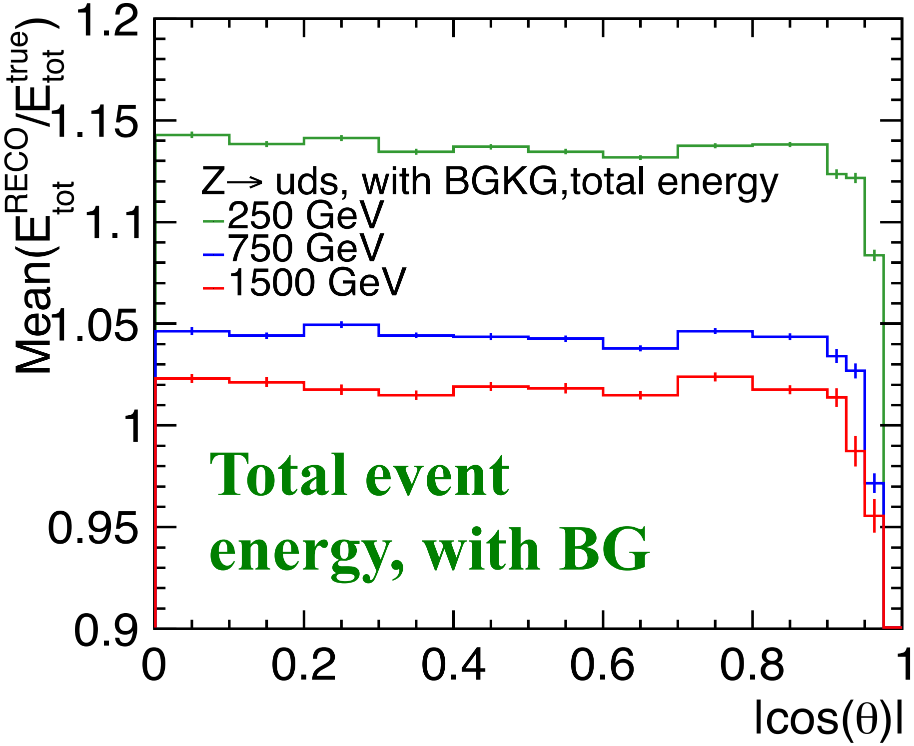
Jet Phi resolutions below 2°, jet theta resolutions below 1° for energies from 50-1500 GeV jets with beam backgrounds overlaid

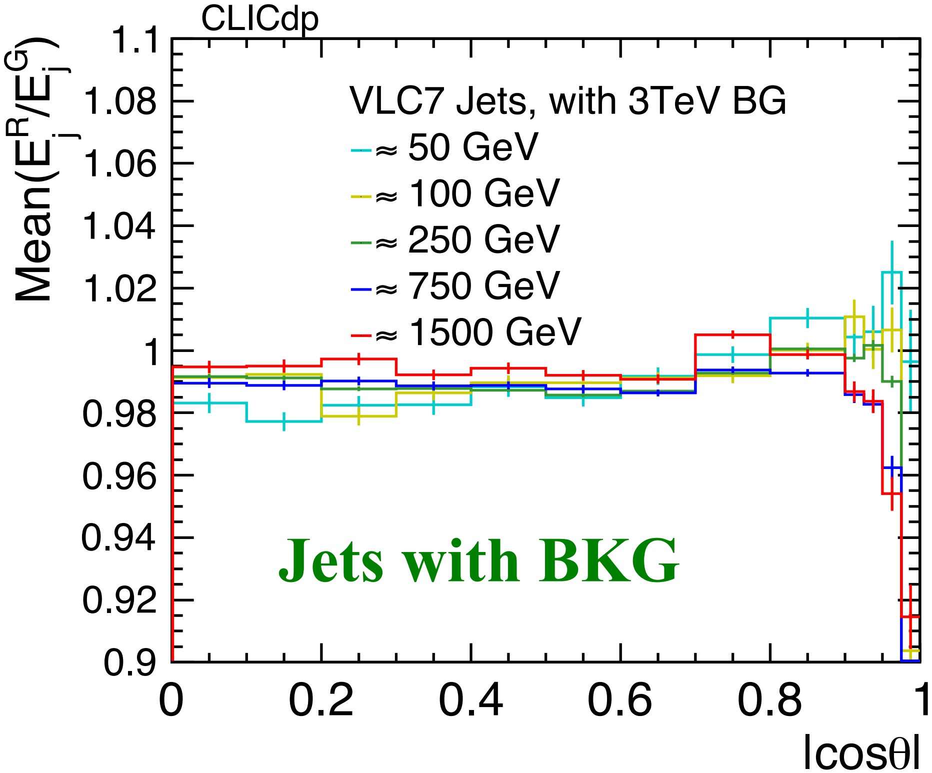
Achieve a W-Z dijet mass separation of 1.7-2.0 σ when including beam backgrounds

→all Jet Studies will be documented in a CLICdp note, in collaboration review right now

BACKUP

Reconstructed jet energy vs MC particle jet energy





Overall event energy is increased by quite a bit after background is added (tight selection) → most of this additional energy is distributed in forward region, not all of this energy ends up in a jet cone

Reconstructed jet energies very close to particle jet energy

W and Z separation

Datasets WW→νμ qq and ZZ→νν qq, where q is a light quark
Veto for WW events where W is offshell, decaying into tb with t decaying leptonically, for Z keep offshell Z→νν (Z→qq always on shell)

- On MC truth: cluster all stable visible particles (status=1, excluding neutrinos), exclude lepton from W (and lepton daughters, e.g. FSR photons)
- On reconstructed level: use all pandora PFOs in events without background, use tightSelected PandoraPFOs when running on events with γγ→hadrons overlayed, remove PFOs around an angle of 25.8° (acos 0.9) of the isolated lepton from W's →with very high rate this removes reconstructed muons and FSR photons and very soft "additional" neutral hadrons
- Jet Algorithm: Valencia Algorithm, R=0.7, β=γ=1.0, exclusive mode with 2 jets, cross-check with k_t algorithm, R=0.7 leads to very similar mass distributions
- W and Z mass calculated from dijet distributions

W and Z mass fits for different boson-energies

Dijet mass distributions have tail to lower mass values (including all events) for low energy sample, energy not sufficiently collected in two jets of ΔR=0.7

- Approach 1: fit first Gaussian over whole range, restrict upper boundary to three sigma (or upper limit of histogram) and 1 sigma to lower side, repeat fitting a gaussian until fitted sigma stable (variation within 2%)
- Approach 2: tail largely reduced if preselecting events where on MC truth 90 % of visible energy (for WW event minus isolated muon from second W) is clustered in the two particle jets → fit first Gaussian over total range, restrict upper boundary to three sigma (or upper limit of histogram) and 2 sigma to lower side, repeat fitting a gaussian until fitted sigma stable (variation within 2%)

→ Around 20 % removed for 125 GeV bosons, 7 % for 250 GeV bosons, below 1 % for higher energies

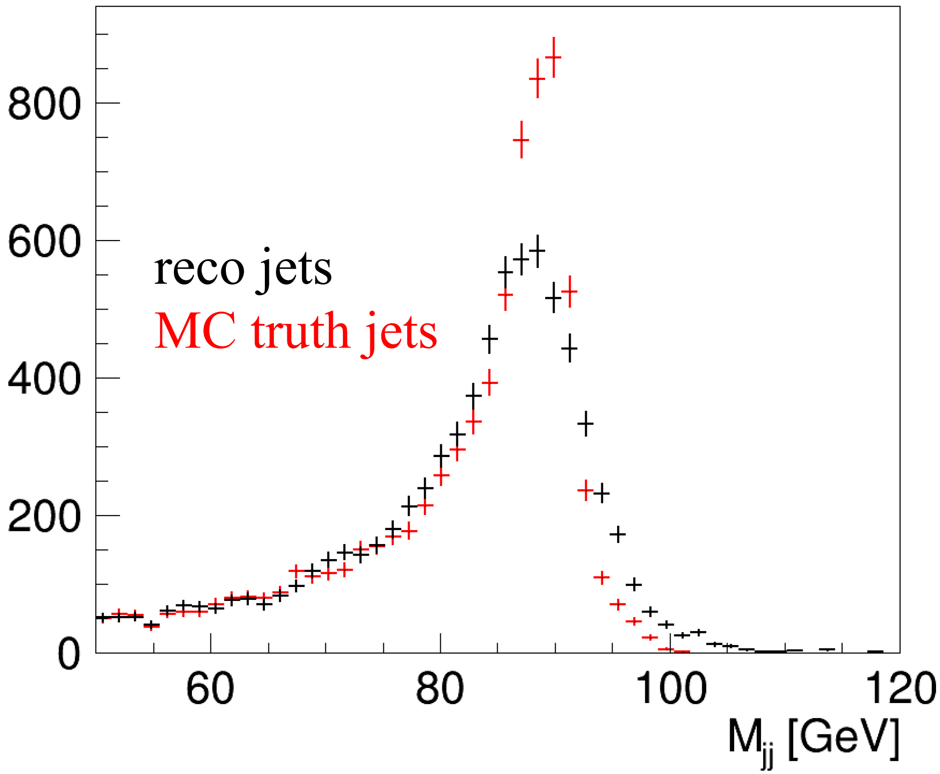
Fit peaks vary with energy → rescale Gaussian fits, so that mean of fit at W-mass (80.4 GeV) and Z-mass (91.2), fix ratio of sigma/mean while rescaling

→ Normalize rescaled Gaussian distributions (for same energy) to the same Integral

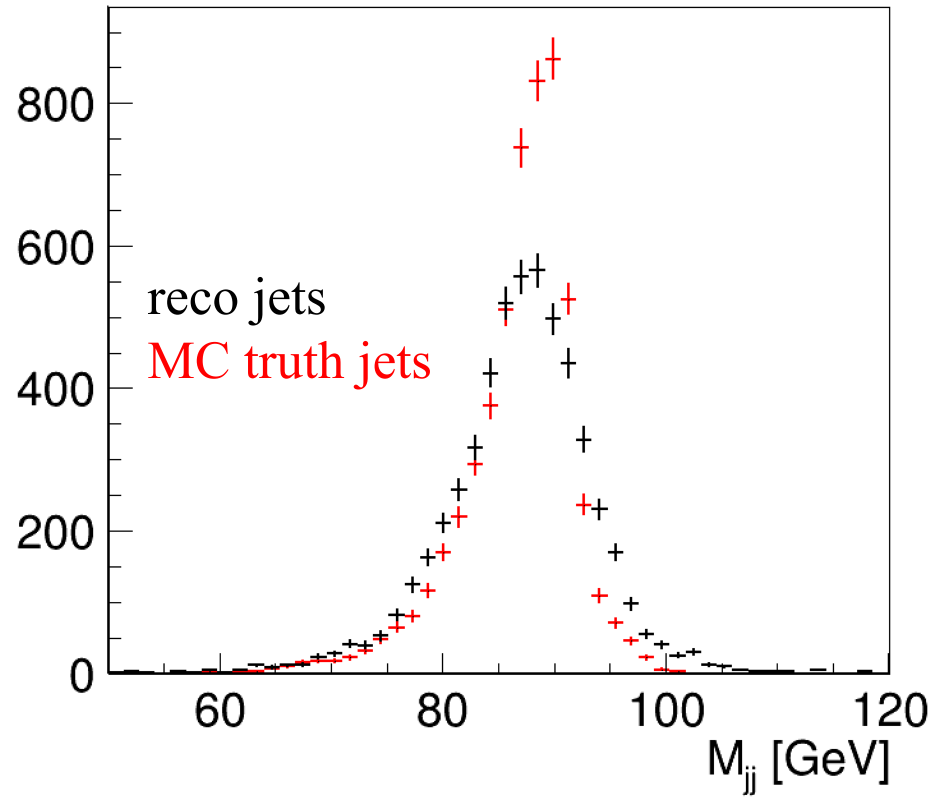
→ Calculate intersection point x_{int}

Z at 125 GeV

All events



Preselection on MC truth:
$(E_1^{true} + E_2^{true})/E_{tot}^{true} > 0.90$



Tail to lower dijet mass values already present on level of true particle jets

→ Largely reduced when cutting on ratio of clustered energy over total energy

→ Events in tail dominated by events with significant energy beyond those clustered in both jets (e.g. a hard third jet)

W and Z overlap fraction

Overlap fraction A_O:

$$A_o = \left(\int_{-500}^{X_{int}} gaussZ(x)\,dx + \int_{x_{int}}^{500} gaussW(x)\,dx \right) / 2$$

Efficiency: integral above/below intersection mass point divided by integral over the whole dijet mass range → average efficiency $E=1-A_O$

Ideal gaussian separation quantified by 2|ROOT::Math::normal_quantile (A_O,1)|

Same result for separation with different approach (seems more intuitive)

$\sigma = (Z_{mass}-W_{mass})/\sigma_{avg}$ with $\sigma_{avg} = (\sigma_Z+\sigma_W)/2$ the averaged σ of the rescaled Gaussian fits on the reconstructed Z and W dijet mass peaks for the different energies