Jet Performance and Validation at CLIC

CLICdp Collaboration Meeting 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

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

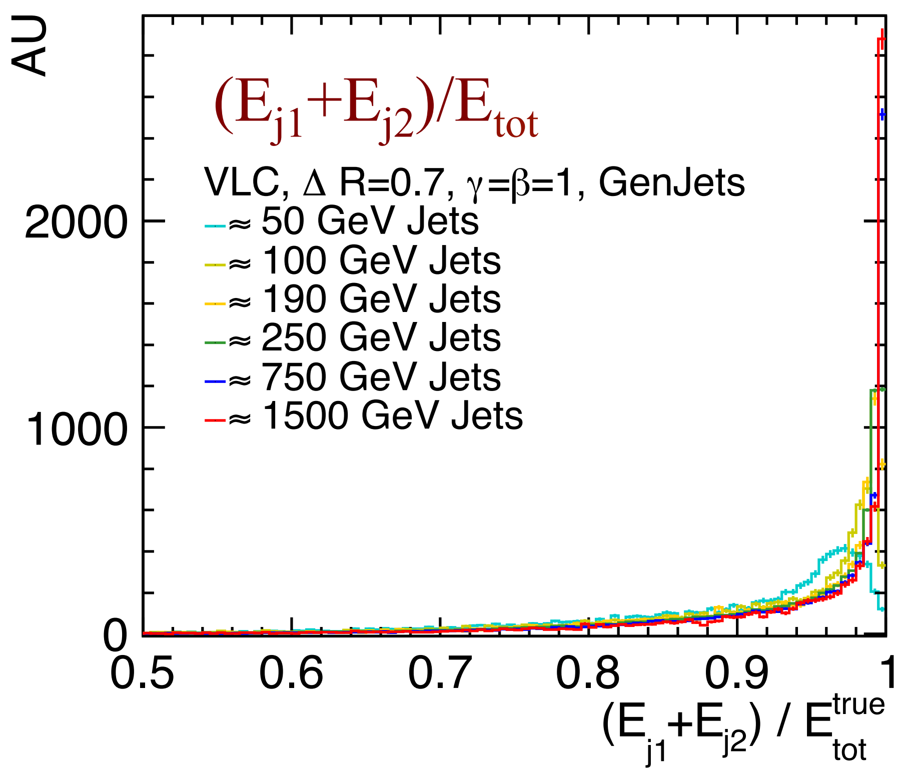
NOW: compare quantities of **reconstructed jets** with quantities of **MC truth jets clustering stable particles**

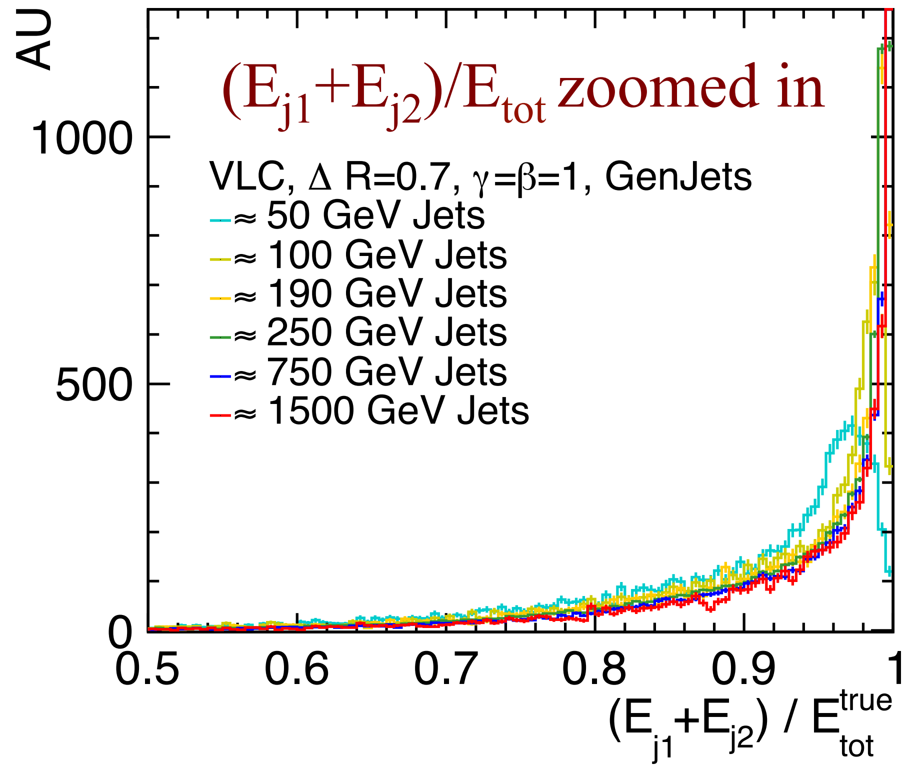
- Ignore neutrinos for MC particle jets
- Define reconstructed jets using all PandoraPFOs (events without background) or TightSelected PandoraPFOs (events with backgrounds overlay from $\gamma\gamma \rightarrow$ hadrons)
- Jet algorithm: Valencia algorithm (VLC) $\gamma=\beta=1.0$, vary radius from R=0.3 up to 1.0, choose R=0.7 as default for plots

Jet energies vs total event energy

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

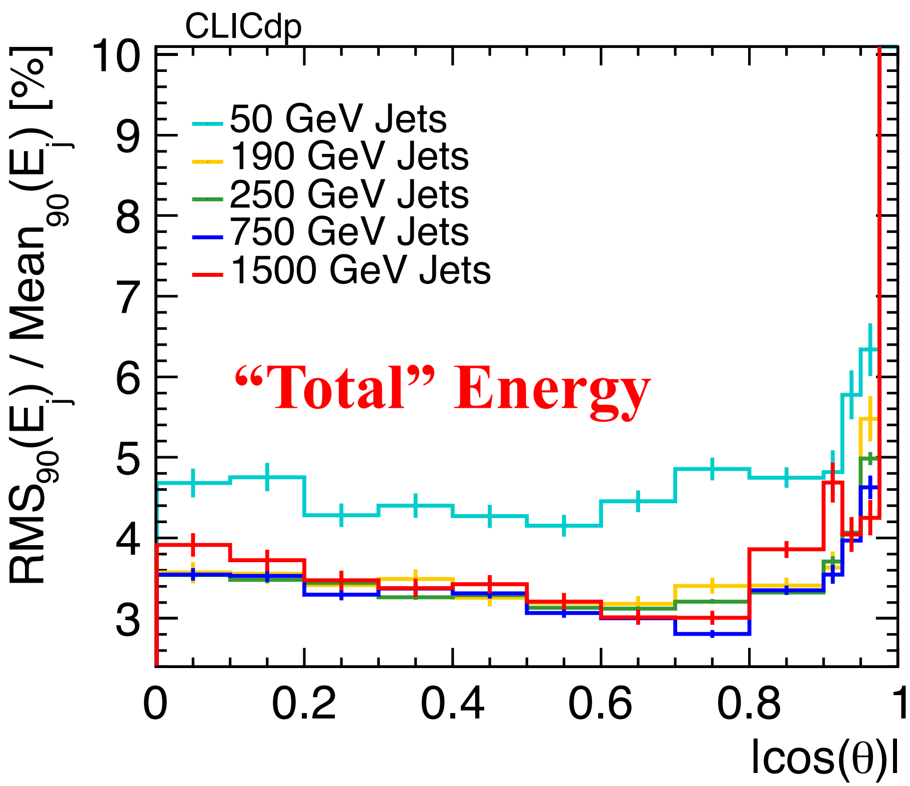
Compare energy sum of both jets vs total energy in event

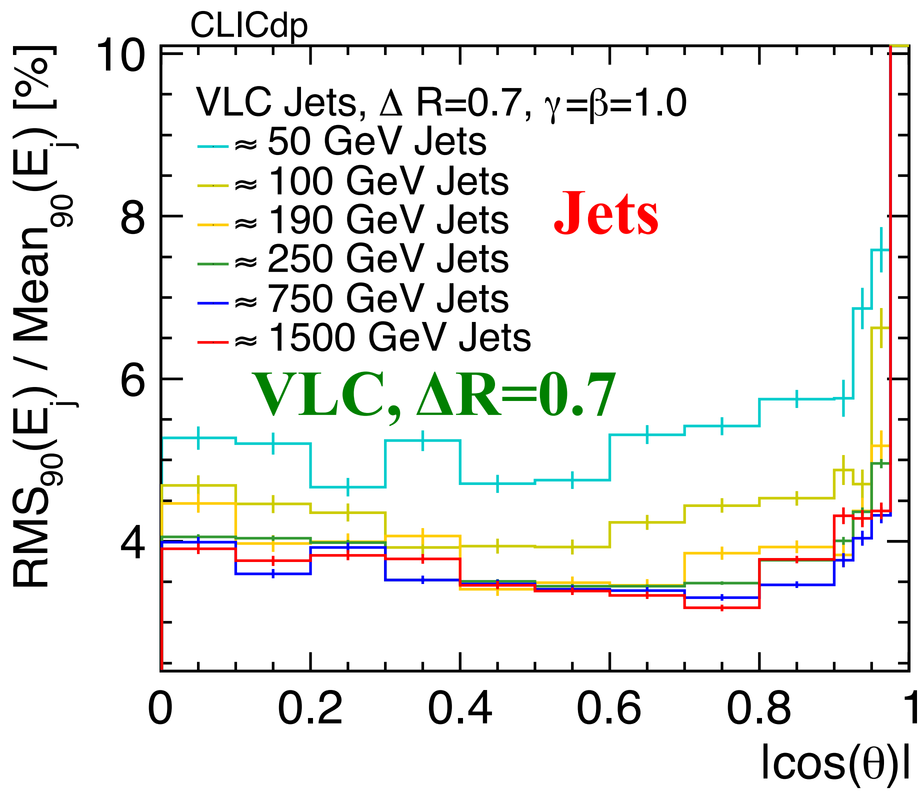




For most events in this preselection vast majority of total event energy contained in both jets, slightly larger tail to lower values for low energetic jets at 50 GeV

Jet Energy resolution (JER): total Energy vs Jets





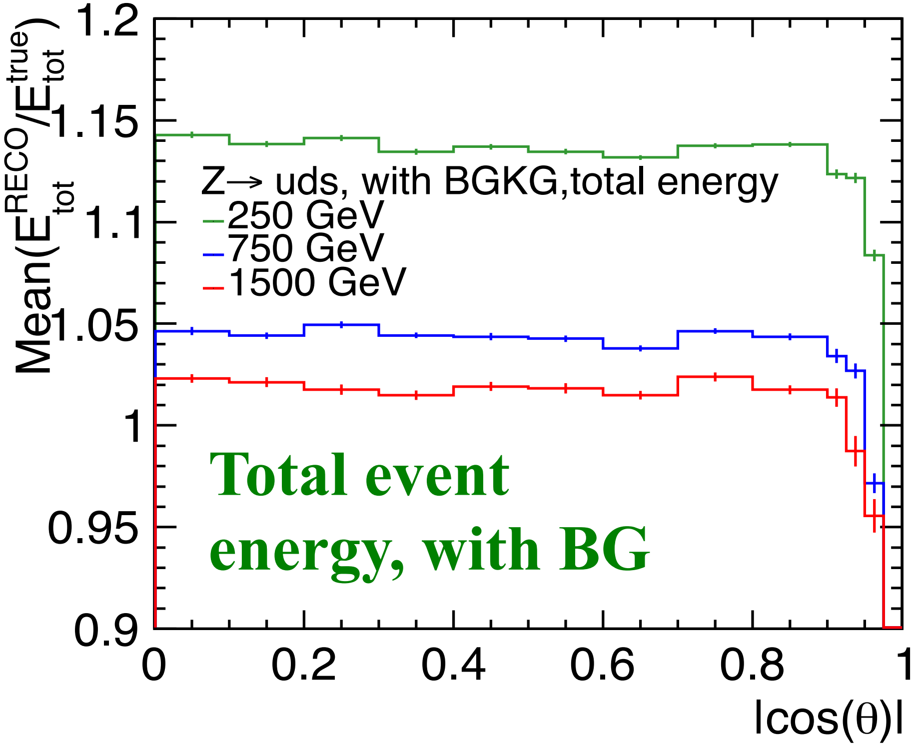
Jet Energy Resolution for several jet energies, as function of |cos θ| of quark

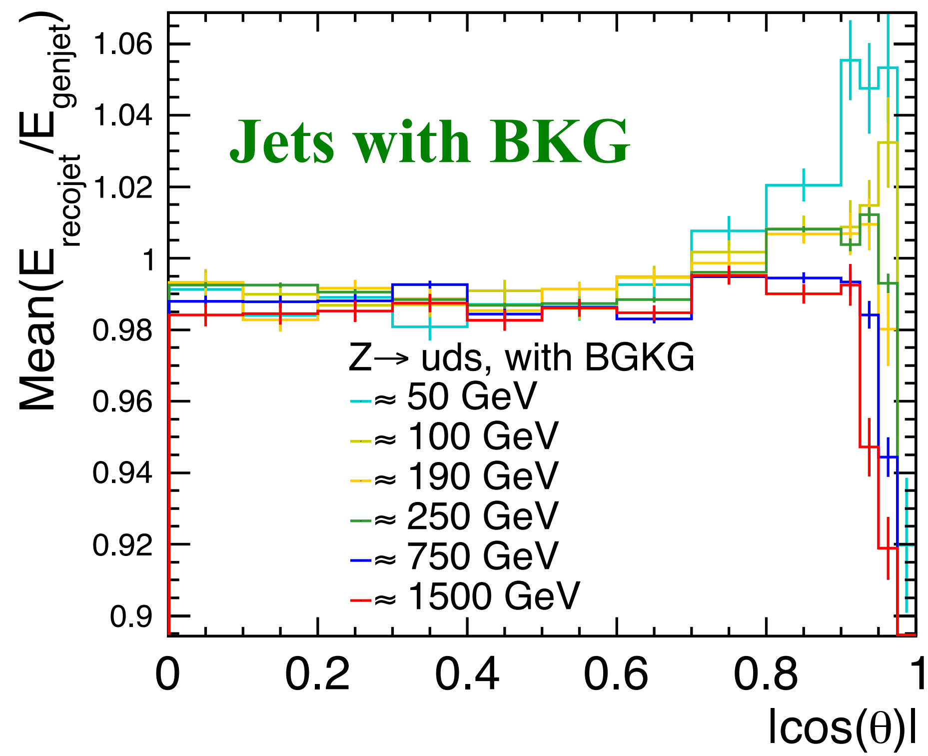
Compare reconstructed jets and particle jets, ΔR = 0.7

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

→ Similar resolution values after jet clustering

Reconstructed jet energy vs MC particle jet energy

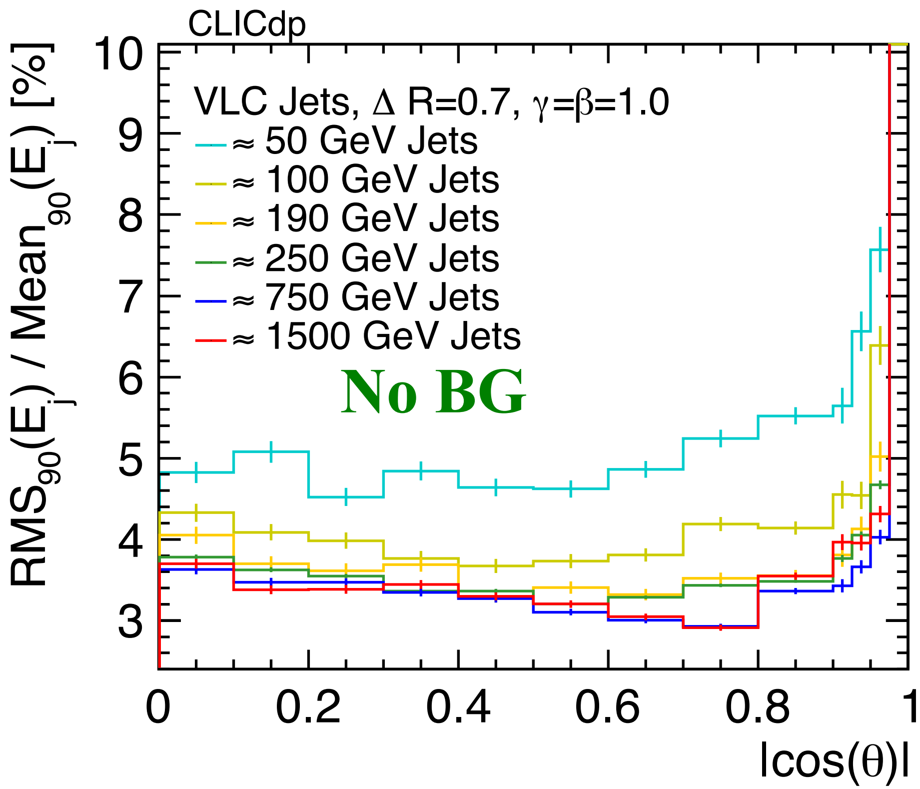


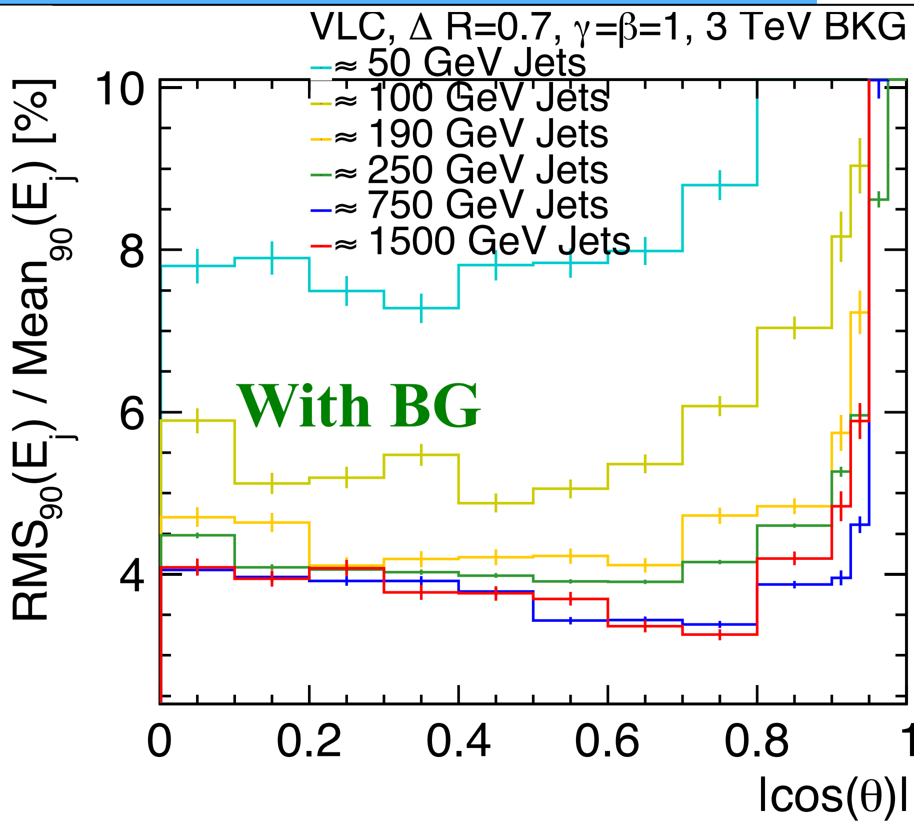


Overall event energy is increased by quite a bit after background is added (tight selection) → most of this additional energy is distributed in forward region, not all of this energy ends up in a jet cone

Reconstructed jet energies very close to particle jet energy

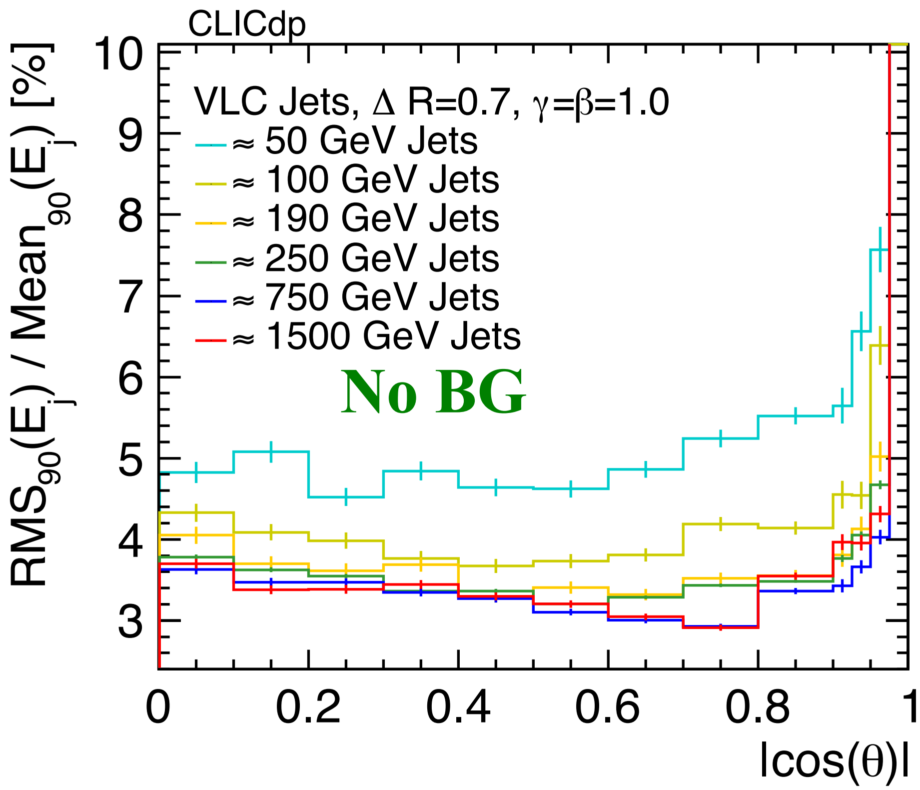
JER vs cosTheta: with and without BG

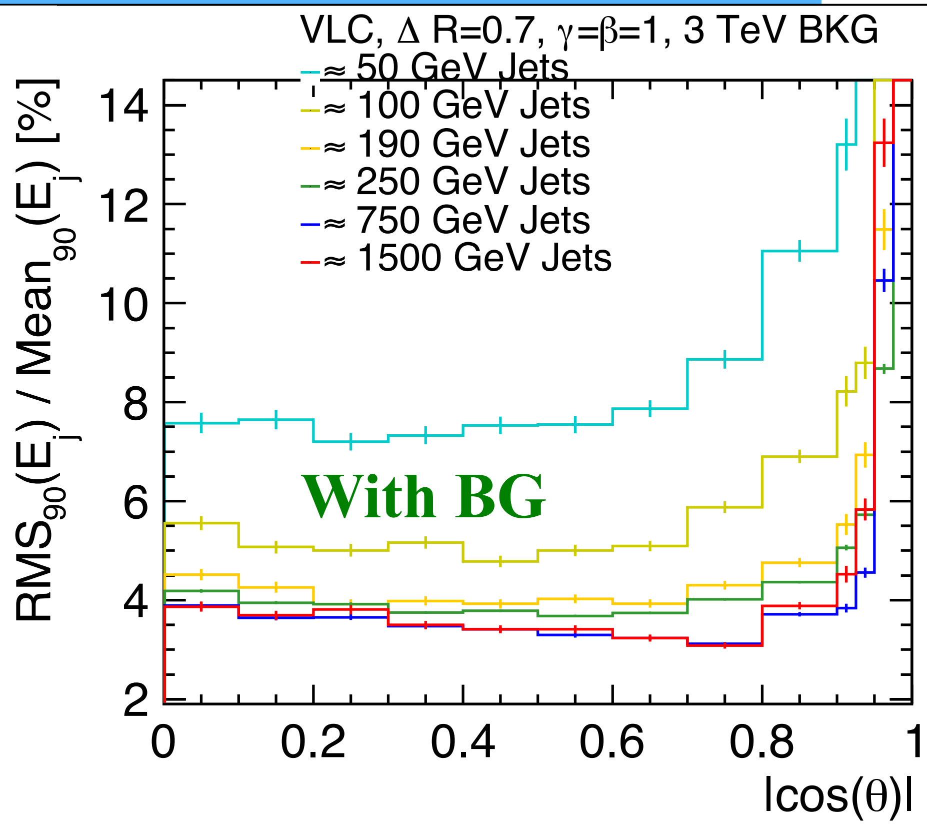




Compare resolution of reconstructed jets →3TeV conditions for overlay
For all energies we add raround100 GeV (tightSelectedPFOs) randomly distributed on event, not all energy will end up in jet cone
→for 100 GeV jets increase from 4 % from 5-5.5% in barrel, 7 % in endcap
At high jet energies mild increase, except for very forward jets

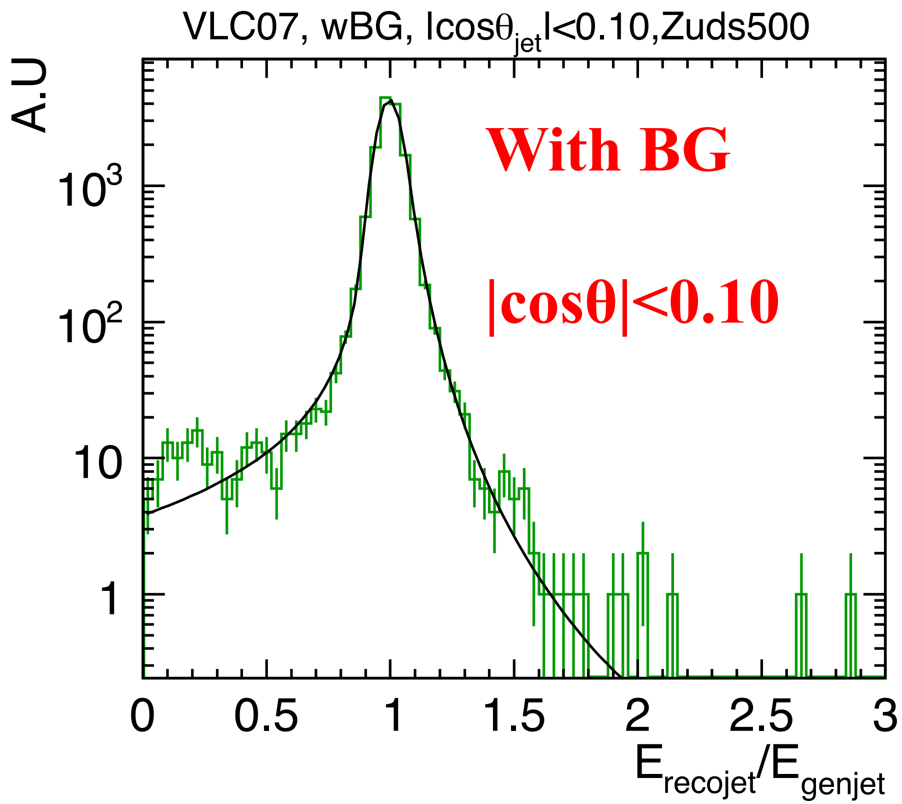
JER: impact of BG, zoom in for forward jets

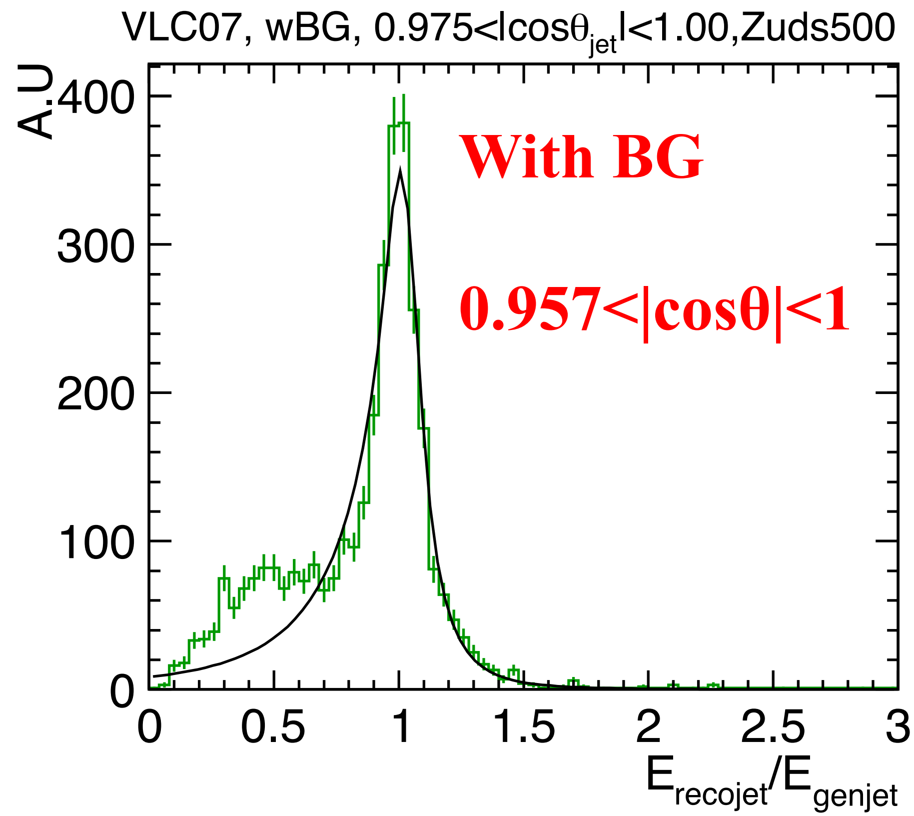




For forward jets as expected larger impact of beam backgrounds

Jet Energy Resolution: Fit resolution curves

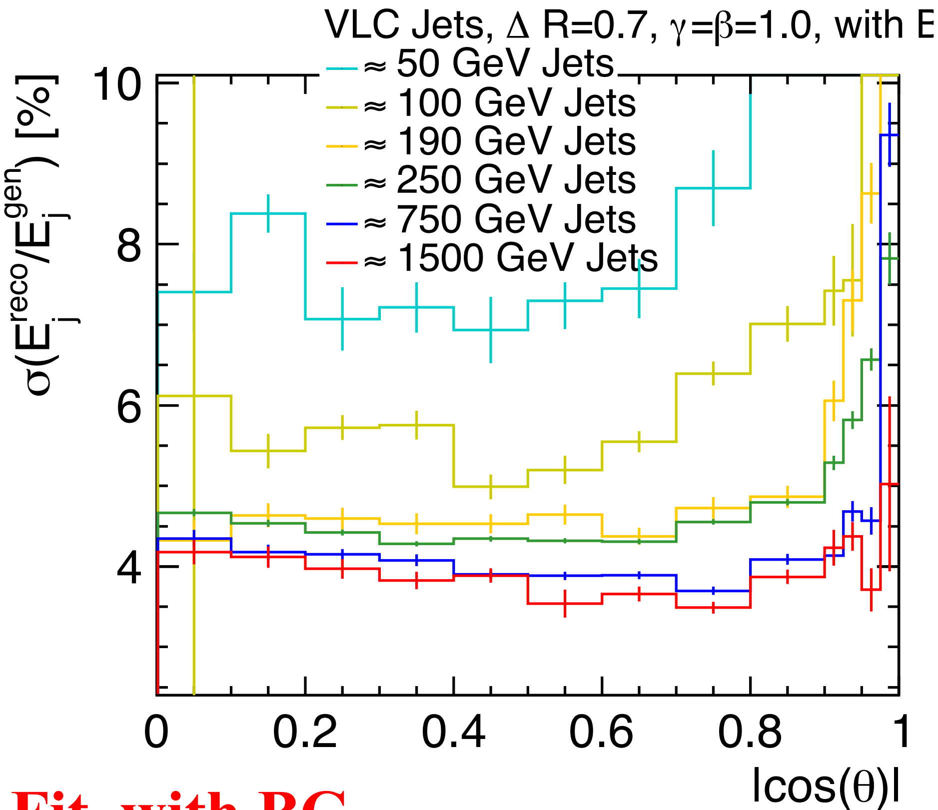




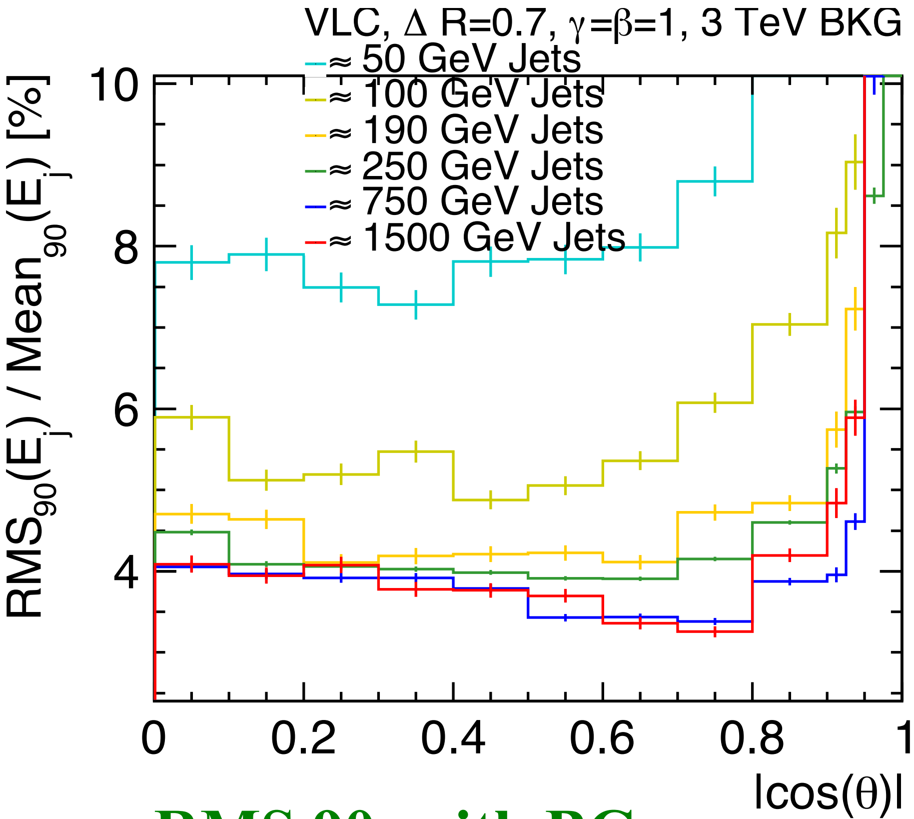
$\gamma\gamma \rightarrow$ hadrons background leads to significant non gaussian tails in the jet energy resolution distribution, double sided crystal ball function (gaussian core and power law tails) fits most of the distribution for all detector regions

- Double sided crystal ball used by CMS
- Low end tail for most forward bin underestimated (only region with bad fit)

Jet Energy Resolution: CB fit σ vs RMS90



Fit, with BG



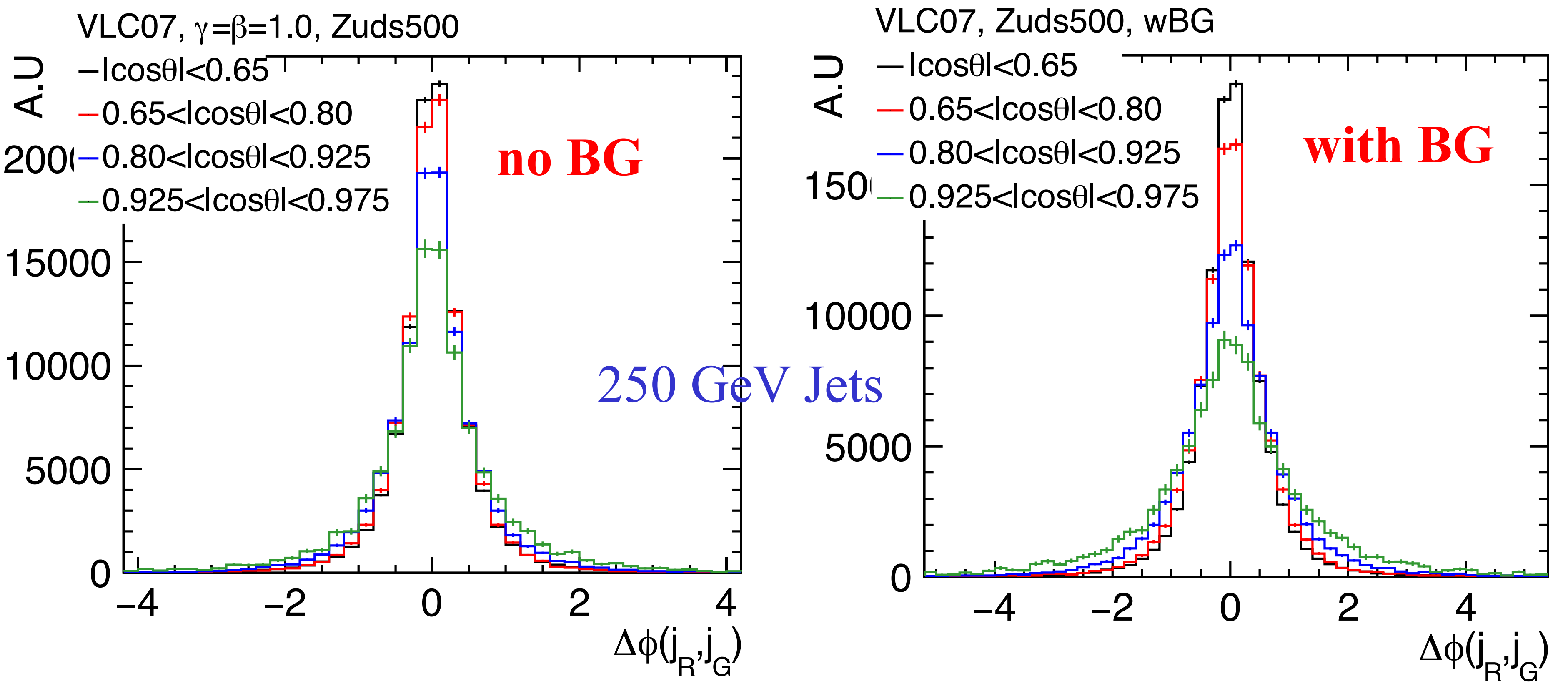
RMS 90, with BG

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

For 50 GeV jets sigma for most of the bins a bit lower, for all other energies resolution values of fit typically within 10-15 % of RMS90 resolution measures

Jet Phi and Theta Resolution

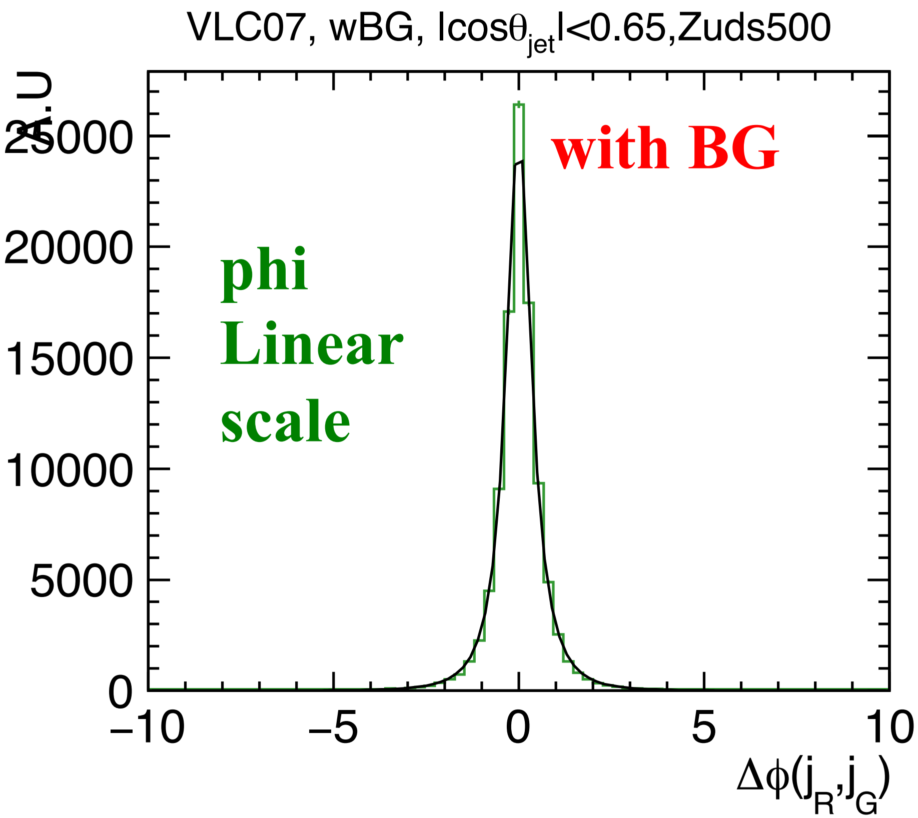
Position Resolution: impact of background

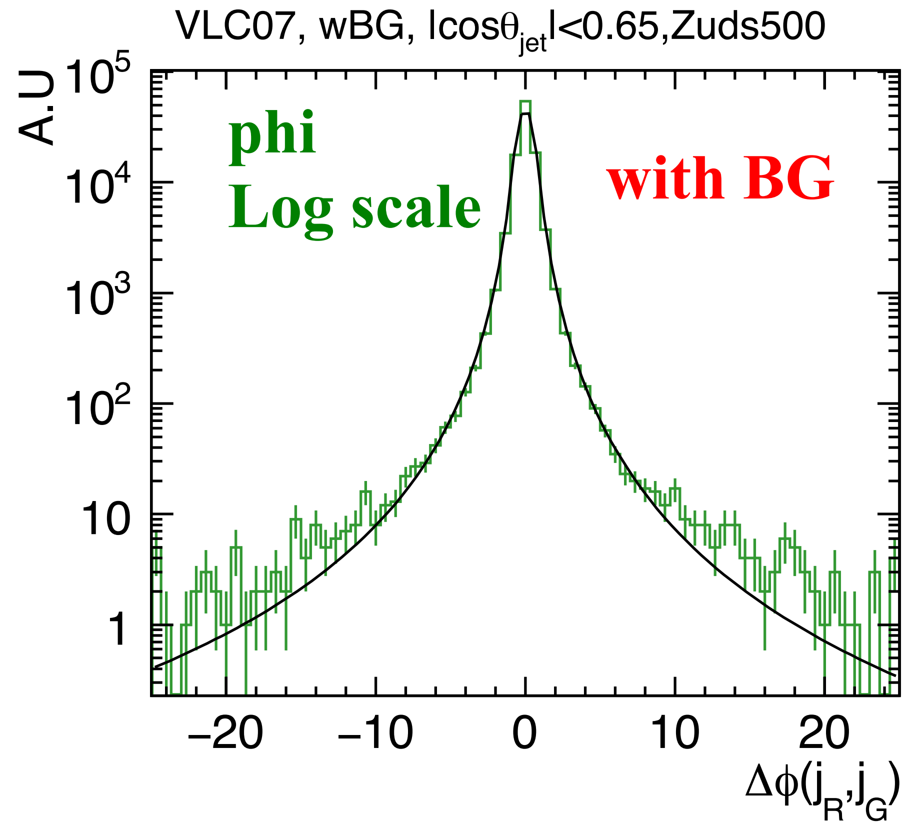


Study position resolution in four different θ regions, unlike for energy resolution studies requirement on angular matching

- Remove events with additional gluon radiation by requiring on MC truthΔφ(jet1,jet2)>2.8
- Background increases resolutions particularly for endcap and forward region, for barrel effects more mild

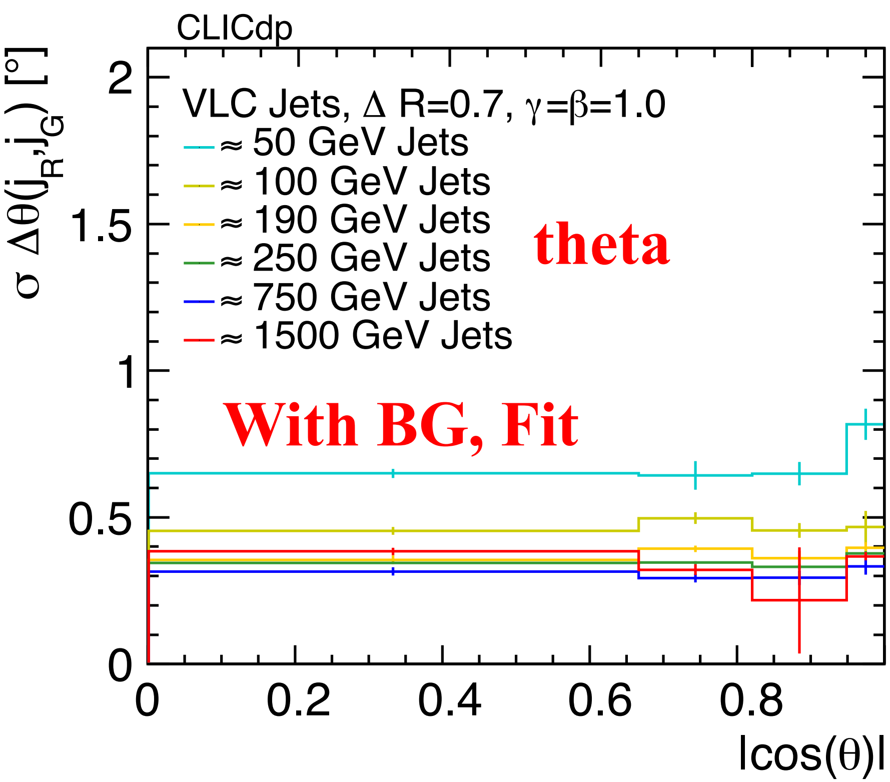
Position Resolution: Fit resolution curves

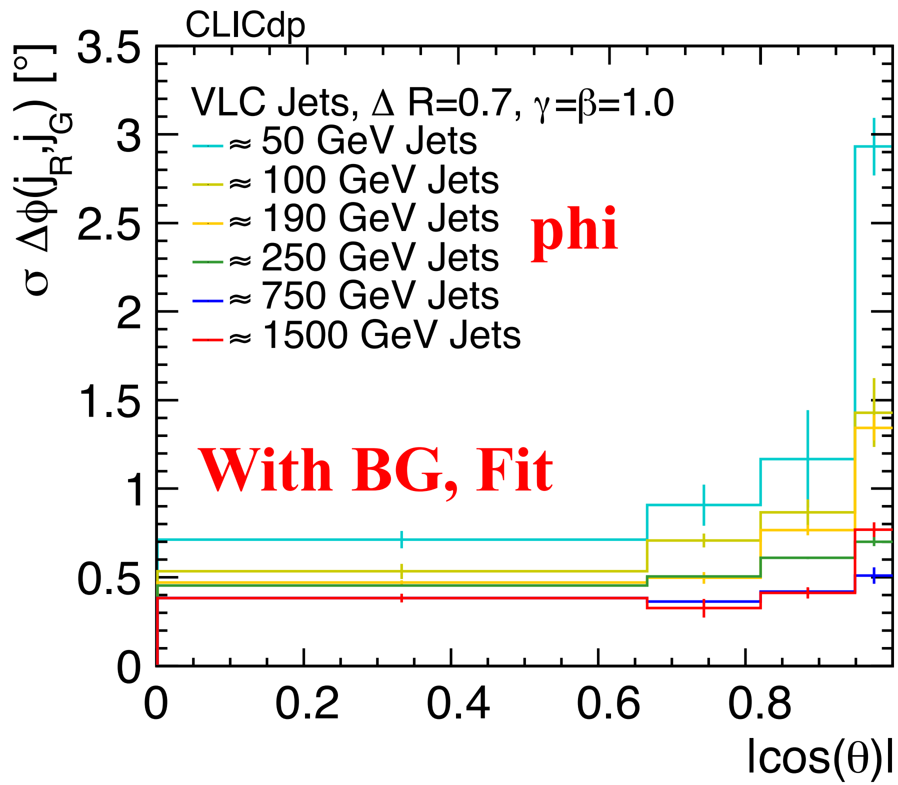




Fit resolutions with a double sided Crystal Ball function →core of distribution and start of tails fit nicely, slight underestimation of events in end of tail

Jet Phi and Theta Resolution





Theta and Phi resolutions below 1 degree for most detector regions, for forward and endcap jets larger phi resolution values

W and Z mass separation

W and Z mass with overlay

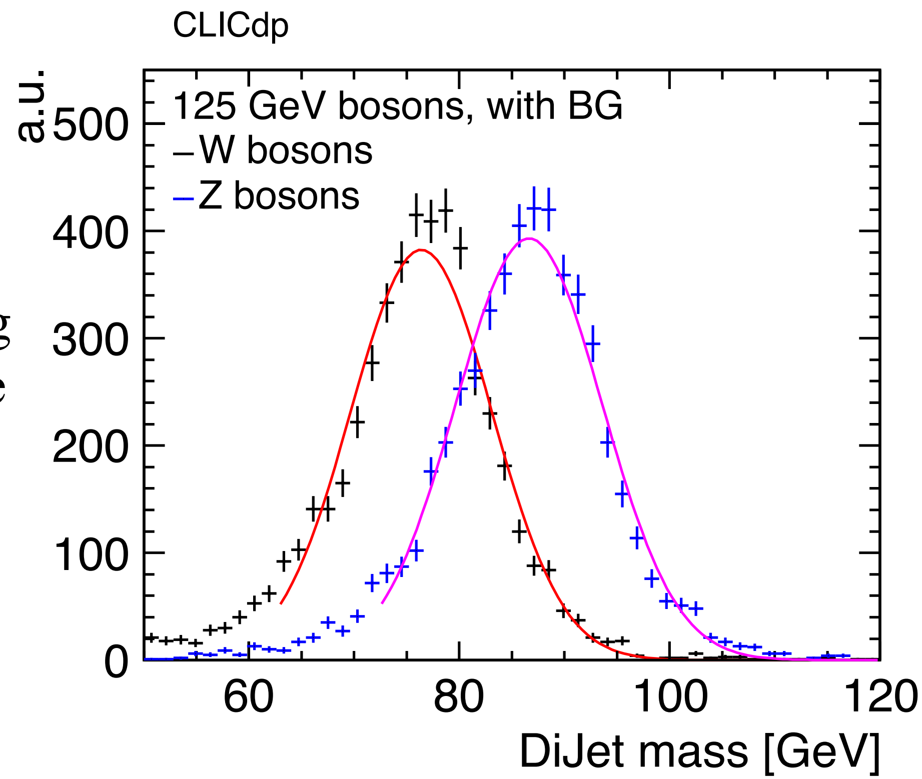
Study dijet mass reconstruction in WW→qq lν and ZZ→qq νν events

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

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

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



W and Z mass separation results

BX	$E_{W,Z}$ [GeV]	$\sigma_{m(W)}/m(W)$ [%]	$\sigma_{m(Z)}/m(Z)$ [%]	ε_W [%]	ε_Z [%]	ε_{avg} [%]	Separation [σ]
0 BX	125	6.0	6.0	87	84	85	2.1
	250	5.8	5.5	87	86	87	2.2
	500	5.8	5.6	87	86	86	2.2
	1000	7.6	6.7	81	81	81	1.8
30 BX	125	8.6	8.2	76	78	77	1.5
	250	7.9	7.1	80	80	80	1.7
	500	7.3	6.8	80	82	81	1.8
	1000	9.3	7.8	76	78	77	1.5

Without background overlap fraction between 15-20 %
Increase of overlap fraction to 20-23 % due to beam background effects

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 8 % for 50 GeV jets, values below 5 % reached for jets energies above 100 GeV

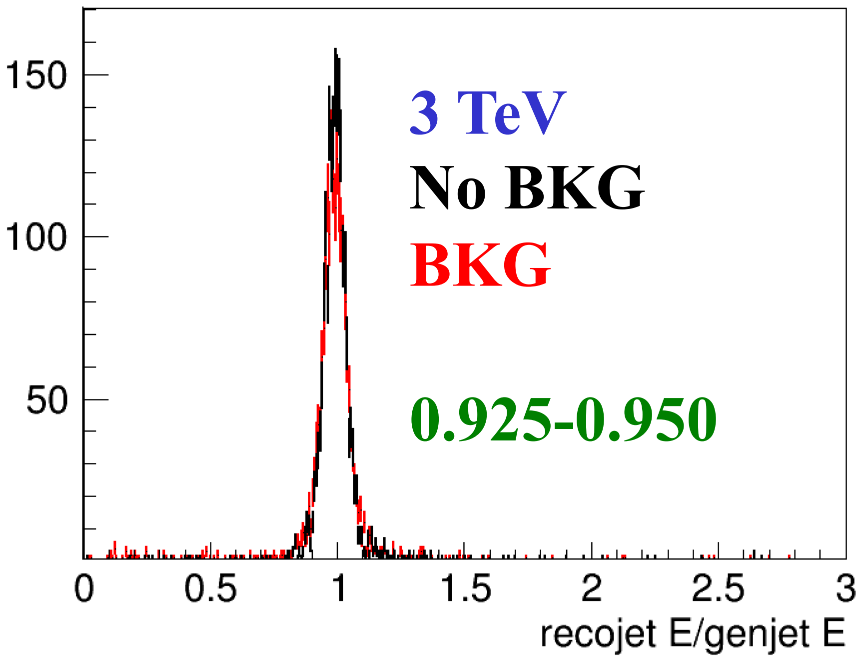
Jet Phi resolutions below 2°, jet theta resolutions below 1° for energies from 50-1500 GeV jets with beam backgrounds overlaid

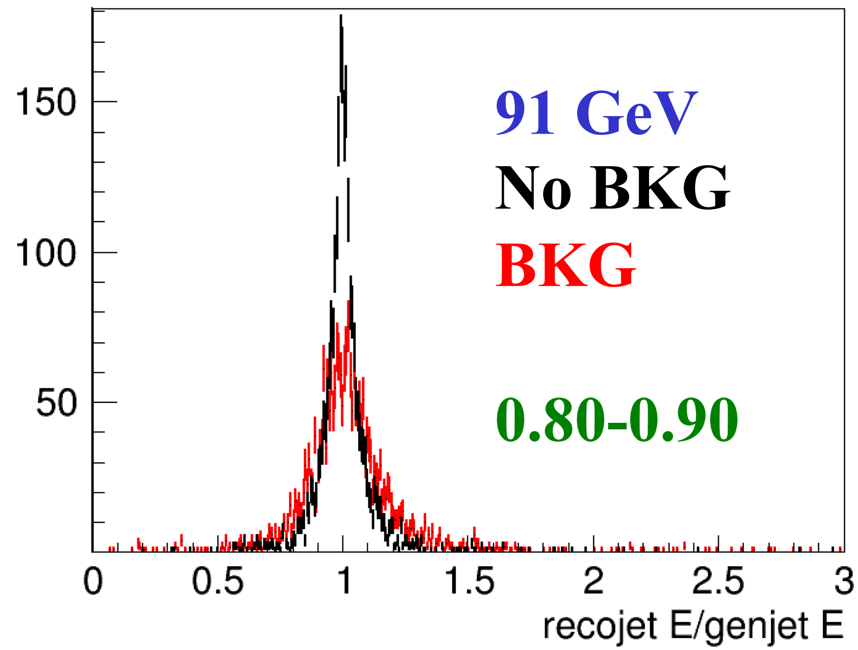
Achieve a W-Z dijet mass separation of 1.5-1.8 σ when including beam backgrounds

→all Jet Studies will be documented in a CLICdp note, target to be in review by October

BACKUP

Jet Energy response with and without background



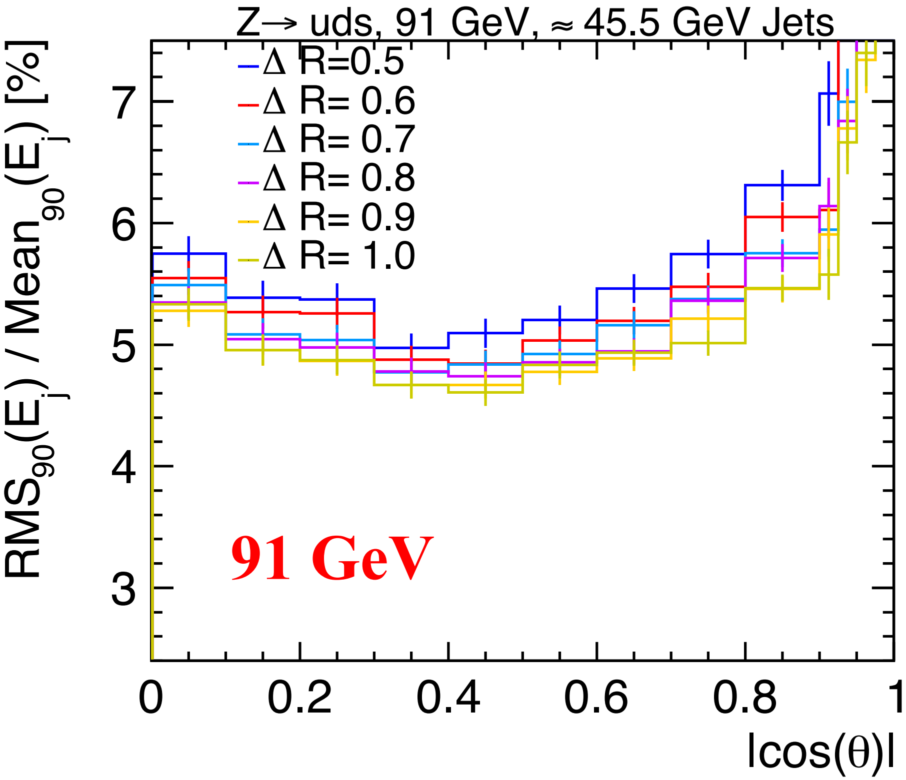


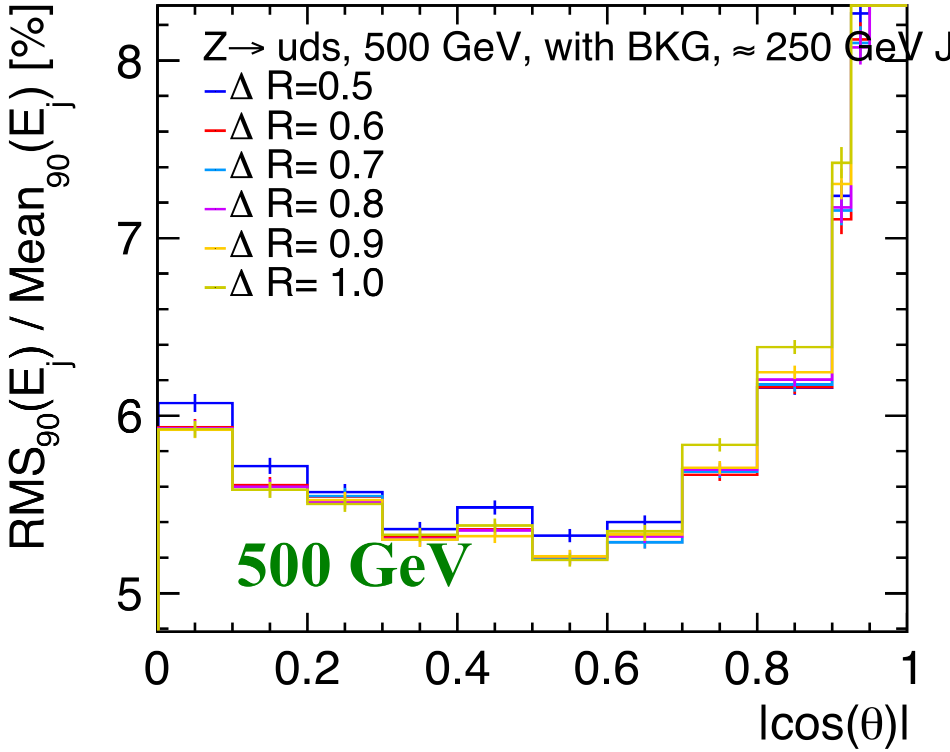
For 3 TeV, response peak reconstructed/generated jet energy largely unchanged, but more events in the tail

At 91 GeV, response peak considerably wider

Jet Energy Resolution vs Delta R (jet)

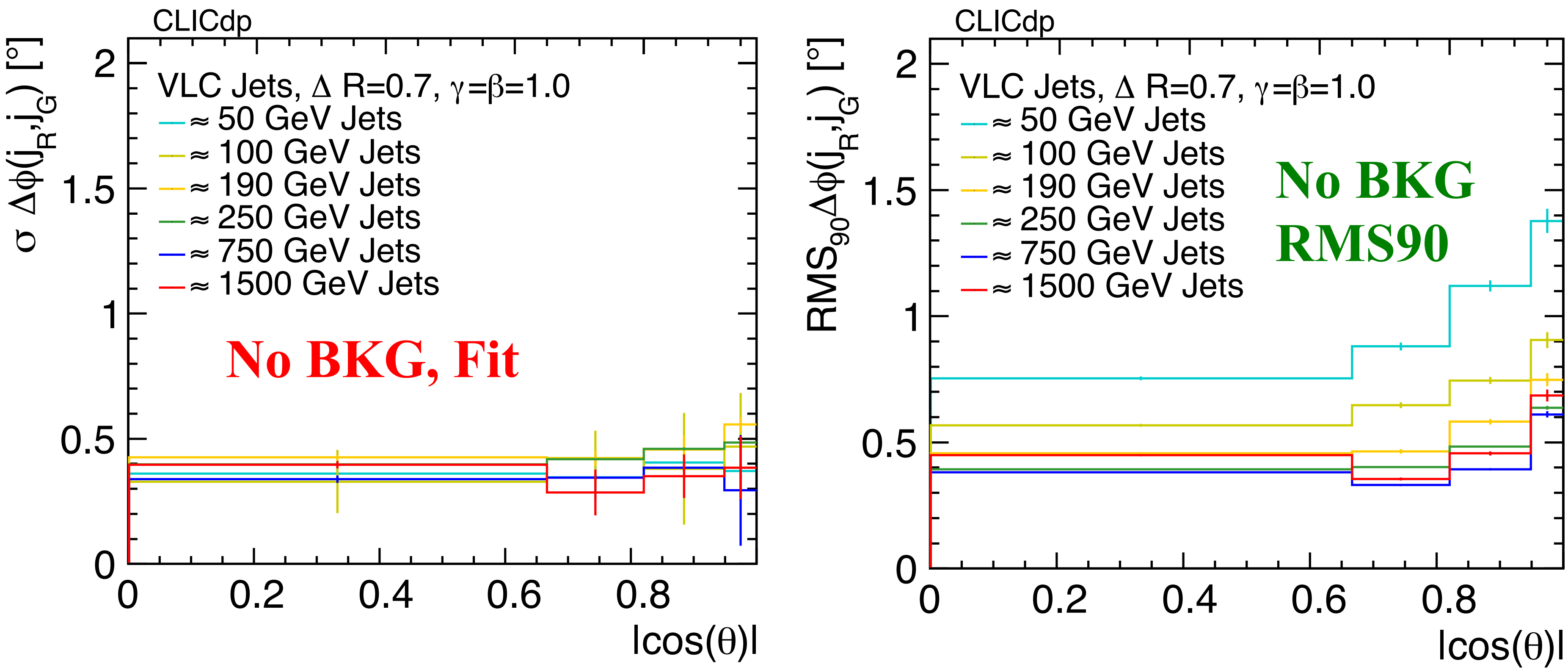
Impact of jet radius on jet energy resolution values





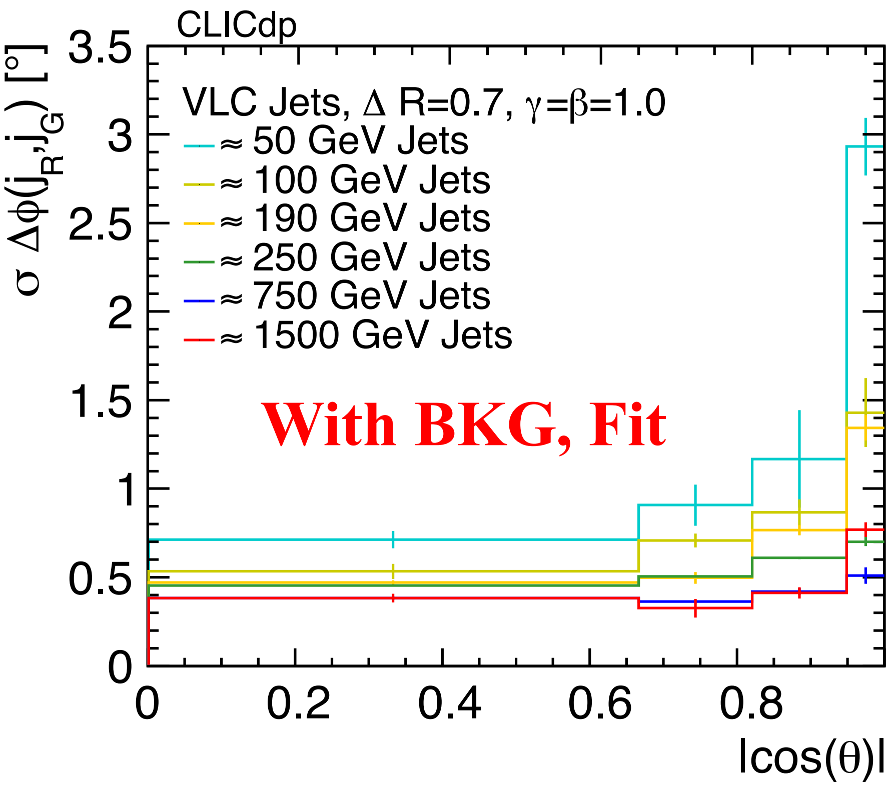
No large dependence observed for different jet radius parameters → conclusion holds for all energies studied

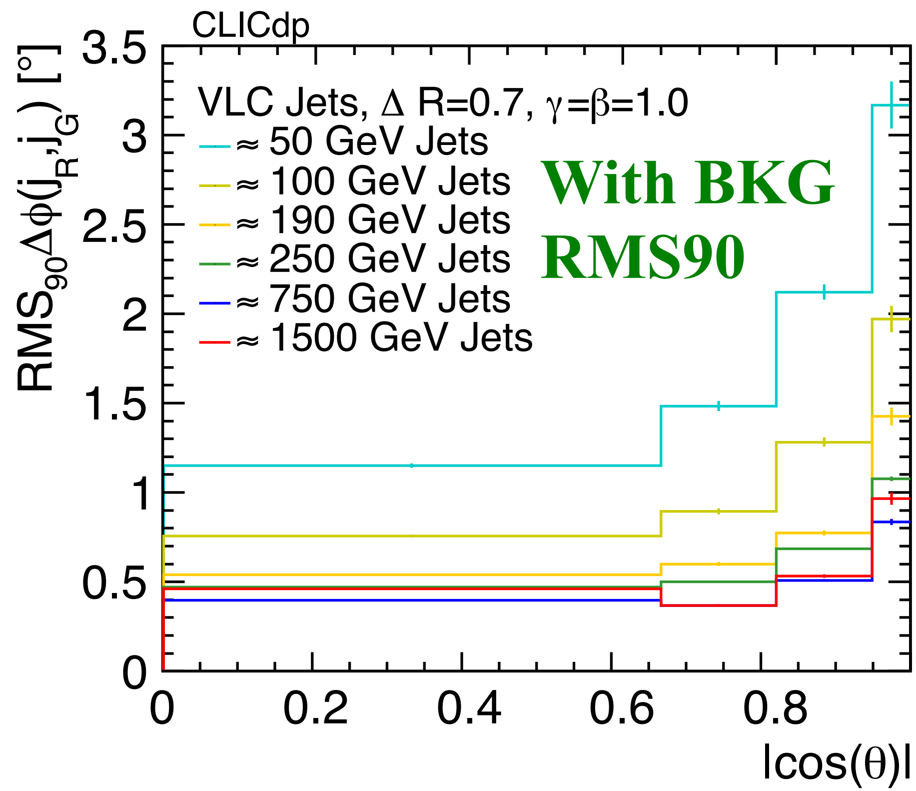
Jet Phi Resolution: Fit vs RMS90



RMS90 values larger for low energetic jets and in forward region, for both measures values below 1.5 degrees

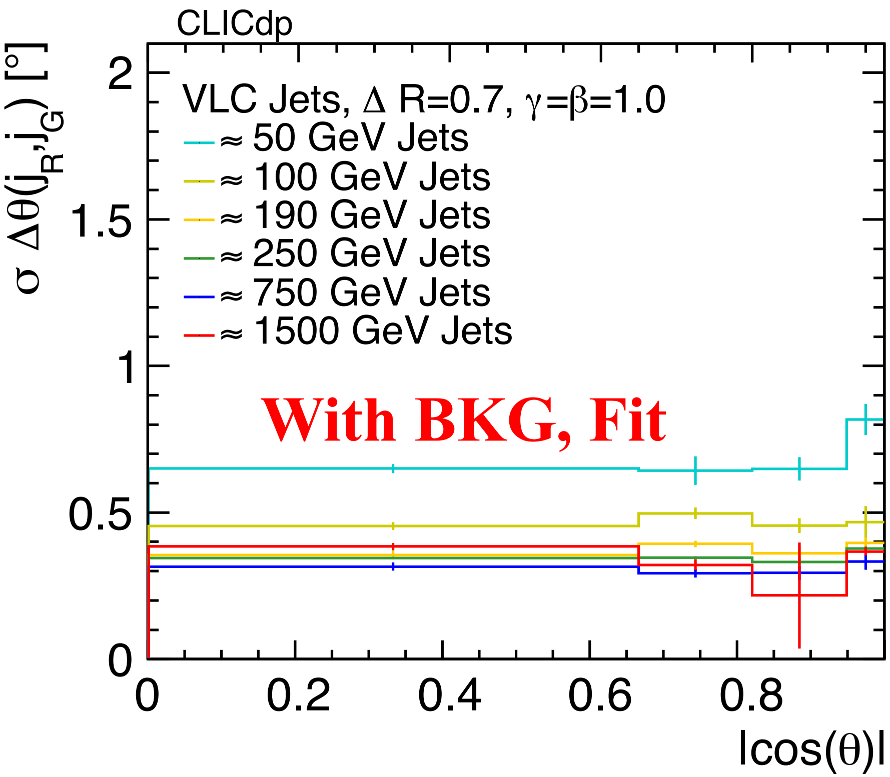
Jet Phi Resolution: impact of background

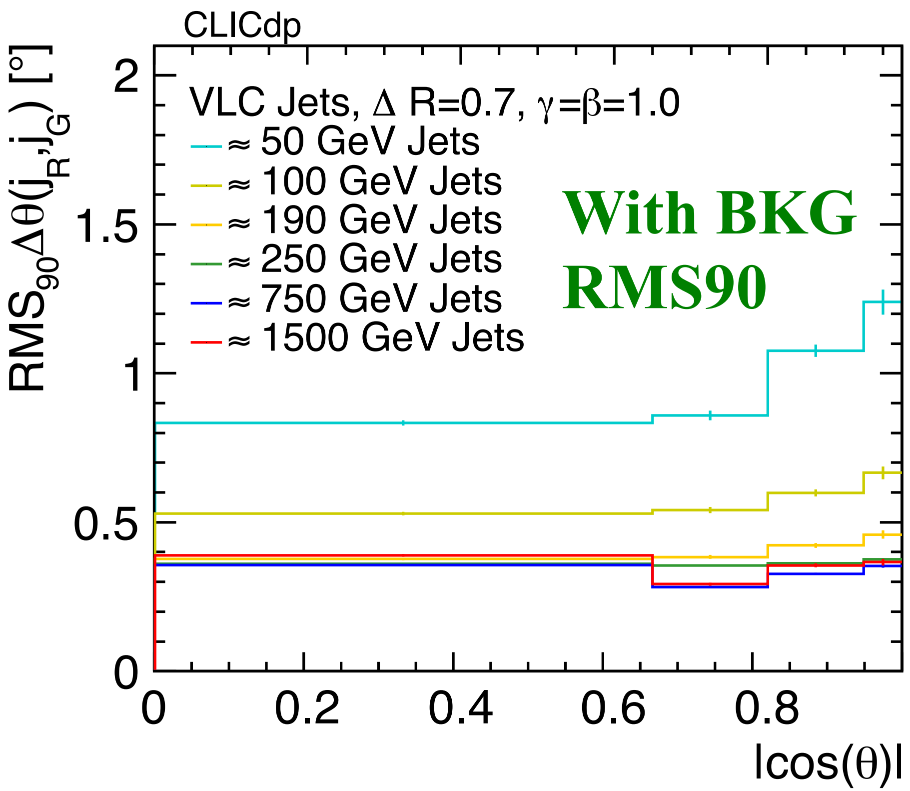




RMS90 values larger for low energetic jets and in forward region, for both measures values below 3 degrees

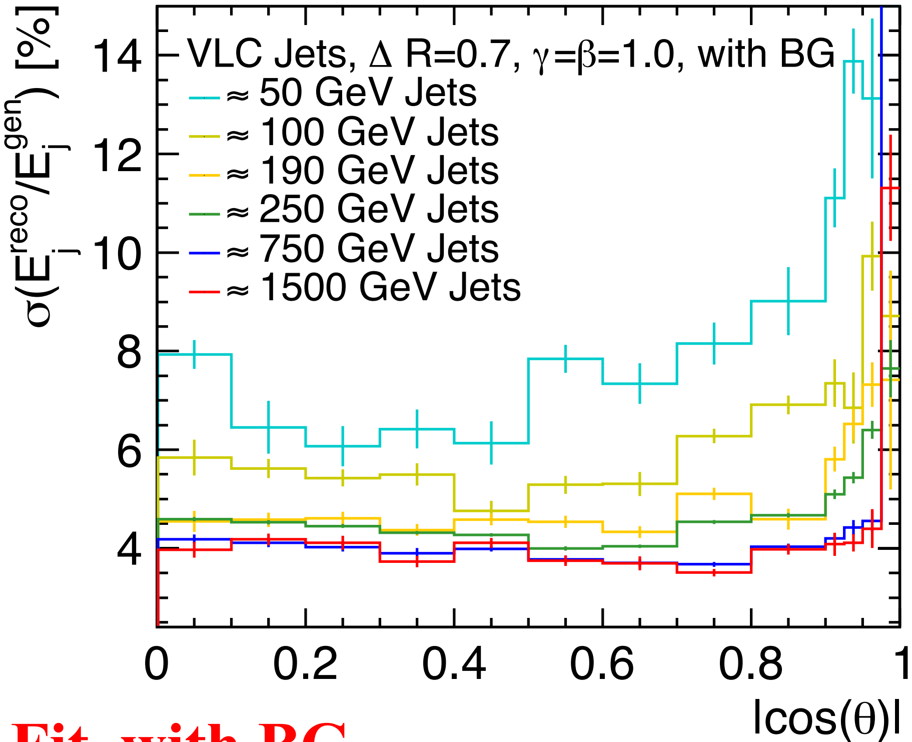
Jet Theta Resolution



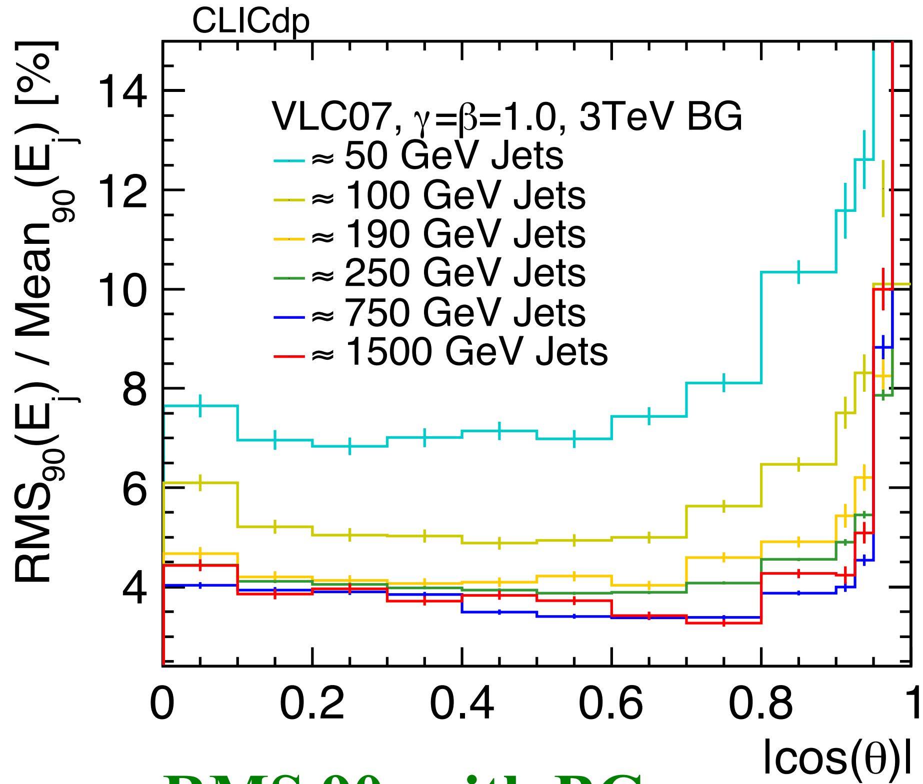


RMS90 slightly larger for low jet energies, values below 1 degree for both measures

JER: CB fit σ vs RMS90 focus on forward jets



Fit, with BG



RMS 90, with BG

Fit jet energy response by double sided Crystal ball, use sigma of the gaussian core as measure for jet energy resolution

For 50 GeV jets fit sigma for most of the bins lower, for all other energies resolution values of fit typically within 10-15 % of RMS90 resolution measures

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, $\beta=\gamma=1.0$, 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)

- 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%)

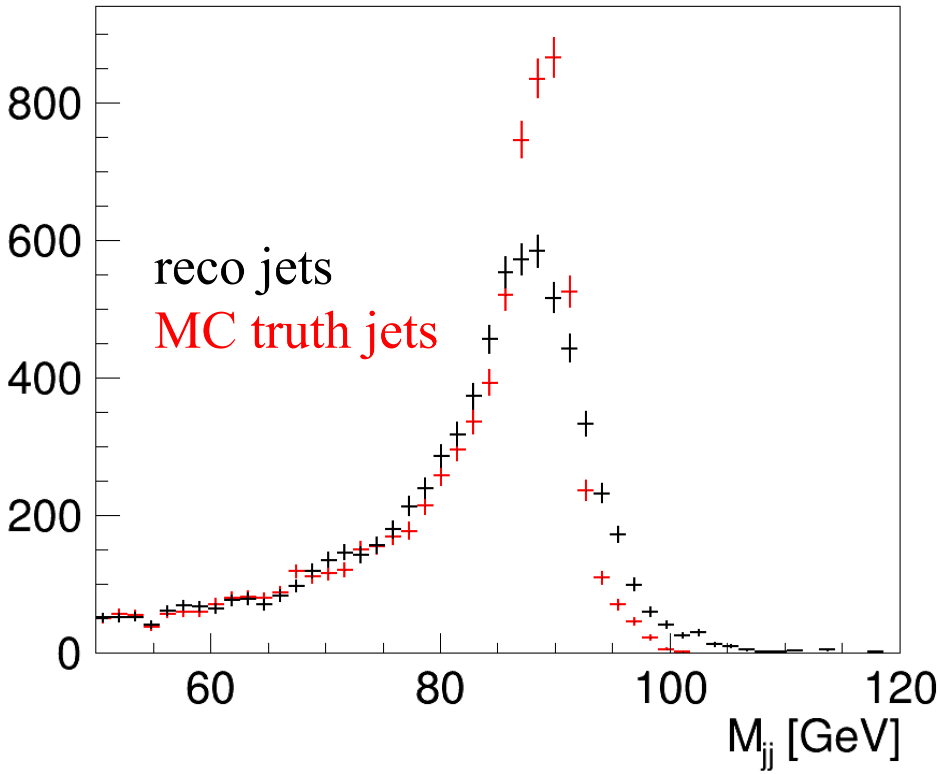
Fit peaks vary with energy → rescale Gaussian fits, so that mean of fit at W-mass (80.4 GeV) and Z-mass (91.2), fix ratio of sigma/mean while rescaling

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

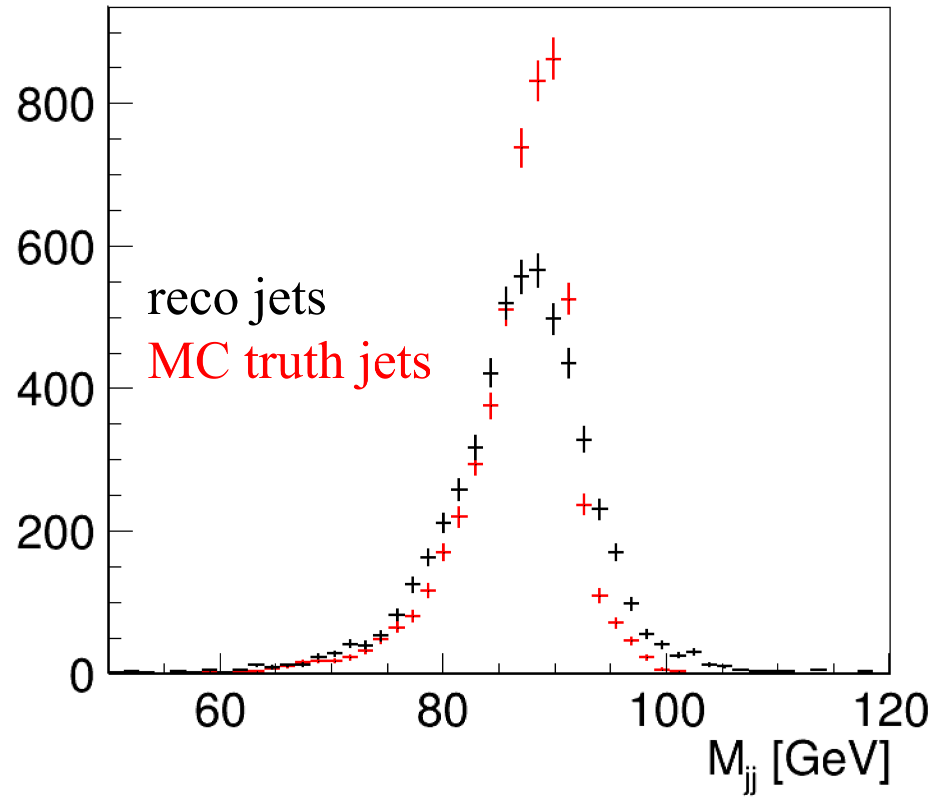
→ Calculate intersection point x_{int}

Example 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:

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

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 $\sigma = 2|\text{ROOT::Math::normal\_quantile}(A_O,1)|$

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