ZH at high energy

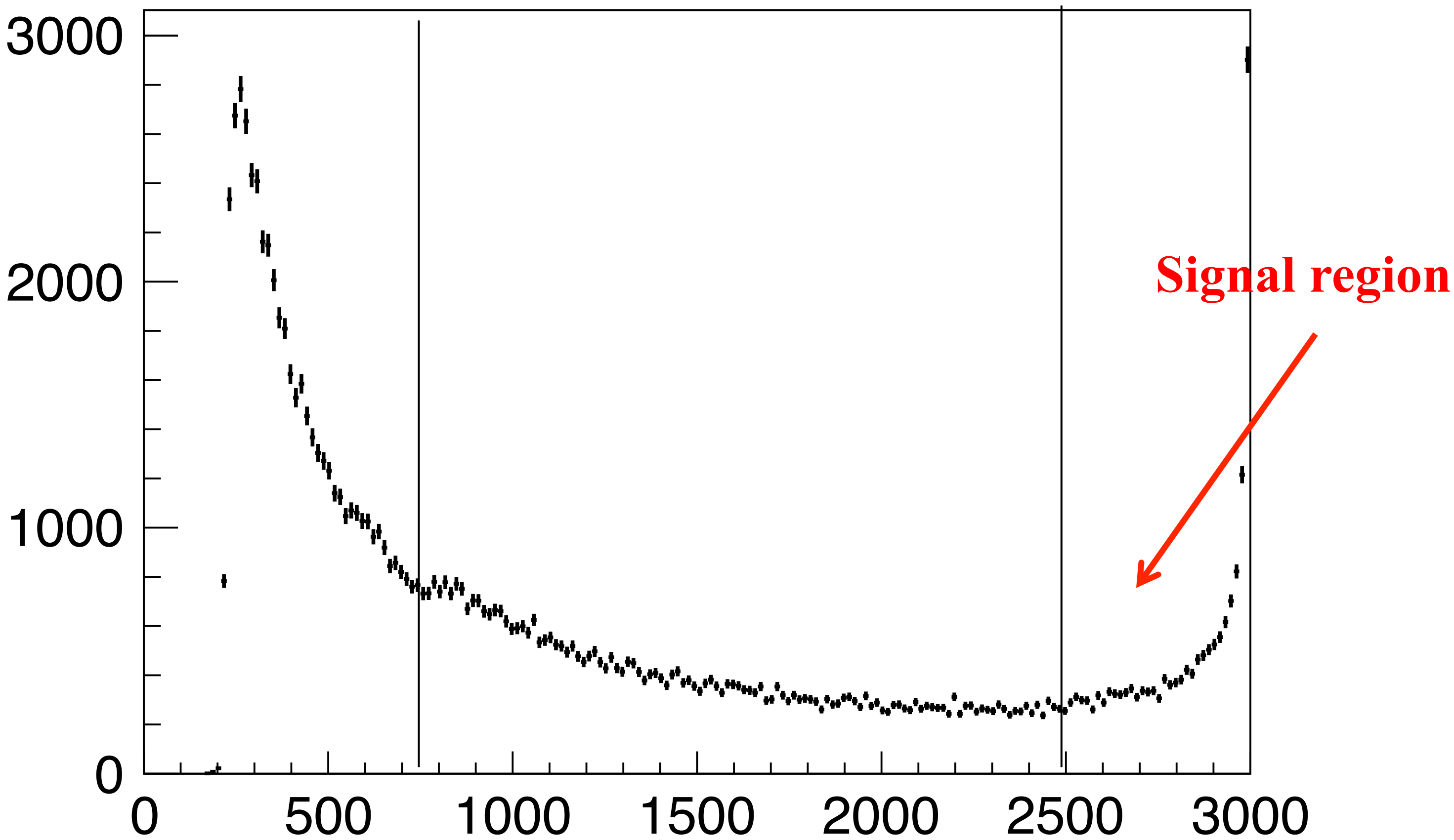
Matthias Weber (CERN)

Effective centre of mass energy for HZ

Effective Centre-of-mass energy of e+e- after ISR photons and beam strahlung on parton level

→cross-section falling with centre of mass energy + luminosity spectrum

→define 3 regions <**750**, **750-2500**,**>2500 GeV**



Baseline analysis strategy

HZ → bb qq at $\sqrt{s_{eff}} > 2500$ GeV characterised by two high-energy boosted fat jets, back-to-back in azimuth and polar anglet

- Excellent jet mass resolution helps to discriminate between signal and background signatures
- Investigate subjet behavior and jet substructure
- Concentrate on H→bb, use b-tagging information to reject backgrounds and to help selecting H jet

→accurate measurement of underlying $\sqrt{s_{eff}}$ beneficial for EFT fits

Objects

Jets defined using VLC algorithm with $\beta=\gamma=1.0$, run in exclusive mode with R=0.7with $n_{jets}=2$
→tight timing and p_T selection applied on particle flow objects for jet clustering

Check for isolated leptons and photons with E>10 GeV
Requirement: relative isolation relIso<0.10 within a cone of 10 degrees
→lepton veto in event selection

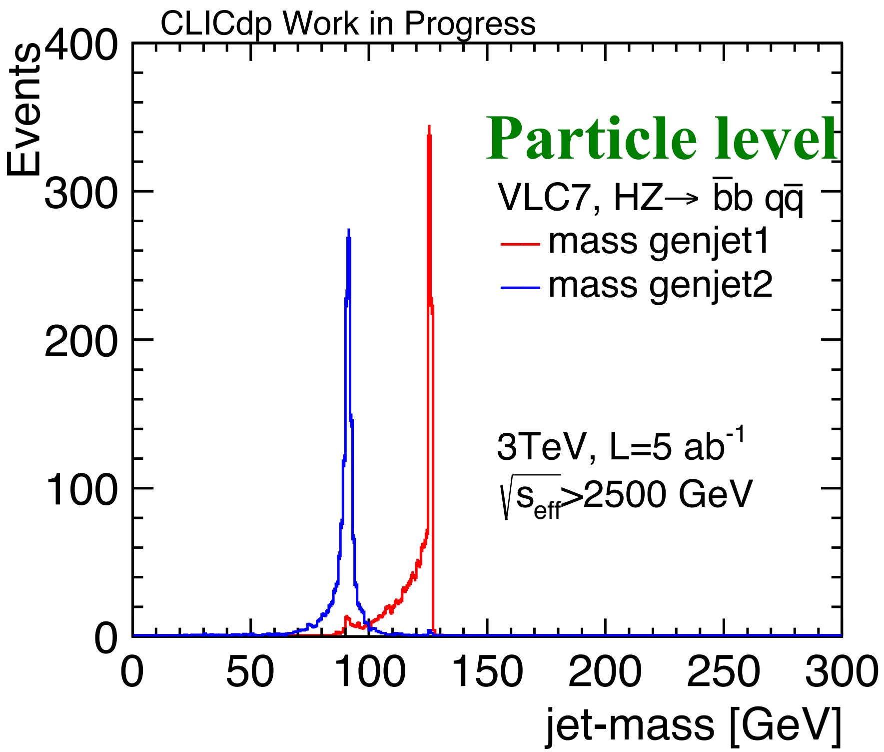
Ordering jets by masses worksm (j1) >m(j2), treat j1 as H jet, j2 as Z jet

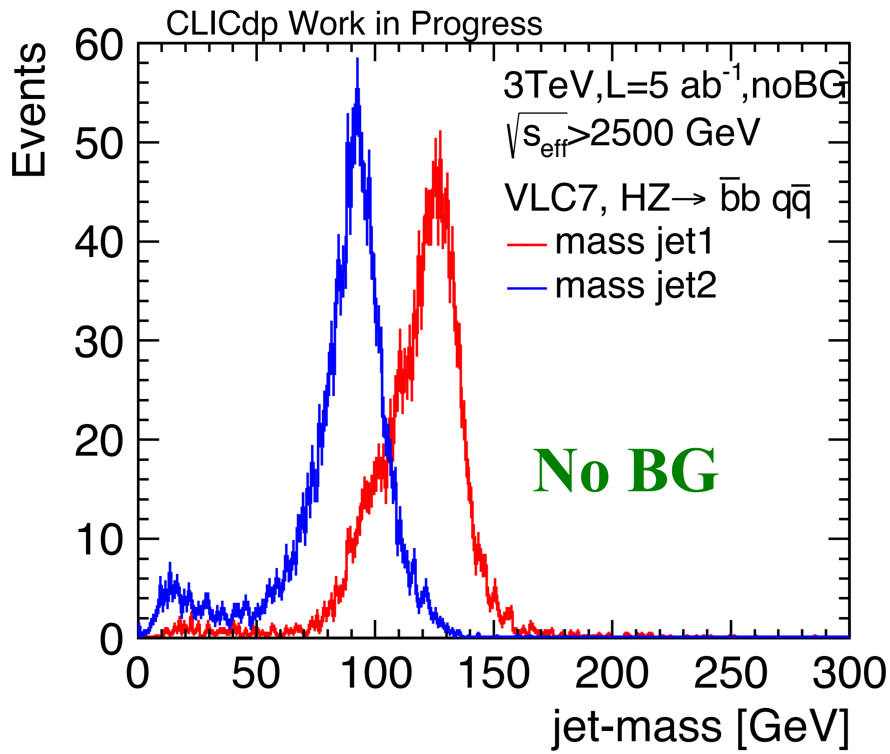
Subjet reconstruction, assume two close-by underlying partons in both of the jets:

- Use the same VLC algorithm parameters, cluster jet in exactly two subjets

Fat jet masses, sqrt(s)>2500 GeV

Assumption: at large sqrt(s) bosons very boosted, using jet with a large cone sufficient to collect almost all boson energy → check if jet clustering works on particle level





Detector effects widen the jet mass distributions significantly, most of the energy collection with radius of 0.7, tail to lower values for b-jet (smeared out on reco level) result of lost jet energy into neutrinos → try to recover energy loss by b-jets

Jet Correction using missing transverse energy

Mass Recovery using missing transverse energy

Idea: neutrinos appear in decays of B-hadrons, typically in boosted regime direction aligned with corresponding jet direction

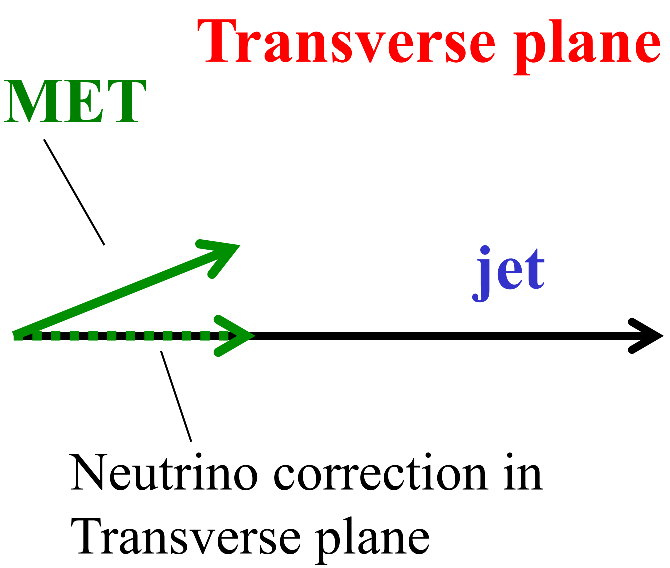
Use missing transverse energy (MET), calculated from all TightSelectedPFOs in event:

→ check if MET in same hemisphere of jet in question

→ project MET onto jet transverse momentum vector, increases jet transverse momentum vector by factor f>1

→ apply the same factor f to z-component of jet momentum

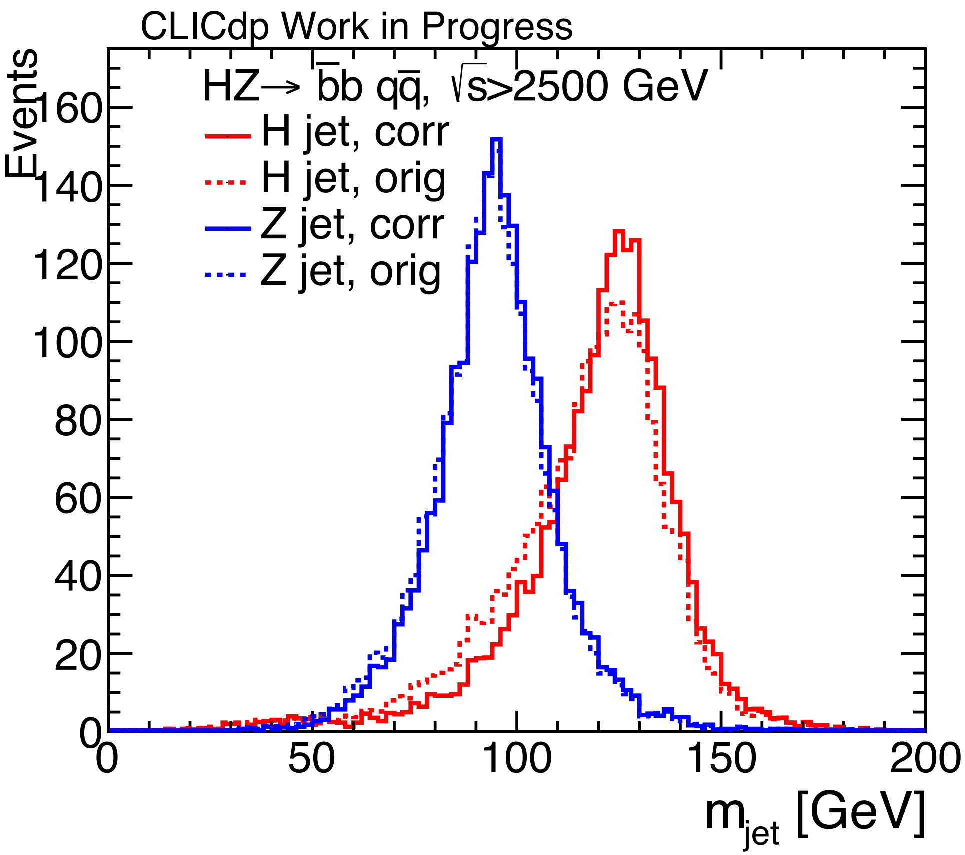
→ Momentum correction (f-1)*p_{jet} with mass zero representation of neutrino vector, i.e. add (f-1)*p_{jet} to original jet energy

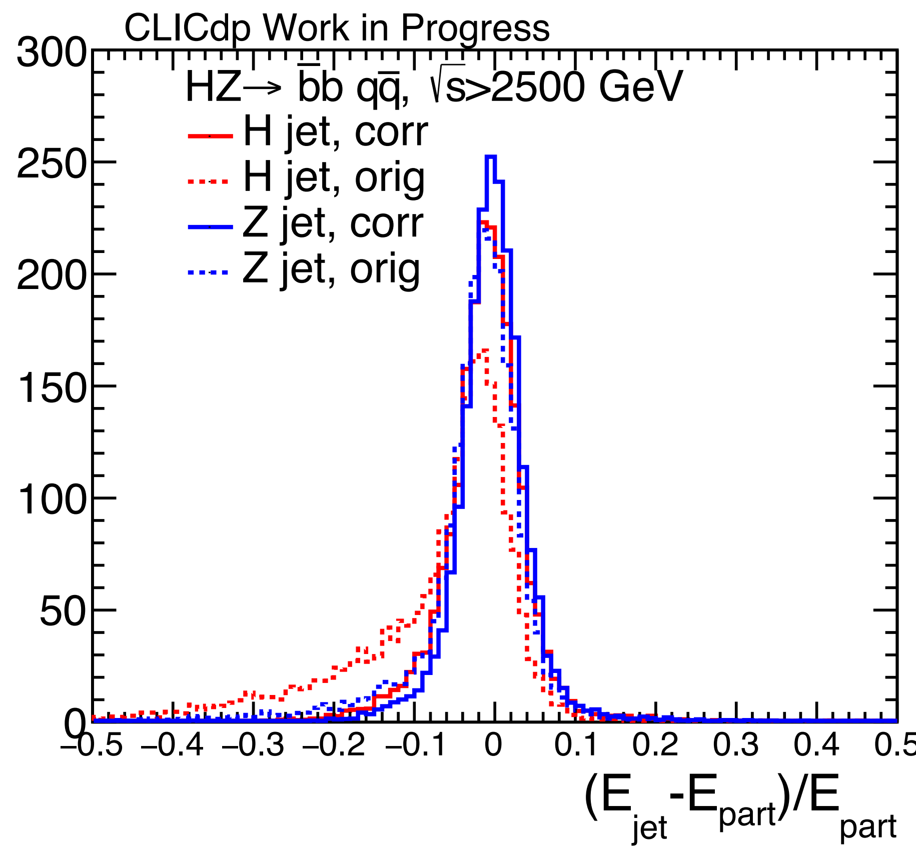


Mass and energy of jets after met correction

Peak of jet mass and tail of mass distribution to lower values reduced, particularly for jet matched to H, energy better reconstructed as well

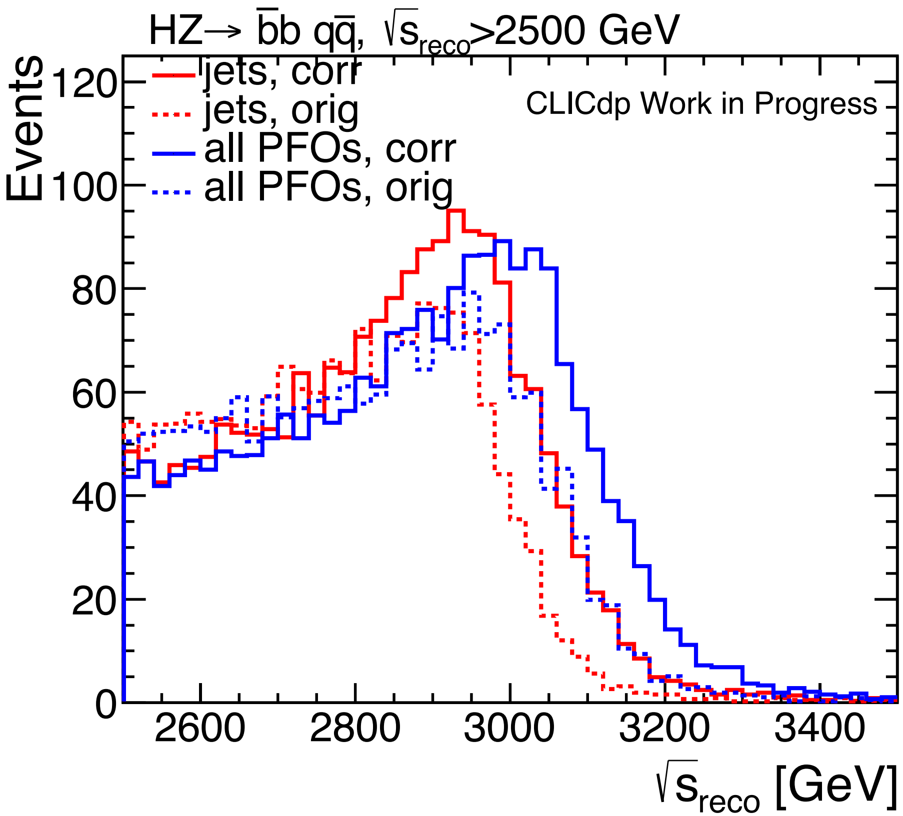
→ MET correction leads to improved $\sqrt{s}$ as well

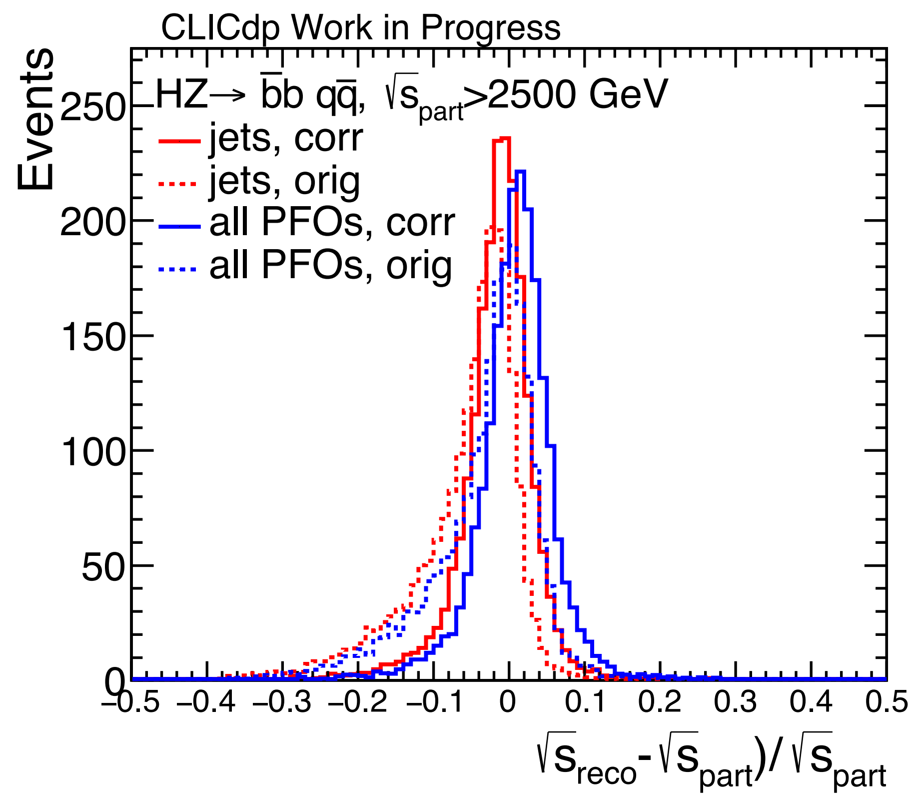


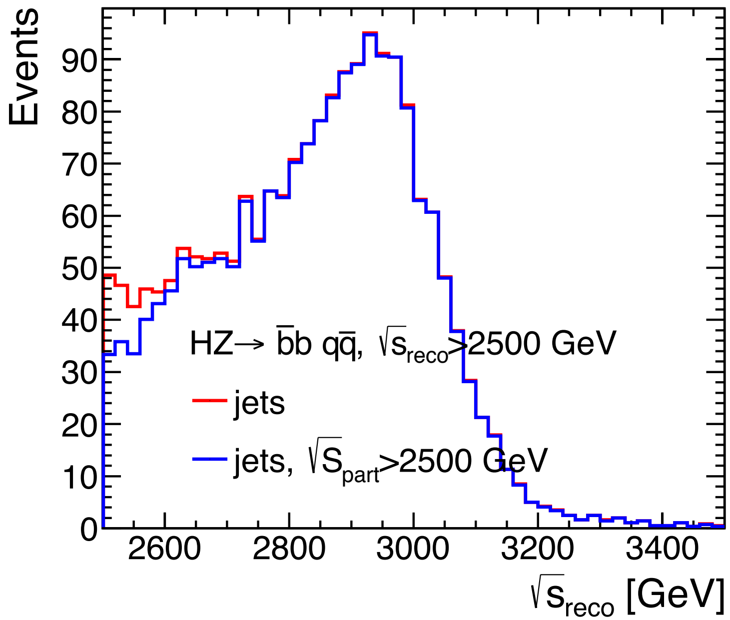


√s after MET correction

Best reconstruction of √s using both leading jets, using all tight selected PFOs leads to slight bias to larger √s values







Calculation method	Evts $\sqrt{s}_{reco}$>2500 GeV	Evts $\sqrt{s}_{reco}$>2500 GeV and $\sqrt{s}_{part}$>2500 GeV	purity
Tight PFOs	10387	9989	96.1
Tight PFOs+ MET correction	11982	11187	93.4
jets	9378	9252	98.7
jets+MET correction	11102	10759	96.9

Jet Charge

Signal Sample:
HZ with Z→qq, cross-section: 3.67 fb, concentrate on H→bb

Jet Charge definition(s)

$$Q^{\kappa} = \frac{1}{(p_{\mathrm{T}}^{\mathrm{jet}})^{\kappa}} \sum_i Q_i (p_{\mathrm{T}}^i)^{\kappa},$$

→ Used now, can also be replaced by weighting with energy, or projection parrallel to jet axis

$$Q_L^{\kappa} = \sum_i Q_i \left(p_{\parallel}^i\right)^{\kappa} \Big/ \sum_i \left(p_{\parallel}^i\right)^{\kappa},$$

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LCFIPlus jet clustering

LCFIPlus is supposed to assign vertices and corresponding tracks to jets, clustered with the VLC algorithm → outputs are so-called refined jets with corresponding matched vertices

Idea: use now these refined jets in analysis, compare with original subjet,

Potential issue: realized energy changes sometimes quite substantially

Printout of all particles of one of these refined jets:

```
[ VERBOSE "MyHZAnalyzer"] jet E 252.816 particles in sj1_rfj1 0 E/px/py/pz 6.04565/4.197/-1.82904/3.94591 PDG 211
[ VERBOSE "MyHZAnalyzer"] jet E 252.816 particles in sj1_rfj1 1 E/px/py/pz 12.9354/8.53676/-3.65458/9.00517 PDG 22
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[ VERBOSE "MyHZAnalyzer"] jet E 252.816 particles in sj1_rfj1 9 E/px/py/pz 100.277/67.24/-29.9308/68.1064 PDG -13
```

Charged particles in the jet are at times double counted → for this jet almost double the total jet energy, so issue not only in assignment of particles to jets

Behavior tested on all builds of ILCSoft from April

First look: assignment of particles to jets

Issue is related only to charged particles

→ In fact issue related to tracks from vertices, see code at https://github.com/lcfiplus/LCFIPlus/blob/master/src/LCIOStorer.cc#L982-L1010

```
// associate particles
double charge = 0.;
for (unsigned int ntr = 0; ntr < flajet->getTracks().size(); ntr++) {
  const lcfiplus::Track* flatr = flajet->getTracks()[ntr];
  lcio::ReconstructedParticle* lciotr = _trackLCIORel[const_cast<lcfiplus::Track*>(flatr)];
  charge += flatr->getCharge();
  lciojet->addParticle(lciotr);
  //cout << "LCIOStorer::ConvertJet: add track: id = " << flatr->getId() << ", energy = " << flatr->E() << flush;
  //cout << ", lcio energy = " << lciotr->getEnergy() << endl;
}
for (unsigned int nneut = 0; nneut < flajet->getNeutrals().size(); nneut++) {
  const lcfiplus::Neutral* flaneut = flajet->getNeutrals()[nneut];
  lcio::ReconstructedParticle* lcioneut = _neutralLCIORel[const_cast<lcfiplus::Neutral*>(flaneut)];
  lciojet->addParticle(lcioneut);
}
for (unsigned int nvtx = 0; nvtx < flajet->getVertices().size(); nvtx++) {
  const lcfiplus::Vertex* flavtx = flajet->getVertices()[nvtx];
  // first, extract all vertex tracks
  for (unsigned int ntr = 0; ntr < flavtx->getTracks().size(); ntr++) {
    const lcfiplus::Track* flatr = flavtx->getTracks()[ntr];
    lcio::ReconstructedParticle* lciotr = _trackLCIORel[const_cast<lcfiplus::Track*>(flatr)];
    charge += flatr->getCharge();
    lciojet->addParticle(lciotr);
  }
```

If track assigned to vertex, it is double counted

Conclusions

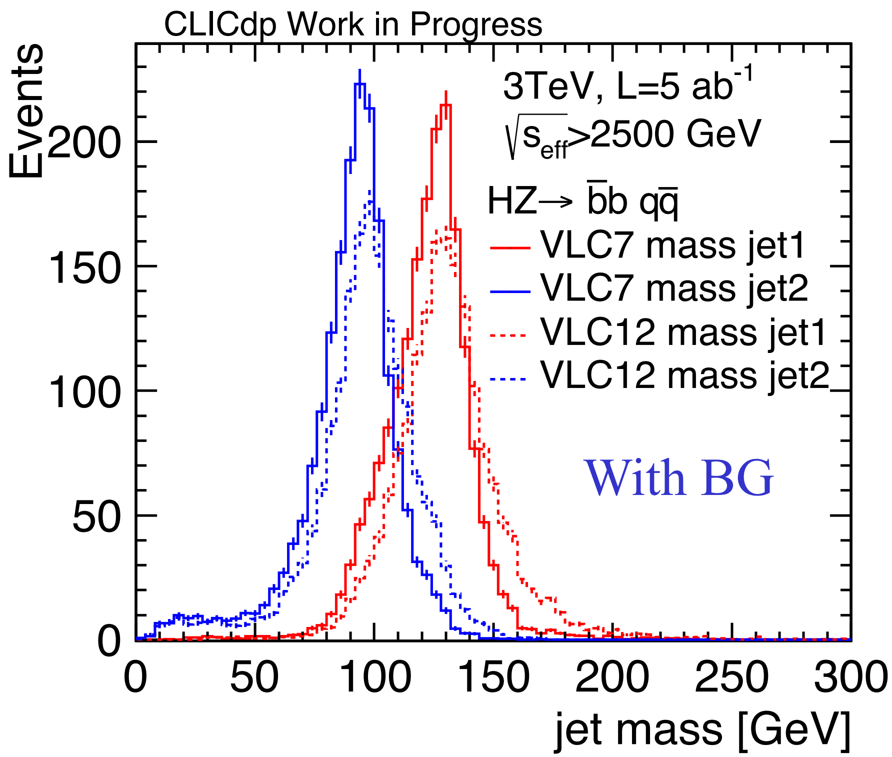
Jet energy and mass reconstruction studied for new detector model →software and reconstruction suite ready to be used for analysis

First look at HZ signal with H→bb, concentrating on high sqrt(s) region:

- Seems in calculation of effective sqrt(s) neutrinos still play a roles
- Large alignment of neutrino/MET vector with b-jet, correlation less pronounced after overlay of beam-induced background
- Decent separation of Z and H masses at a radius of 0.7, no large improvement if going to radii of 1.2 or 1.5
- First look into subjets:

  Basic energy sharing between quarks in Z and bottoms in H reproduced by subjets on particle and on reconstructed level (even with background), angular behavior of subjets reproduce angular structure of spin 1 and spin 0 underlying physics

Jet mass separation vs jet radius



Larger cone has higher chance to collect energy of the whole shower, but at cost of larger impact amount of beam-induced backgrounds, study three cones 0.7,1.0 and 1.2

→larger mass peaks for larger cone, R=0.7 shows better performance than larger jet cones, larger jet mass asymmetric with tail to lower values

For R=0.7 $A_O= 0.5(A_O(j1)+A_O(j2))$ smallest with 17.8%, largest for R=1.2 with 19.4%

sqrt(s) purity

Calculation method	Evts $\sqrt{s}_{reco}$>2500 GeV	Evts $\sqrt{s}_{reco}$>2500 GeV and $\sqrt{s}_{part}$>2500 GeV	purity
Tight PFOs	10387	9989	96.1
Tight PFOs+ MET correction	11982	11187	93.4
jets	9378	9252	98.7
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Jet Charge of subjets

Jet Charge

Jet charge determined from charged particles, weight contribution of particles with jet momentum/energy

$$Q^{\kappa} = \frac{1}{(p_{\mathrm{T}}^{\mathrm{jet}})^{\kappa}} \sum_i Q_i (p_{\mathrm{T}}^i)^{\kappa},$$

→ Used in the following, also checked definition where p_T is replaced by E → similar discrimination power

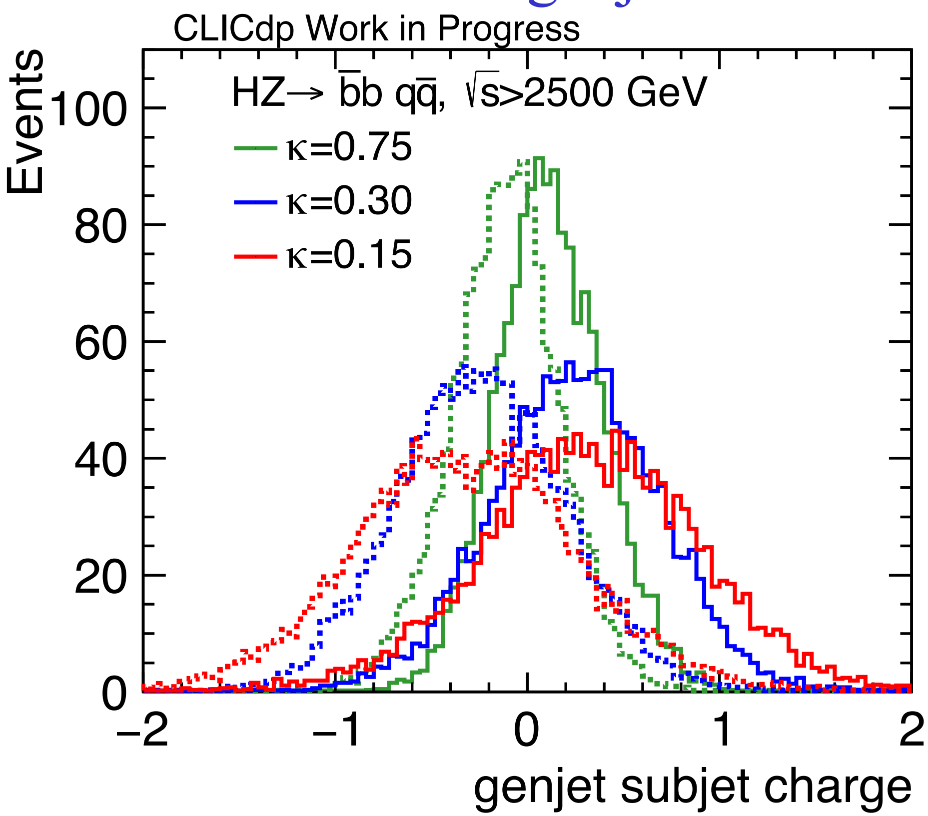
$$Q_L^{\kappa} = \sum_i Q_i \left(p_{\parallel}^i\right)^{\kappa} \Big/ \sum_i \left(p_{\parallel}^i\right)^{\kappa},$$

Slightly less discriminating

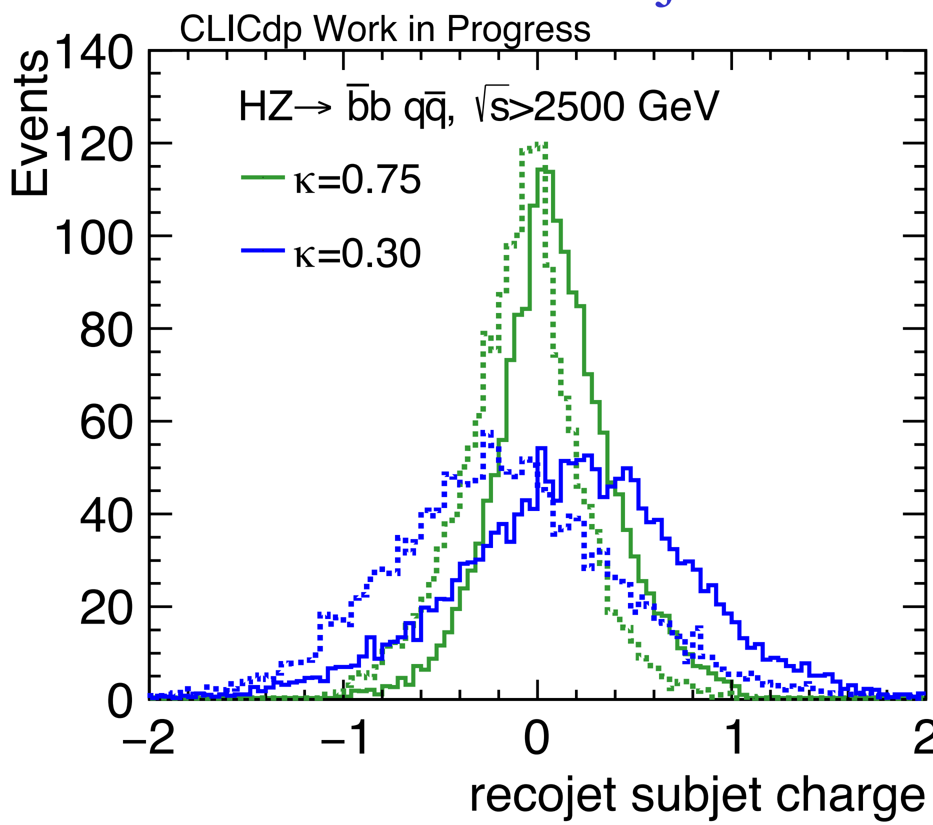
Subjet Charge: different kappa values

Try to differentiate between negatively and positively charged subjet:
→study different kappa parameters from 0.10 to 1.00 to find out which one seems most discriminant

MC truth genjets



Detector level recojets

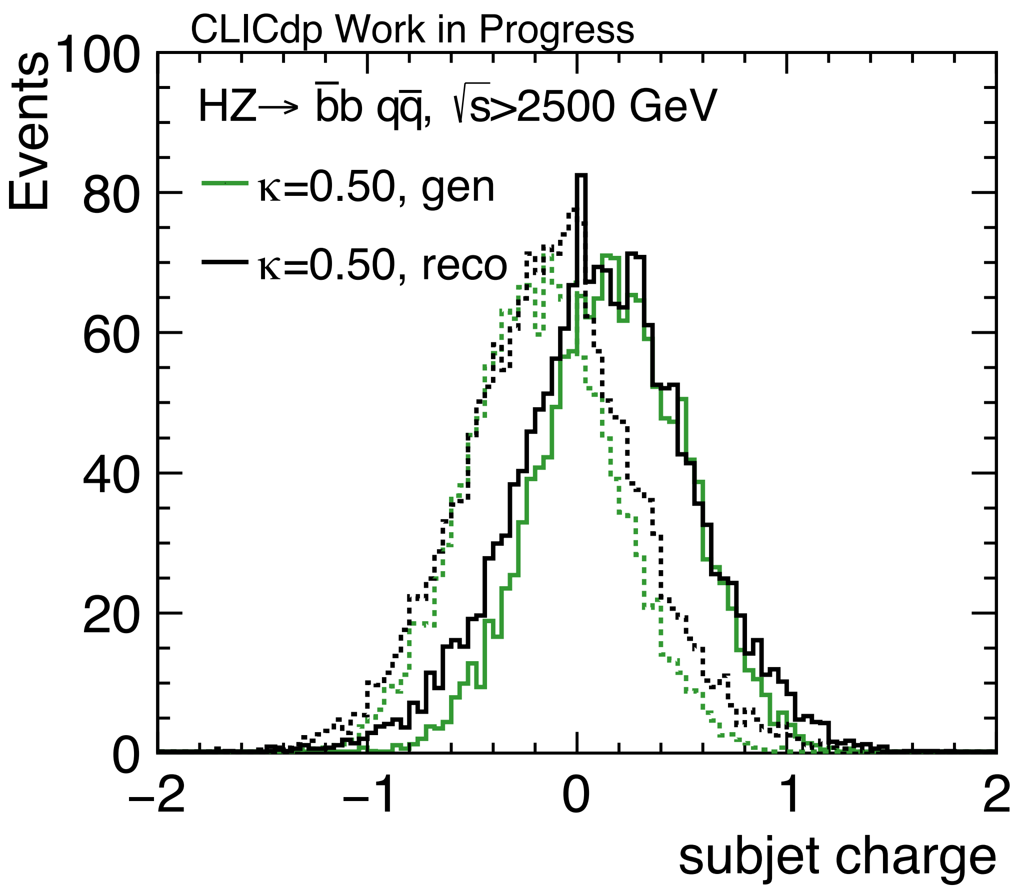


κ values between 0.20 and 0.50 better suited (study done via overlap)→κ=0.30

Subjet Charge: MC truth vs detector jets

Try to differentiate between negatively and positively charged subjet:

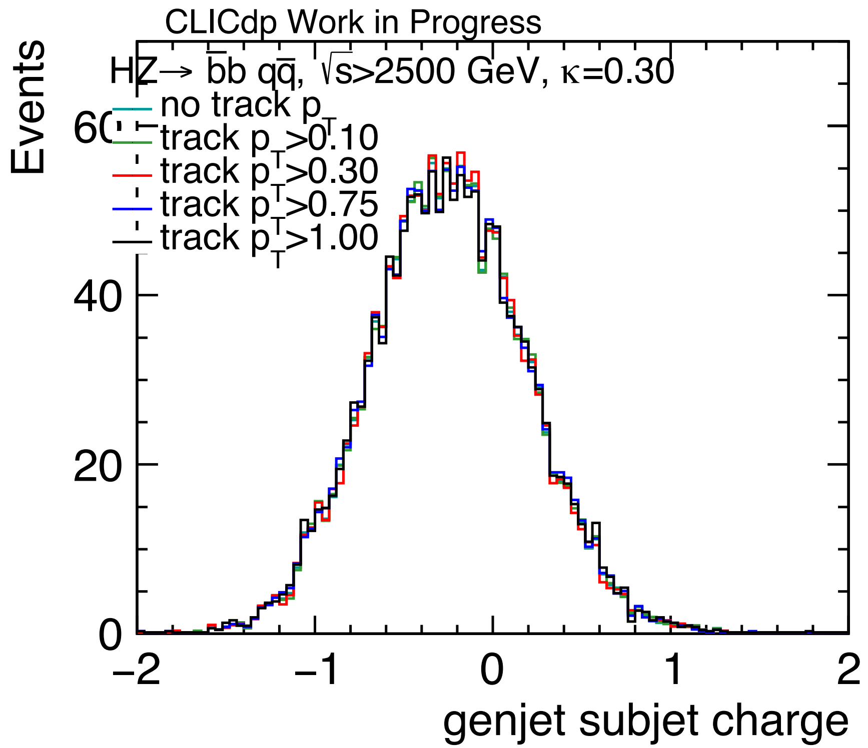
→compare MC truth with detector level jets

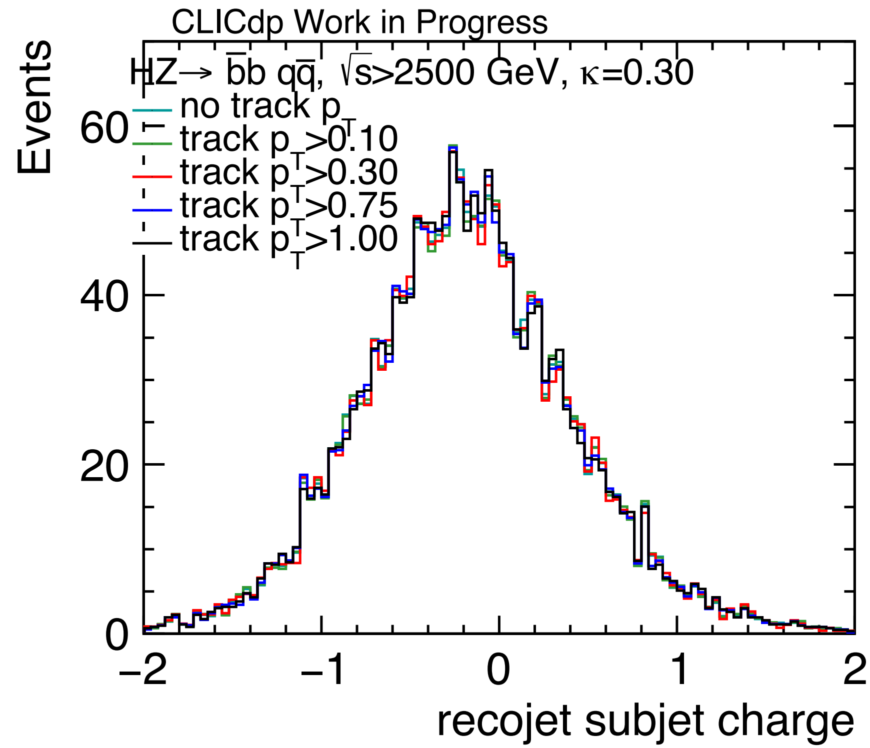


Peak between MC truth and detector jet level relatively stable, though larger tails for detector subjet charge distributions

Subjet Charge: MC truth vs detector jets

Larger Tails in MC truth vs detector level subjet charge → is it track efficiency
→ Study impact of p_T threshold on requirement, fix kappa=0.30





Seems no visible impact of lower trackPt requirement →so tracking efficiency seems not to be the issue

BTagging: LCFIPlus

LCFIPlus jet clustering

LCFIPlus is supposed to assign vertices and corresponding tracks to jets, clustered with the VLC algorithm → outputs are so-called refined jets with corresponding matched vertices

Idea: use b-tagging with jet mass cuts to discriminate against backgrounds: use PFOs from each of the fat jets for vertexing and split those in two refined jets (algo: VLC7), maybe use these in analysis instead of original subjets from Fastjet

Realized the jet energy changed at times substantially, typically to larger energy

Printout of all particles of one of these refined jets:

```
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```

Charged particles in the jet are at times double counted → for this jet almost double the total jet energy, so issue not only in assignment of particles to jets

First look: assignment of particles to jets

Issue observed for charged particles

→ In fact issue related to tracks from vertices, see code a https://github.com/lcfiplus/LCFIPlus/blob/master/src/JetFinder.cc#L345-L373

```
344
345   if (nVertexJets)
346     *nVertexJets = (int)jets.size();
347
348   for (unsigned int i=0; i<tracks.size(); i++) {
349     if (usedTracks[i])continue;
350
351     Jet* jetToAssoc = 0;
352     double minimumangle = vertexassocangle;
353
354     for (unsigned int j=0; j<jets.size(); j++) {
355       Jet* jet = jets[j];
356
357       for (unsigned int k=0; k<jet->getVertices().size(); k++) {
358         const Vertex* vtx = jet->getVertices()[k];
359         TVector3 vpos = vtx->getPos();
360
361         double angle = vpos.Angle(tracks[i]->Vect());
362         if (angle < minimumangle) {
363           jetToAssoc = jet;
364           minimumangle = angle;
365         }
366       }
367     }
368
369     if (jetToAssoc) {
370       jetToAssoc->add(tracks[i]);
371       usedTracks[i] = true;
372     }
373   }
374
```

The jet starts by clustering vertices into prejets, adding the tracks of these vertices to the prejets

Then the code loops over tracks. These are added should they be close to the vertex, tracks from vertices are added again in this step

First look: assignment of particles to jets

Issue is related only to charged particles

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```
    if (jetToAssoc) {
      bool veto_track=false;
      for (unsigned int k=0; k<jetToAssoc->getVertices().size(); k++) {
        const Vertex* vtx = jetToAssoc->getVertices()[k];
        for (unsigned int n=0;n<vtx->getTracks().size();n++){
          if(vtx->getTracks()[n]->Angle(tracks[i]->Vect())<1.e-6 && (vtx->getTracks()[n]->E()-tracks[i]-
            veto_track=true;
            break;
          }
        }
      }
      if(!veto_track){
        jetToAssoc->add(tracks[i]);
      }
      usedTracks[i] = true;
    }
```

Fixed by avoiding tracks from the vertex to be added to the jet once more

Summary

First look at HZ signal with H→bb, concentrating on high sqrt(s) region:

- In calculation of effective sqrt(s) neutrinos still play a roles
- Large alignment of neutrino/MET vector with b-jet, can correct with
- Decent separation of dijet masses → useful for background rejection, together with fact that signal is dominated by central jets, qqqq background peaked in forward region
- Can use jet charge from subjets to assign the parton charge to the subjet
- First look into LCFIPlus → fix to avoid double counting of tracks from vertex in refined jet clustering