# Re-Implementation of the BeamCal Electron Tagging Algorithm

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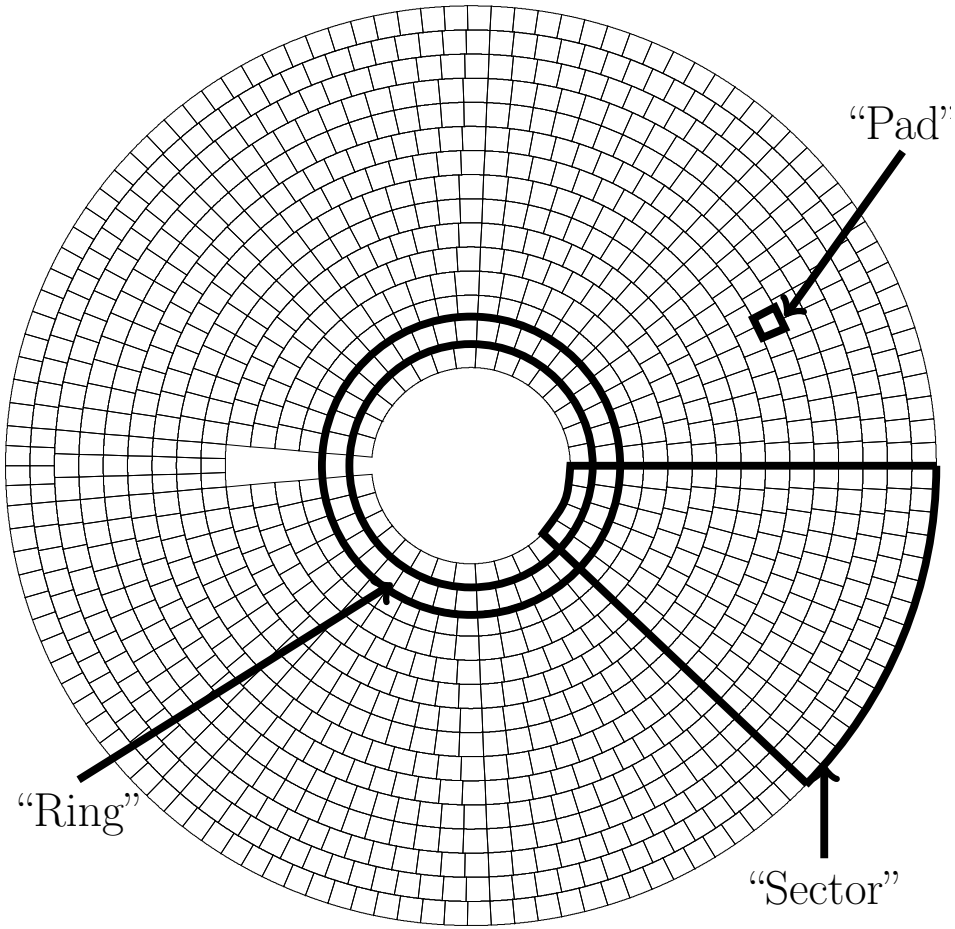
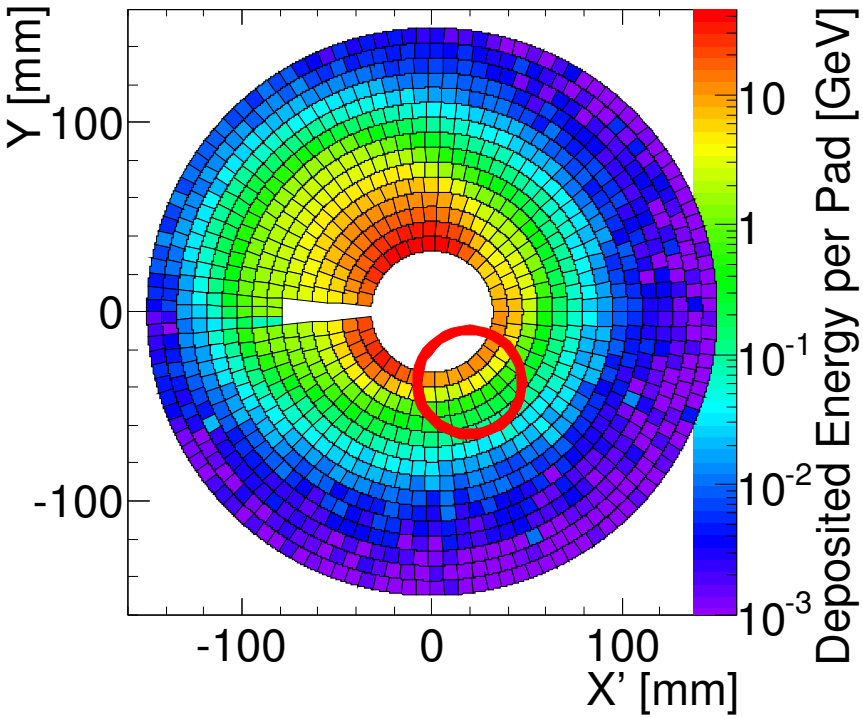
# BeamCal Detector at CLIC

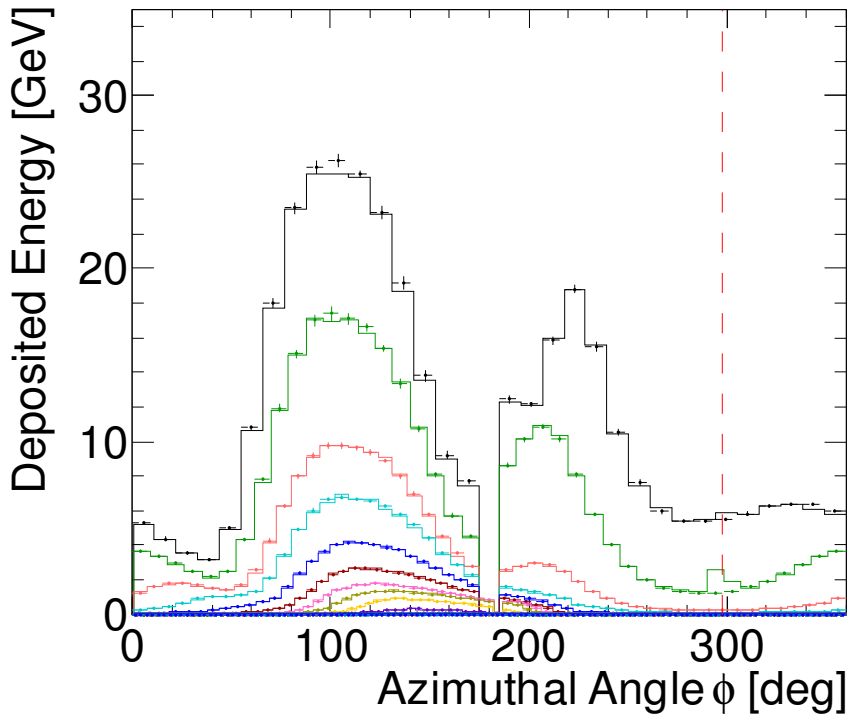
- 10 mrad to 45 mrad (ILC from about 3.5 mrad)
- Absorber for incoherent pairs
- Mask for downstream elements (QD0, BPM)
- Radiation hard sensors required
- Electron tagging for background suppression
- Tungsten sandwich calorimeter, Molière radius of about 1 cm
- Pad size $8 \times 8$ mm$^2$
- ILC opening around outgoing beam pipe larger, different number of pads per sector



# High Energy Electron and Background

- 1.5 TeV Electron on top of 40 BX background
- Have to identify cells and cluster with more energy deposited than average background

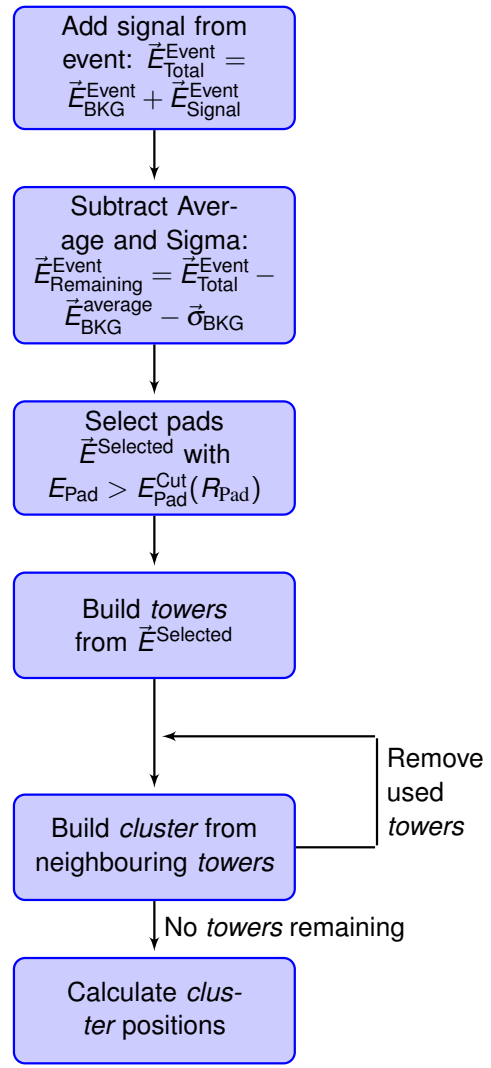


# BeamCal Electron Clustering Algorithm

## General Idea of Clustering

1. Energy in the BeamCal Pads is
   $\vec{E}^{\text{Event}}_{\text{Total}} = \vec{E}^{\text{Event}}_{\text{Signal}} + \vec{E}^{\text{Event}}_{\text{BKG}}$
2. Subtract the average background plus one standard deviation for each cell
   $\vec{E}^{\text{Event}}_{\text{Remaining}} = \vec{E}^{\text{Event}}_{\text{Total}} - (\vec{E}^{\text{average}}_{\text{BKG}} + \vec{\sigma}_{\text{BKG}})$
3. Select the pads with sufficiently large remaining energy, e.g., $E^{i}_{\text{Remaining}} > \sigma^{i}_{\text{BKG}}$
4. Find *towers* in the selected pads: Pads with the same position in different layers
5. Merge neighbouring *towers* into *cluster*
6. Calculate *cluster* position



# Problems with Existing Implementation

- Existing MARLIN Processor too tightly coupled with ILD BeamCal (hardcoded numbers everywhere)
- Some not so nice features in the code (copying 3D arrays by hand everywhere)
- Wanted to use electron tagging for CLIC BeamCal: Different number of layers, radii, cutout angles, etc.
- Re-implemented algorithm more generally

# The Implementation in PseudoCode

- On the next slides the abridged implementation is shown in c++ PseudoCode
- Is nonetheless rather technical
- Showing the types, variables, **important functions**, and geometry functions
- Based on three `classes`
  - `BCPadEnergies`: A vector of the energies per Pad, plus functionality to manipulate, add, subtract, scale, cluster pads
  - `BCPadCuts`: A class to implement pad and cluster selection
  - `BeamCalGeo`: Interface to Geometry information (Gear, DD4hep, . . . )
- Not showing event display and other code
- Not showing const(&), iterators, etc.
  instead of

```
for(std::vector<int>::iterator it = container.begin();
it != container.end(); ++it)
```

  write

```
forall ( int number in container ){}//not valid c++
```

# doClustering

```
BeamCalClusterList doClustering(BCPadEnergies totalEnergy,
                                BCPadEnergies background,
                                BCPadEnergies backgroundSigma,
                                BCPadCuts cuts ) {
  BeamCalClusterList beamCalClusters;
  totalEnergy.subtractEnergies(background);

  PadIndexList selectedPads = getPadsAboveSigma( totalEnergy, backgroundSigma, cuts );

  while( not selectedPads.empty() ) {
    PadIndexList padsForNextRound;
    TowerIndexList myTowerIndices = getTowersFromPads( selectedPads );
    TowerIndex largestTower = max_element( myTowerIndices );
    forall( TowerIndex testTower in myTowerIndices ) {
      if ( not areNeighbours( largestTower, testTower ) ) {
        selectedPads.removeTower( testTower );
        padsForNextRound.addTower( testTower );
      }
    }
    beamCalClusters.addCluster( getClusterFromAcceptedPads( totalEnergy, selectedPads ) );
    //try again for the remaining pads without the cluster that was already found
    selectedPads = padsForNextRound;
  }//while there are towers

  return beamCalClusters;
}
```

# subtractEnergies

```
void BCPadEnergies::subtractEnergies(BCPadEnergies testPads){
  for (PadIndex globalPadID = 0; globalPadID < getNumberOfPadsPerBeamCal();
       ++globalPadID) {
    this->m_PadEnergies[globalPadID] -= testPads.m_PadEnergies[globalPadID] ;
  }
}
```

- Same idea for addition, scaling, etc.
- Everything is based on the vector of energy per pad
- Can be `vectorised`, and easy parallelisation

# getPadsAboveSigma

```
PadIndexList getPadsAboveSigma(BCPadEnergies testPads,
                               BCPadEnergies backgroundSigma,
                               BCPadCuts cuts) {
  PadIndexList selectedPads;
  for (int globalPadID = 0; globalPadID < getNumberOfPadsPerBeamCal(); ++globalPadID ) {

    if( testPads.getLayer( globalPadID ) >= cuts.getStartingLayer() ) {

      double padEnergy = testPads.getEnergy( globalPadID );
      double padSigma = backgroundSigma.getEnergy( globalPadID );

      if( padEnergy > cuts.getPadSigmaCut() * padSigma ) {
        selectedPads.addPad(globalPadID);
      }

    }
  }
  return selectedPads;
}
```

- This functions returns a list of the selected pads (`integers`)
- Only the `globalPadID` is stored
- Energy of the pads can be found from the existing objects

# getTowersFromPads

```
TowerIndexList BCPadEnergies::getTowersFromPads( PadIndexList selectedPads ) {
  TowerIndexList myTowerIndices;
  forall ( PadIndex globalPadID in selectedPads ) {
    myTowerIndices[ globalPadID % getPadsPerLayer() ] += 1;
  }
  return myTowerIndices;
}
```

- Returns the list of *Towers* (is a `std::map<int, int>`)
- The index gives the `globalPadID`
- The value is the number of pads in the *Tower* (could also be the sum of the energy in the tower

# areNeighbours

```
bool areNeighbours( int globalPadID1, int globalPadID2 ) {
  int layerID1, layerID2, ringID1, ringID2, padID1, padID2;
  getLayerRingPad( globalPadID1, layerID1, ringID1, padID1 );
  getLayerRingPad( globalPadID2, layerID2, ringID2, padID2 );
  if( ringID1 == ringID2 ) {
    if( //The index of neighbouring pads differs by 1
        ( abs( padID1 - padID2 ) <= 1 ) or
        // or one is zero and the other is getSegmentsPerRing(ringID1) - 1
        ( ringID1 >= getFirstFullRing() and
          ( ( abs( padID1 - padID2 ) + 1 ) == getSegmentsPerRing(ringID1) ) )
         ) { return true; } else { return false; }
  }
  if( abs( ringID1 - ringID2 ) == 1 ) {
    double phi1 = getPadPhiDegree( ringID1, padID1 );
    double phi2 = getPadPhiDegree( ringID2, padID2 );
    if( fabs( phi1 - phi2 ) < 18.0 ) {
      return true; } else {  return false;
    }
  }
  return false;
}
```

- Checking if two pads (or towers) have adjacent indices
- Azimuthal angle check is a bit untidy, could be improved I think
- Took out the special case where the pads have to be in the same layer

# getClusterFromAcceptedPads

```
BeamCalCluster getClusterFromAcceptedPads(BCPadEnergies testPads,
                                          PadIndexList selectedPads ) {
  BeamCalCluster cluster;
  double phiAverage(0.0), ringAverage(0.0), totalEnergy(0.0);
  double sinStore(0.0), cosStore(0.0);//for average phi
  forall ( PadIndex globalPadID in selectedPads ) {
    double energy( testPads.getEnergy( globalPadID ) );
    cluster.addPad( globalPadID, energy );
    totalEnergy += energy;
    ringAverage += getRing( globalPadID ) * energy;
    sinStore += energy * sin( getPadPhiRad( globalPadID ) );
    cosStore += energy * cos( getPadPhiRad( globalPadID ) );
  }
  if( totalEnergy > 0.0 ) {
    phiAverage =  atan2( sinStore/totalEnergy, cosStore/totalEnergy );
    ringAverage /= totalEnergy;
    cluster.setPhi( phiAverage );
    cluster.setTheta( getThetaFromRing( ringAverage ) );
  }
  return cluster;
}
```

- Take the list of selected pads
- Calculate the energy weighted position of the cluster
- Finished

# doClustering

```
BeamCalClusterList doClustering(BCPadEnergies totalEnergy,
                                BCPadEnergies background,
                                BCPadEnergies backgroundSigma,
                                BCPadCuts cuts ) {
  BeamCalClusterList beamCalClusters;
  totalEnergy.subtractEnergies(background);

  PadIndexList selectedPads = getPadsAboveSigma( totalEnergy, backgroundSigma, cuts );

  while( not selectedPads.empty() ) {
    PadIndexList padsForNextRound;
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    TowerIndex largestTower = max_element( myTowerIndices );
    forall( TowerIndex testTower in myTowerIndices ) {
      if ( not areNeighbours( largestTower, testTower ) ) {
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        padsForNextRound.addTower( testTower );
      }
    }
    beamCalClusters.addCluster( getClusterFromAcceptedPads( totalEnergy, selectedPads ) );
    //try again for the remaining pads without the cluster that was already found
    selectedPads = padsForNextRound;
  }//while there are towers

  return beamCalClusters;
}
```
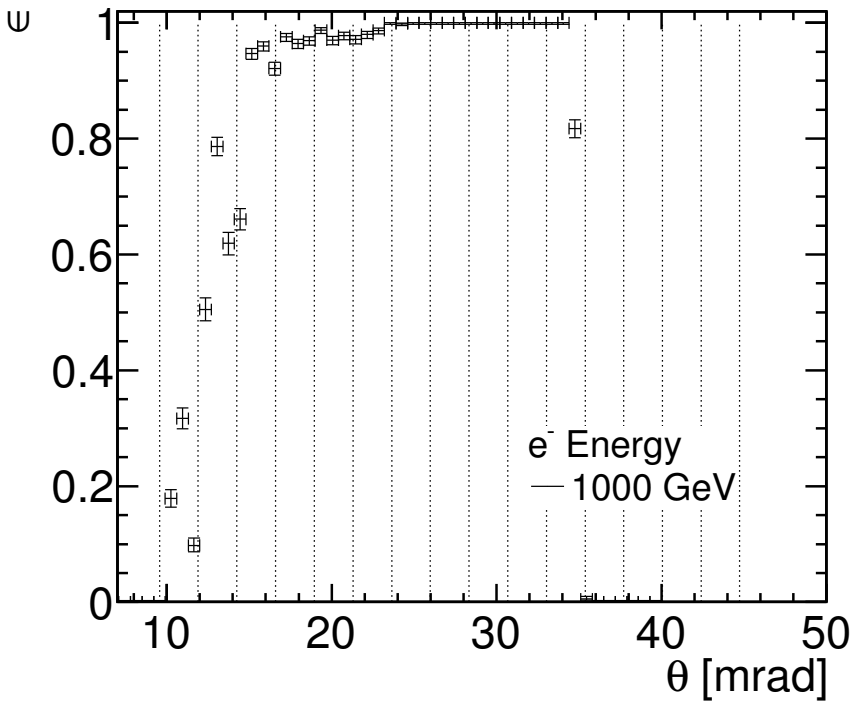
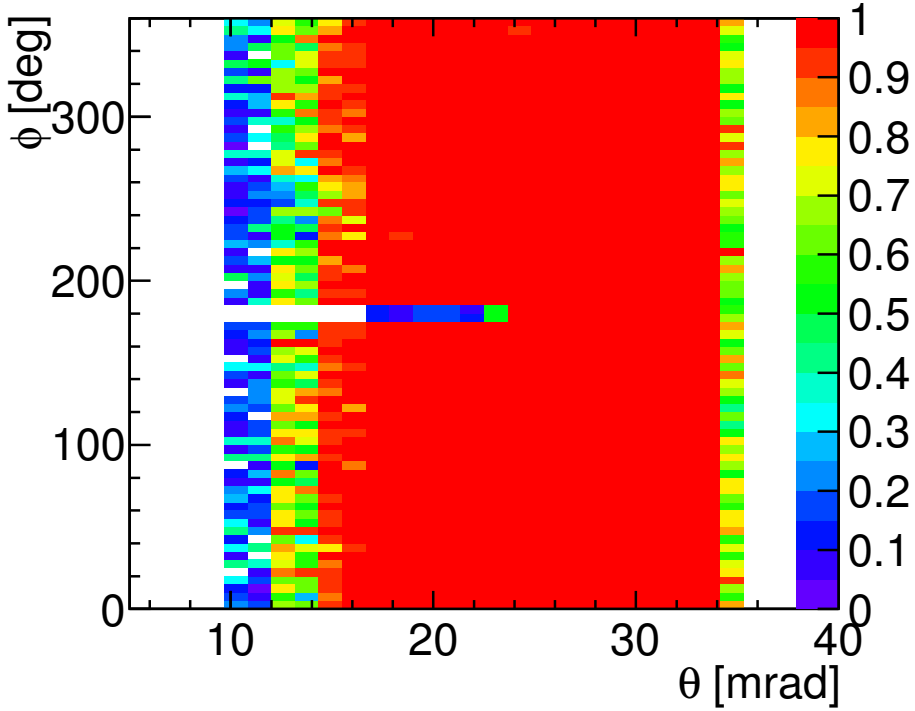

# Application

- Used algorithm to study efficiency of Electron Tagging at 3 TeV
- Example efficiencies for 1 TeV electrons with 40 BX of background



# Summary and Outlook

- Implemented BeamCal Electron Tagging algorithm
- Connect reconstruction to DD4hep geometry interface as a use-case
- Create `LCIO` objects as output, so it can be used in MARLIN reconstruction and analysis chain

# Backup Slides

# Pad ID Functions

```
void getLayerRingPad( int globalPadID, int& layer, int& ring, int& pad ) {
  //layer starts at 1!
  layer = getLayer( globalPadID );
  ring  = getRing ( globalPadID );
  int ringIndex = globalPadID % getPadsPerLayer();
  pad = ringIndex - getPadsBeforeRing( ring );
  return;
}

int getLayer( int globalPadID ) {
  //layer starts at 1
  return ( globalPadID / getPadsPerLayer() ) + 1;
}

int getRing( int globalPadID ) {
  element =  std::upper_bound( getListPadsBeforeRing().begin()+1,
                               getListPadsBeforeRing().end(),
                               globalPadID % getPadsPerLayer() );
  return element - m_PadsBeforeRing.begin() - 1 ;
}
```