strong word...

relative

distance with respect to the primary vertex. Finally, at least one pixel hit is required, as well as hits in at least 5 tracker layers, in order to guarantee a good p_T measurement.

In the case of the monojet analysis described in Chapter 5, the loose muon identification is used to select muons for the muon veto. An additional isolation cut is of 0.2 applied in order to select only prompt muons. The isolation value is computed as the sum of the transverse momenta of all charged hadrons associated to the primary vertex, neutral hadrons, and photons in a cone of $\Delta R < 0.4$ around the muon, relative to the p_T of the muon. The tight muon identification is used as well, to select events in the dimuon and single muon control regions.

huge jargon maybe turn around: "in order to reject muons in jets" or something of that sort.

OK

4.3.6 Particle flow

The particle flow (PF) algorithm [125] reconstructs so-called particle flow candidates by combining information from all different CMS subdetectors, linking different elements, such as tracks in the tracker, calorimeter clusters, and muon tracks. A global picture of the event is thus formed, where each particle is uniquely identified. The obtained collection of particle candidates is subsequently used to reconstruct jets and tau leptons, and to determine the missing transverse energy.

In a first step, the PF algorithm identifies charged particle tracks, as defined in Section 4.3.1 for all tracks, and in Sections 4.3.2 and 4.3.4 for electron and muon tracks in particular. At the same time, the calorimeter clusters are reconstructed with a clustering algorithm designed specifically for the PF event reconstruction. In this algorithm, cluster seeds are first identified as local energy maxima with respect to the four or eight closest cells, if the energy deposited in the cell is above a given seed threshold. The clusters are then formed by accumulating neighbouring cells with an energy above a given cell threshold, suppressing noise.

The PF elements in the different subdetectors are then connected by a link algorithm which avoids any double counting. The link algorithm produces blocks of associated elements, quantifying the quality of the link by defining a geometrical distance between the elements. When an element is linked to multiple other elements, only the link with the shortest distance is kept. More precisely, a link between a track in the tracker and a calorimeter cluster is made by extrapolating it from the last hit in the tracker to the calorimeters. The distance between the position of the extrapolated track and the cluster in the (η, ϕ) plane is then used to define the link distance. At the interaction points between the track and the tracker layers, tangents to the GSF tracks are extrapolated to the ECAL in order to collect the energy of photons radiated by electron bremsstrahlung. A dedicated conversion finder was also developed to identify bremsstrahlung and prompt photon conversions into e^+e^- pairs. Links between calorimeter clusters are established outside of the tracker acceptance, or between the preshower and ECAL clusters in the preshower acceptance. In this case the link distance is also defined as the distance between the position of the clusters. Charged particle tracks can also be linked by a common secondary vertex. Finally, the PF muon identification algorithm associates the muon tracks to the muon energy deposits in the ECAL and HCAL, to improve the muon identification performance.

In a next step, the PF blocks obtained by linking the multiple PF elements, are classified as muons, electrons, or isolated photons. The corresponding elements are then excluded from further consideration. Once electrons, muons, and isolated photons have been identified, the remaining elements are identified as charged hadrons, neutral hadrons, or photons produced in jets. Within the tracker acceptance, the ECAL clusters not linked to any track are classified as photons, while the clusters in the HCAL without a matched track are labelled as neutral hadrons. Outside of the tracker acceptance, charged and neutral hadrons can not be distinguished. ECAL clusters linked to an HCAL cluster are then assumed to arise from the same hadron shower, and the estimated energy for these particles is the sum of the energy deposited in the ECAL and the HCAL. The ECAL clusters that are not linked to an HCAL cluster are classified as photons.

4.3.7 Jet reconstruction

Jets are reconstructed with the anti-k_T algorithm [126], which clusters either the generated particles from event simulation, or the particles reconstructed by the PF algorithm (PF jets), or the energy deposits in

the calorimeters (Calo jets). This procedure takes into account the transverse momentum p_T, also called k_T, of the particles and the distance between particles, defined as

$$\Delta R_{ij} = \sqrt{(\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2}. \tag{4.1}$$

The strategy consists of the following steps:

1. For every pair of particles i and j, a distance d_{ij} defined as
$$d_{ij} = \min\left(\frac{1}{p_{Ti}^2}, \frac{1}{p_{Tj}^2}\right)\frac{\Delta R_{ij}^2}{R^2} \tag{4.2}$$
is calculated.
2. For every particle i, a distance d_{iB} to the beam pipe is calculated with
$$d_{iB} = 1/p_{Ti}^2. \tag{4.3}$$
3. The minimum of d_{ij} and d_{iB} is then determined.
4. If it is d_{ij}, particles i and j are recombined into a new particle by adding the four-momenta of the particles. If it is d_{iB}, particle i is declared to be a jet and it is removed from the list of particles.
5. This is repeated until no particles remain.

In this clustering algorithm, the parameter R determines what is called a jet. If a particle i has no other particles within a distance R, d_{iB} will be smaller than d_{ij} and the particle will become a jet. A consequence of this is that an arbitrarily soft particle can become a jet, and therefore a minimum transverse momentum for a jet to be of interest is defined.

The anti-k_T algorithm favours clustering around hard particles, and the jets then grow outward from this seed. This gives rise to circular jets, with a cone size that is proportional to R. Since it still involves a combination of energy and angle in the distance measure, this is a collinear-safe growth, meaning that the jet will not change when one of the particles of the jet is split collinearly. This algorithm is also infrared-safe, i.e. the same set of jets is obtained when soft particles are emitted.

A reliable determination of the jet energy is not straightforward, since many effects can distort the energy estimation, such as the calorimeter response, the limited particle reconstruction efficiency, the underlying event, the pileup, and the charged particles bending out of the jet cone due to the strong magnetic field. The pileup is mitigated by applying charged hadron subtraction (CHS), which consists of removing charged hadrons associated with vertices other than the primary vertex from the list of PF candidates. Additionally, the jet energy is corrected using a factorised approach, as illustrated in Figure 4.6, with the following steps:

- **Pileup correction (L1).** The first level of jet energy corrections is applied event-by-event and jet-by-jet, and is determined from simulation. It is dependent on the pseudorapidity and transverse momentum of the jet, the average p_T density in the event, and the effective jet area. This effective area is determined by injecting a large number of very soft particles in the event before the jet clustering. The spread of the soft particles in each jet then defines the jet area. When these corrections are applied on data, residual corrections are also applied to take into account the difference between the simulated events and the data.
- **Relative η and absolute p_T corrections (L2L3).** These corrections are also obtained from simulations and correct for the non-uniform response of the calorimeters in η and p_T. They are determined by comparing the reconstructed p_T to the one obtained from the jets built from the generated particles. These corrections have the largest impact on the jet energy.
- **Residual η and p_T corrections (L2L3Residual).** Since the L2L3 correction is derived from simulation, additional residual corrections are needed in order to correct for the remaining small differences between the jet response in data and simulation. These corrections are typically of the order of a few percent.

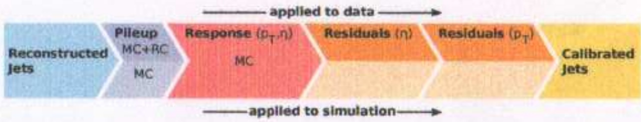

Figure 4.6: Graphical overview of the factorised approach used at CMS to apply jet energy corrections.

Optionally, a set of identification criteria are applied on the PF jets. A jet is required to consist of at least two particles. For jets in the region $|\eta| < 2.7$, the fraction of energy coming from ether neutral hadrons or photons should not exceed 99%. Additionally, for jets restricted to the tracker acceptance ($|\eta| < 2.4$), there should at least be some energy deposited in the HCAL, the jet should contain 1 or more charged constituent, and the fraction of energy corresponding to electrons or photons should not exceed 99%.

Moreover, jets from pileup can be identified as well. This pileup jet identification relies on the topology of the jet shape which is used to disentangle jets coming from the overlap of multiple interaction and real hard jets, the object multiplicity, and the compatibility of the tracks in the jets with the primary vertex. This last property of pileup jets can evidently only be exploited for jets within the tracker acceptance.

It is not used in the analysis, right? possibly drop, or add this is not used. no strong opinion, though

4.3.8 Identification of b-jets

For the identification of jets originating from b quarks, the long lifetime of the B hadrons arising from the hadronization of b quarks is exploited. The B hadrons will therefore decay at ~~a~~ position that is displaced with respect to the primary interaction vertex. The b-jets can then be identified by looking for the presence of displaced tracks from which a secondary vertex may be reconstructed. Additionally, the B hadrons have a probability of 20% to decay into muons or electrons. Consequently, the presence of these charged leptons can be used as well for b-jet identification techniques.

Within the CMS collaboration, two different algorithms are being used during Run 2, namely the Jet Probability and the Combined Secondary Vertex taggers [127]. In this thesis, the latter is used to identify b-jets, combining the information from displaced tracks and secondary vertices in a multivariate technique. Jets are then identified or "tagged" as b-jets by applying a cut on the discriminator output. Three standard operating points are defined, denoted as "loose", "medium", and "tight", corresponding to a misidentification probability of 10%, 1%, and 0.1% for light jets with $p_T > 30$ GeV, respectively.

maybe say it's used as a veto and which operating point used

4.3.9 Reconstruction of tau leptons

Tau leptons can decay into either a charged lepton and two neutrinos, or a few hadrons ~~and~~ one neutrino. The hadronic decays of the tau lepton can be separated from quark or gluon jets by ~~the~~ analysing the decay products. With the PF algorithm, it is possible to resolve the particles originating from the tau decay and to determine its isolation. Hadronic tau decays are reconstructed using the hadrons-plus-strips (HPS) algorithm [128] by using those particles as input. The jet constituent particles are combined into candidates compatible with one of the main hadronic tau decay modes, $\tau^- \to h^-\nu_\tau$, $\tau^- \to h^-\pi^0\nu_\tau$, $\tau^- \to h^-\pi^0\pi^0\nu_\tau$, and $\tau^- \to h^-h^+h^-\nu_\tau$. This PF reconstruction of the tau decay products has significantly improved the reconstruction and identification of the tau leptons compared to the previous method which only took the energy deposits in the calorimeters into account.

where h represents ~~any~~ charged hadron.

4.3.10 Missing transverse momentum reconstruction

While most particles produced in the collisions can be reconstructed from the hits and energy deposits in the detector, some collision products might not leave energy deposits in tracker, calorimeters or muon system. This makes an accurate reconstruction of this type of particles impossible, and an alternative method is used, based on indirect observations. As the detector is hermetically closed such that all other particles in the event can be detected, the missing transverse momentum can be determined. This