DELPHES fast simulation status for the IDEA detector

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DELPHES framework for Fast Simulation

IDEA Baseline Detector description

Validation of the Delphes IDEA card

Comparison between different detectors

compared with the ILD card validated with Full Sim
Fast Simulation of detector concept

Particle trajectory is followed in the detector. It only needs general volumes for acceptances, a resolution driven segmentation, resolution and response functions as obtained from Full Simulation or related to desired/studied performance.

Two frameworks for the fast simulation

**DELPHES**
- Detector geometry: **implemented**
- Validation: **on-going**
- Benchmark studies: **to be done**

**PAPAS**
- Detector geometry: **partially implemented**
- Validation: **to be done**
- Benchmark studies: **to be done**

- Focus on DELPHES to start fast simulation studies: more experience in the group
- Goal: proceed in parallel working on PAPAS in the FCCSW once the details would be fixed
Delphes provides a parametric simulation of a detector taking into account subdetector types (described as cylinders) with their extension, segmentation and resolution:

- a tracker in a solenoidal magnetic field,
- a calorimeter with electromagnetic and hadronic sections,
- a muon system.

Finally, it provides reconstruction of physics objects (electrons and muons, jets, b-jets, \(\tau\)-jets and MET) in the form of output ROOT files.
The real layout

- **A magnetic field** of 2 T with
  - Solenoid length: 5 m
  - Solenoid inner radius: 2.1 m
  - Solenoid outer radius: 2.4 m

- **A Tracker** composed of
  - a drift chamber and a drift chamber service area (**DCH**);
  - silicon pixels and a **silicon strips** double stereo layer;
  - a μ-RWELL double layer as **preshower**.

- **A Dual-Readout calorimeter**

- **A muon system** composed of three μ-RWELL stations (each of them has a bidimensional view)

To understand if it is needed to extend the angular coverage of the detector from **150 mrad** to **100 mrad**, corresponding to \( \eta = 2.6 \) and \( \eta = 3.0 \), respectively.
Implementation in the Delphes card

- **B field description** *(Particle Propagator module)*
  - Half length of the magnetic field coverage: 2.5 m
  - Radius of the magnetic field coverage: 2.25 m
  - Homogeneous magnetic field: 2 T

- **Tracker description** *(TrackingEfficiency, MomentumSmearing)*
  - Half length: 2.6 m
  The response of tracking detectors has been parametrized in the same way for muons, electrons and charged hadrons through an unique efficiency formula and a total resolution formula.

- **Dual-Readout (DR) calorimeter description** *(ECal, HCal)*
  - Half length: 2.6 m
  The implementation in two separated modules is needed to describe the different response to electromagnetic (ECAL) and hadronic (HCAL) component of the showers. This implies:
  - different segmentations according to the different transverse dimensions of the showers;
  - different energy resolution formula for particles which deposit all their energy in ECAL (e±, γ, π0) or (*also*) in HCAL.

The card has been validated assuming a total angular coverage of 100 mrad (η = 3.0).

**WHY?**
- Particle Flow algorithm
- No clustering in Delphes

* K_s^0 deposit 100% of their energy in ECAL (HCAL) with a probability of 30% (70%) and Λ deposit 30% (70%) of their energy in ECAL (HCAL).
The geometry is given in Delphes as a segmentation of the cylinder in cells in $\eta$ and $\phi$ directions:

$$E_{\text{tower}} = E_1 + E_2$$

Since each tower reconstructed in the calorimeter corresponds to a single cell in Delphes workflow, the granularity of the physics objects is considered instead of the real granularity of the calorimeter.

ECAL cell size: $6 \text{ cm} \times 6 \text{ cm}$
HCAL cell size: $\sim 30 \text{ cm} \times 30 \text{ cm}$

$\phi$ coverage: $360^\circ$
$\eta$ coverage: $2.6$ (150 mrad)

Extended to $|\eta| = 3$ to validate the card
**Energy resolution formula**

\[ \sigma = \sqrt{(0.01^2 E^2 + 0.11^2 E)} \]

Same for barrel and endcap regions

The **high energy resolution** on ECAL is one of the most important strengths of the IDEA detector thanks to its DR calorimeter
Energy resolution formula

\[ \sigma = \sqrt{(0.01^2 E^2 + 0.11^2 E)} \]

Same for barrel and endcap regions

- Good energy resolution on photons at different energy
- The resolution improves when particle energy increases
**Energy resolution formula**

\[ \sigma = \sqrt{(0.01^2 E^2 + 0.30^2 E)} \]

Same for barrel and endcap regions

**Good energy resolution** on the hadronic component of the showers
Energy resolution formula

\[ \sigma = \sqrt{(0.01^2 E^2 + 0.30^2 E)} \]

Same for barrel and endcap regions

- Better energy resolution on neutrons at different energy
- The resolution improves when increases particle energy
The description of the Tracker is **preliminary** (waiting for an input from Full Simulation to have a total parametrization of efficiency and resolution):

- The **same tracking efficiency** is assumed for electrons, muons and charged hadrons:

  | | \( |\eta| \geq 3.0 \) | \( 0.00\% \) |
  | E \geq 500 \text{ MeV in } |\eta| \leq 3.0 | 99.7\% |
  | 300 \leq E \leq 500 \text{ MeV in } |\eta| \leq 3.0 | 65\% |
  | E \leq 300 \text{ MeV in } |\eta| \leq 3.0 | 6\% |

- The **same transverse momentum resolution** is assumed for electrons, muons and charged hadrons (**pessimistic**: only DCH contribution considered in the parametrization):

  \[
  \sigma_{P_T}/P_T = \sqrt{(7.0e-07*P_T)^2 + 0.0006^2}
  \]

  **Same for barrel and endcap regions**
The PF algorithm takes Tracks and calorimeter’s Towers as input: in case of an excess of deposited energy wrt the considered track, it helps to evaluate if the excess corresponds to a neutral particle or not.

It combines the information from tracker and calorimeter modules ←→ it works correctly in ECAL.
The PF algorithm takes Tracks and calorimeter's Towers as input: in case of an excess of deposited energy wrt the considered track, it helps to evaluate if the excess corresponds to a neutral particle or not.

It combines the information from tracker and calorimeter modules and it works correctly also in HCAL.
Jets are reconstructed using the **anti-kt algorithm** requiring a **radius of 0.4**

- Jets are reconstructed correctly both in the barrel and endcap region with a good energy resolution
- PF algorithm improves resolution on jets thanks to the tracker
Validation

Particle Flow Performance

IDEA

10 GeV

ILD

10 GeV

10 GeV

100 GeV

100 GeV

100 GeV

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Reconstructed Objects

**Muons**
- isolated and identified with true PID
- reconstructed if they fall into the tracker coverage
- reco efficiency

**Electrons**

**Photons**
- $\mu, e, \gamma$
- calculation based on the calorimetric towers

**MET**
The Z invariant mass and the Higgs recoil mass are reconstructed in a similar way by ILD, CLIC and IDEA detectors in the muon final state.
• The reconstructed Z invariant mass and the Higgs recoil mass are more different between the IDEA detector and ILD - CLIC in the electron final state: greater number of events in the mass peak.
Comparison between two different configurations of the IDEA detector in two different scenarios:

- $|\eta| = 2.6$
- $|\eta| = 3.0$
- REF: ILD

No significant improvement observed (around 1.5-2%): need to study proper benchmark analyses sensible to particles at large acceptance.
Conclusions & Plans

- Implementation of a dedicated IDEA detector description in a Delphes card
  - Focus on the DR calorimeter geometry and resolution
  - Preliminary Tracker description
- Validation of the card in comparison with the ILD detector description
  - checked the correct work flow of the card, efficiency and resolution of the subdetectors, object reconstruction
- Comparison between different detector performance in basic analyses
  - similar performance in muon final states
  - improvement in electron final states
- Extension of the angular coverage of the detector to 100 mrad
  - no significant improvement observed; need to study proper benchmark analyses.

TO DO:
- Implement a precise tracker performance description
  - overall efficiency and transverse momentum resolution considering all the sub-detectors
- Study more in detail object reconstruction and related algorithms (lepton isolation, jet reconstruction, b-tagging, τ-tagging, ...)

GOAL: Provide a complete card to perform physics analyses in order to study the IDEA detector performance and capabilities
Thank you for your attention

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Transverse Momentum Resolution

Effect given by the implementation of the other tracking sub-detectors in the Full Simulation.

For now the red fit has been implemented as Transverse Momentum Resolution parametrization in Delphes.
Validation

Particle Flow Performance

IDEA

Delphes 3.4.1 - delphes_card_IDEAdet_EcalHcal

(resolution in E/E (%) vs \eta)

- e^+, E = 1 GeV
- ECAL
- Track
- Particle-flow

1 GeV

10 GeV

30 GeV

100 GeV

ILD

Delphes 3.4.1 - delphes_card_ILD

(resolution in E/E (%) vs \eta)

- e^+, E = 1 GeV
- ECAL
- Track
- Particle-flow

1 GeV

10 GeV

30 GeV

100 GeV
Attempt to reconstruct the Z invariant mass in **final states with jets**:

- need to optimize the tagging algorithms (basic form)
- need to perform a targeted event selection (not so easy as with leptons)

- BUT the reconstructed objects are available