Fast (and Full) Simulation of the IDEA Detector

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The IDEA Detector Concept

**Beam pipe:** R~1.5 cm

**Vertex:**
- 5 MAPS layers
- R = 1.7-34 cm

**Drift Chamber:**
- 4 m long, R = 35-200 cm

**Outer Silicon Layers:** strips

**Superconducting solenoid coil:**
- 2 T, R ~ 2.1-2.4 m
- 0.74 $X_0$, 0.16 $\lambda$ @ 90°

**Pre-shower:** ~1 $X_0$

**Dual-Readout Calorimeter:**
- 2 m / 8 $\lambda_{int}$

**Yoke + Muon chamber**

MPGD and muRWell for muon detection at an e+e- collider, G. Morello

Drift chamber tracker design experiences, F. Grancagnolo

Dual-Readout Calorimeter recent developments, I. Vivarelli

The IDEA detector concept performance, R. Ferrari
Drift Chamber Performance

Geant4

Transverse Momentum Resolution

\[
\frac{\sigma_{P_t}}{P_t} = \sqrt{(7 \times 10^5 P_t)^2 + 0.0006^2}
\]

On going implementation of a correlation matrix for tracking parameters smearing in fast simulation.

Fast Simulation Tracking, F. Bedeschi
Dual Readout Calorimeter

Barrel (right): 40 towers
Inner length 2.5 m
Tower height 2.0 m

Endcap (right): 39 towers
Inner length 2.25 m
Tower height 2.0 m

Barrel
Endcap
Full endcap
Dual Readout Calorimeter

16 towers around beam axis

256 towers around beam axis
Calorimeter EM Performance

Test beam - Copper

\[ \frac{11\%}{\sqrt{E}} \oplus 1\% \]

\[ \approx 10 - 11\% / \sqrt{E} \]
Calorimeter Had Performance

\[ S = E \left[ \text{fem} + \left( \frac{h}{e} \right)_s \right] (1 - \text{fem}) \]

\[ C = E \left[ \text{fem} + \left( \frac{h}{e} \right)_c \right] (1 - \text{fem}) \]

\[ E = \frac{S - \chi C}{1 - \chi} \]

\[ \chi = \frac{1 - (h/e)_s}{1 - (h/e)_c} \]

Geant4 \[ \approx 30 \% / \sqrt{E} \]

\[ \sigma \]

\[ \frac{E}{E} = \frac{27 \%}{\sqrt{E}} \]

Lead

<table>
<thead>
<tr>
<th>DR Energy</th>
<th>Entries</th>
<th>Mean</th>
<th>Std Dev</th>
<th>( \chi^2 ) / ndf</th>
<th>Constant</th>
<th>Mean (GeV)</th>
<th>Sigma (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9997</td>
<td>3.998e+04</td>
<td>1842</td>
<td>38.69 / 21</td>
<td>1859 ± 22.9</td>
<td>3.999e+04</td>
<td>1709 ± 12.2</td>
</tr>
</tbody>
</table>

\[ \chi^2 / \text{ndf} = 3.283 / 2 \]
A new machine learning inspired technique is a promising solution to also exploit calibrations with hadrons. The single event under reconstruction is compared to only pre stored events with approximately the same electromagnetic fraction.

The correct hadron energy is then given by

\[ E = \frac{1}{2n} \sum_{i}^{n} \frac{E_i}{s_i} \times s + \frac{1}{2n} \sum_{i}^{n} \frac{E_i}{c_i} \times c \]
Machine Learning

Lead based calorimeter - 40 GeV $\pi^-$

### DR Energy
- **Entries**: 9997
- **Mean**: 3.998e+04
- **Std Dev**: 1842
- $\chi^2$/ndf: 38.69 / 21
- **Constant**: 1859 ± 22.9
- **Mean**: 3.999e+04 ± 1.716e+01
- **Sigma**: 1709 ± 12.2

### ML Energy
- **Entries**: 9997
- **Mean**: 4.017e+04
- **Std Dev**: 2157
- $\chi^2$/ndf: 94.12 / 38
- **Constant**: 1852 ± 22.6
- **Mean**: 4.01e+04 ± 1.78e+01
- **Sigma**: 1762 ± 13.3

### DR Equation
$$\frac{\sigma}{E} = \frac{27\%}{\sqrt{E}}$$

### ML Equation
$$\frac{\sigma}{E} = \frac{22\%}{\sqrt{E}} \pm 0.9\%$$

Geant4
Fast simulation

Delphes only needs general volumes for acceptances, a resolution driven segmentation and response functions as obtained from full simulation or related to desired/studied performance.

IDEA Description in Delphes

B field Description:
- 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:
- Same parameterization for electrons, muons and charged hadrons
Comparison with other detectors

No significant discrepancies are observed in analyses using di-lepton invariant masses with respect to different detectors.

\[ ZH \rightarrow e^+e^-b\bar{b} \]
IDEA D/R in Delphes

The calorimeter geometry is given in Delphes as a segmentation of a cylinder in cells in \( \eta \) and \( \phi \) directions.

Dual-Readout Calorimeter (DR):
- Implementation of a monolithic calorimeter in a dedicated IDEA card
- Modified Energy Flow in Delphes (new branch available in Delphes: branch DualReadout).

We apply an energy resolution to electromagnetic and hadronic energy deposits:
- Electromagnetic showers: \( 11\%/\sqrt{E} \)
- Hadronic showers: \( 30\%/\sqrt{E} \)
- Hadronic resolution applied in case of an electromagnetic and hadronic deposit in the same cell

\[ E_{\text{tower}} = E_1 + E_2 \]
Evaluating overlap with jets

Different calorimeter granularities implemented:

- 2 mm x 2 mm
- 3 cm x 3 cm
- 30 cm x 30 cm
- 40 cm x 40 cm
- 60 cm x 60 cm
- 80 cm x 80 cm

Production of events $Z(bb)$, $Z(\tau\tau)$, $ZH(eebb)$, $ZH(\gamma\gamma bb)$, $ZH(\tau\tau+\text{jets})$ with DelphesPythia8:

- Event display
- Mass resolution
- Angular Resolution
- Overlap probability

Caveat: only anti-$k_T$ used so far. Results to be studied also with clustering algorithms optimized for $e^+e^-$ colliders.
The number of towers with both an electromagnetic and hadronic deposit increases when increasing granularity, reaching a mean value of 5 towers for a cell size of 80 cm x 80 cm (1% of the towers).
Jet Energy Resolution

Barrel

Cell size: 3 cm x 3 cm

Cell size: 30 cm x 30 cm

Cell size: 80 cm x 80 cm

Endcap

Cell size: 3 cm x 3 cm

Cell size: 30 cm x 30 cm

Cell size: 80 cm x 80 cm
Jet Angular Resolution

Impact of cell size on the angular resolution for PF jets and Calo jets.

\[ \sigma(\theta) = \theta_{GEN} - \theta \]

<table>
<thead>
<tr>
<th></th>
<th>2 mm x 2 mm</th>
<th>3 cm x 3 cm</th>
<th>30 cm x 30 cm</th>
<th>40 cm x 40 cm</th>
<th>60 cm x 60 cm</th>
<th>80 cm x 80 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF jet</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Calo jet</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.07</td>
<td>0.1</td>
</tr>
</tbody>
</table>

IDEA - Delphes
Particle flow jets

Cell size: 2 mm x 2 mm
Cell size: 3 cm x 3 cm
Cell size: 30 cm x 30 cm
Cell size: 40 cm x 40 cm
Cell size: 60 cm x 60 cm
Cell size: 80 cm x 80 cm

Calo jets

Cell size: 2 mm x 2 mm
Cell size: 3 cm x 3 cm
Cell size: 30 cm x 30 cm
Cell size: 40 cm x 40 cm
Cell size: 60 cm x 60 cm
Cell size: 80 cm x 80 cm
Comparison with other detectors

With a cell size of 30 cm x 30 cm the agreement with other validated Delphes card is good for analysis with di-jet invariant masses.

\[ e^+e^- \rightarrow Z \rightarrow jets \quad \text{and} \quad e^+e^- \rightarrow ZH \rightarrow \tau\taujets \]

Z mass

H mass

Delphes Simulation
\[ e^+e^- \rightarrow Z \rightarrow (u, d, s) \]

Delphes Simulation
\[ e^+e^- \rightarrow ZH \rightarrow \tau\taujets \]
Conclusions

Standalone detectors of IDEA have been studied with dedicated Geant4 simulations. However, combined performances still have to be investigated with full simulations.

Delphes is flexible enough to provide a fast simulation of the IDEA detector. Preliminary results look compatible with different detectors.