A TRACKER LAYOUT MODELLING TOOL

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What is tkLayout?

Evaluation of tracking performance

Validation on a full simulation

Layout comparison

Layout optimization

Conclusions
TKLayout is a lightweight tool to evaluate tracker layouts. It places modules in 3D space and assigns material to the volumes. It uses a simple description of design parameters and makes an a priori estimate on tracking performance. Developed by Nicoletta De Maio, Stefano Mersi.
A lightweight tool

- Meant to compare different layouts
- To narrow down the parameter space
- Help the simulation to focus on:
  - fewer options
  - pre-optimized designs

Before simulation

- Fair comparison of layouts with \textit{a priori} estimate of performance
- Does not depend on (supposedly) optimized reco algos

Instead of simulation

- Does not replace simulation to estimate impact on trigger, physics channels, occupancy, efficiency, ...
3D placement

- Small set of parameters
- Barrel layers
3D placement

- Small set of parameters
  - Barrel layers
  - End-cap disks
3D placement

- Small set of parameters
  Barrel layers
  End-cap disks
- Material assign: active support services
Material

Material on active elements + Material for Services automatically routed
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Resolution estimate

- Error estimation, following
  Baseline: Karimäki [1]
  Multiple scattering introduced by G. Hall [2]
  With variable geometry [3]

- A priori error estimation
  No Monte Carlo
  No fit actually done

    NIM A305 (1991) 187

    (Tracker Week) http://bit.ly/eXvi8L

Error correlation matrix

- Use measurement errors to estimate the errors in track fit parameters
- Multiple scattering treated as (correlated) a measurement error

deviation from the ideal (straight) path
Error correlation matrix

- Use measurement errors to estimate the errors in track fit parameters

- **Multiple scattering** treated as (correlated) a measurement error

![Diagram of error correlation matrix]

Deviation due to scattering:

\[ y_n = \sum_{i=1}^{n-1} (x_n - x_i) \theta_i \]

Correlation matrix:

\[ \sigma_{n,m} = \langle y_n y_m \rangle = \sum_{i=1}^{n-1} (x_m - x_i) (x_n - x_i) \langle \theta_i^2 \rangle \]

\[ \sigma_n^2 = \frac{p^2}{12} \]
Measurement correlation

- Measurement error is:

  **Intrinsic resolution** of the module

  Deviation of the track from the ideal path due to **multiple scattering**

\[
\sigma_{nn} + \sigma_{mod}^2 \quad \begin{pmatrix}
\sigma_{nn} + \sigma_{mod}^2 & \sigma_{nm} \\
\sigma_{nm} & \sigma_{nm}
\end{pmatrix}
\]
Error estimation procedure

- For each $\eta$ value:
  - Find volumes met by straight lines
  - Compute average multiple scattering
- Error correlation matrix
- Expected error in track fitting

Two independent fits evaluated 5 parameters:
(a) $r,z$ plane: straight $\text{ctg}(\theta), dz_0$
(b) $r\phi$ plane: circle $d_0, \Phi, \rho_T$
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A benchmark layout

- Benchmark simulation to reproduce CMS tracker
- Pixel is modelled as another small tracker inside
Material - outer barrel

Distribution of material inside the tracking volume

CMS simulation

Our estimate

Differences are expected and understood
Material - everything

- Distribution of material inside the tracking volume

CMS simulation

Our estimate

Differences are expected and understood
**$p_T$ resolution**

= Error estimate vs. full simulation (muon)

![Graph showing $p_T$ resolution error estimate vs. full simulation for different momenta.](image-url)
Performance @ 100 GeV/c

Transverse momentum error

$\sigma(\delta p_T/p_T)$ [%]

$P_T$

- Full simulation
- Our estimate

Longitudinal impact parameter error

$\sigma(\delta z)$ [cm]

$Z_0$

Transverse impact parameter error

$\sigma(\delta y)$ [cm]

$d_0$

Track azimuthal angle error

$\sigma(\delta \varphi)$ [rad]

$\varphi$

Track polar angle error

$\sigma(\delta \text{ctg}(\theta))$

$\text{ctg}(\theta)$
Performance @ 10 GeV/c
Nuclear interactions

- Most particles are pions
- Interact with the nuclei

\[ p_n = \exp \left[ - \sum_{i=1}^{n-1} \frac{l_i}{\lambda_i} \right] \]

an indicator of how many “good” pion tracks we should expect
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"Simple" upgrade

MORE material

Higher granularity
“Simple” upgrade

New technologies
- DC-DC converters
- CO\textsubscript{2} cooling
- GBT
- CBC

Less layers

Higher granularity

LESS material

MORE material
“Simple” upgrade example

- $10 \times 10 \text{ cm}^2$
- 90 $\mu$m pitch
- Square end-cap

Expected reduction of material amount (even with conservative assumptions)
Further challenge

- LESS material
  - New technologies
    - DC-DC converters
    - CO$_2$ cooling
    - GBT
    - CBC
  - Less layers

- MORE material
  - Higher granularity
Further challenge

New technologies
- DC-DC converters
- CO₂ cooling
- GBT
- CBC

Less layers

Higher granularity

Trigger capabilities!
Triggering pT module

- Several options under study
- One concept sufficiently developed
  - Can work in the outer part
  - See later talk by D. Abbaneo

Sandwich of **strip sensors**
5 cm long strips
Measuring pT locally
**Trigger output**

Reasonably detailed
model of material
Other example - trigger in outer layers

- 10 x 10 cm$^2$
- 90 μm pitch
- Square end-cap

High particle density inside => “simple” modules
Lower density outside => trigger modules
3 example layouts

Some comparisons of these layouts

DISCLAIMER

These examples were selected to show the functionalities of tkLayout, but they are not the only, nor the most significant options under study.
Summary - weight

Reduction of material & layers

Weight [kg]

CMS
Simple
Trigger
Summary - surface

Reduction of layers

Silicon surface [m²]

<table>
<thead>
<tr>
<th>CMS</th>
<th>Simple also</th>
<th>Double-sided only</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>150</td>
<td>250</td>
</tr>
</tbody>
</table>
Summary - power dissipation

![Power Dissipation Chart]

- **CMS**: 20 kW
- **Simple**: 10 kW
- **Trigger**: 50 kW

Note: The chart shows the power dissipation for CMS, Simple, and Trigger systems.
Tracking regions

$\Delta \eta = 0.8$

Roughly same number of tracks expected
Material

Improvement in material & Fewer layers in the barrel

Radiation length [x/X0]

- CMS
- Simple
- Trigger

0 → 0.8
Material

Improvement in material & no inner end-cap

Radiation length [x/X0]

CMS

Simple

Trigger

\( \eta \)

0 \( \rightarrow \) 0.8

0.8 \( \rightarrow \) 1.6

Material CI

\( \eta \)

0 \( \rightarrow \) 0.8

0.8 \( \rightarrow \) 1.6

Material CI

\( \eta \)
Material

Improvement in material

Radiation length [x/X0]

CMS
Simple
Trigger

η

C: 0 → 0.8
I: 0.8 → 1.6
F: 1.6 → 2.4
Comparing p resolution

\[ \sigma(\delta p/p) \text{[\%]} \]

- 100 GeV
- 10 GeV

\[ \eta \]

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
- 1.2
- 1.4
- 1.6
- 1.8
- 2
- 2.2
- 2.4
Comparing p resolution

\[ \sigma (\delta p/p) [\%] \]

\[ 100 \text{ GeV} \]

\[ 10 \text{ GeV} \]

\[ \eta \rightarrow 0.8 \]
Comparing p resolution

\( \sigma(\delta p/p) \) [%]

\( \eta \)

0 \( \rightarrow \) 0.8

0.8 \( \rightarrow \) 1.6

100 GeV

10 GeV
Comparing $p$ resolution

$p$ resolution

$\sigma(\delta p/p)$ [%]

$\eta$

- $0 \rightarrow 0.8$
- $0.8 \rightarrow 1.6$
- $1.6 \rightarrow 2.4$

100 GeV

10 GeV
Comparing $p$ resolution

Resolution @ 100 GeV [%]

Resolution @ 10 GeV [%]

Due to better resolution

Due to less material

A CMS Tracker
B Simple upgrade
C Trigger

$\eta$ 0 → 0.8
Comparing p resolution

<table>
<thead>
<tr>
<th>Resolution @ 10 GeV [%]</th>
<th>Resolution @ 10 GeV [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>2.2</td>
</tr>
<tr>
<td>2.2</td>
<td>2.0</td>
</tr>
<tr>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>1.2</td>
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<td>1.0</td>
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<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Legend:
- **A**: CMS Tracker
- **B**: Simple upgrade
- **C**: Trigger

Extrapolation:
- $\eta$: $0 \rightarrow 0.8$
- $\eta$: $0.8 \rightarrow 1.6$
Comparing $p$ resolution

Resolution @ 100 GeV [%] vs. Resolution @ 10 GeV [%]

- **A**: CMS Tracker
- **B**: Simple upgrade
- **C**: Trigger

$\eta$

- $0 \rightarrow 0.8$
- $0.8 \rightarrow 1.6$
- $1.6 \rightarrow 2.4$
Comparing nucleon interactions

% spoiled pions

% unspoiled pions
Comparing nucl. interactions

% spoiled pions

% unspoiled pions

\eta \rightarrow 0.8
Comparing nucl. interactions

% spoiled pions

% unspoiled pions

η

C
0 → 0.8

I
0.8 → 1.6
Comparing nucl. interactions

% spoiled pions

% unspoiled pions

η

C
0 → 0.8

I
0.8 → 1.6

F
1.6 → 2.4
Nuclear interactions

Pions are very sensitive to improvement in material

Resolution @ 100 GeV [%]

Fraction of spoiled pion tracks

A CMS Tracker
B Simple upgrade
C Trigger

η
0 → 0.8
Nuclear interactions

Fraction of spoiled pion tracks

Resolution @ 100 GeV [%]

Pions are very sensitive to improvement in material

A CMS Tracker
B Simple upgrade
C Trigger
Nuclear interactions

Fraction of spoiled pion tracks

Resolution @ 100 GeV [%]

A CMS Tracker
B Simple upgrade
C Trigger

η
0 → 0.8
0.8 → 1.6
1.6 → 2.4
Photon conversion

Resolution @ 100 GeV [%]

Fraction of spoiled photons

Photons are even more sensitive

A CMS Tracker
B Simple upgrade
C Trigger

\[ \eta \]

0 → 0.8
0.8 → 1.6
1.6 → 2.4
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Layout optimization

Conclusions
Trade-off in number of layers

- More layers
  More measurement points
  Better 100 GeV p resolution

- Less layers
  Less multiple scattering
  Better 10 GeV p resolution
Trade-off in number of layers

- More layers
  More measurement points
  Better 100 GeV p resolution

- Less layers
  Less multiple scattering
  Better 10 GeV p resolution

Let's measure $\Delta(p_{10})$ and $\Delta(p_{100})$ in the central region on a series of barrels
4 barrel layers $\rightarrow$ 16 barrel layers
Trade-off in number of layers

Resolution trade-off
Central region

Resolution @ 100 GeV [%]

Resolution @ 10 GeV [%]

Upgrade variants

CMS Tracker

Simple upgrade

CMS Tracker

Simple upgrade
Resolution trade-off
Central region

Resolution @ 10 GeV [%]

Resolution @ 100 GeV [%]

Tuning possible

Reduction of material

Upgrade variants

CMS Tracker

Simple upgrade

CMS

Upgrade variants

Resolution trade-off in number of layers
Trade-off in number of layers

Resolution trade-off
Central region

Resolution @ 100 GeV [%]

Resolution @ 10 GeV [%]

Upgrade variants

CMS Tracker
Simple upgrade

4 to 16 layers
same model

÷ 1.4
× 1.3
Trade-off in number of layers

Resolution trade-off
Central region

Removing random 10% dead modules

Generally
Quite stable

Hits harder on layouts < 6 layers

Resolution @ 10 GeV [%]

Resolution @ 100 GeV [%]

CMS Tracker
Simple upgrade
Strip pitch optimization

Prejudice: (Originated from current tracker)
The resolution would improve if we reduce the number of channels (material dominates)

Is this true?

Simple test
90 μm pitch
120 μm pitch
Strip pitch optimization

Resolution @ 100 GeV [%]

Resolution @ 10 GeV [%]

Negligible improvement @10
Clearly worse @100

CMS Tracker
Simple upgrade
90/120 Trigger

η

0 → 0.8
0.8 → 1.6
What is tkLayout?

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Layout optimization

Conclusions
is totally generic

needs well understood model of materials to give a solid output

fair comparison between models

quantification of performance

drive the selection of a small number of optimized options for study with full simulation

fast running simple and usable tool
tkLayout

and...

...it's free

http://code.google.com/p/tkgeometry
THANK YOU