CMS reconstruction improvements for tracking in large pile-up events

Marco Rovere, CERN
On behalf of the CMS Collaboration
CMS Tracker

Overview of Tracking and Vertexing in Run I
Pixel: 66M channels, 100x150 μm²
SiStrip: 9.6M channels, 80-100 μm pitch, 10-20 cm

- Double-sided: 100 mrad to provide 3D information
Lower occupancy in Pixel
- In-out tracking from pixel layers
CMS Track and Vertex Reconstruction

• Tracking based on Kalman Filter
  • Seeding, pattern recognition, fitting, selection
• Iterative procedure
  • Remove hits, reduce combinatorial
• Track Cluster with Deterministic Annealing
  • Adaptive vertex fit
  • Vertices sorted by $\Sigma p_T^2$

<table>
<thead>
<tr>
<th>Name</th>
<th>Seeding</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>Pixel triplets</td>
<td>Prompt, high $p_T$</td>
</tr>
<tr>
<td>LowPtTriplet</td>
<td>Pixel triplets</td>
<td>Prompt, low $p_T$</td>
</tr>
<tr>
<td>PixelPair</td>
<td>Pixel pairs</td>
<td>High $p_T$, recovery</td>
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<tr>
<td>DetachedTriplet</td>
<td>Pixel triplets</td>
<td>Displaced--</td>
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<tr>
<td>MixedTriplet</td>
<td>Pixel+strip triplets</td>
<td>Displaced-</td>
</tr>
<tr>
<td>PixelLess</td>
<td>Inner strip pair</td>
<td>Displace+</td>
</tr>
<tr>
<td>TobTec</td>
<td>Outer strip pair</td>
<td>Displaced++</td>
</tr>
</tbody>
</table>
Tracking Developments
It’s all about the pile-up

- Tracking becomes a challenge due to increase occupancy
  - At 25ns bunch-spacing, out of time pile-up causes +45% in SiStrip occupancy (+5% in pixels)
- Pixel are affected by dynamic inefficiency due to saturation of the readout chip
- **Run2:** ~1 fb⁻¹ 50ns<PU25>, ~9 fb⁻¹ 25ns<PU25>, ~9 fb⁻¹ 25ns<PU40>
Run II tracking developments

- New algorithm for strip-seeded steps
  - $\chi^2$ cut from straight line fit of 3 points in the RZ plane.
  - rejects half of the seeds reconstructing the same number of tracks.
- 25ns bx induces an increase in occupancy for the strip detector: 2x on timing and fake rate
- Clusters from out of time pile-up have low collected charge
  - cutting on the cluster charge suppresses the effect
  - can be applied @upfront, @seeding or @pattern-recognition
  - accounts for sensor thickness and trajectory crossing angle

![Graphs showing tracking developments](image-url)
Run II tracking developments

Effects on timing

• The new seeding and the cluster charge cut reduce timing of PixelLess and TobTec by 2x

• Physics performances and timing in different conditions:
  • TTbar samples with
  • BX=25 ns, <PU>=25, 40, 70, 140
  • BX=50 ns, <PU>=25

• Iterative tracking time reduction @25 ns:
  • 2x at PU=25, 3x at PU=40, 4x at PU=70
Tracking Physics oriented developments

Muons

• A loss of muon reconstruction efficiency in the tracker was observed in 2012 data, increasing with pile-up.
• Two additional iterations have been designed:
  • **Outside-in**: seeded from the muon system, recover the missing muon-track in the tracker
  • **Inside-Out**: re-reconstruct muon-tagged tracks with looser requirements to improve the hit-collection efficiency
• Full efficiency recovered with the new iterations
Tracking Physics oriented developments

High-p$_T$ Jets

- Tracking in high p$_T$ jets is crucial for b- and τ-tagging efficiency
- Dense environment:
  - small two-track separation
  - merged clusters: only one hit with bad estimated position and uncertainty
- A new dedicated iteration has been developed
  - regional, along high p$_T$ calo jets
  - threshold trade-off between timing and physics
  - cluster splitting
  - looser tracking cuts to follow combinatorial expansion
- improved efficiency at small ΔR
Physics Performances

Run I and Run II in different PU conditions
Run II Tracking Performances
Run I and Run II with nominal conditions

- The most relevant comparison is with nominal PU conditions
  - Run 1 tracking with $<\text{PU}> = 25$, BX = 50ns
  - Run 2 tracking with $<\text{PU}> = 40$, BX = 25ns
- With much worse conditions, in Run 2 we have the same efficiency for prompt tracks, slightly higher fake rate, slightly lower efficiency for displaced tracks
- Run 2 CMS physics performance ~ the same despite large PU increase, at least for objects based on tracks
Conclusions
Conclusions

• High pile-up is a challenge for tracking

• Many developments have been included in CMS’ tracking code for Run2
  • Timing is now under control
  • Should expect the same or better physics performances as in Run1
  • Work is not over and many other developments are on their way

• Should profit of the experience gained in this process and transfer it into upgrade’s projects.
Backup Slides
SiStrip Cluster Charge Distribution

CMS Data, 2012, $\sqrt{s}=8$ TeV, Preliminary

25 ns
inner barrel layer1

- green: on-track
- blue: off-track

cluster charge [ADC]
Run II Tracking Performances
Run I-like conditions

- TTbar events with $\langle PU\rangle=25$, BX=25,50ns
- Same or higher efficiency for prompt tracks
- 2x reduction in fake rate
- Up to 6x reduction in fake rate in RunII like conditions
Primary Vertex Performances

- The reconstructed vertices vs PU shows a linear trend with slope $\sim 0.7$ up to PU70.
  - Excess of reconstructed vertices for PU140
  - The number of matched vertices has linear trend over all range
    - vertex matches a simulated if $|\Delta z|<1$ mm and $|\Delta z|<3\sigma_z$
  - These results are the effect of a faster than linear increase in fake rate and a linear decrease in efficiency
Primary Vertex Performances

- CMS Simulation, $\sqrt{s} = 13$ TeV, $\bar{t} + PU$, BX=25ns
- Efficiency vs Pileup Interactions
- Merge Rate vs Closest Distance in [cm]
- Fraction of Events vs Signal PV Status in Reco Collection
Fraction of ghost hits vs PU

CMS Preliminary Simulation
$\sqrt{s} = 8\text{ TeV, } t\bar{t}$

- no PU
- $<PU>=20$
- $<PU>=40$
- $<PU>=60$
Unmasked Hits per iterations

CMS Preliminary Simulation
\( \sqrt{s} = 8 \text{ TeV}, t\bar{t} + \langle PU \rangle = 20 \)

- PXB1
- TIB1
- TOB1