CMS reconstruction improvements for tracking in large pile-up events

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On behalf of the CMS Collaboration

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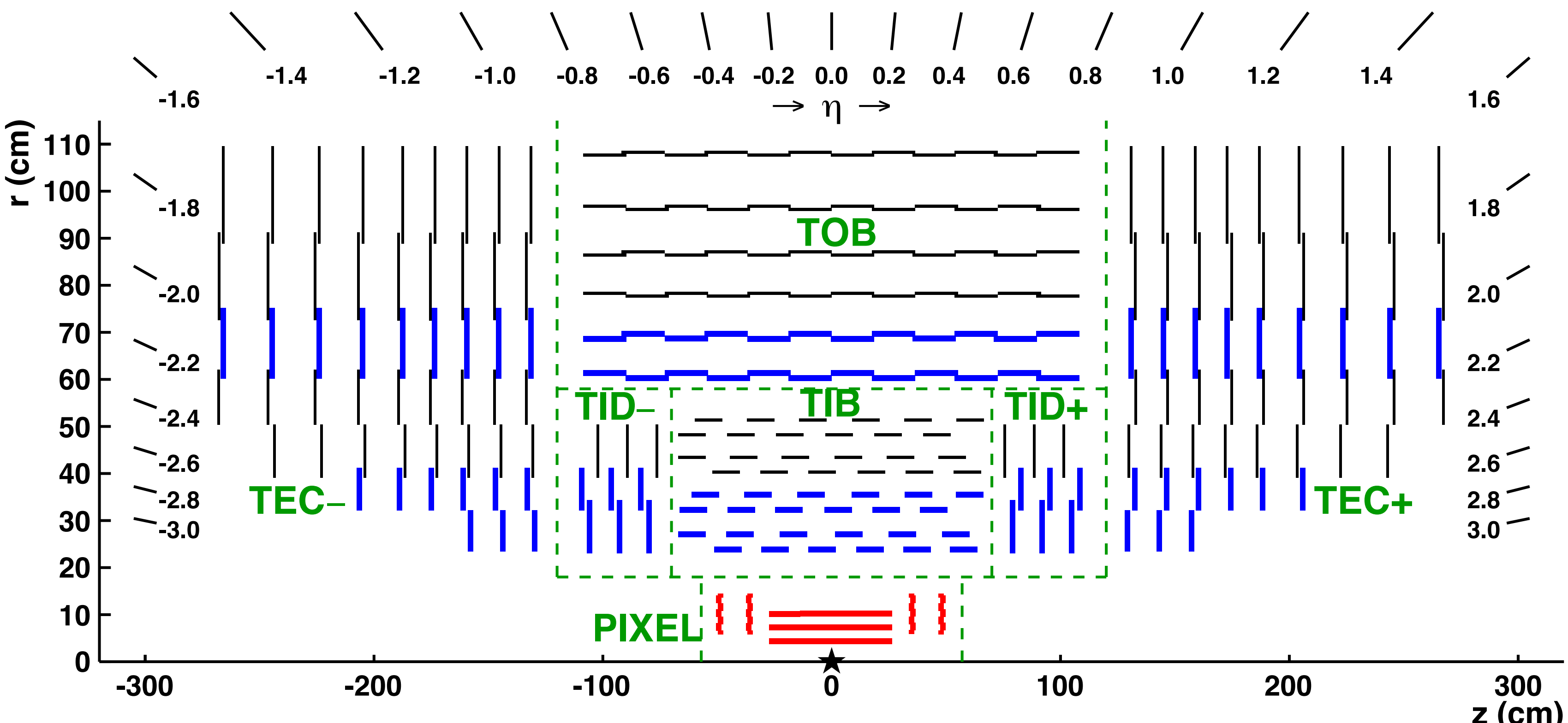
CMS Tracker

Overview of Tracking and Vertexing in Run I

The CMS Tracker



Pixel: 66M channels, 100x150 μm^2

SiStrip: 9.6M channels, 80-100 μm pitch, 10-20 cm

- Double-sided: 100 mrad to provide 3D information

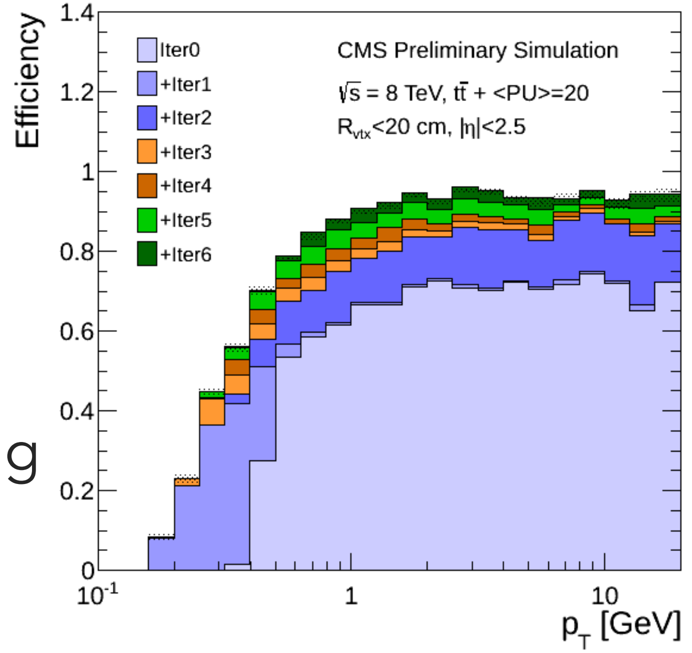
Lower occupancy in Pixel

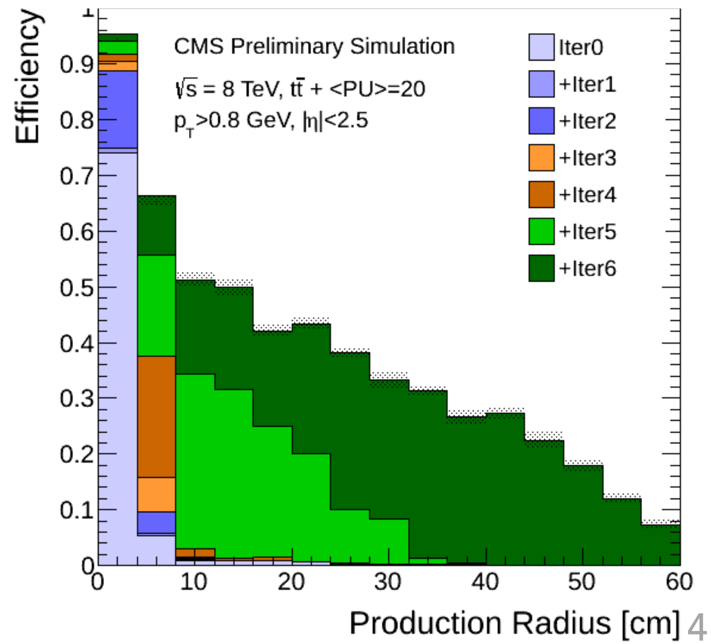
- In-out tracking from pixel layers

CMS Track and Vertex Reconstruction

- Tracking based on Kalman Filter
  - Seeding, pattern recognition, fitting, selection
- Iterative procedure
  - Remove hits, reduce combinatory
- Track Cluster with Deterministic Annealing
  - Adaptive vertex fit
  - Vertices sorted by Σp_T^2

Name	Seeding	Target
Initial	Pixel triplets	Prompt, high p_T
LowPtTriplet	Pixel triplets	Prompt, low p_T
PixelPair	Pixel pairs	High p_T, recovery
DetachedTriplet	Pixel triplets	Displaced--
MixedTriplet	Pixel+strip triplets	Displaced-
PixelLess	Inner strip pair	Displace+
TobTec	Outer strip pair	Displaced++

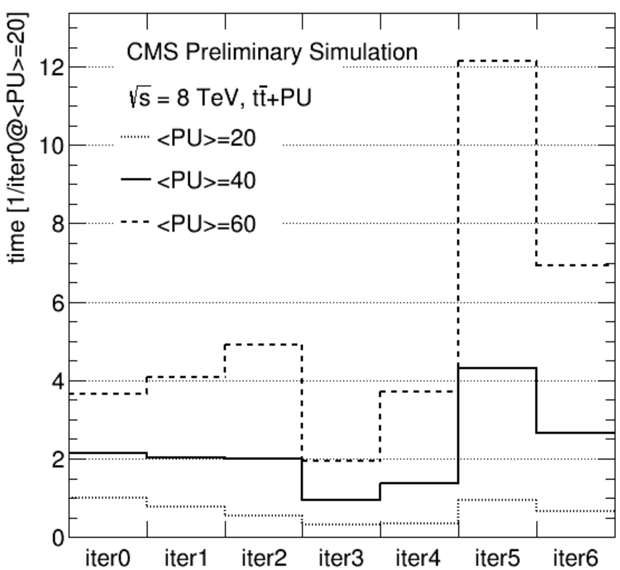


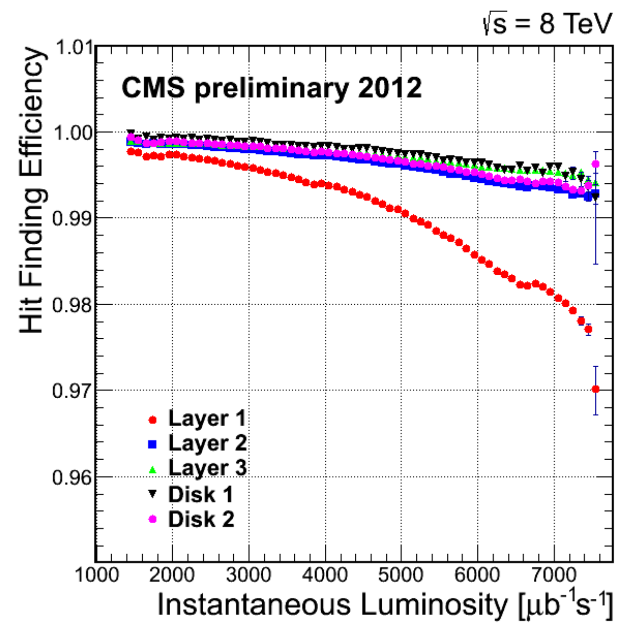


Tracking Developments

It's all about the pile-up

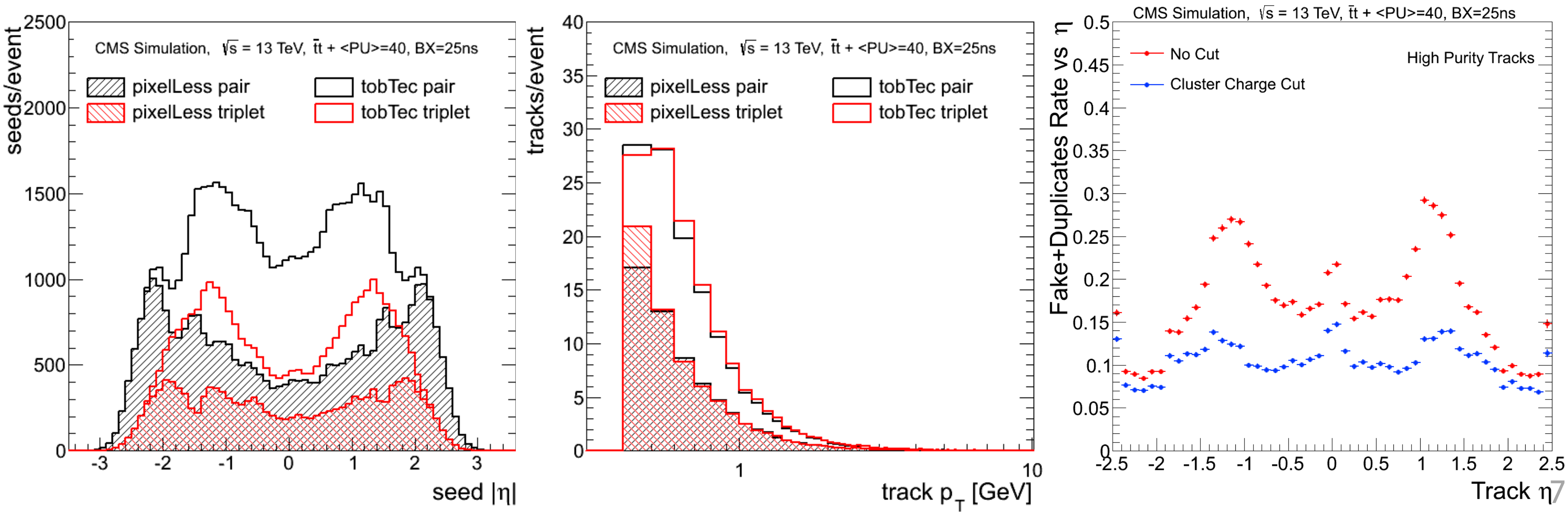
- Tracking becomes a challenge due to increase occupancy
  - At 25ns bunch-spacing, out of time pile-up causes +45% in SiStrip occupancy(+5% in pixels)
- Pixel are affected by dynamic inefficiency due to saturation of the readout chip
- Run2: ~1 fb^{-1} 50ns<PU25>, ~9 fb^{-1} 25ns<PU25>
  ~9 fb^{-1}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





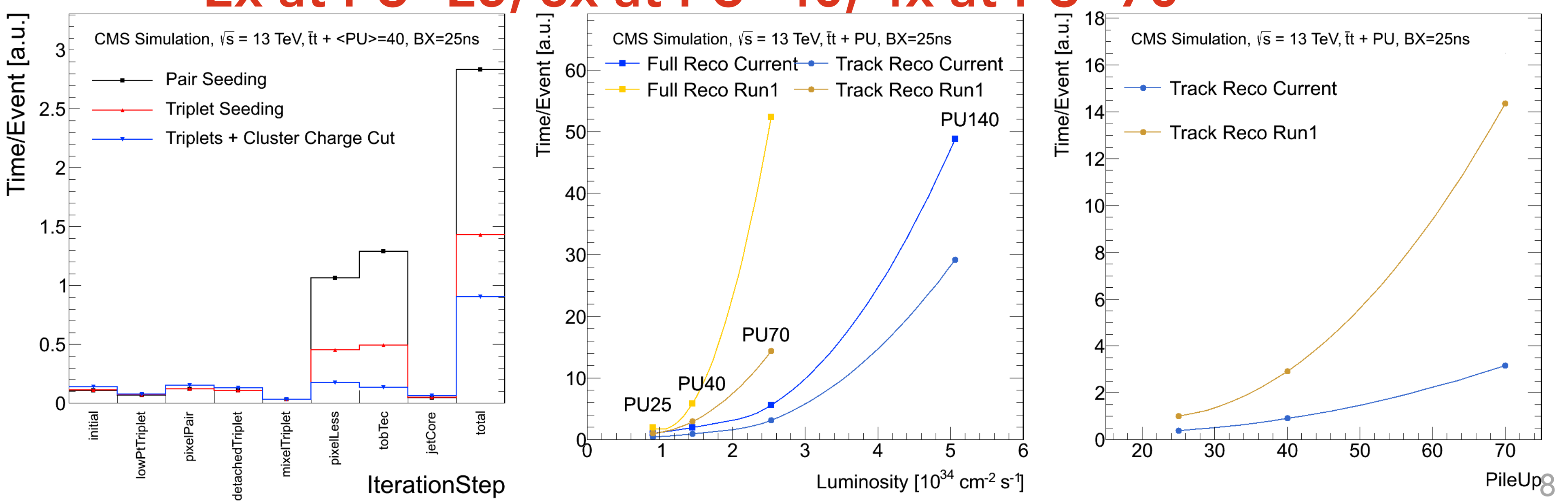
Run II tracking developments

- New algorithm for strip-seeded steps
  - χ^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



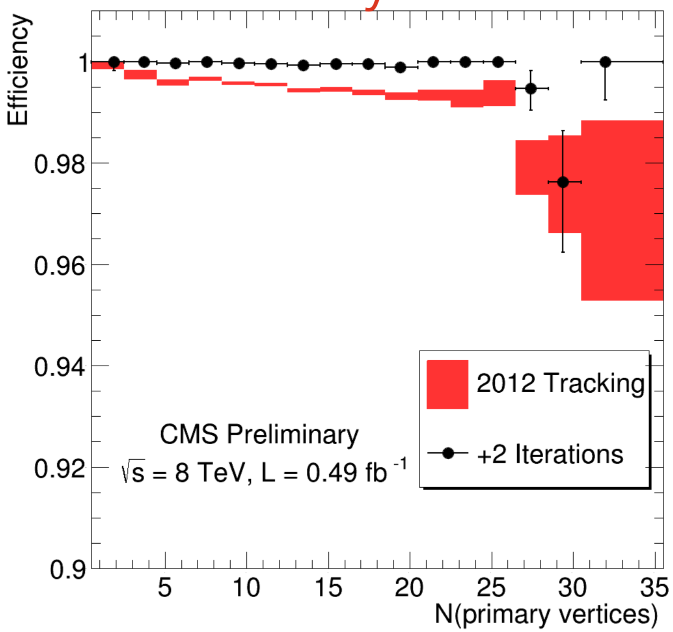
Run II tracking developments
Effects on timing

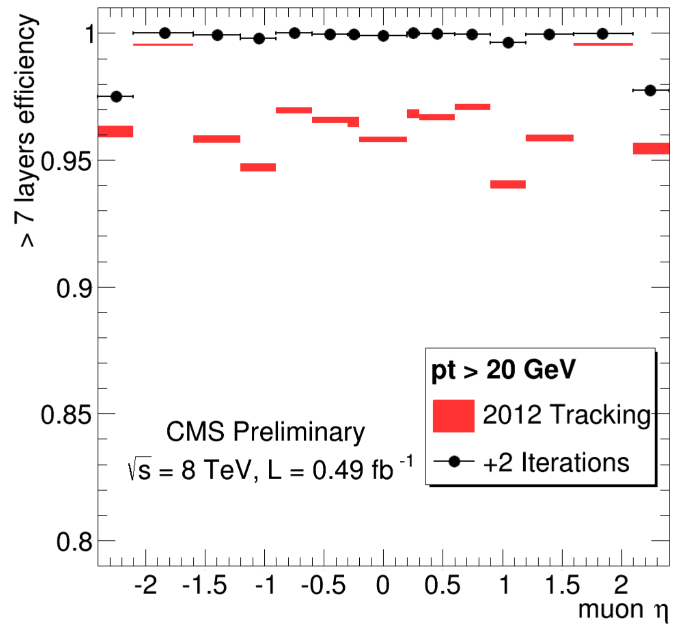
- The new seeding and the cluster charge cut reduce timing of PixelLess and TobTec by 2x
- Physics performances and timing in different conditions:
  - TTbar samples with
  - BX=25 ns, <PU>=25, 40, 70, 140
  - BX=50 ns, <PU>=25
- Iterative tracking time reduction @25 ns:
  - **2x at PU=25, 3x at PU=40, 4x at PU=70**



Tracking Physics oriented developments Muons

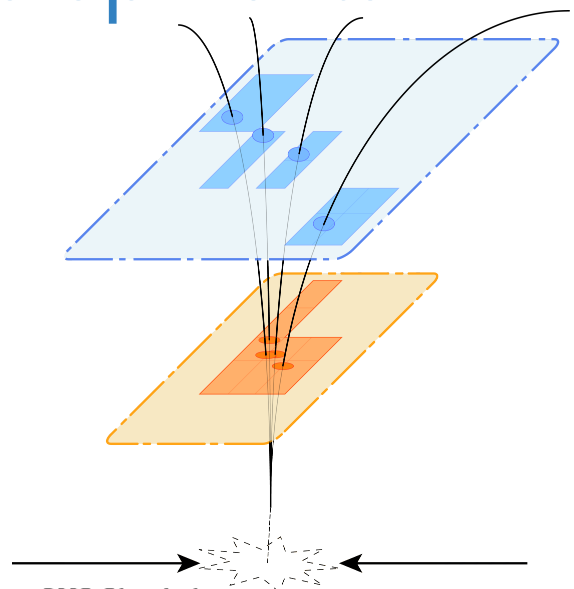
- A loss of muon reconstruction efficiency in the tracker was observed in 2012 data, increasing with pile-up.
- Two additional iterations have been designed:
  - Outside-in: seeded from the muon system, recover the missing muon-track in the tracker
  - Inside-Out: re-reconstruct muon-tagged tracks with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

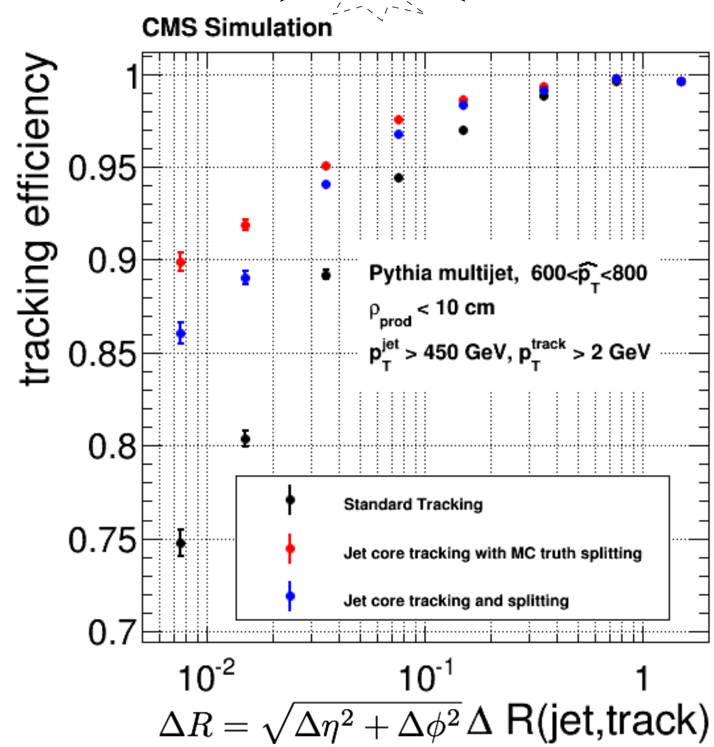




Tracking Physics oriented developments
High-p_T Jets

- 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-of between timing and physics
  - cluster splitting
  - looser tracking cuts to follow combinatorial expansion
- improved efficiency at small ΔR



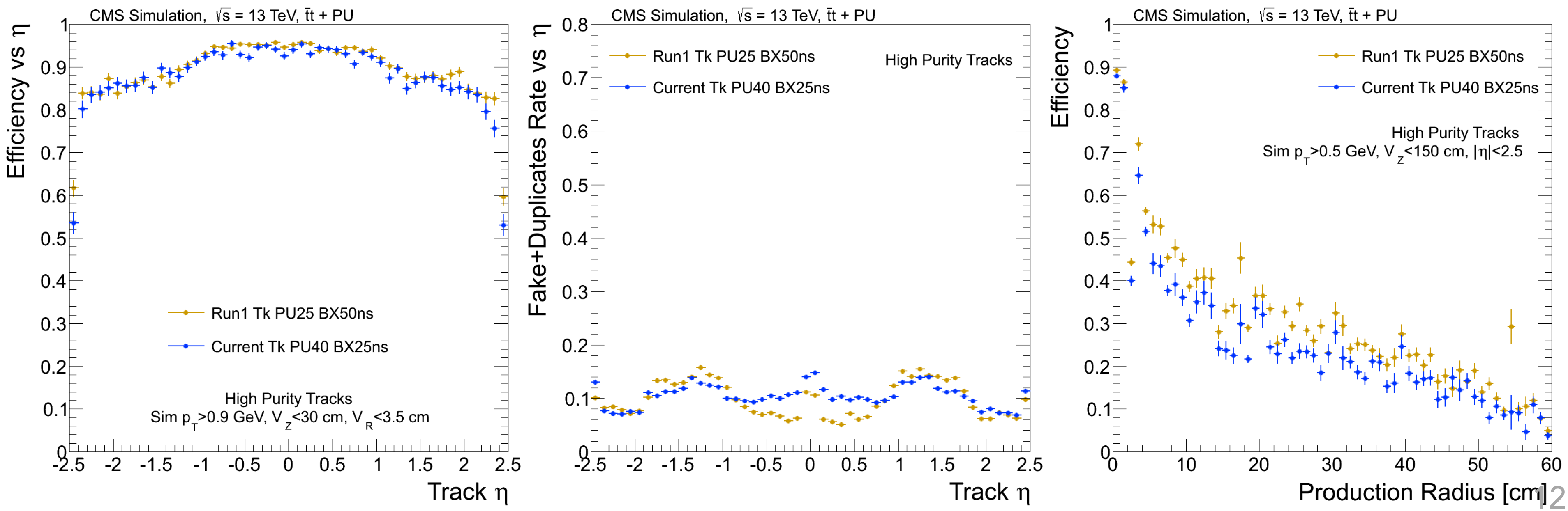


Physics Performances

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
  - Run1 tracking with <PU>=25, BX=50ns
  - Run2 tracking with <PU>=40, BX=25ns
- With much worse conditions, in Run2 we have same efficiency for prompt tracks, slightly higher fake rate, slightly lower efficiency for displaced tracks
- **Run2 CMS physics performance ~ the same despite large PU increase, at least for objects based on tracks**



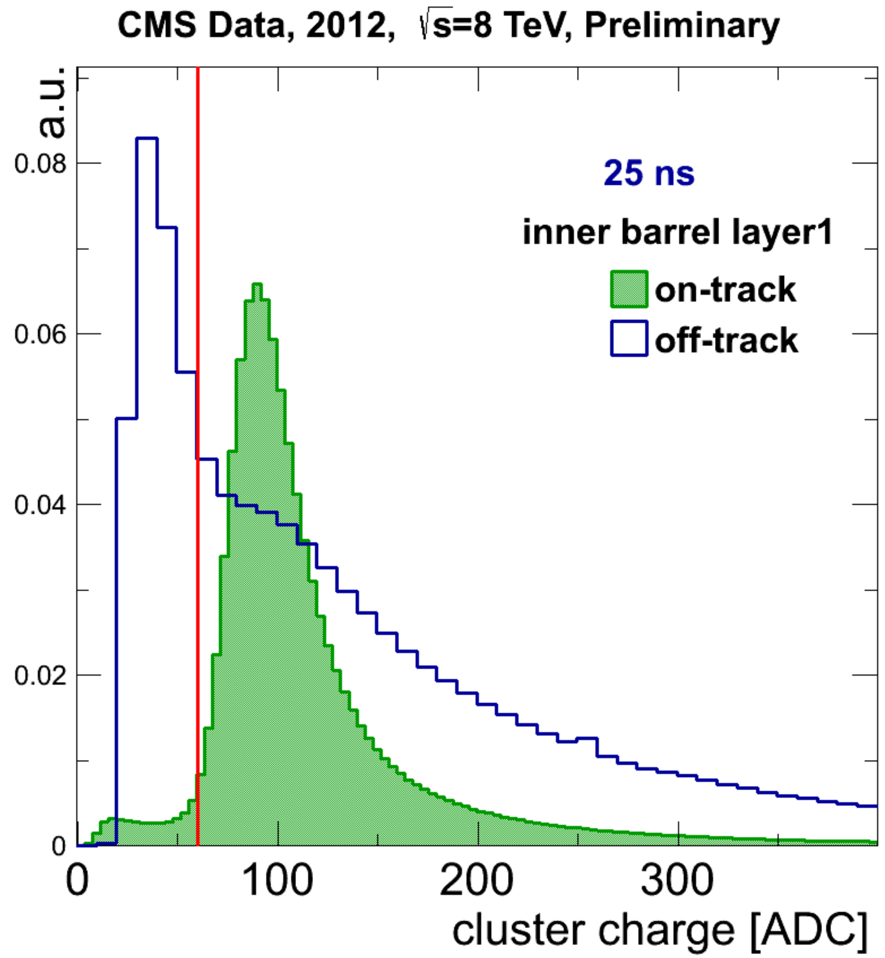
Conclusions

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 RunI
  - 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.

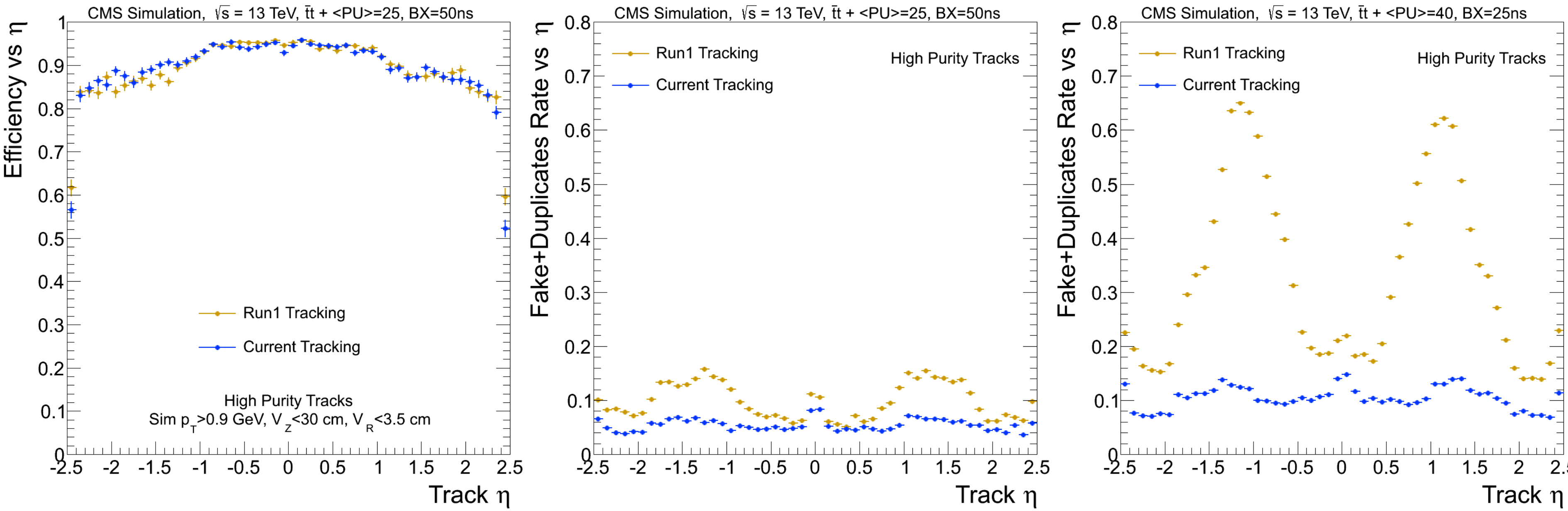
Backup Slides

SiStrip Cluster Charge Distribution



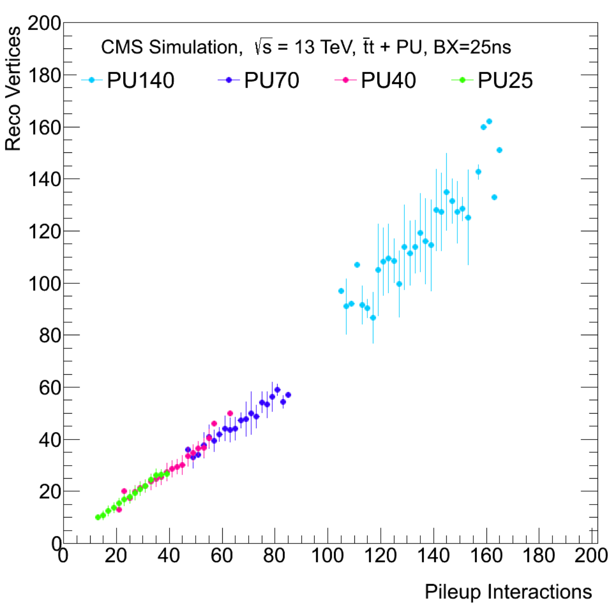
Run II Tracking Performances
Run I-like conditions

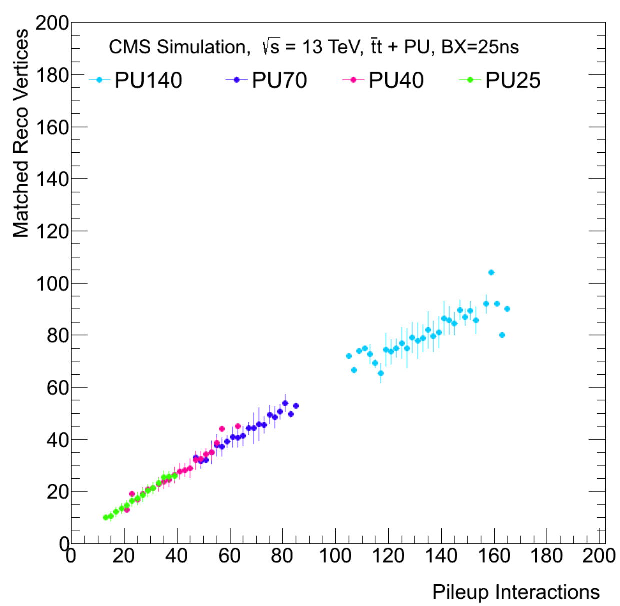
- TTbar events with <PU>=25, BX=25,50ns
- Same or higher efficiency for prompt tracks
- 2x reduction in fake rate
- Up to **6x** reduction in fake rate in **RunII like conditions**

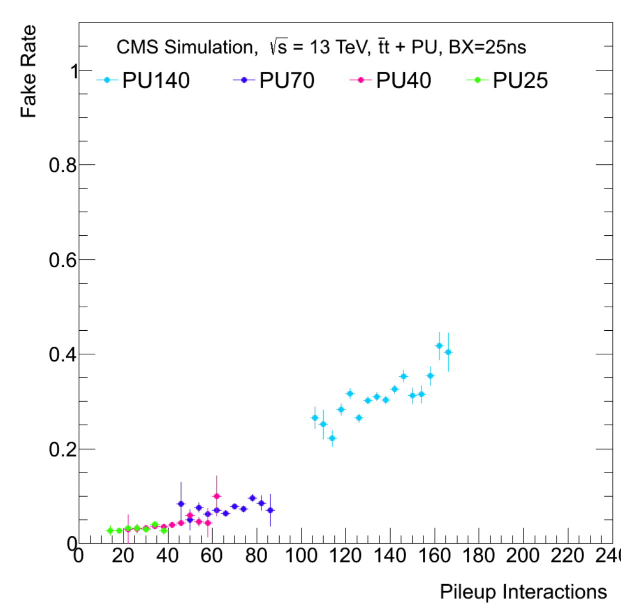


Primary Vertex Performances

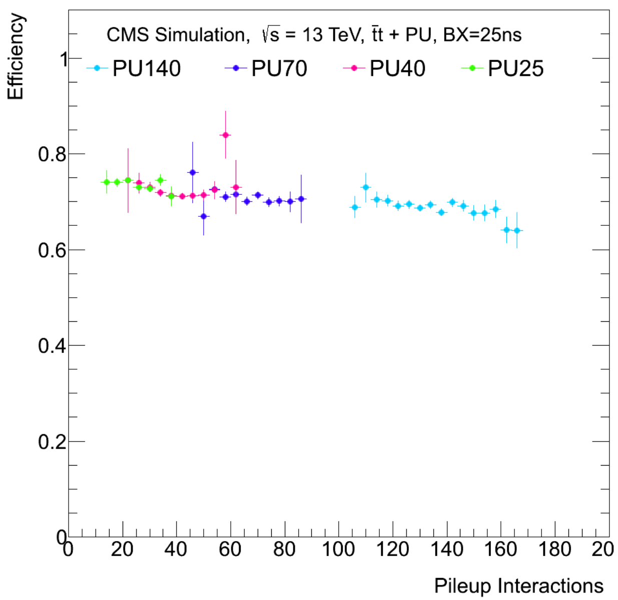
- The reconstructed vertices vs PU shows a linear trend with slope ~0.7 up to PU70.
  - Excess of reconstructed vertices for PU140
- The number of matched vertices has linear trend over all range
  - vertex matches a simulated if $|\Delta z|<1$ mm and $|\Delta z|<3\sigma_Z$
- These results are the effect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

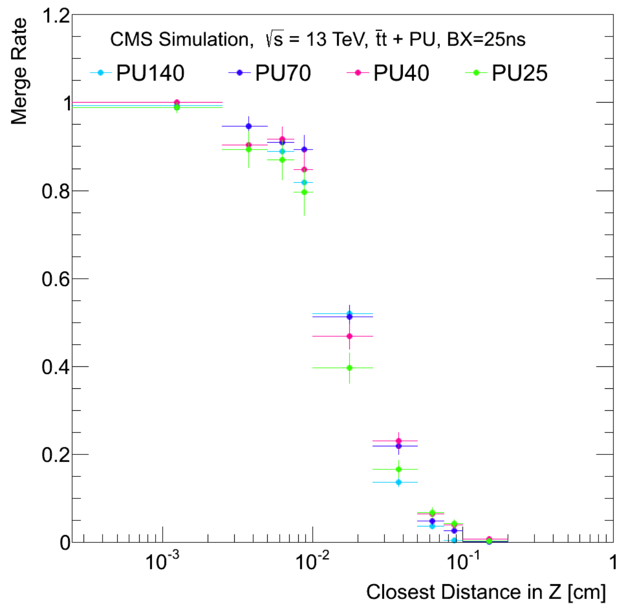


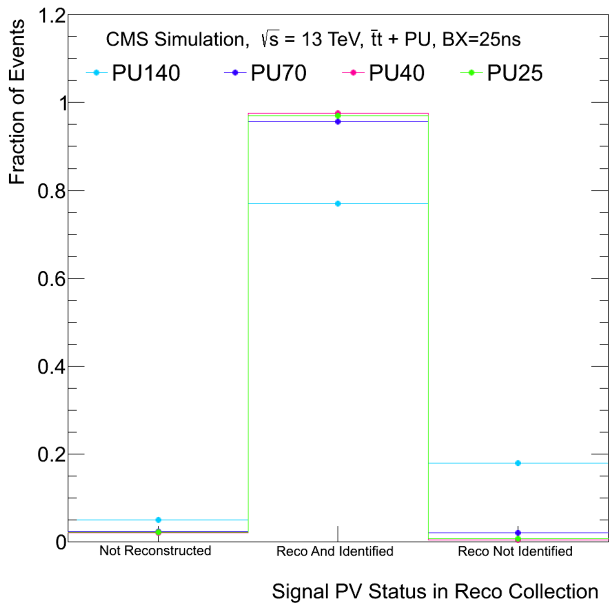




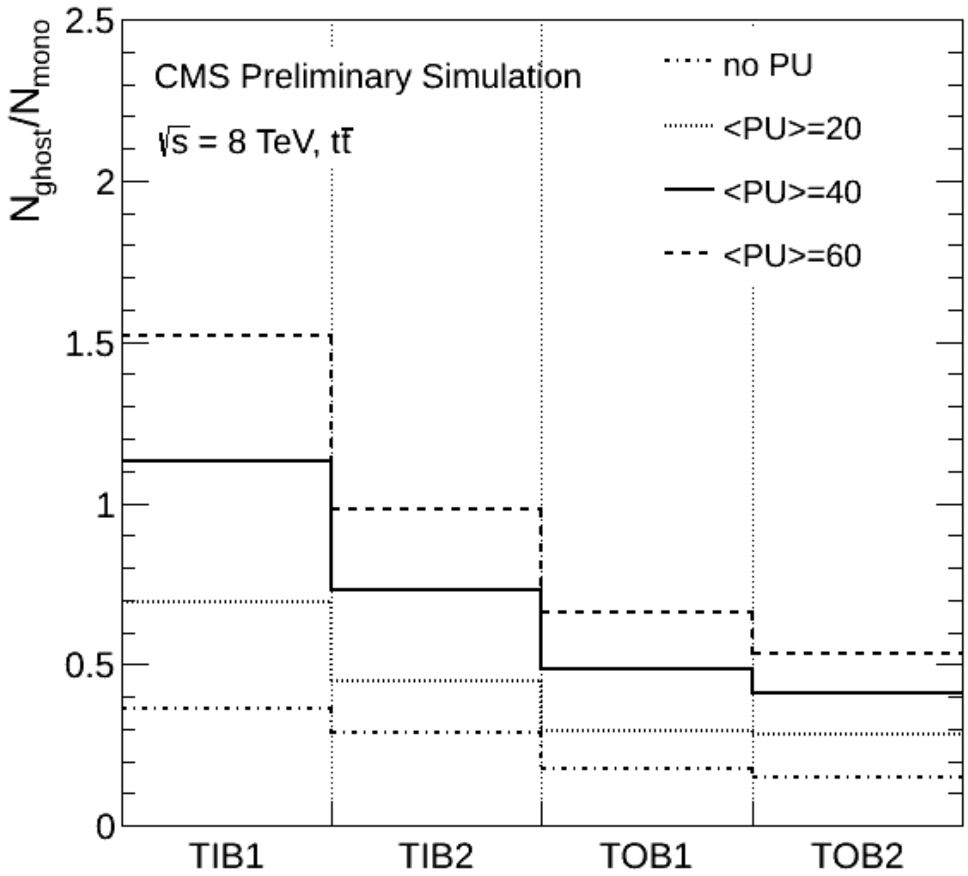
Primary Vertex Performances







Fraction of ghost hits vs PU



Unmasked Hits per iterations