Upgrading the CMS simulation and reconstruction

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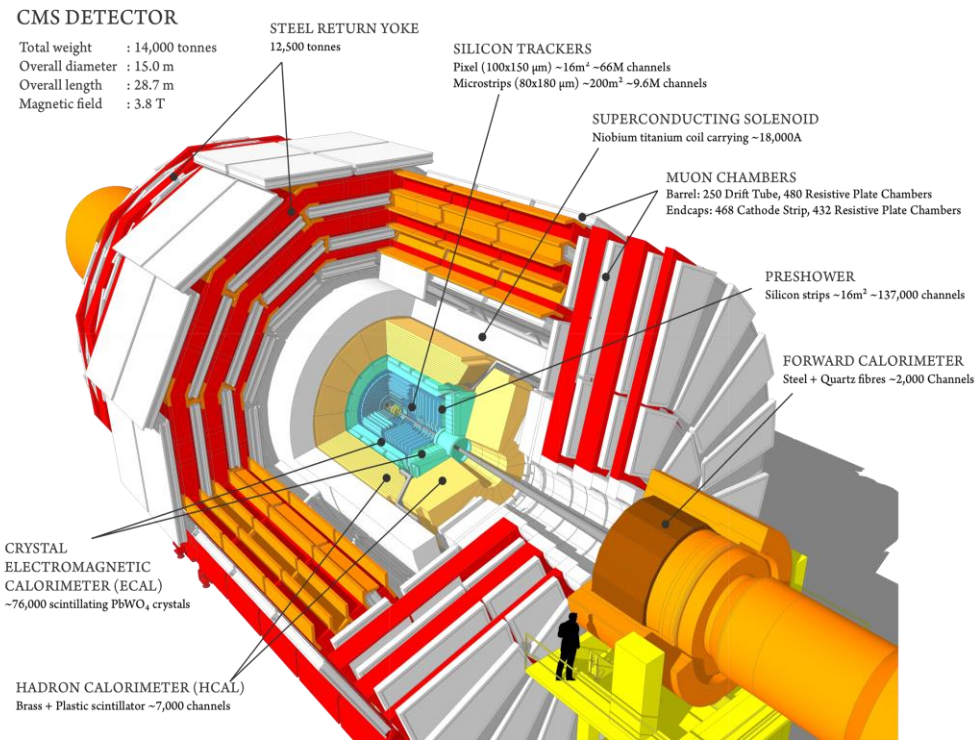
CMS simulation faces significant challenges for both today and tomorrow

The CMS Physics goal is to keep same performances as in Run 1 despite the increasing more harsh conditions.

We are ready for new challenges in 2015

- The higher LHC beam energy means more complex hard-scatter events
- The higher LHC luminosity means larger number of interactions per bunch crossing (higher pileup) and thus more time consuming to simulate and reconstruct
- Higher output rate of trigger (~1kHz) means demand for larger samples of simulated events

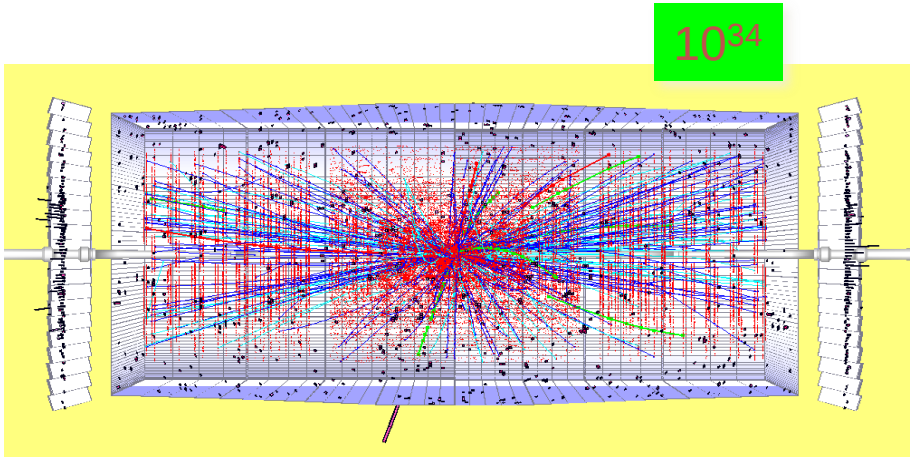


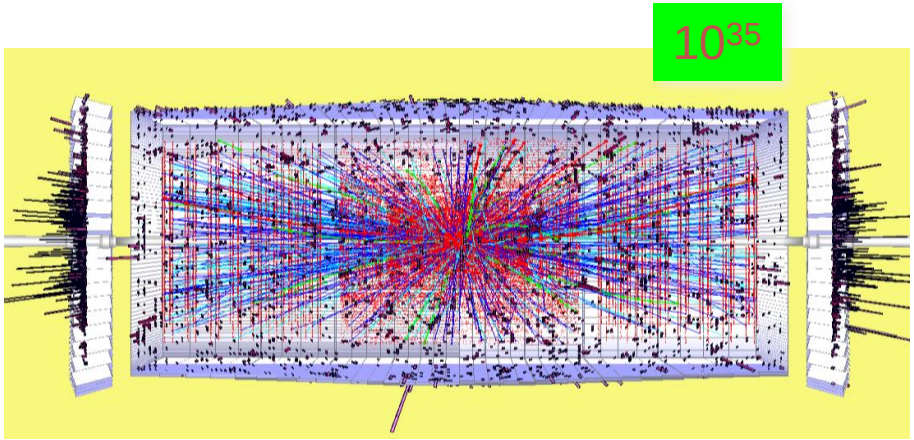
We have achieved significant progress on the resource needs of our simulation during LHC shutdown

CMS simulation faces significant challenges for both today and tomorrow

Preparing for CMS at the start of Phase 2 (HL-LHC):

- The CMS detector configuration is still to be determined
- Even higher output rate of trigger (potentially 10kHz)
- Even higher luminosity and pileup (140+ interactions/crossing)





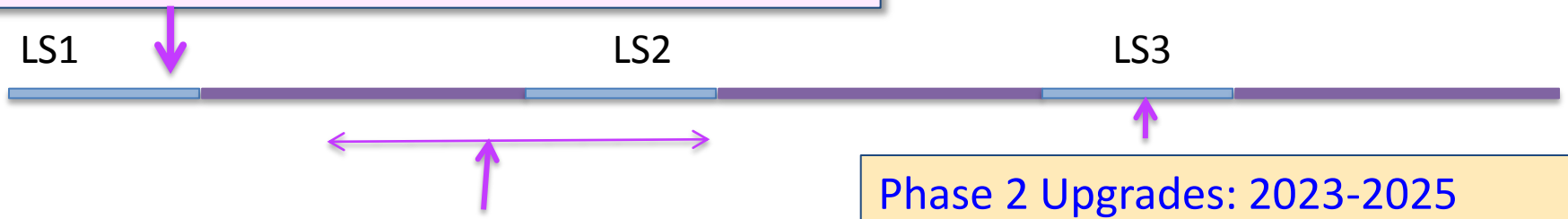
HL-LHC presents increased challenges for Triggering, Tracking and Calorimetry, in particular for low to medium P_T objects

CMS Upgrade Strategy - Overview

Upgrades 2013/14 now complete:

- Completes muon coverage (ME4)
- Improve muon trigger (ME1), DT electronics
- Replace HCAL photo-detectors in forward and outer (HPD → SiPM)

Complete original detector
Address operational issues
Start upgrade for high PU



Phase 1 Upgrades 2017/18/19:

- New Pixels, HCAL SiPMs and electronics, L1-Trigger
- Preparatory work during LS1:
  - new beam pipe
  - test slices of new systems (Pixel cooling, HCAL, L1-trigger)

Maintain/Improve performance at high PU

Phase 2 Upgrades: 2023-2025 (Technical Proposal in preparation)

- Further Trigger/DAQ upgrade
- Barrel ECAL Electronics upgrade
- Tracker replacement/ Track Trigger
- End-Cap Calorimeter replacement

Maintain/Improve performance at extreme PU. Sustain rates and radiation doses

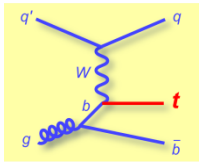
Challenge of simulating 2023 using 2015 software and computing

Estimated resources required per event relative to Run 2

Detector	Pileup	Simulation time ratio	Digitization time ratio	Reconstruction time ratio	AOD size ratio
Phase-I	50	1	4	4	1.4
Phase-II	140	1	9	20	3.7
Phase-II	200	1	13	45	5.4

- Running Phase-II simulations bring big challenges to our simulation and reconstruction applications
- In addition, the trigger output rate will be **5-10x** higher
  - In parallel to supporting detector upgrade program, we have an R+D program towards reducing the computing resources needed in the long term

Simulation approach: Hardscatter and pileup events simulated separately in Geant4 and "mixed" together

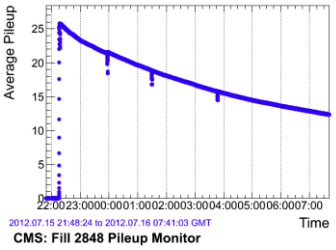


Physics Generators

Particle 4-vectors

Geometry/ Material Description

Geant 4



Simulated Hits from Pileup Interactions

Simulated Hits

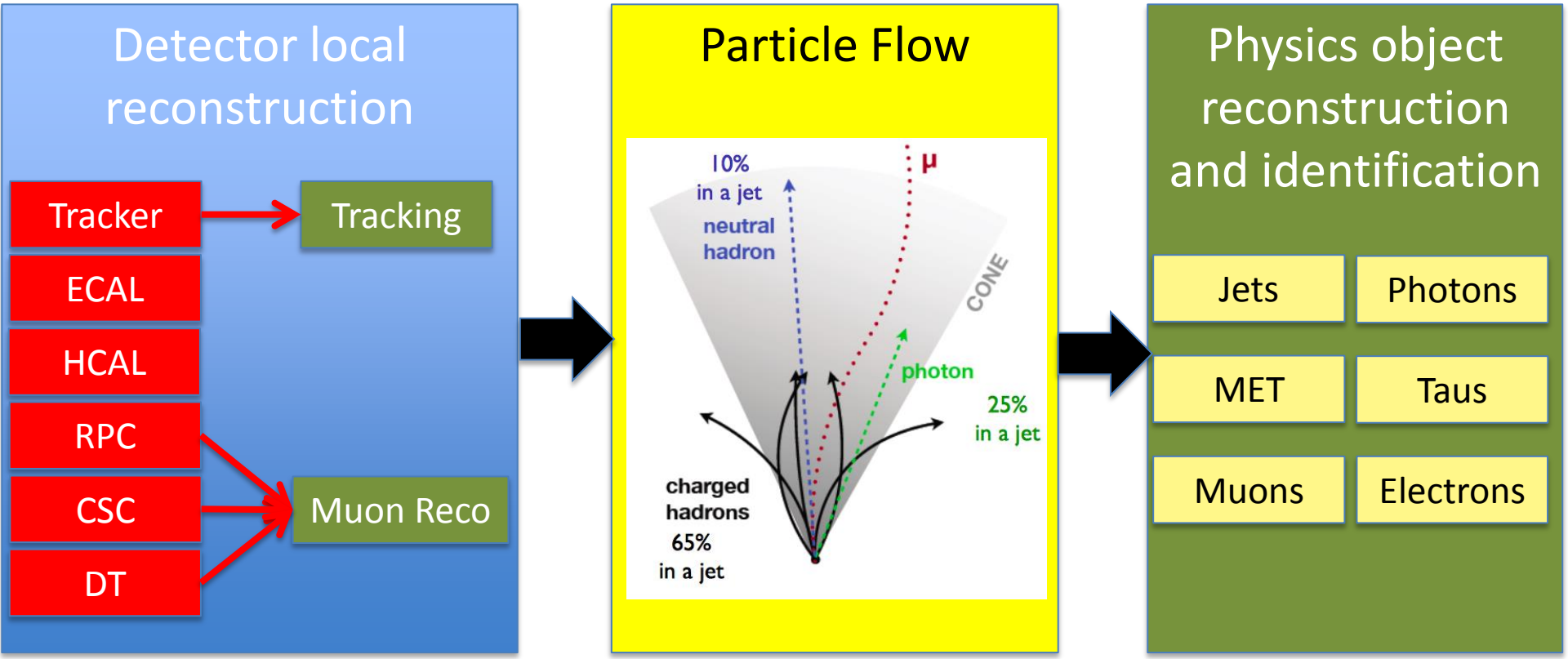
Noise Model

Electronics Simulation

Simulated Raw Data

= "Digitization"

Reconstruction approach: Particle flow driven

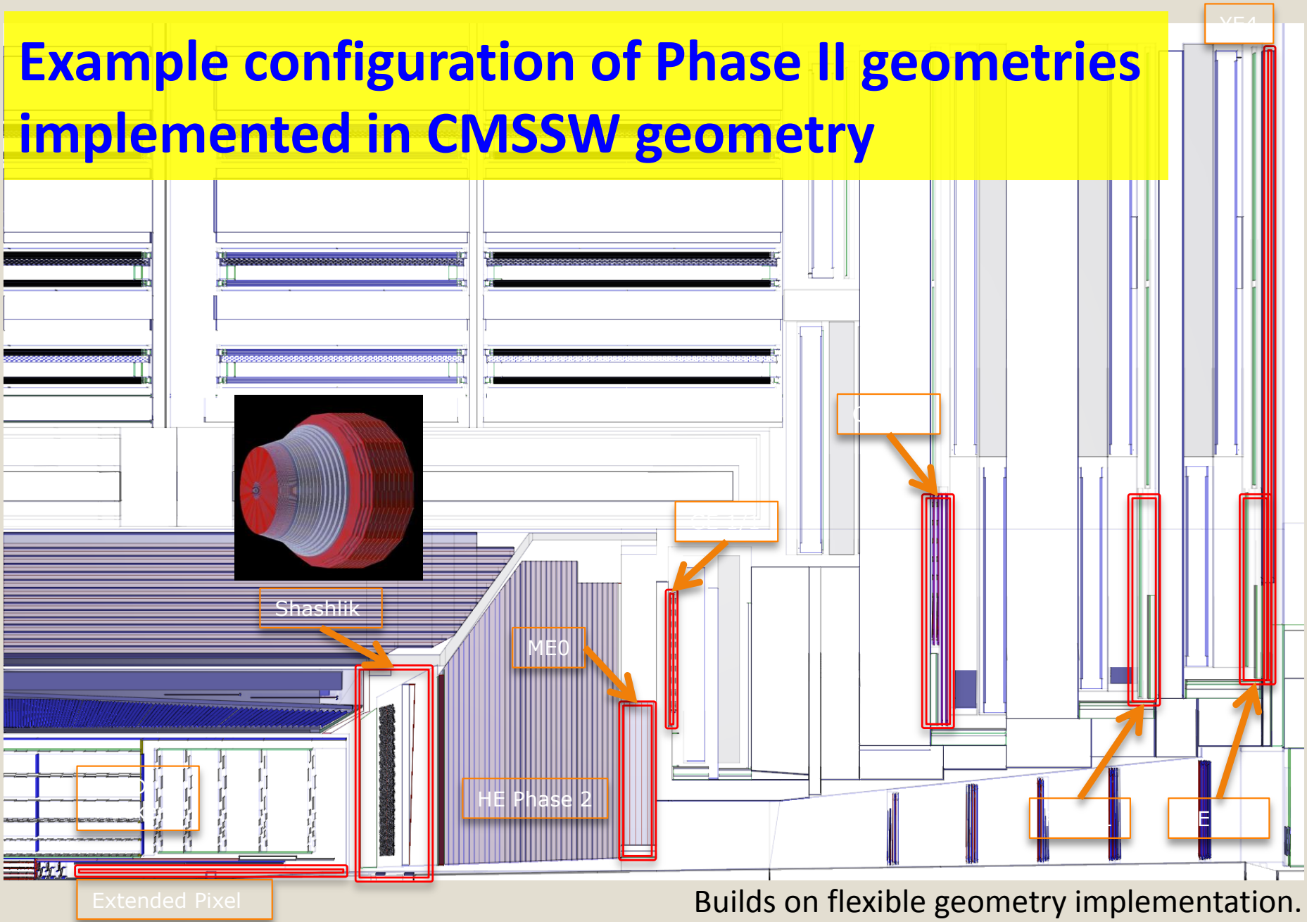


Technical challenges in the CMS approach to simulation and reconstruction

1. Need flexible, modular and adaptable geometry definition infrastructure
2. Pileup simulation: Loading and managing hits from many pileup events just to simulate one hard scatter event
3. Reconstruction: Largest CPU resource consumption workflow in CMS.
   - Constraints on both ends: Need to process all events within resource constraints

GEOMETRY AND MATERIAL DESCRIPTION

Example configuration of Phase II geometries implemented in CMSSW geometry

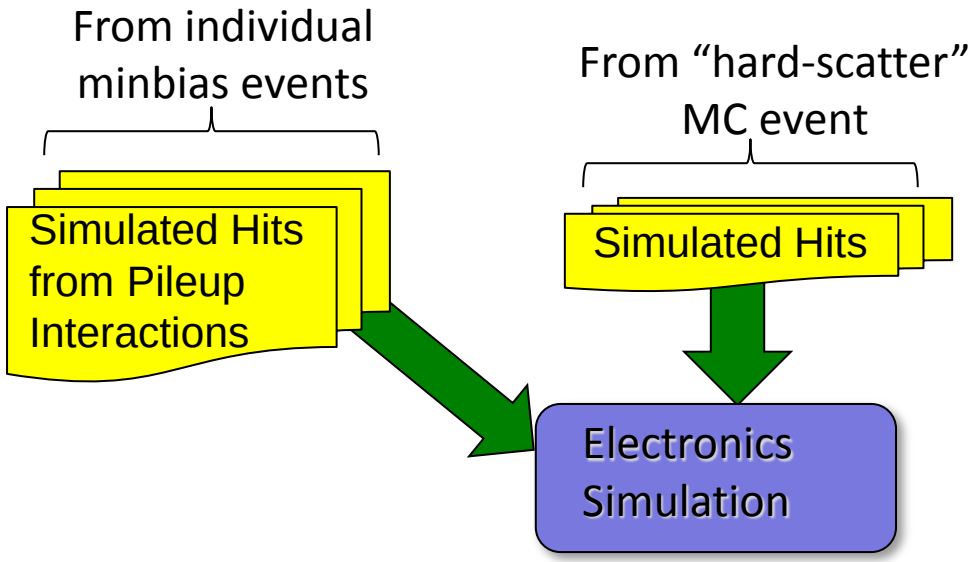


Builds on flexible geometry implementation.
See G. Boudoul talk later this session

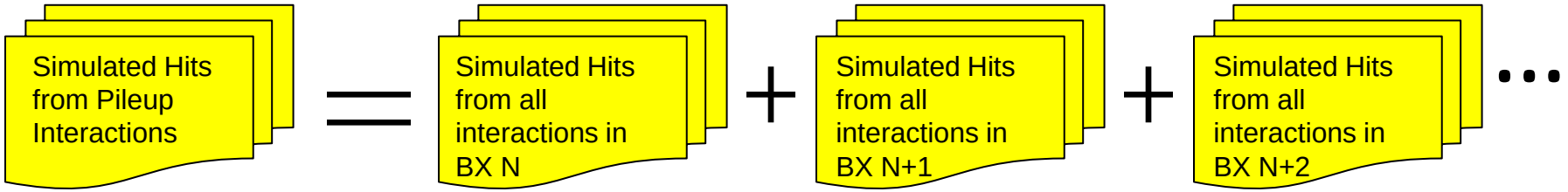
SIMULATION OF PILEUP INTERATIONS

Simulating Extreme Luminosities: The "old" way

- Model pileup by including G4hits from MinBias events generated separately from the hard-scatter event



- The pileup interaction simulation

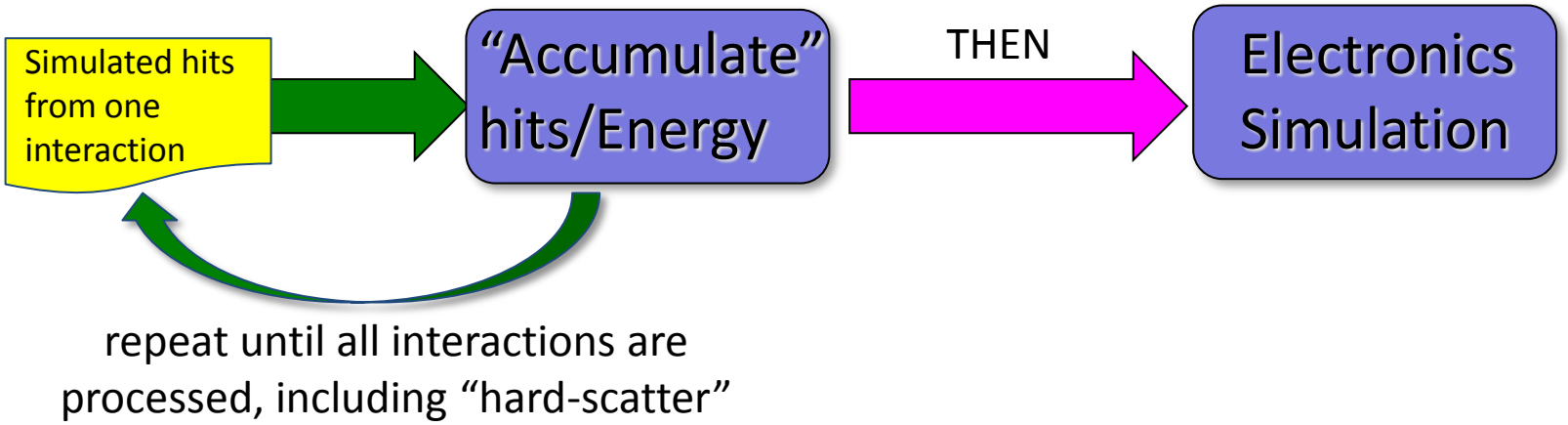


This loads **all** interactions in **all** beam crossings – all in memory simultaneously!

⇒ unsustainable at HL-LHC luminosities: ~140 interactions x 16 BXs = 2240 events in memory

Modifications to allow very high pileup simulation within memory constraints

- We re-factored the pileup simulation to process each interaction sequentially
  - Required substantial rewrite of digitization code, and the re-organization of internal event processing



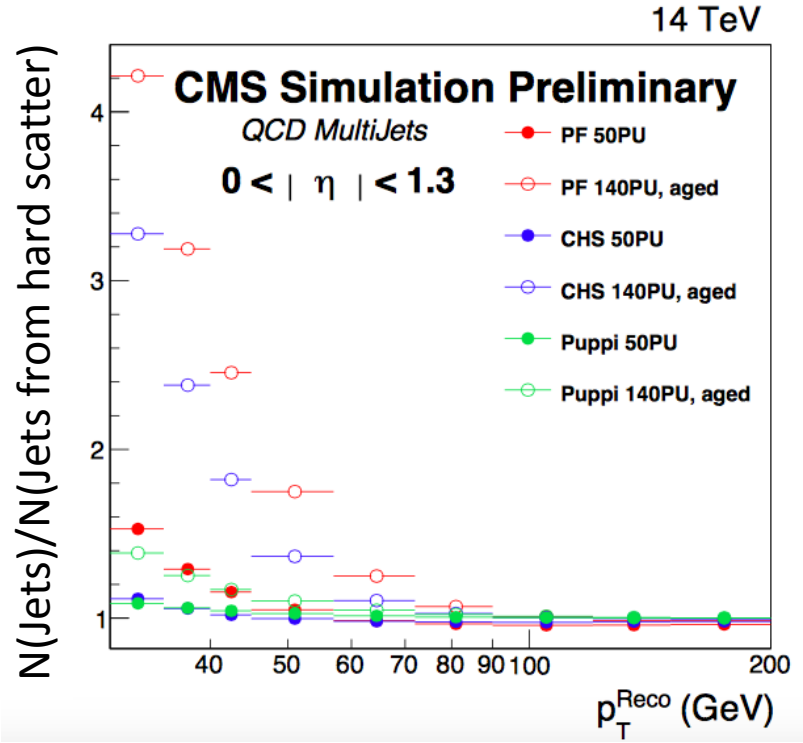
- The content of each event is dropped from memory once processed:
  - Only 1 event in memory at any given time, so arbitrarily many pileup events can be included in the digitization
- Next challenge in pileup simulation for CMS: Reduce the I/O burden from the pileup events to open up more resources for processing

See poster session B: "A New Pileup Mixing Framework for CMS"

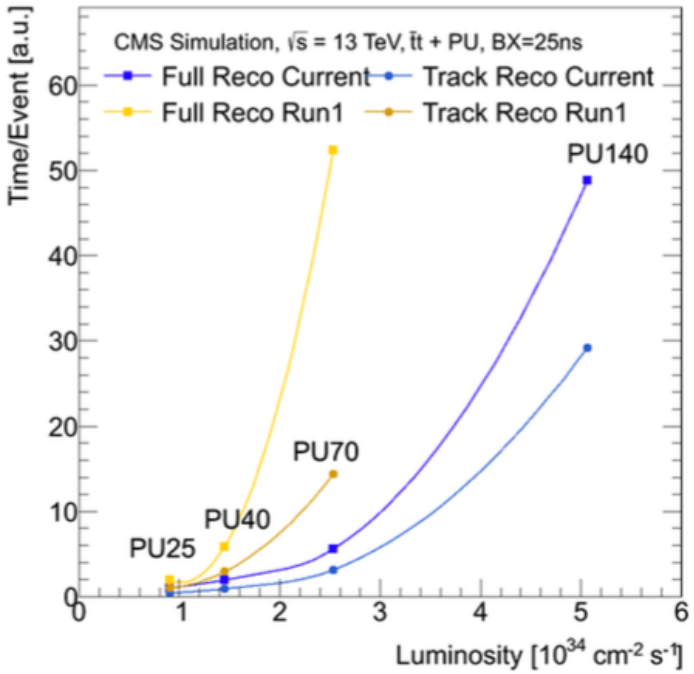
EVENT RECONSTRUCTION

Two sides of reconstruction: Pileup mitigation within resource constraints

Pileup interactions increase algorithmic errors



Computing resources required naturally grows with combinatorics



The upgrade reconstruction program has built on the recent Run 2 reconstruction improvements brought on by higher pileup and 25 ns operating conditions

Example improvement: Pulse shape analysis for out of time pileup mitigation in calorimeters

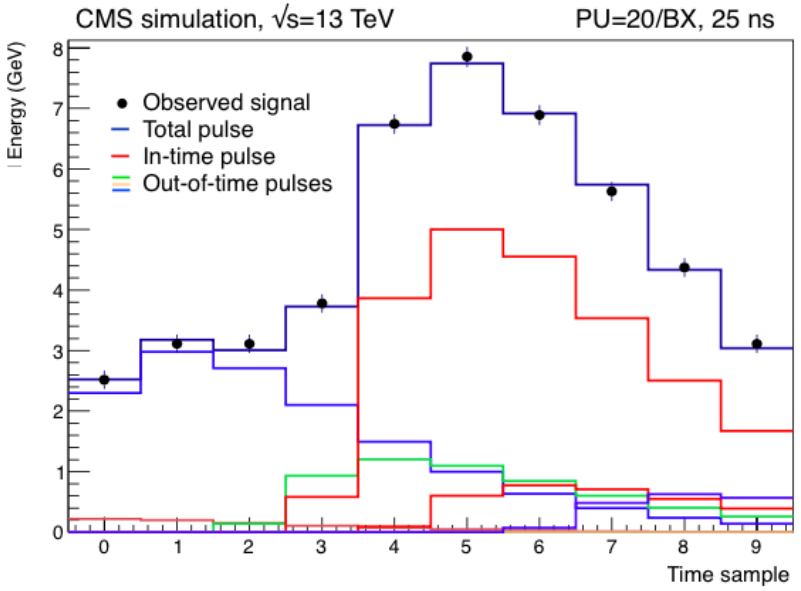
- Determine in-time and out-of-time contributions to calorimeter hits through pulse shape analysis
- ECAL example: Fit for pulse amplitudes in each of 10 time samples using pulse shape templates
- This technique proven essential in recuing out-of-time PU for both run 2 and Phase-II

Fitted pulse amplitude

Pulse template

$$\chi^2 = \sum_{i=1}^{N} \frac{\left(\sum_{j=1}^{M} \mathcal{A}_j p_{ij} - S_i\right)^2}{\sigma_{S_i}^2}$$

Observed pulse in sample



Conclusions

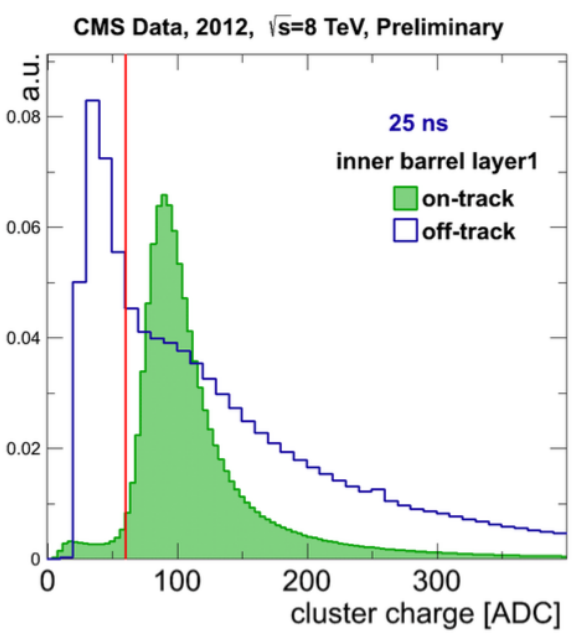
- Recent development work in CMS means a big reduction in simulation resource needs for 2015 even in the face of higher event complexity and trigger rates.

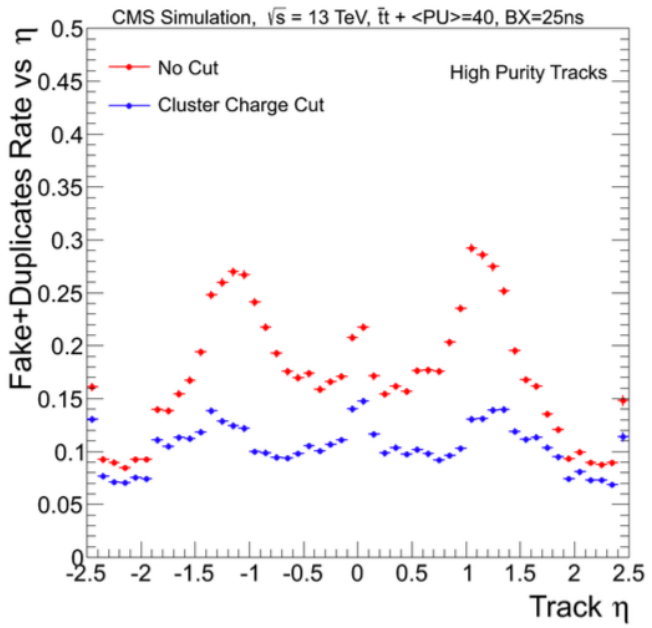
- CMS detector upgrades push us to use today's software/computing for tomorrow's event complexity.
  - The detector upgrade developments have proven to be an excellent platform for the quick deployment of new simulation features

Extra slides

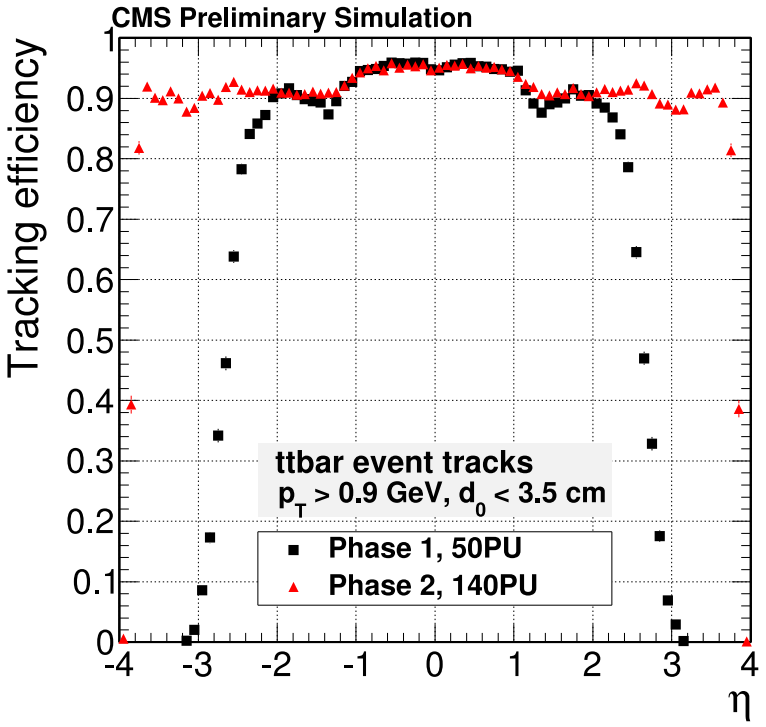
Example improvement: Tracking cluster charge

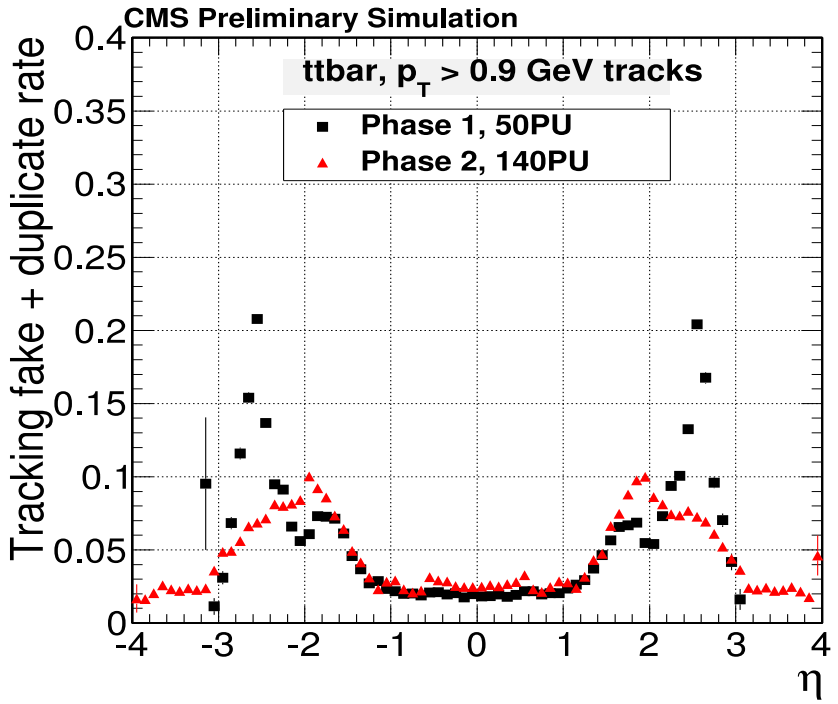
- CMS “Iterative tracking” approach has provided a flexible platform for tracking configurations for new pileup conditions and new tracking detectors
- New requirement on strip cluster charge reduces hits from out-of-time pileup





Phase 2 tracking studies show excellent performance at very high pile up





- Improved fake rate is also a sign of reduced combinators and thus reduced CPU requirements of iterative tracking configuration