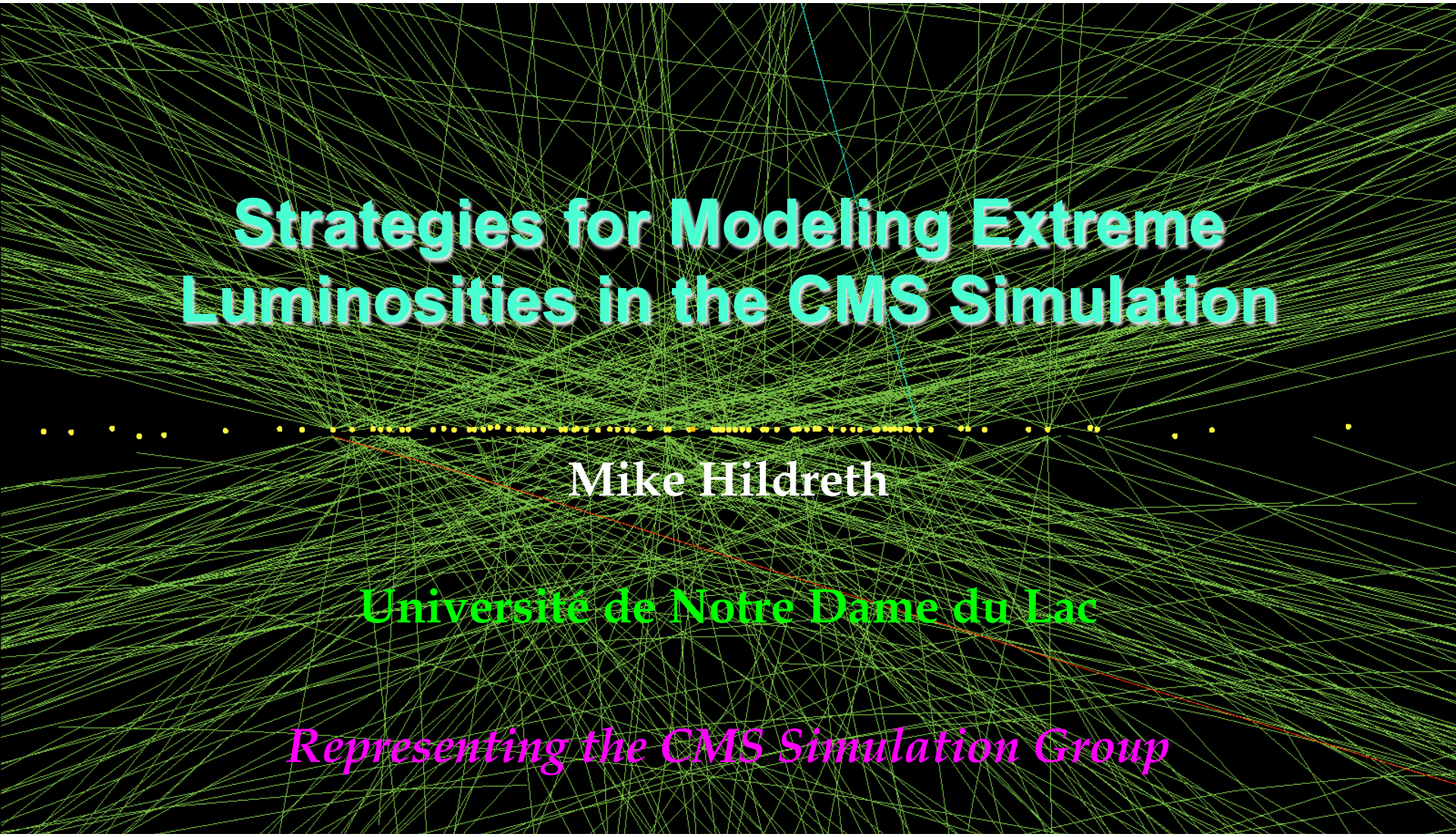

Strategies for Modeling Extreme Luminosities in the CMS Simulation

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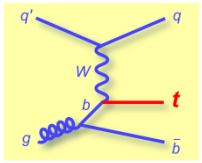
Overview

- Overview of MinBias simulation in CMS
  - Machinery
  - cpu/memory performance
  - Out-of-time Pileup influence(s)
- Simulation Restructuring
  - Digitising with “accumulation”
  - Pre-Mixing
- Prospects

Pileup Simulation Machinery

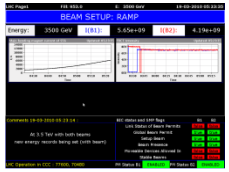


Physics Generators

Particle 4-vectors

Geometry/ Material Description

Geant 4



Simulated Hits from Pileup Interactions

Simulated Hits

Noise Model

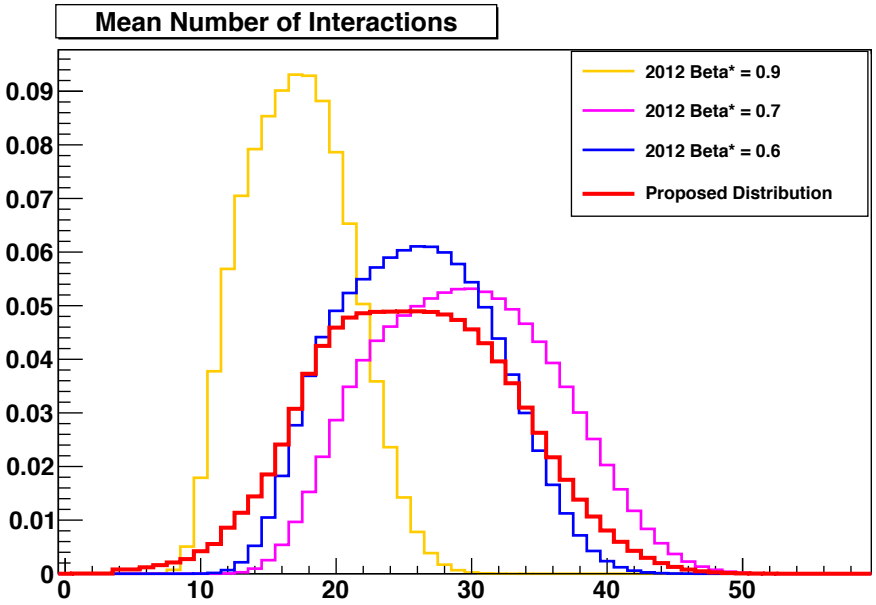
Electronics Simulation

Simulated Raw Data

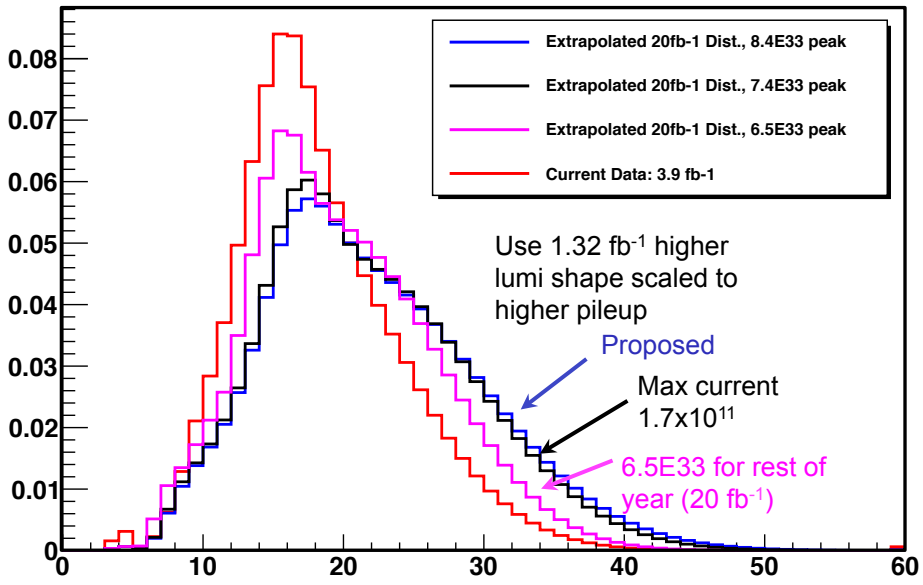
= "Digitization"

Pileup Simulation Overview

- Pure MC inputs used to simulate pileup interactions
  - Pythia6 Tune Z2* for Summer 12 production of minbias events
- Distribution of the number of interactions per beam crossing chosen in advance to simulate a desired luminosity profile:



2012 distribution chosen before data-taking. Extrapolations based on expected instantaneous luminosity and time evolution of accelerator performance.



2012 distribution correction mid-stream (after summer conferences) to create distribution based on observed luminosity, extrapolated performance. Note much lower mean value of pileup interaction multiplicity

Note that MC reweighting to match data is required in both cases

Pileup Simulation Overview (II)

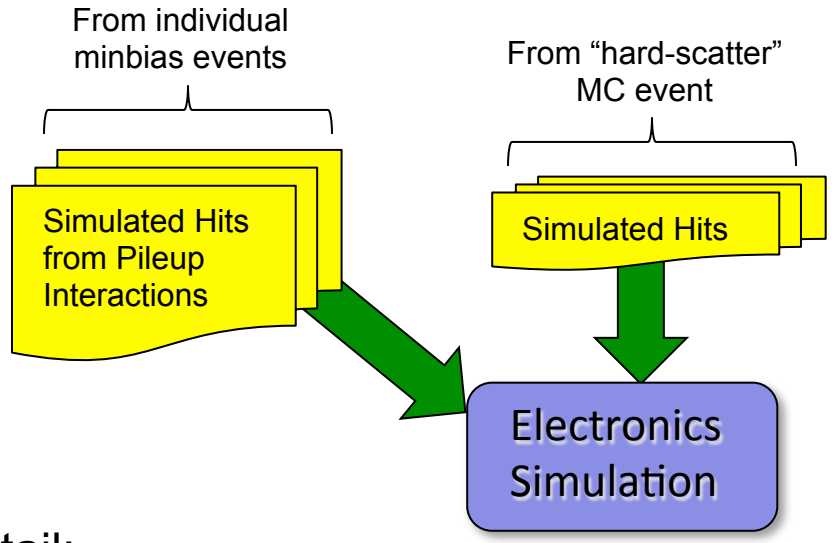
- For each event, the instantaneous luminosity is chosen from the input distribution at random
  - The number of in- and out-of-time interactions to be overlaid are selected individually from a poisson distribution based on the chosen luminosity and the total inelastic cross section
    - (we have used σ_{tot} = 69.3mb @ 8 TeV)
    - Pool of pythia minbias (single interaction) events used as input
  - Out-of-time interactions are simulated for each beam crossing that is "in scope" for a given production run
    - can do any arbitrary bunch configuration in 25ns steps
      - times of Geant SimHits are shifted to match bunch assignment
      - Digitization simulation considers hit times for pulse shapes
    - up to now, simulate ±50ns worth of bunch crossings
- Collection of Geant SimHits from all of the minbias events and hard-scatter "signal" event are merged, then processed by digitization/ electronics simulation
  - no simulation of "double-hard-scatter" (yet)

Simulating Extreme Luminosities

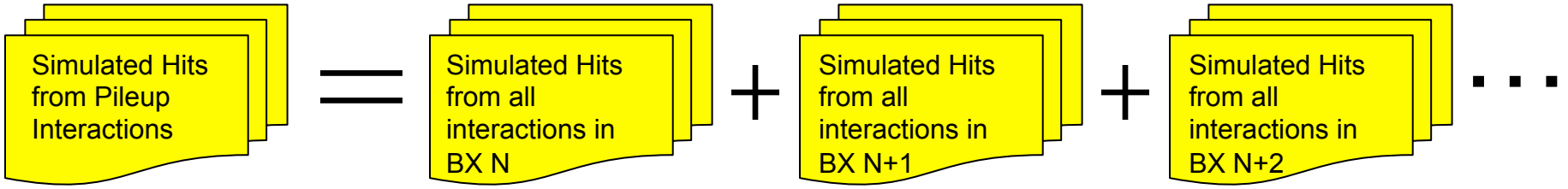
- Importance of Out-of-Time PileUp (OOTPU):
  - Because of signal shaping in readout electronics, CMS Ecal is sensitive to modeling of OOTPU up to 300ns before central BX
    - effects low end of the energy spectrum
    - important for modeling of trigger, etc.
  - Will require the simulation of 16BX for each “hard-scatter” MC event
    - (At a bunch spacing of 25ns)
  - Studies ongoing to establish limits of sensitivity for other detectors, validate OOTPU simulation compared with Data
    - Ecal is likely to be the extreme
    - Drift Tubes (DTs) in Muon system have similar sensitivity, but time determination algorithm provides good rejection
    - Some out-of-time hits seen in tracker simulation

Simulating Extreme Luminosities

- Details of Simulation Structure become important:
  - Reminder of the algorithmic structure for pileup simulation:



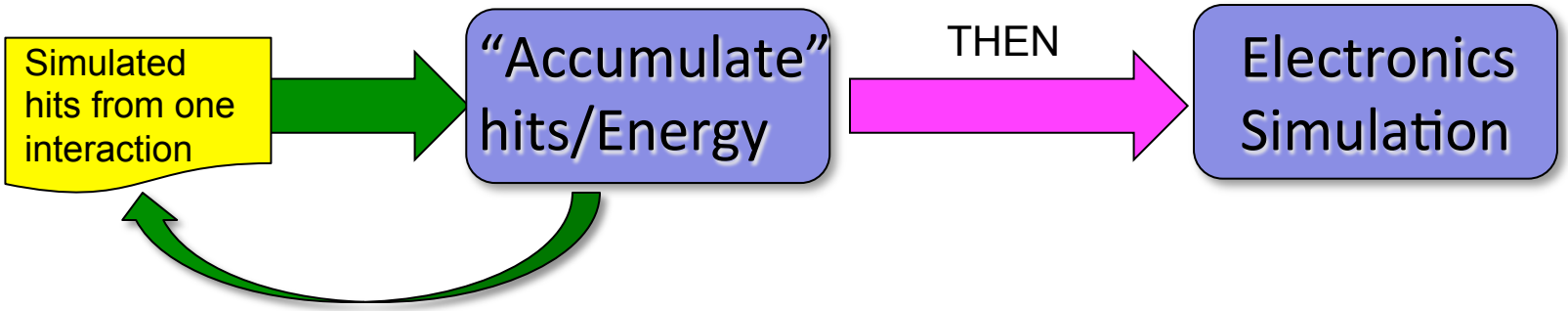
  - In more detail:



Sum contains **all** interactions in **all** beam crossings – all in memory simultaneously!
⇒ unsustainable at sLHC luminosities: ~140 interactions x 16 BXs = 2240 events in memory

Modifications to Simulation Structure

- Re-factorization of code to process all interactions sequentially
  - Required substantial rewrite of Digitization code, re-organization of internal event processing
    - digitization is now internal to the pileup addition process
  - New structure: (available in current CMS SW release)



  - content of individual interaction events is dropped once they have been processed:
    - only 1 event in memory at any given time
    - substantial performance gains (numbers later)
    - makes sLHC simulations possible within CMS infrastructure

CPU/Memory Performance

- Some timing/performance results:
  - Single neutrino events with 8 TeV Pythia minbias events simulating individual interactions
  - Events processed merely through pileup addition and digitization

Scenario	CPU/ev (s)	RSS (MB, 100 ev)	
[-2,2], 50 ns, <PU> = 21	5.2	976	(3 BX only)
[-12,2], 25 ns, <PU> = 20	12.6	1186	(16 BX)
[-12,2], 25 ns, <PU> = 40	27.4	1518	(16 BX)
[-12,3], 25 ns, <PU> = 50	31.2	1500*	(16 BX)

*additional optimisation by dropping memory-intensive diagnostics

  - Memory Reduction for a sample with 100 interactions/crossing:

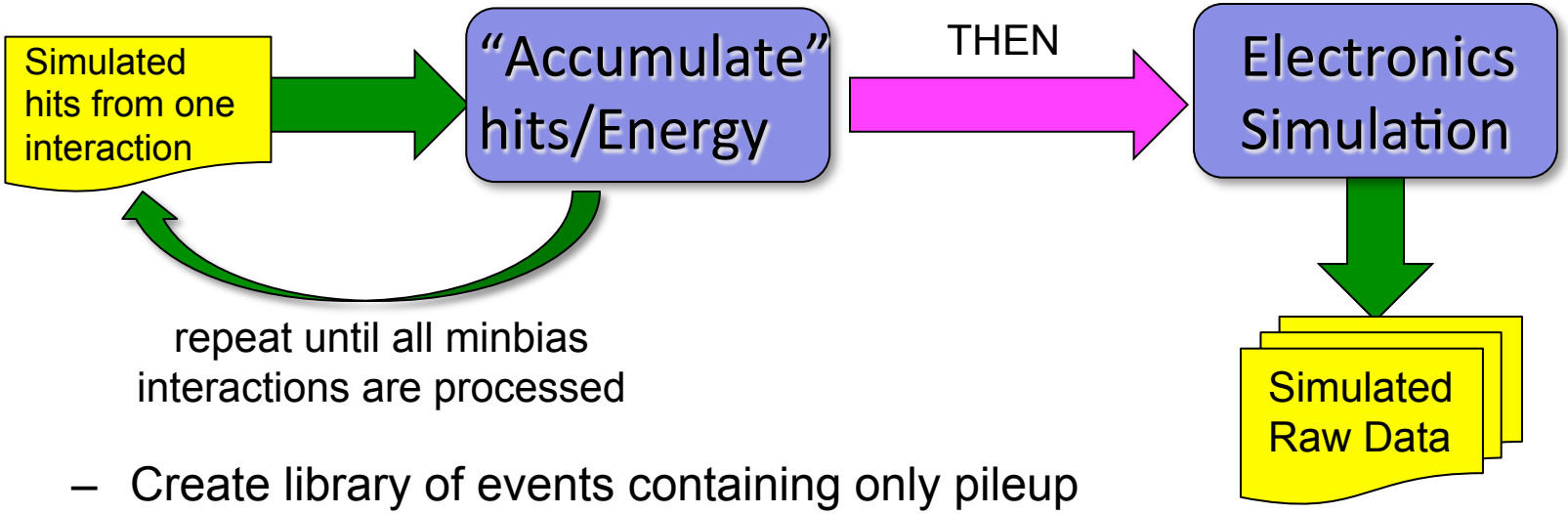
Pileup Configuration	VSIZ (MB)	RSS (MB)
Old Mixing Software	2520	2020
New Mixing Software	1283	933

Simulation meets Computation

Even if the events are read sequentially, it still will require more than 2000 minbias events to produce a single MC event with appropriate pileup at sLHC luminosities

- nightmare for computing infrastructure if huge minbias event files have to be made available to each compute note for MC production

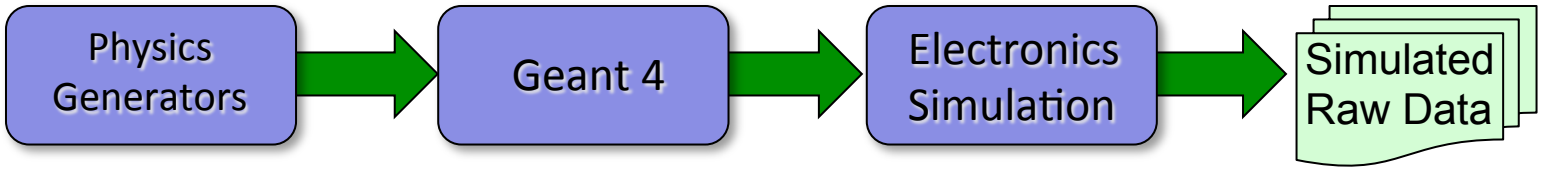
- Potential Solution: "Pre-Mixing"
  - For the pure minbias pileup simulation,



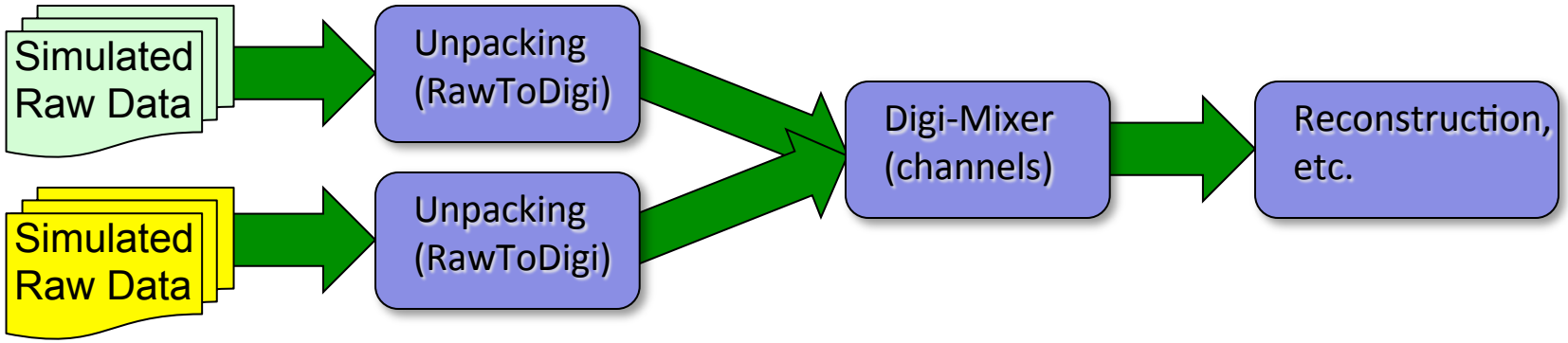
  - Create library of events containing only pileup contributions, following pre-determined luminosity profile to calculate how many interactions to include

Pre-Mixing

- Next, “hard-scatter” sample is created and processed through the digitization step with no pileup, convert to Raw data to save space



- Finally, streams are merged



  - employs “DigiMixing” scheme where Digis are combined at the individual channel level
  - only 1 pileup event is needed for each “hard scatter” MC event
    - much simpler for computing infrastructure

Pre-Mixing Status

- Infrastructure exists
  - (see next slide)
  - currently under validation
  - computing workflows tested and functional
- Caveats
  - In order to correctly combine signals that would have been just below zero-suppression thresholds, events should be produced without zero-suppression
    - impractical for tracking systems
      - impact of this omission under study
    - not a standard production workflow for calorimeters
      - extensive testing/tweaking required

- planned for deployment in time for large scale production of MC for 13 TeV running

Conclusions

- Pileup Simulation is not an easy problem
  - generator issues
    - (not discussed here)
    - do our generators actually match the physics?
  - CPU/Memory consumption will continue to be problematic
    - especially for sLHC
    - constant vigilance required to keep this under control
      - may require simplification of simulations
    - out-of-time pileup is difficult to study/quantify
- Current implementation very successful
  - major reworking of infrastructure has been necessary to confront the challenges of high(est) luminosity simulation
  - with modifications, ready for 13-14 TeV and even sLHC
    - more optimisation possible

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Additional Slides

Digi Overlay

- CMS has developed a framework to combine events at single-channel level (Digitization)
  - or at higher level: Reconstructed objects
  - Data or MC
- Has been used for
  - Trigger studies (Data-on-Data overlay)
  - Tracking & Vertexing efficiency studies (Track embedding)
  - Calorimeter noise studies (Data-on-MC overlay)
- Planned for deployment as a tool for 13 TeV running
  - If zerobias data events used, automatically gives a “post facto” correct description of most pileup effects, including beam backgrounds, noise, etc.