Pileup Issues and Simulation in CMS

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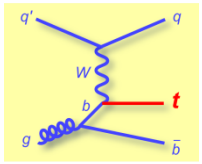
Representing the CMS Collaboration

Overview

- Overview of MinBias simulation in CMS
  - Machinery
  - cpu/memory performance
- Data/MC Comparisons
  - evolution of detector/physics quantities vs. occupancy
  - sensitivity to out-of-time pileup
- Data Overlay

Pileup Simulation Machinery

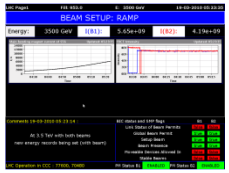


Physics Generators

Particle 4-vectors

Geometry/ Material Description

Geant 4



Simulated Hits from Pileup Interactions

Simulated Hits

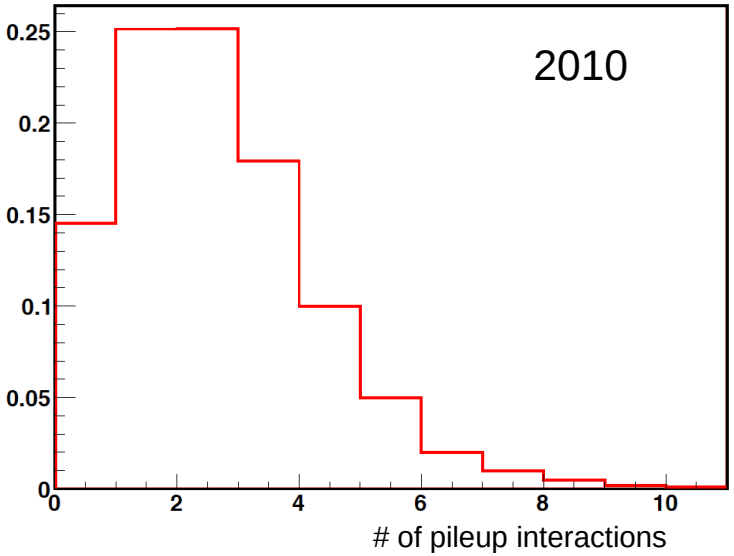
Noise Model

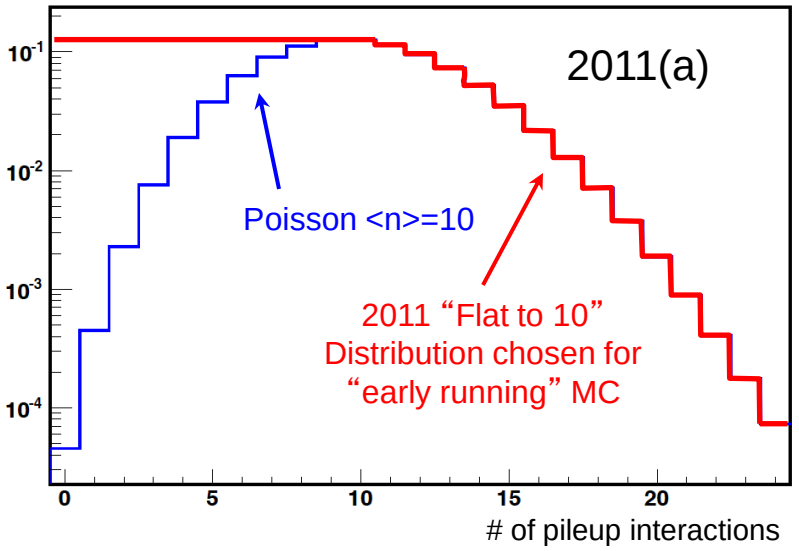
Electronics Simulation

Simulated Raw Data

Pileup Simulation Overview

- Pure MC inputs used to simulate pileup interactions
  - Pythia8 Tune 4C for Summer 11 production of minbias events
- Distribution of the number of interactions per beam crossing chosen in advance to simulate a desired luminosity profile:





2010 distribution chosen half-way through data taking. Extrapolation based on expected instantaneous luminosity. Matched data almost perfectly.

2011 distribution chosen well before running. Designed to generically represent data up to Summer Conferences. Reweighting necessary to match data luminosity distribution.

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} = 71.3mb)
  - 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
    - typically, simulate ±125ns 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)

CPU/Memory Performance Issues

- Some timing/performance results from earlier this year
  - (major improvements since then, not quite finished…)

D. Lange

Scenario	Pileup + Digi time (a.u.)	Reco time (a.u.)
No pileup	2.3	3.0
Flat10+Tail (2011a)	8.9	7.1
Peak=14 (~$3x10^{33}$)	6.6	8.7
Peak=20	9.6	14.5
Peak=32 (~$5x10^{33}$)	12.3	26.1

  - increase in memory usage above no-pileup case:

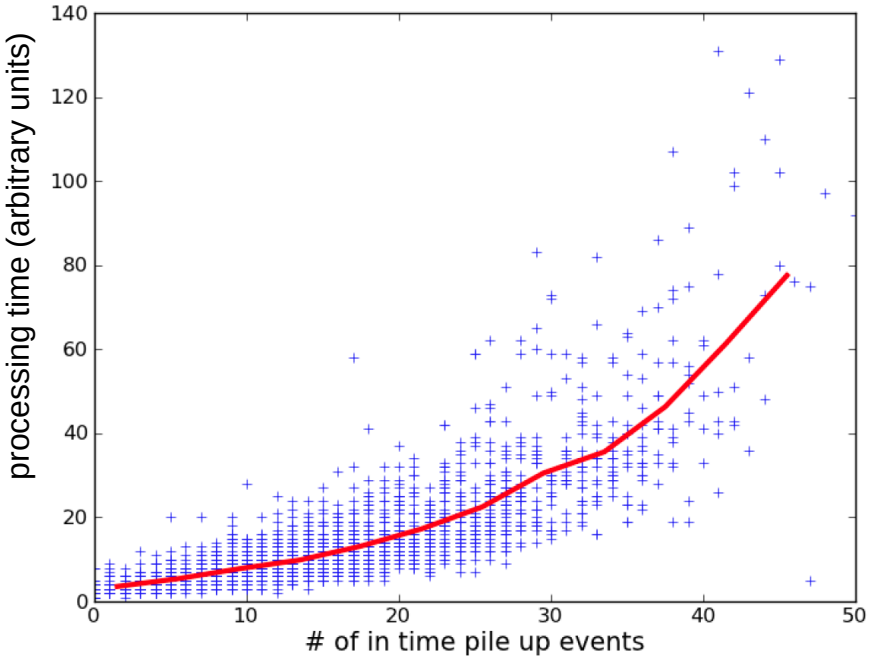
Scenario	ΔDigi Vsiz	ΔReco Vsiz
Peak=14 (~$3x10^{33}$)	+510	+272
Peak=20	+468	+383
Peak=32 (~$5x10^{33}$)	+628	+836

comprehensive evaluation of new code performance not available yet

also dramatically improved recently

The generic worry:

- Any sort of processing time can increase quadratically (or worse):

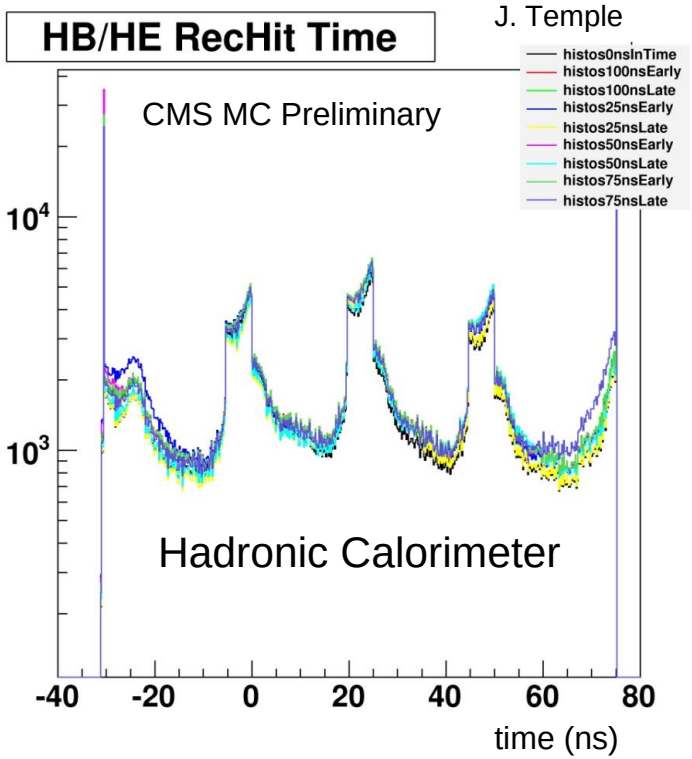


- CMS process: complete re-evaluation of code for Digitization, Pileup overlay, and Reconstruction (on-going)
  - target worst offenders, restructure if necessary
  - currently: re-working of Pileup overlay to cope efficiently with sLHC simulation (250 interactions in- and out-of-time)

Pileup Simulation Validation

- Time of reconstructed hits for interactions at different times:

J. Temple

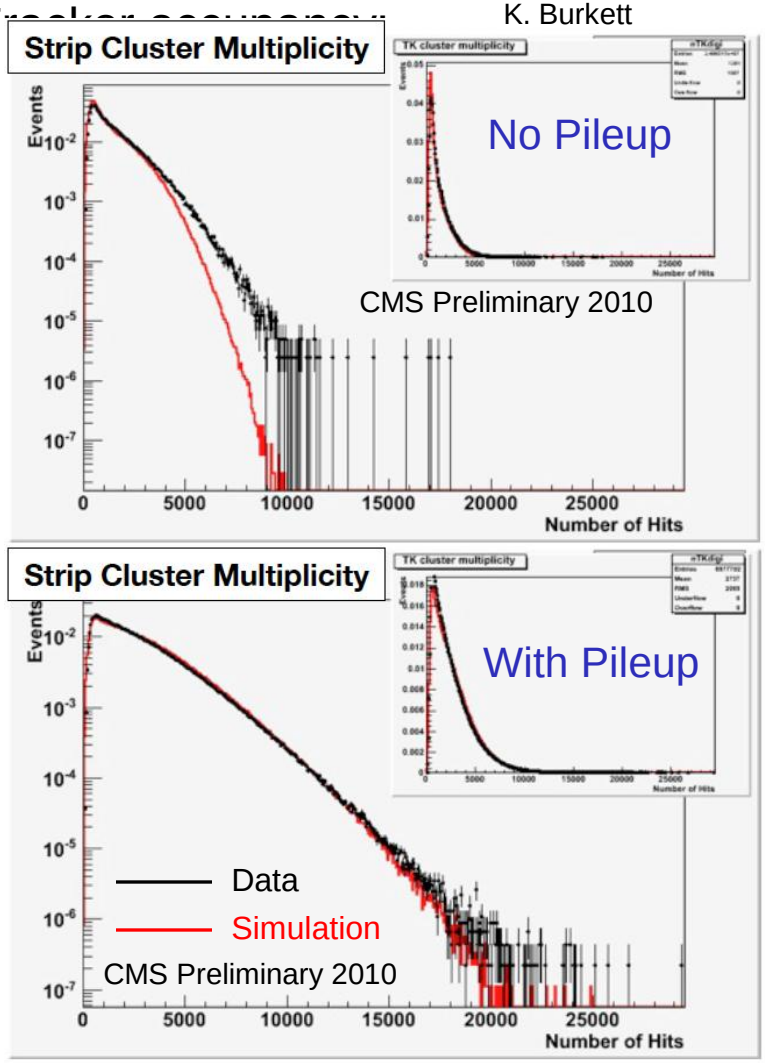


  - proper time shift, simulation and reconstruction of out-of-time

energy

- T[illegible]

K. Burkett



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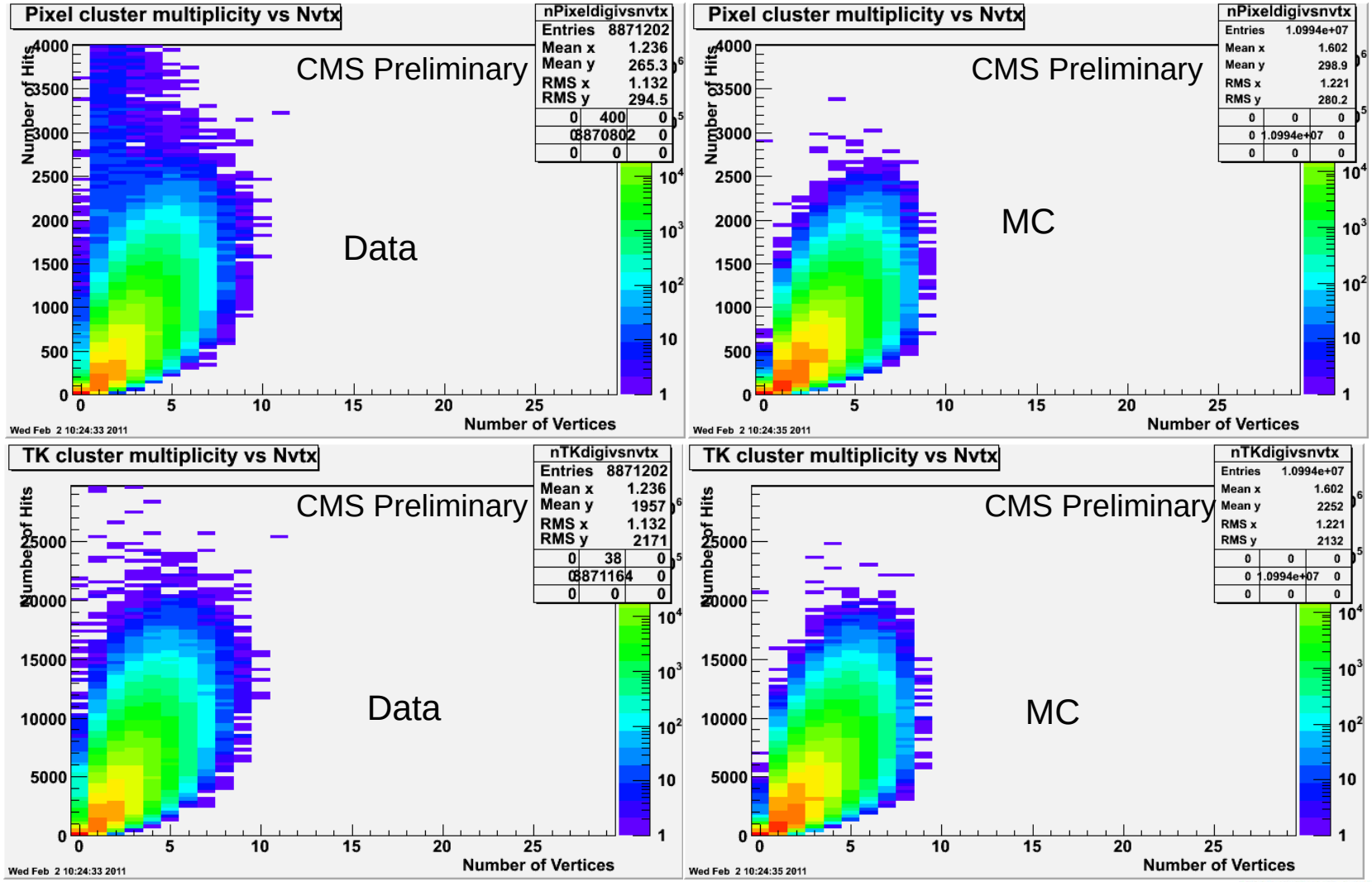
Pileup Simulation Validation (II)

- Tracker Occupancy (2011):

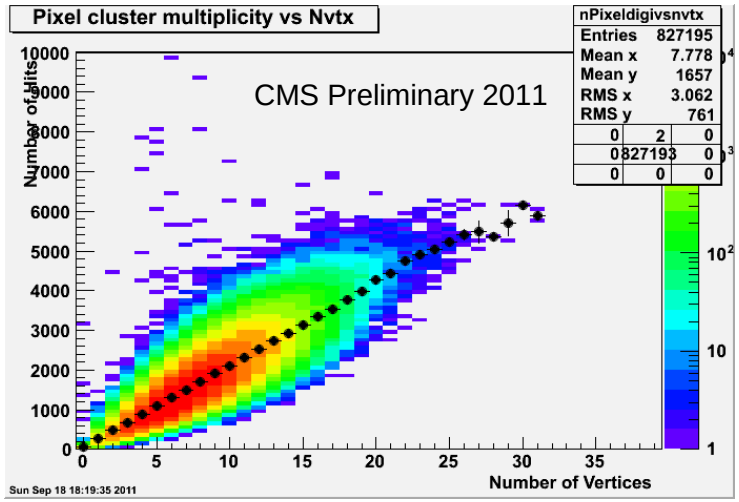
A. Venturi

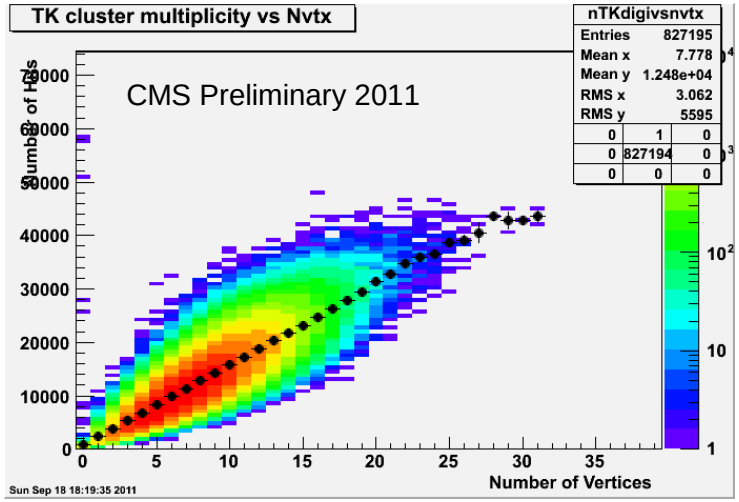


Effects of Pileup

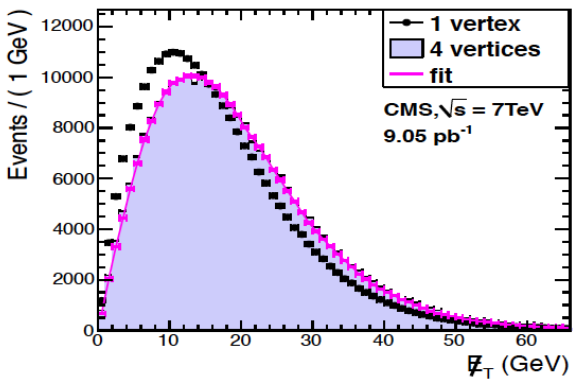
- First, checks of “linearity” assumption with Data:
  - at lower luminosities, does 1+1=2?
  - vertex vs. cluster multiplicities: linear out to large n_{vtx}

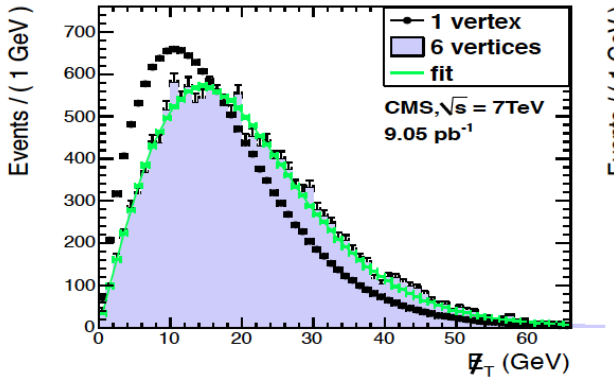
A. Venturi

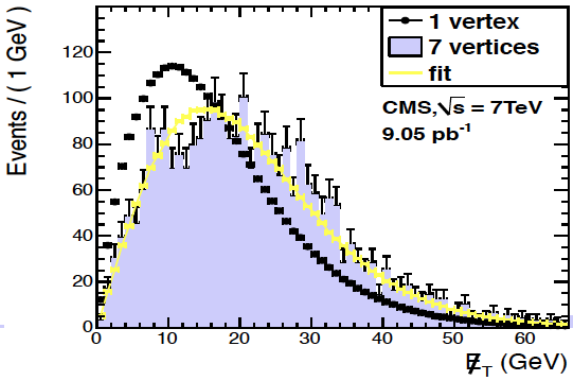




- MET: n vertices = (1 vertex distribution)*n



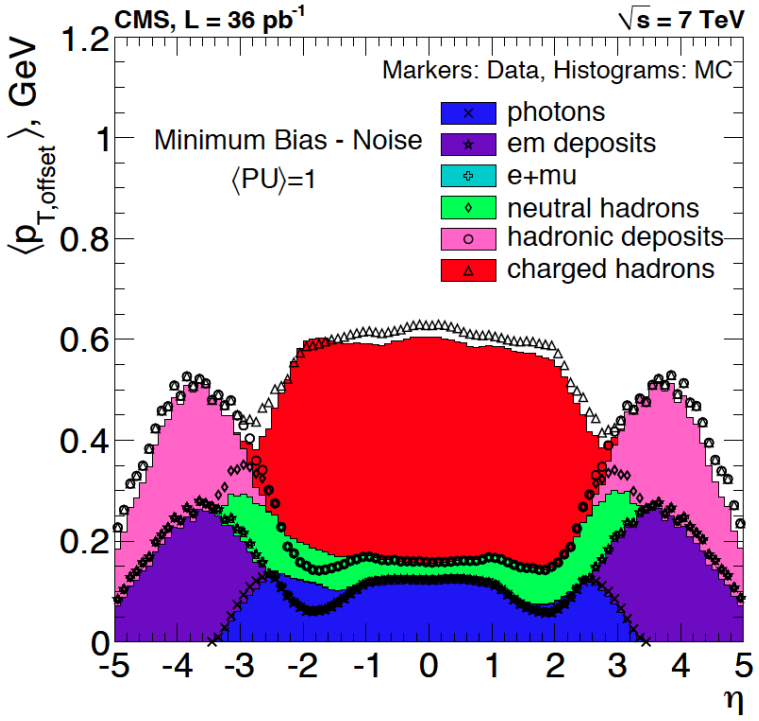




2011 JINST 6 P09001

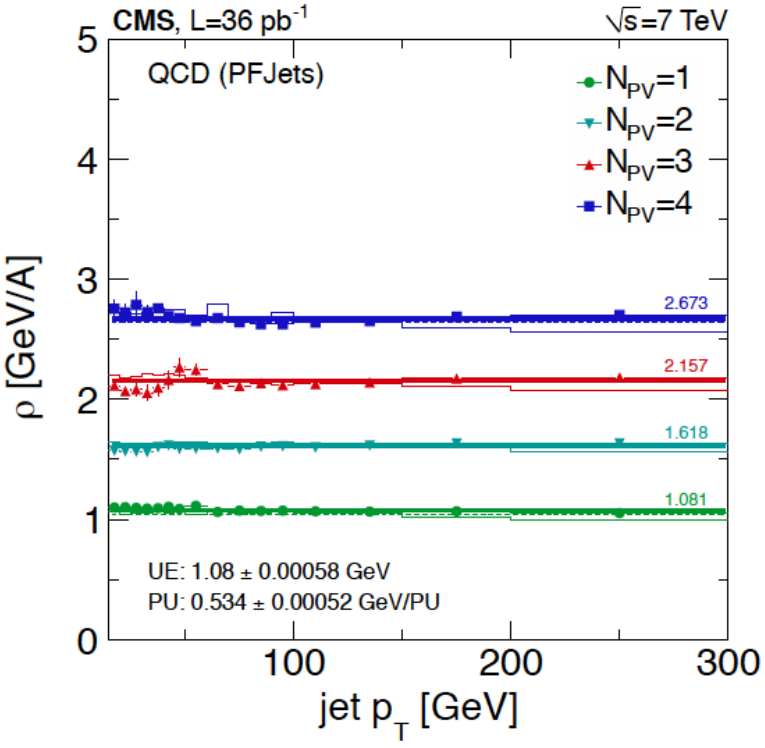
Effects of Pileup

- Occupancies and Jet Resolution:



Composition and angular distribution of measurable energy/particle depositions in CMS for single min-bias events

arXiv:1107.4277; CMS-JME-10-011



- Event-by-event Particle Flow p_T density for different number of additional interaction vertices
- Can be subtracted to mitigate effects of pileup

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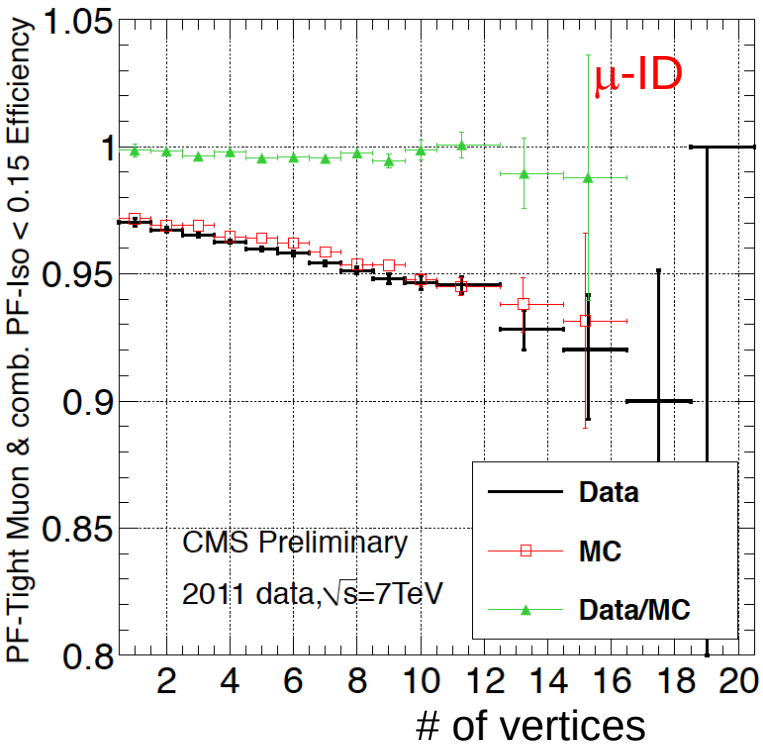
Pileup Modeling

- Degradation of isolation efficiency due to extra energy in cone:



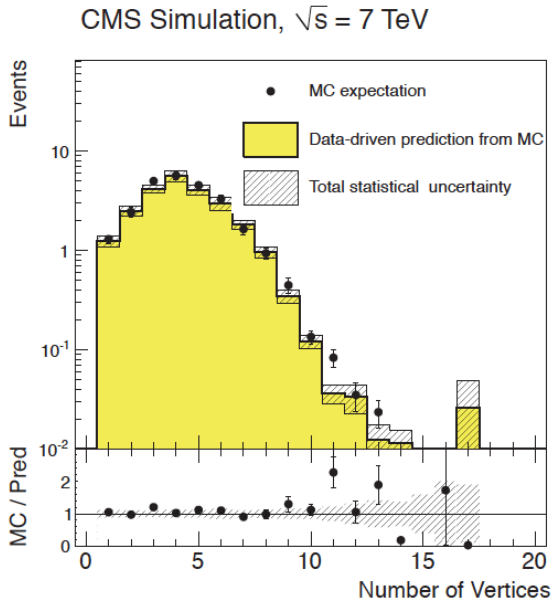
Effect of this trend can be mitigated by subtracting the average energy density ρ in the cone

CMS PAS HIG-11-013

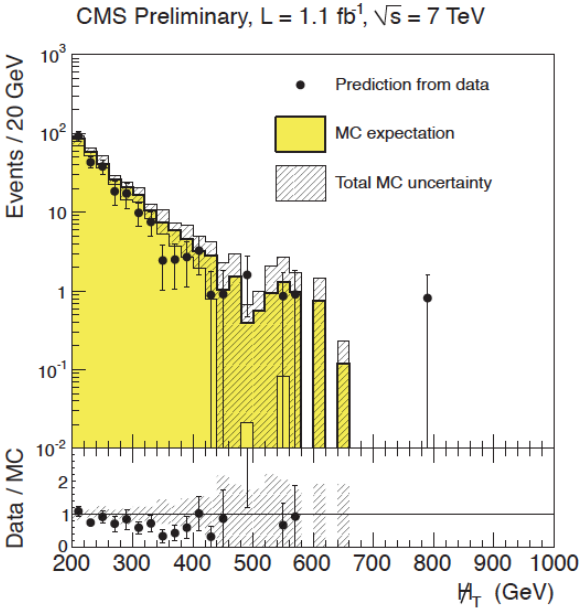
Closure test for modeling the number of vertices: SUSY search in Jets + MET final state

⇩

Proper modeling of tails in missing H_T distribution for higher pileup data



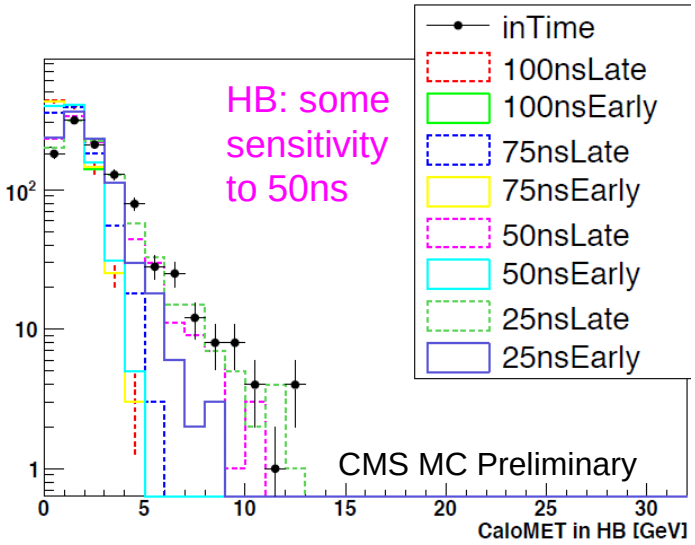
CMS PAS SUS-11-04

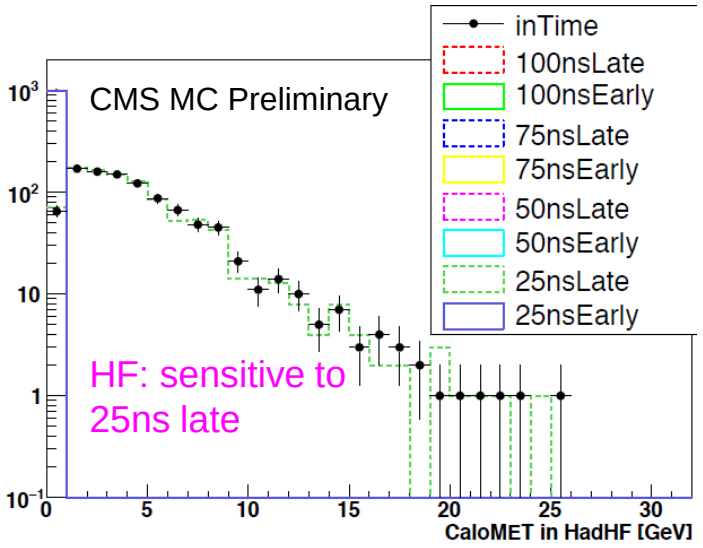


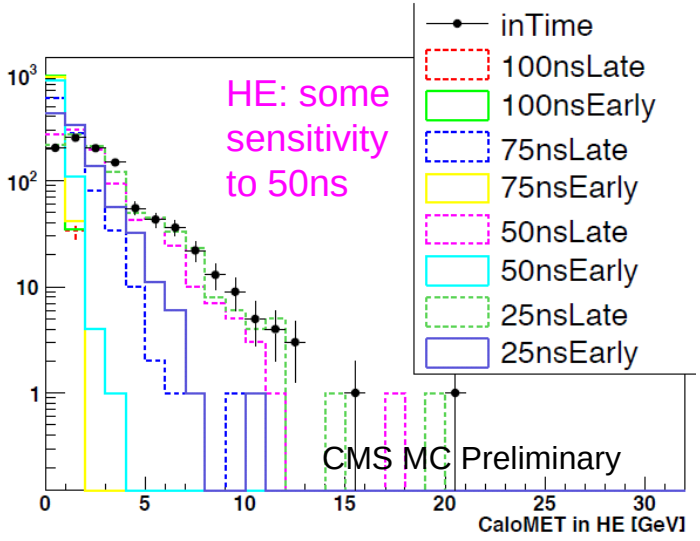
Sensitivity to Out-of-Time Pileup

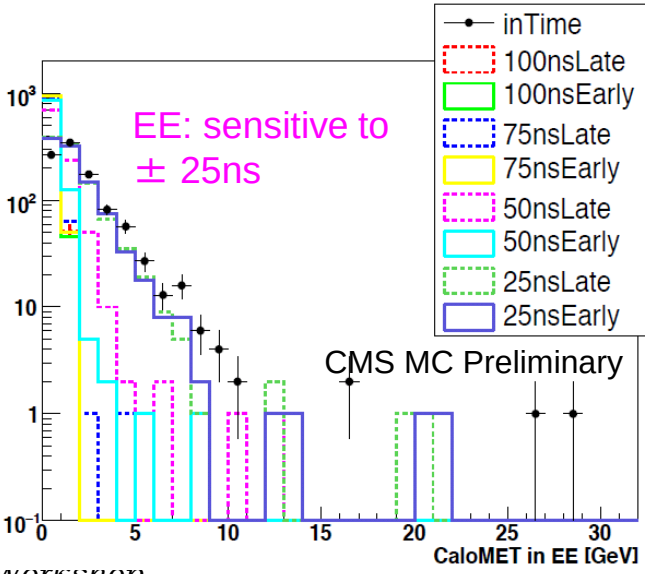
- Pure out-of-time MC minbias samples: plots of MET

A. Apresyan



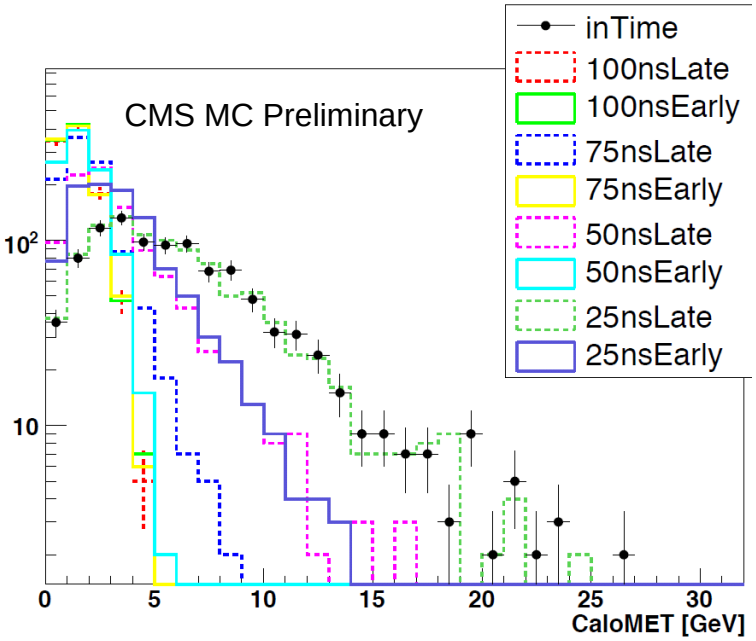


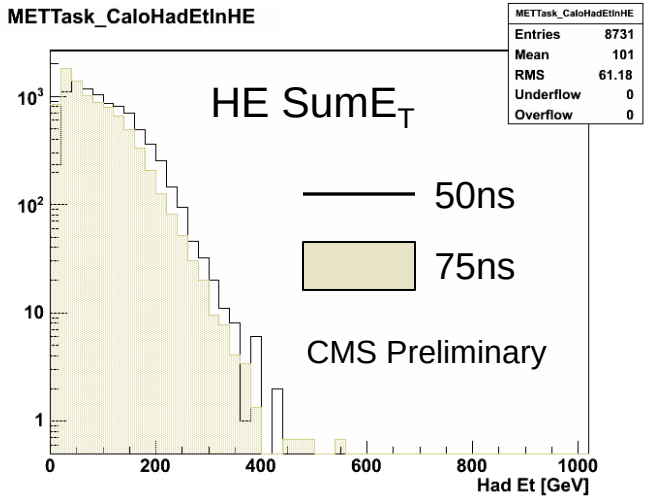




Sensitivity to Out-of-Time Pileup

- Aggregate Result:
  - sensitivity to additional energy in adjacent 25ns and 50ns bunches will cause tails in the MET distributions if readout changes are not made
    - under study
- Comparison of Data taken with 50ns and 75ns bunch spacing
  - equal bunch luminosities
  - expected differences seen in various subdetectors
    - more energy in forward region
  - accuracy of modeling still under study





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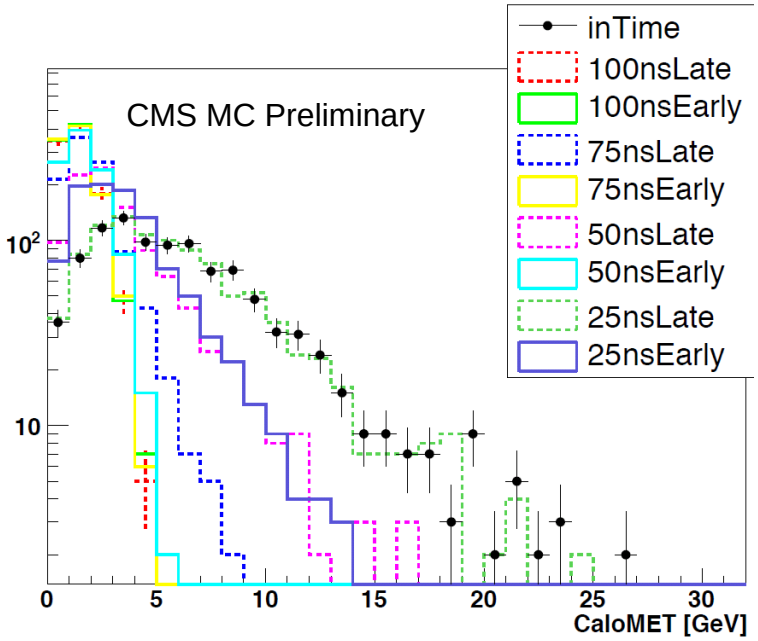

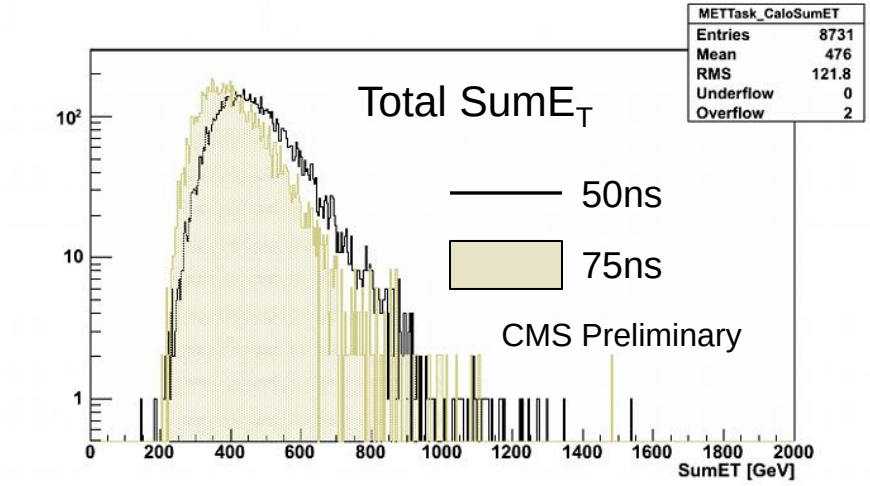

Data Overlay

- CMS also has capability to overlay Data events
  - on Data, or MC
- Hit combination can be done at single-channel level (Digitization)
  - or at higher level: Reconstructed objects
- Has been used for
  - Trigger studies (Data-on-Data overlay)
  - Tracking & Vertexing efficiency studies (Track embedding)
  - Calorimeter noise studies (Data-on-MC overlay)
- Full deployment is pending an “upgrade” to the Tracker MC geometry
  - differences between ideal MC geometry and as-built detector are currently too large for track reconstruction for, e.g., data tracks included in MC events

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 at “modest” luminosity
  - low and high-level objects well-modeled in present simulation
  - detailed studies on-going