From detector building to physics publication: the real story of the data

PART II

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Outline

- Life during operations: get the physics out as fast as possible (really really fast)
  - Taking data
  - Calibrate your data
  - Certify your data

- Life during a shutdown: prepare for next data taking
  - Improve your simulation
  - Improve your reconstruction
  - Improve your computing
Life during a shutdown

Preparing for the next data taking
Challenges of the RunII

Higher Energy - Higher Luminosity - Higher Pile-Up
The data flow

- Monte Carlo Event Generator
- Simulation of the Detector Response
- Trigger
- Event Reco.
- Physics Analysis

IMPROVING THE SIMULATION
Why (do we need) MC generators

MOSTLY TO BE PREPARED! To study signal that we have not seen yet. To develop strategies to cope with different energies/data taking conditions. To develop new detectors. Also to understand our data better...

- We can: calculate inclusive cross-sections
- We can: calculate differential cross sections as a function of variables of interest in the analysis

They make the connection between a theoretical model and reality: simulated events can then be treated in the same way as real data.
Structure of LHC events

- Parton probability distribution in the proton
- Radiation in the process
- Activity due to the proton remnants
- Hadronize partons
- Add initial and final state radiations
- Generate hard process
- Add the parton showers
- Let hadrons decay
- Add the underlying event
What happens after...

- The simulation is the next step in the production of MC samples: the generator level particles are fed to a program that will simulate the detector response.
- The goal is that the simulated data can be treated exactly as the real data with the truth information available for use.
How do we use the MonteCarlo datasets

\[ \sigma = \frac{N_{obs} - N_{bkg}}{\varepsilon \cdot \int L dt} \]

(Assuming we have passed the events through the simulation of the detector)

- calculate what fraction of events from a given decay **falls within the detector acceptance and the selections** of the analysis
- need a **forecast of how the event develops** in space, after the interaction
- the **simulations** are necessary both for known physics objects (Z, W, top production) and even more to build searches for new physics
- the **uncertainties** in the input parameters of the model \( (Q^2, \text{PDF}, \text{ISR}, \text{FSR}...) \) are sources of systematics.
the CMS detailed implementation for FullSim

- Application control
- Object browsing
- User Actions
- Visualization
- Mixing Module
- User Actions

CMSSW – the new framework - ties pieces together

- Event generation
  - PYTHIA, Particle Gun, ...
  - HepMC

- Simulation
  - Geant4 (+GFlash..)
  - (FastSimulation)

- Digitization
  - subsystem-specific packages

- Recomposition
- SimHit Data File
  - (Hit level information, linked to MC truth)

- Digi data file
  - (Data-like, linked to MC truth)

- Geometry
  - Detector Description Database
    - (XML & C++)
    - Sensitive Volumes Interface

- Misalignment Simulation

- Validation Suite

October 6, 2013
Choices, choices, choices

- Every experiment develops one (or more) simulations of their detector response.
- Optimization of which simulation to use for the various purposes is a complex strategy exercise that touches also Reconstruction, and Computing

NOTE: Here will not discuss toy or parametric simulation
the levels of simulation: Full

- Full Simulation is based on GEANT4, a very detailed and sophisticated physics response engine.
- the GEANT program uses generator output (4-vectors) and simulates the interaction of particles within the detector volume (need a good description of the geometry):
  - particle ionization in trackers
  - energy deposition in calorimeters
  - intermediate particle decays/radiation
- Many handles to tune it:
  - geometry/material description of the detector
  - physics lists
  - step length
  - process cuts
- very slow, very precise

COMPARISON OF PROCESSING TIMES
EFFECT OF CHANGING THE PHYSICS LIST
ATLAS calorimeter response to anti-neutrons
(0.1<pT<50GeV)

EFFECT OF CHANGING THE GEOMETRY/MATERIAL
Anomalous hits observed in CMS Calorimeter data.
Origin traced to energy deposit in thin layer of Silicon in the APDs. «After» shows the result after introducing in the simulation geometry extra layers of Silicon in the APDs as sensitive detectors.
Extremely accurate geometry description needed

The tracker geometry is quite complicated...

[Root graphical version of G4 geometry shown]

Material distribution in current CMS Tracker (estimated):

- Very large photon conversion probability
- Large effects of multiple-scattering
  
  At the end of the day must always validate against Data!!!
Validate the tracker geometry with data

Note the superior position resolution of the nuclear interaction data

The beampipe isn’t centered!

NUCLEAR INTERACTION DATA

PHOTON CONVERSION DATA
Validating the tracker material budget

astonishingly good agreement between data and simulation
levels of the simulation: Fast

Several ways to speed up the simulation. All options tried

A variety of versions and names:
CMS: FastSim
ATLAS: AFI&AFIIF
ISF
why do we need a fast(er) simulation?

- Because we need very large amounts of MonteCarlo (--- more later on MonteCarlo Production campaigns)
  - to evaluate background with large cross section and small survival probability.
  - Filtering directly at RECO level is more efficient and less biased
  - To scan a model’s parameter space of evaluate systematics
  - to train MVAs with sufficient statistics
  - to develop and test efficiently reconstruction and analysis algorithms
  - to study/test new geometries and conditions

- Some example in CMS (similar for ATLAS):
  - Top Mass extraction in 2l final states JHGEP 07(2011)049 (mass templates)
  - Black Hole search, PLB 697(2011)434: used for signal samples scan
  - Most of Susy analyses: simplified model signatures parameter scan
Approximate Geometry

- The detectors as ATLAS and CMS have all been built with a similar philosophy: a «onion» with cylindrical symmetry and different components as a function of the radial distance from the interaction point.

- The approach of simplifying the geometry description is then used by both: express the detailed Geant volumes in terms of layers and cylinders.

- The sensitive material is kept the same. A tuning of the inactive material (all clumped up in a few layers) is done on data.

- The navigation of the generated particles across this volumes is much faster! There is no Geant interaction to consider.
Comparing FULL and FAST geometries

ATLAS INNER DETECTOR

CMS TRACKER
Some FastSimulation details (CMS)

- A FastSimulation is not necessarily a «simplistic» simulation. Several effects included.

- The simulated interactions are:
  1. electron Bremstrahlung
  2. Photon conversion
  3. charged particle energy loss by ionization
  4. charged particle multiple scattering
  5. nuclear interactions
  6. electron, photon and hadron showering

- The first 5 are applied to particles crossing the silicon tracker, while the latter is parameterized in the electromagnetic and hadron calorimeters. Muons propagate through the tracker, calorimeters and muon chambers with multiple scattering and energy loss by ionization taken into account in the propagation.

- Very important note: all the calibrations, conditions, dead channels, noise, misalignment can be applied to the FastSim as in the FullSim.
Example: Nuclear Interactions in FastSim

- Having the possibility to properly simulate the number of daughter particles, their angle of emission, and their momentum is very important for the accurate description of tracking efficiency for instance. (ATLAS has it too!)

- Data files of N.I. (2.5M) have been created for 9 different hadrons, 1<E<1000GeV

- When a N.I. occurs a particle is picked at random from these files in the relevant energy range
FastSimulation of the Calorimeters

- The faster simulation of the calorimeter response is based on shower parameterization and tuning (GFLASH or similar).
- FastSim heavily used in production of BSM samples with many scan points or for the production of systematic samples for precision measurement.
FastSimulation of the Tracking

- A better definition is «Tracking Emulation»

- Speed is achieved by skipping the slowest piece of track reconstruction code, the pattern recognition (i.e. finding the hits that belong to a track):
  - The hits are «assigned» to a track based on the MC Truth information. No possibility of «fakes tracks» exist
  - this approach works very well for high purity environment when fake rate is small. need to study what happens with large Pileup.

- the efficiency is emulated applying the same selection cuts (seeding, quality etc) to the track parameters and checking if they are satisfied or not.

- Performance validated with FullSim and data
FATRAS in comparison to data
- ID reconstruction, tracks with $p_T > 500$ MeV
- using exact same sensitive detector elements:
  conditions data being fully integrated

(Actually more recent plots even better)
what’s next?

- big challenge for the future RunII. Ever bigger MonteCarlo productions ahead of us. One approach from ATLAS: ISF

- a new framework where the different simulations approaches are fully integrated in a flexible manner.

- mix-and-match the choice of simulation depending on the physics you are interested into

- Choose at run time!

- (My thought: really cool but can become a validation nightmare...)

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One more player in the game: the PileUp

@Lumi = 1.0 \times 10^{34}
if 50\text{ns} 50 \text{PU}
if 25\text{ns} 20\text{PU} + \text{OOT}
MC productions: guessing the PU ahead of time

- A good guess at the PU distribution to use in the MC campaign ahead of time can make a big difference in the efficiency of the production.
- For instance, if the PU is underestimated when we reweight the distribution, we might lose even a large fraction of the Monte Carlo statistics that was produced.
- Sometimes it is better (more efficient) to resimulate from scratch!
How to simulate it?

- For each event, the instantaneous luminosity is chosen from the input distribution at random.
- The number of in- and out-of-time interaction to be overlaid are selected individually from a poisson distribution based on the chosen luminosity and the total inelastic cross section (CMS uses sigmatot=71.3mb).
- Out-of-time interactions are simulated for each beam crossing that is «considered» for a given production configuration:
  - Arbitrary number of bunches in 25ns steps.
  - The times of the hits are shifted to match the bunch they belong to. The digitization simulation will consider the proper hit times for pulse shapes.
  - Typically simulate ±125ns of bunch crossing, but studies show might need more!
- Various ways to mix the hits from the collection of MinBias events and hard scatter «signal» before the processing:
  - Can mix generator particles, SimHits, digis, tracks, or pre-mix the proper number of events ahead of time and just overlay one «PU-event» with the signal.
  - Being investigated by CMS for future productions.
Some timing/performance results

- here just note the «relative» increase with the PU, and consider that the RunII will have a much higher level

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pileup + Digi time (a.u.)</th>
<th>Reco time (a.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pileup</td>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Flat10+Tail (2011a)</td>
<td>8.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Peak=14 (~3x10^{33})</td>
<td>6.6</td>
<td>8.7</td>
</tr>
<tr>
<td>Peak=20</td>
<td>9.6</td>
<td>14.5</td>
</tr>
<tr>
<td>Peak=32 (~5x10^{33})</td>
<td>12.3</td>
<td>26.1</td>
</tr>
</tbody>
</table>

- increase in memory usage above no-pileup case:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>ΔDigi Vsiz</th>
<th>ΔReco Vsiz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak=14 (~3x10^{33})</td>
<td>+510</td>
<td>+272</td>
</tr>
<tr>
<td>Peak=20</td>
<td>+468</td>
<td>+383</td>
</tr>
<tr>
<td>Peak=32 (~5x10^{33})</td>
<td>+628</td>
<td>+836</td>
</tr>
</tbody>
</table>
Validation of PU simulation

- Studies have shown that the effect of the OOT PU on the calorimeters is significant.
- Need to simulate up to 300ns «before»
- This means mixing in even more events: consequences on production performance

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Time (s/ev)</th>
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<tbody>
<tr>
<td>Summer12</td>
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<tr>
<td>&lt;PU&gt;\sim21, [-2,2], 50 ns</td>
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</tr>
<tr>
<td>&lt;PU&gt;=20, [-12,2], 25 ns</td>
<td>12</td>
</tr>
<tr>
<td>&lt;PU&gt;=40, [-12,2], 25 ns</td>
<td>26</td>
</tr>
<tr>
<td>&lt;PU&gt;=140, [-2,2], 50 ns</td>
<td>56</td>
</tr>
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</table>
The data flow

Monte Carlo Event Generator
Simulation of the Detector Response
Trigger
Event Reco.
Physics Analysis

IMPROVING THE RECONSTRUCTION
Tying it all together

- Our detectors are very complex beasts, made up by many subdetectors with different purposes and characteristics.
- Sometime useful to consider higher level physics objects like separate entities (electrons, muons, jets…). This is the tradition for most of the collider experiments.
- However a collision event can also be looked at as a «whole». correlations and interconnections across the detectors taken into account.
- The way of performing the reconstruction combining in an optimal way the information of all our detectors: Particle Flow approach (at CMS).
- Developed and used in CMS only (due to different detector characteristics). Might be considered also by ATLAS for the future to be used to fight the harsher PU conditions.

The whole is greater than the sum of its parts (Aristotle)
moves the reference system from the «detector based» to the «particle based» using/combining the full information available into the event

through combination of information it allows to maximally mitigate the PU effects

List of individual particles is then used to build jets, determine missing transverse energy, to reconstruct and identify taus from their decay products, to tag b jets…
the particle flow

- hits in the tracker
- cells in the calorimeter
- hits in muon detectors

link the single objects with geometrical requirements on the extrapolated trajectories and create **blocks**
Comparison of Jet performance

- **Calorimeter jet:**
  - \( E = E_{\text{HCAL}} + E_{\text{ECAL}} \)
  - \( \sigma(E) \sim \text{calo resolution to hadron energy: } 120 \% / \sqrt{E} \)
  - direction biased (B = 3.8 T)

- **Particle flow jet:**
  - charged hadrons
    - \( \sigma(pT)/pT \sim 1\% \)
    - direction measured at vertex
  - photons/electrons
    - \( \sigma(E)/E \sim 1\% / \sqrt{E} \)
    - good direction resolution
  - neutral hadrons
    - \( \sigma(E)/E \sim 120\% / \sqrt{E} \)

Still poor resolution, but neutral hadrons are the smallest component of the jet/event particles:
- 70% charged hadrons
- 20% photons
- less than 10% neutral hadrons
Factor two improvement in the Missing $E_T$ resolution compared to calorimeter based Missing $E_T$ and more robust against PileUp.

$$\overrightarrow{E_{miss}} = - \sum_{i=1}^{N_{particles}} \overrightarrow{E_T^i}$$
wasn’t it good for PU mitigation?

Tracker is in the central region

Flag with Vertexing

Flag with some uncertainty (vtx + shapes)

Guilty by Association (rely on clustering)

Charge Hadron Subtraction: Flag from another vertex and remove it

No tracker Must rely on shapes to identify
Methods for PileUp mitigation

- Subtraction of tracks non associated with the Primary Vertex
- Subtraction of average energy deposit under the jet area from the PU event
- (On these «cleaned» jets) PileUp jet Identification based on Jet Shapes variables
PileUp Jet ID in data & MVA MET

As expected, the PileUp jet fraction increases at larger eta.

PileUp Jet-ID helps remove also the OOT PU.

Factor 4 improvement in PU dependence for MET resolution.
The data flow

Monte Carlo Event Generator
Simulation of the Detector Response
Trigger
Event Reco.
Physics Analysis

COMPUTING CHALLENGES & MONTECARLO PRODUCTION
Offline and Computing challenges for 2015

- In 2015 there are 3 main factors that drive the need to increase computing resources.
  - we expect an increase in the number of pile-up events that with the current code would require a factor of 2.5 increase in reconstruction time to process.
  - the average trigger rate expected to grow a factor of 2.5 higher (if we do not change the thresholds)
  - currently the code reconstruction speed depends on out-of-time pile-up in the tracker (might have a solution for this)

- With no changes in the way the experiment works, we would require a factor of 6 increase in the processing resources to maintain the current activities. Need then to make changes since budget constrain will not allow that.
  - One different operationg mode will be to move PromptReconstruction processing from the T0 to the T1 as well.
    - procedure validated
    - less need for big reprocessing, more space at T1s

- Actually IF these assumptions hold the situation is not so gloomy, however...need always to plan for the worse.
The disk space needs scale because of moving to AOD and not using RECO for analysis even if running at a new energy.

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>Increase from 2012</th>
<th>2014</th>
<th>Increase from 2013</th>
<th>2015</th>
<th>Increase from 2014</th>
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<tr>
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<td>121</td>
<td>0%</td>
<td>121</td>
<td>0%</td>
<td>256</td>
<td>111%</td>
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<tr>
<td>Tier-0 Disk</td>
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<td>0%</td>
<td>7000</td>
<td>0%</td>
<td>3250</td>
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<td>Tier-0 Tape</td>
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<td>26000</td>
<td>0%</td>
<td>38000</td>
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<tr>
<td>CAF CPU</td>
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<td>0</td>
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<td>12</td>
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<tr>
<td>CAF Disk (TB)</td>
<td>0</td>
<td>0%</td>
<td>0</td>
<td>0%</td>
<td>12100</td>
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<tr>
<td>T1 CPU</td>
<td>165</td>
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<td>175</td>
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<tr>
<td>T1 Disk (TB)</td>
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<td>0%</td>
<td>26000</td>
<td>0%</td>
<td>24000</td>
<td>-8%</td>
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<tr>
<td>T1 Tape (TB)</td>
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<td>11%</td>
<td>55000</td>
<td>11%</td>
<td>79500</td>
<td>43%</td>
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<tr>
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<td>0%</td>
<td>27000</td>
<td>4%</td>
<td>31400</td>
<td>16%</td>
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</table>
Possible gains: multicore

- **In any case:**
  - Improved reconstruction algorithms in general (especially Tracking as we have seen)
  - Technical improvements on code size/layout, performance optimization. This always pays off.
    - *<average>* Physicist does not code very efficiently, maybe new generations better?

- **Multicore scheduling:** up to know we have been sending ~one job per core on multicores CPU.
  - During LS1 will switch the scheduling to Multicore on all T1 sites.
  - In first approximation the switch will not increase total throughput right away. Still need to reduce memory requirements etc...
  - In principle the number of jobs would drop from ~80-120K to 10-20K remaining constant.
  - Production will run multicore, analysis will stay single-core but scheduled within a multi-core job
Possible gains: data management and computing model

- Enough disk space to store all the data (twice!) however, static placement ensures safety but it is not the most efficient use of the resources.

- Several technologies ideas developed during LS1:
  - dynamic data placement and cleaning
  - remote access to data in other sites
  - separation of «archival» storage from disk storage at T1s

- Move away from the model of «pre-placing data» at a specific place and sending jobs needing those data only there.
  - Combine use of CRAB/Xrootd/CMSSW popularity + site readiness, Victor (data cleaner), PhEDEx --> triggering automatic transfer of data when needed
  - work in a more central(group) storage space for a more efficient use of the processing power.
Something new: Opportunistic Computing

- During LS1 there will be a significant push into using additional «opportunistic» resources. These are resources usually processing capacity rather than storage, that do not «belong» to CMS/ATLAS, but to which we have access for various reasons.

- This will build on a number of technologies we have adopted over the years to allow for a very «light» footprint at these sites: GlidInWMS, xrootd/AAA, CVMFS, Frontier, Parrot, remote stageout, etc...

- As we are not the primary users of these resources some sites may have «eviction» policies which require us to vacate the resources with little notice.

- Maximing our throughput on those resources might require additional developments.

- In addition, another avenue for increased «opportunistic» use is «volunteer computing», i.e. SETI@Home or BOINC-style processing.
Lesson learned: Software developments from 2001 to 2012

- Going from 7 to 8 TeV step had to cope with improved LHC operations: higher energy, luminosity and PileUp.

- Some improvement came from technical advancement in computing performance, orthogonal to physics event reconstruction.

- Algorithmic development needed as well to cope with higher trigger rate without compromising physics.

- Main gain from tracking algorithm optimization.
Maybe you want a sample?

(Tools for MC production)

- Maybe you want ~100 of them (scan)
  - Imputing/editing each of them by hand is tedious

- Maybe you need it "very fast",
  - It involves several steps and manual interventions

- Maybe you need it right
  - The generator configuration is subject to mistake

- Maybe you need it with a slight change of configuration
  - Which means manual intervention

- Maybe you need it for a given date
  - Which means everyone does and we need a schedule

- Maybe you just want it
  - And it can be lost in manual intervention, lack of book keeping, silent failures, ...

- Specialized tool to handle all the requests
  Bookekeeping via DB. Chaining of similar request, campaign definitions.

- Most important (for the analyzer) improved the monitoring and traceability of the jobs
the complicated life of a MC request
Optimizing the resources: strategy!

CMS Production since January 2013: 8TeV data reprocessing with optimal calibrations taking up most of the T1s

Or to opportunistic computing as San Diego Super Computing (SDSC)

Move the MC production to the T2s!
The plan keeps going... outlook for 2013!

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<tbody>
<tr>
<td></td>
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<tr>
<td>&amp;2 rel. for GEN-SIM</td>
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<td>2011 cond.</td>
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<tr>
<td>Valid.</td>
<td>62X rel.</td>
<td>Valid.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>samples for ECFA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**HLT**
- 2011 Data Hgg
- New 2011 Data Alignment
- Valid.
- 62X rel.
- Valid.
- Valid.
- Valid.
- 2011 Data re-RECO (53X)

**T0**
- 2011 Data Hgg
- GEN-SIM 7TeV 2011 (53X)
- 2011 Data re-RECO (53X)

**T1**
- DR P2
- DR P1
- RD Hgg
- GEN-SIM 7TeV 2011 (53X)
- DIGI-RECO 7TeV MC
- DIGI-RECO 13TeV PostLS1 MC

**T2**
- GEN-SIM Phase2
- GEN-SIM Top
- GEN-SIM 13 TeV
- DR HLT 13TeV
- DR Top

The life of a Data Preparation Coordinator...

Patrizia Azzi - HCPSS 2013

dimanche, 1 septembre 13
MonteCarlo Productions & Reprocessing

- Snapshot of what is going on now in CMS for the «Production» point of view:
  - reprocessing of 7 TeV data with legacy calibrations and reconstruction
  - production of corresponding 7 TeV MC with legacy calibrations and reconstruction
  - production of 13 TeV MC samples to start studies for RunII
  - production of 13 TeV MC for Upgrades studies: detector degradation, new PhaseI configuration, new PhaseII configuration

- All these productions go along with a preliminary validation period before being launched.

- These special validation campaign add up on top of the regular release software validation for the new developments.

- A shutdown is not a vacation for everyone! ;-)
Planning the strategy for the future

- Based on the lessons learned during the past run we need to extrapolate:
  - The amount of MC that will need to be produced ahead of time does not depend only on how much data to expect (x1.3), but which conditions as well.
  - In the beginning small productions with «guesses» at beam spot, PU etc. Need to be trashed away and redone quickly.
  - the time/CPU it will take based on the expected performance of the code need to work hard on the improvement to be able to sustain the HLT rate without reducing the Physics input (i.e. keeping same thresholds as RunI).
  - make sure processing time keeps up with the data flow.
  - the computing model for processing and analysis will need to evolve even more.

- Readiness for Physics in the very beginning of RunII will be crucial. All the eyes will be on us.
Summary & Conclusions &

- During a shutdown there activity is fully projected into the future. Any improvement in technology, algorithms, or just good ideas in terms of strategy and models of operations are crucial.
- It can make all the difference in times of tight budgets. Computing requests need to be reasonable but robust...not easy to predict the future.
- A fast and accurate simulation of the detector, smart reconstructions algorithms and a well organized MC production ahead of collisions will allow analyzers to be ready to come out with physics results in a very short amount of time.
- in between we will have also improved all those certification and calibration tools I talked to you about the other day

I want to thank the School Organizer for giving me the possibility of showing you these aspects of an experimental physicist life. Hope to see you all working with us very soon!