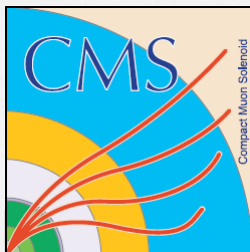


Trigger and DQM at CMS

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Fermilab

Feb 14 2012



Outline

- ❖ Collider Experiment
 - Large Hadron Collider and Compact Muon Solenoid
- ❖ Physics Results in 2011
 - Supersymmetry and Standard Model Higgs searches
- ❖ Trigger System
 - Physics Example
- ❖ Data Quality Monitoring System
 - Focus on Graduate Students' Work

Collider Experiment

Collider Experiment

- o One of main experimental inputs to High Energy (Particle) Physics
- o Consists of an accelerator and detector(s)
 - Accelerator boosts particles and make them collide
 - Can produce 'new' particles
 - Detector measures properties of particles coming out from collided particles

How to Produce An Apple from Oranges?

- o Zero-th degree approximation of Collider Physics is to make an apple from oranges
 - Of course it doesn't happen!
 - But if we replace fruits with particles, what happens?

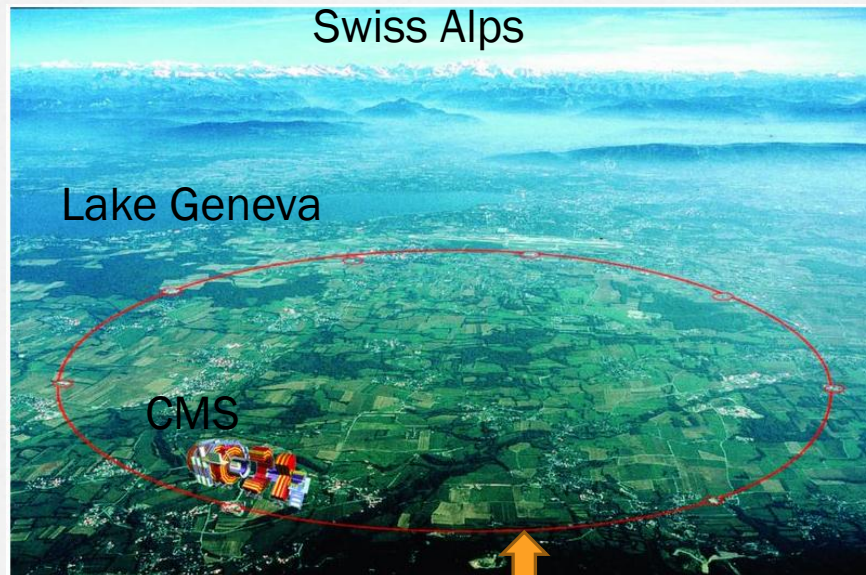


Take QFT courses if interested

LHC and CMS

- o Large Hadron Collider is the proton-proton (heavy ion) collider which delivers the highest center of mass energy
 - ❖ p-p run 7TeV so far, and 8TeV in 2012
 - ❖ It is on the French-Swiss border
 - Opportunity to stay in France or Swiss
- o Compact Muon Solenoid is one of the general purpose detectors at LHC (more than 3000 collaborators)

LHC and CMS



LHC Tunnel

Human Beings

What HEP Experimentalists Do?

- o Design and Build a detector
 - ❖ Less likely in these days as a detector became huge and expensive
 - ❖ May work on detector upgrade (e.g., Pixel, Tracker, Muon Chamber)
- o Perform Analysis
 - ❖ Writing analysis code (most likely in C++) and paper
 - ❖ Giving talks internally and going to conference (APS, Moriond, etc)
- o Work for experiment
 - ❖ 'Service' is required
 - ❑ Hardware & software maintenance/update
 - ❑ Run operation (participating in shifts)
 - ❑ Coordination, peer-review paper
- o Better chance of being funded
 - ❖ Typically only 2 years of Teaching



UC Davis on CMS

- o Contribution
 - pixel and muon detector
 - tau, top, exotics, and higgs physics

- o New faculty
 - ❖ Mike
- o New Postdocs
 - ❖ Justin and Scott
- o 1st Generation Graduate Students & Postdoc left
 - ❖ Evan, Jorge, Christian, and myself
- o 2nd Generation graduating
 - ❖ James, Tia, and more
- ✓ CDF graduate students graduated or graduating as well
 - New Graduate Students should join!



Physics Results in 2011

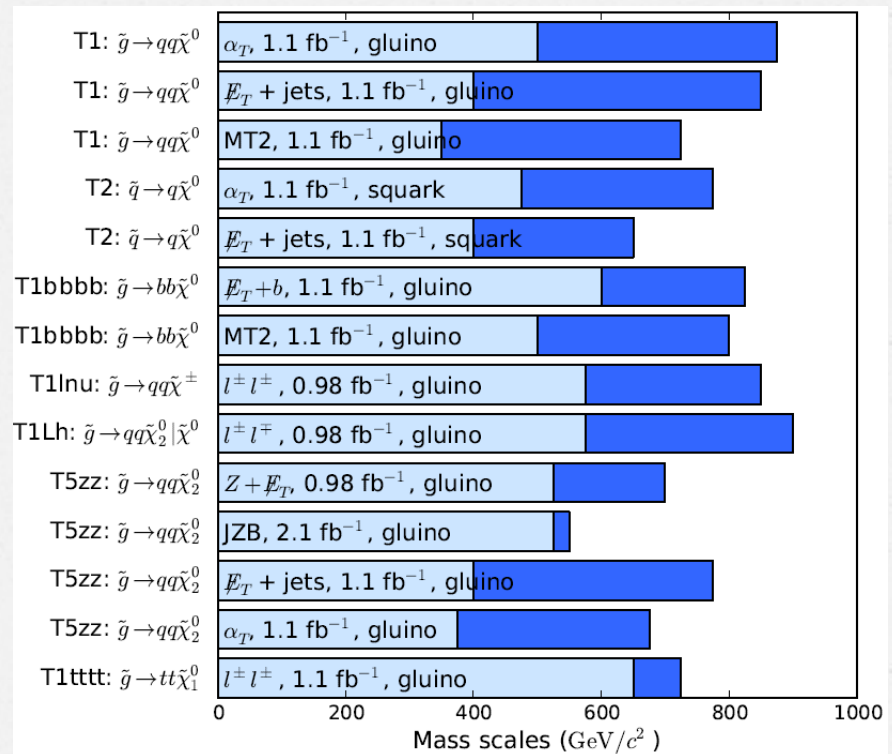
CMS SUSY Results in 2011

- o No discovery
 - ❖ Setting limits on various models
 - (e.g., SUSY)
- Limits on Gluino and Squark masses
- With the mass relation



$$m(\tilde{\chi}^{\pm}), m(\tilde{\chi}_2^0) \equiv \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}.$$

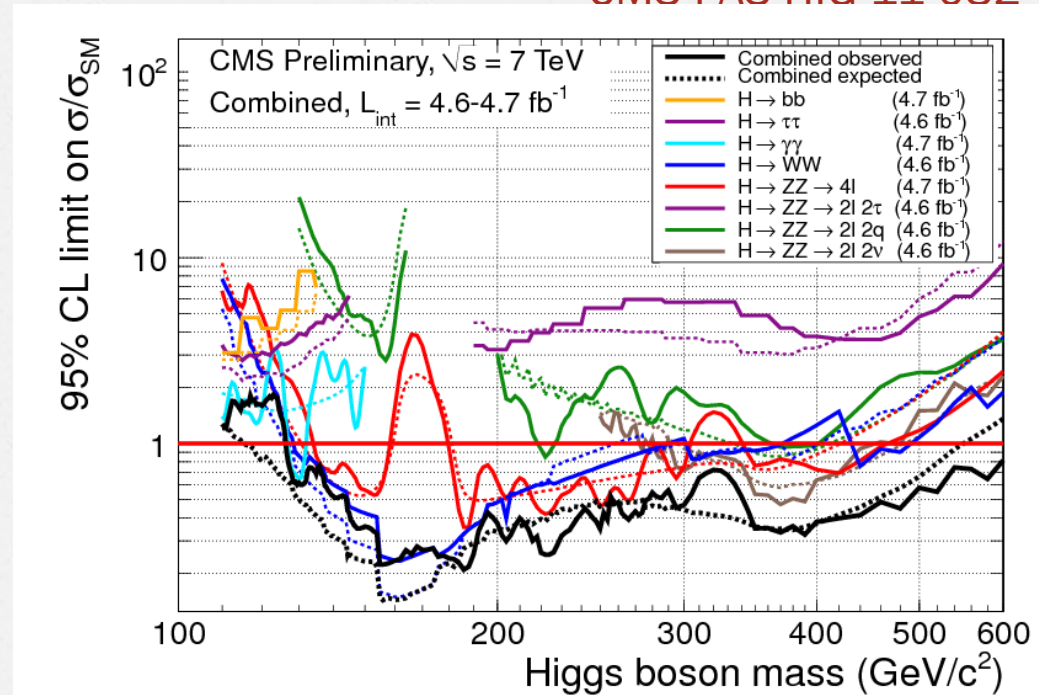
$m(\tilde{\chi}^0)$ is varied from 0 GeV/c² (dark blue) to $m(\tilde{g}) - 200$ GeV/c² (light blue)



CMS Higgs Results in 2011

CMS-PAS-HIG-11-032

o SM Higgs Evidence?

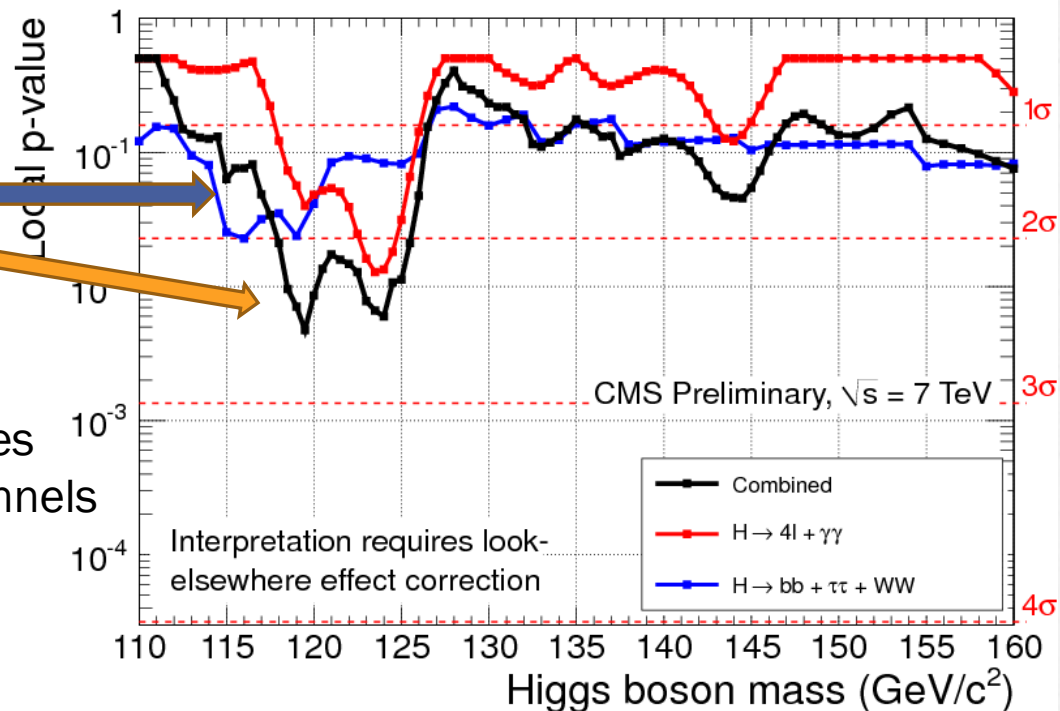


Excluded SM Higgs mass from 127 to 600 GeV/c 2 at 95% C.L.

CMS Higgs Results in 2011 (2)

Wiggles between 115 and 125 mass region

- Mass resolution varies among different channels
 - 1-20%

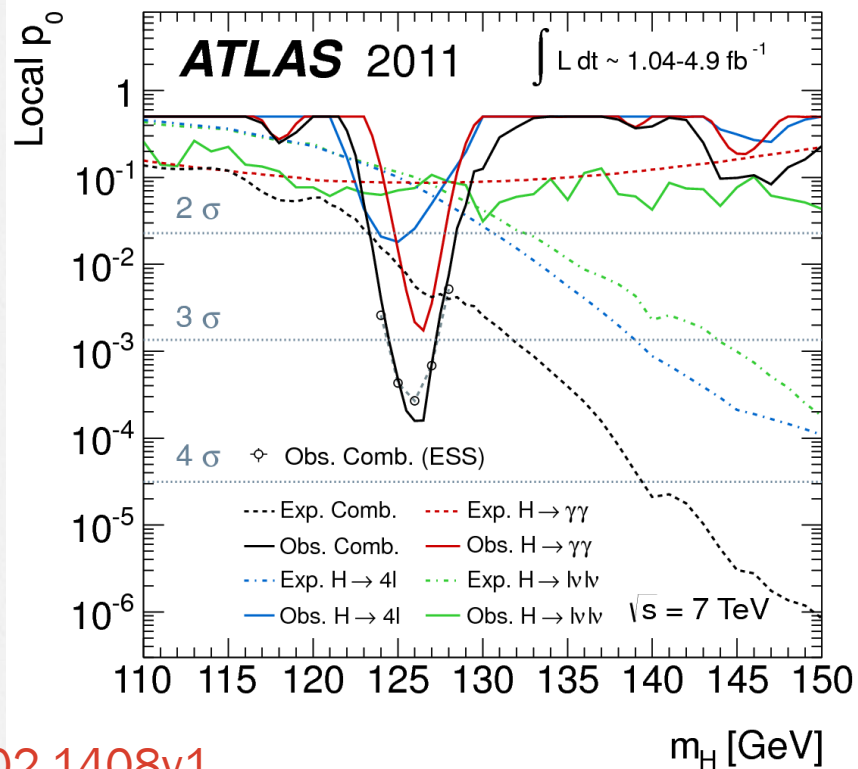


Take Stats course if interested

ATLAS Higgs Results in 2011

❖ ATLAS 'confirmation'?

- Similar results
- ATLAS sees wiggles as well

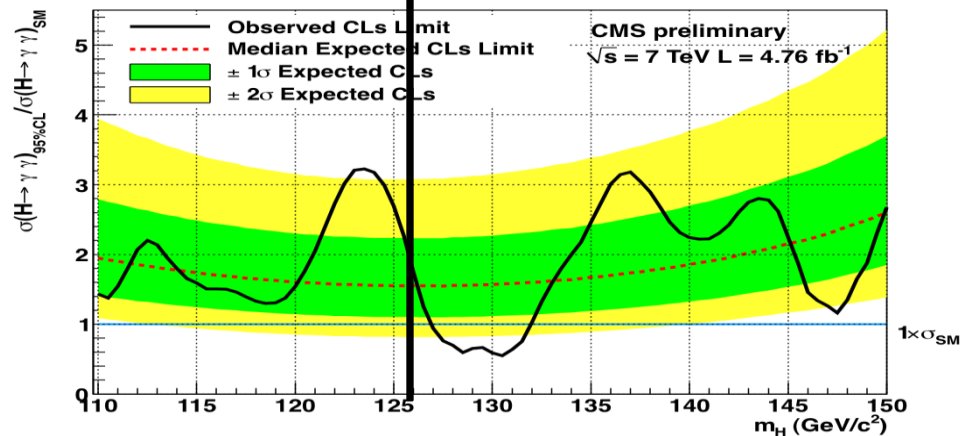
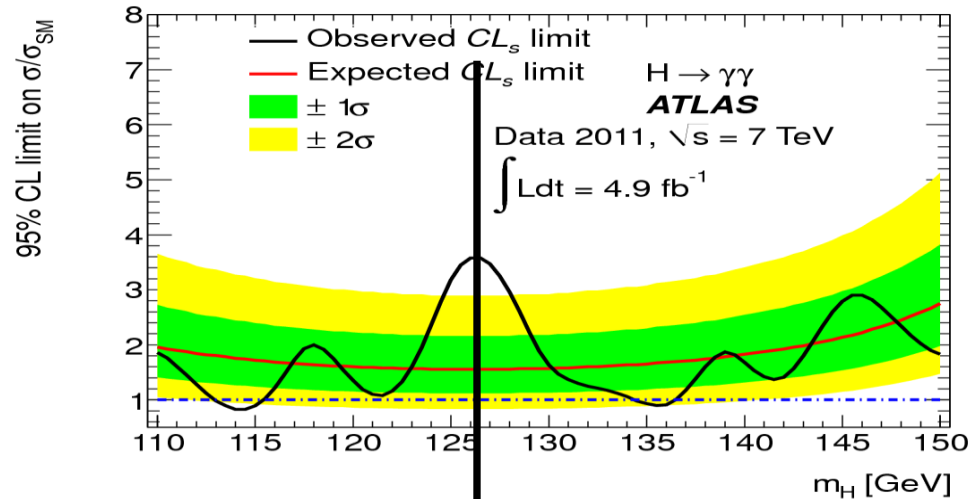


[arXiv:1202.1408v1](https://arxiv.org/abs/1202.1408v1)

LHC Higgs Results in 2011

- Higgs to diphoton
- Off by a half wavelength
- Destructive Interference?

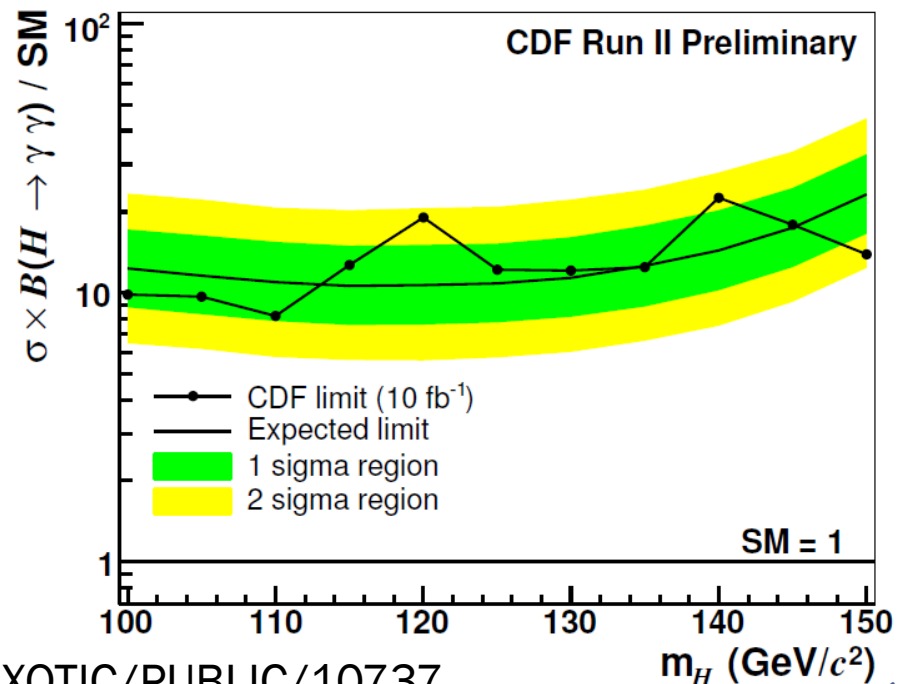
Could be Background fluctuation



CDF Higgs Results in 2011

❖ CDF 'confirmation'?

- Higgs to diphoton
- A little more events around 120 GeV/c²

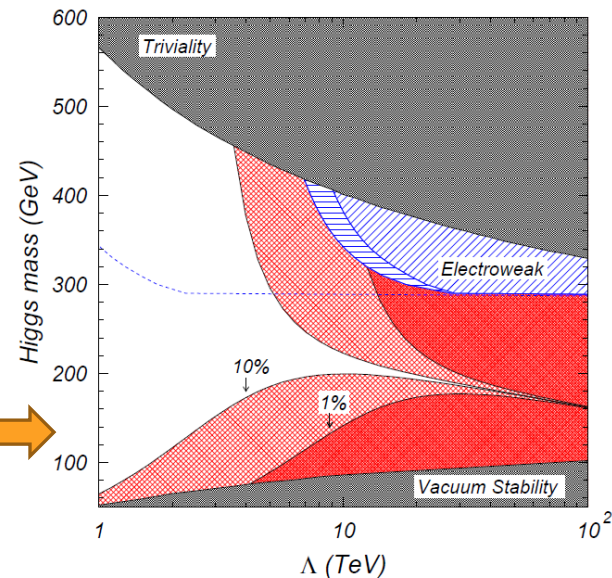


CDF/PUB/EXOTIC/PUBLIC/10737

Implication of SM Higgs (1)

- If SM Higgs has been seen at LHC
 - ❖ The new energy scale could be low enough to be probed at LHC

- If Nature tolerates $O(1\%)$ fine tuning & SM Higgs mass $\sim 120\text{GeV}/c^2$
- New Physics Energy Scale $\sim 7\text{TeV}$

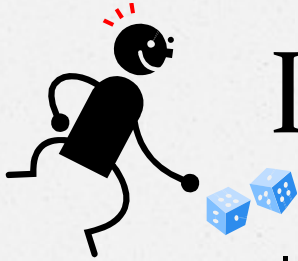


Kolda et al, hep-ph/0003170

Implication of SM Higgs (2)

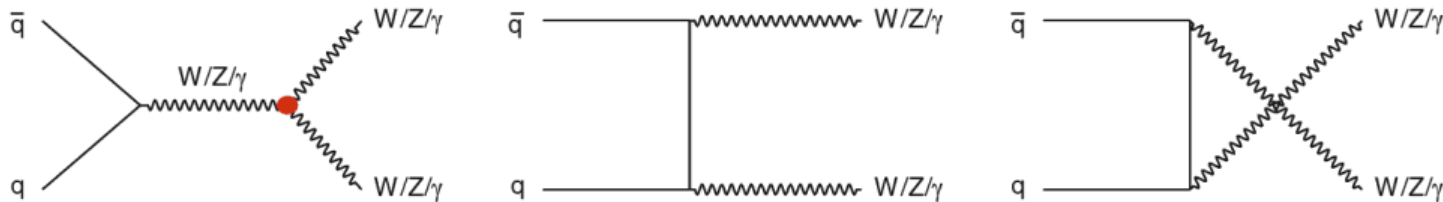
- If SM Higgs has been seen at LHC
 - ❖ LHC Physics will be centered on measurements of Higgs properties
 - Mass, spin, cross section, etc
 - Good/bad news for BSM theories
 - Simple SUSY models prefers low mass Higgs
 - Constrains such models otherwise
 - Good news for linear collider advocates
 - Center of mass energy doesn't have to be so high; can be built with existing technologies?





If it's a fluctuation...

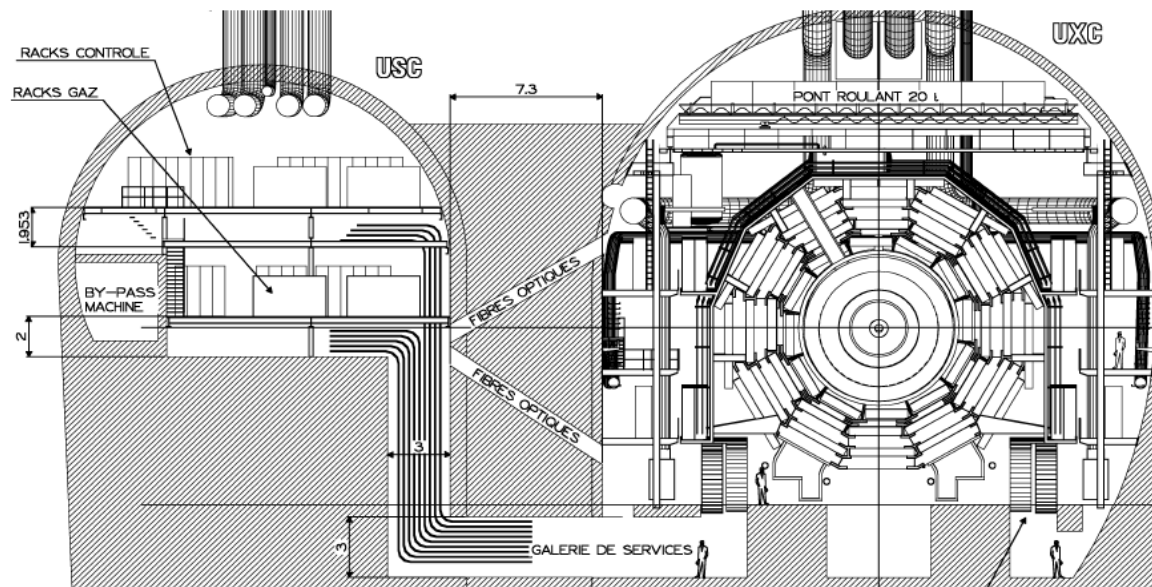
- Is existing theory/model right in higher energies?
 - ❖ No! SM remains incomplete
- Is it the end of LHC?
 - ❖ No! Wider parameter space can be probed
 - ❖ Relax/constrain assumptions accordingly
- Even within EWK, we can study multi-boson processes
 - ❖ Many di-boson events already in 2011
 - Leptonic WZ events alone > 300 after event selection
 - ❖ Tri-boson $O(100\text{fb}^{-1})$ needed, beyond 2012
- Theorists will tell us what to do



Trigger at CMS

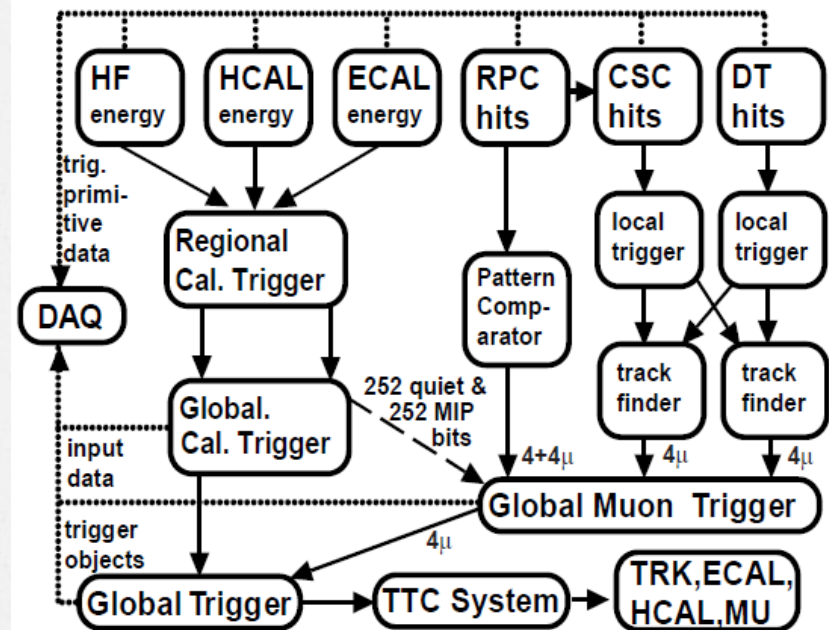
Trigger

- ❖ Hadron collider produces tons of soft QCD jets
 - ❑ Cannot save all events, and signal is tiny
- Two-Level Trigger System
 - Level 1 and High Level



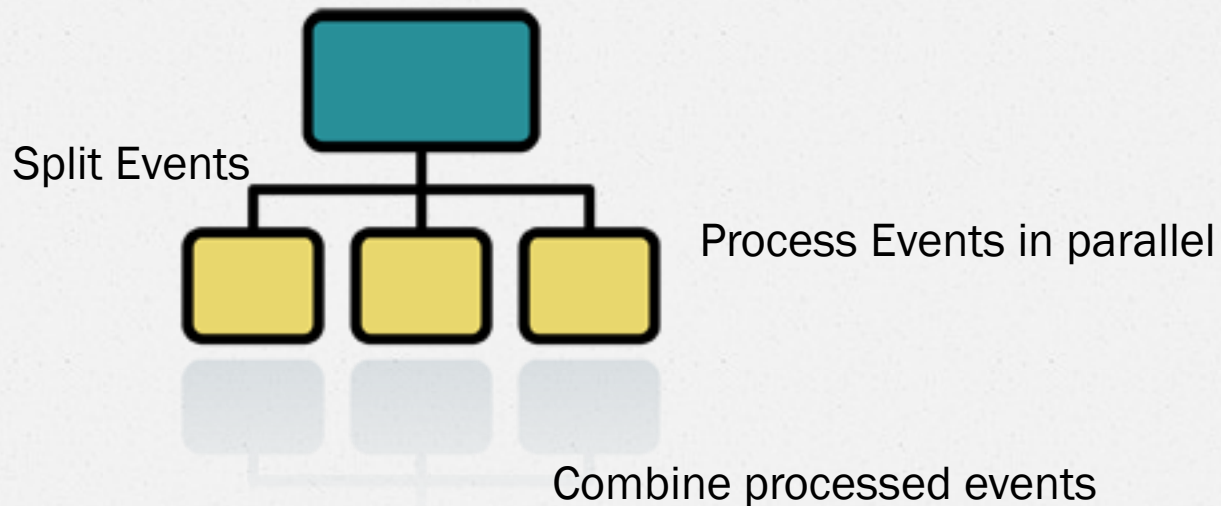
Level 1

- o Custom electronics
 - FPGA and ASIC
- o Placed on detector and in Counting Room
 - Radiation Hardness
- o Bunch crossing time; 50ns
 - Fast decision
- o Pipelined Memory
 - Latency; 3.2 microns
- o Reduce 40MHz to 100kHz



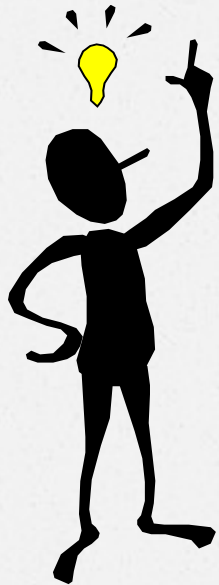
High Level

- CPU farm
 - Sophisticated even selection is possible
 - Iterative algorithm may take too much time
- Reduce 100kHz to 300Hz



Physics Example

One day, some theorist...



- Gets up in morning and writes down a godsend lagrangian
- He/she checks the signal is visible at LHC
- He/she asks experimentalists to confirm the signal
- Then experimentalists will say...

Experimentalists say...

- o Data is too small
 - If the signal is single medium P_T lepton/jet
 - Only 2010 data can be used; 36pb^{-1}
 - Single Muon with $P_T > 13\text{ GeV}/c$
- o Data is not adequate
 - If the signal is medium P_T two-objects, or $(M)E_T$ sum
 - 2010 plus some fraction of 2011 data $O(\text{fb}^{-1})$
 - Two Muons with $P_T > (17,8)\text{ GeV}/c$
 - $(M)E_T$ sum > 200 or 750 GeV
- o Great! Let's find out
 - ❖ Otherwise, multi-object cross trigger have lower threshold in general

Trigger Strategies

- o Elect your graduate student trigger contact
 - Your trigger need is well maintained
 - Considerably high workload
 - Trigger menu reviewed and revised every 2 weeks (2011)
 - Unattended paths will be dropped
 - Not considered as service work, but other people free-ride your effort
- o Choose decay chain similar to important SM background
 - Your trigger need is always guaranteed by someone else
 - May suffer from large BG
 - Still be careful with trigger threshold
 - E.g, inclusive W was quite difficult in 2011
 - Leptonic Z will be harder in 2012

Analysis Specific Trigger

- o You may tailor-made your trigger
 - As an example, here is 'α_T' trigger in SUSY

[arXiv:1101.1628v2](#)

$$\alpha_T = \frac{E_T^{\text{jet}_2}}{M_T} = \frac{E_T^{\text{jet}_2}}{\sqrt{\left(\sum_{i=1}^2 E_T^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^2 p_x^{\text{jet}_i}\right)^2 - \left(\sum_{i=1}^2 p_y^{\text{jet}_i}\right)^2}}$$

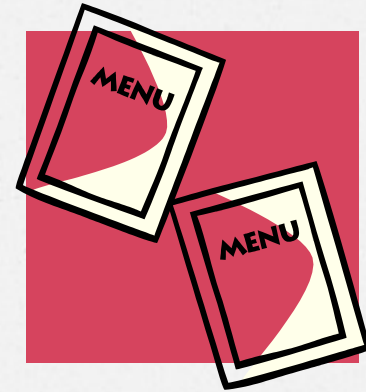
$$M_T = \sqrt{\left(\sum_{i=1}^n E_T^{j_i}\right)^2 - \left(\sum_{i=1}^n p_x^{j_i}\right)^2 - \left(\sum_{i=1}^n p_y^{j_i}\right)^2} = \sqrt{H_T^2 - (H_T^{\text{miss}})^2}$$

QCD dijet events have $\alpha_T = 0.5$

Different mass points in SUSY have preferred α_T value

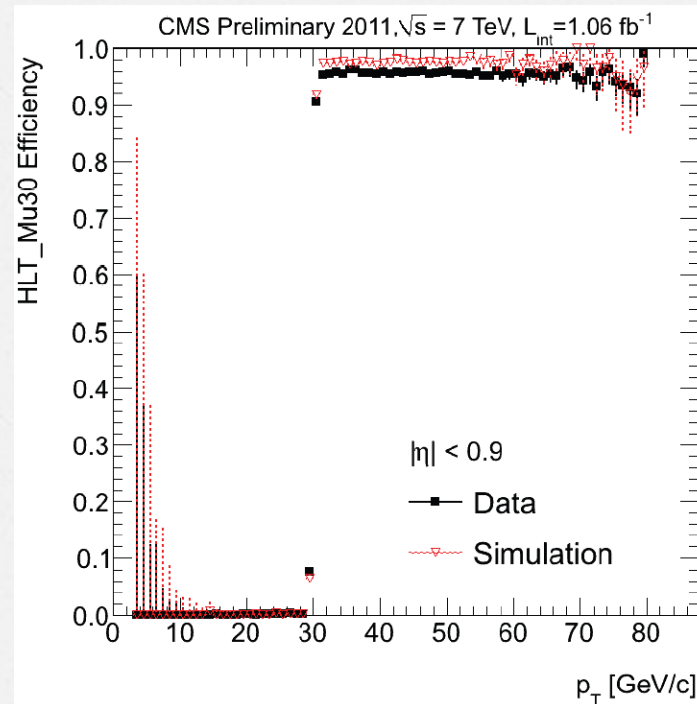
Trigger Menu

- o Level 1 Trigger paths
 - ❑ Algorithm = 2^7 bits for 'physics'
 - ❑ Technical = 2^6 bits for sanity check
 - ❑ Usually open slots available
- o High Level Trigger paths
 - ❑ Unlimited slots (~500 in 2011)
 - ❑ New paths need to be approved by Physics Office and Trigger Study Group
 - Motivation plus Performance
 - Usually maintained by graduate students and postdocs
- ❖ Prescale 'columns'
 - L1 and HLT have separate prescales
 - Prescale = accept an event in N events
 - For BG estimation



Trigger Performance

- Signal Efficiency
 - How much signal can be obtained?
- Purity of Trigger
 - How many triggered events can be used?
 - Often purity is low (as low as O(5%))
- Trigger Rate
 - Estimated from data and simulation
 - Usually O(1Hz)
- CPU time at HLT
 - OK if it doesn't increase total time significantly



Bandwidth Allocation



- o Trigger System Capability is limited
- o Large chunks are allocated to analysis groups; EWK, TOP, EXOTICA, SUSY
 - Each group allocate bandwidth to each analysis sub-group
- o Cannot make everyone happy (hard time in 2011 due to budget)
 - Even harder competition with higher luminosity and Pileups

Trigger Trend (1)

- o Trigger threshold is Level 1 limited
 - Rate reduction at HLT may not be sufficient
- o Non-linear increase in almost all paths
 - Few exceptions are non-isolated multi-lepton cross triggers
- o No drastic improvement expected in 2012
 - Trigger conditions will be tightened
- o Improvements in 2011
 - Particle-flow (better E_T resolution) with fast enough PF Tracking at HLT
- o Improvements in 2012
 - L1 Pileup subtraction (better turn-on)?
- ❖ Energy will be 8TeV, but most likely less increase in instantaneous luminosity in 2012 compared to 2011
 - $\sim 16 \text{ fb}^{-1}$ integrated luminosity projection is based on $\sim 6\text{E}33$
 - 8TeV impacts at the beginning, and less change after that?

Upgrade

Direct
Indirect

- o Long Shutdown Phase I (~2014)
 - ❖ Replacing Sub-detector electronics, Forward Muon
- o Long Shutdown Phase II (~2017?)
 - ❖ New Pixel, HCAL photo-detector, Forward Muon, micro-TCA (better debugging and maintenance)
- o Long Shutdown Phase III (~2021?)
 - ❖ New Tracker, Tracking Trigger
- Not easy to lower trigger threshold

DQM at CMS

DQM

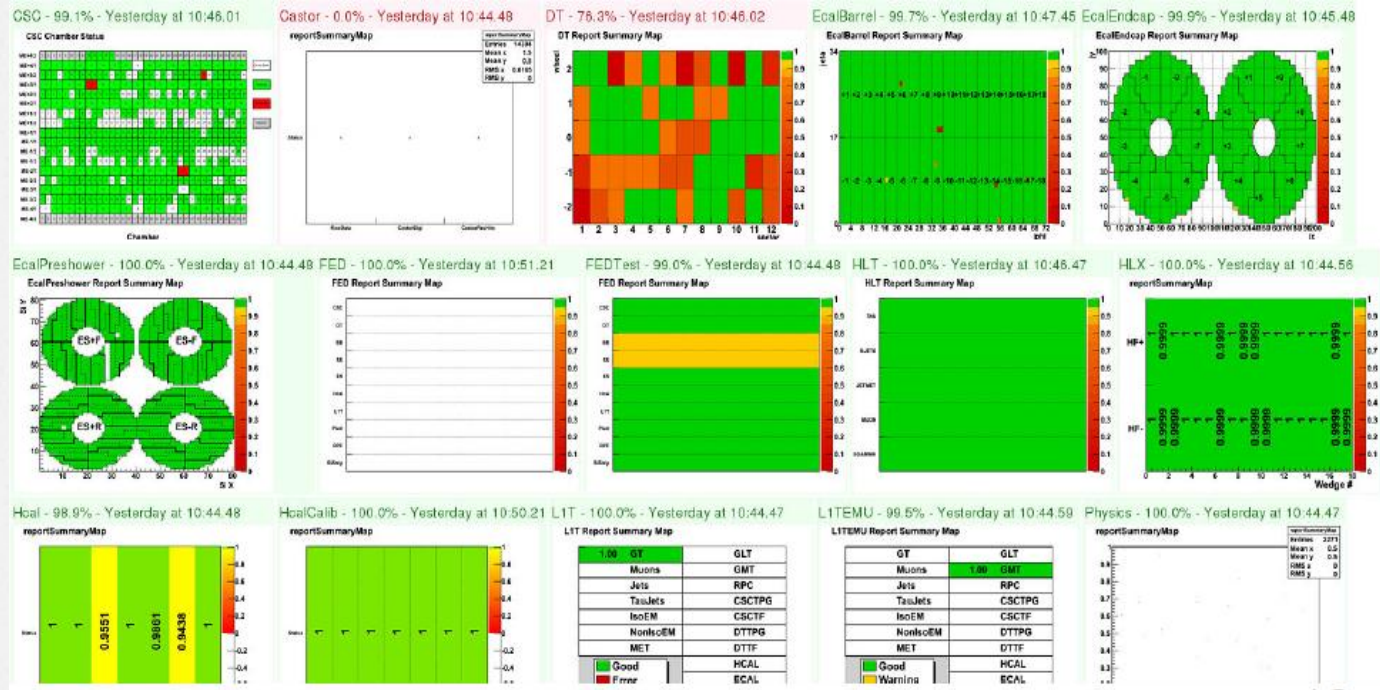


- Data Quality Monitoring
 - ❑ Is for maximizing the amount of usable data
 - ❑ Delivered Luminosity is always larger than recorded luminosity (human error, hardware/software crash)
 - ❑ Recorded Luminosity is always larger than certified luminosity (sub-detector conditions, calibration)
- ❖ To accomplish this goal, each sub-detector and physics object is monitored online and certified offline by DQM shifter and corresponding experts
 - ❑ Data Certification is crucial for publication in timely manner
 - ❖ Recorded data is certified everyday after event reconstruction (~2days delay)
 - ❖ Each analysis group updates results accordingly

DQM Shifts

- Two types of shifts
 - Online at Control room (P5) in France
 - Focus on detector response
 - Offline at CERN, DESY (Germany), and FNAL (IL)
 - Physics object reconstruction is checked
- Each institution is asked to deliver 'central' shift points based on #collaborators
 - DQM shifts are considered as central shifts
 - 2010, there was punishment for violators
 - 2011, no penalty as far as I know
 - 2012, 7.3 points times #collaborators
 - About 200 for UCD, ~40 signed up so far

DQM GUI



Example Summary Plots
Usually **Green** = Good, and **Red** = Bad

DQM Software

- o DQM needs updated inputs for each sub-detector and physics object
 - Reference plots are provided and updated as often as necessary in DQM GUI
 - This is considered as 'service' work in DPG, POG, and PAG
- o DQM shifters check that incoming data is consistent with past 'good' data
 - Certify runs good or bad
- o Experts are notified if new data seem much different from the past good one
 - 'On-call' shifts are available for experienced shifters



DQM Upgrade

- o DQM was not a part of CMS Technical Design Report
 - Thus there was no upgrade plan!
- o A proposal is just made and under review
 - Main goal is to have a clear picture and keep experts funded
 - Integrate various tools and groups for DQM
 - Needs to be approved

Summary

Recap

- o LHC 2012 data will be a big impact in HEP whether SM Higgs is there or not
- o Trigger conditions will be most likely tightened continuously until 2021(?)
- o Reviewed trigger system and implementation, and DQM system and operation, where you may contribute and be credited



For Students

- No problem to graduate on time
 - ❑ Enough Data to write your thesis!
 - ❑ Talk to theorists and cook up something
- Opportunity to learn something different
 - ❑ Living abroad (and accumulate mileage flew)
 - ❑ Working with people from other US universities, non-US organization
- ❖ Keep up the good work for distinction
 - CMS Thesis Award
 - CMS Achievement Award (each sub-detector)



Thank you!