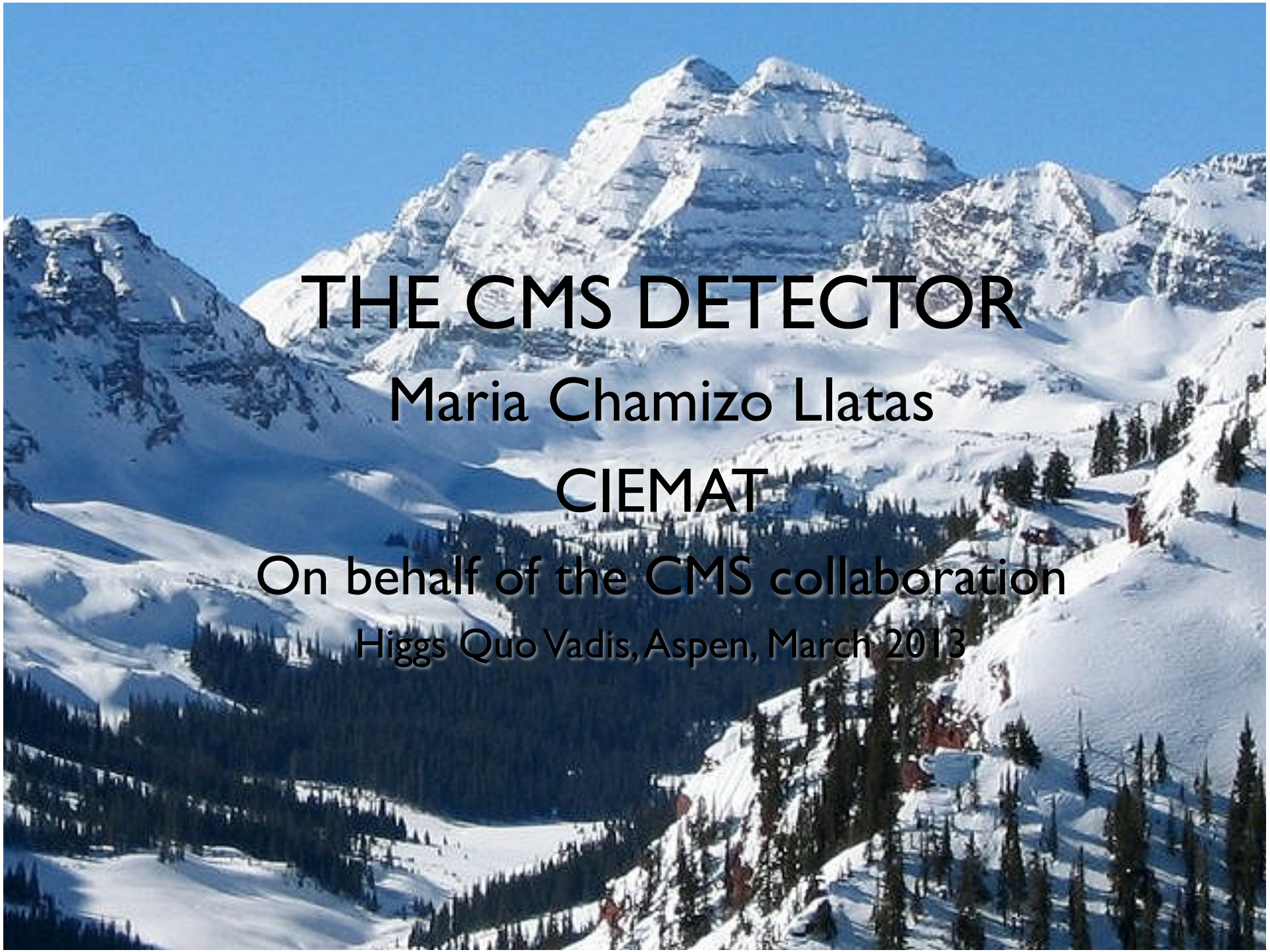


THE CMS DETECTOR

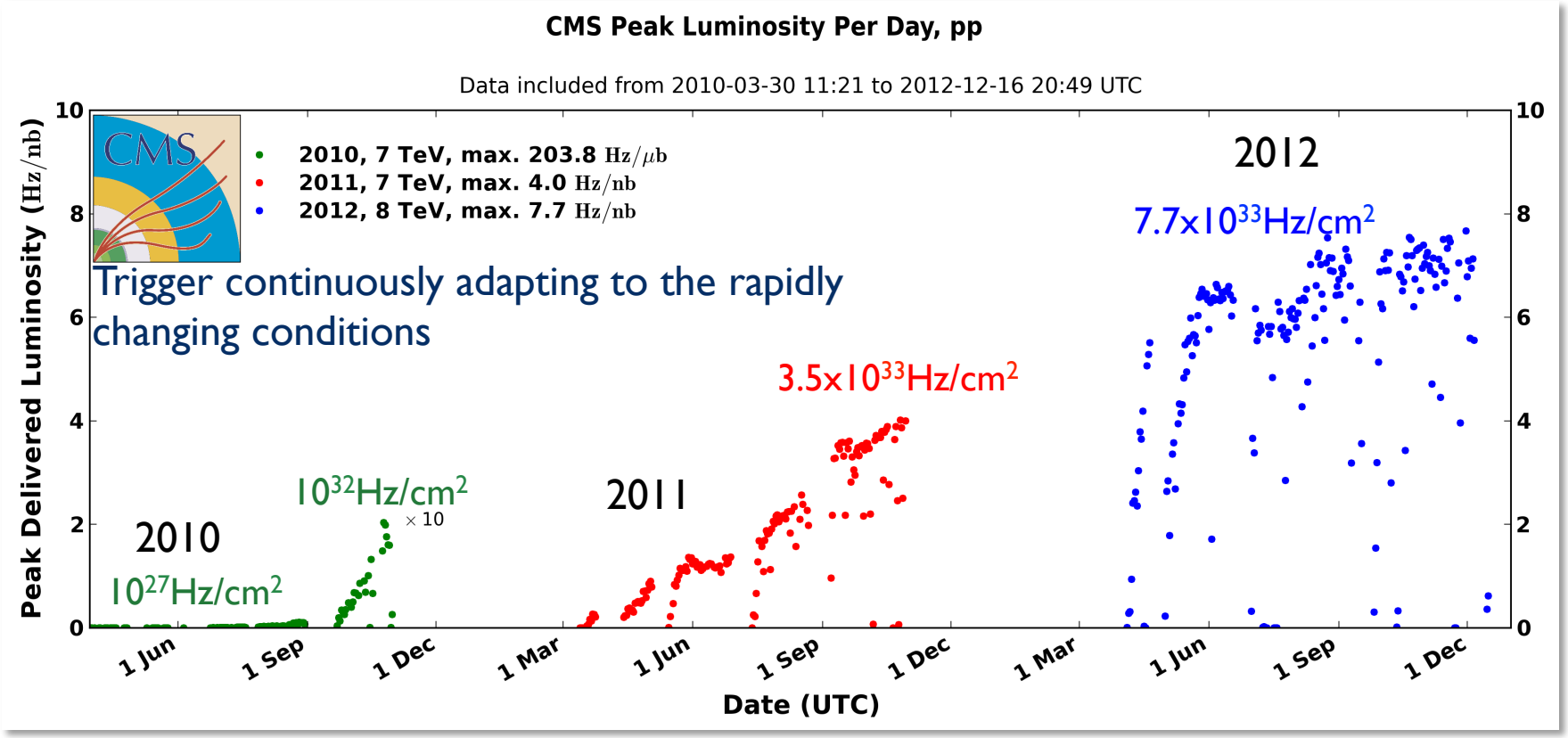
Maria Chamizo Llatas

CIEMAT

On behalf of the CMS collaboration

Higgs Quo Vadis, Aspen, March 2013

CMS instantaneous luminosity

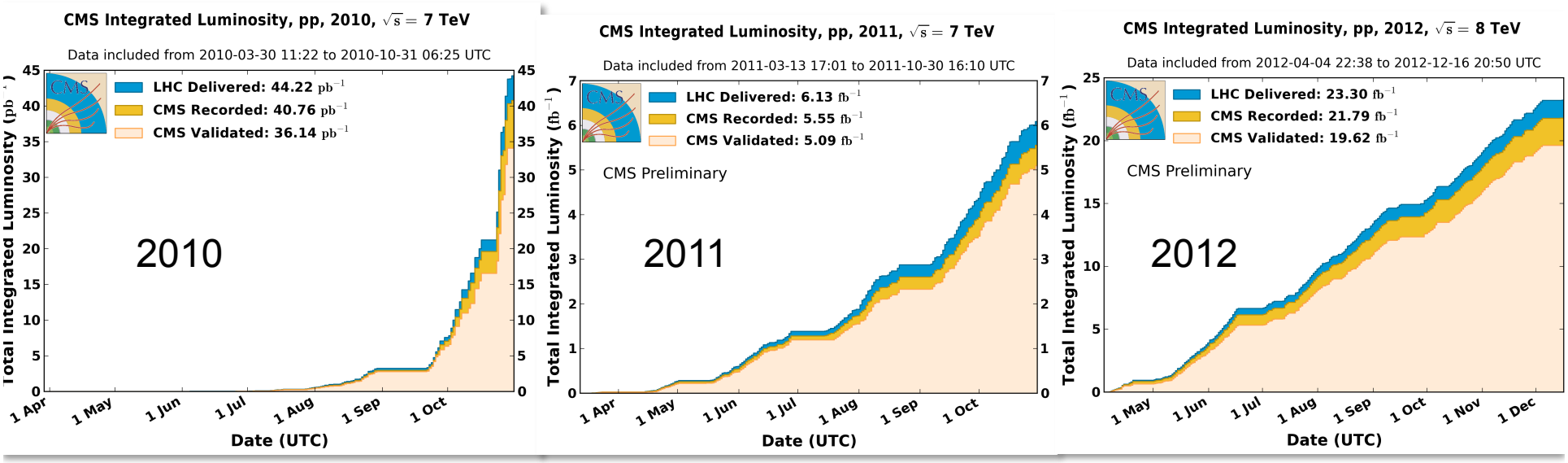


In 2010: luminosity increased by 5 orders of magnitude

In 2011: instantaneous luminosity reached 40% of the nominal LHC luminosity

In 2012: The LHC reached 77% of the nominal luminosity

Data taking efficiency and data validated



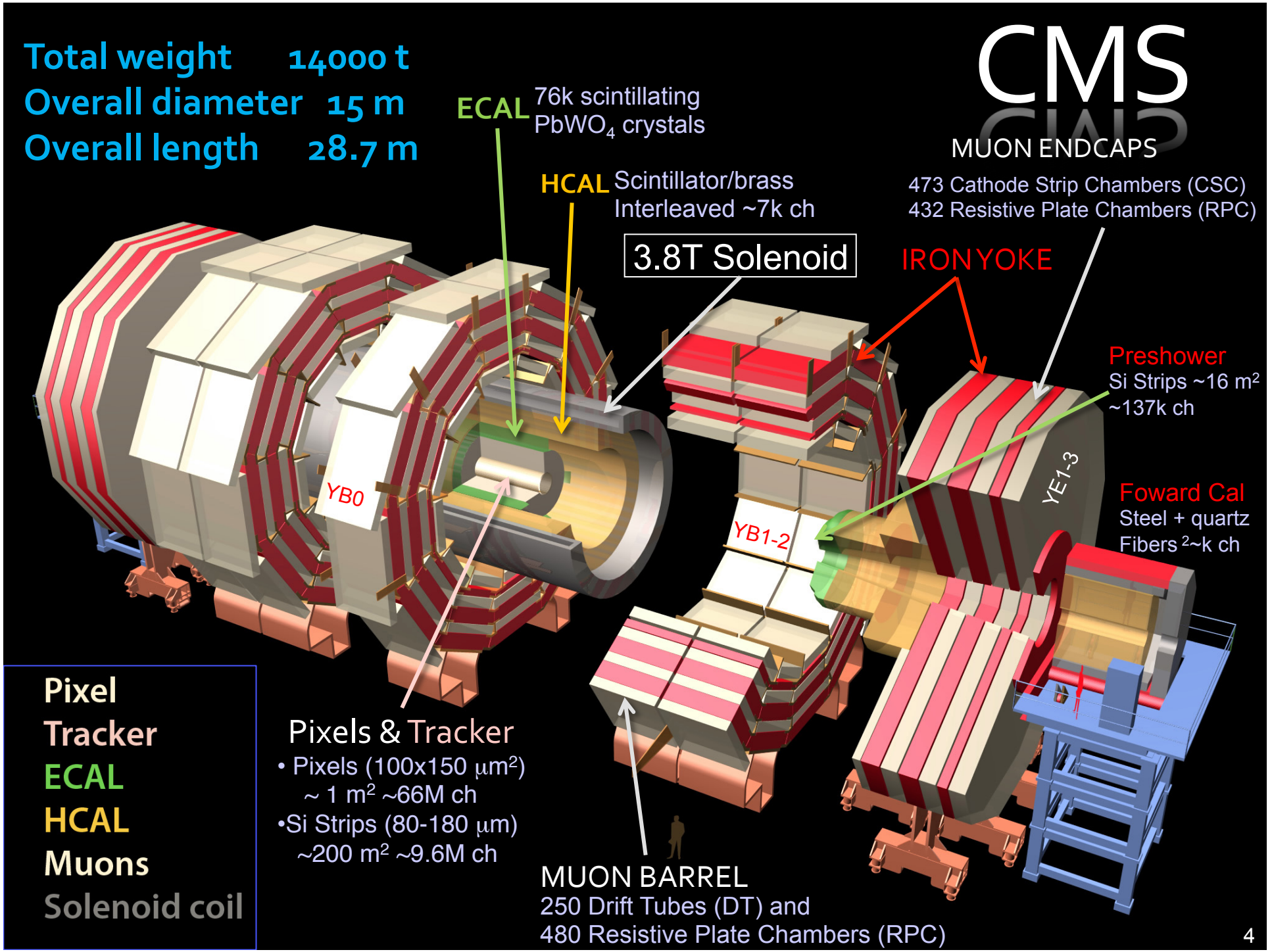
Data taking efficiency

- Increased in 2012 due to development of automatic recovery procedures

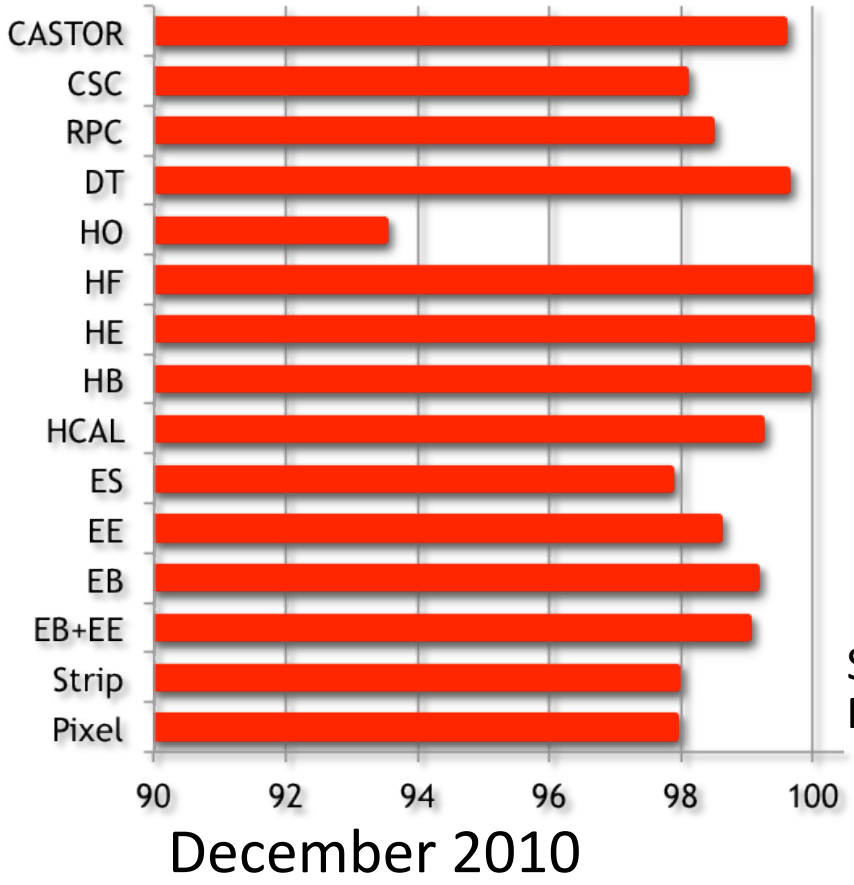
Data validated

- Very stable over time ~90%

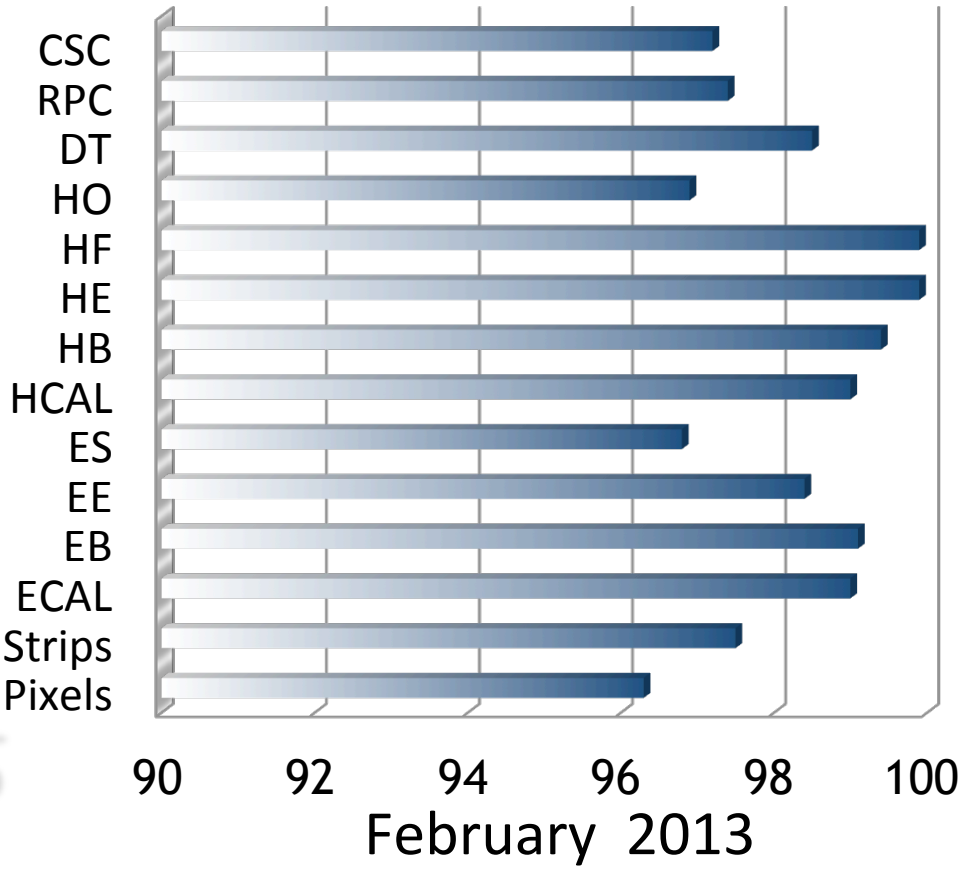
Period	$\sqrt{s}$ [GeV]	Delivered luminosity [fb^{-1}]	Data taking efficiency [%]	Data validated [%]
2010	7	0.044	92.2	88.6
2011	7	6.13	90.5	90.1
2012	8	23.20	93.5	90.0


Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m
CMS
ECAL 76k scintillating PbWO4 crystals
HCAL Scintillator/brass Interleaved ~7k ch
3.8T Solenoid
IRON YOKE
MUON ENDCAPS
473 Cathode Strip Chambers (CSC)
432 Resistive Plate Chambers (RPC)
Preshower
Si Strips ~16 m2
~137k ch
Foward Cal
Steel + quartz Fibers 2~k ch
YB0
YB1-2
YE1-3
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm2) ~ 1 m2 ~66M ch
•Si Strips (80-180 μm) ~200 m2 ~9.6M ch
MUON BARREL
250 Drift Tubes (DT) and
480 Resistive Plate Chambers (RPC)

Percentage of CMS active channels



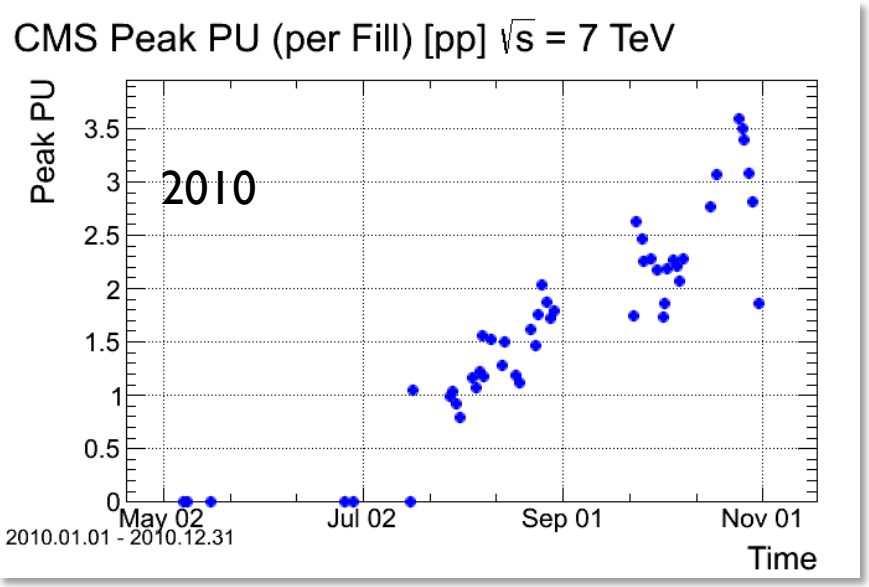
December 2010

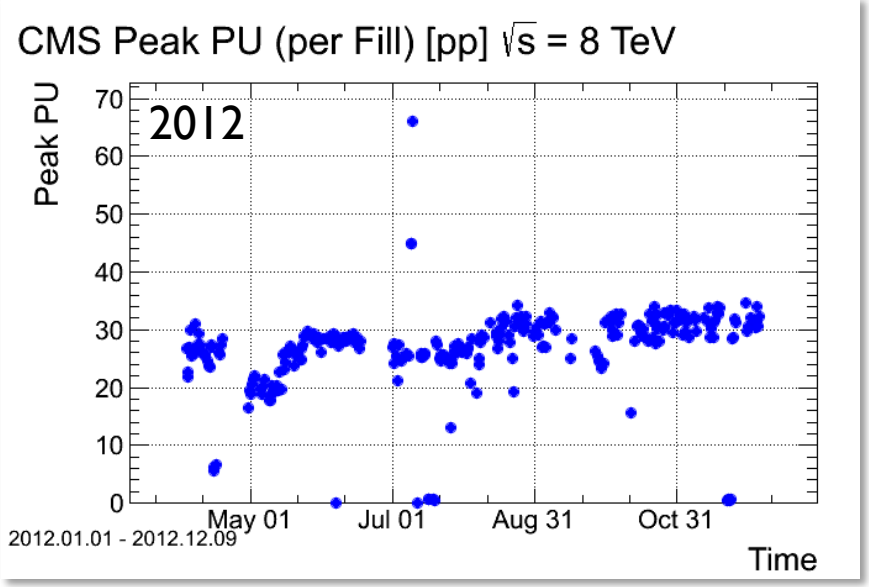


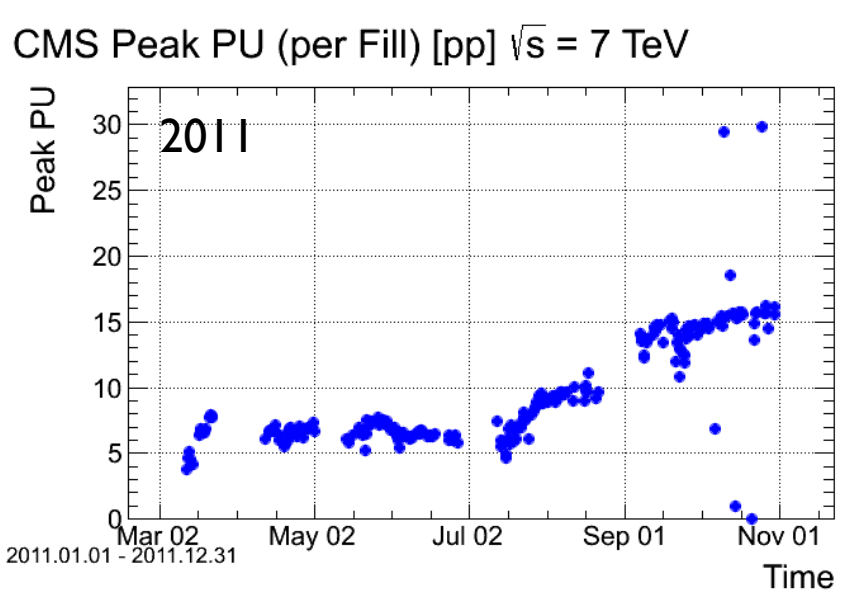
February 2013

CMS Subsystem	CSC	RPC	DT	HCAL Outer	HCAL forw.	HCAL end.	HCAL barrel	HCAL	Presho wer	ECAL end.	ECAL barrel	ECAL	Strips	Pixels
% operational Feb 2013	97.2	97.4	98.5	96.9	99.9	99.9	99.4	99	96.8	98.4	99.1	99	97.5	96.3

Pile up evolution 2010-2012





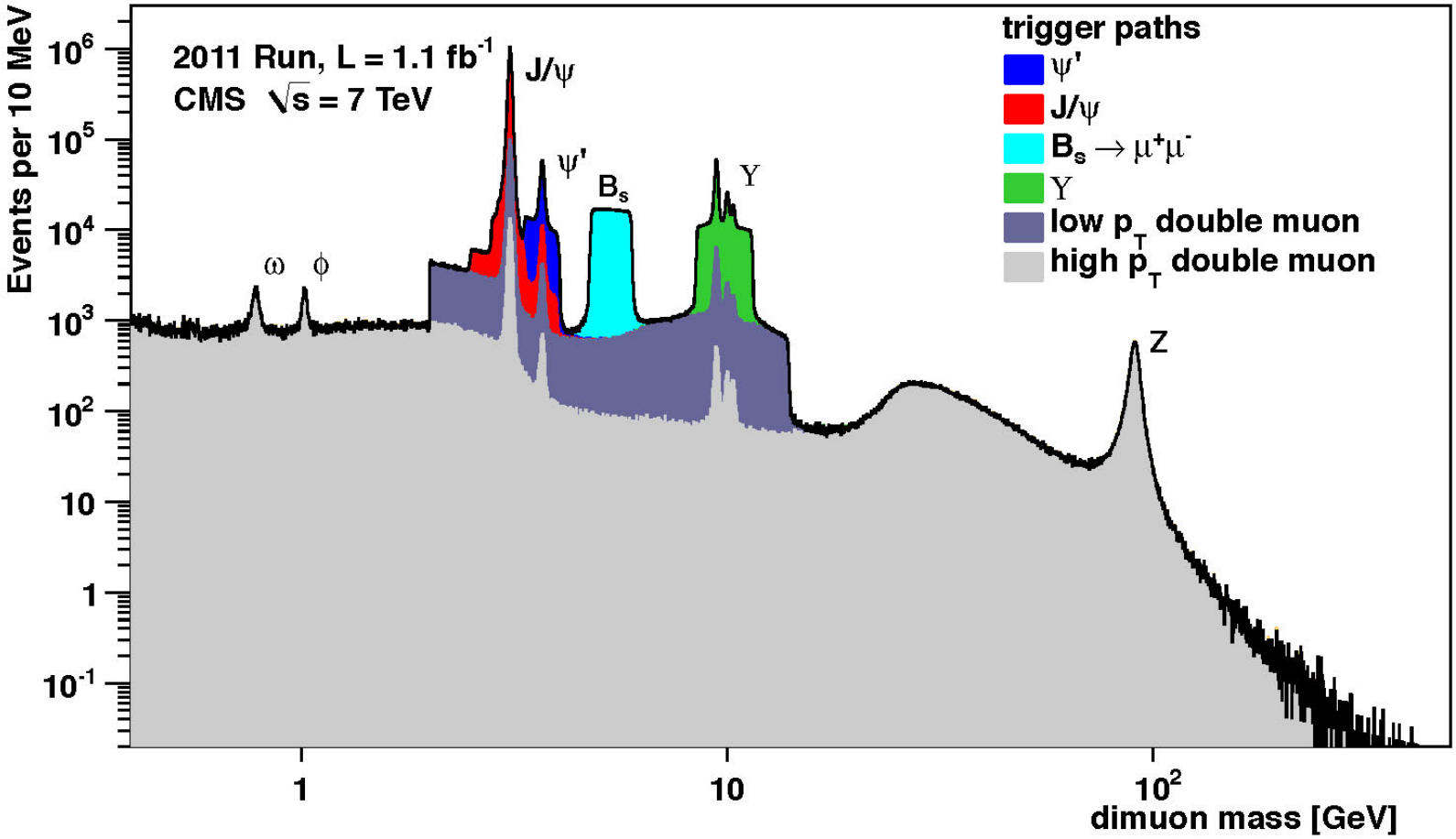


LHC parameters optimized to reach higher luminosities

→ Higher higher pile up

Period	Peak average pile up
2010	3.5
2011	18.6
2012	34.5

Re-discovery of the Standard Model 2011

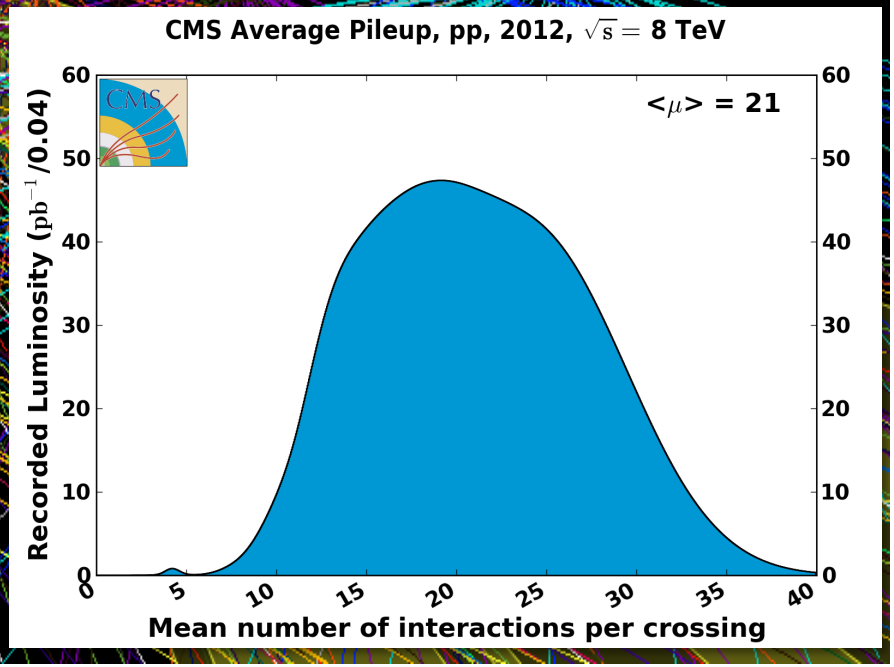


Trigger with full dimuon acceptance at the beginning of 2011

We did not keep it for the whole year→ need bandwidth for other triggers

The challenge in 2012

CMS design value: 25 pile up events at luminosity $10^{34}cm^{-2}s^{-1}$ and 25 ns bunch spacing



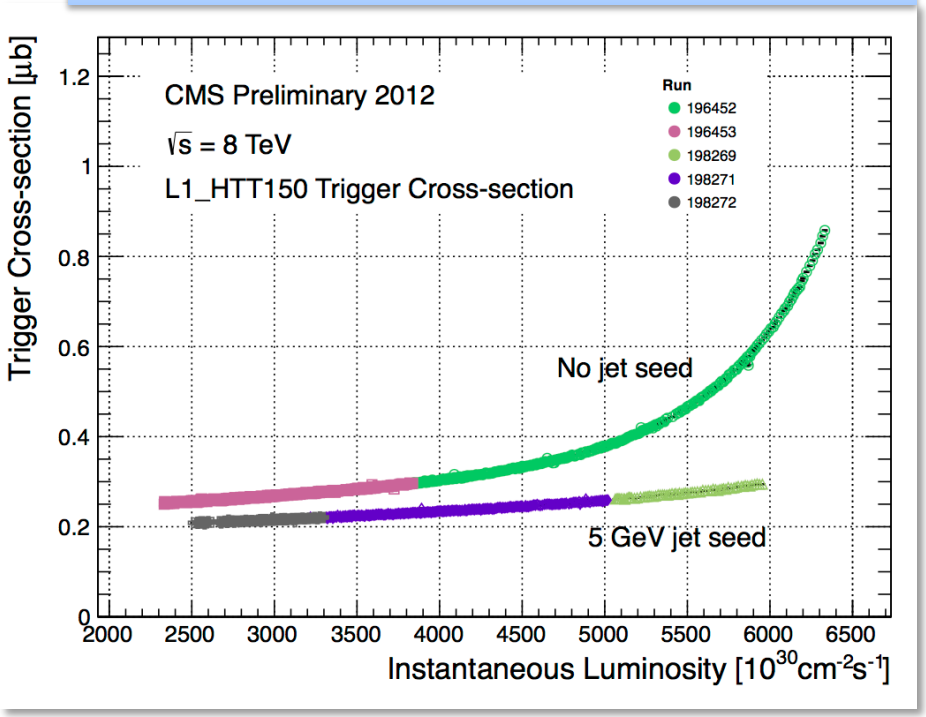
Raw ΣE_T~2 TeV
14 jets with E_T>40 GeV
Estimated PU~50

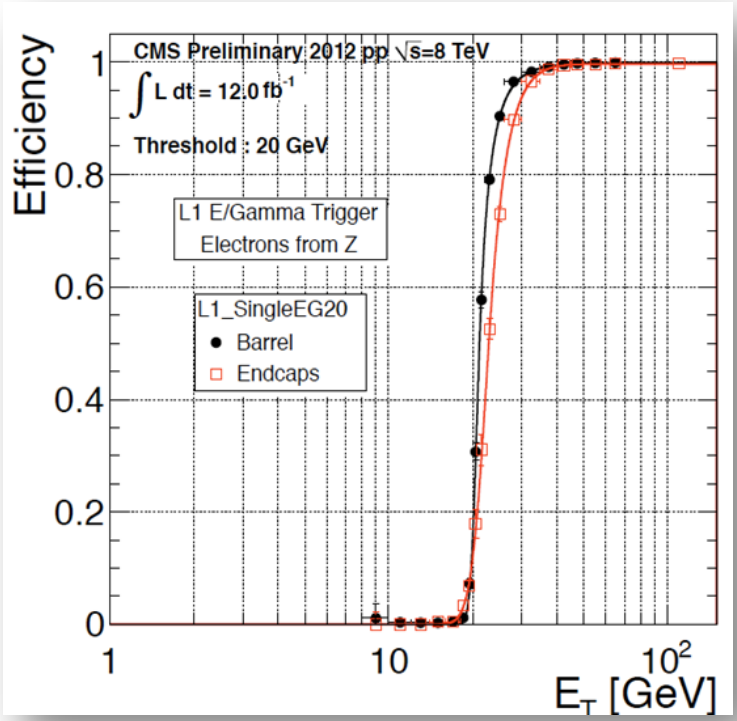
Level 1 Trigger

Optimization for high pile up in 2012 to control the rates

- Jet seed thresholds > 5 GeV introduced
- ECAL transparency corrections applied

Trigger cross section=trigger rate/luminosity





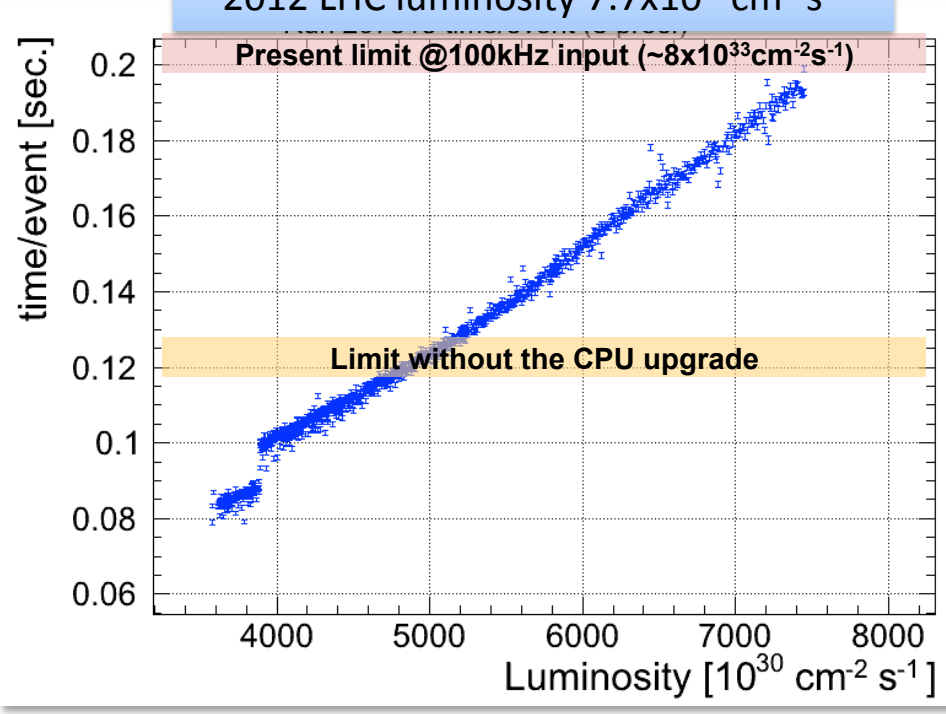
Efficiency of the e/γ 20 GeV threshold trigger	Energy Barrel [GeV]	Energy Endcap [GeV]
50%	21.2	22.8
95%	27.3	30.9
99%	35.7	38.5

High Level Trigger in 2012

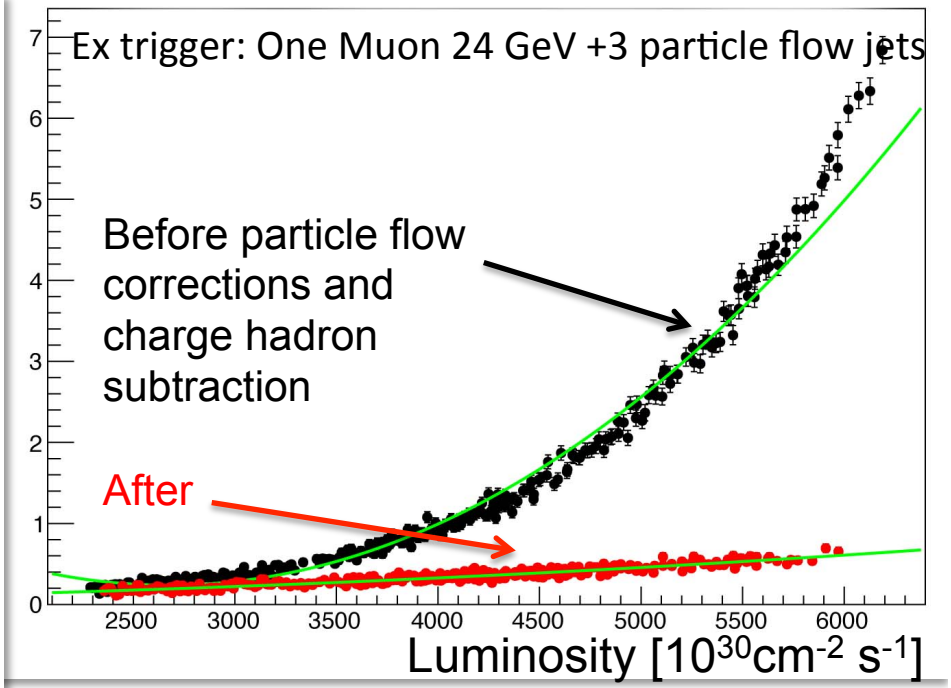
Keep high trigger efficiency maintaining the rates within budget

- More CPU at HLT was installed the end of 2011
- Usage of Particle flow at HLT cured non linearities of many trigger paths
- Jet energy corrections and pile up mitigation tools at HLT

HLT working fine up to the maximum 2012 LHC luminosity $7.7 \times 10^{33} cm^{-2} s^{-1}$



Trigger cross section=trigger rate/luminosity



CMS recorded data

Core data (300-500Hz)

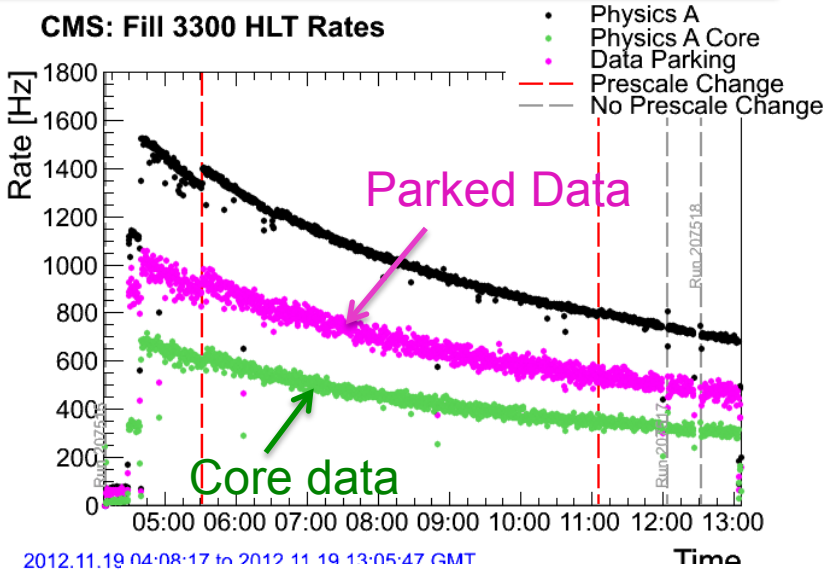
Datasets for Physics program

Parked Data (300-600Hz) : new in 2012

Physics triggers with looser cuts

New triggers with small overlap

Processed during 2013-2014 shutdown



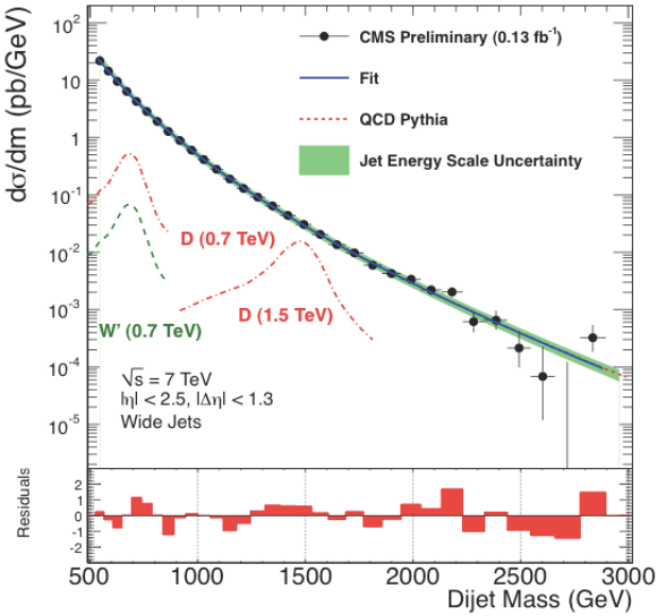
Scouting data: new in 2012

Explore new physics channels with low thresholds

Reduced event content (store calorimeter jets reconstructed at HLT) → higher rate O(1kHz)

No raw data → no offline reconstruction

Scouting extended the dijet search below 1 TeV.
Tested feasibility in 2011



Calibration loop since 2011

Three different paths

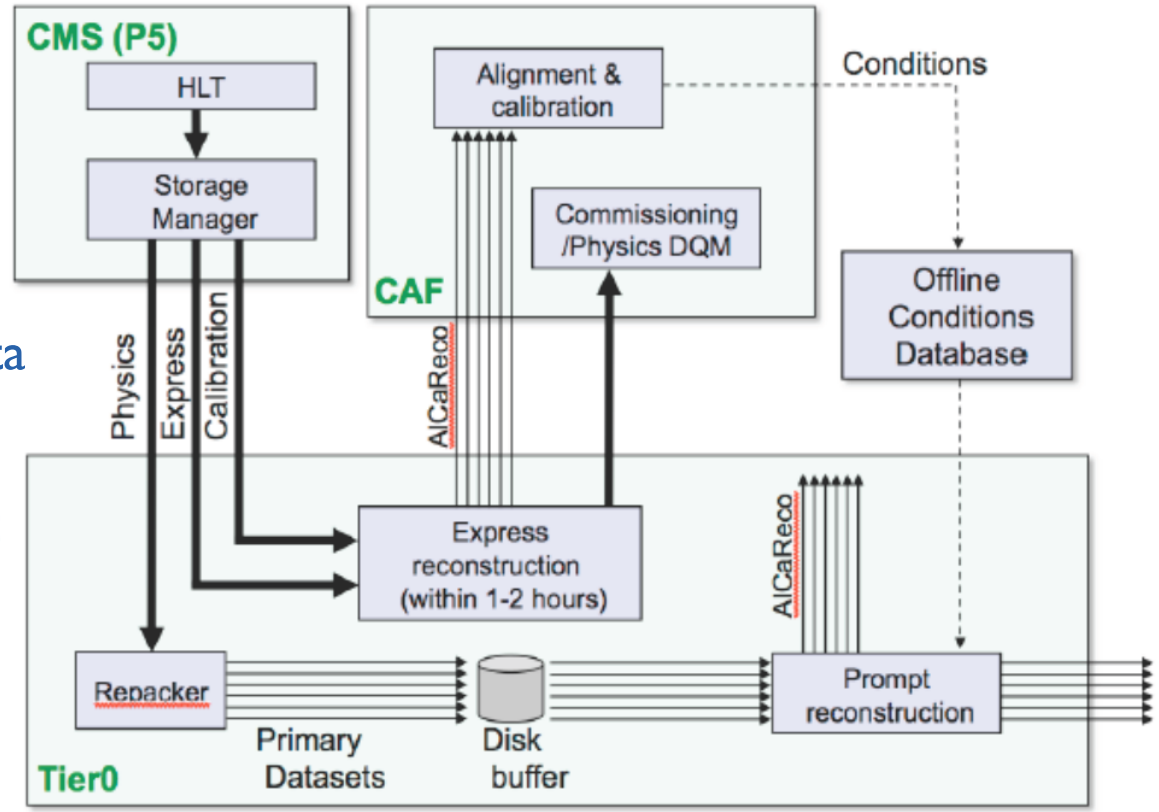
- Physics raw data
- Express
- Online calibration

Express reconstruction

- Small sub-set of physics data
- Reconstructed in 2 hours
- → Alignment & calibration

Prompt reconstruction

- Includes alignment & calibration from express
- Starts 48 h after the data are collected



Reduce the need for offline reconstruction

Computing over the past three years

Reconstructed events

- > 20 billion simulated events
- > 12 billion data events

Improvements in the reconstruction code

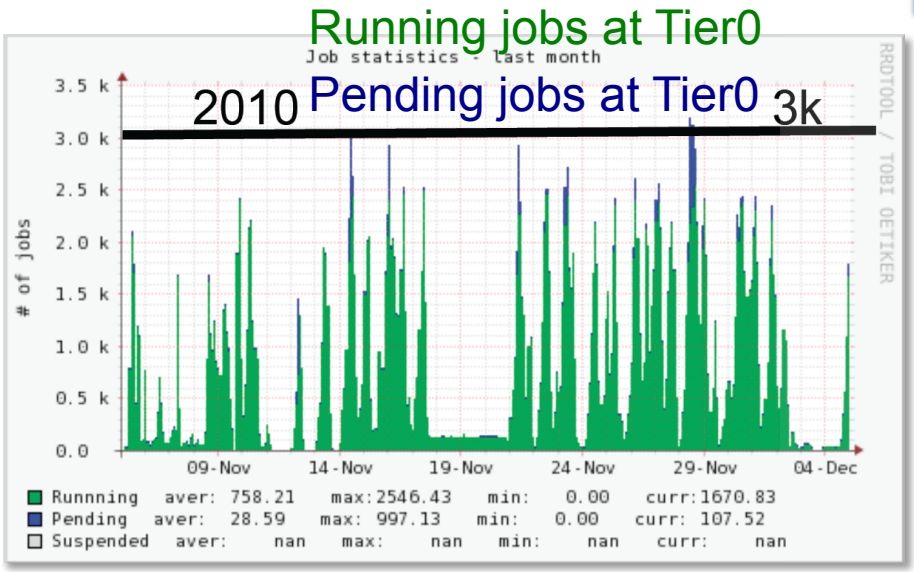
- To deal with more complex events
- Reduced reconstruction time per event
- Maintaining the physics performance

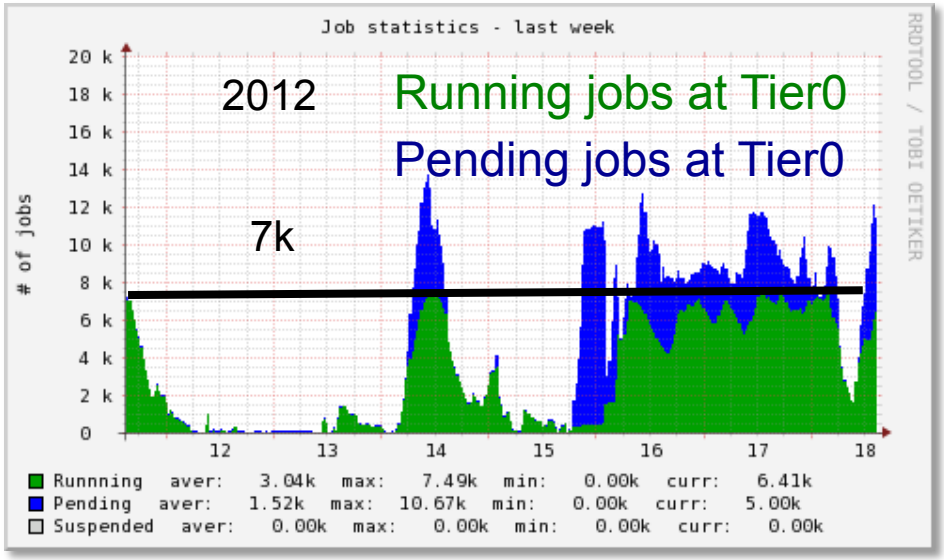
Data volume

- More than 25PB moved to Tier-1s
- 70PB moved to Tier-2s

70M Grid processing requests submitted

In 2012, for luminosities ~$7x10^{33}cm^{-2}s^{-1}$ CMS Tier0 was close to the limit of computing resources





Pile up challenges

Reconstruction of hard collisions needs high granularity detectors

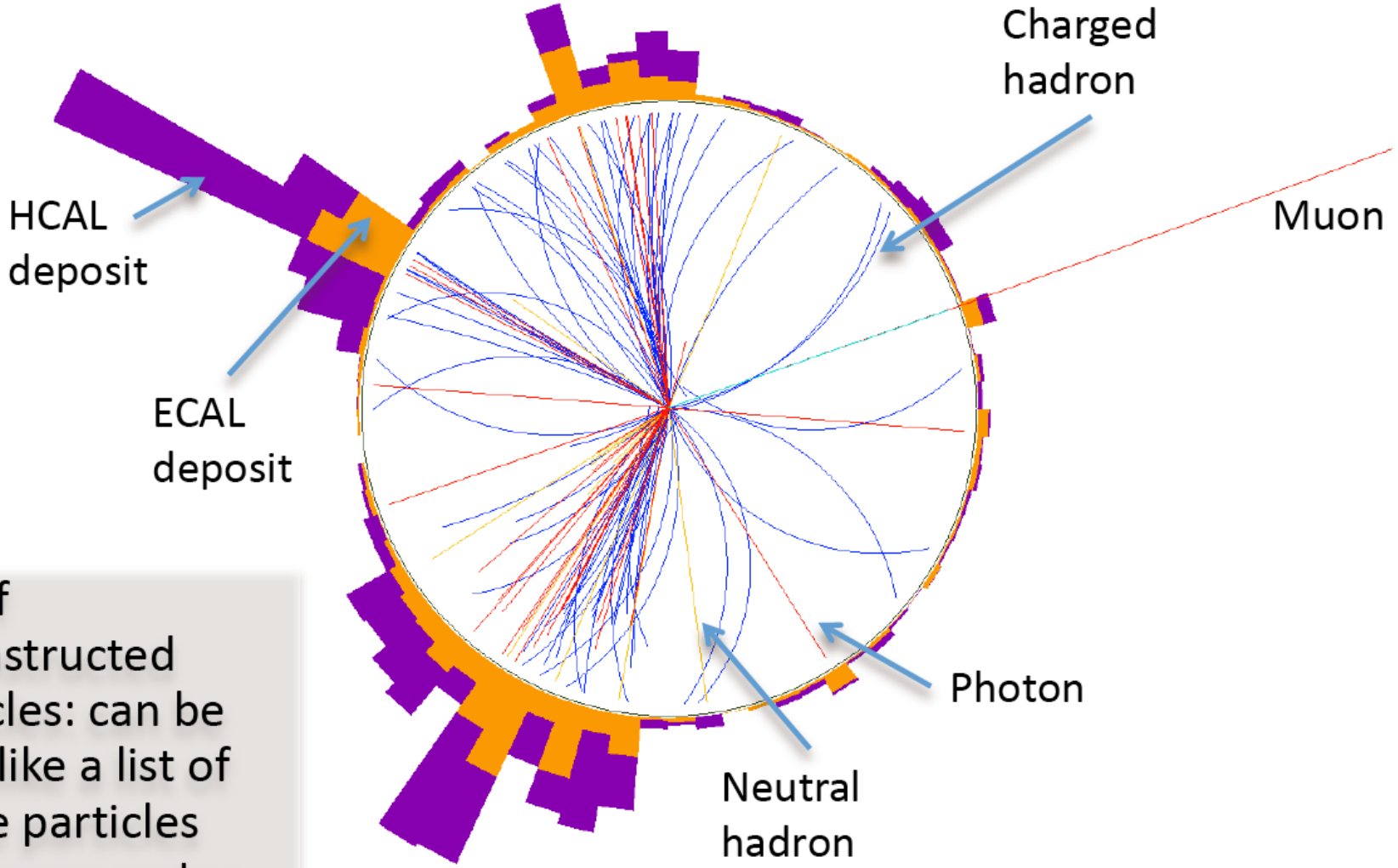
- Efficient association of charged tracks to collision vertices
- Reconstruction of charged and neutral particles in jets
- Neutral particles corrected with global energy density (ρ)

Physics with high pile up requires full particle flow reconstruction

- Precise jet energy correction
- Robust missing energy measurement
- Efficient lepton isolation

Very efficient reconstruction code to stay within computing budget

Global Event Description (Particle Flow)

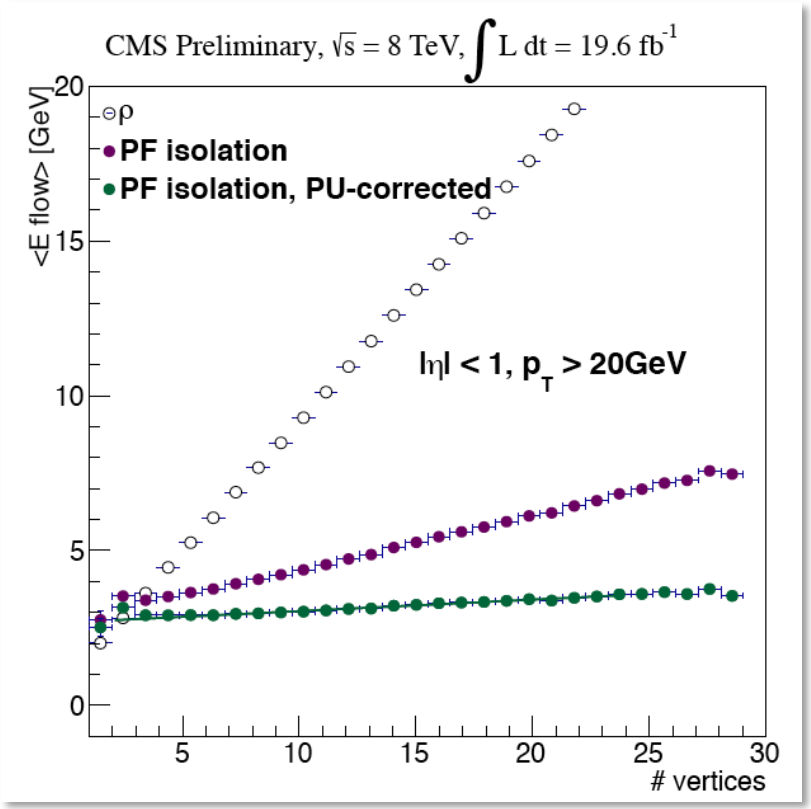


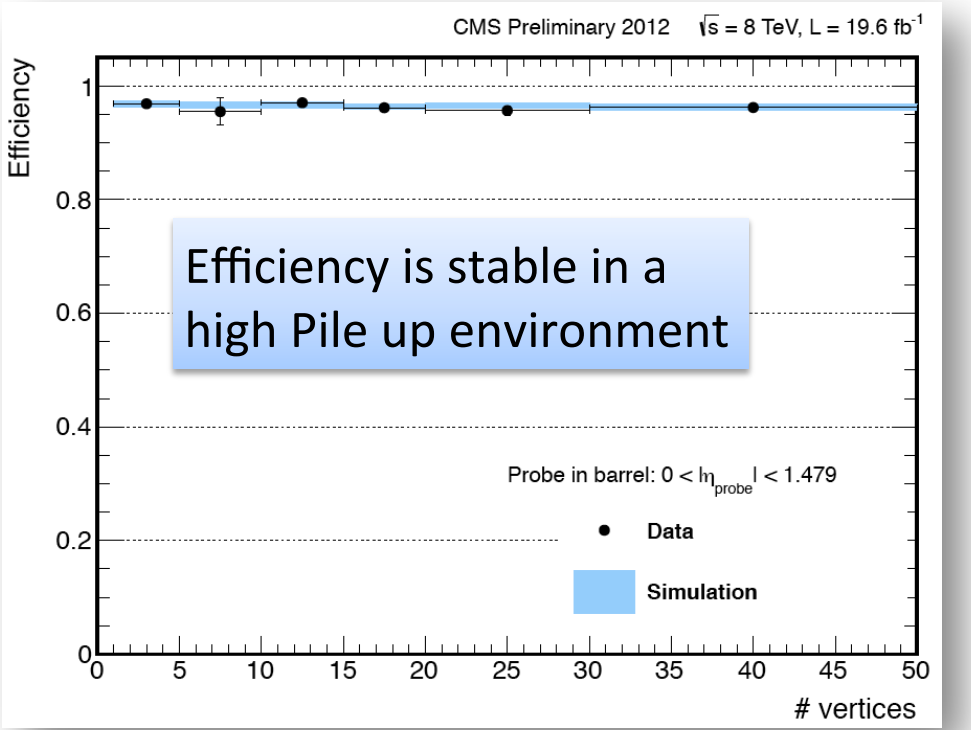
List of reconstructed particles: can be used like a list of stable particles from a generator

Electron isolation and efficiency

Isolation very stable with pile up

- Created summing energy deposits from individual particles ΔR=0.4 cone around the lepton
- Negligible contribution from charged hadrons from primary vertex
- Neutral contribution corrected using the average energy density

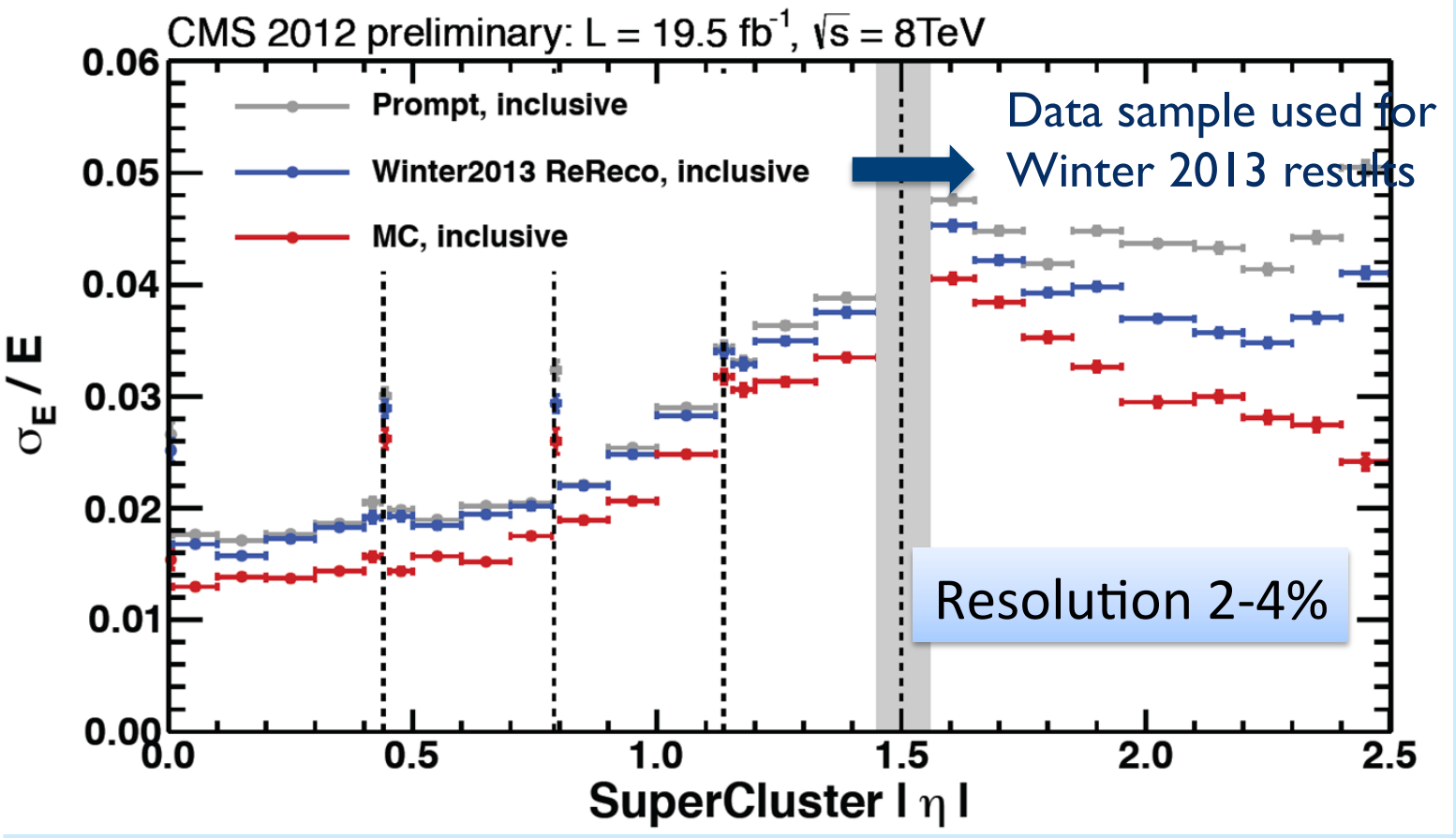




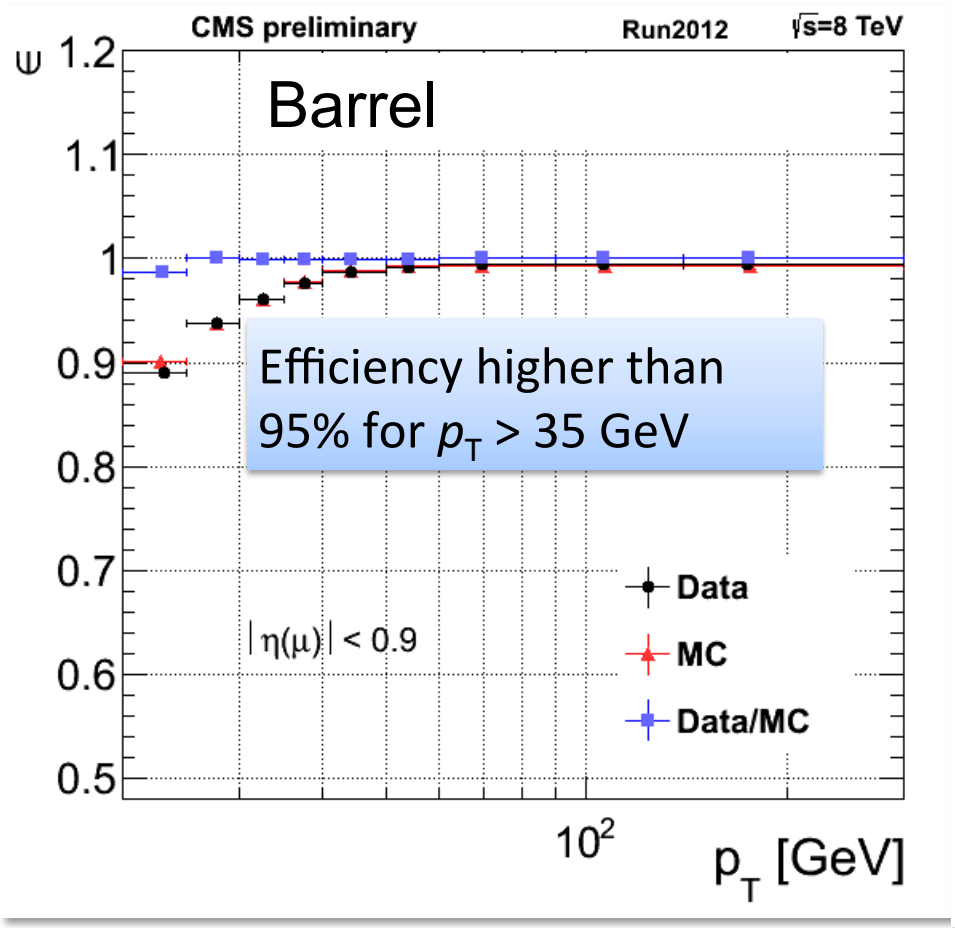
ECAL energy resolution

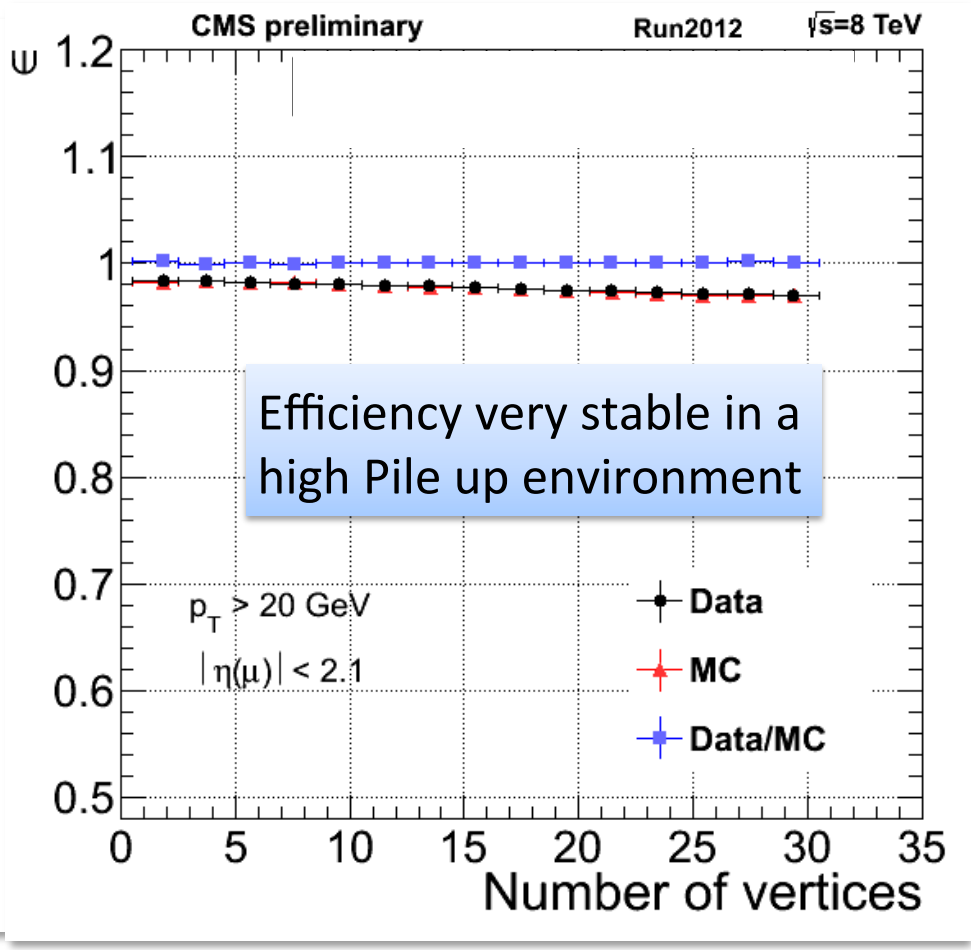
Electron energy resolution from Z→ee decays

Improved for high |η| values in the Winter 2013 Re-reconstruction



Muon identification efficiency

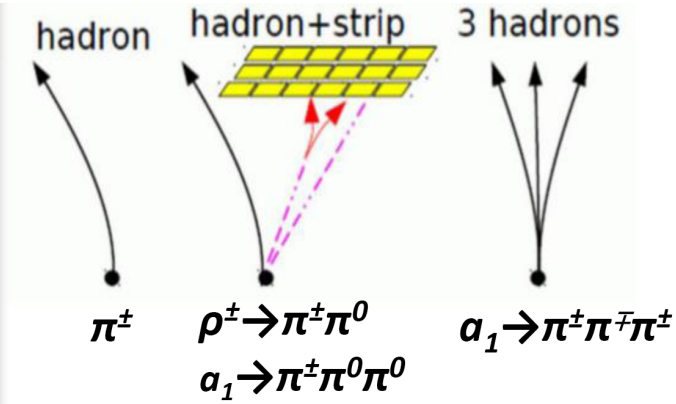




Tau identification

Identification

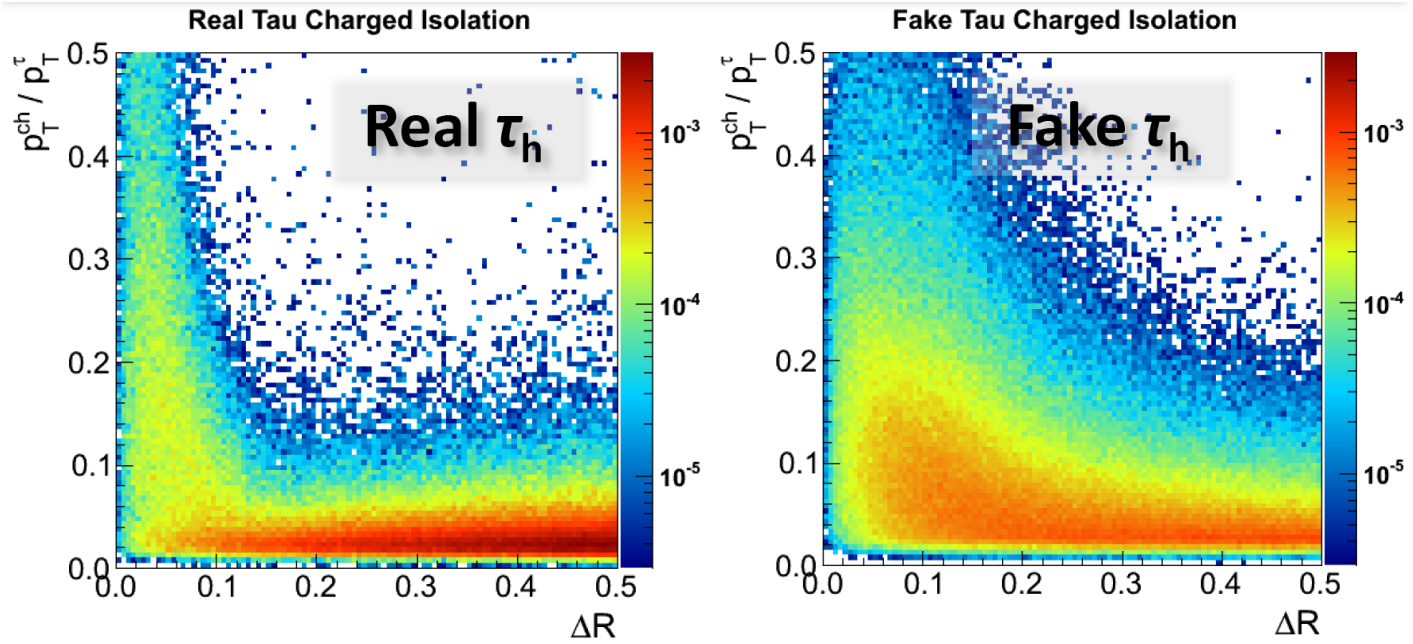
Hadronic taus reconstructed based on decay modes: charged hadrons + EM strips



Isolation

New in 2012

Multivariate isolation using relative Σp_T of particle flow candidates in concentric rings around the τ



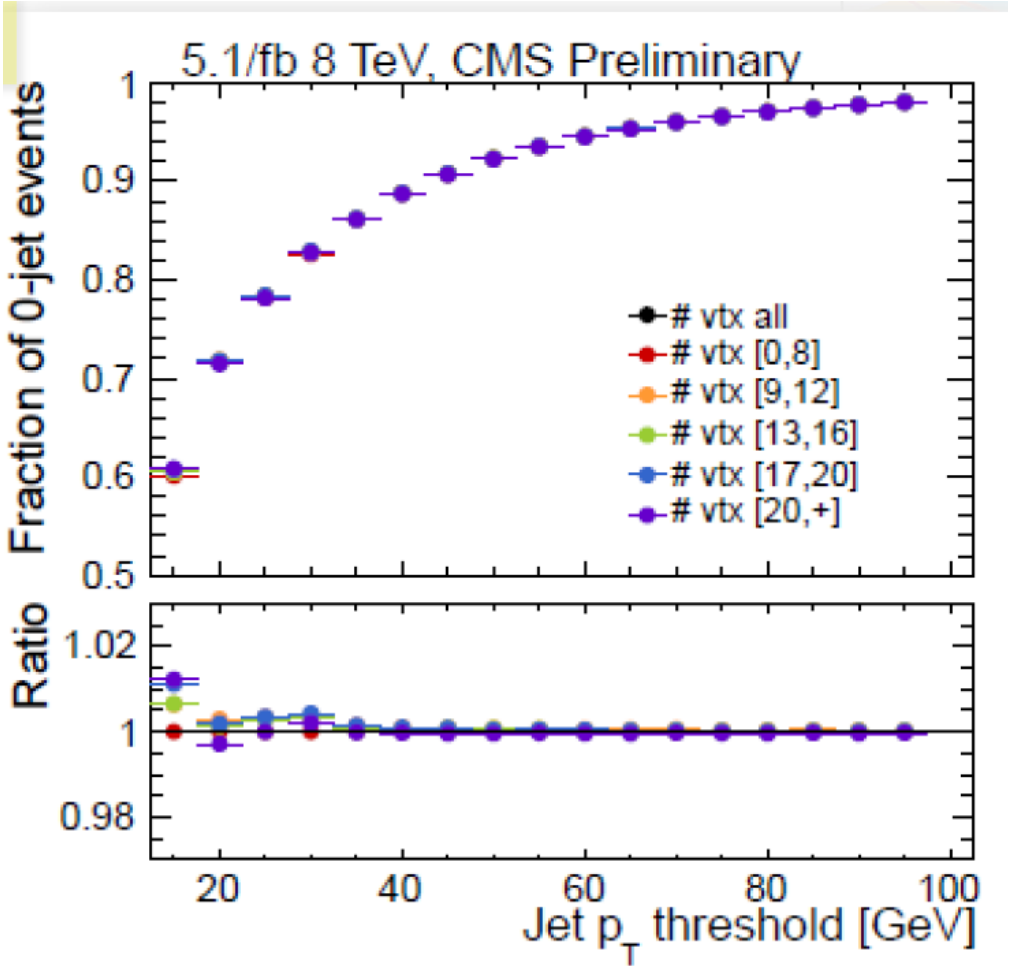
Jets

Pile up discrimination

Multi variate anti pile up discriminant exploits shape and tracking variables

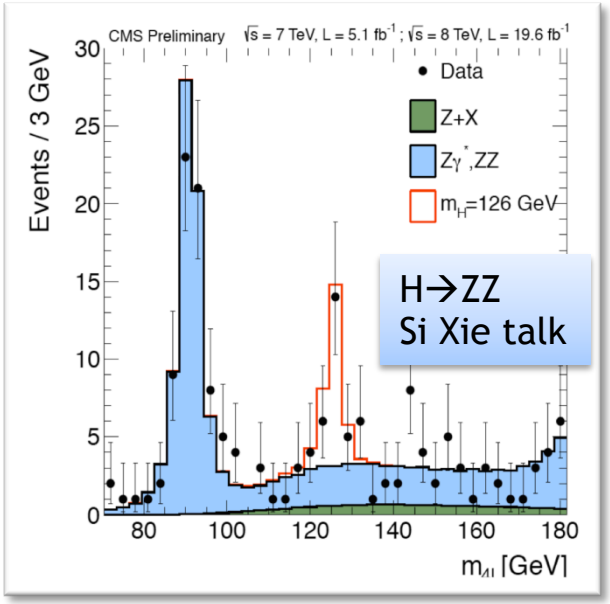
B-tagging

Life-time based, use information about track impact parameter, secondary vertices

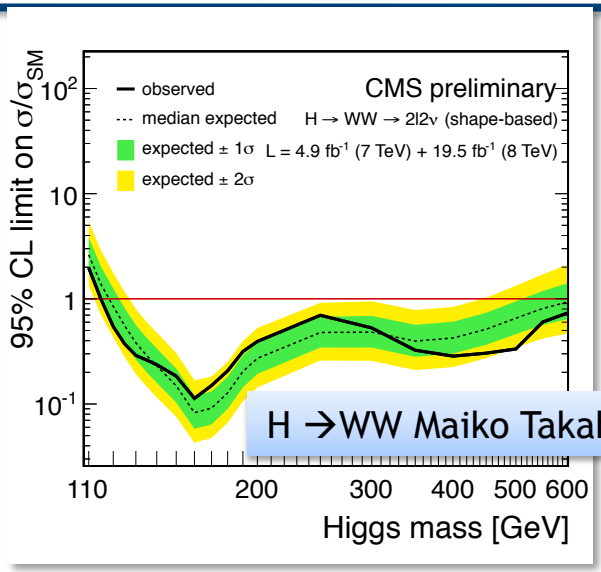


Summary of CMS physics results in G.Dissertori's talk

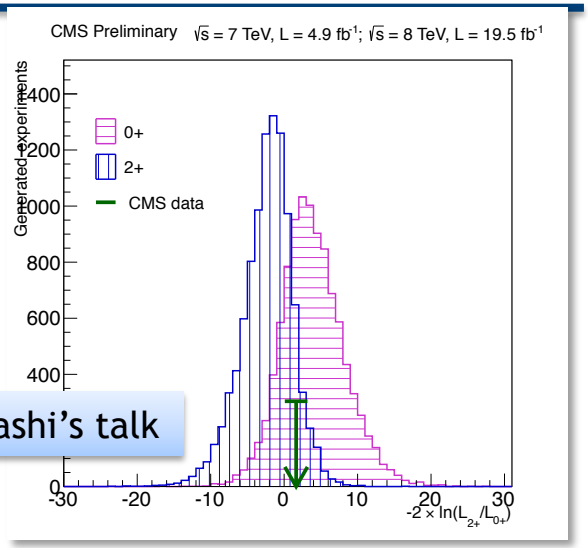
Higgs updates for Winter 2013

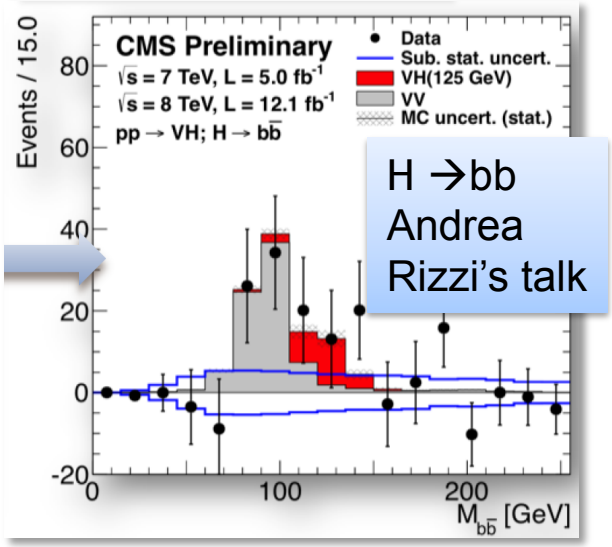


H→ZZ
Si Xie talk

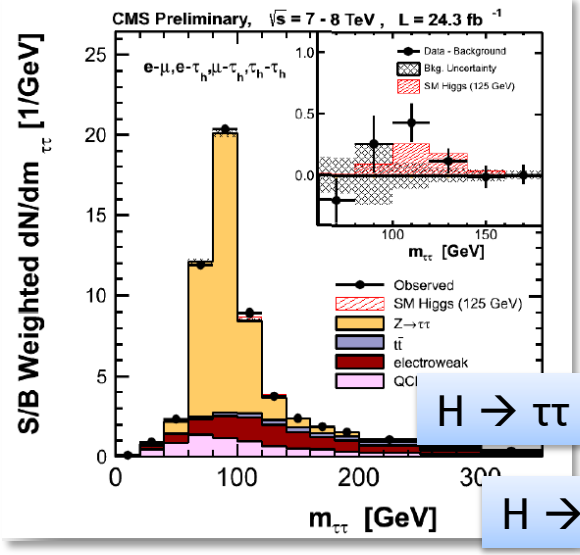


H →WW Maiko Takahashi's talk

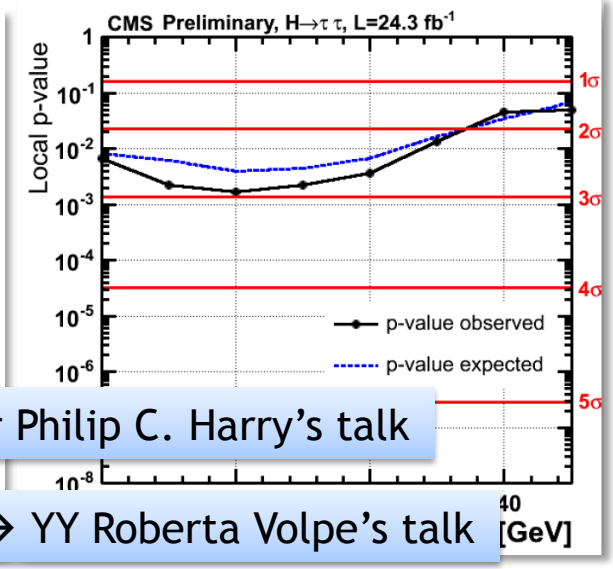




H →bb
Andrea
Rizzi's talk



H → ττ Philip C. Harry's talk



H → YY Roberta Volpe's talk

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
The great success was possible thanks to the LHC teams, CMS online teams, sub-detector teams, trigger, technical, computing, offline, physics validation and physics analysis teams

CMS Upgrade

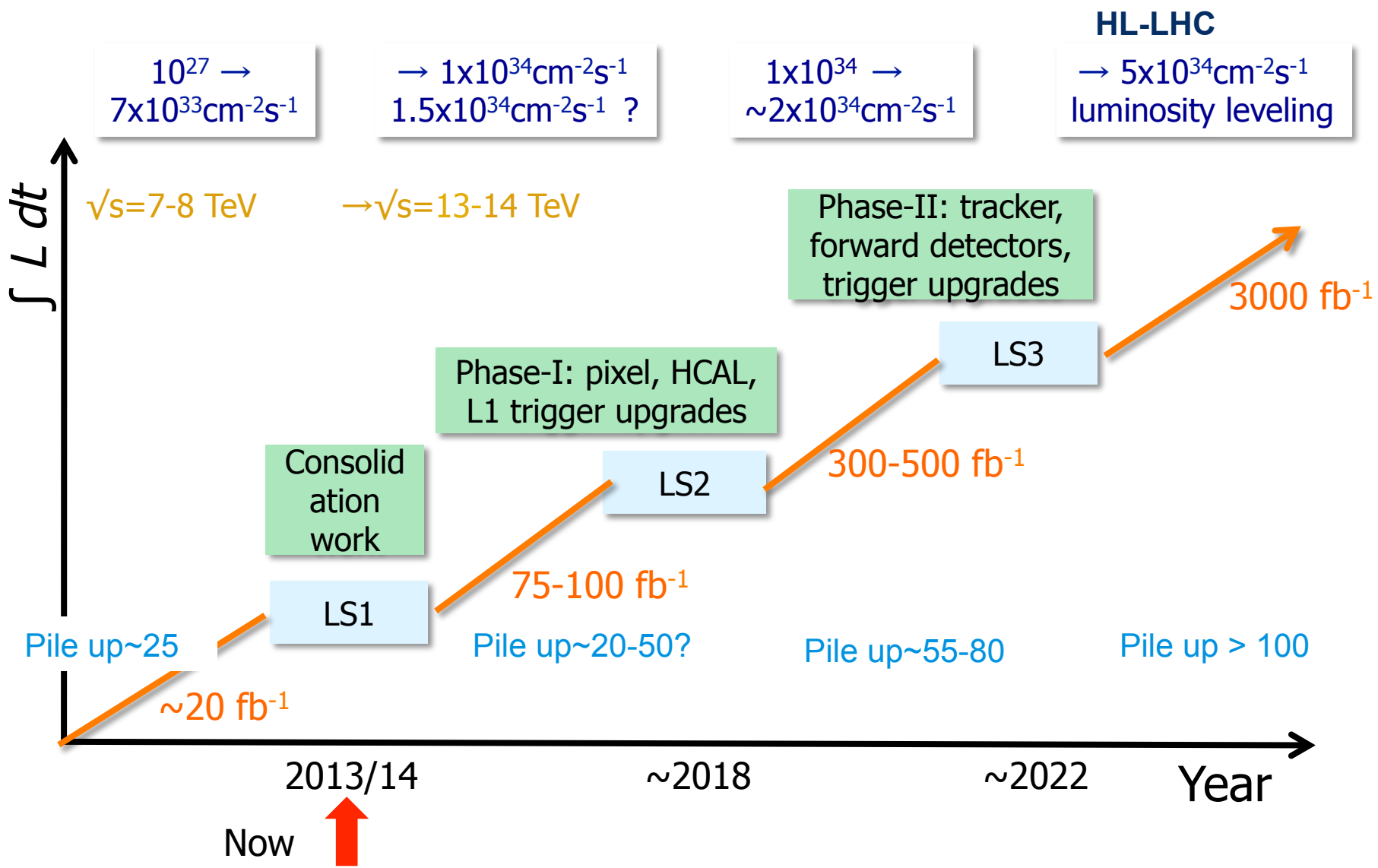
Physics priorities

- With $\sqrt{s}$=7-8 TeV data 2010-2012 (23fb^{-1})
  - Initial characterization of the Higgs like particle
  - Spin/parity at 3-4 sigma level
  - Combined signal strength with 15% precision
  - Search for natural SUSY and other possible new physics

- With $\sqrt{s}$=13-14 TeV data until 2022 (300-500fb^{-1})
  - Measure Higgs-like boson properties (couplings with 5-10% precision)
  - Search for new physics at higher mass scale

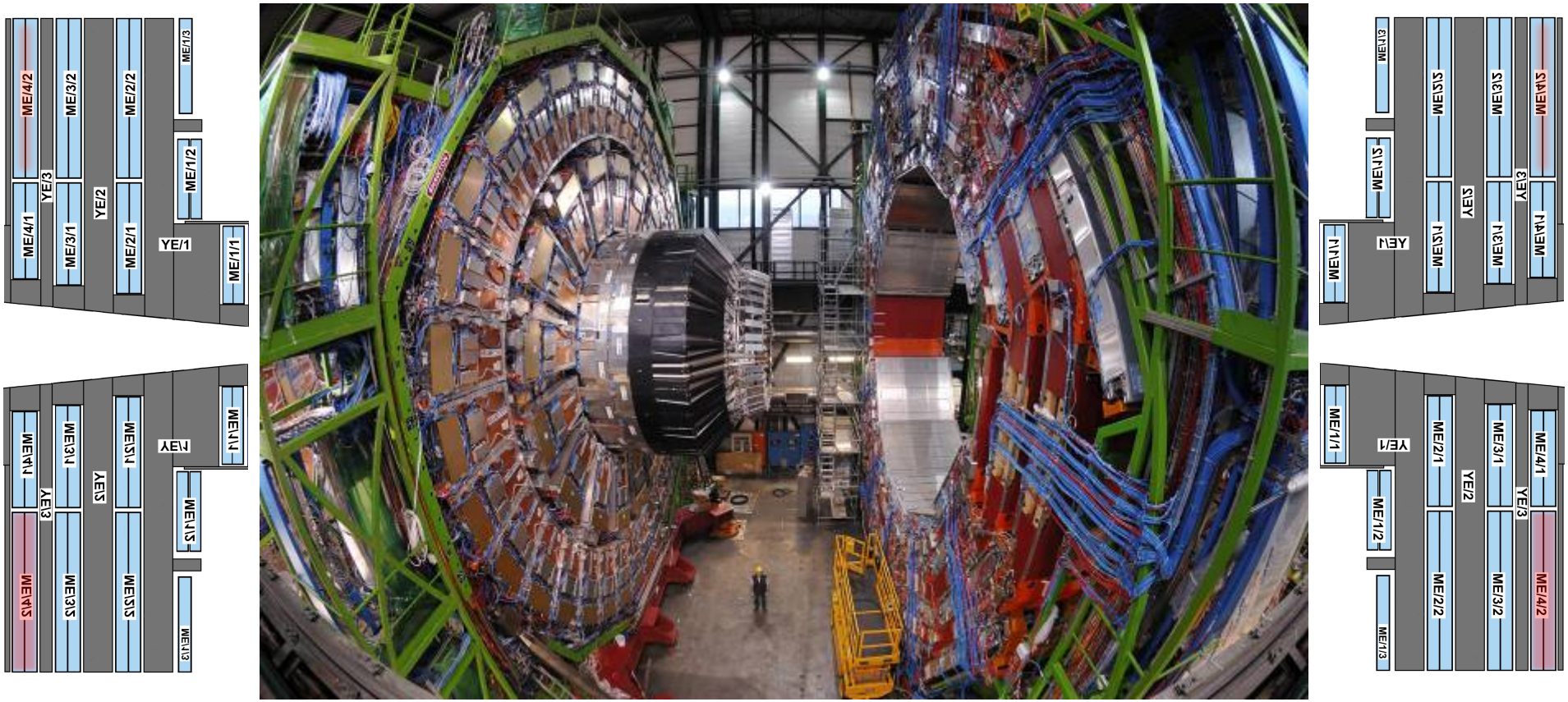
- With $\sqrt{s}$=13-14 TeV data until 2032 (~3000fb^{-1})
  - Measure Higgs-like couplings with ultimate precision
  - Study WW scattering
  - Seach for new physics in rate processes

LHC-CMS upgrade



Consolidation work during LS1 2013-2014

Complete the muon coverage in the end caps (ME4)
Improve end cap muon trigger (ME1) and muon barrel electronics
Replace HCAL photo-detectors in the Forward (new PMT) and Outer (HPD→SiPM)
New DAQ system with increased sub-detector readout bandwidth



Preparations for 2015 run: Run II

Average reconstruction time at Tier 0 in 2012 was 20ms per event

With the present code:

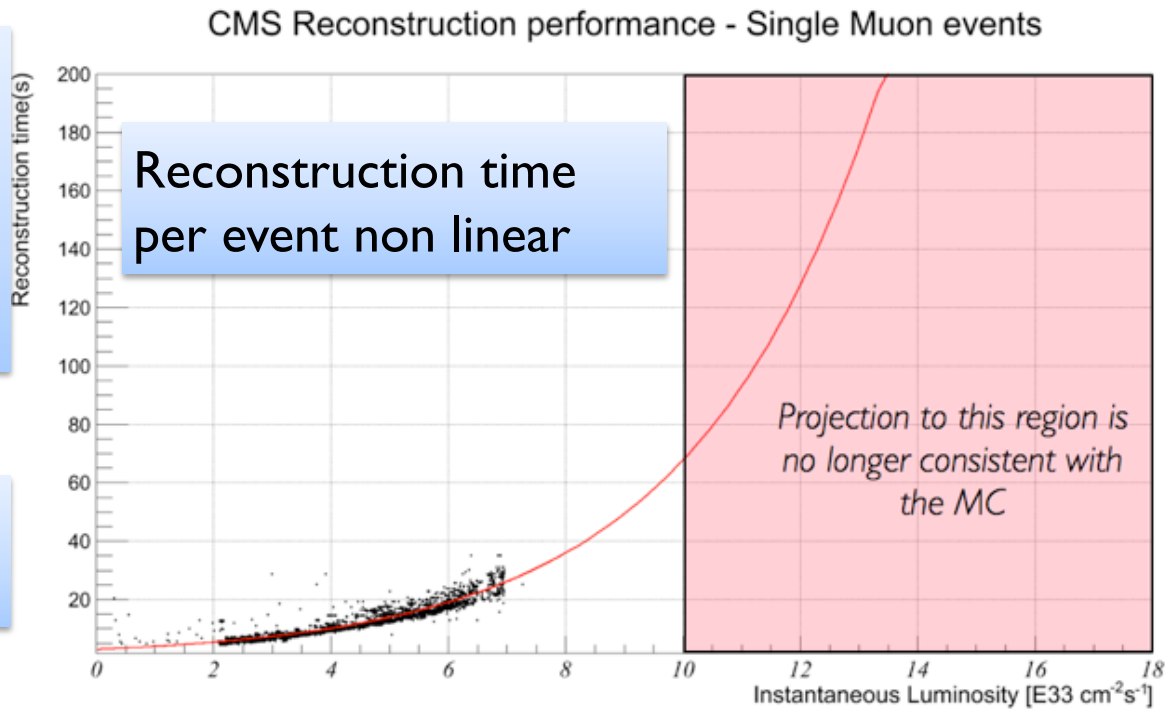
The reconstruction time at lumi ~0.9x10^{34}cm^{-2}s^{-1} increases by a factor 2.5

In 2015 we will run at $\sqrt{s}$=13-14 TeV

Higher energy means higher multiplicity→ more complex events

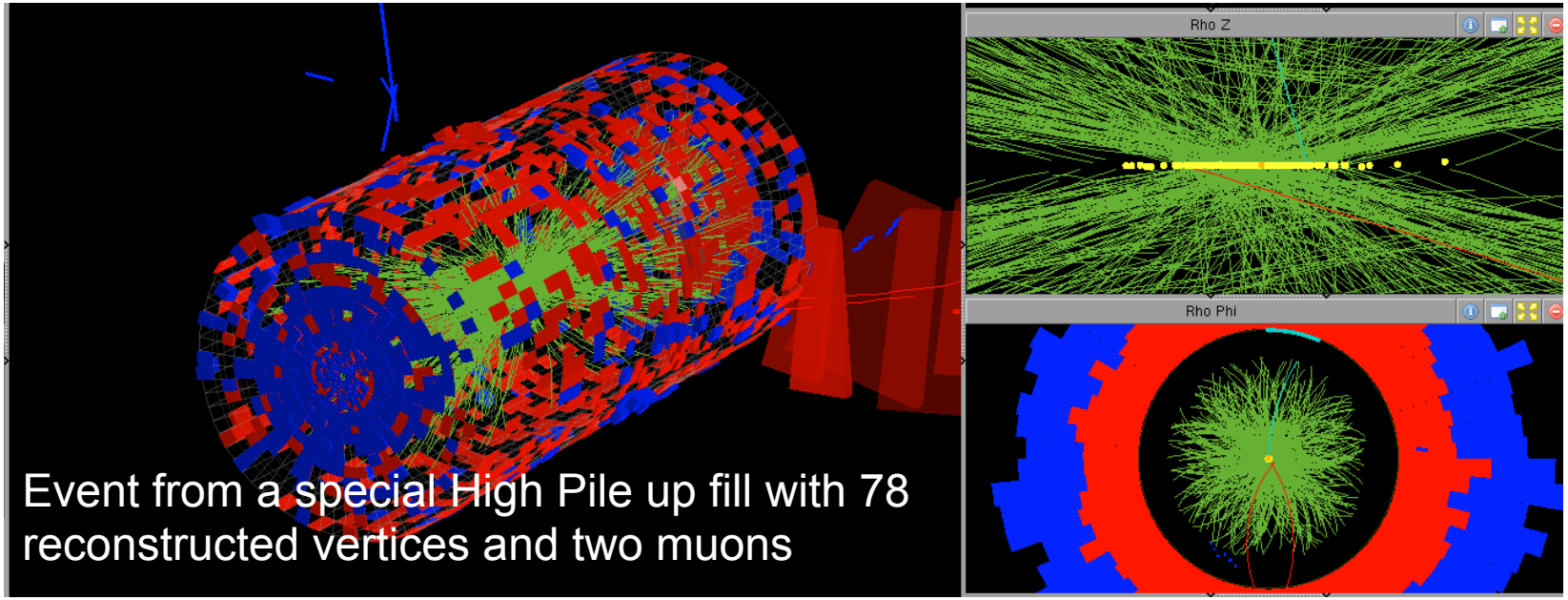
High pile up has detrimental impact on trigger, computing and physics. CMS studying solutions on to deal with it after LS1

CMS has a clear preference to run at 25ns after LS1



Upgrade Phases

- Phase I Upgrade: twice the LHC design luminosity
  - Pile up reaches 50 collisions per crossing (@25ns)
  - Factor 5 increase of trigger rates relative to 2012 run
- Phase II Upgrade: 5x design LHC luminosity
  - Pile up reaches 125 events per crossing (@25ns)
  - Need solutions to cope with high rates, radiation and pile up

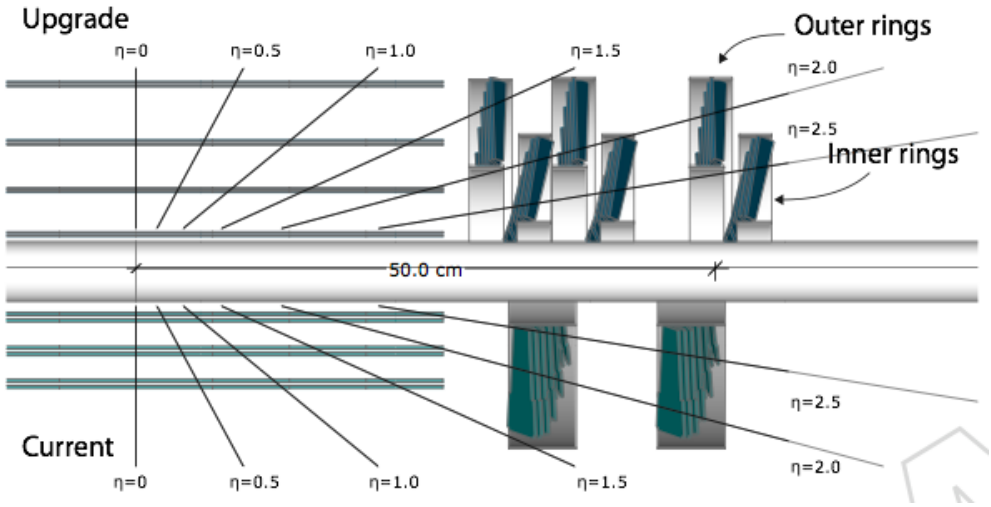


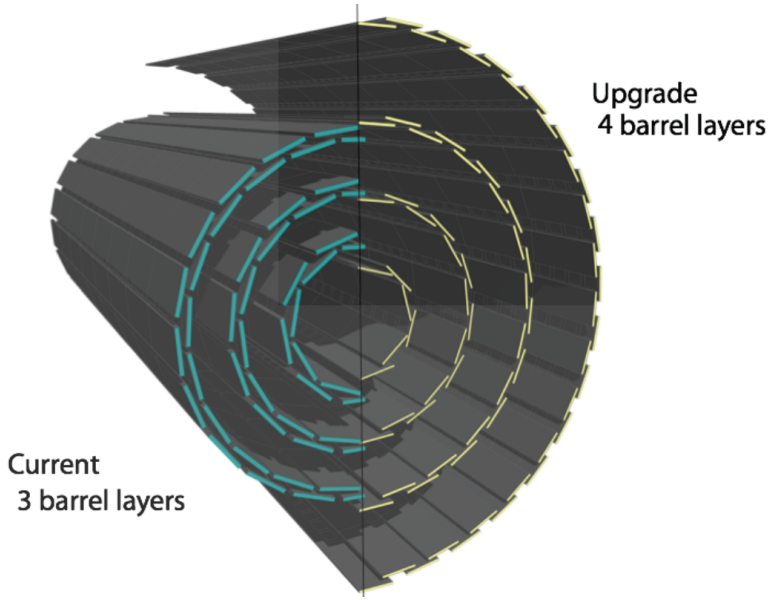
Phase I Upgrades

Pixel Upgrade

New pixel detector

- Guarantees high tracking and b-tagging efficiency with high pile up
- 4 barrel layers to improve tracking efficiency and less fakes
- Less material and better radial distribution
- New readout chip recovers inefficiency at high pile up



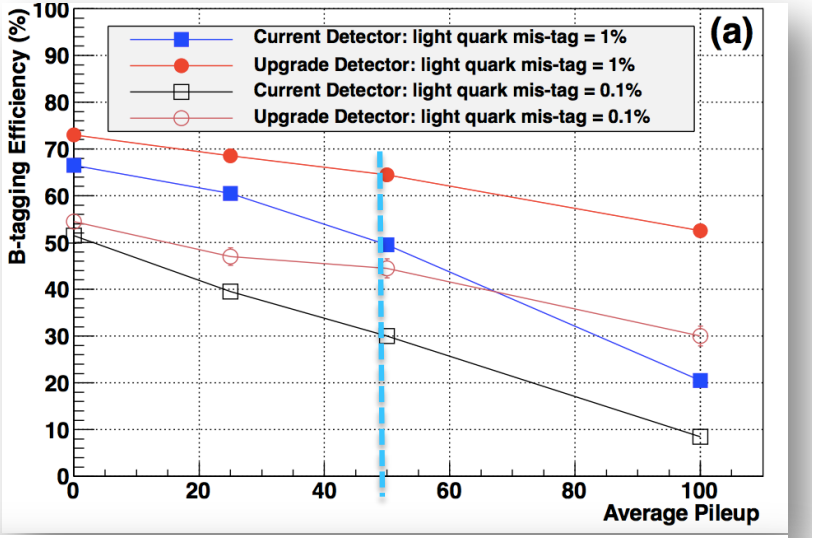


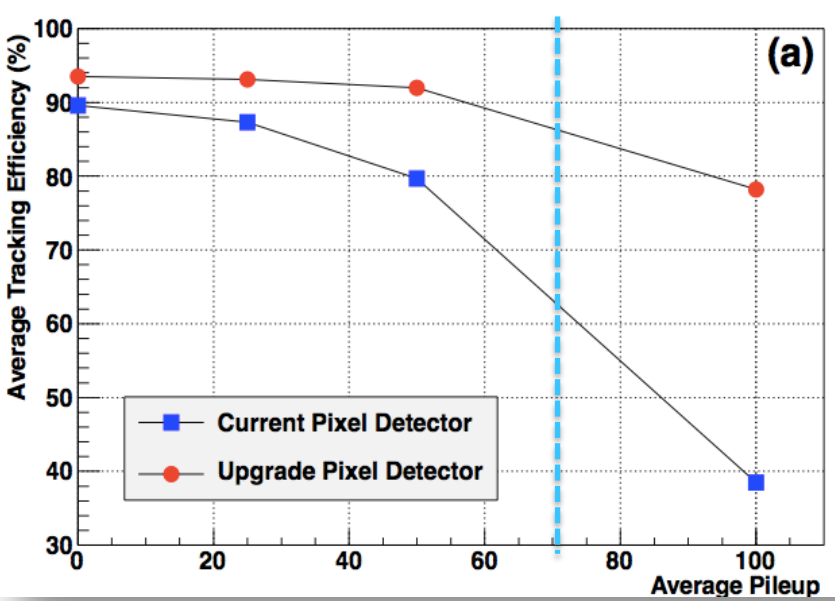
- Can tolerate $L=2x10^{34}cm^{-2}s^{-1}$, integrated luminosity of $500fb^{-1}$
- To be installed in the Year End Technical stop 2016-2017

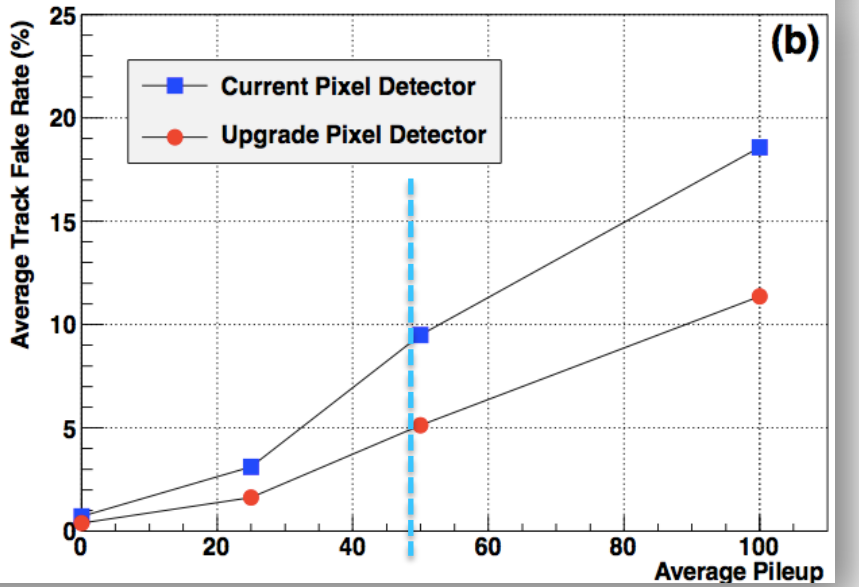
Improved Tracking & b-tagging

CMS Full simulation in ttbar events

- b-tagging efficiency 30-50% higher for 50 pile up events
- Tracking efficiency at 65-70 pile up equal to the current detector at 25
- Fake rate reduced by 2 @ 50 PU events







CMS HCAL and Trigger Upgrades

Upgraded HCAL

- Improve background rejection
- Improve MET resolution
- Improve Particle Flow
  - *via improved S/N photodetectors*
- Identify depth of shower max
  - *via longitudinal segmentation, timing*

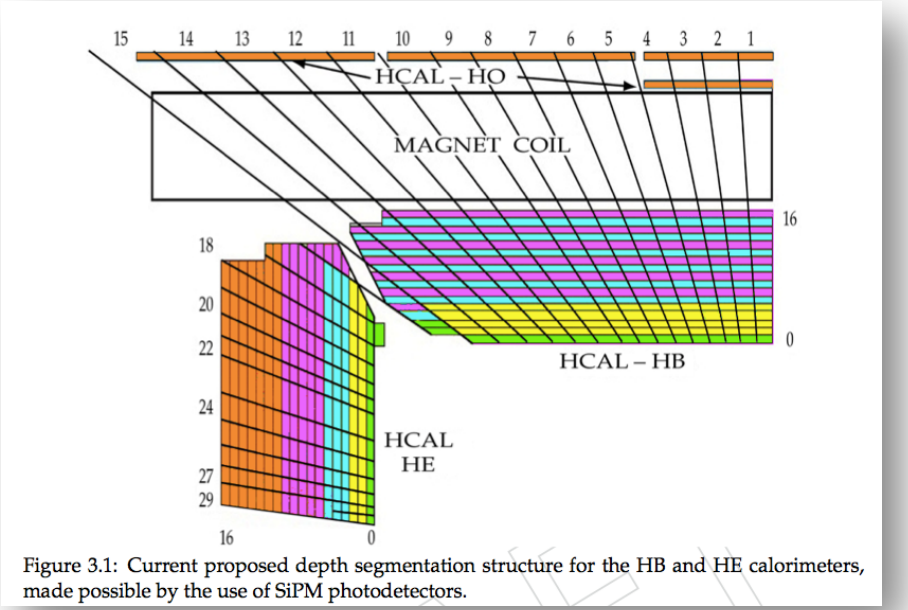
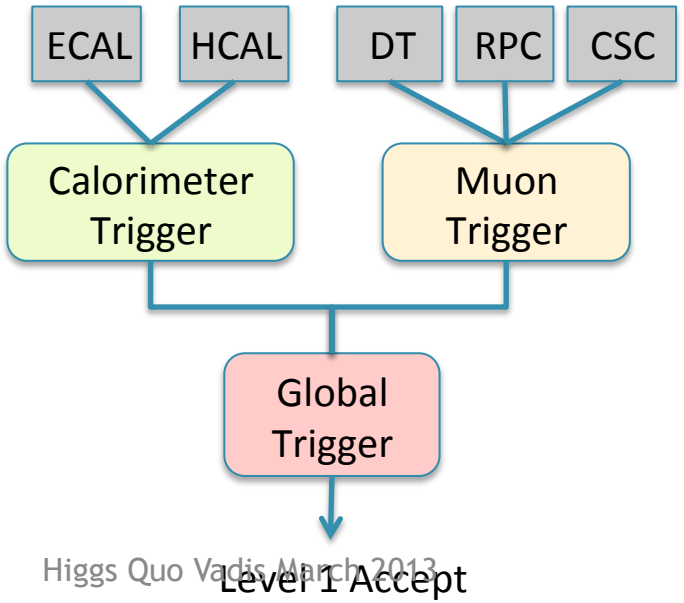


Figure 3.1: Current proposed depth segmentation structure for the HB and HE calorimeters, made possible by the use of SiPM photodetectors.



Upgraded Trigger

- Higher calorimeter granularity and improved pile up subtraction
- Better muon reconstruction
- Global Level I trigger with more inputs and correlated quantities
- Commissioning in 2016

CMS Upgrades impact

H→ZZ→4l

50% improvement on signal yield relative to current detector

ZH→μμbb

Higher muon ID efficiency and b-tagging efficiency

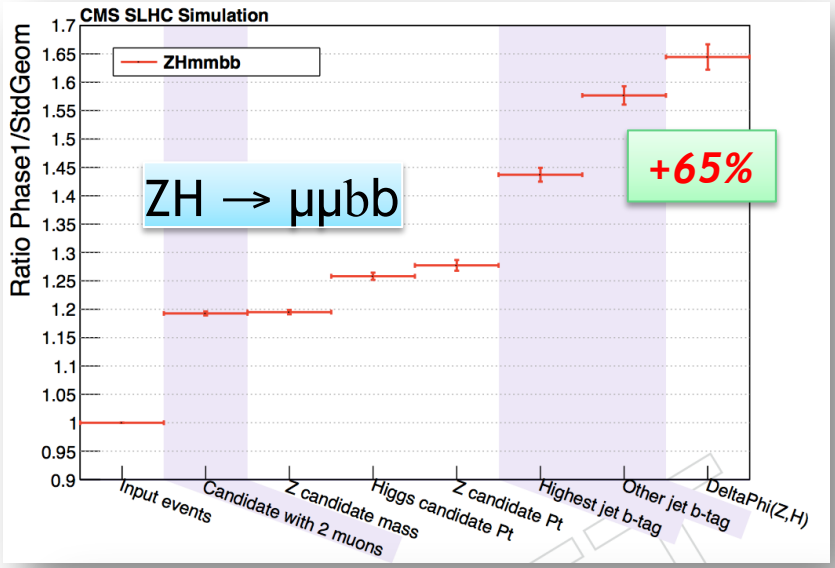
Good dijet mass resolution

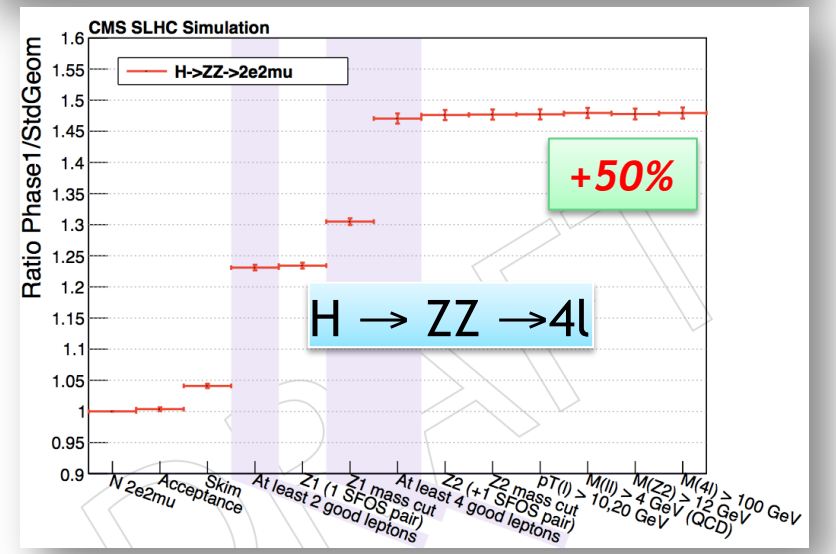
65% improvement on signal yield

H→ τ τ (VBF)

Better MET resolution, forward jet tagging, tau identification

Improved mass resolution





Phase II Upgrades

Towards Phase II

High Luminosity LHC physics program

- The European Strategy Physics Group discussing future HEP machines
- LHC Experiments need to provide physics perspective
- Common ECFA workshop ATLAS-CMS (Jun/October 2013) to coordinate efforts

Detector requirements

- CMS will have to replace the Tracker (silicon & pixels-II), forward detectors (HE, EE) and triggering systems
- Detector upgrades need to maintain current performance in a much harsher environment

Towards a Phase 2 Technical Proposal in 2014

- Must understand performance longevity, approaching LS3 and beyond
- Working Groups to define overall scope, and targeted R&D program

Conclusions

- CMS has run for three years with excellent performance
- Final results expected in 2013 with full Run I statistics
- LSI consolidation work under way
- Preparing for Run II needs optimization of computing resources
- Phase I upgrade well defined and TDRs written
- Phase II Upgrades, TDR will appear in 2014

More information

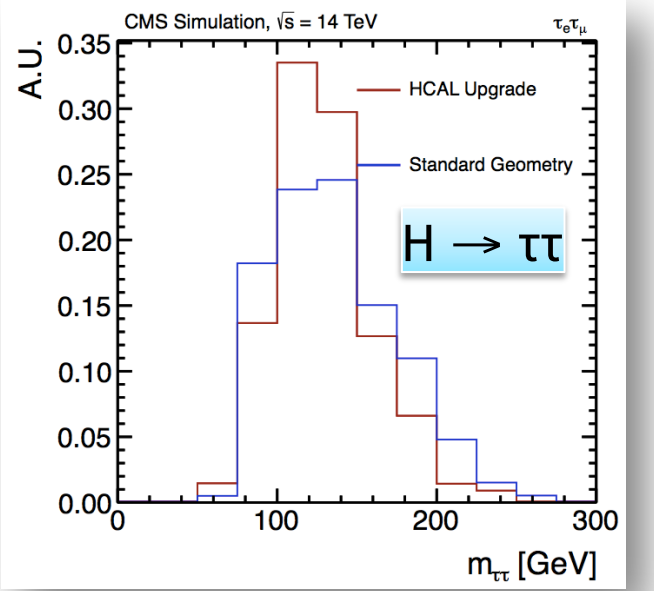
Upgrades impact

H→ τ τ (VBF)

Better MET resolution, forward jet tagging, tau identification

Improved mass resolution

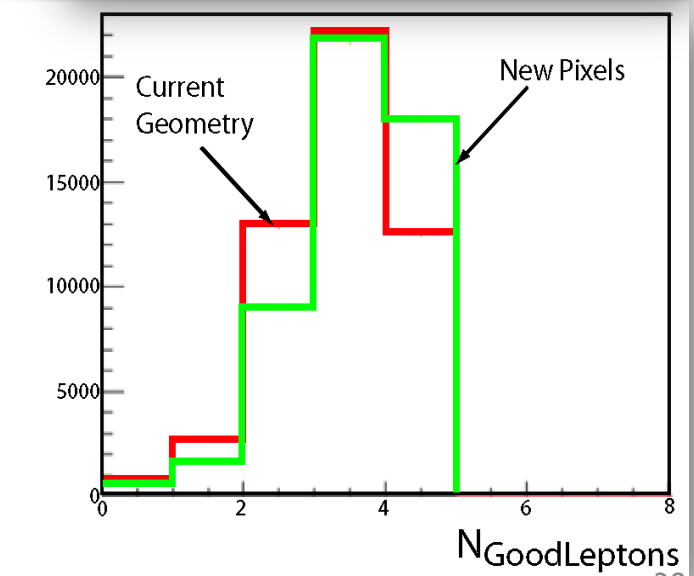
Improved $m_{\tau\ \tau}$ resolution



Higher number of good leptons

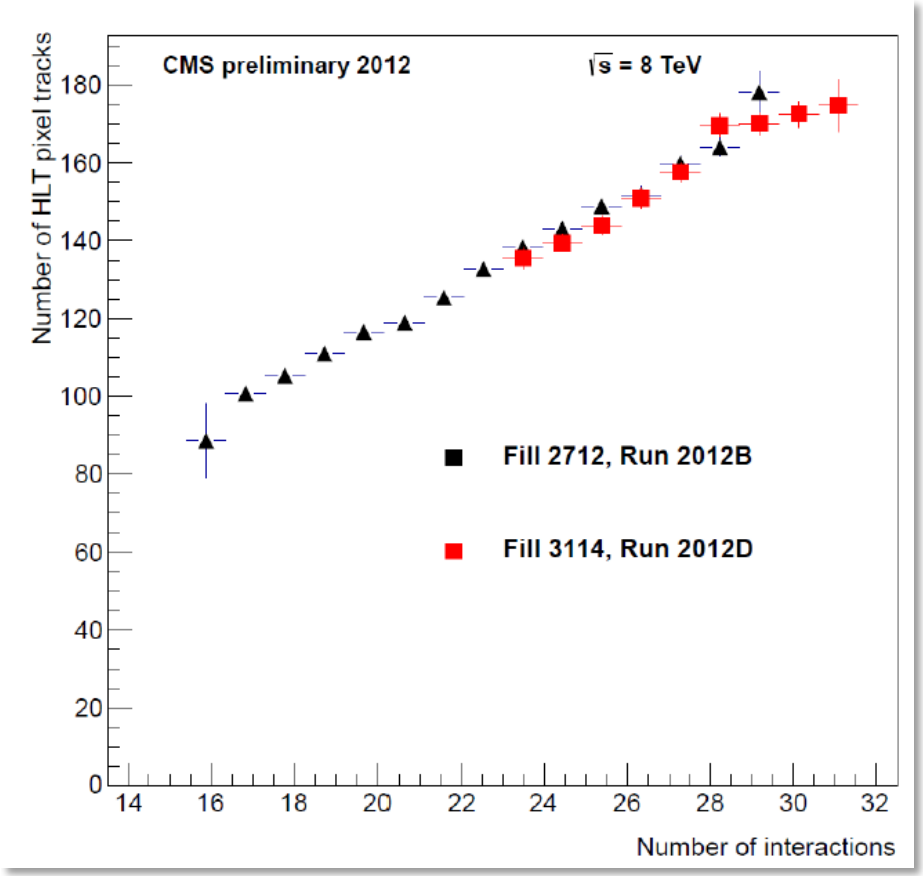
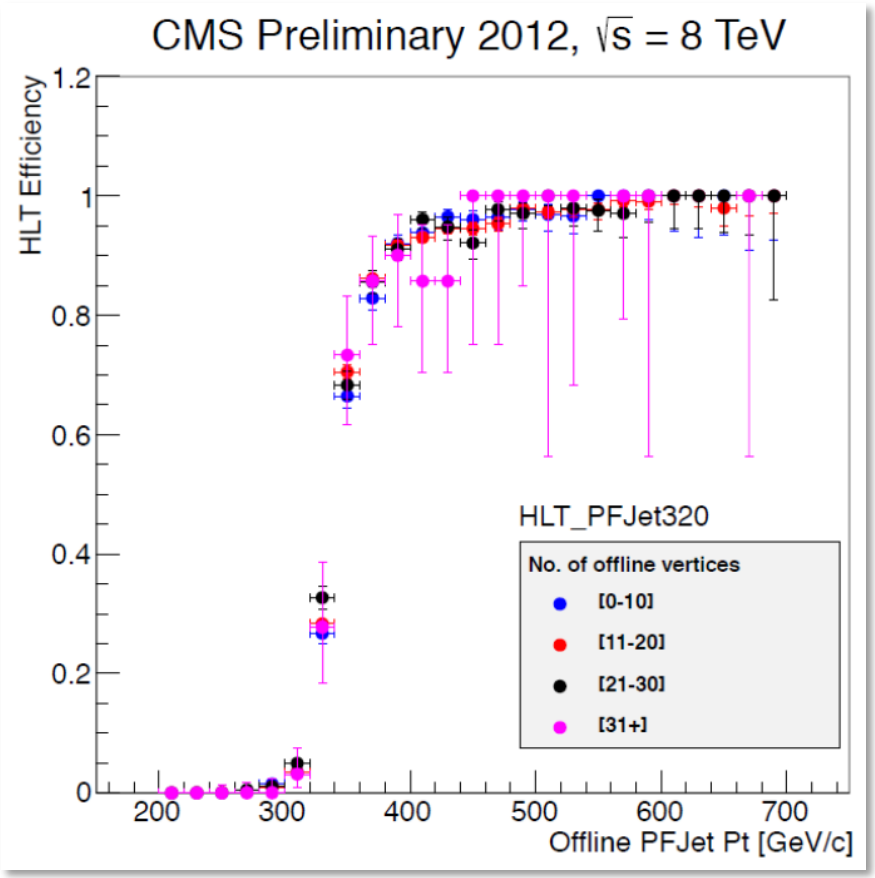
Translates into better tracking and isolation

More good leptons →
better tracking & isolation



High Level Trigger

HLT tracking linearity vs pile up



Jet HLT turn on curve for a particle flow jet cut of 320 GeV for different pile up