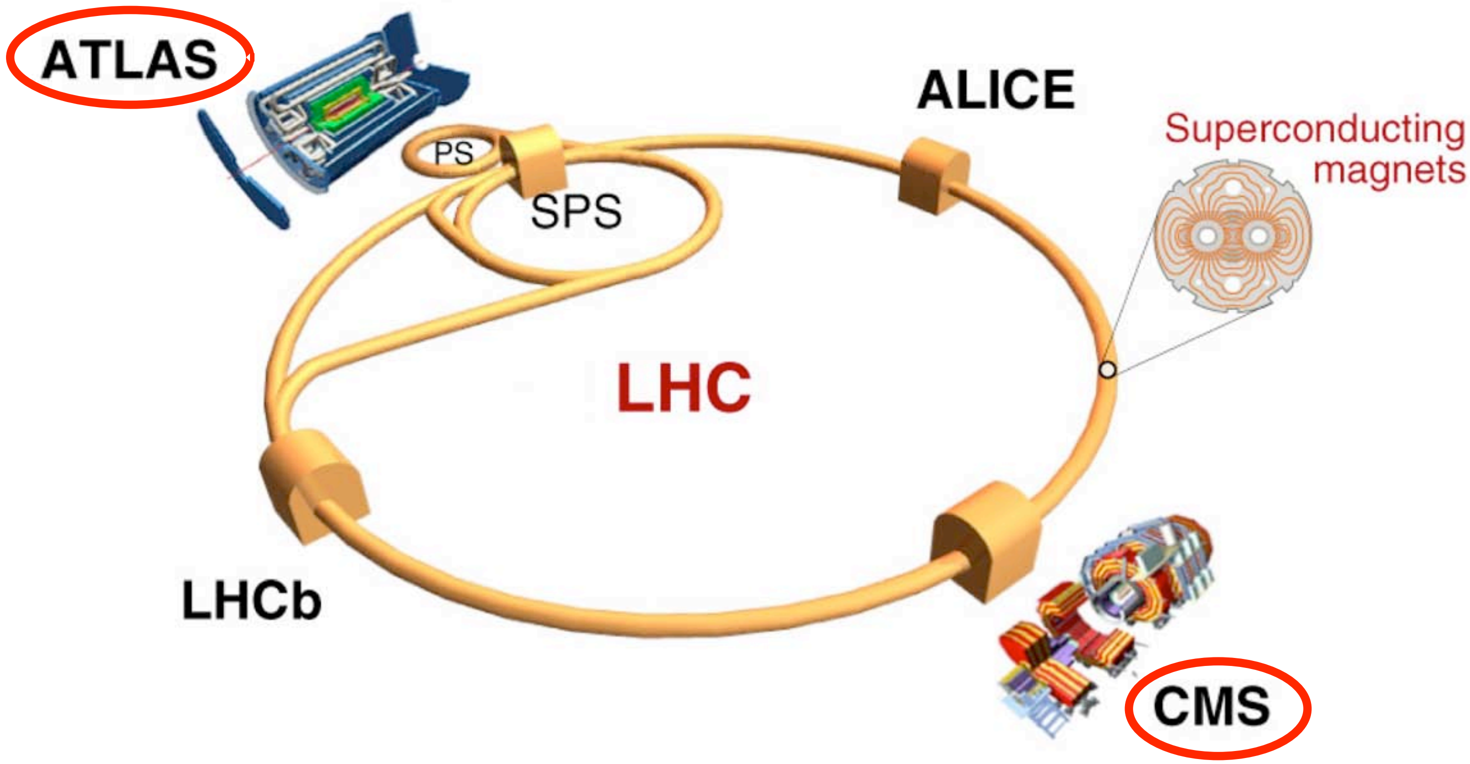
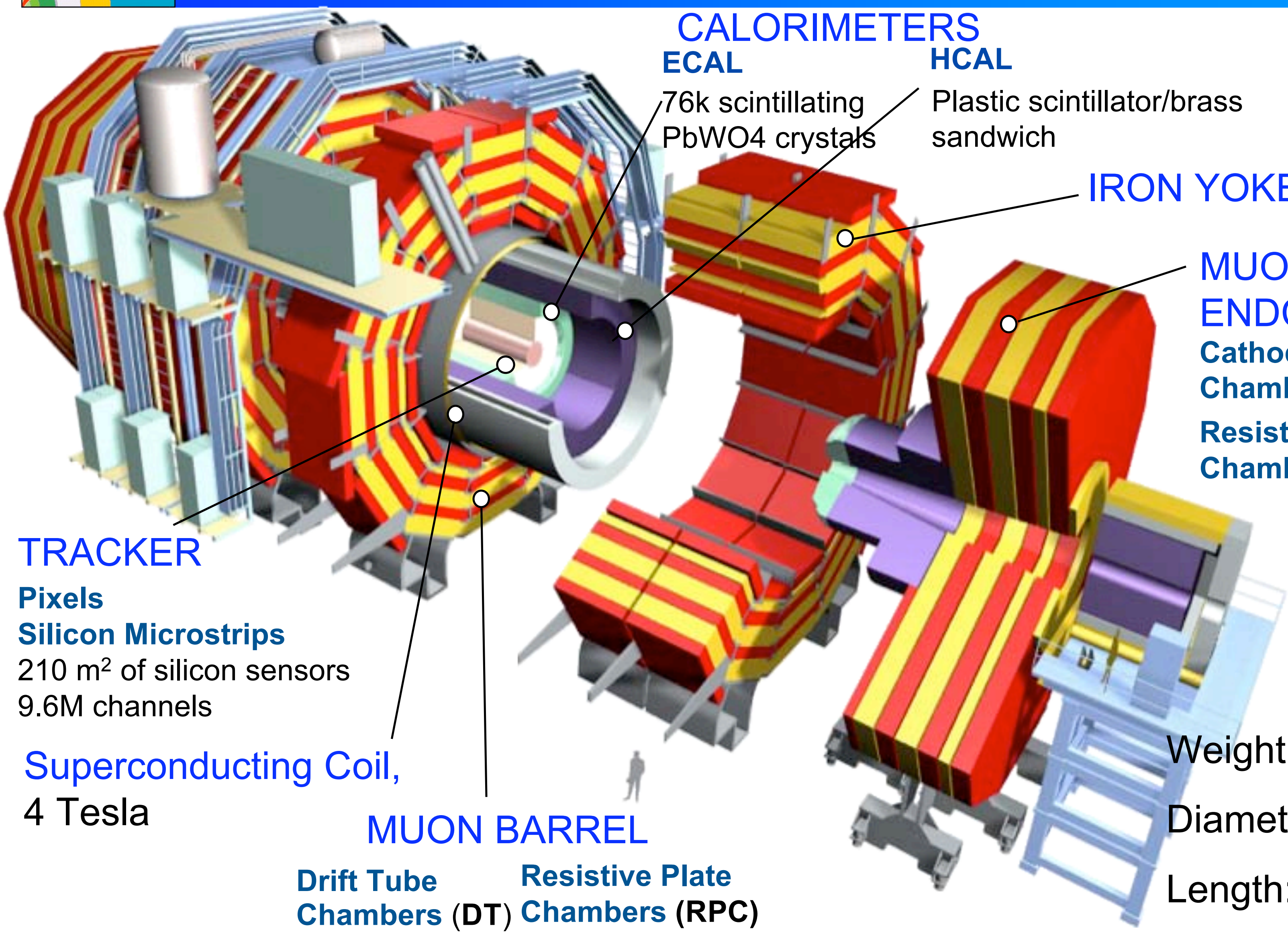
CMS Status and Plans for Physics with First Data

Sridhara Dasu, University of Wisconsin, CMS Collaboration

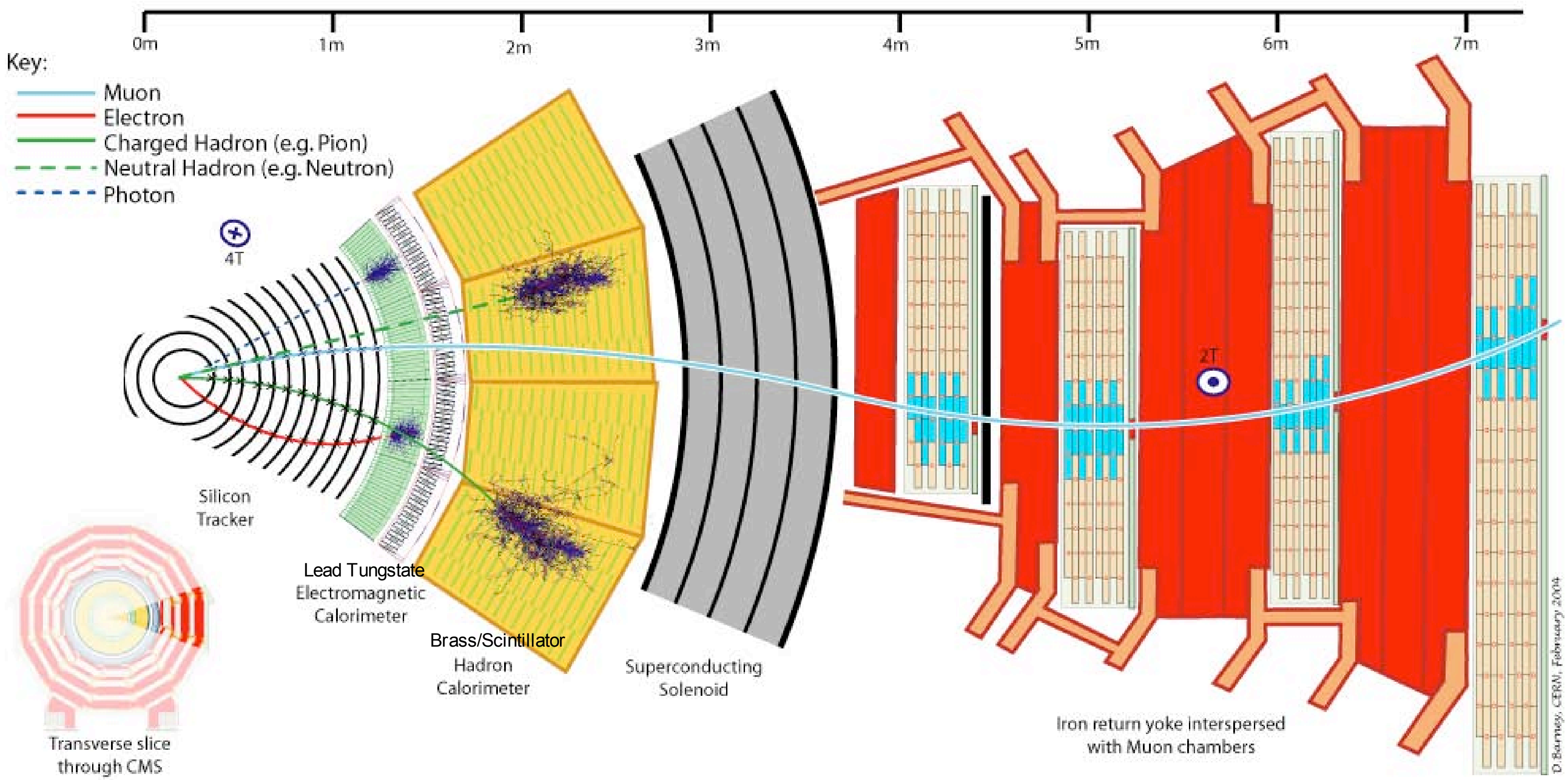


LHC, ATLAS Status & Early Physics Prospects - Fabiola Gianotti
CMS Status & Early Trigger - This Talk

Compact Muon Solenoid



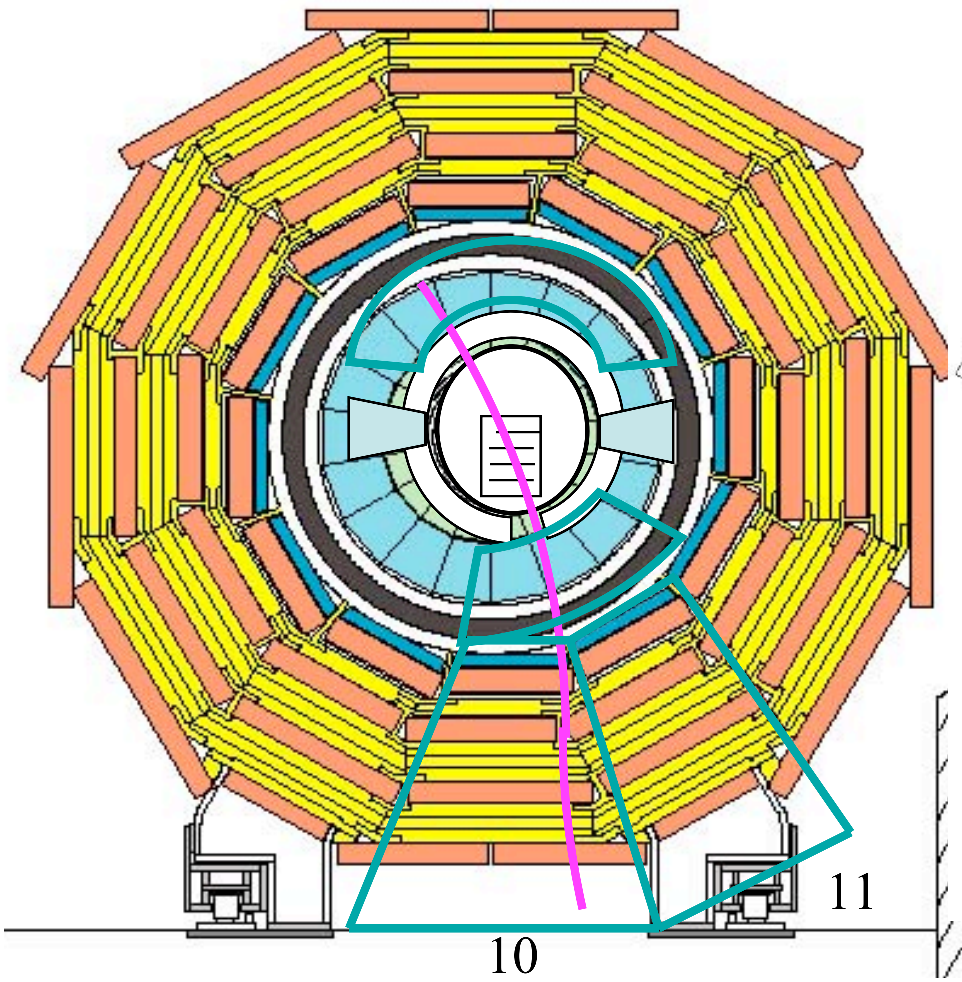
Transverse Slice of CMS



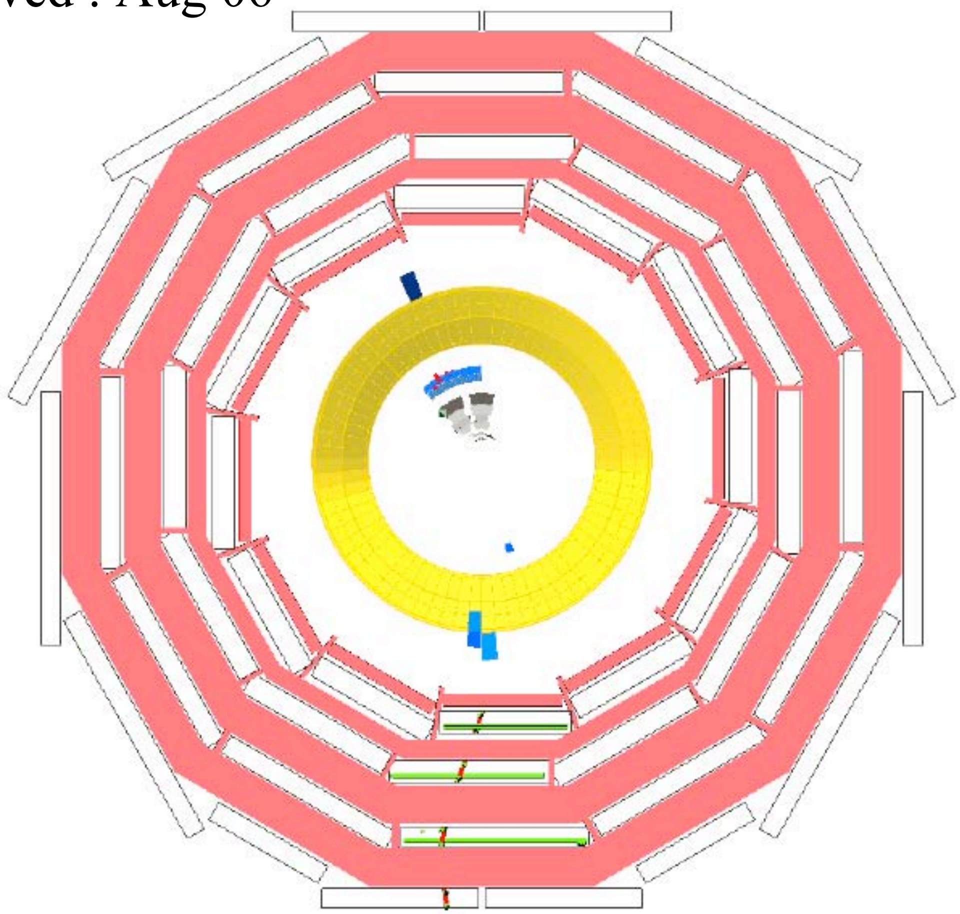
Magnet Test, Cosmic Rays

4T Magnet commissioned on Surface in 2006

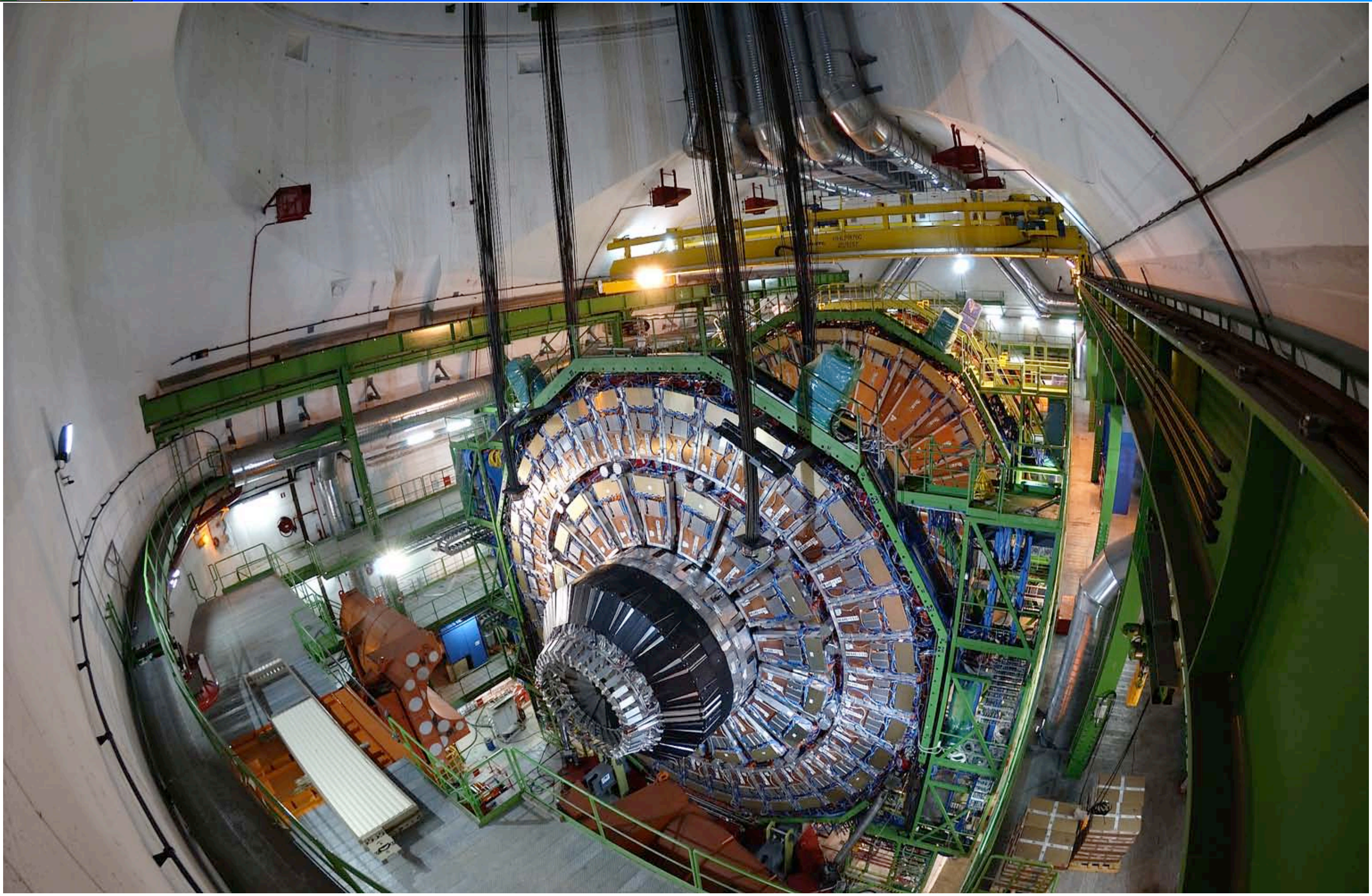
Aim Jun 04



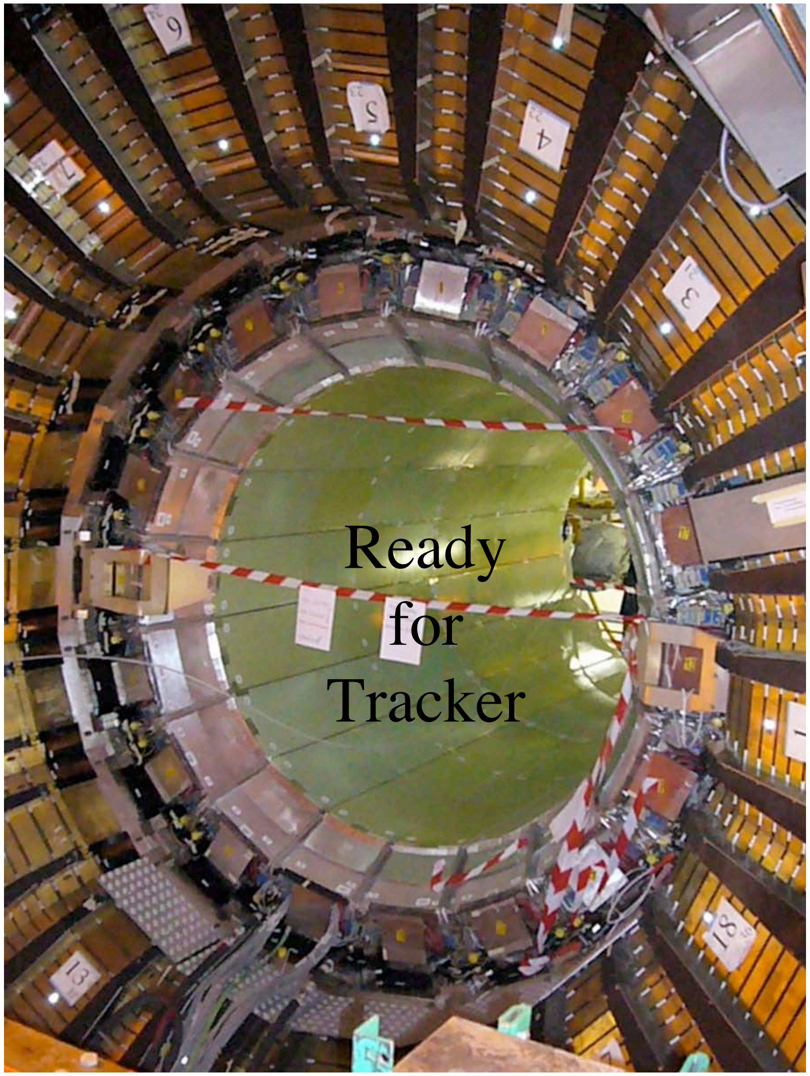
Achieved : Aug 06



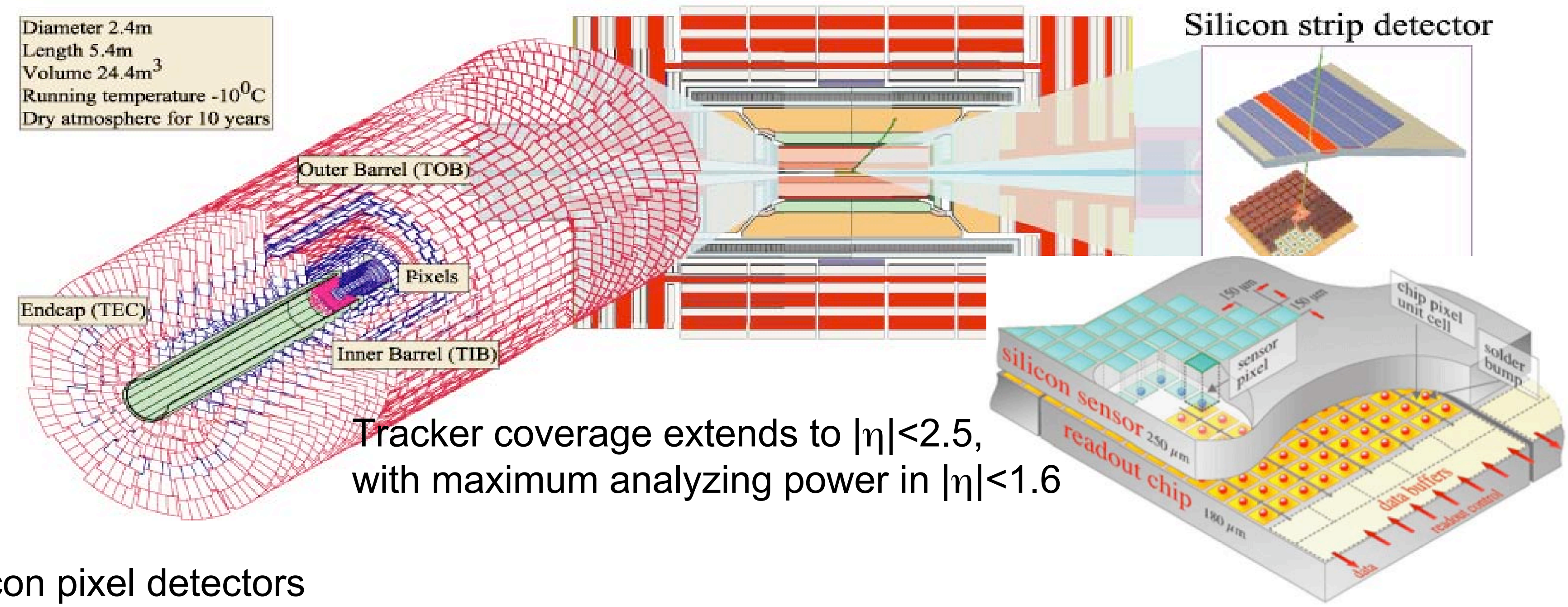
CMS is Built on Ground & its Disks & Wheels Lowered with μ-chambers



Central Wheel Lowered
Calorimeters Installed



Tracker



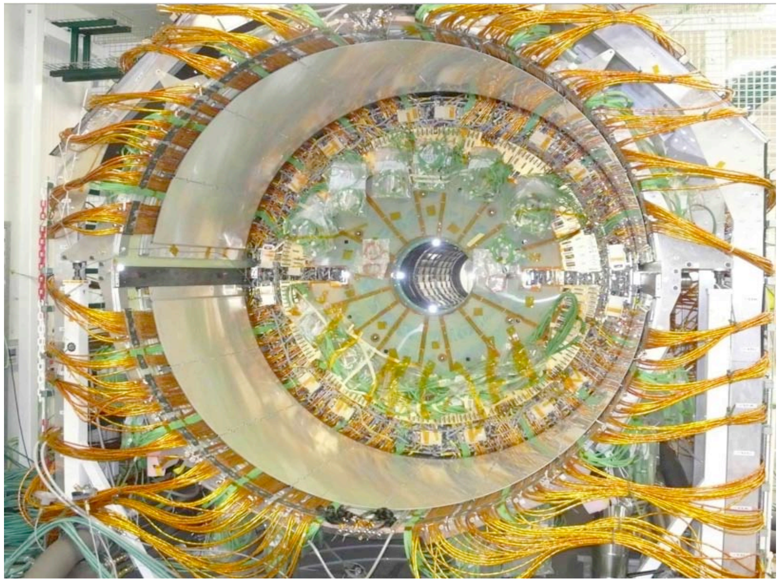
Tracker coverage extends to $|\eta|<2.5$, with maximum analyzing power in $|\eta|<1.6$

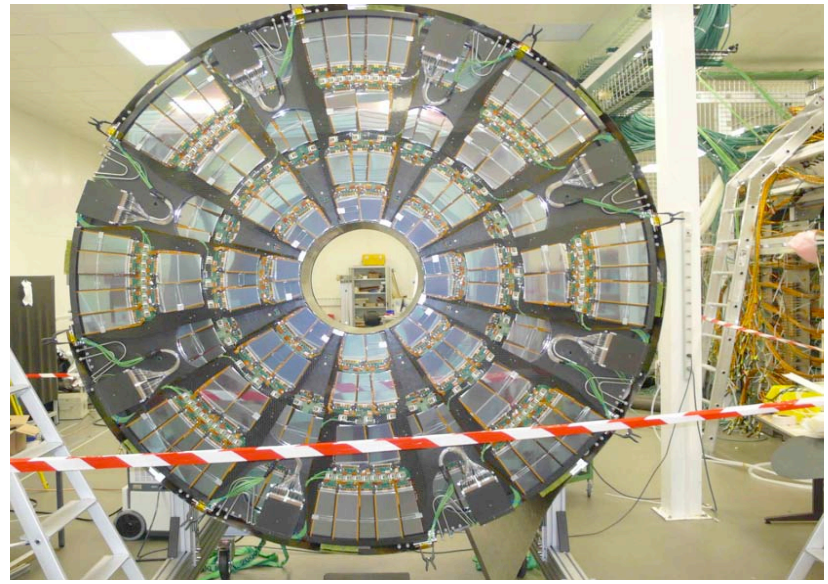
Silicon pixel detectors used closest to the interaction region

Silicon strip detector used in barrel and endcaps

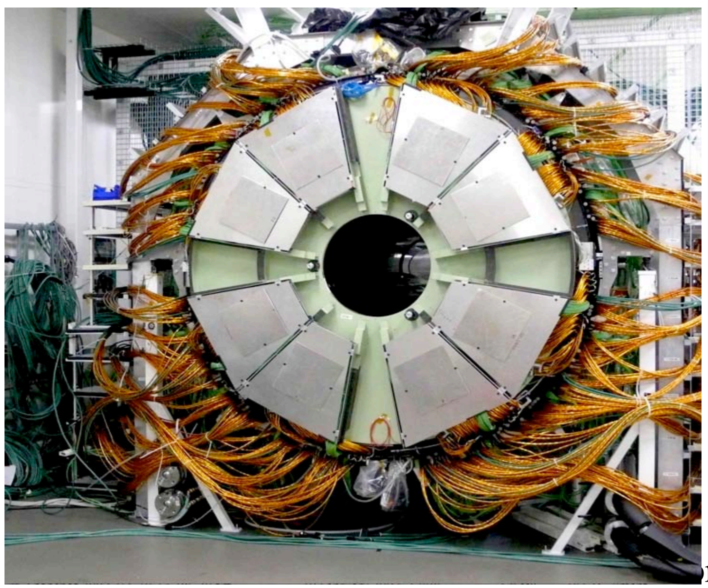
Tracker in Integration Facility

Tracker Barrel





Tracker Endcap



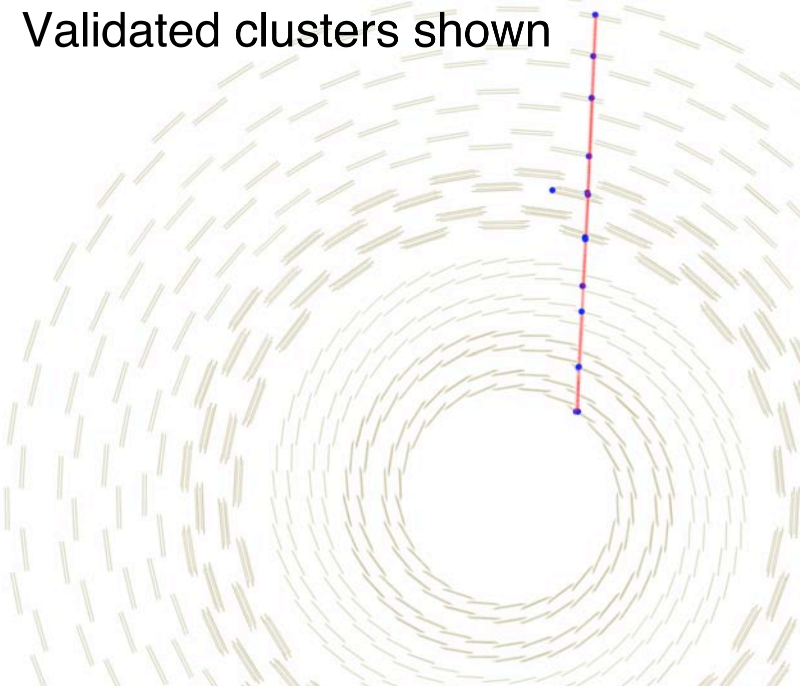
Trackers Assembled and tested in TIF

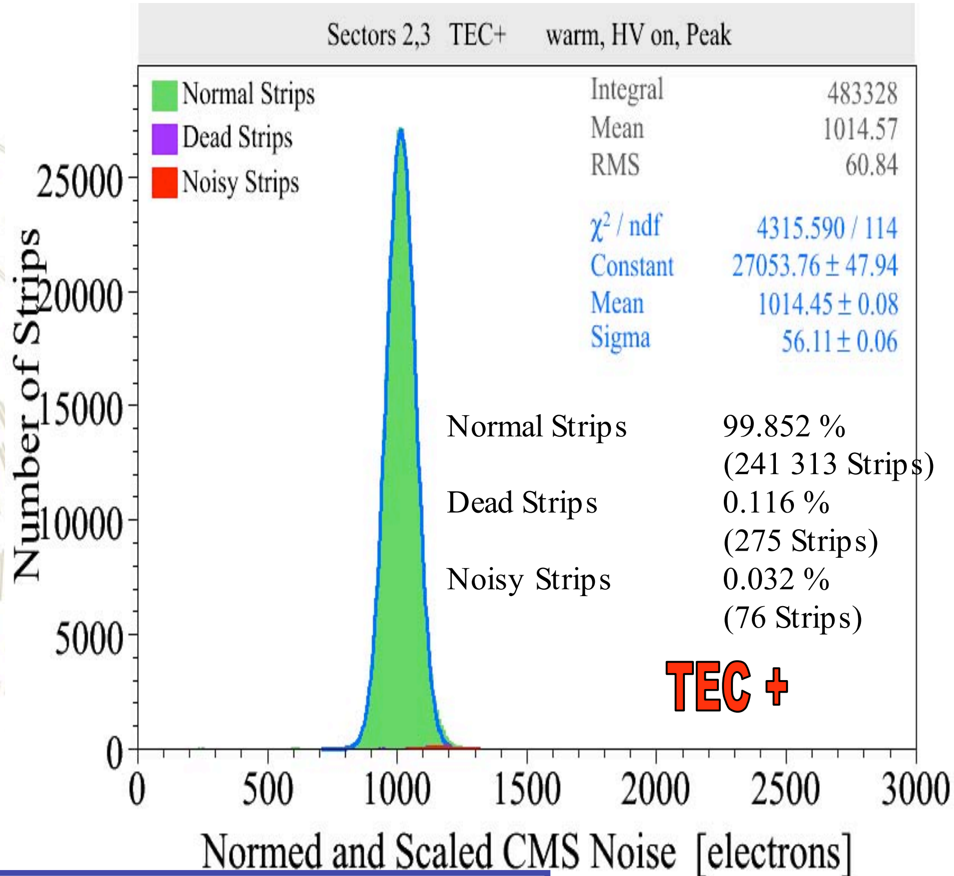
Ready for installation in September

Cosmics in the Tracker

A cosmic at -15°C

Validated clusters shown



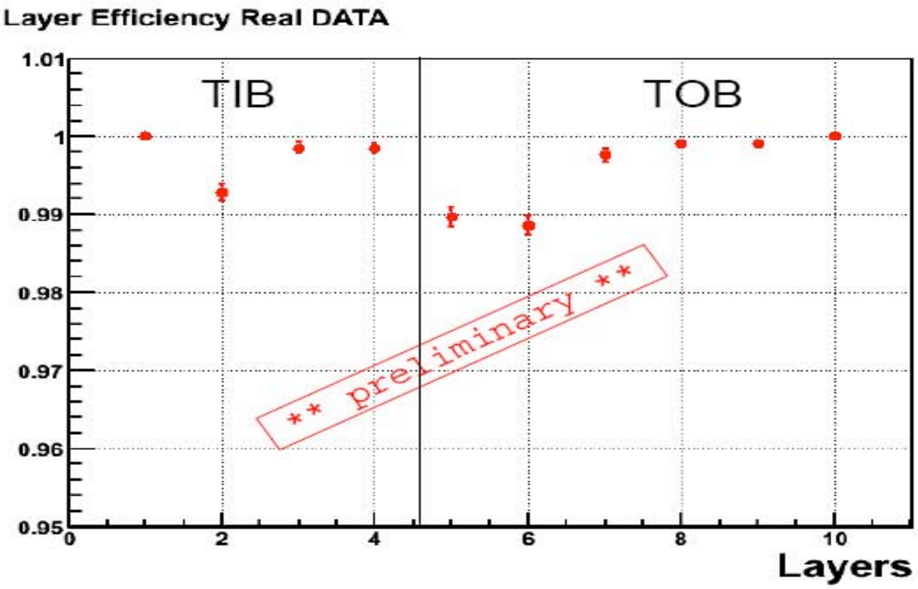


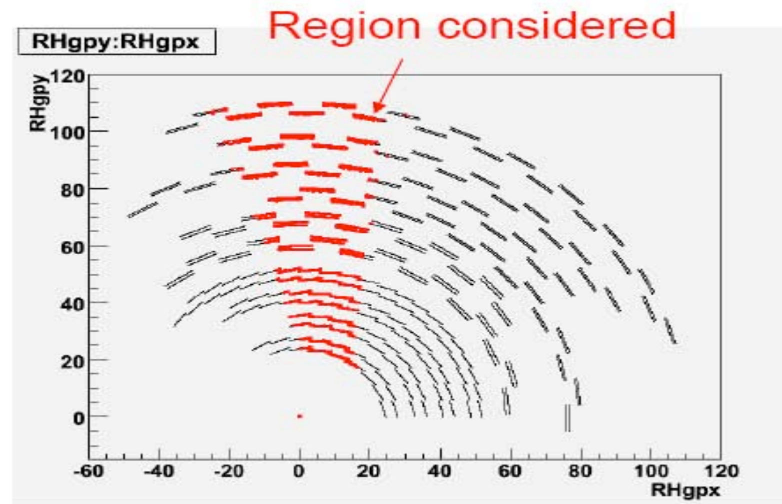
- **The Quality of the CMS Tracker is Excellent:**
- Dead or Noisy Strips < 3 / 1000
- Signal:Noise > 25:1 in Peak Readout Mode
- Enormous experience gained in operating the Tracker at TIF

Measured Tracker Efficiency

Real Data: Layer efficiency Summary

The alignment position error (APE) is set to 2 mm





The layer efficiency in the region considered is more than 99.7% for single side layers and more than 99% for double side layers.
Further cross check need for double side layers.

02 May 2007 Daniele Benedetti - Università&INFN Perugia 14

Pixels

Barrel

Module production: ~80% out of 800 modules produced

12 module system test being conducted

Material budget expected to smaller than in simulation

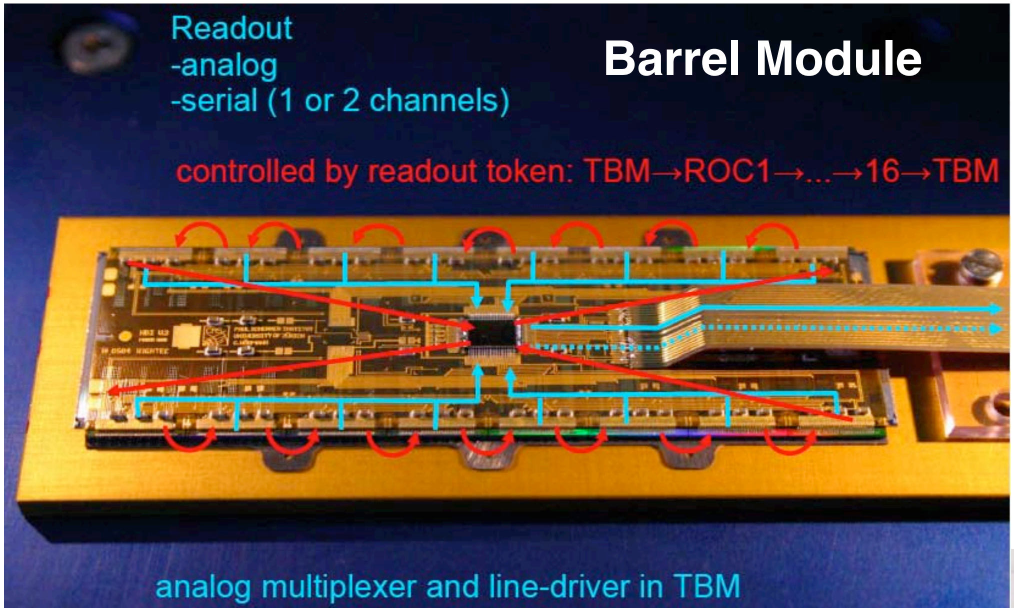
Final system: one side ready for soak testing in ~ November and the other in ~ December. Ready for Installation in January 2008.

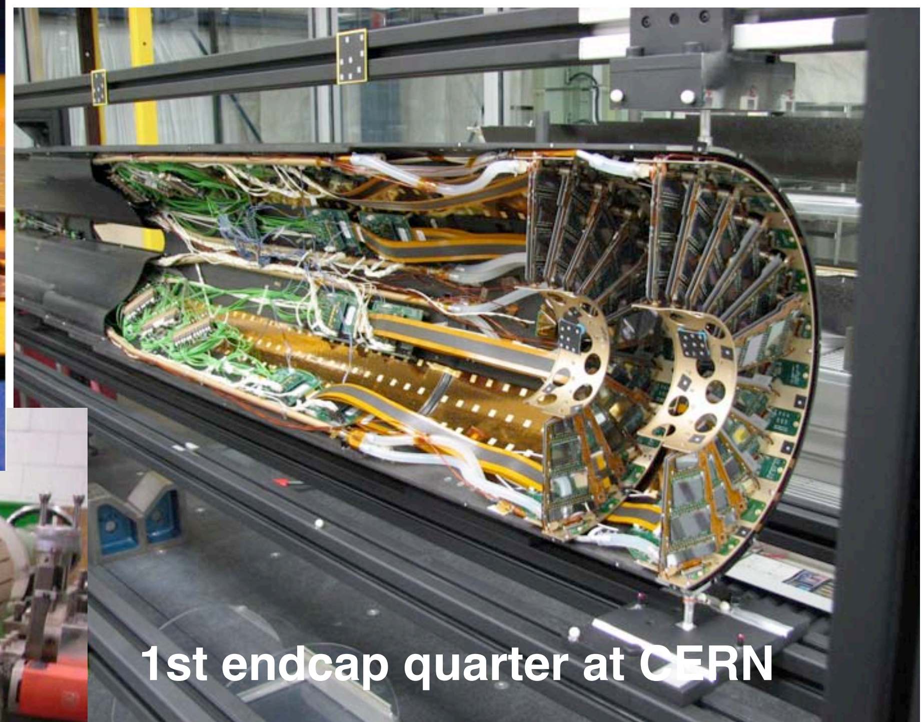
Endcap

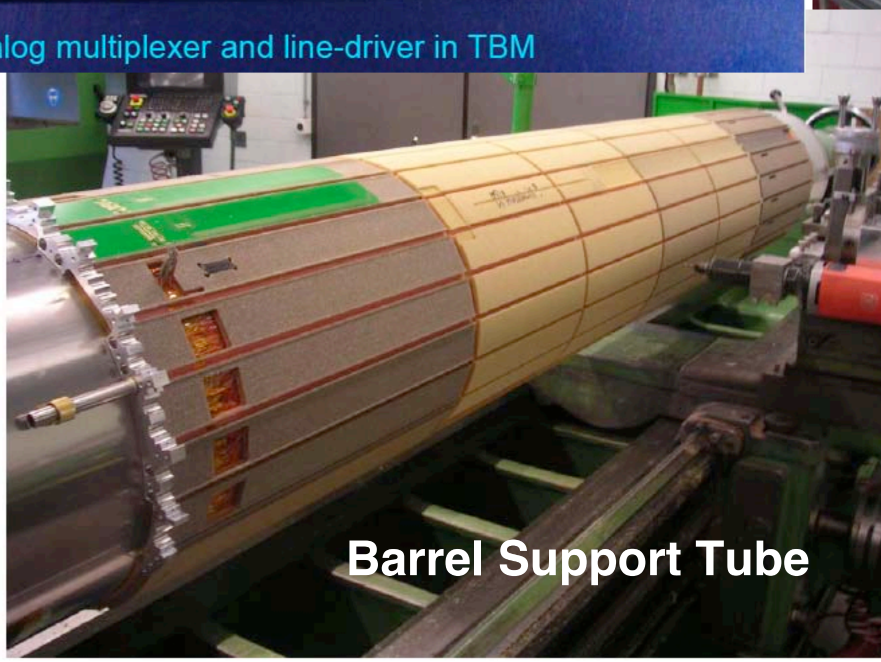
2 quarters delivered to CERN, the last quarter by Sept/Oct

Vulnerabilities workshop held at FNAL. Preliminary conclusion - detector OK if bias is switched off until beams are stable.

Pixels





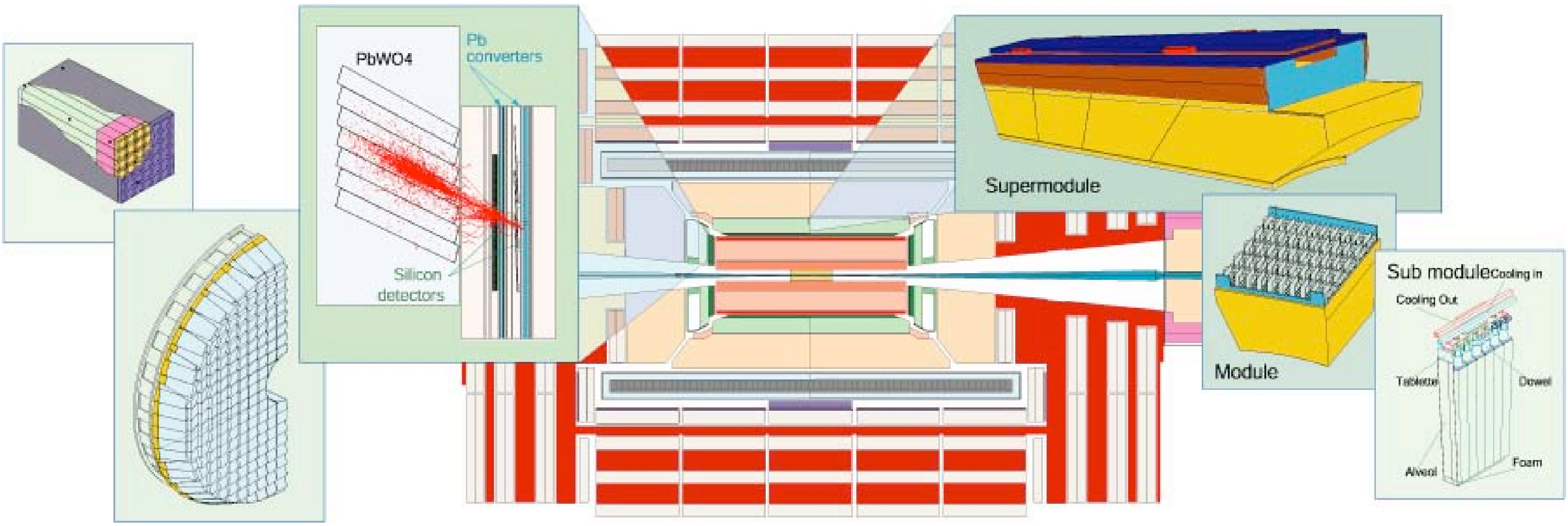


Pixels system will be installed a few weeks before closure.

Electromagnetic Calorimeter

- ECAL measures e/γ energy and position to |η| < 3
- ~76,000 lead tungstate ($PbWO_4$) crystals
  - High density
  - Small Moliere radius (2.19 cm) compares to 2.2 cm crystal size
- Resolution: $$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.83\%}{\sqrt{E}}\right)^2 + \left(\frac{124MeV}{E}\right)^2 + (0.26\%)^2$$

Barrel Installed

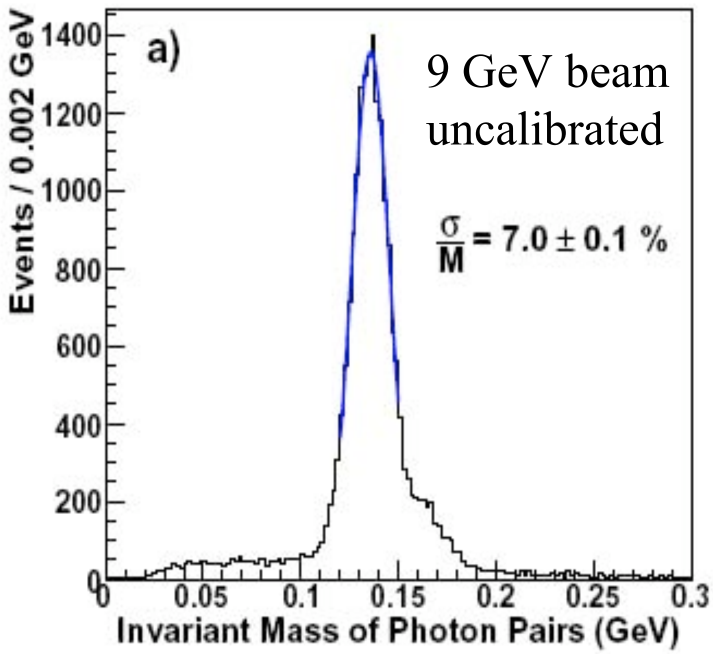


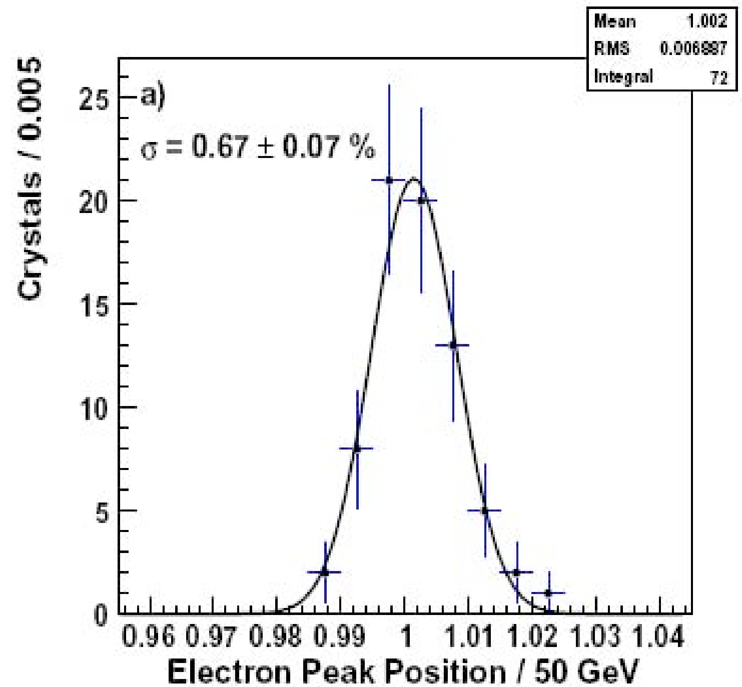
Endcap still in construction

Test Beam: ECAL Calibration

Fitted positions of the peaks of the individual energy spectra for the 50 GeV electrons centered on different crystals after calibration with ~ 140 p^0s/crystal.

0.67% , consistent with statistical expectation

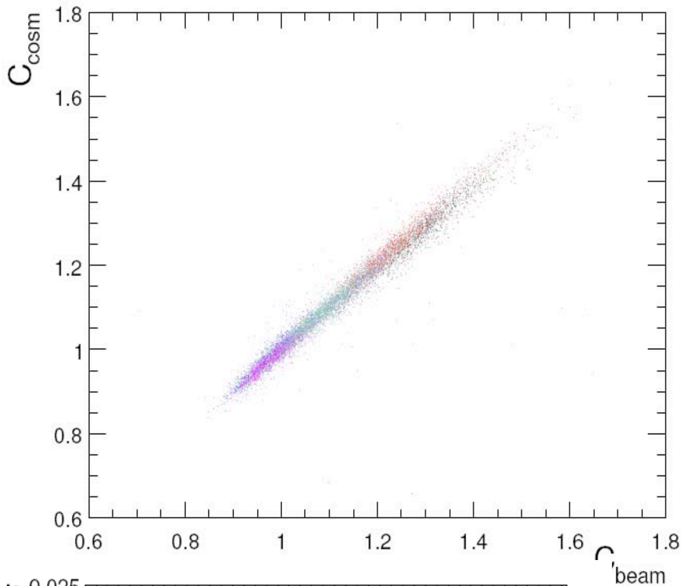


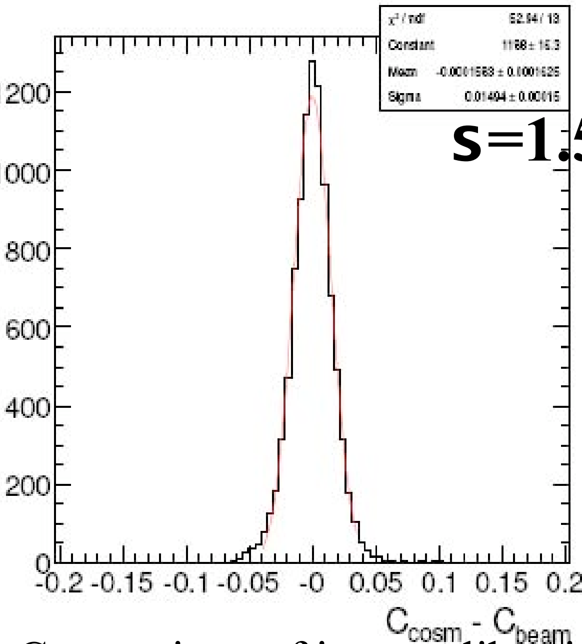


Raw p^0 mass

50 GeV electrons

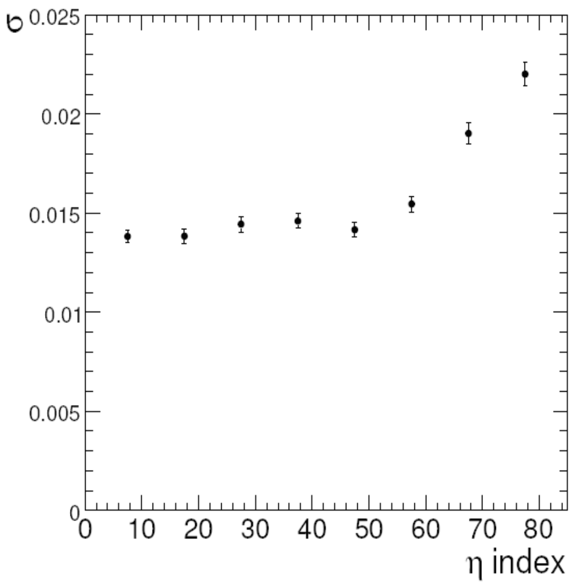
Cosmic rays calibration





s=1.5%

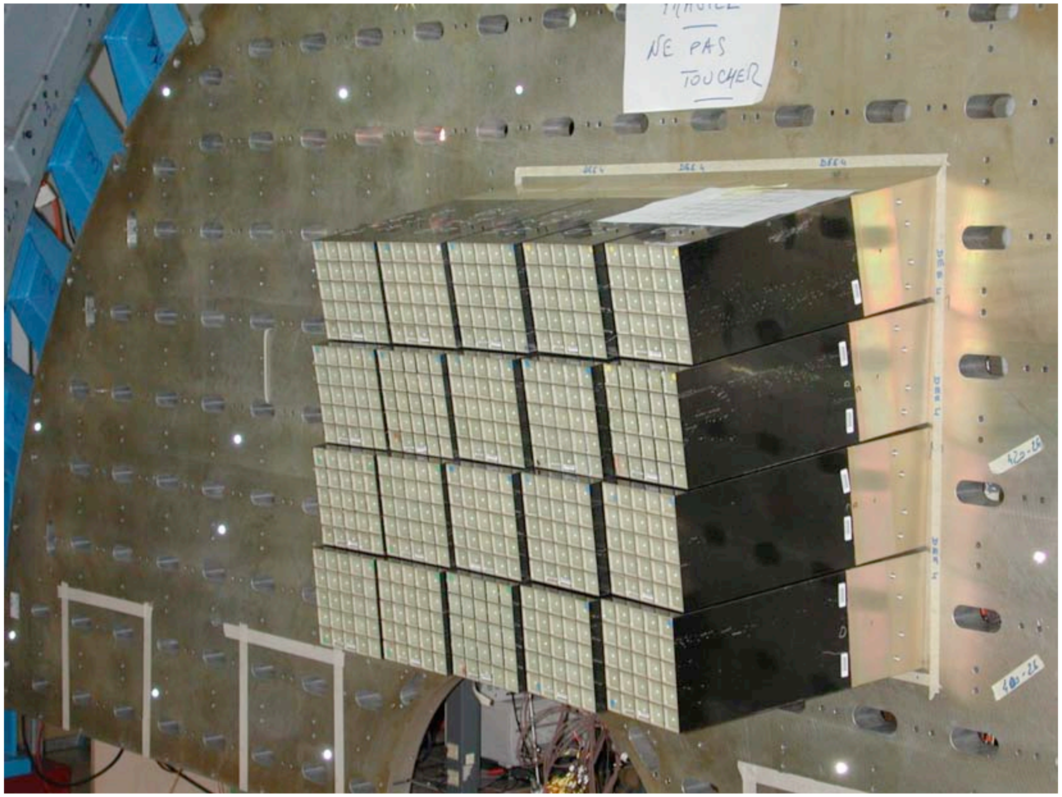
Comparison of inter-calibration coefficients obtained with the beam (C_{beam}) and with cosmic rays (C_{cosm}).

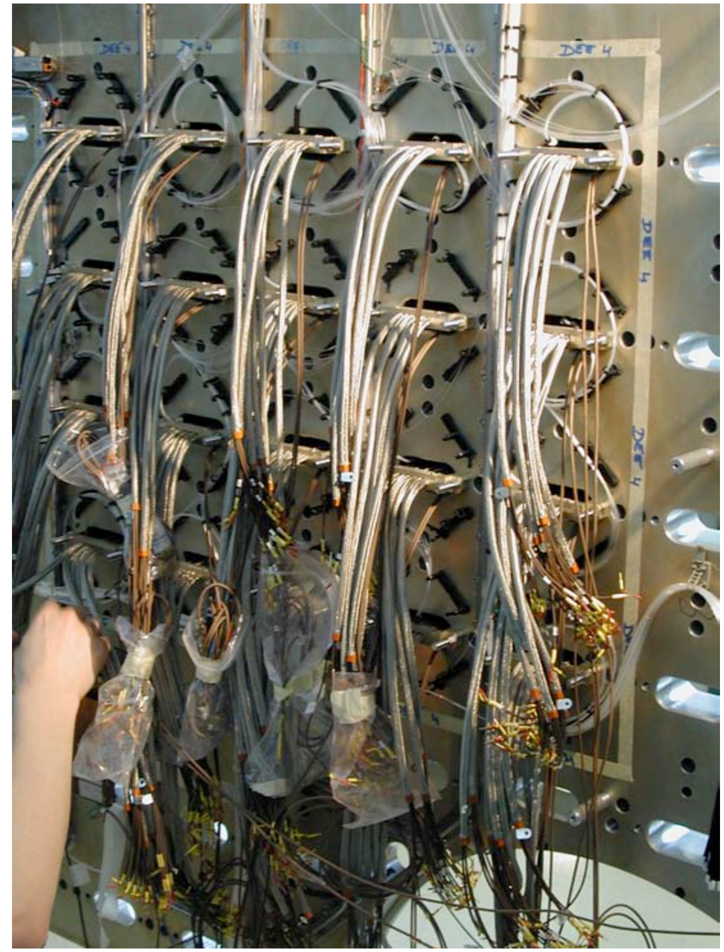


Inter-calibration accuracy as a function of h

Prior to installation all Barrel Supermodules have been pre-calibrated with cosmic rays with an average accuracy of 1.5%

Endcap ECAL 'Dee4'





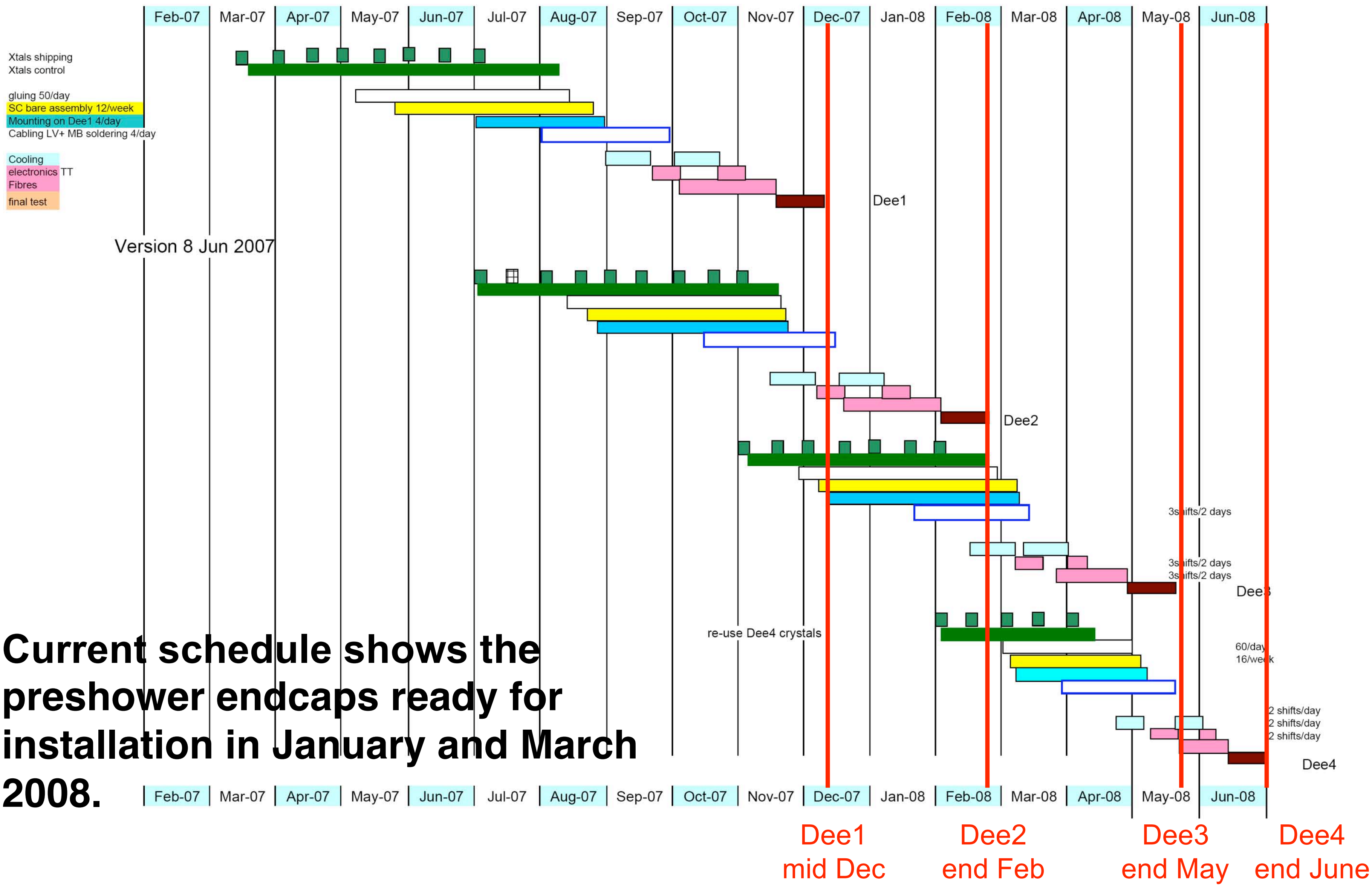
20 SCs mounted – confirmation of geometry
All 500 VPTs tested and working.

Cables in the back …

Steady Assembly Progress

Crystals Production: last crystals to be delivered end-Mar08

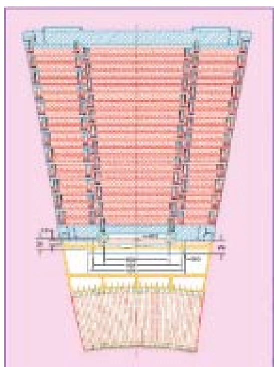
EE Schedule

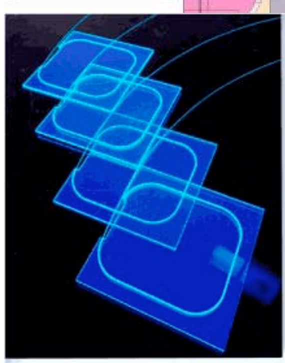


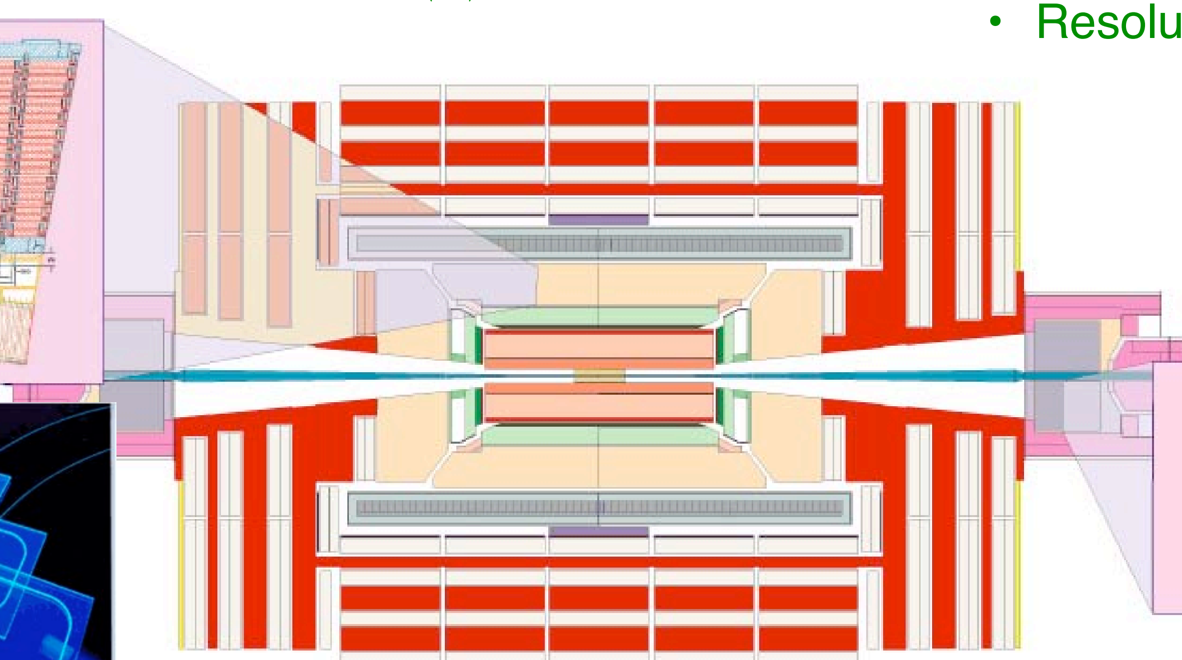
Current schedule shows the preshower endcaps ready for installation in January and March 2008.

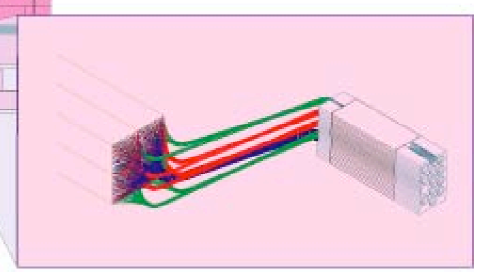
Hadronic Calorimeter

- HCAL samples showers to measure their energy/position
  - HB/HE -- barrel/endcap region
    - Brass/scintillator layers
    - Coverage $|\eta| < 3$
    - Resolution: $\left(\frac{\sigma}{E}\right)^2 = \frac{115^2}{E} + 5.5^2$
  - HF -- forward region
    - Steel plates/quartz fibers
    - Coverage to ±5
    - Resolution: $\left(\frac{\sigma}{E}\right)^2 = \frac{280^2}{E} + 11^2$





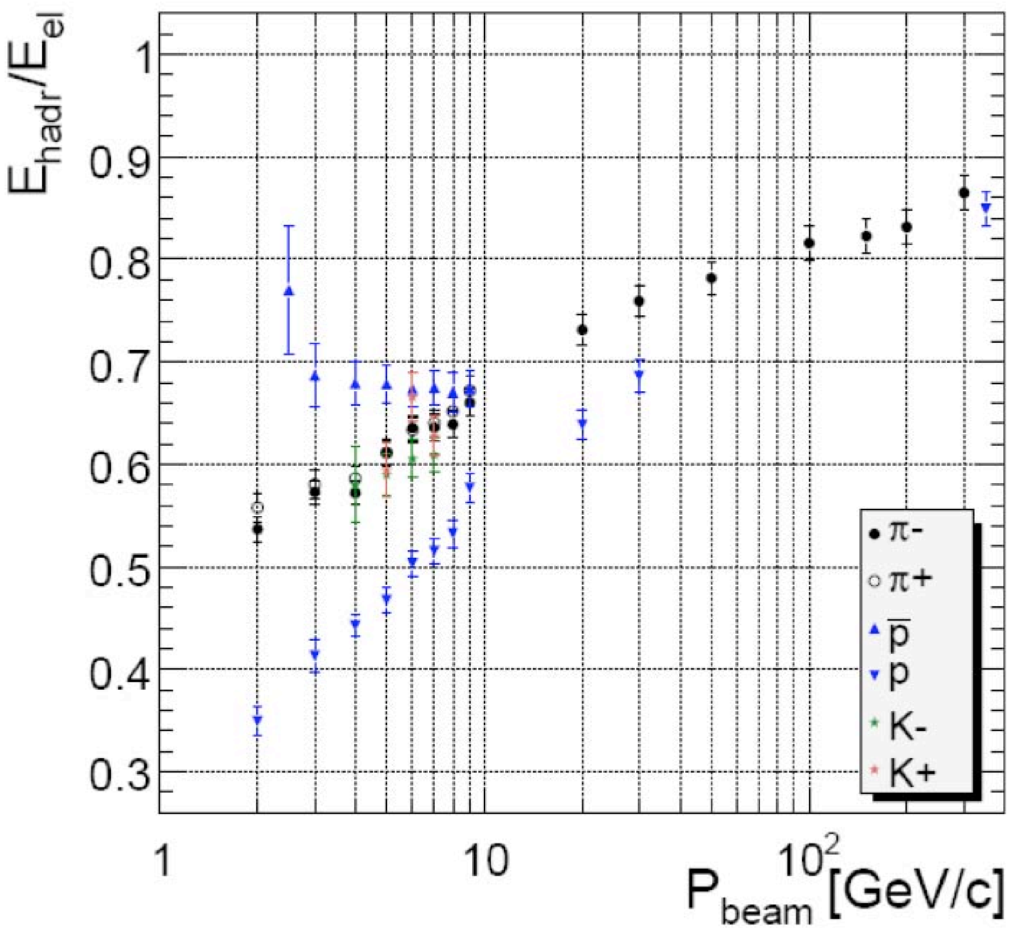


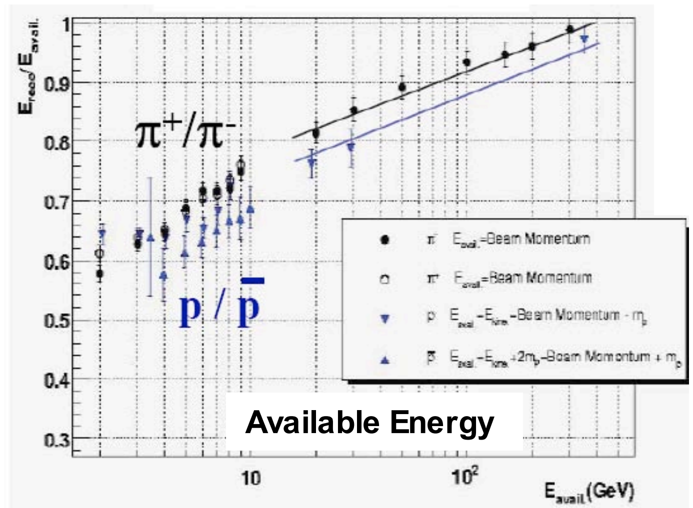


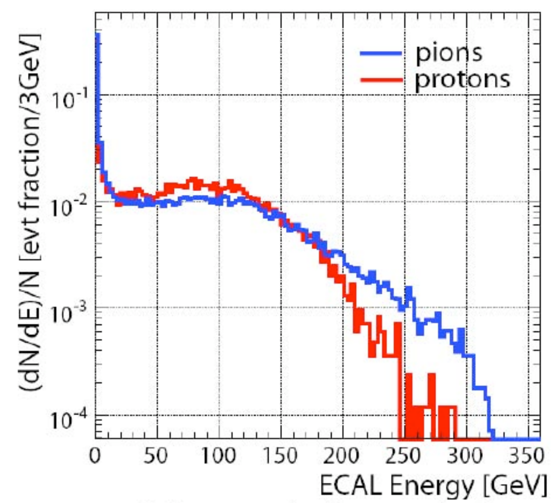
HCAL is fully installed
- being commissioned

ECAL+HCAL response to Hadrons

2-300GeV with particle id.

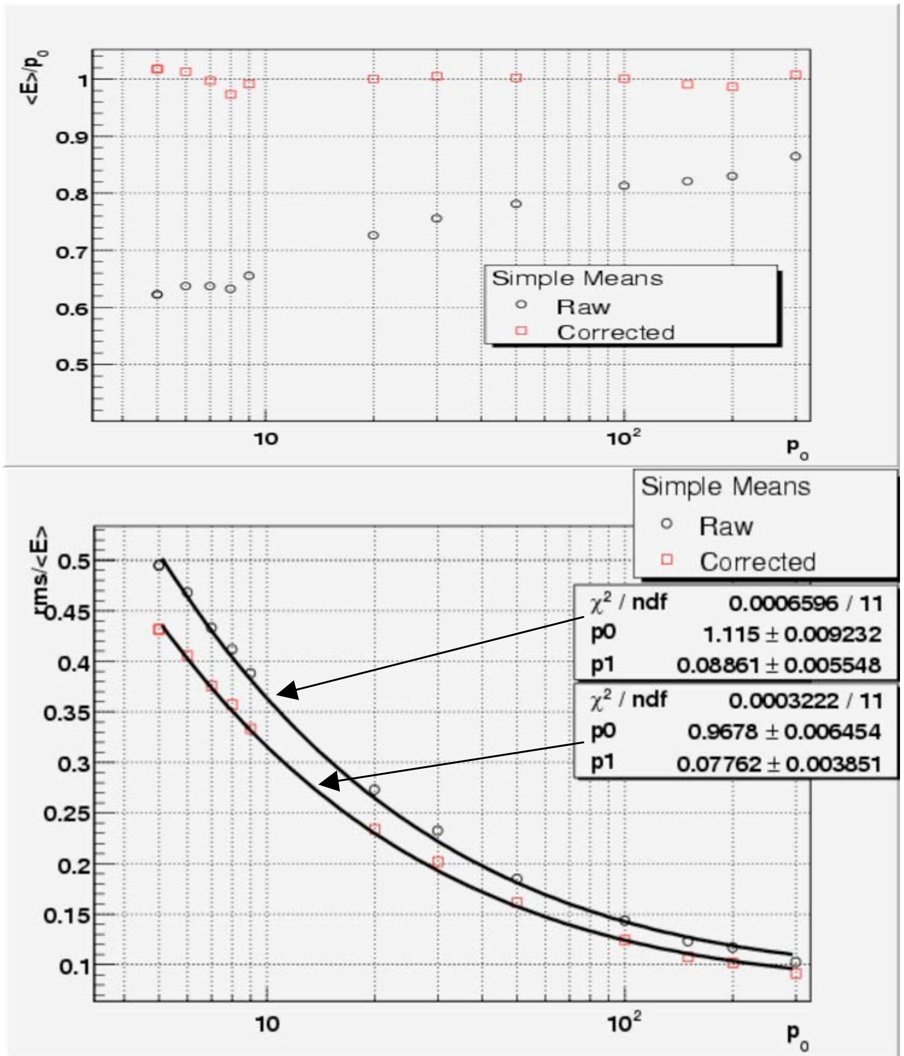






Not much forward π^0
in p+N interaction.

Resolution for Corrected Data
(Simple Mean & RMS)



- Blue points are the Raw Data
- Red points are the corrected data (using an e/h correction algorithm)
- Response is increased by ~40% @ 5 GeV and 15% @ 300 GeV.
- Stochastic term of resolution is improved by ~15%.

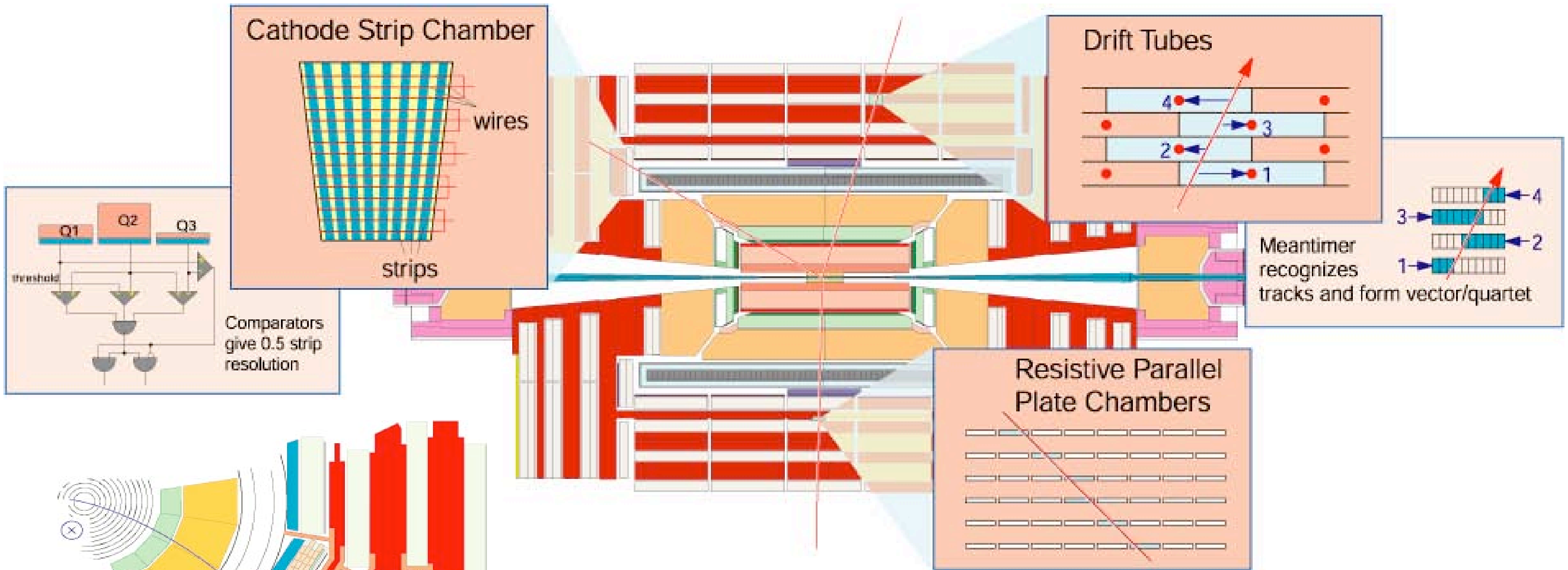
97% < Corrected Response < 102%

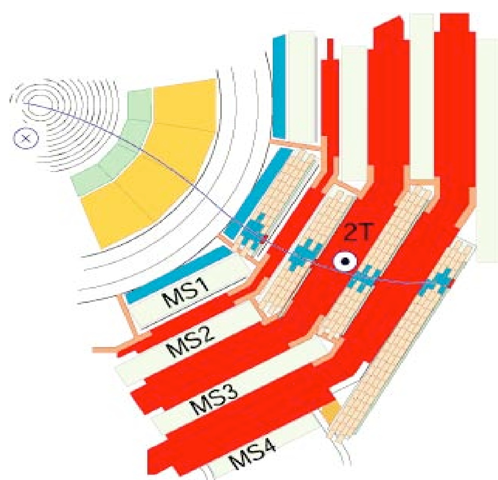
Resolution for Raw Data:
$\sigma/E \sim 112\%/\sqrt{E} \oplus 9\%$

Resolution for Corrected Data:
$\sigma/E \sim 97\%/\sqrt{E} \oplus 8\%$

- HCAL commissioning underway
- HF+ is the first CMS detector to be fully operational in UX5.
- Starting to commission HE+ and HB

Muon System





All chambers but those near heavy lifting mounts installed - many commissioned

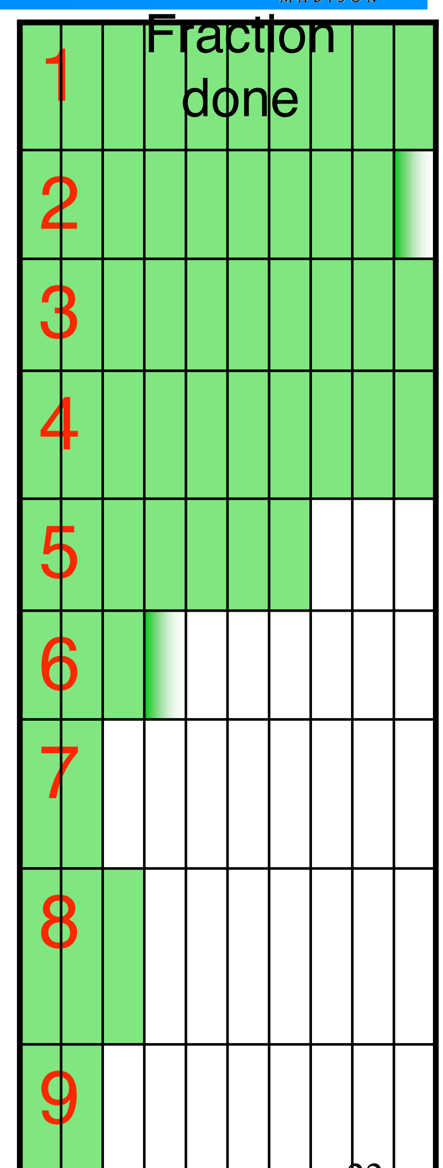
Muon chambers identify muons and provide position information for track matching.

- Drift tube chambers max area 4m x 2.5m cover barrel to $|\eta|=1.3$
- Cathode strip chambers in endcaps use wires and strips to measure r and ϕ, respectively. Coverage $|\eta|=0.9$ to 2.4.
- Resistive plate chambers capture avalanche charge on metal strips. Coverage: current $|\eta|<1.6$ - eventual $|\eta|<2.1$

Muons: DT Status

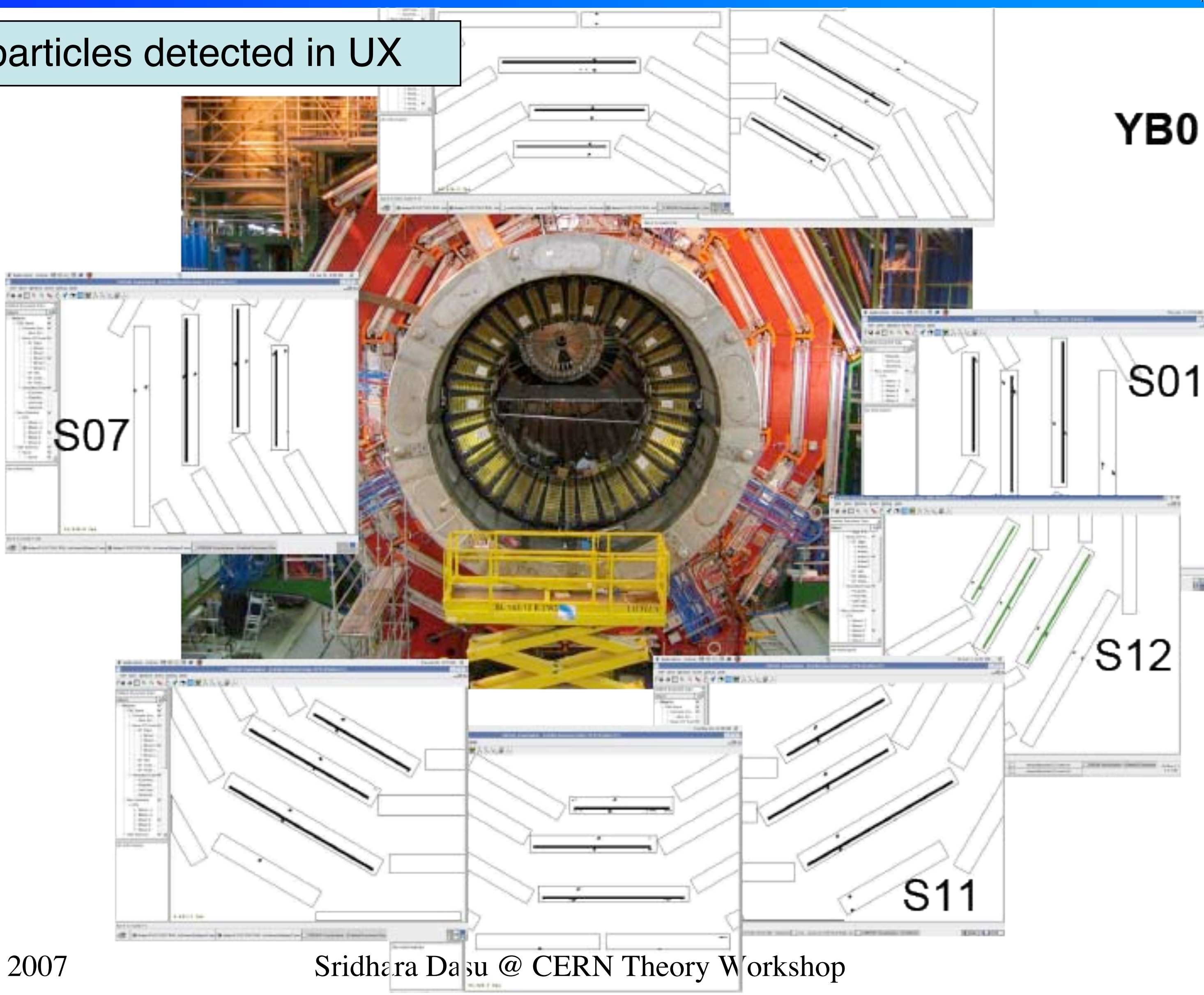
1. **All chambers tested, equipped with MiniCrates (Trigger/Readout electronics) and retested.**
2. **All chambers installed, except 8:**
   MB2, MB3 in sectors S1,S7 of wheels YB-1,YB-2
3. **On-wheel cooling and gas piping**
4. **All installed chambers+MCs tested and commissioned with cosmics before installing tower electronics**
5. **On wheel cabling from chambers to Tower electronics (HV, LV, Tr/RO, DCS fibers, TTC fibers) and test**
6. **Install tower electronics (HV(done),LV,Tr/RO, DCS)**
7. **Test and commission from chambers up to towers: ready for connection to USC**
8. **When wheel lowered in UXC, cable to USC and Install and commission USC electronics**
9. **Install and test final software suite; Connect to central DAQ, Trigger, TTC**

In red- activities with current focus.



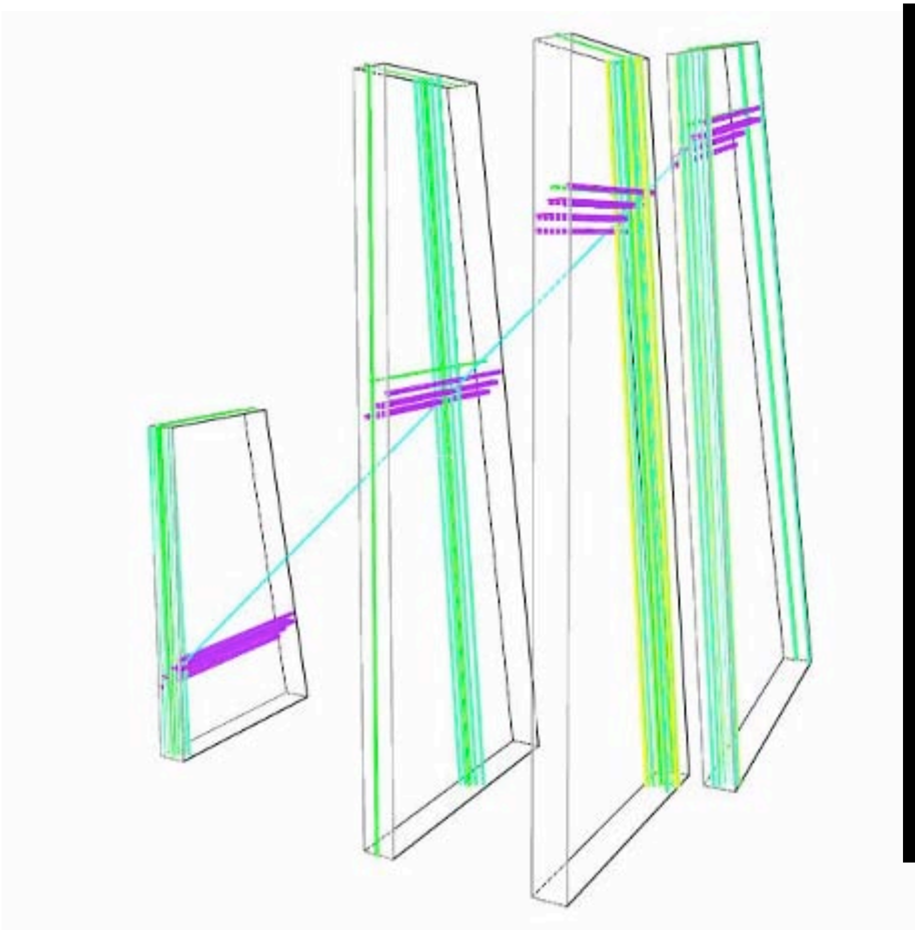
MB0 Stations Underground

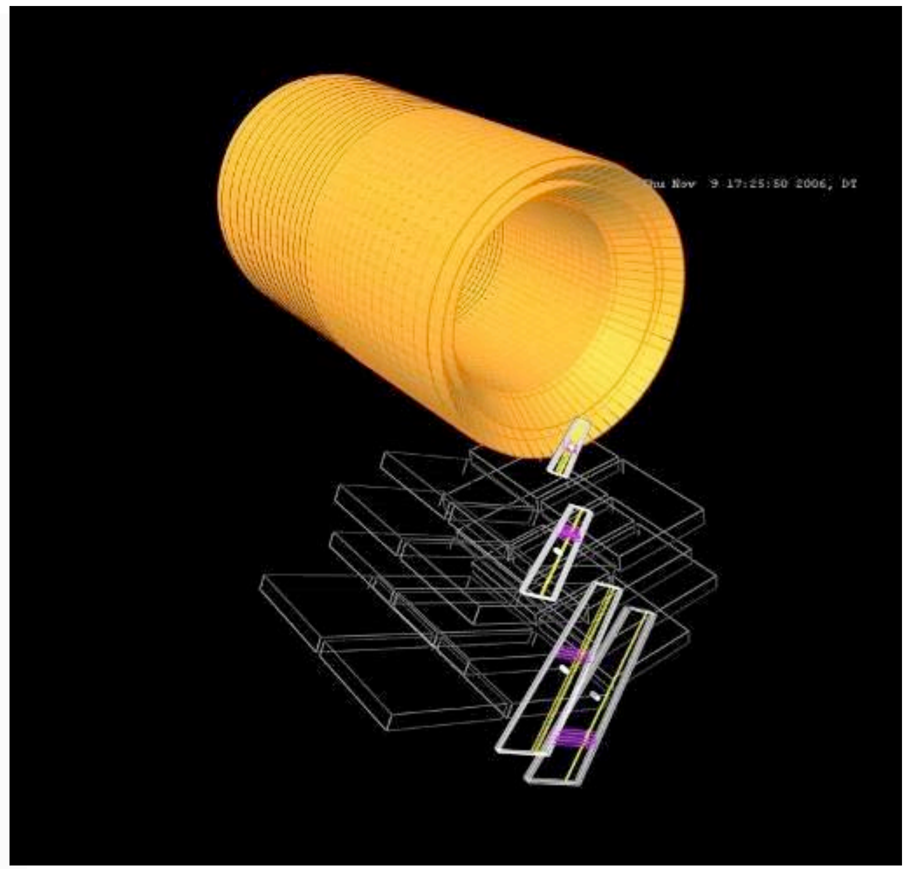
First particles detected in UX



CSCs

- Access to chambers underground is restricted
  - Services being installed and commissioned as possible
- Chambers tested using cosmic rays above ground





RPCs

Barrel installation and commissioning

Hardware installation and pre-commissioning mostly done

Forward installation and commissioning:

Low-η system Pre-commissioning done.

Full system commissioning

YE+ commissioning in November. All system commissioned by Feb 08.

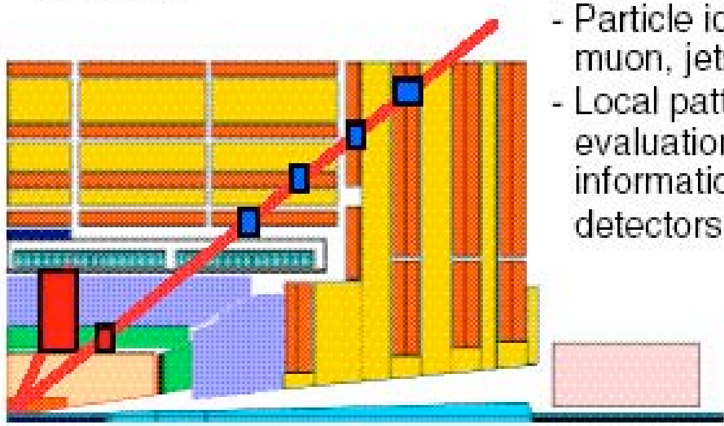
Completion of Muon System

- Positive Wheels and Disks: completion of services commissioning whenever accessible
- Taking data with commissioned chambers in global runs every month
- Negative Wheels and Disks lowering in October-December

Trigger: Selects Interesting Events

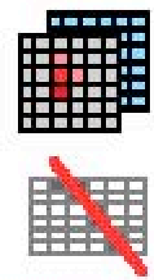
What events are interesting, depends on available luminosity.

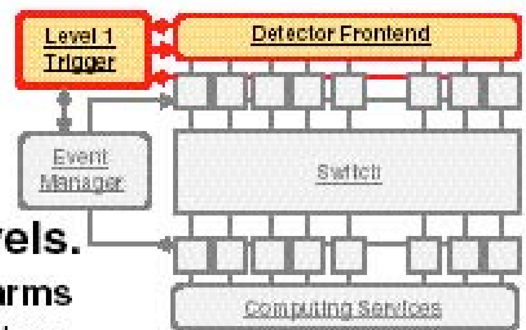
40 MHz



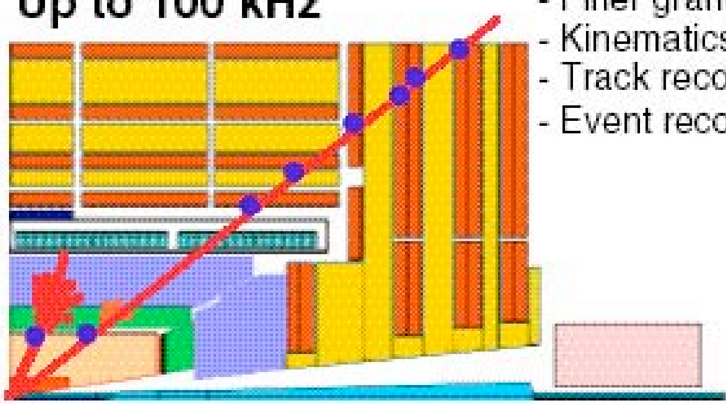
Level-1. Specialized processors

- Particle identification: high p_T electron, muon, jets, missing E_T
- Local pattern recognition and energy evaluation on prompt macro-granular information from calorimeter and muon detectors





Up to 100 kHz

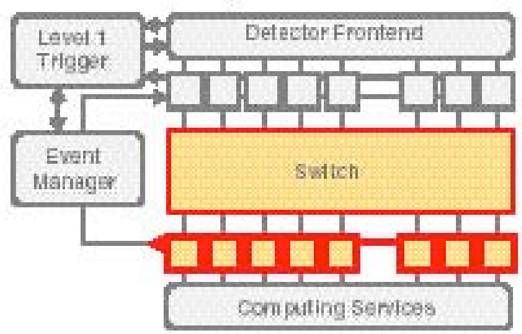


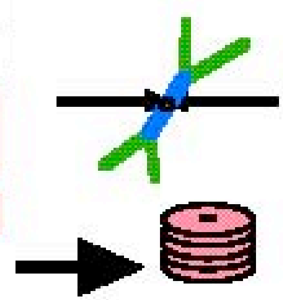
High trigger levels.

Network and CPU farms

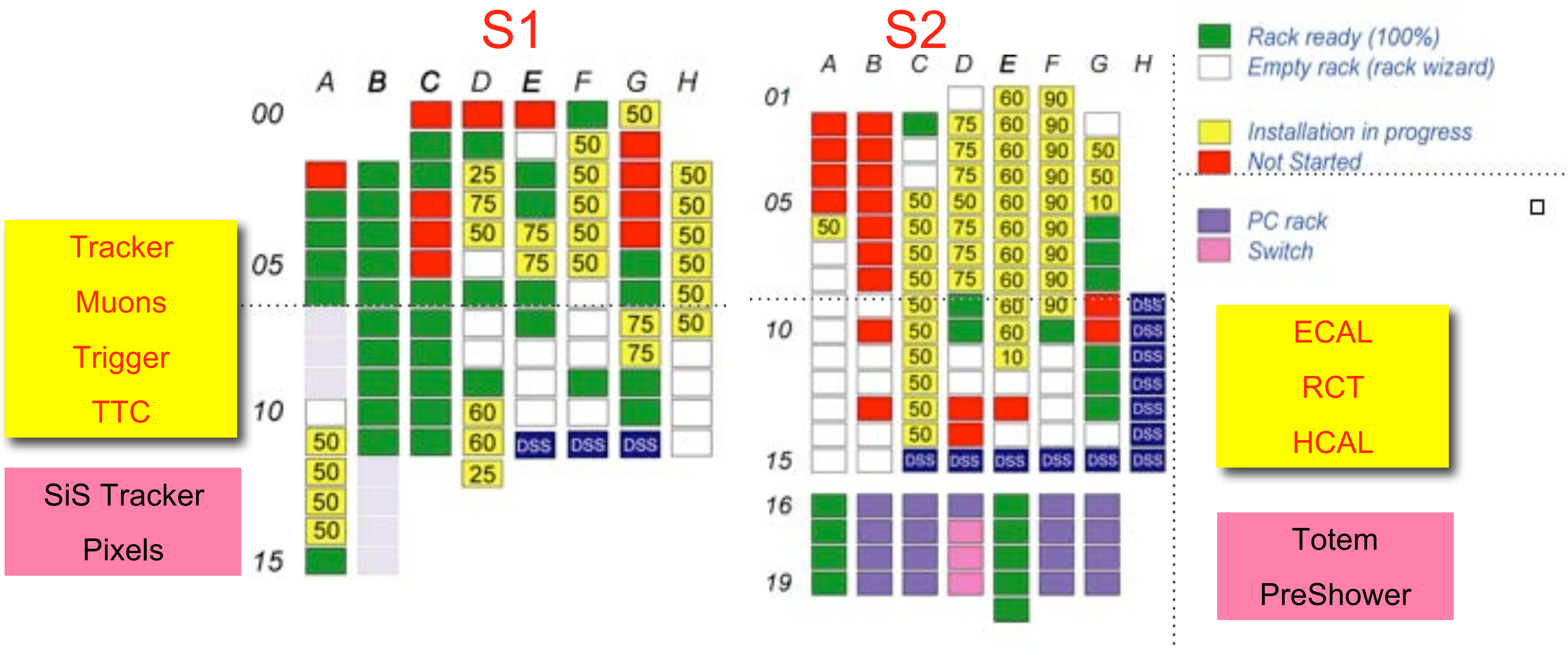
- Clean particle signature
- Finer granularity precise measurement
- Kinematics. effective mass cuts & event topology
- Track reconstruction and detector matching
- Event reconstruction and analysis

≈ 100 Hz





Off-Detector Electronics



More than 80% of Frontend Drivers (FEDs) installed.
Central DAQ Connectivity test has shown no problems

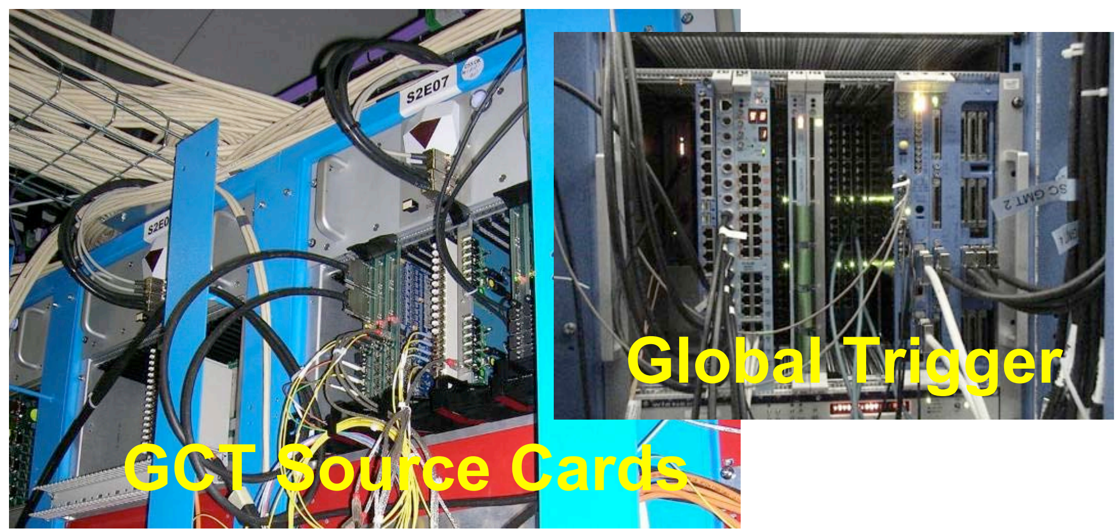
DAQ System FED test done with HCAL, ECAL, CSC, Tracker, RPC: iterations needed in all cases to improve configuration and/or firmware

Trigger Commissioning

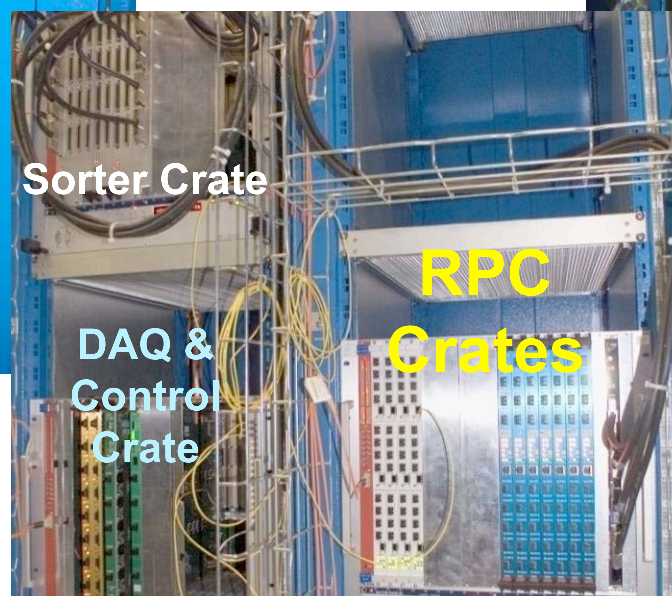
Electronics installation and commissioning are underway in USC55

- Participate in global runs
- Generate triggers for cosmics
- Readout multiple subsystems
- DT muons farthest ahead

Calorimeter Trigger



Muon Trigger

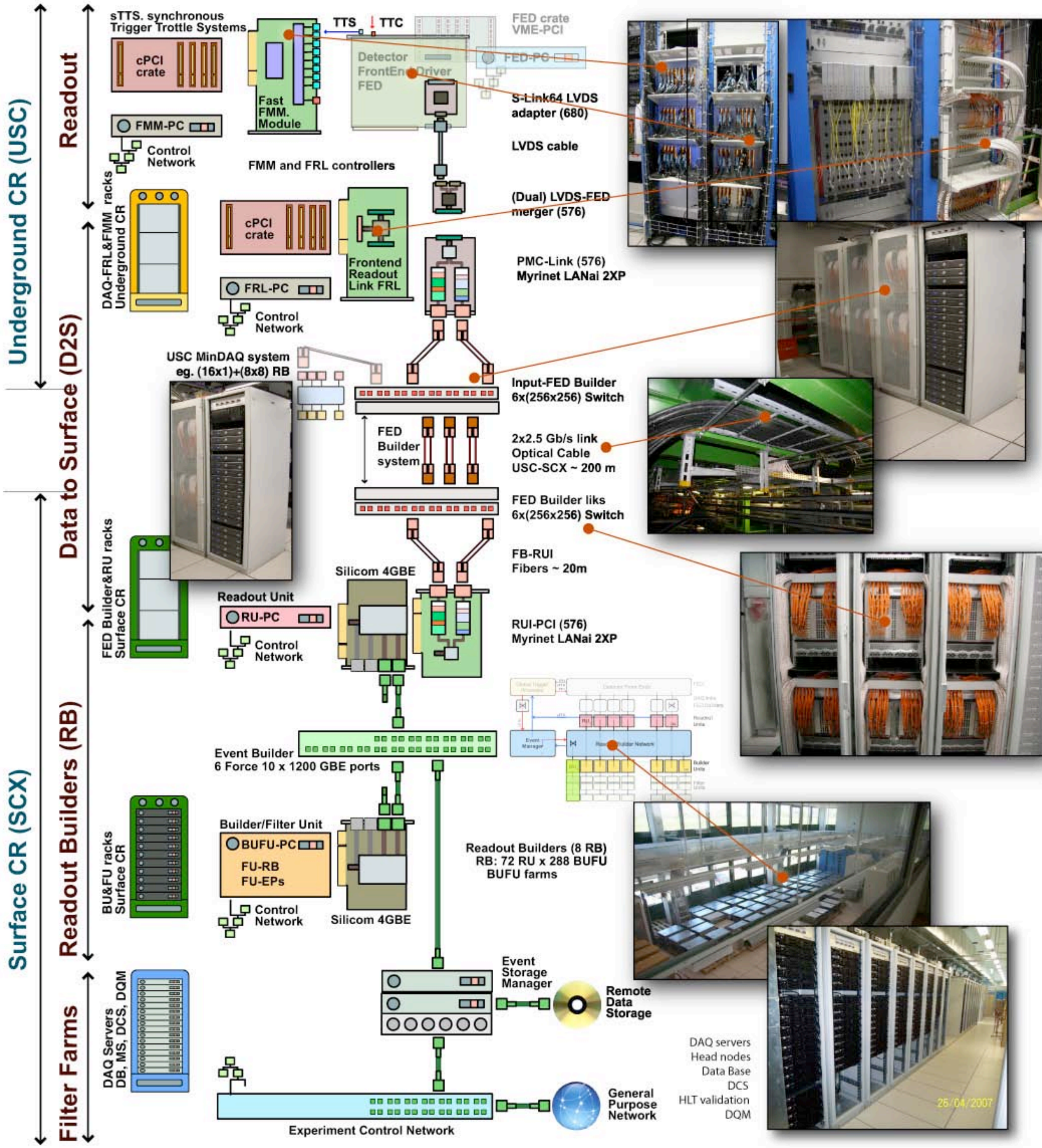


DAQ

Frontend Readout
- **INSTALLED & tested**

Data To Surface (USC-SCX)
- **INSTALLED & Tested**
- Myrinet switches
- Myrinet Fibers (1024)

Surface Hall SCX (DAQ Farms)
- 800 PC 2x2 2GHz Xeon, 4 GB **DELIVERED**
- 650 RU/BU PCs (650) **INSTALLED**
- Event Builder GBE switches (Force10) **INSTALLED**
- Mass storage (22 TB, 1GB/s) **ORDERED**
- Filter farm order in Dec 07



Offline Computing

Commission the global computing infrastructure

- Transition from commissioning to stable operations **while supporting on-going physics studies and detector commissioning**

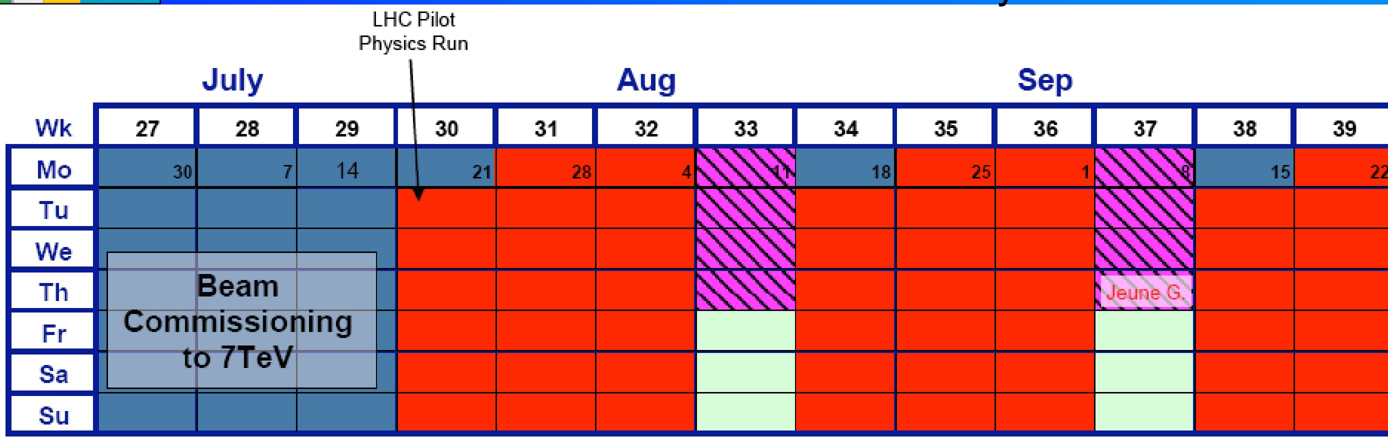
Making end-to-end tests of computing systems through **participation in 2007 physics exercise (50 M events/month generated at T2 and reconstructed at T0-T1), global data taking and cosmic runs and Computing Software Analysis challenge CSA07 (50% of 2008)**

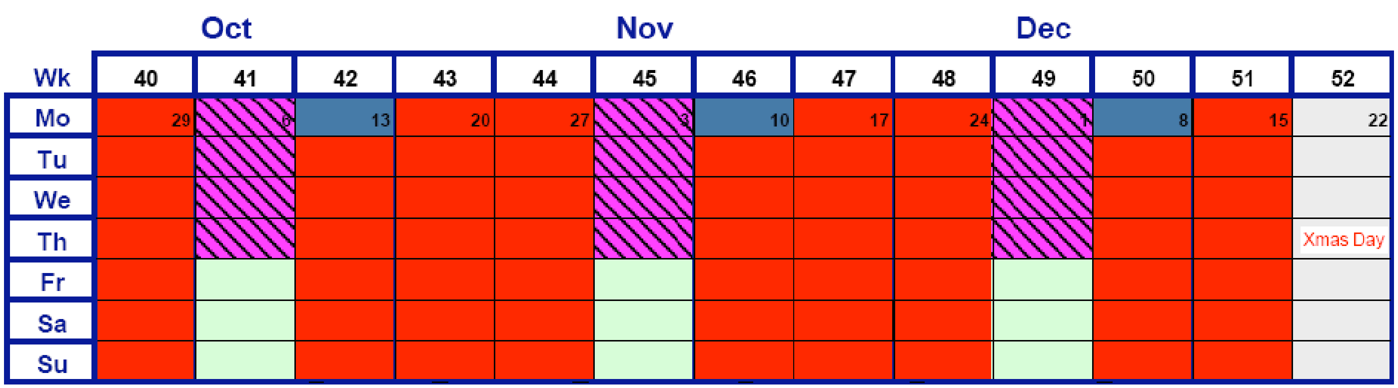
Scale of CMS data transfers increased significantly. T0-T1 channels reached production operations in reliability & performance.

T2s are being commissioned for analysis as a part of CSA07

LHC 2008 Run Plan

From Talk by L. Evans to June 2007 SPC





- LHC Physics
- LHC Machine Development
- LHC Setup with beam
- LHC Technical Stop

- Beam commissioning starts May 2008
- First collisions at 14 TeV c.m. July 2008
- Pilot run with 156 bunches @ 10^{32} $cm^{-2}.s^{-1}$ by end 2008

CMS Objectives

Cosmics Run, CMS Closed & Field ON - Mar 2008

Commission and operate the detector

Prepare the Collaboration for data taking and analysis.

- End-September 07 Tracker insertion
- Dec. 07 recording cosmics with Tracker/EB/HB etc. (CMS open)

14 TeV Collisions: Mid-2008

CMS commissioned and ready for efficient physics data taking, the CMS Collaboration trained and ready for analysis of data at 14 TeV

Physics-wise: focus on discovery

- **Standard Model studies: a necessary step**
  - - Obviously, lots of good physics there as well
- **But priority is in preparing for the main (new) physics that the LHC is conceived for**

2008 Operational Modes

From Mike Lamont talk at CMS week

Bunches	β*	I_b	Luminosity	Event rate
1 x 1	18	10^{10}	10^{27}	Low
43 x 43	18	3×10^{10}	3.8×10^{29}	0.05
43 x 43	4	3×10^{10}	1.7×10^{30}	0.21
43 x 43	2	4×10^{10}	6.1×10^{30}	0.76
156 x 156	4	4×10^{10}	1.1×10^{31}	0.38
156 x 156	4	9×10^{10}	5.6×10^{31}	1.9
156 x 156	2	9×10^{10}	1.1×10^{32}	3.9

- 2008 will see physics with rapidly varying conditions
  - Extracting best physics in a timely way from this run requires
    - Optimal online trigger selection and well calibrated offline reconstruction of physics objects …
  - Trigger and data acquisition operations must track the rapidly varying conditions

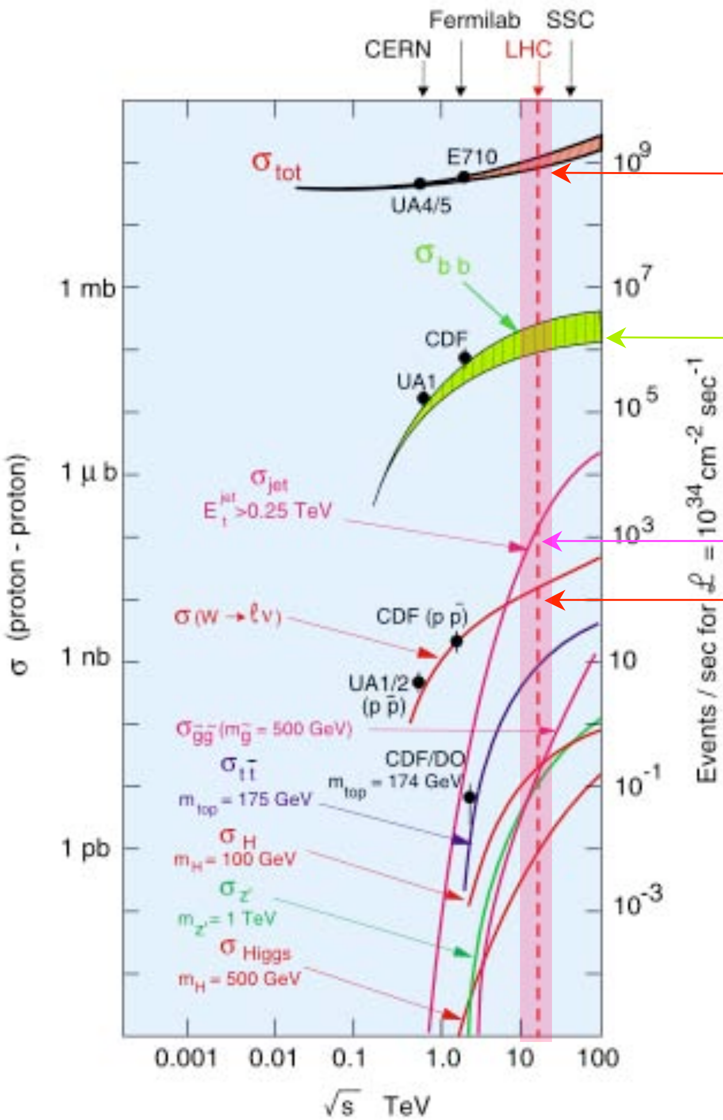
2008 Physics

- Rediscovering the SM: QCD, W/Z, top, third generation decays
  - Emphasis on multiple channels and cross-checks
- Early BSM searches:
  - Z′ to leptons
  - Low scale SUSY
    - ME_T will be difficult to tame, especially w/ the new detectors (EE) installed!
  - Dijet resonances
    - May take a while to get JES right at high E_T
  - Extra dimensions (ee, gg)
  - Something VERY spectacular (fireballs, black holes, etc.)
- Early Higgs searches:
  - First look at h → ZZ, h → WW, prepare for h → gg
  - Very first look at H/A → t t , often in association with b-jets
  - High-mass Higgs in the golden 4m, 4e modes
- This report:
  - Online trigger configuration results and status
  - Offline analysis analysis plans as part of CSA07

2008 Trigger – Standard Candles

- J/Y and Y serve as early standard candles (with μ)
  - Need special (prescaled) triggers
- Inclusive leptonic W and Z samples will be needed across early physics analyses
  - Calibration & Alignment
  - Lepton Efficiency Calculation
  - Luminosity Measurement/Cross Check
  - Jet Energy Scale, ME_T resolution, etc
  - Absolute ME_T scale via W(en) and Z(t t)
- Baseline L1 triggers are capable of accepting most of produced W/Z
  - HLT quality cuts need to be tuned carefully to not lose events
  - Boot strap calibrations and alignments from early data

Expected Trigger Rates



10^{33}	10^{32}	10^{31}	10^{30}
10^{8}	10^{7}	10^{6}	10^{5}
10^{5}	10^{4}	10^{3}	10^{2}
10^{2}	10^{1}	10^{0}	10^{-1}
10^{1}	10^{0}	10^{-1}	10^{-2}

Bandwidth in 2008:

L1T Out < 5×10^4 Hz

HLT Out < 1.5×10^2 Hz

We prepared and studied 10^{32} table recently (HLT Exercise) and are moving to lower luminosities

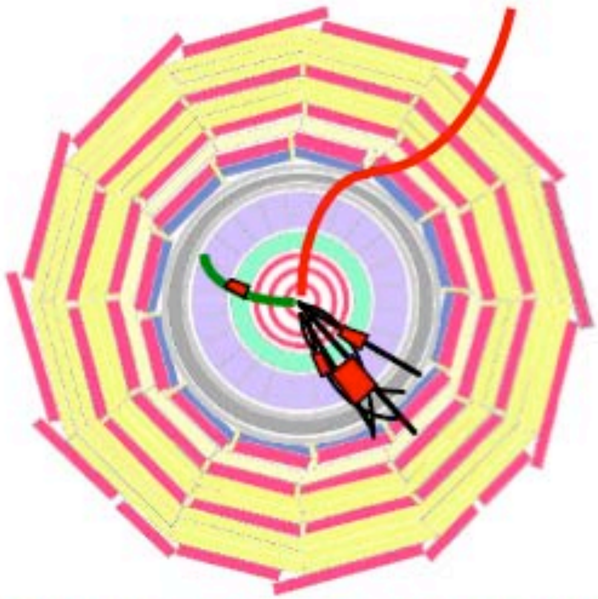
We cannot trigger on all events even early in 2008

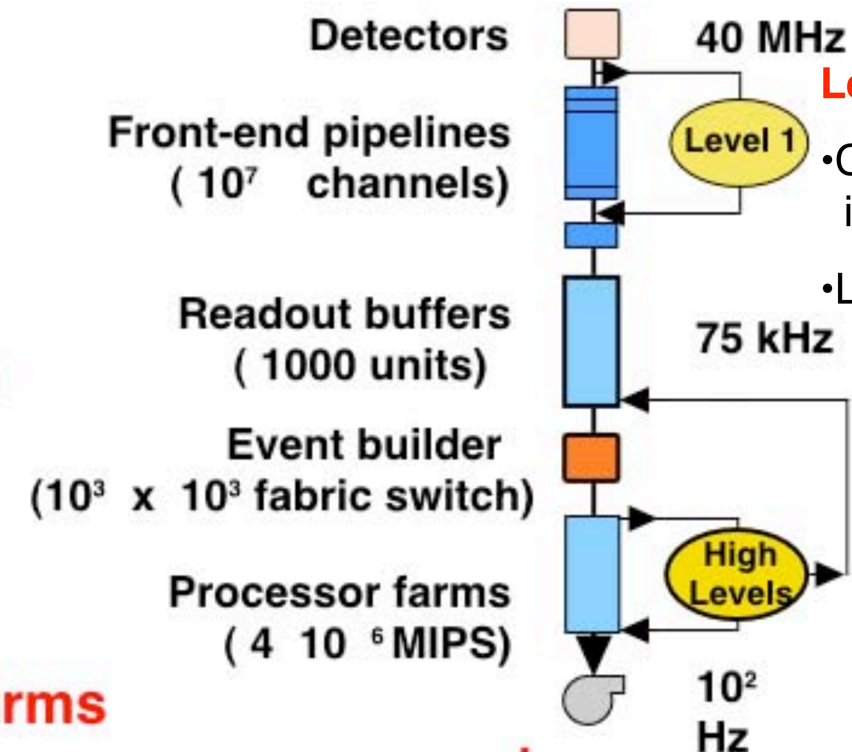
Jet and soft lepton triggers need to be operational at 10^{30} cm^{-2}s^{-1}

Isolated electron triggers also need to be operational at 10^{31} cm^{-2}s^{-1}

All triggers need to be operational at 10^{32} cm^{-2}s^{-1}

Multi Level Trigger Strategy





Level 1

- Coarse object identification
- Limited isolation

High level triggers. CPU farms

- Finer granularity precise measurement
- Clean particle signature (π^0-γ, isolation, ...)
- Kinematics. Effective mass cuts and topology
- Track reco and matching, b,τ-jet tagging
- Full event reconstruction and analysis

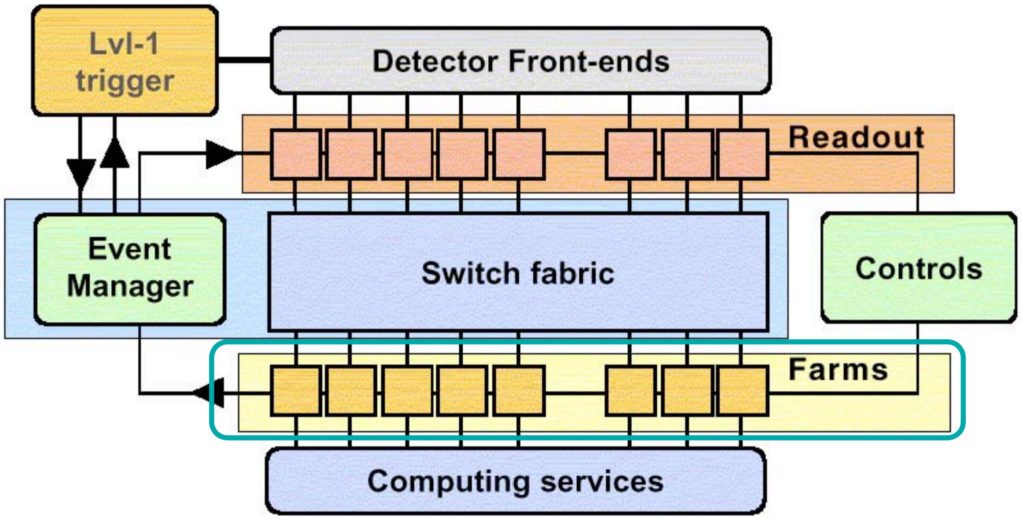
Successive improvements : background event filtering, physics selection

Ground Reality at L1 Trigger

- No tracker in level-1 trigger
  - Electron, photon and p^0 looks the same
  - Trigger level muon P_T is poorly measured
- Jet trigger limitations
  - Limited capability to get low P_T jets
    - Limited calorimeter resolution: $100\% / \sqrt{E}$
    - Calibration to take out h,f variation in response
- Poor measurement of missing E_T
  - At best the resolution can be: $100\% \sqrt{\sum E_T}$
  - Calibration not possible
  - Underlying event and pileup contribution
  - Additional limitations due to trigger calculations

Most of L1 output are mistags - Another factor of 1000 rejection at HLT

The High-Level Triggers

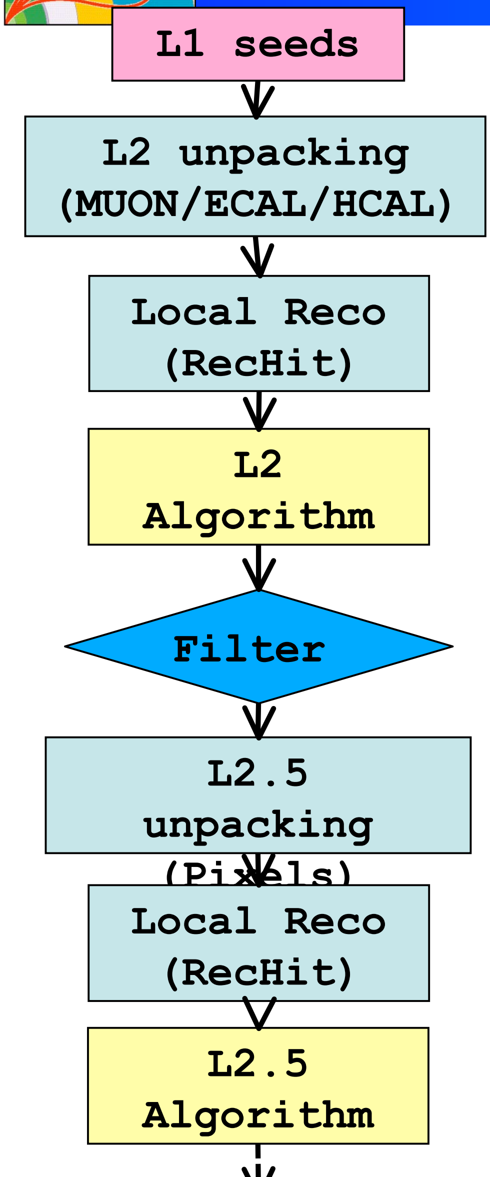


- In CMS all trigger decisions beyond Level-1 are performed in a Filter Farm running ~normal CMS reconstruction software on "PCs"
  - The filter algorithms are setup in several steps
- HLT does partial event reconstruction "on demand" seeded by the L1 objects found, using full detector resolution
  - Algorithms are essentially offline quality but optimized for fast performance

The 2007 "HLT exercise"

- Determine CPU-performance for early physics-run
  - Implementation for 2008 physics-run (14 TeV) Trigger Menu at $\mathcal{L}=10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
- Uses real code that will be used online in 2008
  - Algorithms in CMSSW ported from ORCA, tested offline
  - Algorithms optimzed for HLT with L1 emulator seeding
  - Starts from Raw data (unpacking included)
- Entire trigger table exercised at once
  - Jointly optimized L1T and HLT trigger table respecting the bandwidth (including overlaps) is used
- Caveats
  - Not exercised in Online Environment yet

HLT algorithm design



“Global” vs. “Regional”:

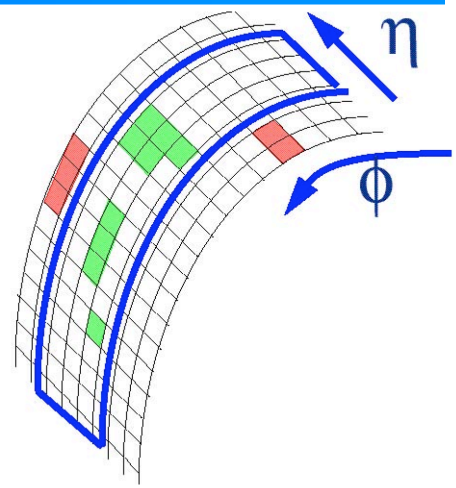
- All algorithms (except for Jets) regional by now
  - Seeded by previous levels (L1, L2, L2.5)
- Can benefit significantly by doing regional data-unpacking and local reconstruction across HLT
- Have implemented regional ECAL unpacking/RecHit for Egamma and Muon trigger paths
- Started planning (& development) of regional unpacking across rest of detectors, HLT paths

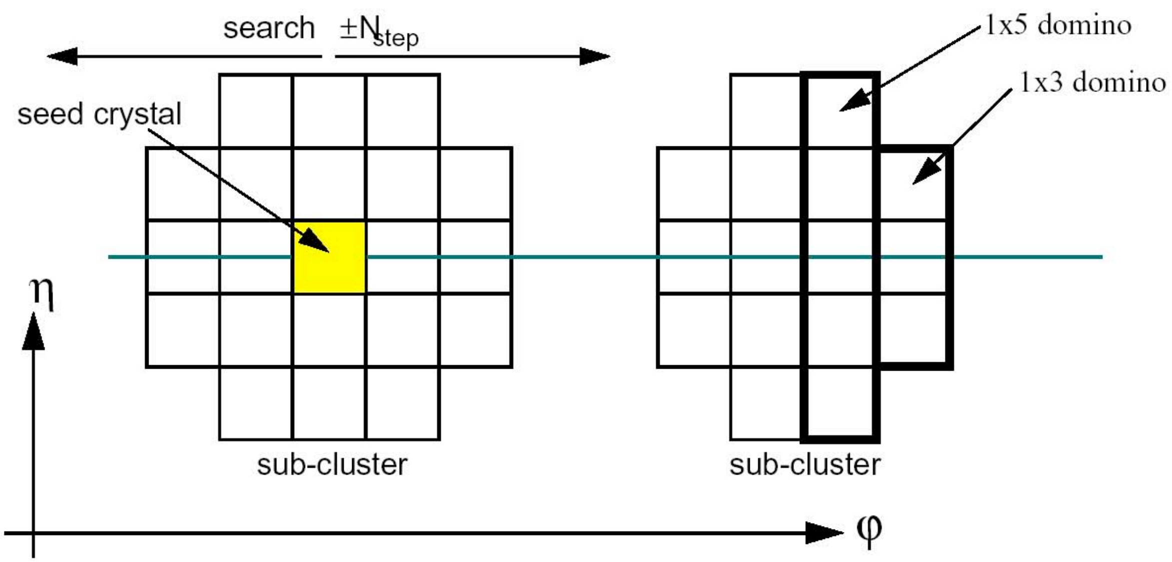
“Local”: using one sub-detector only
“Regional”: using small (η, φ) region

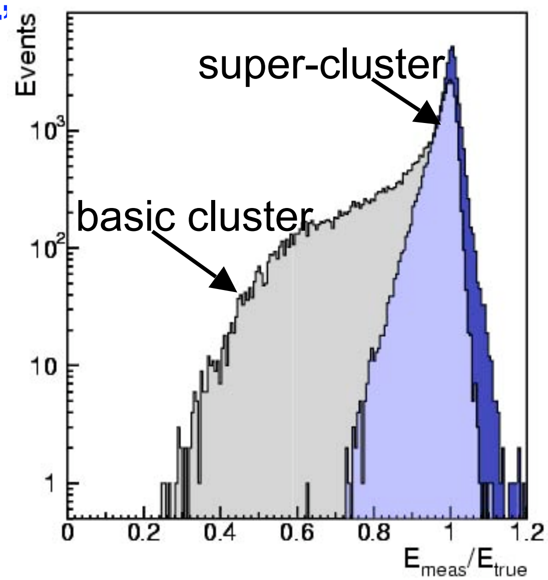
HLT Framework Design & Implementation:
Martin Gruenewald

HLT e/γ Selection

- Initial steps using calorimeter ("Level-2 e/γ"):
  - Search for matching Level-1 e/γ object
    - Use 1-tower margin around 4x4-tower trigger region
  - Bremsstrahlung recovery "super-clustering"
  - Select highest E_T cluster
- Bremsstrahlung recovery:
  - Road along f — in narrow η-window around seed
  - Collect all sub-clusters in road → "super-cluster"







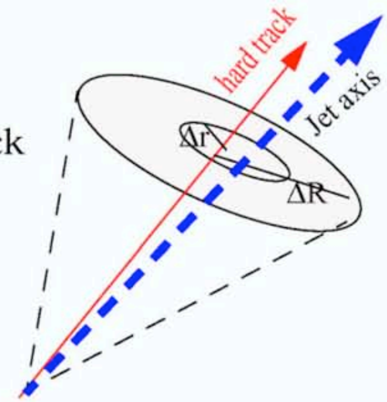
HLT t -jet tagging

τ-jet ($E_t^{\tau\text{-jet}} > 60$ GeV) identification (mainly) in the tracker:

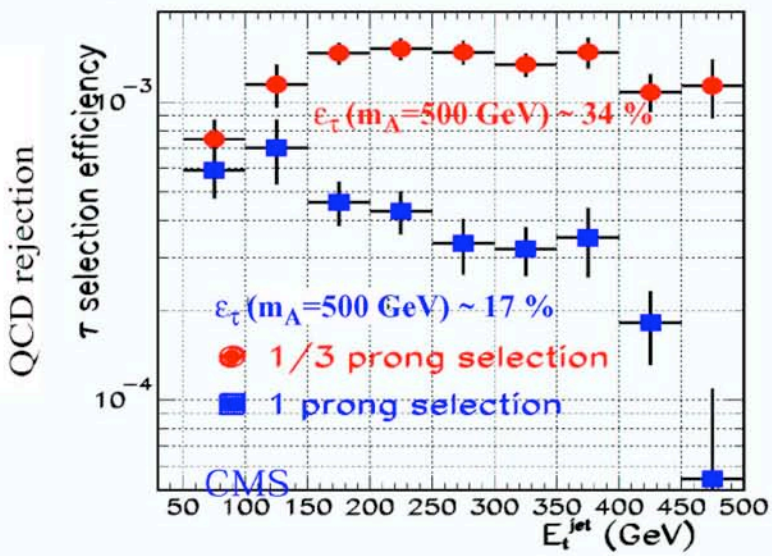
Hard track, $p_t^{max} > 40$ GeV, within $\Delta R < 0.1$ around calorimeter jet axis

Isolation: no tracks, $p_t > 1$GeV, within $0.03 < \Delta R < 0.4$ around the hard track

For 3-prong selection 2 more tracks in the signal cone $\Delta r < 0.03$



QCD jet rejection from isolation and hard track cuts



Further reduction by ~ 5 expected for 3-prong QCD jets from τ vertex reconstruction (CMS full simulation)

Final steps in HLT paths involve tracking which is more time consuming

Reconstruct tracks only in the region of interest around "Level-2" tagged objects

HLT Exercise Configuration

HLT Timing is influenced by

- Trigger menu (L1T & HLT)
  - Determined by physics priorities
  - Instantaneous luminosity
    - Chose to make a menu for 10^{32} cm^{-2} s^{-1}
    - Maximum luminosity in 2008
- Input L1Trigger rate
  - Parameters of various L1T algorithms, e.g., H/E
  - Limited by bandwidth ⊗ safety factor to 17 kHz
- HLTrigger algorithms
  - Standard trigger paths at HLT seeded by L1 trigger bits
  - Order of modules and filters in a path
  - Parameters of the modules and filters

We settled on one setting for the HLT Exercise

L1T Menu: Single + Double

L1 Trigger	Threshold (GeV)	Prescale	Rate (kHz)
A_SingleMu3	3	1000	0.01 ± 0.00
A_SingleMu5	5	1000	0.00 ± 0.00
A_SingleMu7	7	1	1.11 ± 0.04
A_SingleMu10	10	1	0.47 ± 0.03
A_SingleMu14	14	1	0.18 ± 0.02
A_SingleMu20	20	1	0.09 ± 0.01
A_SingleMu25	25	1	0.06 ± 0.01
A_SingleIsoEG5	5	10000	0.00 ± 0.00
A_SingleIsoEG8	8	1000	0.01 ± 0.00
A_SingleIsoEG10	10	100	0.04 ± 0.01
A_SingleIsoEG12	12	1	2.47 ± 0.06
A_SingleIsoEG15	15	1	1.10 ± 0.04
A_SingleIsoEG20	20	1	0.32 ± 0.02
A_SingleIsoEG25	25	1	0.14 ± 0.01
A_SingleEG5	5	10000	0.00 ± 0.00
A_SingleEG8	8	1000	0.01 ± 0.00
A_SingleEG10	10	100	0.04 ± 0.01
A_SingleEG12	12	100	0.03 ± 0.01
A_SingleEG15	15	1	1.51 ± 0.05
A_SingleEG20	20	1	0.52 ± 0.03
A_SingleEG25	25	1	0.25 ± 0.02

L1 Trigger	Threshold (GeV)	Prescale	Rate (kHz)
A_SingleJet70	70	100	0.02 ± 0.01
A_SingleJet100	100	1	0.43 ± 0.02
A_SingleJet150	150	1	0.07 ± 0.01
A_SingleJet200	200	1	0.02 ± 0.01
A_SingleTauJet40	40	1000	0.02 ± 0.01
A_SingleTauJet80	80	1	0.68 ± 0.03
A_SingleTauJet100	100	1	0.20 ± 0.02
A_HTT250	250	1	2.56 ± 0.06
A_HTT300	300	1	0.65 ± 0.03
A_HTT400	400	1	0.08 ± 0.01
A_HTT500	500	1	0.02 ± 0.00
A_ETM20	20	10000	0.00 ± 0.00
A_ETM30	30	1	5.69 ± 0.09
A_ETM40	40	1	0.40 ± 0.02
A_ETM50	50	1	0.05 ± 0.01
A_ETM60	60	1	0.01 ± 0.00
A_DoubleMu3	3	1	0.28 ± 0.02
A_DoubleIsoEG8	8	1	0.28 ± 0.02
A_DoubleIsoEG10	10	1	0.08 ± 0.01
A_DoubleEG5	5	10000	0.00 ± 0.00
A_DoubleEG10	10	1	0.19 ± 0.02
A_DoubleEG15	15	1	0.05 ± 0.01
A_DoubleJet70	70	1	0.58 ± 0.03
A_DoubleJet100	100	1	0.11 ± 0.01
A_DoubleTauJet20	20	1000	0.02 ± 0.01
A_DoubleTauJet30	30	100	0.08 ± 0.01
A_DoubleTauJet40	40	1	2.36 ± 0.06

L1TEmulator Developers +
Werner Sun, SD, Pedram Bargassa

L1T Menu : Mixed

L1 Trigger	Threshold (GeV)	Prescale	Rate (kHz)
A_Mu3_IsoEG5	3,5	1	0.95 ± 0.04
A_Mu5_IsoEG10	5,10	1	0.04 ± 0.01
A_Mu3_EG12	3,12	1	0.09 ± 0.01
A_Mu3_Jet15	3,15	20	0.30 ± 0.02
A_Mu5_Jet15	5,15	1	1.62 ± 0.05
A_Mu3_Jet70	3,70	1	0.10 ± 0.01
A_Mu5_Jet20	5,20	1	1.18 ± 0.04
A_Mu5_TauJet20	5,20	1	0.66 ± 0.03
A_Mu5_TauJet30	5,30	1	0.38 ± 0.02
A_IsoEG10_Jet15	10,15	20	0.15 ± 0.01
A_IsoEG10_Jet30	10,30	1	1.95 ± 0.05
A_IsoEG10_Jet20	10,20	1	3.04 ± 0.06
A_IsoEG10_Jet70	10,70	1	0.26 ± 0.02
A_IsoEG10_TauJet20	10,20	1	1.95 ± 0.05
A_IsoEG10_TauJet30	10,30	1	1.33 ± 0.04
A_TauJet30_ETM30	30,30	1	1.96 ± 0.05
A_TauJet30_ETM40	30,40	1	0.26 ± 0.02
A_TripleMu3	3	1	0.01 ± 0.00
A_TripleJet50	50	1	0.22 ± 0.02
A_QuadJet30	30	1	0.58 ± 0.03
A_MinBias_HTT10	10	large	0.40
A_ZeroBias	0	large	0.40
Total L1 Trigger Rate (kHz)			16.67 ± 0.15

Table 8.1: Trigger table showing L1 rates at chosen thresholds for $\mathcal{L} = 10^{32}$ cm^{-2} s^{-1}.

L1T Menu

- Optimized to fit in the budget
- μ and e/γ thresholds yield good W, Z efficiencies, but not τ
- Jet thresholds low enough to cover Tevatron range well
- MET only L1T used at HLT in combination with jets
- Double and mixed triggers for specific physics channels added

L1TEmulator Developers +
Werner Sun, SD, Pedram Bargassa

HLT Menu : μ + X

HLT path	L1 condition	Thresholds (GeV)	HLT Rate (Hz)	Total Rate (Hz)
Single Isolated μ	A_SingleMu7	11	18.3 ± 2.2	18.3
Single Relaxed μ	A_SingleMu7	16	22.7 ± 1.5	37.7
Double Relaxed μ	A_DoubleMu3	(3, 3)	12.3 ± 1.6	48.5
$J/\psi \to \mu\mu$	A_DoubleMu3	(3, 3) $M_{\mu\mu} \in [2.9, 3.3]$	2.0 ± 0.8	49.4
$\Upsilon \to \mu\mu$	A_DoubleMu3	(3, 3) $M_{\mu\mu} \in [8, 12]$	1.8 ± 0.5	50.5
$Z \to \mu\mu$	A_DoubleMu3	(7, 7) $M_{\mu\mu} \in [80, 100]$	0.1 ± 0.0	50.5
Triple Relaxed μ	A_TripleMu3	(3, 3, 3)	0.1 ± 0.0	50.5
Same-sign double μ	A_DoubleMu3	(3, 3)	5.7 ± 1.2	52.5
$b \to \mu$ tag 1-jet Prescale 20	A_Mu5_Jet15	20 $\Delta R(\mu, j) < 0.4$	4.0 ± 0.1	56.1
$b \to \mu$ tag 2-jets	A_Mu5_Jet15	120, $p_T^{\mathrm{rel}}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	0.5 ± 0.0	56.1
$b \to \mu$ tag 3-jets	A_Mu5_Jet15	70, $p_T^{\mathrm{rel}}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	0.3 ± 0.0	56.1
$b \to \mu$ tag 4-jets	A_Mu5_Jet15	40, $p_T^{\mathrm{rel}}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	0.4 ± 0.0	56.1
$b \to \mu$ tag H_T	A_HTT250	300, $p_T^{\mathrm{rel}}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	2.6 ± 0.2	56.6
$b \to J/\psi(\mu\mu)$	A_DoubleMu3	(4, 4) $M_{\mu\mu} \in [2.95, 3.25]$	0.7 ± 0.1	56.8
$\mu + b$-jet	A_Mu5_Jet15	(7, 35)	0.1 ± 0.0	56.8
$\mu + b \to \mu$-jet	A_Mu5_Jet15	(7, 20)	0.1 ± 0.1	56.8
μ + jet	A_Mu5_Jet15	(7, 40)	6.3 ± 0.7	60.8
$e + \mu$	$\star$	(8, 7)	0.5 ± 0.4	61.2
$e + \mu$ relaxed	$\star$	(10, 10)	0.1 ± 0.0	61.3
$\mu + \tau$	A_Mu5_TauJet20	(15, 20)	0.0 ± 0.0	61.3

Juan Alcaraz Maestre,
Adam Everett,
Muriel Vander Donckt, …

Meenakshi Narain, …

Lotte Wilke

Greg Landsberg, Duong Nguyen,
Len Christofek, Muriel Vander Donckt,
Sylvia Goy Lopez

Vuko Briglevic

Rates: Pedram Bargassa

HLT Menu: Jet MET

HLT path	L1 condition	Thresholds (GeV)	HLT Rate (Hz)	Total Rate (Hz)
Single-Jet	A_SingleJet150	200	9.3 ± 0.1	70.1
Double-Jet	A_SingleJet150 A_DoubleJet70	150	10.6 ± 0.0	74.4
Triple-Jet	†	85	7.5 ± 0.1	78.8
Quad-Jet	‡	60	3.9 ± 0.1	80.5
$\not\!\!E_T$	A_ETM40	65	4.9 ± 0.7	84.0
Acopl. Double-Jet	A_SingleJet150 A_DoubleJet70	125	1.4 ± 0.0	84.0
Acopl. Single-Jet + $\not\!\!E_T$	A_ETM30	(100, 60)	1.6 ± 0.0	84.2
Single-Jet + $\not\!\!E_T$	A_ETM30	(180, 60)	2.2 ± 0.1	84.4
Double-Jet + $\not\!\!E_T$	A_ETM30	(125, 60)	1.0 ± 0.0	84.4
Triple-Jet + $\not\!\!E_T$	A_ETM30	(60, 60)	0.6 ± 0.0	84.4
Quad-Jet + $\not\!\!E_T$	A_ETM30	(35, 60)	1.2 ± 0.1	84.6
H_T + $\not\!\!E_T$	A_HTT300	(350, 65)	4.4 ± 0.1	86.2
Single Jet Prescale 10	A_SingleJet100	150	3.5 ± 0.0	87.9
Single Jet Prescale 100	A_SingleJet70	110	1.5 ± 0.0	89.1
Single Jet Prescale 1000	A_SingleJet30	60	0.8 ± 0.4	89.9
VBF Double-Jet + $\not\!\!E_T$	A_ETM30	(40, 60)	0.2 ± 0.0	89.0
SUSY 2-jet+$\not\!\!E_T$	A_ETM30	(80,20,60)	2.0 ± 0.1	90.4
Acopl. Double-Jet + $\not\!\!E_T$	A_ETM30	(60, 60)	1.0 ± 0.0	90.4

Len Apanasavich

Rates: Pedram Bargassa

HLT Menu: e, γ, τ, b + X

HLT path	L1 condition	Thresholds (GeV)	HLT Rate (Hz)	Total Rate (Hz)
Single Isolated e	A_SingleIsoEG12	15	17.1 ± 2.3	107.5
Single Relaxed e	A_SingleEG15	17	9.6 ± 1.3	109.3
Double Isolated e	A_DoubleIsoEG8	10	0.2 ± 0.1	109.4
Double Relaxed e	A_DoubleEG10	12	0.8 ± 0.1	109.9
Single Isolated γ	A_SingleIsoEG12	30	8.4 ± 0.7	118.1
Single Relaxed γ	A_SingleEG15	40	2.8 ± 0.2	118.5
Double Isolated γ	A_DoubleIsoEG8	(20,20)	0.6 ± 0.4	119.0
Double Relaxed γ	A_DoubleEG10	(20,20)	1.8 ± 0.5	120.1
High E_T e	A_SingleEG15	80	0.5 ± 0.0	120.4
High E_T e	A_SingleEG15	200	0.1 ± 0.0	120.4
Lifetime b-tag 1-jet	$\diamond$	180	1.3 ± 0.0	120.5
Lifetime b-tag 2-jets	$\diamond$	120	2.1 ± 0.0	121.2
Lifetime b-tag 3-jets	$\diamond$	70	1.7 ± 0.0	121.8
Lifetime b-tag 4-jets	$\diamond$	40	1.8 ± 0.0	122.6
Lifetime b-tag H_T	$\diamond$	470	2.5 ± 0.1	123.1
Single τ	A_SingleTauJet80	15	0.2 ± 0.0	123.2
τ + $\not{E}_T$	A_TauJet30_ETM30	15	1.8 ± 0.2	124.7
Double τ (Calo+Pixel)	A_DoubleTauJet40	15	4.9 ± 0.6	129.4
e + b-jet	A_IsoEG10_Jet20	(10, 35)	0.1 ± 0.0	129.4
e + jet	A_IsoEG10_Jet30	(12, 40)	11.6 ± 1.2	135.8
$e + \tau$	A_IsoEG10_TauJet20	(12, 20)	0.2 ± 0.0	135.8
Prescaled e/γ	See Table 3.9		5.0 ± 0.0	140.8
Prescaled μ	See Table 2.3		3.0 ± 0.0	143.8
Min.Bias	A_MinBias_HTT10	—	1.5 ± 0.0	145.3
Pixel Min.Bias	A_ZeroBias	—	1.5 ± 0.0	146.8
Zero Bias	A_ZeroBias	—	1.0 ± 0.0	147.8
Total HLT rate (Hz)				148 ± 4.9

Monica Vazquez Acosta,
Marco Pieri,
Alessio Ghezzi, …

Ian Tomalin

Simone Gennai

Greg Landsberg, Duong Nguyen,
Len Christofek, Nadia Eram

Marta Felcini

Rates: Pedram Bargassa

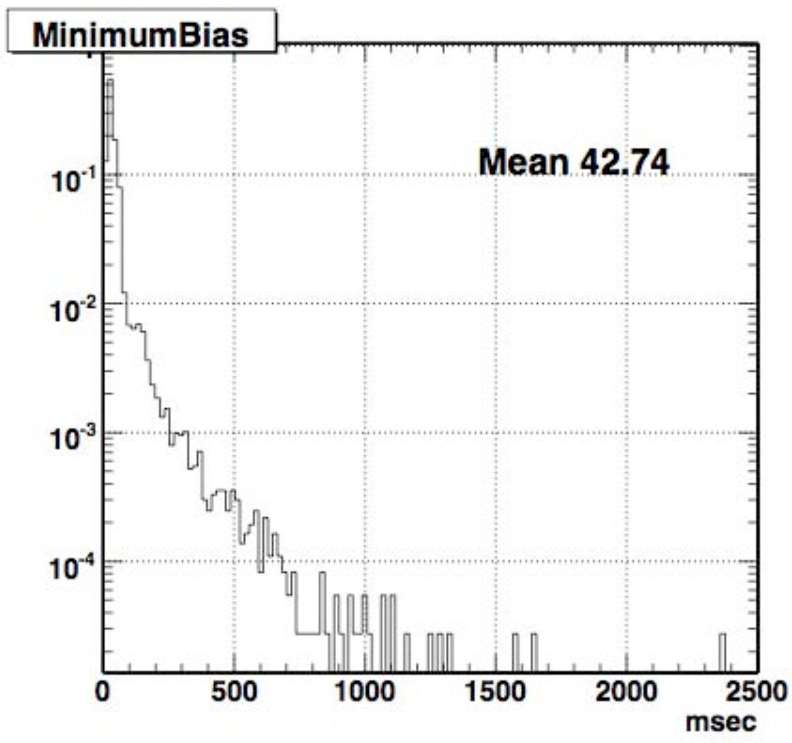
HLT Timing Table

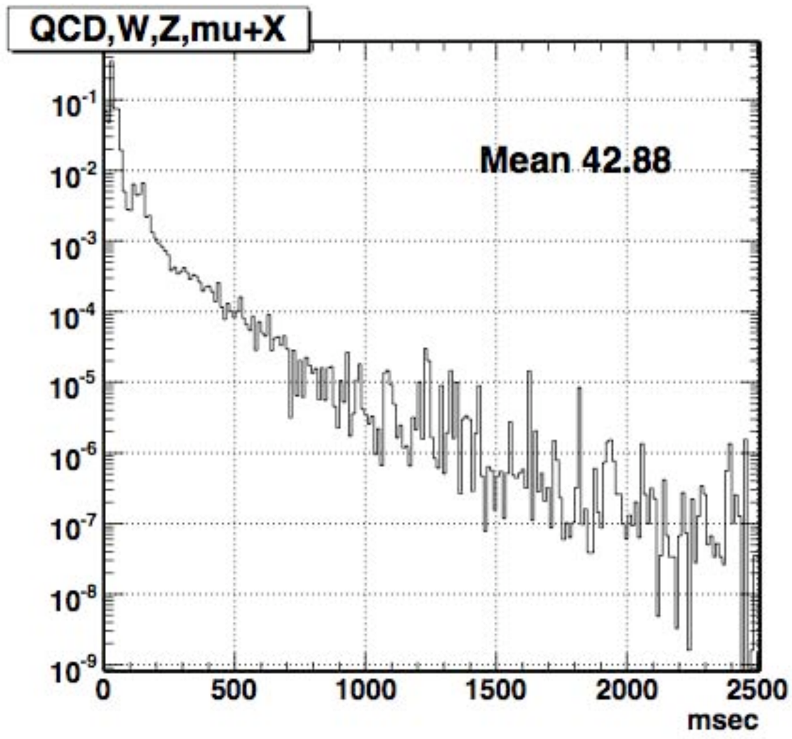
Sample	L1 efficiency (%)	L1 eff. $\times$ σ (pb)	Average time (ms)
Minimum bias	—	—	42.7
QCD $\hat{p_T} \in [0, 15]$ GeV/c	0.08 ± 0.01	$(1.50 \pm 0.17) \times 10^8$	31
QCD $\hat{p_T} \in [15, 20]$ GeV/c	2.08 ± 0.11	$(3.14 \pm 0.17) \times 10^7$	36
QCD $\hat{p_T} \in [20, 30]$ GeV/c	5.75 ± 0.18	$(3.71 \pm 0.11) \times 10^7$	40
QCD $\hat{p_T} \in [30, 50]$ GeV/c	21.70 ± 0.41	$(3.57 \pm 0.07) \times 10^7$	47
QCD $\hat{p_T} \in [50, 80]$ GeV/c	63.36 ± 0.84	$(1.38 \pm 0.02) \times 10^7$	53
QCD $\hat{p_T} \in [80, 120]$ GeV/c	95.96 ± 1.23	$(2.96 \pm 0.04) \times 10^6$	73
QCD $\hat{p_T} \in [120, 170]$ GeV/c	99.87 ± 1.18	$(4.93 \pm 0.05) \times 10^5$	143
QCD $\hat{p_T} \in [170, 230]$ GeV/c	100.00 ± 0.00	$(1.01 \pm 0.00) \times 10^5$	264
QCD $\hat{p_T} \in [230, 300]$ GeV/c	100.00 ± 0.00	$(2.45 \pm 0.00) \times 10^4$	385
$pp \to \mu X$	42.96 ± 0.00	$(1.03 \pm 0.00) \times 10^7$	74
$W \to e\nu$	92.58 ± 0.00	$(7.31 \pm 0.11) \times 10^3$	280
$W \to \mu\nu$	84.67 ± 0.00	$(8.38 \pm 0.08) \times 10^3$	123
$Z \to ee$	99.54 ± 0.00	$(8.16 \pm 0.05) \times 10^2$	739
$Z \to \mu\mu$	99.99 ± 0.00	$(7.82 \pm 0.09) \times 10^2$	184
Weighted sum of QCD, W, Z and $pp \to \mu X$ contributions			42.9 ± 6.4

Table 9.3: Average processing wall-clock times for running the High-Level Trigger Menu at $\mathcal{L} = 10^{32}$ cm^{-2} s^{-1} on L1-accepted events at an idle Core 2 5160 Xeon 3.0 GHz machine.

Times: Tulika Bose

HLT Times: Minbias vs QCD-EWK Soup





Time Plot: Tulika & Simone

HLT Physics performance: eγ, μ

Muon HLT efficiency for benchmark channels

Signal	HLT Single Relaxed muon eff.(%)	HLT Double muon eff.(%)	HLT Single Isolated muon eff.(%)	(Level-1)*HLT acceptance (%)
$Z \to \mu\mu$	98.6	91.2	95.8	98.1
$W \to \mu\nu$	86.9	-	81.4	76.7

Muons

Egamma HLT efficiency for benchmark channels

Signal process	Isolated single electron	Relaxed single electron	Isolated double electron	Relaxed double electron
HLT: $Z \to ee$	83.3	85.2	63.8	64.4
HLT: $W \to e\nu$	62.5	61.2	-	-
L1*HLT: $Z \to ee$	80.0	82.6	62.6	63.2
L1*HLT: $W \to e\nu$	52.1	52.4	-	-

Electrons

Signal process	Isolated single photon	Relaxed single photon	Isolated double photon	Relaxed double photon
HLT: $H \to \gamma\gamma (m_H$=120 GeV)	80.5	76.8	75.8	75.7
L1*HLT: $H \to \gamma\gamma (m_H$=120 GeV)	78.8	76.8	75.8	75.7

Photons

Signal process	single high energy EM	Single very high energy EM	Total
$Z' \to ee$ ($M \geq 200$ GeV)	67	7.0	67
$Z' \to ee$ ($M \geq 500$ GeV)	91	69	93
$Z' \to ee$ ($M \geq 1000$ GeV)	94	92	98
$Z' \to ee$ ($M \geq 2000$ GeV)	90	97	98
$G \to \gamma\gamma$ ($M \geq 2000$ GeV)	91	97	98

High-E_T EM candidates
(apply high E_T cuts, loosen-up isolation)

Good *W/Z* efficiencies for muon, egamma HLT

HLT Physics performance: τ

HLT efficiency:Higgs

Table 5.2: Efficiencies and rates of the SingleTau HLT path.

	$H^{\pm} \to \tau\nu$		QCD
	$M_H = 200\,GeV/c^2$	$M_H = 400\,GeV/c^2$	$\hat{p_T}$ 120-170
Level-2 $\not{E}_T$ cut	59%	81%	6%
Level-2 Jet Reconstruction and Ecal Isolation	81%	85%	53%
Level-2.5 SiStrip Isolation	67%	76%	27%
Level-3 SiStrip Isolation	70%	72%	18%
HLT	23%	38%	0.15%
L1 * HLT	16%	29%	-

HLT efficiency: Z

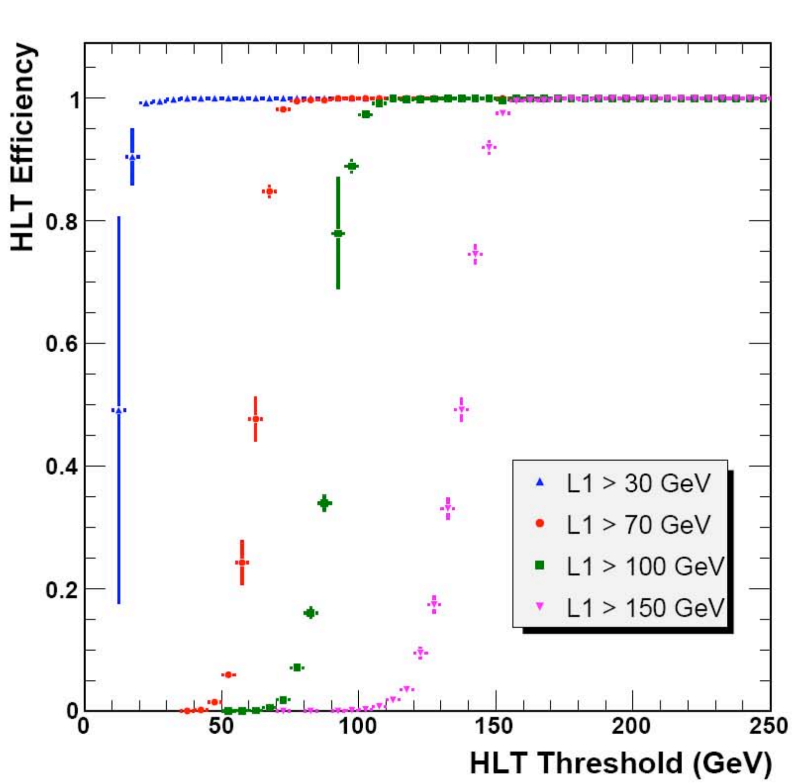
Table 5.4: Efficiencies and rates of the DoubleTau HLT path.

	$Z \to \tau\tau$	QCD $\hat{p_T}$ 120-170
Level-2 jet reconstruction	91%	58%
Level-2 Ecal Isolation	86%	37%
Level-2.5 Pixel Isolation	28%	0.77%
HLT	22%	0.17%
L1 * HLT	8.6%	-

Can increase Higgs/W/$Z \to \tau$ efficiencies with different L1 bandwidth, isolation at HLT

HLT Physics Performance: jets & b-jets

Using jet corrections at both L1 and HLT



Turn-on curves for single-Jet for various L1 bits

b HLT trigger name	Efficiency for hadronic $t\bar{t}$ events	Efficiency (Rate) for minimum bias events	
b-lifetime			
bHLTpath1	0.045	0.0014	(1.5 Hz)
bHLTpath2	0.055	0.0022	(2.4 Hz)
bHLTpath3	0.13	0.0017	(1.9 Hz)
bHLTpath4	0.20	0.0019	(2.1 Hz)
bHLTpathHT	0.15	0.0026	(2.9 Hz)
.OR. of above	0.23	0.0045	(5.0 Hz)
$b \rightarrow \mu$			
bμHLTpath1 prescaled by 20	n/a	0.82×10^{-3}	(2.4 Hz)
bμp_tHLTpath2	0.037	0.14×10^{-3}	(0.35 Hz)
bμp_tHLTpath3	0.06	0.64×10^{-4}	(0.16 Hz)
bμp_tHLTpath4	0.10	0.12×10^{-3}	(0.33 Hz)
bμp_tHLTpathHT	0.12	0.35×10^{-3}	(1.6 Hz)

b-jet efficiencies for t-tbar events

2008 < 10^{30}: Level-1 Trigger

Minbias

- Scintillators in forward region
  - Technical trigger
- Feature bits
  - Reprogram so that any trigger tower with energy greater than noise will issue a trigger

Jets, Egamma, …

- Can operate the triggers with low thresholds (just a little bit above noise)

Muons

- Any muon that makes it (no threshold)

Rate limit at 12.5-50 kHz (1-4 DAQ slices)

- Minbias trigger without prescale for most of the period

$2008 < 10^{30}$: High Level

Validate L1T and run simple HLT algorithms

- HLT algorithms could be calorimeter and muon based
  - Must quickly align and calibrate tracker for HLT
- Apply thresholds (none applied at L1)
  - Stream data by trigger type
- Calibration triggers
  - ECAL: pizero
  - Jets: gamma + Jet
  - Tracks: J/y → mm
- Prescale minbias

Rate limit ~150 Hz full events, 1-5 kHz small events

Bandwidth limit 1 GB/s

Trigger Summary

LHC Trigger is Challenging

- The choice of physics studied is already made at level-1 trigger
  - Choices made with calorimeter and muon systems only
- Complete object reconstruction at higher level trigger
  - Optimum resolution online with calibration and alignment
  - Includes b/t tagging in high level trigger farms
- 10^{32} trigger menu done, now preparing menus for $10^{30,31}$
- Both ATLAS and CMS have designed trigger systems for golden discovery modes (lepton, diphoton, muti-jets…)
  - Startup triggers setup to restablish the Standard Model
  - Pickup searches for new particles where left off by Tevatron
  - Definitive exploration of higgs sector is assured
  - Exploit qqH, WH, ttH production to cover difficult regions
- Innovative designs may allow more measurements
  - Topological selection starting from level-1
  - Measurement of Yukawa couplings
  - Low mass & some MSSM higgs decays to t t (hadrons) , $\chi\chi$ (invisible)

Startup Preparation

Detector Installation, Commissioning & Operation		**Preparation of Software, Computing & Physics Analysis**
	June	HLT Exercise
Barrel ECAL Inserted	July	Pre CSA07
	Aug	Software Release 1_6 (CSA07, CCR1)
Trigger/DAQ Ready Commissioning Tracker Inserted	Sep	CSA07
CMS Cosmic Run CCR1 (+end)	Oct	SW Release 1_7 (CCR2, HLT Validation)
Test Magnet at low current Tracker cabled & Commissioned	Nov	100^{-1} pb Physics Analyses Completed
Last Heavy Element Lowered **CMS Cosmic Run CCR2 (YB0)**	Dec	Software Release 1_8 (Lessons of ‘07)
CMS Cosmic Run CCR3 (-end,RE)	Jan	
Beam-pipe Closed and Baked-out	Feb	Software Release 2_0 (CCR4, Production of startup MC samples)
≥ 2 EE Dees Installed, Pixels installed **CMS Cosmic Run CCR4 (4T)**	Mar	**MC Production for Startup**

Ready for Startup