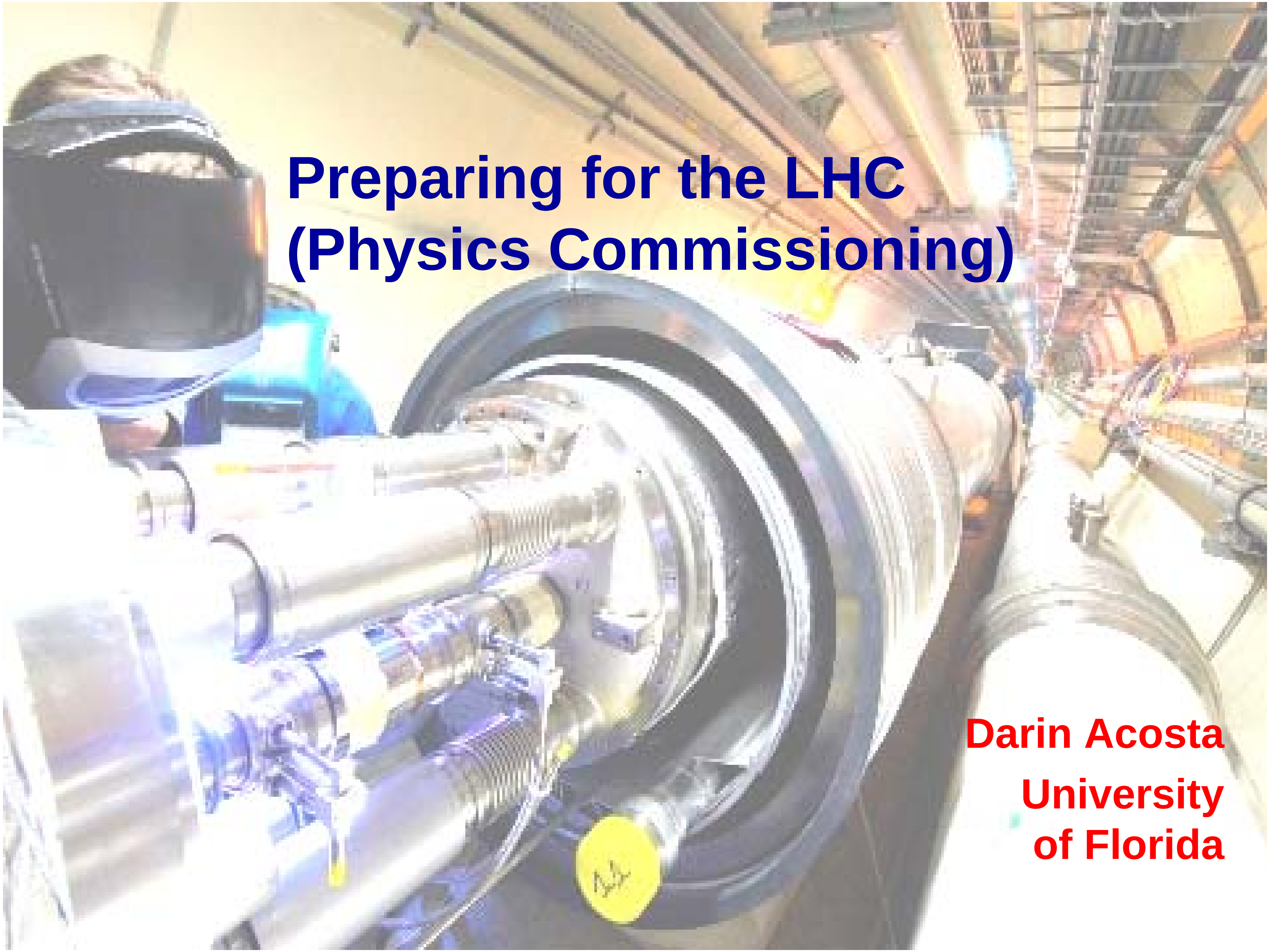
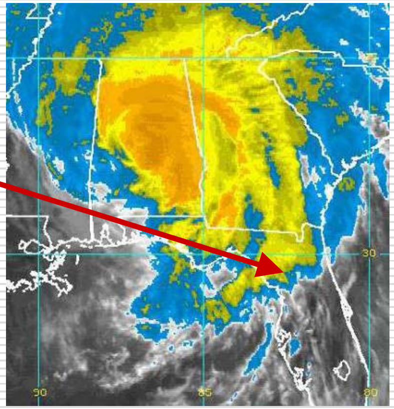


Preparing for the LHC (Physics Commissioning)

Darin Acosta
University of Florida

Who I am

- Associate Professor
  Physics Department
  University of Florida
- Have worked on:
  - e+e- experiment (CLEO)
  - ep experiment (ZEUS)
  - $p\bar{p}$ experiment (CDF)
  - pp experiment (CMS)
- Currently working as
  - Deputy commissioning coordinator of CMS (still learning the job ☺)
- Past experience with
  - Designing electronics
  - Muon detectors, calorimeters
  - Various physics groups



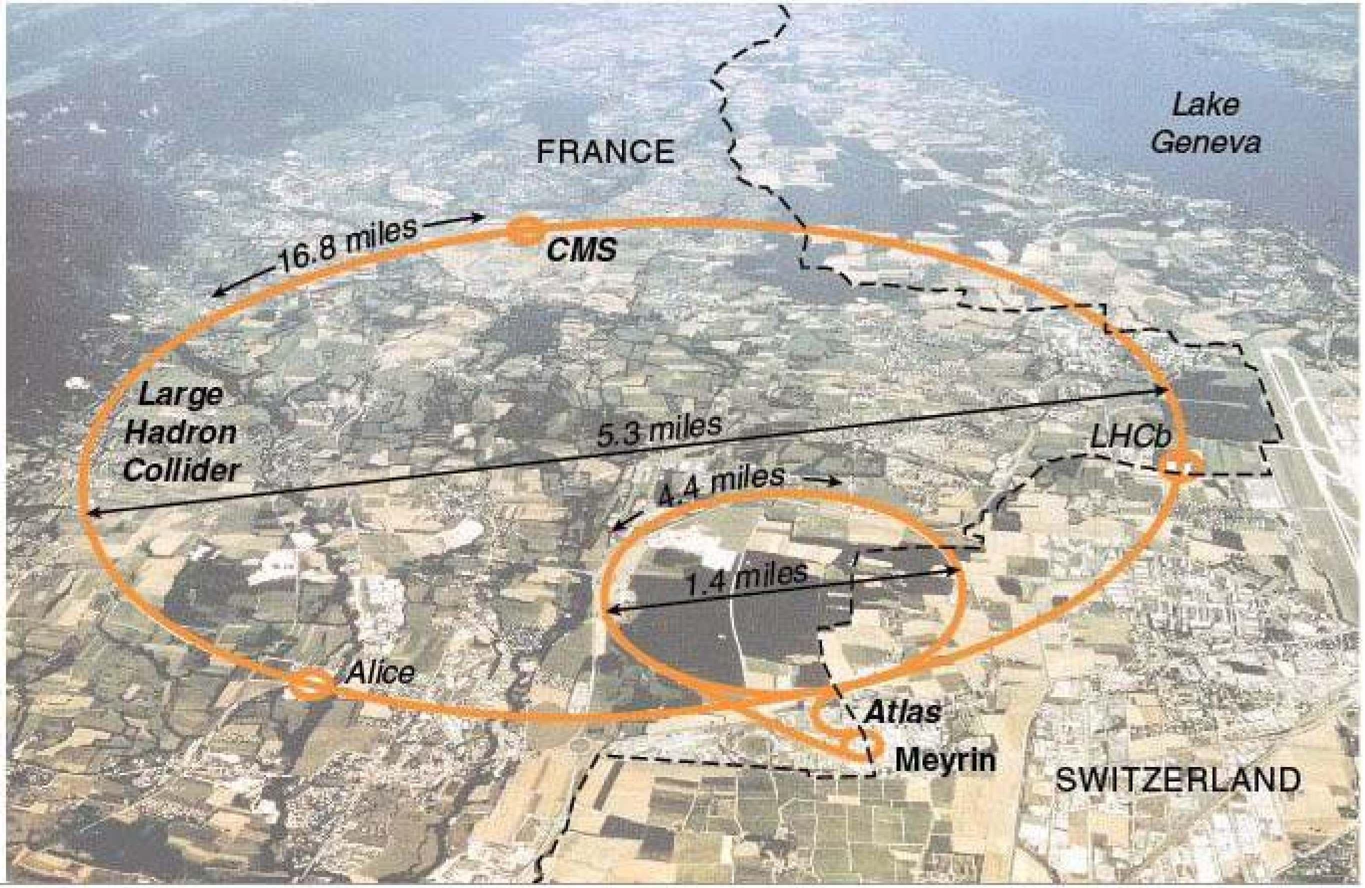
The LHC in the News

The New York Times

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | NEXT

The Large Hadron Collider of Cern (European Organization for Nuclear Research)

In a tunnel 300 feet below Switzerland and France, scientists are putting the final touches on a 16.8-mile long particle accelerator that will smash protons together in an attempt to create forces and particles that existed shortly after the Big Bang and rarely, if ever, today.



Source: Cern; Physics World, Sept. 2004; Lawrence Berkeley National Laboratory

Graham Roberts, David Constantine, Mika Gröndahl, Erin Aigner/ The New York Times

So you want to discover…

- The Higgs boson
- Supersymmetry
- Extra dimensions
- New gauge bosons
- All of the above!

- What does it take to prepare?

Timeline of an Experiment

- Generic detector R&D
- Experiment proposed (Collaboration forms)
- More detector R&D and system design
- Construction
- Testing
- Installation
- Commissioning
- Operations
- Analysis
- Publication!

This set of lectures

Outline of Lectures

- What is commissioning?
- Scale of the problem
  - Detectors, electronics, software, computing
- Commissioning activities
  - Test beam programs
  - Detector "Slice Tests"
  - Magnetic field measurements

Lecture 1

- Detector performance
  - Temporal alignment (synchronization)
  - Spatial alignment
  - Material budget
  - Calibration

Lecture 2

- Operating the Experiment
  - What it takes to run a large experiment
  - Data quality monitoring

Lecture 3

Outline, Cont'd

Lecture 3

- Preparing for physics measurements
  - Luminosity measurement & beam conditions
    - Impact of pile-up
  - Understanding the detector performance from data
    - Impact of instrumental issues (noisy/dead channels, zero suppression) on basic physics objects
    - Missing Transverse Energy – catch-all of instrumental problems
    - Jet Energy scale
- Early LHC physics measurements
  - Underlying event
  - Calibrating the Standard Model backgrounds
    - e.g. QCD jet production, Electroweak measurements, Top quark measurements

Lecture 4

What is Commissioning?

- Bring the detectors, electronics, power, cooling, safety and monitoring systems into nominal operation
- Prepare the experiment for efficient data-taking operations and expected detector performance
  - Synchronize, calibrate, and align detectors
  - Monitor the detector performance
  - Achieve efficient and reproducible data operations
- "Physics commissioning"
  - Calibrate Standard Model processes
  - Understand and remove instrumental and beam backgrounds

Scale of the problem

"Nope, there's no scale" – Apollo program

Scale: LHC Collaboration sizes

Experiment	Institutes	Countries	Collaborators
ALICE	104	30	1000
ATLAS	164	35	1900
CMS	155	37	1940
LHCb	48	15	680
TOTEM	11	8	80

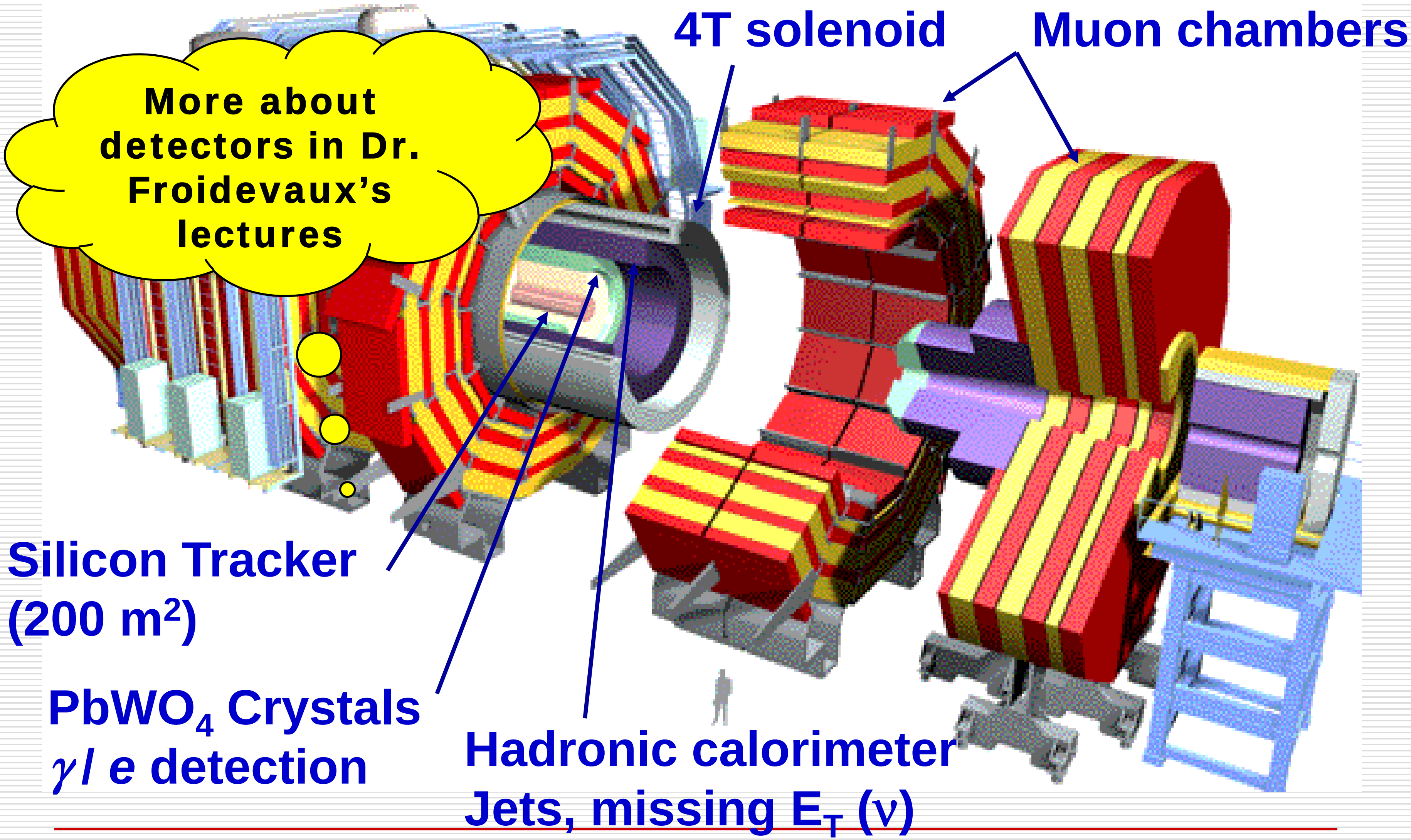
Go where no one has gone before…

	Tevatron / CDF	LHC / CMS
Beam energy	1 TeV	7 TeV
Inst. Lumi.	10^{32}	10^{34}
Electronic channels	1M	80M
Bunch xing freq	2.5 MHz (7.6 MHz clk)	40 MHz
L1 output rate	25 kHz	100 kHz
L2 output / HLT input	400 Hz	100 kHz
L3 output rate	90 Hz	100 Hz
Event size	0.2 MB	1 MB
Filter Farm	250 nodes	O(1000) nodes

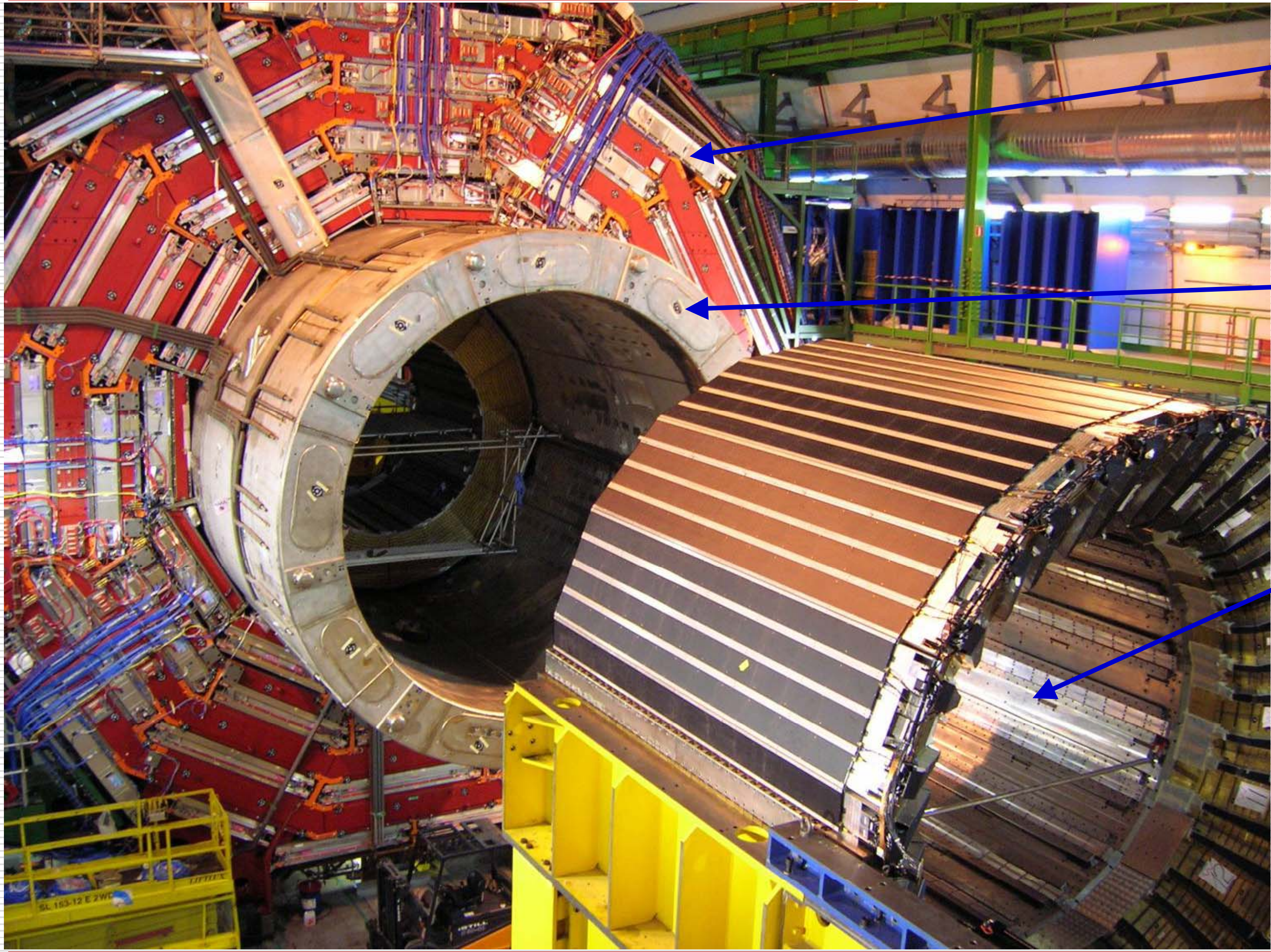
More particle occupancy, thus more granularity in detectors

Complexity in electronics and computing increases

The "Compact" Muon Solenoid (CMS) Experiment

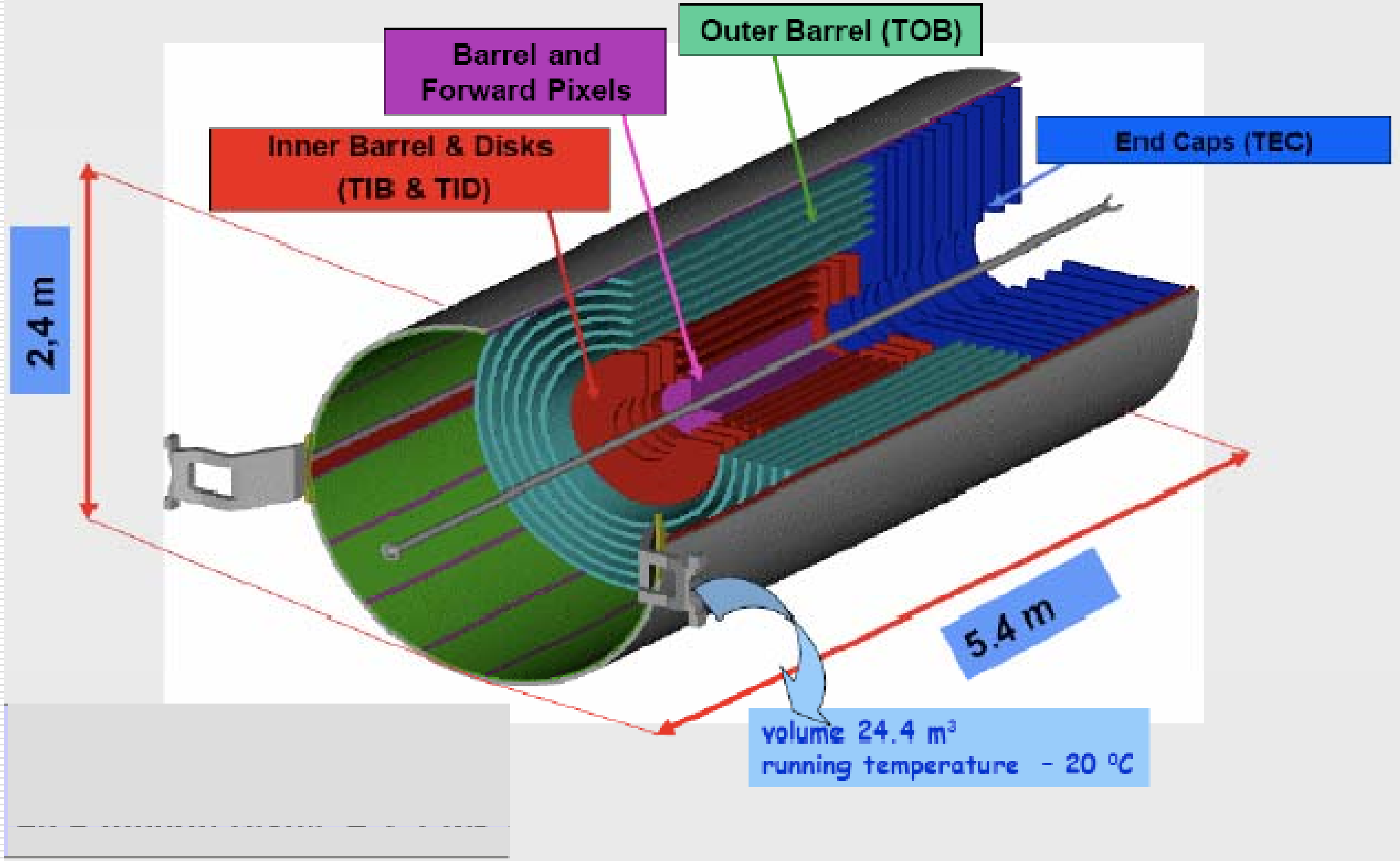


CMS: Preassembled on surface, in final installation underground

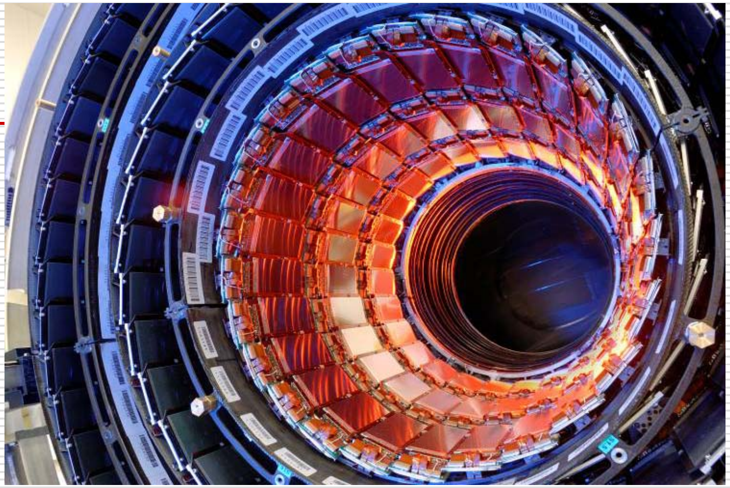


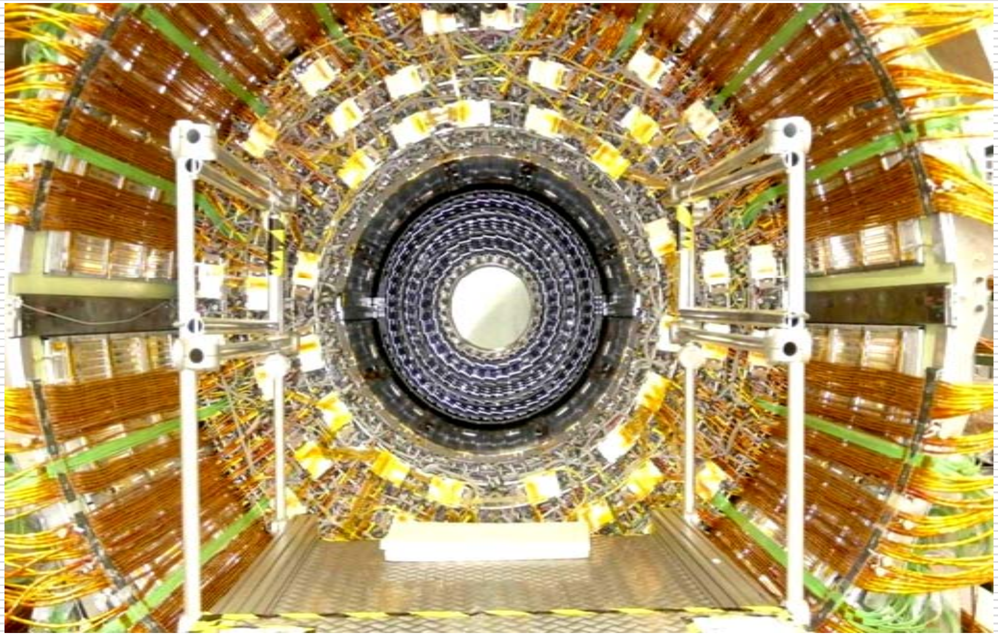
March 2007

CMS Silicon Tracker



CMS Silicon Tracker

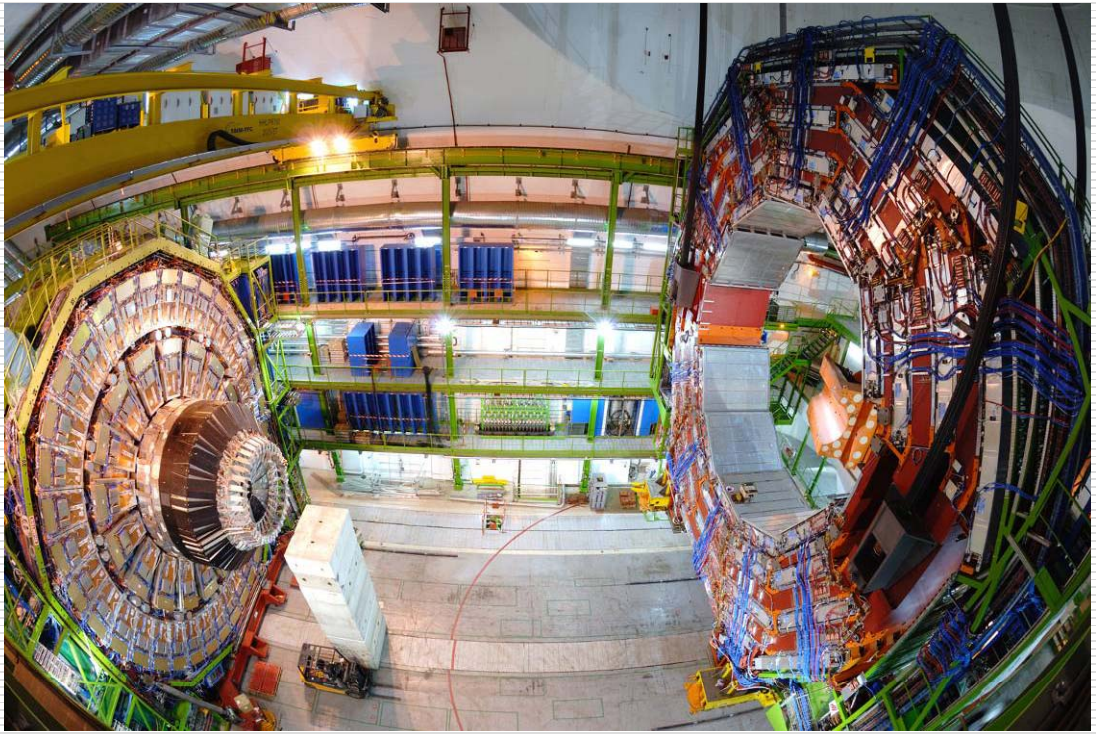




- Strip Tracker
  - 200 m^2 coverage
  - 10μm precision measurements
  - 9.6M electronic channels
    - For comparison, CDF inner vertex detector < 1M
- Inner Pixel tracking system (not shown)
  - 66M channels!

CMS Muon Systems

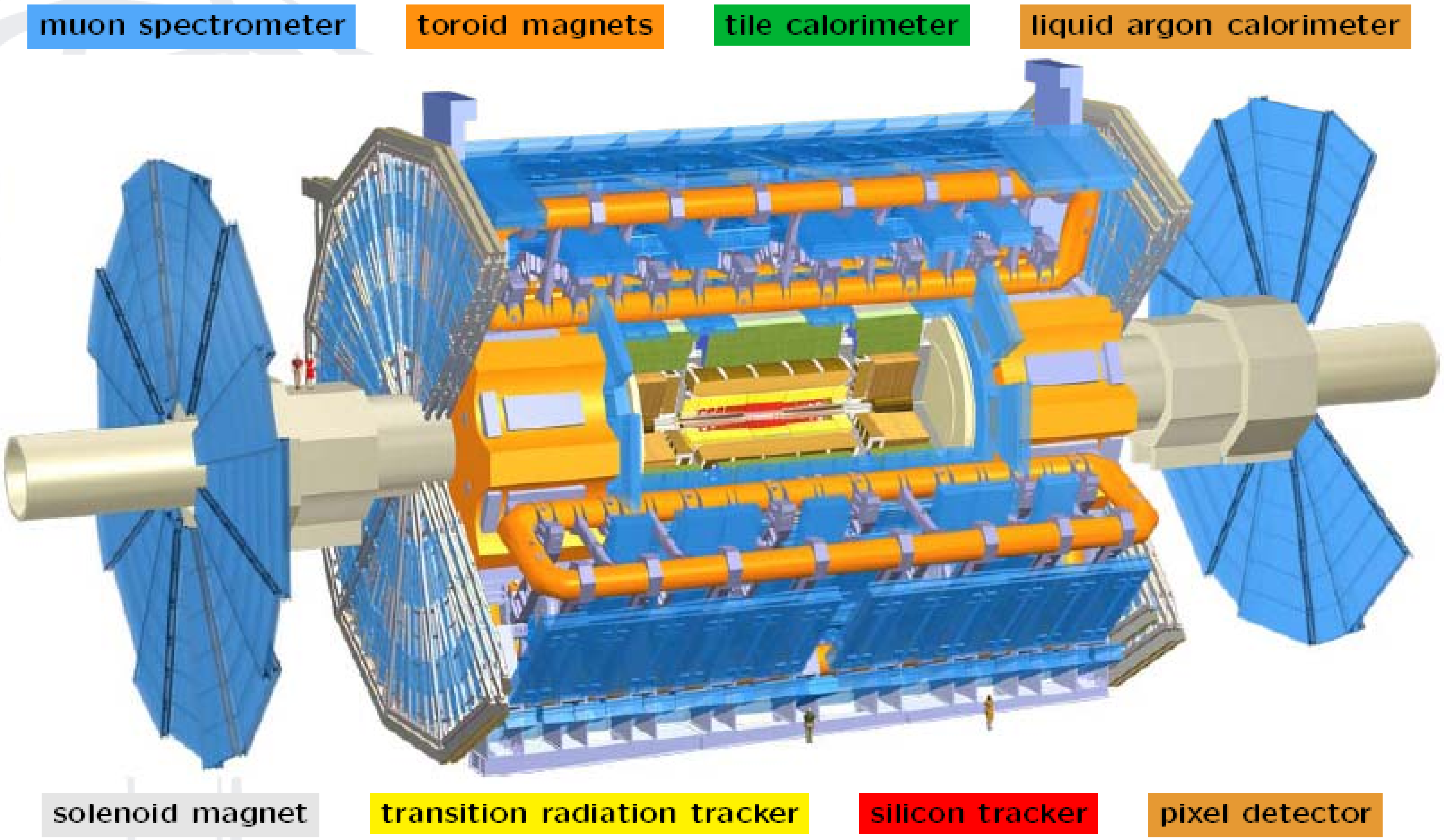
- 3 technologies:
  - drift-tubes, cathode strip chambers, resistive plate chambers
- 25000 m^2 of active detection planes
  - 100µm precision on position
- About 1M electronic channels
  - For comparison, the CDF muon system has "only" 8K channels



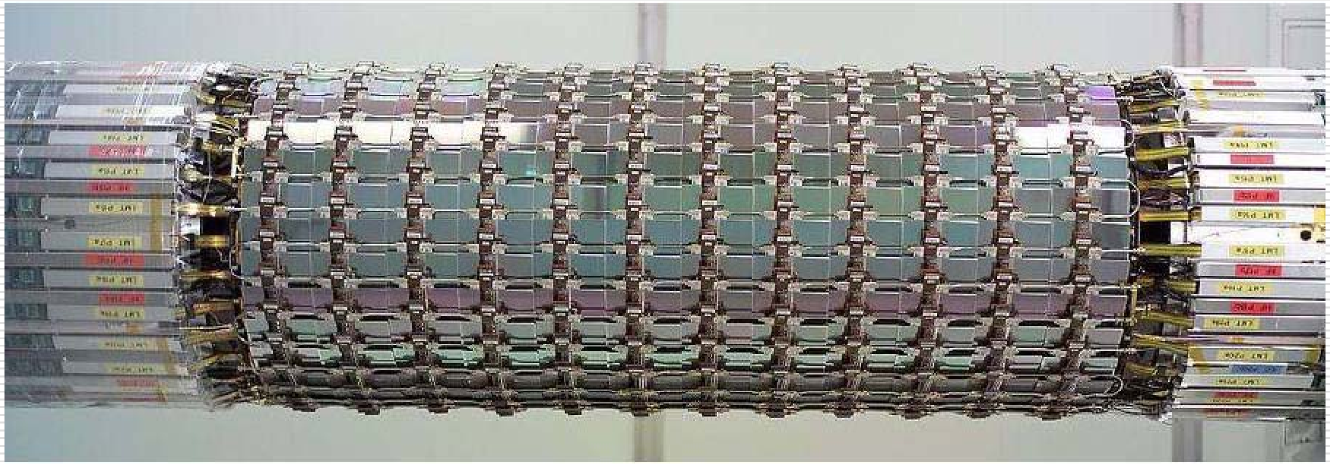
ATLAS

- **ATLAS detector:**

  diameter 25 m, length 46 m, mass 7,000 tons, 10^8 channels, 3,000 km cables

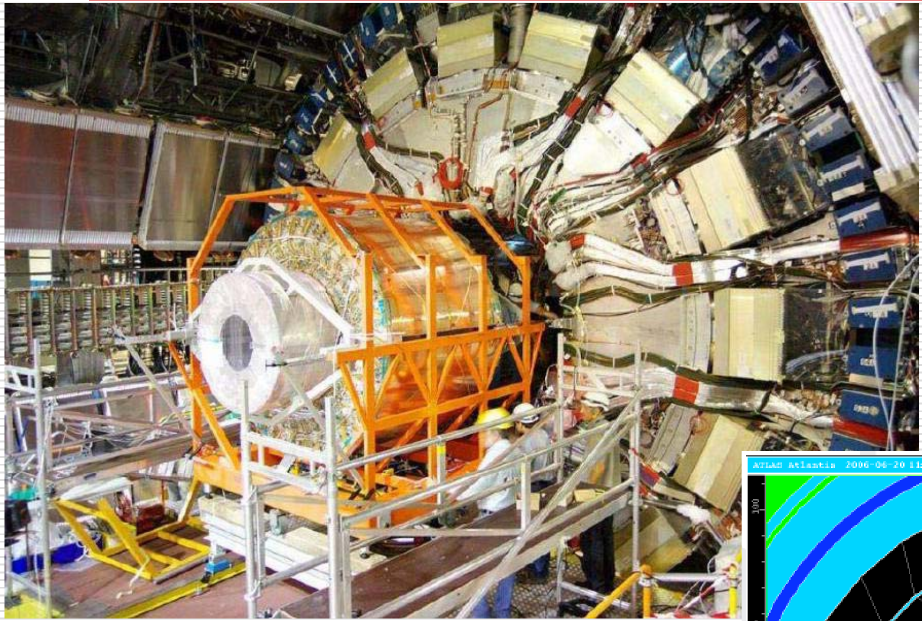


ATLAS Tracking Detectors

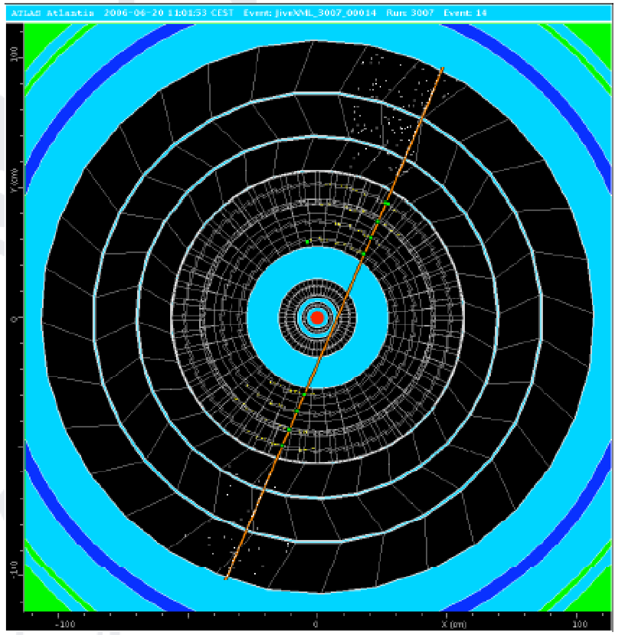


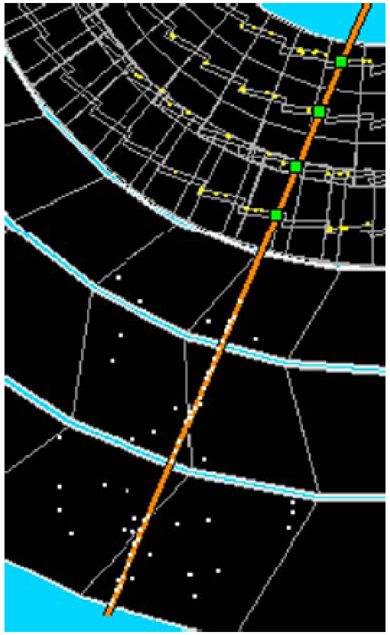
- Transition Radiation Tracker
  - Straw tubes, 0.4M channels
- Strip Tracker
  - 6M electronic channels
- Pixel system (not shown)
  - 80M channels
  - Assembly almost complete

ATLAS Tracking installation and commissioning



Cosmic-ray recorded in tests on surface





Scale: Software

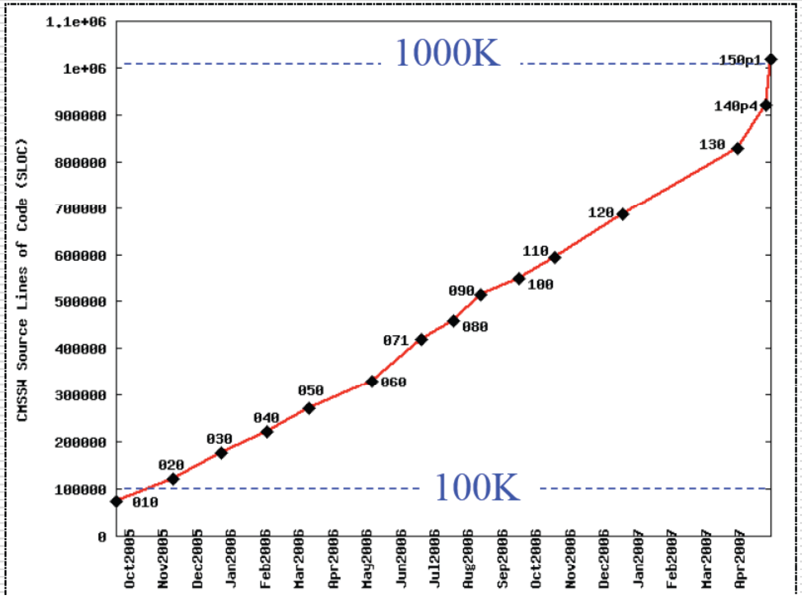
- Extensive amount of software is required for controlling electronic hardware, monitoring, and data acquisition and storage
  - Load firmware, download settings, spy on error counters, log data to mass storage, etc.
- Moreover, an even greater amount of software is required to process raw data, e.g.
  - Convert ADC counts → energy deposition
  - Cluster neighboring energy deposits into a single shower → electron energy
  - Convert TDC counts → drift time → hit position
  - Associate hits → particle trajectory → momentum (from curvature)

Software, 2

- The process of converting logged raw data into useable objects for physics analysis is referred to as "reconstruction"
  - Detector-specific local reconstruction and clustering, tracking algorithms, vertex reconstruction, muon identification, jet reconstruction, electron reconstruction, etc.
- Software is also needed to simulate collisions and the detector response in order to understand data in an analysis
  - e.g. efficiency determination, mass resolution
- Finally, you must write your own software to take reconstructed or simulated data and perform data analysis!

Software, 3

- Modern collider experiments require more then 1M lines of code for offline software
- CMS:
  - Lines of SW in last 1.5 years
  - ~300 developers
  - C++ language →



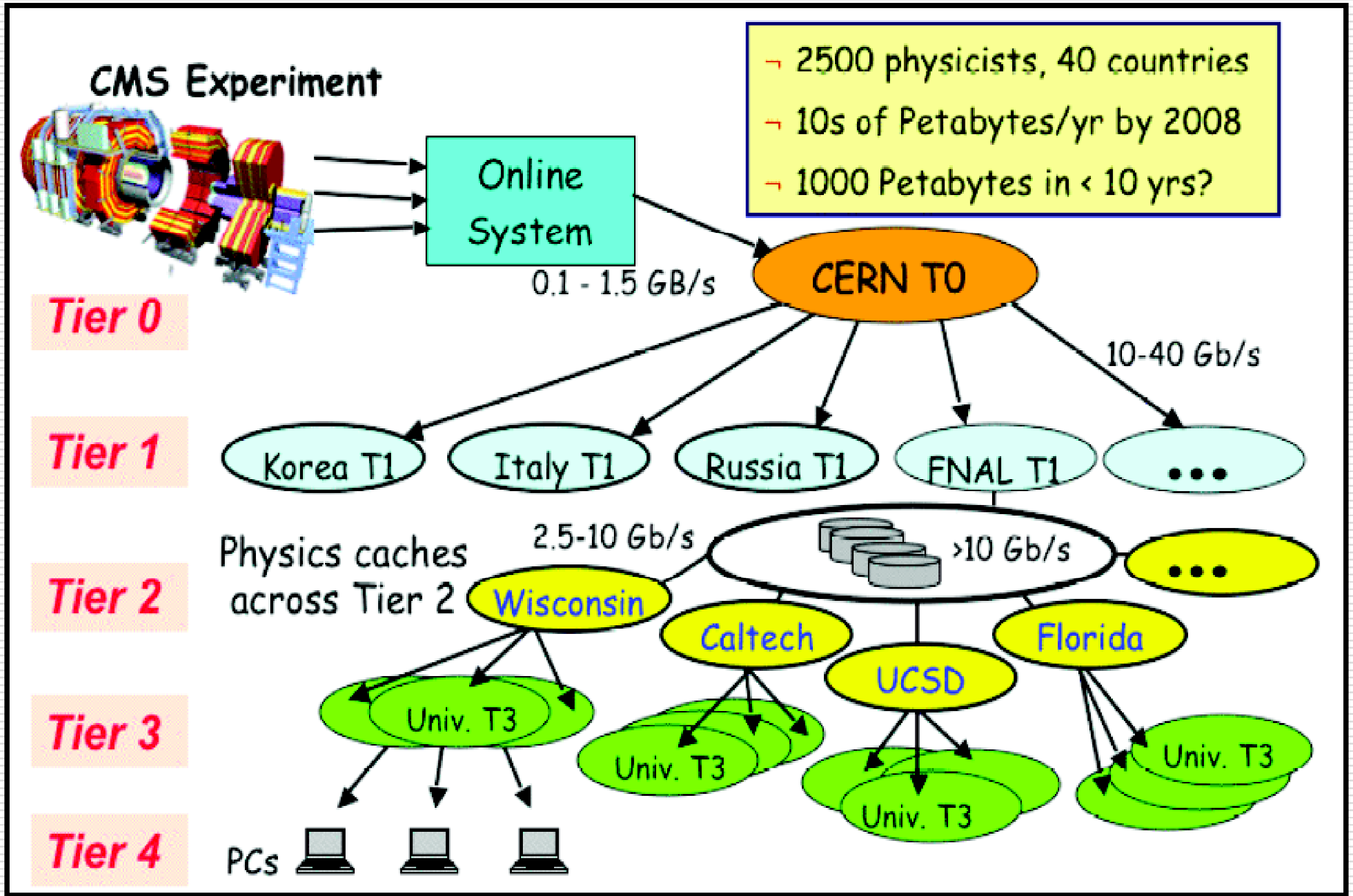
- Though tempting, nowadays you cannot write all the software you need on a modern collider experiment
  - Take your rate of writing code and determine your graduation date!
  - Must rely on others, but you should understand it all!
- SW needs commissioning too (thorough validation!)

Scale: The LHC Distributed Computing Model

WLCG

Open Science Grid

Enabling Grids for E-science in Europe



Scale: CMS 25% Scale Test in 2006 (CSA06)

- Tier-1: 7 centres

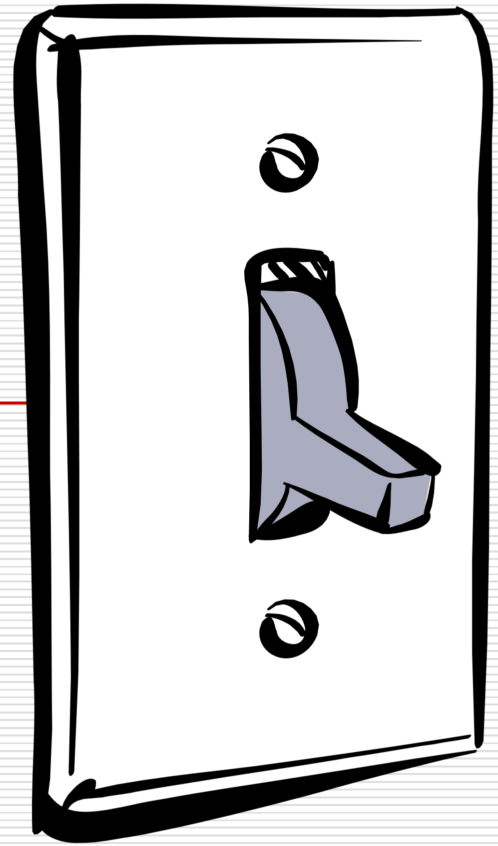
Site	CPU[kSI2k]	CPU[#]	Disk[TB]	Network[Gb/s]
ASGC	(228)	(140)	48+(36)	2
CNAF	225	300	40	10+(10)
FNAL	2200	1800	700	11
GridKa	220+(220)		40+(30)	10
IN2P3		250	70	10
PIC	150	120	50	1
RAL	200		60+(20)	11

Tier-2: 27 centres

Site	CPU[kSI2k]	CPU[#]	Disk[TB]	Network[Gb/s]
Aachen		94	5	1
Bari		30	5	1
Belgium_IIHE	150	84	25	0.1
Belgium_UCL	110	38	25	1
Budapest		85	2	0.5
Caltech	330	256	55	10
CIEMAT	260	200	10	1
CSCS	30	20	4	1
DESY		100	35	10
Estonia		100	15	1
Florida	320	240	25	10
IFCA		100	15	0.6
ITEP		20	1	1
JINR		10	1	1
KNU		56	15	10
Legnaro		150	16	1
London_IC		264	4	1
MIT	182		5	1
Nebraska	350	252	21	0.6
Pisa	76	50	6	1
Purdue		228+(256)	30 +(170)	10
Rome		48	5+(10)	1
SINP		24	1	1
SPRACE	311	242	28	1
Taiwan		20	6	2
UCSD		150	10	10
Wisconsin	547	428	90	10

- Tier-0 (CERN):
  - 1400 CPUs
- Scale by 4X for 2008 physics operation

Commissioning



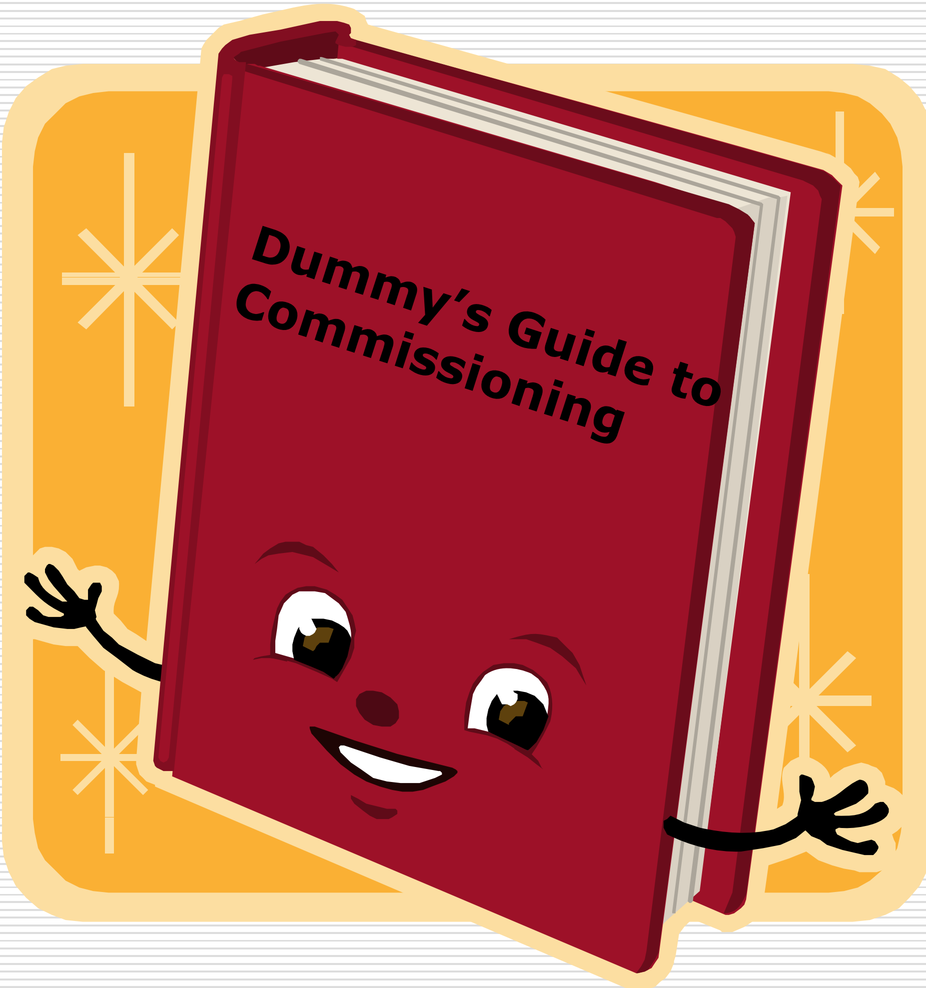
Everything is installed, let's just turn it on!
(i.e. What's the problem?)

Why an Experiment is not a Monte Carlo generator

- Are all the cables connected properly?
- Are all electronic channels working, and boards functioning properly?
- Are the power supplies and cooling systems working reliably, and are the monitoring and safety systems working to protect your priceless detectors and electronics?
- Do all data fragments correspond to the same beam crossing?
- Are the detectors where you think they are, or at least where your software thinks they are?
- Has the software been debugged?
- Are the detectors delivering their expected performance?
  - e.g. are mass peaks showing up where they should be?

It all has to work!

Commissioning is a big job…

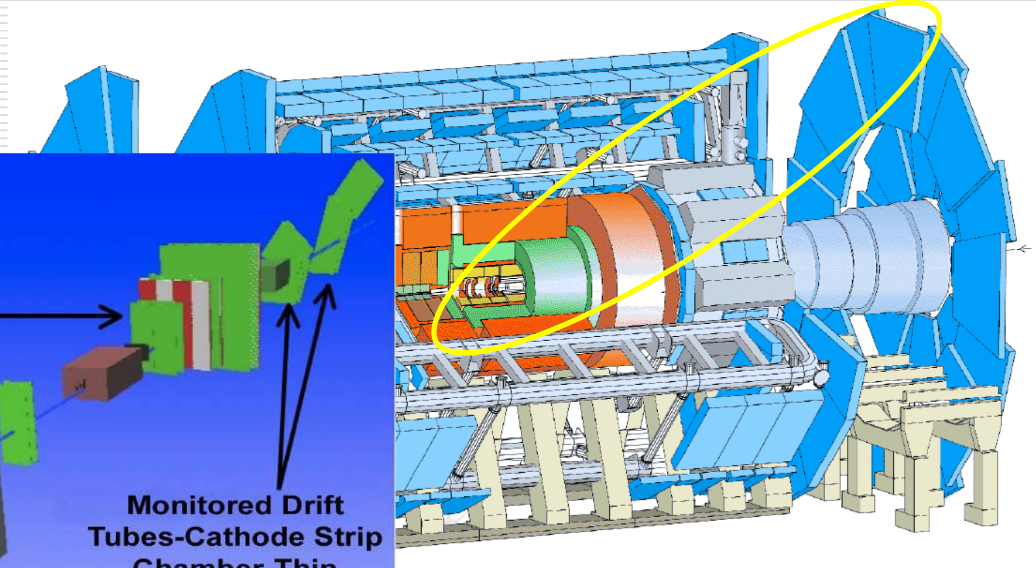


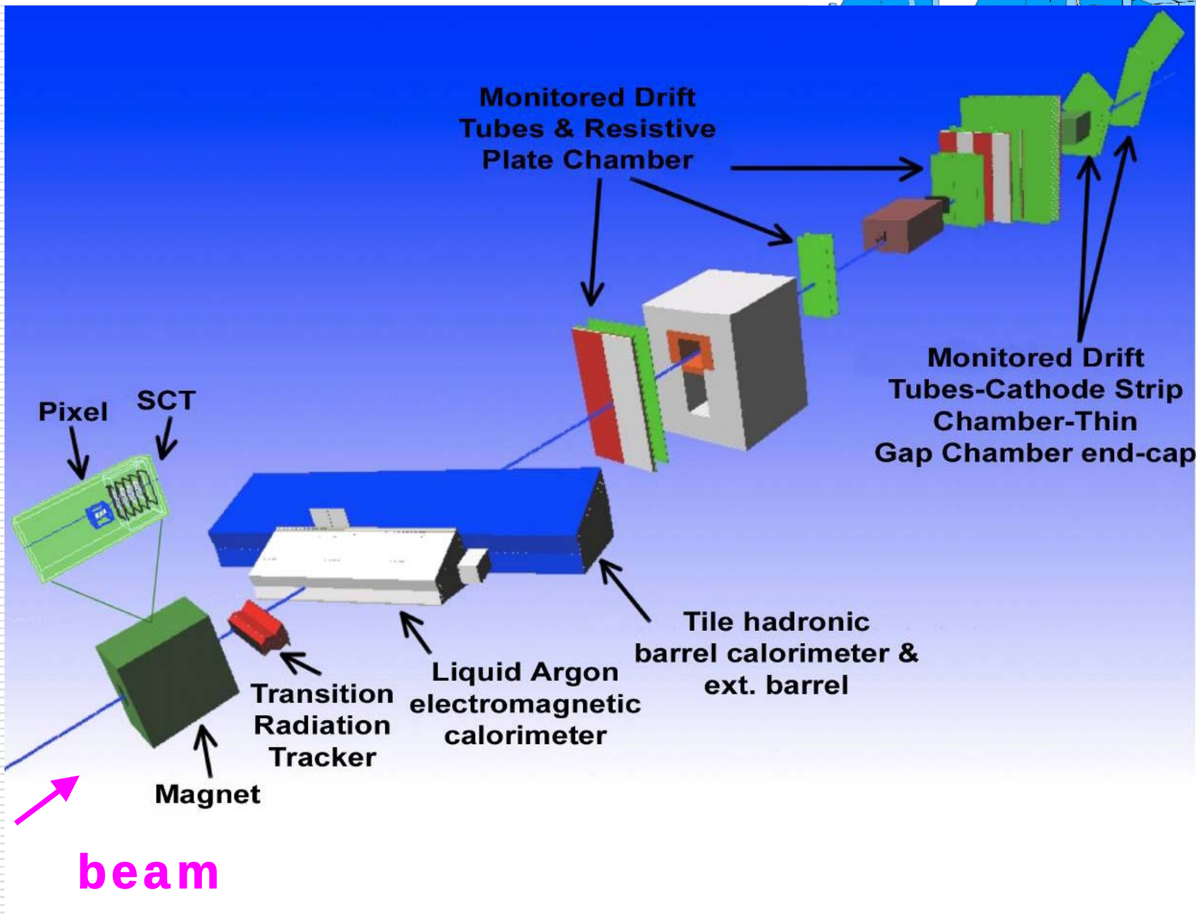
- And still waiting for this book to come out

Dress Rehearsals

Commissioning efforts

ATLAS Combined Testbeam, 2004





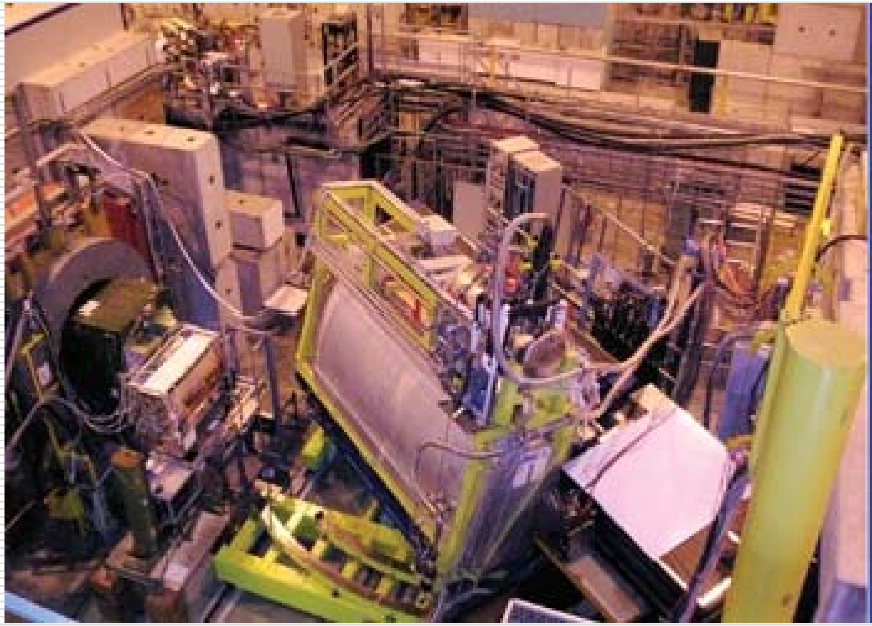
- Dedicated test of a complete slice of the ATLAS experiment in a test beam at CERN

Purpose of a Combined System Test

- Study the performance of a slice of the experiment
  - Collect a lot of data
  - Make comparisons between data and Monte Carlo simulation
- Calibrate the detectors (calorimeters)
- Gain experience with many commissioning issues in a global way
  - Integration of many complex subsystems
  - Experience with software (and subsequent debugging, improvements)
  - Test data handling system (the computing model)

H8 Beam line

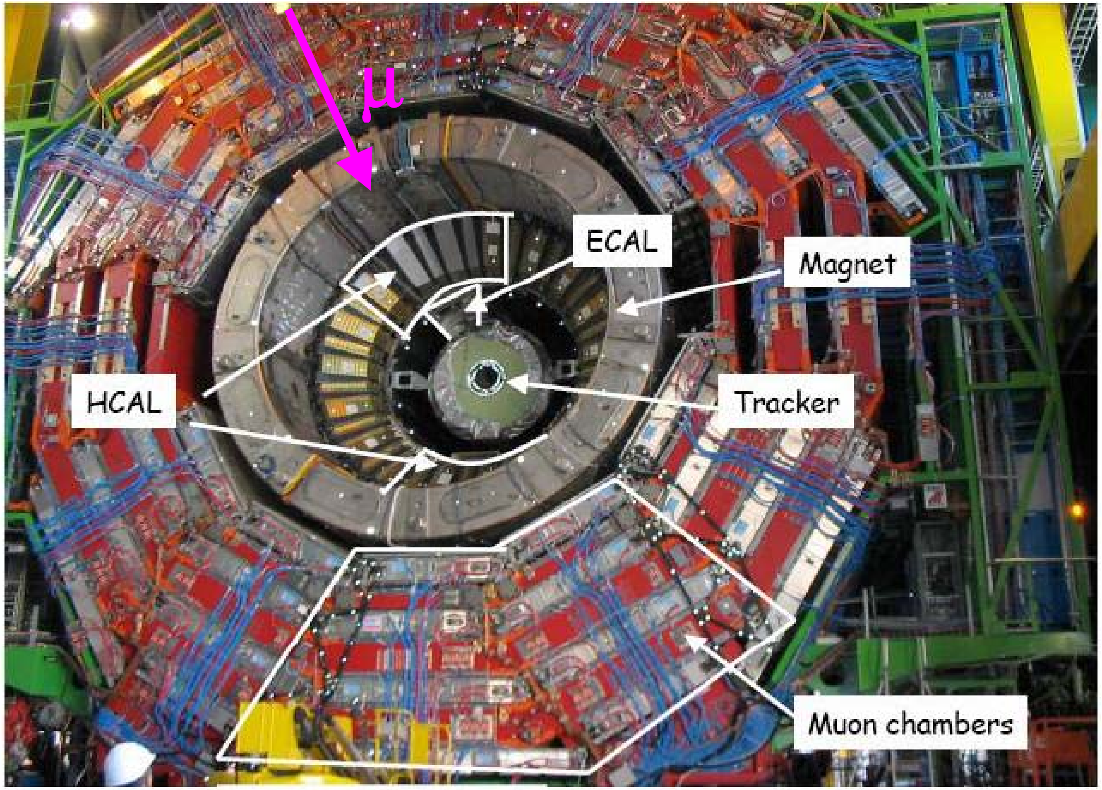
- Particles: e, π, μ, γ
- Energies: 1 – 350 GeV
- Area spans 50m !



Calorimeters and particle identification

Muon system

CMS Magnet Test and Cosmic Challenge (MTCC)



Aug. – Nov. 2006

Operates world's most energetic magnet! (2.7 GJ)

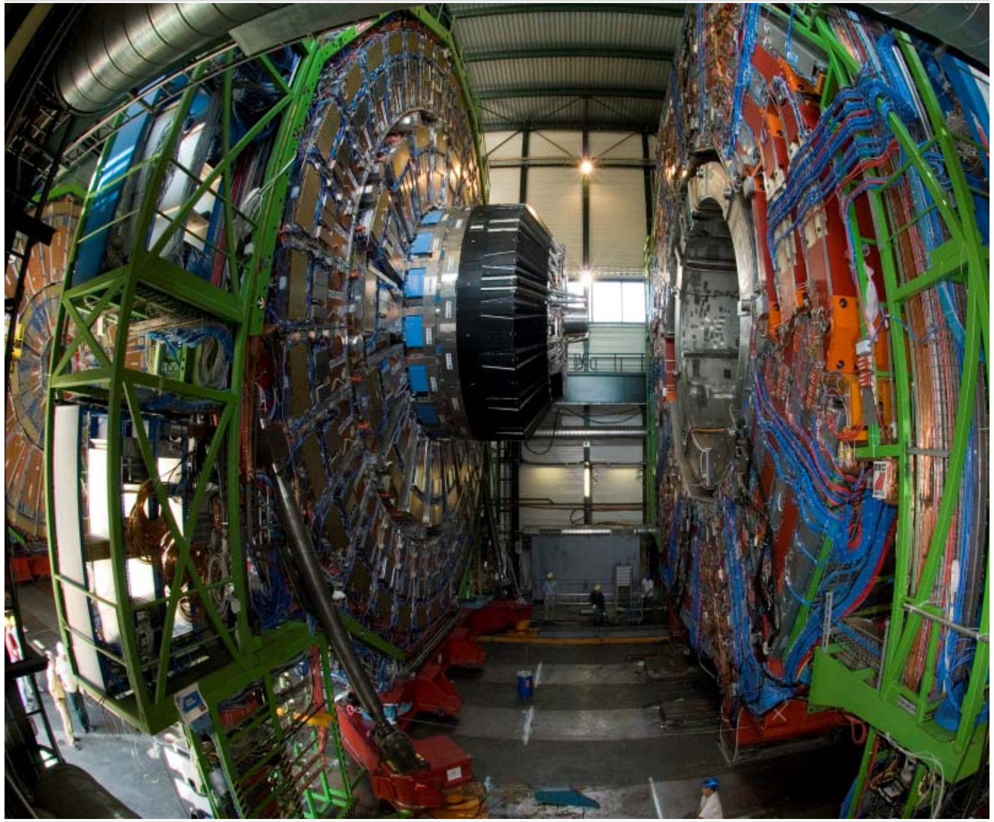
Operating a vertical slice of CMS:

- Muon Detectors (6–8%):
  - Drift-tubes
  - Cathode strip chambers
  - Resistive plate chambers
- Barrel Hadron Calorimeter (22%)
- Barrel electromagnetic calorimeter (5%)
- Tracker (~1%)
- DAQ and Trigger

Two Phases:

- **Phase 1: all detector elements participate, B=0, 3.8T**
- **Phase 2: remove tracker+ECAL, and insert B field mapper**

Valuable Experience Installing and Closing CMS on the Surface, before Commissioning Underground



HB Insertion: First one took two weeks, while plus side took three days

EB Insertion

As well as integrating services (cabling, cooling, safety systems) and operations (calibration, alignment)

The Magnet Worked!

e-log Selection | General | Subsystems | Test
Shift

Shift

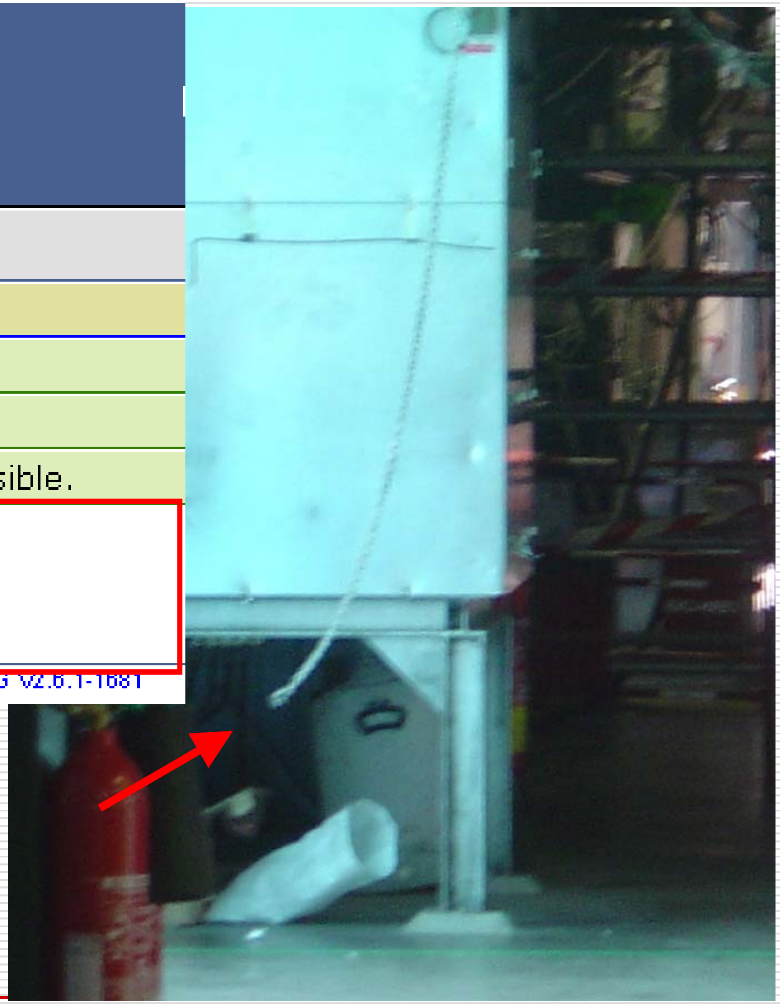
Find | Login | Help

Message ID: **412** Entry time: **Fri Aug 11 13:19:56 2006**

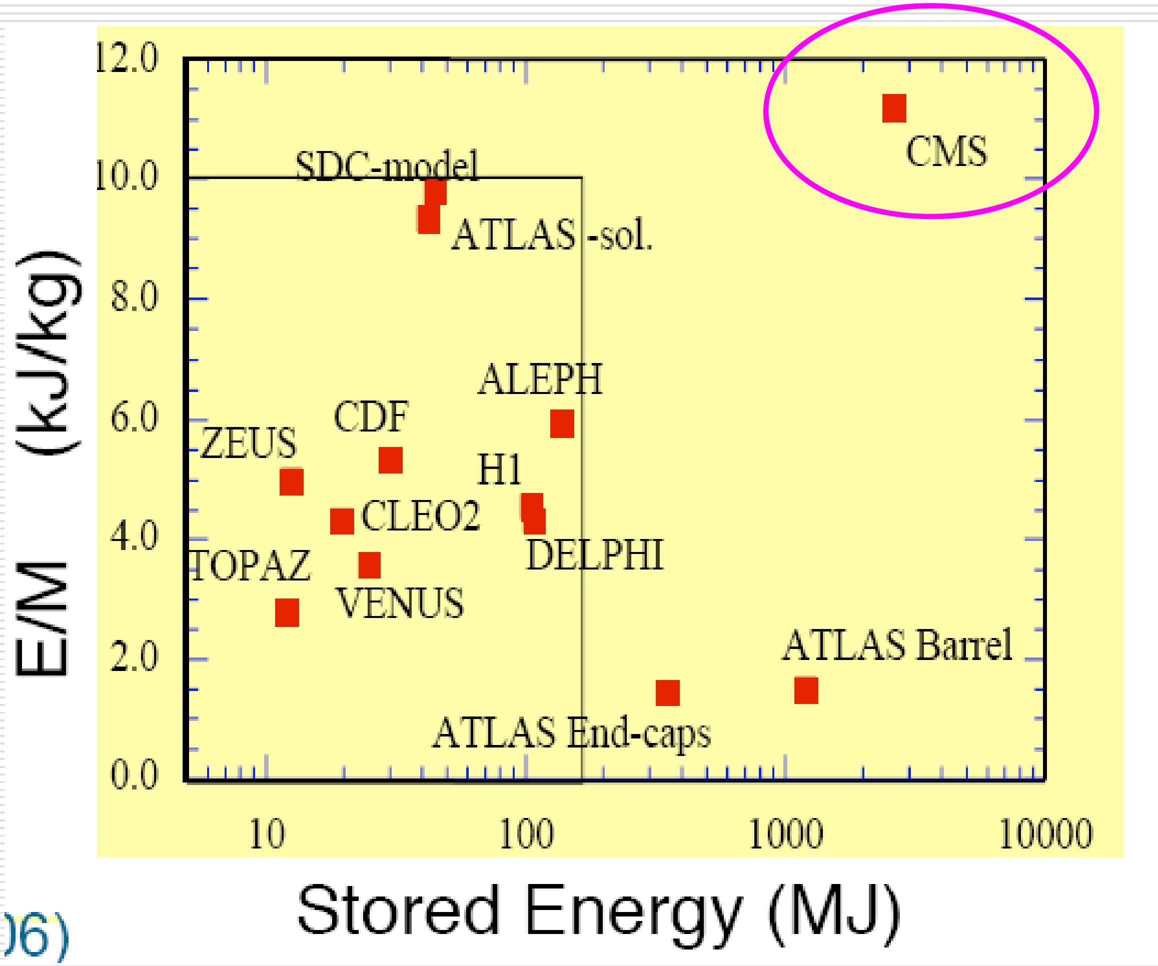
Author:	Austin Ball, Austin.Ball@cern.ch
Type:	
Subject:	Ramping towards 3 T. Fringe field effects visible.

Balcony barrack shielding not very effective.
Air conditioner already stopped...switched off.
60 G at RPC PS's.
Take care with opening and closing rack doors!!!

ELOG V2.6.1-1681



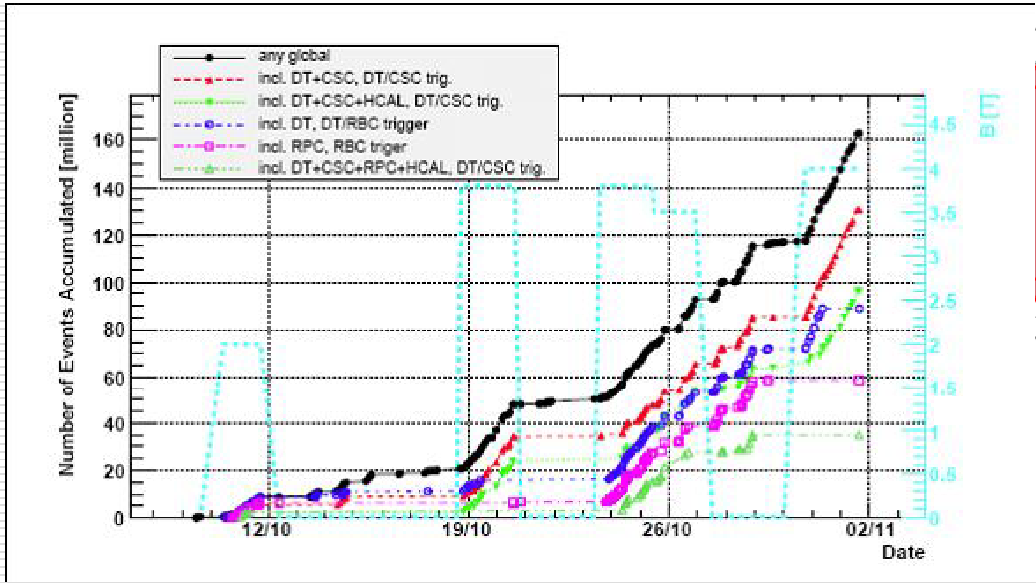
Why it was a non-trivial result

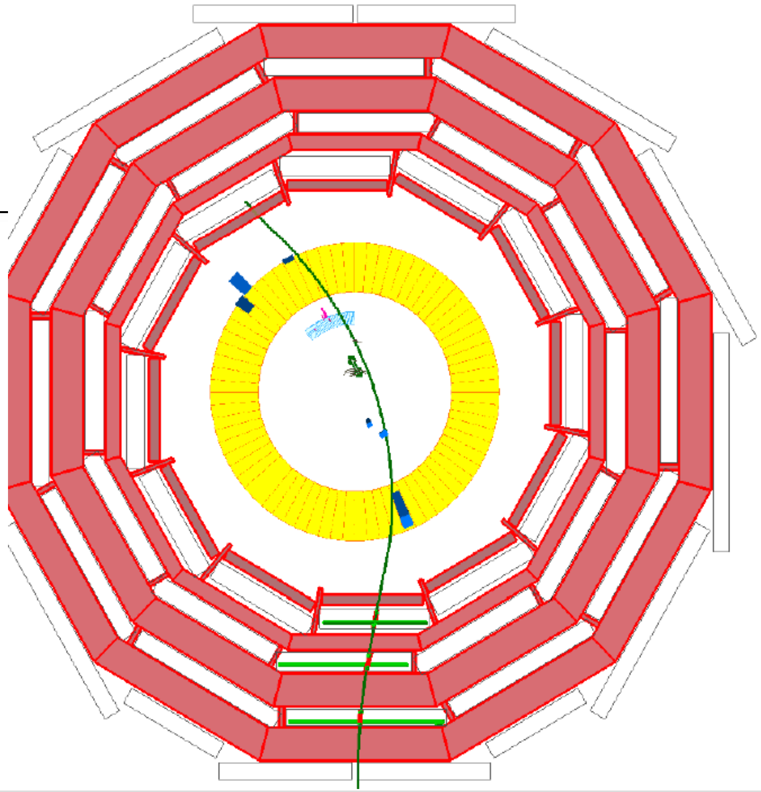


The Detectors, Trigger and DAQ worked

- Recorded ~200M cosmic muon events from Aug. – Nov. 2006
- Trigger rate up to 200 Hz

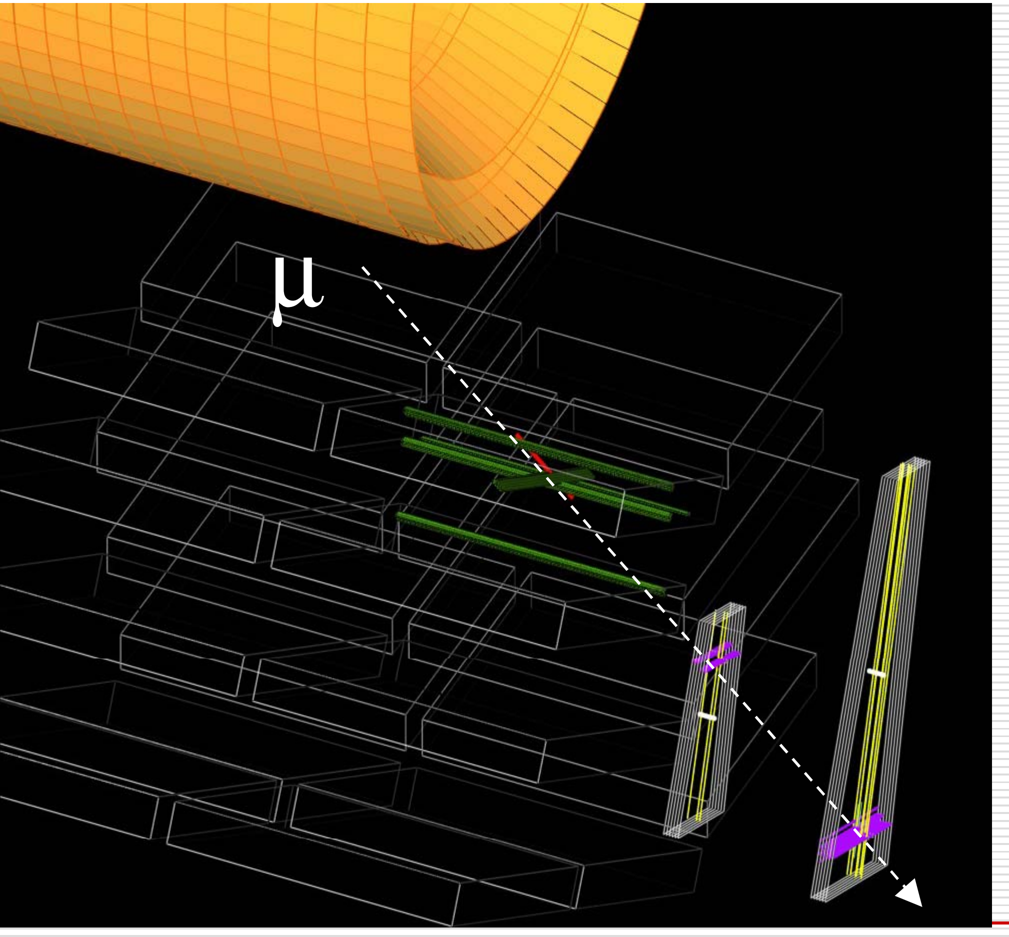
Run 2605/Event 3981
B=3.8 Tesla
27 august 2006



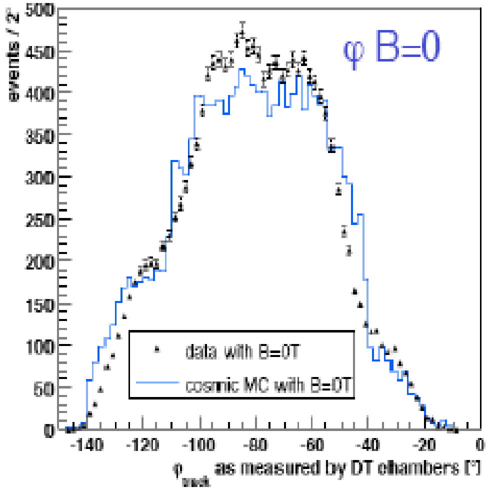


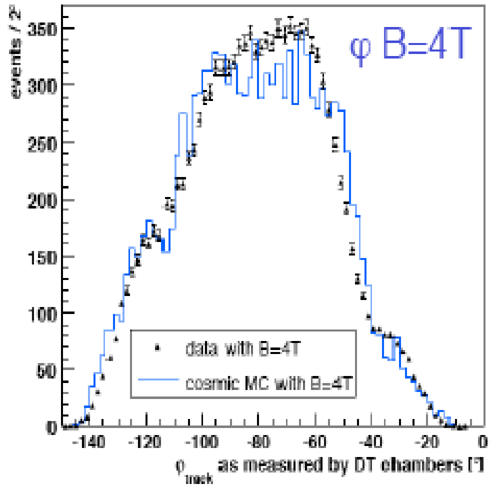
A Golden Cosmic Muon Event

- Cosmic muon through CSC and DT muon systems, triggered through Global Muon Trigger, and read out by central DAQ

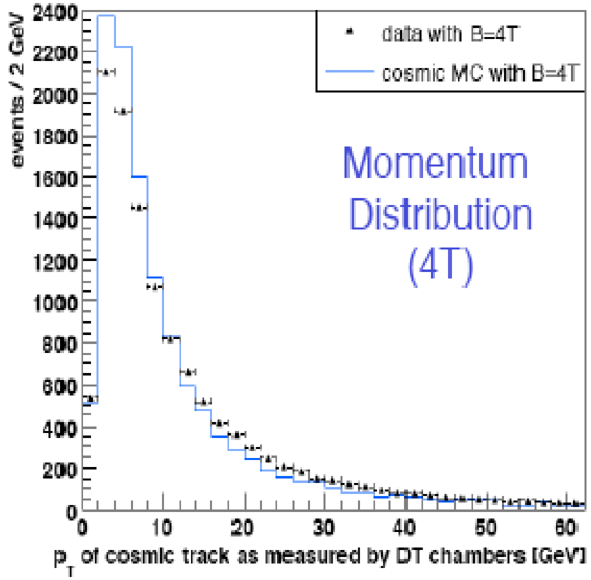


Muon Spectra Measured in 4T Field (CMS MTCC)





Azimuthal distribution measured by DTs.



Cosmic muons data normalised to Monte Carlo simulation

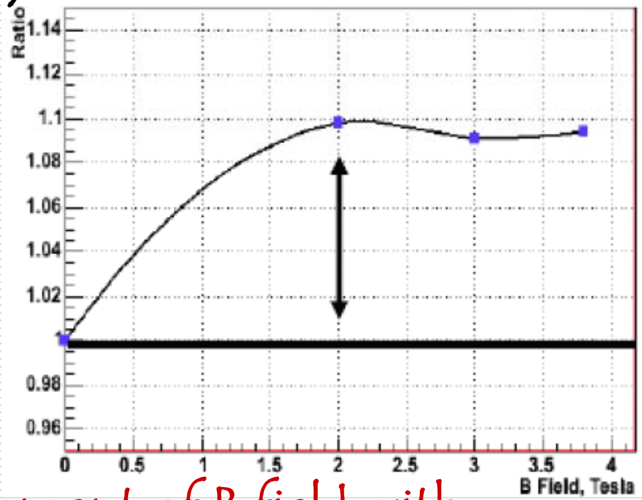
Reasonable agreement between data and simulation.

Almost every aspect of final CMS from detector to CMSSW had to work to produce these plots.

11

Some of the Experience Gained at MTCC

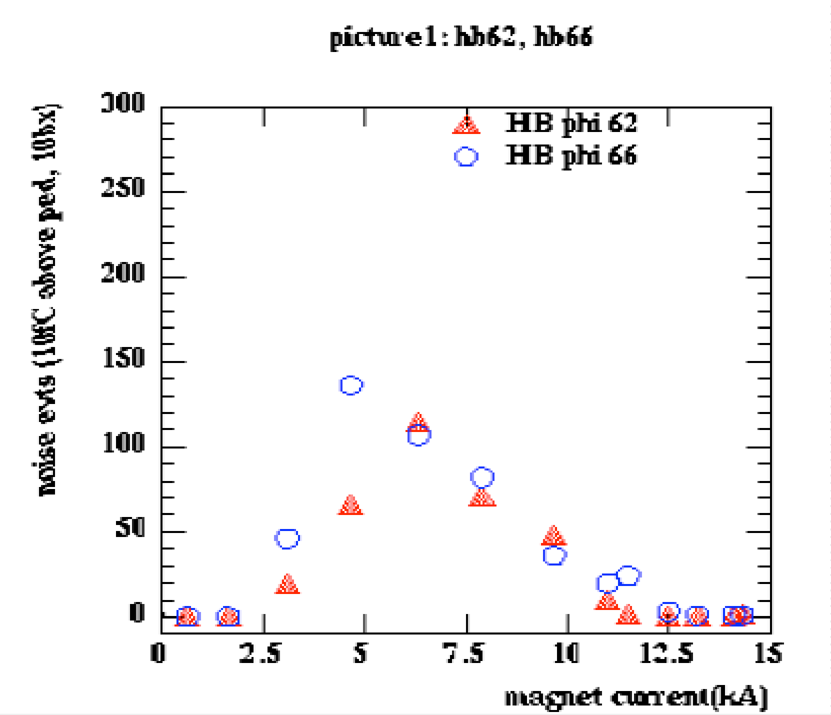
- Identification and replacement of magnetic components (ferrite inductors)
  - Part of alignment system
- Measurement of scintillator brightening effect in B-field for in-situ calorimeter
  - 10% effect



- Observation that some photodetectors are not aligned with B field
  - Hybrid Photodetector (HPD) relies on alignment of B field with tube axis – calculation was off for those connected to the outer hadron barrel detector (25° difference)
  - Result is large pixel-to-pixel cross talk
- Observation of high rate of electrical discharges in hybrid photodetector (HPD) elements in hadron calorimeter, especially at certain field strengths (1-2 T)

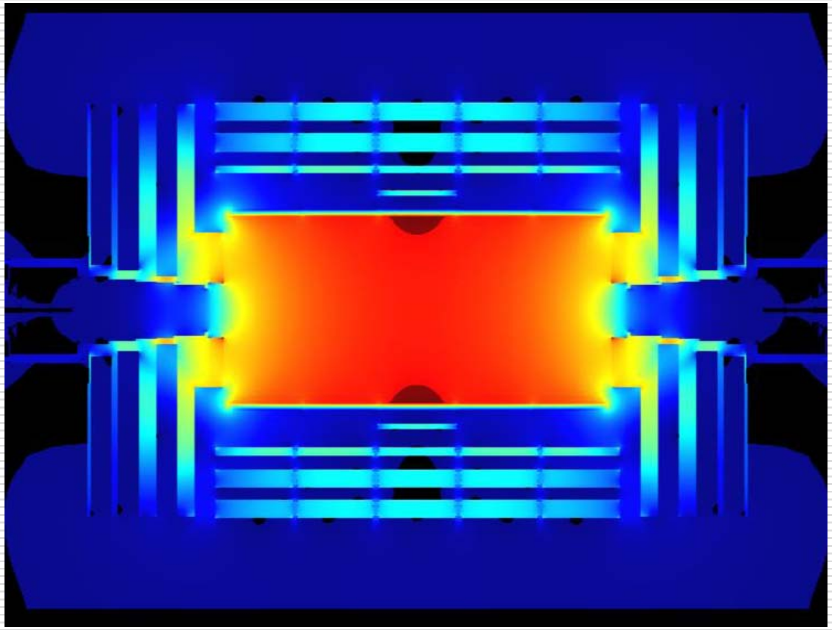
HPD Noise Effect

- Discovered that the hybrid photodetectors used to read out the scintillation light from the barrel hadron calorimeter suffered significantly increased noise around 1-2T
  - Cannot operate well at those field strengths (but 4T is nominal pt.)



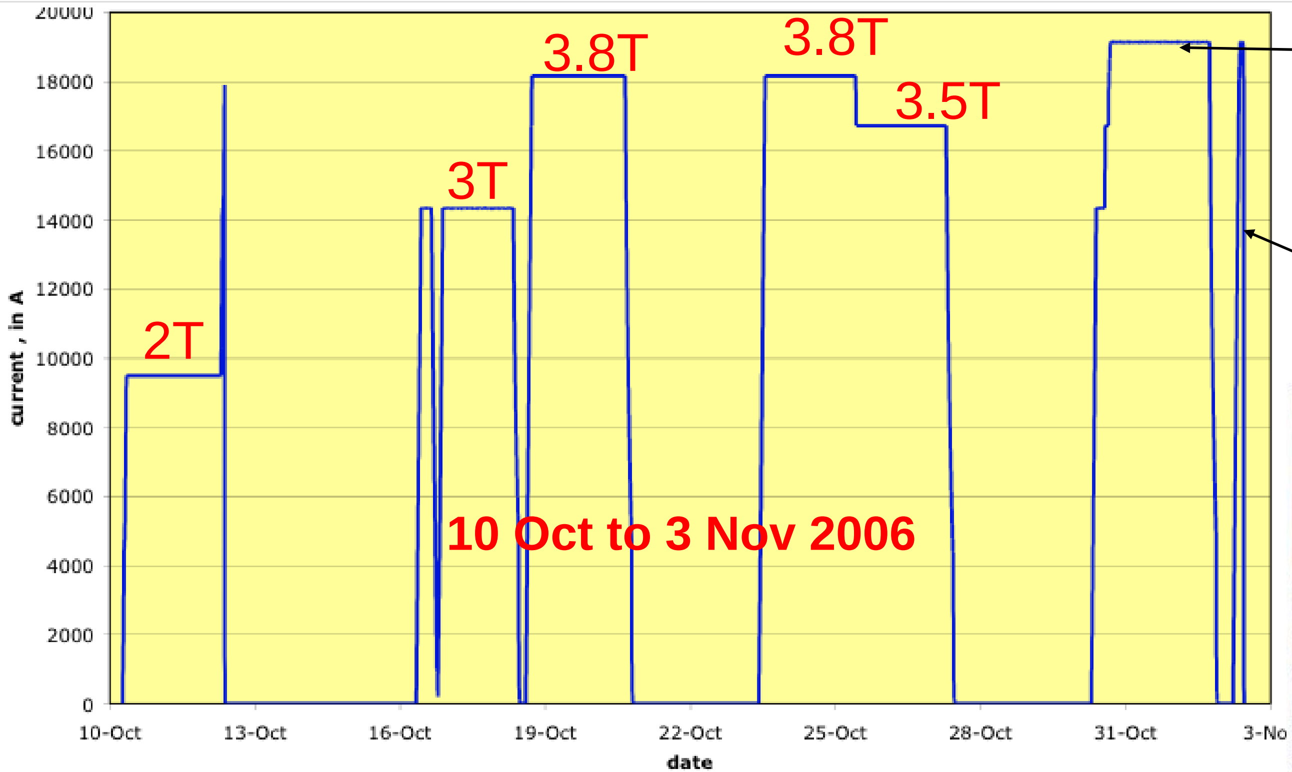
Magnetic Field Measurements

- Precise knowledge of the magnetic field map is crucial to track reconstruction
  - Momentum measurement depends on charged particle bending
  - More information in second lecture
- Detailed calculations followed by probe measurements



CMS 4T solenoid field in cross section

Mapping of CMS Magnetic Field



4T = 19.140kA: stable operation confirmed

Temp stability margin 0.6 K

Field Mapper carriage insertion and test

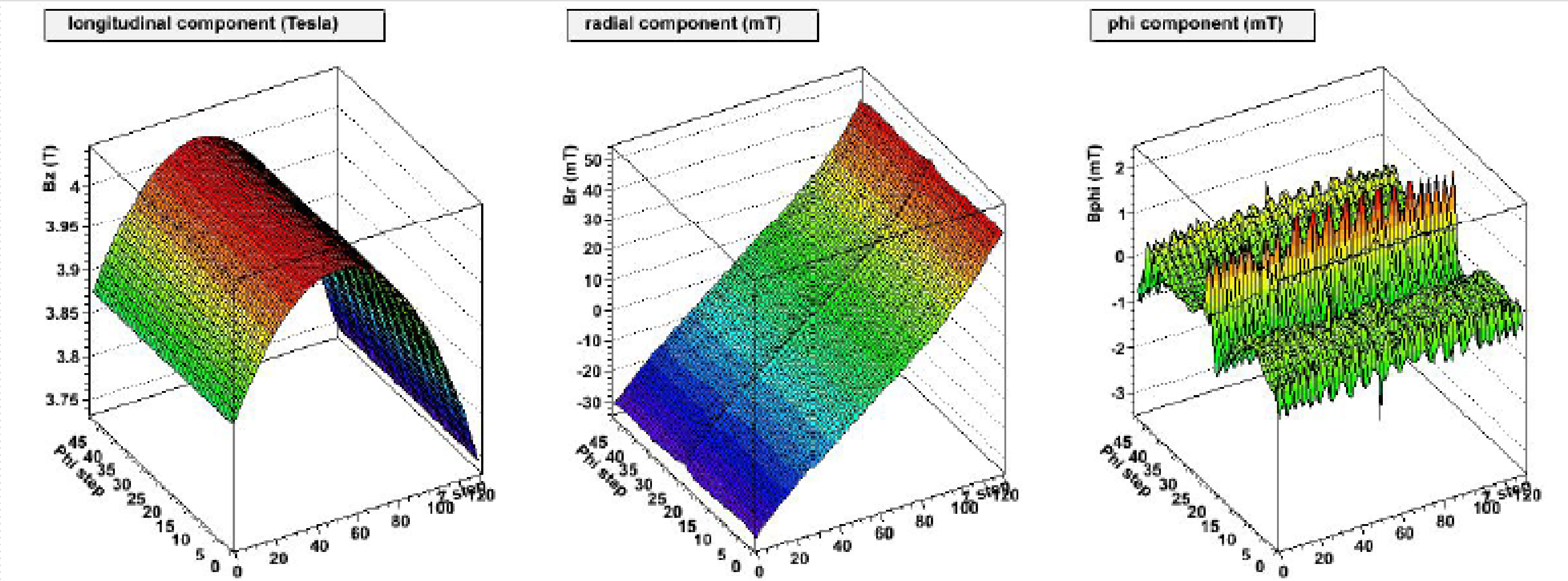
Field mapped at: 2.0, 3.0, 3.5, 3.8(twice) & 4.0 T with 0T references.

statistical precision of 10^{-4} achieved

Hall probe and NMR probe

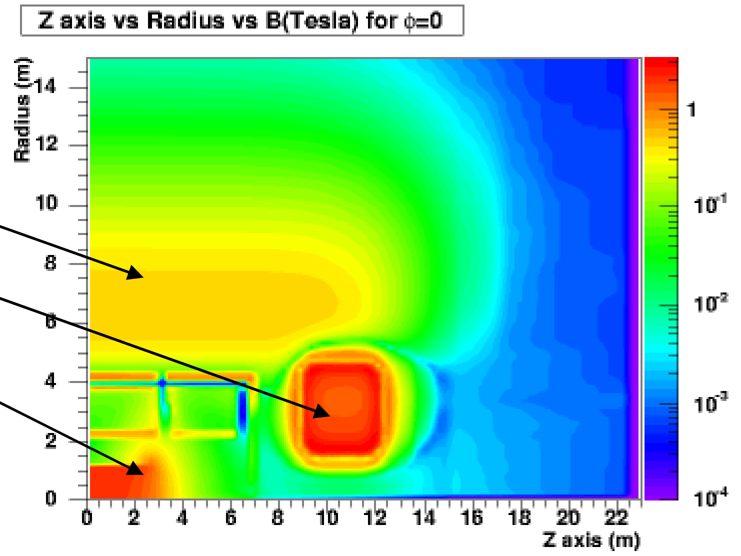
Magnetic Maps

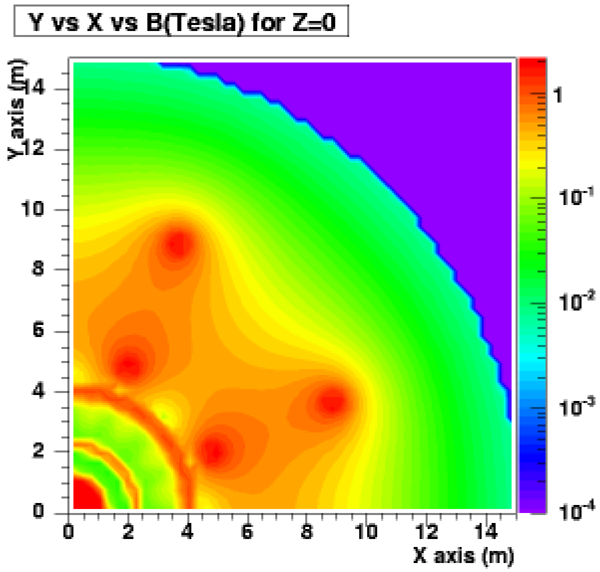
- Sort of data collected: B_z , B_r B_ϕ
  - Analysis ongoing



ATLAS Map – Even more complicated

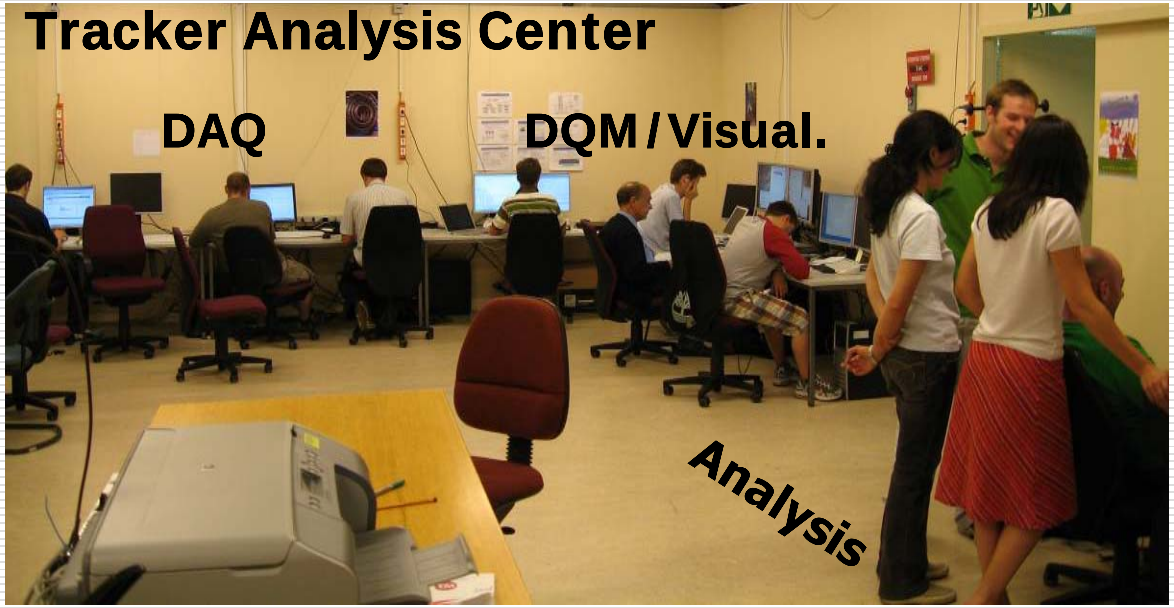
- Barrel toroid
- Endcap toroid
- Central solenoid 2T

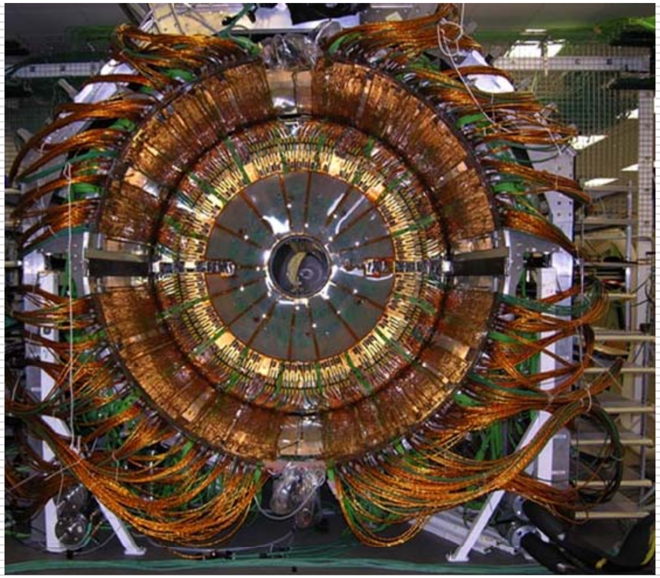




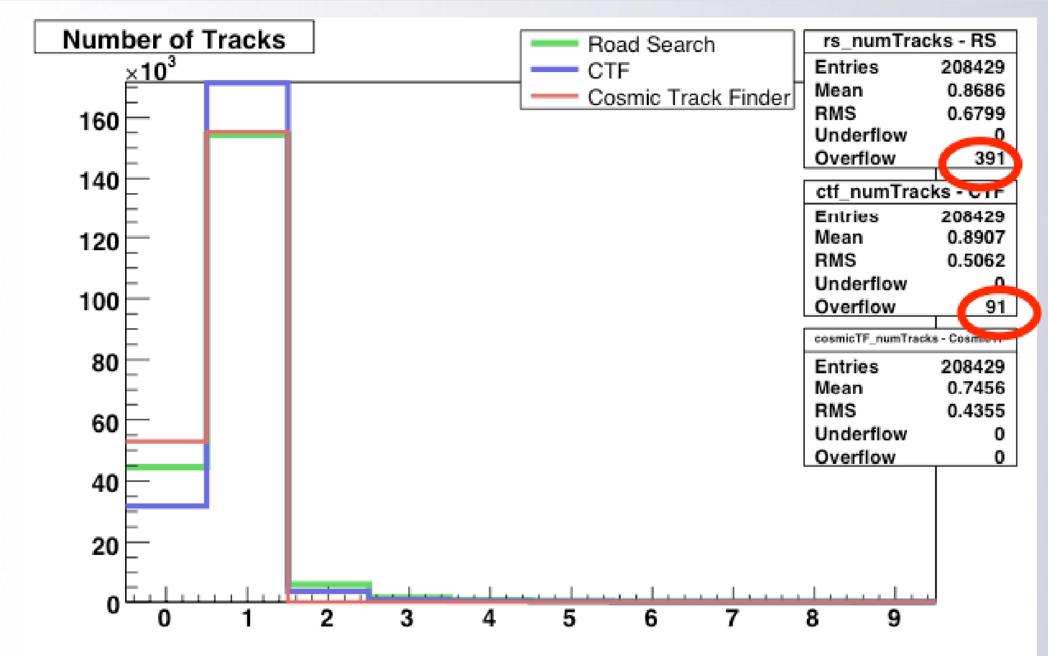
CMS Tracker Integration and Analysis Facility

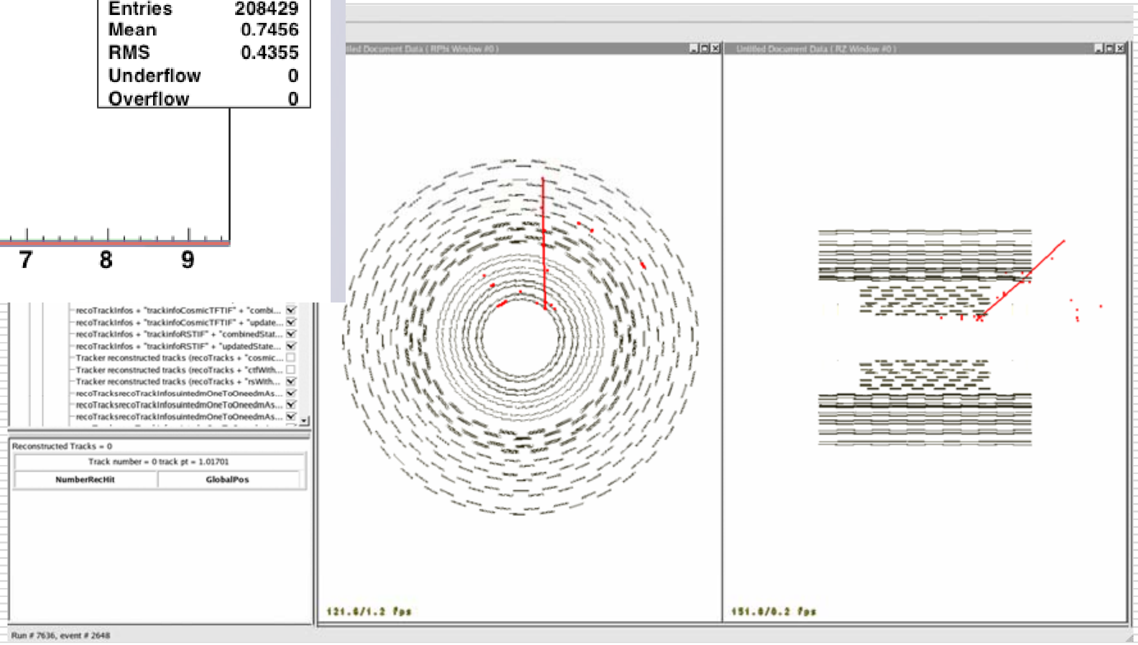
- 20% of the silicon strip tracker connected and readout from January – June 2007 in dedicated surface facility
  - About 2M channels, more than CDF silicon vertex detector
- Gain operational experience, alignment studies, detector performance studies
  - >1M cosmic muon tracks collected



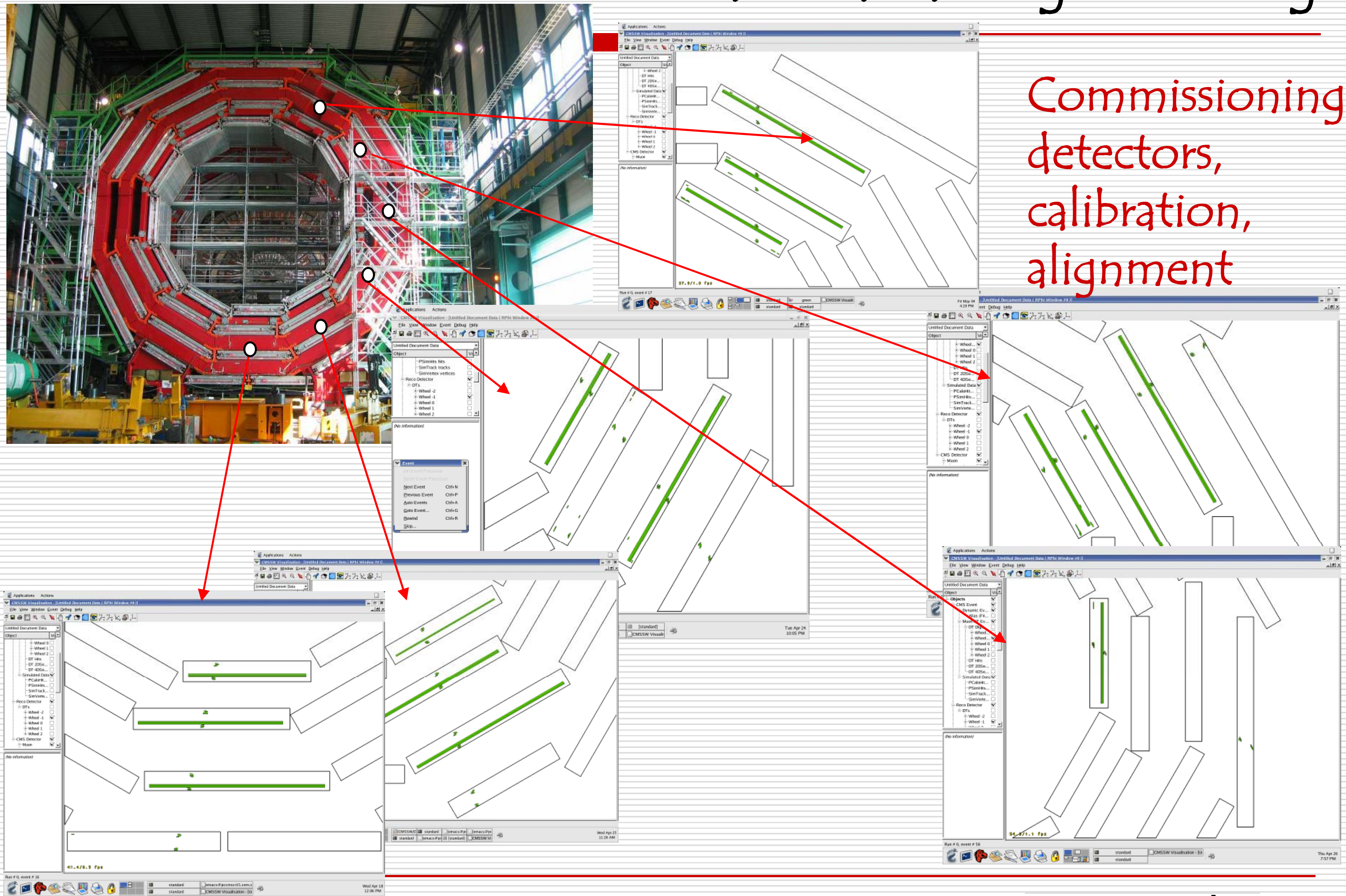


Track reconstruction and event display





Other Commissioning Slice Tests: CMS Drift Tubes on surface (awaiting lowering)



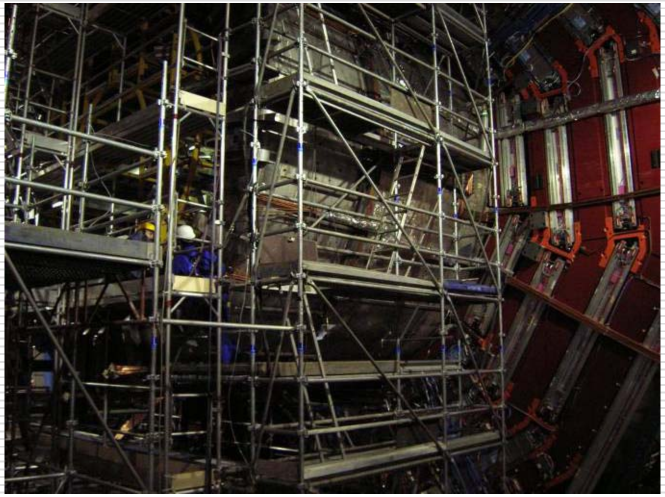
Commissioning detectors, calibration, alignment

Unanticipated Roadblocks in Commissioning

- Don't underestimate the low-tech problems that get in your way, such as access to cooling water for electronics
  - Cannot yet operate this nice disk of muon chambers underground,
  - Because some cooling water valves that need to be opened are blocked by other disks and wheels of iron, because we needed space for this scaffolding

Just didn't think of it before closing detectors…

The giant caverns are actually tight!



Computing Commissioning

- CMS Combined Computing, Software, and Analysis Challenge
  - A 50 million event exercise to test the workflow and dataflow associated with the data handling model of CMS at 25% scale
- Major components:
  - Preparation of large simulated datasets
  - Prompt reconstruction at Tier-0 (CERN):
    - Reconstruction at 40 Hz (create tracks, electrons, muons, …)
    - Application of calibration constants from an offline database
    - Splitting of a trigger-tagged sample into 10 streams
  - Distribution of data to all 7 participating Tier-1s @ 150 MB/s
  - "Skim jobs" at some Tier-1s with secondary datasets copied to Tier-2 centers (e.g. University of Florida)
  - Physics jobs at Tier-2s and Tier-1s on data (50K jobs/day!)

CSA06 Summary in a Nutshell

- CSA was launched on October 2, 2006
- Operations lasted ~6 weeks until mid-November
  - Everything on previous page has been successfully tested!
  - Tier-0 prompt reconstruction of 207M events including application of calibration constants via database
  - Total network transfers exceeded 1 PB = 10^{15} B !
  - Sustained >150 MB/s T0→T1

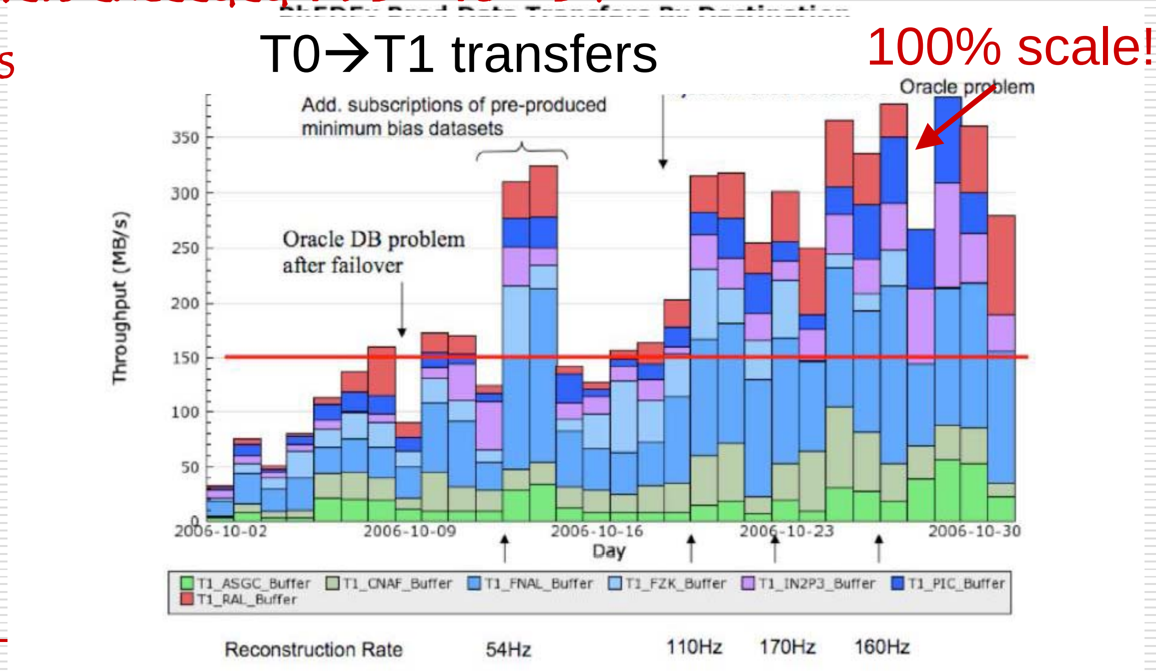


Figure 14: The rate of data transferred between the Tier-0 to the Tier-1 centers in MB per second.

Commissioning & Run Coordination

- What I think my job duties are
- Coordinate commissioning efforts across detector subsystems, trigger, DAQ, and offline data handling
- Facilitate problem-solving across subsystems
- Schedule and prioritize global data-taking activities
- Ensure adequate monitoring, diagnostics, and logging of essential e
- Ensure effi nted procedures for data-taking
- Oversight on achieving the expected detector performance at the level of basic detector objects
- Shift organization

In other words, provide the "glue", but not the parts, to prepare an experiment for physics

Summary of Commissioning Exercises

- You always learn something!
  - Expect the unexpected (electronics failures, detector noise, …)
- It is important to test slices of the complete system for functionality (vertical slice tests), and the portions of the full system for scale (horizontal slice tests)
- Because of the importance of the LHC turn-on, and the possibility of new discoveries right at the beginning, we are trying to pre-commission as much as we can before beams
- But this implies trade-offs:
  - Commissioning exercises vs. installation activities
  - Global data-taking exercises vs. subsystem commissioning
- It's a "chicken-or-egg" problem:
  - If we wait for installation to be over, we have not pre-commissioned in time
  - We can't commission until we are installed…

Performance

Success in commissioning will be judged quantitatively by achieving the design performance from the detector subsystems

Credits

- ATLAS
- CDF
- CMS
- Christoph Amelung
- Paolo Bartalini
- Adolf Bornheim
- Rick Cavanaugh
- Sergio Cittolin
- Pawel De Barbaro
- Domenico Giordano
- Slawek Tkaczyk
- Jim Virdee