The ATLAS Semi-Conductor Tracker Construction, Operation and Performance

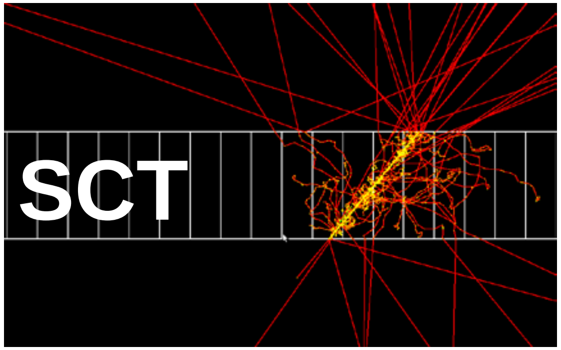
Steve McMahon

RAL

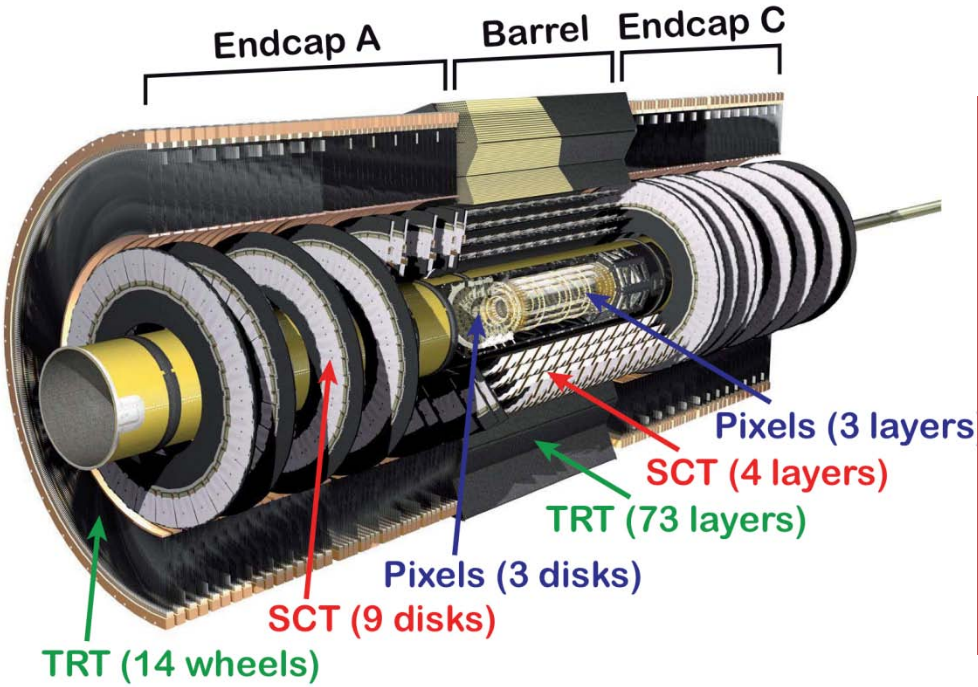
Friday 1st July 2011

The Tyndel-Fest

Science & Technology Facilities Council



The Semi-Conductor Tracker inside the ATLAS ID



Some SCT Facts & Figures

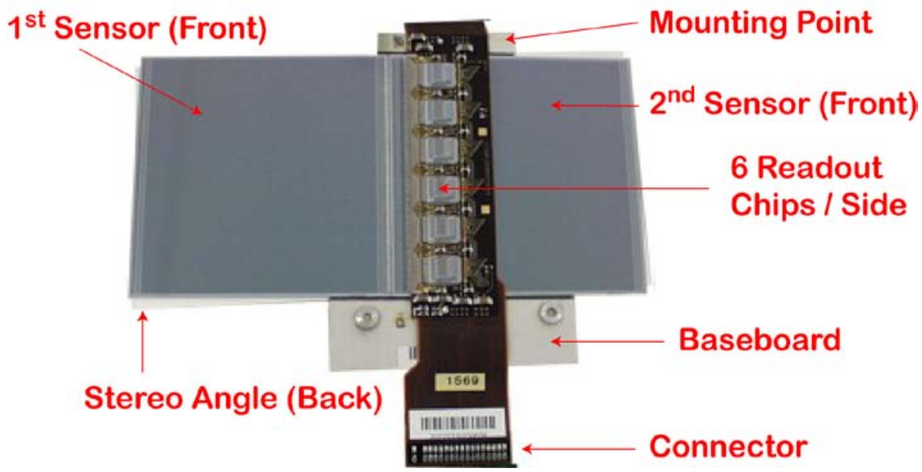
Barrel	4 layers 2112 modules
End-Caps	2 x 9 disks 1976 modules
Coverage	30 cm < r < 52 cm $\lvert\eta\rvert < 2.5$
Active Material	61 m^2 silicon
Readout	6.3 $x10^6$ channels

Some SCT Operational Parameters

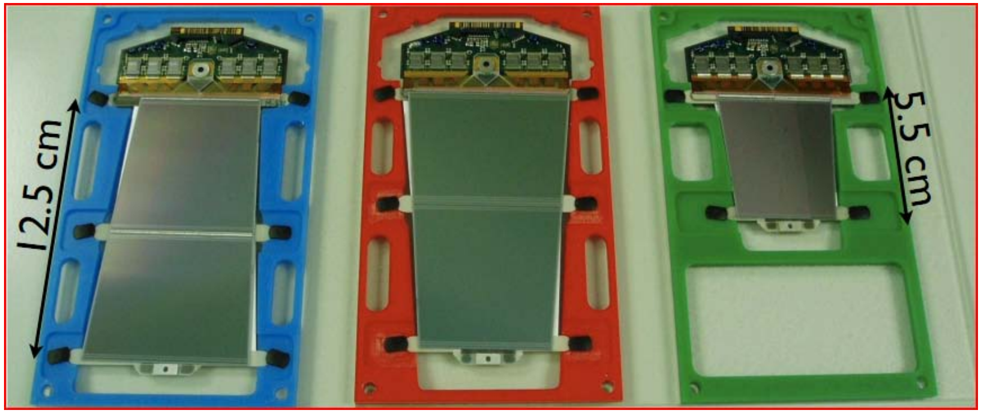
- 150 V reverse bias voltage ($U_{standby}$ = 50 V)
- Binary Readout with 1 fC/hit threshold (standard setting)
- 3 time bin readout (25ns / bin = LHC clock)
- C_3F_8 cooling: -7°C to +4.5°C (temp on the surface of silicon)

The SCT Modules (The basic detector unit)

- **Sensor Paramaters**
  - 770 (768 bonded) p-strips on n-type silicon
  - 80 μm pitch (B)
  - 285 μm thick
  - 4(2) single-sided sensors glued back-to-back
  - Stereo angle of 40 mrad
  - 83 % Hamamatsu, 17 % CiS
- **Sensor Length**
  - 12 (2x6) cm (B), 6-12 (1or2 x 6cm) cm (ECs)
- **Resolutions**
  - ~17 μm(rφ, bending plane), ~580 μm (z)
- **Baseboard**
  - Thermal Pyrolitic Graphite
  - Mechanical & thermal structure
- **Readout**
  - Rad-hard front-end readout chips (ABCD)
  - 6 chips/side, 128 channels/chip
  - 48 modules served by 1 ROD
  - 11 (12) RODs send data to 1 Atlas ROS
  - TIM provides trigger signal & clock



Barrel Module



End Cap Modules

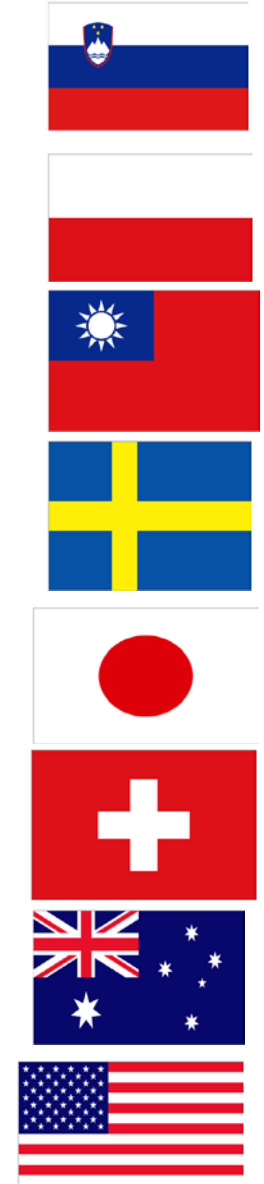
A recent history of the SCT....

I can't hope tell you everything but I can give you a flavour of what was happening at various locations at various times.

The SCT is a collaboration of 42 Institutes from 16 Countries

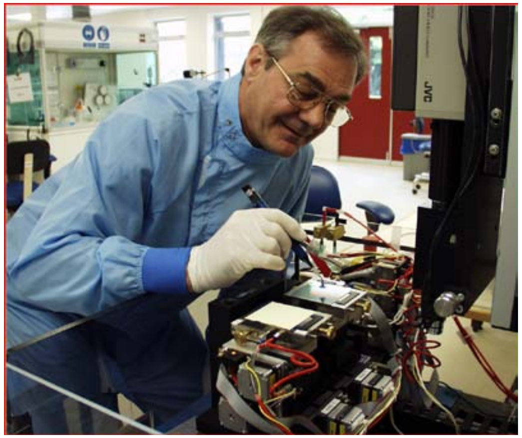
In reviewing the construction I concentrate on the UK activities

- Birmingham
- Cambridge
- Glasgow
- Lancaster
- Liverpool
- QM London
- UCL London
- Manchester
- Oxford
- RAL
- Sheffield



2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**

Making Barrel Modules in R12 at RAL



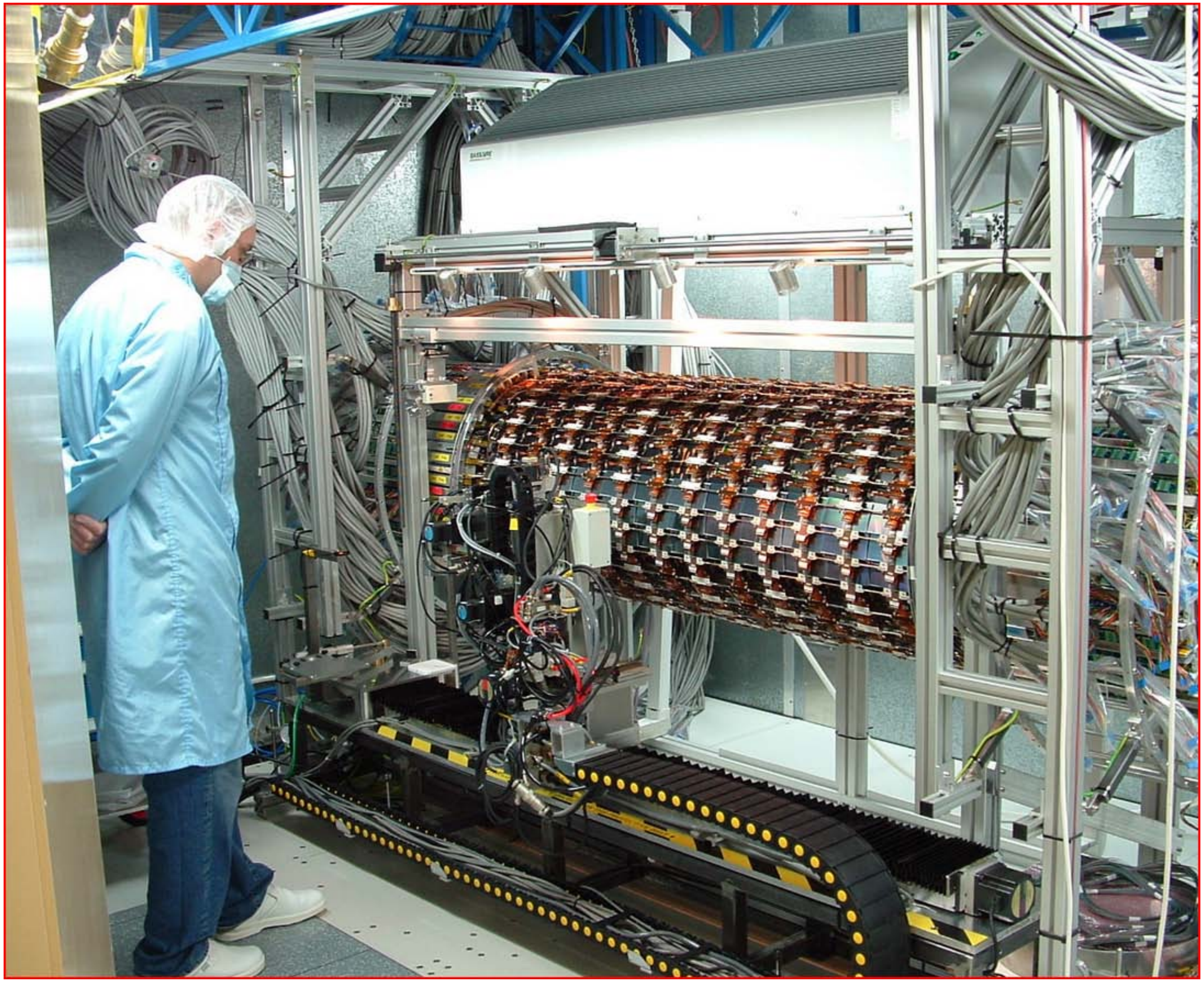
Sensor alignment

Hybrid Mounting

Wire Bonding

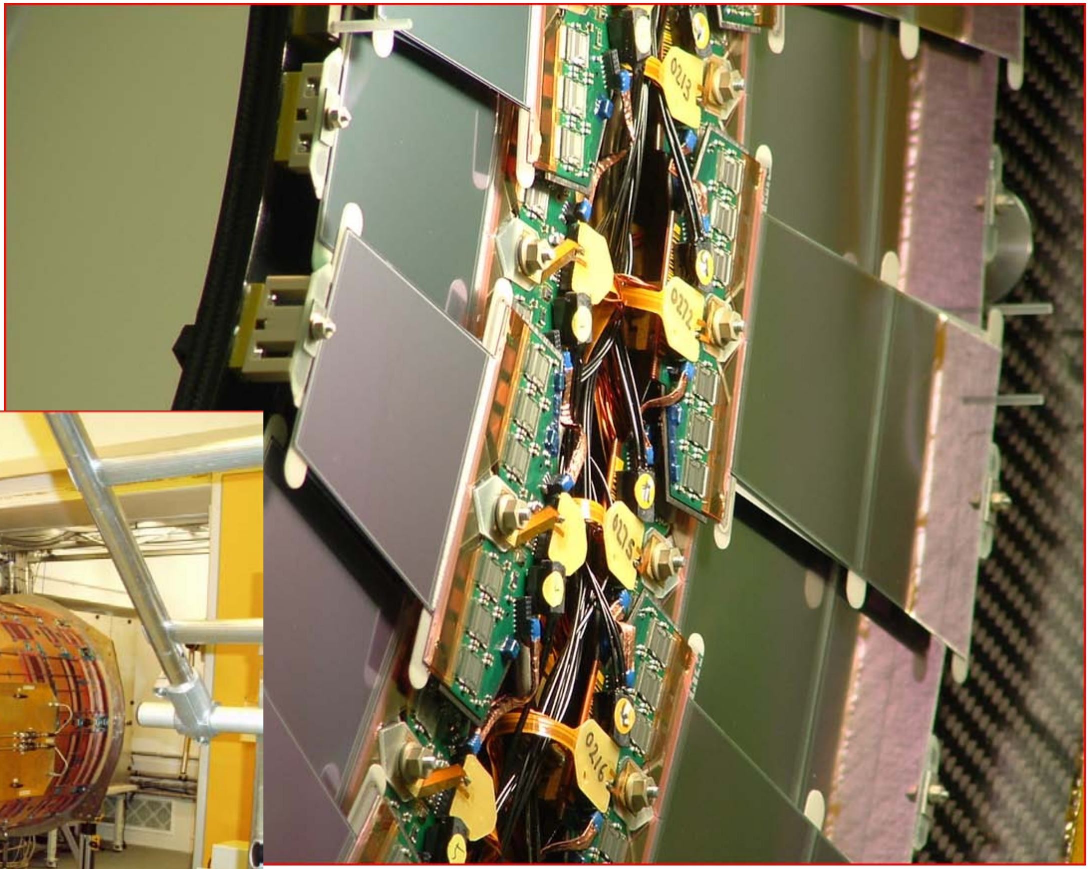
2003	2004	2005	2006	2007	2008	2009	2010	2011

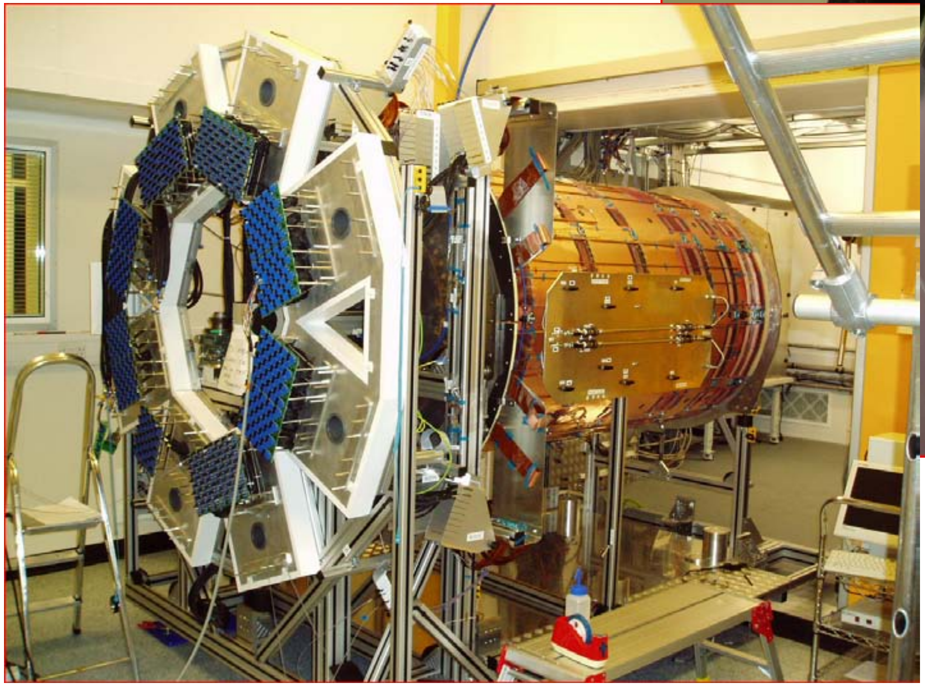
Mounting Modules to Barrels in Oxford



2003	2004	2005	2006	2007	2008	2009	2010	2011

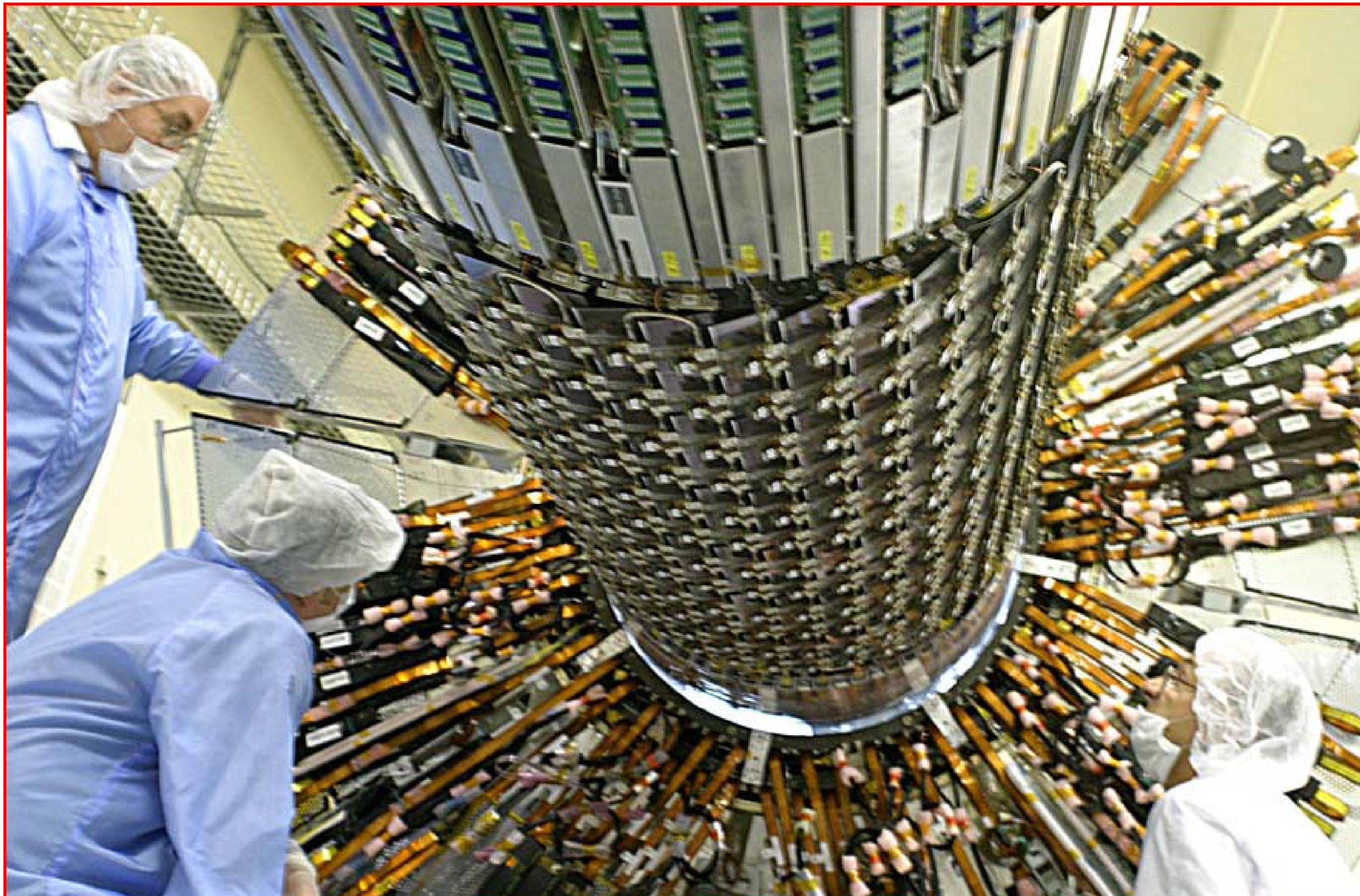
End-Cap-C construction in Liverpool





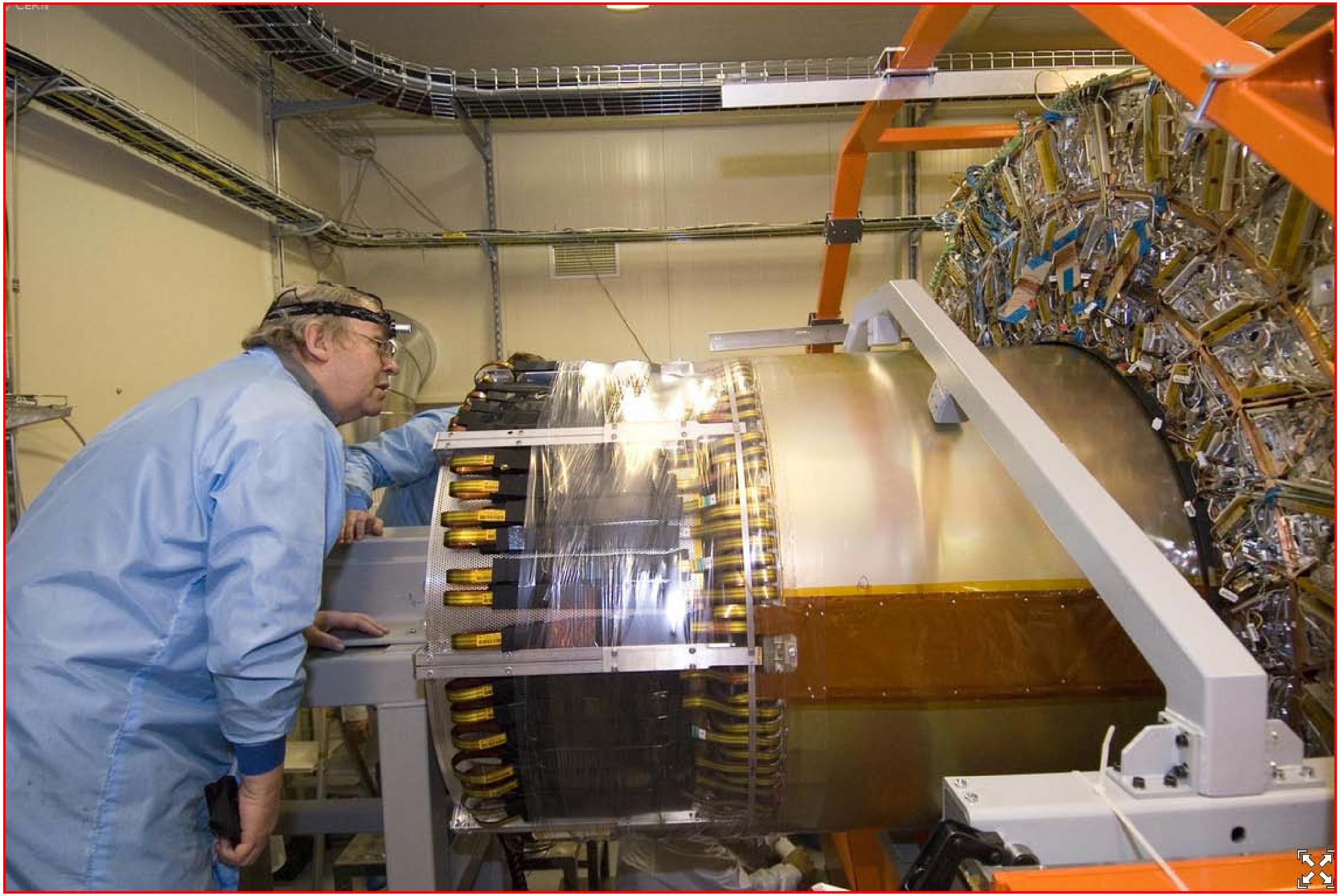
2003	2004	2005	2006	2007	2008	2009	2010	2011

Integration in SR1 (surface building at CERN)



2003	2004	2005	2006	2007	2008	2009	2010	2011

Inserting the Barrel into the TRT



2003	2004	2005	2006	2007	2008	2009	2010	2011

Preparing the Barrel for the Cryostat

2003	2004	2005	2006	2007	2008	2009	2010	2011

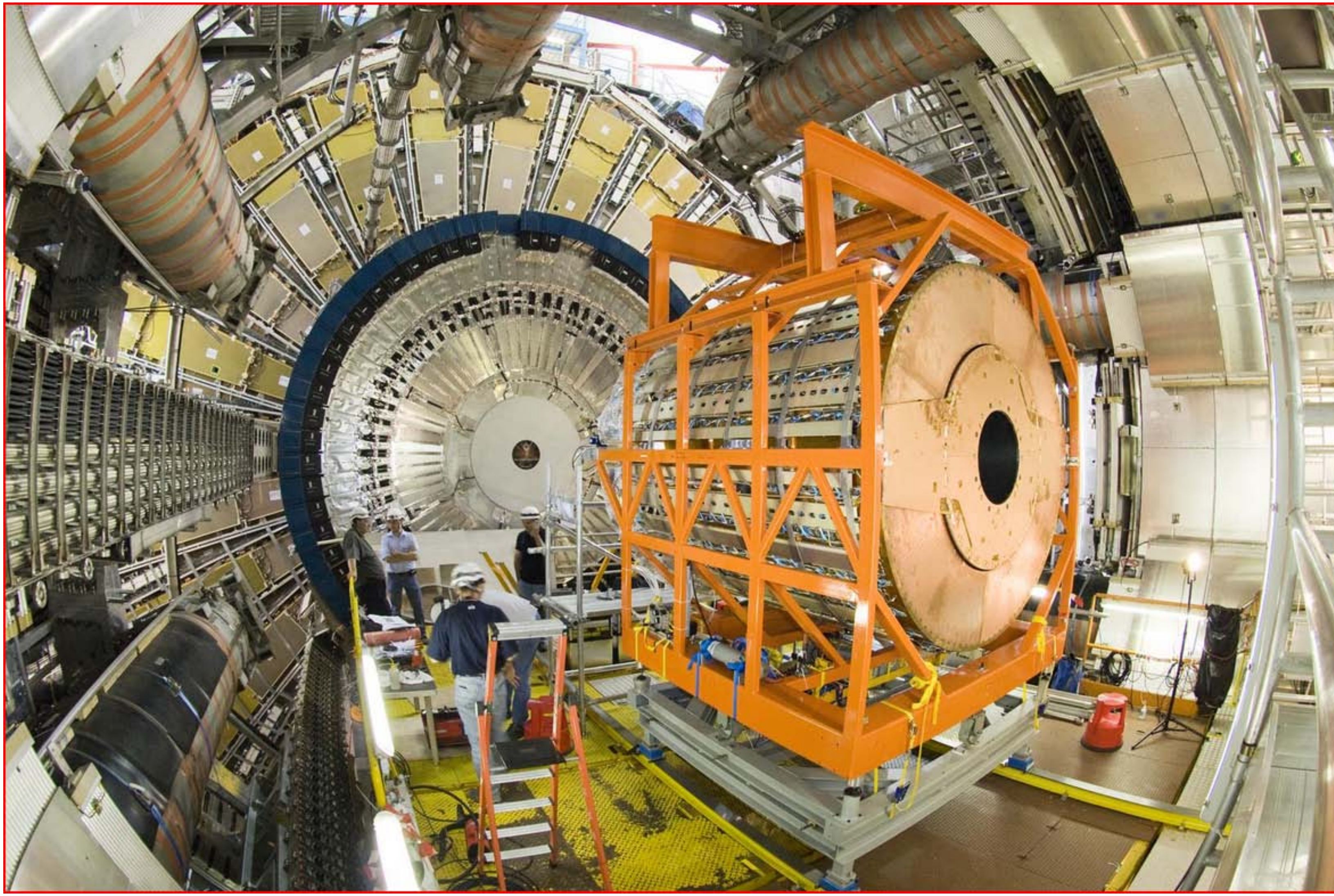
Mounting Barrel to Cryostat

2003	2004	2005	**2006**	2007	2008	2009	2010	2011

Setting the scale of ATLAS

2003	2004	2005	2006	2007	2008	2009	2010	2011

Mounting EndCaps into the Cryostat



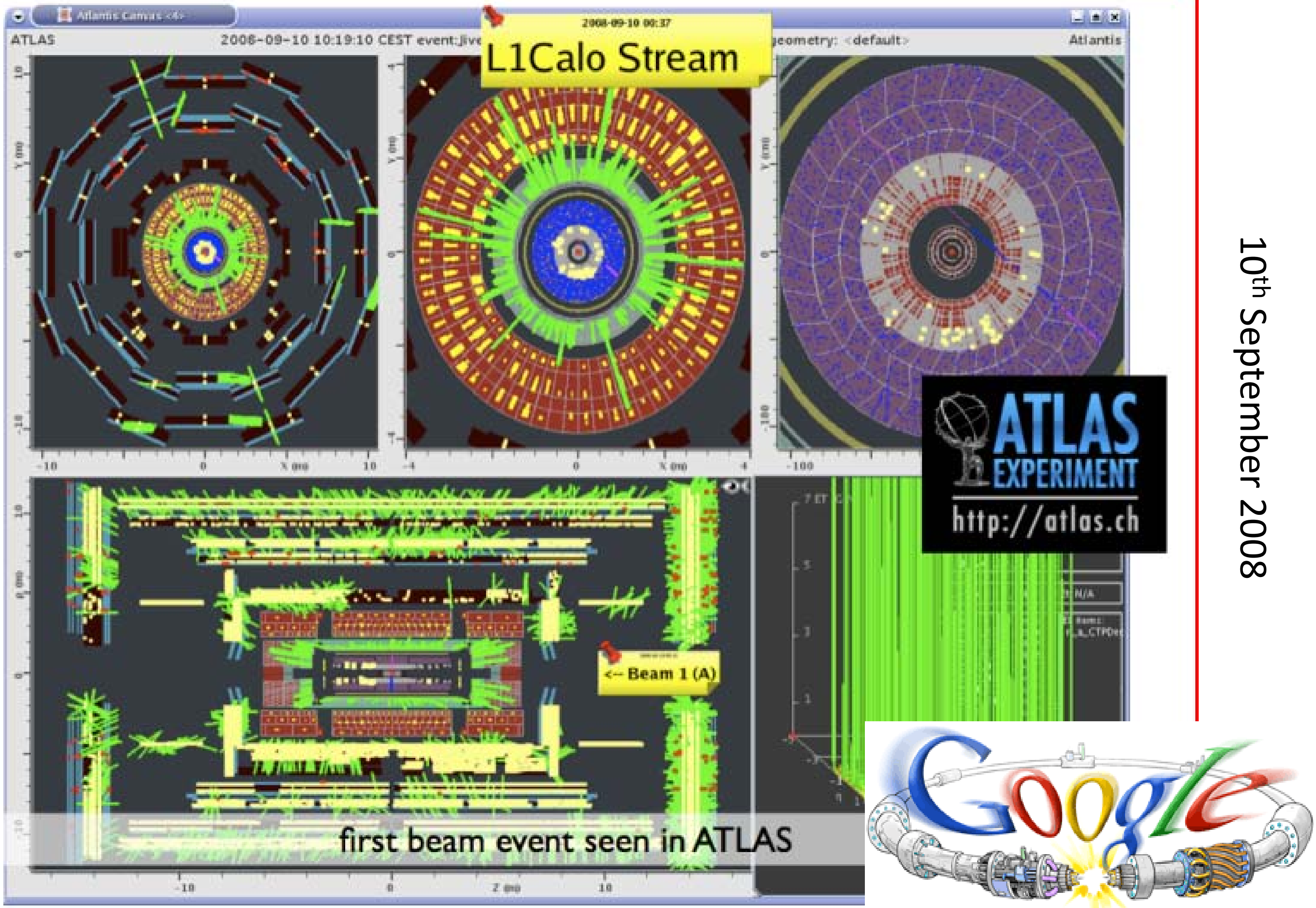
2003	2004	2005	2006	2007	2008	2009	2010	2011

Finished : The view at the end of the ID

30th May 2007

2003	2004	2005	2006	2007	2008	2009	2010	2011

First Beam Splash Events in ATLAS



10th September 2008

2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**

Friday 19th September 2008 : The catastrophe

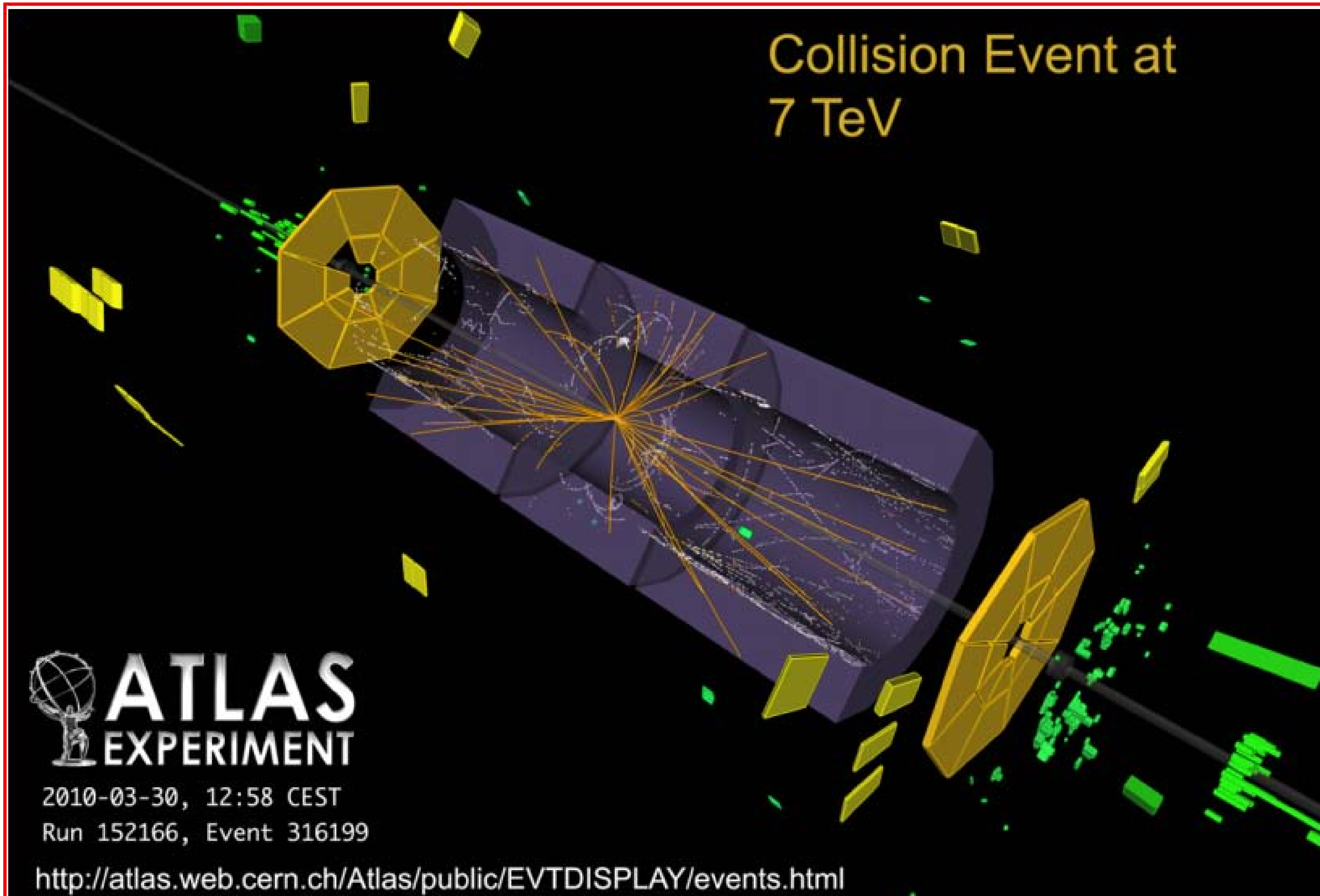
19th September 2008

2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**

First Collisions in ATLAS

2003 2004 2005 2006 2007 2008 **2009** 2010 2011

First Collisions 7TeV collisions in ATLAS



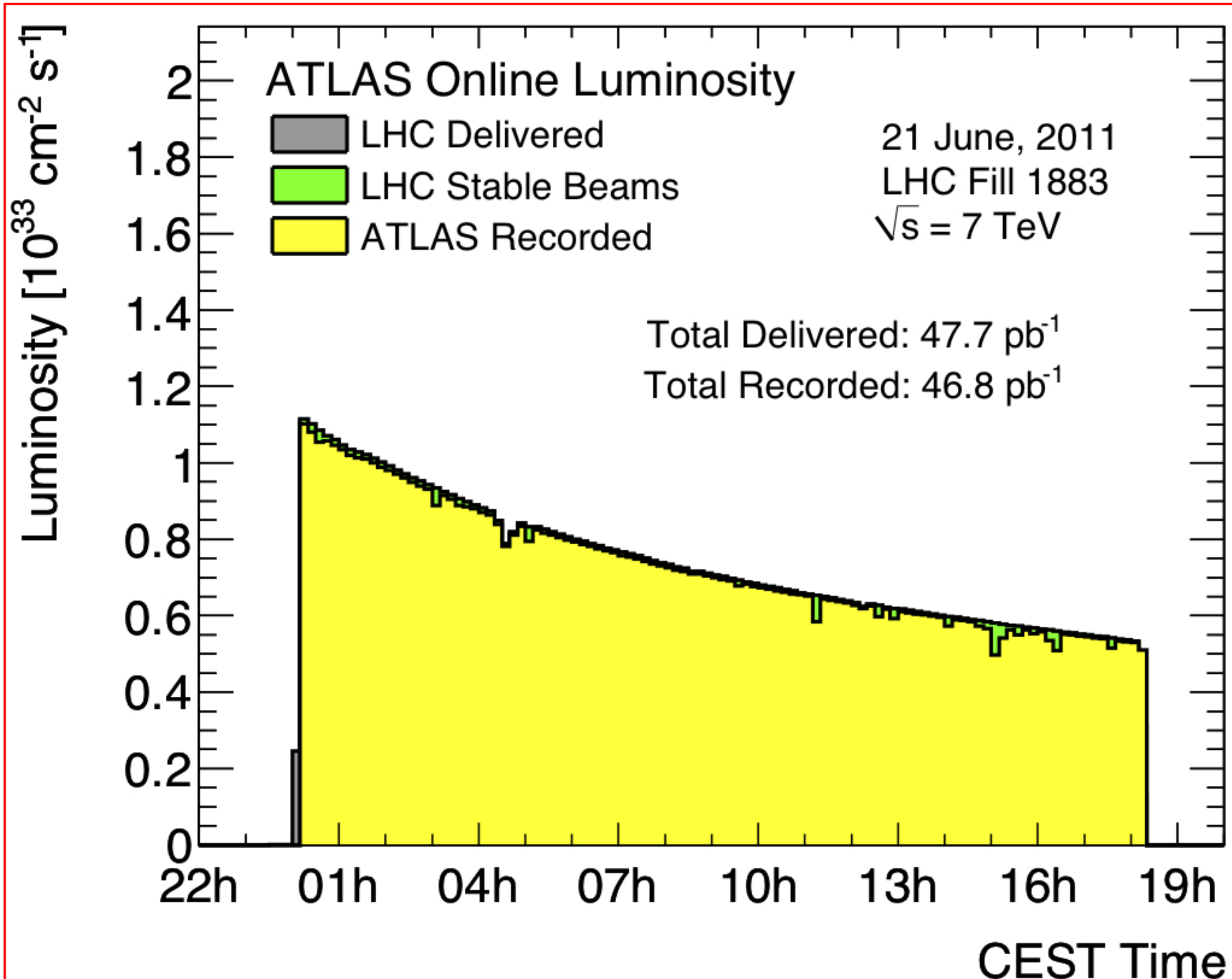
30th March 2010

2003	2004	2005	2006	2007	2008	2009	2010	2011

First Collisions 7TeV collisions in ATLAS

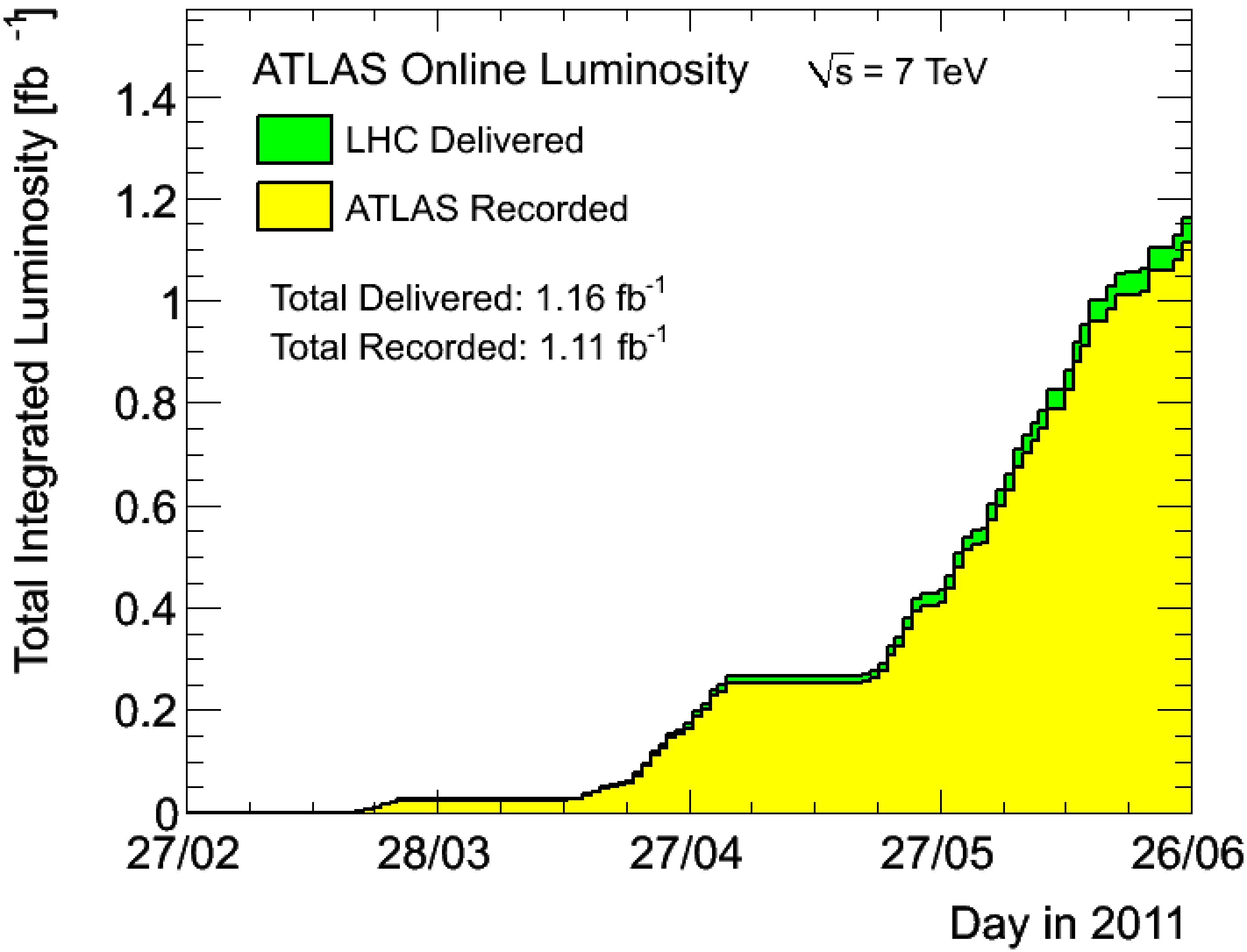
2003	2004	2005	2006	2007	2008	2009	2010	2011

Integrating luminosity in 2011



2003	2004	2005	2006	2007	2008	2009	2010	2011

Integrating luminosity in 2011



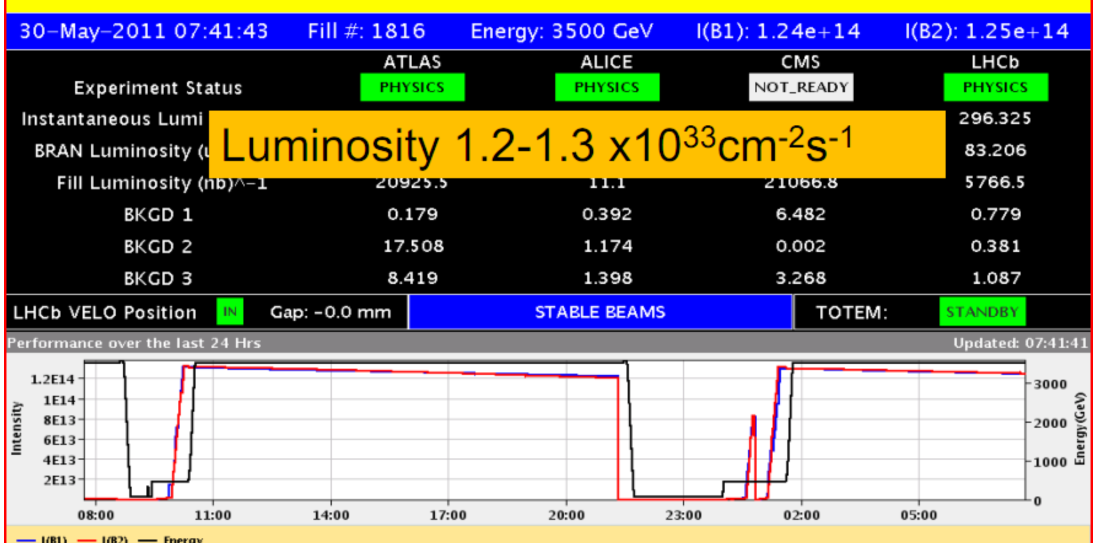
2003	2004	2005	2006	2007	2008	2009	2010	2011

Some LHC statistics so far in 2011

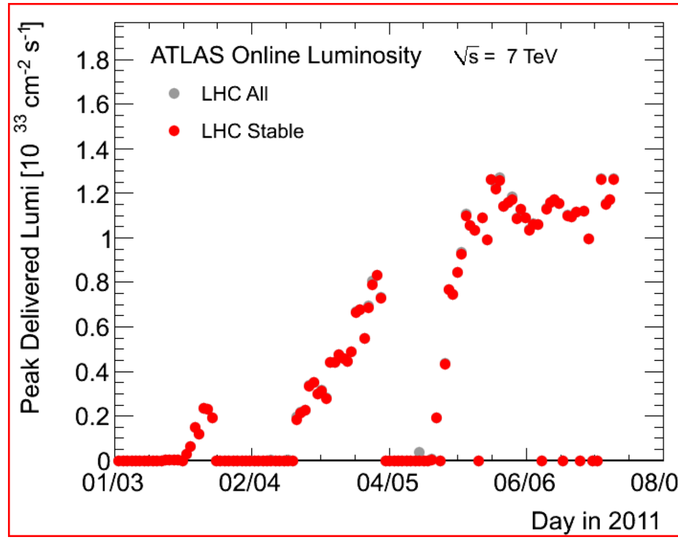
- ✓ Beam energy 7TeV (14 TeV nominal)
- ✓ Bunch spacing 50ns (25ns nominal)
- ✓ Bunch intensity 1.25 $\times 10^{11}$ (above spec)
- ✓ Peak stable luminosity 1.26 $\times 10^{33}$ cm^{-2} s^{-1} (2 $\times 10^{32}$ in 2010)
- ✓ Maximum luminosity in 1 fill 62.1 pb^{-1} (Monday)
- ✓ Maximum length of a fill 19.2 hrs
- ✓ Max average num interaction per Xing 8.93
- ✓ Max number of colliding bunches 1318 (348 in 2010)

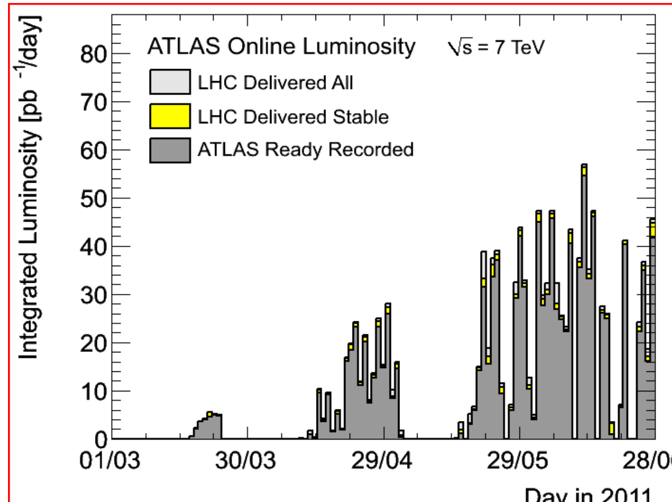
Integ Luminosity to date 1.22fb^{-1}
0.47 Billion physics events

back to back fills with 1092 bunches



Luminosity 1.2-1.3 $\times 10^{33} cm^{-2} s^{-1}$





SCT Performance topics (one”ish” slide on each)

- ✓ Configuration
- ✓ Calibration
- ✓ Intrinsic silicon efficiency
- ✓ Timing (including 50ns operation)
- ✓ Occupancies, data & error rates and DAQ
- ✓ Alignment (including stability and the FSI)
- ✓ The onset of radiation damage
- ✓ Problems we had along the way & improvements
- ✓ Material in the inner detector
- ✓ Operation, data taking efficiency and data quality

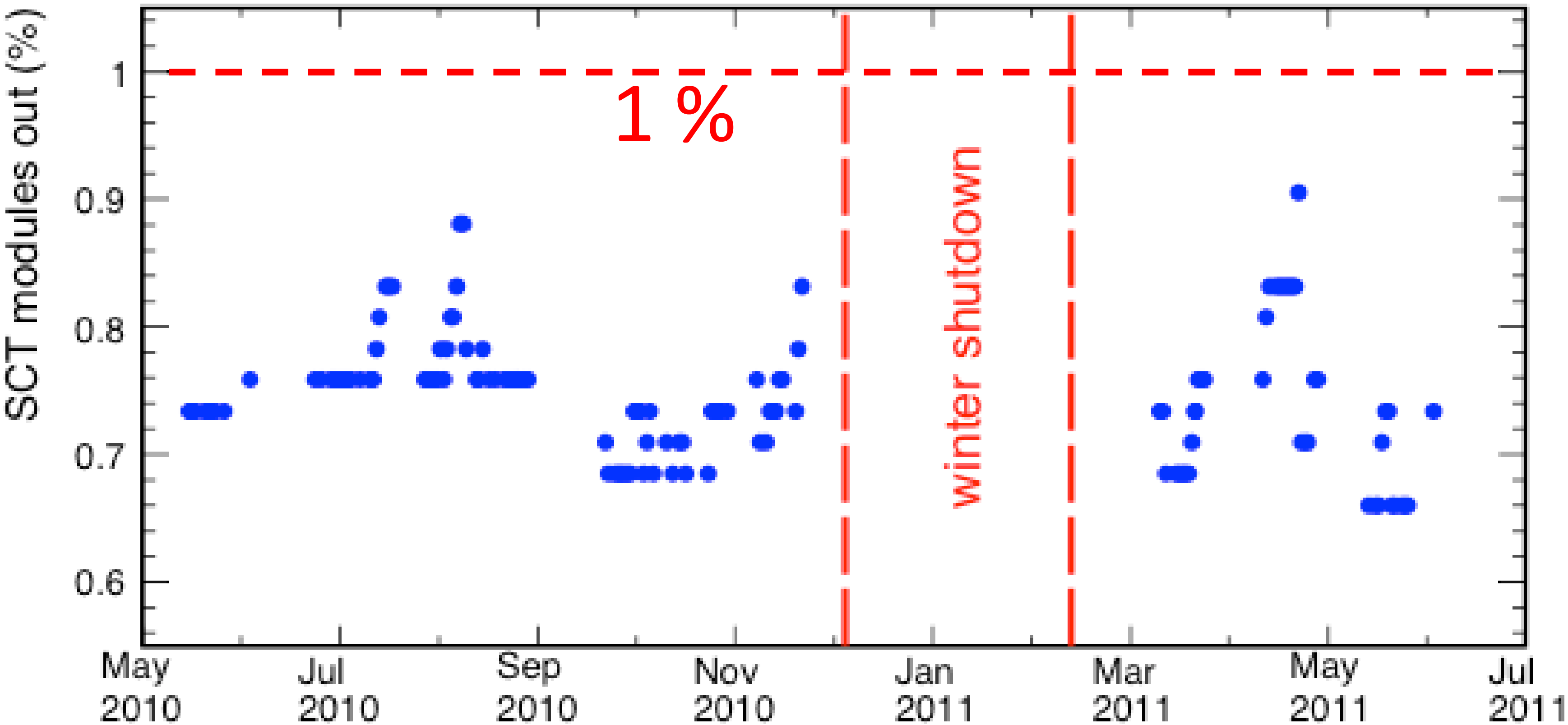
The SCT Detector Configuration (snapshot)

Modules out of the physics configuration

	Endcap A	Barrel	Endcap C	SCT	Fraction (%)
Total	5	10	15	30	0.73
Fraction (%)	0.5	0.2	1.5	0.7	
Cooling	0	0	13	13	0.32
LV	0	6	1	7	0.17
HV	4	1	1	6	0.15
Readout	1	3	0	4	0.10

Disabled Readout Components	Endcap A	Barrel	Endcap C	SCT	Fraction (%)
Disabled Modules	5	10	15	30	0.73
Disabled Chips	5	24	4	33	0.07
Masked Strips	3,364	3,681	3,628	10,673	0.17
Total Disabled Detector Region					0.97

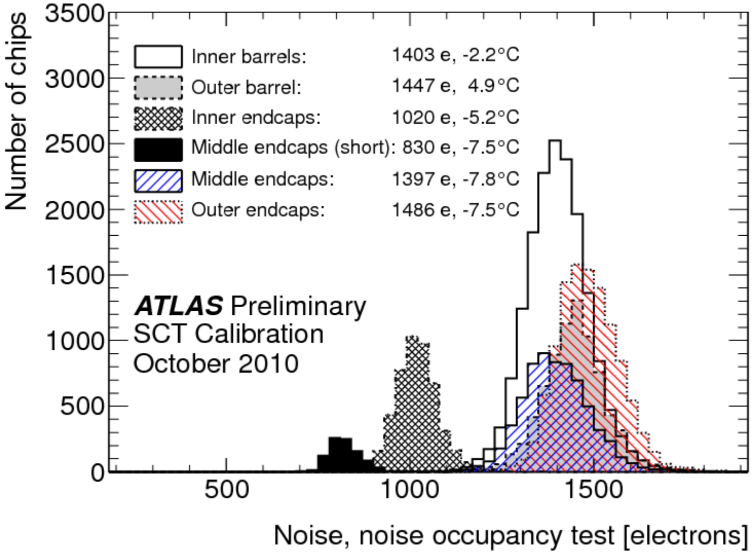
The SCT Detector Configuration (history)

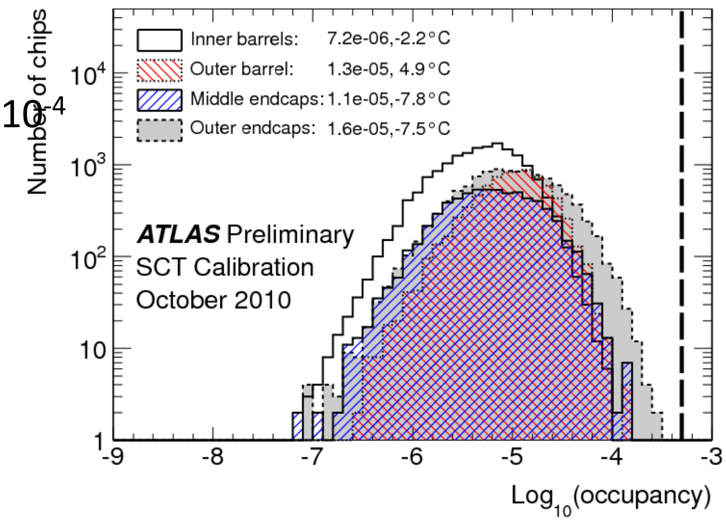


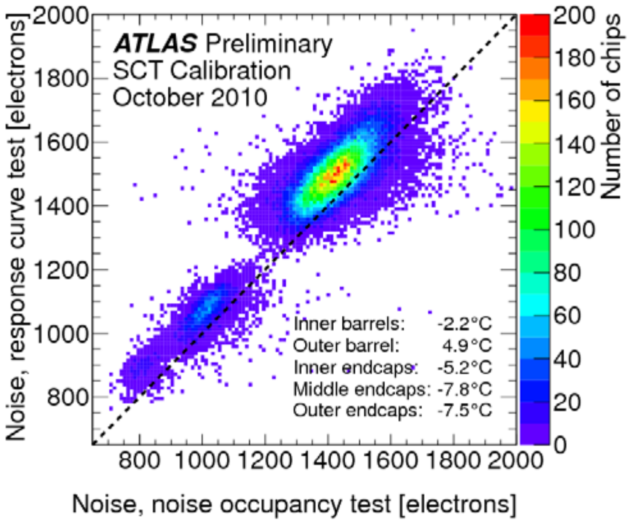
The number of SCT modules out of the physics configuration as a function of time during 2010 and 2011 up to June.

Noise & Noise Occupancy

- Calibration Measurement
  - Charge injection circuit in readout chip (0-16) fC
  - Measure hits vs. threshold (S-curve)
  - Fit by complementary error function
  - Width characterizes noise
  - SCT noise < 1500 e
  - Hit threshold ~ 6200 e
- Online Measurement
  - Count hits in random triggers (empty bunches)
  - SCT NO ~ 10^{-5}
  - Design NO < 5 * 10^{-4}
- Both methods in good agreement

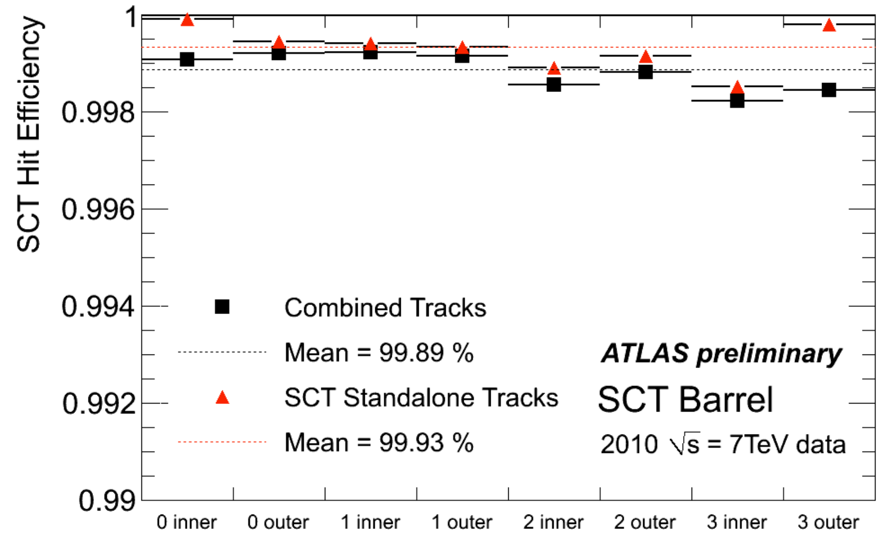


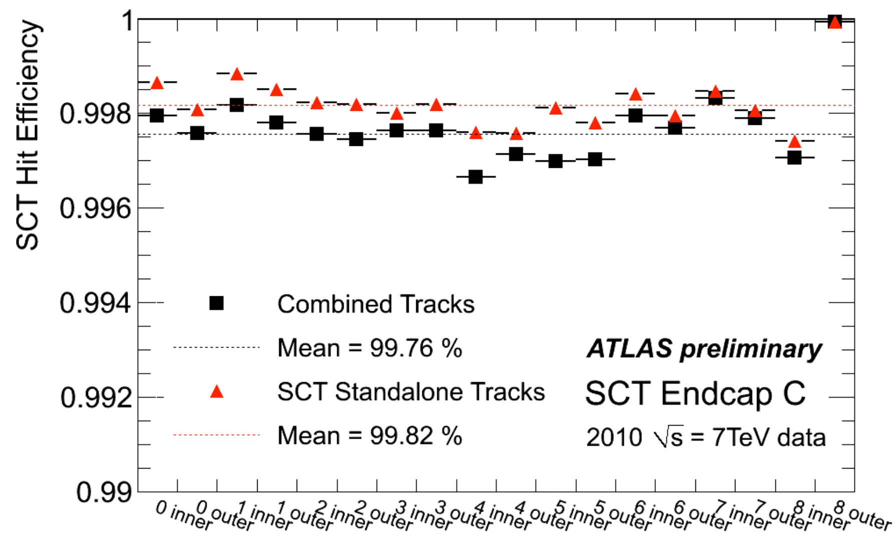




SCT Intrinsic Silicon Efficiency

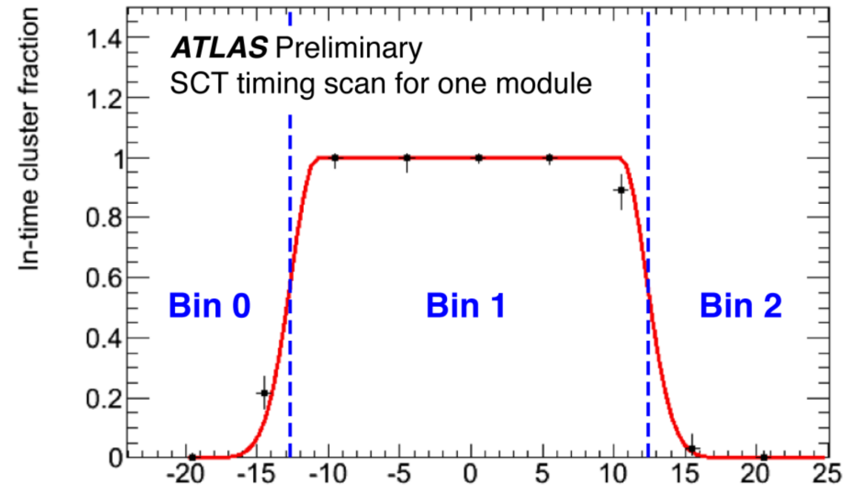
- Efficiency =
- # of hits / # of possible hits (on tracks)
- Dead modules & chips accounted for
- Barrel: all layers
  > 99.8% efficiency
- End-Caps: all disks
  > 99.6% efficiency
- Time stability: ± 0.1 %
- Above design spec of 99.0 % efficiency

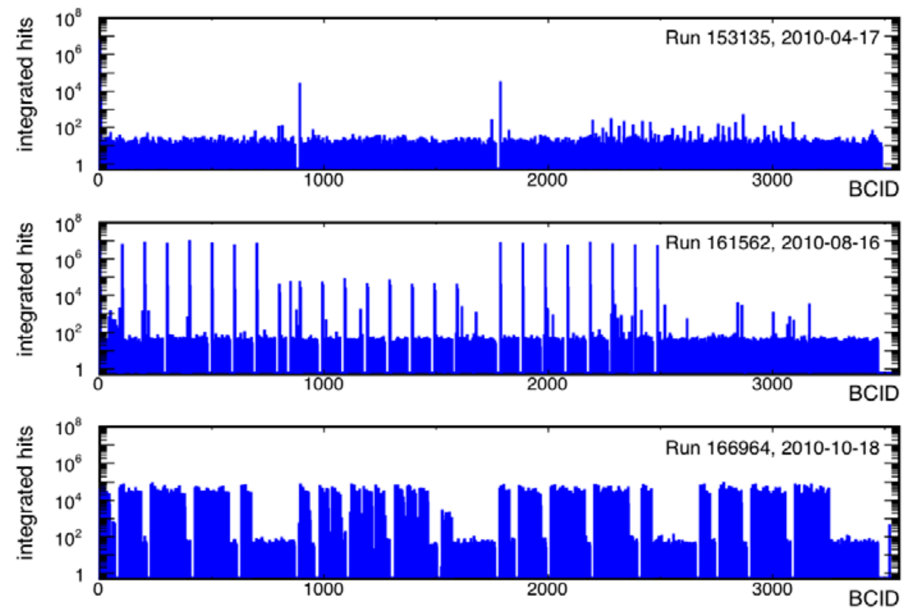




SCT Readout and Timing

- Binary readout (hit or no-hit)
- 3 time bins of 25 ns (LHC clock) around trigger accept signal
  charge > threshold = hit
- 3 different readout modes:
  - **XXX**: a hit in any time bin
  - **X1X**: hit in bin 1 required
  - **01X**: hit in bin 1 required, no hit in bin 0 allowed
- Ran in **XXX** in 2010
  (bunch distance ≥75 ns)
- Due to 50 ns bunch trains, switched to **X1X** in 2011
- Will switch to **01X** for 25 ns trains (2012)
- SCT timed in using dedicated timing scans





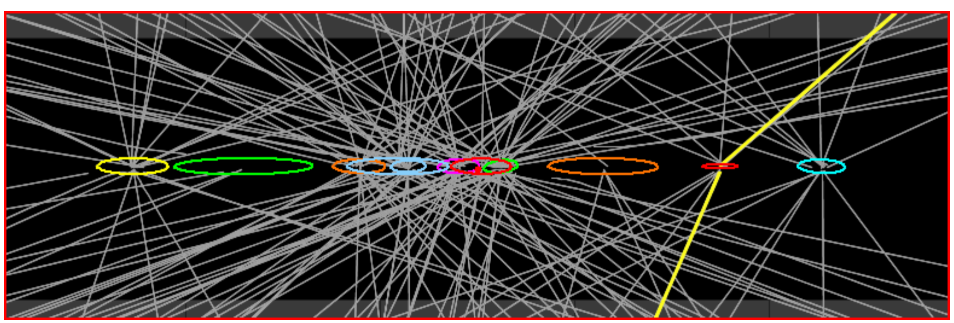
SCT Occupancy in proton-proton beam operation

SCT designed to operate with up to 23 proton-proton interactions per bunch crossing.
ROS event size limit: 65 kB (configured)

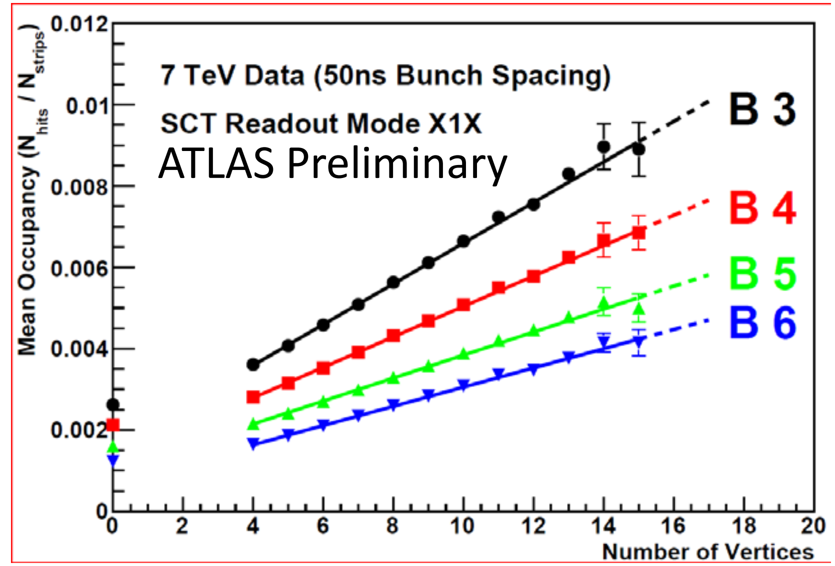
Scaling plots to right for 23 interactions and for 14TeV operation expect around 1% peak occupancy in Barrel 3.

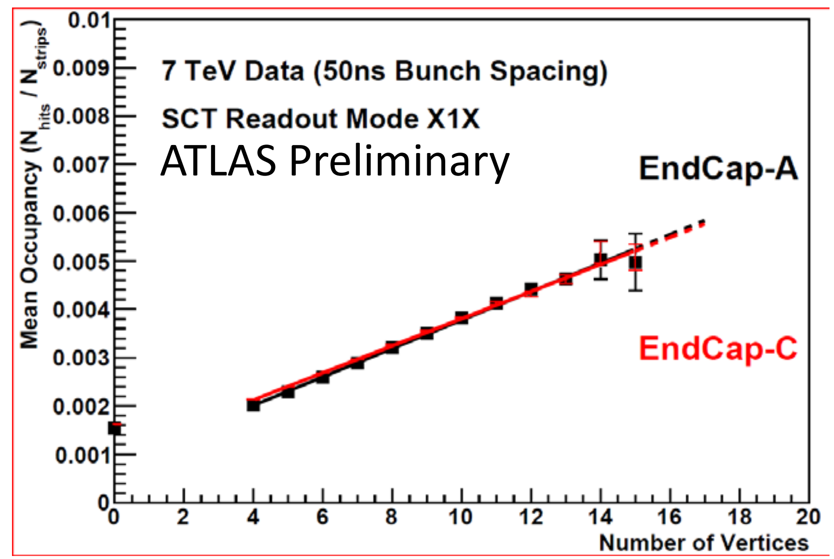
Typical occupancies in Heavy Ions ~10%

SCT is not limiting ATLAS L1 rates



11 vertices "typical" in 2011 operation

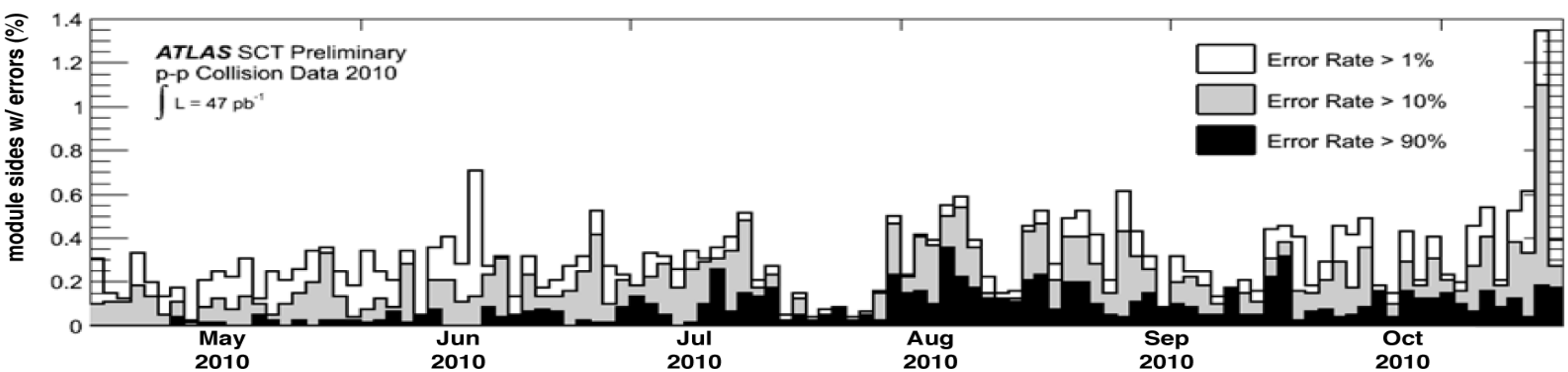




The SCT Data Acquisition System

Occupancy (%)	Rate Limit (kHz)		Complex DT	Event Size/ROD (kB)
	ABCD	S-Link		
0	754	2000	8/53	0.056
1	**233**	**89**	**8/170**	**2**
10	28	10	8/1395	15.6
20	14.5	5.2	8/2755	31

- ATLAS goal is to be able to take data up to a L1 trigger rate of 75kHz.
- Peak rates in 2011 are already touching 60 kHz. (Peak L2 output = 3.9kHz, Physics 400Hz)
- Above see SCT readout rate for different occupancies
- Below error rates measured at 20kHz in 2010. Error rates of front end are low.

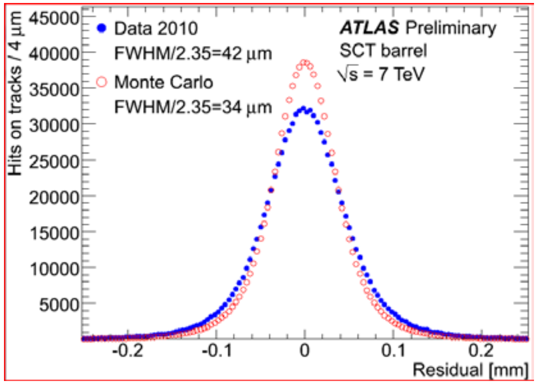


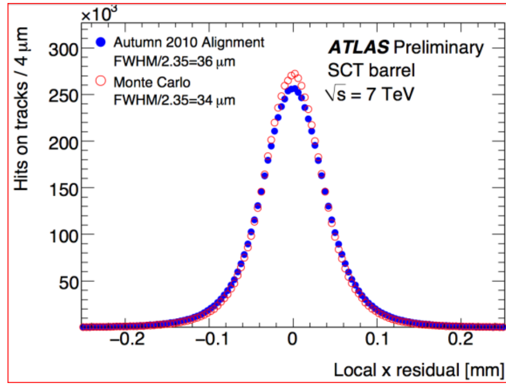
SCT and ID Detector Alignment

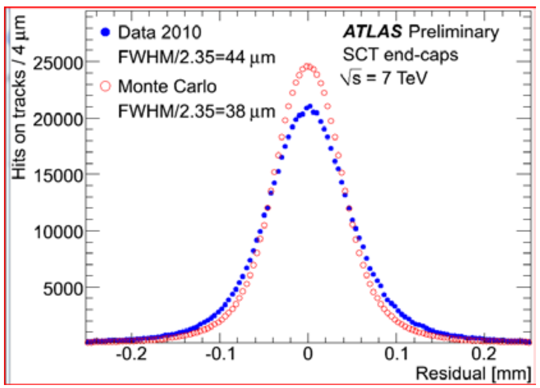
Track Based Alignment with global χ^2

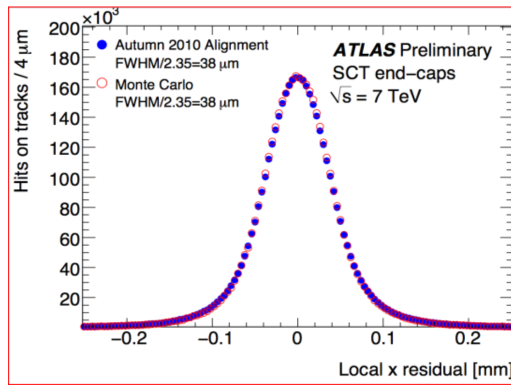
May 2010

October 2010









SCT-Barrel
Local X co-ordinate
May 2010 : 42µm
Oct 2010 : 36µm
Simulation : 34µm

SCT-End-Cap
Local X co-ordinate
May 2010 : 44µm
Oct 2010 : 38µm
Simulation : 38µm

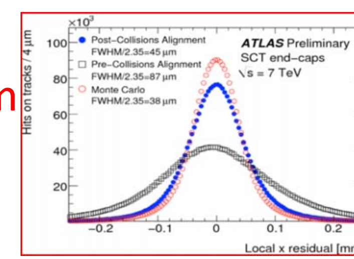
Optimal track parameters only determined when the alignment of the detectors understood

Minimize global χ^2 based the track residuals

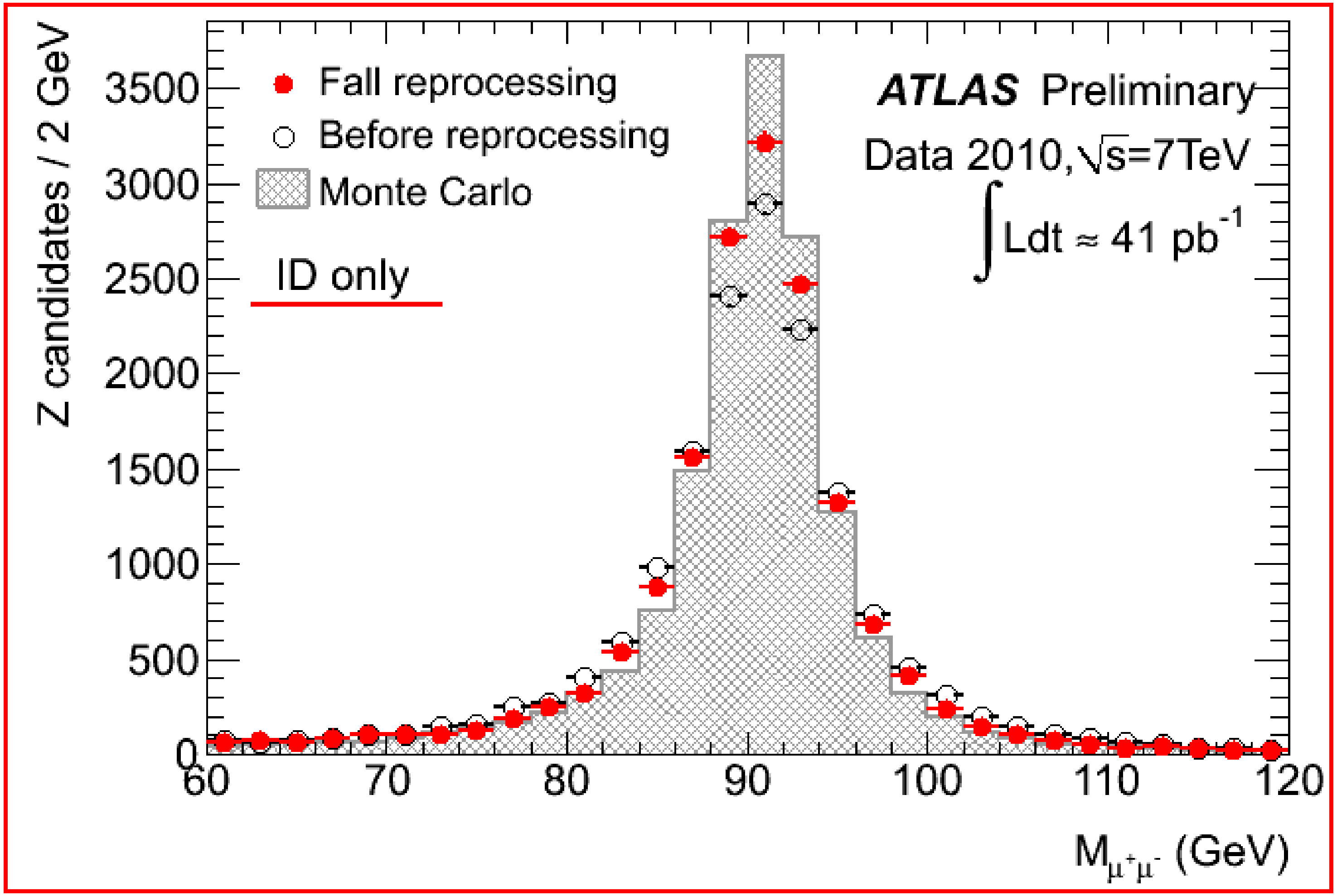
For PIX and SCT this is Iterative procedure with ~ 35,000 degrees of freedom

Initial Alignment from survey and 2008 & 2009 cosmic ray data

Followed by 2009 900GeV data and more cosmic ray data



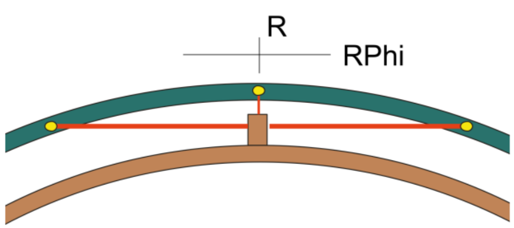
SCT and ID Detector Alignment

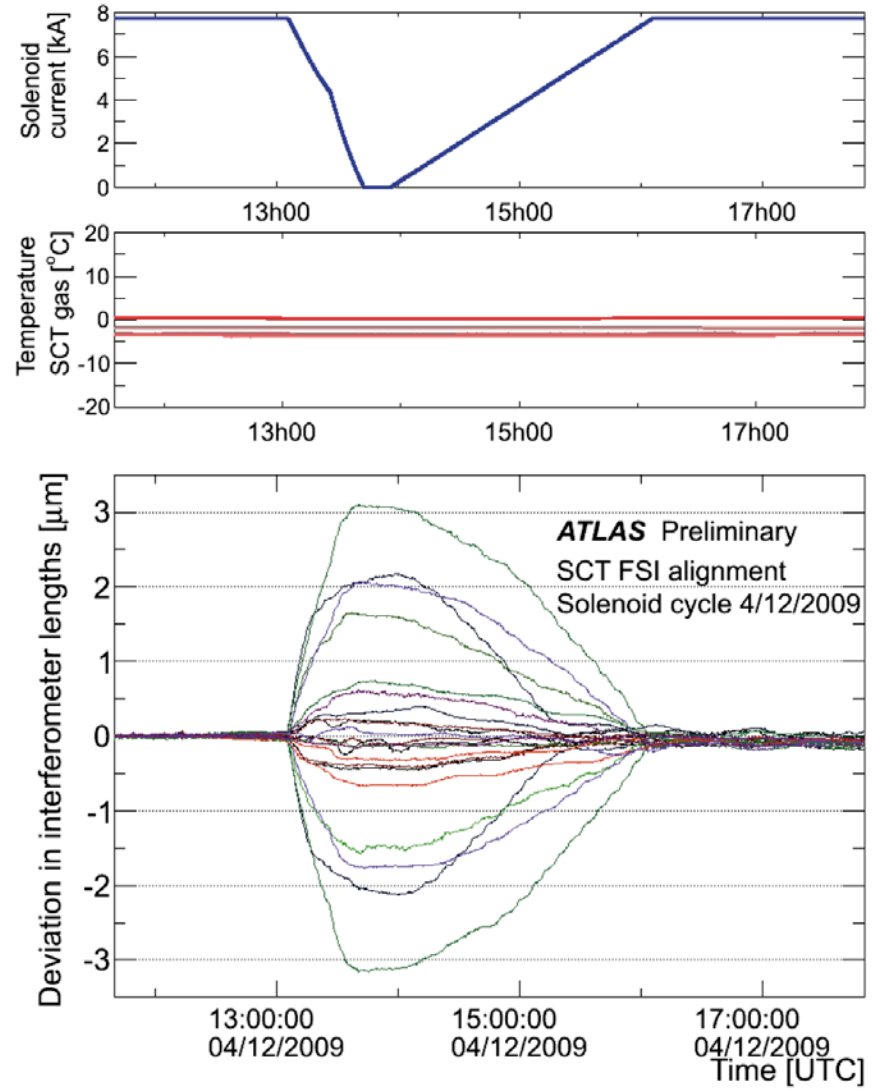


The effect of the new alignment on the Z mass reconstructed with ID tracks only. Before the processing is seen in the open circles and after seen in red.

SCT Internal Alignment and Stability

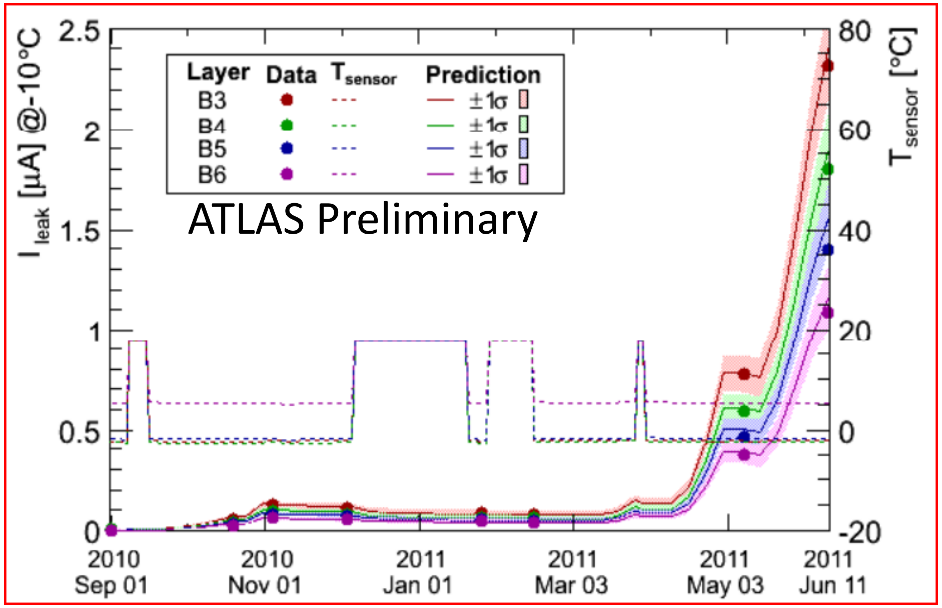
- Monitor long term stability of SCT geometry
- Optical alignment system using Frequency Scanning Interferometry
- **842** interferometers form geodetic grid of distance measurements
- Detected movements
  - Before magnet ramp down: position deviations $\sigma \sim 11$ nm
  - During solenoid ramp: movements $\leq 3\ \mu$m
  - After full magnet cycle: position deviations $\sigma \sim 49$ nm

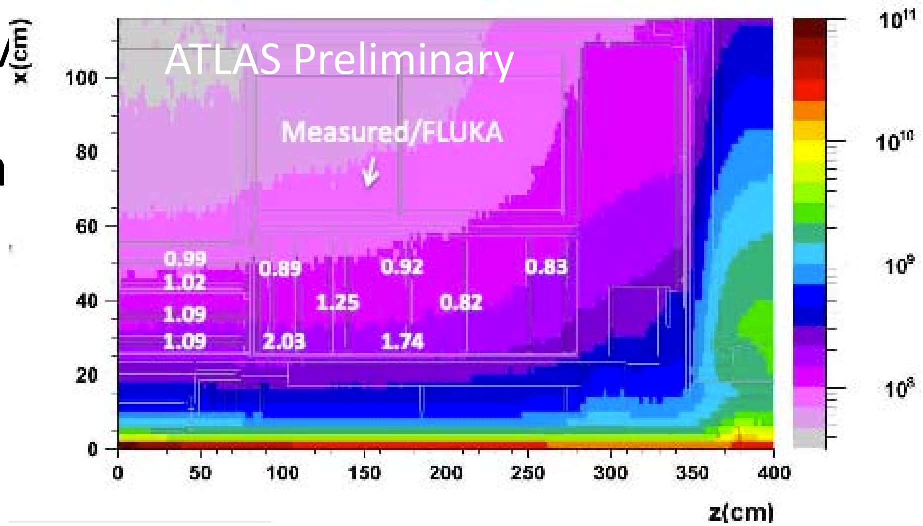




SCT and the onset of radiation damage.

- Radiation damages detector & electronics
- Monitoring needed to predict future performance of current & upgrade SCT
- Linear relation between leakage current & fluence (if T, V = const)
- Measure fluence on-detector
- Barrel: Excellent agreement with simulation
- Endcaps: Good agreement in outer / middle rings
- Inner Rings: Radiation larger than in simulation
- Need to understand difference
- Trip limits increased in Jun '11

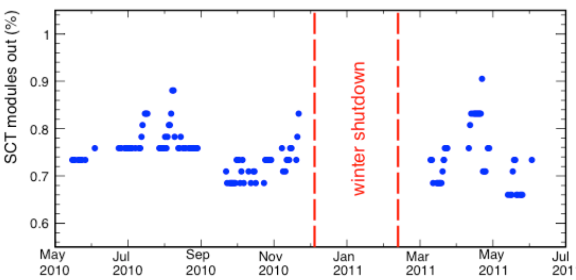




SCT Past problems and ongoing worry list

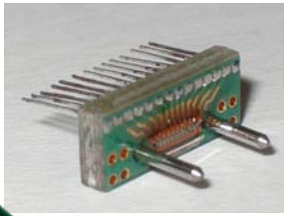
✓ Cooling and Environment

– Multiple problems of evaporative cooling and control system during installation and commissioning.
– Evaporative Heater failures
  • Control system, connectors, feed-back-failures
– The compressor problems
  • A long saga that led to the Thermo-siphon project.
– The heater pad problems
  • Loss of connection to 3 pads around barrel after field ON.

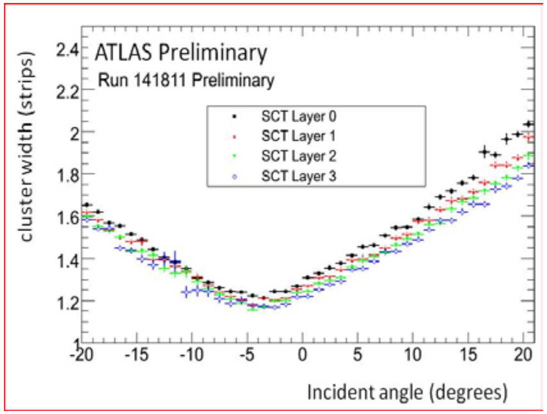


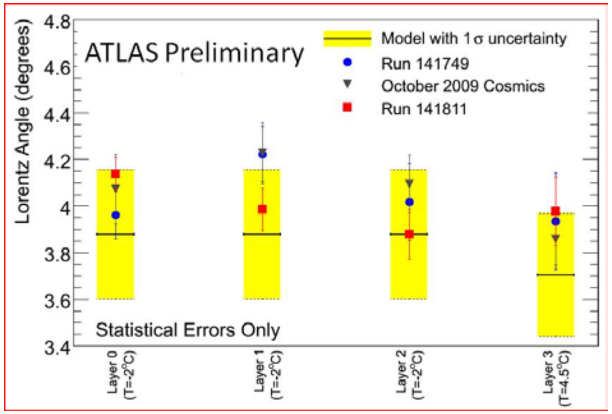
✓ Optical transmitters

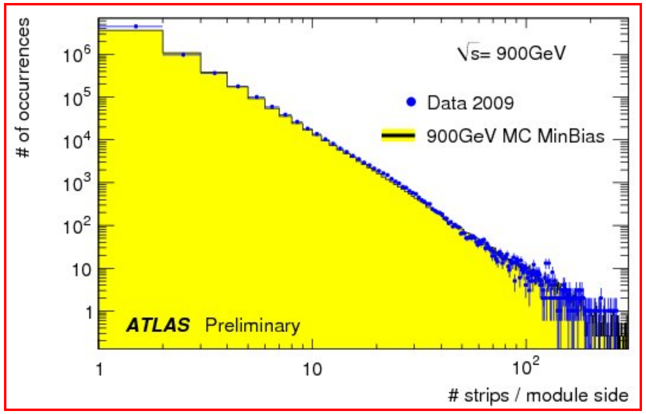
– Each SCT module has 3 optical connections
– 2 of these are used to send data from the module
– 1 of these is used to send data to the module (clock and command). These are sent from crates in the side caverns by TX transmitters
– Poor reliability and frequent failures of the *off detector* VCSELS.
– Initially thought to be due to ESD (wrong!)
– Eventually traced to humidity ingress.
– New developments underway. Very optimistic!
– Redundancy scheme critical to high efficiency



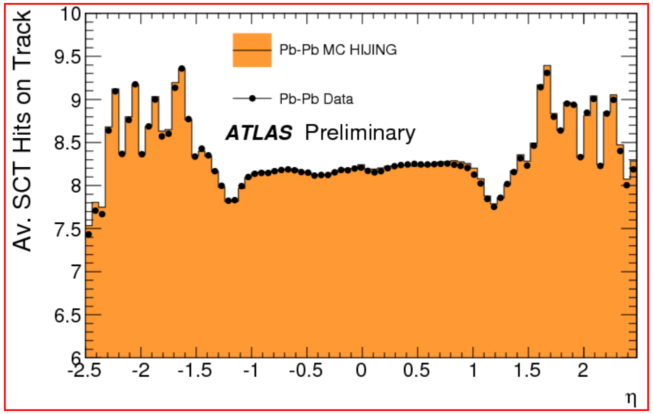
Some SCT Performance Plots

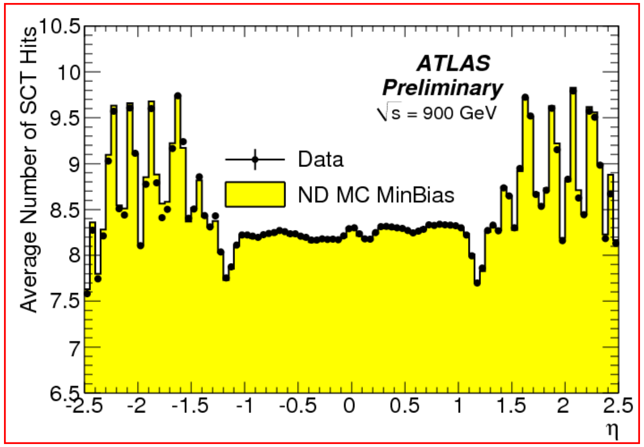






- Top Left: Cluster size vs incidence angle of track
- Top Middle: Lorentz angle for 4 barrels
- Top Right : Number of strips hit on a module.
- Bottom right : Number of SCT hits on track vs pseudorapidity (p-p)
- Bottom Left :Number of SCT hits on track vs pseudorapidity (HI)



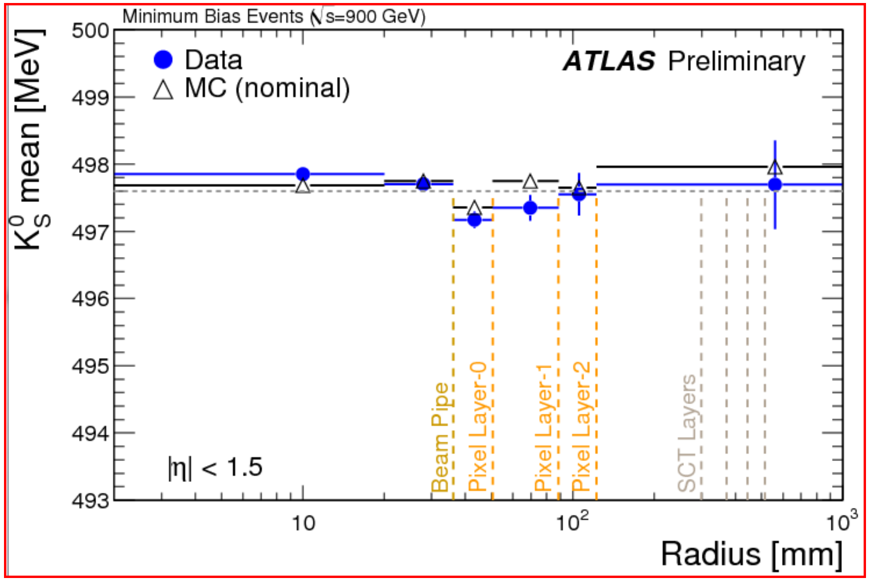


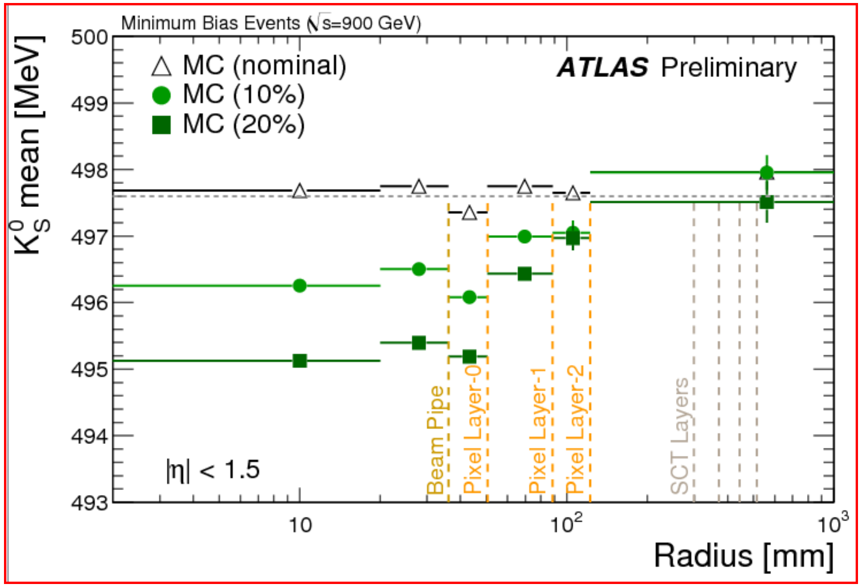
Inner Detector Material Plots : did we get it right?

Several different geometries are used to compare simulated samples with data.

The *nominal sample* is the default comparison as used in simulation and in reconstruction.

The additional samples scale structures in the Inner Detector to produce *roughly 10% and 20% more material* in the simulation in terms of radiation length





ATLAS & SCT Data Taking Efficiency and Data Quality

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.5	100	89.3	92.7	94.3	99.5	100	99.5	100	99.9	98.5	97.9

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and June 6th (in %). The inefficiencies in the LAr calorimeter will partially be recovered in the future. The magnets were not operational for a 3-day period at the start of the data taking.

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	96.9%
SCT Silicon Strips	6.3 M	99.1%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.5%
Tile calorimeter	9800	97.9%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.8%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.4%

SCT The first few years : Summary and Conclusions

- ✓ SCT is performing very well indeed
  - Operational fraction of the detector > 99.1%
  - Product of Operational Efficiency and Data Quality > 99.4%
- ✓ General Performance
  - Calibration, timing, intrinsic efficiency, alignment, mechanical stability, cooling are all making good progress. The onset of radiation damage has started and is following the predictions.
- ✓ Problems
  - Being addressed in an efficient and timely way
- ✓ Most importantly
  - ***Contributing to the rich physics program of ATLAS.***

Mike Tyndel and Taka Kondo at CERN on 24th March

THANKS – MIKE !!!

What is next ? .... The road to a-few x 10^{34} $cm^{-2}s^{-1}$