The Status of the ATLAS Inner Detector

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for the ATLAS Collaboration

Outline

- Introduction
    - Tracking in ATLAS
- ATLAS ID
    - Pixel detector
    - Silicon Tracker
    - Transition Radiation Tracker
- System Aspects
- Schedule
- Conclusions

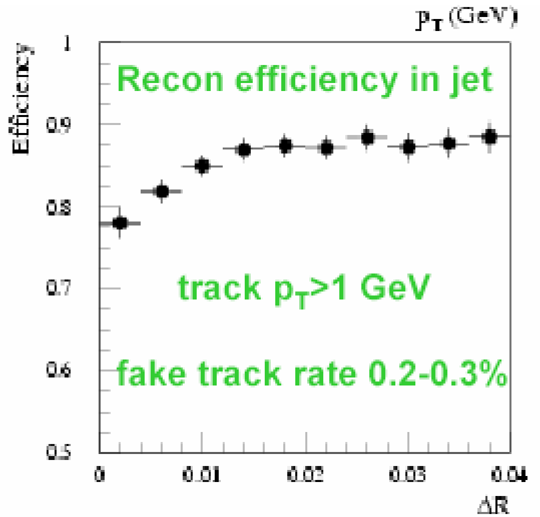
Requirements for Tracking in ATLAS

- Rapidity coverage: $|\eta| < 2.5$
- Momentum resolution for isolated leptons: $\sigma p_T / p_T \sim 0.1\ p_T$ (TeV)
- Track reconstruction efficiency (high-p_T) > 95%, (isolated tracks)

  > 90%, (in jets)
- Ghost tracks < 1% (for isolated tracks)
- Impact parameter resolution:

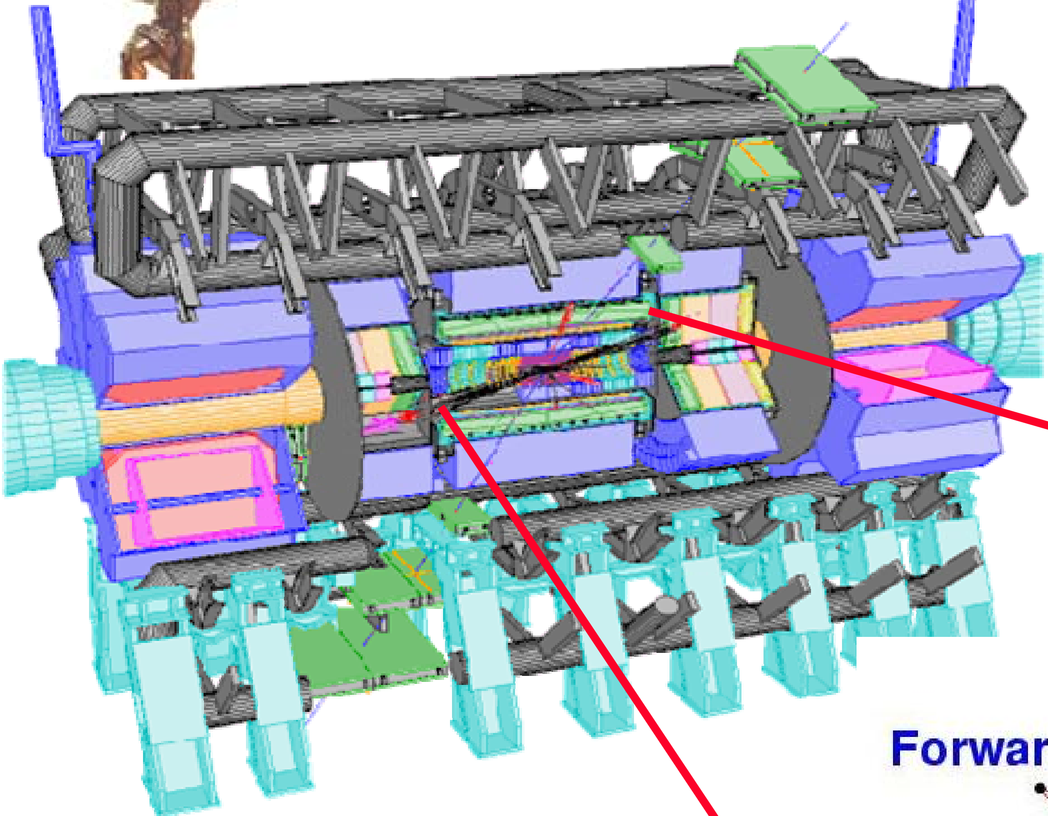
  $\sigma_{r\text{-}\phi} = (11 +^2 60/\ p_T)\ \mu m$,

  $\sigma_z = (70 +^2 100/\ p_T)\ \mu m$,
- Low material budget
- Lifetime > 10 LHC years

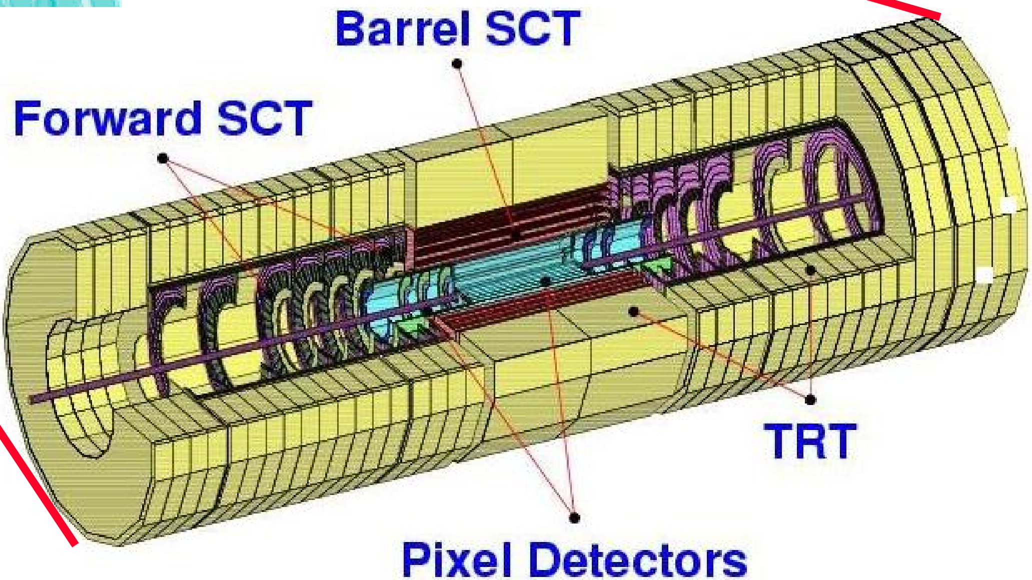


- Occupancy: 700 tracks per high luminosity event inside acceptance
- Short bunch crossing time (25 ns)
- High radiation: up to 10^{14} neutrons/cm^2/year (1 MeV equivalent)

ATLAS and ATLAS Inner Detector



ID length: 7 m
ID diameter: 2m



The ATLAS Inner Detector

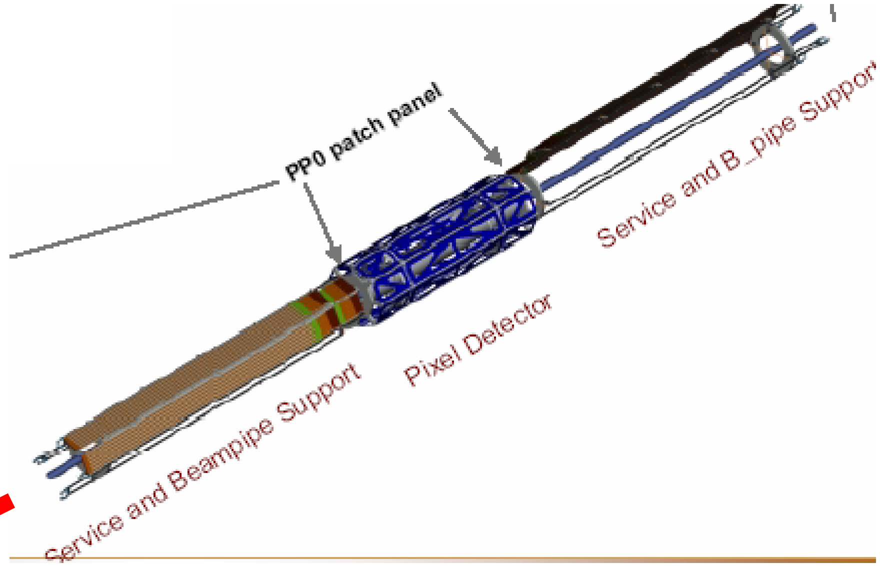
Three subdetectors using different technologies to match the requirements of granularity and radiation tolerance

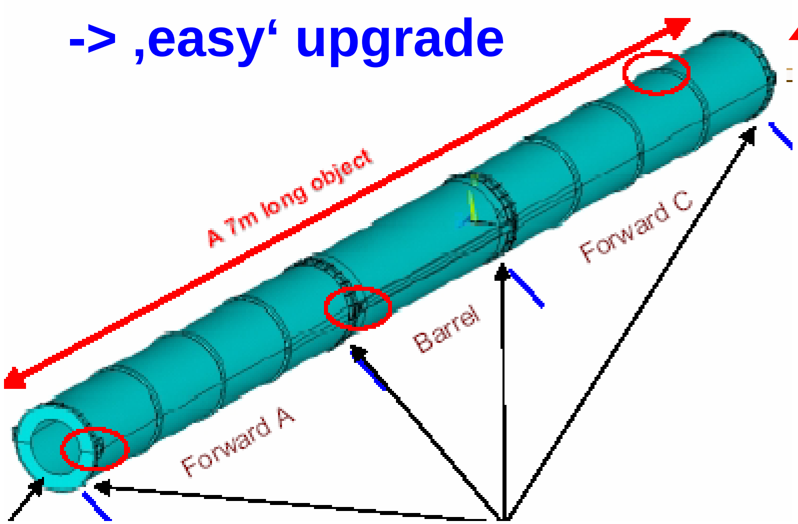
Sub-Detector	r(cm)	element size	resolution	hits/track	channels
Pixel (Silicon)	5-12.5	50μm x400μm (3D)	12μm x 60μm	3	93x10^6
SCT (Silicon Strip)	30-52	80μm x 12cm (stereo)	16μm x 580μm	4	6x10^6
TRT (Straw Tubes)	56-107	4 mm x 74cm (projective)	170μm	36	0.4x10^6

Pixel Detector Layout

3 barrel cylinders
2 x 3 endcap disks

Insertable layout
-> can be inserted after installation of SCT/TRD
-> ‚easy' upgrade





Only the support tube needs to be installed beforehand

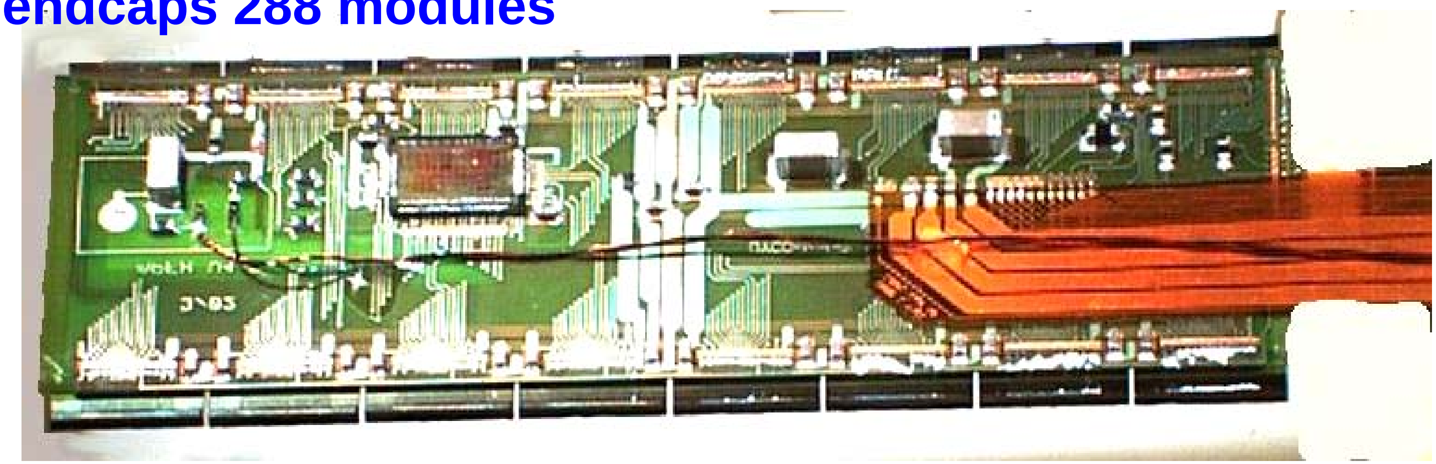
Decouples SCT/TRT and Pixel schedule

Last subdetector to be installed!

Pixel Modules

Each Module (16.4 x 60.8 mm^2) has one sensor with 46080 pixels
16 frontend chips are bump-bonded on the sensor for readout

3 barrel layers need 1744 modules
2x3 endcaps 288 modules

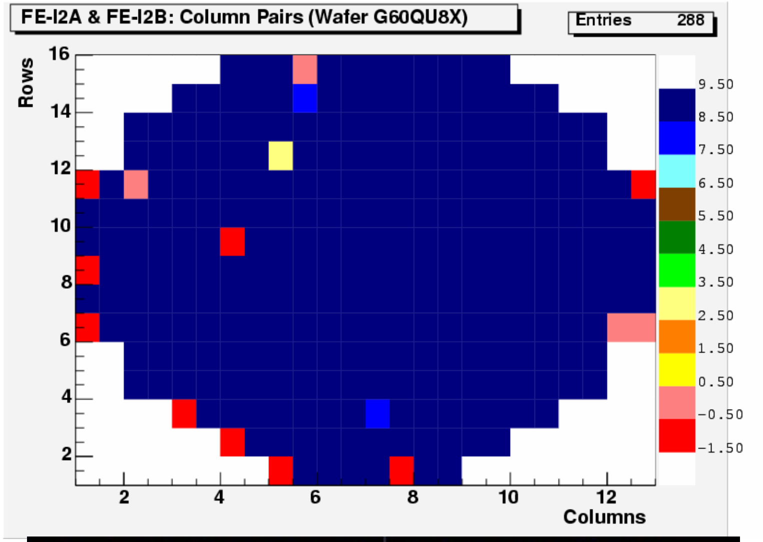


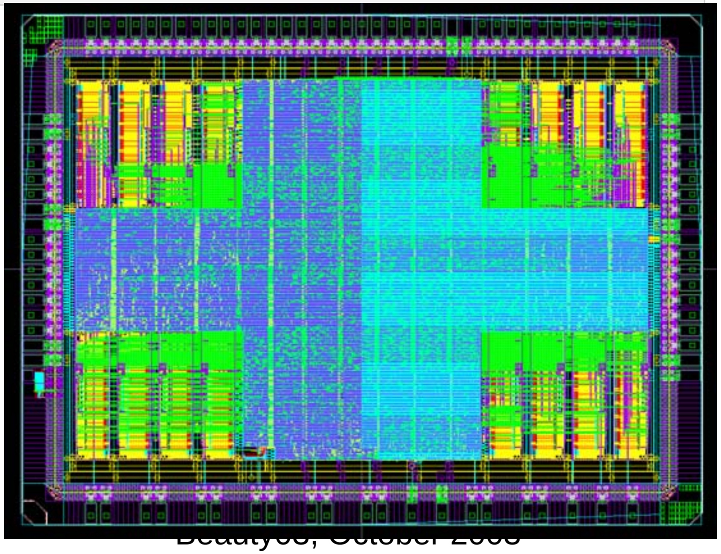
Sensors are in production:
CiS (Germany): 600 produced, 400 in production
Tesla (Czech Republic): 50 produced, full series to start

Pixel Electronics

FE readout chip in Deep Submicron (DSM) technology
(DMILL failed)
First prototype batches basically working, however, some fixes necessary
Production yield >90% !

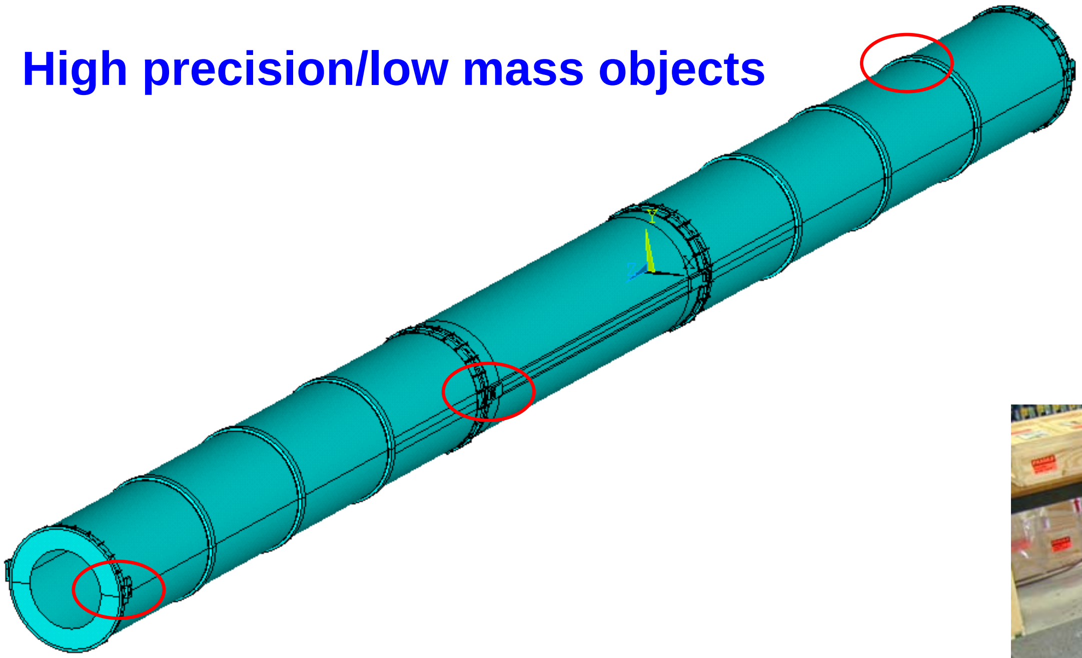
MCCI2 (module control)
New version with triple logic for SEU (single event upset) tolerance
Final production expected to be ready by now





Pixel Support

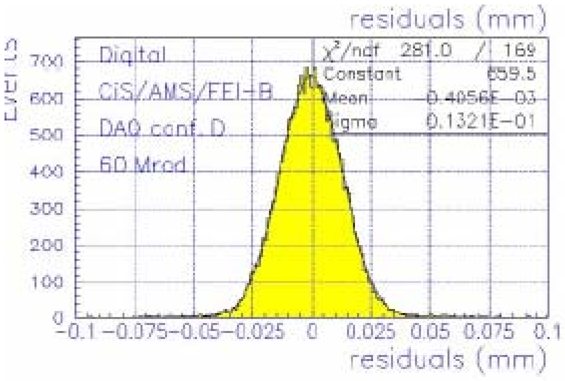
High precision/low mass objects



Support tube in production
(needs to be ready first!)

Global support ready
Local supports (staves and sectors) in production
A bit late, but not critical

Test Beam Results

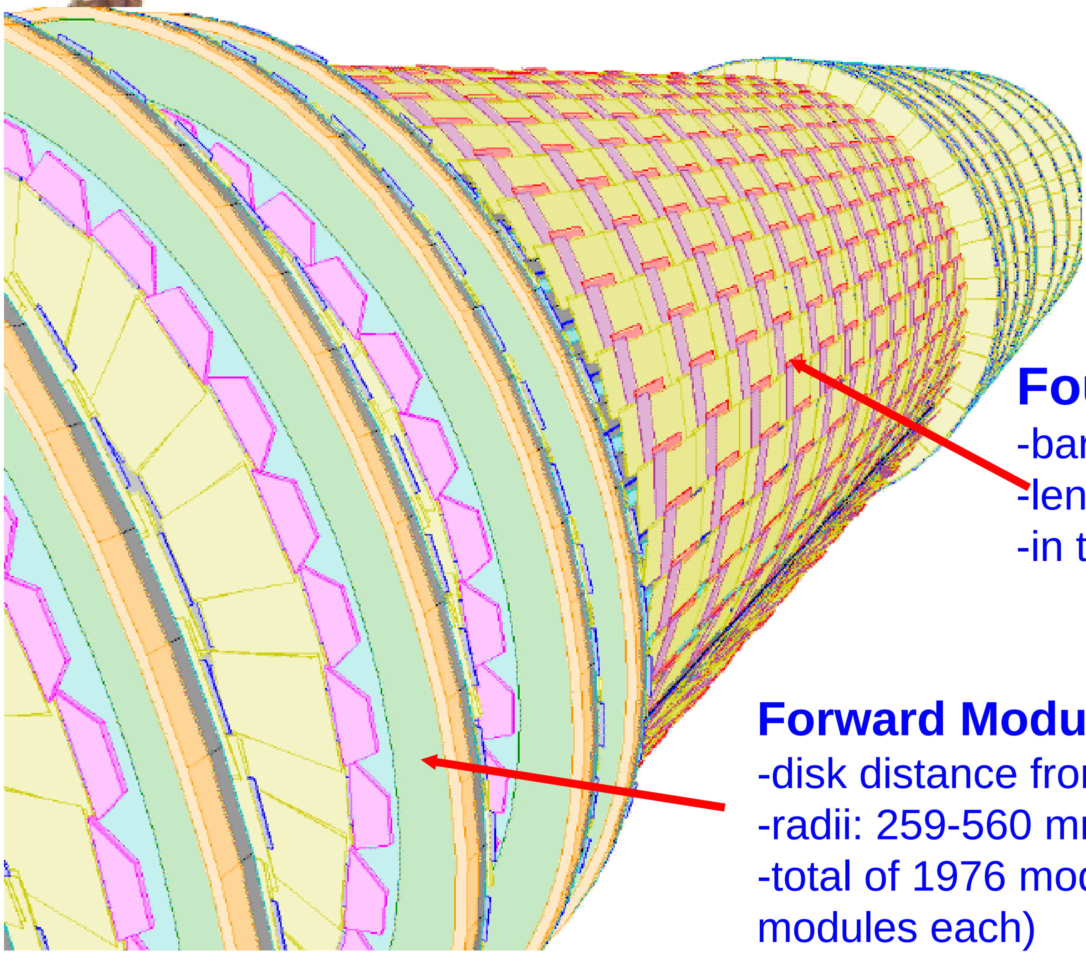


Resolution:
13.2 μm after irradiation

Efficiency:
99.3% before irrad. **97.7% (60 Mrad)**

Operation of 6 modules in parallel with one power supply/cable:
No change of performance

SCT Layout



Four barrel layers

-barrel radii: 300, 371, 443 and 514 mm;
-length 1600 mm
-in total 2112 modules

Forward Modules on 2x9 disks

-disk distance from z = 0: 835 - 2788 mm,
-radii: 259-560 mm
-total of 1976 modules (3 rings: 40,40, 52 modules each)

SCT Modules

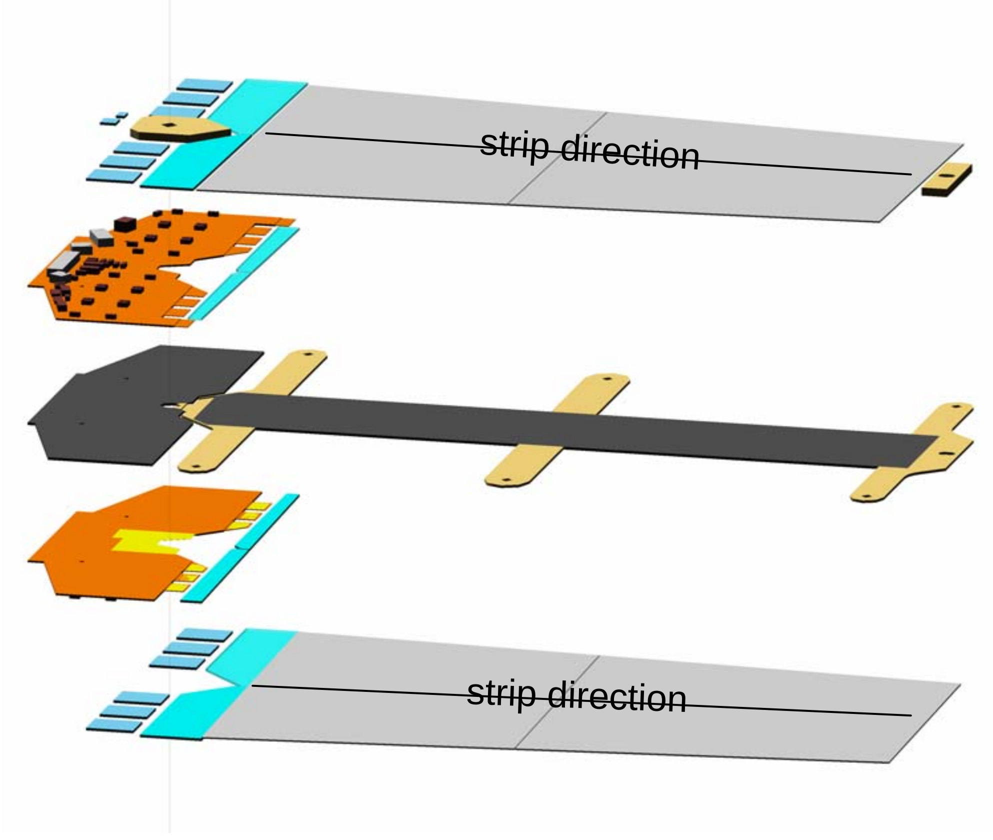
Basic Concept (Endcap)

-4 Si-strip detectors in 2 planes (40 mrad stereo)

-Mechanical carrier made from Thermal Pyrolytic Graphite (C_k>1700 W/m/°K) and AlN

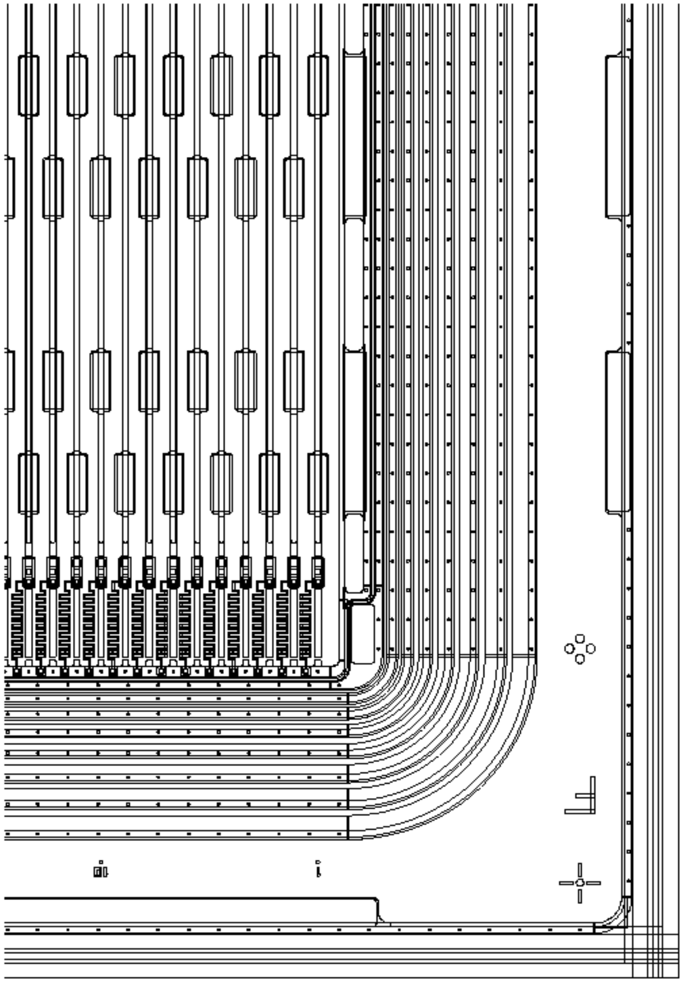
-Flex Hybrid (Kapton) on carbon substrate with ASIC readout electronics

-Glas pitch adaptors for mechanical/electrical connection detector-electronics (heat barrier)

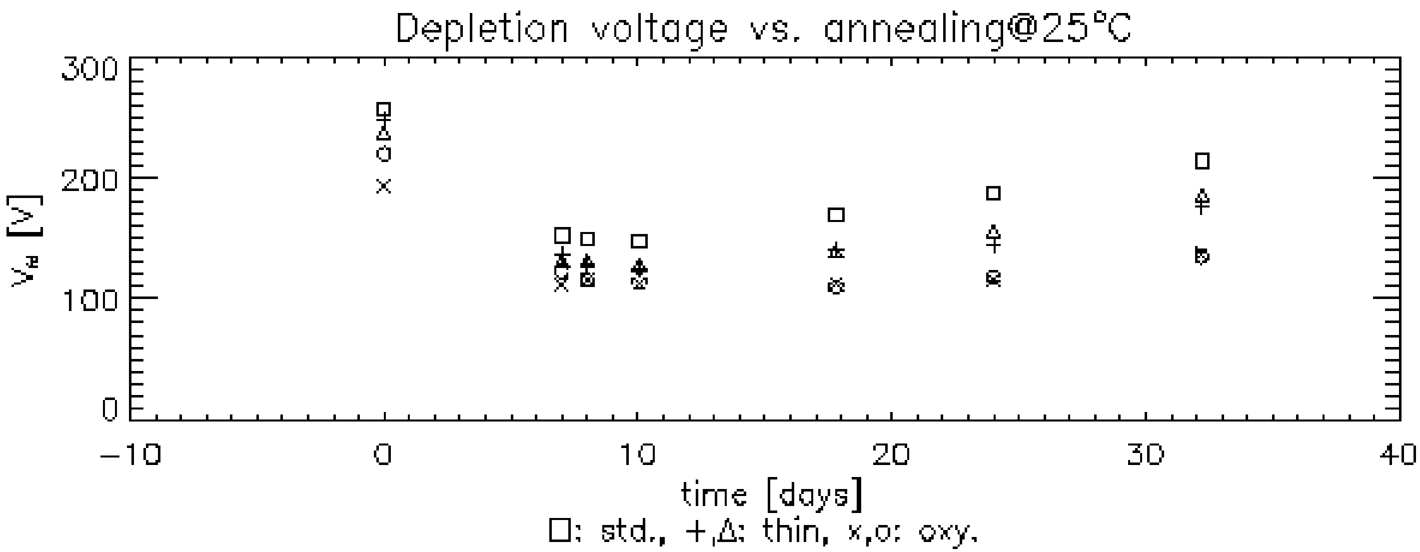


SCT Silicon Detectors

- Radiation tolerant up to $3x10^{14}$ p/cm^2
- p-on-n single sided detectors
- 285 micron 2-8 kOhm
- 4“ substrate
- Barrel: 64x64 mm^2
- Forward: wedge shaped (5 shapes)
- 768 readout strips with ca 80 μm pitch
- No intermediate strips
- AC coupled strips
- Polysilicon or implanted bias resistors
- Multiguardring structure to ensure stability up to 500 V
- Ca. 20000 needed
- Produced by Hamamatsu and CIS (competed, excellent quality)



Detectors: Radiation Hardness



After irradiation: high depletion voltage
Short period (10 days): annealing reduces V_{dep}
Afterwards V_{dep} rises steadily with time (at high temperatures): Reverse annealing -> keep Si cool (-10 C)

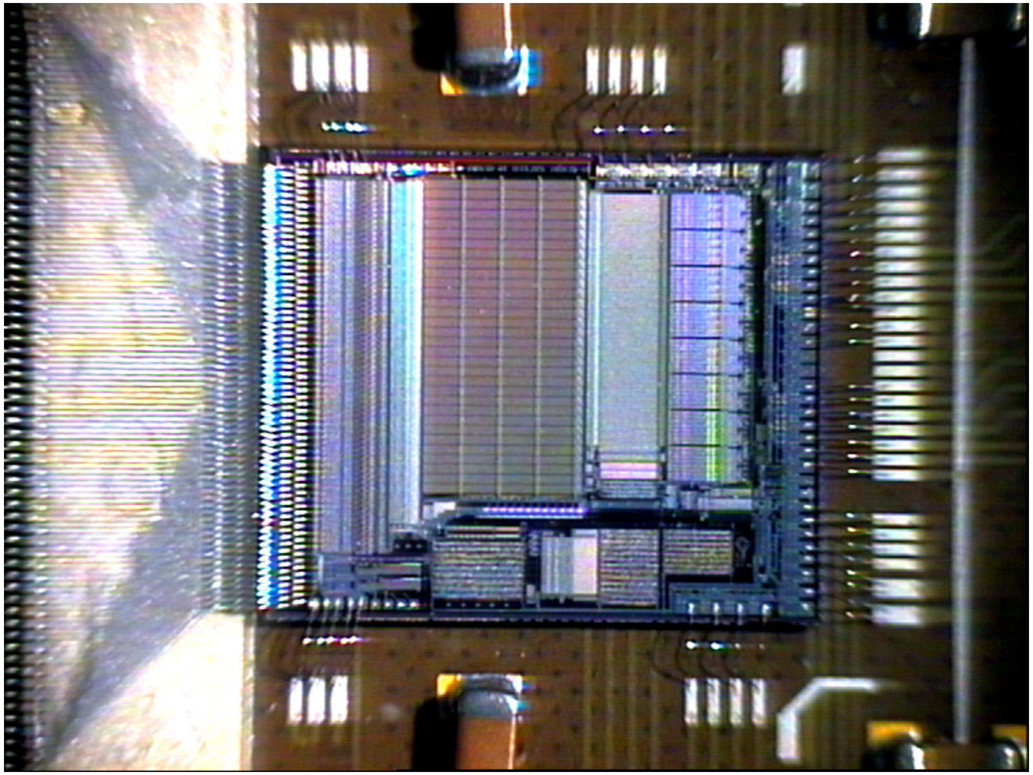
Problems in very exposed regions close to the beam or high η

- **Reduced thickness: 285 -> 260 μm   ca. 50V**
- **Oxigenated detectors: less damage and slower reverse annealing**

SCT Electronics

ABCD
128 channels
bipolar frontend
DMILL rad hard process
Shaping time: 20ns
Binary Readout (single threshold)
132 cell pipeline

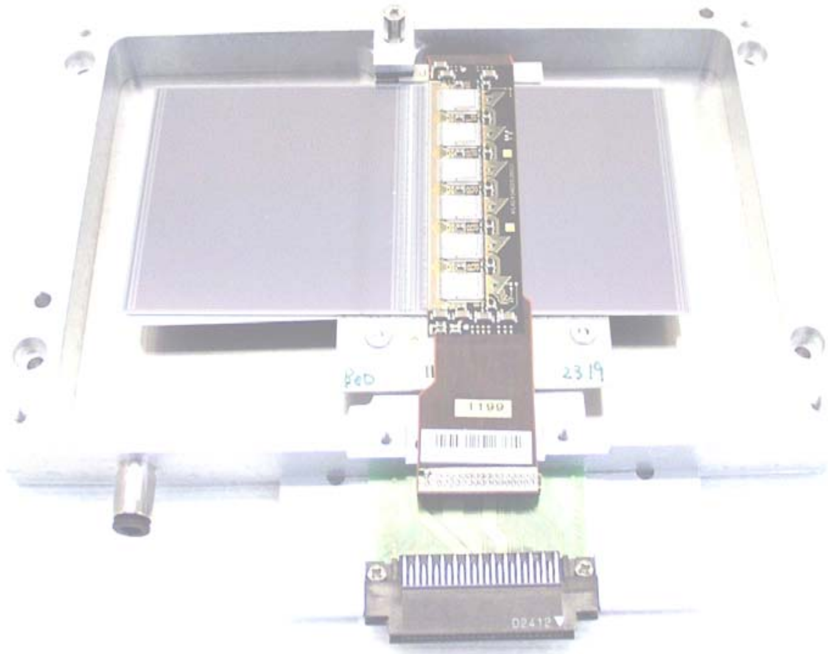
Production finished
Low yield, need to use chips with one dead channel to complete detector (ca. 15%)

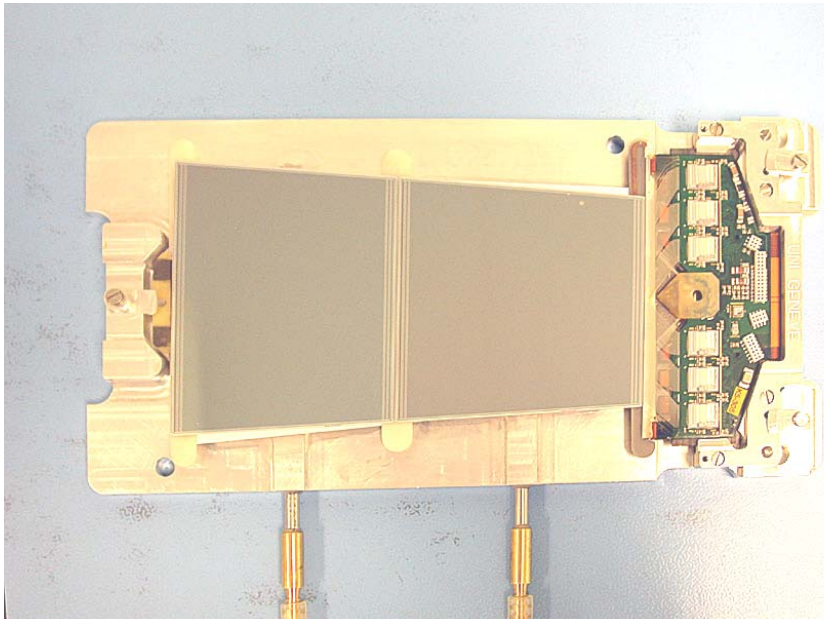


Module Production

Barrel Modules

Endcap Modules





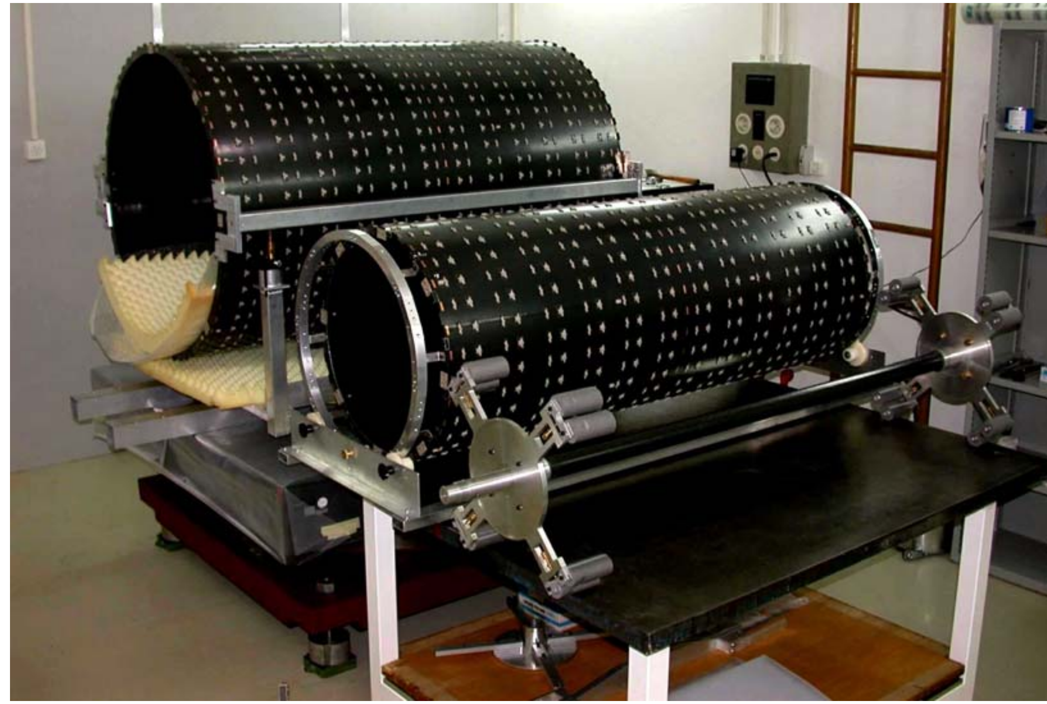
Production running at 4 locations
Ca. 500 modules produced & tested

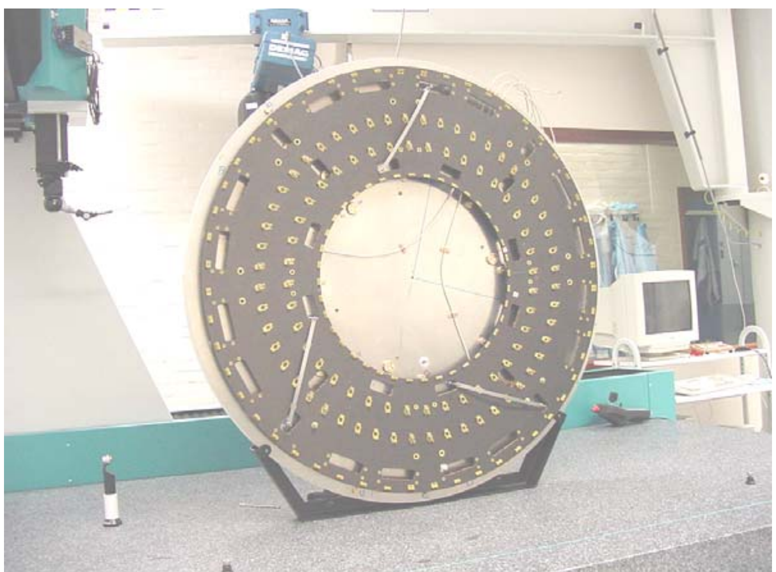
Production at 7 locations
Commissioning of production sites
Start in October

Engineering

Carbon cylinders for barrel support are ready

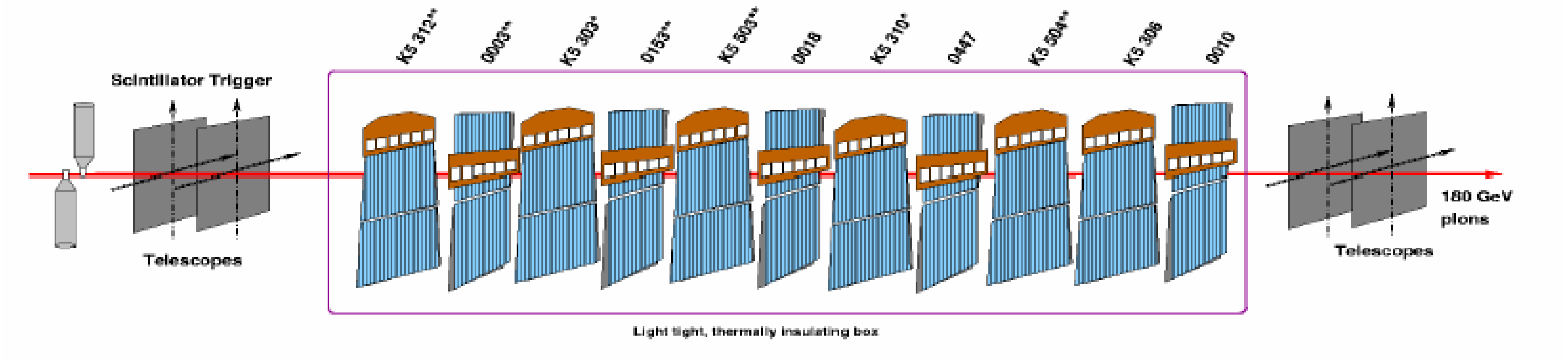
Need to be equipped with services





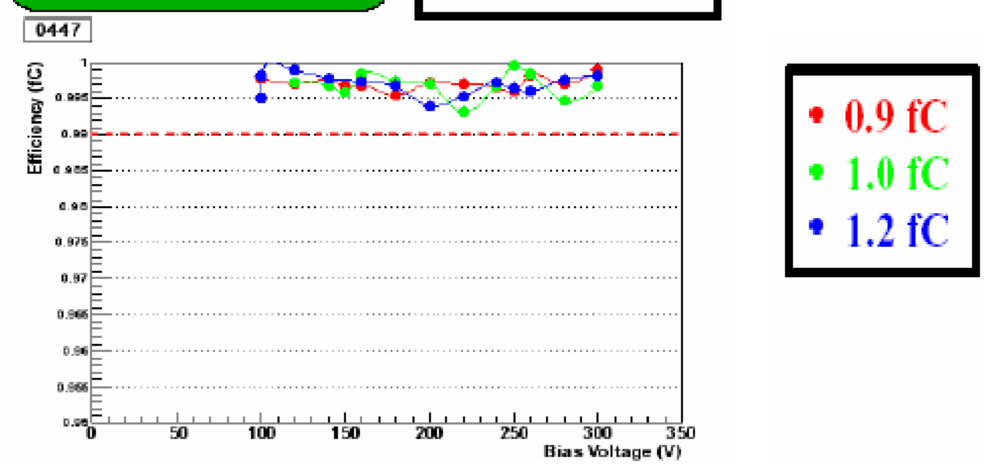
4 of the 18 carbon disks for the endcap module support are produced
Need to be equipped with services
Again, high precision/low mass objects
Disk flat to +- 60 μm over 2 m!

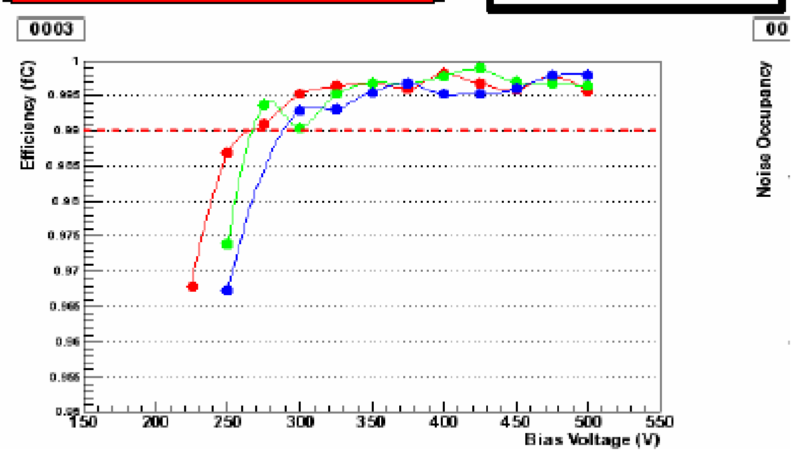
Testbeam Results



Non-irradiated | **Barrel 0447**

Fully irradiated barrel | **Barrel 0003****





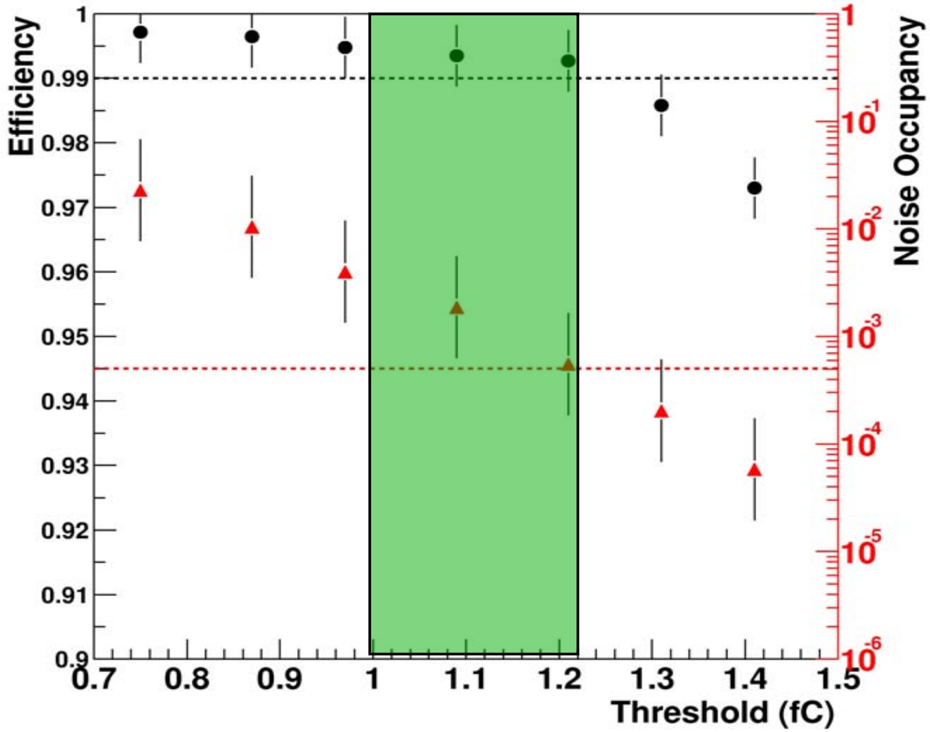
Testbeam Results

Nominal specifications (after irradiation):

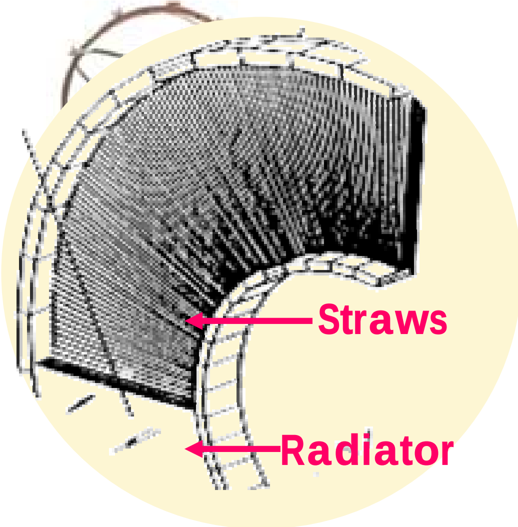
>99% efficiency
< 5x10^{-4} occupancy
(readout bandwidth limit)
@ 1 fC threshold

Ok for barrel modules

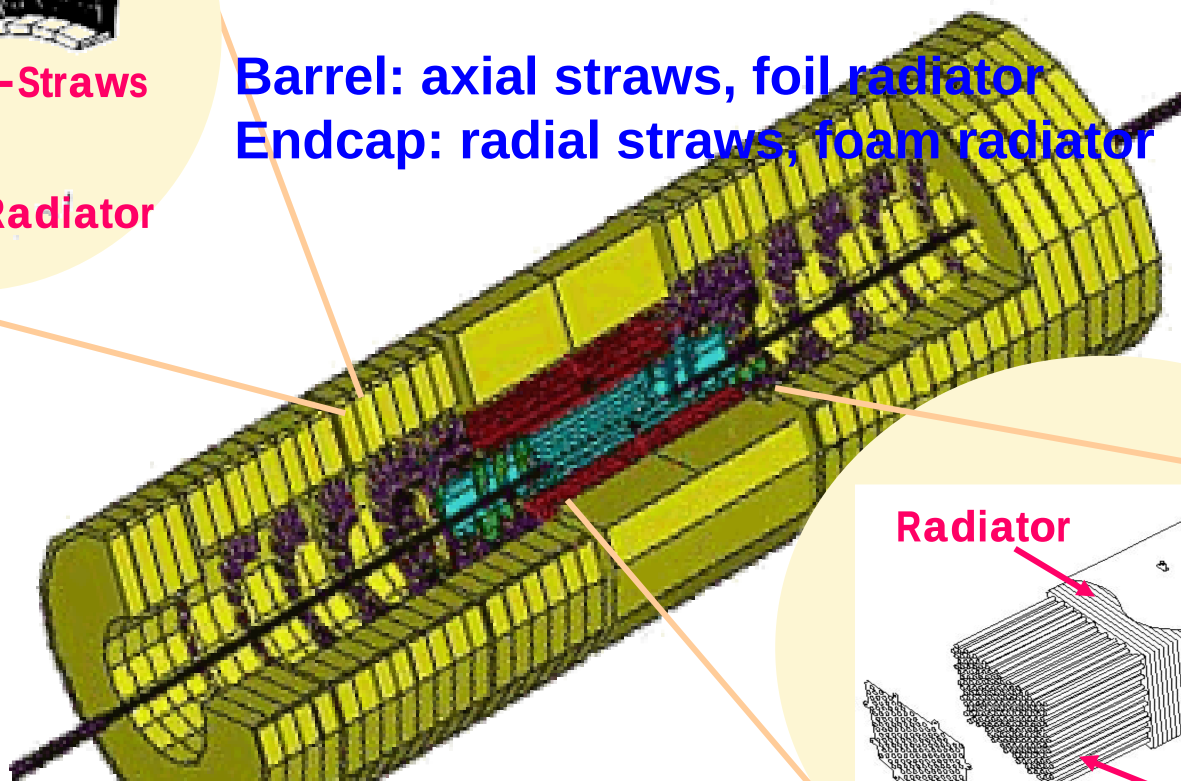
Endcap modules have slightly higher noise.
Still possible to meet the specs tuning the threshold

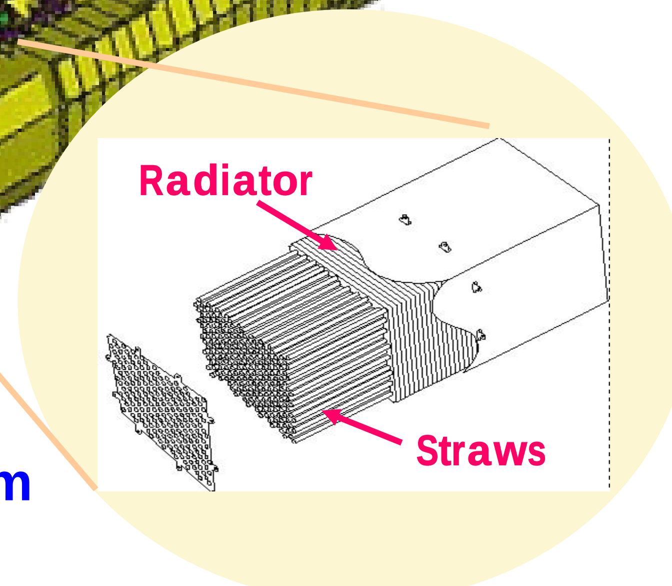


TRT Layout



Barrel: axial straws, foil radiator
Endcap: radial straws, foam radiator

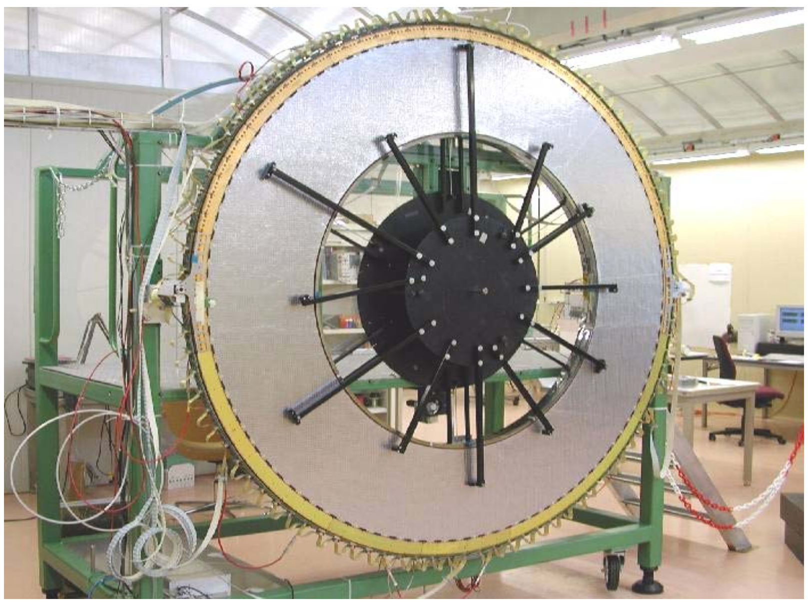


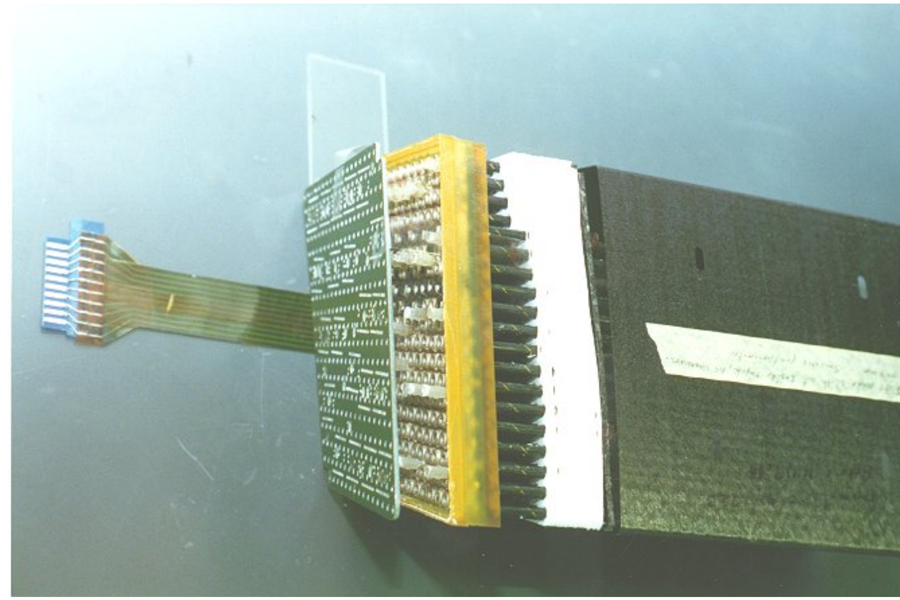


Tracking: up to 36 points with σ=170 μm
improves pattern recognition,
equivalent to a single point with 50 μm precision
Transition radiation: e/π ~ 100

TRT Modules

Barrel Module Production completed, being tested





Endcap Module production was delayed due to problems with the front-end boards (‚WEBs‘), should be completed in May 2005 (still on critical path)

TRT Gas Mixture

Original gas mixture:

Xe(70%) CF_4(20%) CO_2(10%)

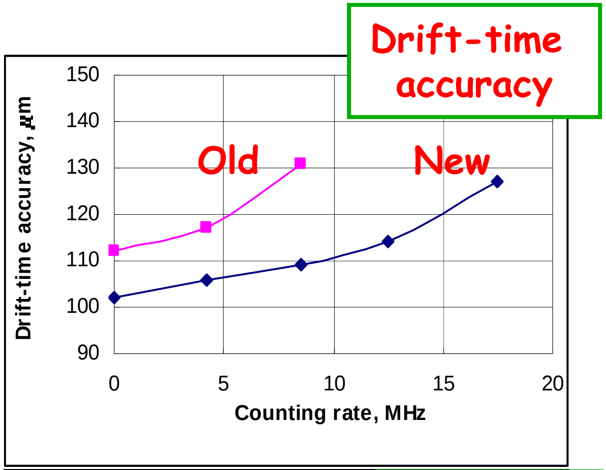
However, CF_4 radicals destroyed glass wire joints (discovered in 2001, after >20% produced)

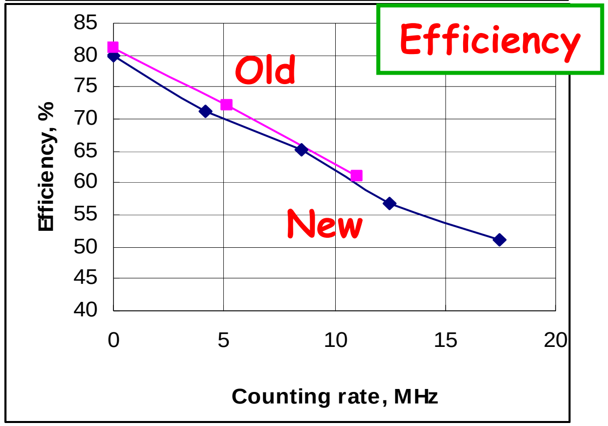
1. **Use polyimide/epoxy joint.... Too late**
2. **Change gas mixture:**

Xe(70%) CO_2(27%) O_2(3%)

acceptable operation stability
equivalent physics performance (but slower)

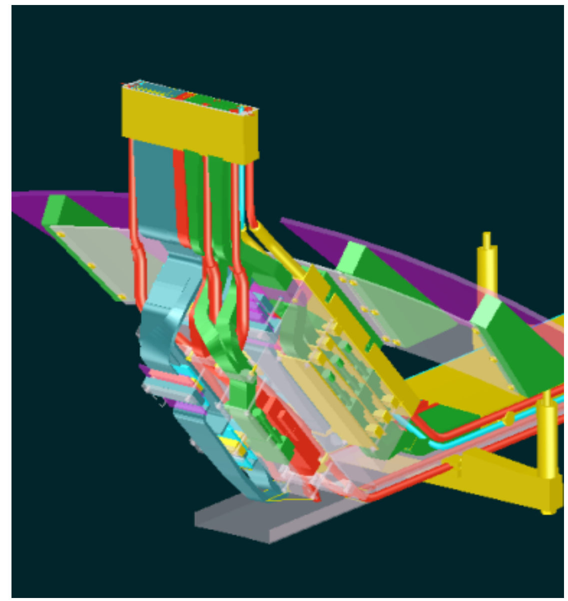
Requires periodical wire cleaning with Ar/CO_2/CF_4 to remove Si deposit, if found (demonstrated)





Inner Detector: System Aspects

- Cooling
- Gas system
- Services
- Structure/Supports
- Integration
- Installation



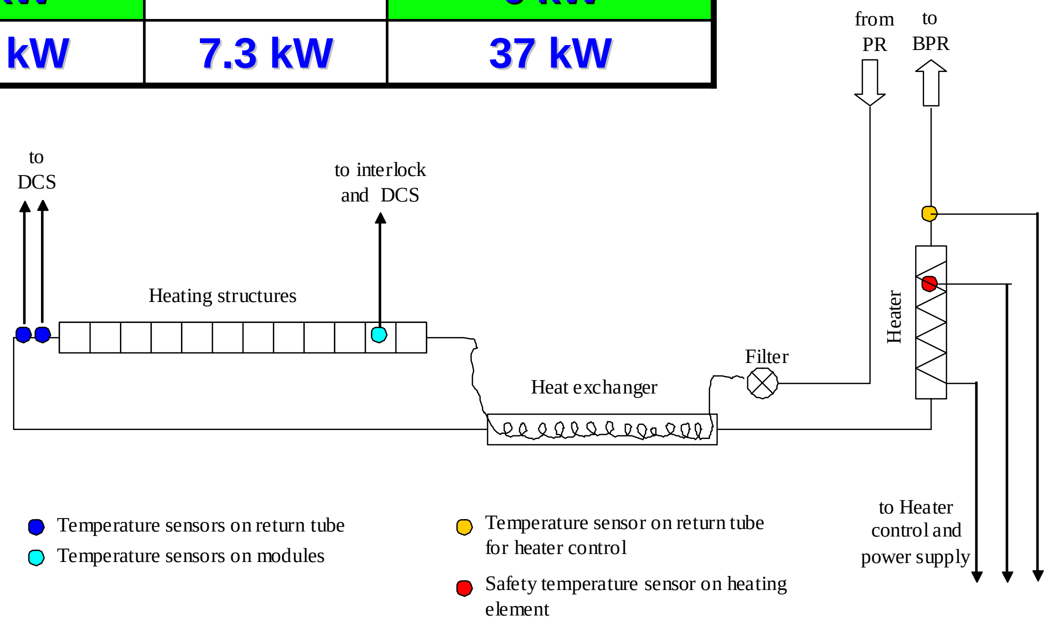
e.g. patch panel to connect electrical & optical and cooling services

Cooling

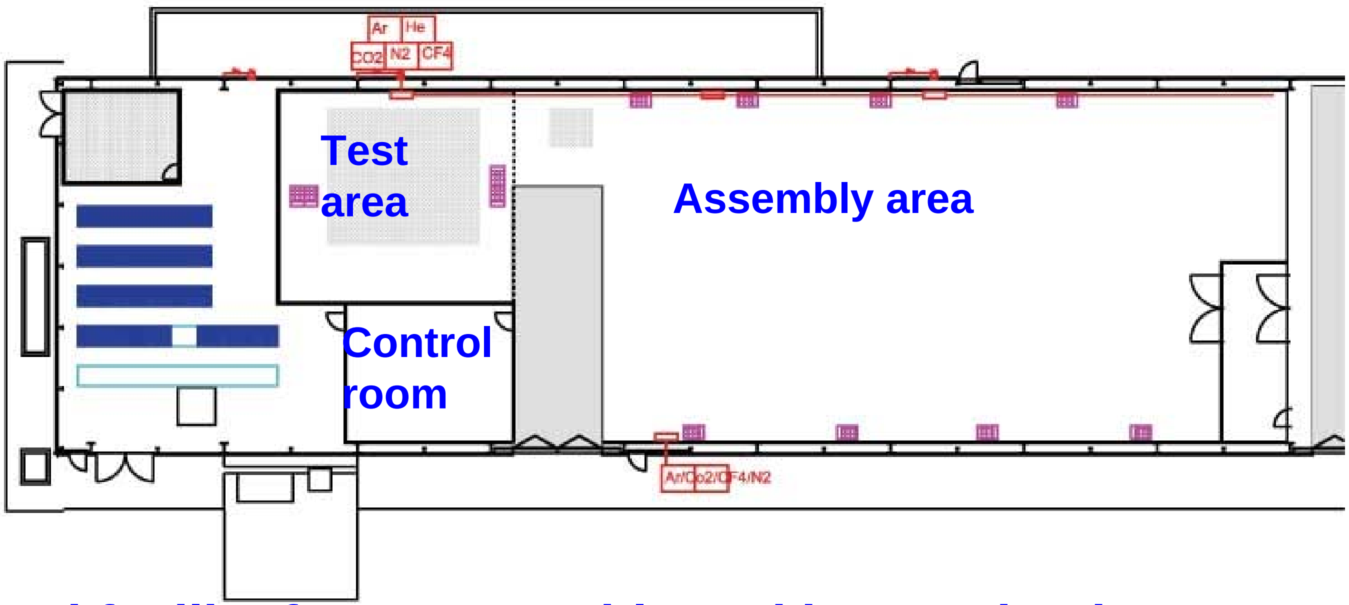
	INSIDE ID VOLUME			OUTSIDE ID VOLUME
	electronics	cables	Thermal enclosure	cables
PIXEL	12.5 kW	3 kW	1.3 kW	11 kW
SCT	39 kW	3.6 kW	6 kW	20 kW
TRT	46 kW	1 kW	-	6 kW
Total	96.5 kW	7.6 kW	7.3 kW	37 kW

Green: Warm monophase

Red: Evaporative system Using C_3F_8 (–30°)



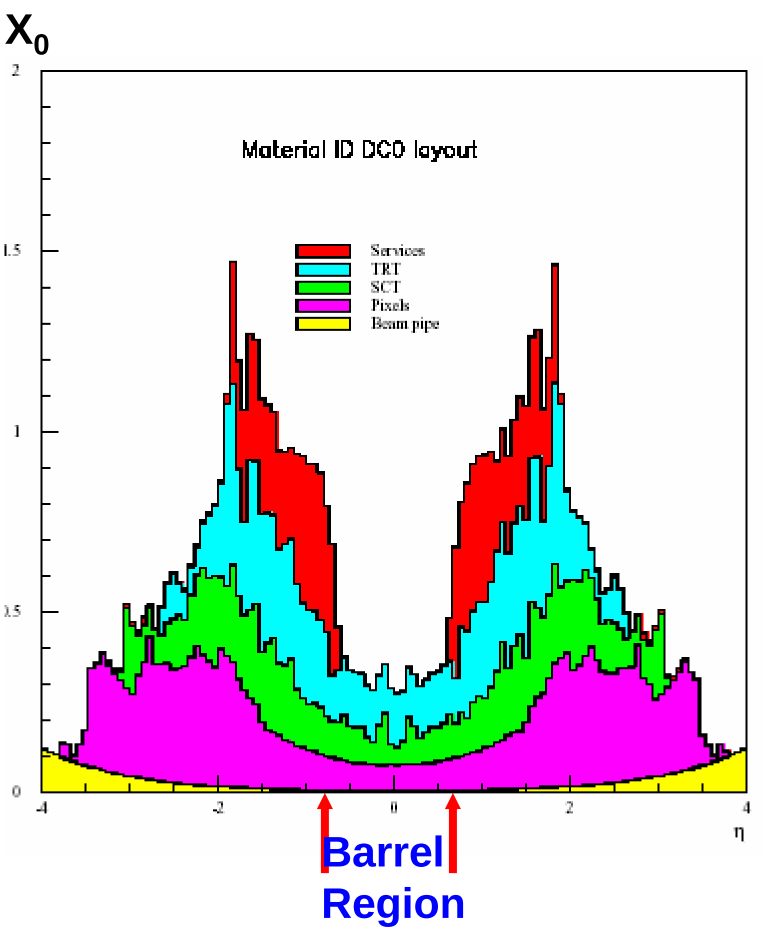
Assembly and integration



A dedicated facility for ID assembly and integration is set up close to the ATLAS pit.

- **Assembly of SCT barrel, tests of SCT endcaps, TRT assembly**
- **SCT/TRT integration and testing**
- **Pixel Detector assembly**

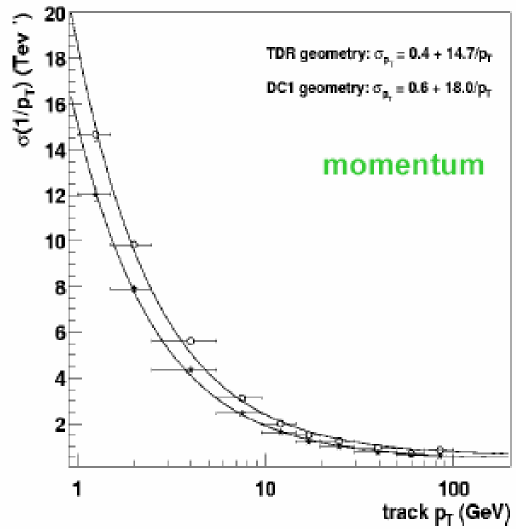
Expected Performance

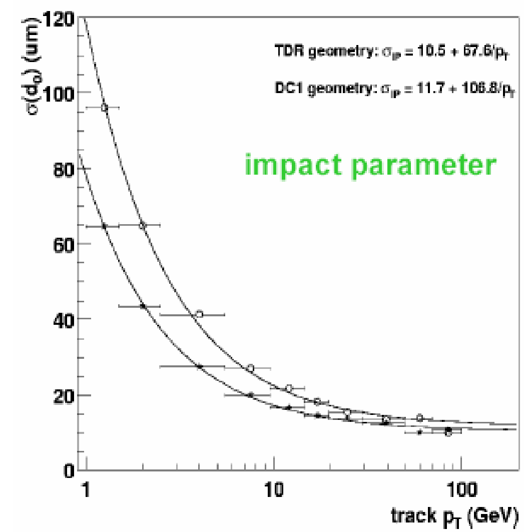


Material in ID changed compared to initial (‚TDR‘) layout (increased, of course)
-increased pixel sensor thickness
-More realistic engineering and services

Radius of inner pixel layer 4.3cm -> 5cm

Some impact on momentum and impact parameter resolution

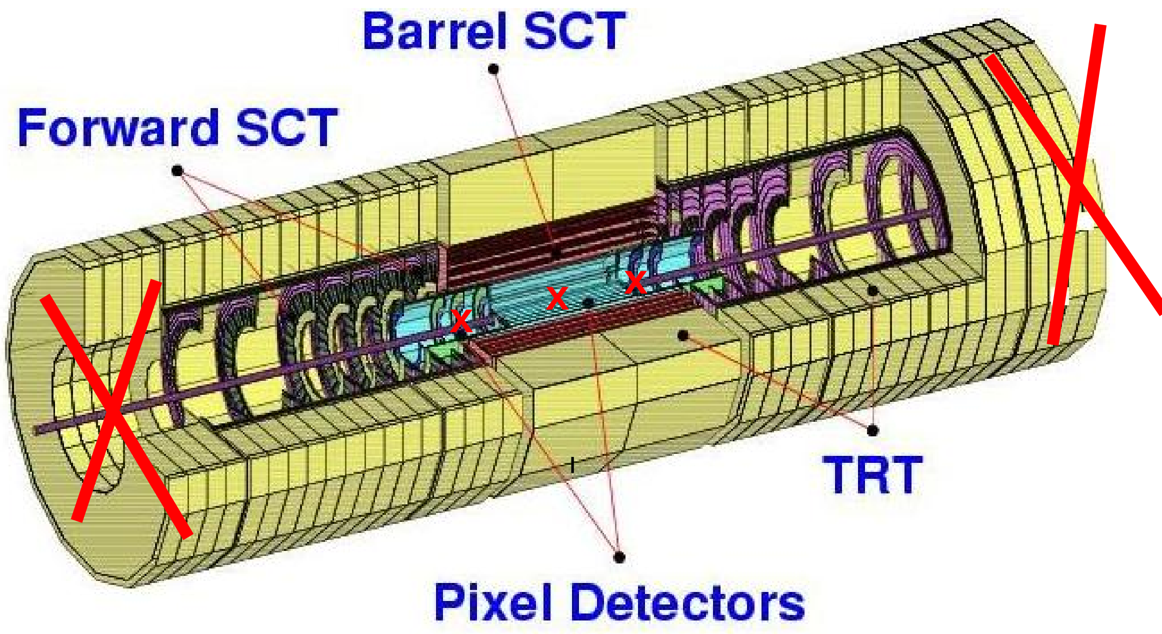




Staged Items

However, because of funding and schedule problems the initial detector will not have:

- **Middle pixel layer,**
  at R=9 cm,
- **Middle pixel disks,**
  at z = +/- 58 cm
- **TRT ‚C' wheels,**
  at IηI > 1.7



Consequences

Impact on:

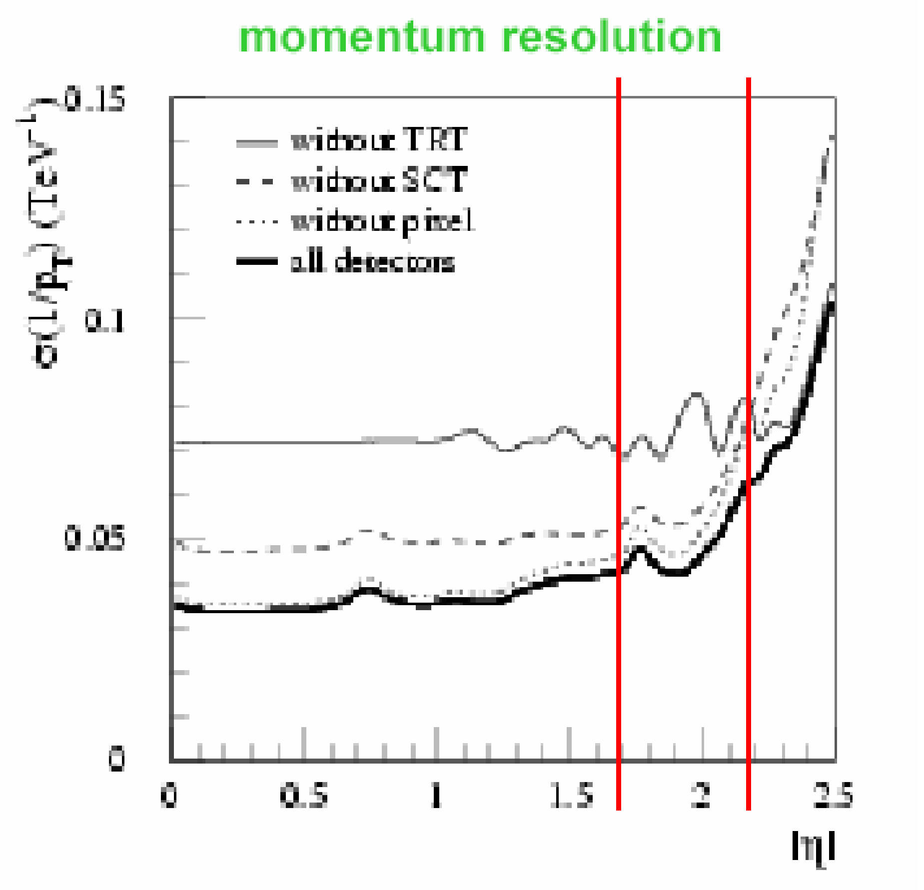
Missing pixel layers

-> worse impact parameter resolution

-> reduced b-tagging performance

Missing TRT C-wheels

-> worse momentum resolution at $|\eta| > 1.7$



Schedule

Start assembly in SR building:	**April 04**
SCT barrel ready:	**January 05**
SCT endcap C ready	**April 05**
SCT endcap A ready	**August 05**
TRT barrel ready	**January 05**
TRT endcap C ready	**October 04**
TRT endcap A ready	**September 05**
ID barrel ready for installation in ATLAS	**July 05**
ID endcap C ready for installation	**November 05**
ID endcap A ready for installation	**March 06**
Staged items:	
3rd pixel layer	***August 06***
TRT C wheels	***July 06***

Conclusions

Most of the technical problems are resolved

Production of detector modules and structures has started

Preparations for detector integration started

Main worry is the tight schedule and fighting delays

We are confident to be ready for physics in 2007