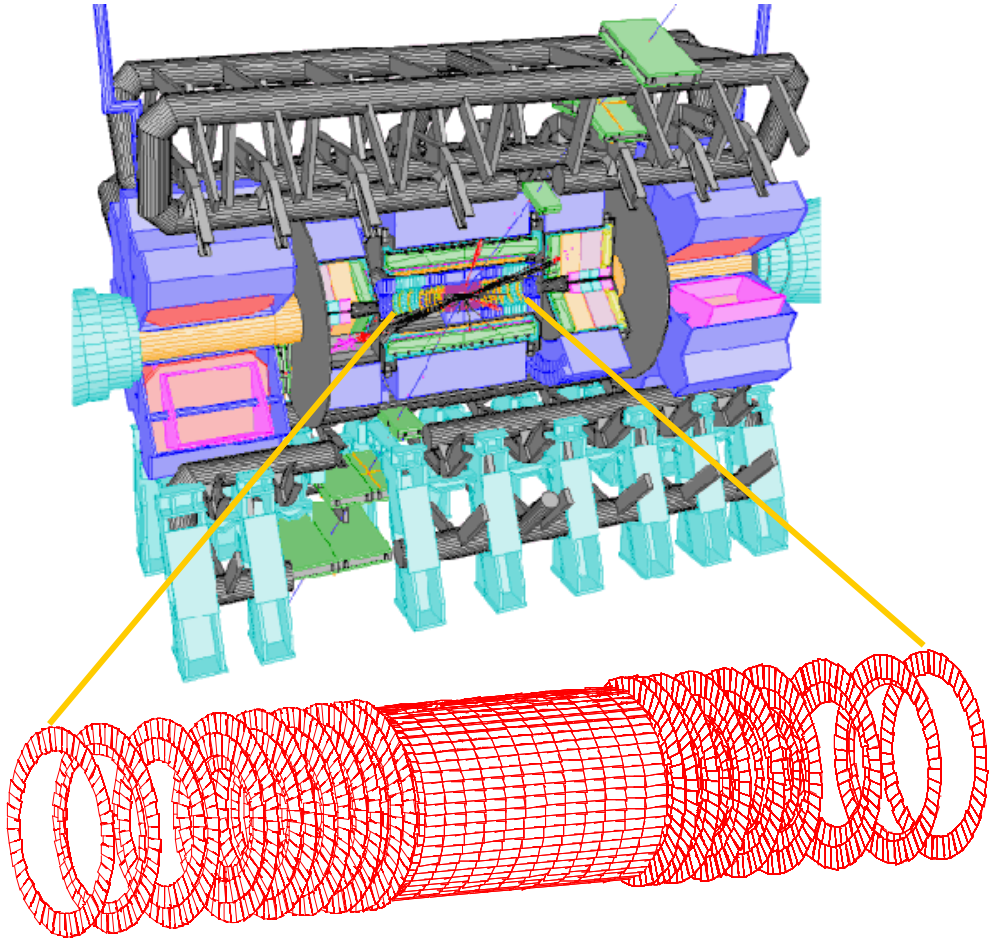
9th Topical Seminar on Innovative Particle and Radiation Detectors
23 - 26 May 2004 Siena

The ATLAS Silicon Microstrip Tracker

Zdenek Dolezal,
Charles University at Prague, for the ATLAS SCT Collaboration

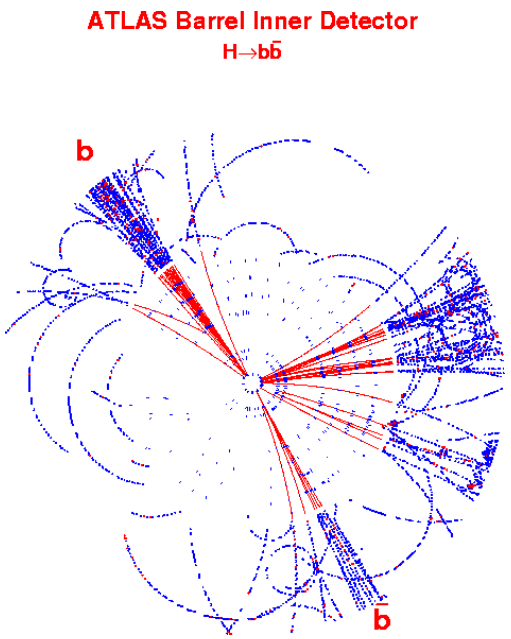
- introduction
- system design
- sensors
- module design
- electronics
- hybrids
- construction
- integration



LHC means high rate and high multiplicity

at full luminosity $L=10^{34}$ cm^{-2} s^{-1}:

- ~23 overlapping interactions in each bunch crossing every 25 ns (= 40 MHz)
- inside tracker acceptance ($|\eta|<2.5$) 750 charged tracks per bunch crossing
- per year: ~5×10^{14} bb; ~10^{14} tt; ~20,000 higgs; but also ~10^{16} inelastic collisions
- severe radiation damage to detectors
- detector requirements: speed, granularity, radiation hardness

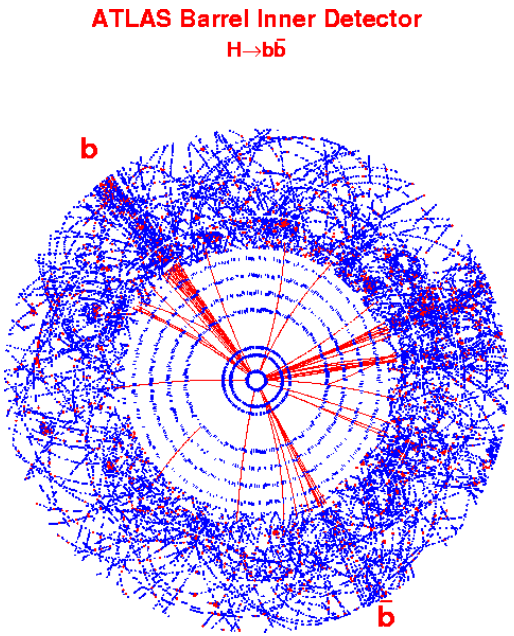


a H->bb event

LHC means high rate and high multiplicity

at full luminosity $L=10^{34}$ cm^{-2} s^{-1}:

- ~23 overlapping interactions in each bunch crossing every 25 ns (= 40 MHz)
- inside tracker acceptance ($|\eta|<2.5$) 750 charged tracks per bunch crossing
- per year: ~5×10^{14} bb; ~10^{14} tt; ~20,000 higgs; but also ~10^{16} inelastic collisions
- severe radiation damage to detectors
- detector requirements: speed, granularity, radiation hardness

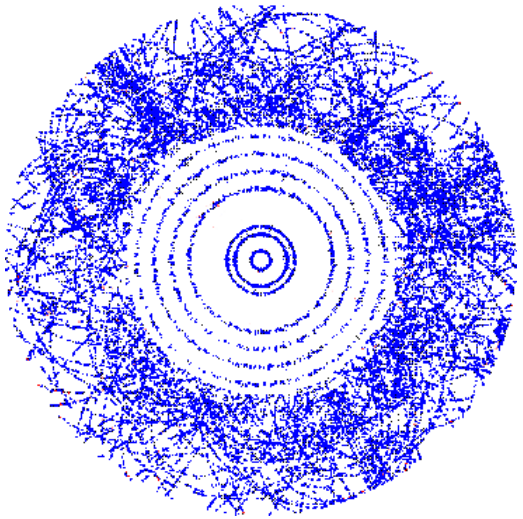


a H->bb event as observed at high luminosity (22 minimum bias events added)

LHC means high rate and high multiplicity

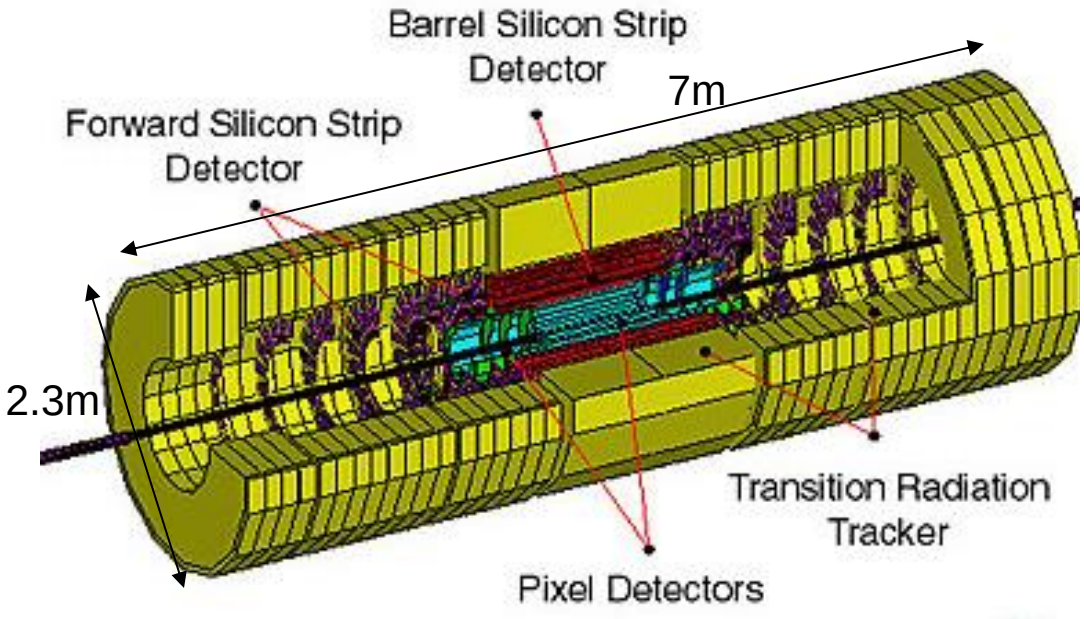
at full luminosity $L=10^{34}$ cm^{-2} s^{-1}:

- ~23 overlapping interactions in each bunch crossing every 25 ns (= 40 MHz)
- inside tracker acceptance ($|\eta|<2.5$) 750 charged tracks per bunch crossing
- per year: ~5×10^{14} bb; ~10^{14} tt; ~20,000 higgs; but also ~10^{16} inelastic collisions
- severe radiation damage to detectors
- detector requirements: speed, granularity, radiation hardness



a H->bb event as observed at high luminosity (22 minimum bias events added)

ATLAS Inner Tracker



system	area (m^2)	resolution (μm)	channels (10^6)
Pixel	2.3	12 / 66	140
SCT	61.1	16 / 580	6.2
TRT		170 per straw	0.42

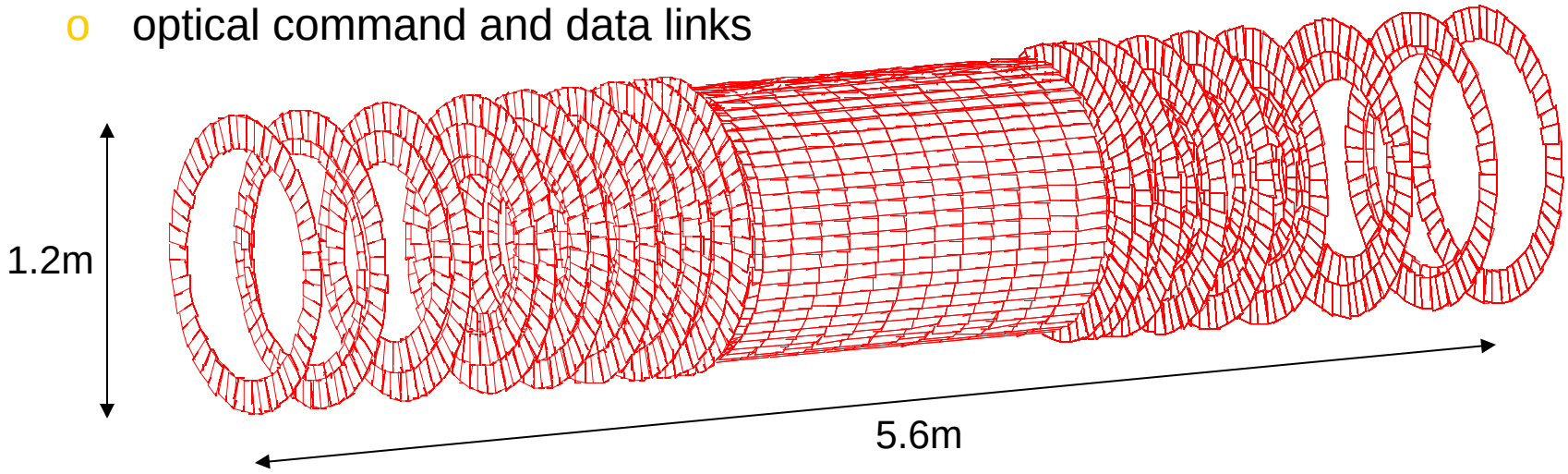
inside a solenoid providing 2T magnetic filed

Performance:

- rapidity coverage: $|\eta| < 2.5$
- momentum resolution for isolated leptons: $\Delta p_T / p_T \sim 0.1\ p_T$ (TeV)
- track reconstruction efficiency (high-p_T)
  - for isolated tracks $\varepsilon > 95\%$, within jets $\varepsilon > 90\%$,
  - ghost tracks < 1% (for isolated tracks)
- impact parameter resolution at high-p_T $\sigma_{r\text{-}\phi} < 20\ \mu m$, $\sigma_z < 100\ \mu m$
- low material budget for tracker and ECAL performances
- lifetime > 10 LHC years

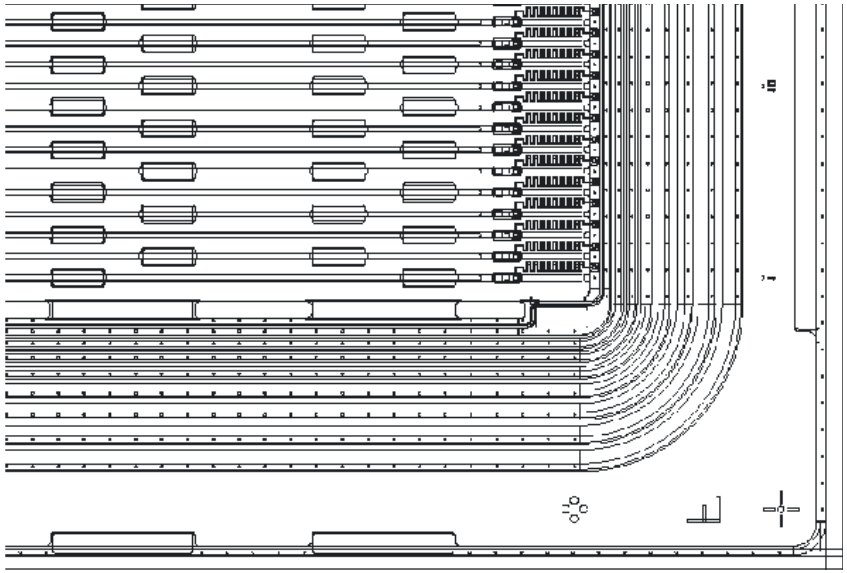
ATLAS Silicon Microstrip Tracker SCT

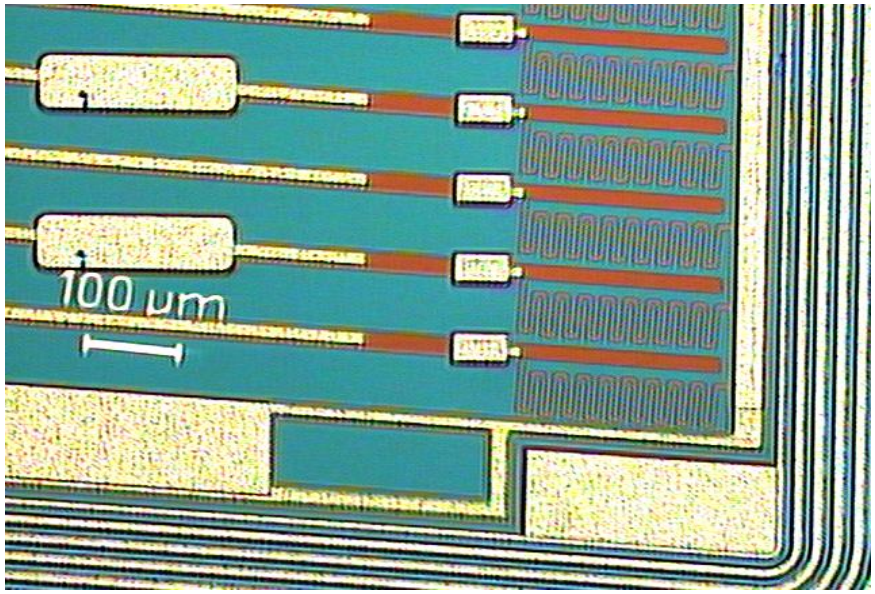
- 4 barrel layers
  - barrel radii: 300, 371, 443 and 514 mm; length 1600 mm
  - in total 2112 modules
- 2 x 9 forward disks
  - disk distance from z = 0: 835 - 2788 mm, radii: 259-560 mm
  - in total 1976 modules (3 rings: 40, 40, 52 modules each)
- all 4088 modules double sided
- 15,392 sensors of total 61.1m²
- total length of diode: 716 km
- 49,056 front-end chips, total 6.3 Mio. channels
- optical command and data links



ATLAS SCT Sensors

- p-on-n single sided detectors
- 285µm thick
- 2-8 kΩ.cm
- 4“ substrate
- barrel
  - 64x64mm²
  - 80µm pitch
- forward
  - 5 different wedge shaped sensors
  - radial strips
  - 50...90µm pitch
- 768 read-out strips
- AC coupled to read-out
- polysilicon or implanted resistors
- multiguard structure for HV stability
- ~20000 sensors needed
- produced in Hamatsu and CIS



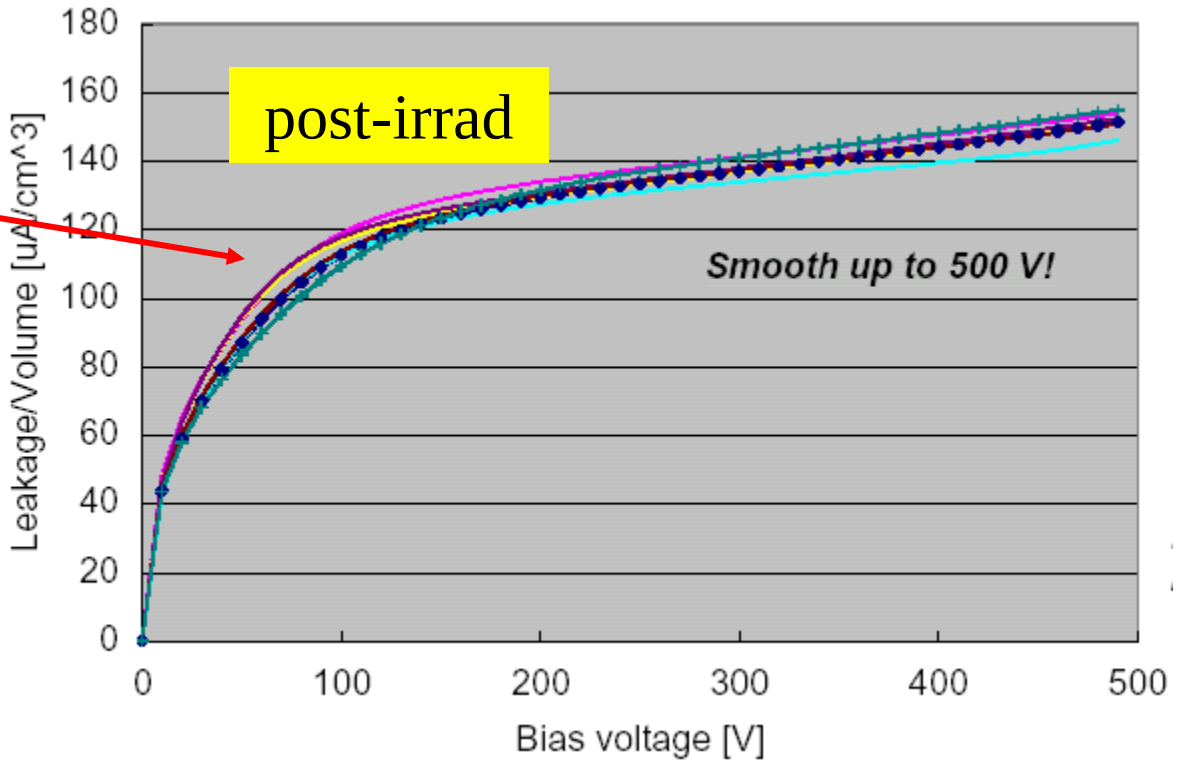


Radiation Environment

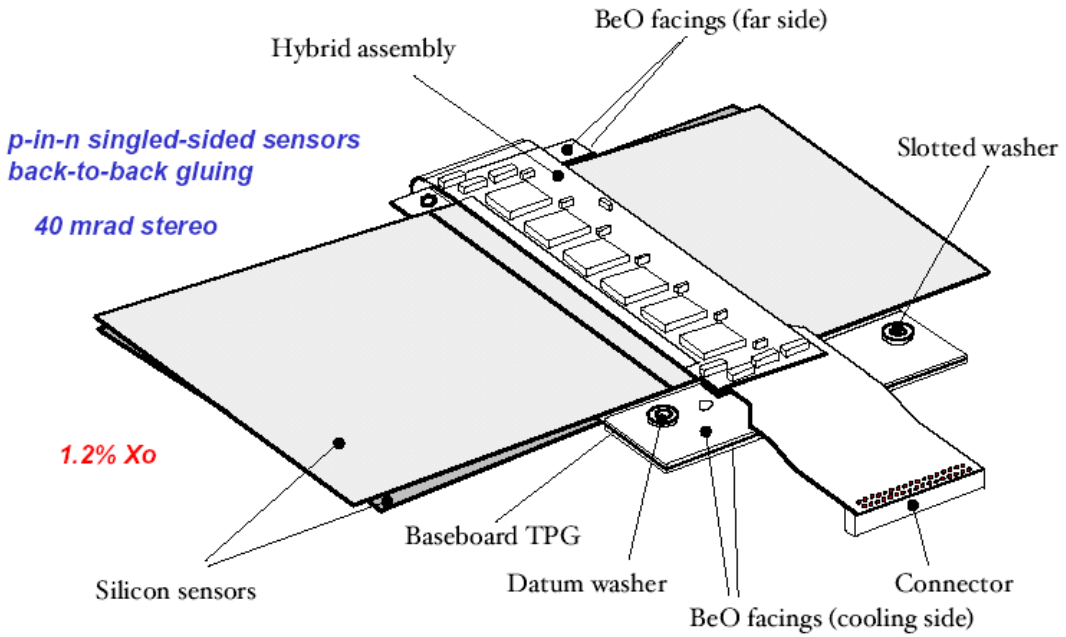
- in SCT volume up to
- **1.2x10^{14} 1-MeV-n/cm^2**
- **5 Mrad** for **10 years** of LHC running

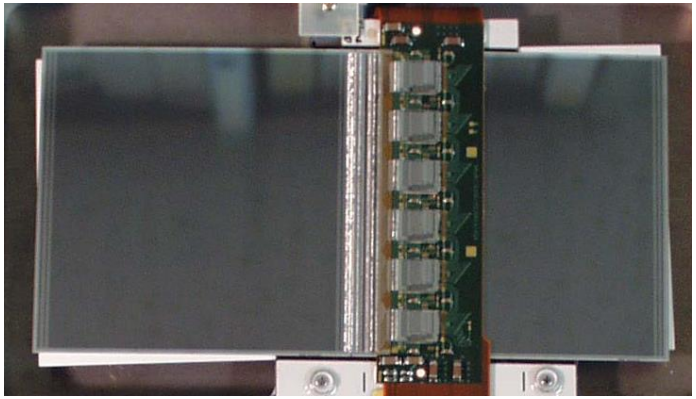
Sensors

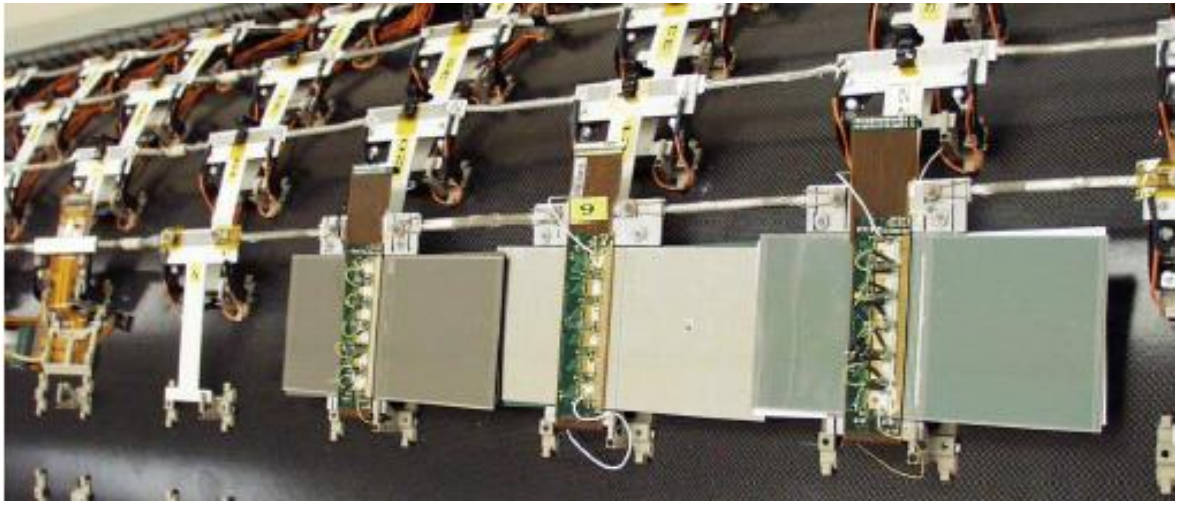
- IV curves for SCT detectors after **3x10^{14}** p/cm^2 (7 days annealing at 25°C)
- Spec: **<250** µA at 450V and -18°C
- Currents after irradiation 3 orders of magnitude higher



Barrel Modules



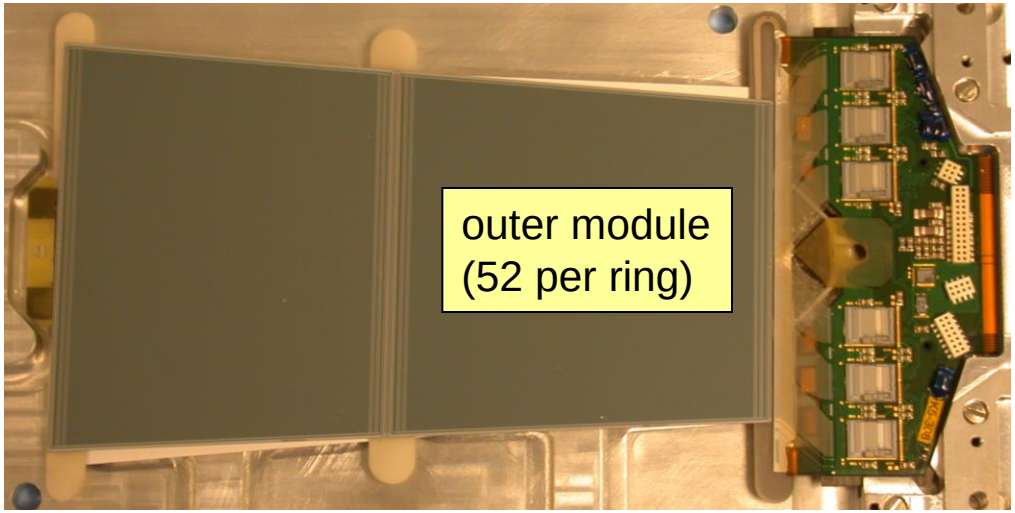


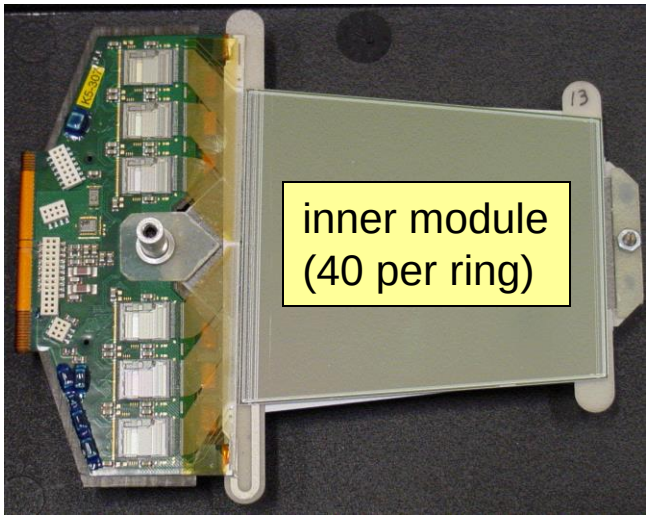


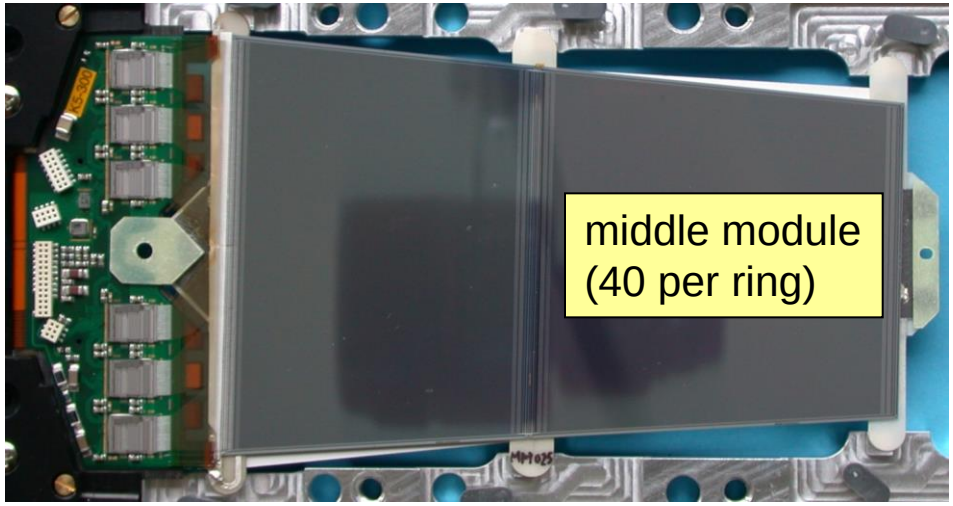
Endcap Disks covered by 3 Rings of Modules

- 9 disks in each endcap, ~1.2m diameter CF structure
- 132 detector modules on a full disk, 1976 endcap modules in total
- modules have central mounting and cooling point →module overlap easy
- each module serviced by a power tape and 3 optical fibres
- evaporative cooling circuits serve up to 13 modules

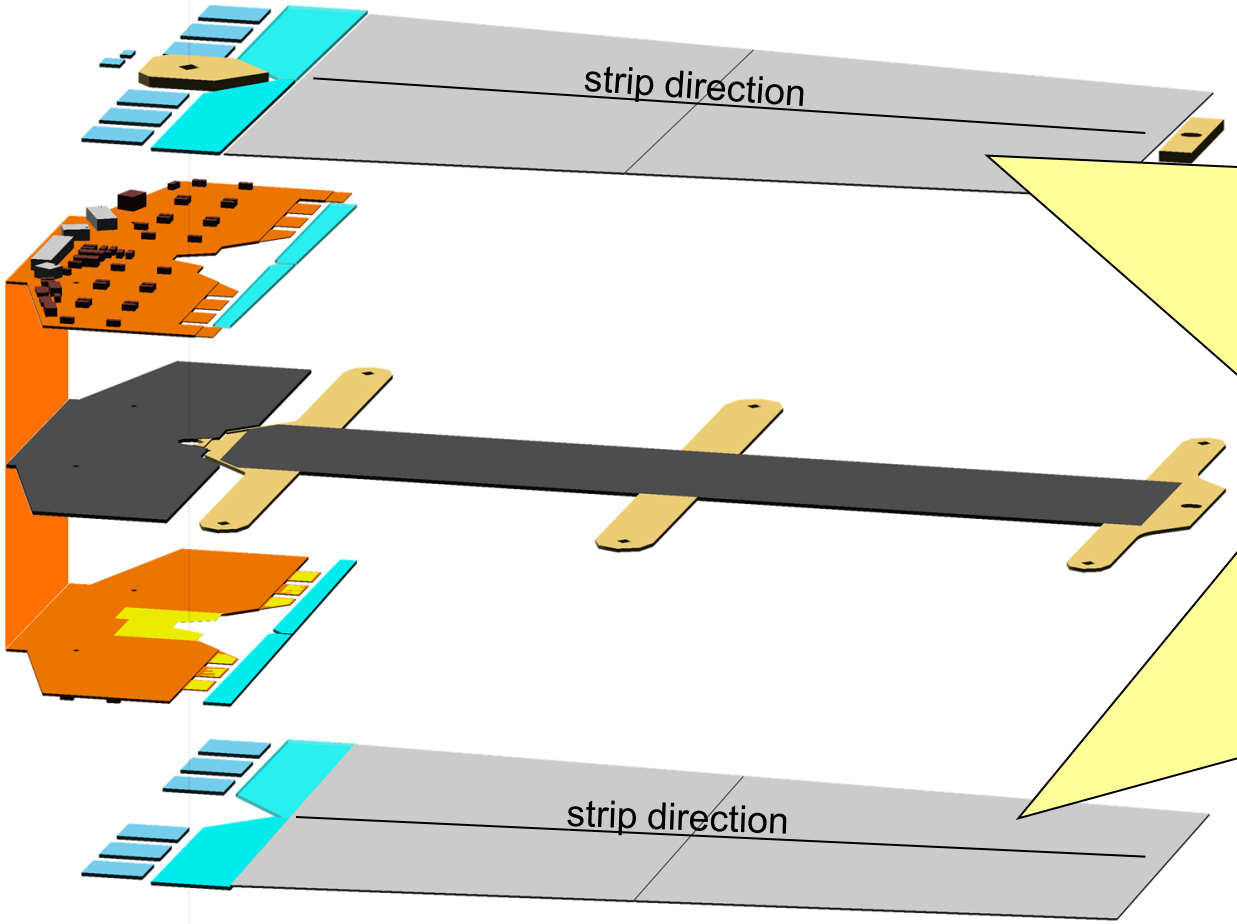
3 Module Types







Endcap Module Design: Silicon Sensors



4 wedge shape silicon sensors

768 p-in-n strips, single sided

supplied by Hamamatsu and CiS

sensor alignment < 5µm

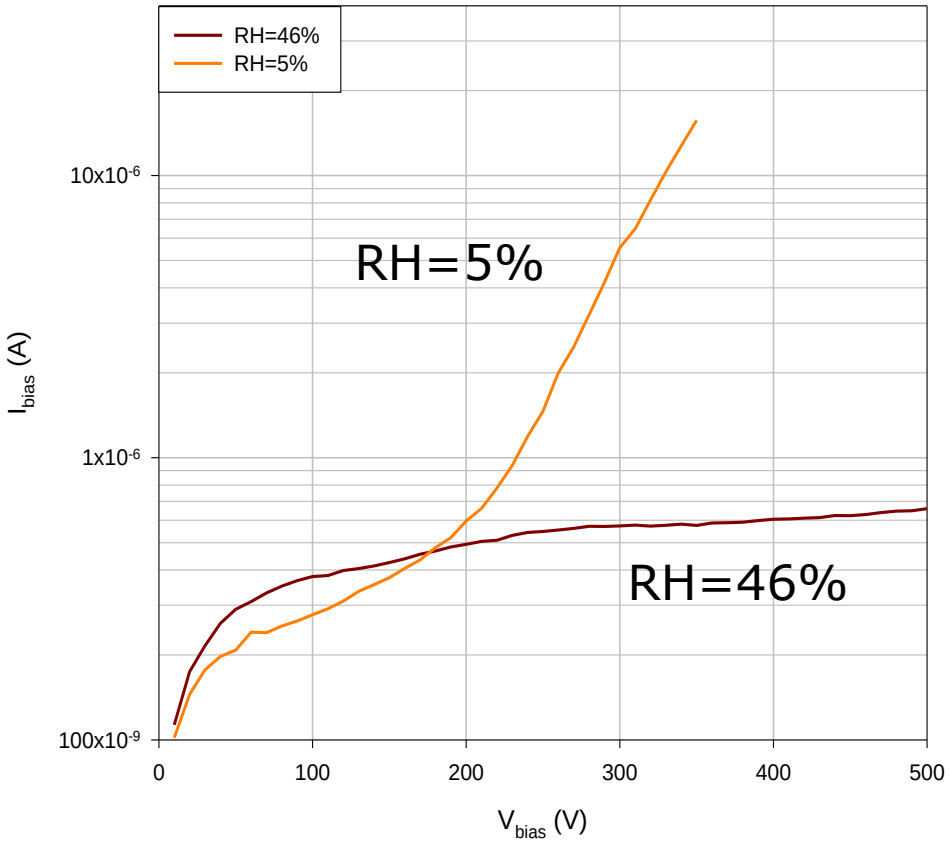
40mrad stereo angle

Endcap Module Design: Silicon Sensors

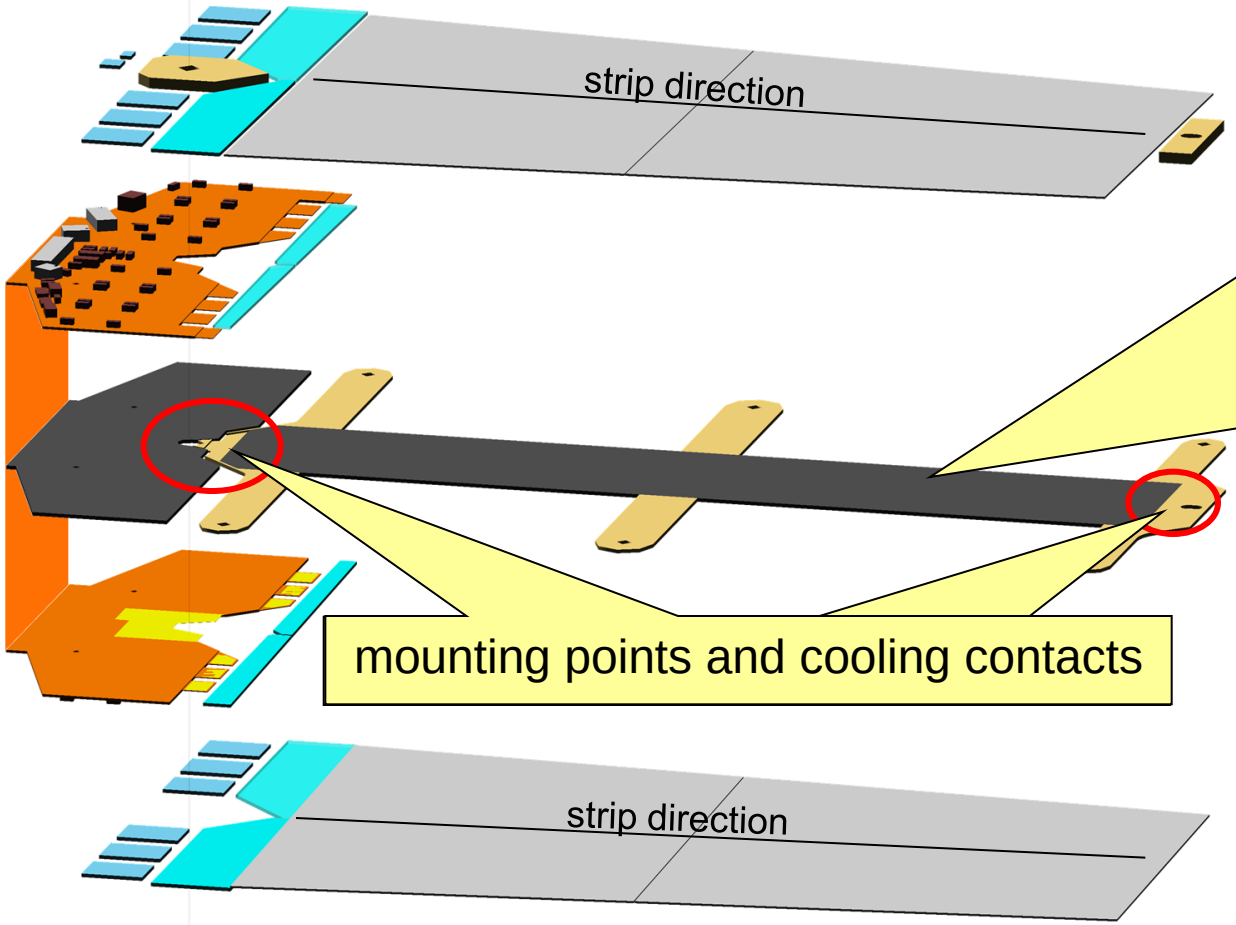
Recent 'surprise'

CIS detectors breakdown when operated in dry Nitrogen.

Study underway to establish safe selection procedure, QA regime and operating parameters.



Endcap Module Design: „Spine“



sensors are glued to „spine“:

TPG bar for heat removal (1700 W/m/K)

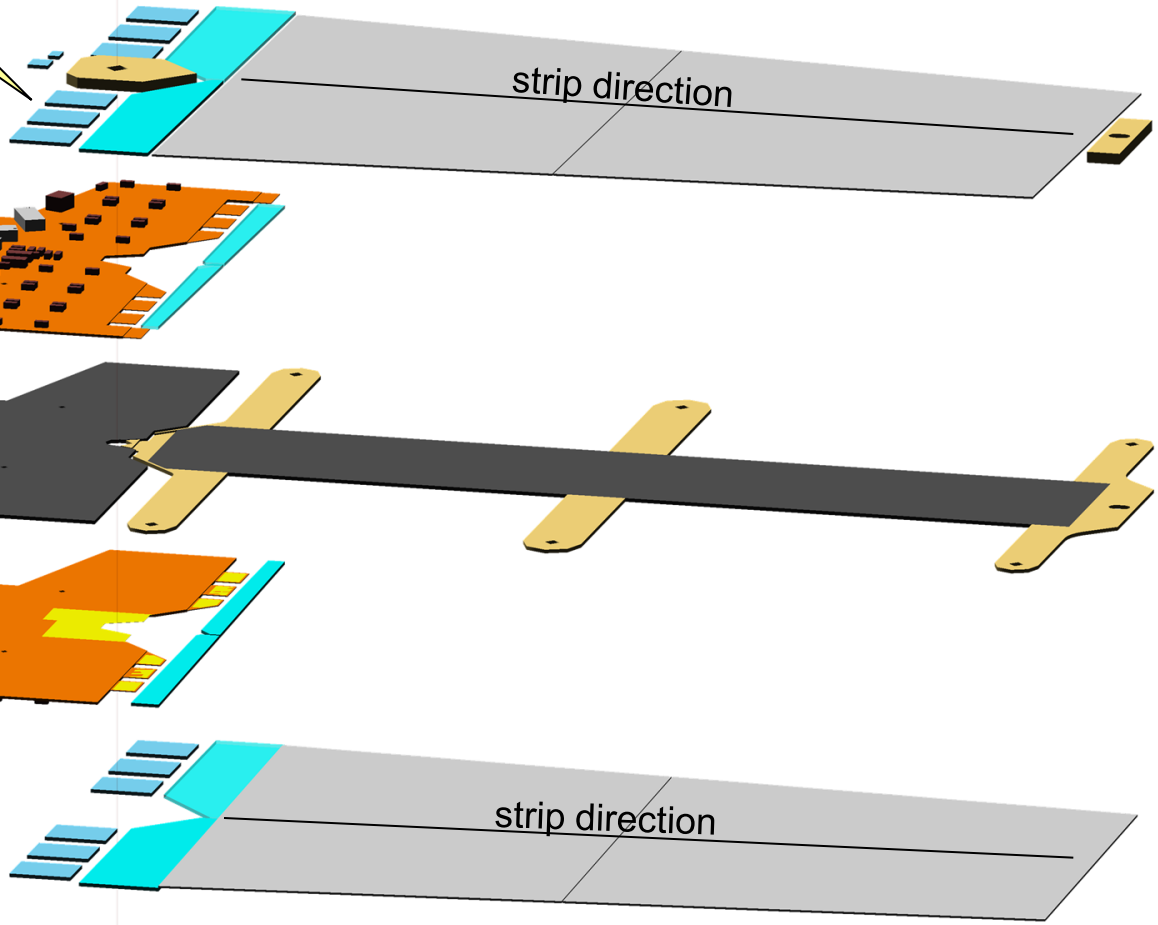
AlN wings for mechanical stability

Endcap Module Design: Hybrid

12 ABCD3TA binary read-out chips (DMILL)

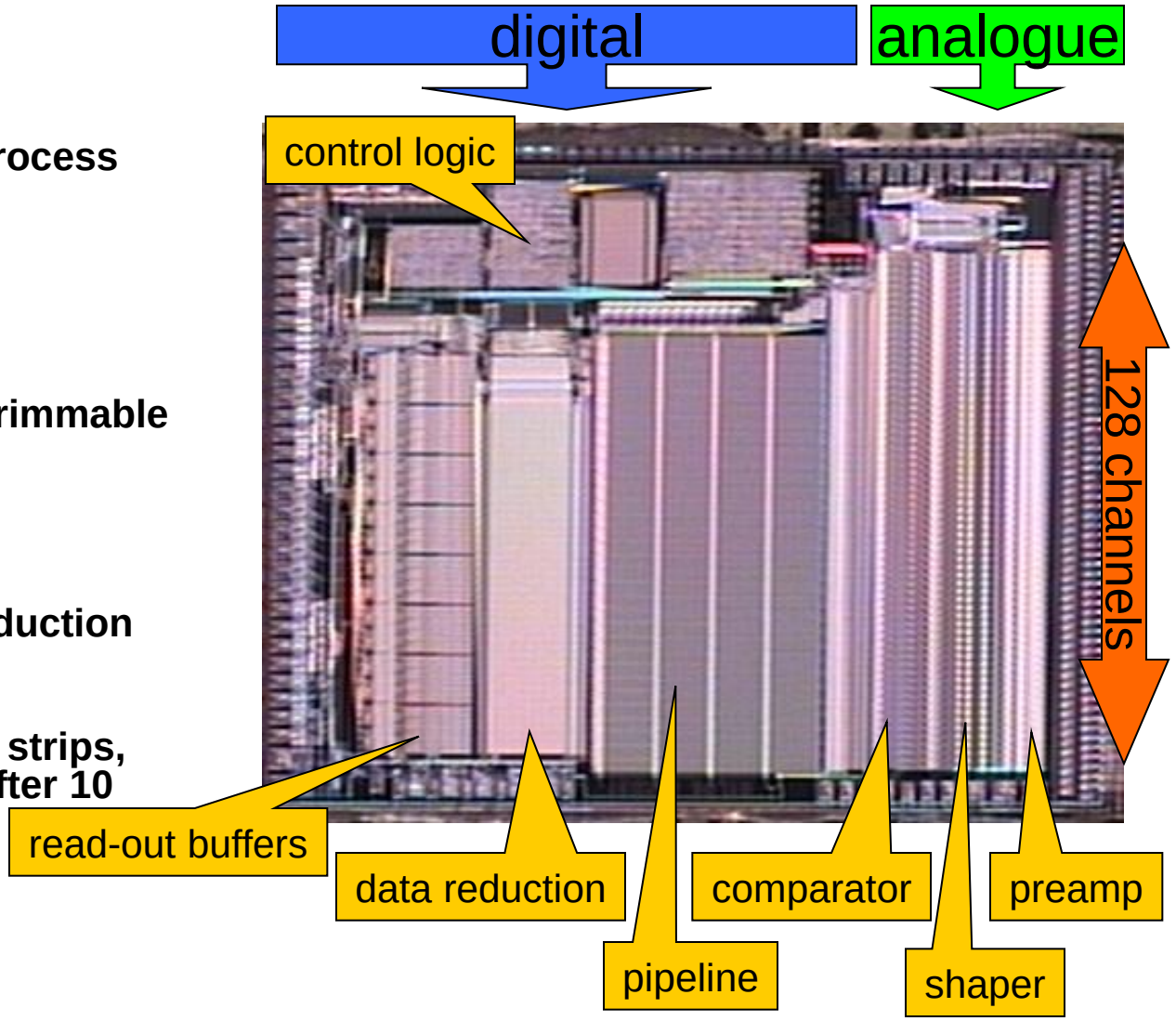
hybrid connected to sensors only by fanins → thermal split

hybrid: flex circuit on carbon-carbon



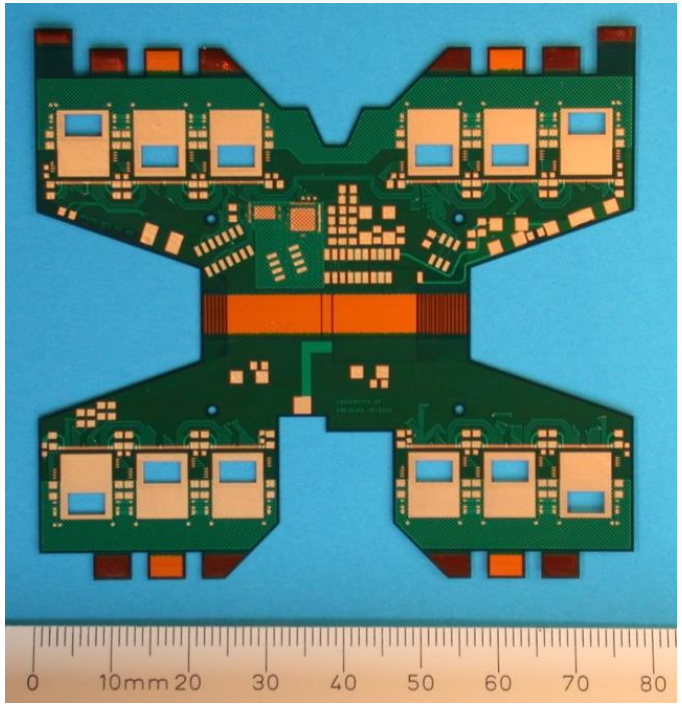
Front-End ASIC ABCD3T

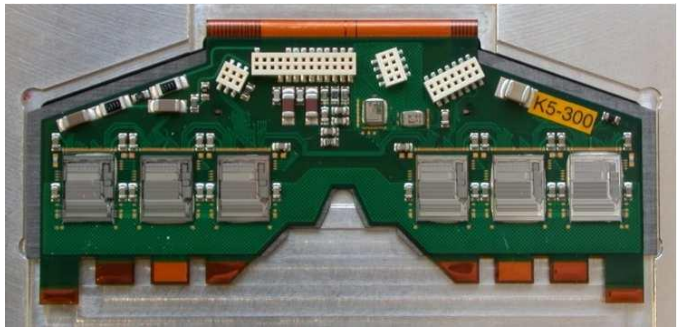
- **binary read-out**
- **128 channels**
- **DMILL radiation hard process**
- **bipolar input transistor**
- **shaping time ~20ns**
- **comparator threshold trimmable for each channel**
- **132 cell pipeline**
- **edge detection, data reduction and multiplexing**
- **ENC ~ 1500 e for 12 cm strips, increasing to ~1800 e after 10 years of irradiation**
- **~4 mW/channel**



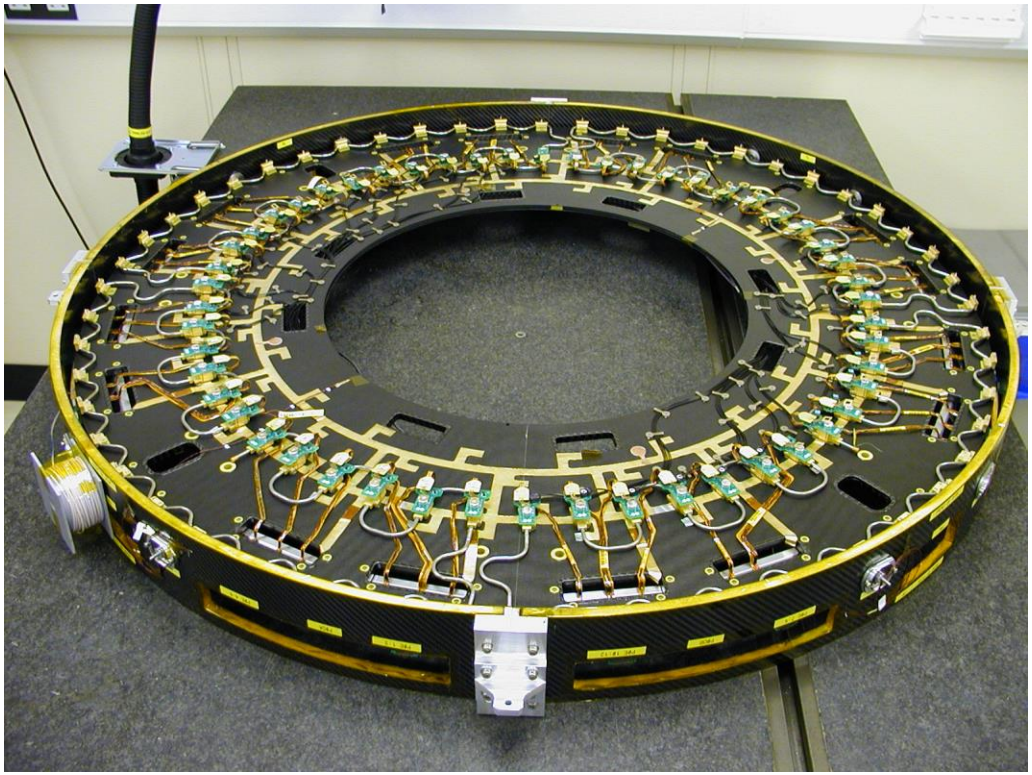
Hybrid

- development of hybrid was critical and needed several iterations
- very low impedance is key for successful operation of binary ABCD chips
- requirements:
  - double sided, 12 readout chips
  - supply well filtered analogue/digital power
  - com/data lines and drivers for optical link
  - detector bias supply (up to 500V)
  - heat removal (7W)
  - low mass
- implementation:
  - 6 layer copper/Kapton flex circuit
  - ~75µm feature size, ~3000 micro vias
  - flex folded around carbon-carbon substrate
  - full assembly and basic testing in industry
- similar technology used for barrel hybrid

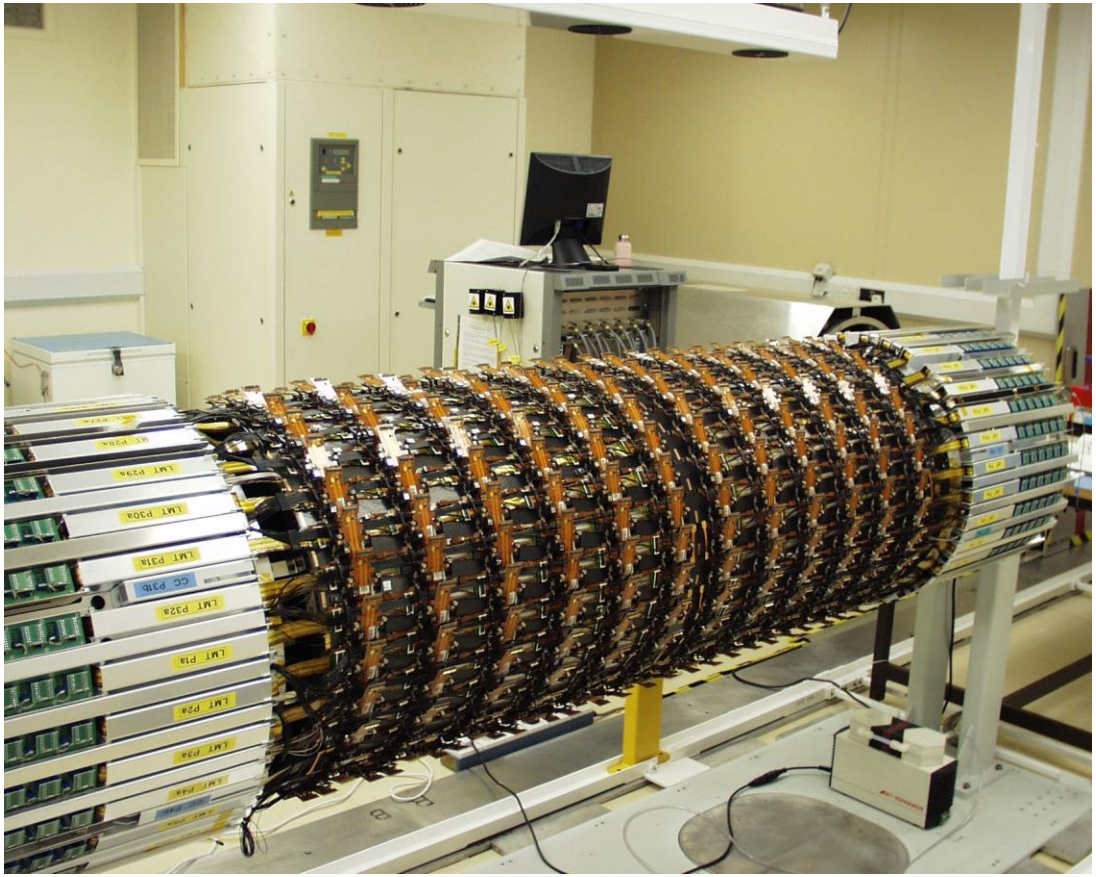


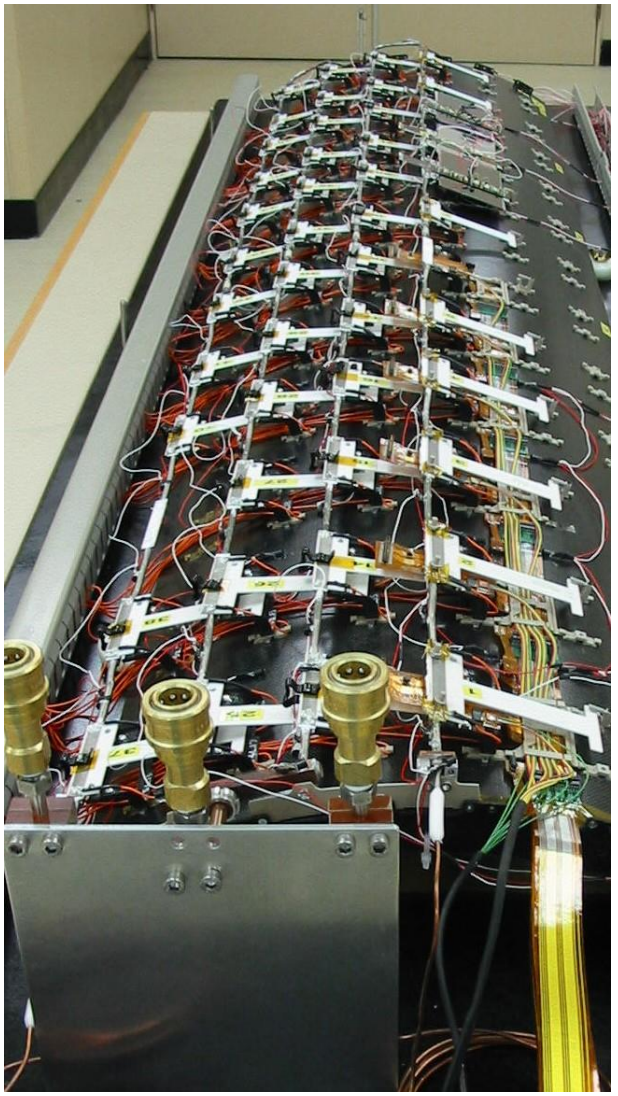


End Cap: infrastructure



Barrel: infrastructure

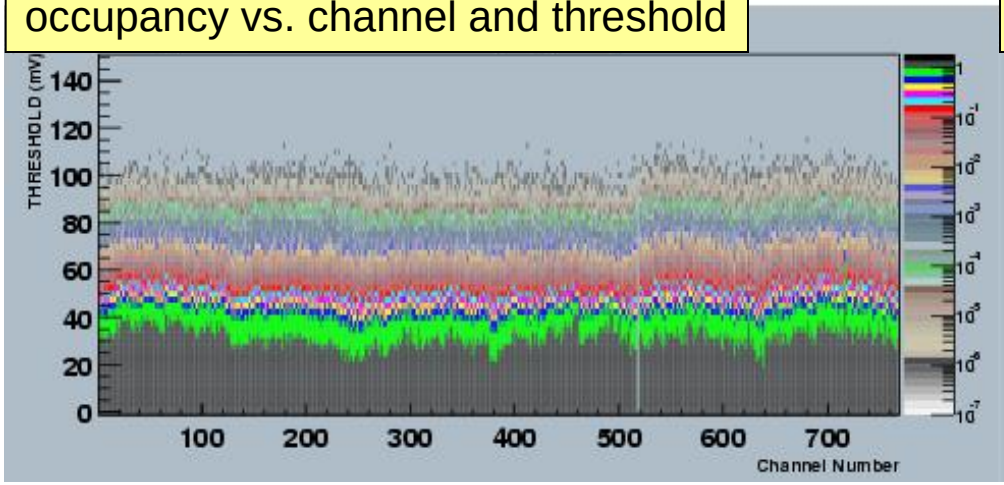




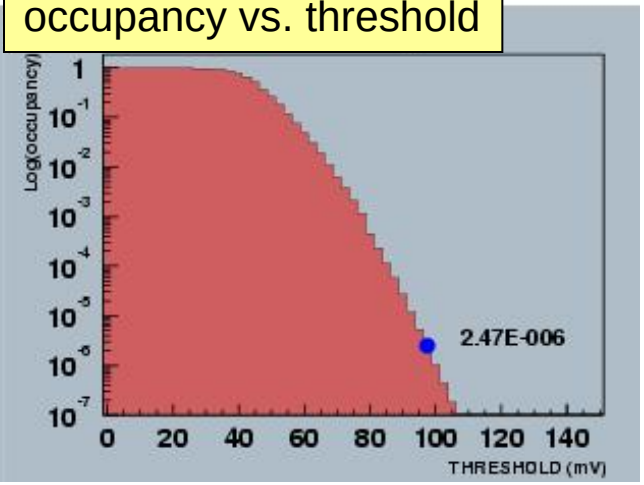
Electrical Performance

- binary front-end chip → occupancy vs. threshold → „s-curves“
- signal height and noise are derived from „s-curves“
- relevant for operation: hit efficiency and noise occupancy
- noise occupancy determined by
  - front-end noise (fixed for given ASIC and detector)
  - channel-to-channel threshold variations (threshold trim per channel)
  - additional noise: common mode, feedback etc. (the difficult part...)

occupancy vs. channel and threshold

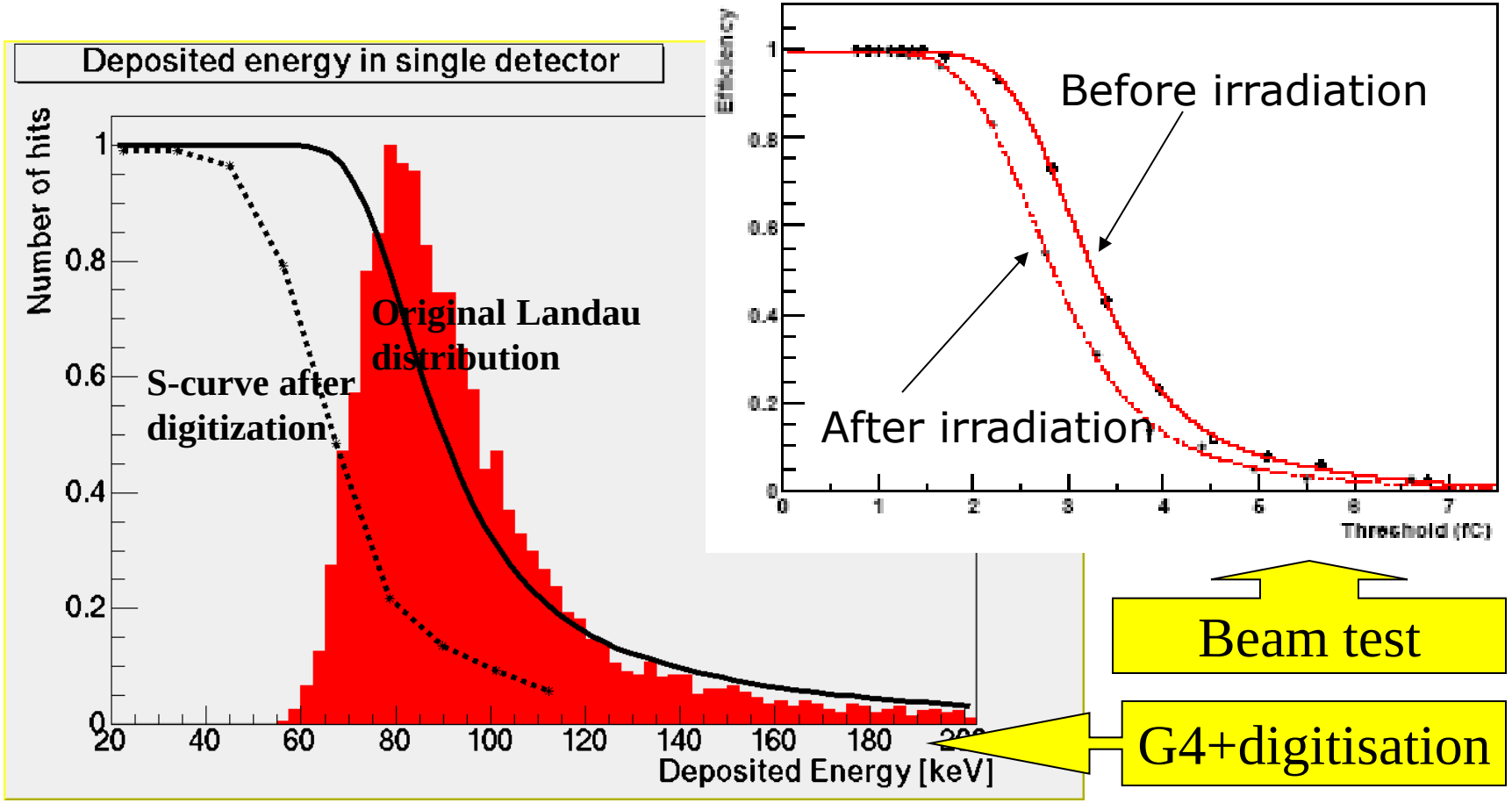


occupancy vs. threshold



Signal determination

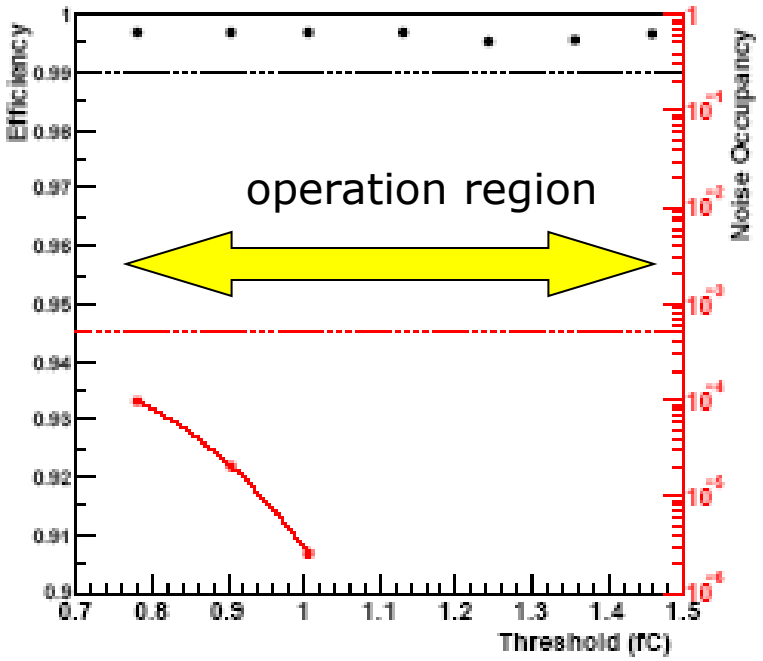
- binary front-end chip → occupancy vs. threshold → „s-curves“
- Measured signal height (charge collected) affected by charge sharing (charge under threshold lost ~20-30%)



Detection performance

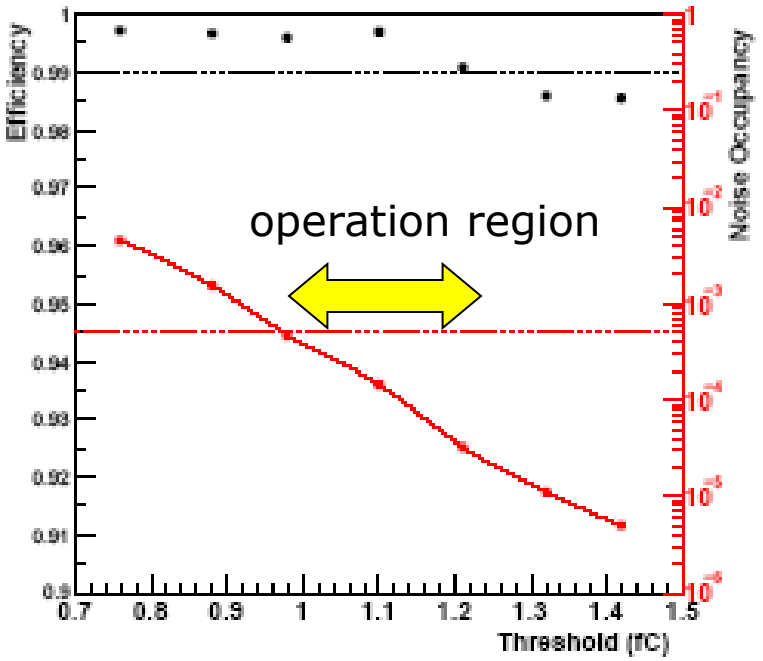
- binary front-end chip → occupancy vs. threshold → „s-curves“
- relevant for operation: hit efficiency and noise occupancy

Before irradiation

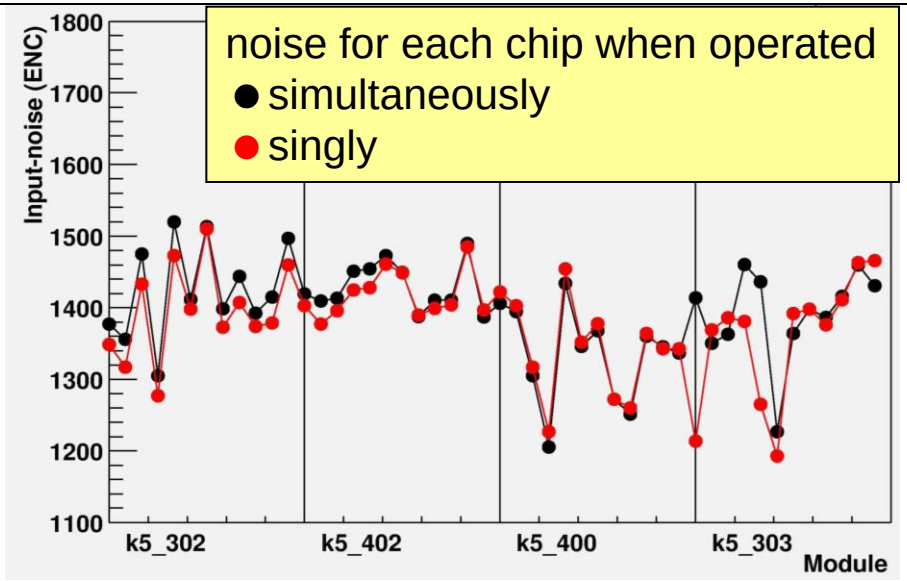


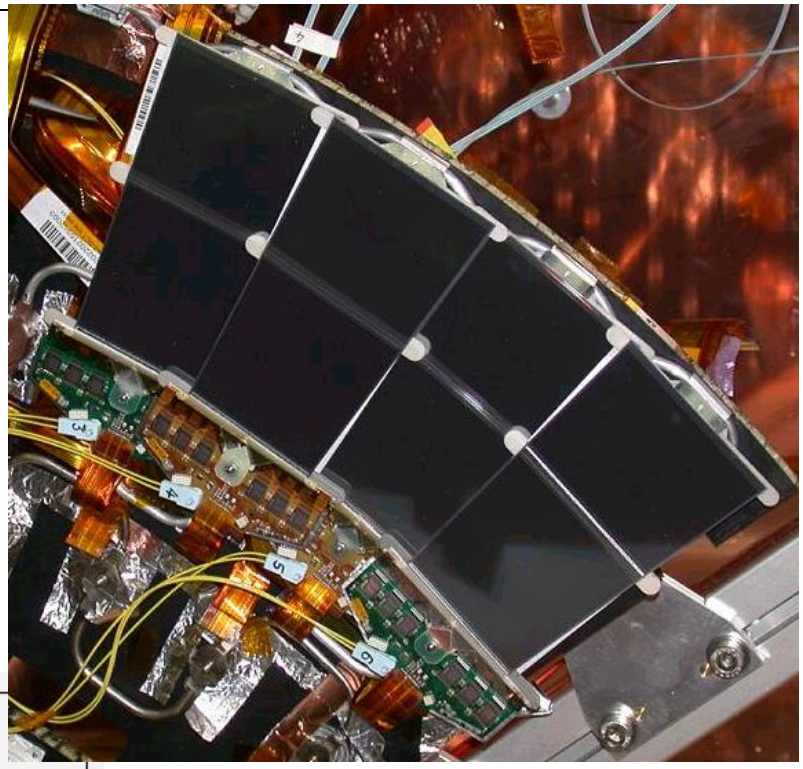
After irradiation

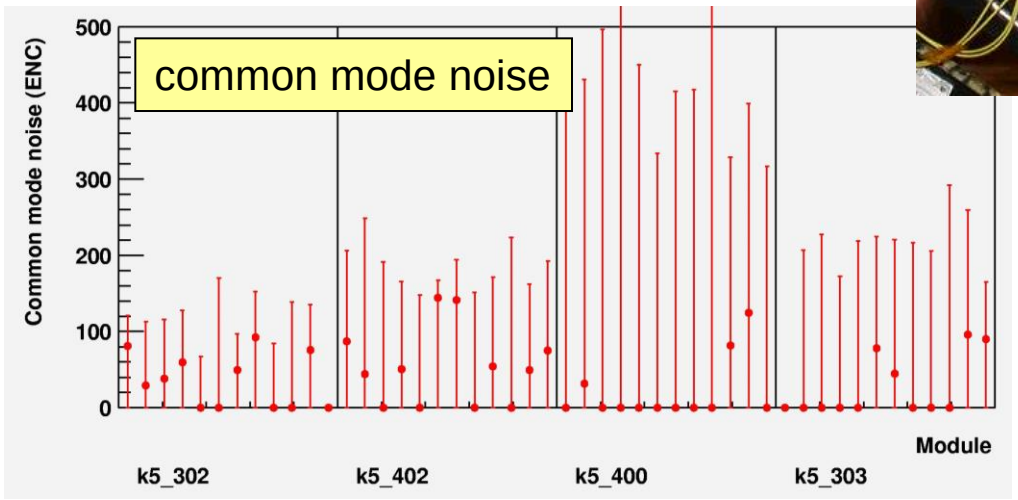
(28 GeV p 3×10^{14} cm^{-2})



System Test: 4 Modules on a Disk Sector







with 4 modules on disk

- no extra noise
- common mode noise negligible

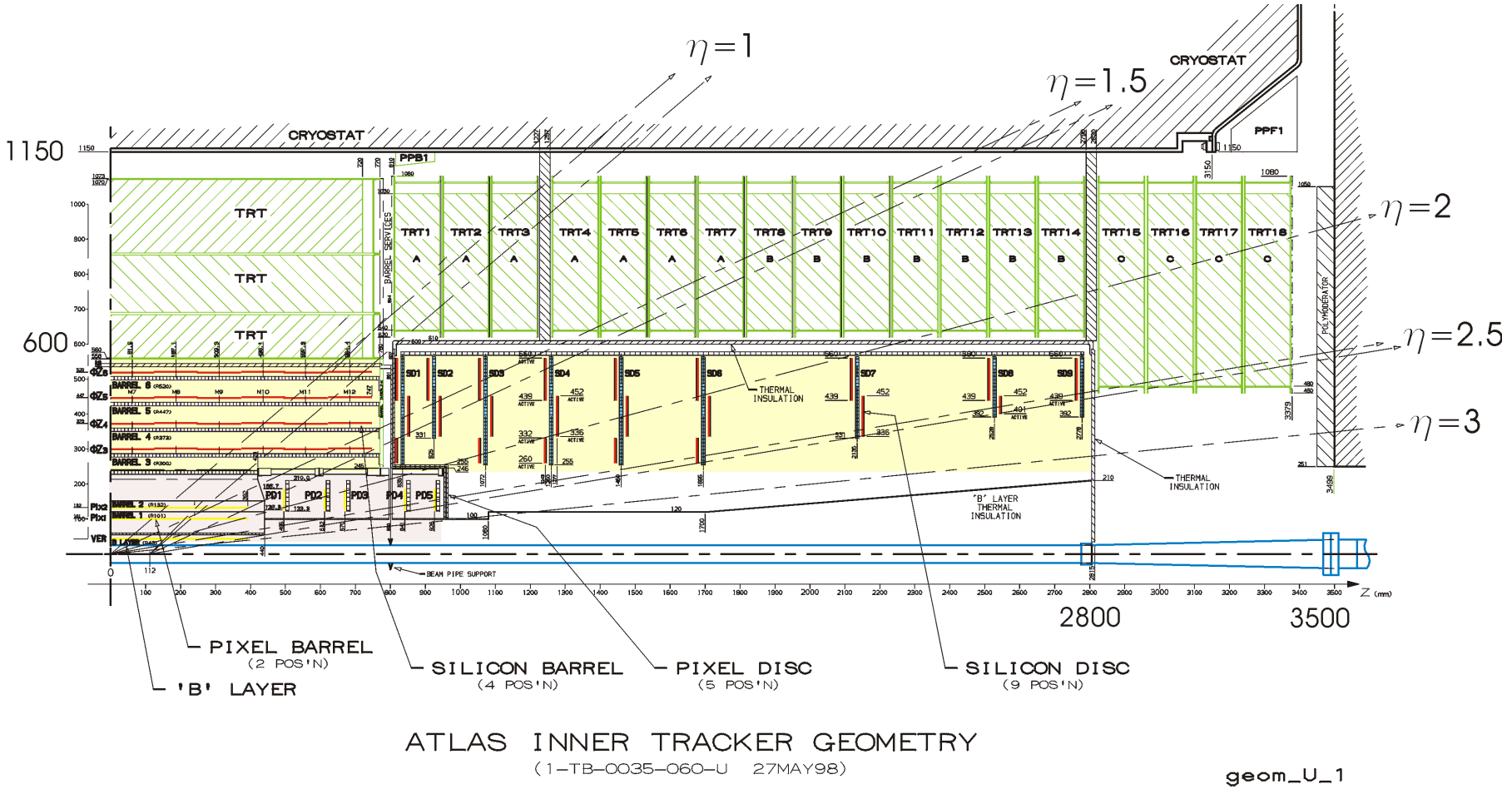
Production Scheme

- distributed, parallel production
- module production and QA (2001-2005):
  - barrel: KEK, RAL, Berkeley, Oslo
  - end cap: Manchester/Glasgow/Liverpool, Valencia, MPI Munich/Prague, Freiburg, NIKHEF, Geneva/CERN, Melbourne
- mounting modules onto structures (2003 -2005):
  - barrel: KEK, Oxford
  - end cap: Liverpool, NIKHEF, Melbourne
- macro-assembly (2004 -2005):
  - integration of 4 barrels at CERN
  - mounting of disks into support cylinders at NIKHEF and CERN/UK
- SCT ready for installation in ATLAS: 2005

Summary and Current Status

- the ATLAS SCT is now in the production phase
- sensor fabrication is completed
- front-end electronics completed
- electronics hybrids production
- modules B: > 60% complete, E: > 10% complete
- off-detector electronics and services in prototyping
- cooling tested on prototypes
- barrel support almost complete
- forward support almost complete

ATLAS Inner Tracker

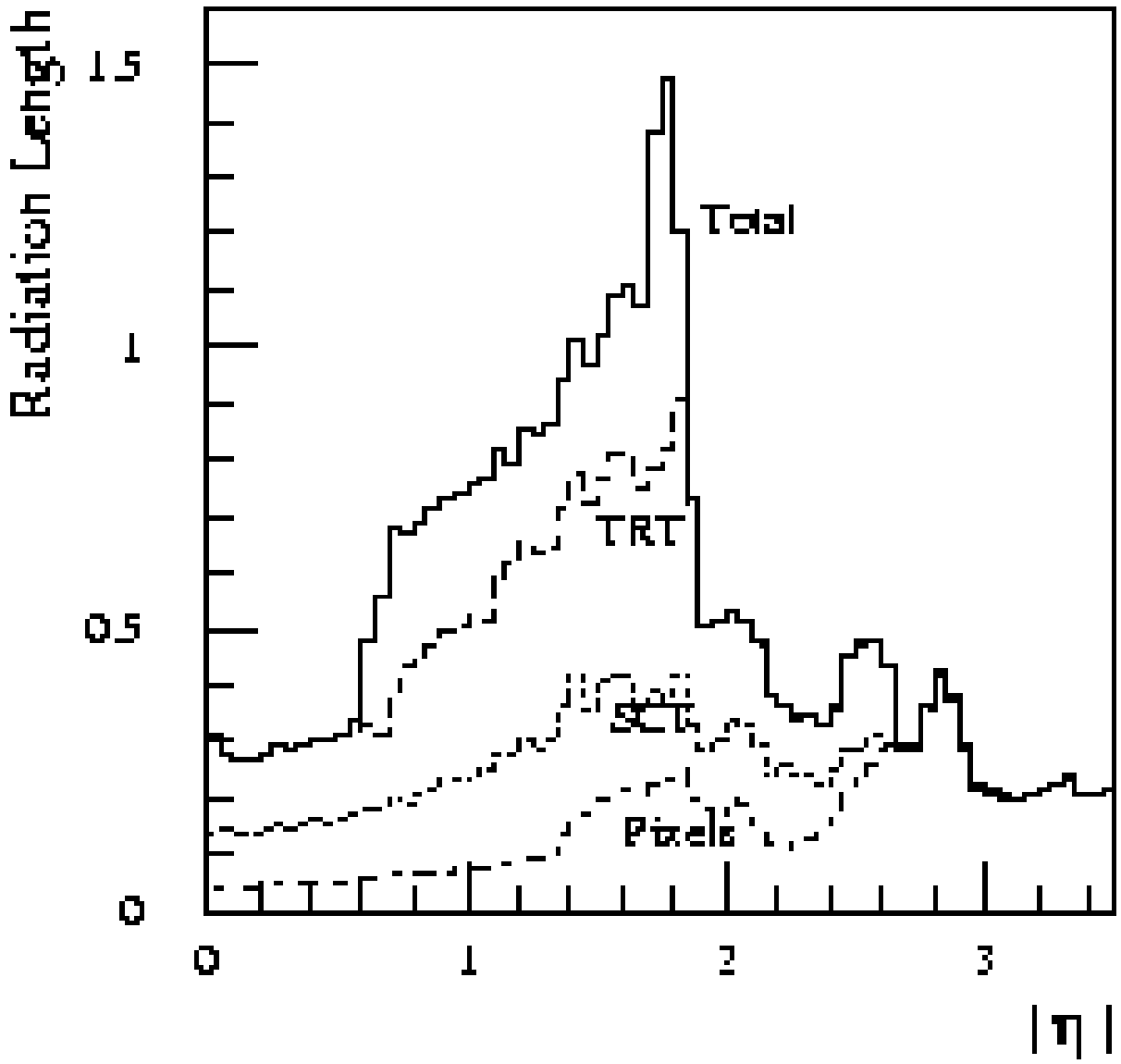


ATLAS INNER TRACKER GEOMETRY

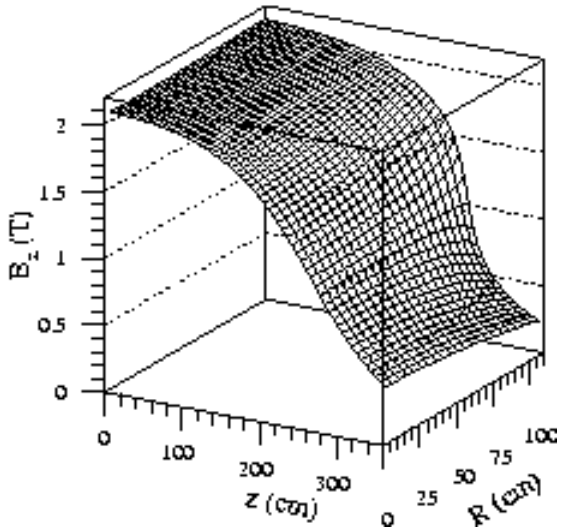
(1-TB-0035-060-U 27MAY98)

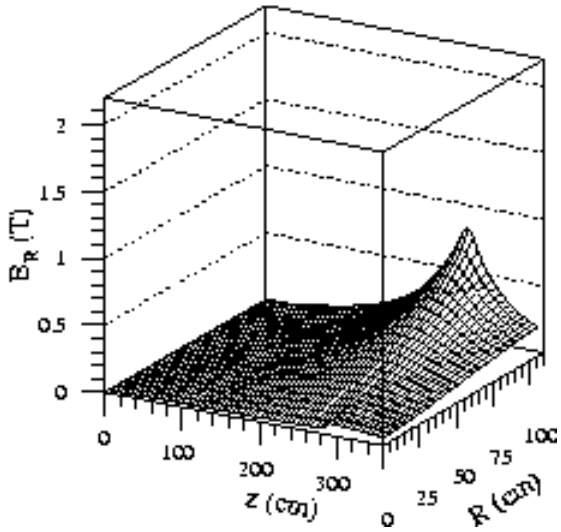
geom_U_1

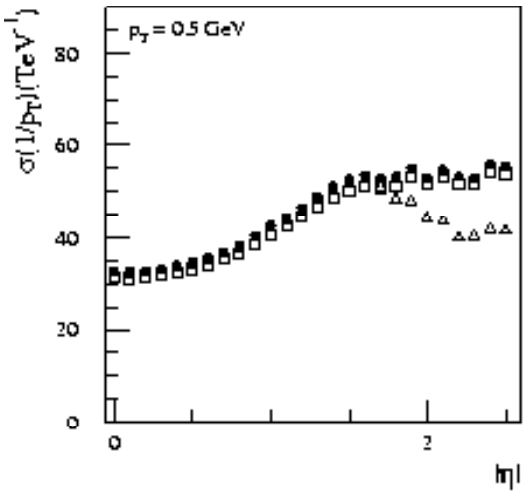
SCT Material Budget

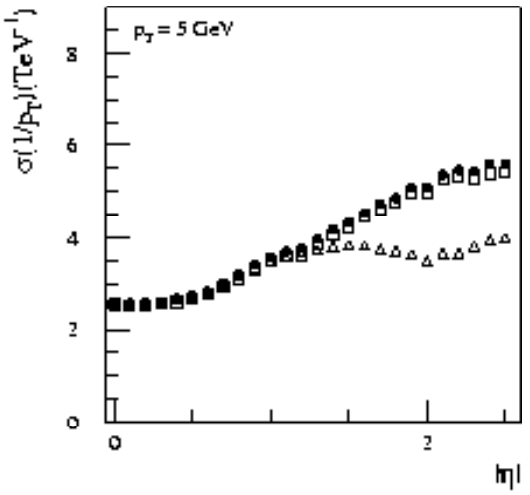


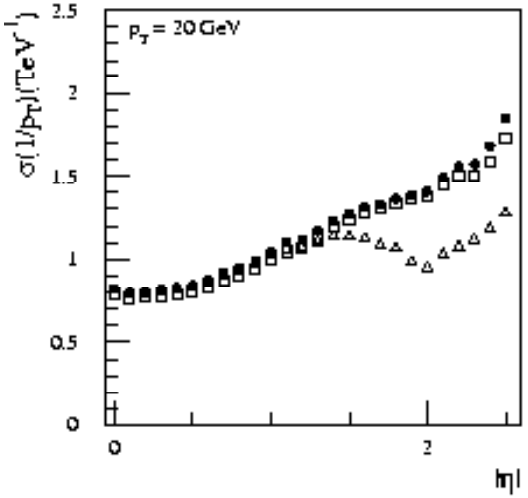
Magnetic Field and p_t Resolution

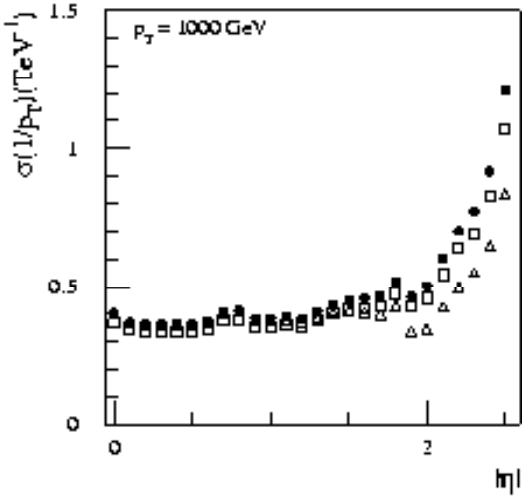






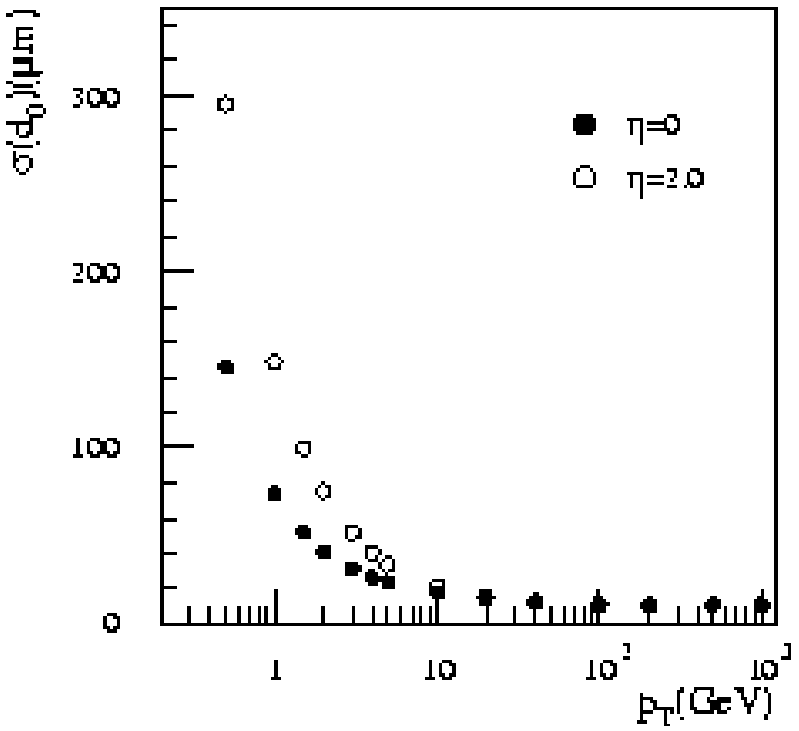


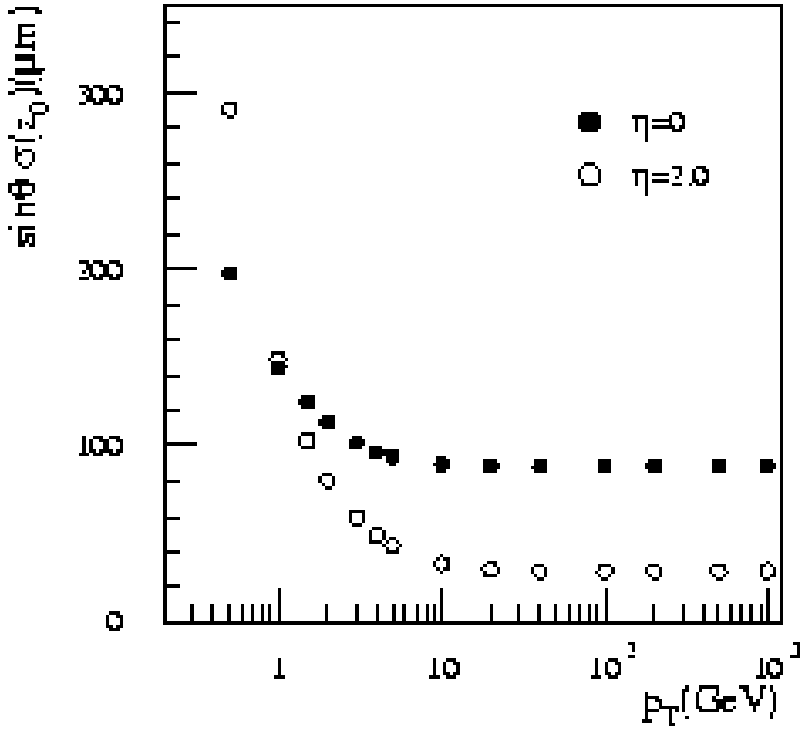




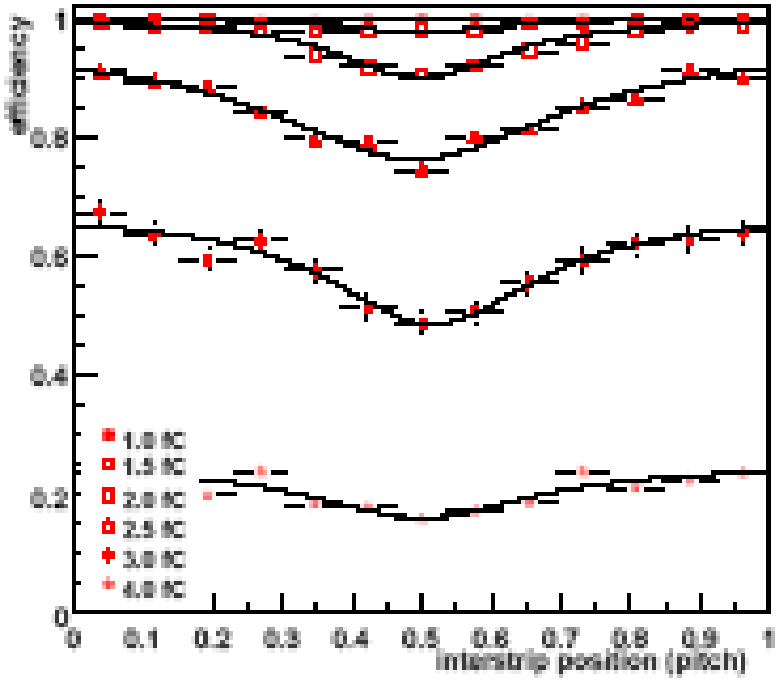
- p_t resolution as a function of |η| for muons of various momenta
- circles and squares show simulation for ATLAS solenoidal field, triangles for uniform field

Impact Parameter Resolution

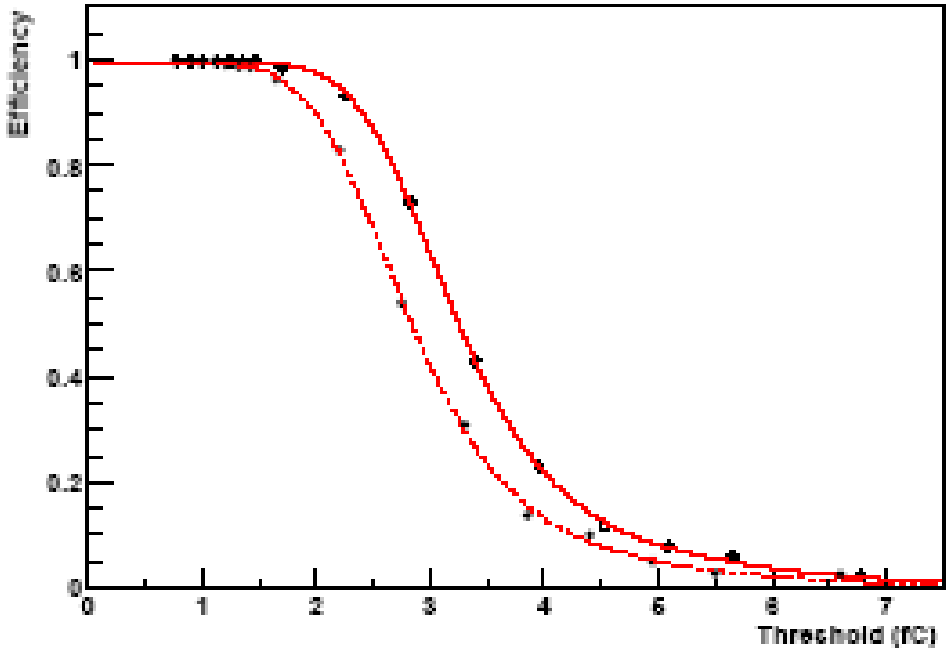




Beam test results



Efficiency vs interstrip position



Efficiency vs threshold

Before and after irradiation