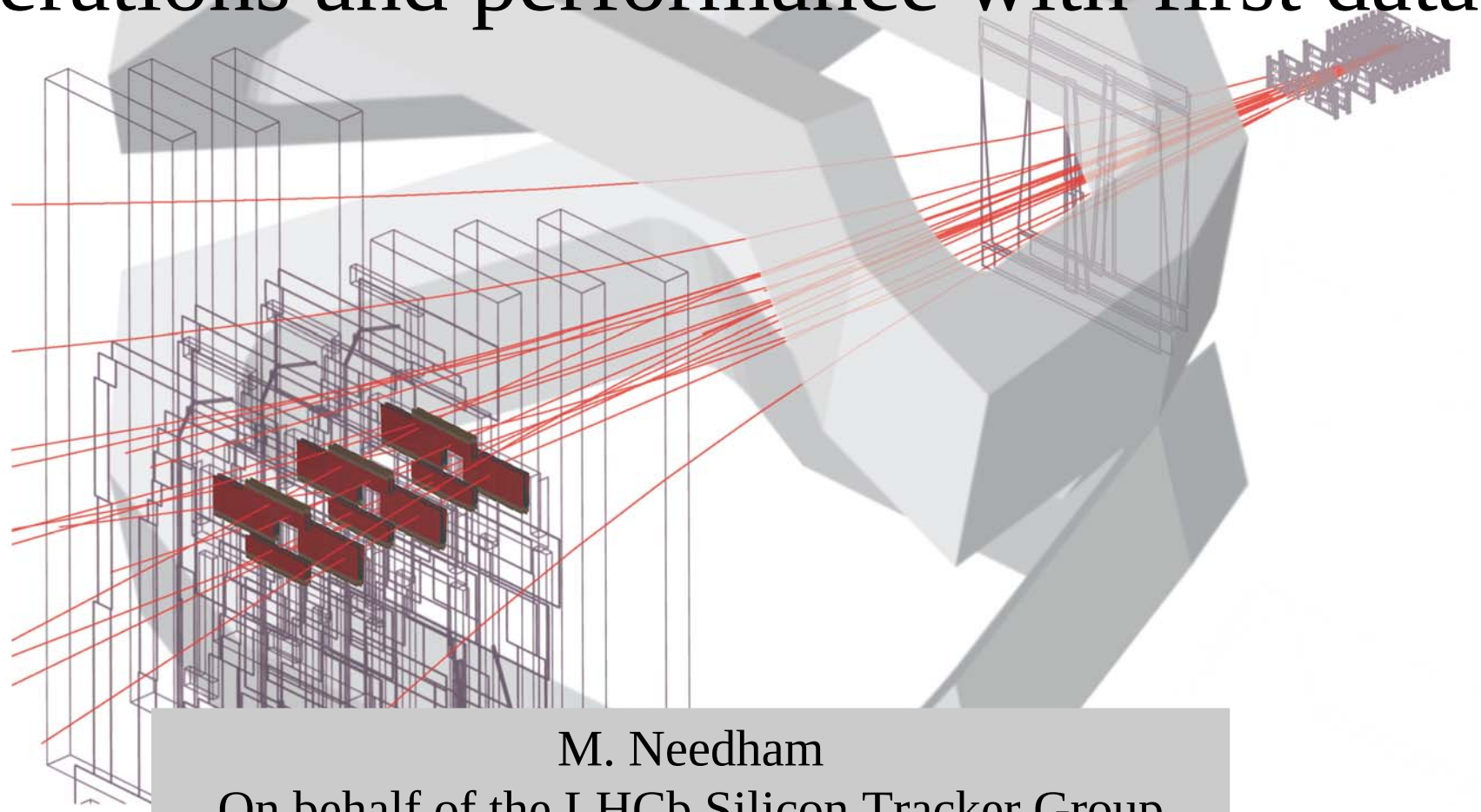
LHCb Silicon Tracker operations and performance with first data



M. Needham
On behalf of the LHCb Silicon Tracker Group
Vertex 2010, Loch Lomond 6th - 11th June 2010

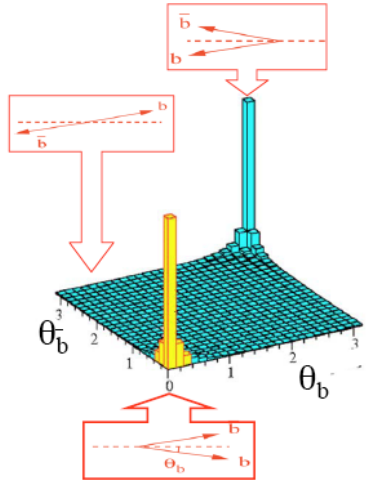
Outline

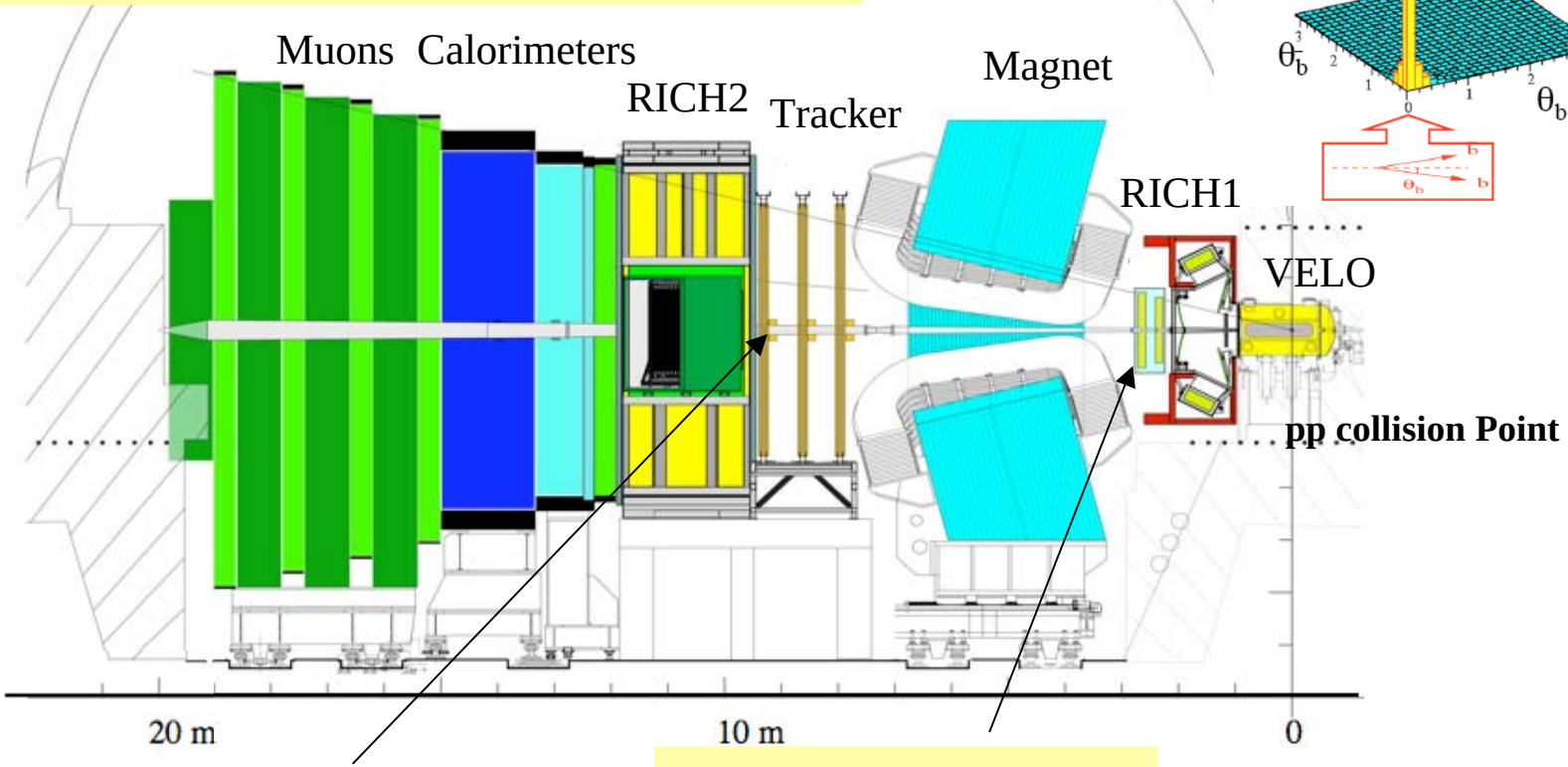
- Introduction
- Commissioning and encountered problems
- Current status
- Detector Performance:
  - Time Alignment
  - Efficiency
  - Occupancies
- Summary

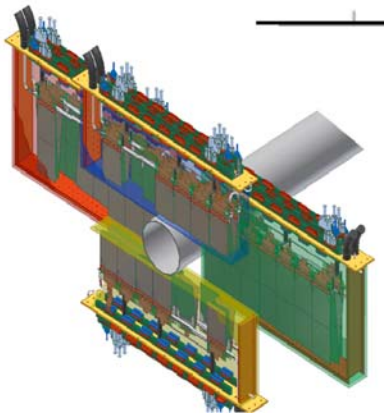
For tracking and alignment performance see talk of M. Gersabeck

LHCb

Dedicated b physics experiment at the LHC
Detector is a single-arm forward arm spectrometer

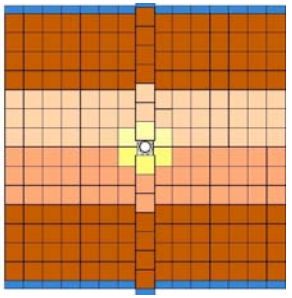






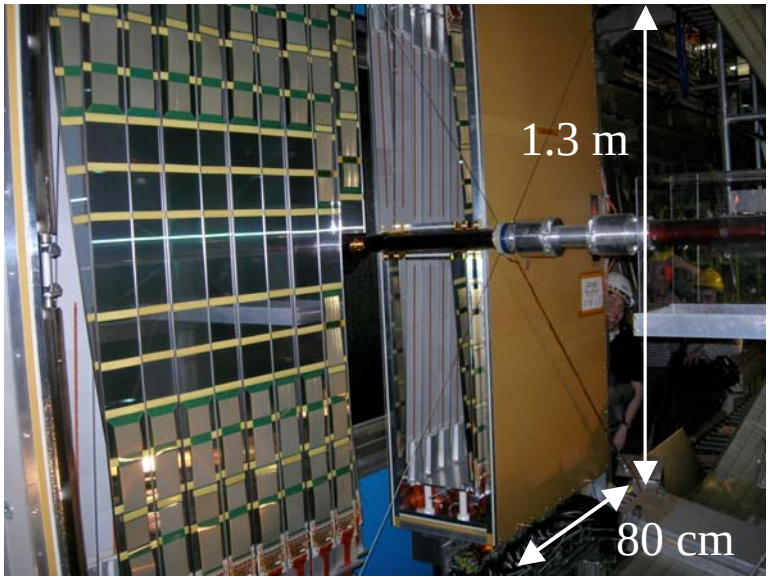
Inner Tracker (IT)

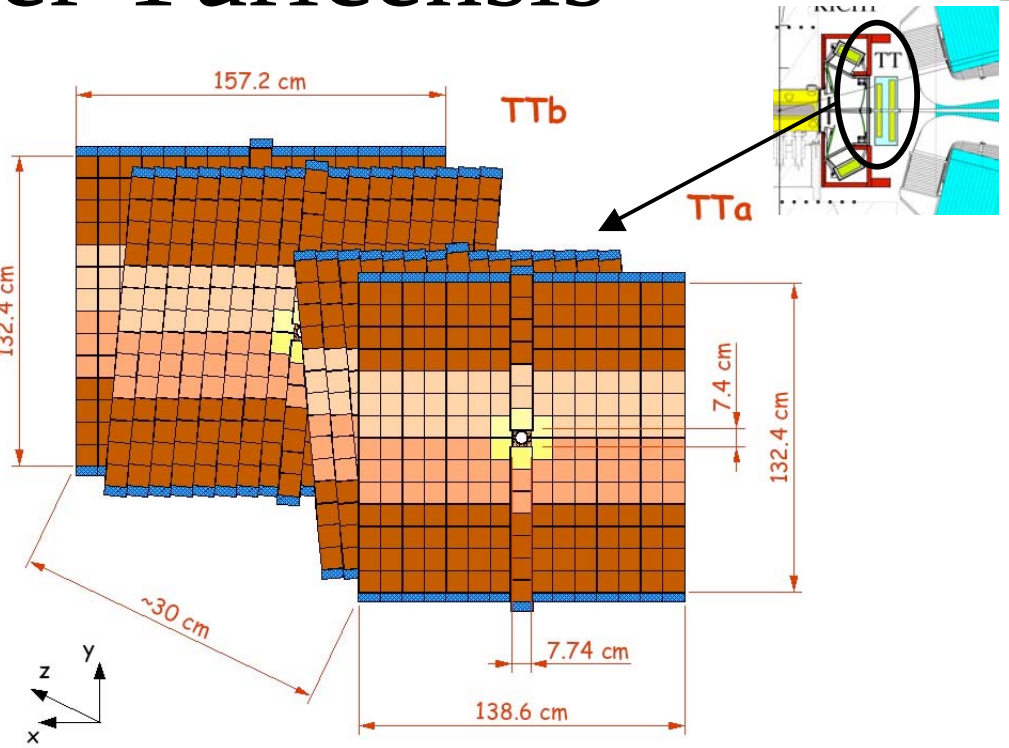
Tracker Turicensis (TT)

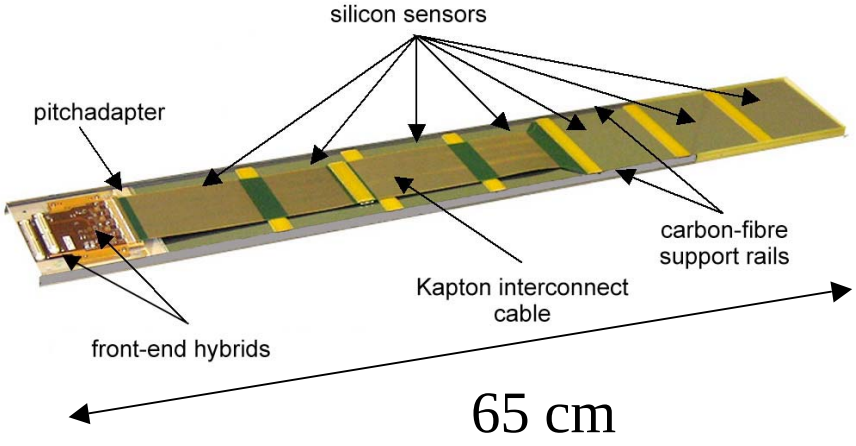


IT + TT developed common project
Silicon Tracker: ~ 35 physicists

Tracker Turicensis

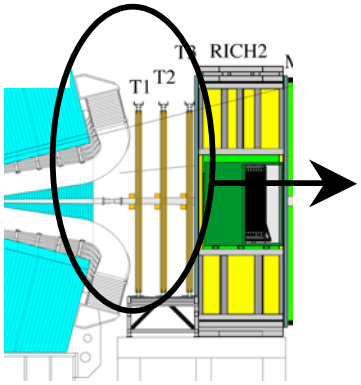


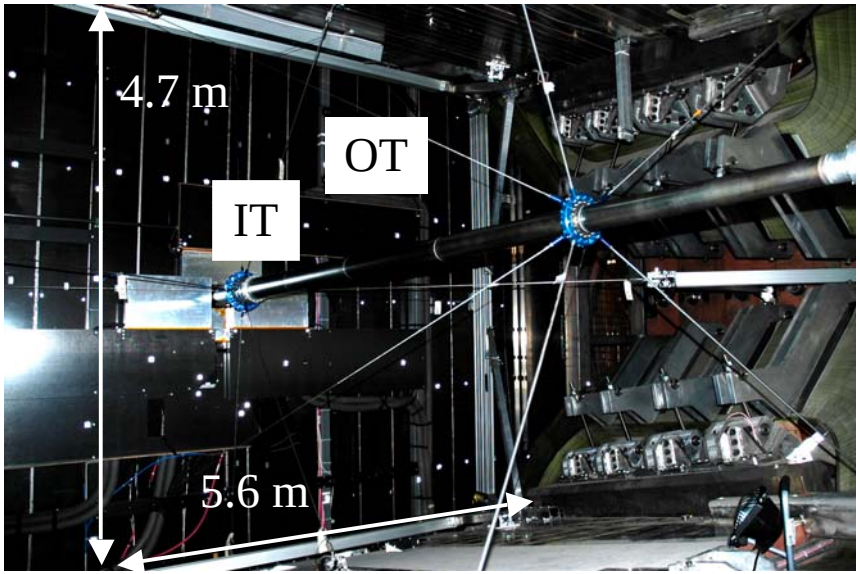


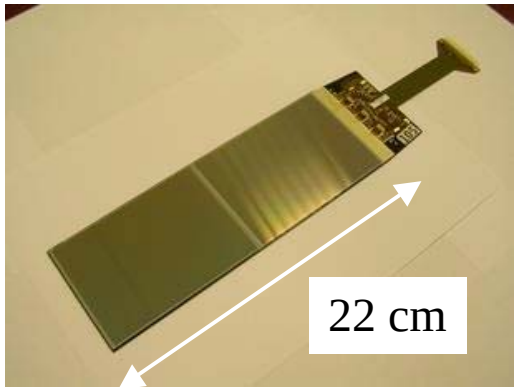


- Four planes of Silicon (0°, +5°, -5°, 0°)
- 500 μm thick, 183 μm pitch, 7-sensor ladders.
- Strip lengths up to 37 cm, Capacitance 56 pF
- Area of 8.2 m^2 covered by Silicon, 143 k strips
- 7 % radiation length
- Detector operated at 5 °C

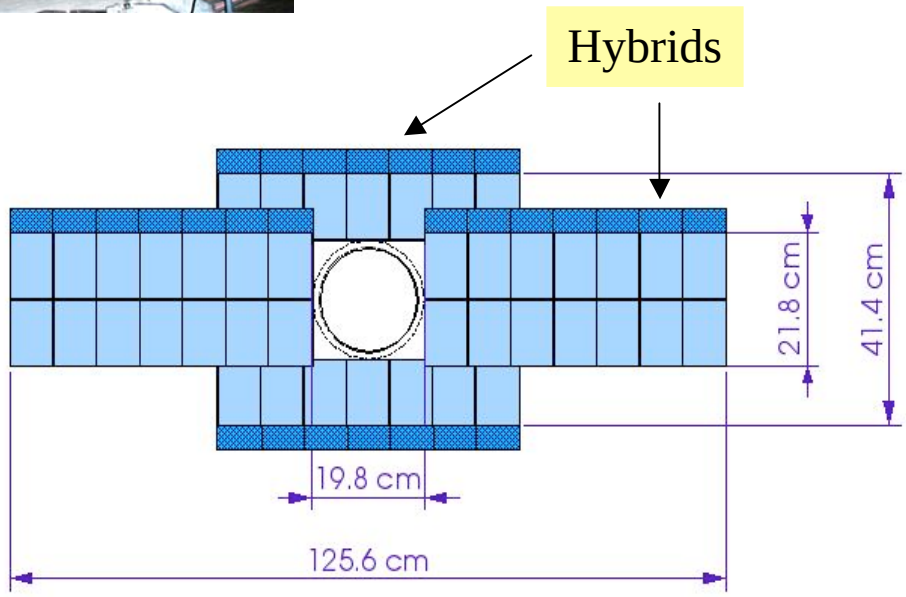
Inner Tracker





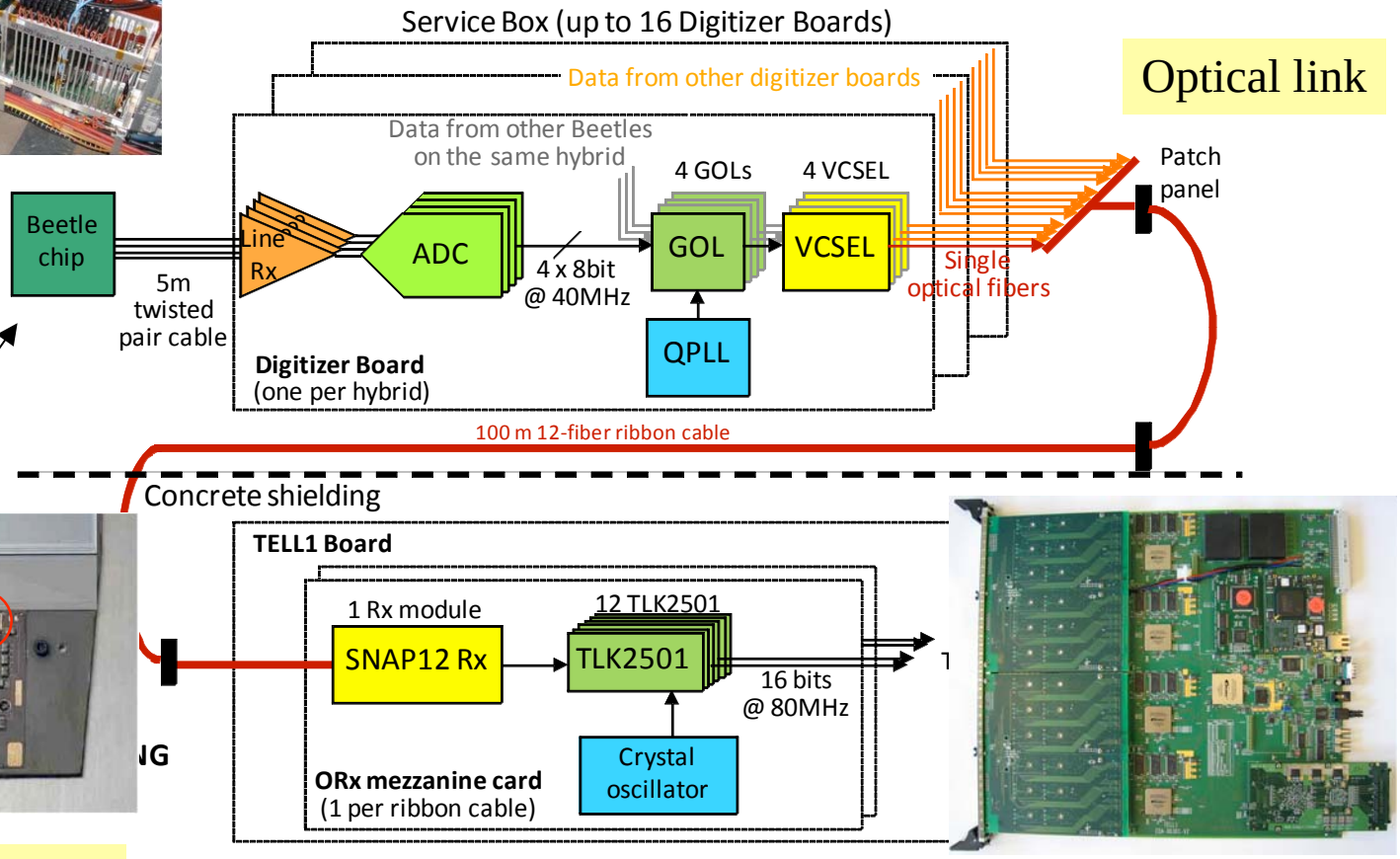


- 3 stations (~4 % X0 each)
- Box contains 4 layers (0°, 5°, -5°, 0°)
- Readout pitch 198 μm
- 320 μm thickness, 1 sensor ladders
- 410 μm thickness, 2 sensor ladders
- Area of 4 m^2 covered
- 336 ladders, 130 k readout strips
- Detector operated at 5 °C

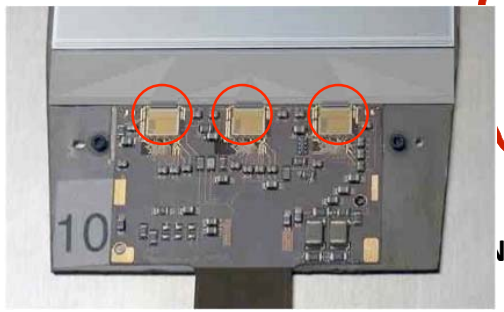


Readout Chain

Digitization: Service box near detector 15 krad in 10 years



Optical link



Front end on detector < 1 Mrad in 10 years

Tell1 readout boards in counting House: Zero Suppression

Access

Tracker Turicensis

- Detector opening + closing relatively straightforward
  - Module replacement smoothly performed several times
- Service boxes located to side of station: easy access

Inner Tracker

- Shares floor space with OT
- Detector box access only possible when IT/OT open, beam-pipe vented
- Service boxes located below detector, access difficult without opening IT and OT

Tracker Turicensis repair work easier than Inner Tracker

Commissioning Timeline

June 2008

Detector installation complete

Learning to run

Cosmics running and injection tests

Oct 2008

High rate tests + repair work

June 2009

Injection tests

High rate tests

Oct 2009

Injection tests

First collisions

June 2010

A lot of valuable operational experience gained before collisions

Commissioning

Standalone running

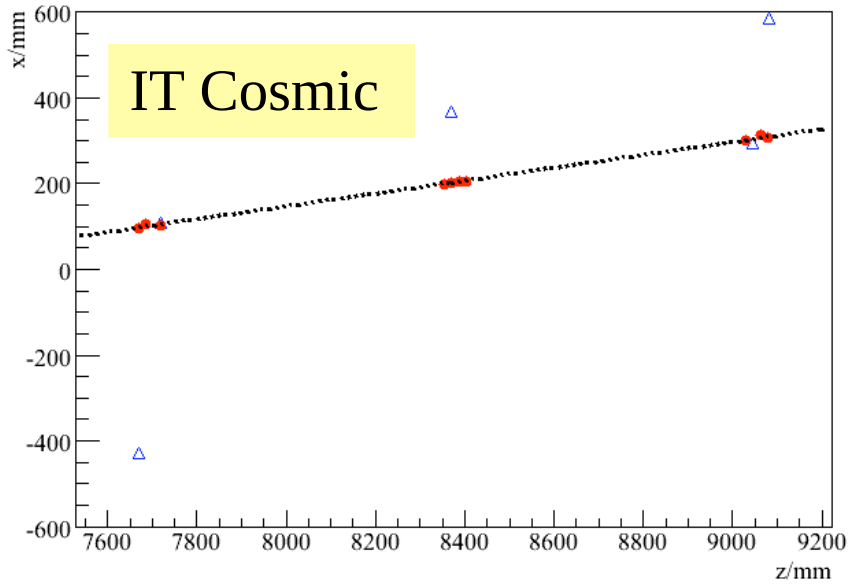
Weekly pedestal runs + 1 MHz tests to identify readout problems/debug Tell1 firmware

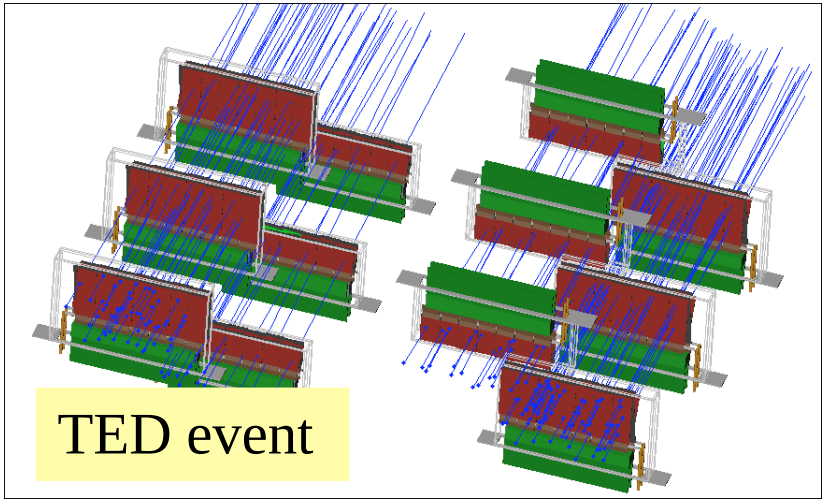
2008 Cosmic running

Small acceptance but 3 reconstructed cosmic tracks in 2.6 million triggers giving hits in all 3 IT stations

2008/2009 TED runs

Spills of 5 $\times 10^9$ protons dumped on a tungsten beam-stopper (the 'TED') 350 m downstream of LHCb.
First time/space alignment





Encountered Problems

- Oscillations in the LV power supplies:
  - Filter out with capacitors
- Failing voltage regulators:
  - Did not test with all different load scenarios
  - Replaced (~ 30 out of 1992)
- Power from VCSEL diode less than -11 dBm sensitivity of Orx
  - Bad alignment between the diode and the optical fiber (damage during mounting)
  - Replaced in IT: 30 out of 1008 diodes , TT: 95 out of 1152
- Internal swaps in optical fiber bundle, bad connections, ….
- Failing Tell1 readout boards (bad vias)

Readout Problems

Fast learning curve to identify,understand + fix readout problems

Hardware repairs

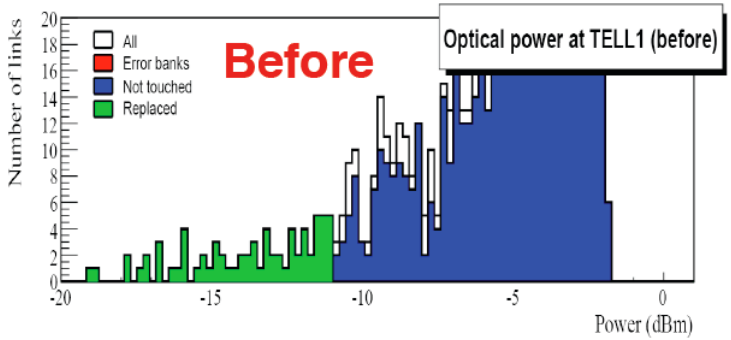
Modify service box mechanics to ease repair
Identify and repair problematic digitizer boards/service boxes
Measurement of optical power, replacement lower power VCSEL diodes

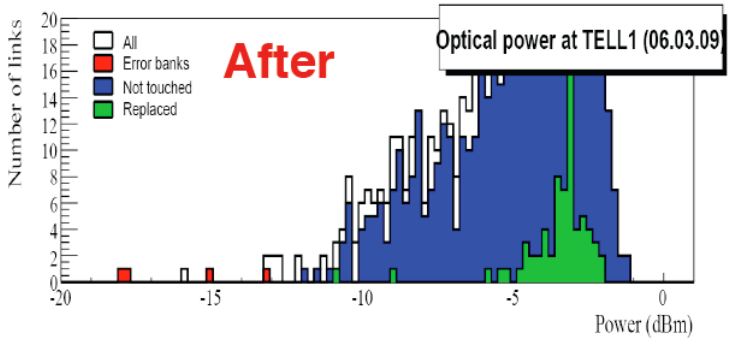
Tell1 Firmware modification

Allow for missing front-end data
Make robust against bit errors/ signal glitches

Decoding Software

Handle missing + corrupted data
Reporting of errors



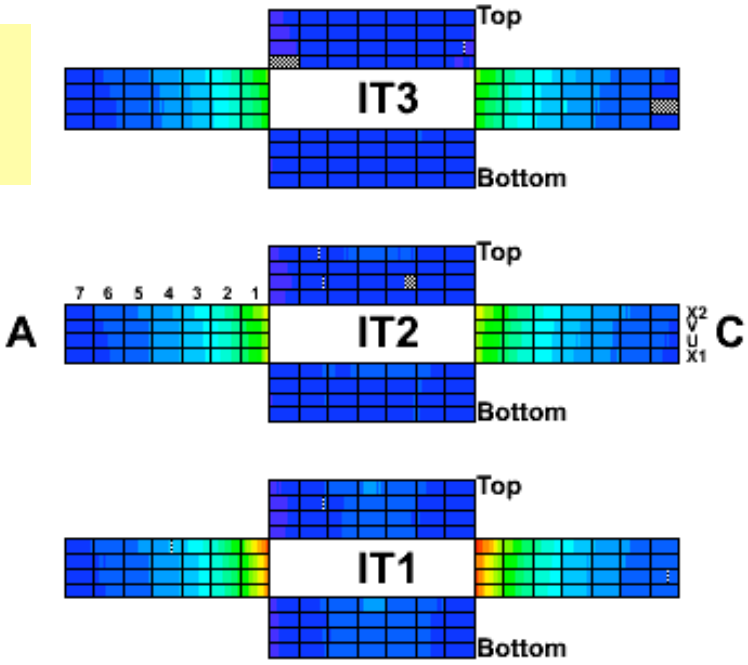


Stable Running

Day-to-Day control of detector in hands of central LHCb shift crew

- Detailed monitoring of detector status/DQ
- Automatic actions/alarms in case of problems
- Experts/piquet on-call

Online IT cluster map



Station 1 Box B

Box hum:

avT.	dew	Hum.
8.44	-31.99	3.83

Box temp [°C]:

n1	n2	n3	n4
8.95	6.86	9.90	8.04

Hybrid temp [°C]:

u	x1	x2	v
5.96	5.85	5.86	5.88
6.05	5.88	5.84	5.95
5.92	5.92	5.86	6.59
6.01	5.92	5.81	5.88
5.85	5.86	5.80	5.82
5.88	5.94	5.76	5.80
5.99	5.81	5.92	5.83

LV Maraton:

SB	Ch.	V.	I[A]
SB1	Ch1	5.32	8.89
SB2	Ch1	5.36	11.25
SB1	Ch2	7.48	6.75
SB2	Ch2	7.51	9.16

High Voltage:

Part.	V.	I[µA]
P1	4.90	0.50
P2	5.00	0.40
P3	4.70	0.00
P4	4.80	1.10
P5	5.00	0.40
P6	5.10	0.00
P7	4.40	1.30

Station 1 Box C

Box hum:

avT.	dew	Hum.
13.05	-20.51	8.04

Box temp [°C]:

n1	n2	n3	n4
12.61	12.57	12.30	14.71

Hybrid temp [°C]:

u	x1	x2	v
5.91	7.93	9.59	8.63
6.03	6.73	5.65	6.50
6.19	6.34	17.20	6.73
6.19	6.92	5.90	6.71
5.93	5.80	5.84	5.86
5.88	5.74	5.81	5.86
5.99	5.85	5.85	5.80

LV Maraton:

SB	Ch.	V.	I[A]
SB1	Ch1	5.45	15.14
SB2	Ch1	5.41	8.19
SB1	Ch2	7.42	8.78
SB2	Ch2	7.51	7.12

High Voltage:

Part.	V.	I[µA]
P1	4.90	0.20
P2	5.20	0.00
P3	4.80	0.10
P4	4.50	0.20
P5	4.80	0.90
P6	5.20	1.30
P7	4.80	0.00

Station 1 Box T

Box hum:

avT.	dew	Hum.
6.70	-22.33	10.49

Box temp [°C]:

n1	n2	n3	n4
6.42	6.40	6.30	7.68

Hybrid temp [°C]:

u	x1	x2	v
5.92	5.81	5.78	5.91
5.95	5.81	5.83	5.78
5.90	5.78	5.74	5.89
5.93	5.79	5.79	5.77
5.97	5.88	5.80	5.87
5.91	5.93	5.81	5.81
6.04	5.85	5.92	5.89

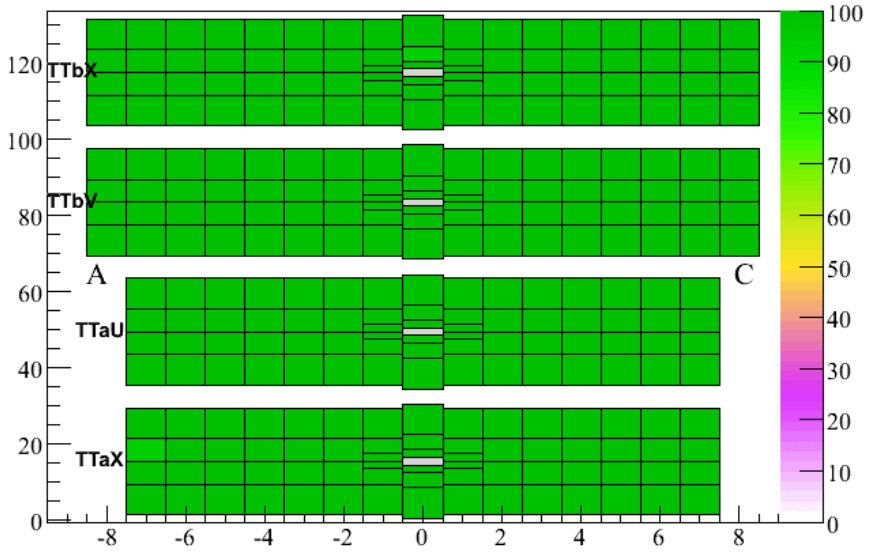
LV Maraton:

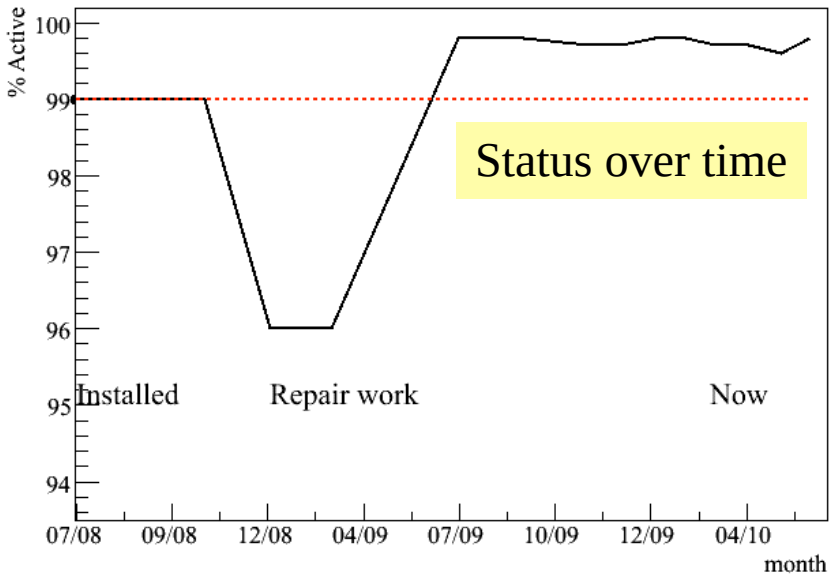
SB	Ch.	V.	I[A]
SB3	Ch1	5.41	10.86
SB4	Ch1	5.39	8.20
SB3	Ch2	7.58	8.90
SB4	Ch2	7.50	7.11

High Voltage:

Part.	V.	I[µA]
P1	5.10	0.00
P2	4.80	0.00
P3	4.60	0.60
P4	5.10	0.00
P5	4.70	0.30
P6	5.00	1.40
P7	5.00	0.60

TT Status

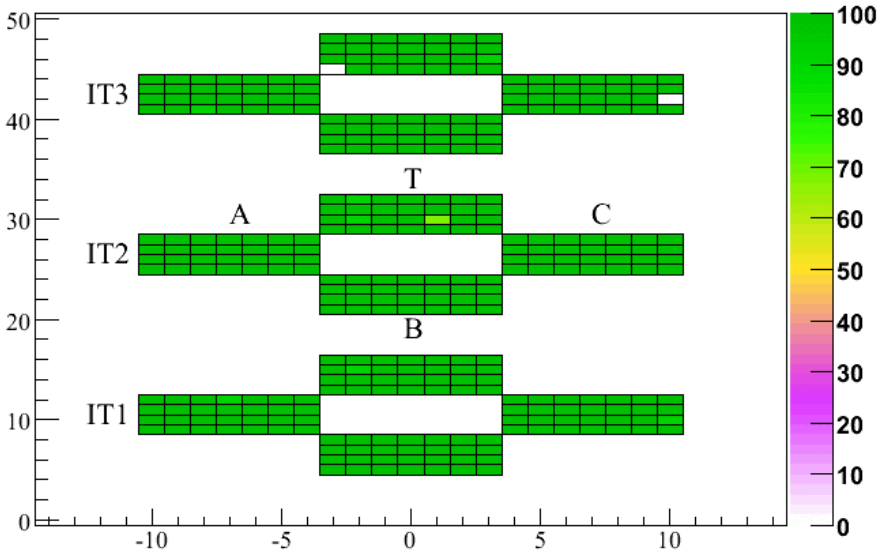


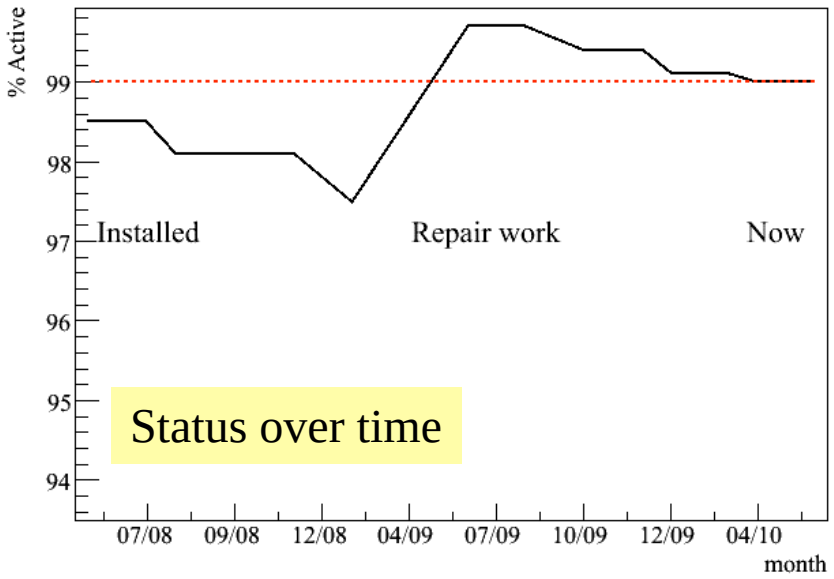


99.8 % of the detector functional

- Repair work in 2009
  - Remove + replace module with HV problem [crack on readout hybrid]
  - Remove + replace modules with broken bonds

IT Status





Status over time

99 % of the detector functional

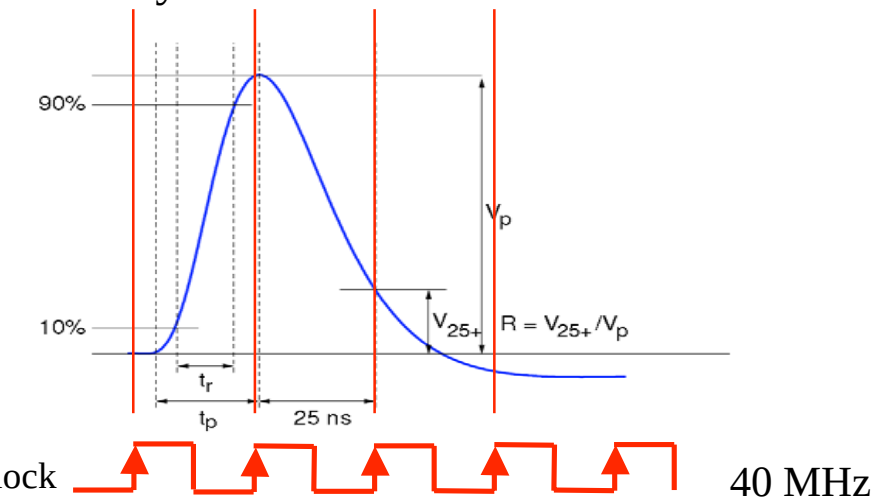
Inefficiency dominated by 2 modules with problems inside detector box

- One with HV fault, one that does not configure

Time Alignment

- Different cable lengths for different detector parts
- Time of flight different per station
- Time delay scans (collected charge vs sampling time)

Synchronized scenario



- Dedicated run taken reading out samples spaced by 25 ns
- Repeat shifting sampling point by -6 ,6, 12 ns
- Fit landau to cluster charge distribution for each sample
- Plot MPV versus sample time and fit pulse shape:

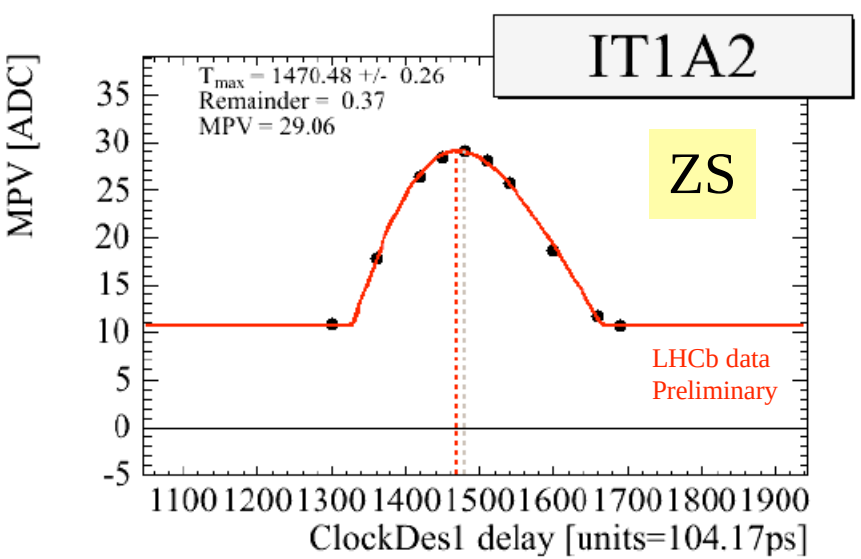
$$f = A \cdot e^{-x} \cdot \left(x^2/2 - x^3/6\right)$$

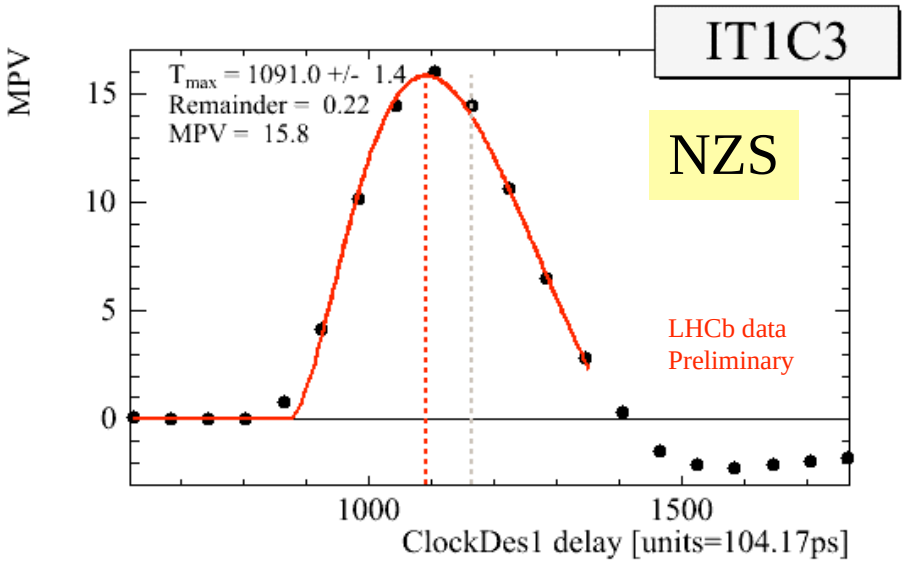
$$x = (t - t_0)/t_{rise}$$

$$\longrightarrow \quad t_{max} = (3 - \sqrt{3}) \cdot t_{rise} + t_0$$

Time Alignment

- Sampling point tunable per service box
- Scans use all clusters in event with S/N > 5
- Can be performed with clusters (ZS data) or NZS data (to see undershoot)





Detector internally time aligned with a resolution of < 1 ns

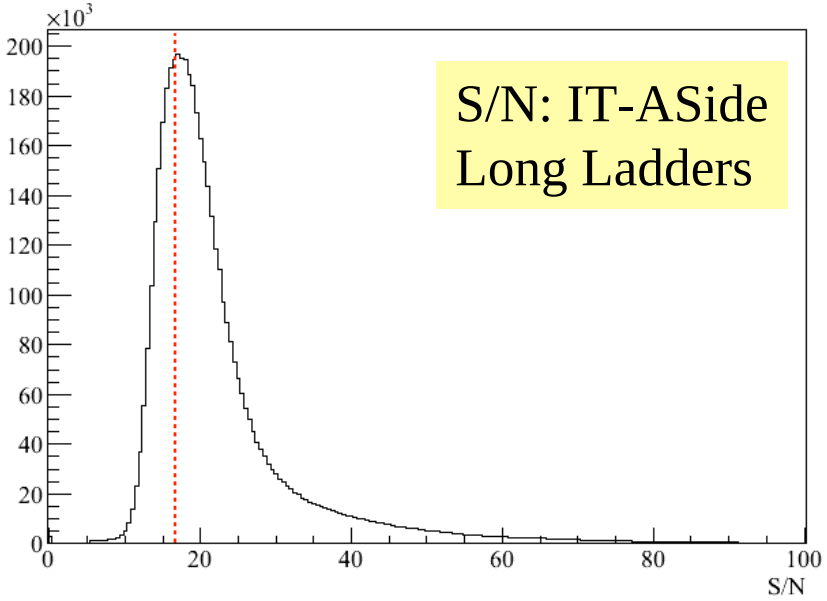
S/N

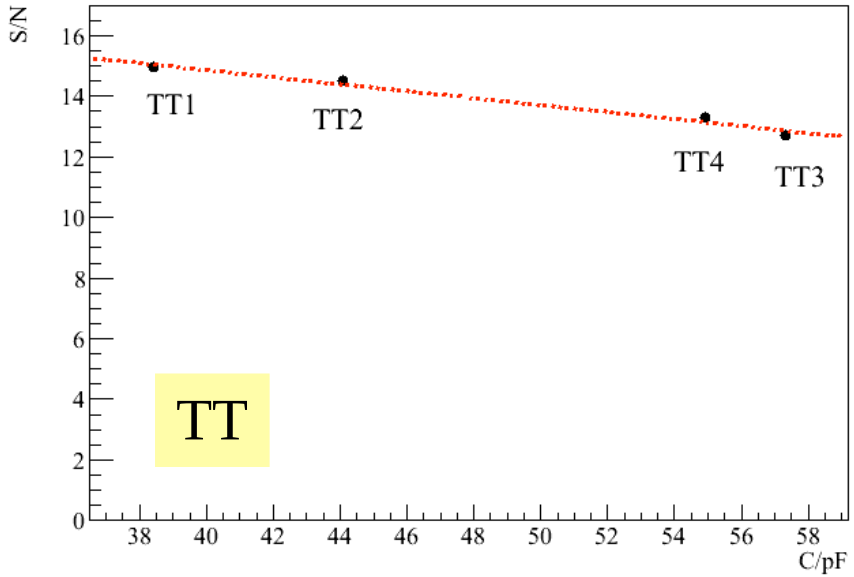
S/N for clusters assigned to tracks with p > 5 GeV

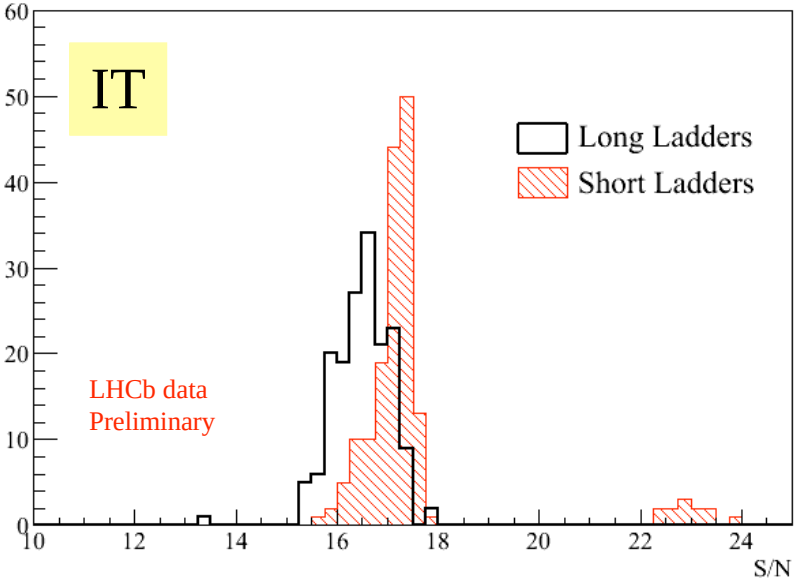
TT: S/N 13 - 15

IT: S/N ~ 16.5 (Long), 17.5 (Short)

Within 10 - 20 % of expectations







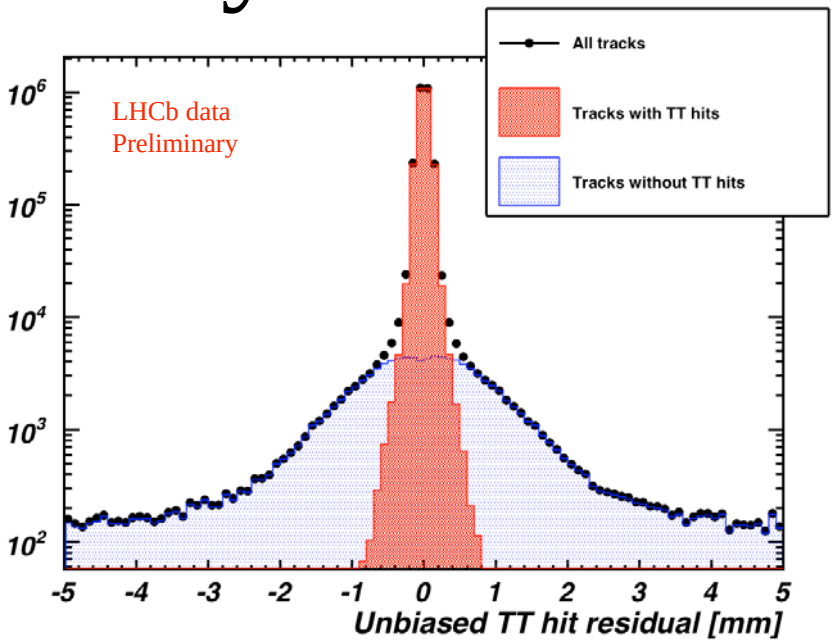
TT Efficiency

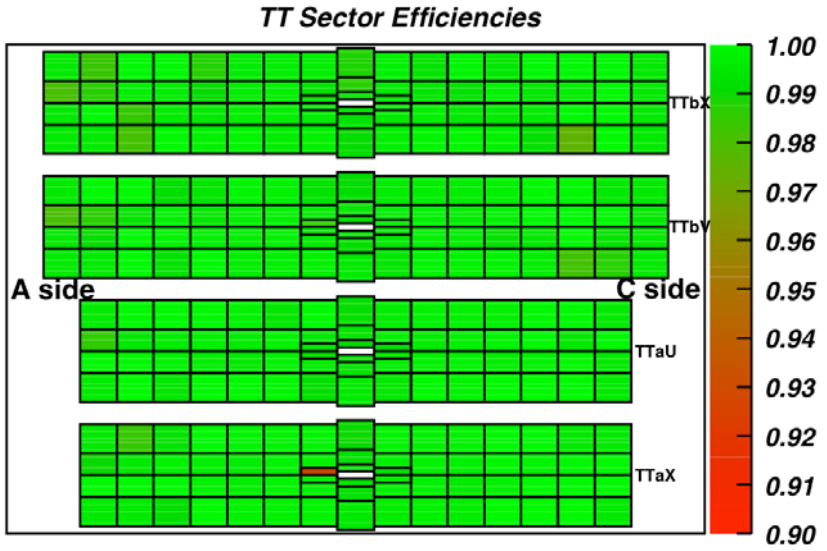
TT Efficiency measured with tracks

- High momentum, p > 10 GeV
- Isolated: little extra activity in 5 mm
- TT hits are not required by the pattern recognition to be on Velo-T tracks
- 2.5 mm window needed to estimate efficiency

Efficiency measured to be 99.3 %

- Clustering threshold, S/N > 5
- Noise cluster rate: 10^{-5}
- 1 sector ~90 efficiency: broken bonds

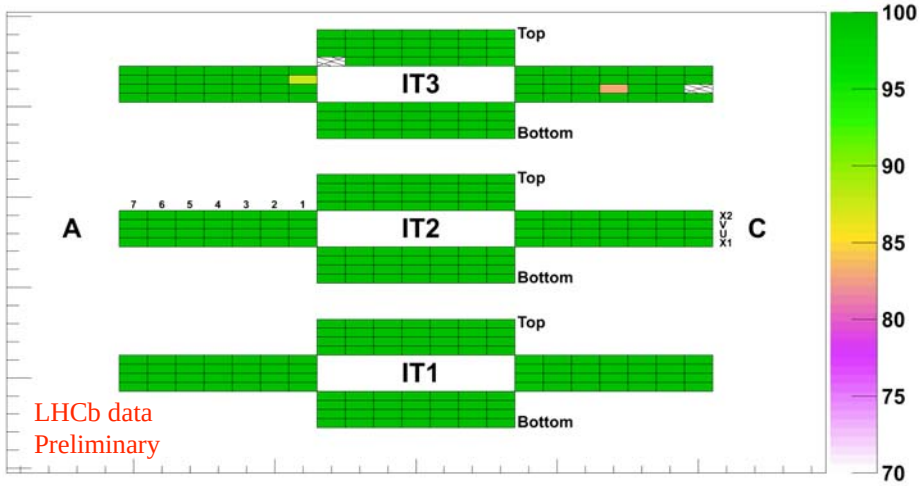




IT Efficiency

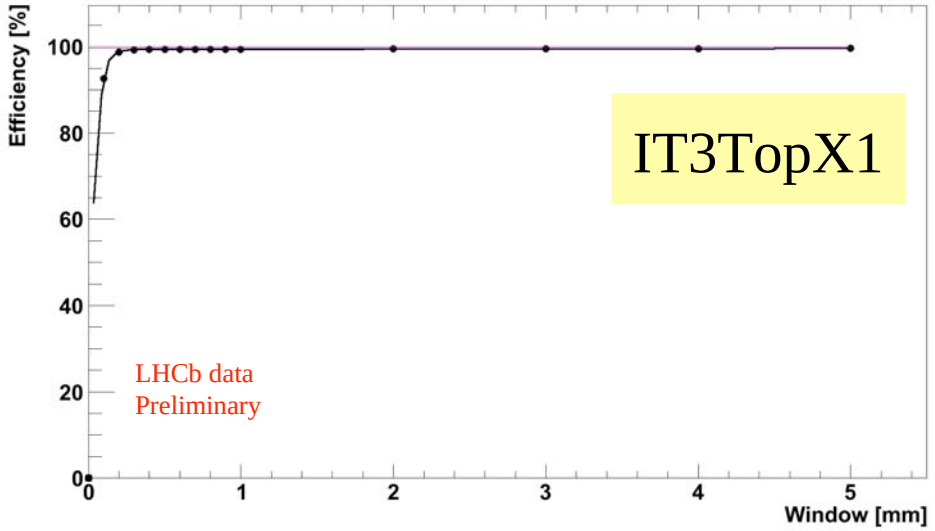
Efficiency with tracks

- Tracks with hits in VELO
- High momentum, p > 10 GeV
- Isolated: little extra activity in 5 mm



Detector efficiency ~ 99.8 %

- Clustering threshold, S/N > 5
- Noise cluster rate: 10^{-5}
- Two low efficiency modules
  - Large Common mode (1.5 l
  - Weak optical link



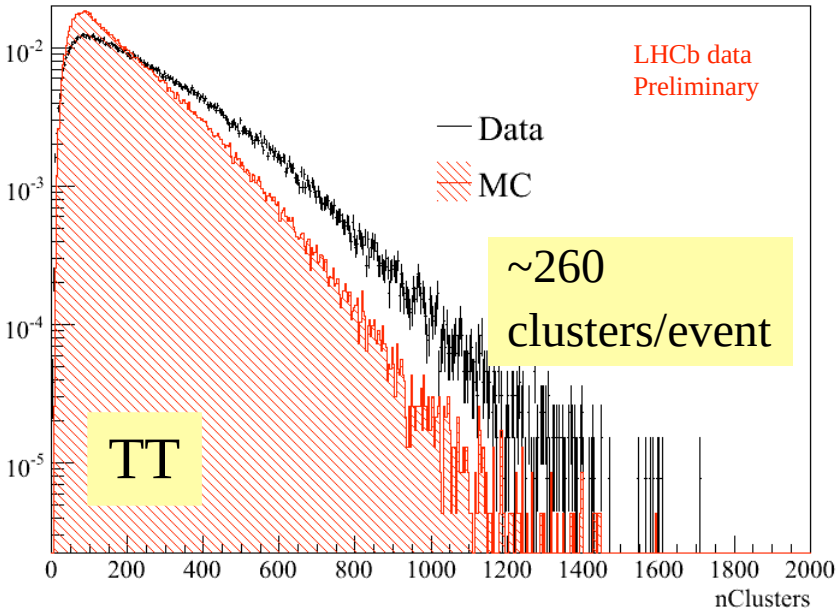
Occupancies

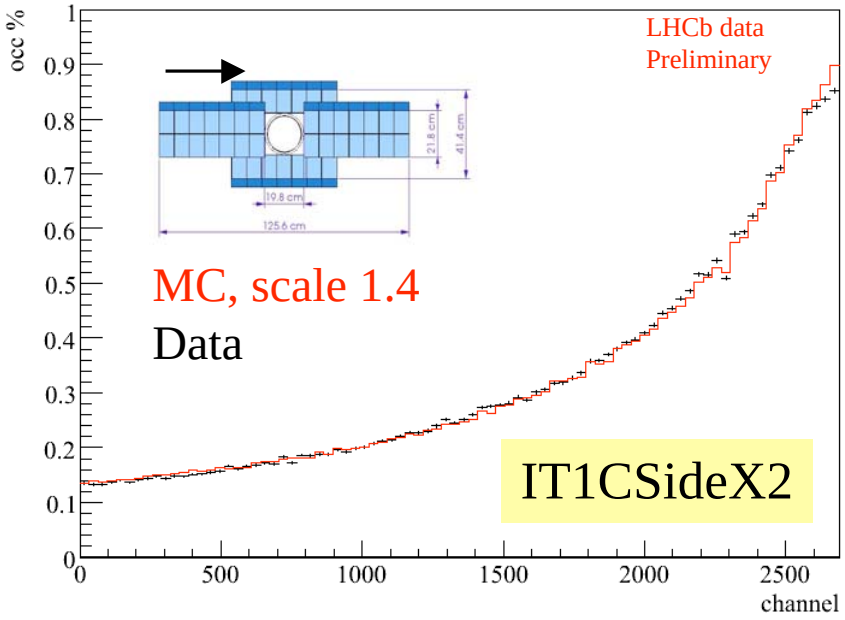
Occupancies in 7 TeV Min bias events with 1 reconstructed PV

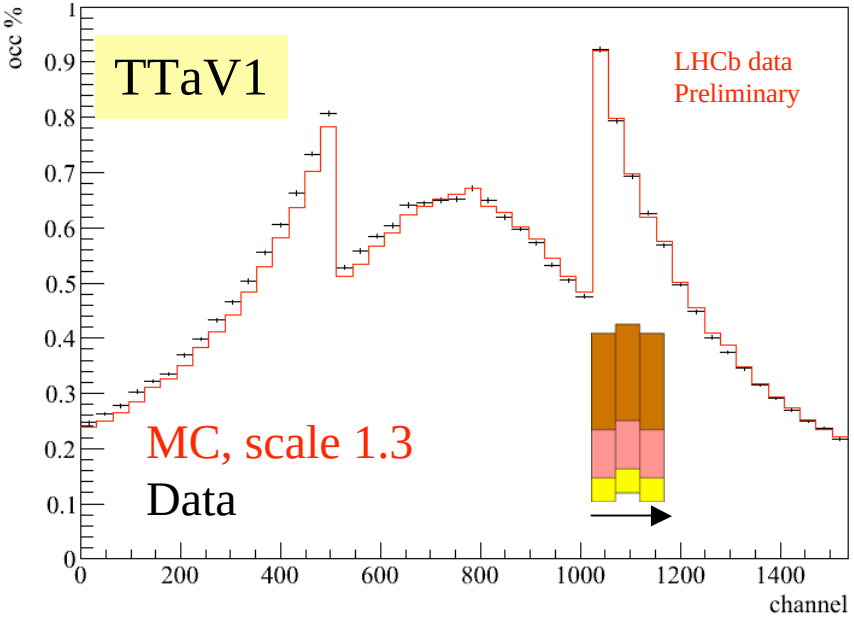
TT 260 clusters/event (MC: 200)

IT 230 clusters/event (MC: 160)

Shapes well described







Outlook

- Detector runs reliably, main concern new optical links with low power
- Since November 2009 5 links (3 TT, 2 IT) show problems
- Seems to be a sudden degradation (the VCSEL diode goes ‘black’)
- TT: disable + replace when possible, IT disable until end of run
- Assuming current failure rate ~98 % detector working by end 2011

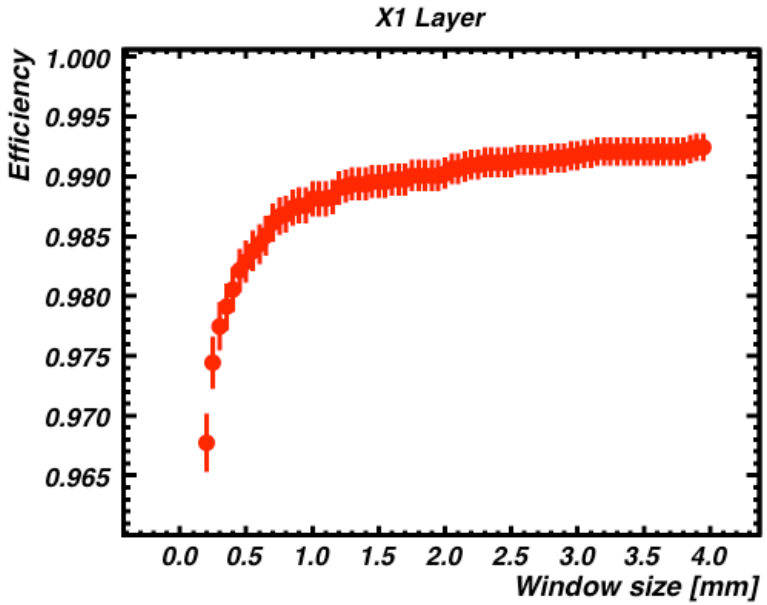
Intervention forseen to fix all remaining IT and TT problems in 2011 shutdown

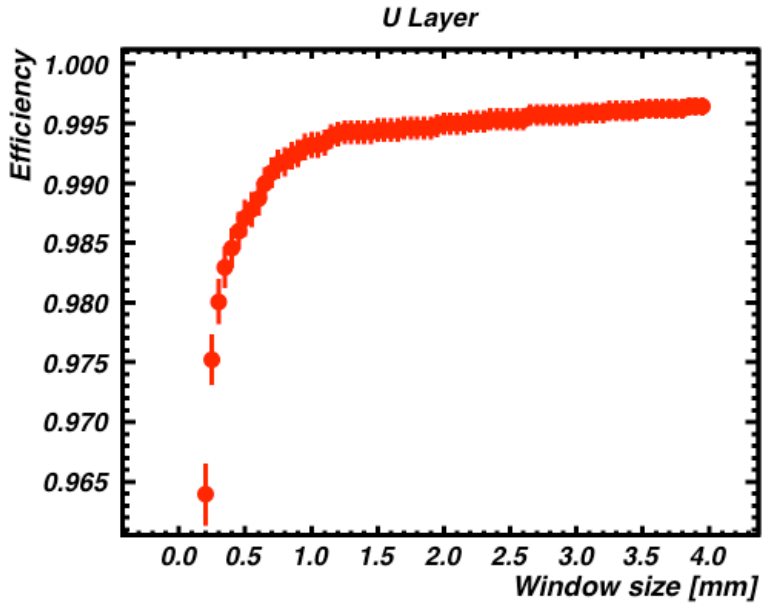
Summary

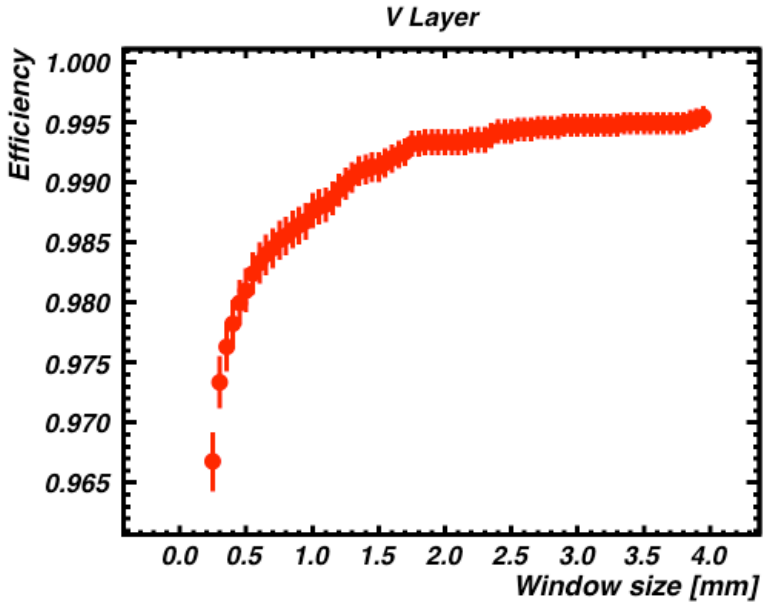
- LHCb Silicon Tracker installed and running reliably
- Performance of the detector is excellant
- S/N 16-18 (IT) , 13- 15 (TT)
- > 99 % of the detector channels are functional
- Efficiency measured to be > 99 % with tracks
- Valuable experience in achieving this gained with cosmics + TED runs in 2008/2009

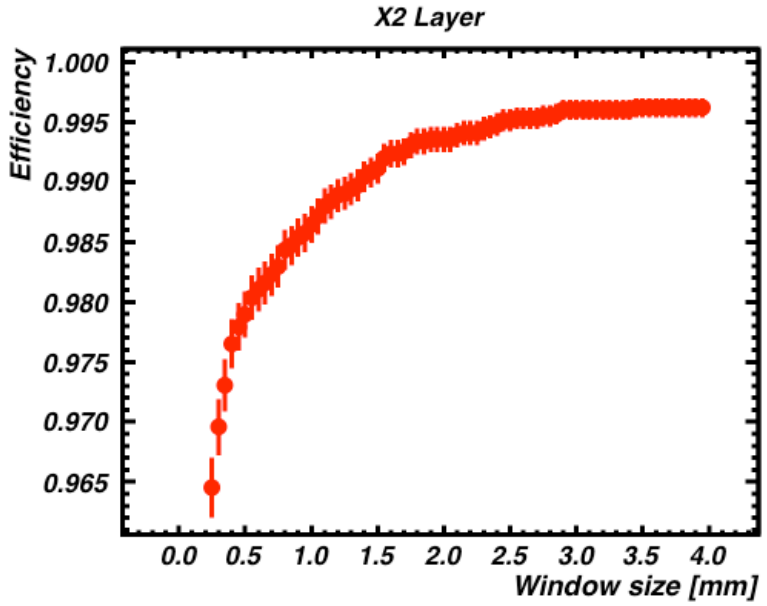
Backup

TT Layer Efficiency

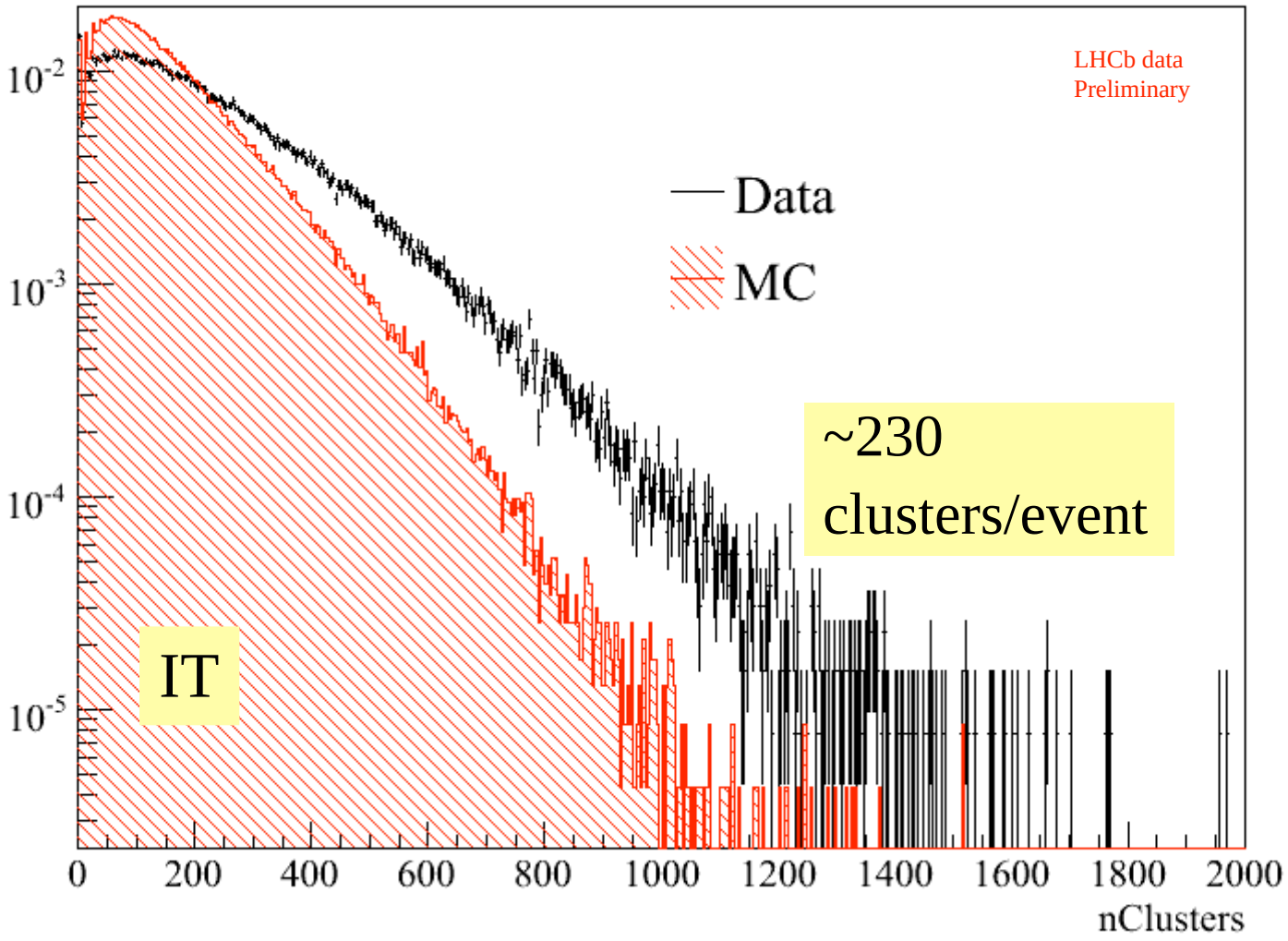




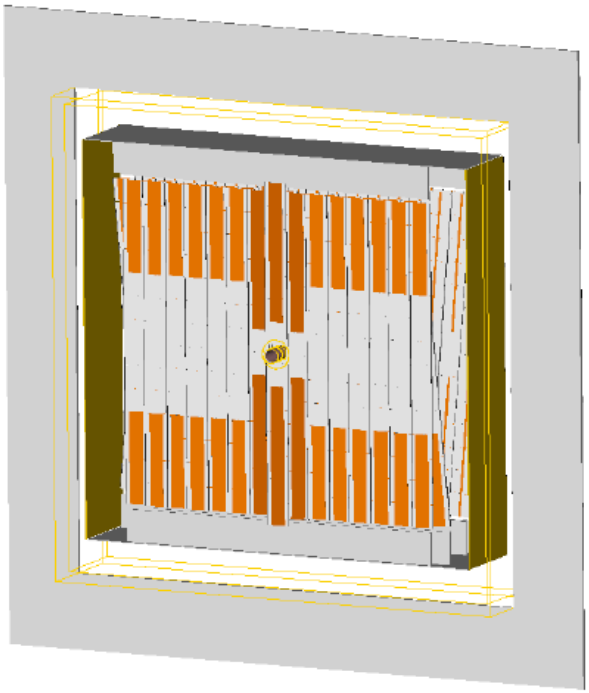


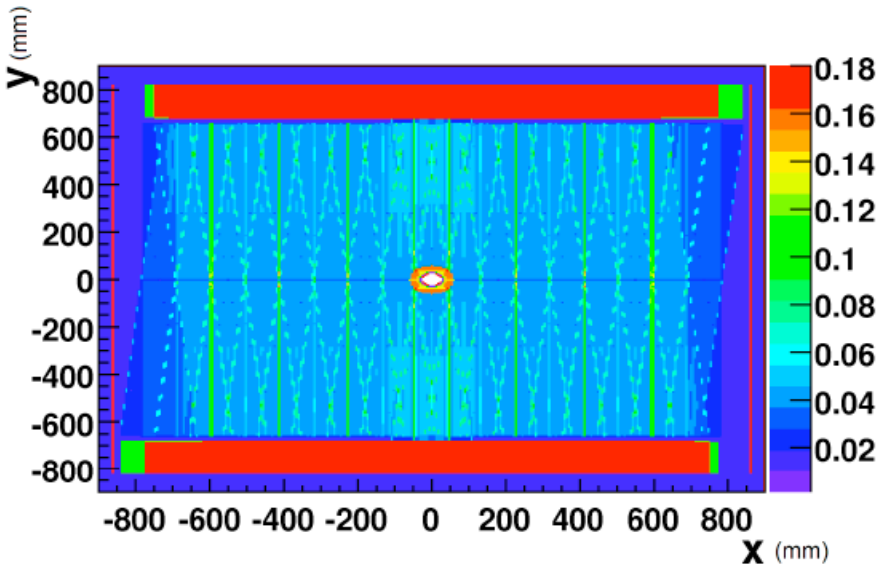


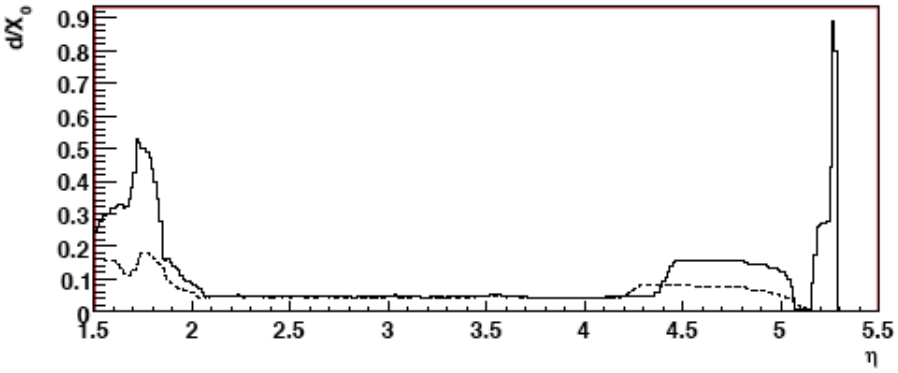
IT Occupancy

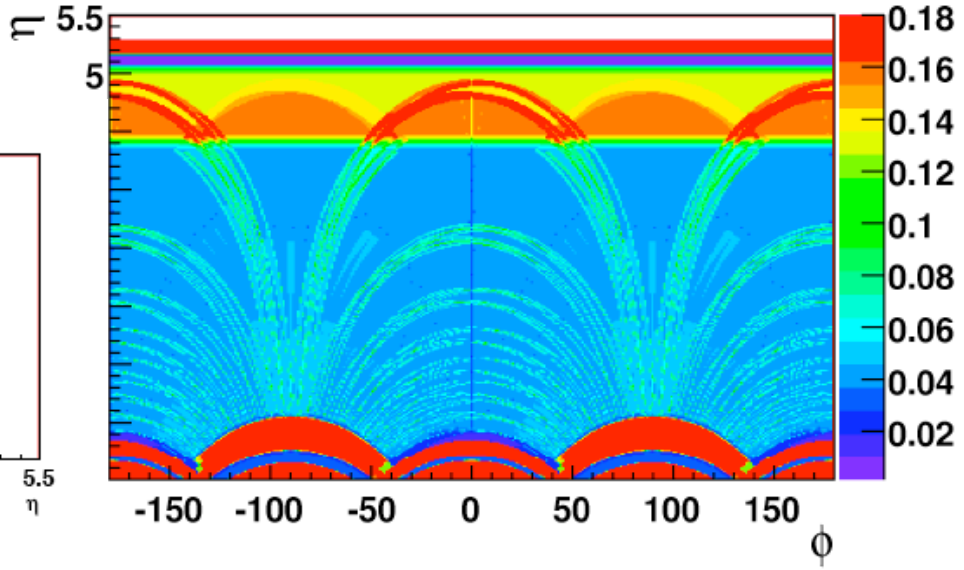


TT Material

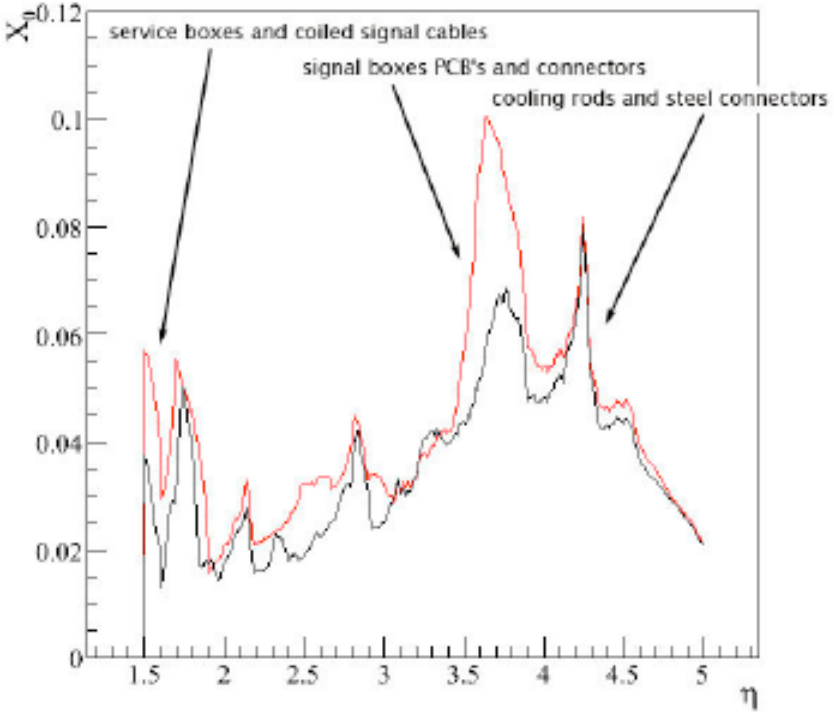


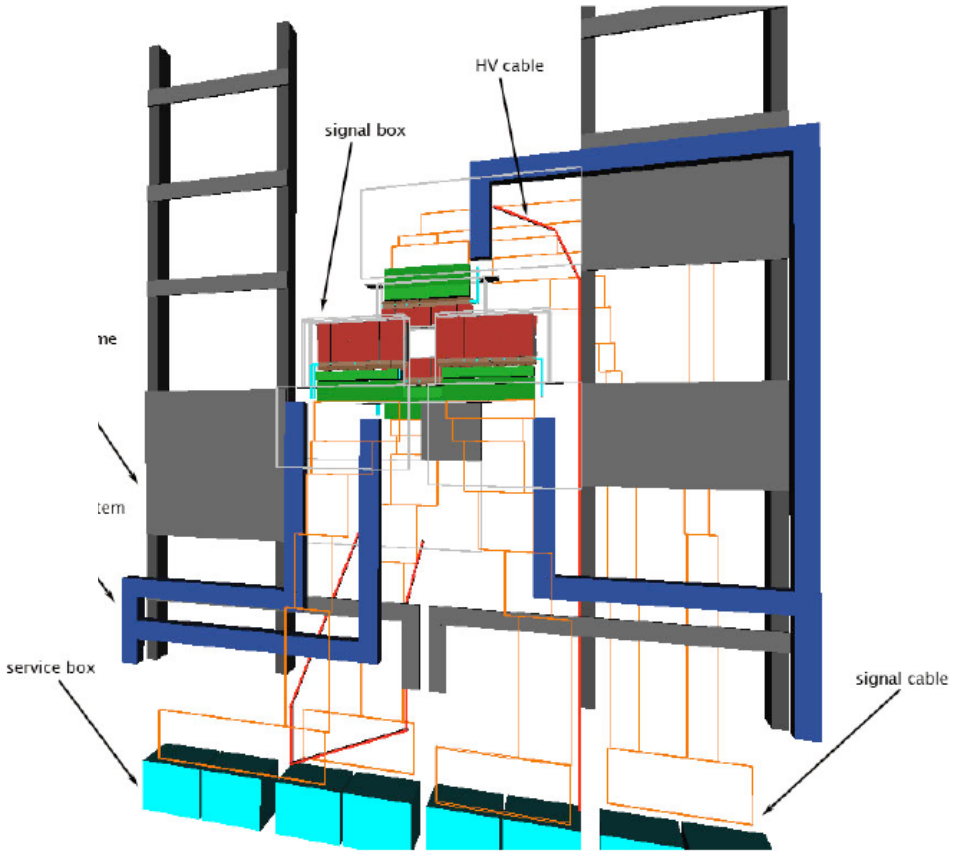

y (mm)
800
600
400
200
0
-200
-400
-600
-800
-800 -600 -400 -200 0 200 400 600 800
x (mm)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02


dX0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.5 2 2.5 3 3.5 4 4.5 5 5.5
η


η
5.5
5
-150 -100 -50 0 50 100 150
ϕ
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02

IT Material


service boxes and coiled signal cables
signal boxes PCB's and connectors
cooling rods and steel connectors
0.12
0.1
0.08
0.06
0.04
0.02
0
1.5
2
2.5
3
3.5
4
4.5
5
η


HV cable
signal box
service box
signal cable

TT Broken Bonds

9 hybrids on 7 readout sectors effected

- Innermost bond row effected, mainly heel breaks
- Effect not reproduced in the lab despite extensive tests + thermal cycling
- Generally breaking (but not always) occurs on pitch adaptor side
- Majority of problems soon after installation, 2 developed in October 2008, one in June 2009

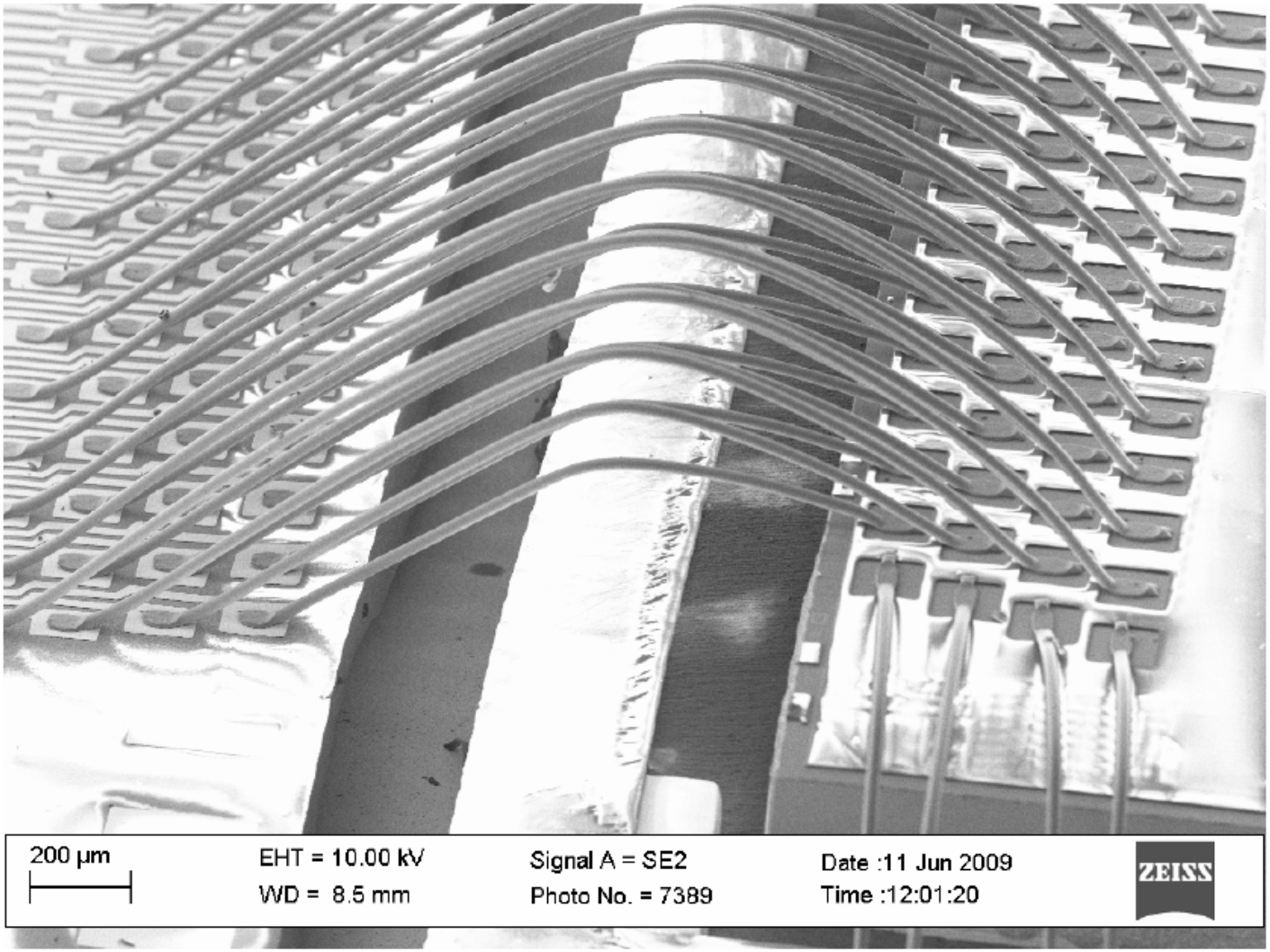
Possible causes of bad bonds:

- Initial cracks due to the bonding process, typically occur at first bonds
    - In this case would expect on Beetle side
- Loop height: should be > 25 % of the bond spacing
- Vibrations/Thermal cycling

bond row	distance between bond pads	bond loop height above pitch adaptor
innermost	1.35 mm	0.48 mm
second	1.70 mm	0.66 mm
third	2.05 mm	0.84 mm
outermost	2.40 mm	1.02 mm

Bond heights for innermost bonds are tight, but if increased outermost bonds become too high

TT Broken Bonds

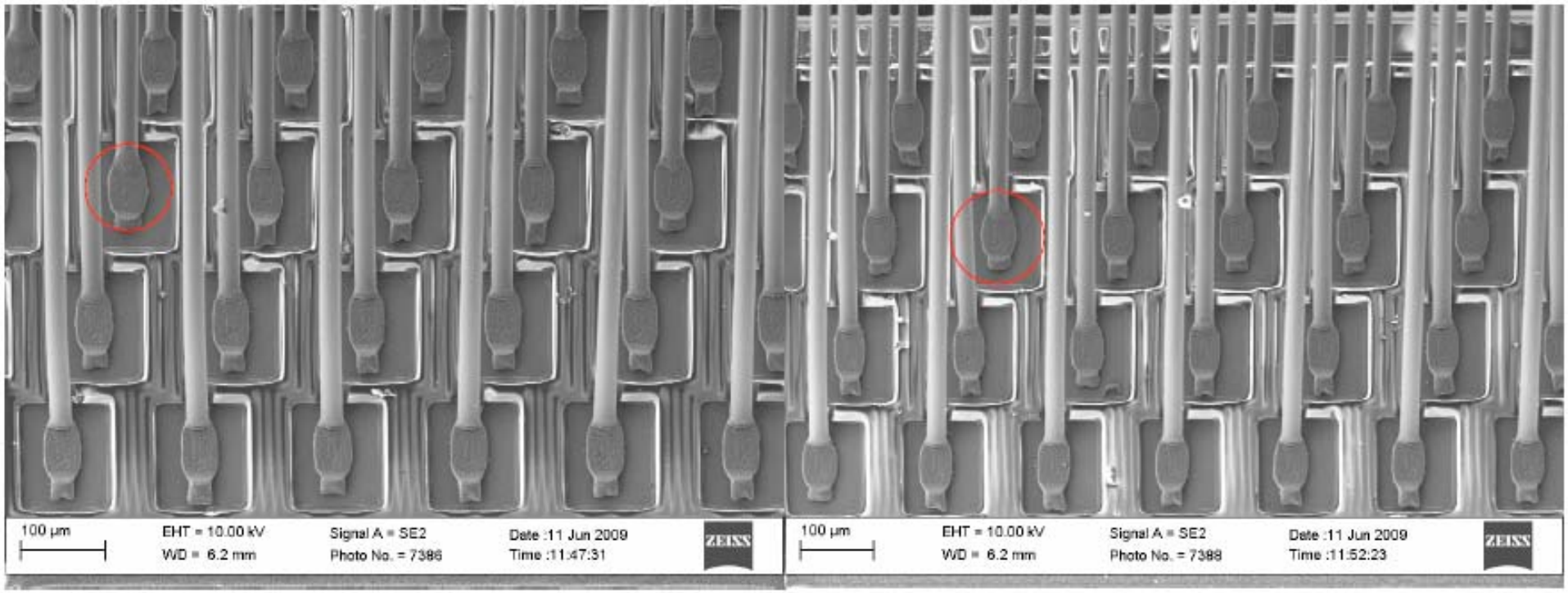


It was not possible to take a picture from a better angle because of collisions with the elektron gun.
So I can't quantify the loop height of the bonds.

TT Broken Bonds

One of the problem hybrids is somewhat atypical

- Broken bonds on Beetle side (first bonds)
- SEM pictures shows presence of initial cracks from bonding



A lot of cracks on the Beetle side. Only two proper bonds, marked with a circle.