AGH University of Science and Technology

Recent results on radiation damage in the LHCb silicon tracking system

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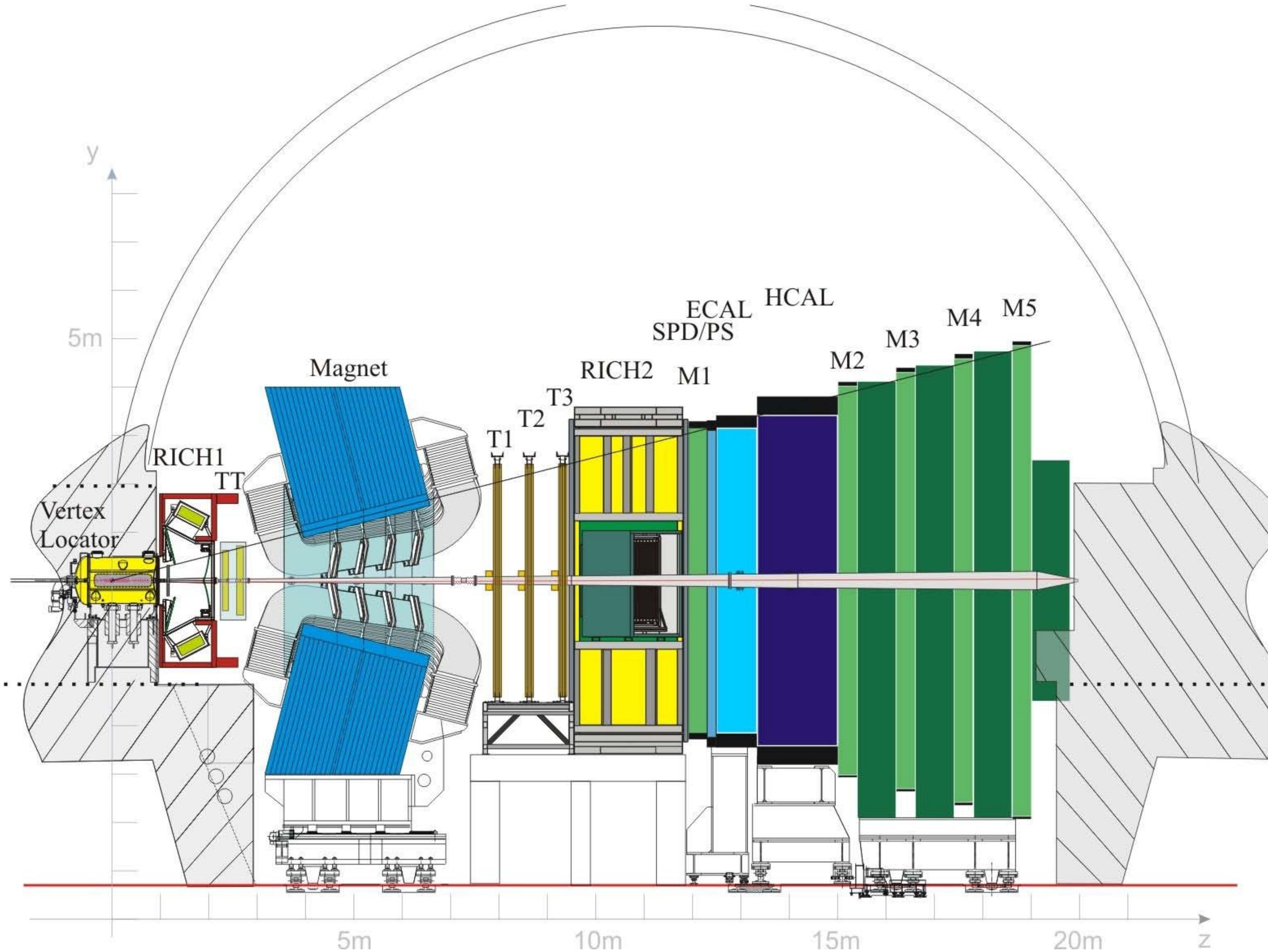
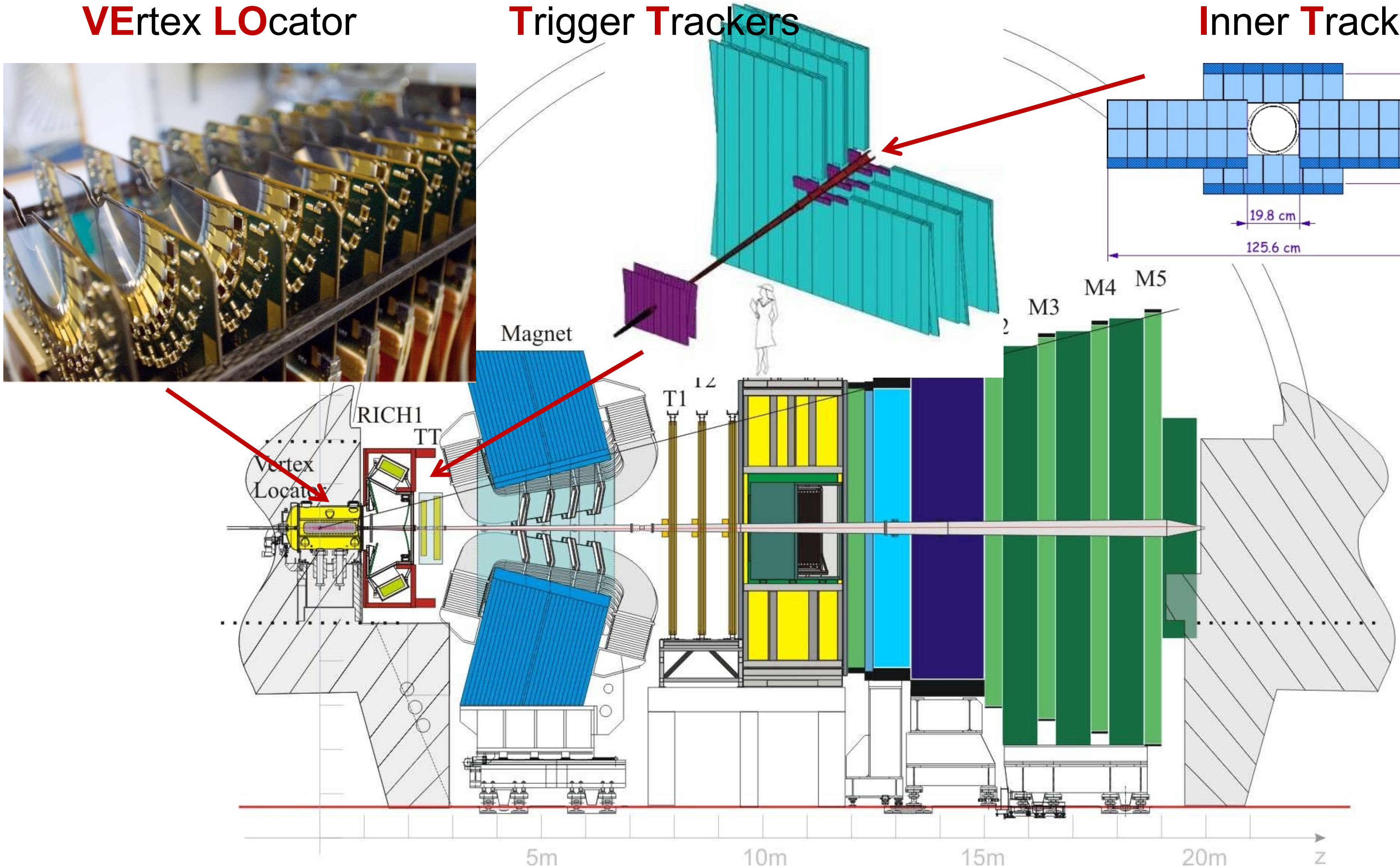
on behalf of VELO & Silicon Tracker

20th RD50 Workshop (Bari,Italy) 30th of May 2012

LHCb spectrometer

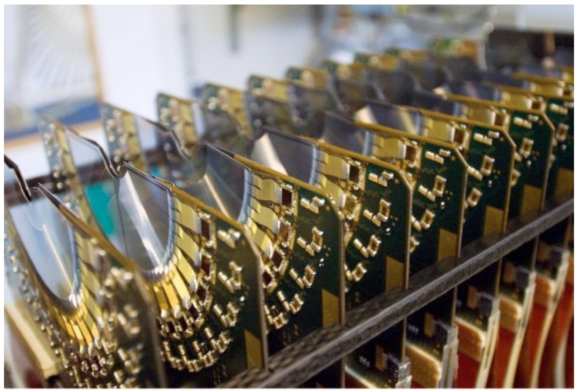


LHCb spectrometer-
silicon tracking systems



VELO

Mobile: opening every fill and centering on the beam with self measured vertices

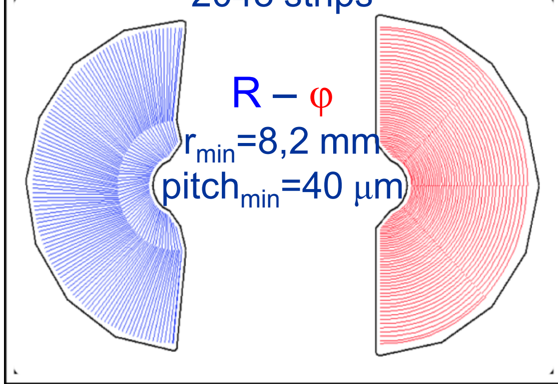


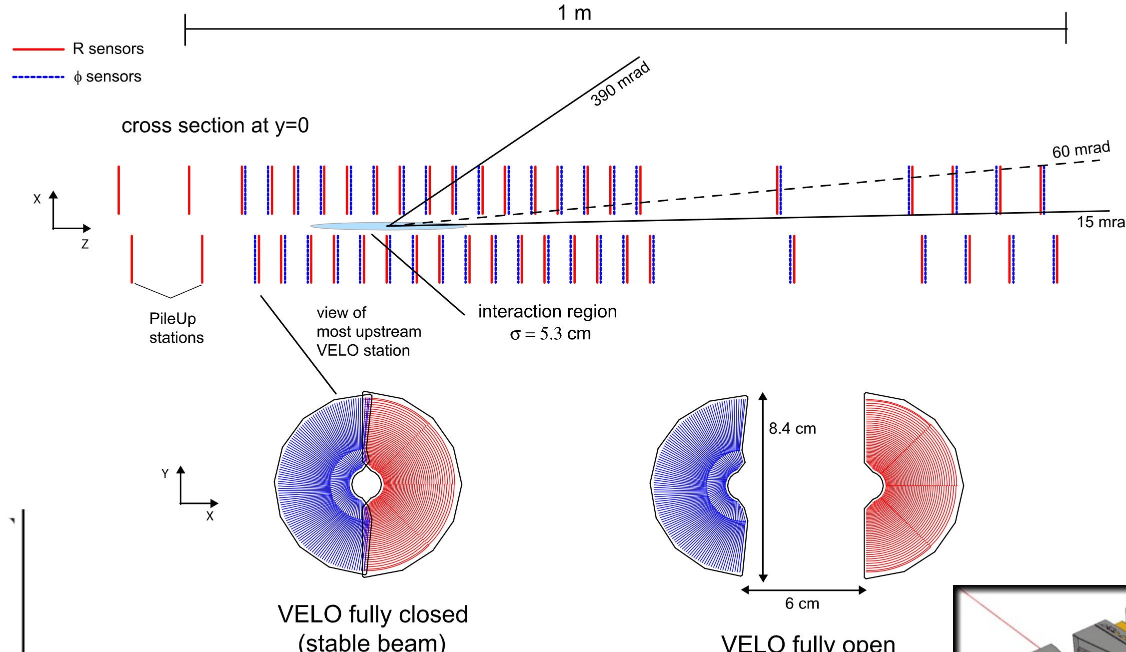
88 silicon sensors

300 μm, n^+n and n on p

double metal layer

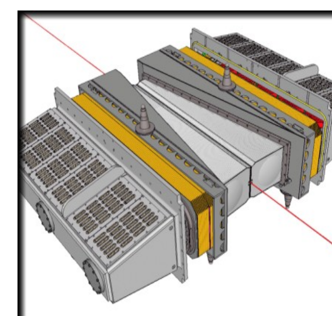
2048 strips





Cooled: by evaporative CO_2 system,

operating in vacuum



VELO goals

Tracking:

- high precision measurement of trajectories close to the interaction point

Vertexing:

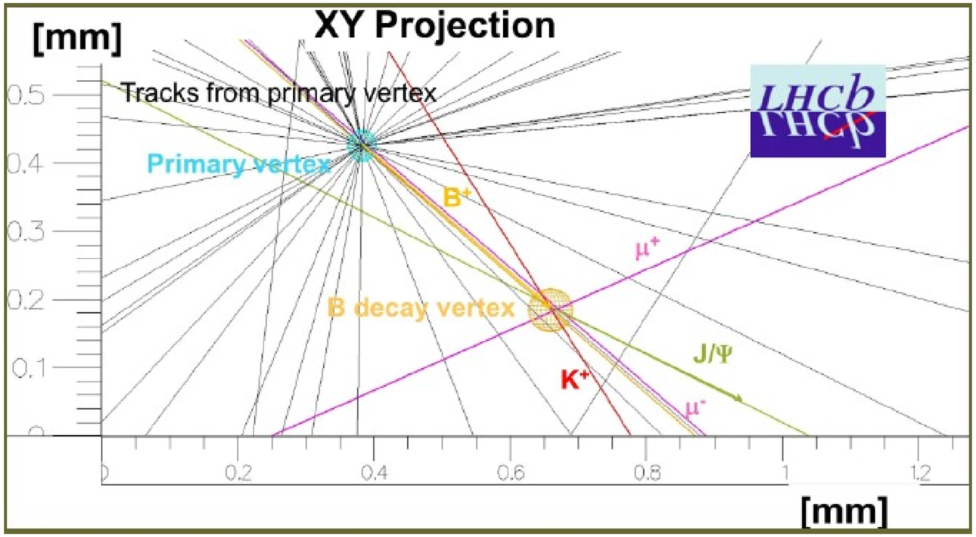
- production and decay vertices of b and c hadrons,
- accurate measurement of decay lifetimes

Tagging:

- impact parameters

Trigger:

- VELO's input is absolutely vital for physics, HLT (high level trigger) relies on all listed quantities



- Hit resolution 4μm
- momentum resolution Δp/p=0.4%-0.55%
- PV resolution 13μm
- IP resolution 13μm for high
- transverse momentum tracks

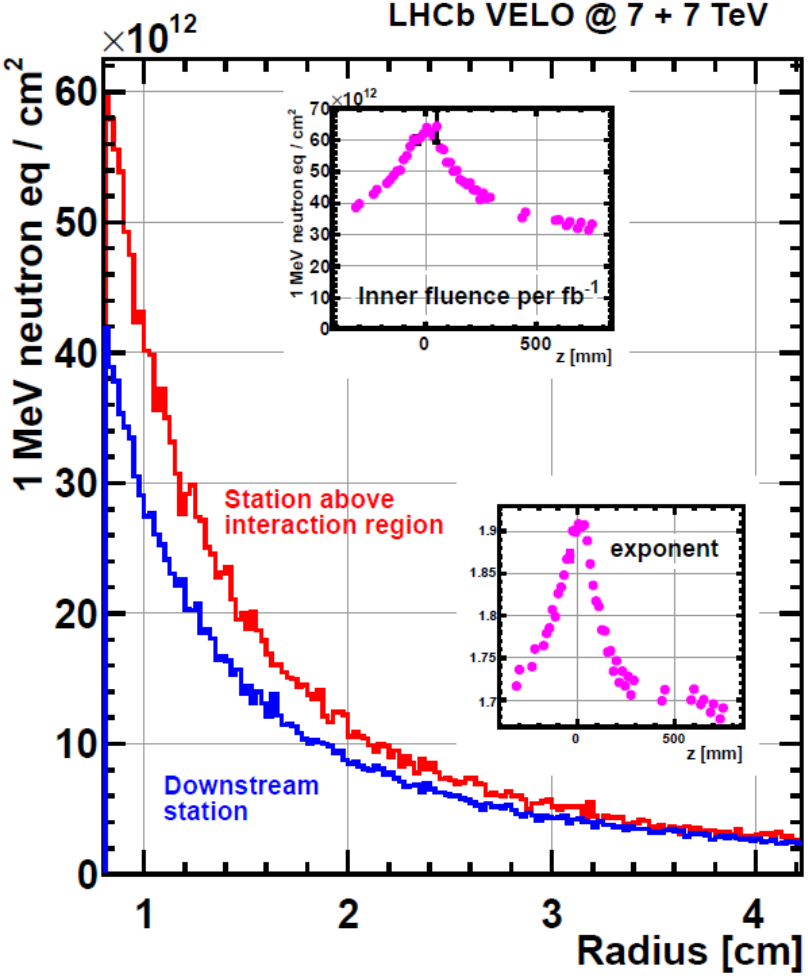
Proper time resolution ~50 fs

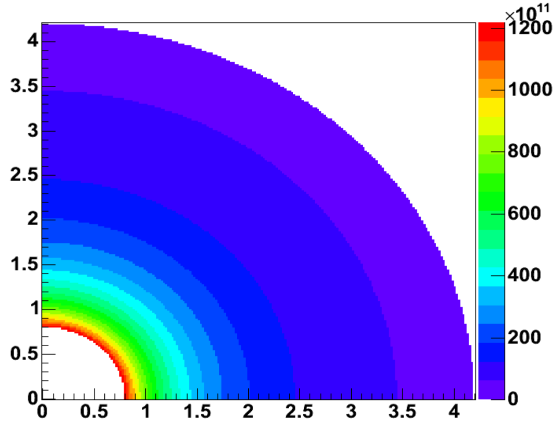
LHCb VELO irradiation at 14 TeV

VELO operates in an harsh and non uniform radiation environment.

- At the nominal LHC energy VELO accumulates maximum of $0.5\times10^{14}\ n_{eq}/cm^2$.
- The detector was designed to sustain 3 years of nominal data taking.
- Operational temperature : -8 - 0°C

Fluence per $1fb^{-1}$





Radiation effects

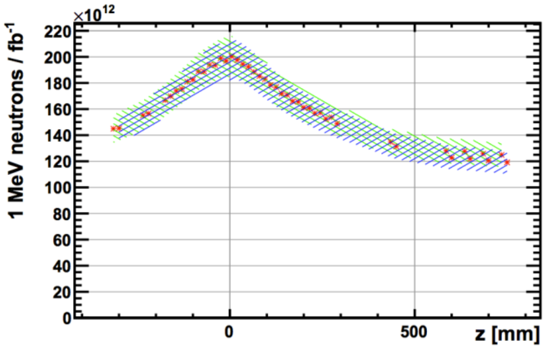
BULK damage due to generation of defects (additional generation and recombination centers) induces:

- Change of depletion voltage (cooling)
- Increase of leakage current (cooling) ✓
- Decrease of charge collection efficiency

SURFACE damage caused by scratches, surface currents in guard rings, edge effects,..

Leakage current in silicon evolution is a well predicted quantity – its change is a way to track the accumulate fluence.

The effects are counted for the integrated luminosity of $1fb^{-1}$ and compared with the measured luminosity and temperature in LHCb.



Leakage current measurement

Current = Bulk current + Surface current

BULK current:
- increases with fluence
- exponential dependence on temperature
- saturates in HV (V_{dep})

SURFACE:
- decreases with fluence
- weak temperature dependence
- HV dependent

In order to follow radiation damage we need to disentangle both of them:

temperature scans (IT - current – temperature)
curent – voltage scans (IV)

LHCb-PUB-2011-020
LHCb-PUB-2011-021
Analysis of P.Collins and VELO group

Monitoring radiation damage

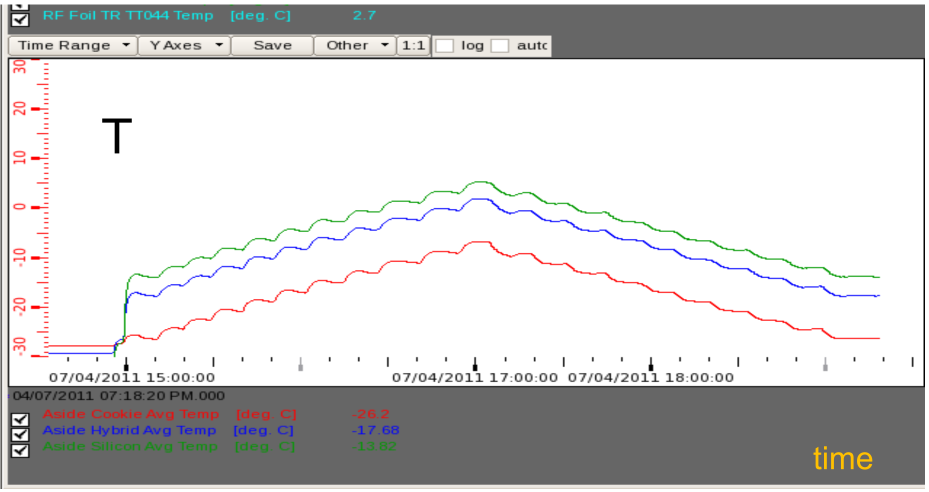
Available data set:

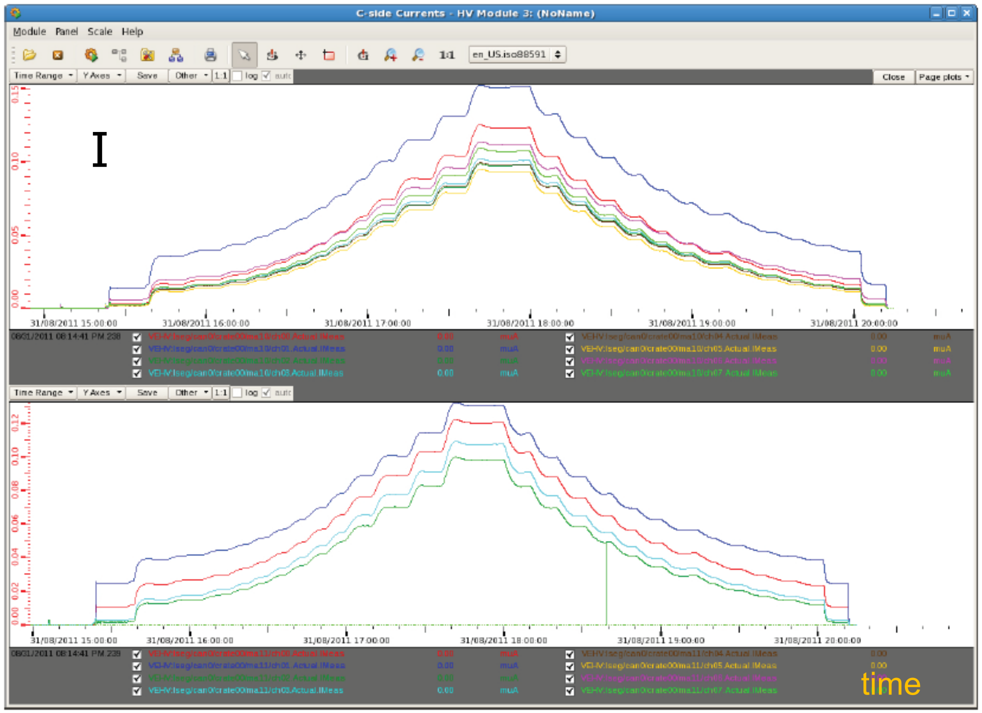
	HV	Lumi [pb^{-1}]
IV scans (2009)	100 V	0
IT scans	100-150 V	480, 821, 1000
IV scans	0 -150- 0 V	weekly

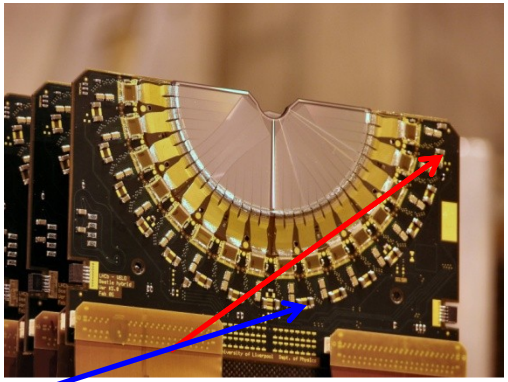
IV scans
taken weekly, no beam, results presented in the monitoring software (GUI),

IT scans :
temperature ramped up & down in range between -30 and 5°C with the step of 2°C,
HV constant 100 or150V,
work on generic analysis software (taken by Krakow group) in progress,

IT - control screen shots





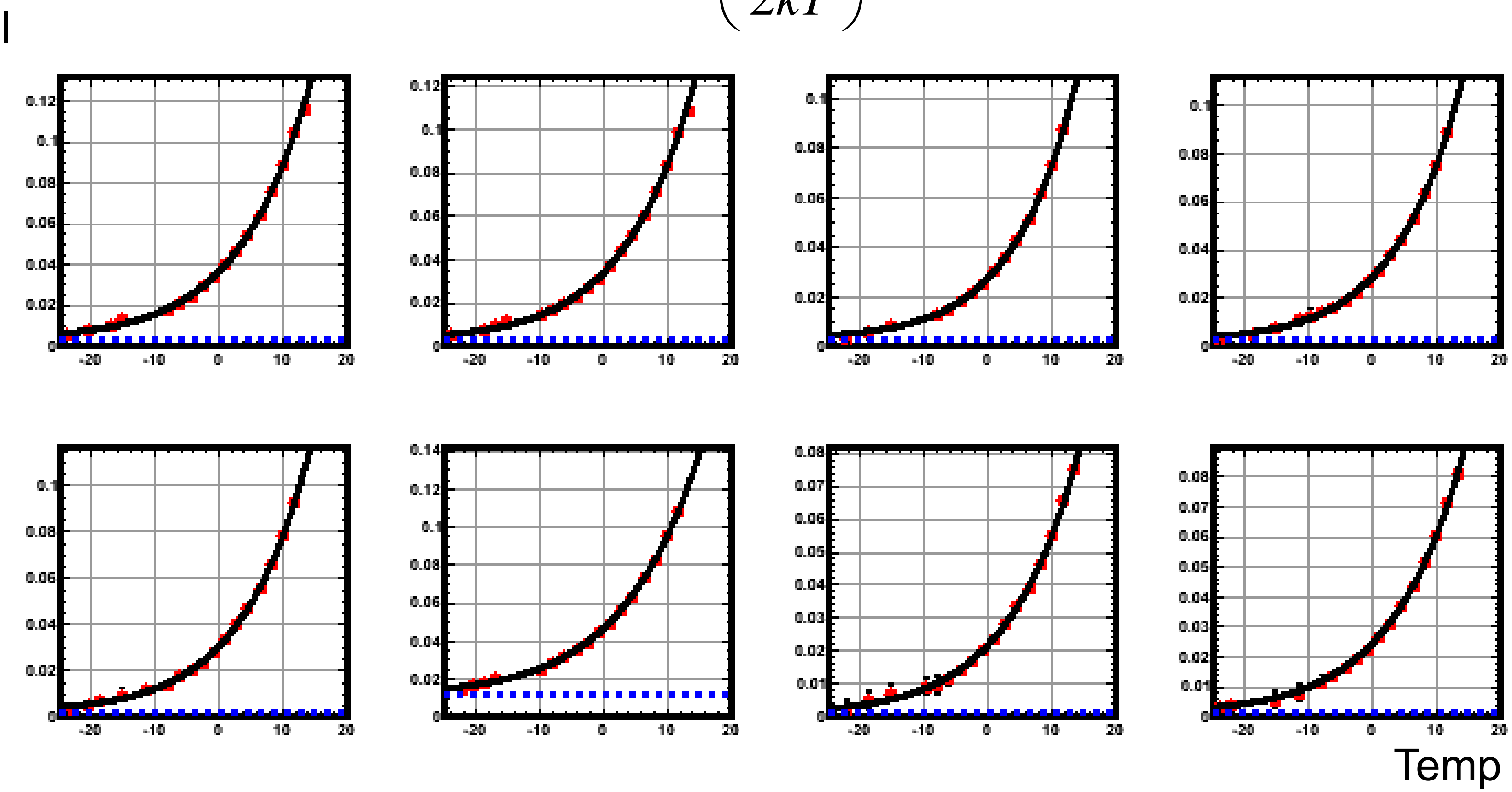


2 NTC to monitor temperature on hybrid

Typical fits to the IT data

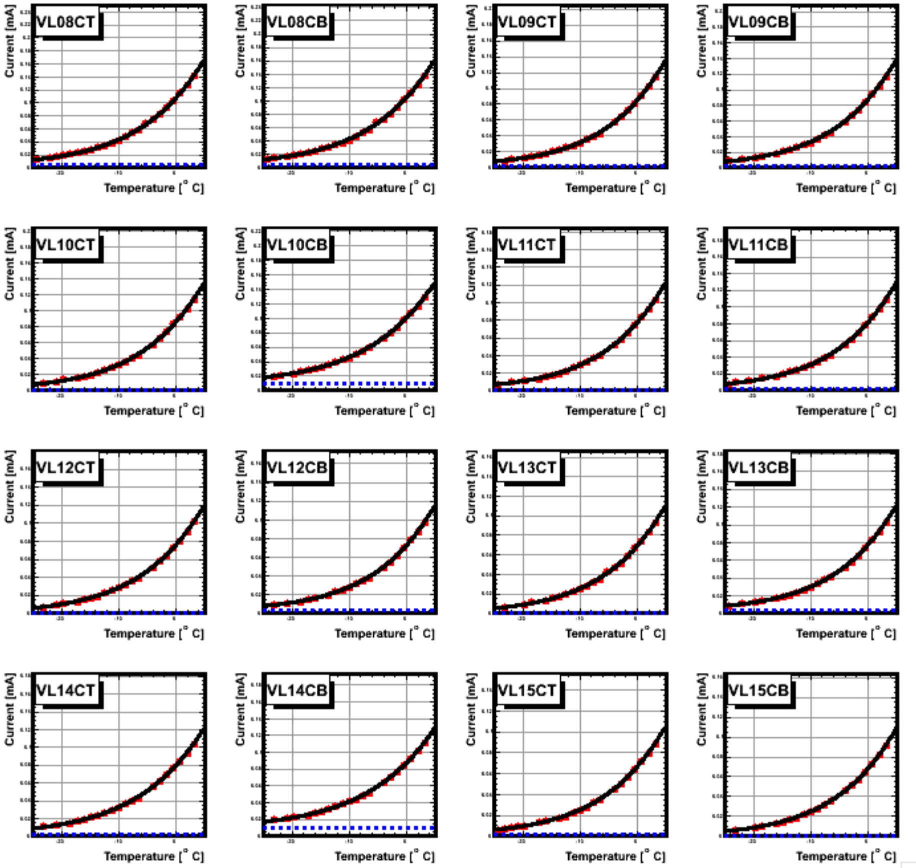
exponential formula (bulk contribution) + constant term (surface current)

$$I(T) \propto \sim T^2 \exp\left(\frac{-E_g}{2kT}\right)$$

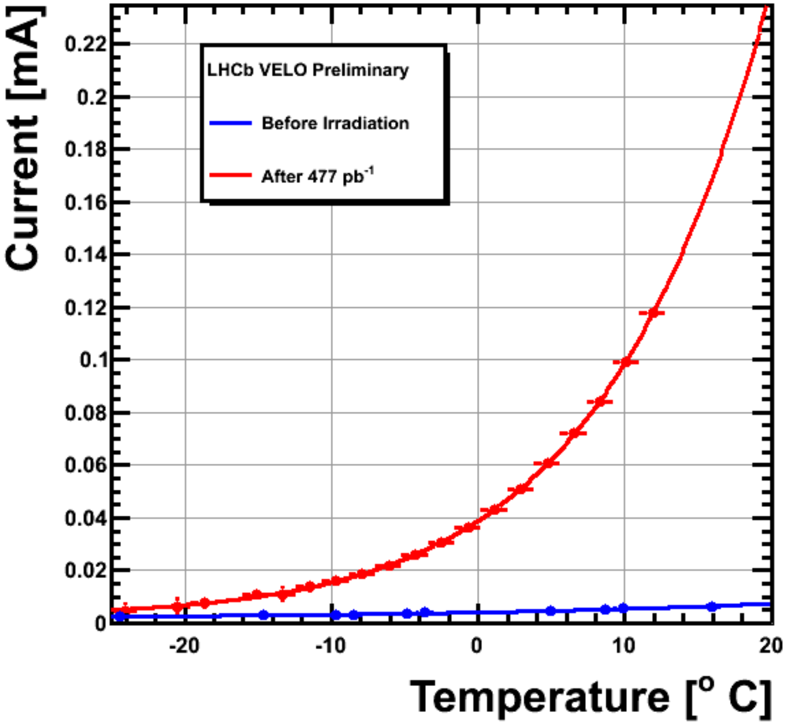


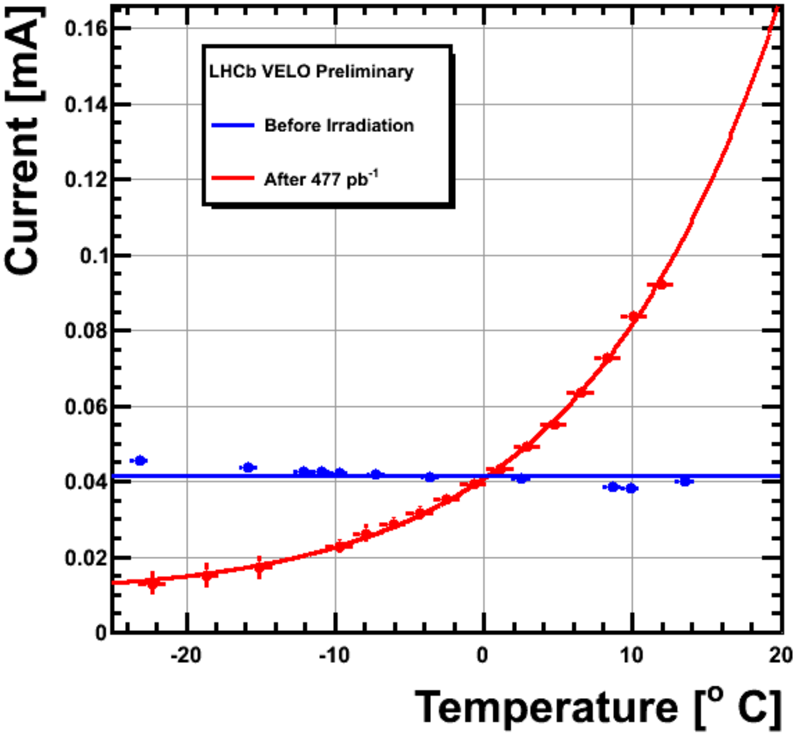
The most recent IT scan

Lumi=1204 pb^{-1}



Bulk & surface currents





Bulk current dominated sensor

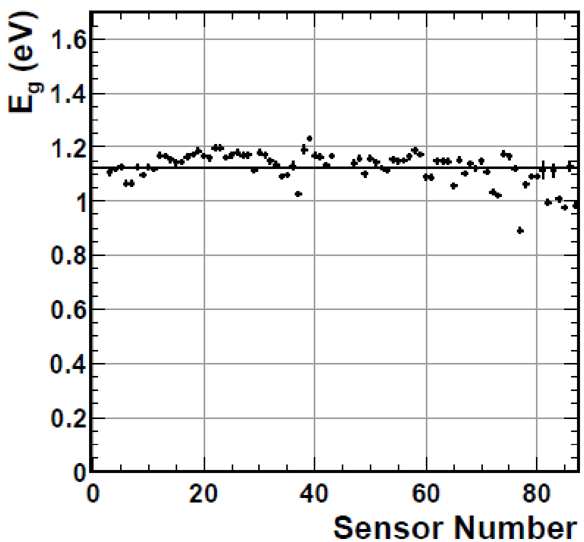
Surface current dominated sensor-annealing

Effective energy gap

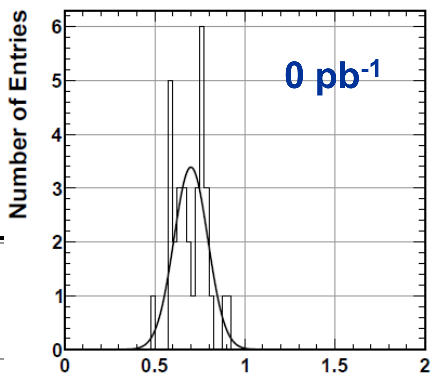
The significant change in temperature for the fit allows to determine the E_g

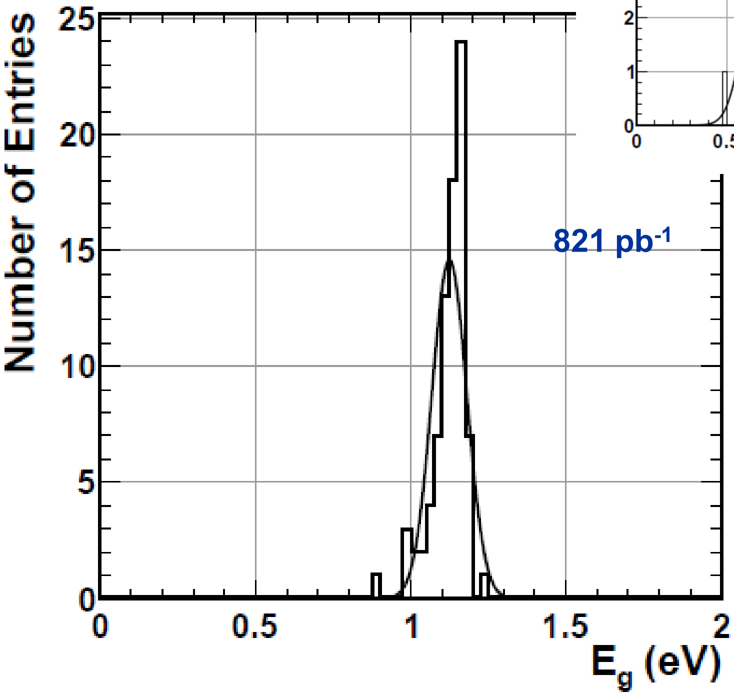
Data set	Lumi [pb-1]	E_g [eV]
IV scans	0	0.69±0.08
IT scan	821	1.13± 0.04
IT scan	1204	1.14 ±0.04 eV

E_g for each sensor:



LHCb preliminary





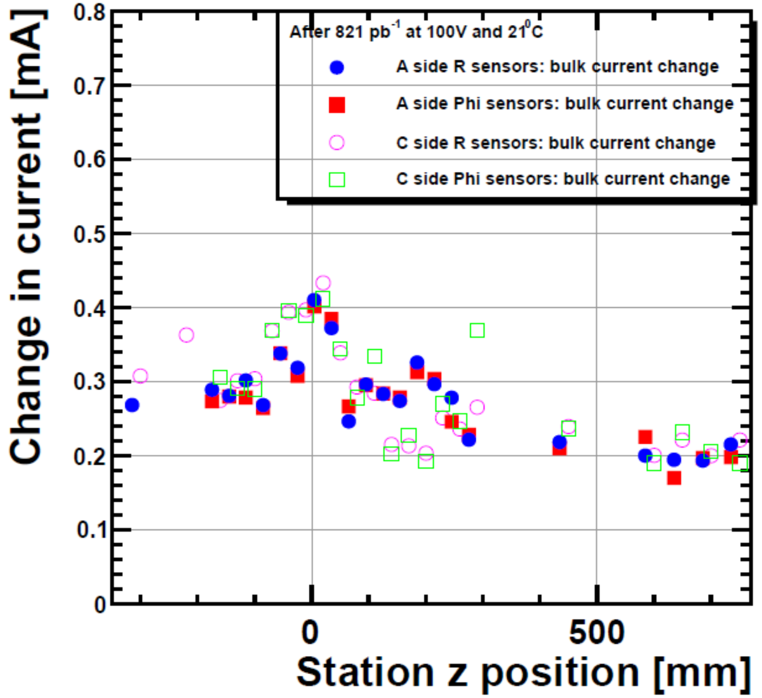
Change in bulk current

Currents are corrected to the same temperature (21°C and 0°C) for all sensors:

$$I(T_{ref}) = I(T)\left(\frac{T_{ref}}{T}\right)^2 \exp\left(-\frac{E_g}{2k}\left[\frac{1}{T_{ref}} - \frac{1}{T}\right]\right)$$

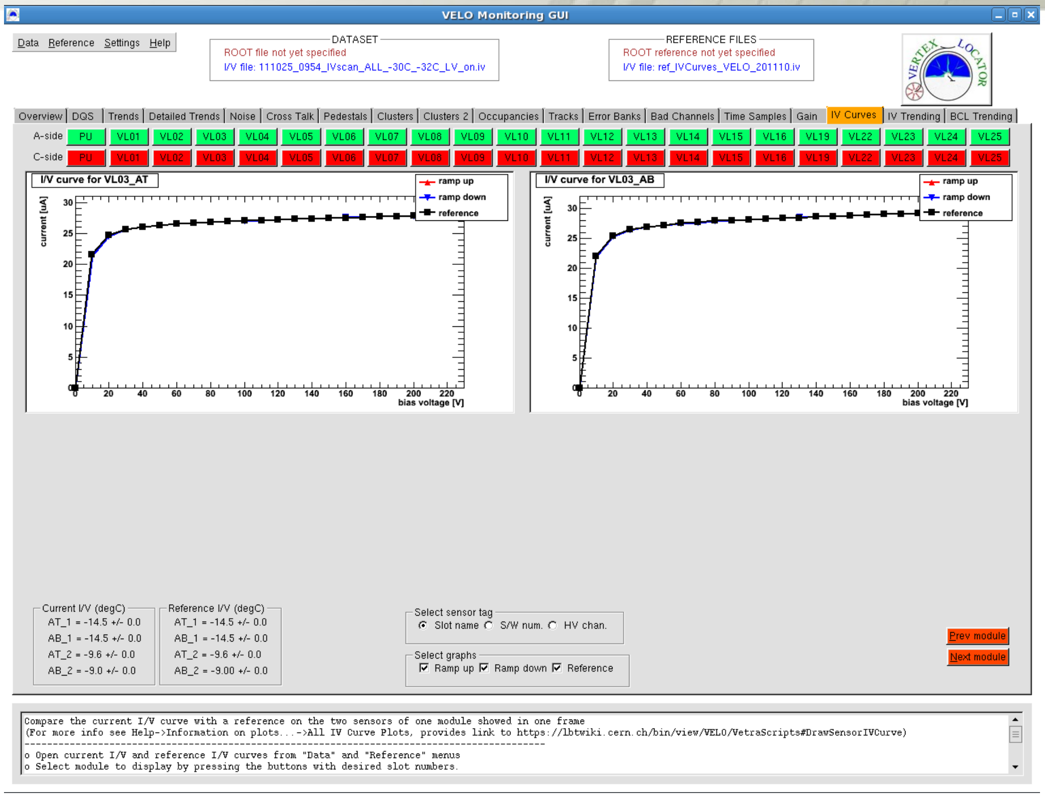
T[°C]	Lumi [pb^{-1}]	ΔI
21	821	0.16÷0.44 mA
-8		9÷26 μA

ΔI dependence on z sensor position:



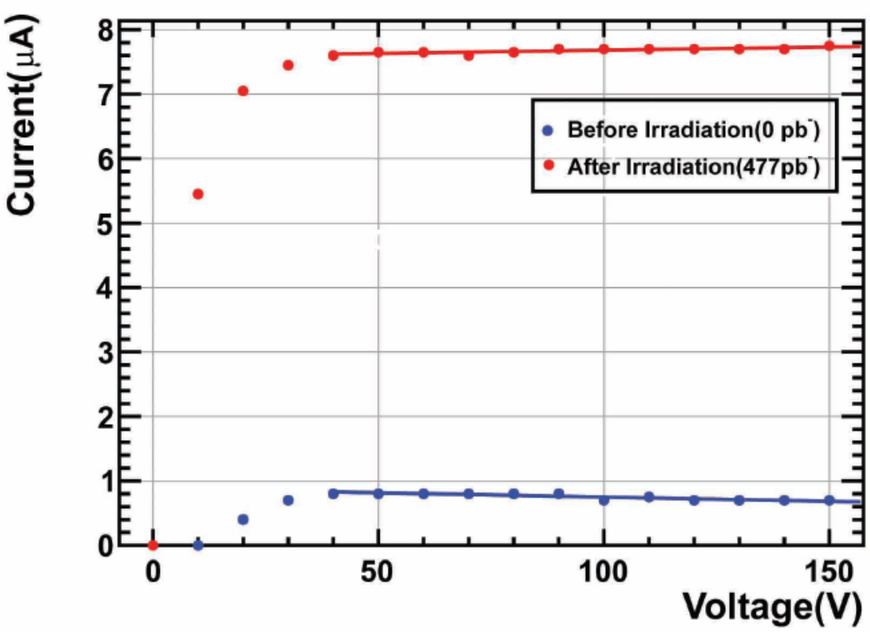
IV scans

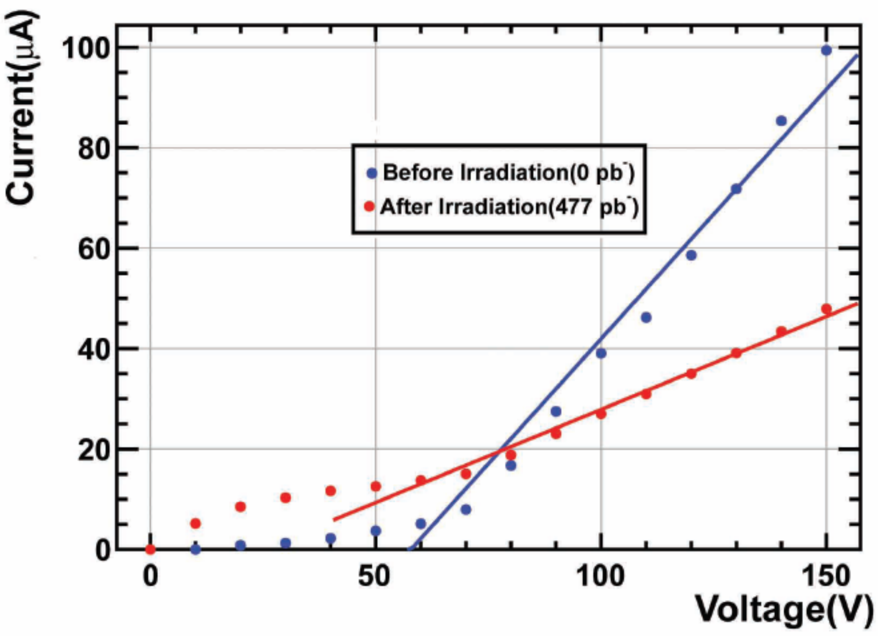
- Surface currents – ohmic behaviour.
- Bulk current – saturates with HV.
- Current-voltage scans are taken every week.
- Periodic voltage scans from 0 to 150V and back down.
- Each measurement recorded with NTC temperature value.
- Monitoring in GUI.



Current-voltage fits

Two main types of current behavior:

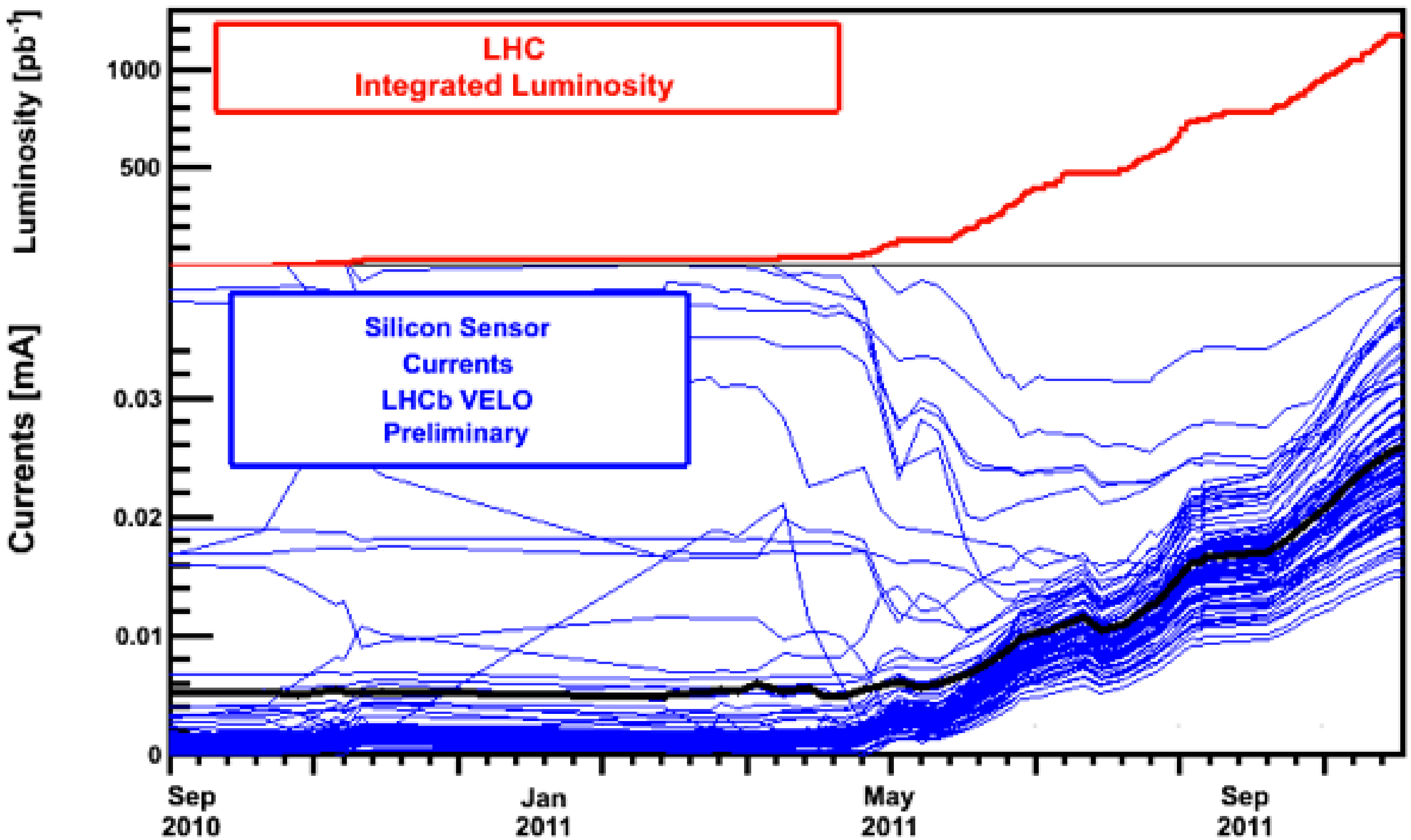




Bulk current dominated sensor before and after irradiation.
Current increses and saturates (59 sensors)

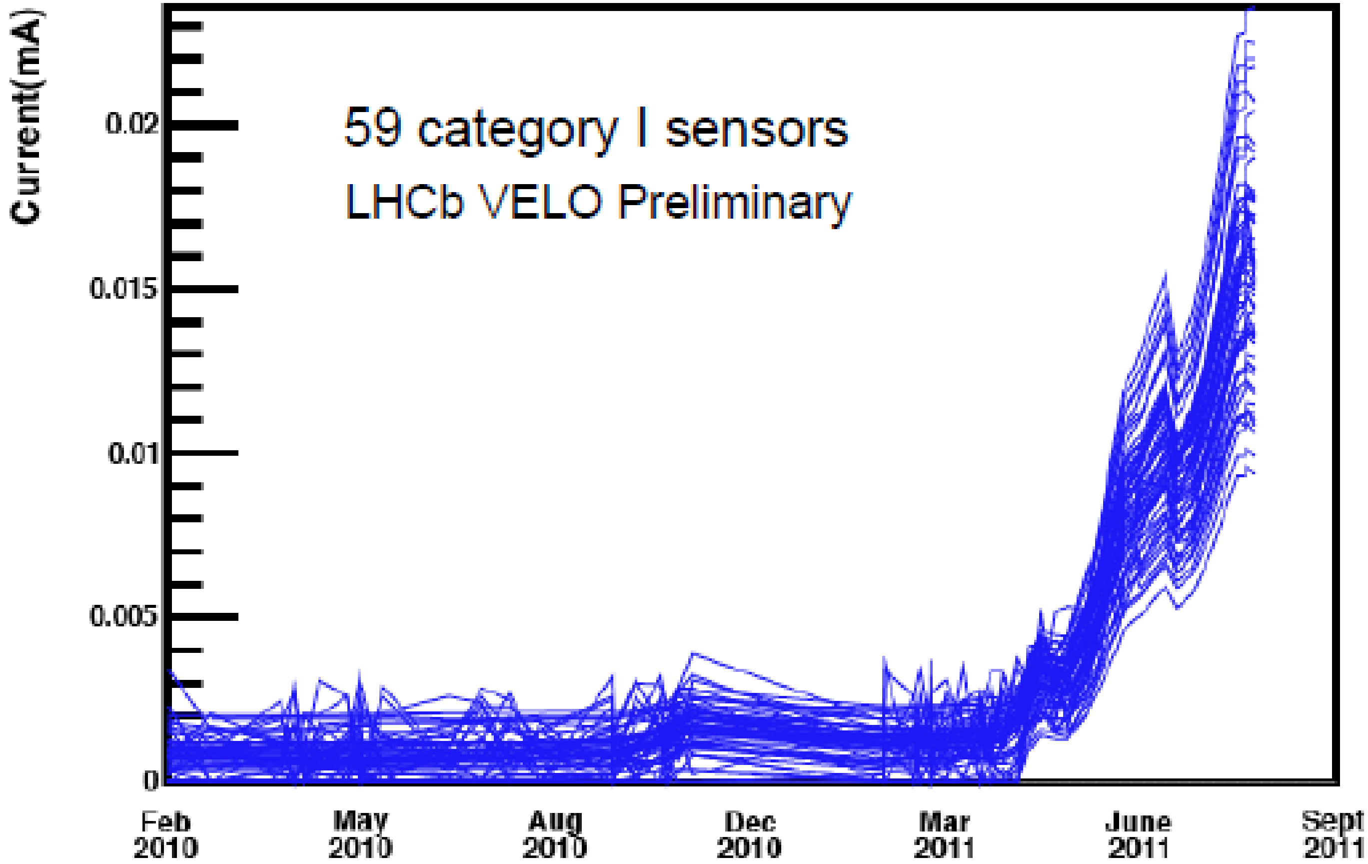
Surface current dominated sensor-ohmic component.
Slopes decrease after irradiation (22 sensors)

Current vs Time



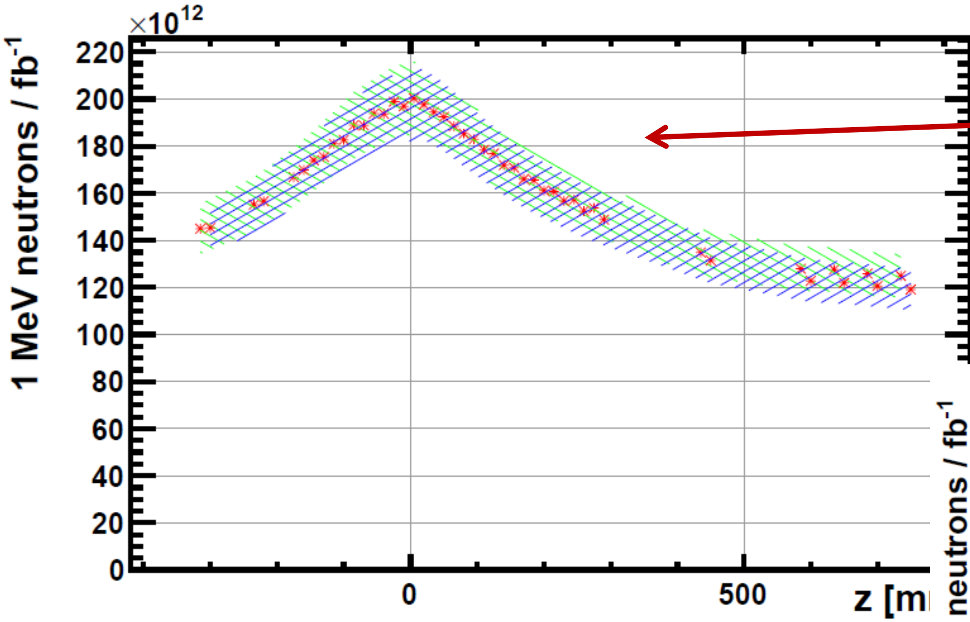
Bulk current sensors

Simple requirements – slope is flat before and after irradiation:



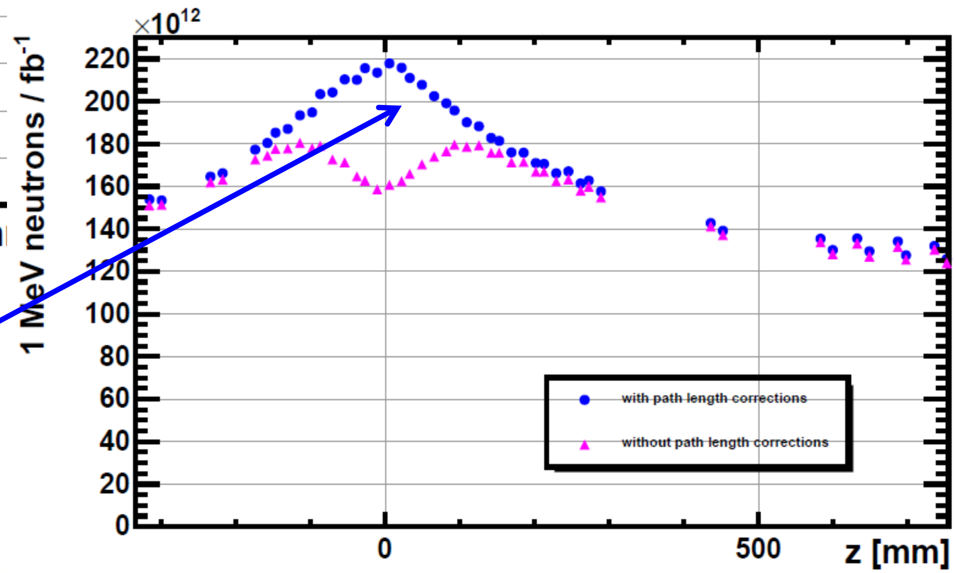
Comparison with fluence prediction

Simulated data – correction for path length in silicon



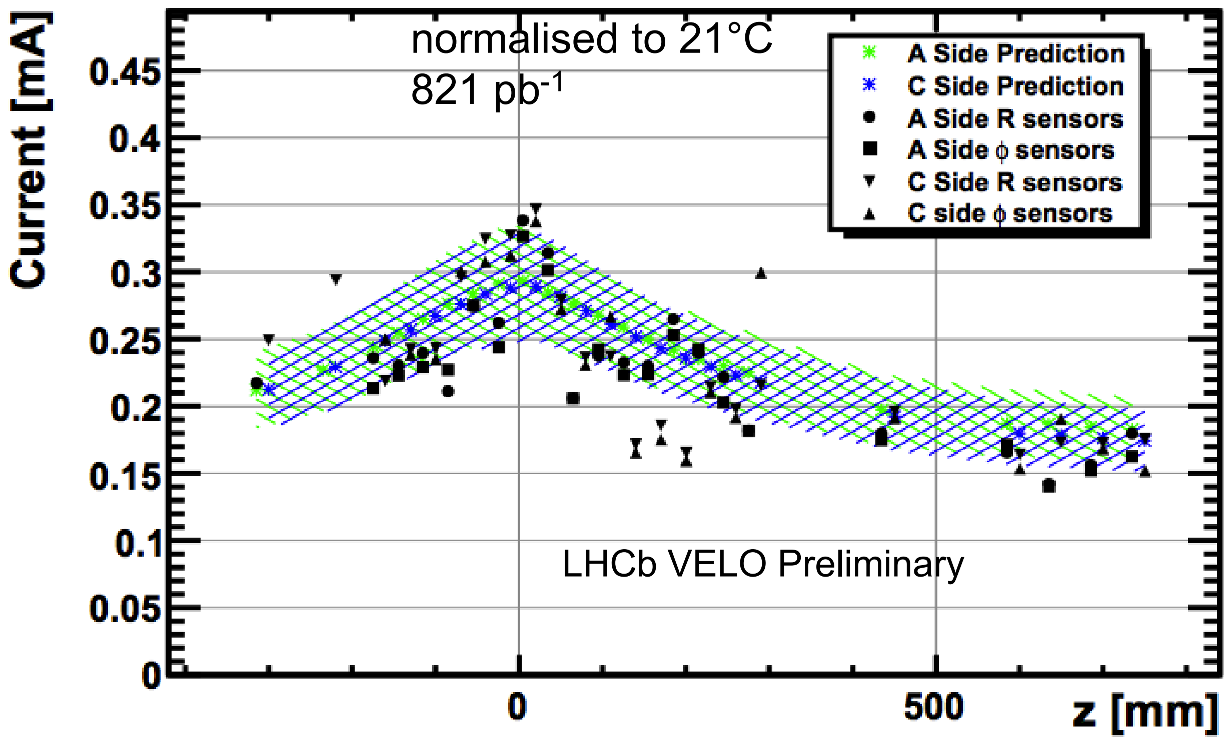
Prediction for the total fluence (beam of 3.5 GeV) for 1 fb^{-1} as a function of a sensor's z – position

Most damage in sensors close to IP and large angles in silicon



Leakage currents prediction

Leakage current increase is consistient with expectation and its change is caused mainly by charged particles directly produces in collisions.



Good agreement – understanding of fluence modeling .

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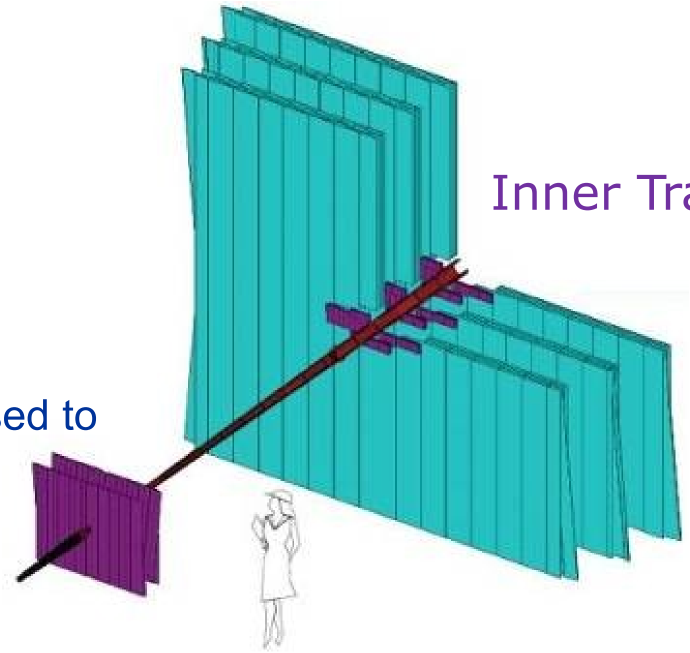
Silicon Tracking system

LHCb

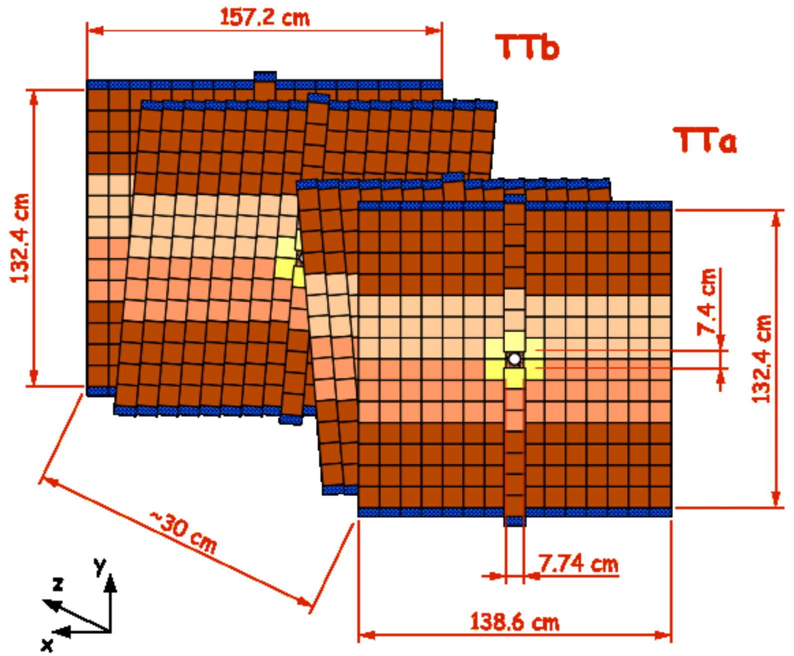
- Silicon Tracker (ST) comprises two detectors:
  Tracer Turiscencis (Trigger Tracker)
  Inner Tracker
- Four stations:
  TT between VELO and magnet
  3 downstream tracking stations

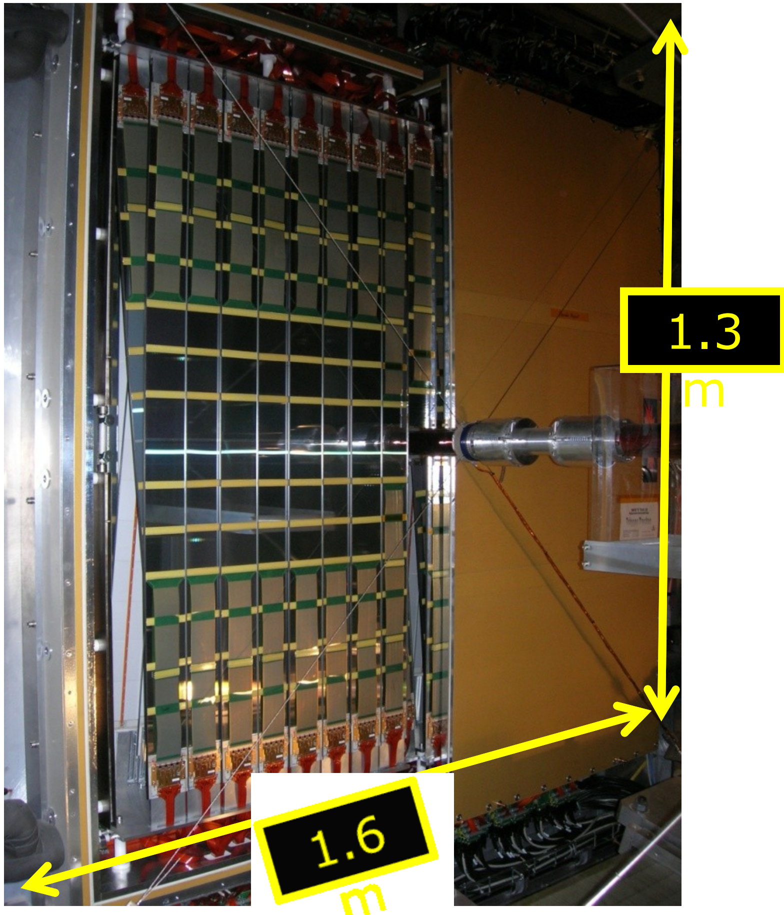
- Hits combined with information from VELO used to reconstruct particle tracks – measure P

- Key properties:
  p+-on-n
  non-oxygenated
  500 µm – TT
  320-410 µm – IT
  No second metal layer



Tracker Turicensis





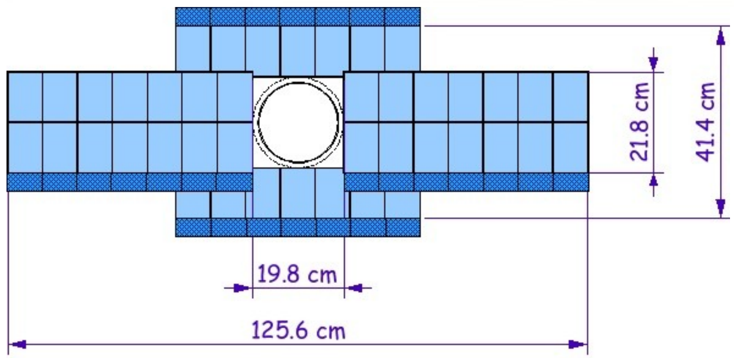
- S
- Four planes (0°, +5°, -5°, 0°).
- Pitch: 183 μm; Thickness: 500 μm.
- Long readout strips (up to 37 cm).

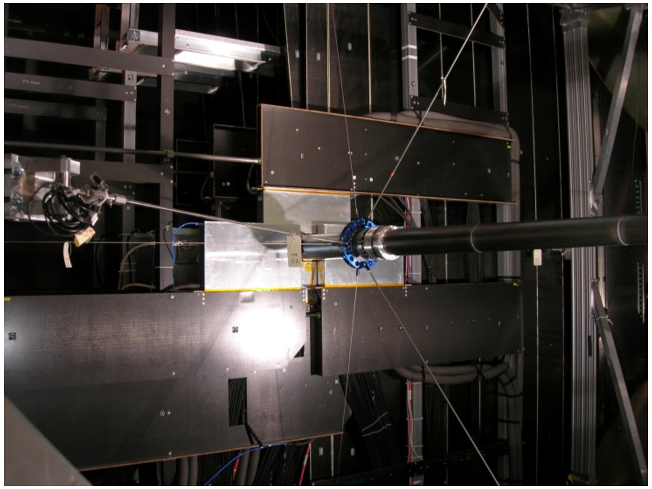
143360 readout channels.

- Total Silicon area is 8 m^2.

  Covers full acceptance before magnet.
- Cooling plant at 0°C: sensors ≈ 8°C.

Inner tracker





- Silicon micro-strip detectors (p-in-n).
- Three stations in z.
  - Four boxes in each station.
  - Four planes (0°, +5°, -5°, 0°)
  - Pitch: 198 μm
  - Thickness: 320 or 410μm
  - 129024 readout channels.
- Total Silicon area is 4.2 m^2.
  - Covers region around beam with highest flux.
- Cooling plant at 0°C: sensors≈10°C.

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Monitoring radiation damage in the ST

- Expected Radiation Dose (10 years):
  - IT: 5 x 10^{13} 1-MeV neutron equivalent.
  - TT: 8 x 10^{13} 1-MeV neutron equivalent.
- Monitor change in leakage currents.
  - Plot the peak current in a fill vs time.
  - Expected changed calculated using (old) FLUKA simulation.
    - IT: $\Delta I(10°C) = 0.103\ (0.031)\ \mu A/pb^{-1}$.
    - TT: $\Delta I(8°C) = 0.065\ \mu A/pb^{-1}$.
- Monitor changes in depletion voltage
  - Charge Collection Efficiency.
- Expect type inversion after 1-2 years.

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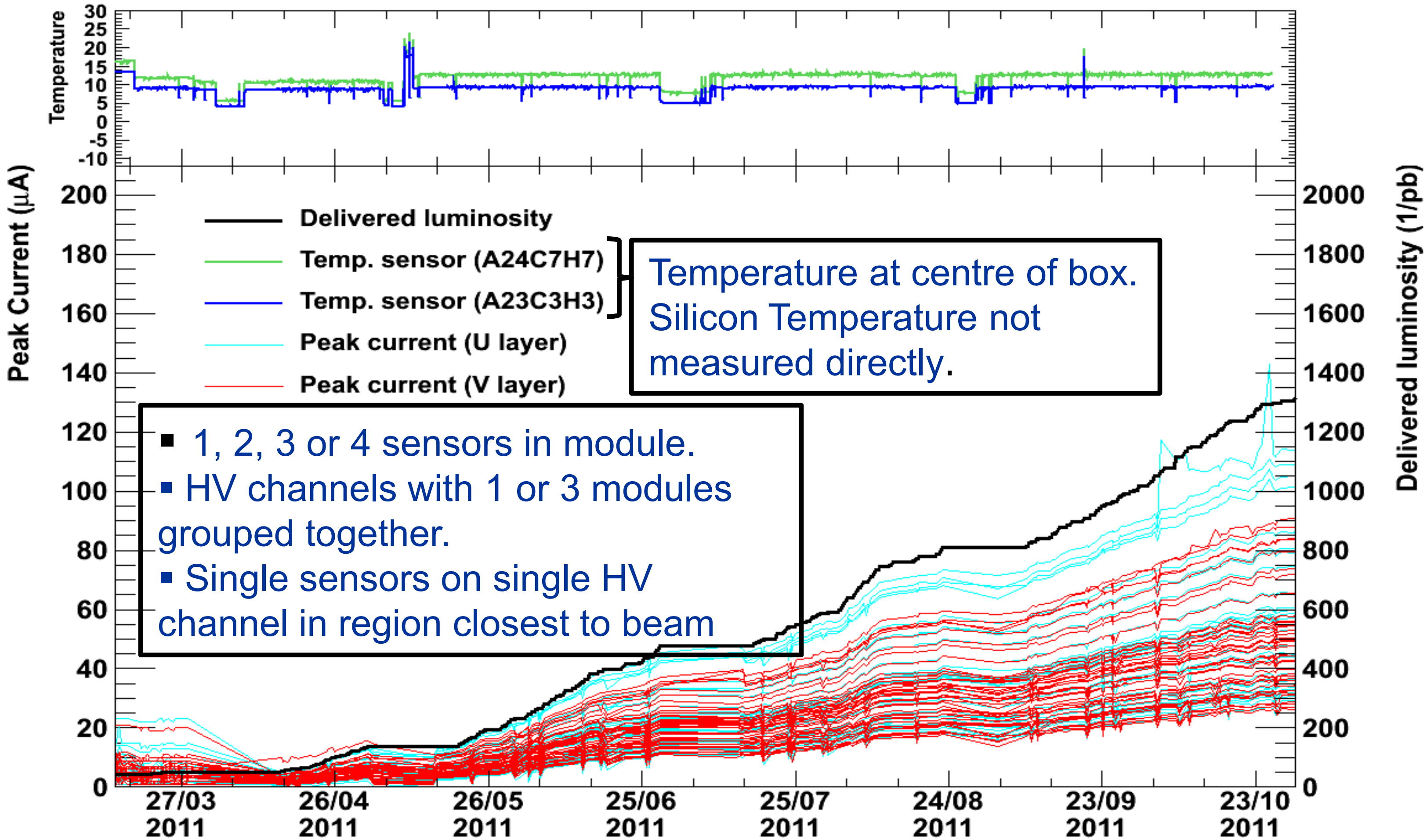
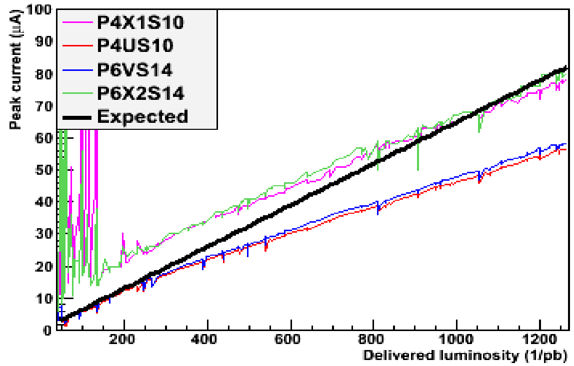
Current evolution in TT

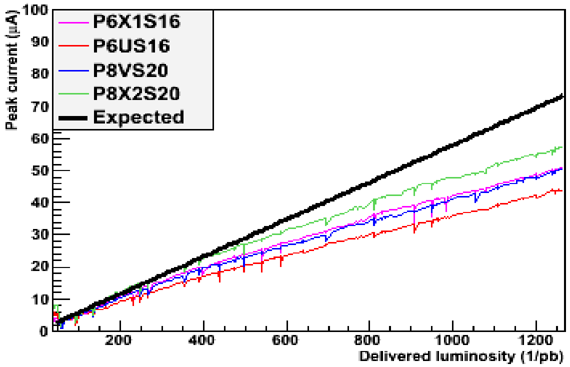


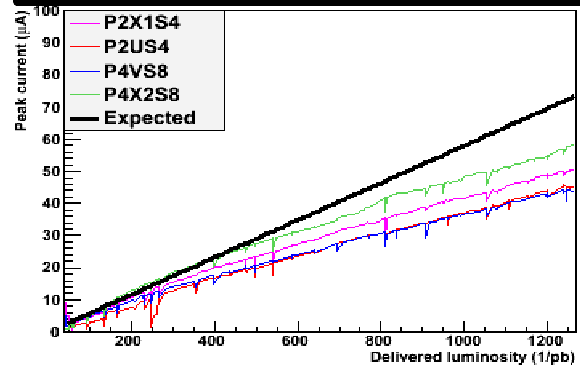
Leakage current evolution in TT

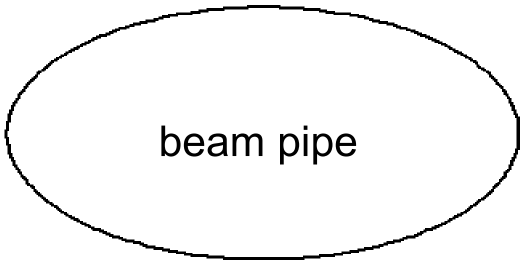
- Sensors closest to the beam.
- Colour indicates layer.

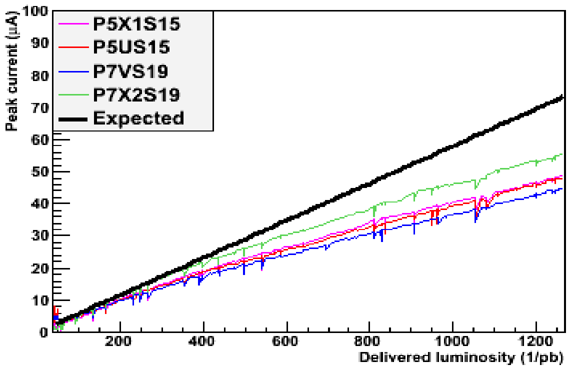
- Results within expectations.
- Need to include annealing in predictions.

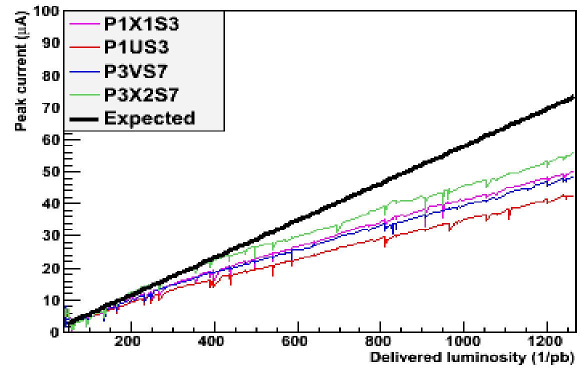


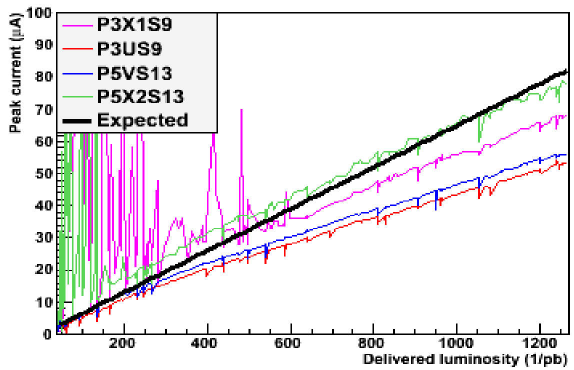






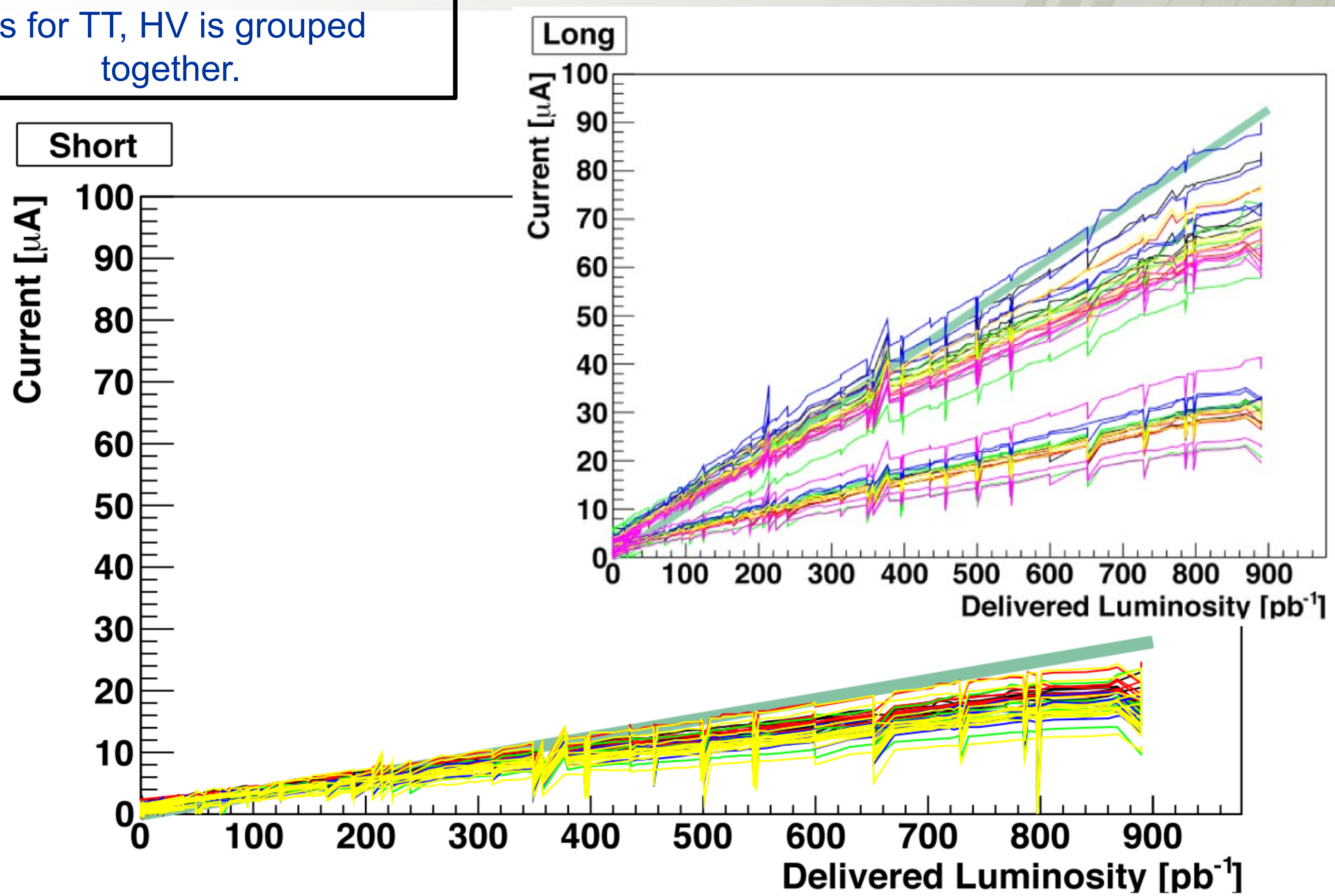






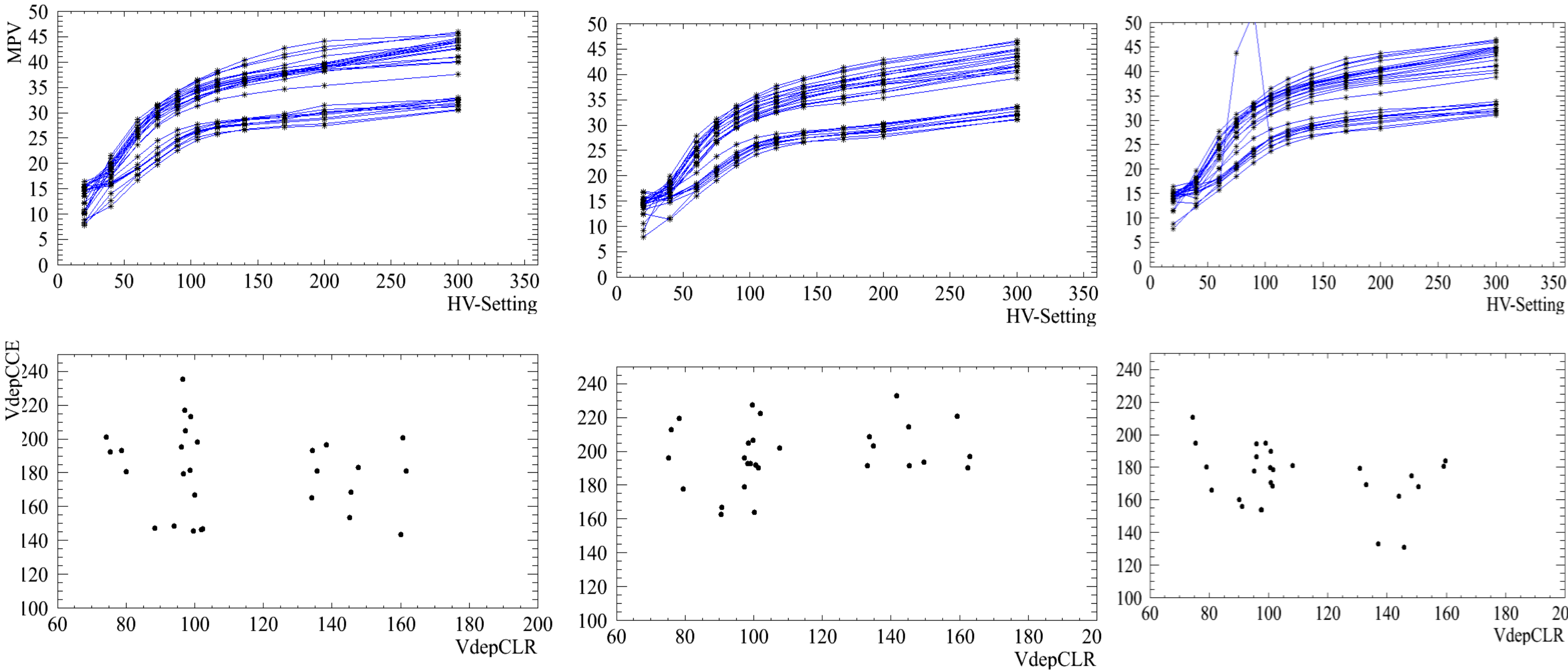
Current evolution in IT

As for TT, HV is grouped together.



IT HV-vs-Depletion Voltage

plot V_{dep} from CCE-scan versus V_{de} from capacitance measurement during production



Analysis still on-going: results here are extremely preliminary

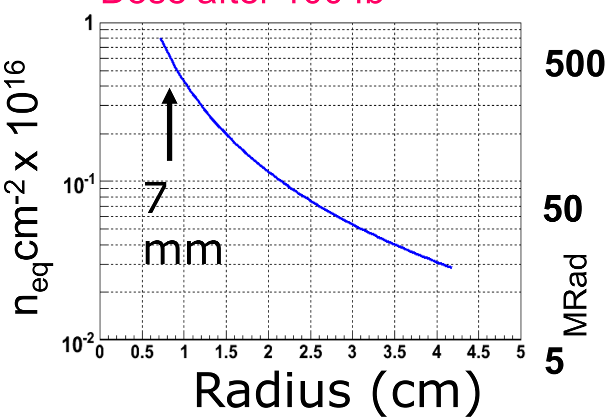
Final remarks

- Two monitoring methods: IV and IT scans provide information on bulk/surface component of leakage current.
- Temperature scans are more accurate and allow to measure E_g.
- VELO data used for measuring fluence and ageing.

What will happen next?

Before the scheduled upgrade (2018-19) VELO will collect ~9 fb^{-1}.
At 7 mm from beam sensor accumulate 8×10^{15} n_{eq}/cm^2 for 100fb^{-1}.

Dose after 100 fb^{-1}



In the absence of accidents and assuming the upgrade keeps to schedule, we would expect not to insert the replacement but change from the current VELO to the upgrade.