VELO operations and performance in 2011

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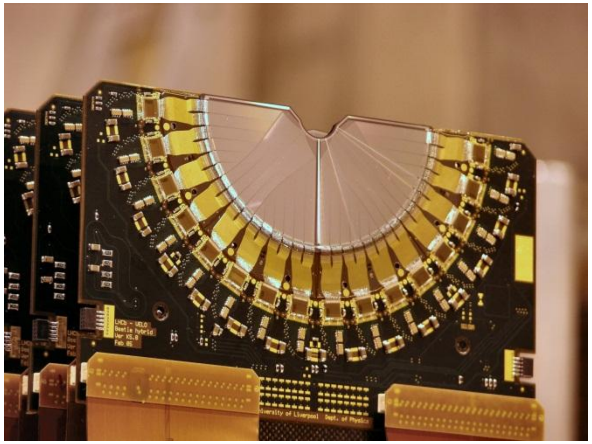
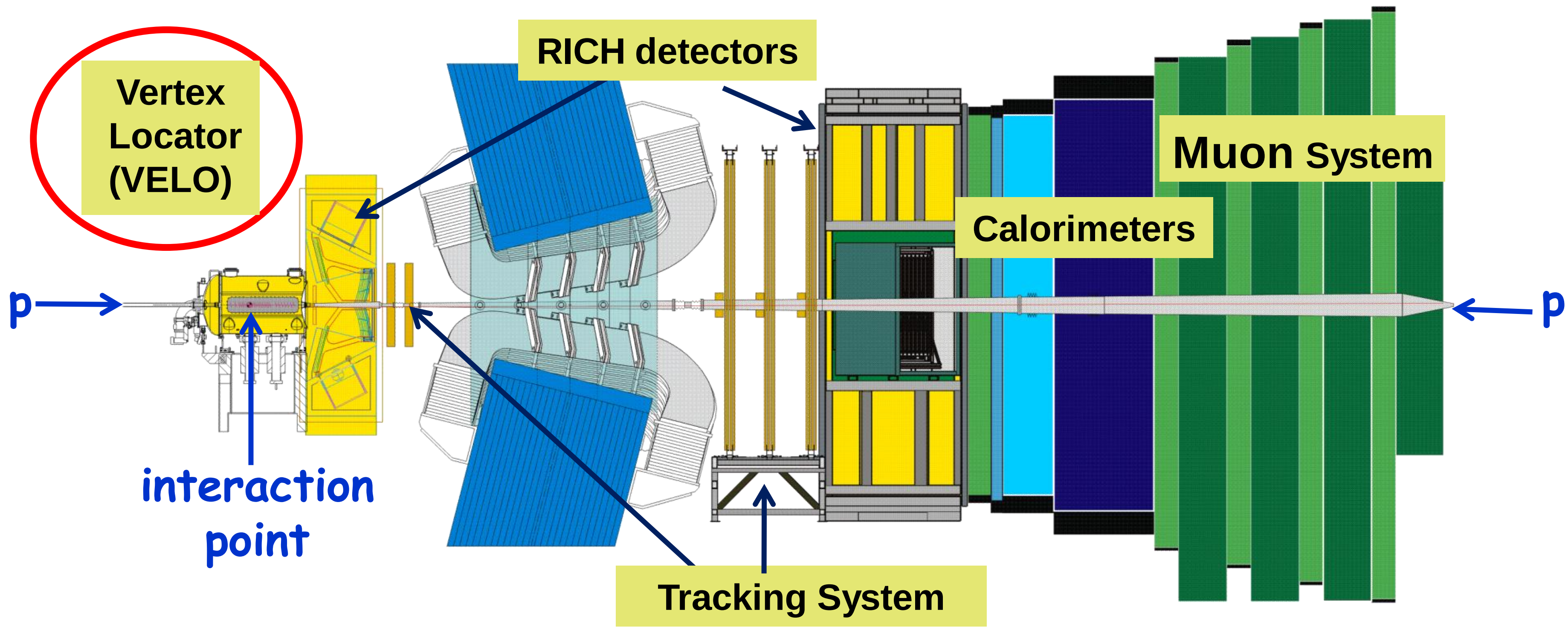
on behalf of the LHCb VELO group

- LHCb
- VELO: layout, sensors, infrastructure, safety
- Operational aspects: luminosity, monitoring, closing, special runs
- Performance: S/N, resolutions
- Summary & Outlook



LHCb

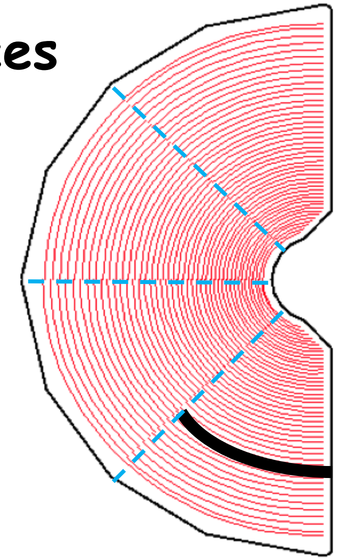
- LHCb detector is optimized for the study of rare decays and CP-violation processes using beauty and charm hadrons.
- Forward-angle spectrometer ($1.9<\eta<4.9$)
- Excellent tracking and PID properties



VELO

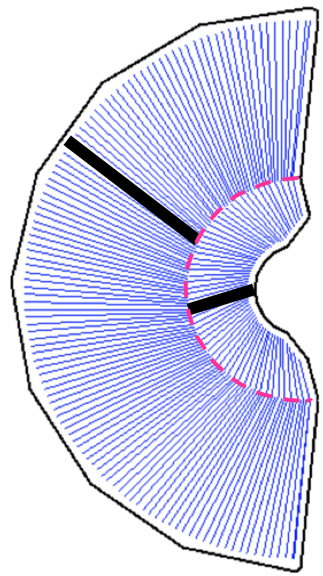
Task:
- reconstruct primary and decay vertices

Requirements:
- High resolution
- Radiation hard design
- Reliability



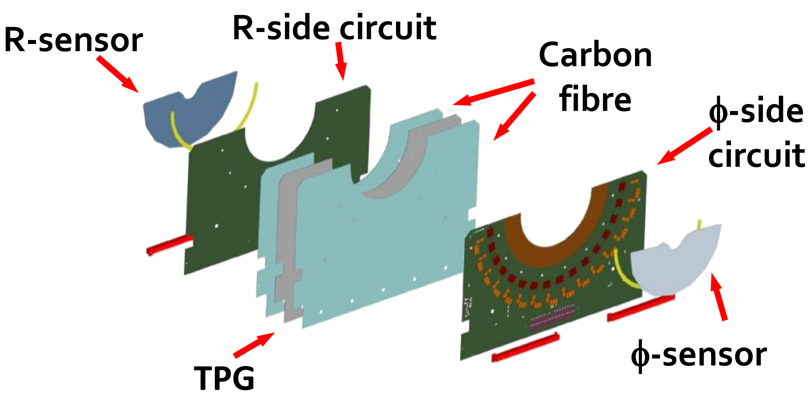
R-sensor
inner radius 7.0 mm
first strip at 8.2 mm
outer radius 42 mm

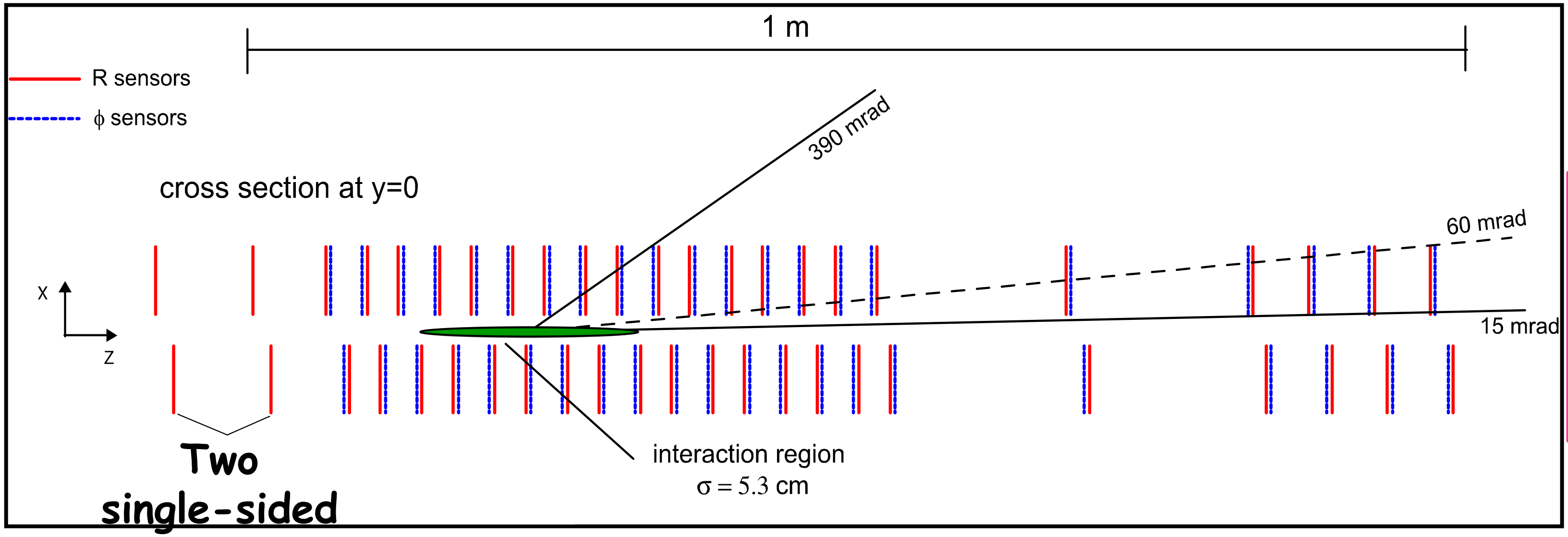
- 300 μm DOFZ n^+-in-n sensors with p spray
- 2 out of 88 are n^+-in-p
- 2048 strips each
- 40-100 μm pitch
- Routing via double metal layer



Φ-sensor
stereo angles:
inner region 20°
outer region -10°

- Each VELO half contains 21 double-sided modules

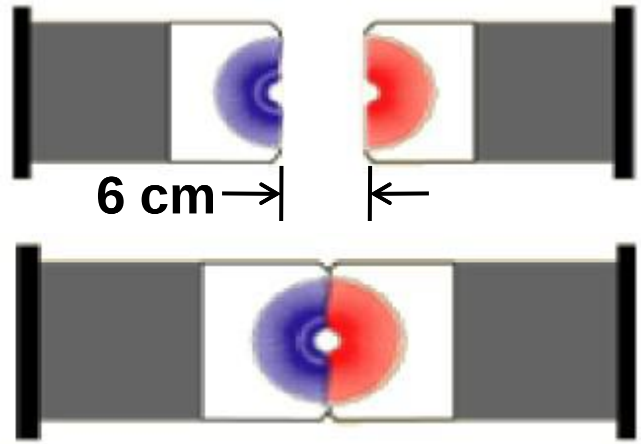


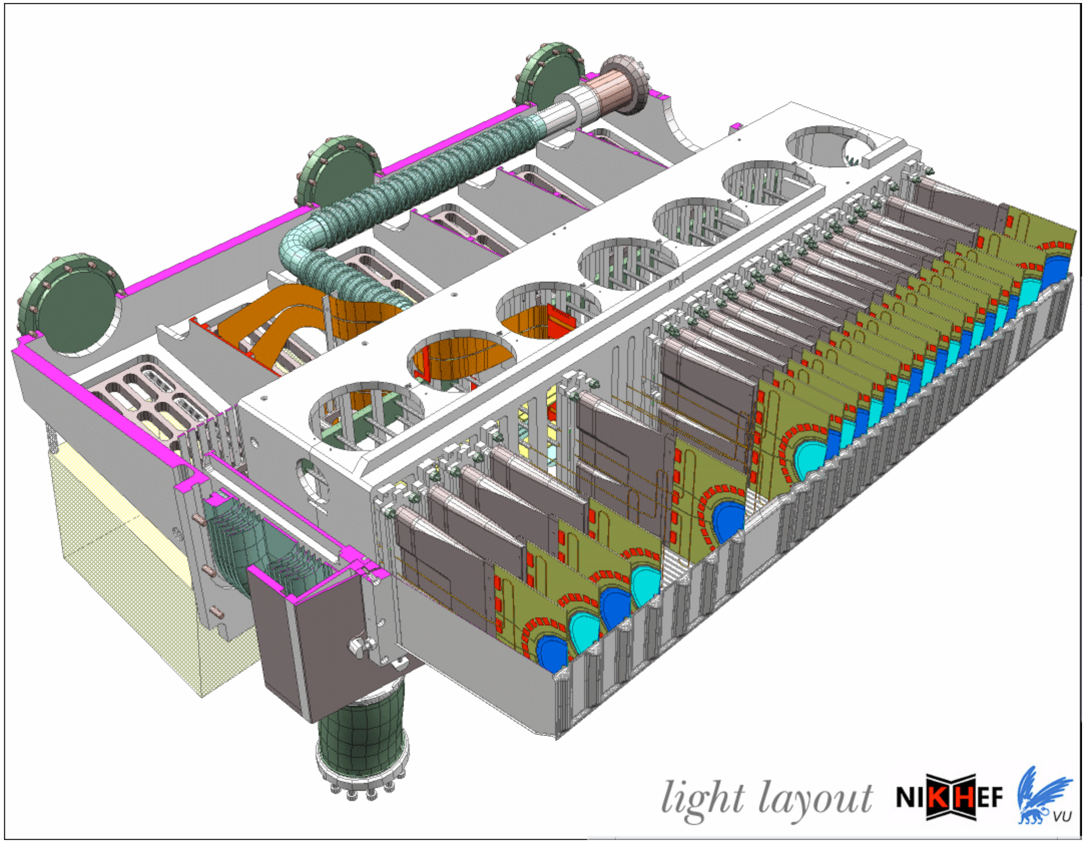


Rest of the LHCb detector

Two single-sided Pile-Up modules

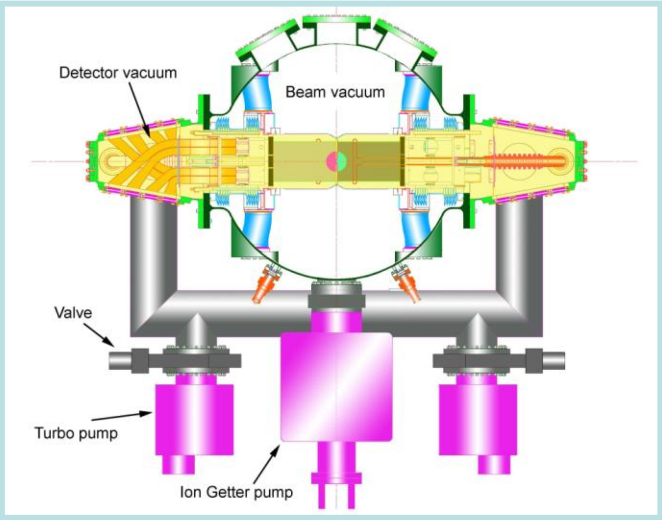
- Detector halves are enclosed in a 0.3 mm thick RF-box at 1 mm from the sensors and operated in a secondary vacuum.
- Two moveable detector halves:
  - open during beam injection
  - closed and centered when Stable Beams are declared



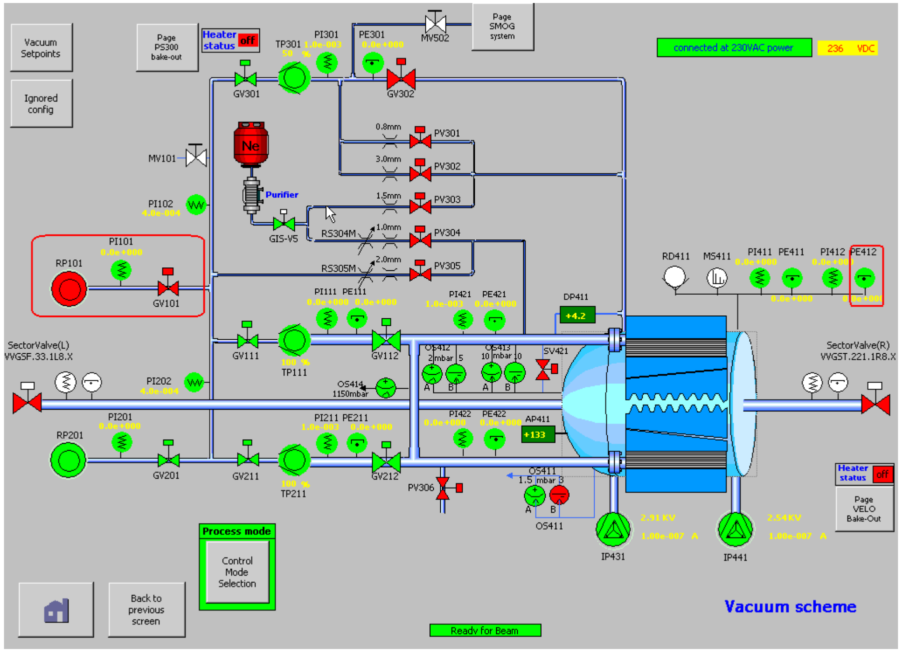


Once closed, the RF-box is at 5 mm from the beams.

Vacuum

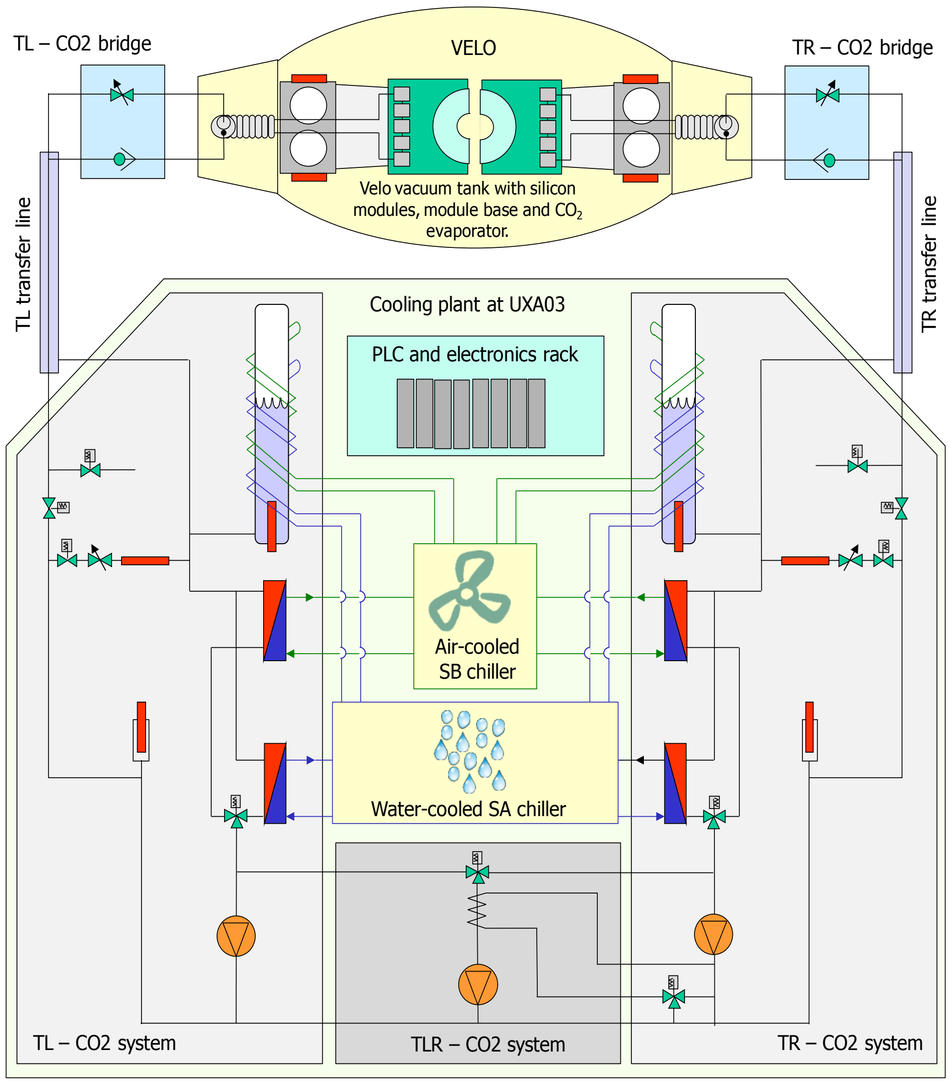


Status and control display of vacuum-PLC



- PLC controlled vacuum system
- 18 vacuum gauges
- 15 valves
- 4 membrane switches
- 3 turbo pumps
- 2 roughing pumps
- 2 ion pumps
- 1 burst disk
- 1 mass spectrometer
- ultrapure neon injection system
- delicate venting and evacuating procedures, since differential pressure must always be < 10 mbar
- hardware interlocks with LHC and VELO-cooling and motion.
- detector vacuum ~10^{-7} mbar
- beam vacuum in $(10^{-9}, 10^{-8})$ mbar range depending on beam specs

Cooling



- evaporative CO_2 cooling system
- PLC-controlled
- "independent" system for either side
- redundancy of pumps and chillers
- 2.5 kW chiller at –40 °C
- 800 W heat load of detectors
- air-cooled backup chiller of 1 kW at -25°C
- 55 m CO_2 transfer line
- 31 pressure sensors
- 192 temperature sensors
- only passive components at VELO
- hardware interlocks with LV
- -28 °C operational temperature
- sensors are kept ≤-7 °C
- stability < 0.1 °C

Safety

HW-based interlock system

Conditions

- Vacuum-PLC
- Cooling-PLC
- Module temperatures
- Temp-boards
- BCM
- Emergency button

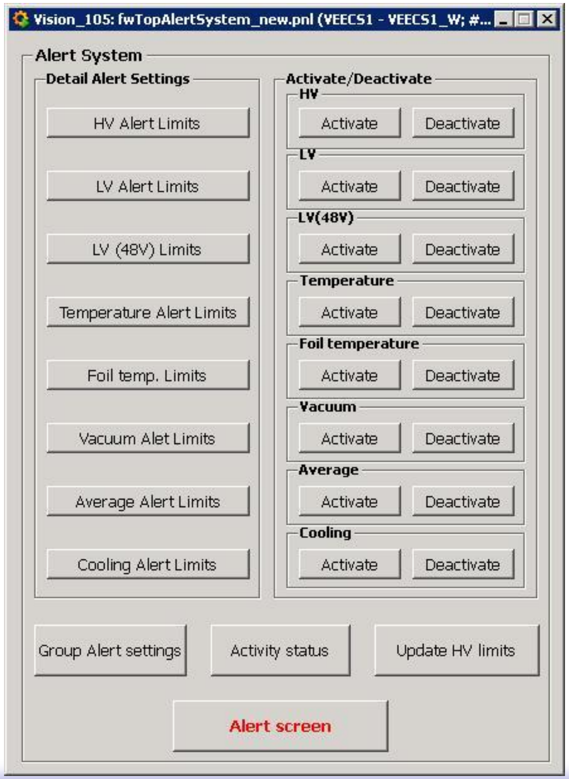
Actions

- LV Off
- HV Off
- Cooling Off
- Retract VELO

Additional HW-interlocks:

- motion system ↔ beam dump
- vacuum system ↔ fast valves of LHC

SW-based warning and interlock system

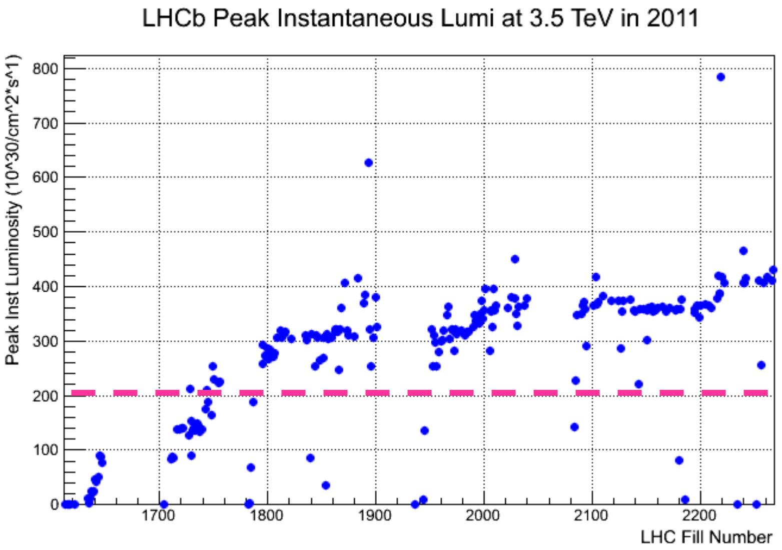


1370 parameters monitored

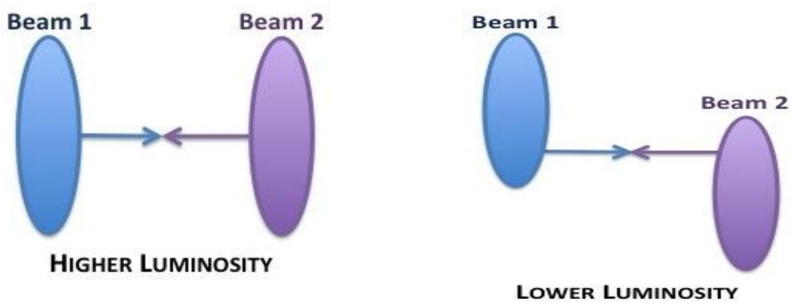
3 levels each:
warning, error and fatal

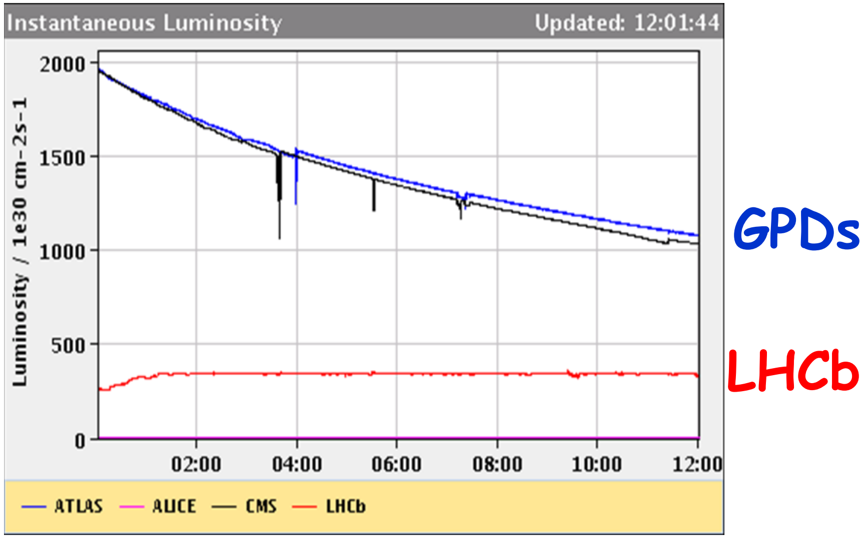
Operations in 2011

- LHCb was designed to run at $\mathcal{L} = 2x10^{32}\ cm^{-2}s^{-1}$
- actual value has increased to $4x10^{32}$
- luminosity leveling implemented. By continuously steering the beams the luminosity is kept constant during the fill.

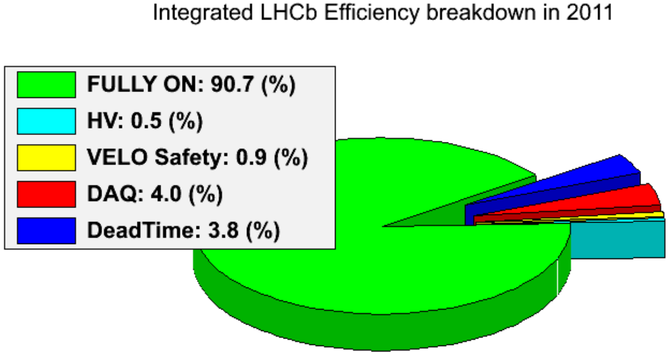


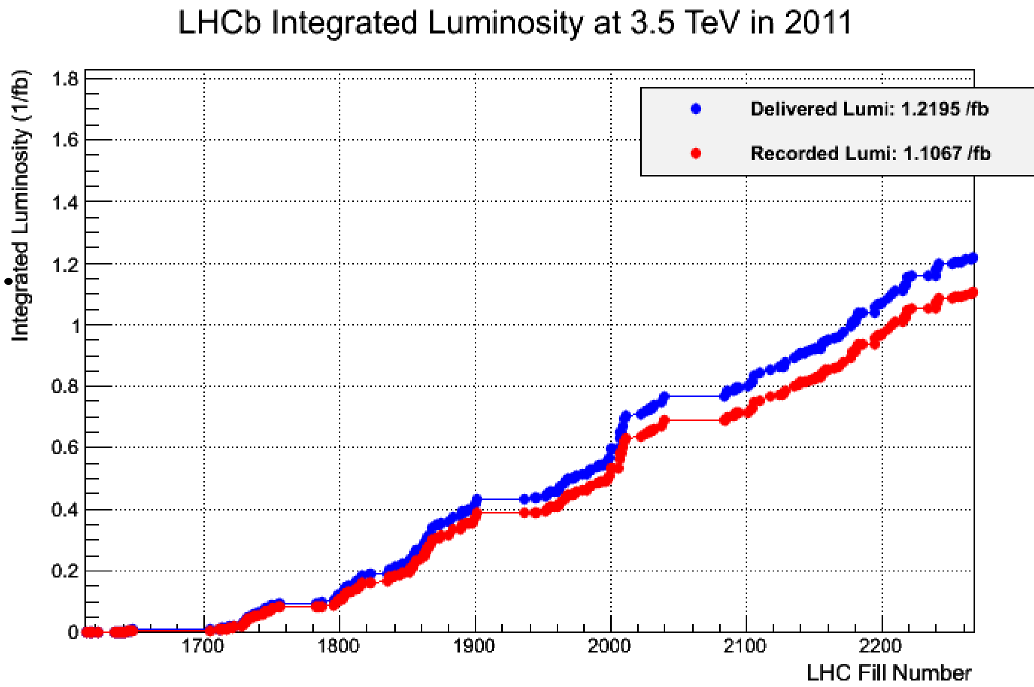
$\sigma_{beam} \approx 40\ \mu m$





- At 3.5 TeV/beam 1.1 fb^{-1} has been recorded
- Overall efficiency was 90.7 %.





- The experiment is effectively run 24/7 by 2 persons: a shift leader and a data quality manager.
- 16 persons with specific HW-expertise on sub-detectors, DAQ, HLT and safety are on-call.
- Besides that there is also VELO-specific data quality monitoring.

VELO-Monitoring

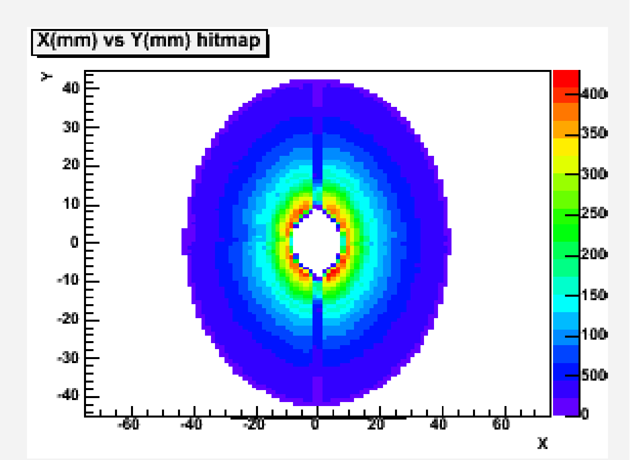
On-line monitoring:

10 Hz of no-bias data → variety of plots.

Off-line monitoring:

Analysis of zero-suppressed data, look for deviations from reference plots and make trend plots.

- occupancies
- cluster sizes
- cluster hitmaps
- dead and noisy channels
- Landau distributions
- track efficiency

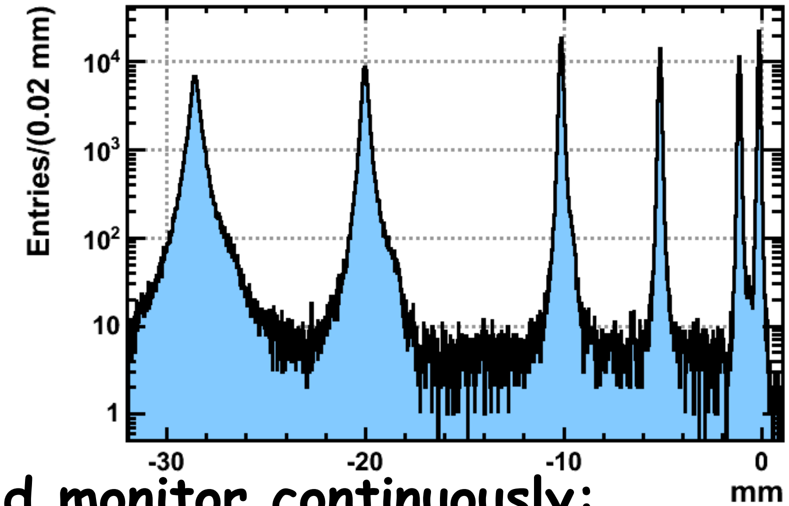


Analysis of 1 Hz non-zero-suppressed data of full VELO (320 kB/event)

- pedestals
- noise distributions and common mode noise
- frequency of SEUs
- cross talk
- system common mode noise
- other collective effects

Closing procedure

- At each detector position calculation of the distance to the luminous region and from that the size of the next movement.
- Closing in four steps: 29 mm (=open)→14 mm→5 mm→1 mm→closed
- Complete procedure takes 5 minutes (~1% inefficiency)



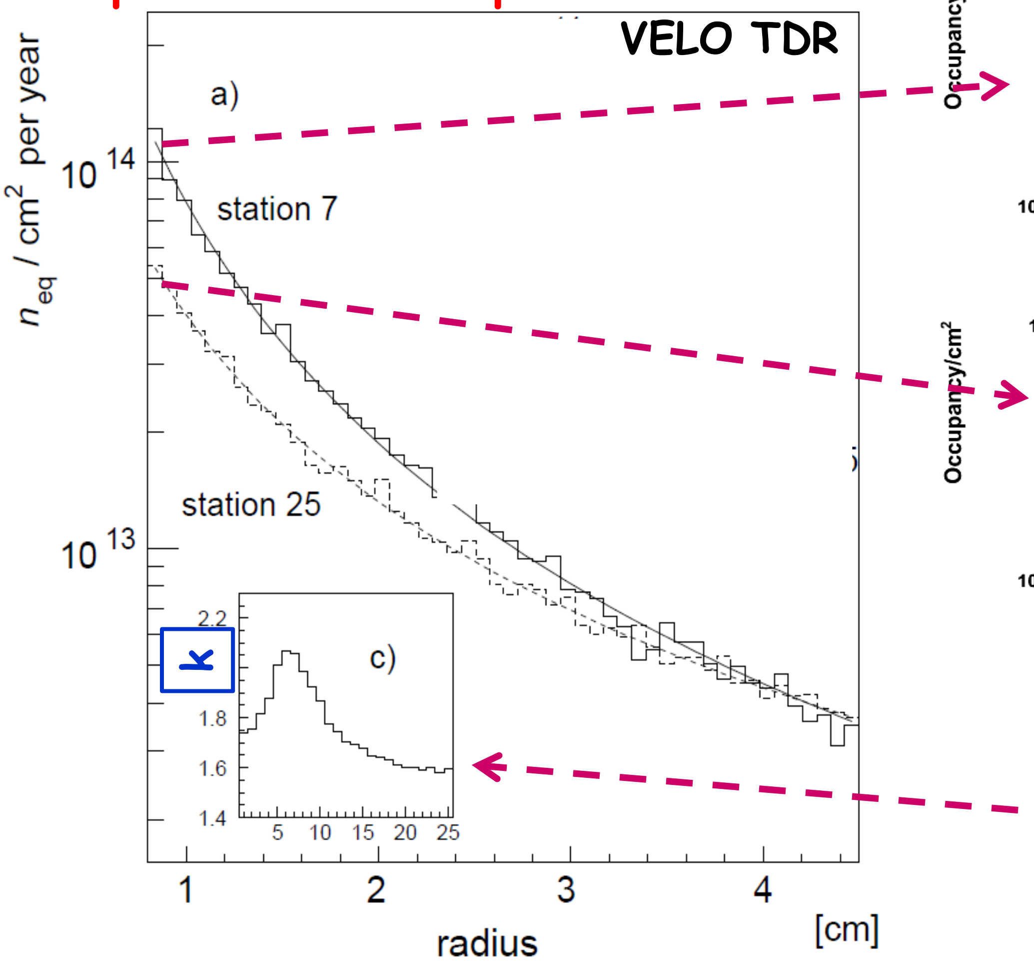
Distance to luminous region at 29, 20, 10, 5, 1 and 0 mm

- Once closed monitor continuously:
  - Beam Condition Monitors (diamond radiation monitors),
  - Beam Position Monitors,
  - vertex position, i.e. DAQ must always be running,
  - HV currents are checked for "abnormal correlated fluctuations"
- Closing procedure executed >100 times in 2011

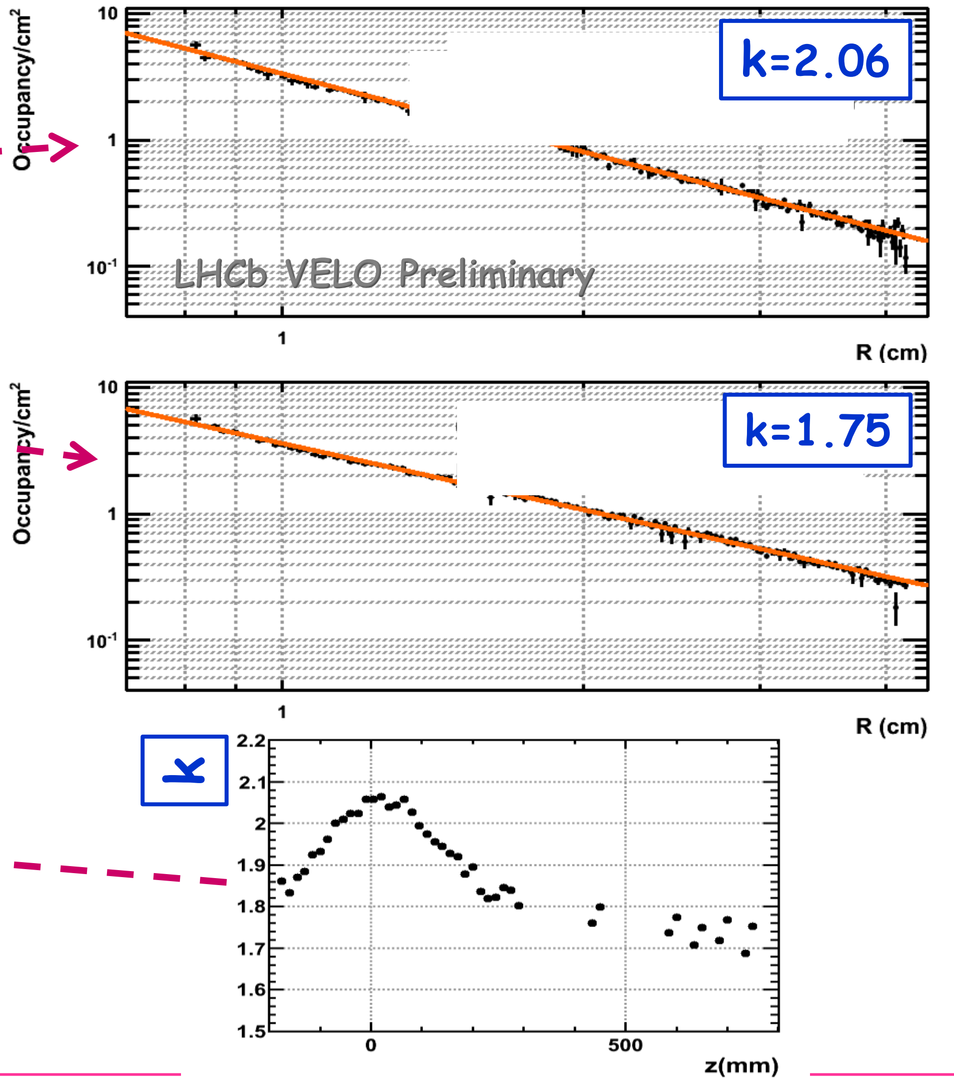
Flux and Fluences

Expected to accumulate 5×10^{13} 1 MeV n_{eq} per fb^{-1} at most irradiated sensor tip

Expected radial dependence Nr^{-k}



Minimum bias data



Special Runs

Without beam:

- Parameter determination for the on-line data processing (when needed, i.e. after firmware upgrade, exchange of digitizer boards, changing experimental conditions; so few times a year)
- Noise versus HV to determine depletion voltages (once a month)
- Current versus HV (IV-scans weekly)
- Currents versus Temperature (IT-scans twice a year)

With beam:

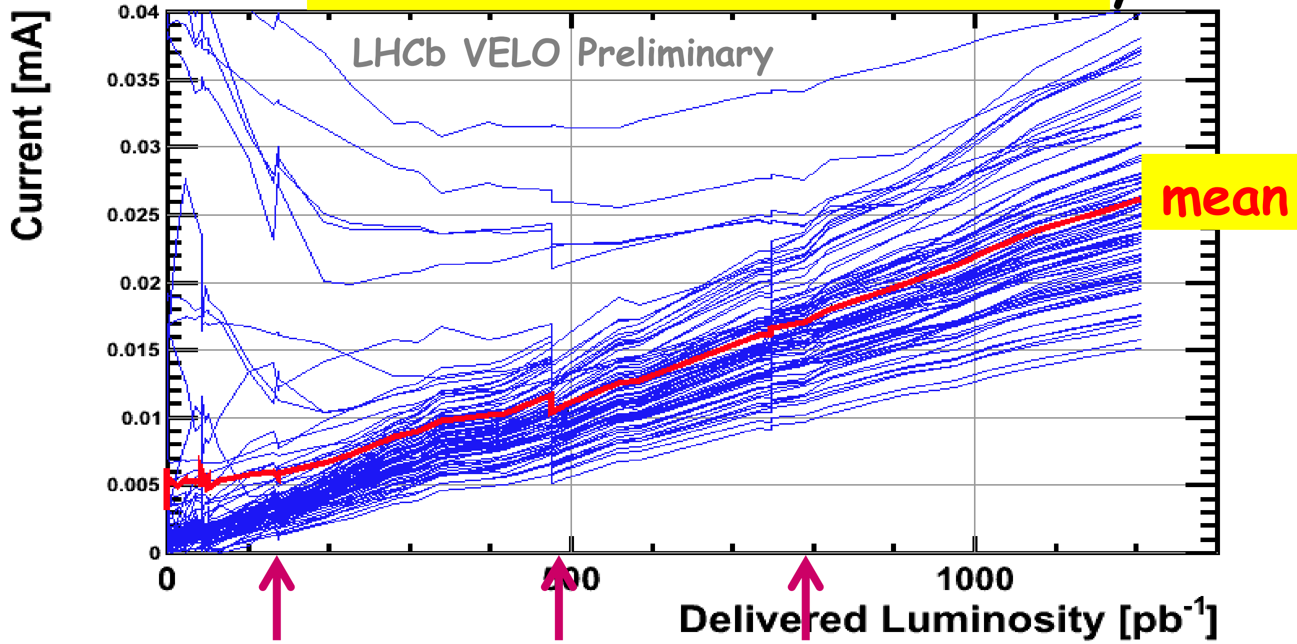
- Scan to determine the optimal timing (twice a year)
- Charge Collection Efficiency versus HV (twice a year)

See talk of David Hutchcroft later today about radiation damage in the VELO.

Silicon bias currents

- Currents are measured in operational conditions, i.e. -8°C and 150 V, without beam.
- Current scales with received luminosity

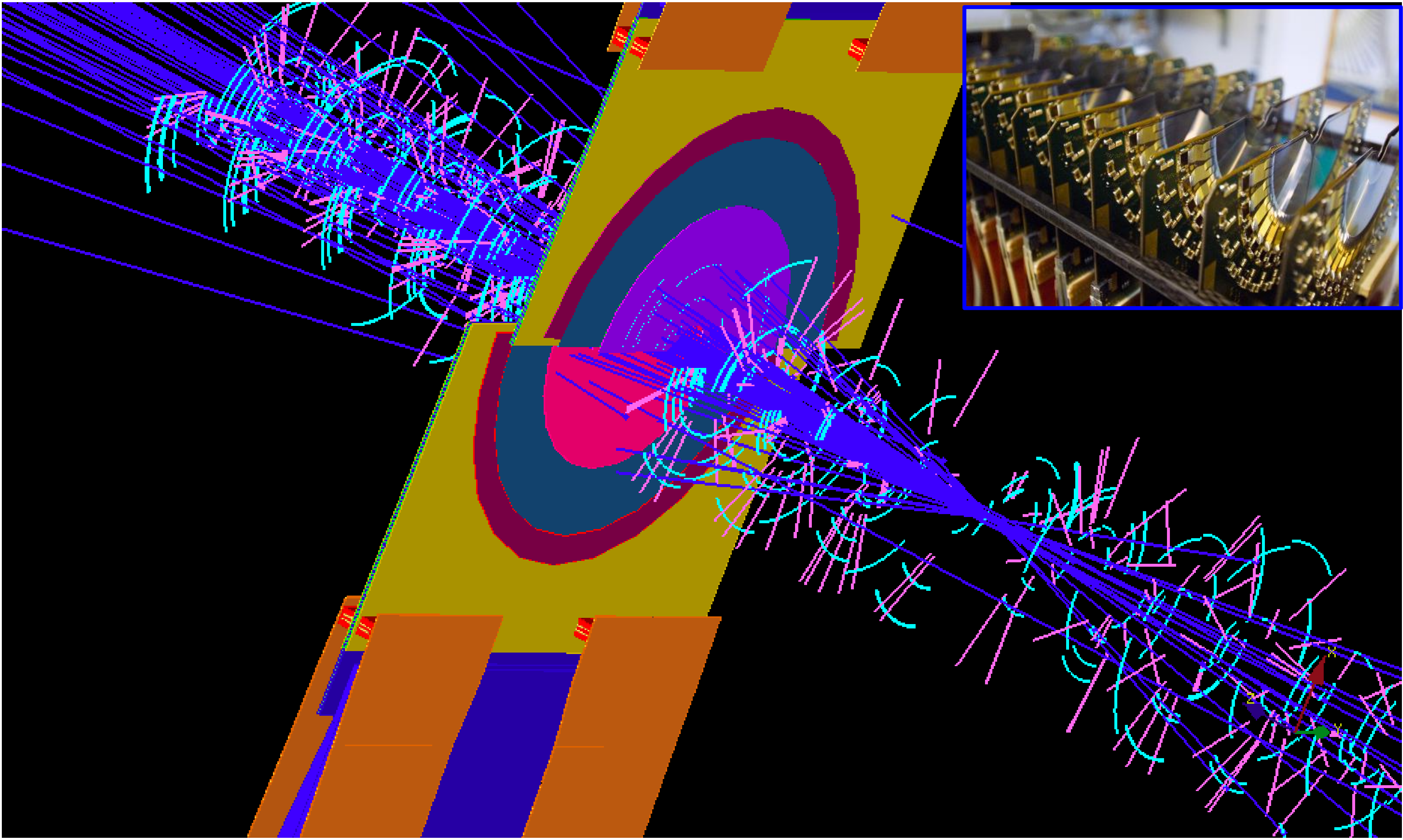
Bias currents versus Luminosity



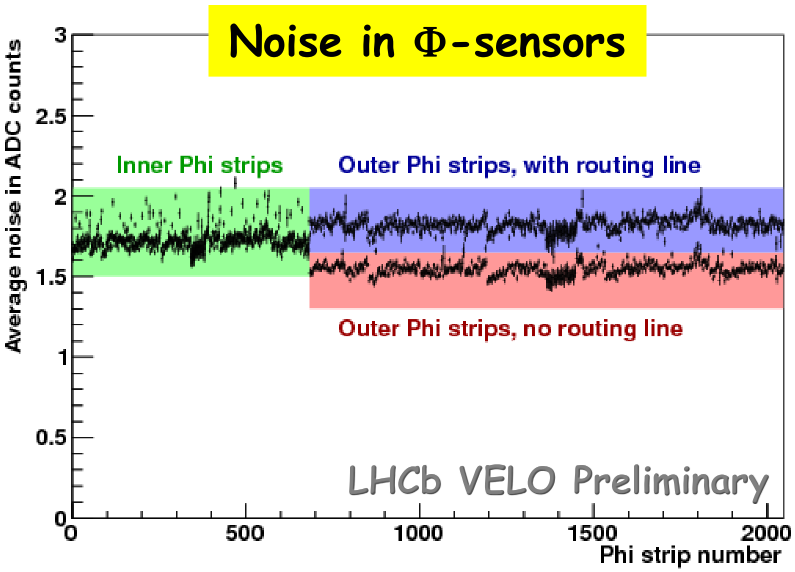
Annealing due to warm-up periods

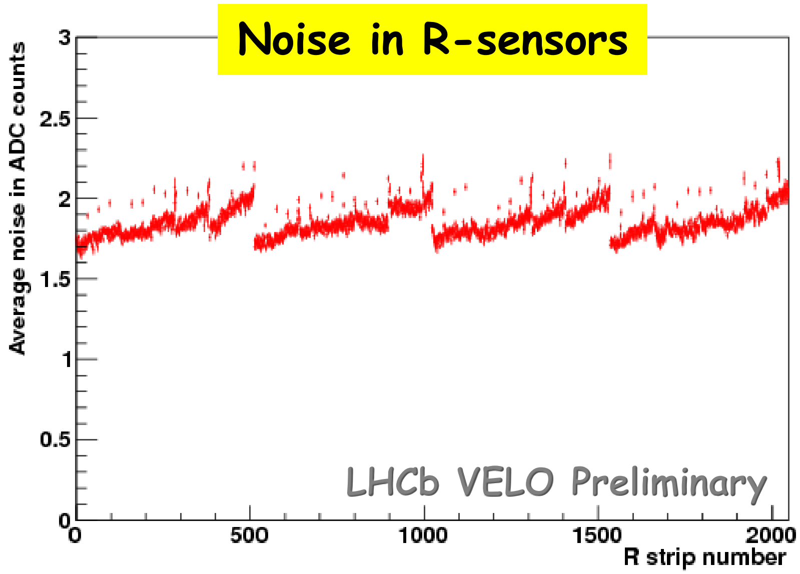
- Increase varies between 15 and 35 μA/fb^{-1}.

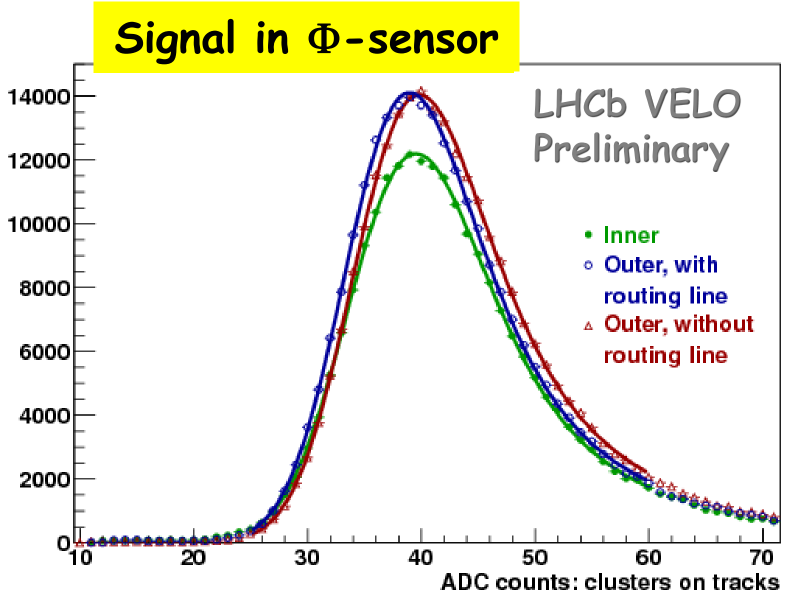
Performance

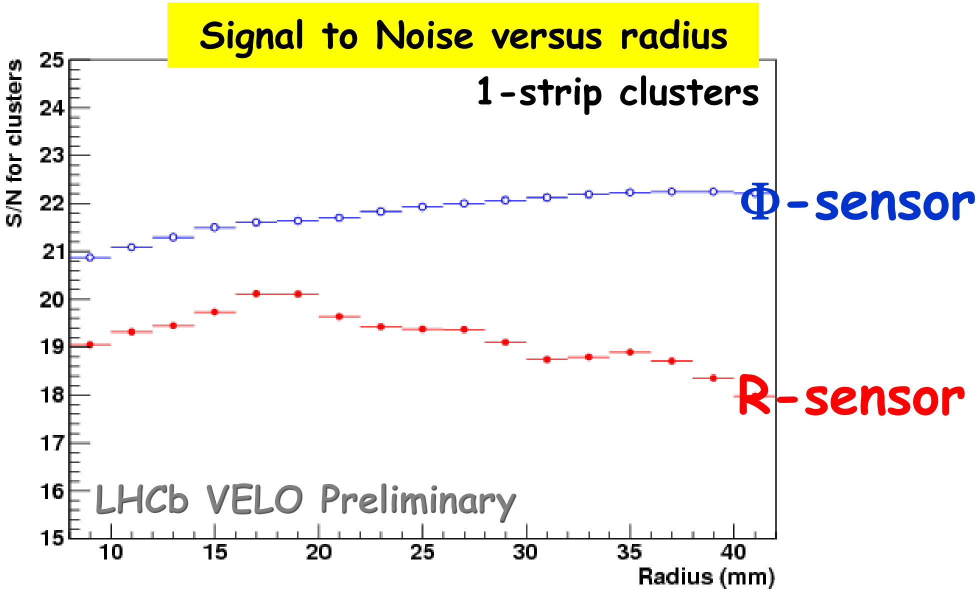


Noise, signal and S/N



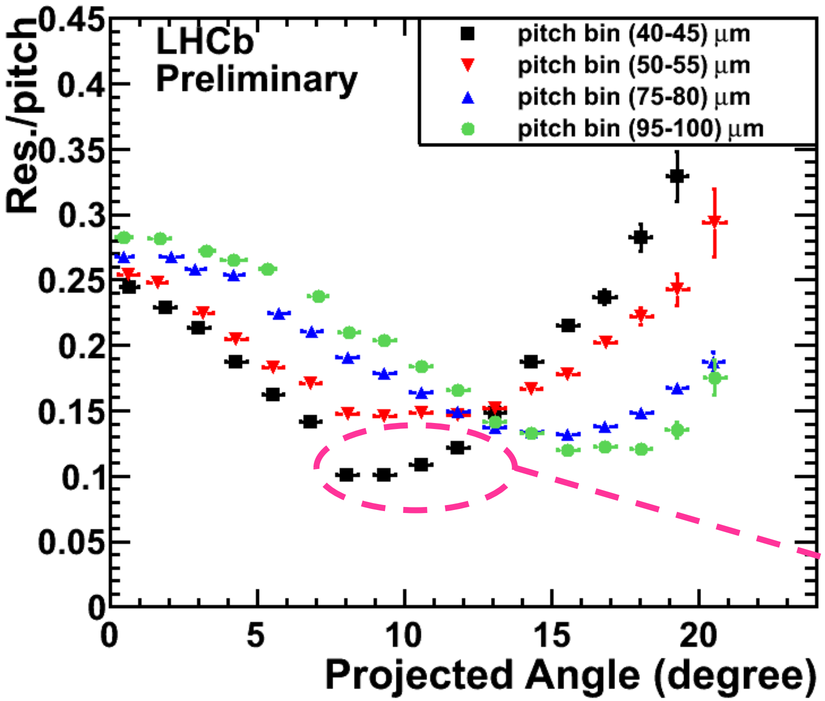




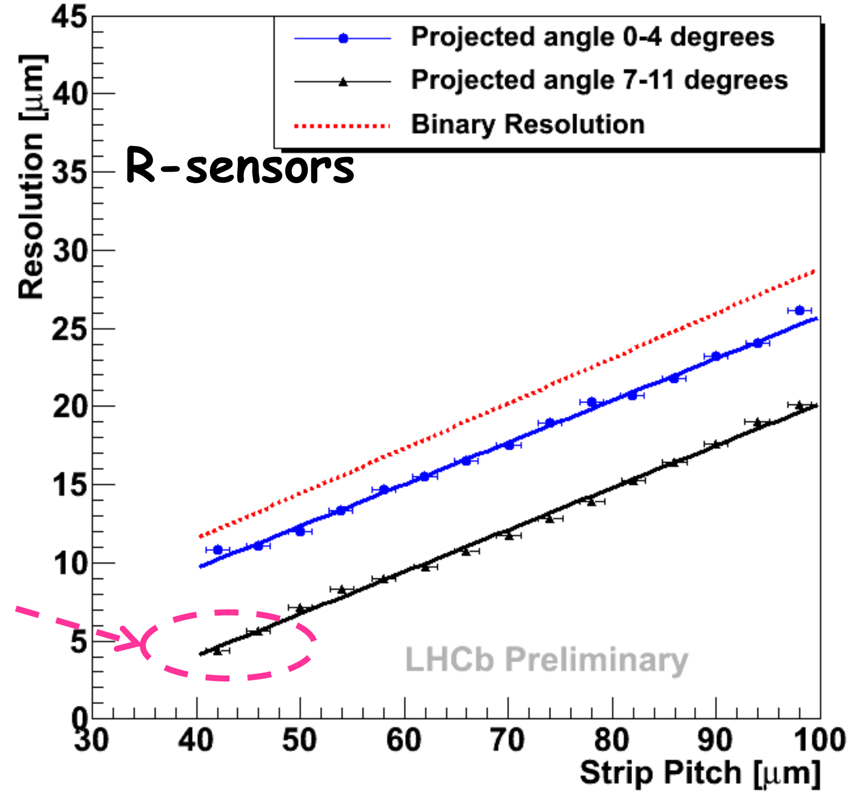


Spatial resolution

Single hit resolution vs proj. angle



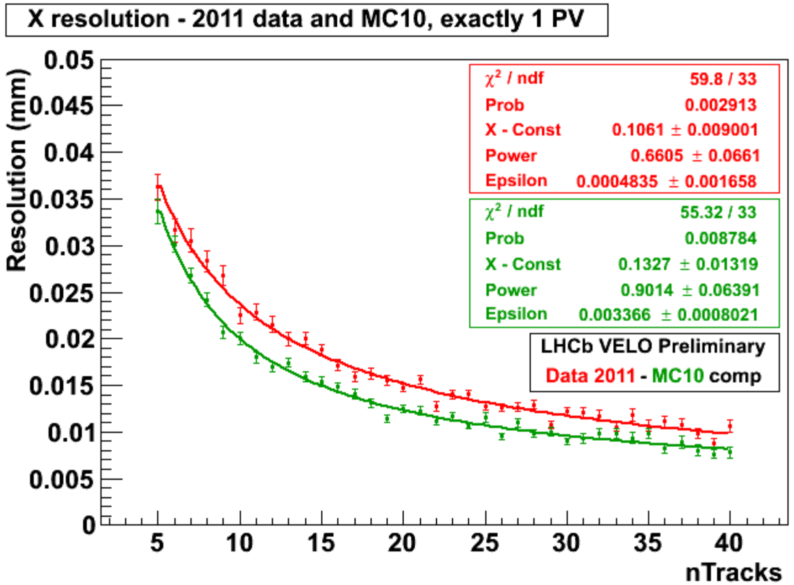
Single hit resolution vs strip pitch

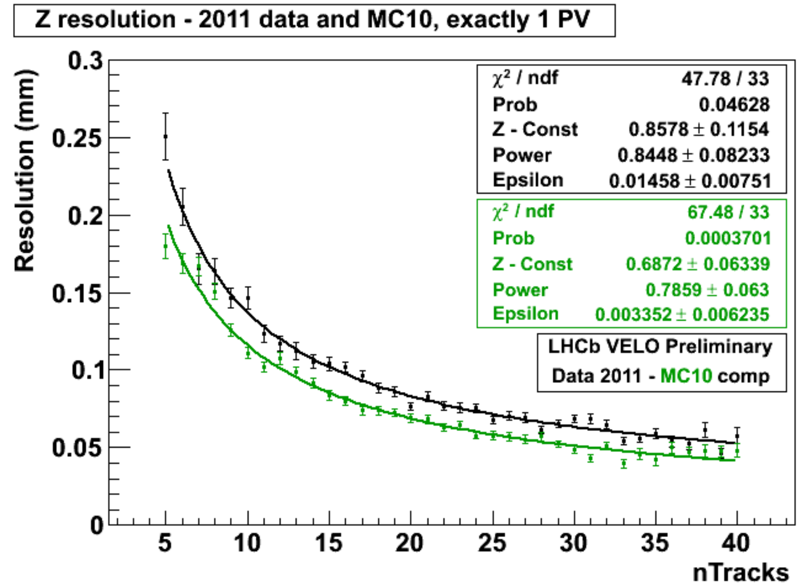


Resolution is ~4 μm for the most optimal angled tracks in the smallest pitch region.

Primary vertex resolution

- split collection of tracks of a primary vertex randomly in two
- perform a vertex-fit on each sub-sample
- build histograms[nTracks] with the differences in fitted positions.
- slice fit per nTracks-bin with a Gaussian
- fit primary vertex resolution with: $\frac{C}{(\mathrm{nTracks})^{p}}+\varepsilon$

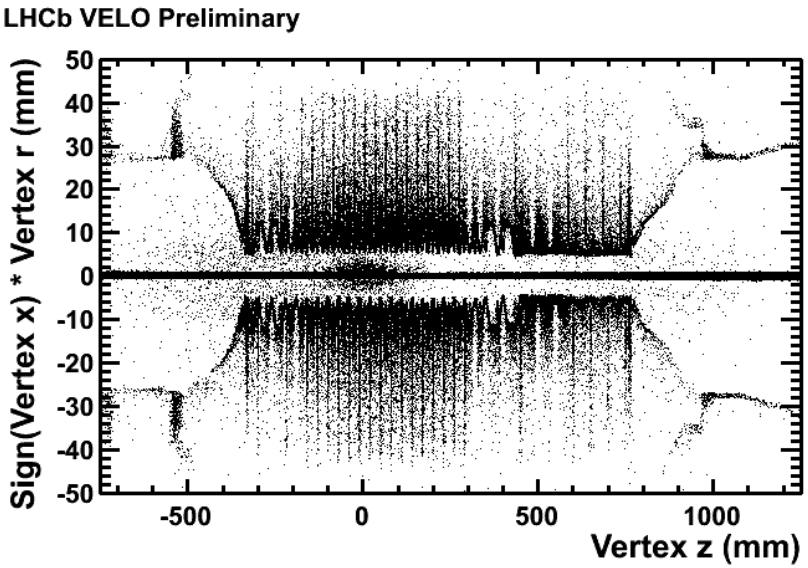


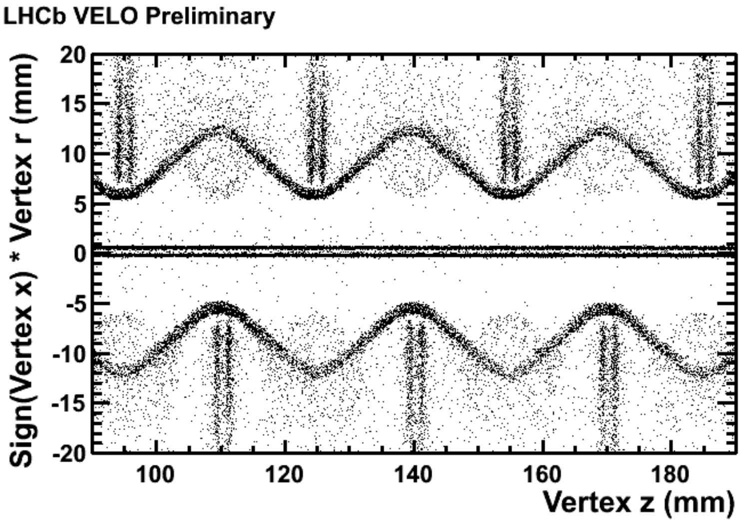


- a typical primary vertex with 35 tracks yields:
  σ_x= 12 μm, σ_y= 12 μm, σ_z= 65 μm

Self-imaging

Vertices in VELO material, like RF-box and sensors, by beam gas events.





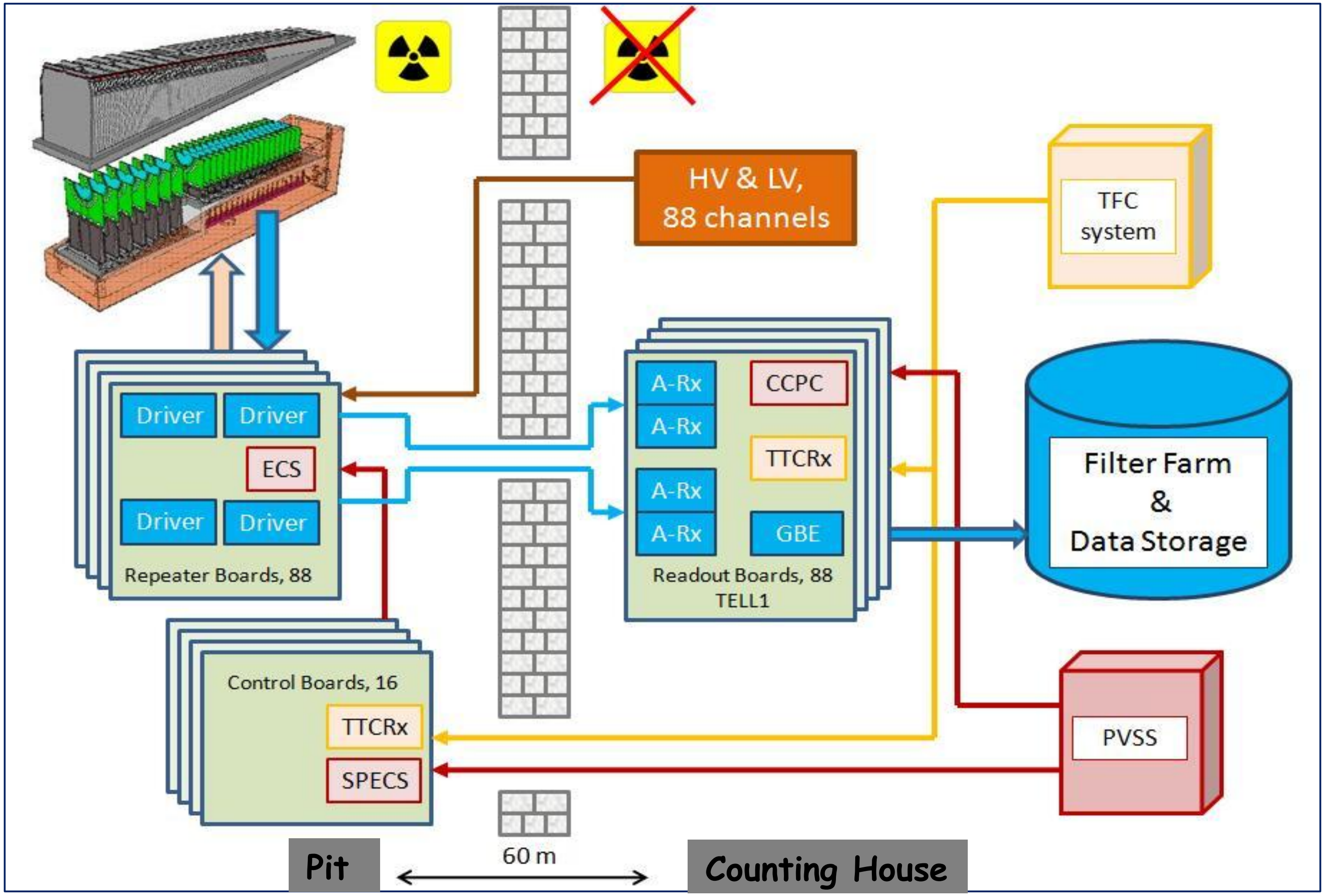
Summary and Outlook

- VELO has operated smoothly and according to expectations in 2011.
- LHCb runs at an instantaneous luminosity of $4x10^{32}$ $cm^{-2}s^{-1}$,i.e. double the design value.
- Recorded luminosity amounts to 1.1 fb^{-1}
- Signs of radiation damage have been observed, but no degradation of the physics performance.

- Replacement detector halves with n^{+}-on-p sensors are being tested in the lab, although the present one should be able to survive till the Long Shutdown 2 of LHC in 2018.
- In LS2 an upgrade of the LHCb detector is foreseen
- Main characteristics:
  - 40 MHz readout of all sub-detectors,
  - full software trigger,
  - $\mathcal{L}$ = $2x10^{33}$ $cm^{-2}s^{-1}$
- For the Upgraded-VELO two alternatives are being investigated
  - modules with VELOpix-chips (successor of the 55x55 μm^2 TimePix3)
  - modules with silicon strips

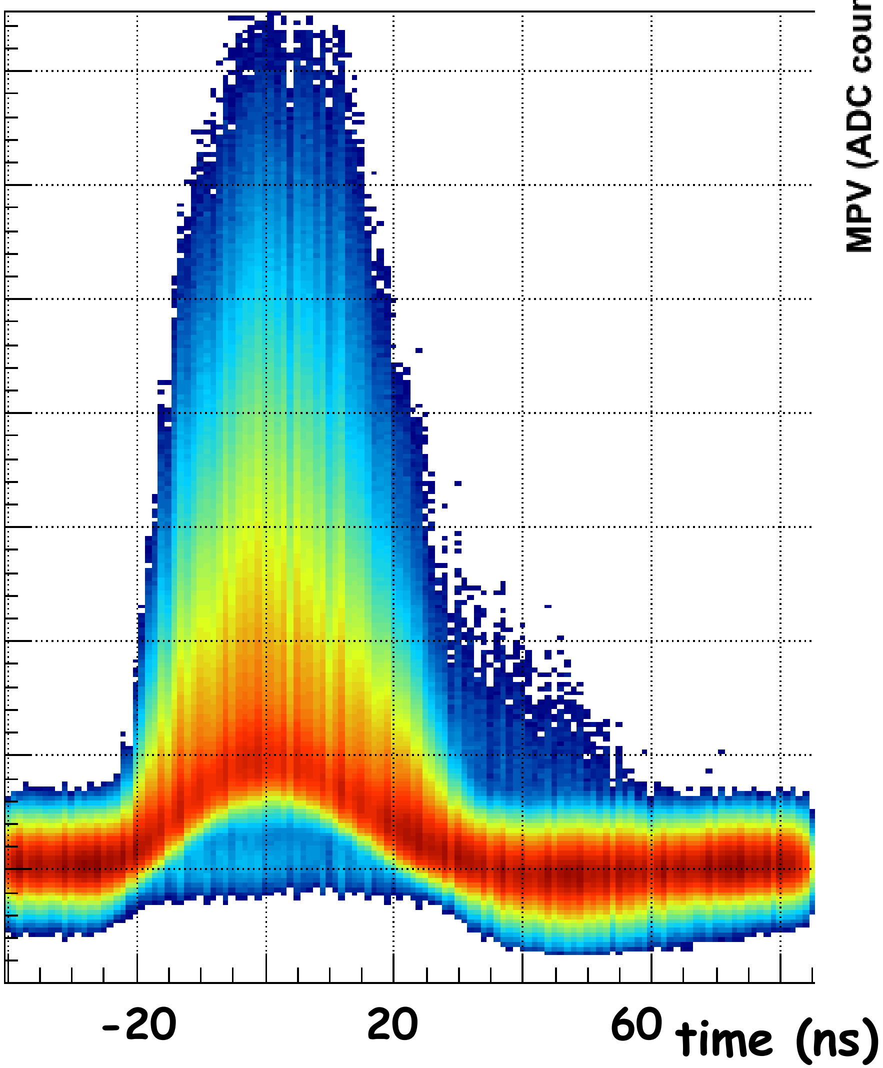
Backup slides beyond this point

Readout, controls and data

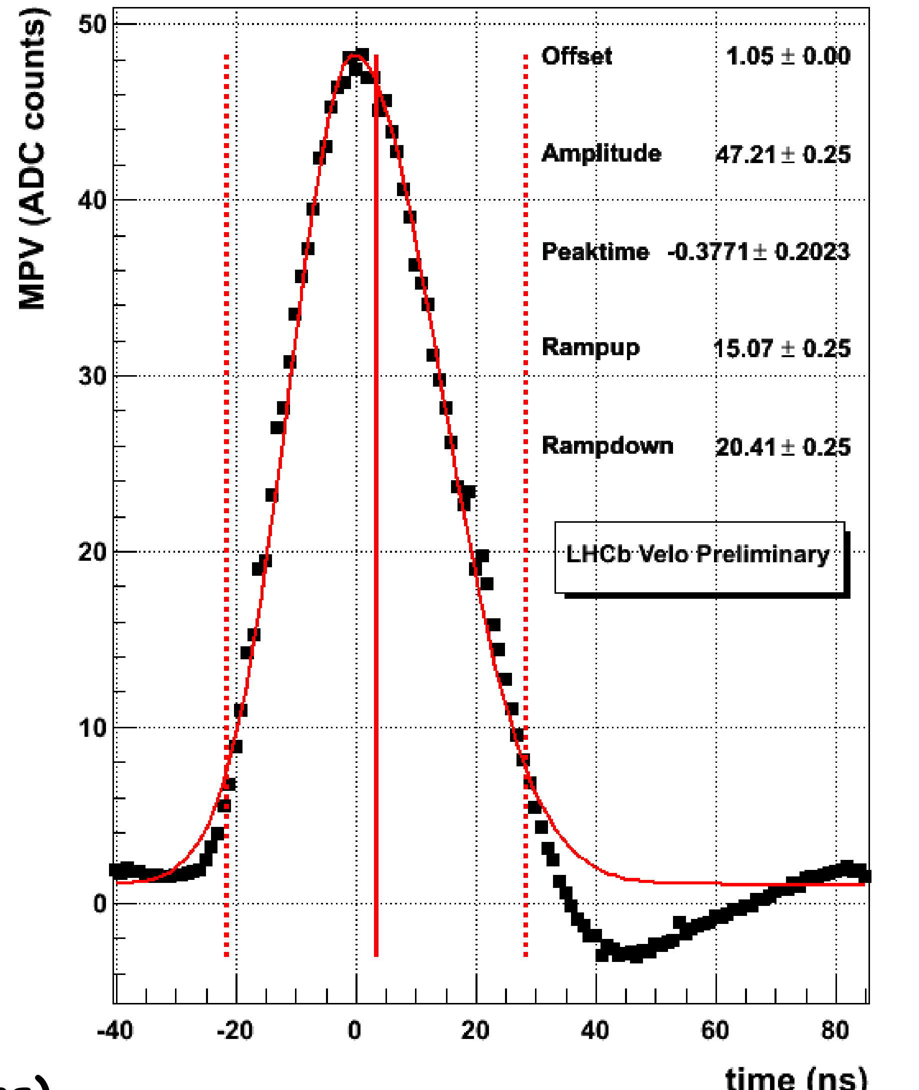


Beetle pulse shape determined from a timing scan

combined pulse shape



MPV from Landau X Gaussian Fit

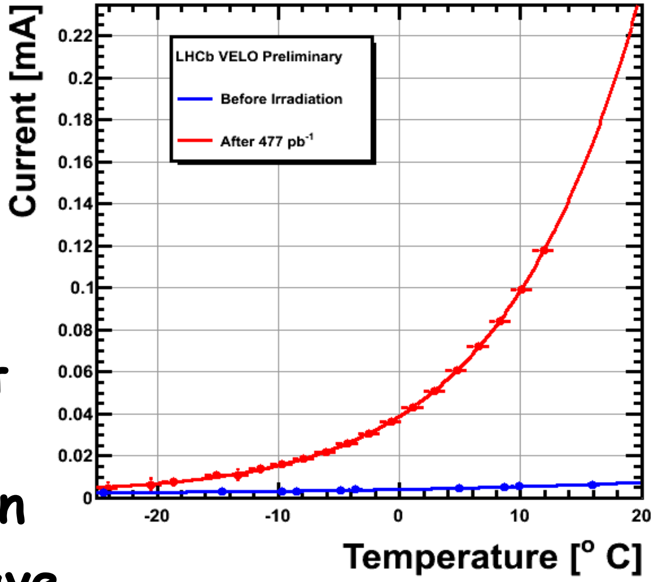


Beetle pulse shape

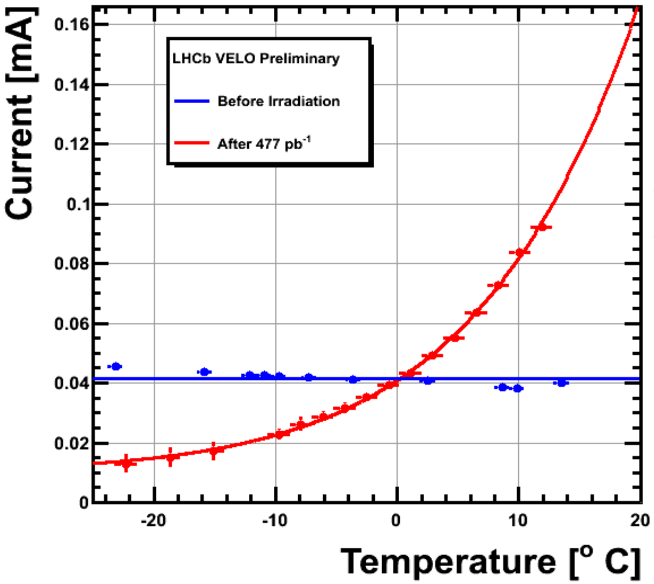
- Analog readout with Beetle chip
  - 0.25 μm CMOS technology
  - 128 channels
- Rise time = 18 ns
- Sampling time tuned for equal pre-spill and spill-over
  - Spill-over at 25 ns = 11 %
  - Spill-over at 50 ns = -7 %

Silicon leakage current f(temperature)

- Initially 2 types of behaviour
  - with and without significant (temperature independent) surface current contribution
- After irradiation sensors behave similar, i.e. bulk dominated

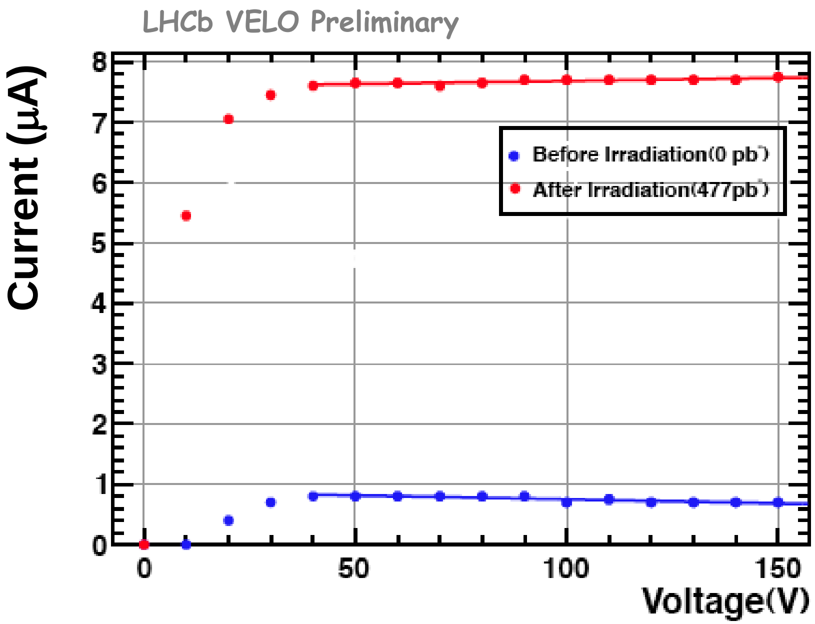


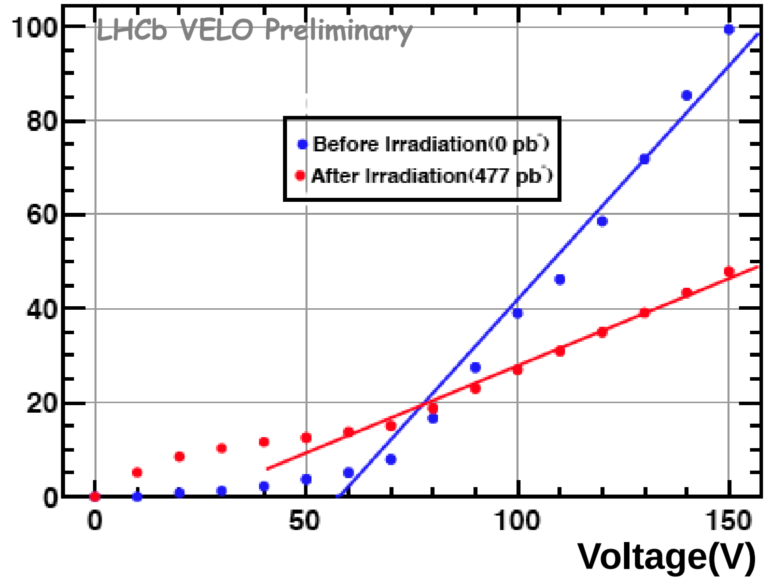
Bulk current dominated sensor both before and after irradiation



Surface current dominated sensor before irradiation, bulk dominated after

IV curves before and after 0.48 fb^{-1} irradiation

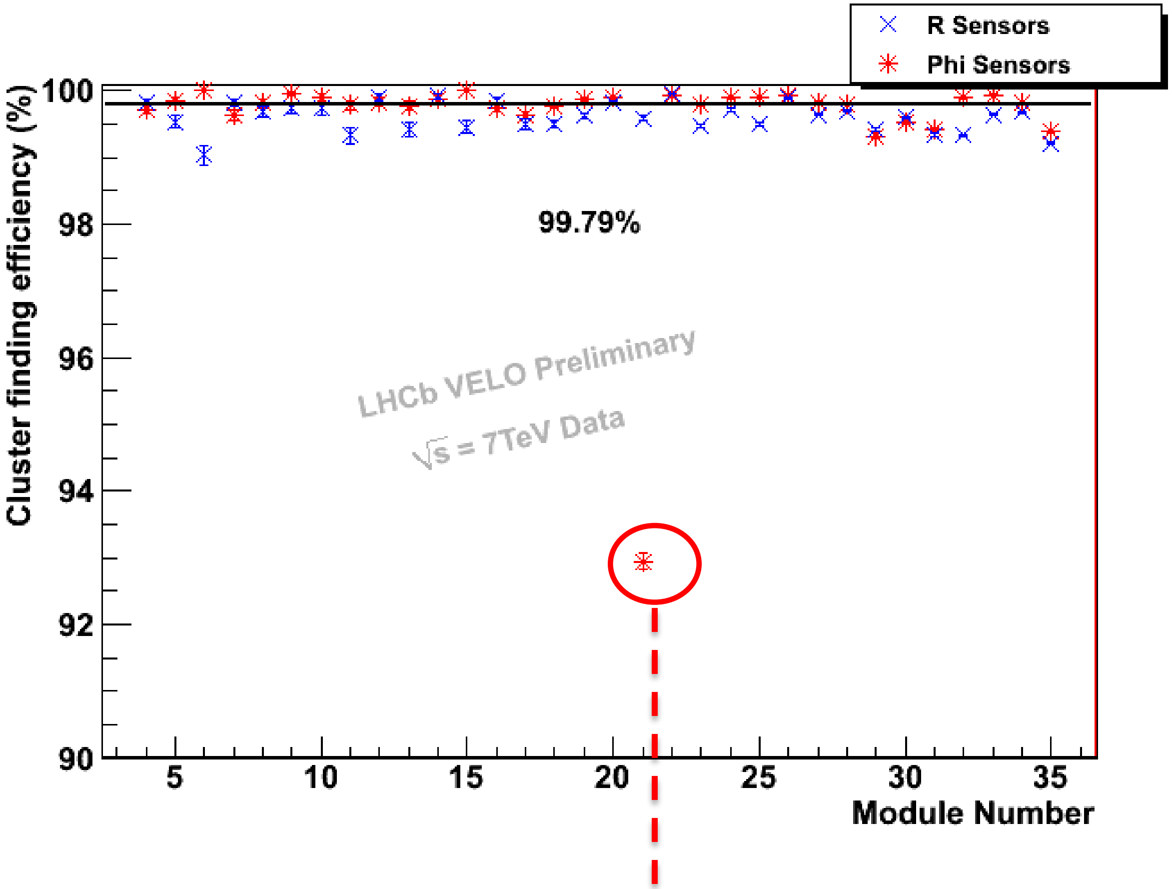




Bulk current dominated sensor before and after irradiation

Surface current dominated sensor before irradiation, mixture afterwards

Cluster Finding Efficiency



CFE ~99.8 % when known bad strips are accounted for.
99.4 % otherwise.

One chip died after installation