A novel approach to detector calibration parameter determination and detector monitoring

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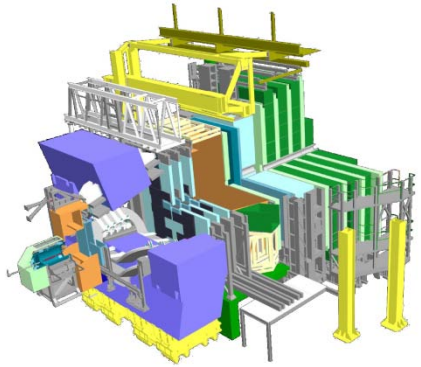
On behalf of the LHCb VELO Group

CHEP 2010, Taipei, Taiwan, 21 October 2010



OUTLINE:

- ***LHCb, vertex detector***
- ***Data processing***
- ***Detector parameters optimisation***

The LHCb experiment @ the LHC

Forward spectrometer

Acceptance: ~10 – 300 mrad

Luminosity: $2 \bullet 10^{32}\ cm^{-2}\ s^{-1}$

Nr of B's / $2fb^{-1}$ (nominal year): 10^{12}

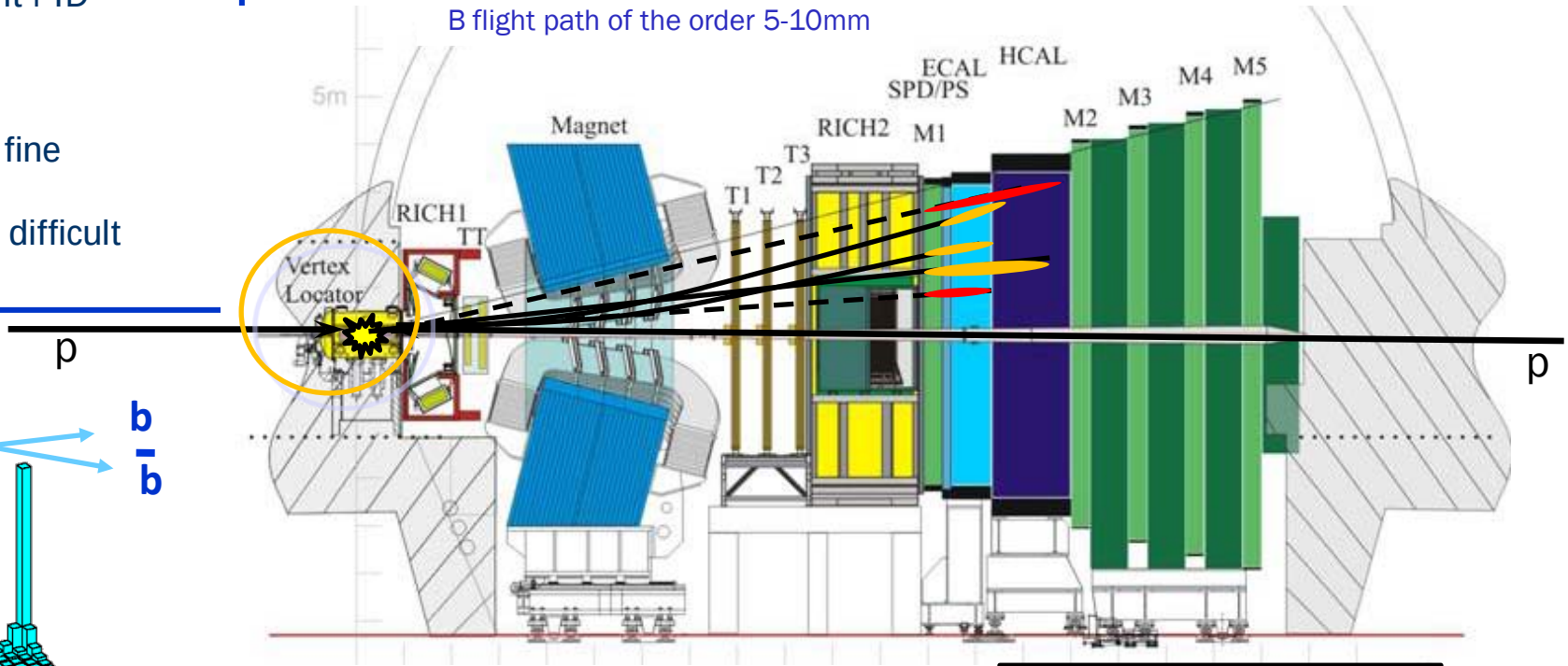
Detector: excellent tracking
excellent PID

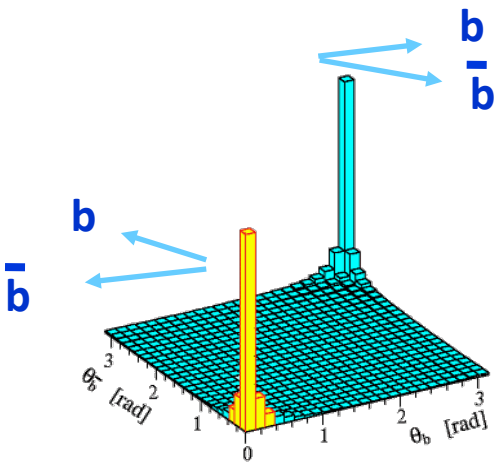
Reconstruction:
- muons: easy
- hadronic tracks: fine
- electrons: OK
- π^0's: OK, though difficult
- neutrinos: no

Mission statement

- Search for new physics probing the flavour structure of the SM
- Study CP violation and rare decays with beauty & charm hadrons

B flight path of the order 5-10mm





σ(inclusive) ~ 80 mb
σ(b bbar) ~ 0.5 mb

All b-hadron species produced

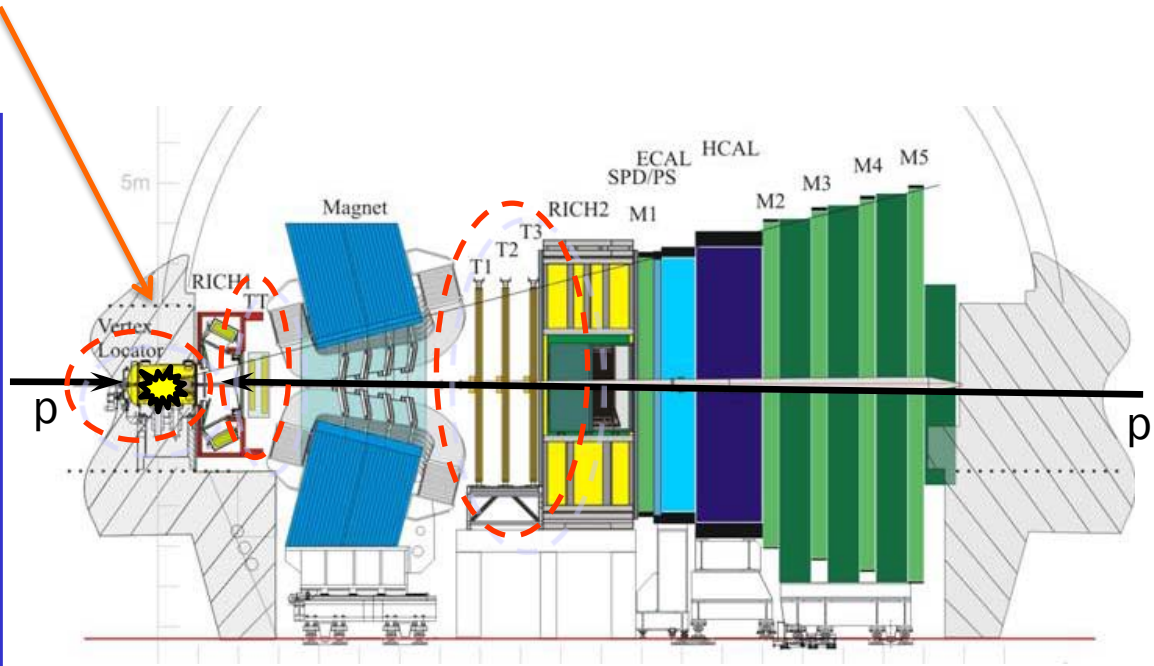
Tracking system requirements

Vertexing

- Precise reconstruction and separation of primary and secondary vertices
  - identification of beauty & charm meson decays

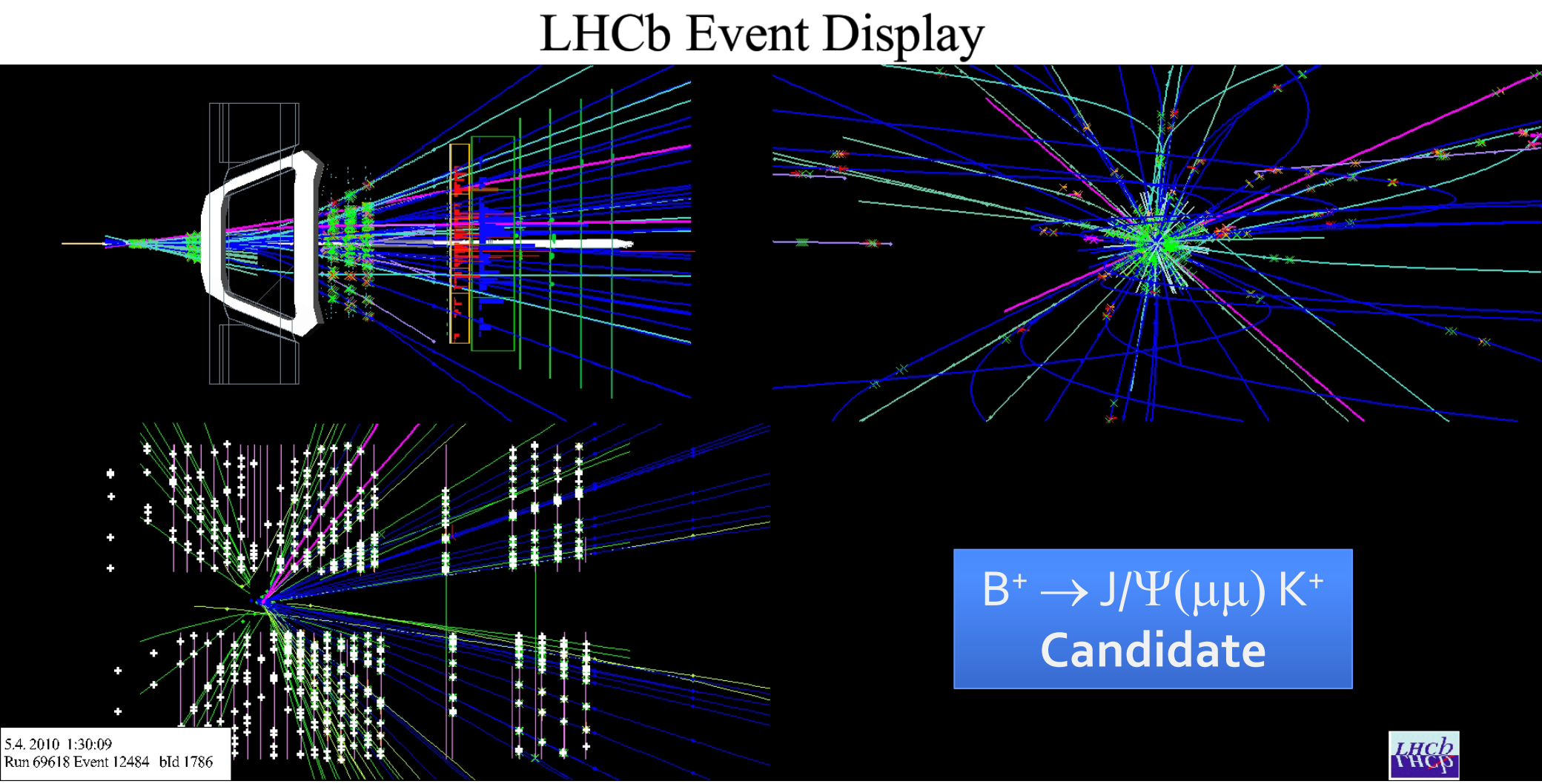
Tracking

- Excellent pattern recognition
- Precise determination of track parameters
  ⇒ excellent momentum resolution
  $\delta p/p$ = 0.35% to 0.55%
  ⇒ excellent impact parameter (IP) resolutions



Beauty & charm mesons
Excellent
- *mass resolution* 15-40 MeV
- *propertime resolution* ~50 fs

21 April 2010: first reconstructed beauty particle



Precise tracking and vertexing (1/2)

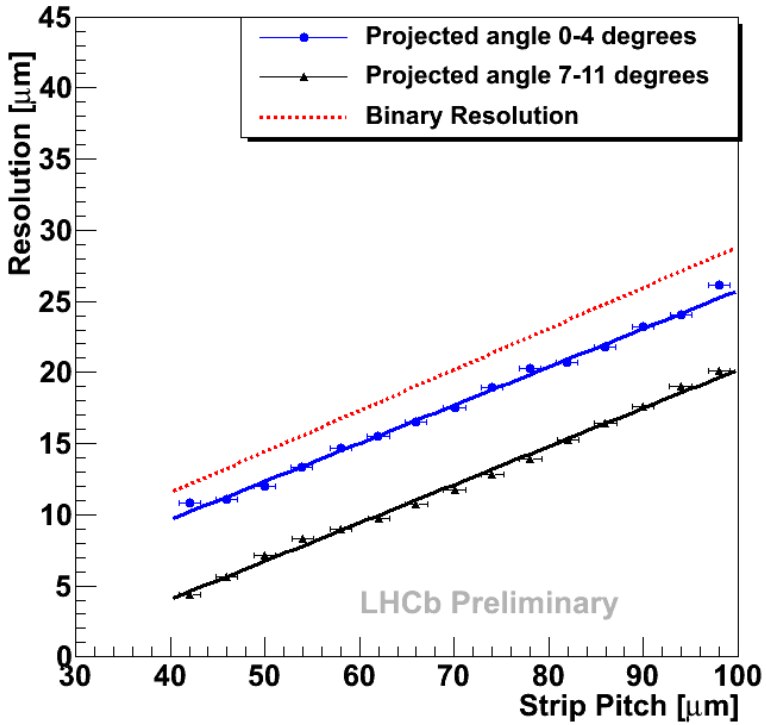
Crucial to LHCb physics programme

- Hit resolution versus strip pitch for 2 bins of the projected angle
- Evaluated for R sensors using residuals of long tracks

Hit resolution depend to 1st order on:

- projected angle
- strip pitch

Hi resolution for VELO sensors

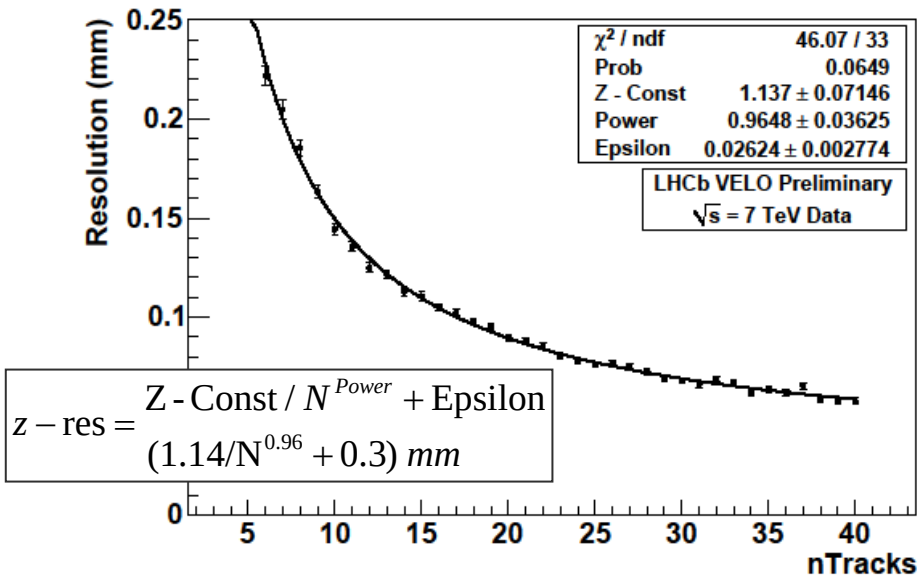


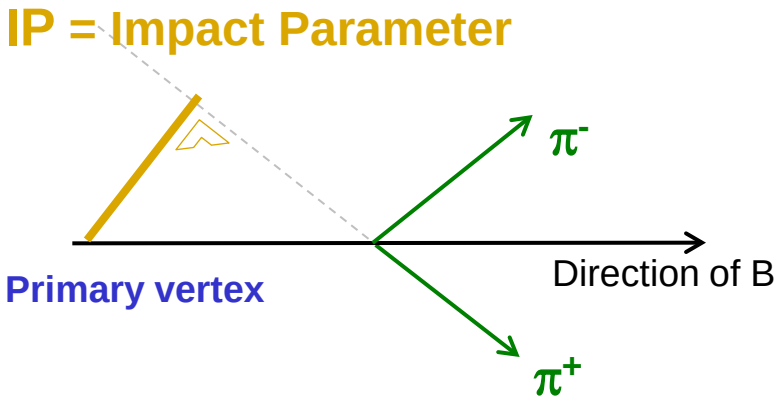
Precise tracking and vertexing (2/2)

Crucial to LHCb physics programme

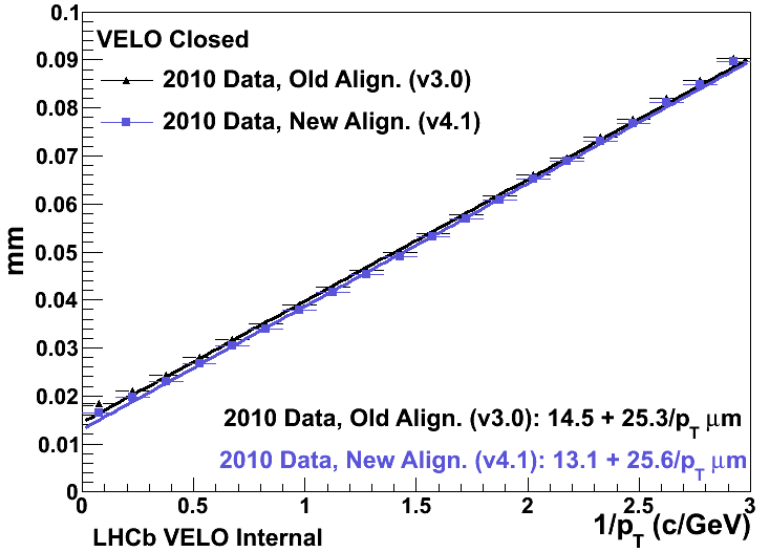
- Best such resolutions at the LHC

Primary vertex resolution in Z





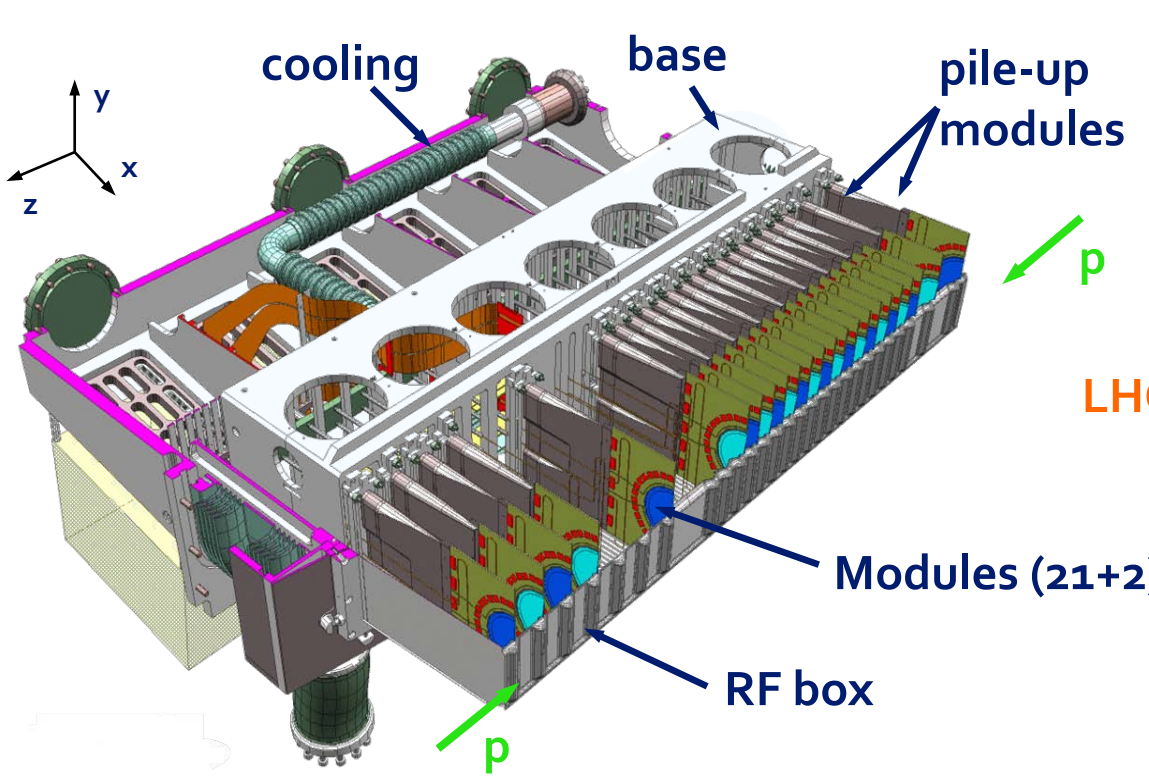
IP_X Resolution Vs $1/p_T$

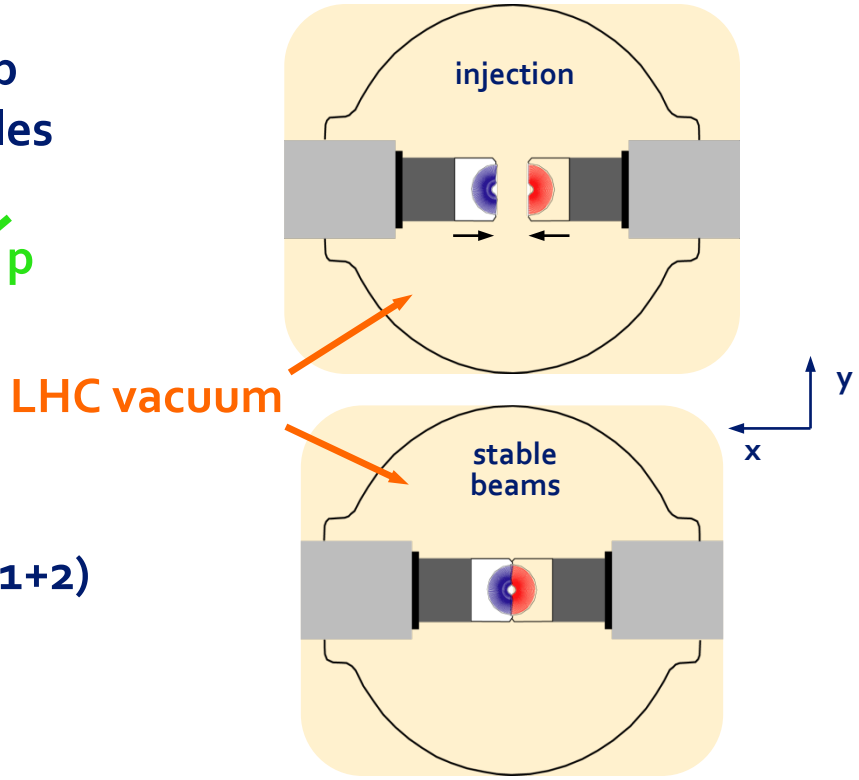


The LHCb VErtex LOcator

Highest precision vertex detector at the LHC

VELO – VErtex LOcator



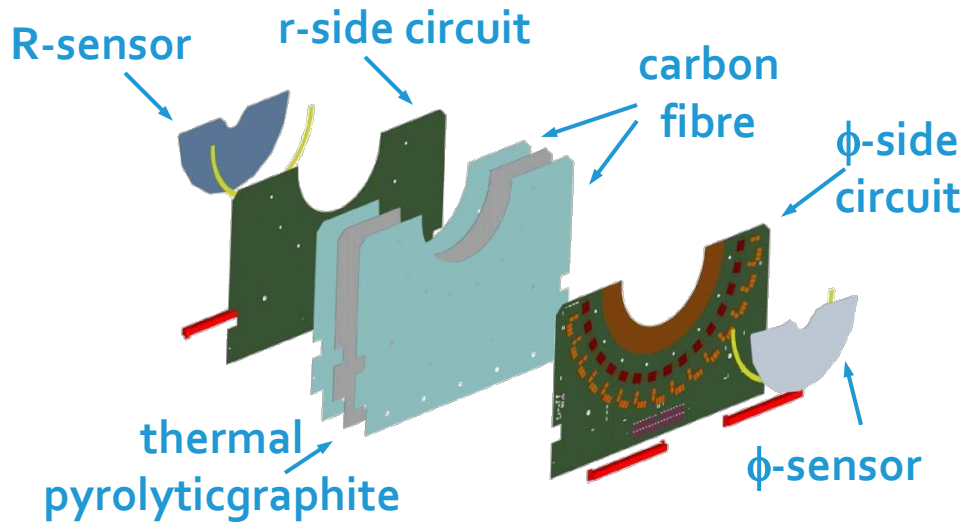


- **2 retractable detector halves:**
  ~8 mm from beam when closed, retracted by 30mm during injection
- **21 stations per half with an R and a ϕ sensor**
- **2 extra pile-up stations per half**
  - recognition of multiple interaction collisions at the trigger level
- **# read-out channels: ~ 200k**
- **Non-zero suppressed data rate ~ 4 GB/s !**

VELO – modules

Purpose :

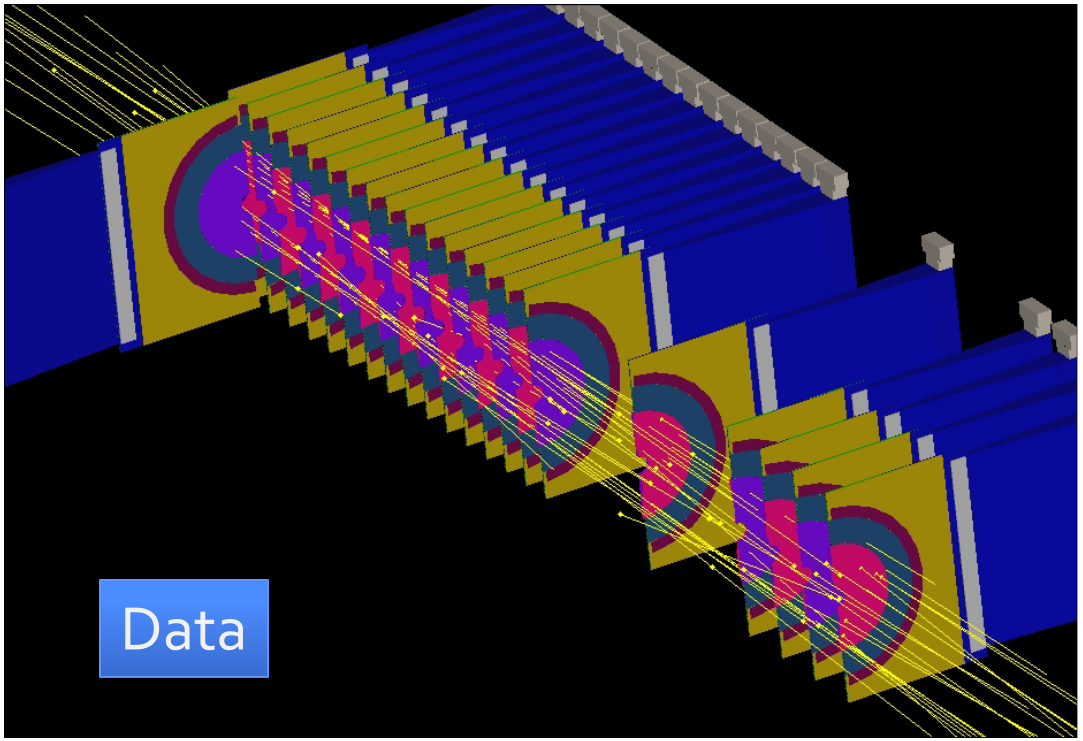
- Hold the sensors fixed wrt module support
- Connect electrical readout to the sensors and routing of signals to DAQ system
- Provide means of cooling to the sensors

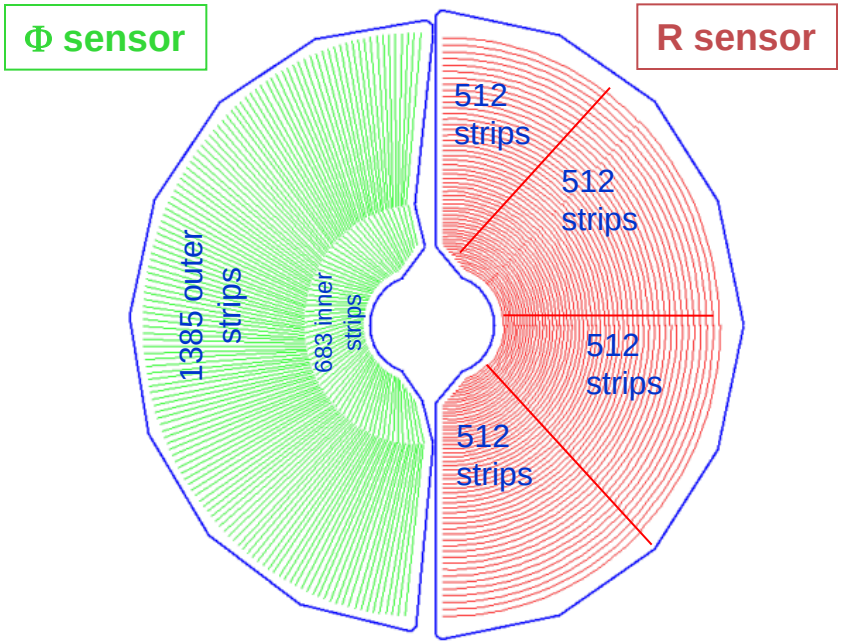


- Sensor-sensor positioning accuracy < 5μm

VELO – sensors

- Highly segmented; n^+ on n
- 2048 strips per sensor
- Design operation at -7 degrees
- Read out at 1 MHz



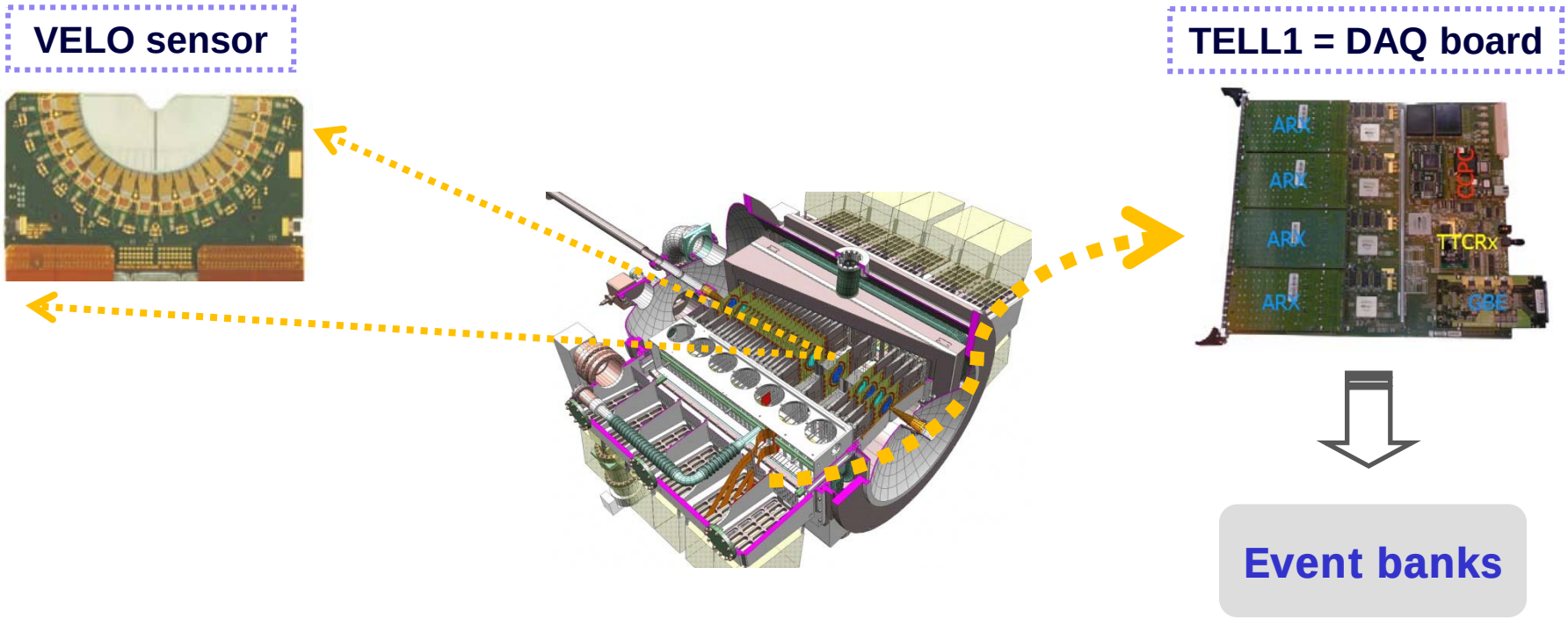


Φ sensors	R sensors
▪ Measure the azimuthal angle ▪ Stereo angle 20° for the inner strips (10° for the outer strips) ⇒ 2 regions ▪ Pitch: 36 -97 μm	▪ Measure the radial distance ▪ Divided in quadrants ▪ Pitch: 40 -102 μm

VELO data processing

Achieving the best performance

Data processing chain



- VELO sends analogue → signal **digitised on TELL1s**
- TELL1s: 4 **FPGAs** with firmware, which **work on integers**
  (Why FPGAs? Faster / better / more reliable / cheaper)
- Mimicking the integer operations on FPGAs: need for a **software emulation**

VELO data output (i.e. raw event) types

Raw event types
(main ones)

- **Zero-suppressed banks**
  ⇒ **main input to the reconstruction**
  - clusters from hits
  - 1 bank per sensor
- **Non-zero suppressed (NZS) banks**
  ⇒ **Full data as read out by a sensor**
  - main input to emulation
- **Error banks**
  ⇒ **Contains information on errors produced by the TELL1 boards**

- **ZS data rate: 50 bytes x 1 MHz = 50 Mb / s**

TELL1 acquisition boards processing

= not used for now

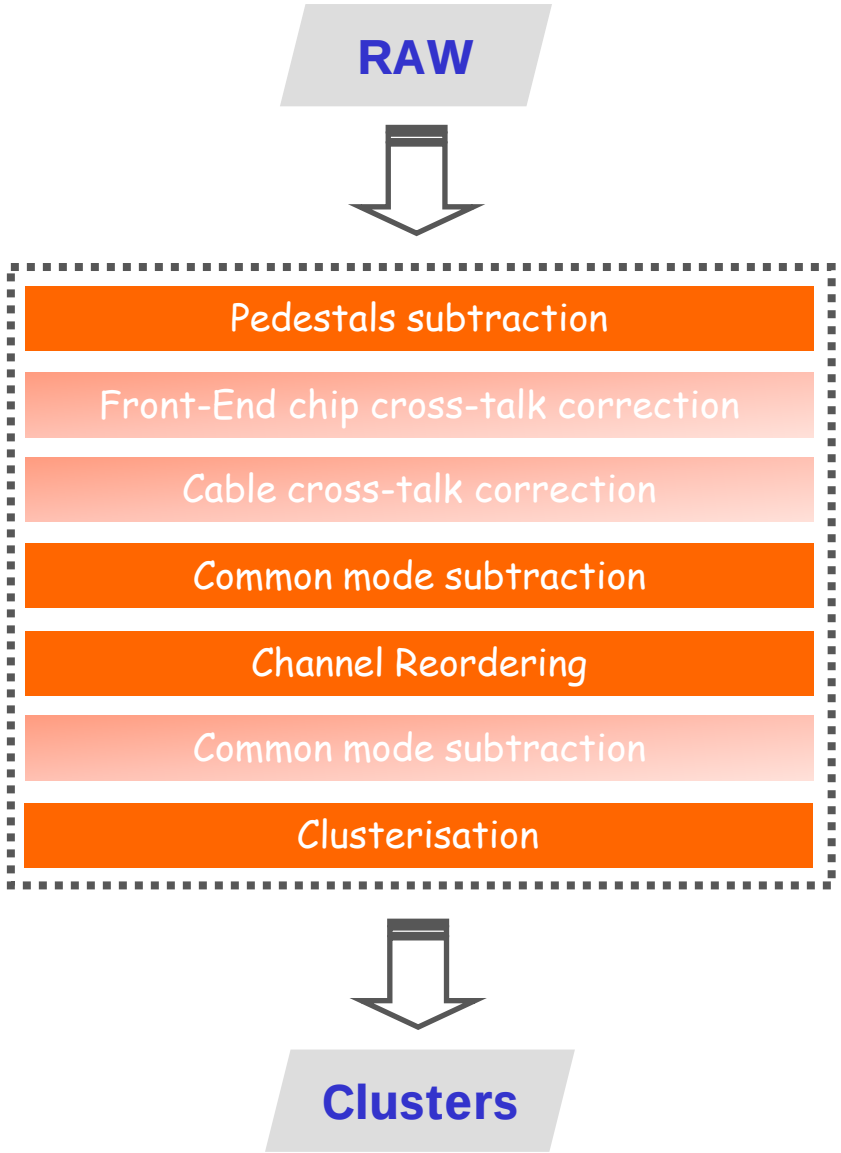
Set of algorithms on TELL1 board

- Data synchronisation, buffering
- TELL1s first digitise the analogue signals from the sensors
- Suppress noise and perform clusterisation
- Algorithms implemented in FPGAs on TELL1s

Algorithms require ~ 10^6 configuration parameters:

- Most important are
  - Pedestals
  - Clusterisation thresholds

⇒ **Need to be determined and optimised !**
How … ?



Detector parameter determination & optimisation

Standard approach :

- **FPGA algorithm parameters typically determined via standalone calculations or measurements**

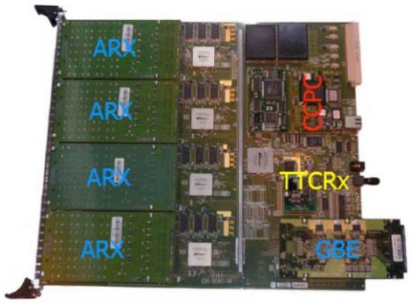
But how to achieve the best performance given
- complex chain of algorithms
- very large number of configuration/calibration parameters

Novel approach :

- **Integrate determination of detector parameters in the data processing framework itself**
  - Full integration in the LHCb software framework
- **Use non-zero-suppressed data output by the TELL1s and emulate the data processing to tune its calibration parameters**

TELL1 processing and emulation

TELL1 = DAQ board



NZS bank

TELL1 emulation

~10^6 configuration parameters !

TELL1 processing

Emulated ZS bank = emulated clusters

(emu. = RAW ⇒ bit perfectness)

ZS bank = clusters

Emulation + NZS data: means of determining and optimising the TELL1 processing parameters

The Vetra software project

Main characteristics of Vetra :

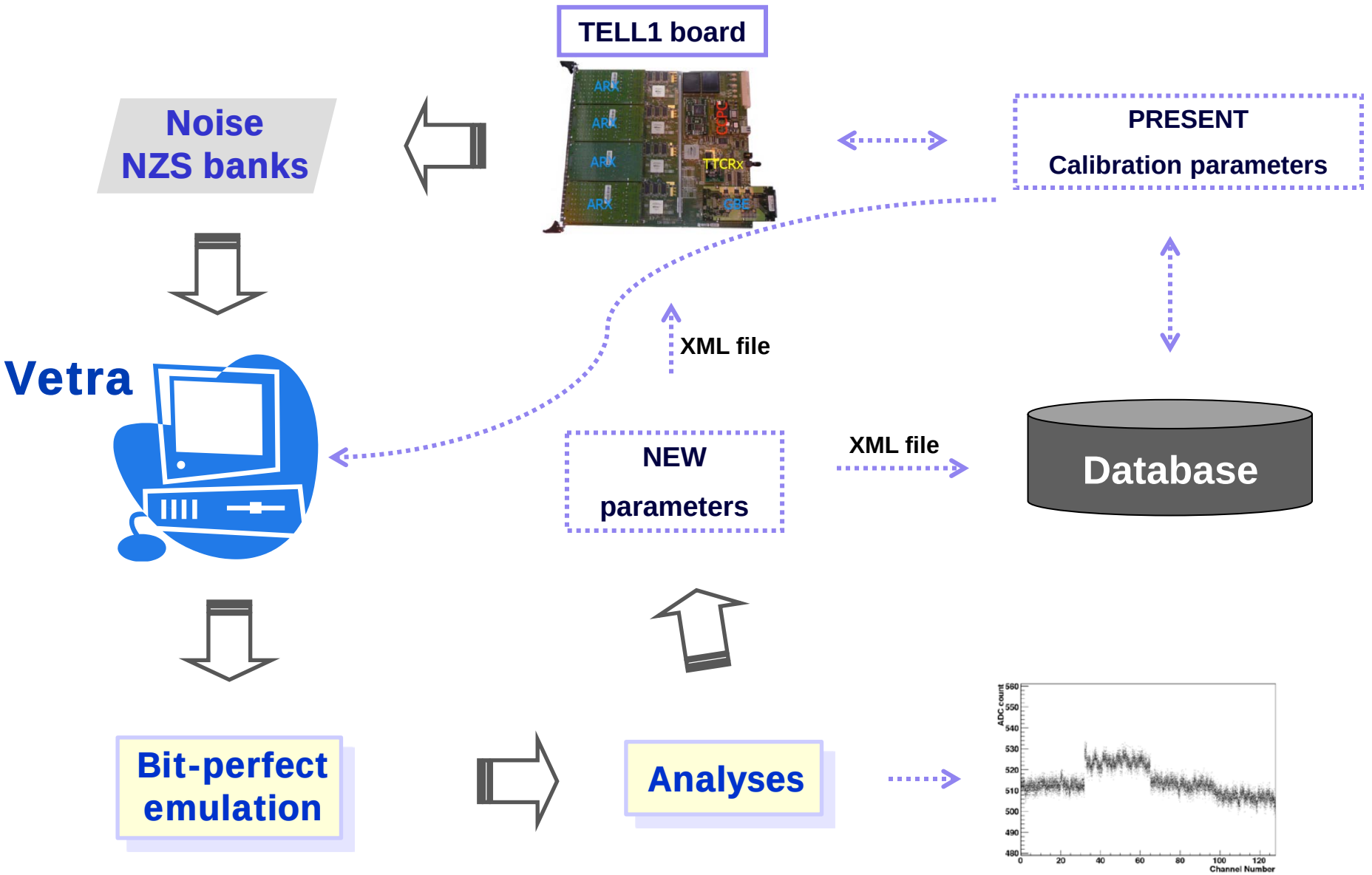
- LHCb software project for the VELO detector (also silicon tracker)
- Mimics the whole processing sequence
- Implements in C an emulation of the TELL1 algorithms run on the FPGAs (VHDL)
- Can treat as input the same data format(s) as output by the TELL1s
  - NZS, ZS, etc.
- Highly flexible and configurable, with Python

$\Rightarrow$ **Unique framework for the determination and tuning of the various types of TELL1 parameters**

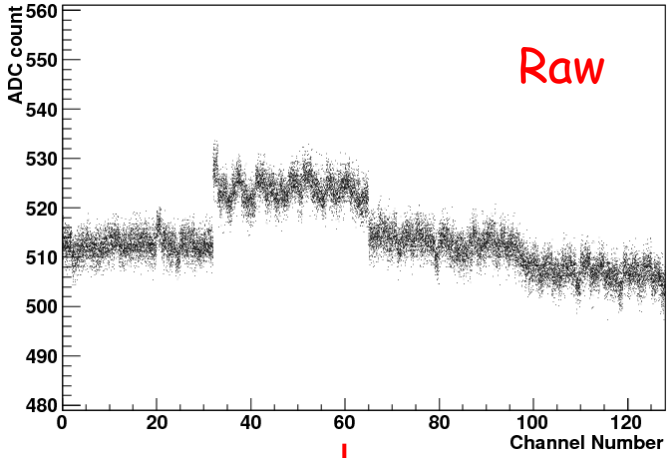
Other benefits :

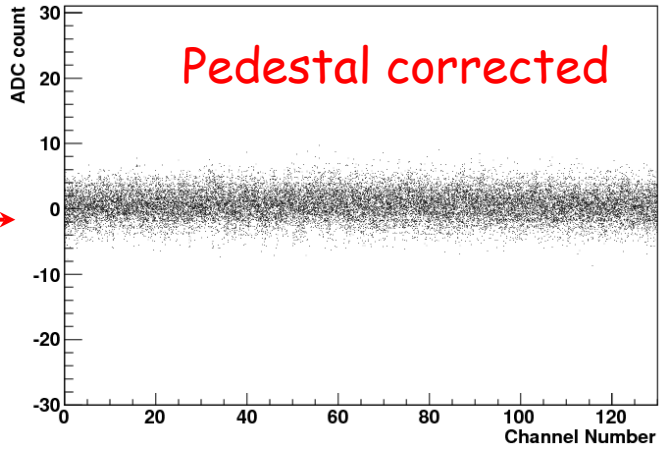
- Allows for self-consistency checks $\leftrightarrow$ bit-perfectness of the TELL1 emulation
- Provides monitoring of all processing steps
- Provides at the same time a software framework and tools for TELL1 studies (e.g. new algorithms) and the online and offline monitoring of the VELO
- Also used in test-beam and laboratory tests

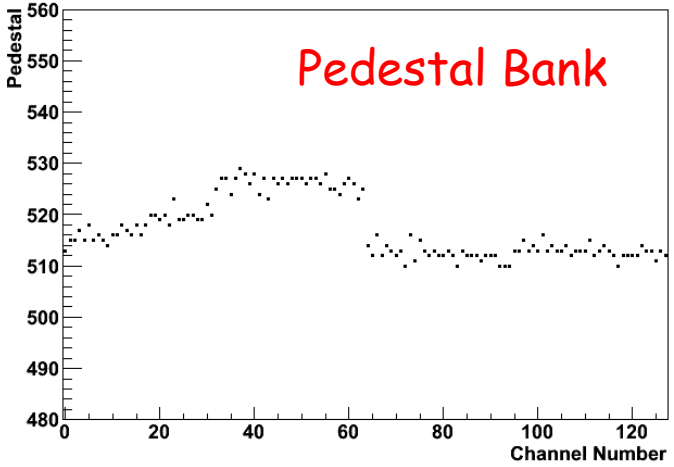
TELL1 parameter determination – procedure

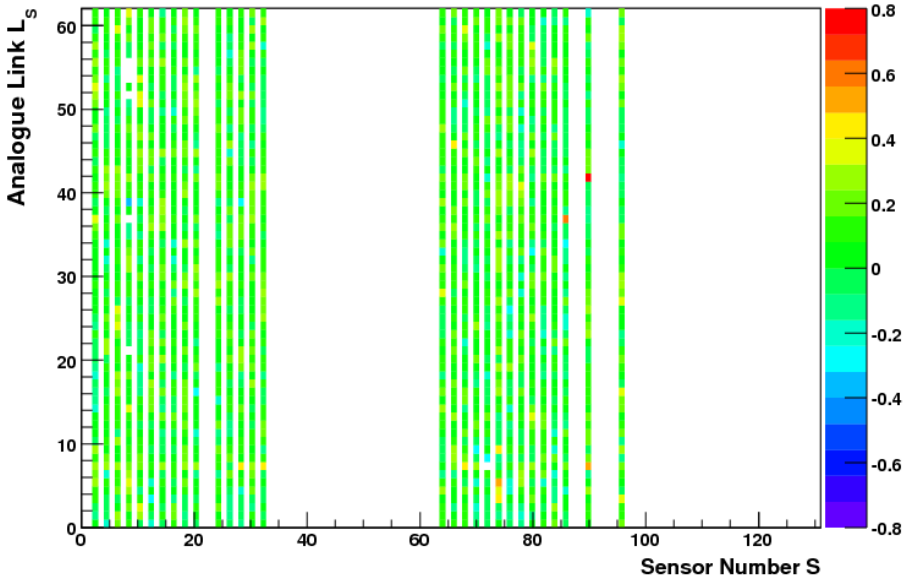


Pedestal correction and its monitoring



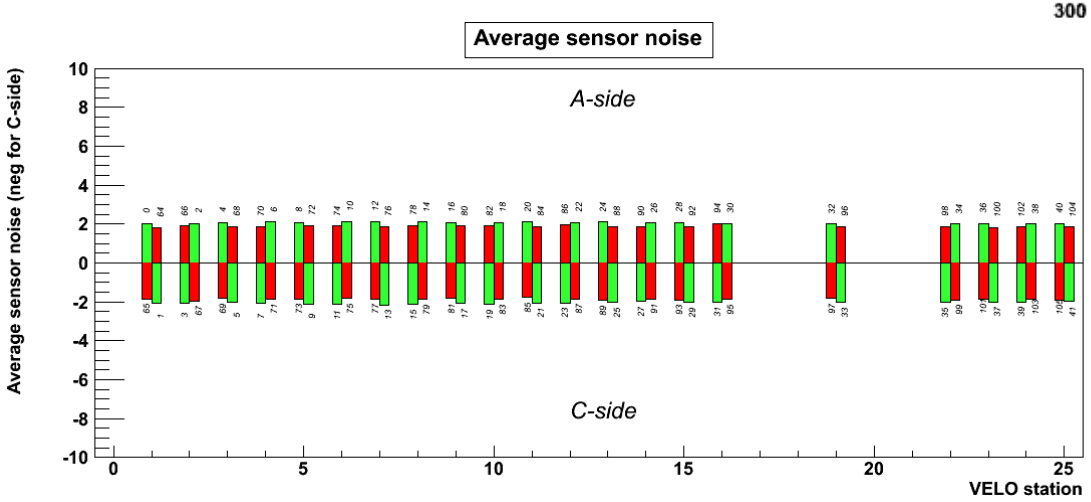


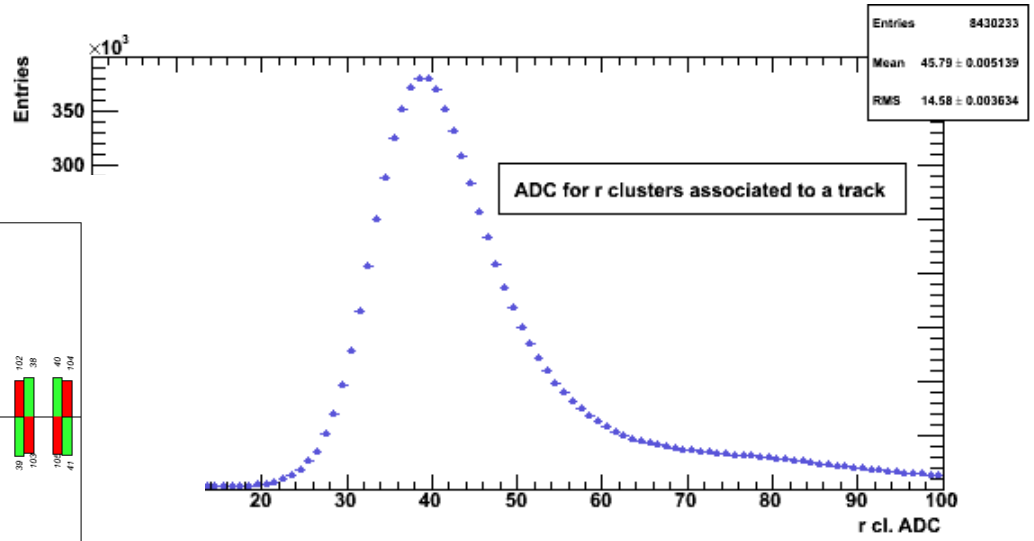


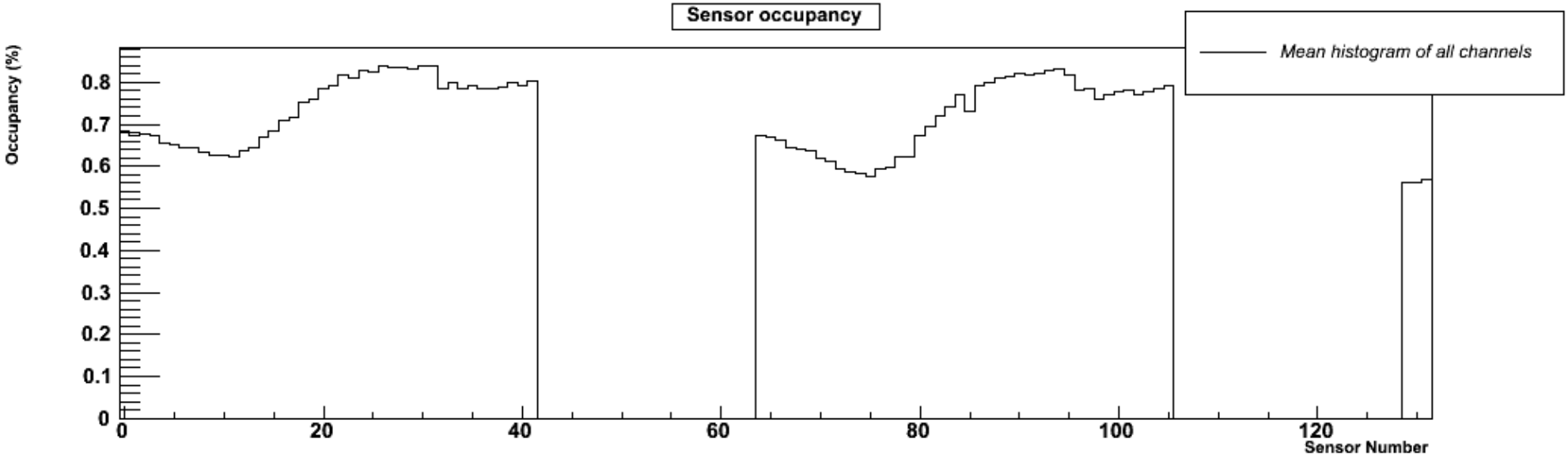


Detector monitoring and data quality

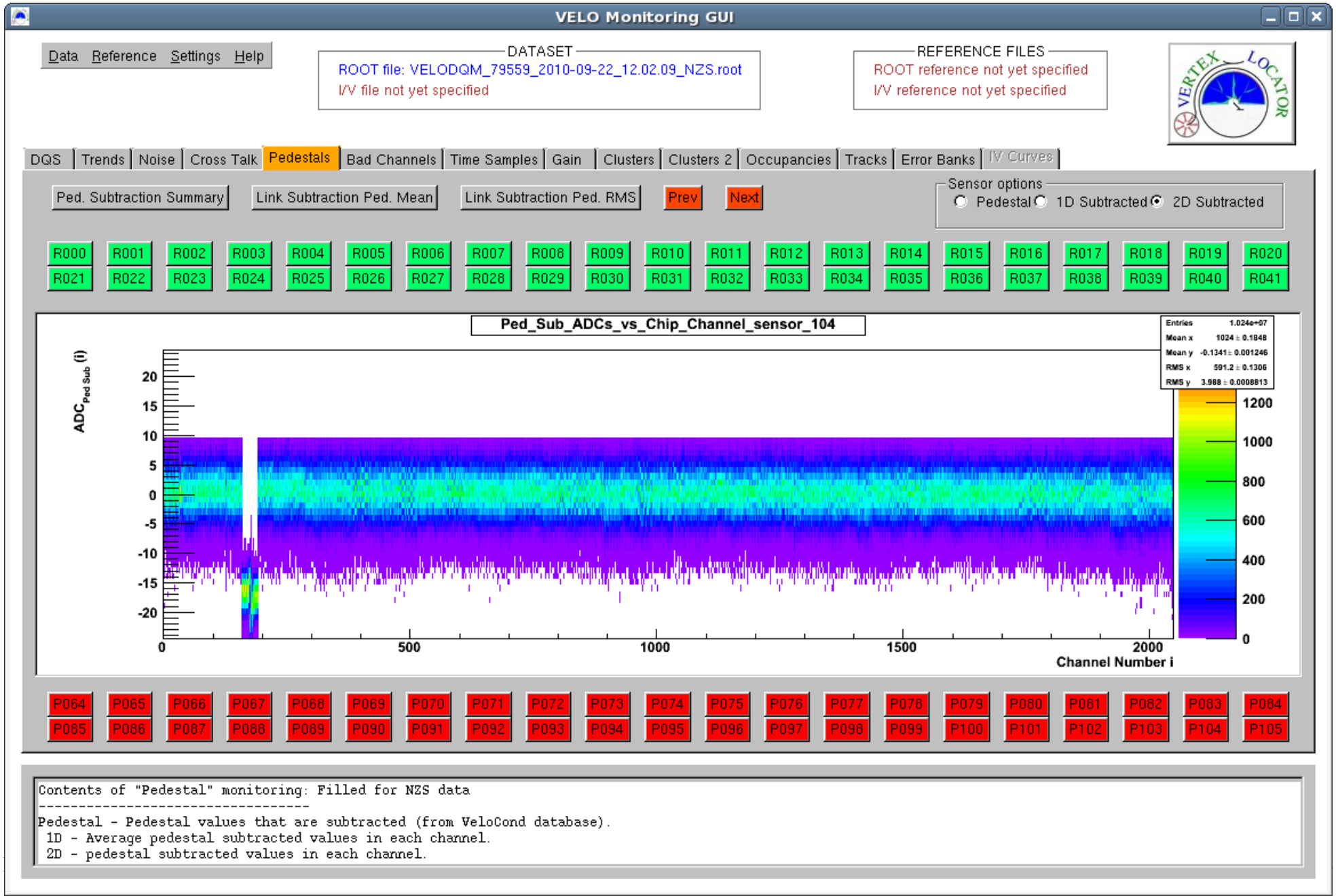
- Uses the Vetra framework and “tools”



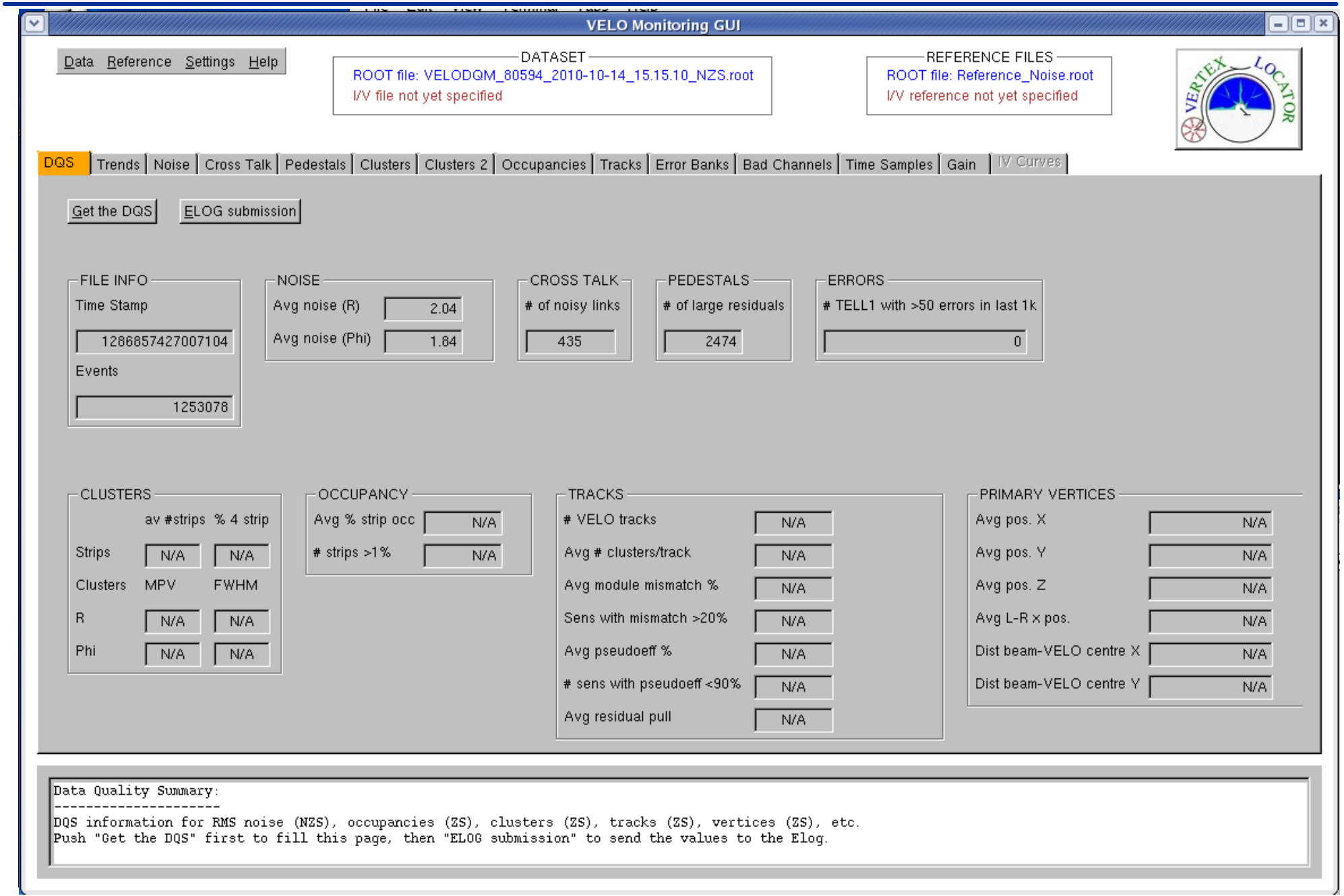




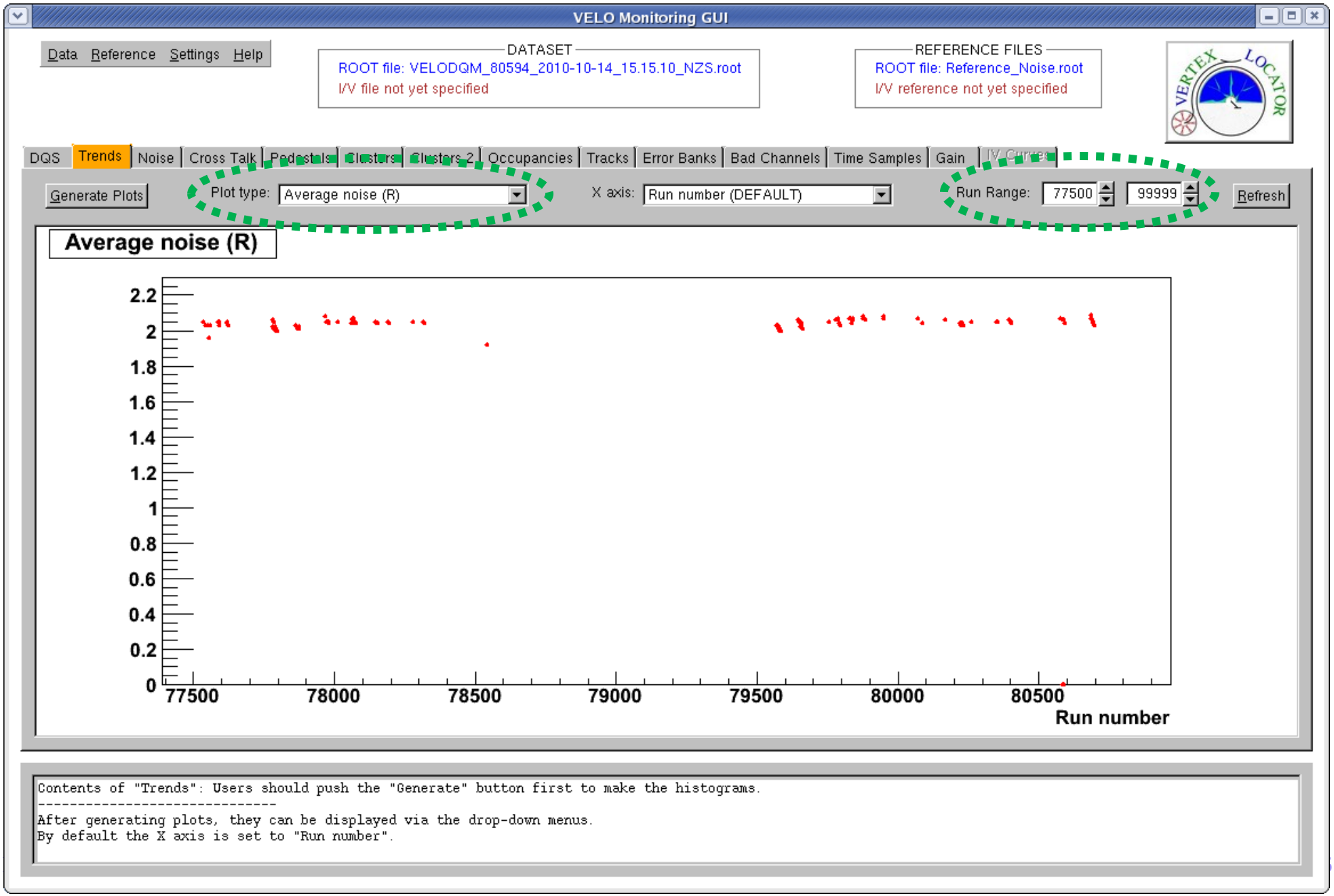
Monitoring – the VeloMoniGUI



VeloMoniGUI – Data Quality Summaries (DQS)



VeloMoniGUI – trending also possible



Experience from the 2010 run

- We coped with the increase in LHC luminosity
  (LHCb runs under different conditions wrt ATLAS/CMS)

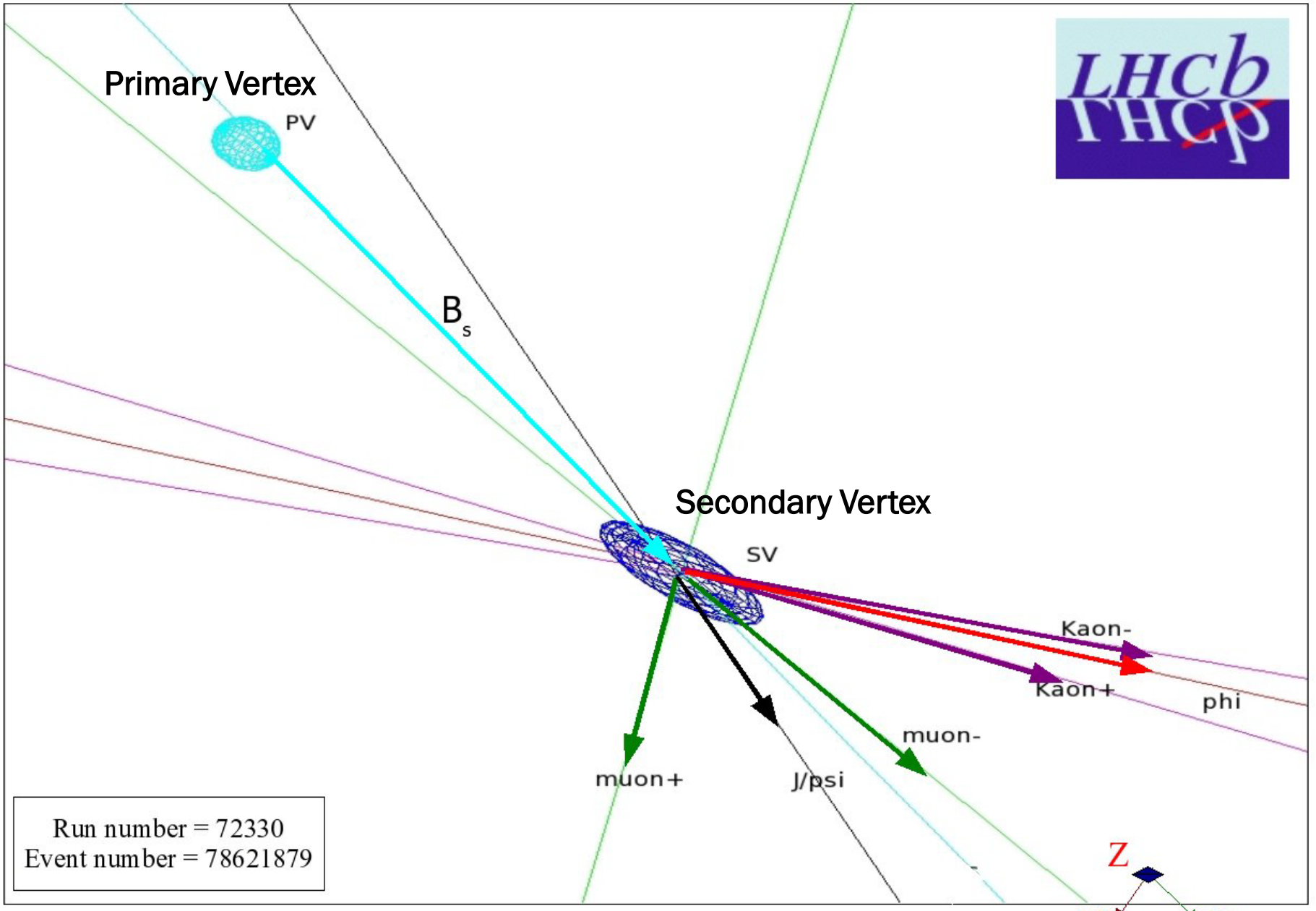
- VELO calibration performed with the emulation suite
  - New parameters determined and uploaded to the TELL1s acquisition boards when/if necessary
  ⇒ allows us to cope with extra increases in rate, via regular monitoring and determination of new parameters

- Approach successfully applied to collision data taken in 2010
  - Integration in the data processing framework was the choice to make

- Regular monitoring of the detector done on a daily basis
  - Noise, pedestals stability, hit and cluster reconstruction performance, etc.

- The Vetra software framework has also been adopted by the silicon tracker group for their tracking stations

So, does it work?



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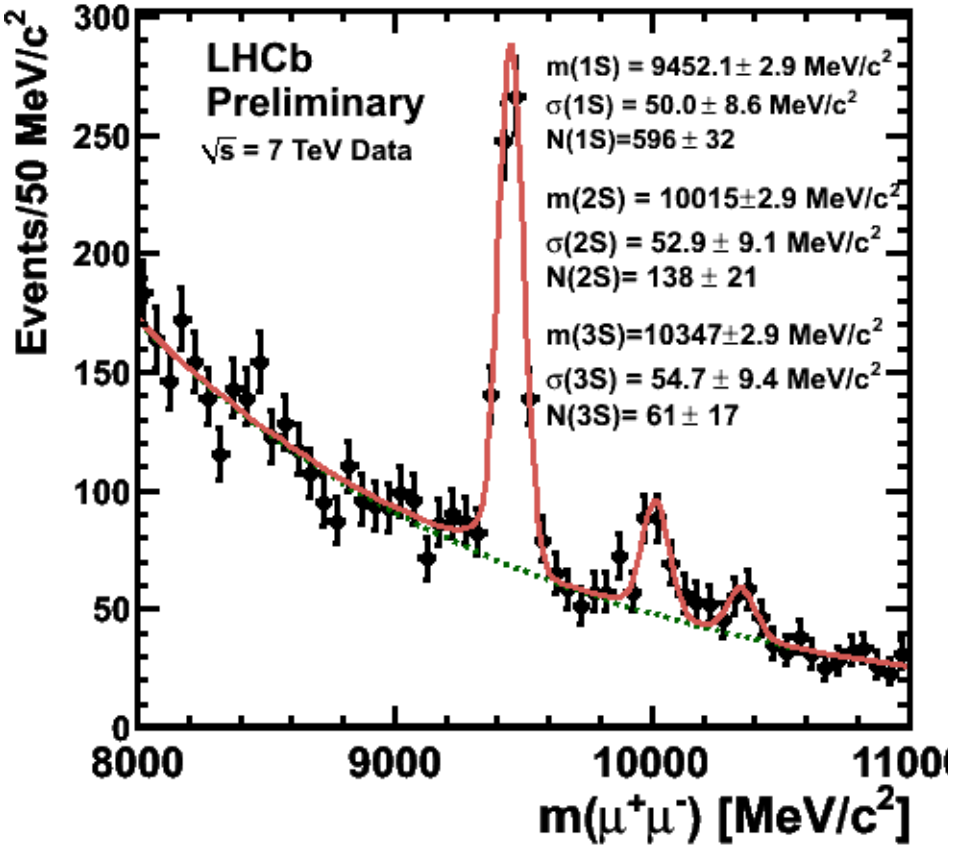
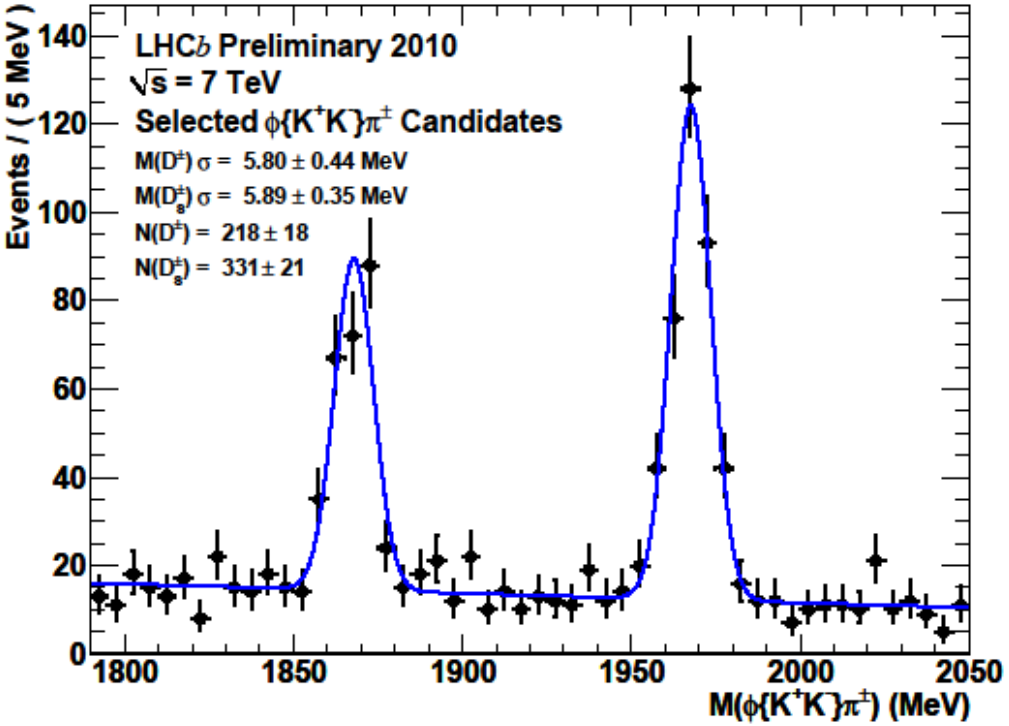
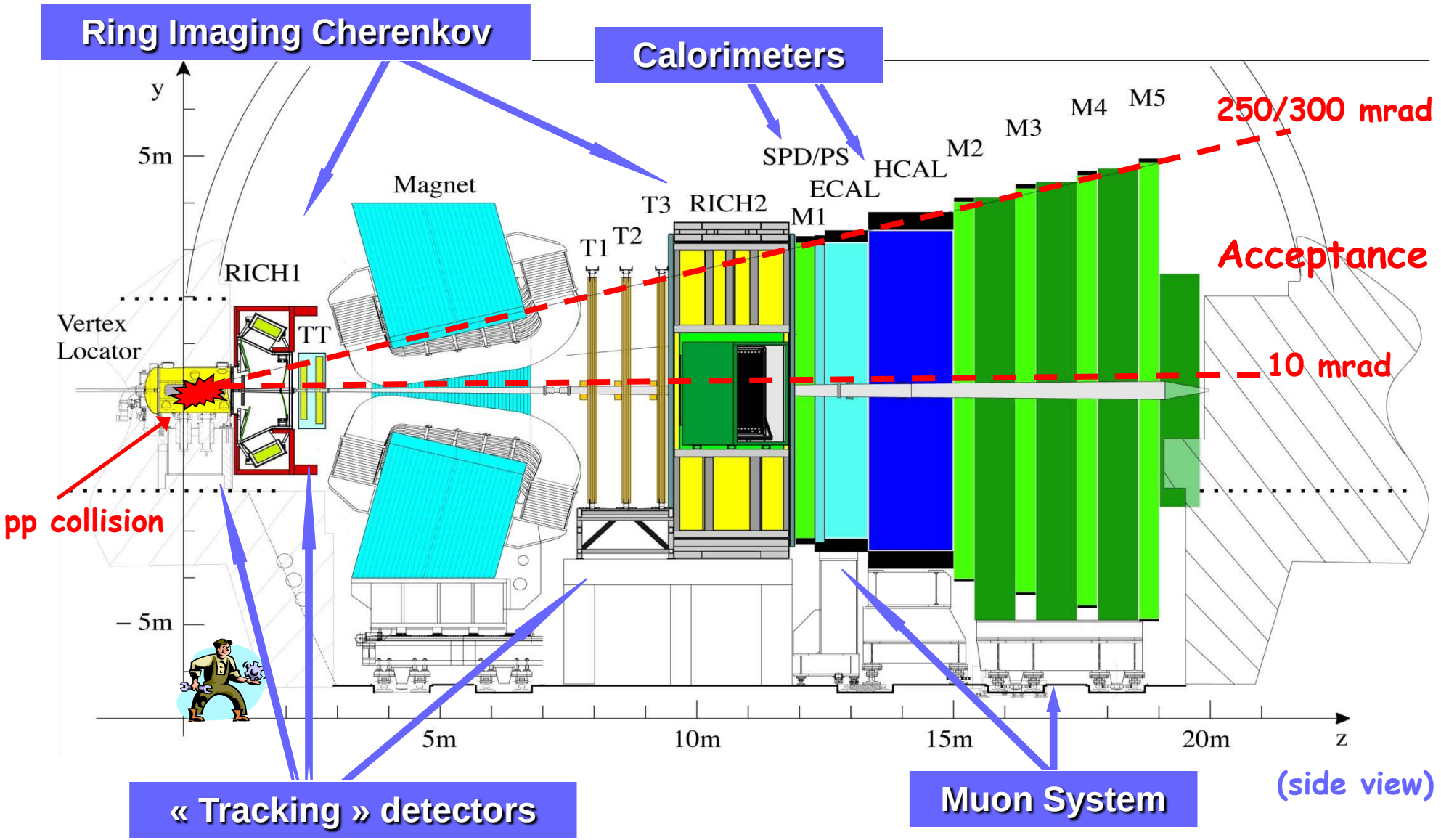




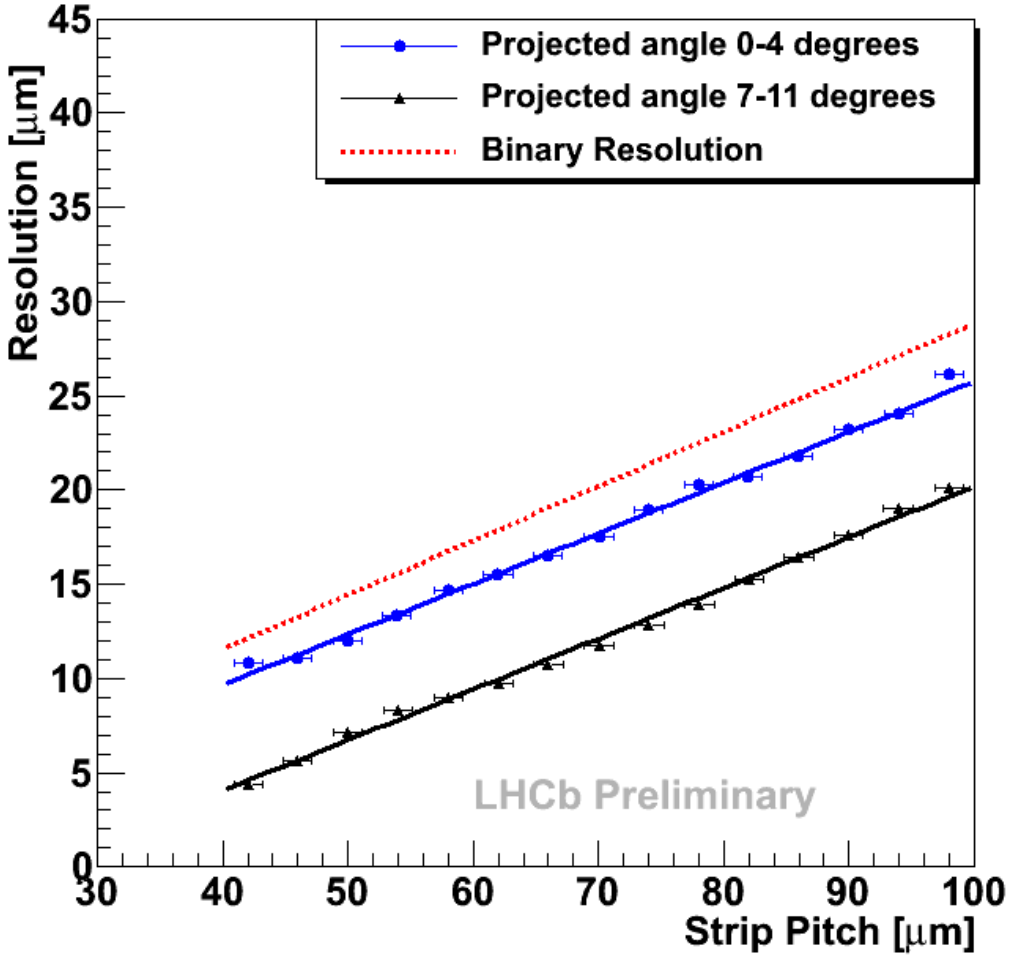
Back-up slides

The LHCb detector



Hit resolutions for VELO sensors

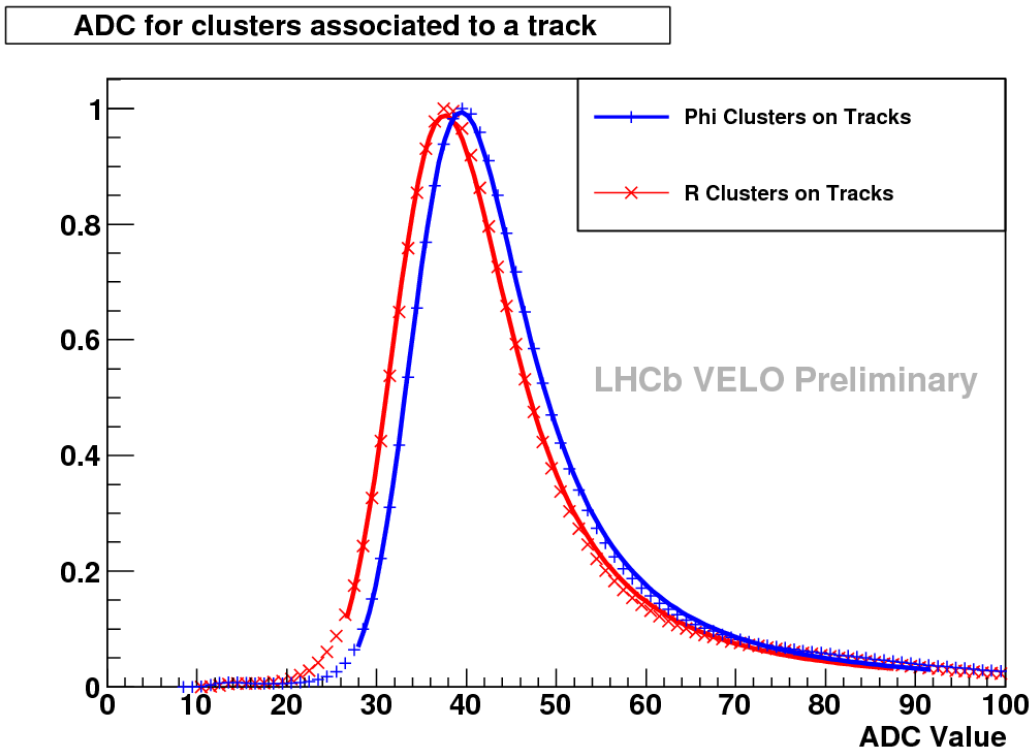
- Hit resolution versus strip pitch for 2 bins of the projected angle
- Evaluated for R sensors using residuals of long tracks

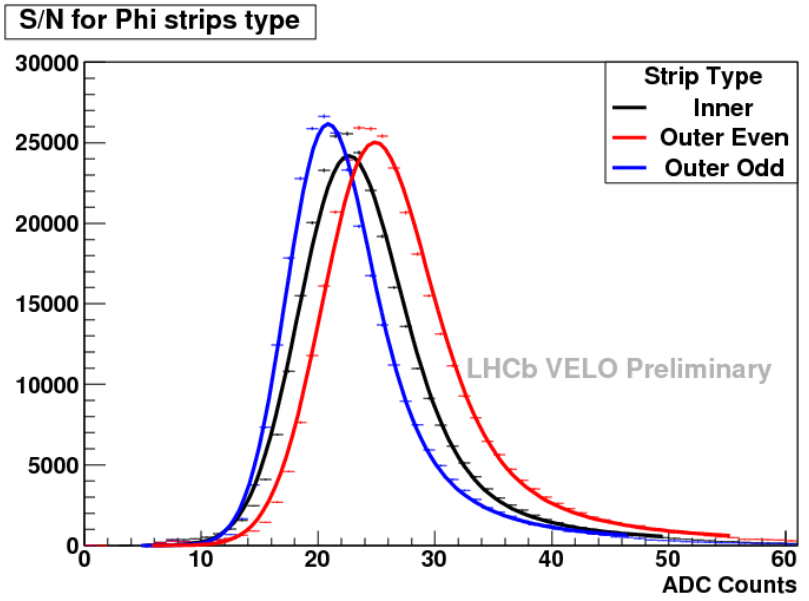


Hit resolution depend to 1st order on:

- projected angle
- strip pitch

Landaus – clusters and noise in the VELO





Detector	S/N
R	18.3
Phi Inner Strips - Routed over outer strips	21.2
Phi Outer Strips - *No* overlaid routing lines	23.3
Phi Outer Strips - Overlaid routing lines	19.6