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On behalf of the LHCb VELO Group

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Results from the first LHC beam reconstructed tracks in the LHCb Vertex Locator

The LHCb detector @ the LHC

VELO – VErtex LOcator

VELO commissioning highlights

First LHC-induced tracks with the VELO

The LHCb experiment @ the LHC

Forward spectrometer

Acceptance: $1.8 < \eta < 4.9$

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

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

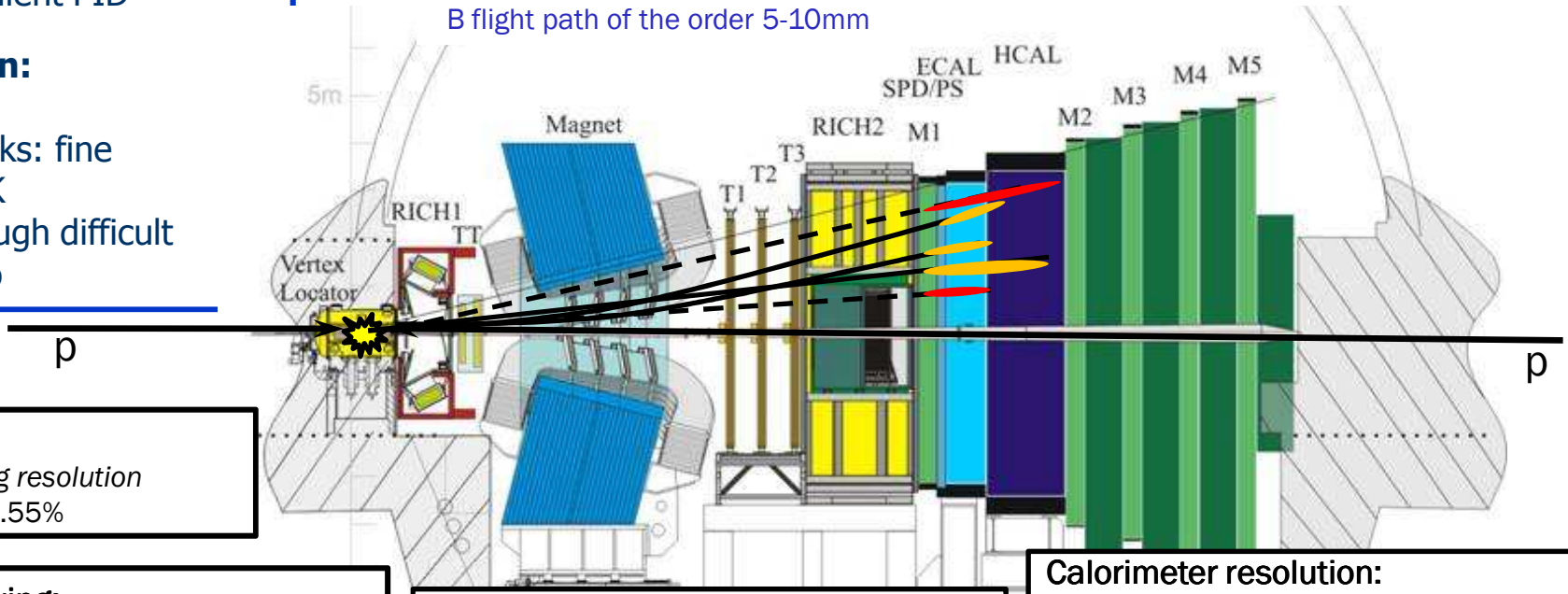
Detector: excellent tracking
excellent PID

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



Tracking:
Expected tracking resolution
δp/p=0.35% to 0.55%

Vertexing:
Expected primary vertex resolution
~10μm transverse plane and
~60μm in the longitudinal one
Expected Impact parameter resolution σ_{IP}=13μm+35μm/p_T

RICH performance:
Cherenkov angle resolution 0.6-1.8 mrad
Particle identification in p range 1-100 GeV
π, K ID efficiency > 90%, misID<~10%

Calorimeter resolution:
Design ECAL resolution
$\sigma(E)/E = 10\%\sqrt{E} + 1\%$ *(E in GeV)*
HCAL resolution from test-beam data
$\sigma(E)/E = (69\pm5)\%\sqrt{E} + (9\pm2)\%$ *(E in GeV)*

The VErtex LOcator – VELO

Trigger

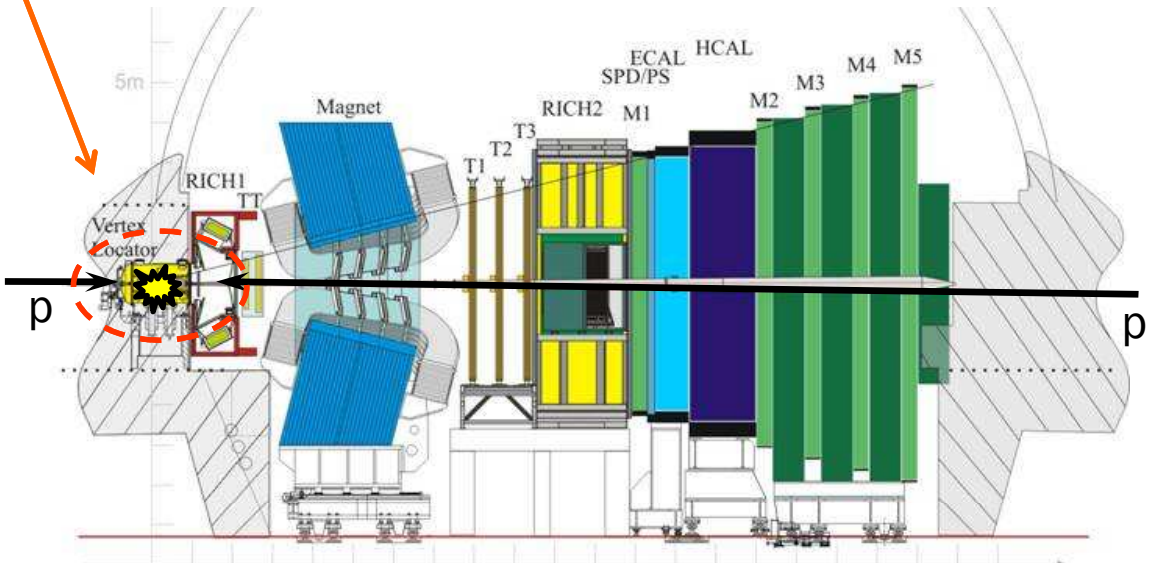
- Fast reconstruction of primary vertices
  - select single-interaction collisions
- Enrichment of B-content in selection

Tracking

- Excellent pattern recognition
- Precise determination of track parameters

Vertexing

- Precise reconstruction and separation of primary and secondary vertices



Vertexing:& Tracking

Expected primary vertex resolution
~10μm transverse plane and
~60μm in the longitudinal one

Expected tracking resolution
δp/p=0.35% to 0.55%

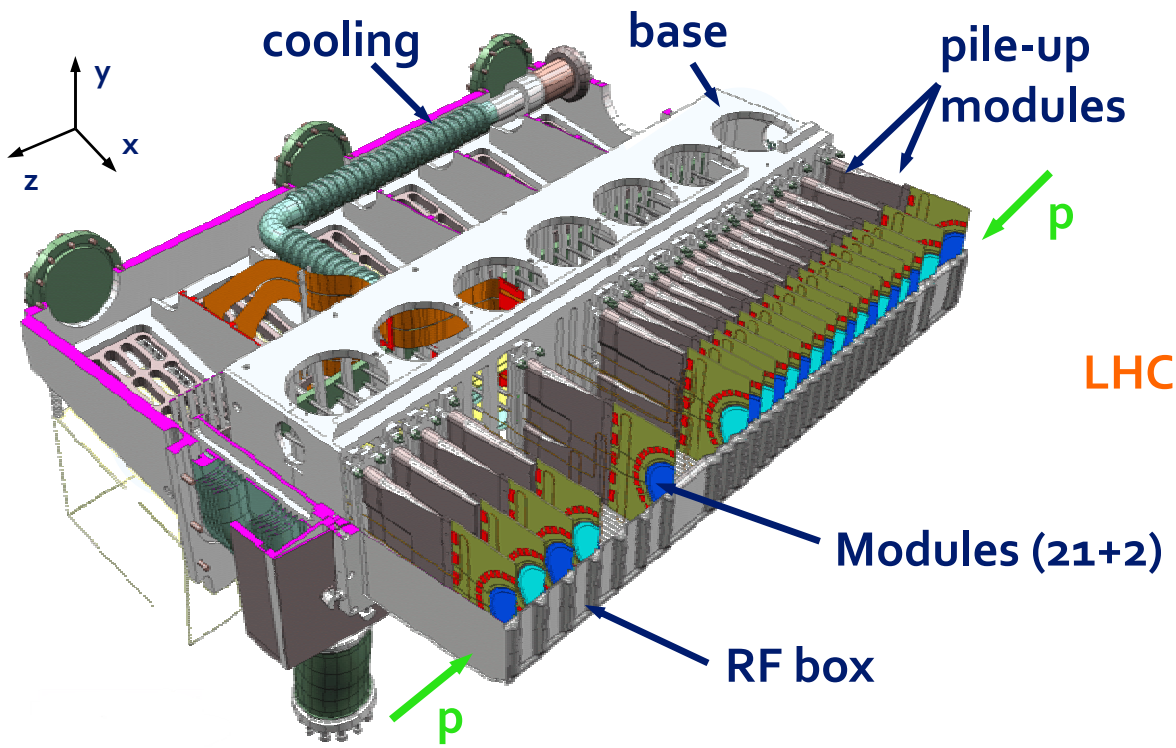
Expected Impact parameter resolution σ_{IP}=13μm+35μm/p_T

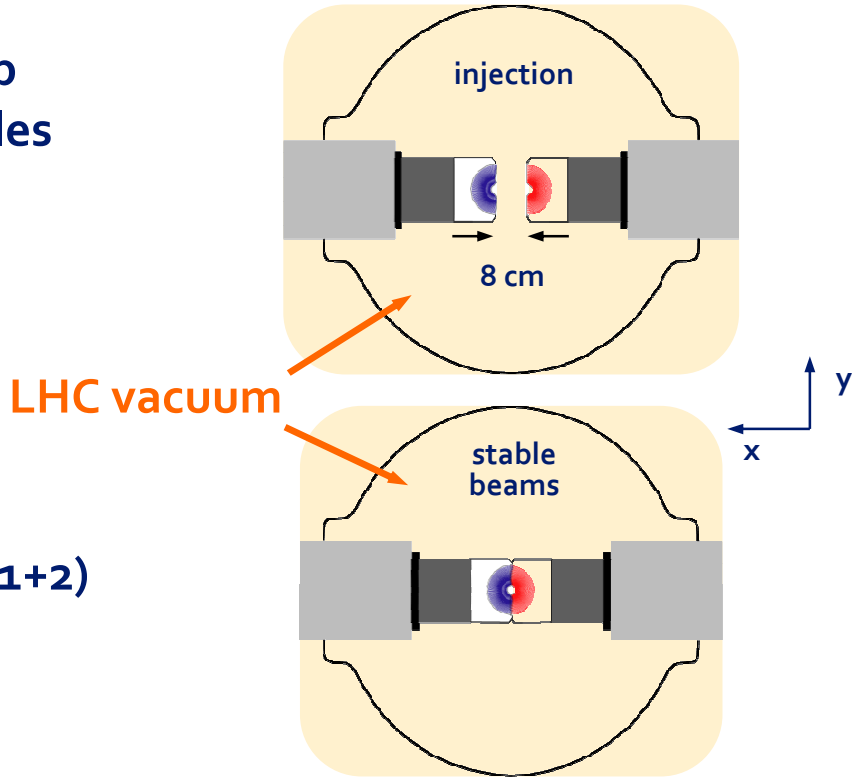
B-mesons

Expected mass resolution
12-25 MeV

Expected proper-time resol.
*~40*fs

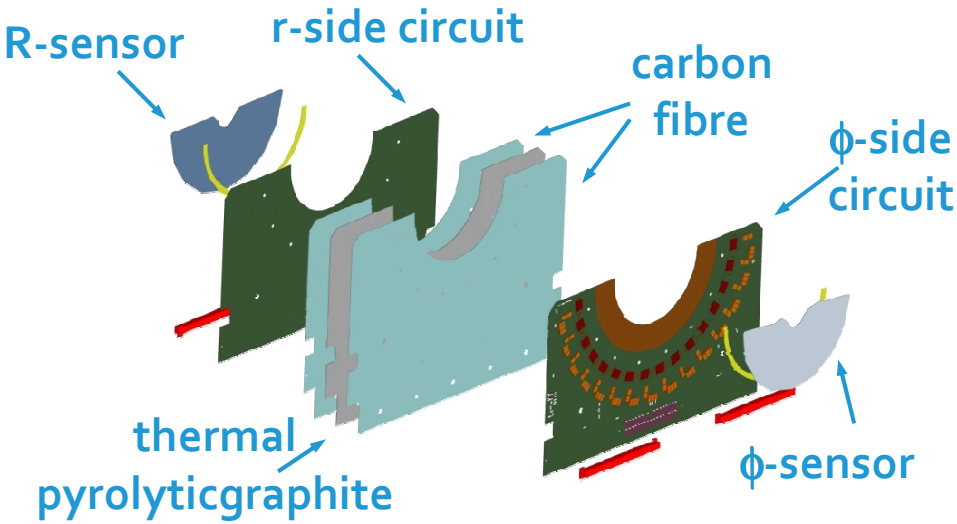
VELO – overview





- **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
- **Operation in secondary vacuum**
- **300μm foil separates detector from beam vacuum**
- **Bi-phase CO_2 cooling system**

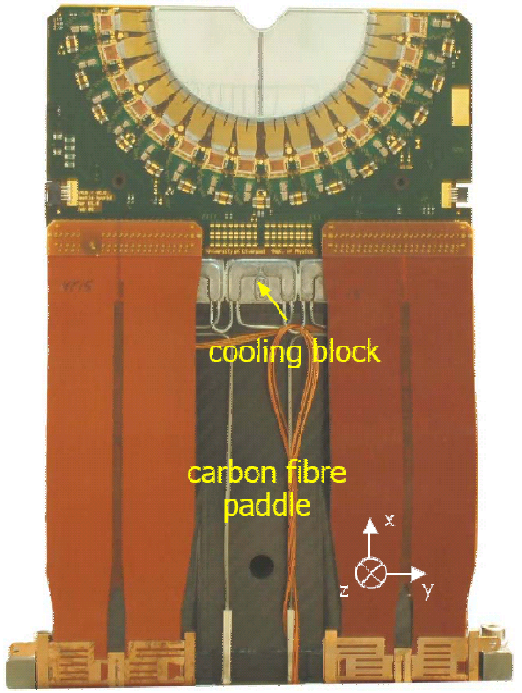
VELO – modules



Purpose :

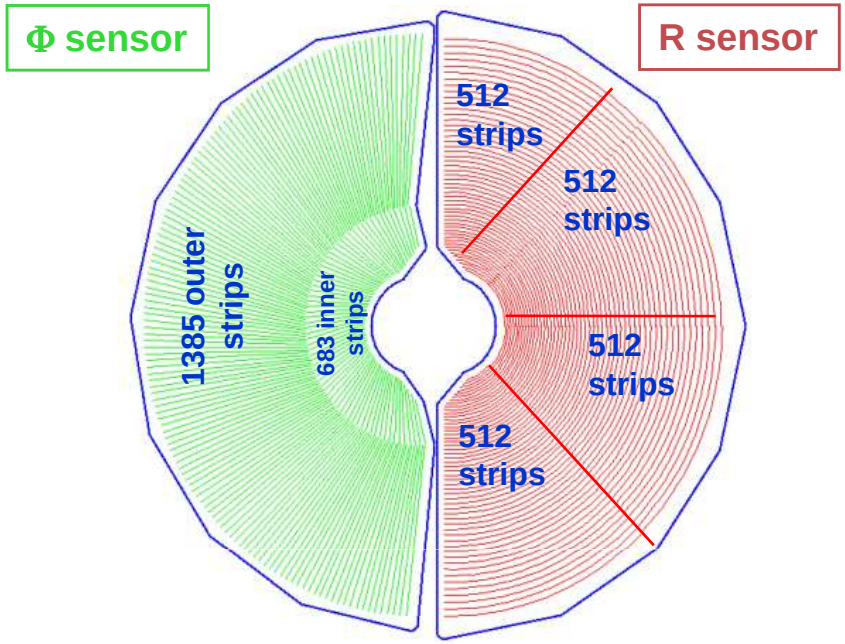
- Hold the sensors fixed wrt module support
- Connect electrical readout to the sensors
- Provide means of cooling to the sensors

- Sensor-sensor positioning accuracy < 5μm



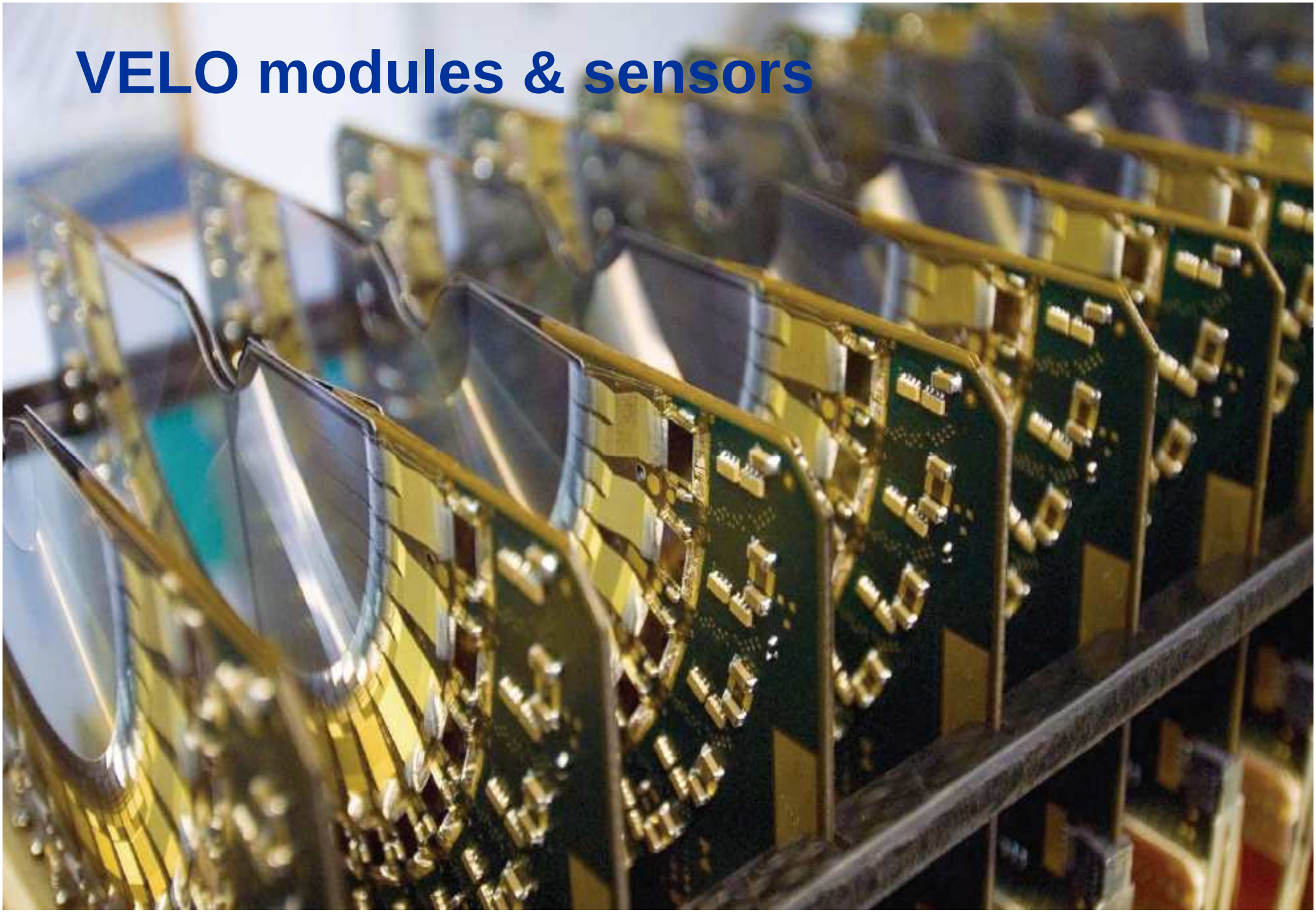
VELO – sensors

- Highly segmented; n^+ on n
- 2048 strips per sensor
- Radiation tolerant. Expected ratiation dose:
  - $1.3 \cdot 10^{14} n_{eq}/cm^2/year$ at r = 0.8 cm
  - $5 \cdot 10^{12} n_{eq}/cm^2/year$ at r = 4.2 cm
- Design operation at -7 degrees



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 modules & sensors



Commissioning – overview

2007

- Installation
- Cosmics cannot be used for commissioning

2008

- Comparisons of noise level with data taken in assembly
- Single module operations under Neon atmosphere
- Multi-module testing, full half powered for the first time, etc.
- First operation in vacuum on 18th June
- Full detector operated under vacuum
- Cooling down of detector with modules @ -5 C
- Beam in SPS-to-LHC transfer line stopped on the « TED beam dump » on 22nd-24th August and 5th-6th September

2009

- TED run in June
- Tuning of the timing
- High rate tests at 1 MHz
- Operation under final conditions (vacuum and temperature)
- Next TED run just a week away – 12th Oct. !

"TED runs": see next slides …

Tests with beam-induced tracks – TED runs

What are these "TED runs" ?

- Passage of secondary tracks through the LHCb detector coming from a dump of LHC's beam 2 on the TED
- TED=Transfer line External beam Dump
  - 4m W/Cu/Al/graphite rod in 1m iron casing
  - absorber located 340m before LHCb

Typical TED beam runs

- 1 shot every 48 seconds
- ~5×10^9 protons / shot
- typical duration: 2 days

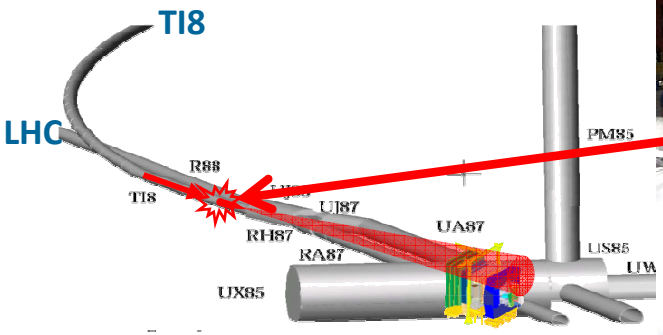
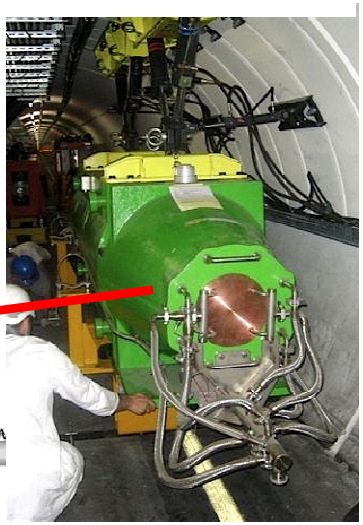


Photo during installation

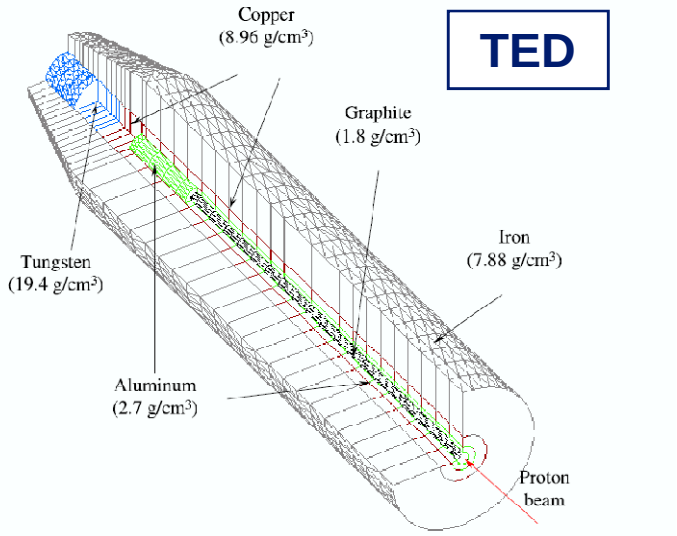


Why does the VELO need them ?

- Cosmics not exploitable given the VELO geometry

Goals of these real data sample studies:

- Test the "DAQ recipes"
- Tuning the timing
- Commission the monitoring (online, offline)
- Test the pattern recognition
- Check performance of alignment algorithms



TED runs – runs & data samples

1st RUN

22-24 August 2008

↔ 22nd :10 modules powered on (5 in each half)

24th : all HV on; 76 sensors read out

2nd RUN

5-6 September 2008

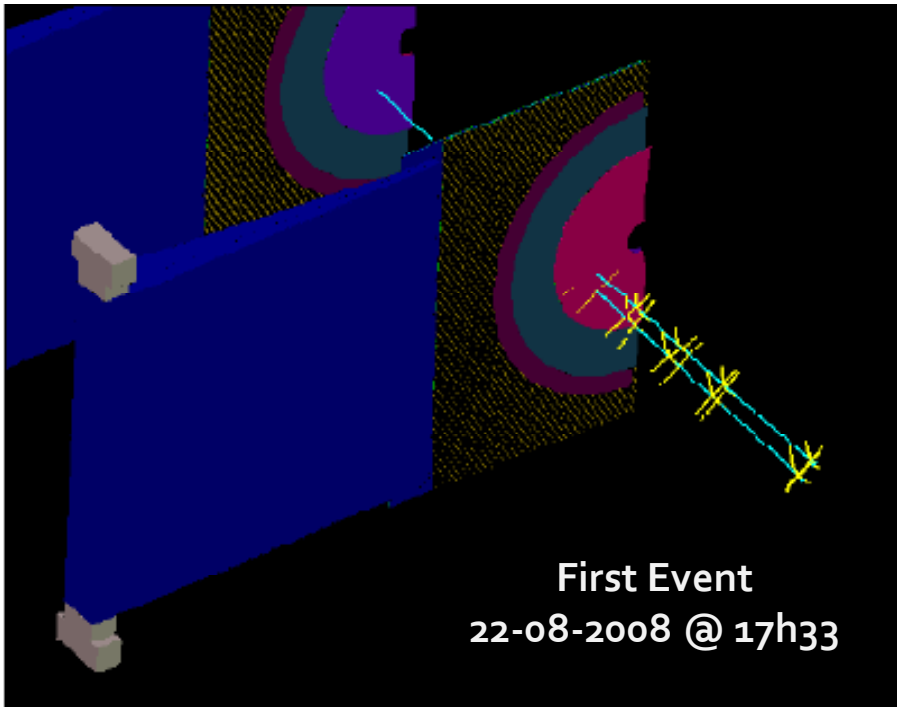
↔ - All HV on
- 76 sensors read out

3rd RUN

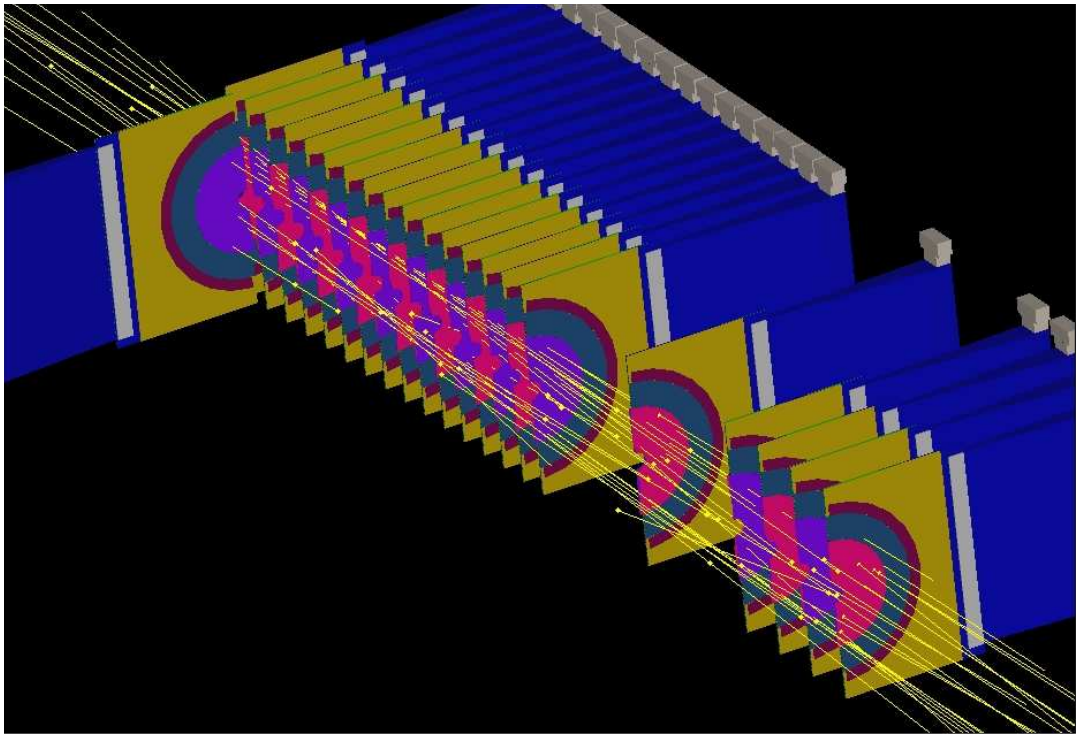
6-7 June 2009

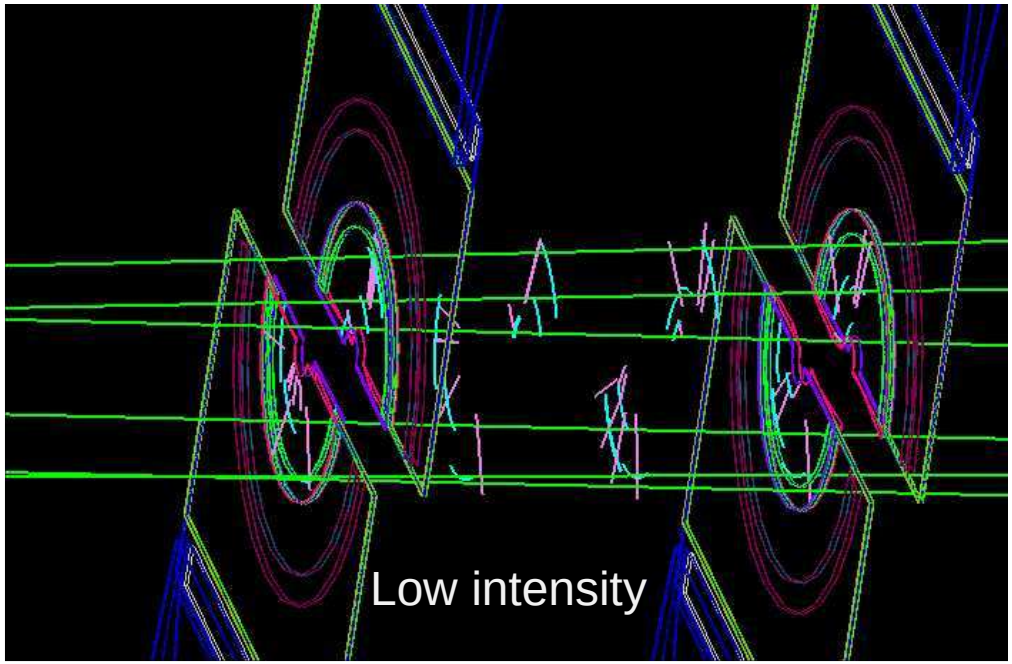
↔ All HV on

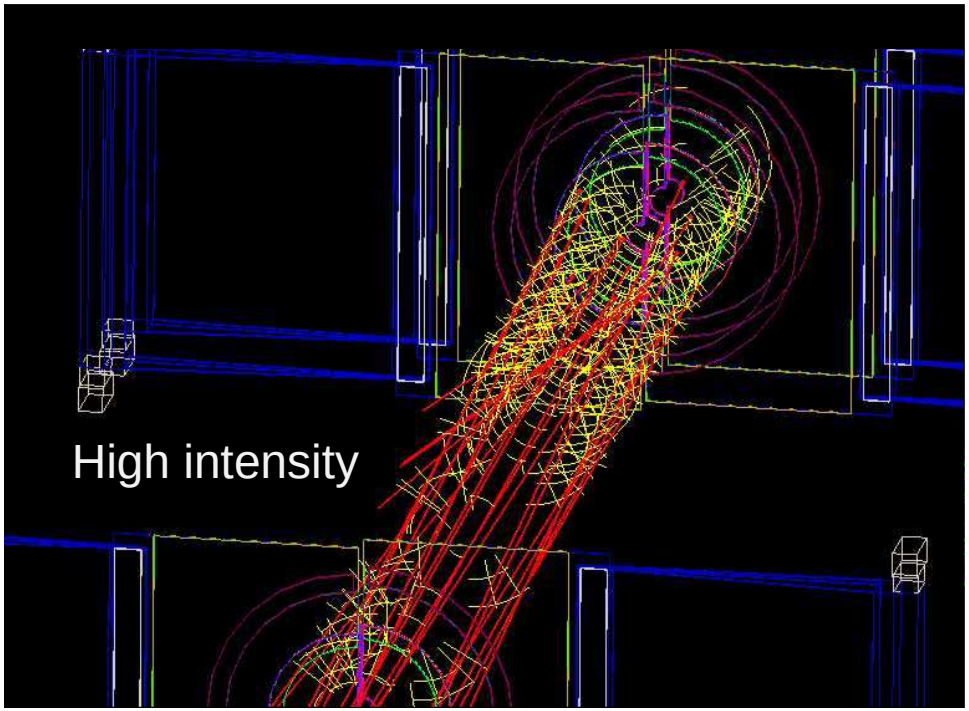
http://lhcb-vd.web.cern.ch/lhcb-vd/html/first_events.htm

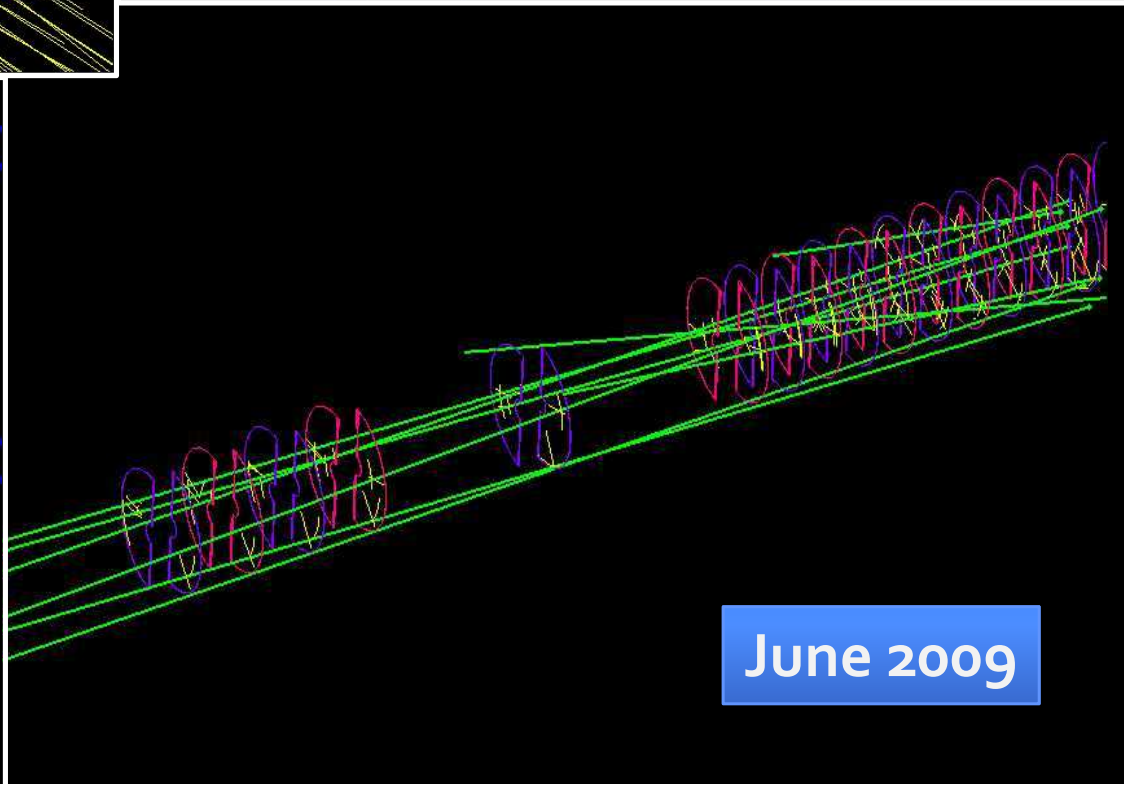


About 60000 tracks collected in total !




Low intensity


High intensity


June 2009

June 2009 TED run – VELO timing (1/2)

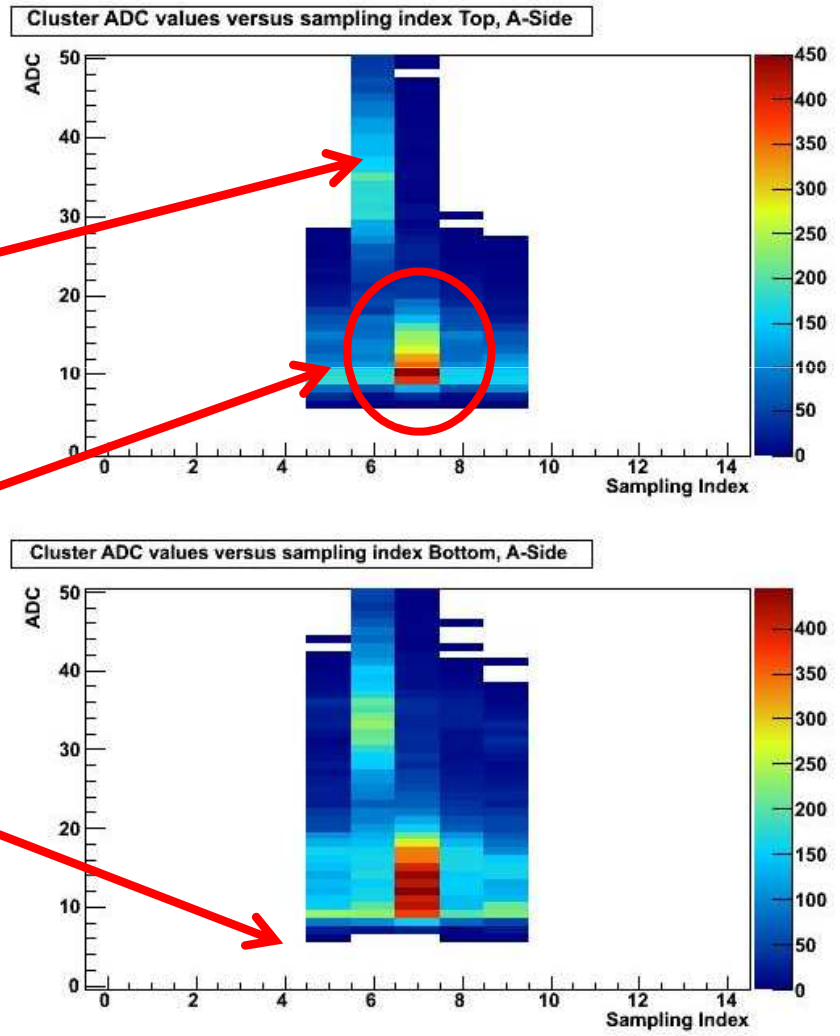
Procedure :

- (Timing first estimated from cable lengths, known delays)
- Sample in time slots of ±25ns around best guess of timing settings for signal
- Perform the tuning using TED data

Signal peak slightly off from “nominal” (index=7)

Spillover on top of noise

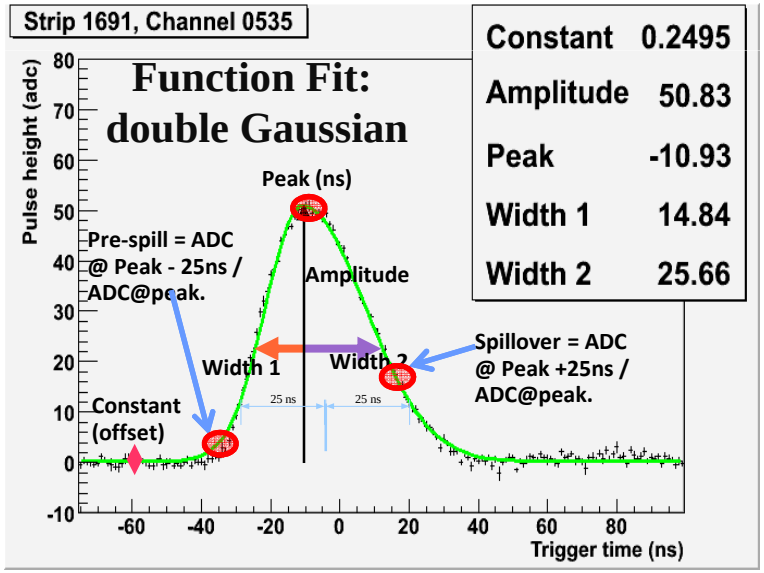
Threshold effect

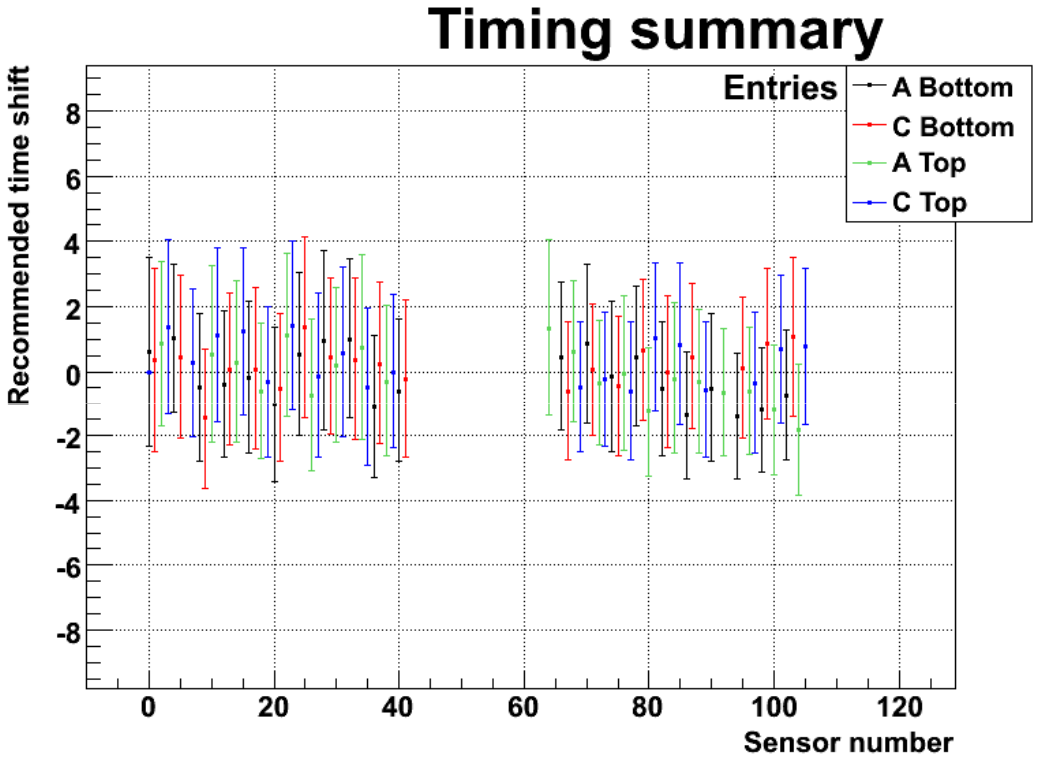


- All monitored online, with zero-suppressed data

June 2009 TED run – VELO timing (2/2)

- **Timing could be set with precision better than 2ns with ~100 clusters/sensor/step**





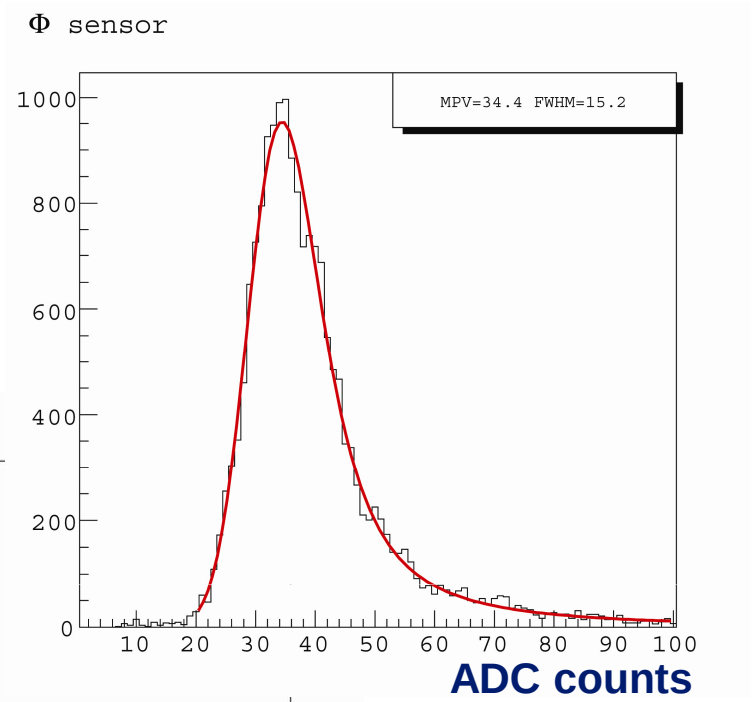
June 2009 TED run – signal-to-noise

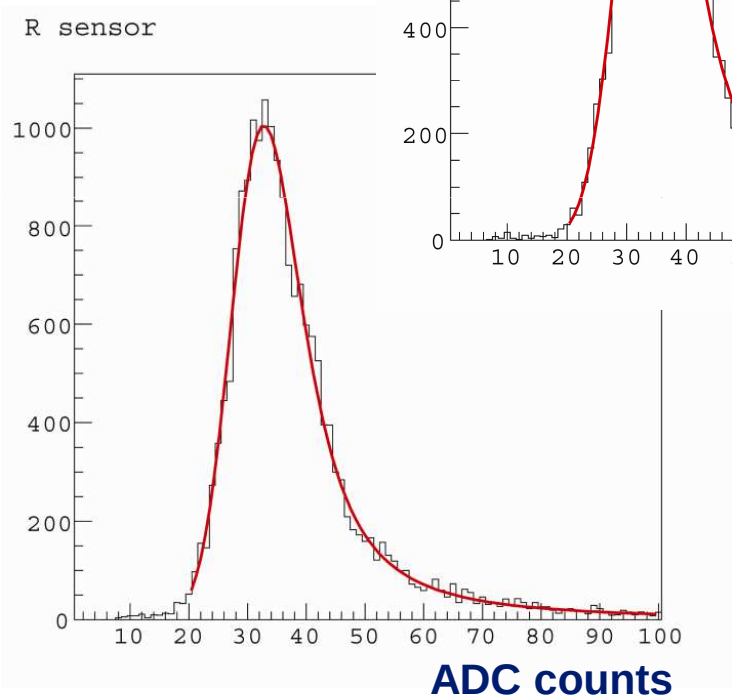
MPV – Most Probable Value of ADC distribution

- **Use clusters on tracks**
  - **Φ : 34.4**
    - ***Outer w/o Meta l: 35.3***
    - ***Inner : 34.4***
    - ***Outer w Metal : 33.6***
  - **R : 32.8**

⇒ signal-to-noise:

- **Φ : 20**
  - ***Outer W/Metal : 19***
  - ***Inner : 20.5***
  - ***Outer w/o Metal : 23***
- **R : 18**

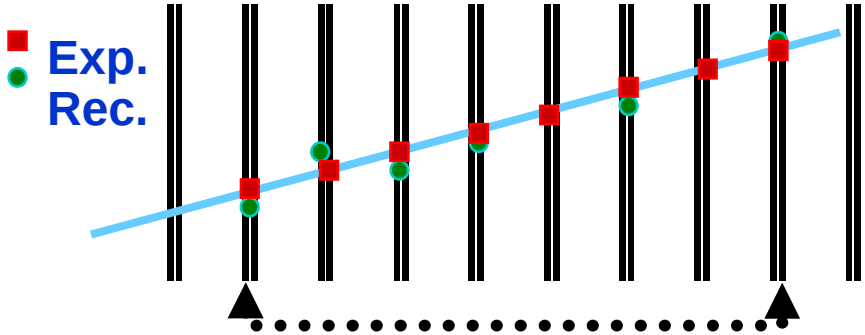




(ADC distributions fitted with a Landau)

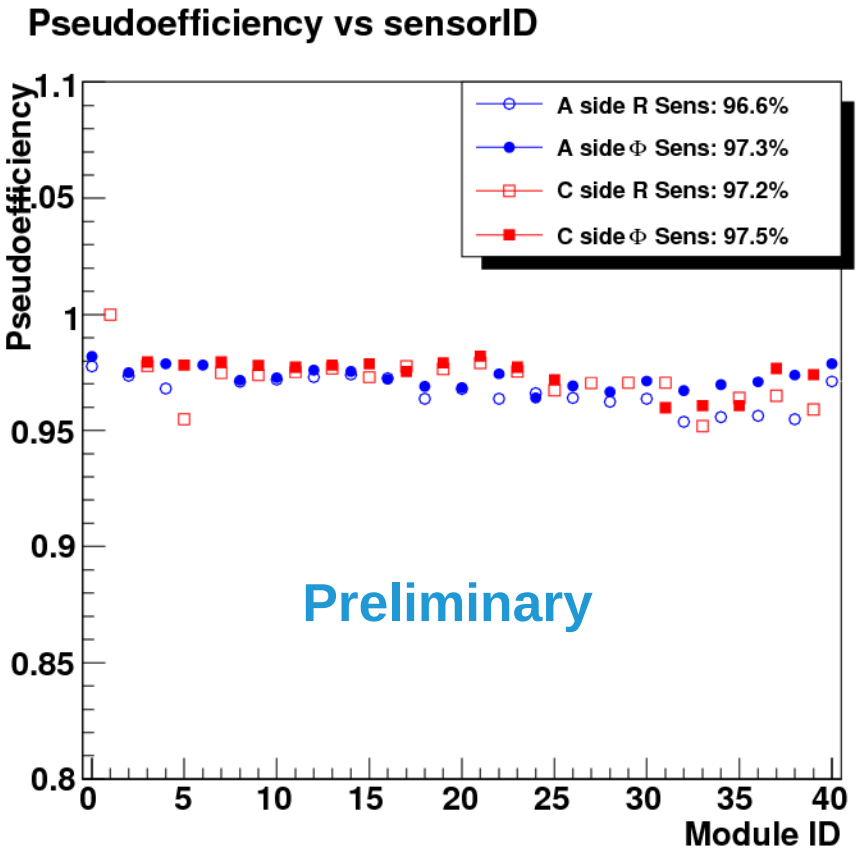
June 2009 TED run – pattern recognition

- Pseudo-efficiency calculated by interpolation, per sensor



⇒ pseudo-efficiencies:

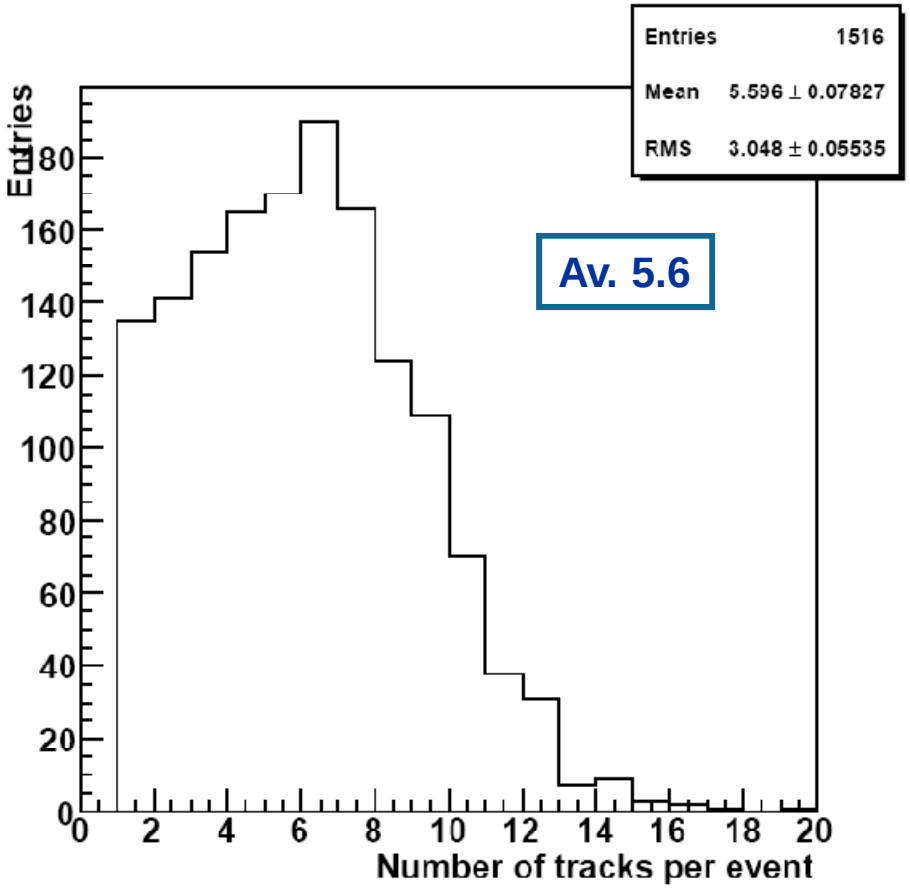
- Φ sensors: ~ 97.4%
- R sensors: ~ 96.9%



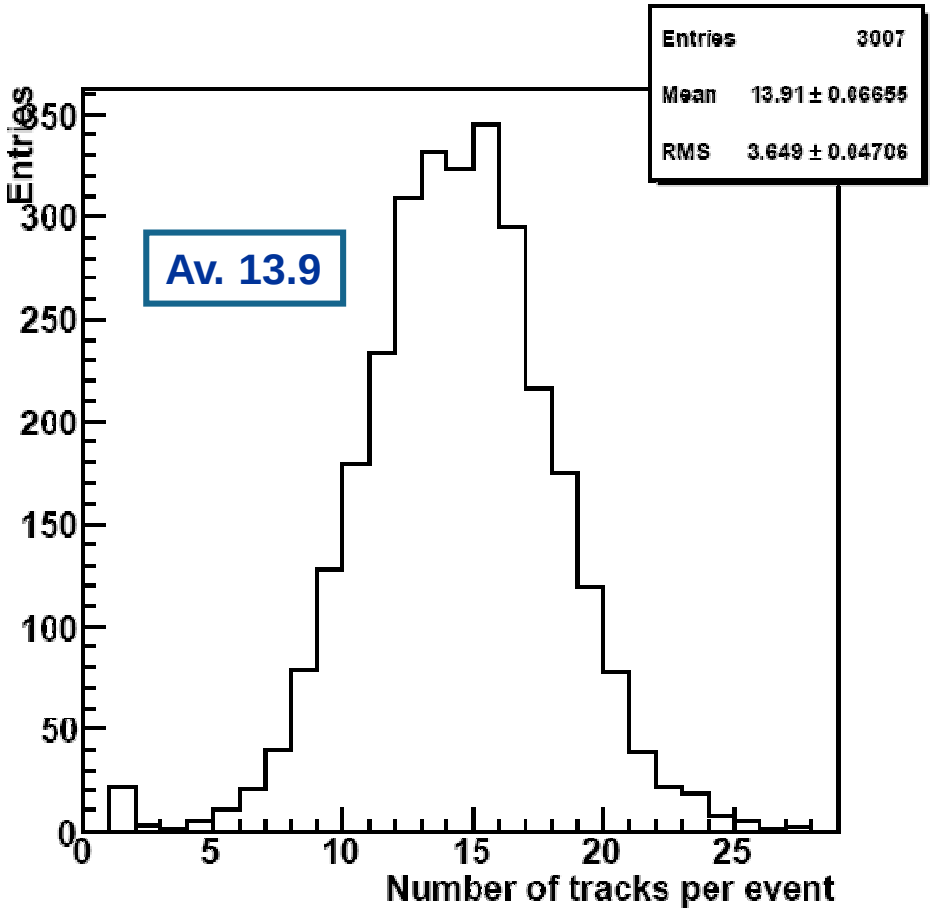
Large search window: 5σ of resolution + tolerance of 100 μm (5 mrad)

June 2009 TED run – tracks

Low intensity run: 2-5x10^9 protons



High intensity run: ~10^{10} protons



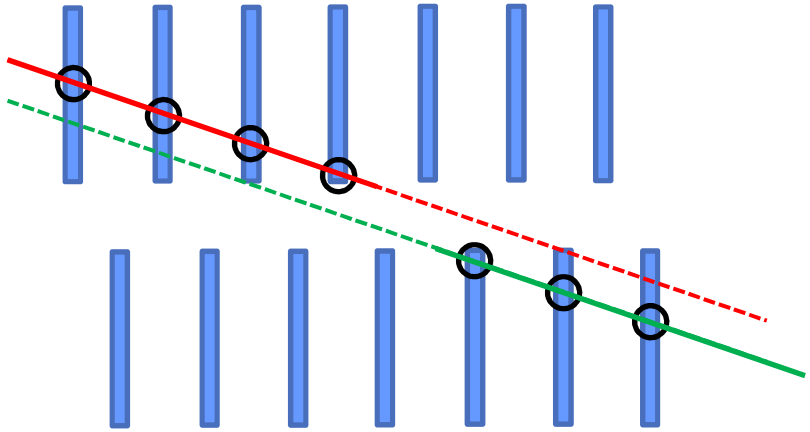
TED runs – alignment

2008

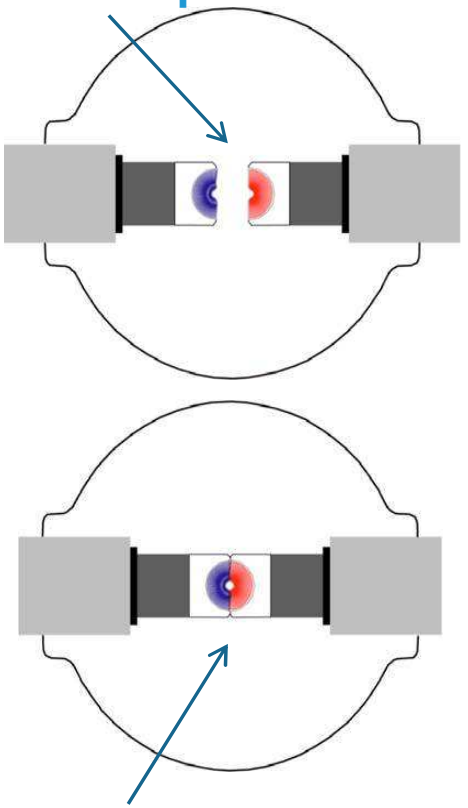
- First alignment with real tracks
- Modules position differences with respect to metrology within 10 μm

2009

- High statistics
  ⇒ possible to check for the 1st time the distance between detector halves with “traversing tracks”

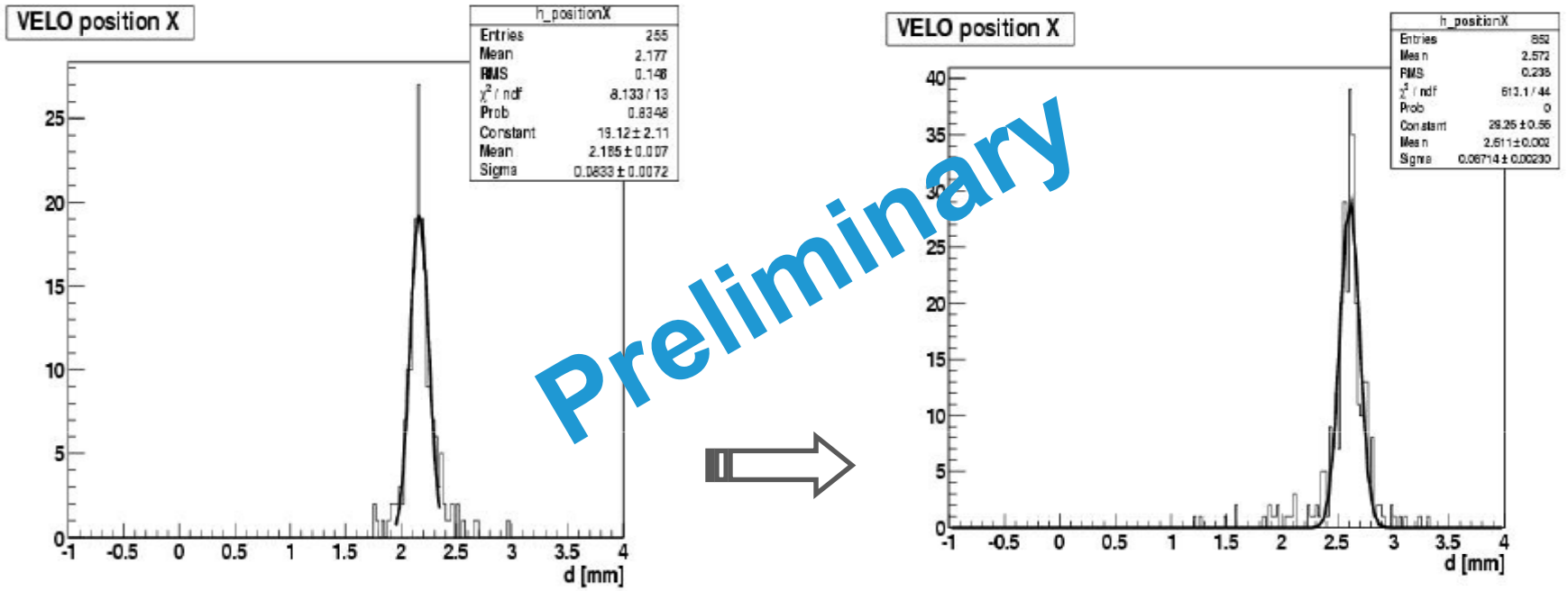


Detector open



Detector closed:
slight overlap of sensors

June 2009 TED run – VELO halves separation



- Detector halves separated by 2.000mm and then moved to 2.450mm, i.e. Δx = 450 μm
- Analysis based on only 1000 tracks determined the relative distance between the detector halves to be Δx = 445 ±10 μm !

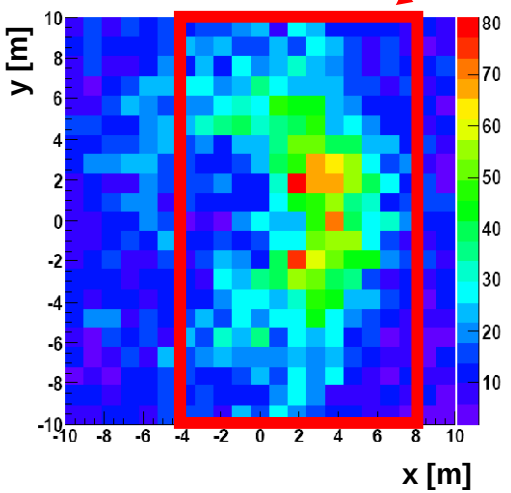
June 2009 TED run – resolutions

- **Selecting 'high-p' tracks: selecting particles coming from the TED region**
  - x(-4 m, 8 m) and y(-10 m, 10 m) at z=350m
  - Mean θ : 16 mrad (θ <35 mrad)
  - 85%-90% 1-strip clusters

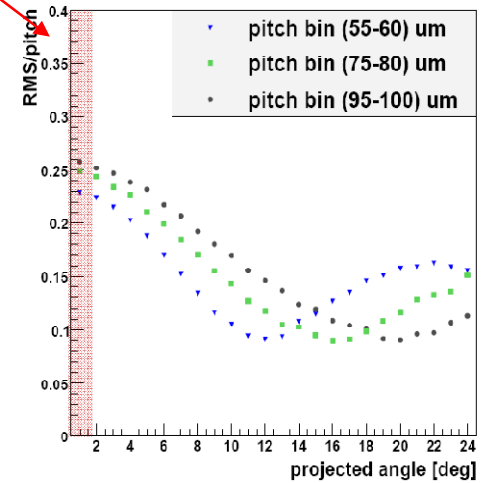
⇒ binary resolution expected

TED selected tracks

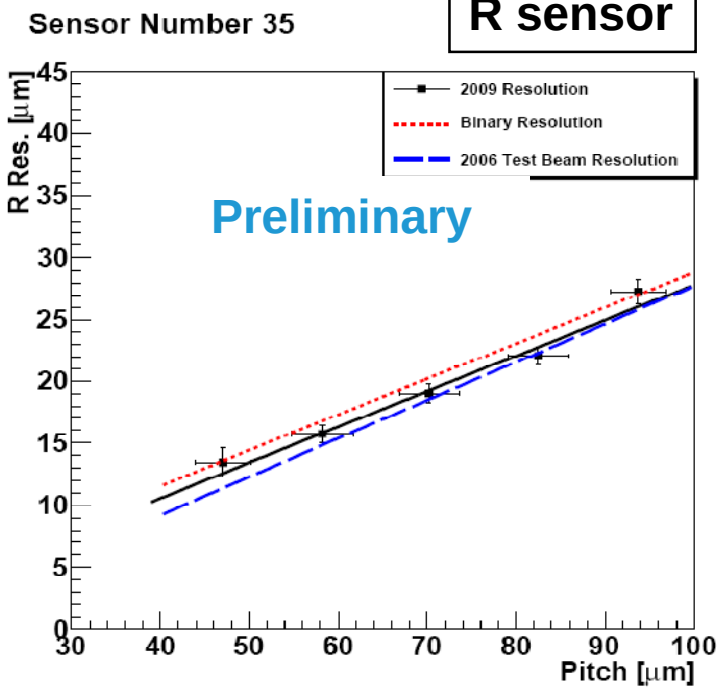
Extrapolation to the TED



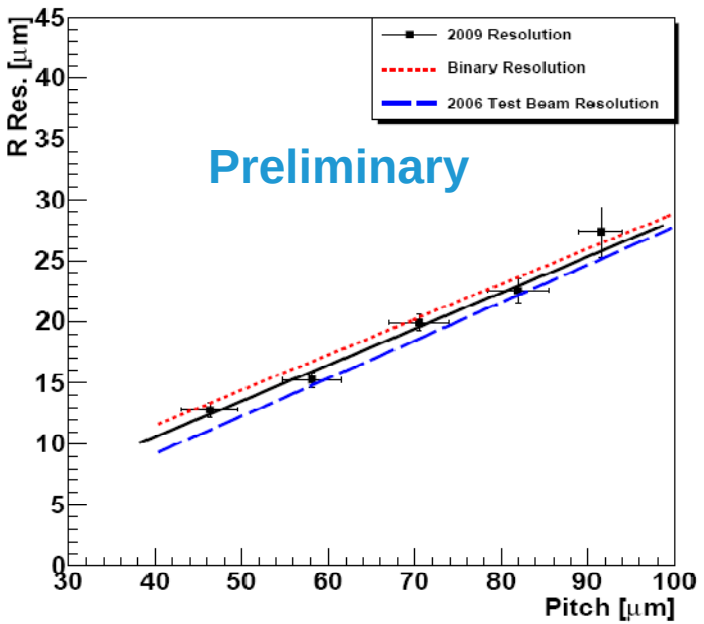
Expected resolution versus projected angle



R sensor



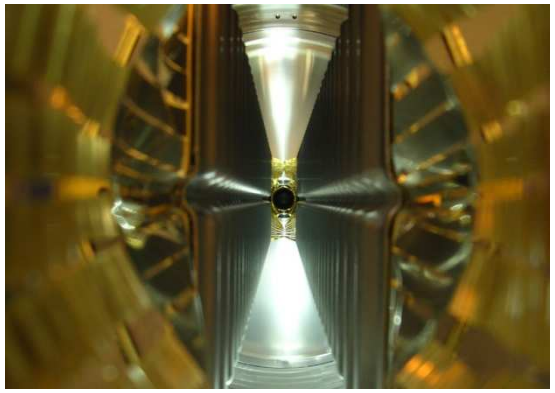
Φ sensor



Conclusions and Outlook

- VELO fully installed and tested
- First operation of full VELO back in June 2008
- First ever beam-induced tracks seen in August 2008
- Very successful commissioning with ~60000 tracks reconstructed
- Obtained resolution ~10μm and alignment better than 10μm
- Required performance for physics has been achieved

VELO ready for when the LHC beam will see



when traversing it !