Status and prospects of the LHCb Vertex Locator

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On behalf of the LHCb VELO group

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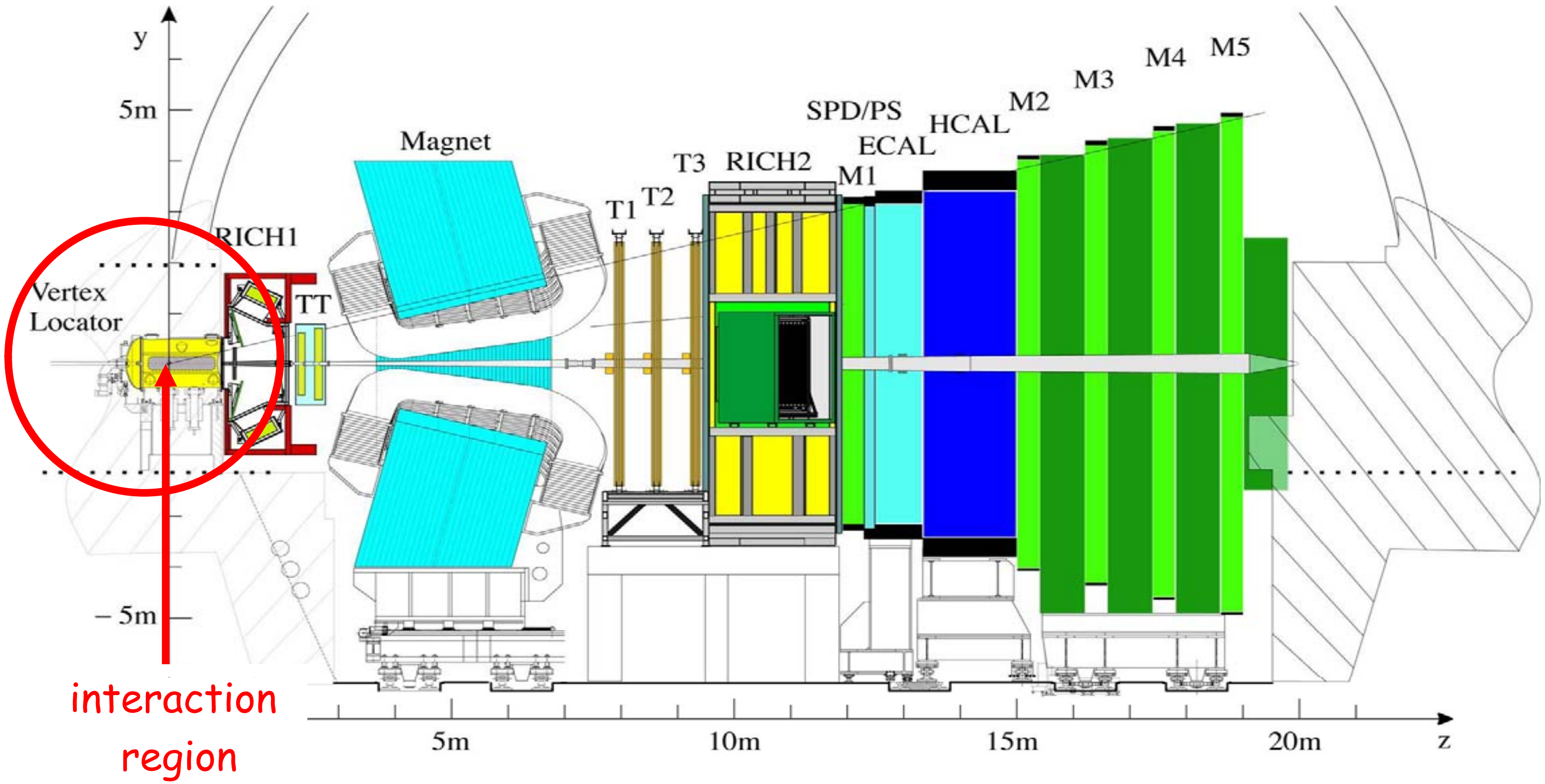
Outline:

- Introduction to LHCb and VErtex LOcator (VELO)
- Status of VELO
  - Positioning, vacuum, cooling system (this presentation)
  - Silicon modules (Tony Affolder's presentation)
- Beamtest @ CERN
- Upgrades
- Summary

LHCb overview



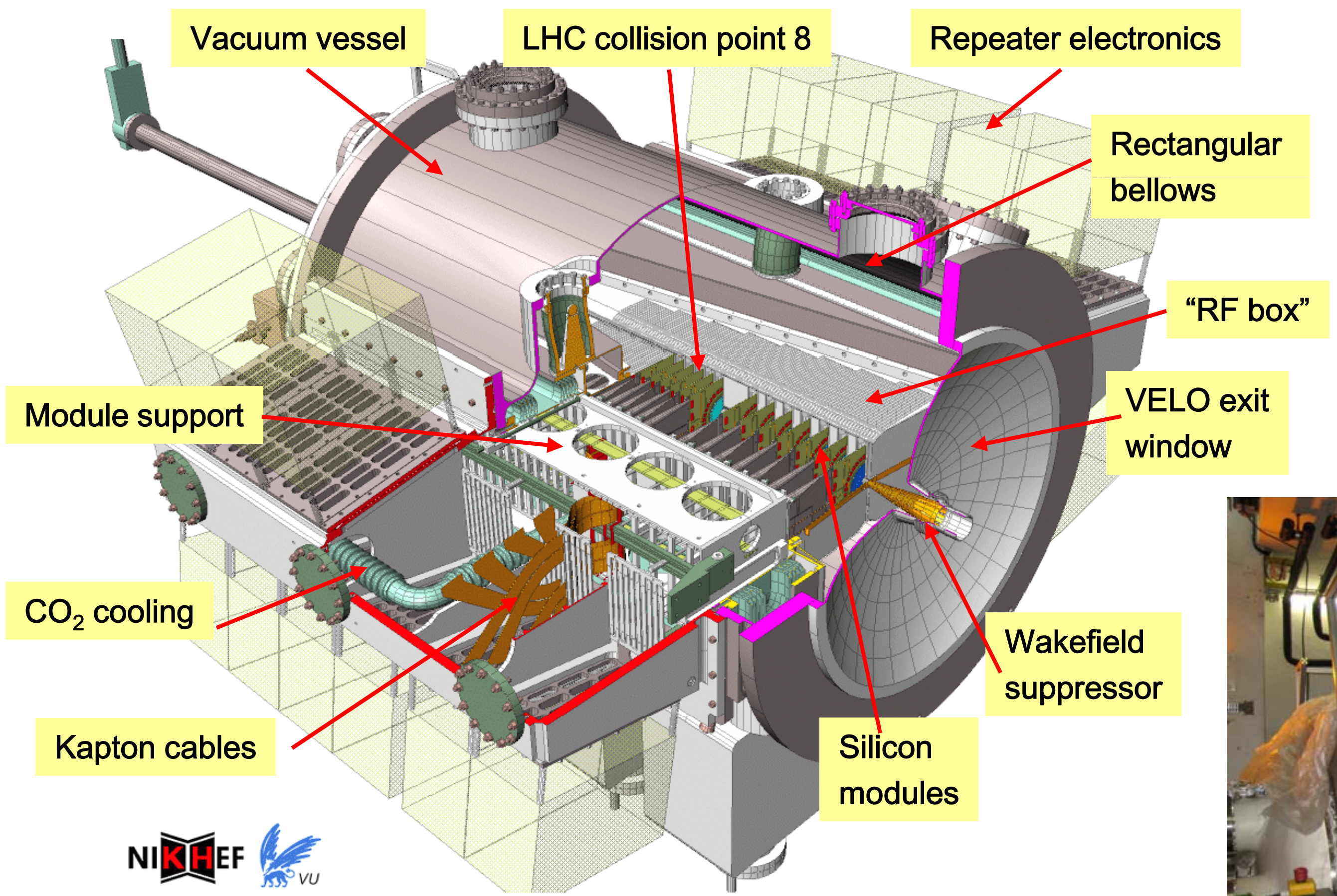
Large Hadron Collider

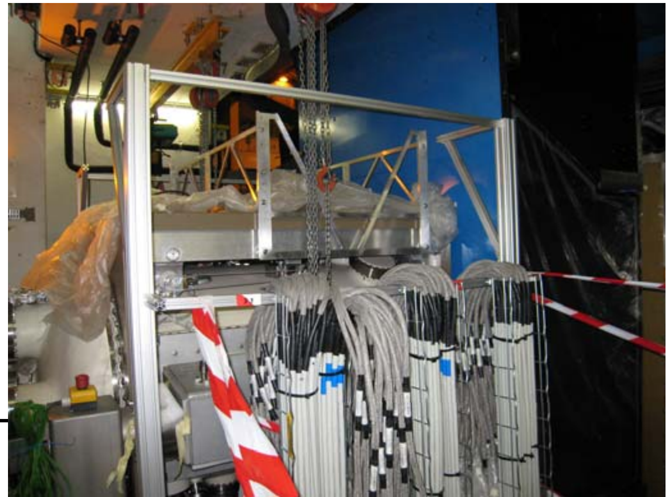
- pp collisions: $\sqrt{s}$ = 14 TeV
- bunch crossing every 25 ns

LHCb

- Studies physics of b-flavoured hadrons (CP violation)
- B-hadrons produced at small angles
  - -> Single arm forward spectrometer
- 10 – 300 (250) mrad in bending plane (non bend.)
- Luminosity $2 \cdot 10^{32}$ cm^{-2} s^{-1}

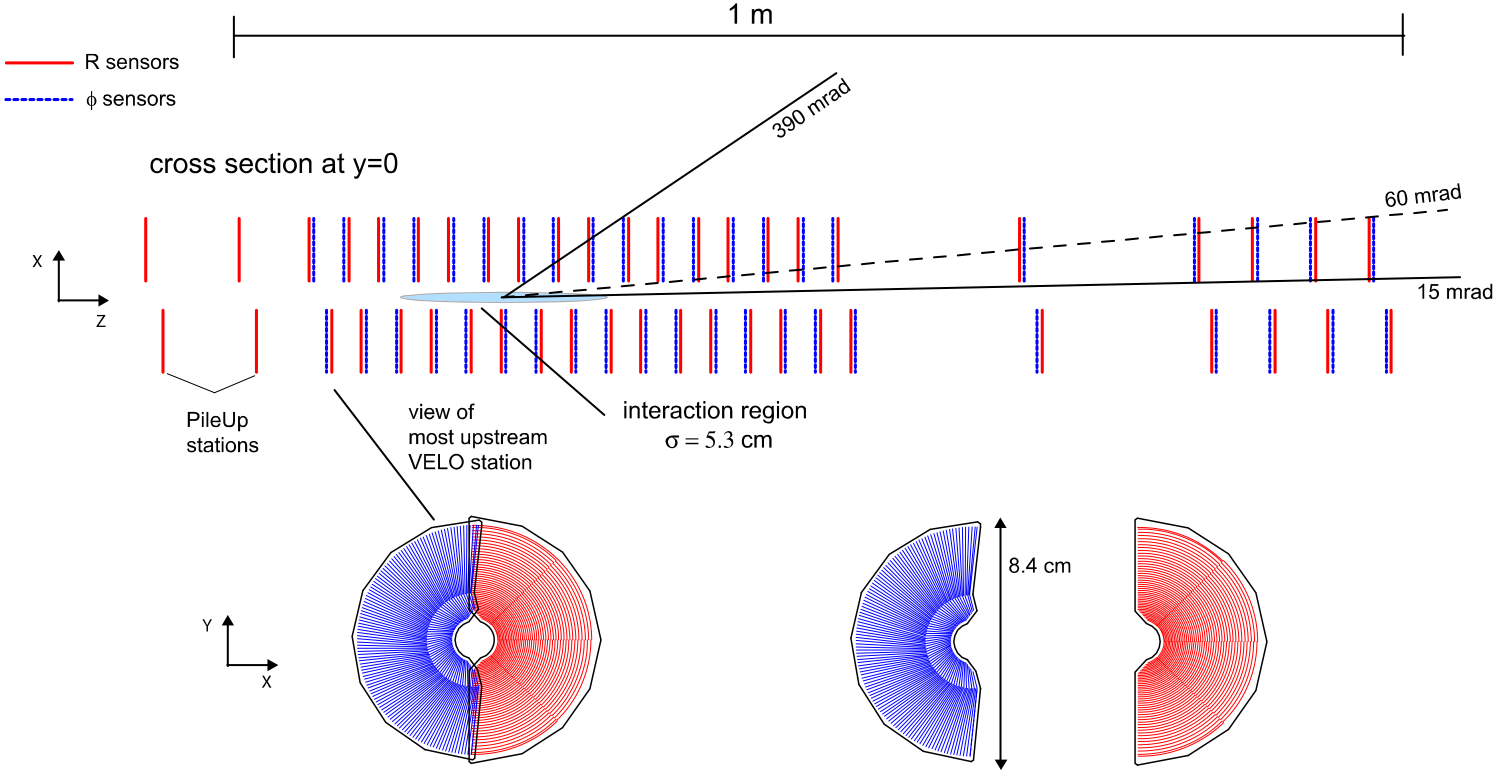
Vertex Locator





- 2 retractable detector halves with
- 21 silicon microstrip modules / side + 2 PileUp trigger modules
  - Each module has R and ϕ strip geometry
- Silicon modules in secondary vacuum inside so-called RF-box

Vertex Locator cross section

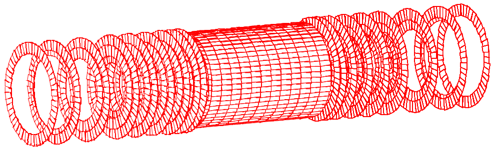
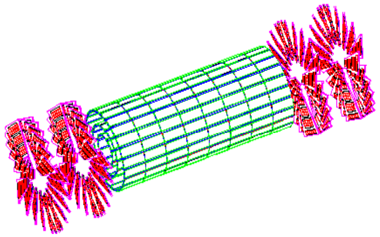
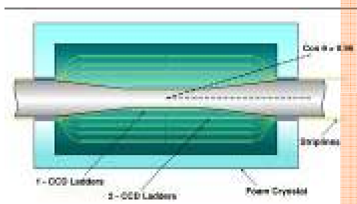
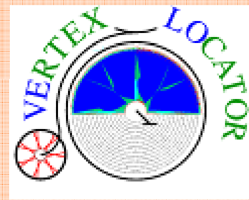


VELO fully closed (stable beam)

VELO fully open

- 2 retractable detector halves, range 35 mm each
  - allow for beam injection/ramping
  - correct for fill to fill beam position variation (max 5 mm)
- Overlapping sensors when fully closed
- Innermost strip only 8.2 mm from beam

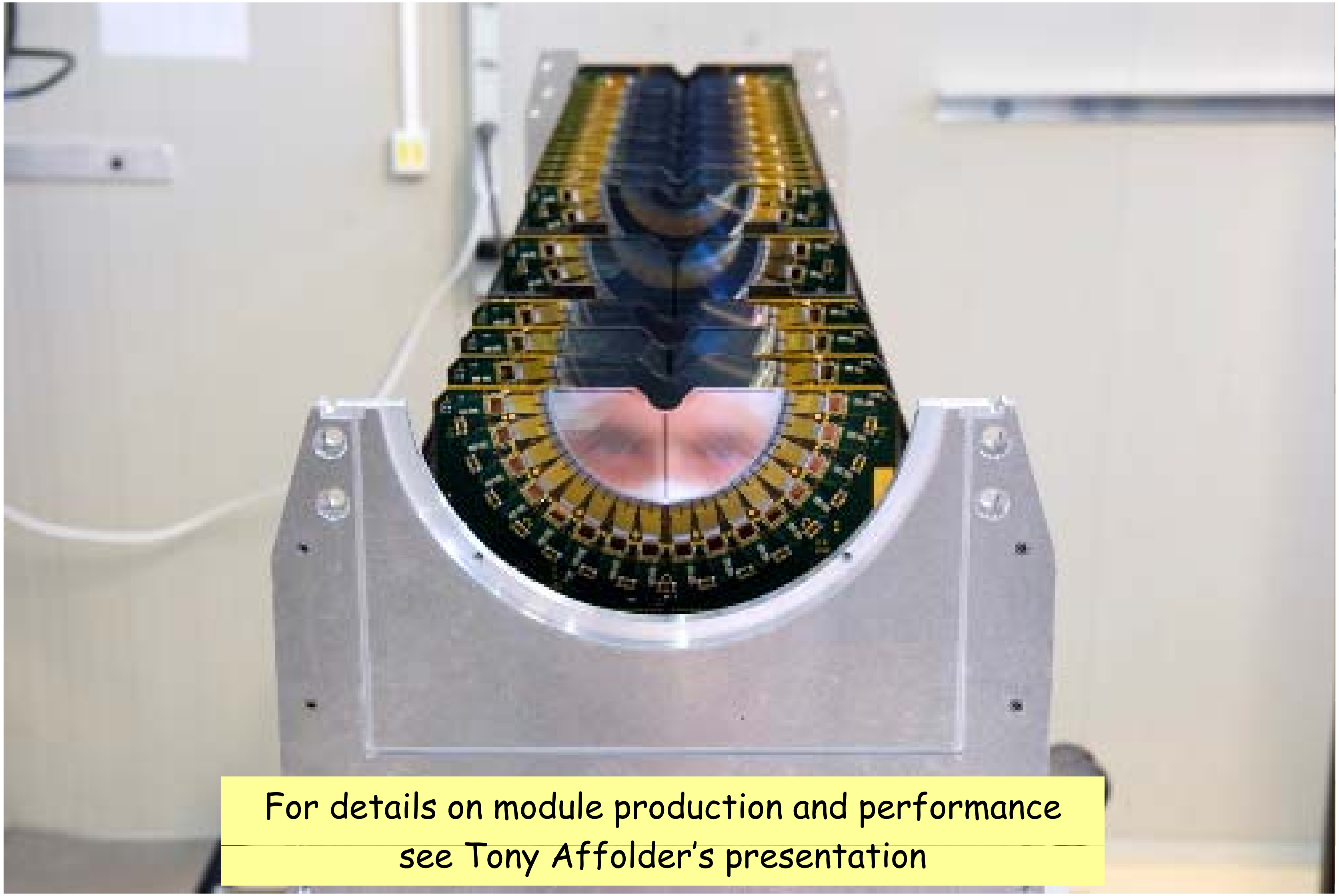
A very brief comparison

	ATLAS SCT strips	CMS Pixels	ILC CCD	LHCb VELO
Area (m^2)	60	2	0.3	0.3
Chann. (10^6)	6	33	800	0.2
Trigger	No	No	N/A	Yes!
Precision (um)	20	12	4	5
Beam at (cm)	30	4	1.5	0.8
Dose ($10^{14}\ n_{eq}\ yr^{-1}\ cm^{-2}$)	0.2	3.0	0.01	1.3

=> VELO: small, yes, but … high precision at high fluence!

The actual detector



For details on module production and performance
see Tony Affolder's presentation

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  - Silicon modules
- Beamtests
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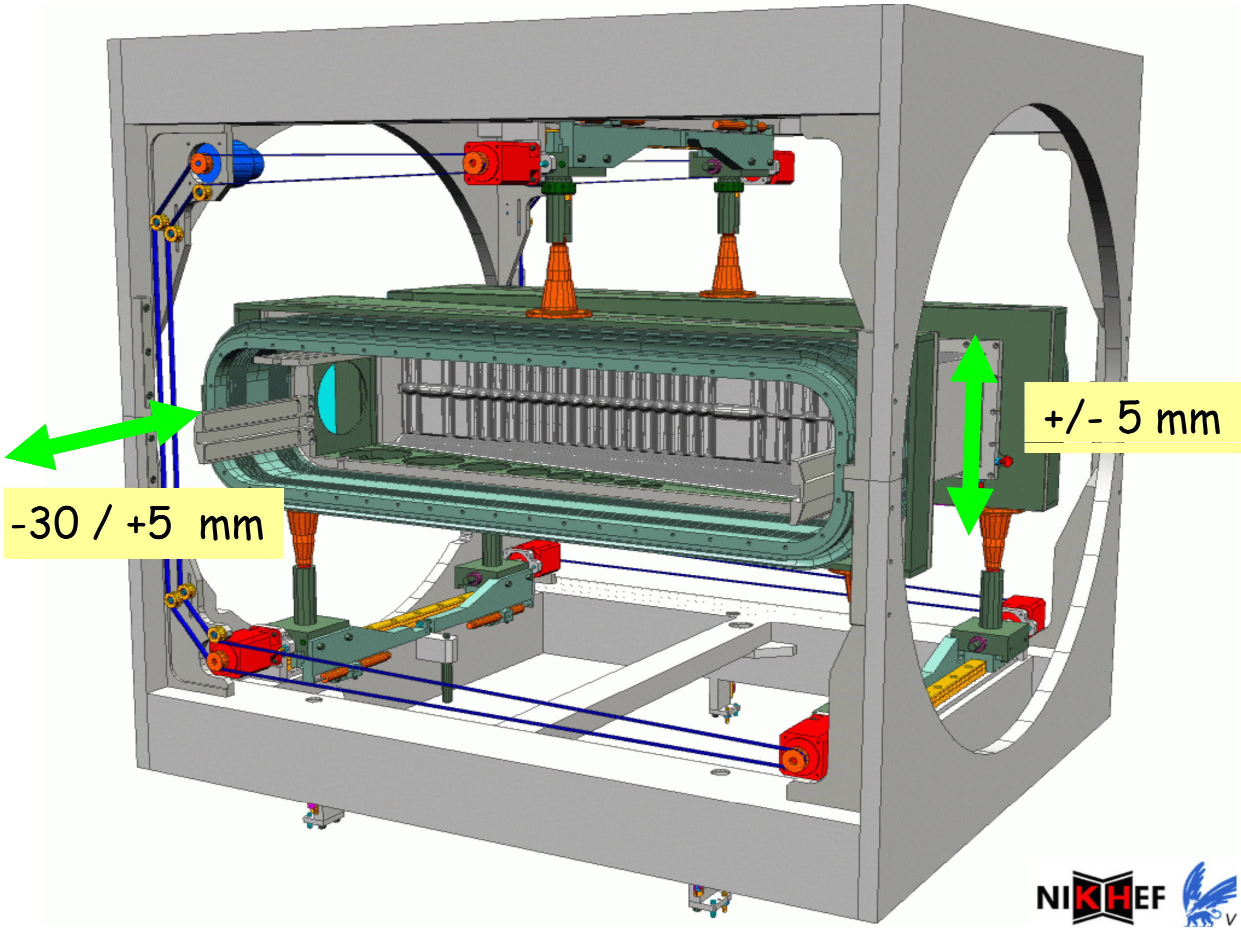
Positioning system



- Move out detector during filling and ramping of beam
- Vertical movement common for both halves
- Left/right independent

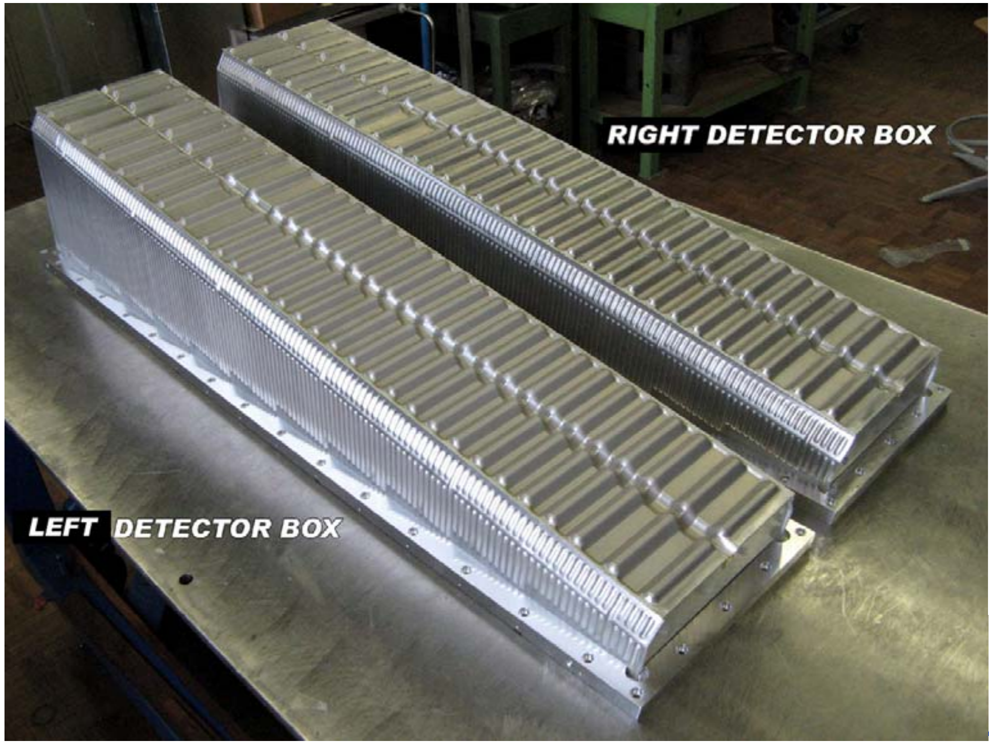
- Radhard stepper motors + gear boxes
- Radhard resolvers for position verification
- Potentiometers for coarse absolute position readout
- Movement controlled by PLC + safety end-switches

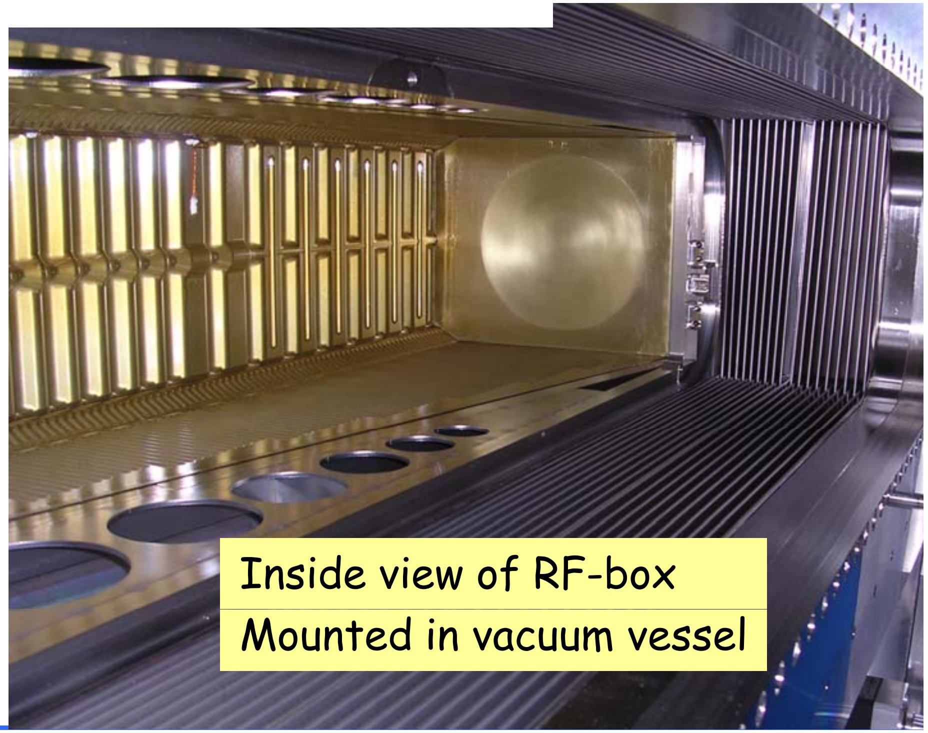
- The reproducibility is ≤10 μm (limited by probe/setup)

Positioning system

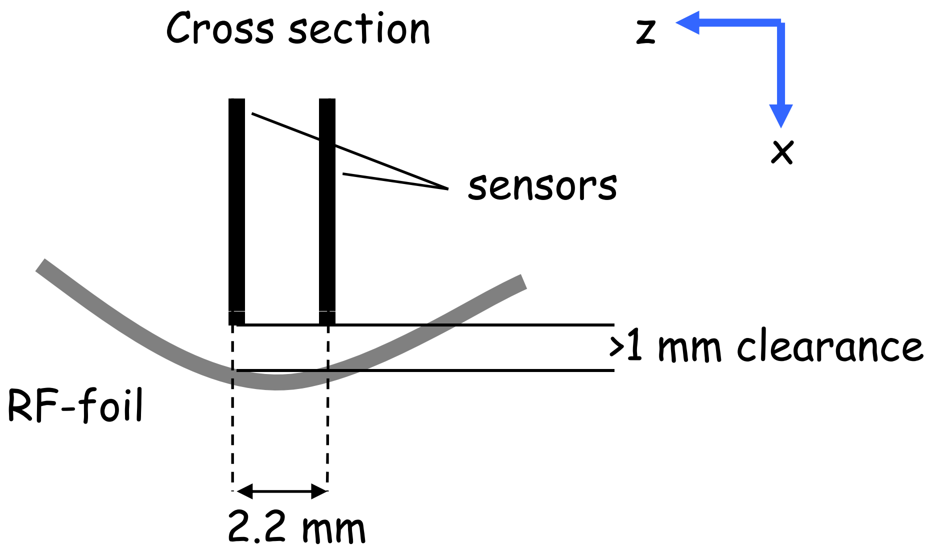
RF box

- Modules separated from beam vacuum by 300 μm AlMg3 foil (RF box)
  - Foil shape allows for overlapping sensors (eases alignment)
  - Large area, 100 x 20 cm
  - Maximum allowed pressure difference 10 mbar (= 20 kilos!)
  - Huge engineering effort
  - Shield against beam induced EMI
  - Wakefield suppressor to adapt to beam pipe diameter

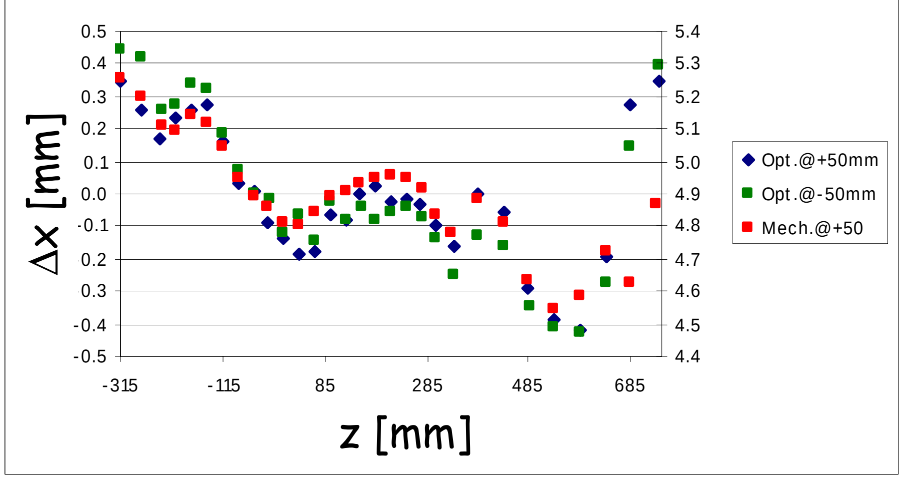




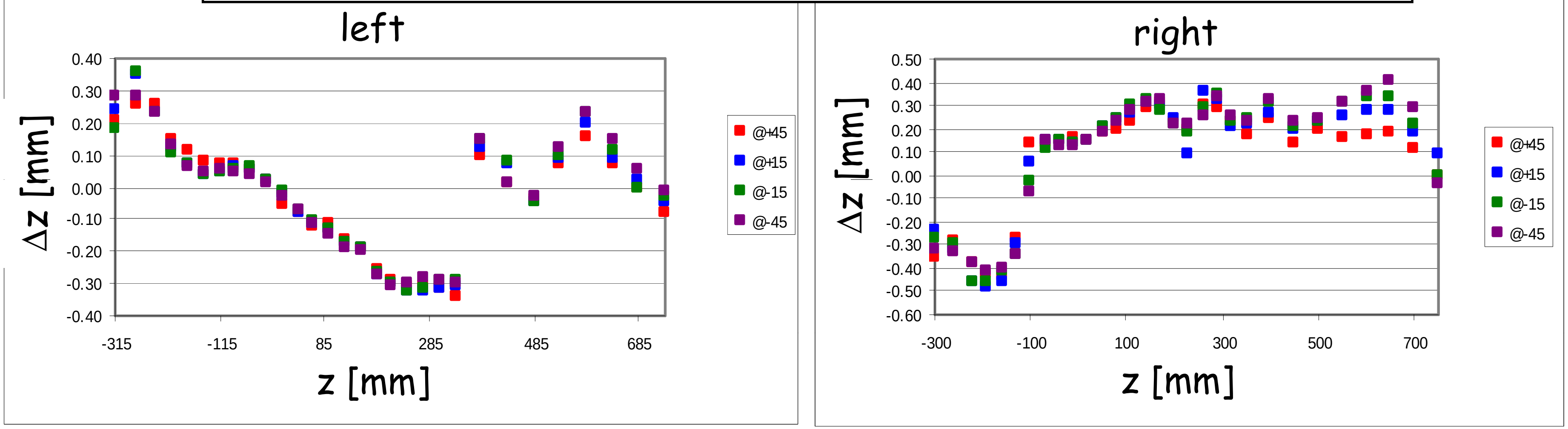
Metrology of RF boxes



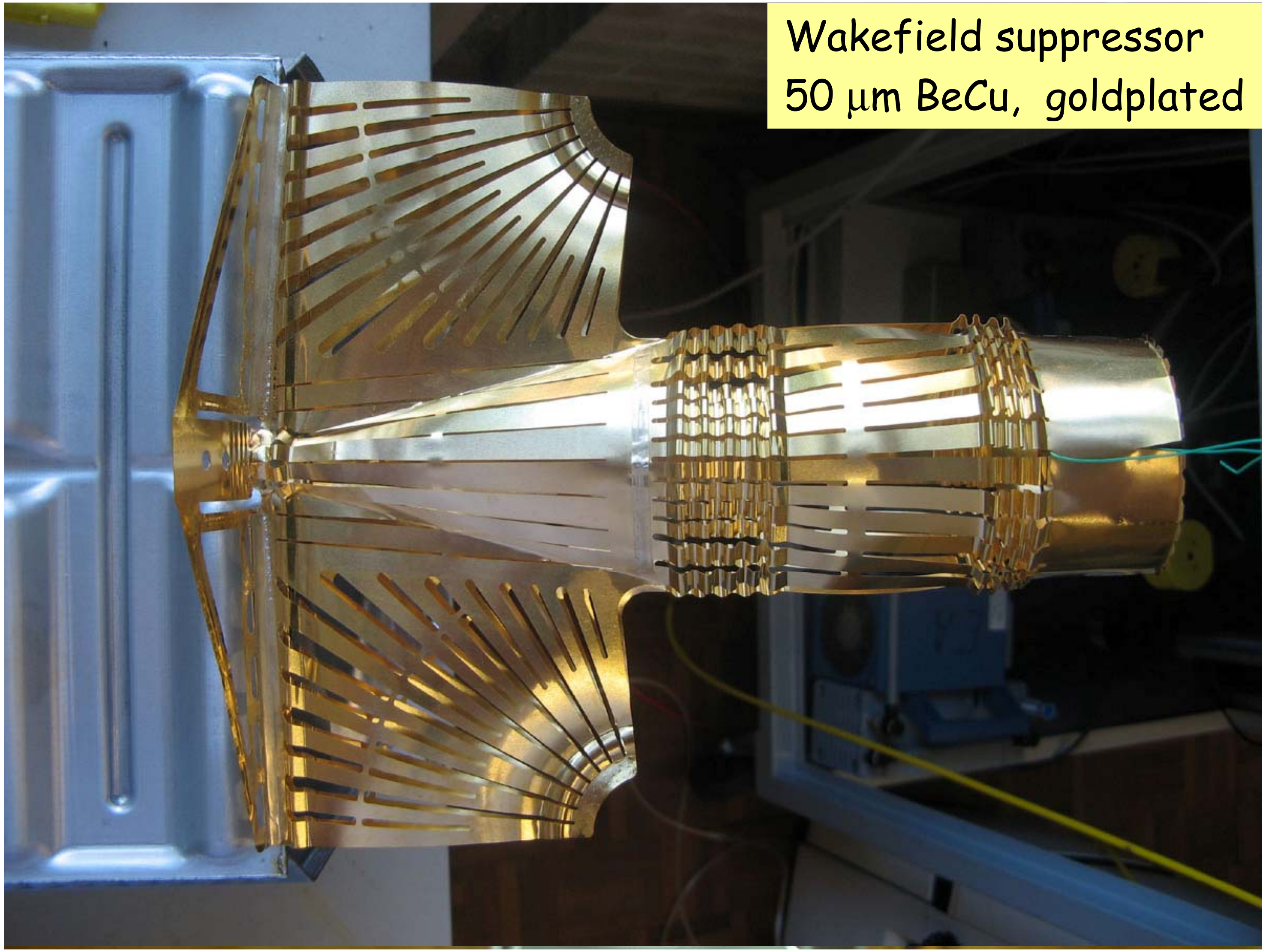
Height offset of slot w.r.t. nominal (1 mm)



z-offset of slot w.r.t. nominal position

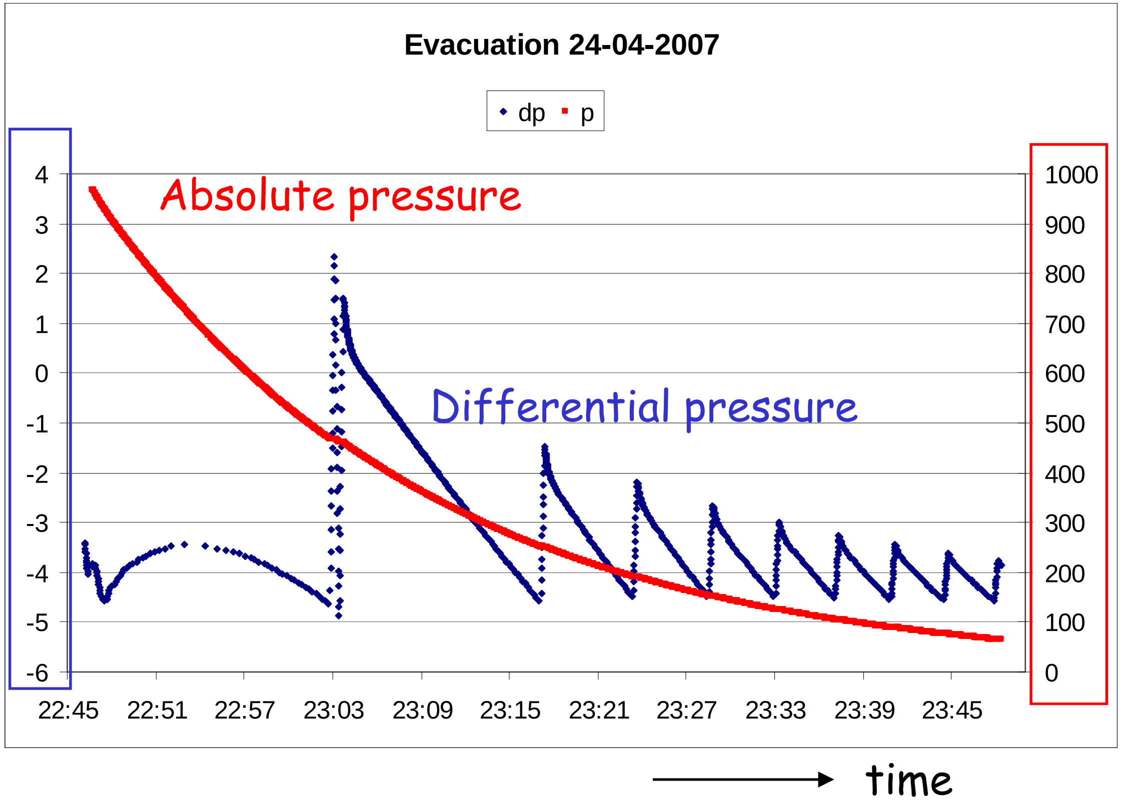


View from the beam



Wakefield suppressor
50 μm BeCu, goldplated

Vacuum performance



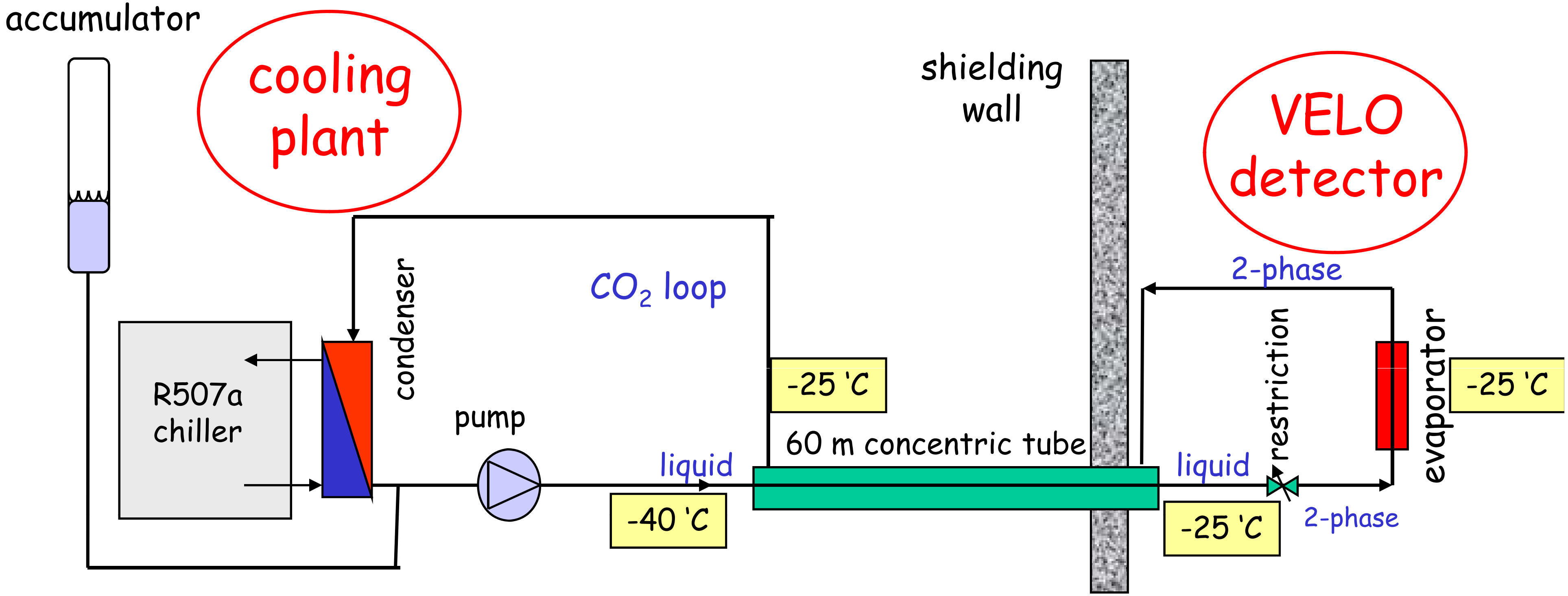
- Differential pressure between beam and detector vacuum must be always < 10 mbar
- Diff. pressure < 5 mbar controlled by PLC during pump down/venting
- Extra mechanical safety valve if diff. pressure > 7mbar

- Absolute pressure of primary (beam) vacuum after bake out: 3.5×10^{-10} mbar (requirement < 10^{-8} mbar)
- Expected secondary (detector) vacuum < 10^{-4} mbar

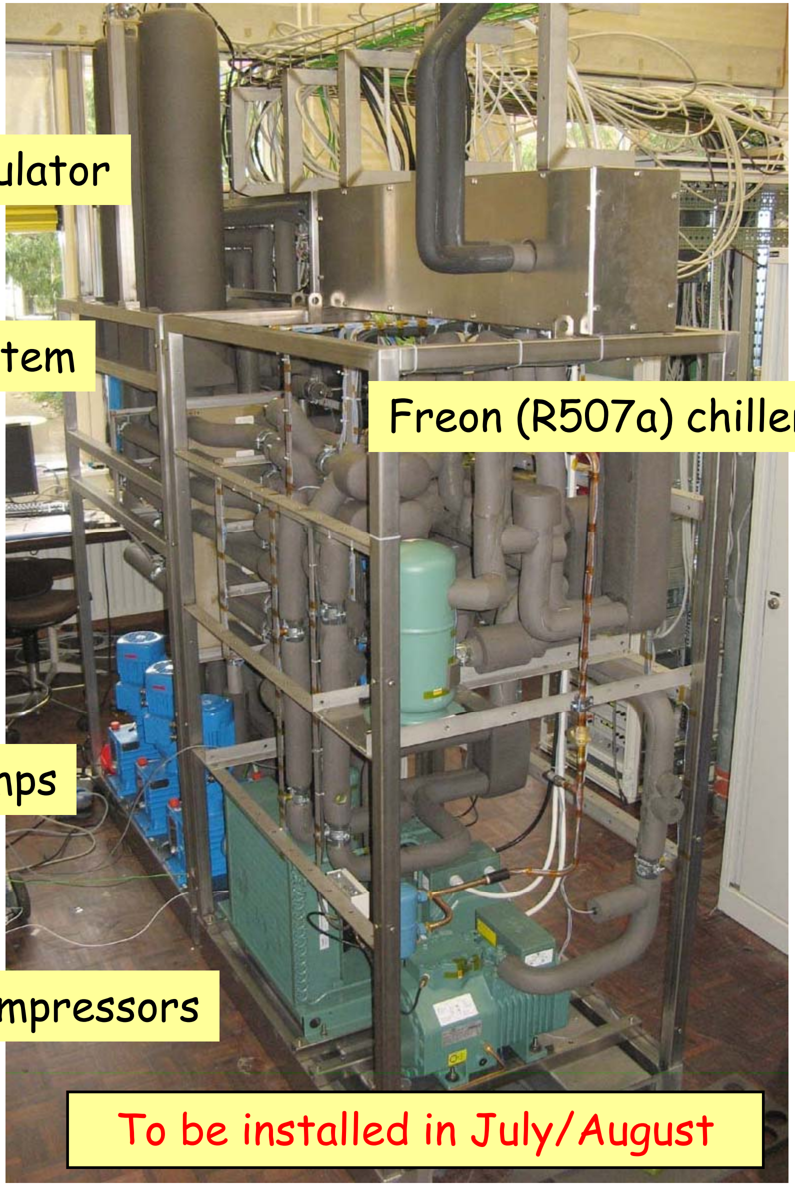
CO_2 cooling system

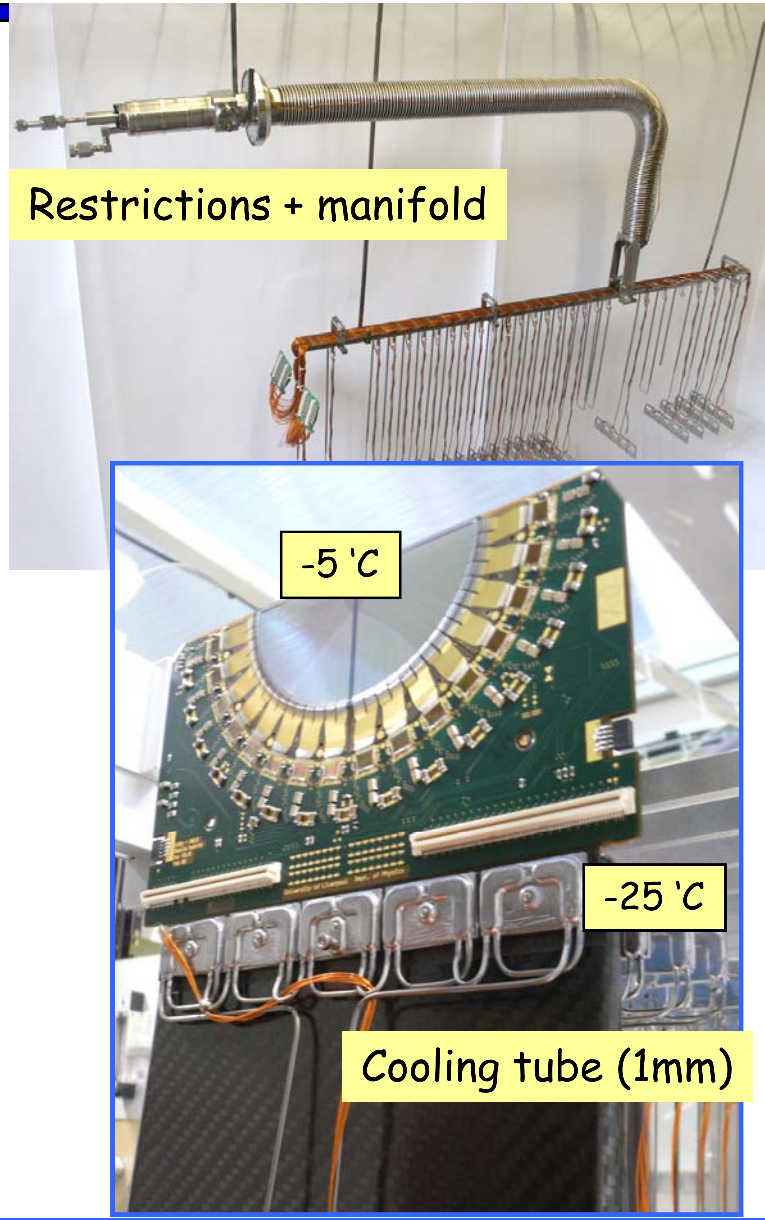
- Total power of electronics in vacuum ~1.5 kW
- Sensor must always be kept at < -5 'C (reverse annealing)
- 2-phase CO_2 cooling system
  - Low mass
  - Radiation hard
  - Redundant / backup system

- Only passive components in radiation area
- Detector temperature (evaporator) is controlled by pressure in accumulator
- Isothermal because of liquid-vapor mixture



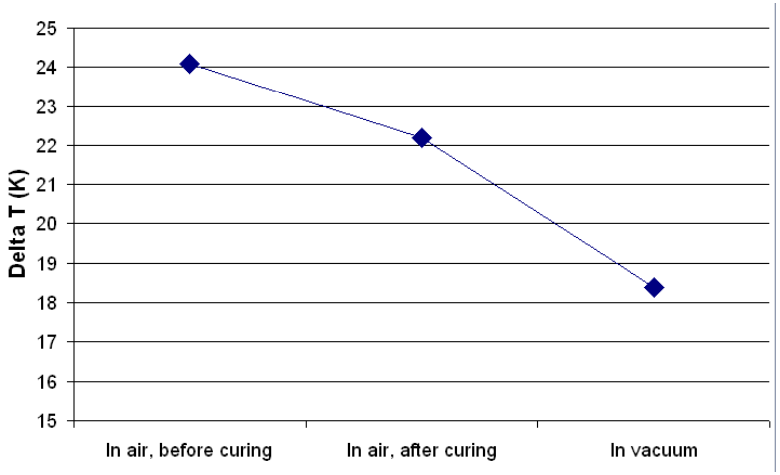
CO_2 cooling system



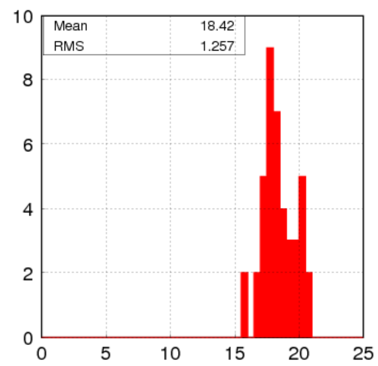


Thermal Performance

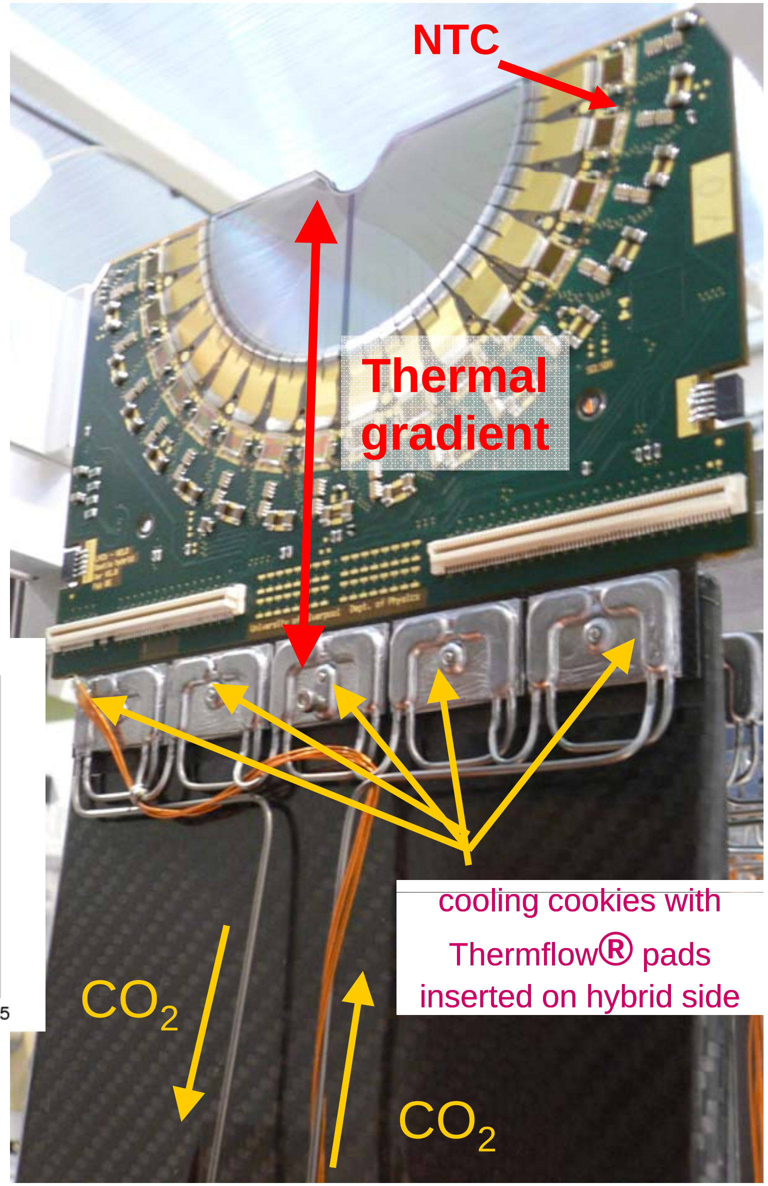
- Thermal gradient is defined between cooling cookies and silicon centre (most irradiated part)
- Pads of Thermflow®: a phase change thermal interface material, are applied between the cookies and the hybrid, and the cookie screws are tightened to 25 N cm. The cookies are then cured at 47°C for 10 minutes
- The thermal performance is checked first in air and finally in vacuum, by reading out an NTC (Negative Temperature Coefficient Thermistor) close to the silicon, which is known to be about 2 degrees cooler than the silicon itself.
- The final temperature gradient achieved at the silicon is approximately 20°C when cooling a single module. When multiple modules are cooled this is expected to improved by 2-3 degrees, putting the cooling performance comfortably within specifications.



Influence of Thermflow and vacuum



ΔT cookie-NTC, all modules



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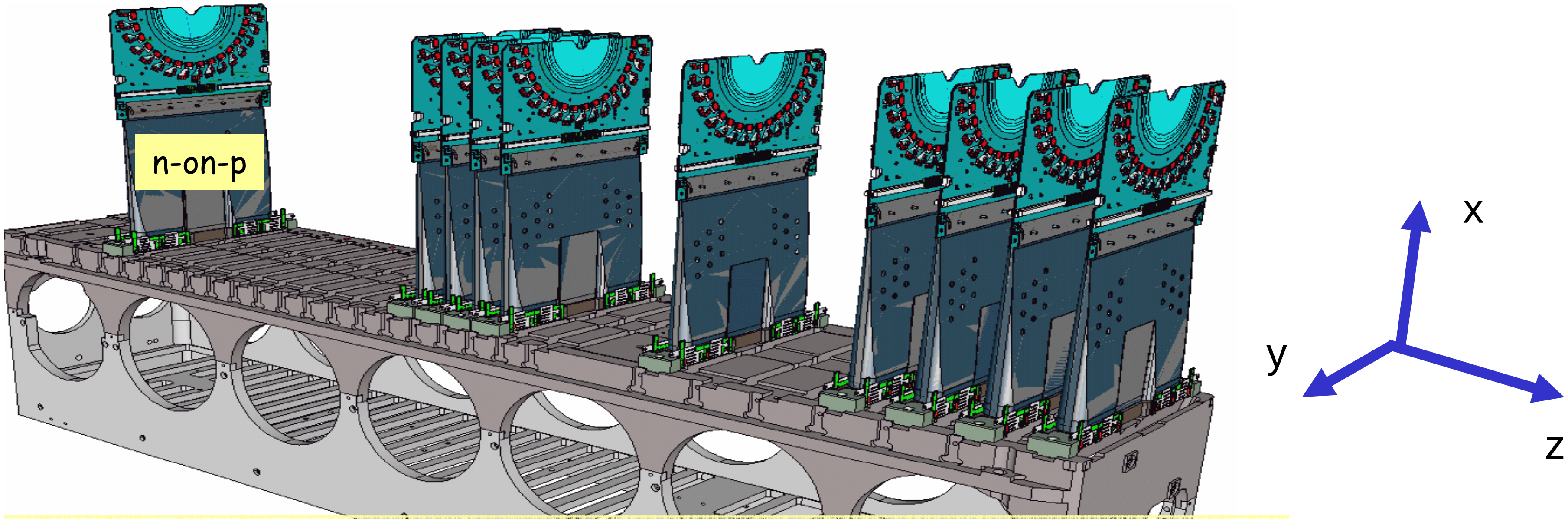
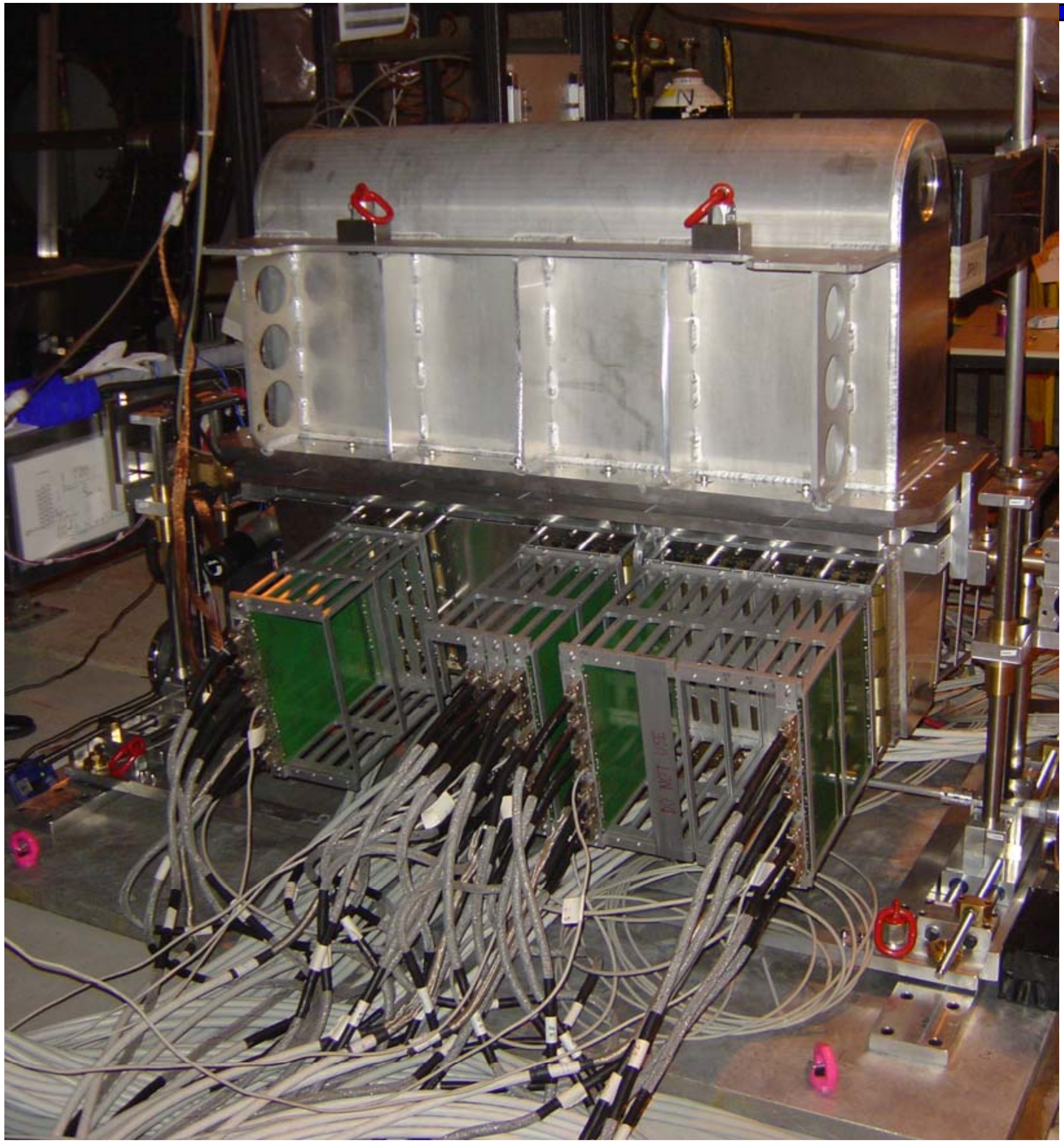
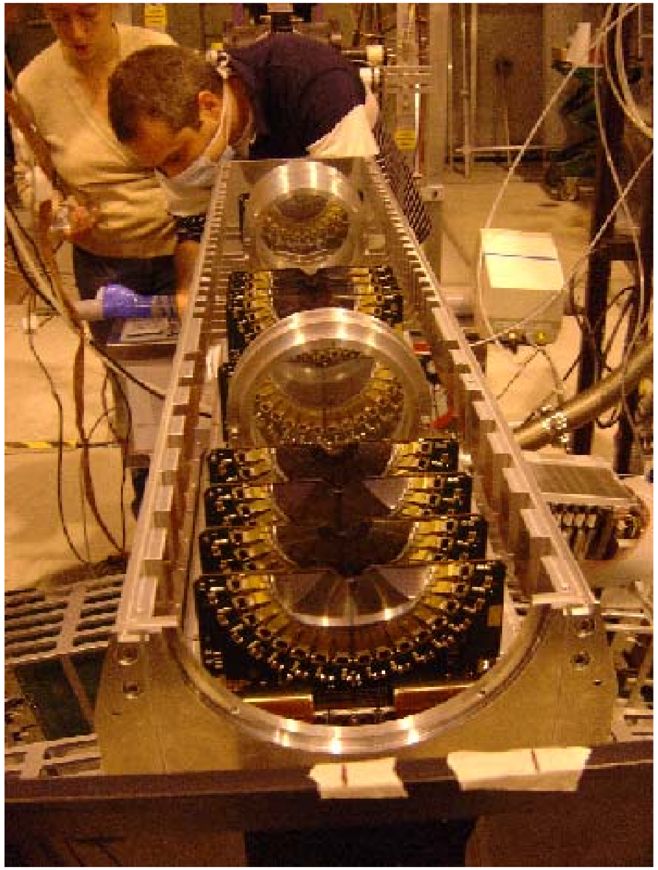
Beamtest configuration



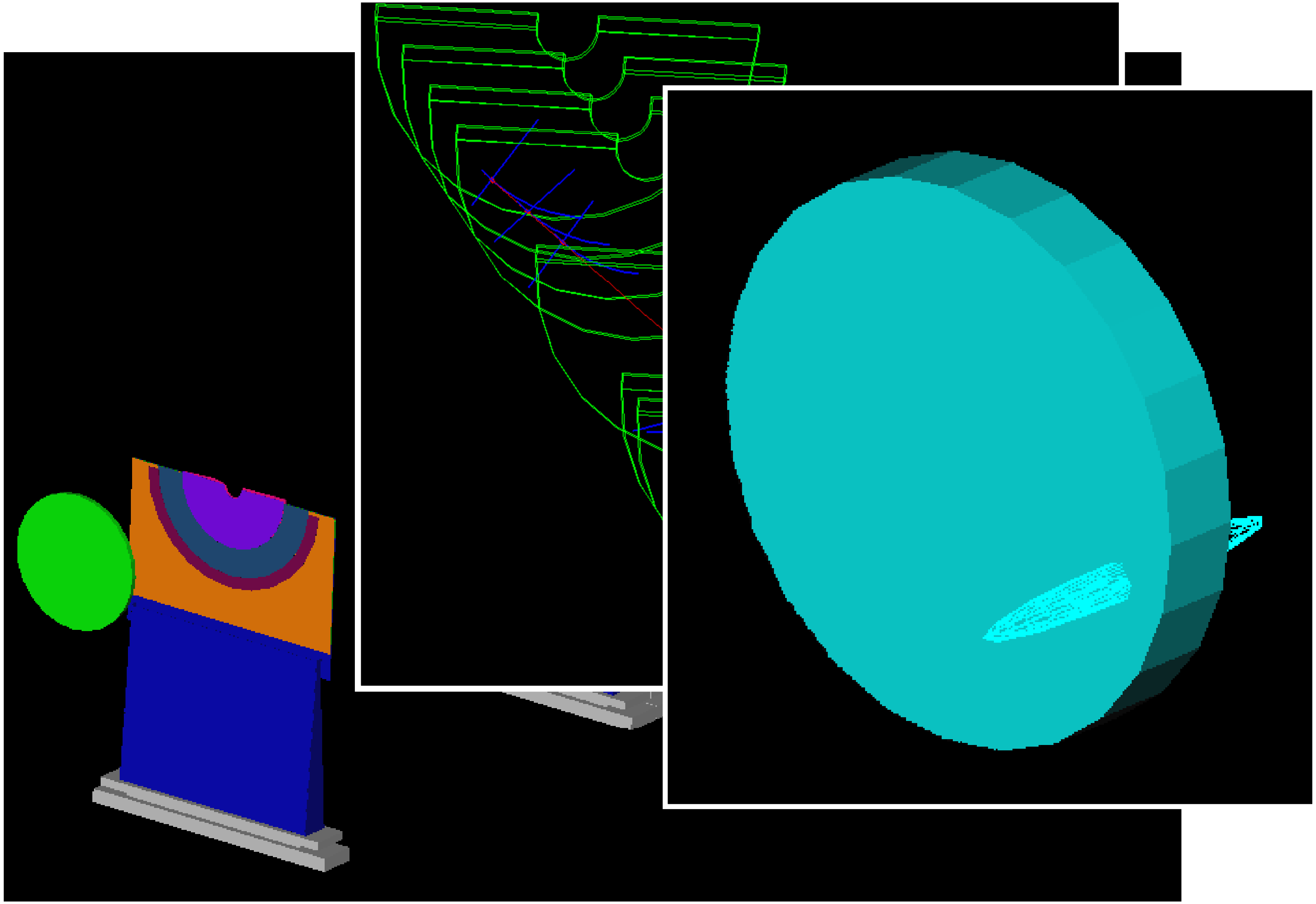
- 9 n-on-n production-type modules + 1 n-on-p prototype
- 6 modules readout simultaneously
  - Full readout chain with final electronics boards
- Software: DAQ, ECS, tracking, vertexing, online monitoring
- Small scale CO_2 cooling system
- 180 GeV π / p beam
- Data for 0, 4 and 8 degrees, and target data
- >50 Mevents to disk

Testbeam setup



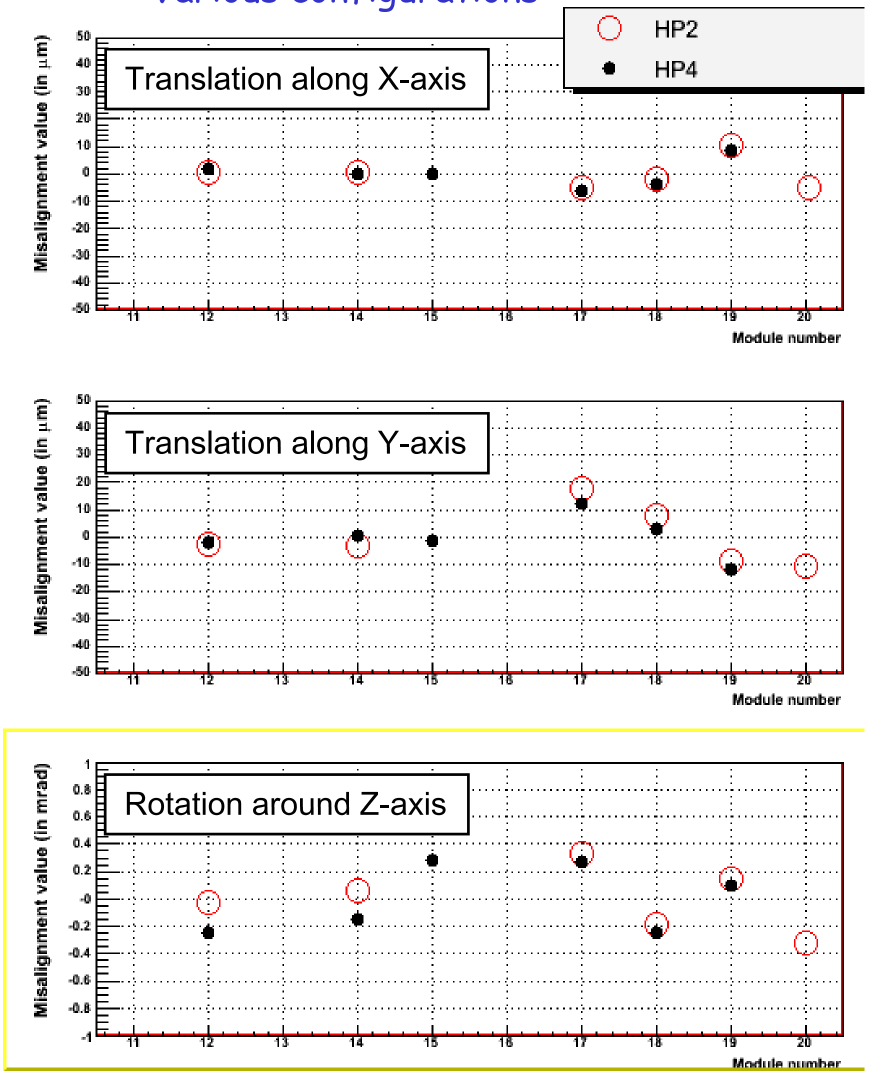


An event visualized



Alignment

Misalignment parameters for
Various configurations



Step1: internal alignment

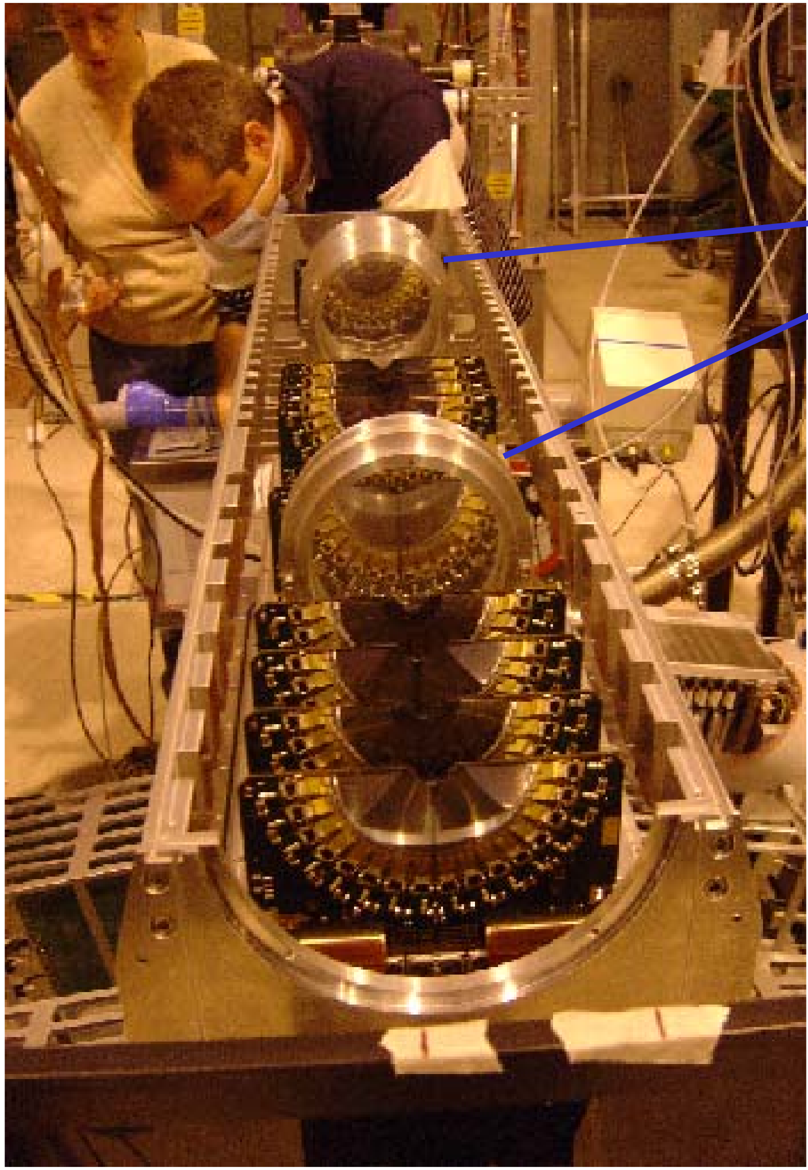
- Relative within detector half
- Tracks from halo, beamgas interactions
- Use metrology data as starting point
- Successfully tested on 2006 testbeam data

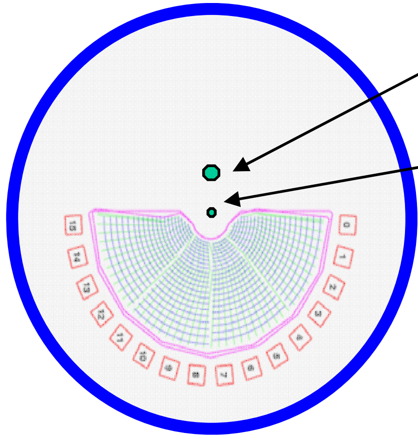
Step2: box alignment

- Detector halves w.r.t. each other and beam
- Using primary vertices and overlapping tracks
- Tested on MC

During testbeam the detector was moved, rotated, cooled etc. Alignment stays virtually the same

Target runs



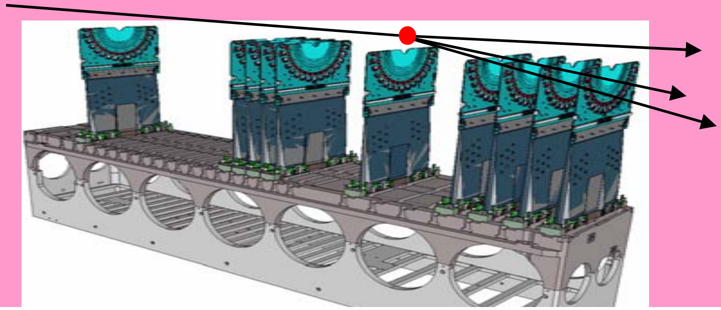


- 8 Pb targets
- Interaction data
  - test tracking and vertex reconstruction
- Emulate open and closed VELO

vertex reconstruction

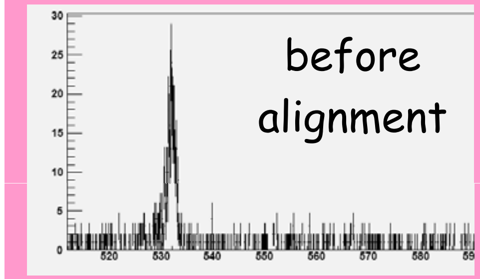
Using testbeam data we searched for interactions

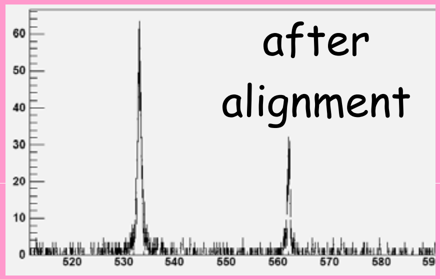
•In the targets



Simulates how we will reconstruct the beam position before moving the VELO

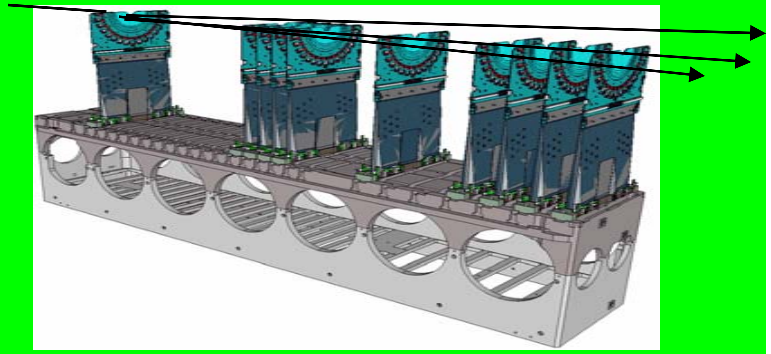
vertices reconstructed as a function of z

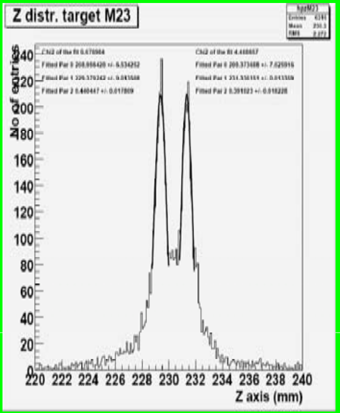


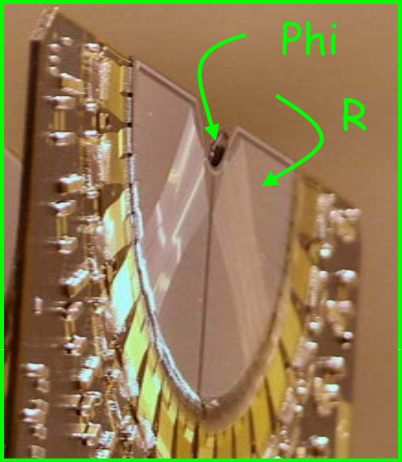


successful alignment and pattern recognition

•In the silicon modules themselves







R and Phi sensors clearly separated

The resolutions and efficiencies are different to that expected in LHCb (lower energy, less tracks) but compatible with MC predictions for this setup

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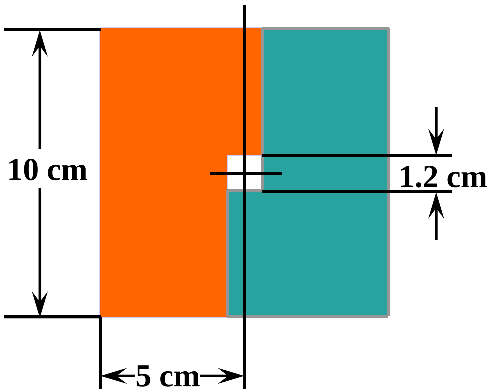
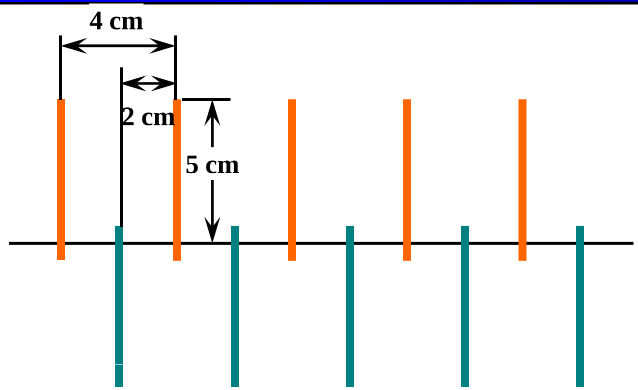
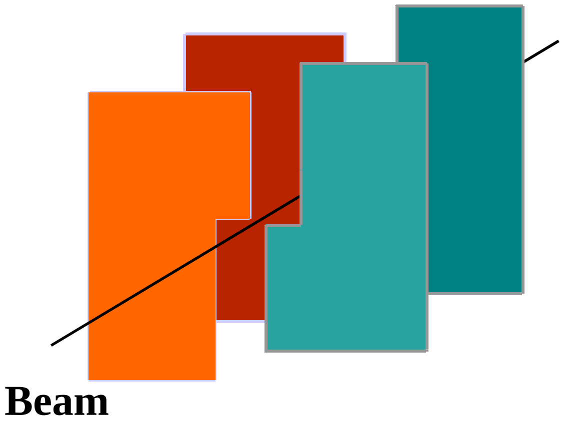
Upgrade

- Plans for running at 10x higher luminosity (also possible with SLHC)
- + Readout complete LHCb detector at every bunch crossing
  - Large parts of the LCHb front-end electronics must be replaced
  - Long R&D time (> 5 years)
- Harsh radiation environment will limit the lifetime of the VELO
  - Useful lifetime at least 3 years at nominal luminosity (2 fb^{-1} / year)
- Short term plan: build replacement VELO with n-on-p instead of n-on-n sensors
  - N-on-p sensors are more radiation hard
  - Performance shown in November 2006 beam test
  - All tooling / experience available, hence relatively short production time
- Long term plan: completely new VELO design
  - Cope with increased radiation (factor of 10)
  - Pixels instead of strips?
  - Fast readout
  - Investigations by different groups along different lines

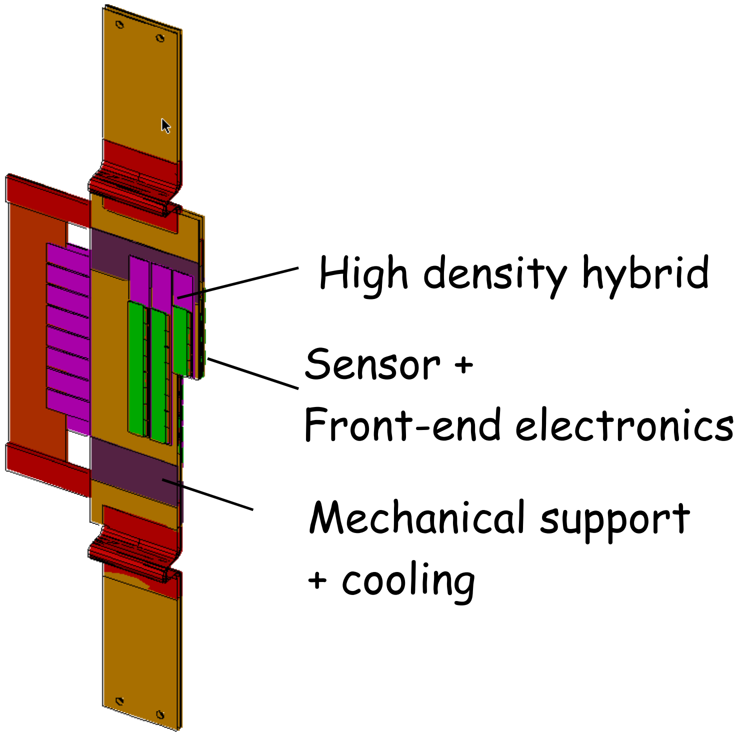
Option: Pixel telescope



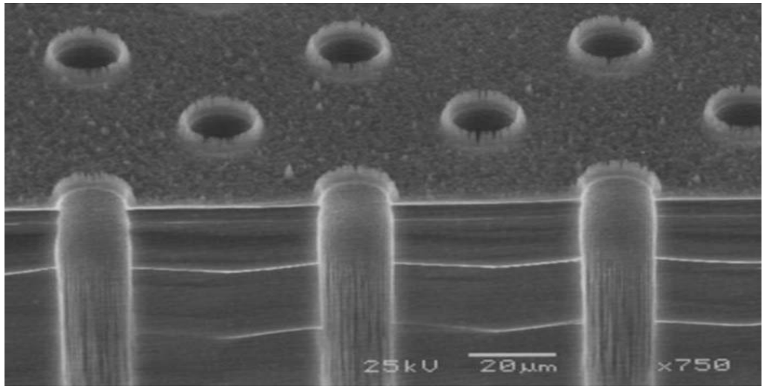


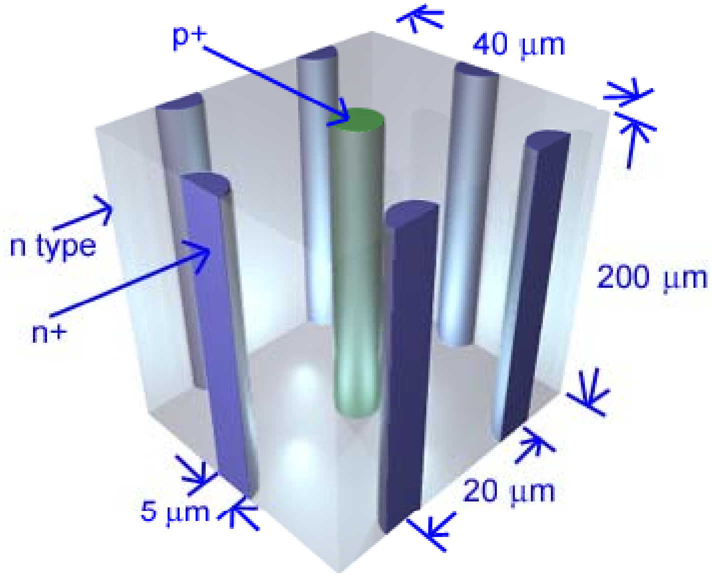


- Profit from BTeV experience
- Beam test at FNAL fall 2007
  - Infrastructure: Pixel telescope available



Option: 3D silicon





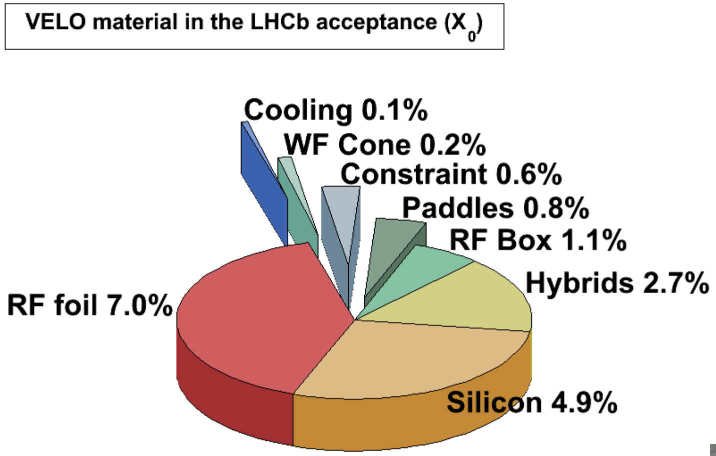
Advantage

- Extremely radiation hard
- Drift field independent of sensor thickness
- Low bias voltage
- Little dead area on edge -> tiling

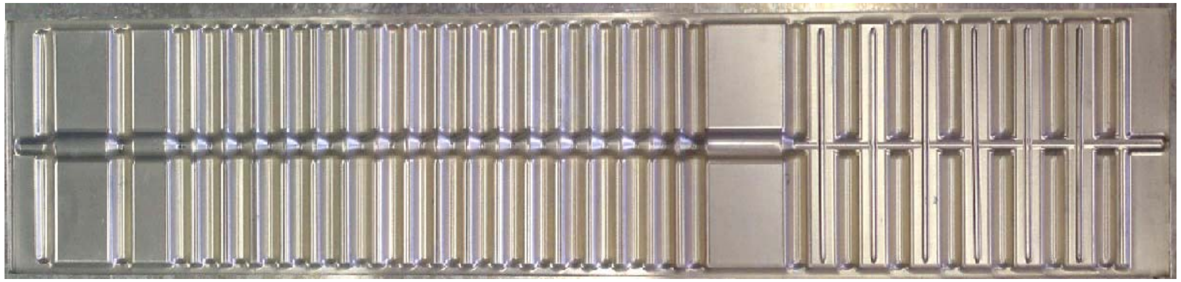
Disadvantage

- Complex processing

Upgrade: reduce material in VELO



- Radiation length of total VELO: ~18 % X_0
- Largest contribution from RF-foil and sensors
- Thin sensors (200 μm) already tested extensively
- Thinner RF-foil is under investigation



- BTeV planned sensors in primary vacuum
  - Beam (mirror) current via wires/strips
  - Cryo pumping against outgassing
- Totem (@LHC)
  - 150 μm Inconel (Ni-Cr) foil 1 mm from beam

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Current status:

2 complete detector halves ready for installation

Vacuum + detector positioning system installed

Cooling system nearly finished

Electronics boards + cabling being installed

Working versions of DAQ, ECS, alignment, tracking, vertexing SW

Soon ready for full system commissioning and for collìsions

Beam tests:

Successful test of alignment, tracking & vertexing software

Dress rehearsal for detector commissioning

Upgrade:

Short term plan: build spare VELO with n-on-p modules

Long term plan: investigating various options like pixel telescope, 3D silicon. New readout electronics and thinner RF foil

The End