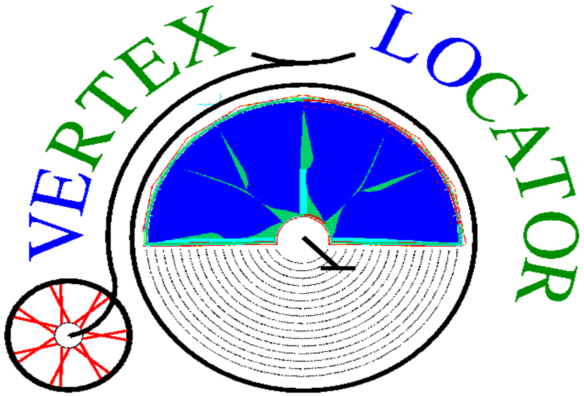
THE UNIVERSITY of LIVERPOOL

The LHCb Velo detector



A high precision silicon device for vertexing, tracking and triggering in LHCb.

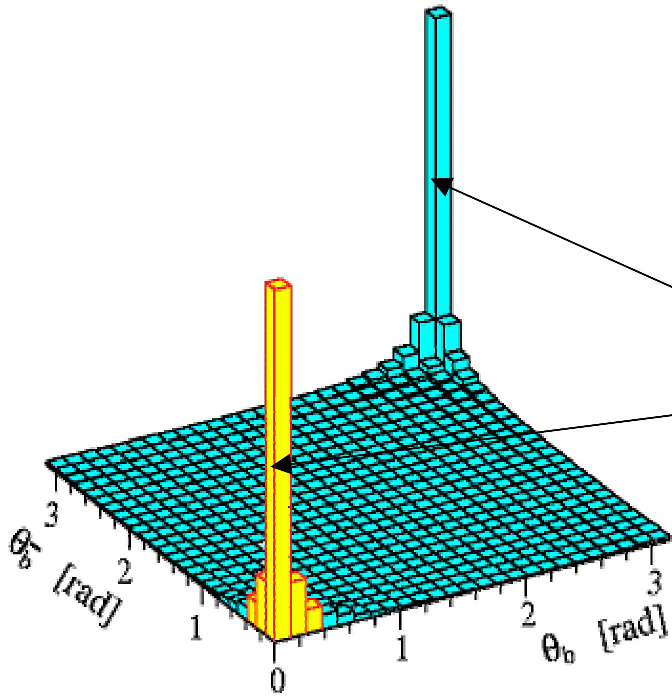
J.P. Palacios, University of Liverpool

Talk Overview

- The LHCb detector
  - Physics reach
  - General layout of components
- Velo Requirements
  - Physics
  - System and mechanical
- Velo Layout
- Silicon R&D
- Outlook
- Conclusions

THE UNIVERSITY of LIVERPOOL

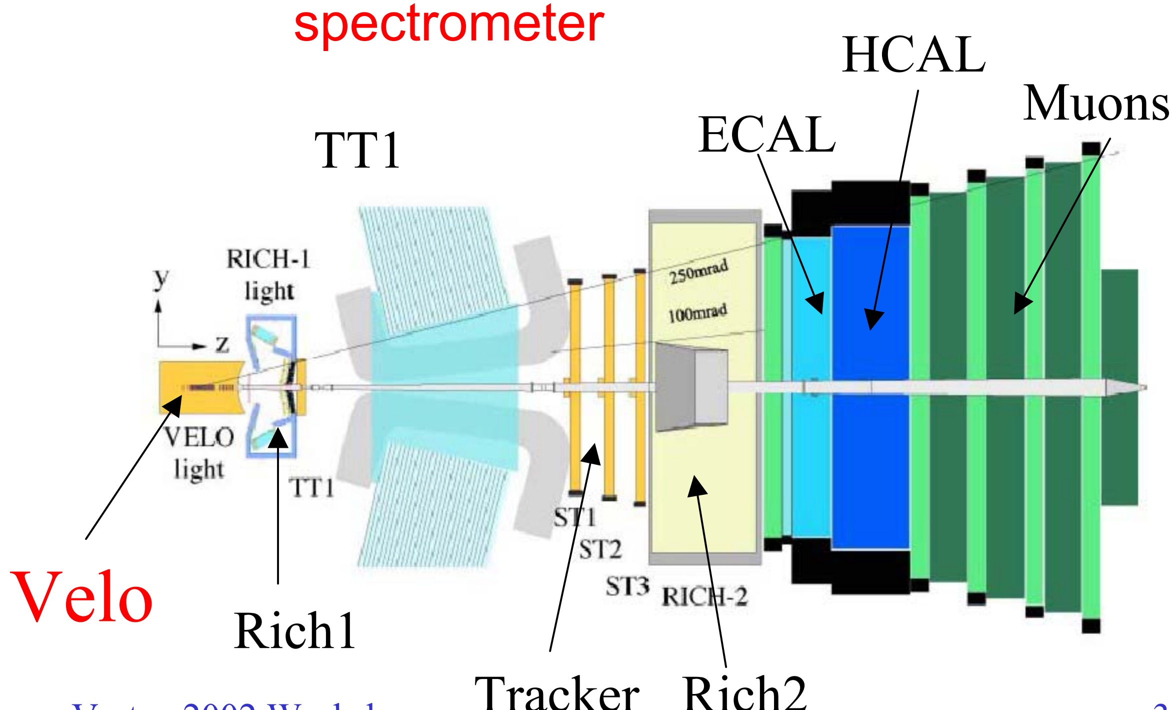
The LHCb Decector



- Physics: where are the Bs?
  - LHC 14TeV pp collisions
  - For $\mathcal{L} = 2x10^{32}cm^{-2}s^{-1}$ and σ_{bb}~500μb have 100K bb/s produced!
  - O(10^{12}) bb pairs/year at LHCb
  - 0.5% of total inelastic cross section
  - Cross sections forward peaked and correlated

Opt for a small angle forward spectrometer

LHCb is a day one experiment! Full physics even at LHC startup luminosity!



Velo Requirements (1)

- Primary & secondary vertex reconstruction
  - Sensitive area as close to beam as possible
  - Highest resolution close to beam line
  - Coverage in forward and backward hemispheres
  - Interaction point distributed in Z with $\sigma = 5.3$ cm
  - Interesting events show displaced vertices from B and Charm decays. Resolution on these crucial to sensitivity of LHCb measurements.
  - "Busy" secondary vertices can point to multiple interactions
  - Minimal material between vertex and first measured point

High resolution on first measurement!

THE UNIVERSITY of LIVERPOOL

Requirements (2)

- Trigger (see talk by Niels Tuning)
  - **FAST** 2D (***rz***) and 3D (***rz*ϕ**) standalone tracking for **L1 Trigger**: **Choose RΦ geometry!**
  - Rejection of multiple interactions

- **Baseline Sensor Design**

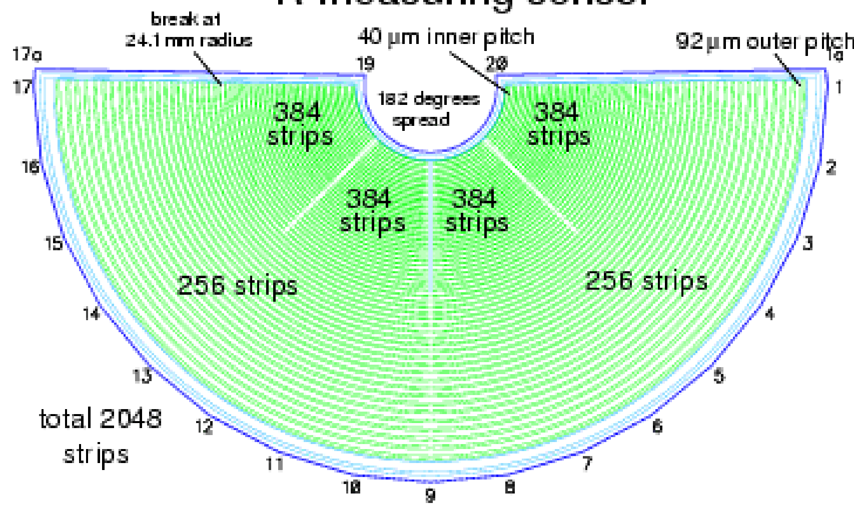
  •Sensors: 7mm>R>44mm

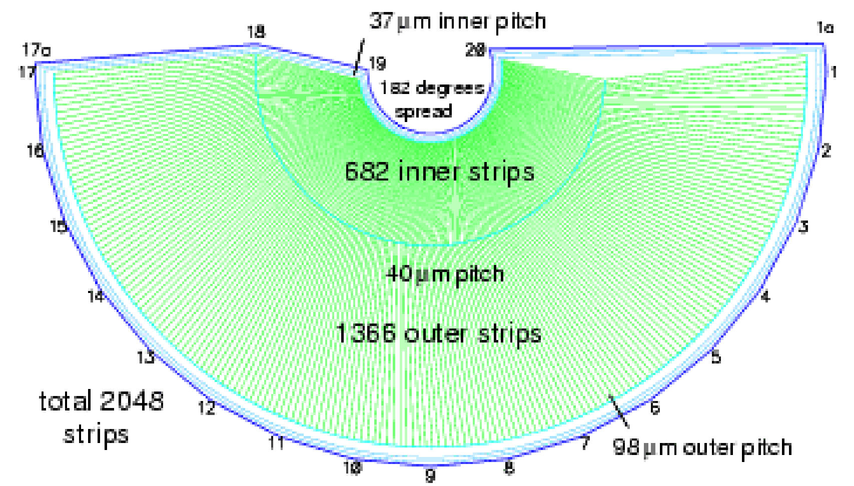
  (Active area 8mm to 43mm)

  •182° angular coverage

  - R sensors
    - Pitch 40μm to 92μm
    - 45° inner, 90° outer sections
  - ϕ sensors
    - Pitch 37μm to 40μm and 40μm to 98μm
    - Double stereo angle

R-measuring sensor



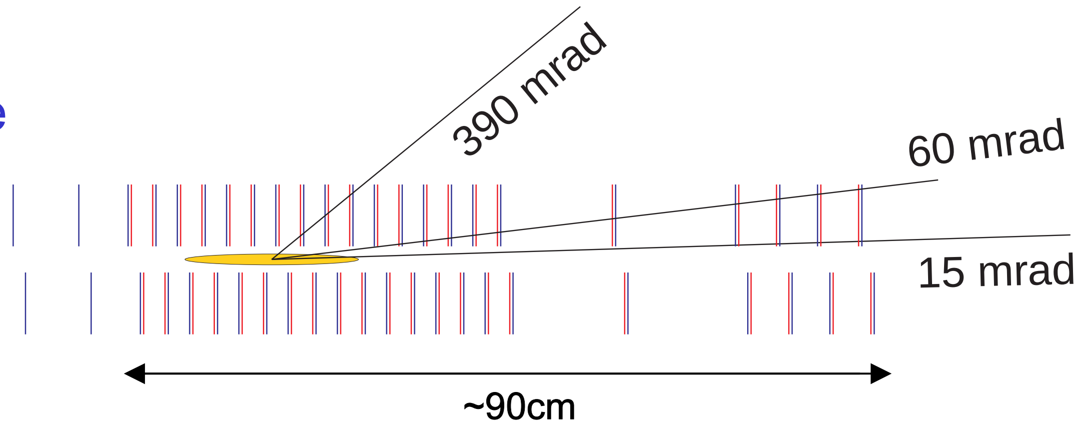


ϕ-measuring sensor

Requirements (3)

- LHCb Tracking system (see talk by F. Lehner)
  - Track reconstruction for B and Charm decays
    - Match LHCb forward acceptance (15 to 390mrad)
    - Sufficient hits/track: at least 3 hits
    - Single hit efficiency > 99% for S/N > 14
  - Good extrapolation of Velo tracks into rest of LHCb tracking system
  - Minimize material seen by tracks going through Velo: dealing with tracks of Energy $\mathcal{O}$(GeV)

Velo XZ slice

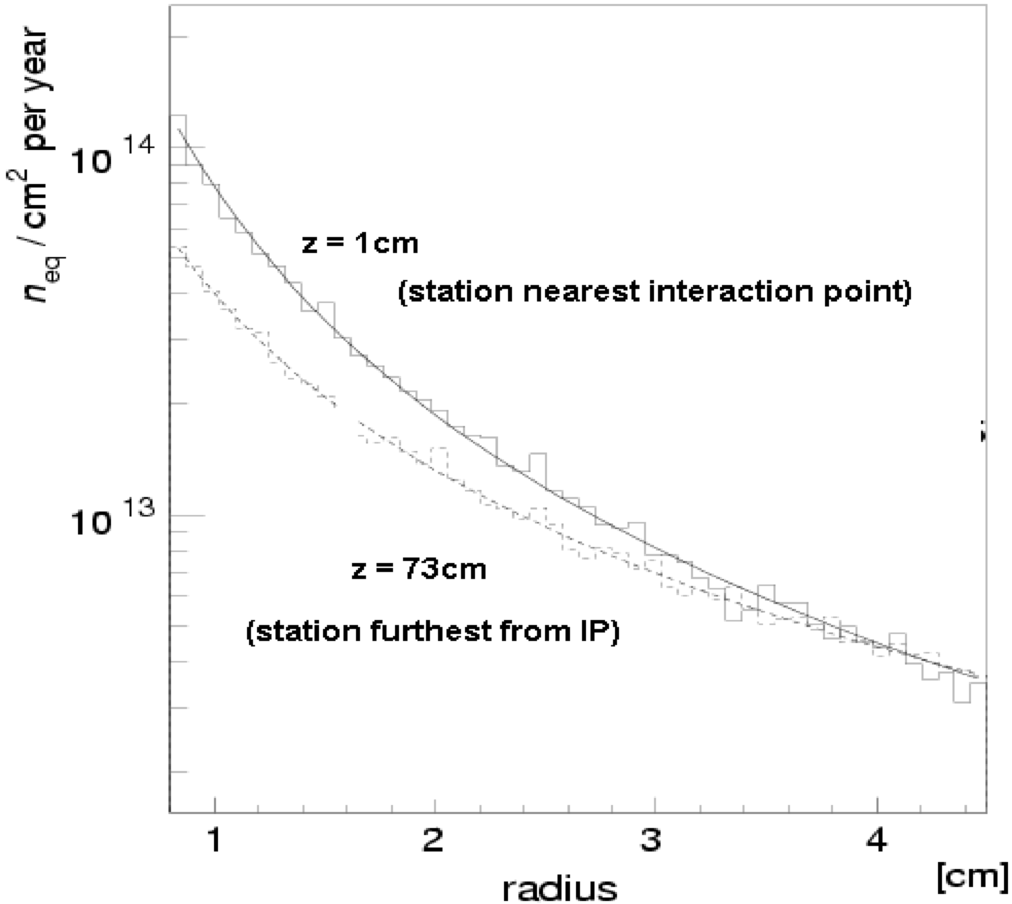


Requirements (4)

All this in an extreme radiation environment:

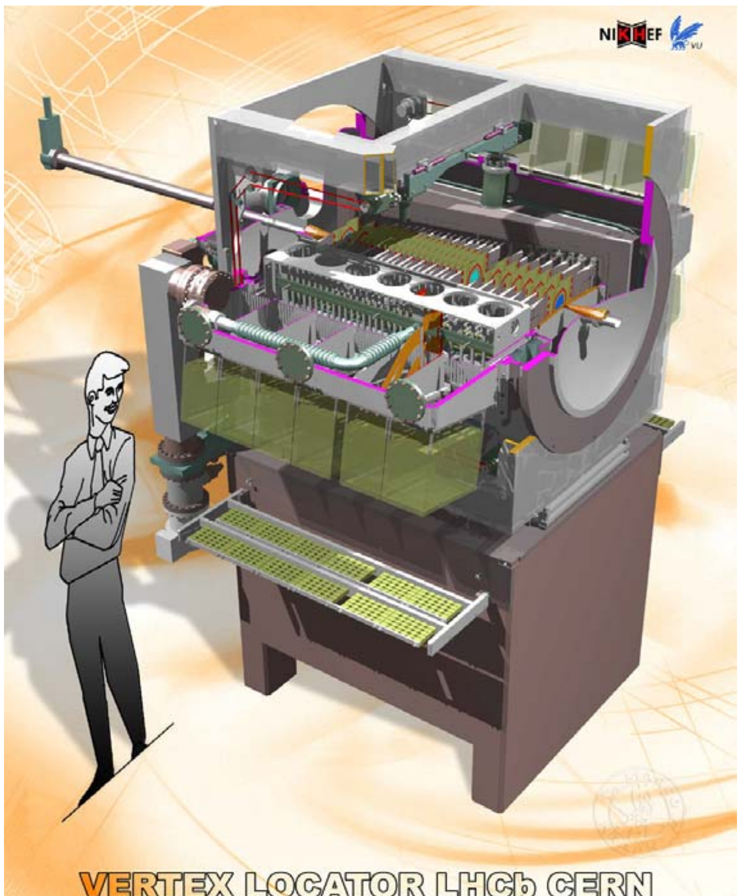
Flux between $5 \times 10^{12} n_{eq} cm^{-2}$ /year and $1.3 \times 10^{14} n_{eq} cm^{-2}$ /year depending on r and z

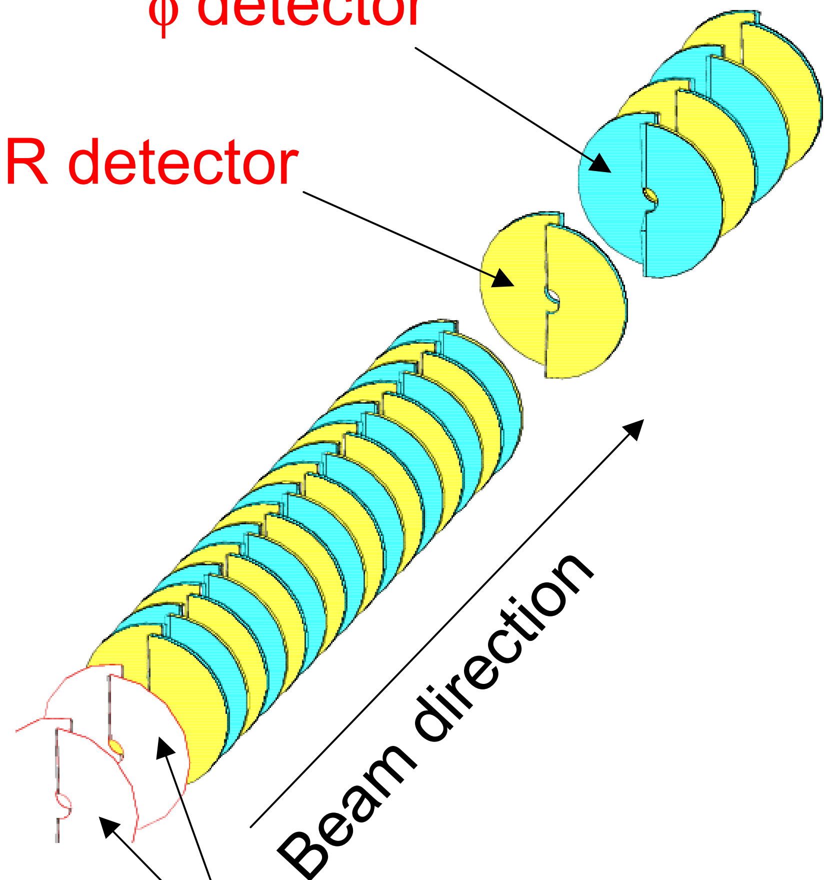
Velo silicon must be operational for at least 2 years under these conditions



Velo layout (1)

- 21 stations with 2 R and 2 Φ sensors each
- Z range -17cm to 74cm



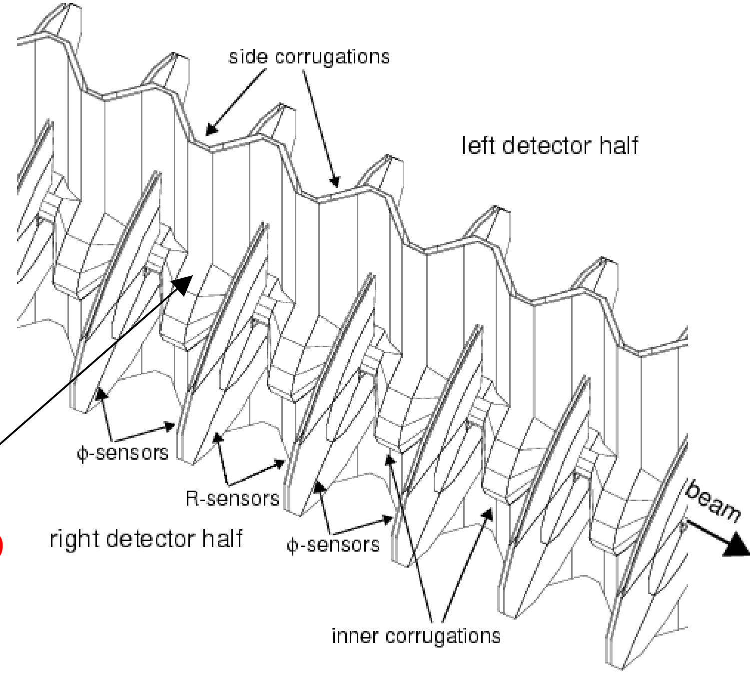


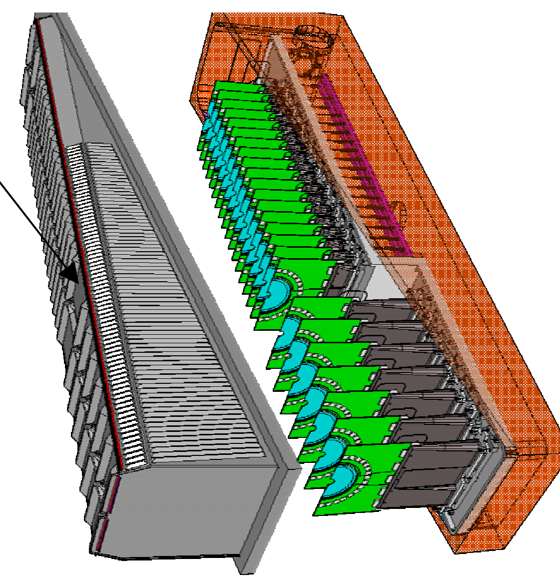
Velo Layout (2)

To get to small R Velo has no beam pipe! Need to:

- Shield from RF pickup
  - Shielding must be retractable by 30mm
  - Must have ~1mm clearance from sensors
- Protect LHC vacuum
  - Must withstand pressure differential of ~15 mBar between primary and secondary vacua
- Guide the wakefields

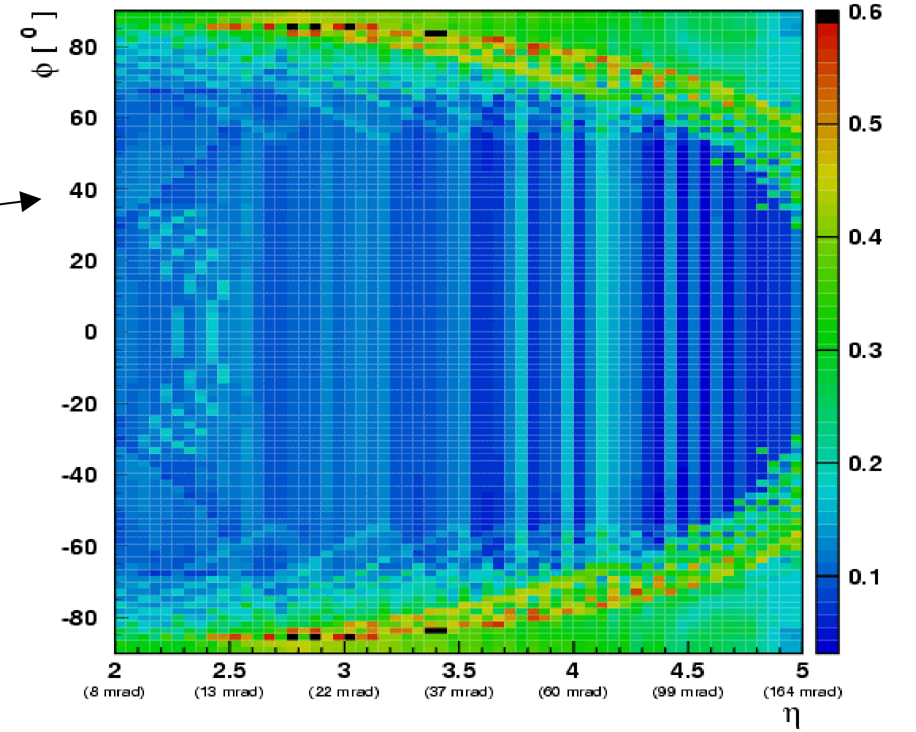
This is tricky to fabricate!

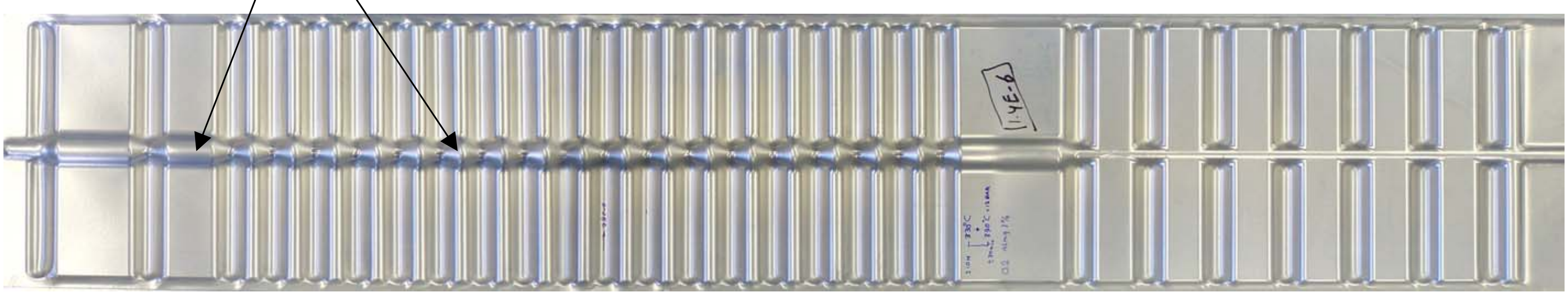




Velo Layout (3)

- All this complicated by physics performance reasons:
  - Minimise material between Velo halves and in LHCb acceptance
  - Minimise material before first measured hit: inner corrugations





First full size foil from NIKHEF! Al Mg alloy with superplastic deformation

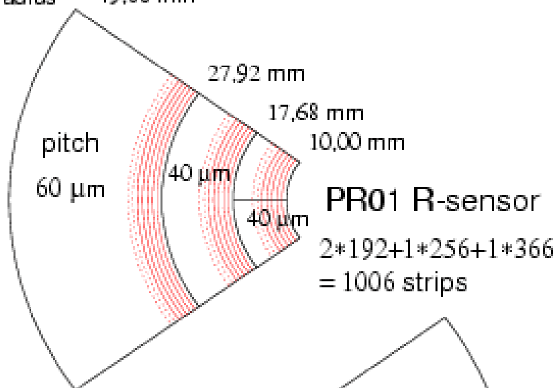
Silicon R&D

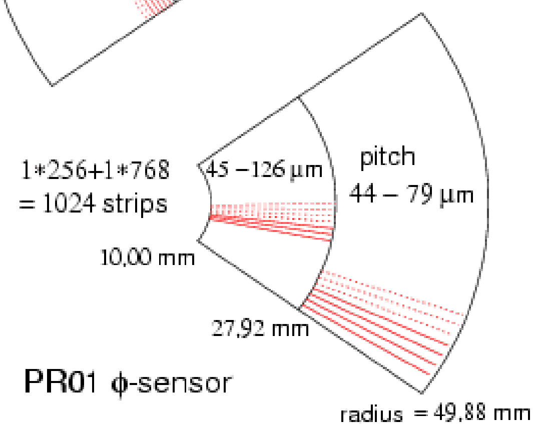
- Main issues investigated
  - ★ – Efficiency, S/N, resolution vs. irradiation and V_{dep} (n-on-n vs. p-on-n)
  - – RΦ geometry validation (tracking, alignment)
  - ★ – Double metal layer pickup
  - – Cryogenic operation
  - – Floating strips
  - – Non-uniform irradiation (see talk by Gianluigi Casse)

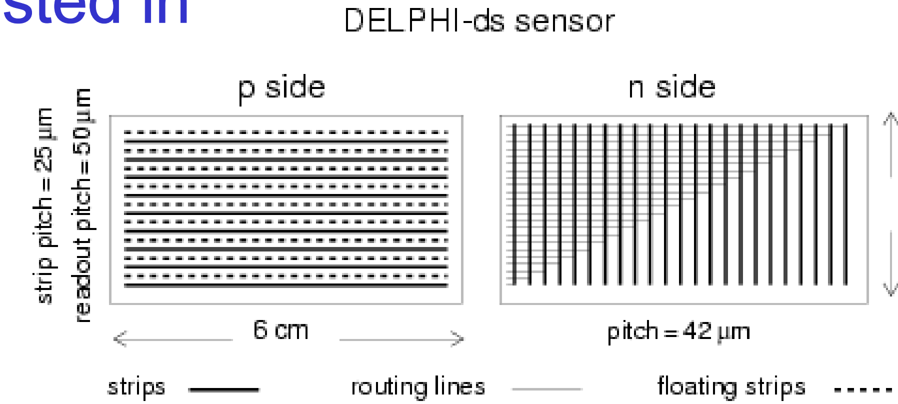
THE UNIVERSITY of LIVERPOOL

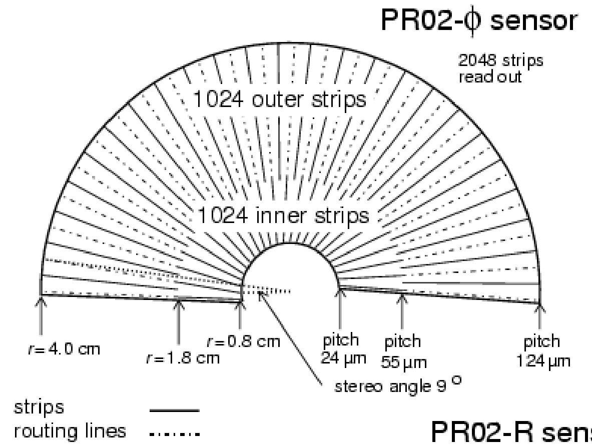
Silicon R&D Program

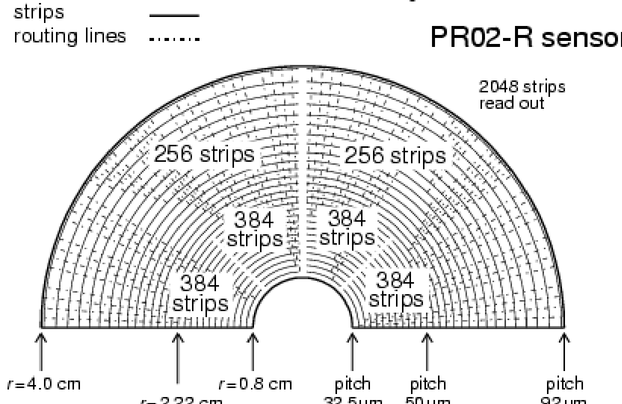
- Some of the detectors tested in beam and lab:

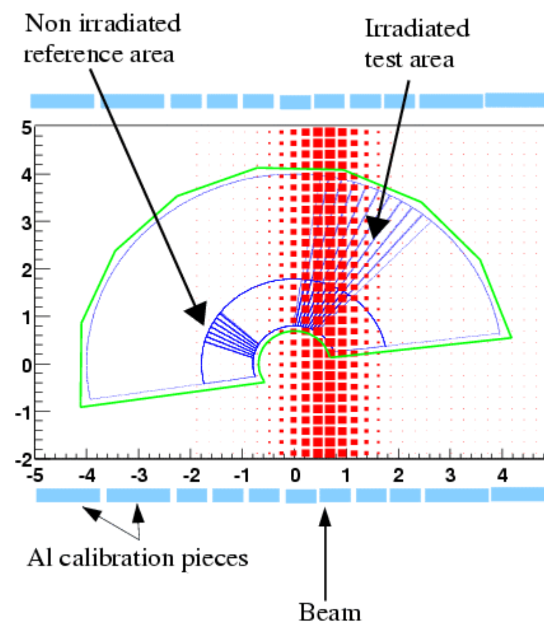






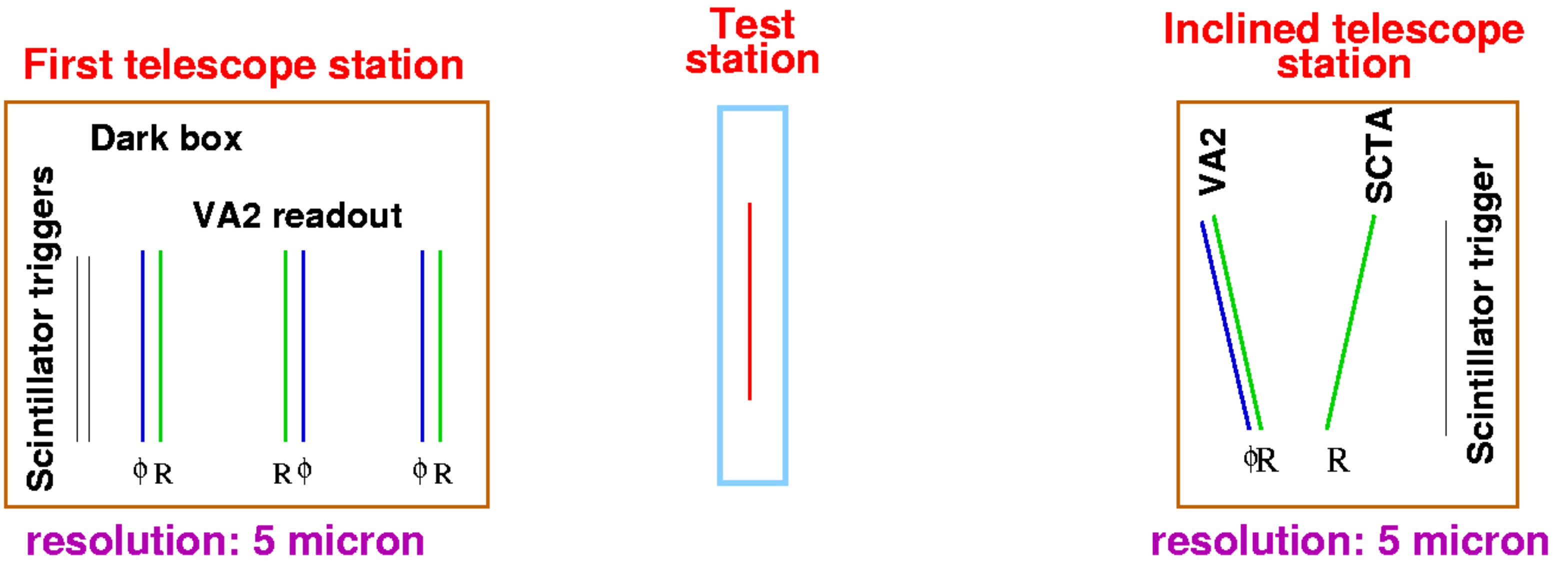






Silicon R&D (2)

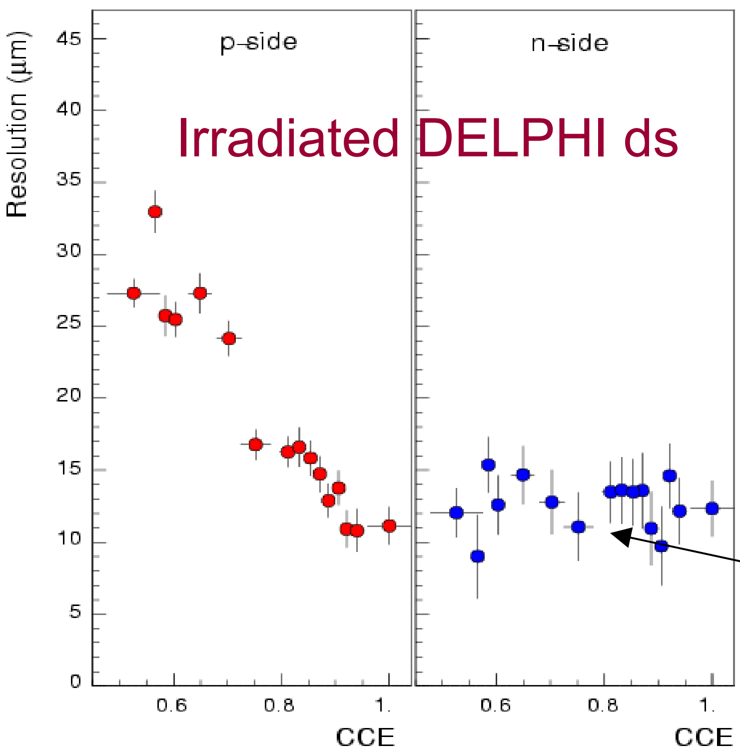
- Test beam experimental setup
  - 120 GeV μ and π from CERN SPS
  - Hamamatsu PR01 telescopes for track extrapolation into test detector
  - **Telescope sensors validated RΦ geometry**



THE UNIVERSITY of LIVERPOOL

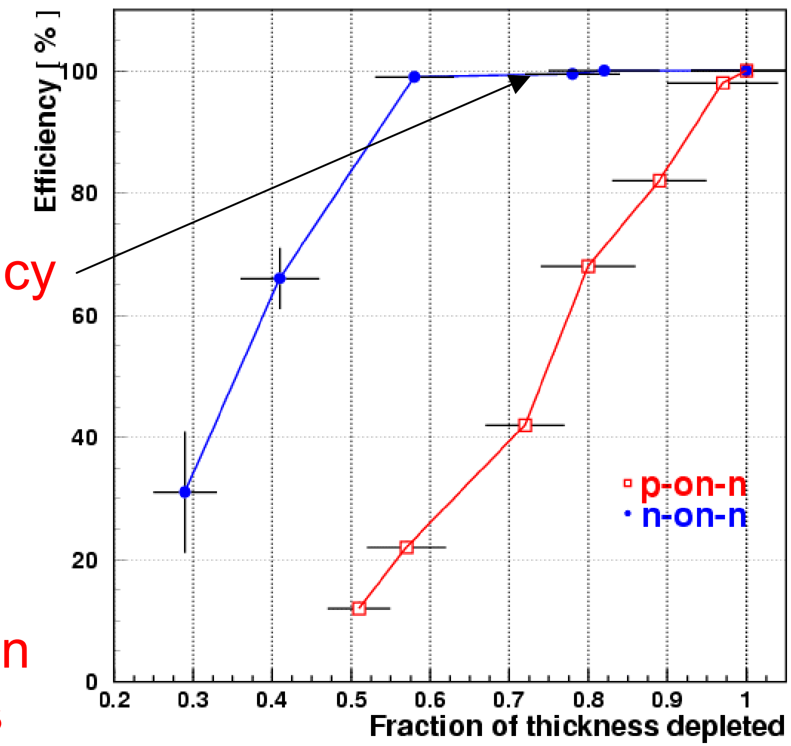
Silicon R&D (3)

- Results from DELPHI, PR01,PR02 show n-on-n has clear advantages over p-on-n in resolution and efficiency when operated underdepleted
- n-bulk becomes effective p after irradiation. Depletion evolves from n implant side…



Full efficiency at 0.6V $_{dep}$!

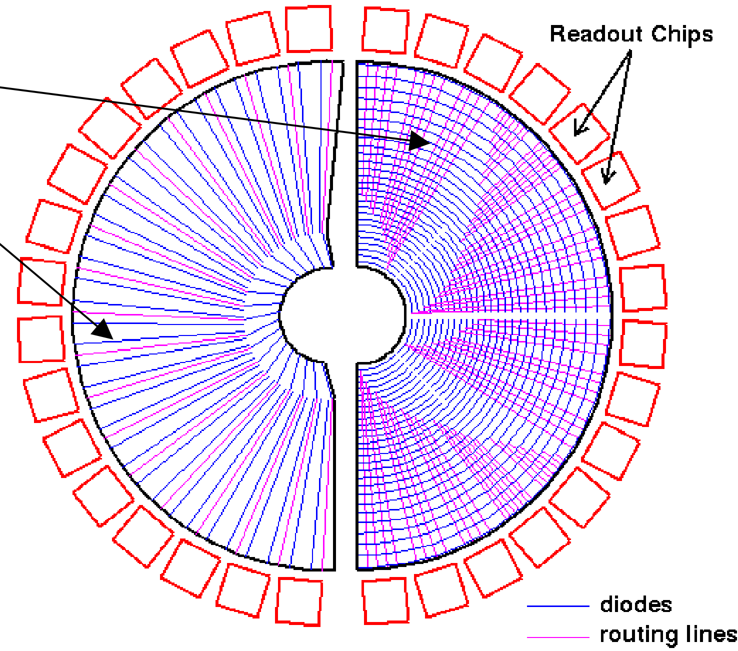
Resolution robust Vs CCE!

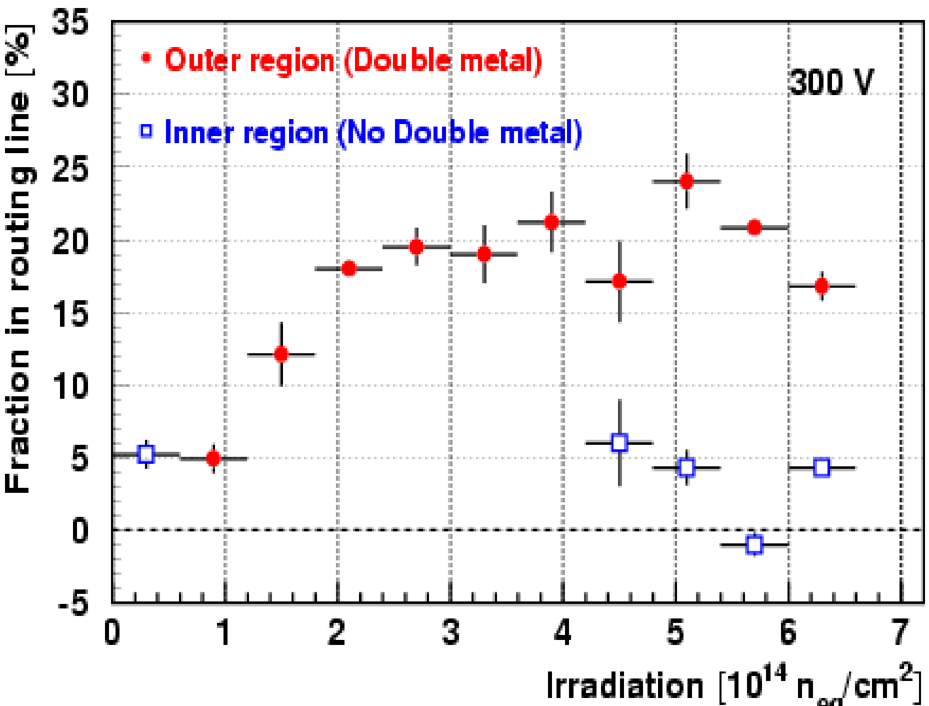


THE UNIVERSITY of LIVERPOOL

Silicon R&D (4)

- Double metal layer
  - A concern: we have lots of it!
  - Charge pickup from double metal layer a problem, particularly for irradiated p-on-n





Effects on n-on-n currently under study. Expect better performance vs. irradiation

See Bowcock et al. NIM 478 (2002) 291-295

Silicon R&D (5)

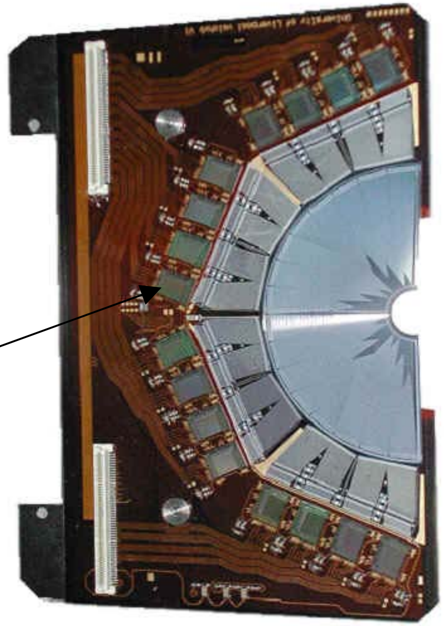
- Cryogenic operation
  - Found to bring detectors back to life… but for limited periods of time. NIM A 440 (2000) 17
- Floating strips
  - Φ strip pitch increases with R. Outer region pitch ~100mm
  - Use floating strips to increase resolution for no extra channels?
  - Data available for non-irradiated n-on-n. Need irradiated.
  - What about double metal?
- Future ideas
  - High resistivity CZ substrate
    - Test beam data of prototype undergoing analysis
  - P-bulk detectors
    - See talk by G. Casse and NIM A 487 (2002) 465-470
  - Thin detectors:
    - Produced 150μm n-on-n PR03.

Silicon R&D (6)

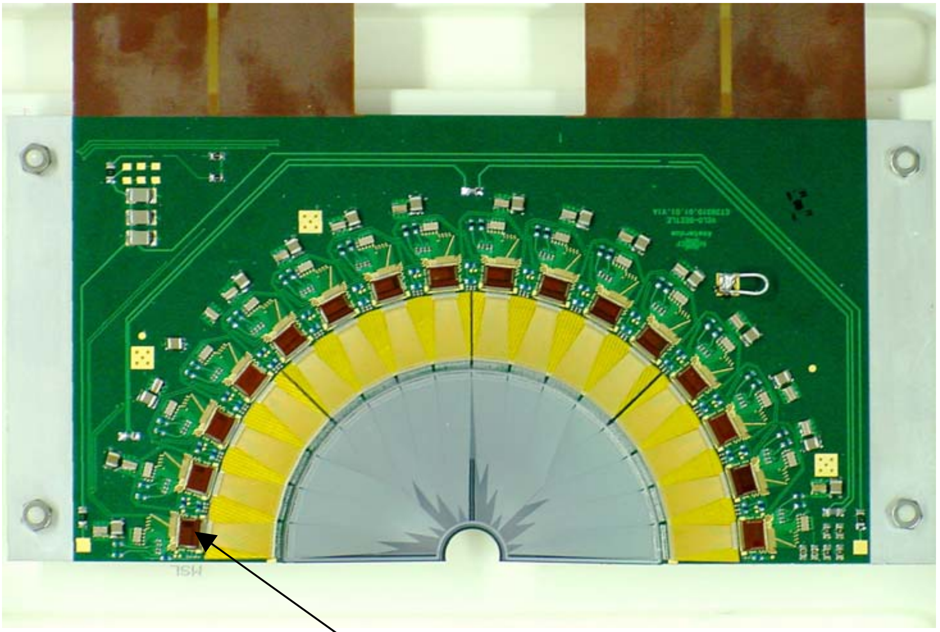
- Conclusions from silicon research
  - n-in-n a clear choice for Velo
    - All requirements for irradiated detectors met
    - Operational below full depletion
  - Floating strips remain an option for replacement of Velo if necessary
  - R ϕ geometry allows fast tracking (Trigger)
    - Final R and Φ strip layout decision imminent
  - Open to technology improvements for future Velo sensors (eg CERN RD50)

Readout Electronics

- LHCb L1 trigger input 1MHz (cf ATLAS, CMS 100kHz)
  - Readout time 900ns
  - 1 readout line per 32 channels
- 2 options: SCTA_VELO and Beetle chip
  - Hybrids built and tested. Analysis under way. Decision making process advanced…



SCTA_VELO



Beetle

Outlook

- Silicon sensor design for Velo near completion.
- Hybrid prototype tested succesfully
- First Mechanical module being built
- Plan to have complete Velo in 2005 and place in test beam in 2006
- Startup in 2007

Conclusions

- The Velo is in an advanced stage of design. Prototyping is underway
- A range of issues regarding the choice of silicon technology have been investigated and a baseline design for the first Velo completed
- The performance of the system exceeds the physics and system requirements of LHCb

Backup Slides

Silicon R&D

- Ongoing program to determine the technology choice for first Velo and further iterations.

  - **Tested in test beam and lab:**
  - **DELPHI ds XY 6cmX3.4cm**
    - **P pitch 25 μm (readout 50 μm)**
    - **n pitch 42 μm**
  - **Hamamatsu R, Φ 300μm n-on-n, 72° (PR01)**
    - **pitch 40-126 μm**
    - **up to 2.5•10^{14} n$_{eq}$/cm^2**
  - **MICRON Φ 200 μm, p-on-n, 182° (PR02)**
    - **pitch 24-124 μm**
    - **irradiated up to 6.4•10^{14} n$_{eq}$/cm^2**
  - **ALICE, GLAST**
  - **Micron R, 300 μm**

Lab tests with IR laser and 40MHz electonics.
See talk by Gianluigi Casse

R/ϕ geometry validation and test beam telescope

Velo Layout

- 21 stations with Si perpendicular to beamline
  - Stations divided into opposing modules with an R and a ϕ 182^o Si strip sensor
  - 2048 channels per sensor read out with 16 chips
  - Hybrid: readout electronics, thermal conductivity, mechanical support