The LHCb VELO: Status and Upgrade Developments

Overview

- The LHCb detector and the VELO
- VELO sensor performance
- Possible upgrade solution
  - Czochralski Silicon
- Current status

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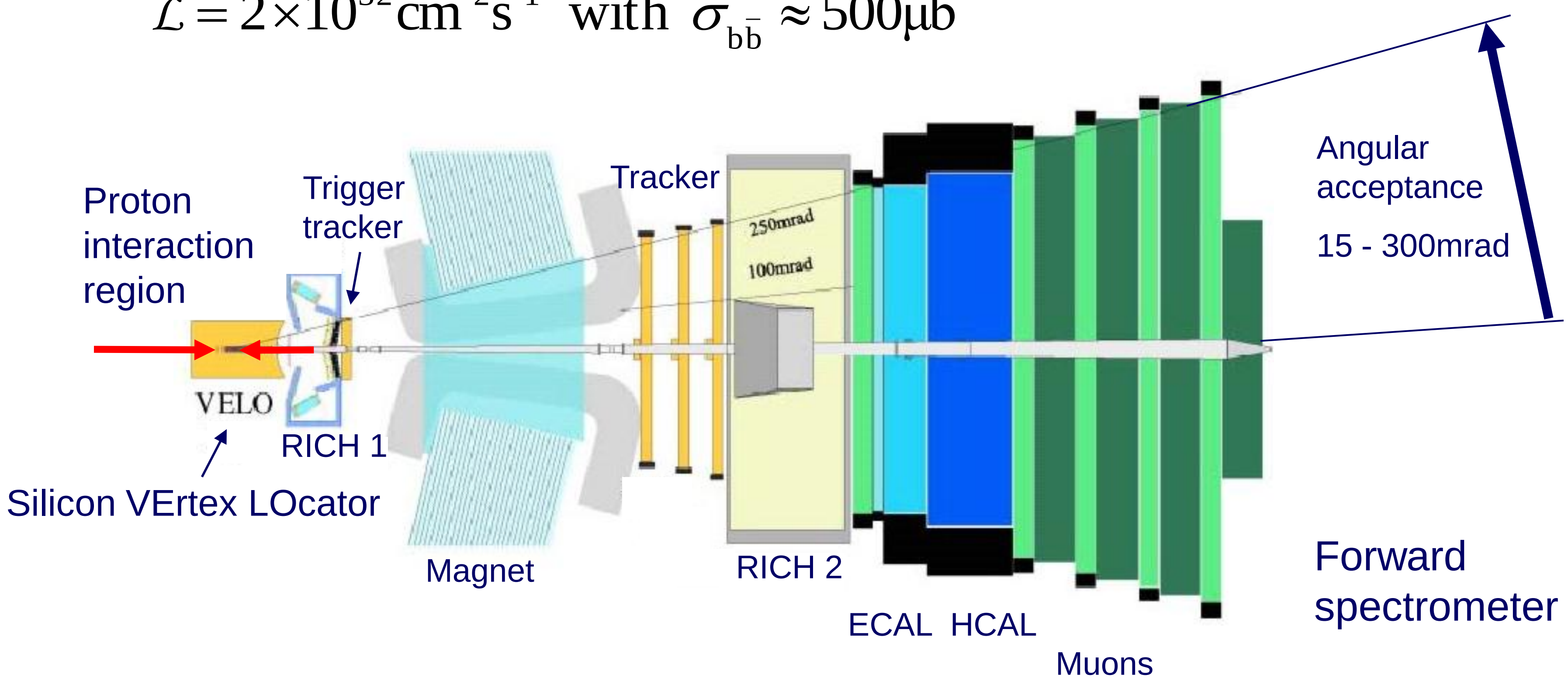
LHCb

Aim: to study CP violation in B meson systems

- Detector at the LHC analysing 14 TeV proton-proton collisions
- ~10^{12} bb pairs produced every operational year

$$\mathcal{L} = 2\times10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1} \text{ with } \sigma_{b\bar{b}} \approx 500\mu\mathrm{b}$$

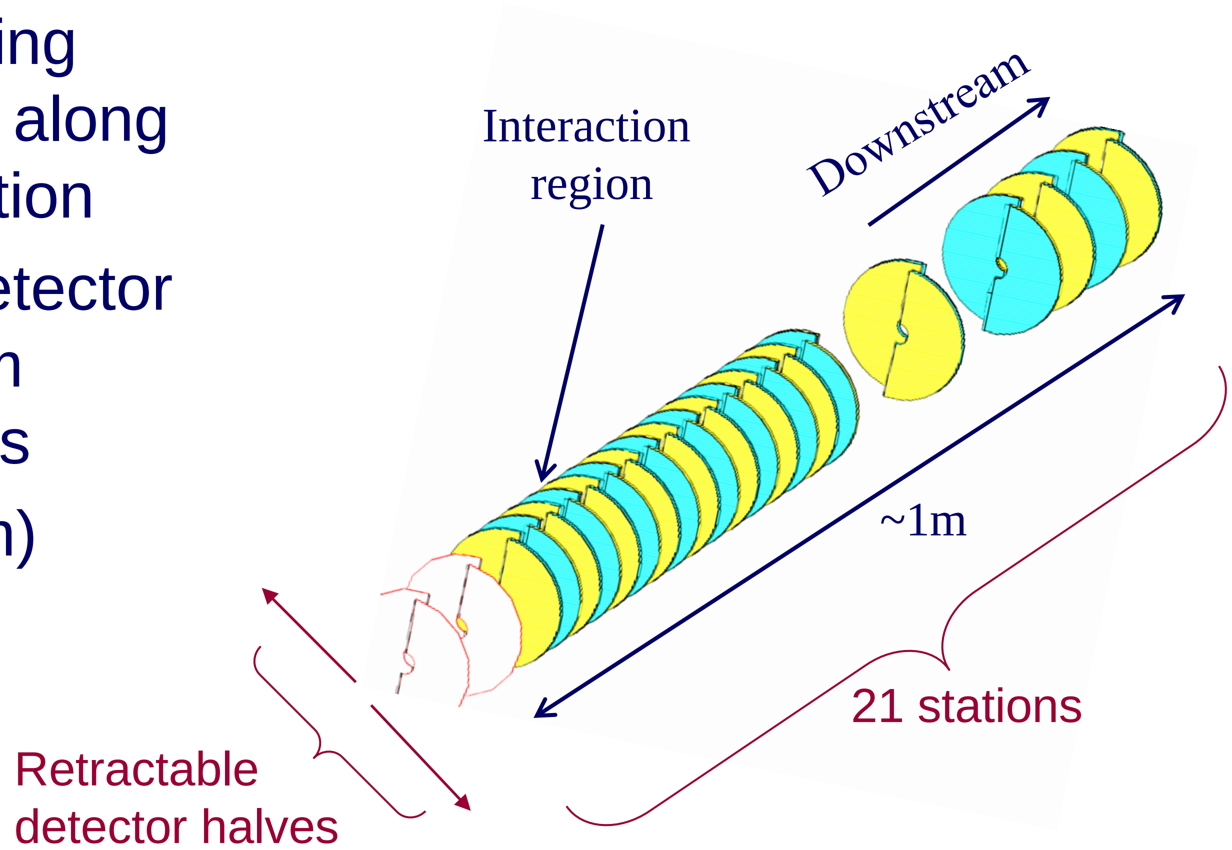


VErtex LOcator

- Vertex reconstruction is a fundamental requirement for LHCb

- 21 silicon tracking stations placed along the beam direction
- 2 retractable detector halves for beam injection periods

  (up to 30 mm)

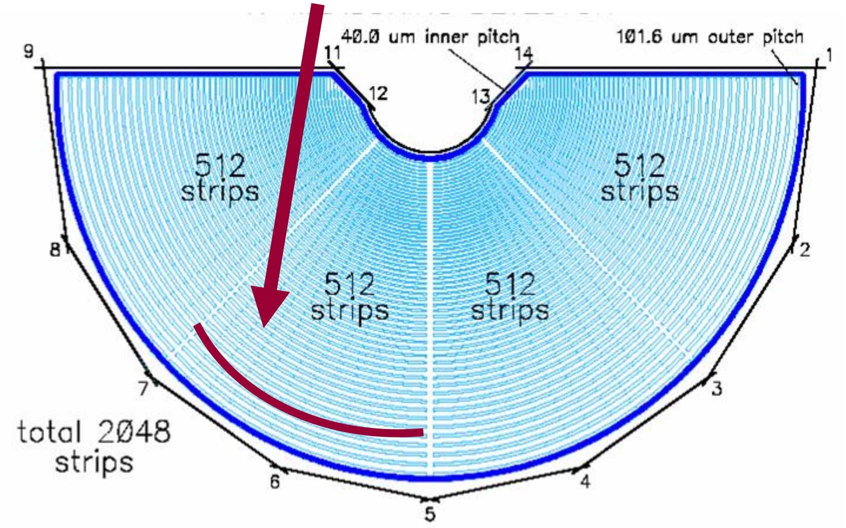


VELO Sensor design

- 2 sensor types: R and Φ
  - R measuring gives radial position
  - Φ measuring gives an approximate azimuthal angle
- Varying strip pitch
  - 40 to 102 μm (R – sensor)
  - 36 to 97 μm (Φ – sensor)
- First active silicon strip is 8.2 mm from the beam line
- n^+-on-n DOFZ silicon
  - minimises resolution and signal loss after type inversion
- Double metal layer for detector readout

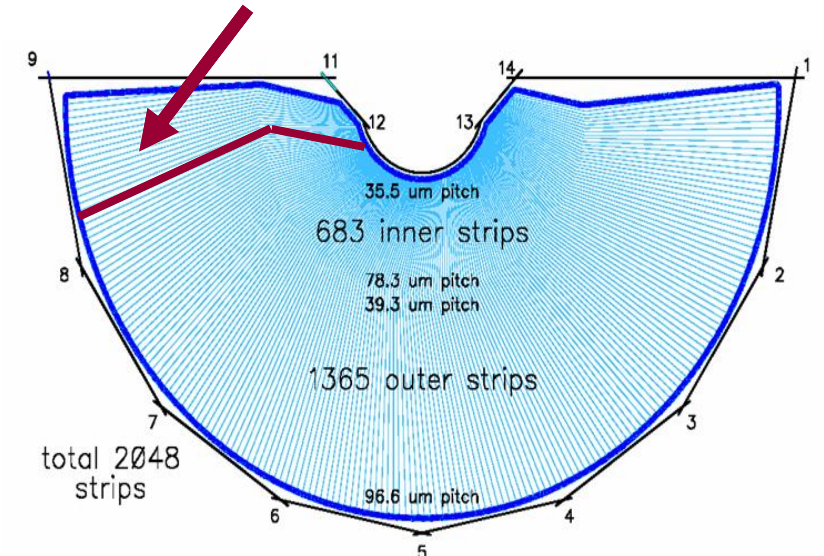
R-measuring sensor:

(concentric strips)

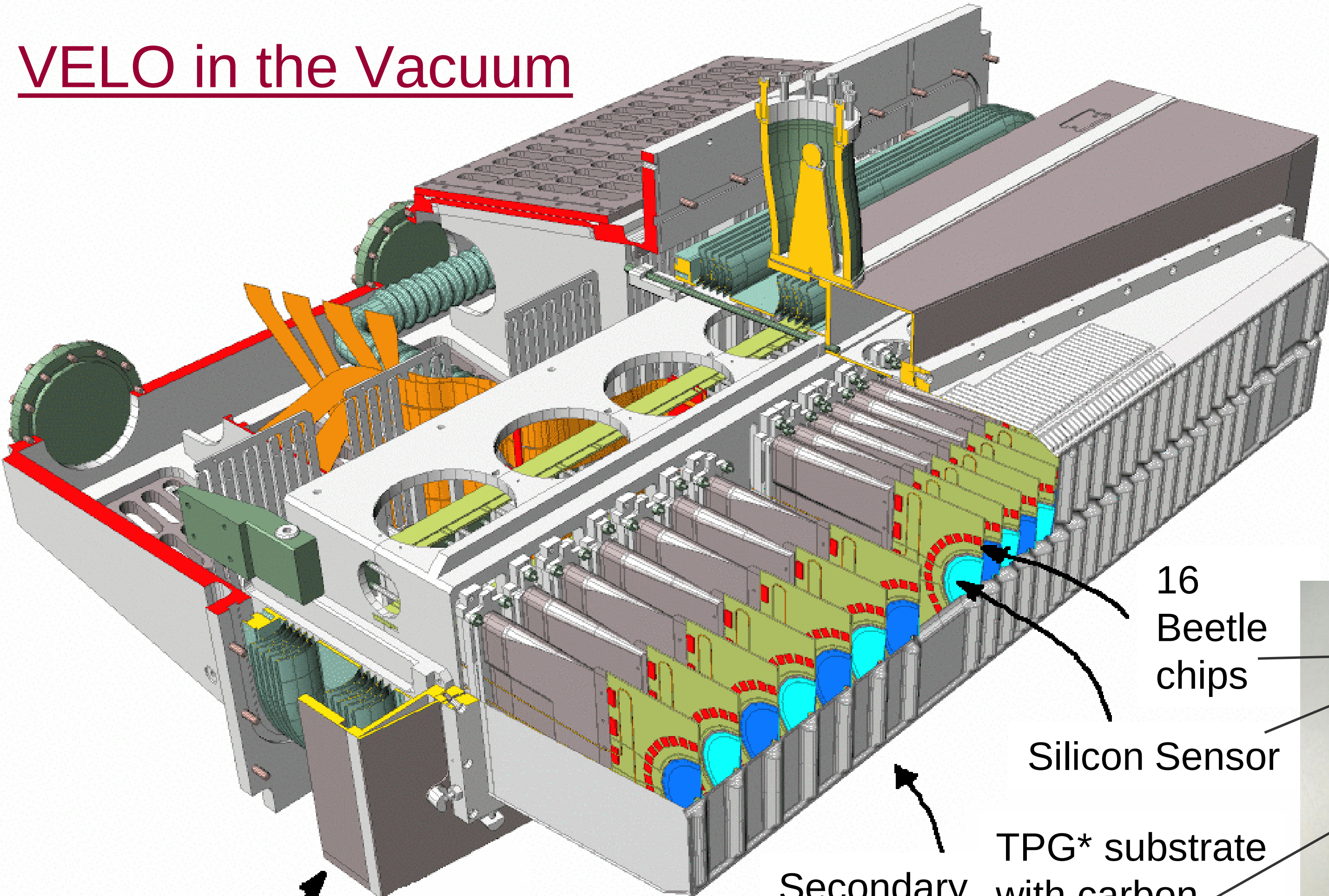


Φ–measuring sensor:

(Radial strips with a stereo angle)



VELO in the Vacuum



Double sided modules

(1 x R and 1 x Φ sensor)

16 Beetle chips

Silicon Sensor

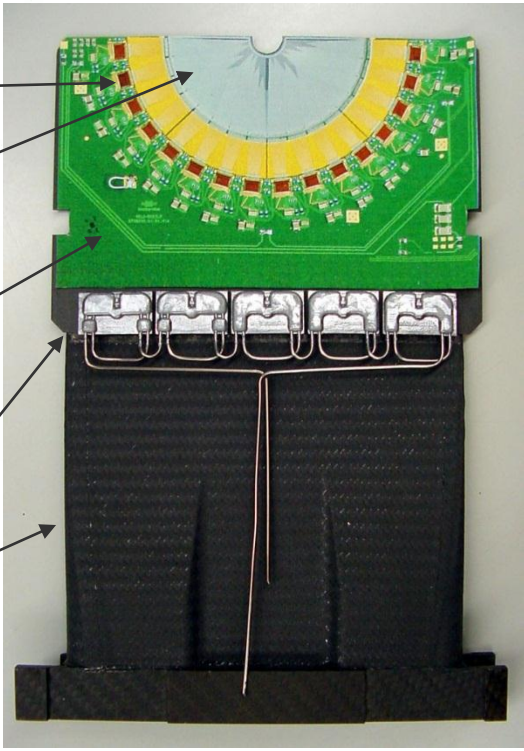
TPG* substrate with carbon fibre frame

Cooling contacts

Carbon fibre paddle

Secondary vacuum Chamber

Retracting Detector Half



Silicon operating temperature -7°C

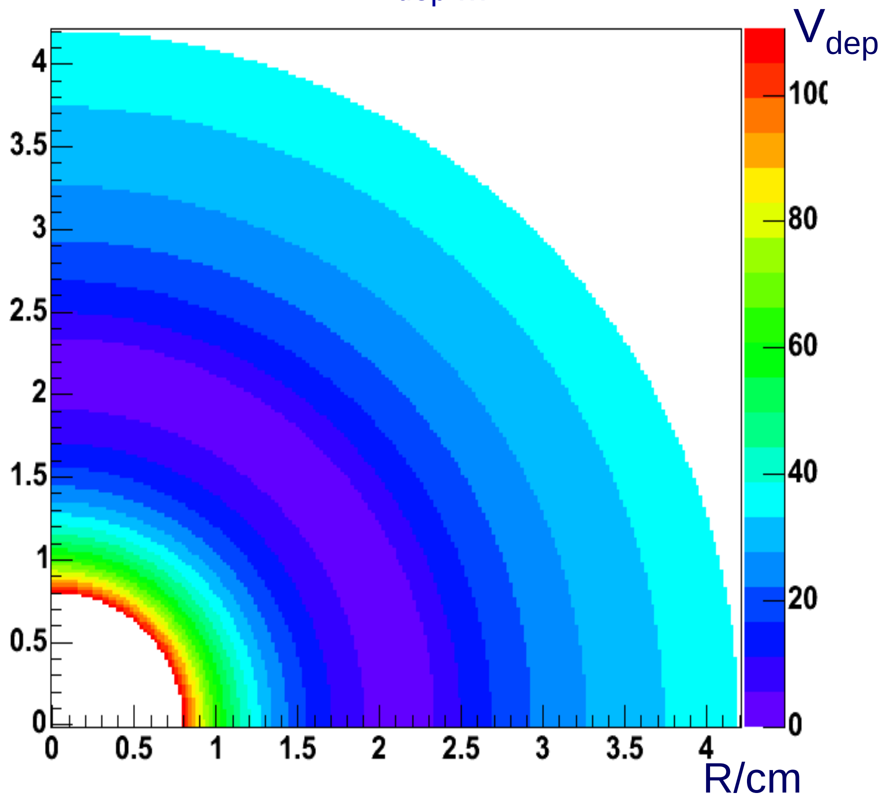
*Thermalised Pyrolytic Graphite

VELO environment

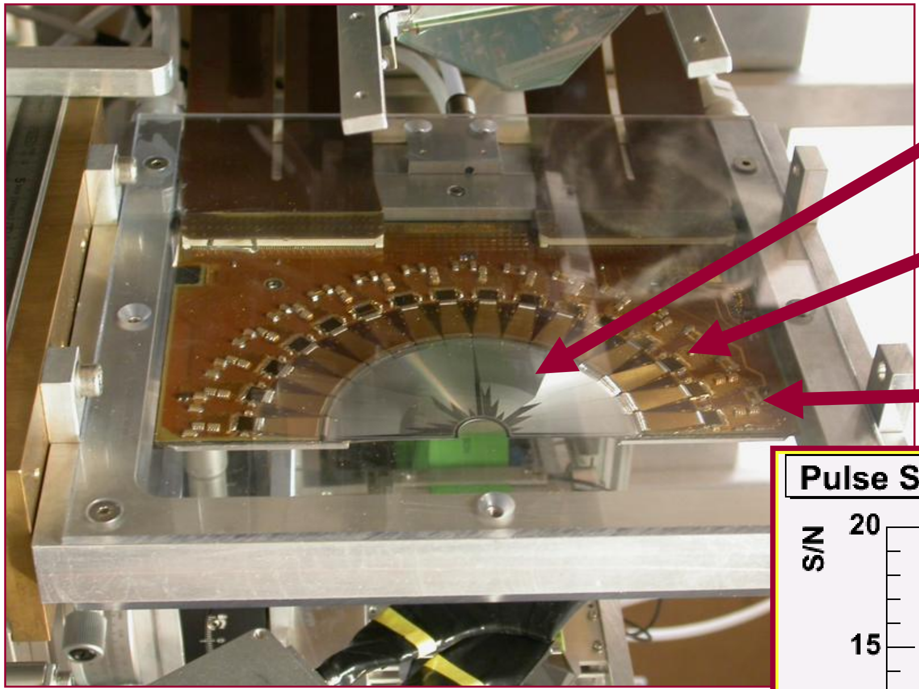
- VELO sensors operate in a harsh non-uniform radiation environment
  - fluence to inner regions $1.3 \times 10^{14}\ n_{eq.}/cm^2$
  - fluence to outer regions $5 \times 10^{12}\ n_{eq.}/cm^2$

- Estimated to survive 3 years

Illustration of V_{dep} …



May 2004 test beam results



300μm n+-on-n R sensor

16 readout chips

(Beetle 1.3)

Prototype hybrid (K03)

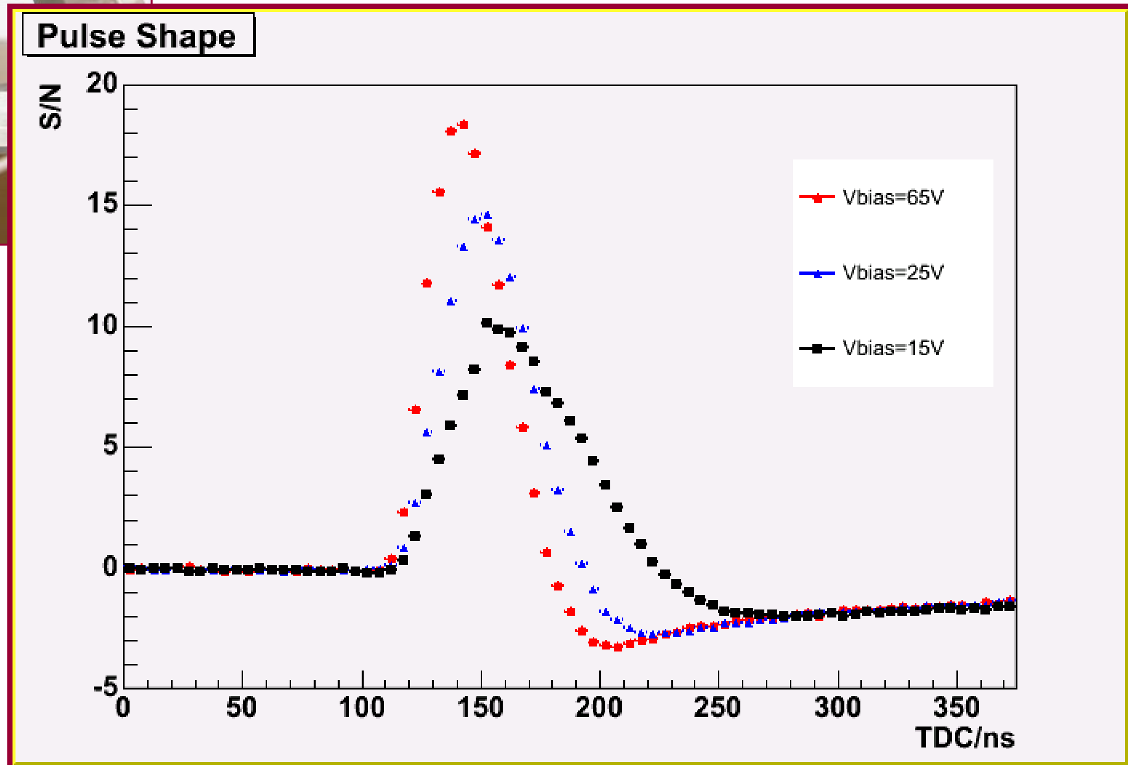
300μm S:N =18:1

200μm S:N =12:1

spillover: signal at 25ns after peak in % of the peak signal

30% (100V bias)

(30% is the maximum before displaced vertex trigger performance degraded.)

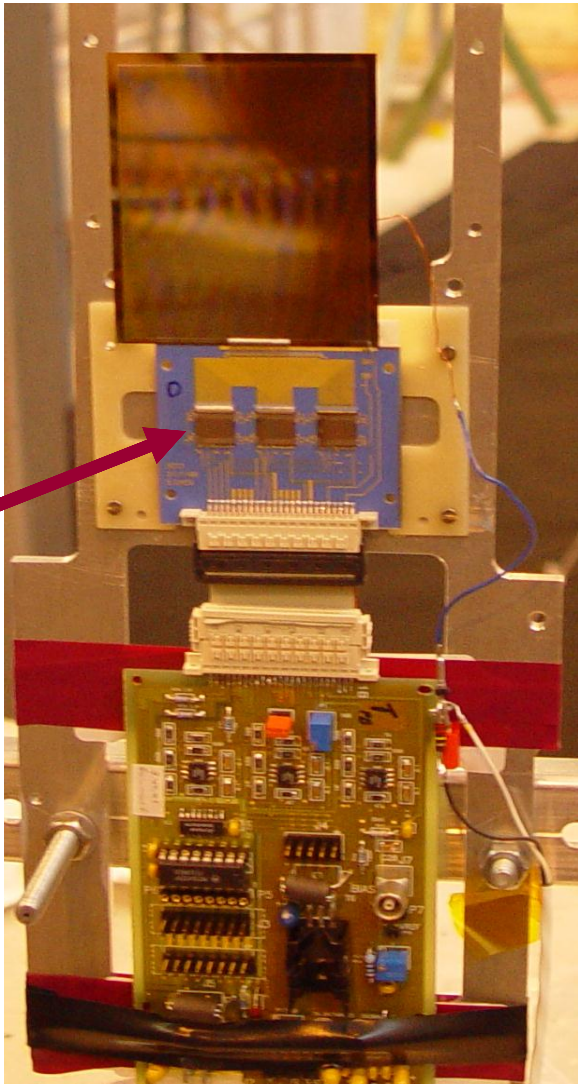


Possible upgrade choices for 2010

n^+-on-p, pixels, 3D, …many possibilities

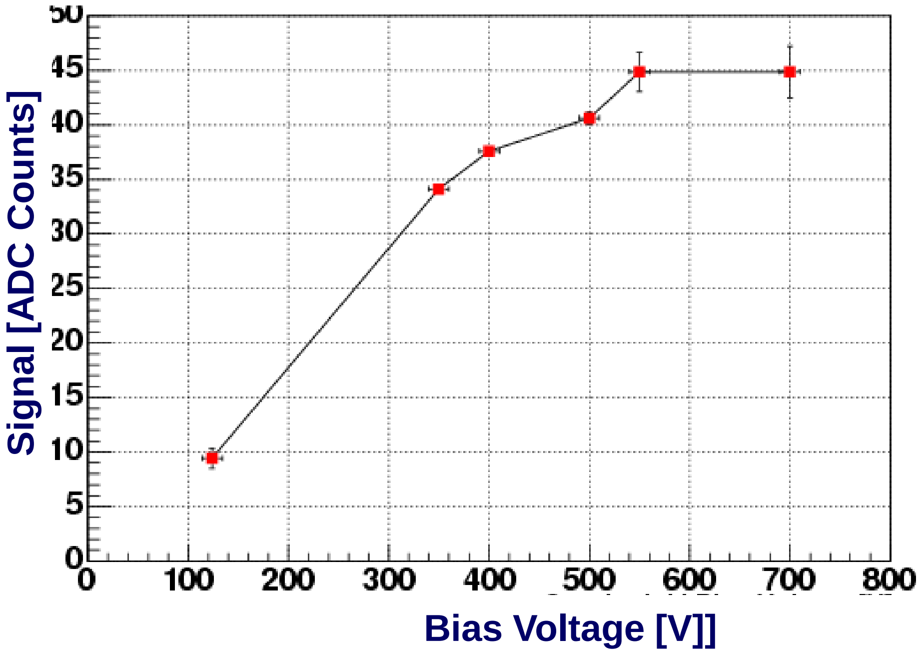
- Magnetic Czochralski silicon
  - Standard industrial method of producing silicon
    - Cheap
    - Naturally high Oxygen content
      - more radiation hard?

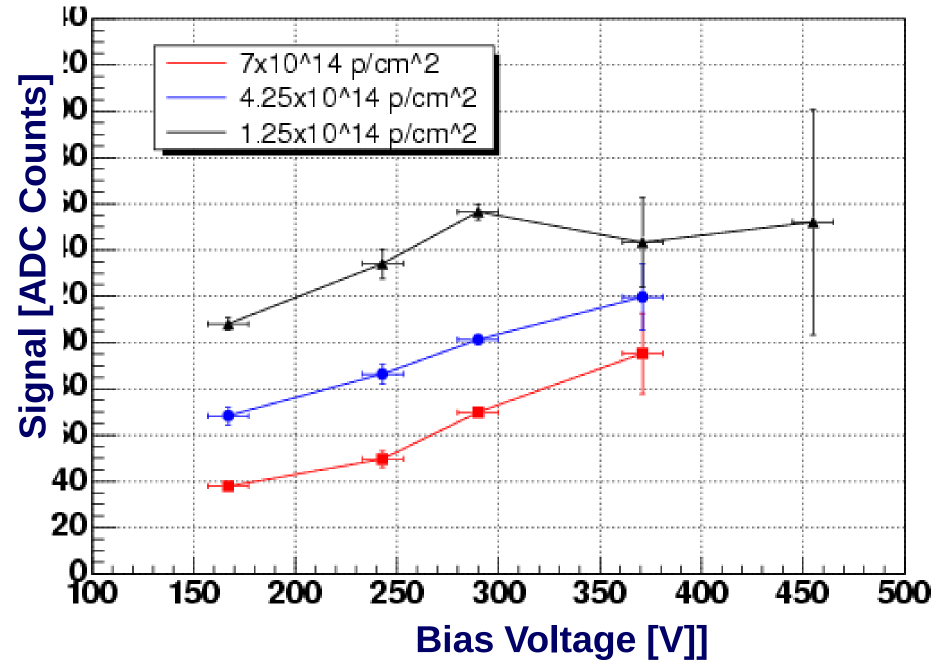
- Test beam at the CERN SPS of a MCz detector* before and after irradiation
  - LHC speed electronics (40 MHz)
    (3 SCTA (analogue) chips)
  - p^+-on-n MCz material
  - Area $_{\text{read out}}$ = 6.1 x 1.92 cm
  - 380 μm thick, 50 μm pitch



*Many thanks to the Helsinki Institute of Physics for the MCz detector

MCz test beam results





✓ **Depleted the detector (~550 V)**
(CV measured Vdep ~ 420 V)

S / N > 23.5 + 2.5

(380 μm thick)

- 1.3×10^{14} 24 GeV p/cm^2 S/N = 15
- 4.3×10^{14} 24 GeV p/cm^2 S/N = 11 (under depleted)
- 7.0×10^{14} 24 GeV p/cm^2 S/N = 7 (under depleted)

Further MCz benefits

- The VELO currently uses n^+-on-n DOFZ silicon detectors
  – This is necessary because we want material where the high field side is always on the strip side in order to prevent loss of resolution and signal
  – However, n^+-on-n is expensive and restricts the choice of processing company (requires double-sided processing)

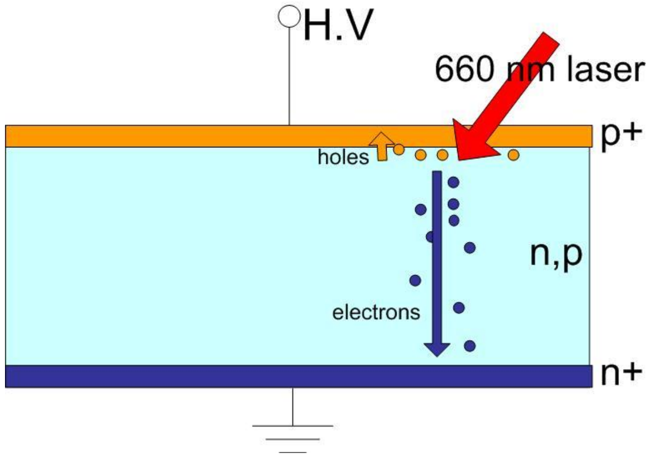
We have found that MCz **does not type invert** using the Transient Current Technique (measured to 5 x 10^{14} p/cm^2)*

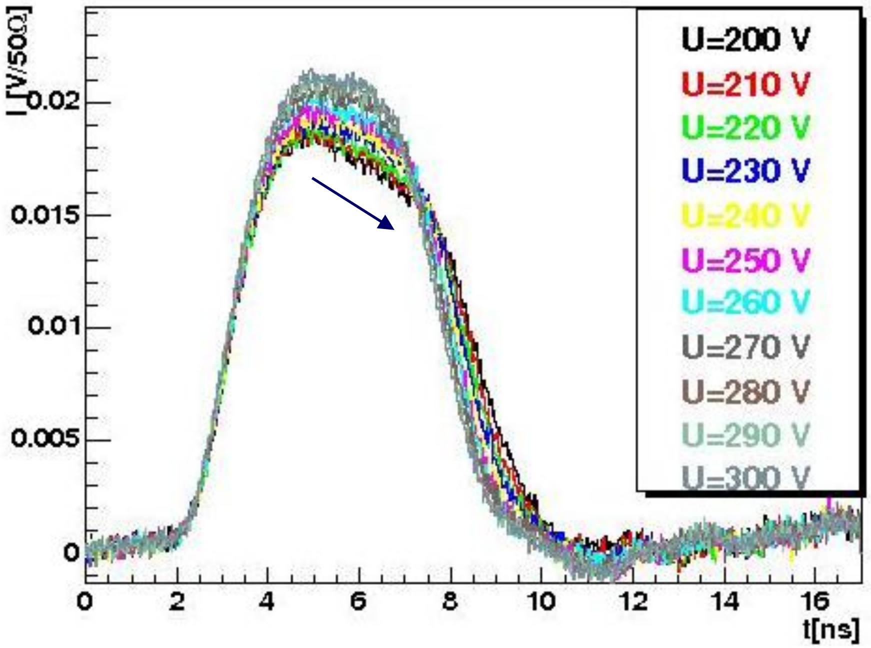
*Work performed under the PH-TA1/SD group, CERN (A Bates & M Moll)

Transient Current Technique

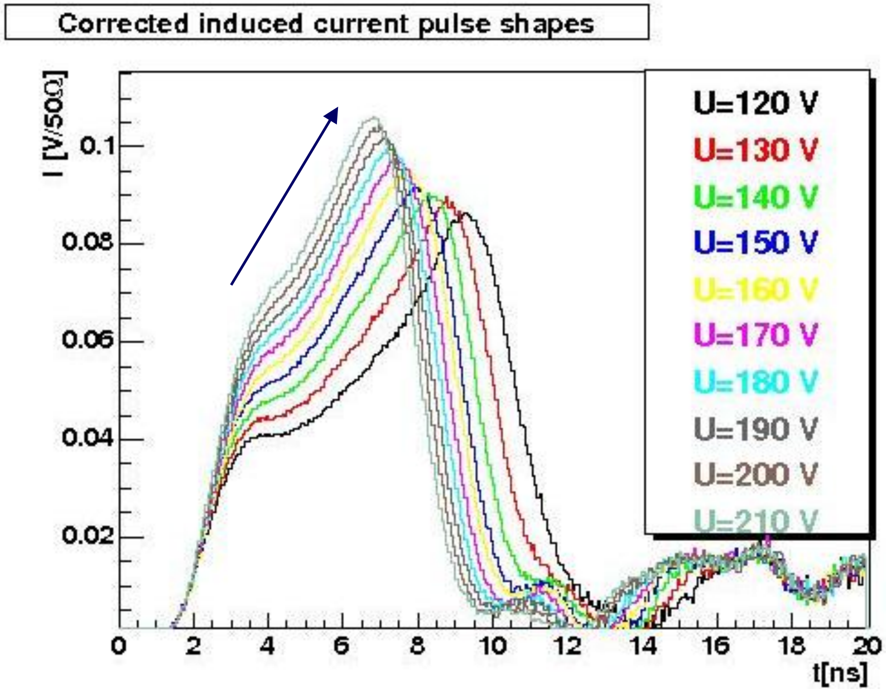
- experiment which probes the electric field inside the detectors

type inversion in FZ silicon



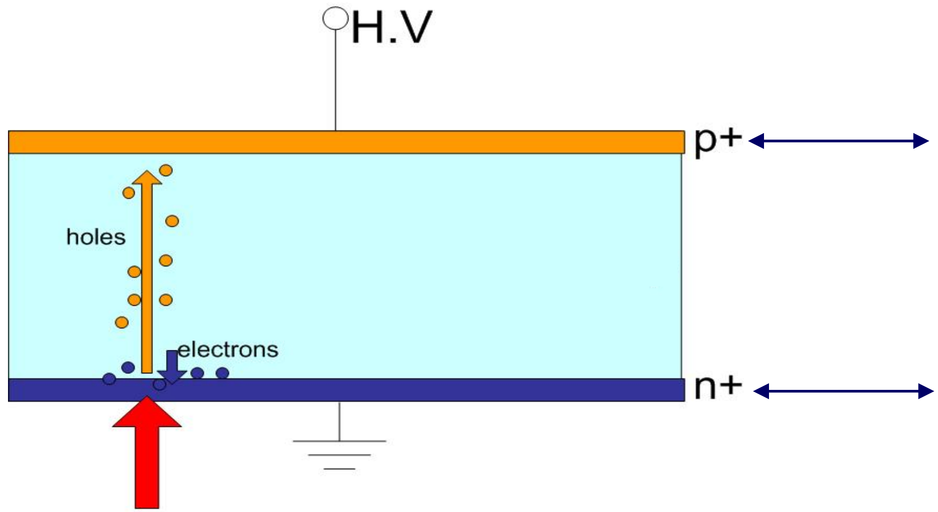


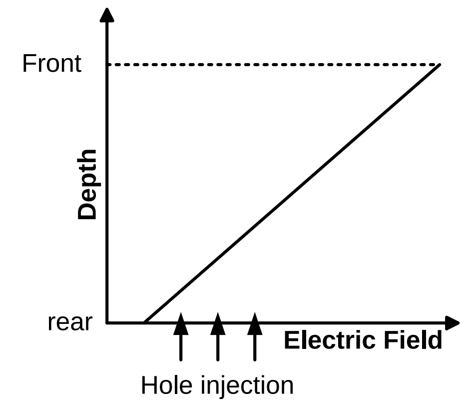
$\Phi = 1.74 \times 10^{13}$ 24 GeV/c p

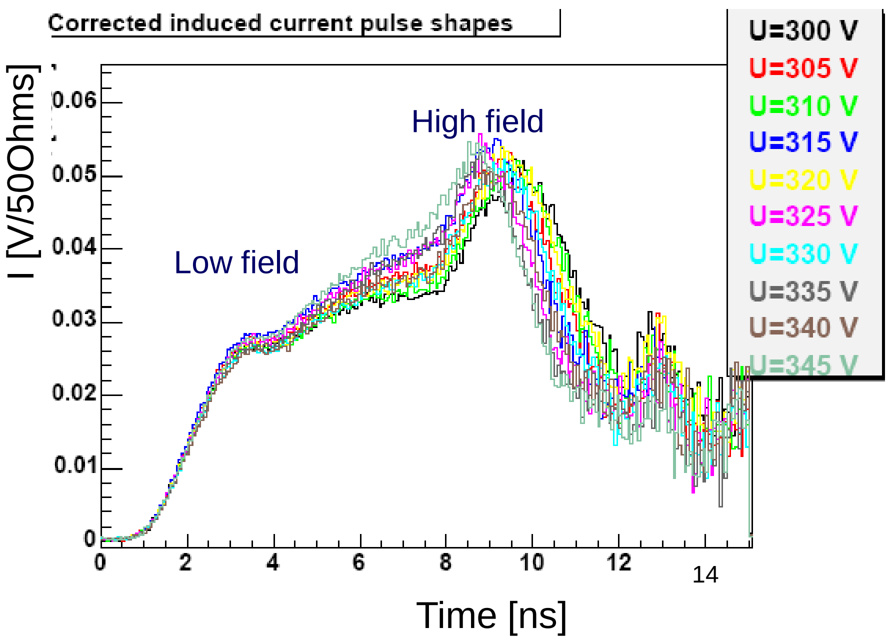


$\Phi = 3.61 \times 10^{14}$ 24 GeV/c p

TCT in MCz





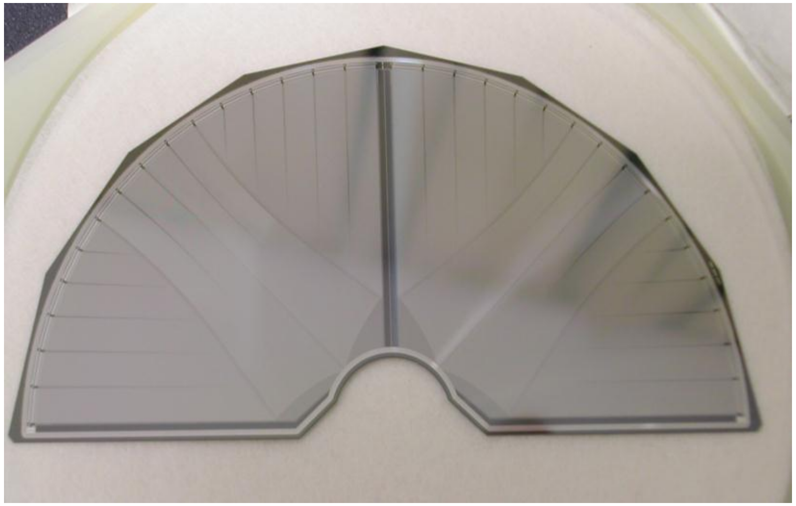


MCz silicon always has the high field on the strip side of the detector

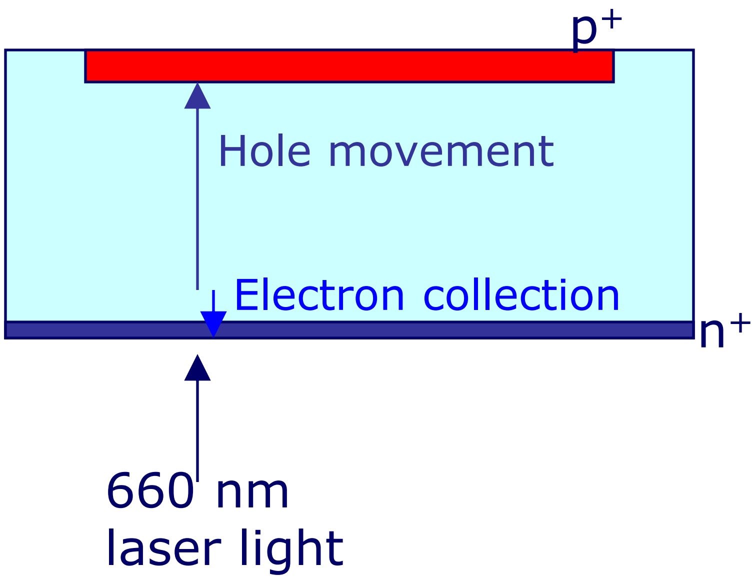
=> standard p⁺-on-n MCz detectors could replace the VELO n⁺-on-n DOFZ silicon, however, further investigation of the radiation tolerance of MCz is required

Status & Conclusions

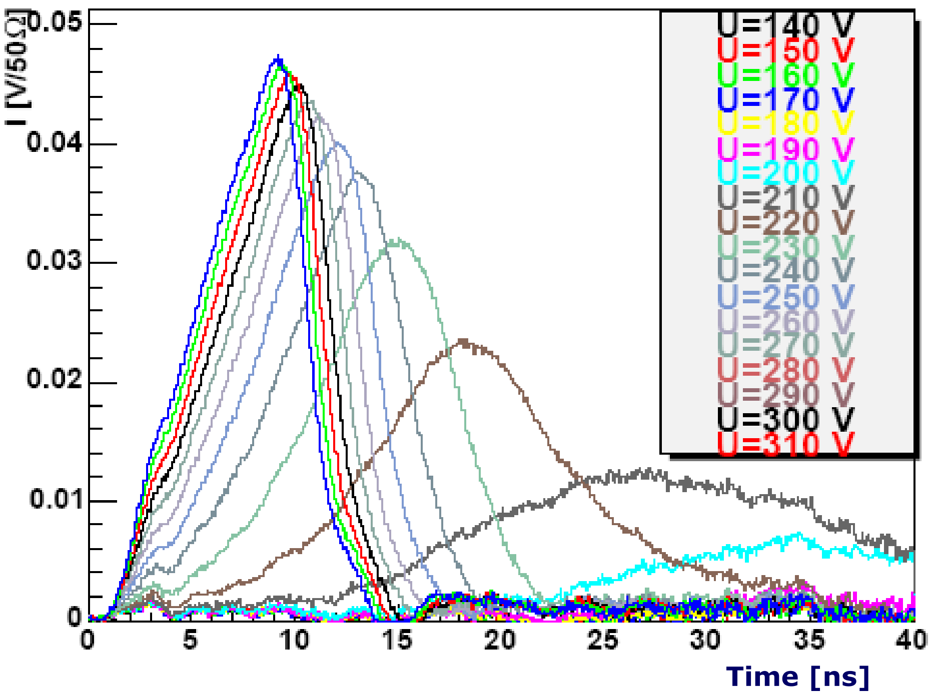
- The VELO is moving from the last prototype testing to sensor production
  - first pre-production sensors are just arriving (October 2004)
  - test beam of final module configuration in November 2004
- R&D for possible upgrade solutions is continuing e.g. for MCz
  - first operation of full size MCz sensor with LHC speed electronics in test beam
    - further test beam studies planned
  - non-inversion of MCz material under radiation demonstrated
    - additional microscopic studies underway



TCT Review



- Illuminate front (p^+) or rear (n^+) side of detector with 660 nm photons
- Light penetrates only a few μm depth
- Ramo's theorem dictates signal will be dominated by one type of charge carrier
- $I(t) = q\ \ E(\upsilon(t))\ \ \upsilon(t)_{drift}$
- e.g. hole dominated curent (hole injection)
  - Illuminate rear (n+) side of detector



Signal treatment

- Deconvolution of the true signal from the measured signal

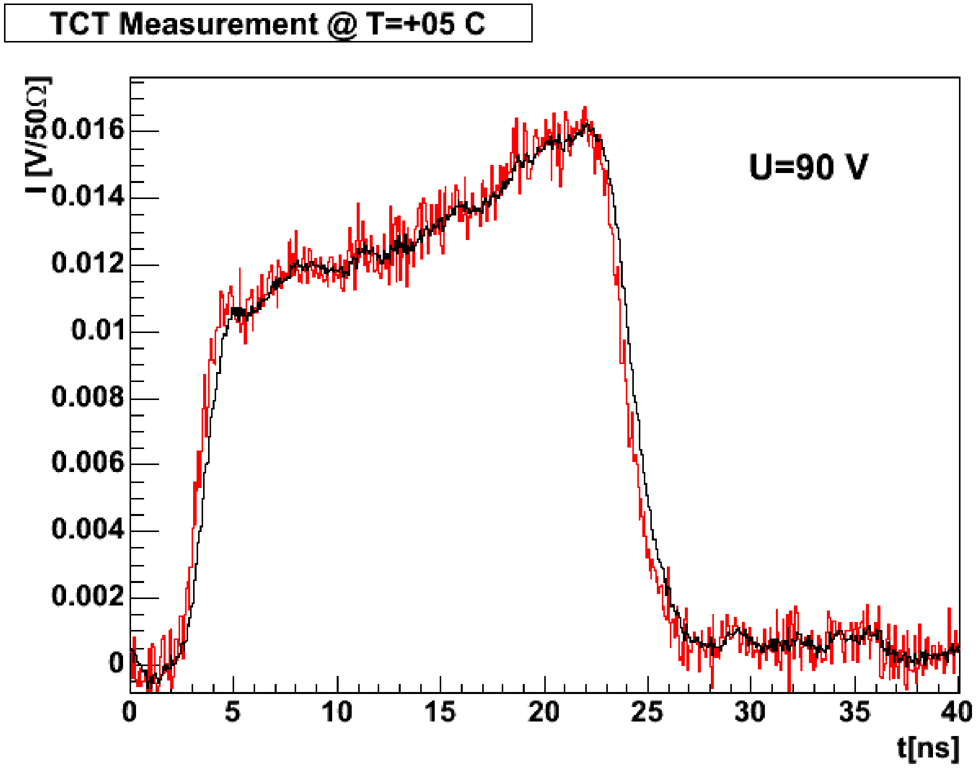
Measured signal = detector signal ⊗ transfer function

Transfer function:

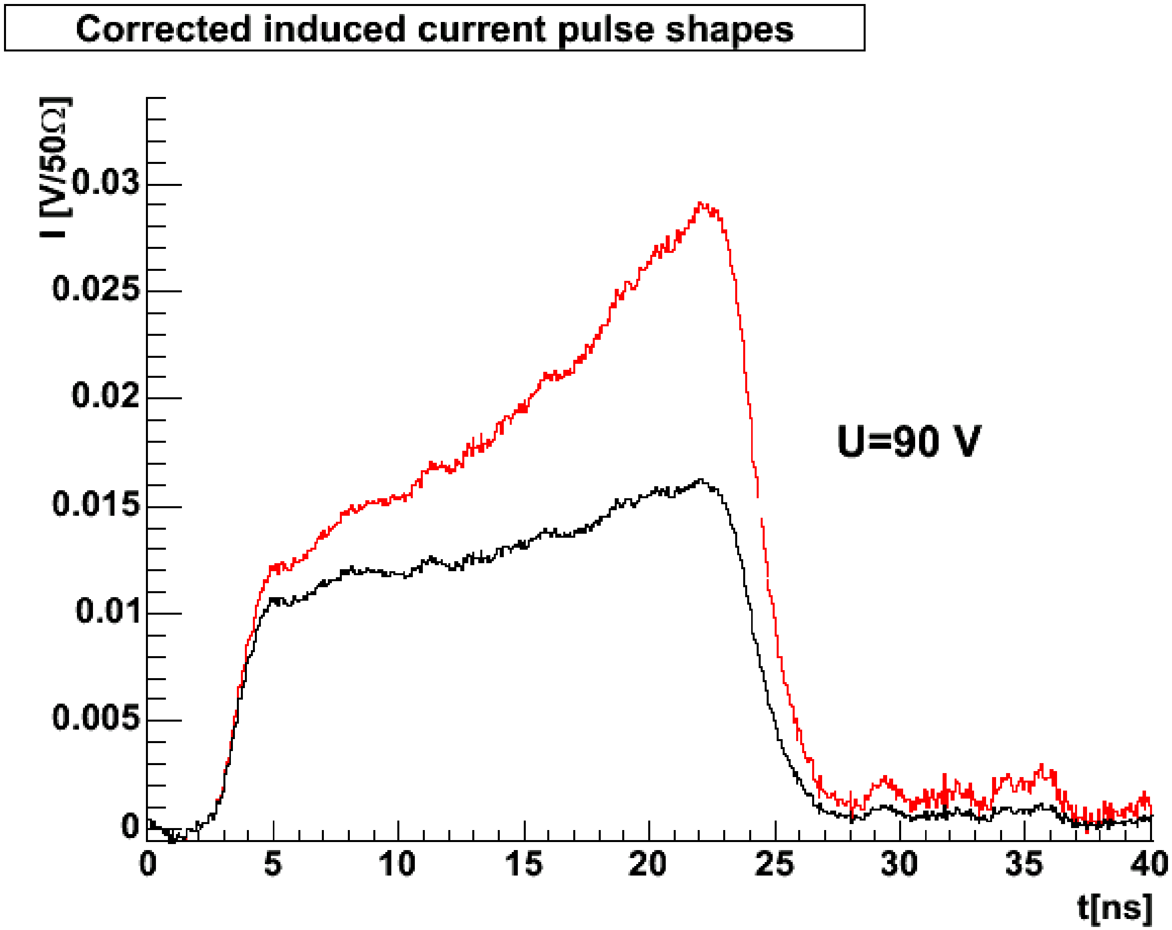
$I(t) = \tau_{TCT}/R \times dU_{osc}(t)/dt + U_{osc}(t)/R$

R = 50Ω from input of preamp

$\tau_{TCT} = RC_d$ (C_d = detector capacitance)



Back up slide 2 – signal examples

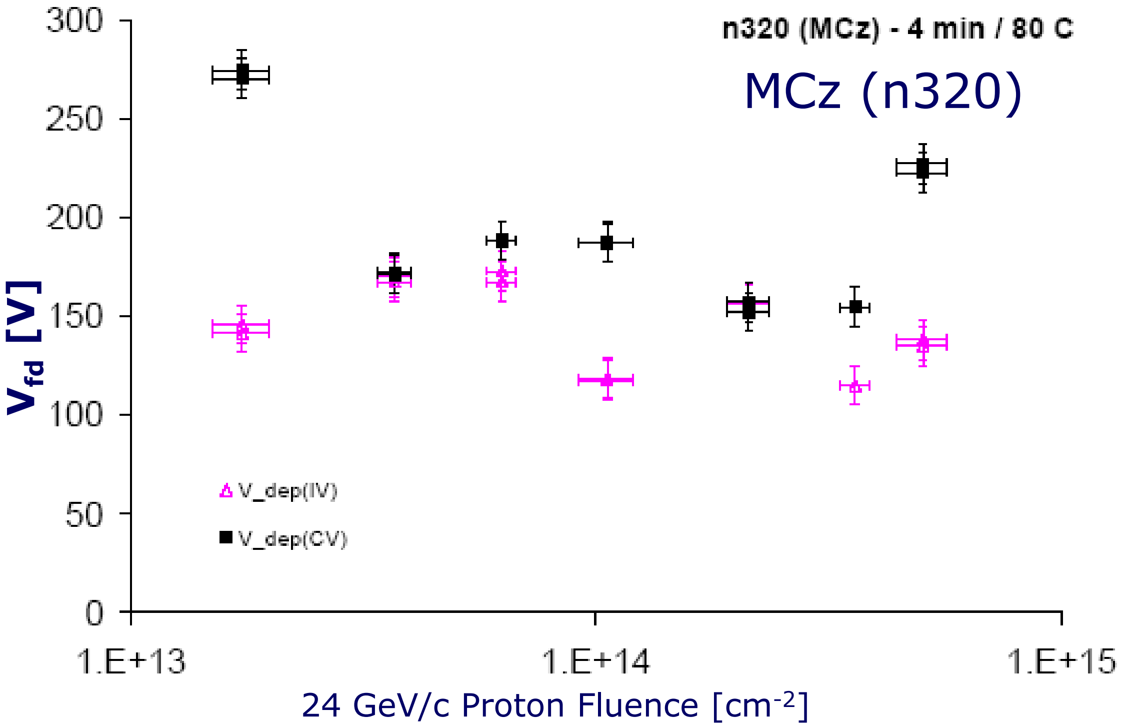


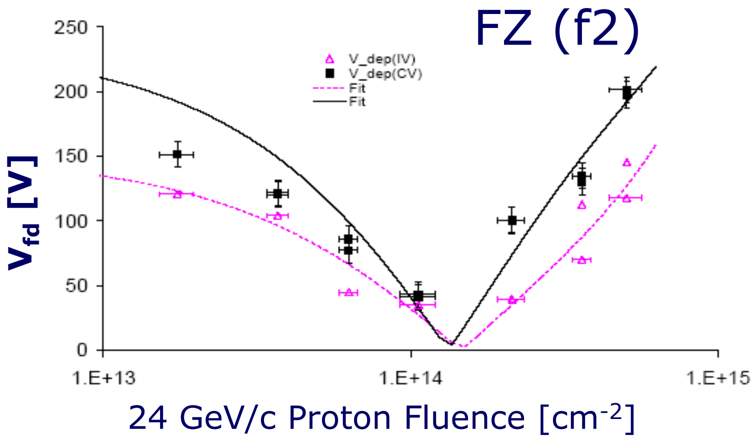
Black = signal as measured on the scope

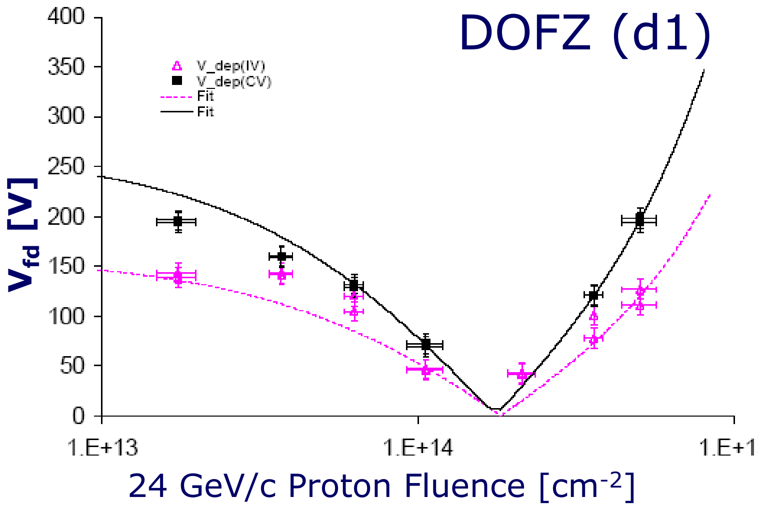
Red = Trapping corrected signal

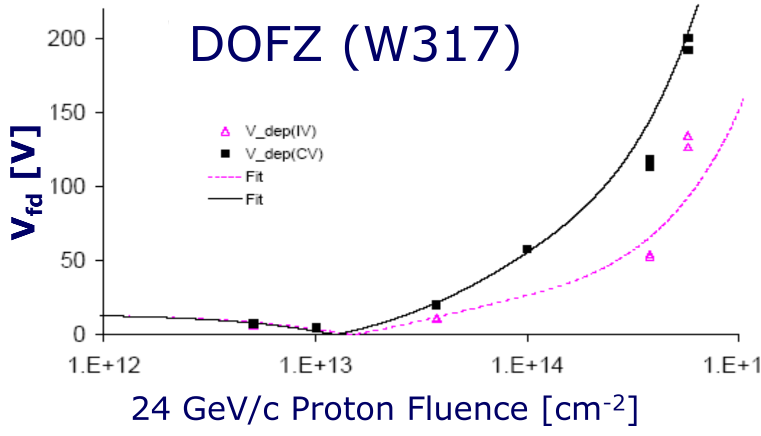
IV/CV analysis

- CV measurements - 10kHz
- Measurement at room temperature, then corrected to 20^{o}C
- Guard rings grounded
- Annealed for 4 min / 80^{o}C

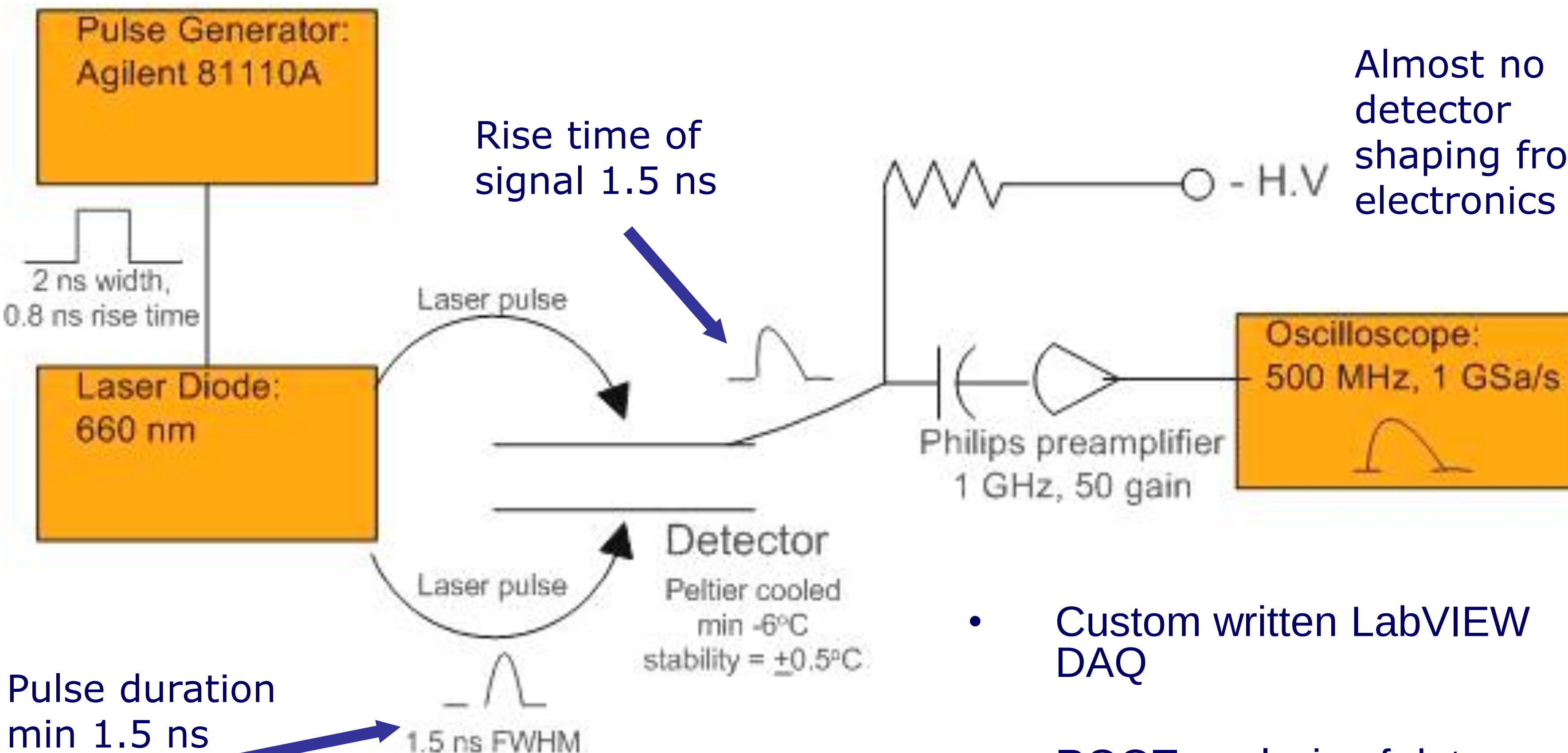








TCT Diagram



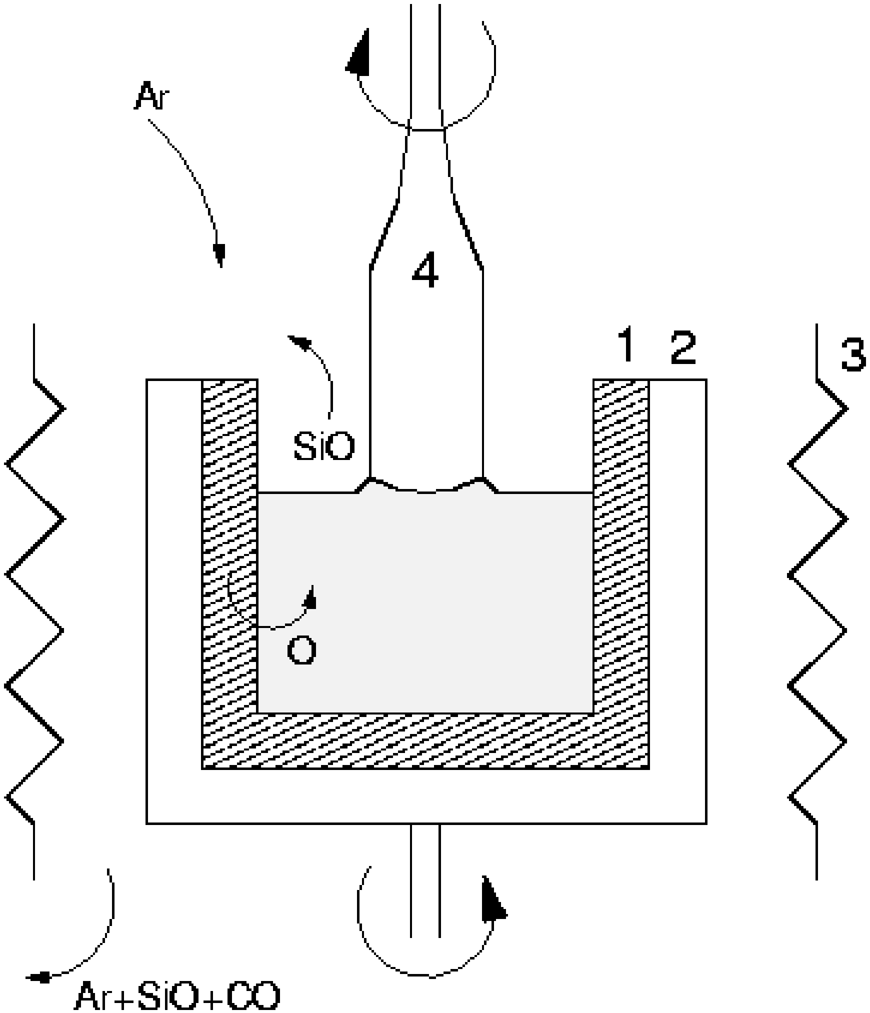
Rise time of signal 1.5 ns

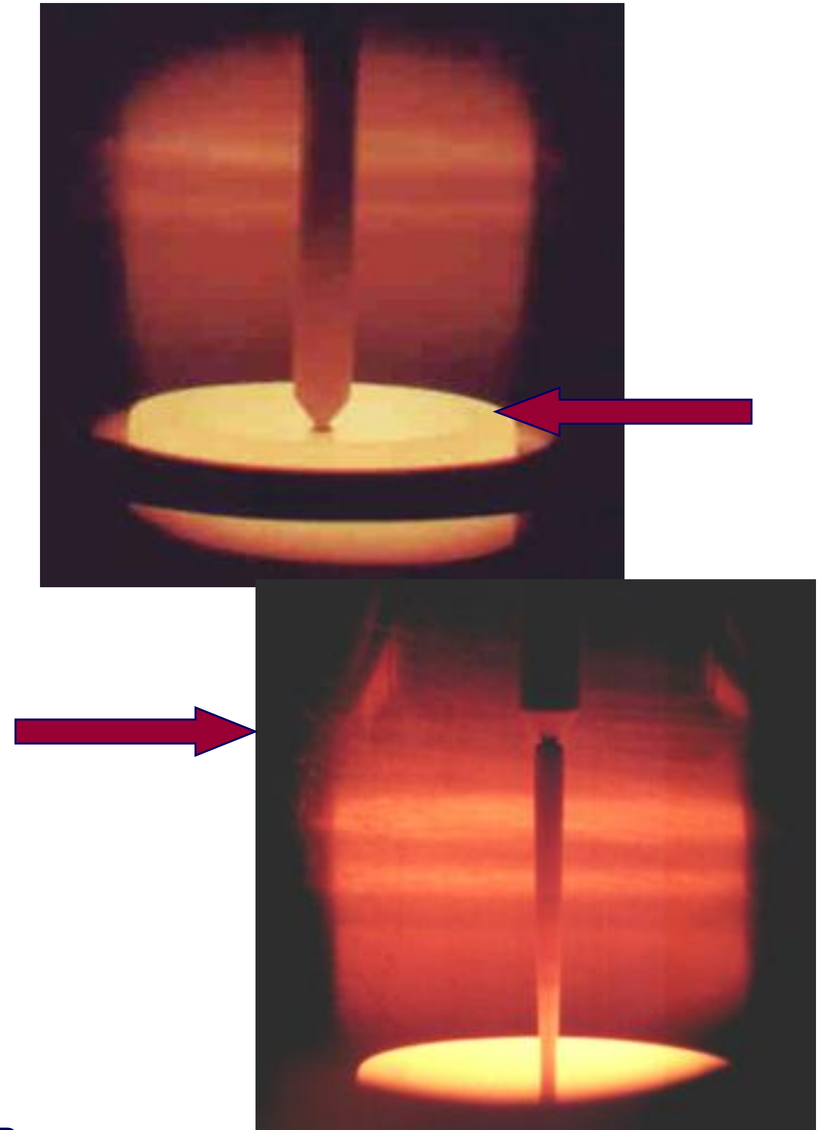
Almost no detector shaping from electronics

Pulse duration min 1.5 ns FWHM

- Custom written LabVIEW DAQ
- ROOT analysis of data

MCz



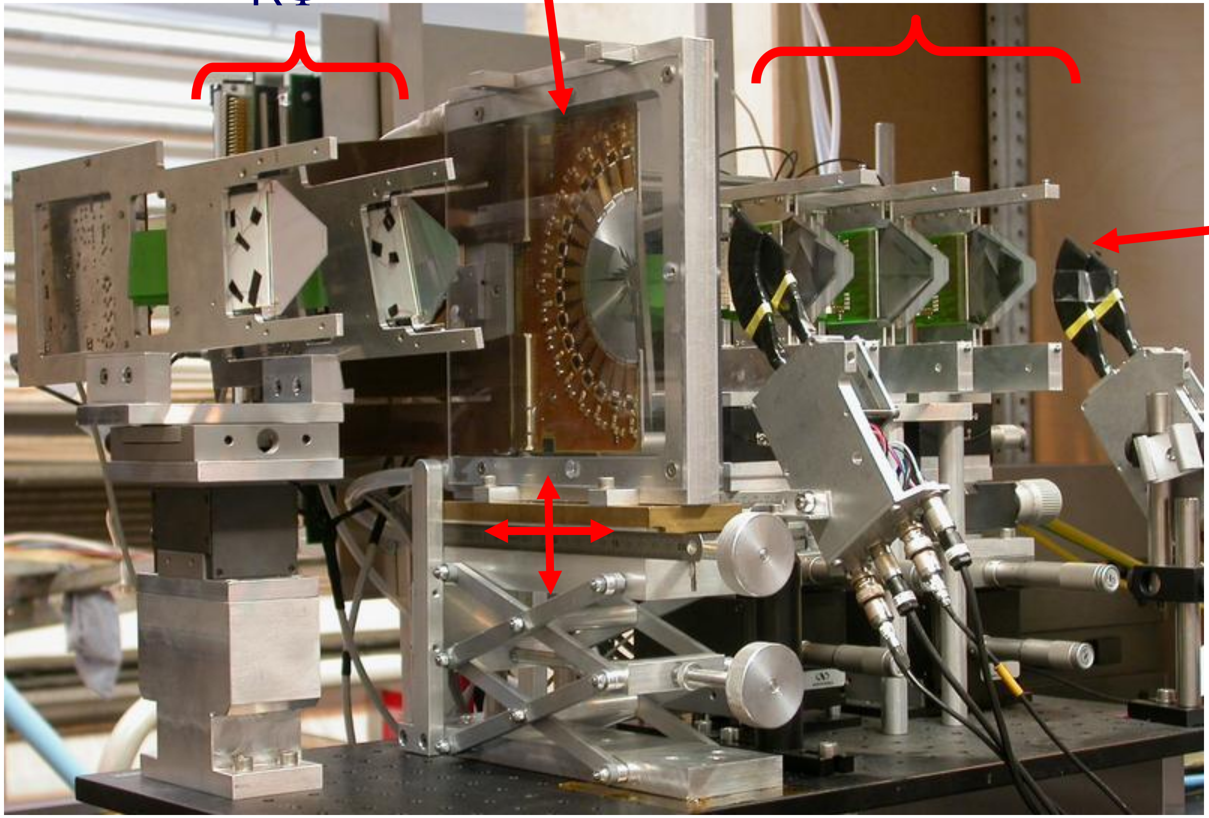


Beam Test: Setup

test module

Far station
RΦ

first telescope station
ΦR RΦ ΦR



CERN SPS X7
120GeV μ/π

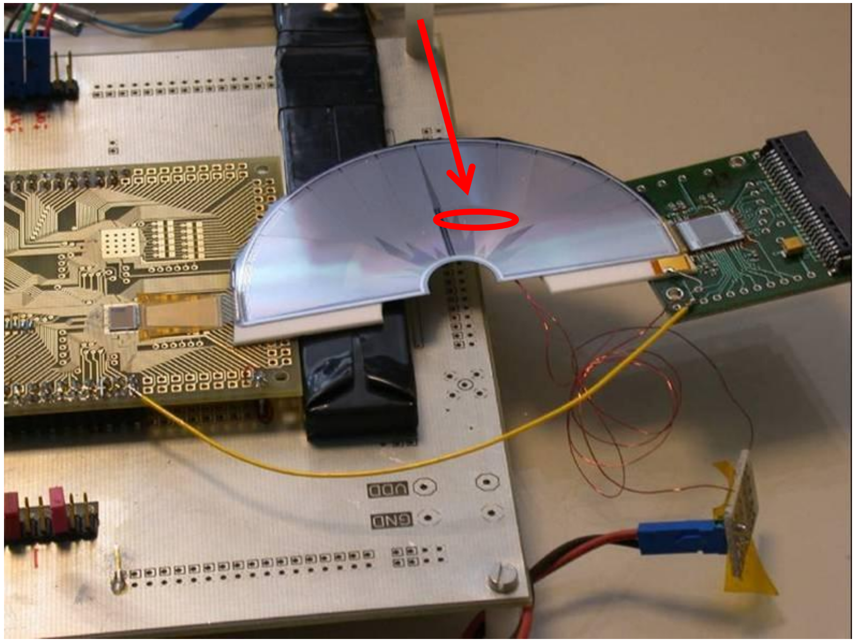
Back up slide from D Eckstein, Vertex 2004

Modules recently tested

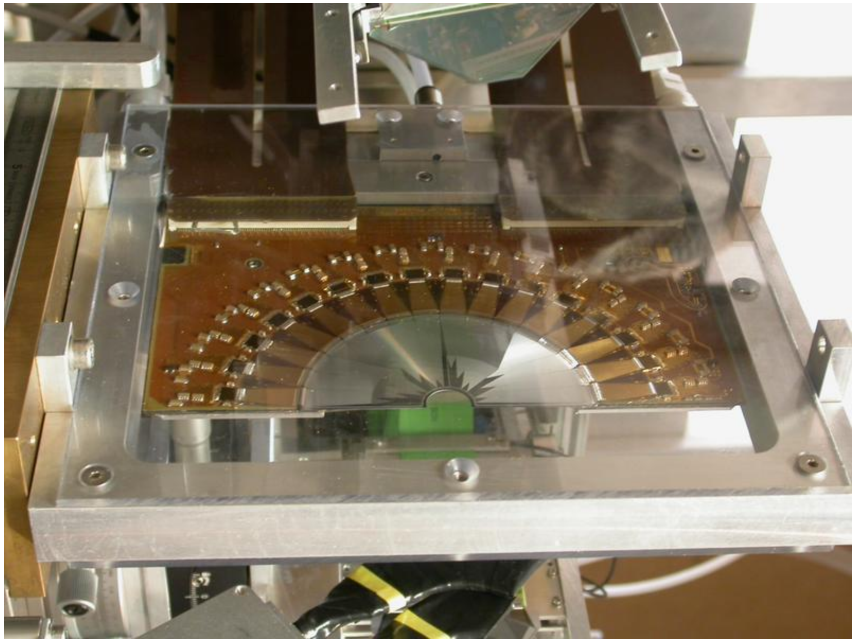
- in Summer 2003:
- 200μm thick PR03
- n-on-n R-sensor
- 1 Beetle1.2 on PCB
- 1 chip region read out

- in June 2004:
- 300μm thick PR03
- n-on-n R-sensor
- fully populated K03 hybrid
- Beetle1.3 tested

many regions read out



Data with tracks in telescope
single sample



track data not yet analysed – use stand-alone
15 consecutive samples read out

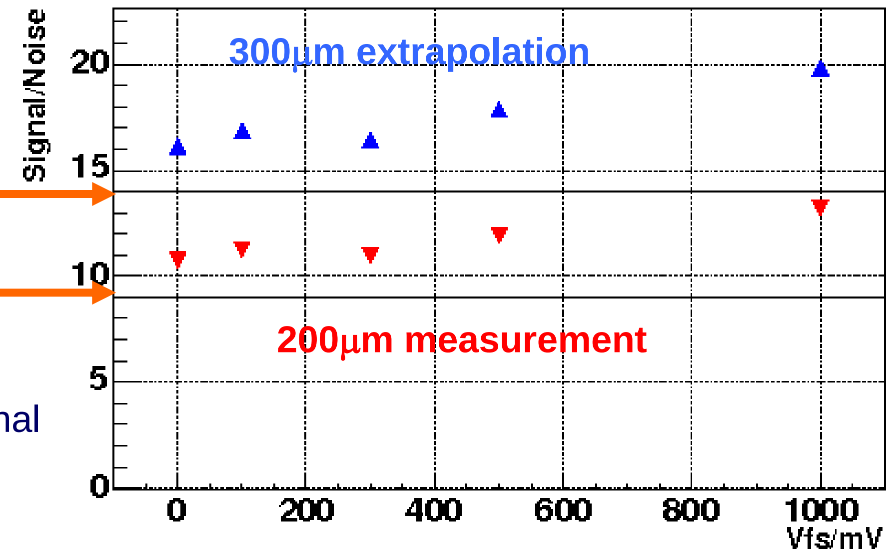
Back up slide from D Eckstein, Vertex 2004

Beam Test 2003 – Results

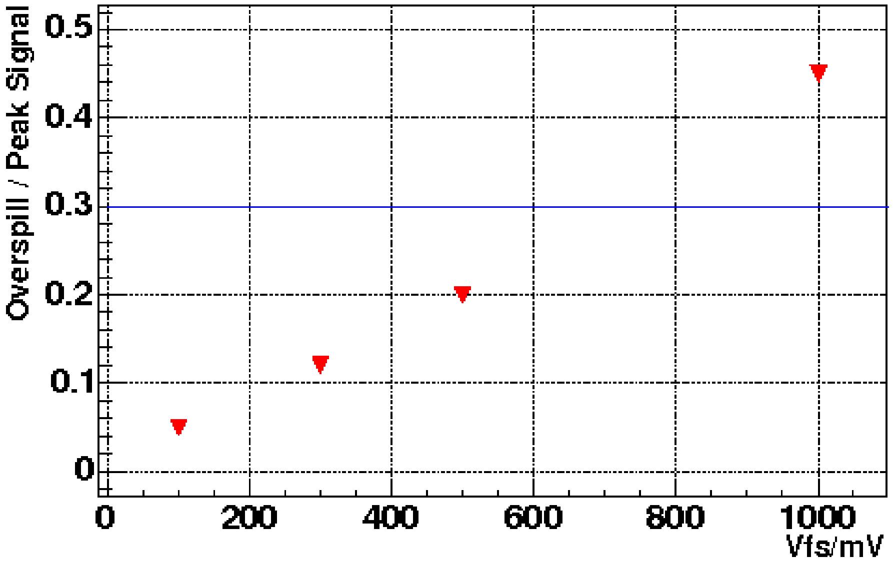
S/N and Spillover for a set of Beetle Bias settings

Minimum at LHCb startup

Minimum requirement for Trigger



spillover: signal at 25ns after peak in % of the peak signal



Maximum requirement from Trigger

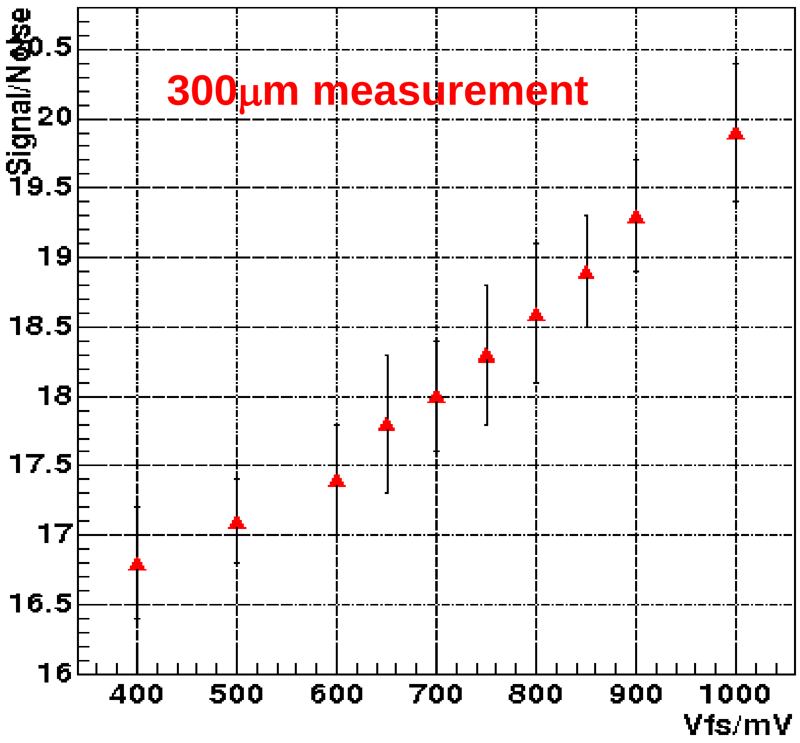
S/N for 200μm at the lower side

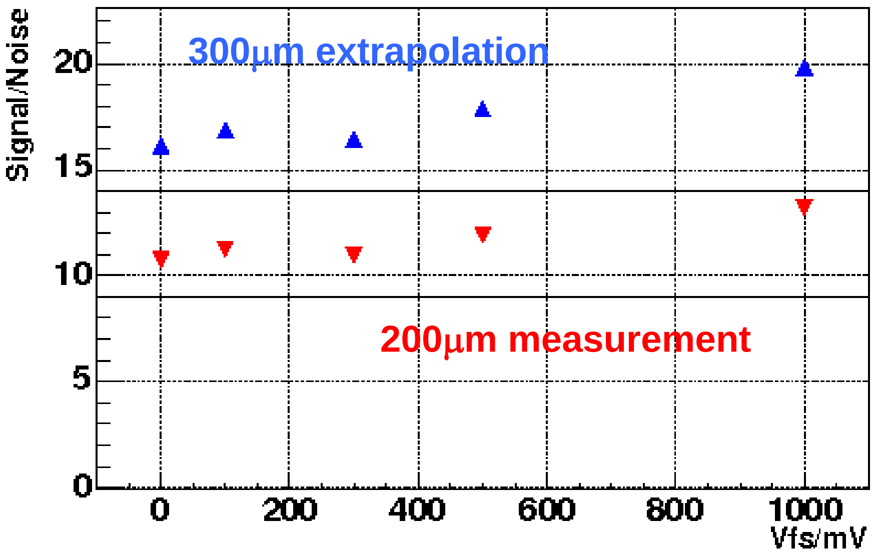
→ test 300μm

Back up slide from D Eckstein, Vertex 2004

new 2004 Data- Results

➔S/N for 300μm agrees with scaled 200μm





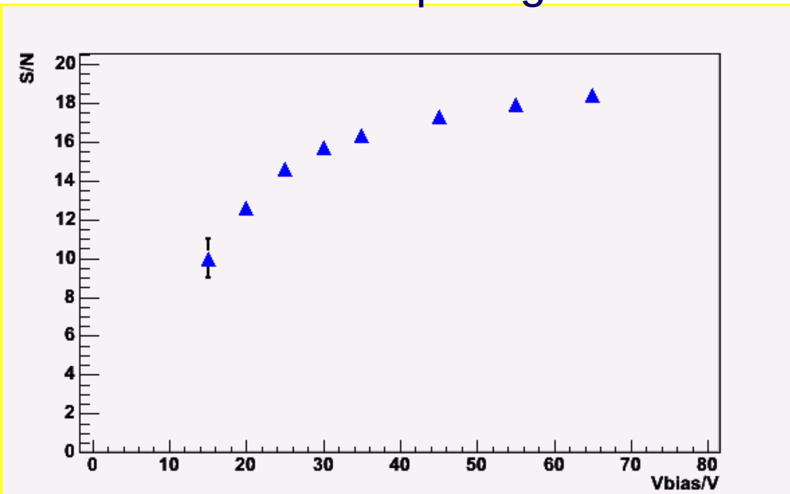
➔the K03 hybrid (and other components in the chain) do not add noise
➔S/N in agreement with requirements – should we use the thicker sensors?

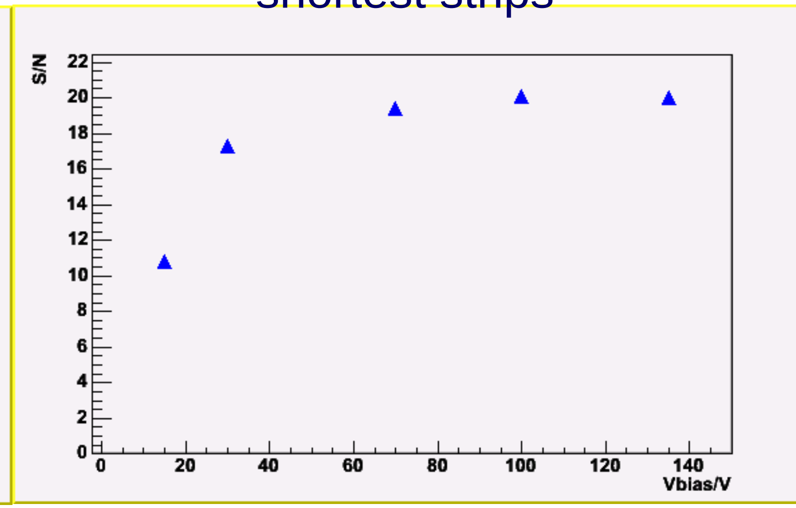
Back up slide from D Eckstein, Vertex 2004

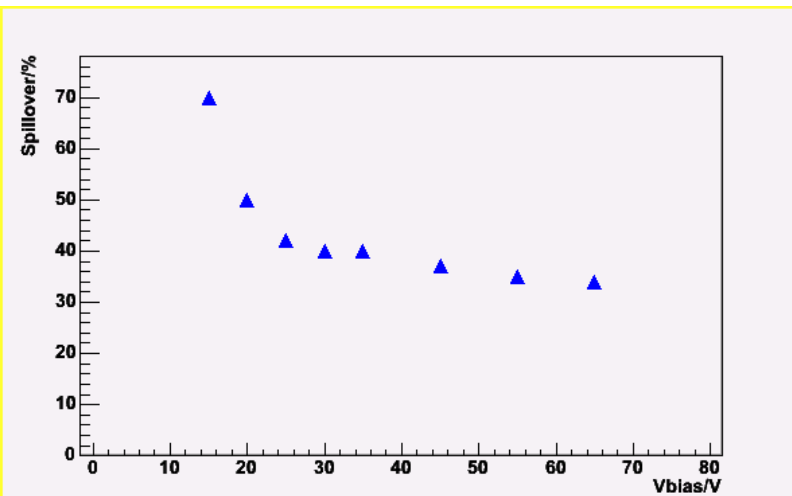
new 2004 Data- Results

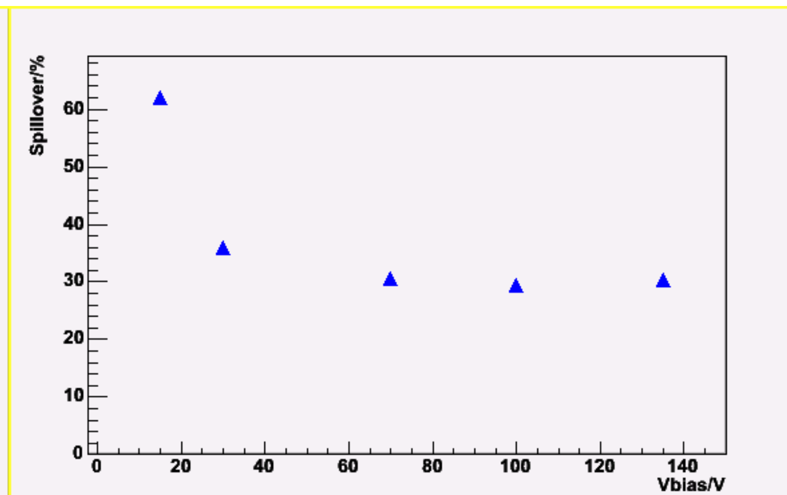
medium strip length

shortest strips









it is safer to run at ~100V

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