



Vertex'05 Workshop
Lake Chuzenji, Nikko
November 9, 2005

Long Ladder Performance

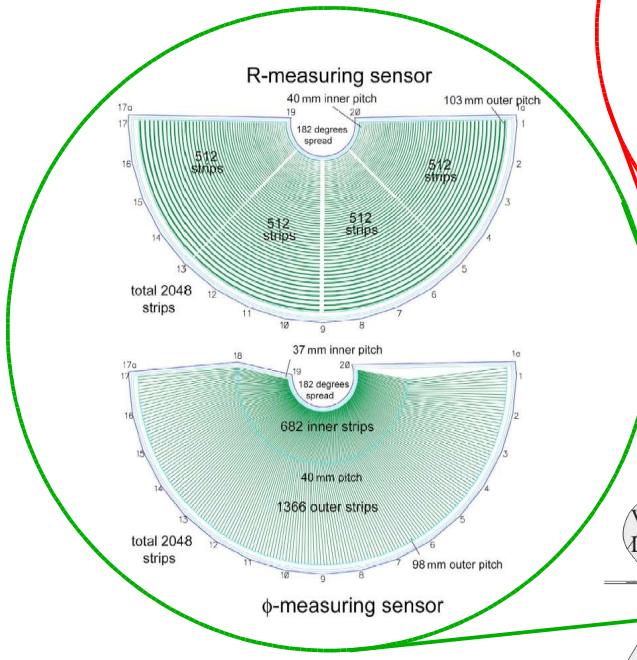
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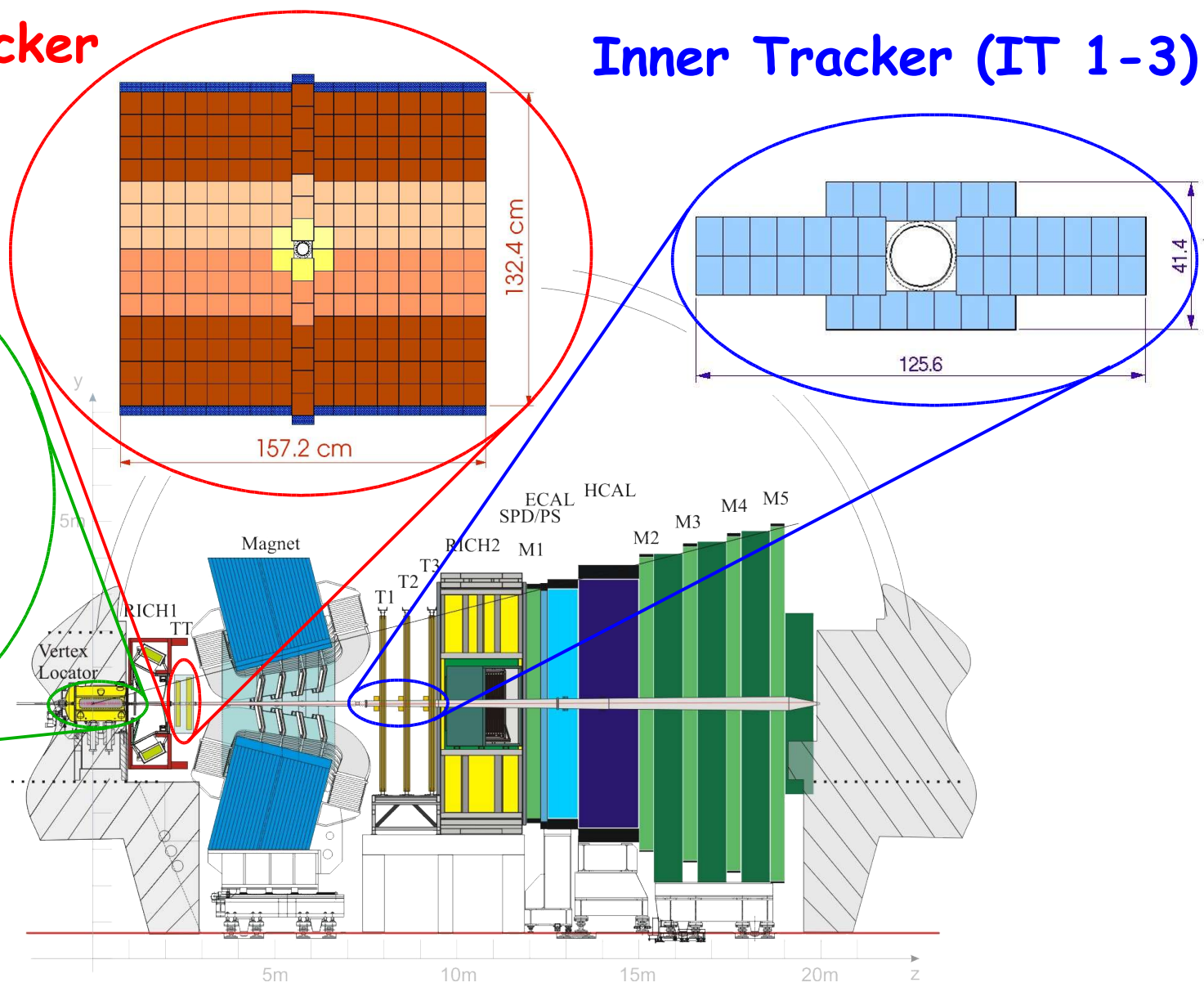
LHCb Silicon Detectors

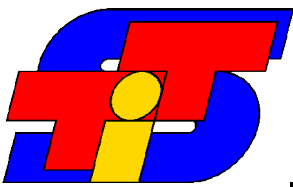
Trigger Tracker (TT)

Inner Tracker (IT 1-3)

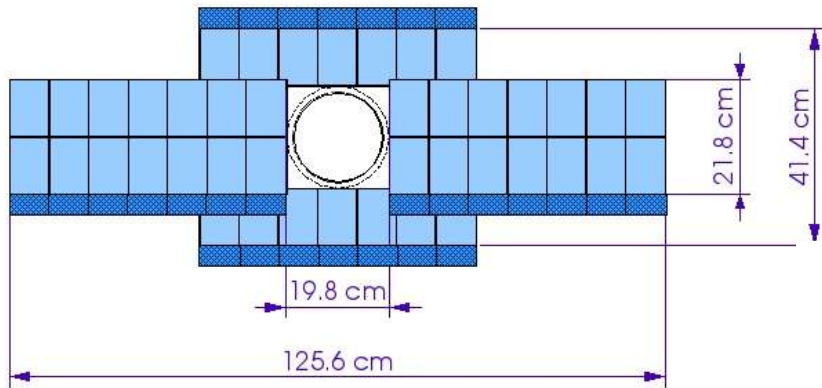


Vertex Locator (VELO)





Inner Tracker

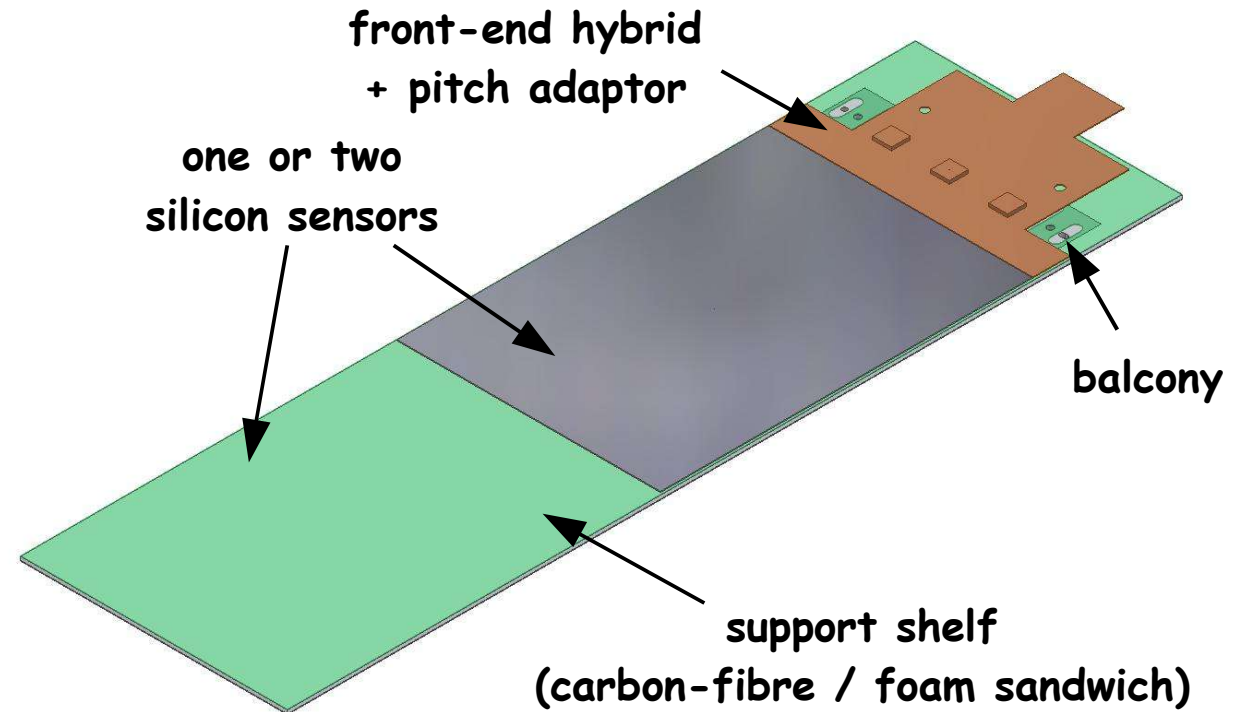


Three stations with four layers each:

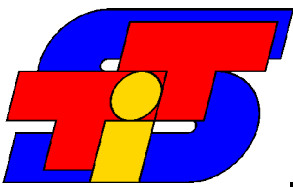
- 1-sensor ladders above/below beam pipe
- 2-sensor ladders left/right of beam pipe

Silicon sensors (UniZH):

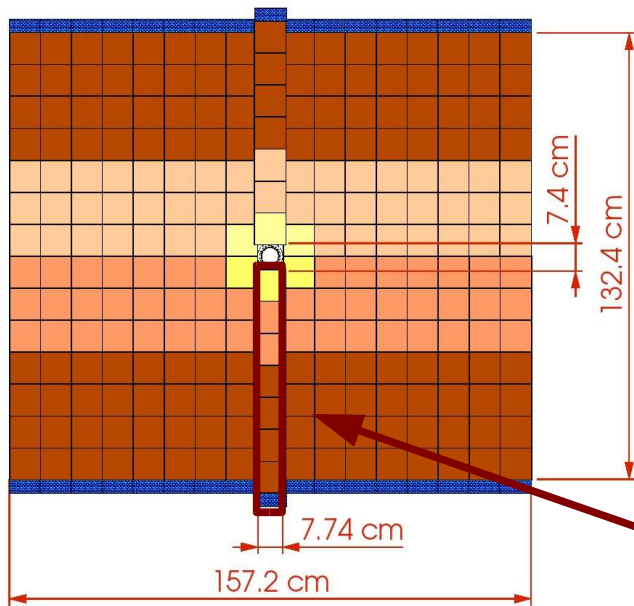
- 320 μm and 410 μm thick
- 384 readout strips
- 108 mm long
- 198 μm pitch, w/p = 0.25
- produced by HPK



=> total of 504 silicon sensors, 336 ladders, 130k readout strips



Trigger Tracker

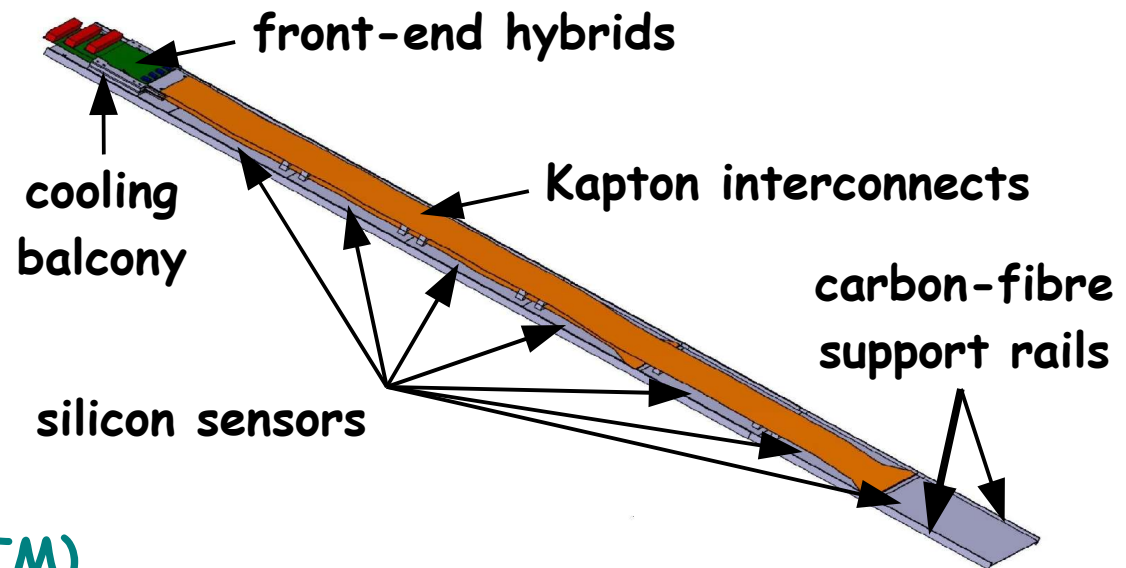


One station with four detection layers:

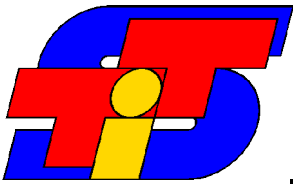
- 7-sensor long "half-modules"
- 1-/2-/3- and 4-sensor long readout sectors
- all front-end hybrids outside of acceptance
- "inner" r/o sectors: Kapton interconnects

Silicon sensors (CMS-OB2):

- 500 μm thick
- 512 readout strips
- 91.57 mm long
- 183 μm pitch, w/p = 0.25
- produced by HPK (pre-series: STM)



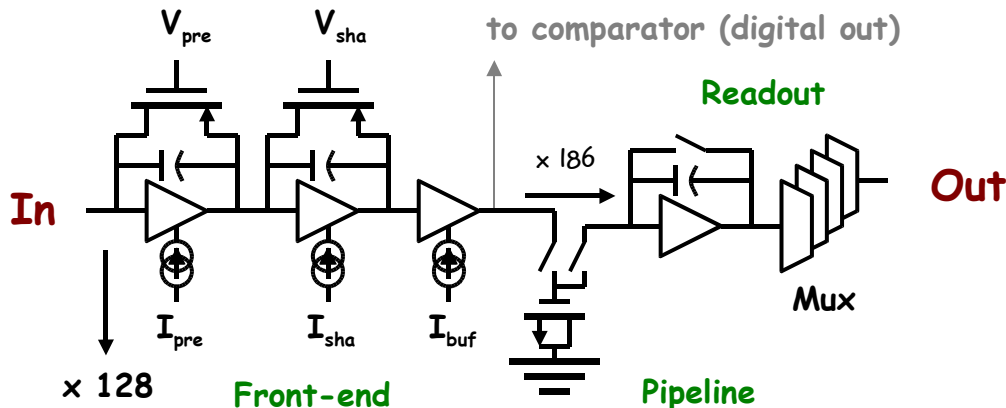
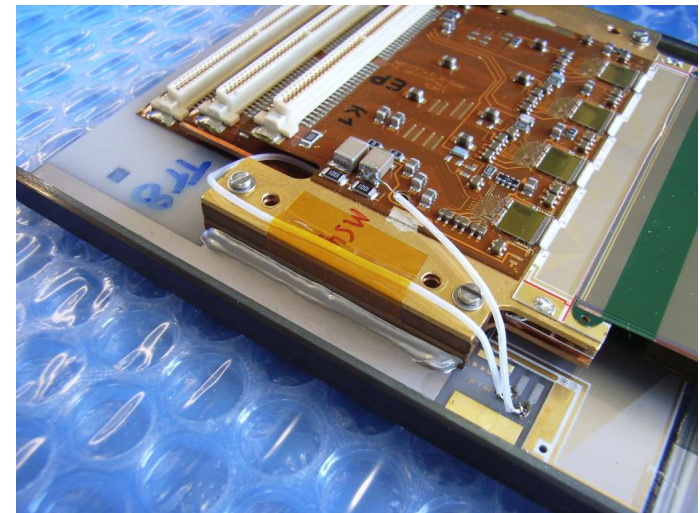
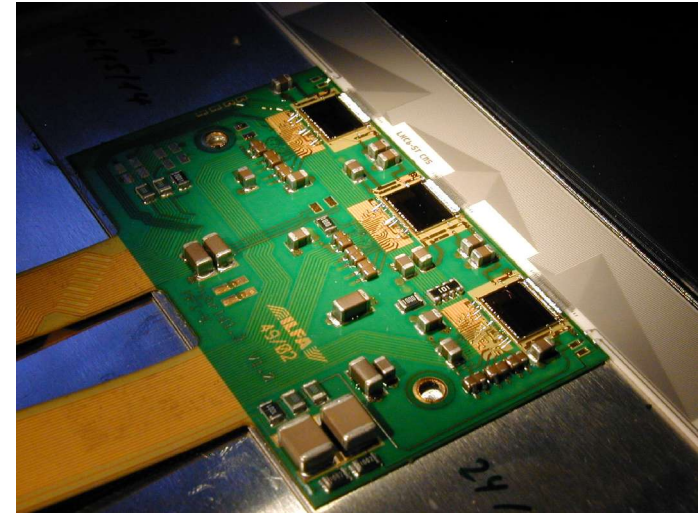
=> total of 896 silicon sensors, 280 readout sectors, 143k readout strips

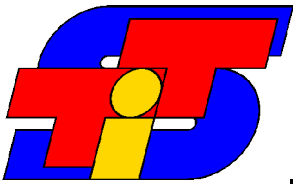


"Beetle" Readout Chip

Common development for LHCb silicon strip detectors (ASIC lab HD):

- designed to meet LHCb trigger requirements
- 0.25 μm CMOS, triple-redundant logic
- 128 channels, analog pipeline
- multiplexed readout via four analog ports
- front-end amplifier optimised for speed and noise performance
- "RC-CR" shaper with shaping time of ~ 25 ns
=> adjustable within certain range (via V_{fs})

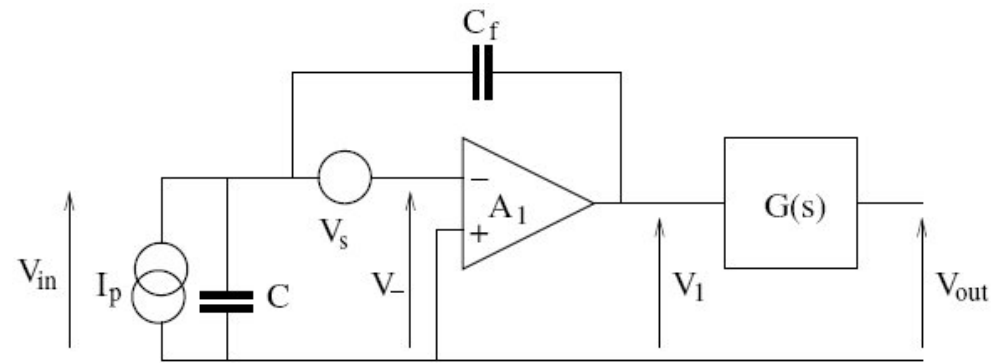




Noise Model

Charge-sensitive amplifier:

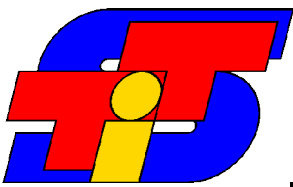
- $G(s)$: transfer function of shaper
- C : load capacitance
- V_s : serial noise of input FET
- I_p : parallel noise from leakage currents



$$ENC^2 = \int_0^{\infty} \frac{1}{2\pi} \cdot \left(\frac{8kT}{3g_m} (C + C_f)^2 \omega^2 + 2eI_{bias} \right) \cdot \frac{|L(V_0 \cdot v(t))|}{V_0} d\omega$$

- calculate serial noise using measured Beetle response function $V_0 \cdot v(t)$
=> good agreement with values measured on a test bench

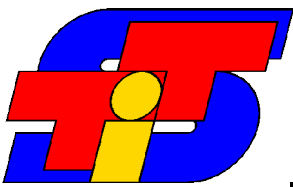
V_{fs} [mV]	0	100	400	1000
calculated serial noise [e/pF]	51.2	50.9	49.0	43.0
measured serial noise [e/pF]	52.6	51.9	49.4	45.2



Tested Detectors

Various thicknesses, strip lengths and strip geometries:

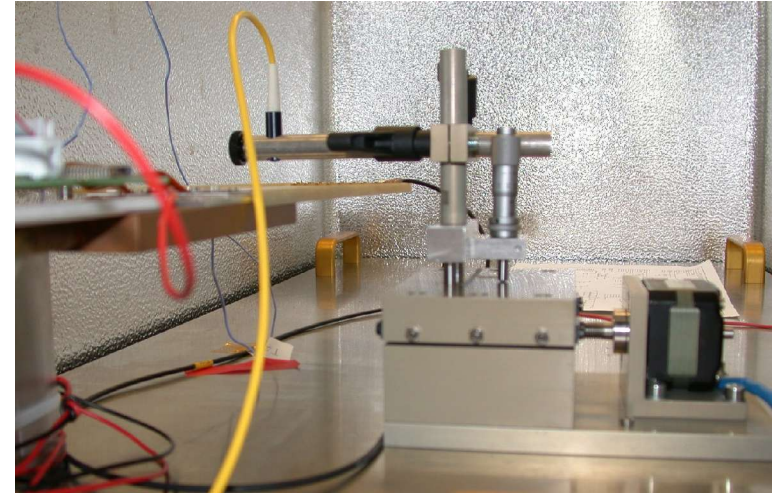
- 320 μm thick (IT prototype sensors)
 - strip pitch: 198 μm and 237.5 μm , w/p: 0.25, 0.3 and 0.35
 - strip length 108 mm (1 sensor), 216 mm (2 sensors), 324 mm (3 sensors)
- 410 μm thick (GLAST sensors)
 - strip pitch 228 μm , w/p: 0.25, strip length 263 mm (3 sensors)
- 500 μm thick (CMS-OB2 sensors)
 - strip pitch 183 μm , w/p: 0.25, strip length 289 mm (3 sensors)
 - also: 3 sensor long ladder with 40 cm long Kapton interconnect cable
- strip resistances measured and calculated => results in good agreement
- strip capacitances measured and calculated in 2D Maxwell simulation
=> results agree within 10 % (Maxwell being consistently lower)
- inductances calculated in 2D Maxwell simulation



Test Setups

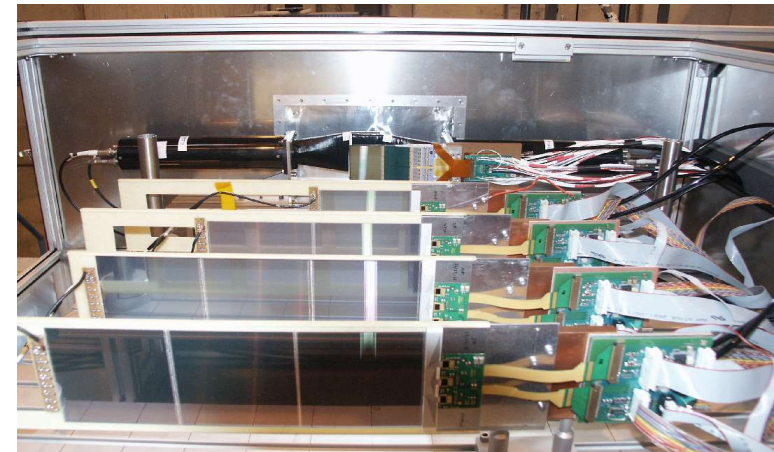
Infrared laser teststand (at UniZH):

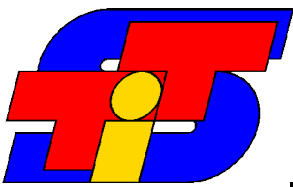
- pulsed laser beam, focussed to $\sim 10 \mu\text{m}$
- can be moved across strips in $5 \mu\text{m}$ steps
 - => detailed studies of signal shapes
 - => relative measurement of CCE as a function of position in between strips
 - => does NOT permit absolute noise measurements (signal size unknown)



Test beams (at CERN):

- 120 GeV/c charged pions from the SPS
- impact position measured to $\sim 15 \mu\text{m}$
- permits absolute noise determination using measured S/N and the expected charge deposition for 120 GeV/c pions ($\approx 8.000 e^-$ per $100 \mu\text{m}$)



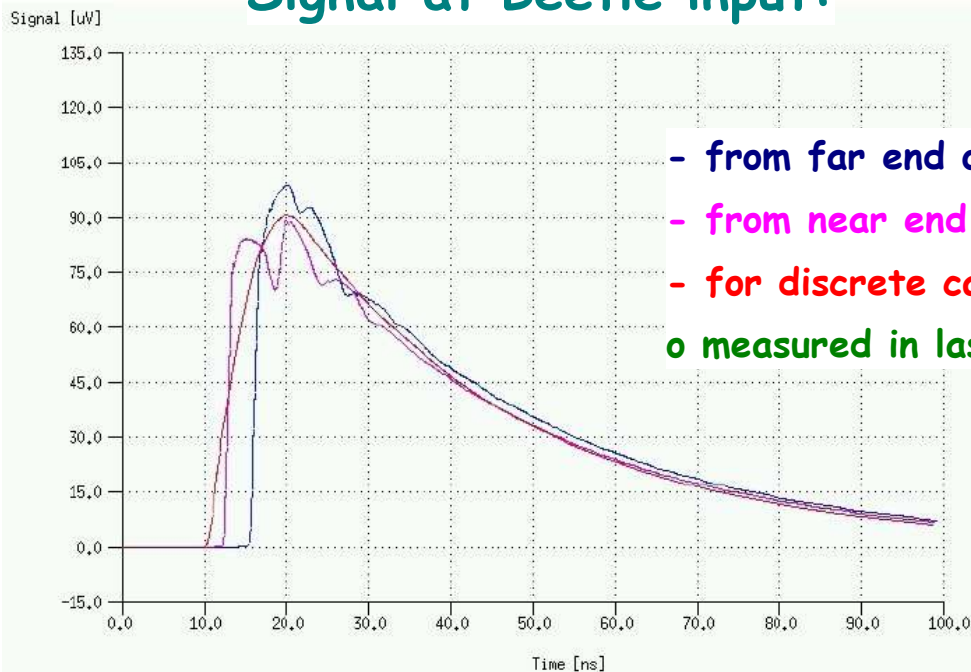


Calculated Signal Shapes

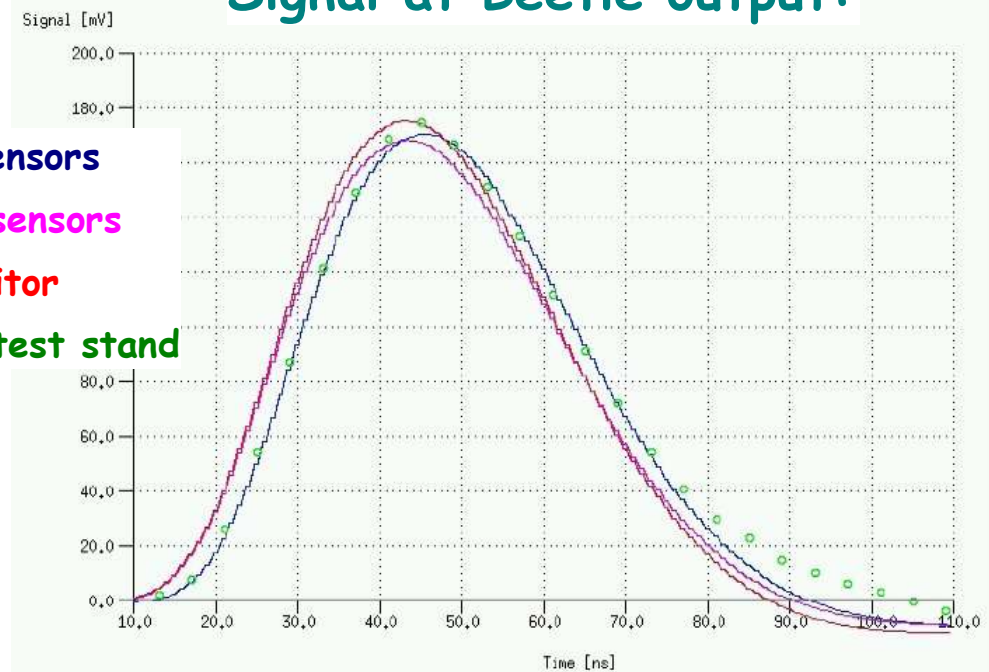
Spice simulation of long readout strips (10 RLC elements / cm):

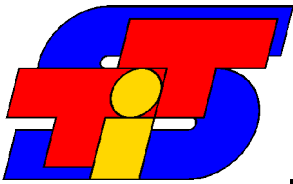
- Example: 3 sensor long CMS-OB2 ladder with Kapton interconnect cable
=> R,L,C determined separately for sensor and interconnect cable !
- Beetle output signal determined using measured Beetle response function
=> signal from far end: peaks ~ 3 ns later, pulse height is ~ 4% smaller

Signal at Beetle input:

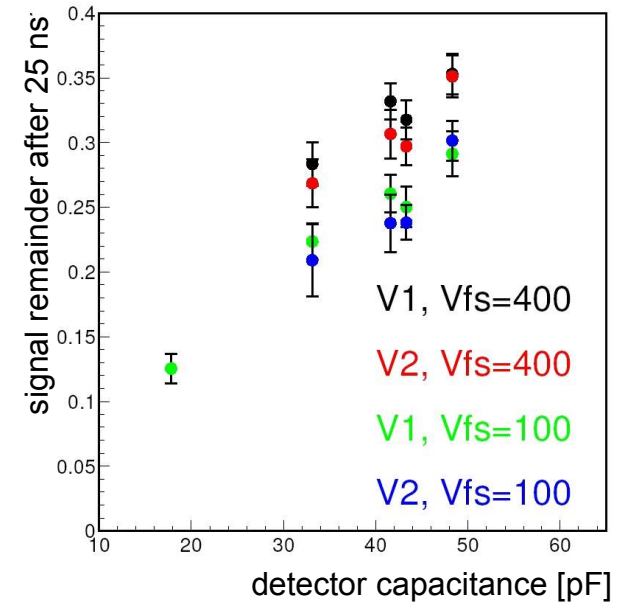
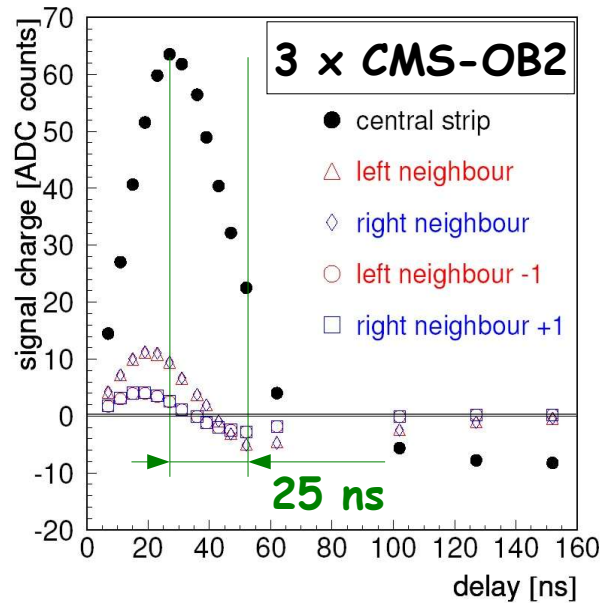
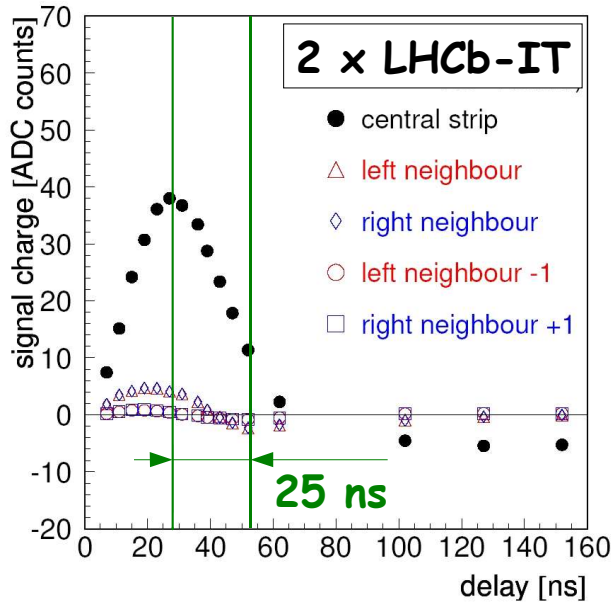


Signal at Beetle output:





Measured Signal Shapes

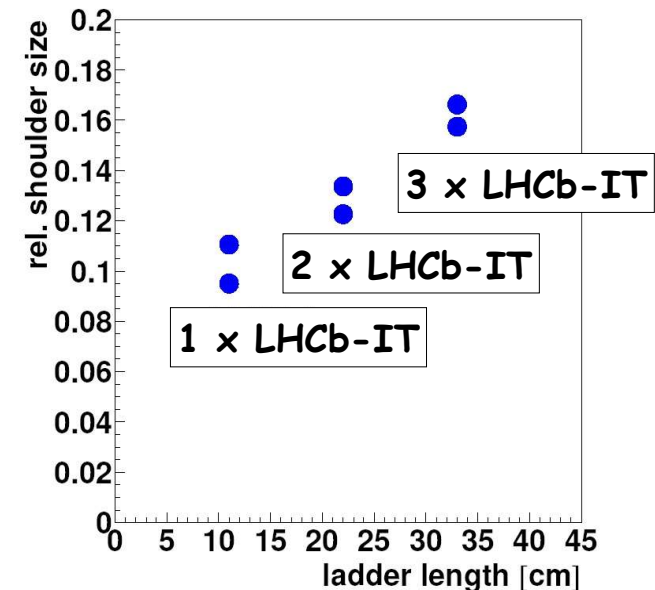


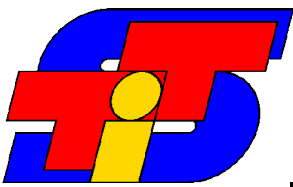
Signal remainder after 25 ns (next BX from LHC)

- increases ~ linearly with detector capacitance
- can be tuned via Beetle settings
- does not depend on overbiasing

Cross-talk signals due to capacitive coupling

- increases ~ linearly with strip length
- peaks and undershoots earlier than main signal





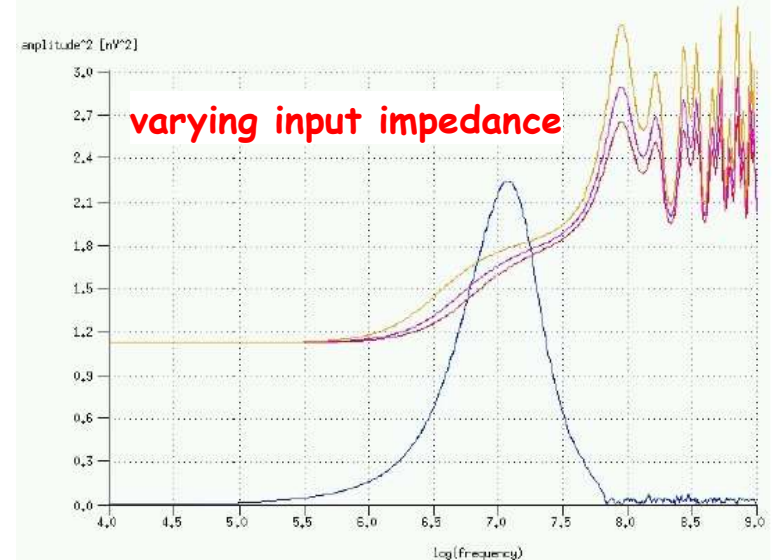
Serial Noise

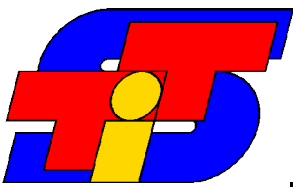
Noise spectrum from the same spice simulation:

- FET equivalent noise resistor (68Ω)
 - “white” noise spectrum
- strip lines:
 - negligible noise at low frequencies
 - resonating behaviour above 100 MHz (lowest Eigenfrequency of the system)

Beetle frequency response spectrum:

- peaks around 10 MHz
 - in rising part of noise spectrum
 - sensitive to details of simulation
 - e.g. significant systematic effect from effective Beetle input impedance





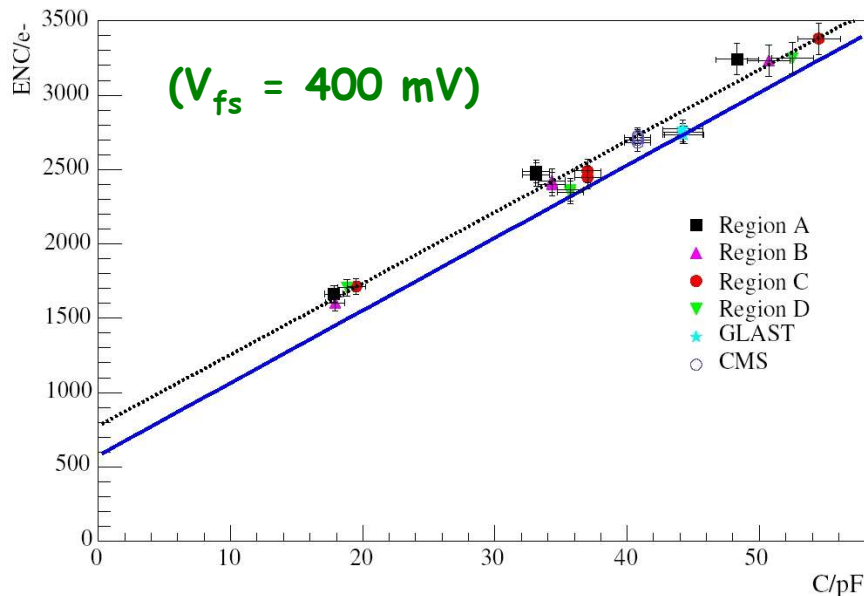
Serial Noise

Convolution of squared noise spectrum and Beetle response spectrum

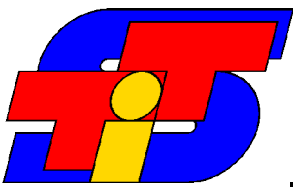
- for 3 x CMS + cable: 3800 e⁻
 - discrete capacitance of 57 pF: 3300 e⁻
- } ~ 15 % increase due to strip resistances

but significant uncertainty on this result !!!!

Measured noise as a function of load capacitance:



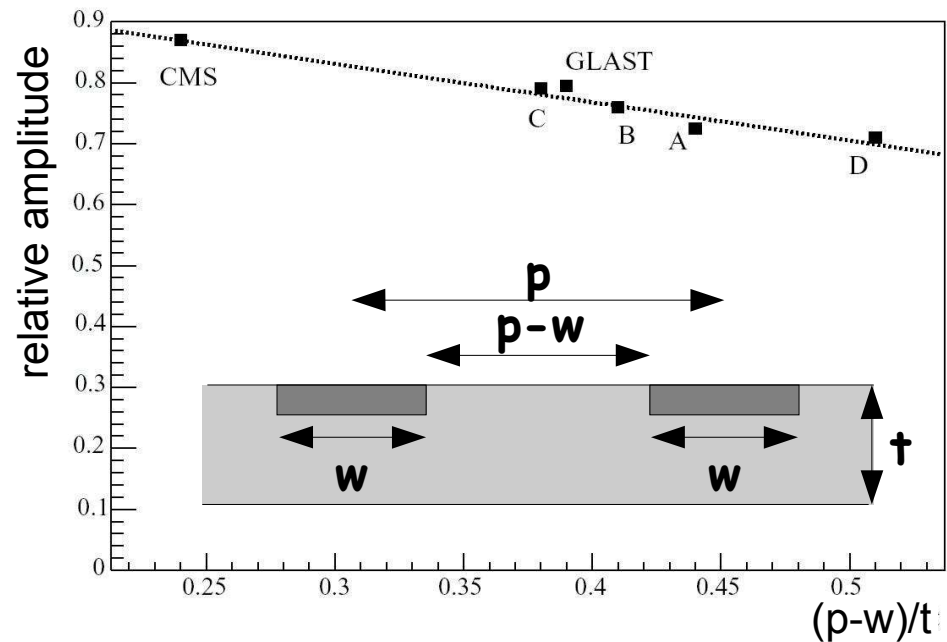
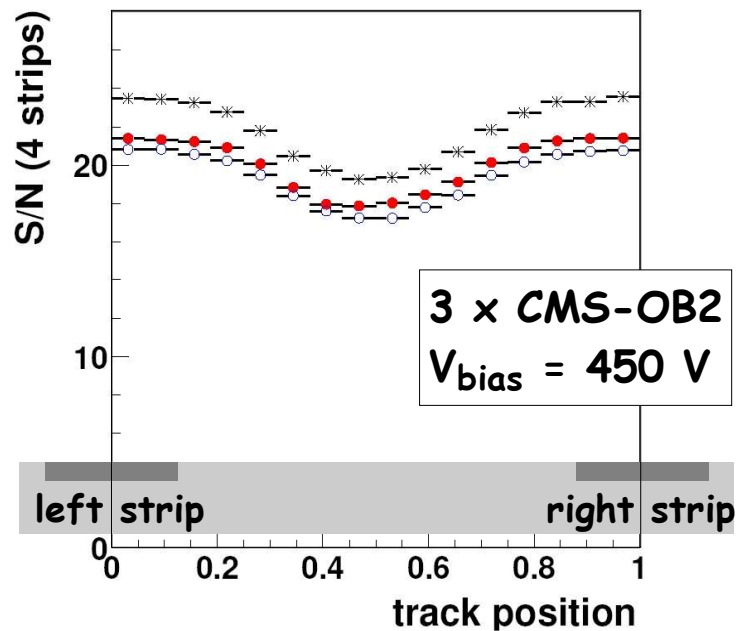
- Test beam with long ladders:
ENC = 770 e⁻ + 47.9 e⁻ / pF
- Test bench measurements with discrete load capacitances:
ENC = 580 e⁻ + 48.8 e⁻ / pF
- good agreement of slopes, no indication for any effect from strip resistances

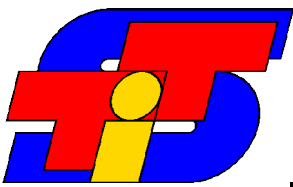


CCE Drop Between Strips

Observe drop of CCE in central region in between two strips:

- is independent of strip length
- depends \sim linearly on ratio (pitch-width) / thickness
- at least qualitatively understood in simulation of charge collection
=> charges trapped at bulk-oxide interface in between strips



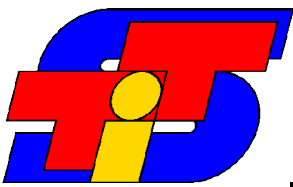


Production Status

Series production started (TT) / about to start (IT):

- achieved sensor alignment better than $\pm 15 \mu\text{m}$ (aim at spatial resolution of $\sim 50 \mu\text{m}$)
- have overcome several HV-related hickups
- some production delays on interconnect cables
- new: bonding problems on IT pitch adaptors (under investigation / production on hold)
- aim for production speed of
 - 5 modules / week (TT)
 - 12 modules / week (IT)
- lots of attention to burn-in test stands
 - use close-to-final detector box
 - use final readout system
- detector installation foreseen June/July '06





Summary

Silicon Tracker uses silicon strip detectors with

- strip pitch around 200 μm
- readout strips of up to 40 cm in length
- up to 40 cm long Kapton interconnect cable between sensor and readout chip
- readout electronics with shaping times around 25 ns

Observations on prototype detectors:

- only small dependence of signal shape on hit position along the strip
 - > also no deterioration of signal shape from long Kapton interconnect
- linear increase of noise with strip capacitance for all tested strip lengths
 - > slope compatible with that obtained from discrete load capacitances
 - > no significant noise contribution from strip resistance
 - > SPICE simulation predicts small effect, but with large uncertainties
- significant CCE loss in central region between two strips
 - > scales roughly with $(p-w) / d$, seems due to charge trapping at surface