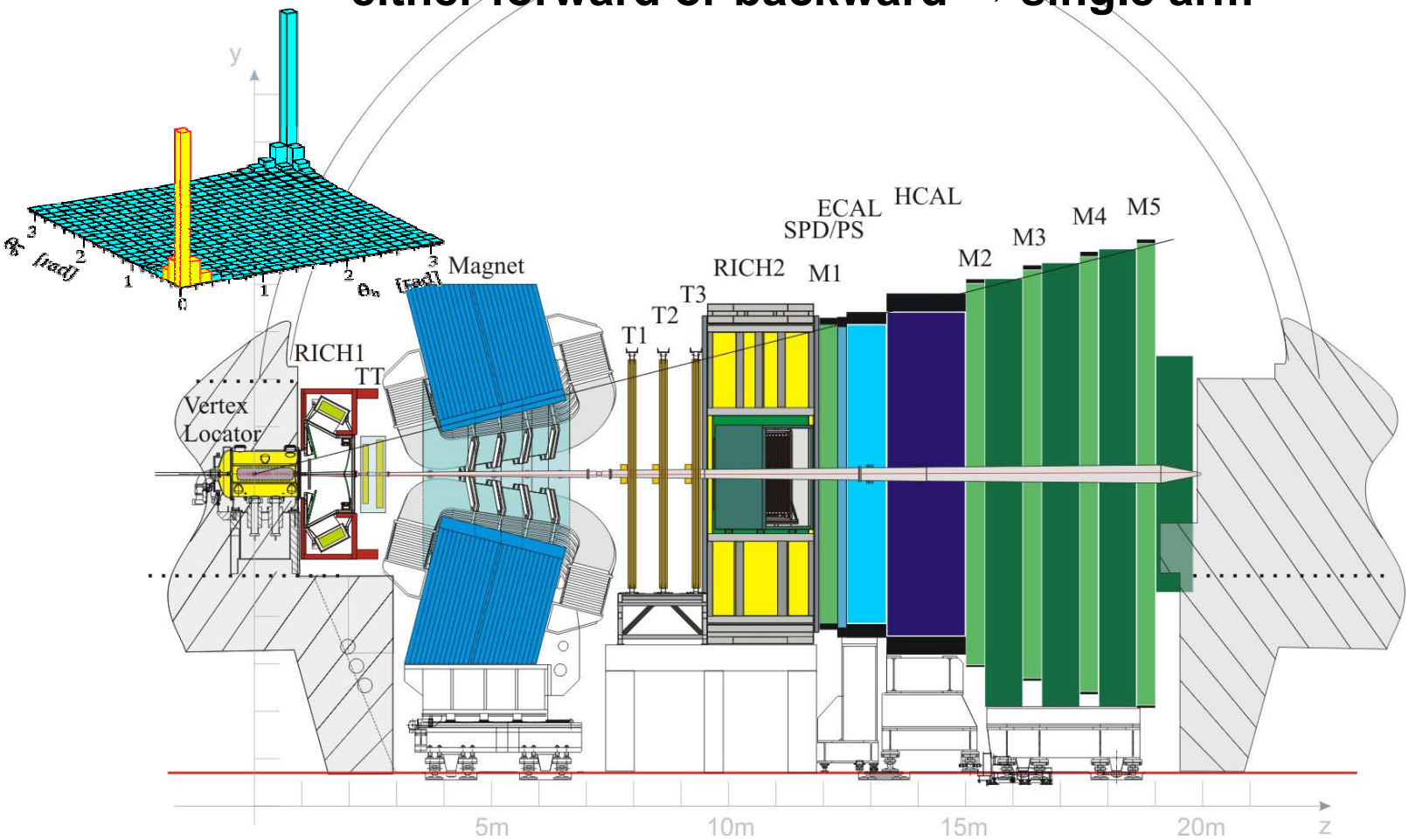
The Silicon Tracker of the LHCb experiment

Stefan Koestner
on behalf of the
LHCb Silicon Tracker Collaboration

IEEE - Nuclear Science Symposium
ROME, Oct. 20th 2004

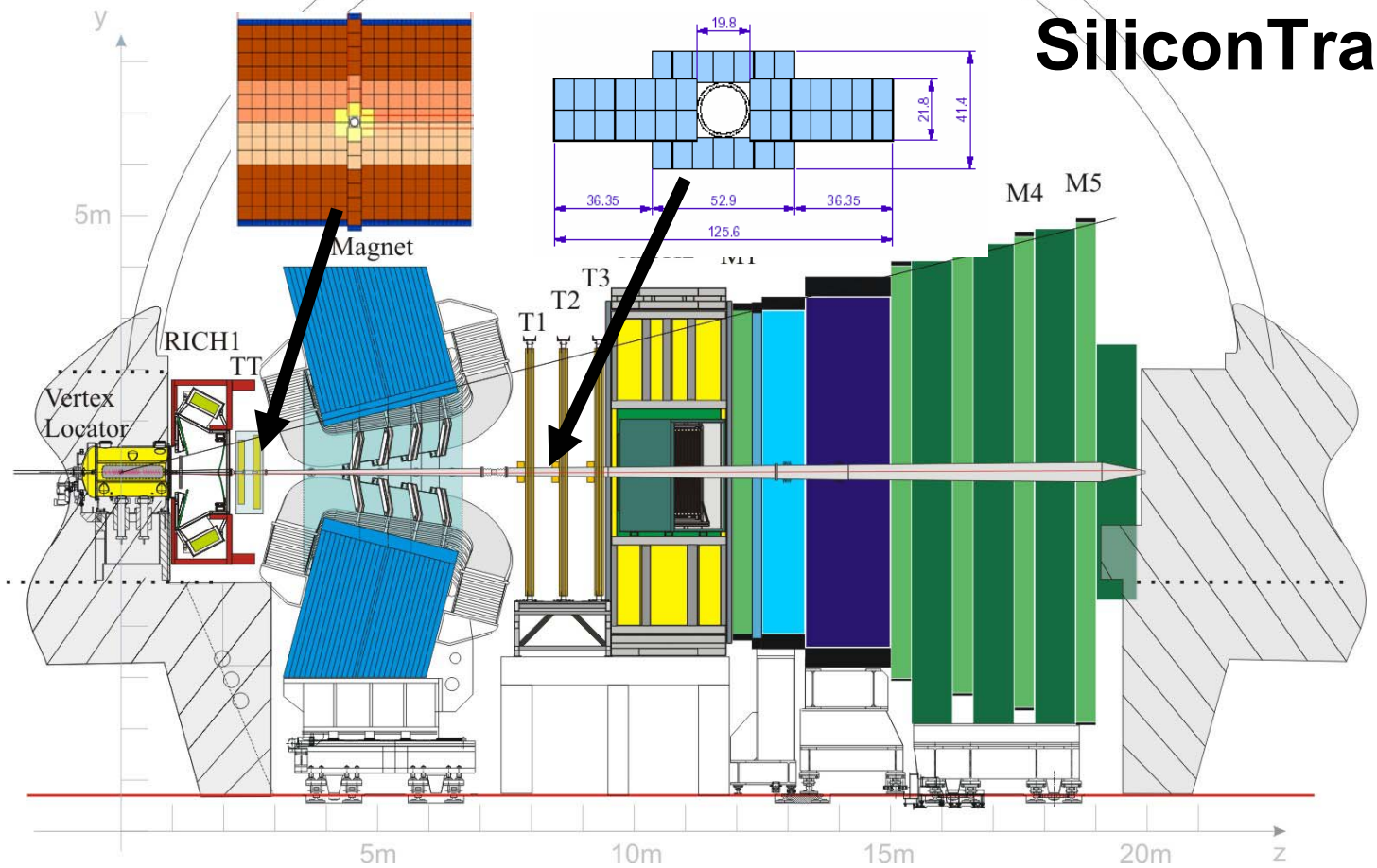
The LHCb experiment

angular distribution of $b\bar{b}$-pairs → forward spectrometer (15-300 mrad)
either forward or backward → single arm

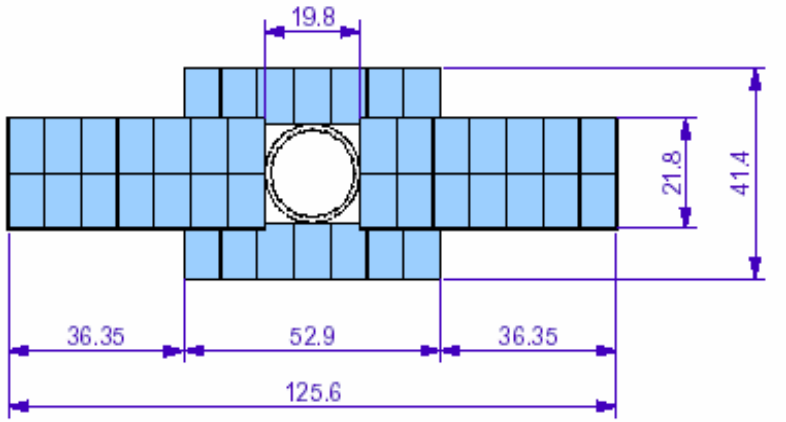


The LHCb experiment

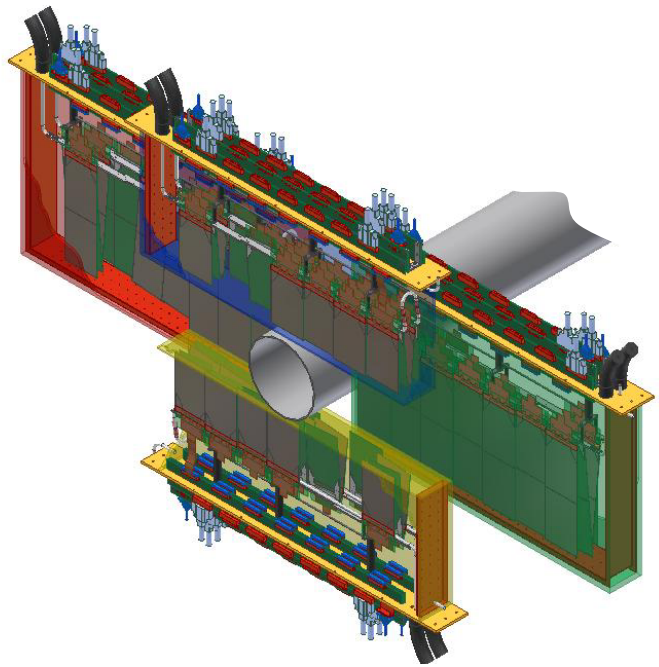
TriggerTracker + InnerTracker = SiliconTracker



The Inner Tracker



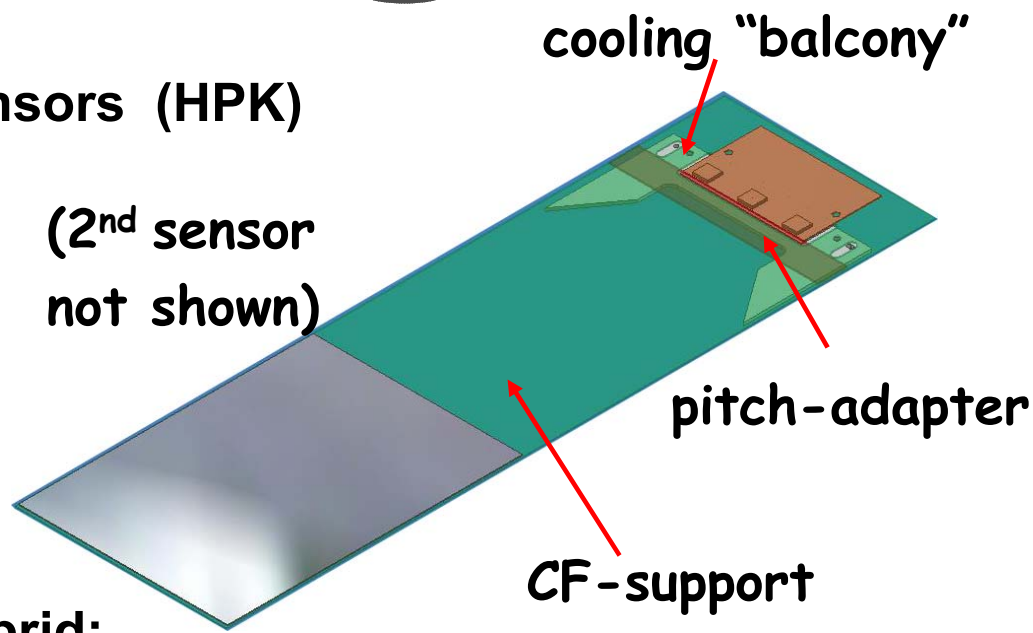
- 4 individual boxes per station (3 in total)
- 4 layers per box (2 stereo layers ±5º)
- 2 module types: 11 and 22cm long

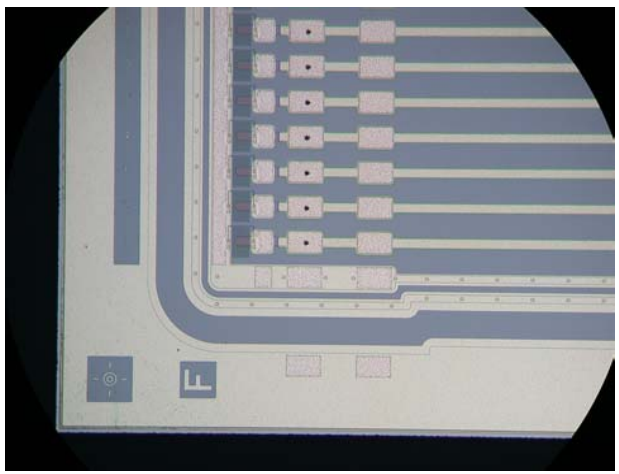


- 4.3m^2 silicon
- 1.3% of total acceptance
  20% of reconstructed tracks
- operation at ~5°C

IT-Design

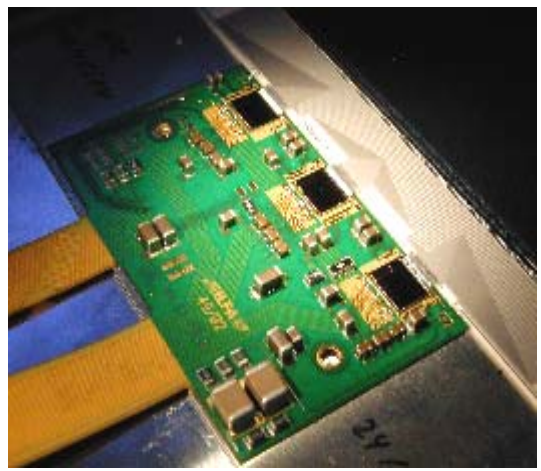
- p-on-n silicon micro-strip sensors (HPK)
- 108 mm long strips
- 384 readout strips
- 320 (410) µm thickness
- 198µm pitch
- w/p=0.25



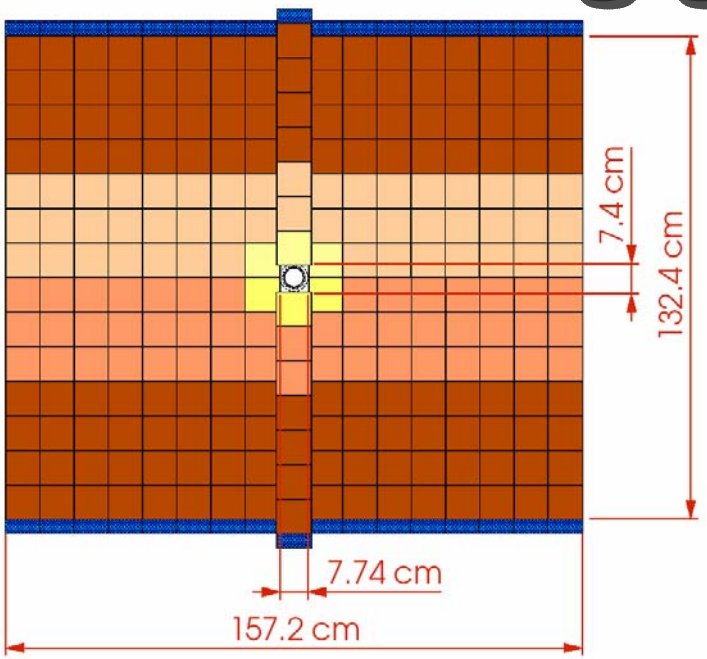


Hybrid:

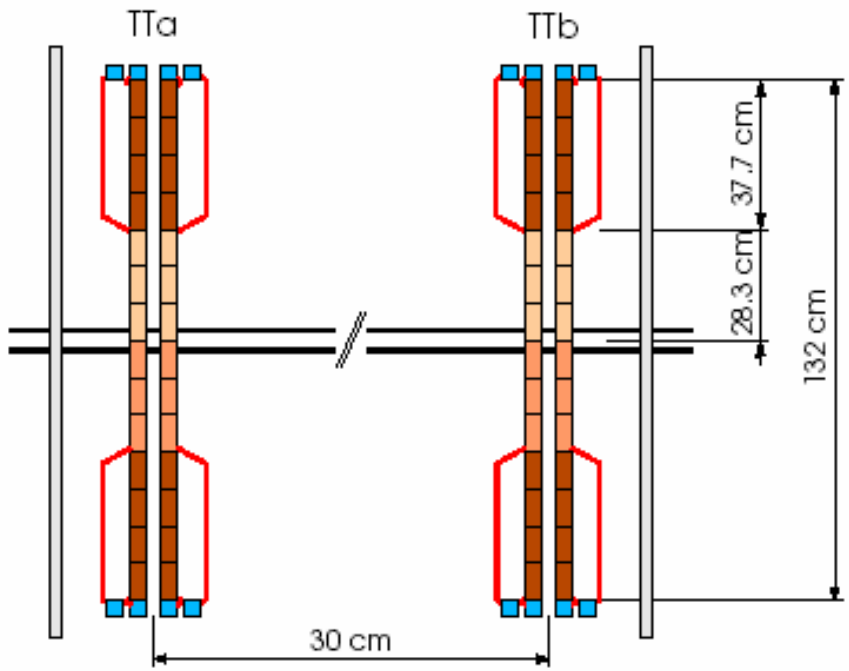
- 3 Beetle preamps
- 0.25µm CMOS
- 40 MHz clock
- programmable shaping time (V_{fs})



The Trigger Tracker



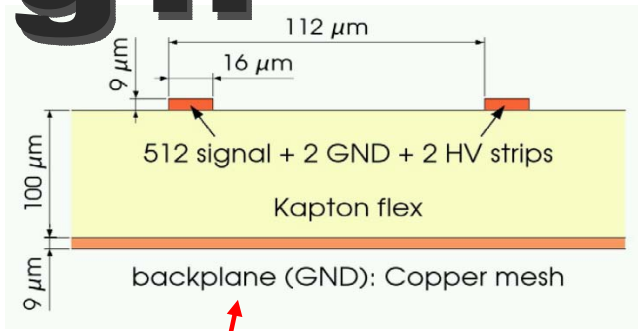
- 4 layers in 2 half stations
- 2 layers ±5° stereo angle
- 7.9m² silicon
- readout sectors with 1,2,3 and 4 sensors



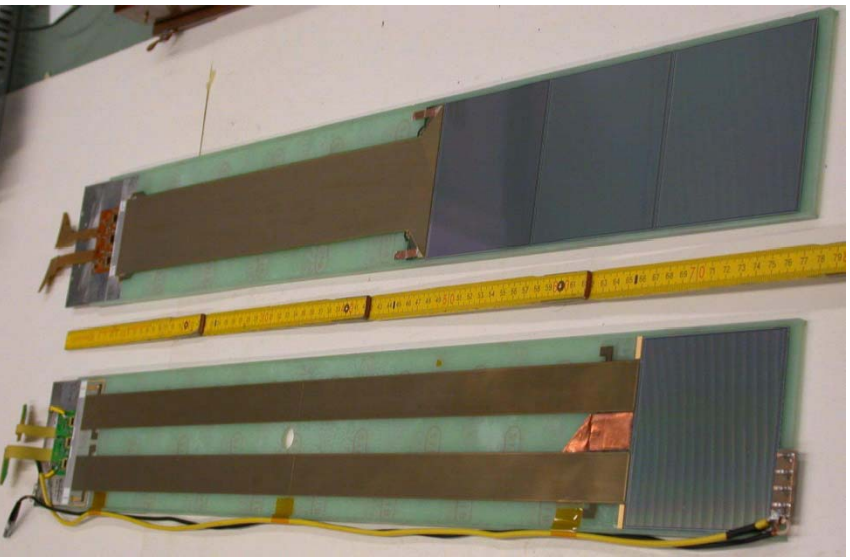
- hybrids with Beetle readout at the edge outside of the acceptance
- inner modules connected via Kapton interconnect cables
- operated at ~5°C

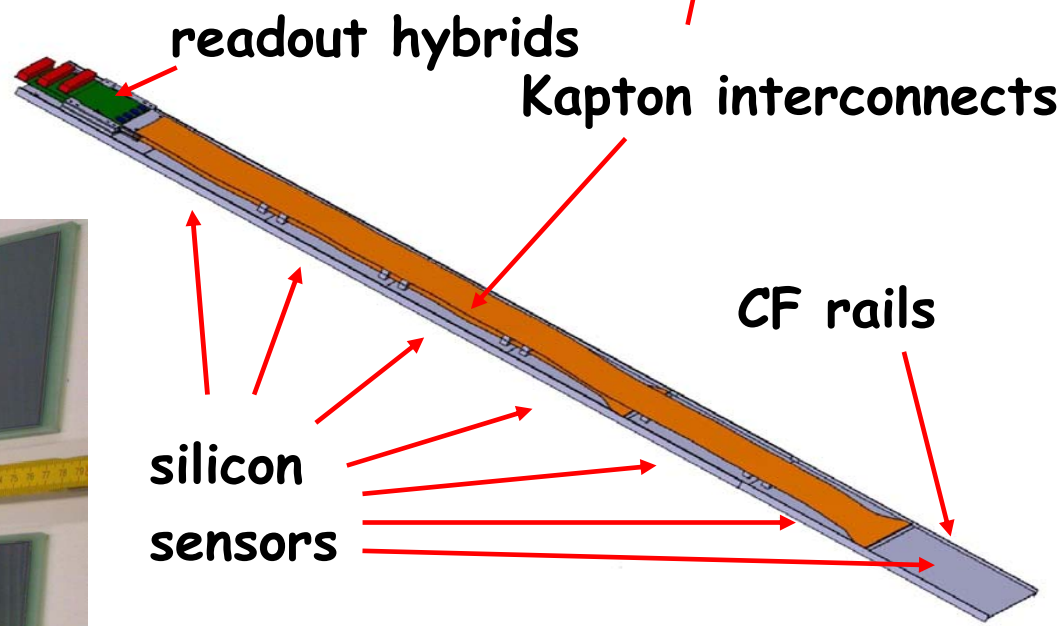
TT-Design

- CMS-OB2 sensors design (HPK)
- 183 µm pitch, w/p=0.25
- 500 µm thickness



- 4 sensor ladder → 38cm
- 3 sensor + 40cm Kapton
- 1 sensor + 58cm Kapton





additional load capacitance!
up to 57pf → minimize for S/N
(IT 35 pf)

Testbeam(s)

120 Gev pions @ CERN X7

- TB 2003:
  - choose w/p & thickness of sensors
  - studying shaping parameters → spill over

  ladders of different length & thickness:

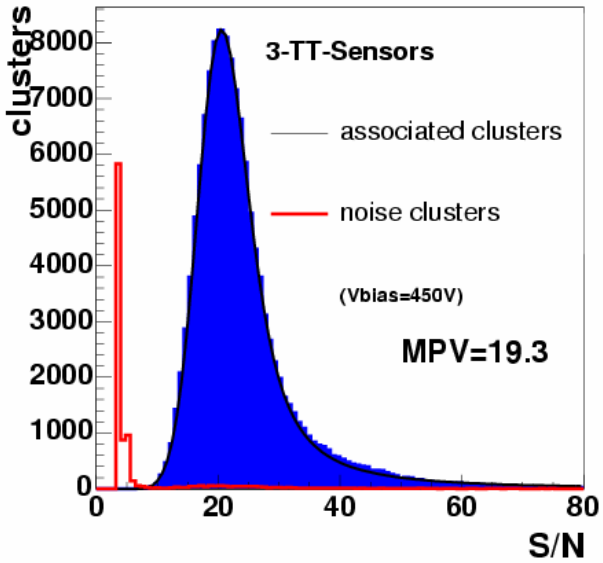
  320 µm - multigeometry, 410 µm - Glast, 500 µm - CMS
- TB 2004:
  - confirmation of extrapolations (prototypes)
  - irradiation tests

  (3 sensors + Kapton flex cable, Lhcb @ 10yrs radiation)

In addition

laser measurements

Testbeam - Results



Landau-Gauss Convolute for S/N:

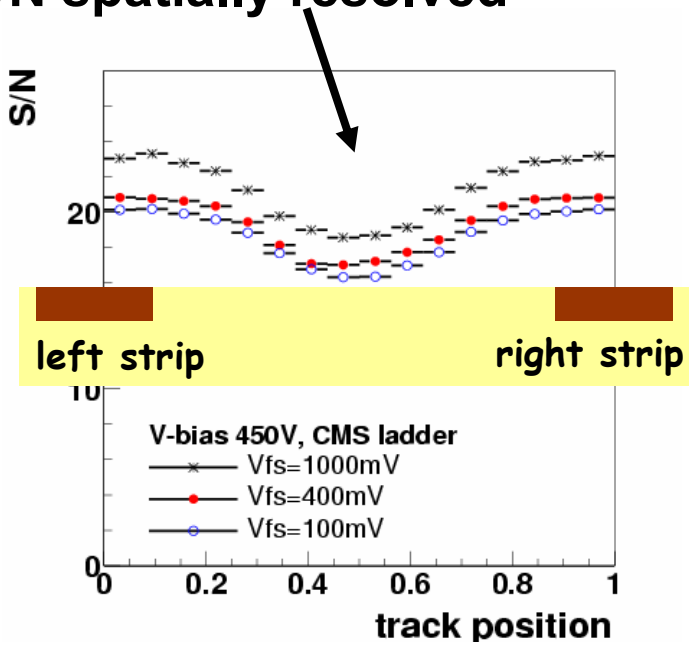
1-sensor (320µm, 198 µm pitch) → 15 ✓

2-sensor (320µm, 198 µm pitch) → 11

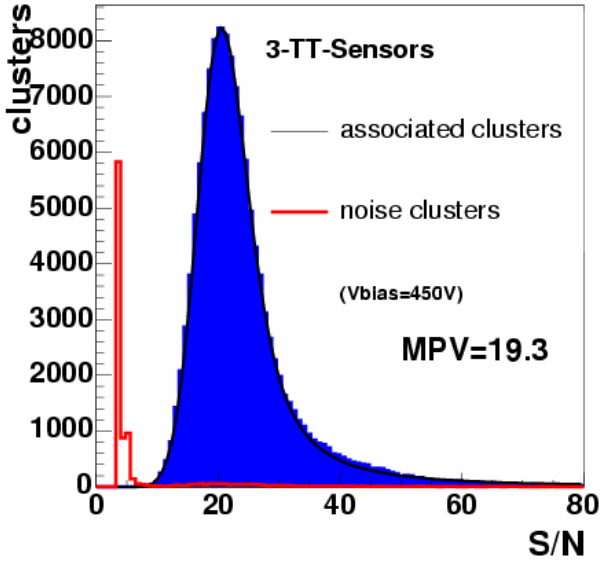
IT-2 sensor ladder 410 µm ✓

3-sensors (500µm, 180µm pitch) → 19 ✓

S/N spatially resolved



Testbeam - Results



Landau-Gauss Convolute for S/N:

1-sensor (320µm, 198 µm pitch) → 15 ✓

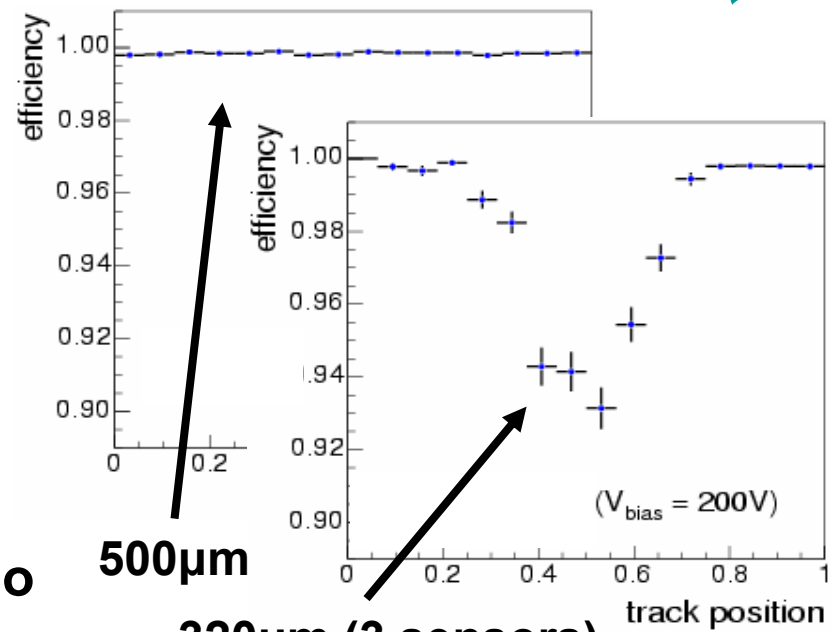
2-sensor (320µm, 198 µm pitch) → 11

IT-2 sensor ladder 410 µm ✓

3-sensors (500µm, 180µm pitch) → 19 ✓

almost full efficiency at a noise rate ~0.04%

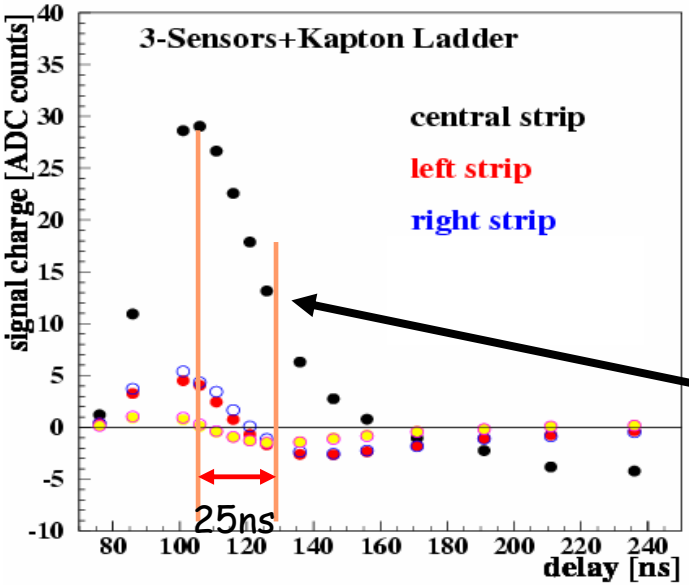
- **efficiency dip for 3 sensor ladders with 320 µm**
- **for higher S/N full efficiency also between strips**



500µm

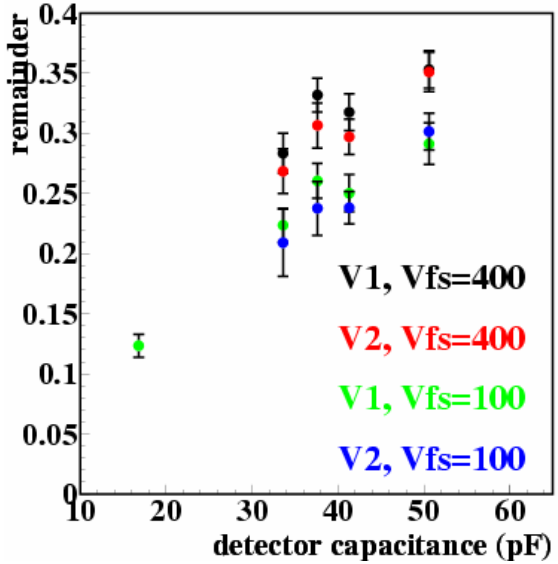
320µm (3 sensors)

Testbeam - Results



- load capacitance affects pulse shape

signal remainder 25ns after peak
→ spill over (BX 25ns)



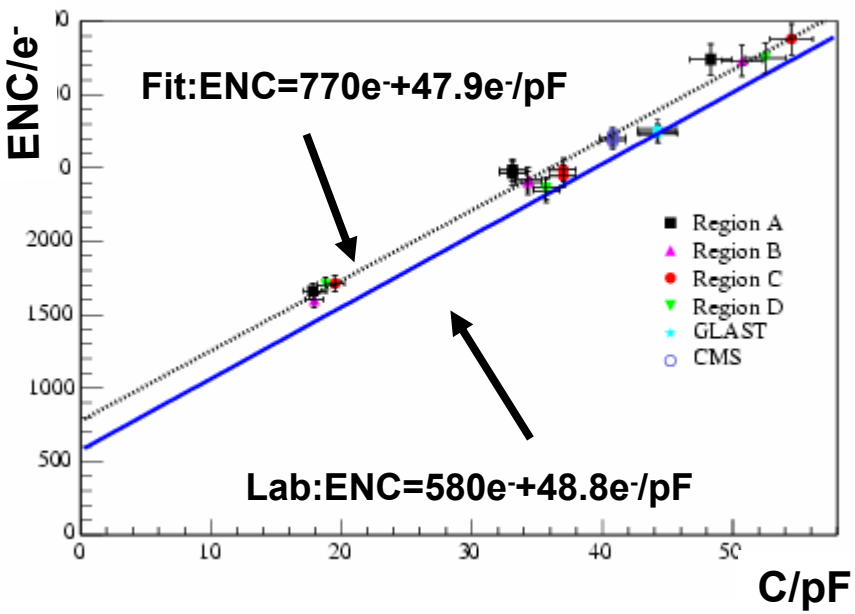
signal remainder
requirements less than:

- 50% (TT)
- 30% (IT)

longer
shaping time:

- less noise
- more remainder

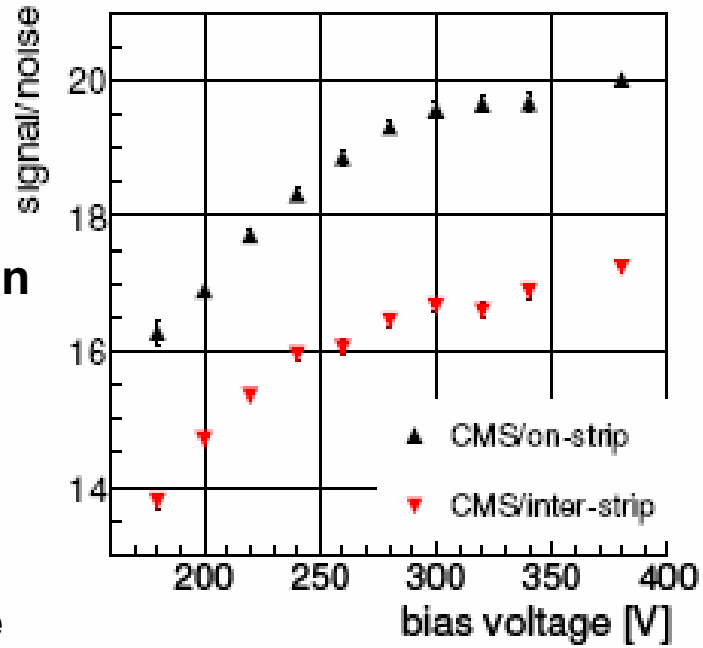
TB - Results



- noise dependent on load capacitance
- extrapolations done from testbeam 2003 for long TT ladders with Kapton flex confirmed by prototype in testbeam 2004 (analysis ongoing)

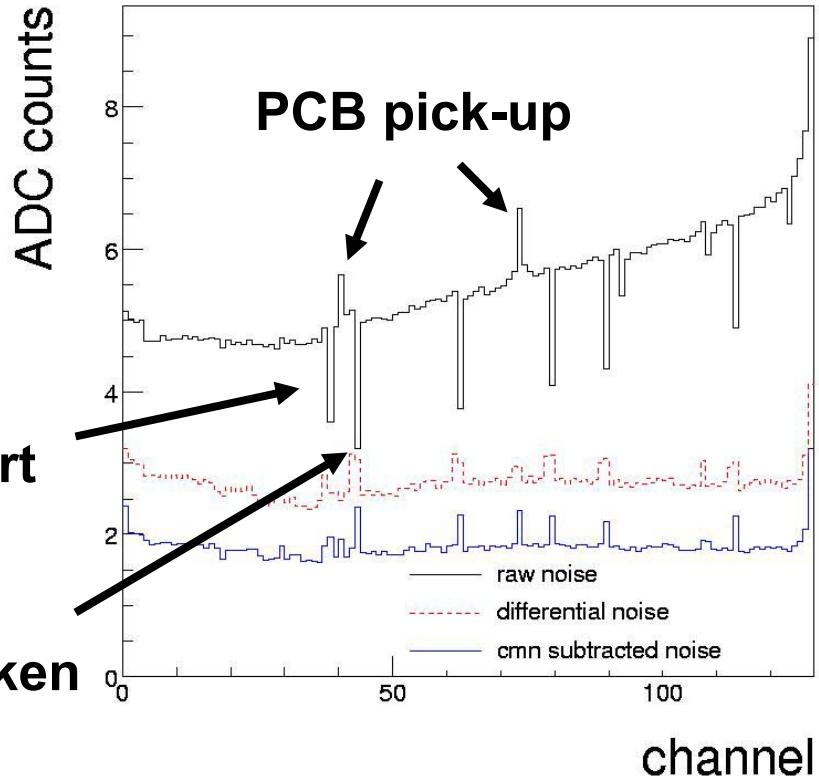
- full charge collection efficiency (CCE) at 300 V for 500µm ladders
- S/N dip does not disappear with overdepletion

- no significant charge loss in 320µm (IT) after 10yrs. irradiation (1 Mrad or $9 \cdot 10^{12}$ Neut.equiv.) full CCE at ~350V



Electrical Tests for Production

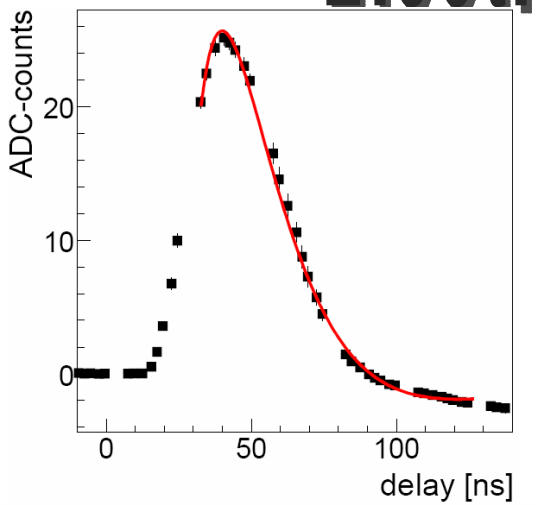
Detecting defects in sensors:
(shorts, broken bonds, pinholes)
Noise pattern not always significant,
confusing, dependent on grounding!



- **defects cause change in load**
  → response of Beetle
  signal height & shaping time
- **using internal calibration pulses**
  → no additional hardware required

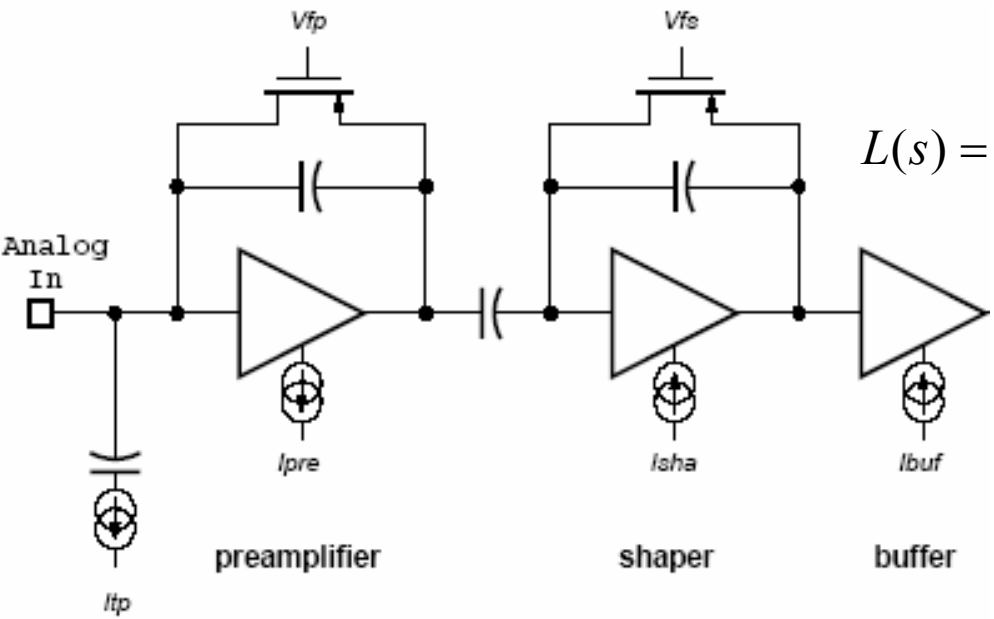
→ high significance in detecting and identifying various defects

Electrical Tests for Production



Fitting turned out to be tricky:

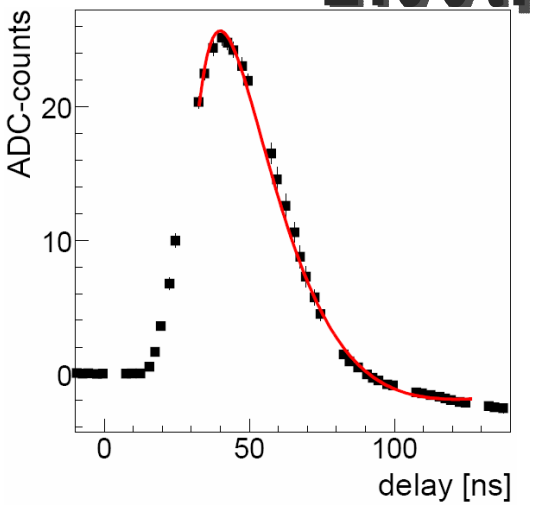
- **Model Beetle in Laplace space**
- **convolute non-ideal preamp & CR-RC shaper**
- **Inverse Laplace to obtain parametrization in time domain**



$$L(s) = \frac{Q}{C_f}\frac{1}{1+s\cdot\tau_{pre}}\bullet\frac{1}{1+s\cdot(RC)_{high}}\bullet\frac{s\cdot(RC)_{low}}{1+s\cdot(RC)_{low}}$$

3 poles → 3 fit parameters
(returns ~15ns shaping time)

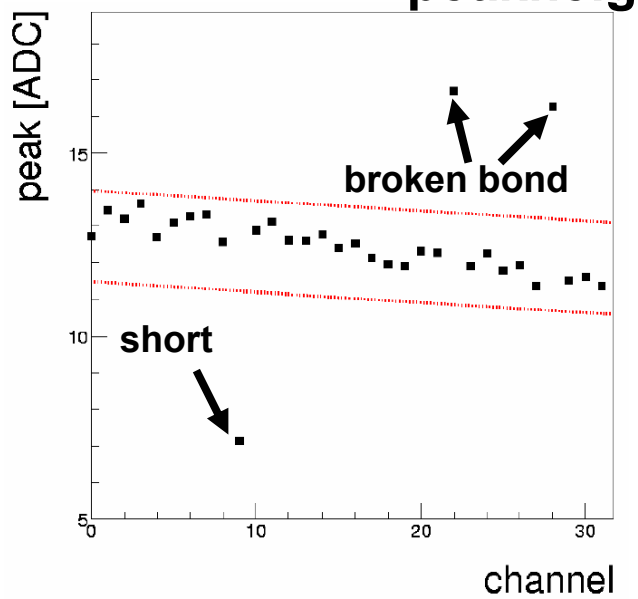
Electrical Tests for Production



Fitting turned out to be tricky:

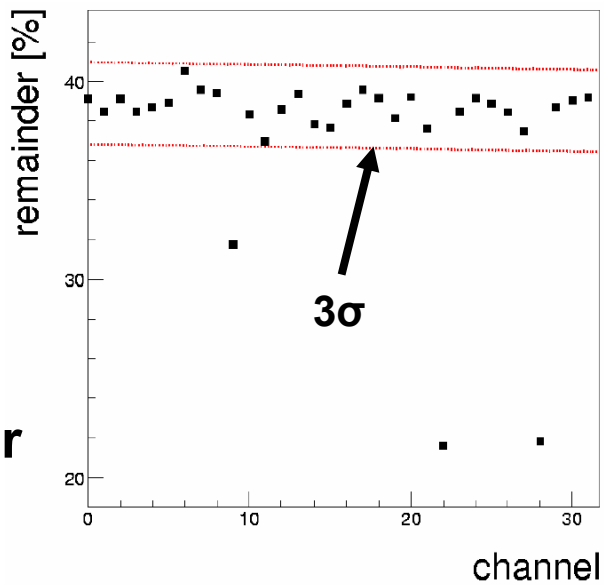
- **Model Beetle in Laplace space**
- **convolute non-ideal preamp & CR-RC shaper**
- **Inverse Laplace to obtain parametrization in time domain**

peakheight

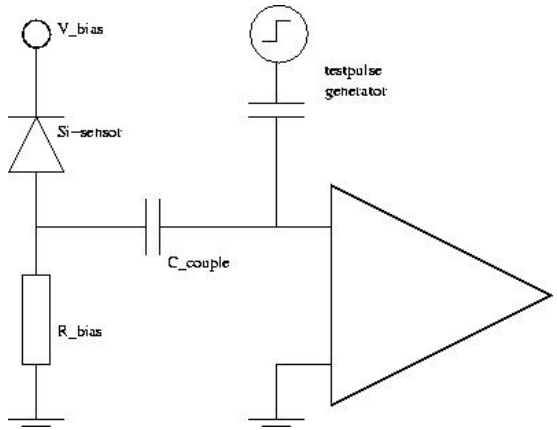


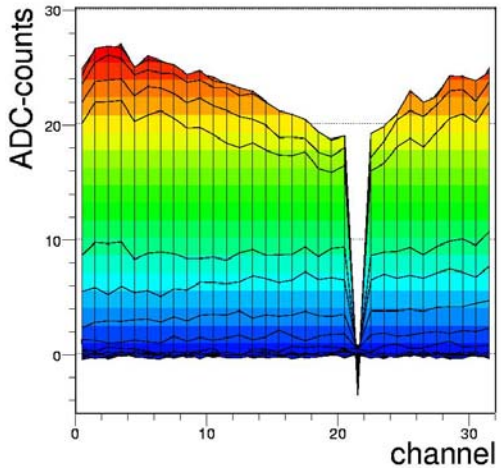
distribution of response in 3-sensor ladder

remainder



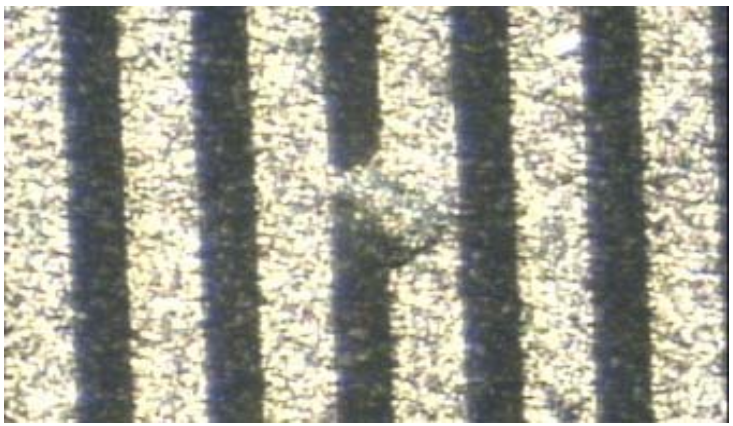
Electrical Tests for Production





Pinholes less easy to detect - but Beetle seems to be stable at high leakage

Operating at -0.5 Volts bias affects response (currents, working point)



- **Even found defects we were not aware of!**

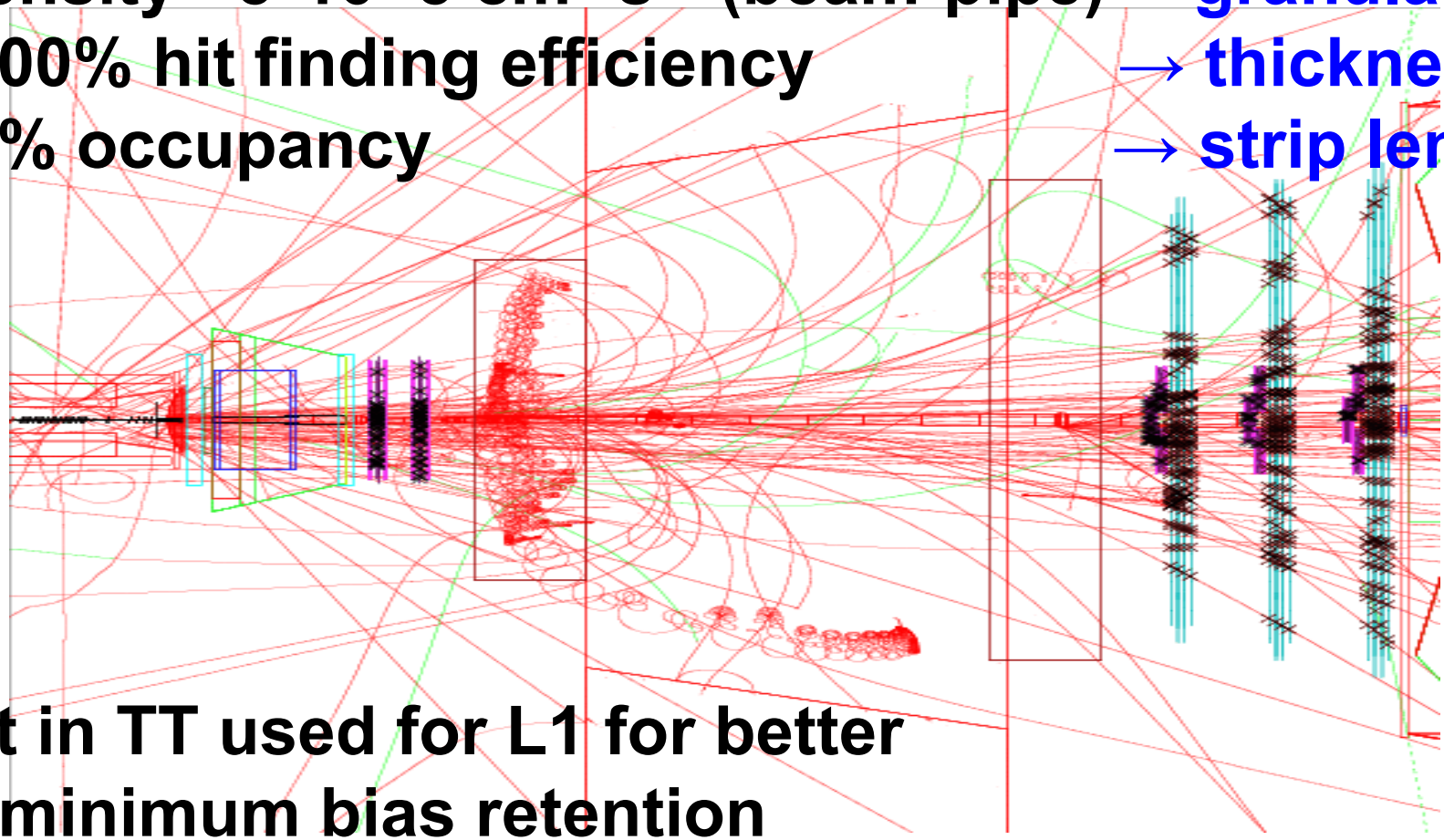
Conclusions

- **Presented current design of Silicon Tracker**
- **Geometry for silicon sensors is finalized**
  - **wide pitch ~200µm**
  - **long strips up to 38 cm / 28cm+40cm Flex**
  - **fast readout (25 ns)**
- **Test-beam performance satisfies requirements**
  - **fast shaping → spill over**
  - **sufficient S/N → efficiency**
  - **S/N of long Kapton Flex ladder as expected**
  - **irradiated ladders (320 µm @ 10yrs LHCb) fully depleted and sufficient S/N**
- **Pre-Production start up soon**
  - **able to detect defects at high significance**

Backup – Slides:

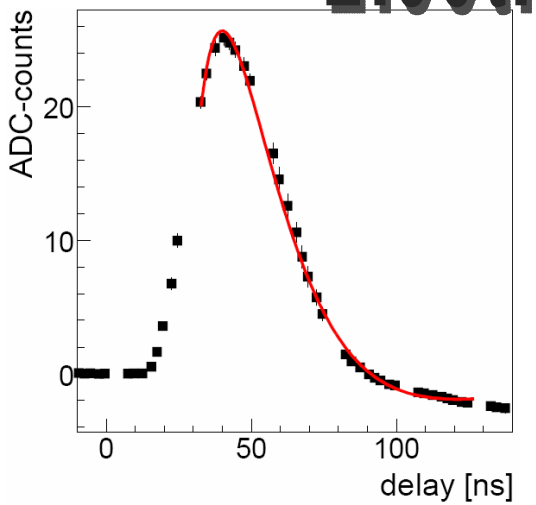
Requirements for ST

- Δp/p ~0.4%, mass resolution 14 MeV →pitch
- density ~5*10^5 $cm^{-2}s^{-1}$ (beam-pipe) →granularity
- ~100% hit finding efficiency → thickness
- ~1% occupancy → strip length



- pt in TT used for L1 for better minimum bias retention

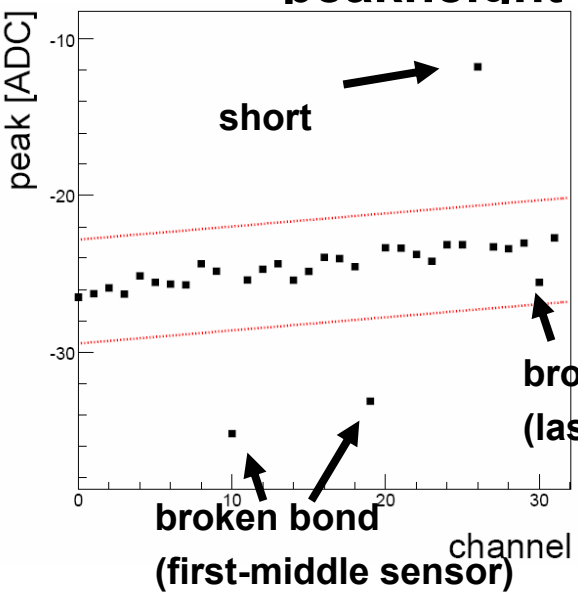
Electrical Tests for Production



Fitting turned out to be tricky:

- **Model Beetle in Laplace space**
- **convolute non-ideal preamp & CR-RC shaper**
- **Inverse Laplace to obtain parametrization in time domain**

peakheight

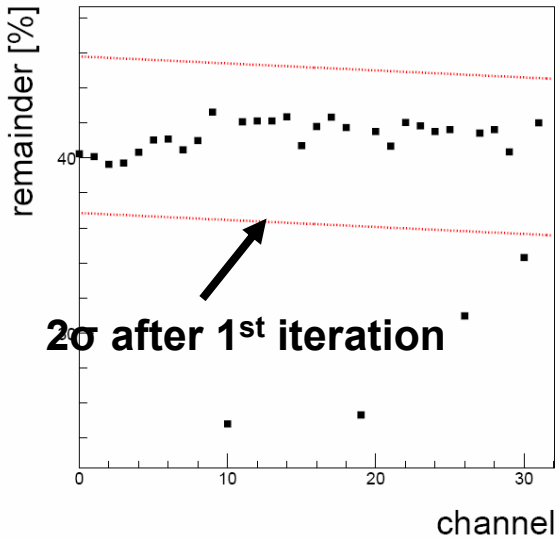


broken bond (first-middle sensor)

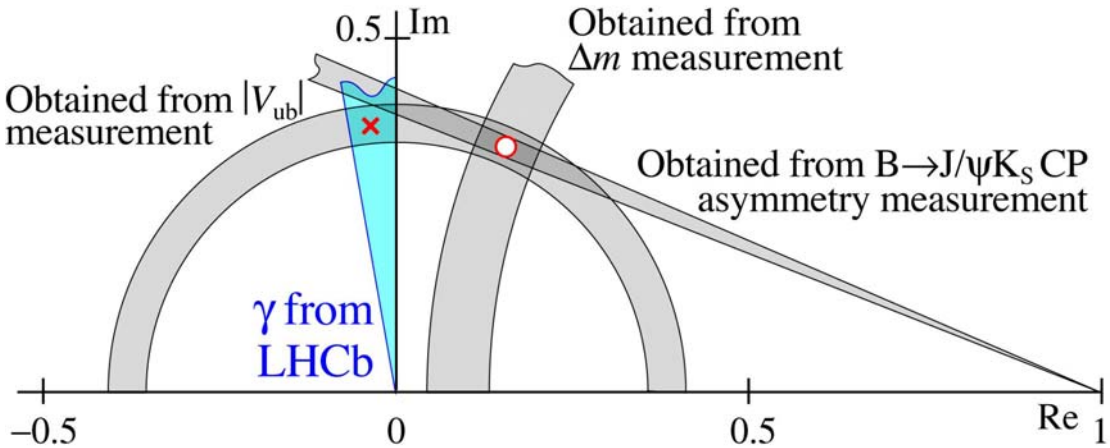
broken bond (last-middle sensor)

distribution of response in 3-sensor ladder (negative polarity)

remainder



2σ after 1st iteration


0.5
Im
Obtained from
Δm measurement
Obtained from |V_ub|
measurement
Obtained from B→J/ψK_S CP
asymmetry measurement
γ from
LHCb
–0.5
0
0.5
Re
1