Karlsruhe Institute of Technology

Functionality Tests and Characterization of the CMS Binary Chip

T 35.10

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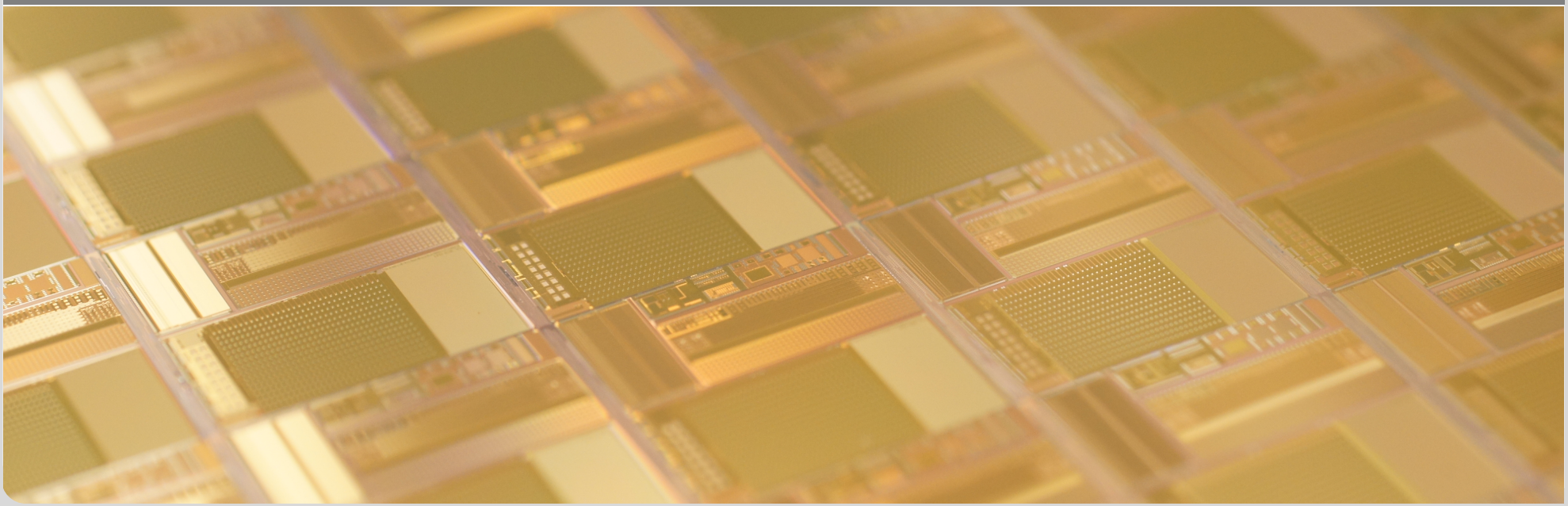
INSTITUT FÜR EXPERIMENTELLE TEILCHENPHYSIK



The Phase-2 Outer Tracker Upgrade

Requirements for High Luminosity Operation

- improved radiation tolerance ($10^{15}\,\mathrm{n_{eq}\,cm^{-2}}$ for the innermost layers)
- increased granularity (pileup of 140 to 200)
- contribution to level-1 trigger
- reduced material budget

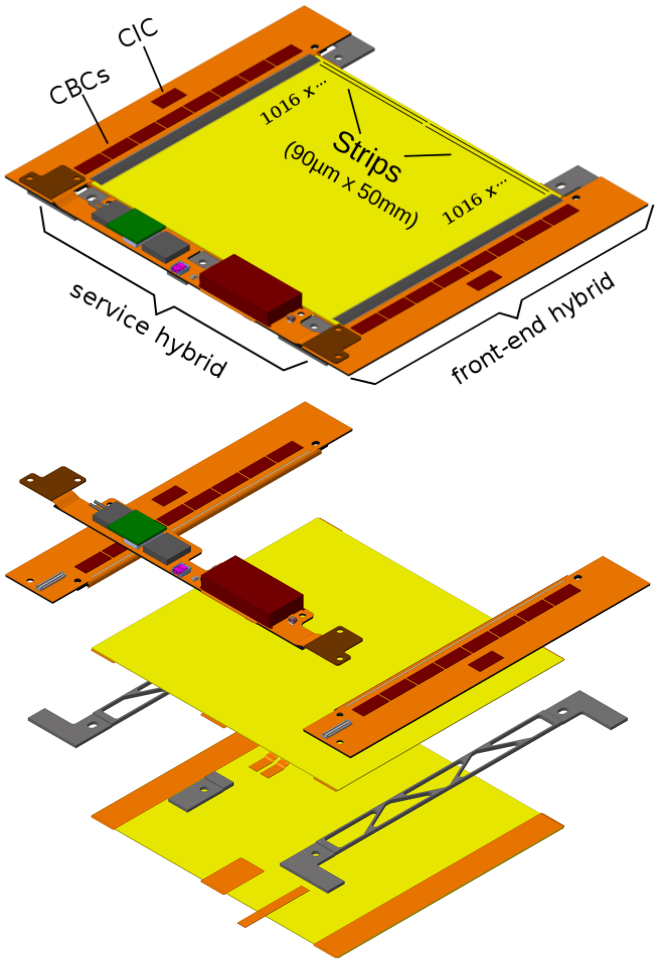
The Phase-2 Outer Tracker Upgrade

- p_T modules to identify and trigger high p_T particles on module level
- 7680 **2S** and 5616 **PS modules**

The 2S module

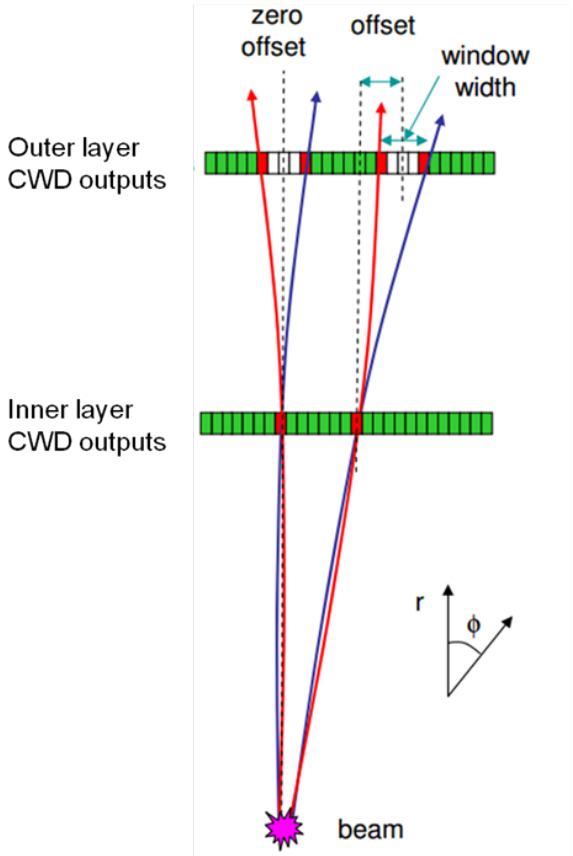
- two p-type silicon strip sensors aligned in parallel
- 2032 strips each, 5 cm long, 90 $\mu\mathrm{m}$ pitch
- two front-end hybrids (FEH), each with 8 CBCs and 1 CIC
- one service hybrid

2S module



The CMS Binary Chip (CBC)

- binary readout chip for the 2S modules
- designed by Imperial College London and Rutherford Appleton Laboratory
- readout of 254 strips equally divided among the sensor layers
- key component for level-1 trigger contribution
  - measuring curvature of the trajectory of charged particles in magnetic field
  - search for hits in both layers within programmable coincidence interval



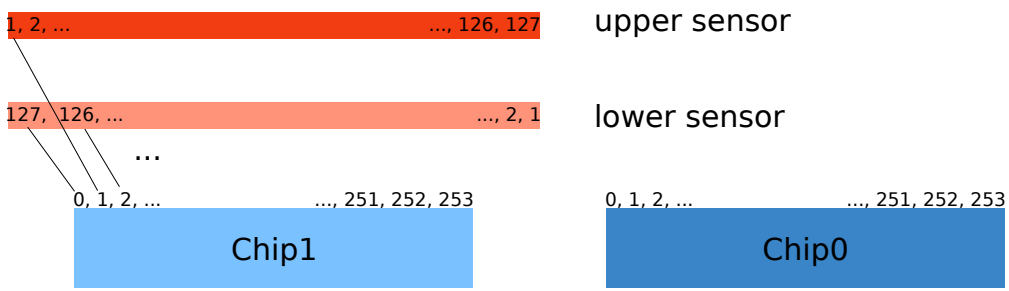
Hall et al.: *CBC2: A CMS microstrip readout ASIC with logic for track-trigger modules at HL-LHC*, Nucl.Instrum.Meth. A765 (2014) 214-218

Braga, Prydderch: *CBC2 User Guide*

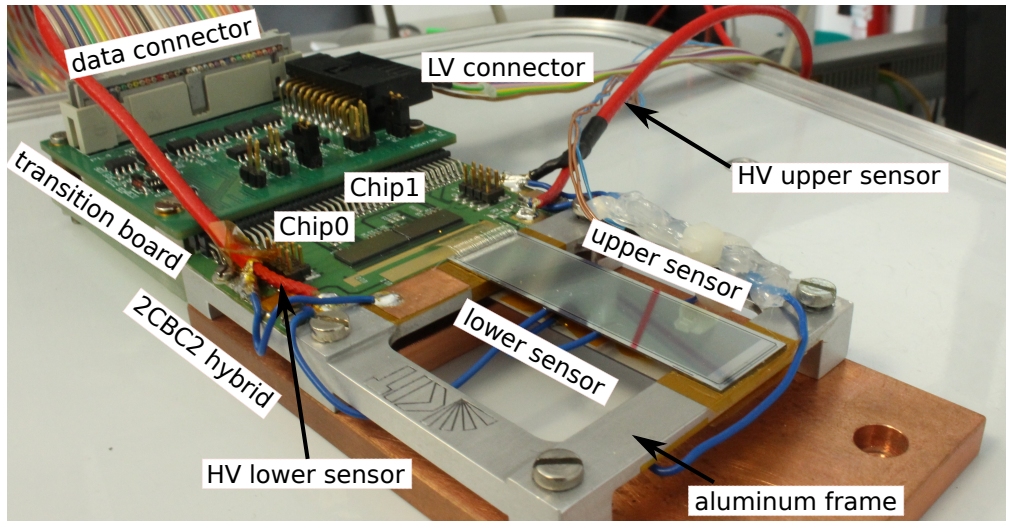
2CBC2 Mini Module

- prototype front-end hybrid for 2 x CBCs of version 2
- 2 x irradiated sensors
  - 127 strips, 5 cm long
  - 240 μm thickness
  - 2.75 mm spacing
- transition board
- FC7[1] evaluation board
- LV and HV power supplies
- sensors cooled down to $-9\,^{\circ}\mathrm{C}$

[1] **Pesaresi** et al.: *The FC7 AMC for generic DAQ and control applications in CMS*, JINST 10 (2015) no.03, C03036



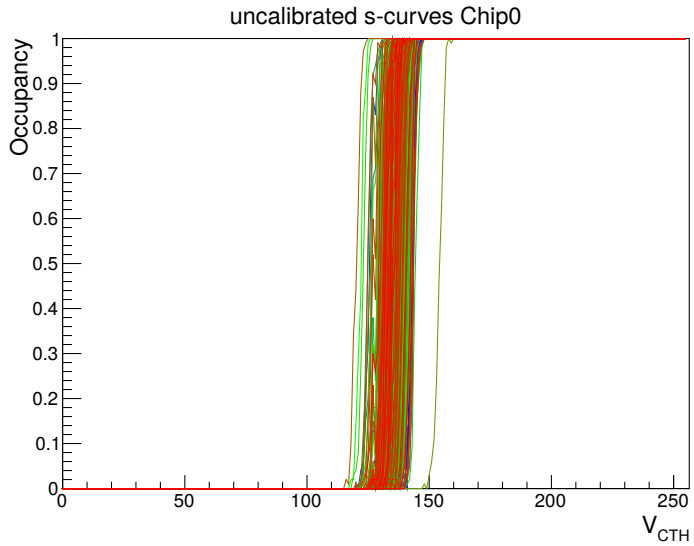
channel mapping

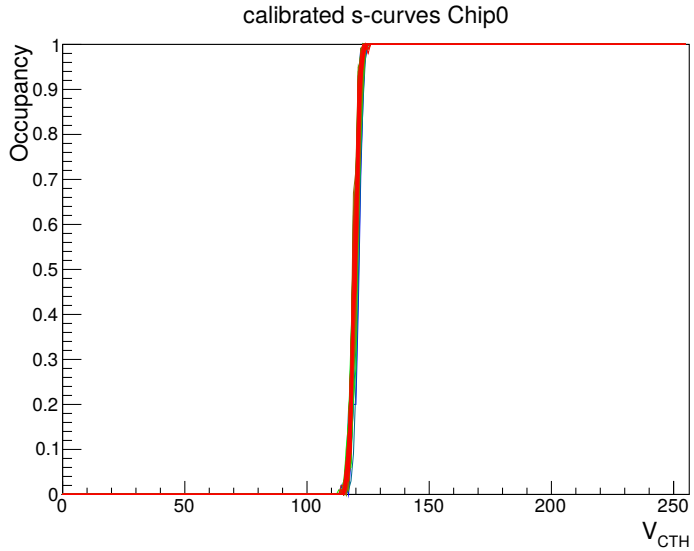


Characterization and Functionality Tests

Offset Calibration

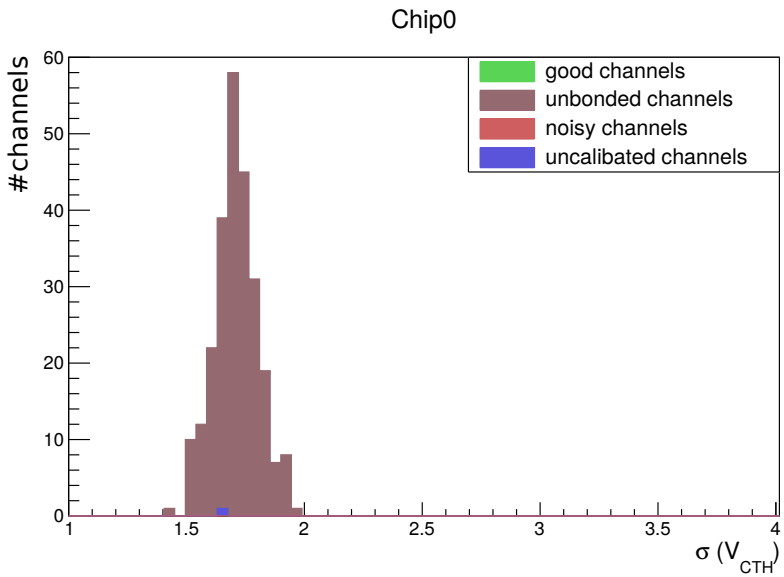
- equalizes the response behavior of the channels
- characterized by the position of the s-curves
  - $\rightarrow$ threshold scan of the channel occupancy
- shift of the pedestals to a common comparator threshold V_{CTH}
- large V_{CTH} corresponds a small threshold

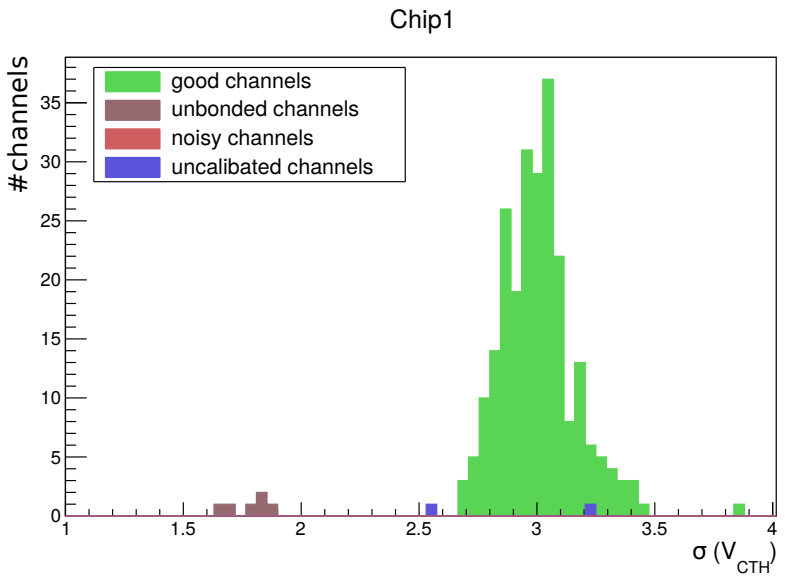




Noise Measurement

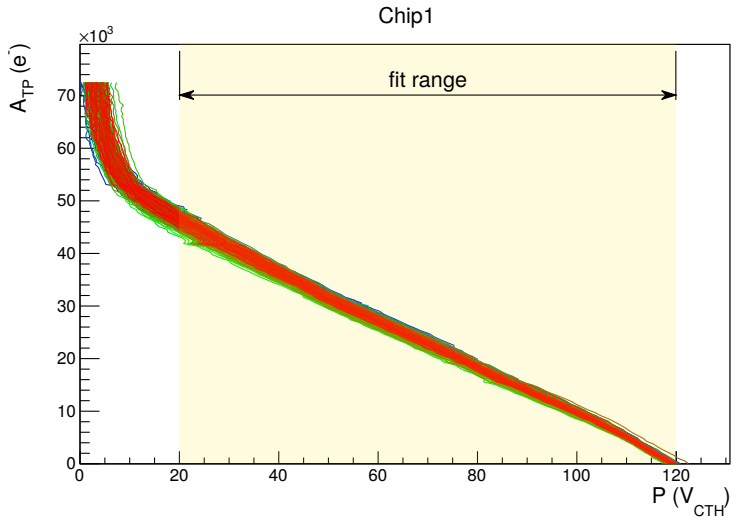
- noise corresponds to the width of the s-curve
- larger noise σ for bonded channels expected
  - $\langle \sigma_{\mathrm{Chip0}} \rangle = 1.6\ V_{CTH}$ $\rightarrow$ unbonded
  - $\langle \sigma_{\mathrm{Chip1}} \rangle = 2.7\ V_{CTH}$ $\rightarrow$ bonded

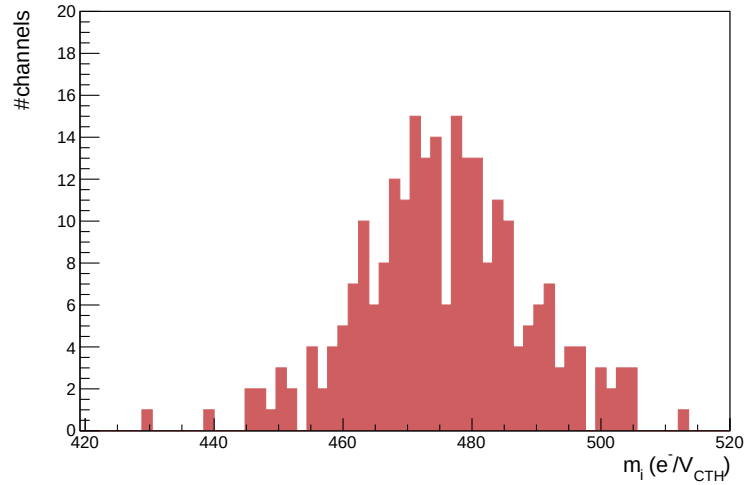




Test Pulse Calibration

- conversion of V_{CTH} into electrons
- internal test pulses for charge injection
- s-curves shifted to higher threshold
- linear fit of pedestal (P_{50}) and test pulse amplitude (A_{TP}) in e^-
  $\rightarrow$ conversion factors m_i
- Chip1:
  $$\langle m \rangle = (476 \pm 13)\, e^- / V_{CTH}$$



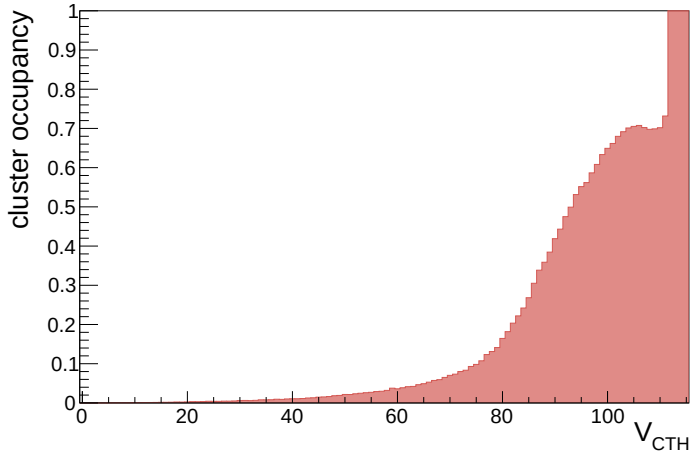


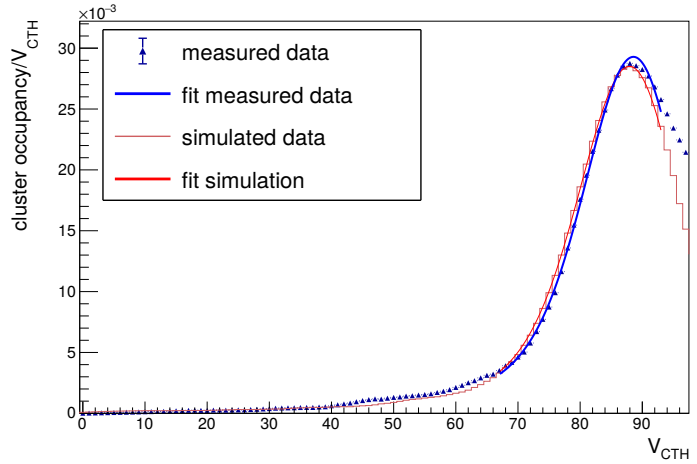
^{90}Sr Signal Reconstruction

- validate test pulse calibration
- record cluster occupancy for threshold scan
- smoothening and differentiating to reconstruct the ^{90}Sr signal spectrum
- Monte Carlo simulations to estimate uncertainty caused by smoothening
- comparison of MPV with reference measurements $(\mathrm{MPV}_{ref} \approx 13\,700)$

sensor	MPV (e^-)
lower	$13\,744 \pm 498$
upper	$13\,692 \pm 508$

integrated signal spectrum





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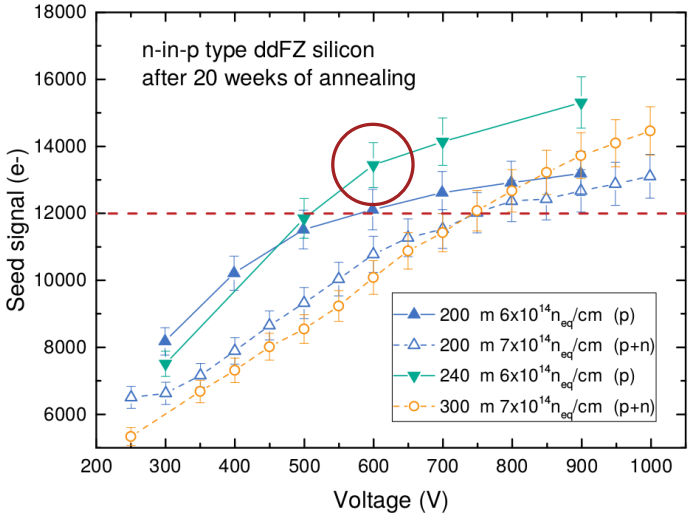

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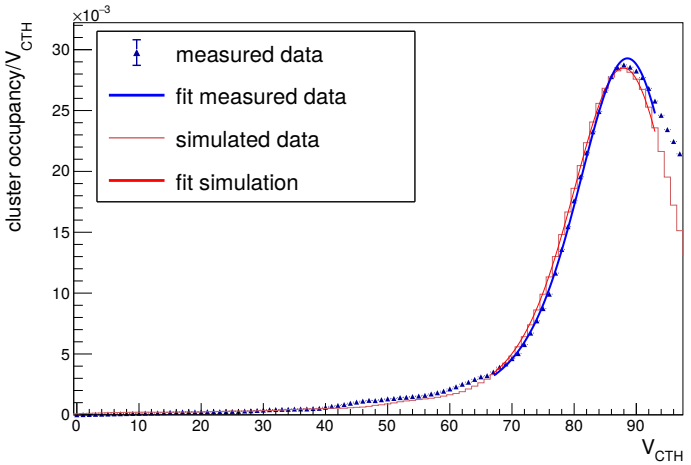


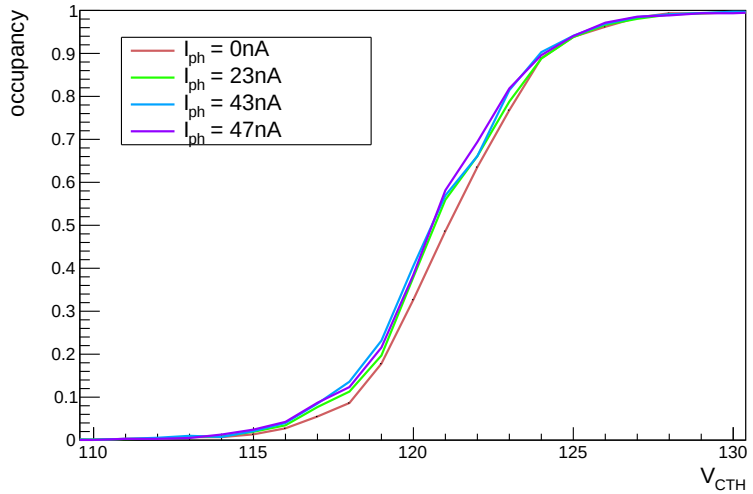
Pinhole Study

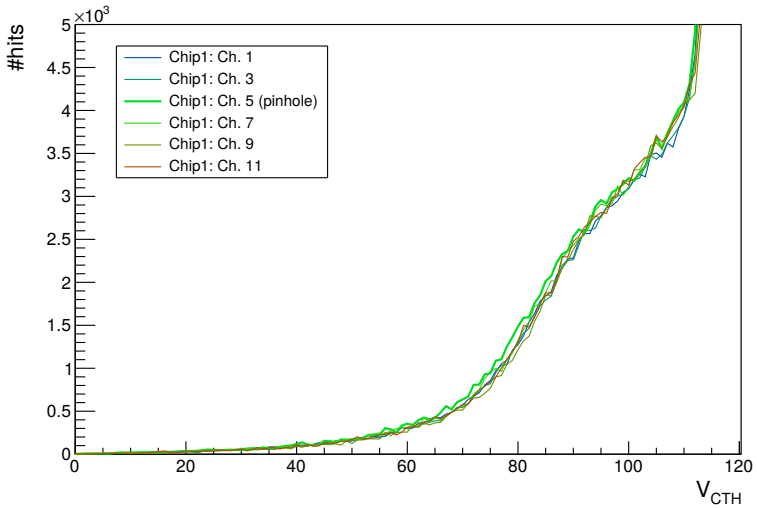
- short between implant and aluminum strip
  $\rightarrow$ AC readout becomes DC
- current from the sensors drain into the CBC's front-end
  $\rightarrow$ malfunction or damages?
- CBC2 designed for AC & DC readout (max. 1 μA)
- pinhole simulation:
  connect AC and DC pad of one strip with a wire bond

Pinhole Study

Noise behavior

- illumination to generate additional charge carriers
- record S-Curves for different I_{ph}
- noise and pedestal do not change





^{90}Sr data acquisition

- record threshold scan
- compare hits detected from pinhole channel with neighbor channels
- no malfunction or damage detected

Pinhole Study

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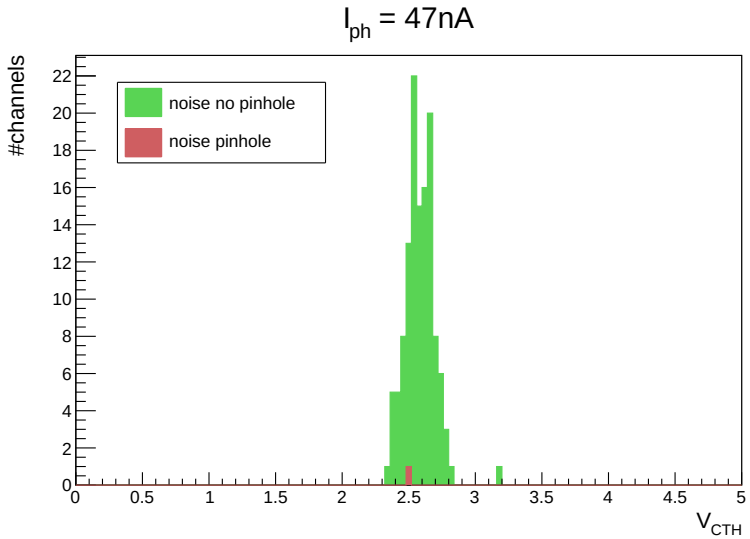

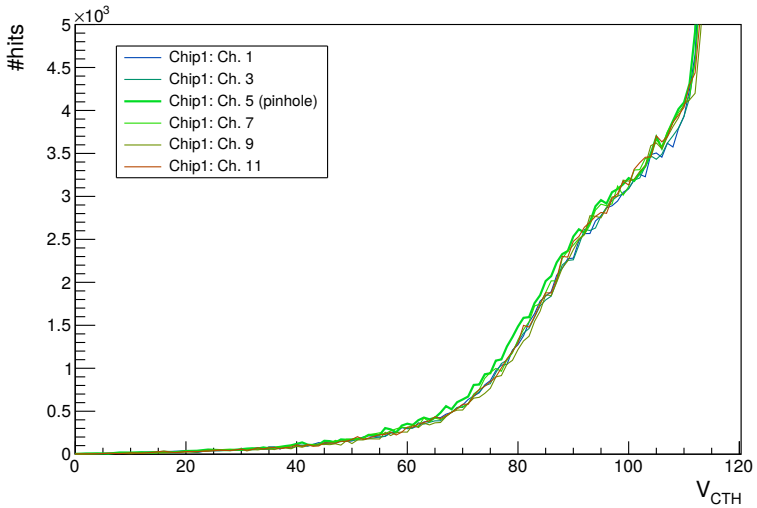

^{90}Sr data acquisition

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Conclusions

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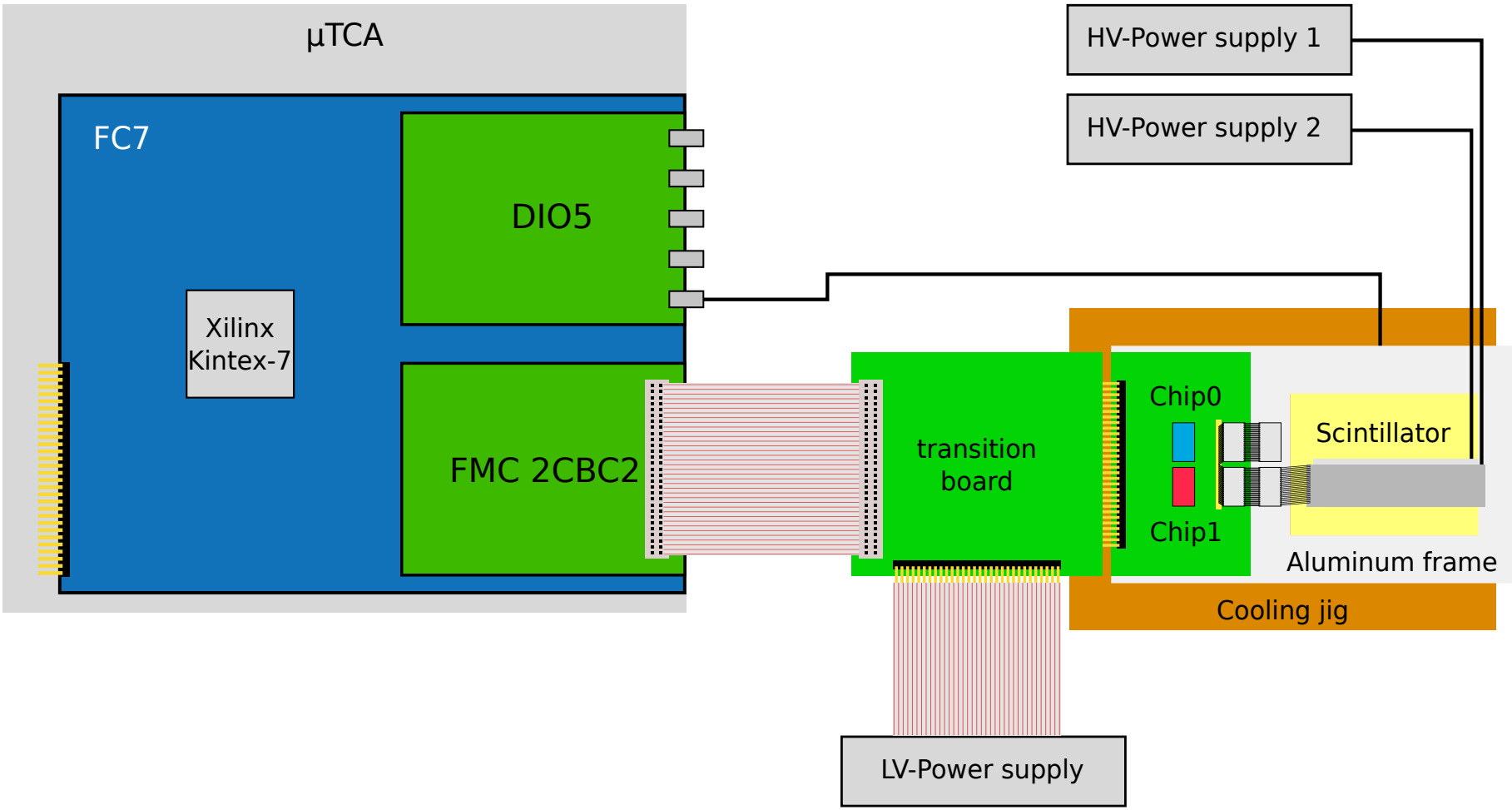
- CMS Phase-2 Upgrade
- characterization of 2S module's prototype readout chip **CBC2**
- CBC2 noise within specs ($\leq 1000\, e^-$)
- calibration of V_{CTH} in numbers of e^- using internal test pulses
- verification of test pulse calibration by reconstructing the ^{90}Sr signal spectrum in irradiated sensors
- CBC2 tested on pinholes

Backup

2CBC2 Mini Module Setup



Toy Monte Carlo Simulation

- examine influence of Savitzky-Golay filter on MPV
- simulation steps:
  1. using signal reconstruction results to generate integrated spectrum,
  2. reconstruction of the simulated signal spectrum parameters (MPV, widths, area),
  3. repeat step 1 and 2 several times to reduce statistical uncertainties.
- additional uncertainty estimated:

$$\sigma_{\mathrm{filter}} = |\langle \mathrm{MPV}_{\mathrm{sim}} \rangle - \mathrm{MPV}_{\mathrm{rec}}|$$

Pinhole Study

- S-Curve parameters for pinhole channels compared to all others

I_{ph} (nA)	**Chip1 Ch. 5 (pinhole)**		**Chip1 all other bonded channels**	
	pedestal (V_{CTH})	noise (V_{CTH})	mean pedestal (V_{CTH})	mean noise (V_{CTH})
0	121.13 ± 0.01	2.45 ± 0.01	121.22 ± 0.40	2.52 ± 0.11
23	120.86 ± 0.01	2.56 ± 0.02	120.98 ± 0.42	2.59 ± 0.11
43	120.71 ± 0.01	2.61 ± 0.02	120.97 ± 0.41	2.59 ± 0.11
47	120.70 ± 0.01	2.51 ± 0.02	120.94 ± 0.41	2.58 ± 0.11