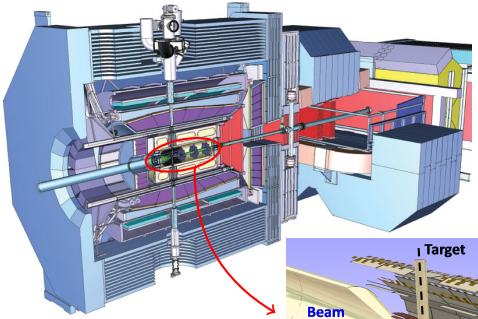
Readout system for the Micro-Vertex-Detector of $\overline{\text{P}}$ANDA

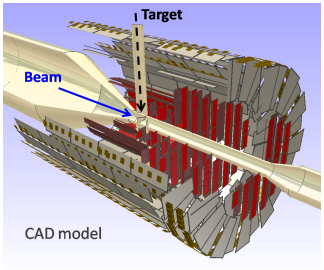
Marvin Peter

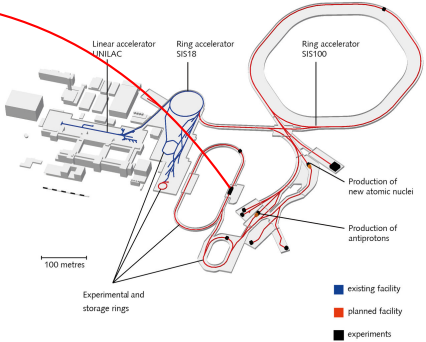
From Justus-Liebig-Universität Giessen
For the $\overline{\text{P}}$ANDA collaboration

$\overline{\text{P}}$ANDA CM Prague 2023

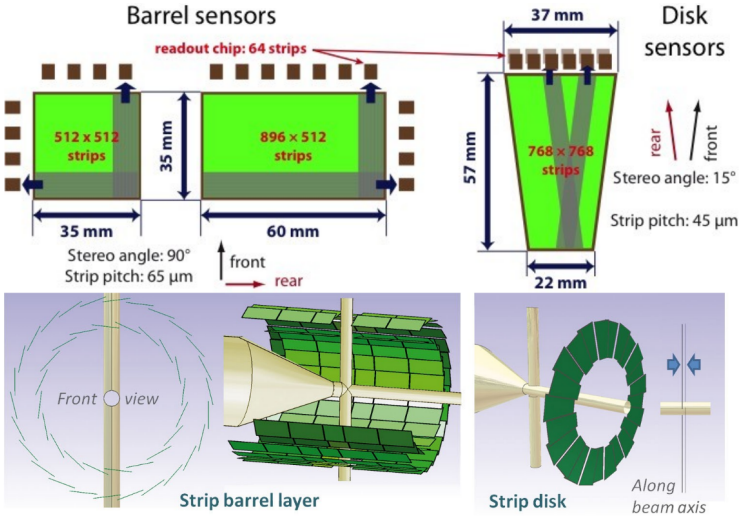
The Micro-Vertex-Detector of the $\overline{\text{P}}$ANDA Experiment at FAIR







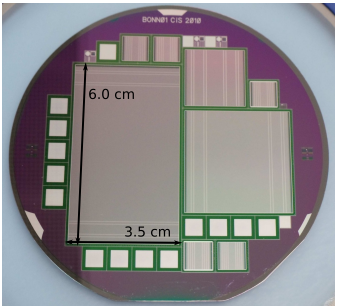
Strip Sensors

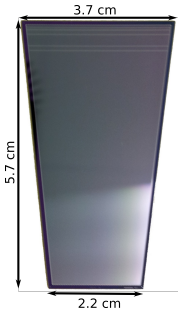


Strip Sensors

Barrel sensor	
Thickness	285 µm
Strips	896 x 512
Pitch	65 µm
Readout	every 2nd strip
Stereo angle	90°

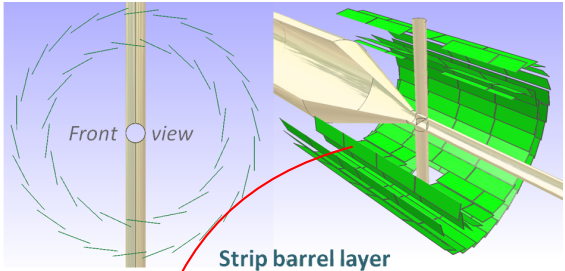
Wedge sensor	
Thickness	285 µm
Strips	786 per side
Pitch	45 µm
Readout	every 2nd strip
Stereo angle	15°

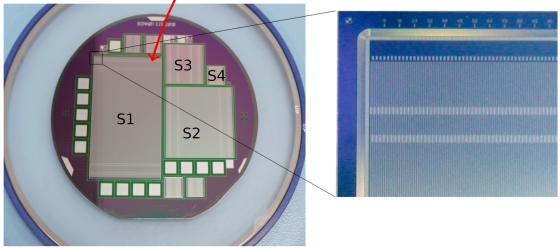


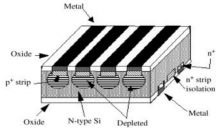


Strip Sensors

- Double sided strip sensors w/ AC-coupled microstrips
- Manufactured by CiS in Erfurt
- Small sensors used for prototyping
- More information: Thu, 16:45 - Nils Tröll





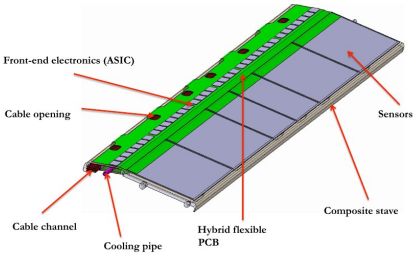


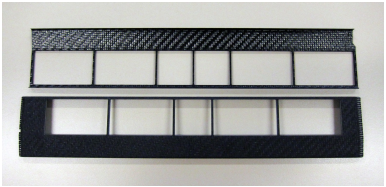
CiS Forschungsinstitut für Mikrosensorik GmbH

Torino Amplifier for silicon Strip detectors (ToASt) Frontend ASIC

- 64-channel charge sensitive, self triggering amplifier
- ToT method for digitization
- Per-channel calibration
- Developed in Turin, functionality verified

Specification	Min	Max	Unit
Input capacitance	2	16	pF
Max rate per strip		50	kHz
Input charge range	1	40	fC
Max noise		1500	e-
Peaking time	50	>=100	ns
Channels per chip	64		
Reference clock		160	MHz
Charge resolution	8		bits
Time resolution (pk-pk)		6.25	ns
Time resolution (r.m.s.)		1.8	ns
Power consumption		256	mW
Chip dimensions	3.24×4.41		mm^2





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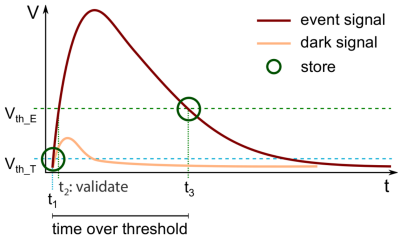

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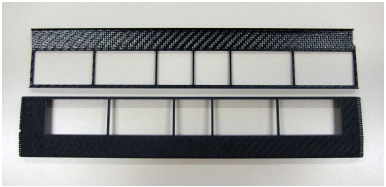
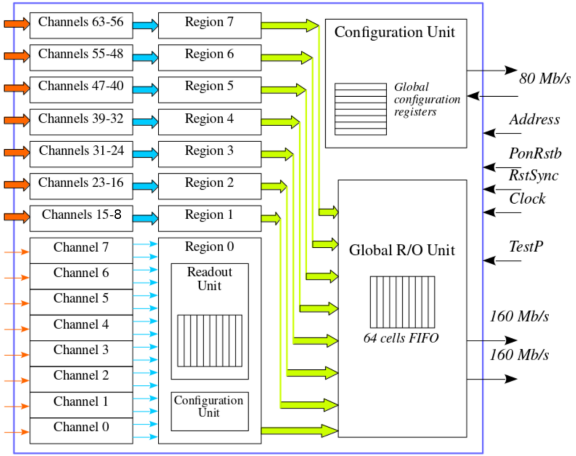


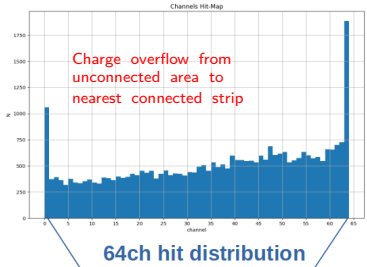
Torino Amplifier for silicon Strip detectors (ToASt) Frontend ASIC

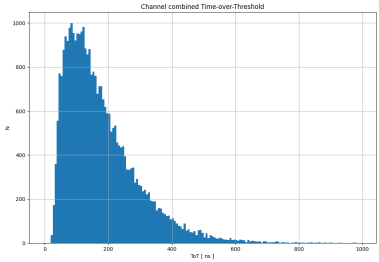
- Thresholds and ToT current can be adjusted globally (coarse) and for each channel (fine)
- Readout of 8 channels of each region to FIFO
- Packing of all data in each time frame
  (12 bit at $160\,\text{MHz} \sim 25.6\,\mu\text{s}$ rollover)

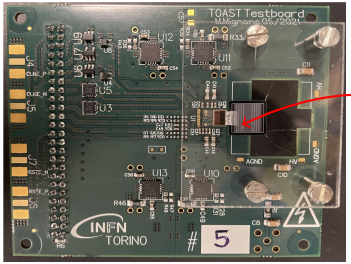


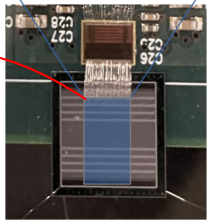
ToASt Test PCB

- First time connecting $\overline{\text{P}}$ANDA sensors to ToASt January 2023 in Turin
- Test readout system based on Xilinx ML605
- Test measurement with ^{90}Sr source is promising



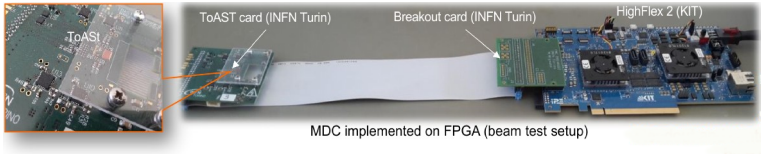




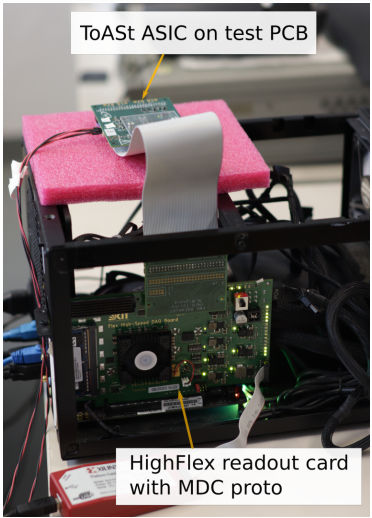


New Readout Electronics

- New readout electronics for the ToASt
- Designed at KIT in Karlsruhe
- Based on HighFlex readout card
- Features Module Data Concentrator
- First MDC architecture designed on FPGA

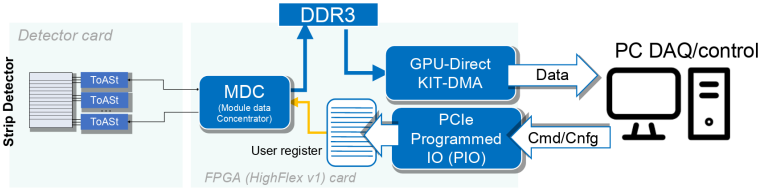


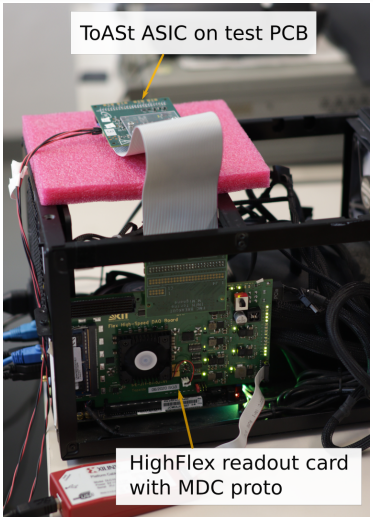
MDC implemented on FPGA (beam test setup)



New Readout Electronics

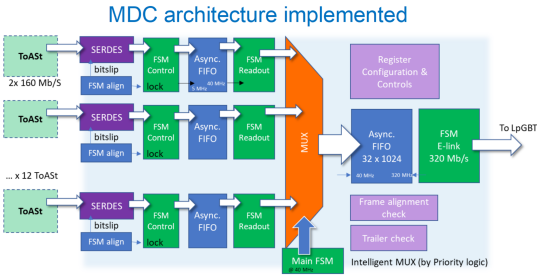
- Readout based on PCIe Gen 3, compatible to any PC
- Data can be streamed directly to GPU (NVIDIA GPUDirect)
- Up to 120 Gb/s data throughput for simultaneous readout of multiple ToASt





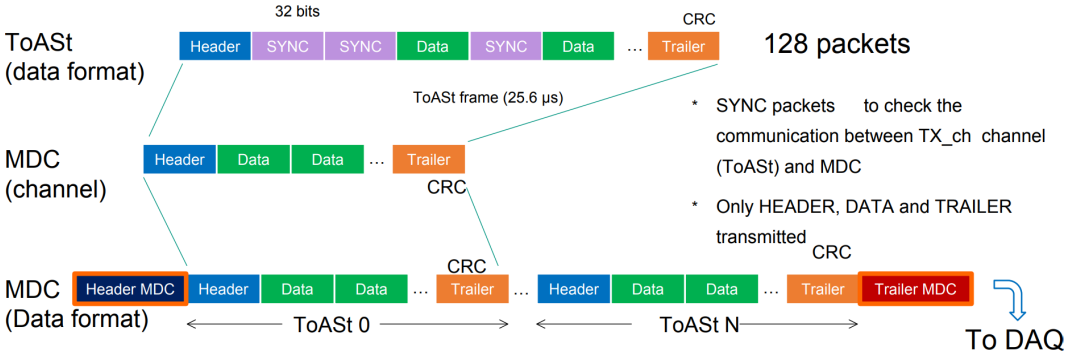
Module Data Concentrator (MDC)

- Readout of up to 12 ToASt
- Dynamic configuration of number of active ToASt and high-speed links
- Non-active links kept in low-power mode
- Intelligent multiplexing logic to balance the data occupancy between the serial links
- Frame number alignment



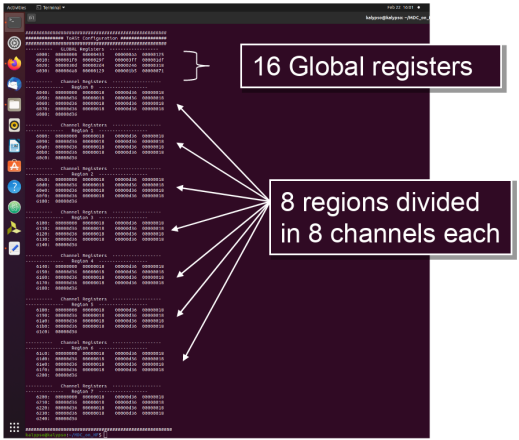
Module Data Concentrator (MDC)

Data stream format



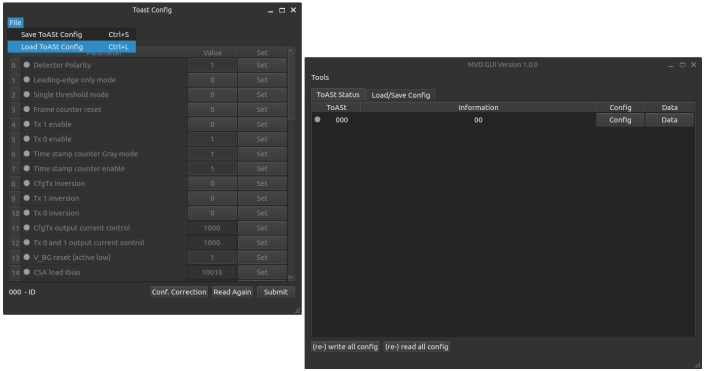
ToASt Configuration

- MDC works as PCIe device in Linux
- Configuration is mirrored and synched with ToASt chips
- Read/write of different addresses for configuration



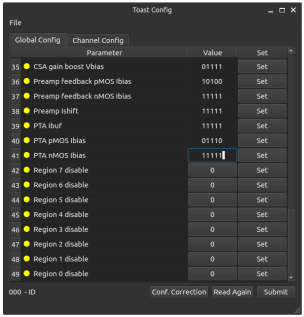
ToASt Configuration

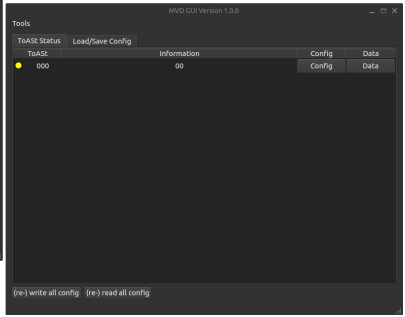
- Full control with graphical user interface (PyQT6)
- Save / load configuration of single or multiple ToASt boards
- Status indicator shows MDC / ToASt configuration mismatch



ToASt Configuration in GUI

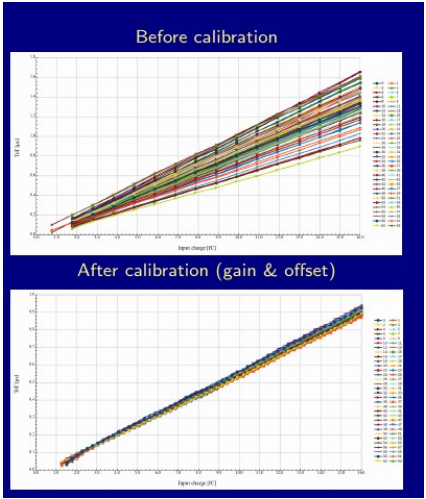
- Grey: Disabled / initial
- Green: All good
- Yellow: Edited / not synced
- Red: Mismatch





ToASt Calibration

- Use of testpulse generated by ToASt
- Calibration registers for each channel
- Calibrate by:
  - Gain (time over threshold / charge)
  - Offset
  - Threshold (s-curve fit)



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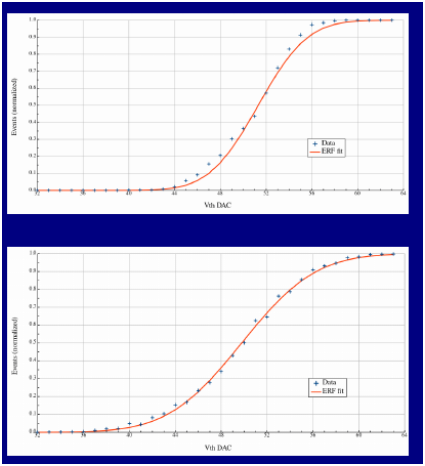


ToASt Calibration in GUI

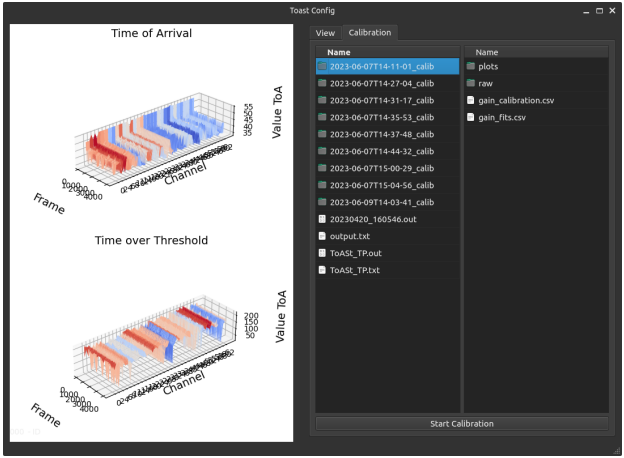
- Automatic sweep over calibration parameters
- Taking mean and sigma of time-over-threshold
- Automatic calibration, results saved in a file
- Calibration result can be applied to config

	ch_id	ib_calib	tot_calib	tot_m	tot_s
0	0	7.872	16	247.106247	24.895483
1	1	7.872	16	260.700012	52.442476
2	2	7.872	16	236.500000	33.547547
3	3	7.872	16	477.549988	35.351764
4	4	7.872	16	347.125000	22.471620
..	...	...	...	...	...
315	59	16.000	16	268.087494	51.616437
316	60	16.000	16	465.168762	78.924939
317	61	16.000	16	46.493752	29.506731
318	62	16.000	16	341.924988	18.321488
319	63	16.000	16	332.824982	25.258684

[320 rows x 5 columns]

Online Data Display

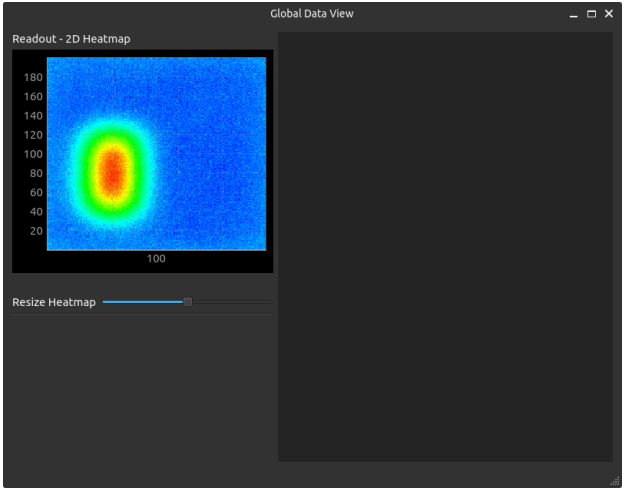
- Already displaying data inside GUI
- Performance will be optimized
- More options will be implemented
  - Single channel histogram
  - Calibration fits
  - Toggle full / avg over frames



Online Data Display

Future features in development:

- 2D heatmap from 2 perpendicular strip layers
- Interactive channel matching
- Live update



Beamtime Preparation

- Synchronization with other hardware:
  - External clock
  - External trigger, reset and epoch counter
- Design software:
  - Graphical user interface
  - Online analysis
  - Automatic configuration and calibration
- In-Lab test of the system:
  - Tests with source
  - Data integrity tests
- Beamtime tests this year at COSY with $3\,\mathrm{GeV/c}$ protons - first time beam time test of ToASt in beam

Summary

- Test PCB of ToASt connected to small strip sensor
- Readout system ready for testing with the ToASt
- Graphical user interface already has basic functionality
- More features to be implemented, more bugs to be fixed
- Upcoming beamtime at COSY

The Micro-Vertex-Detector of the $\overline{\text{P}}$ANDA Experiment at FAIR

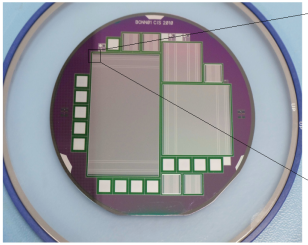
Why is it needed?

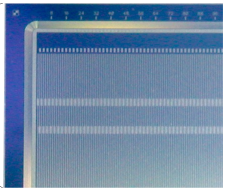
- **Primary** and **secondary vertex reconstruction**
- Improve **momentum reconstruction**
- support **PID** via dE/dx
- **Event building** in continuous data stream

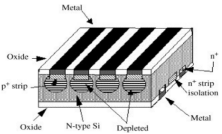
Requirements:

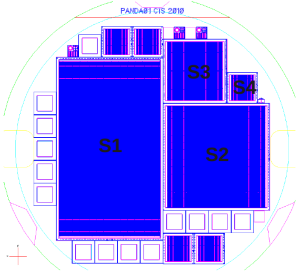
- **Spatial** resolution
- **Time** resolution
  $\leq 10\,\text{ns}$
- **Continuous** readout
- **Radiation** tolerance
  $\sim 10^{14}\,\text{n}_{\text{eq.}}/\text{cm}^2$ and $100\,\text{kGy}$
- Limited **material budget**
  $\text{X}/\text{X}_0 \leq 1\,\%$ per layer
- $\geq$ 4 hits per track
- Operation at room **temperature**
- **Routing** and **services** from the back

Strip Sensor Details







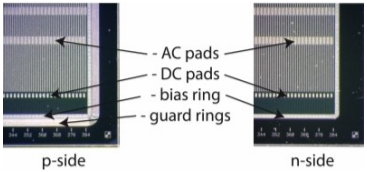


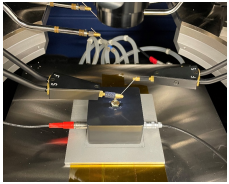
- Double sided strip sensors w/ AC-coupled microstrips (CiS/Erfurt)
- Wafer with different sensor and test structures

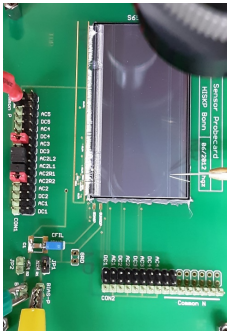
Property	Value	Unit
General		
wafer material	FZ Si, 4″	
thickness	285±10	µm
resistivity	2.3. . . 5.0	k Ωcm
n-side isolation	*p*-spray	
guard rings	8	
stereo angle	90	°
passive rim	860	µm
S1		
p-side/*n*-side strips	896/512	
pitch/width	65/30	µm
active area	58.275×33.315	mm^2
S2		
p-side/*n*-side strips	512/512	
pitch/width	65/30	µm
active area	33.315×33.315	mm^2
S3		
p-side/*n*-side strips	384/384	
pitch/width	50/20	µm
active area	19.230×19.230	mm^2
S4		
p-side/*n*-side strips	128/128	
pitch/width	65/30	µm
active area	8.355×8.355	mm^2

Strip Sensors

- All required strip sensors tested and delivered
- Quality checks with probing station in Gießen by Nils Tröll utilizing:
  - LCR-Meter Sourcetronic ST2826
  - Voltage supply Keithley 2410
- Tested: leakage current, depletion voltage and capacitance





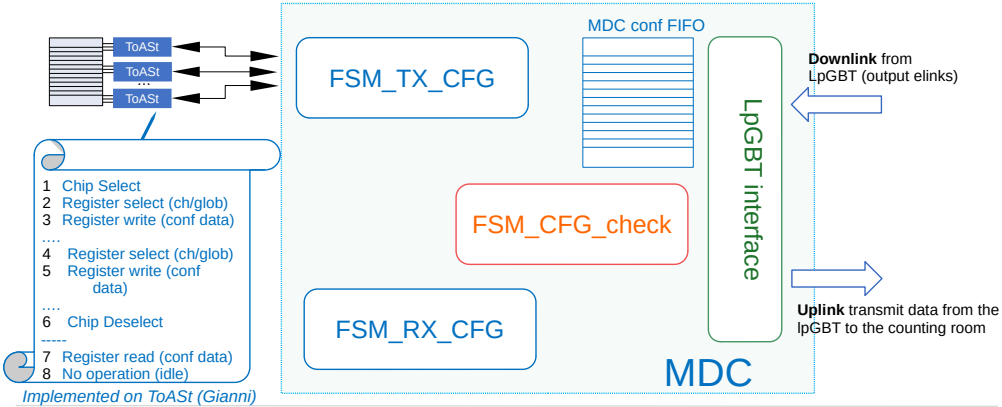


ToASt Details

Input capacitance	2 - 16 pF
Max rate per strip	50 kHz
Input charge range	1 - 40 fC
Max noise	1500 e^-
Peaking time	50 - 100 ns
Channels per chip	64
Channel pitch	66 µm
Reference clock	160 MHz
Charge resolution	8 bits
Time resolution	6.25 ns (pk-pk) 1.8 ns (r.m.s.)
Output drivers	2×160 MS/s
Max power consumption	
(estimated, full TMR)	360 mW (5.6 mW/ch)
(estimated, no TMR)	257 mW (4 mW/ch)
Die size	3.24×4.41 mm^2
Pads position	On two sides only

MDC ToASt configuration module

ToAst configuration and “error protection” architecture



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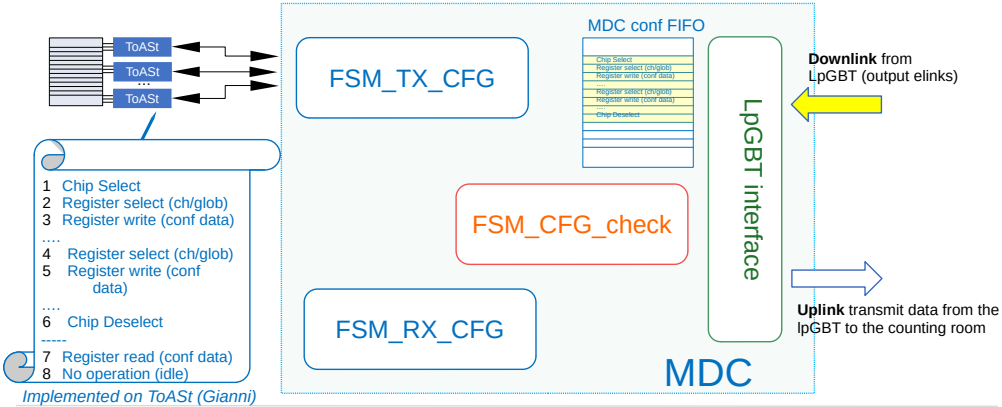
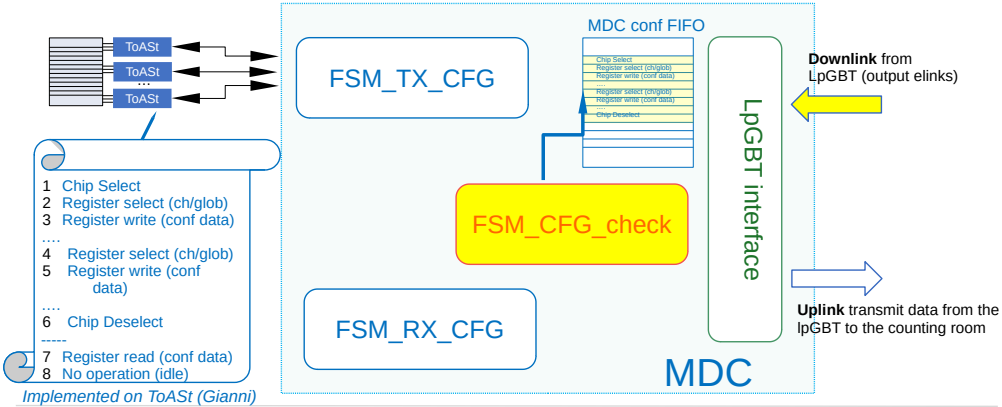


MDC ToASt configuration module

ToAst configuration and “error protection” architecture



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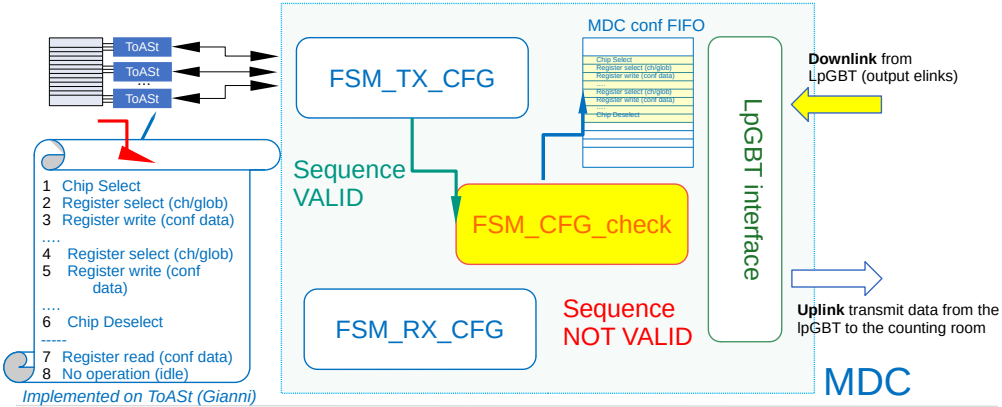

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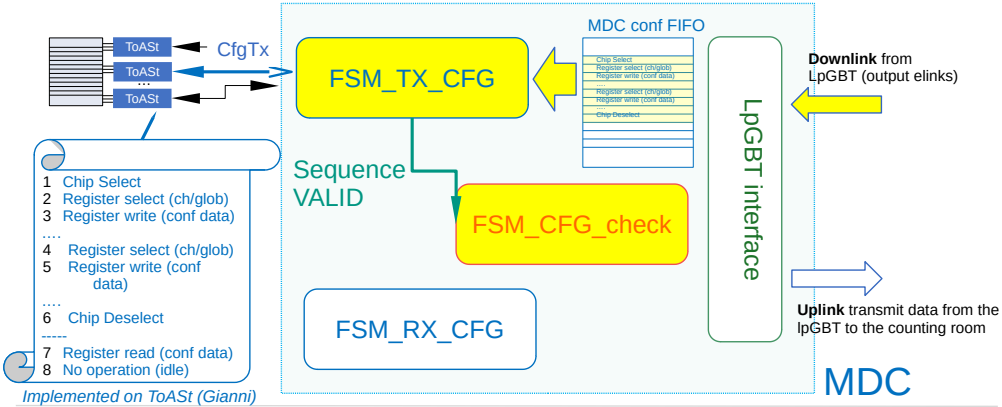

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