The PANDA MicroVertex Detector: Design and Prototype Results

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On behalf of the PANDA MVD Group

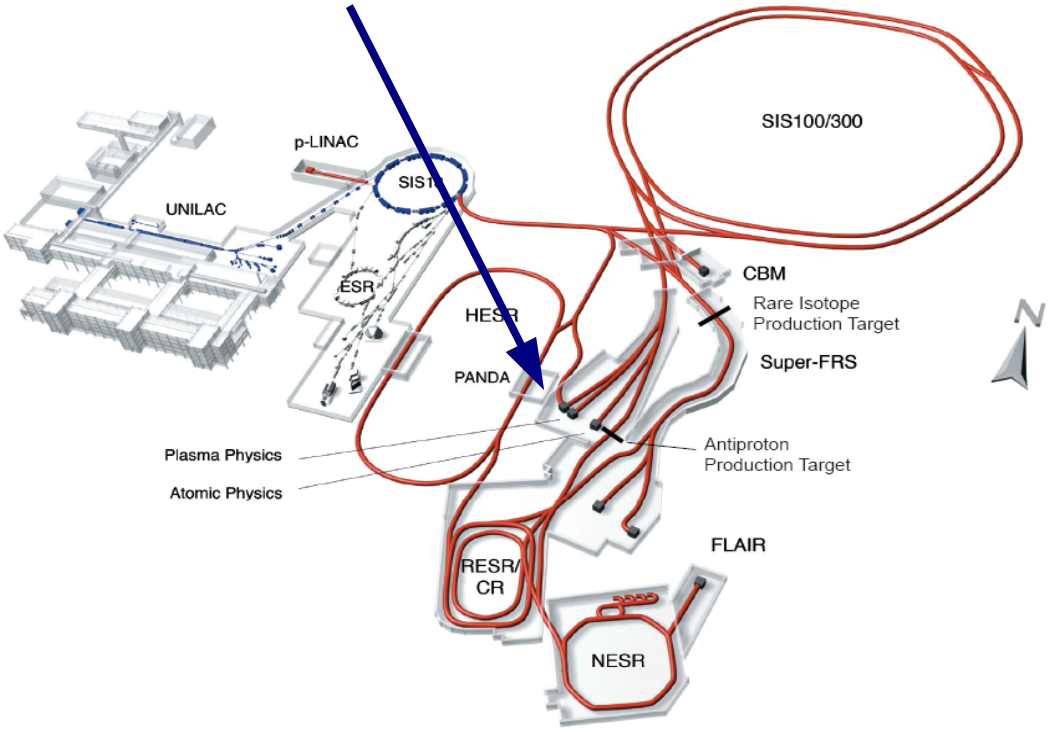
Outline

- **The context: FAIR and PANDA**
- **The MVD detector: requirements**
- **The MVD detector: design concept**
- **Results from first prototypes**
- **Summary and outlook**

PANDA @ FAIR

- **FAIR=Facility for Antiproton and Ion Research.**
- **A new facility located at the GSI site near Darmstadt, Germany.**
- **It will provide antiprotons, protons and ion beams for different projects.**

$\overline{\text{P}}$ANDA=antiProton Annihilation at Darmstadt



HESR in a nutshell

The HESR is an antiproton storage ring

High luminosity mode

Momentum: 1.5 to 15 GeV/c

$\Delta p/p = 10^{-4}$

10^{11} antiprotons

Stochastic cooling

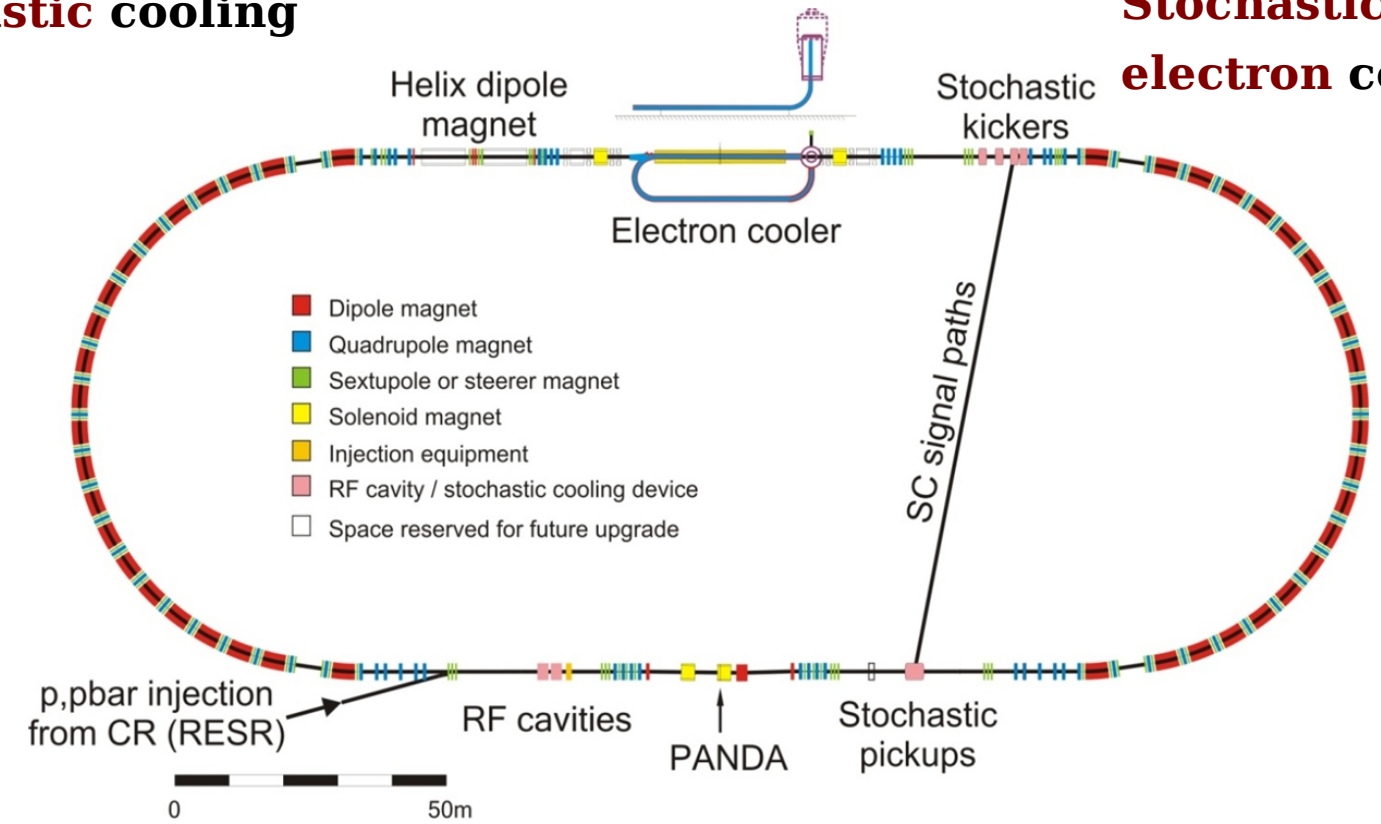
High resolution mode

Momentum: 1.5 to 8.9 GeV/c

$\Delta p/p = 10^{-5}$

10^{10} antiprotons

Stochastic cooling plus electron cooling



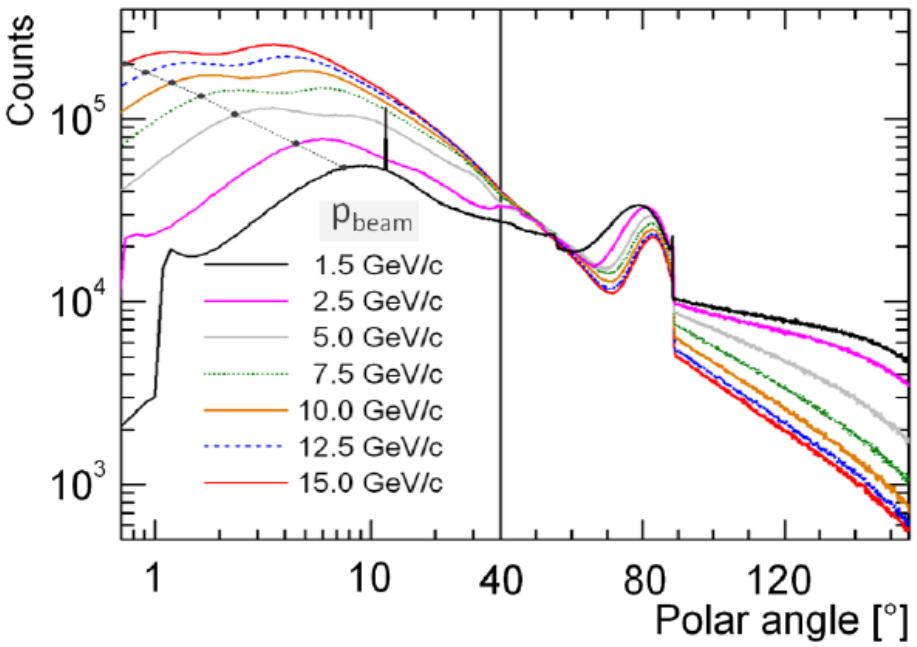
Physics@$\overline{\text{P}}$ANDA

Fixed target setup for high precision QCD studies with cooled $\bar{p}$ beams

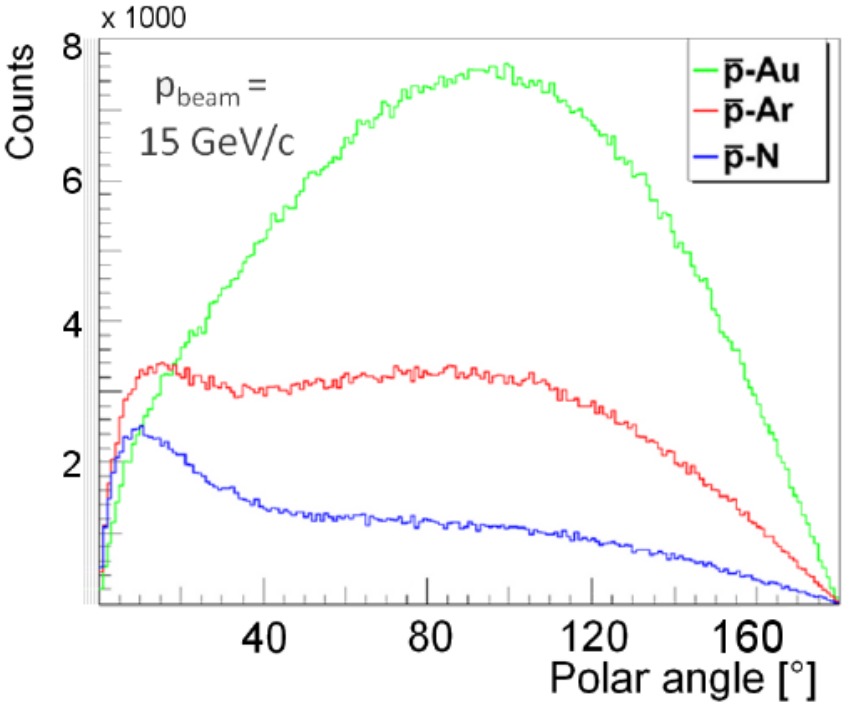
- **Charmonium spectroscopy:**
  - Precise measurements of all states below and above open charm threshold.
  - Several thousands $c\bar{c}$ states per day, directly produced in $p\bar{p}$ annihilations.
  - Open charm spectroscopy.
- **Search for gluonic excitations:**
  - Hadrons in which gluons act as principal constituent.
  - Glueballs.
- **In medium modifications of hadrons.**
- **Hypernuclear physics.**
- **Electromagnetic processes.**

Multipurpose apparatus with triggerless Data Acquisition

Particle distribution



Simulated particle distribution in $\bar{p}p$.

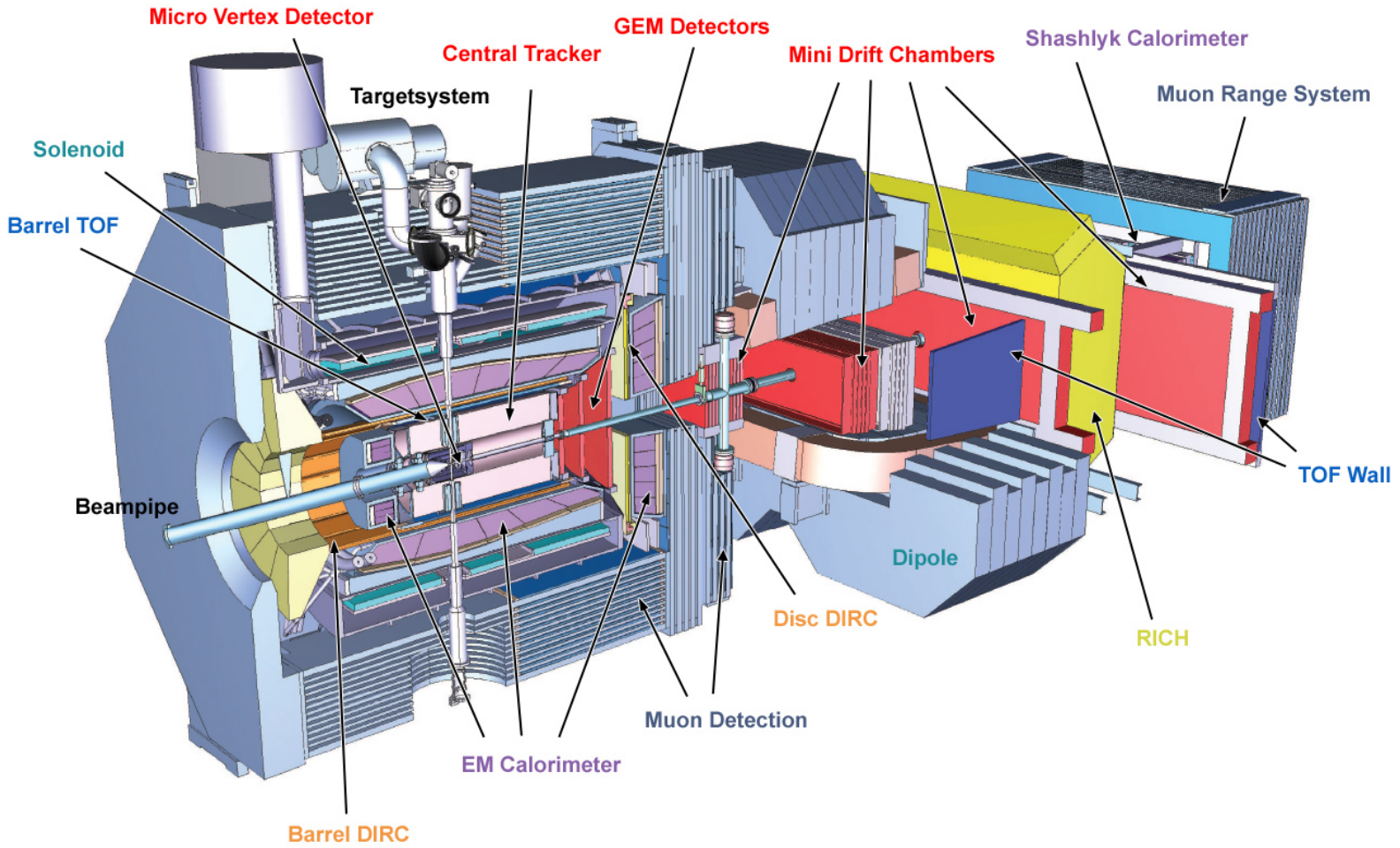


Simulated particle distribution with nuclear targets.

- **Strong forward peak in $\bar{p}p$ but in p-nucleus particle distribution privileges high polar angles .**

Need of 4π coverage

PANDA layout

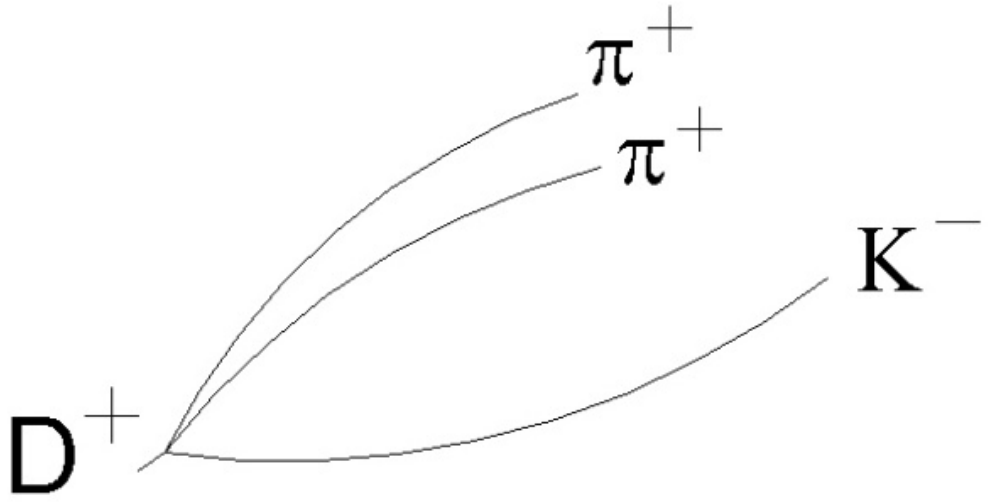


- **Double spectrometer layout:**
  - **Target spectrometer: barrel geometry. 2T superconducting solenoid.**
  - **Forward spectrometer: fixed target layout with resistive dipole with 2 Tm.**

The PANDA MVD

The MVD is the innermost detector of the PANDA apparatus

- **It must combine good space resolution with accurate time-tagging**
- **Main functions:**
  - Primary vertex reconstruction.
  - Detection of secondary vertexes.
  - Improvement in momentum resolution.
  - Support PID of low momentum particles via dE/dx measurements.



$c\tau$=312~μm

MVD specifications

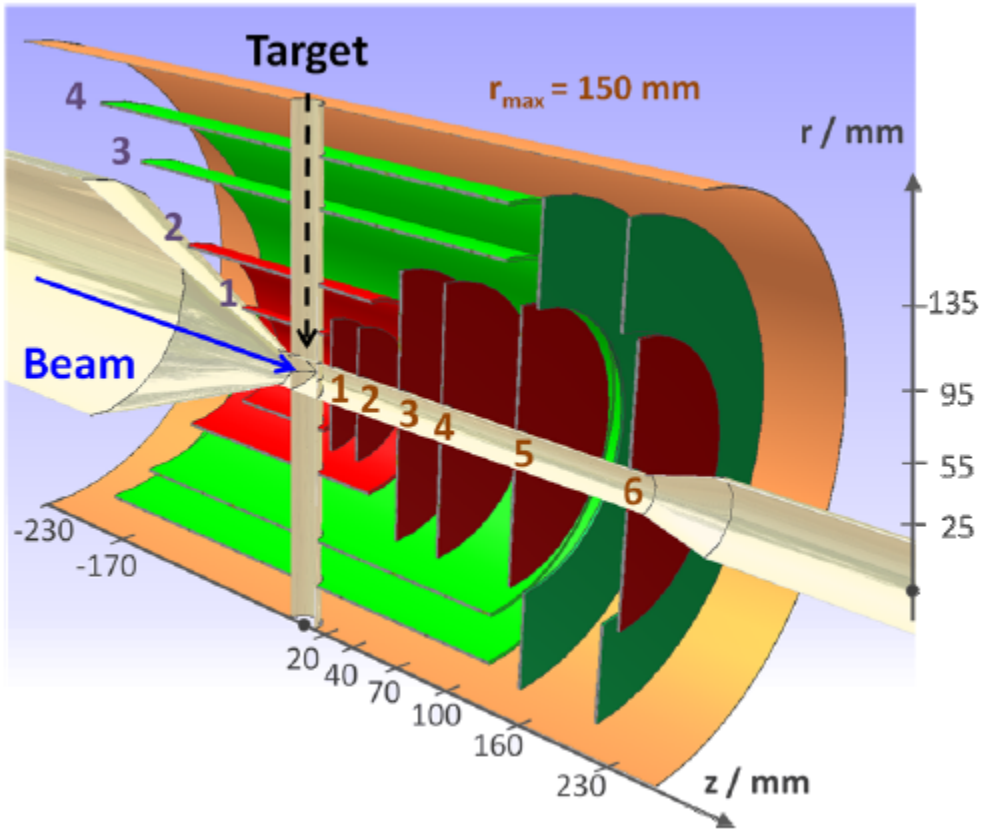
Requirements:

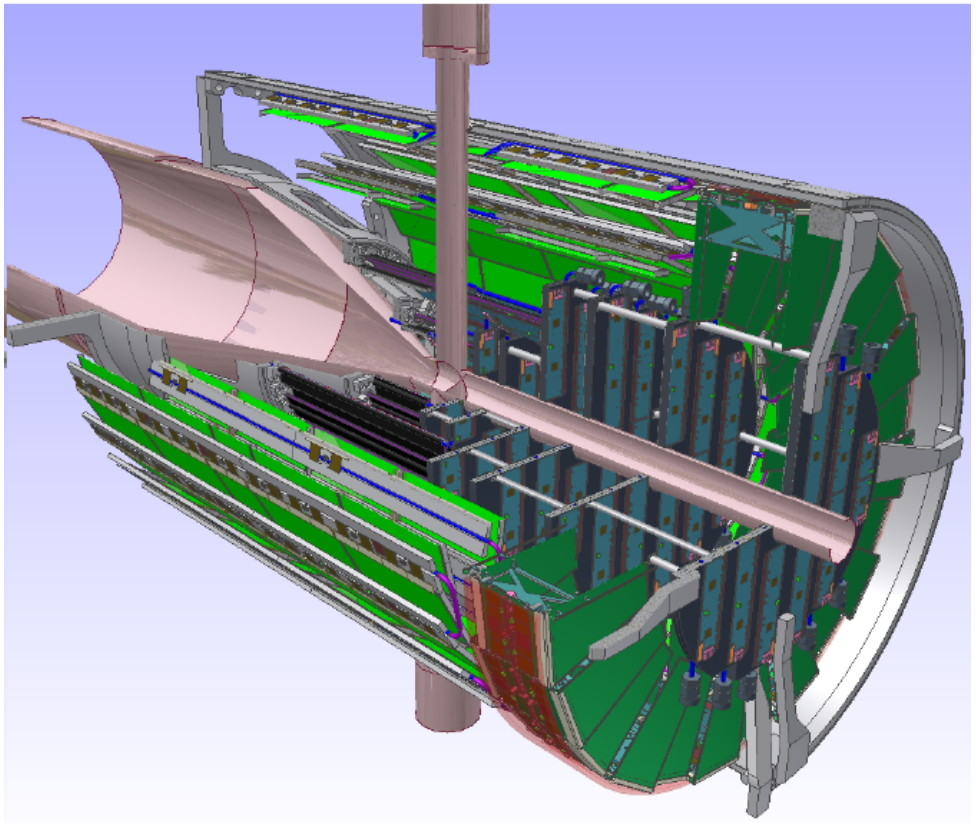
- **Provide at least four track points with:**
  - Good time resolution: < **5 ns rms.**
  - Good space accuracy **O(30 μm) in rϕ, better than 100 μm in z.**
- **Low material budget (1% of X_0 per layer).**
- **Read-out rate capabilities: better than 6~MHz/cm^2**
- **Max geometrical coverage around the interaction point: ± 23 cm.**
- **Radius: 15 cm.**

Operating conditions and constraints:

- **Room temperature operation.**
- **Radiation tolerance to 10 Mrad and 10^{14} 1~MeV/cm^2 equivalent neutrons.**
- **Services only in the backward region.**

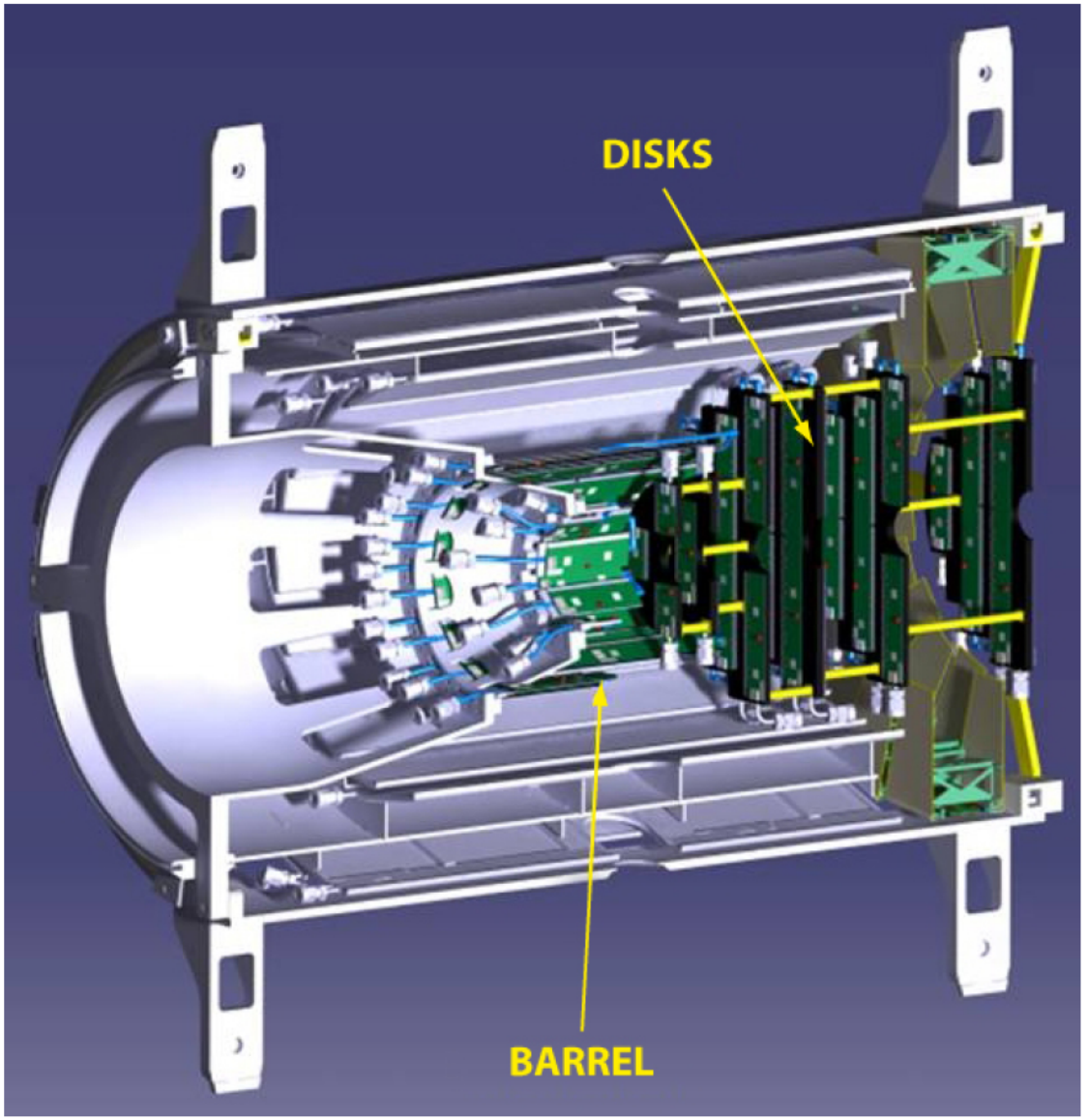
MVD layout



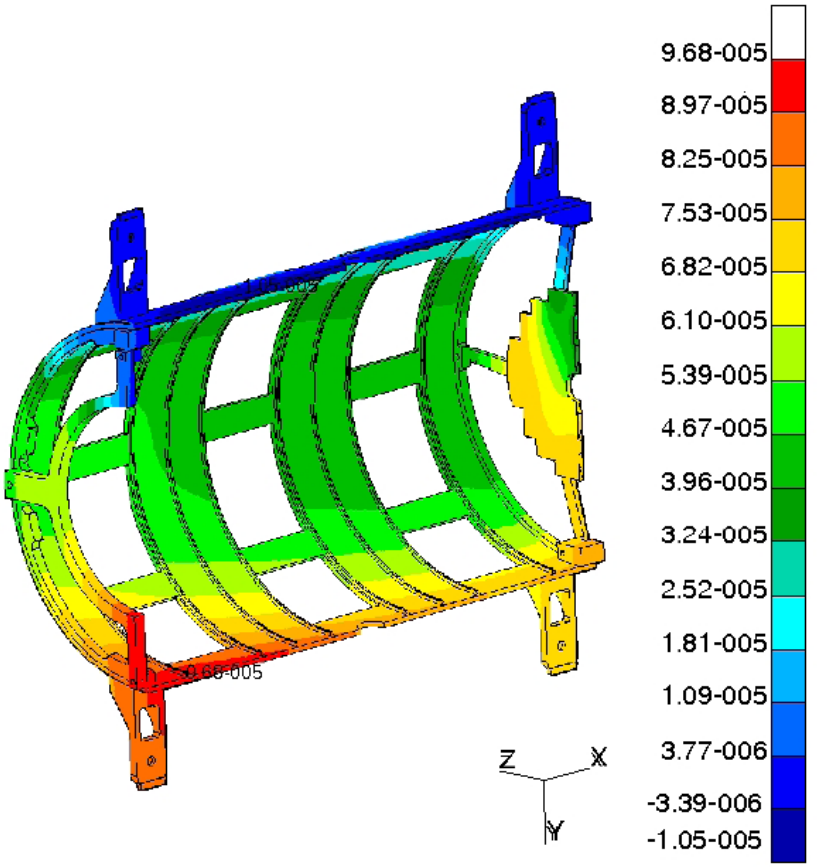


- **Barrels: two pixel layers plus two strip layers with double sided strips.**
- **Forward region: six disks:**
  - **Four disks only equipped with pixels.**
  - **Two disks with pixels in the inner and strips in the outer part.**

MVD mechanics

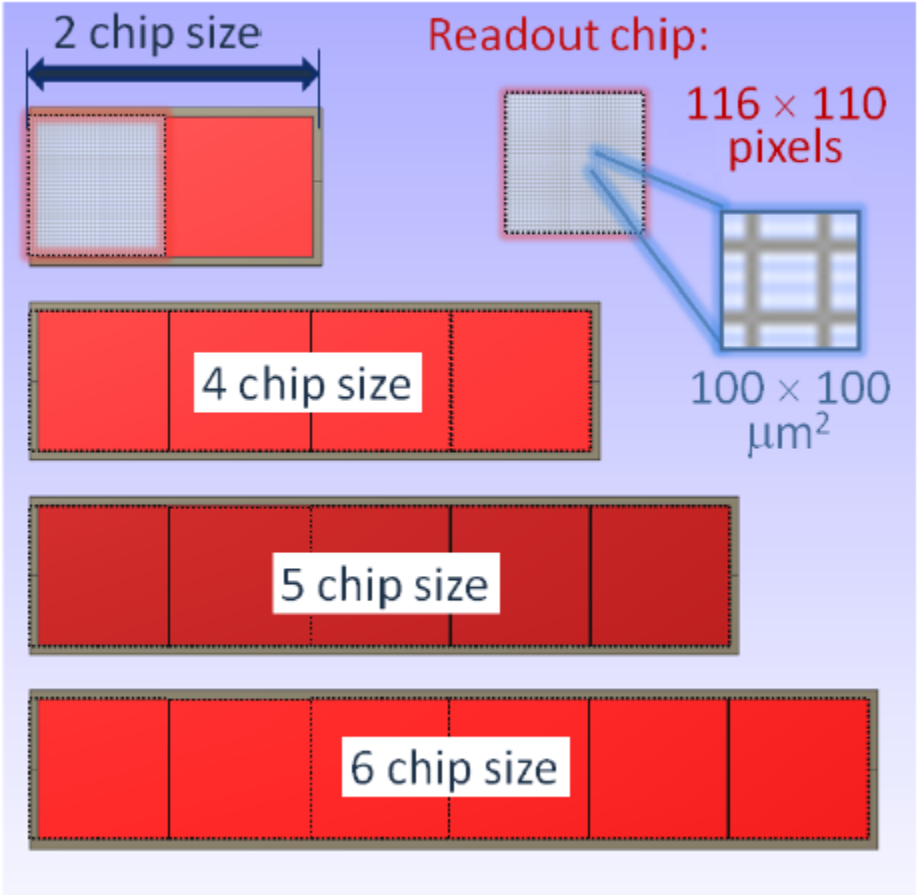


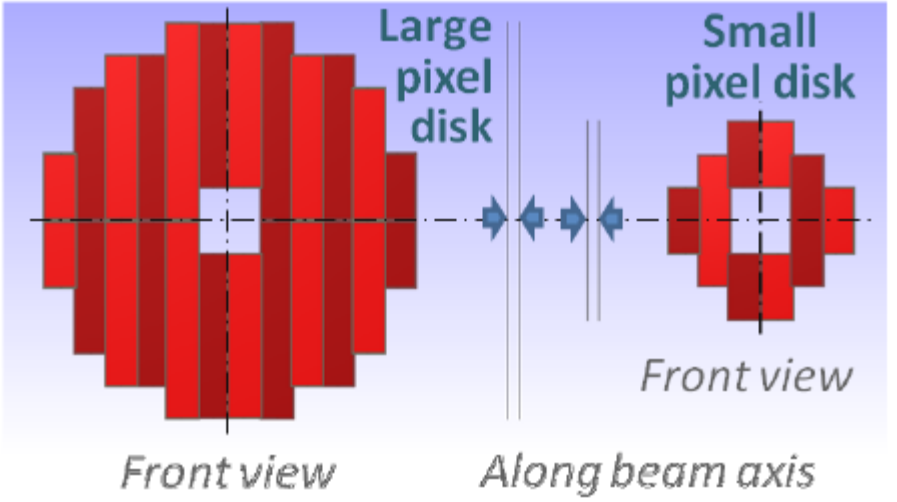
Deformation under full load

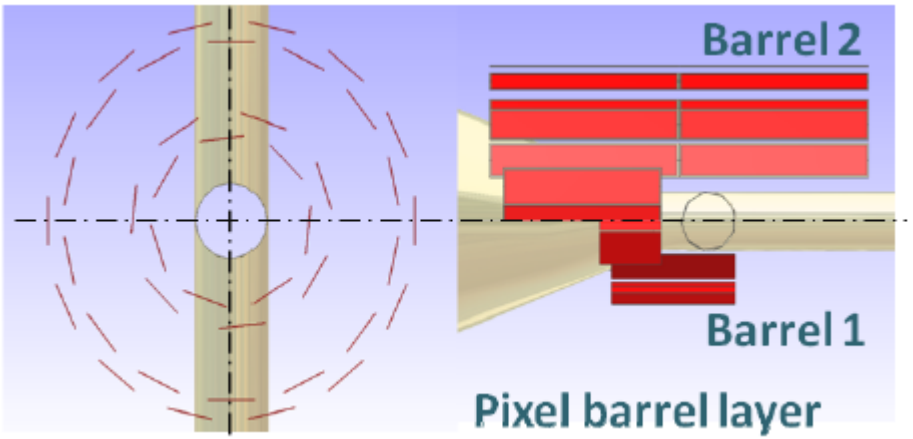


Two halves clamped around the beam/target pipe.

Pixel detector ladders

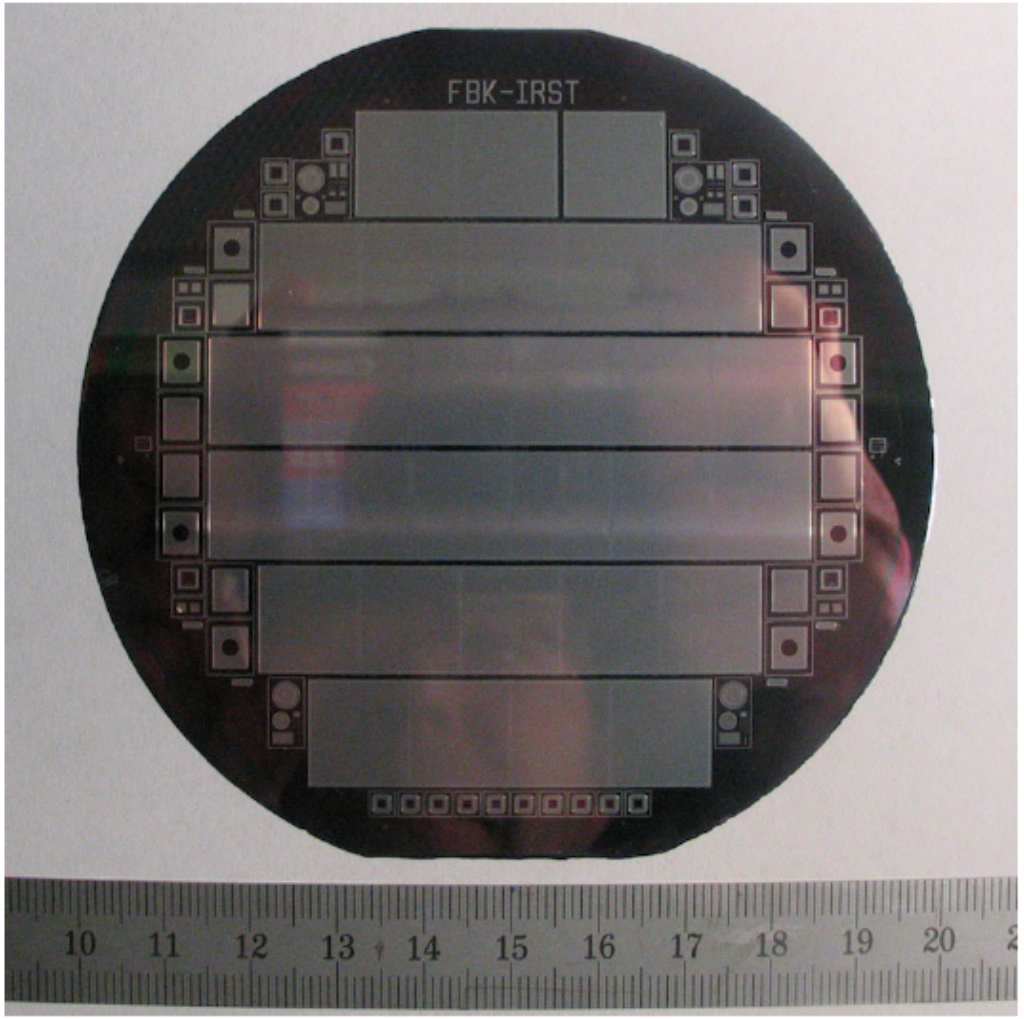


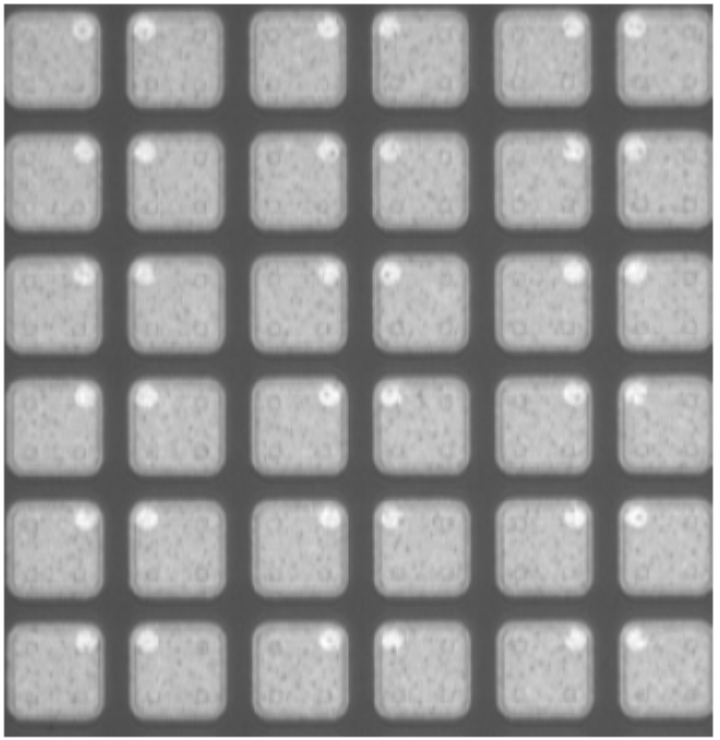




- **Layout based on a basic unit corresponding to the readout chip size.**
- **Ladders are obtained by tiling from two to six units.**
- **Size of the basic unit chosen to minimize the number of sensors.**

Epitaxial silicon sensors (1)

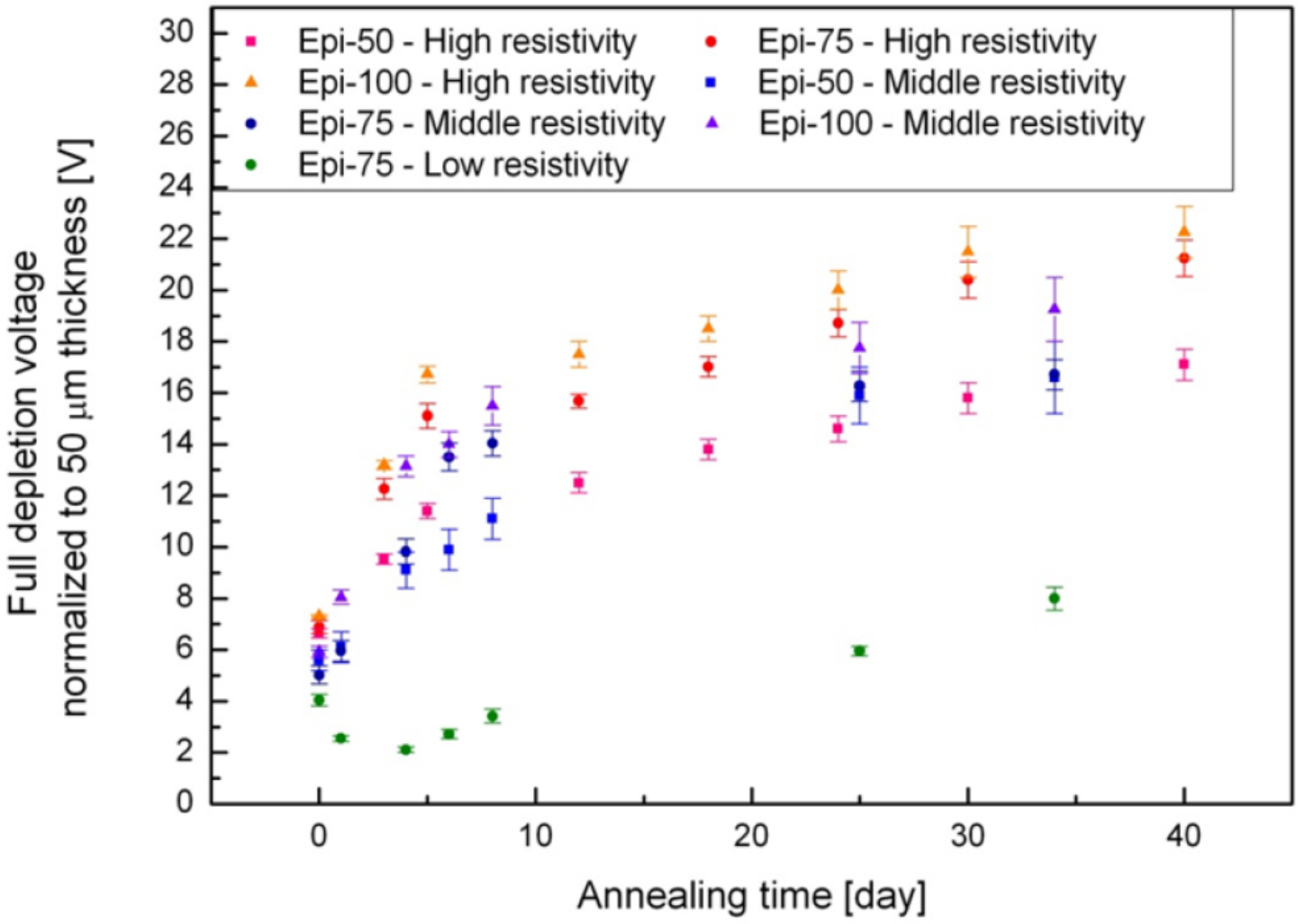




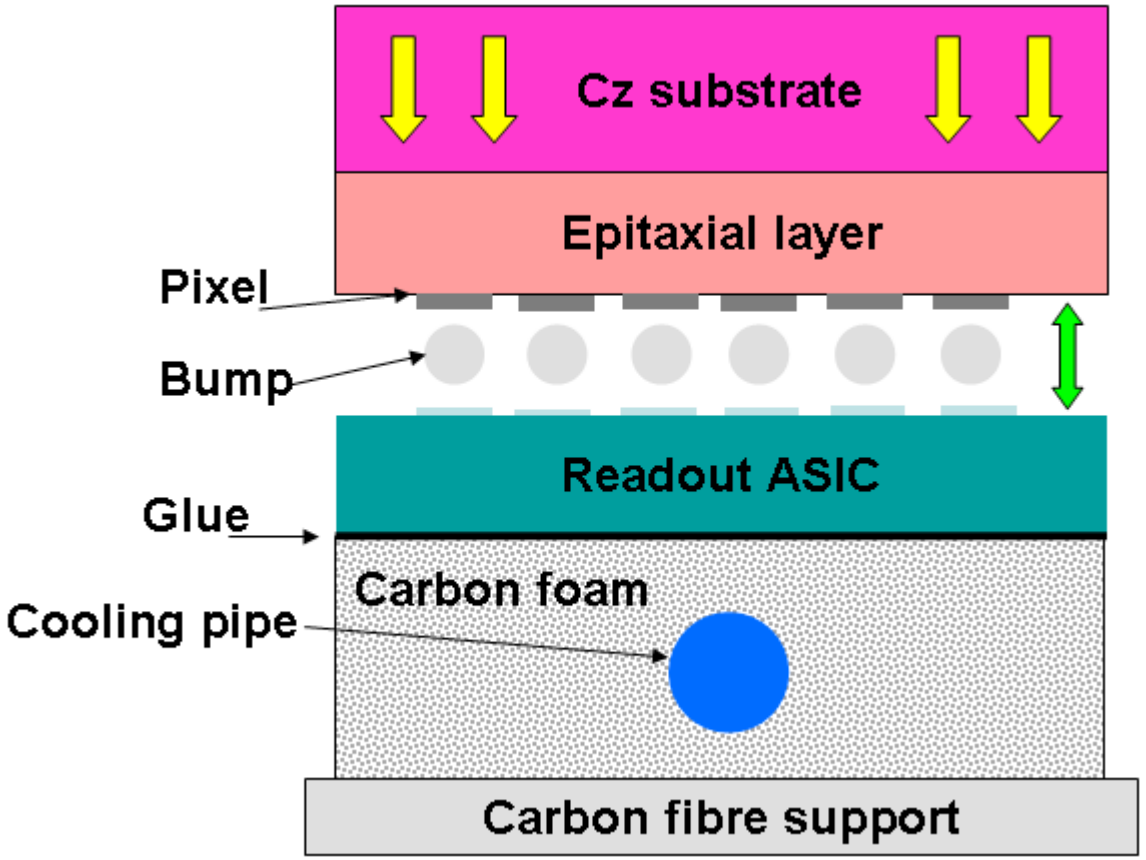
Bond pad distribution reflects the double column structure of the readout chip.

- **Baseline choice: epitaxial silicon sensors.**
- **Raw wafers provided by ITME (Varsaw) and processed by FBK Trento.**
- **Several epi-thicknesses tried, 100 μm chosen.**

Irradiation tests of epi-diodes



Pixel assembly concept

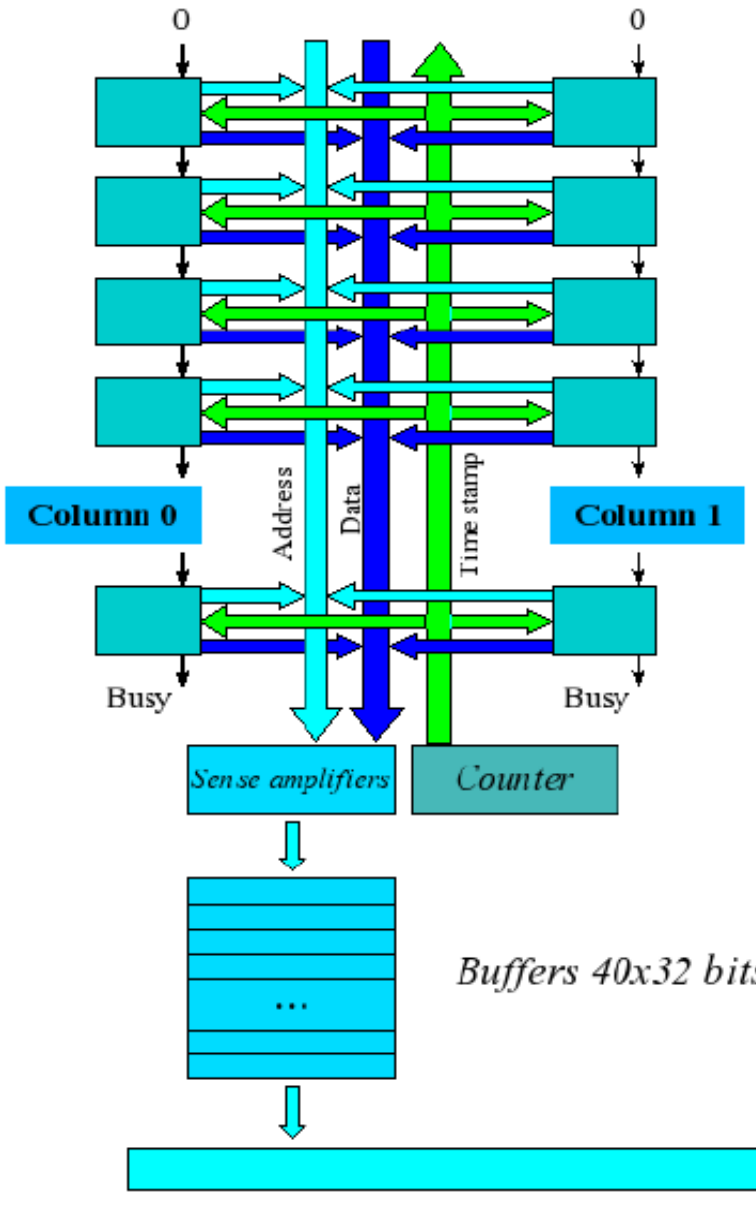


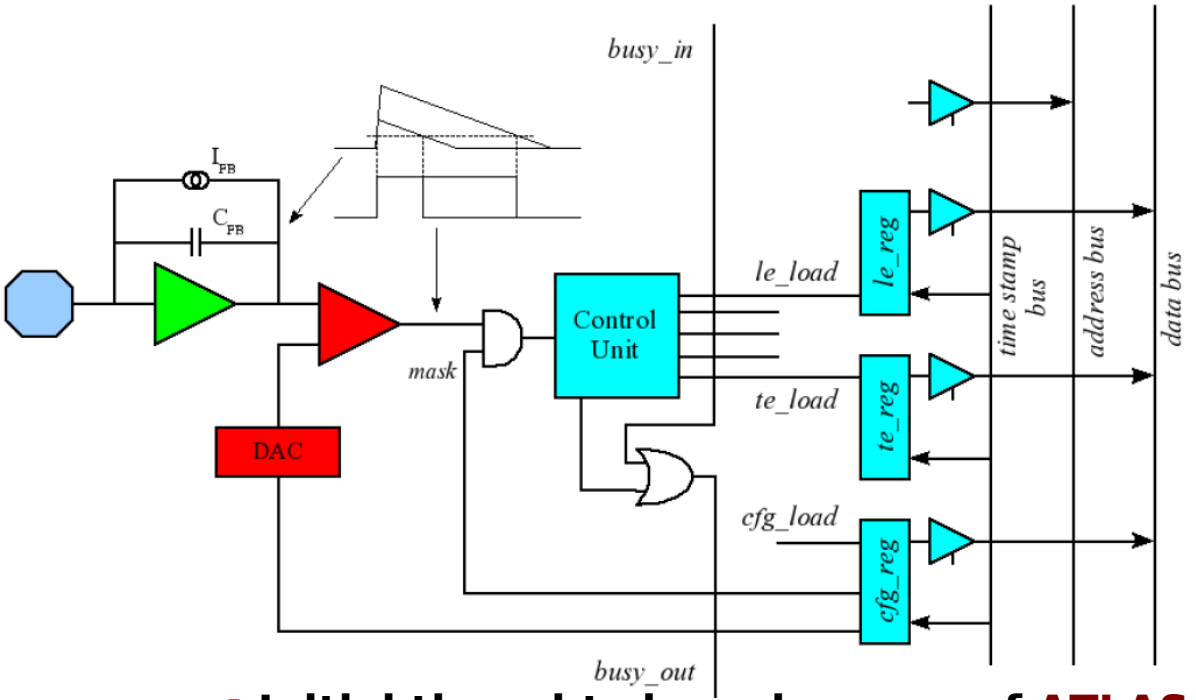
Pixel electronics requirements

Pixel size	100 µm x 100 µm
Chip active area	11.4 mm x 11.6 mm
Noise floor	< 200 rms electron
Counter dynamic range	12 bits
System clock	155.52 MHz
Time stamp LSB	6.25 ns
Power consumption	< 1 W/cm^2
Total ionizing dose	10 Mrad
1 MeV equivalent neutron	10E14/cm^2

- **Technology for the front-end ASIC: CMOS 0.13 µm.**
- **Front-end designed to cope with sensor of either polarity.**
- **Charge encoding with Time over Threshold (ToT).**
- **Data rate per chip O(300 Mb/s).**

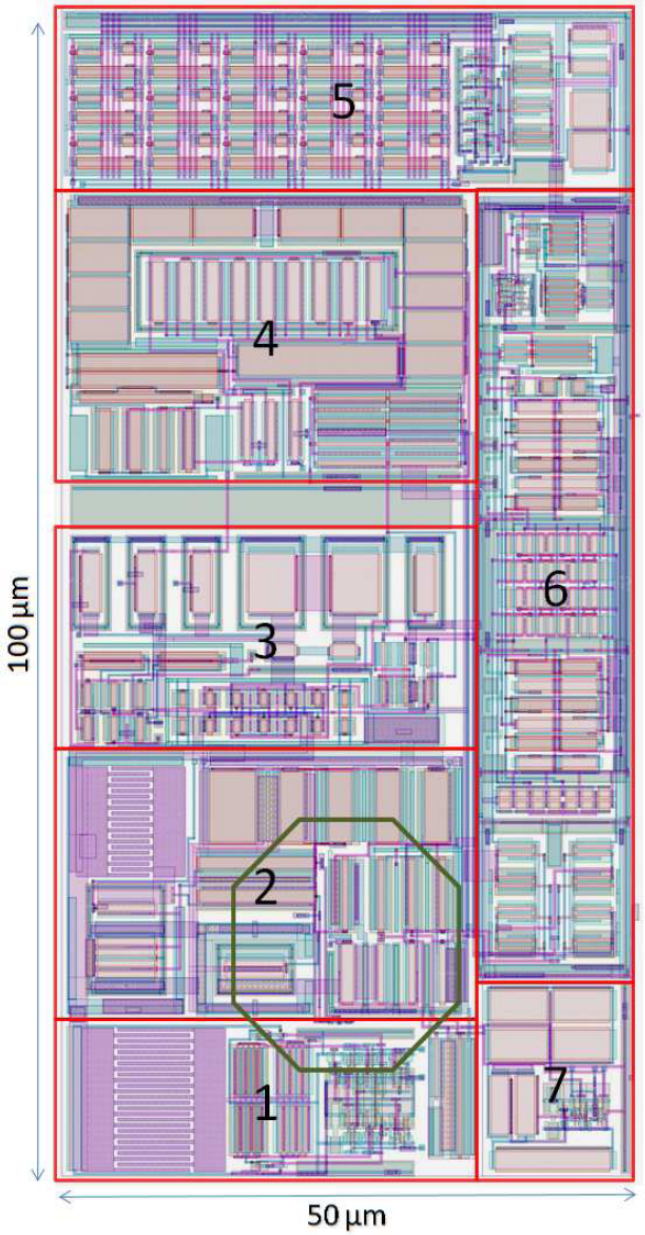
Front-end architecture

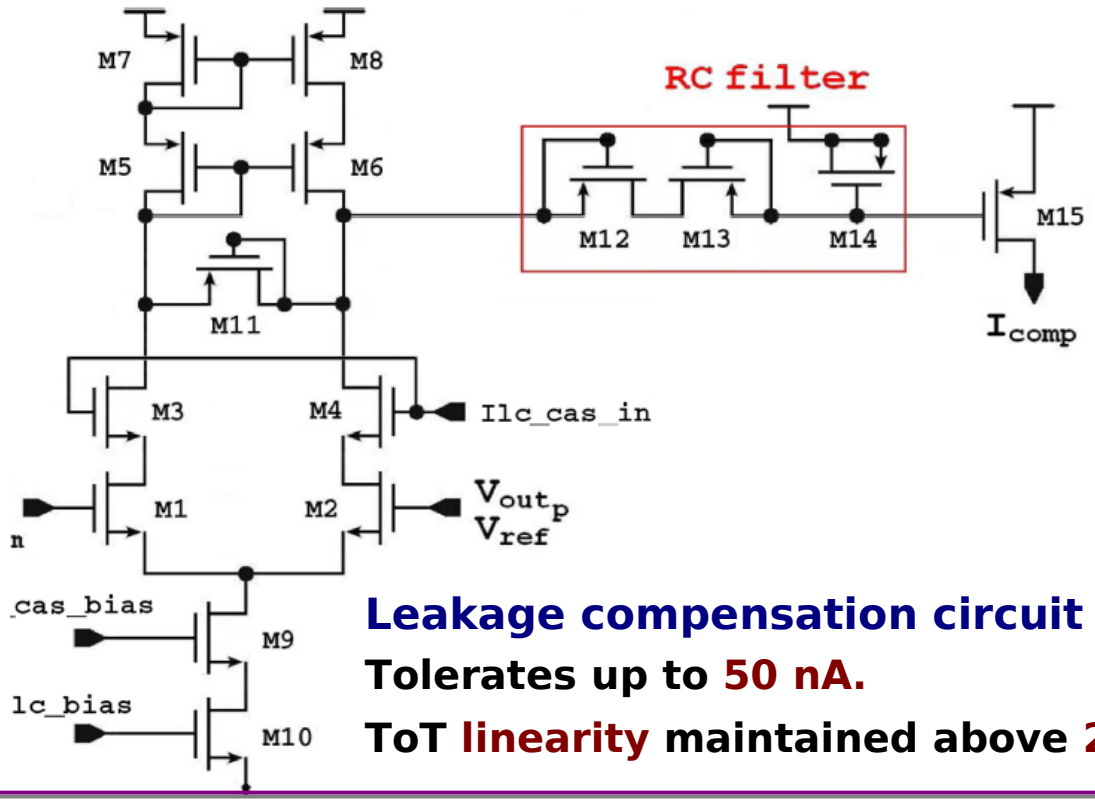




- **Initial thoughts based on use of ATLAS FEI3.**
- **Several constraints (pixel size, triggerless structure, mechanical factors) pushed for an ad hoc development.**
- **Interesting FEI3 features retained.**
- **Full free running time-tagging engine.**

Pixel front-end details





Leakage compensation circuit

Tolerates up to 50 nA.

ToT linearity maintained above 20 µs.

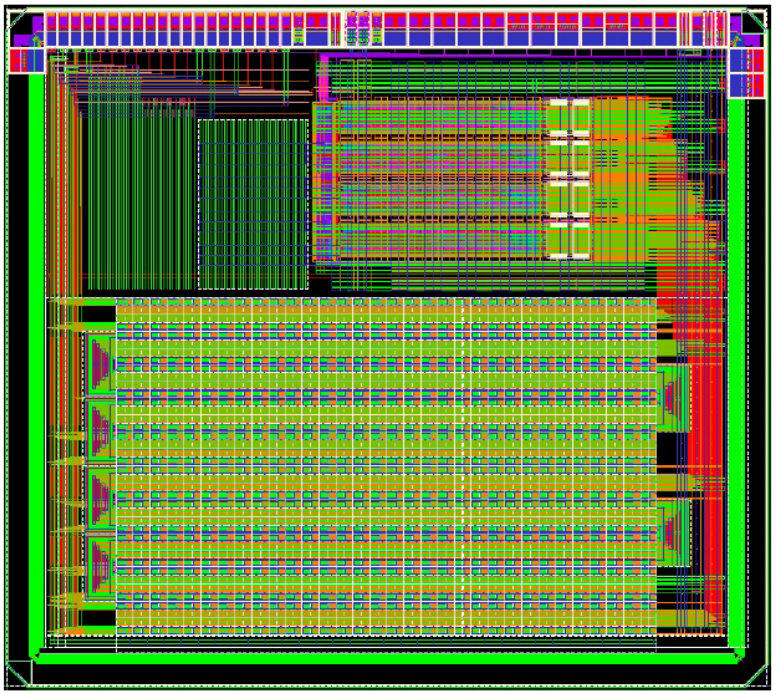
Analog building block (fit in 50 µm x 50 µm)

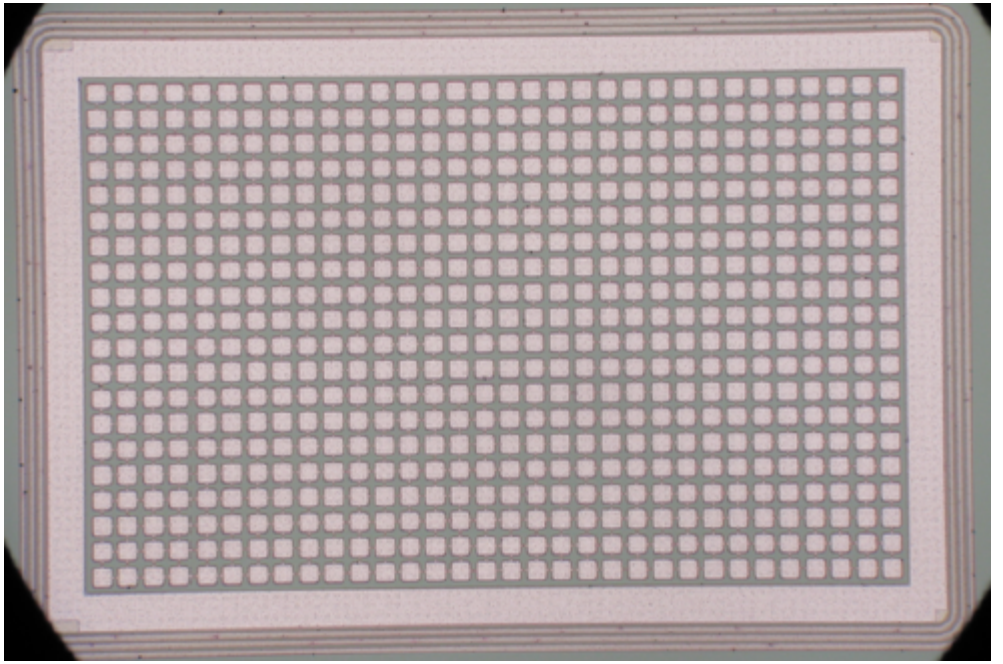
- **1. Calibration circuit**
- **2. CSA**
- **3. Constant current feed-back**
- **4. Leakage compensation**
- **5. DAC**
- **6. Comparator**
- **7. Clipping circuit**

Prototyping

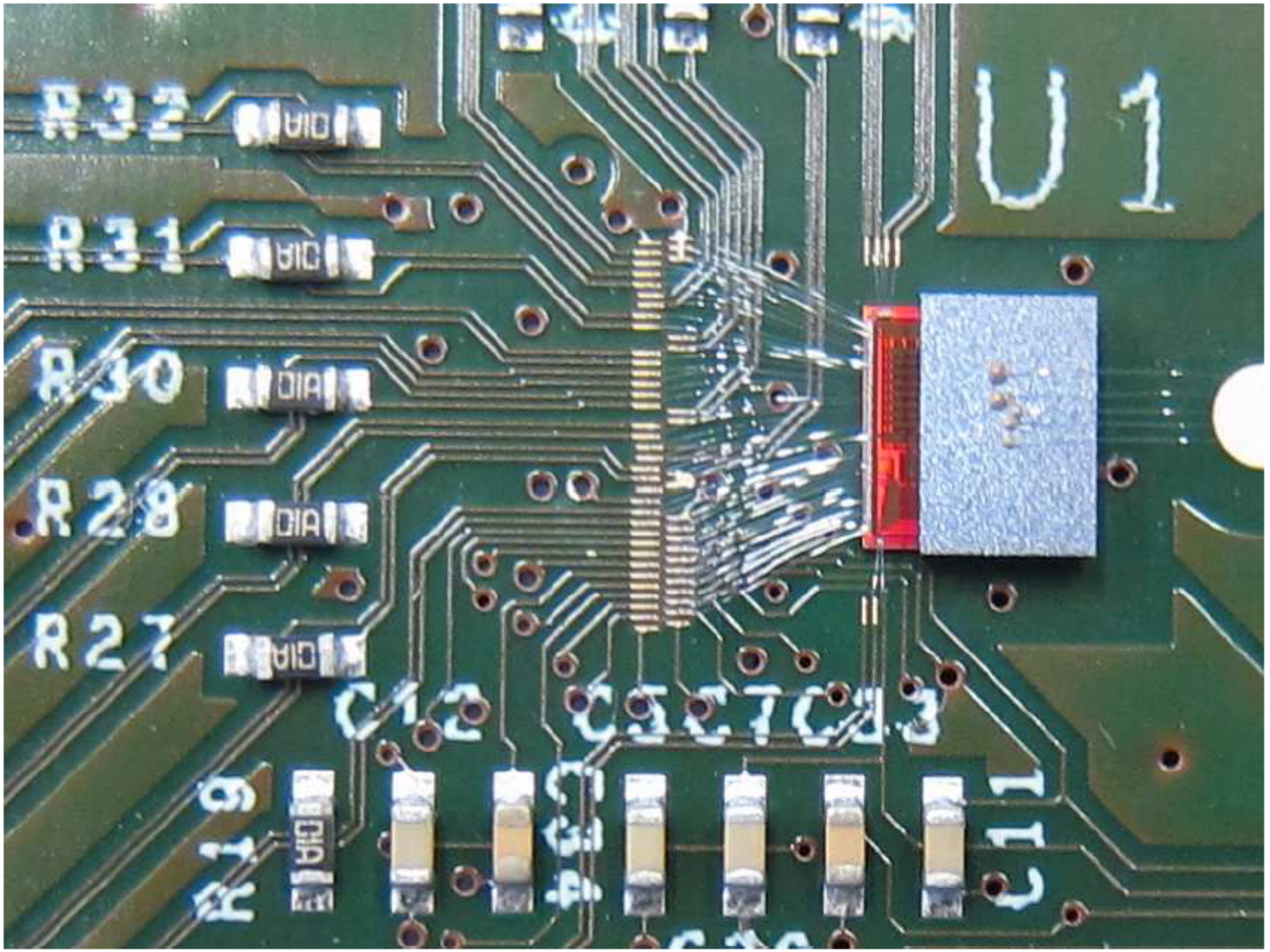
Try to address relevant issues with small prototypes produced in MPW

- **Third generation prototype contains all the relevant features.**
- **Snaked columns to combine realistic column length (power supply drop, data transmission issues) with acceptable chip form factor.**
- **2 long column of 128 pixels folded in four segment.**
- **2 short side columns with 32 pixels as reference.**
- **Chip can be connected to a baby sensor.**



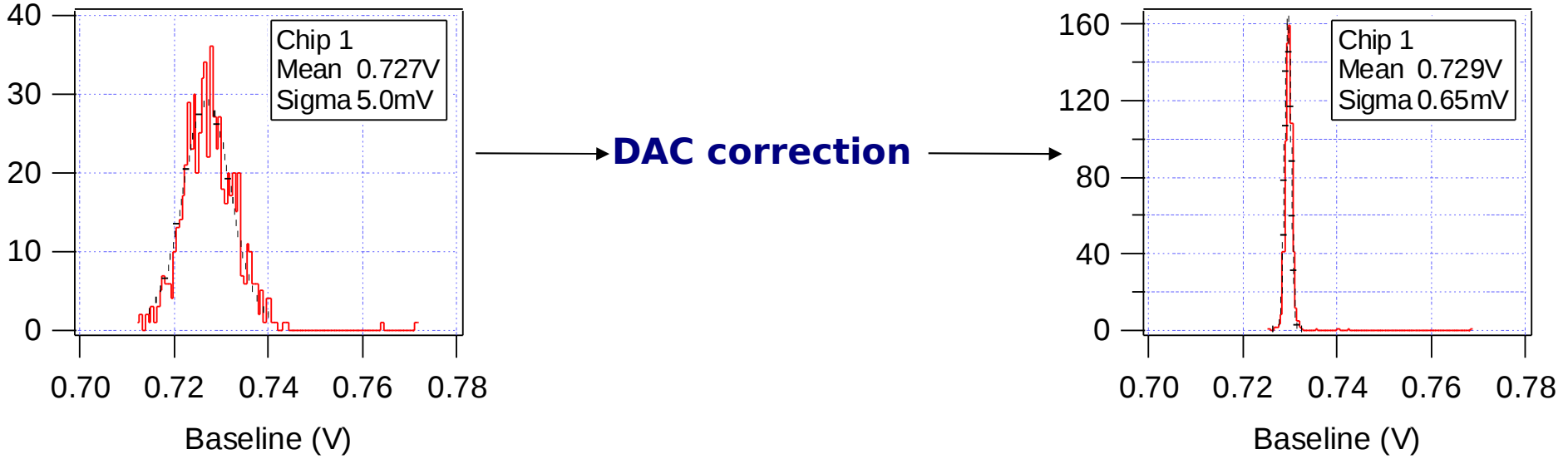


Chip and sensor assembly

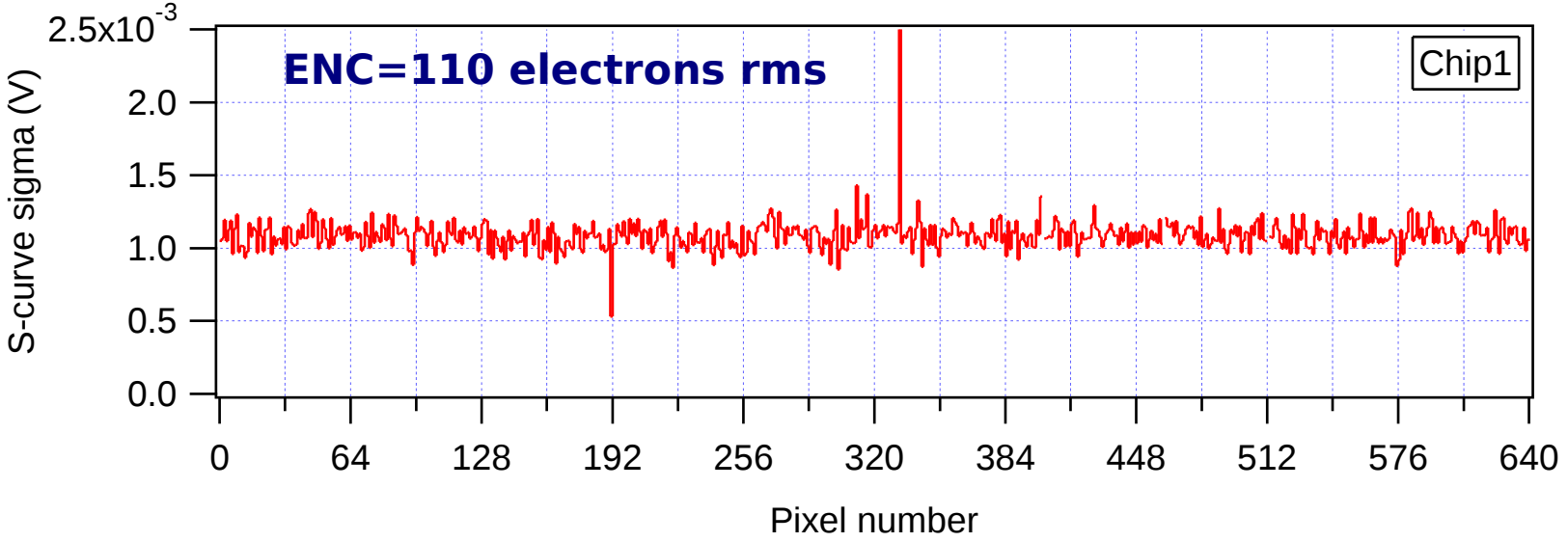


Threshold and noise

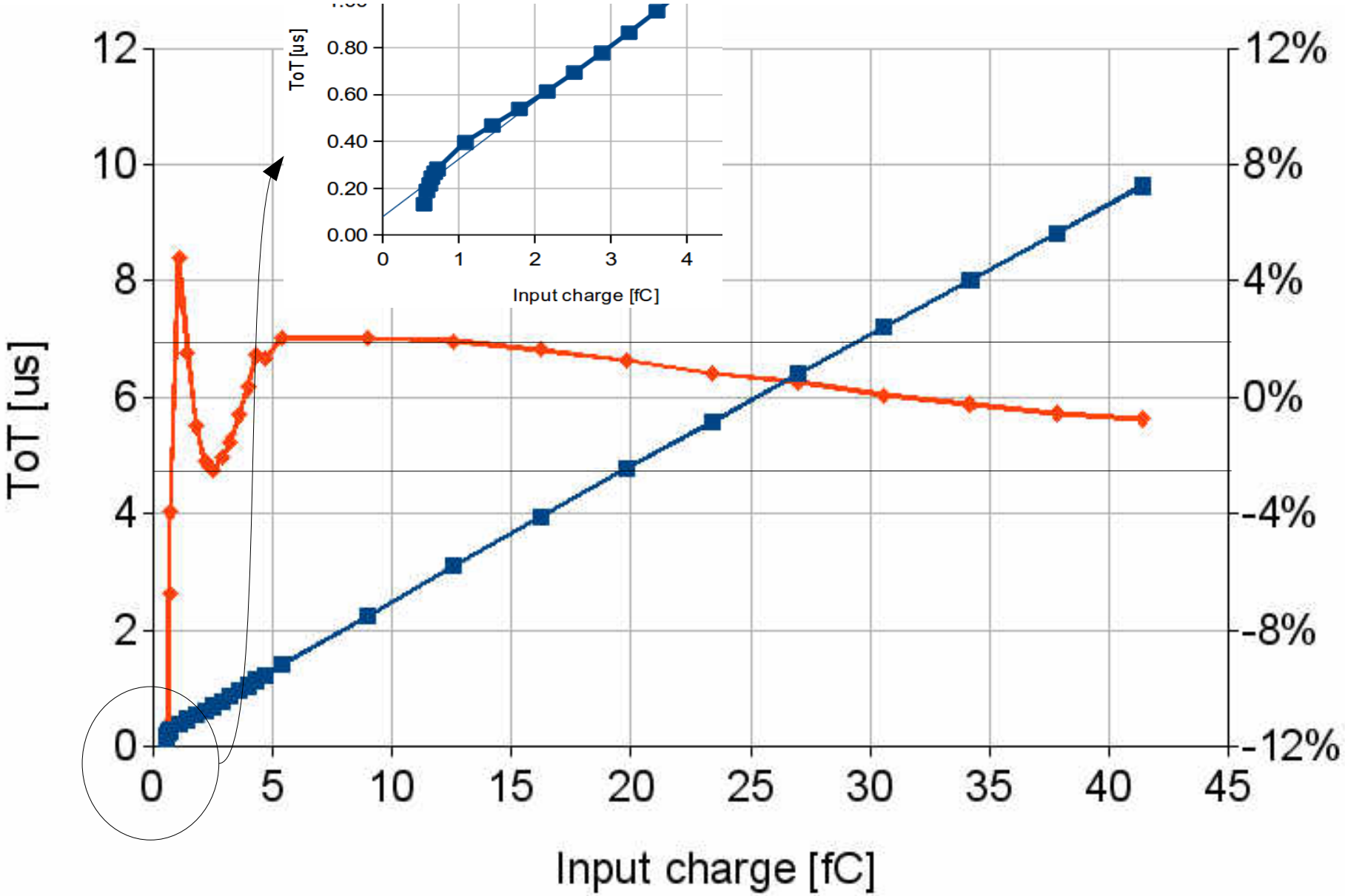
473 electrons rms → **62 electrons rms**



Operation threshold=1000 electrons, 12 μW/pixel analog power

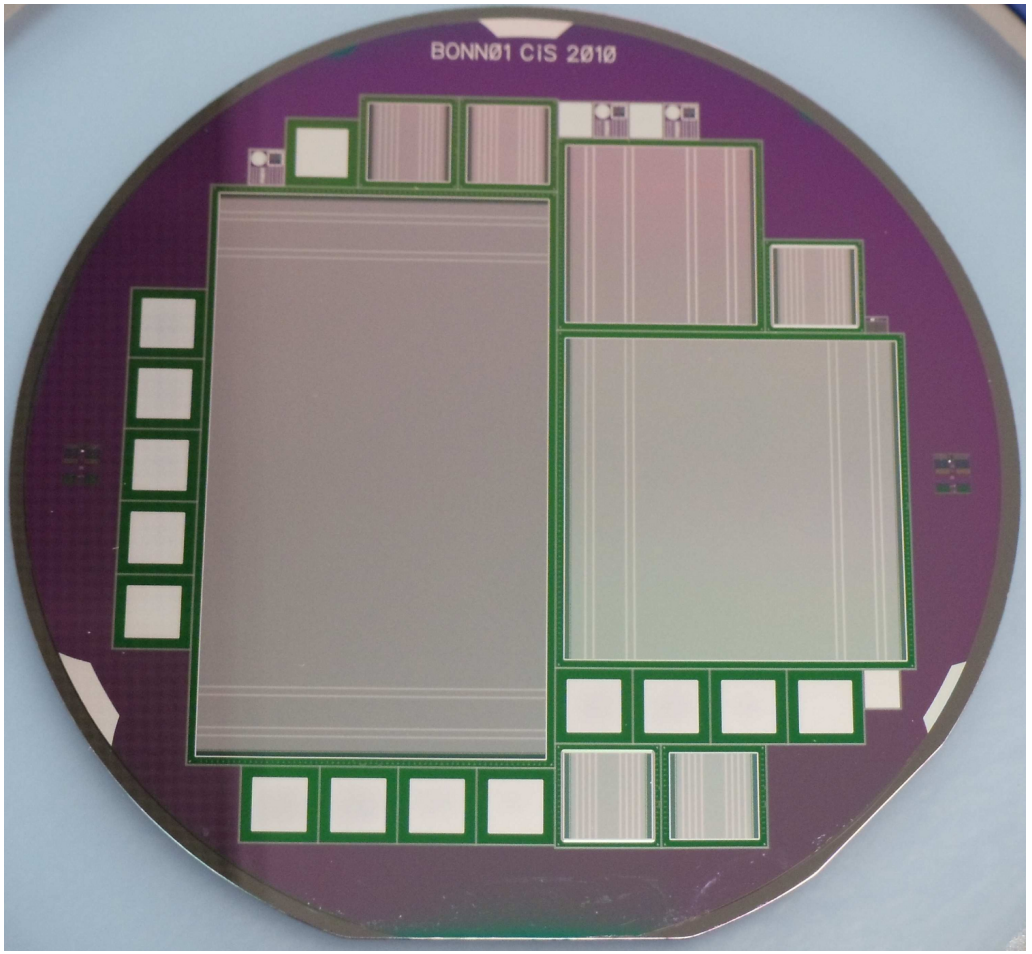


ToT linearity

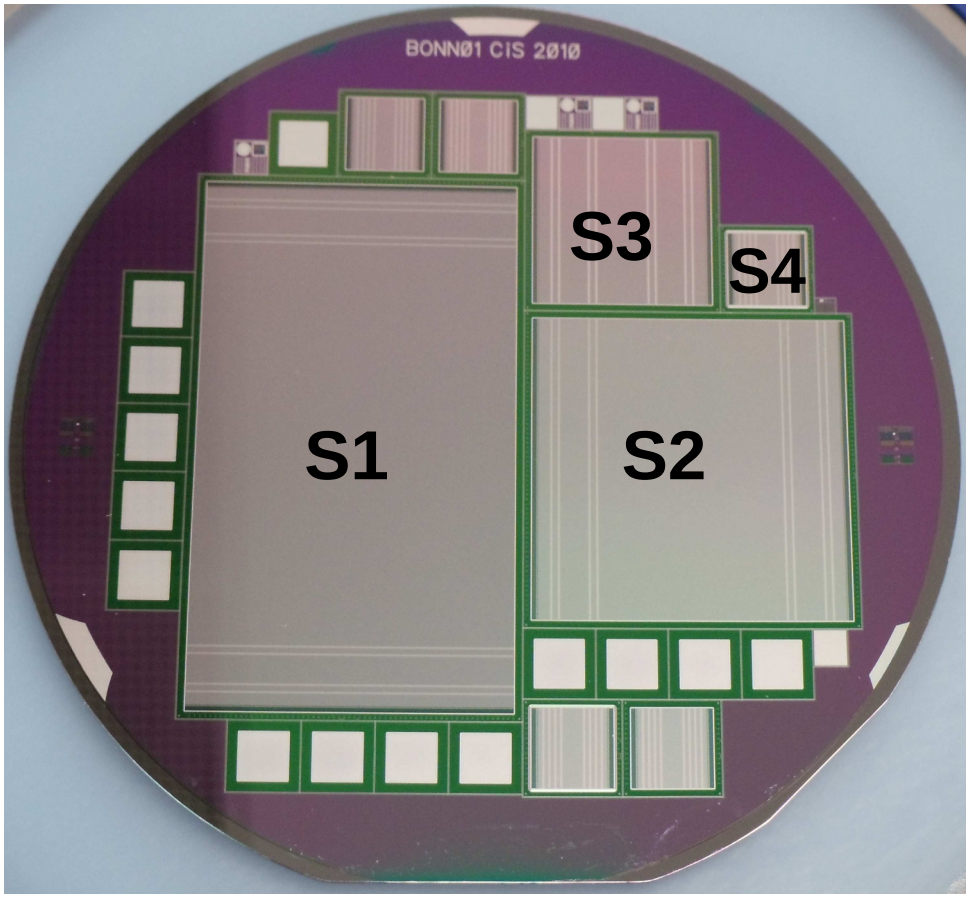


Double-sided Silicon Strip Detectors

- CiS GmbH Erfurt
- FZ Si, 4”, p-in-n
- 285 ± 10 µm
- 2.3 … 5.0 kΩcm
- p-spray isolation
- 8 guard rings
- punch-through biasing
- AC-coupling
- 90° stereo angle
- 65/50 µm pitch



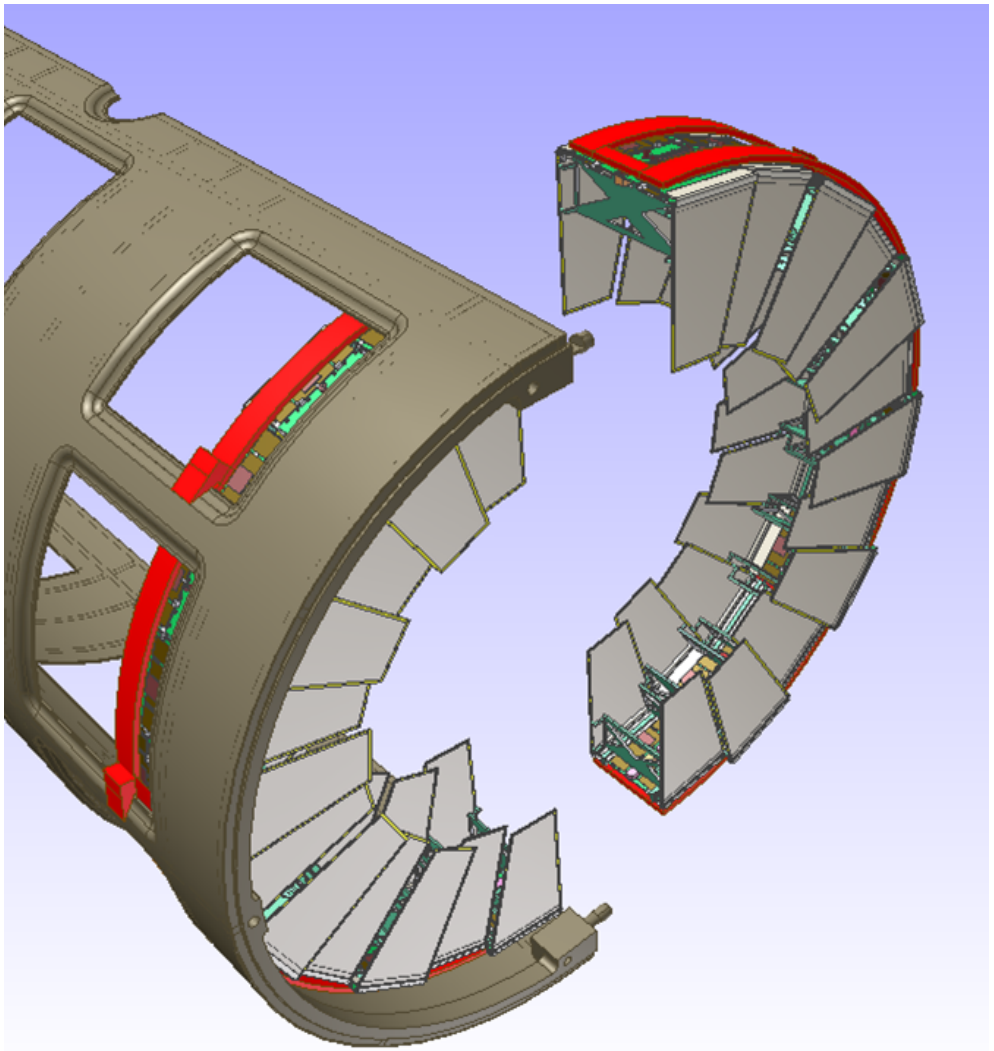
Barrel strip details

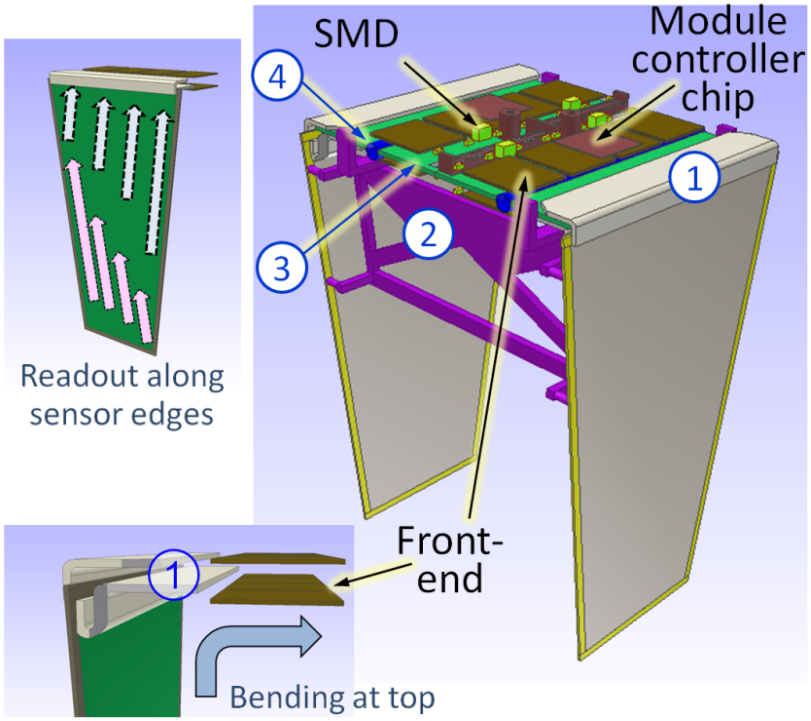


Sensor	Active Area mm²	# Strips
S1	58.275 x 33.315	896 x 512
S2	33.315 x 33.315	512 x 512
S3	19.230 x 19.230	384 x 384
S4	6.410 x 6.410	128 x 128

S1 and S1 are the final sensors.

Forward strips





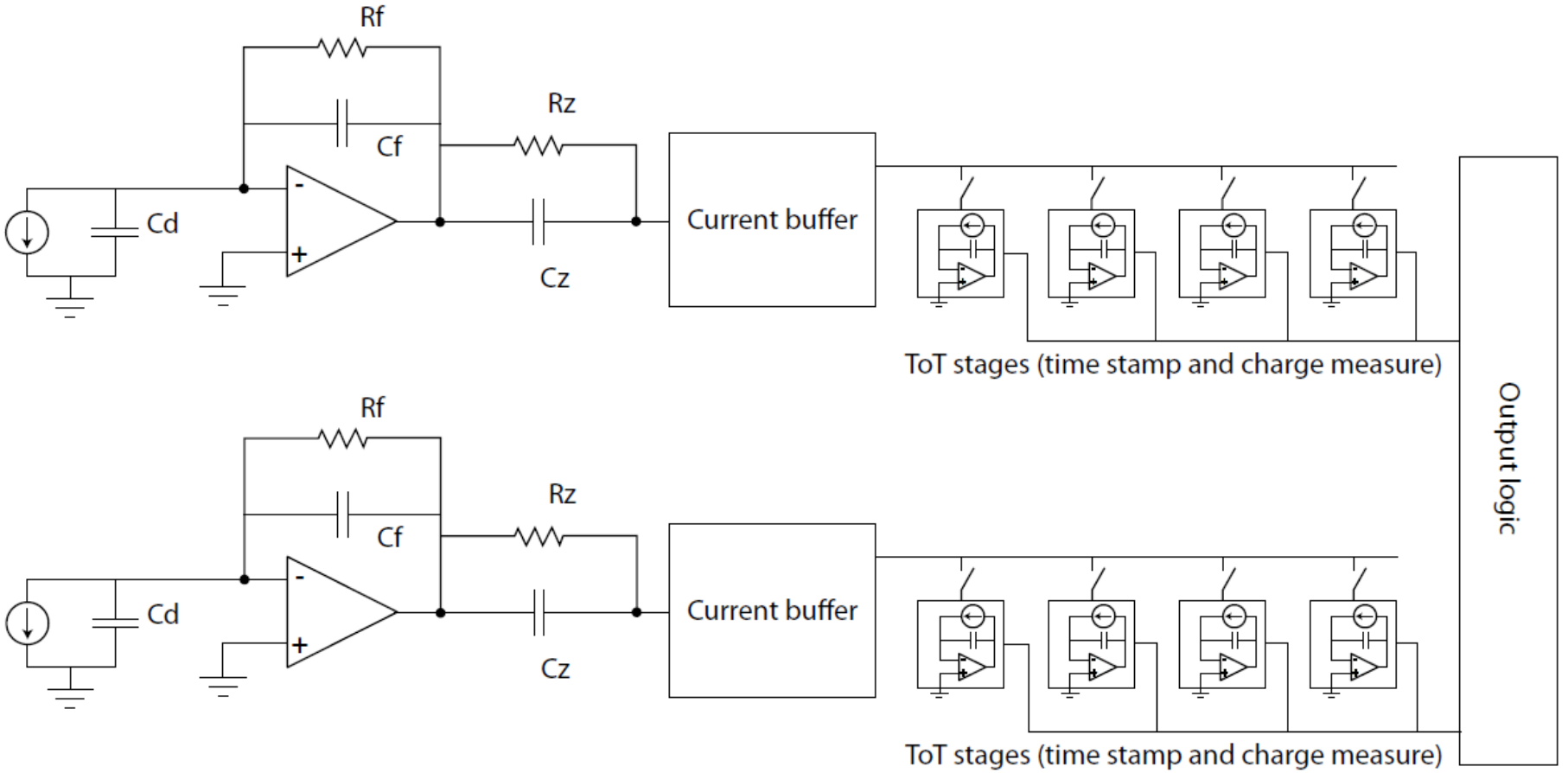
Pitch	67.5 µm
Strip orientation	|| to sensor edge
Number of strips	512/side
Stereo angle	15°
Sensor height	57.67 mm
Total area	1688 mm^2
Active area	89.9%

- **Used in the outer part of the last two forward disks.**

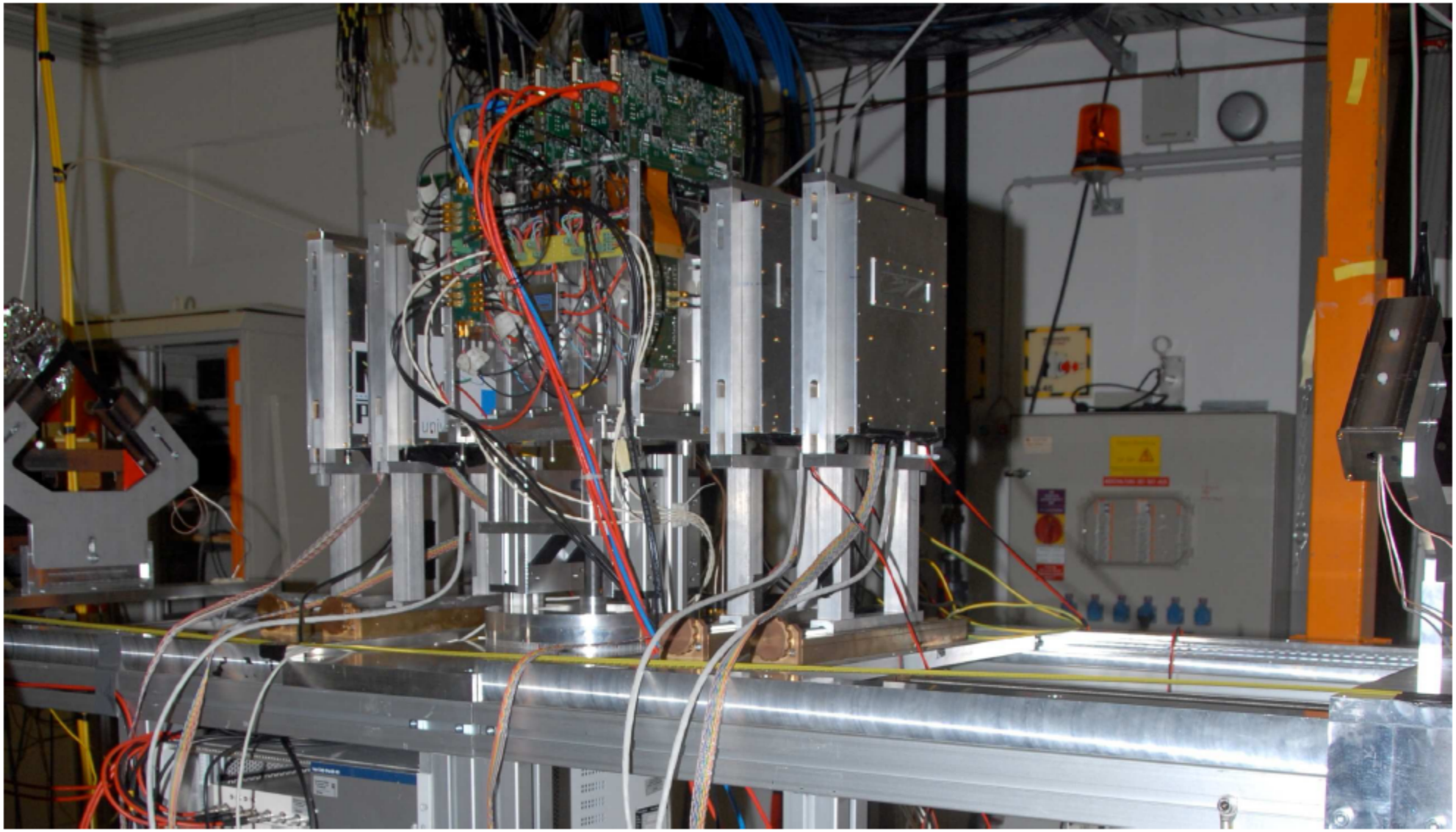
Strip front-end electronics

Development of dedicated strip front-end electronics just started.

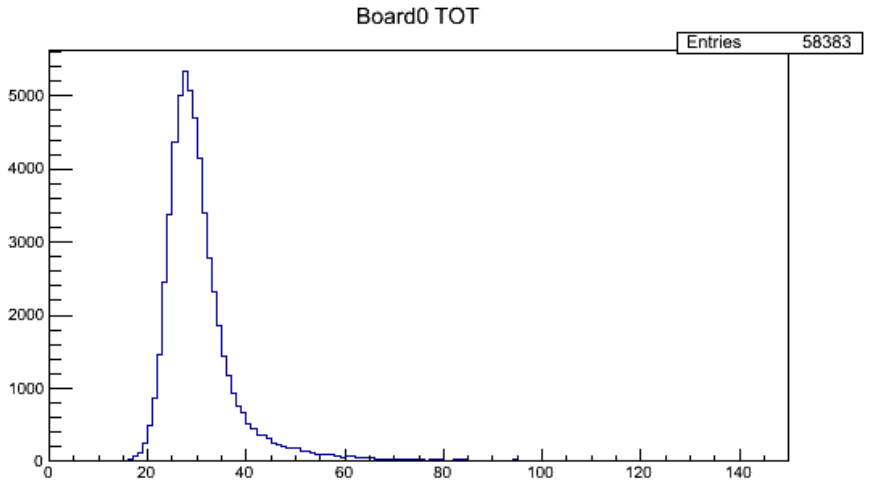
- **Time-based reaout with ToT similar to the pixel.**
- **Necessary adaptations due to different input capacitance and rate.**

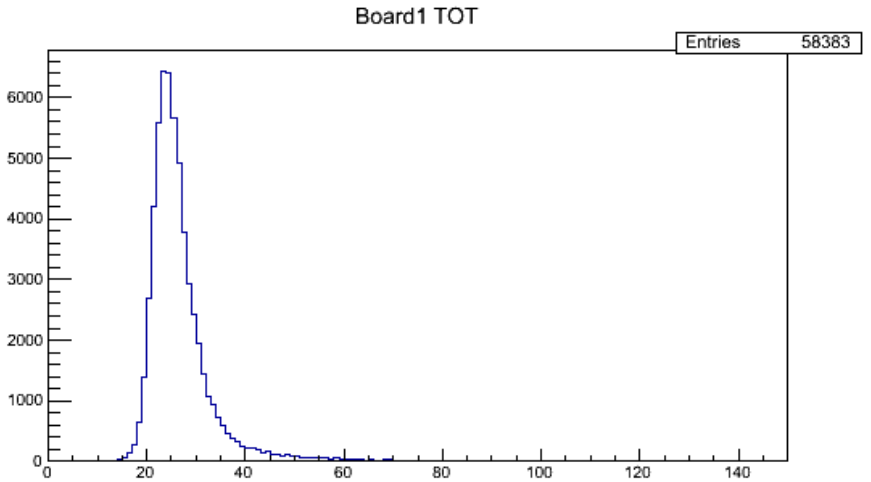


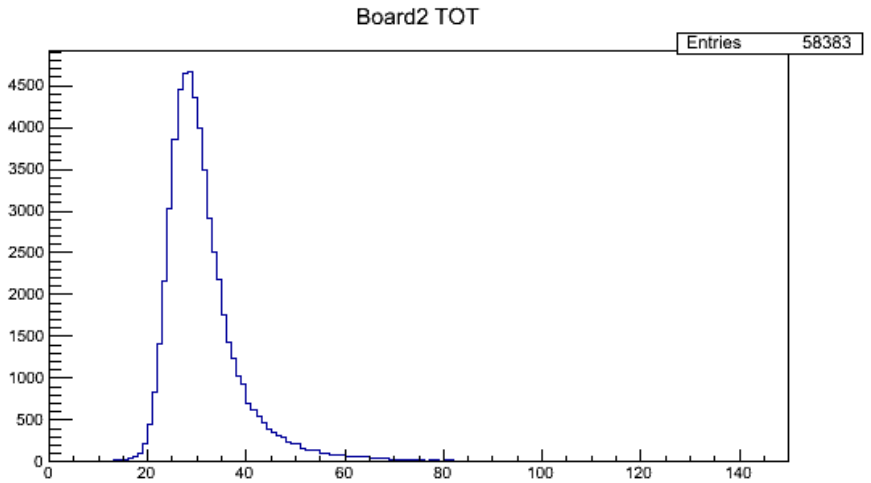
Combined pixel and strip set-up

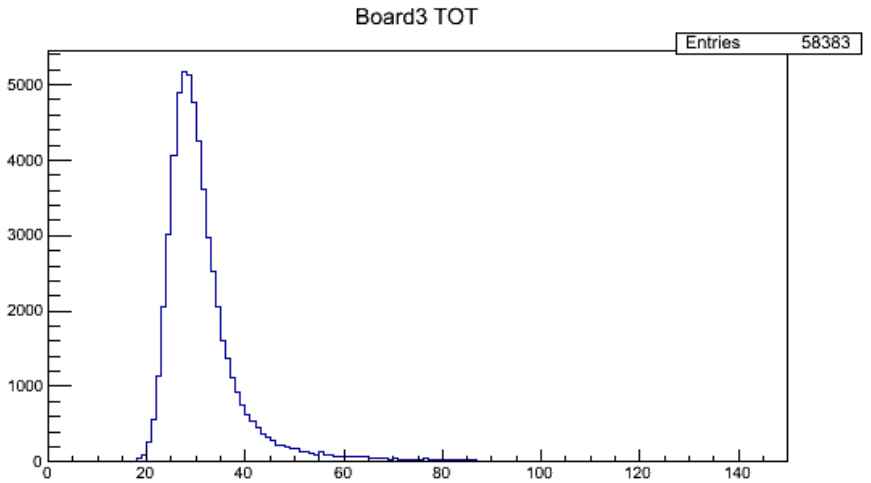


Landau from four pixels planes

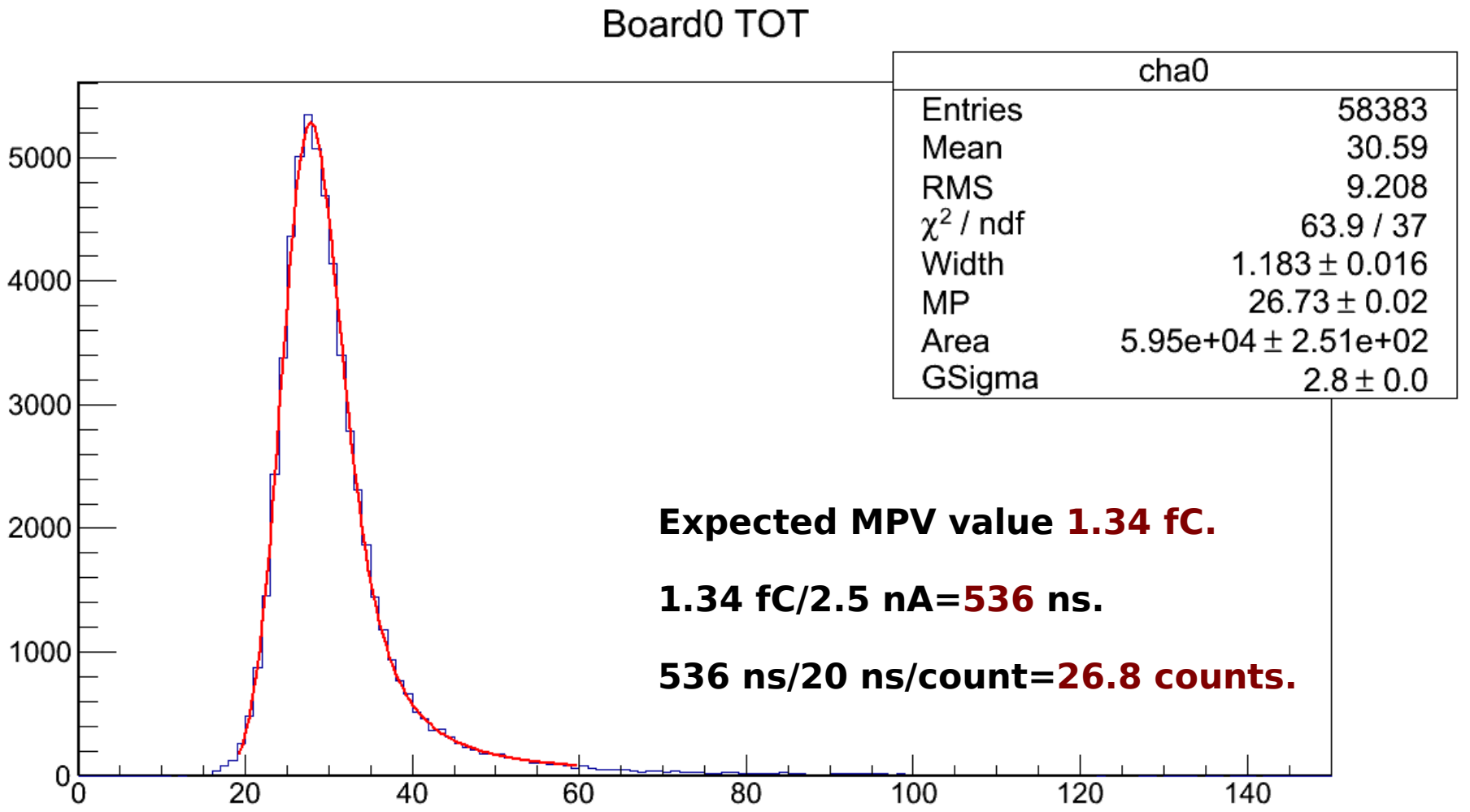








Beam tests: Landau from pixels

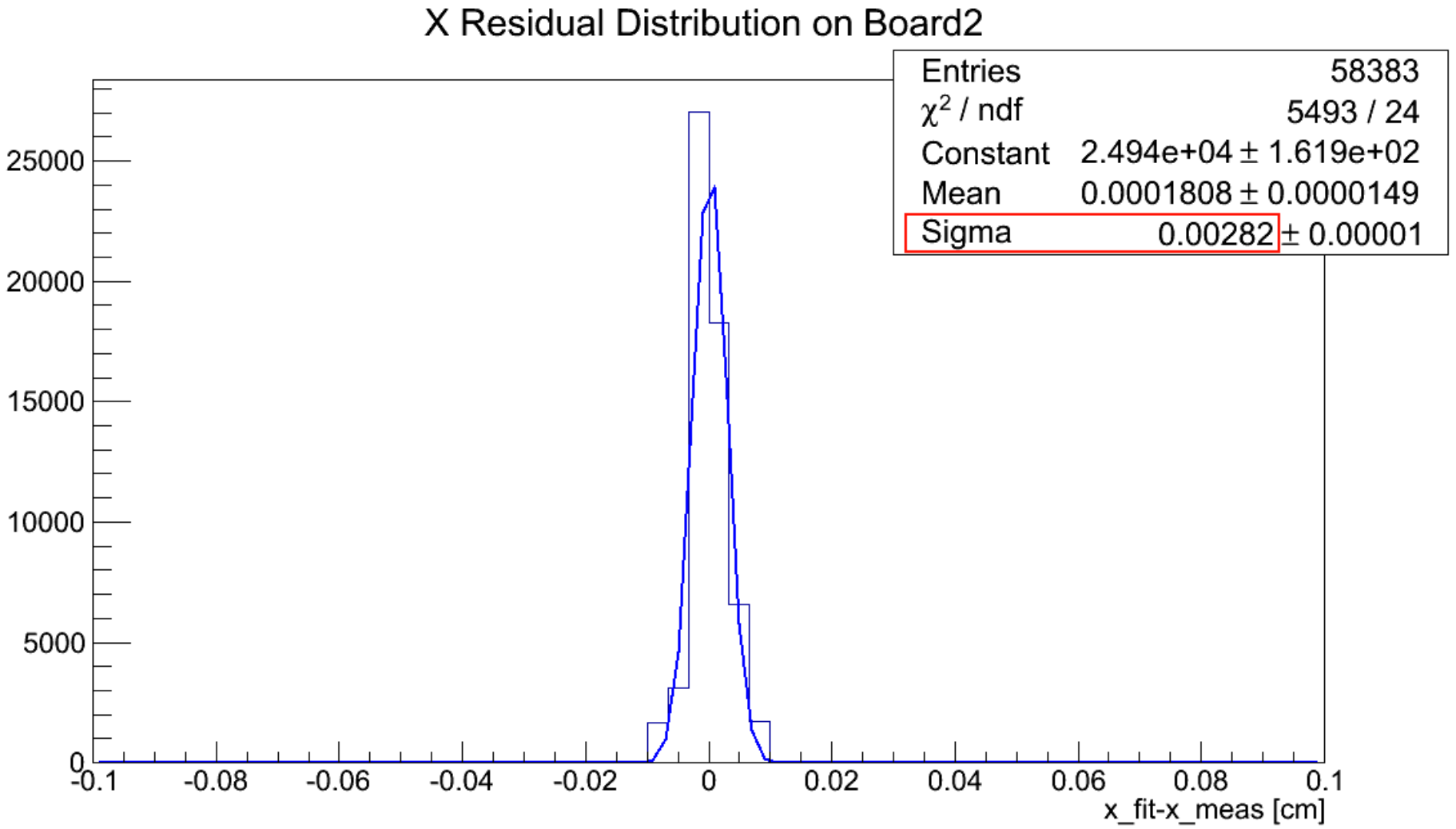


Expected MPV value 1.34 fC.

1.34 fC/2.5 nA=536 ns.

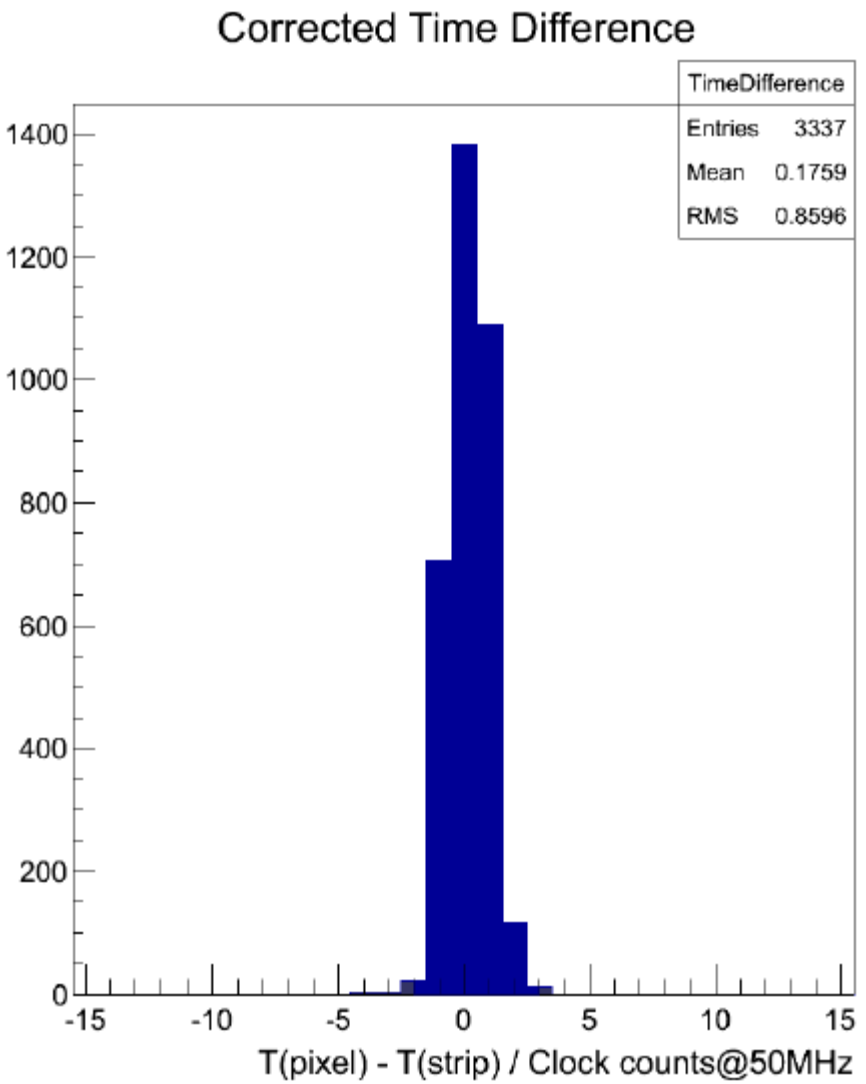
536 ns/20 ns/count=26.8 counts.

Single pixel resolution



- **Single pixel resolution of 28 μm as expected.**

Strip-pixel time correlation



Summary and outlook

- The design of the PANDA MVD is well advanced.
- Final sensor prototypes for both strips and pixels produced.
- Prototypes of pixel electronics tested together with sensors
- Design front-end electronics for strip sensors.
- Full size design of pixel front-end.
- Full size assembly prototype and testing.