Front-End Electronics developments for the Microvertex detector of the PANDA Experiments at FAIR

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FAIR: Facility for Antiproton and Ion Research.

PANDA: Pbar ANnihilation at Darmstadt. Multipurpose experiment:
- charmonium spectroscopy
- glueballs and hybrids
- hadrons in nuclear matter
- open charm production
- $\gamma$-ray spectroscopy of hypernuclei

HESR = High Energy Storage Ring

High luminosity mode
- Luminosity = $2 \times 10^{32}$ cm$^{-2}$s$^{-1}$
- $\delta p/p \sim 10^{-4}$ (stochastic cooling)

High resolution mode
- $\delta p/p \sim 10^{-5}$ (el. cooling < 8 GeV/c)
- Luminosity = $10^{31}$ cm$^{-2}$s$^{-1}$

TRIGGERLESS READOUT
The Micro-Vertex Detector

6 disk layers
4 barrel layers

Silicon detectors:
- Hybrid pixel detectors
- Double-sided microstrip detectors
The Micro-Vertex Detector

- 10 million pixel channels on 176 modules
- 200,000 strip channels on 254 modules
Baseline solution based on well-proven technology (hybrid pixel with bump bonding)
Custom development only where strictly needed (e.g. front-end chip)
Specs for the pixel detector

- **Pixel cell specs:**
  - **Pixel size:** 100 μm x 100 μm.
  - **Noise level:** < 200 e- rms.
  - **Linear dynamic range:** up to 50 fC.
  - **Power consumption:** < 20 μW.
  - **Selectable input signal polarity.**
  - **Leakage insensitive up to 50 nA.**

- **ASIC specs:**
  - **Self triggering**
  - **Clock 160 MHz**
  - **Active area:** O(1 cm²)
  - **Data rate:** O(0.8 Gbit/sec.)
  - **Radiation tolerance:** LHC grade.
  - **Simultaneous time stamping and charge measurement.**

- **No existing chip could match simultaneously all the PANDA requirements.**

- **Custom solution under investigation.**

- **Technology:** CMOS 0.13 μm.
Time-stamp (Gray encoded) distributed to the pixels and stored into local registers (à la ATLAS).

Sixteen cells deep-FIFO at the end of each column.

800 Mbit/sec per cm² max data rate.

Power supply: 1.2 V.
Pixel cell architecture

- **I_{fb}**
- **C_{int}**
- **preamp**
- **comp**
- **DAC**
- **baseline restorer**
- **control logic**
  - **reset**
  - **freeze**
  - **read_cmd**
  - **read_le**
  - **read_te**
  - **config_phase**
- **latch**
- **enable**
- **mask**
- **le_reg**
- **te_reg**
- **cfg_reg**

A. Rivetti
Front-end amplifier

- Direct cascode with NMOS input transistor and split current source
- Triple well NFET input and cascode.
- Two selectable PMOS or NMOS output buffers.
- Current: $2 \mu A$ in the input device, $1 \mu A$ in the source follower.

DC level fixed by transistor bias (0.3 V)

Output DC level regulated by the baseline restorer. (0.3 V for n-type sensor, 0.8 V for p-type)
Differential current switch.

At the equilibrium provides an equivalent 8MΩ feedback resistor.

Issue: low-value of feedback current (2.5nA to 10 nA) leads to long devices.
With large dynamic range ToT signals can be very long (10-20 µs).

Leakage compensation must be very narrowband, otherwise a non-linearity will result.

Need to implement compact filtering resistors with very high value.
Chip prototype

- Test chip produced in a MPW.
- Size: 5 mm x 2 mm.
- Column length: 12.8 mm.
- Column folding => full bus length.

- Full pixel cell (analog and digital parts).
- Simplified end-of-column logic.
- Two folded columns with 128 pixels.
- Two short column with 32 pixels.
- Sixteen pixels with wire bonding pad.
Reconstructed pulse shape

Time (µs)

Unbonded
Wire-bonded to pixel
Wire-bonded to board, 1pF cap
Across chip ToT variation

ΔToT/ToT (%)

Discharge current (A)
Measure: threshold dispersion

Baseline (V)

Topix2
- Before correction
- After correction

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Measure: calibration with Am source

Standard p-type sensor 300 µm thick:

Topix2
Am241 (\(\gamma\) 60keV)
- ch 019
- ch 020
- ch 023

TOT (clk) * tail slope (V/clk)
Epitaxial silicon sensor (1)

Lightly doped epitaxial layer

Highly doped Cz substrate:
\[ r = 0.01 - 0.02 \, \Omega \, \text{cm} \]

Several studies indicate that sensor build on epi wafer have good radiation tolerance.

Interest for PANDA: radiation tolerance adequate with standard p-type design.

Wafers supplied by ITME and processed by FBK-IRST in Trento Project partially funded with through the ULISI-FP7 program

Substrate properties:
- Diameter: 100 ± 0.5 mm.
- Doping type: n/Sb.
- Thickness 525 ± 25 µm.
- Resistivity: 0.01 - 0.02 Ω cm.

Epi layer properties:
- Doping: time n/P.
- Thickness 50/75/100 µm.
- Variation: <4%/8%/8%
- Resistivity: 2500 - 5000 Ω cm.
Low cost R&D reusing existing electronics and sensor design:

- Electronics: ALICE front-end chip provided by CERN
- Sensor: masks developed by INFN-Ferrara for NA62 project.

Three types of epi assemblies:

- 3 with 150 μm total thickness (100 μm epi)
- 7 with 120 μm total thickness (75 μm epi)
- 1 with 100 μm total thickness (50 μm epi)

Spare sensors to be wire-bonded to the prototype
First spectra with an epi-sensor

Fit results:
Peak 31.1
Sigma 1.7

Topix 2 50MHz
50µm epi sensor
Am241 60keV γ
Data transmission cables

• 2-3 300 Gbit/sec link per front-end
• Al cable with 2Gbit/sec under study
• Transmission from the MVD to the counting room via the GBT chip set (under development at CERN).
Next steps

• Submit a new version on the front-end chip (scheduled for Nov. 2010)
  – Minor modifications in the analogue part
  – Opening for bump bonding
  – Migration to the baseline flavor of the process (thick upper metals for power distribution).
  – Full end of column logic
• Bump bonding with epitaxial silicon sensors
• 2011 devoted to detail testing
• Start the preparation of the engineering run in 2012.
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SPARE SLIDES
Dynamic range

- Linear mode (core amplifier not saturated): the signal charge is integrated on the feed-back capacitor $C_{\text{feed}}$ and removed by a constant current: $0.7 \, \text{V}/24 \, \text{fF} = 16.8 \, \text{fC}$.

- Saturated mode (core amplifier gain drops): the signal is integrated on the input capacitor and removed by a constant current

  $$Q_{\text{max}} = 0.3 \, \text{V} \times 200 \, \text{fF} = 60 \, \text{fC} \, \text{(n-type sensors)} \text{ or } 0.7 \, \text{V} \times 200 \, \text{fF} = 140 \, \text{fC} \, \text{(p-type sensors)}.$$
Saturation and cross-talk (1)

Pixel Matrix

- hit event
- no hit event

Adjacent Coupled Detectors

Particle hit

\[ J_{in1} \neq 0 \]

\[ J_{in2} = 0 \]
Saturation and cross-talk (2)

- **Linearity** $Q_{in} = 4 \text{ fC}$, baseline = 200 mV
  - $V_{o1}(t)$
  - $V_{o2}(t)$
  - $V_{th} = 300 \text{ mV}$

- **Non-Linearity** $Q_{in} = 40 \text{ fC}$, baseline = 200 mV
  - $V_{o1}(t)$
  - $V_{o2}(t)$
  - $V_{th} = 300 \text{ mV}$