ASIC Development for APD readout of the PANDA EMC
Overview

- Avalanche Photo Diode - Readout
- First calculations
- Prototype requirements

- Summary
PANDA Detector

- Layout of the electromagnetic calorimeter:
  - 22000 crystals
  - Three detector components:
    - Barrel
    - One front and rear endcaps
  - Almost $4\pi$ solid angle coverage
  - Evaluation of two scintillator-types:
    - Bi$_4$Ge$_3$O$_{12}$ (BGO) and PbWO$_4$ (PWO)
  - Envisaged energy resolution: < 1% at 1 GeV
- Calorimeter in magnetic field
# PWO vs. BGO

<table>
<thead>
<tr>
<th>Property</th>
<th>PbWO₄ PWO</th>
<th>BGO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [g/cm³]</td>
<td>8.28</td>
<td>7.13</td>
</tr>
<tr>
<td>Rad. length [cm]</td>
<td>0.89</td>
<td>1.12</td>
</tr>
<tr>
<td>Moliere rad [cm]</td>
<td>2.19</td>
<td>2.33</td>
</tr>
<tr>
<td>dE/dx [MeV/cm]</td>
<td>13.0</td>
<td>9.2</td>
</tr>
<tr>
<td>Decay time [ns]</td>
<td>5 - 15</td>
<td>60 - 300</td>
</tr>
<tr>
<td>Max. emission [nm]</td>
<td>420 - 440</td>
<td>480</td>
</tr>
<tr>
<td>Rel. Lightyield (NaI(Tl))</td>
<td>0.01</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Szintillator

PWO:

+ Fast scintillator
+ Low cost material
- Light yield and energy resolution show strong temperature dependence

BGO:

+ Sufficient light yield
+ Light yield and $\sigma_E/E$ are nearly temperature independent
- Slow scintillator
APD function

Layout of an Avalanche Photo Diode (APD):
Photodiode with an additional avalanche region

- Strong internal electric field:
  → Electrons generate electron-hole pairs
  → Avalanche process
APDs for PANDA

- APDs as readout of the PANDA calorimeter:
  - Operation in strong B fields of 1.5 T
  - First test measurements with PWO and BGO:
    → Qualification of an APD as readout detector
  - Readout area of the crystals: 22 x 22 mm²
    → Readout area coverage with an active area of 5 x 5 mm² too small

→ Development of Large Area APDs (LAAPDs)
  with an active area of 10 x 10 mm² (Hamamatsu)
### Requirements for Preamp

<table>
<thead>
<tr>
<th>Crystal</th>
<th>APD</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PWO: 390 photons / MeV</td>
<td>• Detector capacity: ≈ 300 pF</td>
</tr>
<tr>
<td>• Rate: 300 kHz / Crystal</td>
<td>• Leakage current: ≈ 50 nA</td>
</tr>
<tr>
<td></td>
<td>• Gain: 50</td>
</tr>
<tr>
<td></td>
<td>• QE: 70%</td>
</tr>
</tbody>
</table>

→ **13.000 e⁻/ MeV**

### Preamplifier

- Dynamic range: 1 MeV – 10 GeV
- Low noise
- Low power
- Compact design
APD - Readout

Preamplifier

Semi-Gaussian shaper

Differential - Output stage

ASIC
First Calculations
Folded Cascode

Basic design of the preamplifier: Folded Cascode

**Operation method:**

- $I_{B1} = I_1 + I_2$ choose: $I_1 = 10I_2$
- Input signal leads to current change
- $I_{B1} = \text{const.} \rightarrow \Delta I_2 = -\Delta I_1$
- $\Delta U_{\text{out}} = \Delta I_2 \cdot R_L$
- $M_C$ decouples input transistor from output signal
Noise Source

\[ i_b1 \]

\[ i_{B1} \]

\[ i_d \]

\[ i_C \]

\[ i_R \]

\[ i_L \]

Input

Bias

Output

Dominating noise source
Noise Sources

Shot noise due to detector leakage current:

\[ i_L^2 = 2qI_L \]

- \( I_L \): leakage current

Thermal Noise:

\[ i_t^2 = \frac{8}{3}k_B T g_m \]

- \( g_m \): transconductance

1/f Noise:

\[ i_f^2 \sim \frac{I_1}{L^2 f} \]

- \( f \): frequency
- \( L \): gate length

→ Noise depends on current
→ Noise depends on transistor area
Preamplifier Noise: $\tau_s = 100\text{ns}$

- Width: $W = 10,000 \, \mu\text{m}$
  $\rightarrow$ ENC $\approx 2600 \, \text{e}^{-} @ 2 \, \text{mA}$
Preamplifier Noise: $\tau_s = 250\text{ns}$

- Width: $W = 10,000\ \mu\text{m}$
  $\rightarrow$ ENC $\approx 1700\ e^- @ 2\ mA$
Preamplifier Noise: $\tau_s = 500\text{ns}$

- Width: $W = 10,000\ \mu\text{m}$
  $\rightarrow$ ENC $\approx 1200\ e^- @ 2\ mA$
First Prototype
Readout Path

Requirements (Prototype)
- Dynamic Range: 1 – 1000 MeV
- Max. event rate: 300kHz
- Less than 13.000 e⁻ noise @ 300pF detector capacitance

\[ \tau_1 = R_1 \cdot C_1 \]
\[ \tau_2 = R_2 \cdot C_2 \]
Pole-Zero Cancellation

\[ \tau_1 = R_1 \cdot C_1 = R_2 \cdot C_2 = \tau_2 \]

\[ \tau_1 = R_1 \cdot C_1 \neq R_2 \cdot C_2 = \tau_2 \]

03.04.2006

Wieczorek Peter, GSI
Transient Simulations @ -25°C

- **Preamplifier out** @ 1 MeV input
  - Voltage: 600µV
  - Time: 0.5 µs

- **1st Integrator out** @ 1 MeV input
  - Voltage: 1000µV
  - Time: 1.5 µs

- **2nd Integrator out** @ 1 MeV input
  - Voltage: 1850µV
  - Time: 2.5 µs

03.04.2006
Wieczorek Peter, GSI
Signal to Noise Ratio @ -25°C

Input: 13.000 e-
Output signal: 1845 µV
Peaking time: 240 ns
Simulated noise: 622 µV
Corresponds to 4400 e-
Input: 13.000 e⁻  
Output signal: 2070 µV  
Peaking time: 330 ns  
Simulated noise : 839 µV  
Corresponds to 5300 e⁻
- Dynamic range for prototype:
  1 – 1000 MeV
  (1 MeV = 13.000 e⁻)
- Behaviour of the circuit is linear
Power Consumption

Charge sensitive Preamplifier
Differentiator Pole-Zero cancellation

2nd/3rd order Integrator
Output driver

In

8.6 mW

4.6 mW

6.9 mW

21 mW per channel
Summary and Outlook

- Complete Front-end circuit has been designed and optimized for best noise performance
- Design fulfills noise, rate and power requirements
- Design is robust against process, supply voltage and temperature variations
- Layout has just started

MPW Run – Submission is planned for summer 2006

Still open Questions:
- Max. input rate
- Radiation background