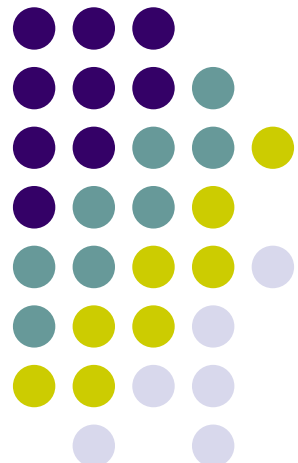
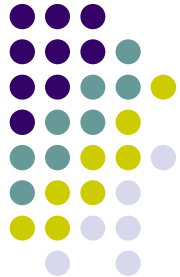
ASIC Development for APD readout of the PANDA EMC



Overview

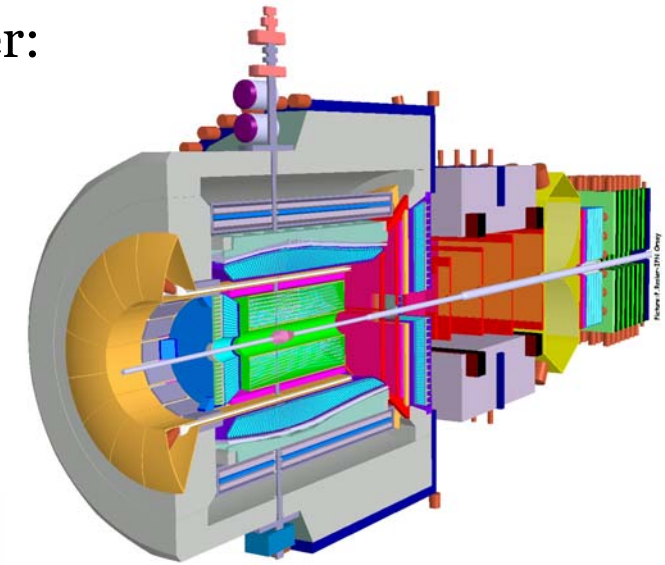


- **A**valanche **P**hoto **D**iode - Readout
- First calculations
- Prototype requirements

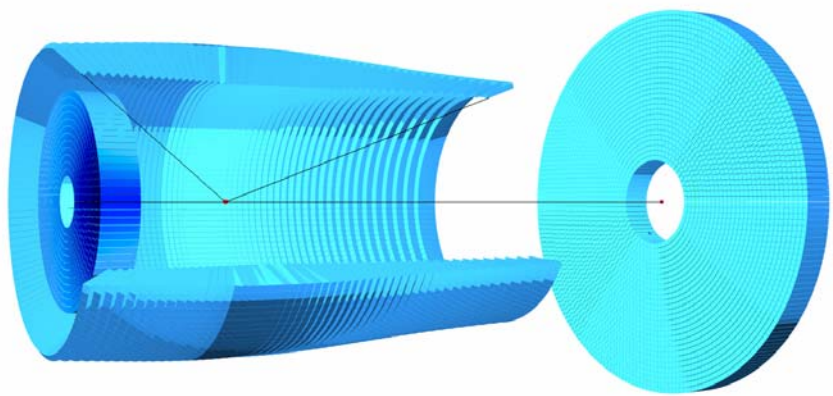
- Summary

PANDA Detector

- Layout of the electromagnetic calorimeter:
- 22000 crystals
- Three detector components:
  - Barrel
  - One front and rear endcaps
- Almost 4π solid angle coverage
- Evaluation of two scintillator-types:
  - $Bi_4Ge_3O_{12}$ (BGO) and $PbWO_4$ (PWO)
- Envisaged energy resolution: < 1% at 1 GeV



- Calorimeter in magnetic field



PWO vs. BGO

Property	$PbWO_4$ PWO	BGO
Density [g/cm³]	8.28	7.13
Rad. length [cm]	0.89	1.12
Moliere rad [cm]	2.19	2.33
dE/dx [MeV/cm]	13.0	9.2
Decay time [ns]	5 - 15	60 - 300
Max. emission [nm]	420 - 440	480
Rel. Lightyield (NaI(Tl))	0.01	0.15

Szintillator

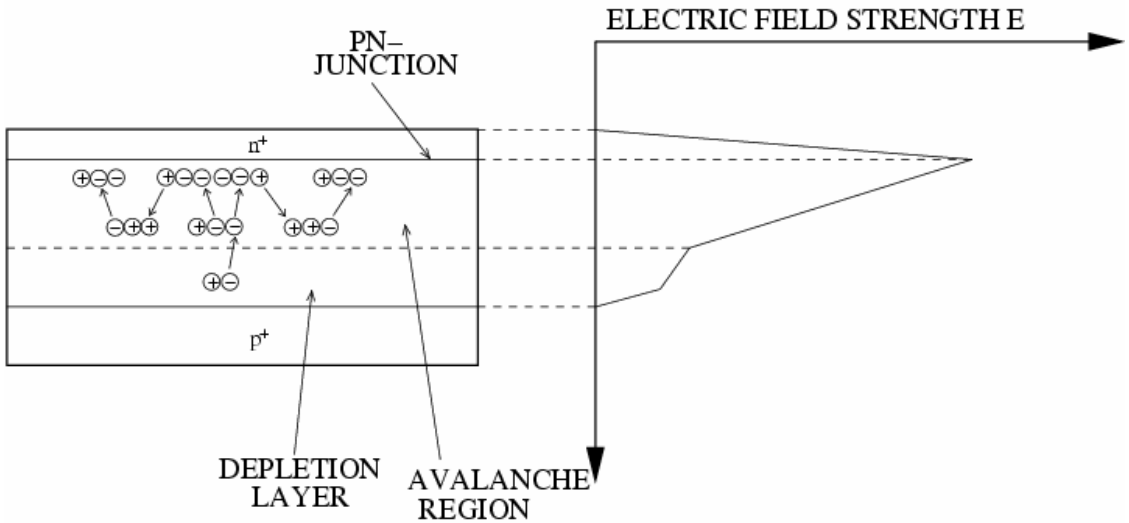
PWO:

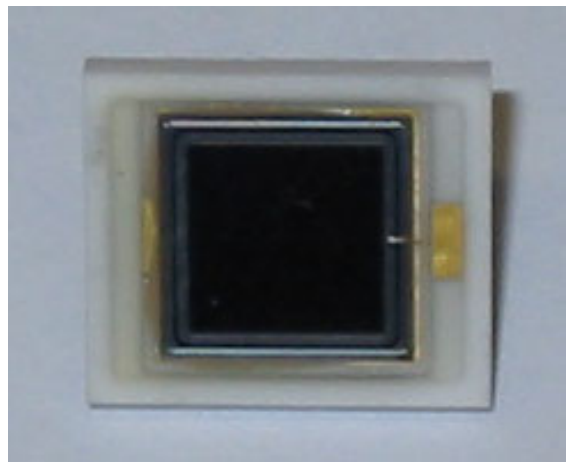
+ Fast scintillator
+ Low cost material
- Light yield and energy resolution show strong temperature dependence

BGO:

+ Sufficient light yield
+ Light yield and σ_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
    → **R**eadout 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

Crystal

- PWO: 390 photons / MeV
- Rate: 300 kHz / Crystal

APD

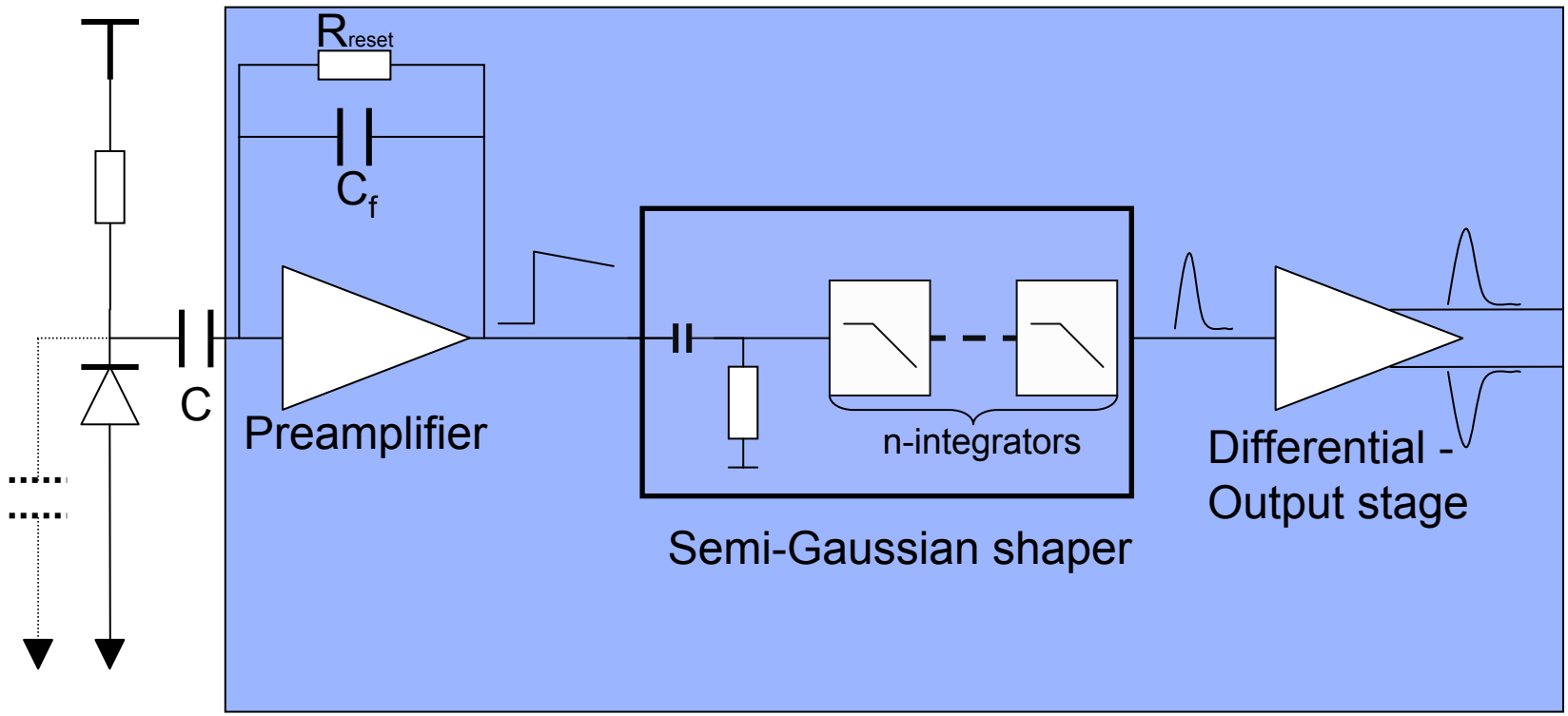
- Detector capacity: ≈ 300 pF
- Leakage current: ≈ 50 nA
- Gain: 50
- QE: 70%

→ 13.000 e^- / MeV

Preamplifier

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

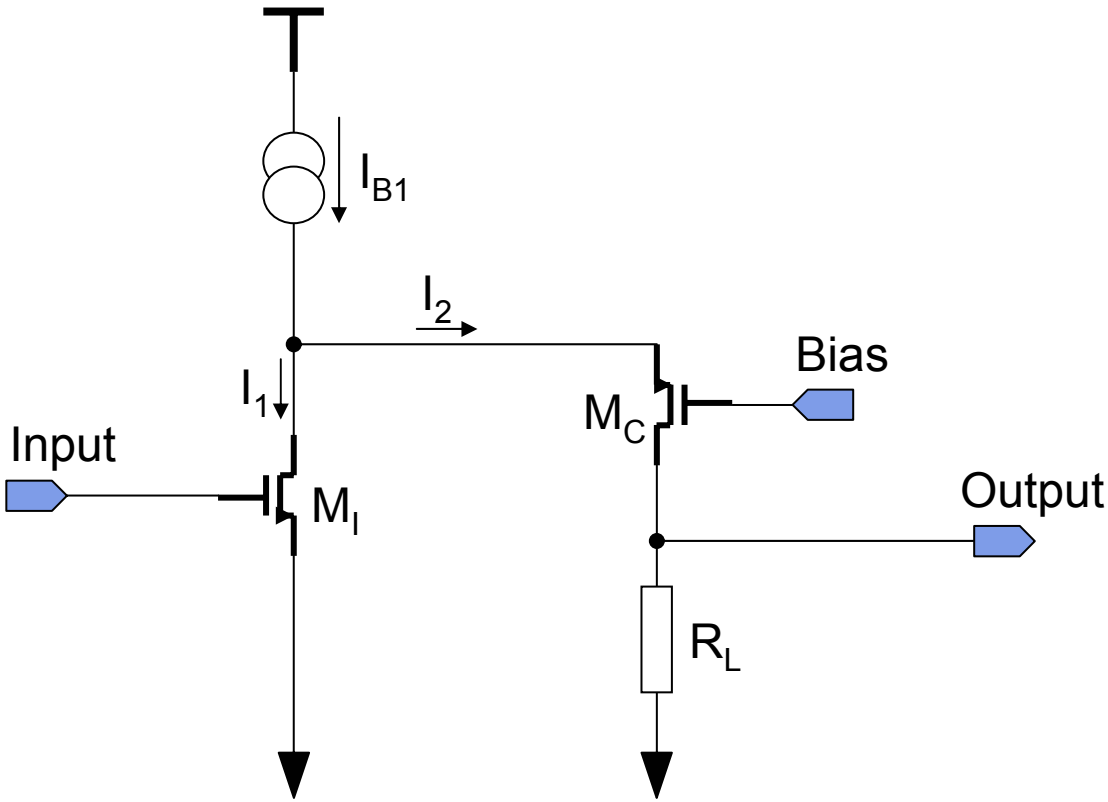
APD - Readout



ASIC

First Calculations

Folded Cascode

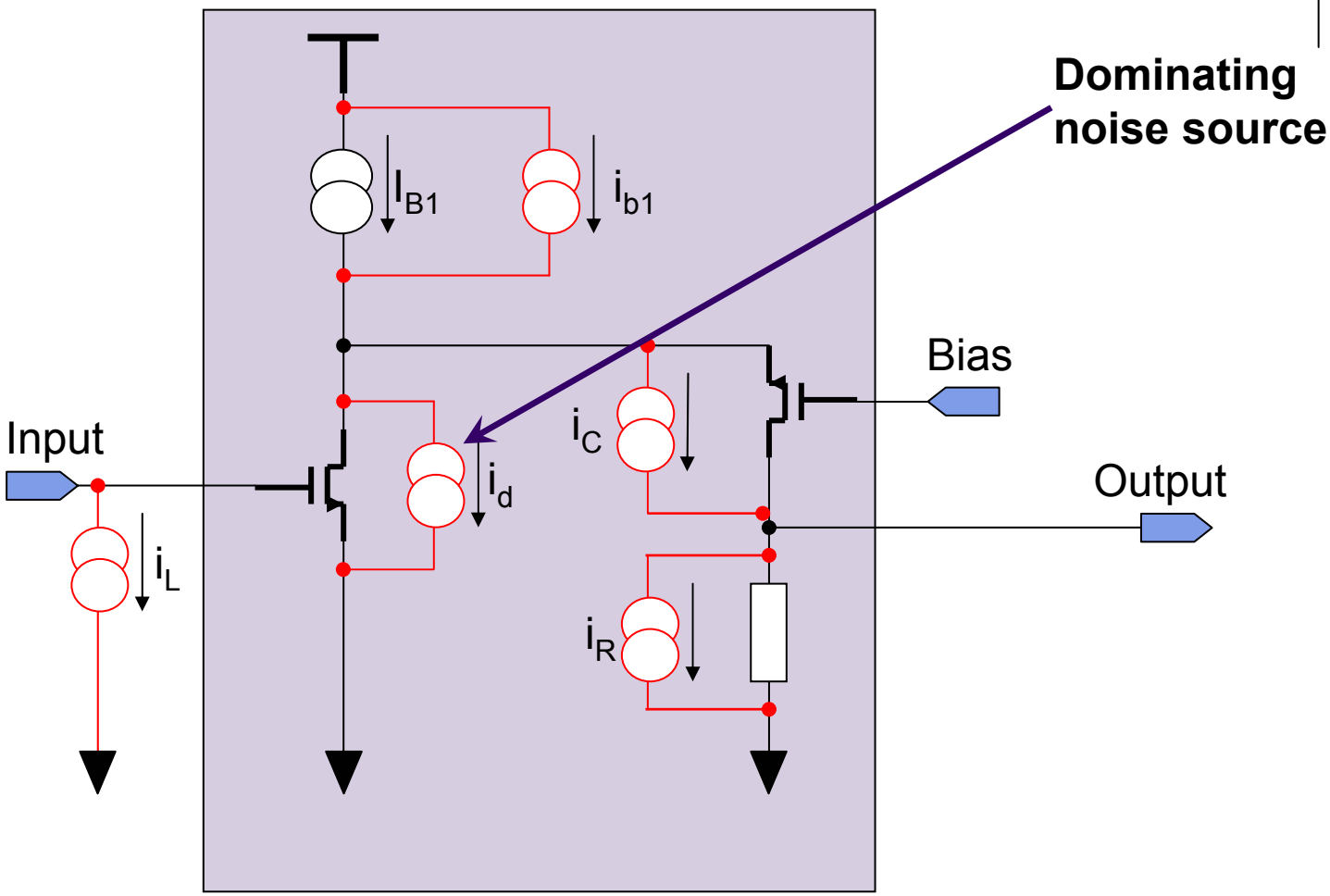


Basic design of the preamplifier: Folded Cascode

Operation method:

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

Noise Source



Noise Sources

Shot noise due to detector leakage current:

$$i_L^2 = 2 \cdot q \cdot I_L$$

- I_L: leakage current

Thermal Noise:

$$i_t^2 = 8/3 \cdot k_B \cdot T \cdot g_m$$

- g_m: transconductance
- f : frequency

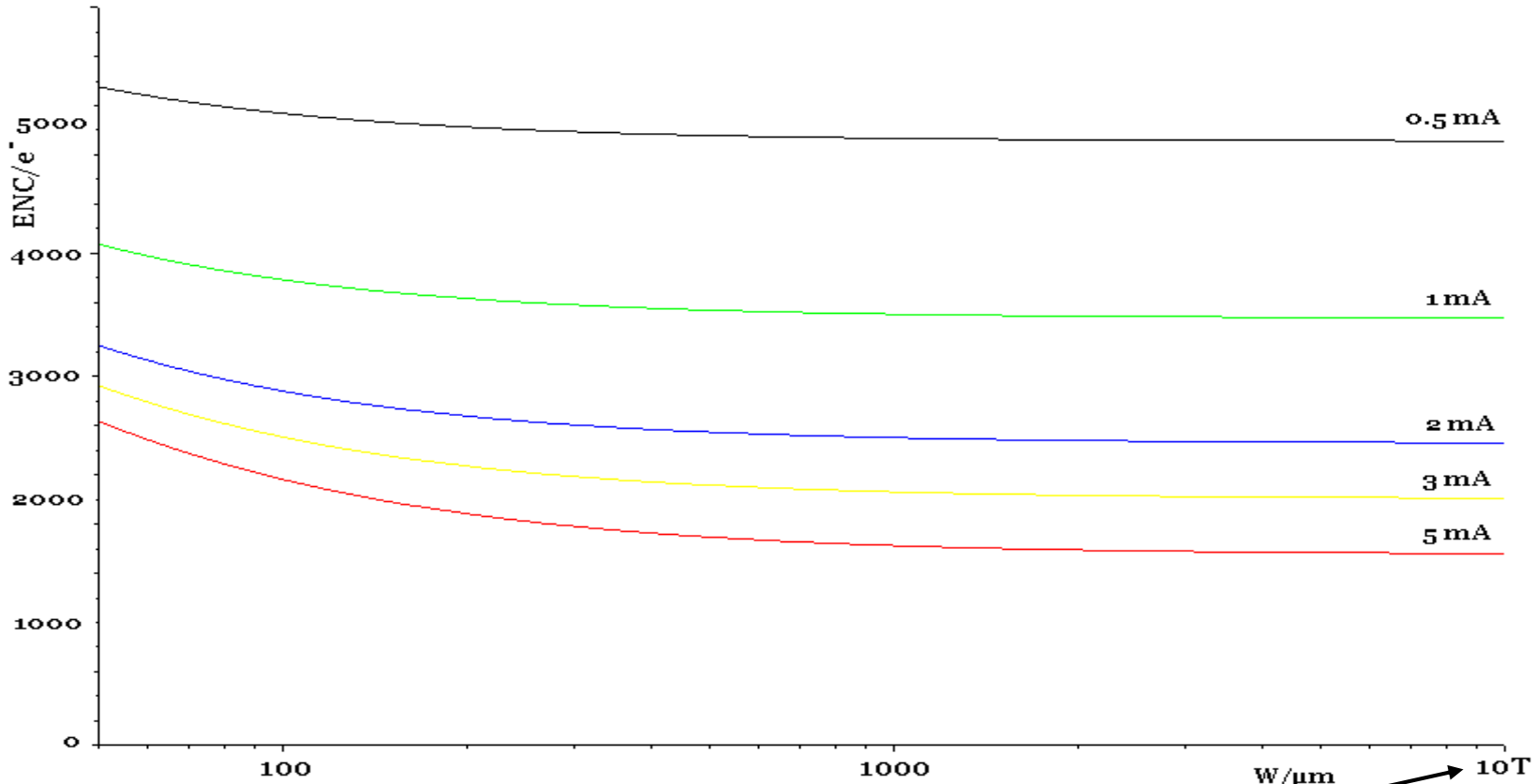
1/f Noise:

$$i_f^2 \sim \frac{I_1}{L^2 \cdot f}$$

- L : gate length

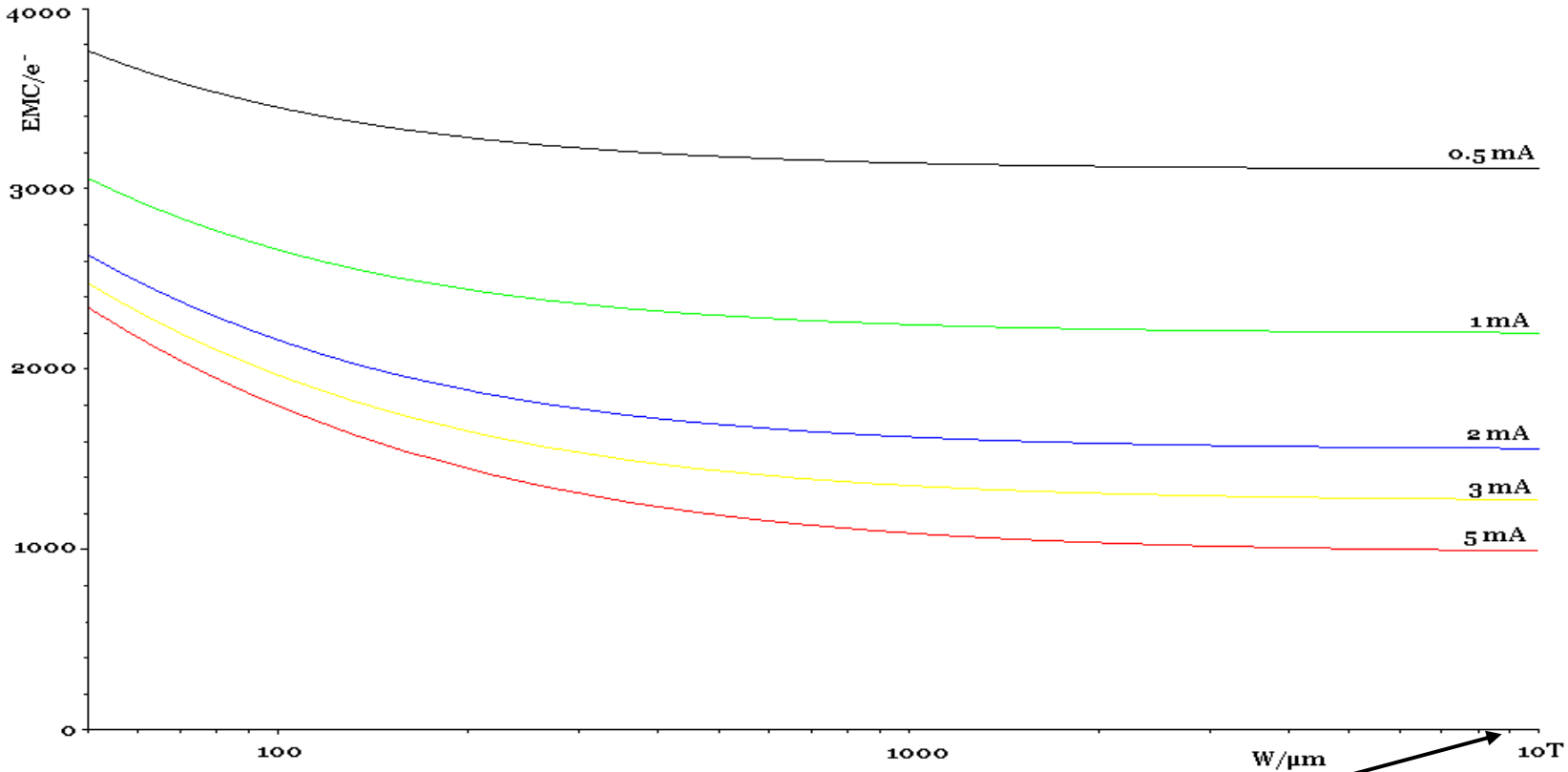
→ Noise depends on current
→ Noise depends on transistor area

Preamplifier Noise: τ_s=100ns



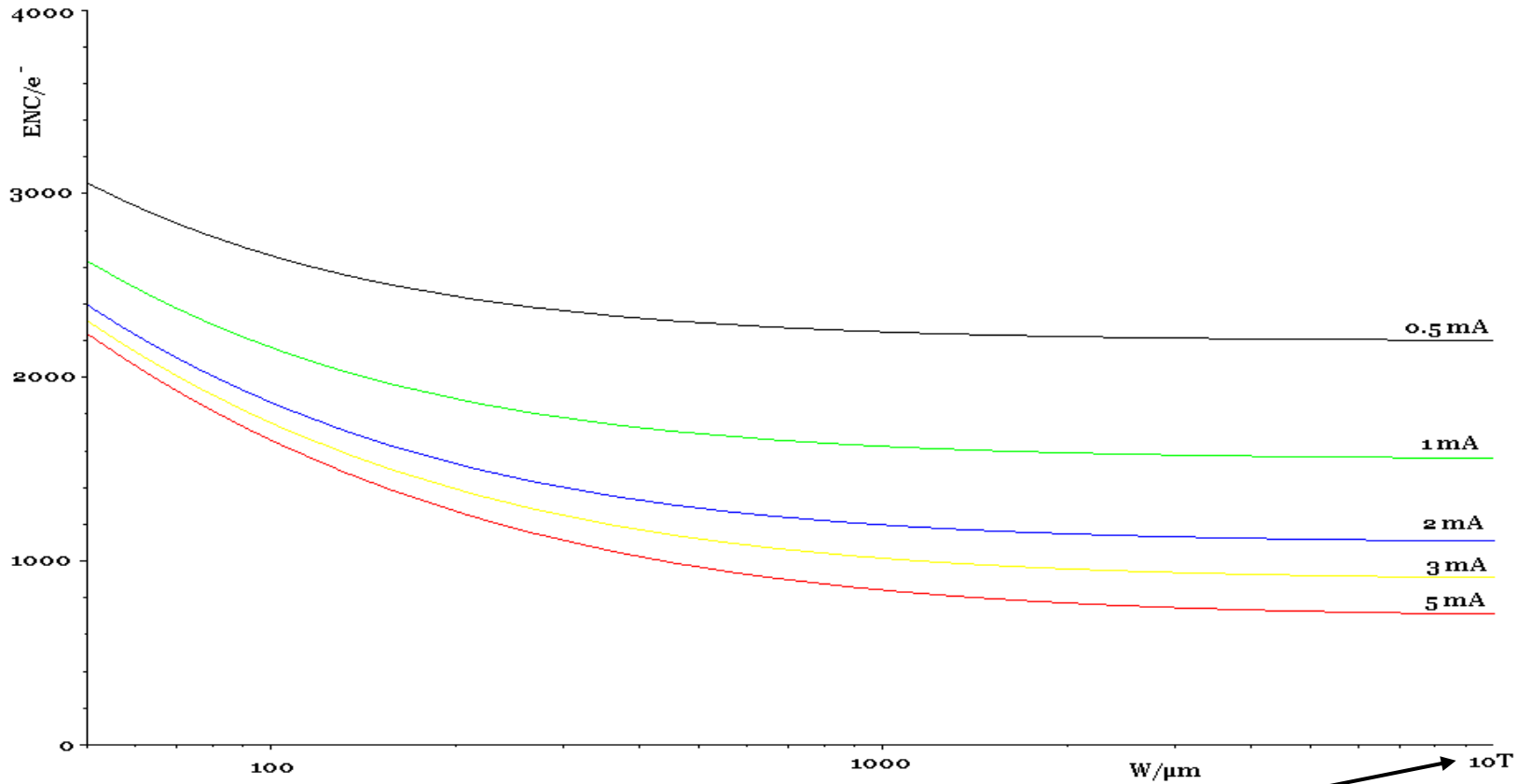
- Width: W=10.000 µm
  → ENC ≈ 2600 e^- @ 2 mA

Preamplifier Noise: τ_s =250ns



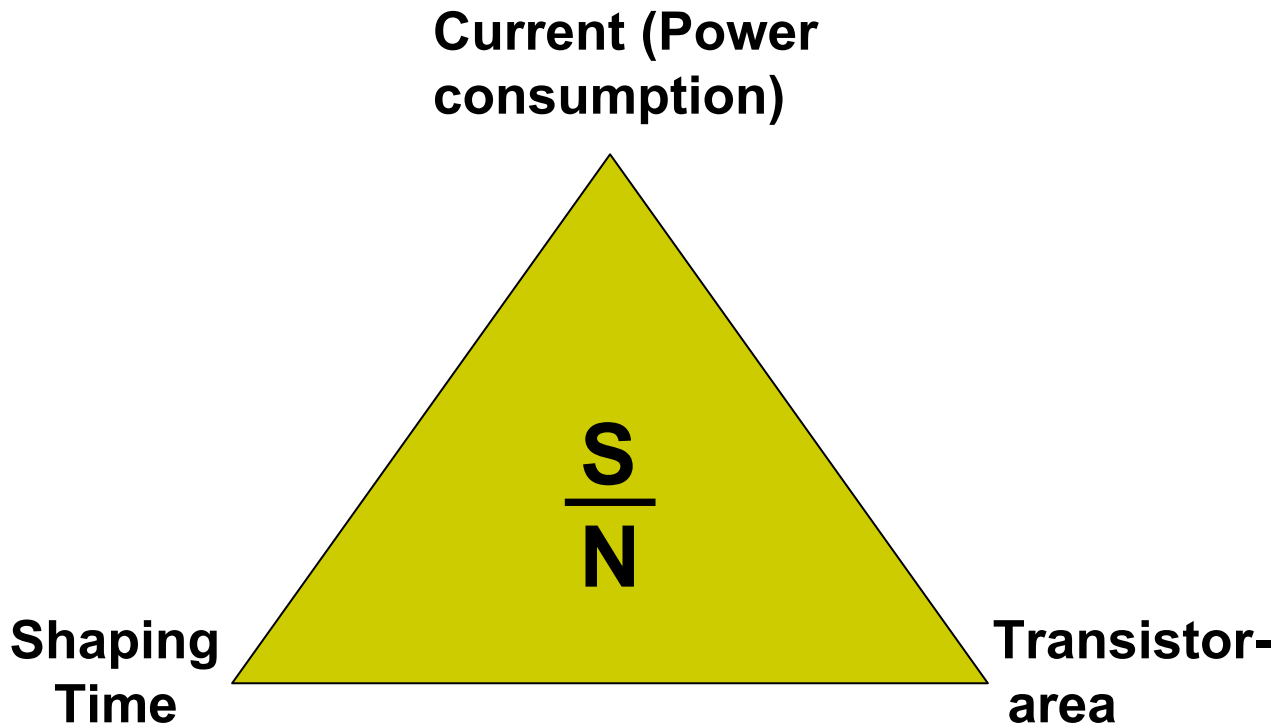
- Width: W=10.000 µm
  → ENC ≈ 1700 e^- @ 2 mA

Preamplifier Noise: τ_s=500ns



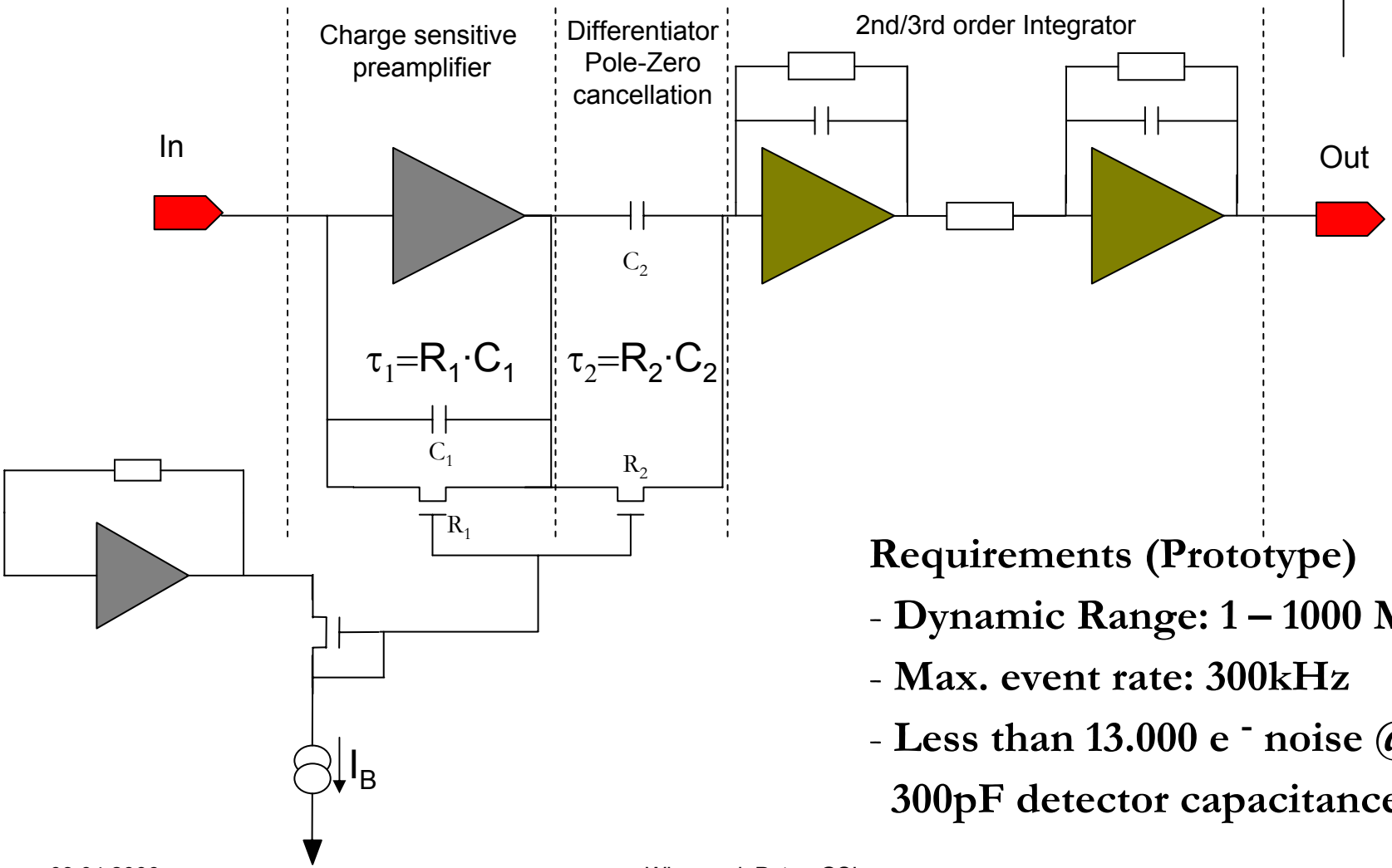
- Width: W=10.000 µm
  → ENC ≈ 1200 e^- @ 2 mA

Signal to Noise



First Prototype

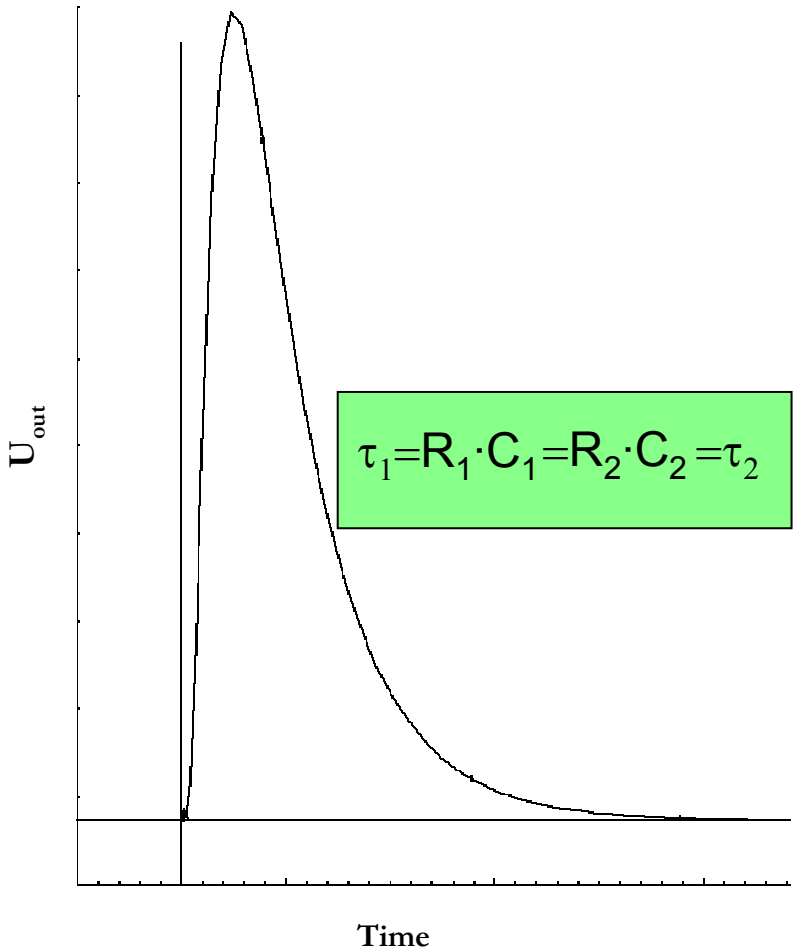
Readout Path

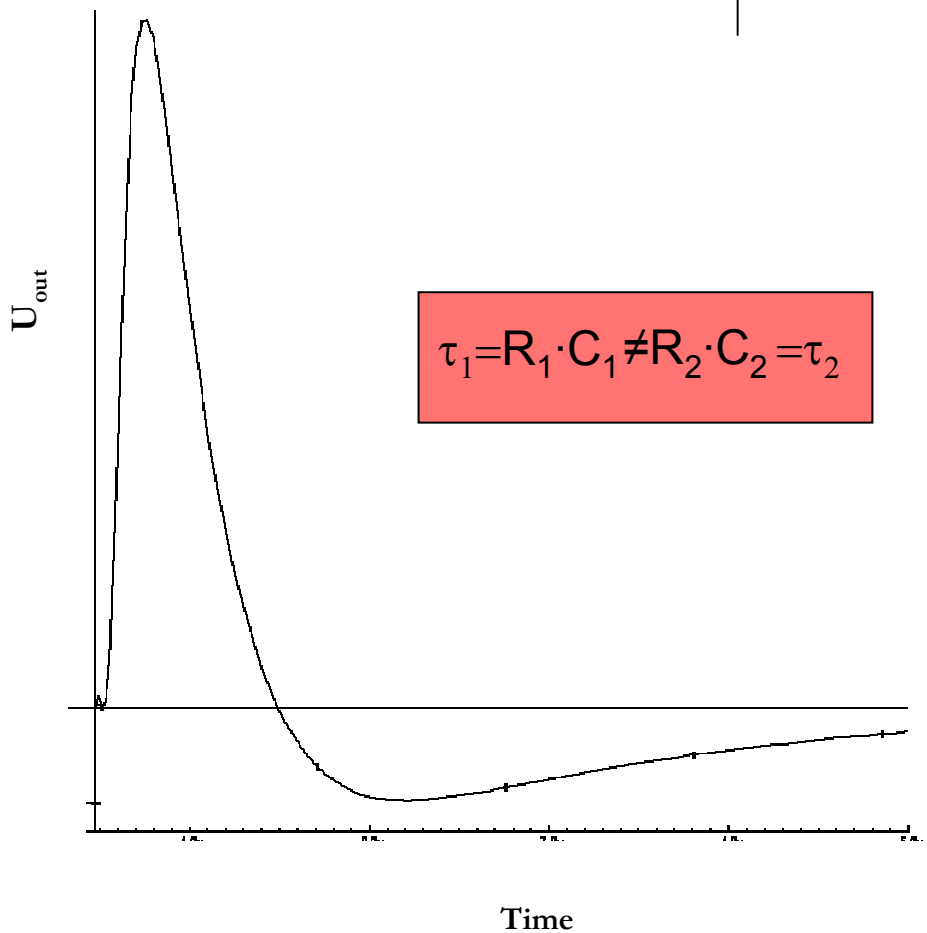


Requirements (Prototype)

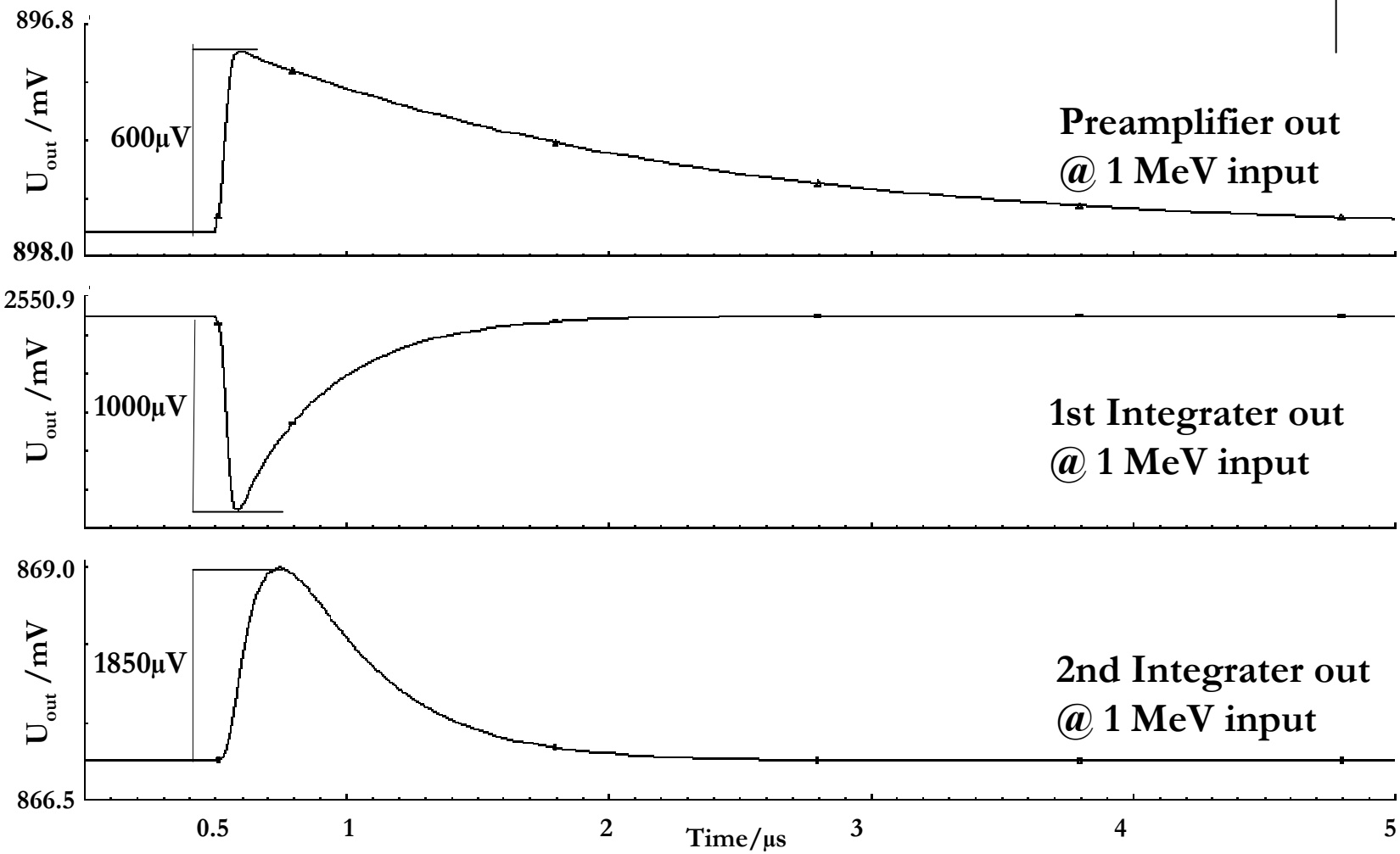
- **Dynamic Range: 1 – 1000 MeV**
- **Max. event rate: 300kHz**
- **Less than 13.000 e $^-$ noise @ 300pF detector capacitance**

Pole-Zero Cancellation

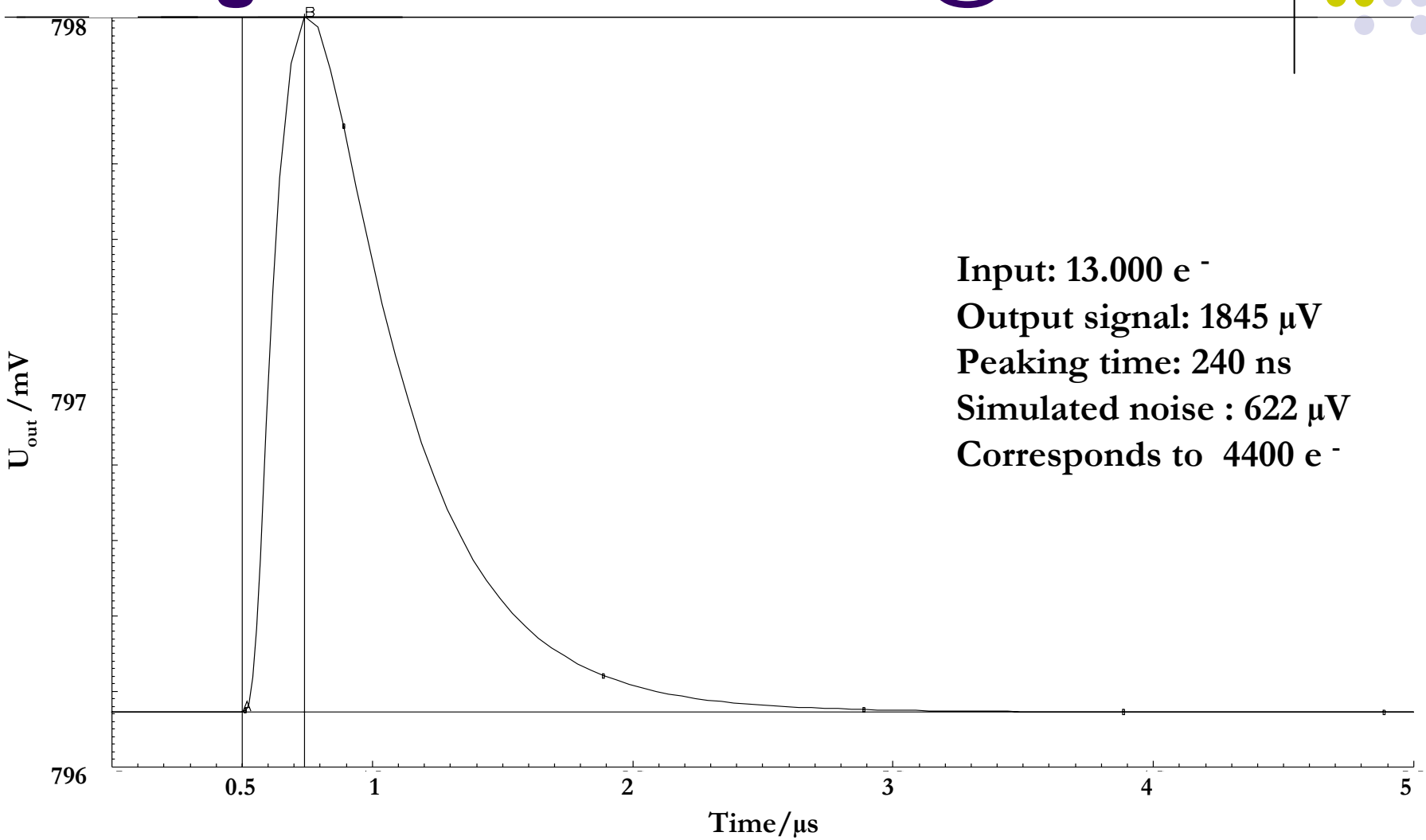




Transient Simulations @ -25°C

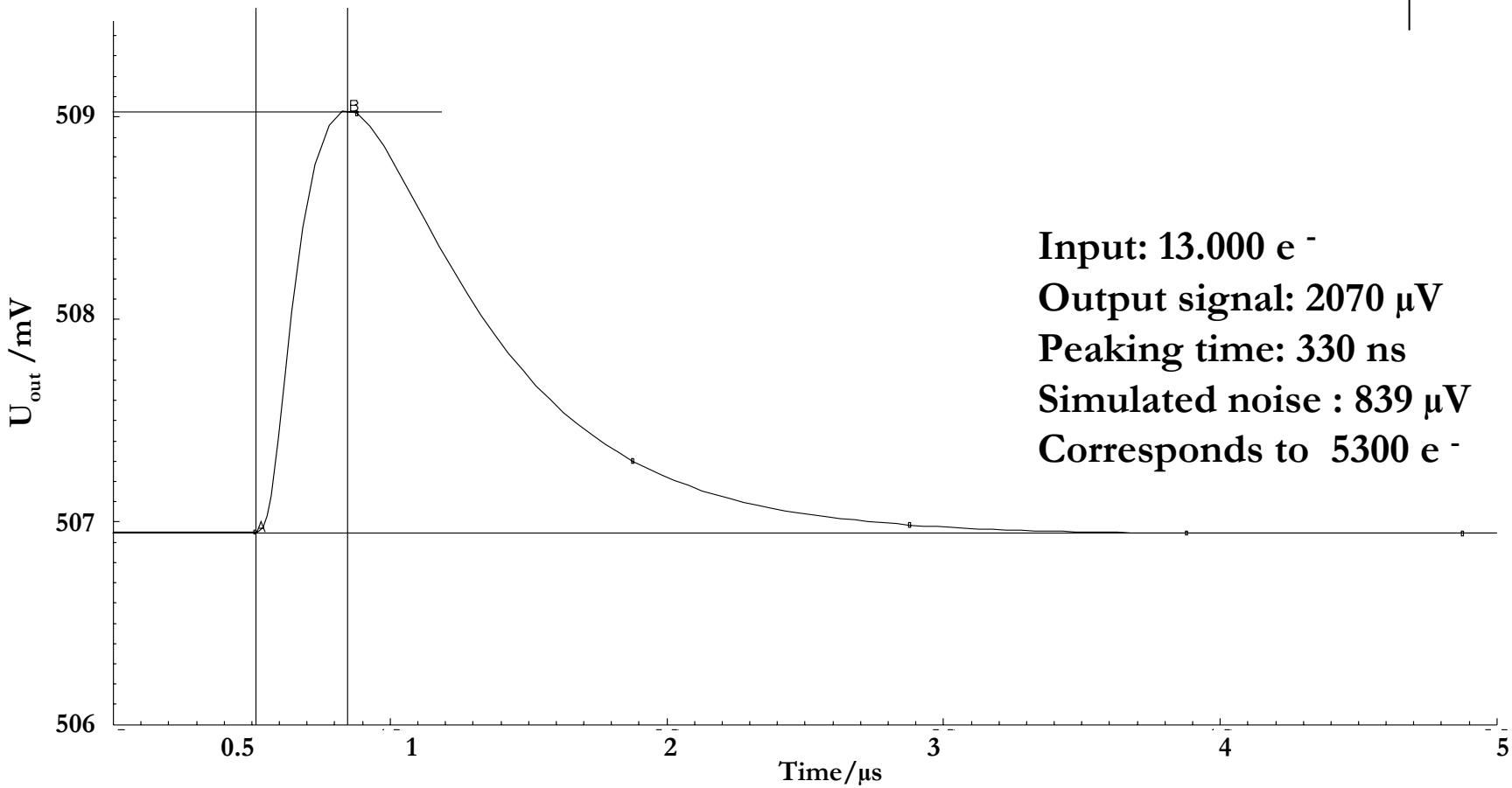


Signal to Noise Ratio @ -25°C

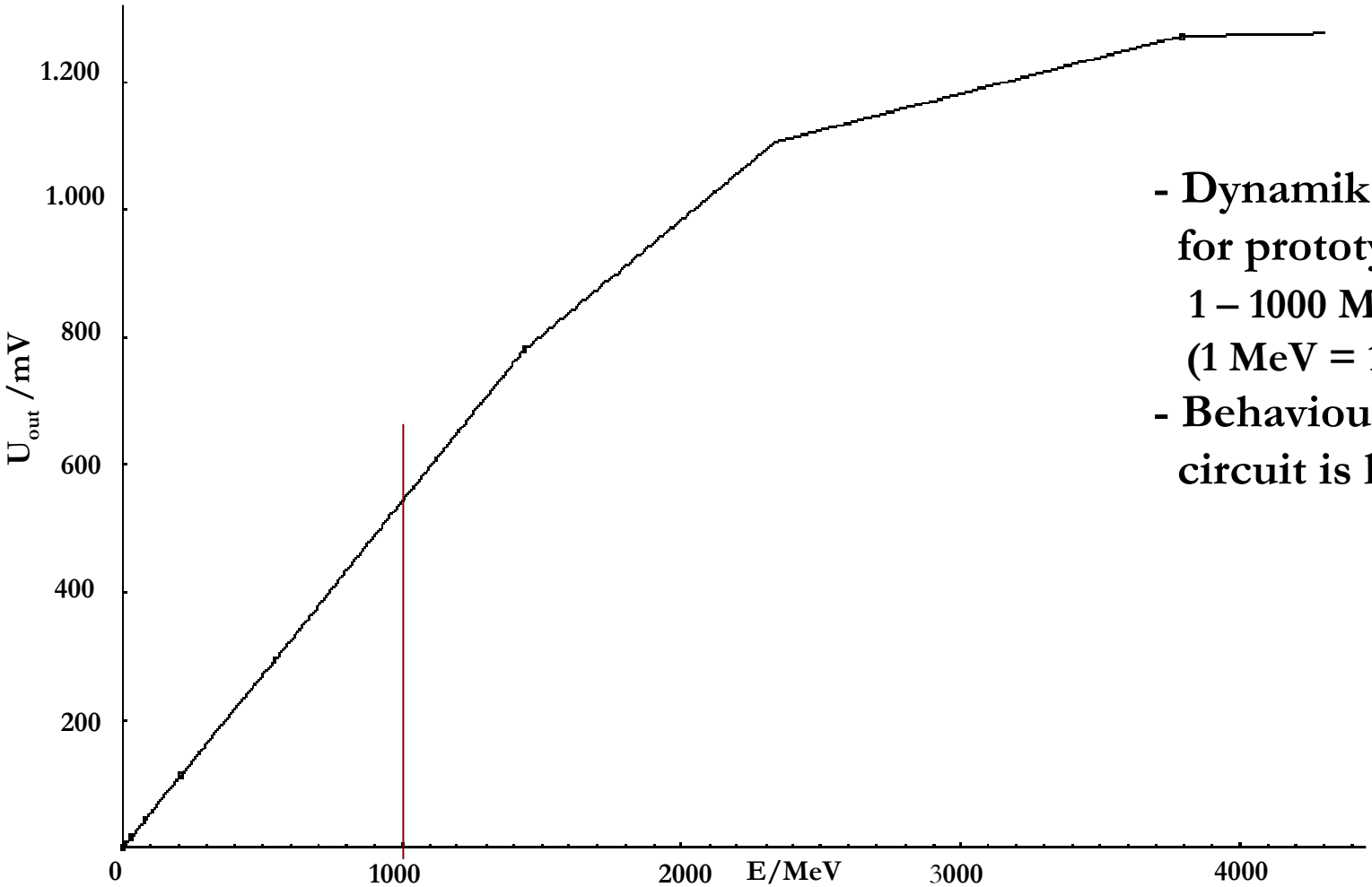


Input: 13.000 e $^-$
Output signal: 1845 µV
Peaking time: 240 ns
Simulated noise : 622 µV
Corresponds to 4400 e $^-$

Signal to Noise Ratio @ +25°C

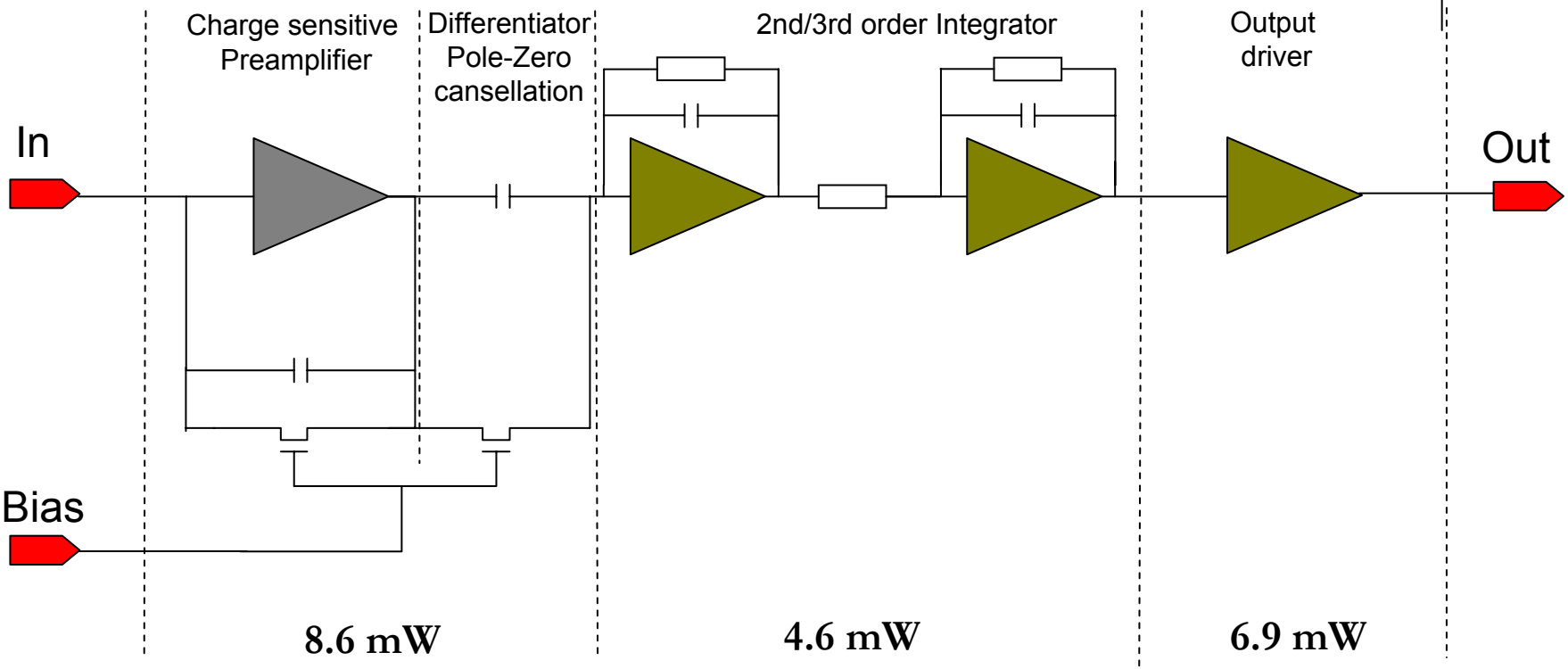


Linearity



- Dynamik range for prototype:
  1 – 1000 MeV
  (1 MeV = 13.000 e^-)
- Behaviour of the circuit is linear

Power Consumption



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 planed for summer 2006

Still open Questions:

- Max. input rate
- Radiation background