Strategies for the integration between FE Electronics and Detectors

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Introduction

New high-energy experiments in accelerator machines require particle detectors
to have high counting capabilities, high time resolution and high spatial resolution.
These requests have a major impact on the design of gas detectors and on
the electronic front end

Increasing the counting capacity implies moving the amplification from the gas to the
electronics which must have high gains and very low noise

Increasing the time resolution requires very rapid multiplication processes in the gas,
very intense electric fields, and fast electronics and the measurement of the signal
Amplitude for the correction of the rising time

Comparison: solid state detectors v.s. gas detectors evolution

Solid state detectors	**gas detectors**
• no gain	high gain
• low gain	low gain

Time resolution evolution

Solid state detectors

- mm thickness
- Low thickness

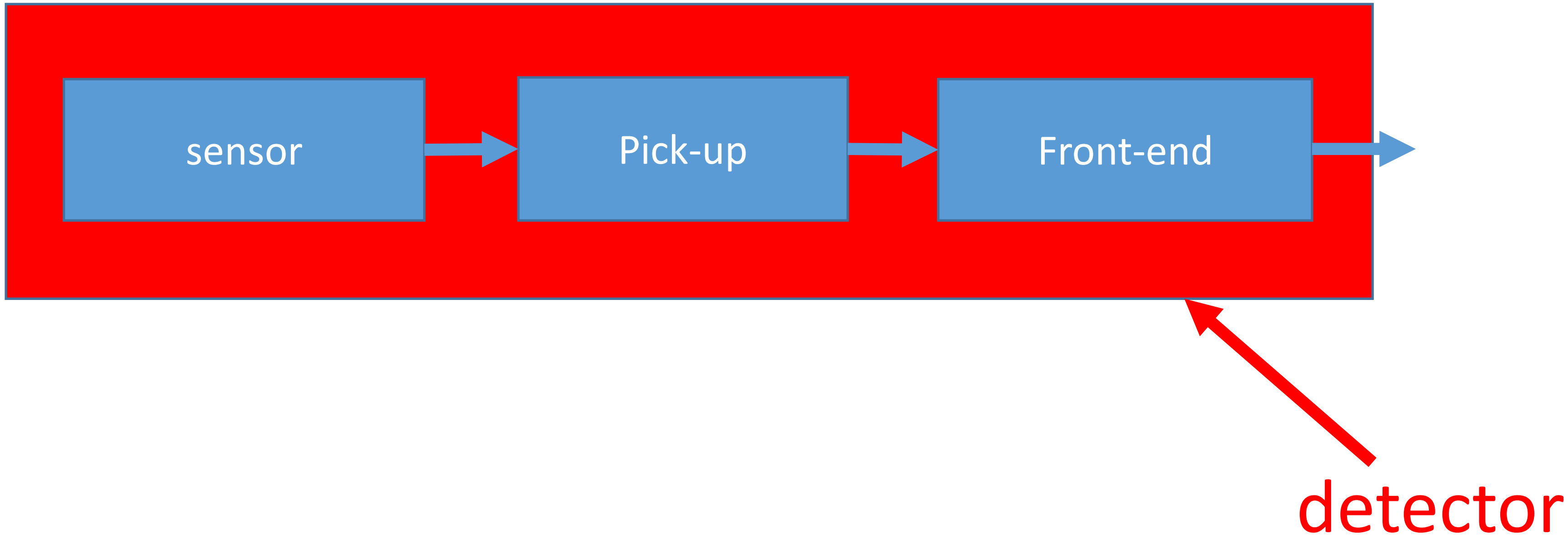
gas detectors

radial electric field

uniform electric field

Front End – Detector integration

From what has been said it can be deduced that the detector and the front-end electronics are so interconnected that they must be considered as a single block and therefore the integration of the detector and the electronics assumes a fundamental role.



Connection between detector and front-end

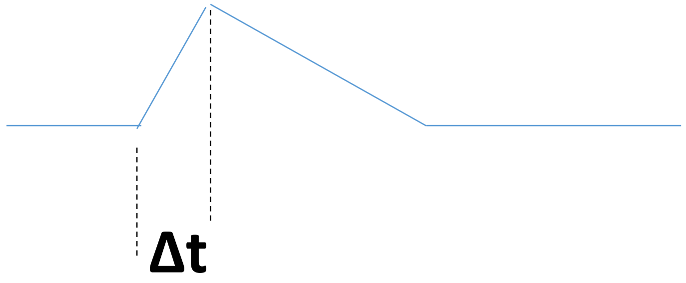
The connection between the detector and the front-end is made through the pick-up which must simultaneously satisfy two needs:

- to maximize the collection of charges produced in the detector(Ramo’s theorem)
- to transfer the signal to the front-end without distortion.

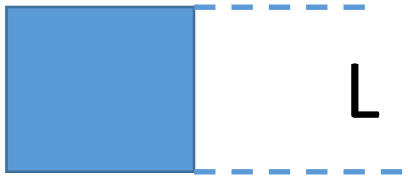
Pick-up normally used

$$\lambda = \Delta t * c$$

C=propagation velocity



Pad $\lambda > L$



capacitive adaptation

Strip-line $\lambda < L$

resistive adaptation

Noise considerations

Equivalent capacity calculation to evaluate electronic noise

Pad → $C=K*L^2$

strip-line → $C=K*\lambda$

Test

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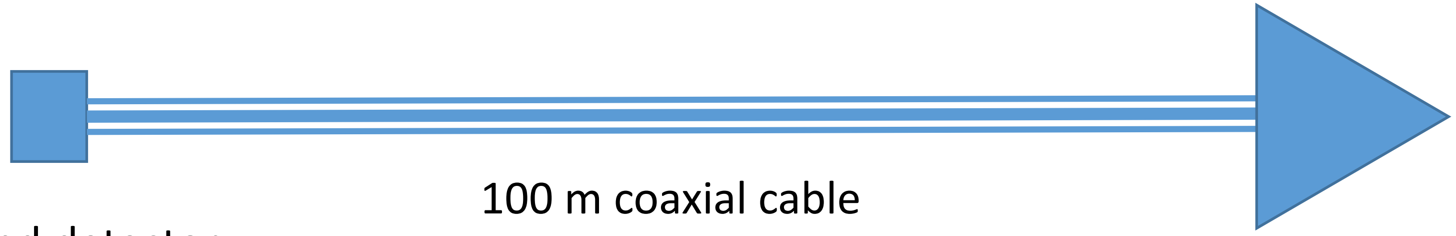


Diamond detector

100 m coaxial cable

Zin= 50Ω coaxial cable impedance

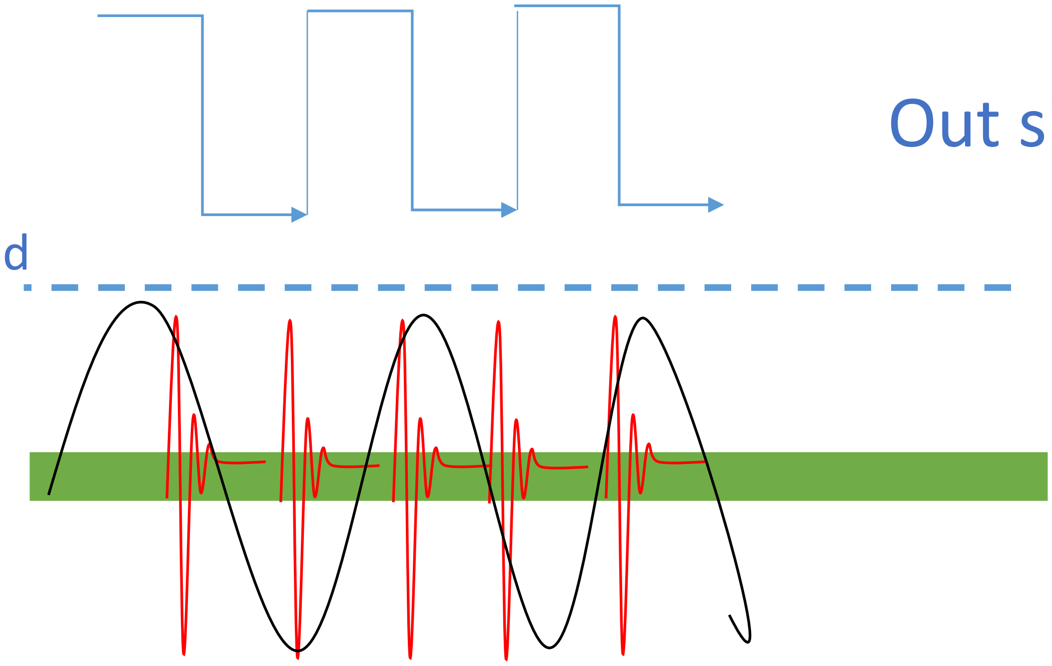
noise = 1000 e^- RMS

Noise considerations

Electronic noise can be summarized as composed of three types:

1) **intrinsic noise** (Jonson , 1/f, … , Noise) unavoidable
2) **induced noise** (radiofrequency, ………. Noise) Faraday's cage
3) **self-induced noise** (common mode current noise produced by low impedance output signals) differential signals, ground connections

Forms of the different types of noise



Out signal

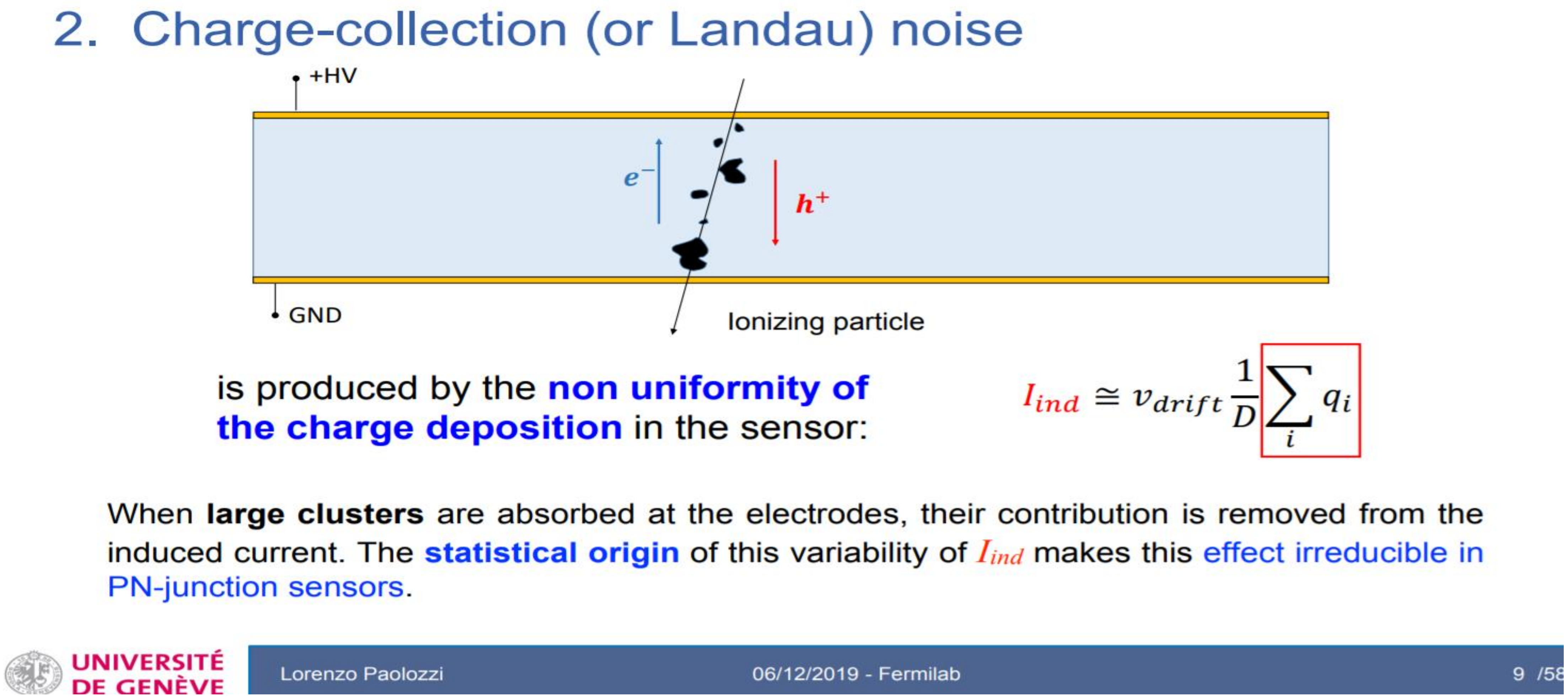
minimum possible threshold

intrinsic noise

induced noise

self-induced noise

Landau noise



2. Charge-collection (or Landau) noise

is produced by the **non uniformity of the charge deposition** in the sensor:

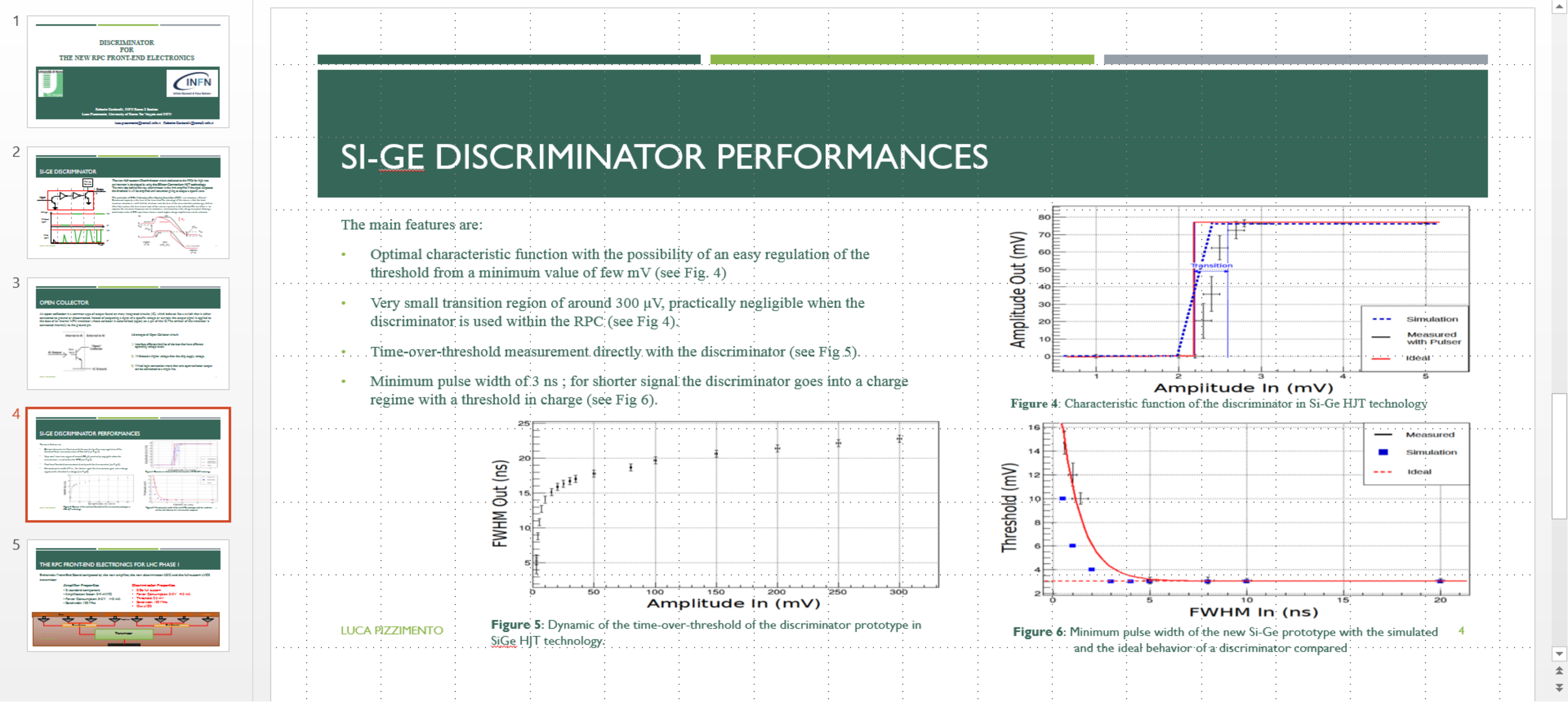
$$I_{ind} \cong v_{drift} \frac{1}{D} \boxed{\sum_i q_i}$$

When **large clusters** are absorbed at the electrodes, their contribution is removed from the induced current. The **statistical origin** of this variability of I_{ind} makes this effect irreducible in PN-junction sensors.

Minimum possible threshold

Once induced and self-induced noises have been eliminated, the number of spurious signals produced by the discriminator are:

- Vth=nσ F = P(nσ)*BW
- **F** frequency of false pulses discriminator from noise
- **P(nσ)** probability of having a higher tension (n * sigma noise)
- **BW** passband amplifier



SI-GE DISCRIMINATOR PERFORMANCES

The main features are:

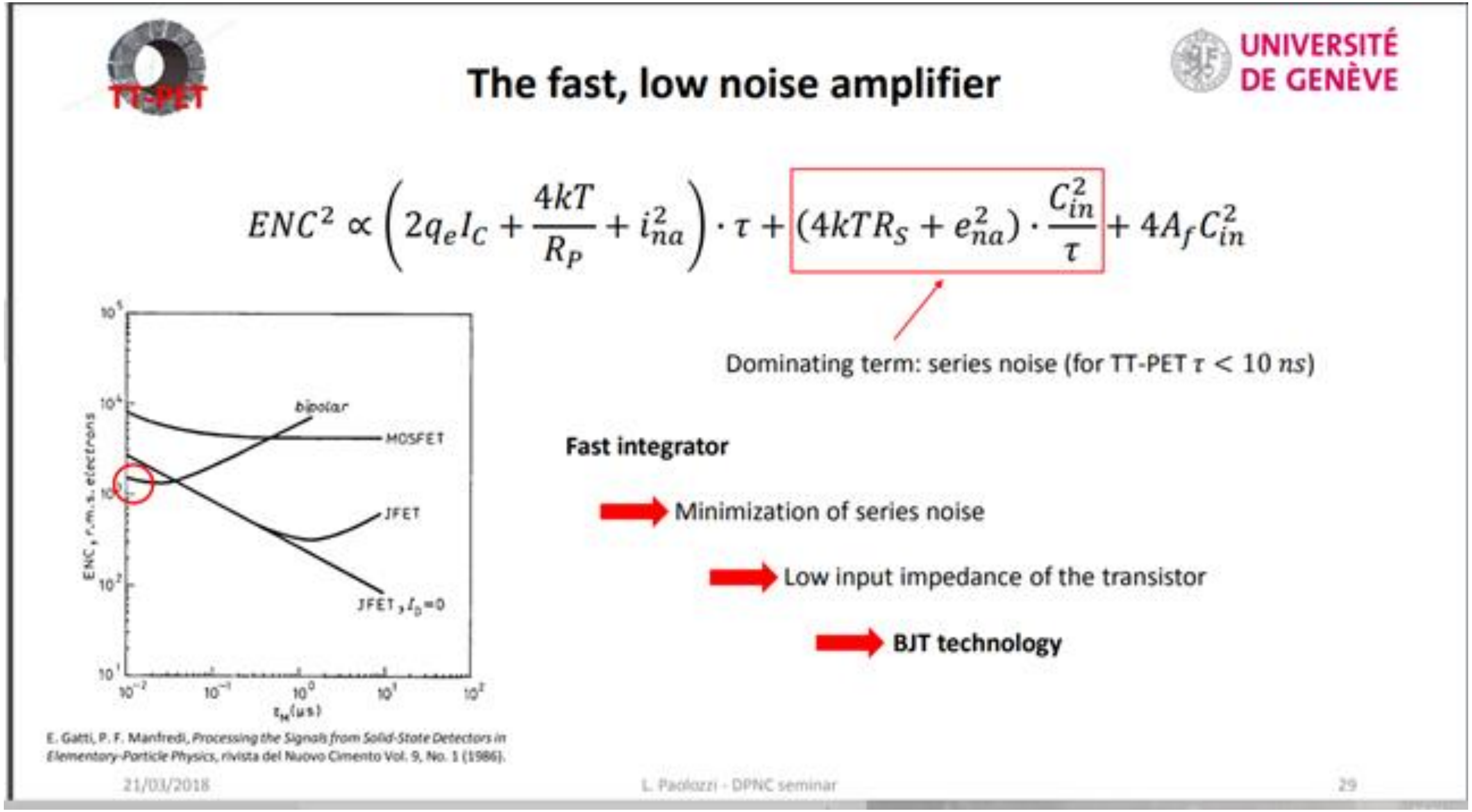
- Optimal characteristic function with the possibility of an easy regulation of the threshold from a minimum value of few mV (see Fig. 4)
- Very small transition region of around 300 µV, practically negligible when the discriminator is used within the RPC (see Fig 4).
- Time-over-threshold measurement directly with the discriminator (see Fig 5).
- Minimum pulse width of 3 ns ; for shorter signal the discriminator goes into a charge regime with a threshold in charge (see Fig 6).

Figure 4: Characteristic function of the discriminator in Si-Ge HJT technology

Figure 5: Dynamic of the time-over-threshold of the discriminator prototype in SiGe HJT technology.

Figure 6: Minimum pulse width of the new Si-Ge prototype with the simulated and the ideal behavior of a discriminator compared

Low noise amplifier



The fast, low noise amplifier

$$ENC^2 \propto \left(2q_e I_C + \frac{4kT}{R_P} + i_{na}^2\right)\cdot\tau + \boxed{(4kTR_S + e_{na}^2)\cdot\frac{C_{in}^2}{\tau}} + 4A_f C_{in}^2$$

Dominating term: series noise (for TT-PET $\tau < 10\ ns$)

Fast integrator

➡ Minimization of series noise

➡ Low input impedance of the transistor

➡ **BJT technology**

E. Gatti, P. F. Manfredi, *Processing the Signals from Solid-State Detectors in Elementary-Particle Physics*, rivista del Nuovo Cimento Vol. 9, No. 1 (1986).

BJT Si v.s. SiGe

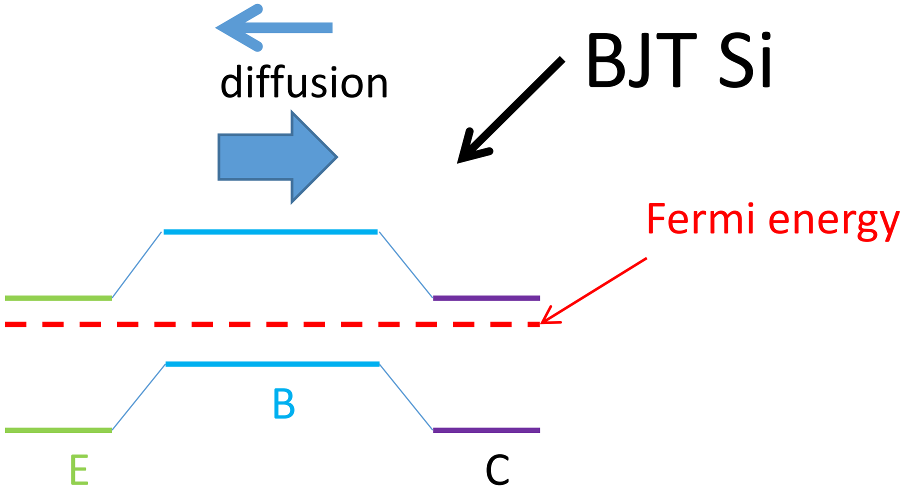
BJT performances

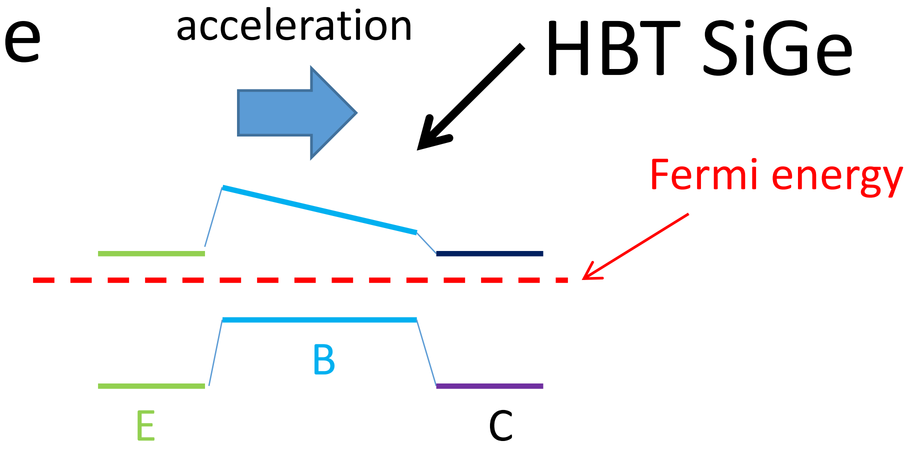
- $\beta = \tau_c / \tau_t$
- $f_t = 1/\tau_t$
- $N = K^* \tau_t$

τ_c=hole recombination time in Base

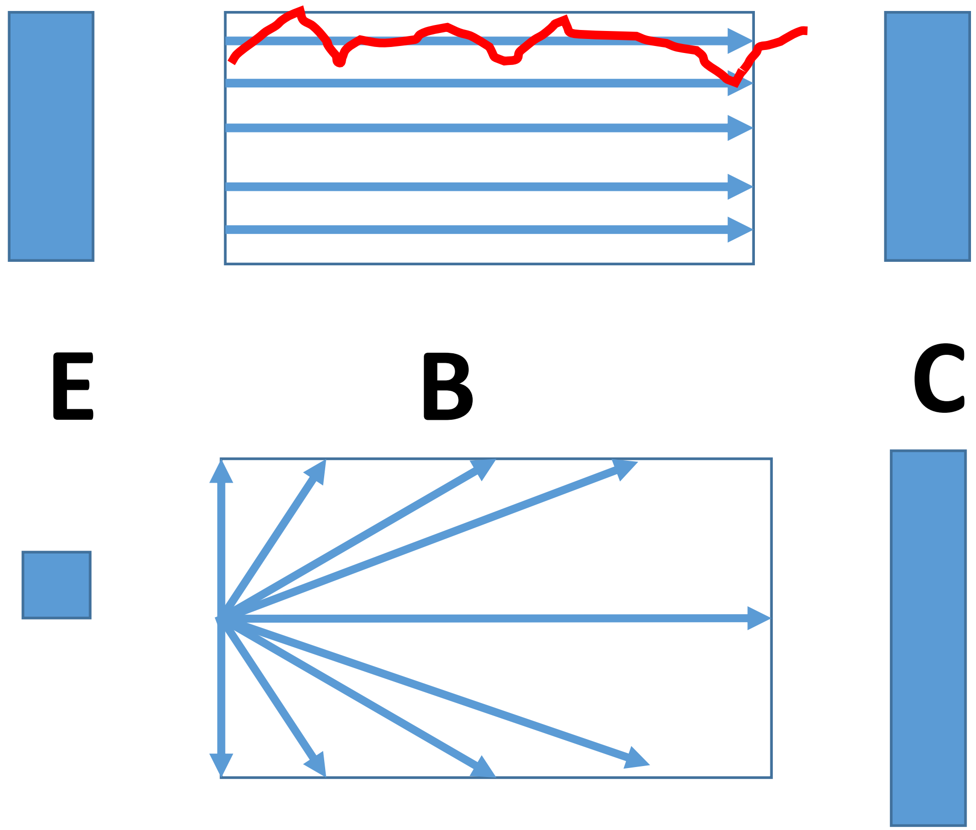
τ_t = base transient time

τ_t (Si) >> τ_t (SiGe)





Comparison BJT v.s. HBT SiGe



Ft = 350 GHz β = 900

HBT SiGe

E

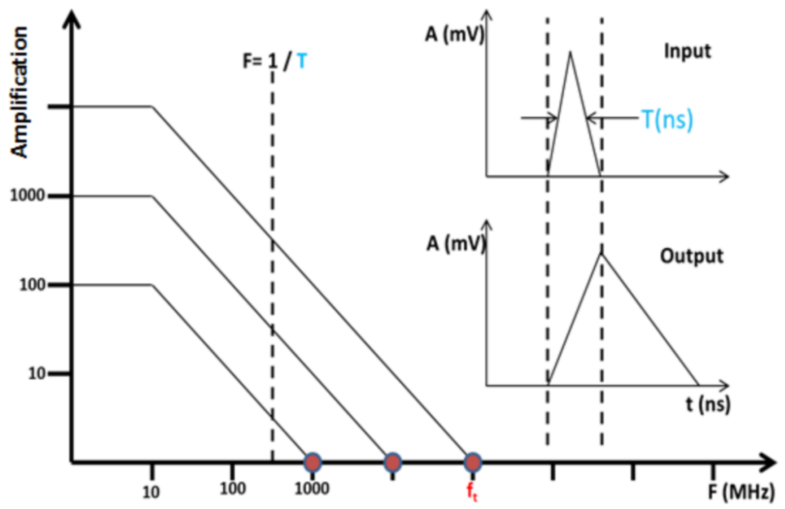
B

C

Ft = 10 GHz β = 30

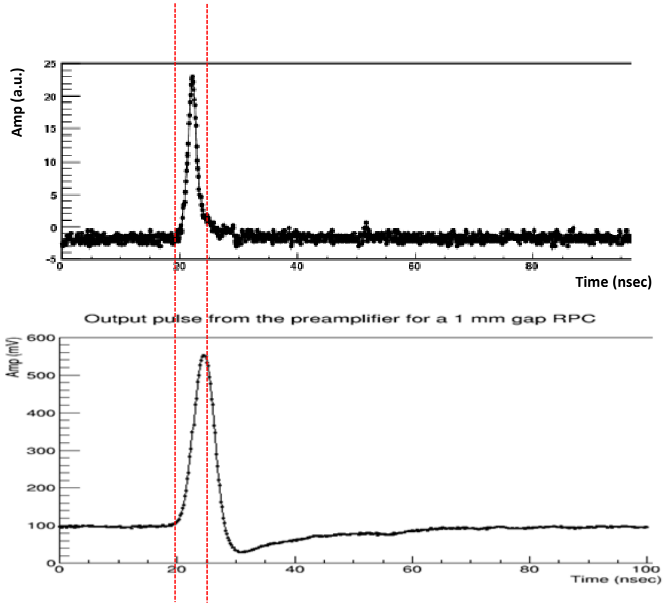
BJT

Strategy for the new front-end (SiGe)

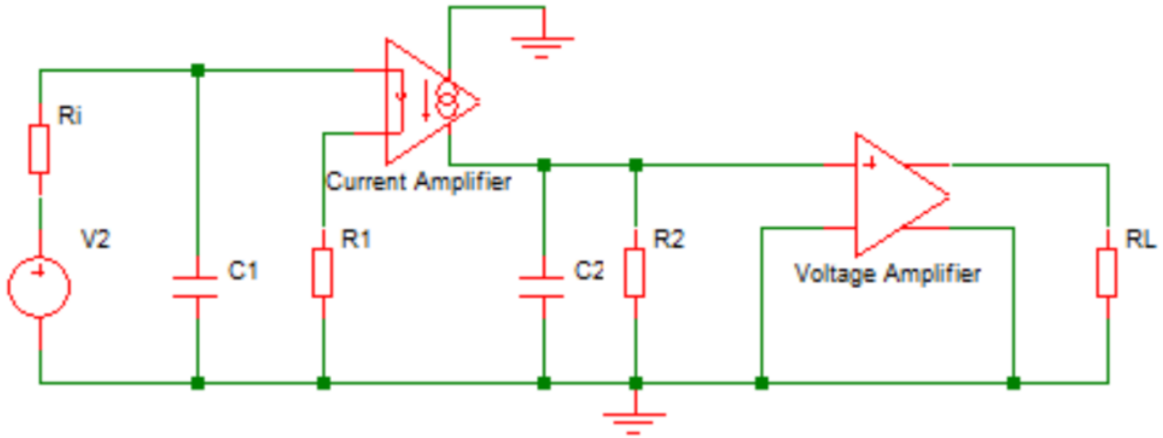


Working strategy

Actual result for the RPC signal



The block diagram of the preamplifier



The same scheme can be used for both Silicon and SiGe technology for a comparison.

Silicon technology

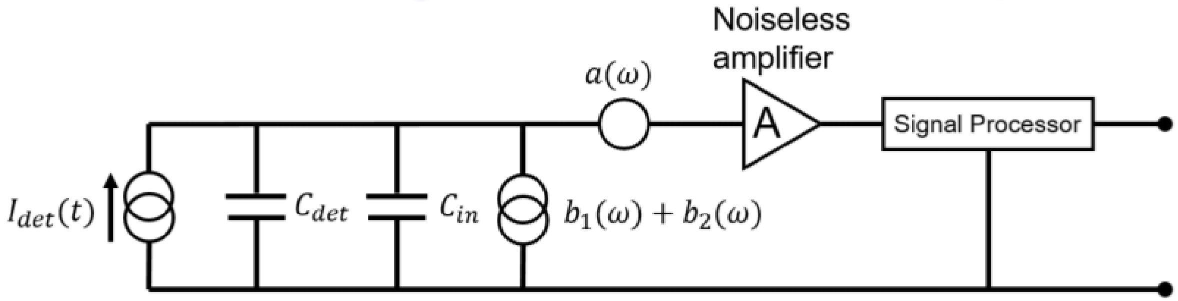
Voltage supply	3–5 Volt
Sensitivity	2–4 mV/fC
Noise (independent from detector)	4000 e^- RMS
Input impedance	100–50 Ohm
B.W.	10–100 MHz
Power consumption	10 mW/ch
Rise time $\delta(t)$ input	300–600 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}

SiGe technology

Voltage supply	2–3 Volt
Sensitivity	2–6 mV/fC
Noise (independent from detector)	500 e^- RMS
Input impedance	50–200 Ohm
B.W.	30–100 MHz
Power consumption	2 mW/ch
Rise time $\delta(t)$ input	100–300 ps
Radiation hardness [4]	50 Mrad, 10^{15} n cm^{-2}

Noise v.s. β and R_b

Equivalent Noise Charge: device comparison



$$ENC^2 = \boxed{A_1 \frac{a_W}{\tau_M}(C_{det} + C_{in})^2} + A_2 \cancel{\frac{ln2}{\pi} c(C_{det}} + C_{in})^2 + \cancel{A_3(b_1 + b_2)}\tau_M$$

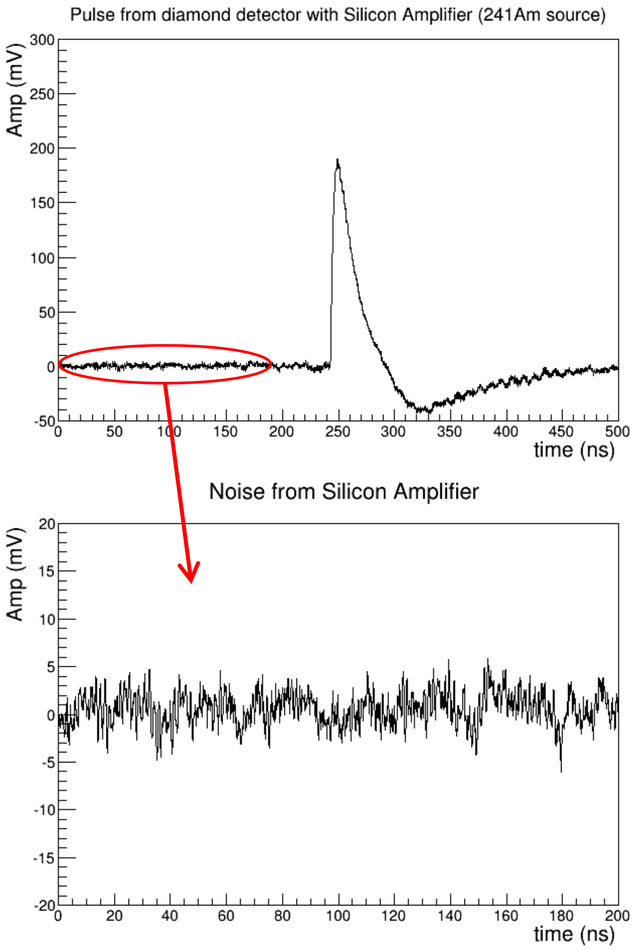
BJT based amplifier

$$\xrightarrow{} ENC_{\text{series noise}} \propto \sqrt{k_1 \cdot \frac{C_{tot}^2}{\beta} + k_2 \cdot R_b C_{tot}^2}$$

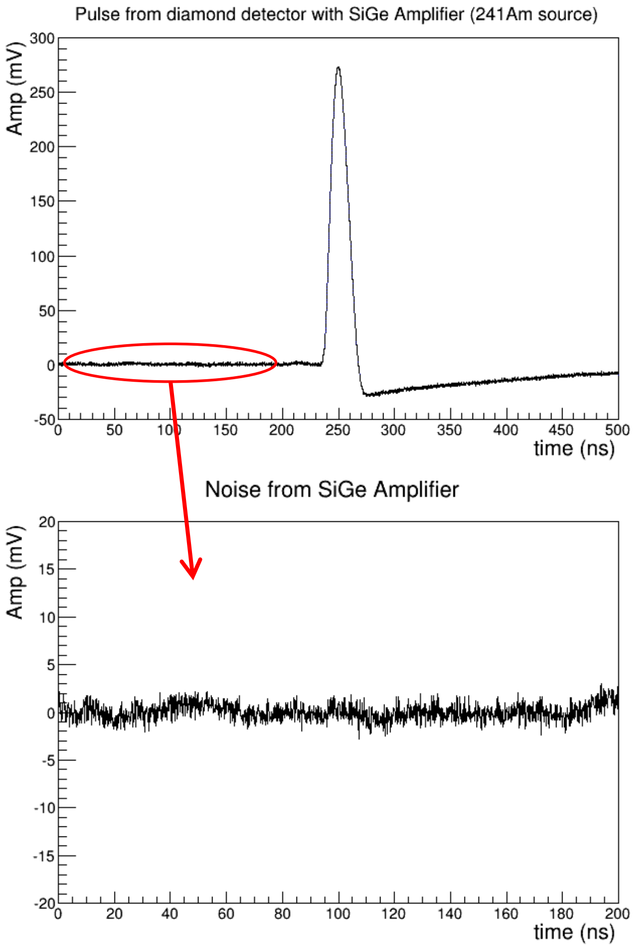
Signal and noise from SiGe Amplifier and Silicon Amplifier

Pulses recorded from a 500 micron diamond sensor irradiated by ^{241}Am source.

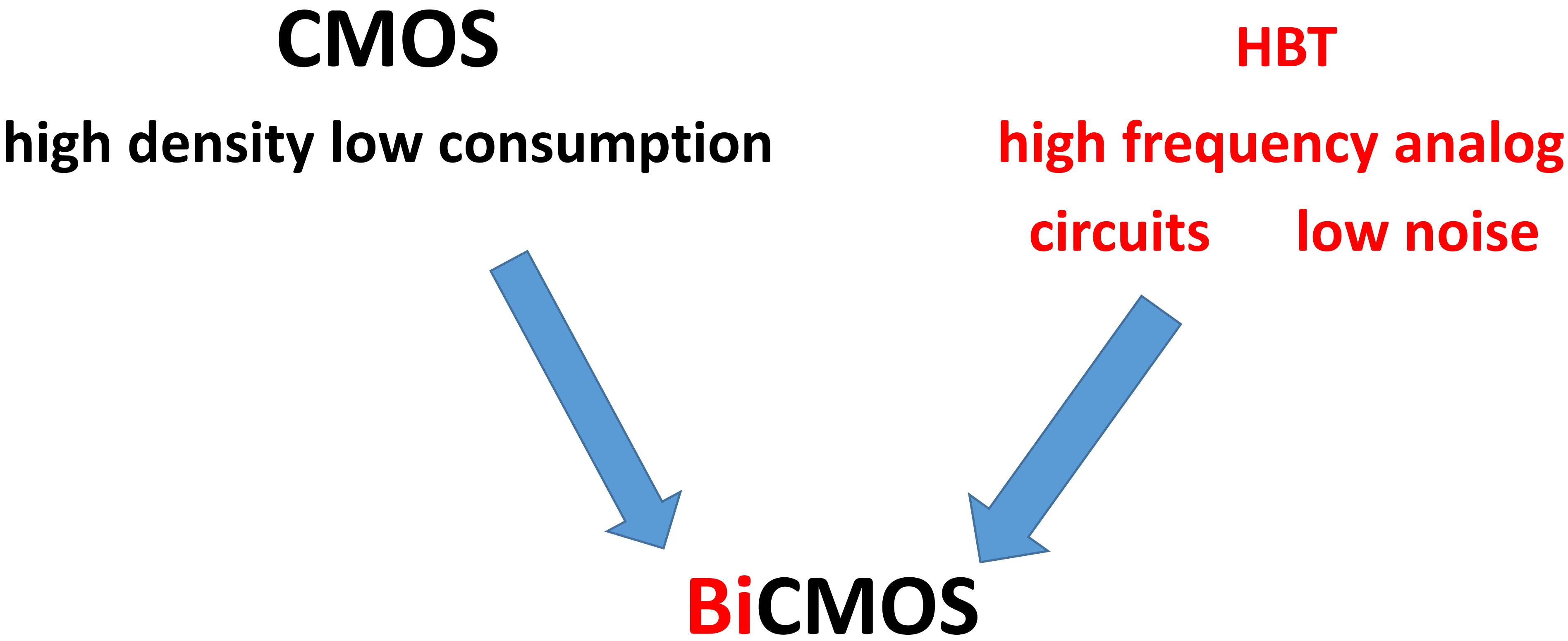
Silicon amplifier



SiGe amplifier



CMOS and HBT comparison



CMOS

high density low consumption

HBT

high frequency analog

circuits low noise

BiCMOS

Possible developments

BiCMOS **CMOS**

- **60 nm β=900 Ft=350GHz** **today** **20nm**
- **20 nm β=1500 Ft=1 THz** **next years** **10-7 nm**

- **BCMOS high flexibility and high development potential**
- **CMOS development limit of atom size, difficulty in making precise simulation models**

Conclusions

Given the high performance required for the gas detectors in future experiments, the integration between the detector and the front-end electronics acquires a fundamental importance. The choice of technology must be made by rewarding flexibility and the possibility of development, for these reasons we recommend BiCMOS.