Solid-state particle detector based on latchup effect

BUG-EYE

a **B**ased on latch**U**p i**G**nition **E**xperiment for the design of a micro-e**YE** pixel-like sensor)

Alessandro Gabrielli

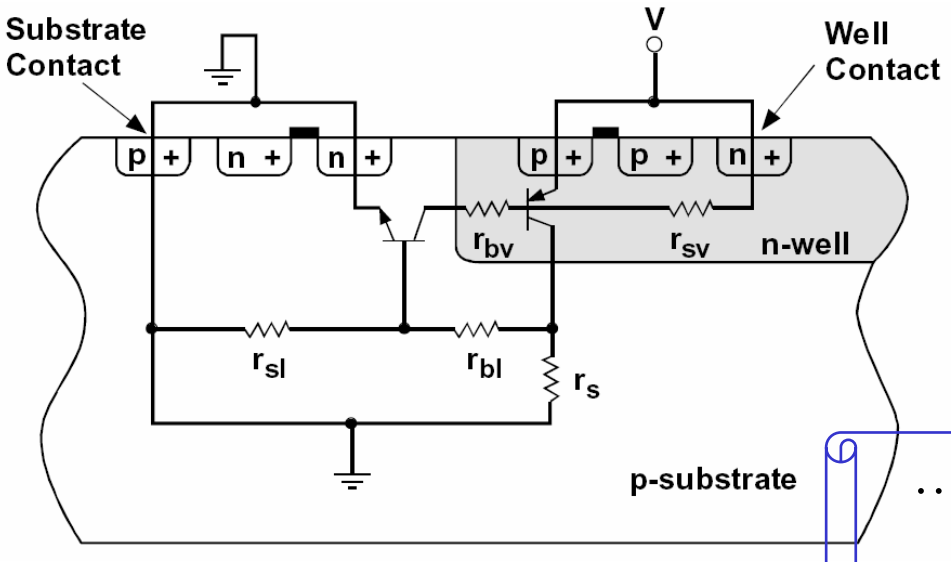
Physics Department of Bologna University

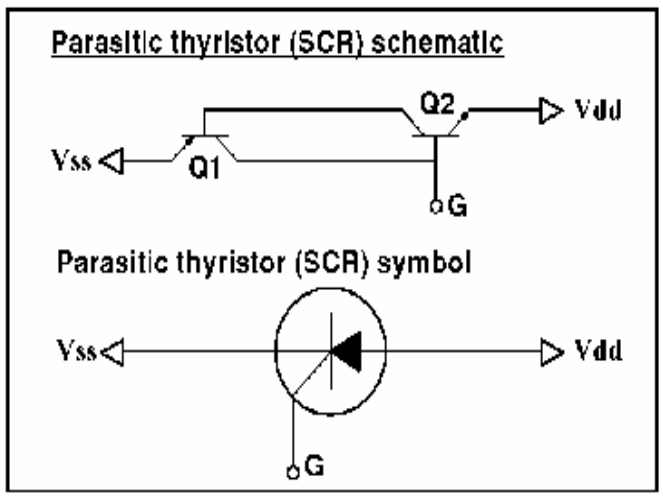
I.N.F.N. Bologna

The stimulated ignition of latchup effects caused by external radiation has so far proven to be a hidden hazard for CMOS technologies

Here the latchup effect is proposed as a powerful means of achieving the precise detection and positioning of a broad range of particles

What the “Latchup Effect” is





Basically it is an ingnition af a parasitic thyristor-like structure within a CMOS device and ..

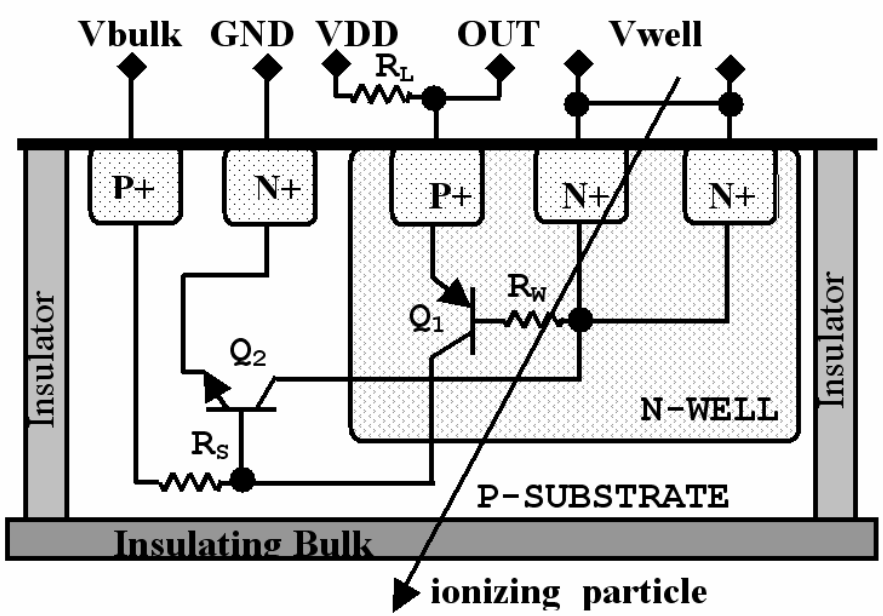
….is ignited by induced charges inside the silicon whatever their origin.

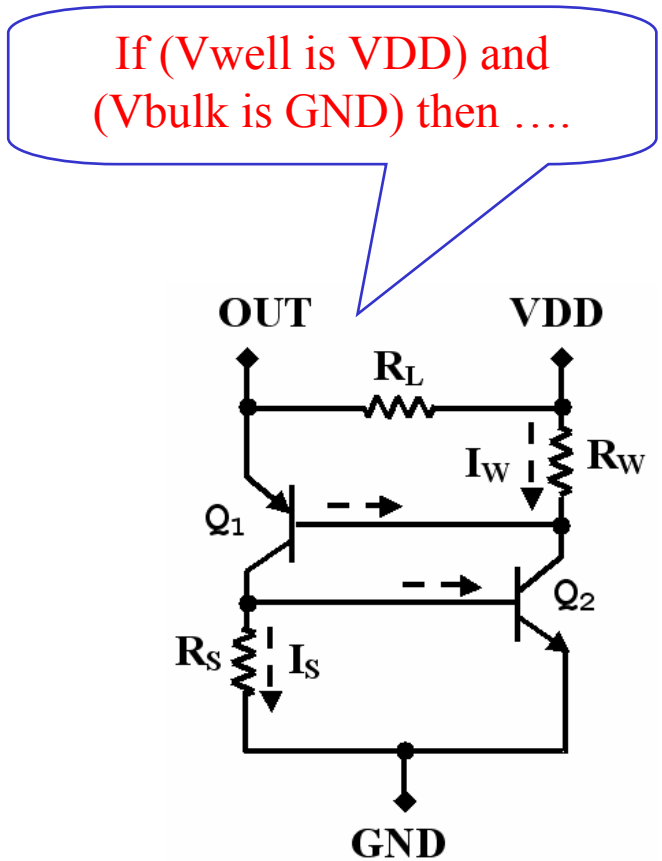
-Electrically induced on I/O pads,

-Due to ionizing particles.

Traditional CMOS technologies into radiation environments may be susceptible and damaged by latchup

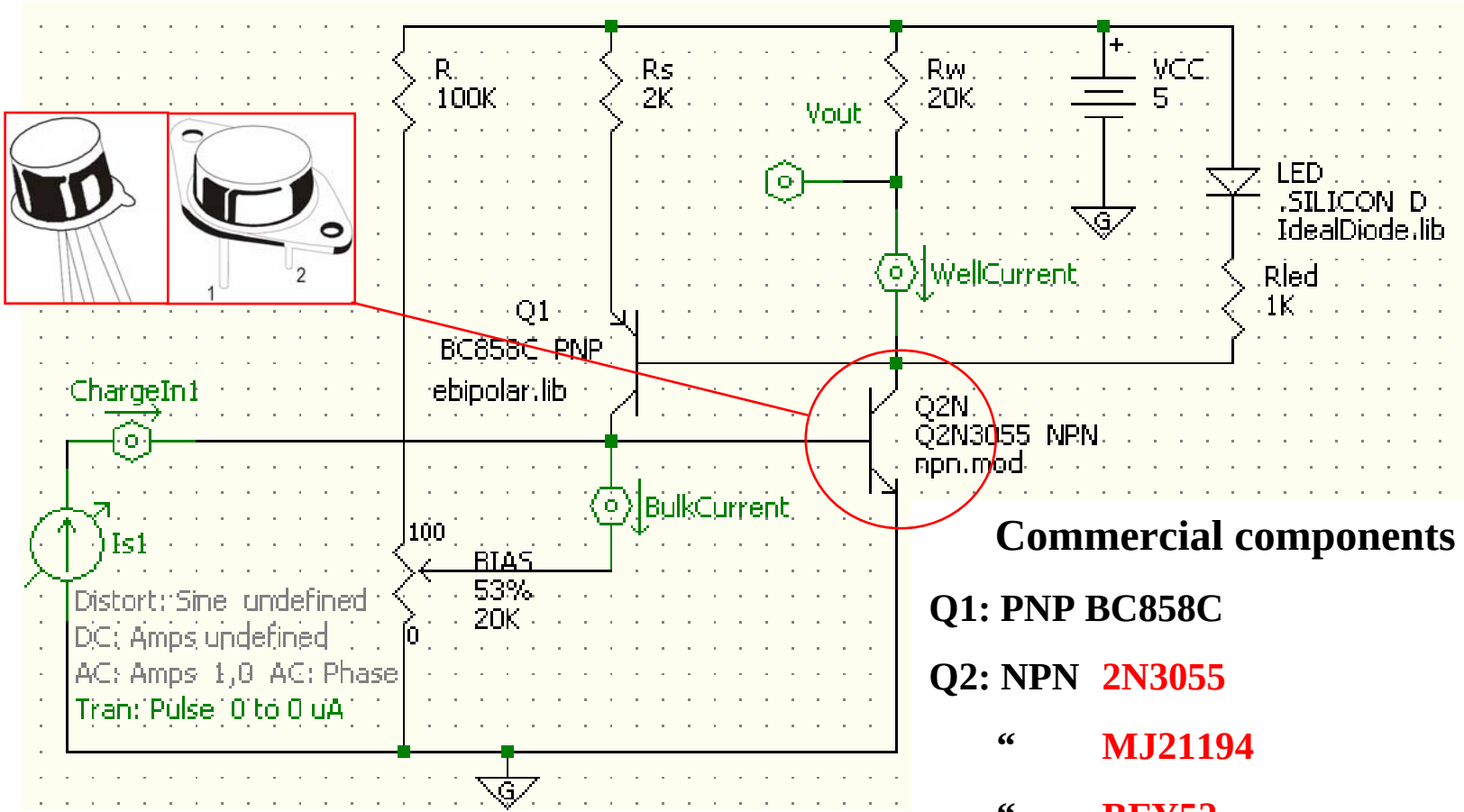
Prototype design





It is not a reverse-biased diode plus the transistor has an internal current gain

Prototype 1: circuit



Commercial components

Q1: PNP BC858C

Q2: NPN 2N3055

“ MJ21194

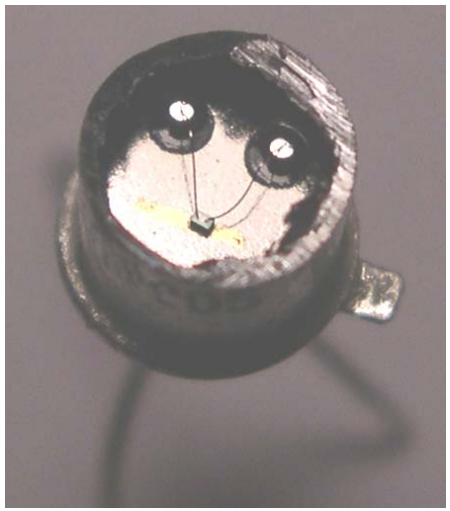
“ BFY52

“ 2N2222A

R_N: multiturn variable resistors

A. Gabrielli, El. Let. 41/11, (2005), 25

(Q2 = 2N2222A BFY52 2N3055)



TO-18 metal can

Estimated B-E charge collection area

10÷100 μm^2

TO-39 metal can

Estimated B-E charge collection area

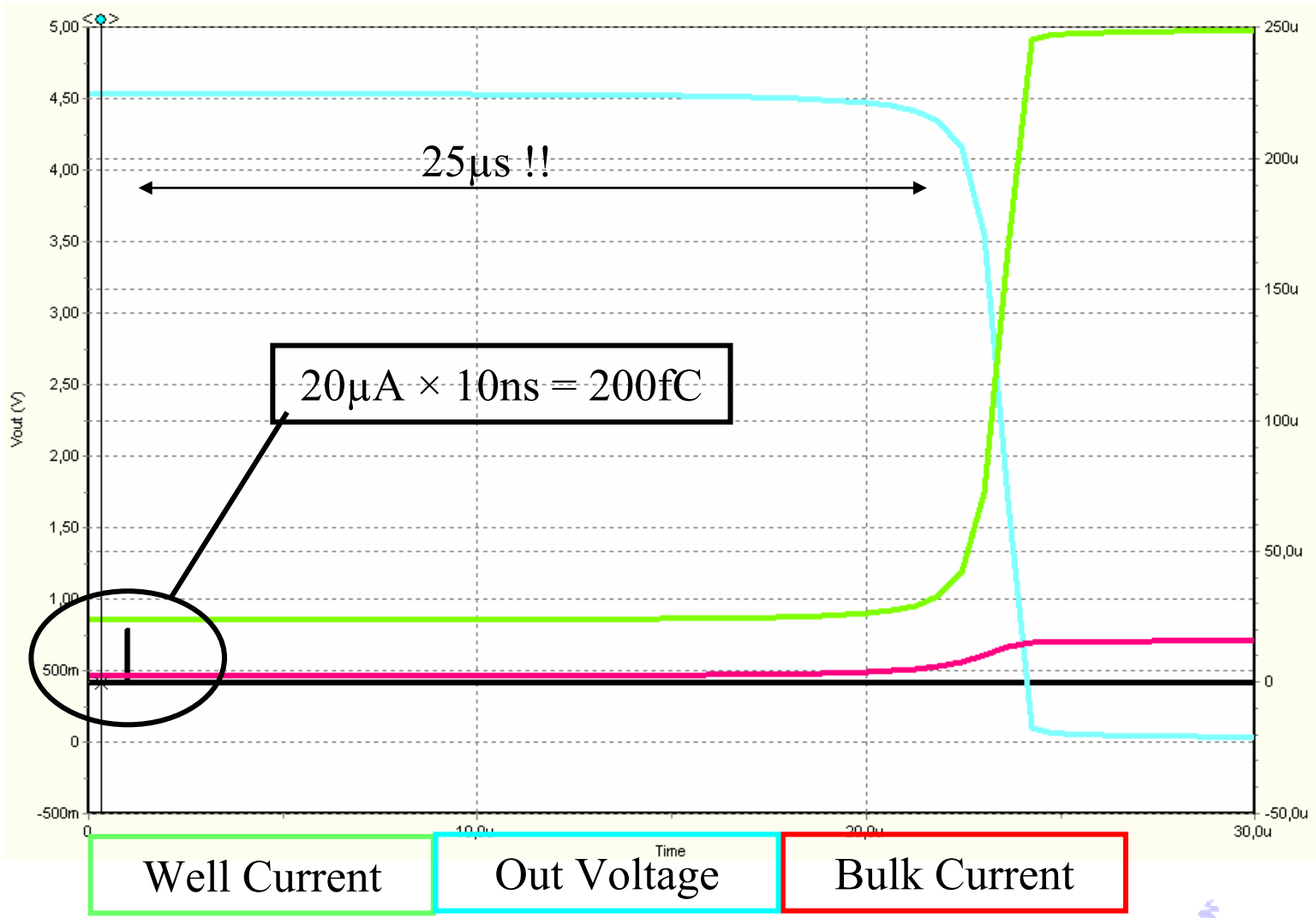
100÷10000 μm^2

TO-3 metal can

Estimated B-E charge collection area

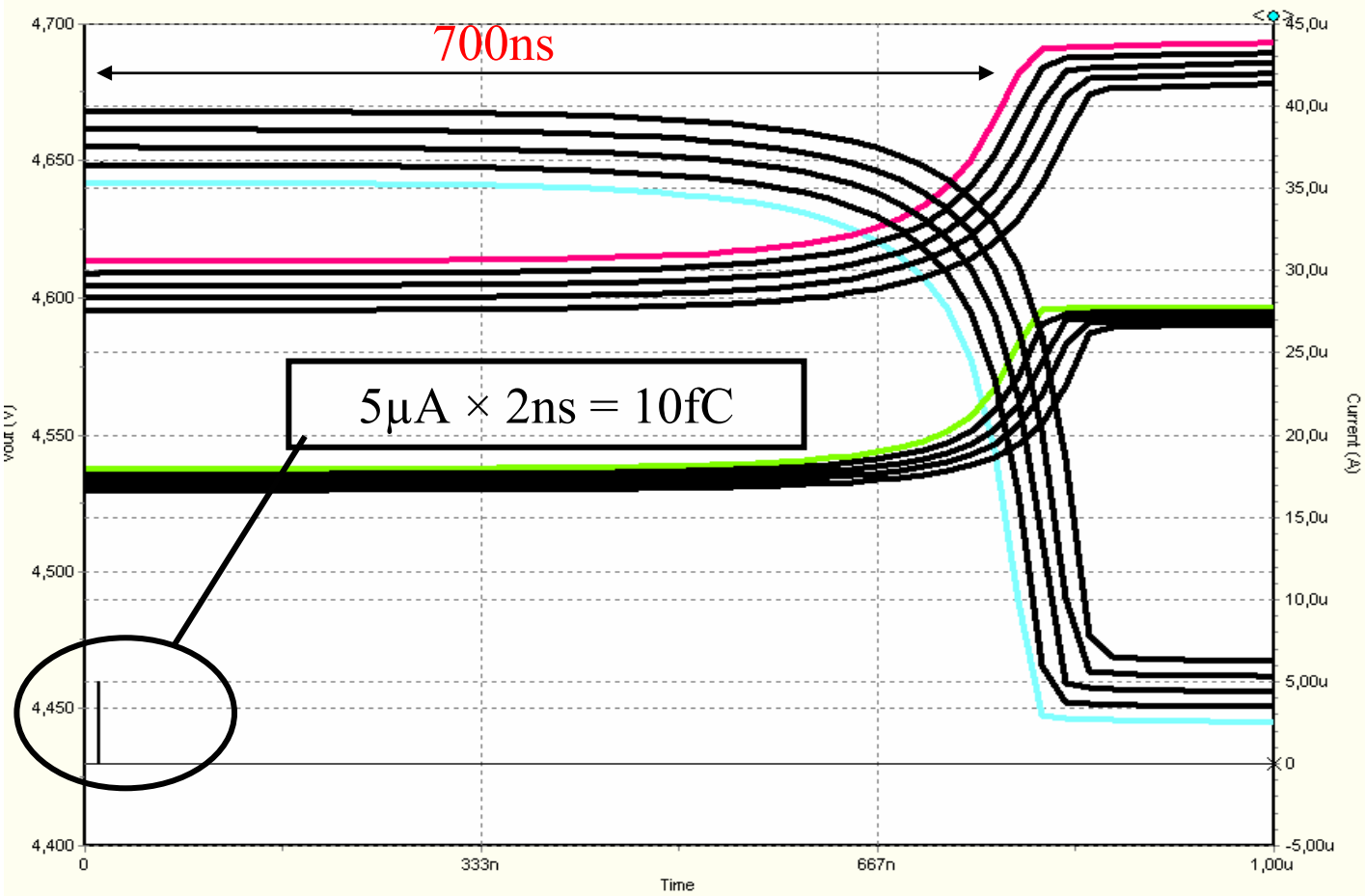
1 mm^2

Prototype 1: Spice simulation (Q2=2N3055)



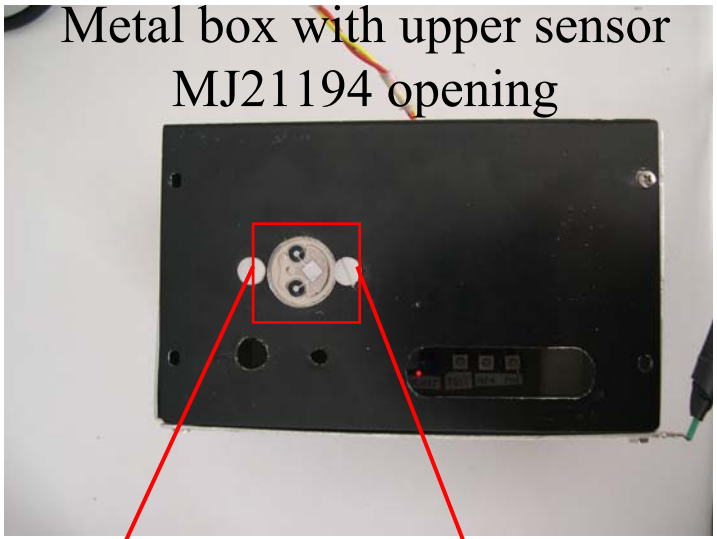
Prototype 1: Spice simulation (Q2=BFY52)

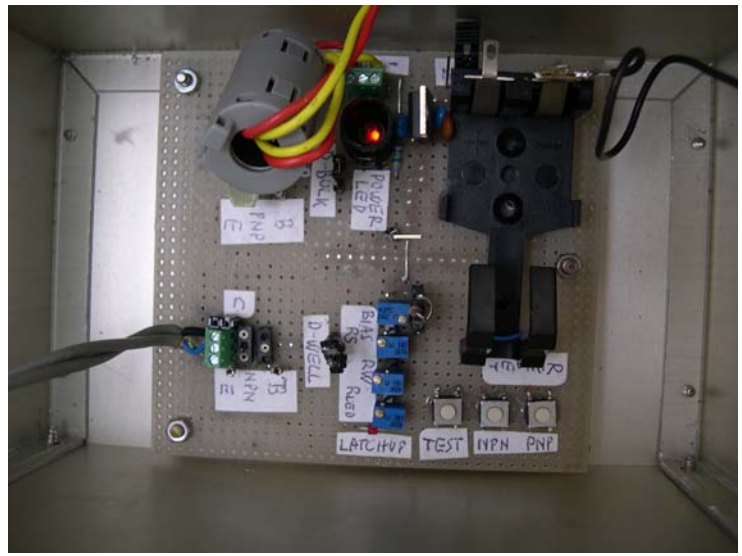
Temperature from 30 to 40ºC



Well Current | Out Voltage | Bulk Current

Prototype 1: Construction (Q2=MJ21194)





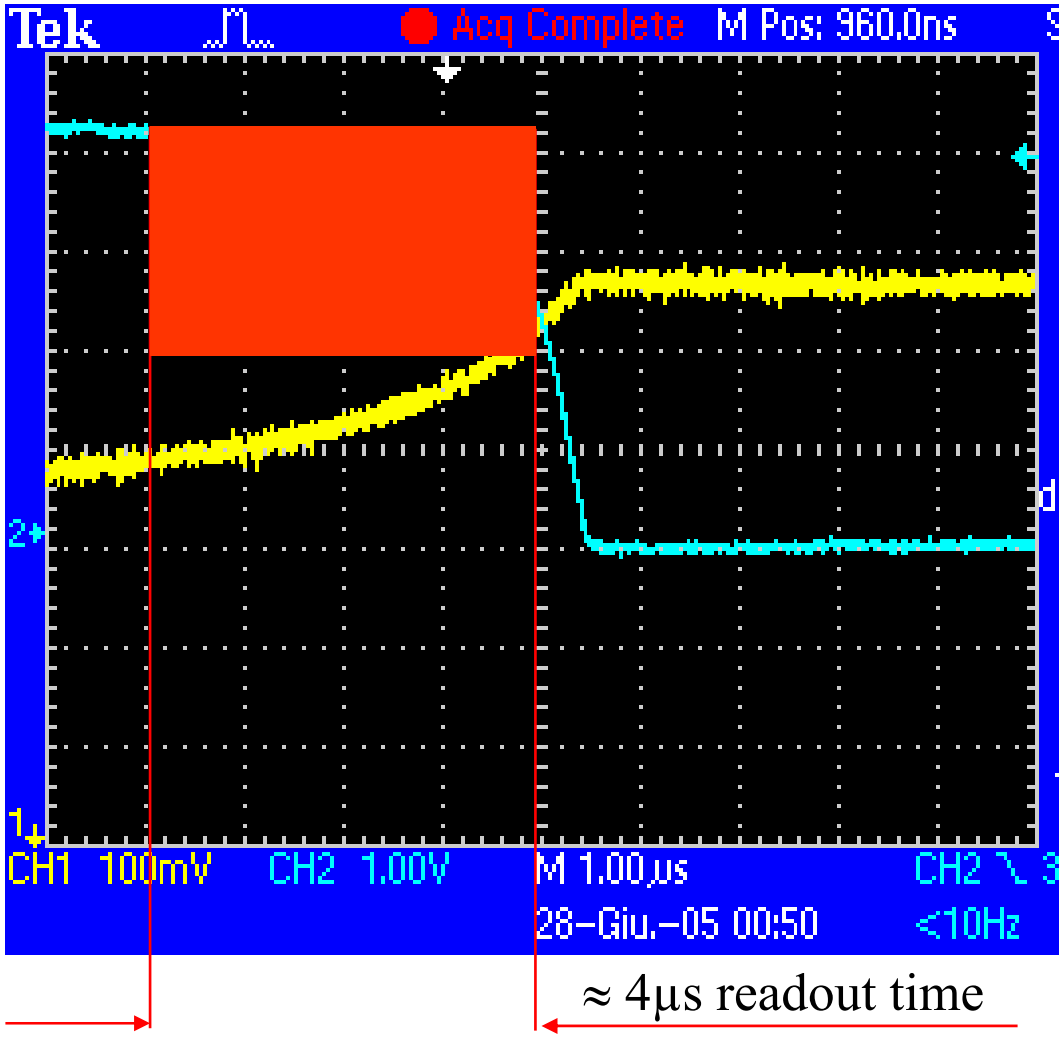
The latchup circuit inside the box

Transistor Base-Emitter bondings of the power bjt MJ21194

Prototype 1: 1pC via day-light in a dark room (≈ 1 lux)

Out signal

Transistor B-E
1pC-estimated
injected charge



NPN

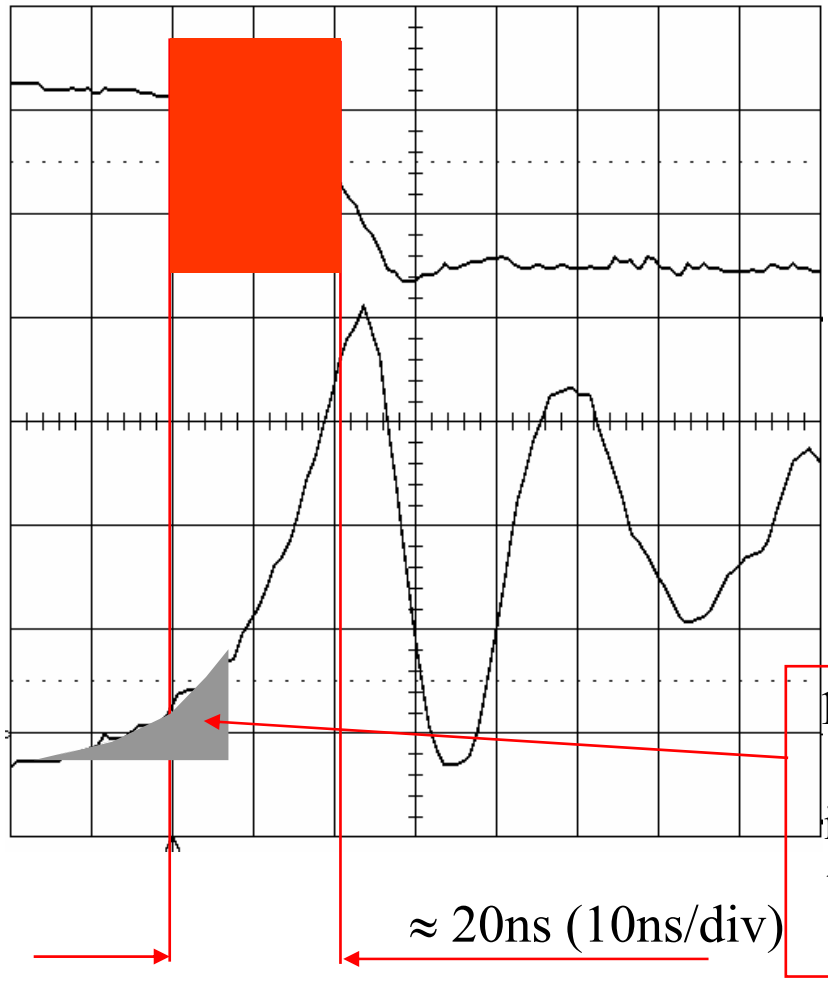
MJ21194

Power-BJT

Same behaviour but different numbers compared to simulations

MOST SENSIBLE

Prototype 1 (Q2=BFY52)
3.3pC via pulse generator



Out signal
(2V/div)

Transistor base input

(5mV/div)

10^{-8}Vs divided by the 3 kΩ input's impedance of the transistor returns 3.3×10^{-12} C

≈ 20ns (10ns/div)

To date tests summary

Test with photons

- Tests in a dark room with an equivalent moonlight intensity: ≈ fraction of 1 lux.
- By considering 100 μm^2 of BE collection area, 0.1 as photon/collected_electron conversion factor and 1.5÷3 eV/photon, it follows:

$$1\ Lux \approx 10^{-9}\ W/mm^2 \Rightarrow \approx 1pC\ collected\ charge$$

Test with αs

- Tests in a dark room with 1 μCi, Am-241, 5.5 MeV α source: were negative!! BUT…
  - 5.5 MeV α have 28 μm stopping-range in Si (4 cm in air) and deposit 240 fC,
  - BE implant depths ranges within a few μm,
  - 1.5÷3 eV photons are absorbed in a fraction of μm and set one electron free each

The prototype senses injected charges of the order of 1pC

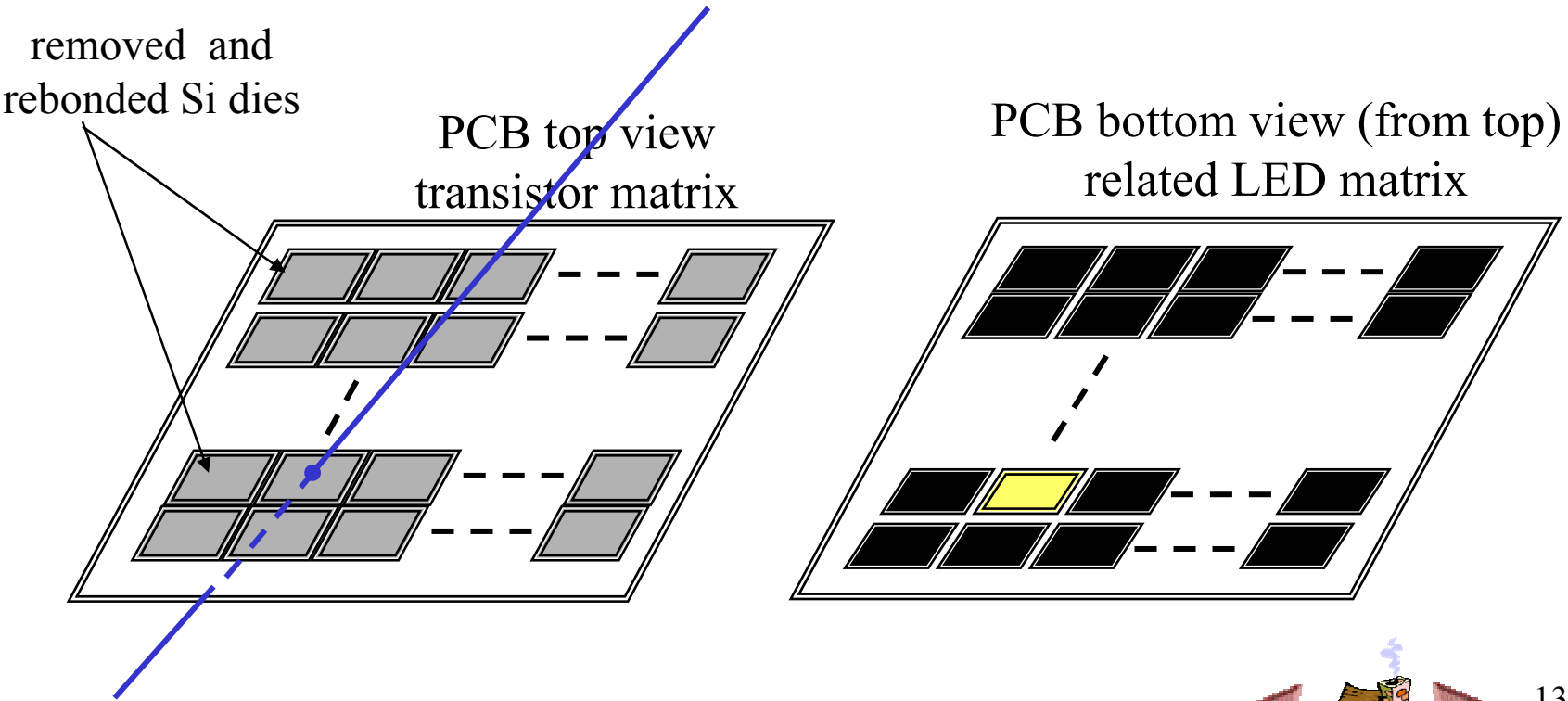
Probably α particles induce too few charges within the BE area of the "*COTS*"

Next Workplan

- 3th Q 2005: Tests under hevy ions via a ion implant machine

  Tests under 100 KeV electron beam via a TEM

- 4th Q 2005 : Start of a feasibility study for a detector construction made of commercial transistors (Hopefully!!)



CONCLUSIONS

By constructing an integrated silicon pixel detector based on latchup effect it is expected to have the following features due to the technology scaling:

-Each cell retains the position of the crossing particle with a spatial resolution of the order of 1 μm,

-Each cell, once ignited, can drive a relatively high current (≈1mA) sufficient to lit a micro-led; this leads to optical readout systems,

-The array may be designed via standard technologies (Bipolar, BiCMOS) that are intrinsecally more radiation tolerant ($\rho \approx 1\ \Omega \times cm$) than those used for solid state detector ($\rho \approx 10^{3\div4}\ \Omega \times cm$)

APPLICATIONS

- Beam monitor for its intrinsic radiation hardness

- Ion (partcle) selector for the ignition threshold tuning