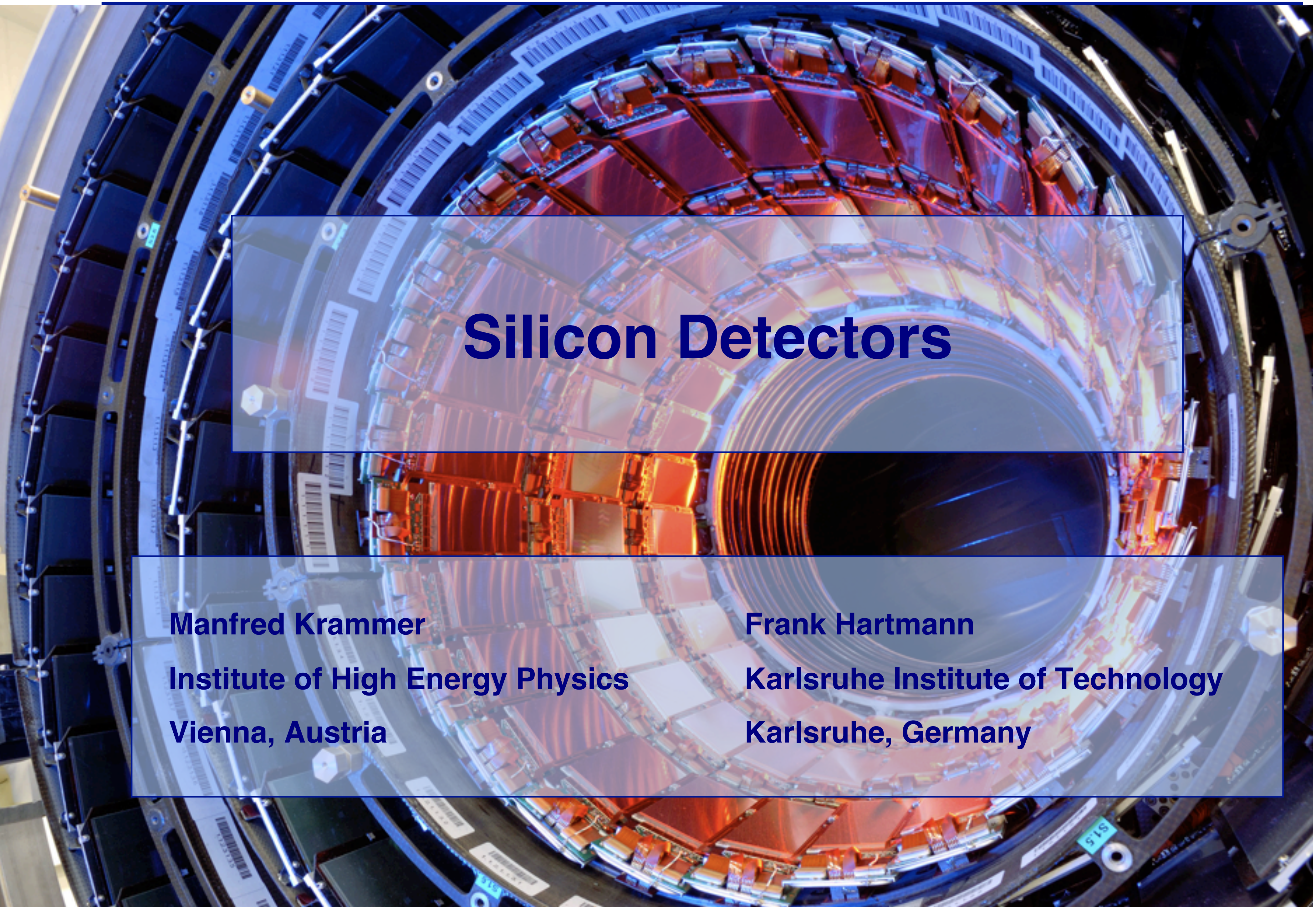

Silicon Detectors

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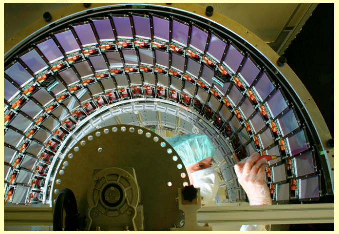
Content

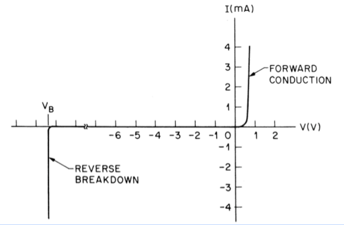


1 Material Properties

2 Detector Structures

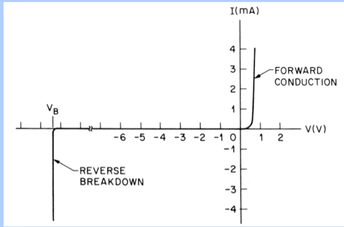
3 Performance

4 Detector Systems

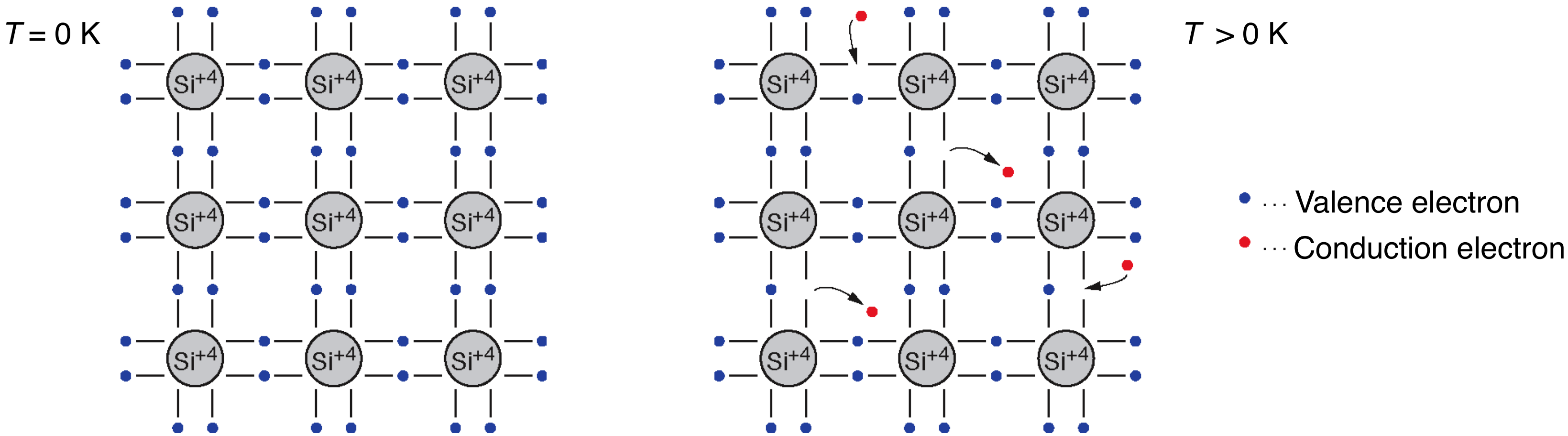


1 Material Properties

1.1 Material Properties
Bond model of semiconductors



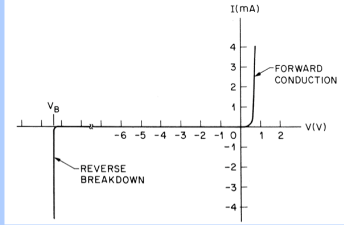
Example of column IV elemental semiconductor (2dim projection) :



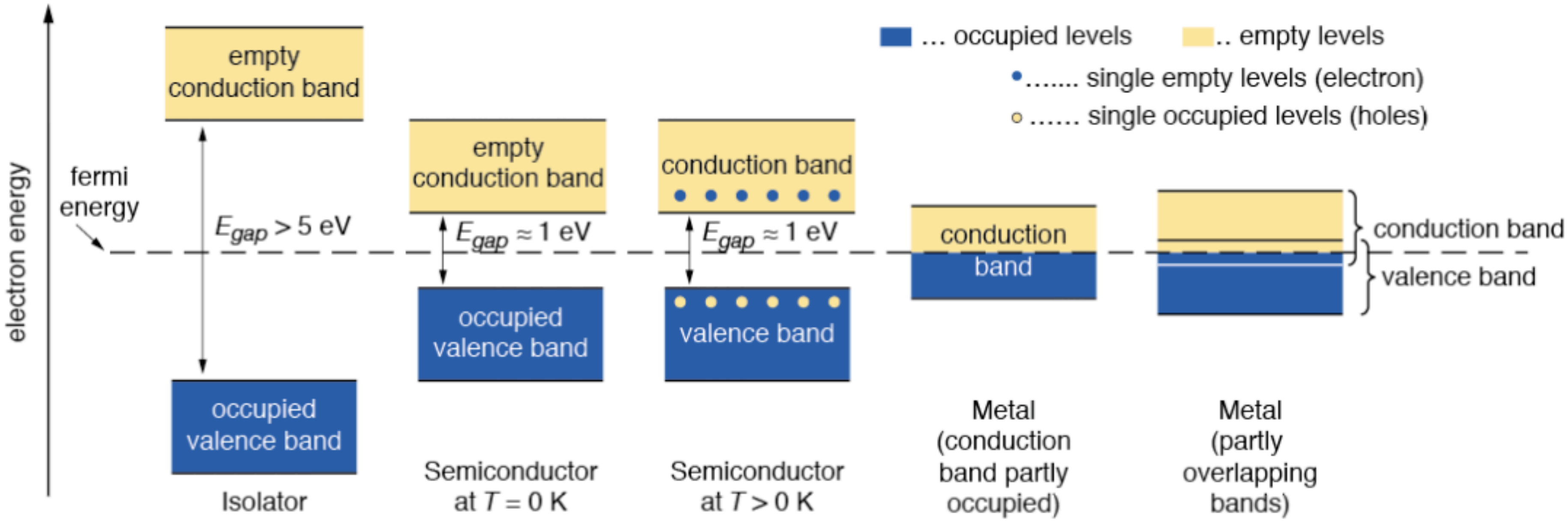
- ★ Each atom has 4 closest neighbors, the 4 electrons in the outer shell are shared and form covalent bonds.
- ★ At low temperature all electrons are bound
- ★ At higher temperature thermal vibrations break some of the bonds ➔ free e^- cause conductivity (electron conduction)
- ★ The remaining open bonds attract other e^- ➔ The “holes” change position (hole conduction)

1.1 Material Properties

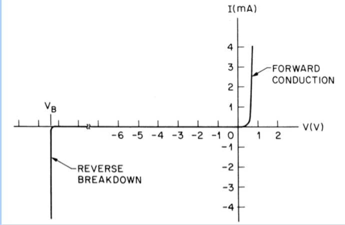
Energy bands: isolator–semiconductor–metal



In an isolated atom the electrons have only discrete energy levels. In solid state material the atomic levels merge to energy bands. In metals the conduction and the valence band overlap, whereas in isolators and semiconductors these levels are separated by an energy gap (band



1.1 Material Properties
Intrinsic carrier concentration



★ Due to the small band gap in semiconductors electrons already occupy the conduction band at room temperature. Silicon E_g=1.11 eV (T=300 K)

★ Electrons from the conduction band may recombine with holes.

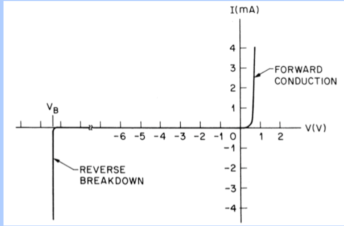
★ A thermal equilibrium is reached between excitation and recombination
Charged carrier concentartion $n_e = n_h = n_i$
This is called intrinsic carrier concentration:

$$n_i = \sqrt{N_C N_V} \cdot \exp\left(-\frac{E_g}{2kT}\right) \propto T^{\frac{3}{2}} \cdot \exp\left(-\frac{E_g}{2kT}\right)$$

In ultrapure silicon at room temperature the intrinsic carrier concentration is $1.45 \cdot 10^{10}$ cm^{-3}.

With approximately 10^{22} Atoms/cm^3 about 1 in 10^{12} silicon atoms is ionised.

1.1 Material Properties
Drift velocity and mobility



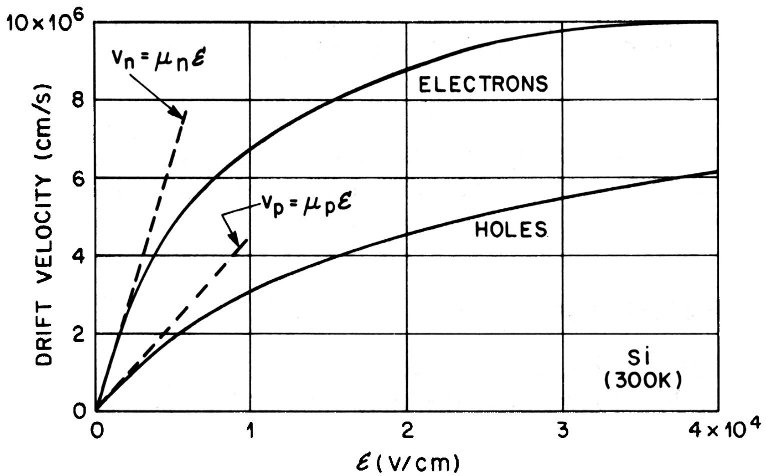
Drift velocity

For electrons: $\vec{v}_n = -\mu_n \cdot \vec{\mathrm{E}}$ and for holes: $\vec{v}_p = \mu_p \cdot \vec{\mathrm{E}}$

Mobility

For electrons: $\mu_n = \dfrac{e\,\tau_n}{m_n}$ and for holes: $\mu_p = \dfrac{e\,\tau_p}{m_p}$

μ_n(Si, 300 K) ≈ 1450 cm^2/Vs μ_p(Si, 300 K) ≈ 450 cm^2/Vs

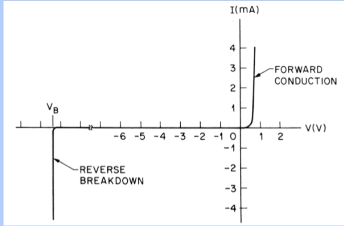


e	…	electron charge
E	…	external electric field
m_n, m_p	…	effective mass of e^- and holes
τ_n, τ_p	…	mean free time between collisions for e^- and holes

Source: S.M. Sze, *Semiconductor Devices* , J. Wiley & Sons, 1985

1.2 Constructing a Detector

The ideal semiconductor detector



★ Charged particles penetrating or traversing the detector create electron-hole pairs. The electron-hole pairs are separated by an electric field and drift to the electrodes. This is the signal we are looking for.

★ One of the most important parameter of a detector is the signal to noise ratio (SNR). A good detector should have a large SNR. However this leads to two contradictory requirements:

✘ Large signal

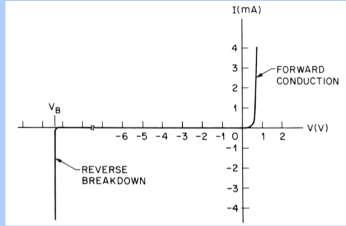
➔ particles should produce many electron-holes ➔ low ionization energy ➔ small band gap

✘ Low noise

➔ very few intrinsic charge carriers ➔ large band gap

1.2 Constructing a Detector

Estimate SNR in an intrinsic silicon detector



Let's make a simple calculation for silicon:

Mean ionization energy $\boldsymbol{I_0}$ **= 3.62 eV**, mean energy loss per flight path of a mip (minimum ionizing particle) ***dE/dx*** **= 3.87 MeV/cm**

Assuming a detector with a thickness of d = 300 μm and an area of A = 1 cm².

➔ Signal of a mip in such a detector:

$$\frac{dE/dx \cdot d}{I_0} = \frac{3.87 \cdot 10^6 \,\mathrm{eV/cm} \cdot 0.03\,\mathrm{cm}}{3.62\,\mathrm{eV}} \approx 3.2 \cdot 10^4 \; \mathrm{e^- h^+ - pairs}$$

➔ Intrinsic charge carrier in the same volume (T = 300 K):

$$n_i \, d \, A = 1.45 \cdot 10^{10}\,\mathrm{cm^{-3}} \cdot 0.03\,\mathrm{cm} \cdot 1\,\mathrm{cm^2} \approx 4.35 \cdot 10^8 \; \mathrm{e^- h^+ - pairs}$$

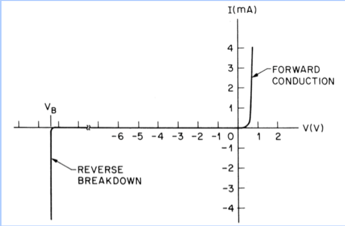
➔ Number of thermal created e^-h^+-pairs is four orders of magnitude larger than signal!!!

Charge carrier have to be removed!

➔ Depletion zone in reverse biased **pn junction**

1.2 Doping

pn junction needs doped materials



A pn junction consists of n and p doped substrates:

★ Doping is the replacement of a small number of atoms in the lattice by atoms of neighboring columns from the atomic table (with one valence electron more or less compared to the basic material). Typical doping concentrations for Si detectors are $\approx 10^{12}$ atoms/cm^3 (10^{14} und 10^{18} atoms/cm^3 for CMOS elements).

★ These doping atoms create energy levels within the band gap and therefore alter the conductivity.

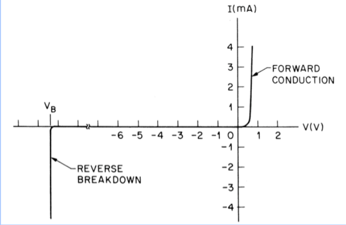
★ An undoped semiconductor is called an intrinsic semiconductor

★ A doped semiconductor is called an extrinsic semiconductor.

★ In an intrinsic semiconductor for each conduction electron there exists the corresponding hole. In extrinsic semiconductors there is a surplus of electrons or holes.

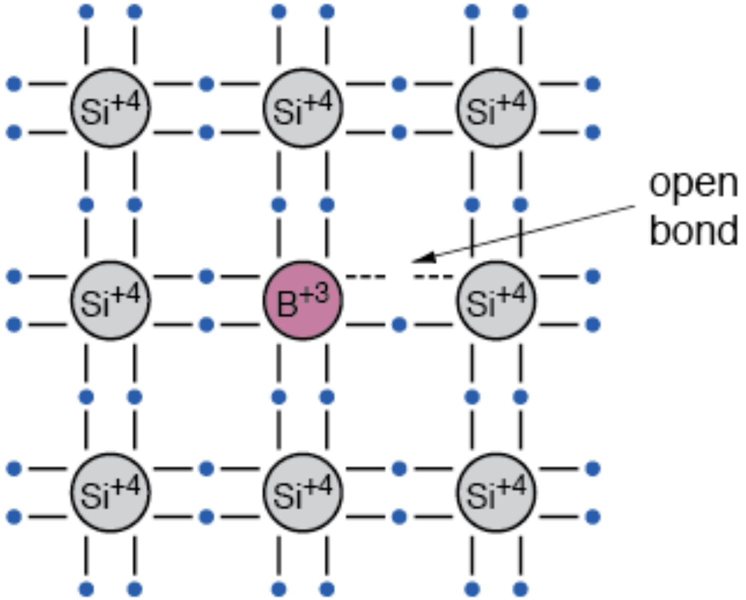
1.2 Doping

Bond model: p-doping in Si

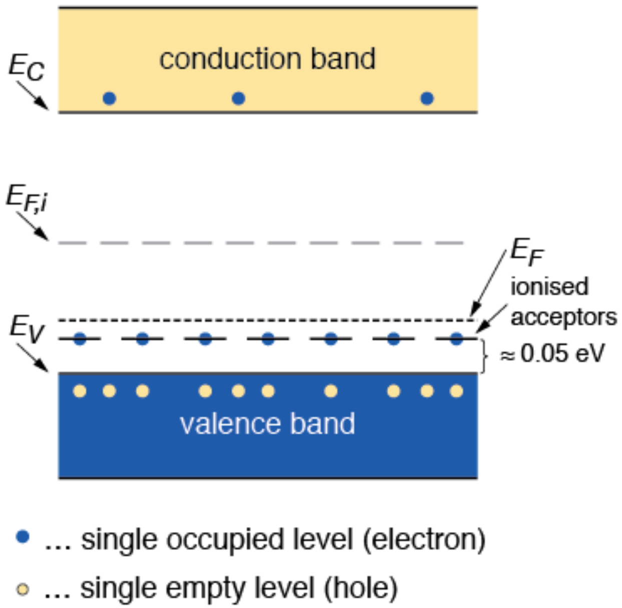


Doping with an element 3 atom (e.g. B, Al, Ga, In). One valence bond remains open. This open bond attracts electrons from the neighbor atoms.

The doping atom is called acceptor.

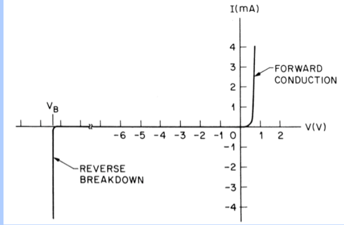


- The energy level of the acceptor is just above the edge of the valence band.
- At room temperature most levels are occupied by electrons leaving holes in the valence band.
- The fermi level E_F moves down.



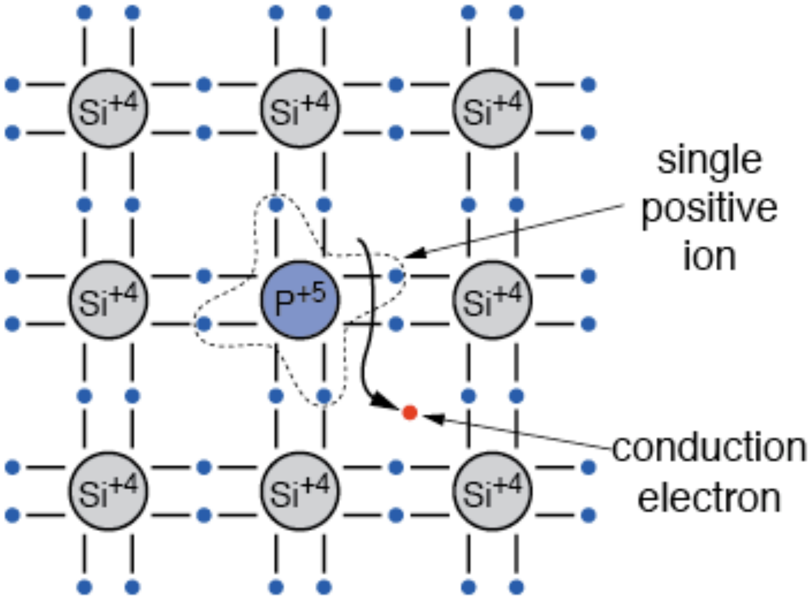
1.2 Doping

Bond model: n-doping in Si

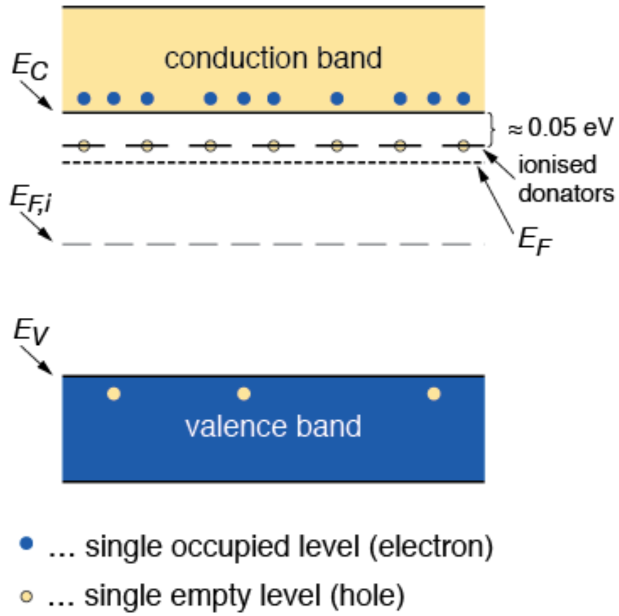


Doping with an element 5 atom (e.g. P, As, Sb). The 5th valence electrons is weakly bound.

The doping atom is called donor

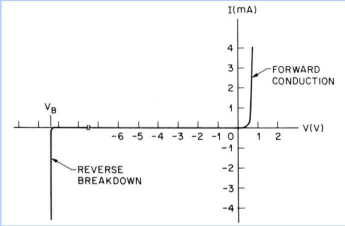


- The energy level of the donor is just below the edge of the conduction band.
- At room temperature most electrons are raised to the conduction band.
- The fermi level E_F moves up.



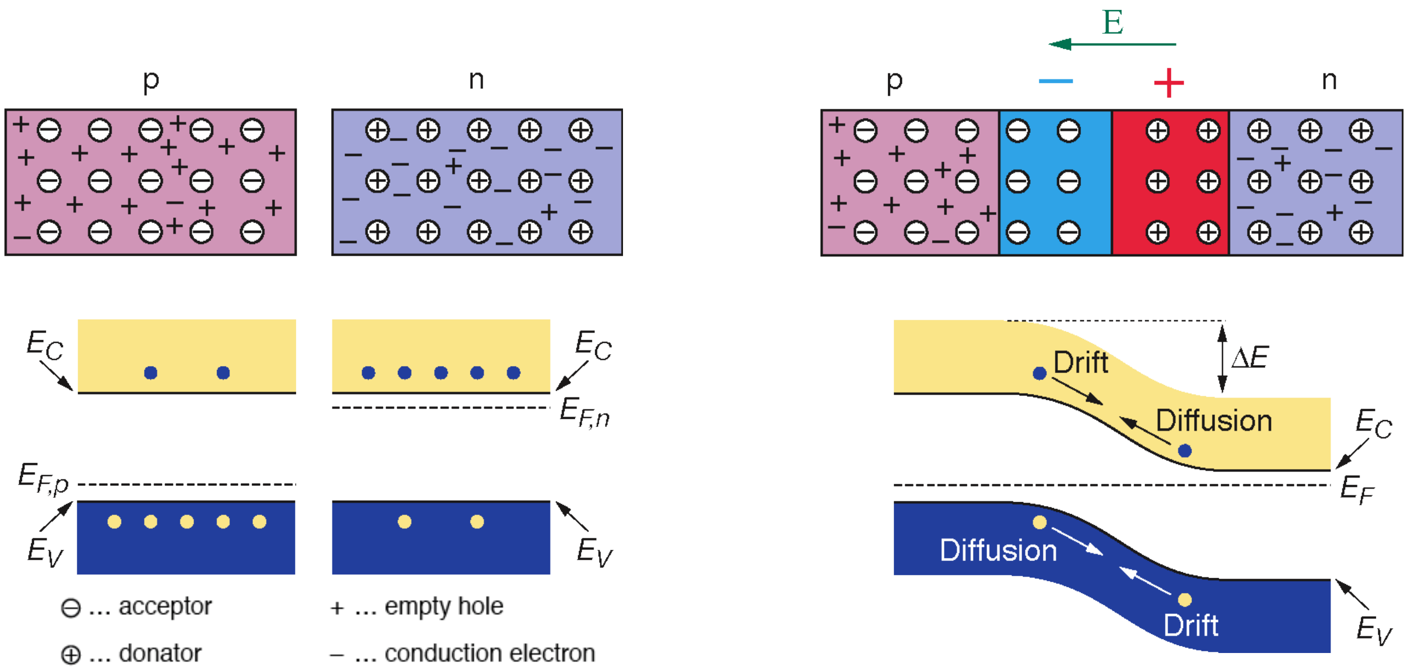
1.3 The p-n Junction

Creating a p-n junction

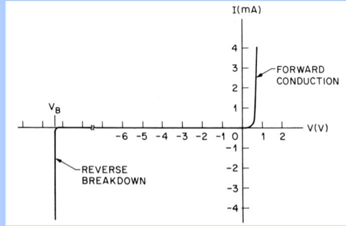


At the interface of an n-type and p-type semiconductor the difference in the fermi levels cause diffusion of surplus carries to the other material until thermal equilibrium is reached. At this point the fermi level is equal. The remaining ions create a space charge and an electric field stopping further diffusion.

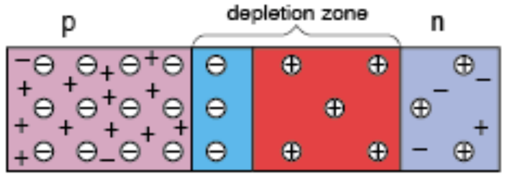
The stable space charge region is free of charge carries and is called the depletion zone.



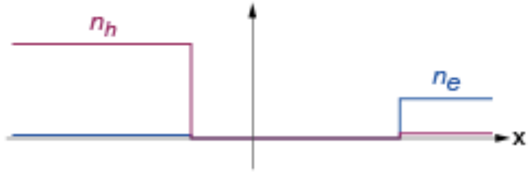
1.3 The p-n Junction
Electrical characteristics



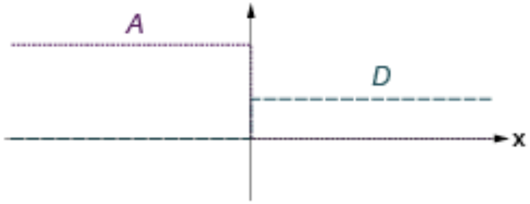
pn junction scheme



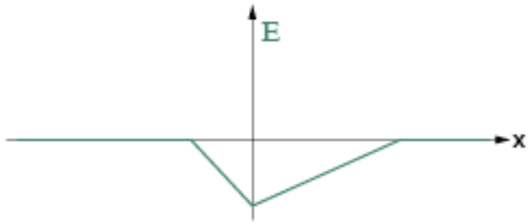
concentration of free charge carriers



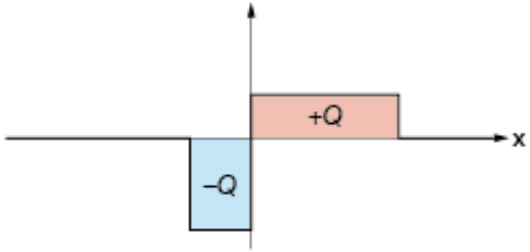
acceptor and donator concentration



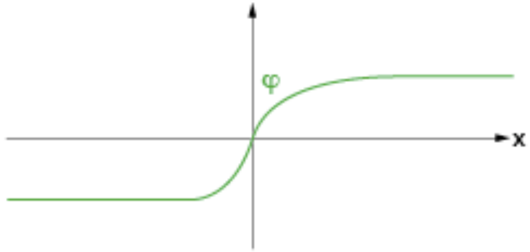
electric field



space charge density



electric potential

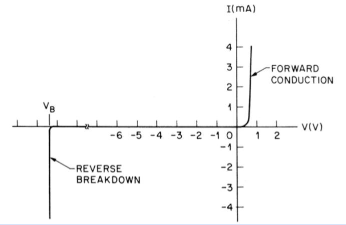


⊖ … acceptor + … empty hole

⊕ … donator − … conduction electron

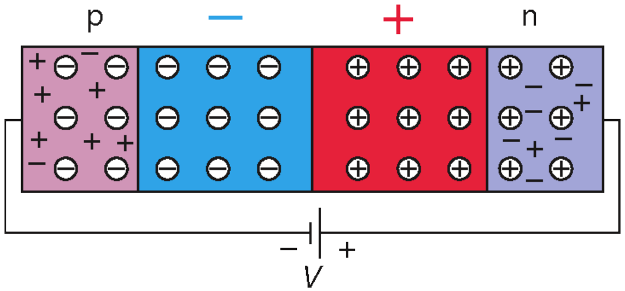
1.3 The p-n Junction

Operation with reverse bias

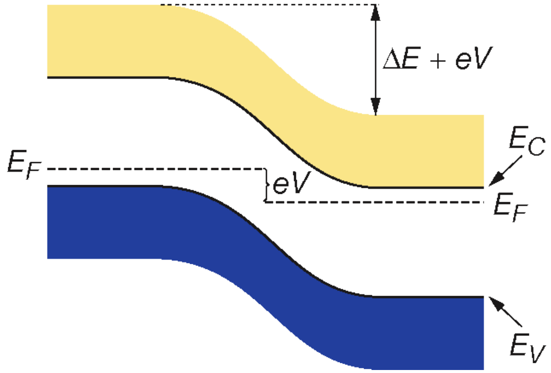


Applying an external voltage V with the cathode to p and the anode to n e- and holes are pulled out of the depletion zone. The depletion zone becomes larger.

p-n junction with reverse bias



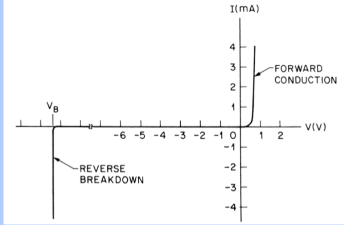
The potential barrier becomes higher by eV and diffusion across the junction is suppressed. The current across the junction is very small "leakage current".



➔ That's the way we operate our semiconductor detector!

1.3 The p-n Junction

Width of the depletion zone



Example of a typical p^+-n junction in a silicon detector:

Effective doping concentration $N_a = 10^{15}\ \mathrm{cm}^{-3}$ in p+ region and $N_d = 10^{12}\ \mathrm{cm}^{-3}$ in n bulk.

Without external voltage:

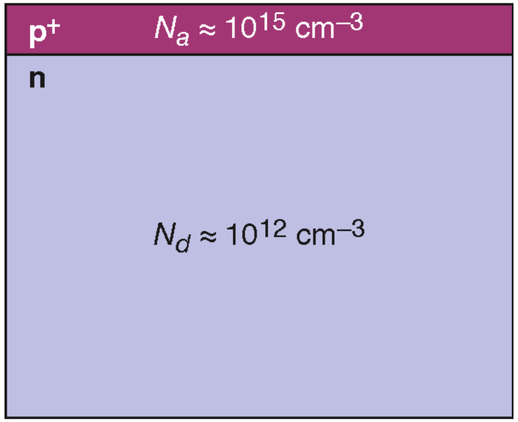
$$W_p = 0.02\ \mu\mathrm{m}$$

$$W_n = 23\ \mu\mathrm{m}$$

Applying a reverse bias voltage of 100 V:

$$W_p = 0.4\ \mu\mathrm{m}$$

$$W_n = 363\ \mu\mathrm{m}$$



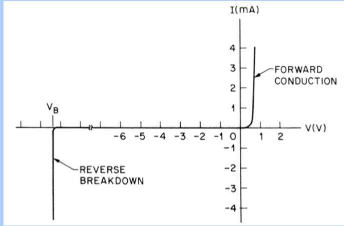
p^+n junction

Width of depletion zone in n bulk:

$$W \approx \sqrt{2\varepsilon_0 \varepsilon_r \mu \rho |V|} \quad \text{with} \quad \rho = \frac{1}{e \mu N_{eff}}$$

- V … External voltage
- ρ … specific resistivity
- μ … mobility of majority charge carriers
- N_{eff} … effective doping concentration

1.3 n-type and p-type Detectors



Note:

The previous slide explains an n-type detector (detector bulk is n-type silicon)

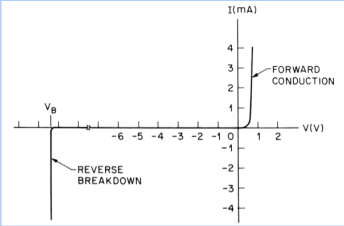
Using p-type silicon and exchanging p^+ and n^+ would give a perfectly working p-type detector.

For tradition and production reasons most detectors used are n-type detectors. p-type detectors have some advantages in high radiation environment (see later).

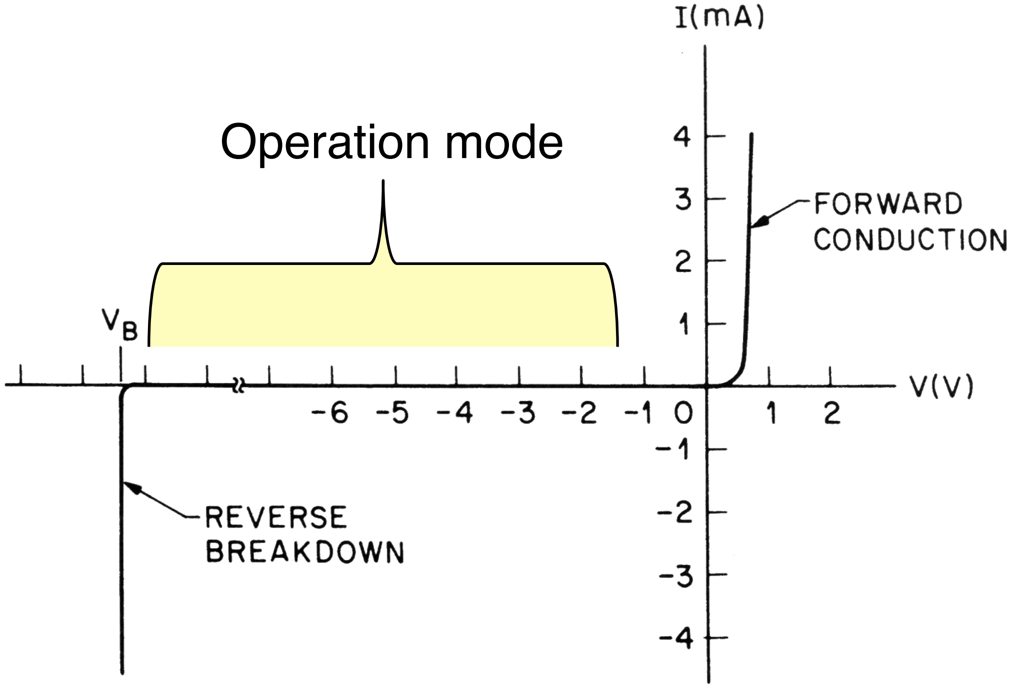
For simplicity I will continue discussing n-type detectors only...

1.3 The p-n Junction

Current-voltage characteristics

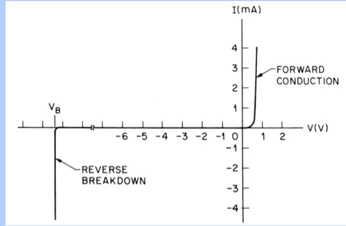


Typical current-voltage of a p-n junction (diode): exponential current increase in forward bias, small saturation in reverse bias.

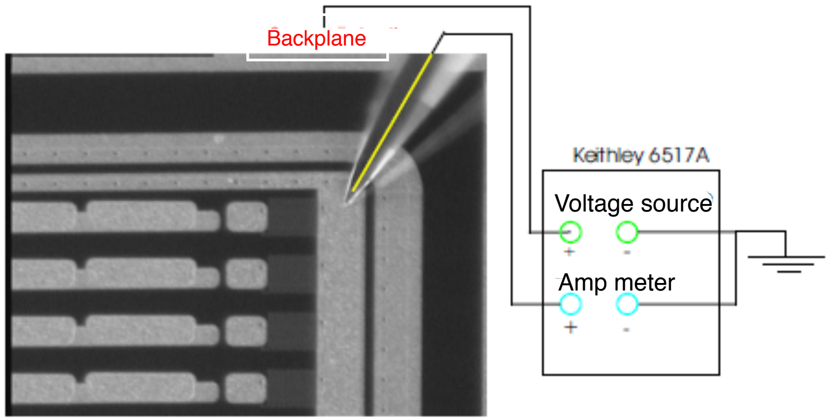


S.M. Sze, *Semiconductor Devices* , J. Wiley & Sons, 1985

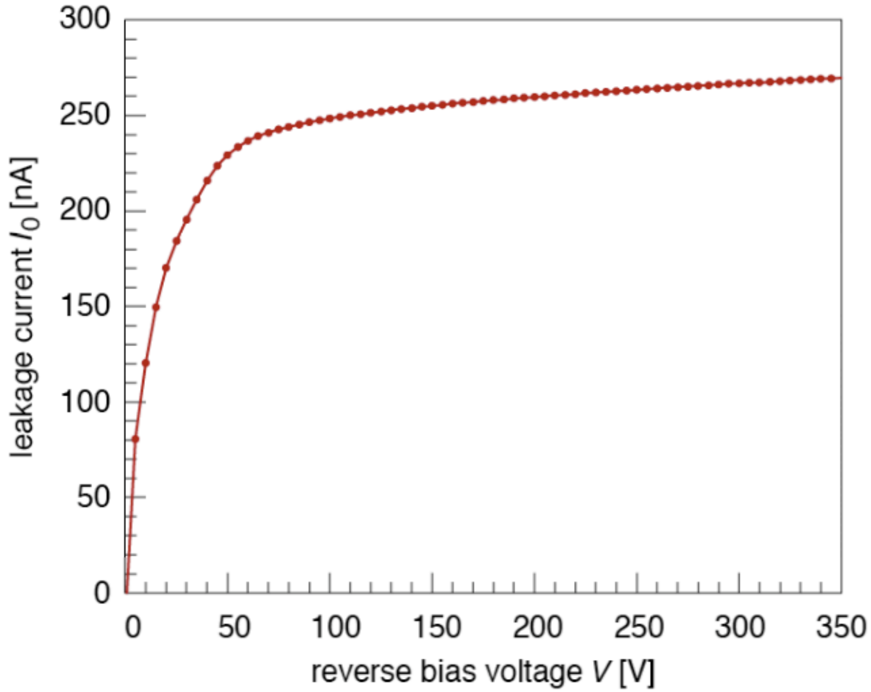
1.4 Detector Characteristics
Leakage Current



A silicon detector is operated with reverse bias, hence reverse saturation current is relevant (leakage current). This current is dominated by thermally generated e^-h^+ pair. Due to the applied electric field they cannot recombine and are separated. The drift of the e^- and h^+ to the electrodes causes the leakage current.

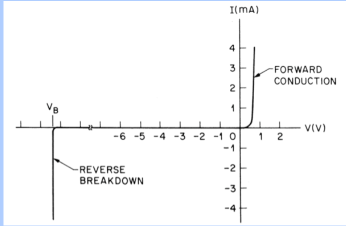


Measured detector leakage current, CMS strip detector (measurement at room temperature):



1.4 Detector Characteristics

Capacitance and Depletion Voltage of a detector



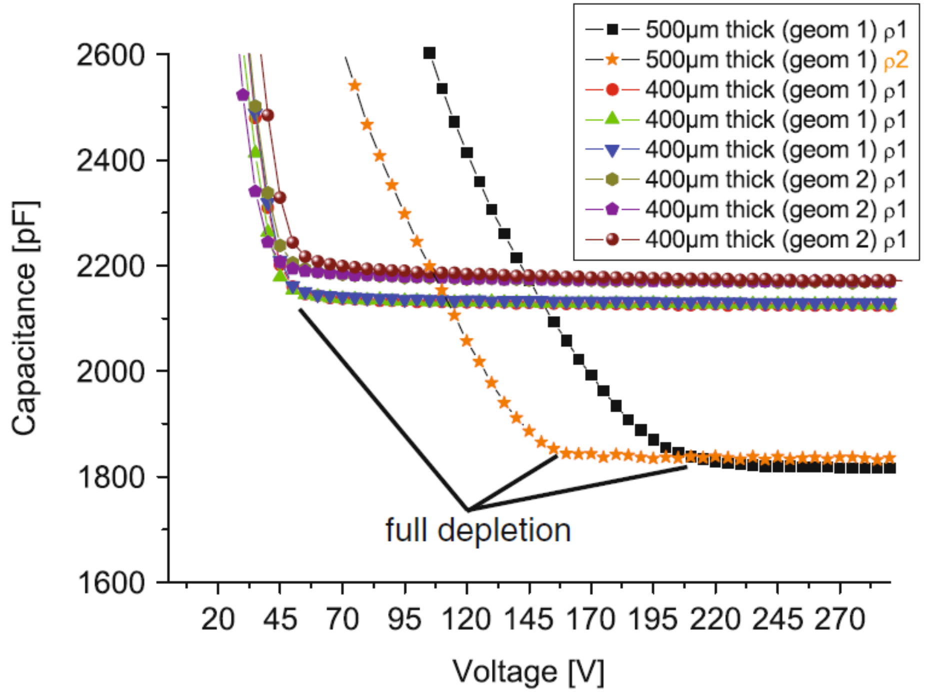
The depletion voltage is the minimum voltage at which the bulk of the sensor is fully depleted. The operating voltage is usually chosen to be slightly higher (overdepletion).

High resistivity material (i.e. low doping) requires low depletion voltage.

$$V_{FD} = \frac{D^2}{2\varepsilon\mu\rho}$$

For a typical Si p-n junction ($N_a >> N_d >> n_i$) the detector capacitance is given as:

$$C = \sqrt{\frac{\varepsilon_0\varepsilon_r}{2\mu\rho|V|}} \cdot A$$

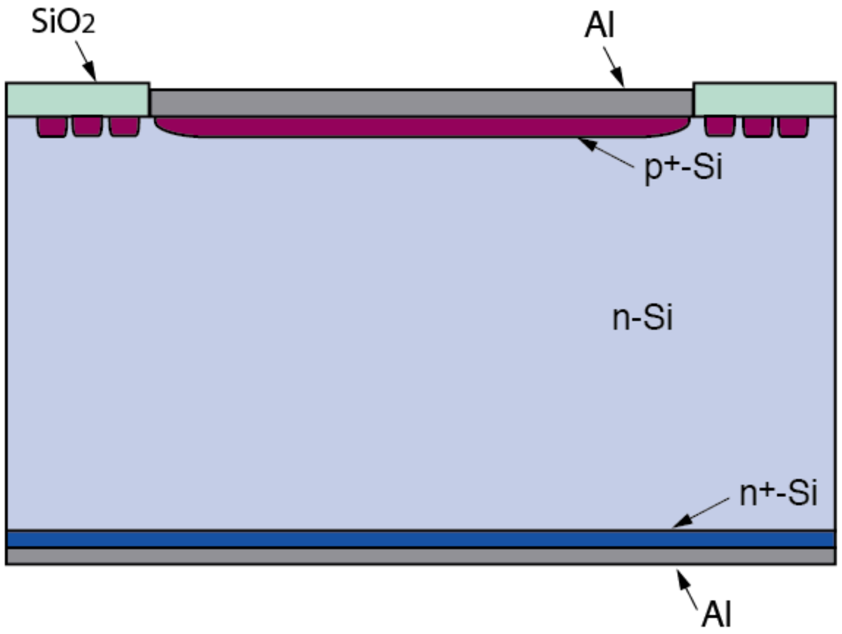


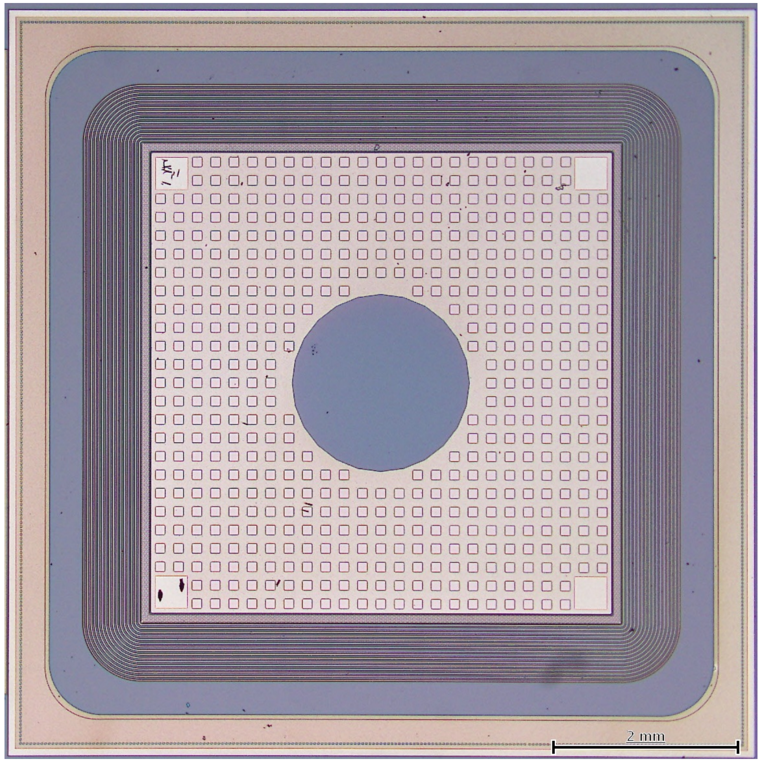
ρ … specific resistivity of the bulk
μ … mobility of majority charge carrier
V … bias voltage
A … detector surface
D … detector thickness

2 Detector Structures

2.1 Pad Detector

The most simple detector is a large surface diode with guard ring(s).
Such a device will be used during hands-on exercise.





2.2 Microstrip Detector
DC coupled strip detector

Traversing charged particles create e⁻h⁺ pairs in the depletion zone (about 30.000 pairs in standard detector thickness). These charges drift to the electrodes. The drift (current) creates the signal which is amplified by an amplifier connected to each strip. From the signals on the individual strips the position of the through going particle is deduced.

A typical n-type Si strip detector:

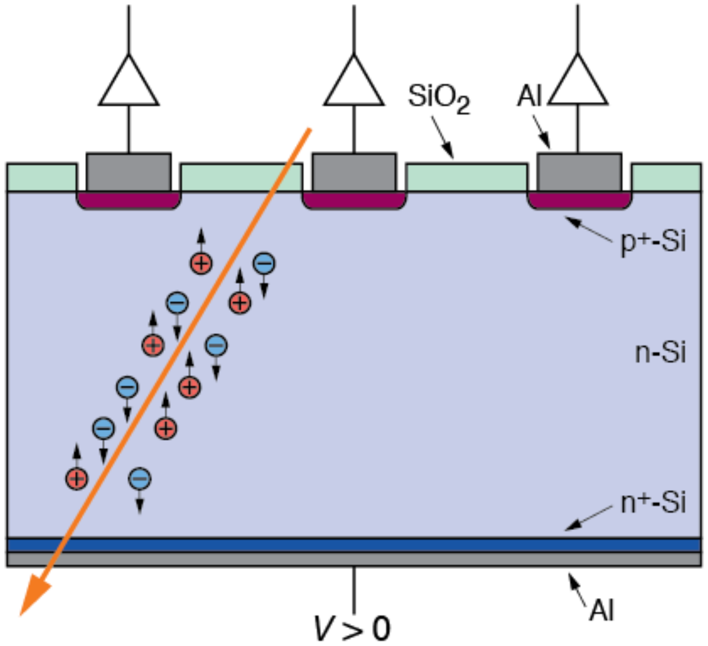
★ p^+n junction:
$N_a \approx 10^{15}$ cm^{-3}, $N_d \approx 1–5 \cdot 10^{12}$ cm^{-3}

★ n-type bulk: $\rho > 2$ kΩcm
➔ thickness 300 μm

★ Operating voltage < 200 V.

★ n^+ layer on backplane to improve ohmic contact

★ Aluminum metallization



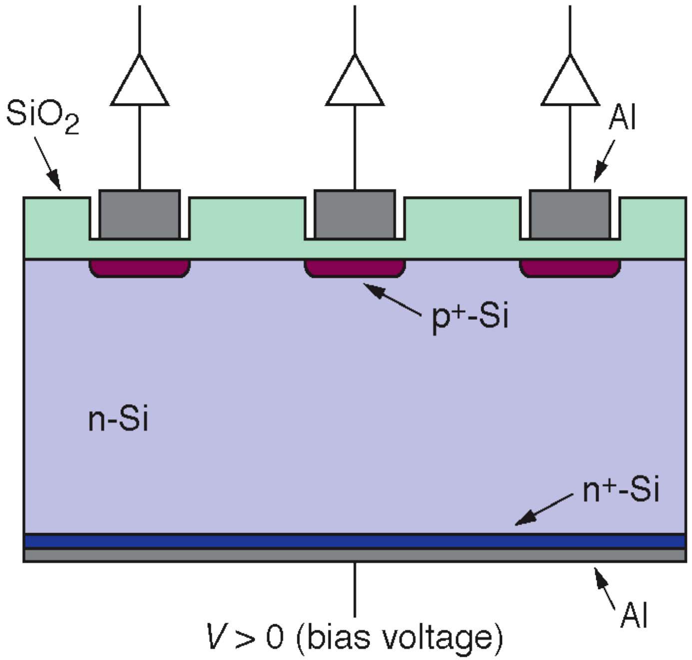
2.2 Microstrip Detector

AC coupled strip detector

AC coupling blocks leakage current from the amplifier.

- ★ Integration of coupling capacitances in standard planar process.
- ★ Deposition of SiO_2 with a thickness of 100 –200 nm between p+ and aluminum strip
- ★ Depending on oxide thickness and strip width the capacitances are in the range of 8–32 pF/cm.
- ★ Problems are shorts through the dielectric (pinholes). Usually avoided by a second layer of Si_3N_4.

AC coupled strip detector:

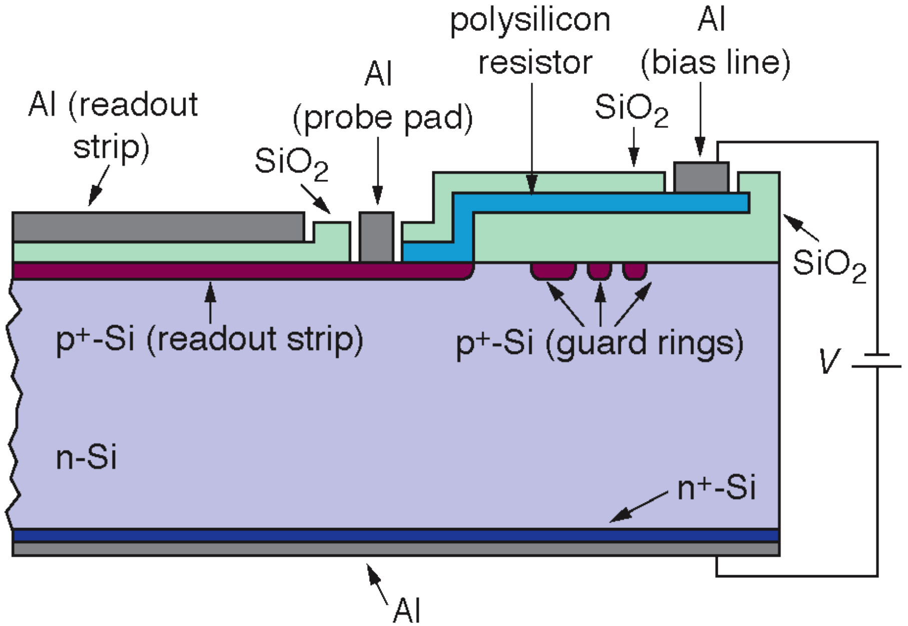


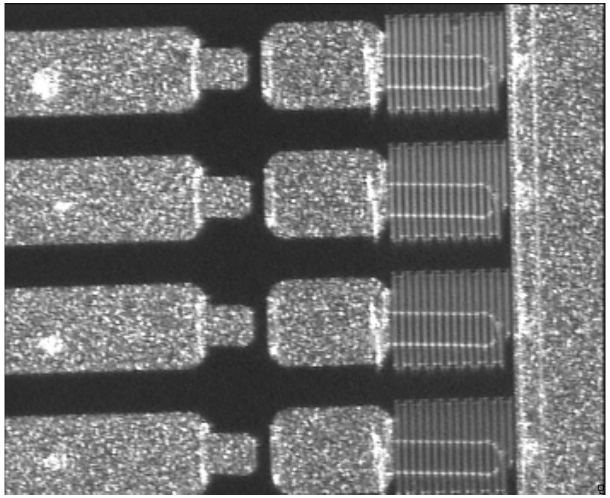
Several methods to connect the bias voltage: polysilicon resistor, punch through bias, FOXFET bias.

2.2 Microstrip Detector

Polysilicon bias resistor

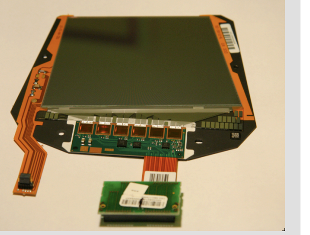
- ★ Deposition of polycristalline silicon between p^+ implants and a common bias line.
- ★ Sheet resistance of up to $R_s \approx 250\ k\Omega/\square$. Depending on width and length a resistor of up to $R \approx 20\ M\Omega$ is achieved ($R = R_s \cdot length/width$).
- ★ To achieve high resistor values winding poly structures are deposited.

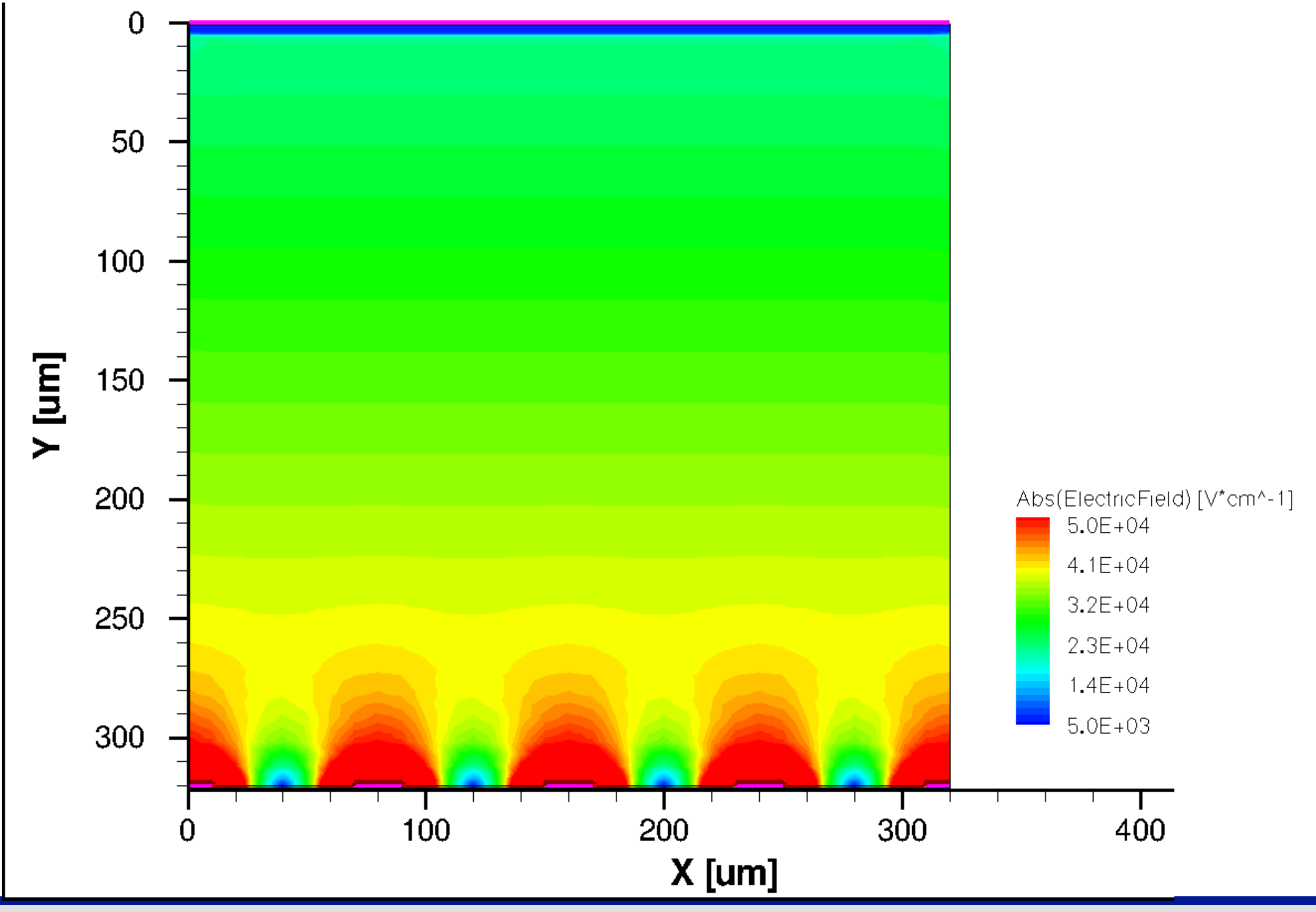




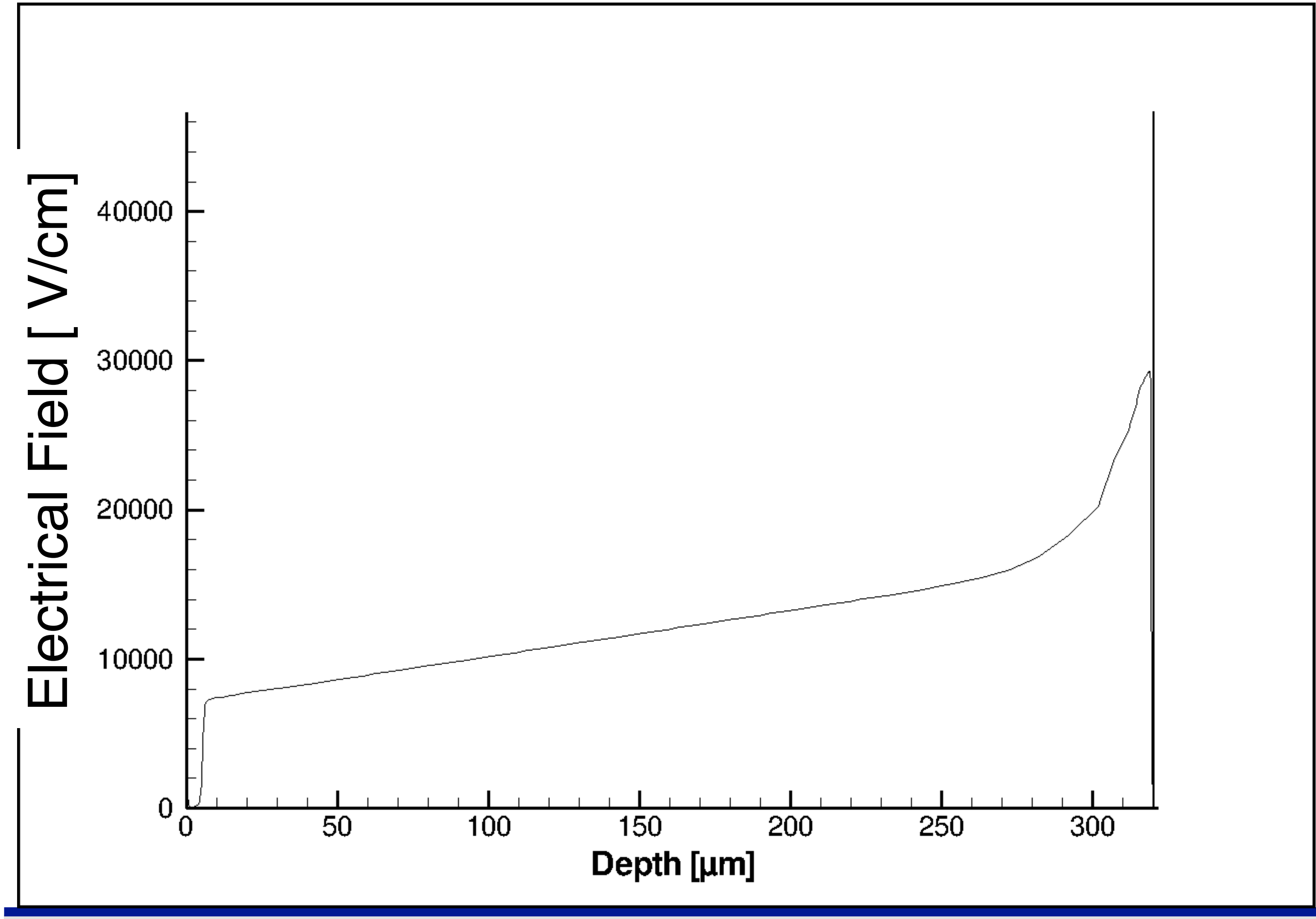
Cut through an AC coupled strip detector with integrated poly resistors:

2.2 Electrical Field Configuration of a Strip Sensor

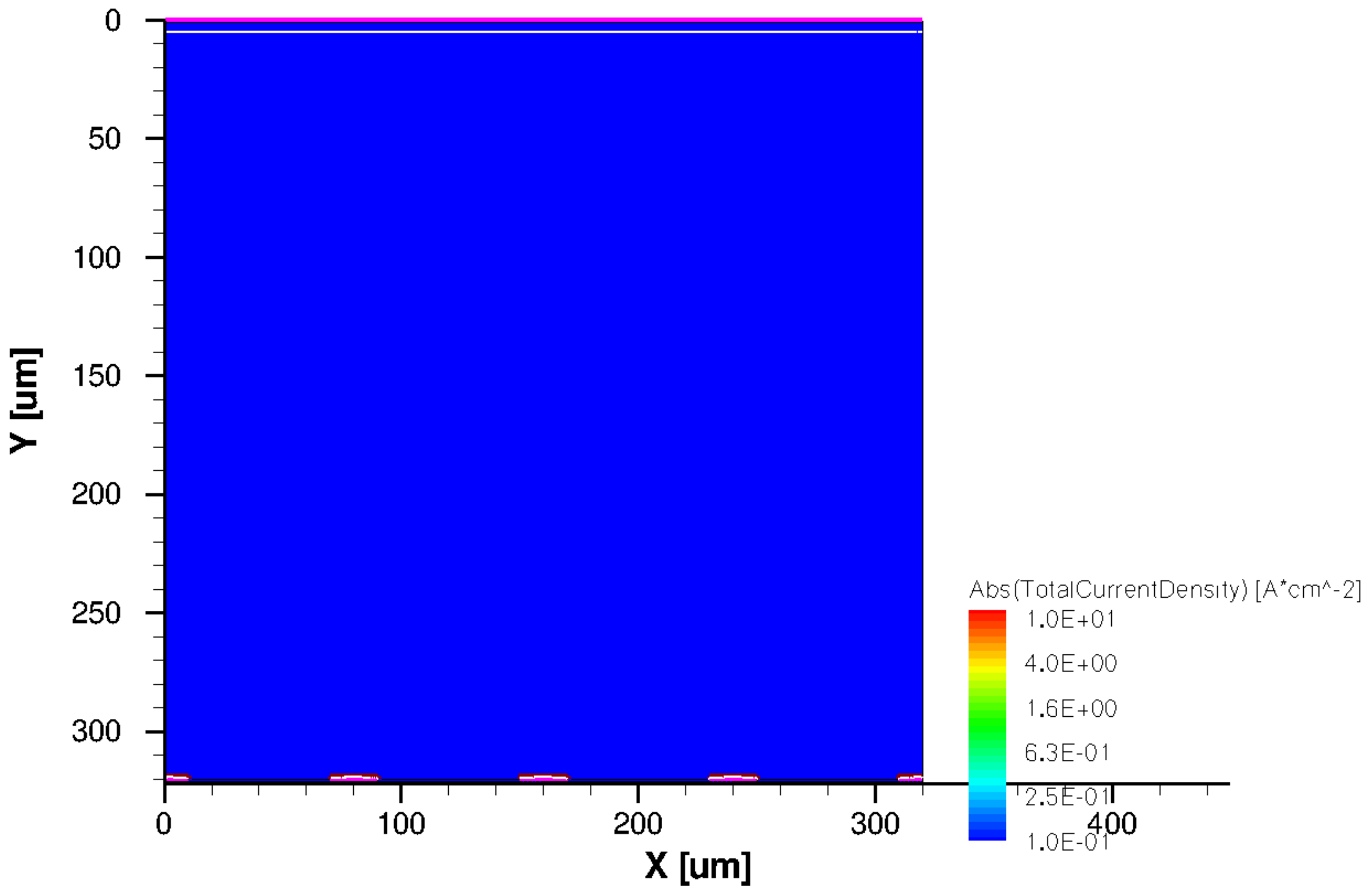




2.2. Electrical Field across a Strip

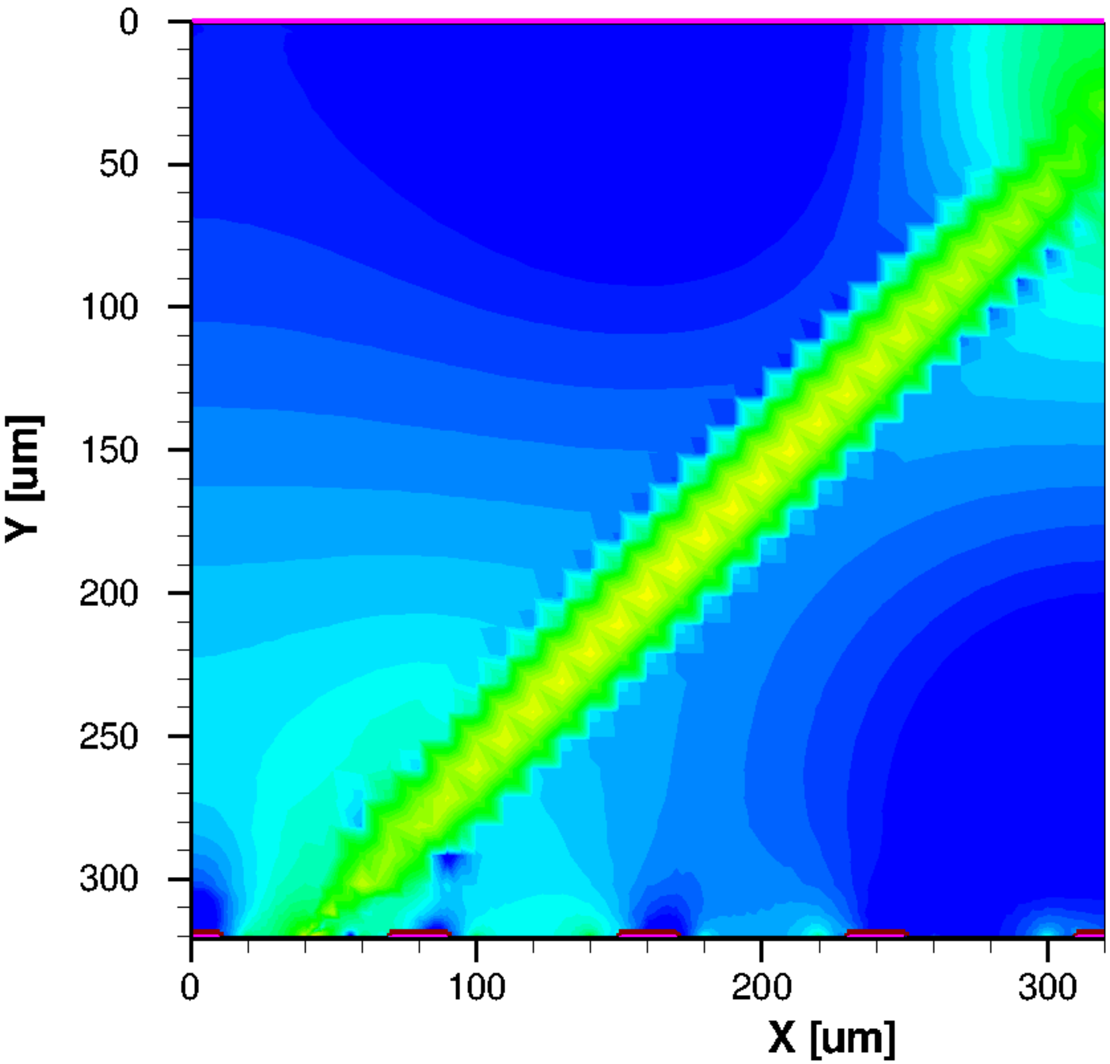


2.2. Simulated Current Density
Ionizing particle with 45° angle t=0 s



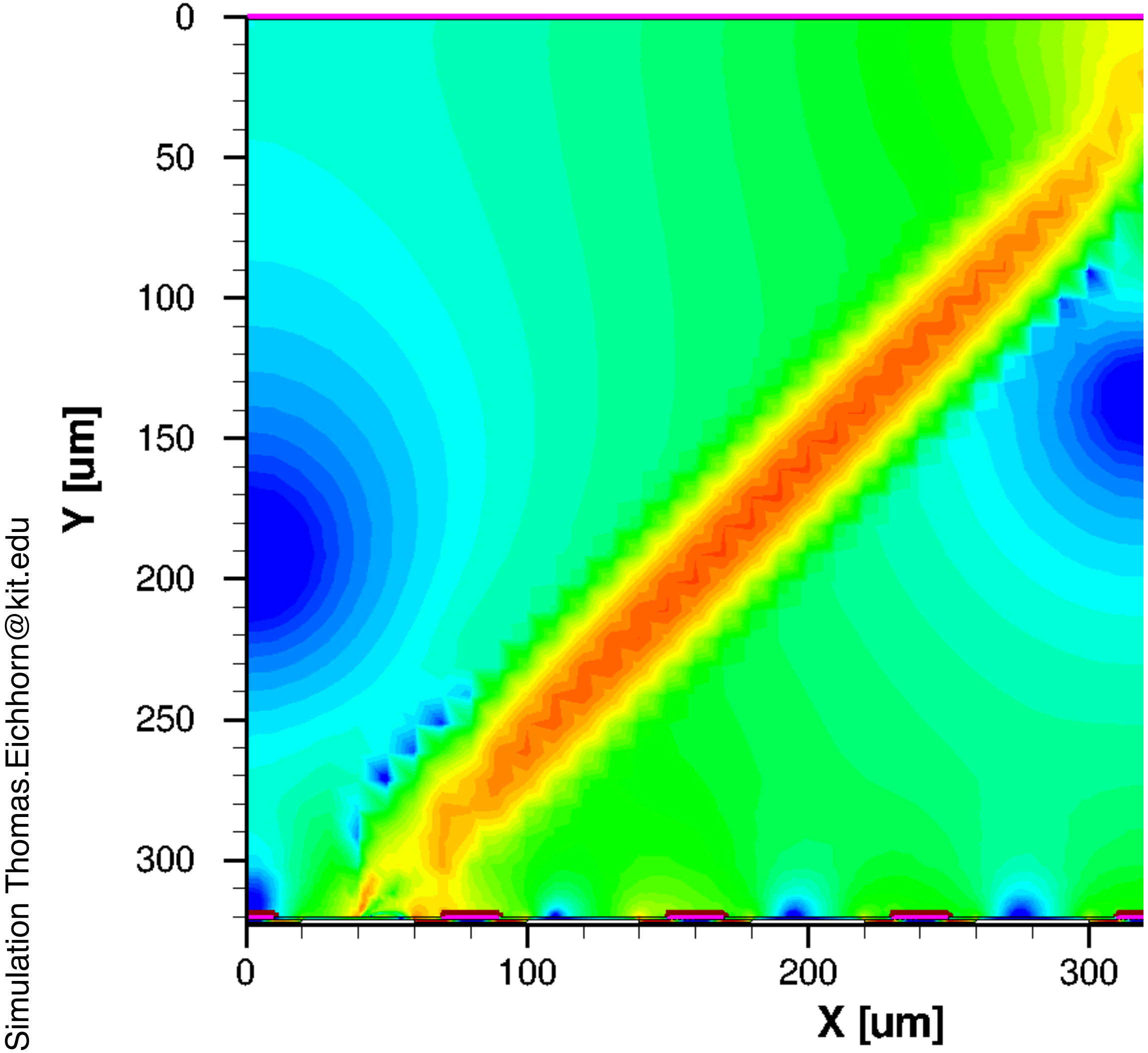
Simulation Thomas.Eichhorn@kit.edu

2.2. Simulated Current Density
Ionizing particle with 45° angle t=1 ns

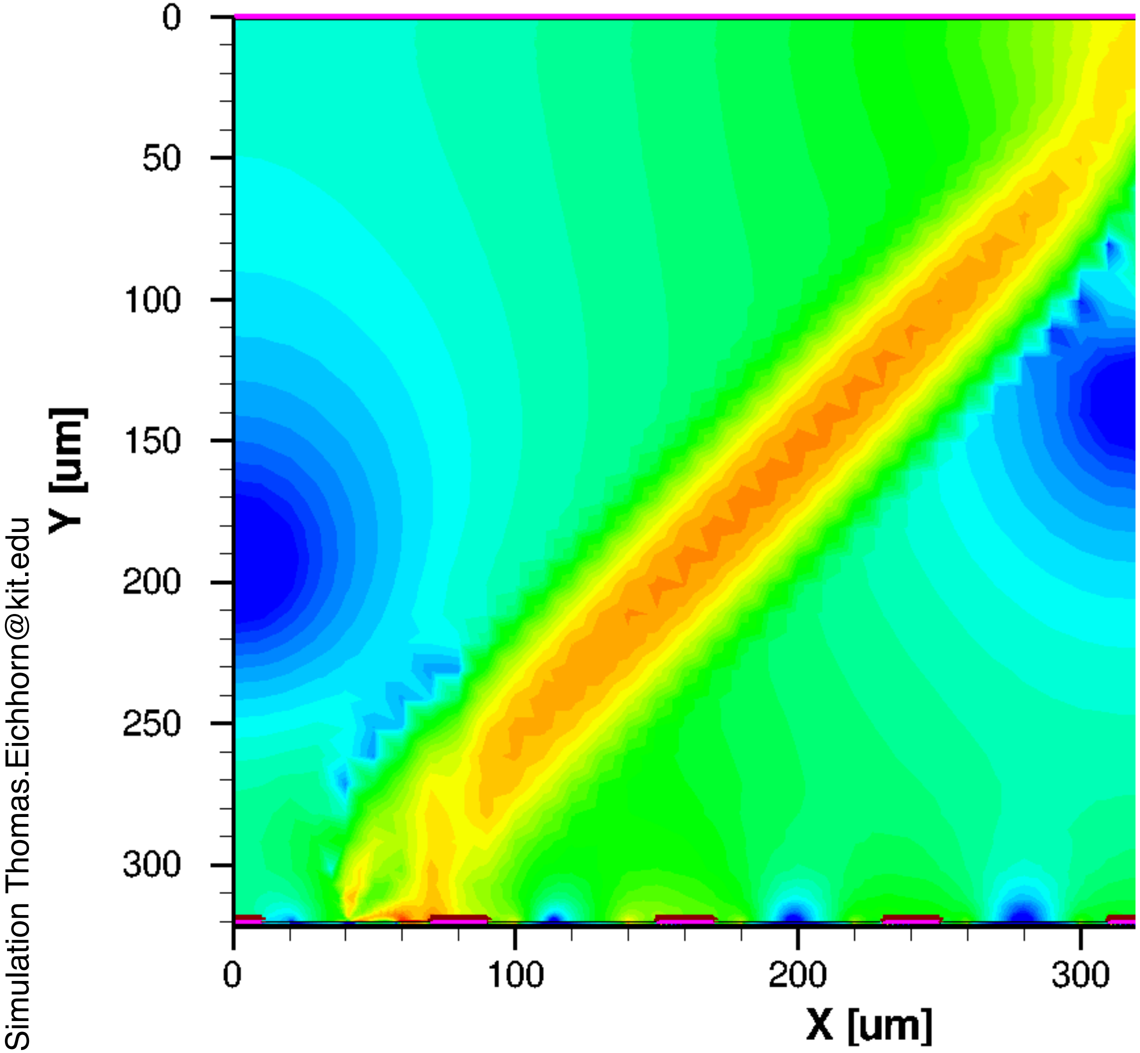


Simulation Thomas.Eichhorn@kit.edu

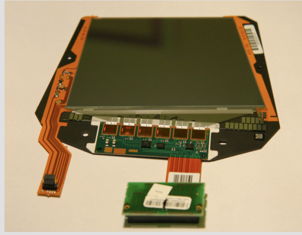
2.2. Simulated Current Density
Ionizing particle with 45° angle t=1,1 ns

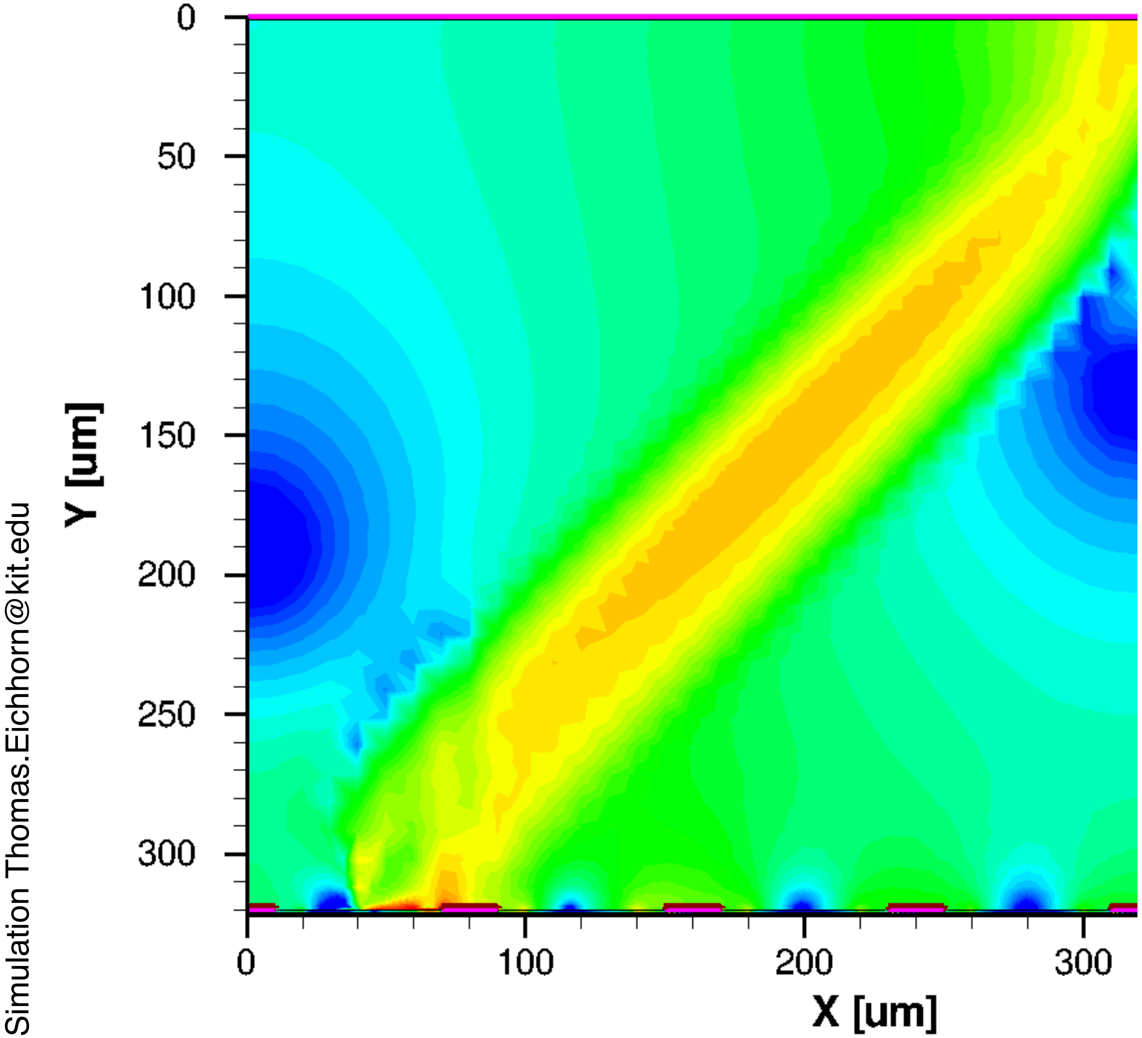


2.2. Simulated Current Density
Ionizing particle with 45° angle t=1,2 ns

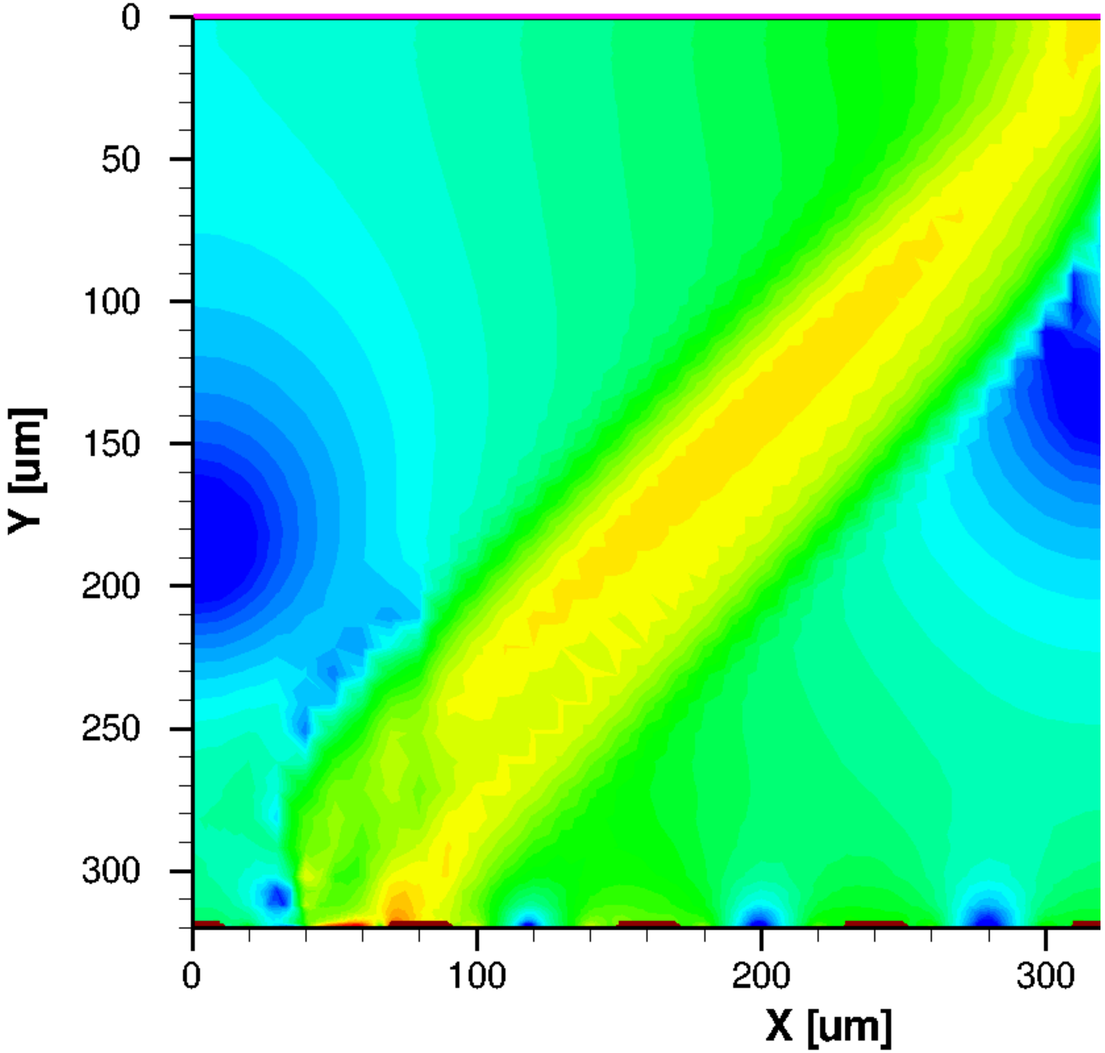


2.2. Simulated Current Density
Ionizing particle with 45° angle t=1,3 ns





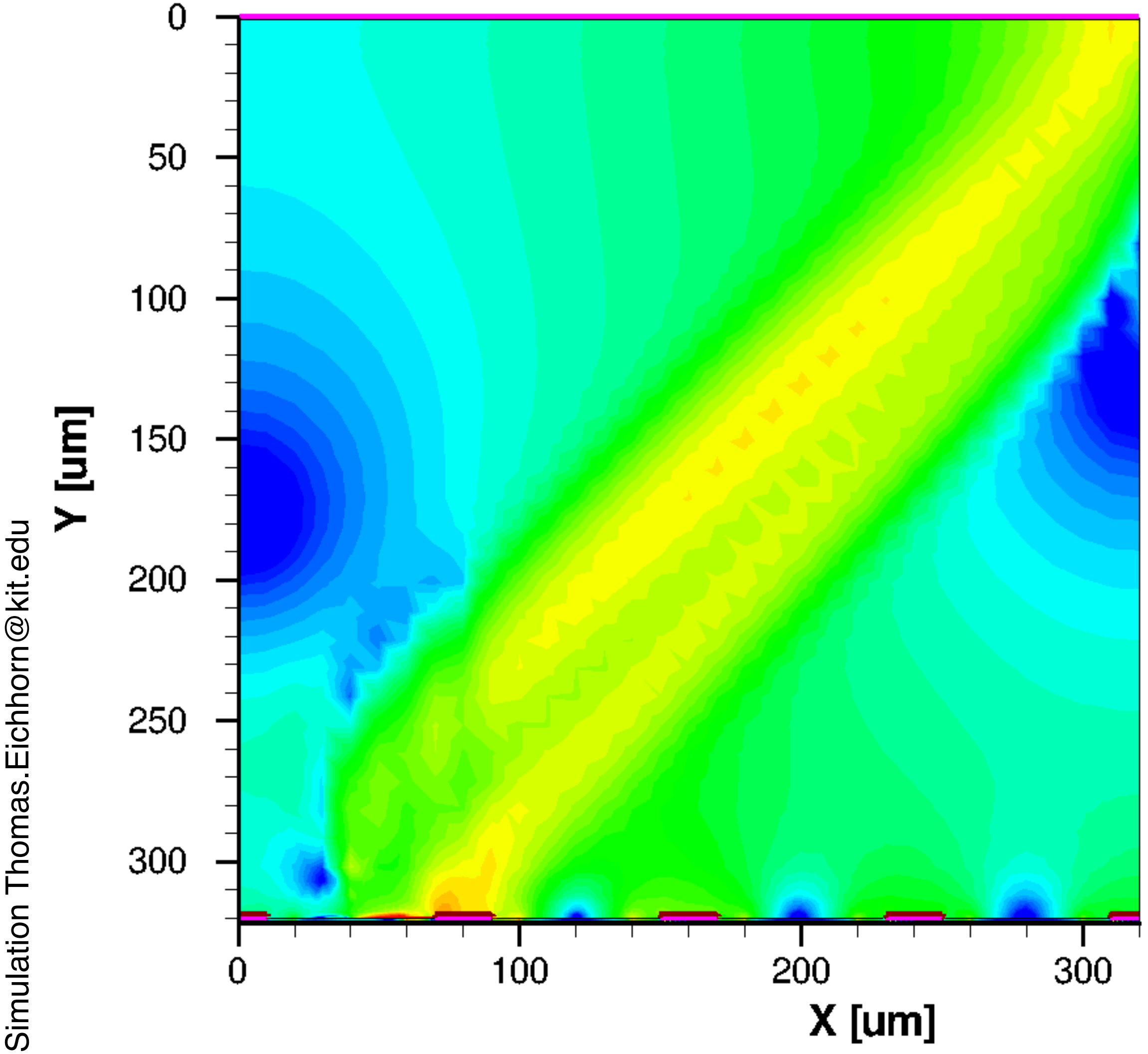
2.2. Simulated Current Density
Ionizing particle with 45° angle t=1,4 ns



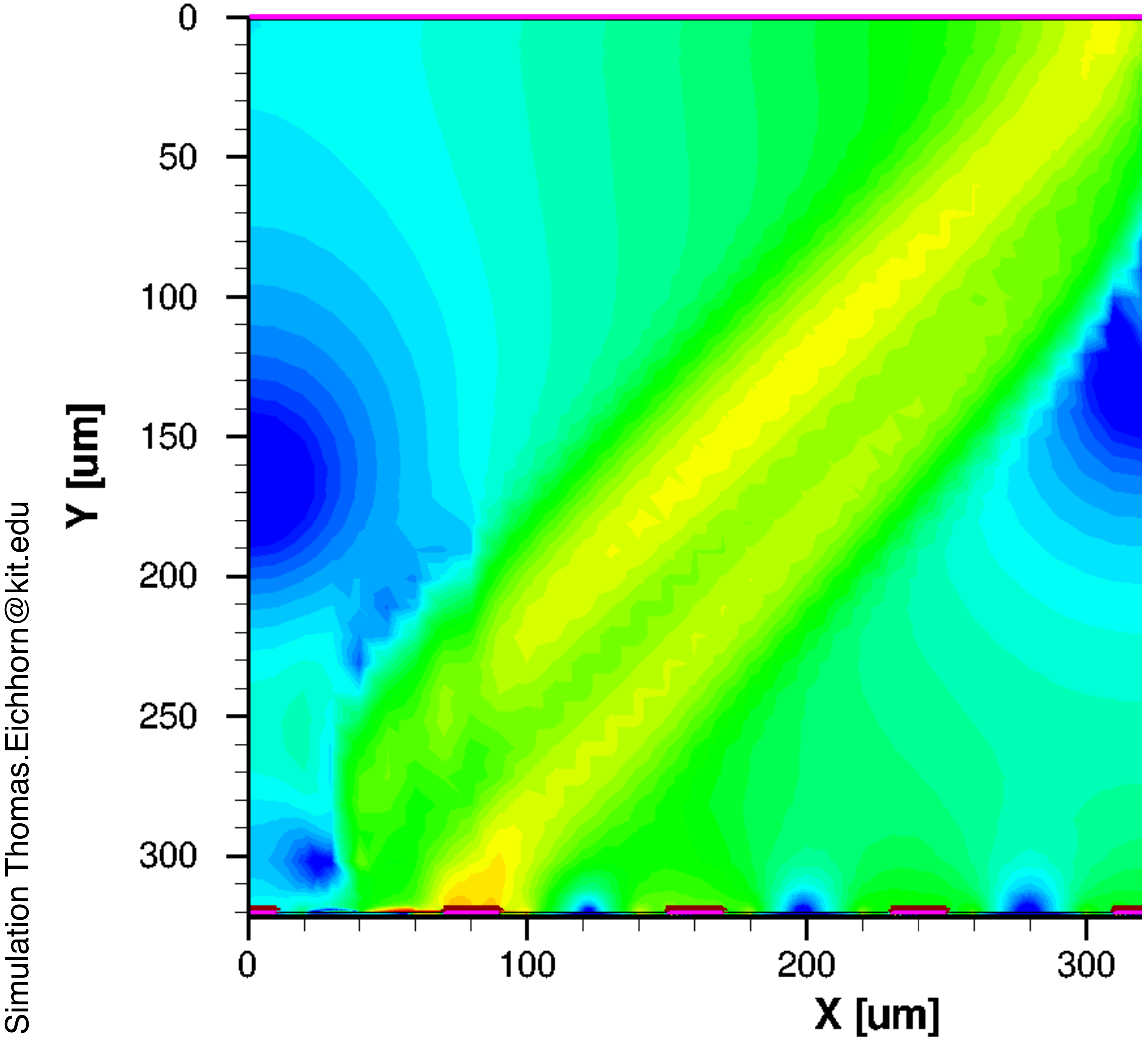
Simulation Thomas.Eichhorn@kit.edu

2.2. Simulated Current Density

Ionizing particle with 45° angle t=1,5 ns

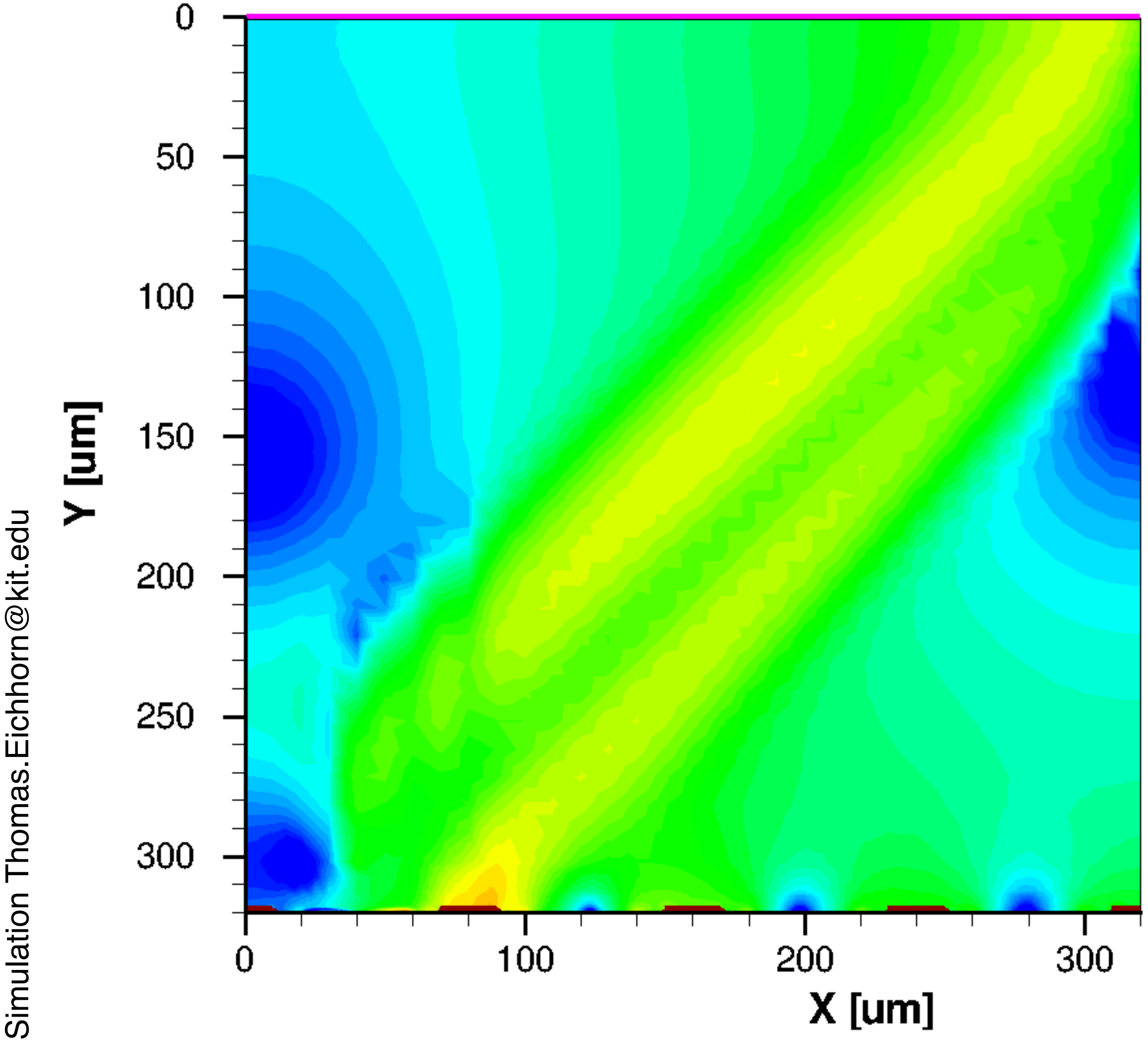


2.2. Simulated Current Density
Ionizing particle with 45° angle t=1,6 ns



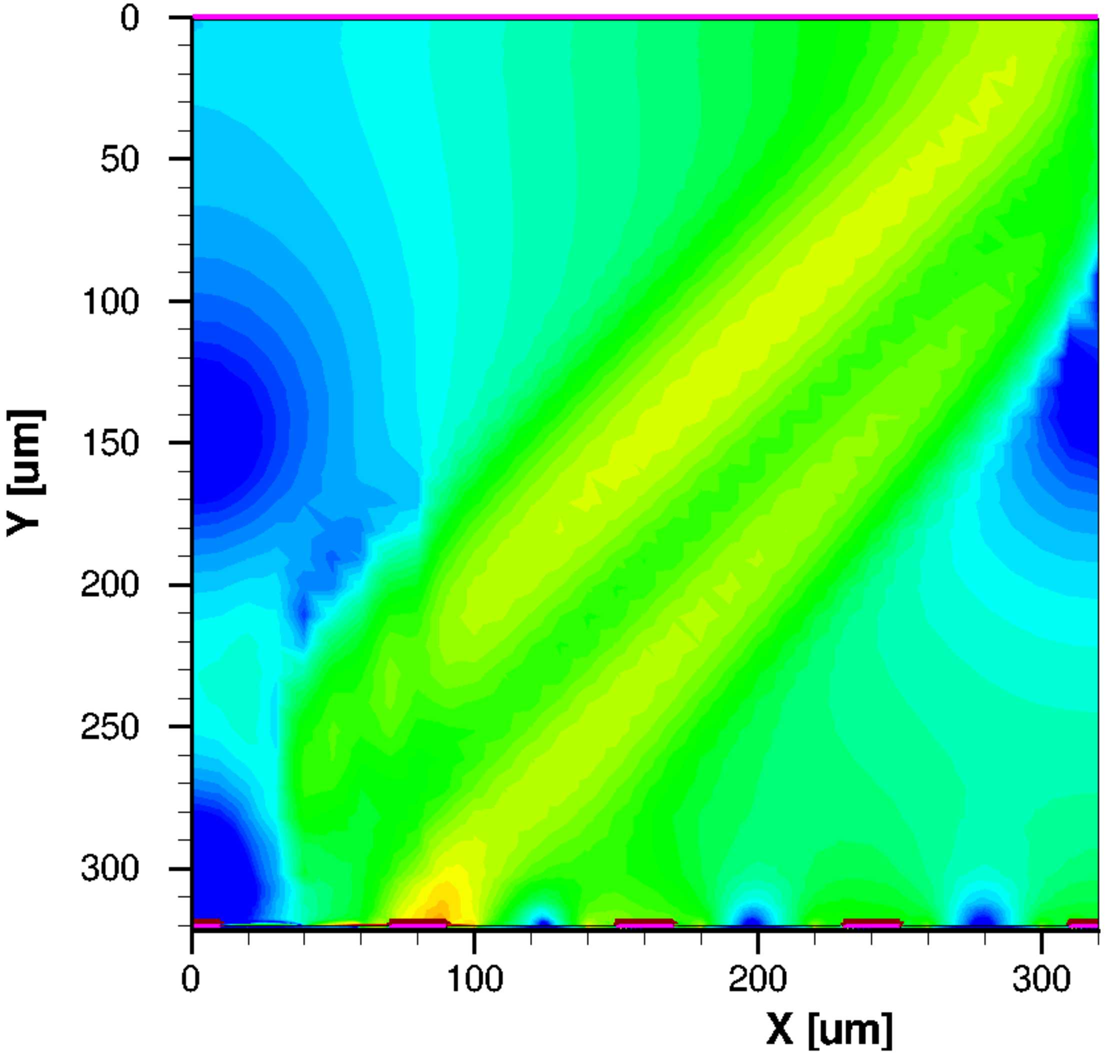
2.2. Simulated Current Density

Ionizing particle with 45° angle t=1,7 ns



2.2. Simulated Current Density

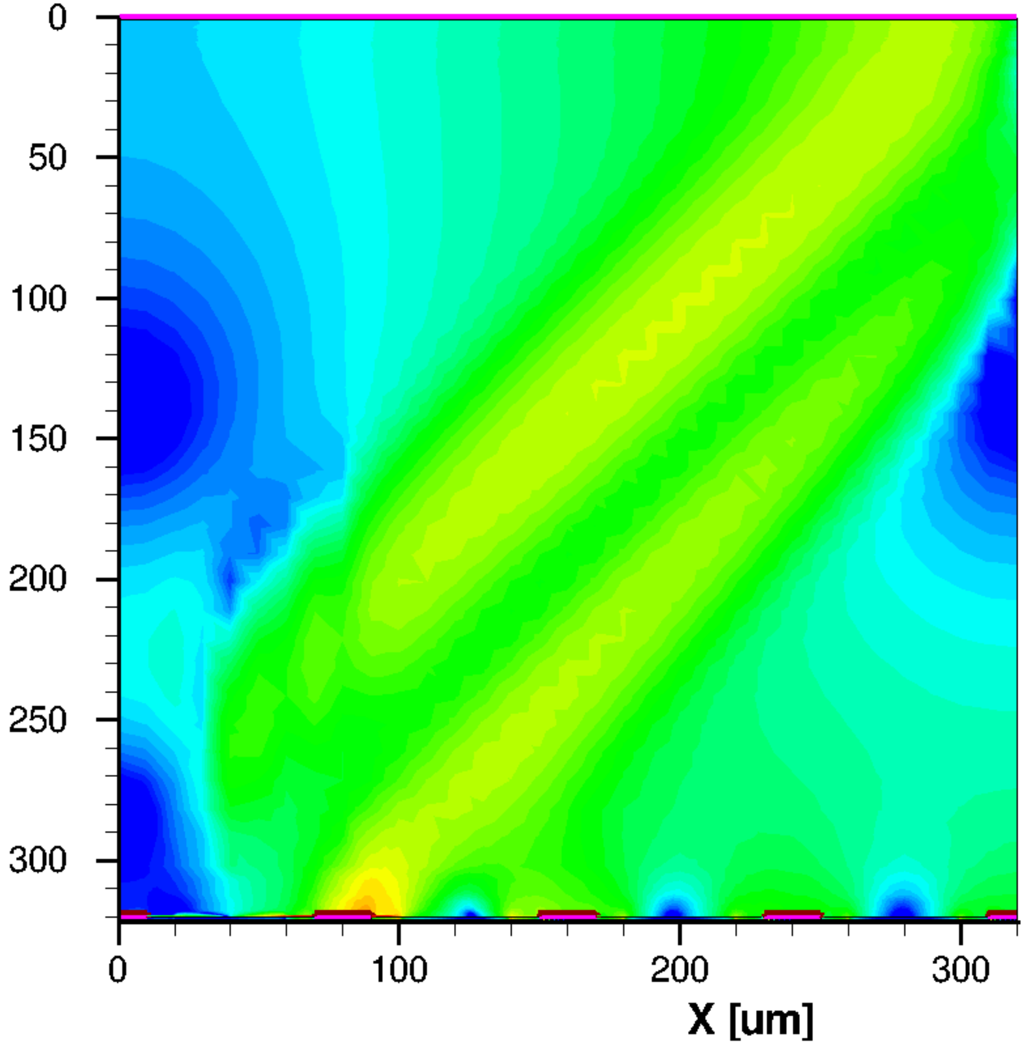
Ionizing particle with 45° angle t=1,8 ns



Simulation Thomas.Eichhorn@kit.edu

2.2. Simulated Current Density

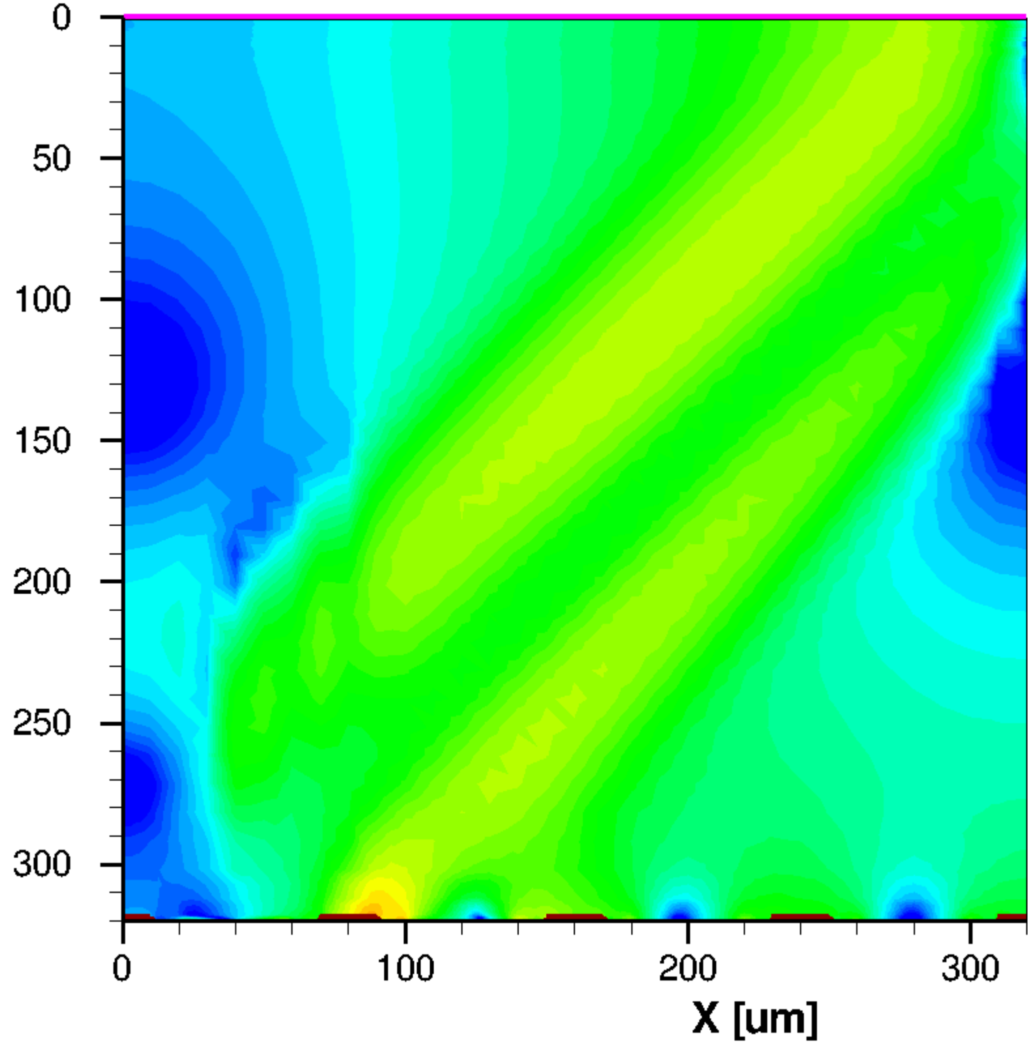
Ionizing particle with 45° angle t=1,9 ns



Simulation Thomas.Eichhorn@kit.edu

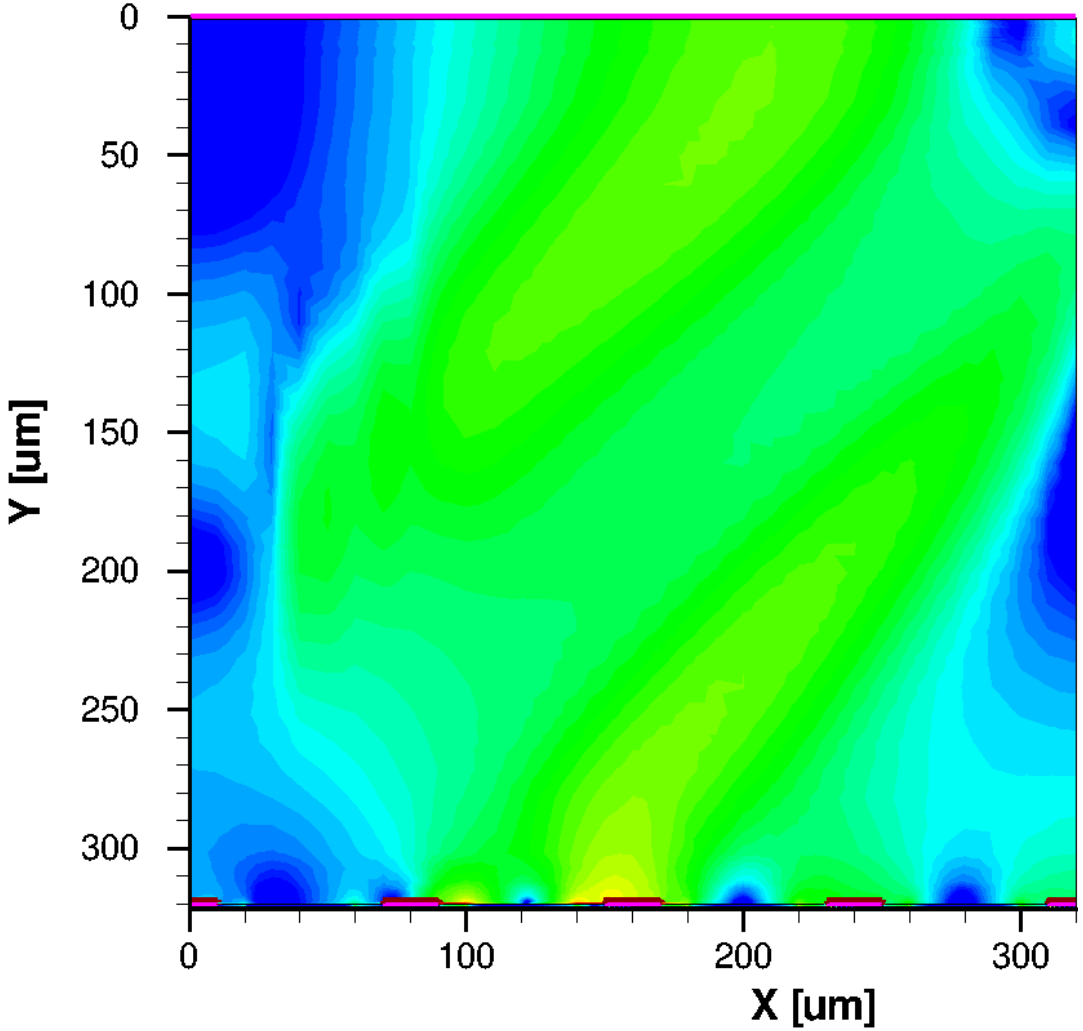
2.2. Simulated Current Density

Ionizing particle with 45° angle t=2 ns



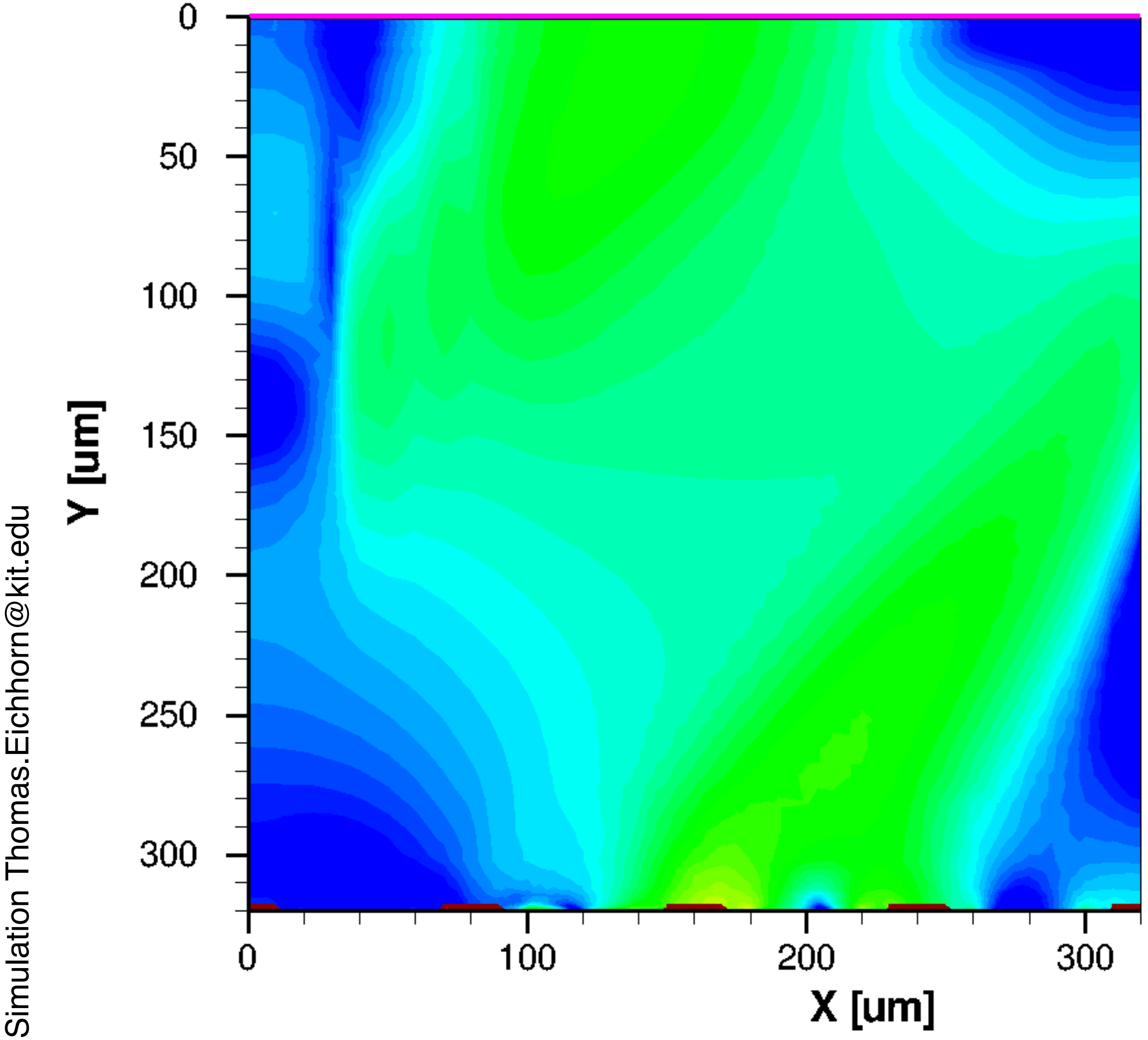
Simulation Thomas.Eichhorn@kit.edu

2.2. Simulated Current Density
Ionizing particle with 45^{o} angle t=3 ns

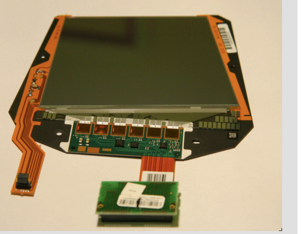


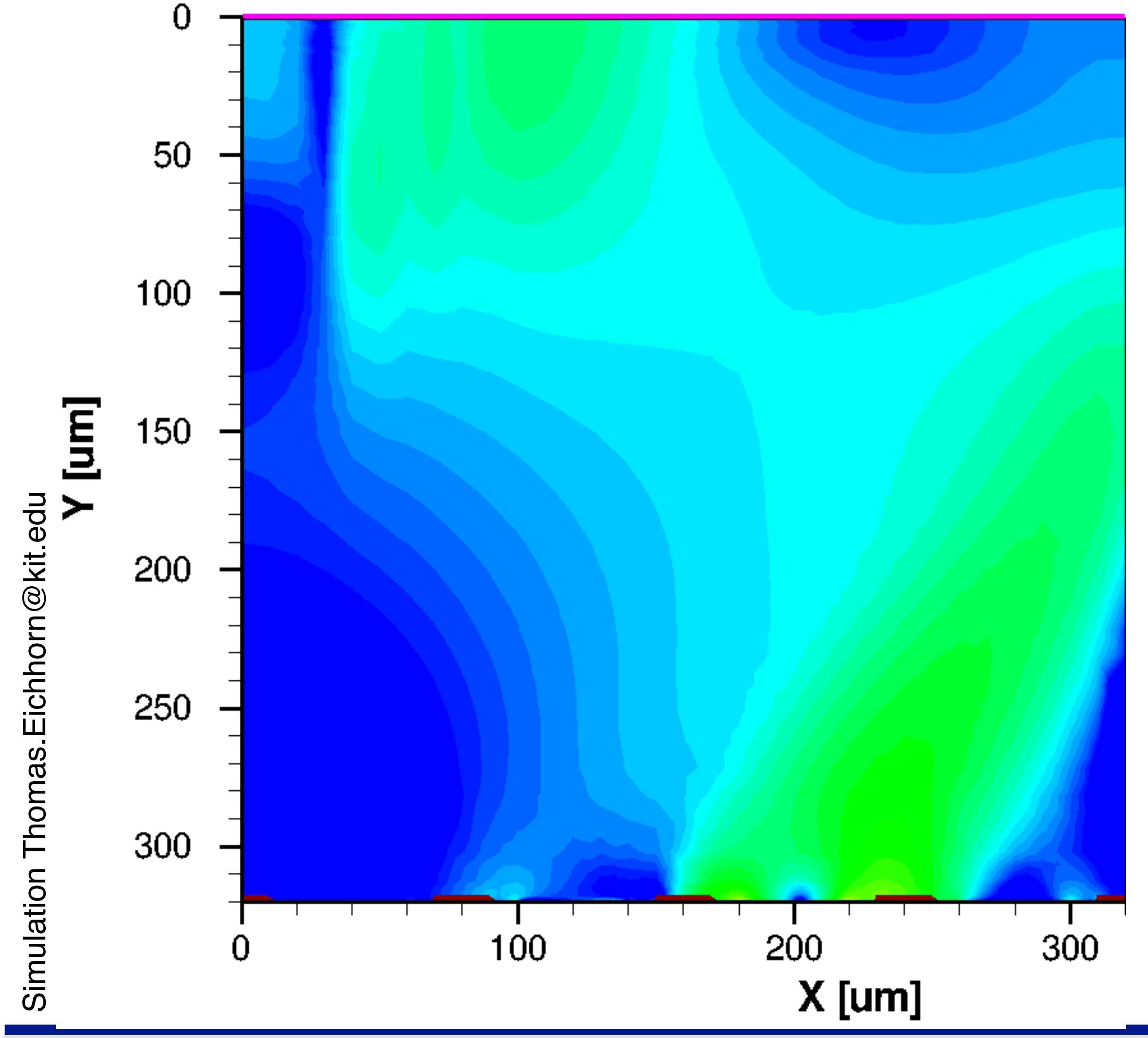
Simulation Thomas.Eichhorn@kit.edu

2.2. Simulated Current Density
Ionizing particle with 45° angle t=4 ns

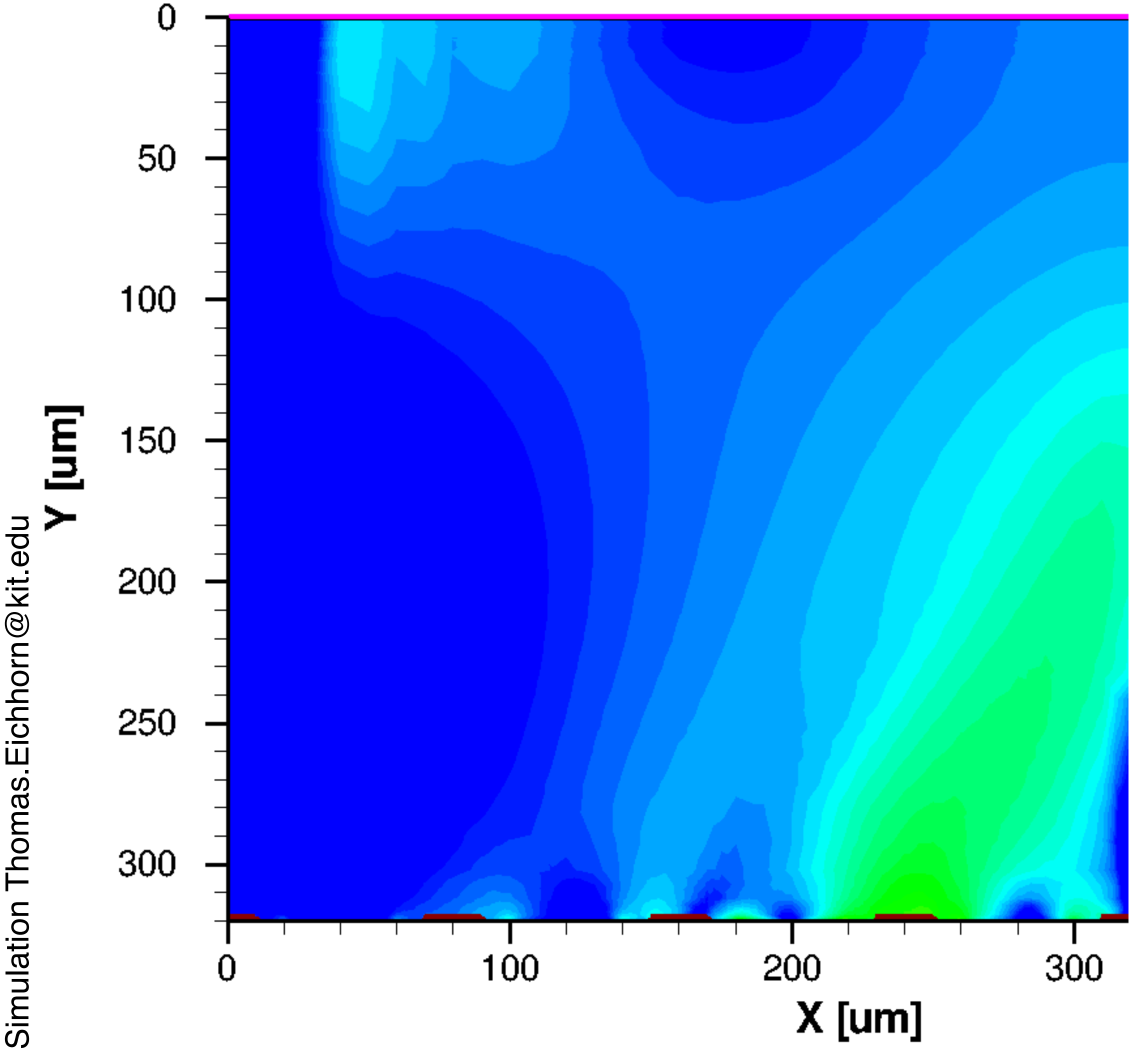


2.2. Simulated Current Density
Ionizing particle with 45° angle t=5 ns





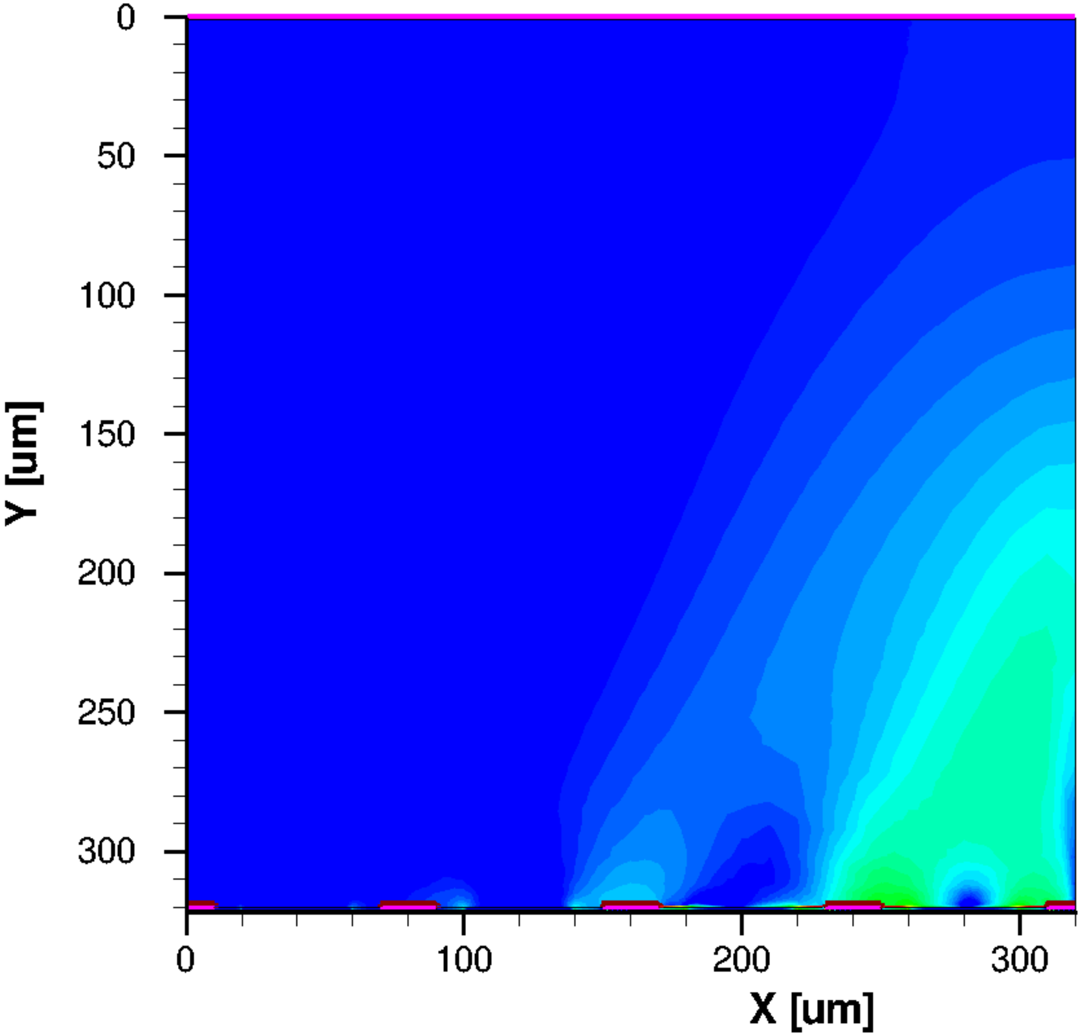
2.2. Simulated Current Density
Ionizing particle with 45° angle t=6 ns



2.2. Simulated Current Density

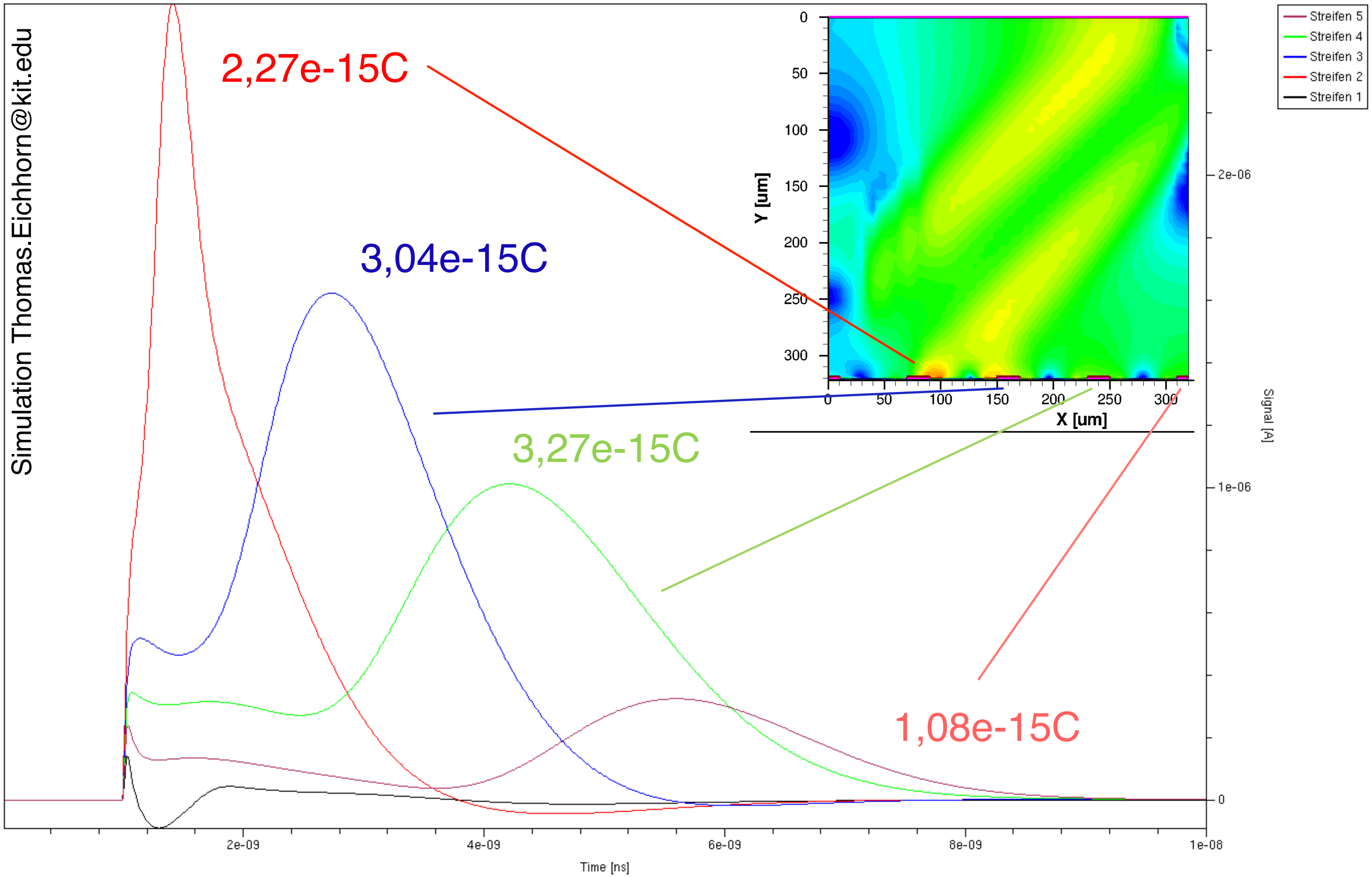
Ionizing particle with 45° angle t=7 ns

Simulation Thomas.Eichhorn@kit.edu

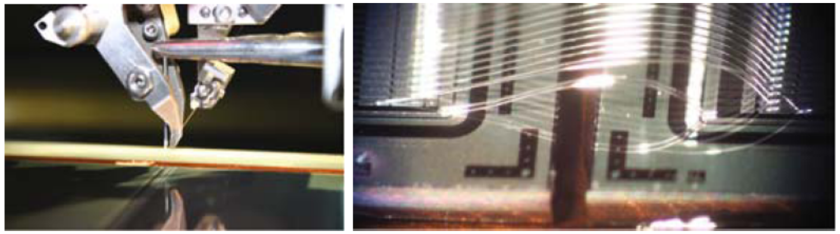


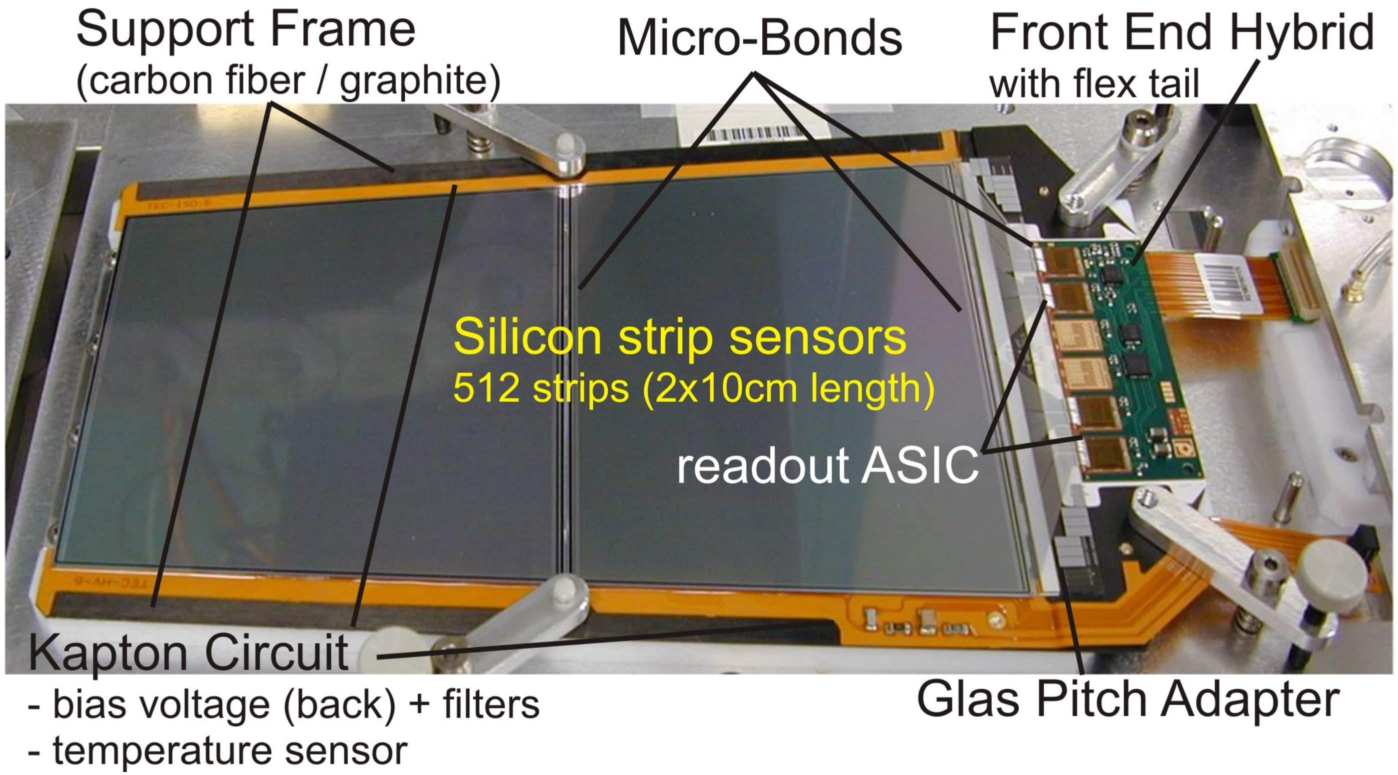
Mind all electrons collected

2.2. Hole Charge Collection (strip & time resolved)



2.2 Strip Sensor to Module

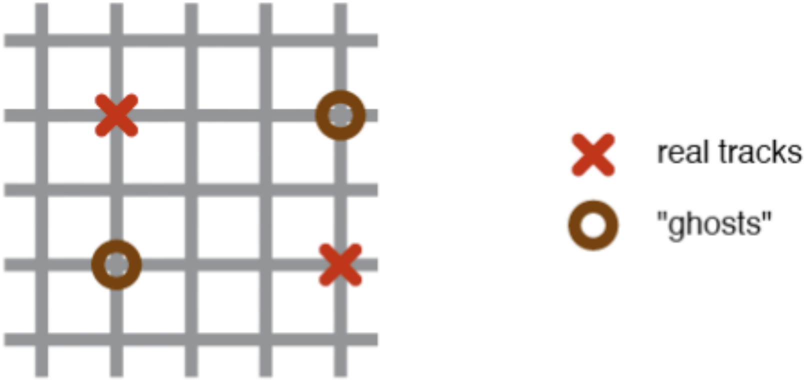




2.3 Strip vs. Pixel Detectors

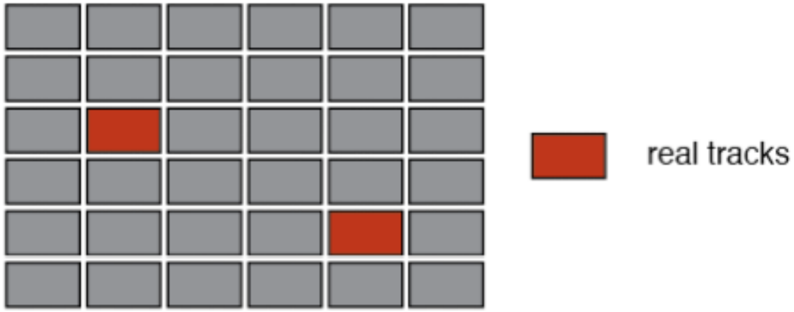
★ A strip detector measures 1 coordinate only. Two orthogonal arranged strip detectors could give a 2 dimensional position of a particle track. However, if more than one particle hits the strip detector the measured position is no longer unambiguous. “Ghost”-hits appear!

True hits and ghost hits in two crossed strip detectors in case of two particles traversing the detector:



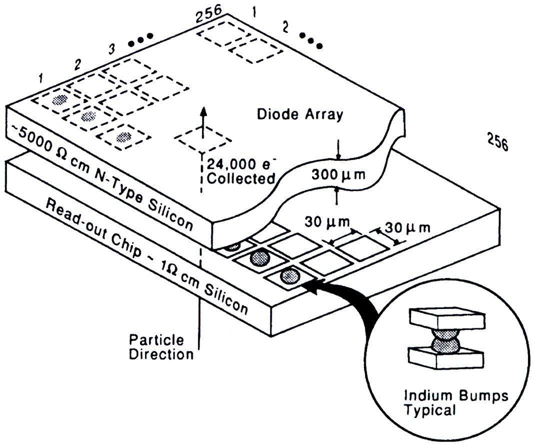
★ Pixel detectors produce unambiguous hits!

Measured hits in a pixel detector in case of two particles traversing the detector:



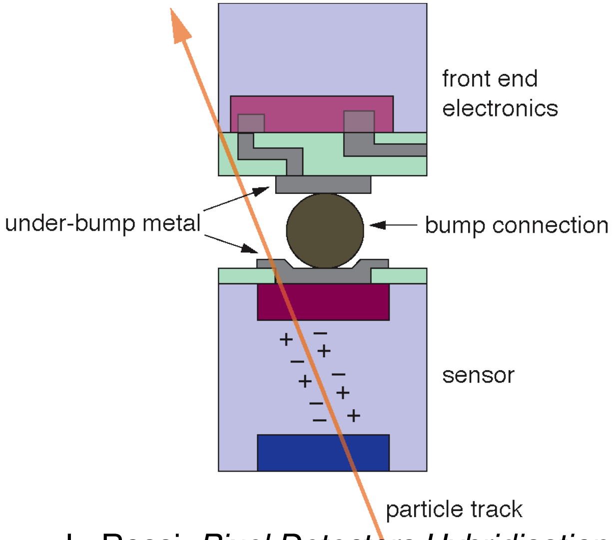
2.3 Hybrid Pixel Detectors
Principle

"Flip-Chip" pixel detector:
On top the Si detector, below the readout chip, bump bonds make the electrical connection for each pixel.



S.L. Shapiro et al., *Si PIN Diode Array Hybrids for Charged Particle Detection*, Nucl. Instr. Meth. A **275**, 580 (1989)

Detail of bump bond connection. Bottom is the detector, on top the readout chip:



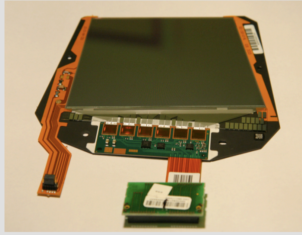
L. Rossi, *Pixel Detectors Hybridisation*, Nucl. Instr. Meth. A **501**, 239 (2003)

Drawback of hybrid pixel detectors: Large number of readout channels

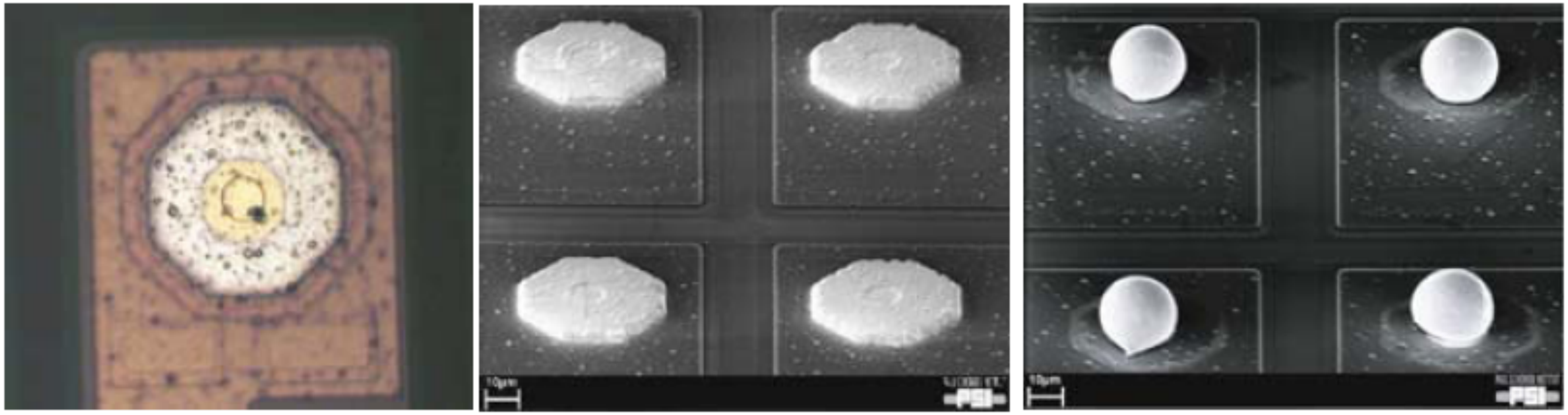
→ Large number of electrical connections and large power consumption.

2.3 Hybrid Pixel Detectors

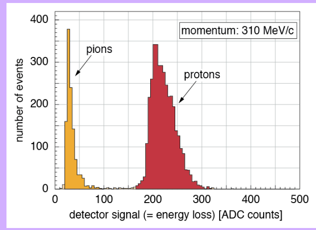
Bump bonding process



Electron microscope pictures before and after the reflow production step.
In bump, The distance between bumps is 100 µm, the deposited indium is 50 µm wide while the reflowed bump is only 20 µm wide.



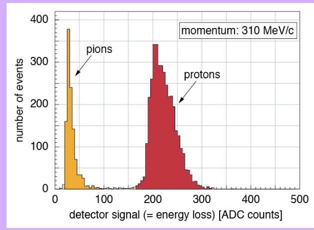
C. Broennimann, F. Glaus, J. Gobrecht, S. Heising, M. Horisberger, R. Horisberger, H. Kästli,J. Lehmann, T. Rohe, and S. Streuli, *Development of an Indium bump bond process for silicon pixel detectors at PSI, Nucl. Inst. Met. Phys, Res. A565(1) (2006) 303–308 82*



3 Performance

3.1 Signal to Noise Ratio

Introduction

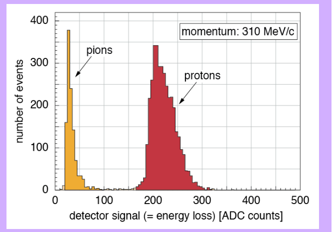


★ **The signal** generated in a silicon detector depends essentially only on the thickness of the depletion zone and on the dE/dx of the particle.

★ **The noise** in a silicon detector system depends on various parameters: geometry of the detector, the biasing scheme, the readout electronics, etc.

Noise is typically given as "equivalent noise charge" ENC. This is the noise at the input of the amplifier in elementary charges.

3.1 Signal to Noise Ratio
Noise contributions



1. Leakage current (ENC_I)

$$ENC_I = \frac{e}{2}\sqrt{\frac{I t_p}{e}}$$

2. Detector capacity (ENC_C)

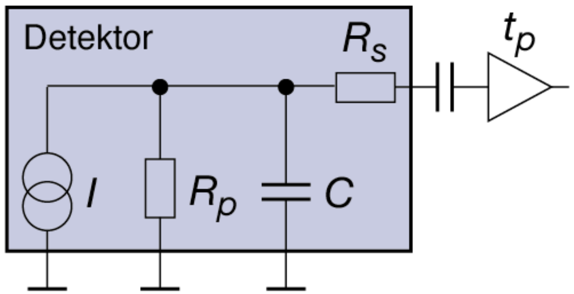
$$ENC_C = a + b \cdot C$$

3. Det. parallel resistor (ENC_{Rp})

$$ENC_{Rp} = \frac{e}{e}\sqrt{\frac{kTt_p}{2R_p}}$$

4. Det. series resistor (ENC_{Rs})

$$ENC_{Rs} \approx 0.395\, C\sqrt{\frac{R_s}{t_p}}$$



Alternate circuit diagram of a silicon detector.

e .... Euler number (2.718...)
e ... Electron charge
C .... Detector capacity in pF

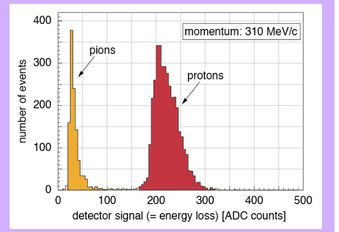
t_p ...Integration time in μs
R_{Rs} ...Series resistor in Ω
R_{Rp} ...Parallel resistor in Ω

The overall noise is the quadratic sum:

$$ENC = \sqrt{ENC_C^2 + ENC_I^2 + ENC_{Rp}^2 + ENC_{Rs}^2}$$

Typical values for SNR are 15 to 40.

3.2 Position Resolution
Introduction



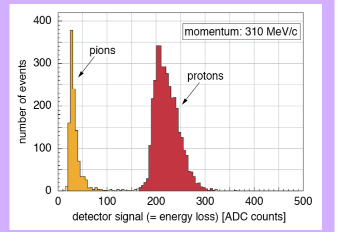
The position resolution – the main parameter of a position detector – depends on various factors, some due to physics constraints and some due to the design of the system (external parameters).

★ Physics processes:
- Statistical fluctuations of the energy loss
- Diffusion of charge carriers

★ External parameter:
- Binary readout (thresh hold counter) or read out of analogue signal value
- Distance between strips (strip pitch)
- Signal to noise ratio

3.2 Position Resolution

Drift and Diffusion



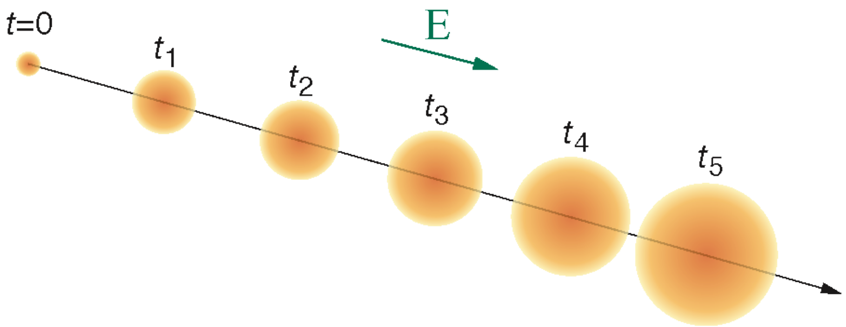
★ After the ionizing particle has passed the detector the e^+h^- pairs are close to the original track.

★ While the cloud of e^+ and h^- drift to the electrodes, diffusion widens the charge carrier distribution. After the drift time *t* the width (rms) of the distribution is given as:

$$\sigma_D = \sqrt{2Dt}$$

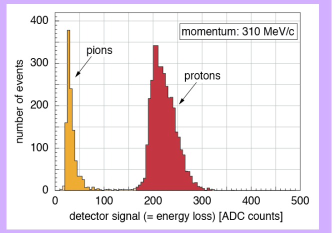
σ_D … width "root-mean-square" of the charge carrier distribution
t … drift time D … diffusion coefficient

Drift and diffusion acts on charge carriers:



3.2 Position Resolution

Threshold readout versus analogue readout



★ Threshold readout (one strip signal):

➔ position: $x = \text{strip position}$

➔ resolution: $\sigma_x \approx \frac{p}{\sqrt{12}}$

p … distance between strips (readout pitch)

x … position of particle track

★ Analogue readout with interpolation (signal on two strips):

➔ Position (charge center of gravity):

$$x = x_1 + \frac{h_1}{h_1 + h_2}(x_2 - x_1) = \frac{h_1 x_1 + h_2 x_2}{h_1 + h_2}$$

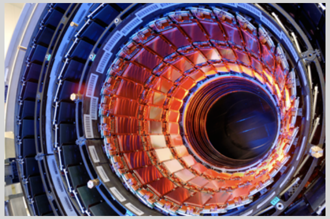
➔ resolution: $\sigma_x \propto \frac{p}{SNR}$

x_1, x_2 … position of 1st and 2nd strip

h_1, h_2 … signal on 1st and 2nd strip

SNR … signal to noise ratio

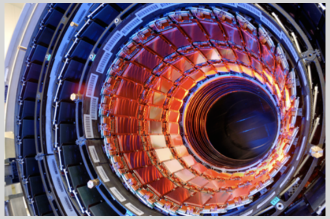
A position resolution of a few *μ*m is achievable with analogue readout !



4 Detector Systems

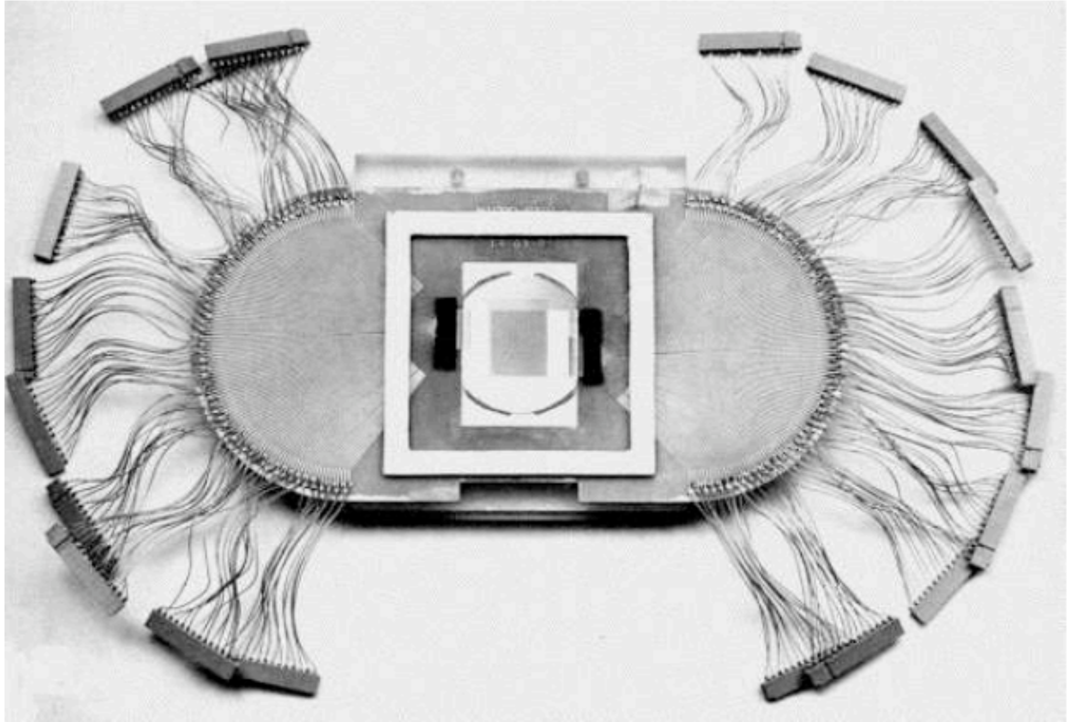
4.1 First Silicon Strip Detector in HEP

The NA11 silicon detector 1983



Experiments NA11/NA32 at CERN

Goal: Measure lifetime and mass of the charm mesons D^0, D^-, D^+, D^+_s, D^-_s



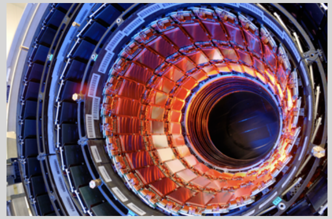
NIM205 (1983) 99

Surface 24 cm^2 (2" wafer)
1200 strip, 20 μm pitch
Ever 3rd/6th strip connected.
Precision 4,5 μm !

8 silicon detectors
(2 in front, 6 behind the
Target)

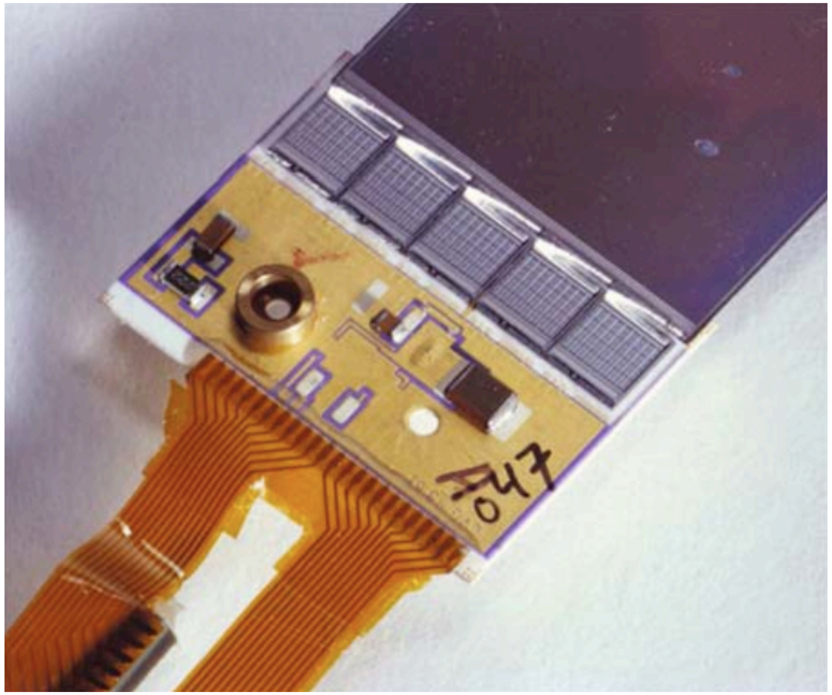
Ratio detector surface to nearby electronics surface 1:300 !

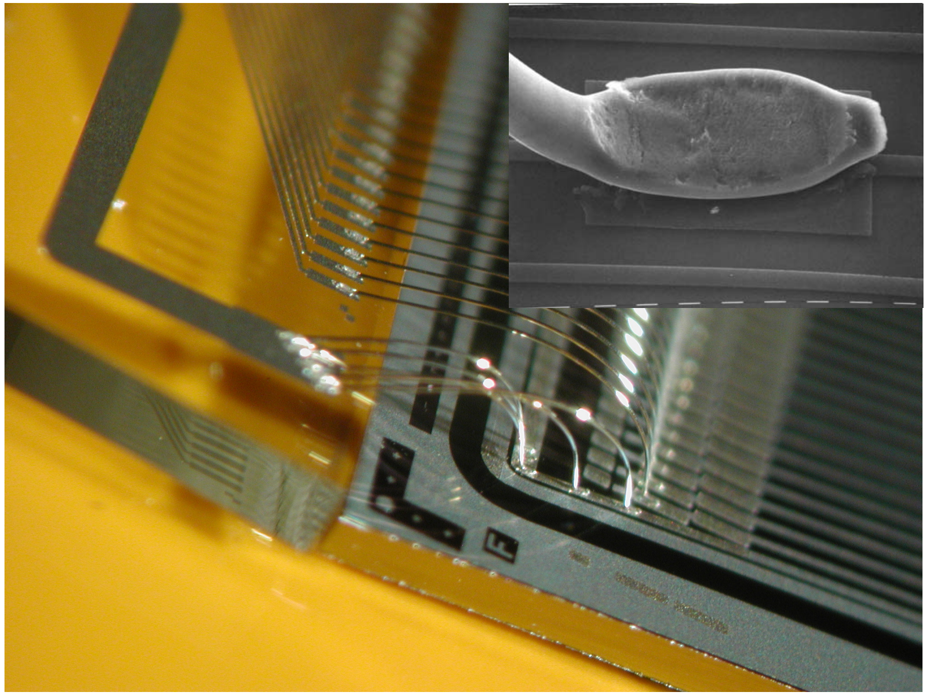
4.2 Towards Complex Detectors
Progress in electronics integration



★ Development of costume designed VLSI chips with up to 128 readout channels. Chips containing preamplifier, shaper, pipeline, multiplexer, etc.

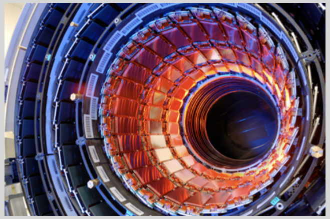
★ Connection to the strips on the sensors using thin pitch wire bonding





Detail from the DELPHI Vertex detector

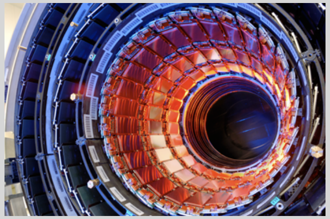
4.3 Silicon Trackers at the LHC

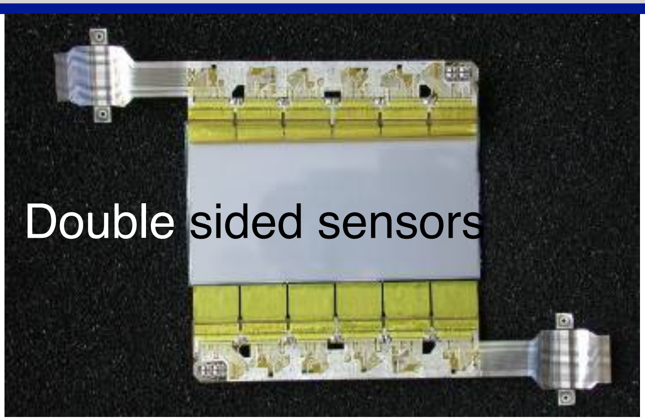


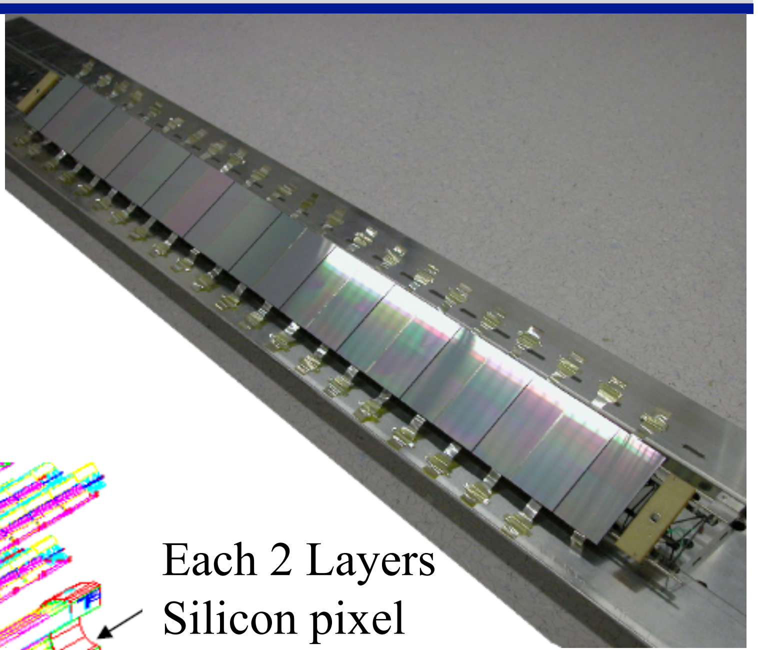
25 years and many developments later:

Silicon Trackers in the LHC Experiments

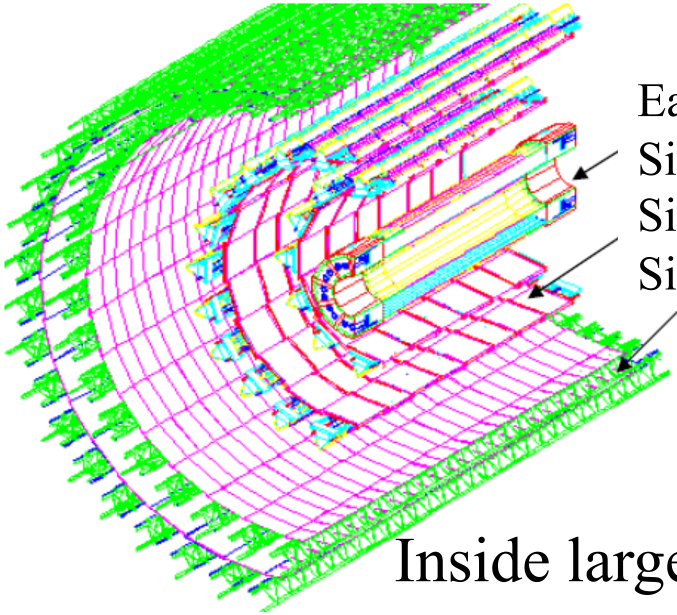
4.3 ALICE



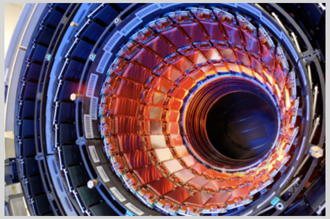




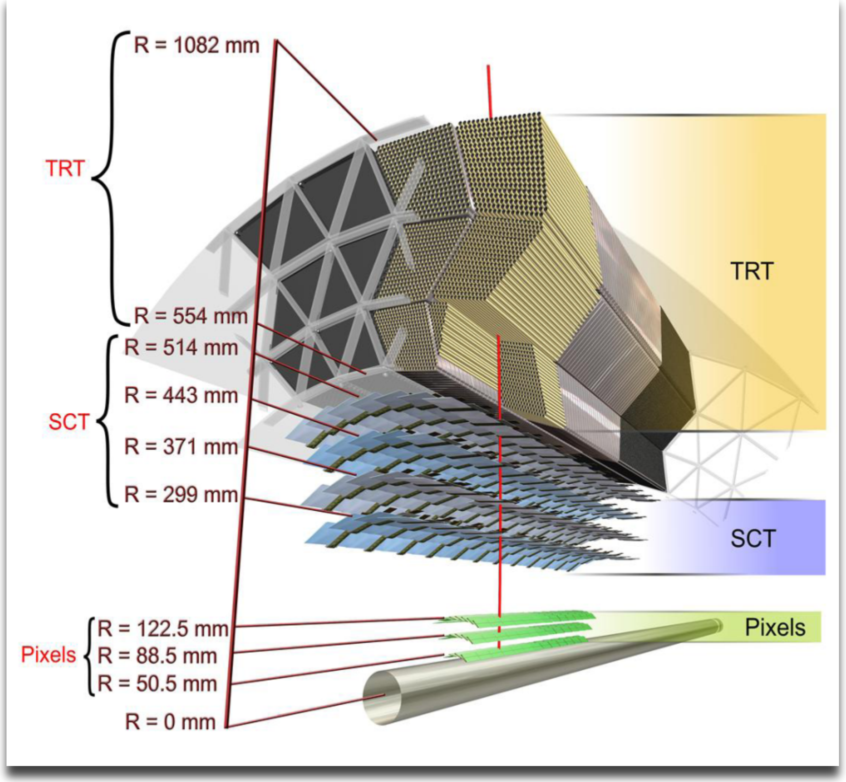
Final folded configuration

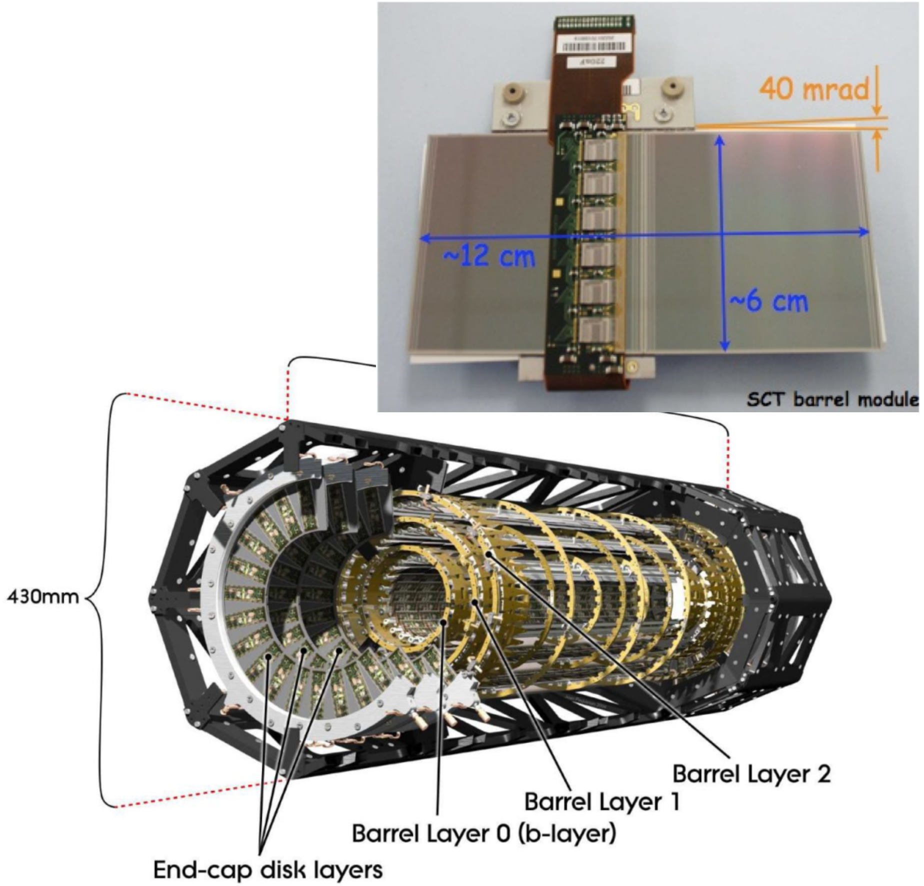


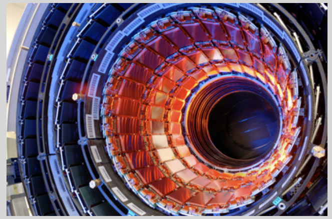
4.3 ATLAS
The ATLAS Inner Tracker



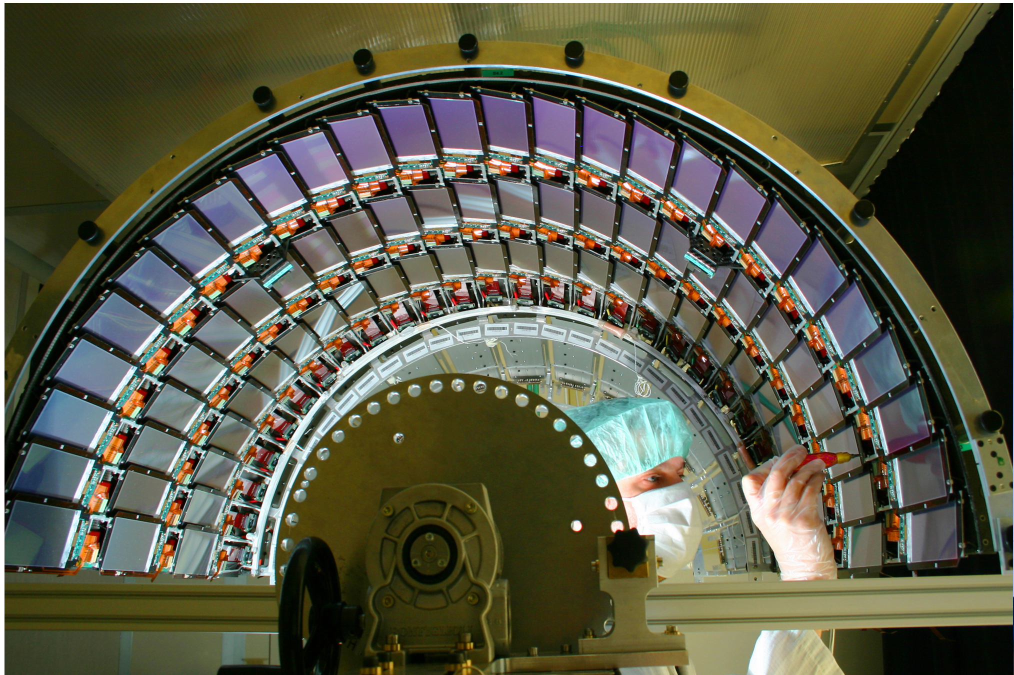
Silicon Pixels, Silicon Strips, and a Transition Radiation Tracker.

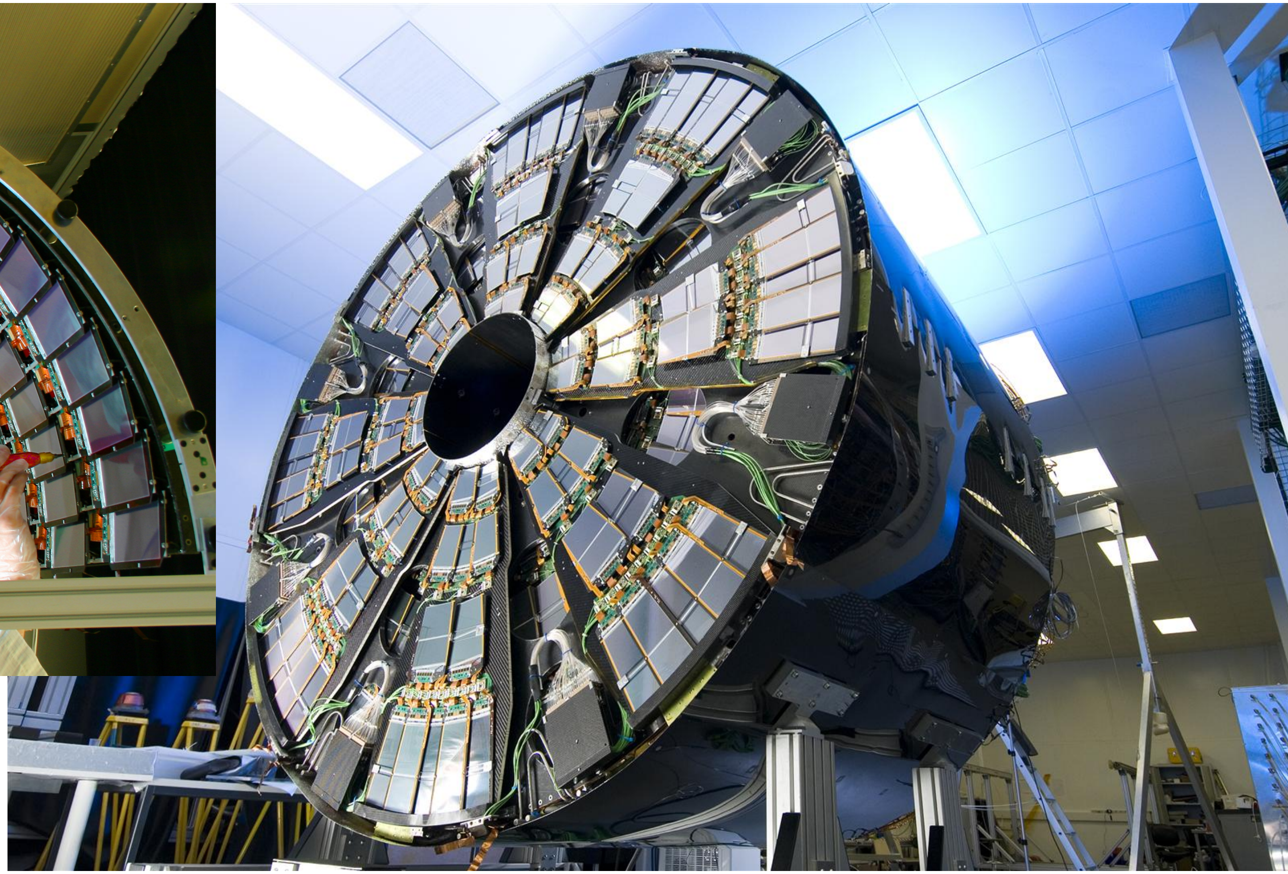


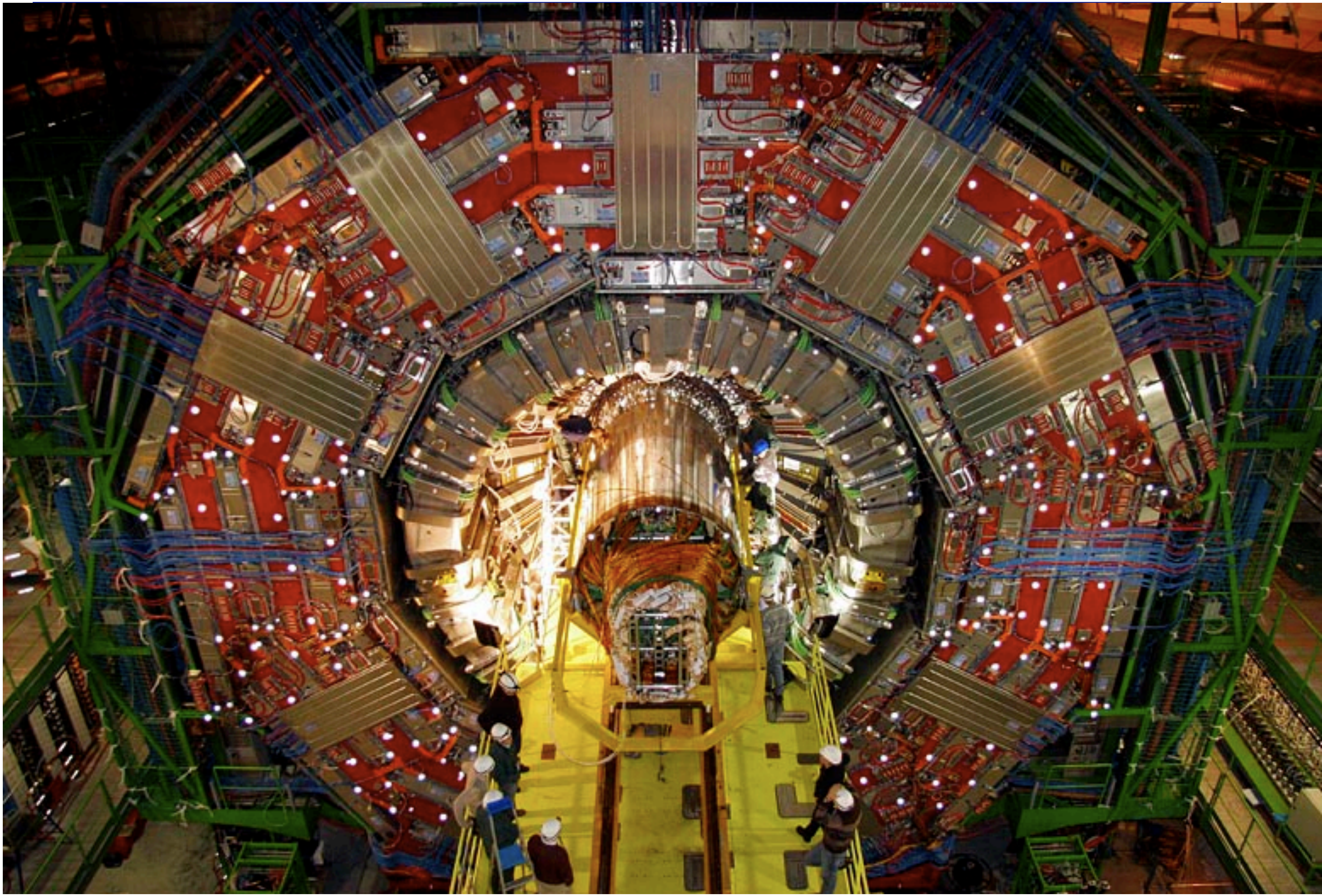




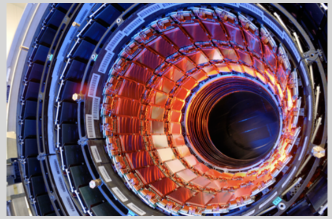
The largest Silicon Device, 200 m^2, >70 million channels



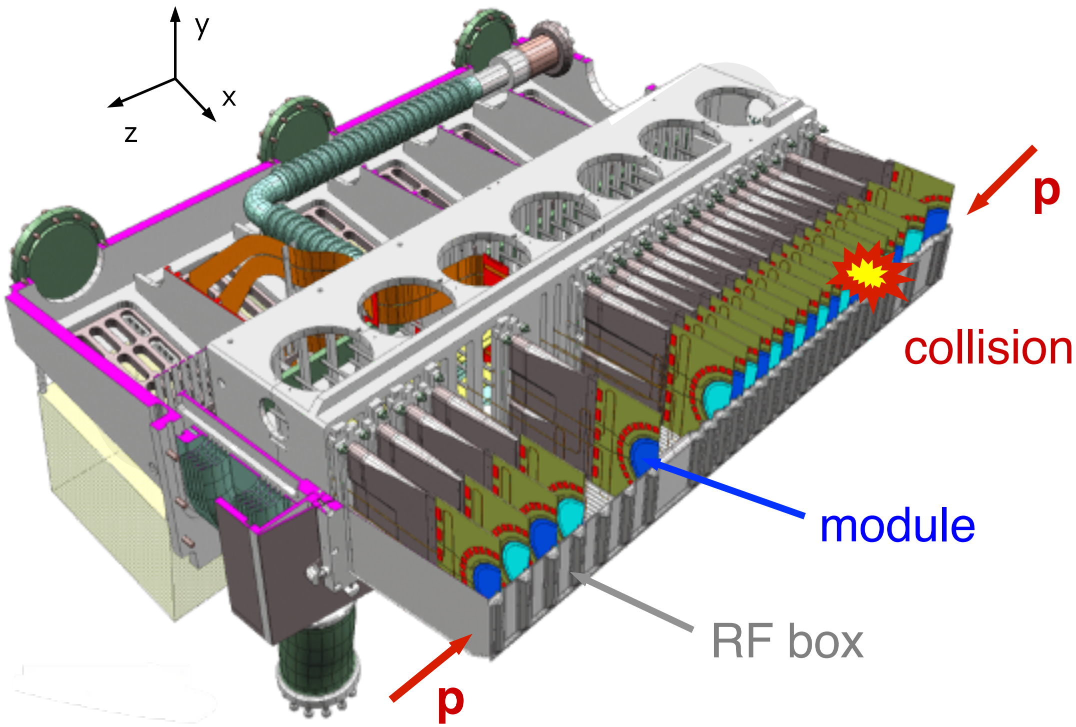


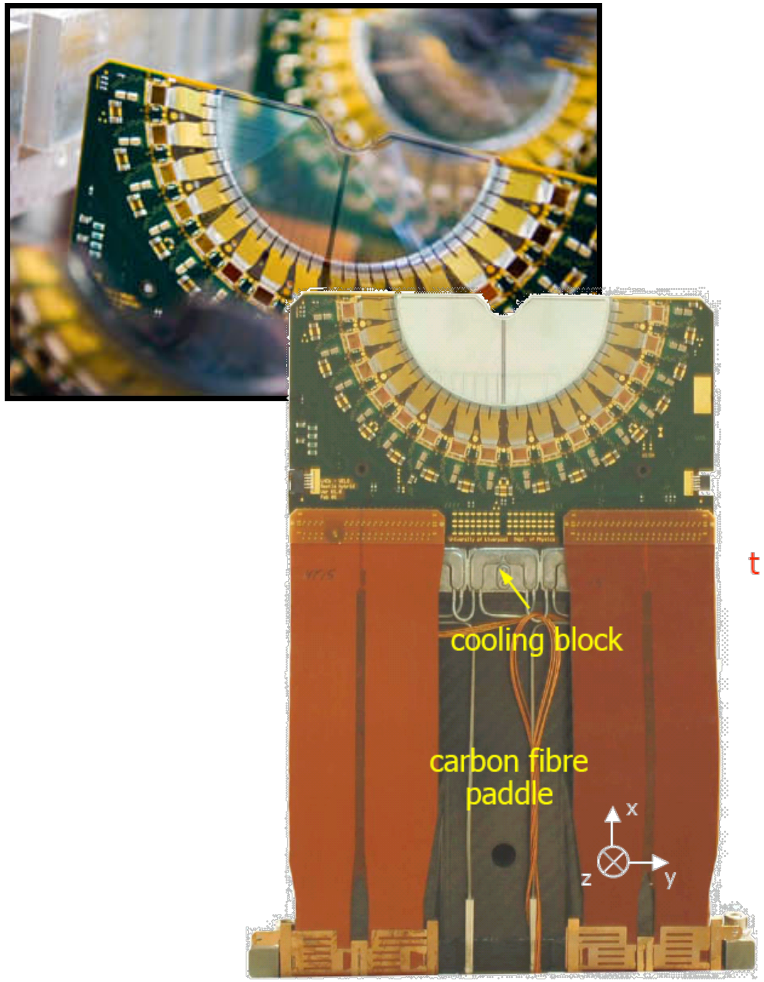


4.3 LHCb

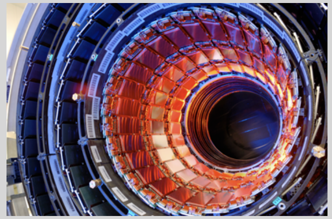


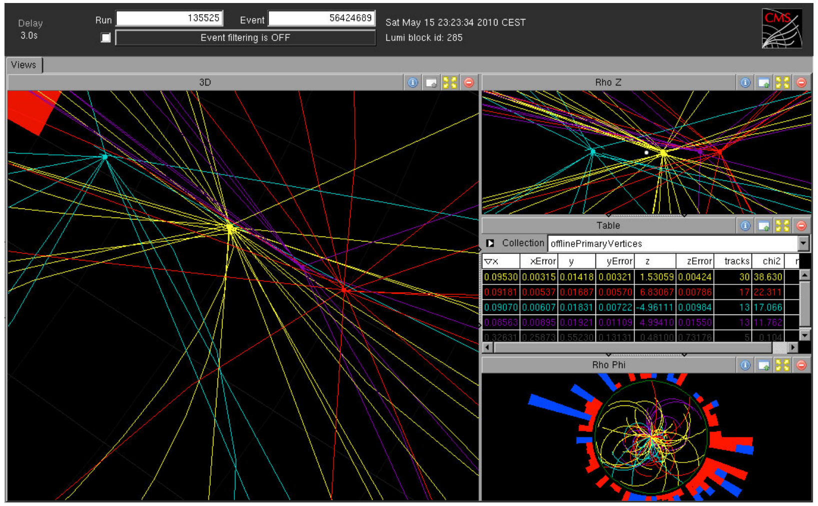
The LHCb VELO, as close as possible to the beam.

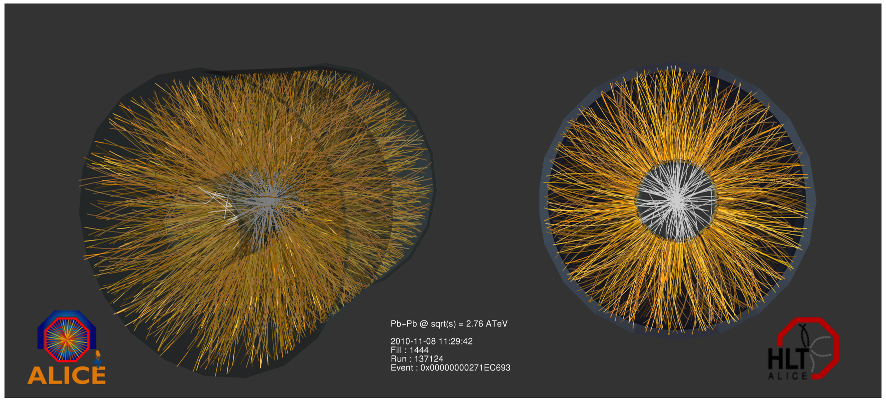




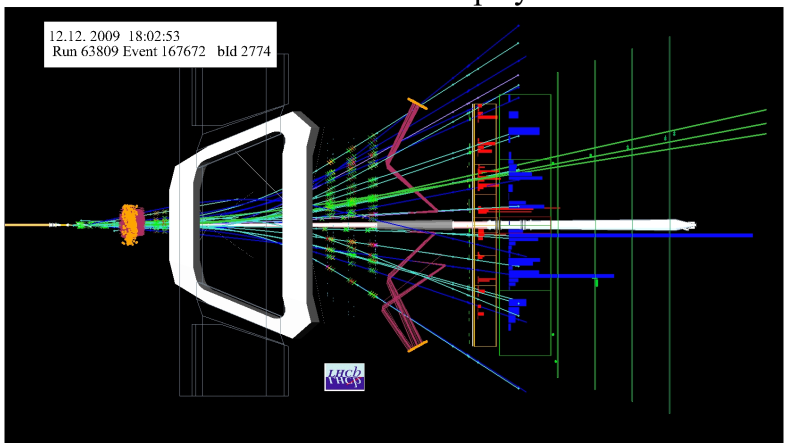
4.4 Some first results

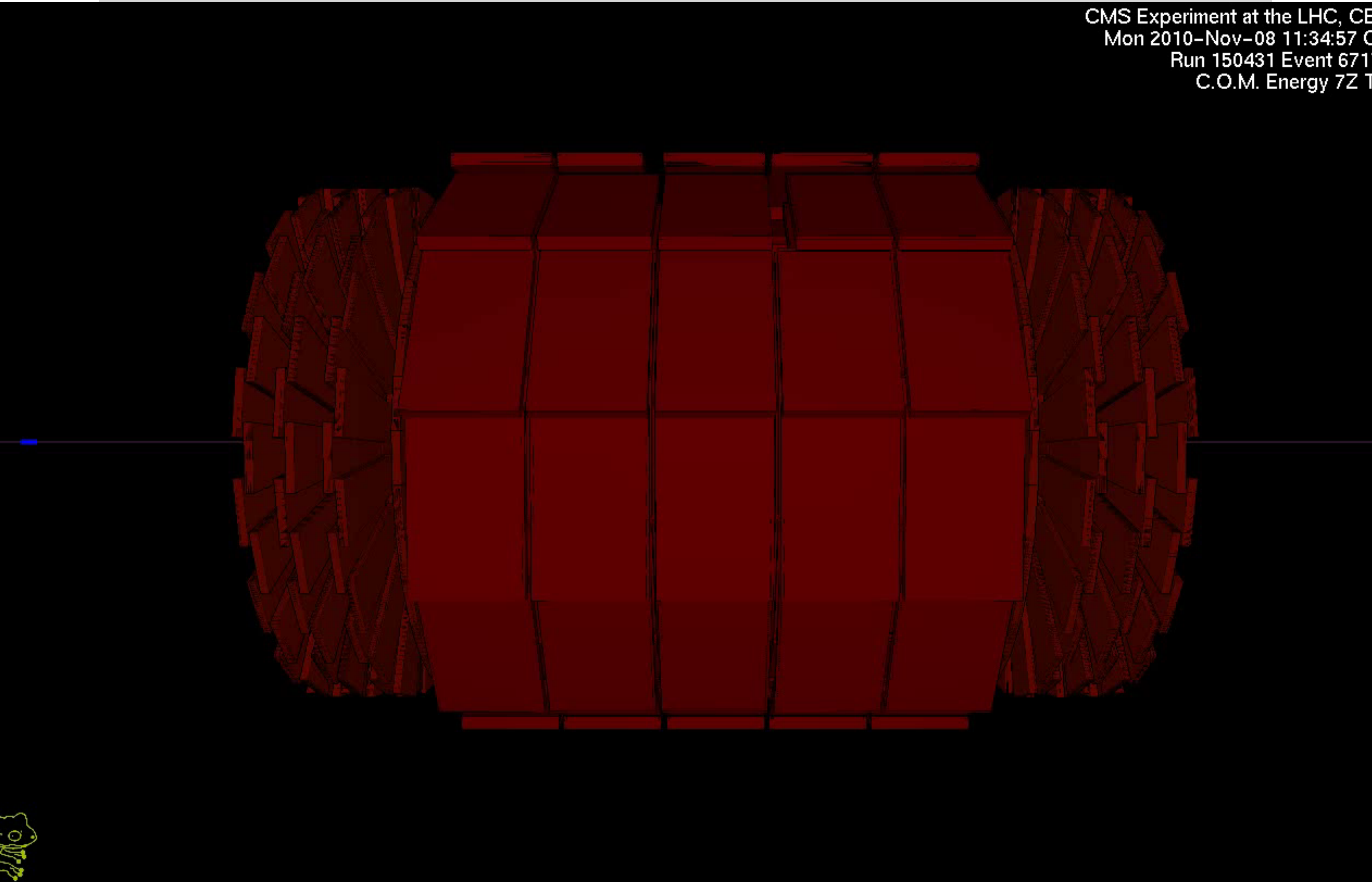


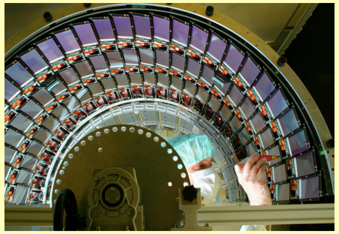




LHCb Event Display




CMS Experiment at the LHC, CE
Mon 2010-Nov-08 11:34:57 C
Run 150431 Event 671
C.O.M. Energy 7Z T

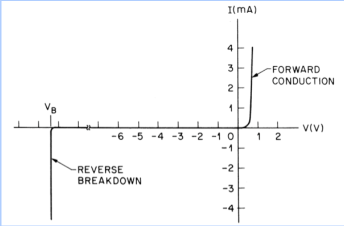


THE END

of this lecture, but not the end of silicon sensor developments for experiments in high energy physics.

Manufacturing Si Detectors

Wafer production



Properties of Si bulk required for detectors:

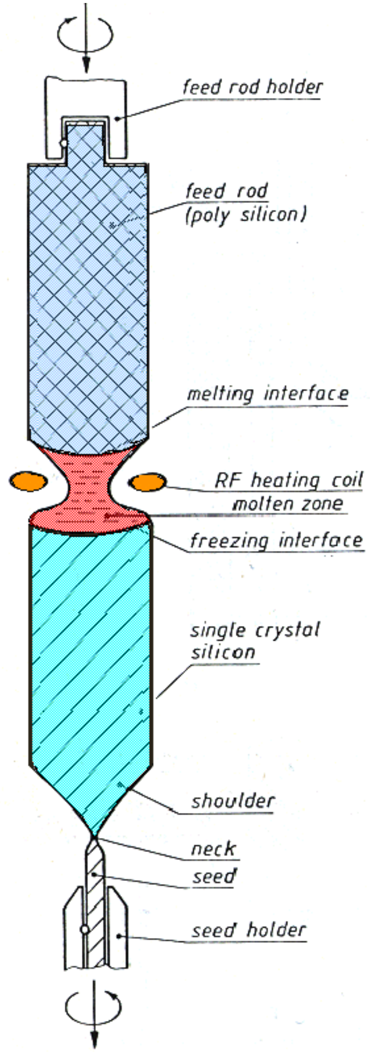
- Diameter: 4 or 6 inches
- Lattice orientation <111> or <100>
- Resistivity 1–10 kΩcm

Therefore, float-zone technique for ingot production is used

- technique moves a liquid zone through the mater

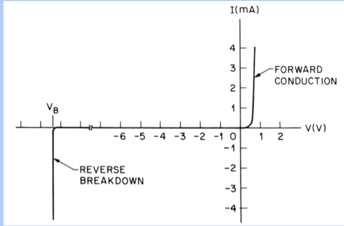
- Result: **single-crystal ingot**

Chip industry: Czochralski process

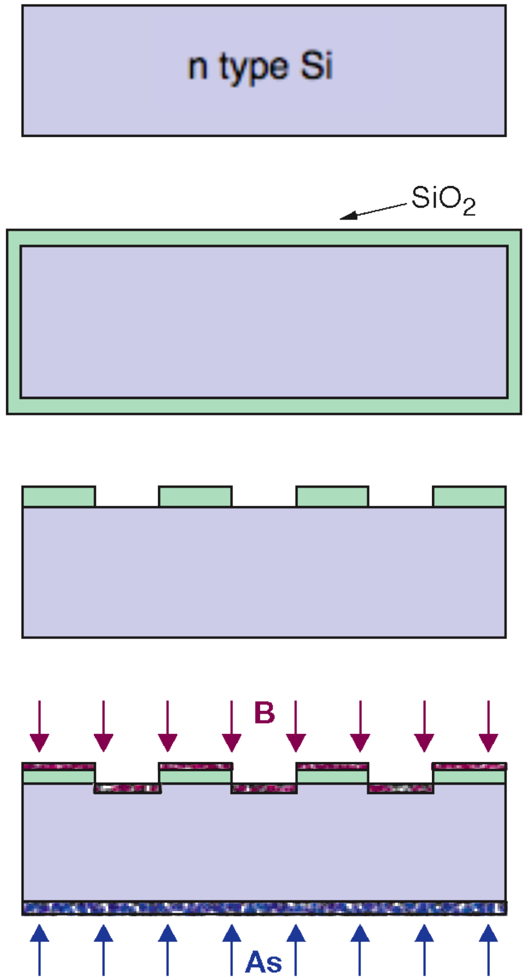


Manufacturing Si Detectors

Planar process - 1

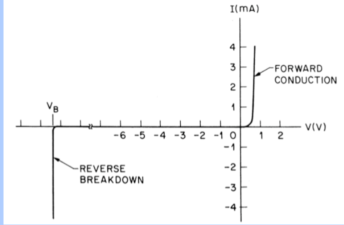


1. Starting Point: single-crystal n-doped wafer ($N_D \approx 1–5 \cdot 10^{12}$ cm^{-3})
2. Surface passivation by SiO_2-layer (approx. 200 nm thick). E.g. growing by (dry) thermal oxidation at 1030 °C.
3. Window opening using **photolithography technique** with etching, e.g. for strips
4. Doping using either
   - Thermal diffusion (furnace)
   - Ion implantation
     - p^+-strip: Boron, 15 keV, $N_A \approx 5 \cdot 10^{16}$ cm^{-2}
     - Ohmic backplane: Arsenic, 30 keV, $N_D \approx 5 \cdot 10^{15}$ cm^{-2}



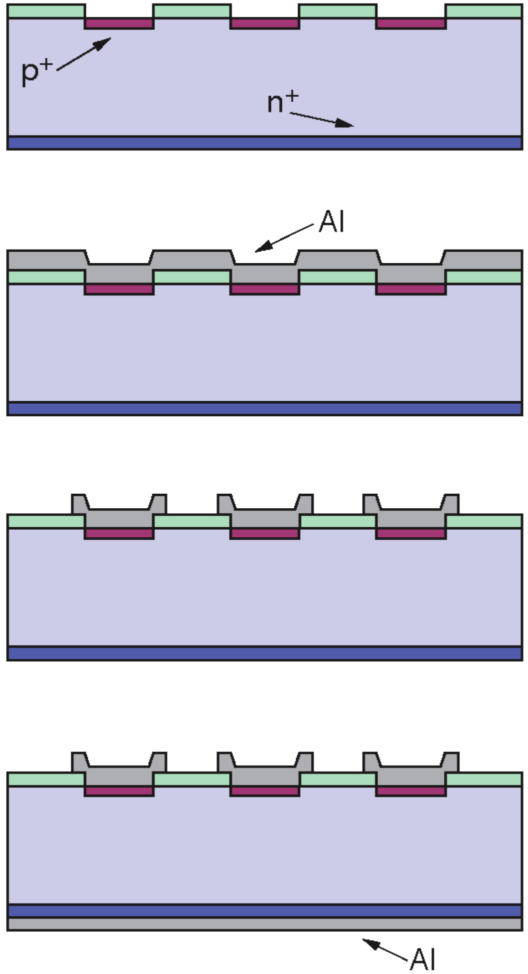
Manufacturing Si Detectors

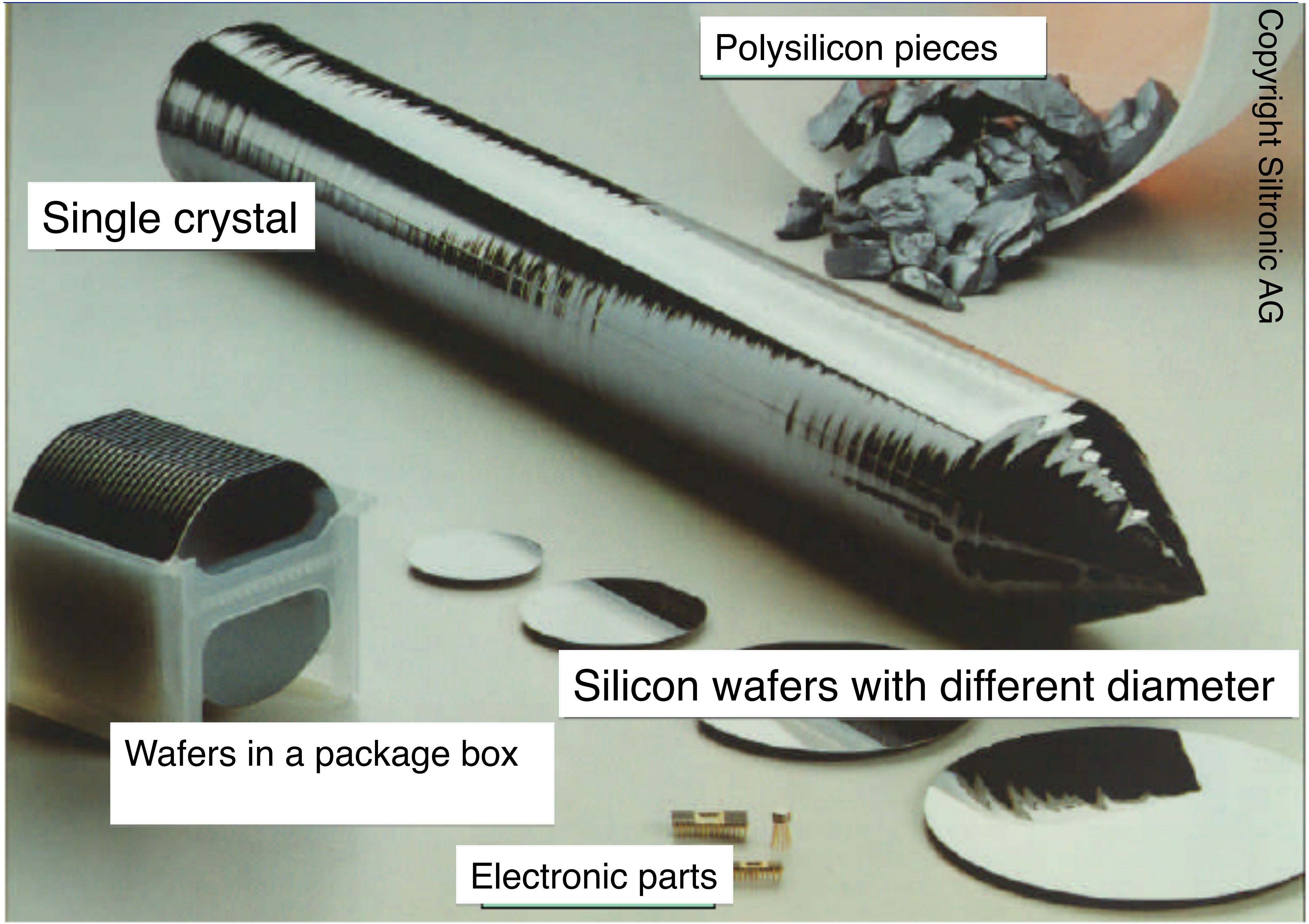
Planar process - 2



5. After ion implantation: Curing of damage via thermal annealing at approx. 600°C, (activation of dopant atoms by incorporation into silicon lattice)
6. Metallization of front side: sputtering or CVD
7. Removing of excess metal by photolitography: etching of non -covered areas
8. Full-area metallization of backplane with annealing at approx. 450°C for better adherence between metal and silicon

Last step: wafer dicing (cutting)




Polysilicon pieces
Single crystal
Silicon wafers with different diameter
Wafers in a package box
Electronic parts
Copyright Siltronic AG