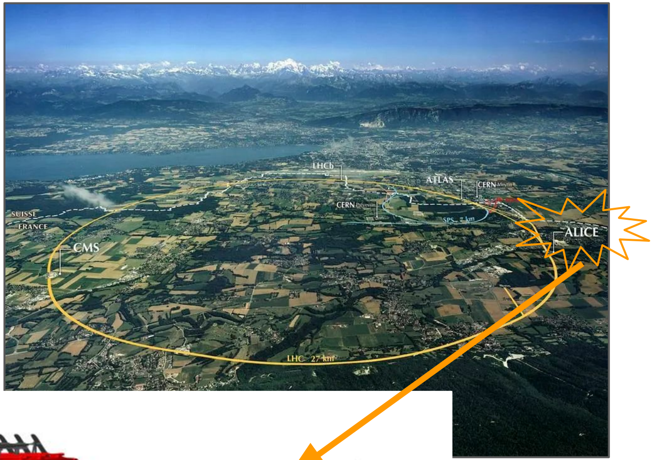
ALICE Inner Tracker System

Robin Kan Particle Detection 20-03-2024

ALICE

- **A** **L**arge **I**on **C**ollider **E**xperiment
- One of the experiments at the LHC
- Relatively small detector
- Inner Tracker System 2 (ITS2):
    - Installed in the LHC shutdown from 2019-2021



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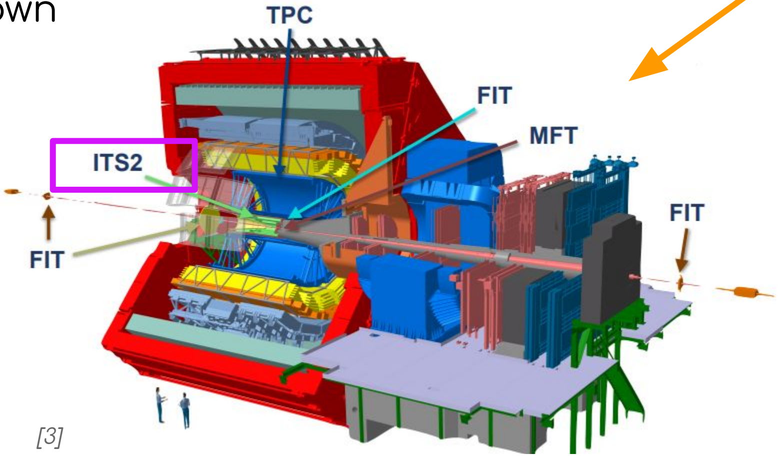
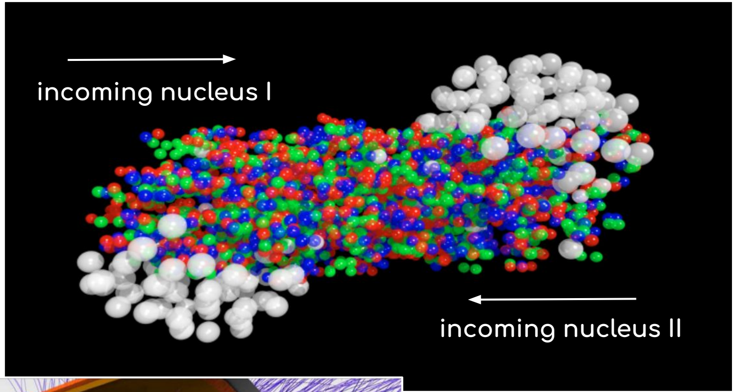


[3]

Information obtained from: [1]

Objectives ALICE

- Recreating and studying the primordial quark-gluon plasma
- Highly energetic Pb-Pb collisions
- The collision of two heavy ions at near-light speed creates a droplet of QGP
- Temperatures up to > 100,000 times hotter than the core of the Sun
- Plasma cools → quarks and gluons recombine and 'ordinary particles' speed away in all directions, which are detected by the detector



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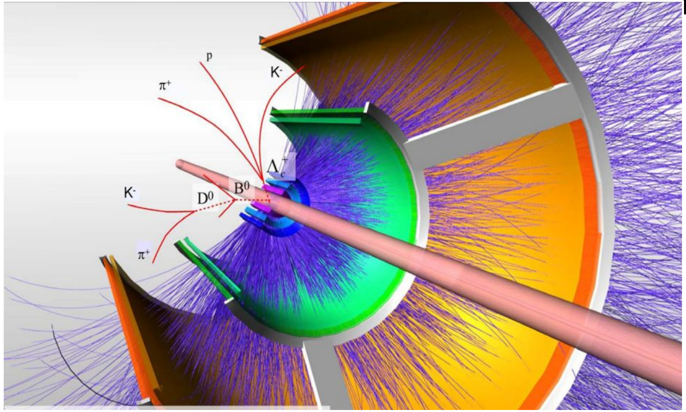
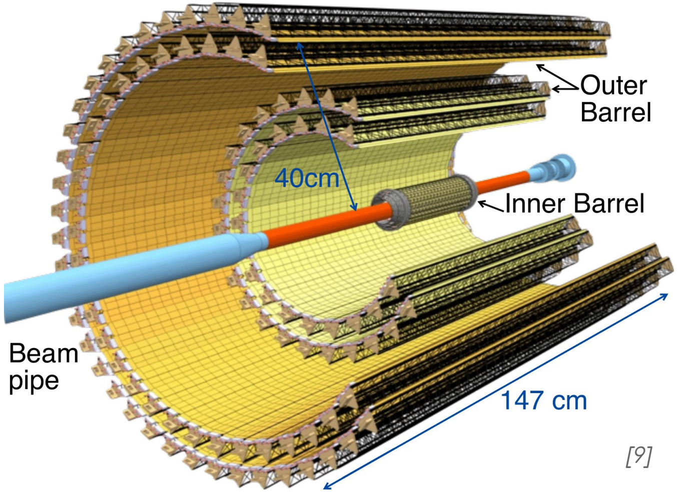


[7]

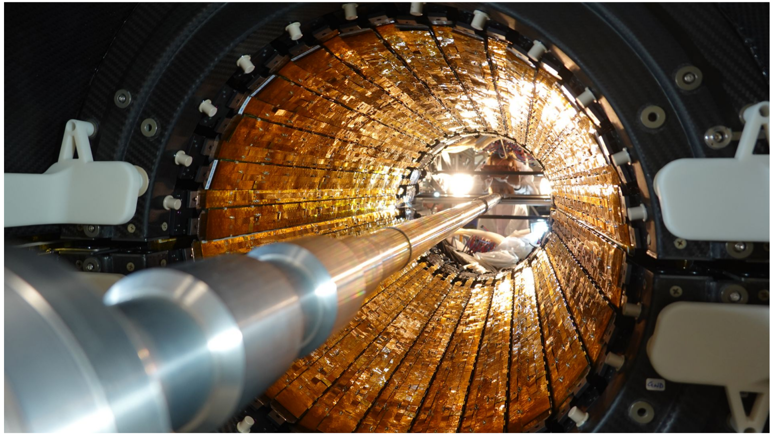
Information obtained from: [4,5]

The ITS2



[9]

- Inner Tracker System 2
- Consists of silicon Monolithic Active Pixel Sensors (MAPS)
  - ALPIDE design

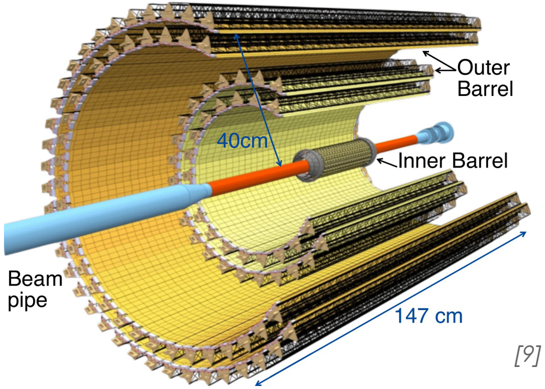


[10]

- With an active area of ~10 m² and 12.5 billion pixels it is the largest and most granular pixel detector ever built

Information obtained from: [3,8]

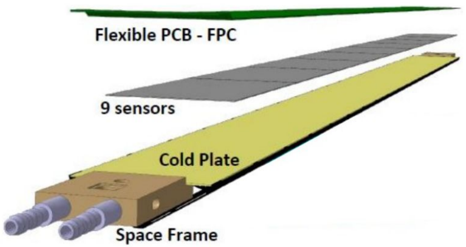
Structure ITS2



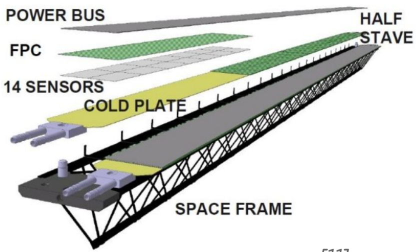
[9]

- 7 layers in total: 3 in the inner barrel, and 4 in the outer barrel
- The sensors are mounted on staves, which are configured concentrically around the beam axis

Inner Barrel Stave



Outer Barrel Stave



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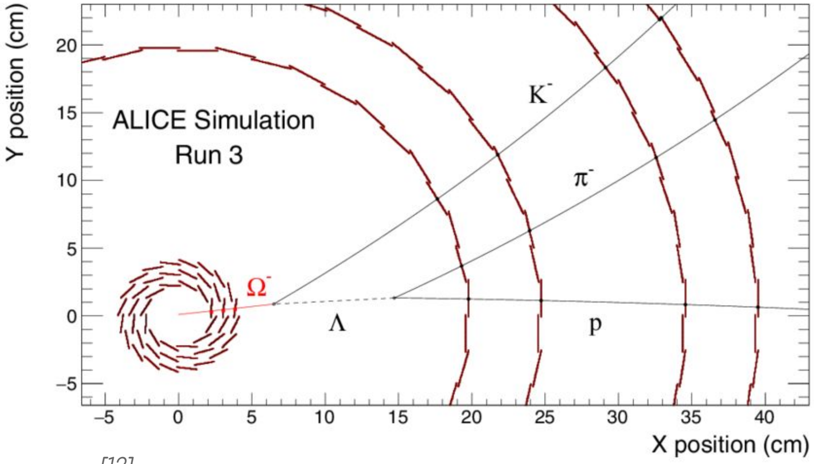


[12]

Information obtained from: [8]

Physics objectives ITS2

I. Highly efficient tracking over an extended momentum range, with special emphasis on very low momenta;

II. Very precise reconstruction of secondary vertices from charm and beauty hadron decays

Example of 'strangeness tracking'

- Charm is exclusively produced in initial hard scatterings, providing unique insight into the QGP

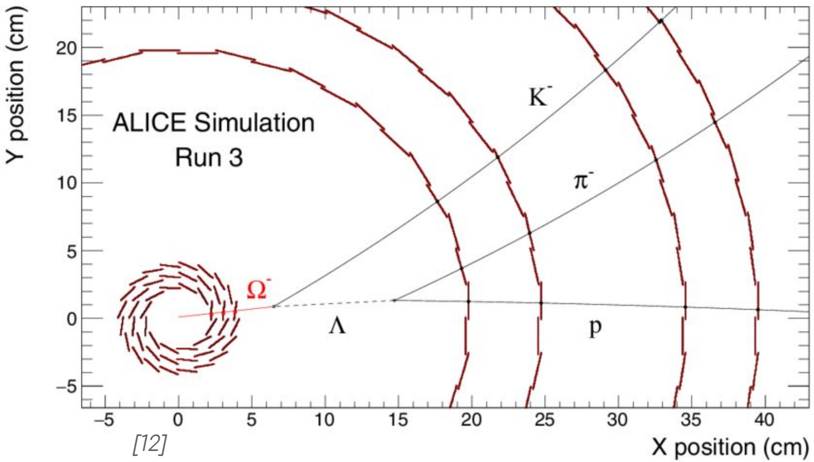
$$\Omega_c^0 \rightarrow \Omega^- \pi^+$$

→ Ω^- points most accurately to the PV

$$\Omega^- \rightarrow K^- + p$$

- But Ω^- only has a proper lifetime of 2.5 cm

→ ITS2 makes it possible to track Ω^- very close to the primary vertex

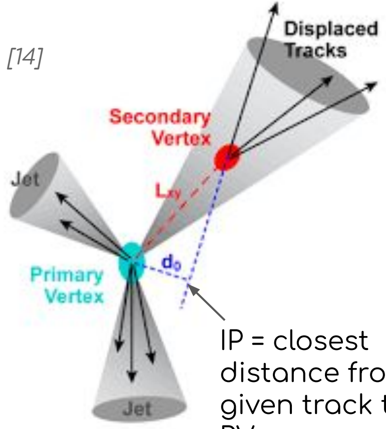


[12]

Information obtained from: [8,12]

How to reach objectives ITS2

[14]



IP = closest distance from given track to the PV

Indicator of whether the particle that was tracked originated from a primary vertex

I. Improve impact parameter resolution

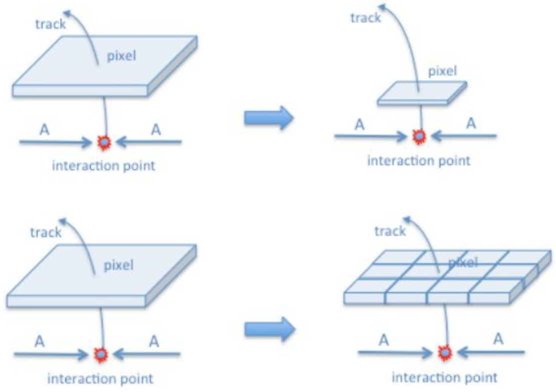
How?
→ getting closer to the IP
→ reducing material budget inner layers
→ reducing pixel size

II. Improve tracking efficiency and resolution at low transverse momentum

How?
→ increasing granularity: pixel size and more layers

III. Fast readout
Increased from 1 kHz to 100 kHz in Pb-Pb collisions

LHC interaction rate of ~50 kHz for Pb-Pb collisions



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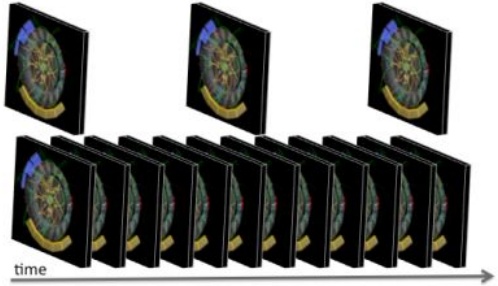
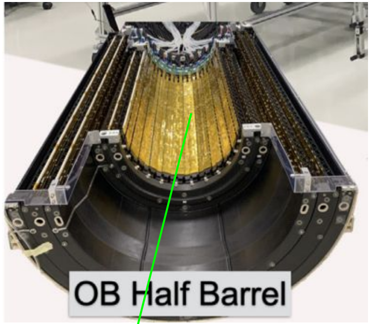


[3]

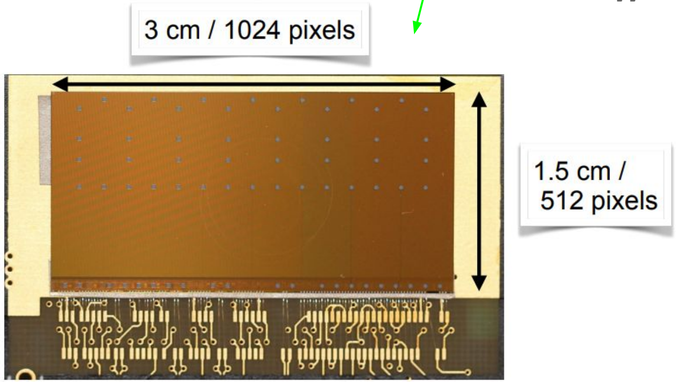
Information obtained from: [1,8,13]

ALPIDE - the Monolithic Active Pixel Sensor for ITS2

- CMOS Monolithic Active Pixel Sensors (MAPS)
  - Integrated read-out electronics
- ALPIDE chip
- Have to be radiation-hard to maintain spatial resolution
  - Have to be tolerant against 700 krad of total ionising dose and fluence of 10^{13} MeV n_{eq}/cm^2



[1]



ALPIDE die on carrier card [3]

Specifications of ALPIDE chips

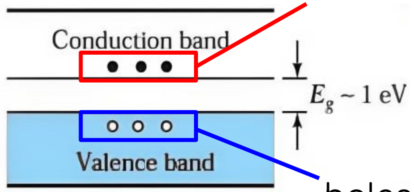
parameter	**value**
chip dimensions	15 mm x 30 mm (rϕ x z)
thickness	50 μm (inner layers)
spatial resolution	5 μm
detection efficiency	> 99%

Information obtained from: [1,8]

Working principle MAPS

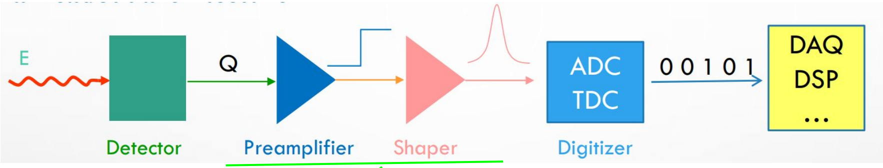
electrons partaking in conduction

excitation



holes

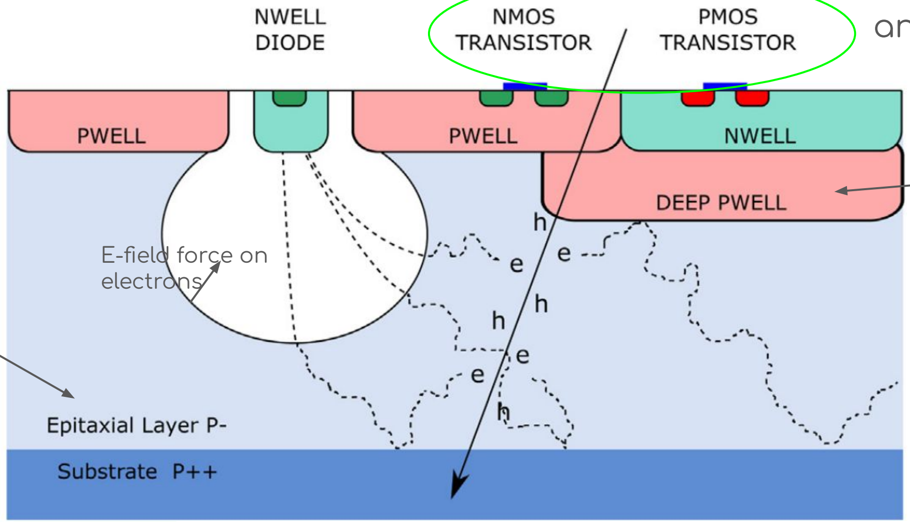
Adapted from [16].



[15]

CMOS read-out electronics: in-pixel amplification, shaping, and discrimination

[1]



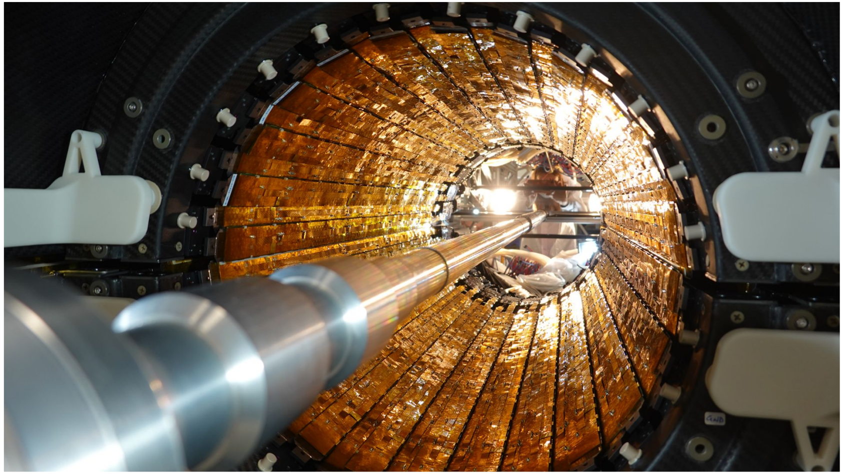
Makes sure that nwell of PMOS doesn't compete with collection nwell

different resistivity than substrate

Information obtained from: [8]

Conclusion

- ITS2 is innermost detector of the ALICE detector
- Allows us to study the primordial quark-gluon plasma even better by providing greater precision closer to the beam axis
- Consists of Monolithic Active Pixel Sensors with integrated electronics
- To this day the largest and most granular pixel detector



[10]

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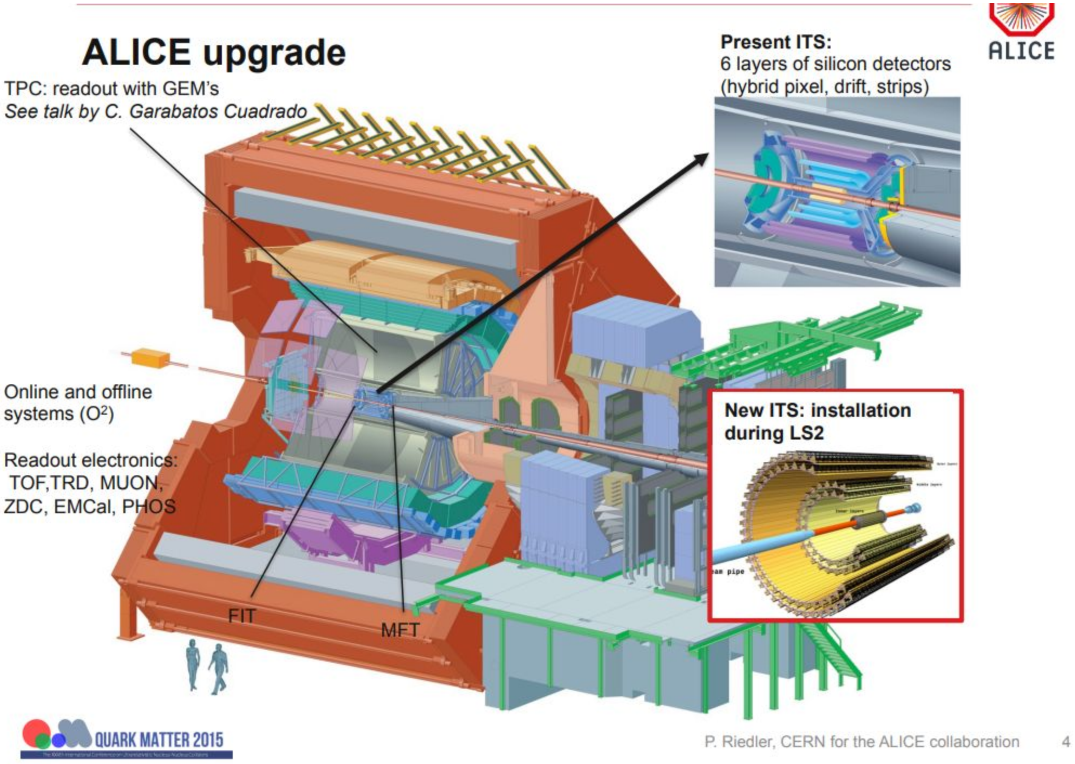
Backup

Differences ITS and ITS2



[17]

Differences ITS and ITS2

Table I. Main technological features of updraded ITS (ITS2) compared to the older ITS (ITS1). The radial positions are the average between the minimum and maximum radii of the innermost layer.

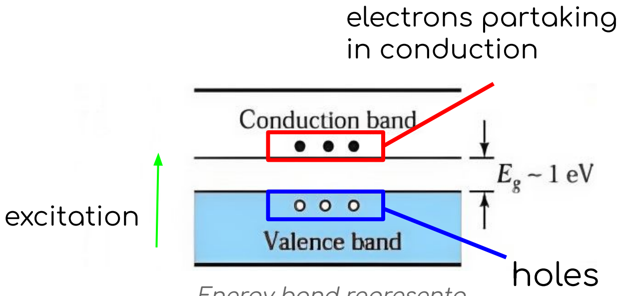
	ITS1	ITS2
Readout rate	up to 1 kHz	> 100 kHz (Pb–Pb)
		> 400 kHz (pp)
Material budget	1.1% X_0	0.36% X_0 (Inner Barrel)
		1.1% X_0 (Outer Barrel)
Pixel size	50×425 μm^2	27×29 μm^2
Pointing resolution (p_T = 500 MeV/c)	~240 μm (z)	~50 μm (z)
	~120 μm ($r\varphi$)	~40 μm ($r\varphi$)
Standalone tracking efficiency (p_T = 200 MeV/c)	~60%	~90%
Radius (innermost layer)	3.9 cm	2.5 cm

[11]

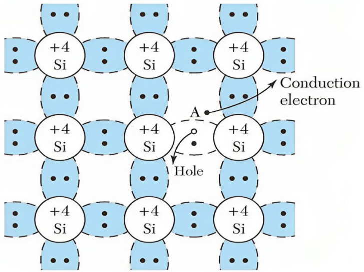
Working principle silicon sensors

- Incident particle excites electron from the valence band into the conduction band, leaving behind a positively charged hole

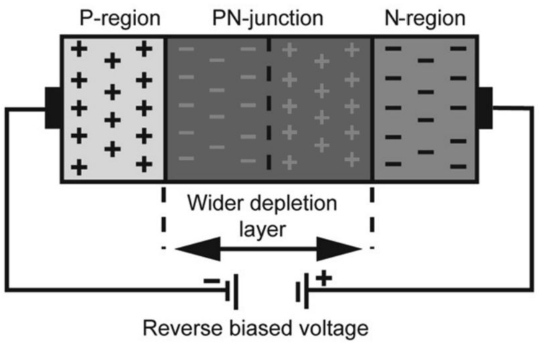
  → charge conduction



Energy band representation for semiconductors. Adapted from [16].



2D representation of bond breaking in silicon [16].



A p-n junction under a reverse bias voltage. Adapted from [18].

- Silicon sensors are based on the concept of a p-n junction
- Doping: the addition of impurity atoms to increase the conductivity
  - n-type: electrons are majority charge carrier
  - p-type: holes are majority charge carrier