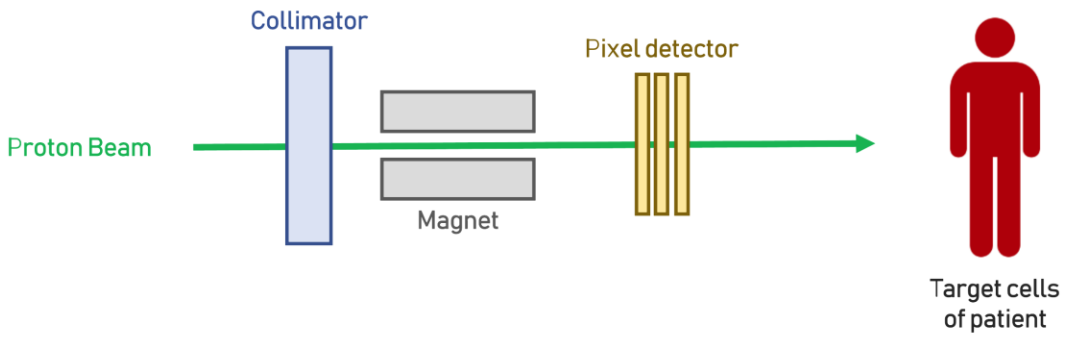
Pixel Detector Based System for Beam and Quality Monitoring in Hadron Therapy



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Motivation

- Those who received proton therapy experienced far fewer serious side effects than in traditional radiation, the researchers found.
- Within 90 days of starting treatment, 45 patients (12%) in the proton therapy group and 301 patients (28%) in the traditional radiation group experienced a severe side effect—that is, an effect severe enough to warrant hospitalization[1].
- Proton therapy appeared to work as well as traditional radiation therapy to treat cancer and preserve life.
- After 3 years, 46% of patients in the proton therapy group and 49% of those in the traditional radiation therapy group were cancer free. 56% of people who received proton therapy and 58% of those who received traditional radiation were still alive after 3 years.
- In the depth comparison, the 2 and 4 Gy dose cases yielded similar mean depth errors between 1 and −1 mm, and the deviation was <2 mm[2].

Motivation

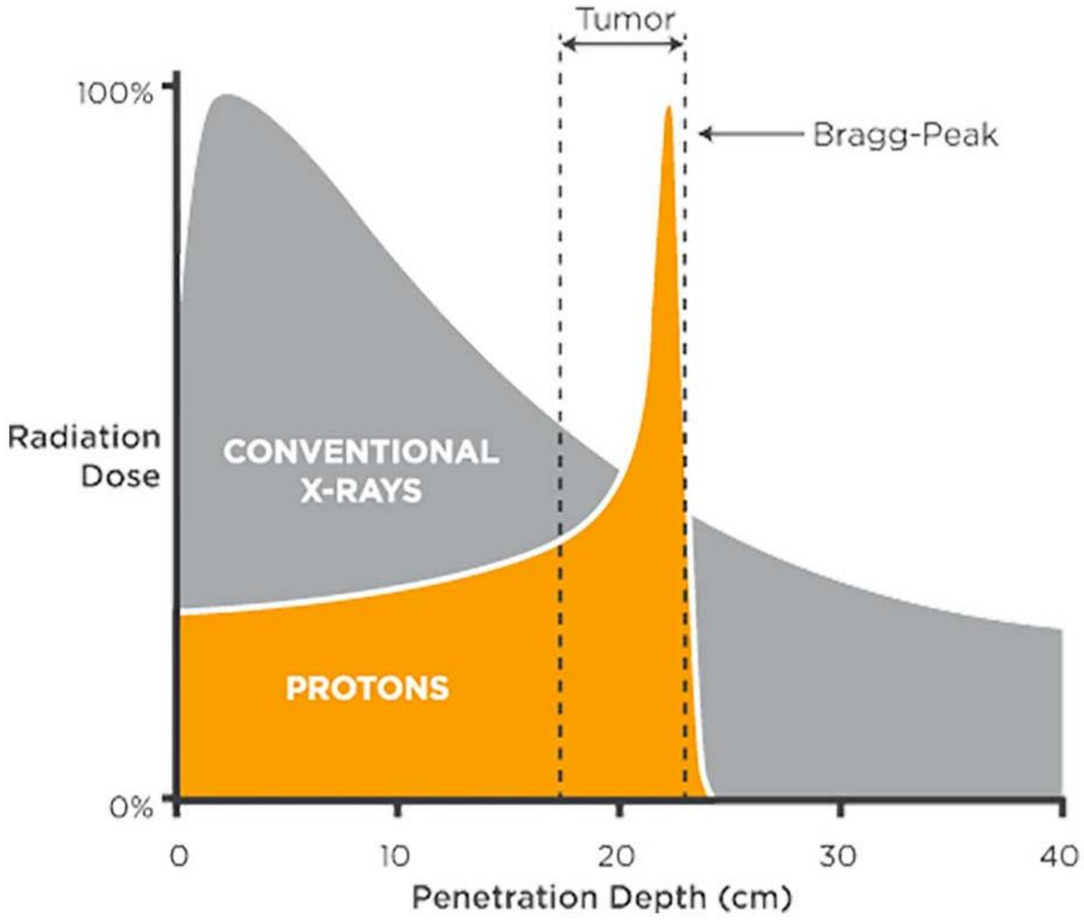


Figure 1. Bragg Peak: Radiation dose vs penetration depth at a fixed energy.

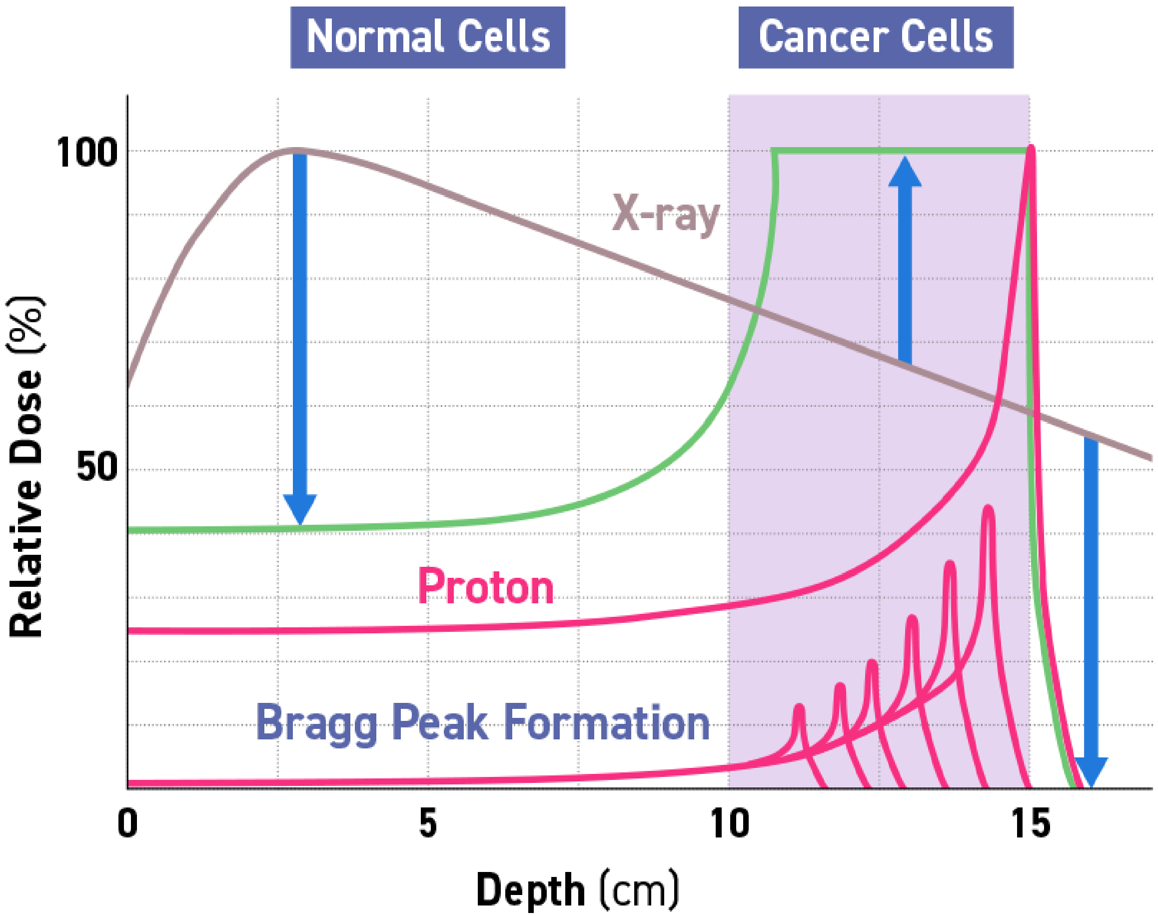


Figure 2. Bragg Peak: Radiation dose vs penetration depth at different values of energy..

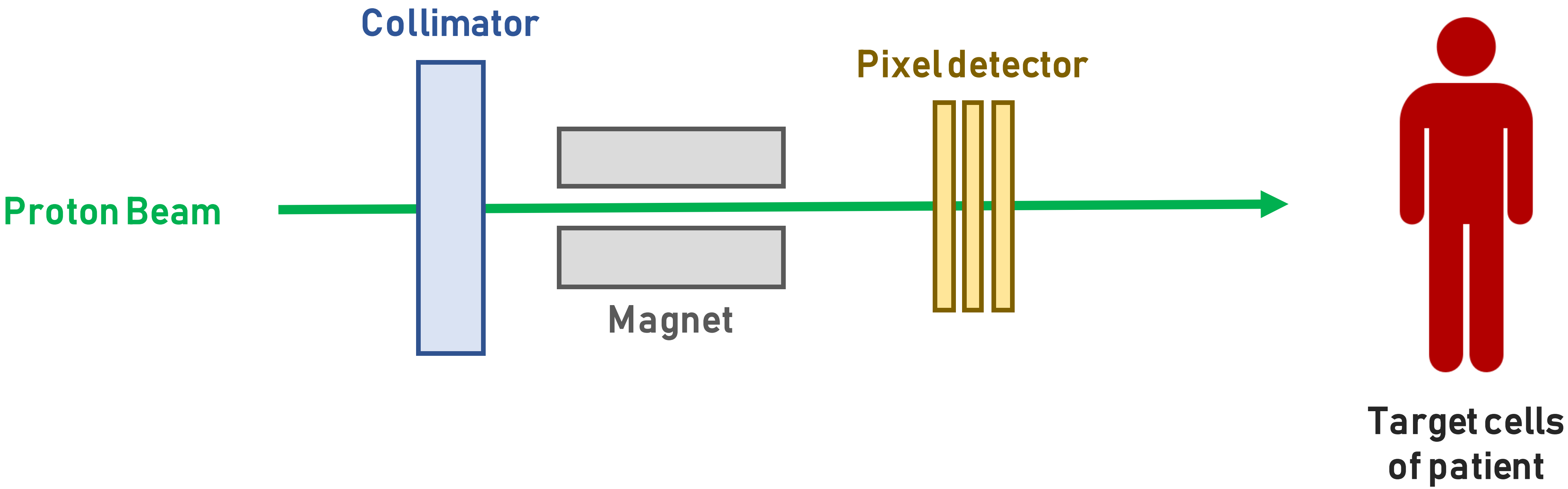
Goals

With three layers of pixels, it's possible to control the correct direction of the proton beam

Beam control can assure that the dose is given correctly to the patient

This decreases the probability of irradiating healthy tissues and organs, hence reducing the risk of side effects

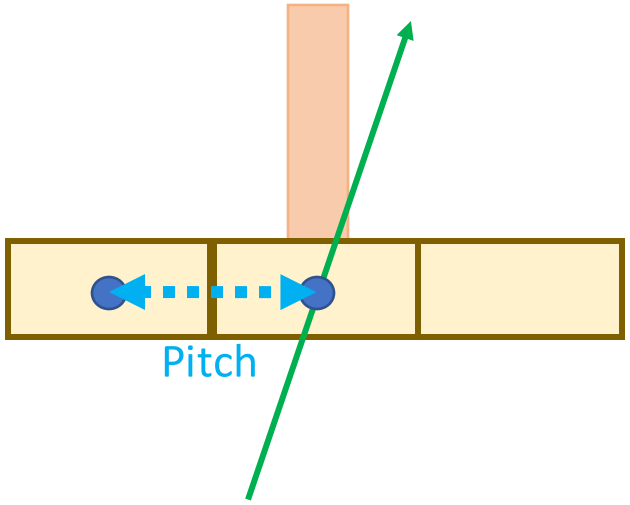
Beam monitor design



Methodology

Position measurement comes from segmentation

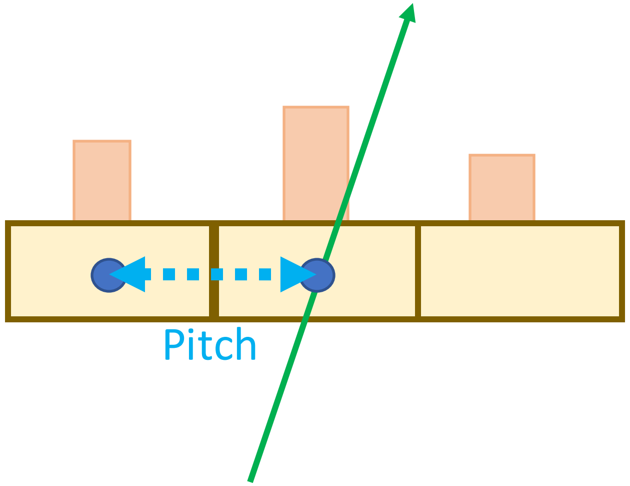
Smaller the pixel, higher the resolution !



$$\sigma_x = \frac{p}{\sqrt{12}}$$

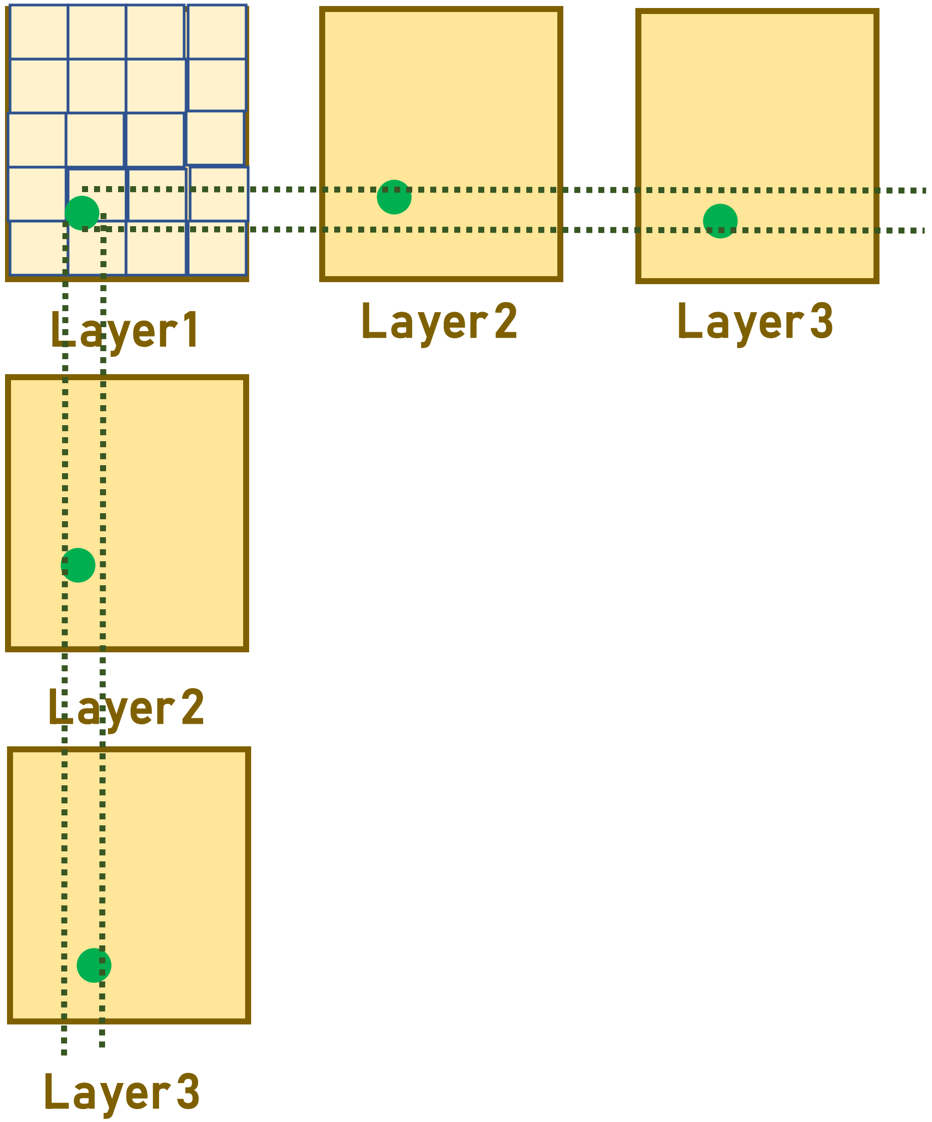
Improve the resolution with signal sharing

Must consider the problem of charge sharing.
Solution may be managing the signal threshold,
software online processing



$$\sigma_x = \frac{p}{(S/N)}$$

Methodology



Knowing the 2D position of the beam as it passes the detector is fundamental to know if the direction is correct.

Even a small difference can affect the correct application of the dose in the patient, thus damaging healthy organs and tissues.

Methodology

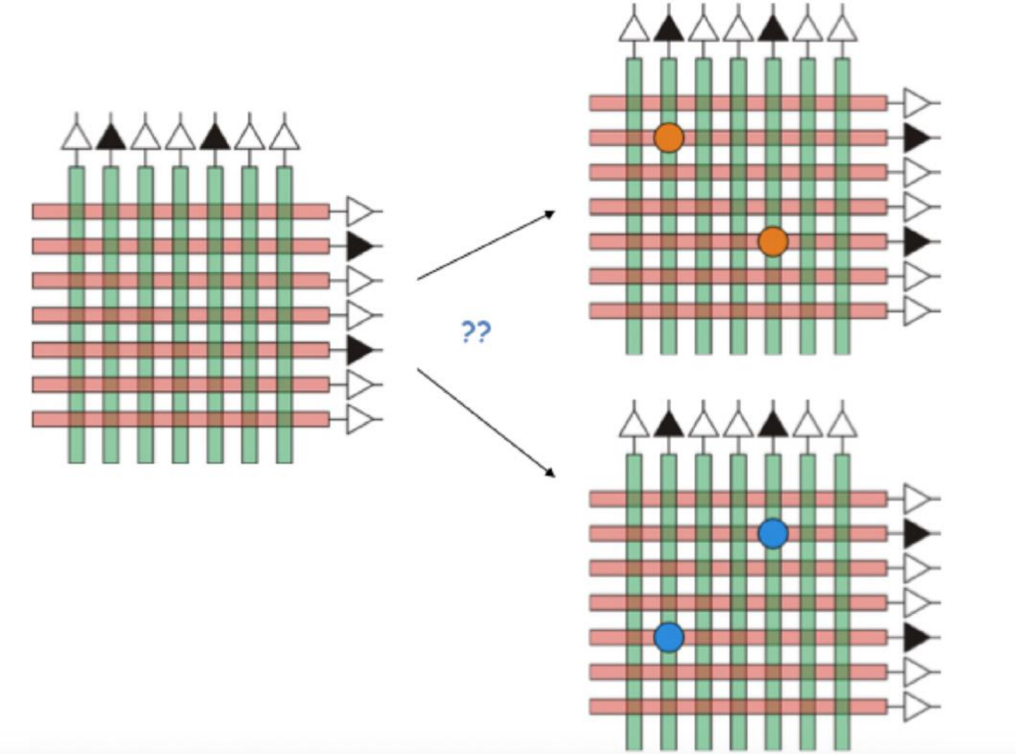


Fig. 3. Ghost trakcs in pixel detectors.
Semiconductor Detectors, *Mengqing Wu, ESIPAP 2023*

Why 3 or more layers?

- Reduce risk of ghost tracks (Fig. 3)
- We can reconstruct the trajectory of the beam, actually in 3D! We know where the pixel layers are fixed (x-axis), then the position recorded by the detector gives the y and z position!

Higher control of dose

Higher resolution of target hit

Lower risk of hitting healthy tissues and organs

Silicon sensor

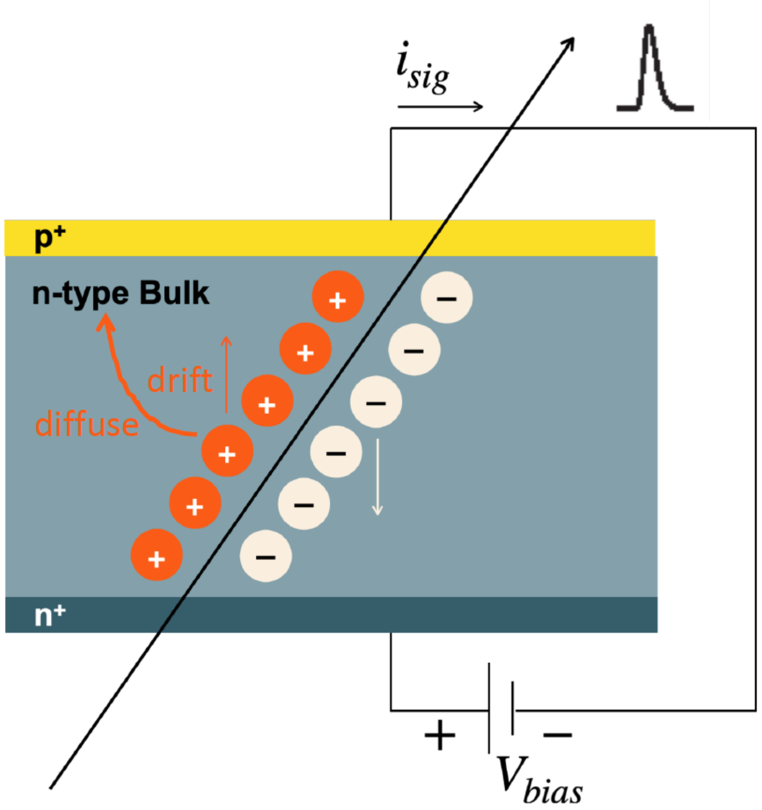


Fig. 4. Basic building block of a Silicon sensor.
Semiconductor Detectors, *Mengqing Wu, ESIPAP 2023*

When the silicon is crossed by a particle:

- It loses its energy by ionizing atoms thus creating electron-hole pairs

- Typical velocity is ~ 50 um/s to cross the depletion zone:

T = (width of silicon)/(drift velocity)

Thin silicon → Very quick pulse will flow to readout electronics → Fast readout electronics is needed

Amplitude of the pulse proportional to the energy loss

Other materials for the pixels ?

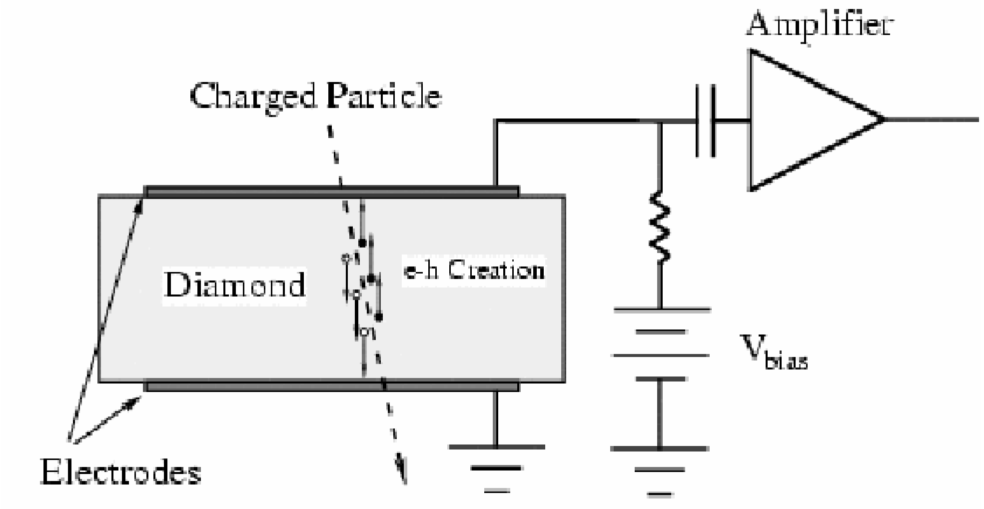


Fig. 5. Schematic layout of a diamond particle detector. [3]

Diamond	Silicon
Bandgap = 5.5eV	Bandgap = 1.12eV
w_i = 13eV	w_i = 3.6eV

- Higher the bandgap, the lower the leakage current, the lower is the noise.
- Higher ther energy w_i to crete an electron hole pair, the smaller the amplitude of the signal.

- Must consider the industrial processes currently used for the production.
- Must consider the cost of the material.

Solution: compromise.
Study on materials is important

Hybrid sensor Vs Monolithic sensor

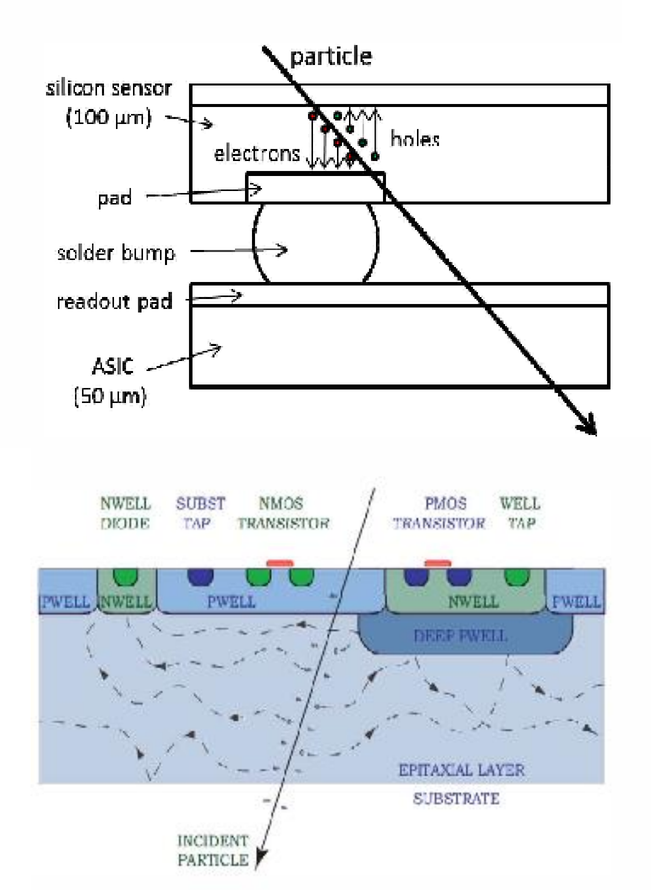


Fig. 6. Structure of hybrid pixel detector (on top) and monolithic pixel detector (on bottom). [4]

	Hybrid Sensors	Monolithic Sensors
Pro	• Collected charge is defined by thickness, • Every pixel is connected to one channel	• Low noise, • Small pixels, • Low material budget
Cons	• Bump-bonding is expensive • Higher material budget (sensor 200÷250um, electronics 100÷200um)	• Slow timing • R/O architecture

Our focus

Make or Buy ?

Buy

Pro	• Immediate access to existing expertise and resources. • No need to invest in equipment or facilities. • Reduced risks associated with production. • Shorter time to market.
Cons	• Less control over the design and production processes, which may lead to sub-optimal performance and/or customization • Limited intellectual property ownership and reliance on the supplier. • Higher long-term costs and less potential for cost savings.

Make or Buy ?

Make

Pro

- Complete control over the design, production, and testing processes, which allows for customization and optimization.
- expertise can be developed, which can be beneficial for future projects and operations.
- Intellectual property is owned by the organization.
- The potential for lower long-term costs and greater cost savings.

Cons

- The organization may need to invest in equipment, facilities, and personnel, which can be costly.
- The organization may have to take on additional risks associated with production, such as quality control and liability.
- Time-consuming, which can delay project timelines.

Resources

- Access to a proton source facility is necessary during the project for R&D.
- The project team should be composed by:
  - Two physicist: preferred one expert in medical physics and one in particle physics;
  - Three engineers: these positions should require two electronics engineers for the design of the required electronics, one electronic engineer with background on semiconductor devices;
  - One instrumentation technician is required to manage the instrumentation and help during experimental trials;
  - One project manager, with experience in business management, preferred in scientific field
- Collaborations with semiconductor facilities should be made to produce prototypes.
- Data analysis tools for simulations and development are required

Project costs

The costs can be divided in two groups: directs costs and indirect costs

Direct costs

- Salaries of the project team members (physicists, engineers, technician, and project manager).
- Equipment, facilities, and supplies required for R&D, production, and testing.
- Costs associated with collaborations with semiconductor facilities.
- Cost of the proton source facility.
- Cost of data analysis tools.

Indirect costs

- Overhead costs, such as rent, utilities, and insurance.
- Administrative costs, such as legal and accounting fees.

Project costs

Assuming a team of 7 people working full-time for 5 years, from January 2024 until December 2029

Direct costs

- With an average salary of $50,000 per year, the total salary cost would be around $1.75 million.
- Equipment, and supplies required for R&D, production, and testing. depending on the complexity of the design, the equipment and supplies required could be significant. A rough estimate would be around $750,000.
- Costs associated with collaborations with semiconductor facilities: depending on the extent of collaboration, these costs could be around $250,000.
- Cost of data analysis tools: The cost of these tools will depend on the specific software and licensing fees. A rough estimate would be around $25,000

Costs of the project

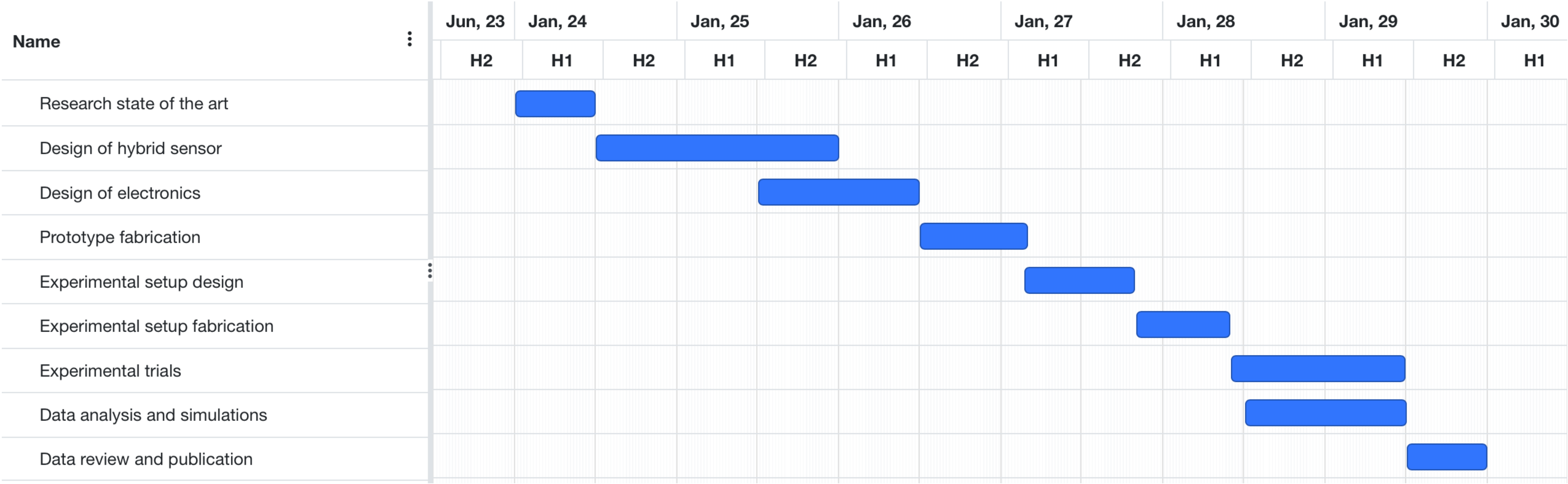
Indirect costs

- Overhead costs: the total overhead cost would be around $2 millions.
- Administrative costs: These costs will depend on the complexity of the project and the specific administrative tasks required. A rough estimate would be around $150,000.

Direct costs	+	Indirect costs	=	Total costs
2,775,000 $	+	2,150,000 $	=	4,925,000 $

Time management

The project is expected to start in January 2024, until December 2029, for a total duration of 5 years.



Thank you for your attention

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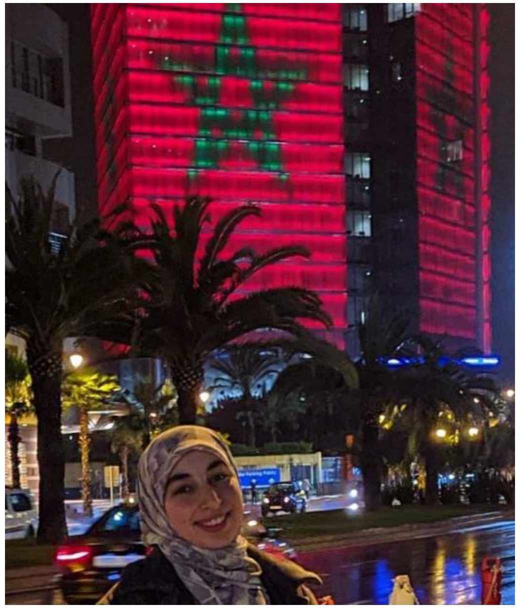

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Bibliography

[1] January 12, 2023, December 22, 2022, & December 2, 2022. (n.d.). *Is proton therapy safer than traditional radiation?* National Cancer Institute. Retrieved March 9, 2023, from https://www.cancer.gov/news-events/cancer-currents-blog/2020/proton-therapy-safety-versus-traditional-radiation

[2] Zhang, J., Lu, Y., Hsi, W., Zhang, J., Sheng, Y., Shi, L., Wang, W., Lu, J., Zhou, R., & Cheng, J. (2018, October 24). *Evaluation of proton therapy accuracy using a PMMA Phantom and pet prediction module*. Frontiers. Retrieved March 9, 2023, from https://www.frontiersin.org/articles/10.3389/fonc.2018.00523/full

[3] Mikuz, Marko & Cindro, V. & Dolenc, I. & Kagan, H. & Kramberger, G. & Frais-Kölbl, Helmut & Gorisek, Andrej & Griesmayer, E. & Macek, B. & Mandic, I. & Niegl, M. & Pernegger, H. & Smith, Dale & Tardif, Diane & Trischuk, W. & Weilhammer, Peter & Zavrtanik, Marko. (2008). The ATLAS beam conditions monitor. Journal of Instrumentation. 3. 1914 - 1917. 10.1109/NSSMIC.2007.4436530.

[4] Cavicchioli, C. (1970, January 1). *New Pixel Detectors for the upgrade of the Alice Inner Tracking System: Semantic scholar*. 2012 IEEE Nuclear Science Symposium and Medical Imaging Conference Record (NSS/MIC). Retrieved March 9, 2023, from https://www.semanticscholar.org/paper/New-pixel-detectors-for-the-upgrade-of-the-ALICE-Cavicchioli/edb3e0f2be06fc5e425fcab0c0d7eebf98b3dfee