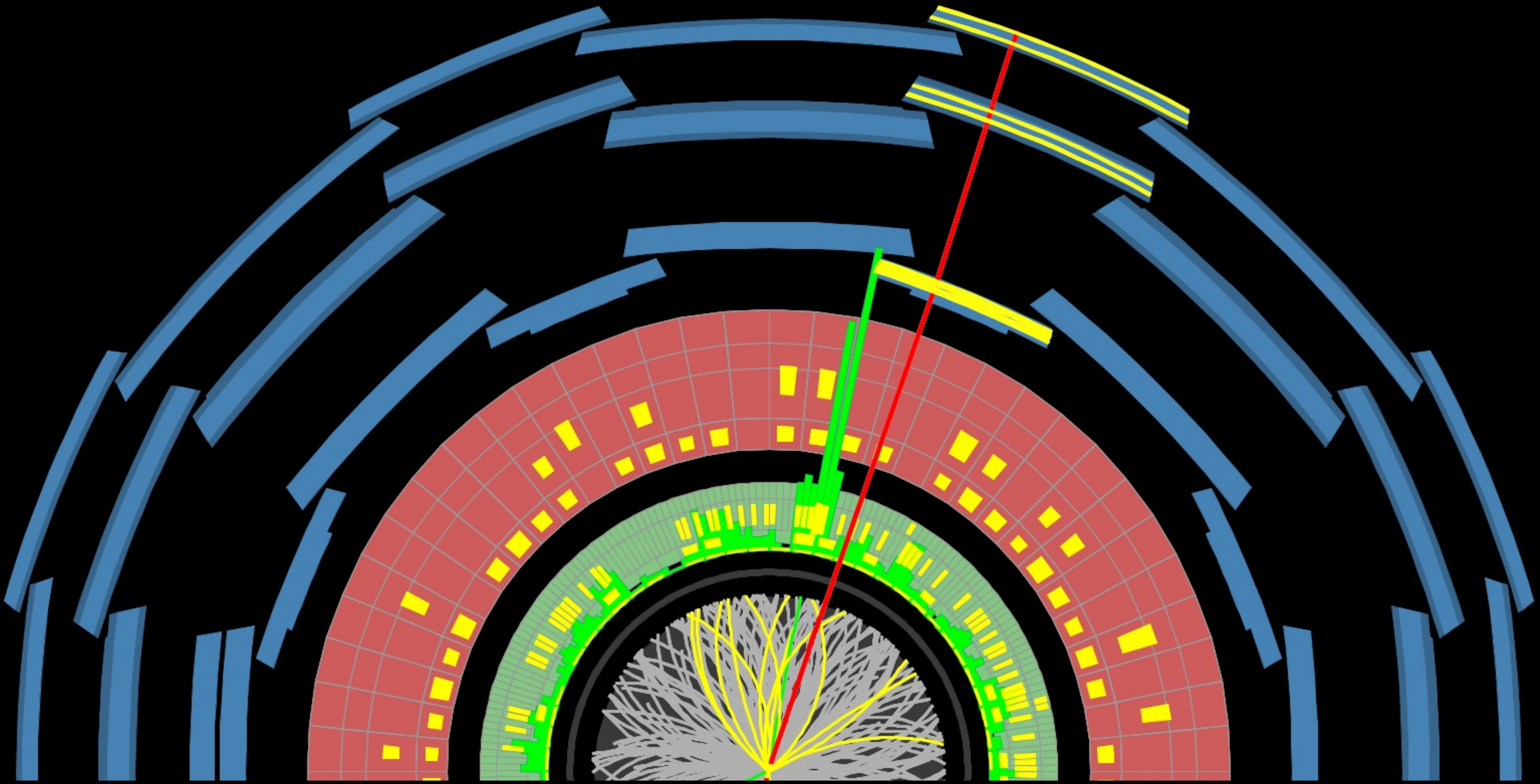


ATLAS detector & tracker upgrade

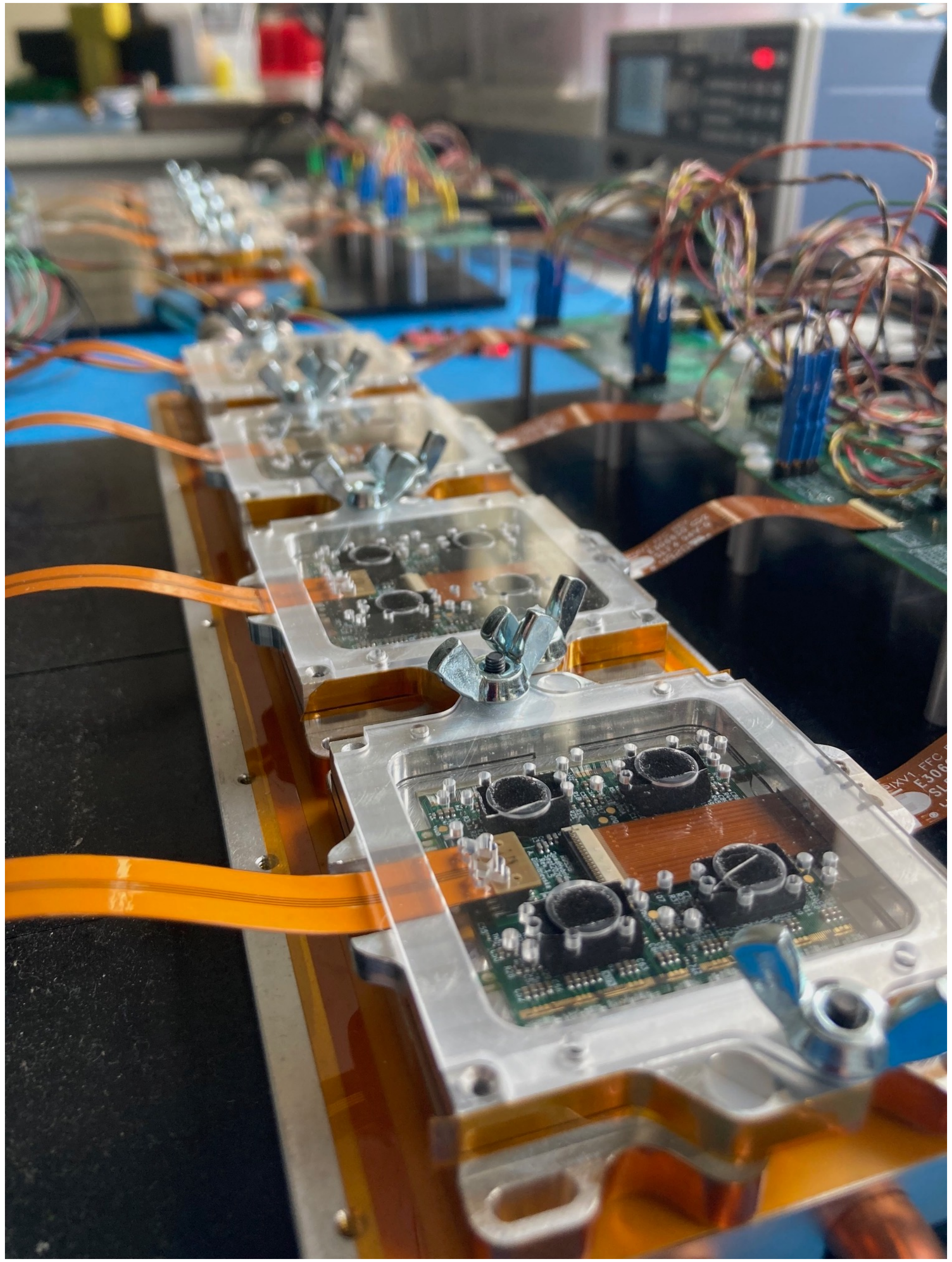
ATLAS EXPERIMENT

QuarkNet Bay Area | Emily A. Thompson | Feb. 3, 2024

BERKELEY LAB

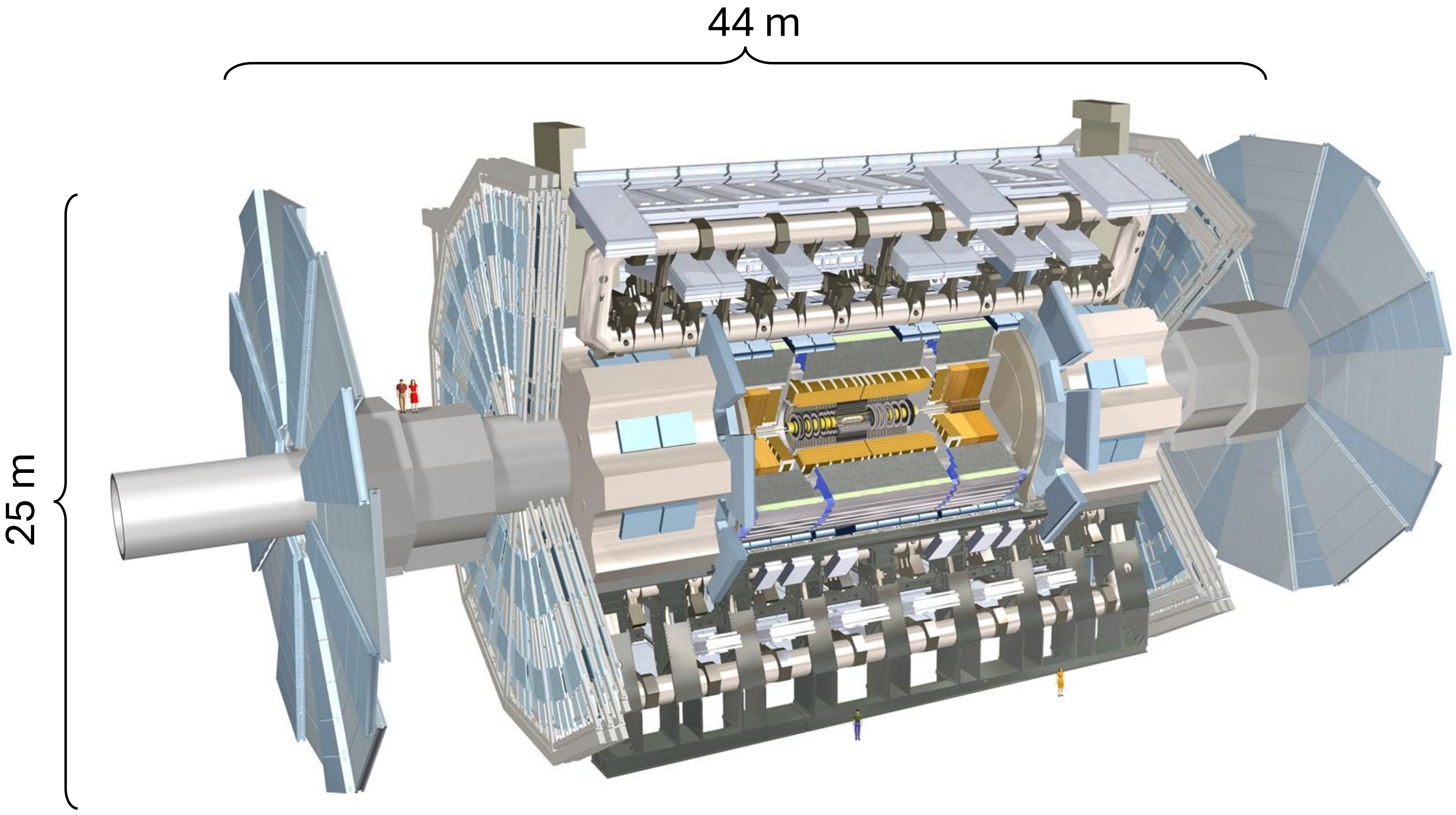
Overview

1. Overview of the **ATLAS detector**
2. Design our own **silicon tracking detector**
3. Construction of a new silicon tracker for the **High-Luminosity LHC**



The ATLAS detector

The ATLAS detector is one of the general-purpose detectors at the LHC



CERN-GE-0803012

The ATLAS detector

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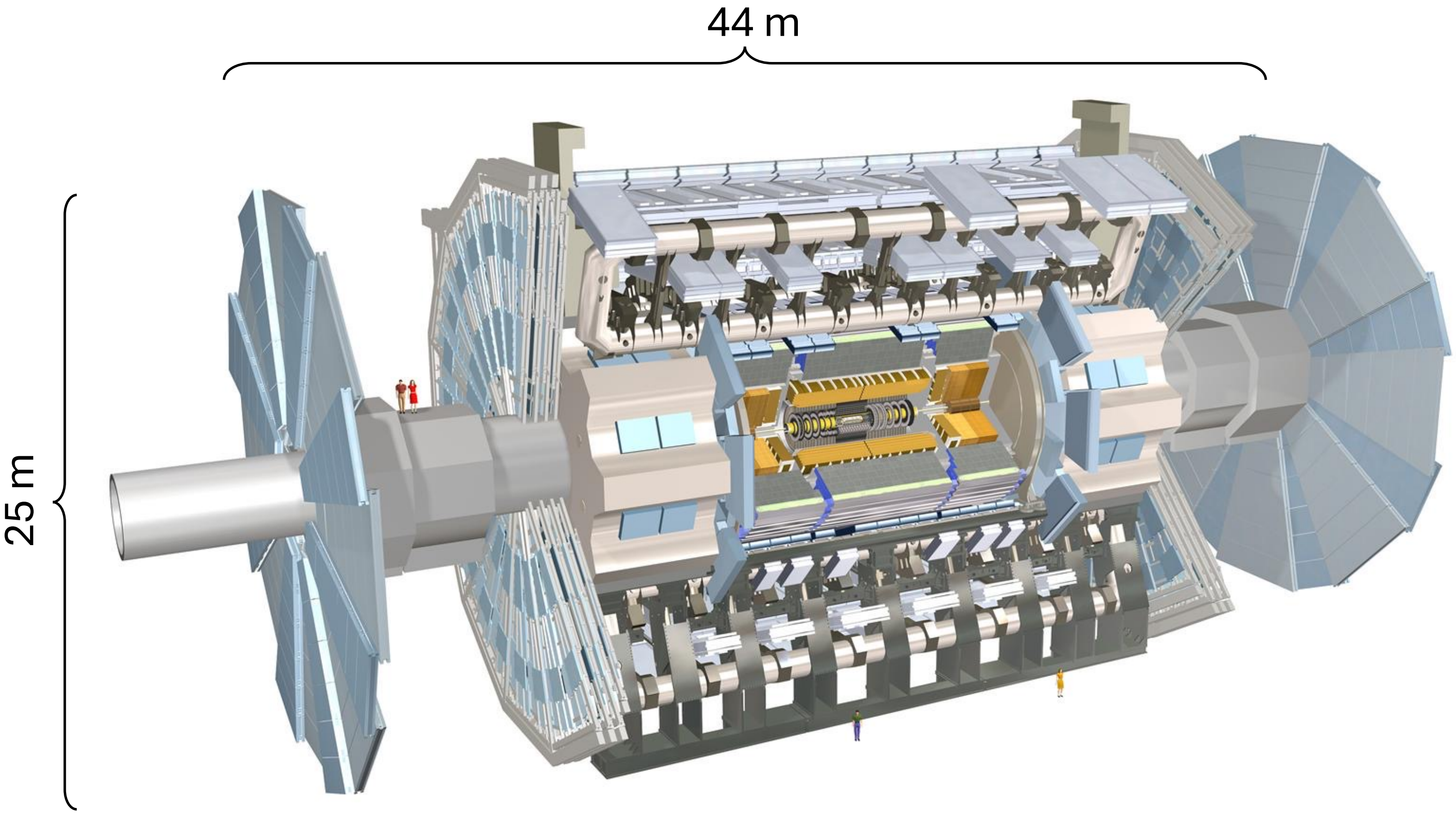


Superconducting magnets bend trajectory of charged particles

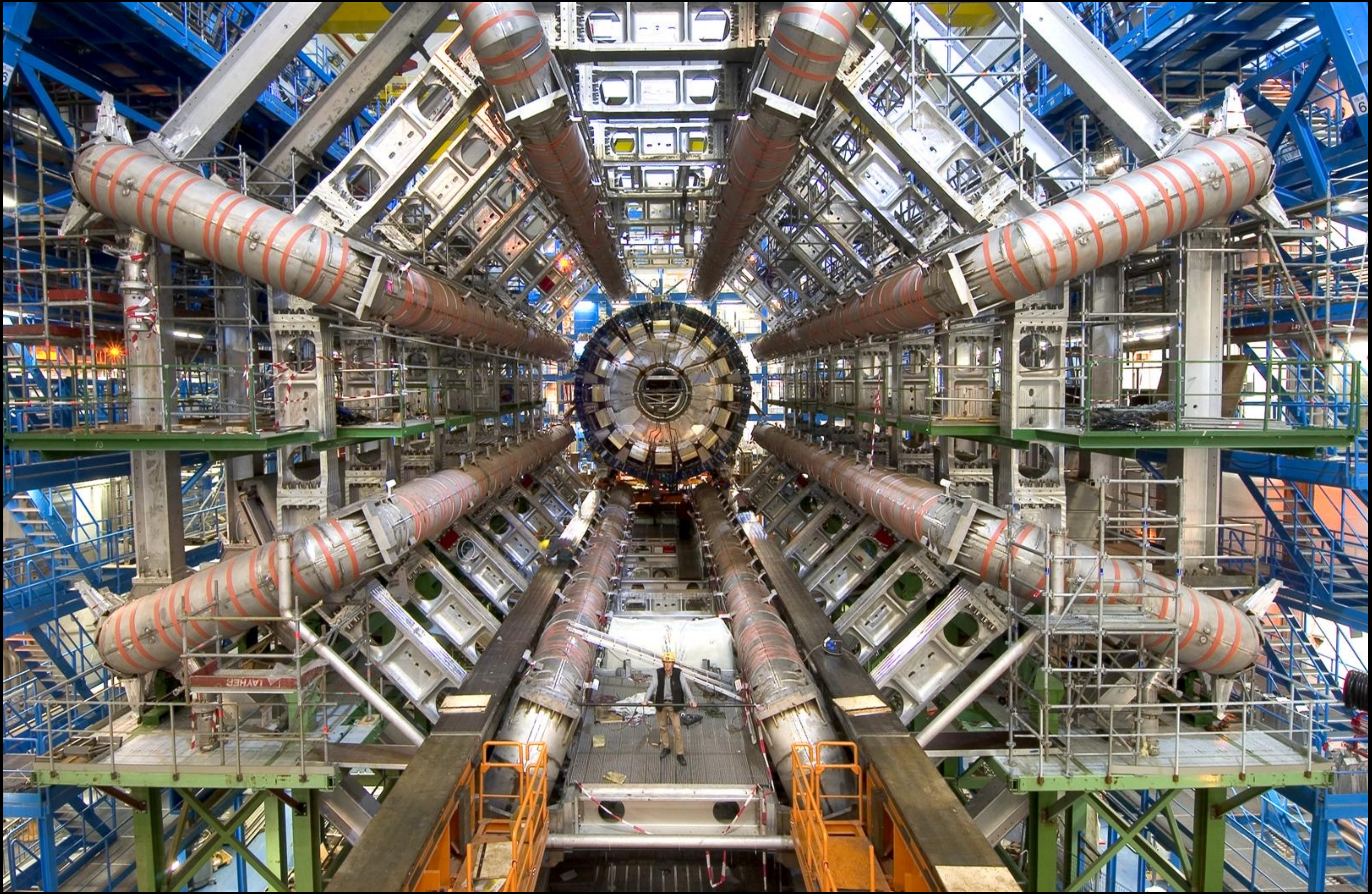
Each layer of ATLAS has a different particle-detecting technology:

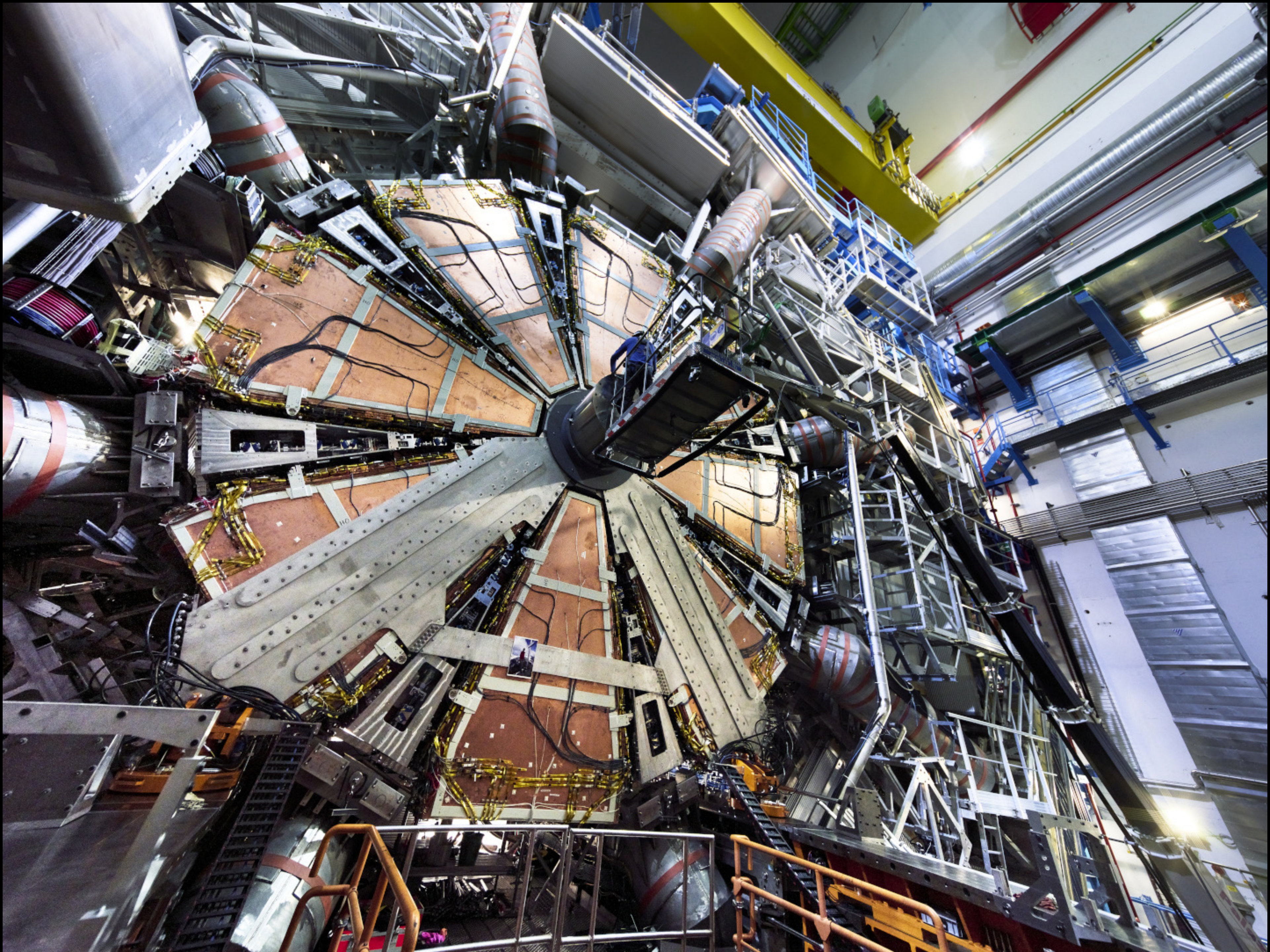
1. **Tracking detectors**
   Leave particles undisturbed but track their trajectory

2. **Calorimeters**
   Stop most particles and measure their energy

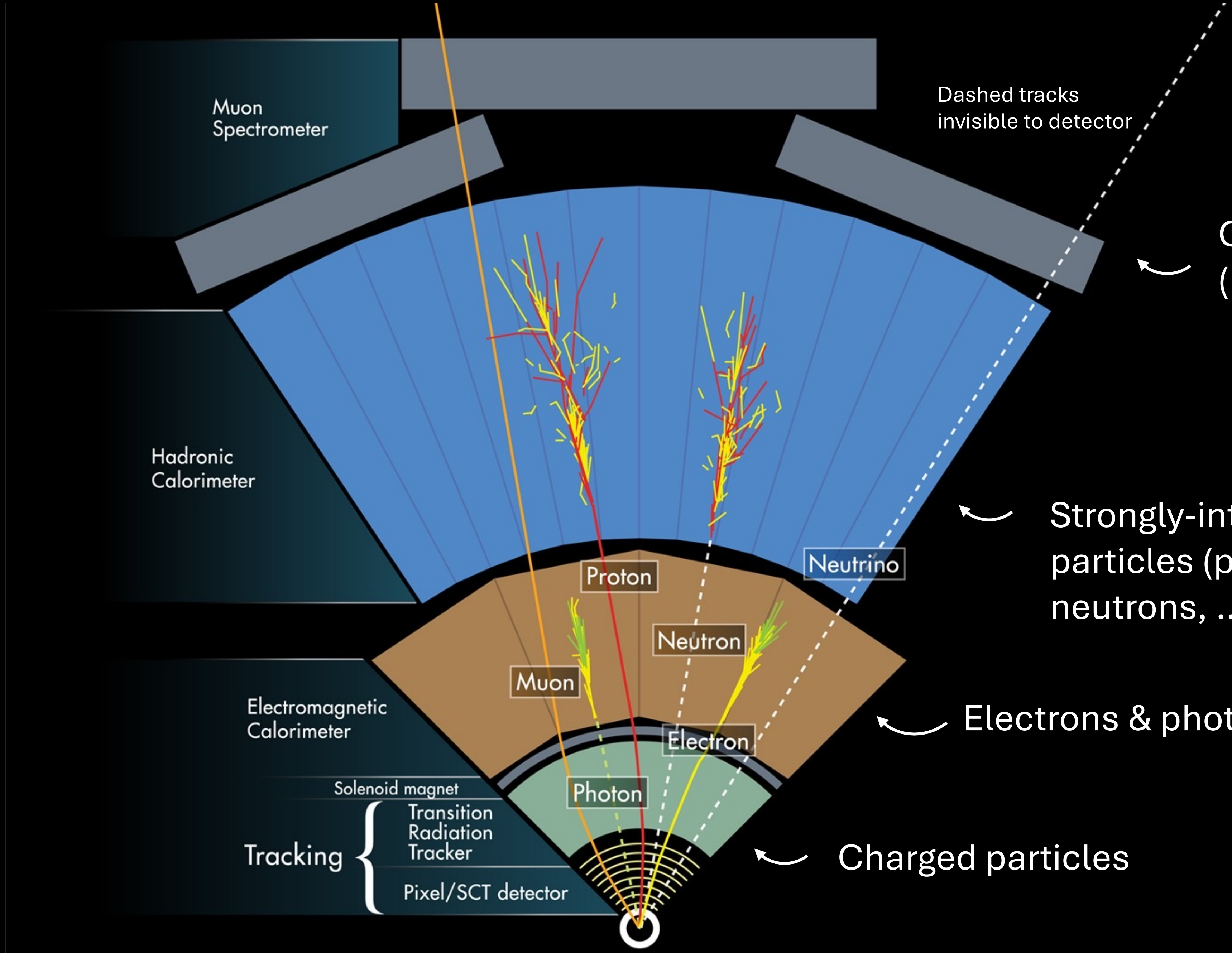
3. **Muon spectrometer**
   Track trajectory of particles that traverse calorimeters (muons)

CERN-GE-0803012





Particle identification in ATLAS detector



Dashed tracks invisible to detector

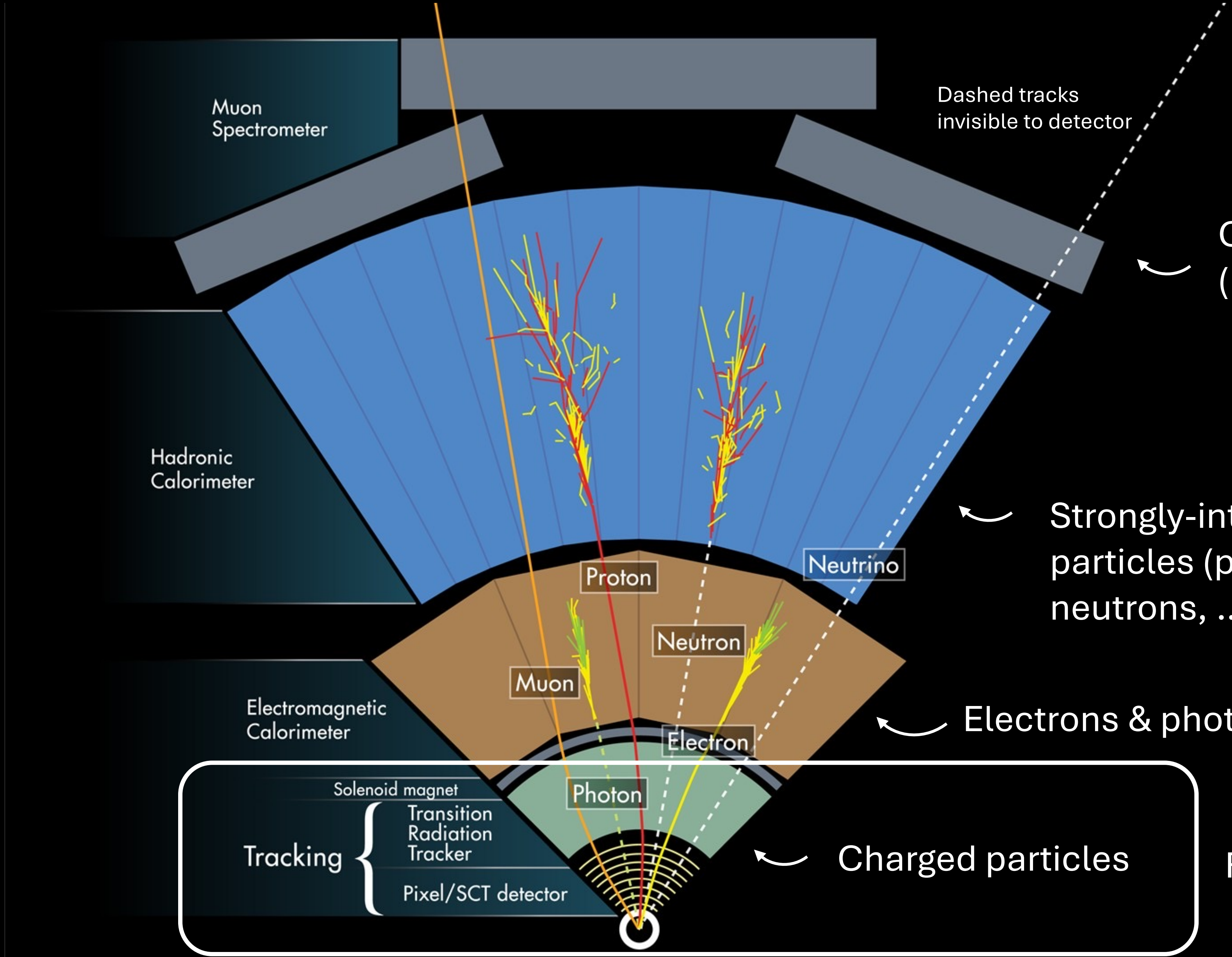
Charged particles (muons)

Strongly-interacting particles (photons, neutrons, ...)

Electrons & photons

Charged particles

Particle identification in ATLAS detector



Dashed tracks invisible to detector

Charged particles (muons)

Strongly-interacting particles (photons, neutrons, ...)

Electrons & photons

Charged particles

Focus of this talk

Goal of particle tracking

Goal of tracking is to measure precisely the trajectory of charged particles

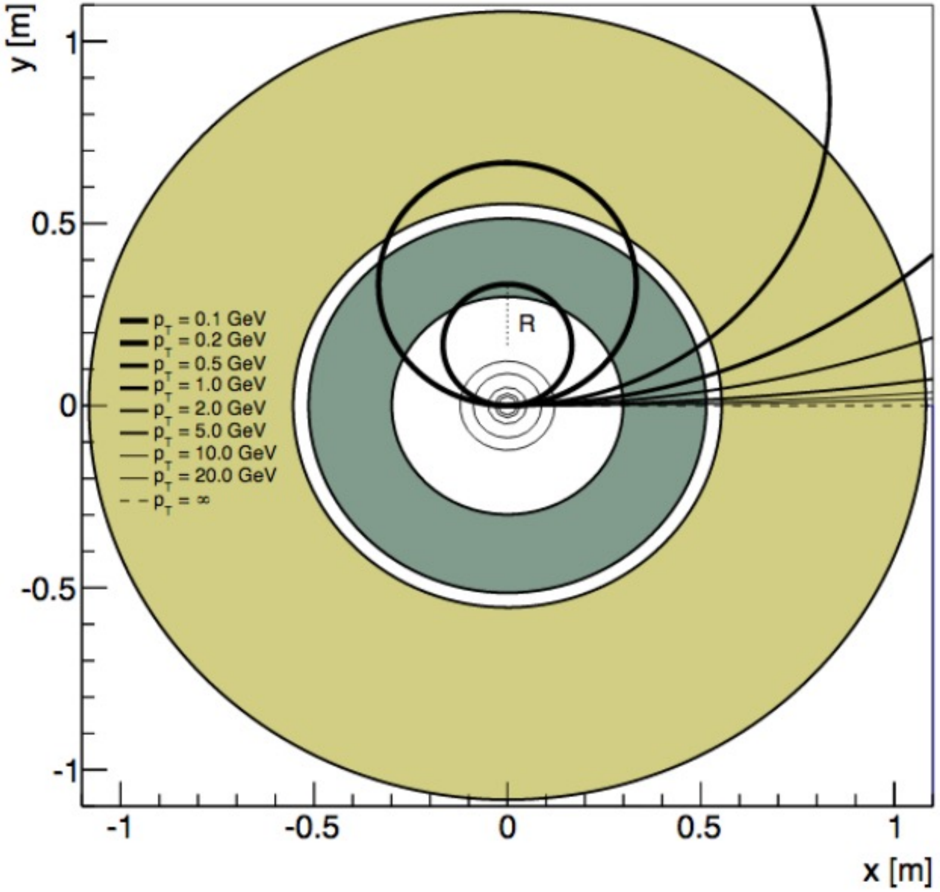
Goal of particle tracking

Goal of tracking is to measure precisely the trajectory of charged particles

- ✓ Gives measurement of momentum

$$\frac{p_{\mathrm{T}}}{\mathrm{GeV}} \approx 0.3 \left(\frac{B}{\mathrm{T}}\right) \left(\frac{R}{\mathrm{m}}\right)$$

Particle with p_T = 0.3 GeV will have bending radius of 1 meter in 1 T field

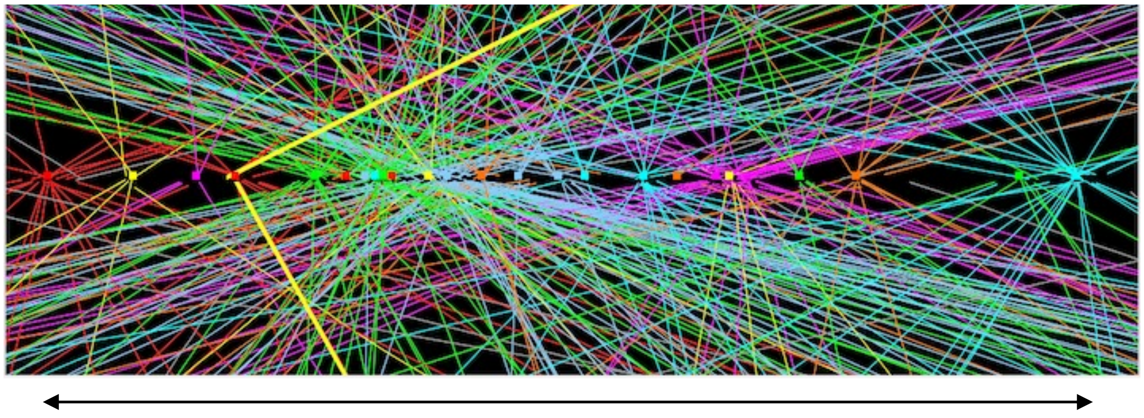


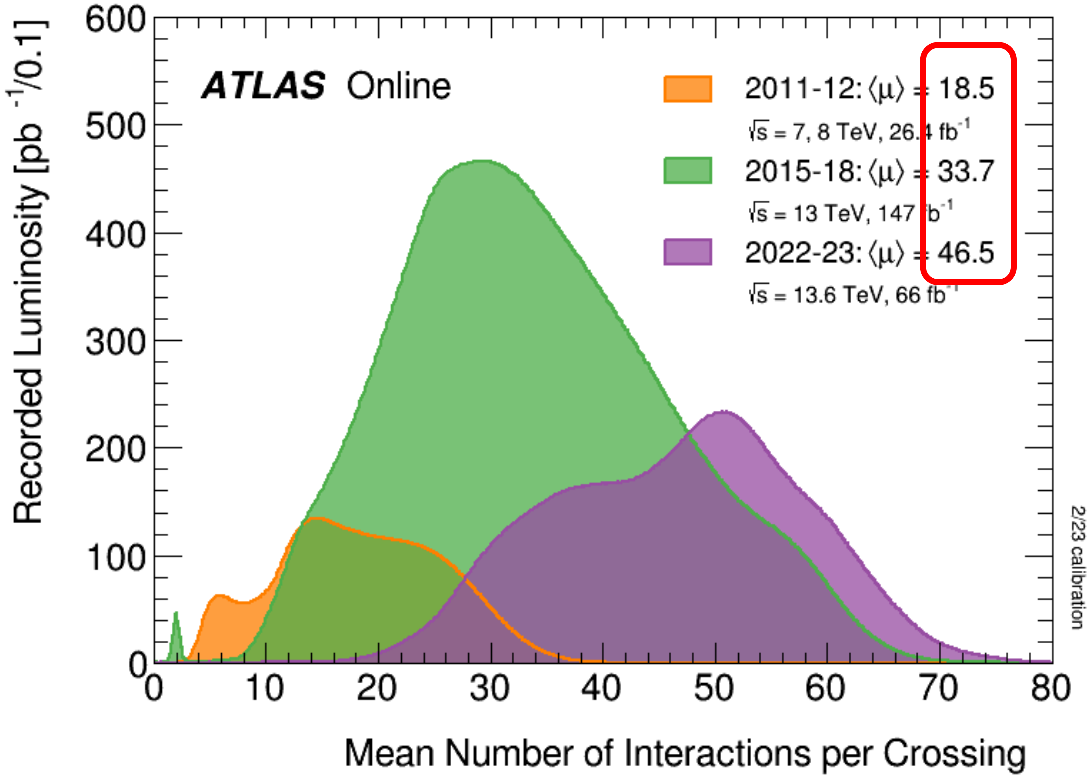
Goal of particle tracking

Goal of tracking is to measure precisely the trajectory of charged particles

- ✓ Gives measurement of momentum
- ✓ Determine if particle comes from primary interaction (impact parameter resolution)

Many protons interact in every bunch crossing – but we are only interested in the primary interaction





Silicon as a particle detector

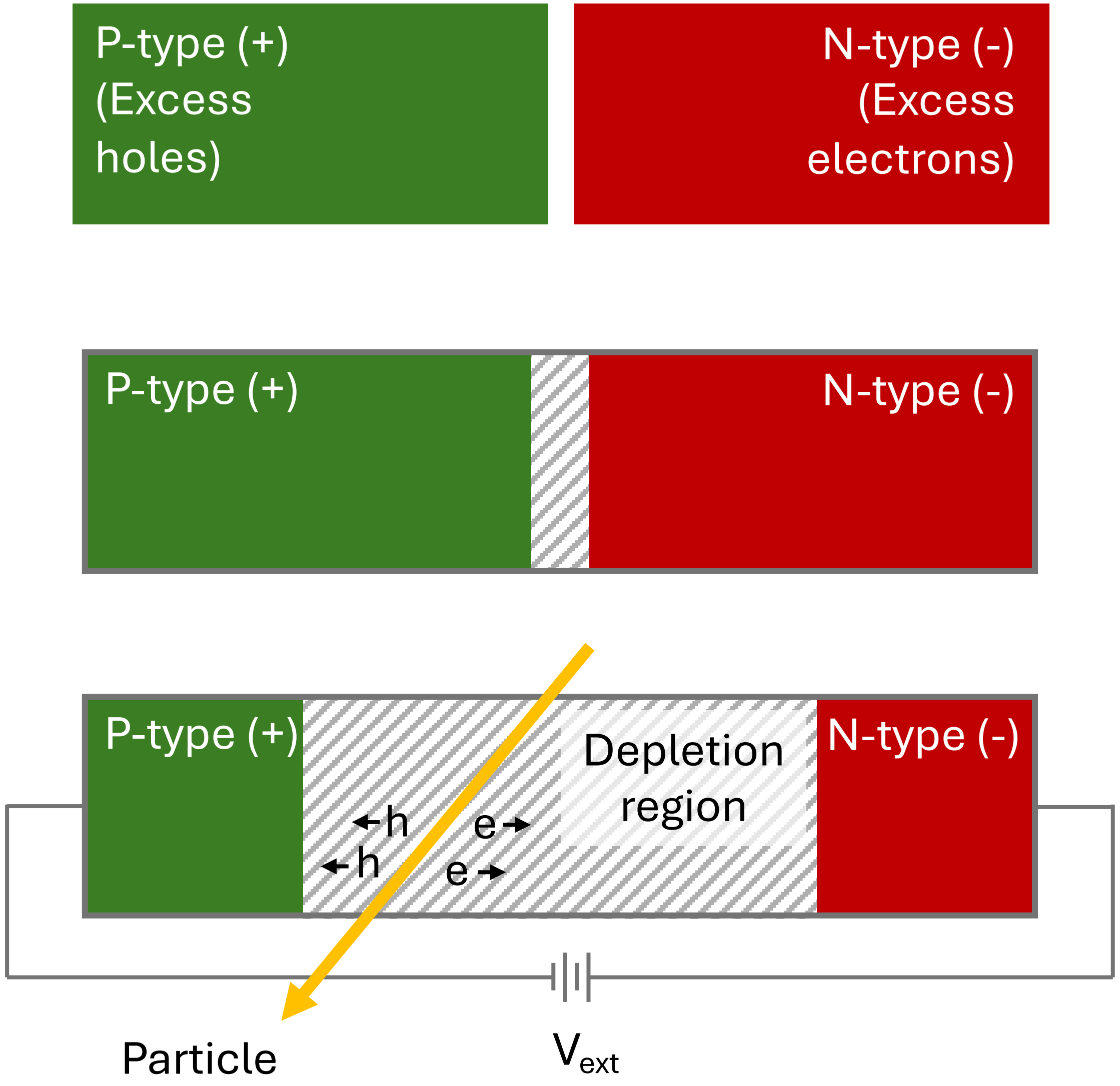
Silicon is a semiconductor (between insulator and conductor)

Doping alters properties of silicon → introducing impurities into the crystalline lattice

A pn junction in silicon creates **depletion region**, which is extended with external voltage

Particles passing through silicon will create free electron-hole pairs, and drift of those charge carrier creates **measurable current**

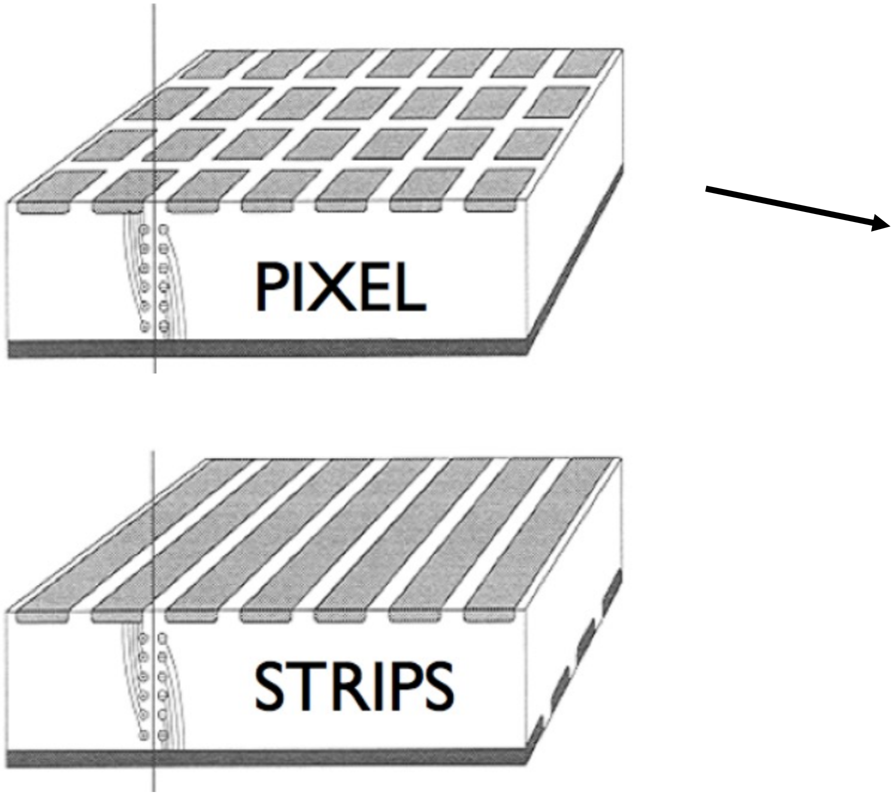
pn-junction as a particle detector:



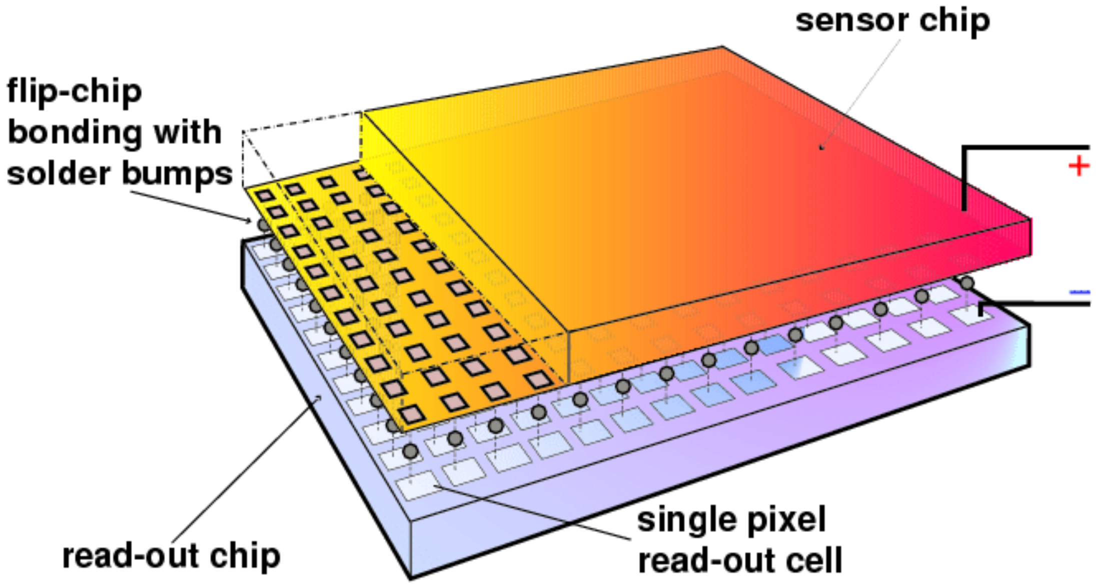
Silicon as a particle detector

Silicon doped regions are segmented into **pixels or strips**

Pixels / strips are connected to **readout chip** (ASIC) to collect signal from drifting charges

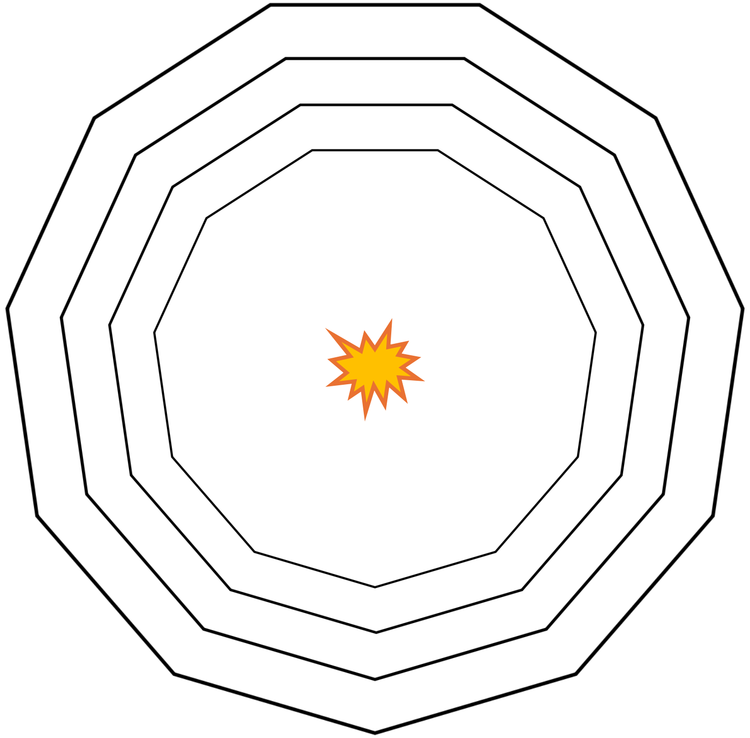


"Hybrid" pixel detector:



Let’s design a silicon tracker!

With good momentum and impact parameter resolution



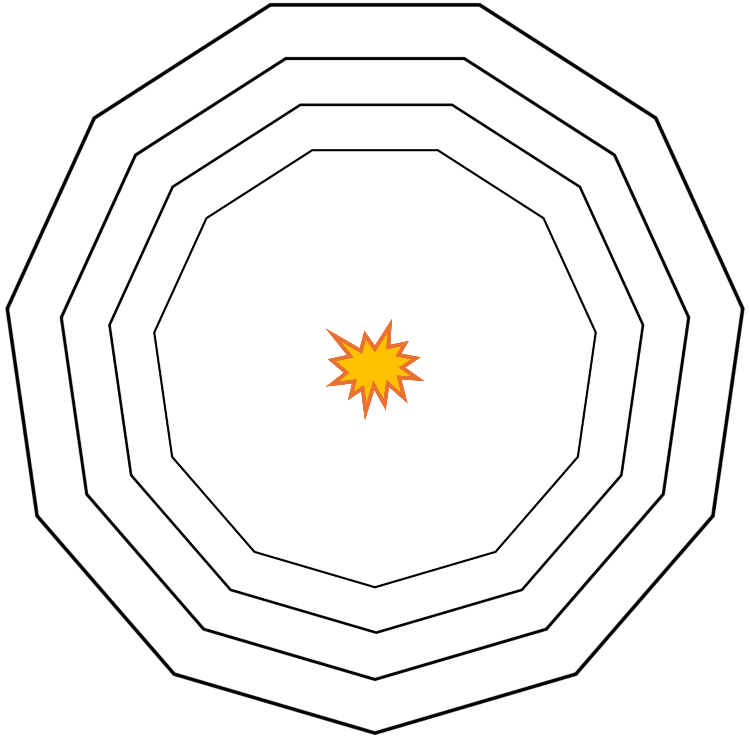
Let’s design a silicon tracker!

With good momentum and impact parameter resolution

Momentum resolution estimated with Gluckstern formula:

$$\underbrace{\frac{\sigma_{p_T}}{p_T}}_{\text{✅ Small}} \approx \underbrace{\sqrt{\frac{720}{N+4}}\left(\frac{\sigma_x p_T}{0.3BL^2}\right)}_{\text{How to minimize?}}$$

L: track length
B: magnetic field strength
σ_x: detector resolution
N: # of measurements



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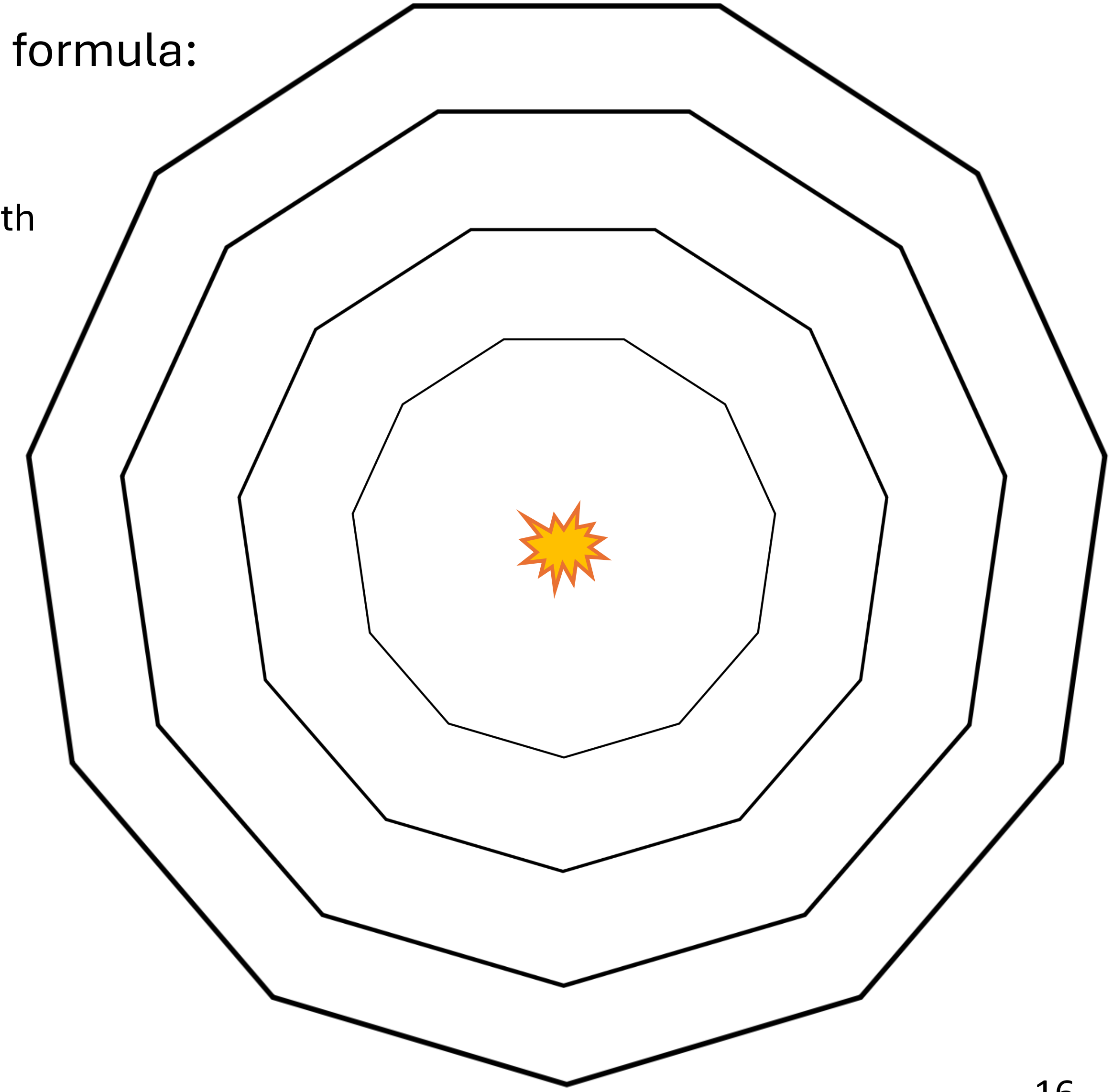
1. Make large detector



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L: track length

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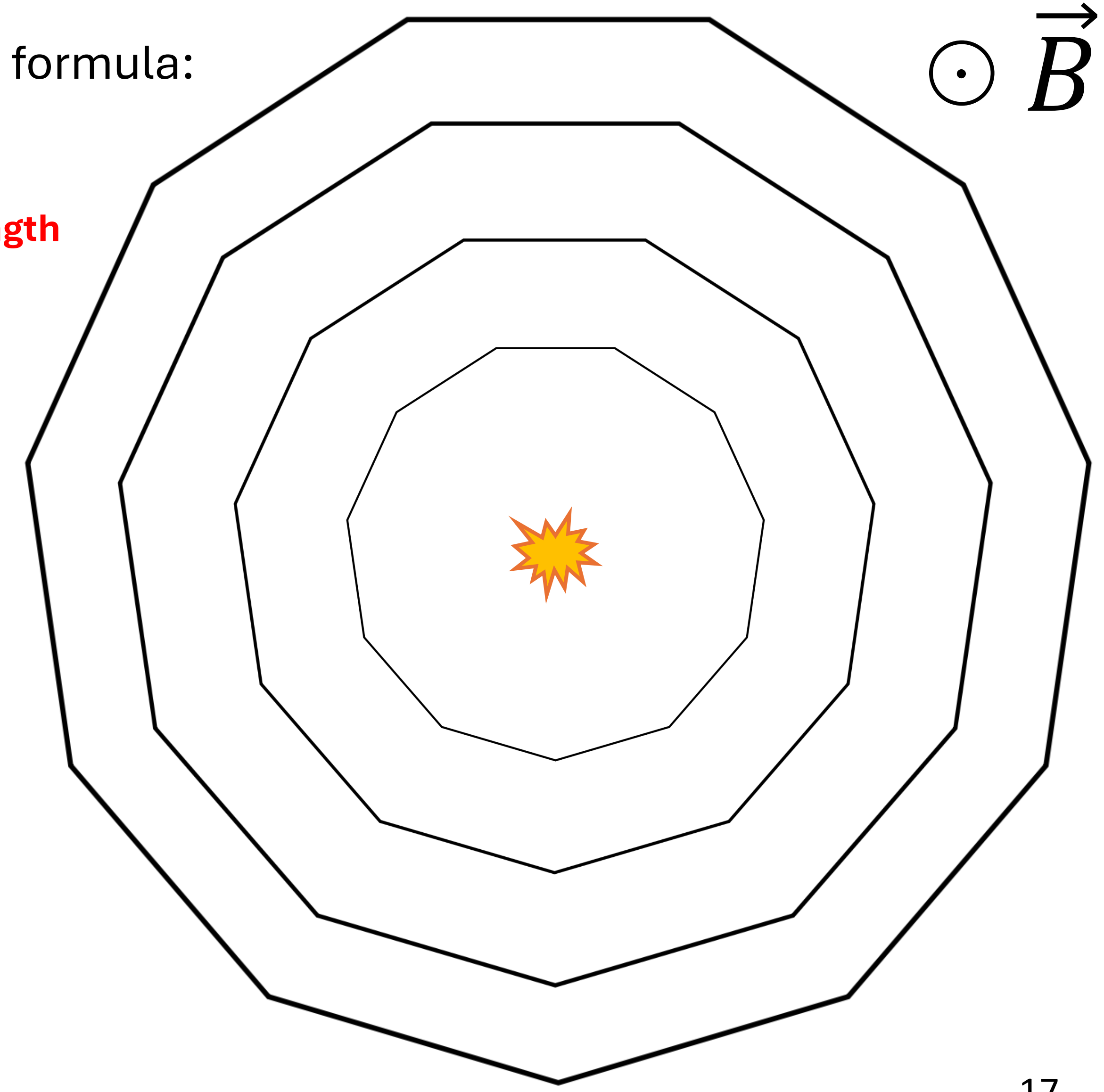
1. Make large detector
2. Use strong (but not too strong) magnetic field



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L: track length
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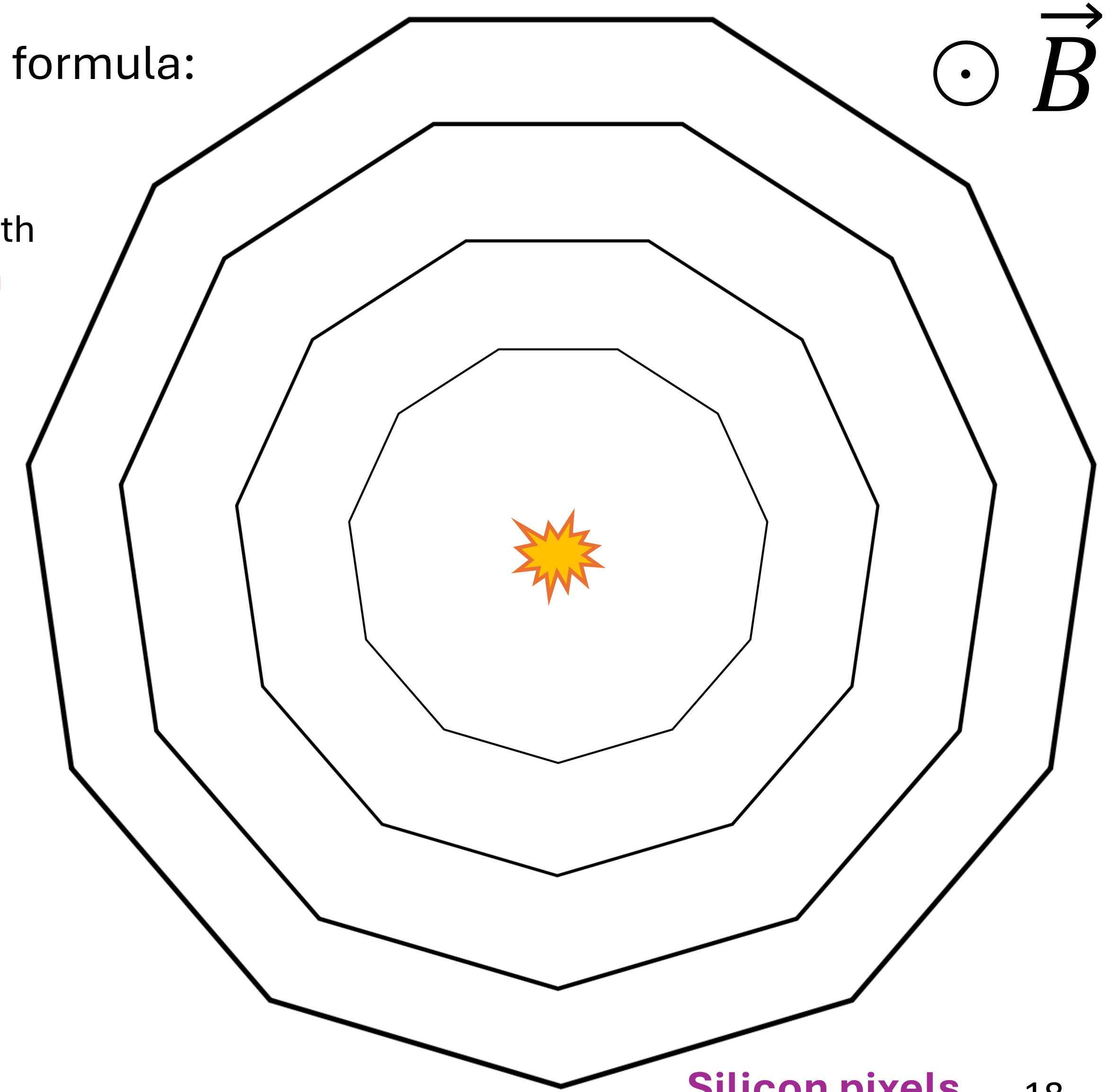
1. Make large detector
2. Use strong (but not too strong) magnetic field
3. Use high-resolution detector (pixels > strips)



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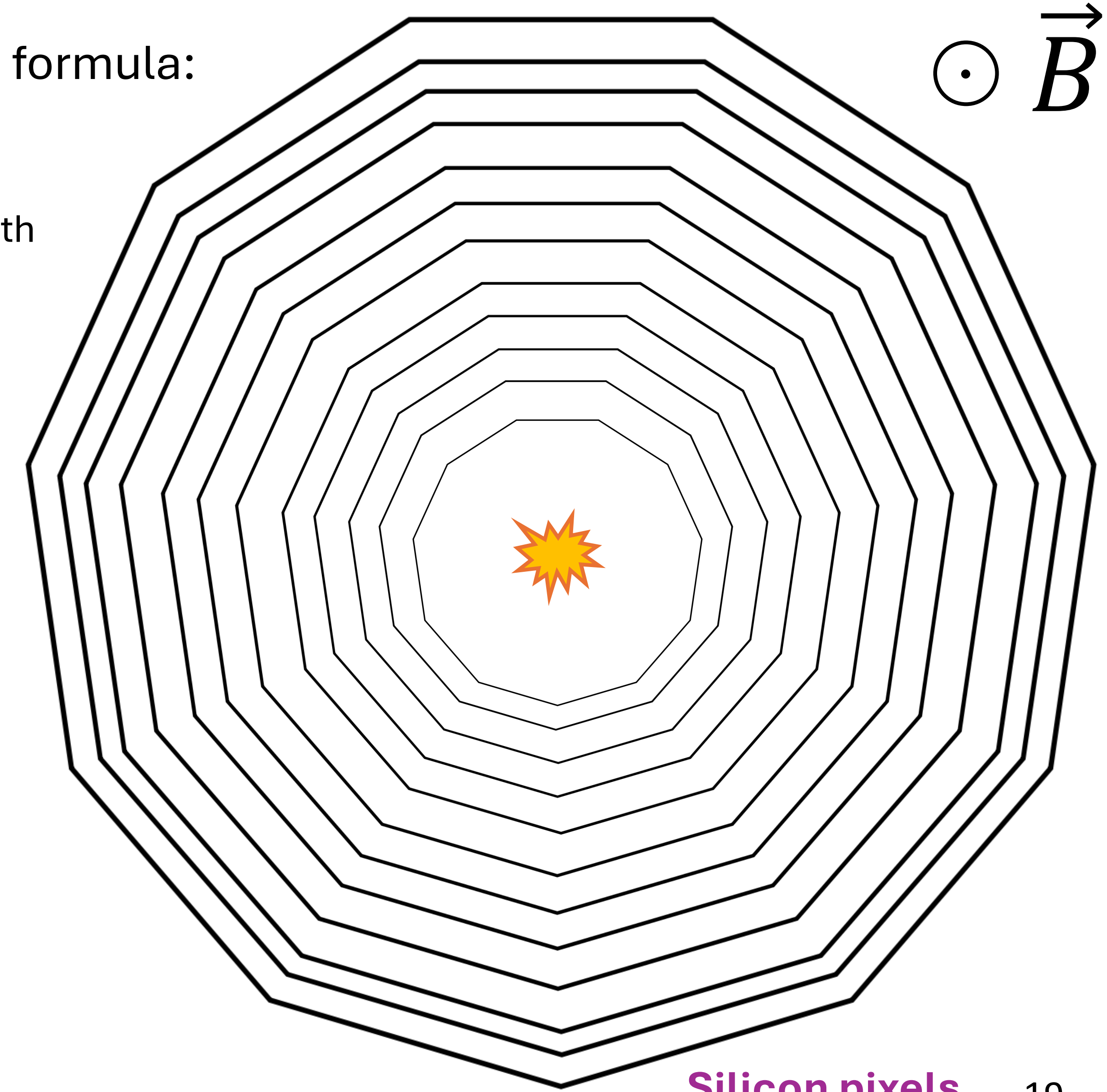
L: track length
B: magnetic field strength
σ

1. Make large detector
2. Use strong (but not too strong) magnetic field
3. Use high-resolution detector (pixels > strips)
4. Have many tracking layers



Silicon pixels

Let’s design a silicon tracker!

With good momentum and impact parameter resolution

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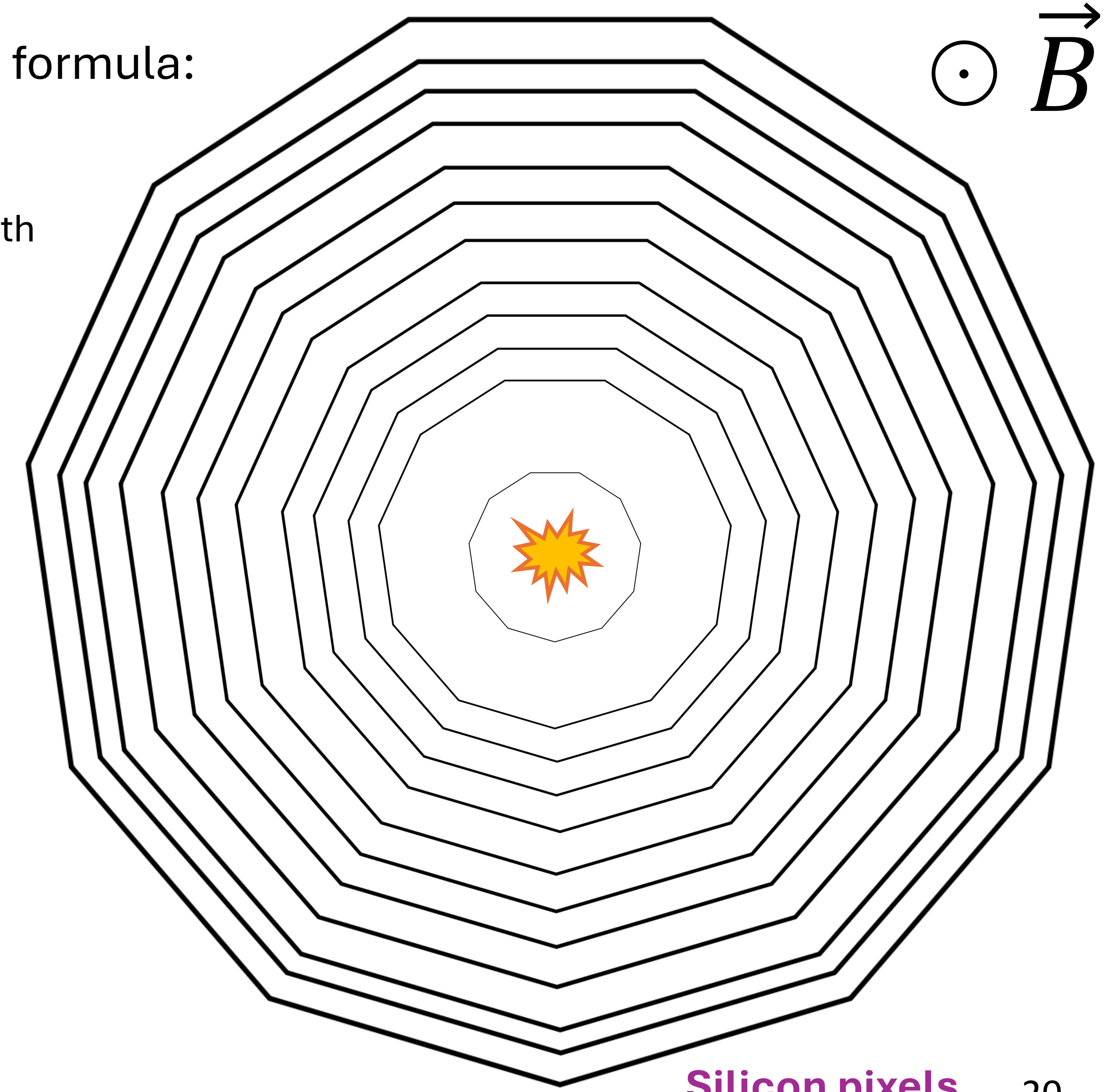


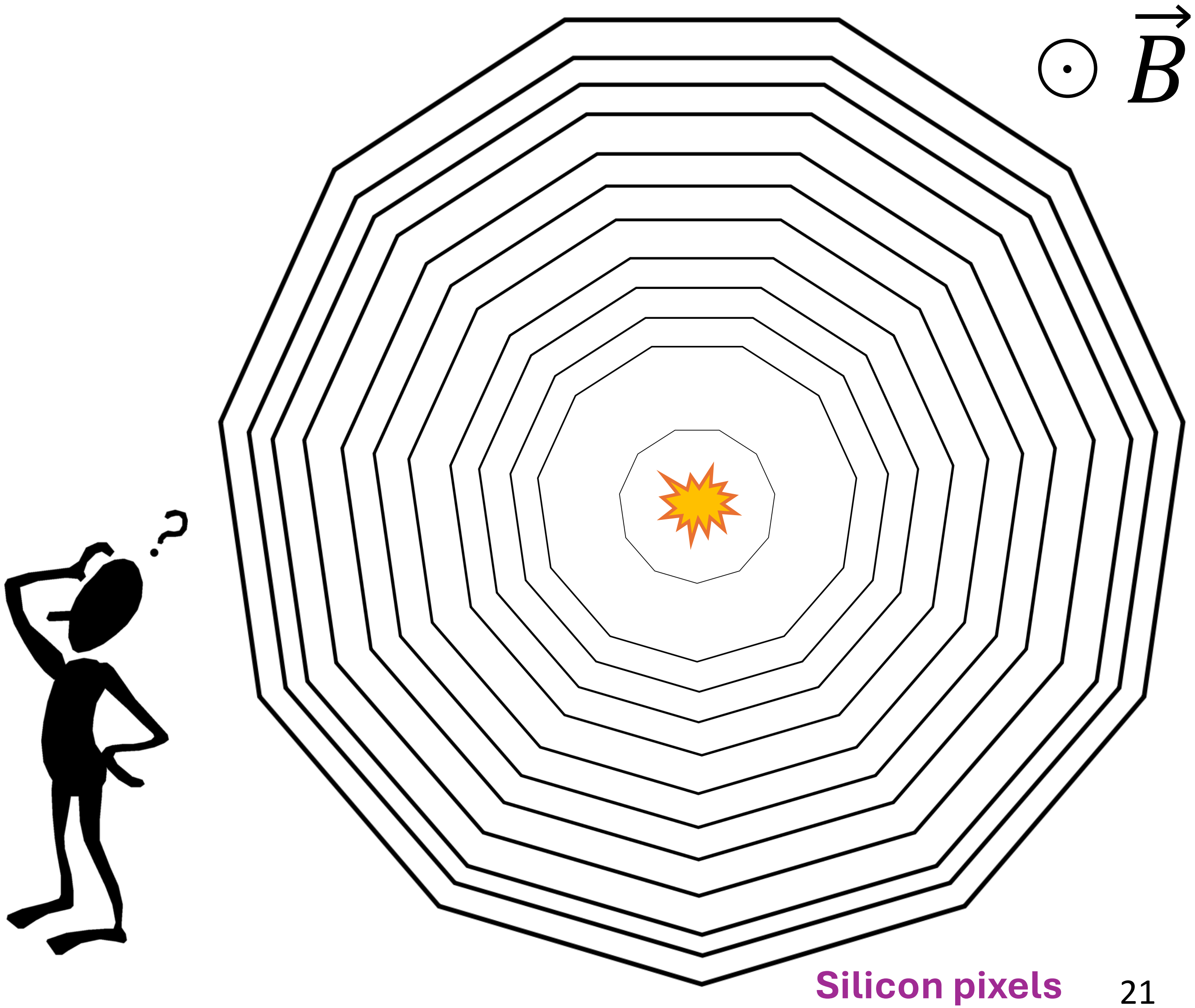
1. Make large detector
2. Use strong (but not too strong) magnetic field
3. Use high-resolution detector (pixels > strips)
4. Have many tracking layers
5. First layer close to interaction point

Silicon pixels

Let’s design a silicon tracker!

~~With good momentum and impact parameter resolution~~

We forgot two important concepts:



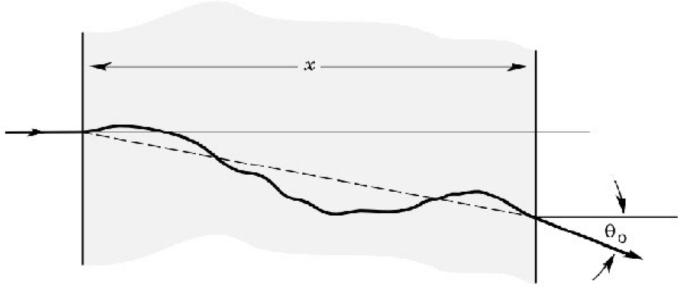
Let’s design a silicon tracker!

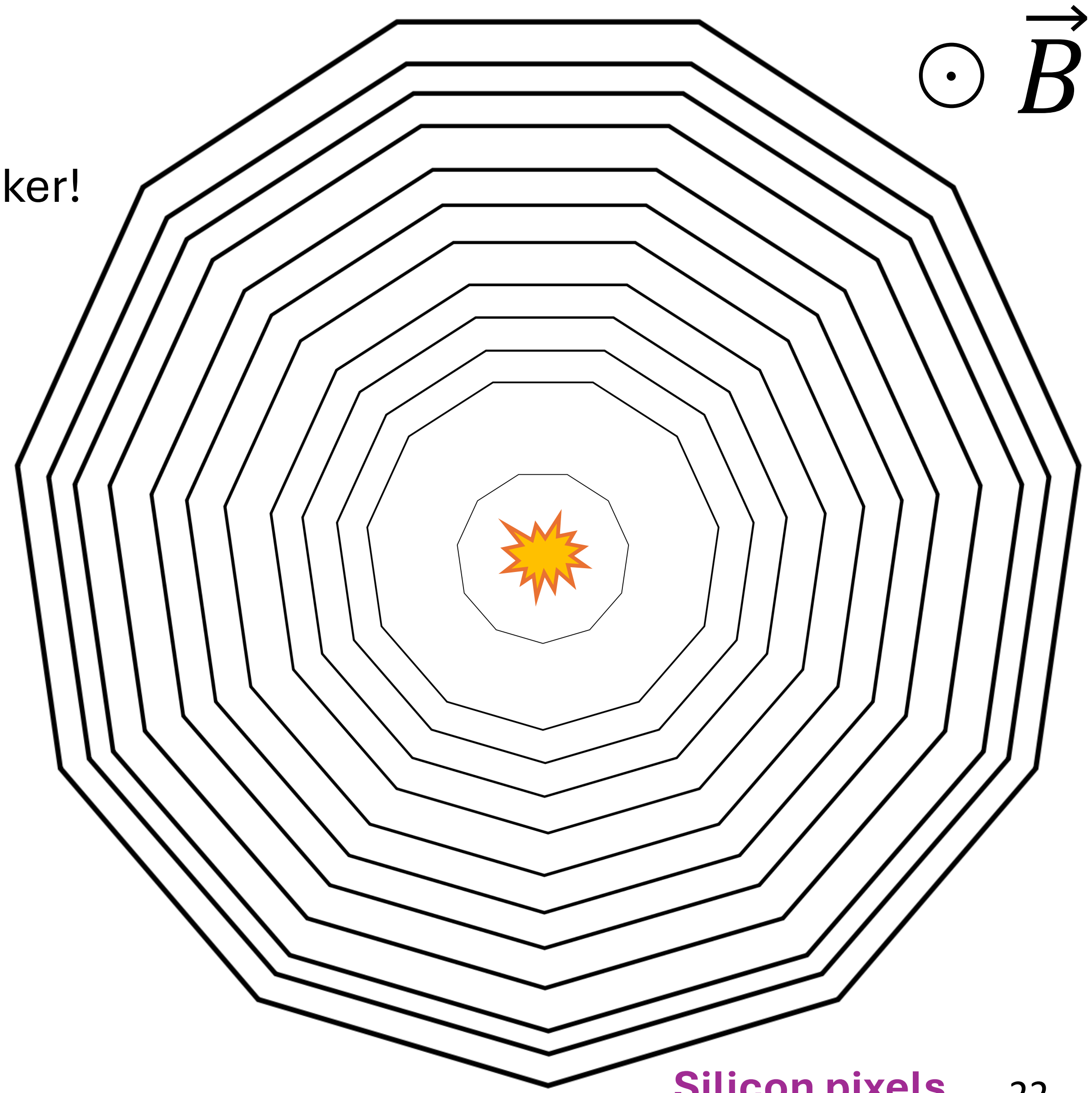
~~With good momentum and impact parameter resolution~~

We forgot two important concepts:

1. We do not want to disturb particles in the tracker!

   More material = more particle scattering





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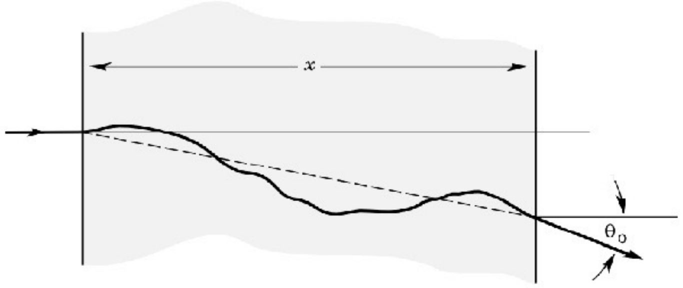
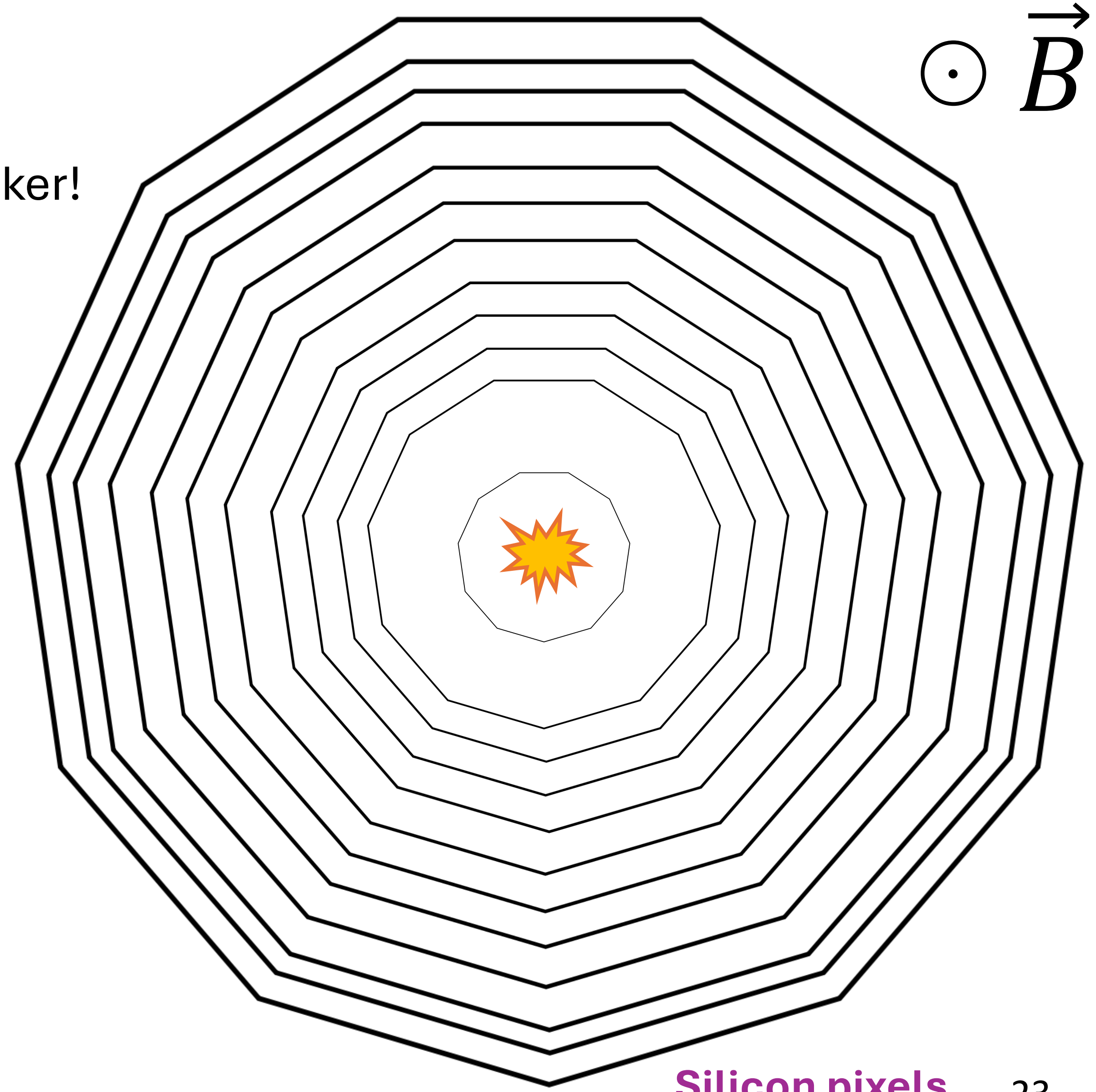


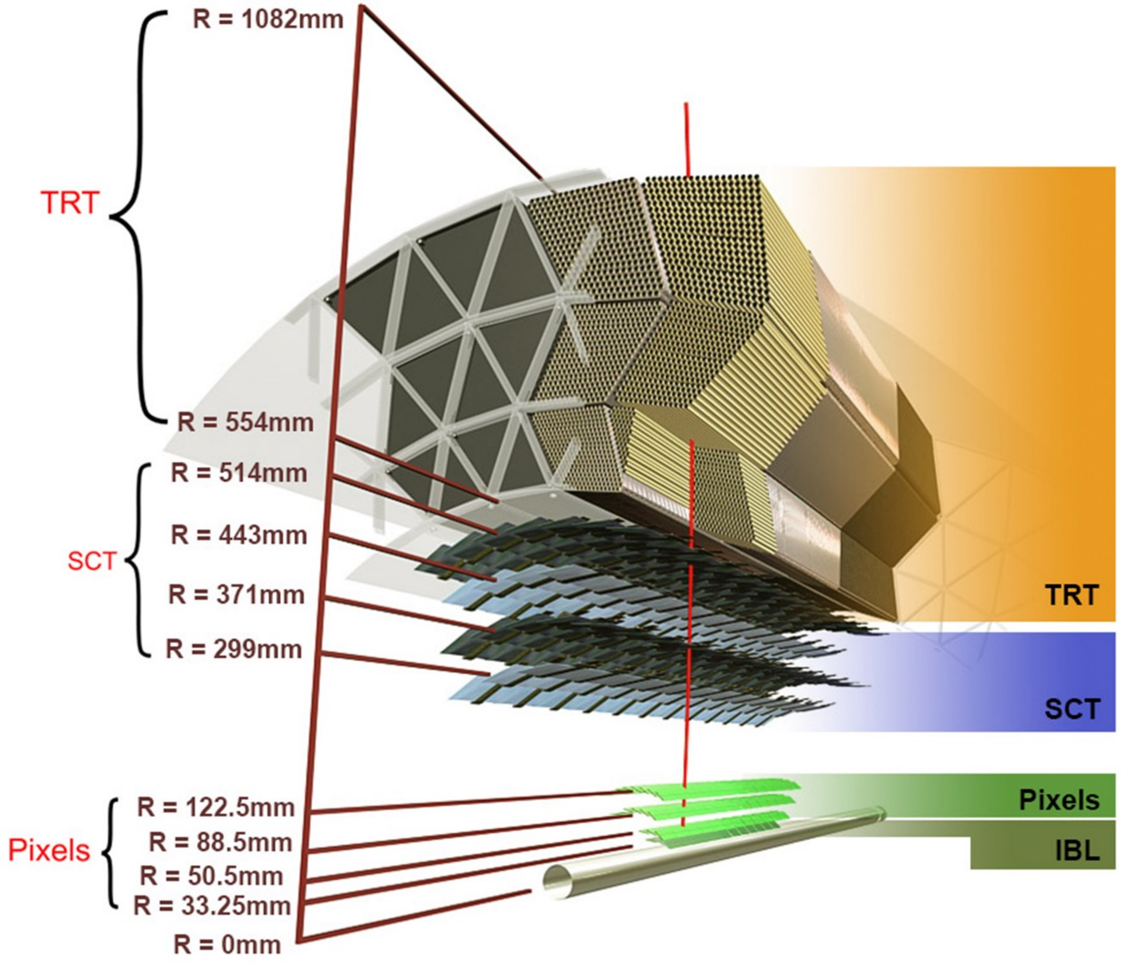
2. Cost

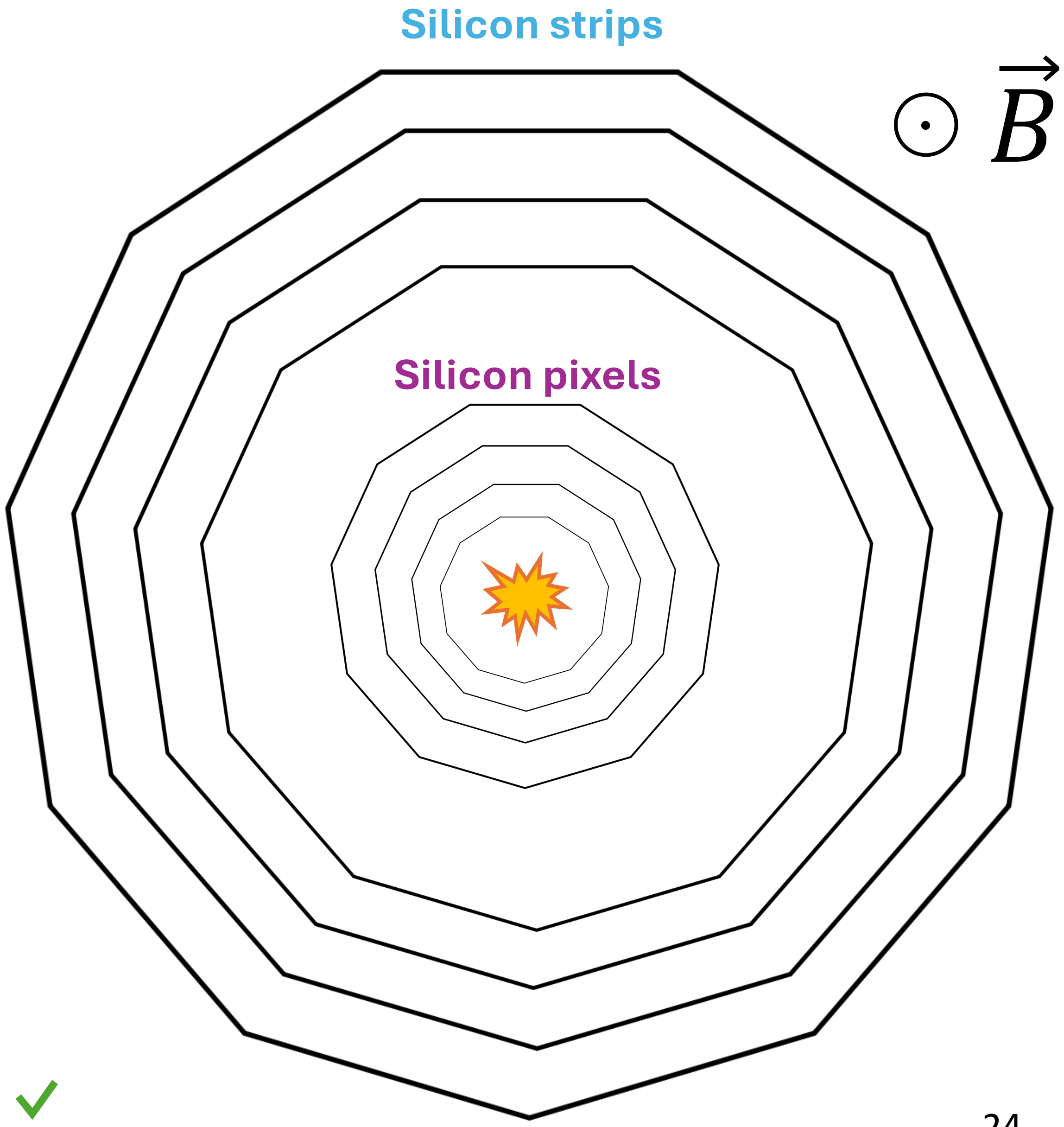


Silicon pixels

Let’s design a silicon tracker!

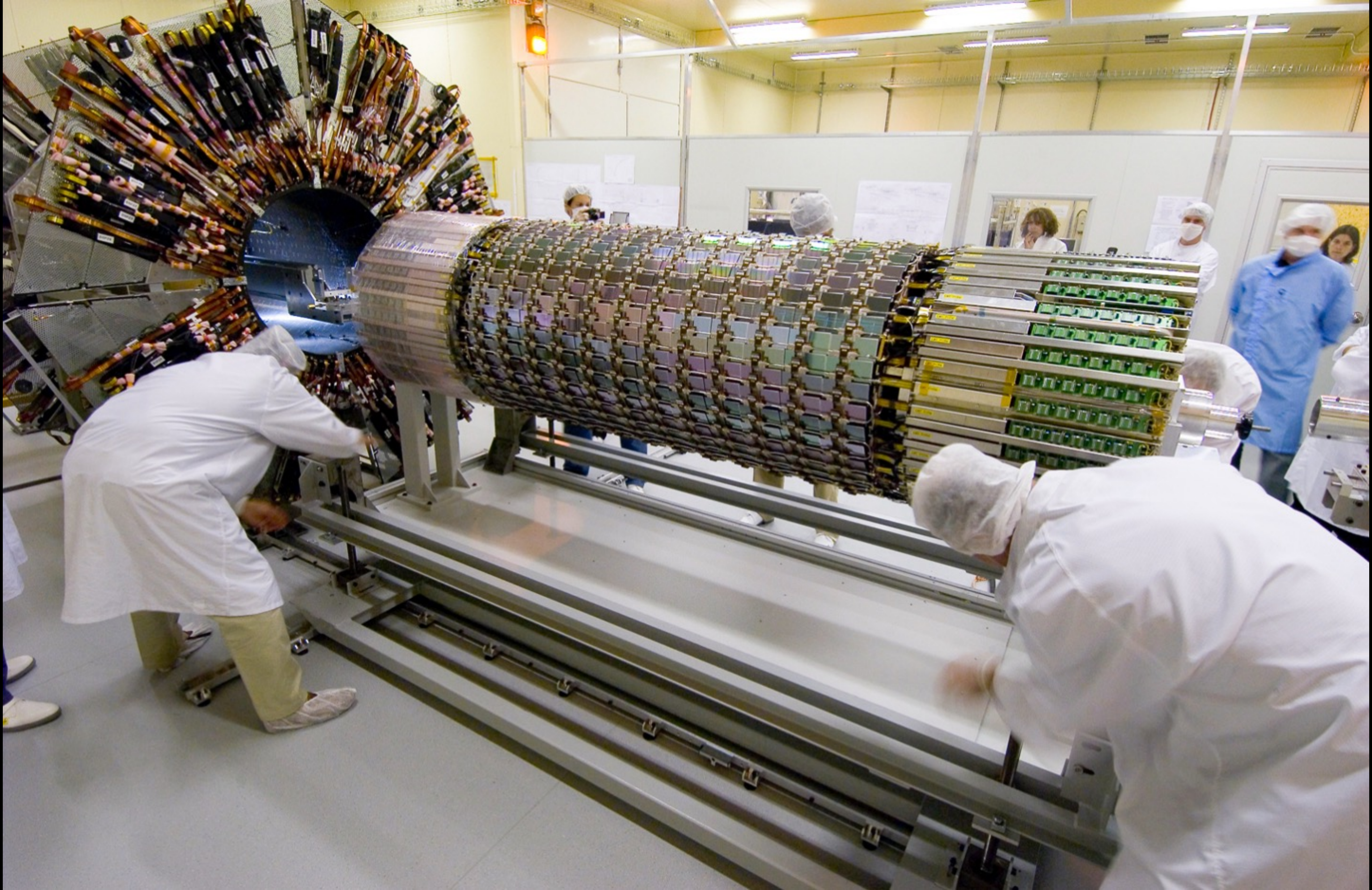
The ATLAS inner detector:

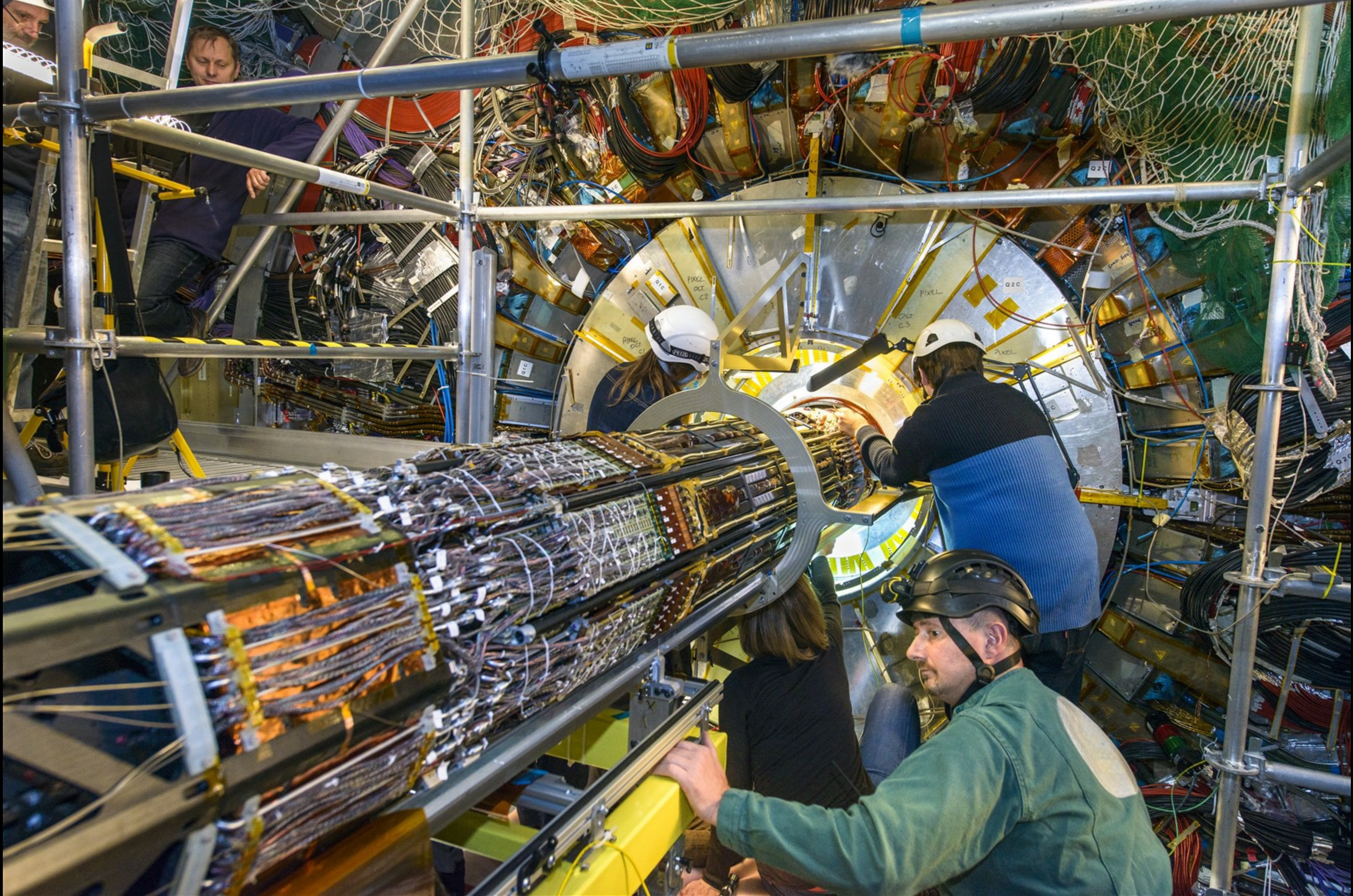




Good momentum resolution ✓

Good position resolution ✓




PIXEL
Q2C
Q1C

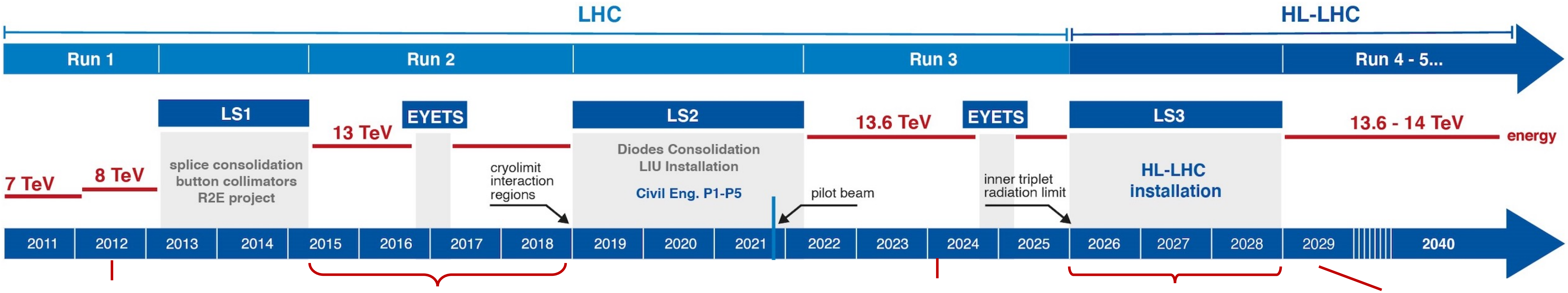
What’s next?

The **High-Luminosity LHC** (HL-LHC):

What? More proton collisions per second → more data to analyze

Why? Measure more rare Standard Model processes, search for new physics

How? Stronger beam focusing magnets, better collimators, ...



Discovery of Higgs Boson

Exploration of Higgs Boson + Standard Model, searches for new physics ...

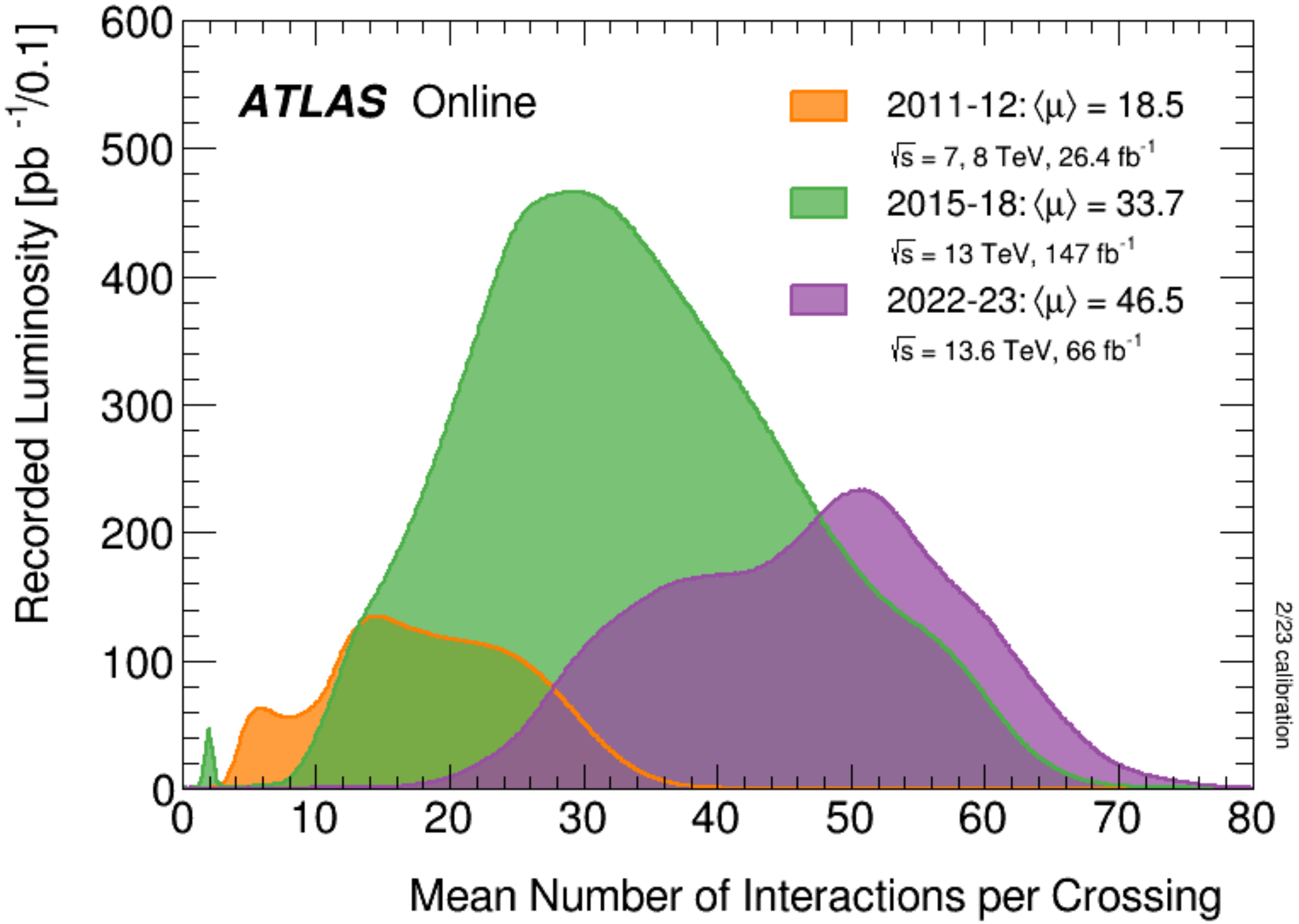
We are here

Upgrade of LHC and detectors

Start of data-taking in HL-LHC

What’s next?

There will be 5x higher instantaneous luminosity at the HL-LHC:



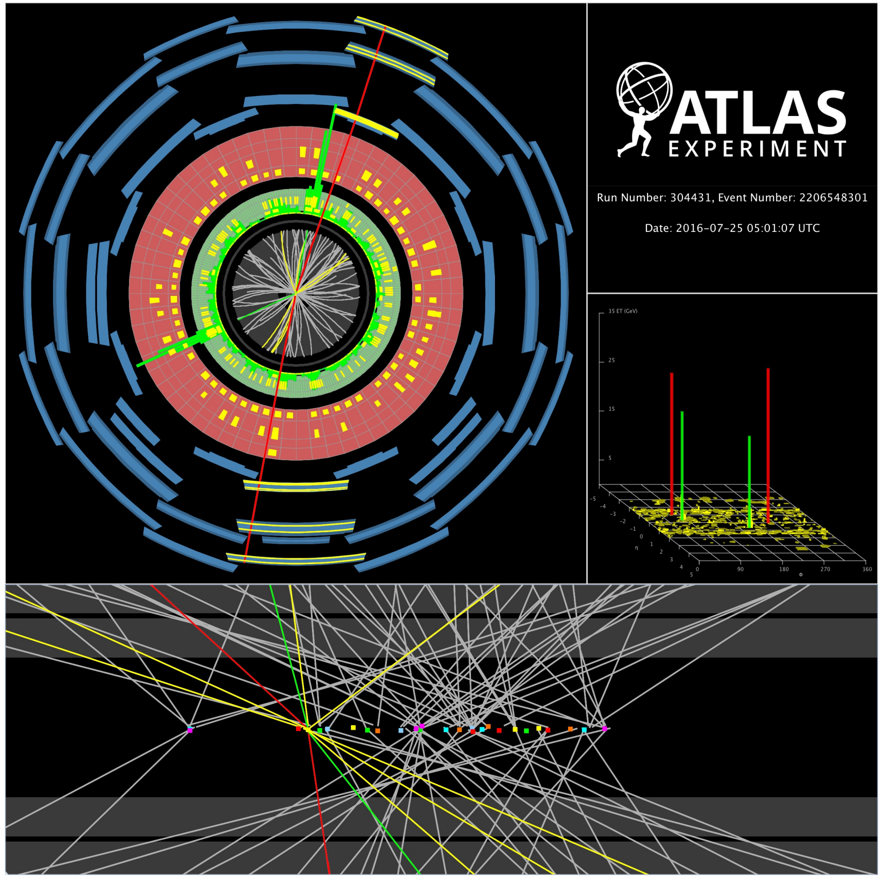
→ Expect ~ **200 interactions** / proton bunch crossing in the HL-LHC

What's next?

* All tracks with $p_T > 1$ GeV

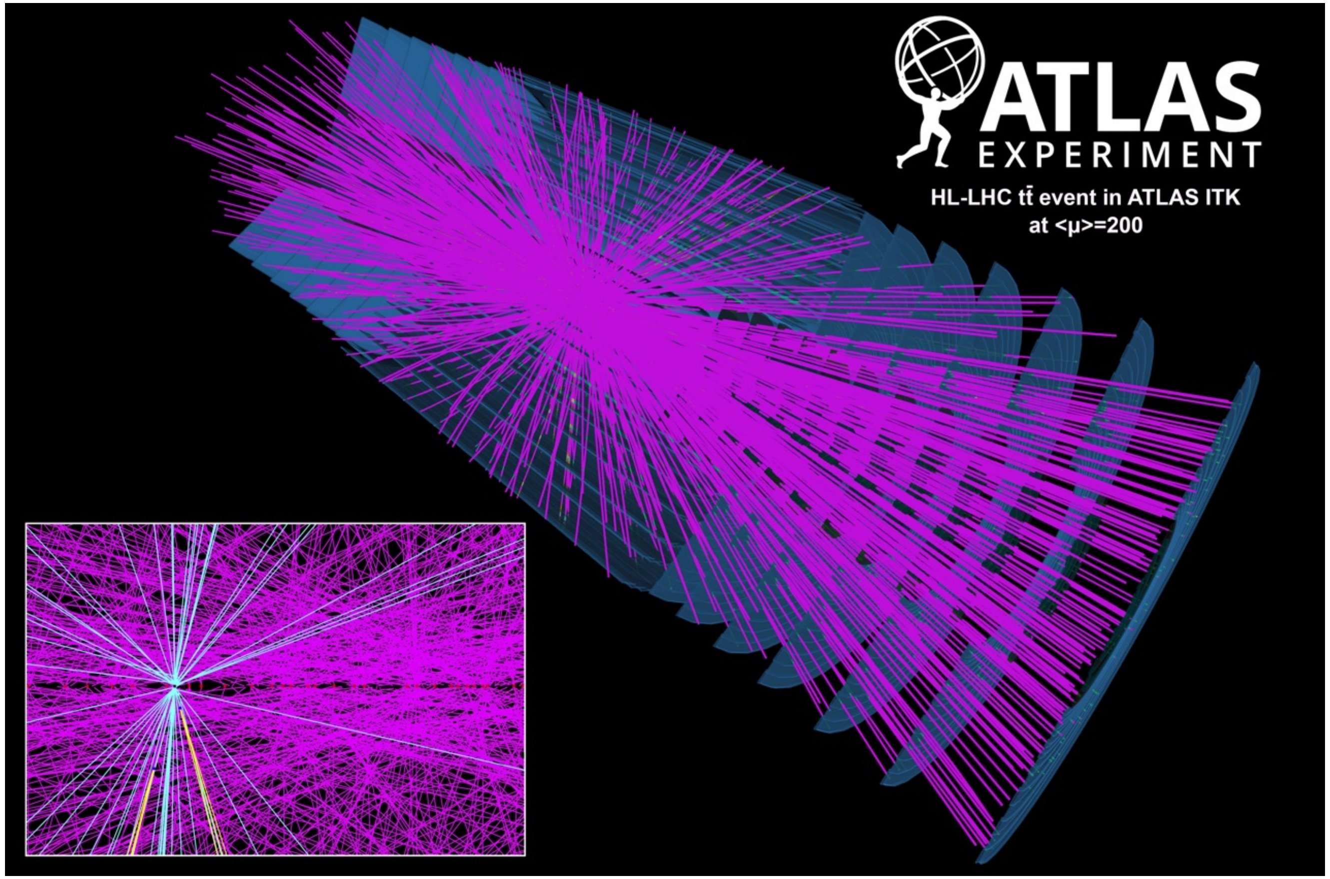
There will be 5x higher instantaneous luminosity at the HL-LHC:

Event at **LHC**



25 interactions / bunch crossing

Event at **HL-LHC**



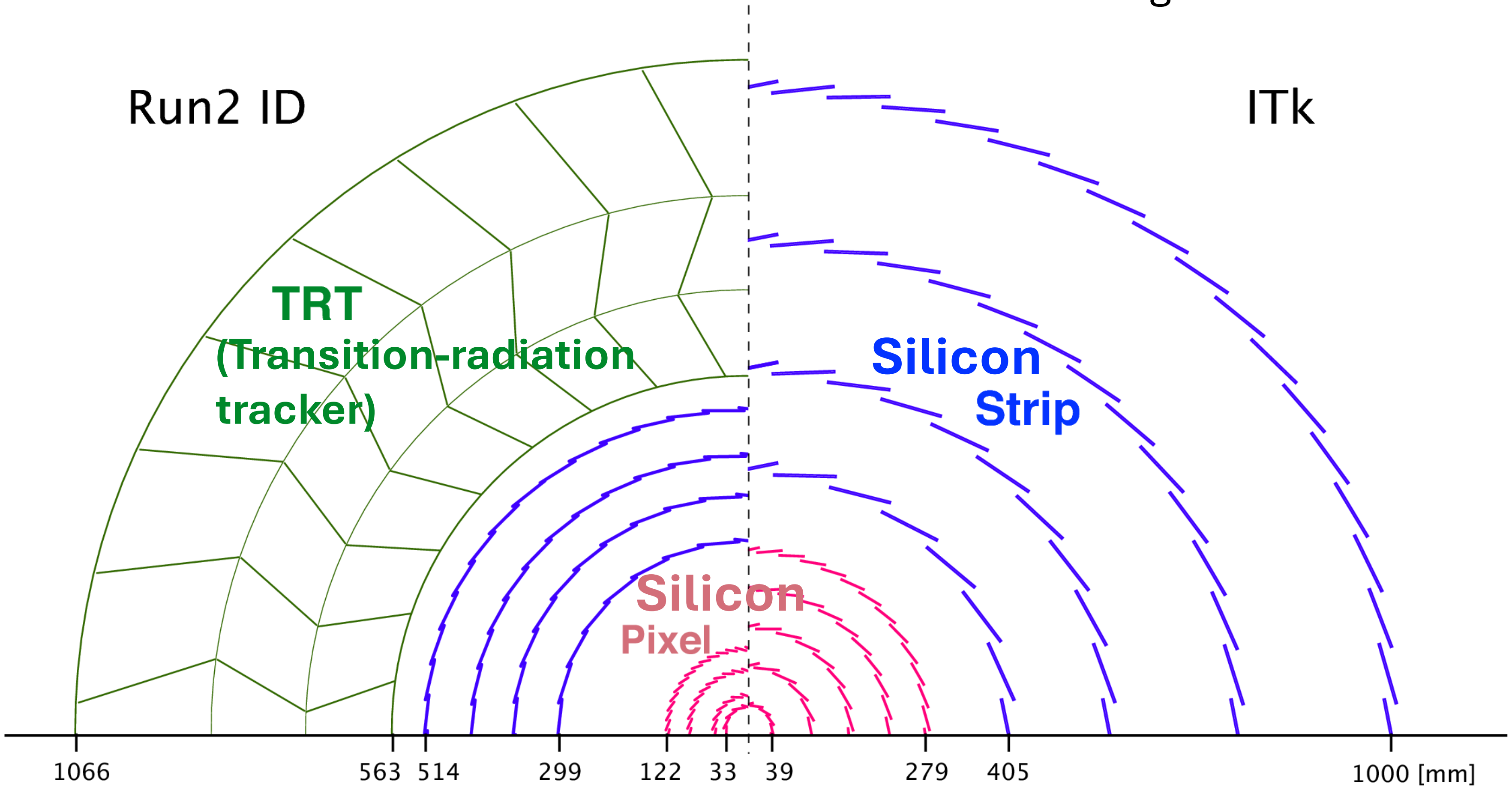
200 interactions / bunch crossing

Upgraded ATLAS inner tracker

The entire inner detector of ATLAS will be **replaced with an all-silicon tracking detector (ITk)**:

What we have now:

What we're building for HL-LHC:



ITk – the stats

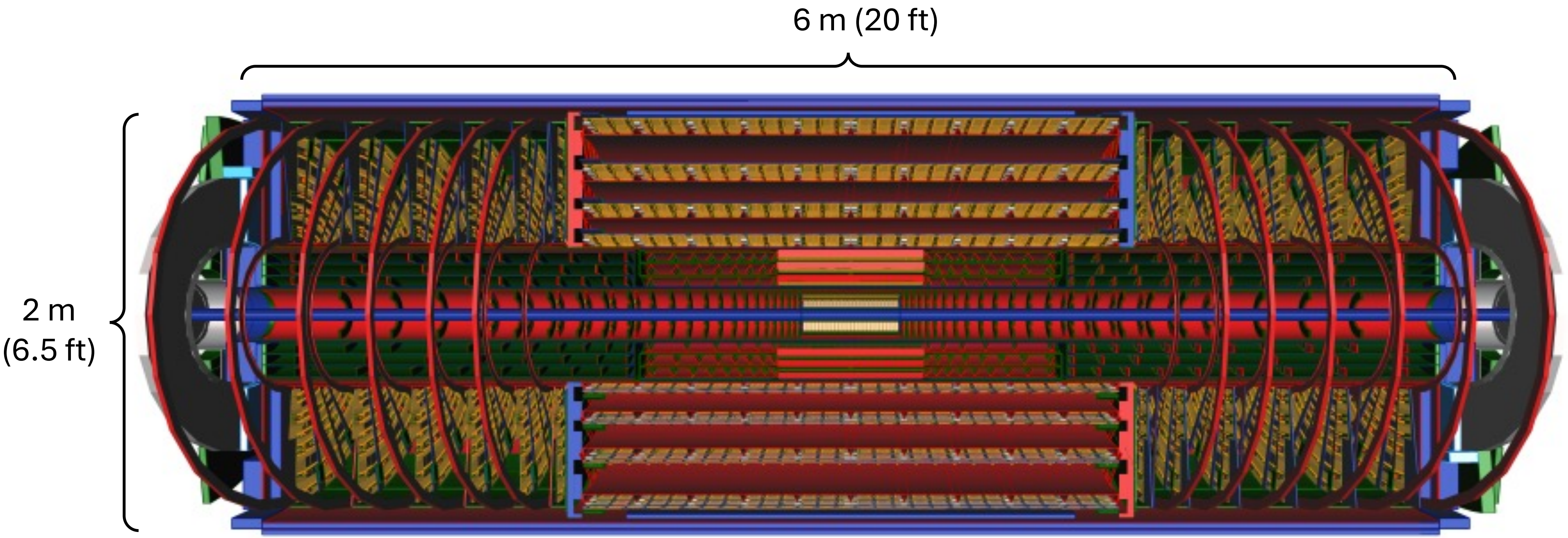
Increased granularity to keep detector at < 1% occupancy

- Pixel : 50x400 μm^2 → 50x50 μm^2 : 8x smaller
- Strip (length) : 128 mm → 24 mm : 5x smaller

More coverage → fewer particles escape close to beamlines

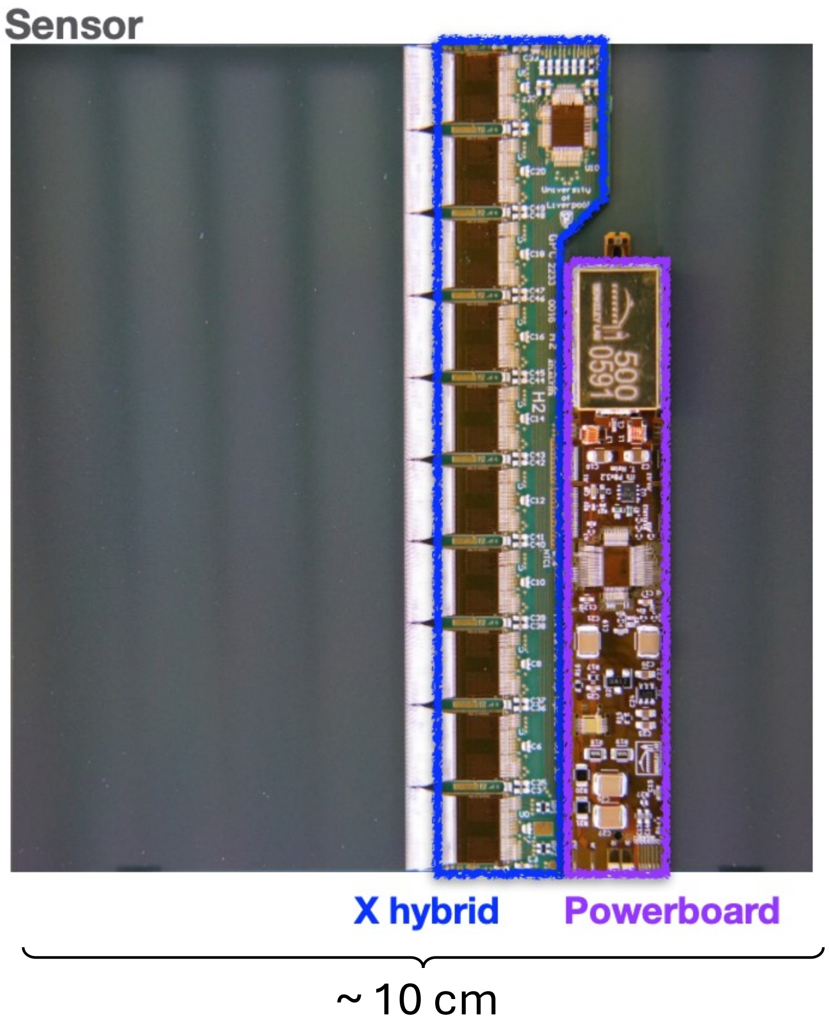
Reduction in material (Serial powering scheme, thinner chips, low mass support structures, ...)

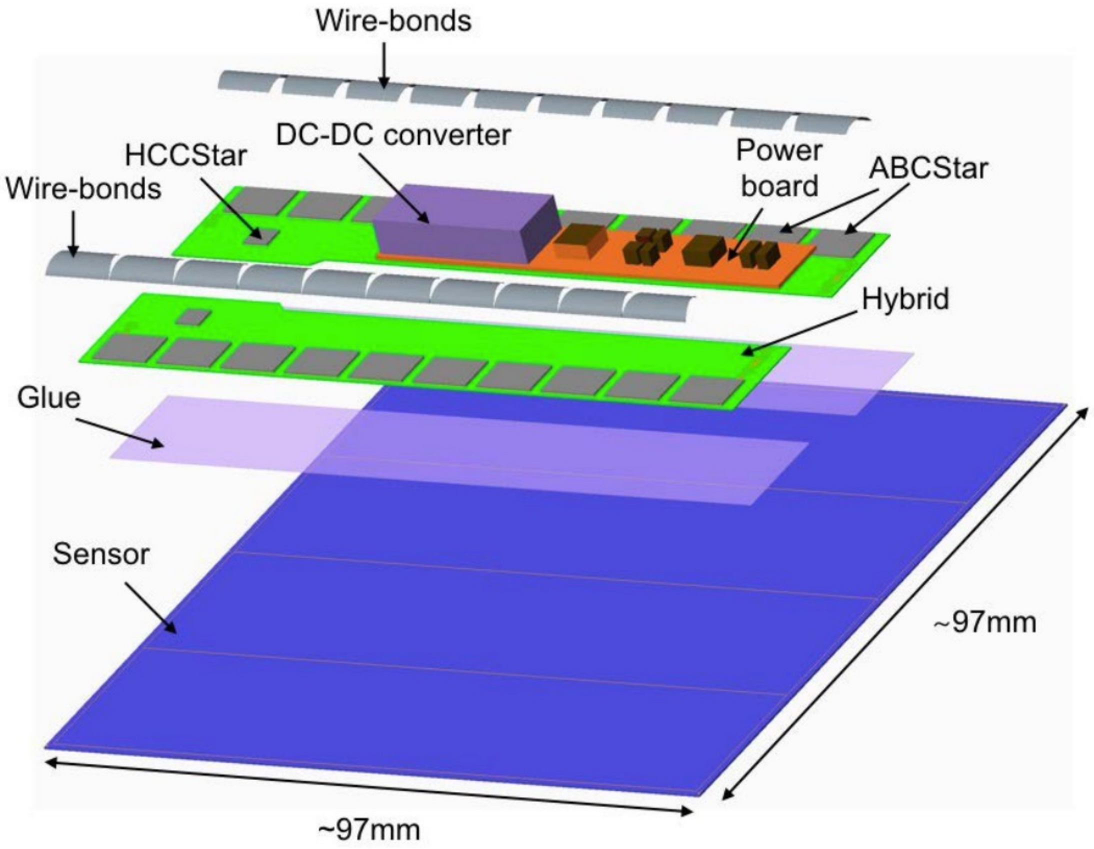
Radiation hard technology



ITk Strip detector

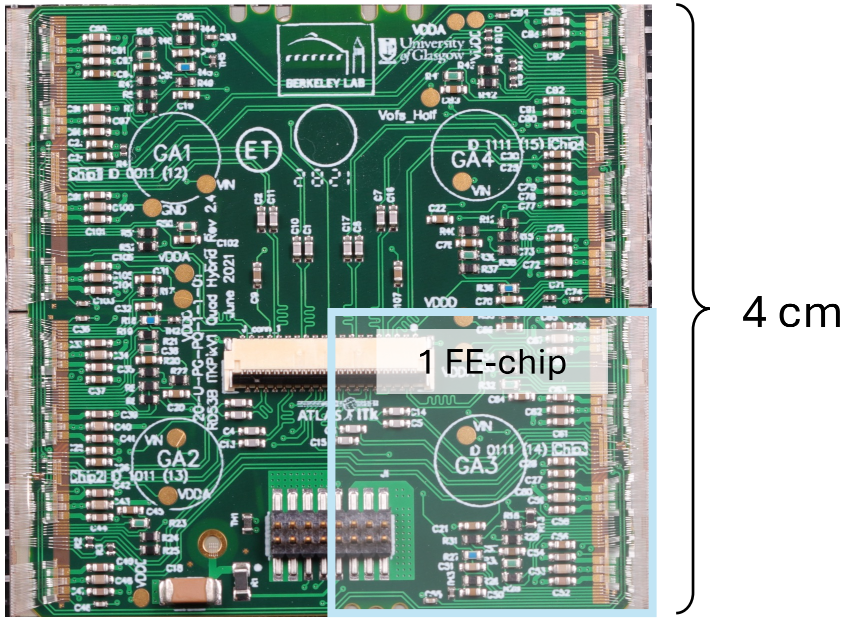
LBNL is involved in the construction and testing of **ITk silicon strip modules**

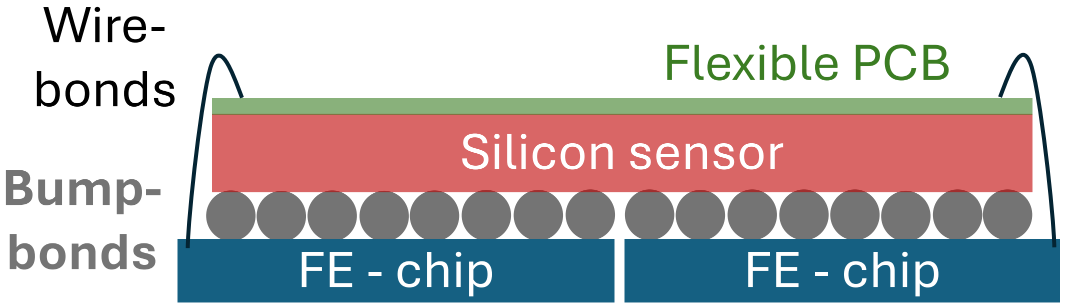


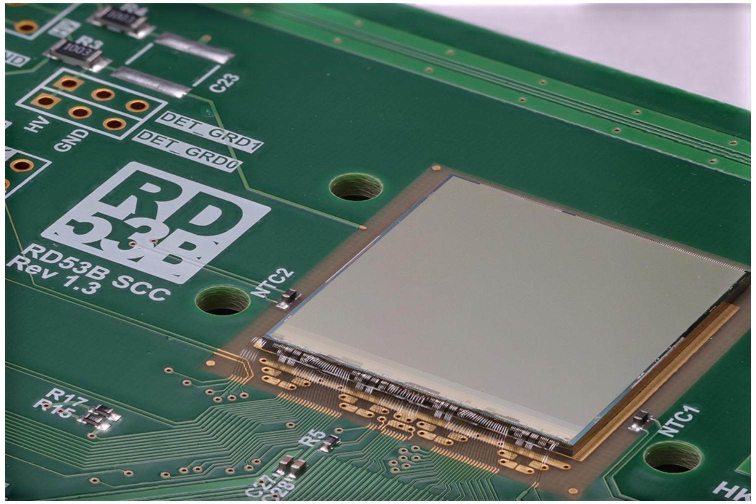


ITk Pixel detector

LBNL is involved in the testing of **ITk silicon pixel modules**

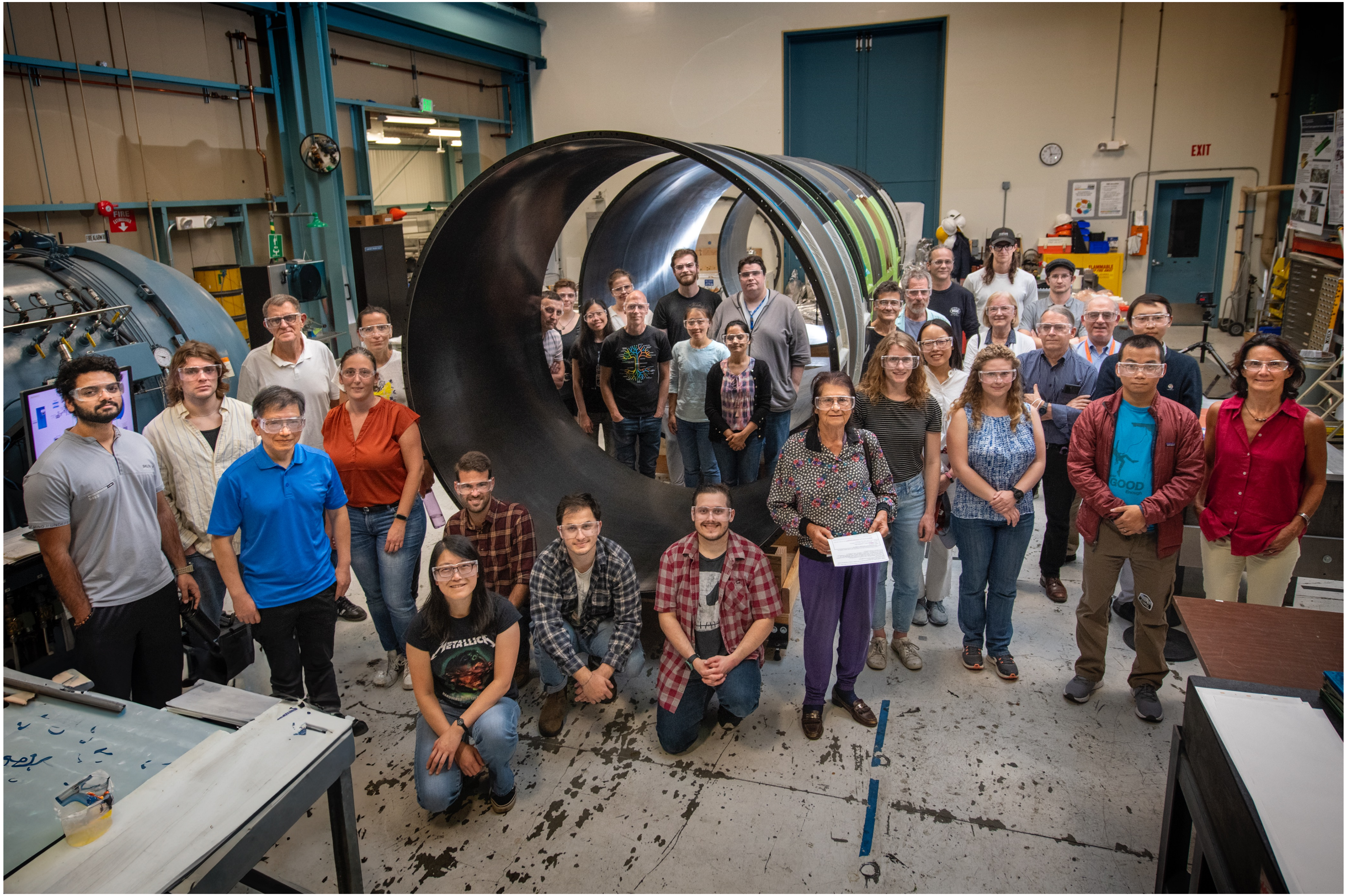






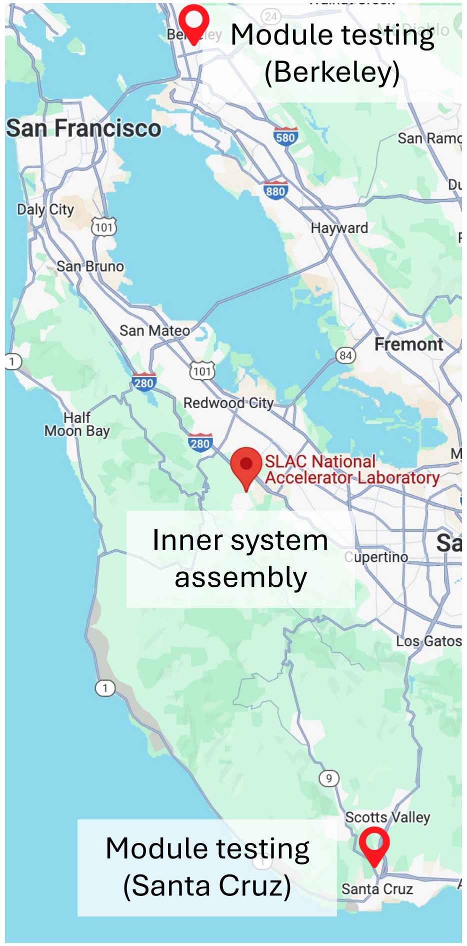
And also in the design of the **front-end readout chip**

Upgraded ATLAS inner tracker



ITk detector – a global endeavor

Construction of ITk detector is a **global effort**.



Module testing (Berkeley)

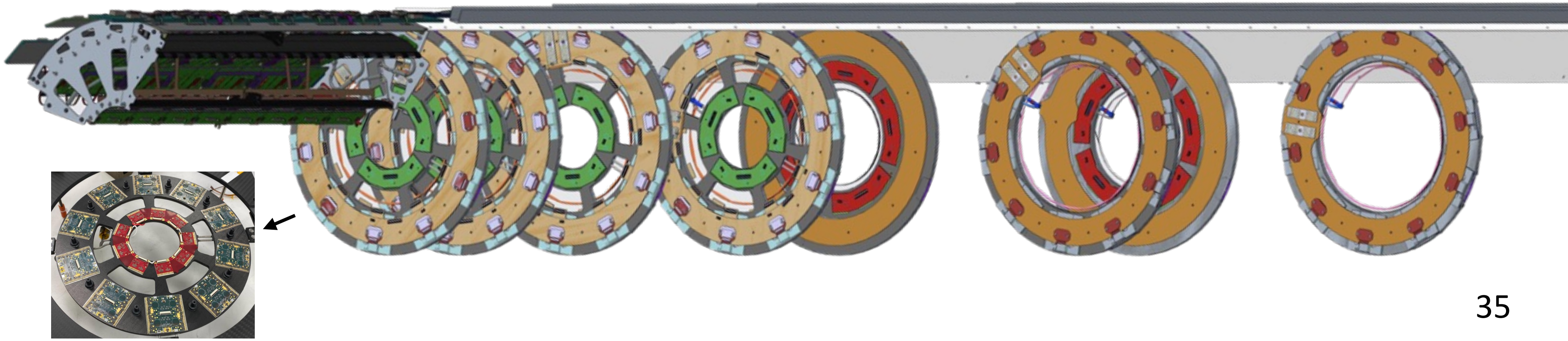
Inner system assembly

Module testing (Santa Cruz)

For example, consider ITk inner pixel system (innermost two tracking layers)

- Modules assembled and tested in **US, Italy, Spain, Norway, and Germany**
- Good modules sent to **SLAC** for assembly of inner system
- Inner system sent to **CERN** for integration into detector

Very exciting that this piece of detector will be assembled in our neighborhood!



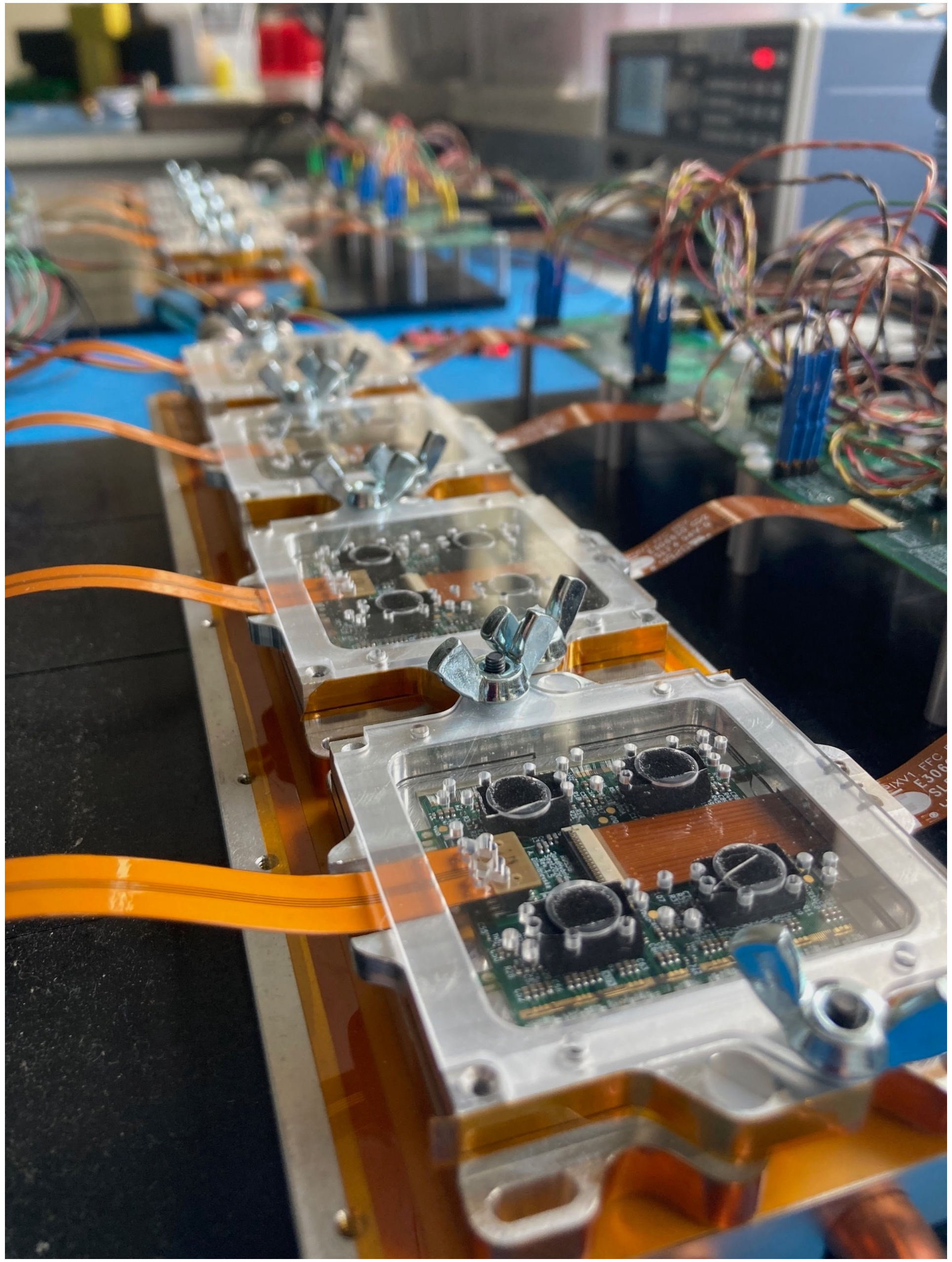
"Quarter shell"

Summary

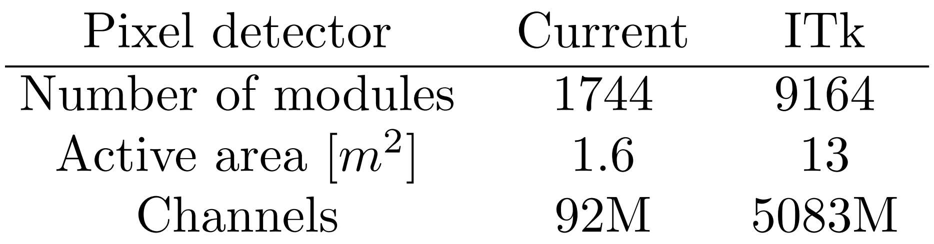
Silicon tracking detectors are a vital piece of the ATLAS detector → measure momentum and determine origin of particles

We are constructing a **new tracking detector** (ITk) that will be installed in ATLAS for the **HL-LHC**.

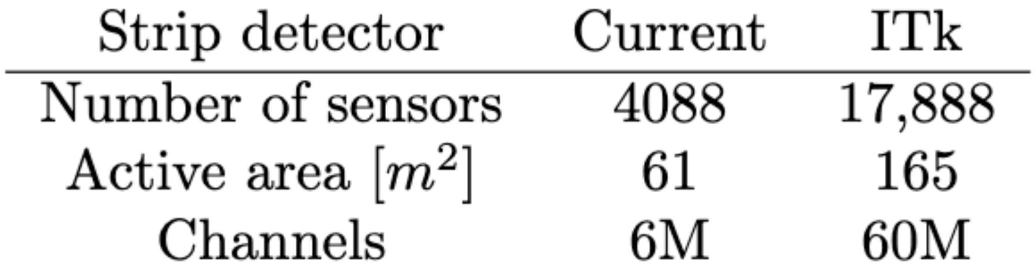
LBNL is heavily involved in both the ITk strips and pixel detectors → lab tours this afternoon!



Backup



Pixel detector	Current	ITk
Number of modules	1744	9164
Active area $[m^2]$	1.6	13
Channels	92M	5083M



Strip detector	Current	ITk
Number of sensors	4088	17,888
Active area $[m^2]$	61	165
Channels	6M	60M