# The CMOS Strips Project

**Naomi Davis** on behalf of the CMOS Strip Detectors Project

1st PIER Workshop on Detector Research

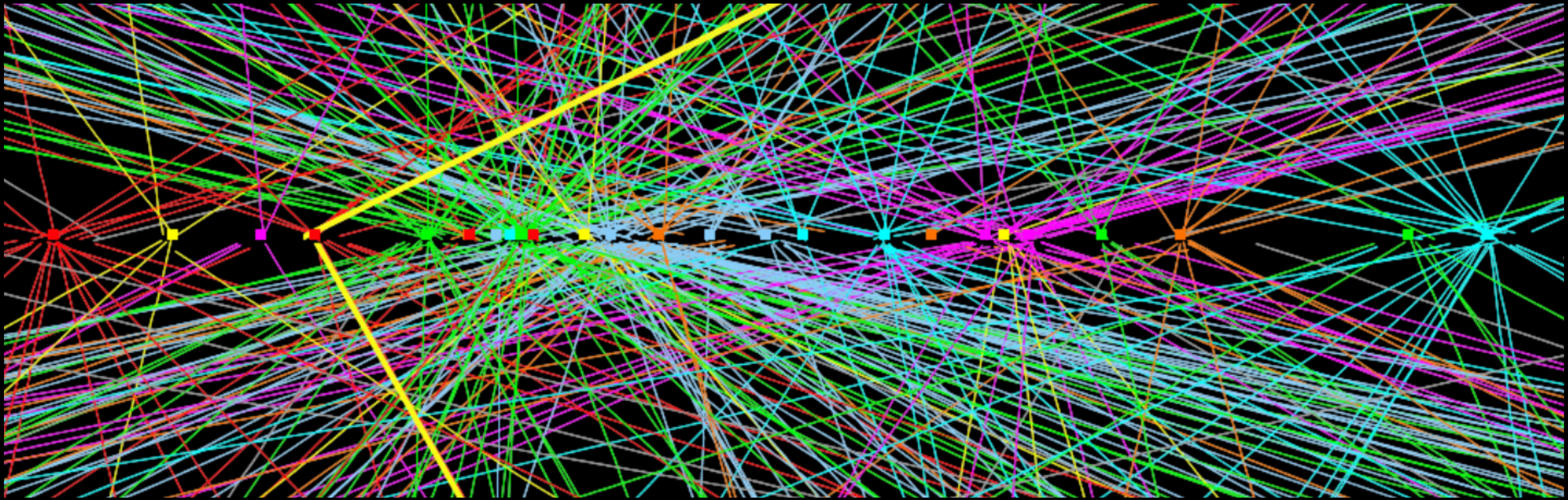
June 1st

HELMHOLTZ

# Tracking with Silicon Sensors

## How to detangle particle collision events?

$Z \longrightarrow \mu\mu$



"Pile-up" complicates things…

Image: ATLAS Experiment/CERN
Run Number: 201289, Event Number: 24151616
Date: 2012-04-15 16:52:58 CEST

# Tracking with Silicon Sensors

## How to detangle particle collision events?

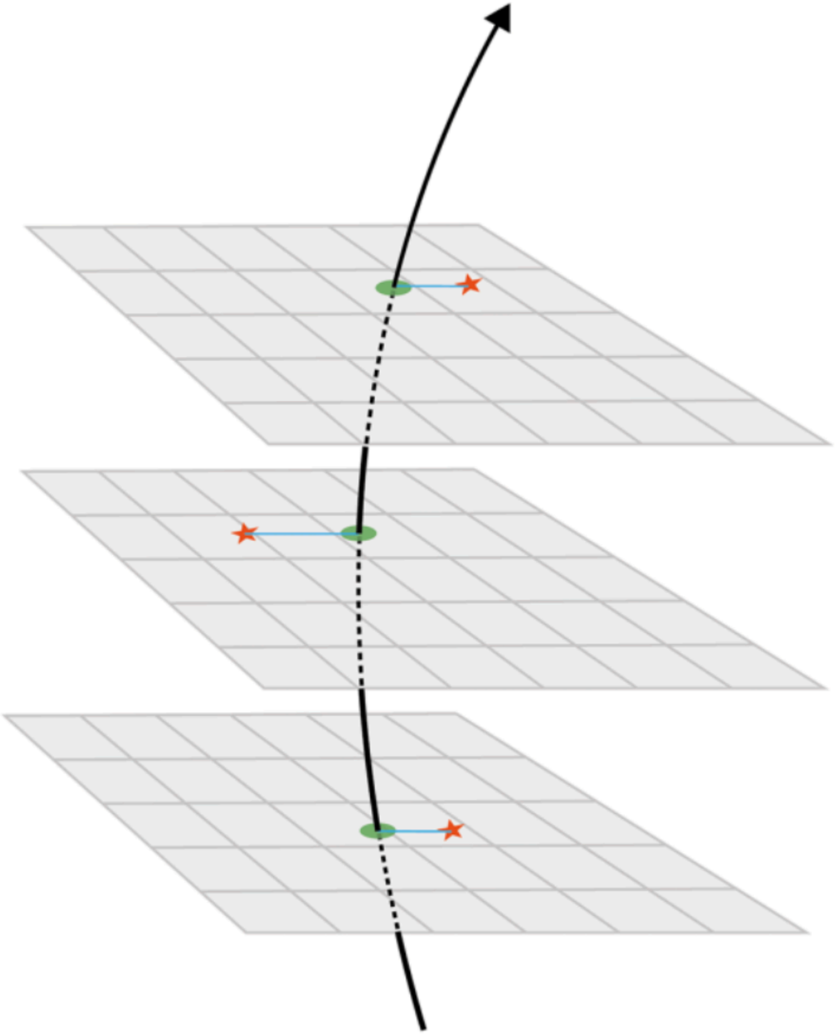
- Reconstruction of charged particle tracks

  ✴High granularity

  ✴High precision

  ✴Radiation hardness

  ✴Reliability and Longevity



*ATLAS Experiment/CERN, https://cds.cern.ch/images/ATLAS-PHOTO-2020-018-1*

# Tracking with Silicon Sensors

## The need for alternative silicon sensor designs

- Silicon sensors have become indispensable in high energy physics.
- They are…

  … main tracking devices

  … immense cost-driver

  … only available from few foundries

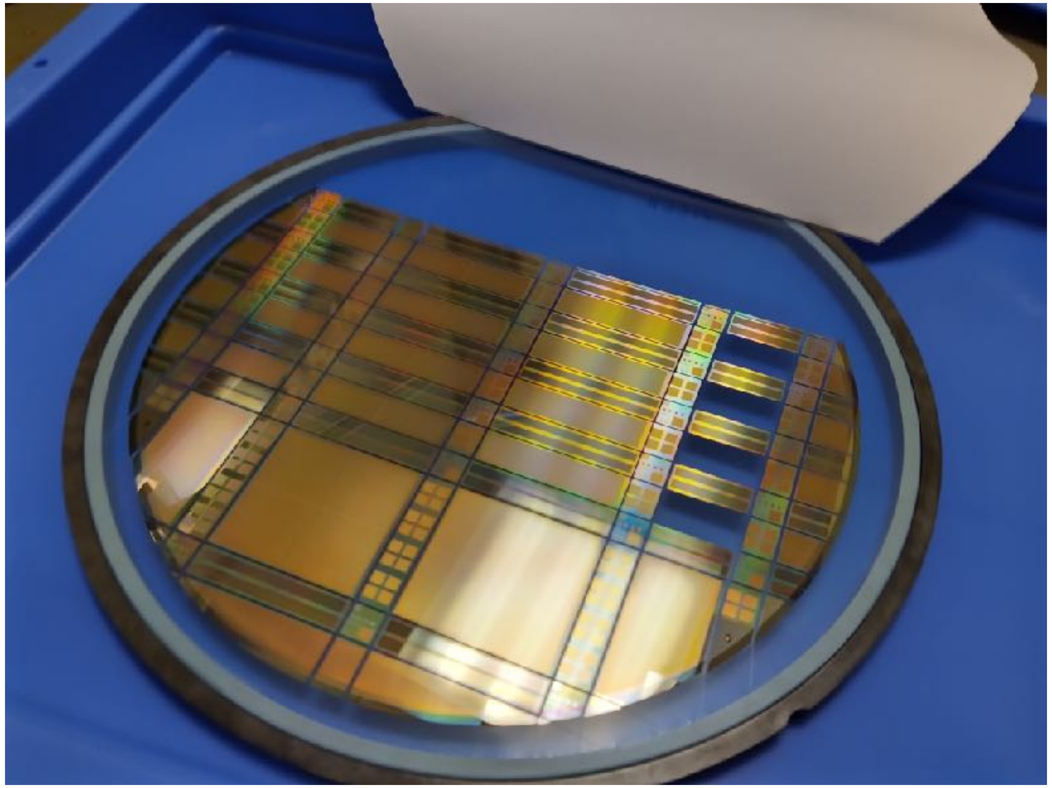
Alternative concepts?

Alternative vendors?

# CMOS Technology

## A promising candidate

- CMOS imaging process
- Possible cost reduction
- Fast, large-scale production
- Wafer-scale industrial production
- Large vendor choice

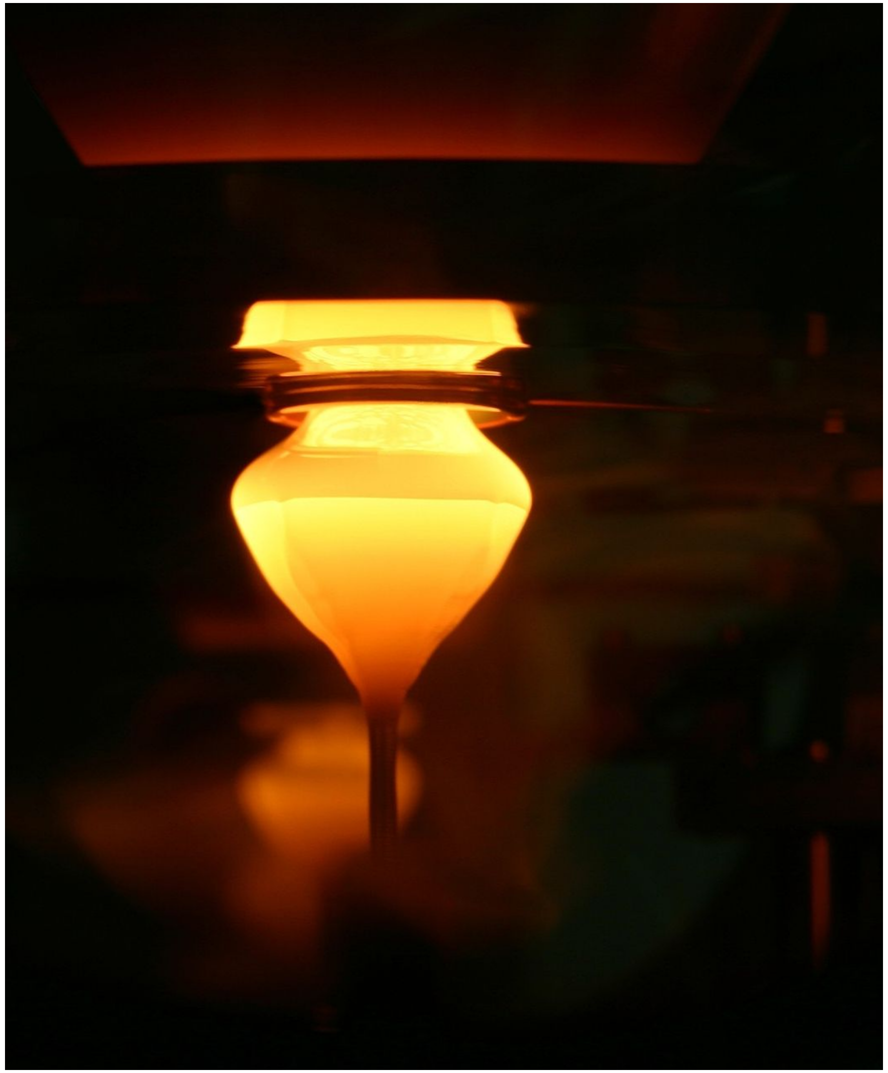


# CMOS Technology

## Silicon fabrication

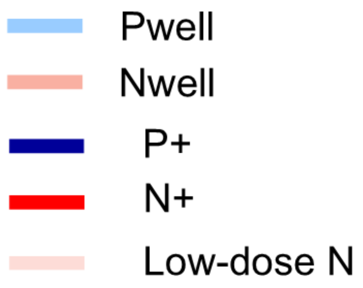
- Detector-grade Silicon:
  - ✶Low impurity concentration
  - ✶Homogeneous dopant concentration
  - ✶High resistivity $3 - 5\ \mathrm{k\Omega \cdot cm}$
  - ✶Maximum crystal diameter: 8″

Beginning of Float-Zone Silicon Growth

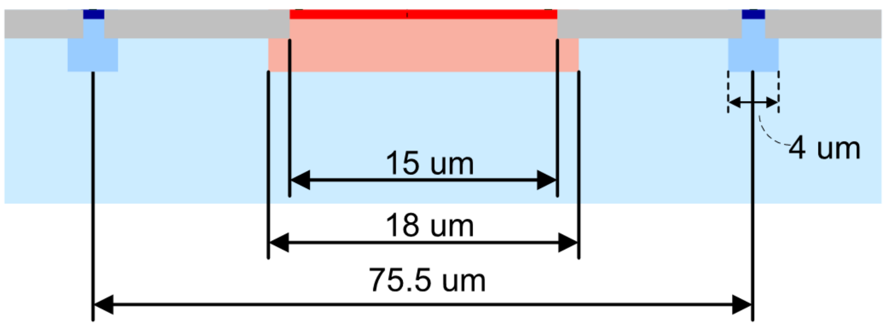


# Passive CMOS Sensor Design

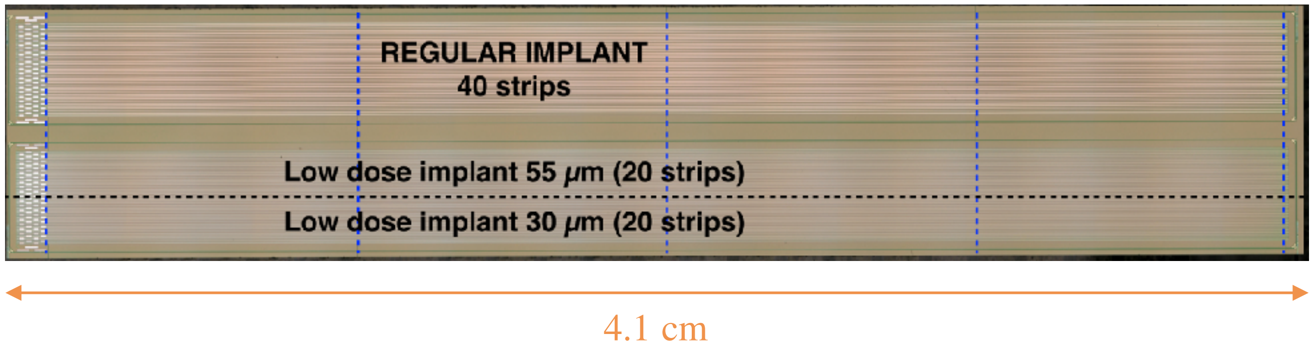
## Varying n-well characteristics

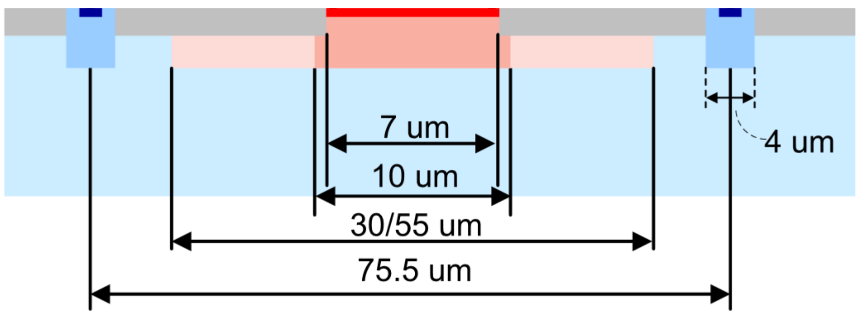



- n-in-p sensor, 150 nm LFoundry technology
- 150 ± 10 um thickness, 75.5 um strip pitch
- Varying n-well doping concentration and width




Regular implant strip design



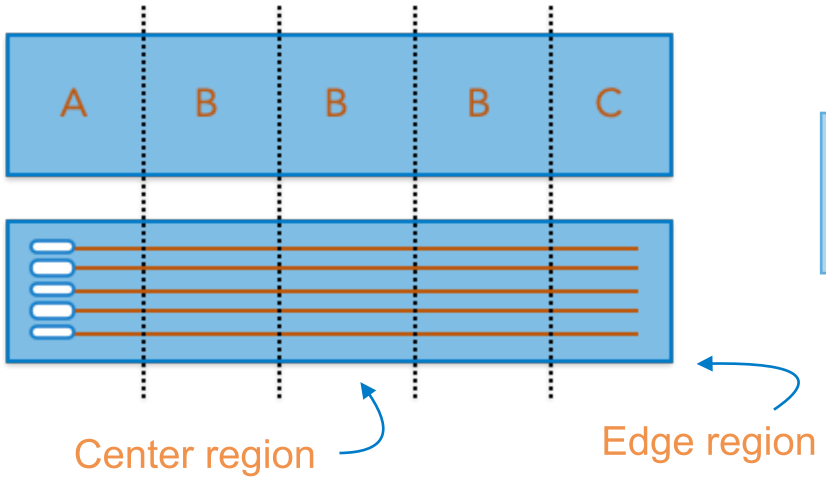

Low Dose (LD) implant strip design

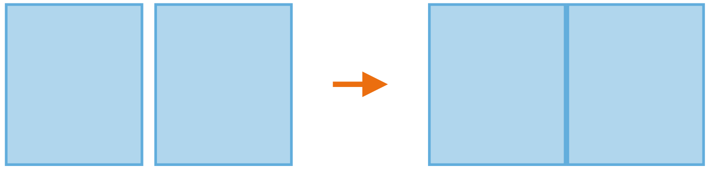
L. Diehl et al., *"Characterization of Passive CMOS Strip Sensors"*, NIMA, Vol 1022 (2022)
https://doi.org/10.1016/j.nima.2022.166671

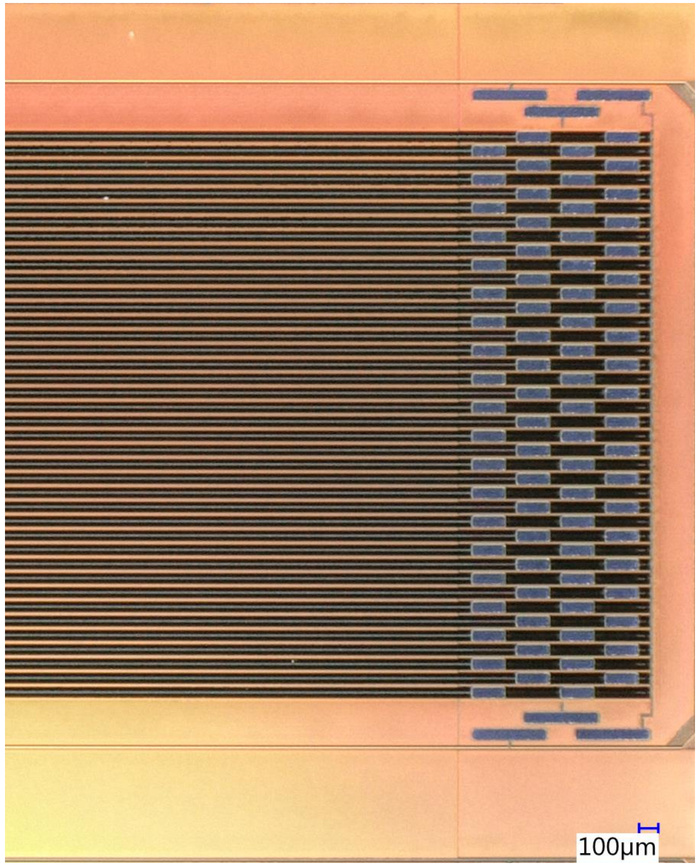
# Passive CMOS Sensor Design

## Stitched strip sensors

- Sensor is divided into different design blocks
- Design blocks are implemented individually
- Merging of design blocks by tiny overlap

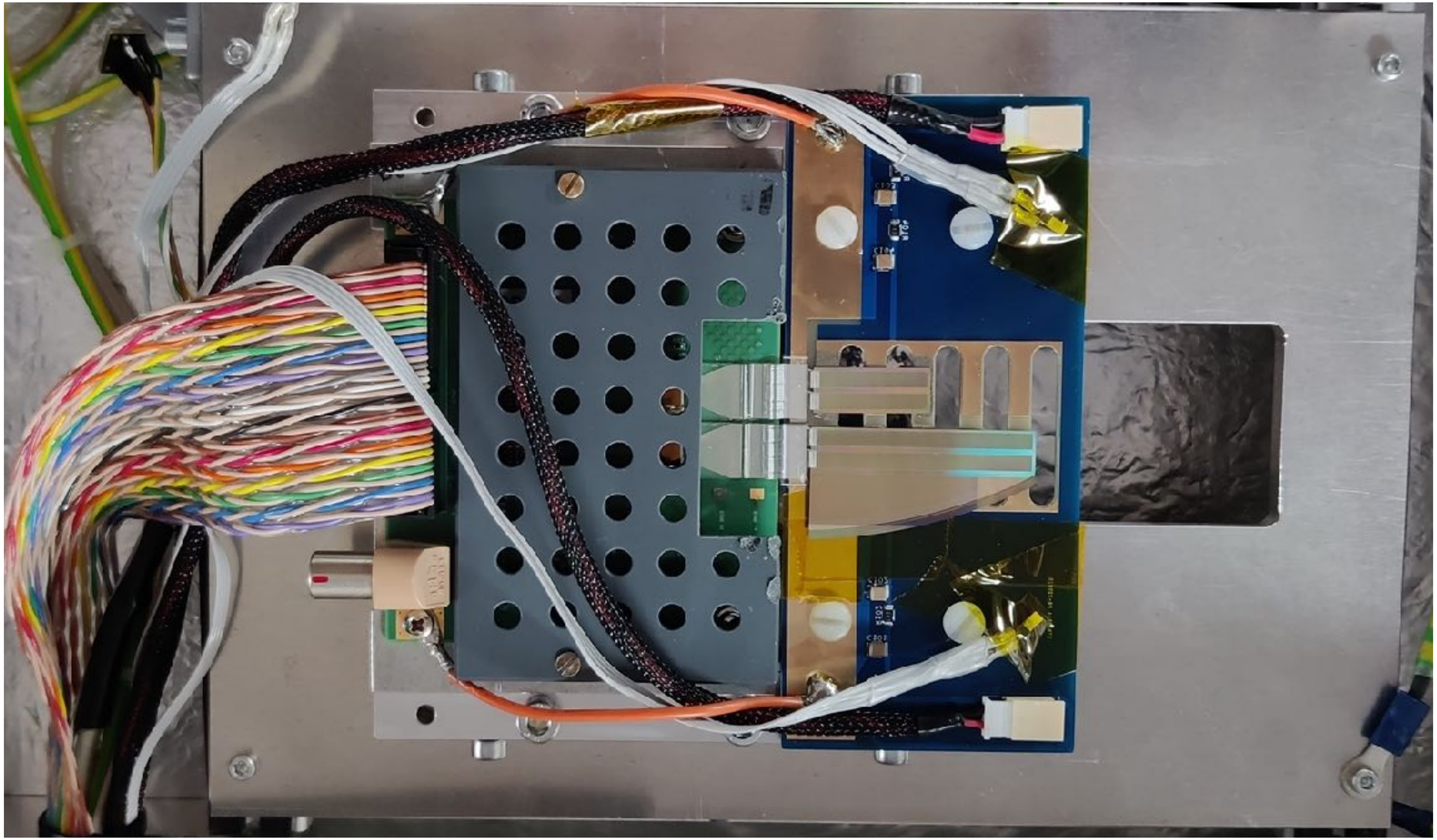




# Sensor Characterisation

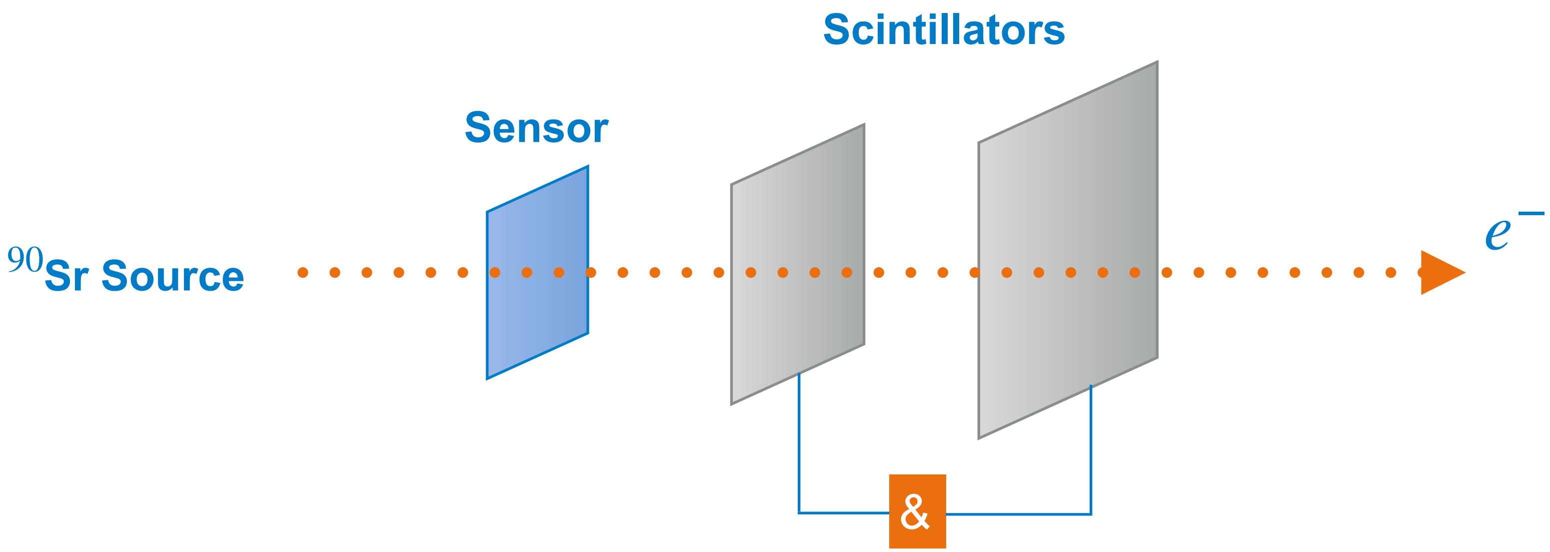
## ALiBaVa readout system



# Sensor Characterisation

## Source measurement with a $\beta$-Setup

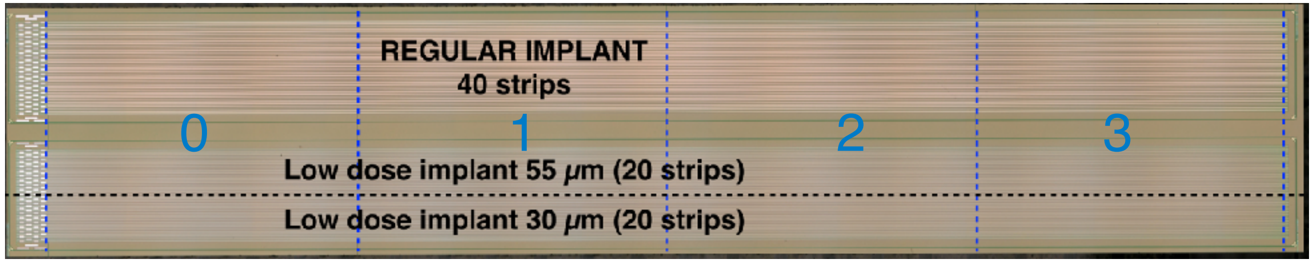
- Charge collection measurement with $^{90}$Sr source (MIP-like)
- Trigger by two scintillators in coincidence
- ALiBaVa system for data acquisition

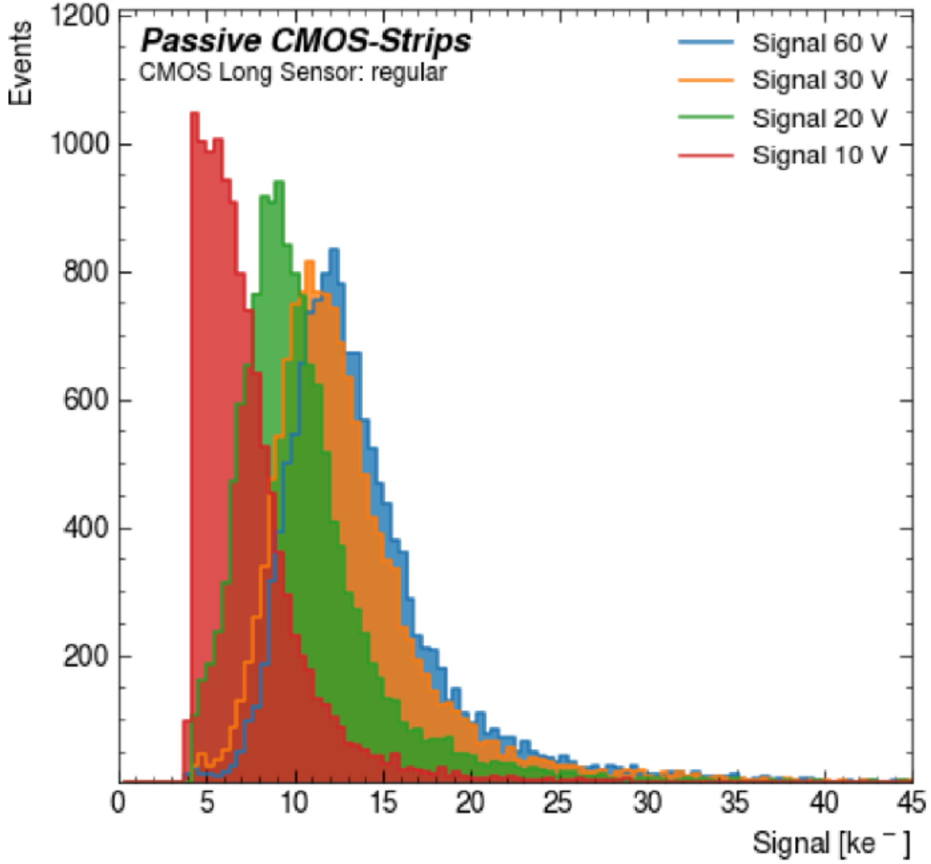


# Sensor Characterisation

## Does stitching affect charge collection?

- Charge collection at different bias voltages
- Collected Charge: MPV of Landau-Gauss fit to signal distribution
- No significant difference between stitched areas




Measured signal in $\beta$-Setup (long)

L. Diehl et al., *"Characterization of Passive CMOS Strip Sensors"*, NIMA, Vol 1022 (2022)
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# Sensor Characterisation

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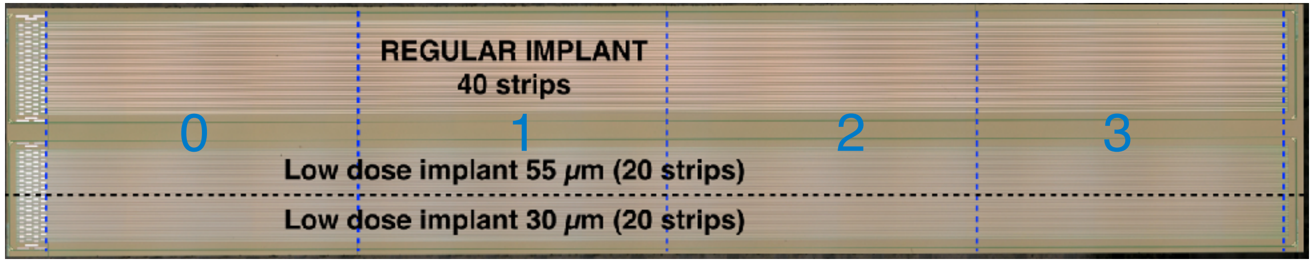


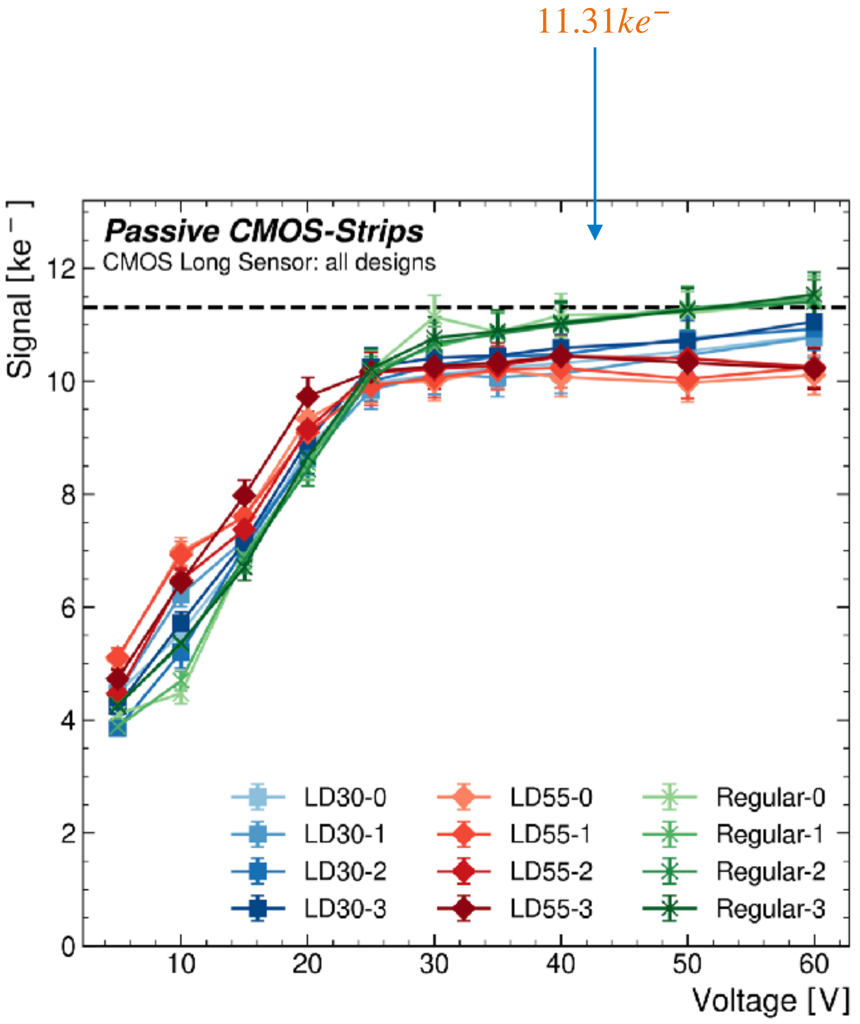


Charge Collection in stitched areas (long)

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# Summary & Outlook

## What we have learned and what's next ...

- Stitching does not impact charge collection!
- Ongoing sensor studies:
  - TCAD Simulation, electrical characterisation, TCT, irradiation campaigns, Test Beam measurements

- New sensor submission in discussion
- Particle physics and medical applications

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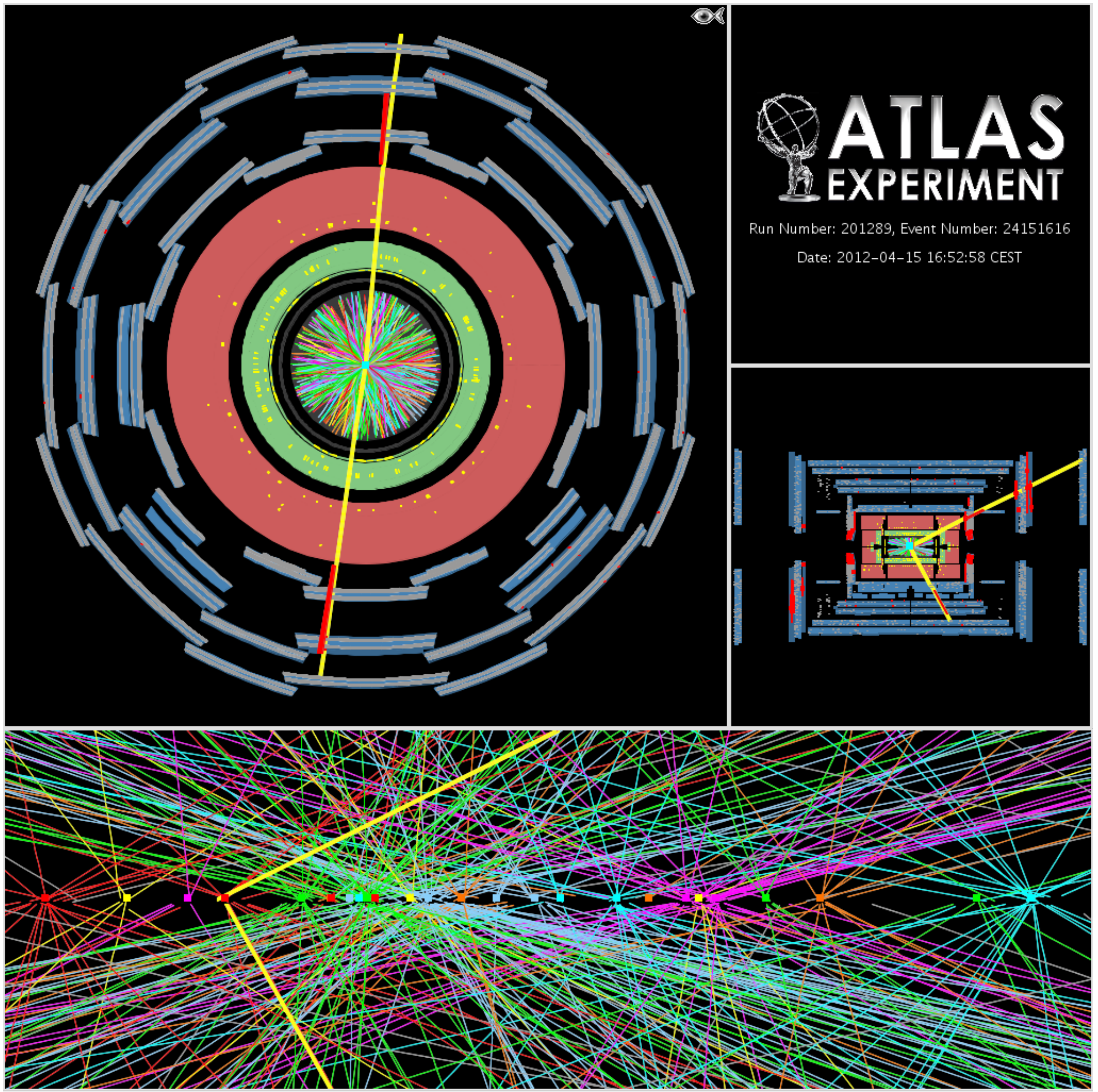
# Backup

# ATLAS Experiment Event Display $Z \longrightarrow \mu\mu$

## High pile-up environment in 2012

- Collision energy of 8 TeV
- Z boson event in the dimuon decay
- 25 reconstructed vertices
- track $p_T$ threshold is 0.4 GeV
- track requirements: 3 Pixel and 6 SCT hits
- Vertex reconstruction: tracks with $p_T$ > 0.4 GeV

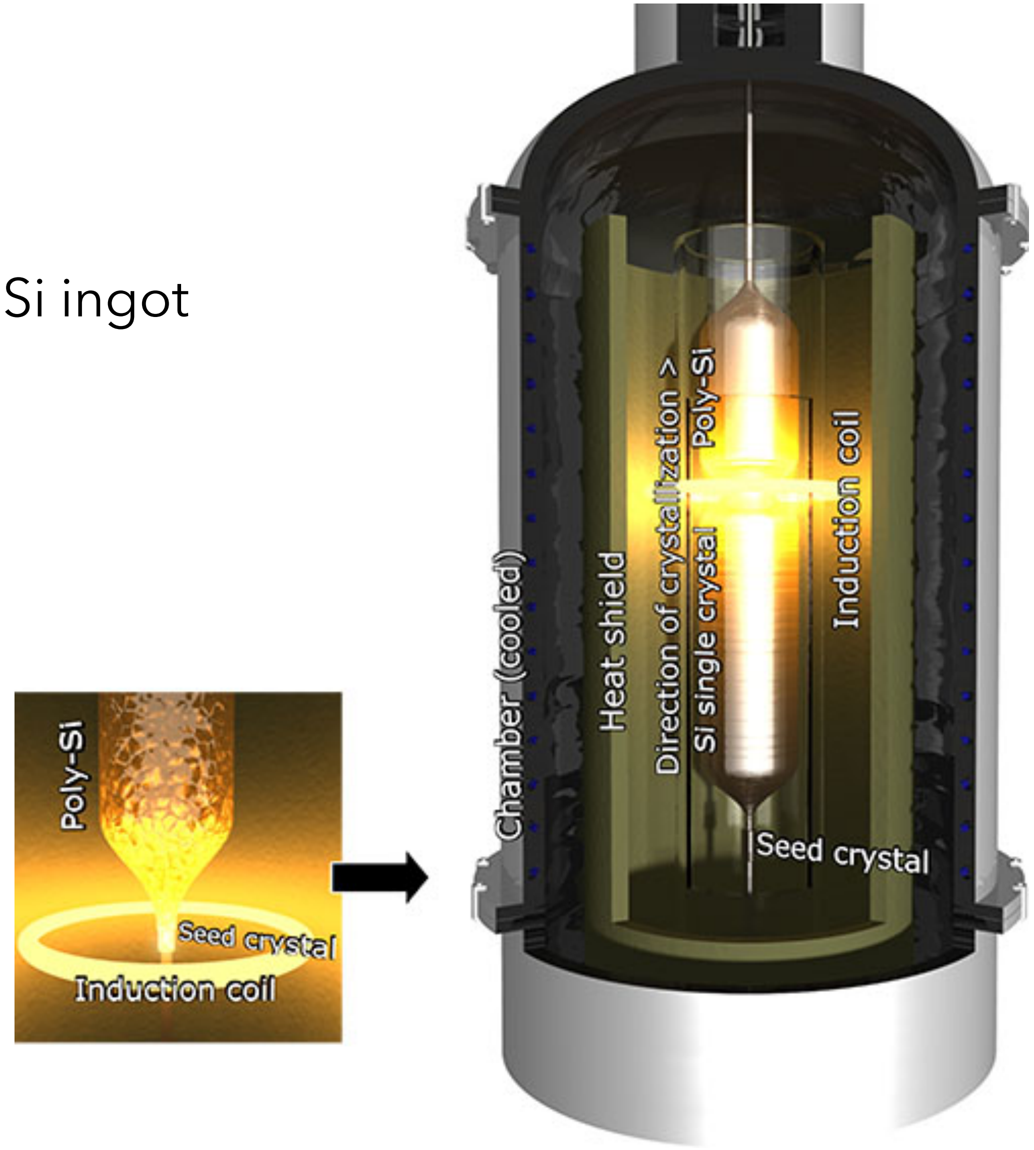



ATLAS Experiment, *"ATLAS Stand-Alone Event Displays"*, https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayStandAlone#2012_Z_mu_mu_event_with_high_pil

# Silicon Ingot Production

## Float-Zone Technique

- mono-crystalline Si seed crystal + poly-crystalline Si ingot
- RF coil melts region of poly-silicon
- Cools down to mono-crystalline silicon
- RF coil and melted zone move along the ingot
- Impurities gather near crystal end




Microchemicals GmbH, *"Silicon Ingot Production: Czochralski- and Float-Zone Technique"*, https://www.microchemicals.com/products/wafers/silicon_ingot_production.html

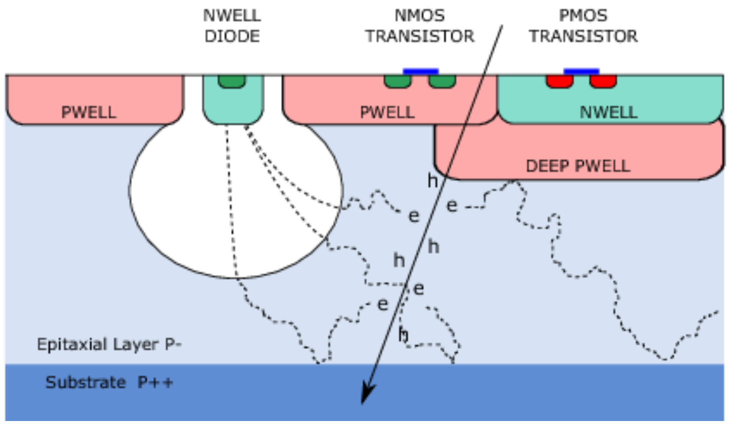
# Requirements for future Si tracking detectors in HEP

S. Spannagel, PCR93

| | Lepton Colliders | (HL-) LHC (ATLAS/CMS) |
|---|---|---|
| Material budget | < 1% $X_0$ | 10% $X_0$ |
| Single-point resolution | ≤ 3 µm | ~ 15 µm |
| Time resolution | ~ ps – ns | 25 ns |
| Granularity | < 25 µm x 25 µm | 50 µm x 50 µm |
| Radiation tolerance | $< 10^{11}\ n_{eq} / cm^2$ | **$O(10^{16}\ n_{eq} / cm^2)$** |

# CMOS Imaging Technology

- CMOS: Complementary Metal Oxide Semiconductor
- conversion of photons to electrons
  - Image creation in digital cameras
- Production with photolithography
- Integration of n-channel (NMOS) and p-channel (PMOS) FETs




Canon, *"See New Possibilities in 120 MP Resolution",* https://canon-cmos-sensors.com/canon-120mxs-cmos-sensor/

Besson, A. et al , "From vertex detectors to inner trackers with CMOS pixel sensors", Nucl. Instrum. Methods Phys. Res., A 845 (2017) 33-372 (2022) https://doi.org/10.1016/j.nima.2016.04.081