Istituto Nazionale di Fisica Nucleare
Sezione di Genova

The ATLAS tracking system for HL-LHC

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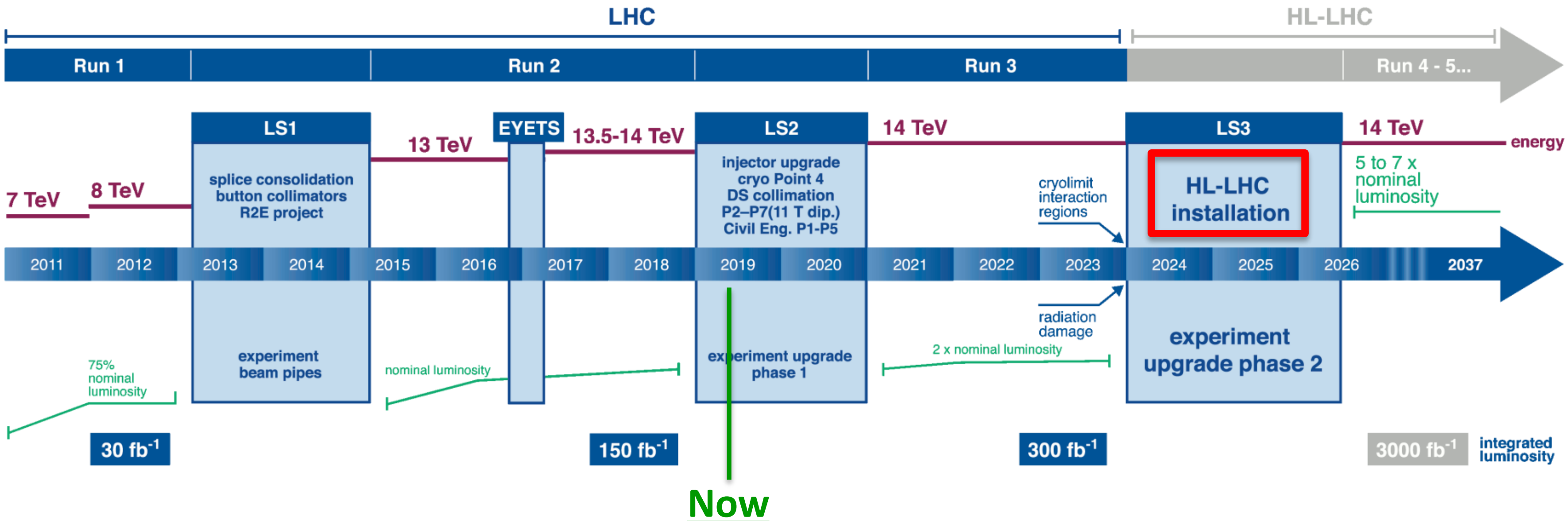
The future of ATLAS: Run 3 and HL-LHC

LHC proton-proton collisions $\sqrt{s} =$ 7/8/13 TeV (2011-2018) + 13/14 TeV (2021-2023)

High Luminosity LHC (HL-LHC) $\sqrt{s} =$ 14 TeV (2026-20XX)

Instantaneous Luminosity a factor 5 to 7 higher than LHC: $\mathcal{L} = 7.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

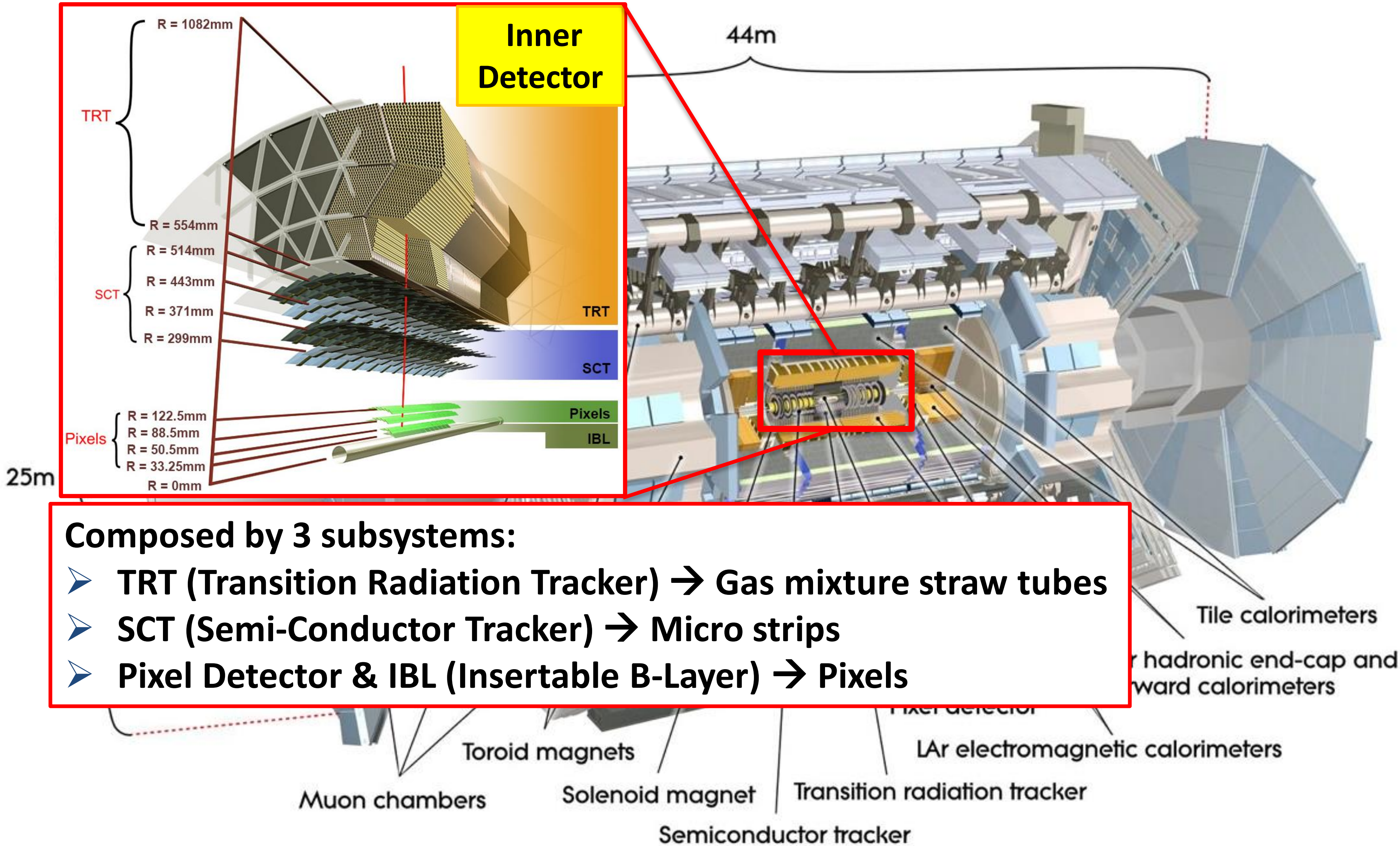
Expect up to 200 pile-up events



At HL-LHC, harder conditions for the ATLAS detector (especially for the tracking system):

- **increase in occupancy → finer granularity**
- **larger readout bandwidth → faster detector readout**
- **radiation damage → better radiation hardness**

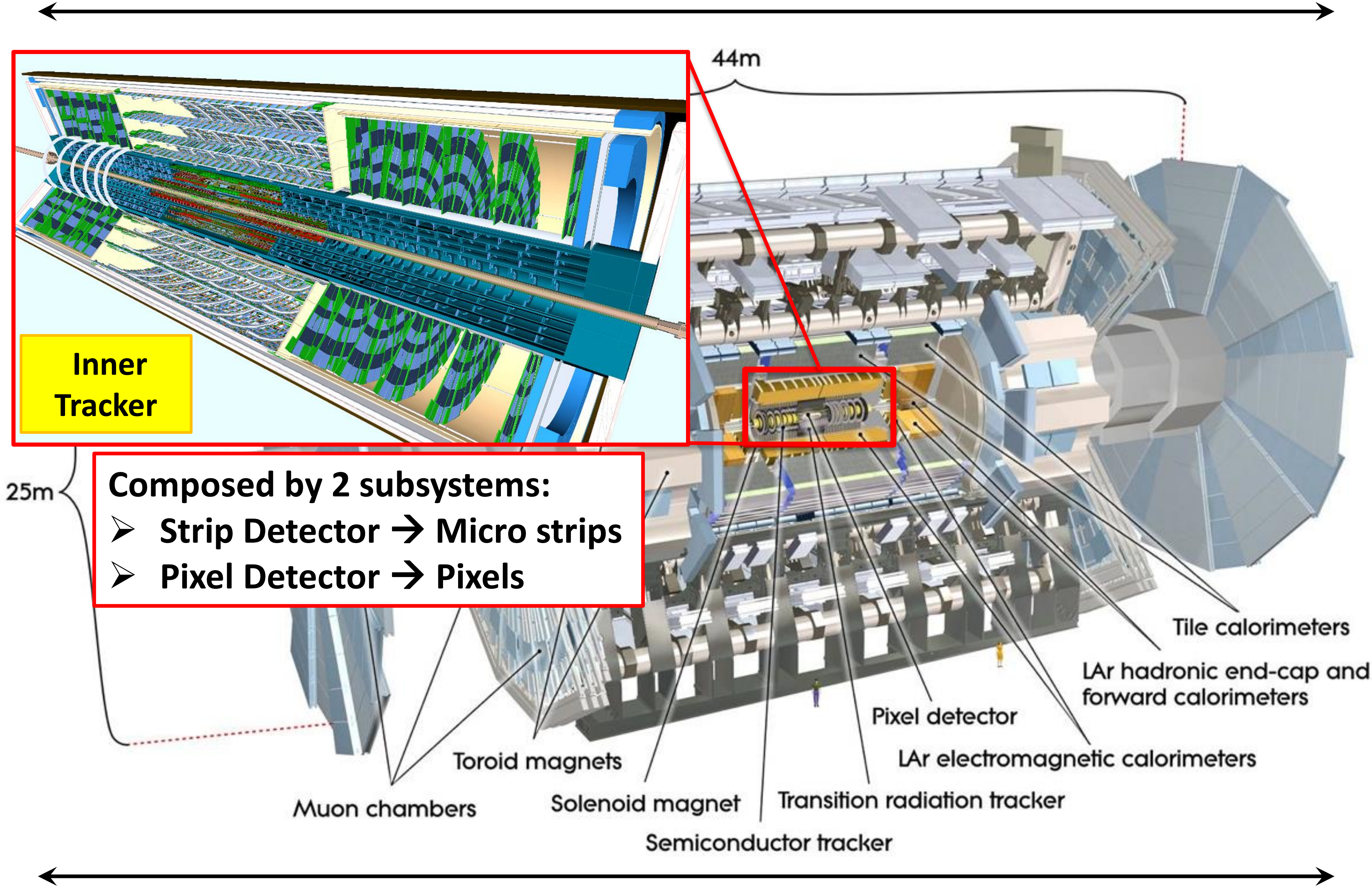
The current ATLAS tracking system



Composed by 3 subsystems:

- **TRT (Transition Radiation Tracker) → Gas mixture straw tubes**
- **SCT (Semi-Conductor Tracker) → Micro strips**
- **Pixel Detector & IBL (Insertable B-Layer) → Pixels**

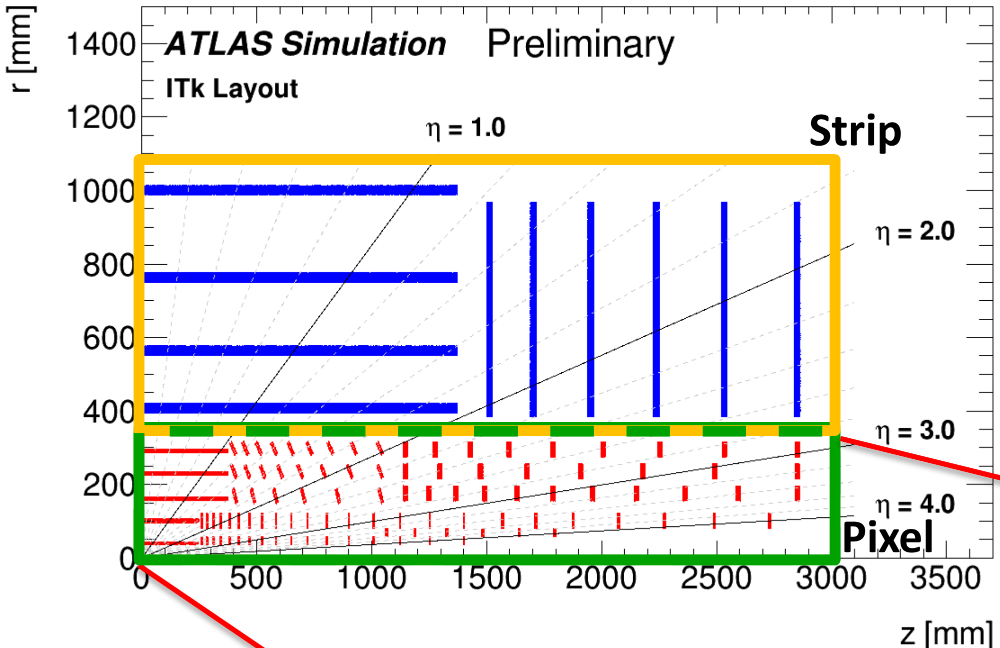
The future ATLAS tracking system: Inner Tracker (ITk)

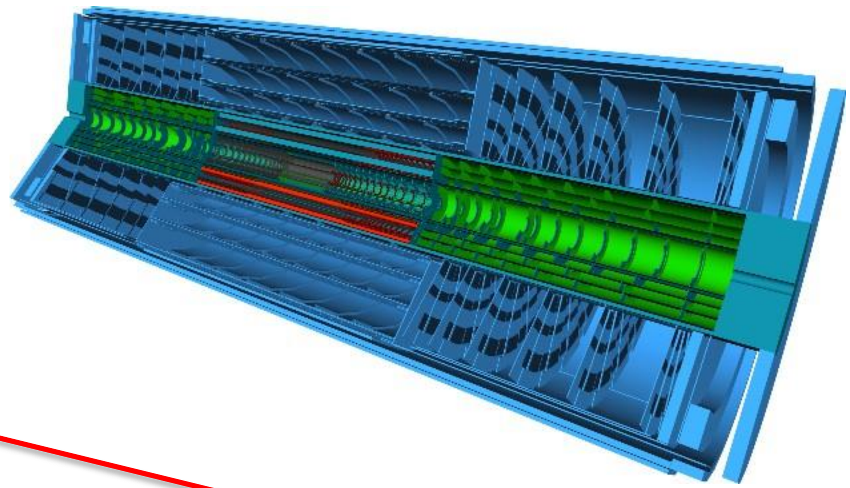


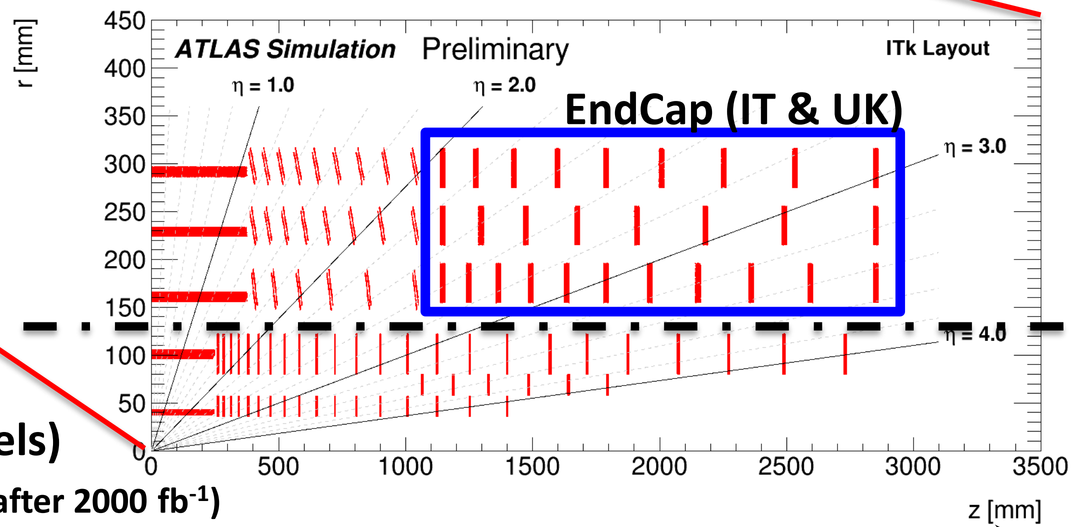
Composed by 2 subsystems:

- **Strip Detector → Micro strips**
- **Pixel Detector → Pixels**

Inner Tracker detector layout



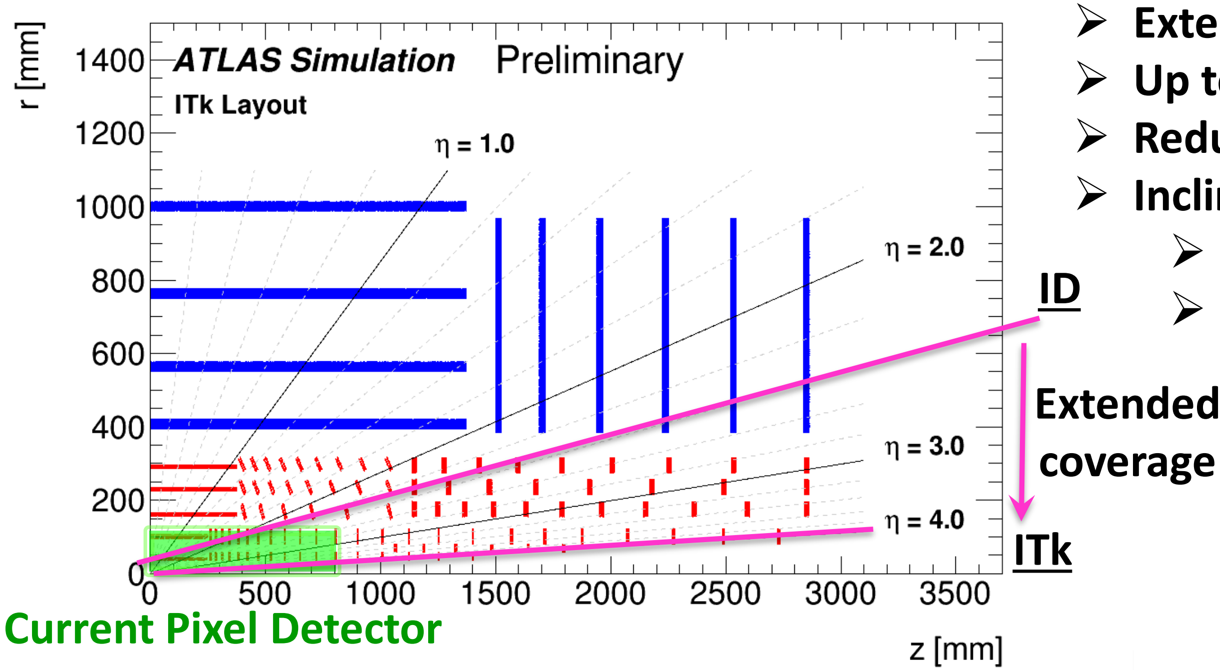




ATLAS-TDR-25
ATLAS-TDR-30
ATLAS-PHYS-PUB-2019-014

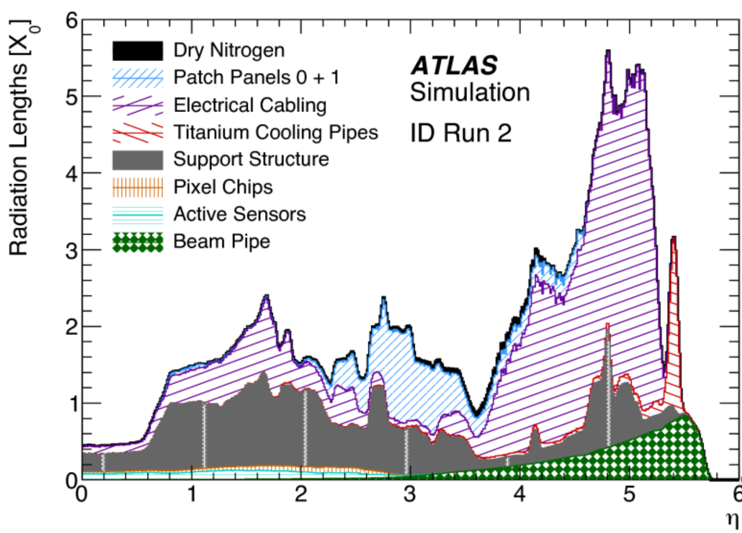
- **Inner Tracker**
- **New all-silicon detector**
- **Tracking coverage up to $|\eta| = 4$**
- **Inner pixel det. (13 m^2, 5 M channels)**
- **Outer strip det. (160 m^2, 160 M channels)**
- **First two pixel layers will be replaced (after 2000 fb^{-1})**

Layout, material budget, pseudorapidity coverage

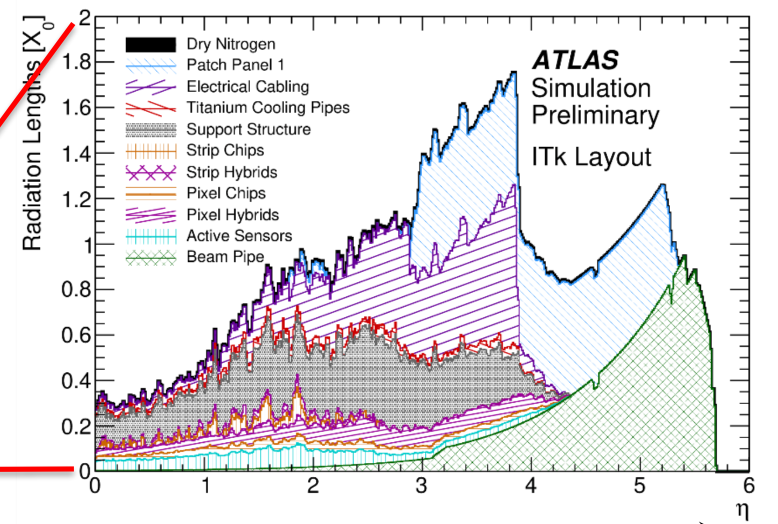


- Extended coverage up to |η| = 4
- Up to 13 hits per crossing particle
- Reduced material w.r.t Inner Detector
- Inclined modules in Pixel Detector
  - Maximize resolution
  - Minimize material

Inner Detector radiation lengths



ITk radiation lengths

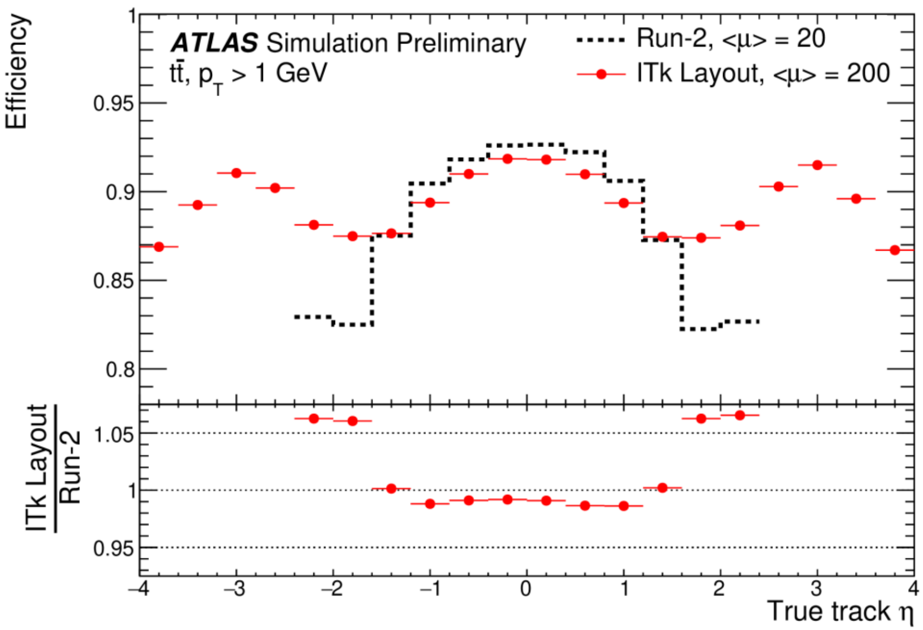


Track efficiency (extended) and fake rate (lower)

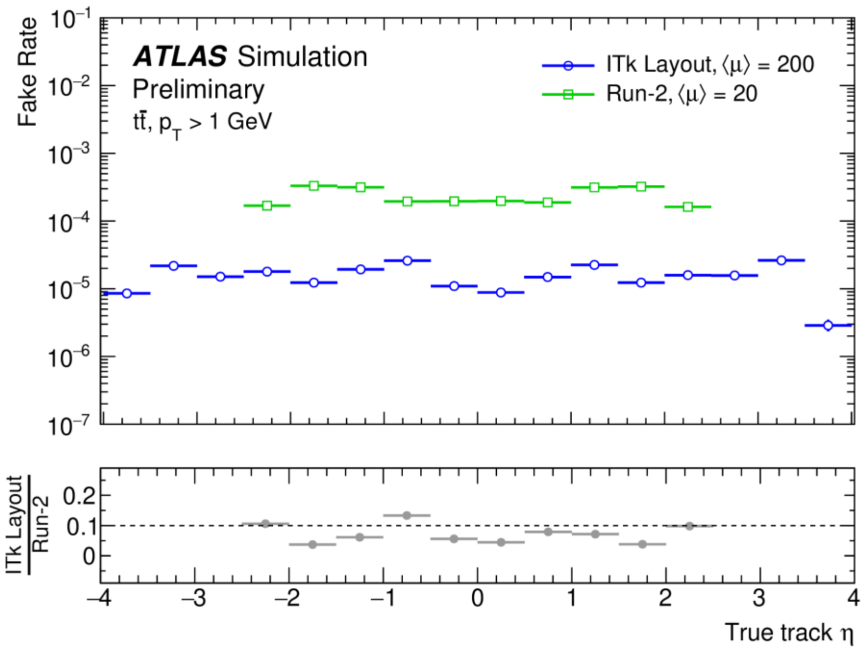
Despite the increase in complexity of the project and the tougher conditions

- **ITk detector will maintain good track reconstruction efficiency (up to |η| = 4)**
- **And lower fake rates compared to the Run 2 Inner Detector performance**

Track reconstruction efficiency



Track fake rate



Simulation on tt events at HL-LHC (<μ> = 200) compared to LHC Run 2 (<μ> = 20)

Pixel detector Outer EndCap

- Two EndCaps
  - Two Half Cilinders
    - 11+8+9 Rings (x 2 Half Rings)

Layer	Radius [mm]	Z [mm]	Rings	Sensors per Ring
2	154.50	1145-2850	11	32 (8 quad)
3	214.55	1145-2850	8	44 (11 quad)
4	274.60	1145-2850	9	52 (13 quad)

Italian organization

Module assembly: Milano, Genova

Module tests: Bologna, Trento, Udine

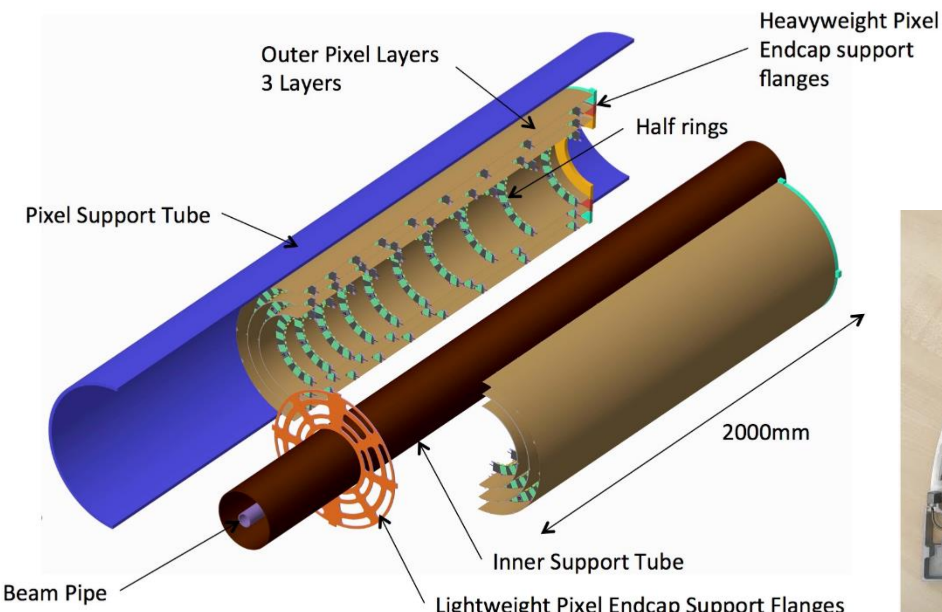
Module loading: Genova, Lecce

Local supports: Genova

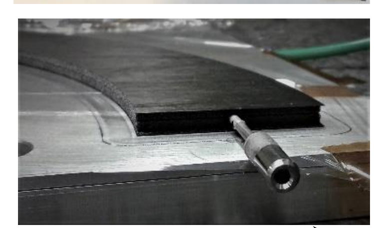
Integration in Half Cilinders: Frascati

CERN

- Effort shared by Italian and UK institutes
- **Italy:** Milano, Udine, Trento, Genoa, Bologna, Frascati, Lecce

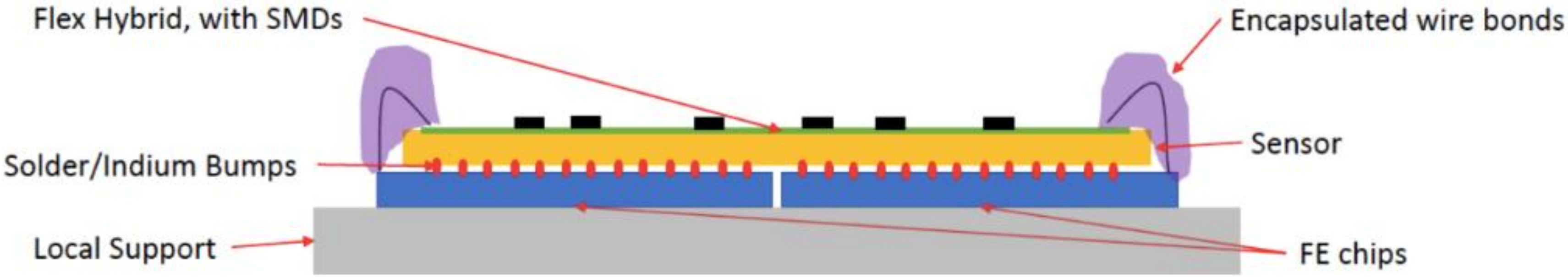


- Half Ring (support and cooling):
  - Sandwiches of carbon-fiber, carbon foam and titanium cooling pipe
  - Modules directly attached on Half Rings



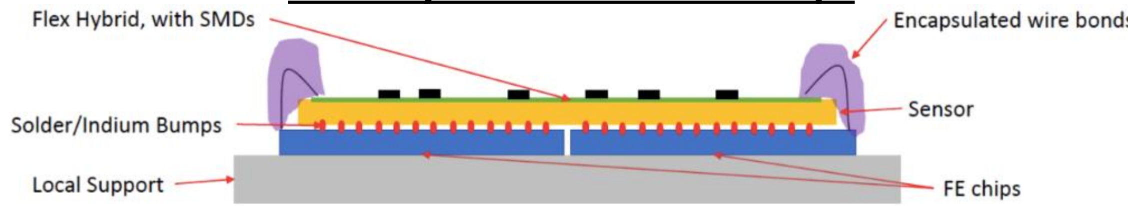
Pixel Detector module

Pixel hybrid-module concept

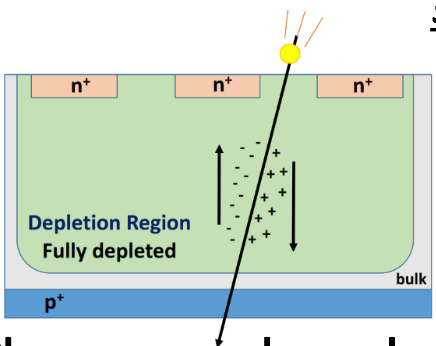


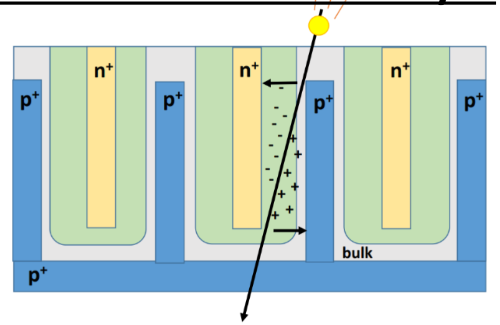
Planar/3D sensor + RD53 chip

Pixel hybrid-module concept



3D in the innermost layer

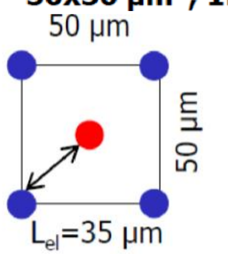


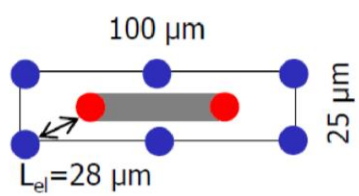


Planar everywhere else

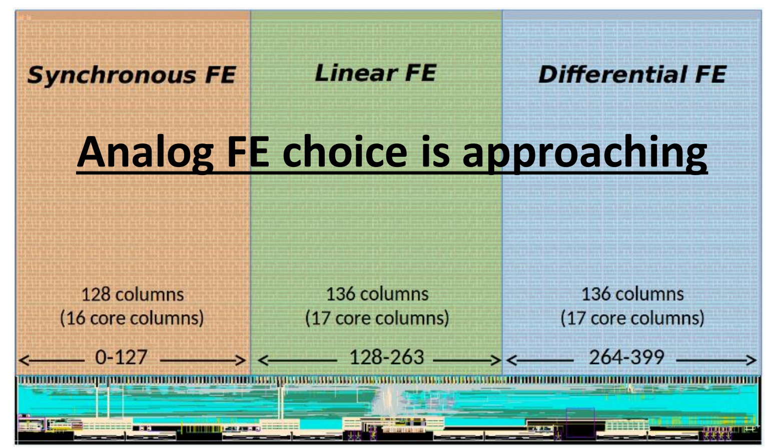
Pixel size: 50x50 or 25x100 μm^2
Thickness: 100-150 µm
Reduced pixel size & thickness →
→ higher radiation hardness

50x50 µm², 1E **25x100 µm², 2E**





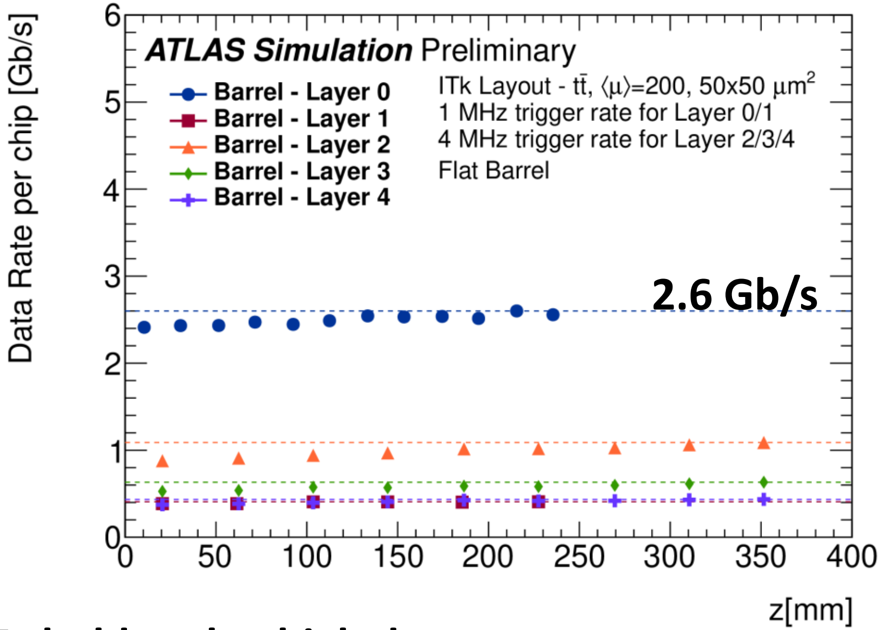
New Front-End chip developed within the RD53 Collaboration
65nm CMOS technology
RD53A prototype: 3 Analog FE flavours
RD53B chip design in few months



Final size: 2x2 cm^2
Total of about 160 k pixels
Bump density: $4{\cdot}10^4$ pixels per cm^2

Data rates and radiation fluences

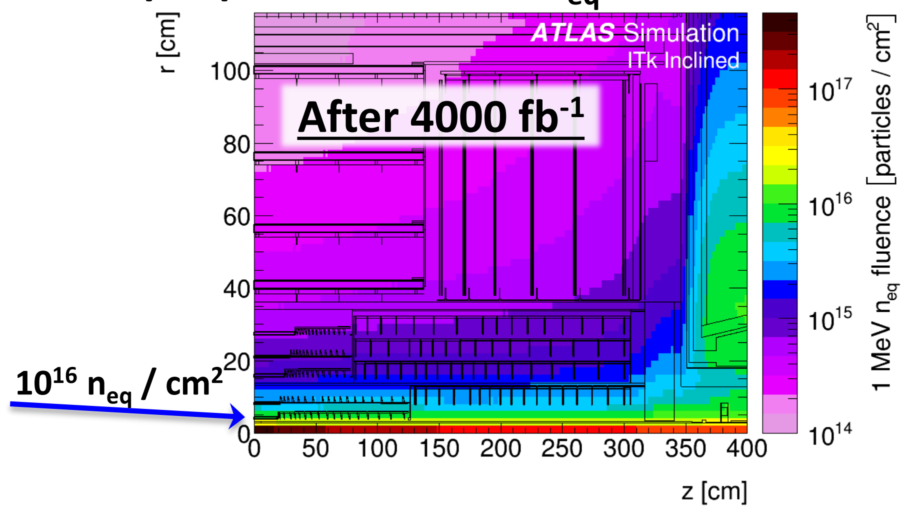
With such a high granularity
Expect high data rates (2.6 Gb/s) at <μ> = 200
Simulation with RD53B readout chip
Pixel Detector barrel section



To hold such a high data rate:

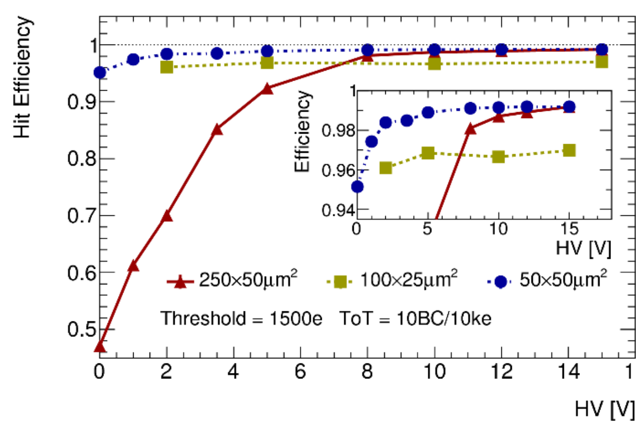
- Developing high speed readout
- 4 x 1.28 Gb/s links (single/quad-mod.)

Pixel: up to 10^{16} 1 MeV n_{eq} / cm^2 fluence
Strip: up to 10^{15} 1 MeV n_{eq} / cm^2 fluence



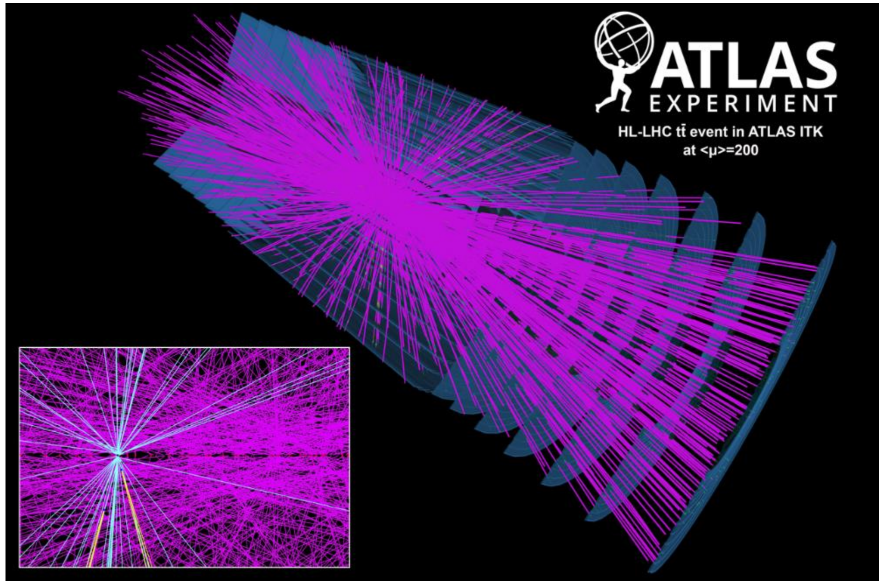
Check survival to high radiation environment:

- Built and test Pixel module prototypes
- Irradiation campaigns at 10^{16} n_{eq} / cm^2



Test beams confirmed efficiency > 97%

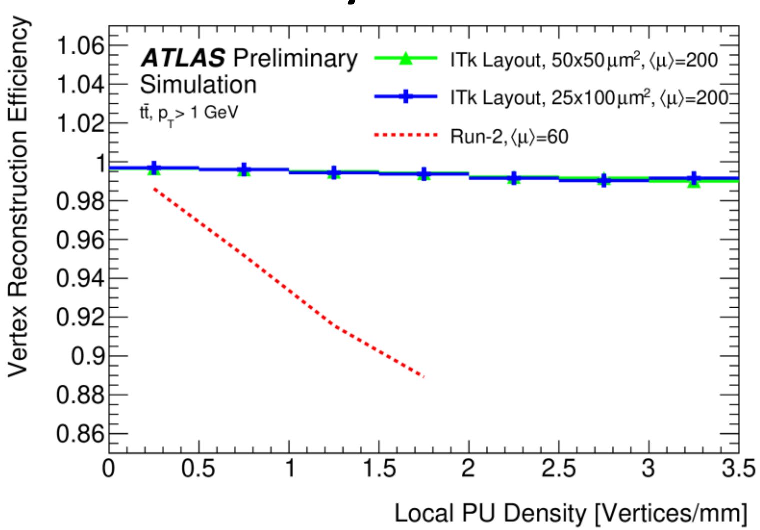
Primary vertex reconstruction, Vertexing resolution



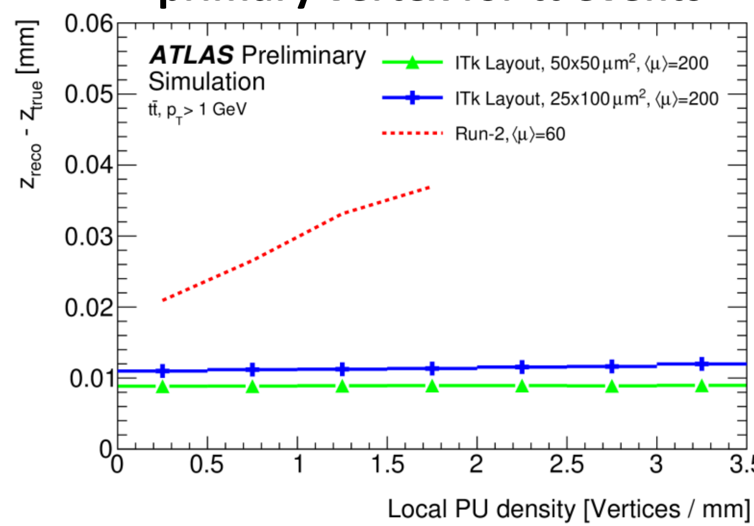
Tougher conditions:
need to ensure
high quality
tracking performance

From simulation studies:
expect better efficiency
and higher resolution in
tracking and vertexing

Primary vertex reconstruction efficiency for tt events

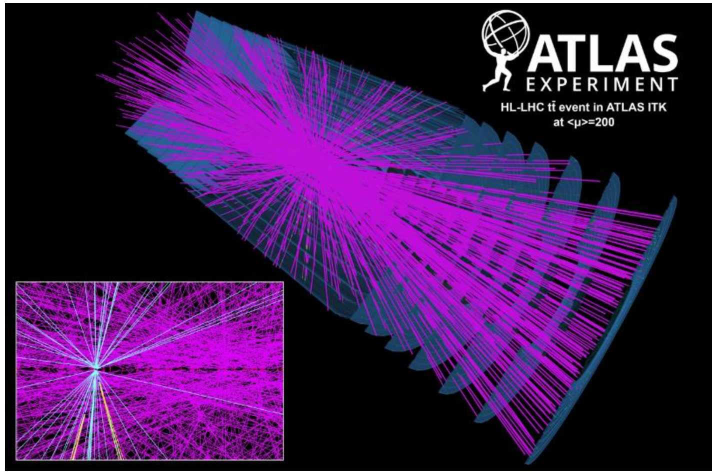


Resolution on z coordinate of the primary vertex for tt events



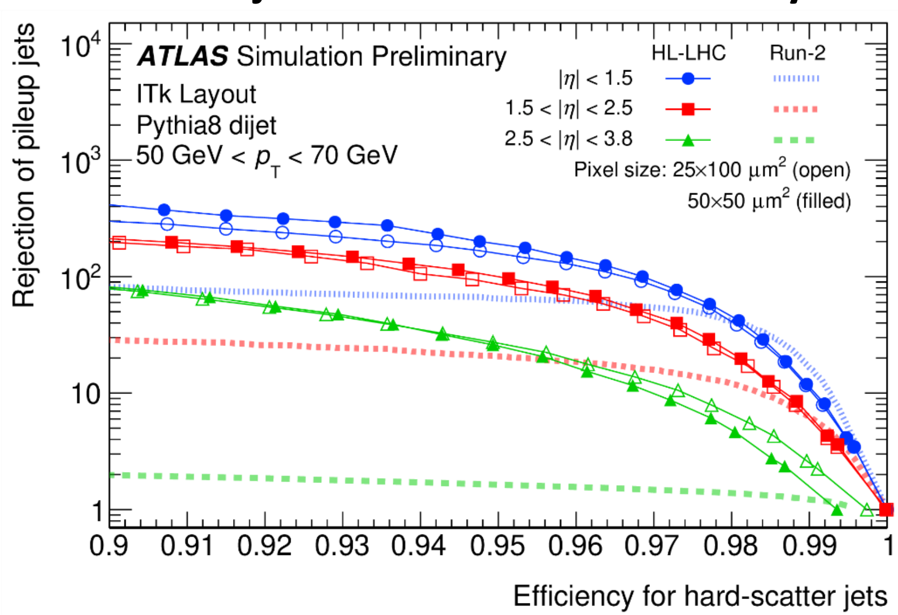
Pile-up jet rejection, b-tagging performance

Tougher conditions:
need to ensure high quality tracking performance

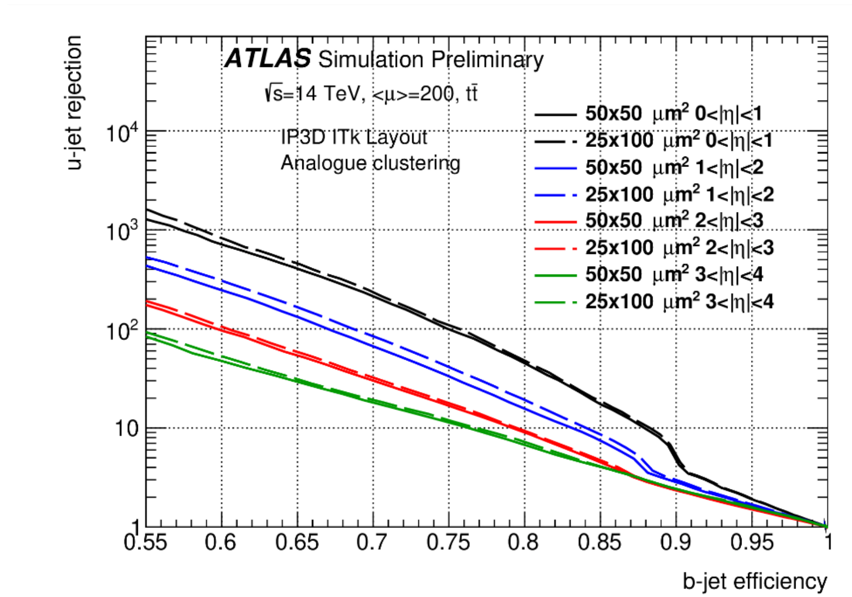


From simulation studies:
expect similar or improved pile-up rejection and b-tagging performance

Pile-up jets rejection as a function of the jet reconstruction efficiency

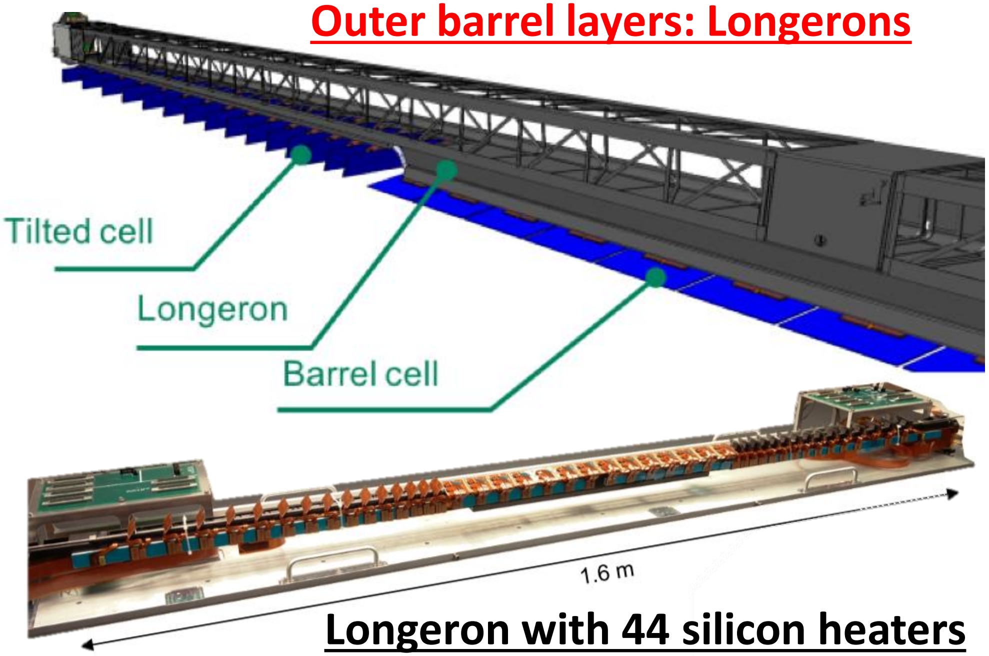


B-tagging performance (light-jet rejection) as a function of b-jet efficiency



Pixel detector R&D phase: prototyping and tests

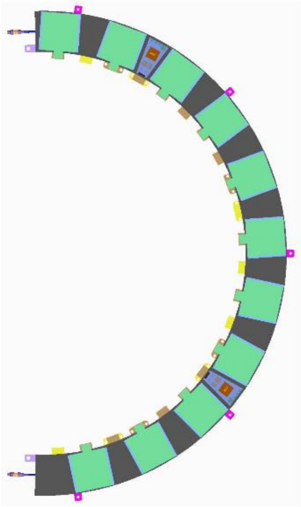
Outer barrel layers: Longerons

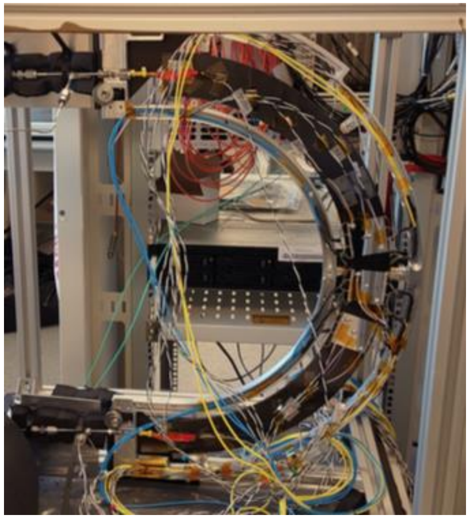


Longeron with 44 silicon heaters

Outer EndCap: Rings

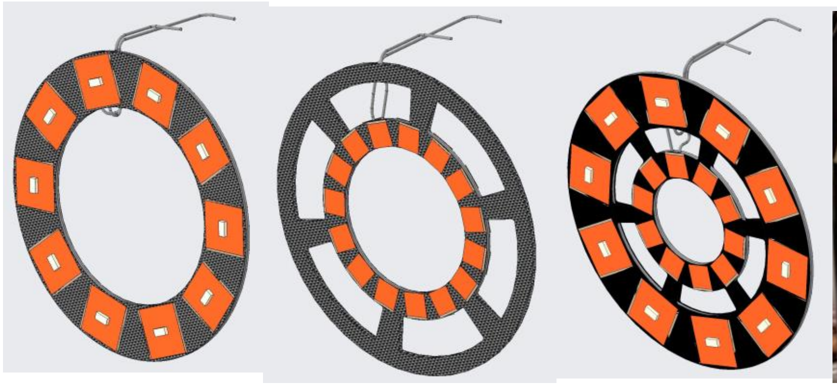
Half ring with heaters and temp. sensors

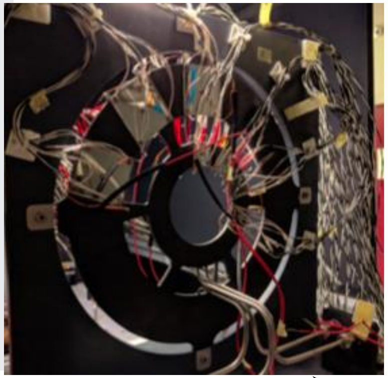




Inner EndCap Rings

Inner system ring with temperature sensors





Inner System Barrel: Staves

Staves for layers 0 and 1

Summary and outlook

The current Tracking System of the ATLAS experiment (ID: Inner Detector) will be replaced by a new all-silicon detector (ITk: Inner Tracker) to cope with the harsher HL-LHC conditions

- A challenging detector with Strips (160 m^2) + Pixels (13 m^2)
- Layout is being refined, carefully checking the tracking performance
  - New results form simulation: ATLAS-PHYS-PUB-2019-014
- ITk detector is expected to have similar or better tracking performance compared to ID
  - Comparable tracking efficiency, lower fake rate
  - Lower material budget, higher pseudorapidity coverage (up to $|\eta| = 4$)
  - Improved primary vertex reconstruction, better vertexing resolution
  - Higher pile-up jets rejection, comparable b-tagging performance

- The ITk Pixel detector will be composed by hybrid Pixel modules (sensor + FE chip)
- Reduced pixel size (50x50 or 25x100 μm^2) and thickness (100-150 µm) compared to ID mod.
  - Confirmed hit detection efficiency higher than 97% after 10^{16} n_{eq} / cm^2 irradiation
- New Front-End chip: RD53A prototype being tested, RD53B being designed
  - High speed links (4 x 1.28 Gb/s), low consumption

- For ITk Pixel detector, 3 main sections are identified: Inner System, Outer Barrel & EndCaps
  - R&D effort is shared by many institutes: currently prototyping and testing
  - The Italian community is committed to build one EndCap