ATLAS HGTD

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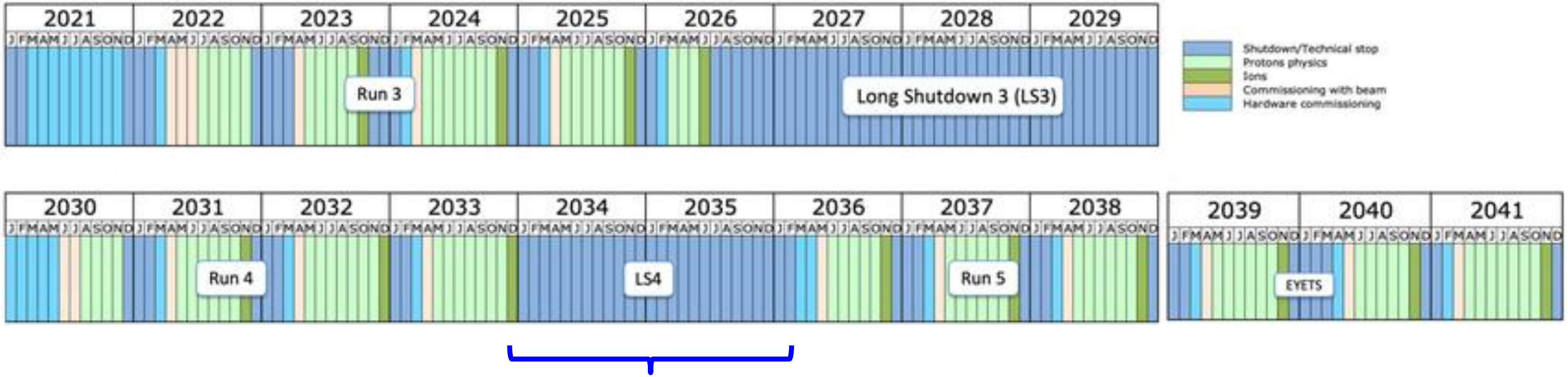
for HGTD F9 (Gregor, Bojan, Jernej, Iskra, Marko P., Brigita, Ajda)

F9 Strategic meeting, Krvavec, 28 September 2026

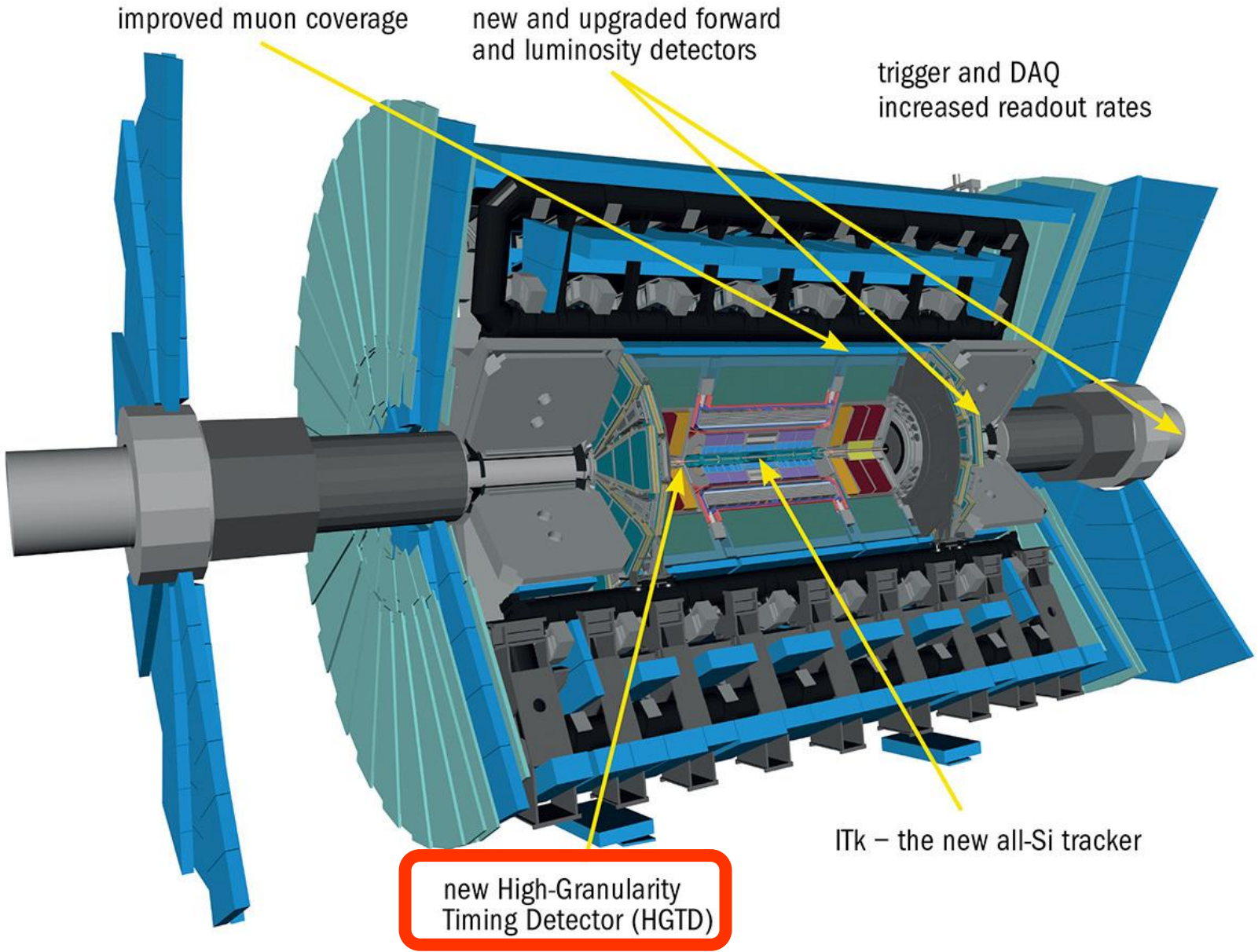
LHC Long term schedule

Long Shutdown 3 (2026-29) :
High Luminosity LHC upgrade

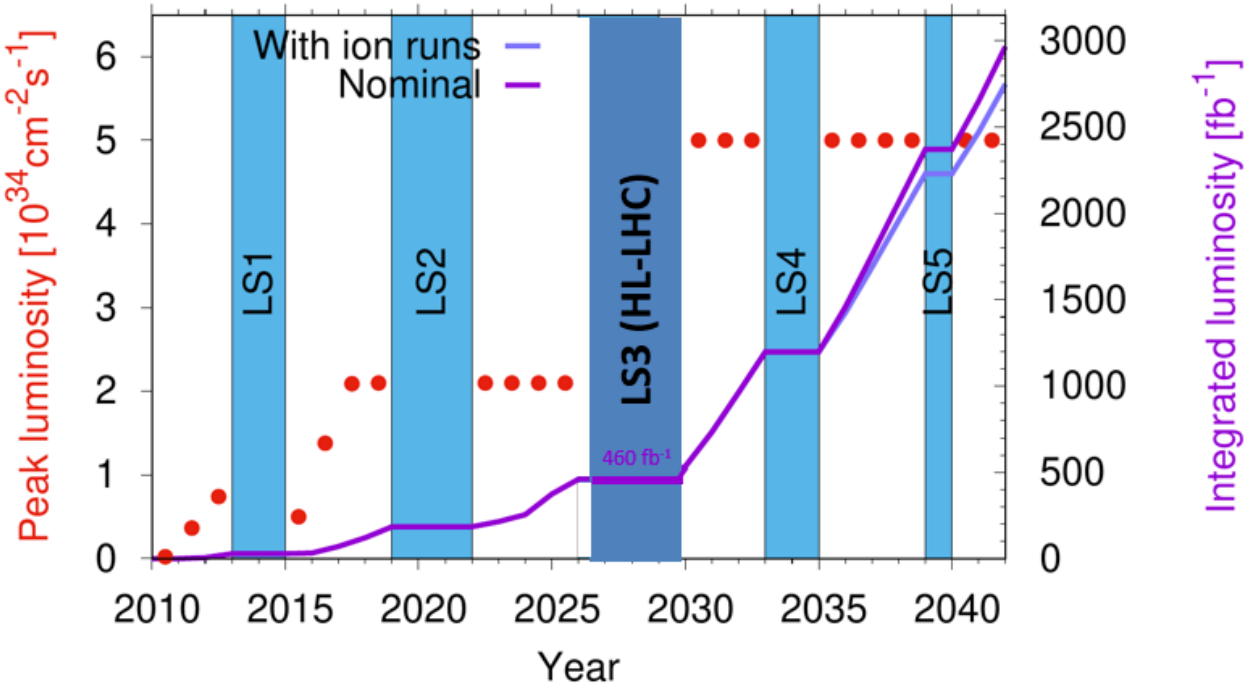


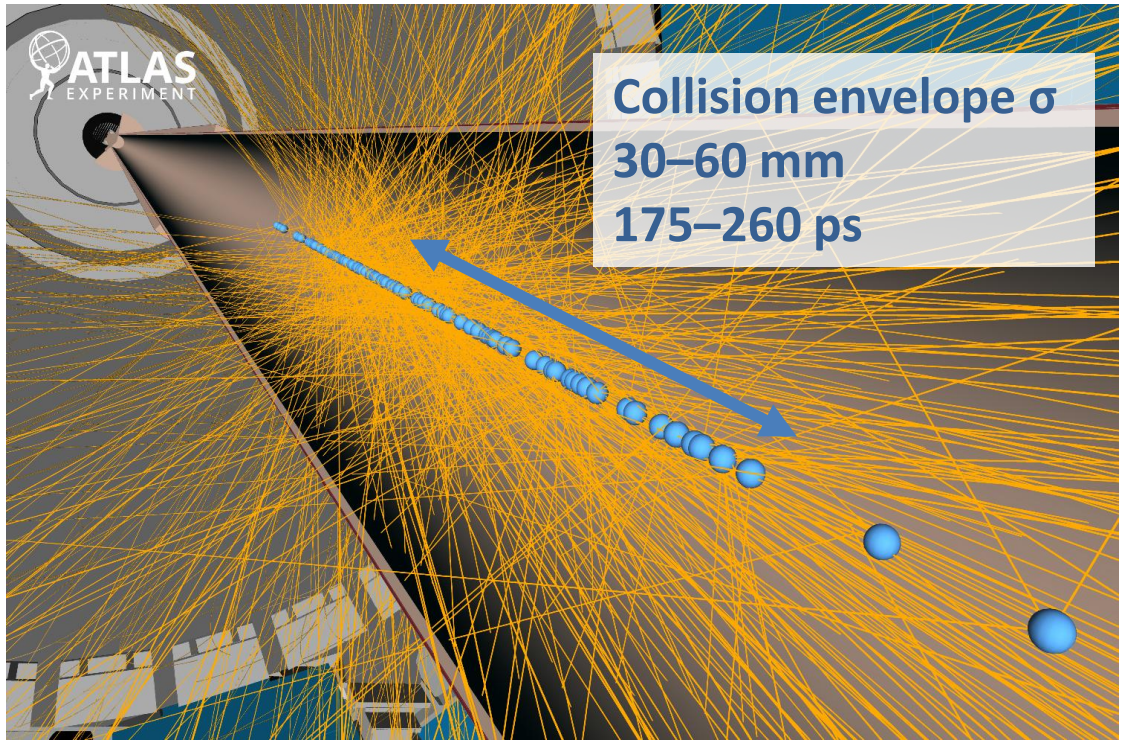
Long Shutdown 4 (2034-36)
Opportunity for detector replacements

ATLAS phase 2 upgrade



HL-LHC collision environment





$\mathcal{L}_{inst}$ = **5 × 10³⁴ cm²/s** at HL-LHC

3000 fb⁻¹ total in High Lumi phase

(2010–2026: 460 fb⁻¹, peak 2.3 × 10³⁴ cm²/s)

Pile-up value of 200 in experiments

Extreme vertex density & radiation damage

Why High Granularity *Timing* Detector?

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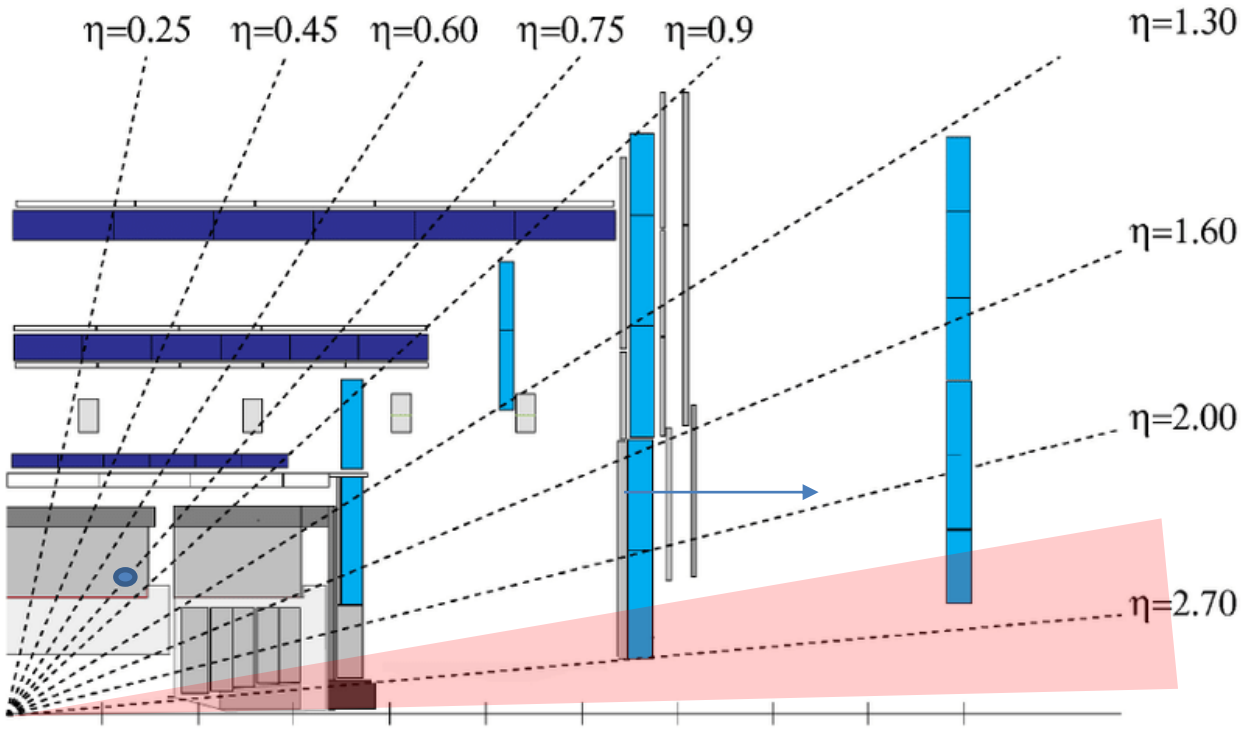
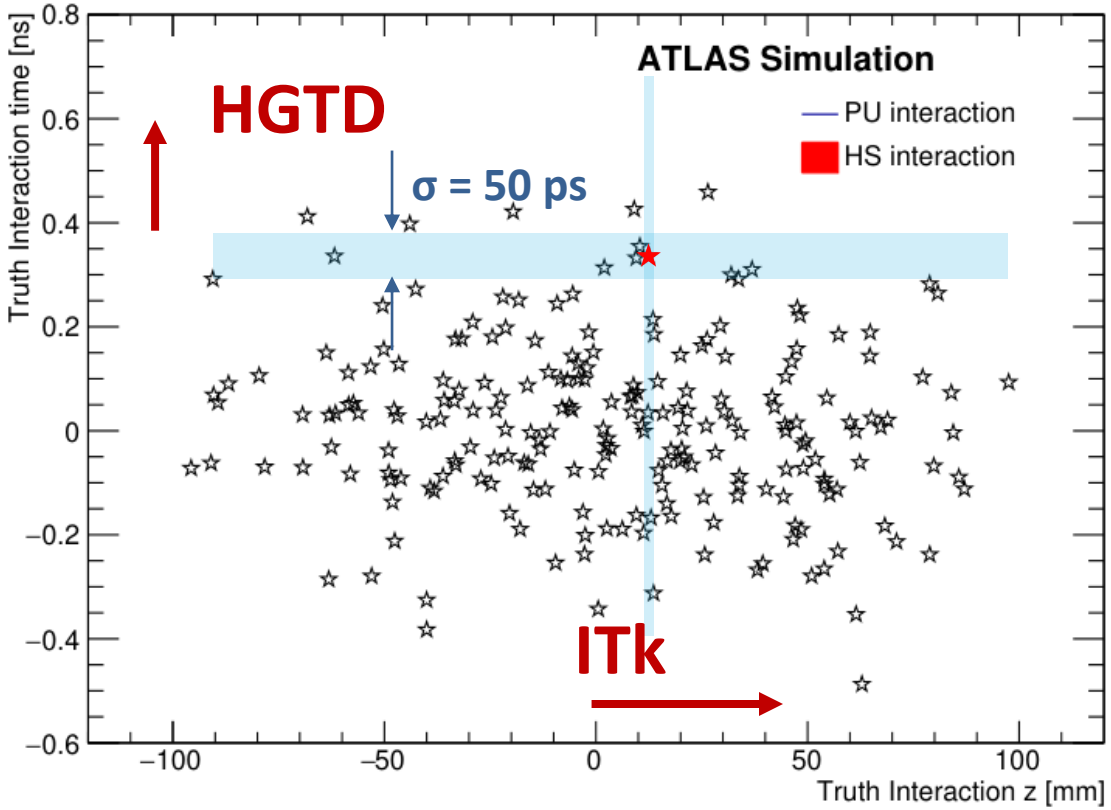


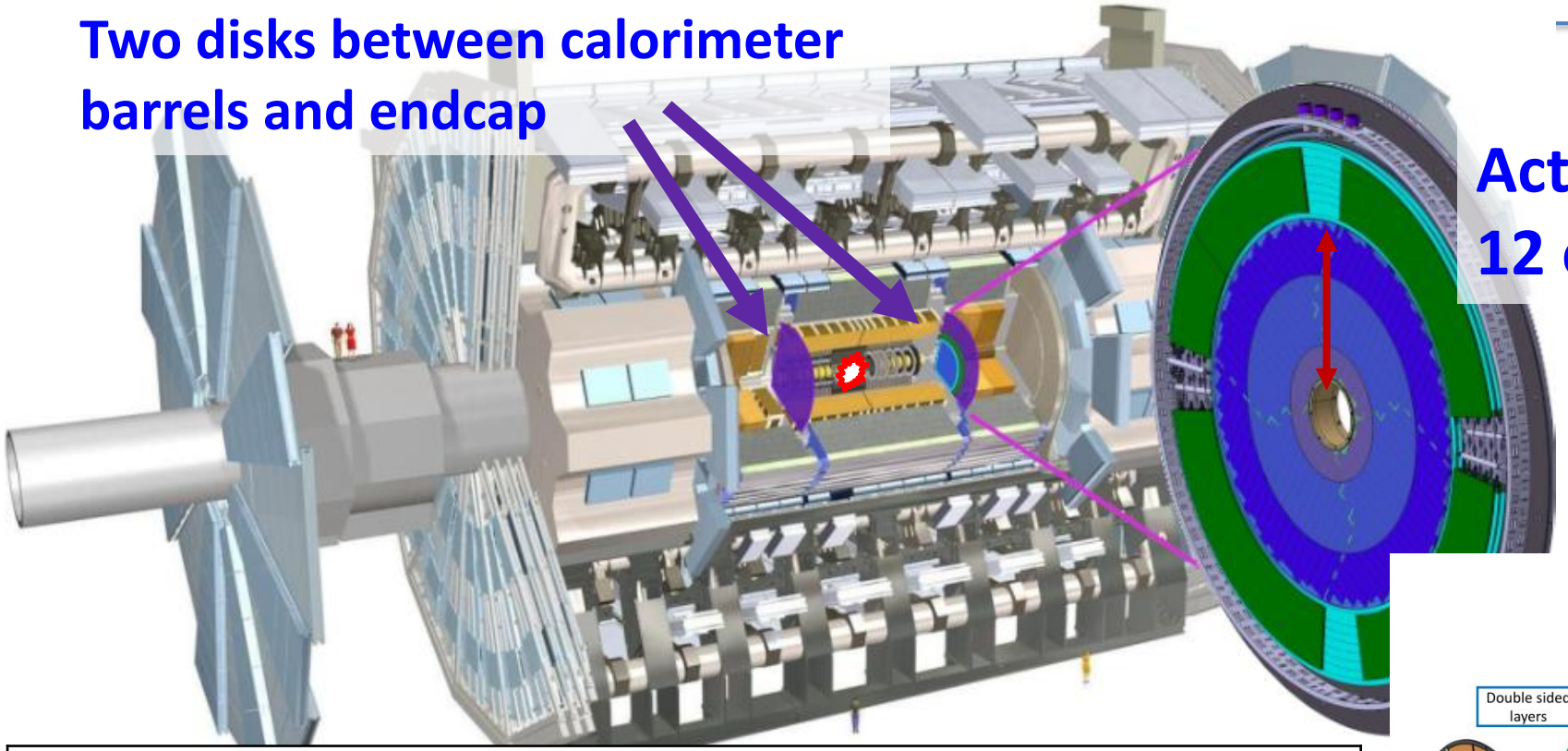


HGTD will complement ATLAS Inner Tracker (ITk) with track time measurement (50 ps resolution)

Improved matching of tracks to vertices (bonus: luminosity measurement)

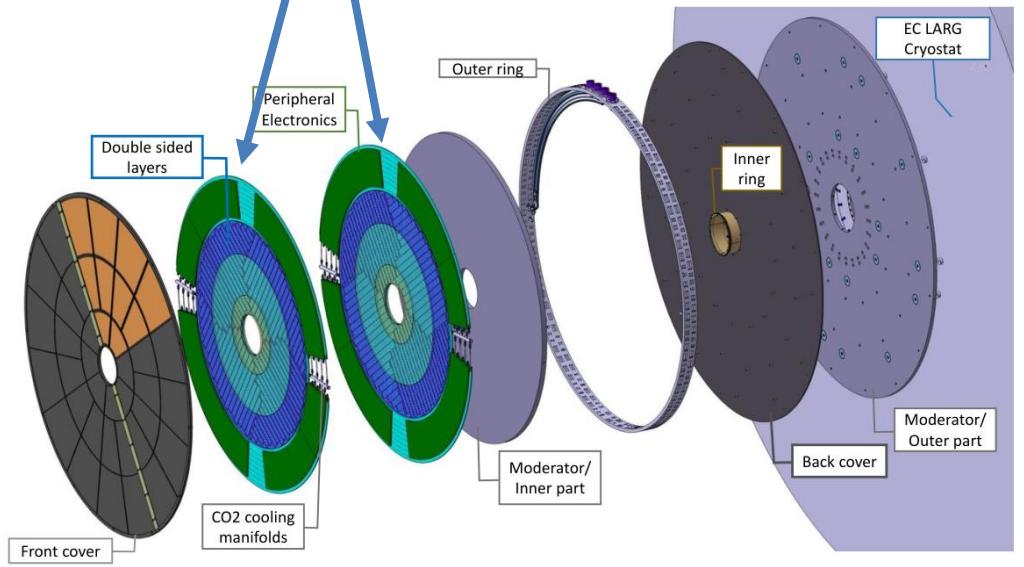
ATLAS HGTD

Two disks between calorimeter barrels and endcap



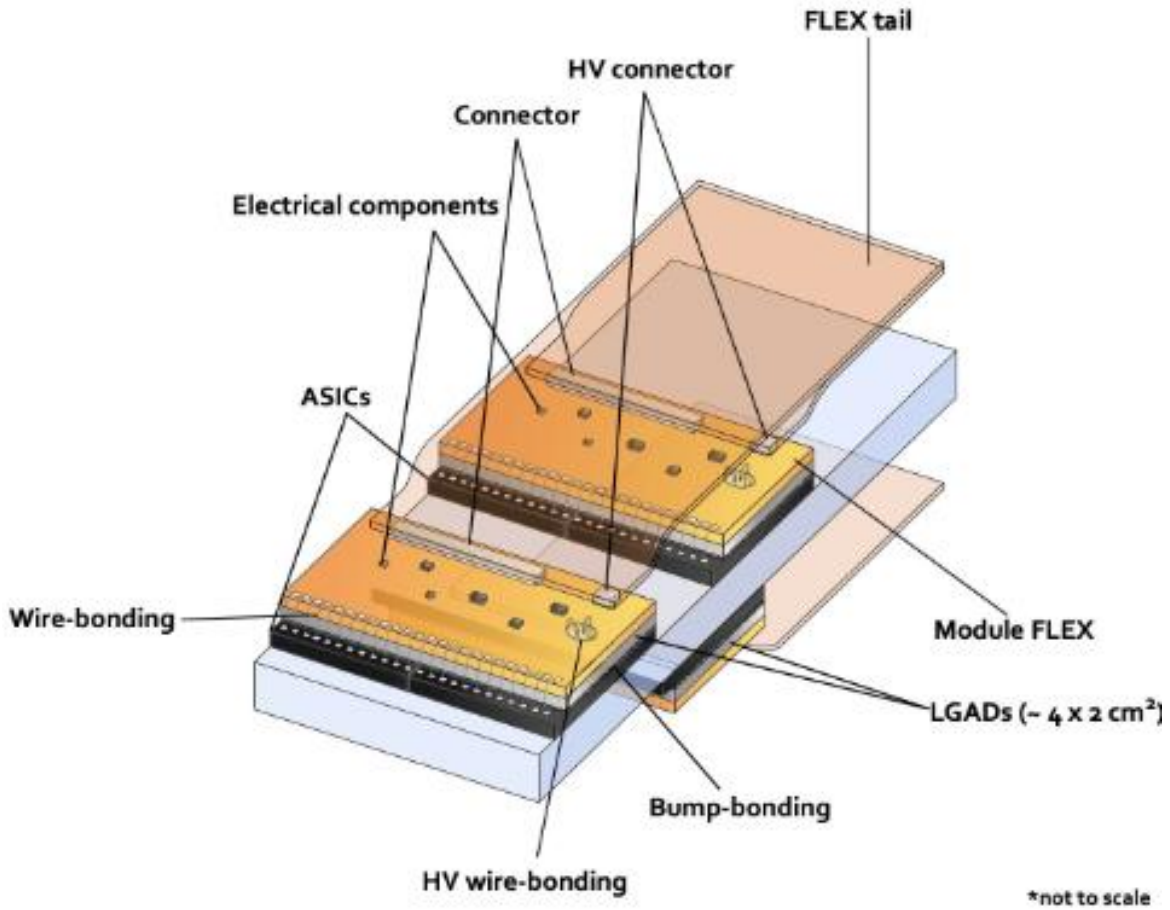
Active area
12 cm < *r* < 64 cm

4 sensor layers in each disk
Total thickness 75 mm

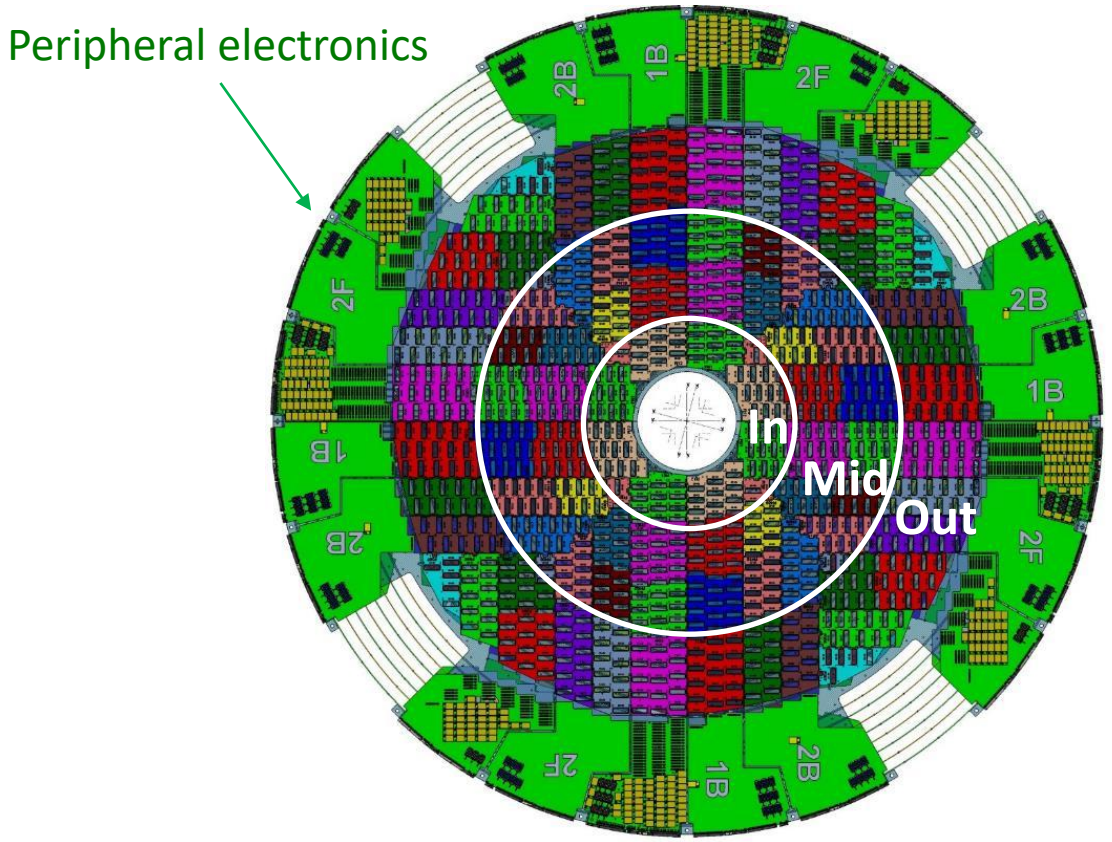


Rapidity coverage	$2.4 < \lvert\eta\rvert < 4.0$
z position	± 3.5 m
No. of readout channels	3.6 M
Working temperature	–30 °C (CO_2)

HGTD components



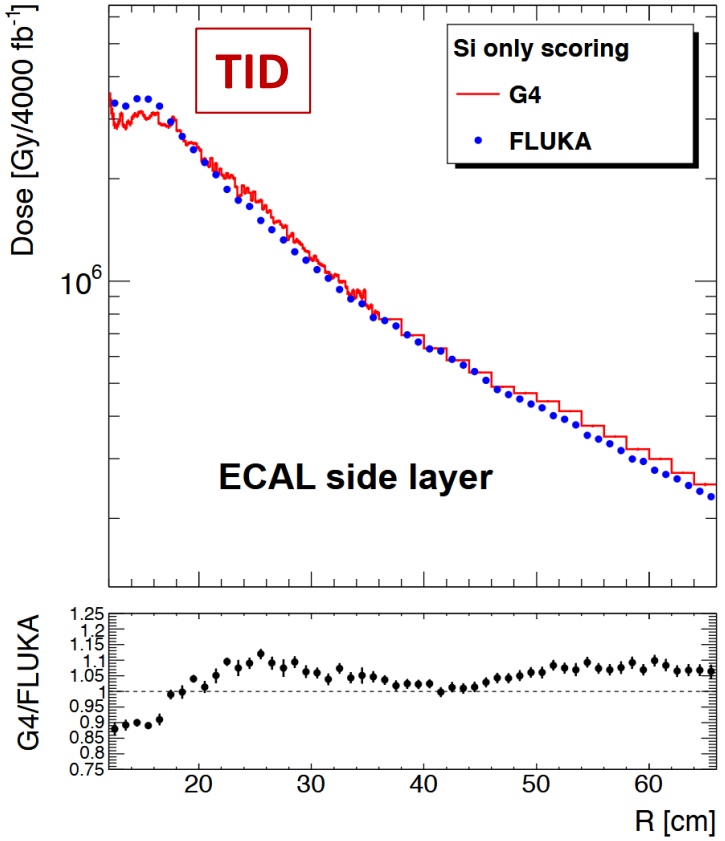
Module: 2 hybrids (sensor + ASIC) + flex circuit
8032 modules in total

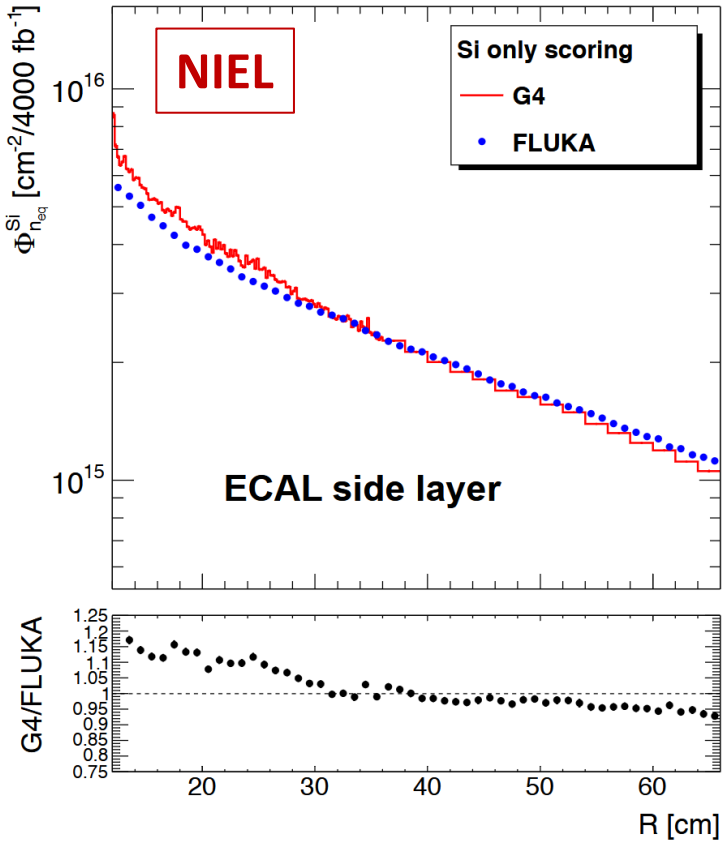


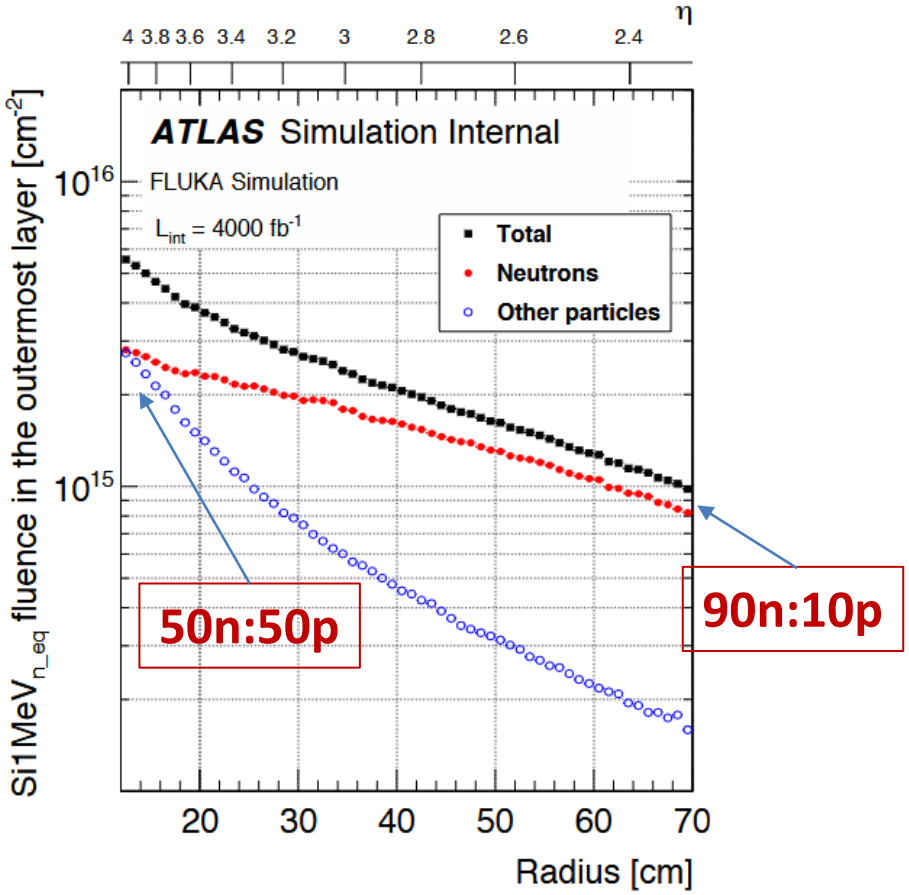
Modules arranged in Detector Units
3 independently replaceable regions (LS4)

HGTD radiation environment

- Simulation of TID, NIEL damage and particle composition in HGTD (for 4000 fb^{-1})
- HGTD is designed for 2.5 ×10^{15} n_{eq}/cm^2, 2 MGy







[M. Huhtinen, CERN]

F9 HGTD activities

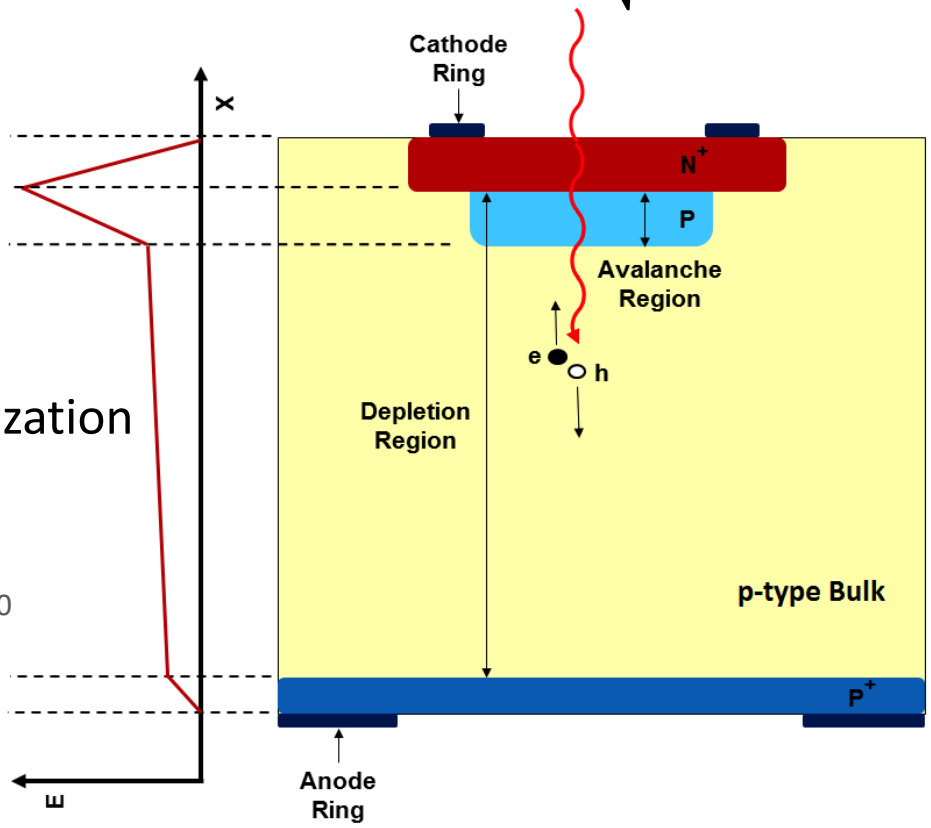
- F9 group activities in HGTD:
- **Sensor group**
  - G. Kramberger is a convener
  - Heavily involved in testing & production quality control (QC)
  - Irradiation test QC performed exclusively at JSI
  - Additional radiation hardness studies – see Iskra's talk on Wed
- **Hybrid and module testing**
  - Emerged as leading site for tests after irradiation (see Marko P.'s talk on Wed)
  - Extending our skillset to ASIC readout
- **Flex tail procurement**
  - Minor contribution of procuring 8.5 % of flex cables

HGTD sensors: Low Gain Avalanche Diodes (LGAD)

- Time resolution on 50 ps level requires specialized sensors
  - Radiation hard (2.5e15 n_{eq}/cm^2 in HGTD ≈ as ATLAS IBL)
  - Fast rise time
  - High signal-to-noise
- Low Gain Avalanche Diode (**LGAD**)
  - Planar n^{++}-p^{+}-p silicon sensor with internal gain
  - Highly doped p^{+} **gain layer**
    - High electric field → charge multiplication by impact ionization
    - Typically 1 µm thick, 25 V to deplete (V_{gl})
  - Gain factor 10–30
    - HGTD sensors 50 µm thick
    - Required charge 4 fC (but 10 fC would be nice)

$$w_{\text{depl.}} = \sqrt{\frac{2\epsilon\epsilon_0}{q_0 N_{\text{eff}}} V_{\text{bias}}}$$

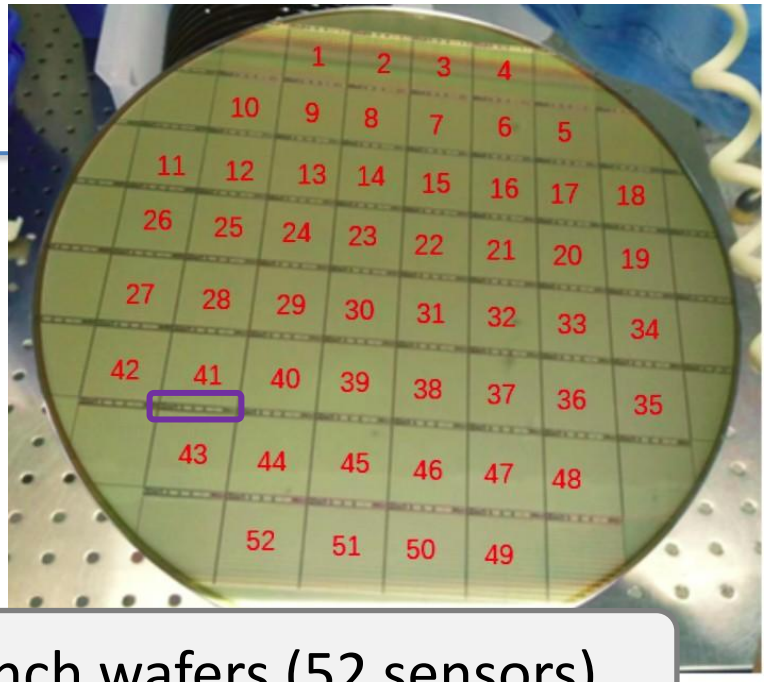
1 fC = 6250 e_0



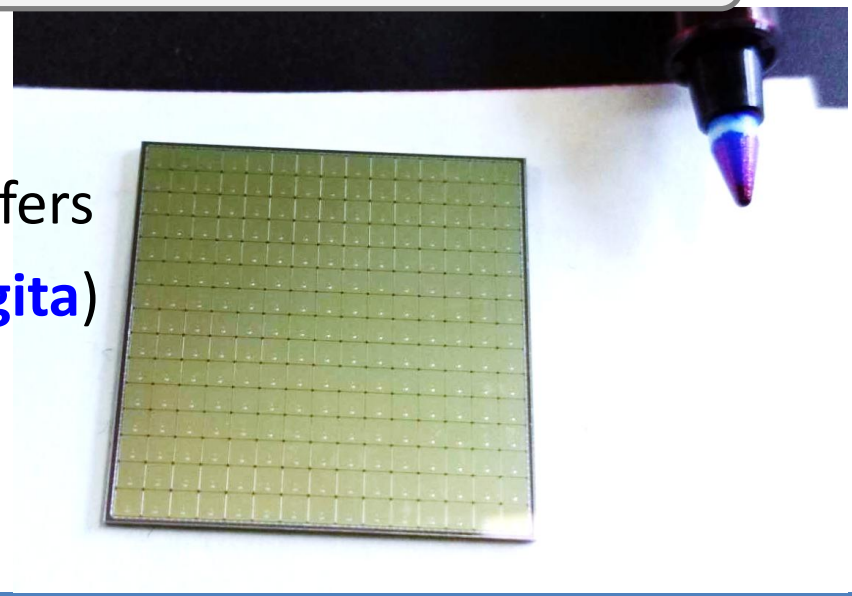
HGTD production sensors

- HGTD sensors produced by IMECAS (China)

Number of pads	15 × 15
Pad size	1.3 mm × 1.3 mm
Effective fill factor	> 85 %
Total size	2 cm × 2 cm
Active/physical thickness	50 µm / 775 µm



8-inch wafers (52 sensors)



- Sensor production is ongoing until mid 2027
  - > 20,000 main sensors required for production ~ 1000 wafers
  - Samples from each wafer irradiated and tested at JSI (**Brigita**)
- Readout ASIC: ALTIROC A (bump bonded)
  - ToA + ToT, 20 ps bin TDC

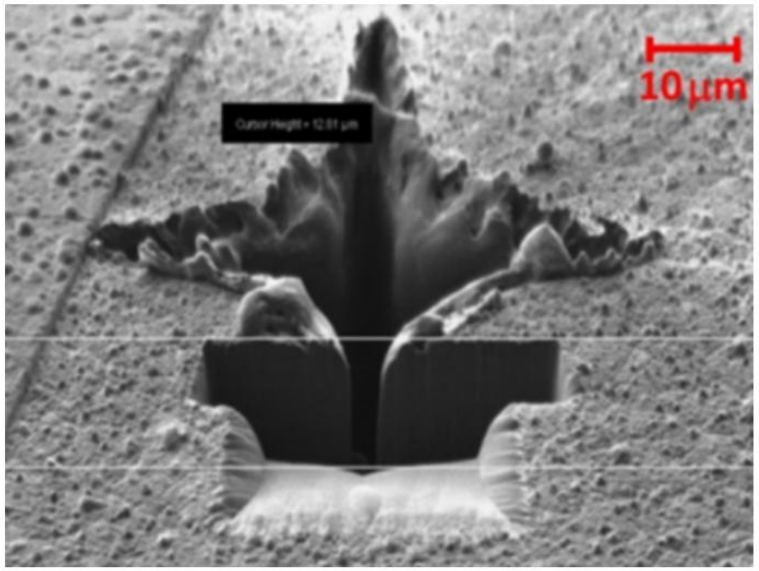
Radiation damage in LGAD

- Neutron and charged hadron radiation damages LGAD sensors
- **Acceptor removal** in gain layer → loss of gain → performance degradation
- Mitigation by increasing operating bias voltage
  - 100 V before irradiation
  - 550 V after irradiation (11 V/µm) is a hard limit due to destructive **Single Event Breakdown (SEB)**
    - SEB investigated by **Alissa Howard** (PhD thesis defended today)

Hot Topic:

Why do we not observe electrical discharge over a 100 µm gap between sensor (550 V) and ASIC (0 V)?

- $V_{\mathrm{gl}} = V_{\mathrm{gl},0} \times e^{-c\emptyset_{\mathrm{eq}}}$
  - ***c*** is called acceptor removal parameter
  - *c* depends on particle type and energy (LHC mix!)
    - Investigated by **Iskra**
    - Test methods: electrical, laser, radioactive ^{90}Sr



HGTD irradiated sensor performance

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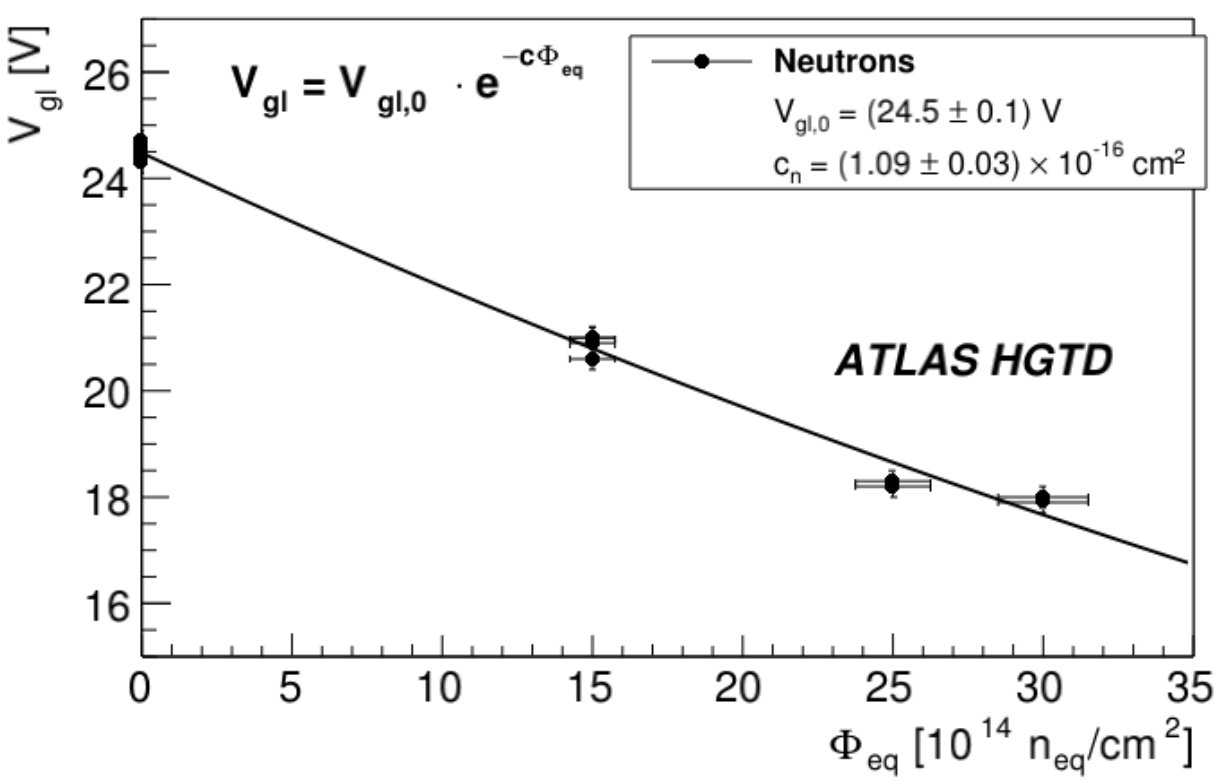
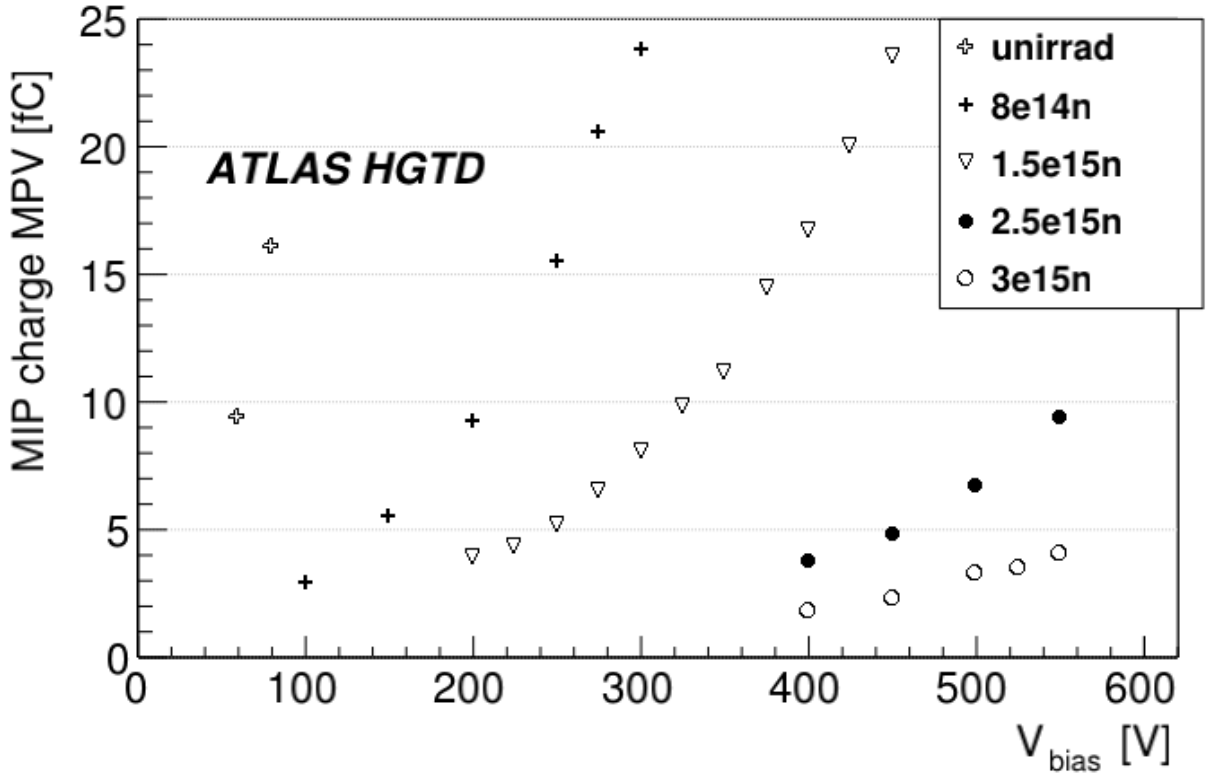
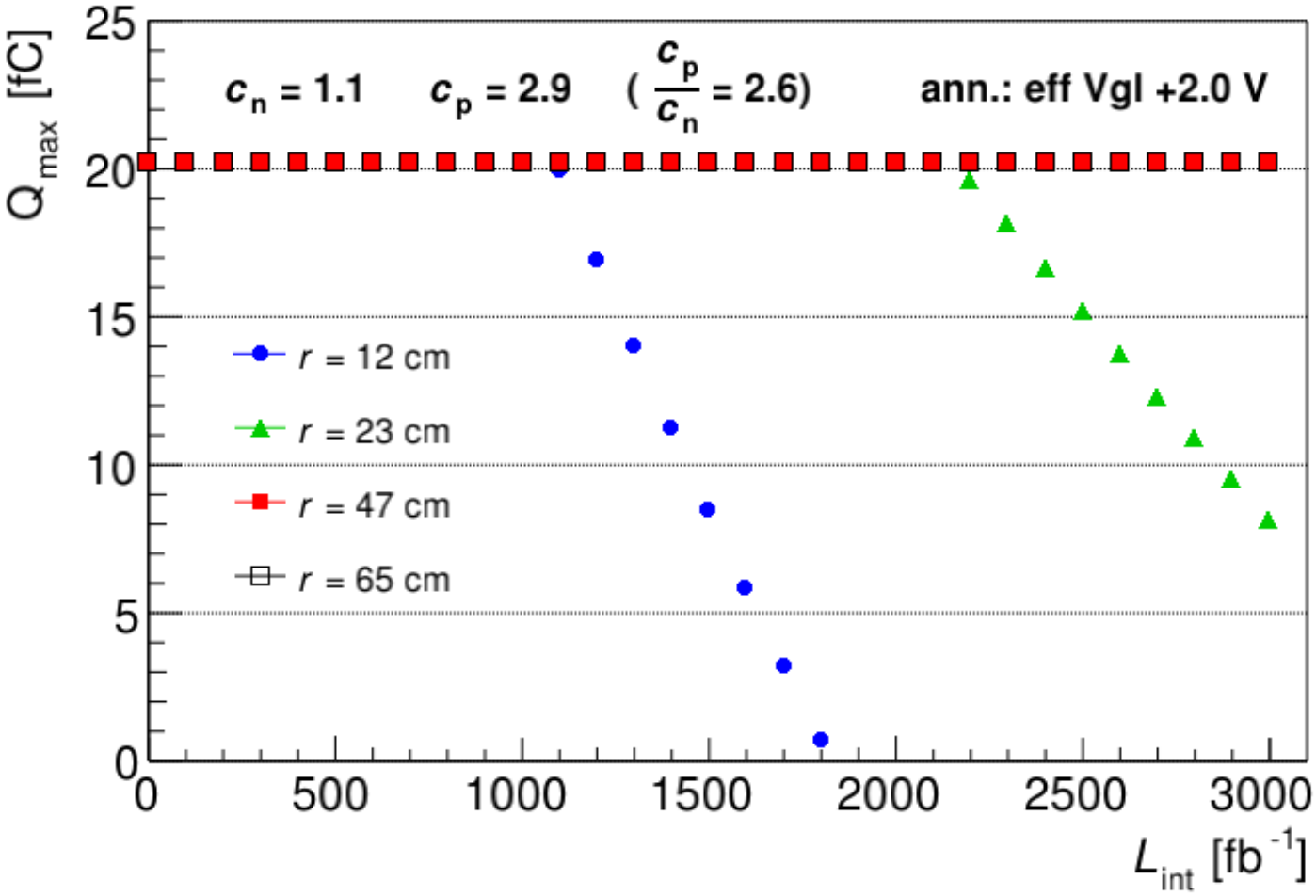


Protons are more damaging – see Iskra's talk



Higher voltage is required at higher fluences to collect a fixed charge

Simulation of sensor performance at HL-LHC



- Simulation of collected charge at HL-LHC
- Degradation at small radius quite fast
- Positive effects of long term annealing will be studied by **Ajda**

HGTD F9 Outlook

- **Production:** Sensors 50 % done, (finished in 2027)
- **System assembly:** at CERN 2027–2029
- **Performance studies:** will continue at JSI (see Iskra, Marko P. talks)
- **Integration into ATLAS software tools**