A High-Granularity Timing Detector for the Phase-II upgrade of the ATLAS Calorimeter system

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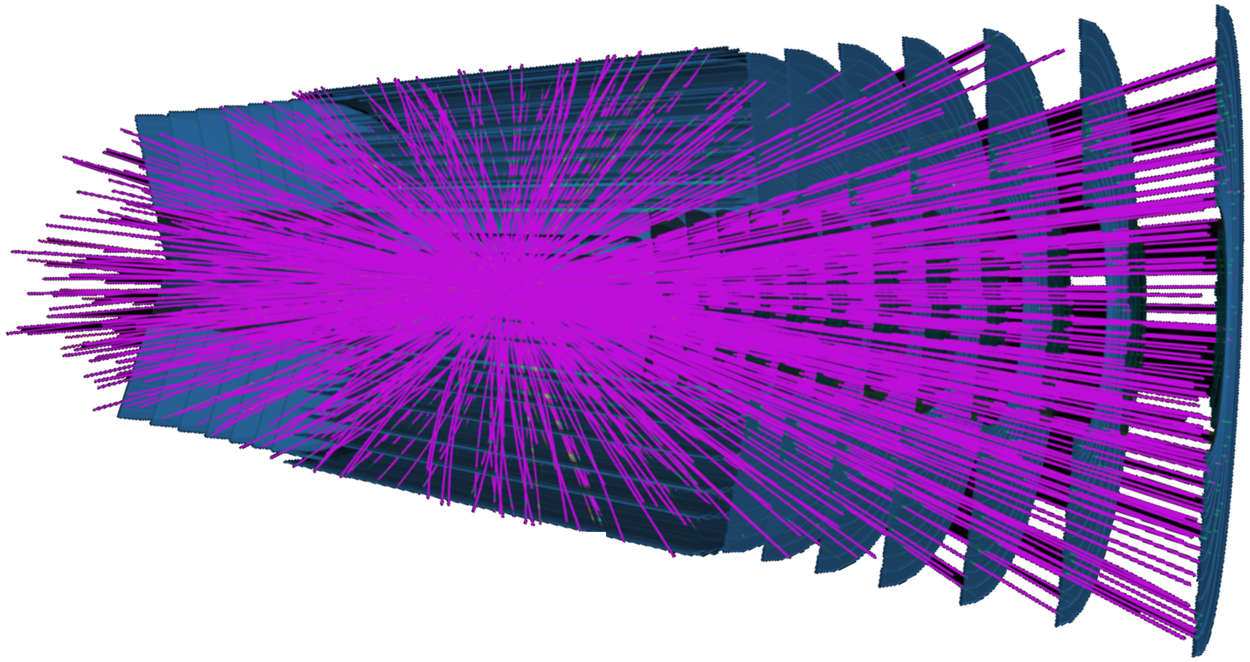
Overview

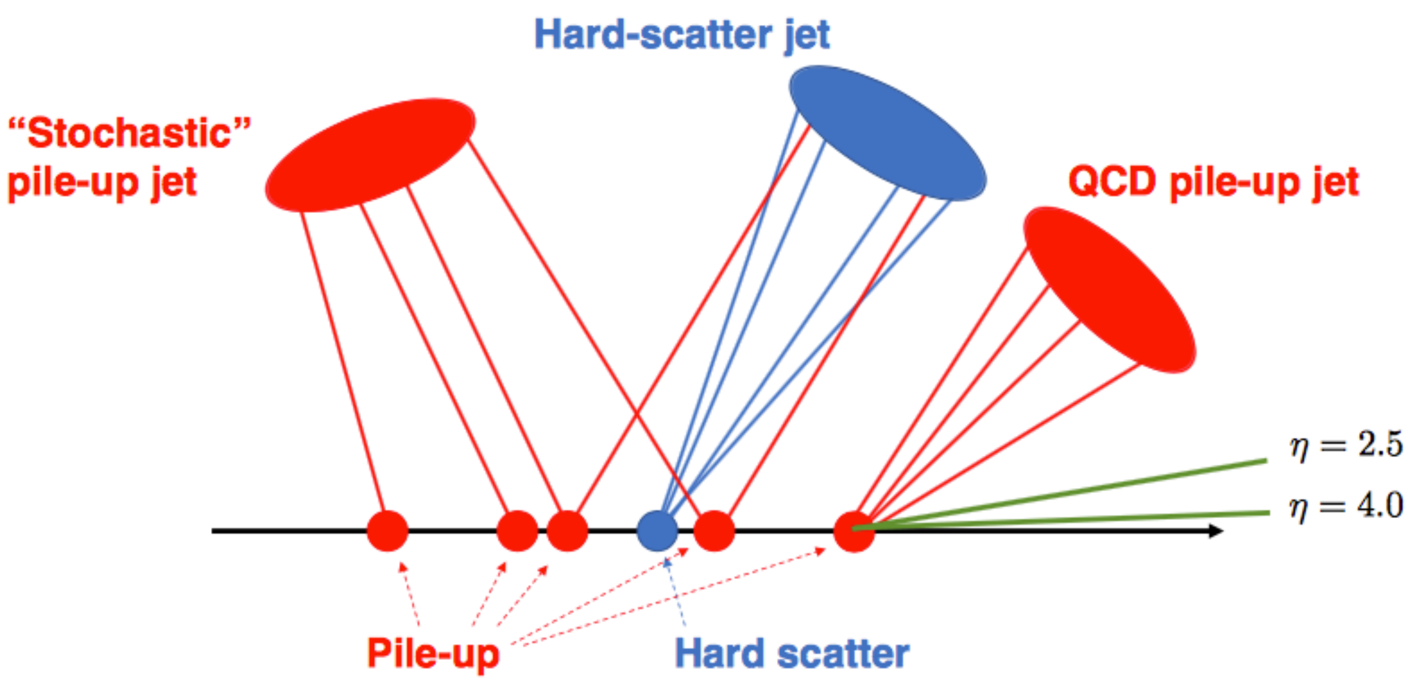
- **Motivation & detector requirements**
- **Expected gains in performance & physics**
- **Sensors tests**
- **Detector assembly**

Motivation
&
Requirements

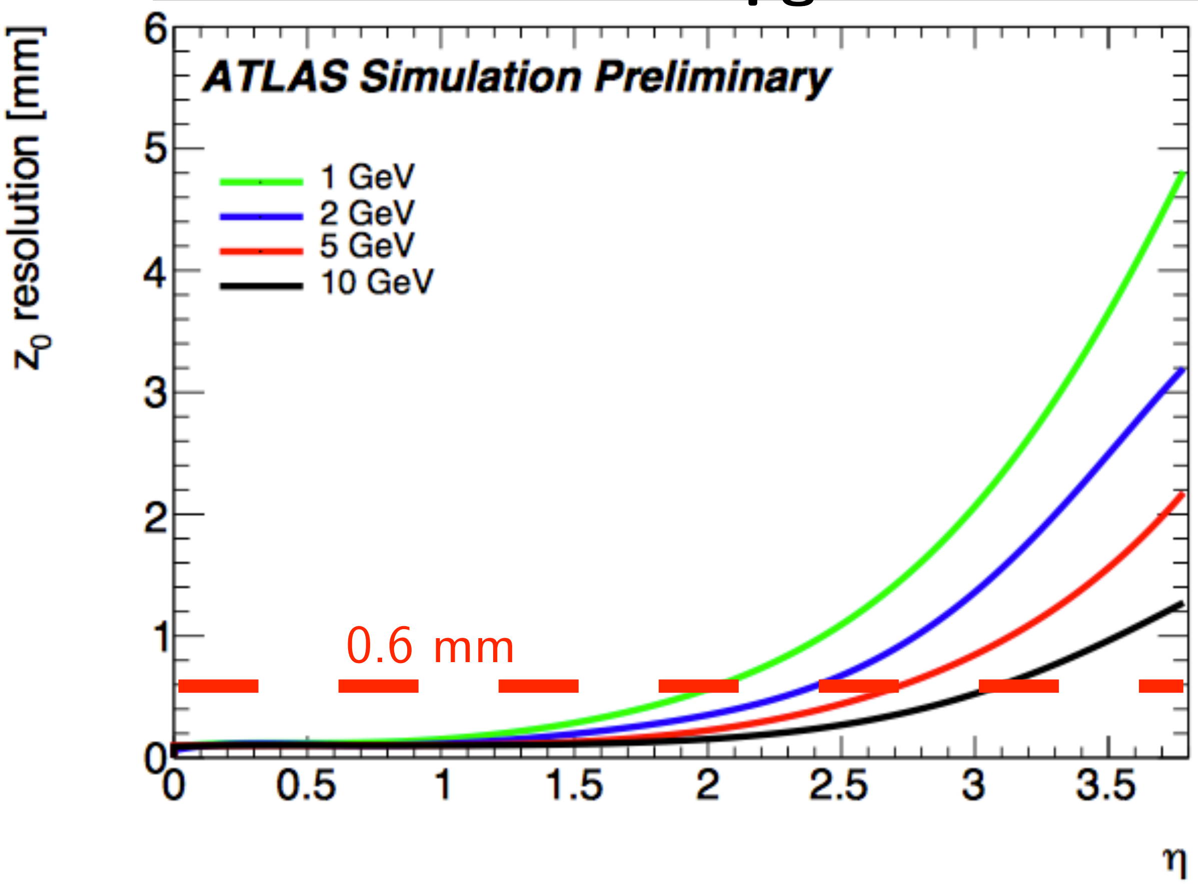


HL-LHC: the problem with pile-up

- **Pile-up at HL-LHC: $<\mu> = 200$**
  - ➡ 1.6 vertices/mm on average
  - ➡ Need $\sigma(z_0) \lesssim 0.6$ mm for track-vertex association



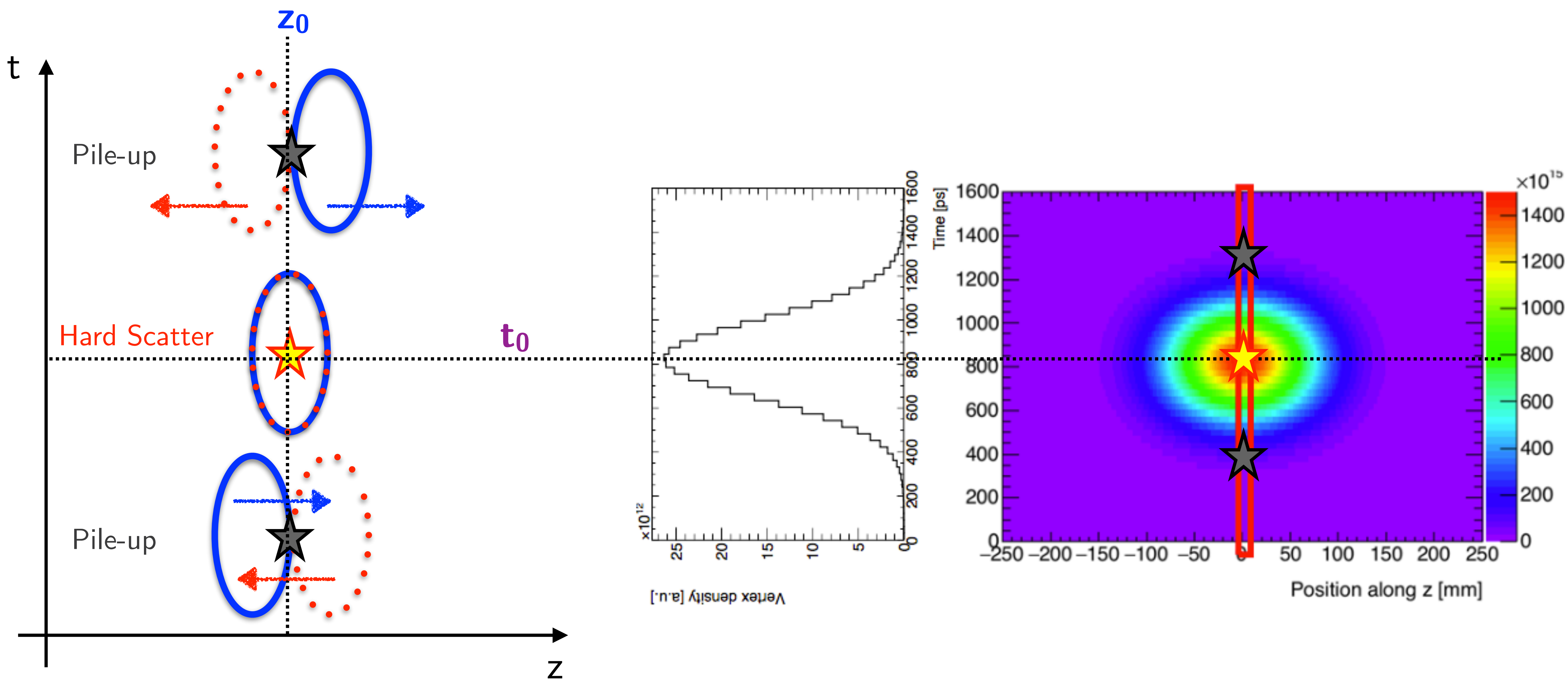
Track resolution - Upgraded tracker



Problem: ITk doesn't have enough resolution in the forward region

- ➡ Reduced pile-up jet rejection
- ➡ Reduced lepton isolation efficiency
- ➡ Reduced b-tagging performance

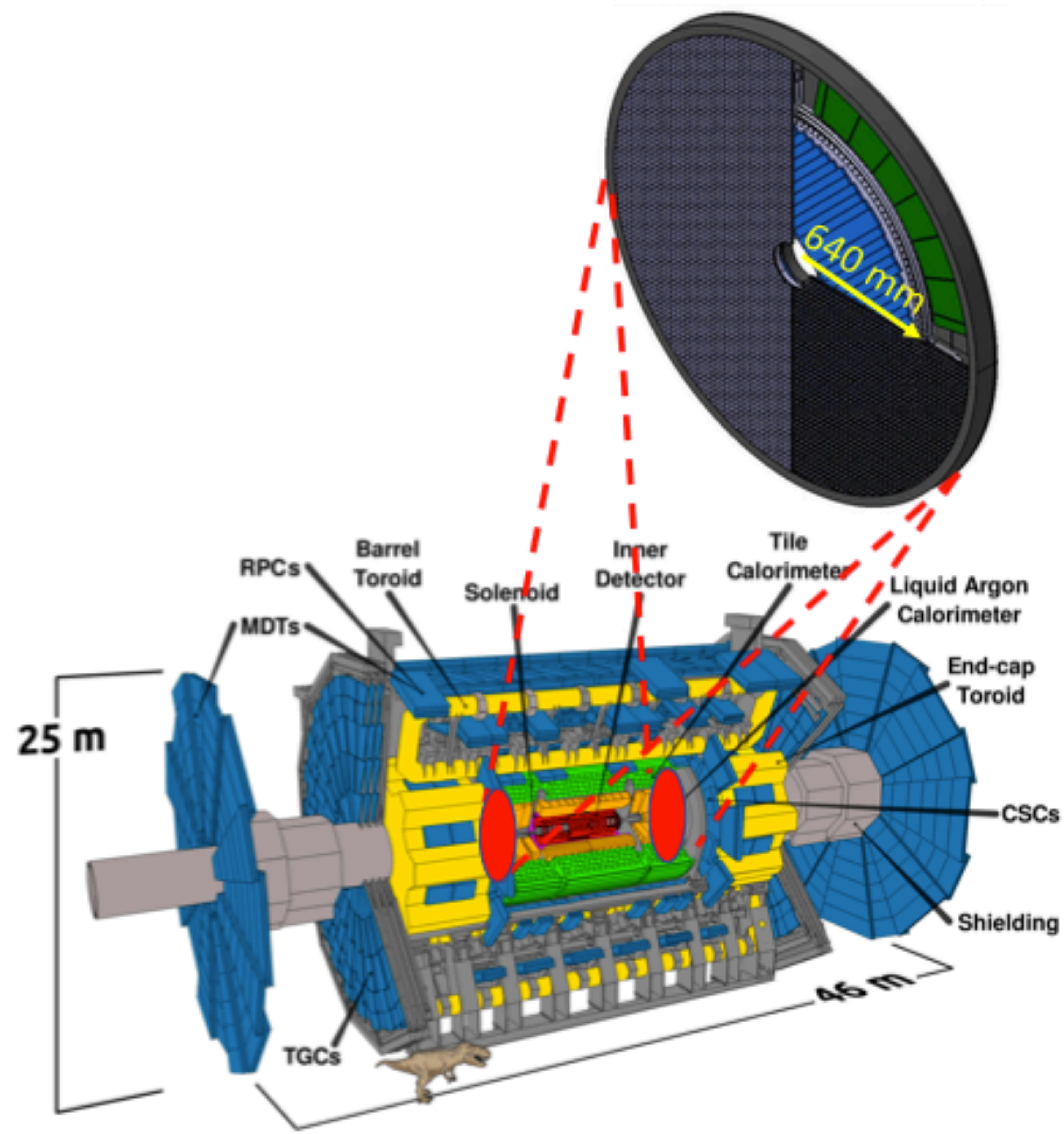
- **Use 2-dimensional track information: z-position & timing**



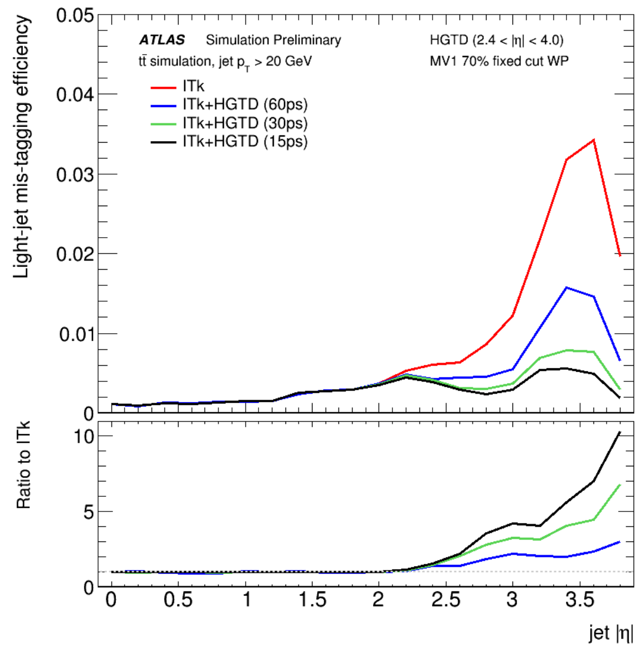
- **Timing helps reject tracks from PU vertices at same z but different t**
- **Expected timing resolution: 30 ps**
  - Timing spread for nominal beamspot: 175 ps
  - ➡ **Improve pile-up rejection by x6**

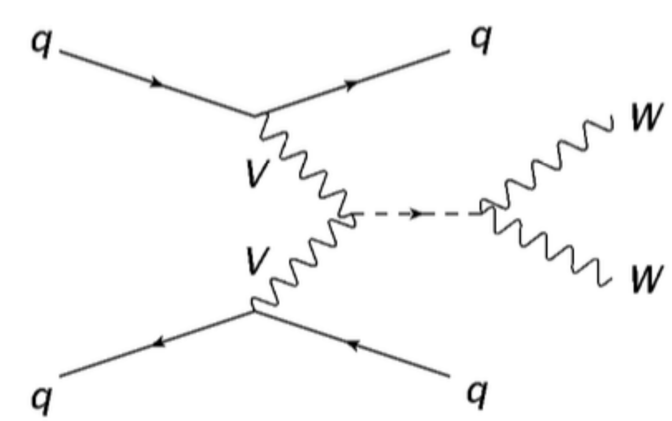
Design requirements for HGTD

- Coverage
  - ➡ Replace MBTS: 2.4 < |η| < 4.0
  - ➡ Active area: 120-640 mm
- Radiation hard up to $4.5 \cdot 10^{15}$ n_{eq}/cm^2 and 4.5 MGy
- Good timing resolution resolution: 30ps/track
  - ➡ Si-based LGAD sensors (thickness ≤ 300 μm)
  - ➡ 2-3 layers (replacement of inner ring |η| > 3.2 at half life of HL-LHC)
- < 10% occupancy
  - ➡ sensor size 1.3 x 1.3 mm^2

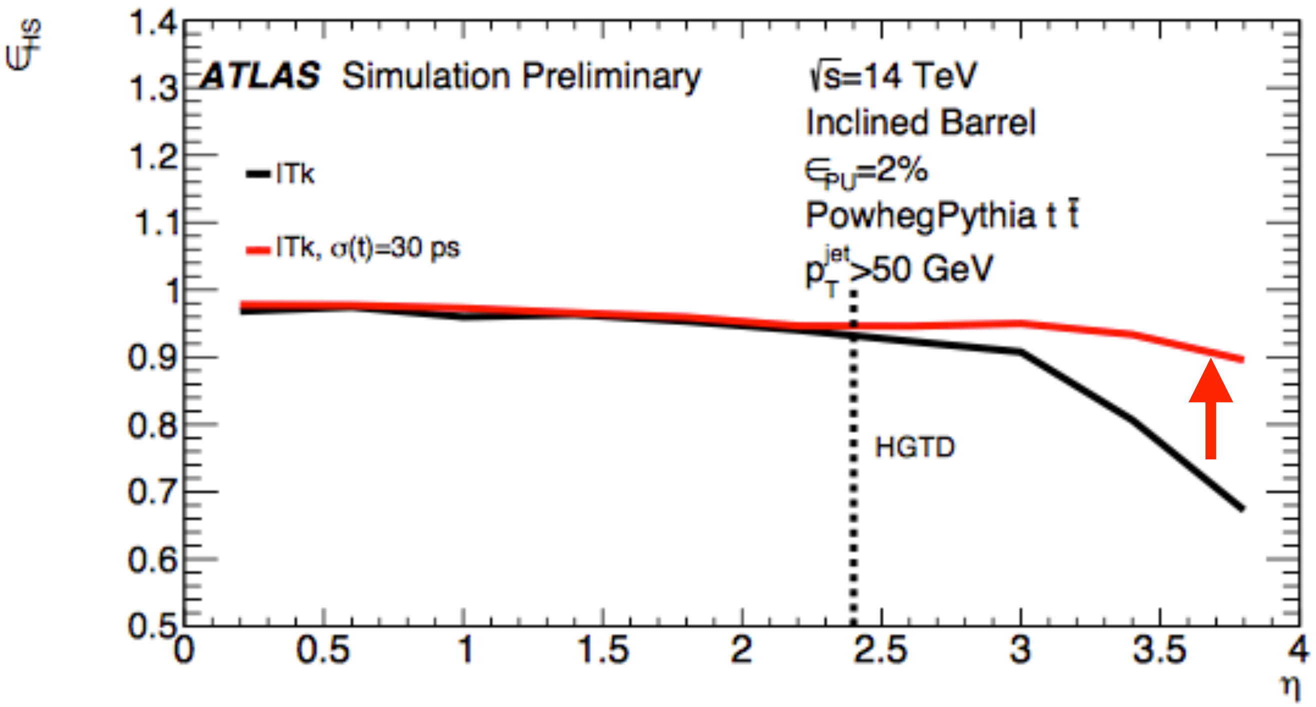


Expected gains in performance & physics

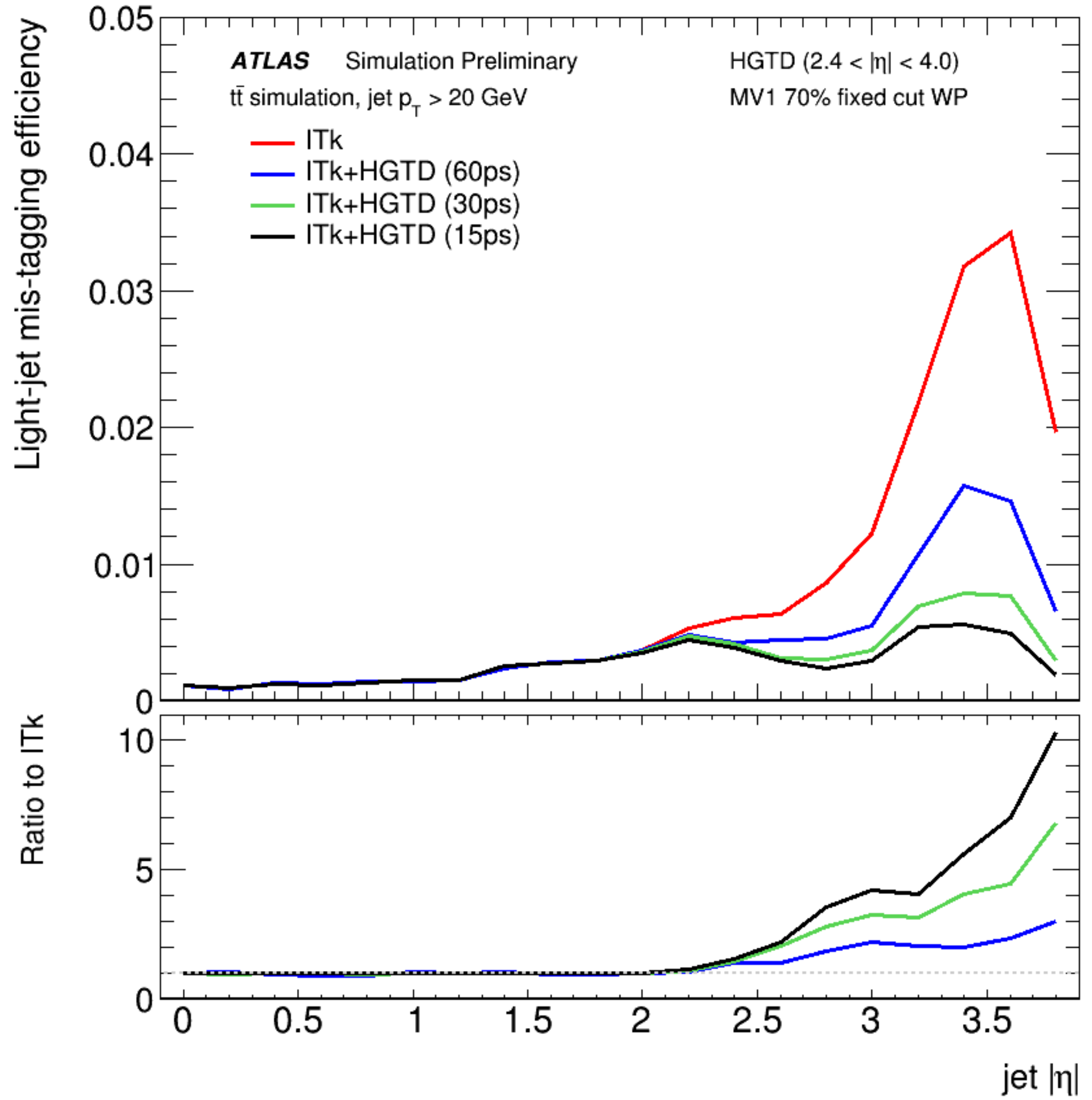




HS jet efficiency vs η



Light-jet tagging eff. vs η

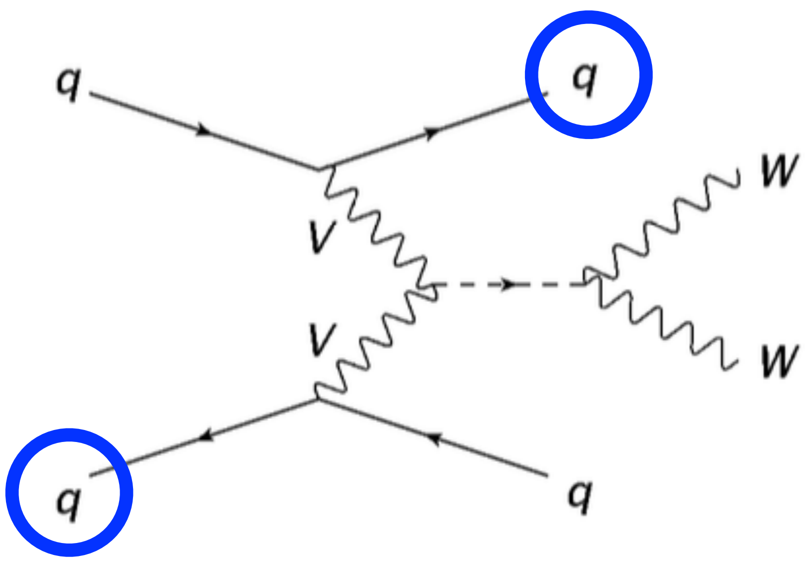


- ✓ x4 improvement in PU jet rejection
- ✓ With HGTD performance in forward region similar to barrel
  - ➡ Important for channels with forward jets
- ✓ x4 improvement of l-jet rejection at high η
  - ➡ Important for channels with forward b-jets
- ✓ 15% improvement in lepton isolation efficiency

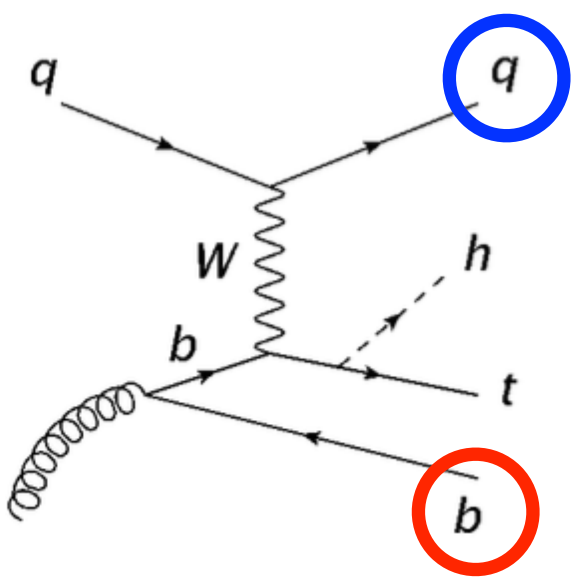
Physics

- Expect improvements in final states with
  - forward jets ⇒ VBF Higgs (8% improvement of sensitivity)
  - forward b-jets ⇒ tH (11% improvement of sensitivity)

VBF H→WW*

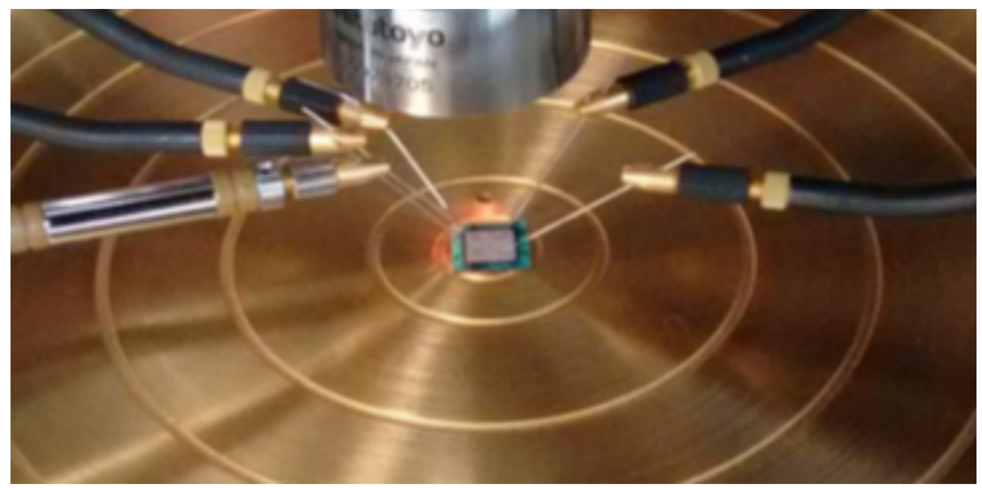


tH(bb)



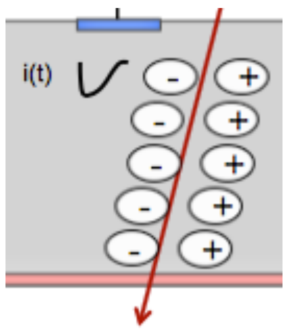
- More ideas under study
  - Impact on channels with forward electrons ⇒ $\sin\theta_W$ measurement
  - VBF H→ττ , VBF production of BSM resonances
  - Long-lived BSM particles with forward signature
- Online luminosity determination

Sensors tests

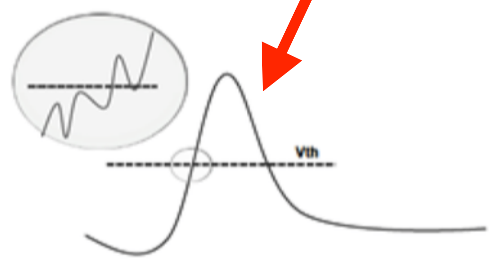


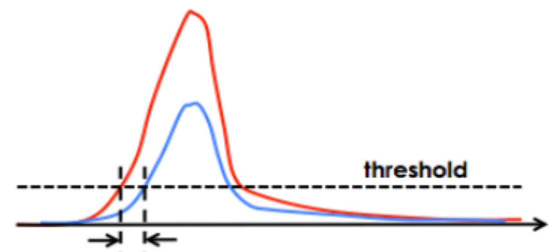
Sensor requirements

$$\sigma^2 = \sigma^2_{\text{Landau}} + \sigma^2_{\text{jitter}} + \sigma^2_{\text{time-walk}} + \sigma^2_{\text{TDC}}$$



- Varying density of e-h pairs along particle path
  ➡ **Thin sensor to minimise fluctuations**





- Digitisation granularity

$$\sigma_{\text{jitter}}, \sigma_{\text{time-walk}} \propto \frac{t_{\text{rise}}}{\text{Signal/Noise}}$$

➡ **Low noise (gain)**

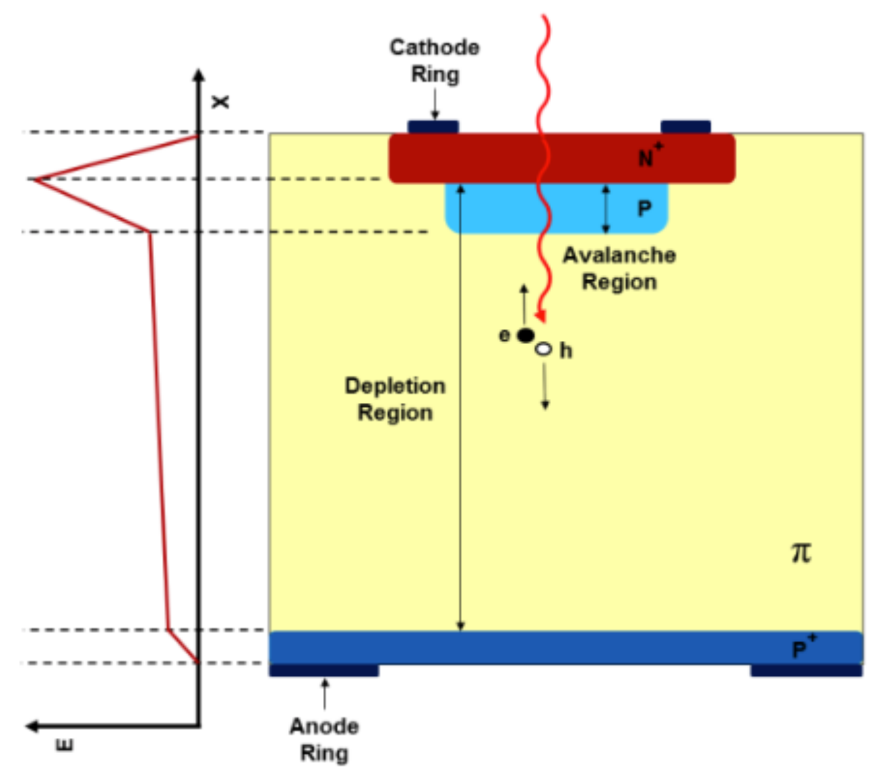
➡ **Thin (small t_{rise})**

Low Gain Avalanche Detectors

✓ Moderate gain (increase signal, limit noise)

✓ Thin detector with short rise time (improves time resolution)

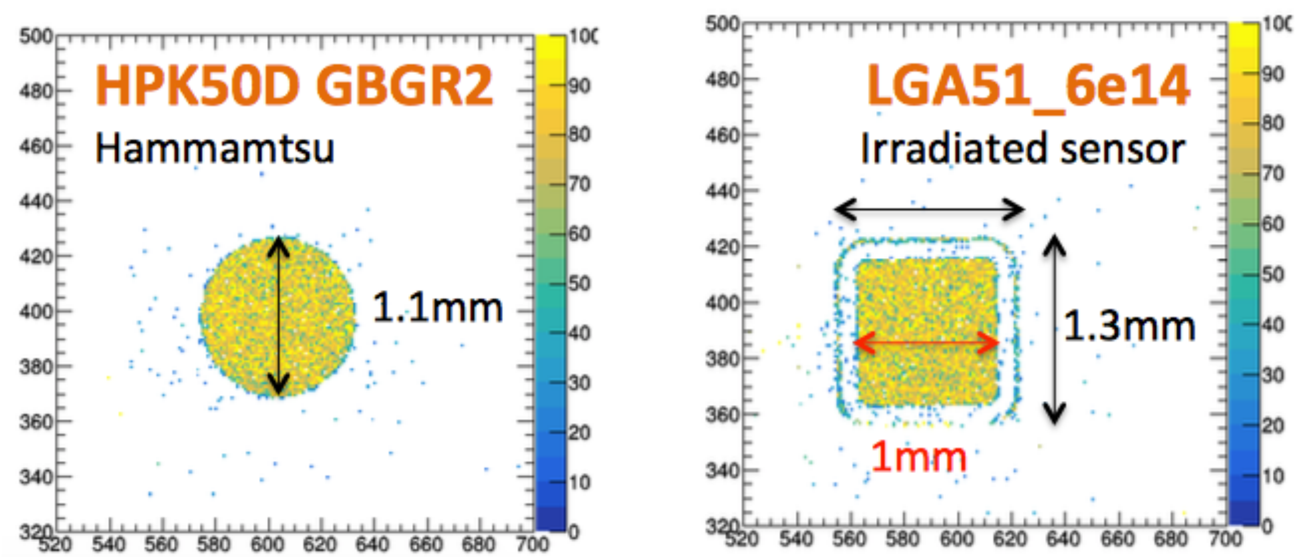
✓ radiation hard



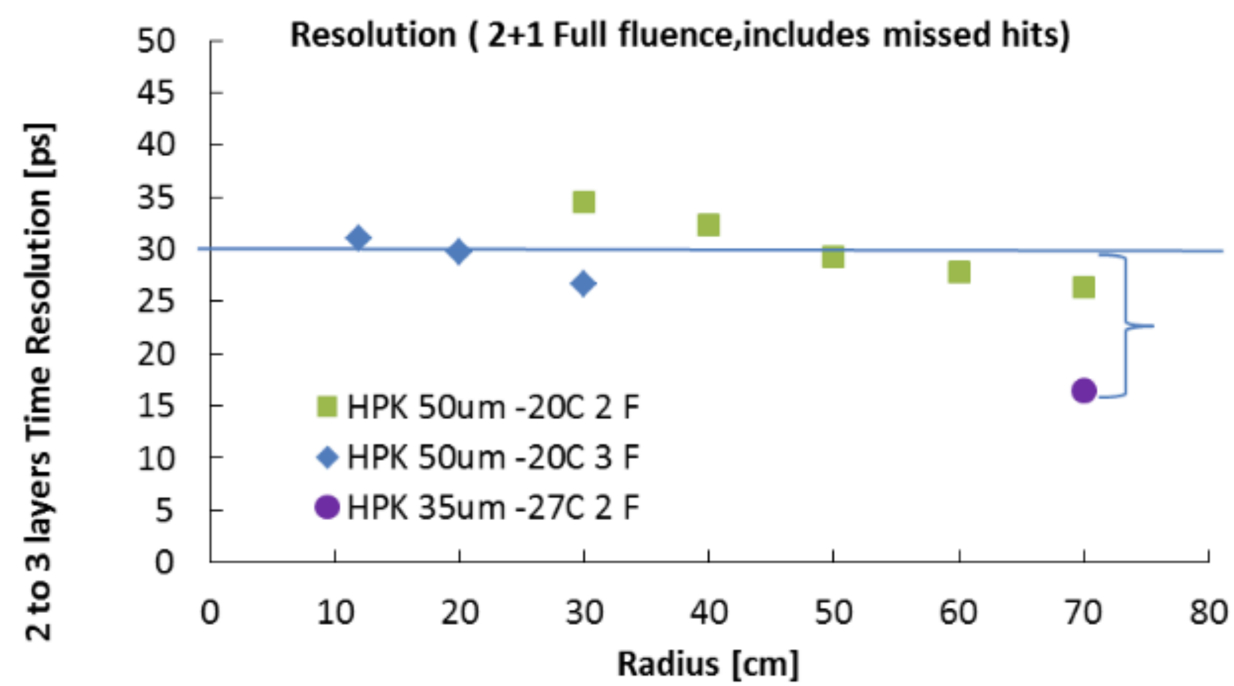
LGAD sensor testing

- 3 vendors (CNM, FBK, HPK) offering 50 μm sensors with different technologies
- Laboratory tests (CNM, HPK)
  - Electrical characterisation (I-V, C-V)
  - 5 beam tests (hit efficiency, timing resolution)

Summer '17 beam test with irradiated sensors



Time resolution vs radius



✓ **Uniform hit efficiency 96-99%**

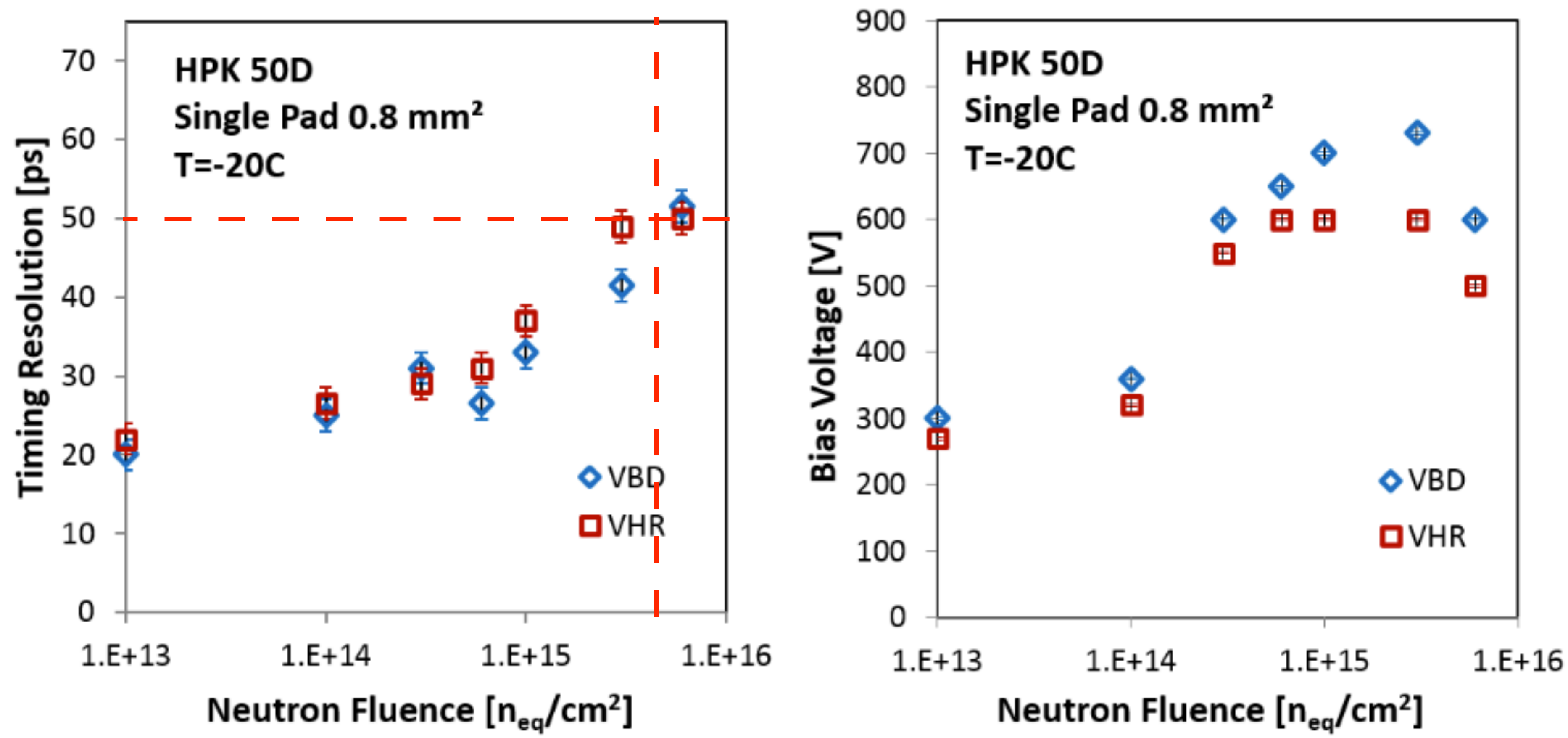
✓ **Good uniformity after irradiation**

✓ **Target timing resolution achieved at a gain of 20**

✓ **New thinner (35 μm) sensors being tested** (same resolution with fewer layers)

LGAD irradiation tests

- Time resolution degrades with increasing fluence
  - Loss of effective doping concentration ⇒ decrease in gain

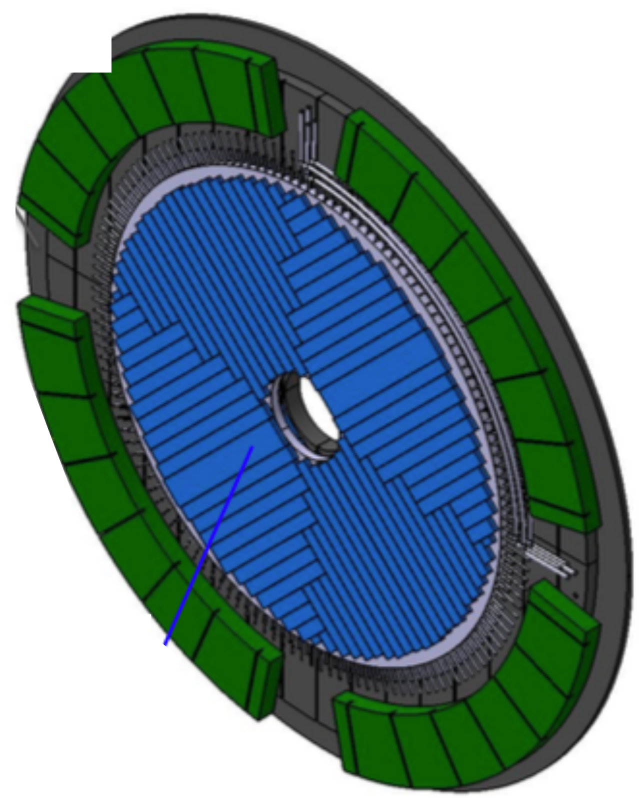


BUT

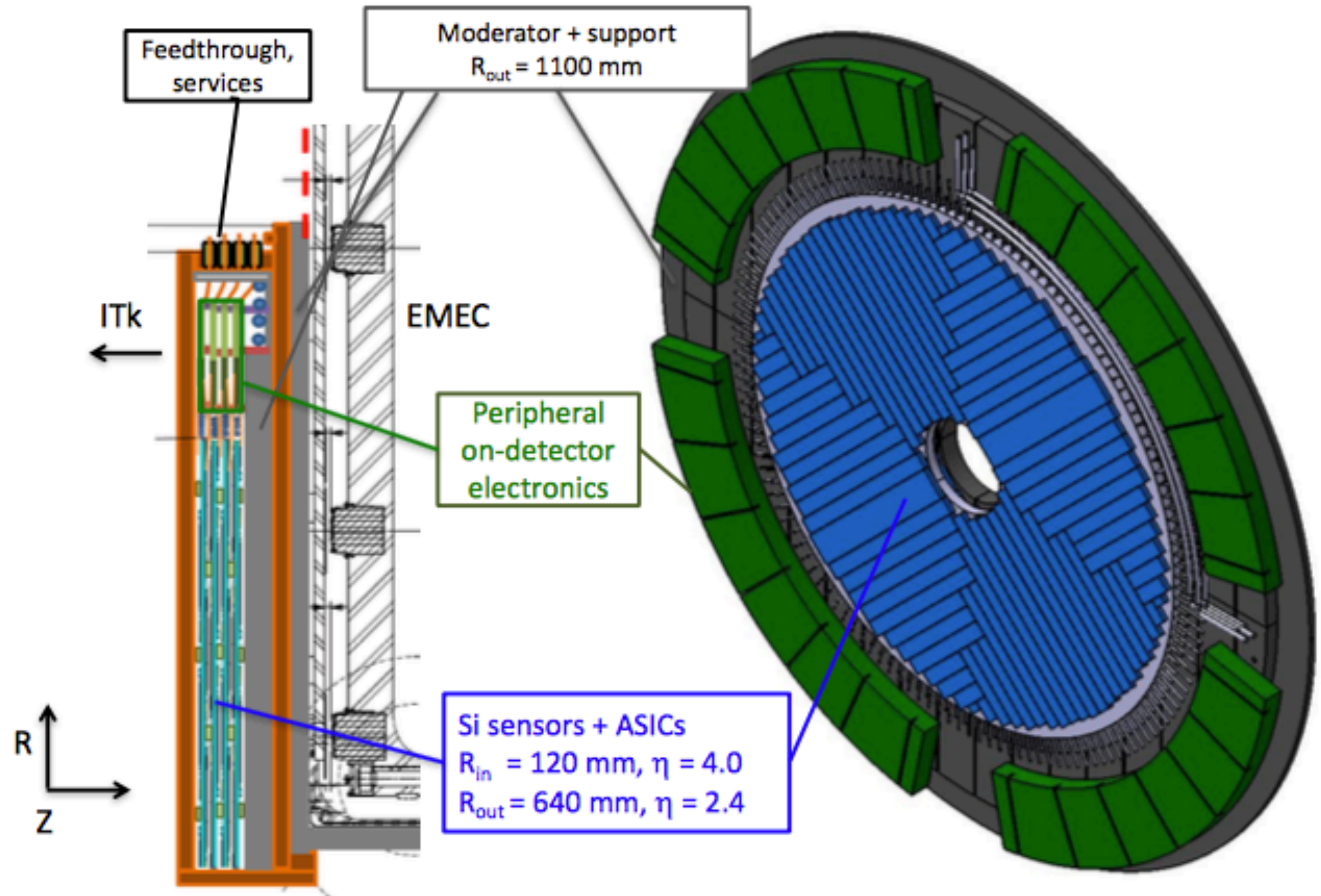
- Higher breakdown voltage after irradiation
  - Gain in the bulk ⇒ compensation of gain loss in multiplication layer

✓ LGAD sensors **keep 50 ps time resolution per layer for HGTD target fluence** 4.5×10^{15} n_{eq}/cm^2

Detector assembly



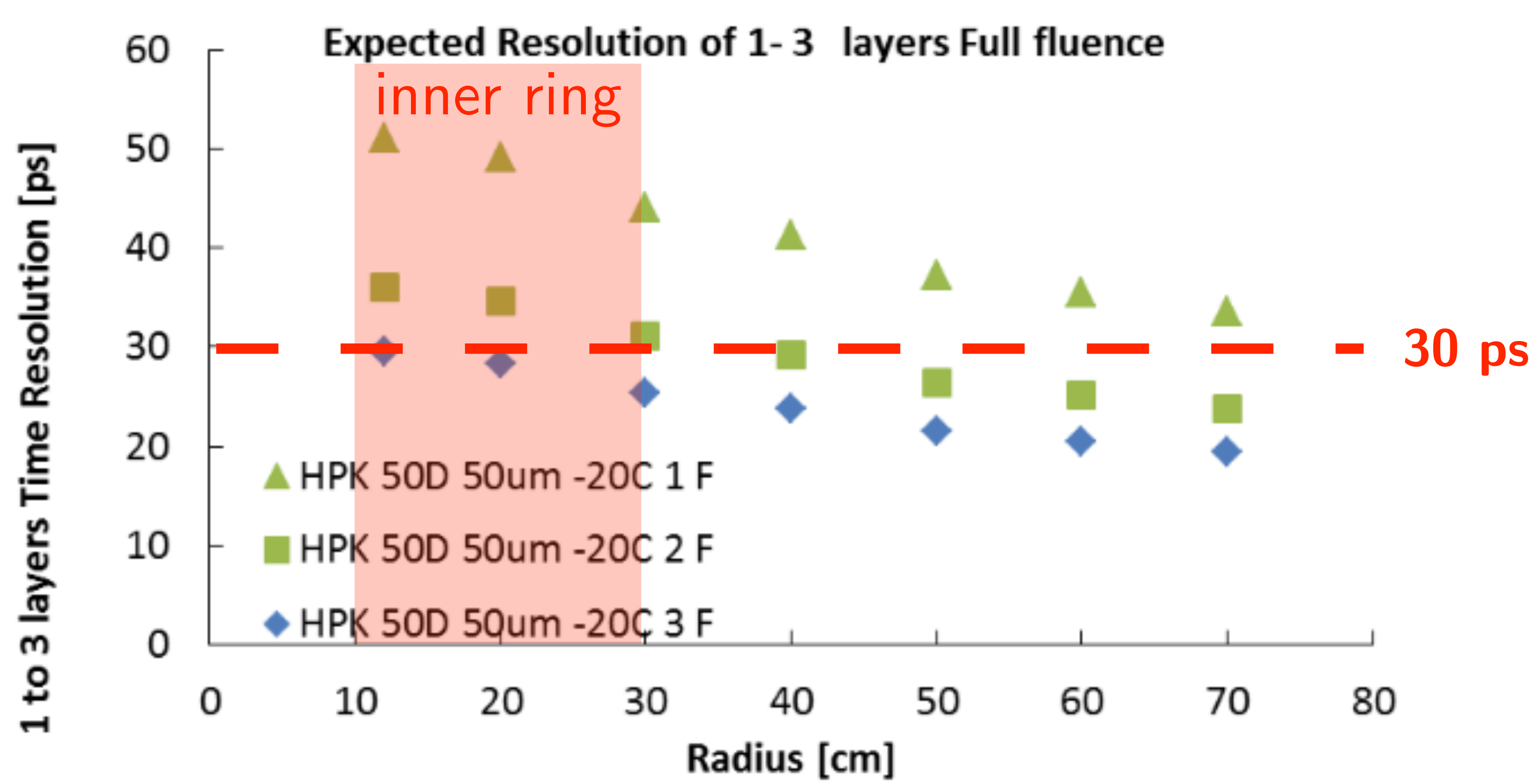
Detector layout



- **Module 2x4 cm**
- LGAD - ALTIROC ASIC (bump bonded)
- LGAD and ASIC wire-bonded to flex cable
- Layout specifics being finalised for Technical Proposal

Number of layers

- 2 full layers + **1 inner ring** (R=10-30cm) gives 30 ps time resolution for reduced cost ⇒ **2L+1 baseline layout**
- target: 2 (3) hits/track for $2.4 < |\eta| < 3.2$ ($3.2 < |\eta| < 4$)



Other ongoing optimisation studies

- Number of staves/geometry
- Module overlap
- Vessel layout

Summary & Timeline

✓ **HGTD will help to mitigate effects of pile-up in forward region**

- Pile-up jet rejection, b-tagging, lepton isolation, physics, luminosity

✓ **Expression of Interest submitted to LHCC at the end of 2017 - Technical Proposal planned for April 2018**

✓ **Technical Design Report to be submitted end of 2018**