The MIP Timing Detector for the CMS Phase II Upgrade

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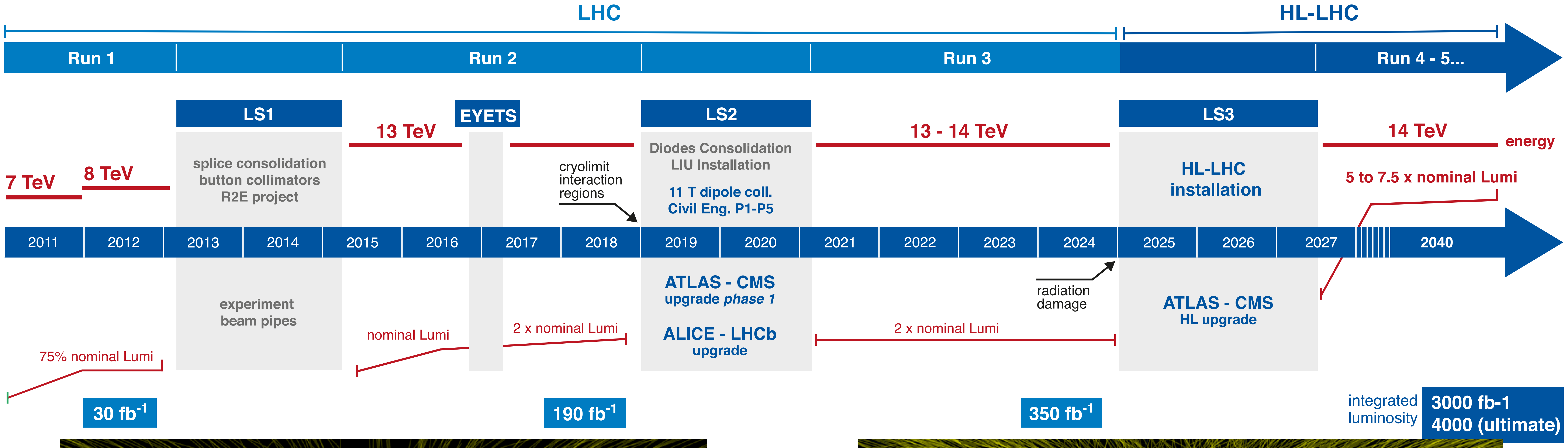
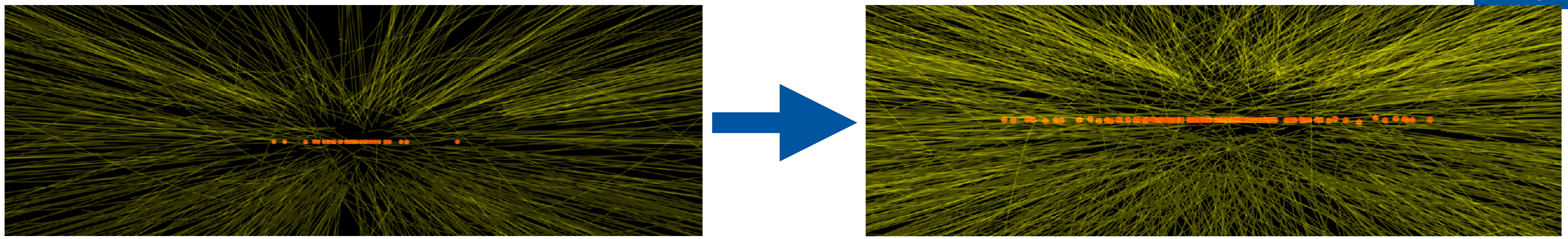
Outline:

- Motivation and introduction
- Barrel timing layer
- Endcap timing layer
- DAQ and clock distribution
- Conclusion

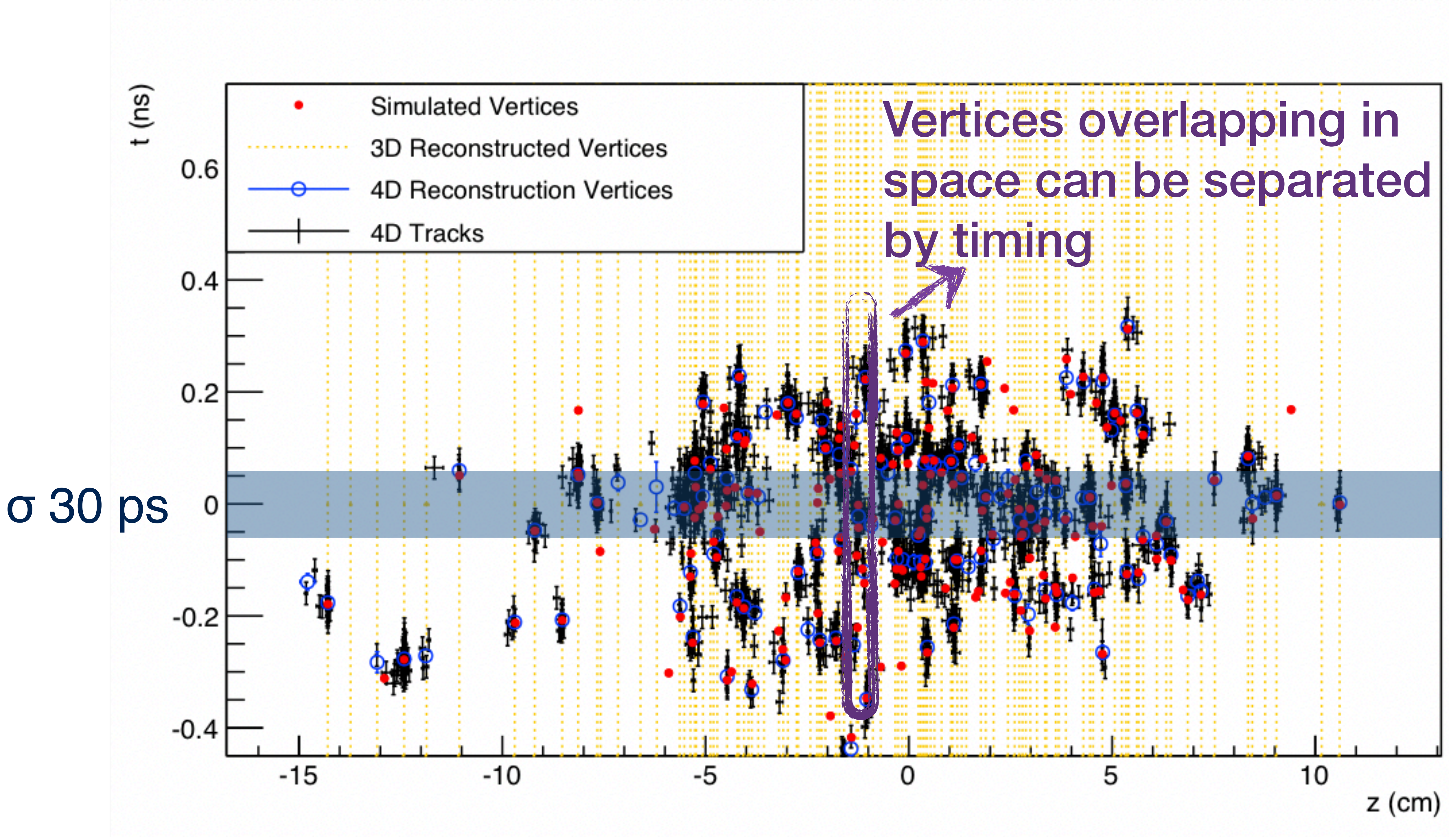
HL-LHC

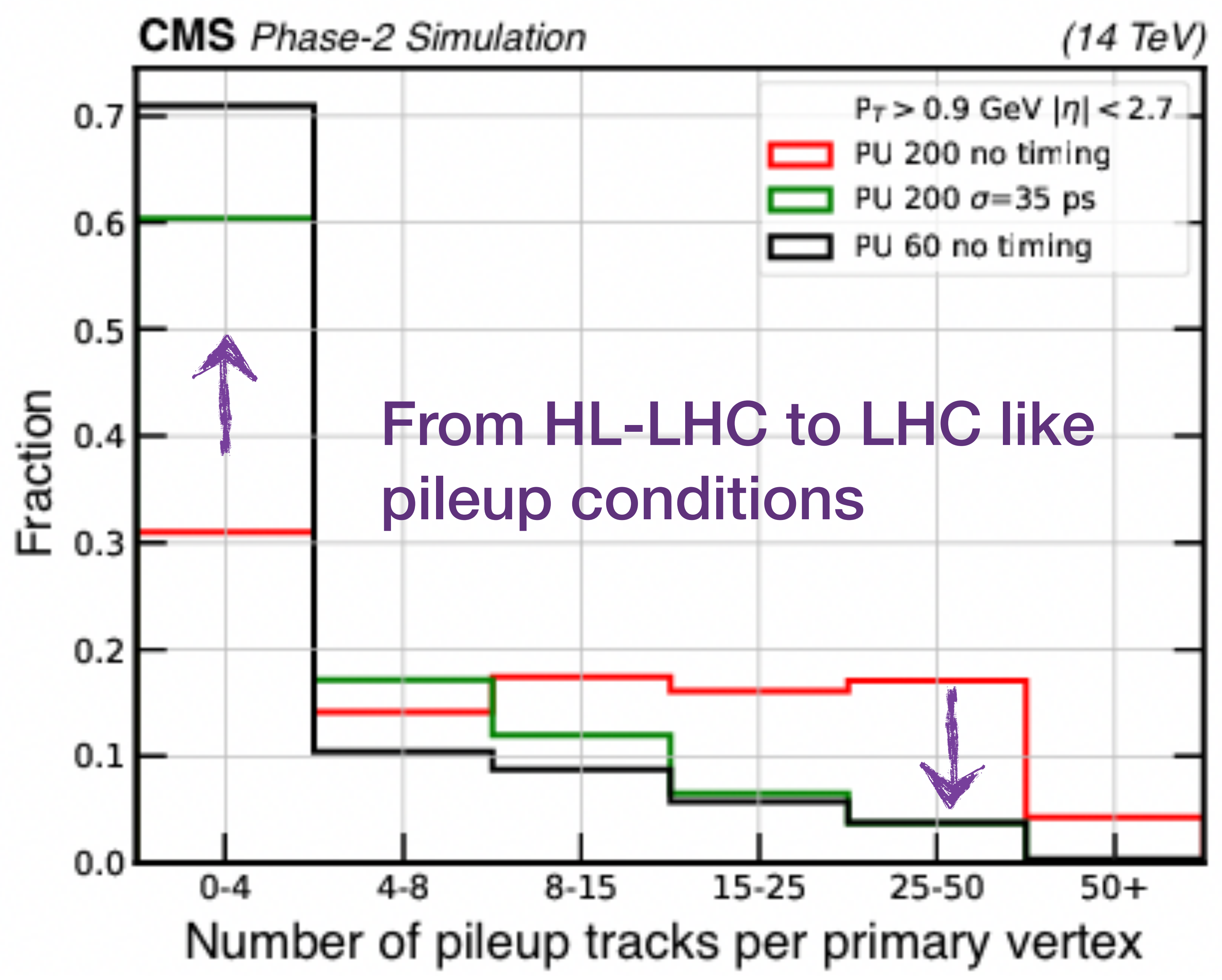




- High Luminosity - Large Hadron Collider will deliver **10 times more integrated luminosity**.
  - Significant challenge for the detectors; up to **5 times more average pile-up** interactions.
- CMS and ATLAS detectors will be upgraded (Phase II - HL upgrade)
  - Cope with the challenging conditions
  - Extend the physics reach.

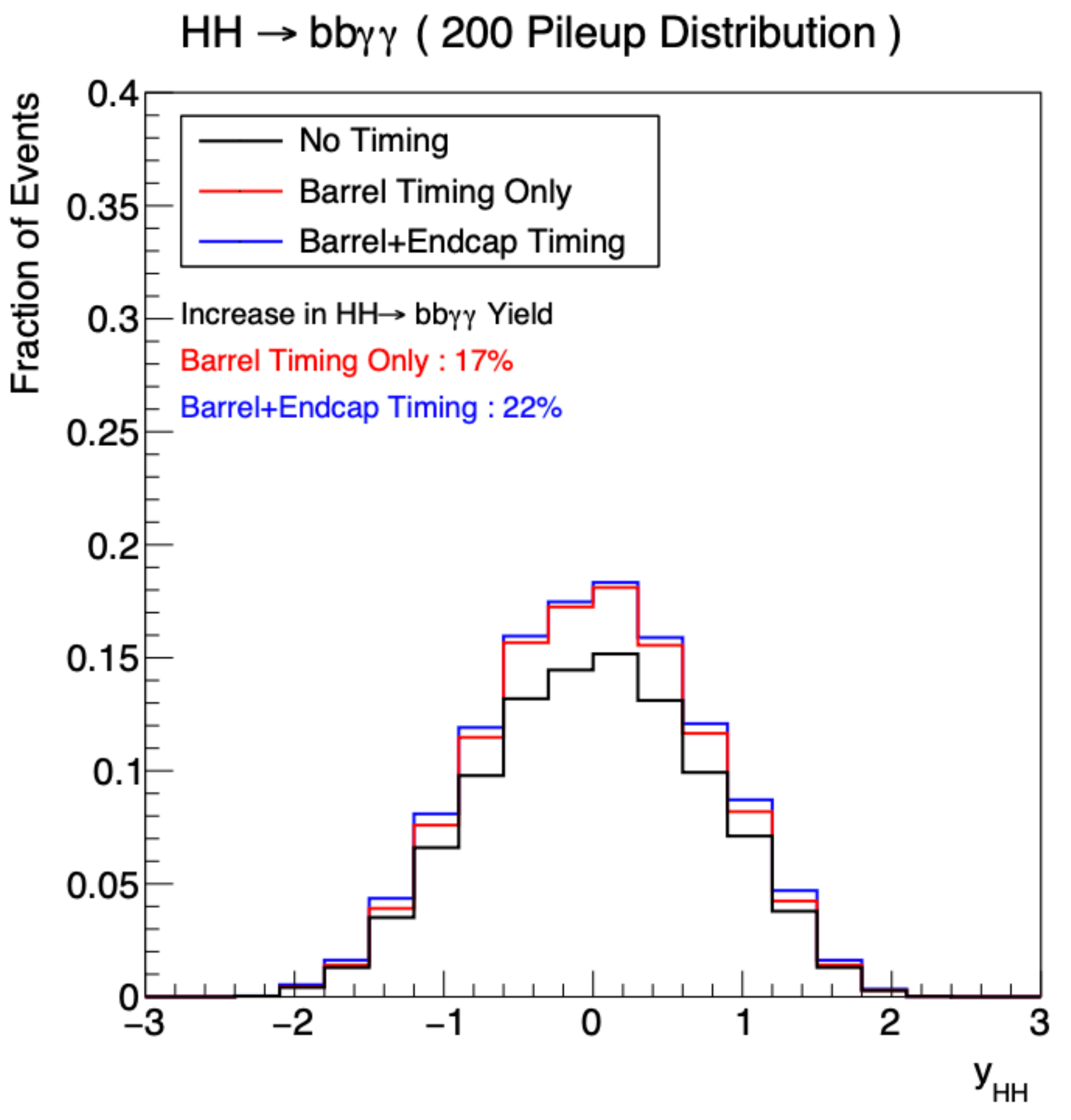
HL-LHC



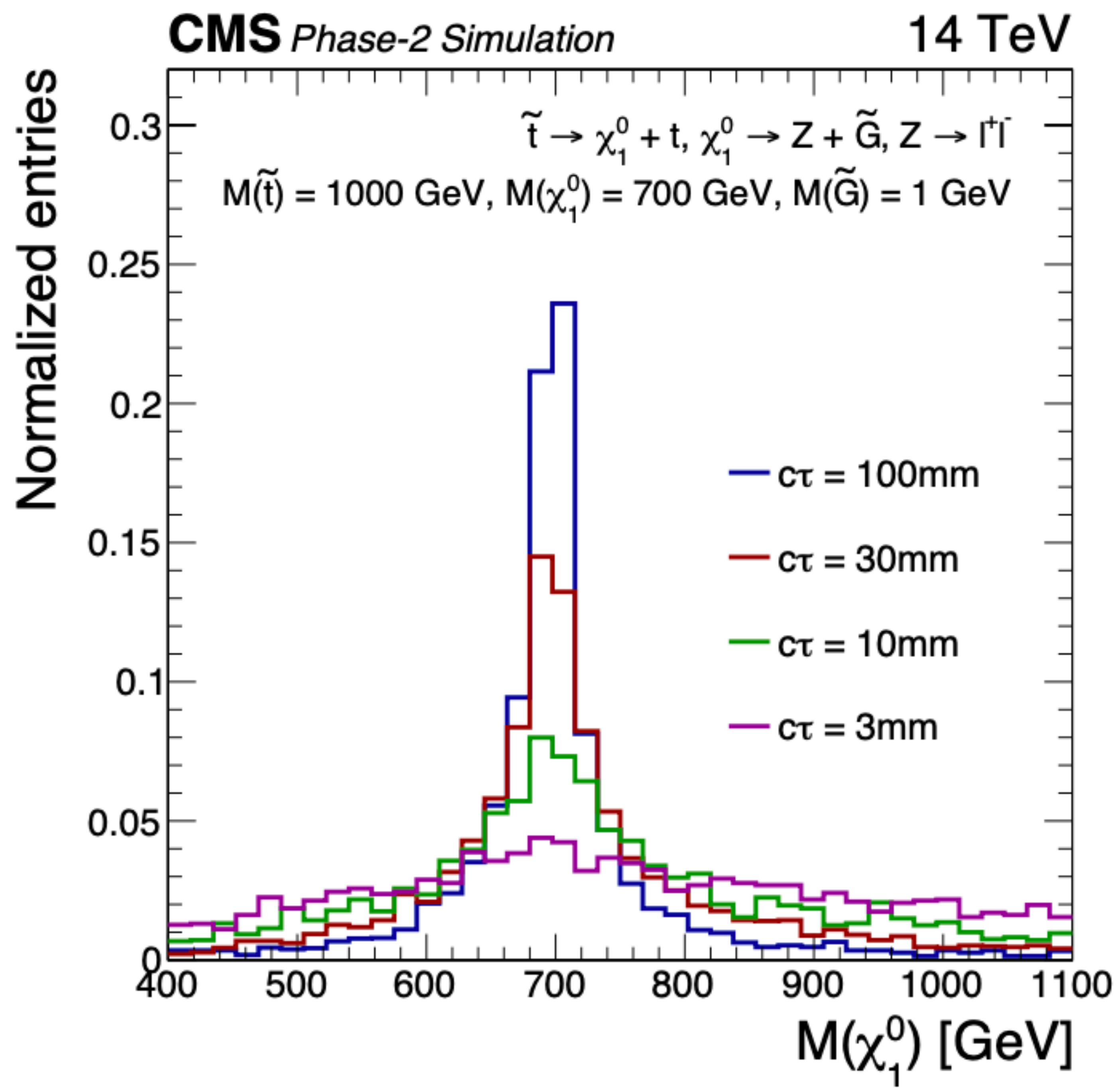


- Increase in the pileup interactions deteriorates association of the tracks with the hard interactions hence worsen the physics performance.
- A timing detector that measures precisely the production time of MIPs will mitigate the pileup impact and enable new physics reach such as search for long-lived particles.

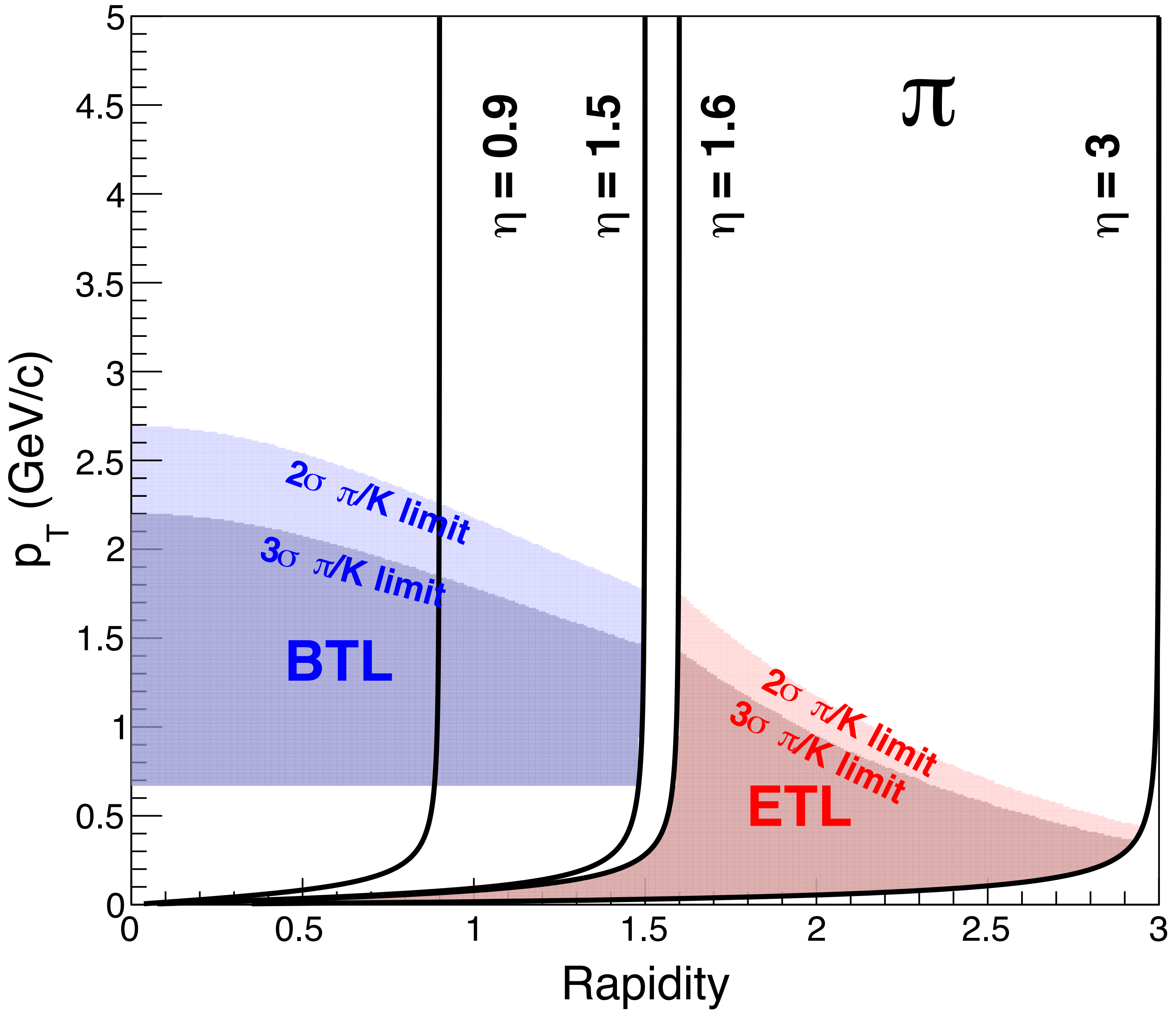
Physics showcase studies



Improve the efficiency of the Higgs self coupling measurements: more than 20% improvement in the HH→bb$\gamma\gamma$.



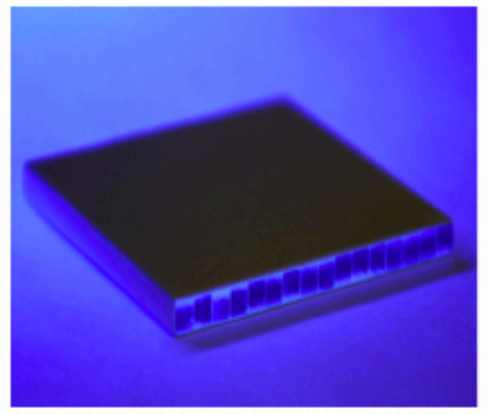
Direct measurement of the LLP mass (only possible with the timing detectors).



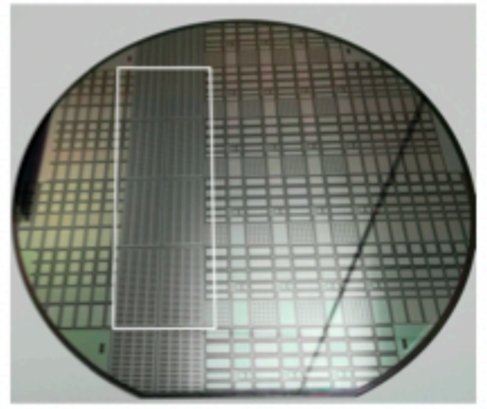
Significant benefits in the heavy ion physics such as charged particle identification capabilities.

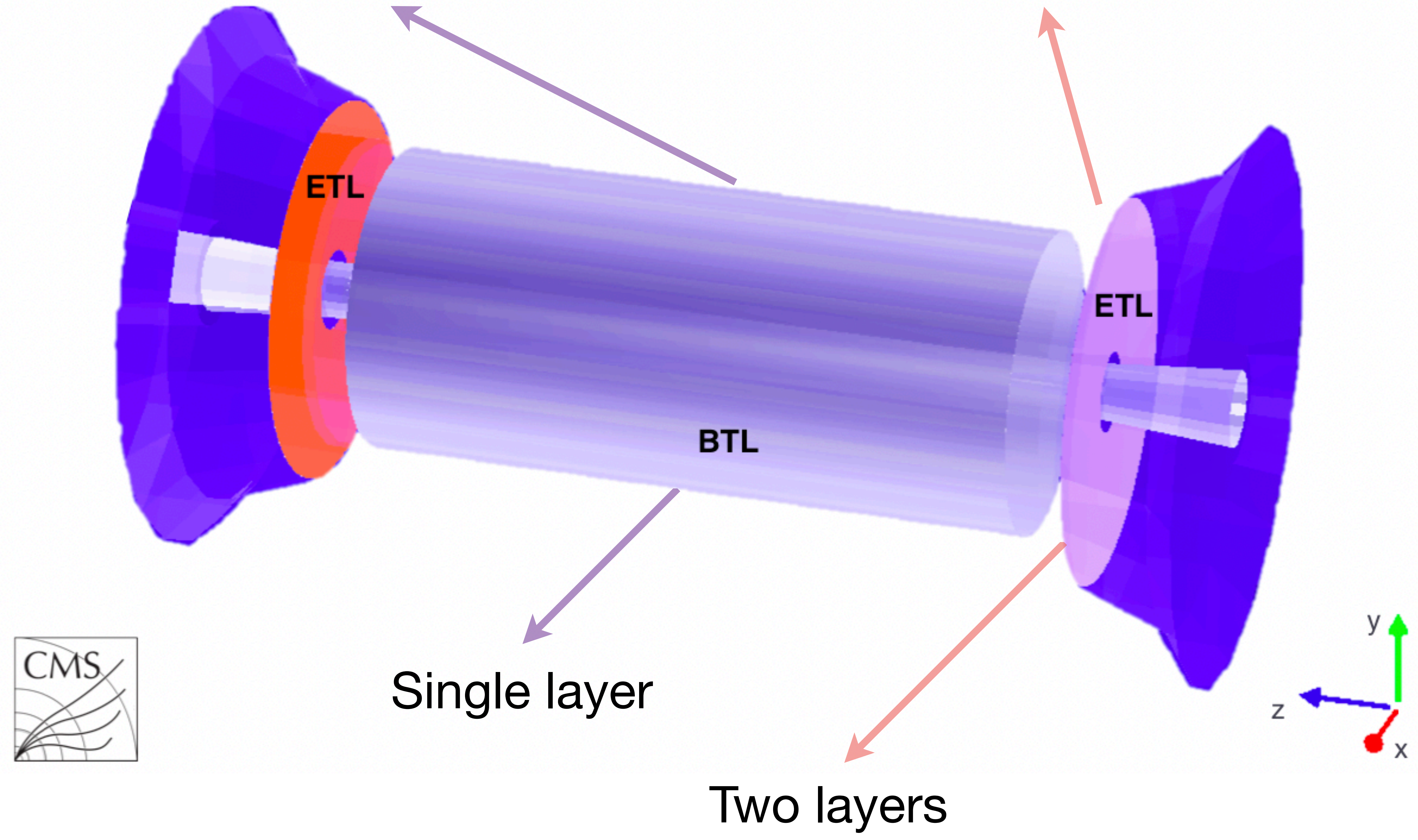
MIP Timing Detector

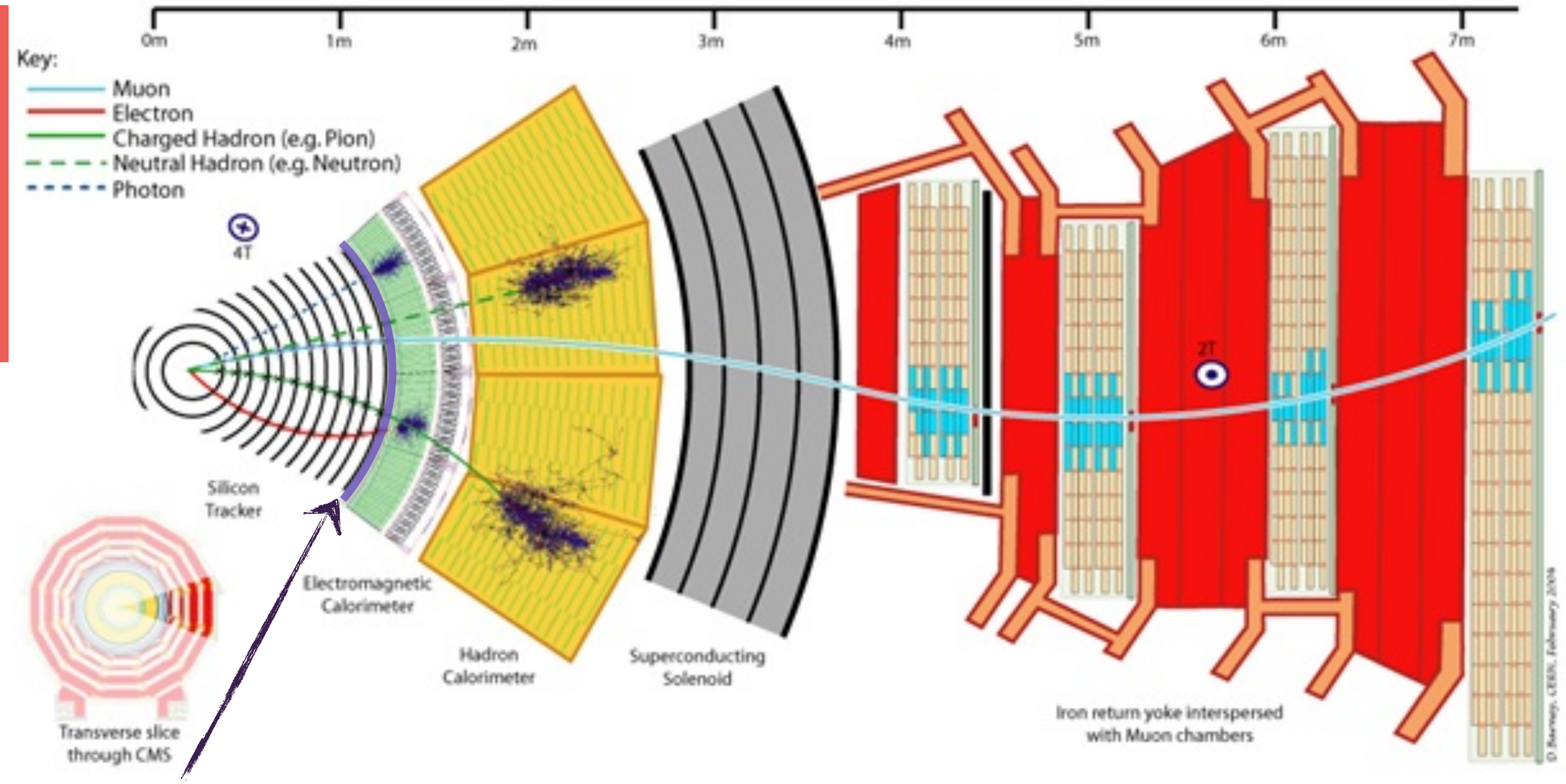
BTL: LYSO bars + SiPM readout:
- TK / ECAL interface: |η| < 1.45
- Inner radius: 1148 mm (40 mm thick)
- Length: ±2.6 m along z
- Surface ~38 m^2; 332k channels
- Fluence at 4 ab^{-1}: $2x10^{14}$ n_{eq}/cm^2



ETL: Si with internal gain (LGAD):
- On the CE nose: 1.6 < |η| < 3.0
- Radius: 315 < R < 1200 mm
- Position in z: ±3.0 m (45 mm thick)
- Surface ~14 m^2; ~8.5M channels
- Fluence at 4 ab^{-1}: up to $2x10^{15}$ n_{eq}/cm^2



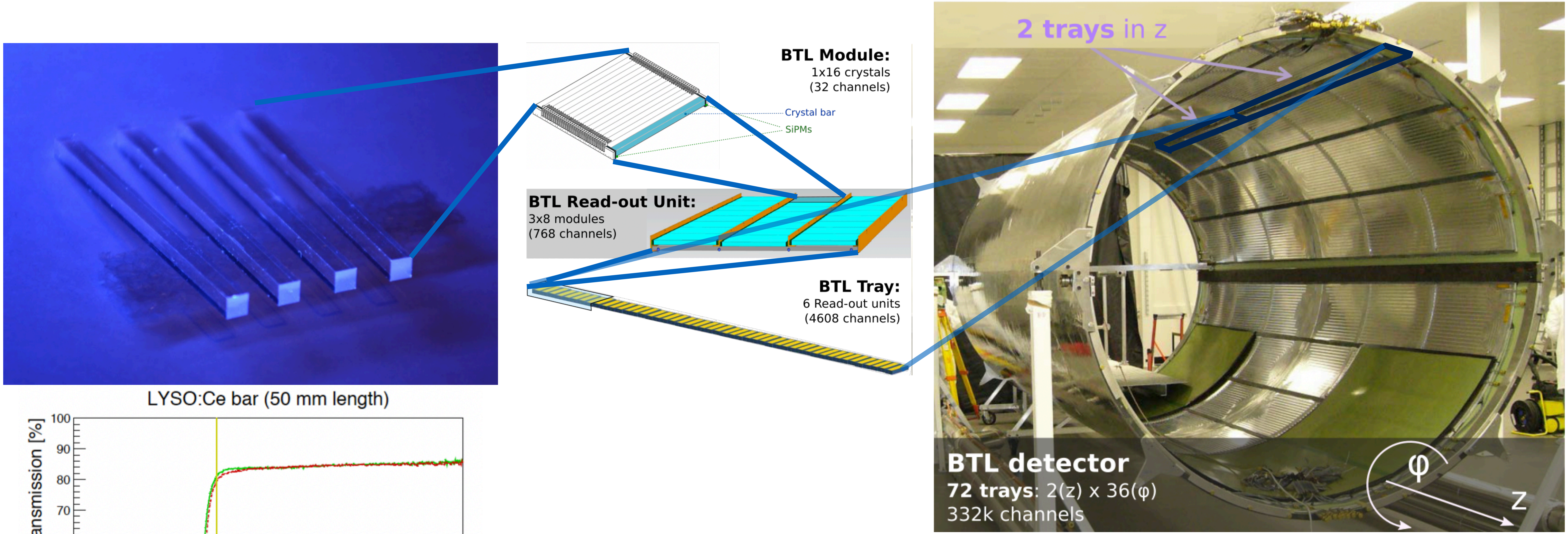




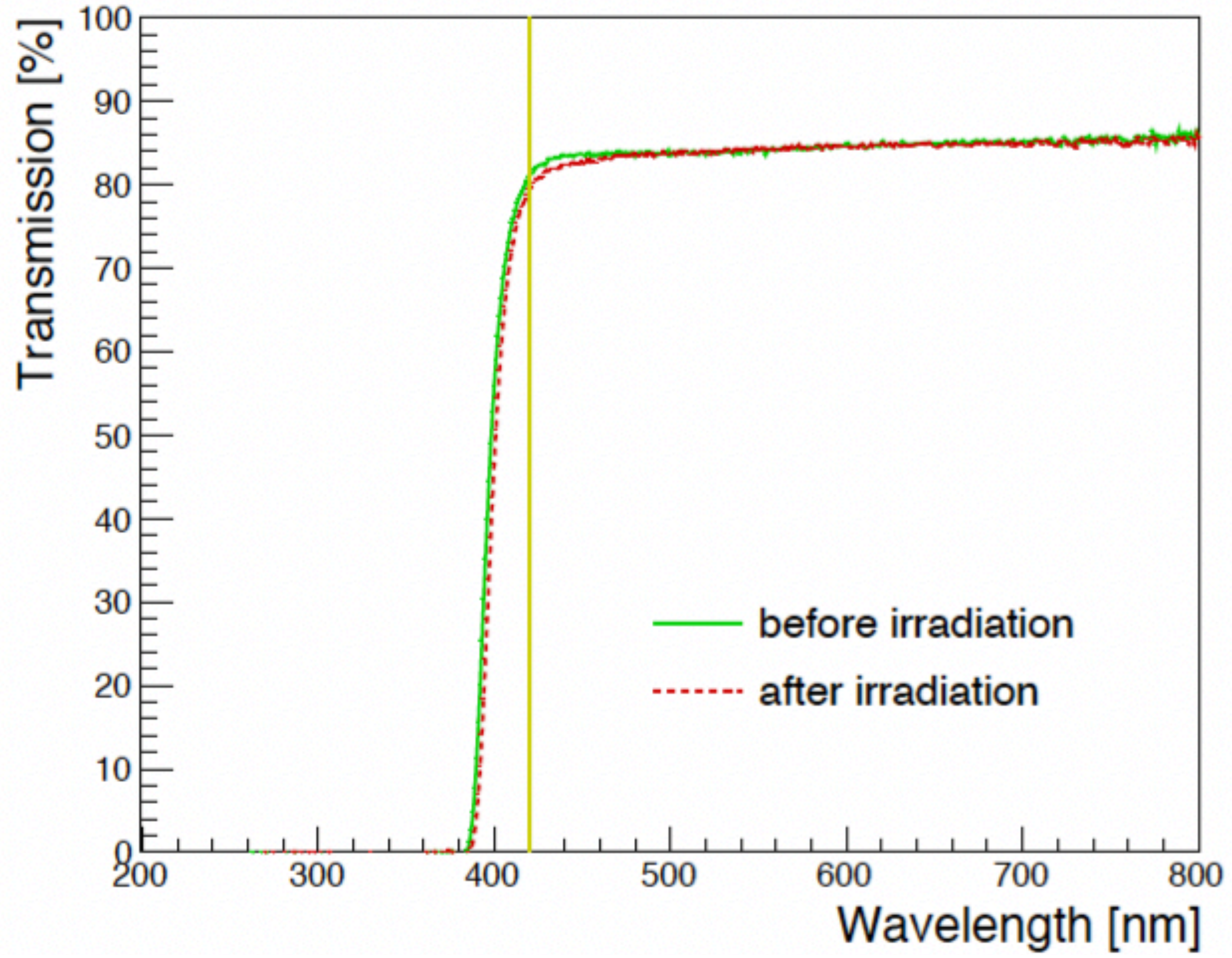
MTD

- The MIP timing detector (MTD) will have 35 ps resolution at the beginning of its lifetime.
- It will have an hermetic coverage up to η=3.
- Why two different technologies?
  - Radiation hardness and cost!

Barrel timing layer

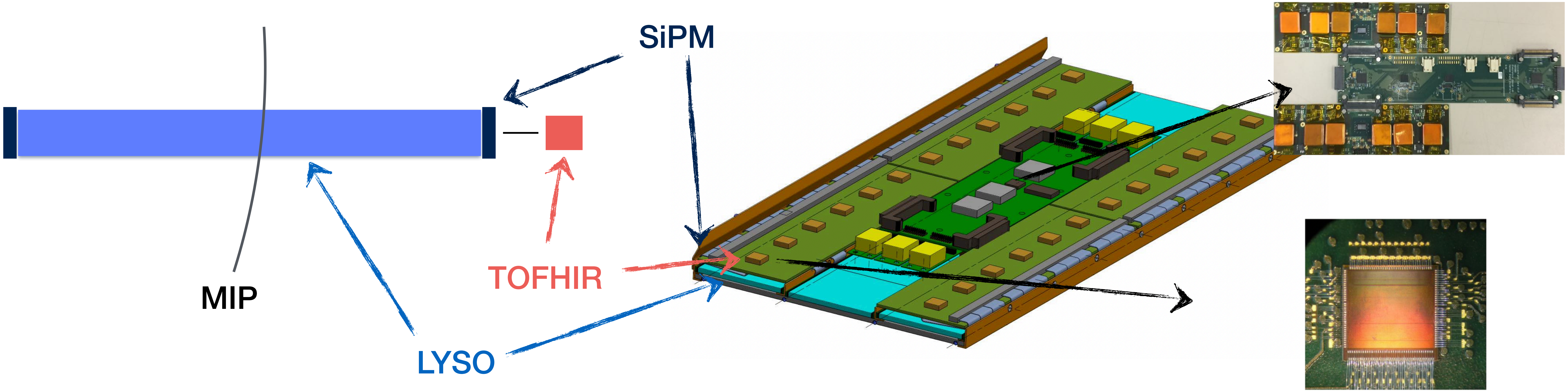


LYSO:Ce bar (50 mm length)



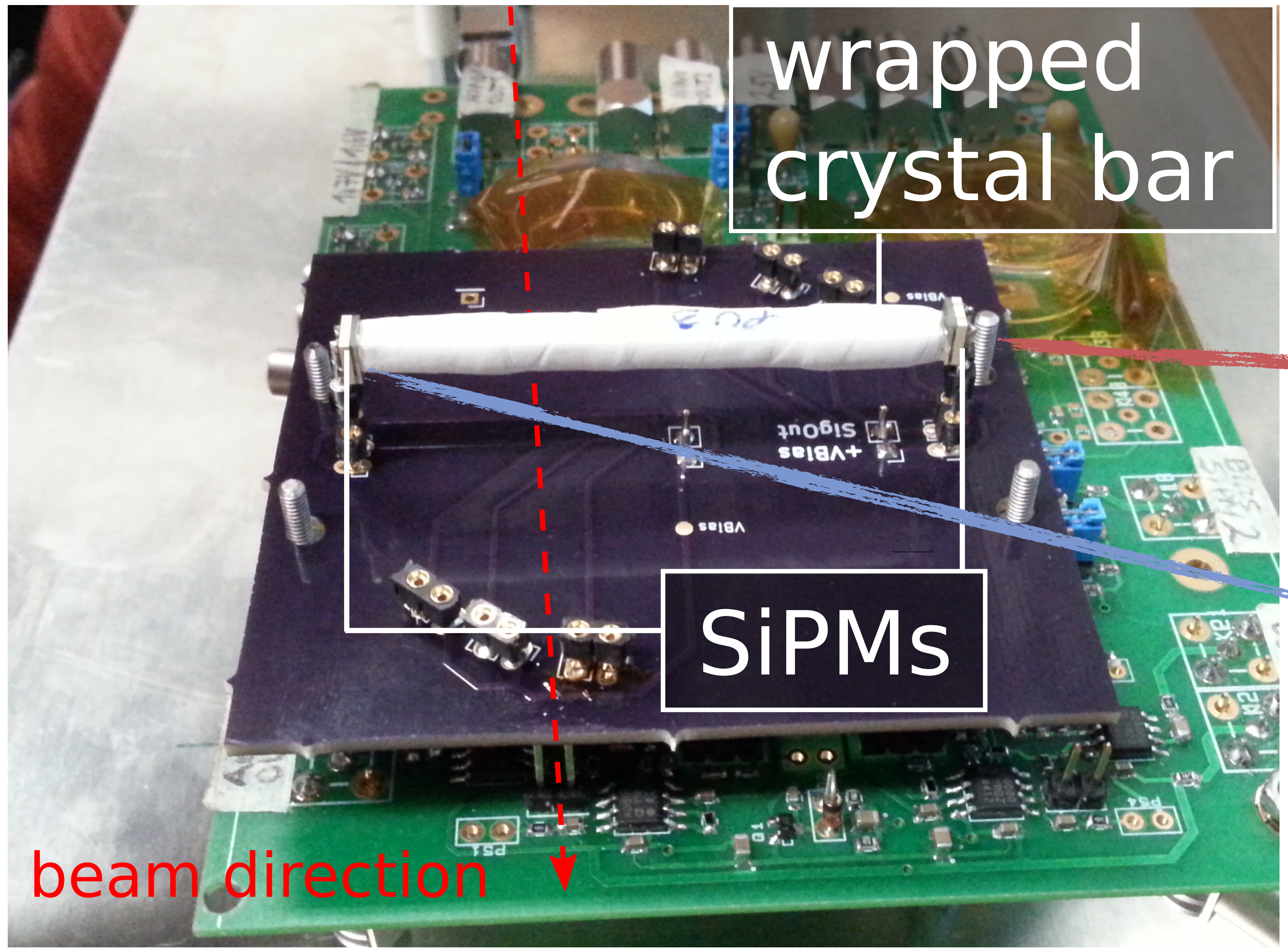
- Barrel timing layer consists of 166k LYSO crystals (32 m2) readout with 332k SiPMs covering up to η=1.48.
- LYSO crystals: high signal to noise ratio, signals with fast rise time, high radiation tolerance.
- 35 ps resolution at the beginning of lifetime, 60 ps resolution by the end of lifetime.

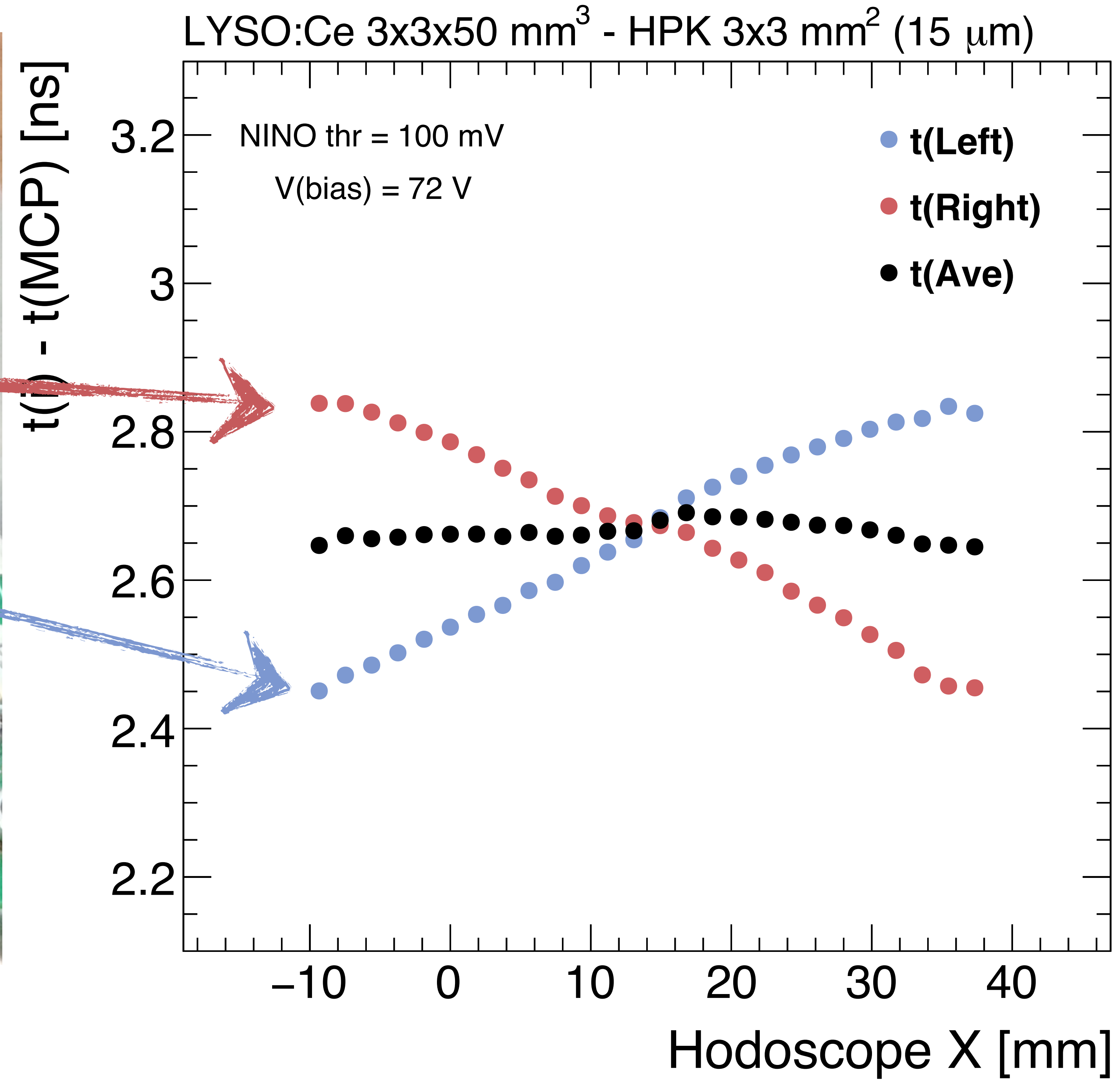
Barrel timing layer

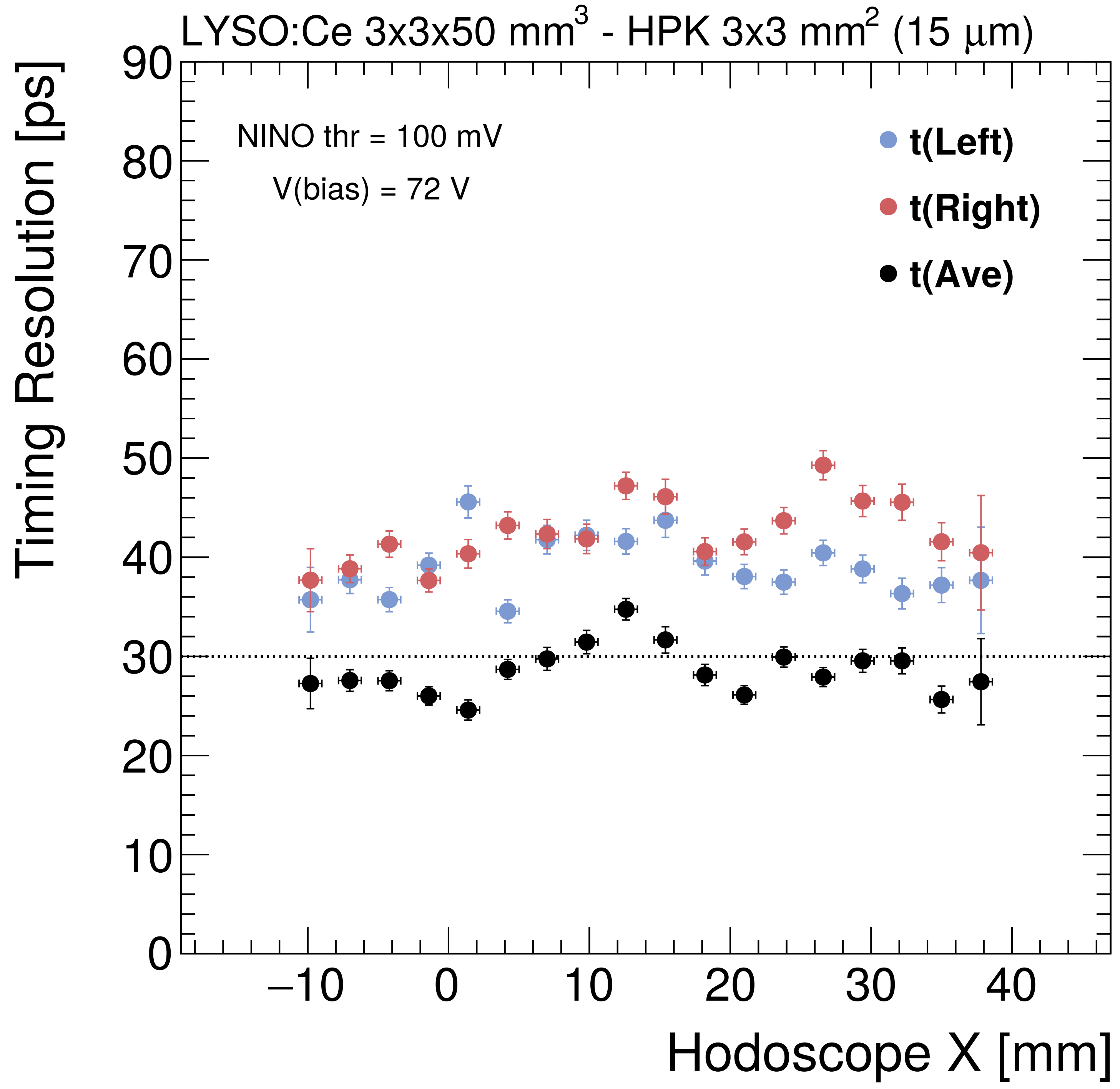


- The readout is performed by silicon photo multipliers (SiPM) and the readout ASIC (TOFHIR).
  - Small cell size SiPM: fast readout, robust against magnetic field and radiation, low power consumption.
  - LYSO crystal bars read out on two sides - improved resolution and response insensitive to position.
- The TOFHIR ASIC has 32 independent channels (can readout 16 crystals), each containing independent amplifiers, discriminators, time-to-digital converters and charge-to-digital converters.

Barrel timing layer: test beam results

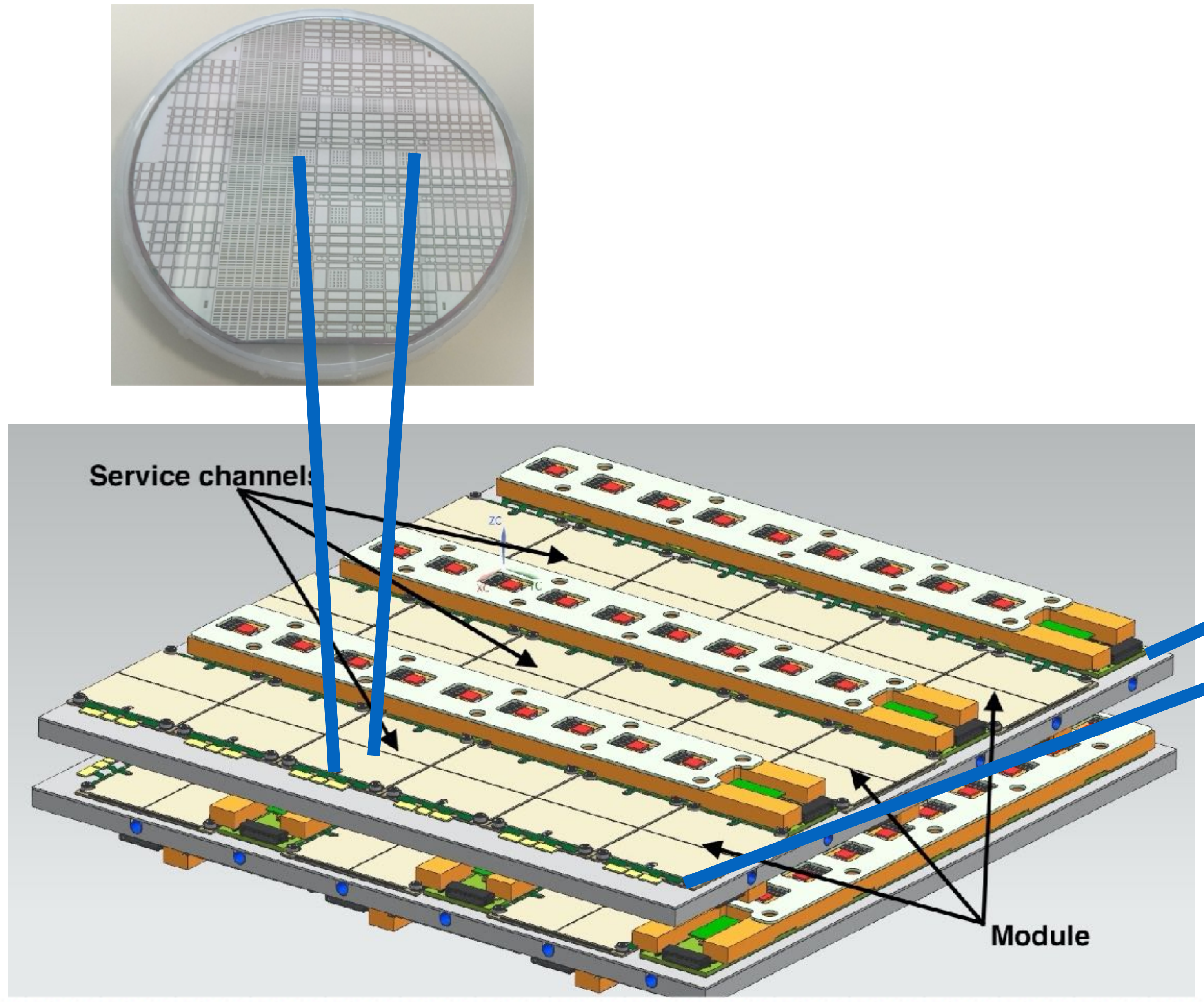


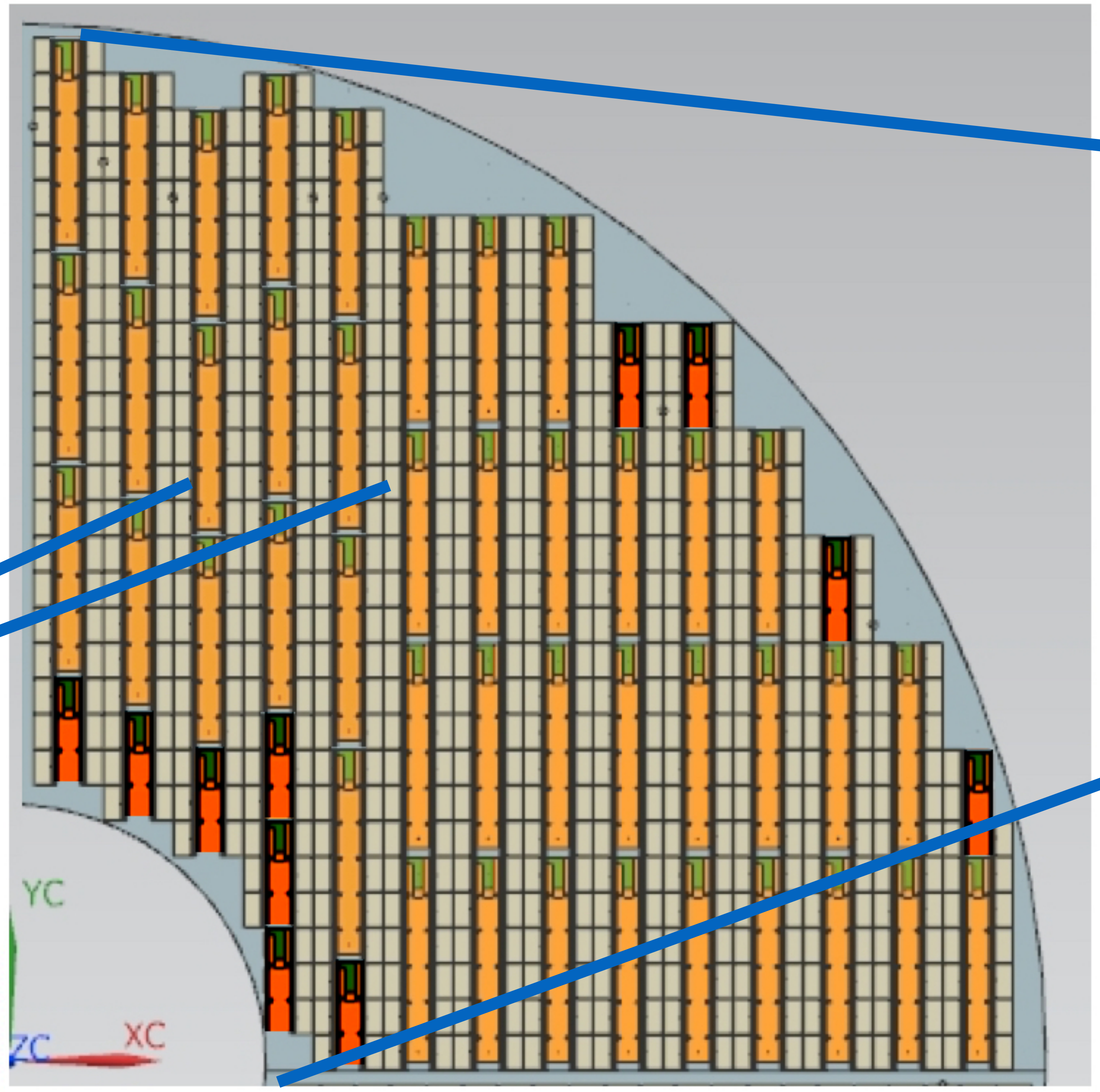


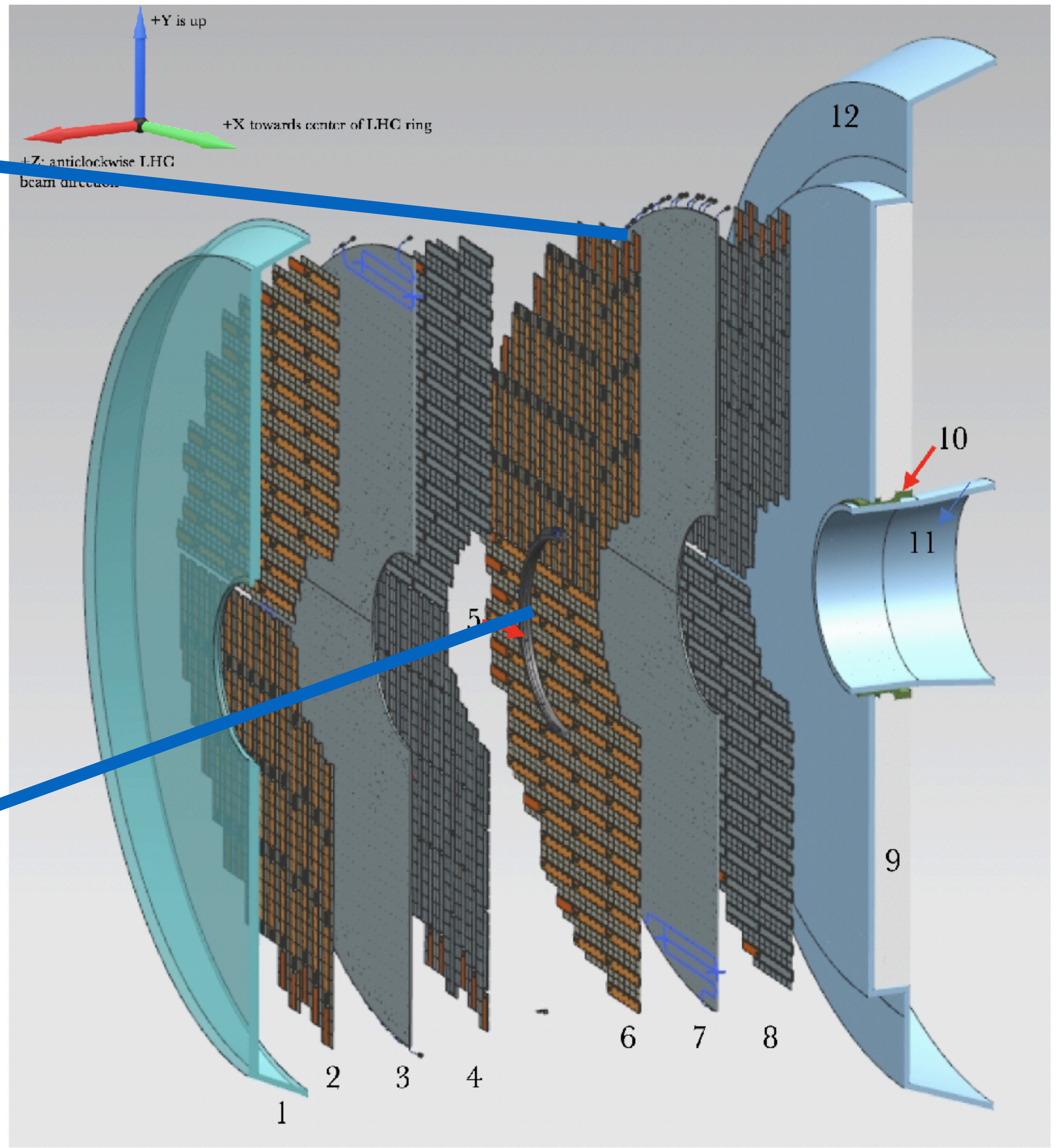


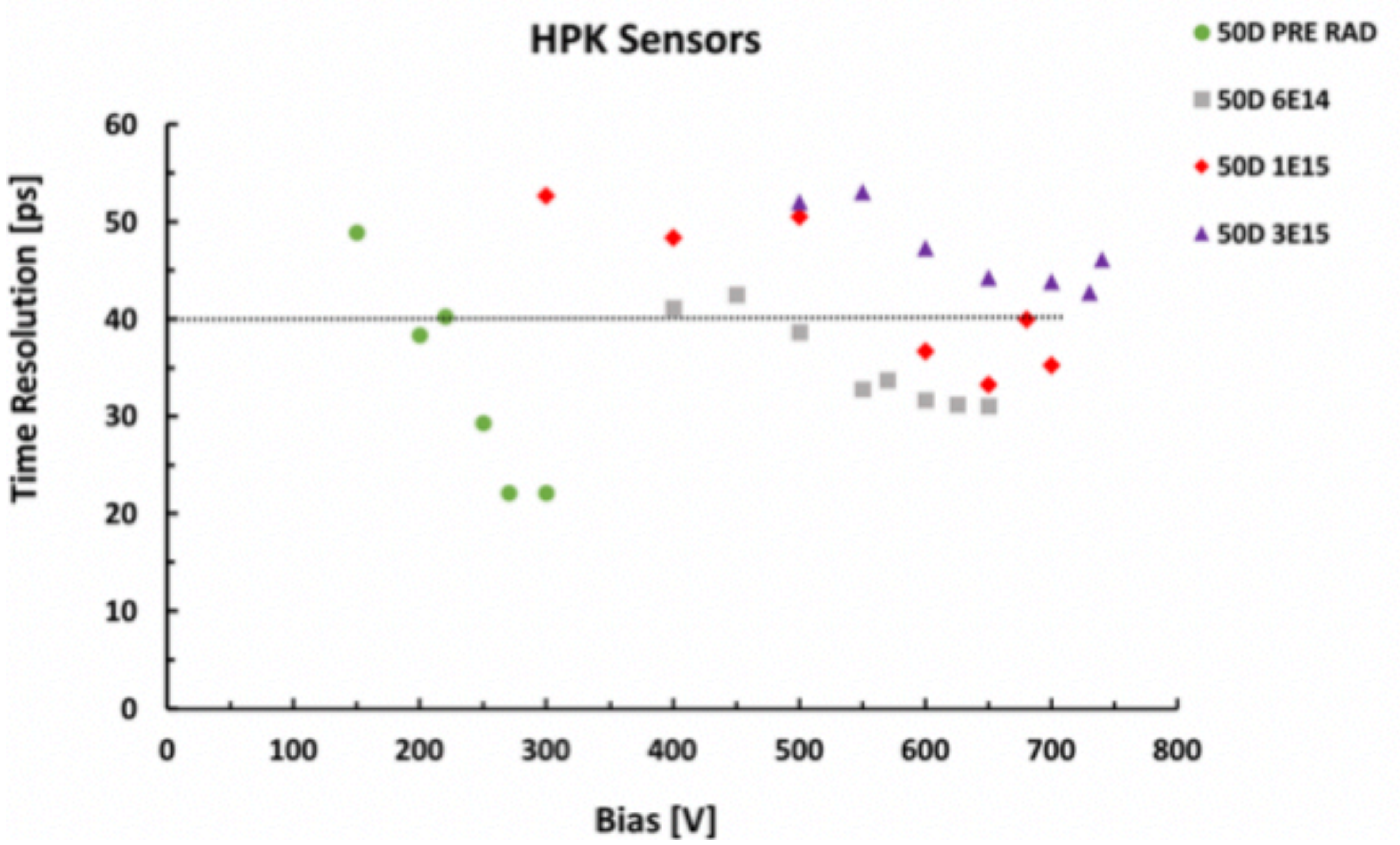
- **Uniform time response and resolution** obtained from both SiPMs,
- Combining both SiPM provides $\sqrt{2}$ **improvement in the resolution!**

Endcap timing layer



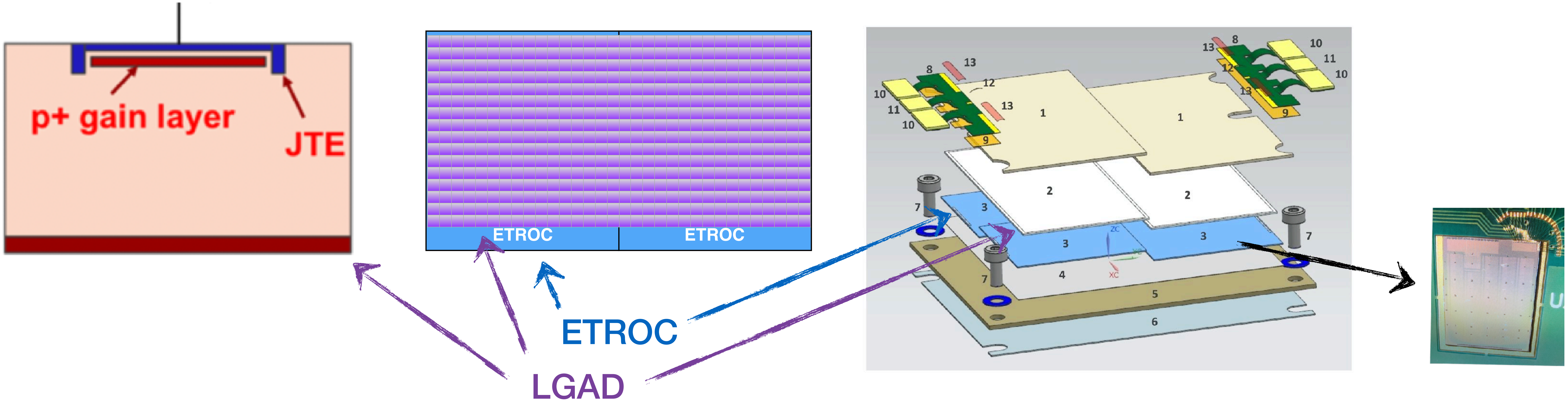




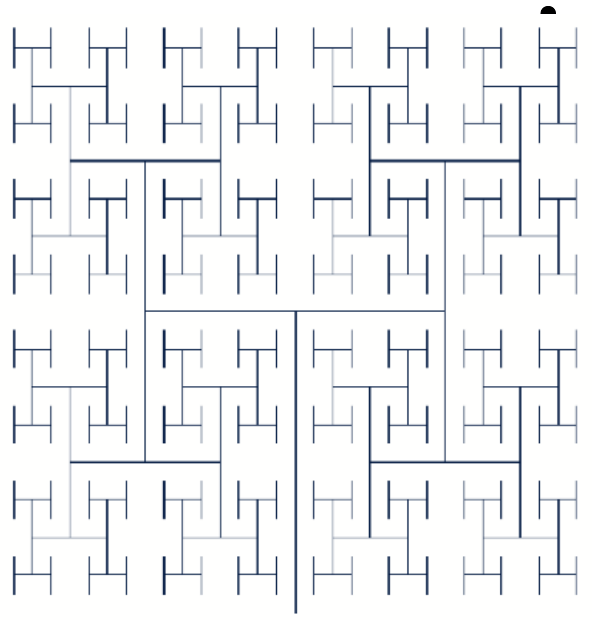


- Endcap timing layer consists of 15.8 m² thin Low-Gain Avalanche Detector (LGAD) sensors (21.2×42 mm² sensor area with 1.3×1.3 mm² pixels) covering from $\eta=1.6$ up to $\eta=3.0$.
  - Thin LGAD sensors: signals with fast rise time, very high radiation tolerance.
  - 35 ps resolution at the beginning of lifetime, 60 ps resolution by the end of lifetime.

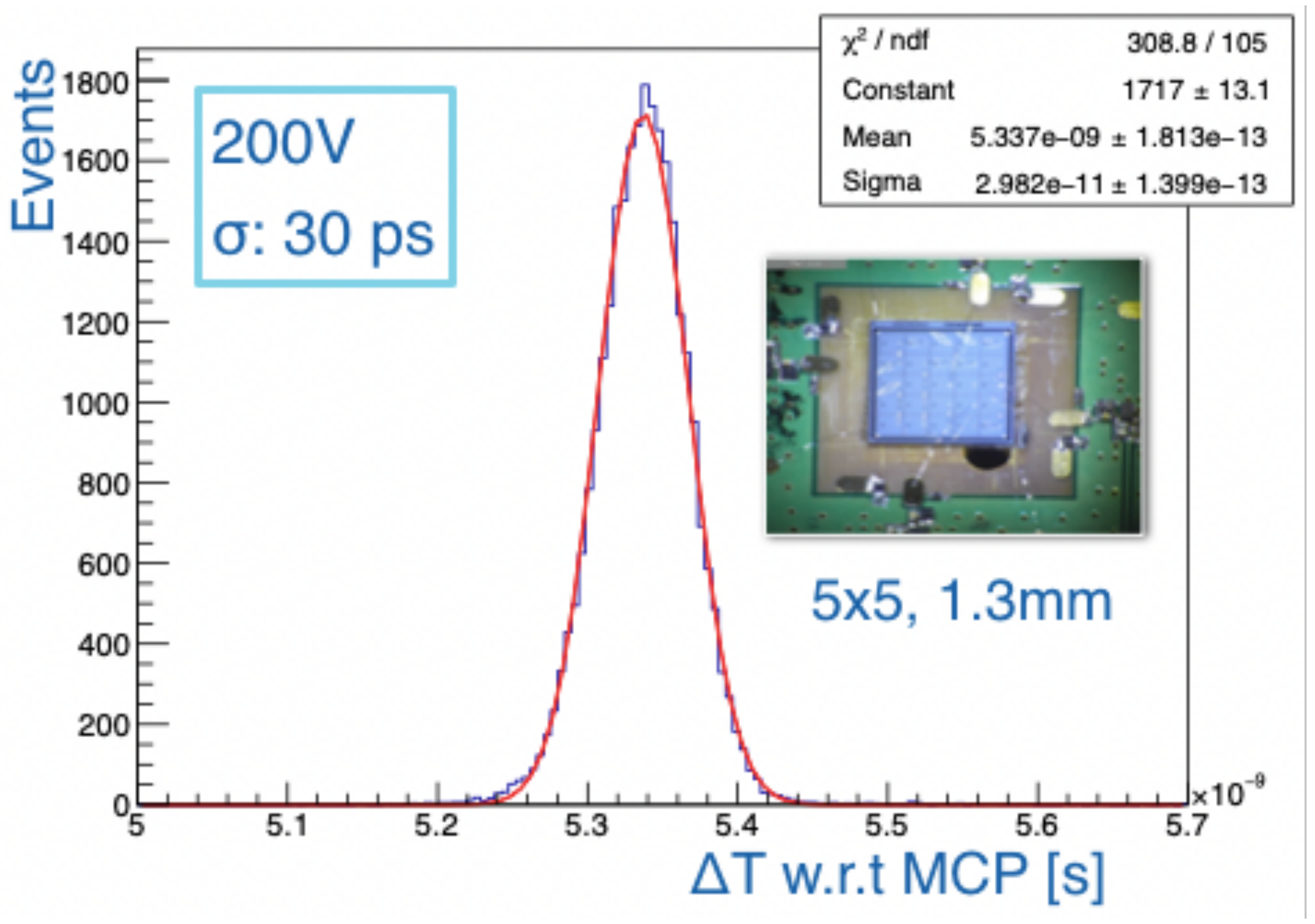
Endcap timing layer

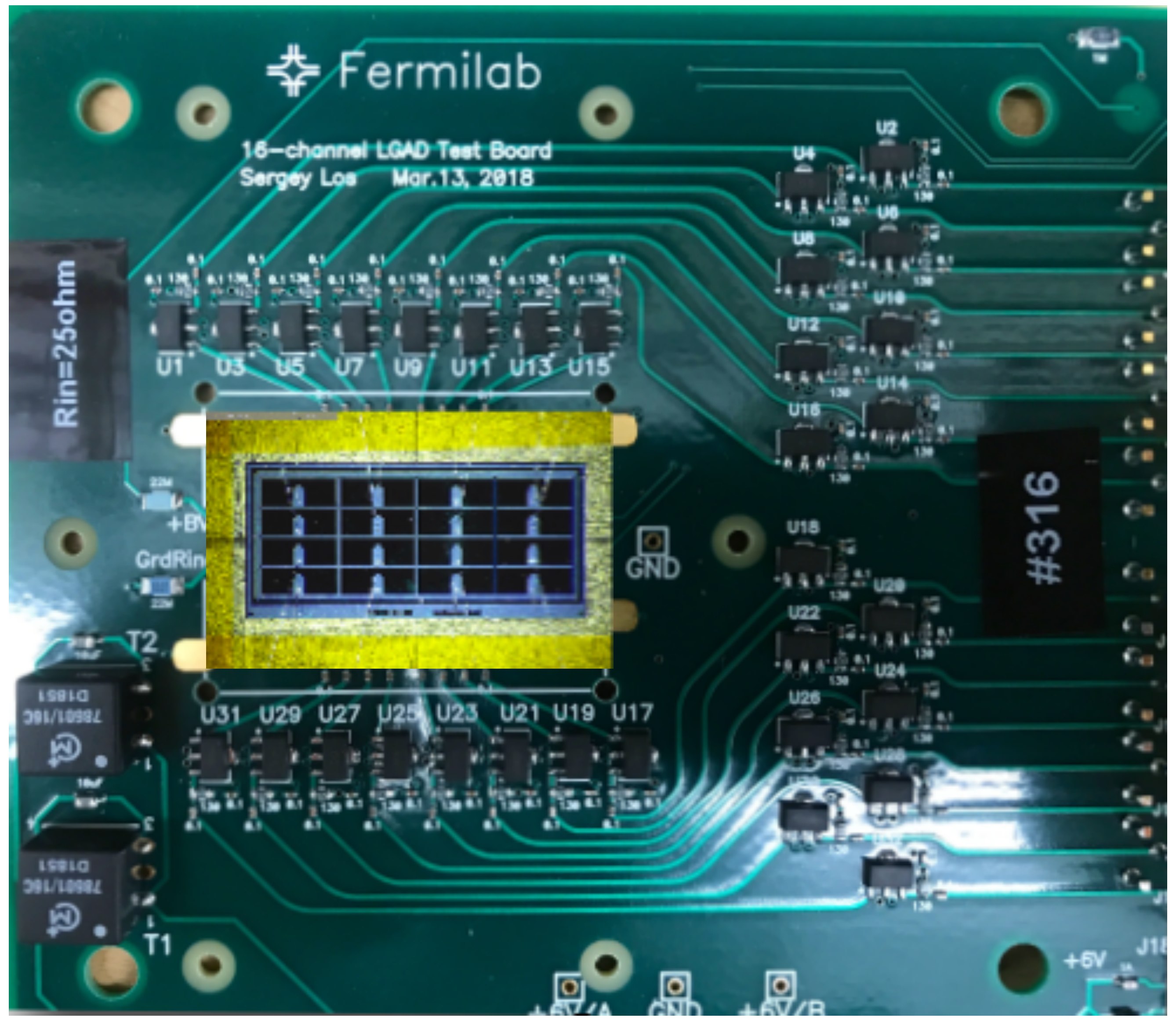


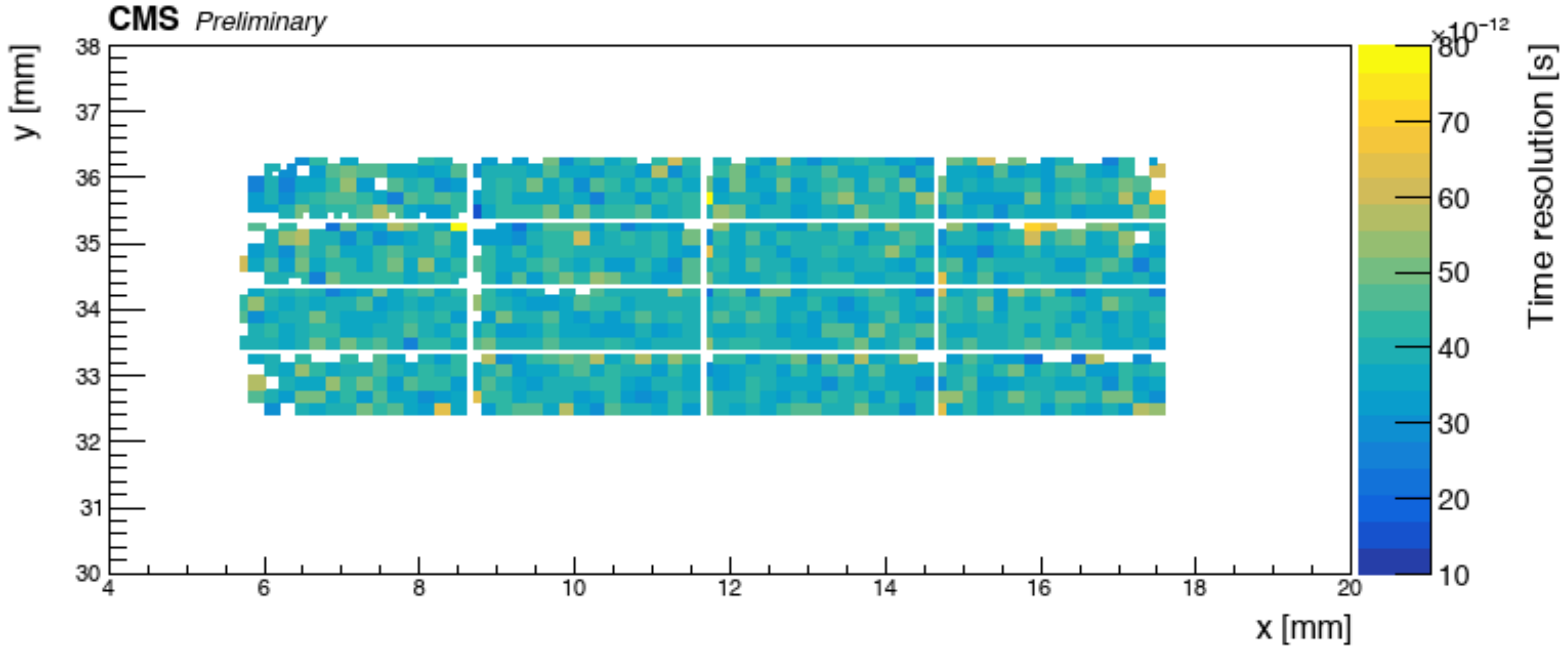
- The Ultra Fast Silicon Detectors can be achieved with an additional gain layer (LGAD) and are optimized for timing.
  - Common CMS & ATLAS development.
- The ETL readout ASIC (ETROC) is designed to handle a 16×16 pixel cell matrix
  - Each channel consists of a preamplifier, a discriminator, a TDC used to digitize the TOA (time of arrival) and TOT (time over threshold) measurements
  - H-tree clock distribution.



Endcap timing layer: test beam

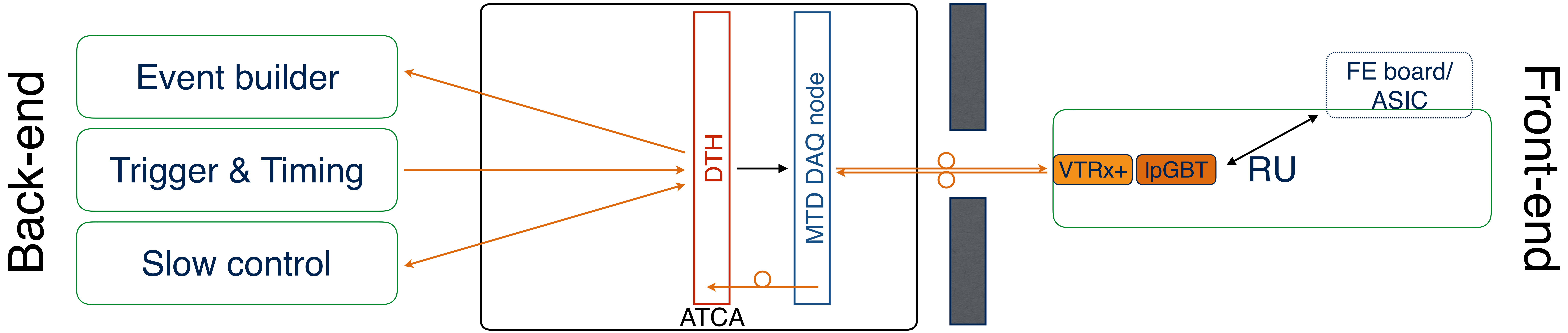




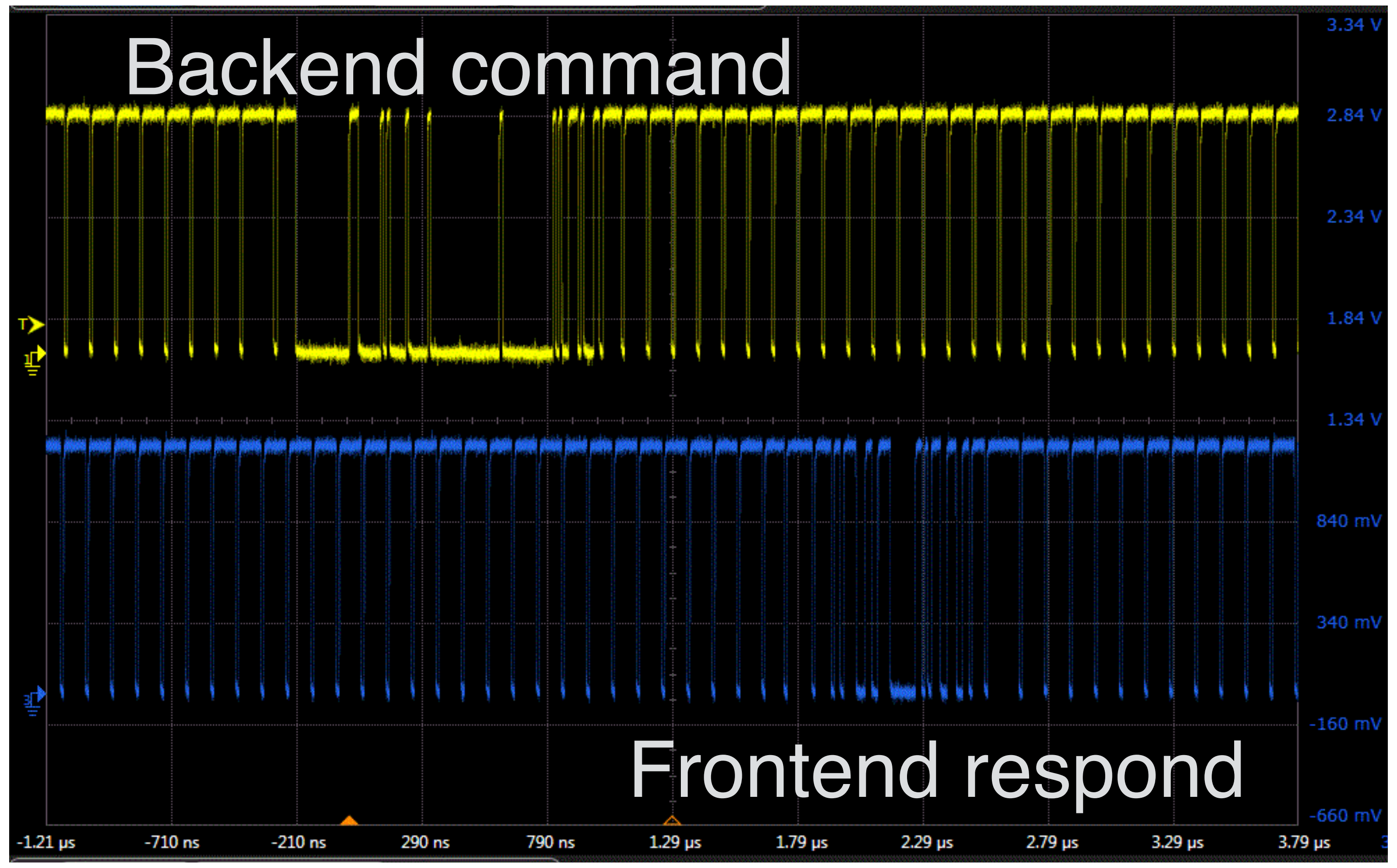


- **30 ps resolution** with a **5x5 sensor with 1.3×1.3 mm² pixels**,
- **Uniform time resolution of 40 ps** after irradiation.

DAQ

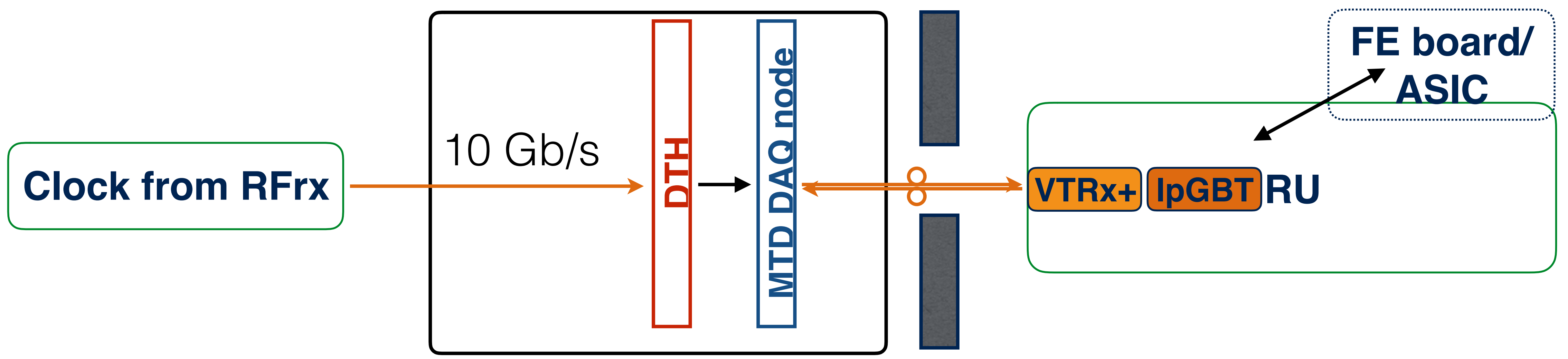


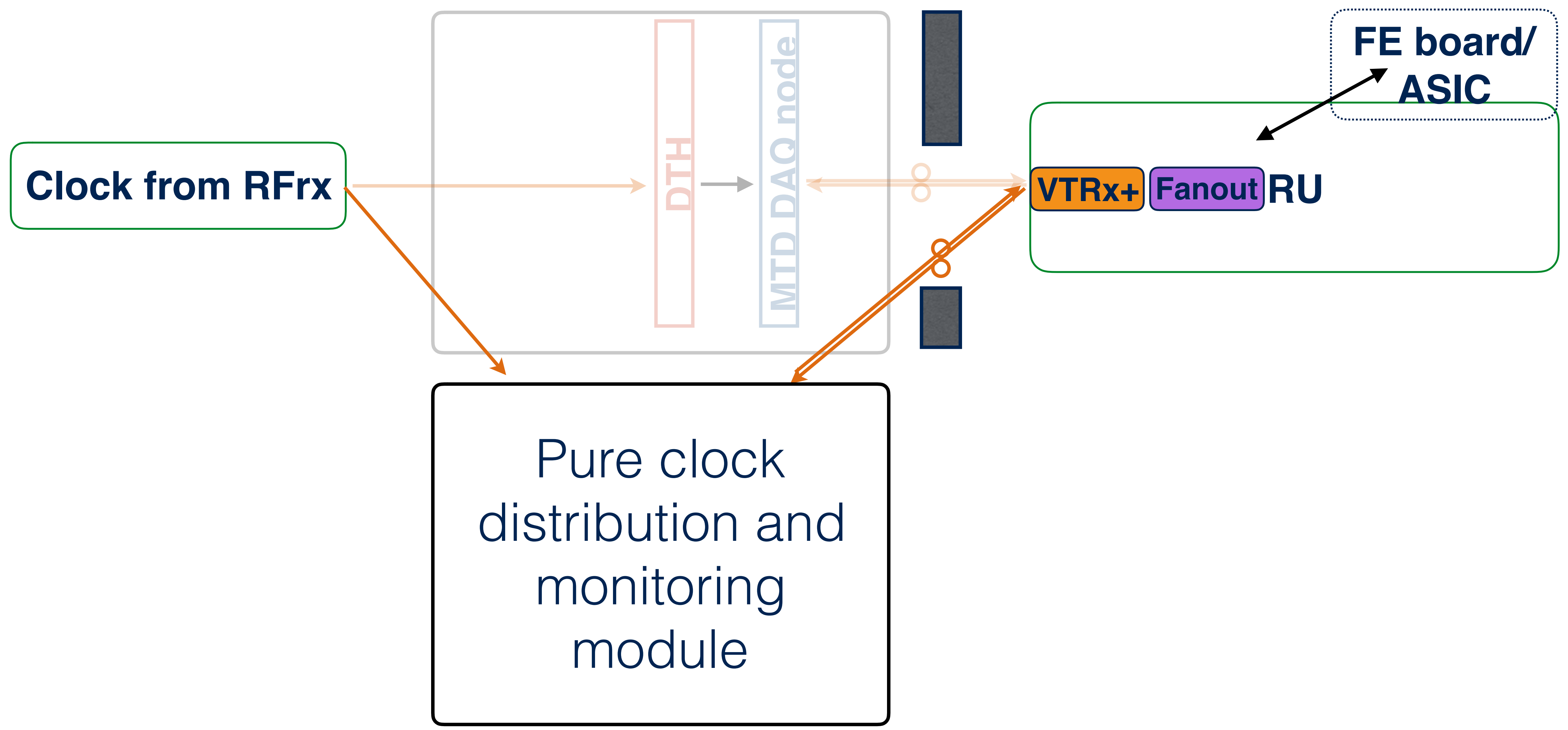
- Slow control, fast control and trigger signals are sent via the DAQ links. Therefore, **all links are bidirectional** and will operate at 10 Gb/s or 5 Gb/s.
    - **ETL: 1600 links (800 per endcap detector)**
    - **BTL: 864 links (432 concentrator cards)**
- MTD DAQ node has 2 FPGAs



Communication with the BTL frontend is established

Clock distribution





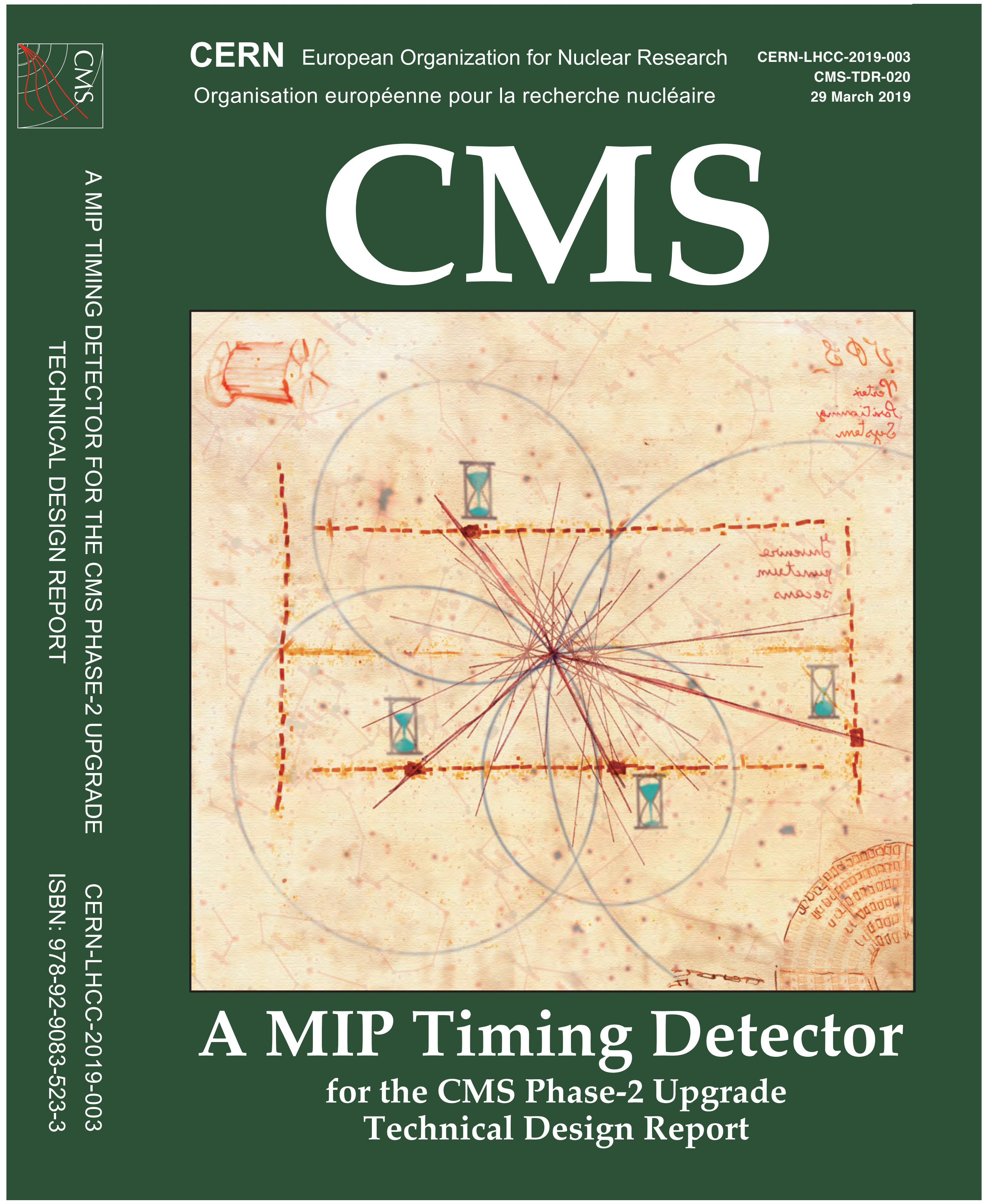
- The **clock distribution** should provide a stable clock with **less than 15ps RMS jitter**.
- In the baseline distribution the DAQ link is used to distribute the embedded clock.
- Characterization results:
  - **Backend system** with characterization board frontend **12 ps RMS jitter at 160 MHz (BTL) and 5 ps RMS jitter at 40 MHz (ETL)**.
    Frontend system with an evaluation board backend **6 ps RMS jitter**
  - **lpGBT -> 3 ps/C and 4 ps/mV**.

- If the **baseline clock distribution fails to meet the performance expectation**, an alternative clock distribution scheme will be used.
- Clock is recovered from RFrx. The clock distributed to the frontend modules without encoding. Requires additional optical fiber and transceivers for each readout unit.
- A clock distribution network better than few ps RMS jitter can be achieved.

Status and schedule

MTD HIGH LEVEL MILESTONES TIMELINE	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
		TDR Submission ♦		♦ BTL EDR		♦ ETL EDR				
Barrel Timing Layer	Design - Demo.		Engin. - Proto.	Pre-prod.	Production and integration		Install. //////	Tracker Installation		Comm.
Endcap Timing Layer	Design - Demo.		Engineering - Prototyping		Pre-production	Production and integration			Install.	Comm.

- The projects is approved!
  - TDR is public: https://cds.cern.ch/record/2667167/files/CMS-TDR-020.pdf
- Production:
  - BTL in 2021-2022,
  - ETL in 2022-2024
- Installation:
  - BTL in 2023,
  - ETL in 2025.
- 2026 commissioning.



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Conclusion

- Large Hadron Collider will undergo to a High Luminosity upgrade,
  - Aims to deliver ten times more integrated luminosity, five times more pileup interactions.
- Precision timing measurements (~30 ps resolution) will be an important tool to mitigate the impact of the pileup.
- The MIP timing detector has an hermetic coverage up to $\eta=3$. It provides precision timing for MIPs.
  - Mitigates the pileup impact - effectively reduces the expected average pileup to the current conditions.
  - Extend the physics reach.
- BTL consists of LYSO crystals and read out with SiPMs and TOFHIR ASIC.
- ETL employs LGAD sensors 1.3 mm^2 pixel, readout with ETROC ASIC.
- Test beams are ongoing. The results are promising and meet the expectations.