Precision Timing with the CMS MIP Timing Detector

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On behalf of the CMS Collaboration.

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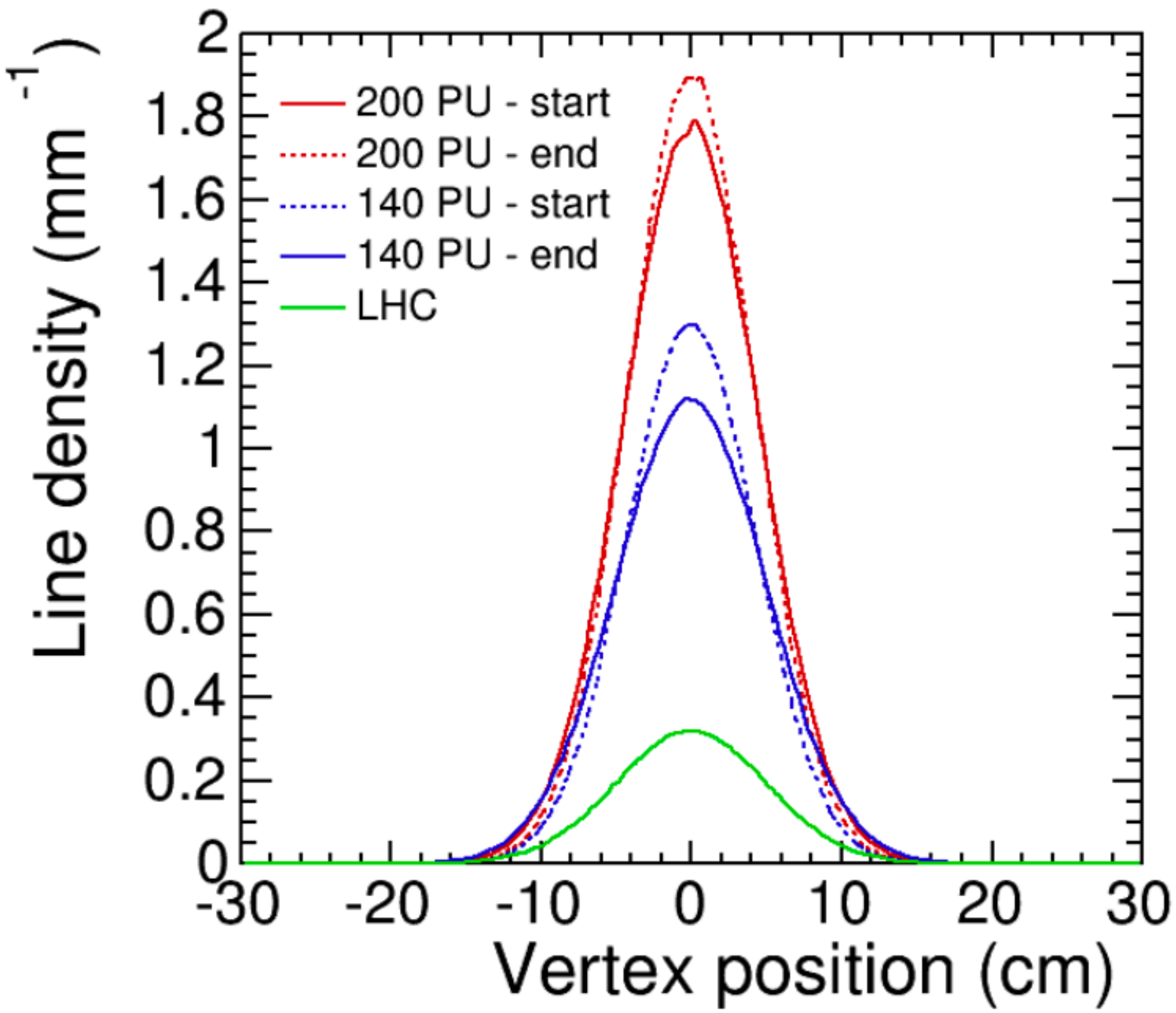
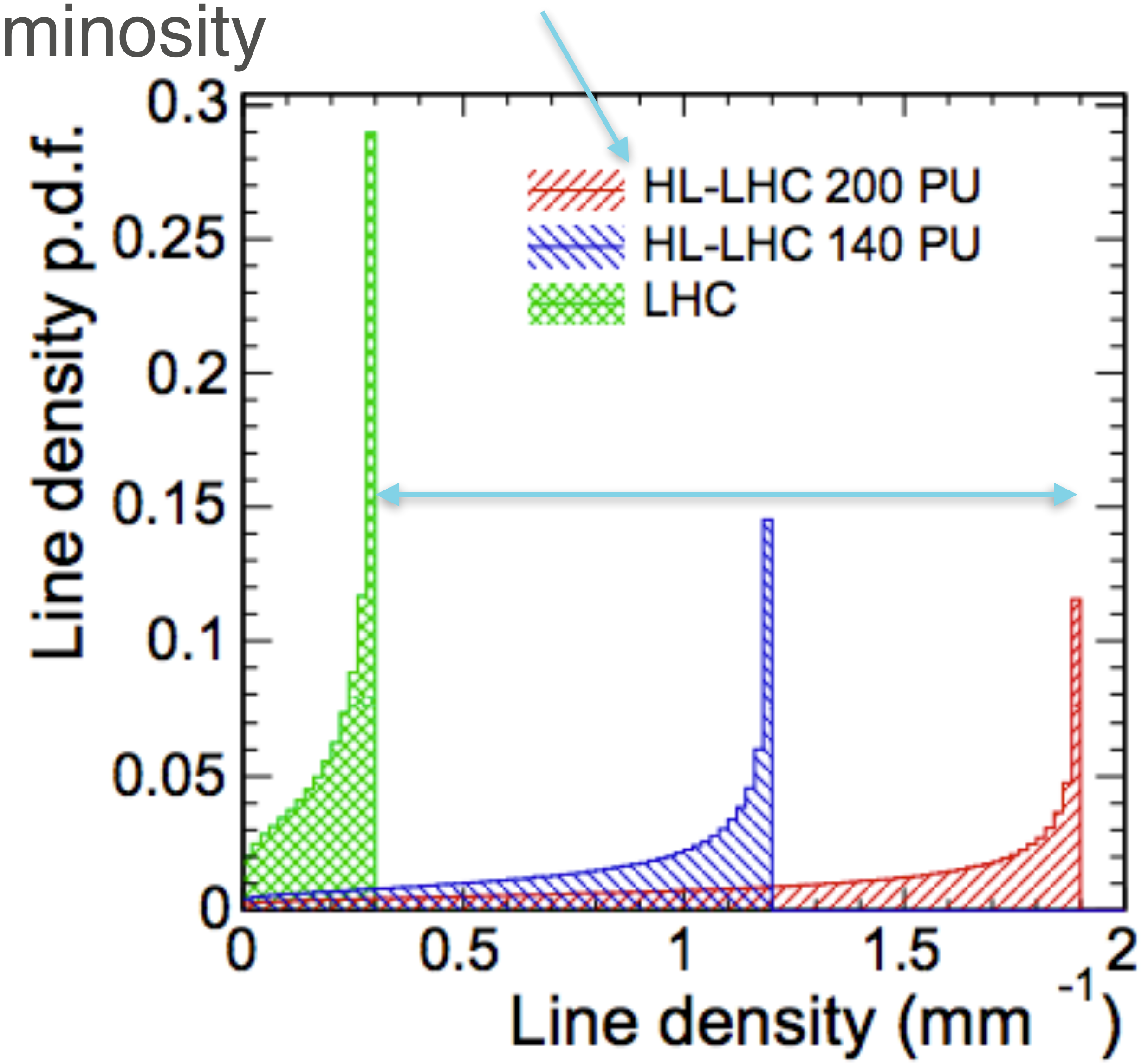
In partnership with:

Introduction

- HL-LHC upgrade will increase beam intensity to achieve O(10) increase in instantaneous luminosity:
  - Baseline: peak L = 5.0 x 10^{34} $cm^{-1}s^{-1}$
  - Baseline: peak L = 7.5 x 10^{34} $cm^{-1}s^{-1}$
- Pileup increases as instantaneous luminosity



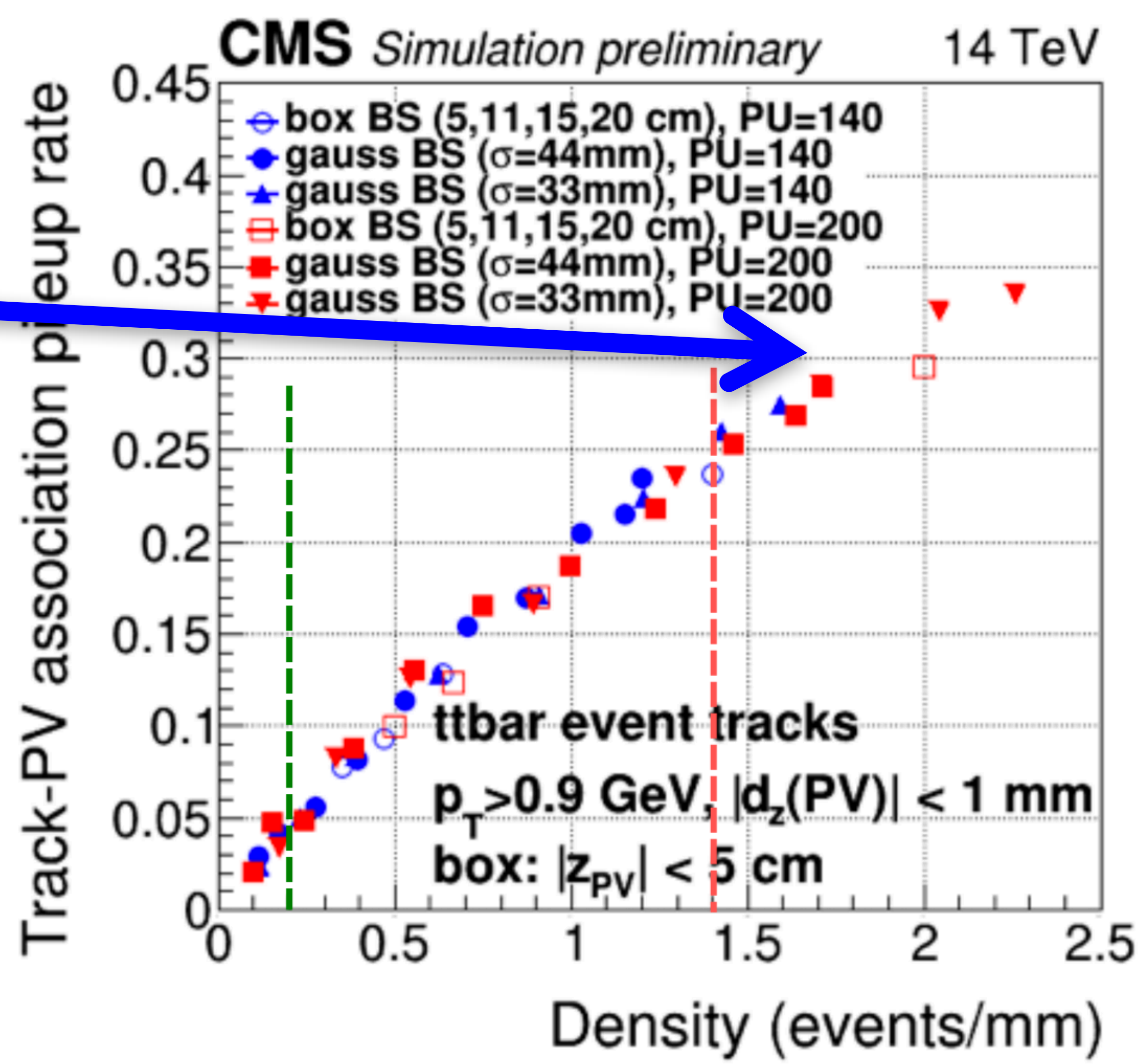
Density of pp collisions per unit distance along beam axis



Impact of pileup in CMS

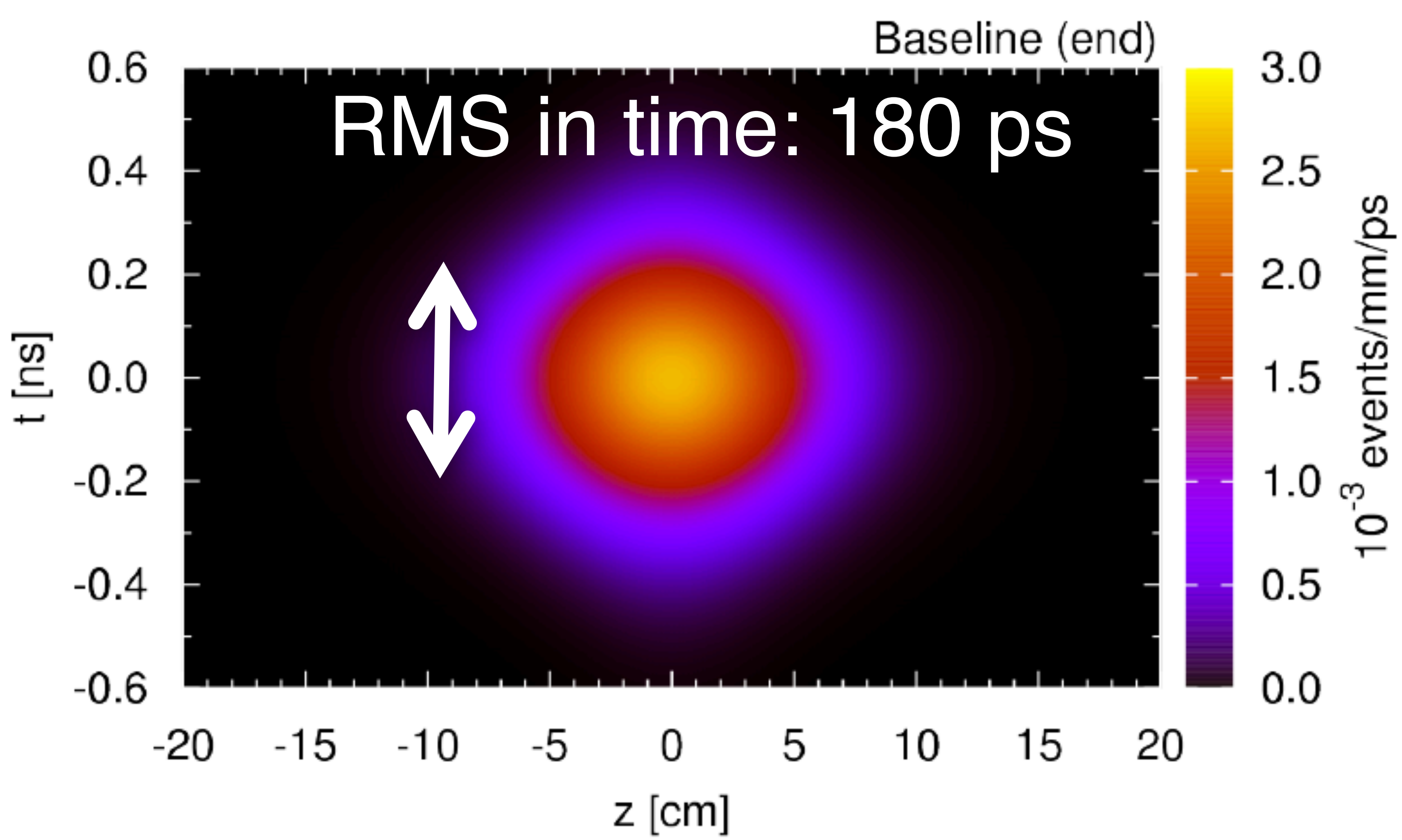
- Due to the increased line density, a larger number of spurious (pileup) tracks are associated to the primary vertex

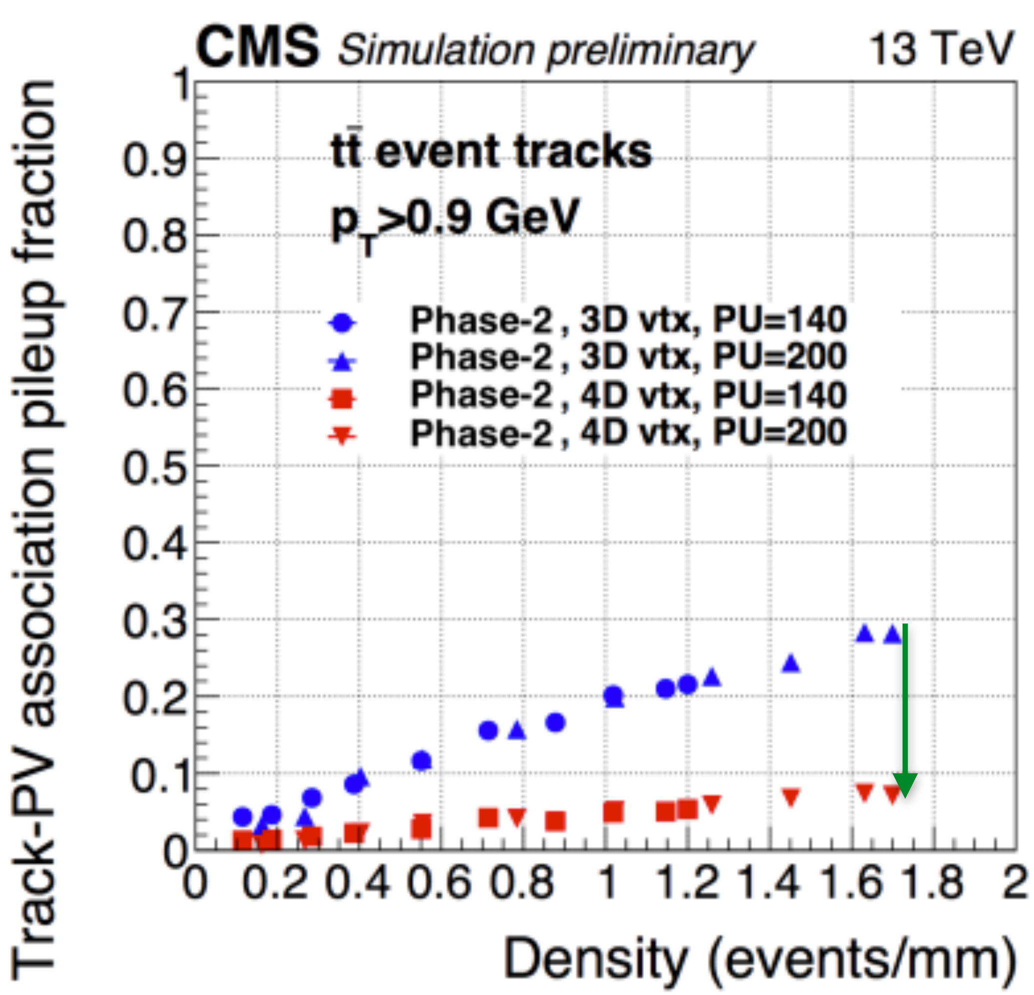
- In the **ultimate** scenario, at the leveled luminosity, 30% of tracks associated to the PV are spurious



Using Precision Timing to Mitigate Pileup

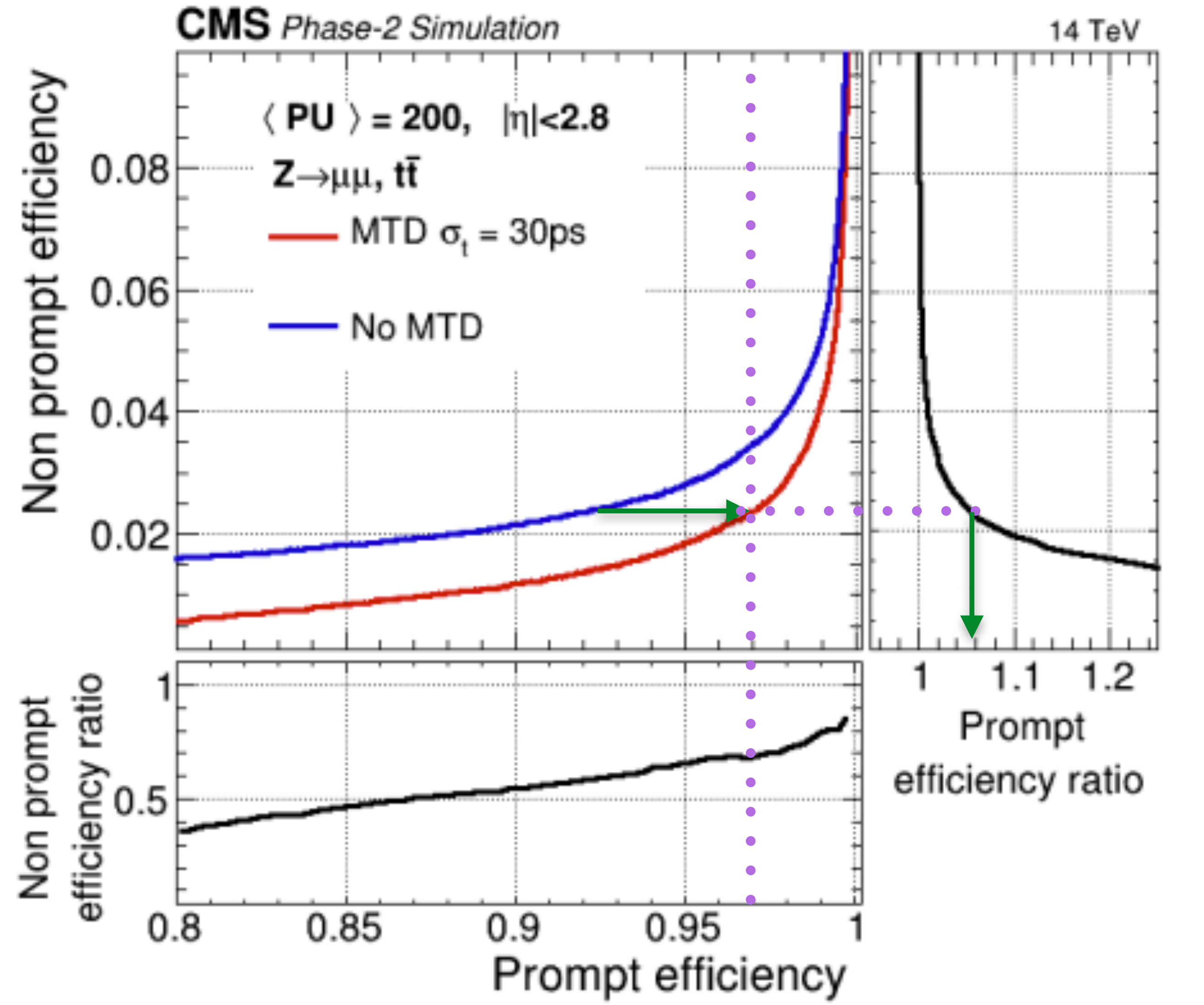
- Time-of-arrival measurement can discriminate between collisions occurring very close in space, but separated in time.
- Suppress spurious track-to-PV association by more than factor of 3





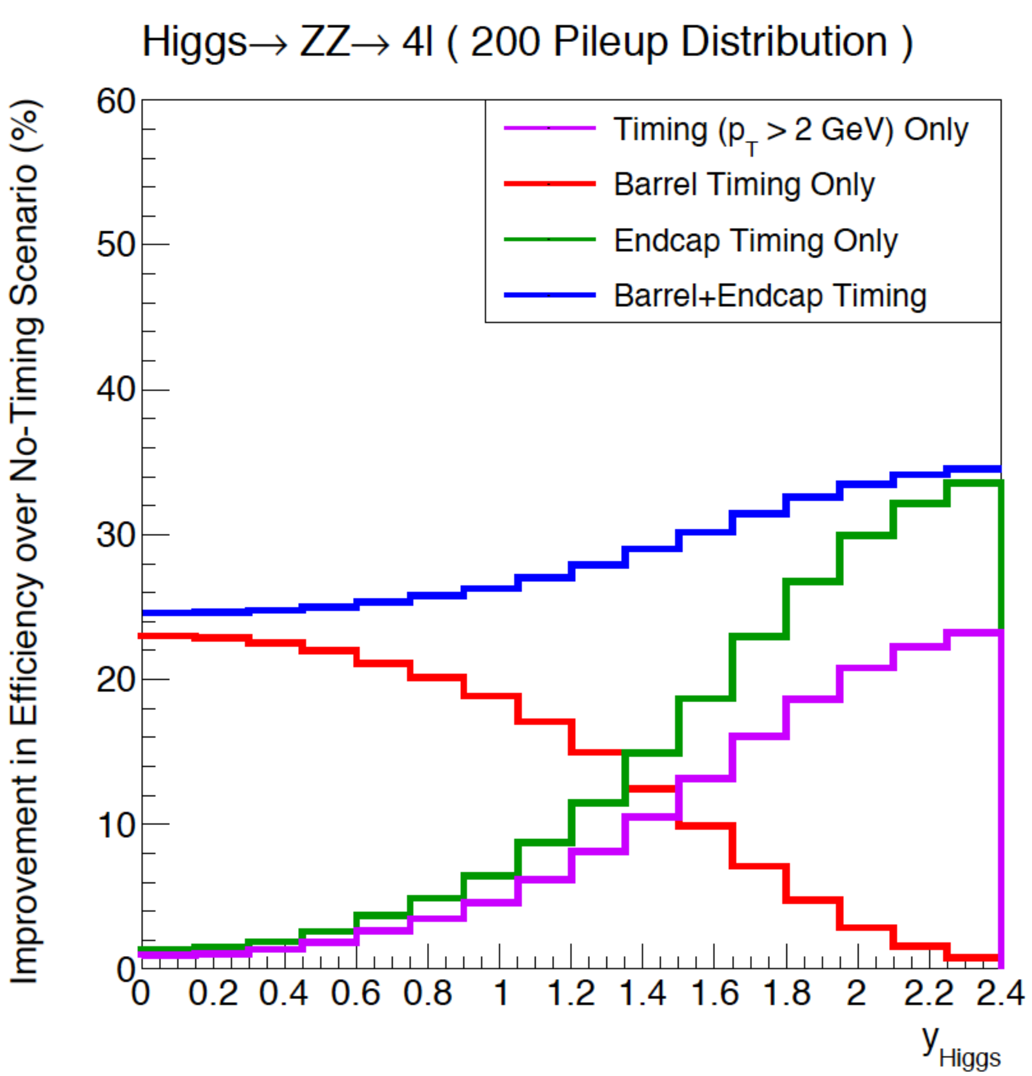
Pileup Mitigation with Timing

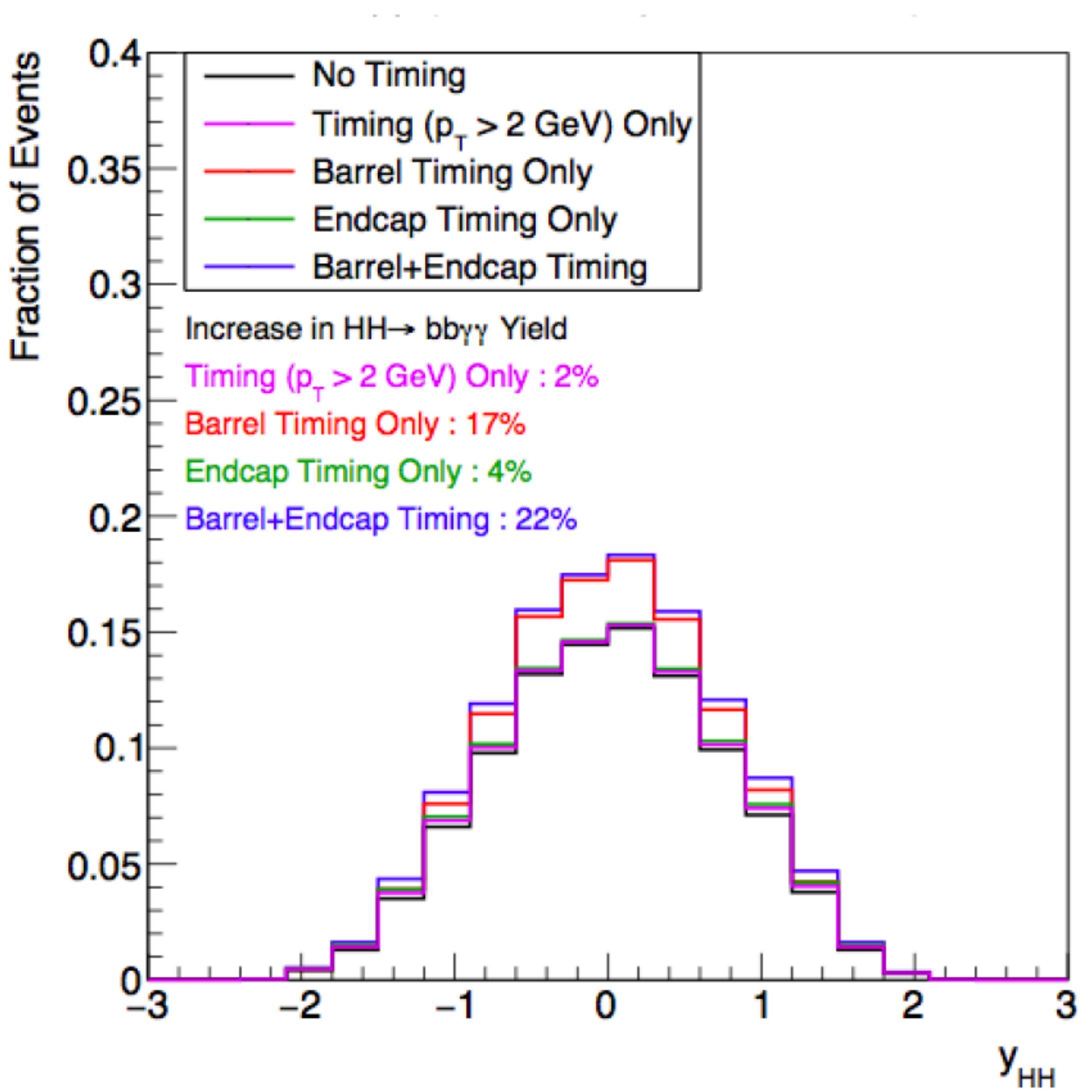
- **Lepton and Photon isolation improves by using timing information**
- At 97% efficiency working point, recover ~6-7% off at the same background rejection
- For precision measurements it's critical to maintain low fake lepton background due to large systematic uncertainties



Significant Impacts on Physics Reach I

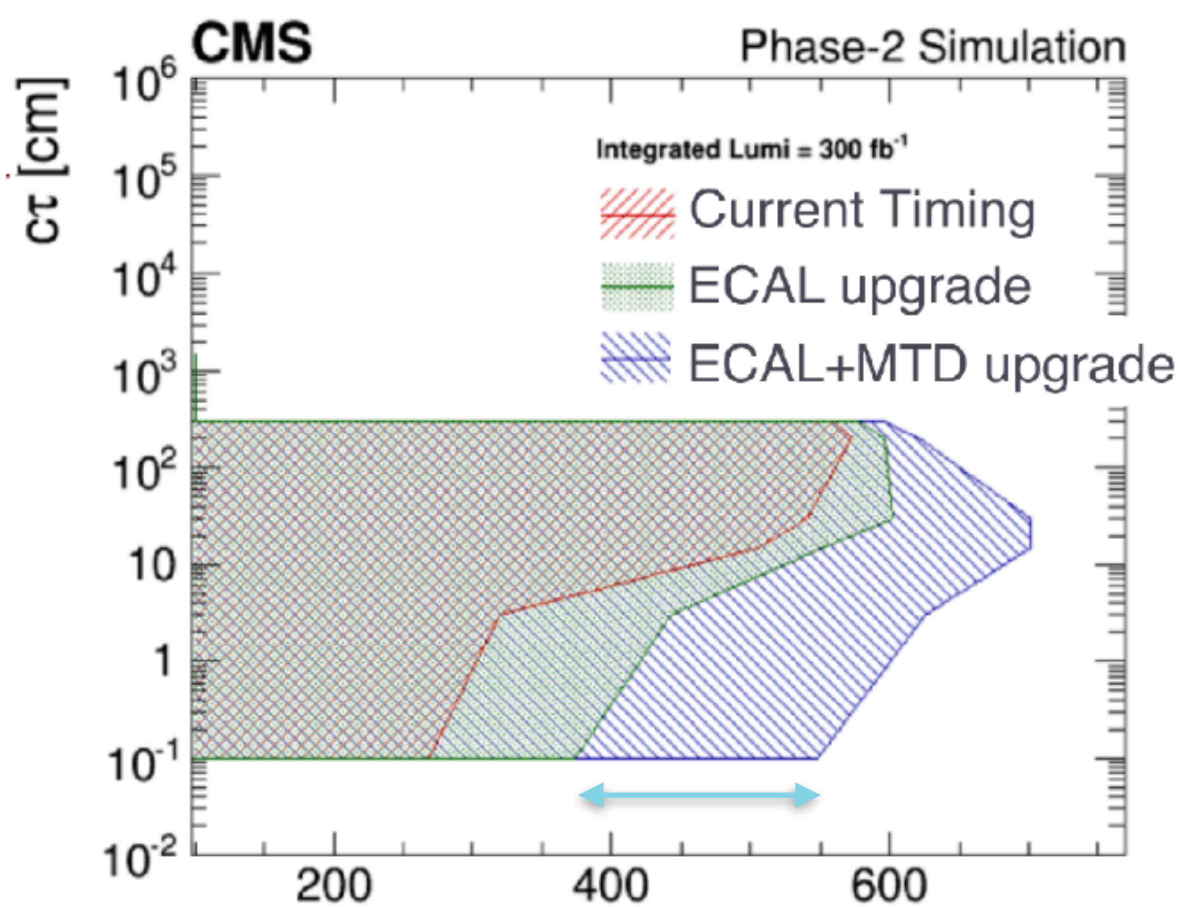
- Significant impact on HL-LHC Higgs program
  - 26% increase in effective luminosity for **H→ZZ→4ℓ**
  - 22% increase in effective luminosity for **HH→bbγγ**
  - 25% increase in effective luminosity for **VBF H→ττ**



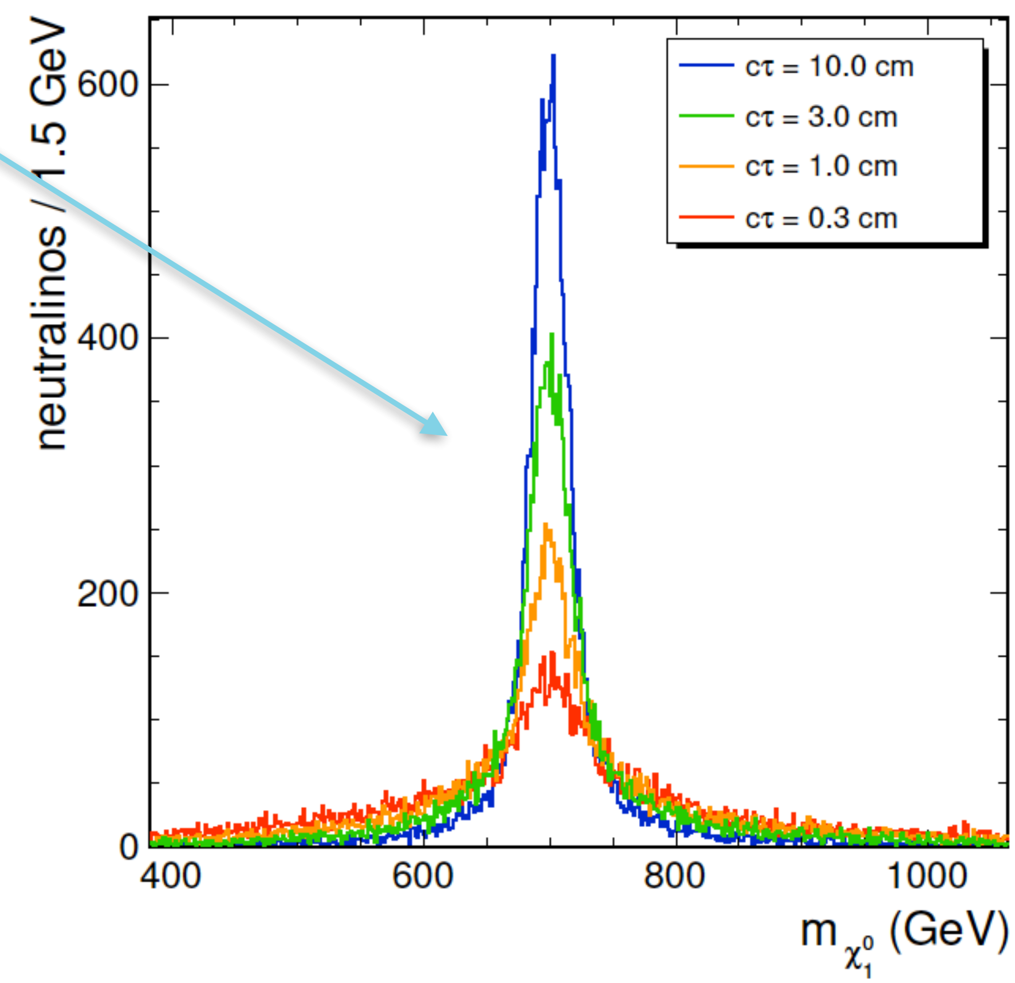


Significant Impacts on Physics Reach II

- New window to probe Long-lived particles.
  - Vertex timing enhances Long-lived particle physics program
  - In topologies involving secondary vertices, **MTD provides a unique handle to reconstruct the mass of the long lived NEUTRAL particles (eg. χ^0)**



(a) $\chi_1^0 \to G + \gamma$ Limits

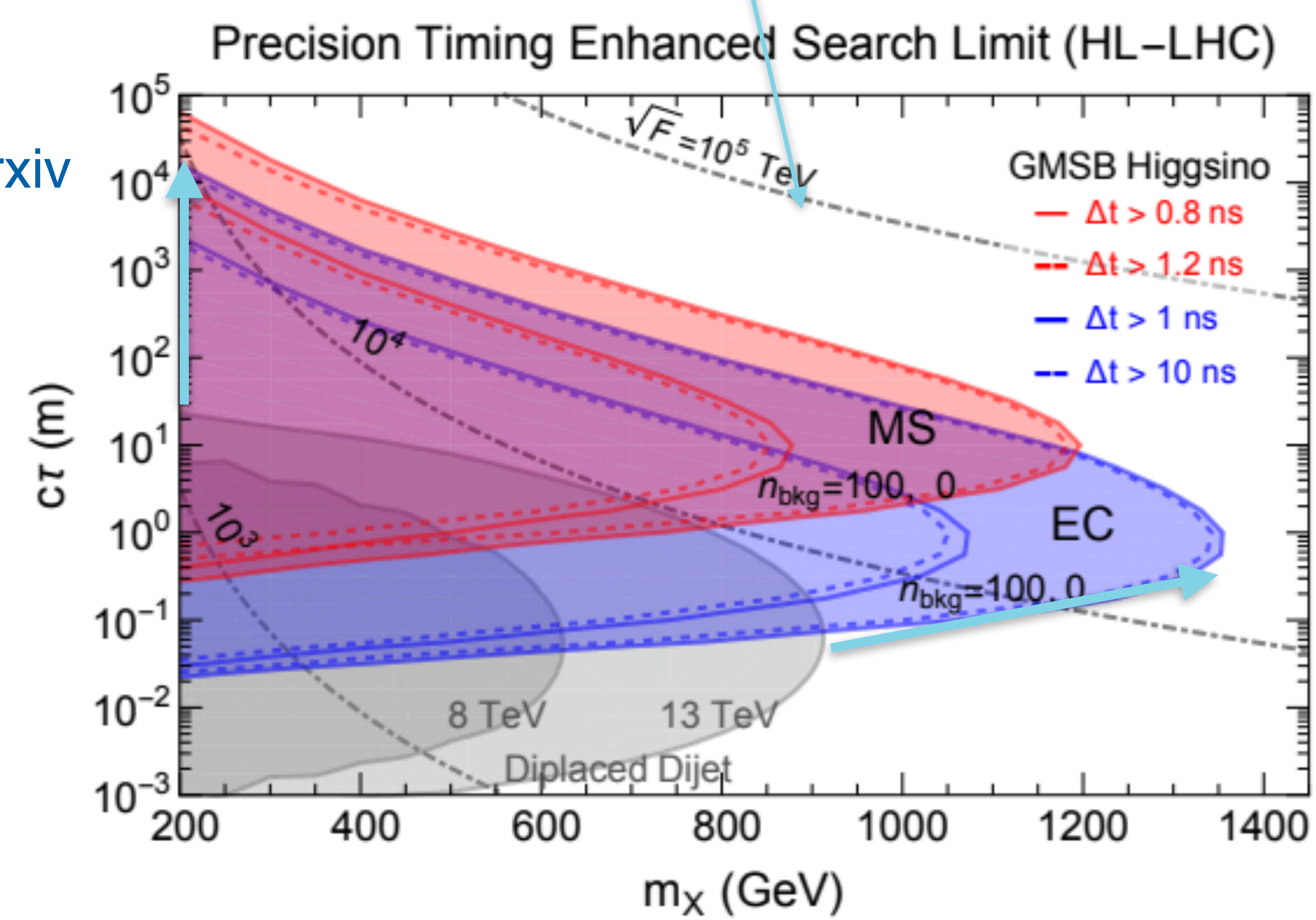


(b) $\chi_1^0 \to G + Z$ Peaking variable

Significant Impacts on Physics Reach III

- New window to probe Long-lived particles.
  - Vertex timing enhances Long-lived particle physics program
  - Using ISR particle to reconstruct vertex time

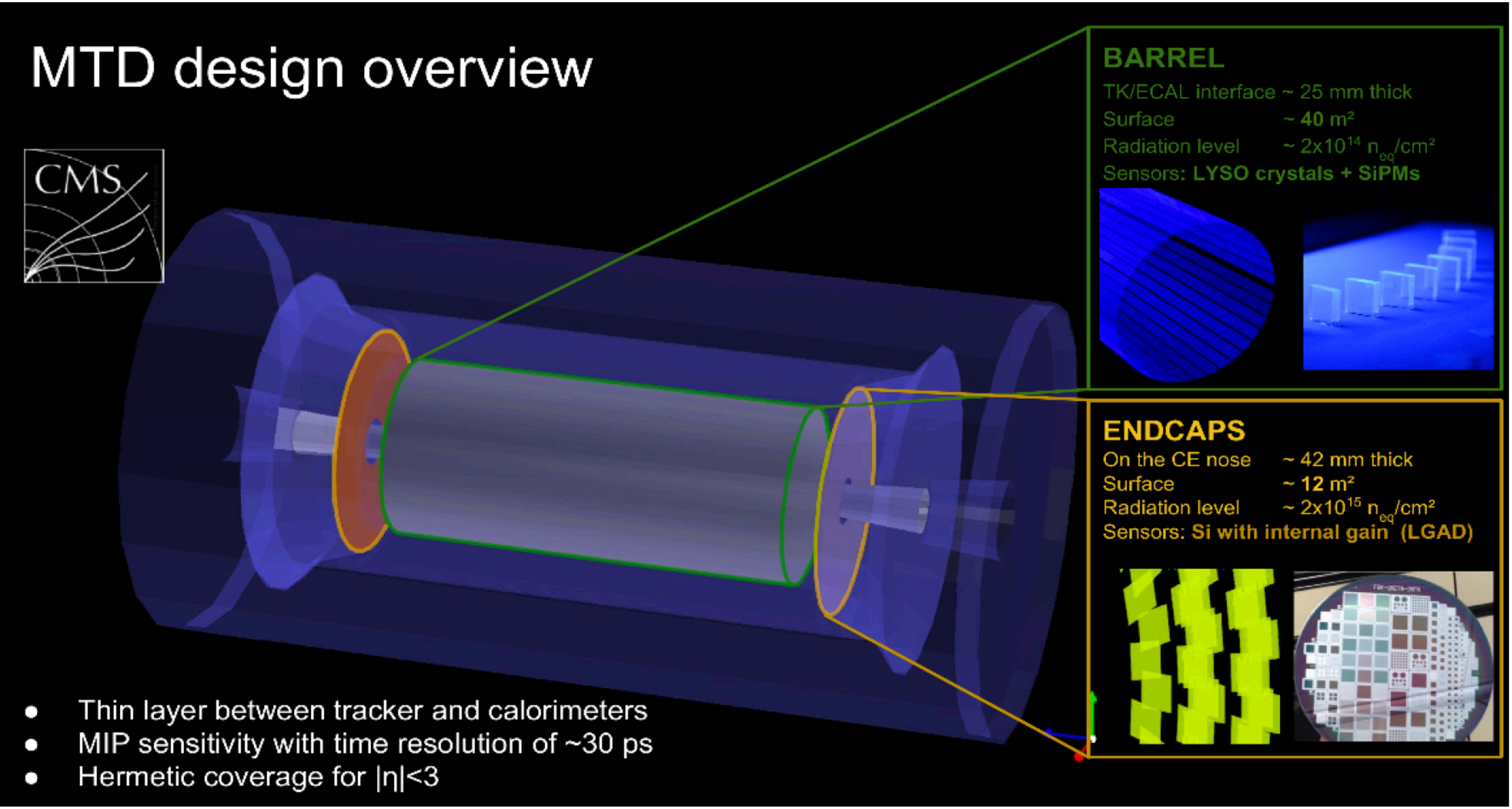
Recent paper in Arxiv



Significant reach Improvement in
- Lifetime
- Mass

Arxiv: 1805.05957 J.Liu, Z. Liu, LT Wang

MTD Design Overview



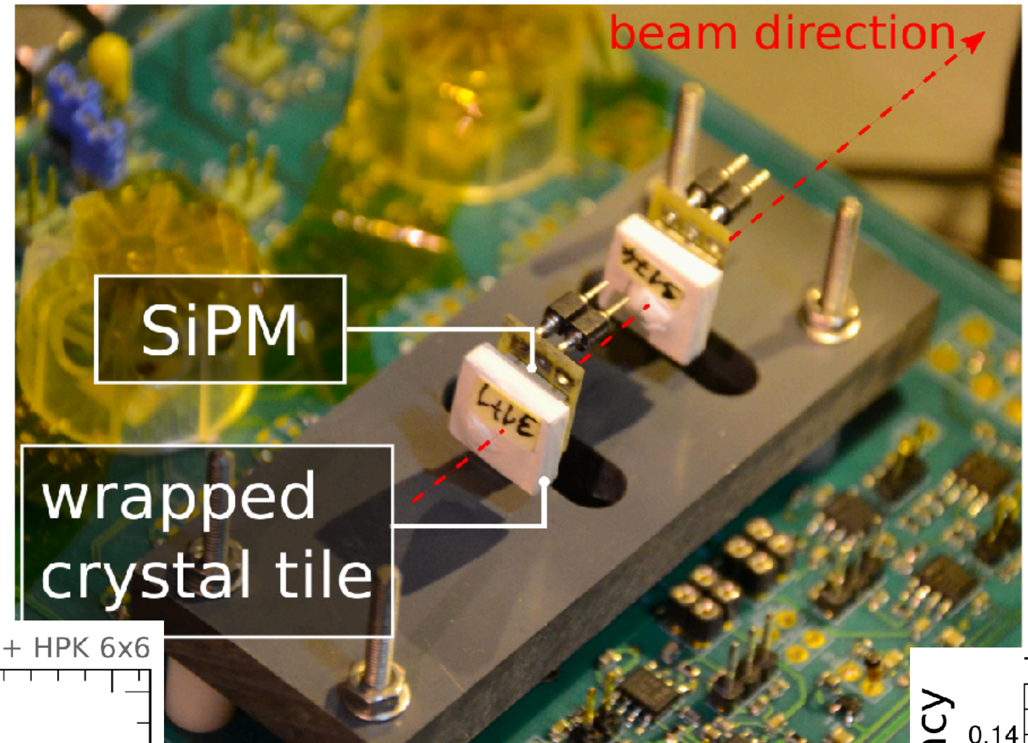
Technology Choice and Considerations

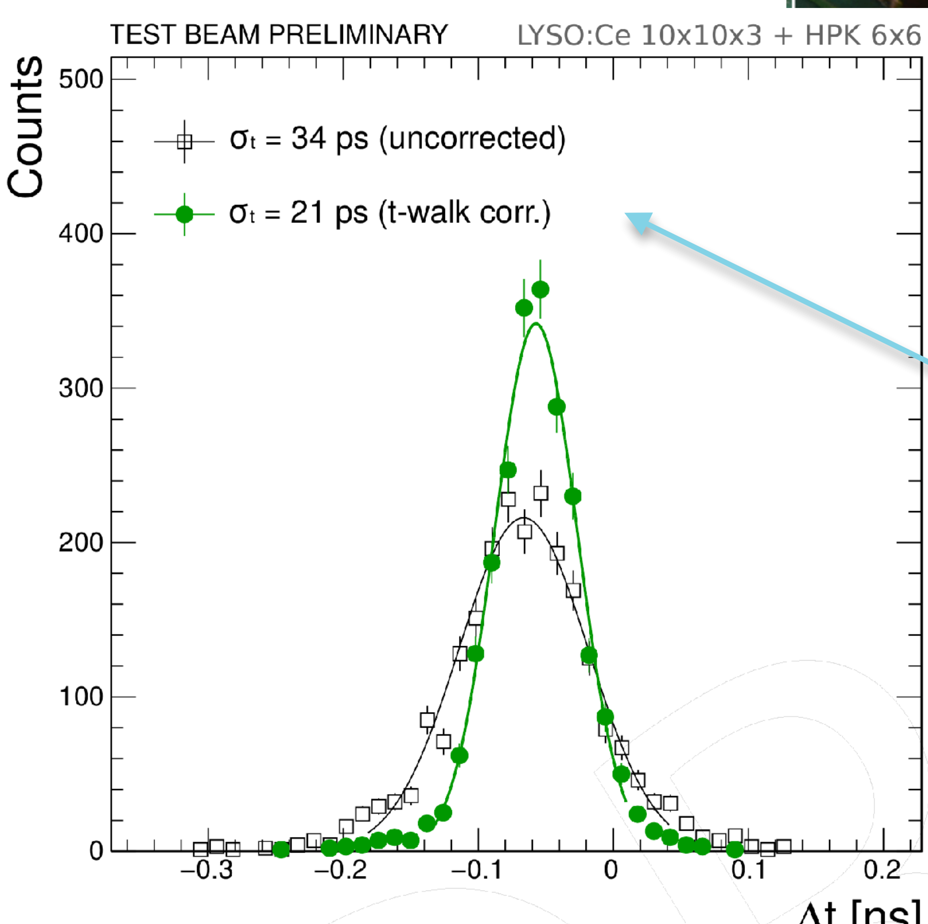
	Barrel LYSO+SiPM	Endcap LGAD
Coverage	$\|\eta\| < 1.5$	$1.5 < \|\eta\| < 3.0$
Surface Area	$\sim 36.5\ m^2$	$\sim 12\ m^2$
Power Budget	$\sim 0.5\ kW/m^2$	$\sim 1.8\ kW/m^2$
Radiation Dose	$\leq$ 2e14 neq/cm^2	$\leq$ 2e15 neq/cm^2
Installation Date	2022	2024

- Barrel Timing Layer (LYSO+SiPM)
  - Larger surface area
  - Lower radiation dose
  - Mature readout ASIC technology
- Endcap Timing Layer (LGAD)
  - Larger radiation dose
  - More flexible installation schedule → time for R&D
  - R&D synergies with ATLAS

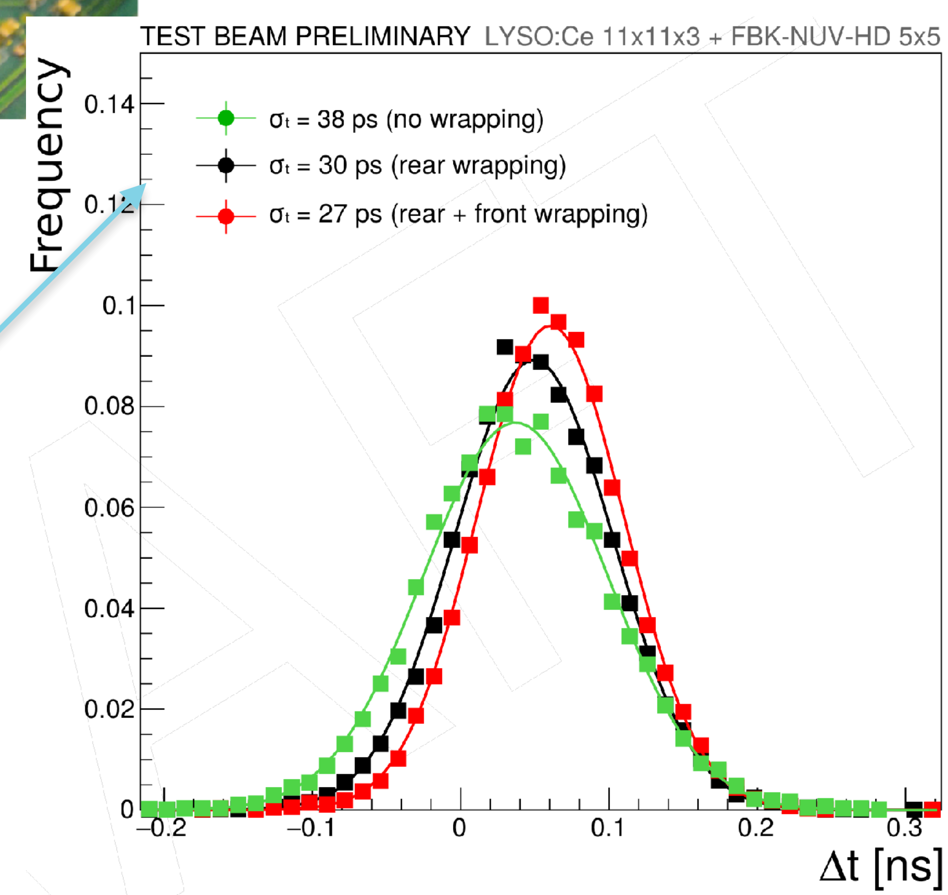
BTL Sensor Performance

Single sensor performance requirement demonstrated

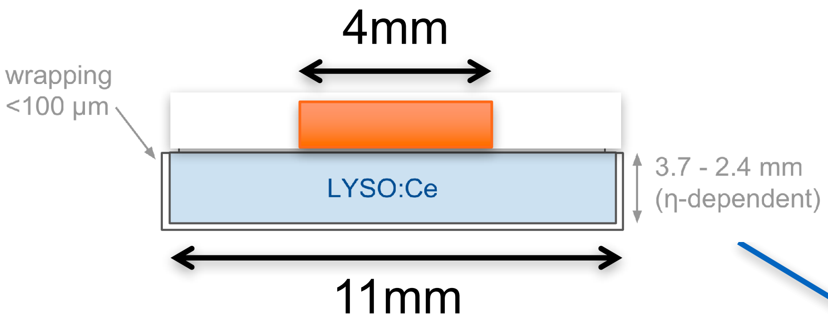




30 ps resolution demonstrated

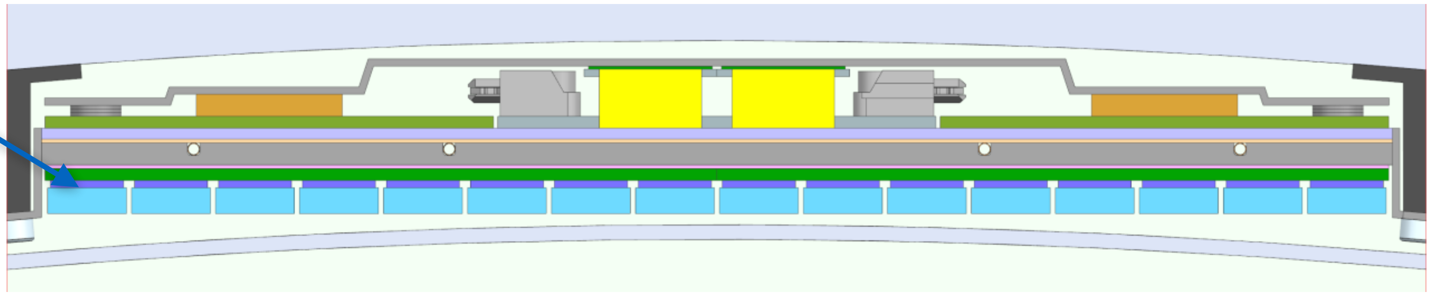


Barrel Timing Layer Design

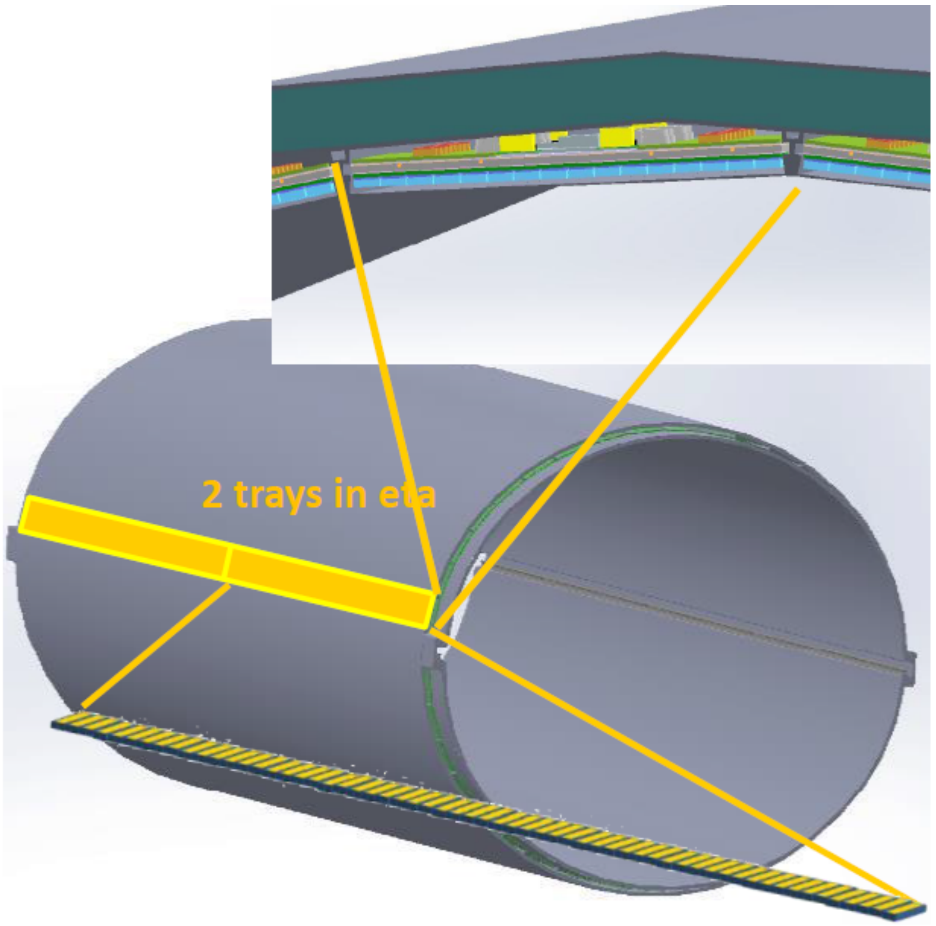


- 11.5x11.5 mm² LYSO tiles
- 4x4 mm² SiPM
- 250k channels

r-ϕ plane



BTL tray in the rails of the tracker support tube (TST)

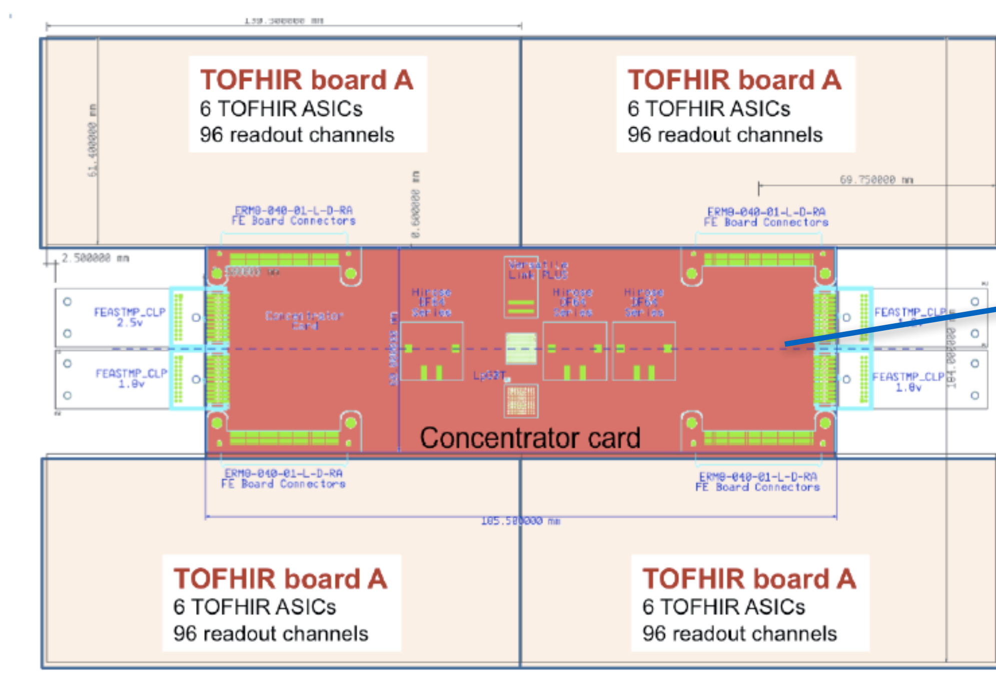


- CO_2 cooling
- Fully tested trays (20 kg) inserted into TST

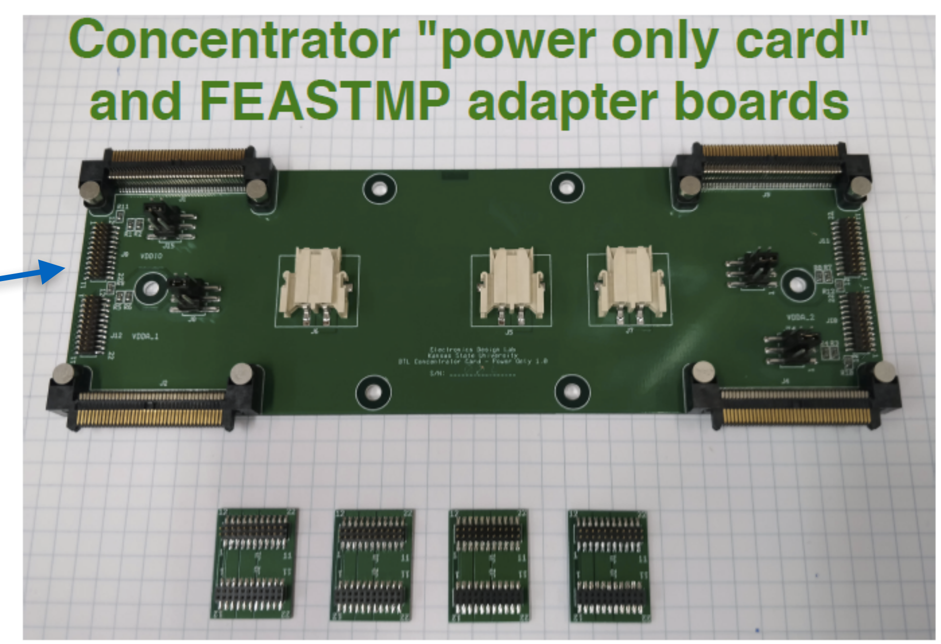
Barrel Timing Layer Electronics

- **TOFHIR ASIC:**
  - Overall chip integration close to finalization
- **Front-end boards:**
  - Engineering design of readout units boards concluded
  - Concentrator card and adapter board at hand
- **Front-end board demonstration:**
  - Nov: board assembled with chip
  - 2019 Q1: board fully validated

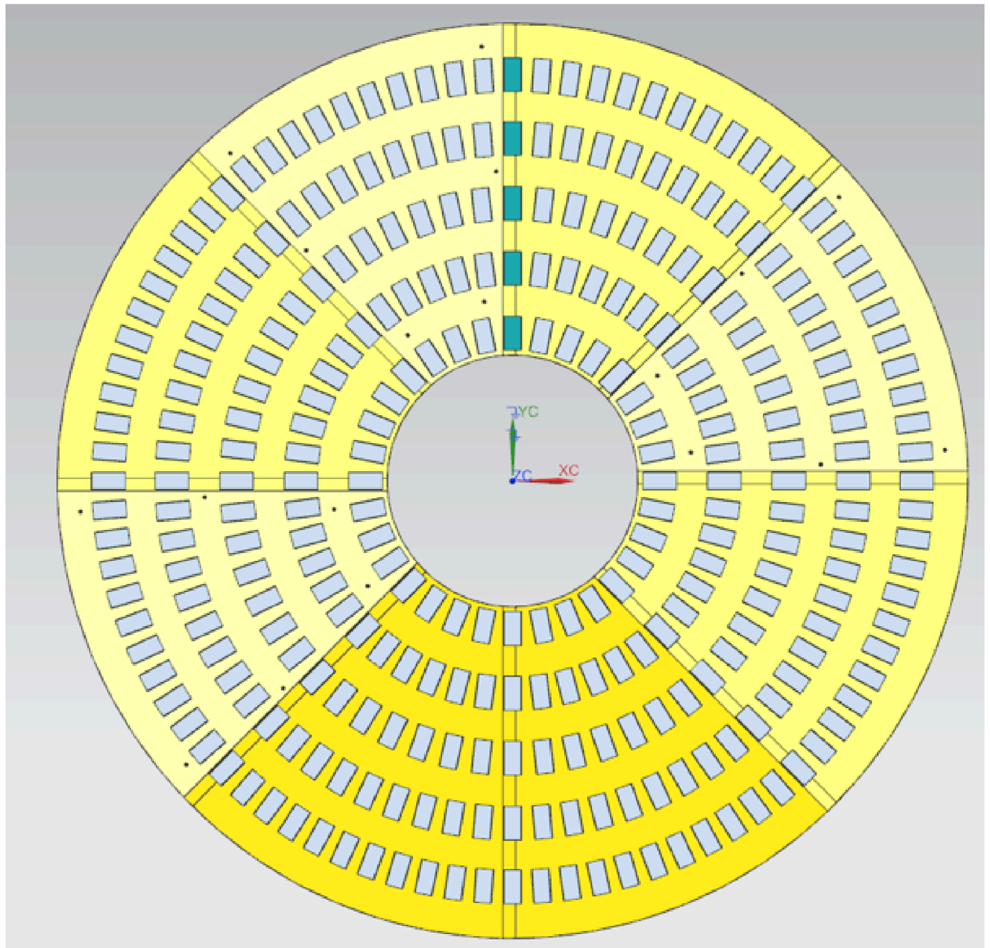
Readout Unit Concept



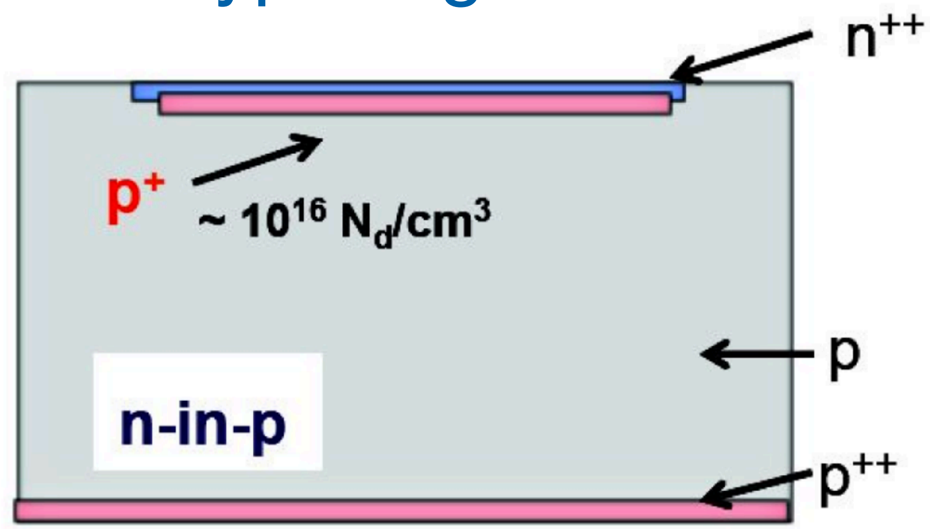
Readout channels: 384   Size: 184 mm x 279 mm

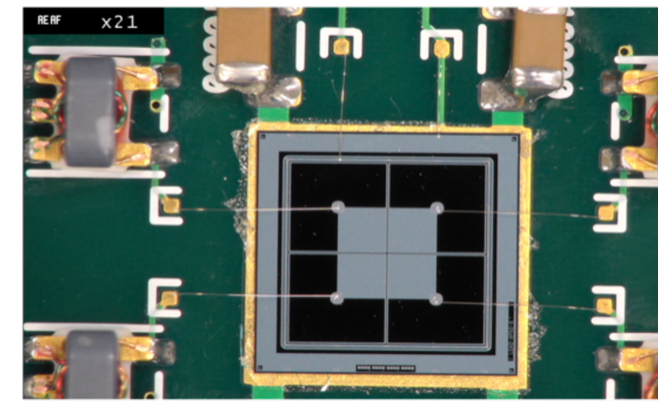


Endcap Design



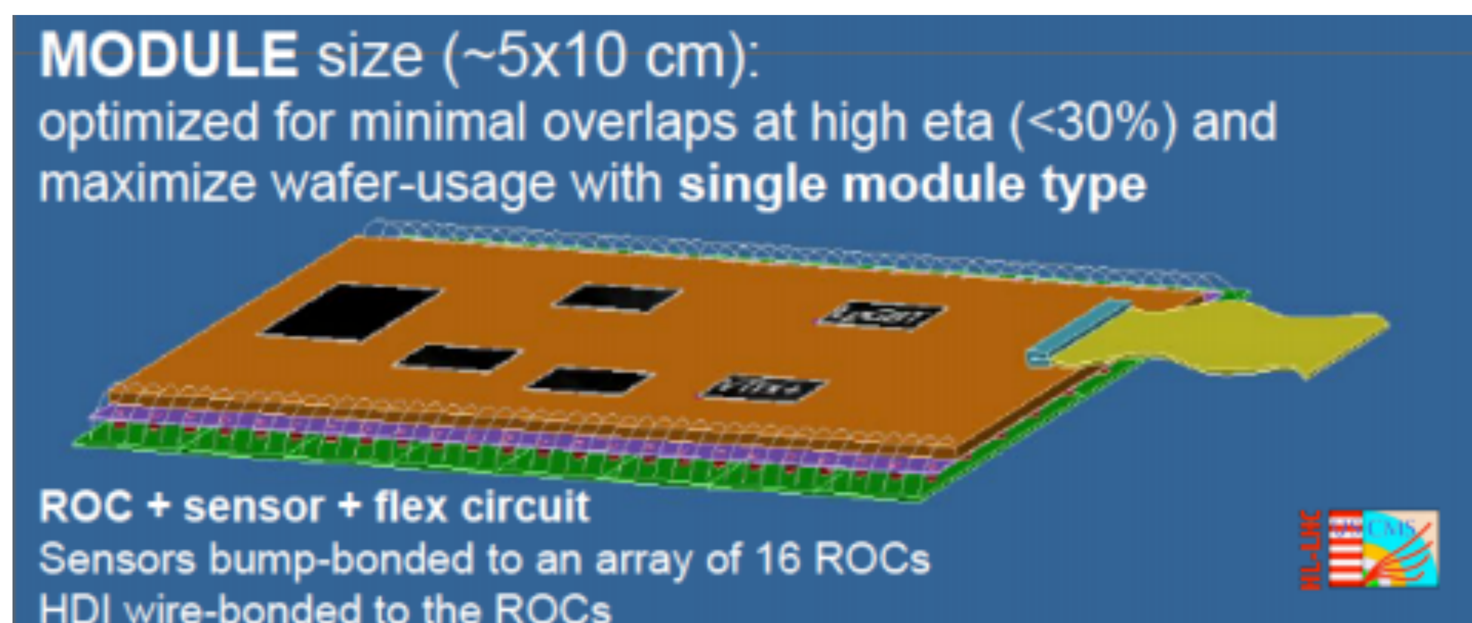
- Low-gain avalanche diode (LGAD) are silicon sensor with a special avalanche gain-layer
  - Typical gain: 10-30





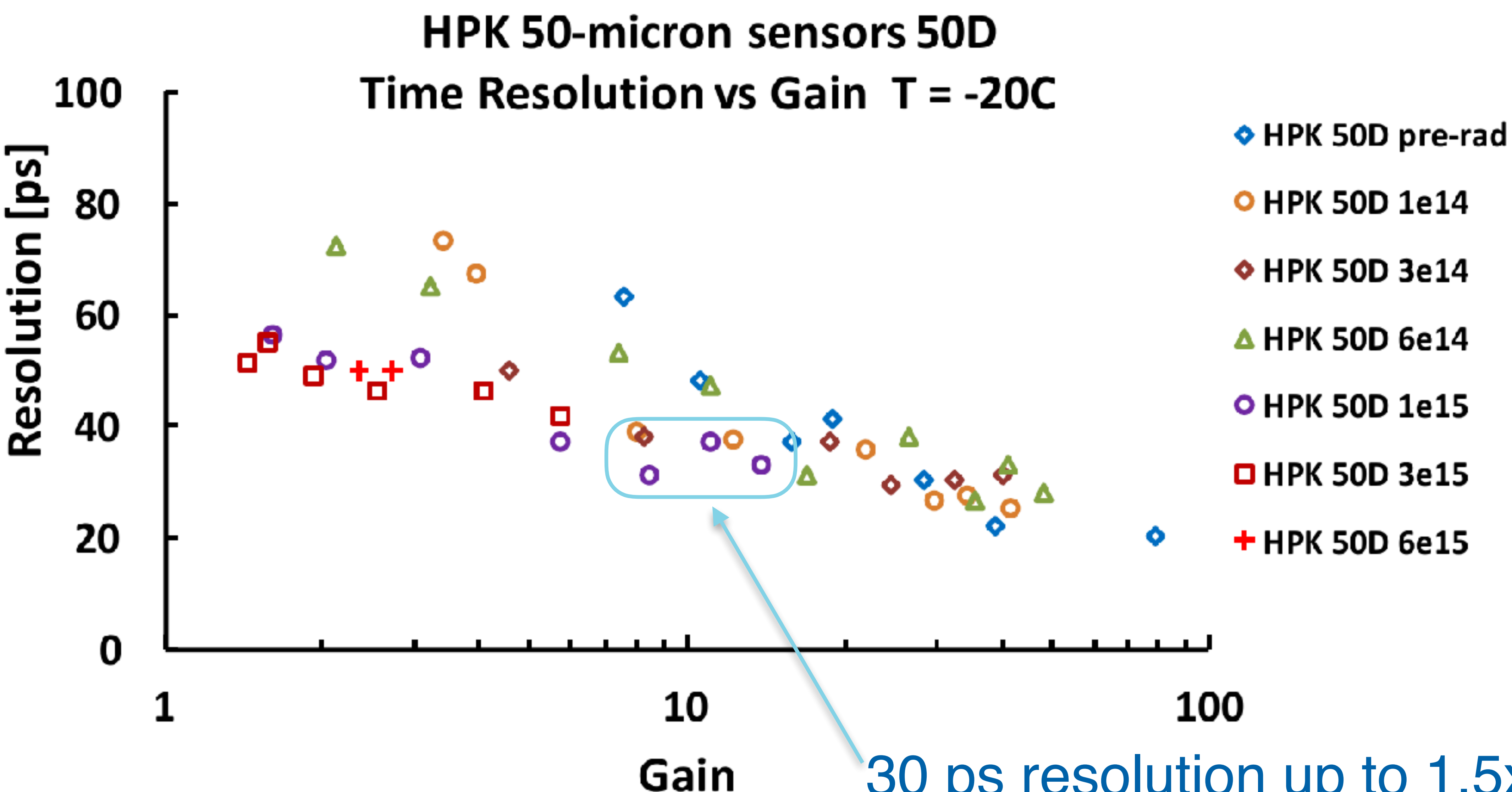
- Overlapping disk structure

- 1x3 mm² sensor channels
- Total 1.8 M channels



ETL Sensor Performance

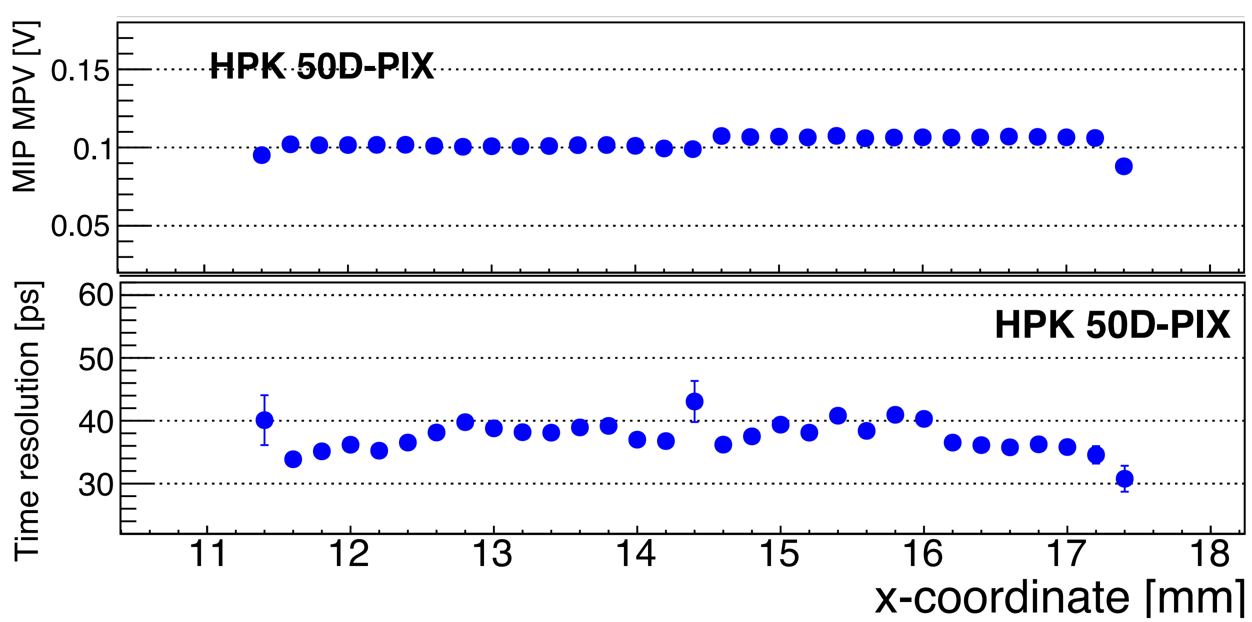
- Target performance has been achieved for sensors irradiated up to fluence of 1.5×10^{15} eq. neutrons

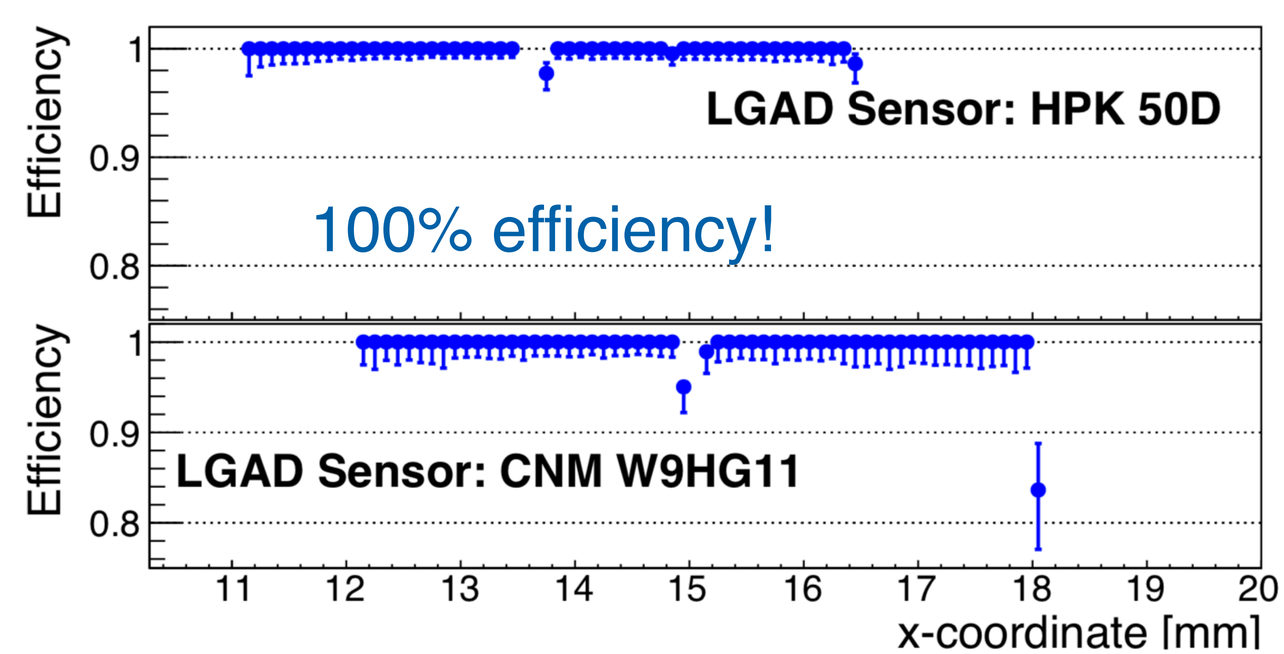


30 ps resolution up to 1.5×10^{15} demonstrated

Sensor performance

- Target performance has been achieved for sensors irradiated up to1.5x10[15] eq. Neutrons
- Sensor uniformity precisely measured. Meets specification
- Efficiency ~100%

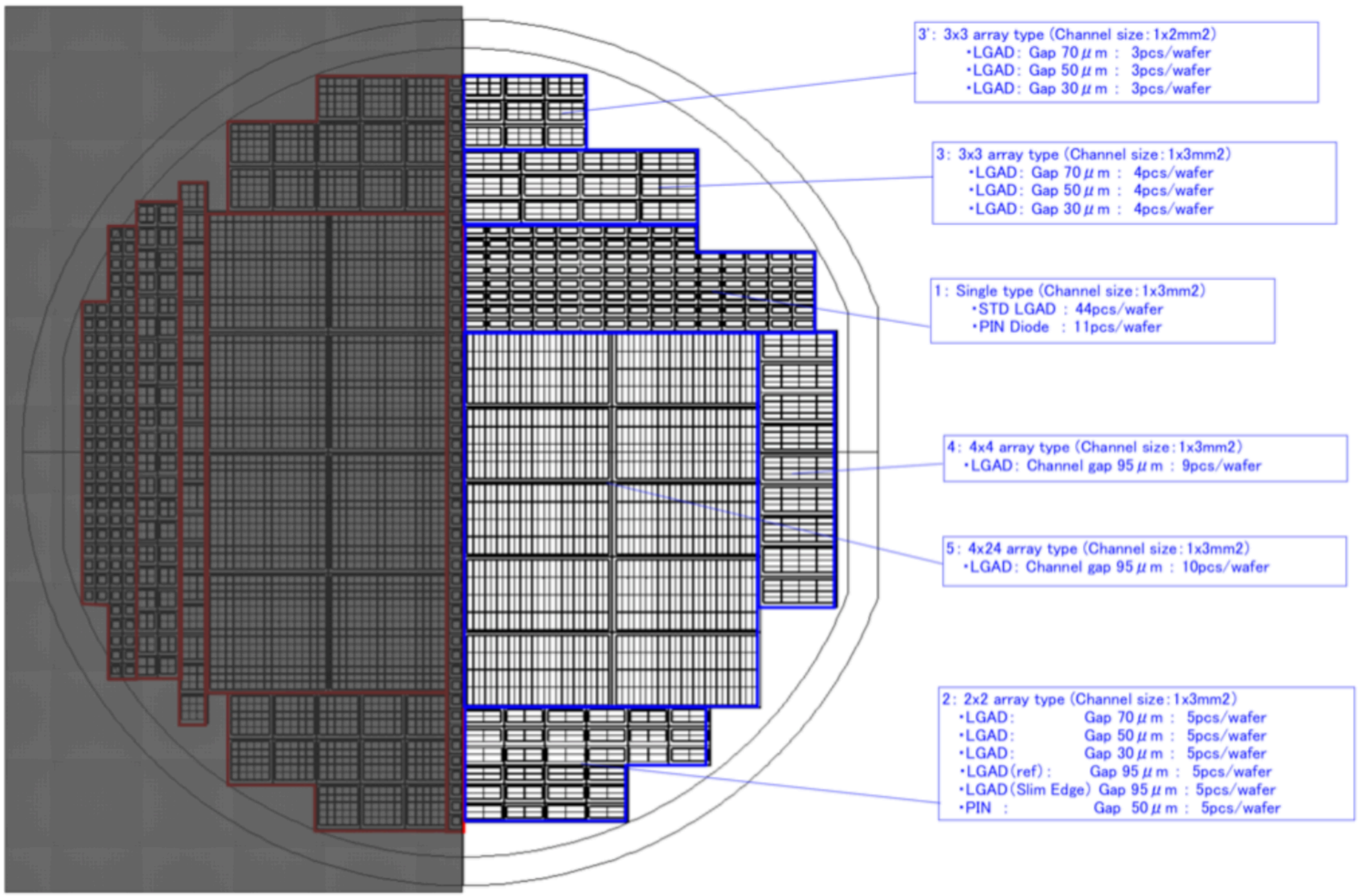




ETL Sensor R&D

- New Production addressing:
  - Increased radiation tolerance
  - Large sensor production
  - Improved fill factor

Conceptual design of HPK mask



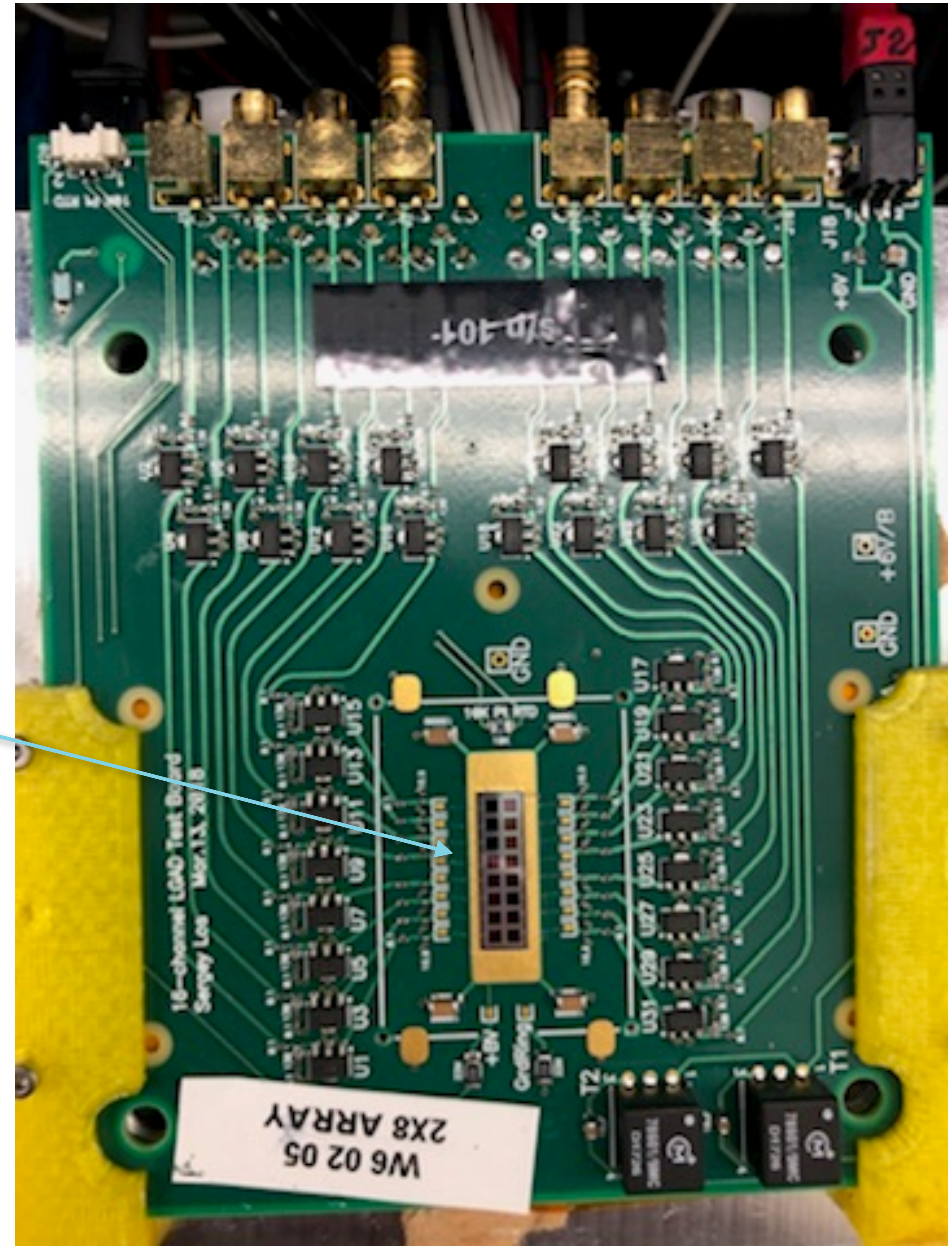
FBK and CNM

They are also underway

ETL Sensor R&D

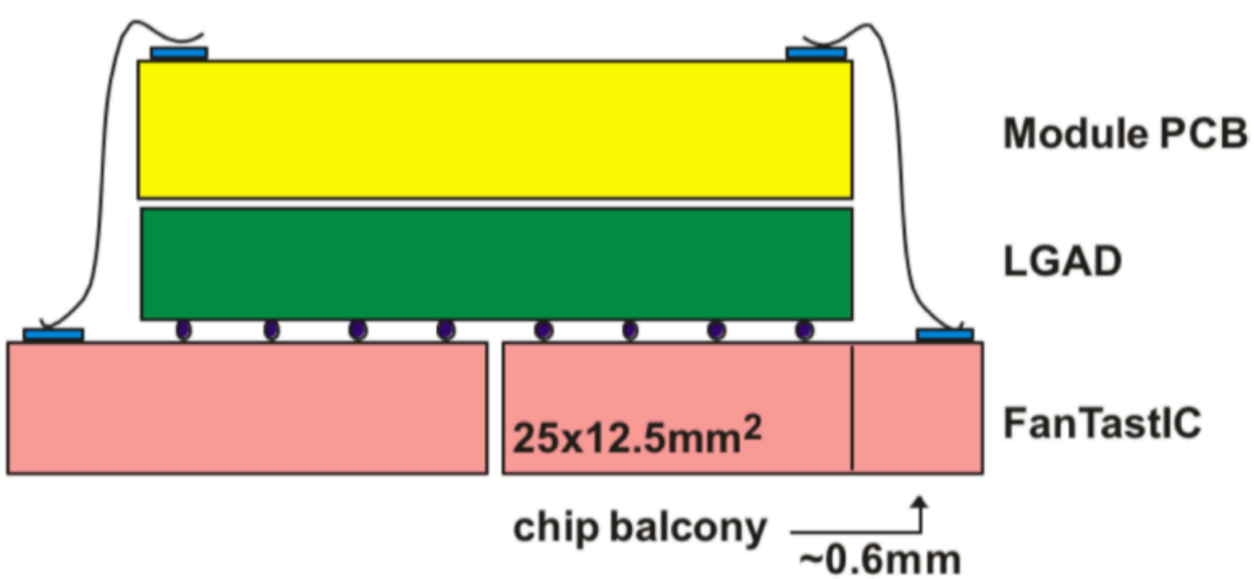
- New Production addressing:
  - Increased radiation tolerance
  - Large sensor production
  - Improved fill factor

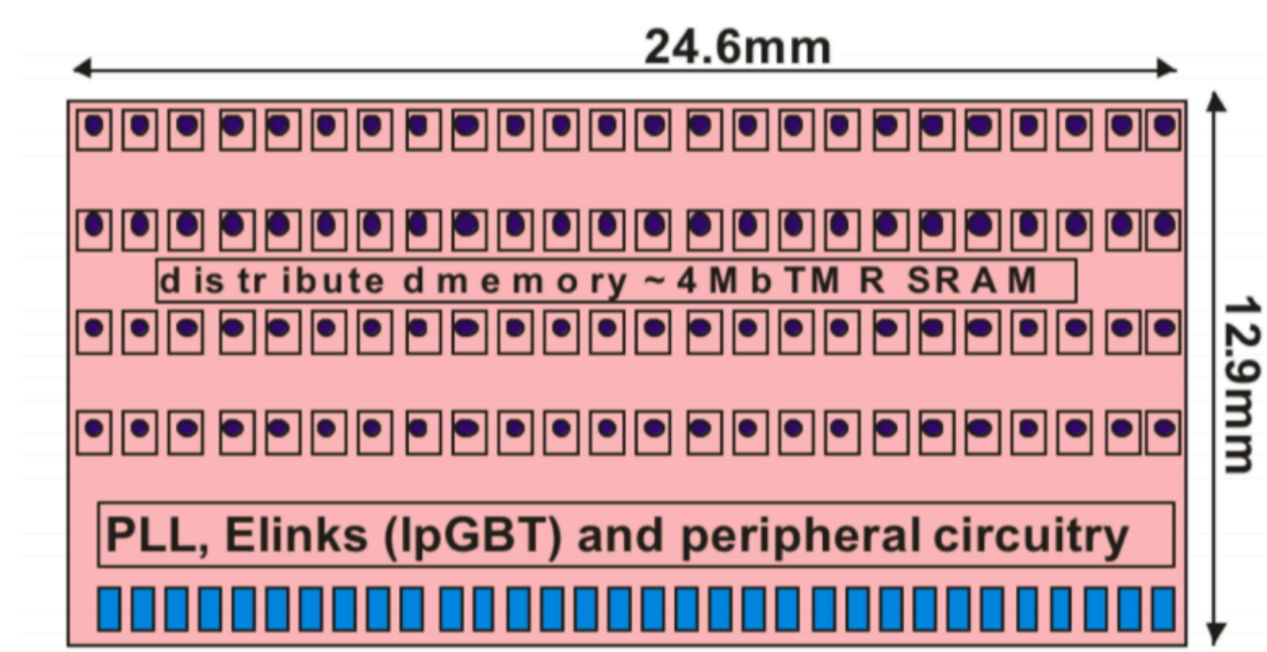
NEW sensor to be test at FNAL
In a few weeks



ETL R&D: ASIC and readout

- **One chip is matrix of ~100 LGAD pixels:**
  - Measurement of Time-of-Arrival in every pixel within 25 ns LHC BX with 30 ps time resolution for the whole system.
- **Chip development lead by Fermilab:**
  - TSMC 65nm: experience, library, rad. dam. models from RD53
  - Ongoing design study of the preamp and CFD implementation
  - Exploring the possibility of common developments with ATLAS





Summary

- CMS MIP Timing Detector will significantly improve detector capabilities and expand physics reach for the HL-LHC program
  - 20-25% effective luminosity increase in crucial Precision Higgs Measurements
  - Expands reach for BSM searches using MET
  - Enables new capability to probe long-lived particles
- Project is significantly advanced.
  - Sensor performance close to specification
  - ASIC and Integration efforts ongoing
- Progress on sensor R&D, beam tests, and engineering design.
  - Optimize sensors to ensure 30 ps time resolution throughout the HL-LHC run

SiPM R&D

R&D advancing on SiPMs to improve light collection efficiency and uniformity

- Large Area Sparse SiPM
- Ordered:
  - 25 of 20µm pitch
  - 25 of 15µm pitch
  - 10 assembled with 11.5x11.5 crystal
- Delivery in Sept 2018