Performance of CMS Endcap Precision Timing Sensors

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On behalf of the CMS Collaboration

University of Kansas

Workshop on Forward Physics and QCD at the LHC, the Future Electron Ion Collider, and Cosmic Ray Physics

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Outline

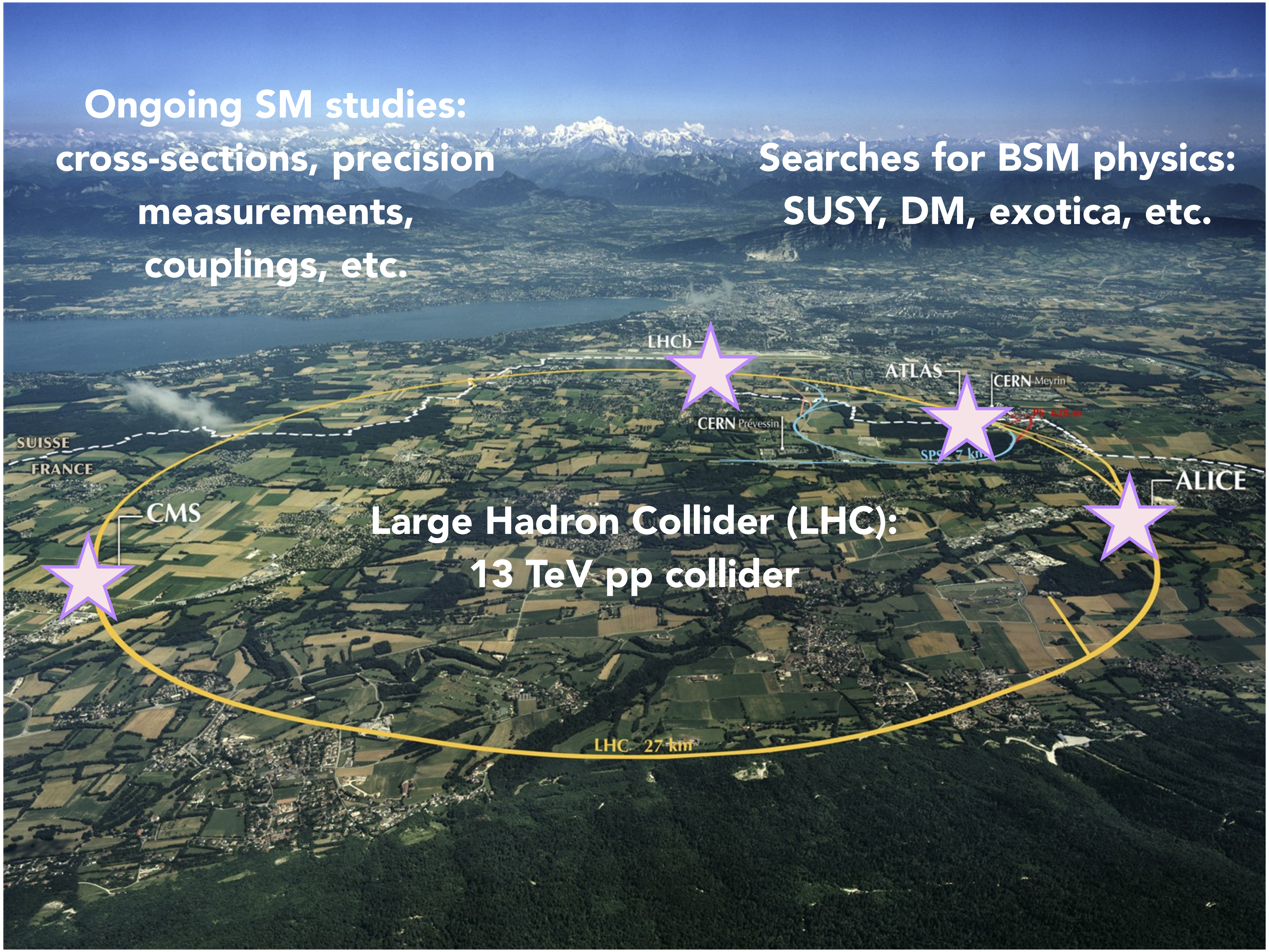
Introduction: LHC, HL-LHC, and the CMS Experiment

Precision Timing and the MIP Timing Detector (MTD)

Endcap Timing Layer

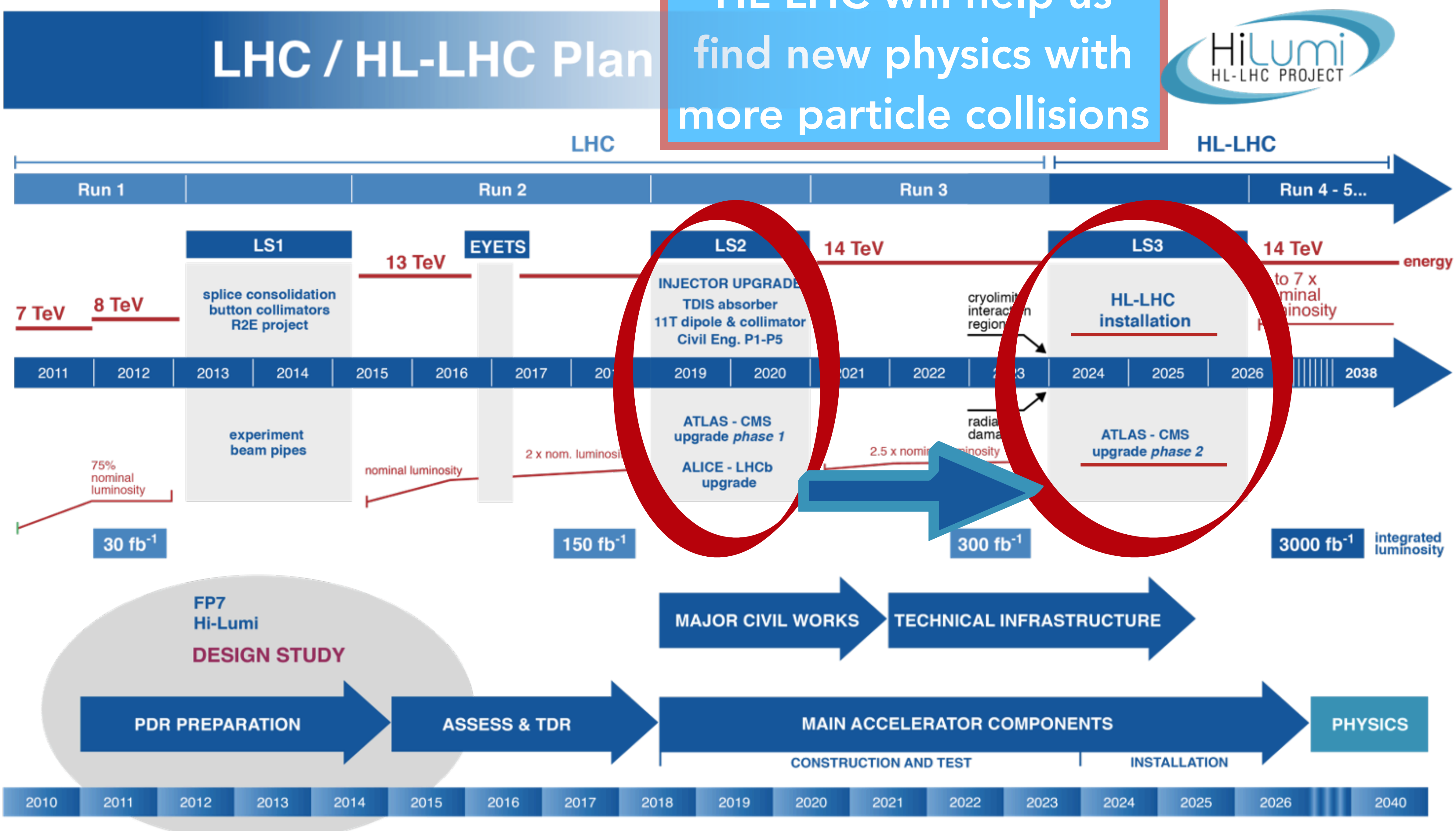
Sensor Performance Requirements and Results

Physics at the LHC

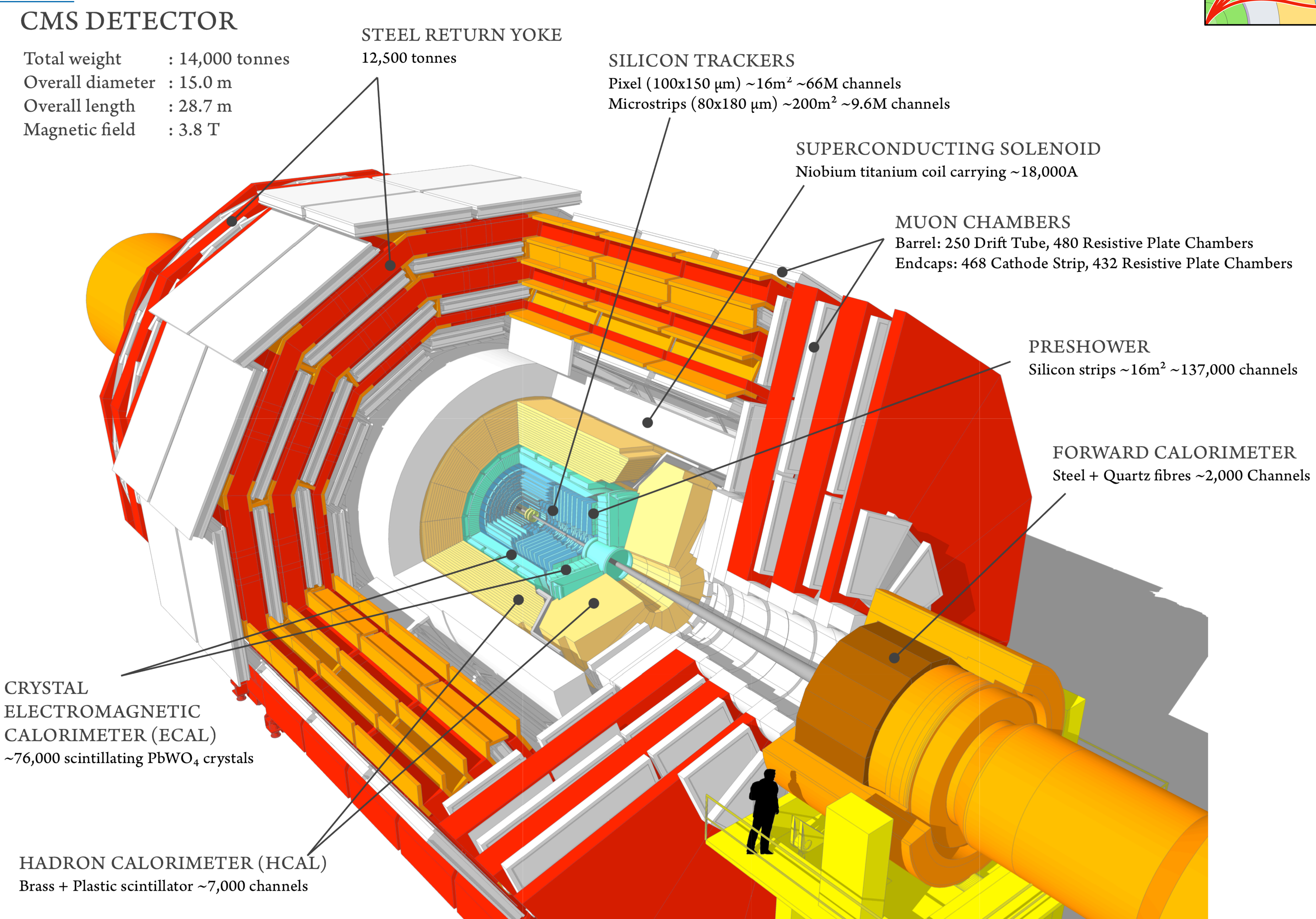


High Luminosity LHC

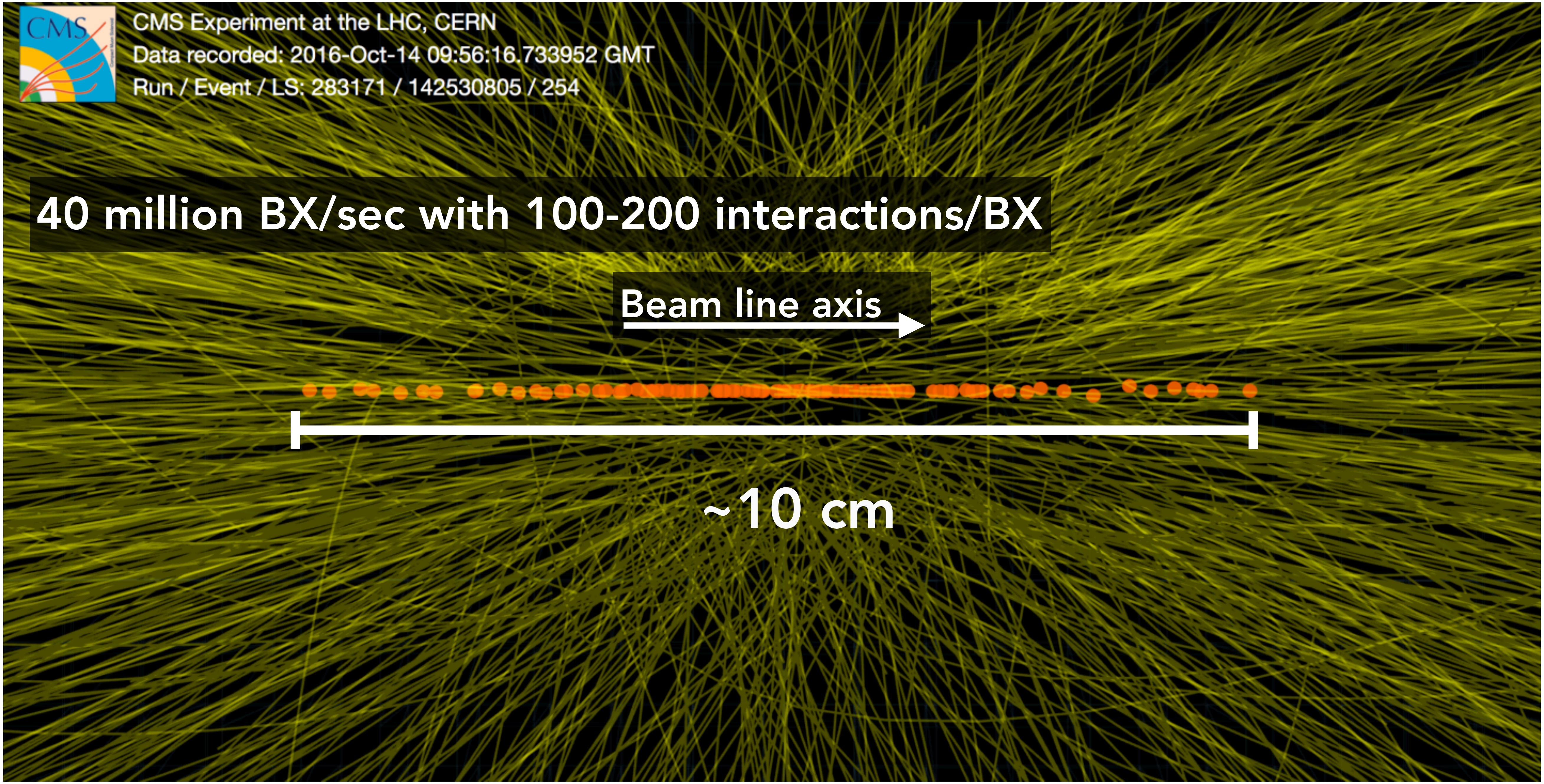
HL-LHC will help us find new physics with more particle collisions



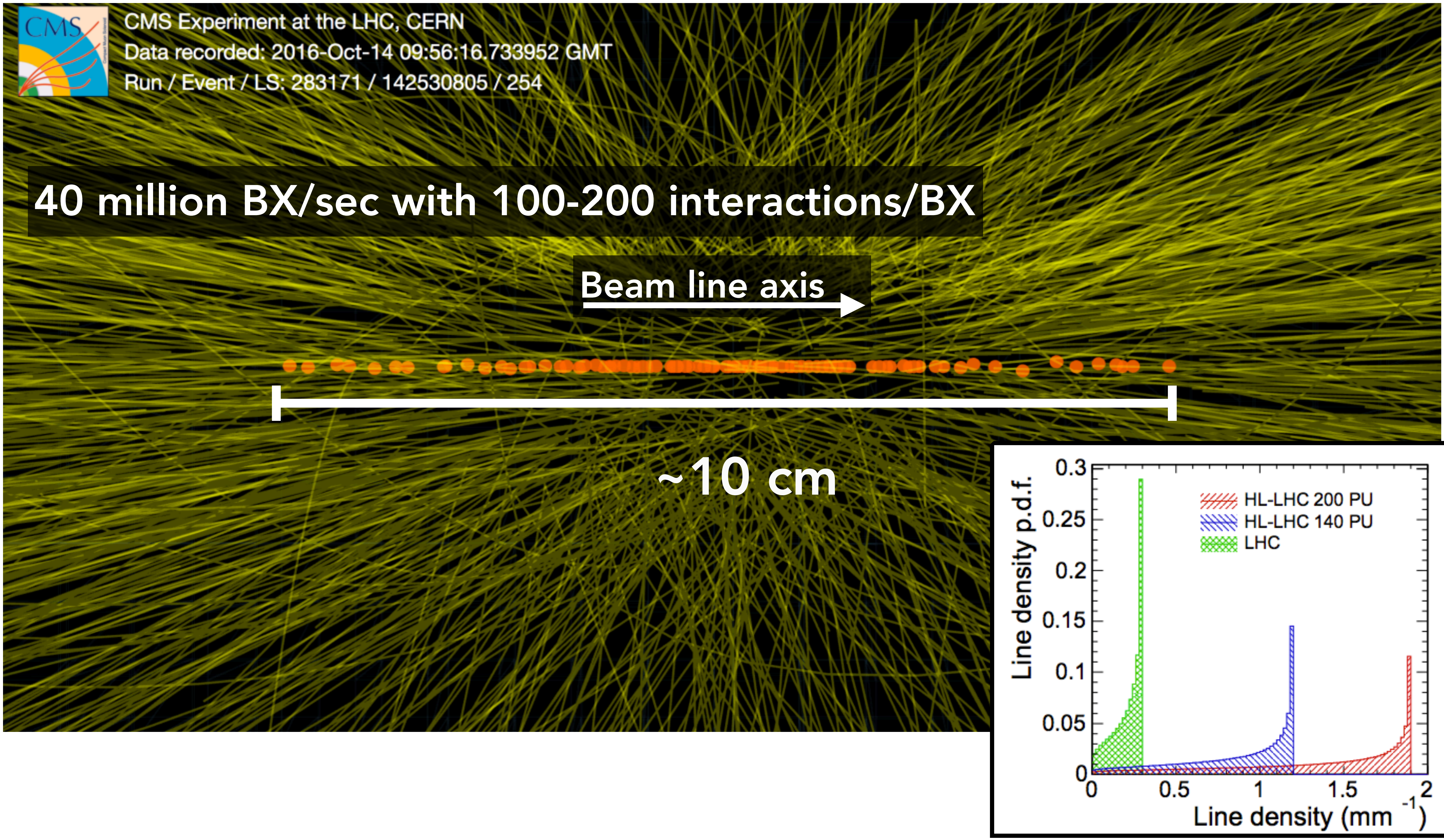
Compact Muon Solenoid (CMS)



Pileup Increase with HL-LHC

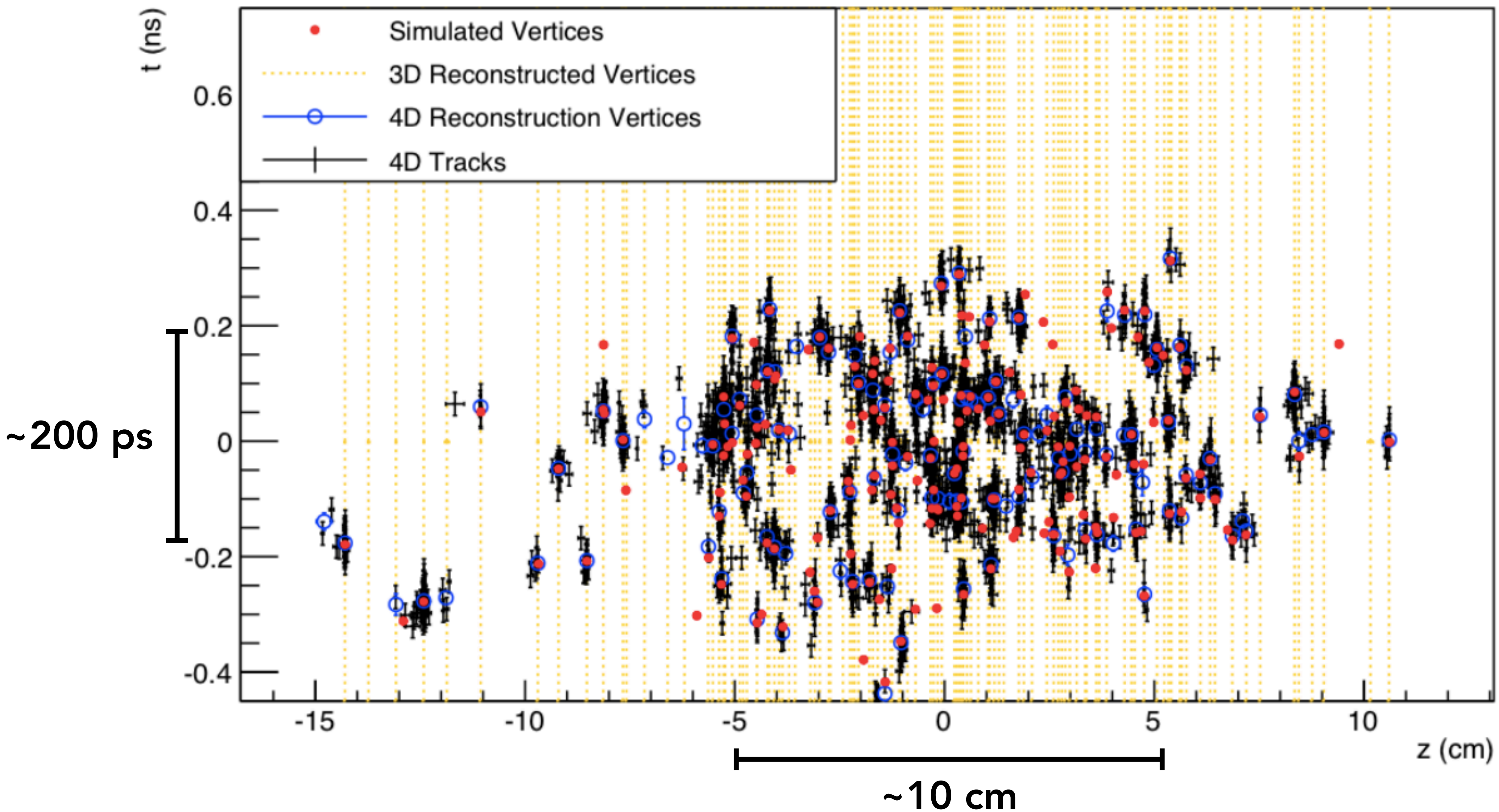


Pileup Increase with HL-LHC

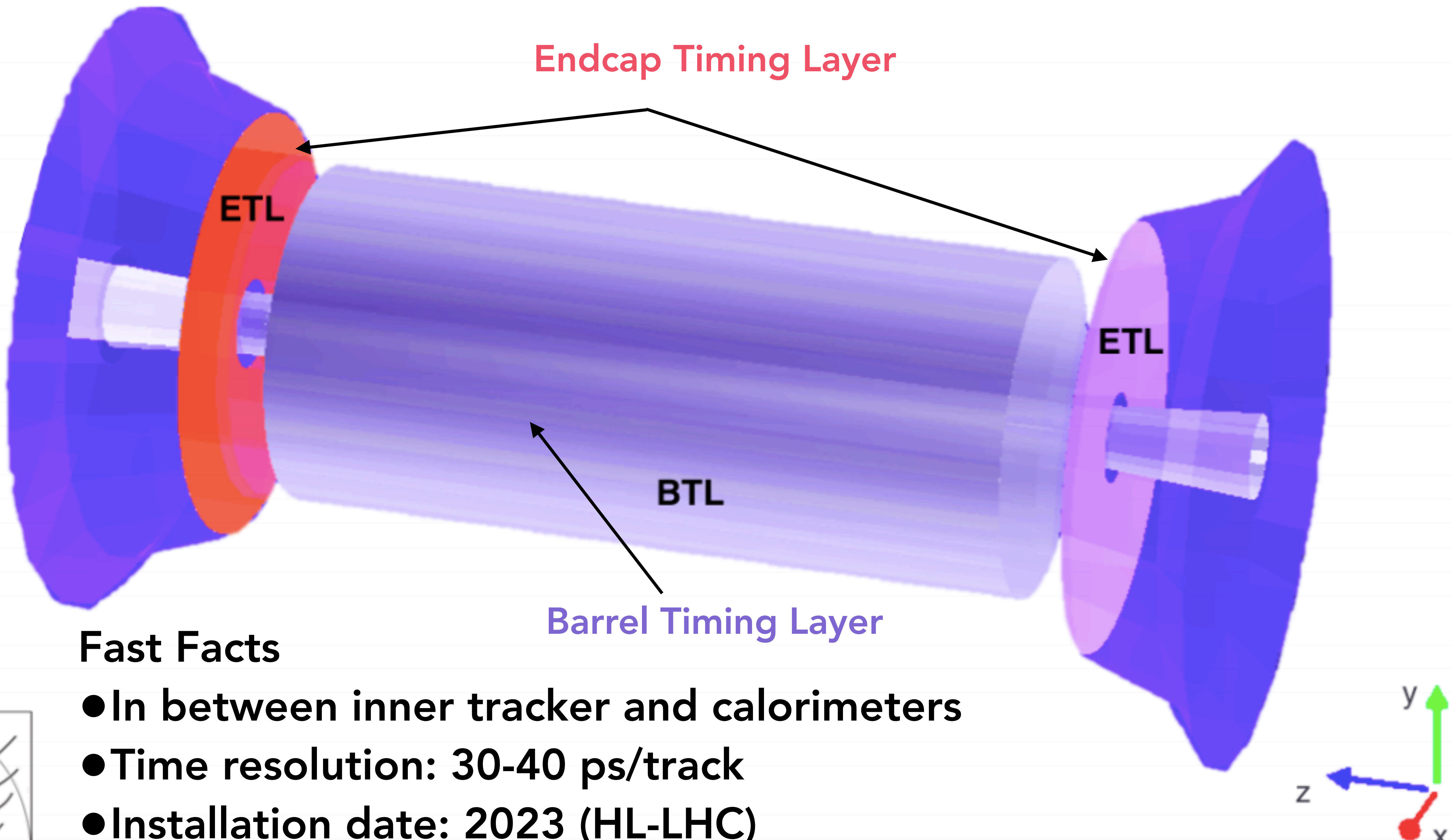


Resolving Pileup With Precision Timing

Vertices that overlap in 3D are clearly separated in 4D



CMS Precision Timing with the MIP Timing Detector (MTD)

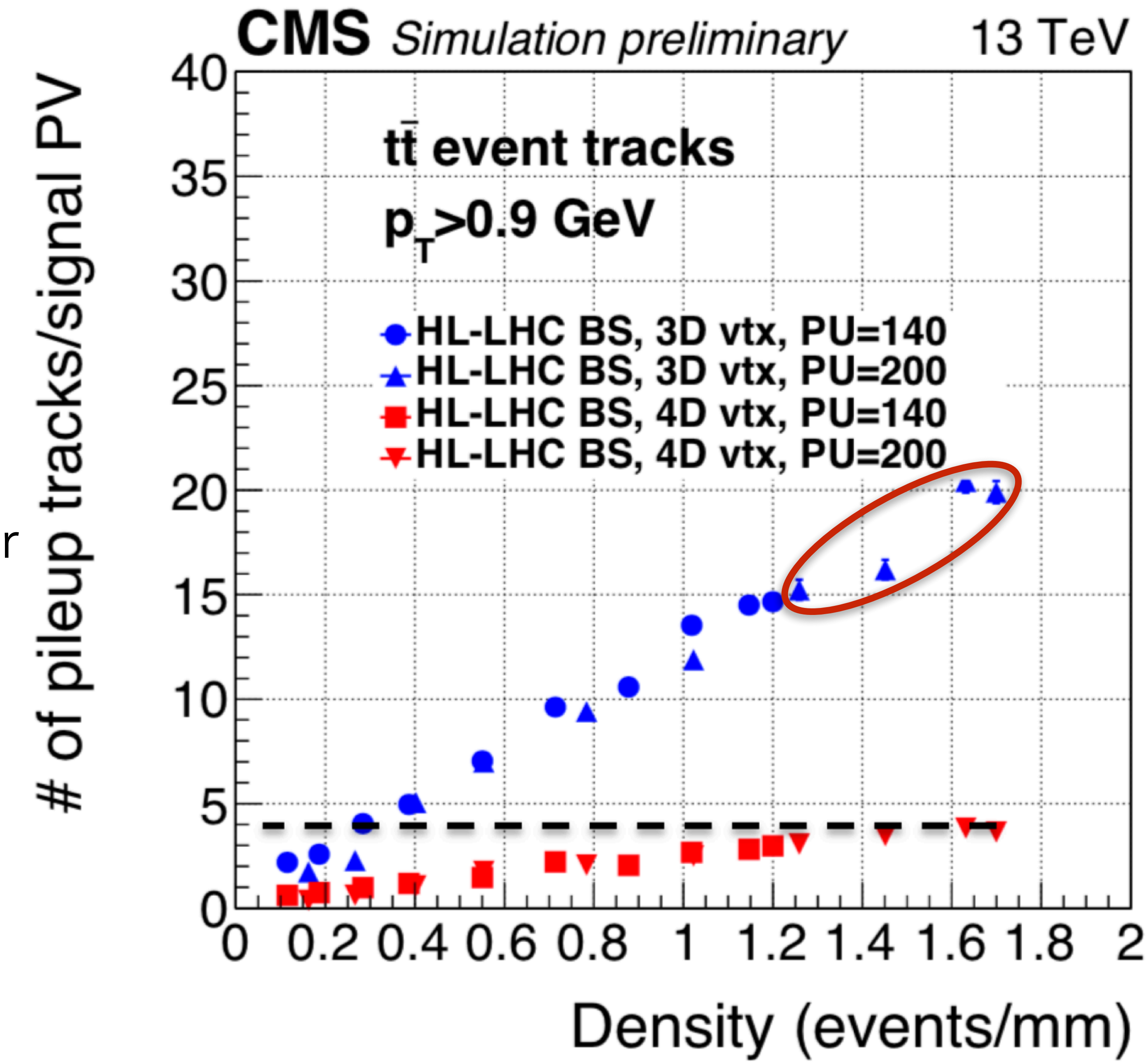


Fast Facts

- In between inner tracker and calorimeters
- Time resolution: 30-40 ps/track
- Installation date: 2023 (HL-LHC)

What else can we see with the MTD?

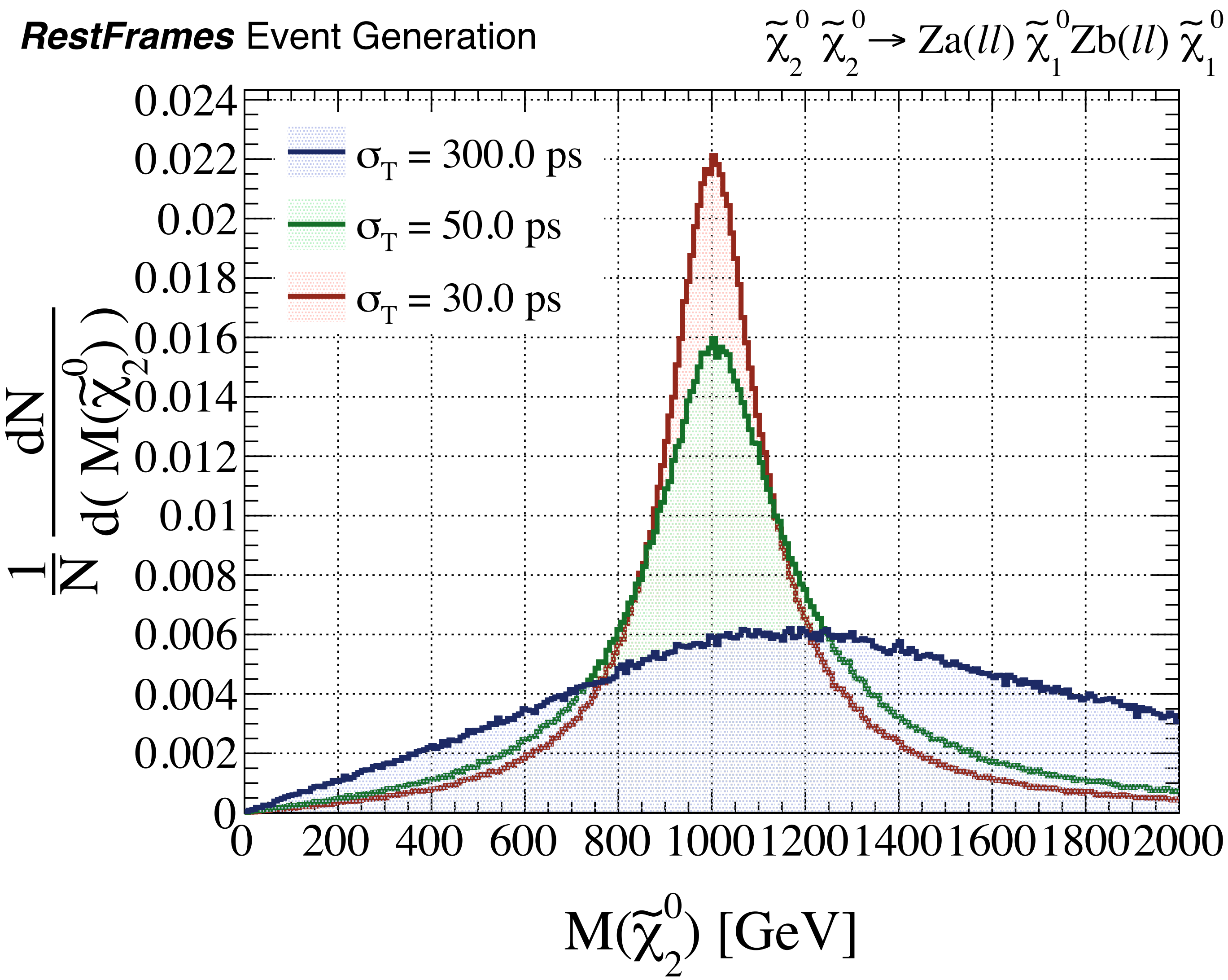
- Improved pileup resolution (CMS LHCC-2019-003)
  - B-tagging + lepton isolation improvement
  - Increased effective luminosity for rarer signals/Higgs Program



Improvement on resolution of tracks/ PV with increased time resolution

What else can we see with the MTD?

- Improved pileup resolution (CMS LHCC-2019-003)
  - B-tagging + lepton isolation improvement
  - Increased effective luminosity for rarer signals/Higgs Program
- Additional physics capabilities
  - Heavy ion studies/low pT hadron studies
  - LLP studies with timing (arXiv:1903.05825v2)



Improvement on resolution of mass measurement for neutralino with increased timing resolution

MTD Structural Overview

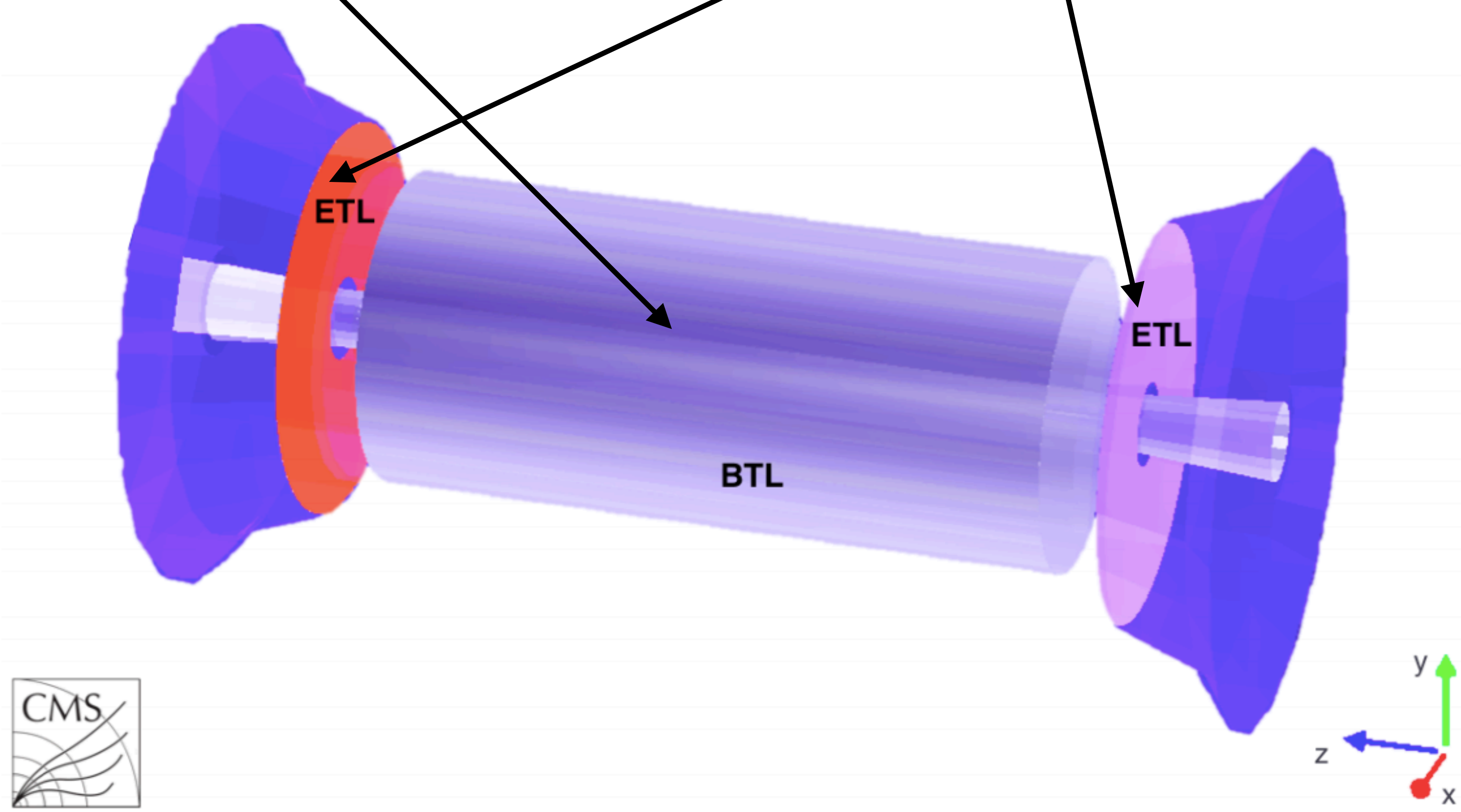
Two main technologies

Barrel Timing Layer (BTL):

Scintillating crystals read out by SiPMs

Endcap Timing Layer (ETL):

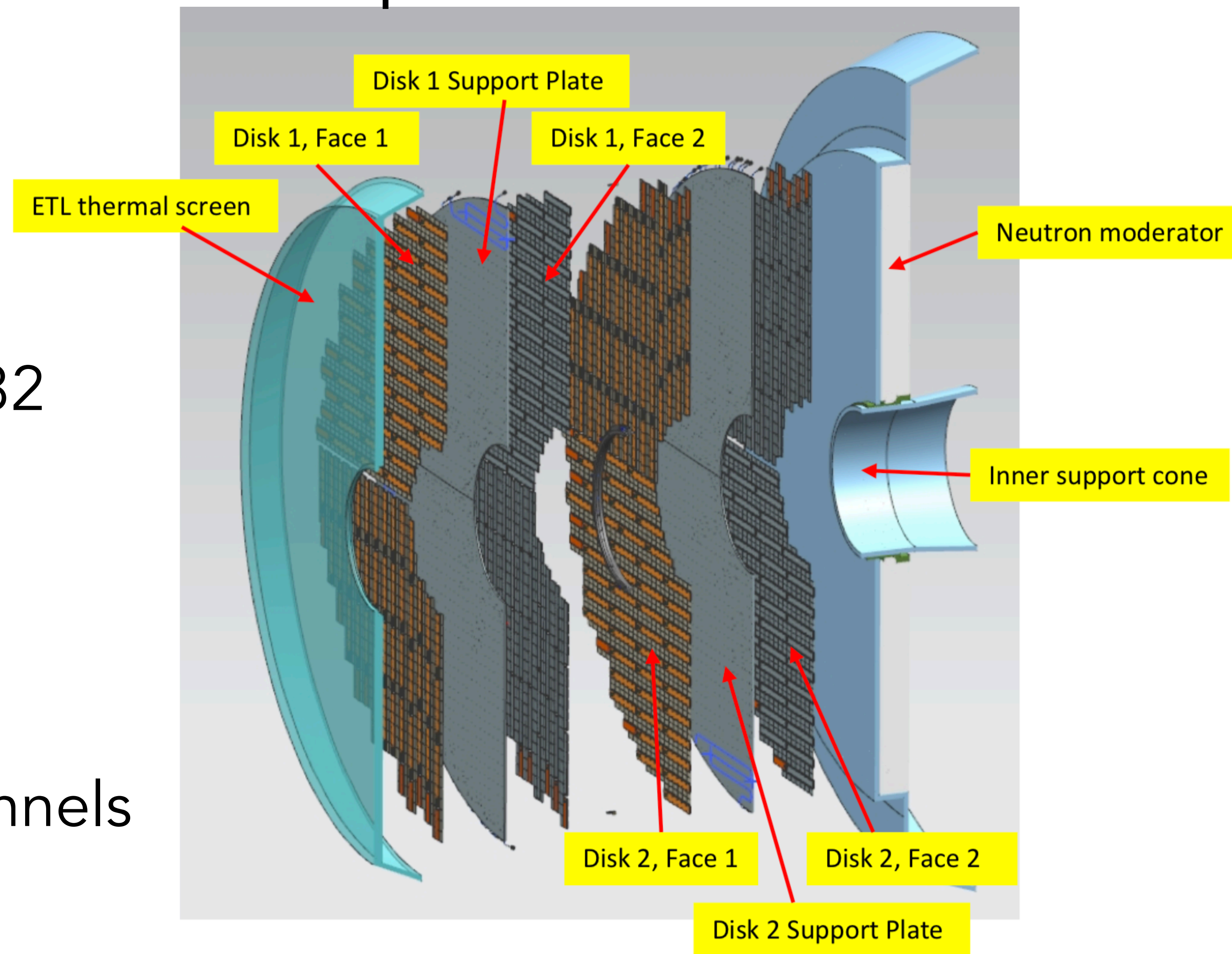
Silicon low gain avalanche detectors (LGADs)



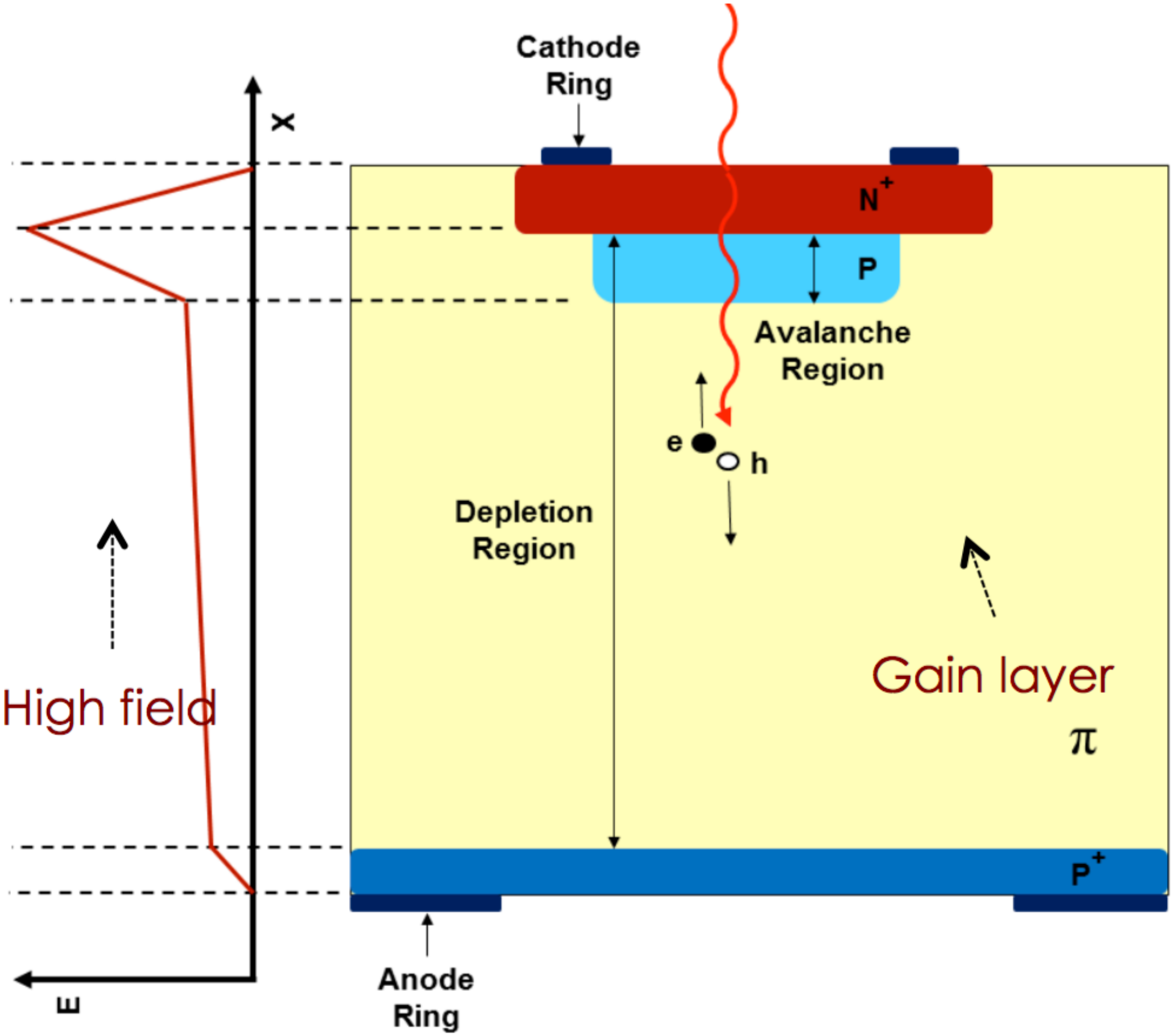
MTD Structural Overview: Endcap Timing Layer (ETL)

- 15 m^2 of silicon
- 2 disks per endcap
- Each LGAD sensor: 16x32 pads (512)
- Each pad: 1.3x1.3 mm
- ~10 million readout channels

Expanded view of ETL disk half



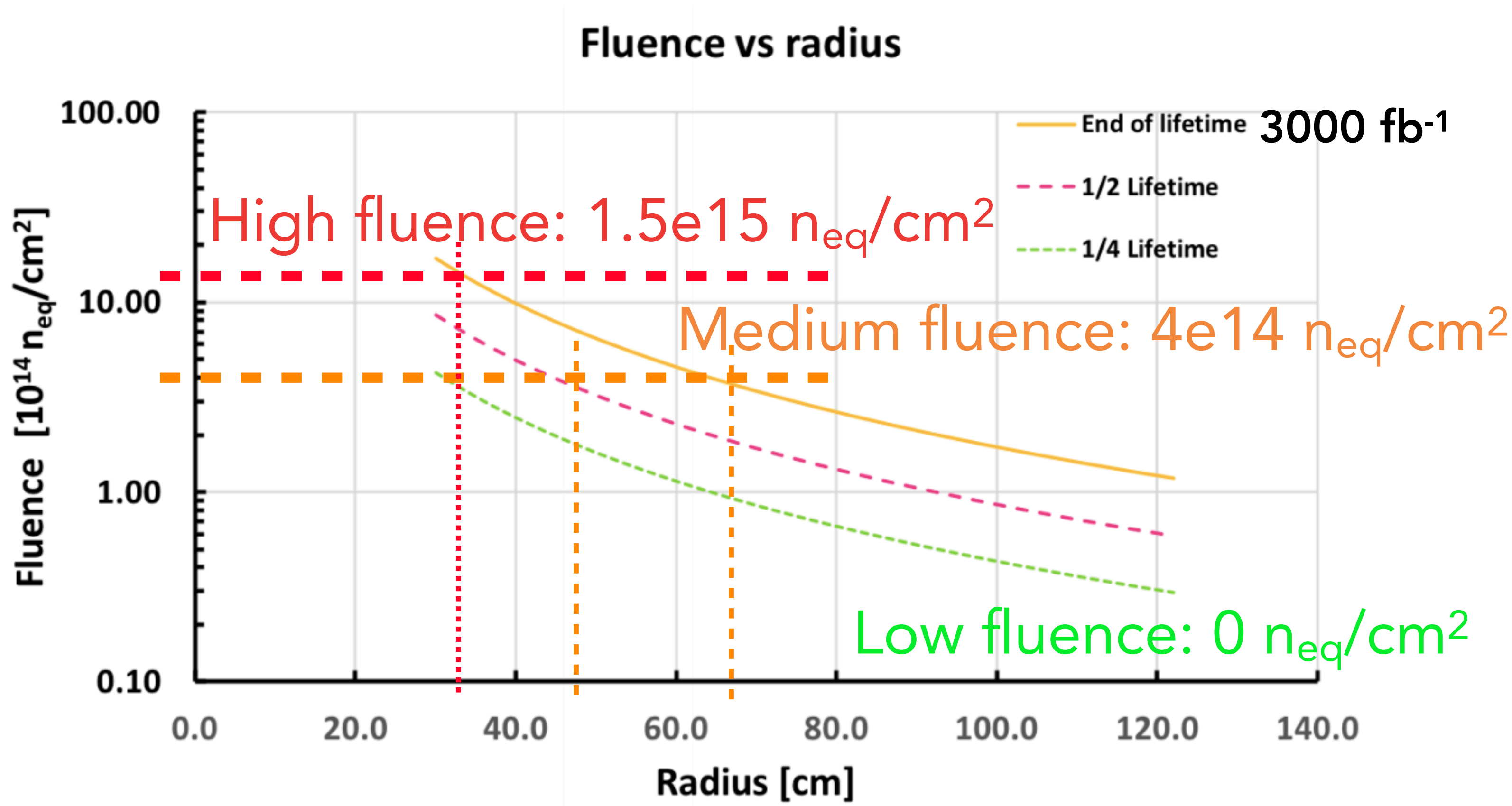
ETL Low Gain Avalanche Detectors



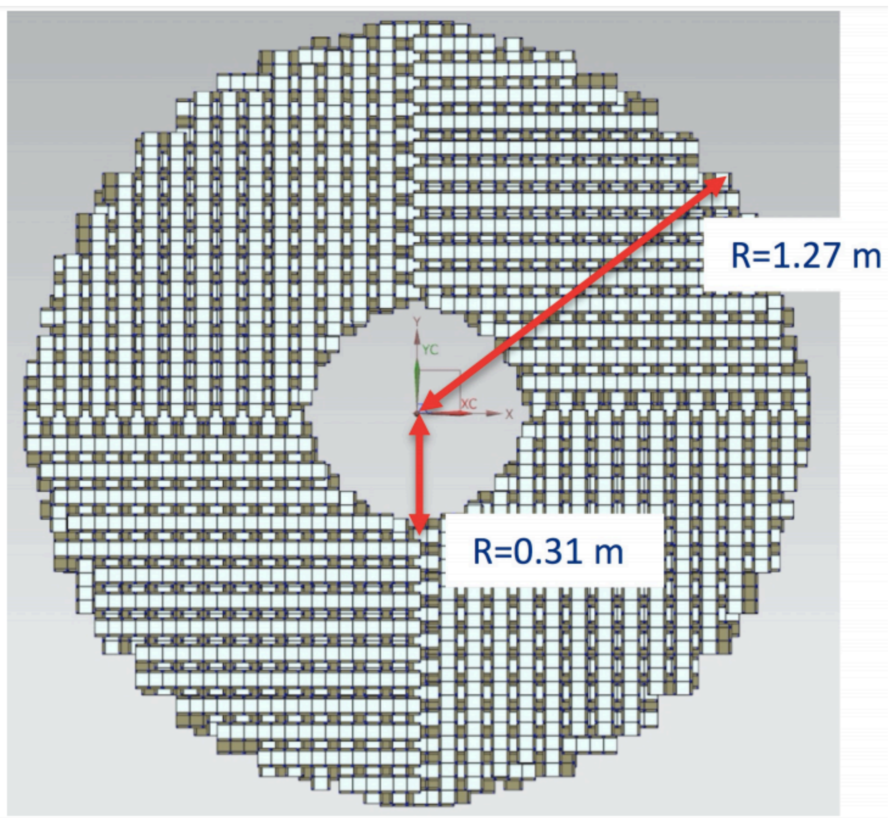
- Silicon with gain layer
- Gain layer creates high E field
- Thin sensors
- Gain ~10-30 (SiPMs ~1000s)

ETL LGAD Sensor Requirements

- Time resolution requirement: 30-40 ps
- Efficiency requirement: ~100% uniformly throughout the sensor
- Radiation tolerance throughout the detector

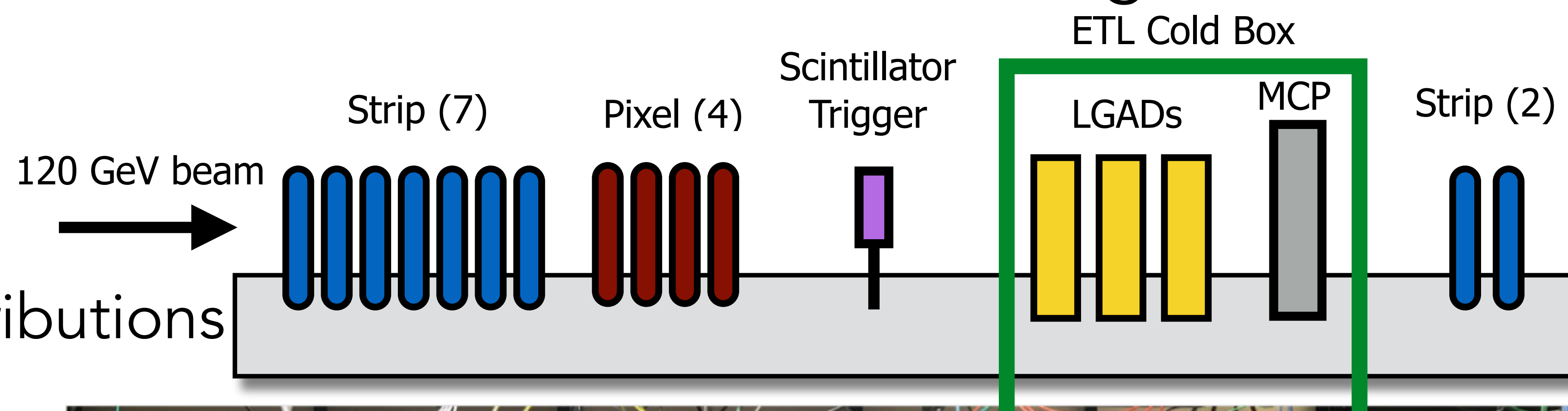


X-Y view of ETL

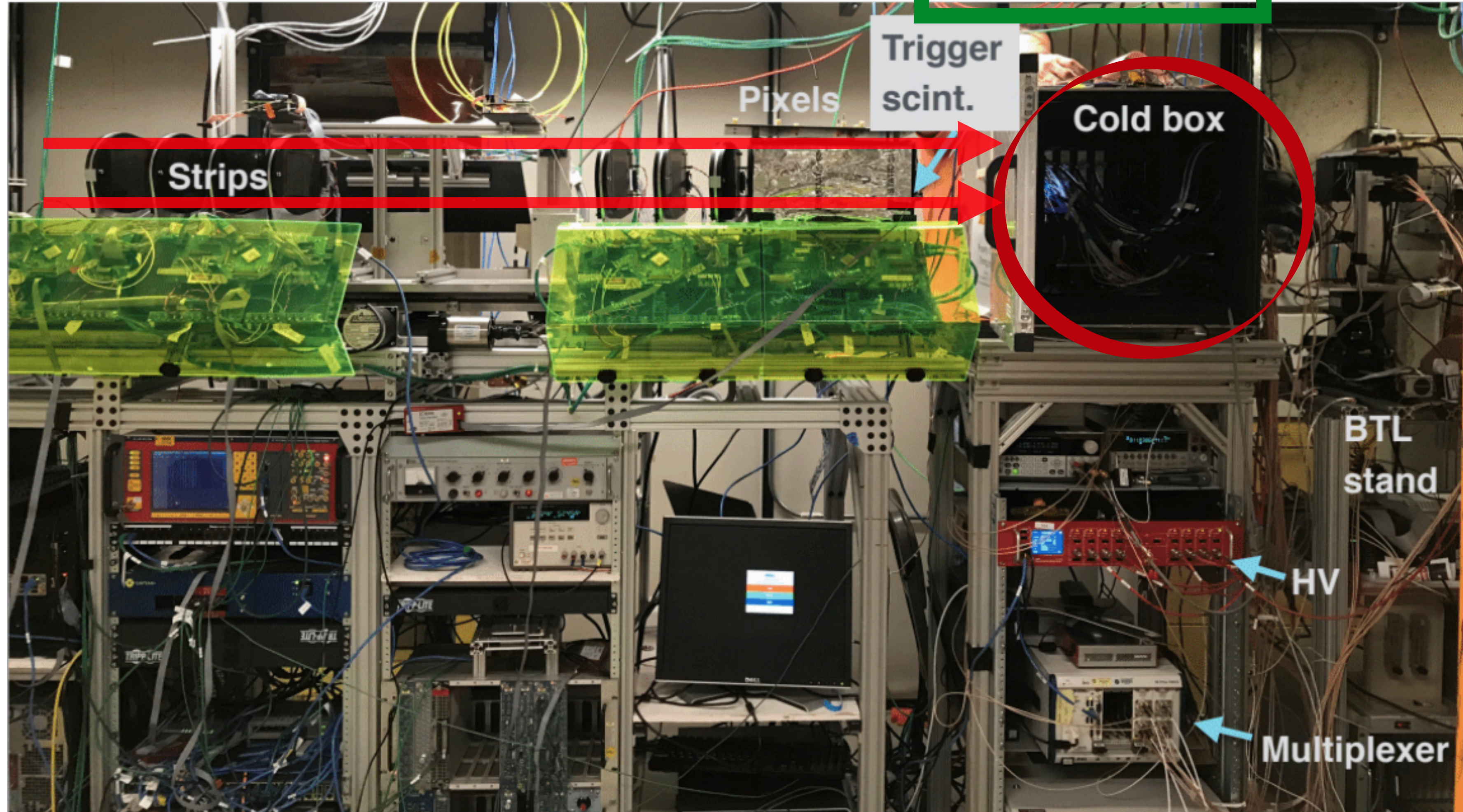


Test Beam Setup @ Fermilab

Characterizing LGAD sensors (different radiation strengths, manufacturers)

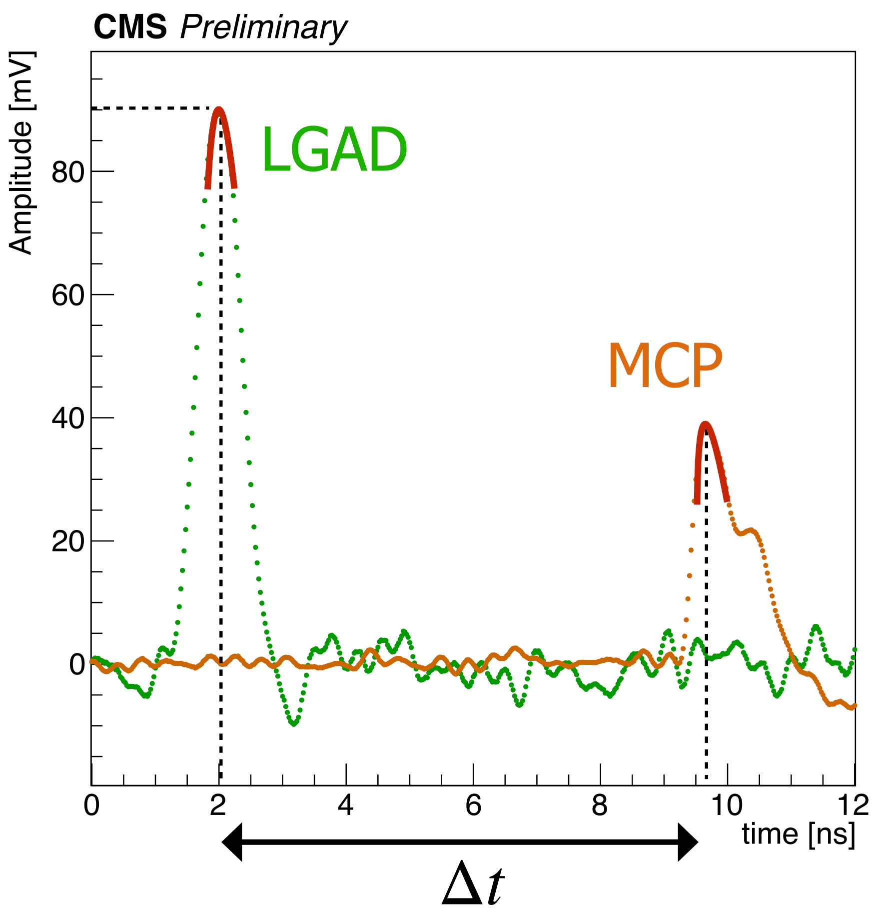


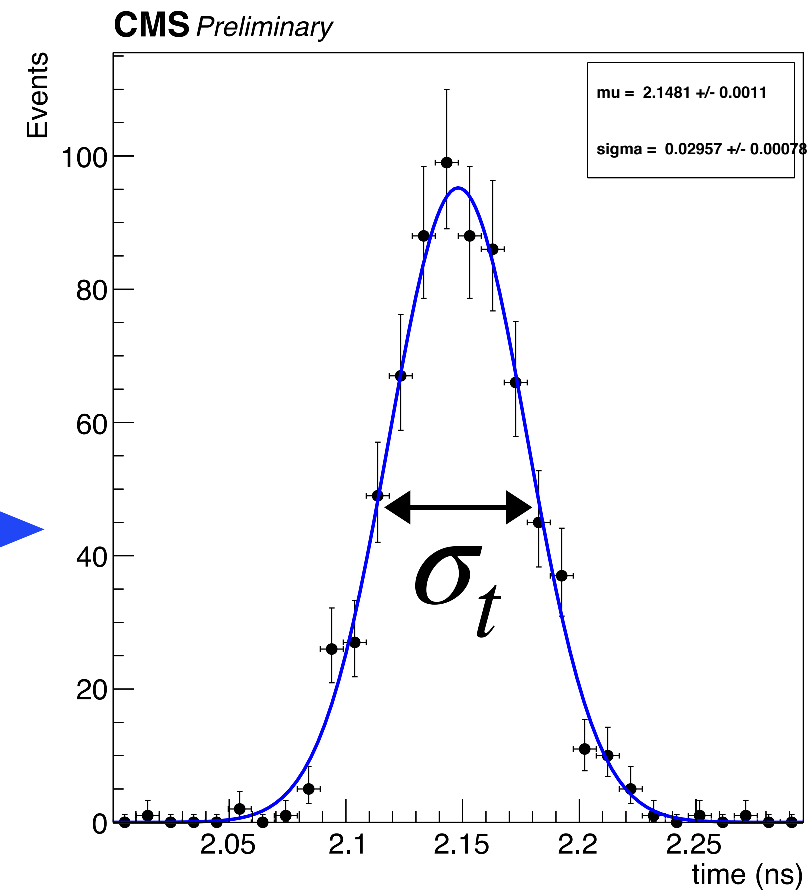
- Amplitude (gain) distributions
- Interpad gap distance
- Efficiency studies
- Timing resolution



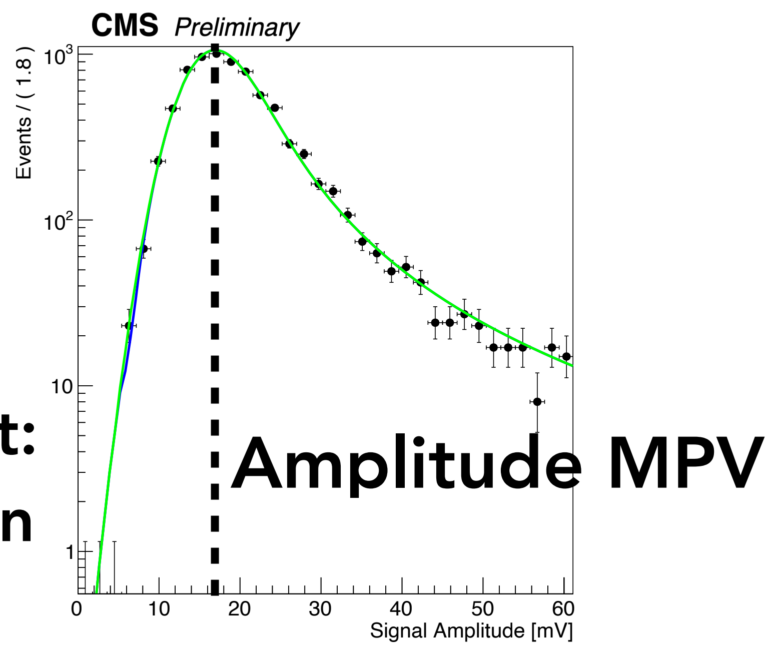
Permanent test beam set-up at Fermilab

LGAD Event Reconstruction





- Take time difference between arrival and LGAD and at MCP
- Make distribution of these time differences (Δt)
- Standard deviation of distribution is time resolution σ_t

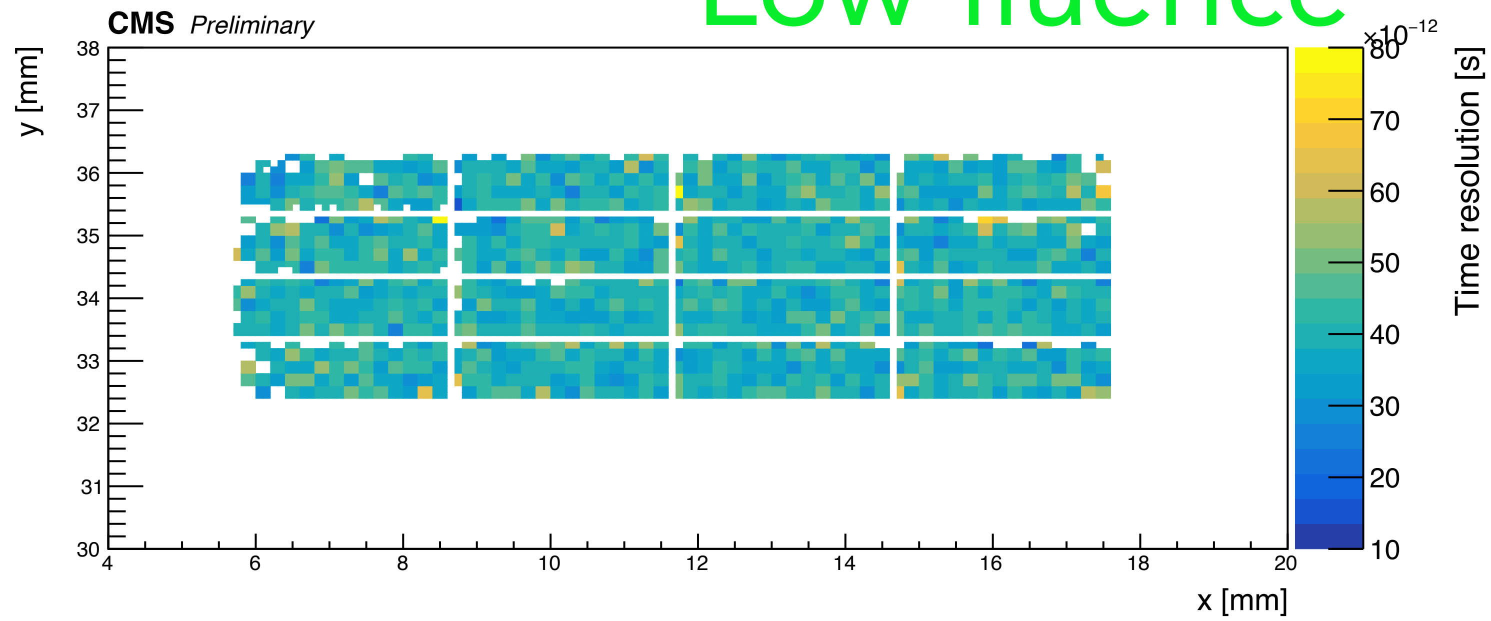


Other values of interest:

- **Most probable value of amplitude distribution**
- **Efficiency of sensor**

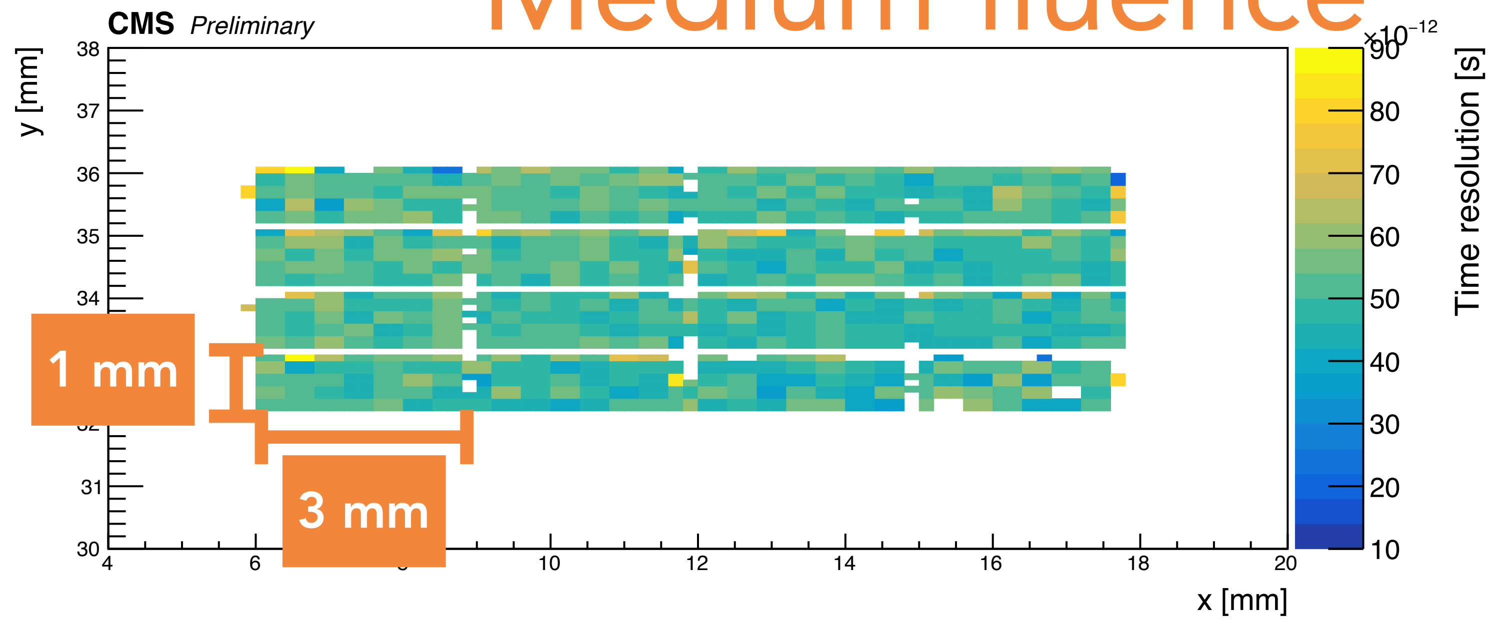
ETL LGAD Studies: Sensor Uniformity - Timing Res.

Low fluence



- ☑ Uniform timing resolution ~ 30 ps

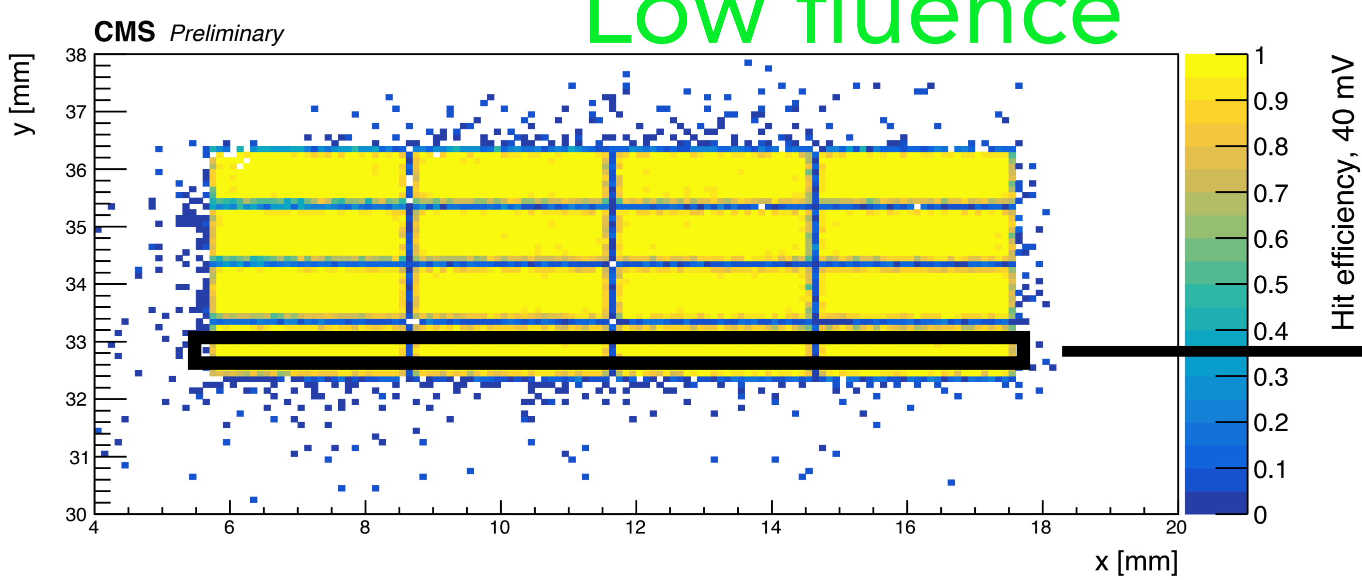
Medium fluence

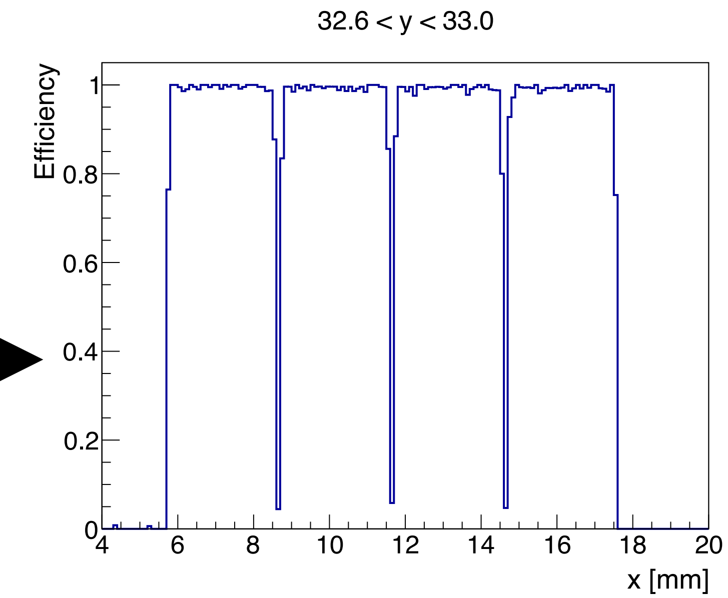


- ☑ Uniform timing resolution ~ 30-40 ps

ETL LGAD Studies:
Sensor Uniformity - Efficiency

Low fluence





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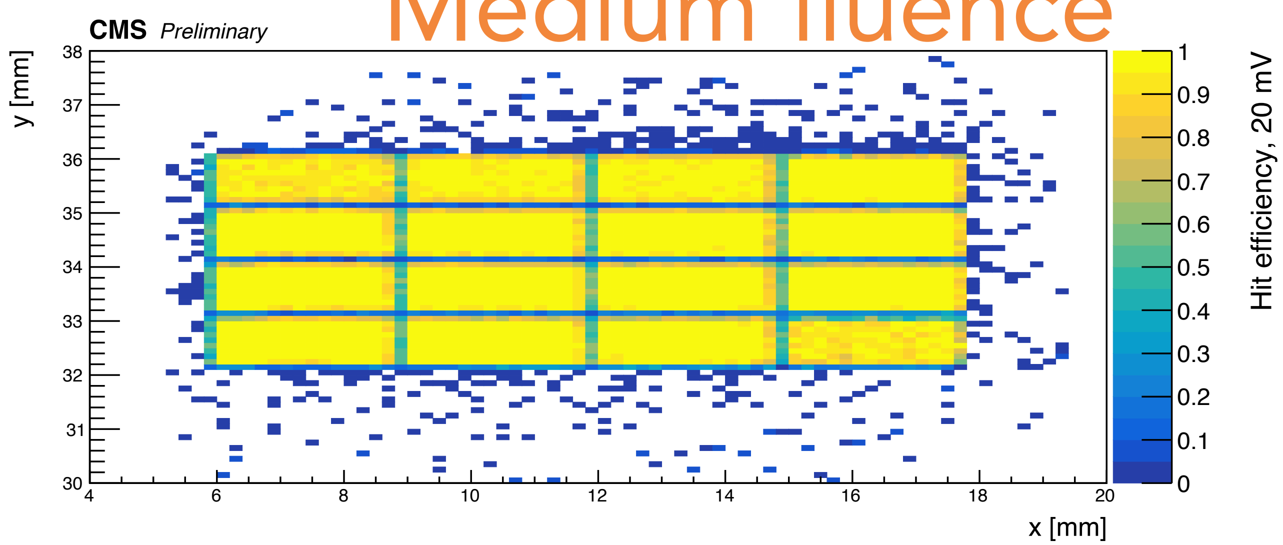
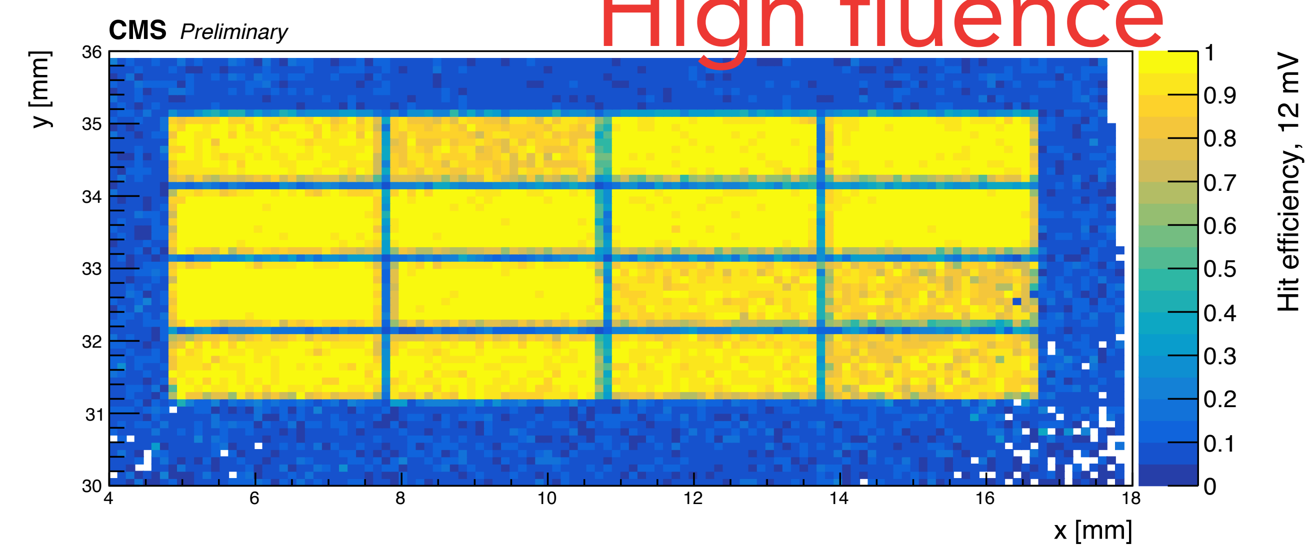
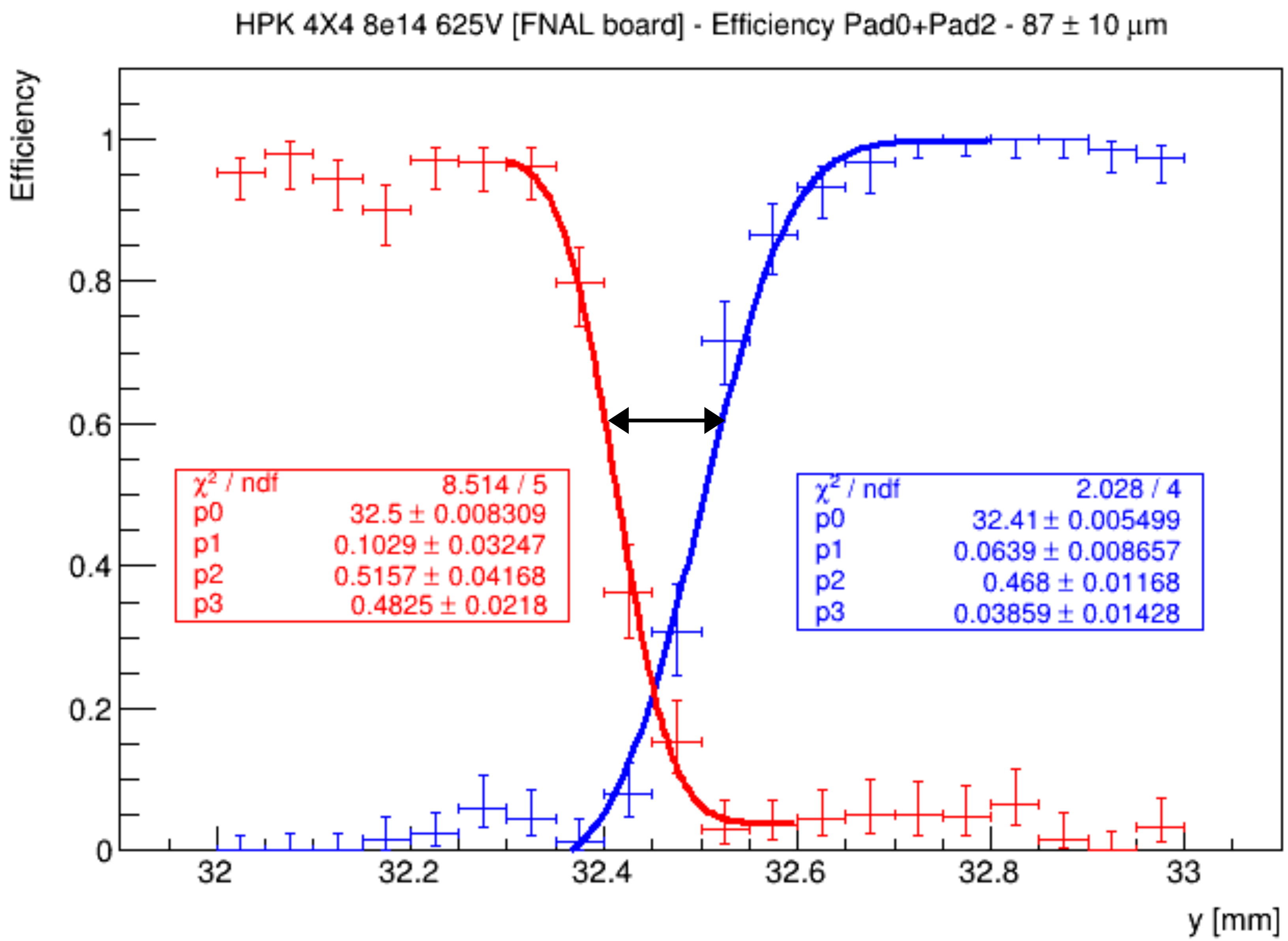


High fluence



- ☑ ~100% Efficiency
- ☑ Uniform Performance
- ☑ Radiation Tolerant

ETL LGAD Studies: Interpad Distance



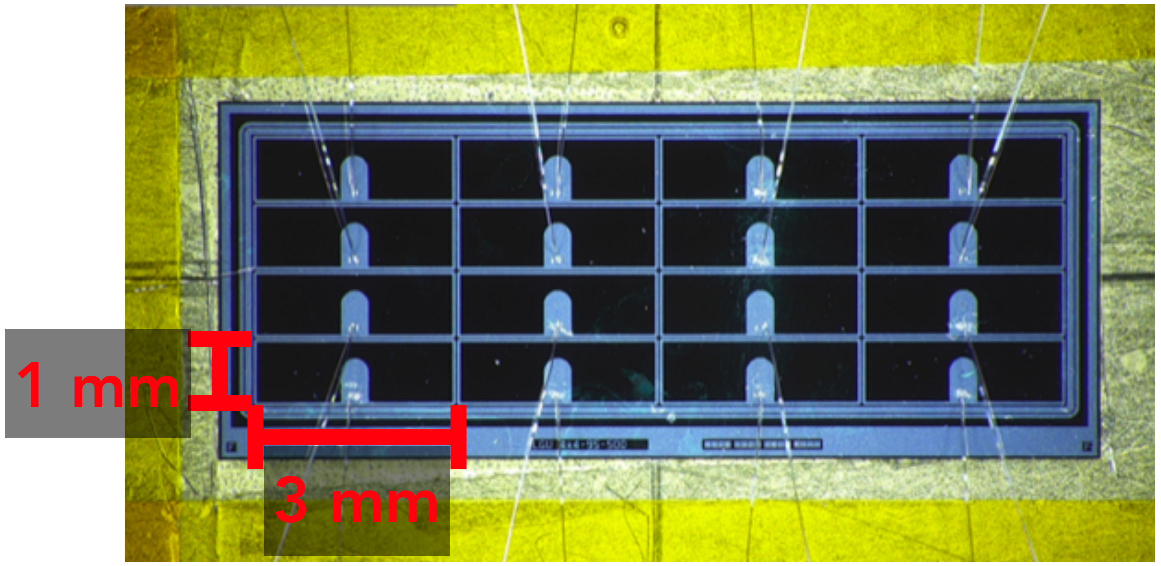
Check "dead area" between pads

Summary

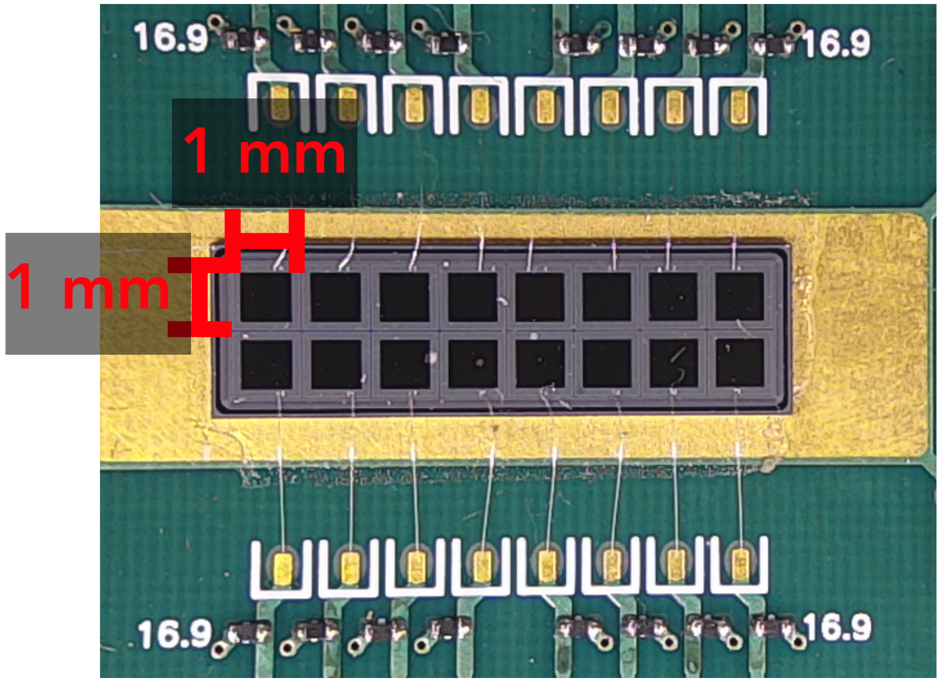
- CMS Phase 2 (HL-LHC) upgrade includes the addition of precision timing hardware, specifically the MTD
  - Precision Timing @ CMS helps to reduce effects of pileup
  - Opens up opportunities for new physics searches
- MTD concluding R&D phase
  - ETL sensors performance meet expectations
  - Results are consistent with timing resolution goal (30-40 ps)

Backup

LGAD Sensors



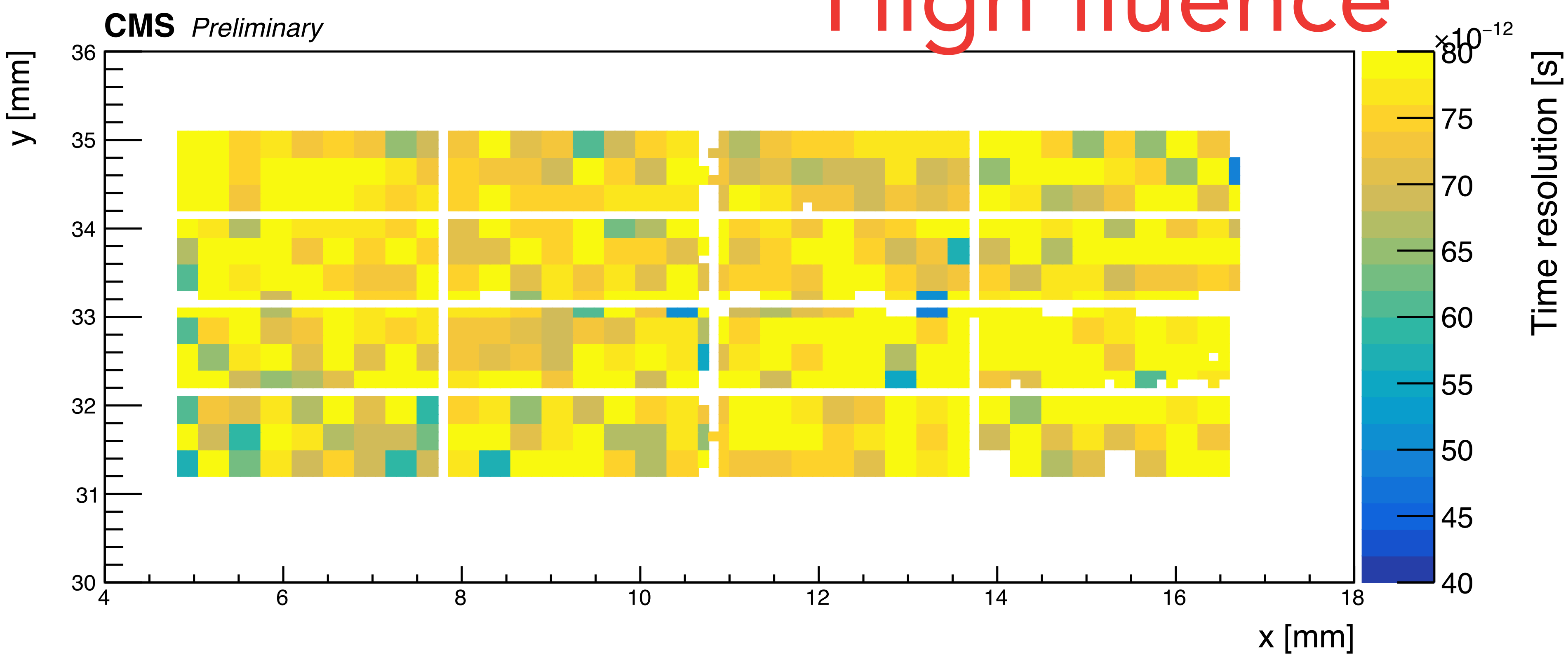
HPK 4x4 LGAD array



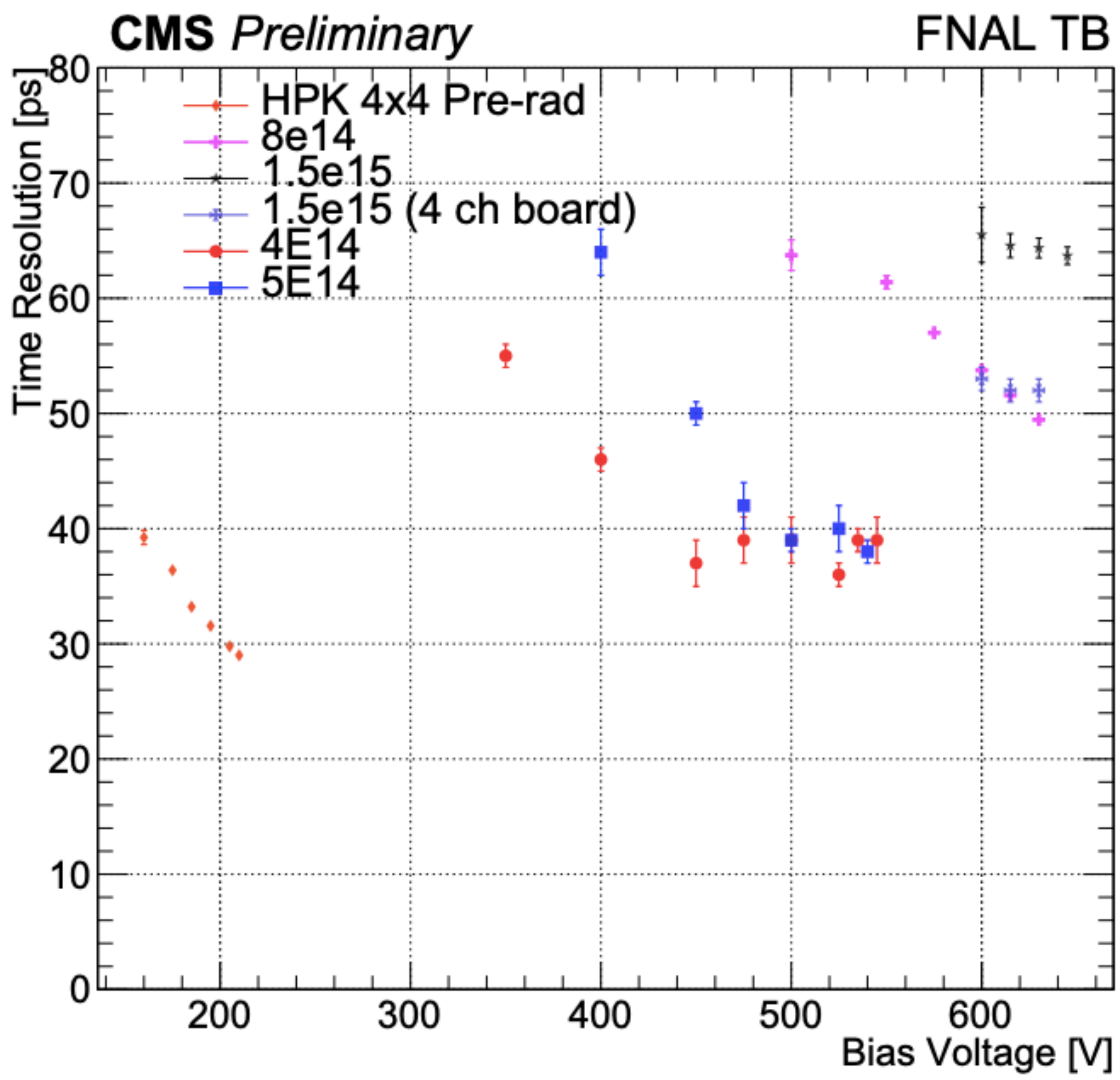
FBK 2x8 LGAD array

ETL LGAD Studies: Sensor Uniformity - Timing Res.

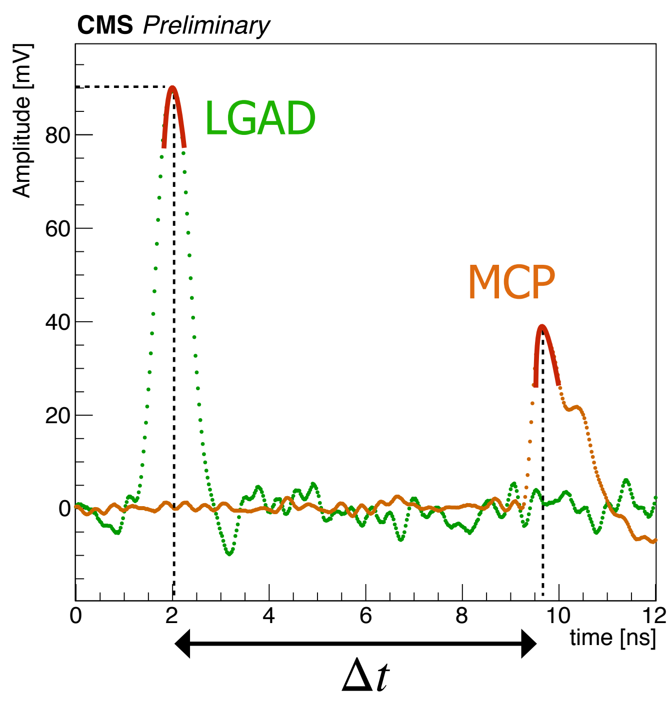
High fluence



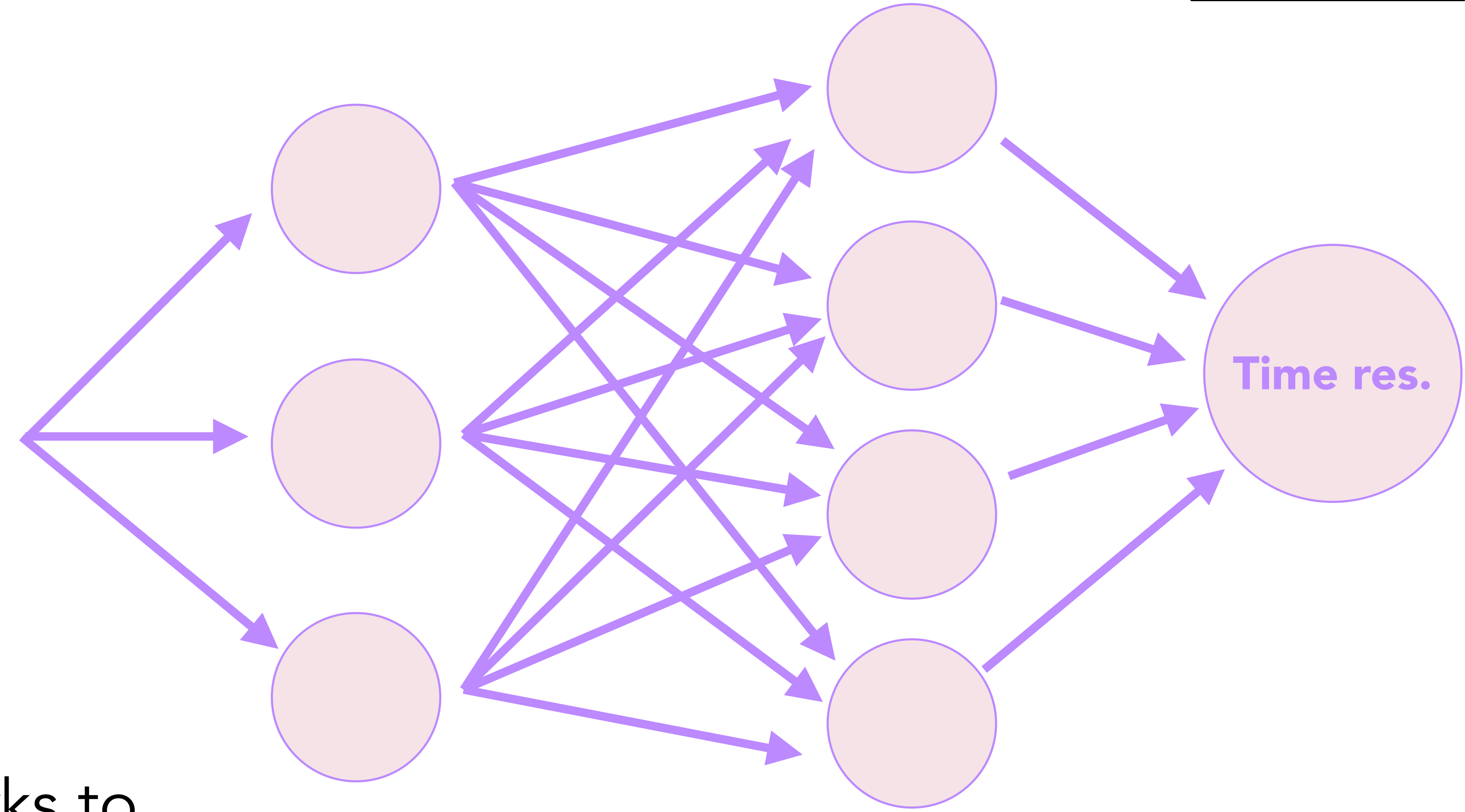
April 2019 Test Beam Results



Machine Learning for Timing



Using neural networks to extract time resolution



Neural network schematic

LLP Mass Calculation

For one LLP

$$\vec{\beta}_{LLP} = \frac{\Delta \vec{x}}{\Delta t}$$

$$m_{LLP} = \frac{\vec{\beta}_{LLP,T} \cdot (\vec{\not{E}}_T + \vec{p}_{Z,T})}{\gamma_{LLP}}$$