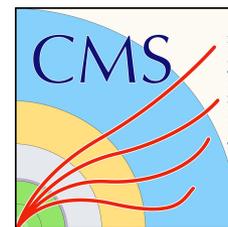


# Precision Timing with the CMS MIP Timing Detector

Lake Louise 2019  
11th February

Fabio Monti on behalf of the CMS Collaboration



# Outline

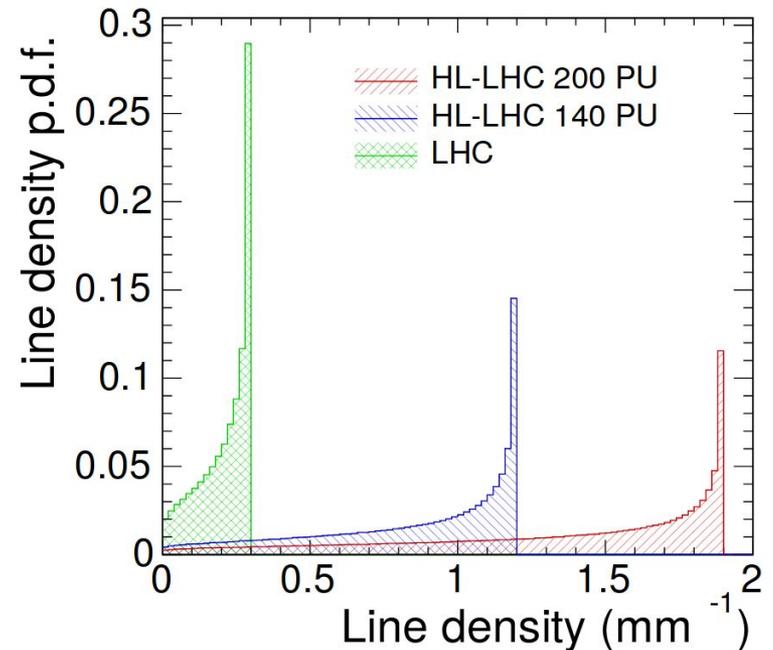
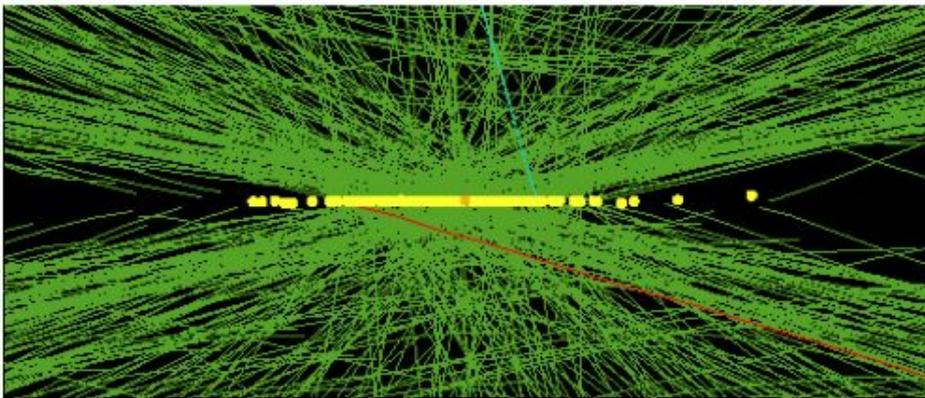
- Motivation for a MIP Timing Detector at High Luminosity LHC
- Physics impact
- Detector layout and test beam results

The Technical Design Report is in preparation

- To be submitted at the end of March 2019
- In this presentation
  - Detector layout pre-TDR
  - Test-beam/laboratory results pre-TDR

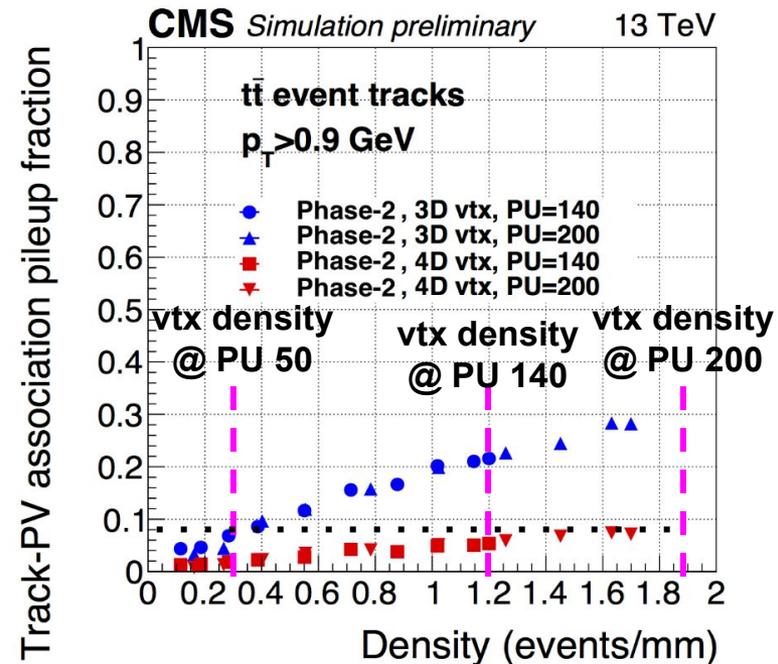
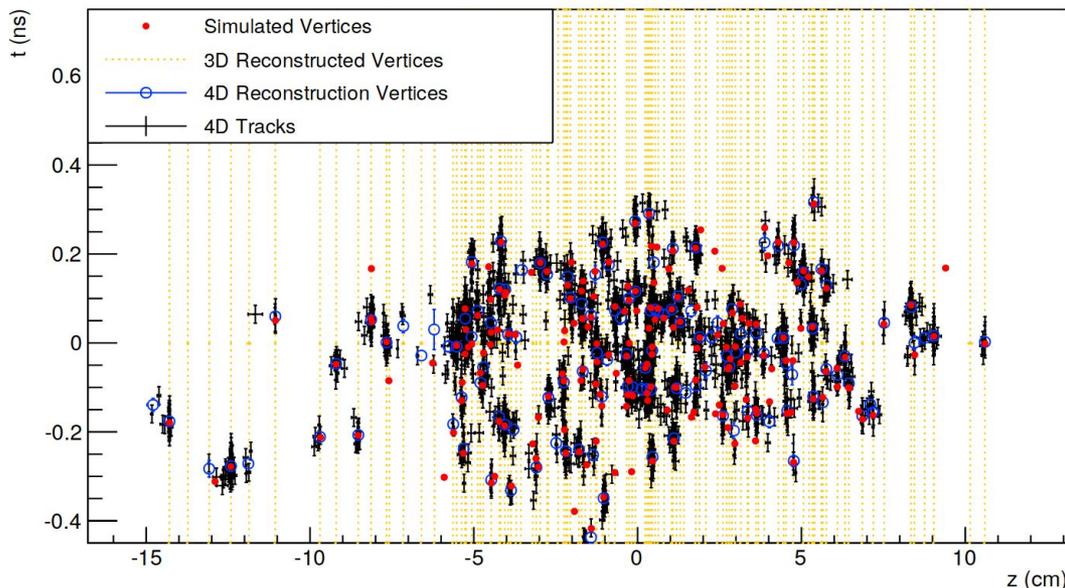
# Motivation for a MIP Timing Detector

- Number of collisions per bunch crossing (pile-up)
  - Phase I LHC: 30-50 collisions / (4.5 cm · 180 ps)
  - High Luminosity LHC: 140-200 collisions / (4.5 cm · 180 ps)
- Increase vertex density of a factor 4-5
- Optimal cut for track-vertex compatibility at  $\sim 1$  mm
  - Not-negligible effect of pileup on physics quantities



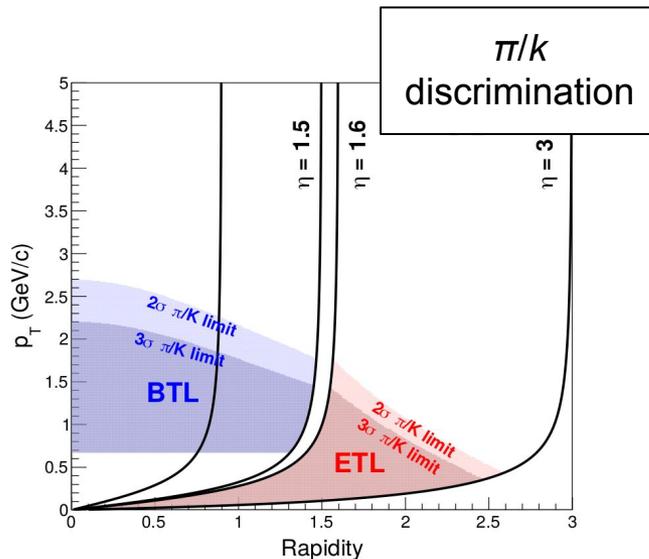
# MIP Timing Detector effective solution against pileup

- Track timing with a resolution of 30-50 ps
  - 4-D vertex reconstruction
  - Requirement of time compatibility for track - vertex association
- Reduce actual pileup to the level of the current LHC
  - Well handled by the CMS detector

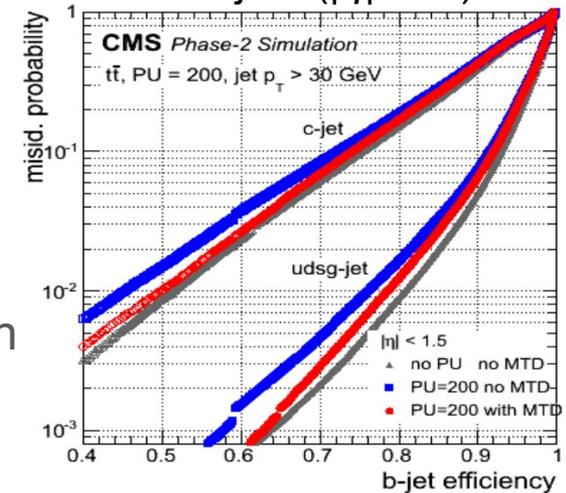


# Impact on performance

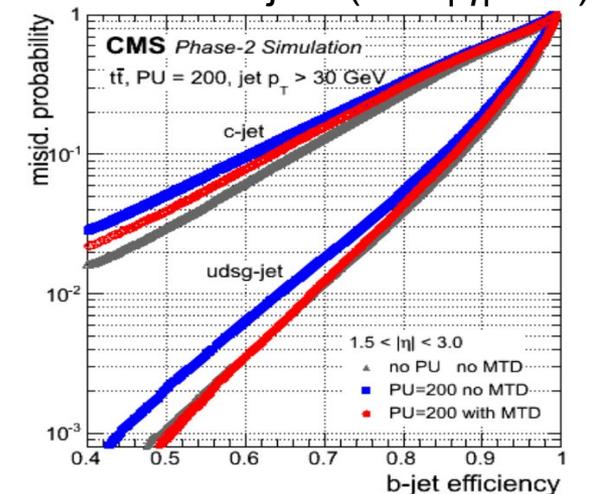
- Reduction of pileup results in:
  - Increase b-tag identification efficiency
  - Increase photon and lepton isolation and ID efficiency (at constant background rejection)
  - Improve missing transverse momentum resolution
  - Reduction of jets from pileup
- TOF for low  $p_T$  hadrons for particle identification



b-tag ROC curve  
Central jets ( $|\eta| < 1.5$ )



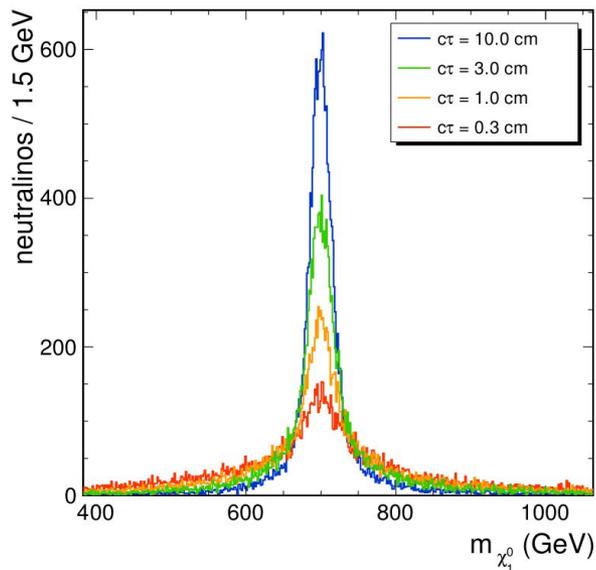
b-tag ROC curve  
Forward jets ( $1.5 < |\eta| < 3.0$ )



# Impact on physics

4D reconstruction of primary and secondary vertices

- Close kinematics of Long Lived Particles decaying within MTD

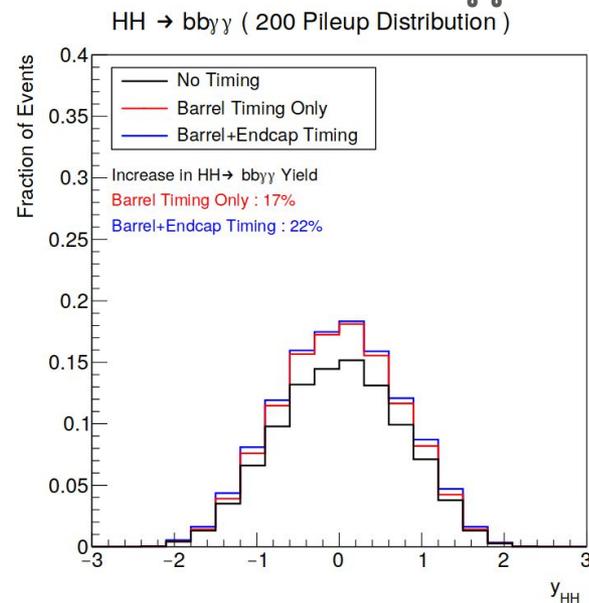


- $\pi - k - p$  discrimination

- New reach for Heavy Ion physics at CMS

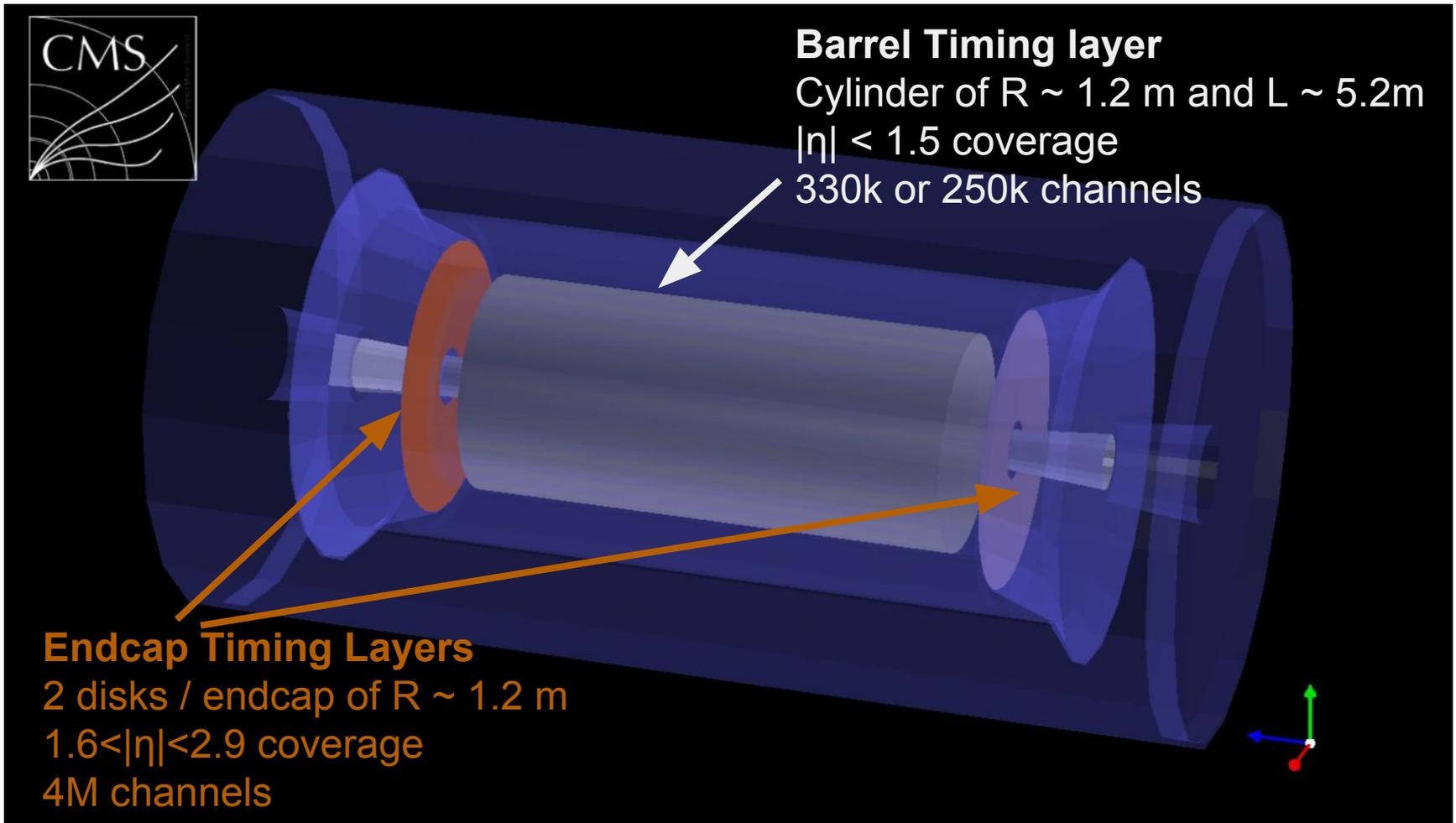
10-20% gain in  $S/\sqrt{B}$  for several Higgs decay channels

- e.g.  $\sim 10\%$  efficiency gain in selection of  $HH \rightarrow b\bar{b}\gamma\gamma$  events



# Detector layout

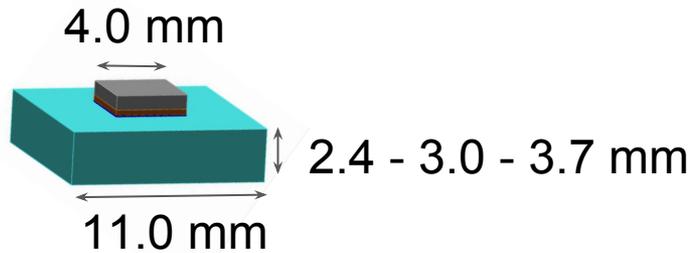
- MTD placed in a small gap between the tracker and the calorimeters



# Barrel Timing Layer construction

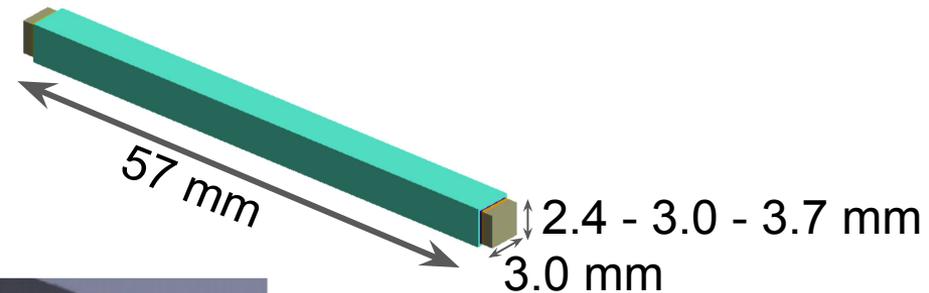
- Two design options for the detector unit

Squared tile of LYSO crystal read out by a square SiPM

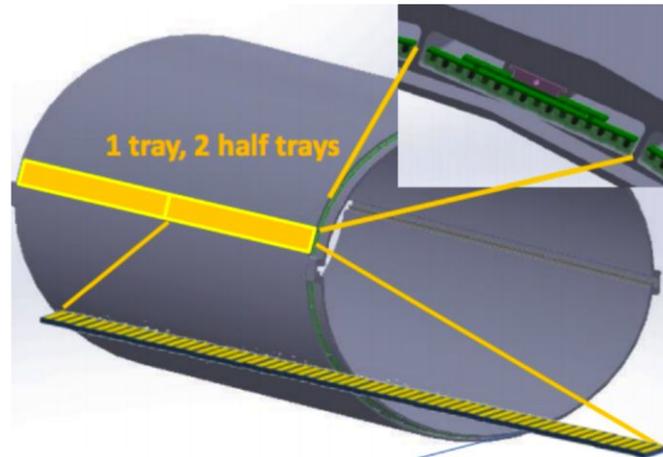


Bar of LYSO crystal read out by SiPMs on both sides

- Oriented along barrel ring ( $\varphi$ )



Barrel modules inserted in trays embedded in tracker support tube



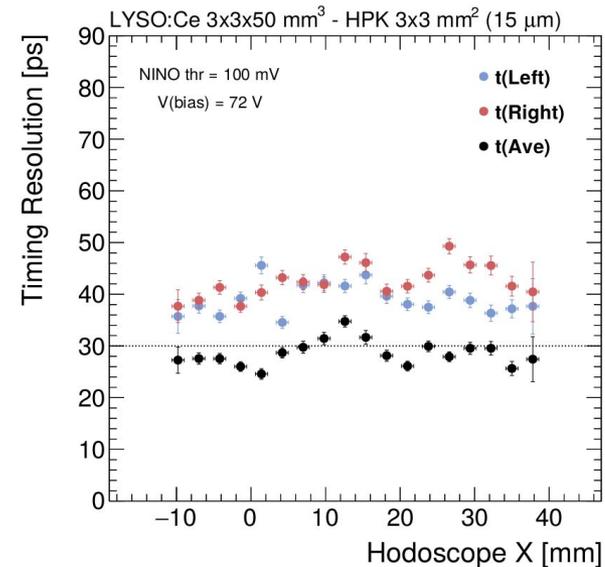
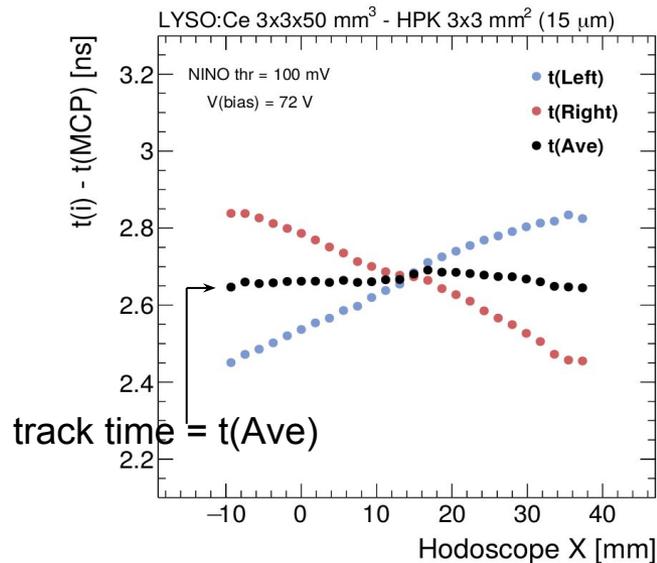
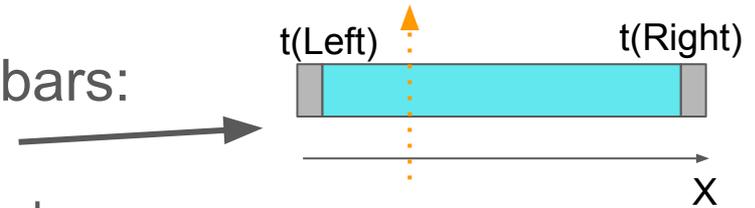
Detector units grouped in modules

- Important constraint:  $2 \cdot 10^{14}$  neutron equiv. /  $\text{cm}^2$  total absorbed dose
  - Increase of leakage current in SiPM → Operating temperature at  $-30^\circ\text{C}$

# Barrel Timing Layer - Test Beam result

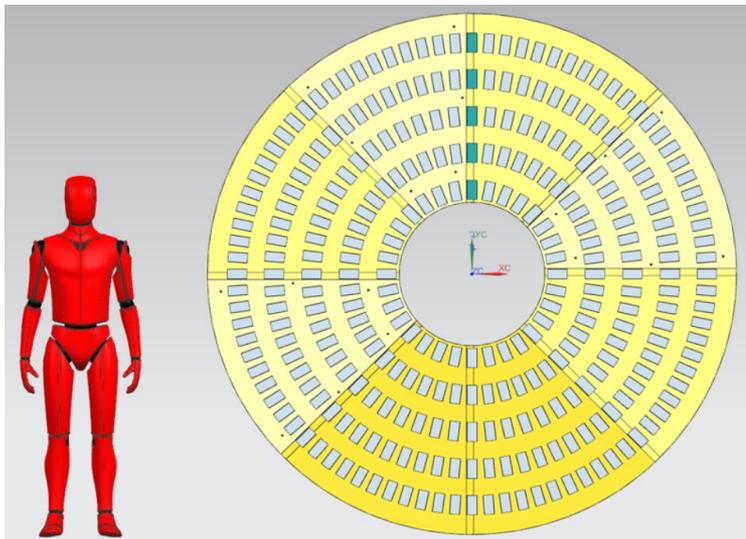
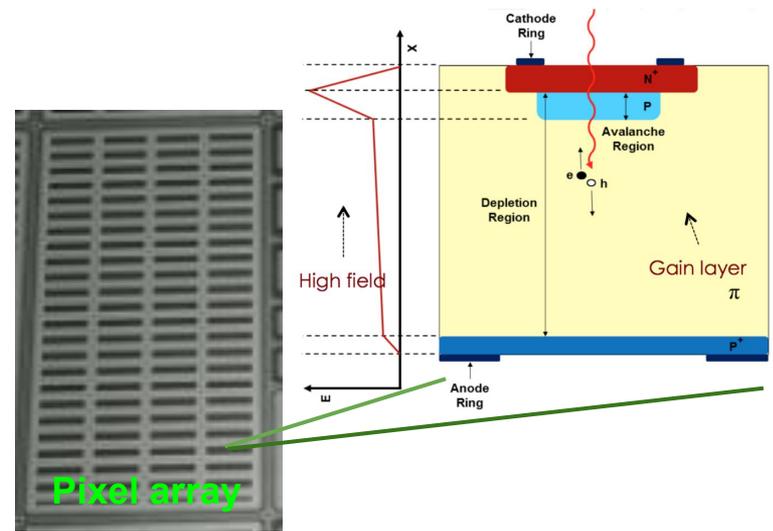
- Recent test beam results for crystal bars:

- Two time stamps for each channel
- Time sensitive to light propagation along bar
- Average time  $(t(\text{Left}) + t(\text{Right}))/2$  ~independent from impact position
- Performance matching the time resolution requirements



# Endcap Timing Layer construction

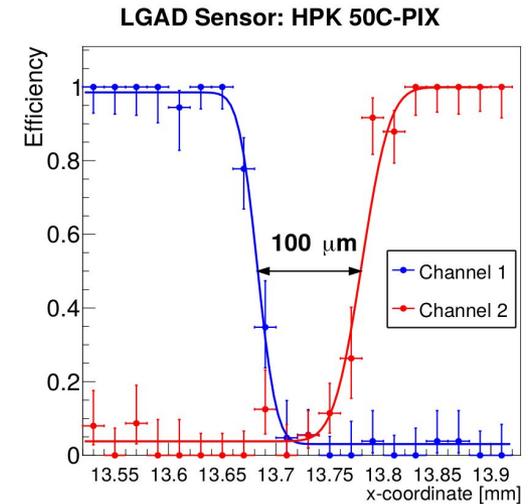
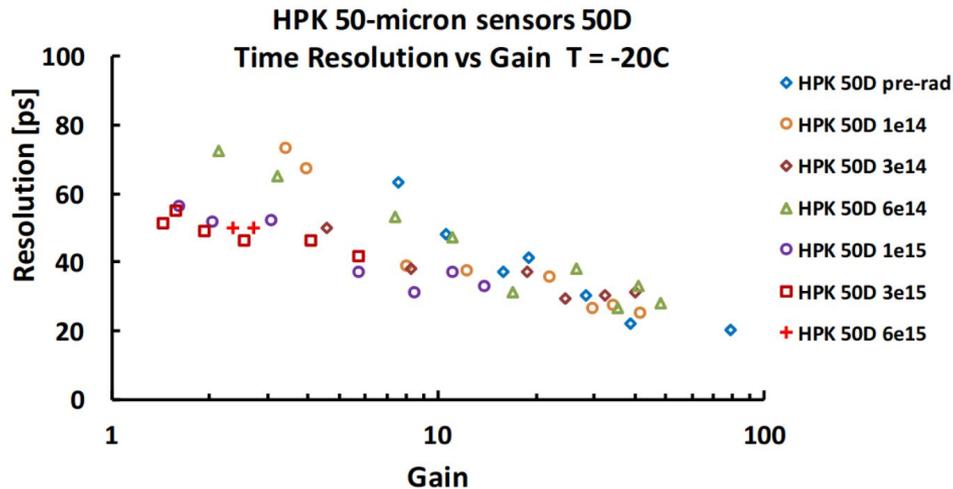
- Detector Unit: Low Gain Avalanche Detector (LGAD)
  - Planar silicon sensors with intrinsic gain layer (gain  $\sim 10 - 30$ )
  - Pixels of  $3 \times 1 \text{ mm}^2$  produced in arrays of  $4 \times 24$  pixels



- Pixel arrays grouped in modules
  - $\sim 1500$  pixels / module
- Modules placed on the 4 faces of the 2 disks per endcap:
  - Radial layout staggered on the 2 disk faces
  - Fill factor of 85% / disk
    - 1.8 hits / track combining the 2 disks

# Endcap Timing Layer - Experimental results and simulations

- Achieved time res. of 30 - 50 ps also for irradiated LGADs
- Efficiency close to 100% within pixel active area



- Further improvements from R&D
  - Reduce pixel size:  $1 \times 3 \text{ mm}^2 \rightarrow 1.3 \times 1.3 \text{ mm}^2$ 
    - Smaller capacitance and noise
  - Radiation tolerance significantly improved by Carbon co-doping
  - New devices with gap between pixels  $< 50 \mu\text{m}$  under study

# Summary

- A timing with a resolution of 30-50 ps will allow a 4-D vertex reconstruction in CMS at the HL-LHC
  - Effective pileup reduced to a level comparable to the current one (50PU)
- High impact on the HL-LHC physics program
- Barrel Timing Layer
  - LYSO crystals read by SiPMs → ~300k channels
- Endcap Timing Layer(s)
  - LGAD pixels placed in 2 disks per endcaps → 2M channels

**BACKUP**

# Crystal bar thickness leveling

- Purpose is to achieve the best uniformity in energy deposit along the z-direction (beam-direction)
  - Reduce the crystal thickness along eta to compensate for the slant thickness actually crossed by the MIP in LYSO crystals
  - Energy deposit in crystal  $\propto$  slant thickness

