Timing for the CMS Phase-2 upgrade

LHCP 2020

Paris, 25th-30th May 2019

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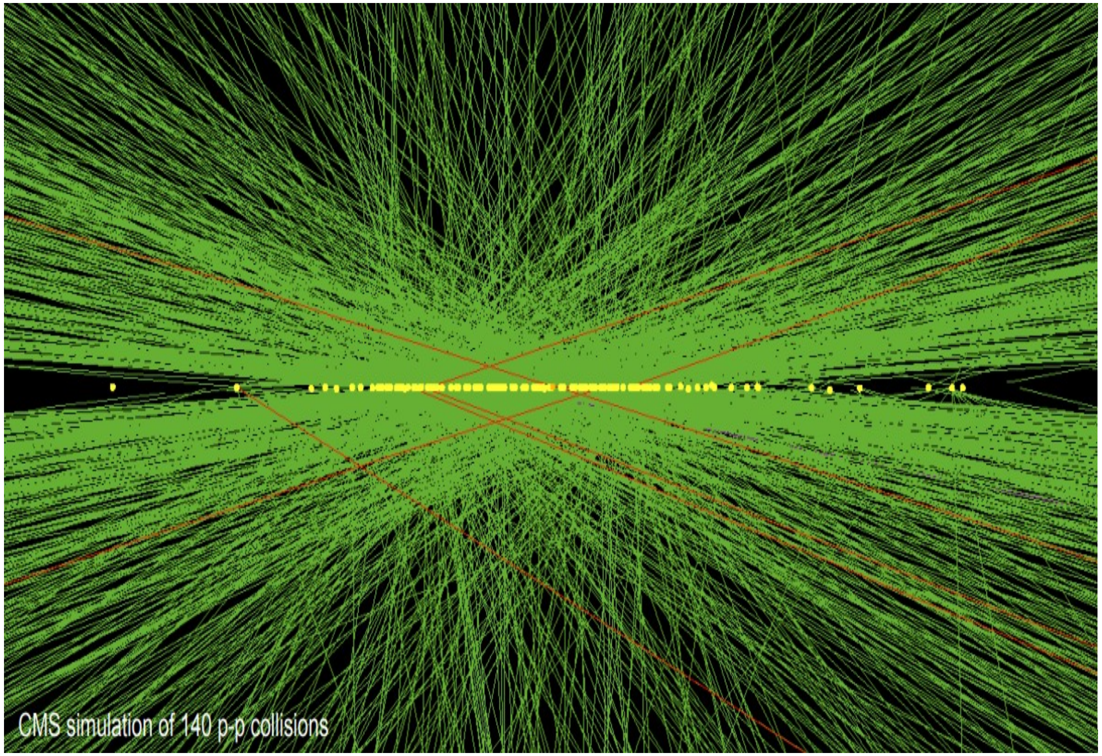
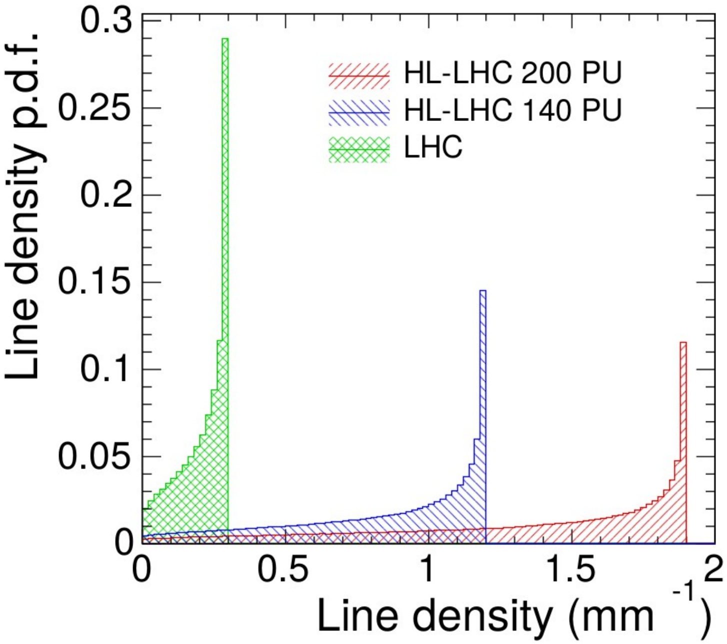
Challenges at the HL-LHC

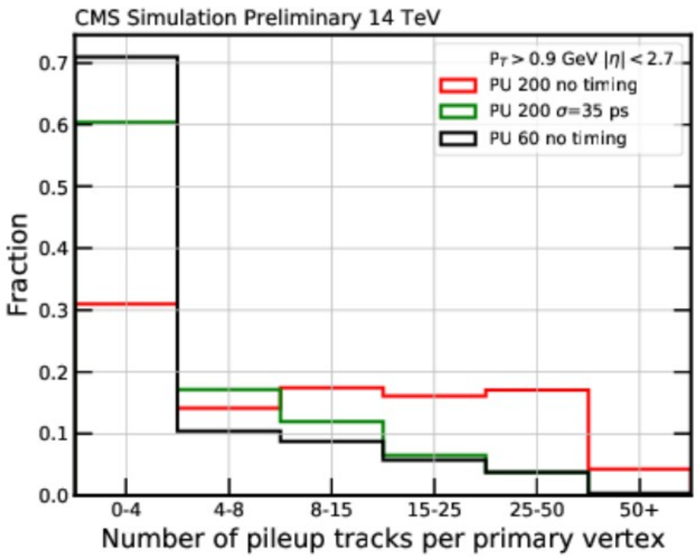
- The physics program at the HL-LHC faces hard conditions in terms of occupancy and pile-up.
- Between 140 and 200 simultaneous collisions expected for every bunch crossing.
- Such a busy environment presents several challenges for the reconstruction of physics objects.
- This can have a large impact on the HL-LHC physics program unless it is mitigated.

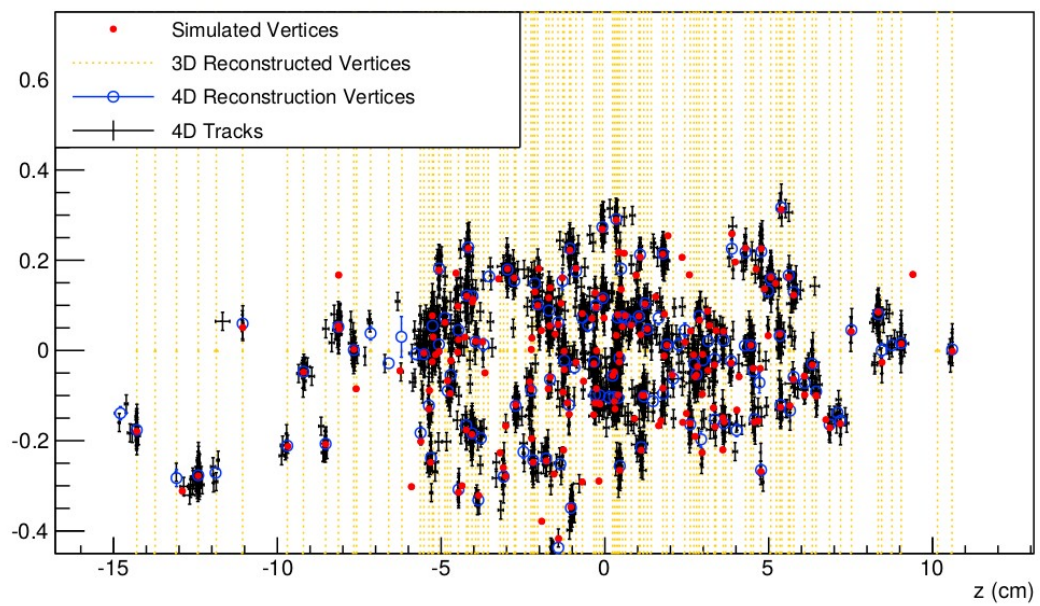




Time tagging at the HL-LHC

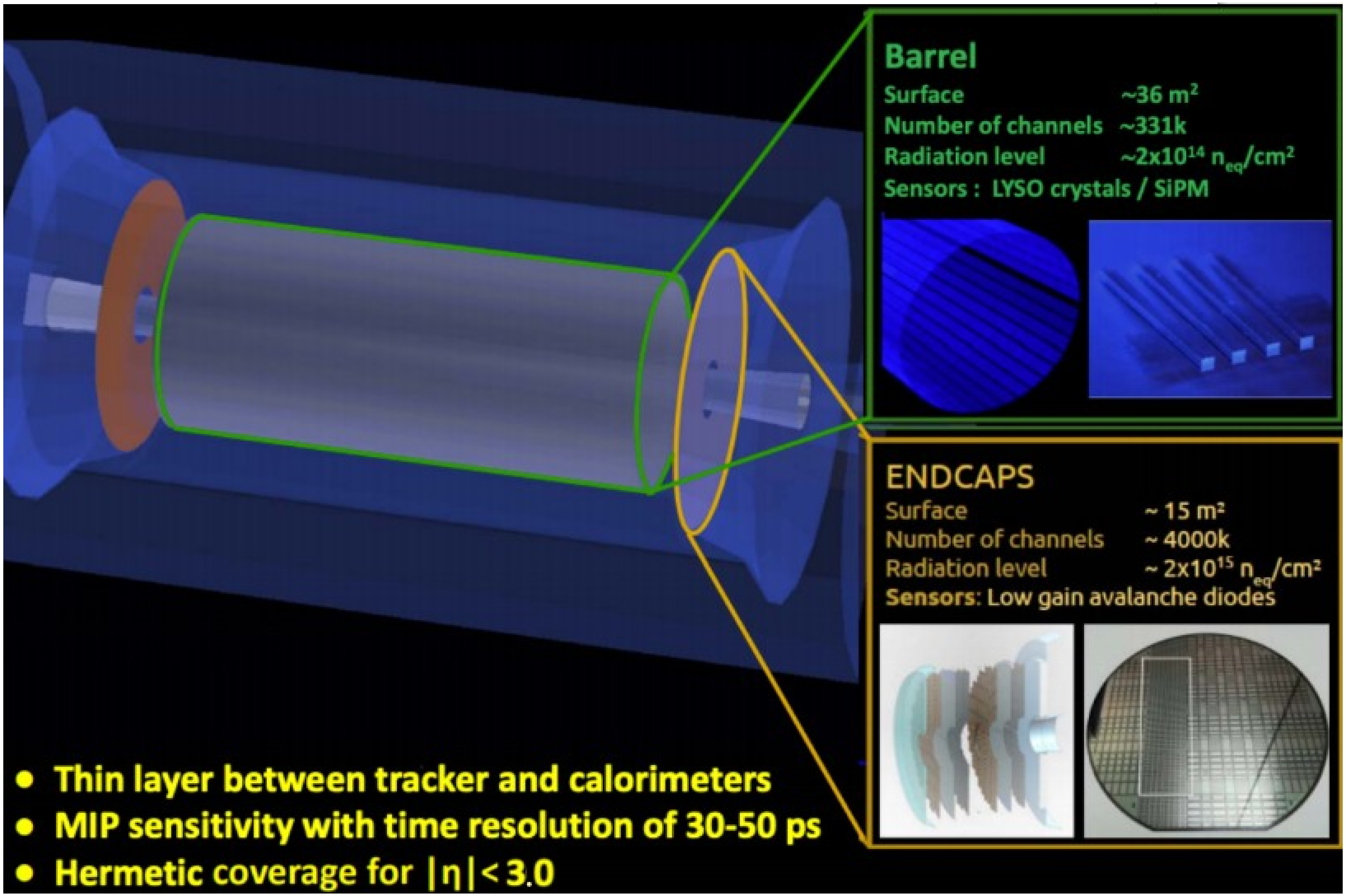
- Vertices at the HL-LHC will be produced with a ~ 180 ps spread distribution on time.
- The MIP Timing Detector (MTD) allows to tag particles with a precision of 30-50 ps.
  - Pile-Up mitigation to levels comparable to the LHC (4D vertexing, time track association).
  - Improvement of Physics Object reconstruction such as jets, lepton isolation, etc.
  - Unique Physics potential by using Time Of Flight tagging in different physics flavours.





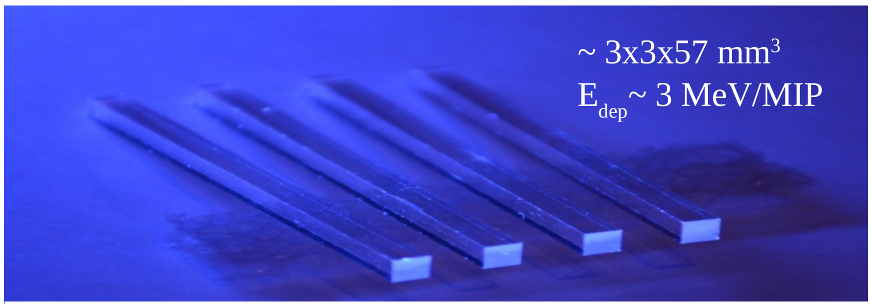
The Mips Timing Detector design

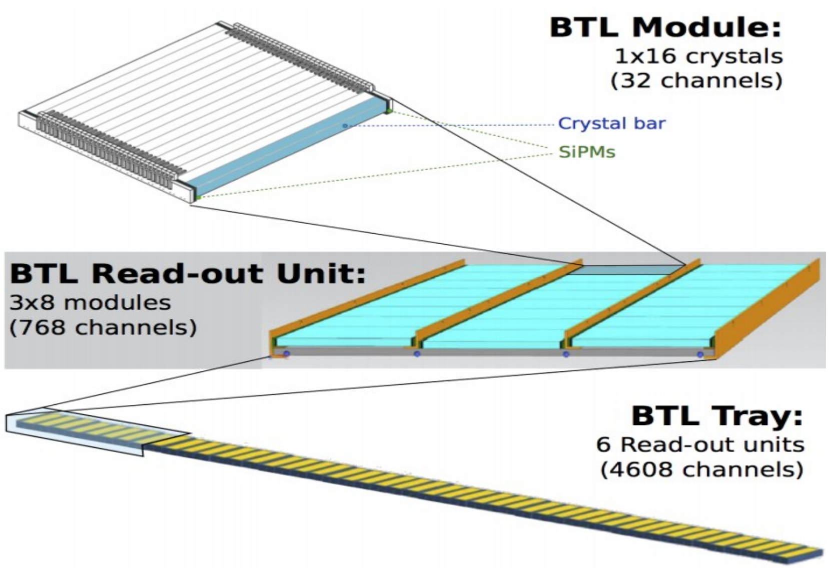
- Two subdetectors (Barrel/Endcap Timing Layer BTL/ETL) installed after the CMS tracker.

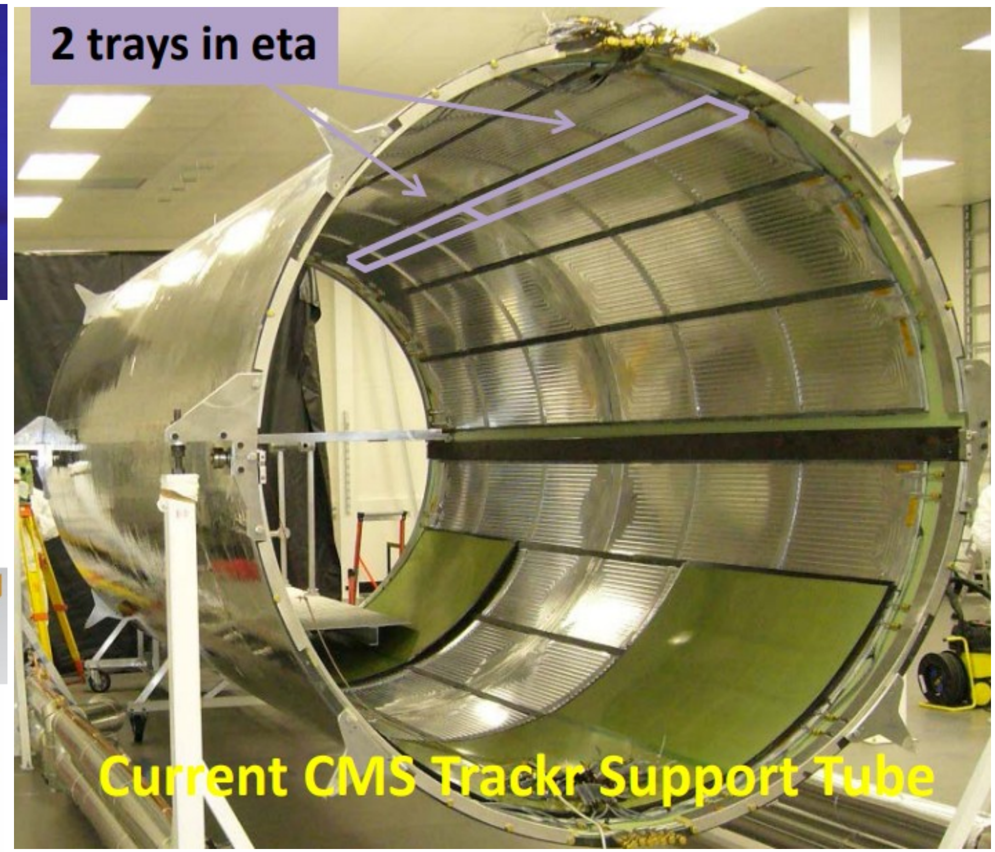


The Barrel Timing Layer (BTL)

- LYSO crystals as scintillator with an excellent radiation tolerance and fast rise and decay times.
- Total of 166k LYSO crystals with SiPMs at the two ends (response insensitive to position).
- Time resolution of 35 ps at the beginning of lifetime and 50-60 ps by the end.

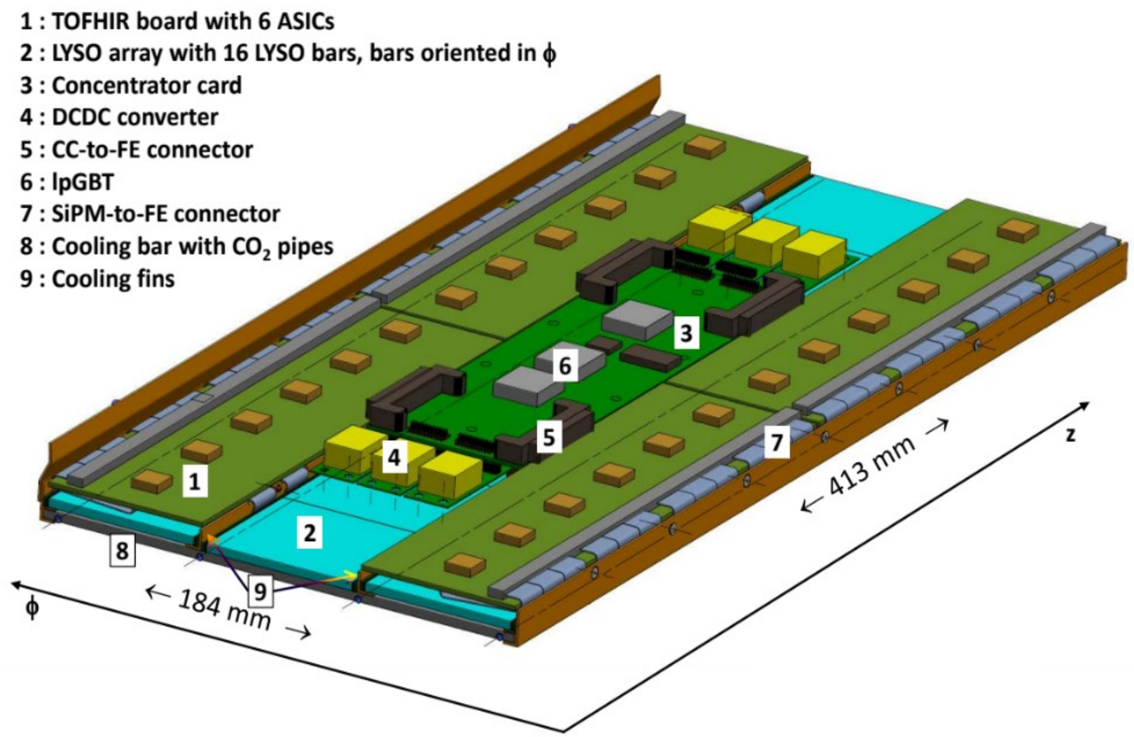


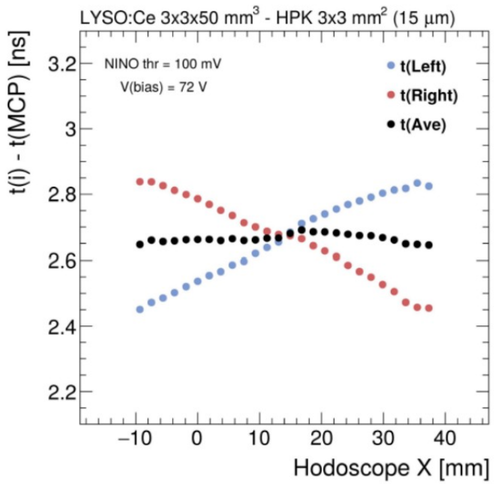


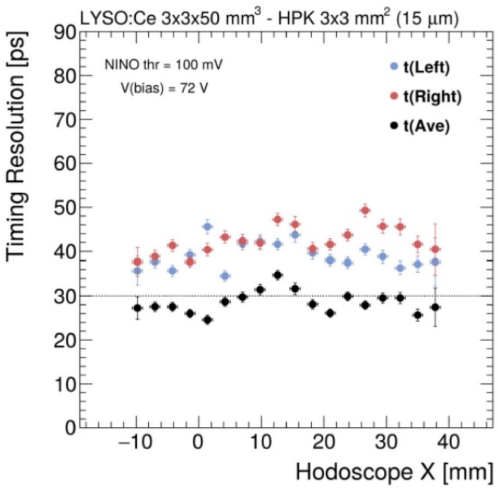


The Barrel Timing Layer (BTL)

- Small SiPM cells: fast readout, robust vs. magnetic field/radiation and low power consumption.
- Readout using TOFHIR board with 6 ASICS each reading up to 16 crystals (32 channels).
- Uniform time response and resolution in test-beams.
- Improved resolution by combining the two SiPMs.

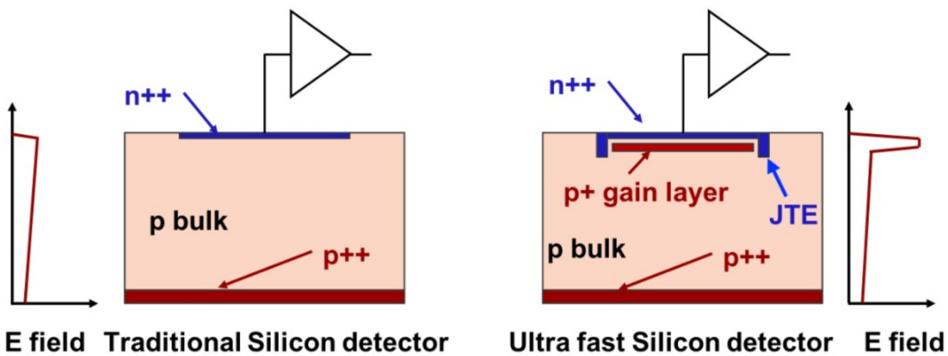


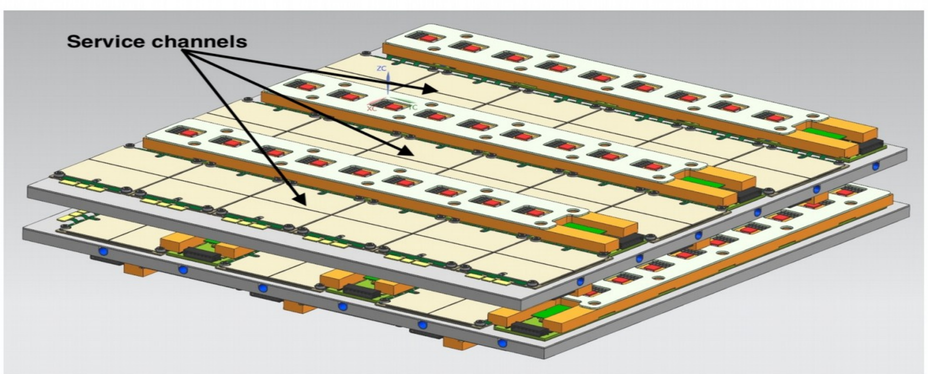


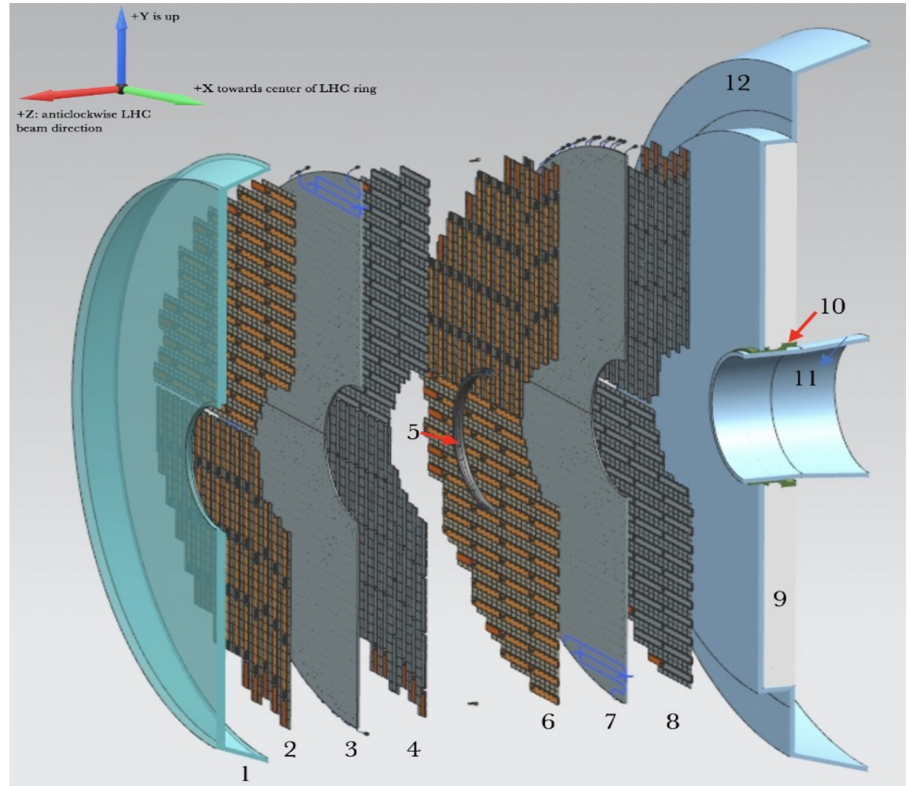


The Endcap Timing Layer (ETL)

- Low Gain Avalanche Diodes (LGADs) with highly doped p+ region just below the n- implants.
  - Radiation tolerance sufficient for endcap fluence (~< 2e15 neq / cm^2)
  - Very good timing response and resolution (30-45 ps at the beginning-end of lifetime).
- A total of 15.8 m^2 detector with two double-sided layers for each endcap.
- Small 1.3 x 1.3 mm^2 pixels for low capacitance.

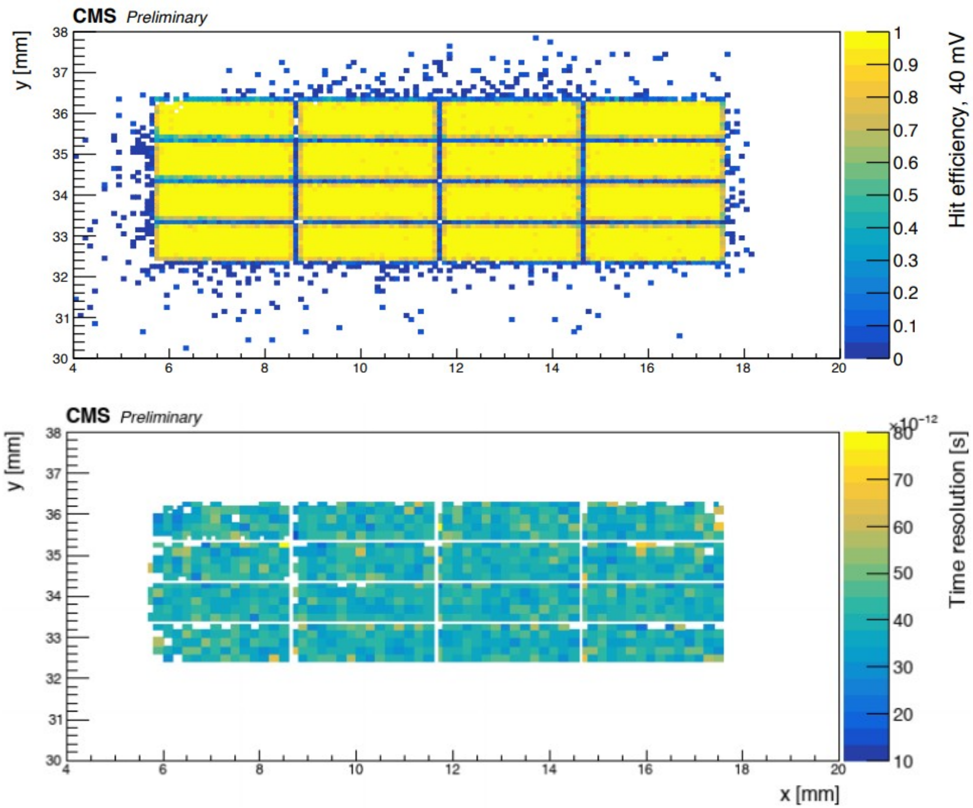


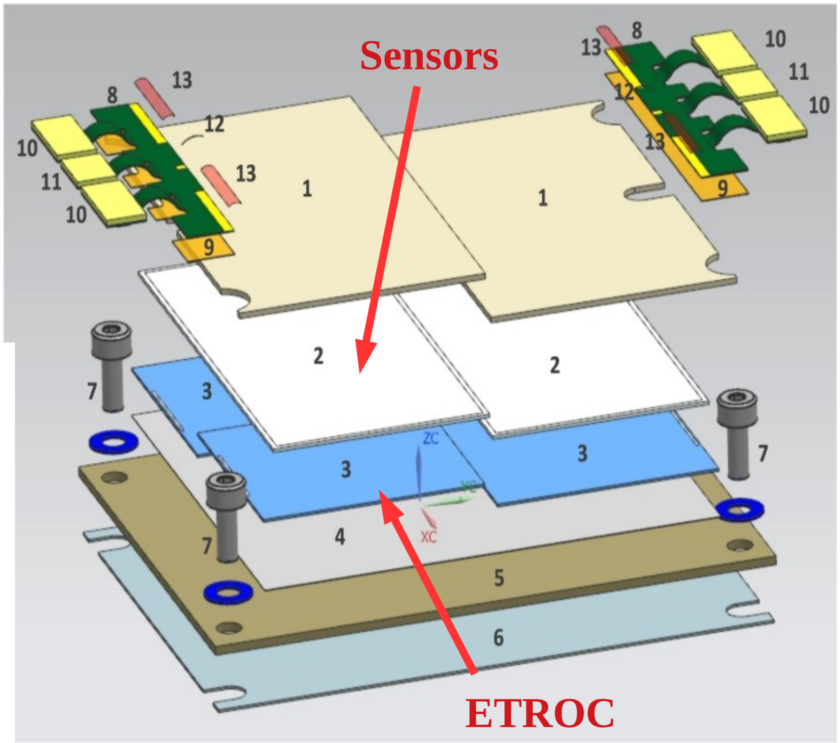




The Endcap Timing Layer (ETL)

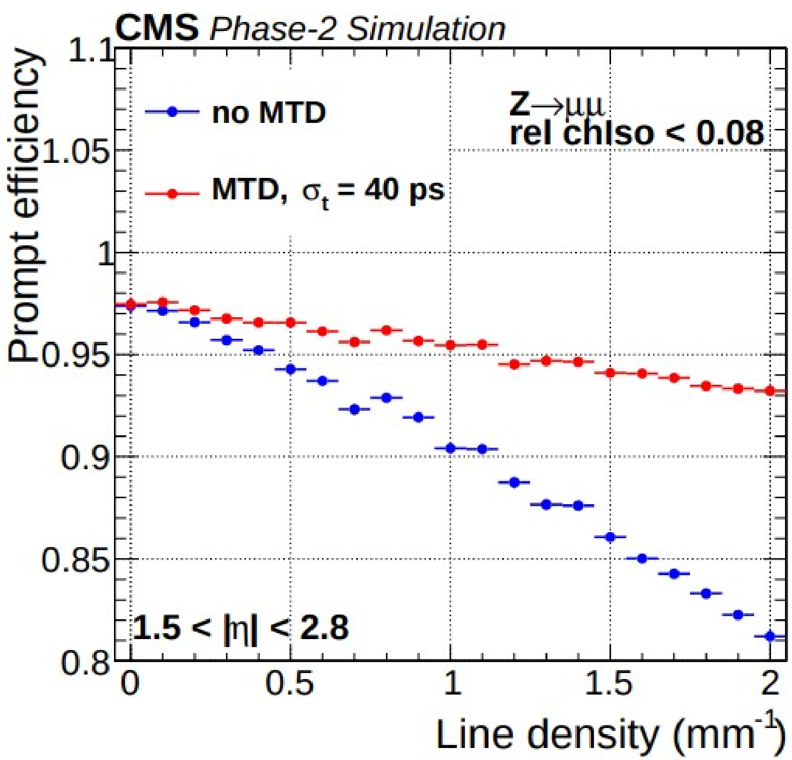
- Sensors are organized in arrays of 16x32 with a size of 21x42 mm^2.
- Two ETL ASICs (ETROC) needed to readout one module (each ETROC has 16x16 channels).
  - Each ETROC consists of pre-amplifier, discriminator and a TDC.
- Excellent efficiency (> 99%) and uniform time resolution in test beams

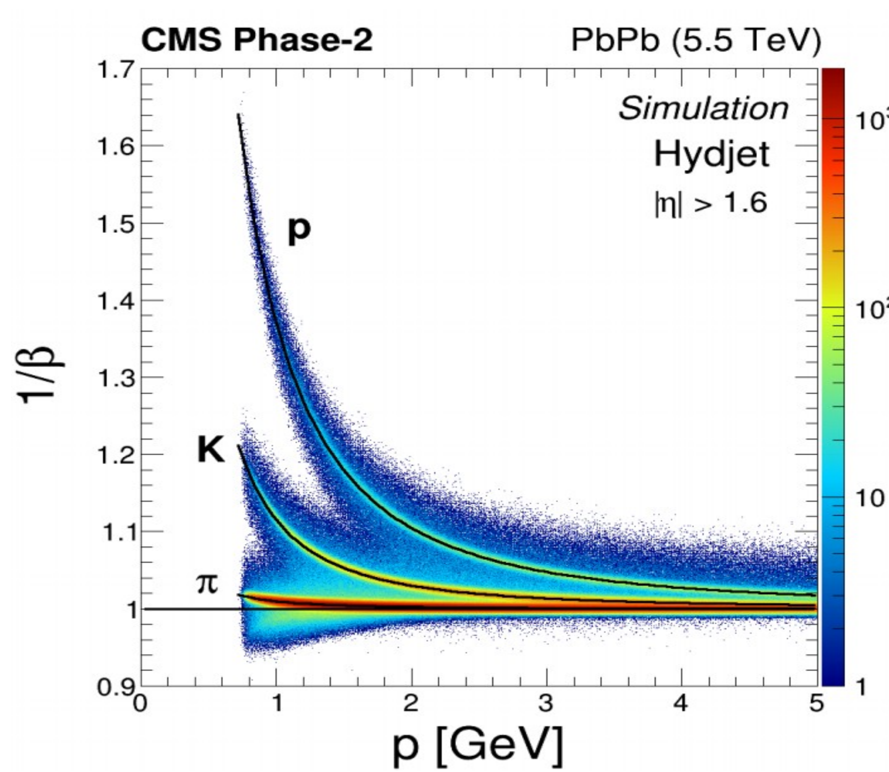




Improving physics objects performance

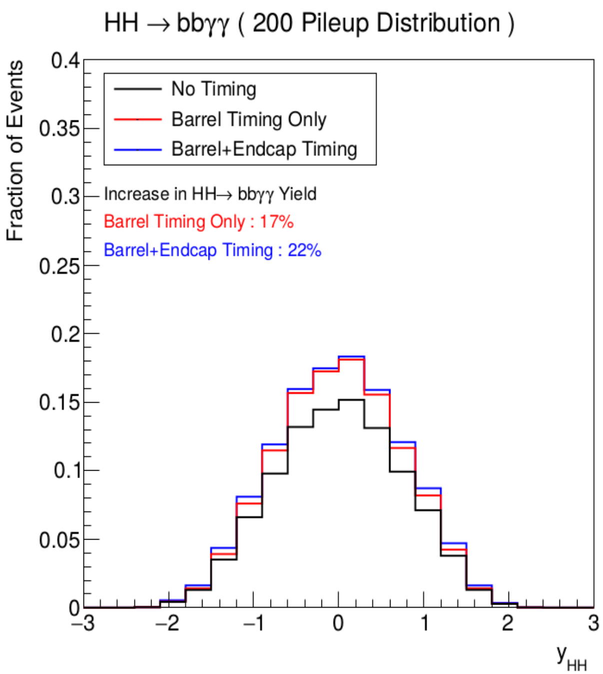
- Time information improves the quality of the reconstruction of physics objects.
  - Track time association allows to remove spourious pile-up tracks from reconstruction.
  - Impact on fake jet reconstruction, lepton isolation and ID, b-tagging, pt_{miss} resolution.
  - Also adding the possibility to perform Time-Of-Flight particle identification.

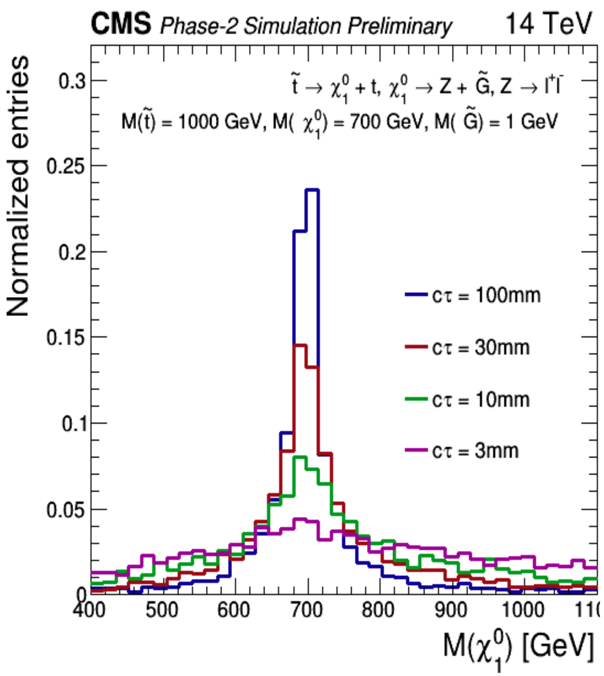


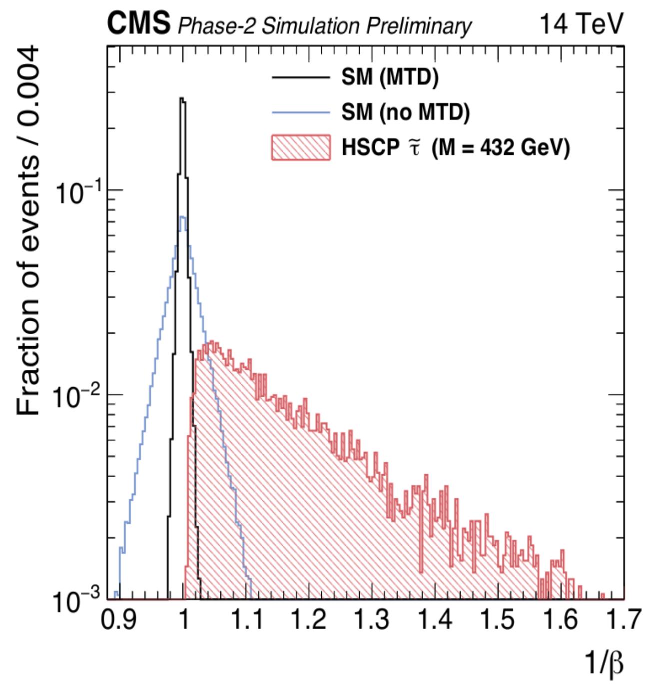


Impact on Physics analysis

- Improved object reconstruction has an impact on the reach of physics analysis.
  - Example: efficiency of HH → bbγγ improved more than a 20% due to better photon RECO.
- Unique physics opportunities profiting from the time information:
  - Example: Long-lived particles → possibility to reconstruct LLP mass in several models.
  - Example: Heavy Stable Charged Particles → improved discrimination through the speed.







Conclusions

- The CMS upgrade program includes a MIP Timing Detector providing 30-50 ps resolution:
  - Barrel Timing Layer (BTL) based on scintillator (LySO) technology.
  - Endcap Timing Layer (ETL) based on sillicon (LGAD) sensors.
- The MTD strongly impacts the pile-up mitigation bringing the HL-LHC profile to LHC levels.
- It enhances and improves the CMS physics object reconstruction:
  - Allows 4D vertexing, Time Of Flight ID, improved isolation, fake jet rejection, etc.
- Object improvements translates into improved sensitivity for important analysis such as HH.
- The MTD also brings unique Physics opportunities in searches for Long Lived Particles.
- **Learn more about the MTD in our TDR:**

https://cds.cern.ch/record/2667167/files/CMS-TDR-020.pdf