Fast sensors in the LHC experiments, medical imaging and autonomous driving

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Time measurements

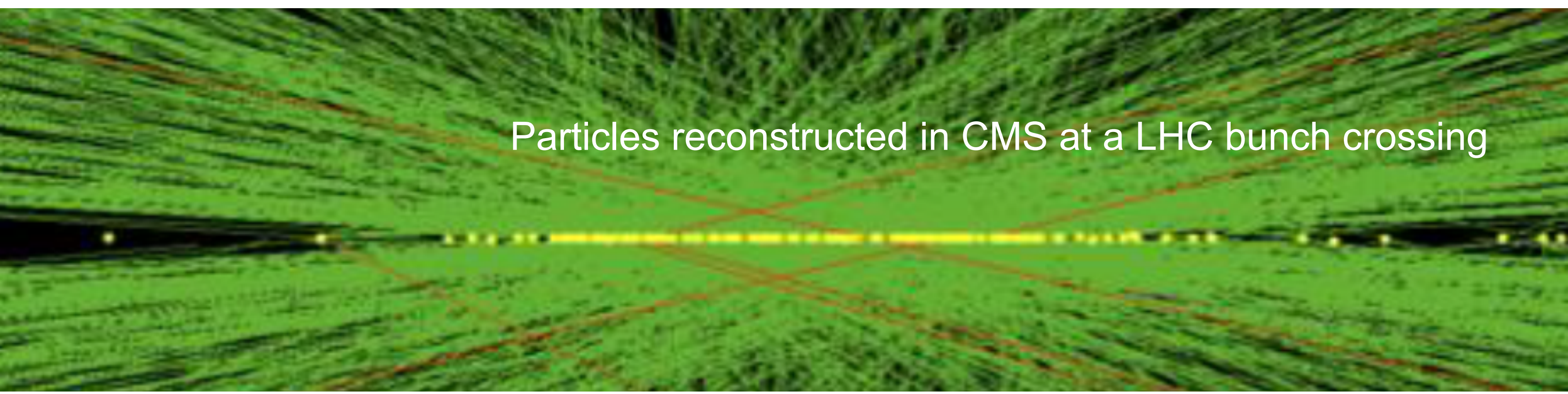
- Measuring time of particles detection:

  - **At LHC:** to correlate particles from the same interaction
  - **In PET:** to measure time-of-flight of photon pairs
  - **In car driving:** to create 3D images of the car’s surrounding space

- High accuracy:
  - precision of ~10 ps (~ 3 mm at speed of light)

Proton collisions at LHC

- Colliding bunches:
  - ~10^{11} protons
  - crossing time ~1 ns (30 cm long bunches)
  - 30-50 proton collisions at each crossing
- Time resolution of CMS detectors:
  - present detectors ~ 0.5 – 1 ns
  - future detectors ~ 10-30 ps



High Luminosity LHC

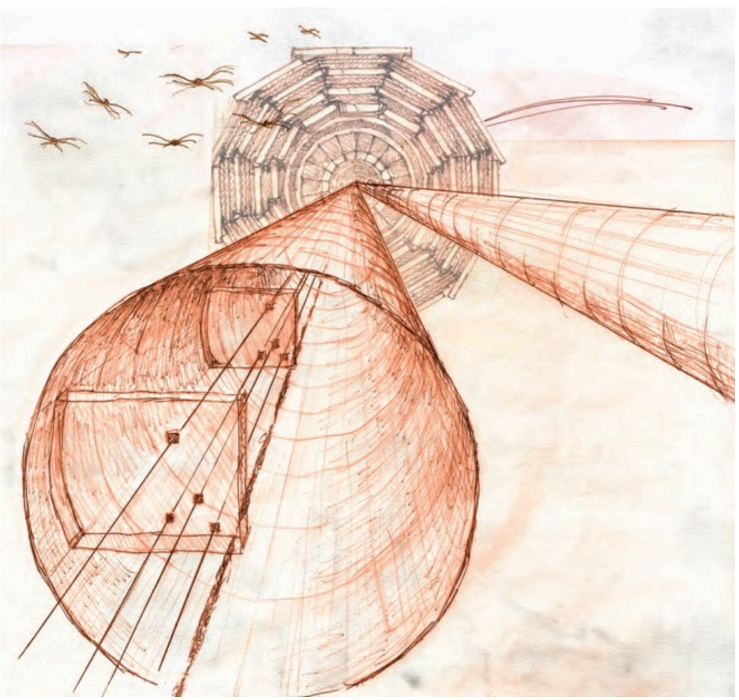
- The LHC will be upgraded to operate at 10x more luminosity
  → HL-LHC
- R&D towards major upgrades of the LHC experiments is starting
- Precise timing is an important requirement

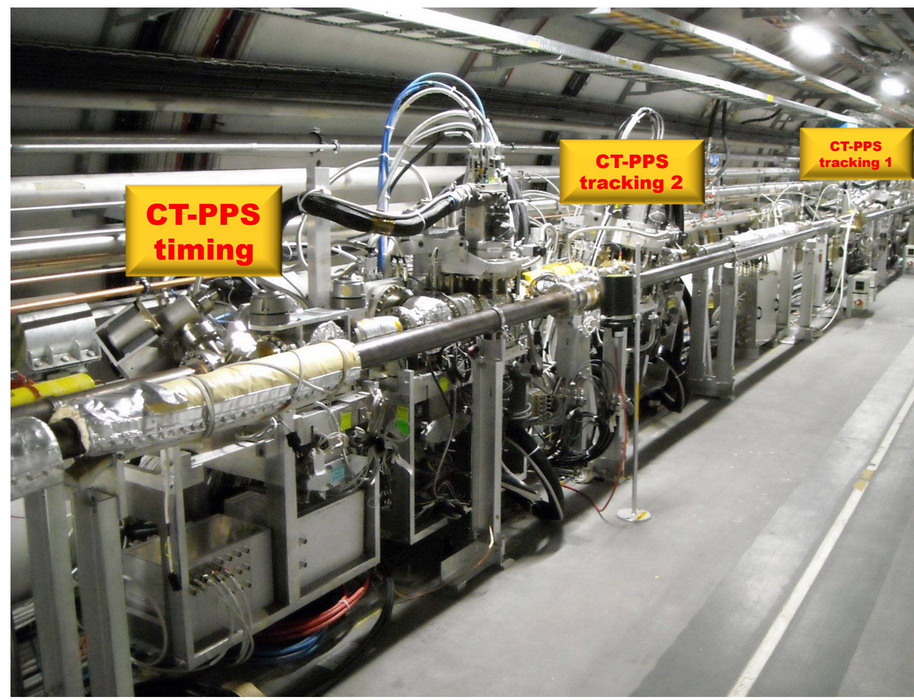
Timing detectors

- Detect individual particles and measure their time of arrival
  - charged particles, high energy photons, light photons
  - very small signals (few thousand electrons)
- Require very fast sensors
  - fast scintillators (e.g. LYSO)
  - Cerenkov radiation
  - detection of light (silicon photomultipliers)
  - fast solid state detectors (e.g. silicon avalanche diodes, diamond sensors)
- Require sophisticated integrated electronics
  - low noise amplifiers and discriminators
  - precise time-to-digital converters
  - fast data acquisition

PPS Proton Spectrometer

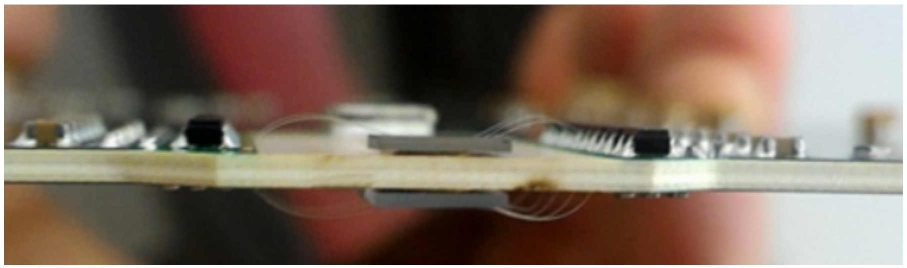
- Spectrometer in CMS to measure forward protons with high precision
- LIP is coordinating the PPS project

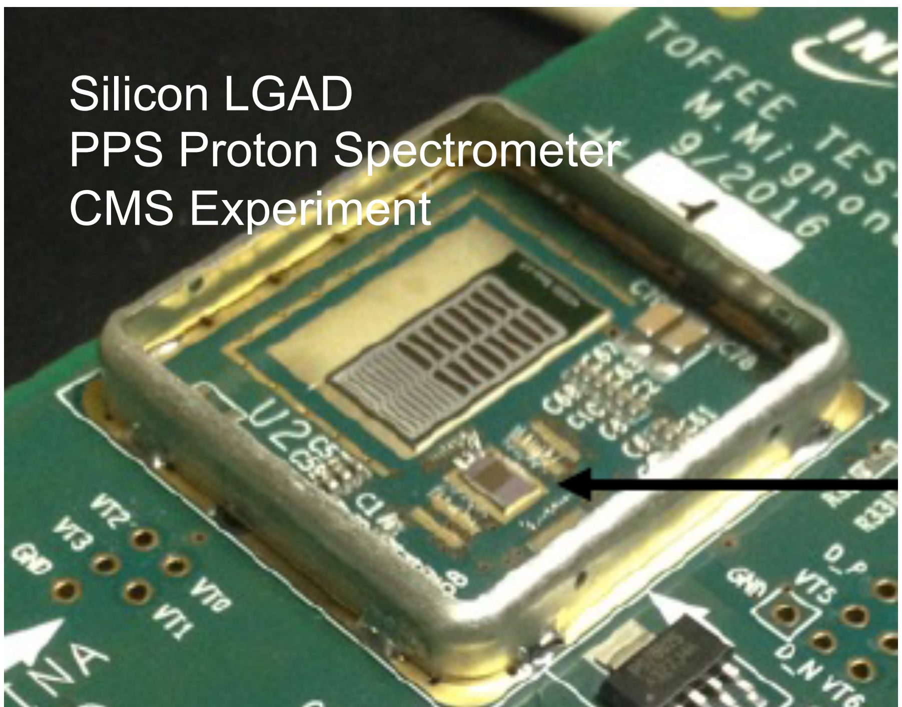




R&D on timing detectors

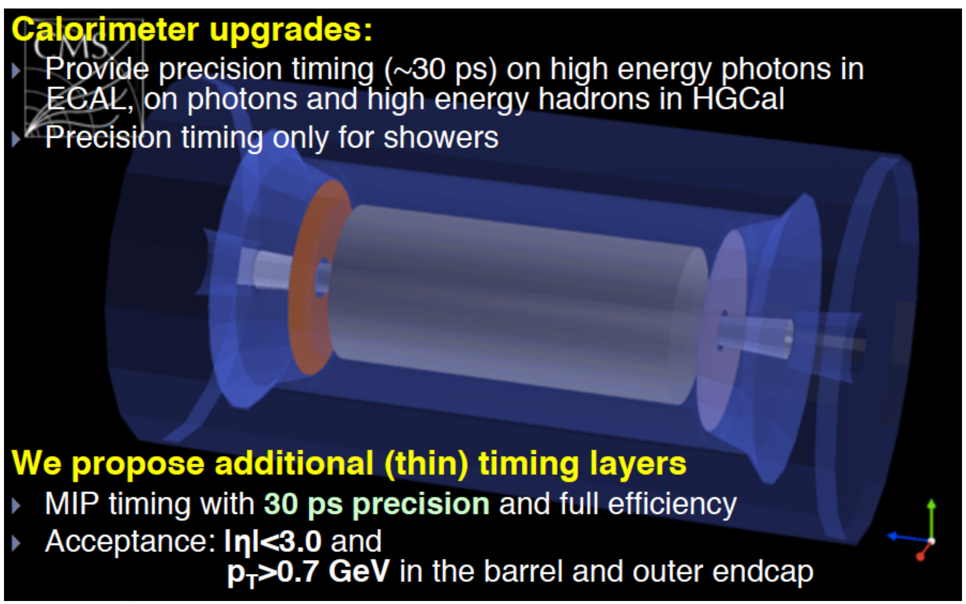
Strong involvement of LIP:

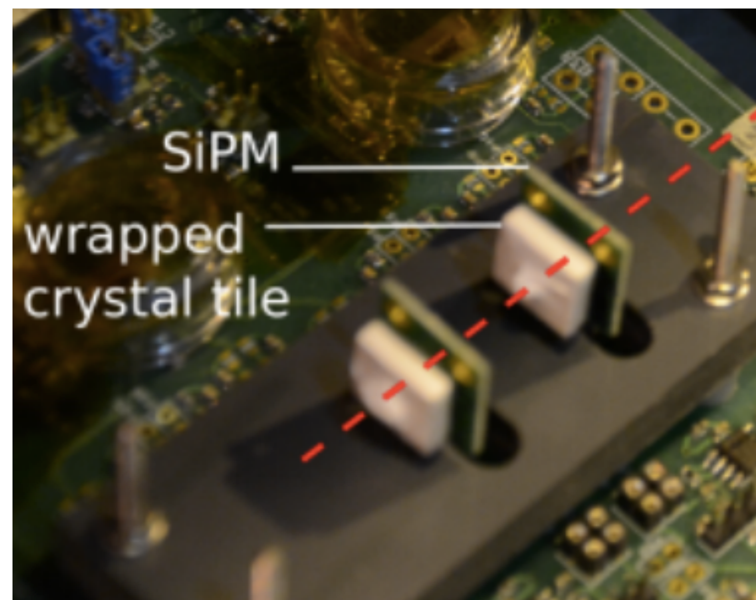




Timing layer for CMS upgrade

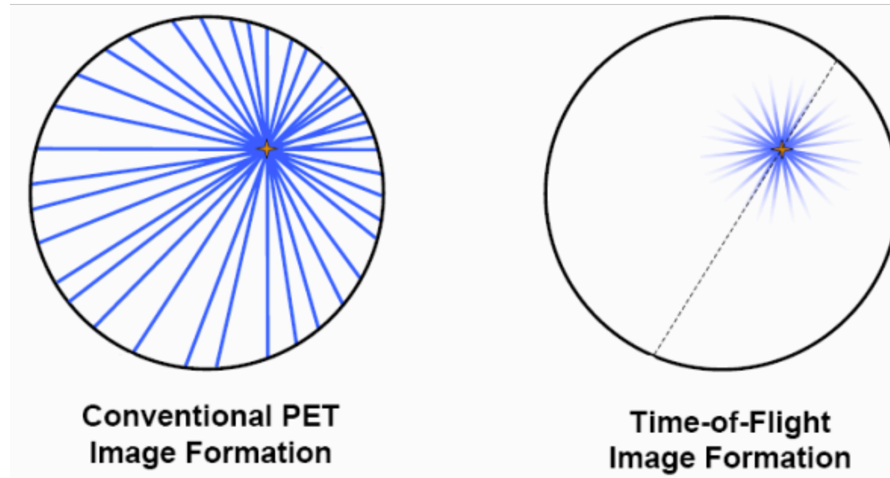
- Timing detector for CMS Upgrade
  - Crystals and Silicon Photomultipliers in the barrel
  - Fast silicon sensors in the endcap
- LIP is leading development of the readout electronics



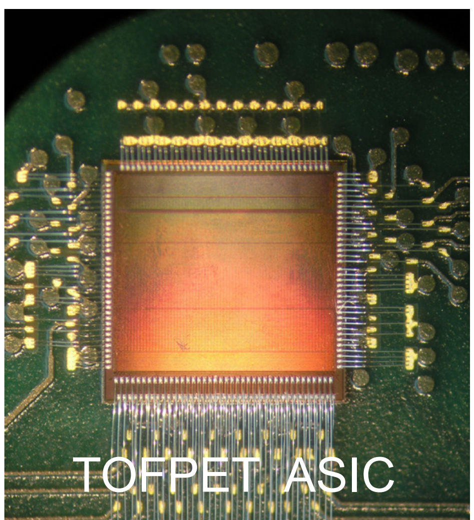


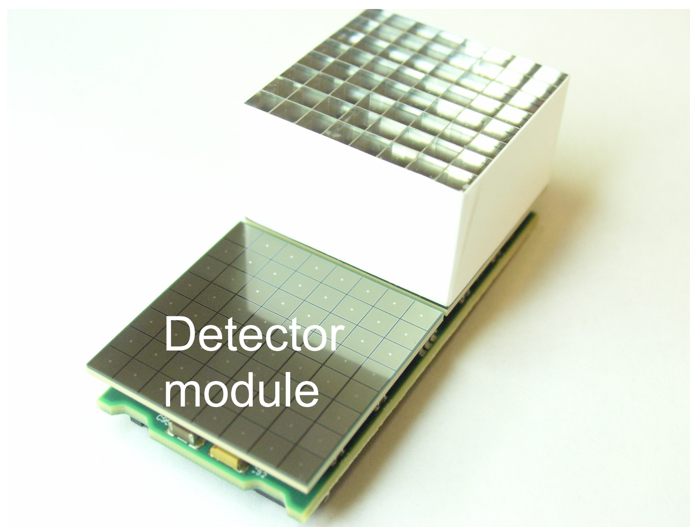
Time-of-flight in PET

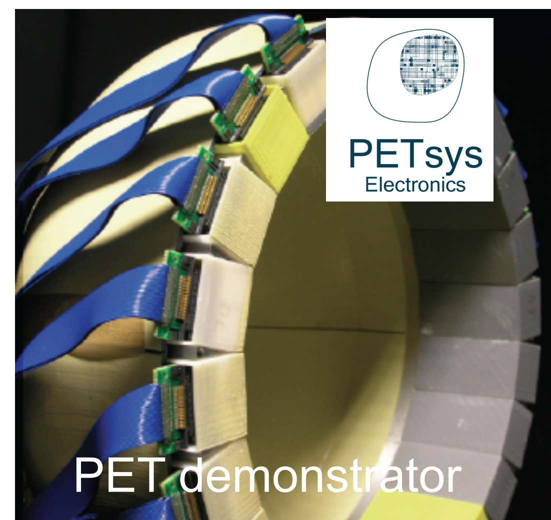
Time-of-flight in Positron Emission Tomography
- time difference of opposite 511 keV photons
- much better images



Developments at TagusLIP (@ Taguspark):

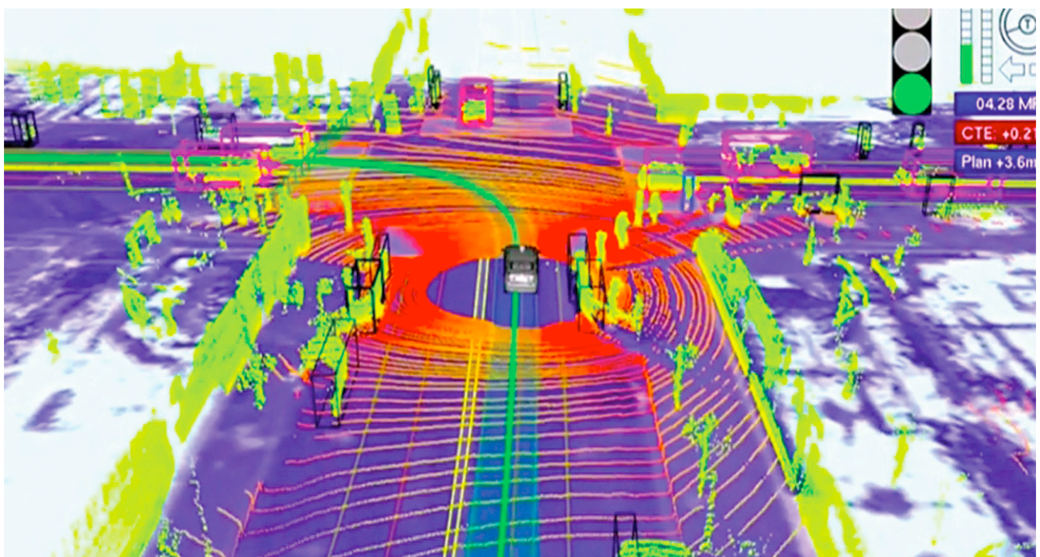


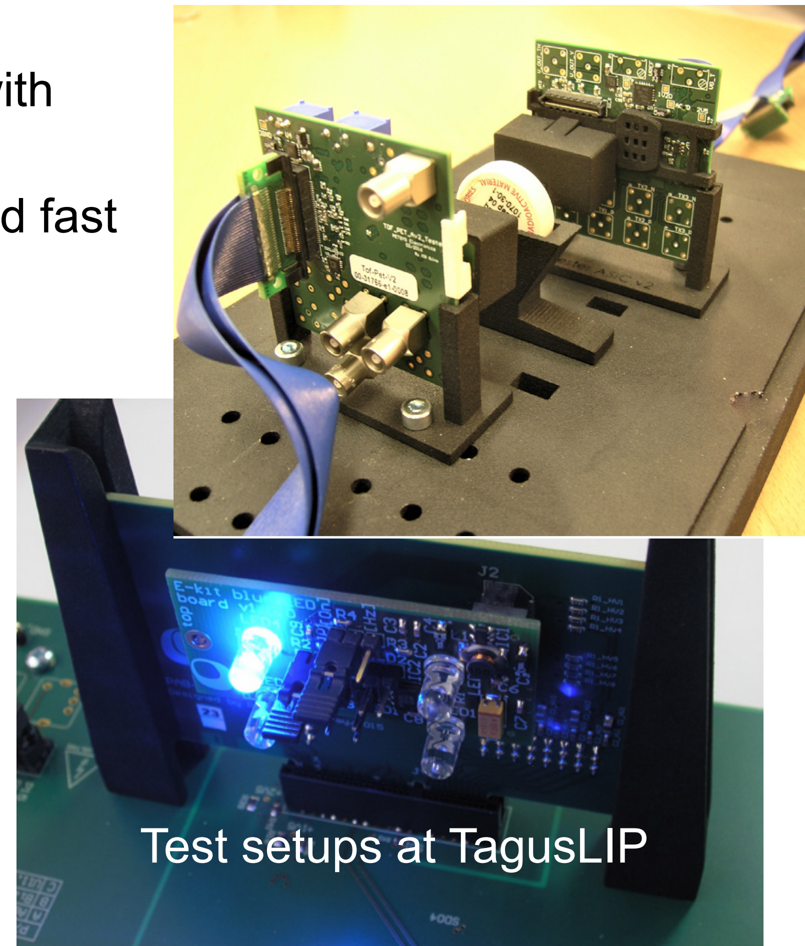




LIDAR in autonomous driving

- In the future, self-driving cars will require laser-based sensing technology
- LIDAR: scan a laser light beam around the car to create a high-resolution 3D map of the surrounding environment.
- Time measurement of reflected laser light with high precision
- Core technology: silicon photomultipliers and fast integrated electronics





Test setups at TagusLIP

Detector development

- Not so easy

- Requires a mix of physics insights, theoretical modeling, computing simulations, many measurements, good intuition and lots of patience

- To see a detector working for real as it was foreseen it is very rewarding

- It may deserve a Nobel prize (MWPC, G. Charpak, 1992)