4D Fast Tracking for Experiments at the High-Luminosity LHC

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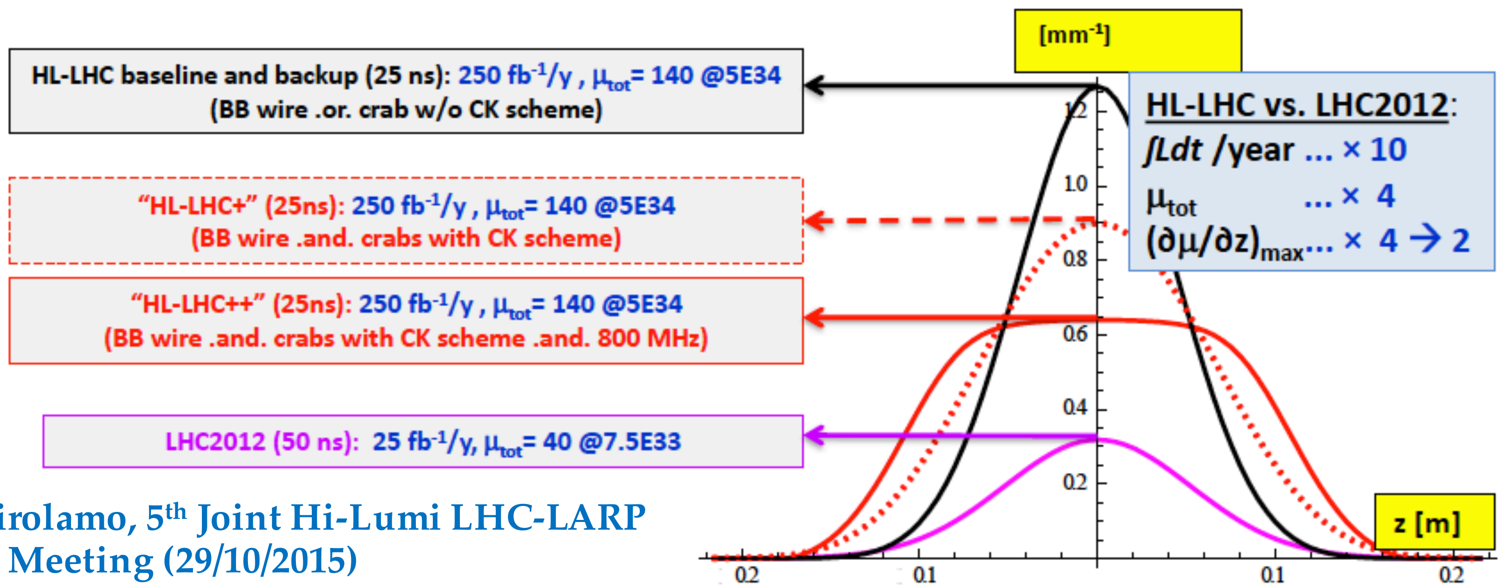
Introduction

- The **High-Luminosity LHC** (HL-LHC) phase will be characterized by an instantaneous luminosity of 5×10^{34} $cm^{-2}s^{-1}$ for the ATLAS and CMS experiments at CERN, and $1\text{-}2 \times 10^{34}$ $cm^{-2}s^{-1}$ for LHCb
- HL-LHC will allow to collect an integrated luminosity up to 250 fb^{-1} per year
- As a side effect the average number of visible interactions per bunch crossing will grow up to 140
- In such environment **precise tracking** will be extremely challenging, not only for the high fraction of expected **ghost tracks**, but also from the **radiation-hardness** point of view

Pile-up at the HL-LHC

- A novel colliding scheme (“crab-kissing”) would reduce the line density of **pile-up events** along the luminous region
- With the foreseen pile-up density profile, a FWHM of about 300-600 ps is expected (depending on colliding scheme)
- A time-tagging resolution of 10-20 ps will greatly help discriminating overlapping events with **hit time-association**



B. Di Girolamo, 5th Joint Hi-Lumi LHC-LARP Annual Meeting (29/10/2015)

The Concept

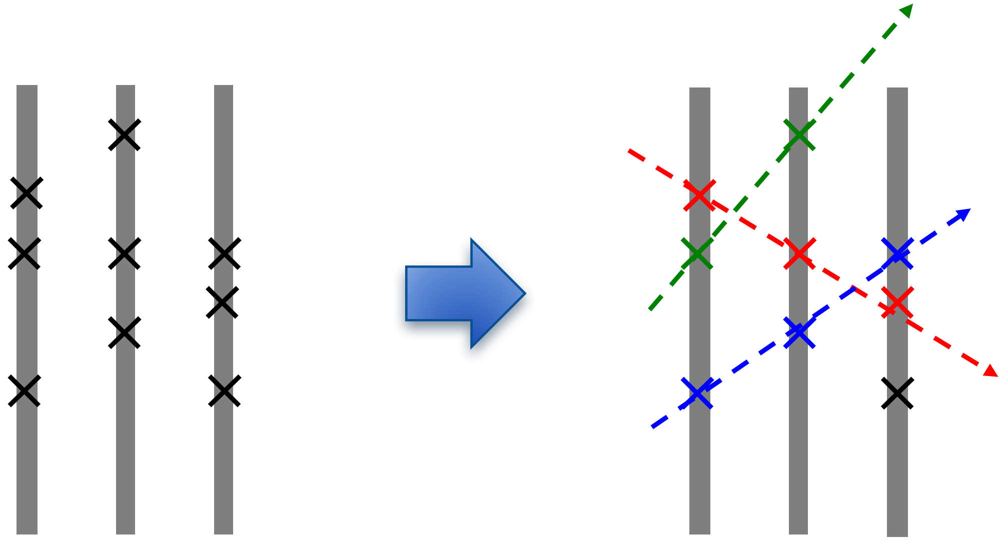
- We aim at developing a prototype of an innovative tracking detector with embedded **4-dimension tracking** capabilities, based on accurate time and position particle hit measurements
- This detector would allow the full exploitation of the physics potential of the HL-LHC, in particular for flavor
- The precise determination of the **time of the track** is recognized to be the key feature needed to **disentangle many overlapping events** and enhance track trigger selection capabilities
- **Real-time track reconstruction** with dedicated processors (FPGA) is proposed to allow efficient operation at high-luminosity

Timing Detector

- In timing measurements the **slope-to-noise ratio** has to be optimized rather than the signal-to noise ratio alone
  - Very low r.m.s. noise σ_n
  - Very steep signal at threshold level $(dV/dt)_{thr}$
- Time resolution is given by the ratio: $\sigma_t = \frac{\sigma_n}{(dV/dt)_{thr}}$
- Many contributing factors to consider:
  - Need large signals, and fast "signal collection"
  - Reduce input capacitance, match amplifier bandwidth
  - Electric (weighting) field uniformity
  - Energy release (total, straggling, direction)
  - Time-walk correction
  - Digitization (e.g. TDC bin size and linearity)
  - …

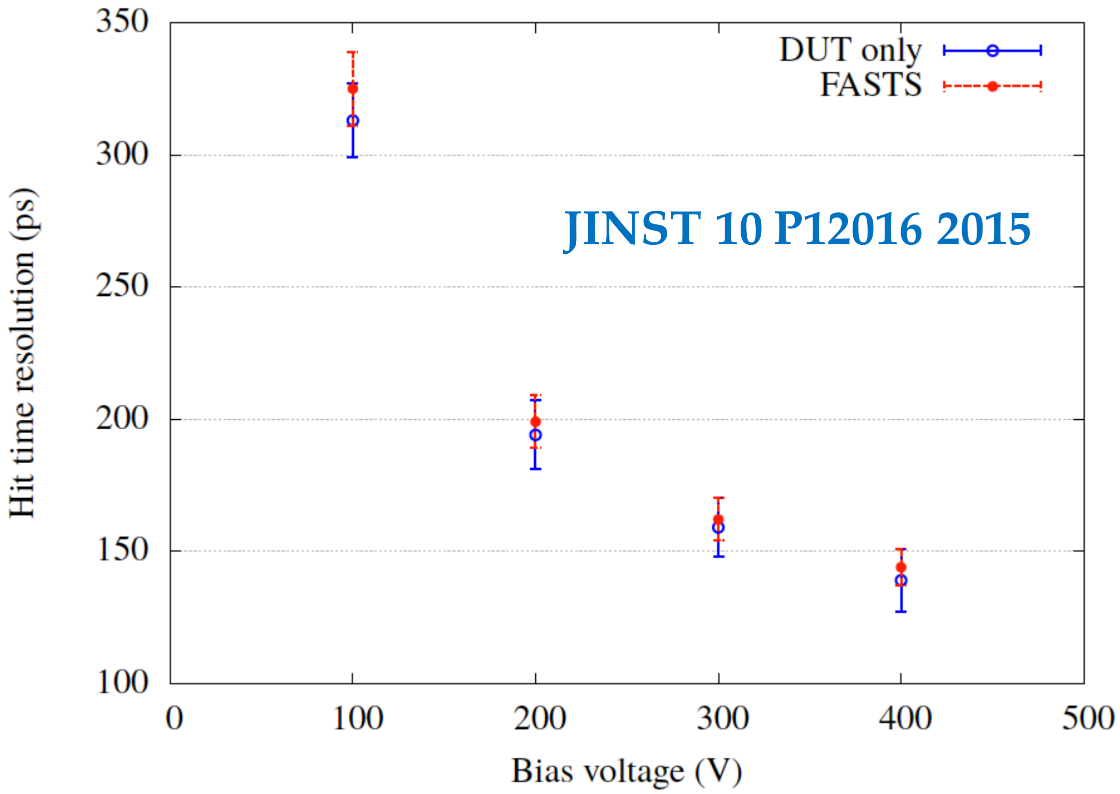
Tracking with Timing

- Precise tracking is mandatory to measure and extrapolate primary and secondary vertices
- The use of **precise timing information** can dramatically improve tracking in the HL-LHC high pile-up conditions
  - Simplification of pattern recognition (increased speed)
  - Significant reduction in ghost tracks



State of the art

- NA62 Gigatracker detector (CERN SPS)
- Hybrid pixel detector
  - 200 μm thick sensor, **300 × 300 μm²** pixels
- 130 nm IBM CMOS read-out ASIC
  - 98 ps TDC bin, time-over-threshold discriminator
- Over-depleted operation (> 300 V)
- Time resolution better than **150 ps**



Proposed detector

- We propose to use **3D silicon sensors**, specifically conceived to operate in environments requiring extreme **radiation hardness**
- 3D sensors geometry allows a very **fast charge collection**, a feature of paramount importance for precise time measurements
- Excellent position resolution can also be achieved thanks to the small pixel size
- The goal is to design sensor and front-end electronics capable to provide hit time resolution of the order of **20 ps**, together with a hit position resolution better than **40 μm**
  - Preliminary simulations show that this timing performance is attainable with tailored sensors with more uniform field

Real-time 4D tracking

- Feasibility studies of a **4D fast track finding system**, using hits' space and time information, has been recently presented (**arXiv:1512.09008**) as a possible solution for the low level track trigger of the HL-LHC experiments
- The system is based on a **massively parallel algorithm** implemented in commercial **FPGAs** using a pipelined architecture and allows a precise real-time determination of the track parameters (including time) while maintaining a low fraction of reconstructed fake tracks
- Such a system would allow to perform flavor physics at LHC while operating at instantaneous luminosities more than one order of magnitude larger than current, with **large tracking efficiency** and **negligible ghost track rate**

Challenges

- **Time resolution** in the order of 20 ps with a very high density of channels
- One of the main challenges for HL-LHC operations is **radiation hardness**
  - Sensors and electronics are required to be able to sustain large hadron fluences, exceeding 10^{16} 1 MeV neutrons equivalent per cm^2
  - The front-end chip will be built using 65 nm CMOS technology
    - Good candidate that matches the radiation hardness requests of the HL-LHC experiments
- **Real-time tracking** at 40 MHz with high efficiency

Potential Impact

- The impact of a fast timing pixel detector with embedded tracking capabilities on the physics reach of **future high-luminosity experiments** is of paramount importance
  - The proposed detector will maximize the potential of the HL-LHC, which will be able to continue playing a leading role in the coming years
- In particular flavor physics experiments at high luminosity would greatly benefit from such detector, by making accessible experimental evidences of phenomena that cannot be explained within the Standard Model
- Such technology may find interesting applications in **space research**, where radiation hard electronics is needed, and **medical physics**