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Upgrades on timing and PID detectors in LHC experiments

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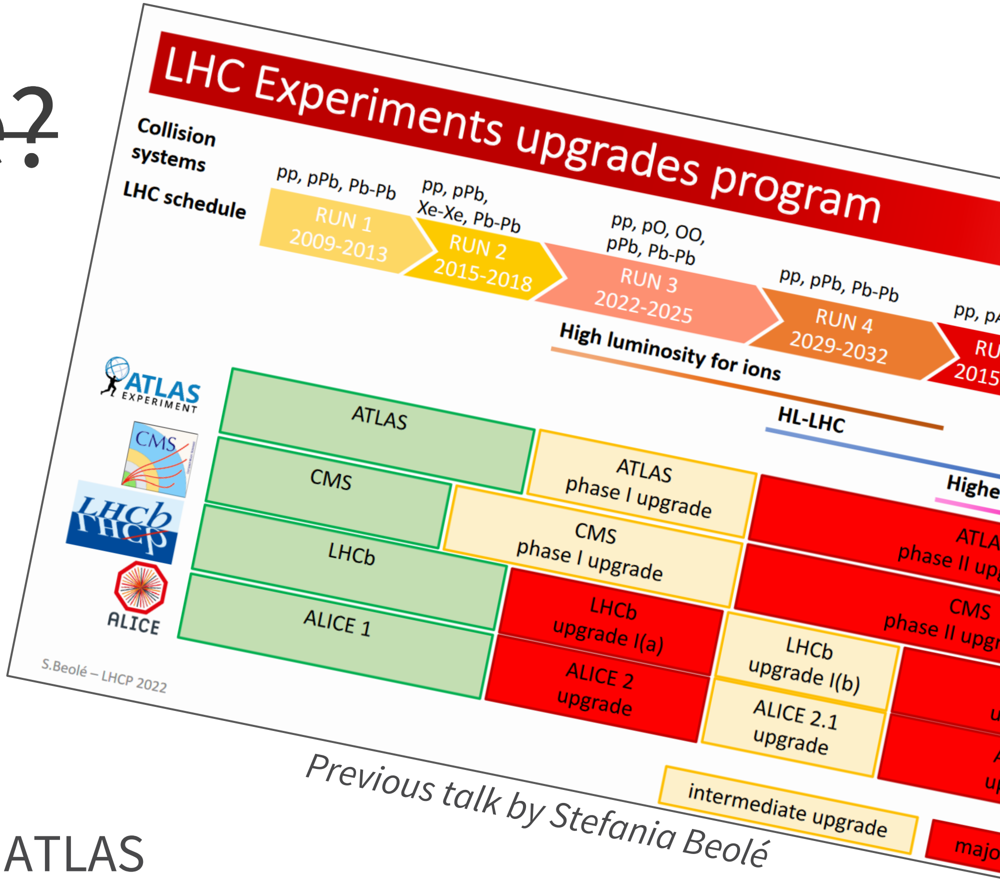
On behalf of the ALICE, ATLAS, CMS, and LHCb collaboration

Maastricht University
Nikhef

HL-LHC: A blessing ~~and a curse?~~



Previous talk by Stefania Beolé

- Higher luminosity desired from physics community
  - More statistics
  - More particles
  - More particles
  - More radiation damage

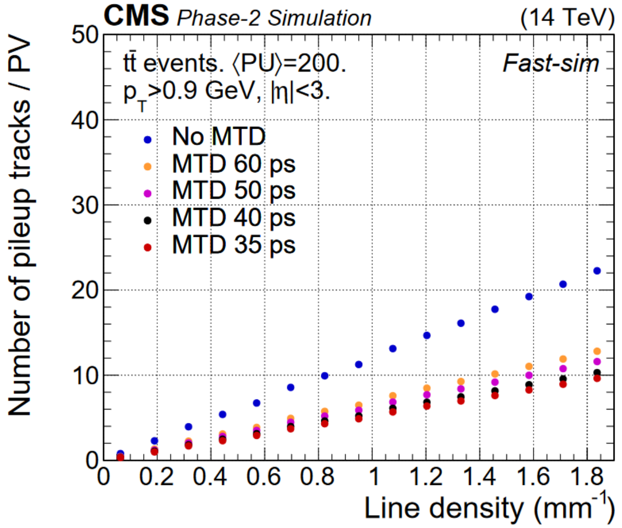
- Initial conceptual work on HL-LHC started in 2010
  - First ideas on how to mitigate increasing pile-up by CMS and ATLAS
  - Add another dimension, **time**!
    - Aids in disentangling spatially overlapping events

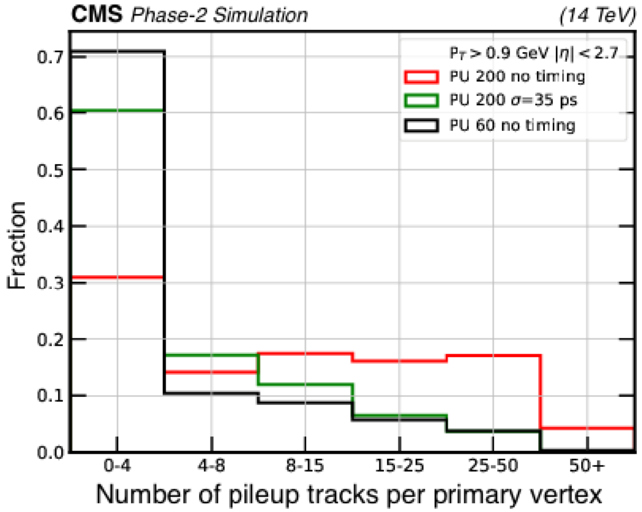
  - In previous years simulations have proved that adding timing **aids** in regaining the desired **physics performance** and **mitigating pileup**

Timing resolves the common problem in LHC

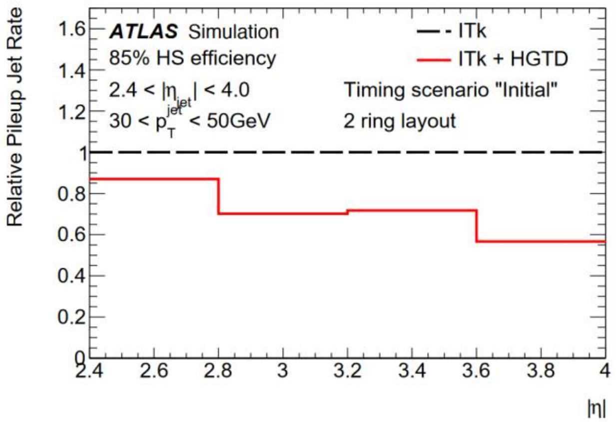
CMS (LHCC-P-009)

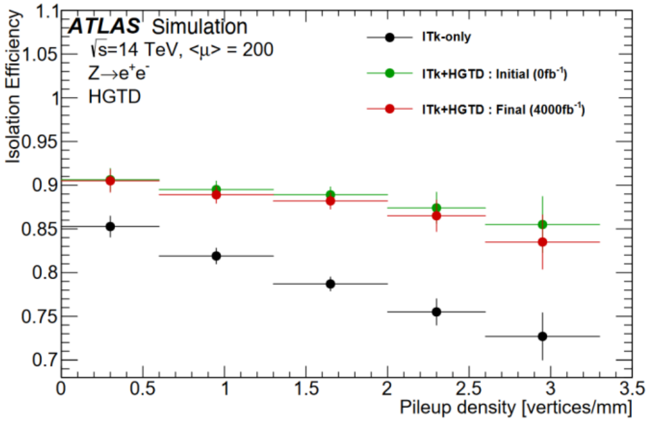
And later on CMS-TDR-020



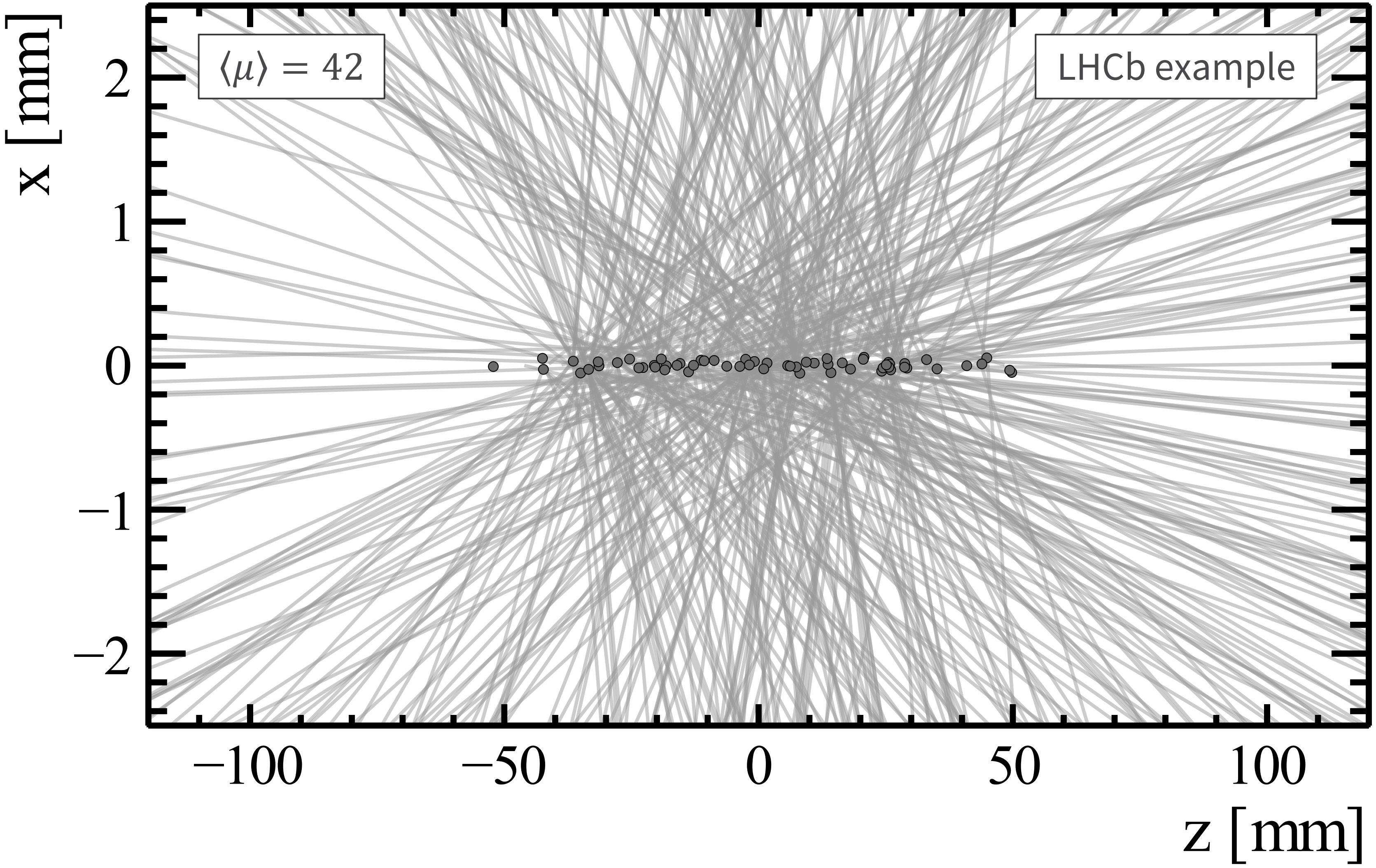


ATLAS (ATLAS-TDR-031)



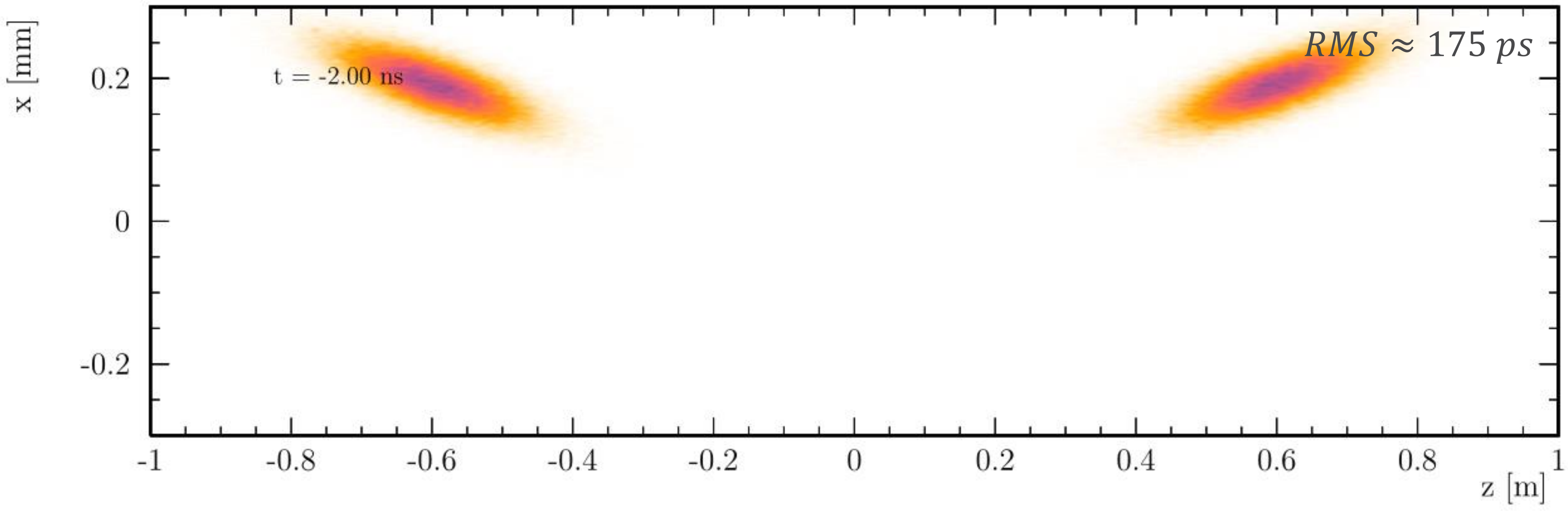


Pile-up challenge for HL-LHC



Increased luminosity moves us to an **extremely challenging environment** to do particle physics

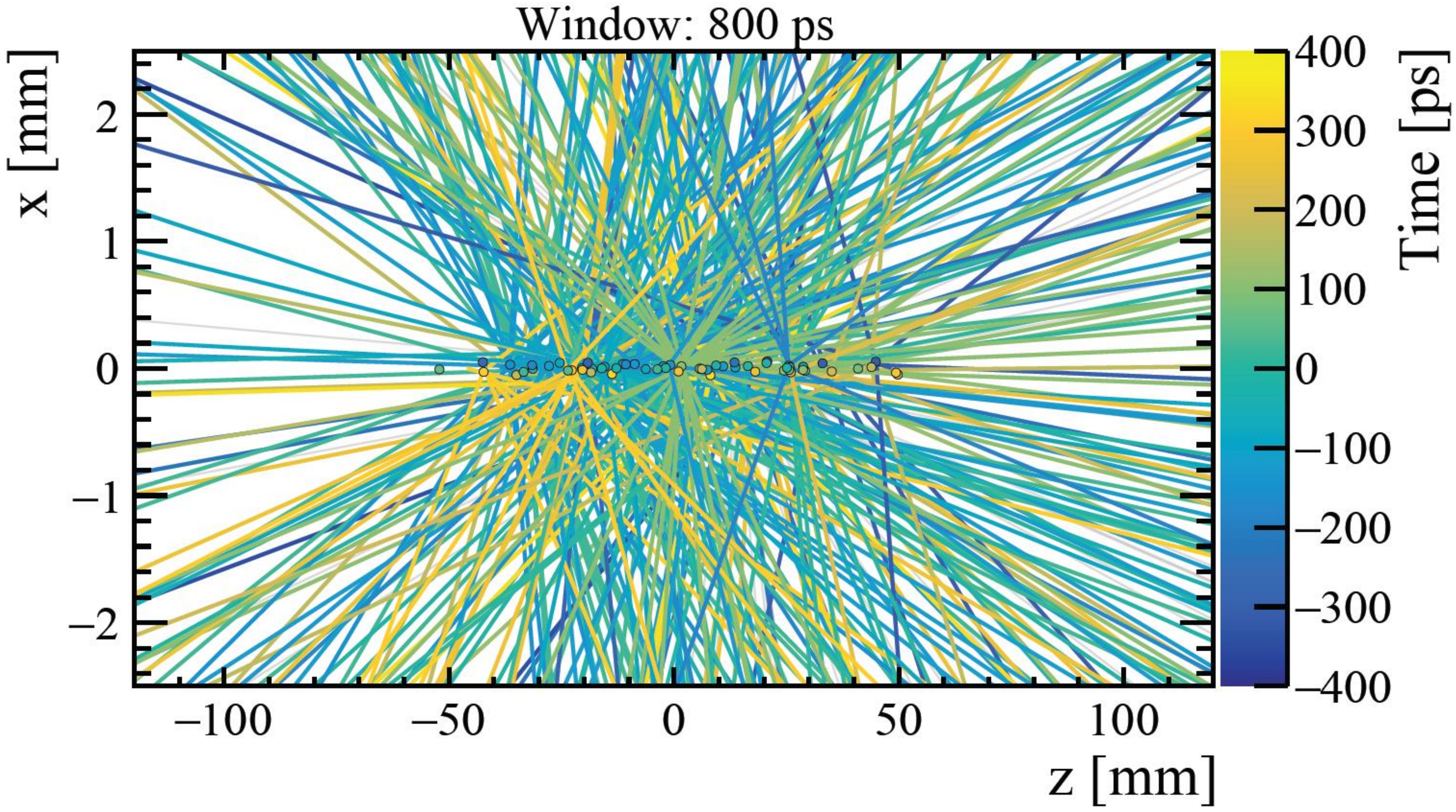
Addition of time information



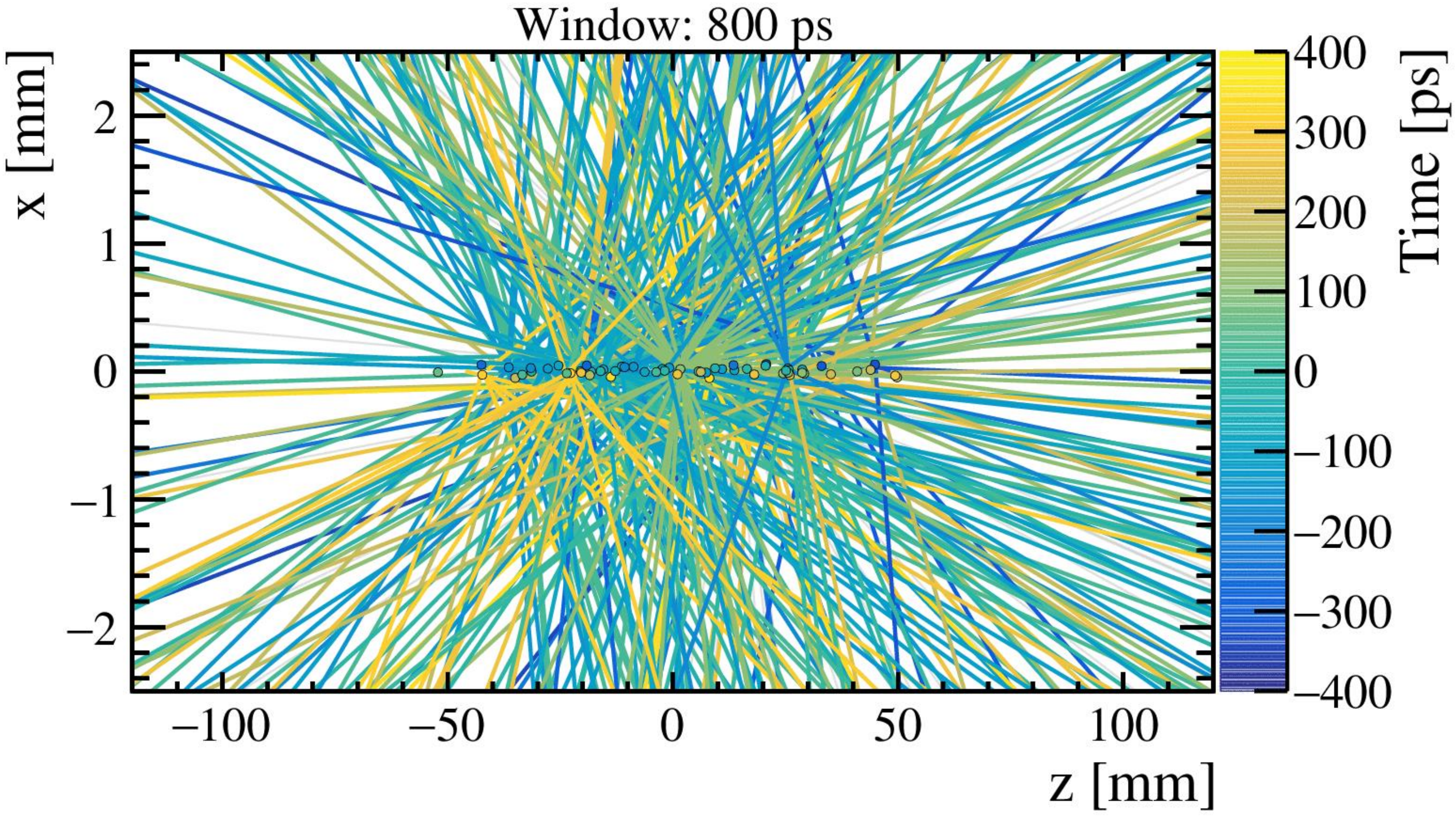
MC of two Gaussian distribution moving – not including the rotation by crab cavities

By T. Evans

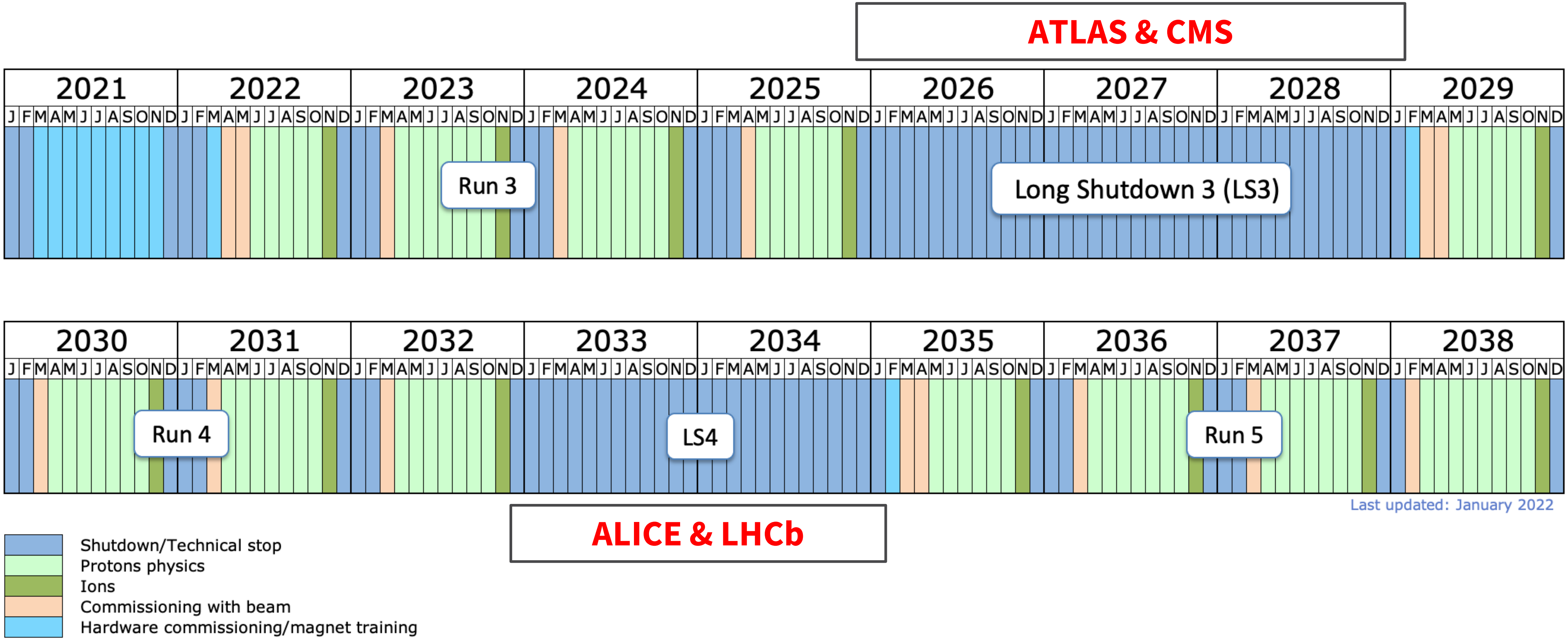
Addition of time resolves pile-up



Addition of time resolves pile-up



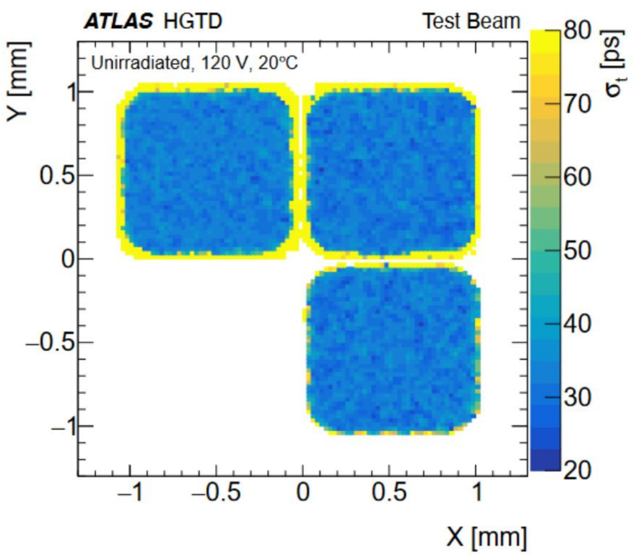
Implementing timing in the experiments

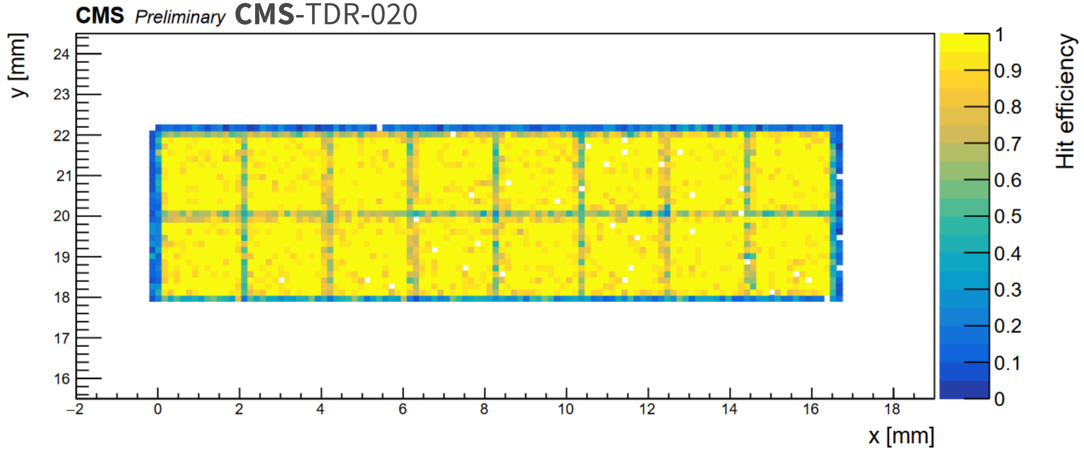


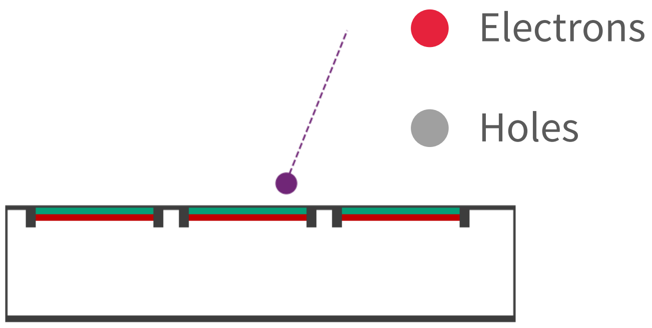
ATLAS and CMS

- (Almost) same case as LHCb: **track density in forward region**
  - For CMS also important physics case in barrel region
- Both will employ "**timing layers**" as end-caps
  - CMS also using a complete barrel consisting of crystals with silicon photomultipliers
- Large pitched Low Gain Avalanche Detectors (**LGAD**) are employed for both endcap designs

ATLAS-TDR-031

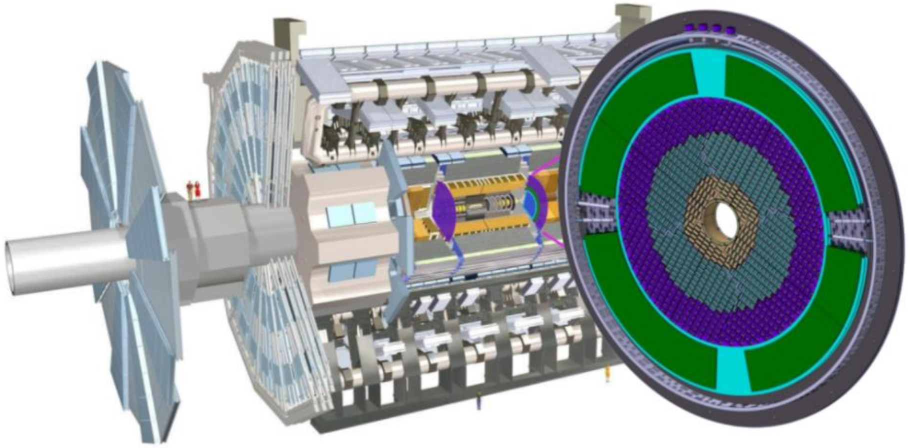






LGAD principle: electron multiplication

ATLAS: HGTD



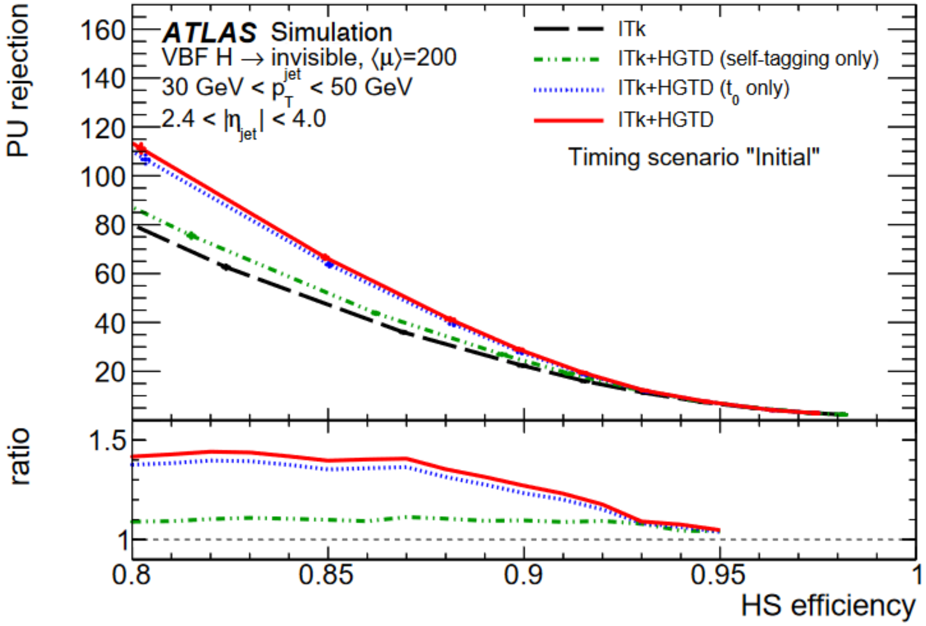
High **G**ranularity **T**iming **D**etector

- Endcaps ±3.3 m from nominal IP
- Radiation-tolerant LGADs in radius of 64 cm
  - Acceptance: 2.4 < |η|< 4
- σ_t = **30 ps** at start – expected to decrease to 60 ps
- **Track timestamping**

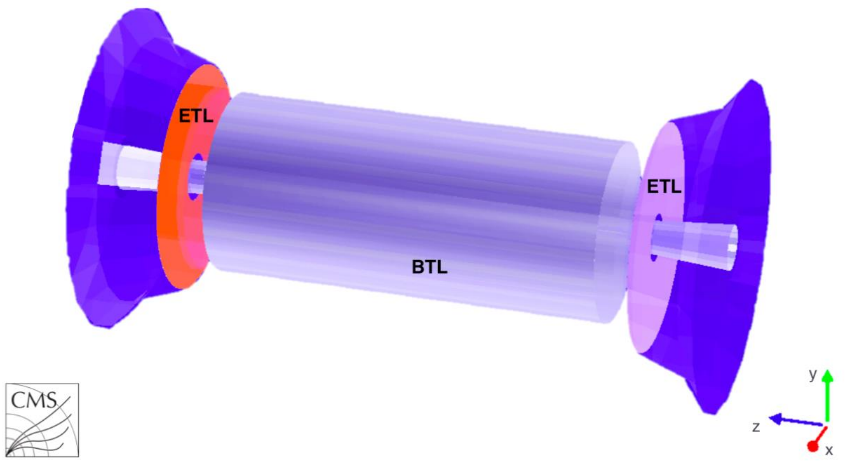
Simulations indicate the performance gain with timing, among others:

- Pile-up jet rejection
- Lepton Isolation
- Heavy-flavour tagging

Pile-up jet rejection



CMS: **MIP Timing Detector** (MTD)

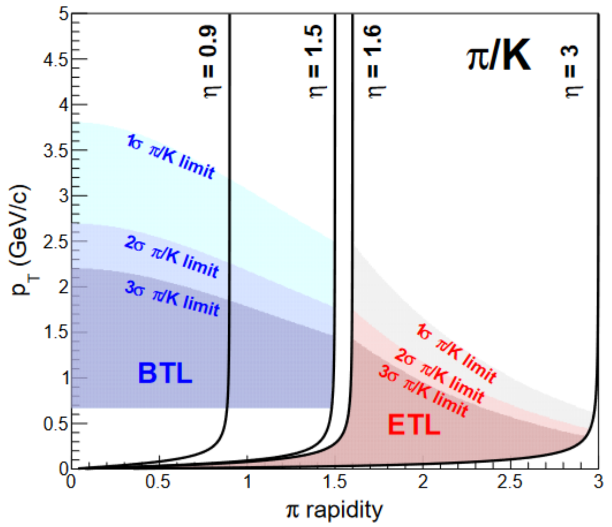


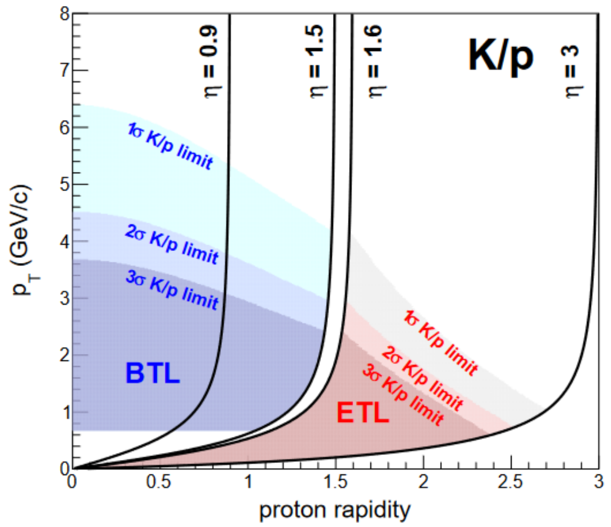
Barrel (BTL) and **endcap (ETL)** design

- Central barrel region based on LYSO:Ce **crystals** read-out with **SiPM** (silicon photomultipliers)
- Two end-caps instrumented with radiation-tolerant Low Gain Avalanche Detectors (**LGADs**).
  - σ_t = **30 ps** at start – expected to decrease to 60 ps

Both are used for track timestamping and **ToF**:

- Timestamping → pile-up suppression
- ToF → PID
- Extending search for Long-Lived Particles





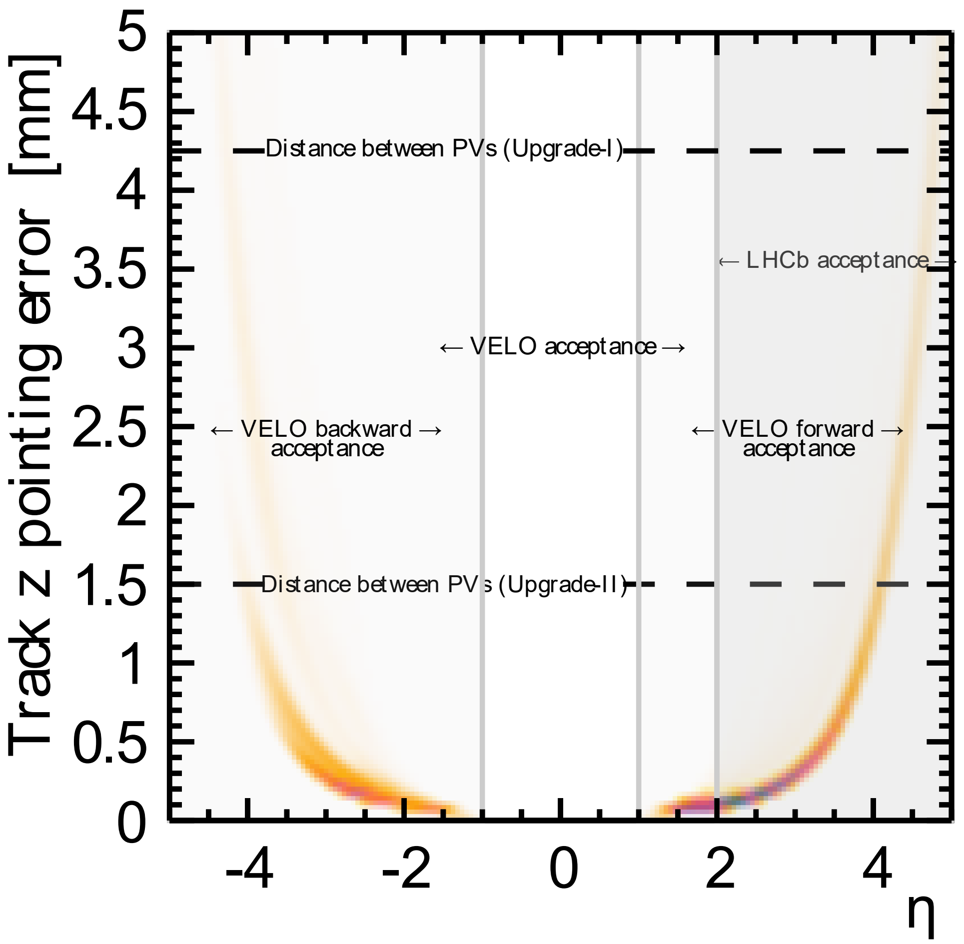
LHCb: VErtex LOcator (VELO)

Silicon pixel detector located around the interaction point

Both **radiation damage** and **track density** will prove **difficult**

- Radiation hardness will rely on technological advances over the coming years in the field of silicon sensors and by R&D from the experiments

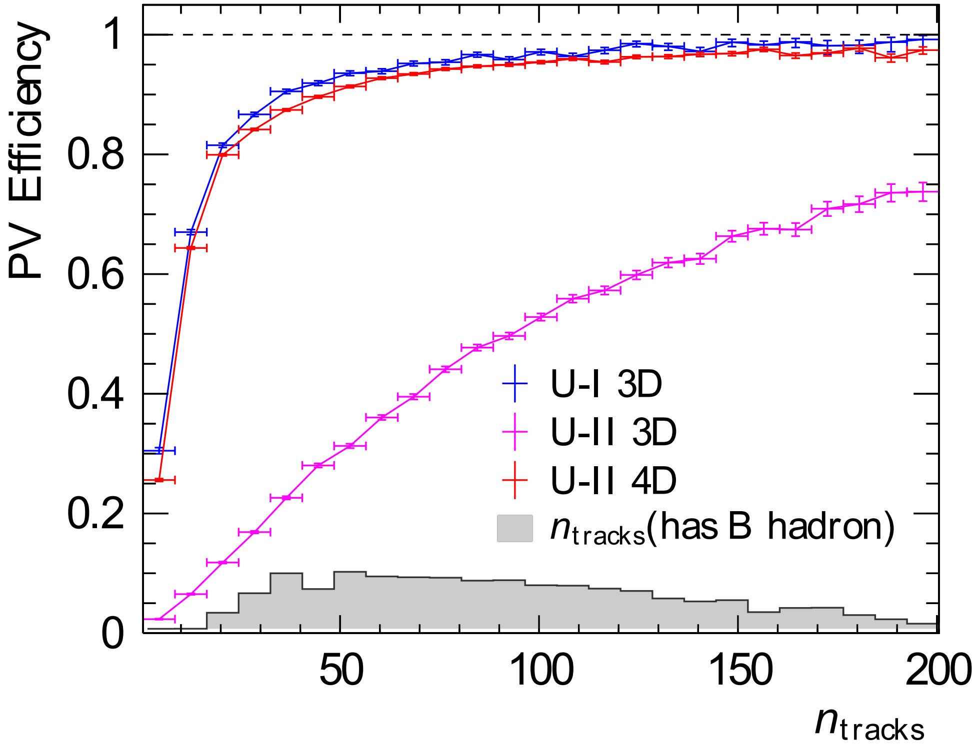
Simulations applying **4D tracking** proved that adding O(50 ps) hit timestamping solves problems on the physics reconstruction side



T. Evans – ICHEP 2020

Physics simulation for VELO

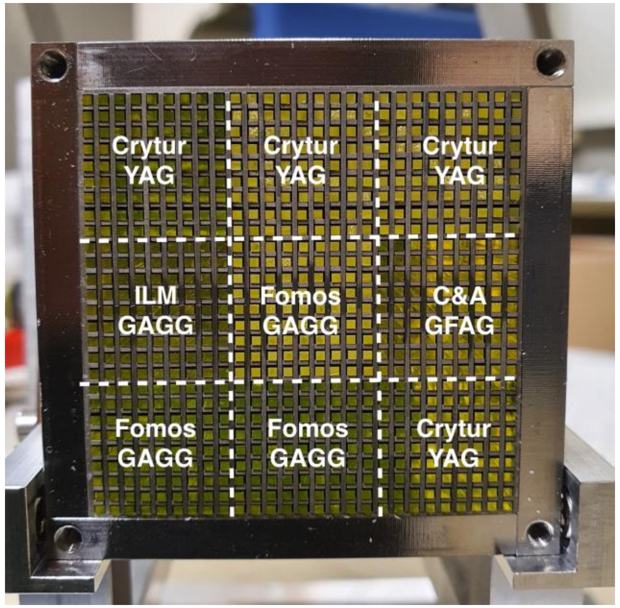
- Current upgrade of LHCb (after LS2, **U1**) as a baseline
- Implementation of **4D tracking** algorithm proved to improve the efficiencies **back to U1 scenario**



- Hardware not yet decided
  - Possibly based of Timepix – similar to U1 choice
- Multiple options still considered for sensors
  - Must be radiation hard!

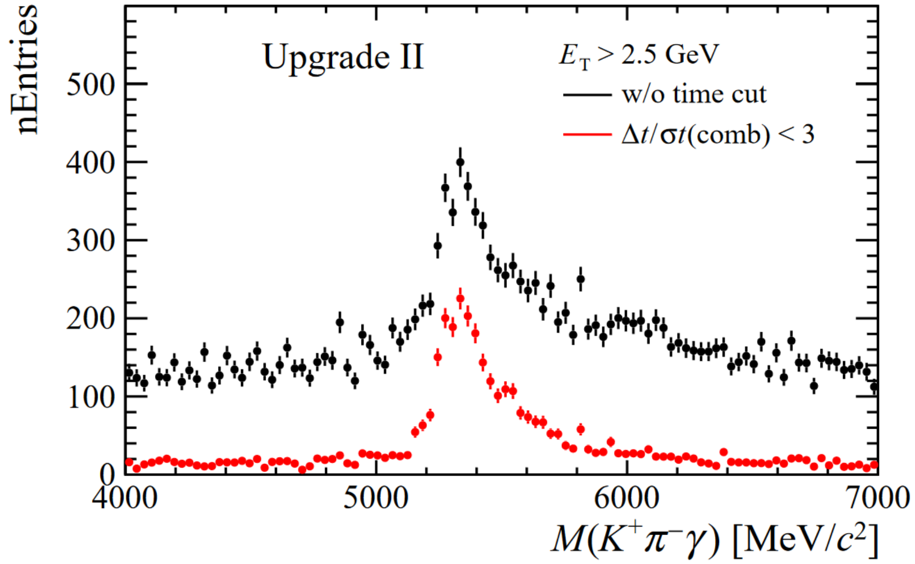
LHCb: ECAL

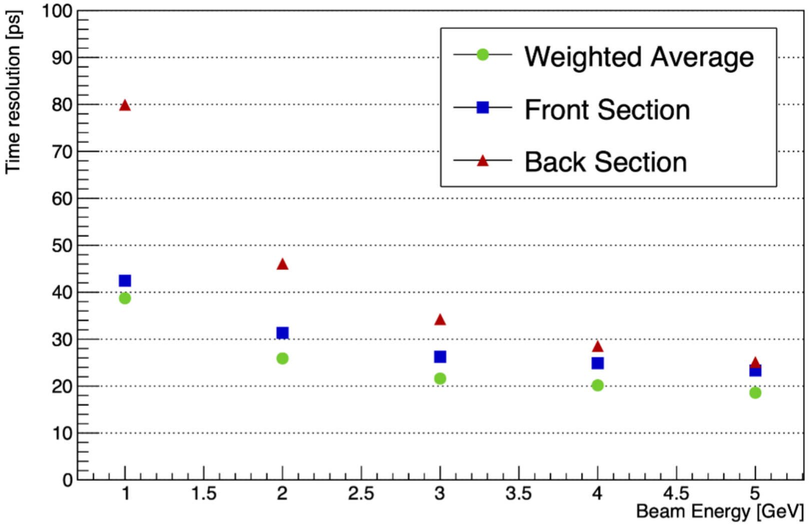
- **Requirements** for Upgrade 2:
  - **Radiation hard** in inner region
  - Keep at least current energy resolution of $\frac{\sigma(E)}{E} \approx 10\%/\sqrt{E} \oplus 1\%$
  - **Pile-up** mitigation **crucial** → timing capabilities with **O(10) ps precision**
- Testbeam shows promising time resolution already!
  - Studies ongoing on different scintillating materials



SpaCal with W absorber and crystal fibres

CERN-LHCC-2021-012

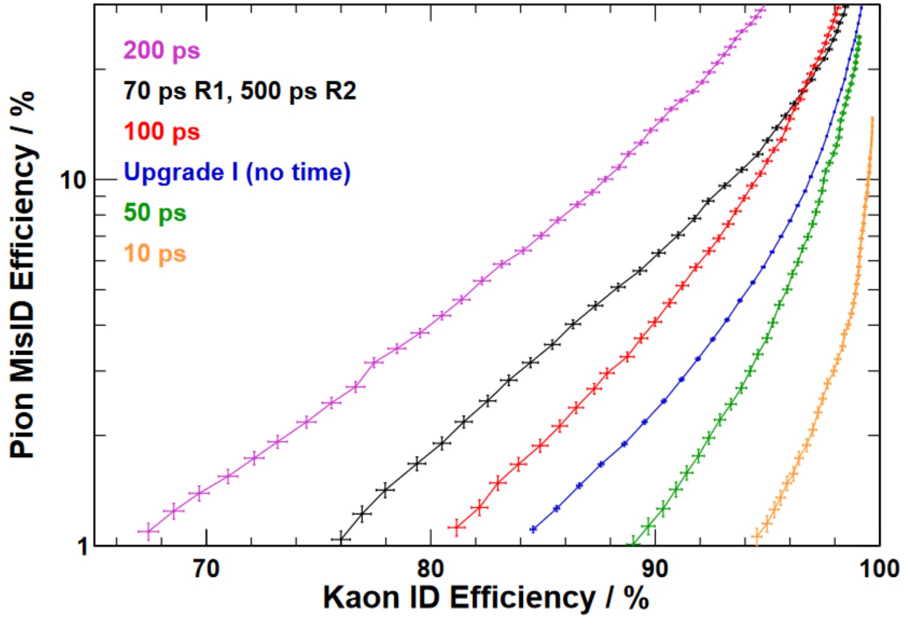


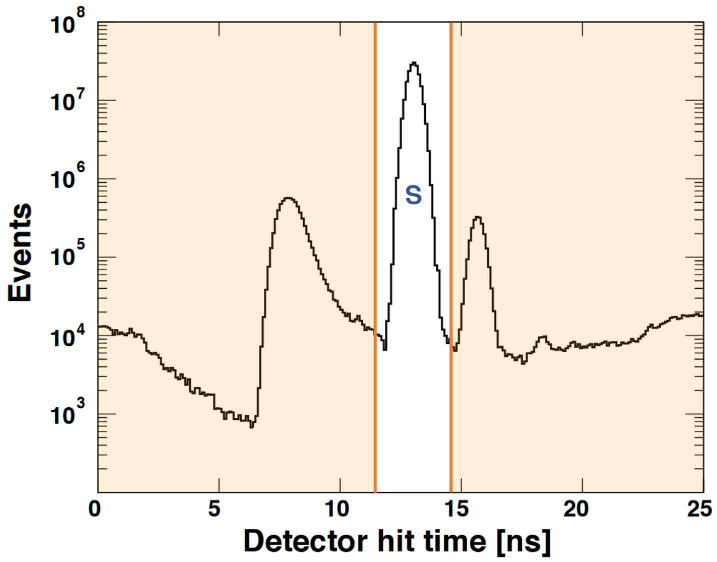


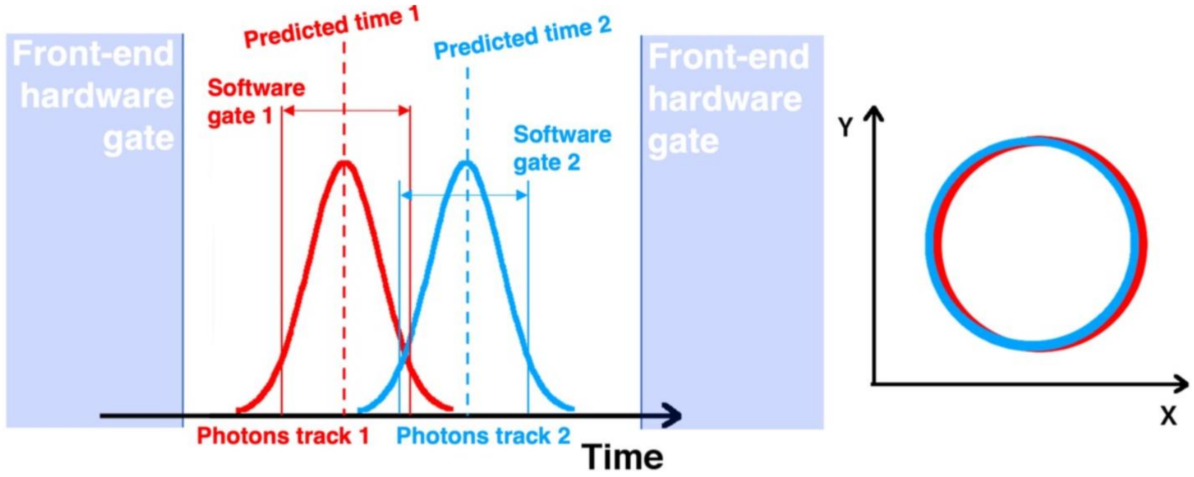
LHCb: RICH

- Reduction of **background** & improvement of **PID**
- Aiming of introducing a **timing gate**

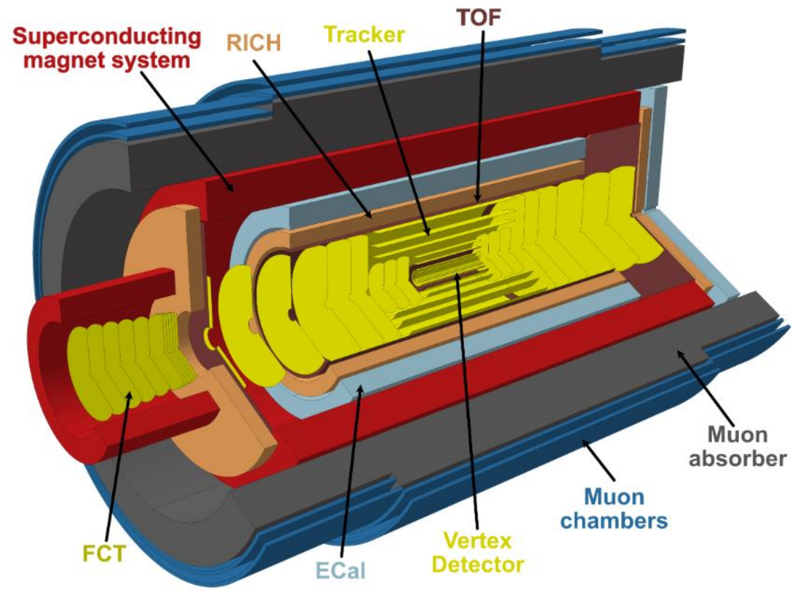
- Photon hit time can be **predicted** to within 10 ps
  - Time estimate can be achieved from tracking
- **SiPMs** are considered, but no choice has been made yet
  - Needs substantial cooling to deal with radiation damage







ALICE 3



ToF based **PID** in inner tracker (2 detector layers)

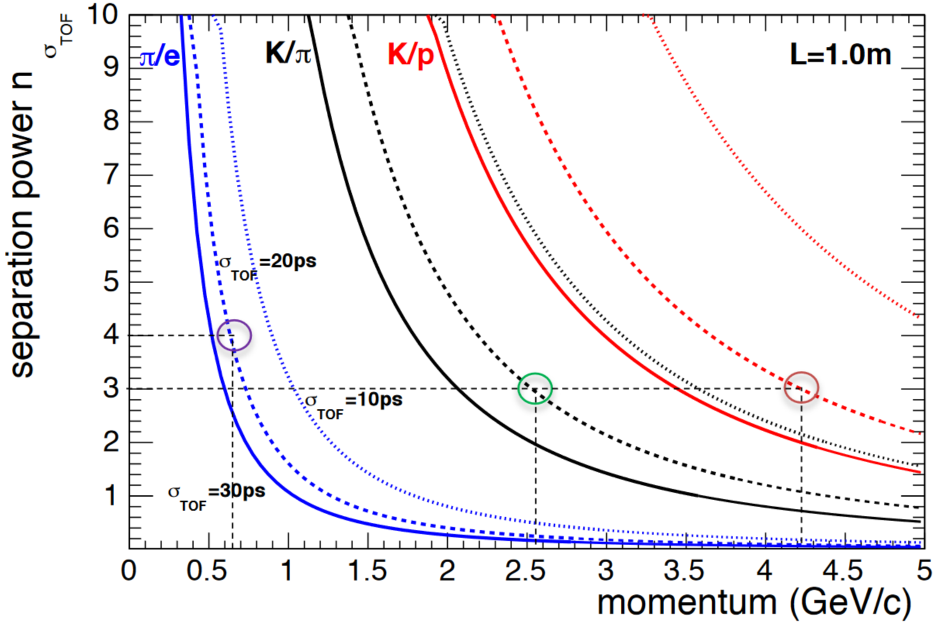
Possibility to be fully silicon (MAPS – bend silicon – like ITS3)

Timescale is much further away compared to ATLAS and CMS

With $\sigma_t < 20$ ps, **studies indicate**:

- e/π (4σ) separation ≲ 650 MeV/c
- π/K (3σ) separation ≲ 2.6 GeV/c
- K/p (3σ) separation ≲ 4.2 GeV/c

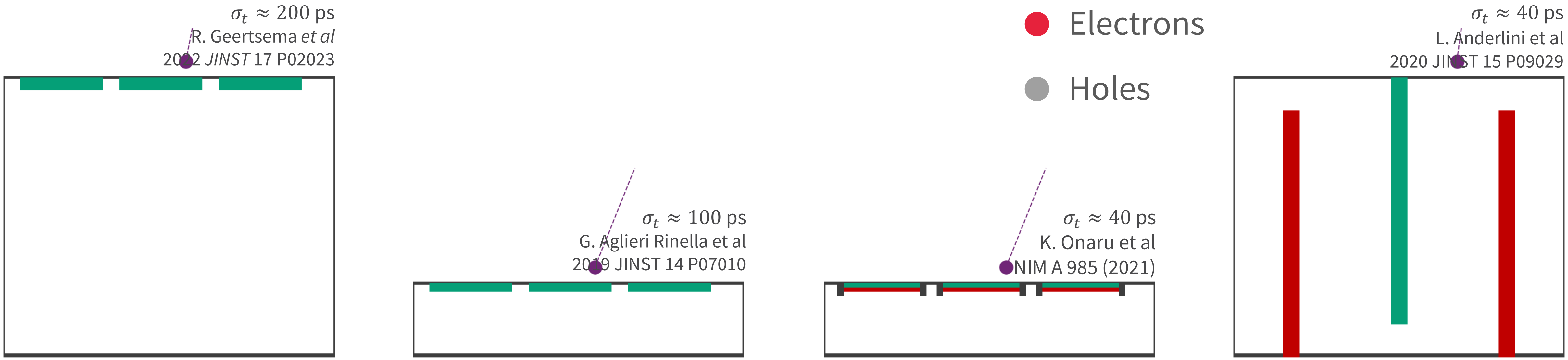
C. Lippmann - 2018



- **Aerogel** based **RICH** (SPAD/SiPM based)
  - Aim for $\sigma_t < 50$ ps
  - Background and noise suppression

Faster silicon sensor-designs

- Improved time resolutions achieved with variety of designs



“Thick planar”	“Thin planar”	LGAD	3D
Traditional detector designs	Monolithic/MAPS	Built in gain layer	Vertical pillars
Large signal but slow	Fast but low signal	Fast & large signal Implemented in MAPS? Not as radiation resistant…	Fast & large signal Low fill factor…

Conclusion and outlook

- **Without** the addition of timing in experiments, it is **impossible** to deal with pile-up
- **Timing** will **aid in**: pile-up reduction, tracking, and PID!
- All four experiments will implement different versions of timing detectors in the next ~15 years

- **Further R&D** is necessary to improve upon the current technologies and enable the possibility of widespread **picosecond timing** in next generation LHC detectors