# Picosecond timing for particle detectors

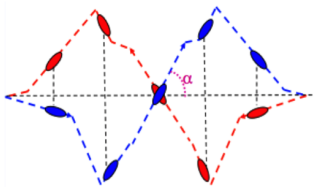
Matthew Rudolph

Syracuse University

August 16, 2023

# LHC frequency

- The LHC collides bunches of protons every 25 ns ($25 \times 10^{-9}$)
- It can't get faster, but we want to have more data (higher *luminosity*)
- So why would we need to know when particles hit our detector within 10 ps ($10 \times 10^{-12}$) or better?



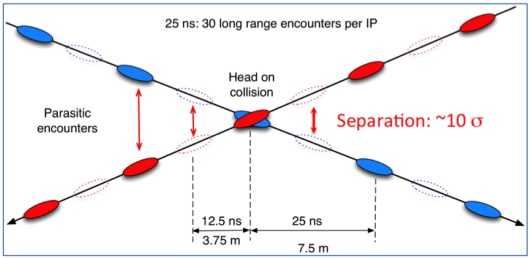
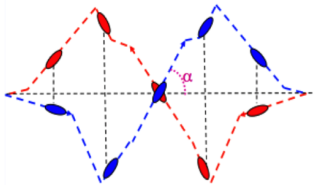




Figure from CERN Bulletin. Angle is exaggerated! At LHCb angle will be $\sim 0.02°$

# LHC frequency

- The LHC collides bunches of protons every 25 ns ($25 \times 10^{-9}$)
- It can't get faster, but we want to have more data (higher *luminosity*)
- So why would we need to know when particles hit our detector within 10 ps ($10 \times 10^{-12}$) or better?
- Within one "bunch-crossing", the time spread is $\sim 150$ ps!



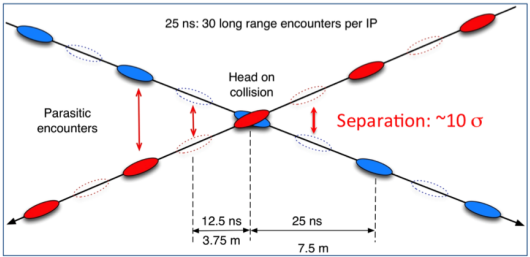




Figure from CERN Bulletin. Angle is exaggerated! At LHCb angle will be $\sim 0.02°$

# Quiz 1

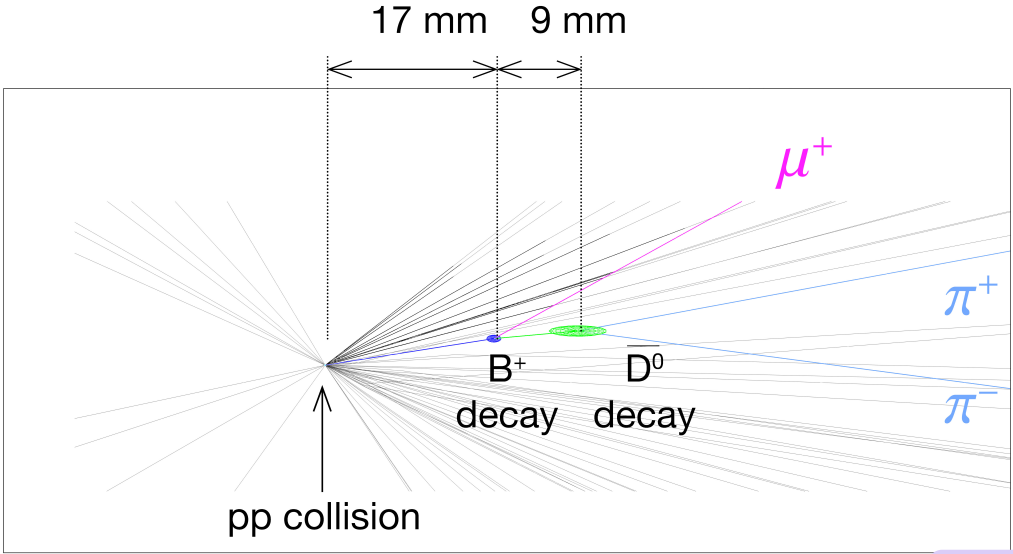
- How long does it take to go one meter at the speed of light?

# Quiz 1

- How long does it take to go one meter at the speed of light?

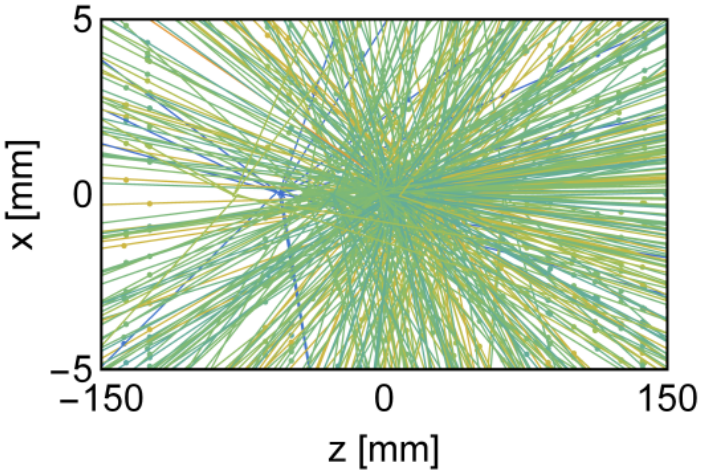
3.3 ns

# LHCb's strength

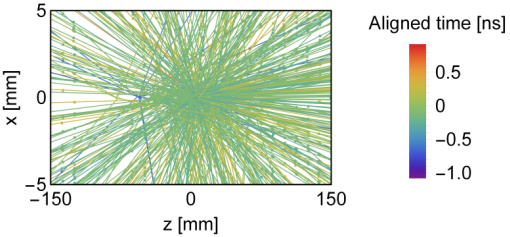


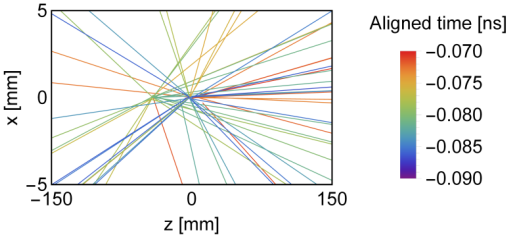
# Pile-up

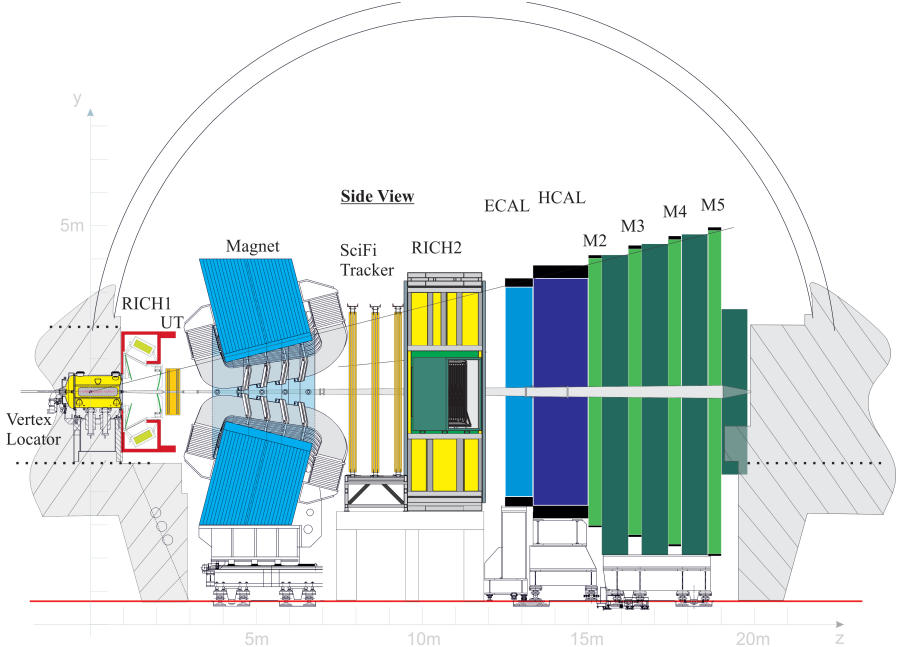
- 40 simultaneous collisions is a huge combinatorial problem



# With timing


5
0
−5
x [mm]
−150
0
150
z [mm]
Aligned time [ns]
0.5
0
−0.5
−1.0


5
0
−5
x [mm]
−150
0
150
z [mm]
Aligned time [ns]
−0.070
−0.075
−0.080
−0.085
−0.090


Side View
y
5m
Magnet
SciFi
Tracker
RICH2
ECAL
HCAL
M2
M3
M4
M5
RICH1
UT
Vertex
Locator
5m
10m
15m
20m
z

# Quiz 2

- A particle in our detector has a momentum $p = 10\,\mathrm{GeV/c}$. If it's a proton, how long does it take to go 10 m? *Hint:* $v \approx 0.995c$

# Quiz 2

- A particle in our detector has a momentum $p = 10\,\mathrm{GeV/c}$. If it's a proton, how long does it take to go 10 m? *Hint:* $v \approx 0.995c$

33.52 ns

- How long would it take a pion? ($v \approx 0.99995$)

# Quiz 2

- A particle in our detector has a momentum $p = 10\,\mathrm{GeV/c}$. If it's a proton, how long does it take to go 10 m? *Hint:* $v \approx 0.995c$

33.52 ns

- How long would it take a pion? ($v \approx 0.99995$)

33.58 ns

- $\Delta t \approx 60\,\mathrm{ps}$!

# Challenge

- Ultimately, our detector signals are effectively an analog electrical pulse on some wire
- Typical timescales 1 ns to 10 ns
- Need to develop new electronics to determine time on tens of thousands of channels every 25 ns!

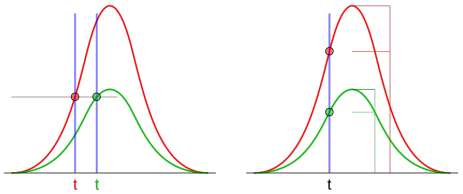



Figure from Dschwen on wikimedia