# *Particle physics: practice 2*
# *Collider physics*

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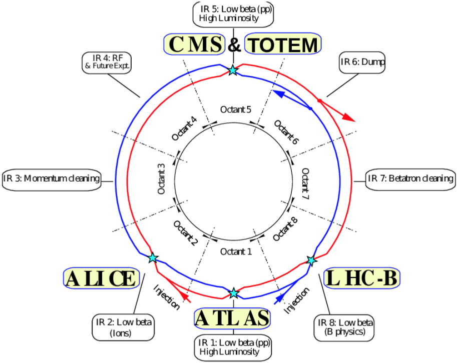
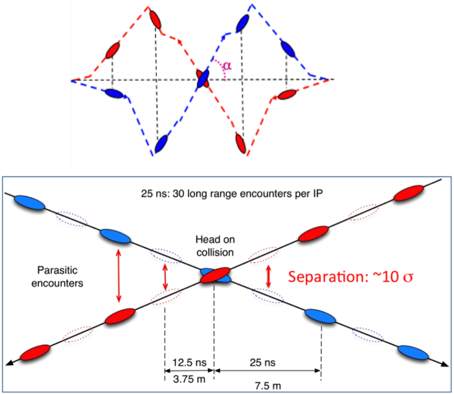
$7^{th}$ October 2022

# WHAT'S COOKING INSIDE THE LHC



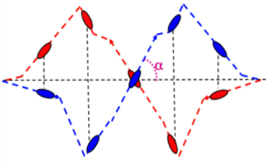

- LHC: Large Hadron Collider.
- Large: 27 km ring. Bend 7 GeV protons with powerful superconducting magnets.
- Hadron: protons or lead ions. Collisions are strong interactions ⇒ huge cross-sections for new discoveries!
- Two beams cross at four collision points ⇒ experiments.

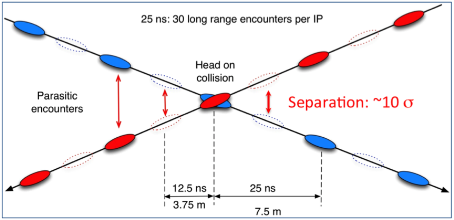
# Colliding femtometer scale objects (protons)




- Protons are packed into bunches, spaced 7.5m (25 ns) apart.
- Corresponds to ⟨???⟩ MHz bunch-crossing rate.
- So in all, 27km/7.5m $\sim$ 3500 max. bunches. In reality, not all bunches can be filled. Filled bunches in steady-state at the LHC is $\sim$ 2500.

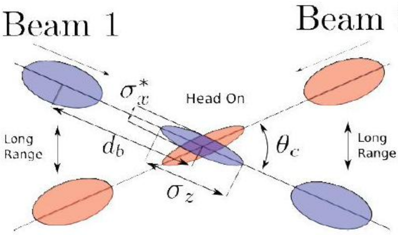
# Colliding femtometer scale objects (protons)




- Protons are packed into bunches, spaced 7.5m (25 ns) apart.
- Corresponds to 40 MHz bunch-crossing rate.
- So in all, 27km/7.5m $\sim$ 3500 max. bunches. In reality, not all bunches can be filled. Filled bunches in steady-state at the LHC is $\sim$ 2500.

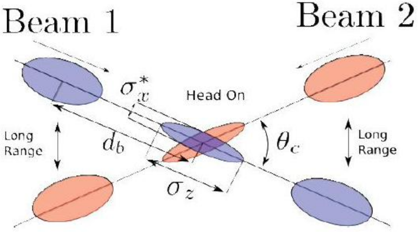
# Colliding femtometer scale objects (protons)




- Each bunch has $n_b = \mathcal{O}(10^{11})$ protons. Note: 1cc of $H_2$ at STP has $10^{19}$ protons.
- Going to higher lumi means tuning this number.
- Beam is then "squeezed down" to $\sigma_x = \sigma_y \sim 16$ microns.

- If $n_b \sim 10^{11}$, $\sigma_z = 7.5$cm. The volume for a single proton in the beam is $V_b \sim \sigma_x \sigma_y \sigma_z / n_b \sim \langle ??? \rangle$.
- Typical atomic radius is in Angstroms $\sim 10^{-10}$m. How does $V_b$ compare to atomic volumes?

# Colliding femtometer scale objects (protons)

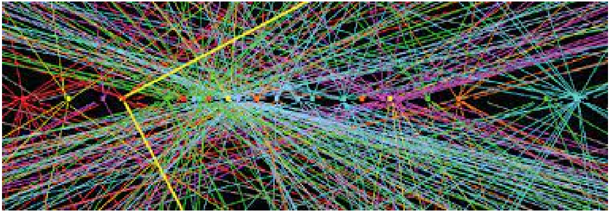



- If proton size is $d = 1$ fm ($10^{-15}$m), then the probability of interaction is $P \sim d^2/\sigma_x\sigma_y \sim 10^{-21}$.
- Number of interactions per bunch crossing is $P \times n_b^2 \sim 50$ interactions/bunch crossing.

- This is called pileup. At the High Lumi-LHC, ATLAS/CMS will see a PU=200!
- Most of the interactions will be non-interesting inelastic events (forward).
- The interesting events will be transverse: "high pT"' physics .

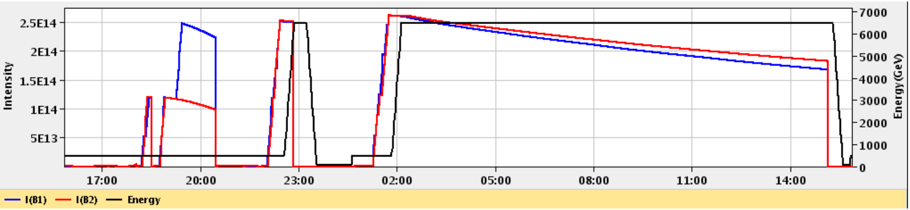
# Pileup

- This means upto 200 potential PV's (typically smaller) for a given reconstructed "interesting" candidate event.



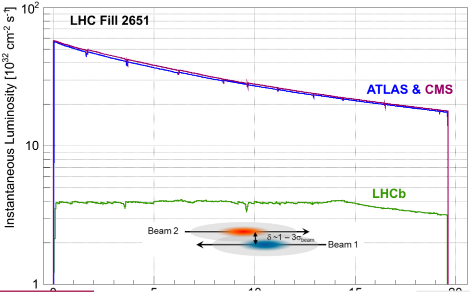
# LHC DATA-TAKING: FILLS

- Machine status: "injection" $\rightarrow$ "ramp" $\rightarrow$ "flat top" $\rightarrow$ "squeeze" $\rightarrow$ "adjust" $\rightarrow$ "stable beams" $\rightarrow$ "dump" $\rightarrow$ "ramp down"
- Good fill lasts several hours till we run out of protons to collide.



# Luminosity levelling at LHCb

- General Purpose Detectors: ATLAS/CMS at high pT (heavy objects like Higgs)
- LHCb is a forward detector (lighter objects like $B$-mesons) designed for much lower luminosity. Else sub-detector occupancies saturate.
- Achieved by lumi-levelling: beams are moved apart as fill progresses

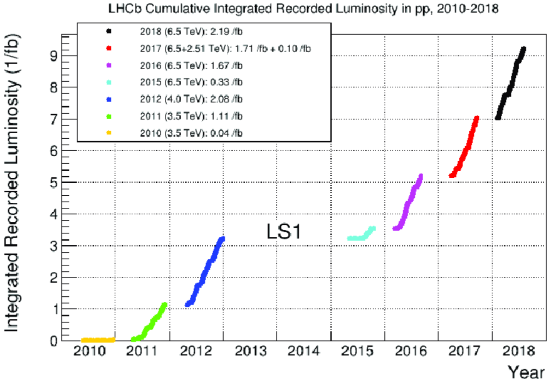


# Luminosity and rates

- $f = 40$MHz bunch crossing rate, $N_{1,2} \sim 10^{11}$ are the number of protons/bunch, $\sigma_{x,y} = 16\mu$m
- Luminosity $\mathcal{L} \sim f N_1 N_2 / (4\pi\sigma_x\sigma_y) = \langle ??? \rangle$
- Number of collisions per cm$^2$ per second.
- The rate for any individual process $\Rightarrow$ multiply by the corresponding cross-section.
- Integrated lumi $\mathcal{L}_{\text{int}} = \int \mathcal{L} dt$ usually expressed as inverse of cross-section.
- Barn $\equiv 10^{-24}$ cm$^2$ (cross-section). Inverse femtobarn $\Rightarrow 10^{13}$ $pp$ collisions.

# Luminosity and rates

- LHCb has collected 9/fb between 2011-18. Plans to collect 300/fb ultimately.




- Note, GPD's have even higher $\mathcal{L}_{\text{int}}$, but they run at higher PU as well.