Filling schemes for the FCChh

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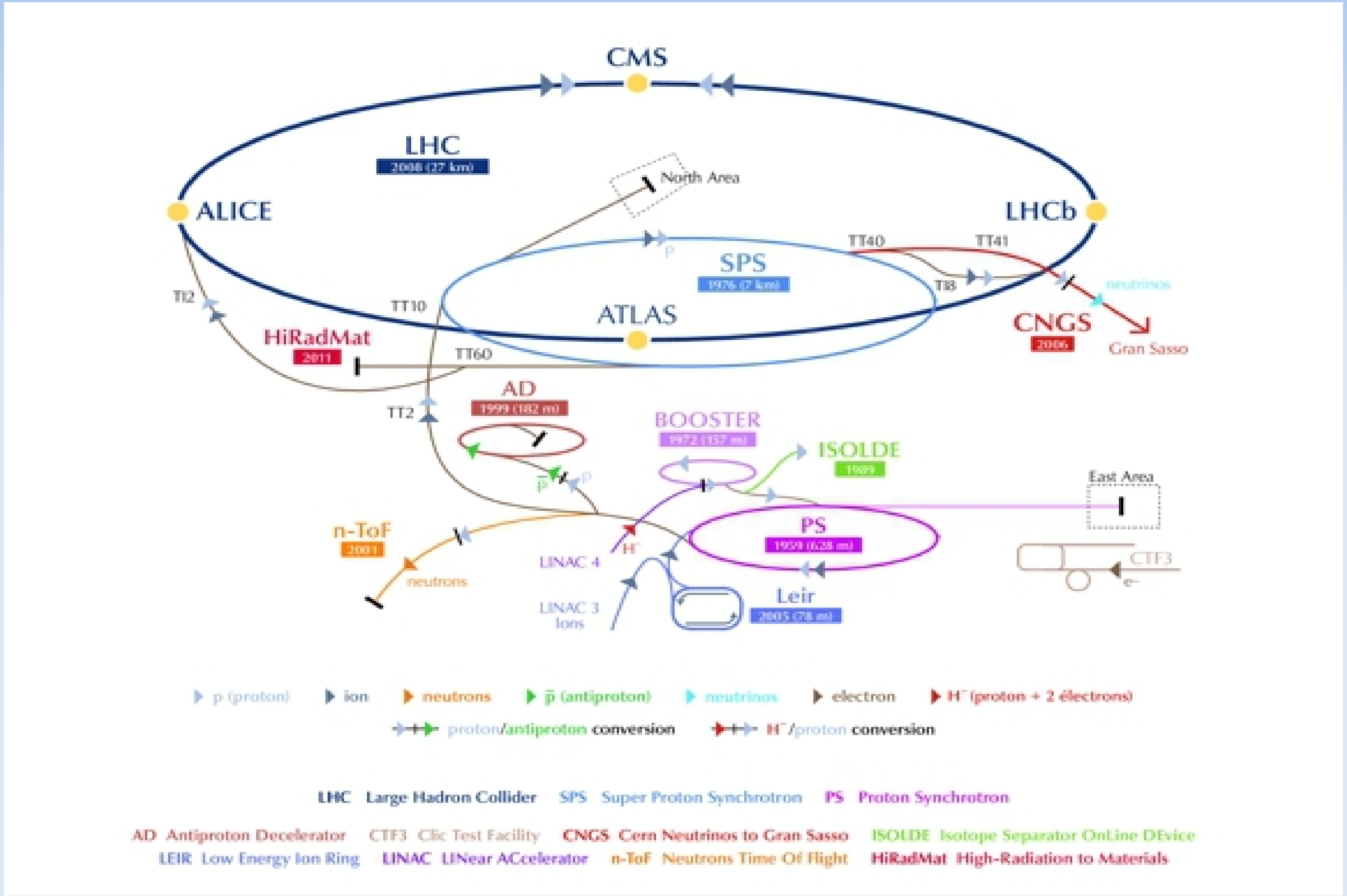
FCC Hadron Collider General Design Meeting, 16th Oct. 2014

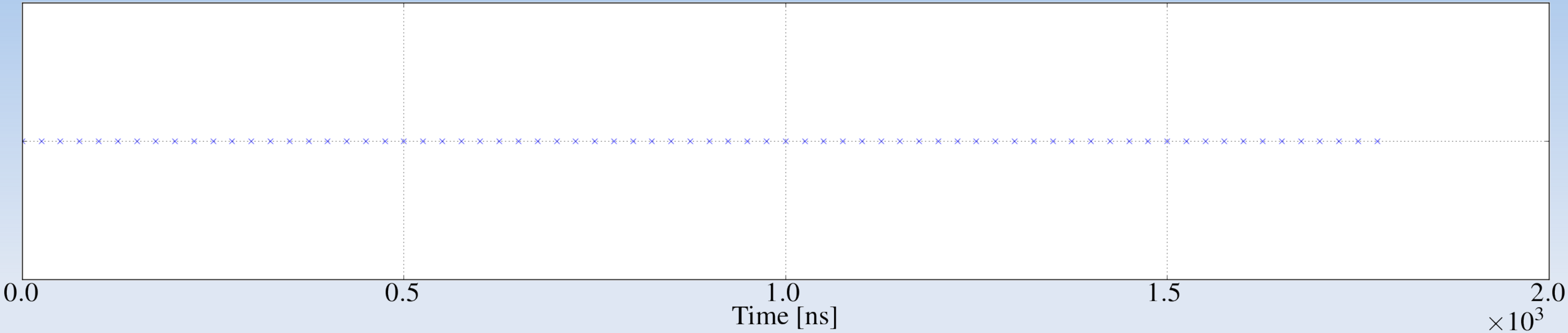
Content

- FCC filling scheme based on nominal LHC's
- LHC-FCC injection scheme
- Filling factor
- Number of collision in each experiment

LHC injector chain



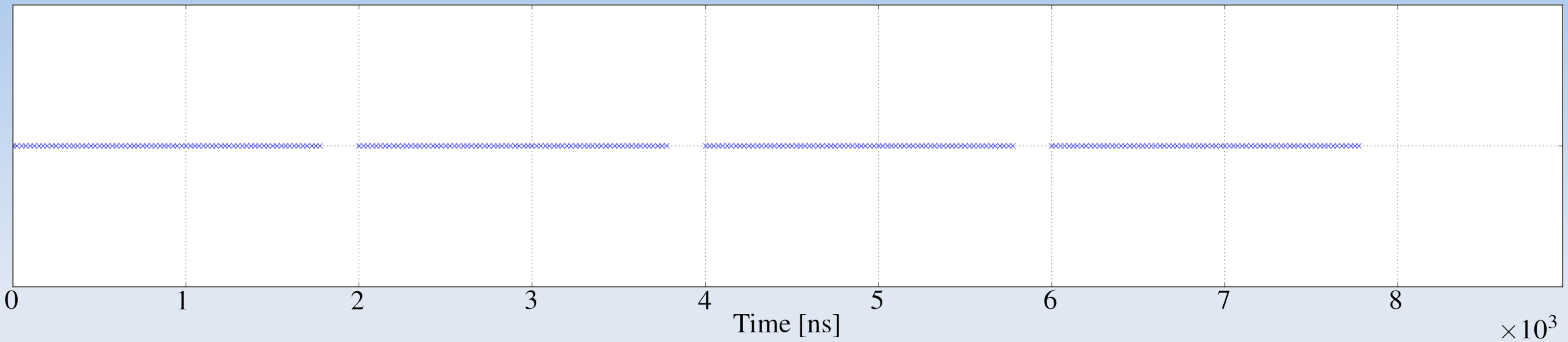
PS batch



- PS Batch : 72 bunches + 8 empty
- SPS Train : 4 * PS Batch + 38 empty
- LHC Train : 9 * SPS Train + 342 empty
- The full LHC train cannot be injected at once in the FCC
  (machine protection constrain → assume 1 SPS train per injection)

  → Need a by-step injection scheme

SPS Train



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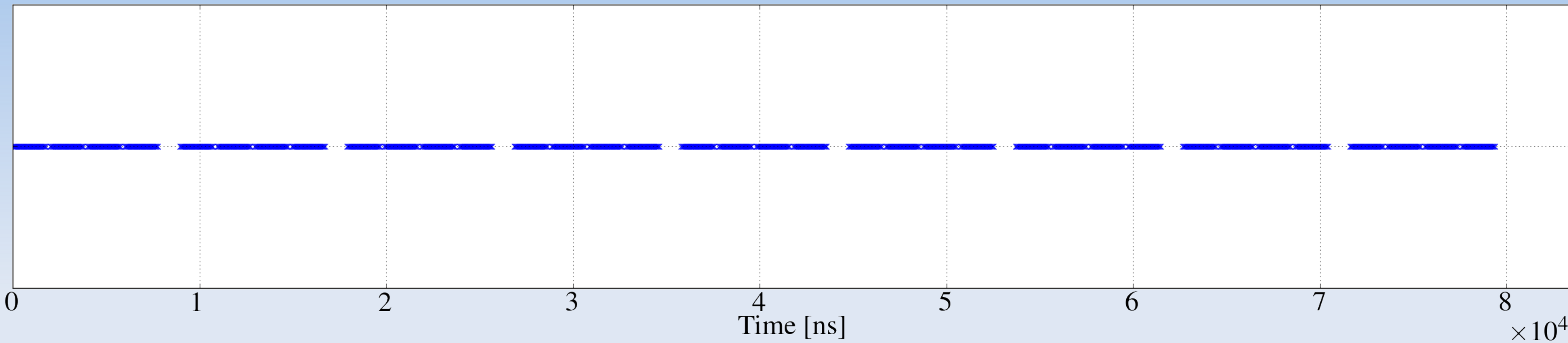

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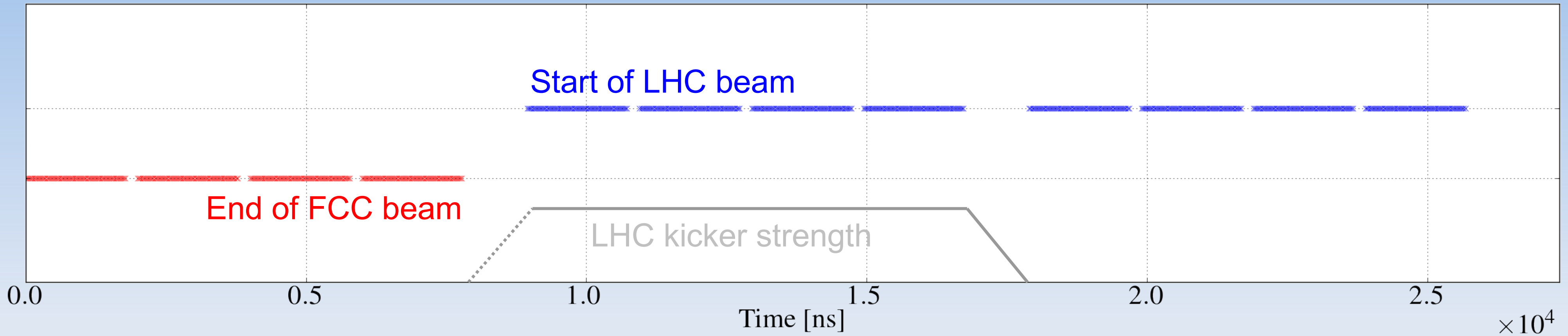
Synchronous by-step injection from LHC to FCC

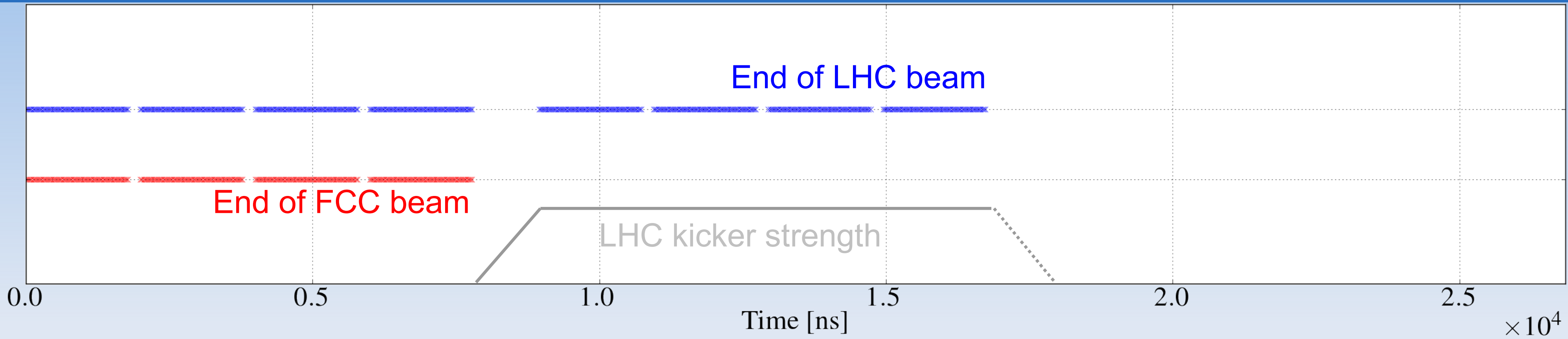


- The spacing between SPS trains is constrained by :
  - The kicker fall time of the LHC

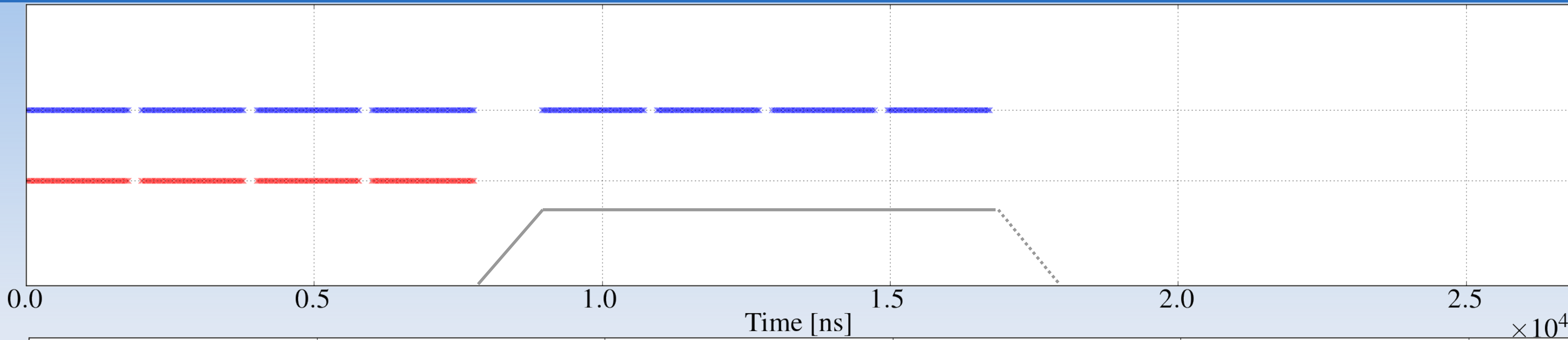
Synchronous by-step injection from LHC to FCC

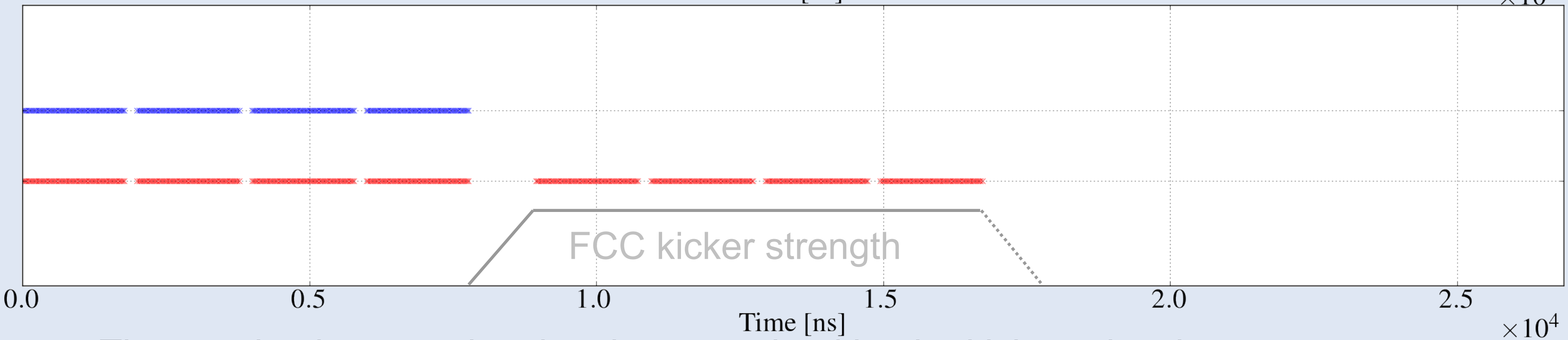
- The spacing between SPS trains is constrained by :
  - The kicker fall time of the LHC
  - The kicker rise time of the FCC
- Injection every 4 FCC turns possible (2 for the 93km option)

Asynchronous by-step injection from LHC to FCC



Asynchronous by-step injection from LHC to FCC





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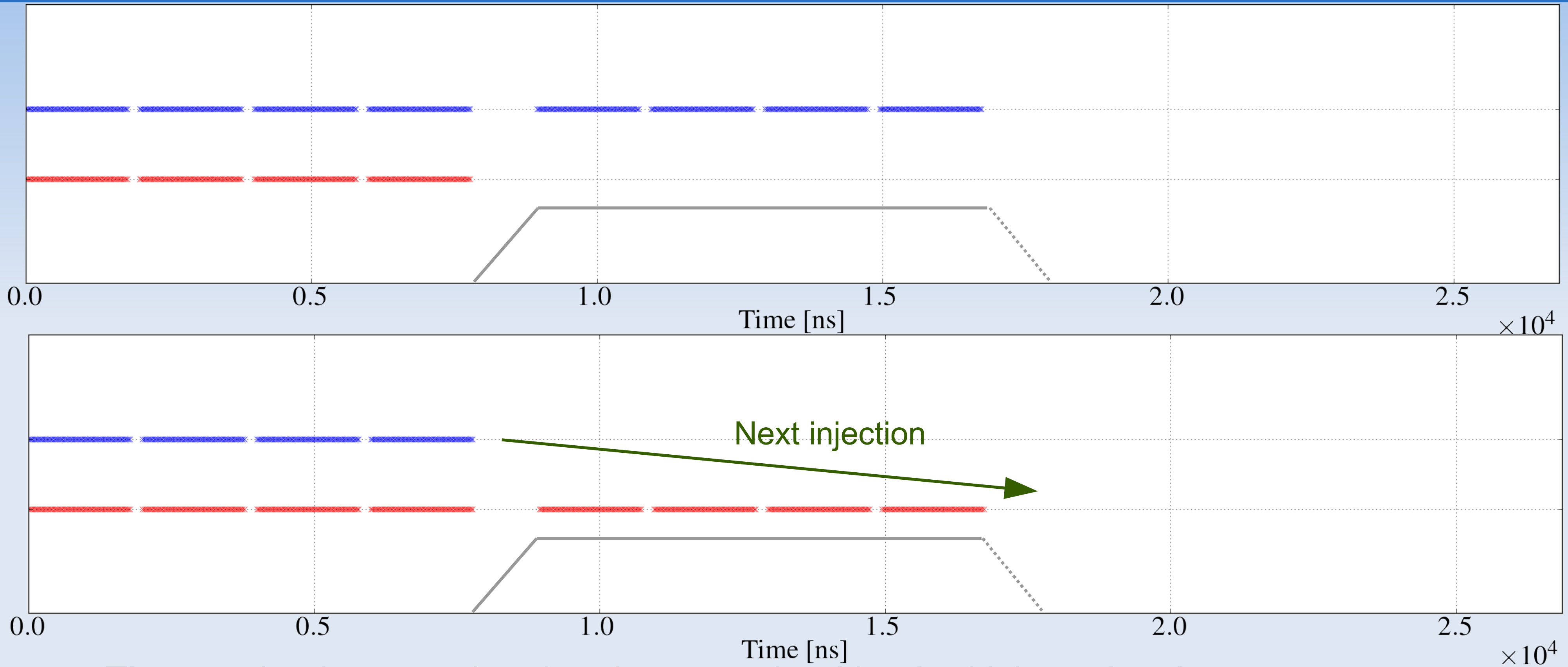
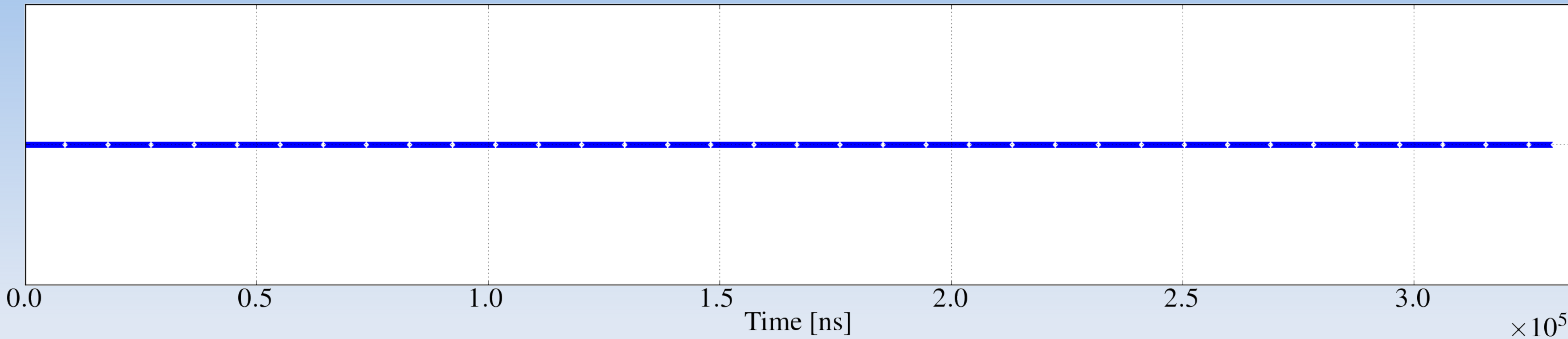
Asynchronous by-step injection from LHC to FCC



- The spacing between batches is constrained by the kickers rise time
- Re-phasing of the two machines is required after each injection step (by the length of two batches)
  - Shorten the length of the FCC → Fast but not flexible
  - RF cogging in the LHC → Flexible but slow

    1.5 s per slot achieved with beam in the LHC (https://indico.cern.ch/event/267783/session/7/material/0/0.pdf)

FCC Filling pattern



- PS Batch : 72 bunches + 8 empty
- SPS Train : 4 * PS Batch + 52 empty → 1.5 μs
- LHC Train : 9 * SPS Train + 156 empty
- FCC : (35 +1/2)* SPS Train + 133 empty → 4.825 μs

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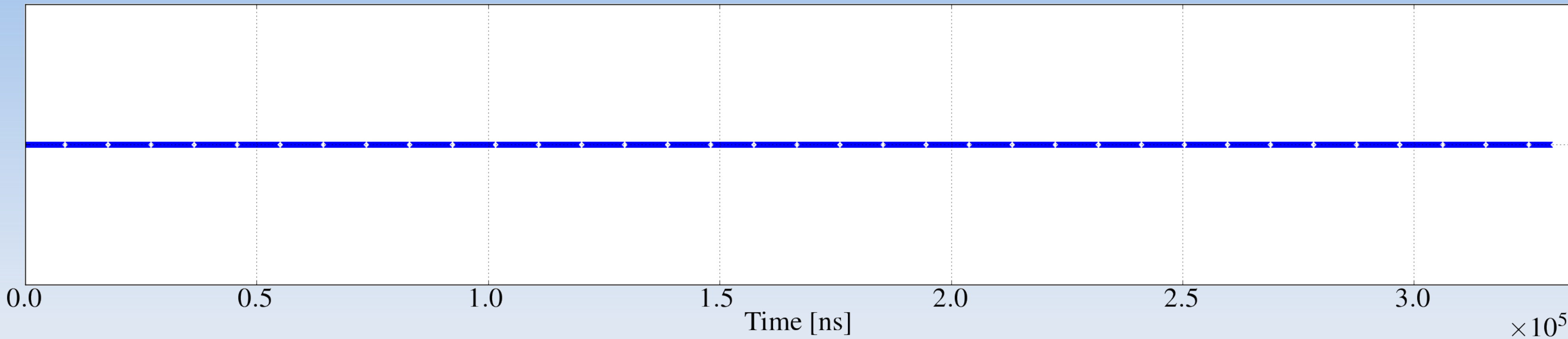

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→ 13'365 slots 10'224 bunches → 76%

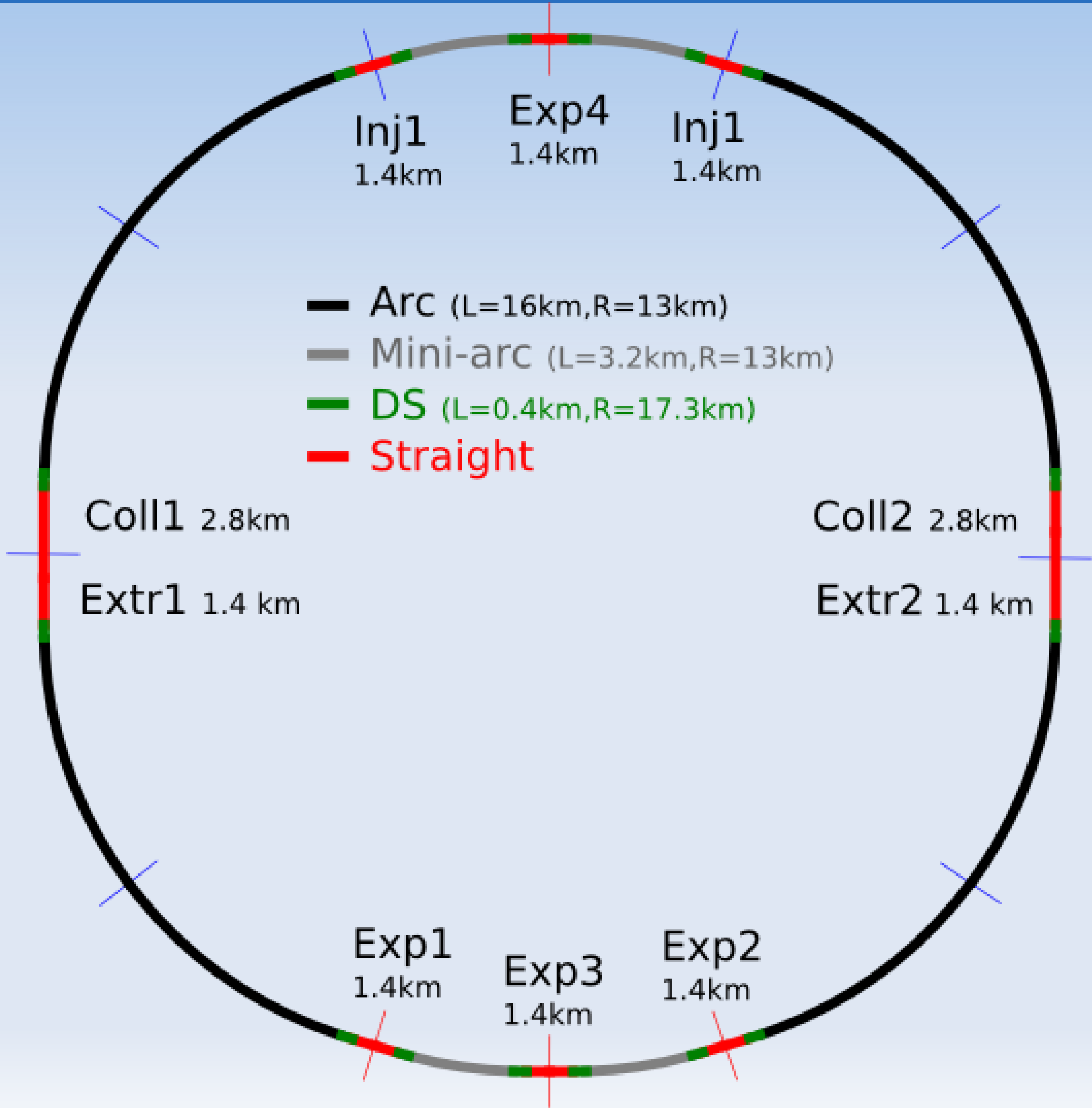
(3.75*LHC)

Contribution of the gaps

- 106 PS-SPS gaps : 848 empty slots : -6.3 %
- 35 LHC-FCC gaps : 2100 empty slots : -15.7%
- FCC abort gap : 193 empty slots : -1.4%

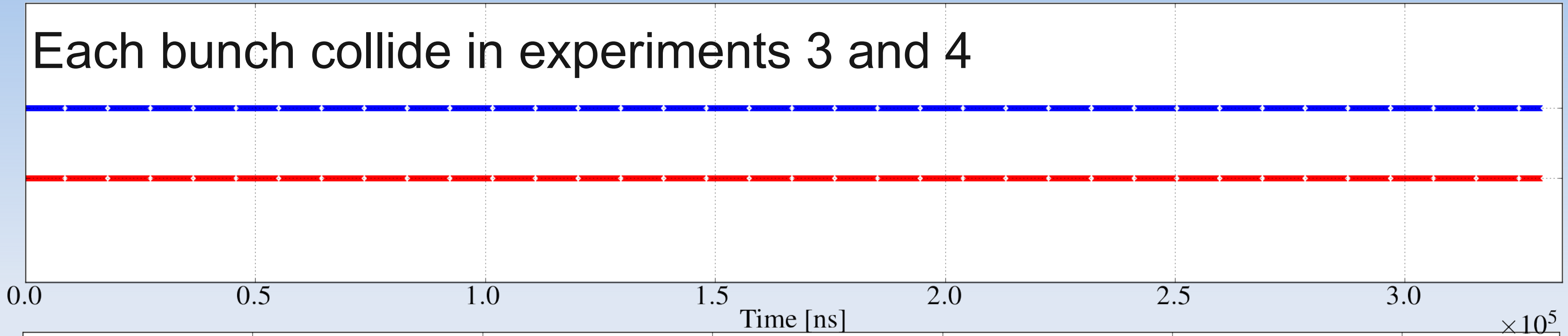
  - Machine protection constrains impose 35 injections from the LHC, is that sufficient ?
  - LHC-FCC gap was chosen conservatively to half what is achieved for the LHC extraction at 7 TeV, can one reduce it ?

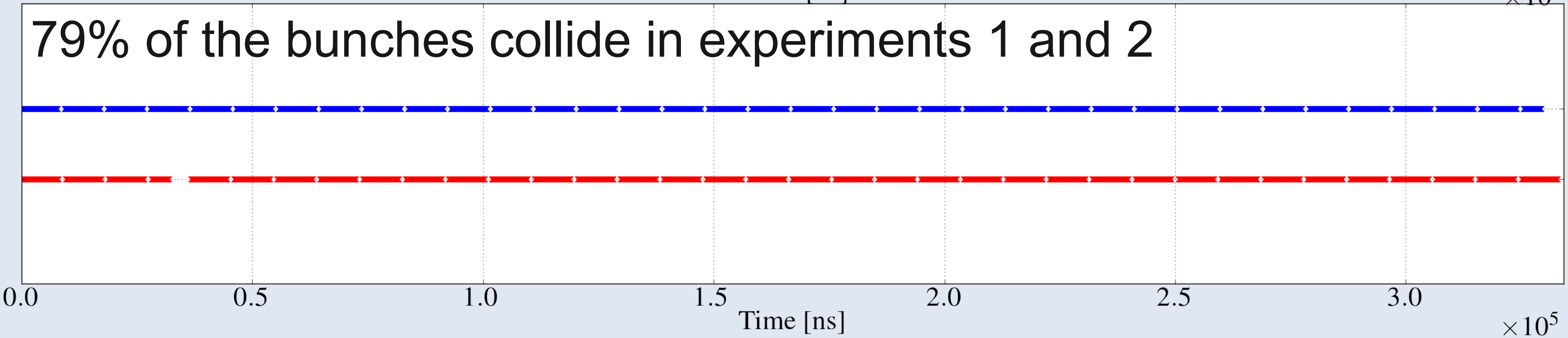
Layout



- Experiments 3 and 4 are located at opposite azimuth
- Experiments 1 and 2 are shifted by 5.4 km (721 slots)

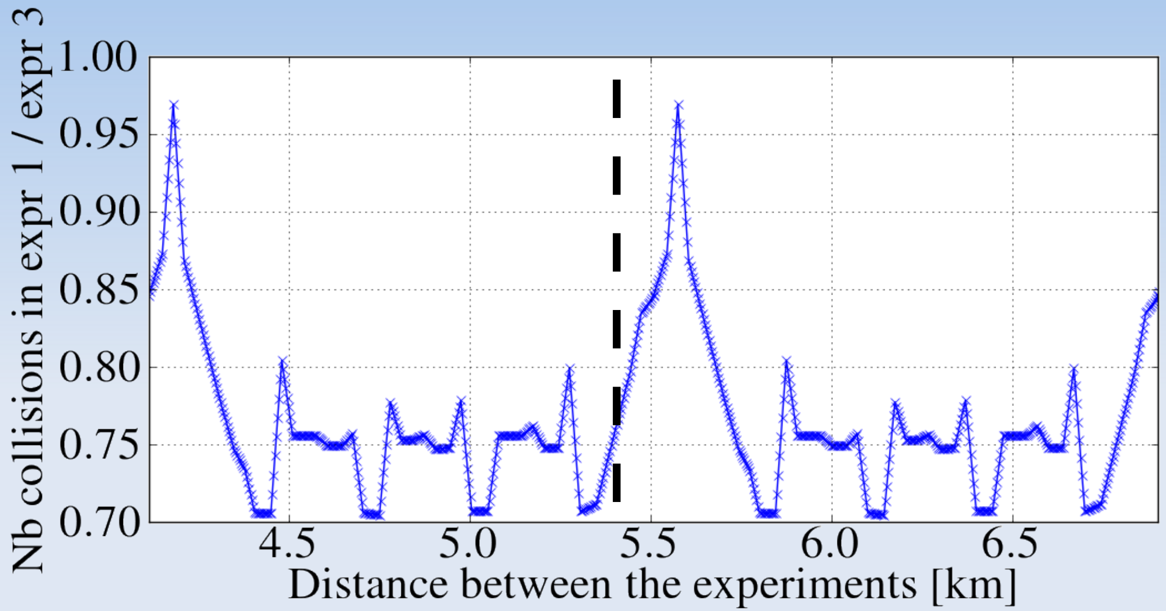
Synchronization of the two beams in each experiment





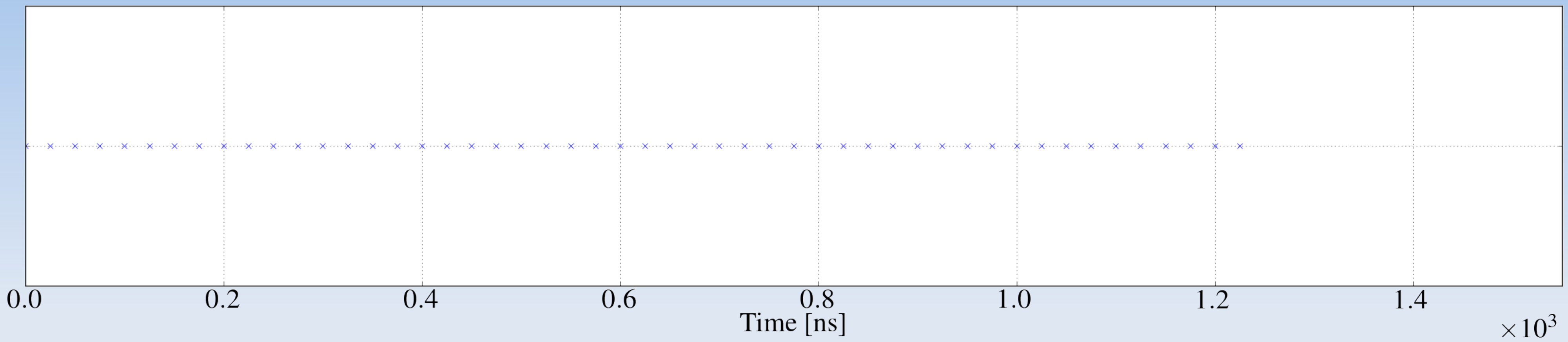
- The location of experiments 3 and 4 (i.e. at opposite azimuth) is more suited for high luminosity experiments

Adjusting the distance between the experiments



- The effect of the gaps could be mitigated by adjusting the distance between the side experiments
- Not robust against changes of the filling scheme
  - Flexibility in the filling scheme proved effective in the LHC (Intensity ramp up, 50ns runs, BCMS, witness bunches, ...)

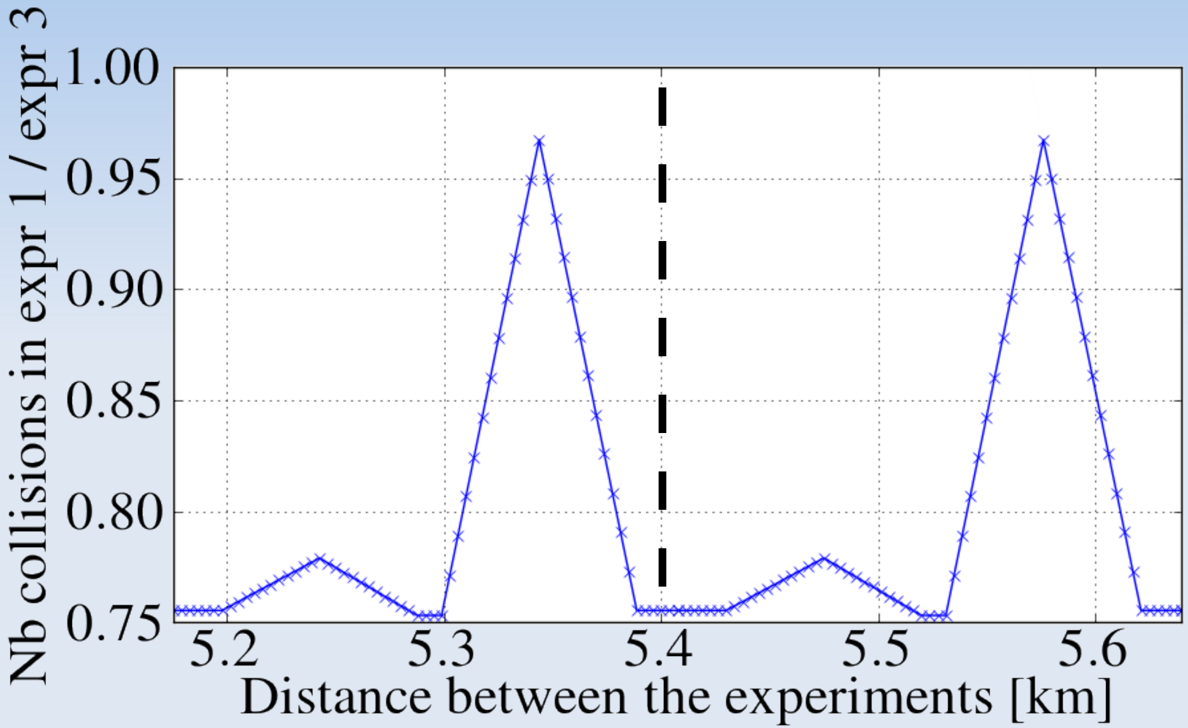
Different filling scheme



- Assume that maximum 50 bunches can be injected at once from the LHC to the FCC (W. Bartmann, et al @ FCC-FHI WG meeting 4th of March 2014)
- Maximum 0.3 μs spacing between batches is required to achieve 80% filling (W. Bartmann, et al @ FCC-FHI WG meeting 4th of March 2014)
  - 214 batches of 50 bunches separated by 12 empty slots
  - 157 slots (3.925 μs) left for the abort gap

  → 10'700 bunches in 13'365 slots (3.75*LHC)

Adjusting the distance between the experiments



Conclusion

- 80% filling is difficult to achieve due to the by-step injection needed between the LHC and the FCC
  - How fast can the kickers be ?
  - How many bunches can be injected at once ?
  - Do we need an asynchronous injection scheme ?
- The luminosity in the side experiments is reduced by few to 30% with respect to the other experiments
  - Optimising the position of this interactions points leads to strong constrains on the filling scheme

    → The interaction points at opposite azimuth are more suited for high luminosity experiment