Potential for Stochastic Cooling of Heavy Ions in the LHC

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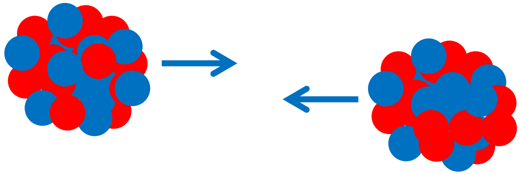
Outline

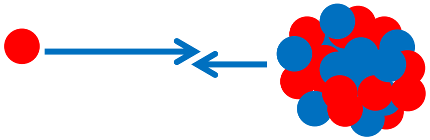
- LHC Ion Programme
- Data Analysis and Simulations from 2011 and 2013
  - Bunch-to-Bunch Differences
  - Beam Evolution and Tracking Simulations
- First Studies for a Stochastic Cooling System at LHC

The LHC Heavy Ion Programme

- Collisions of fully stripped lead ($^{208}\mathrm{Pb}^{82+}$) ions
- 4 weeks run time every year (Nov – Dec)

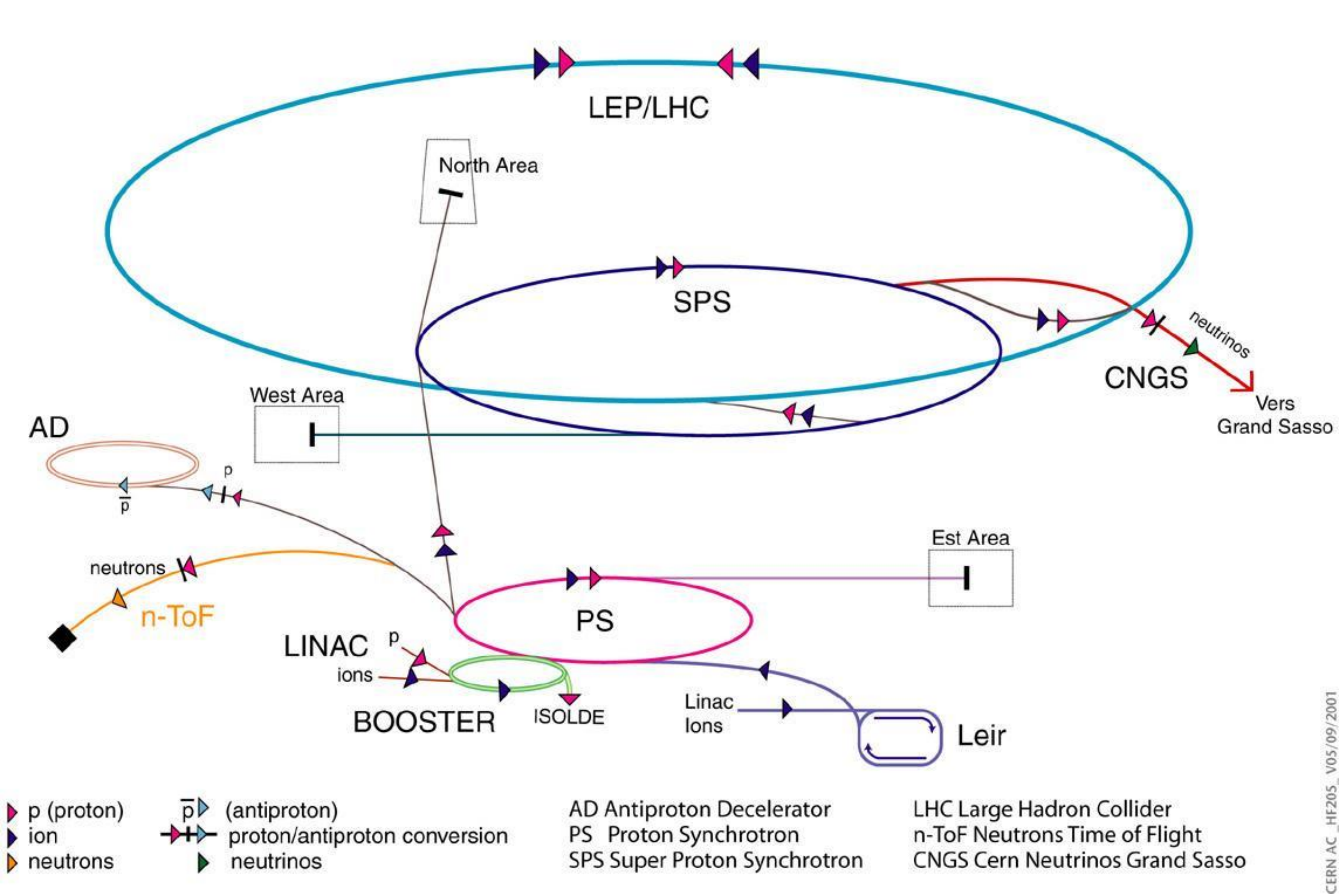


- 2010/11: **Pb-Pb** collisions @ 3.5*Z* TeV beam energy
  - Pb bunch intensities up to 3 × design ⇒ IBS!!



- Jan/Feb 2013: **p-Pb** collisions @ 4*Z* TeV beam energy
  - first LHC upgrade, not mentioned in the design report

Ion Beam Production - LHC Ion Injector Chain



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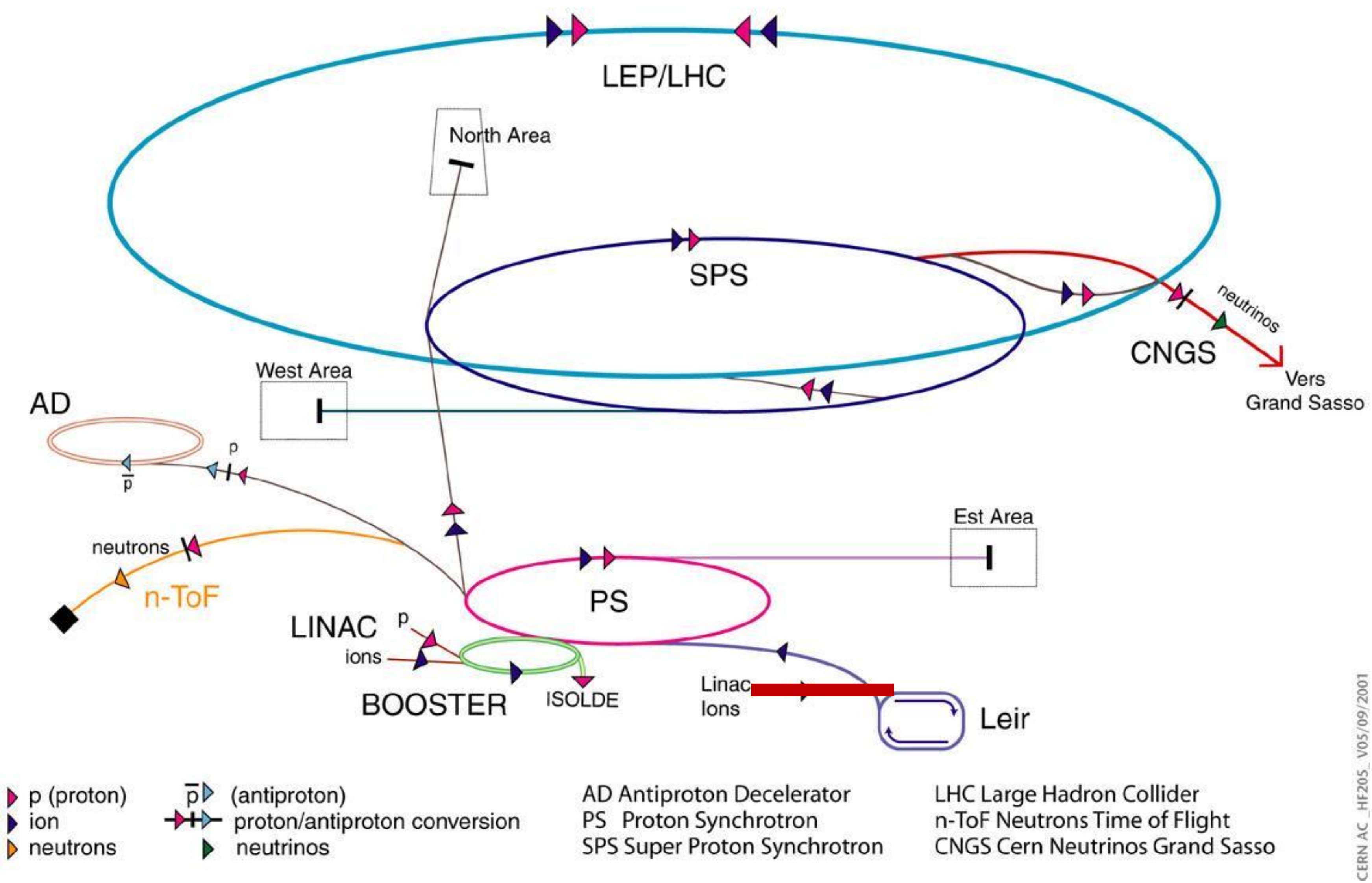

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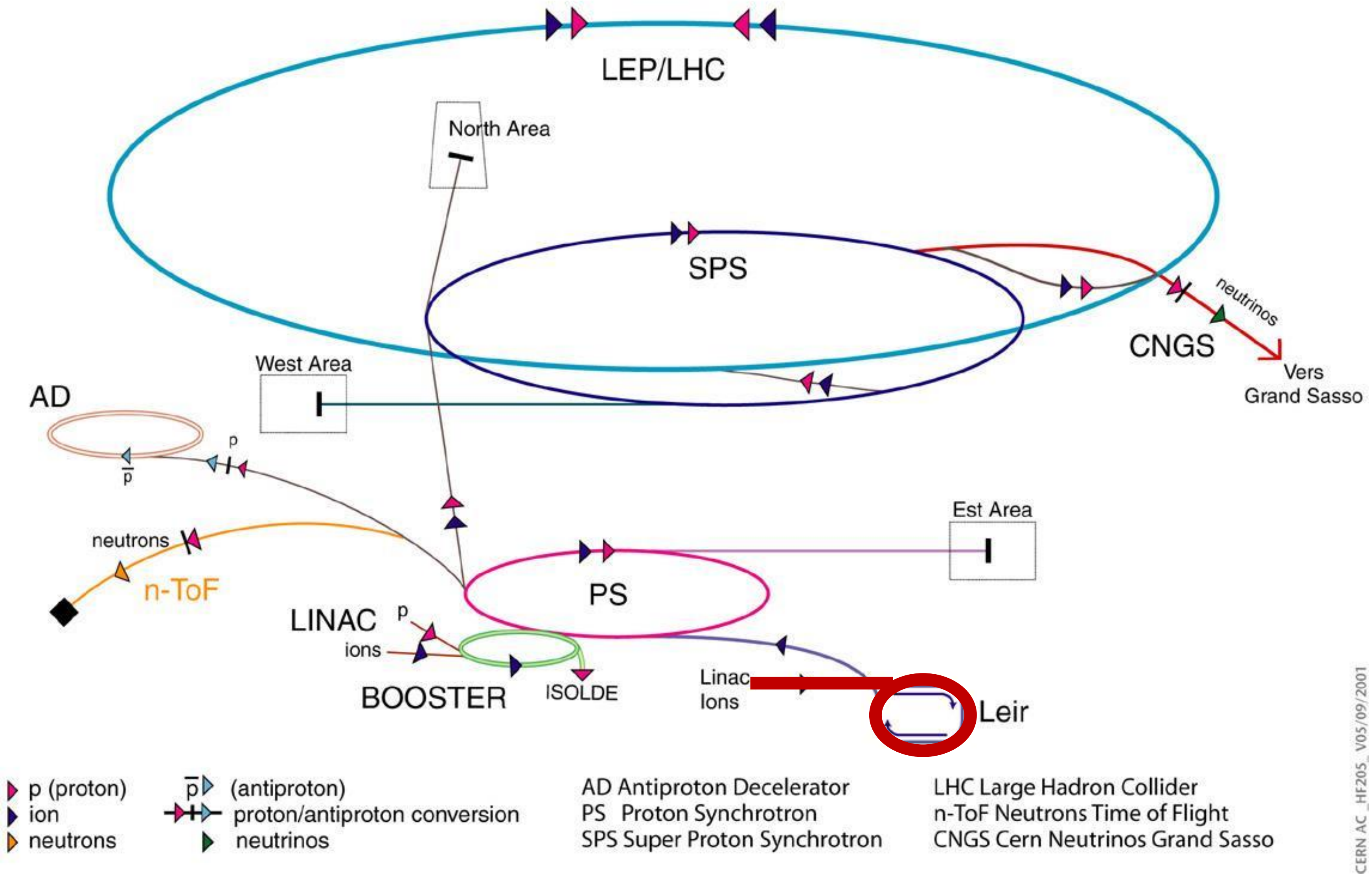

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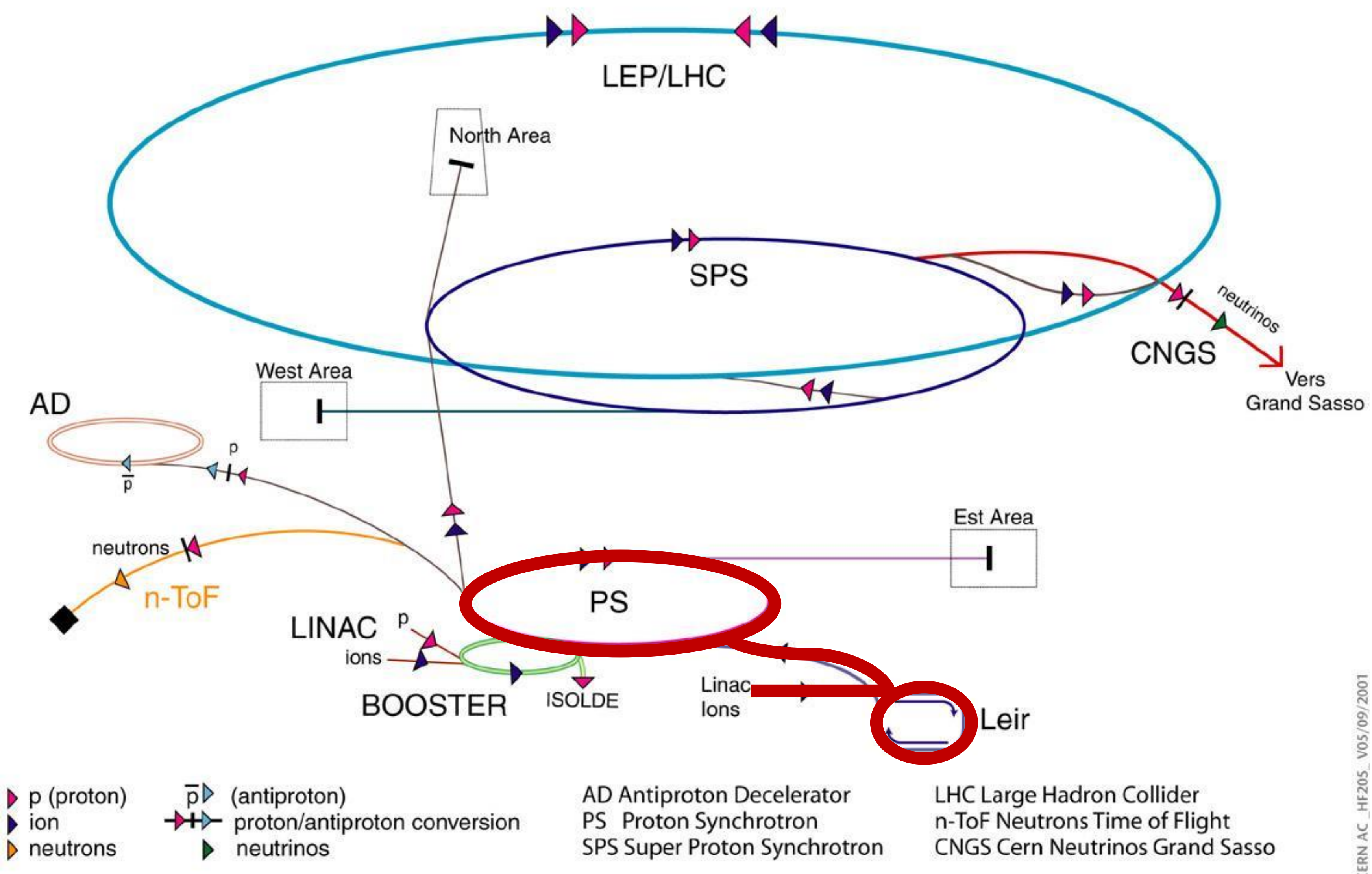

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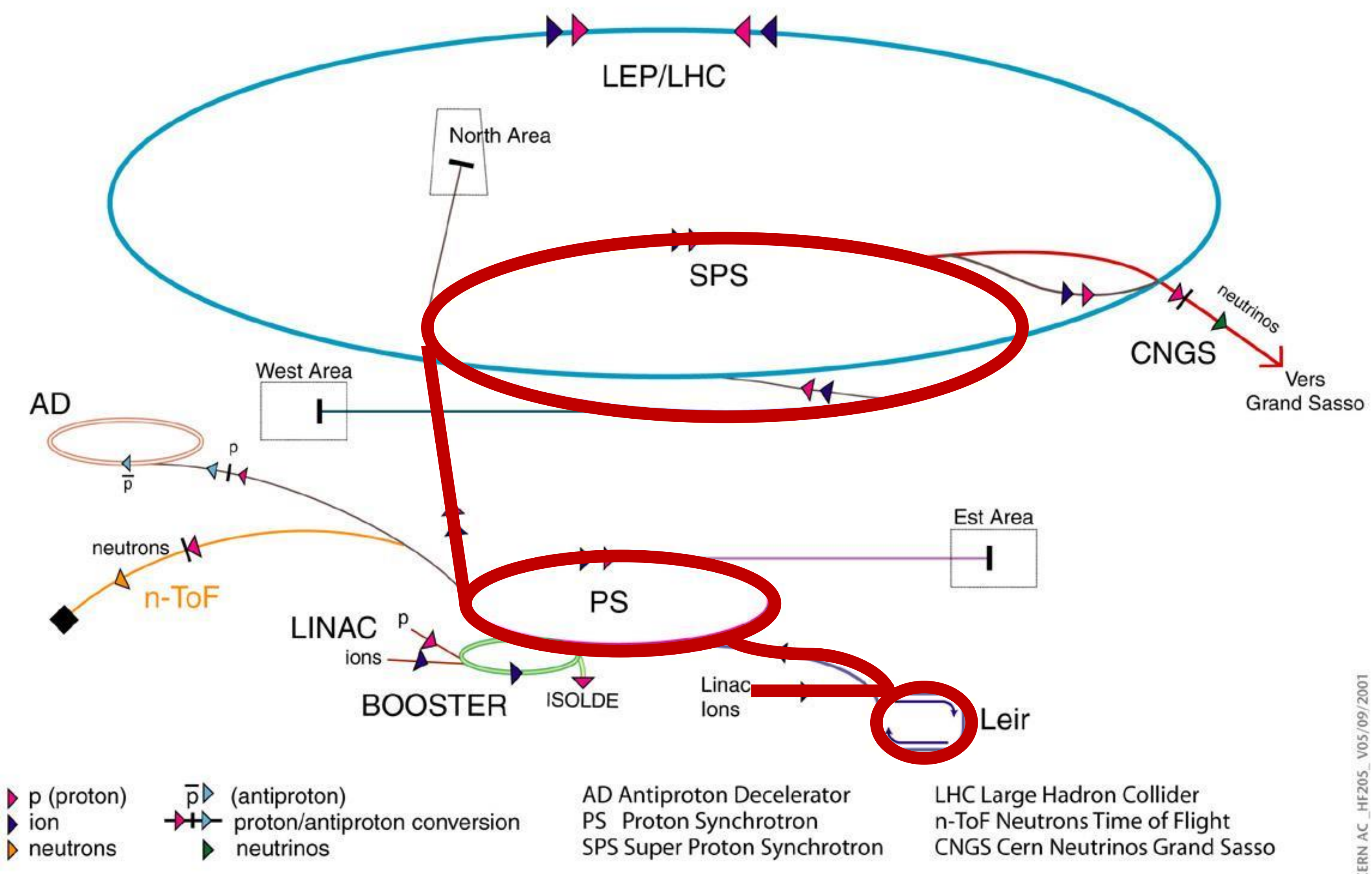

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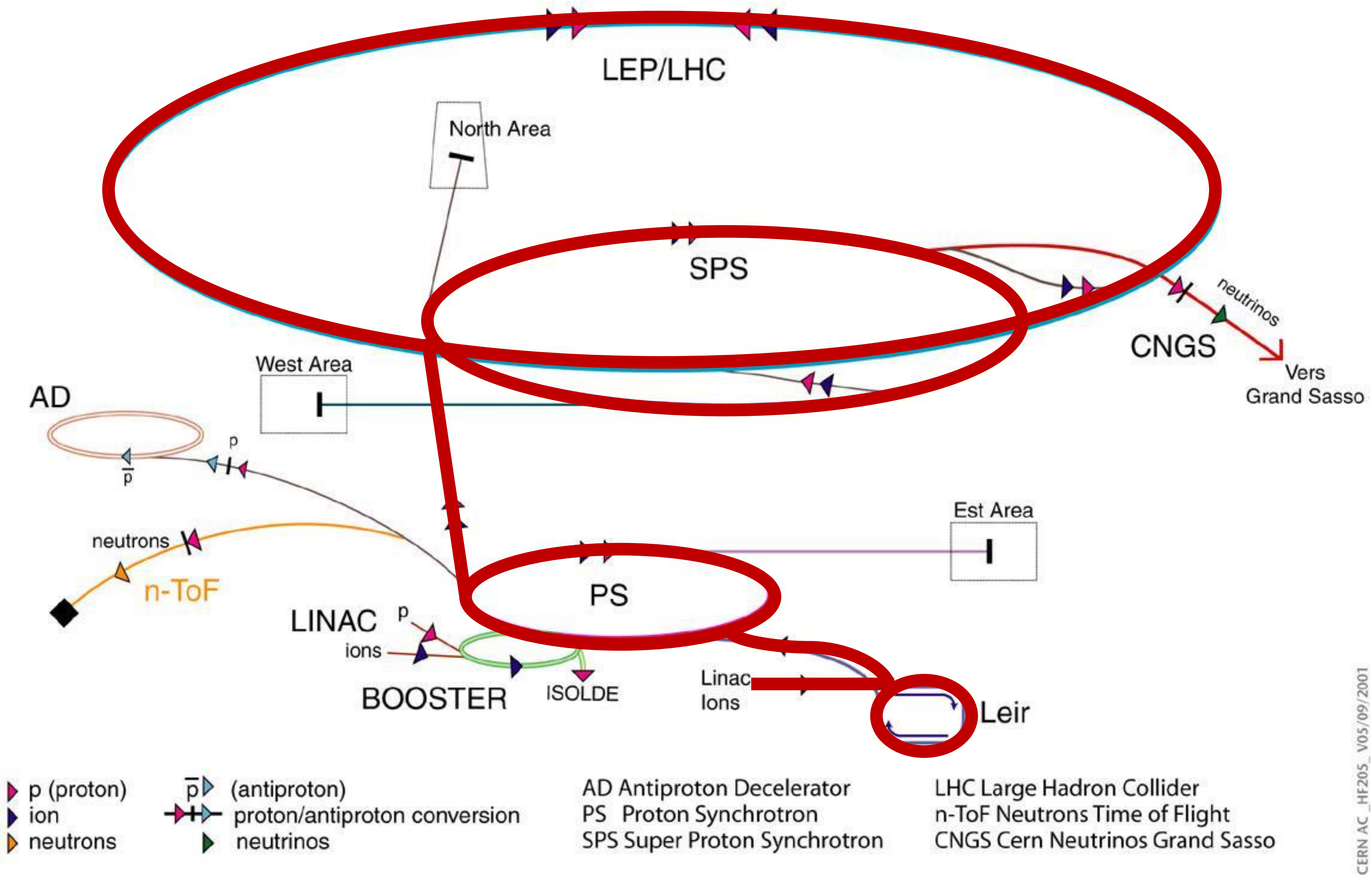


Simulations of beam evolution in LHC ring

Simulations include:

- IBS (various models)
- Burn-off from luminosity production
- Radiation damping and quantum excitation
- Stochastic Cooling

M. Blaskiewicz's Program [1]: developed for RHIC

↓

Collider Time Evolution (CTE) Program [2]: adapted for LHC application

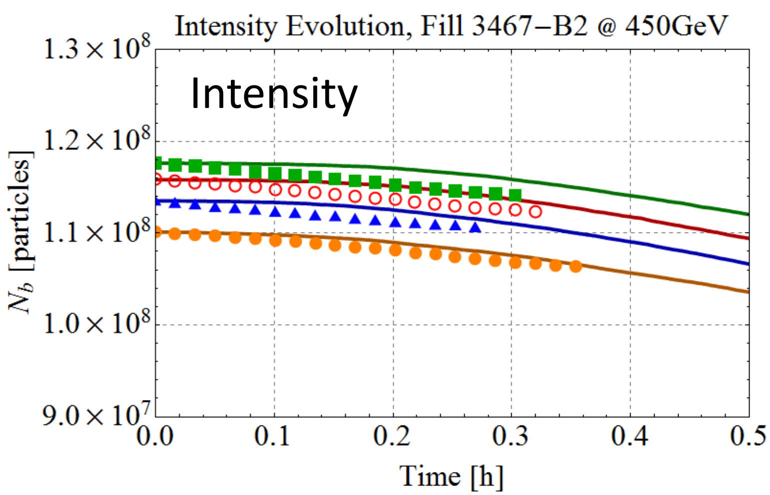
Simulations require:

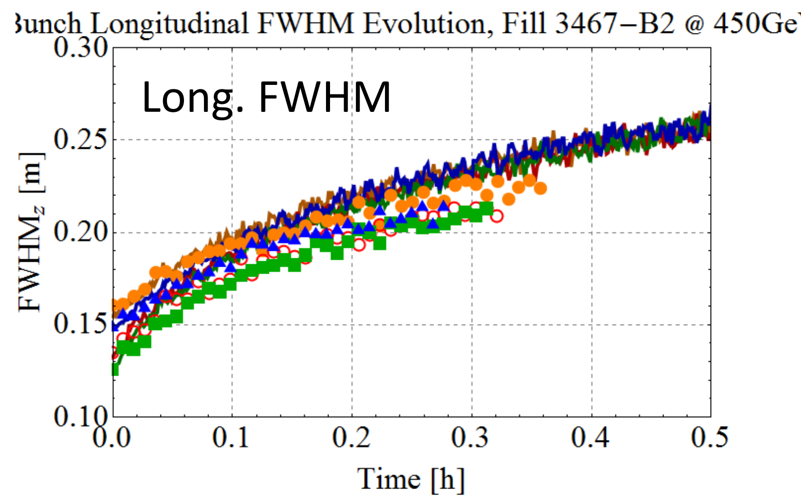
- initial beam parameters (from measurements): e.g. particle type, particles per bunch, emittances, bunch length, RF voltage…
- Properties of stochastic cooling system.

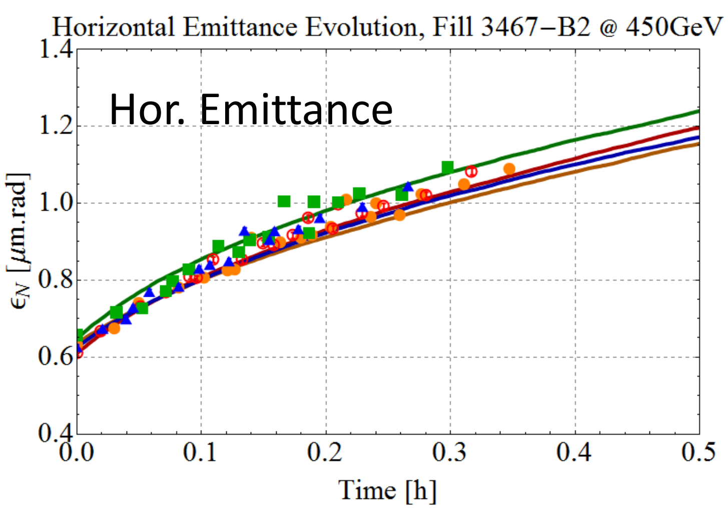
Beam Evolution at Injection (450Z GeV)

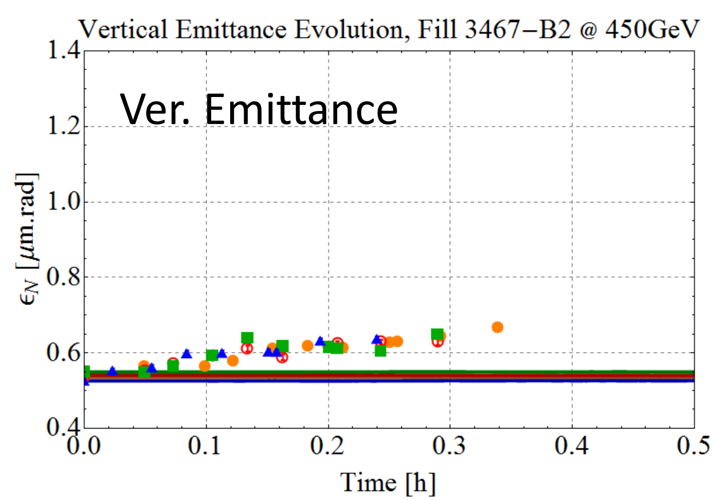
Beams suffer **from strong intra-beam scattering (IBS)**
→ Emittance growth and debunching losses
Simulations and data are mostly in good agreement.

dots = data
lines = simulation

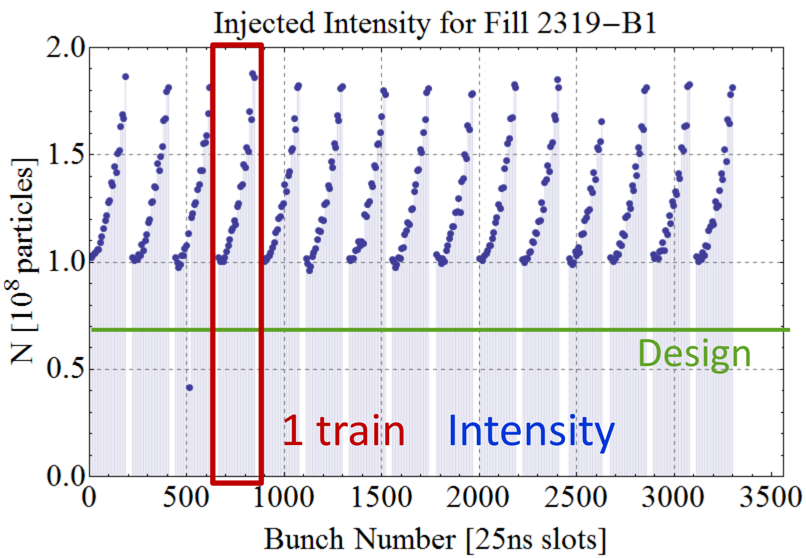


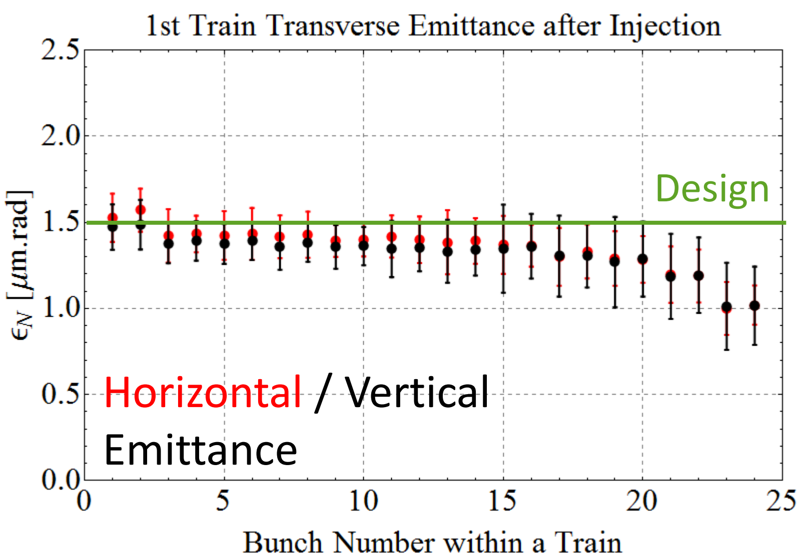






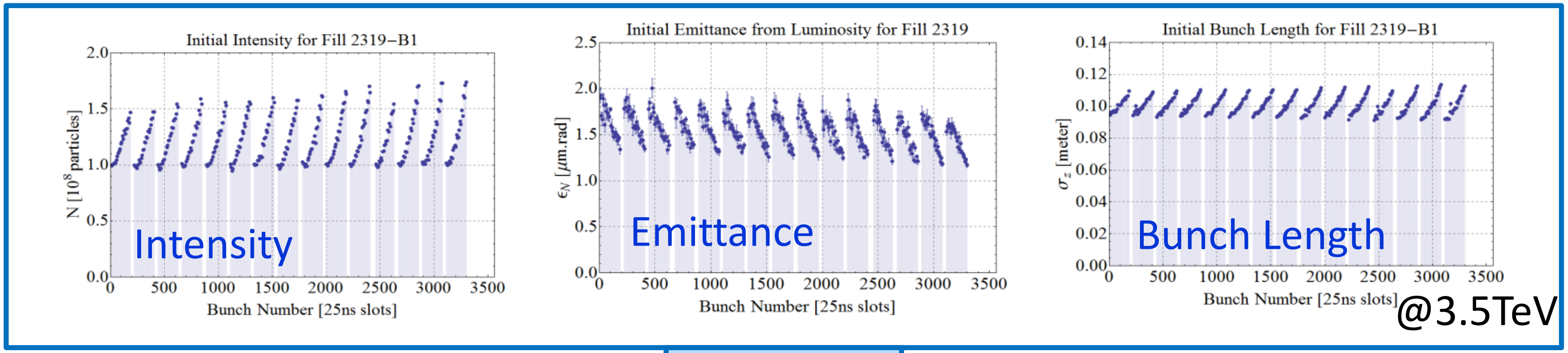
Bunch-by-Bunch Differences after Injection (450Z GeV)

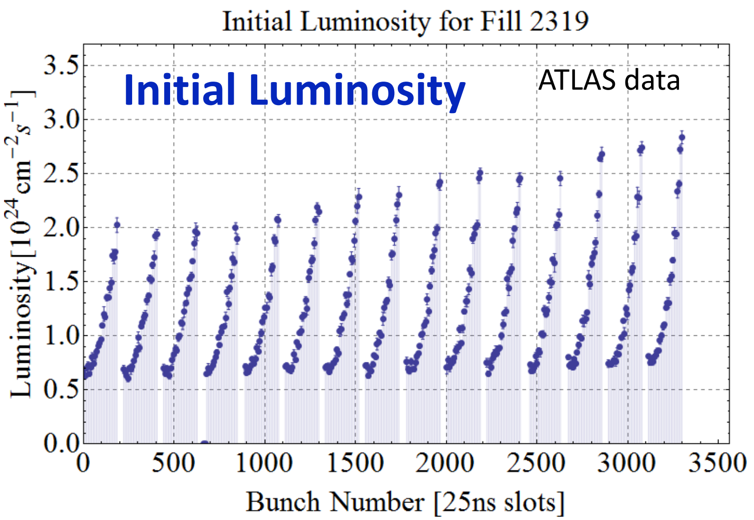


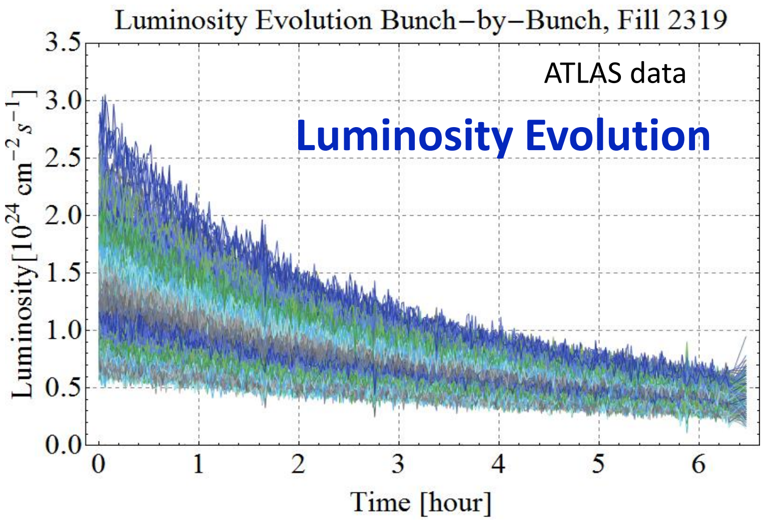


- Structure within a train (1st to last bunch):
  - increase: - intensity
    - bunch length
  - decrease: emittance.
- IBS at the injection plateau of the SPS:
  - while waiting for the 12 injections from the PS to construct a LHC train.
- First injections sit longer at low energy
  → strong IBS,
  → emittance growth and particle losses.

Luminosity

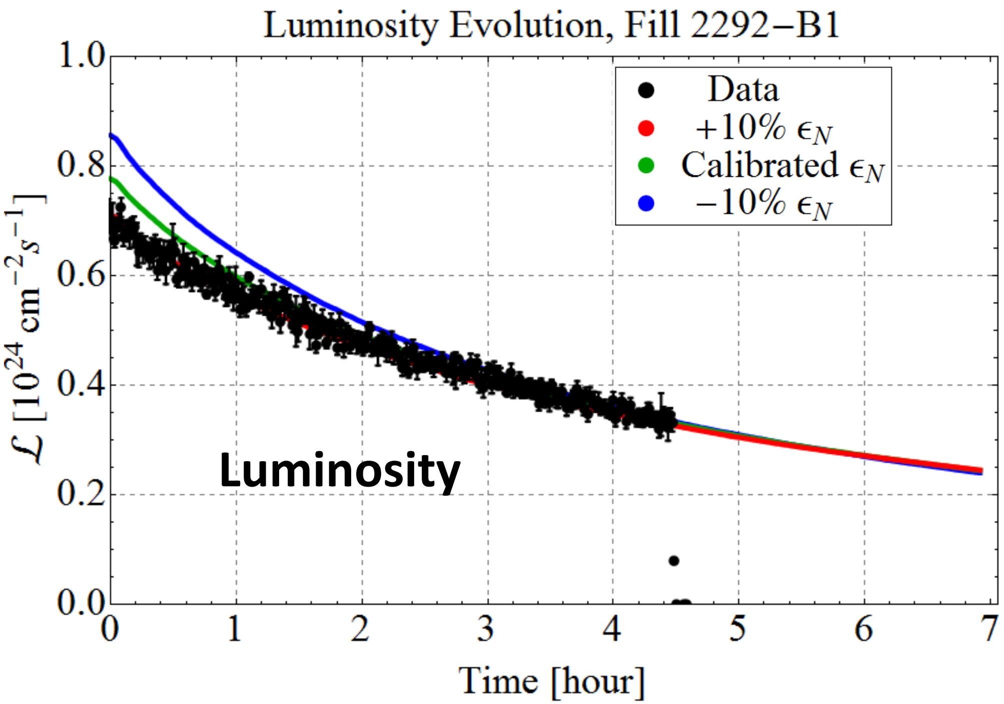




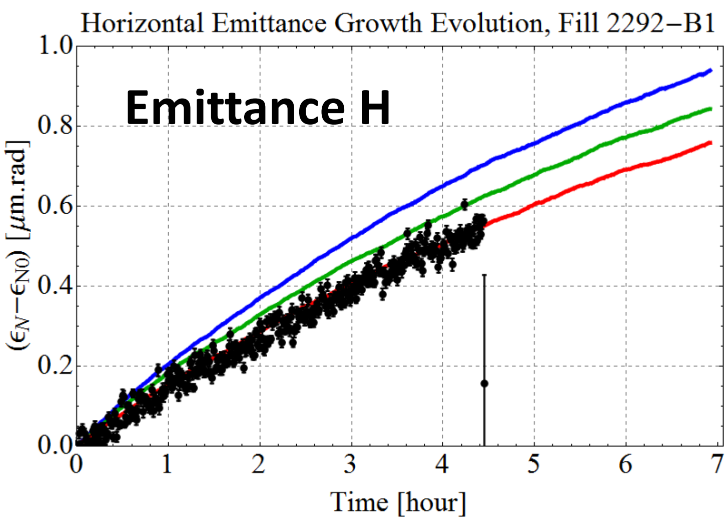


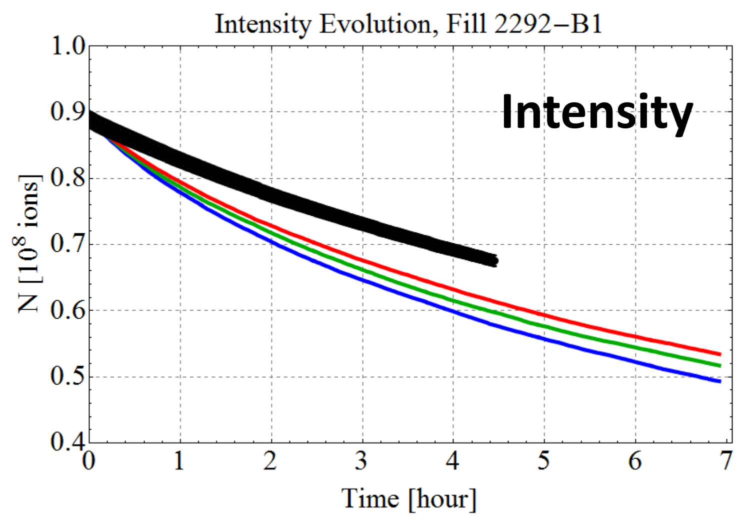
- Significant bunch-by-bunch structure within a train.
- Initial values differ by a factor 5-6!
- Different speed of decay – high initial luminosities decay very fast.

Evolution in Collisions @ 3.5Z TeV

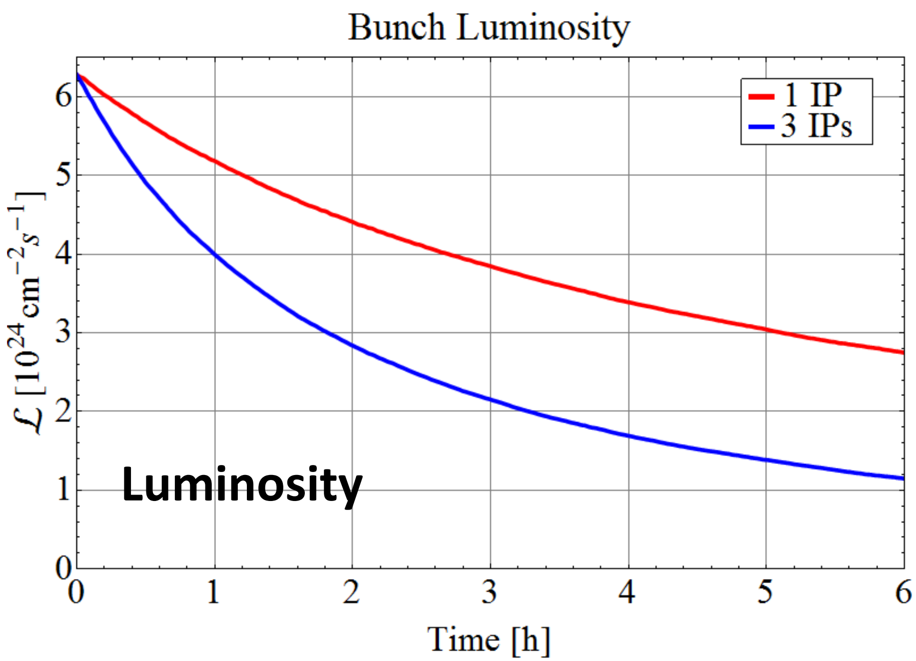


- 2011 Data
- Good agreement between data and simulation.
  - Calibration of transverse emittance is difficult.
- Simulation overestimates particle losses.
  - → Possibly due to non-Gaussian longitudinal distribution.

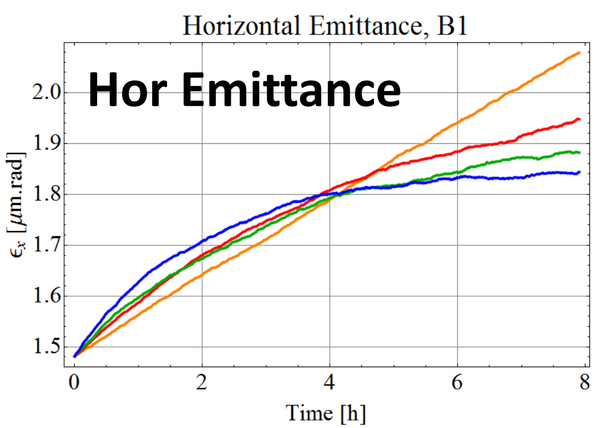


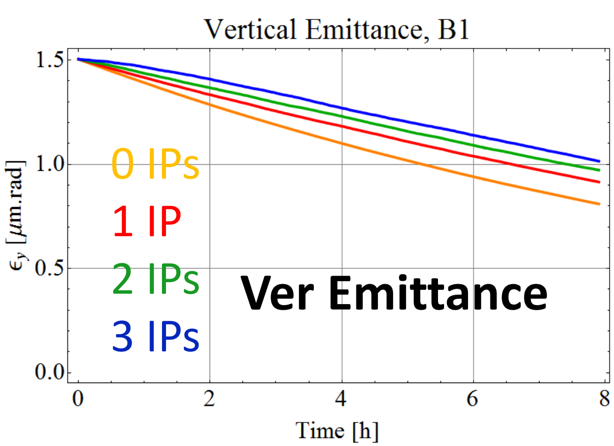


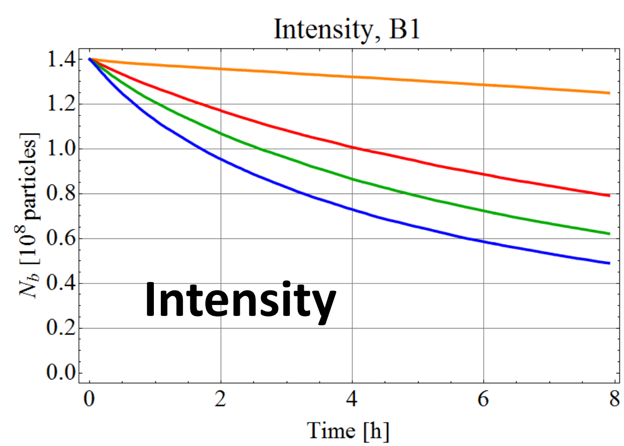
Potential Beam Evolution @ 7Z TeV



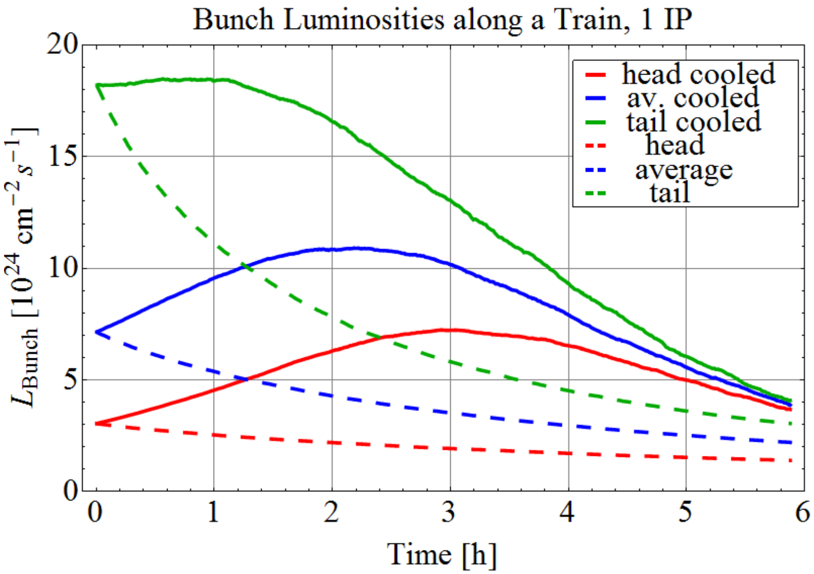
- Simulations [2] with IBS, burn off, radiation damping.
- 3 experiments in collisions lead to very fast burn off: → luminosity ½-life ≈ 2h.
- Turnaround time ≈ 3h.
  → Longer fills are desired.
  → Stochastic cooling as possibility to improve fill lifetime.

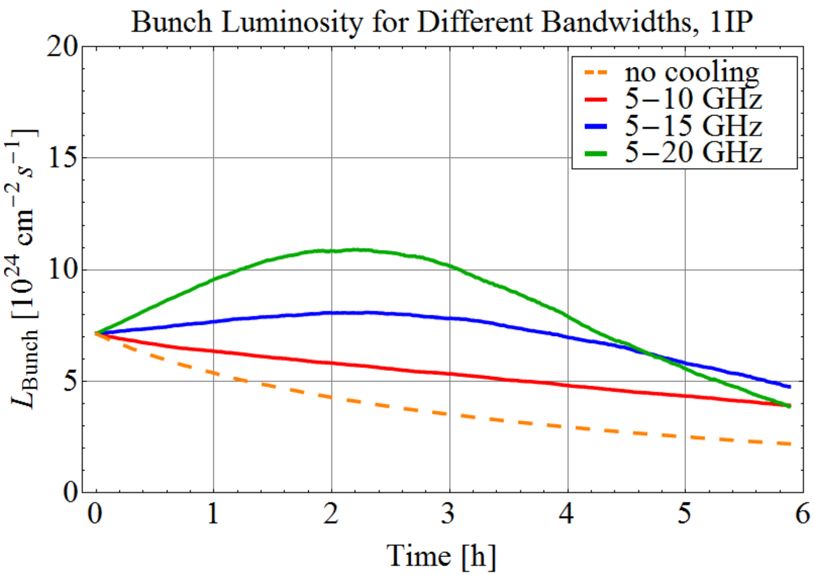






Cooling Simulations





- IBS horizontal growth time ≈ 8h.
- Radiation damping time ≈ 13h
  → radiation damping not included in the simulations on this slide.

- Assuming a stochastic cooling system with a 5-20GHz bandwidth and average 2013 Pb bunches [4]:

$$T_{\text{cool}} = \frac{N_b C_{\text{LHC}}}{4\sigma_z W} \left[\frac{M + U}{(1 - \tilde{M}^{-2})^2} \right] \approx 1.8\,\text{h}$$

- First estimate for RMS voltage per cavity (assuming a system with 16 cavities as in RHIC):

$$V_{cavity} = 2\,\text{kV}$$

- Integrated luminosity could be increased by a factor 2.
- Larger bandwidth and higher upper frequency, lead to higher integrated luminosity.

Conclusions

- Strong IBS at all energies leads to emittance growth and particle losses.
  → Significant bunch-by-bunch differences.
- Short fills, due to the high burn off rate with 3 experiments in collisions.
- Stochastic cooling could equalise bunches and obtain smaller emittances → higher integrated luminosity.
- First simulation results look promising, studies have just started and are on-going.
  - Challenges in hardware design.

THANK YOU FOR YOUR ATTENTION

References:

[1] M. Blaskiewicz et al., WEM2I05, COOL07 (2007).
[2] R. Bruce et al., Phys. Rev. ST AB 13, 091001 (2010).
[3] J. Bjorken, S. Mtingwa, Part. Acc. 13, pp. 115-143 (1983).
[4] D. Möhl, Lecture Notes in Physics 866, Springer (2013).
[5] M. Schaumann et al., TUPFI025, IPAC13 (2013).