TRAIN

X. Buffat

- Physics
- Examples
- Implementation
- Needs and future plans

Self-consistent solutions

Strong beam

- Optics
- Beam parameters

Weak beam

- Optics
- Beam parameters

Self-consistent solutions

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Beam-beam forces

Weak beam

- Disturbed optics
- Disturbed beam parameter

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→ Beam-beam forces →

Strong beam

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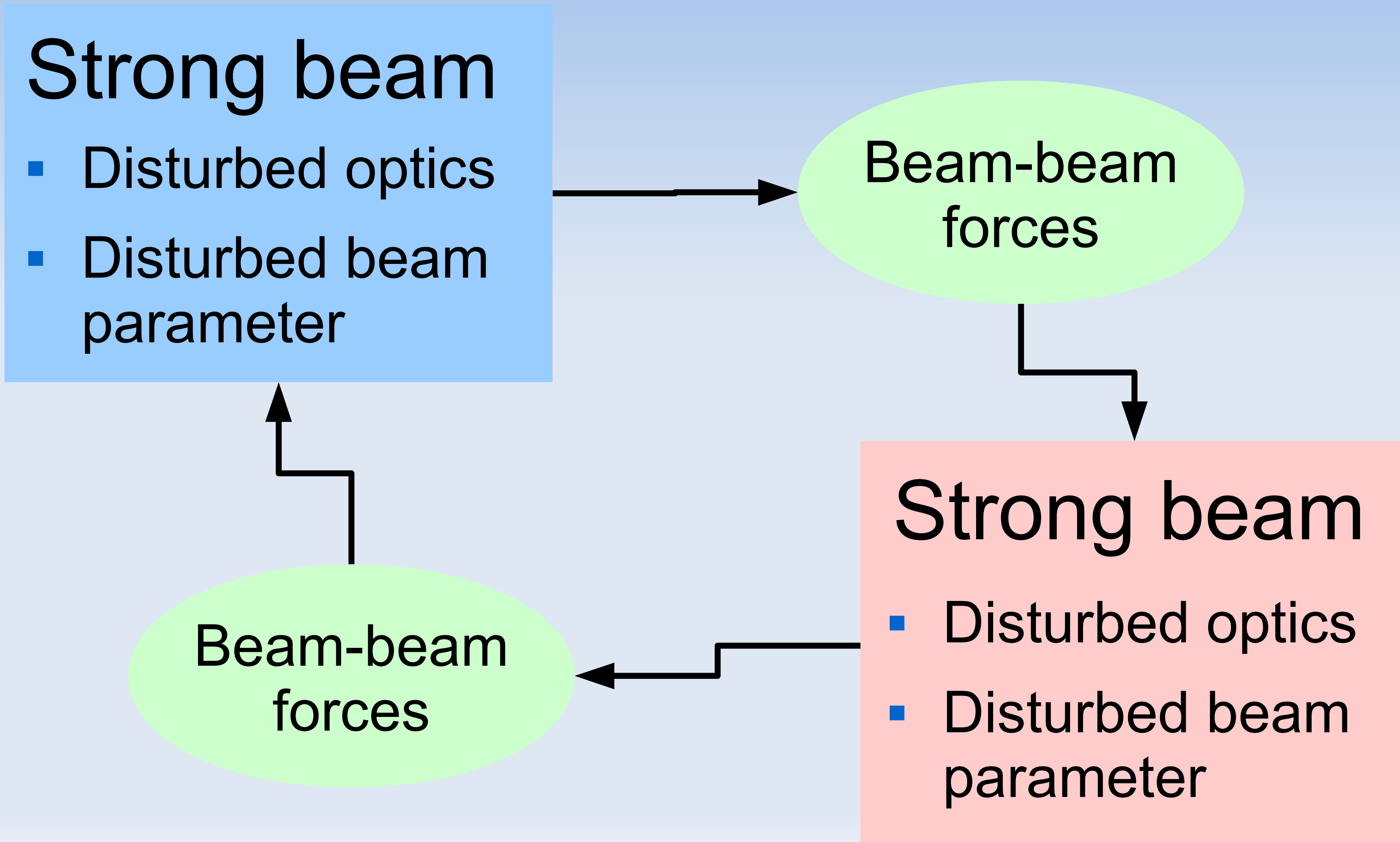
Self-consistent solutions



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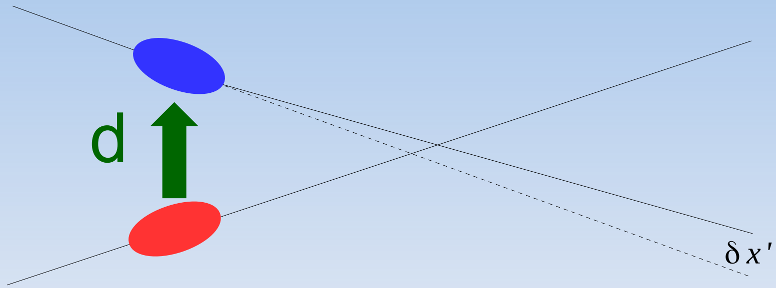
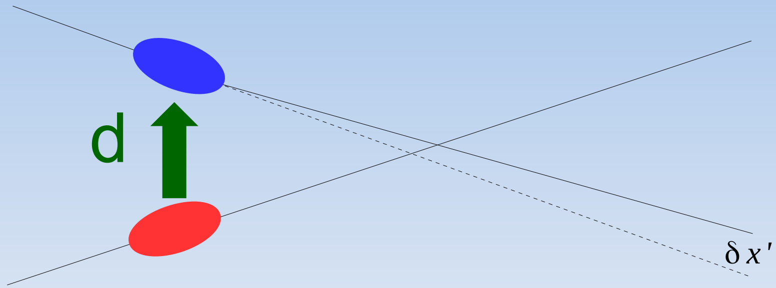


$$\delta x = \delta x' \beta \cot(\pi Q)$$

Self-consistent solutions



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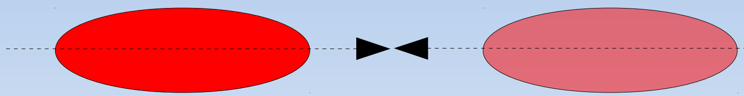
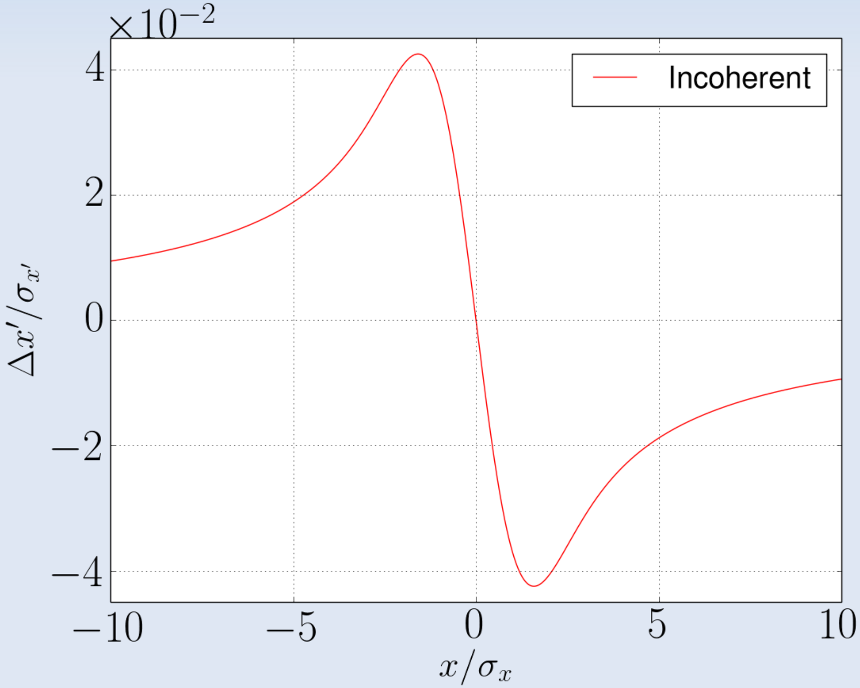
- Weak-strong :

$$\delta x = \Delta x_{coh}'(d) \beta \cot(\pi Q)$$

Coherent beam-beam force

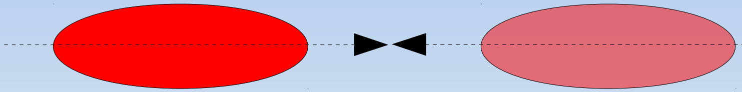


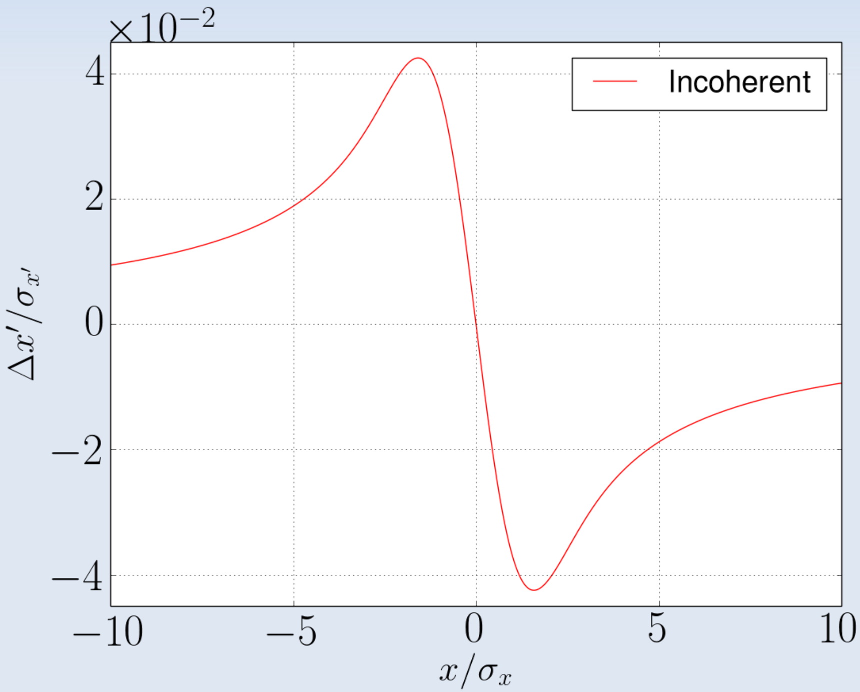


$$\Delta x'(x) = \frac{-2 r_0 N}{\gamma_r} \frac{1}{x} \left(1 - e^{\frac{-x^2}{2\sigma^2}}\right) \approx 4\pi\xi x$$

Coherent beam-beam force

- The average force felt by the particles in the beam is called the coherent force





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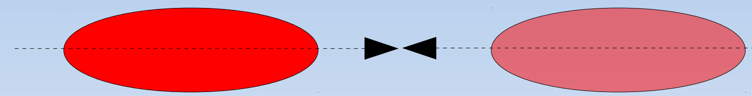
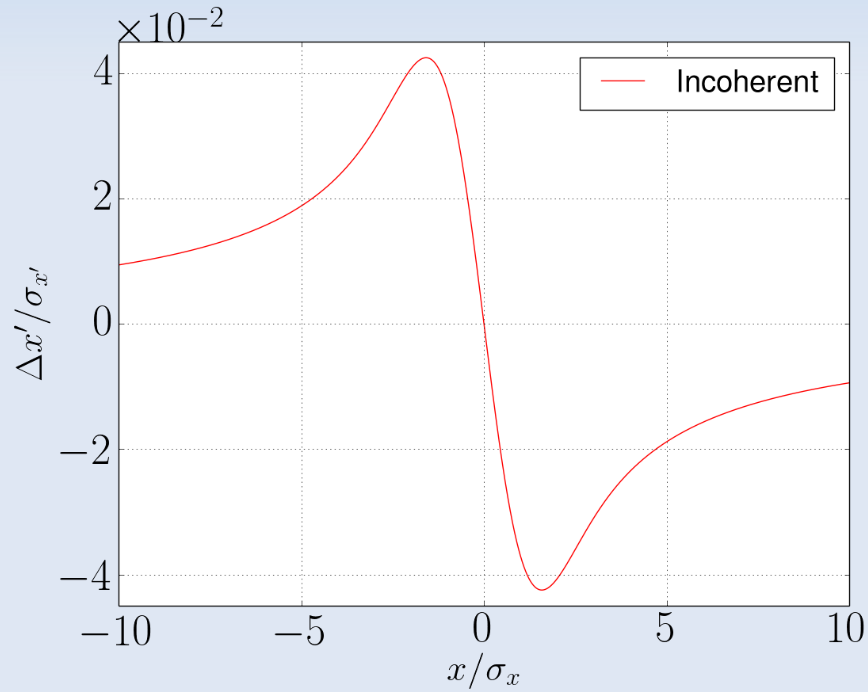


$$\Delta x'_{coh}(\Delta x) = \int_{-\infty}^{\infty} \Delta x'(\Delta x - X)\,\rho(X)\,dX$$



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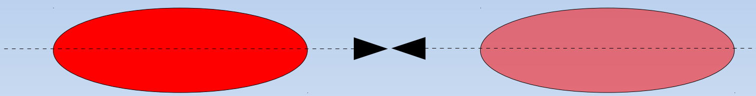

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$$=\frac{-2r_0N}{\gamma_r}\frac{1}{\Delta x}\left(1-e^{\frac{-\Delta x^2}{4\sigma^2}}\right)\approx\frac{4\pi\xi}{2}\Delta x$$

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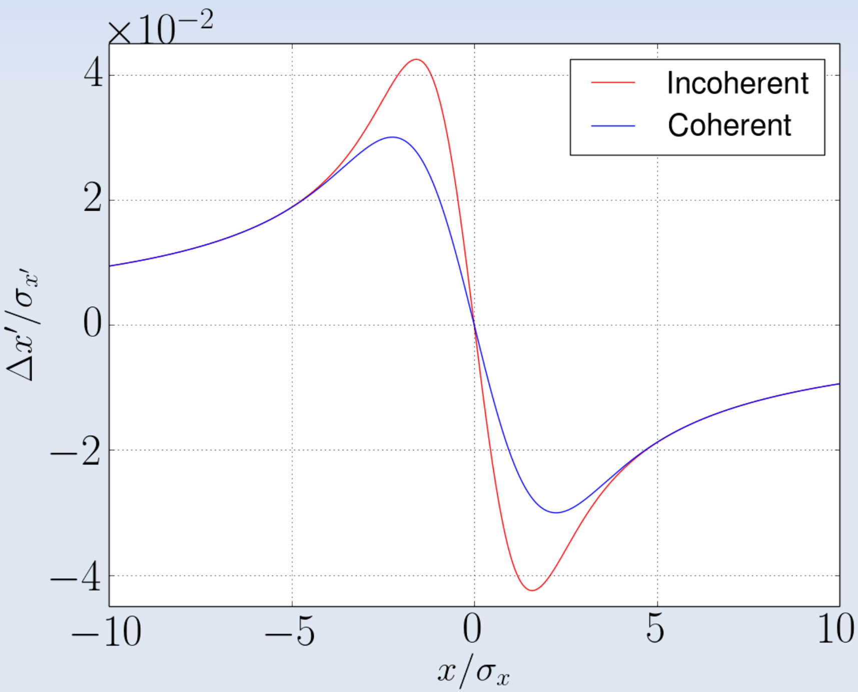
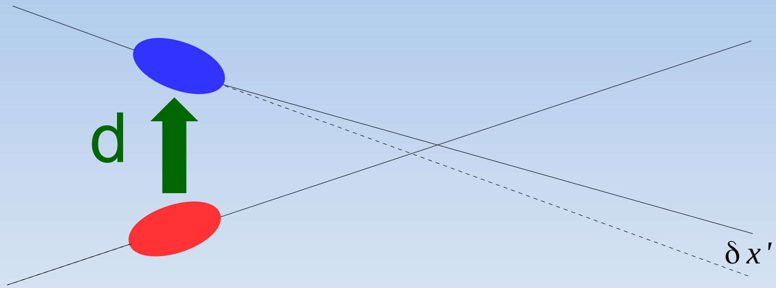


Self-consistent solutions



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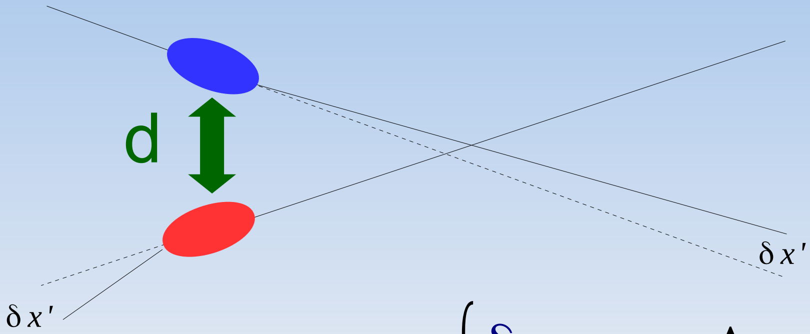

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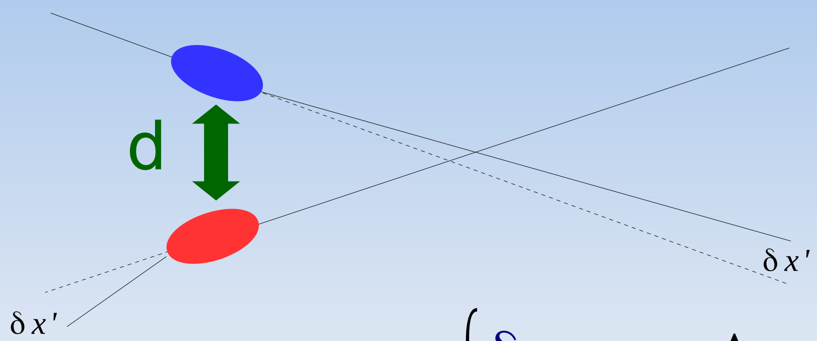
Self-consistent solutions



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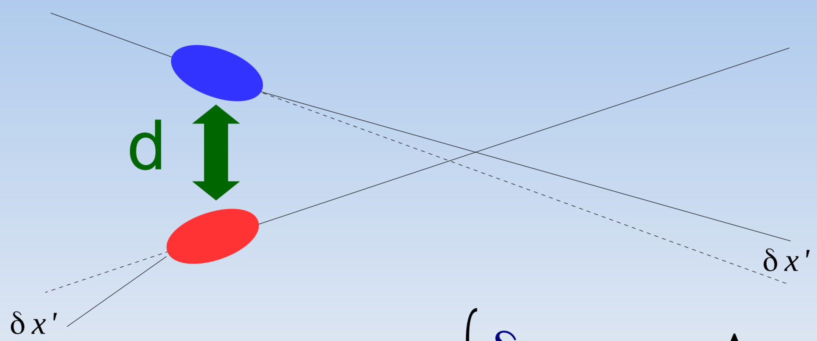
Self-consistent solutions



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  → Simple formulas become non-linear system of equations
  (LHC nominal : 2x2808 equations)

  - Iterative methods are needed to evaluate these effects

TRAIN

- Compute 1st and 2nd order maps between beam-beam interactions using MAD-X
  - Requires a thin lens lattice allowing for the installation of the beam-beam elements (not strictly needed but the current implementation does not allow thick lenses)
- Load the descripiton of the bunch configuration (filling scheme, intensities and emittances) and build the corresponding matrices
- Fixed-point iteration from the unperturbed orbit to self-consitent orbits for all bunches of the two beams inluding the effect of the coherent beam-beam kicks

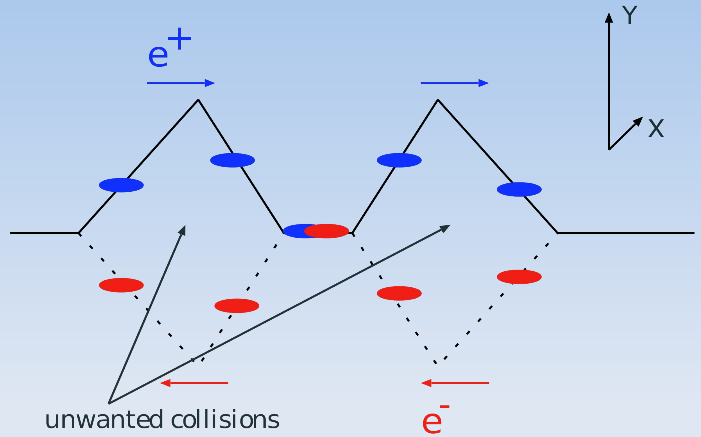
  → Closed orbit search for each bunch with fixed beam-beam kicks as in MAD-X (inner loop)

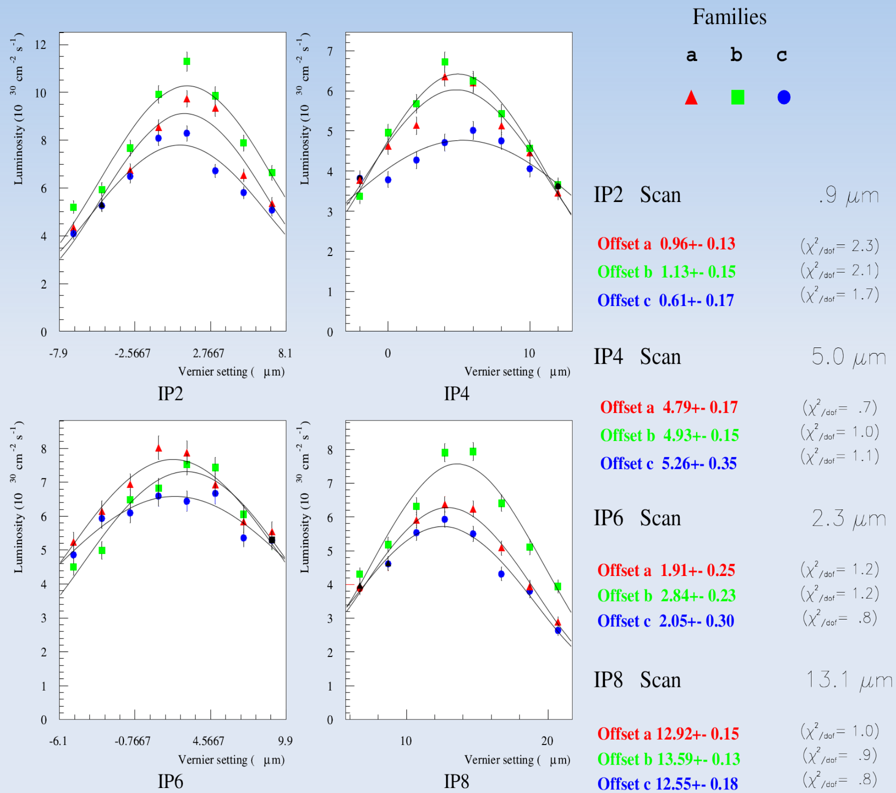
  → Recompute beam-beam kicks with the new orbit (outer loop)
- Compute the optics of all bunches using their closed orbit

→ This results in self-consistent orbits, the optics function are however not self-consistent

E. Keil, Truly Self-Consistent Treatment of the Side Effects with Bunch Trains, CERN/SL/95-075 (AP)
H. Grote, Self-Consistent Orbits with Beam-Beam Effects in the LHC, LHC Project Report 404 (2000)

LEP operation with 4b trains

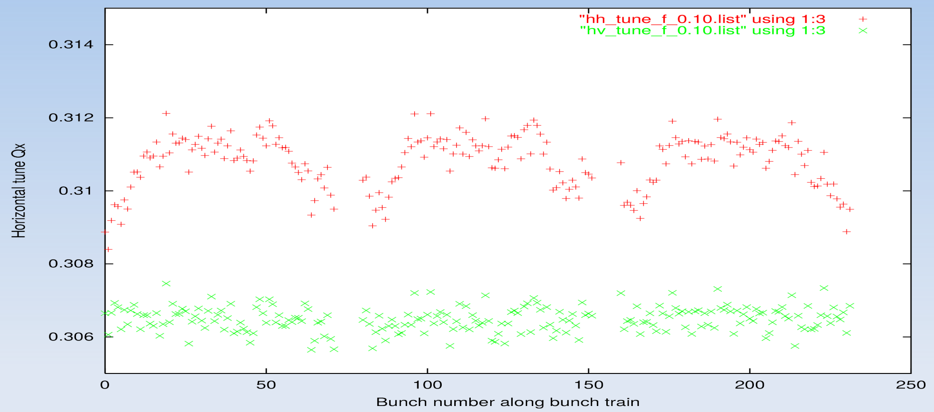


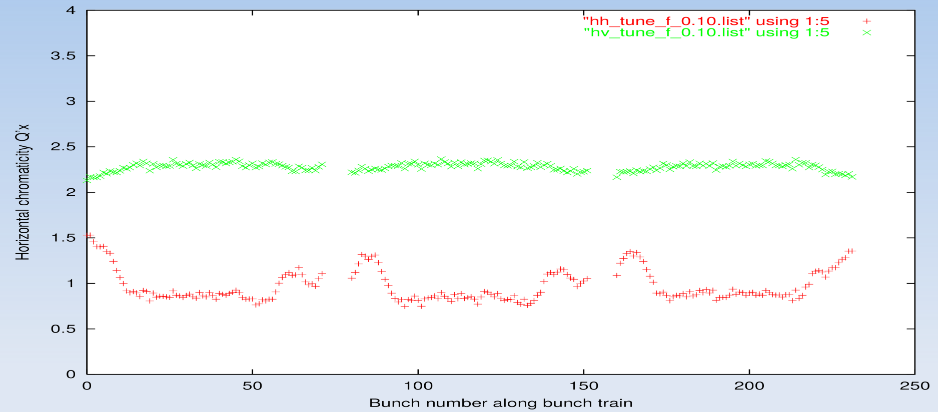


- Few long-range interactions lead to offsets at the IP, resulting in an increase of the β* (dynamic β effect) → important luminosity loss

E. Keil, Truly Self-Consistent Treatment of the Side Effects with Bunch Trains, CERN/SL/95-075 (AP)
W. Herr, Beam-beam issues in the LHC and relevant experience from the SPS proton antiproton collider and LEP, Proceedings of the Beam-Beam Workshop 2001, Fermilab
W. Herr et al., Is LEP beam-beam limited at its highest energy ?, Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

LHC crossing schemes



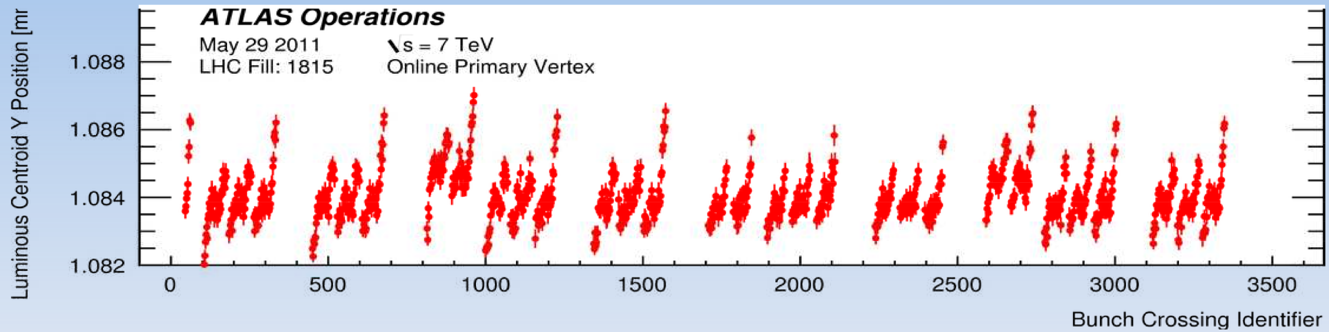


- The PACMAN tune and chromaticity variations due to long-range interactions can be mitigated by alternating the crossing angle plane in the two main experiments

H. Grote, Self-Consistent Orbits with Beam-Beam Effects in the LHC, LHC Project Report 404 (2000)
W. Herr, Features and implications of difference LHC crossing schemes, LHC Project Report 628 (2003)

Observations at the LHC

- Displacements of the luminous regions corresponding to expectations are measured in the LHC



- The orbit effects of both long-range and head-on beam-beam interactions have an important impact on VdM scans and are measurable during separations (OP) scans

M. Schaumann et al., Beam-beam induced orbit effect at the LHC, Proceedings of the Beam-Beam workshop 2013, CERN

W. Kozaneki, Impact of Beam-Beam Effects on Precision Luminosity Determination at the LHC, presented at the Beam-Beam workshop 2013, CERN

A. Gorzawski et al, Long-Range Beam-Beam Orbit Effects in the LHC - Simulations and Observations From Machine Operation in 2016, Proceedings of IPAC 2017

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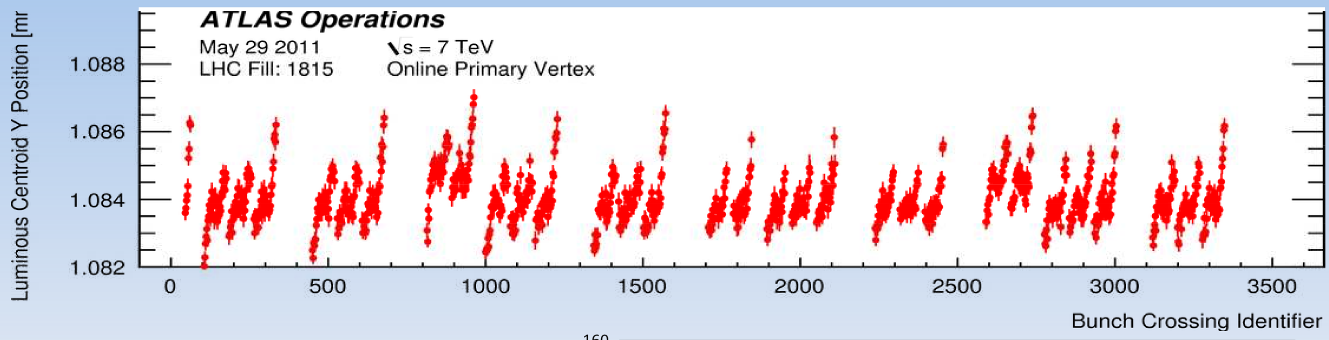

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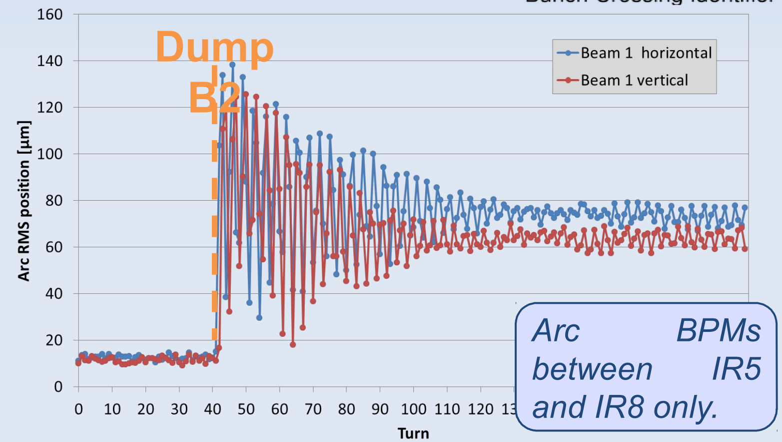
- Modifications of the orbit of the remaining beam are observed when dumping the other



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A. Gorzawski et al, Long-Range Beam-Beam Orbit Effects in the LHC - Simulations and Observations From Machine Operation in 2016, Proceedings of IPAC 2017

T. Baer, Beam-beam effects during the beam dump process, presented at the Beam-Beam workshop 2013, CERN

Summary

- TRAIN is (was) used at CERN to :
  - Evaluate constraints driven by beam-beam interactions, in particular PACMAN effects, in the IR design of the LHC, HL-LHC and FCC-hh
  - Define optimal configurations for VdM scans in the LHC
  - Understand observations in the LEP and the LHC

Implementation

- Main contributors : F. C. Iselin, H. Grote, W. Herr starting~1994, new post-processing developped recently by A. Gorzawski
- The sources are available at https://gitlab.cern.ch/agorzaws/train
- FORTRAN77
- Procedural (single file,12k lines, global variables, goto's, ...)
- No license
- No parallel implementation
- No documentation (except for the references mentionned)

Needs and future plans

- The execution of TRAIN takes few tens of seconds
- A single or a few runs are usually enough to evaluate a given configuration

  → The present resources (desktops/LSF/HTCondor) are appropriate to cover the needs
- Future plans :
  - Remove LHC specific implementations (number of IR, fixed IR design, number of long-range interactions per IR) → Improved flexibility
  - Implement a re-optimisation of the orbit at the IP (lumiscan) to evaluate luminosity loss in realistic configurations
  - Compute the optics in a self-consistent way
  - Migration to MAD-NG ?
- A. Gorzawski and T. Pieloni have been maintaining TRAIN with no official commitment
- A technical student will start this autumn to address the requirements for the HL-LHC
- EPFL is participating in the developement towards FCC-hh