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# TRAIN

## Introduction

TRAIN solves a multivariate, self-consistent and non-linear fixed point problem in order to find the closed orbit of all bunches in both interacting beams once the Filling Scheme and the beam-beam interactions have been introduced. The Filling Scheme is the irregular filling pattern of bunches along the 3564 "buckets" around the machine that can be occupied. The existence of the Filling Scheme gives place to missing long range interactions (PACMAN) and head-on interactions (super-PACMAN), causing different bunches to receive a different number of coherent beam-beam kicks depending on the number of PACMAN and super-PACMAN encounters that each bunch experiences. Consequently, bunch by bunch differences in orbit, tune and chromaticity, that cannot be corrected, will exist.

TRAIN is formed by a set of bash scripts written by A. Gorzawski in order to ease and grant the correct execution of the Fortran core developed by F.C. Iselin, E. Keil, H. Grote, W. Herr and A. Gorzawski.

### Fast execution

1. In the first set up, execute the command

   ```
   make
   ```
2. Execute

   ```
   ./updateMadFiles.sh {OperationConfiguration}
   ```

   where {OperationConfiguration} refers to a MAD-X file containing information about the crossing angles and planes, half parallel separation, the beam definitions , the optics...
3. Execute the command

   ```
   ./runTrainWithFillingScheme.sh {fillingSchemeInputFile}{plot|noPlot}
   ```

   with {fillingSchemeInputFile} the name of the Filling Scheme that will be used in the simulation and the flag {plot|noPlot} that will trigger the appearance of the plots of the full separation in sigma of both beams at the Interaction Points 1 and 5, as well as the horizontal and vertical orbit as a function of the bunch id at these locations.

### Outputs

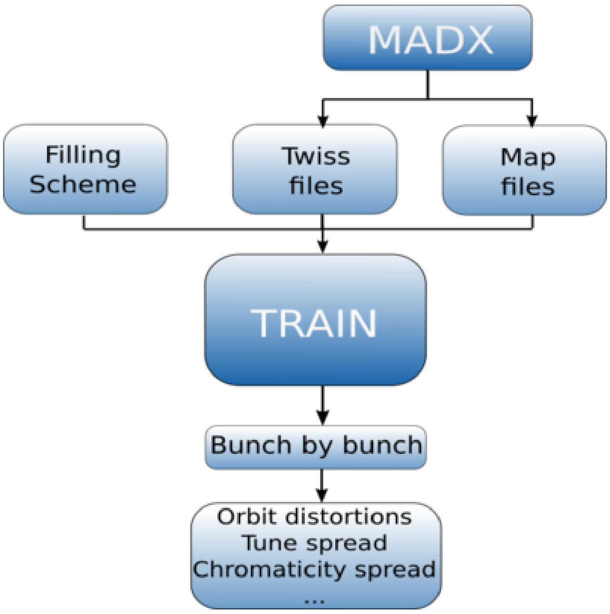
TRAIN allows to obtain information about:

- Orbit effects:
    - Maximum peak to peak global orbit spread and global orbit spread root mean square
    - Horizontal and vertical orbit as a function of the bunch id for all the Interaction Points and the selected extra elements that have been introduced (i.e., crab cavities, triplets...)
    - Horizontal and vertical separation at the Interaction Points (in $\sigma$).
- Horizontal and vertical slop at the Interaction Points.
- Horizontal and vertical dispersion at the Interaction Points.
- Average luminosity as a function of the bunch id at the Interaction Points.
- Collision scheme and equivalent classes that have been computed.
- Tunes and chomaticities:
    - Horizontal and vertical tune.
    - Horizontal and vertical chromaticity.
    - Beam current

- Maximum peak to peak tune and chromaticity.
- Others

## Data flow and operation

In the following, an overview of the functioning of TRAIN is given in order to ease its comprehension. The basic scheme of the data flow of TRAIN can be seen below.




Data flow of TRAIN. The scheme represents the inputs that TRAIN needs in order to produce the bunch by bunch results of orbit, tunes, chromaticities...
In more detail, the overall functioning of TRAIN can be divided into 6 steps:

1. Preparation of the input files of TRAIN:
    - The filling scheme that it is going to be used in the simulation is selected.
    - Execution of **MAD-X** for obtaining the Twiss and map files for beam 1 and beam 2 without beam-beam interactions and a given configuration of the operation cycle.
    - Modification of other parameters using the input file "setup.temp".
2. The interaction points are marked using the information of the Twiss files.
3. Whithin TRAIN the information of the Twiss files and the filling schemes is combined in order to simulate the collision of all the bunches of beam 1 and beam 2 in the different interaction points (half slots), i.e., it simulates all beam-beam encounters.
4. The closed orbits of beam 1 and beam 2 without beam-beam interactions are initialized using the first order maps.
5. Introduction of the beam-beam interaction in the interaction points. A double loop iteration starts:
    - **Inner loop:** Finds the closed orbit with fixed beam-beam kicks.
    - **outer loop:** Updates the bunch positions until the orbit of both beams doesn t change any more, i.e., we reach a stable solution.
6. Tracking of every bunch pair with the second order maps in order to find out their tune, chromaticity and dispersion.

# Full Description and documentation

The detailed functionalities that have been added to TRAIN in addition to the full documentation of all the subroutins and functions defined in the Fortran core are detailed in the following manual

- **TRAIN Manual LaTeX source:** https://www.overleaf.com/17170934gkmjhrvnxfnk

- **TRAIN Manual (preliminar version):** https://twiki.cern.ch/twiki/pub/ABPComputing/TrainWikiPage/TRAIN_reference_manual.pdf

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