Introduction to MAD-X

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Material based on Guido Sterbini, Öznur Mete and Bruce Yee courses

16th of January 2023

GOAL

The goal of this introduction to MAD-X lecture and workshop is to **complement** with "hands-on" numerical exercises the **lectures on Transverse Beam Dynamics** using the beam optics code **MAD-X**. We will focus on **magnet lattice design** and as a consequence you will be exposed to the **transverse beam dynamics concepts** from a new perspective.

DISCLAIMER

- This material is intended to be a very brief introduction to MAD-X: a large part of the code capabilities are not discussed in detail or are not discussed at all!

- If you want to deepen into the subject you can find a lot of material in:
  - ✓ The official MAD-X web site: http://mad.web.cern.ch/mad/

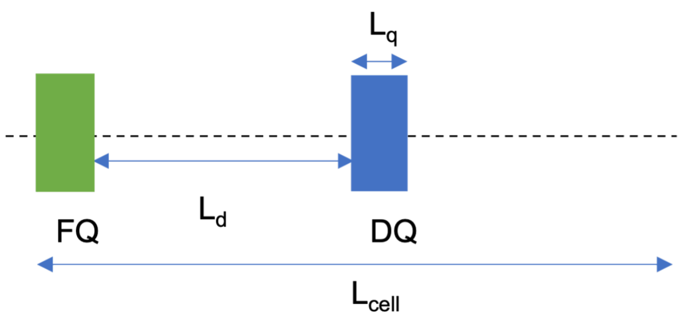
MAD-X workshop overview

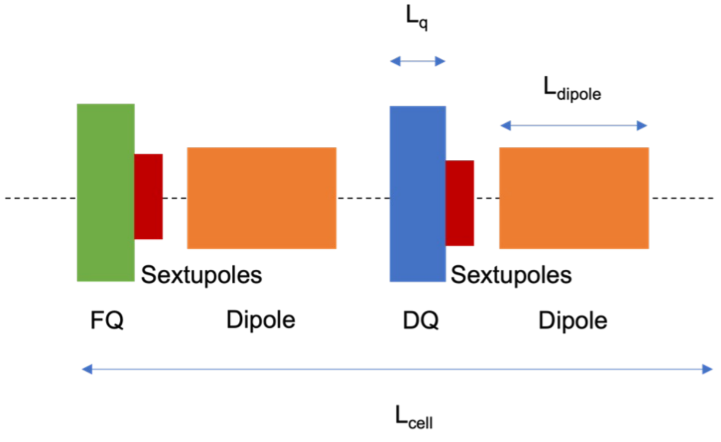
- ❑ **50 minutes lecture** (now!)

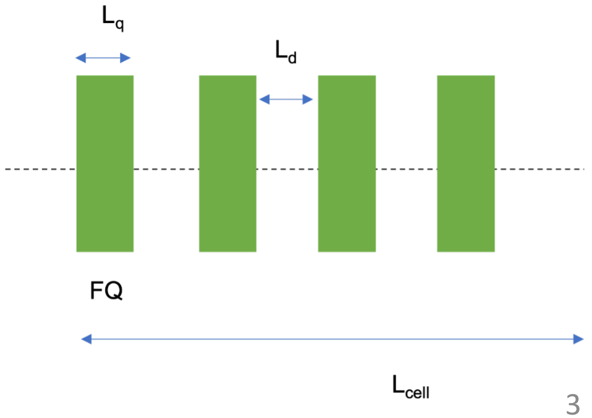
- ❑ **First "hands-on" session (3h)** (today in the afternoon).
  - ✓ **Tutorial 1**: My first accelerator, a FODO cell.
  - ✓ **Tutorial 2**: My first matching.
  - **BREAK (30 minutes)**
  - ✓ **Tutorial 3**: Building a circular machine.

- ❑ **Second "hands-on" session (3h)** (tomorrow in the afternoon).
  - ✓ **Tutorial 4**: Natural chromaticity.
  - ✓ **Tutorial 5**: Chromaticity correction and non-linearities.
  - **BREAK (30 minutes)**
  - ✓ **Tutorial 6**: Building a transfer line.

Tutors: Nuria Fuster-Martínez, Guido Sterbini, Axel Poyet, Davide Gamba.







Outline

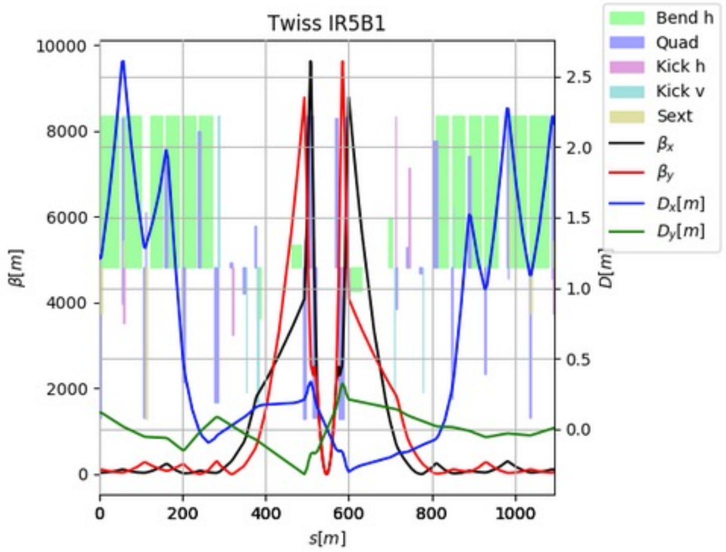
- ❑ Introduction. *Description of basic concepts.*
- ❑ MAD-X language. *Syntax, variables.*
- ❑ MAD-X commands. *Magnets, sequence and beam definition.*
- ❑ Advanced MAD-X commands. *Twiss, matching and tracking.*
- ❑ Example case. *A FODO cell.*
- ❑ How to run MAD-X. *Interactive mode, batch mode and python interface.*

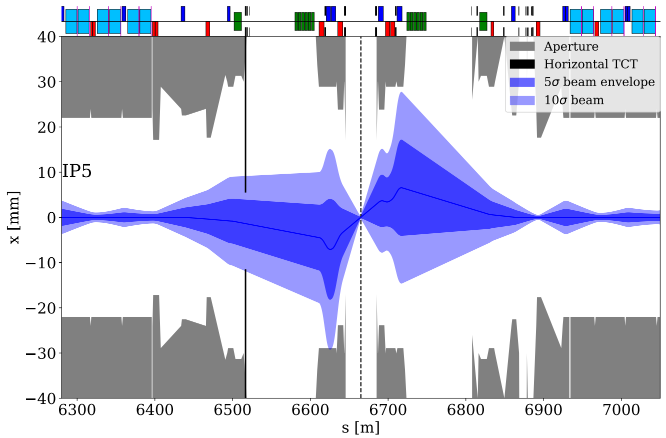
Introduction

- *General purpose of a beam optics code.*
- *What is MAD-X?*
- *Do we use MAD-X for everything? No!*
- *Why MAD-X?*
- *How does it work?*
- *Source code: the basic components.*

General purpose of a beam optics code

- Define the **lattice** of circular or linear accelerators.
- Compute **optics** parameters and **beam properties** along a given lattice.
- Design a lattice for getting the desired properties (**matching**).
- **Simulate** accelerator **imperfections** and design **correction schemes**.
- Simulate **beam dynamics**: study single-particle motion.





LHC Interaction Point 5

What is MAD-X?

```
++++++++++++++++++++++++++++++++++++++++++++
+     MAD-X 5.07.00  (64 bit, Darwin)      +
+ Support: mad@cern.ch, http://cern.ch/mad +
+ Release   date: 2021.05.03               +
+ Execution date: 2021.12.20 16:04:22      +
++++++++++++++++++++++++++++++++++++++++++++
>>>
```

- ❑ **MAD-X** (Methodical accelerator Design).
- ❑ A **general purpose beam optics software**.
- ❑ Distributed **for free by CERN** and used since more than 25 years for machine design and simulations (PS, SPS, LHC, linacs…).
- ❑ MAD-X is written in **C/C++/fortran77/Fortran90** (source code is available under the CERN copyright).

Do we use MAD-X for everything? No!

We use MAD-X to:

- ❑ Perform basic layout design and optimization.
- ❑ Perform basic single-particle tracking and sensitivity analysis of beam lines, synchrotrons, storage rings….

We don't use MAD-X for:

- ❑ Multi-particle and multi-bunch simulations.
- ❑ Simulations requiring non static Machine, i.e., beam changes its own environment (space charge, instabilities, beam-beam effects).
  - ✓ Often the programs used for these kind of studies use inputs from MAD-X.

Why MAD-X?

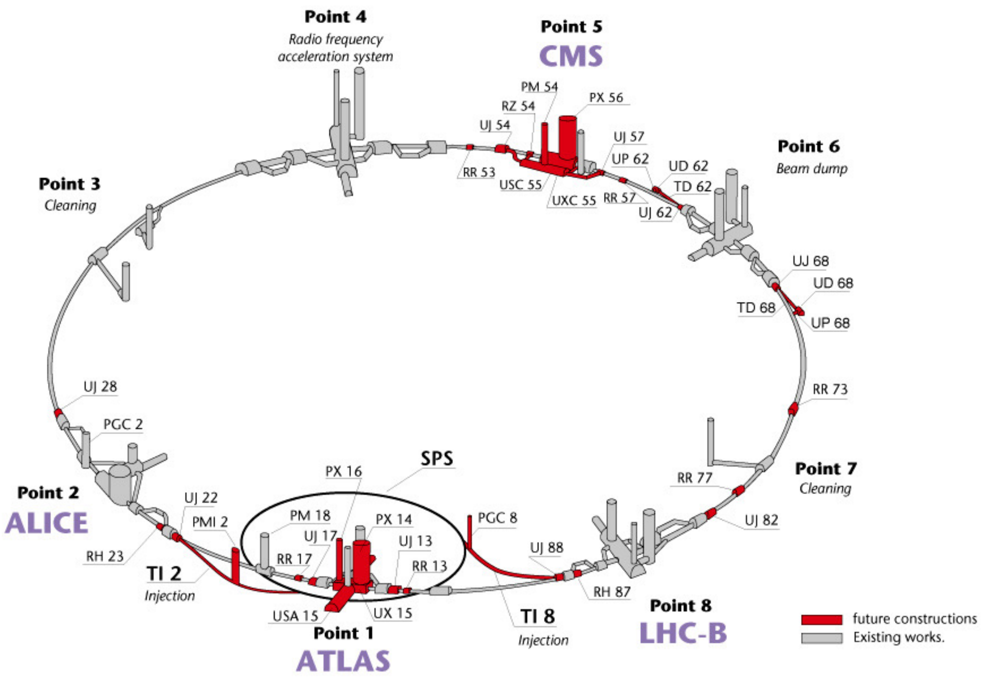
- ❑ **Multipurpose** from early to final stages of design studies.

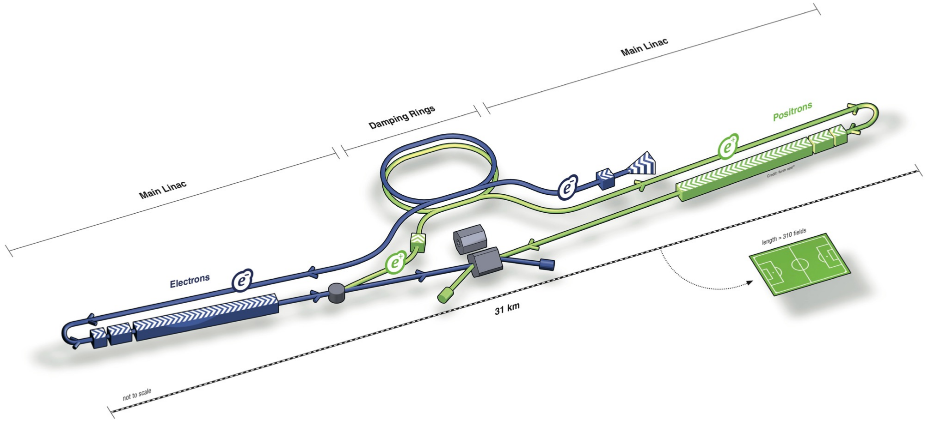
- ❑ **Multiplatform** (Linux, OSX, WINDOWS).

- ❑ Source is **free** and very **flexible** and possible to extend.

- ❑ Developed for complicated applications, powerful and rather complete.

- ❑ Mainly **designed for large projects** (LEP, LHC, CLIC, ILC…) with $\geq 10^4$ elements.

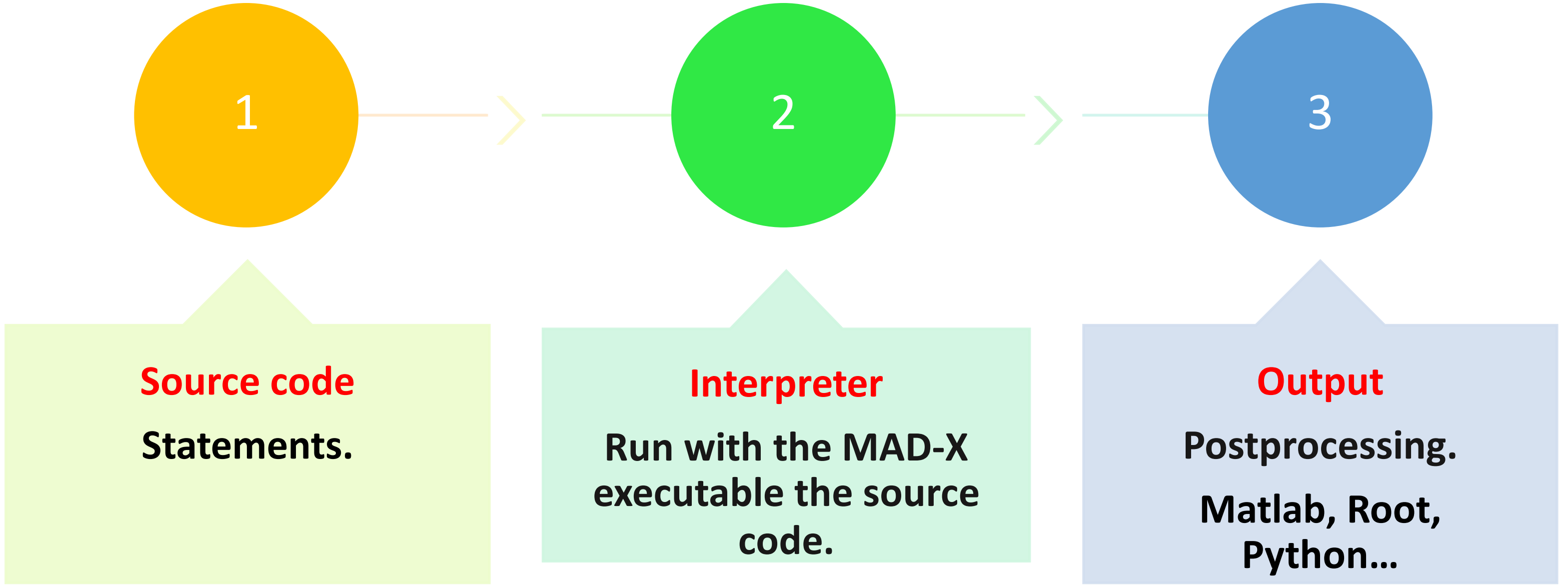




How does it work?

- MAD-X is an **interpreter.**
  - ✓It accepts and executes **statements**.
  - ✓Statements can be **actions** (optics…) **or assignments** (machine properties…).

Basic MAD-X workflow



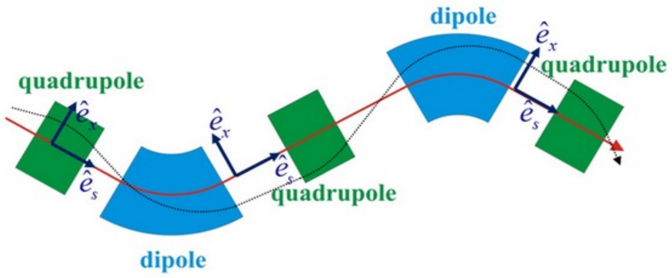
- What is the source code? **Via text.**
  - ✓It can be used in an **interactive way** (input from command line) or in **batch** (input from a file).

- MAD-X has its **own scripting language**, which is used to interface with the software.
  - ✓Strong resemblance to “C” language (but NO need for declaration and NOT case sensitive).
  - ✓Many features of programming language (loops, if, macros…).

Source code: the basic components

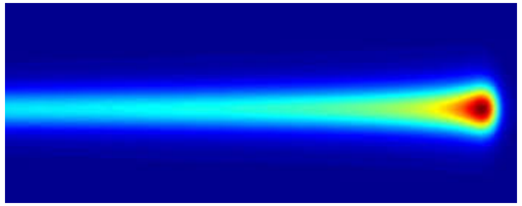
Courtesy of W. Hillert

- ❑ **Description of the machine**
  - ✓ Accelerator elements, physical attributes and location….



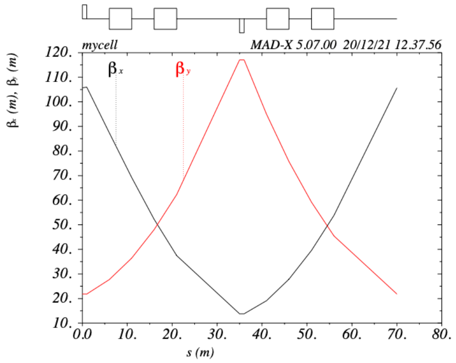
What is the machine in question?

- ❑ **Description of the beam**
  - ✓ Type of particle, energy…



What will be running in the machine?

- ❑ **Actions**
  - ✓ Optics calculation, matching, tracking….



What do you want to study about the machine?

MAD-X language

- ❑ *Language features.*
- ❑ *Conventions.*
- ❑ *Optic variables.*

Language features

- All the sentence end with **semicolon ";"** .
- **Arithmetic expressions**, including basic functions (exp, log, sin…), built-in random number generators and predefined constants (c, e, $\pi, m_e, m_p \ldots$).
- **Assignments**:
  - ✓ Regular (=). **a=b**, if **b** changes **a** does not.
  - ✓ Deferred (:=). **a:=b**, if **b** changes **a** is updated too.
- Variables can be used in **expressions**:
  - ✓ *NBEND = 40;*
  - ✓ *ANGLE=2*PI/NBEND;*
- **Comments:**
  - ✓ Start with two slashes (//) or an exclamation mark (!) for single lines.
  - ✓ Are enclosed by (/*) and (*/) for multiple lines.

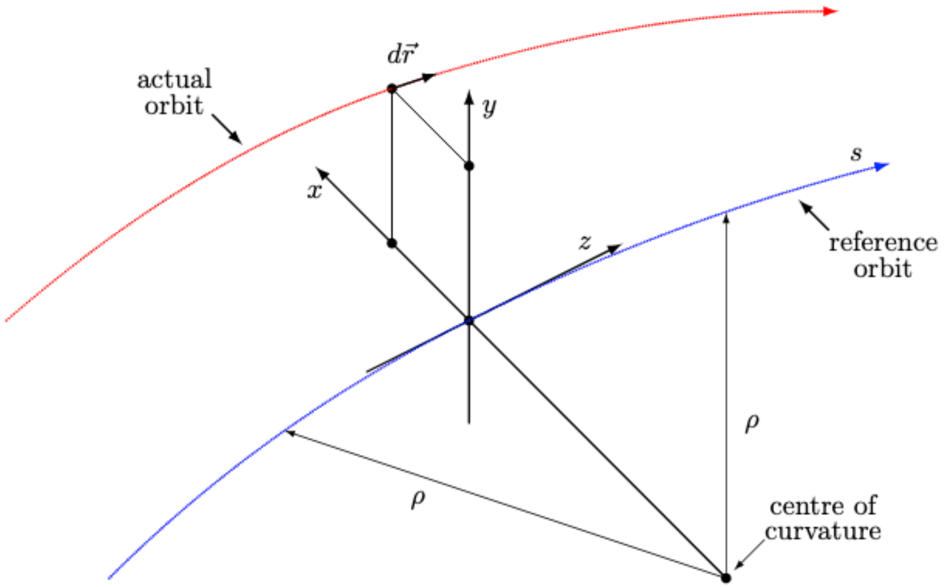
Deferred expressions
Important for the variables you may need to change along the code (e.g. matching parameters…)!

Conventions

- **Units**: all parameters are in terms of **SI** units, except the **energy**, expressed in **GeV**.

- **Horizontal** plane is assumed to be the **bending plane**.

- **Elements are placed along the reference orbit moving along s.**
  - ✓ x = y = 0 in a curvilinear system.
  - ✓ The **reference orbit** is the path of a charge particle having the central momentum of the accelerator though idealised and perfectly aligned magnets.



Optics variables

Coordinates in MAD-X	Description
x, y	Horizontal and vertical positions in [m] referred to the reference orbit.
px, py	Horizontal and vertical canonical momenta of the closed orbit p_x and p_y divided by the reference momentum.
s	Arc length s along the reference orbit in [m].
deltap	Momentum deviation from the design momentum deltap=$\Delta p/ p_0$. This quantity is used to normalize the elements strength.

Optical functions in MAD-X	Description
betx, bety	Horizontal and vertical beta functions in units of [m].
alfx, alfy	Horizontal and vertical alpha functions.
mux, muy	Horizontal and vertical phase advances [2π].
dx, dy	Dispersion function in [m].

MAD-X commands

- ❑ *Generic pattern for MAD-X commands.*

- ❑ *Definition of lattice elements.*
  - ✓ *The strength of the magnets.*

- ❑ *The lattice sequence.*

- ❑ *Basic MAD-X commands.*

Generic pattern for MAD-X commands

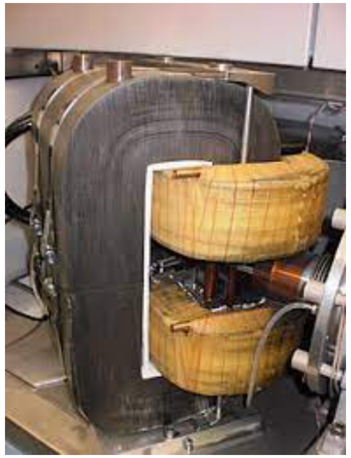
*label: **keyword**, attributes;*

Name given by the USER to the stored command.
If a label is given, MAD-X keeps this command in memory and can be used as '**EXEC label**;'.

Action desired.
Protected by MAD-X, can not be used as label.

Defined data to the command.
String, logical, integer, expression or range selection.

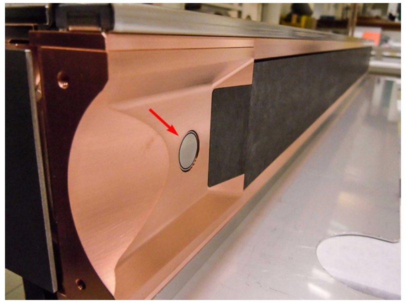
Definition of lattice elements



❑ Each machine element or group of elements must be defined by a command.

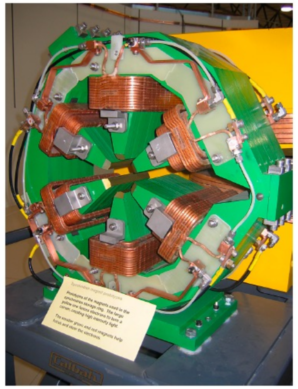
Generic pattern to define an element

label: ***keyword***, *properties*;



❑ MAD-X keywords are used to define the type of element.

❑ Elements can be: magnets, markers, RF cavities, collimators…



❑ Examples:

- ✓ Dipole magnet: *MBL*: ***SBEND***, *L=10.0*;
- ✓ Quadrupole magnet: *MQ*: ***QUADRUPOLE***, *L=3.3*;
- ✓ Sextupole magnet: *MSF*: ***SEXTUPOLE***, *L=1.0*;
- ✓ *Marker:* *MARKER1*: ***MARKER***;

The strength of the magnets

- ❑ The name of the parameter that defines the **normalised magnetic strength** depends on the element:

  - ✓ For a dipole magnet (horizontal bending) is: *angle [rad]*

    MBL: SBEND, ANGLE=0.05, L=10.0;

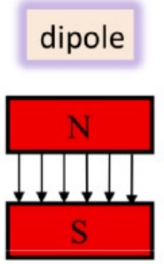
  - ✓ For a quadrupole magnet is *:* $k_1 = \frac{1}{B\rho}\frac{\partial B_y}{\partial x}\,[\,m^{-2}]\left(= \frac{1}{lf}\right)$

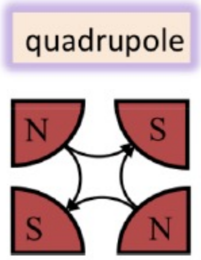
    MQ: QUADRUPOLE, K1=0.00156, L=3.3;

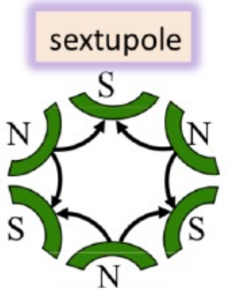
  - ✓ For a sextupole magnet is*:* $k_2 = \frac{1}{B\rho}\frac{\partial^2 B_y}{\partial x^2}\,[m^{-3}]$

    ksf= 0.00015;
    MSF: SEXTUPOLE, K2=ksf, L=1.0;

  - ✓ Octupoles, multiple magnet "thin" element…







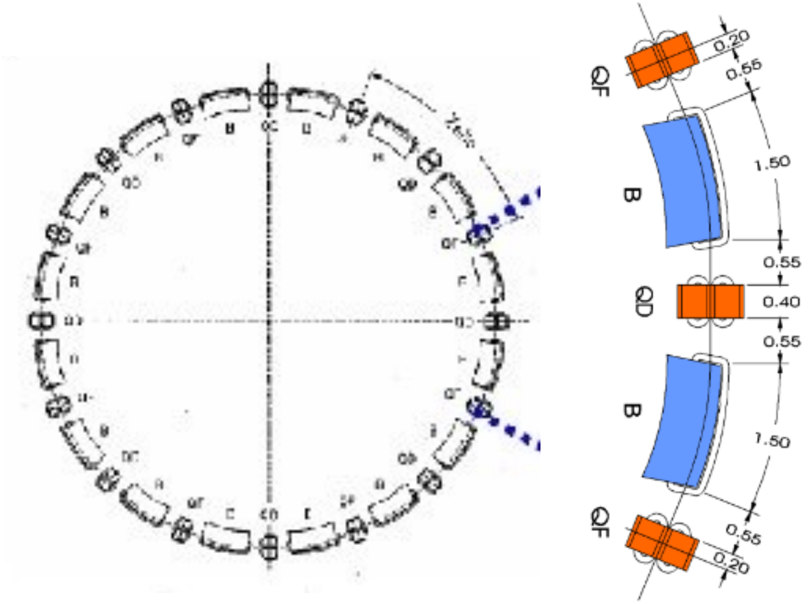
The lattice sequence

- A **lattice sequence** is an ordered collection of machine elements defining the accelerator to be studied.

- The position of each element in the sequence can be defined with respect to the CENTRE, EXIT or ENTRY of the element, the start of the sequence or the position of another element.

- Example:

```
#Element definition
MQ: QUADRUPOLE, L=3.3, K1=0.005;
# Sequence definition
mycell: SEQUENCE, REFER=ENTRY, L=10;
q1: MQ, at s=0;
marker1: marker, at s=2.5;
ENDSEQUENCE;
```



Basic MAD-X commands

- Beam definition:

  ***BEAM**, PARTICLE=particle_type (proton, electron…), ENERGY=value ;*

- A sequence has to be activated in order to be usable for other operations with the USE command:

  ***USE**, SEQUENCE=name_sequence;*

- Call an external file:

  ***CALL**, FILE=name_file.madx;*

- Print a value in the terminal:

  ***VALUE** variable_name;*

- Production of graphical output (e.g. β-function)*:

  ***PLOT**, HAXIS=s, VAXIS=betx,bety, COLOUR=100, FILE="test" ;*

** Note that the data has to be generated first using the advances commands such as TWISS or TRACK.*

Advances MAD-X commands

- *TWISS*. Optics calculations.*

- *MATCHING*. Optics optimization.*

- *TRACKING*. Beam dynamics studies.*

*These commands require a **beam** and an **active sequence**.

TWISS

- The TWISS command will compute the **linear lattice function** (optical functions and the CO) around the machine and optionally the chromatic functions.
- It is a **matrix code** where first and second order matrices are used to get the optics.

 # For a periodic solution

***TWISS**, SEQUENCE=sequence_label, exit(by default), FILE="test.txt", table=TWISS (by default);*

 # For an initial condition (IC) solution

***TWISS**, SEQUENCE=sequence_label, betx=1, alfx=0, bety=1, alfy=0;*

 # More attributes: DELTAP, CHROM…

- **After a successful TWISS run**, MAD-X creates a table of summary parameters named 'SUMM' which includes tunes, chromaticity, etc. as well as a 'TWISS' table and ASCII file if requested with most of the computed parameters.

TWISS output

- ❑ **SUMM table.**
  - ✓ Length of the cell
  - ✓ Tunes: q1, q2
  - ✓ Chromaticity: dq1, dq2
  - ✓ …
  - ✓ Access the data: *a=table(SUMM,dq1);*

++ table: summ

length 70	orbit5 -0	alfa 0.1133597226	gammatr 2.97009686
q1 0.3240223299	dq1 -0.2894713472	betxmax 105.9701387	dxmax 18.28374049
dxrms 14.1747586	xcomax 0	xcorms 0	q2 0.2438418116
dq2 -0.2895087383	betymax 117.0503512	dymax 0	dyrms 0
ycomax 0	ycorms 0	deltap 0	synch_1 0
synch_2 0	synch_3 0	synch_4 0	synch_5 0
synch_6 0	synch_8 0	nflips 0	

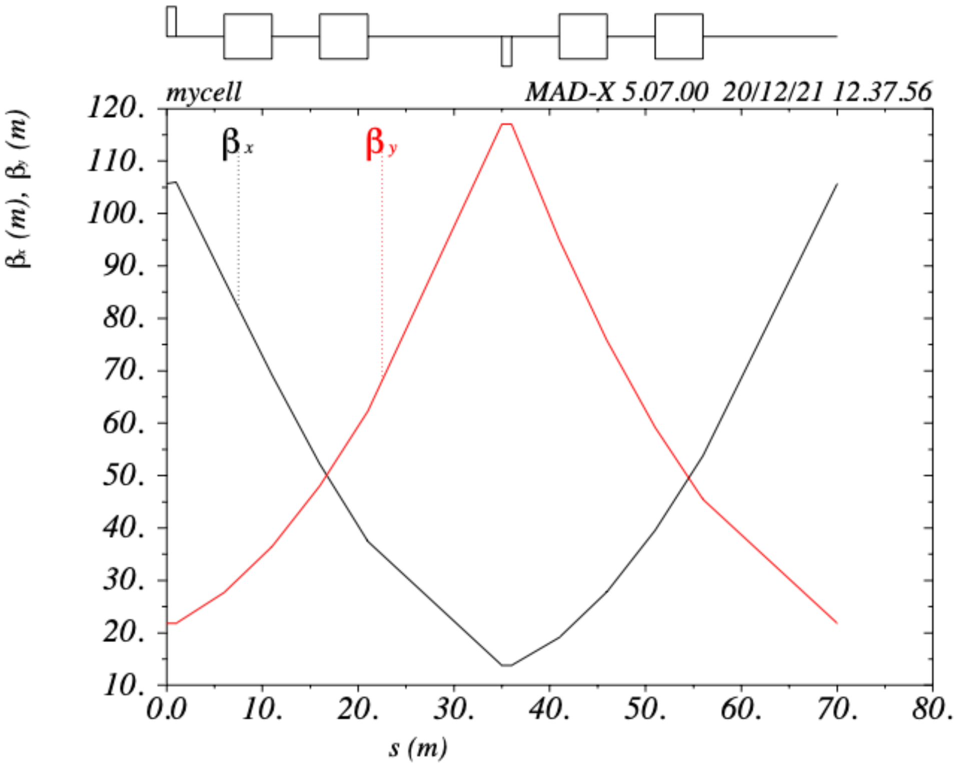
- ❑ **TWISS table.** *a=table(TWISS,q1,betx);*
- ❑ **ASCII file.**
  - ✓ With most of the parameters computed by MAD-X.
  - ✓ ***SELECT**, flag=TWISS, column=name, keyword, s, betx, alfx, mux, bety, alfy, muy;*

* NAME	KEYWORD	S	BETX	ALFX	MUX	BETY	ALFY	MUY
$ %s	%s	%le	%le	%le	%le	%le	%le	%le
"MYCELL$START"	"MARKER"	0	105.6855764	-2.259230089	0	21.7840267	0.4573523215	0
"Q1"	"QUADRUPOLE"	1	105.9701387	1.978472039	0.001493921339	21.7840267	-0.4573523215	0.00735746345
"DRIFT_0"	"DRIFT"	6	87.34479015	1.74659768	0.009769065687	27.74523085	-0.7348885096	0.03995368946
"B1"	"SBEND"	11	69.17896128	1.856667625	0.01997132749	36.48179689	-1.012424698	0.06507035749
"DRIFT_1"	"DRIFT"	16	52.21942634	1.535239362	0.0332266184	47.9937248	-1.289960886	0.08413368703
"B2"	"SBEND"	21	37.43543691	1.397224472	0.05118922695	62.2810146	-1.567497074	0.09870931652
"DRIFT_2"	"DRIFT"	35	13.77011836	0.2931554251	0.1569385083	117.0503512	-2.3445984	0.124924296
"Q2"	"QUADRUPOLE"	36	13.80615426	-0.3296705349	0.1685688634	117.0503512	2.3445984	0.126274979
"DRIFT_3"	"DRIFT"	41	19.11044739	-0.7311880903	0.2183687567	94.99204817	2.067062212	0.1338245632
"B3"	"SBEND"	46	27.82671663	-0.9977190119	0.2530083111	75.70910699	1.789526024	0.1432136723
"DRIFT_4"	"DRIFT"	51	39.59664721	-1.356267103	0.2770733231	59.20152769	1.511989836	0.1551111302
"B4"	"SBEND"	56	53.74757777	-1.450626954	0.294285777	45.46931027	1.234453648	0.1704728215
"DRIFT_5"	"DRIFT"	70	105.6855764	-2.259230089	0.3240223299	21.7840267	0.4573523215	0.2438418116
"MYCELL$END"	"MARKER"	70	105.6855764	-2.259230089	0.3240223299	21.7840267	0.4573523215	0.2438418116

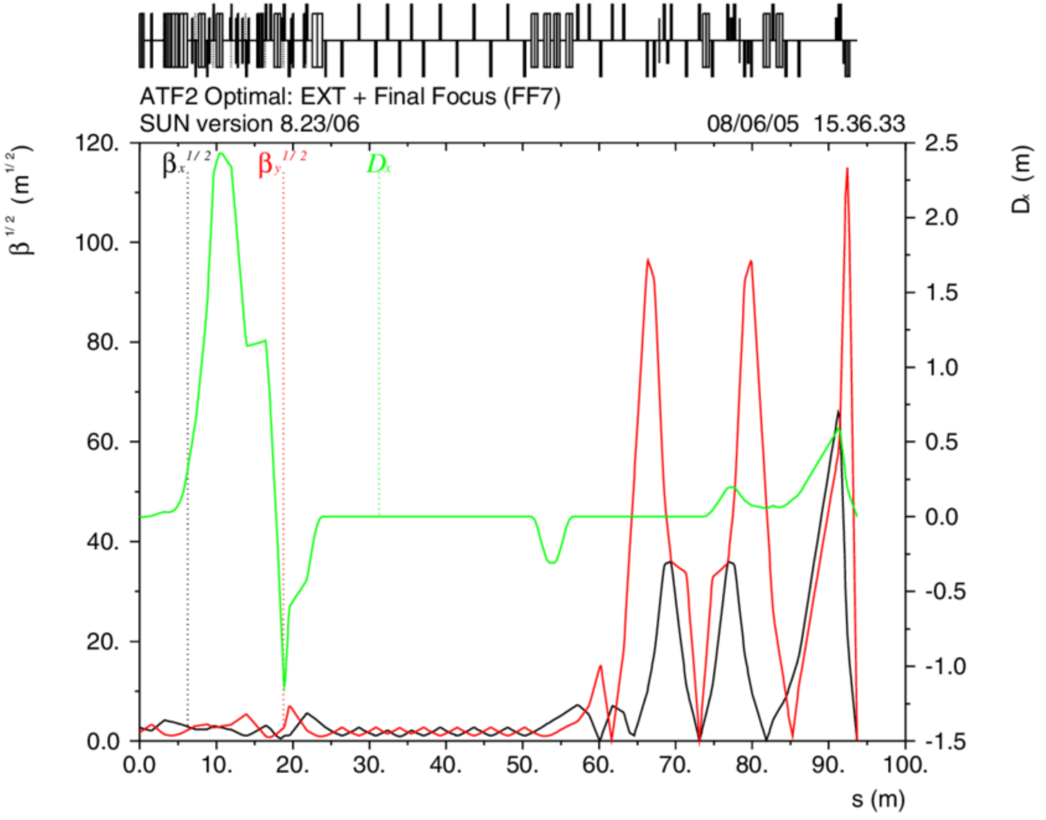
TWISS plot

- Production of **graphical output** of the main optical functions (e.g. β-function):

```
PLOT, HAXIS=s, VAXIS=betx,bety, COLOUR=100, FILE="test" ;
```



FODO cell example



Transfer line example

Global matching

- It is possible to modify the optical parameters of a lattice using the **MATCHING module.**
- Adjusting the magnetic strengths to get the desired **global properties.**
  - ✓ Examples for global parameters: Q1 and Q2 (horizontal and vertical tunes) and dQ1 and dQ2 (horizontal and vertical chromaticity).

- **Example**

```
MATCH, SEQUENCE=sequence_name;

GLOBAL, Q1=26.58; H-tune
GLOBAL, Q2=26.62; V-tune

VARY, NAME=kqf, STEP=0.00001;
VARY, NAME=kqd, STEP=0.00001;

LMDIF, CALLS=50, TOLERANCES=1e-6;

ENDMATCH;
```

} **What we want!** (GLOBAL lines)

} **What we change!** (VARY lines)

→ (LMDIF line)

Methods for the minimization.

LMDIF accepts two attributes: **CALLS**, maximum number of calls to the penalty function; **TOLERANCES**, the desired tolerance for the minimum.

http://mad.web.cern.ch/mad/releases/5.02.08/madxguide.pdf

Other types of matching

- ❑ **Local matching** and **performance matching**:
  - ✓ Local optical functions (insertions, local optics changes).
  - ✓ Any user defined variable.

- ❑ Example:

```
MATCH, SEQUENCE=sequence_name;

CONSTRAIN, range=#s/#e, BETX=50;
CONSTRAIN, range=#s/#e, ALFX=-2;

VARY, NAME=kqf, STEP=0.00001;
VARY, NAME=kqd, STEP=0.00001;

LMDIF, CALLS=50, TOLERANCES=1e-6;

ENDMATCH;
```

What we want! (the two CONSTRAIN lines)

What we change! (the two VARY lines)

Tracking

- The TRACK module allows us to perform **single particle tracking** for given initial conditions.
- It is based on building transfer maps by solving the Hamiltonian equations of each element.

- Example

```
SELECT, FLAG=makethin, SLICE=1;
MAKETHIN, SEQUENCE=seq_name;
```

Convert the thick lattice to a thin lens one!

```
TRACK, dump, file="name", DELTAP=0.01;
```

Off-momentum!

```
   START, x=1e-3, px=0, y=1e-3, py=0;
   START, x=1e-2, px=0, y=1e-3, py=0;
```

Particles initial conditions!

```
   run, turns=100;
```

Number of turns!

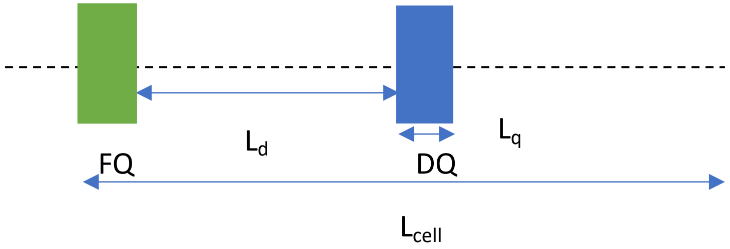
- **Output:** *'TRACK' table, file.txt*

- **Plot:**

```
PLOT, file="track1",table=track, haxis=x, vaxis=px, colour=100;
```

Example case

What is the machine in question?



What will be running in the machine?

What do you want to study about the machine?

```
! ********************************************************************
! Definition of parameters
! ********************************************************************
l_cell=100;
quadrupoleLenght=5;
myK:=0.0012;// m^-2

! ********************************************************************
! Definition of magnets
! ********************************************************************
QF: quadrupole, L=quadrupoleLenght, K1:=myK;
QD: quadrupole, L=quadrupoleLenght, K1:=-myK;
! ********************************************************************
! Definition of sequence
! ********************************************************************
myCell:sequence, refer=entry, L=L_CELL;
quadrupole1: QF, at=0;
marker1: marker, at=25;
quadrupole2: QD, at=50;
endsequence;
```

```
! ********************************************************************
! Definition of beam
! ********************************************************************
beam, particle=proton, energy=2;
```

```
! ********************************************************************
! Use of the sequence
! ********************************************************************
use, sequence=myCell;
! ********************************************************************
! TWISS
! ********************************************************************
select, flag=twiss, column=[name, keyword,betx, bety, alfx, alfy];
twiss, file=MyfirstFODO.madx;
plot, haxis=s, vaxis=betx,bety,dx,colour=100,file=MyfirstFODO;
```

How to run MAD-X

- *Interactive mode.*

- *Batch mode.*

- *Python interface.*

How to run MAD-X: interactive mode

- ❑ You download the last release from the repository and follow the instruction in: http://madx.web.cern.ch/madx/

- ❑ In Windows, run the executable.

- ❑ In Linux (OXS), execute *./madx* in the containing directory.

➡ **Usually not optimum…**

```
(base) lapnuria:MADX nuria$ ./madx

  ++++++++++++++++++++++++++++++++++++++++++++
  +     MAD-X 5.07.00  (64 bit, Darwin)      +
  + Support: mad@cern.ch, http://cern.ch/mad +
  + Release   date: 2021.05.02               +
  + Execution date: 2021.10.07 18:06:19      +
  ++++++++++++++++++++++++++++++++++++++++++++

X:> angle = 2*pi/1232;
X:> value, angle;
angle              =     0.005099988074 ;
X:> dx=gauss()*2;
X:> value, dx;
dx                 =        1.295621501 ;
X:> value, dx;
dx                 =        1.295621501 ;
X:> dx:=gauss()*2;
```

How to run MAD-X: batch mode

- After writing your script in a separate file *myfile.madx*, you can call it in Windows after opening MAD-X:

```
madx
X: ==> call, file=myfile.madx;
```

- In Linux, you can also type in the terminal:

```
./madx myfile.madx
```

myfile.madx

```
! *********************************************************************
! Definition of parameters
! *********************************************************************

l_cell=100;
quadrupoleLenght=5;
f=200;
myK:=1/f/quadrupoleLenght;// m^-2

! *********************************************************************
! Definition of magnets
! *********************************************************************
QF: quadrupole, L=quadrupoleLenght, K1:=myK;
QD: quadrupole, L=quadrupoleLenght, K1:=-myK;

! *********************************************************************
! Definition of sequence
! *********************************************************************
myCell:sequence, refer=entry, L=L_CELL;
quadrupole1: QF, at=0;
marker1: marker, at=25;
quadrupole2: QD, at=50;
endsequence;

! *********************************************************************
! Definition of beam
! *********************************************************************
beam, particle=proton, energy=2;

! *********************************************************************
! Use of the sequence
! *********************************************************************
use, sequence=myCell;

! *********************************************************************
! TWISS
! *********************************************************************
title, 'My first twiss';
twiss, file=MyfirstFODO.madx;
plot, haxis=s, vaxis=betx,bety,dx,colour=100, title="test",file=MyfirstFODO;
```

How to run MAD-X: python interface I

- During the workshop we will use MAD-X trough a **python jupyter interface** based on the python scripting language.

Why?

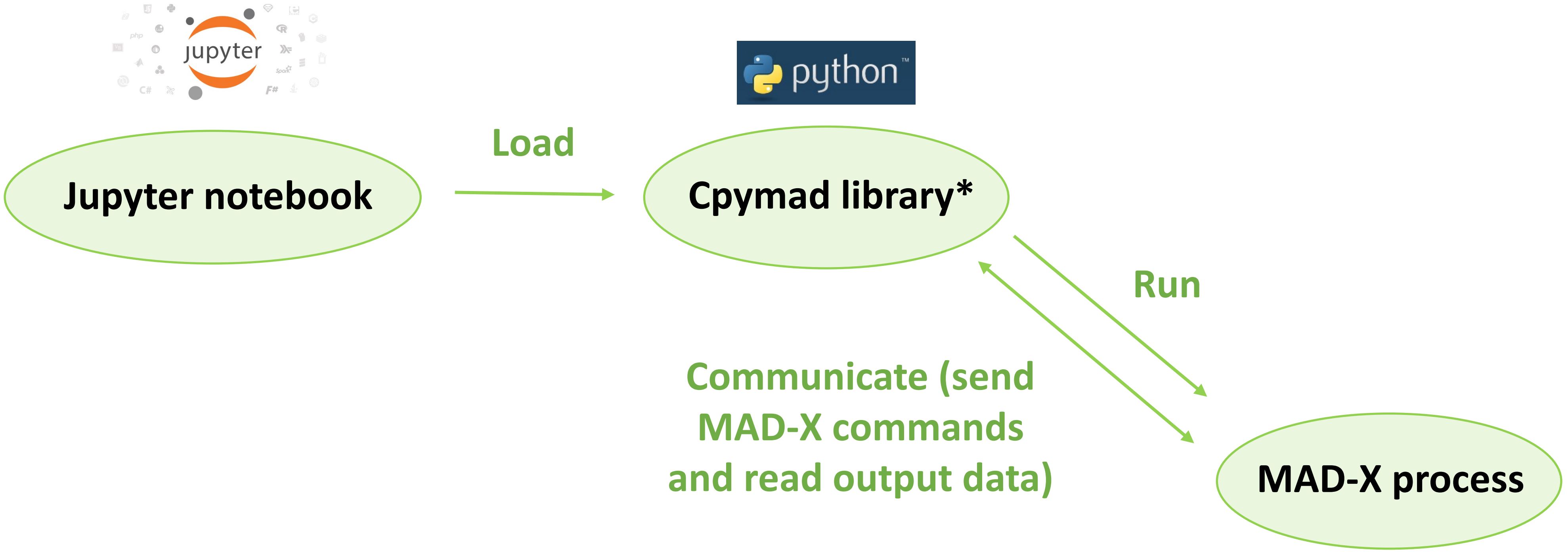
- MAD-X has no graphical interface and for detailed processing of MAD-X results, other programming languages are often used.

- Python is widely used in the physics community and provides powerful numerical and plotting libraries.

- Jupyter is web application that allows to create and share live code.

How to run MAD-X: python interface II

How ?




```
++++++++++++++++++++++++++++++++++++++++++++
+     MAD-X 5.07.00  (64 bit, Darwin)      +
+ Support: mad@cern.ch, http://cern.ch/mad +
+ Release   date: 2021.05.03               +
+ Execution date: 2021.12.20 16:04:22      +
++++++++++++++++++++++++++++++++++++++++++++
```

*It is a binding to MAD-X for giving full control and access to a MAD-X interpreter in python.
http://hibtc.github.io/cpymad/getting-started

How to run MAD-X: python interface III

Load cpymad library*

↓

Run a MAD-X process

↓

Define lattice input file

↓

Use of cpymad.madx methods (call, input, table.twiss.dframe, table.sum.dframe)

↓

Data analysis (plots…)

jupyter-notebook

```python
from matplotlib import pyplot as plt

from cpymad.madx import madx
```

```python
madx=Madx()
```

```python
madx.call("lattice.madx")
```

```python
myString=
'''
beam, particle=proton, energy=2;
use, sequence=myCell;
twiss;
'''

madx.input(myString)
```

MAD-X commands

```python
myTwiss=madx.table.twiss.dframe()

plt.plot(myTwiss["s"],myTwiss["betx"])
```

lattice.madx (ASCII file)

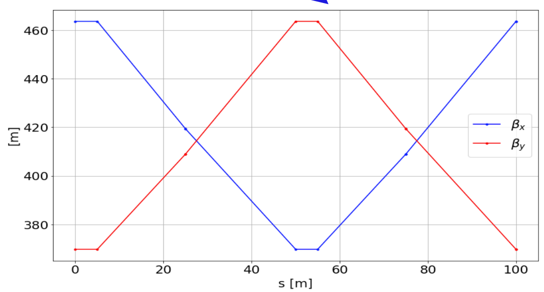
```
! *****************************************
! Definition of parameters
! *****************************************

l_cell=100;
quadrupoleLenght=5;
f=200;
myK:=1/f/quadrupoleLenght;// m^-2

! *****************************************
! Definition of magnets
! *****************************************
QF: quadrupole, L=quadrupoleLenght, K1:=myK;
QD: quadrupole, L=quadrupoleLenght, K1:=-myK;

! *****************************************
! Definition of sequence
! *****************************************
myCell:sequence, refer=entry, L=L_CELL;
quadrupole1: QF, at=0;
marker1: marker, at=25;
quadrupole2: QD, at=50;
marker2: marker, at=75;
endsequence;
```

	name	keyword	s	betx	bety
#s	mycell$start:1	marker	0.0	463.623288	369.779162
quadrupole1	quadrupole1:1	quadrupole	5.0	463.623288	369.779162
drift_0[0]	drift_0:0	drift	25.0	419.394867	408.967742
marker1	marker1:1	marker	25.0	419.394867	408.967742
drift_1[0]	drift_1:0	drift	50.0	369.779162	463.623288
quadrupole2	quadrupole2:1	quadrupole	55.0	369.779162	463.623288



How to run MAD-X: python interface IV

- We provided you with the instructions to **set-up the working environment:** https://fusterma.github.io/JUAS2023/

JUAS2023

MAD-X workshop JUAS2023

N. Fuster-Martínez, D. Gamba, A. Poyet, G. Sterbini

For the MAD-X workshop at JUAS 2023 we will be using the **MAD-X accelerator design software**, together with **Python** as scripting language and **Jupyter** as interface for the analysis.

In order to be ready for the workshop please follow the instructions **before coming** to JUAS to **prepare yourself** and **your laptop** for the course.

For the workshop we will ask you to download the last version of the MAD-X Workshop JUAS2023 repository. In this repository you will find one folder for each tutorial with the corresponding jupyter-notebook and MAD-X input files to be completed during the workshop as well as the corresponding solutions. The tutorials statements can be found here.

I hope you have been successful installing and testing the environment!

- Once the environment is set-up you can **download** the last version of the **"MAD-X Workshop JUAS2023 repository"**, and open a JupyterLab interface and start working on the tutorials!

How to run MAD-X: python interface V

❑ If you had problems with the environment set-up:

✓ You can work using the SWAN CERN service using the CERN computing account.

❑ SWAN CERN service:

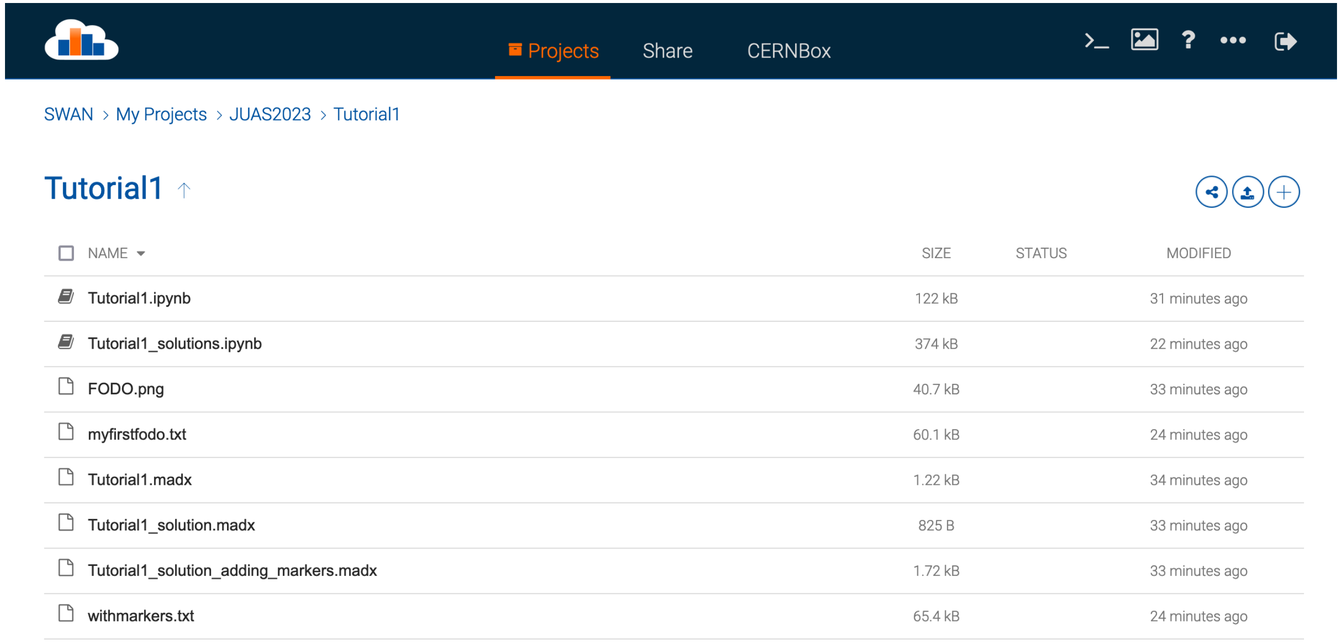
✓ https://swan.cern.ch

✓ Log-in with your credentials

✓ Create a new project, "JUAS 2023"

✓ Load the folders and files in the "MAD-X Workshop JUAS2023 repository" into the new project.

✓ Open the first tutorial jupyter-notebook "Tutorial1.ipynb".



Thank you very much for your attention!

Questions?

Let’s finish with a quick quiz!

Kahoot!