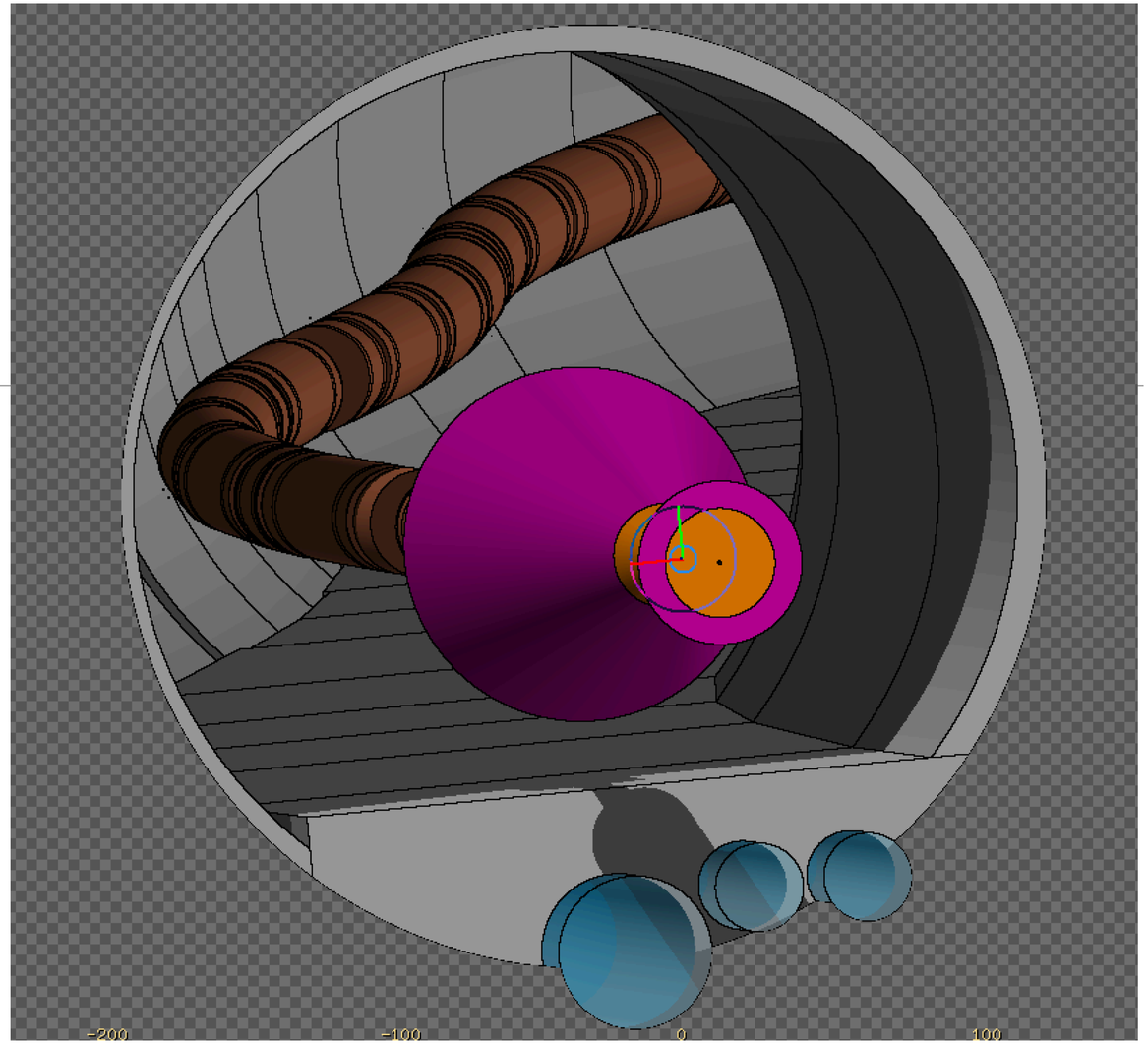
A Flexible Tool for Beam Induced Background Simulations at a Muon Collider



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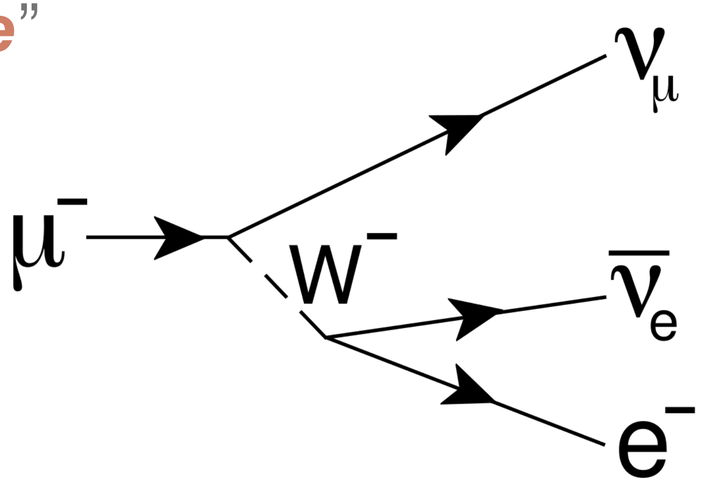
For the International Muon Collider Collaboration

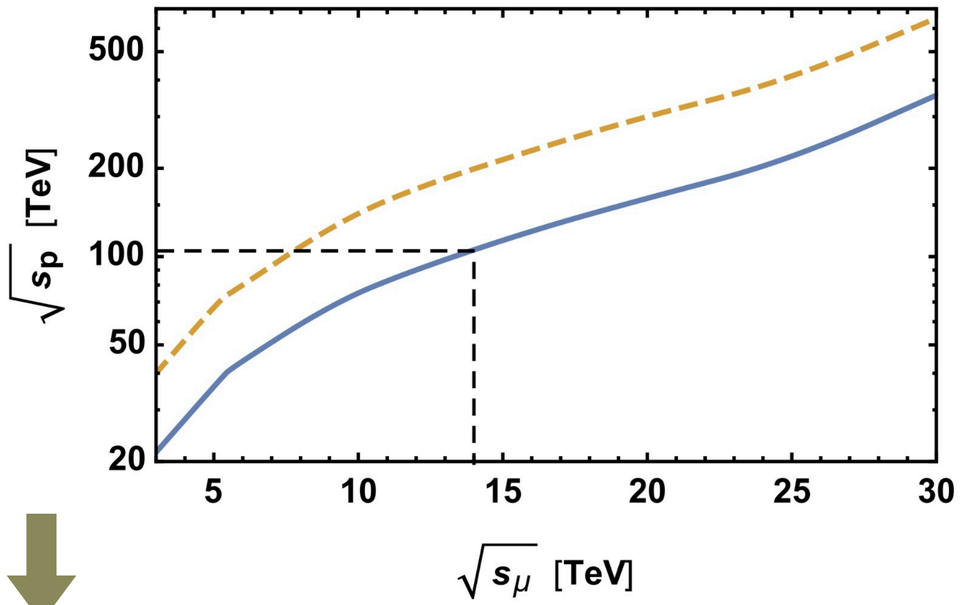
ICHEP - 29.7.20

- A **Muon Collider** could be "the ***dream machine***" for the future of High Energy Physics

☑ All the energy is available in the interaction

☑ Reduced synchrotron radiation losses
➔ high energies are reachable





Huge amount of interesting physics!

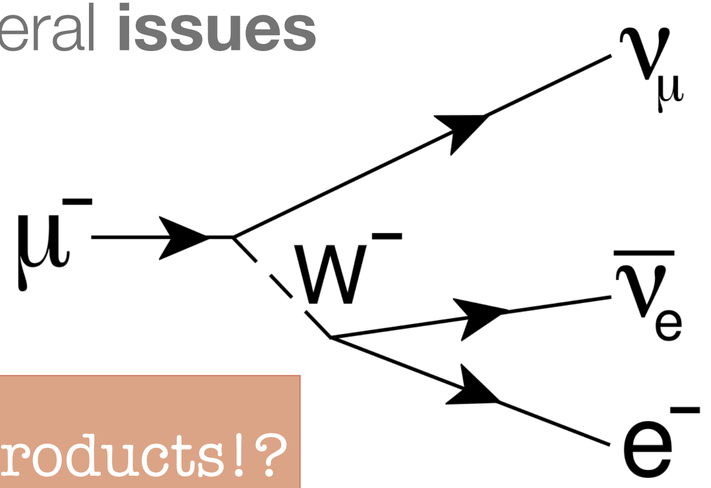
But it comes at a **cost**!
(Actually, a few..)

- ➡ Muon production (from p/e^+..)
- ➡ Muon handling and cooling
- ➡ Muon decay

- Muons' **decay** all along the machine leads to several **issues**

The colliding beams loose intensity

A continuous muon source must be developed to periodically "top-up" the bunches



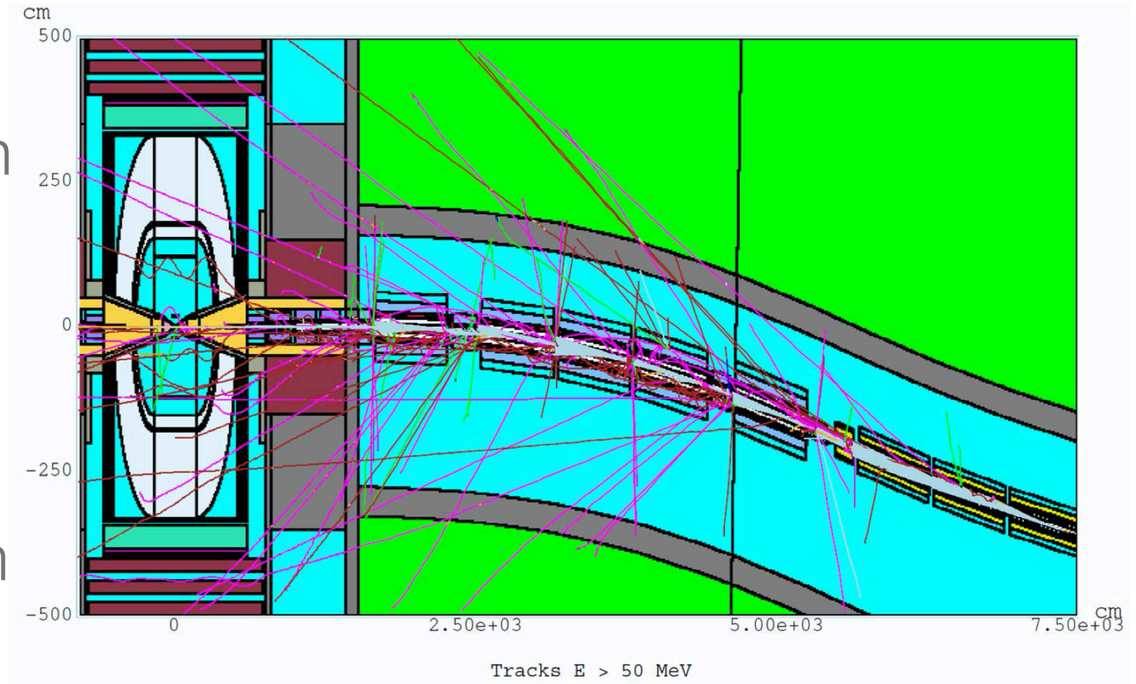
What about decay products!?

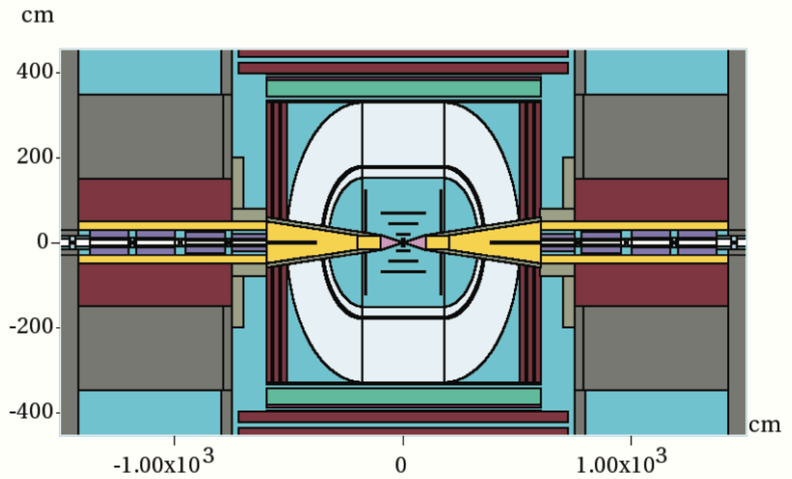
- Magnet quenching
- Detector background
- Radiation protection

Huge amount of interesting physics!

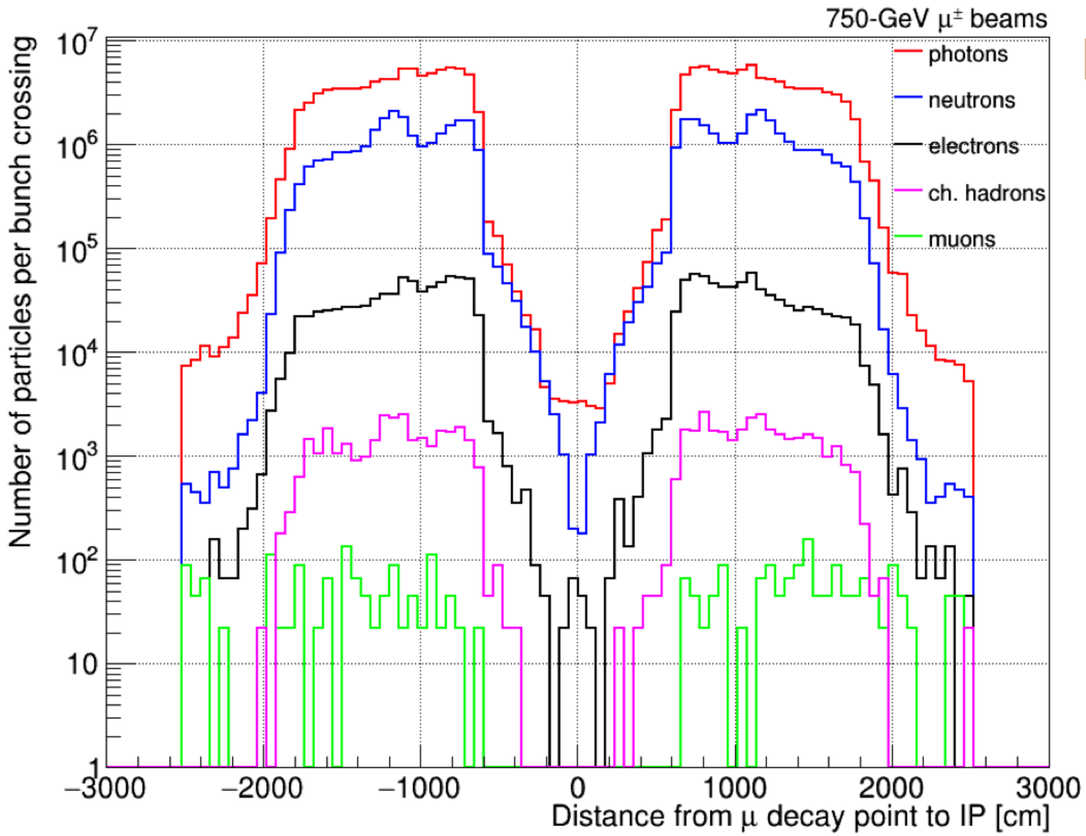
ARE WE ABLE TO SEE IT?!

- **Beam Induced Background** (BIB) in the detector can severely impair its performances
  - **MAP** developed a realistic simulation of BIB in the detector by implementing a model of the tunnel and accelerator **±200m** from the interaction point, **@E_{cm} = 1.5 TeV**
  - Secondary and tertiary particles from muon decays are simulated with *MARS15* then transported to the detector
  - **Two tungsten nozzles** play a crucial role in background mitigation inside the detector

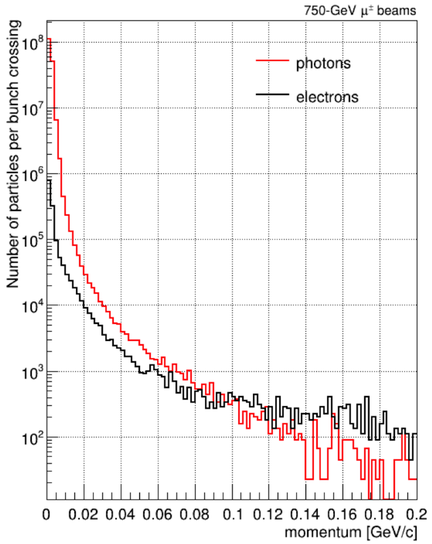


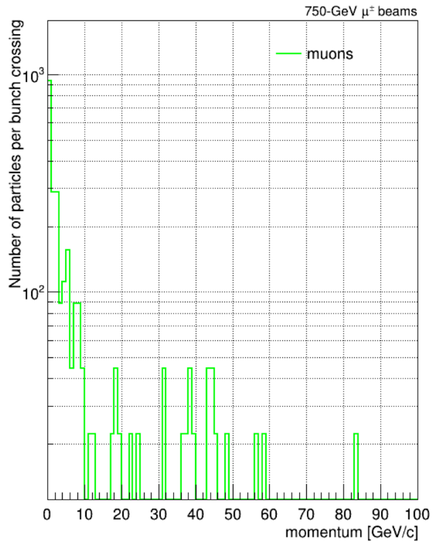


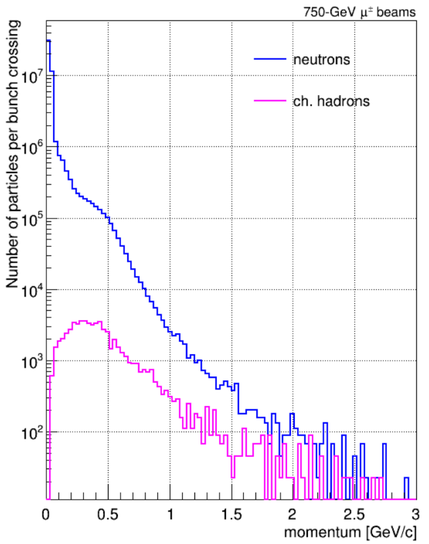
- **MAP results** for BIB @ E_{cm} = 1.5 TeV



Beam Induced Background comes from ~25 meters from the IP







$P_{e/g}$~MeV, $P_{n\,/ch.h}$~500 MeV, P_{mu}~10GeV

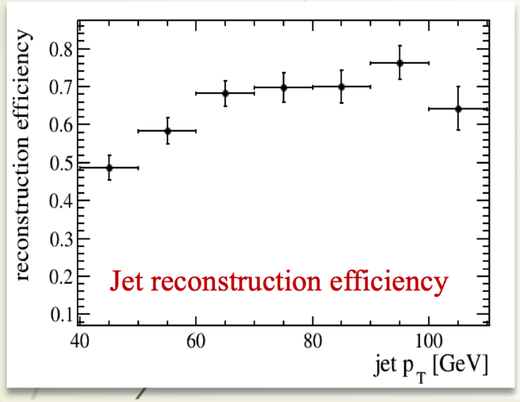
- **MAP results** for BIB @ E_{cm} = 1.5 TeV have been recently used to perform a full event reconstruction

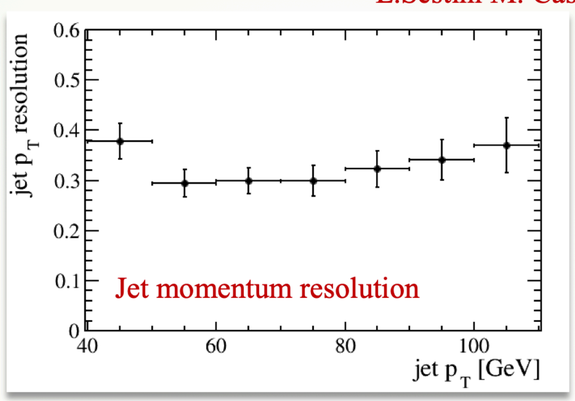
Challenging physics measurements are possible!

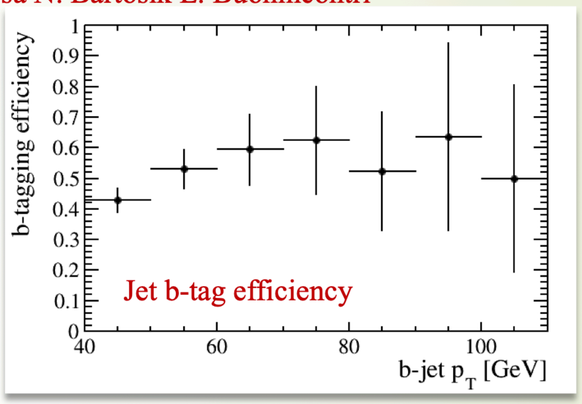
Detector Performance at $\sqrt{s}$ =1.5 TeV

3 Using the MAP detector and framework, performance have been determined using **simple and rough methods** for the reconstruction

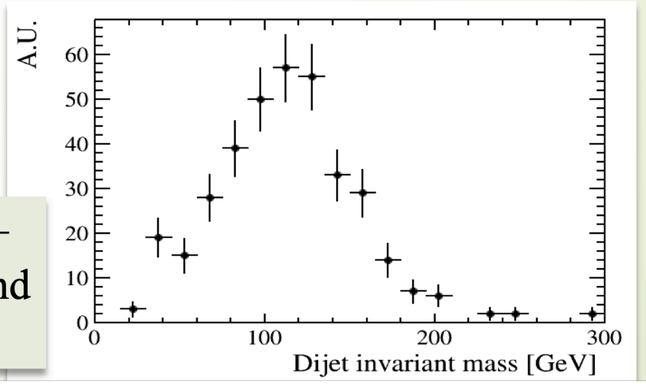
L.Sestini M. Casarsa N. Bartosik L. Buonincontri







Background tagging:
- fake rate: 1 ÷ 3 %
- Tests show fake rate is manageable



$\mu^+\mu^- \rightarrow H\nu\bar{\nu} \rightarrow b\bar{b}\nu\bar{\nu}$ + beam-induced background fully simulated

See Dedicated Today's Talk by M. Casarsa for updated results

REF

BIB @ Muon Collider, let's frame the issue:

- ➡ A Muon Collider has outstanding physics capabilities
- ➡ Beam Induced Background can impair detector performances
- ➡ A first study for the 1.5TeV CM case was done within the MAP program
- ➡ Results suggest challenging physics measurements are possible!

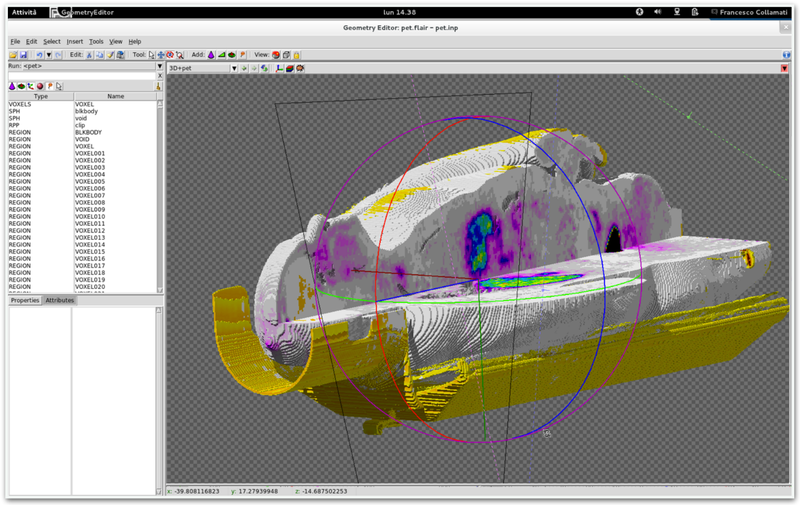
Beam Induced Background must be kept strictly under control!

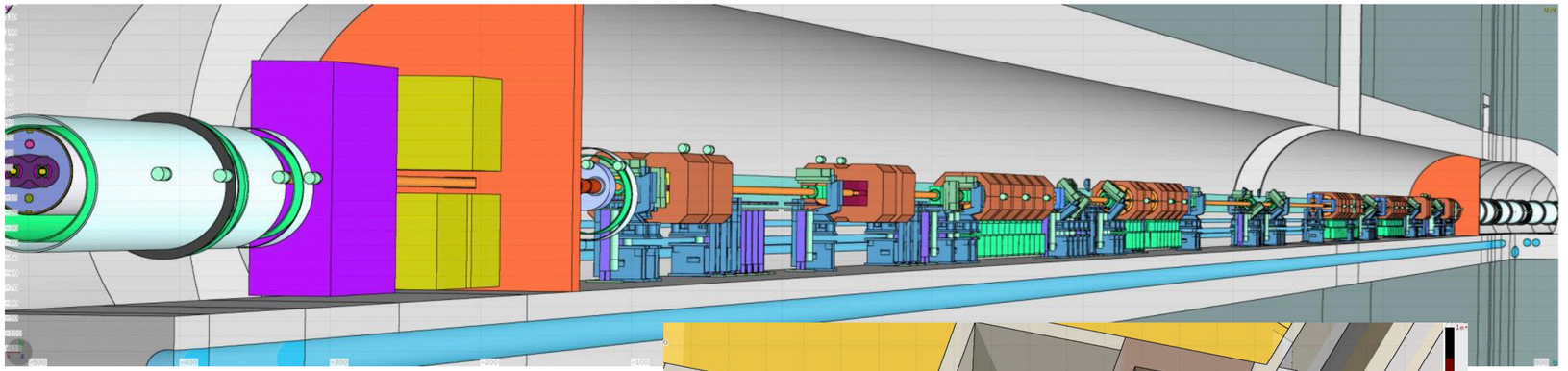
…in each machine configuration!

- ✓ Change beam energy
- ✓ Change machine optics
- ✓ MDI optimisation (nozzle..)

Need for a **flexible** tool to go **from machine optics** to Monte Carlo **simulation**

- **FLUKA** is one of the most common general purpose Monte Carlo software, and is the established standard for example for *radio protection* studies
  - Natively supports very complicated and detailed geometries





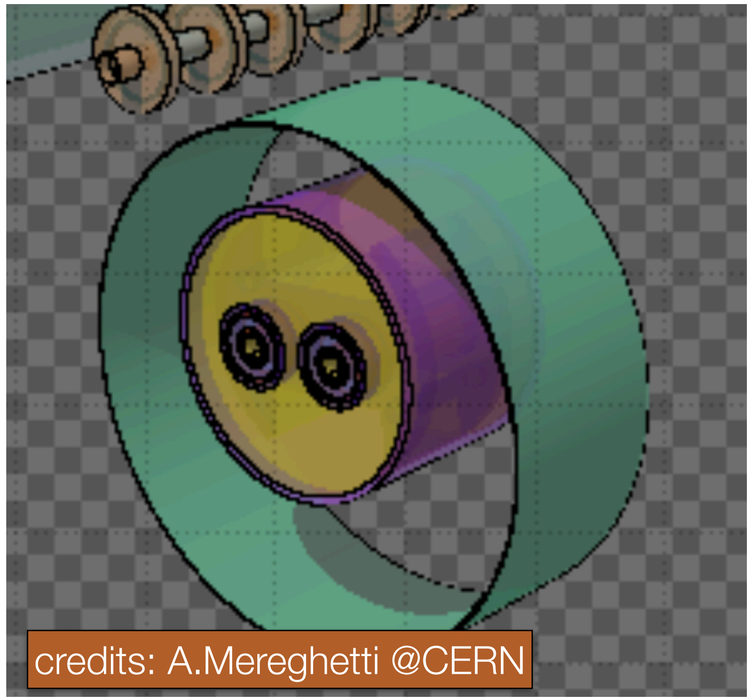
- BUT the **manual construction** of such complicated geometries is
  - **Difficult**
  - **Not** scalable-**flexible**
  - Error prone

✦**FLUKA LINE BUILDER** is a program aimed at automatically build accelerator geometries, consists of 2 parts:

Fluka Element DataBase

```
 > tree fedb/
fedb/
├── [4.0K]  assemblies
├── [4.0K]  bodies
│   ├── [ 787]  myacc_MBS.bodies
│   ├── [ 254]  myacc_MBSORI.bodies
│   └── [ 103]  myacc_MQBODY.bodies
├── [4.0K]  materials
│   ├── [2.3K]  materials.inp
│   ├── [ 251]  myacc_MBS.assignmat
│   ├── [ 135]  myacc_MBSORI.assignmat
│   └── [  96]  myacc_MQBODY.assignmat
├── [4.0K]  regions
│   ├── [ 404]  myacc_MBSORI.regions
│   ├── [1.8K]  myacc_MBS.regions
│   └── [  90]  myacc_MQBODY.regions
├── [4.0K]  stepsizes
├── [2.1K]  structure.py
├── [1.3K]  structure.pyc
├── [4.0K]  test
│   ├── [  18]  expand.sh -> ../tools/expand.sh
│   ├── [2.1K]  flair-autosave.pickle
│   ├── [4.1K]  myacc_MB.inp
│   ├── [1.5K]  myacc_MBorig.inp
│   ├── [1000]  myacc_MQ.inp
│   ├── [ 193]  pippo.inp
│   ├── [  21]  template.inp -> ../tools/template.inp
│   ├── [3.8K]  TestElement_exp.inp
│   ├── [ 865]  TestElement.inp
│   └── [  23]  TestElement.sh -> ../tools/TestElement.sh
└── [4.0K]  tools
    ├── [6.9K]  cut.py
    ├── [ 679]  display_elem.inp.template
    ├── [3.0K]  display_elem.sh
    ├── [1.1K]  expand.sh
    ├── [2.0K]  find_paths.py
    ├── [1.2K]  find_paths.pyc
    ├── [6.0K]  roto_traslate.py
    ├── [6.3K]  scan-fedb.py
    ├── [1.1K]  split.py
    ├── [ 796]  template.inp
    ├── [ 13K]  test_assembly.py
    └── [2.1K]  TestElement.sh
```

Collection of models of single accelerator devices in Ascii files



credits: A.Mereghetti @CERN

Line Builder

myacc_MBSORI.regions - emacs@pcbe16165

File Edit Options Buffers Tools Help

Save Undo

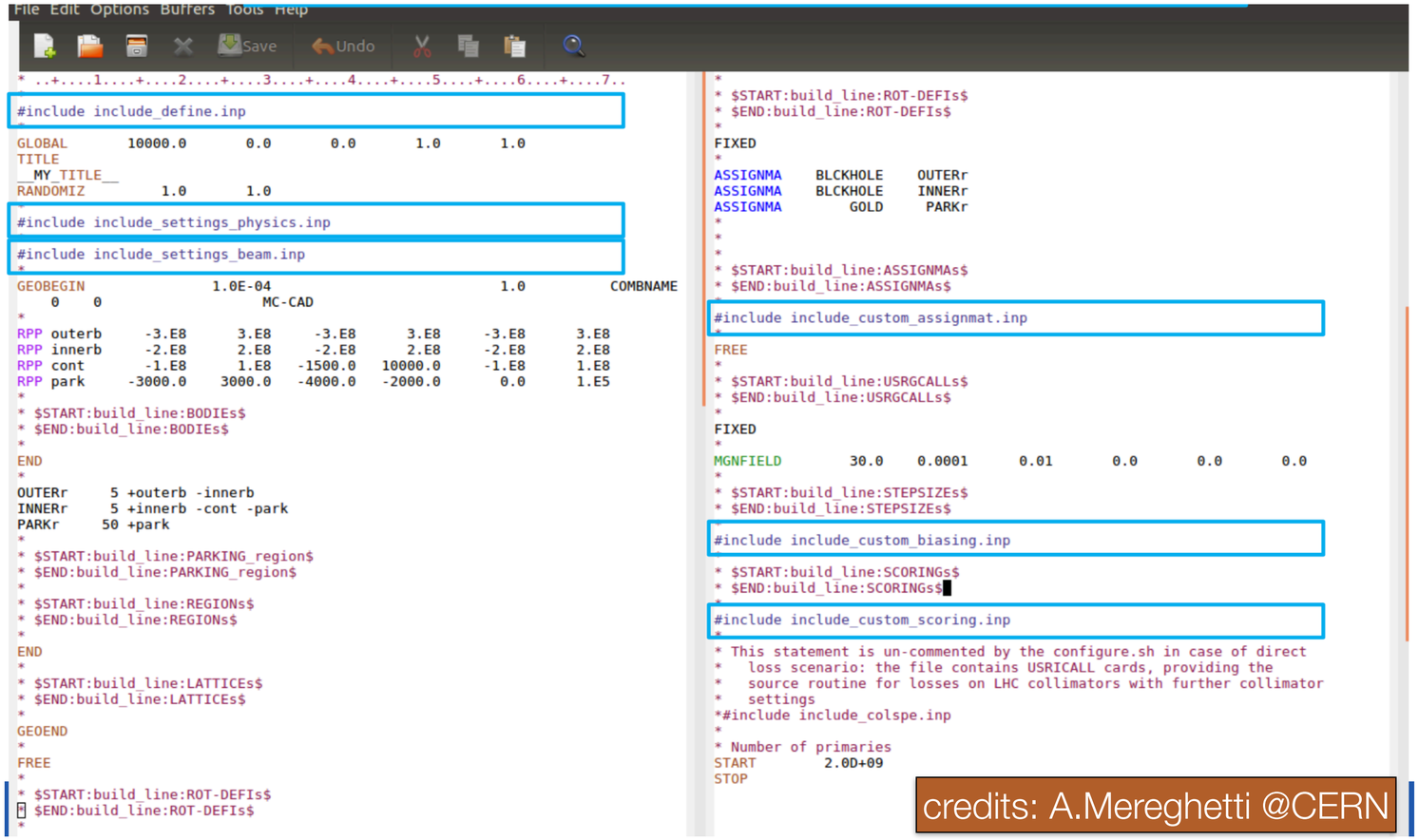
```
*
*    . yoke
RPP dipyoke     -200.0 20. -10.0 10.0 -200.0 30.0
YCC MBSORIKo    -200.0 -200.0 210.0
YCC MBSORIKi    -200.0 -200.0 190.0
*    . pipe
XZP MBSObpu     1.5
XZP MBSObpd     -1.5
YCC MBSObpo     -200.0 -200.0 203.0
YCC MBSObpi     -200.0 -200.0 197.0
*
-:---  myacc_MBSORI.bodies   All (8,0)      (FLUKA Ovwrt)
*
*    . yoke
MBSOYOKE      5 | +dipyoke +MBSORIKo -MBSORIKi -MBSObpu
                | +dipyoke +MBSObpu  -MBSObpd  +MBSORIKo -MBSObpo
                | +dipyoke +MBSObpu  -MBSObpd  +MBSObpi  -MBSORIKi
                | +dipyoke +MBSORIKo -MBSORIKi +MBSObpd
*    . pipe
MBSOBPVC      5 +dipyoke +MBSObpu -MBSObpd +MBSObpo -MBSObpi
*    . out
MBSOOUT_      5 | +dipyoke -MBSORIKo
                | +dipyoke +MBSORIKi
*
-:---  myacc_MBSORI.regions   All (4,14)     (FLUKA)
* dipole:
* ..+....1....+....2....+....3....+....4....+....5....+....6....+....7..
ASSIGNMA         IRON  MBSOYOKE
ASSIGNMA       VACUUM  MBSOBPVC                          1.0
ASSIGNMA       VACUUM  MBSOOUT_
*
-:---  myacc_MBSORI.assignmat   All (5,14)     (FLUKA)
```

Bending Dipole Prototype

✦**FLUKA LINE BUILDER** is a program aimed at automatically build accelerator geometries, consists of 2 parts:

Fluka Element DataBase

Line Builder



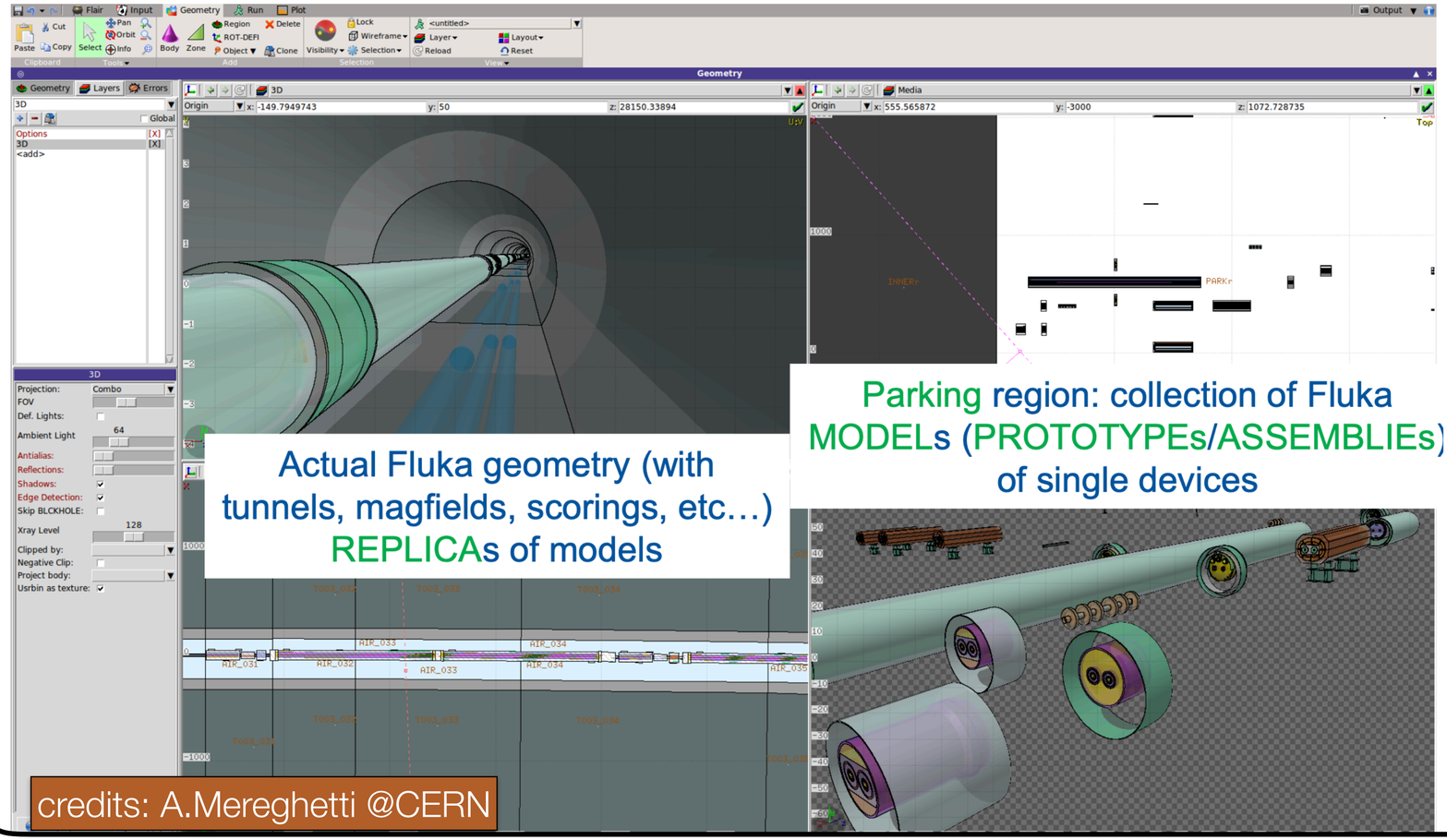
```
File Edit Options Buffers Tools Help
Save  Undo
* ..+....1....+....2....+....3....+....4....+....5....+....6....+....7..
#include include_define.inp
*
GLOBAL       10000.0       0.0       0.0       1.0       1.0
TITLE
__MY_TITLE__
RANDOMIZ          1.0       1.0
*
#include include_settings_physics.inp
#include include_settings_beam.inp
*
GEOBEGIN              1.0E-04                              1.0          COMBNAME
    0    0                  MC-CAD
*
RPP outerb     -3.E8      3.E8     -3.E8      3.E8     -3.E8      3.E8
RPP innerb     -2.E8      2.E8     -2.E8      2.E8     -2.E8      2.E8
RPP cont       -1.E8      1.E8   -1500.0   10000.0     -1.E8      1.E8
RPP park     -3000.0    3000.0   -4000.0   -2000.0       0.0      1.E5
*
* $START:build_line:BODIEs$
* $END:build_line:BODIEs$
*
END
*
OUTERr     5 +outerb -innerb
INNERr     5 +innerb -cont -park
PARKr     50 +park
*
* $START:build_line:PARKING_region$
* $END:build_line:PARKING_region$
*
* $START:build_line:REGIONs$
* $END:build_line:REGIONs$
*
END
*
* $START:build_line:LATTICEs$
* $END:build_line:LATTICEs$
*
GEOEND
*
FREE
*
* $START:build_line:ROT-DEFIs$
* $END:build_line:ROT-DEFIs$
*
*
* $START:build_line:ROT-DEFIs$
* $END:build_line:ROT-DEFIs$
*
FIXED
*
ASSIGNMA    BLCKHOLE    OUTERr
ASSIGNMA    BLCKHOLE    INNERr
ASSIGNMA        GOLD     PARKr
*
*
*
* $START:build_line:ASSIGNMAs$
* $END:build_line:ASSIGNMAs$
*
#include include_custom_assignmat.inp
*
FREE
*
* $START:build_line:USRGCALLs$
* $END:build_line:USRGCALLs$
*
FIXED
*
MGNFIELD        30.0    0.0001      0.01       0.0       0.0       0.0
*
* $START:build_line:STEPSIZEs$
* $END:build_line:STEPSIZEs$
*
#include include_custom_biasing.inp
*
* $START:build_line:SCORINGs$
* $END:build_line:SCORINGs$
*
#include include_custom_scoring.inp
*
* This statement is un-commented by the configure.sh in case of direct
*   loss scenario: the file contains USRICALL cards, providing the
*   source routine for losses on LHC collimators with further collimator
*   settings
*#include include_colspe.inp
*
* Number of primaries
START        2.0D+09
STOP
```

credits: A.Mereghetti @CERN

Python (v2.7) program that inserts the needed magnetic elements in a pre-existent “template geometry” based on machine optics

✦**FLUKA LINE BUILDER** is a program aimed at automatically build accelerator geometries, consists of 2 parts:

Fluka Element DataBase



Line Builder

FINAL RESULT

Once the geometry has been built in FLUKA, we can simulate whatever we want..!

```
@ TYPE             %05s "TWISS"
@ SEQUENCE         %07s "MYACCEL"
@ PARTICLE         %06s "PROTON"
@ MASS             %le           0.9382720812999995
@ CHARGE           %le           1.0000000000000000
@ ENERGY           %le           1.3712601863056616
@ PC               %le           1.0000000000000000
@ GAMMA            %le           1.4614739302545872
@ KBUNCH           %le           1.0000000000000000
@ BCURRENT         %le           0.11463416918410078
@ SIGE             %le           0.0004500000000000
@ SIGT             %le           0.0755000000000000
@ NPART            %le  199999999999.99996948242187500
@ EX               %le           0.0000017106018439
@ EY               %le           0.0000017106018439
@ ET               %le           0.0010000000000000
@ BV_FLAG          %le           1.0000000000000000
@ LENGTH           %le          44.56637061435915115
@ ALFA             %le           0.02452735406345014
@ ORBITS           %le          -0.0000000000000000
@ GAMMATR          %le           6.38520212960327616
@ Q1               %le           2.23430396971649170
@ Q2               %le           2.39886628492304776
@ DQ1              %le         -13.15027500931211080
@ DQ2              %le         -12.03854917694575200
@ DXMAX            %le           3.72418111948598485
@ DYMAX            %le          -0.0000000000000000
@ XCOMAX           %le           0.0000000000000000
@ YCOMAX           %le           0.0000000000000000
@ BETXMAX          %le          56.74023186627047721
@ BETYMAX          %le          30.53217555627889368
@ XCORMS           %le           0.0000000000000000
@ YCORMS           %le           0.0000000000000000
@ DXRMS            %le           1.95163328969153160
@ DYRMS            %le           0.0000000000000000
@ DELTAP           %le           0.0000000000000000
@ SYNCH_1          %le           0.0000000000000000
@ SYNCH_2          %le           0.0000000000000000
@ SYNCH_3          %le           0.0000000000000000
@ SYNCH_4          %le           0.0000000000000000
@ SYNCH_5          %le           0.0000000000000000
@ TITLE            %08s "no-title"
@ ORIGIN           %16s "5.05.01 Linux 64"
@ DATE             %08s "11/06/19"
@ TIME             %08s "14.17.20"
* NAME              KEYWORD                    S                    L                 TILT                 KICK                HKICK                VKICK                ANGLE
$ %s                %s                        %le                  %le                 %le                  %le                  %le                  %le                  %le
 "MYACCEL$START"    "MARKER"    0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_0"          "DRIFT"     0.19999999999999996  0.39999999999999991  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "S.ARC.12"         "MARKER"    0.39999999999999991  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_1"          "DRIFT"     0.44999999999999996  0.10000000000000009  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "MB.1T2"           "SBEND"     2.07079632679489656  3.14159265358979312  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  1.57079632679489656
 "DRIFT_2"          "DRIFT"     3.69159265358979294  0.10000000000000009  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "E.ARC.12"         "MARKER"    3.74159265358979320  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_3"          "DRIFT"     4.14909265358979340  0.81499999999999995  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "MQ.1X2"           "QUADRUPOLE" 4.64159265358979312  0.17000000000000001  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_4"          "DRIFT"     5.64159265358979312  1.83000000000000007  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "MQ.2X2"           "QUADRUPOLE" 6.64159265358979312  0.17000000000000001  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_5"          "DRIFT"     6.77659265358979290  0.10000000000000053  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "BPM.2X2"          "MONITOR"   7.07659265358979361  0.50000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_6"          "DRIFT"     7.94159265358979294  1.22999999999999865  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "MQ.3X2"           "QUADRUPOLE" 8.64159265358979312  0.17000000000000001  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_7"          "DRIFT"     9.64159265358979134  1.82999999999999829  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "MQ.4X2"           "QUADRUPOLE" 10.64159265358979134  0.17000000000000001  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_8"          "DRIFT"     11.13409265358978928  0.81499999999999950  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
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 "DRIFT_9"          "DRIFT"     11.59159265358978885  0.09999999999999964  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "MB.2T3"           "SBEND"     13.21238898038468612  3.14159265358979312  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  1.57079632679489656
 "DRIFT_10"         "DRIFT"     14.83318530717958339  0.09999999999999964  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "E.ARC.23"         "MARKER"    14.88318530717958232  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "DRIFT_11"         "DRIFT"     15.29068530717958296  0.81499999999999950  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
 "MQ.1X3"           "QUADRUPOLE" 15.78318530717958268  0.17000000000000001  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000  0.00000000000000000
```
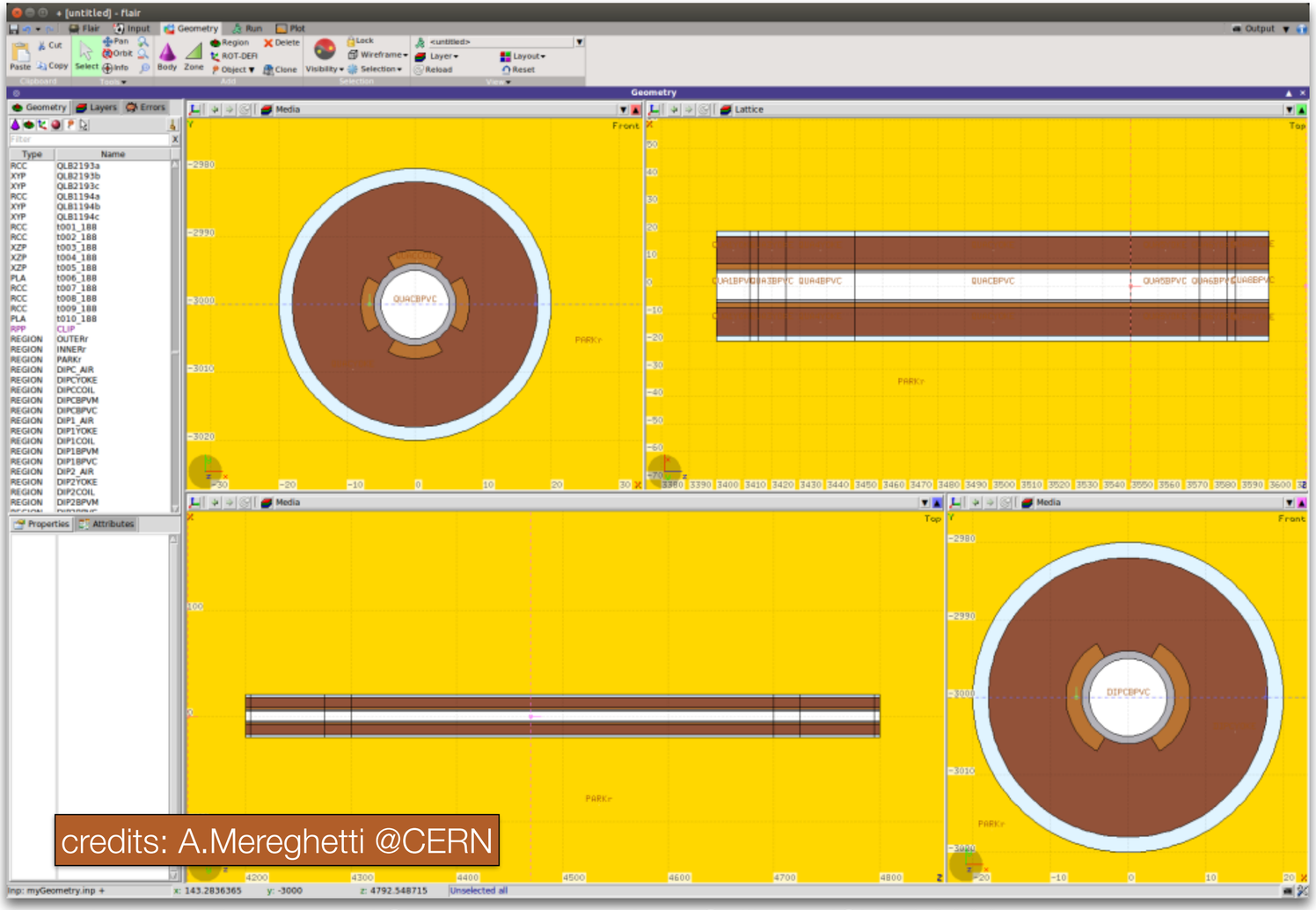
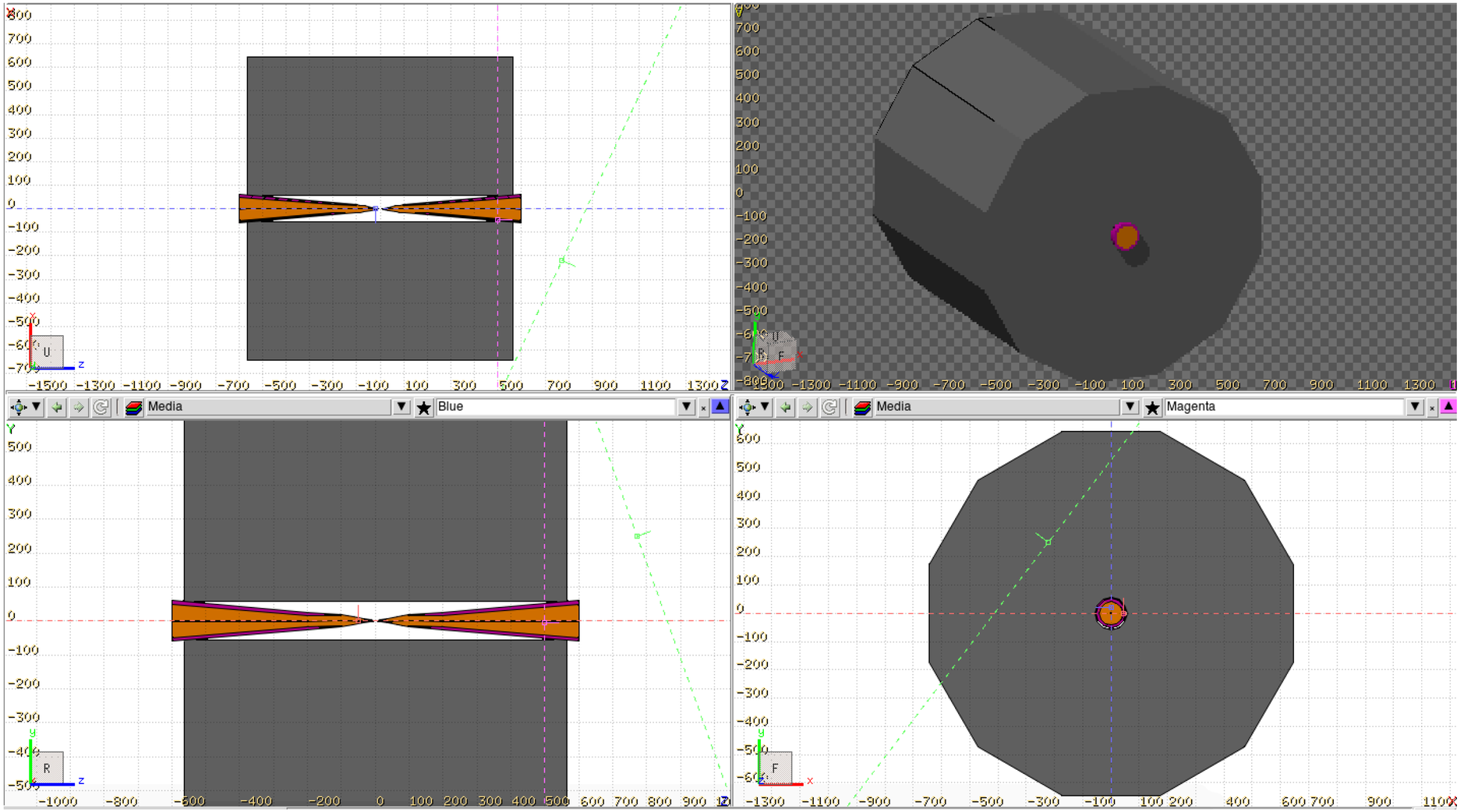

First goal: reproduce MAP results @ 1.5TeV CM

- We started from the muon collider **machine optics** from **MAP** Studies
  - ➡ Old optics format! (Mad-8)
  - ➡ Different conventions from LHC studies
  - ➡ Very limited use of markers

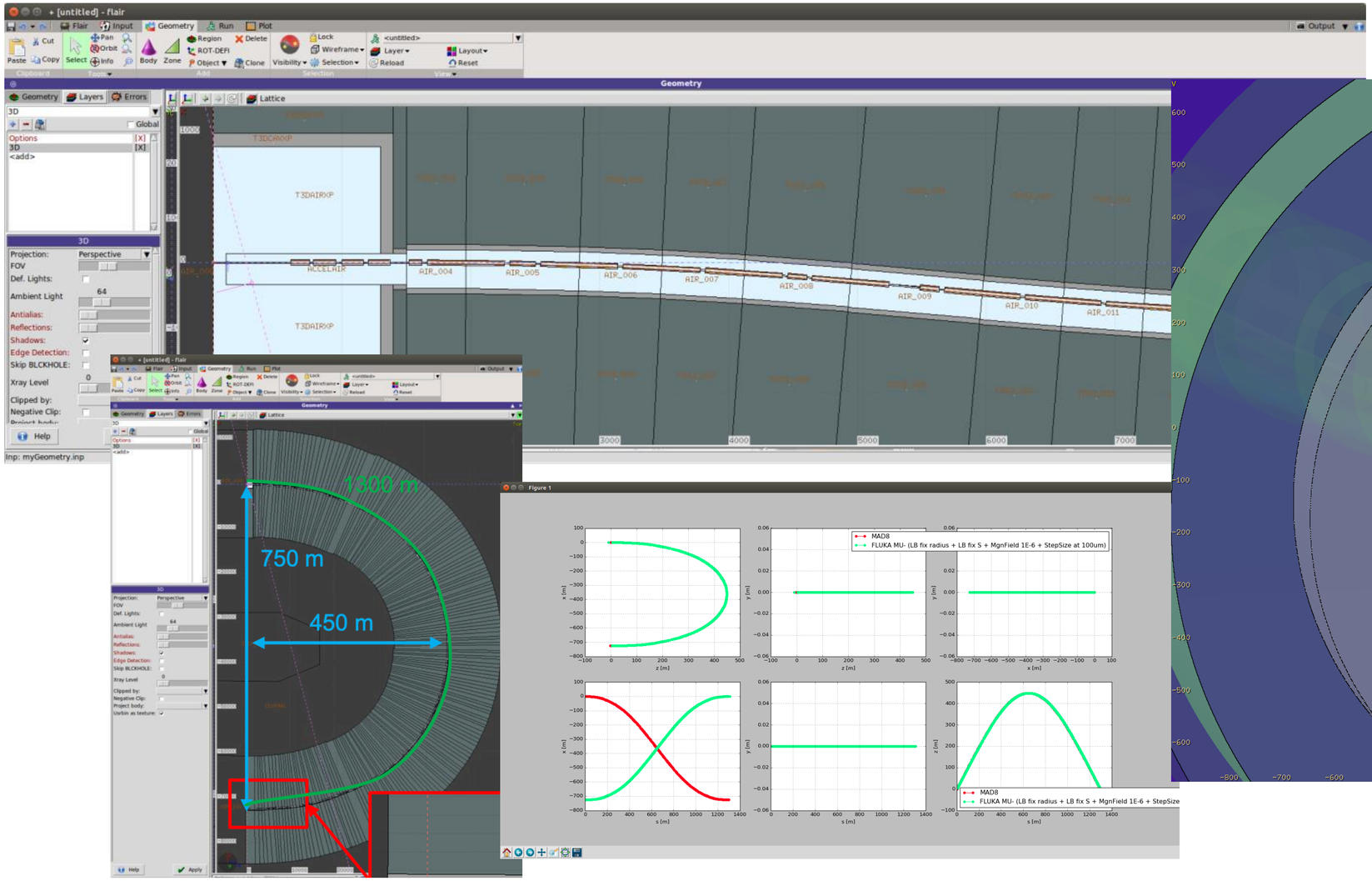
- A first **Fluka Elements Data Base** has been developed with some “First order” magnetic elements geometries: *Dipoles, Quadrupoles* and *Sextupoles*

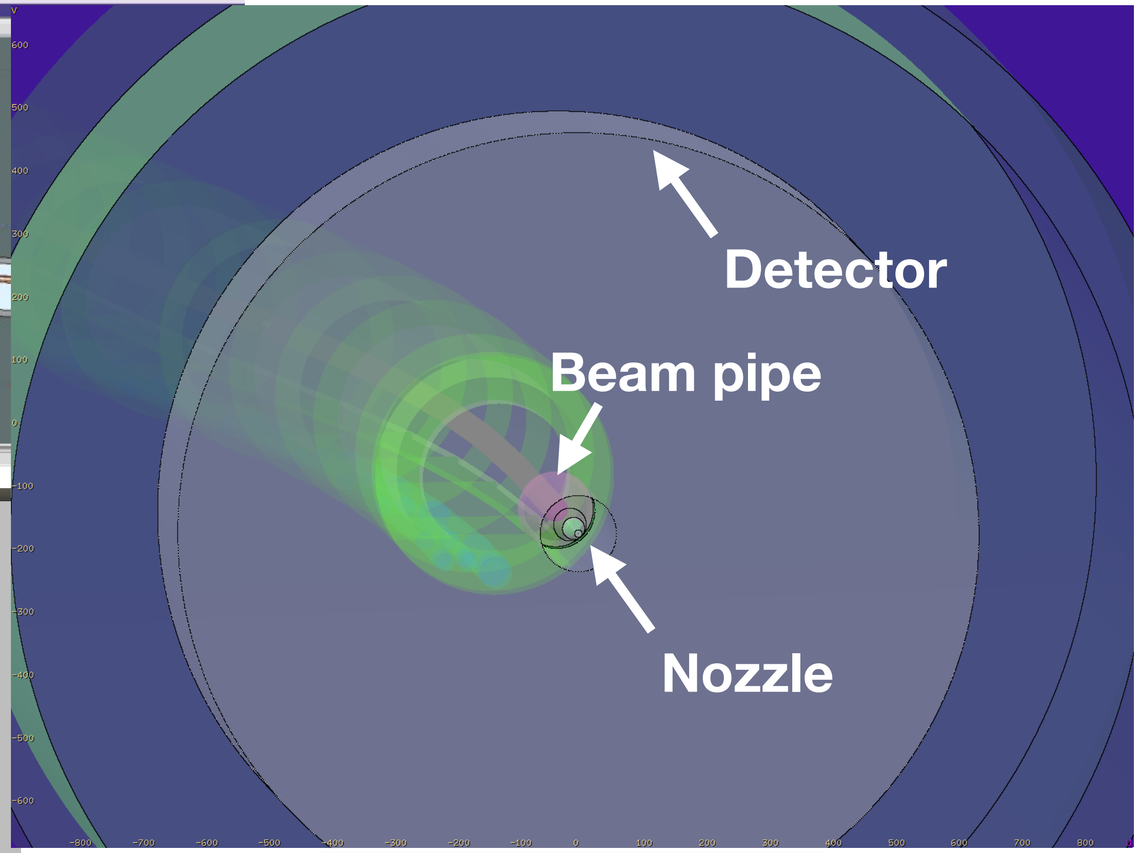


- The **detector** (w/ nozzle) has been added to the geometry (via an automatic script working on its *.gdml* file)



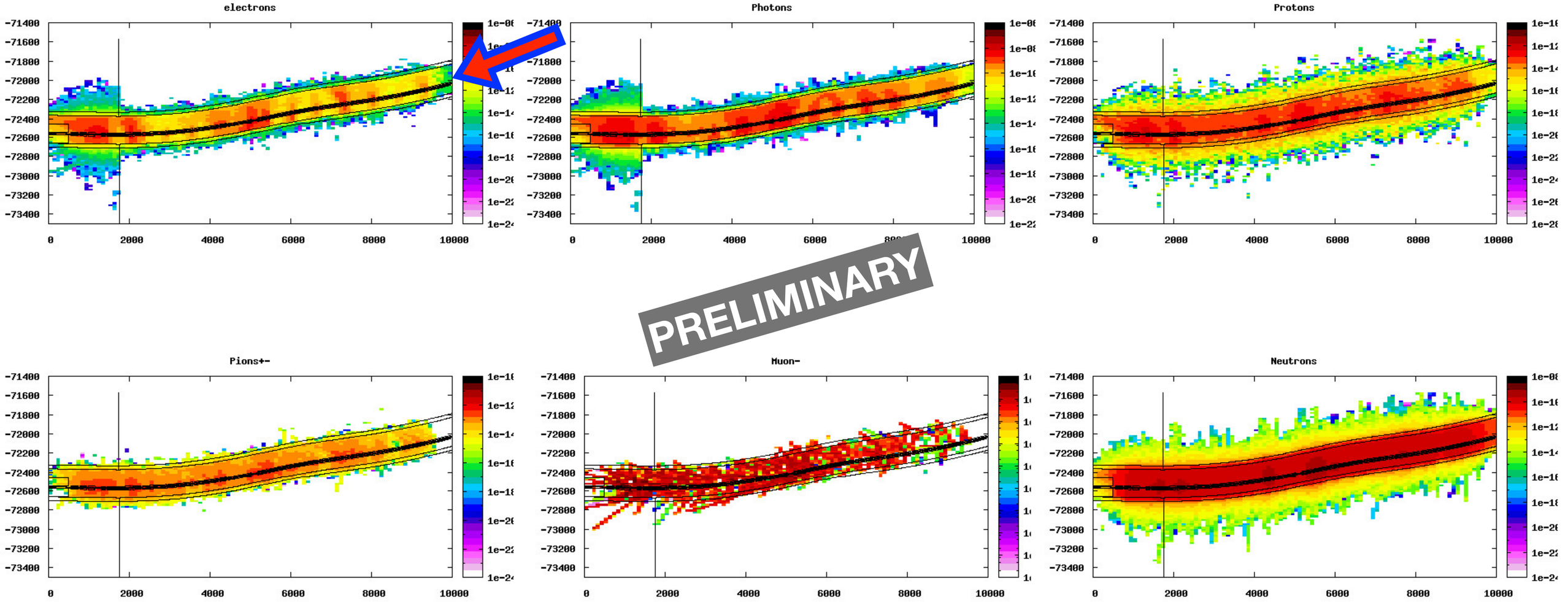
- A very first geometry of the whole muon collider (half ring) has been produced…





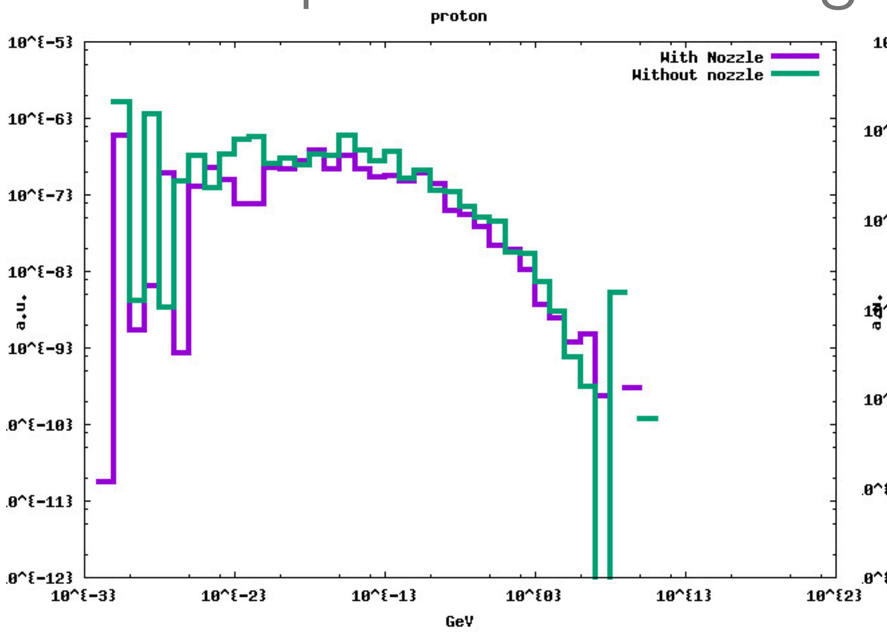
credits: A.Mereghetti @CERN
P. Sala @ INFN-Mi

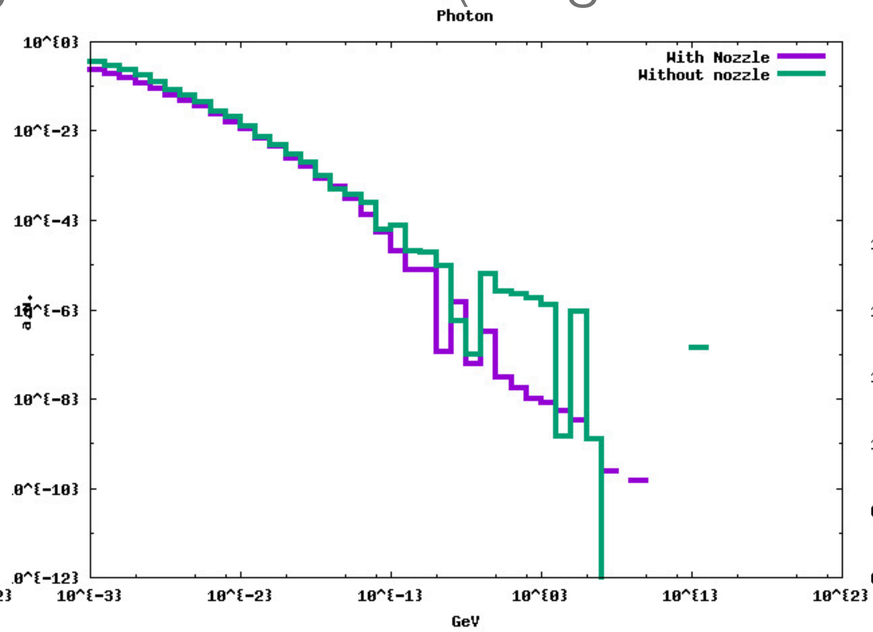
- Flux of produced particles (firing 750GeV mu+)

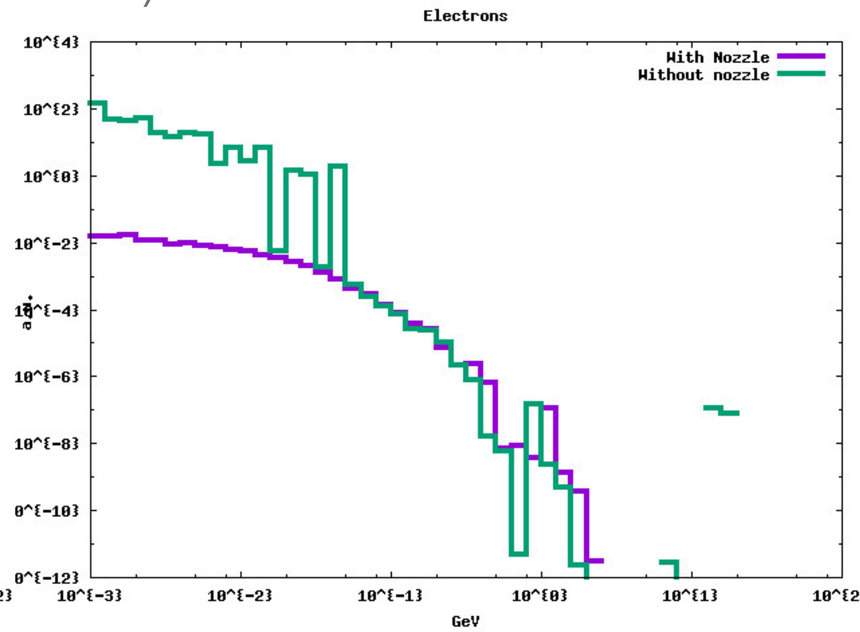


credits: Paola Sala

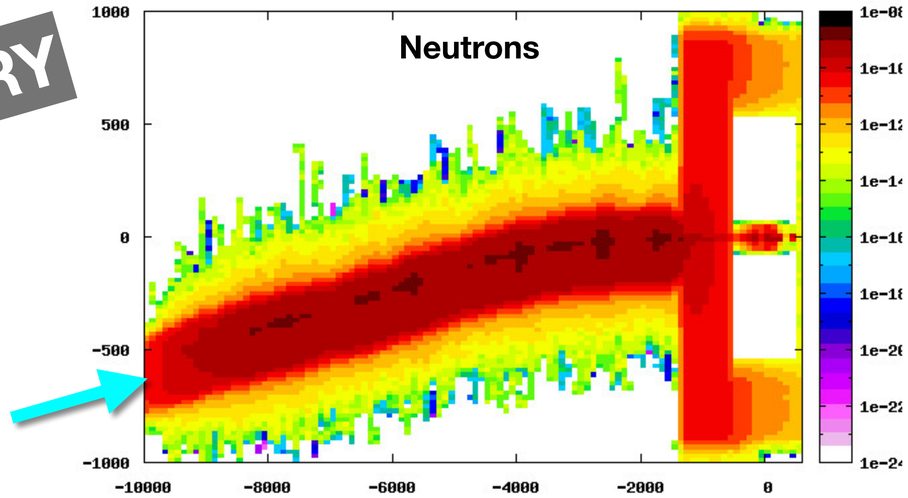
- Flux of particles entering the detector (firing 750GeV mu+)

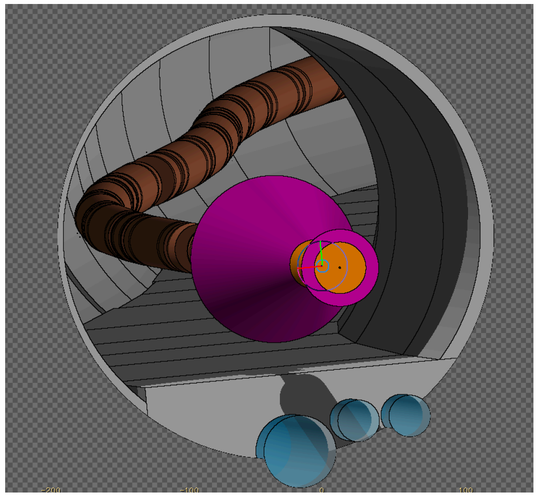






PRELIMINARY





credits: Paola Sala

To Sum Up

- **Beam Induced Background** in the experimental area of a Muon Collider is mainly due to **muon decays** and can impair physics measurements
- A powerful **flexible tool** for **simulating** such sections of the machine starting from the optics is needed
- **FLUKA Line Builder** has been chosen and started to use with first descriptions for optics element and detector

THANK YOU FOR YOUR ATTENTION!