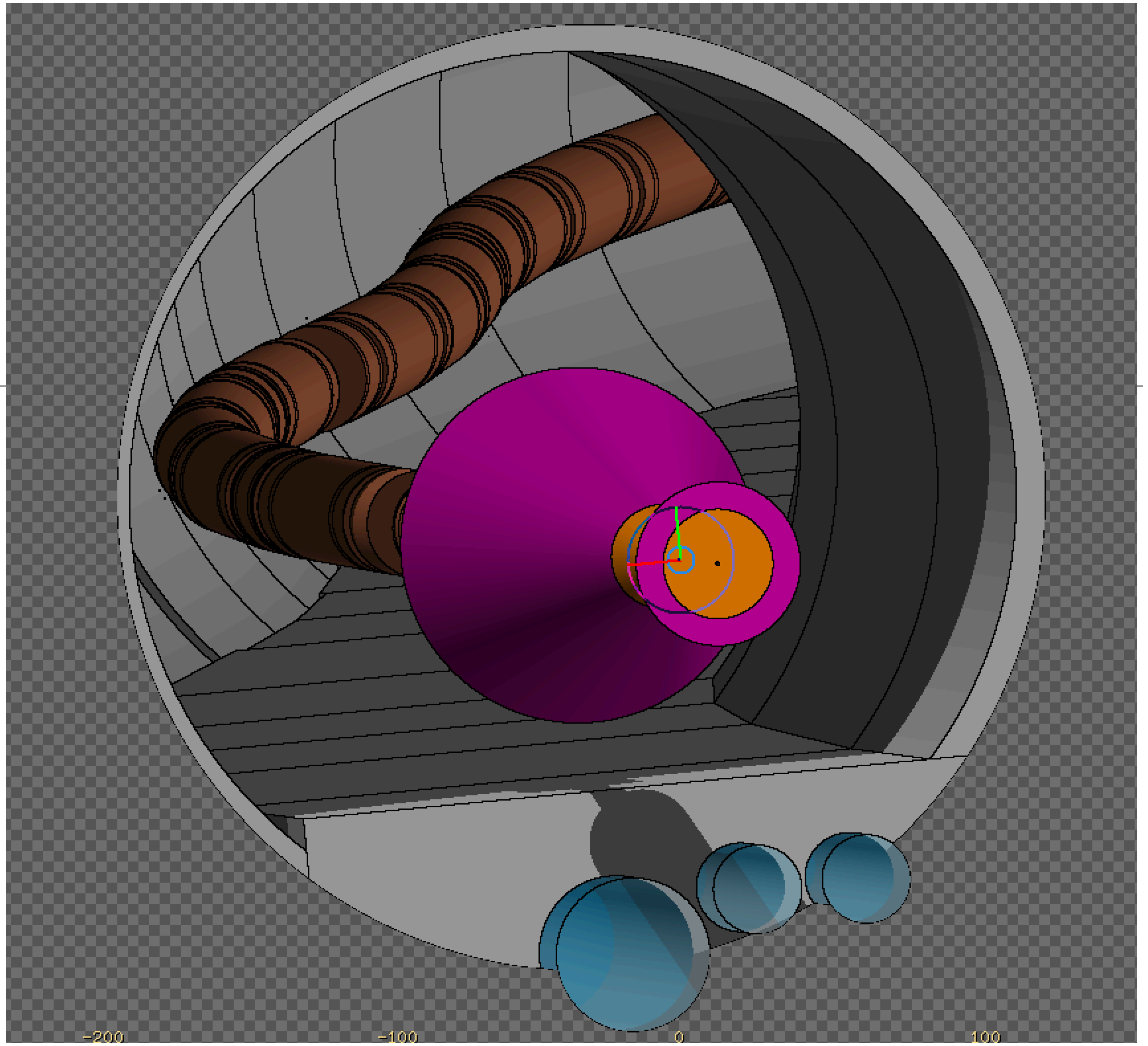
MDI simulation and optimisation at a Muon Collider

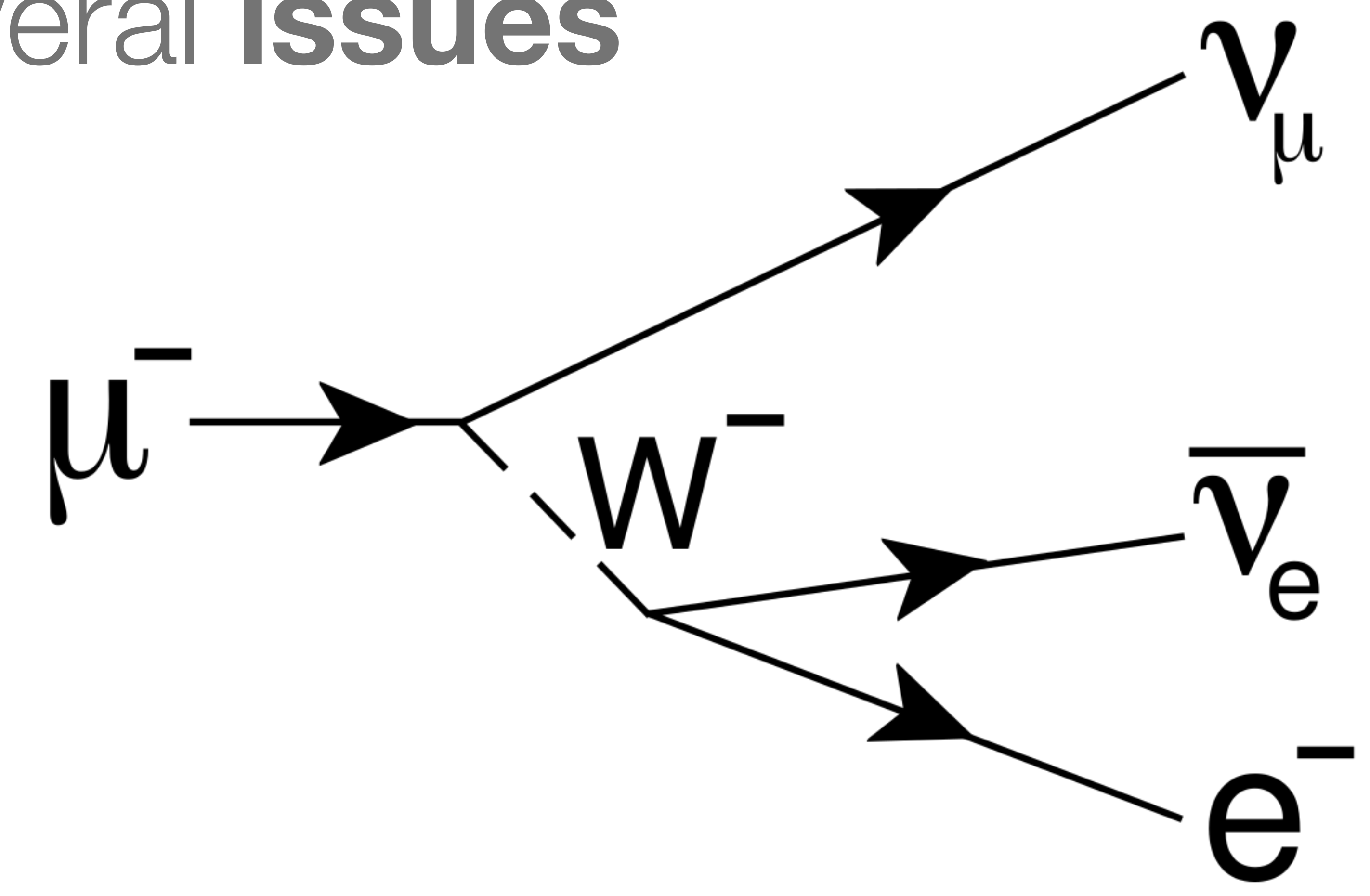


F. Collamati - INFN Rome
francesco.collamati@roma1.infn.it

Paola Sala, Camilla Curatolo, Alessio Mereghetti, Donatella Lucchesi, Massimo Casarsa, Nazar Bartosik, Lorenzo Sestini, Nikolai Mokhov, Mark Palmer

CERN WORKING GROUP MEETING - 21.9.20

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



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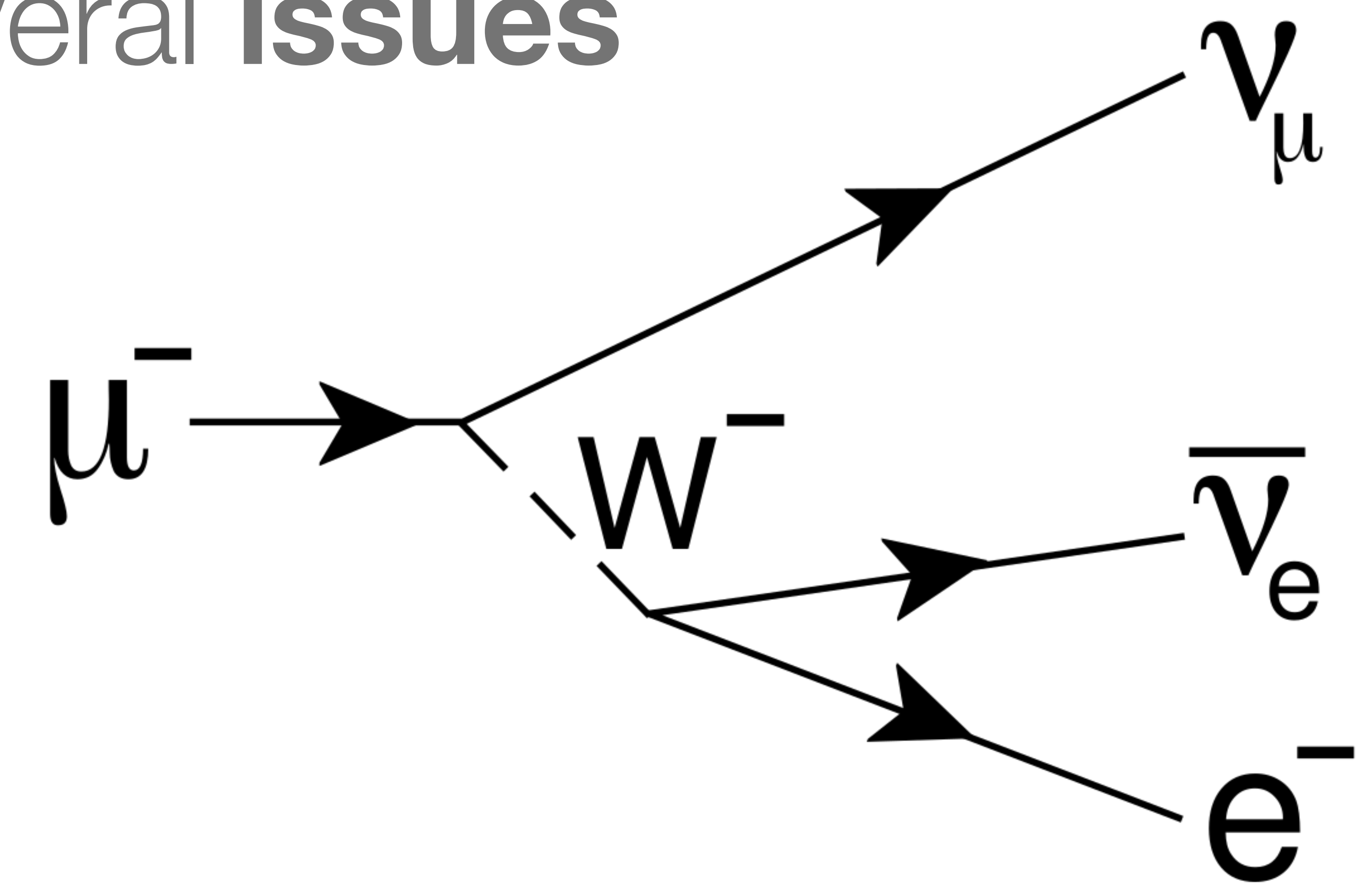

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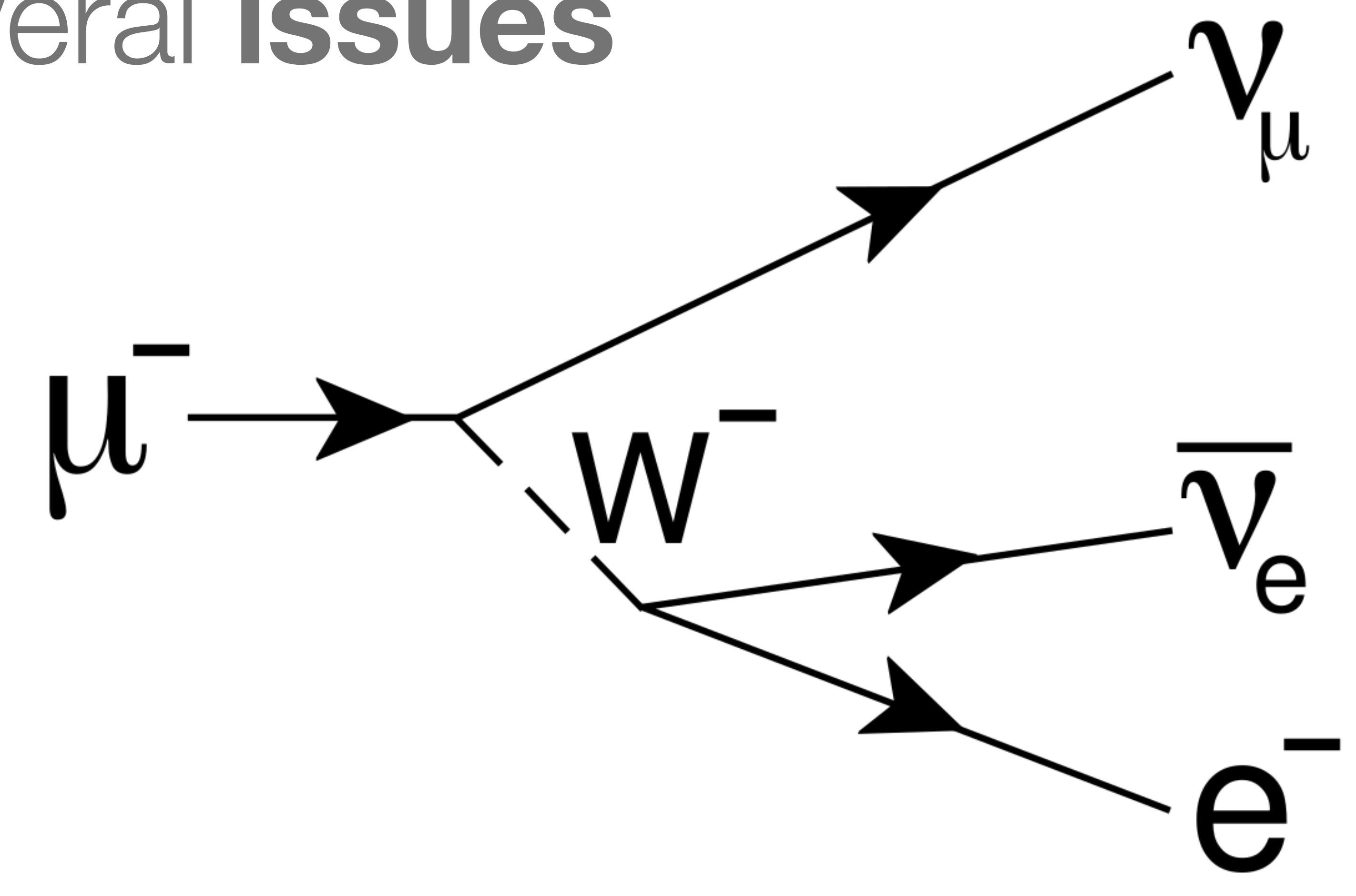

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Magnet quenching

Detector background

Radiation protection

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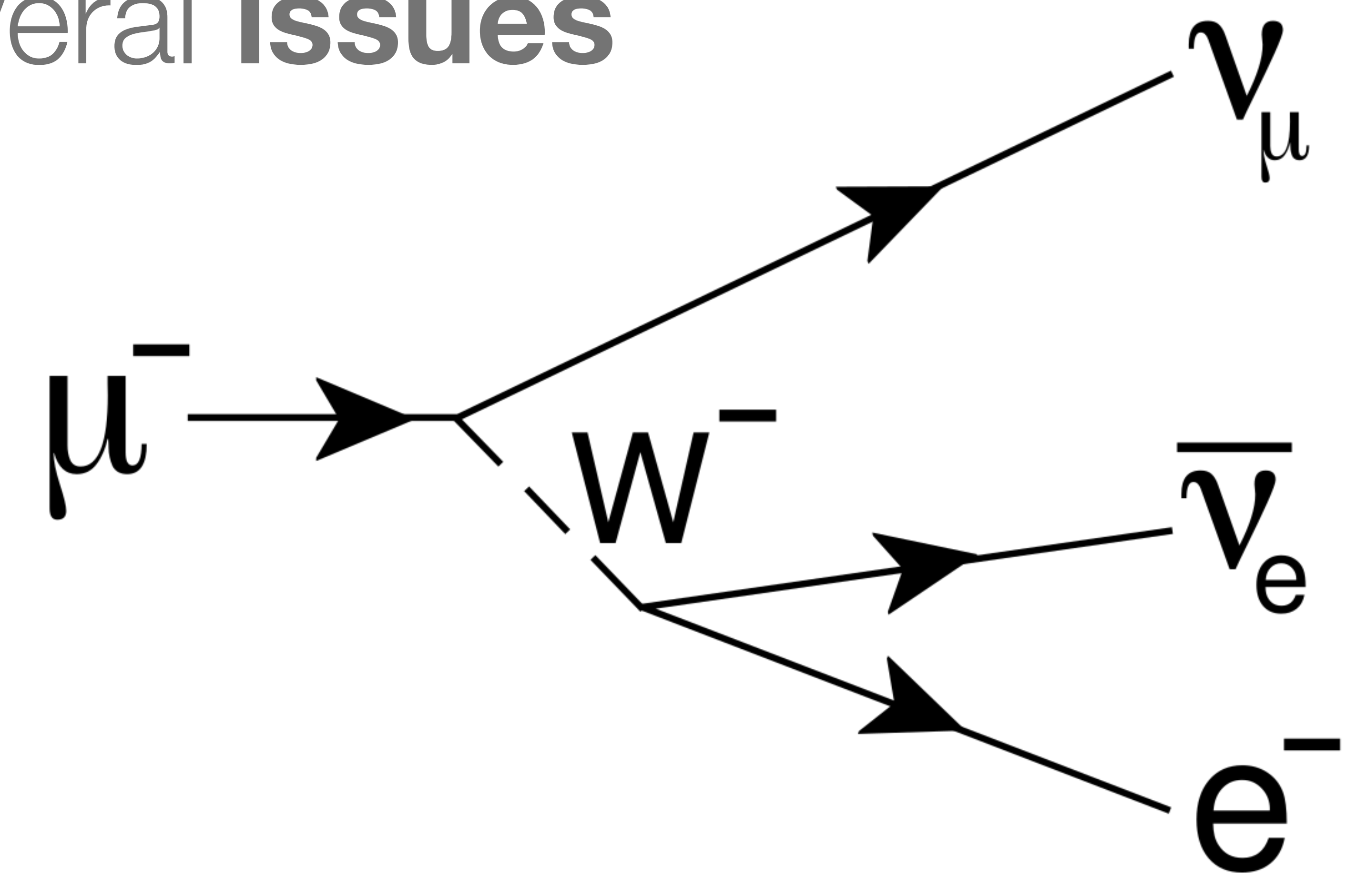

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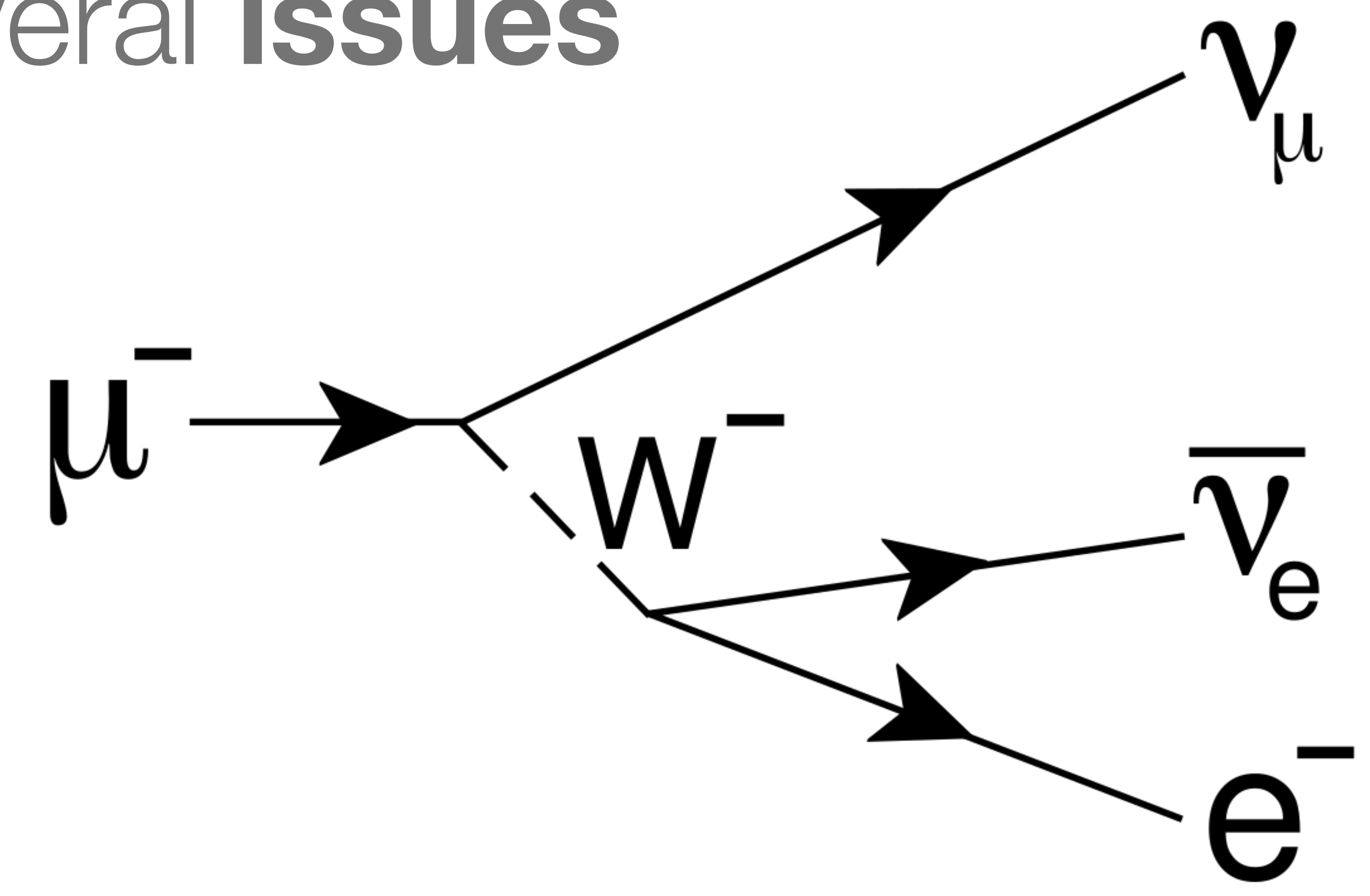

What about decay products!?

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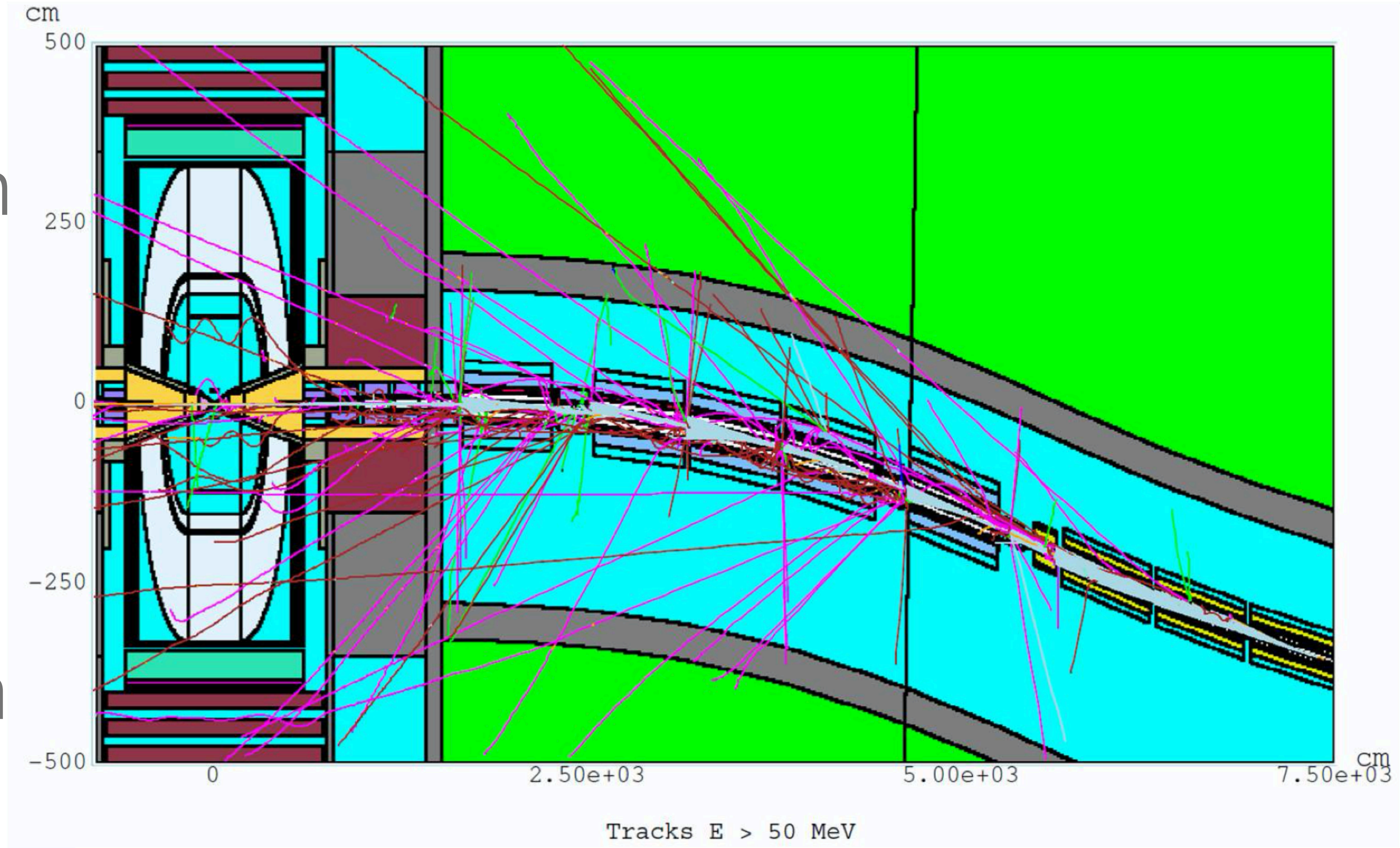
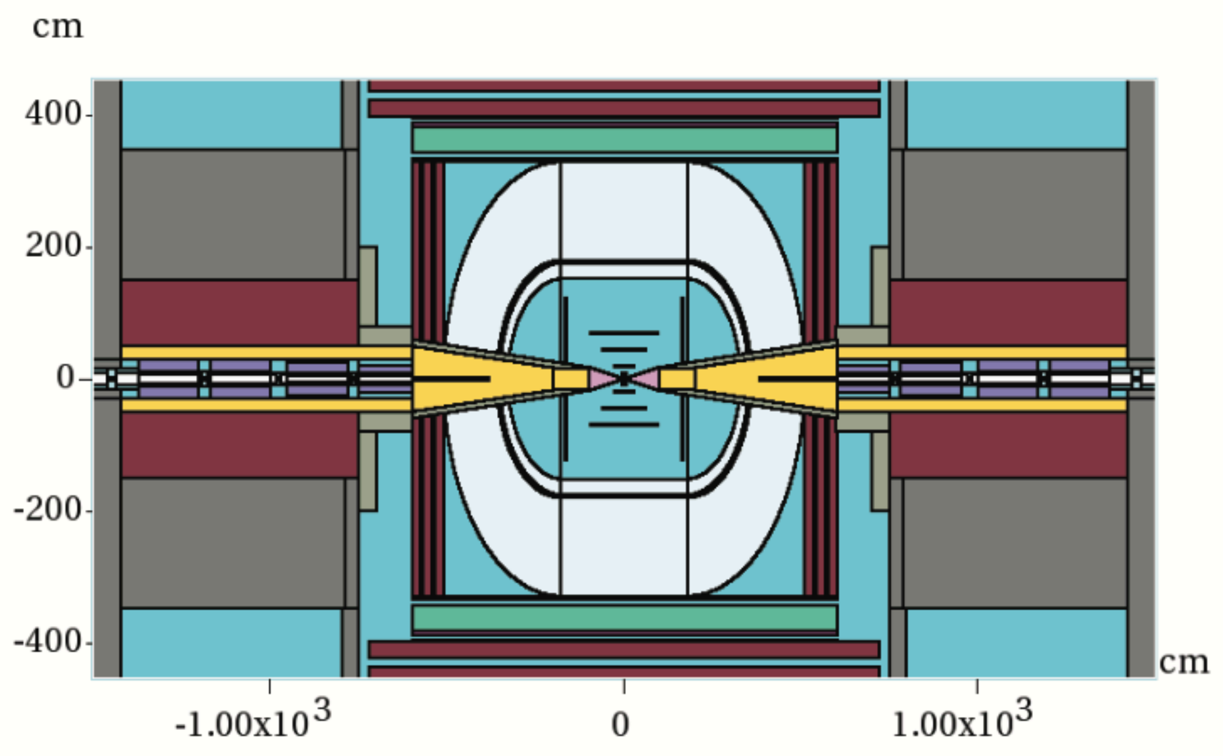
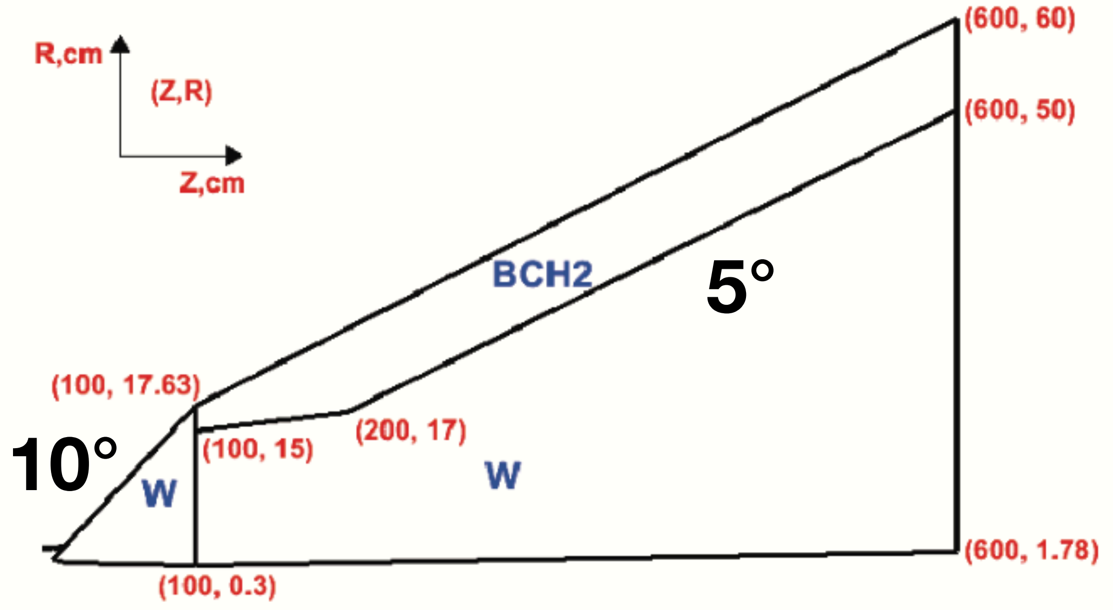
ARE WE ABLE TO SEE IT?!

- **Beam Induced Background** (BIB) in the detector can severely impair its performances

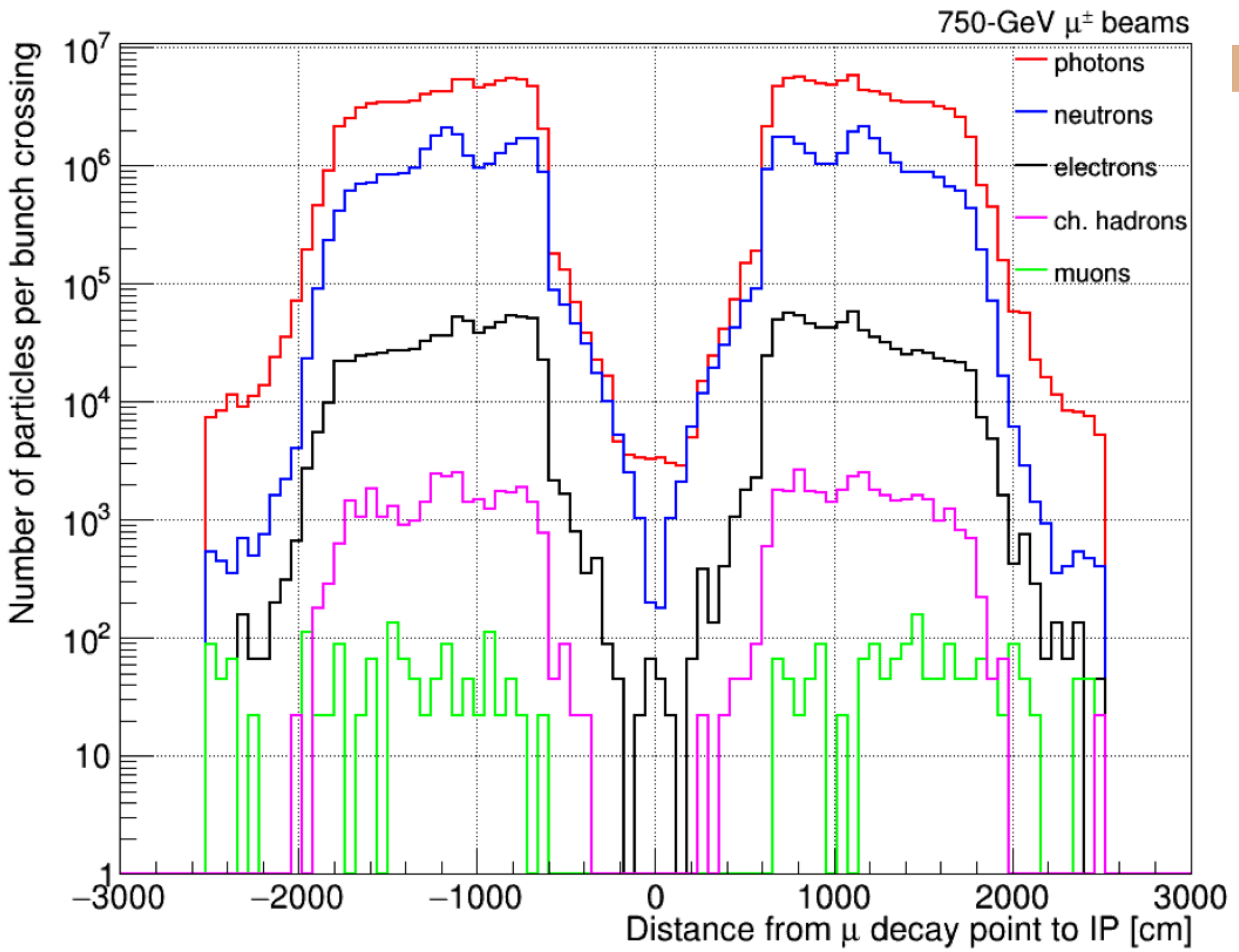


  - **MAP** developed a realistic simulation of BIB in the detector by implementing a model of the tunnel and accelerator **±200m** from the interaction point, **@E_{cm} = 1.5 TeV**
  - Secondary and tertiary particles from muon decays are simulated with *MARS15* then transported to the detector
  - **Two 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

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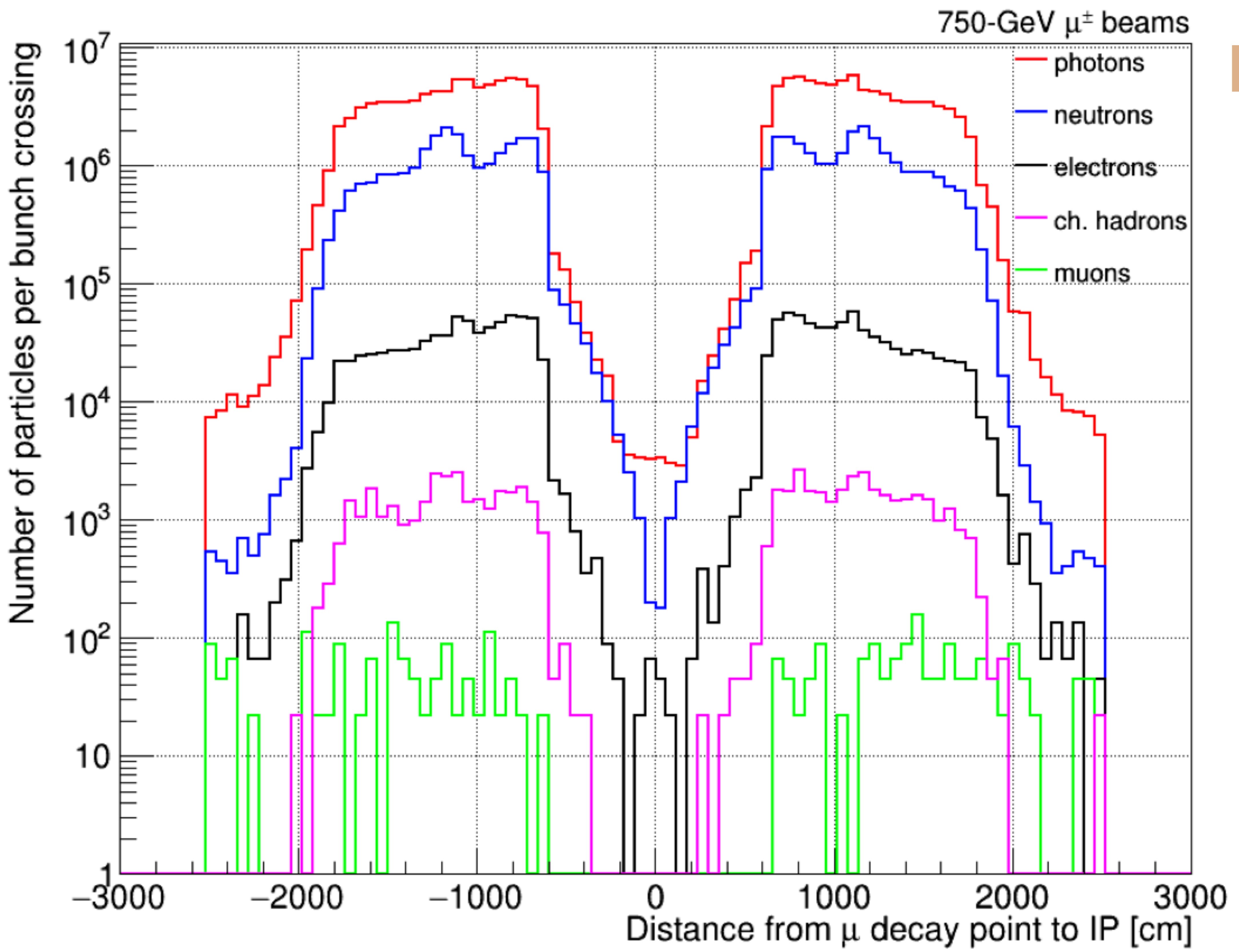

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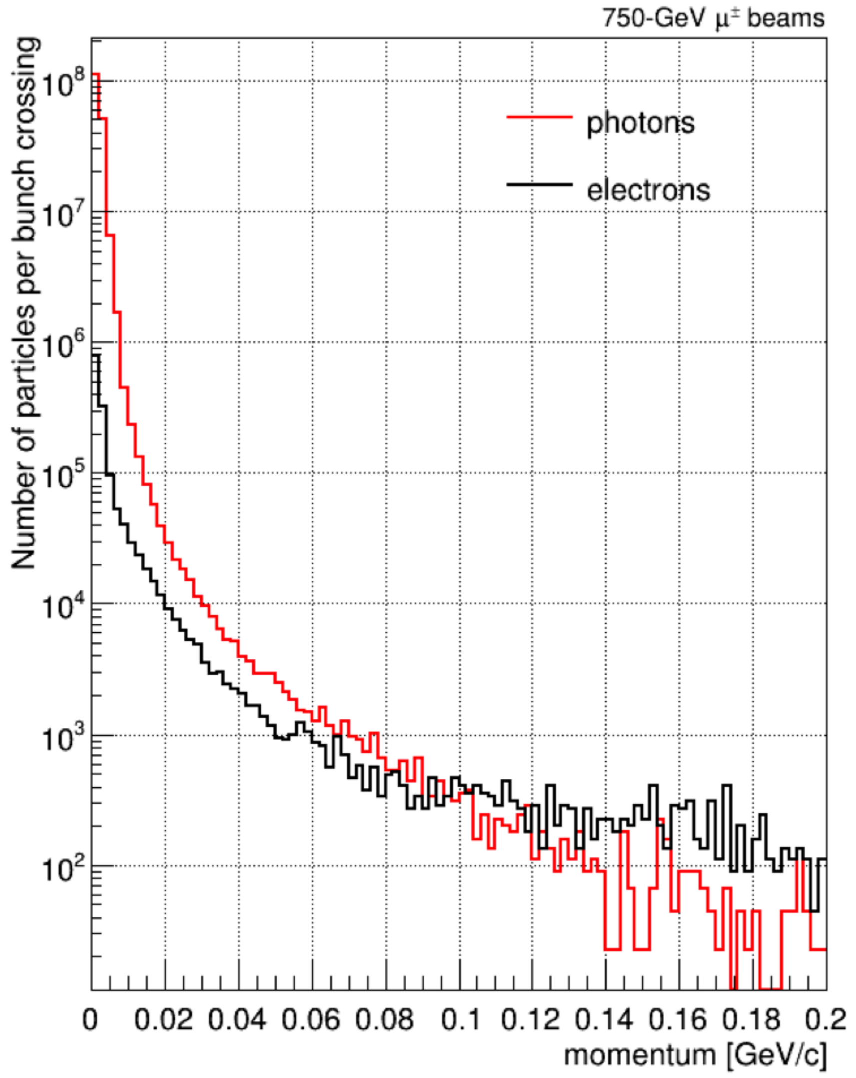

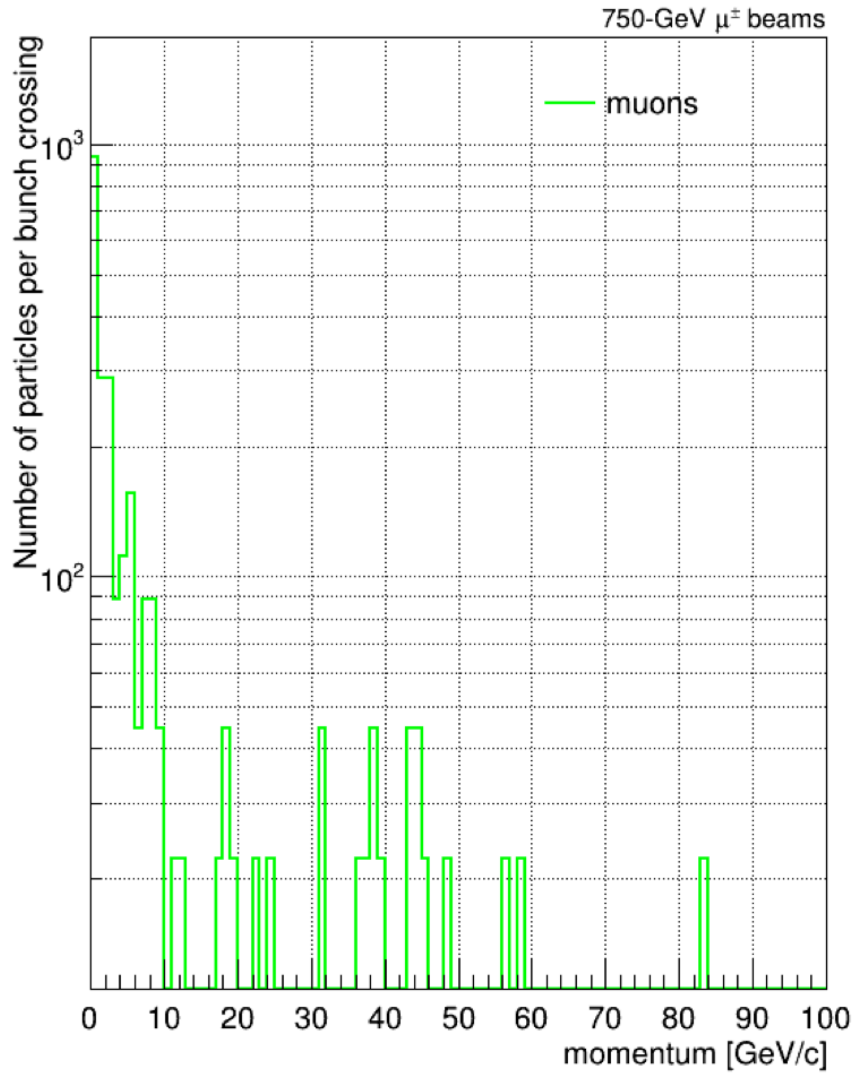

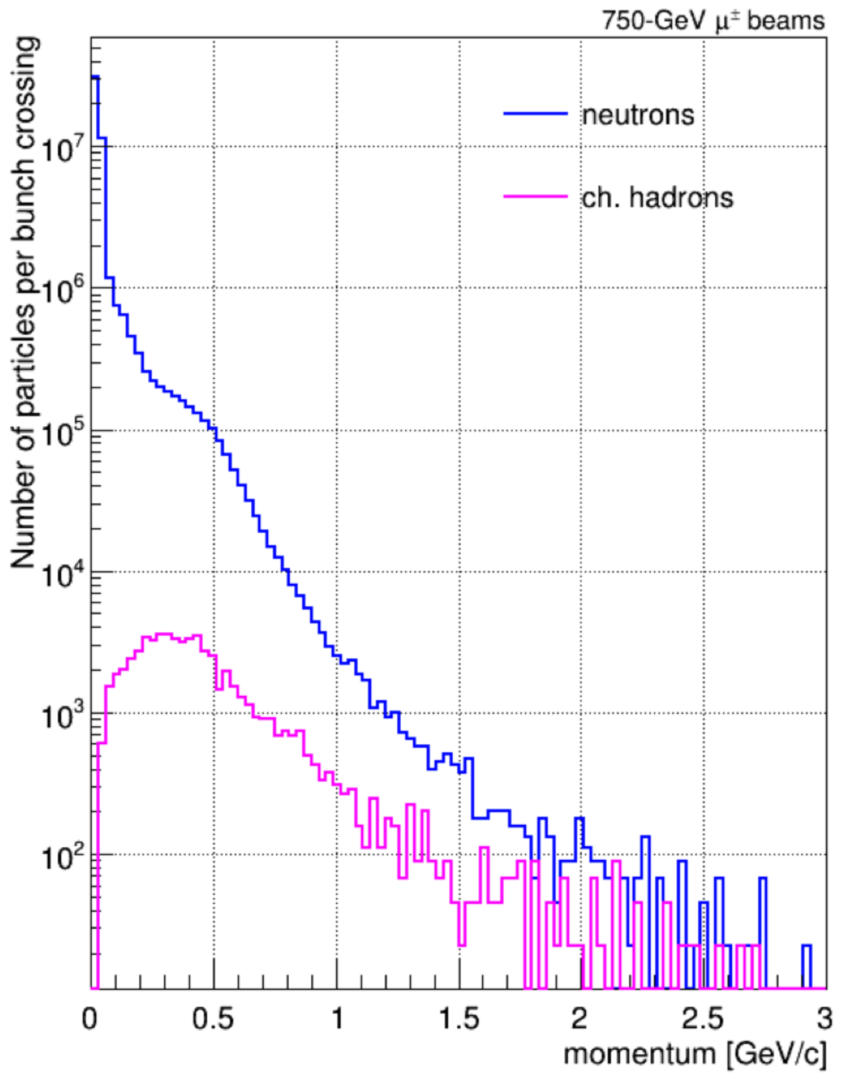

$P_{e/g}$~MeV, $P_{n\ /ch.h}$~500 MeV, P_{mu}~10GeV

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

- A Muon Collider has outstanding physics capabilities
- Beam Induced Background can impair detector performances
  - This bkg depends on both Center Of Mass energy and Machine Design
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  A study for 125GeV CM has been done (see N. Bartosik's talk)
- Results suggest challenging physics measurements are possible!

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

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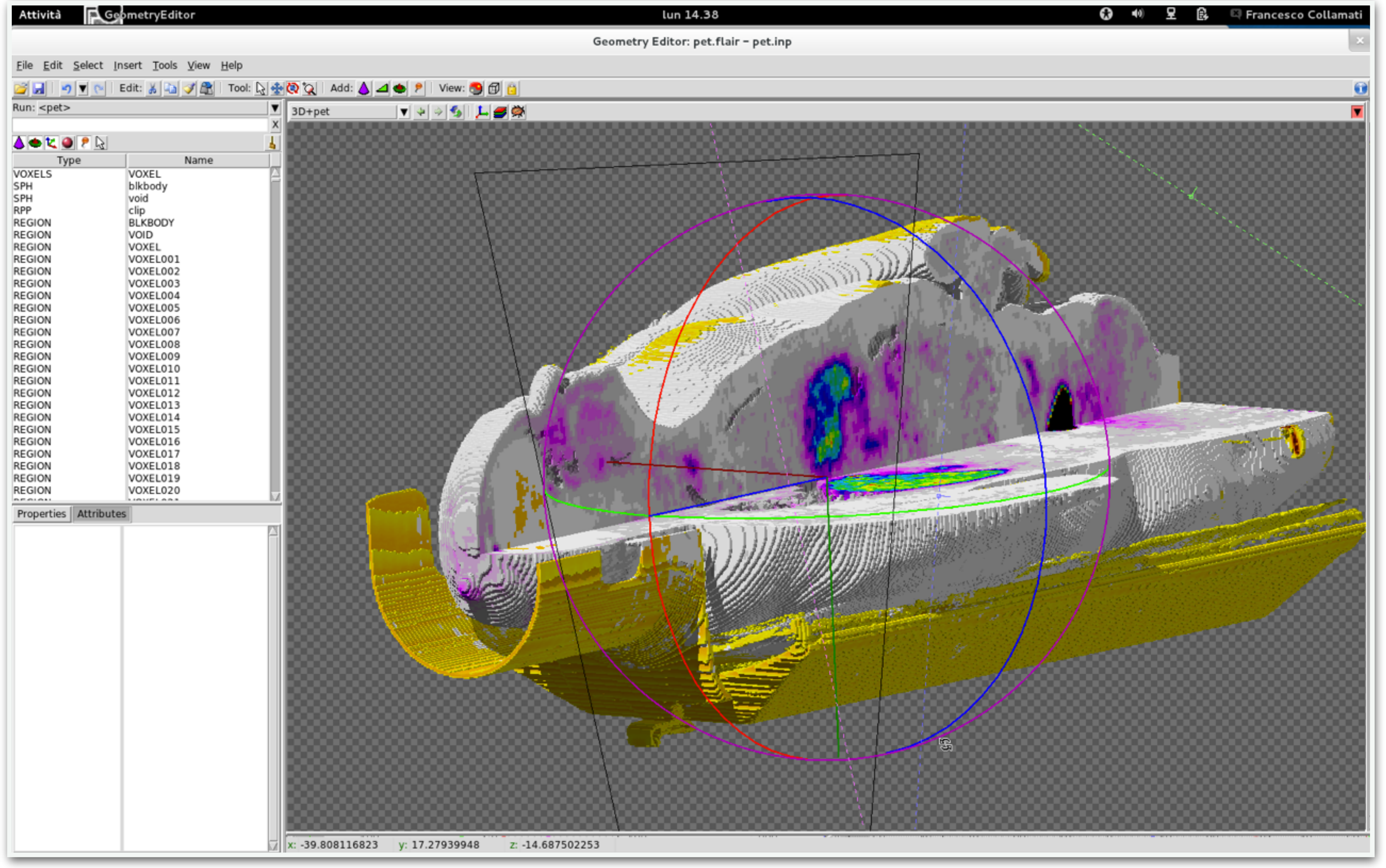
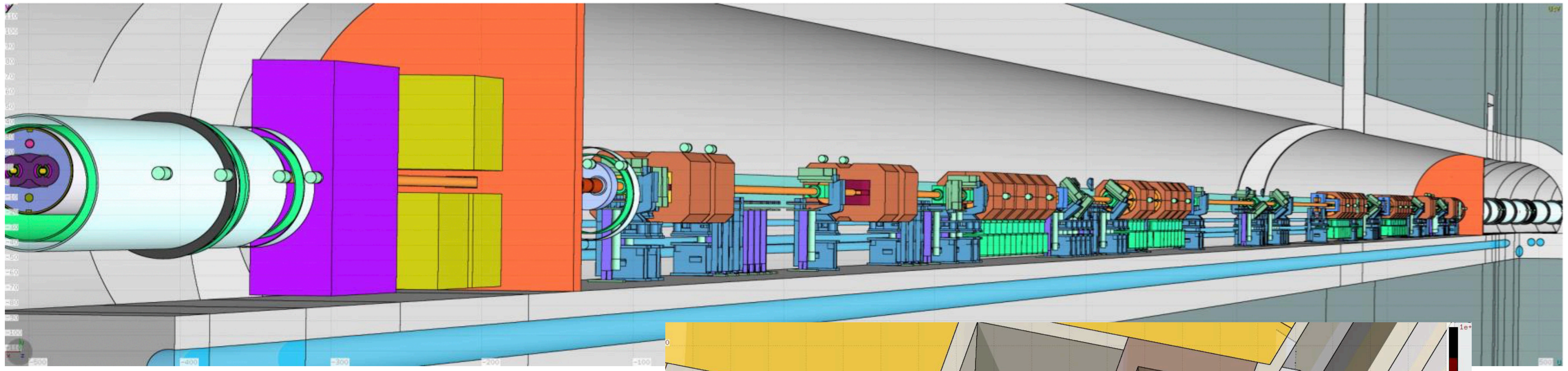
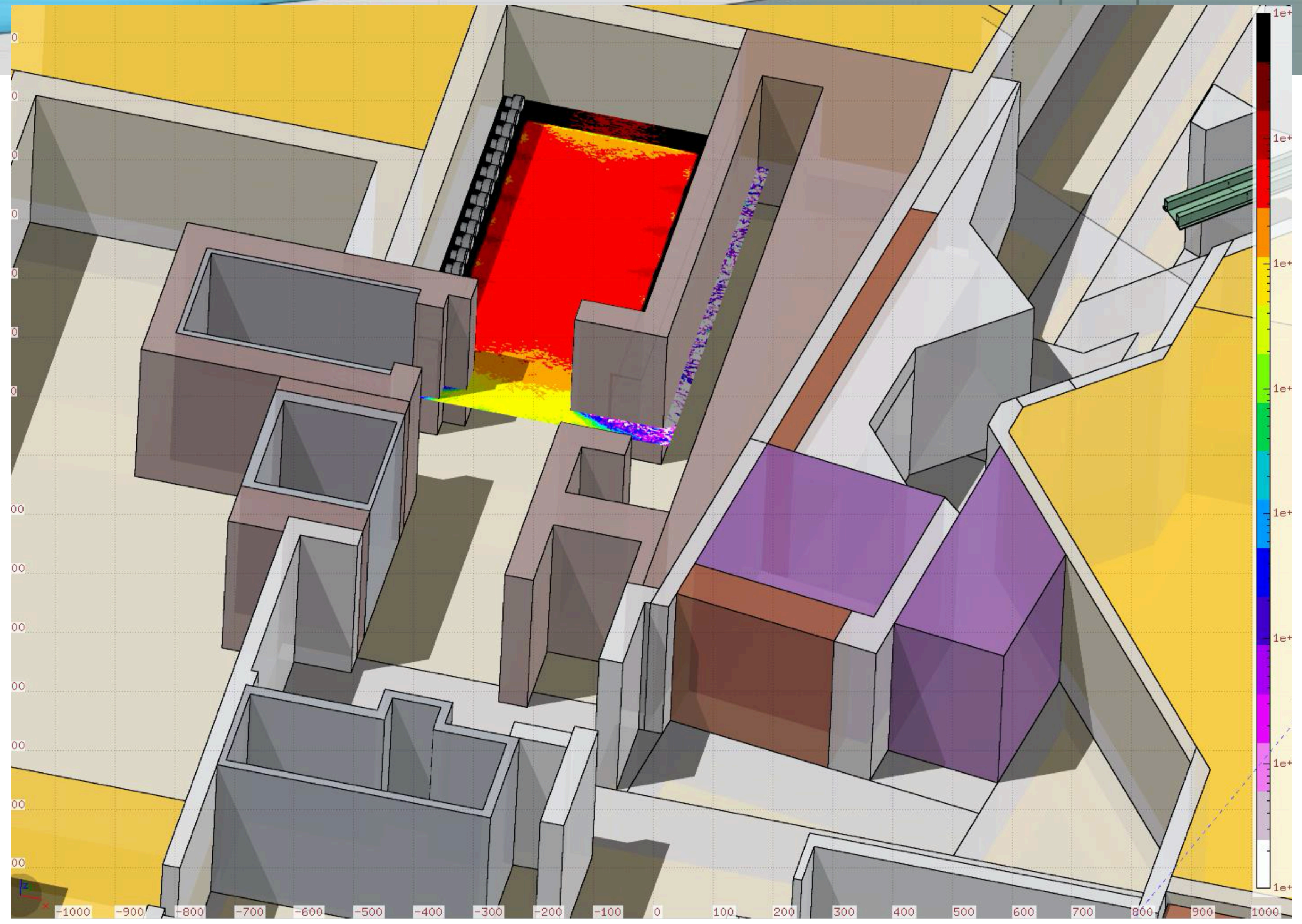
✦Natively supports very complicated and detailed geometries







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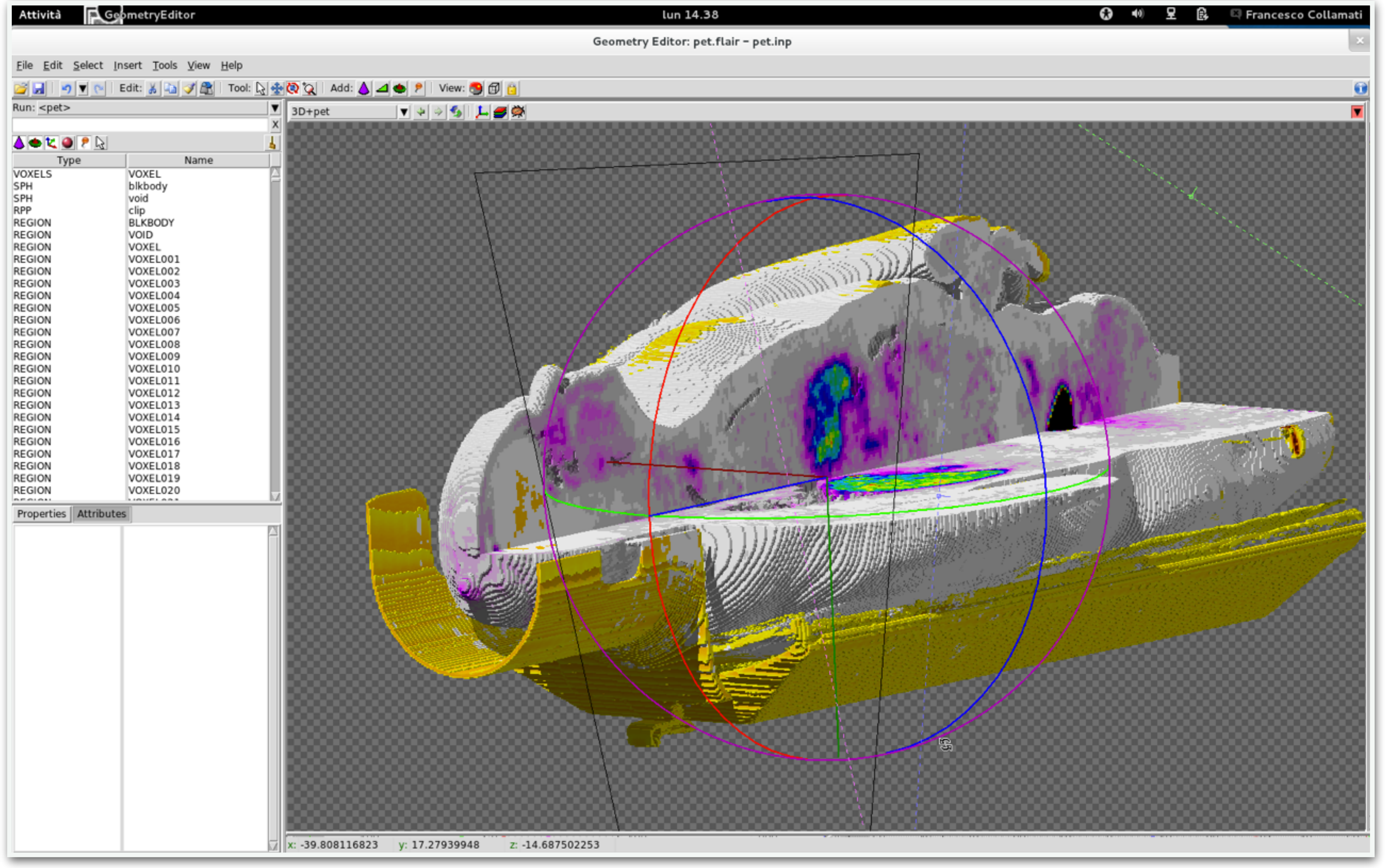
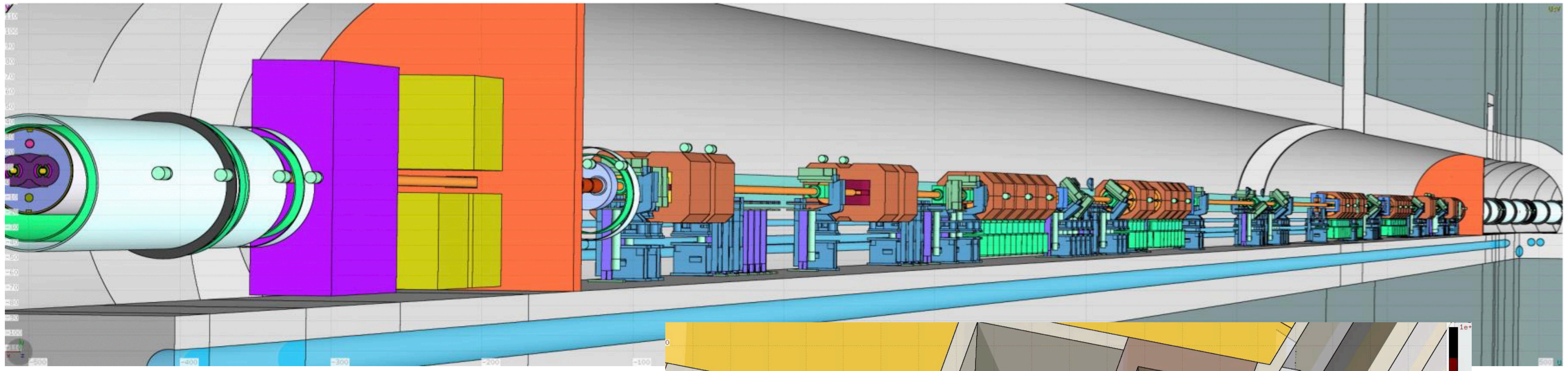
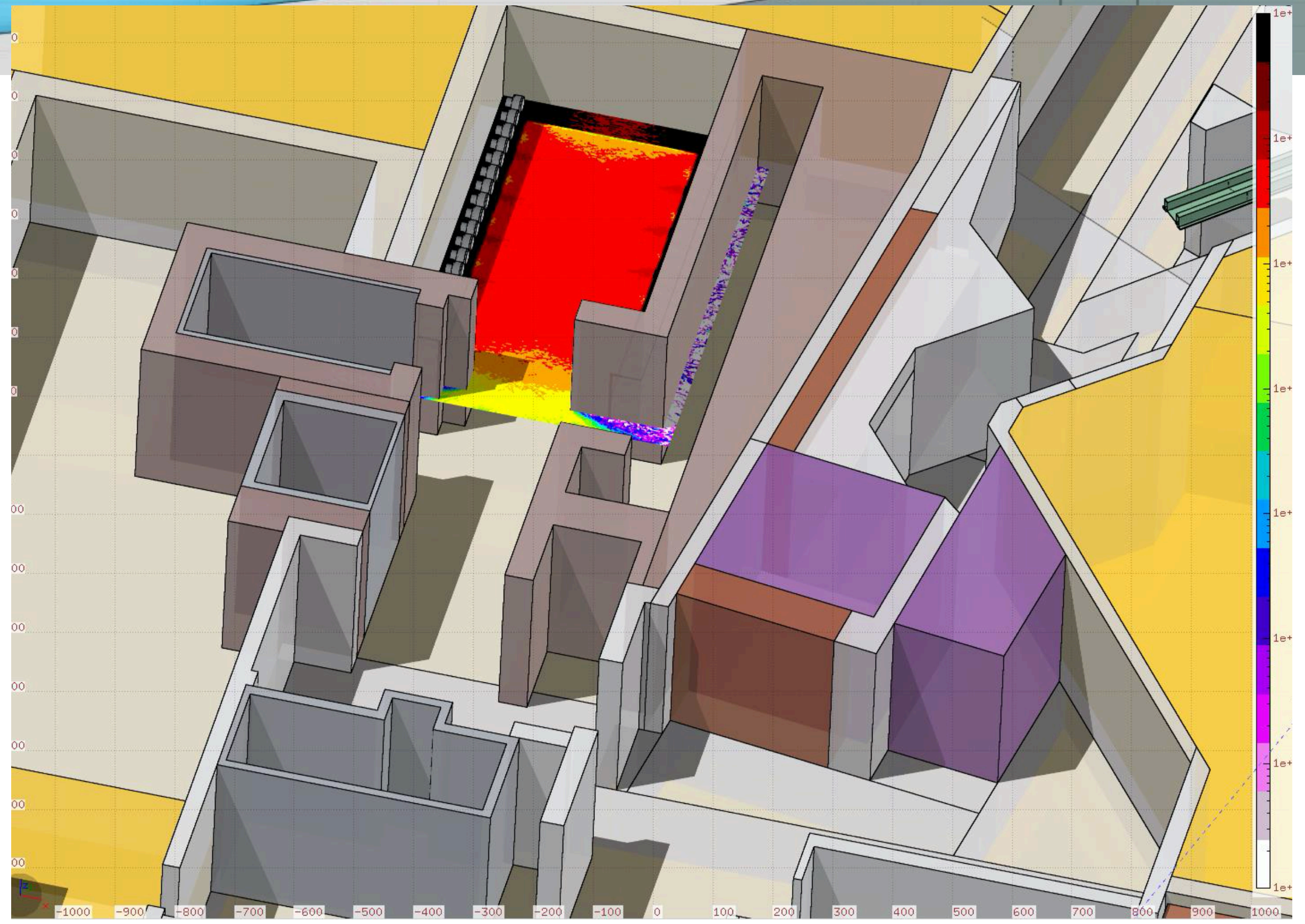






✦Ideal if coupled with automation tool for geometry construction!

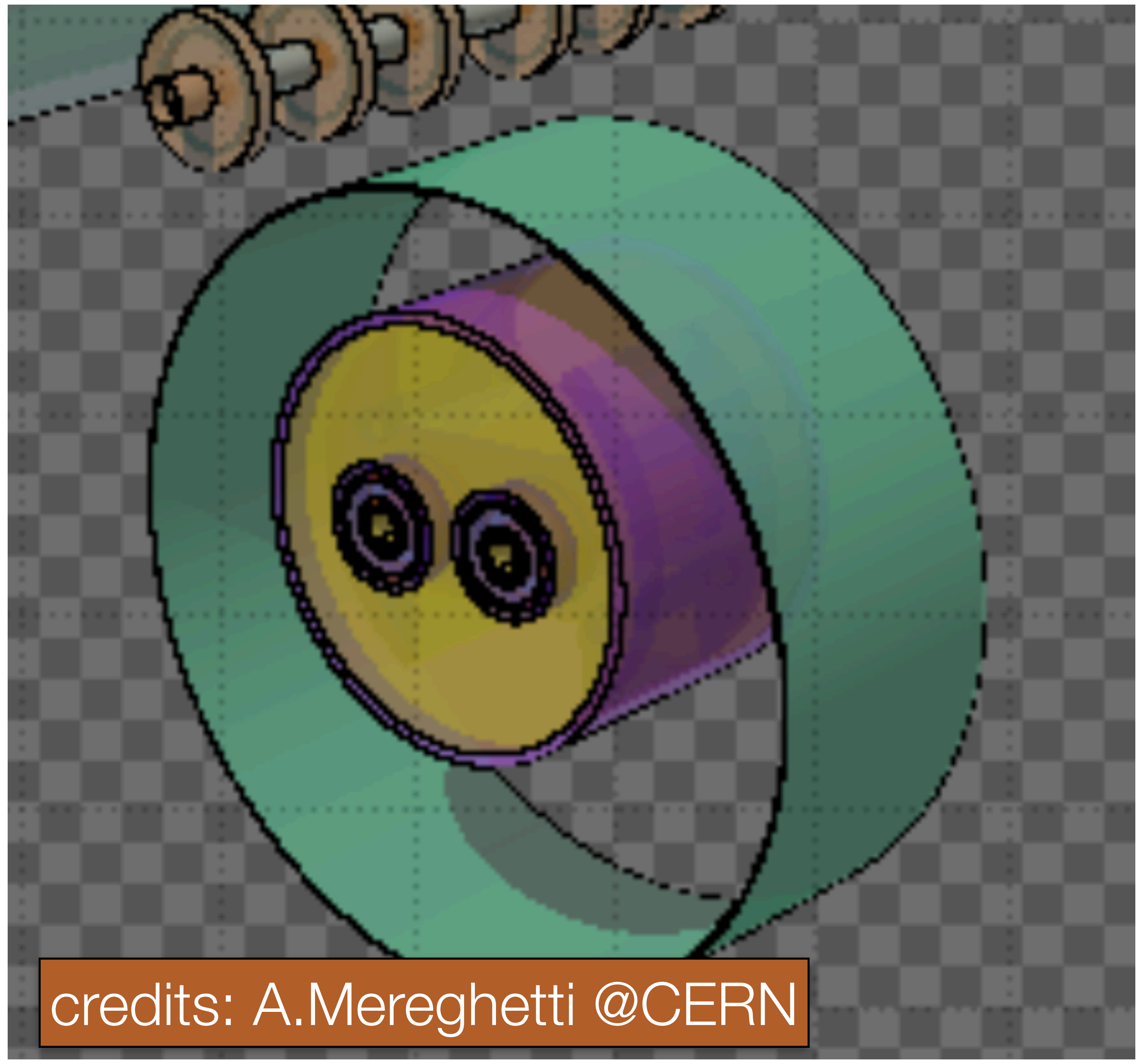
The Problem → **The Tool Identification** → The Procedure → Results

✦**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



Line Builder

```
myacc_MBSORI.regions - emacs@pcbe16165
File  Edit  Options  Buffers  Tools  Help
*
*  . 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

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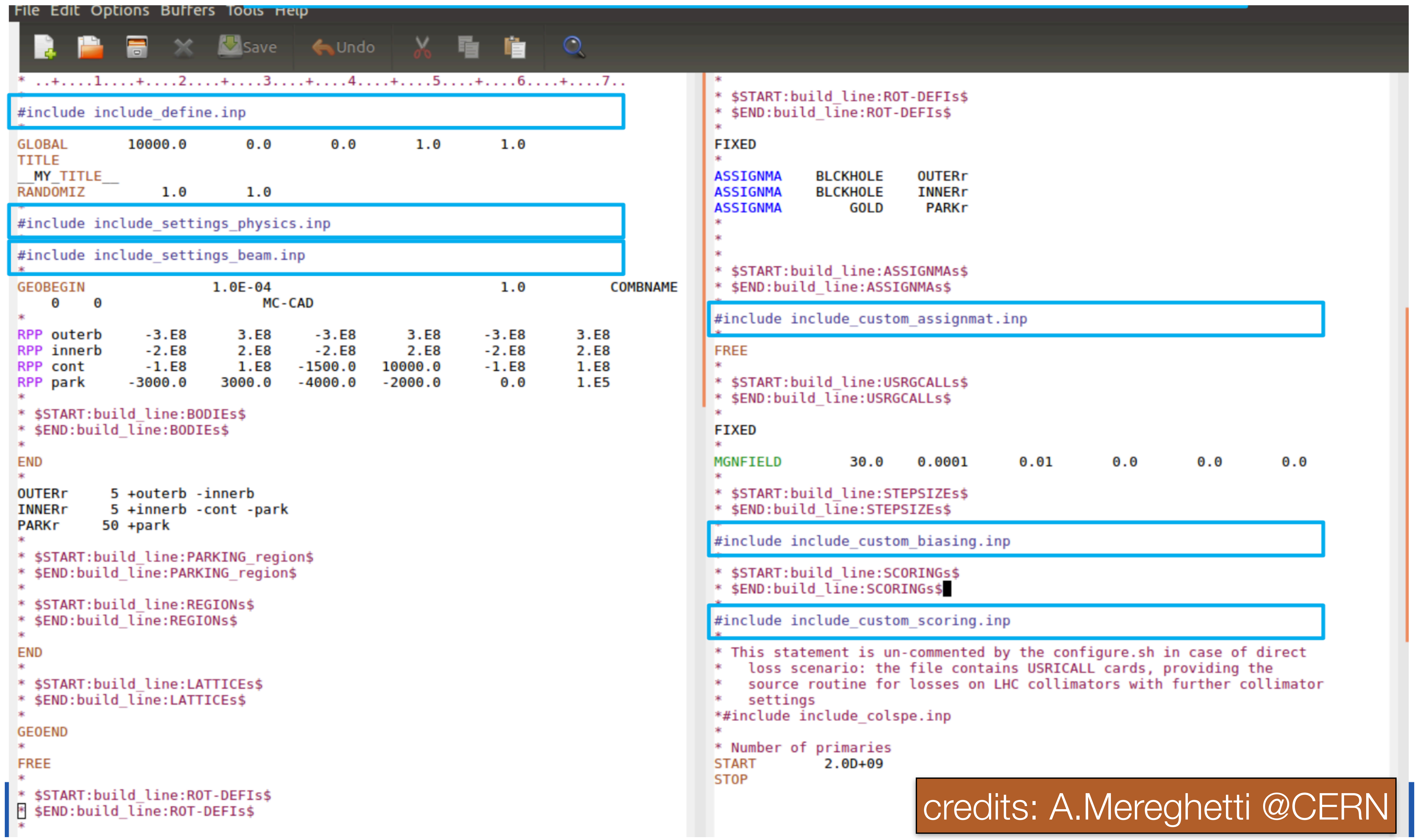
Line Builder



```
* ..+....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

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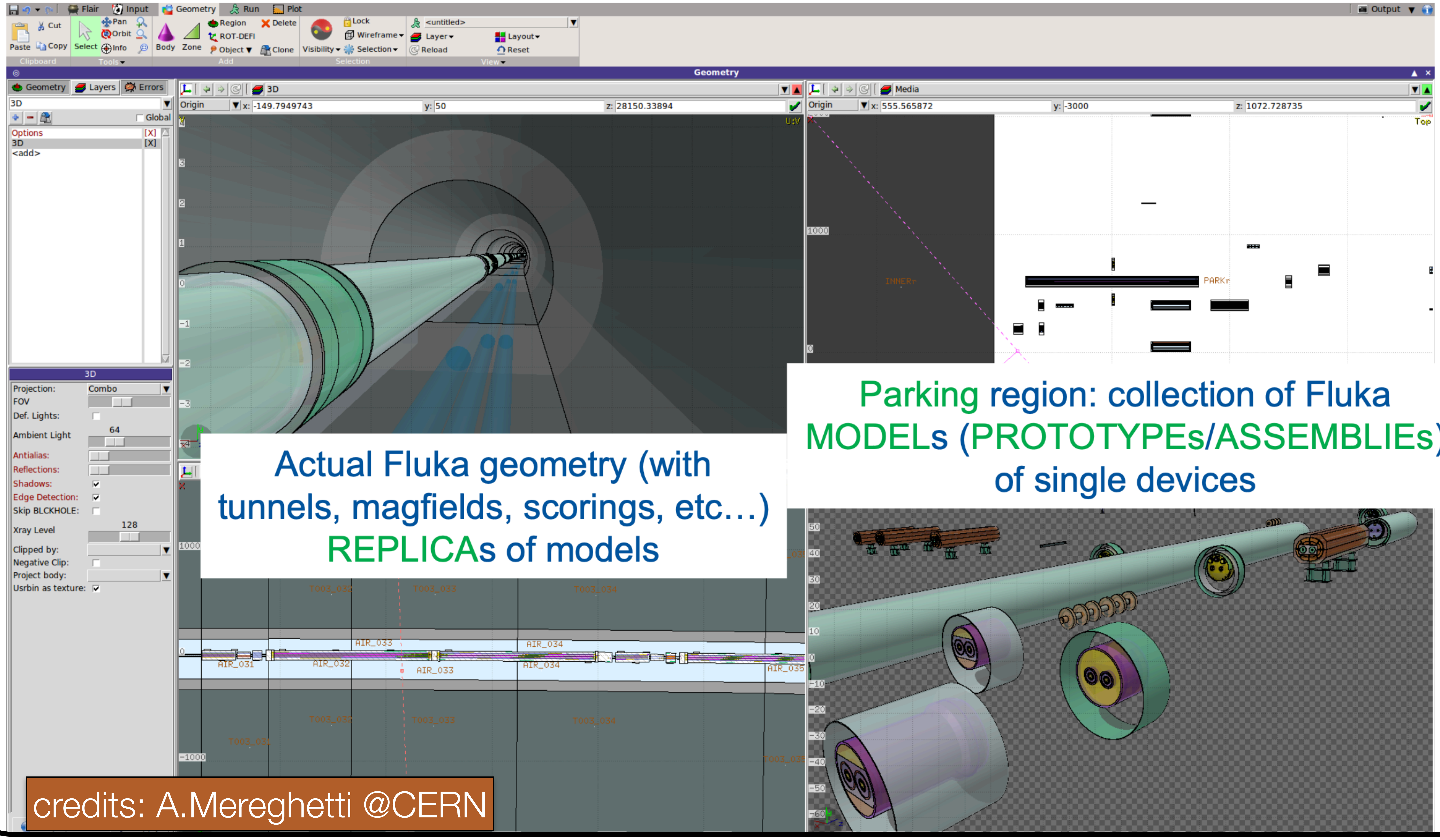
Fluka Element DataBase **Line Builder**



FINAL RESULT

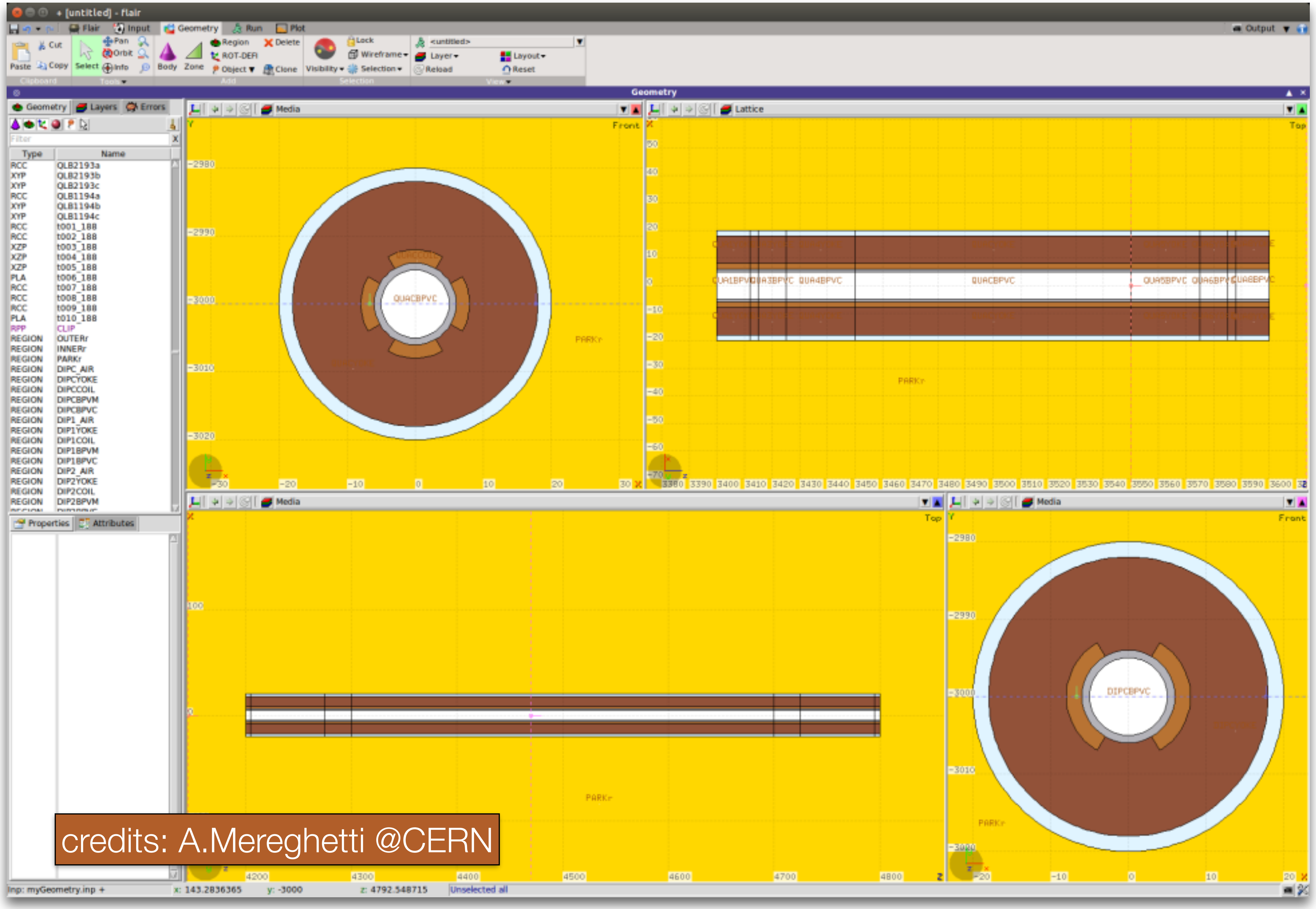
Once the geometry has been built in FLUKA, we can simulate whatever we want..!

```
@ TYPE              %05s "TWISS"
@ SEQUENCE          %07s "MYACCEL"
@ PARTICLE          %06s "PROTON"
@ MASS              %le        0.93827208129999995
@ CHARGE            %le        1.0000000000000000
@ ENERGY            %le        1.3712601863056601 6
@ PC                %le        1.0000000000000000
@ GAMMA             %le        1.4614739302545847 2
@ KBUNCH            %le        1.0000000000000000
@ BCURRENT          %le        0.11463416918410078
@ SIGE              %le        0.00045000000000000
@ SIGT              %le        0.07550000000000000
@ NPART             %le   199999999999.99996948242187500
@ EX                %le        0.00000171060184396
@ EY                %le        0.00000171060184396
@ ET                %le        0.00100000000000000
@ BV_FLAG           %le        1.0000000000000000
@ LENGTH            %le       44.566370614359151 15
@ ALFA              %le        0.02452735406345014
@ ORBIT5            %le       -0.0000000000000000
@ GAMMATR           %le        6.3852021296032761 6
@ Q1                %le        2.2343039697164917 0
@ Q2                %le        2.3988662849230477 6
@ DQ1               %le      -13.150275009312110 80
@ DQ2               %le      -12.038549176945752 00
@ DXMAX             %le        3.7241811194859848 5
@ DYMAX             %le       -0.0000000000000000
@ XCOMAX            %le        0.0000000000000000
@ YCOMAX            %le        0.0000000000000000
@ BETXMAX           %le       56.740231866270477 21
@ BETYMAX           %le       30.532175556278893 68
@ XCORMS            %le        0.0000000000000000
@ YCORMS            %le        0.0000000000000000
@ DXRMS             %le        1.9516332896915316 0
@ 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"        0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_0"           "DRIFT"         0.19999999999999996   0.39999999999999991   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "S.ARC.12"          "MARKER"        0.39999999999999991   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_1"           "DRIFT"         0.44999999999999996   0.10000000000000009   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "MB.1T2"            "SBEND"         2.0707963267948965 6  3.1415926535897931 2  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    1.5707963267948965 6
 "DRIFT_2"           "DRIFT"         3.6915926535897929 4  0.10000000000000009   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "E.ARC.12"          "MARKER"        3.7415926535897932 0  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_3"           "DRIFT"         4.1490926535897934 0  0.81499999999999995   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "MQ.1X2"            "QUADRUPOLE"    4.6415926535897931 2  0.17000000000000001   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_4"           "DRIFT"         5.6415926535897931 2  1.8300000000000000 7  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "MQ.2X2"            "QUADRUPOLE"    6.6415926535897931 2  0.17000000000000001   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_5"           "DRIFT"         6.7765926535897929 0  0.10000000000000053   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "BPM.2X2"           "MONITOR"       7.0765926535897936 1  0.50000000000000000   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_6"           "DRIFT"         7.9415926535897929 4  1.2299999999999986 5  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "MQ.3X2"            "QUADRUPOLE"    8.6415926535897931 2  0.17000000000000001   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_7"           "DRIFT"         9.6415926535897913 4  1.8299999999999982 9  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "MQ.4X2"            "QUADRUPOLE"   10.641592653589791 34  0.17000000000000001   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_8"           "DRIFT"        11.134092653589789 28  0.81499999999999950   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "S.ARC.23"          "MARKER"       11.541592653589789 92  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_9"           "DRIFT"        11.591592653589788 85  0.09999999999999964   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "MB.2T3"            "SBEND"        13.212388980384686 12  3.1415926535897931 2  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    1.5707963267948965 6
 "DRIFT_10"          "DRIFT"        14.833185307179583 39  0.09999999999999964   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "E.ARC.23"          "MARKER"       14.883185307179582 32  0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "DRIFT_11"          "DRIFT"        15.290685307179582 96  0.81499999999999950   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
 "MQ.1X3"            "QUADRUPOLE"   15.783185307179582 68  0.17000000000000001   0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000    0.0000000000000000
```

<u>First goal:</u> reproduce MAP results @ 1.5TeV CM

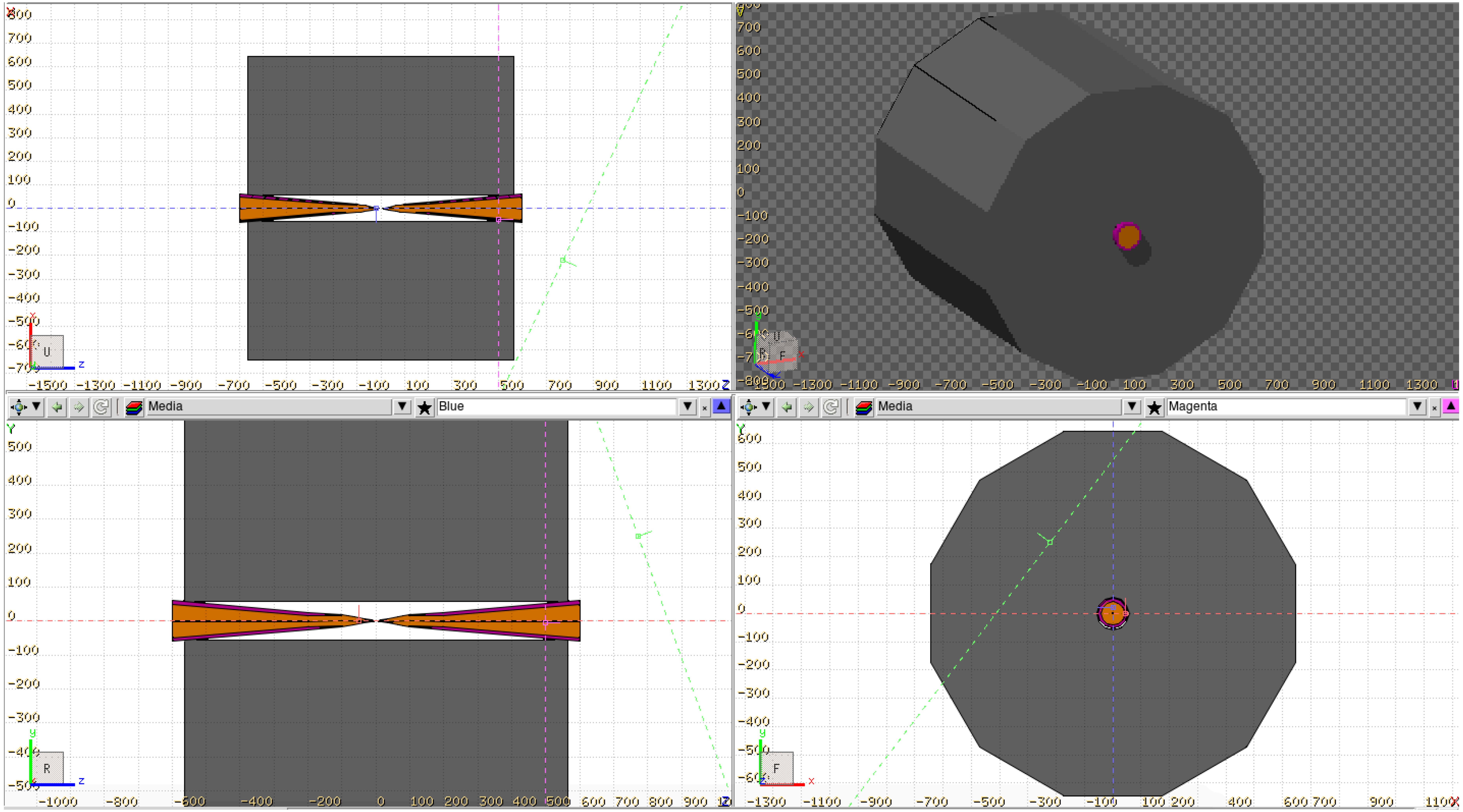
- We started from the muon collider **machine optics** from **MAP** Studies
  - ➡ Old optics format! (Mad-8)
  - ➡ Different conventions from LHC studies
  - ➡ Very limited use of markers

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

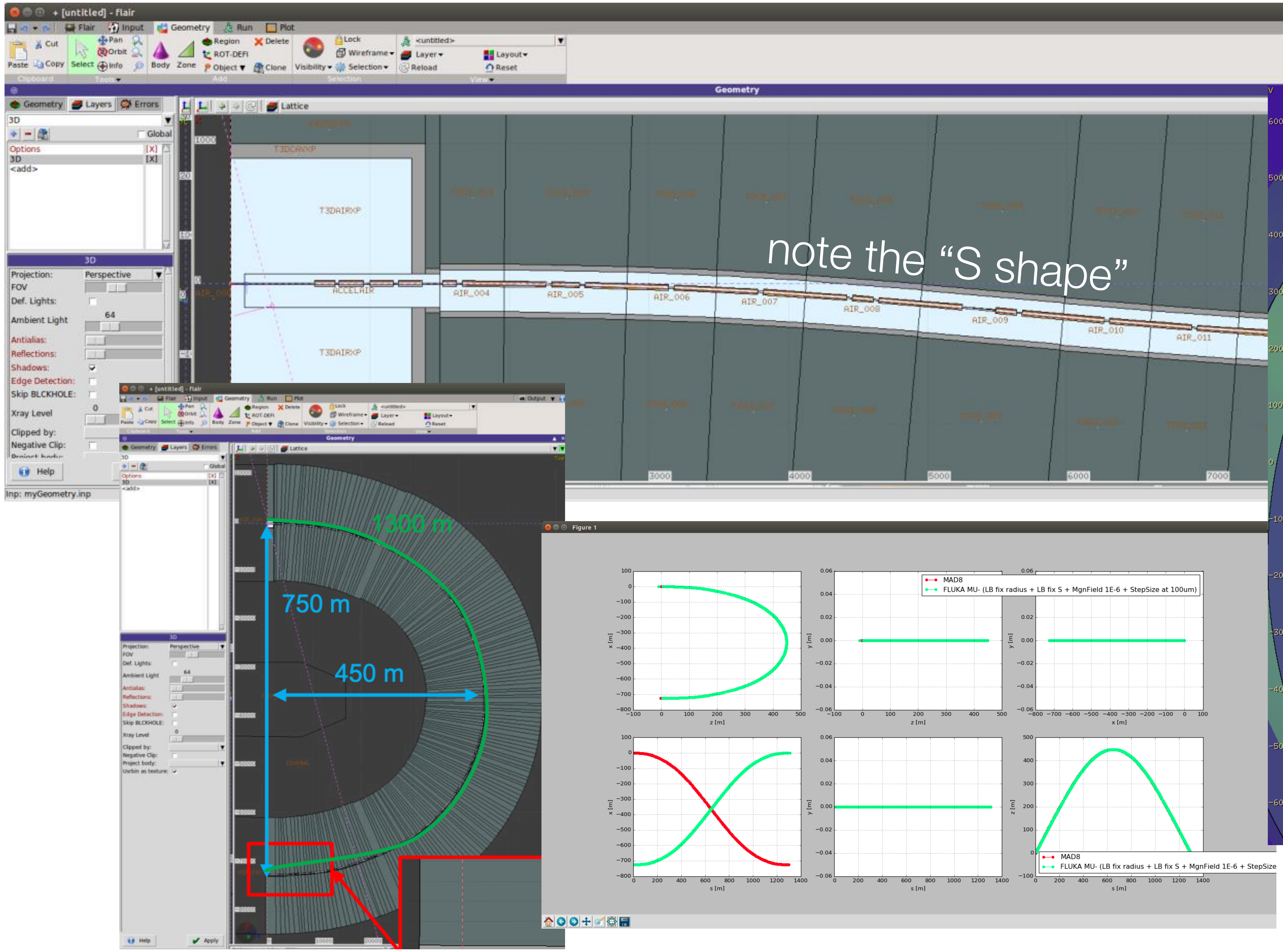


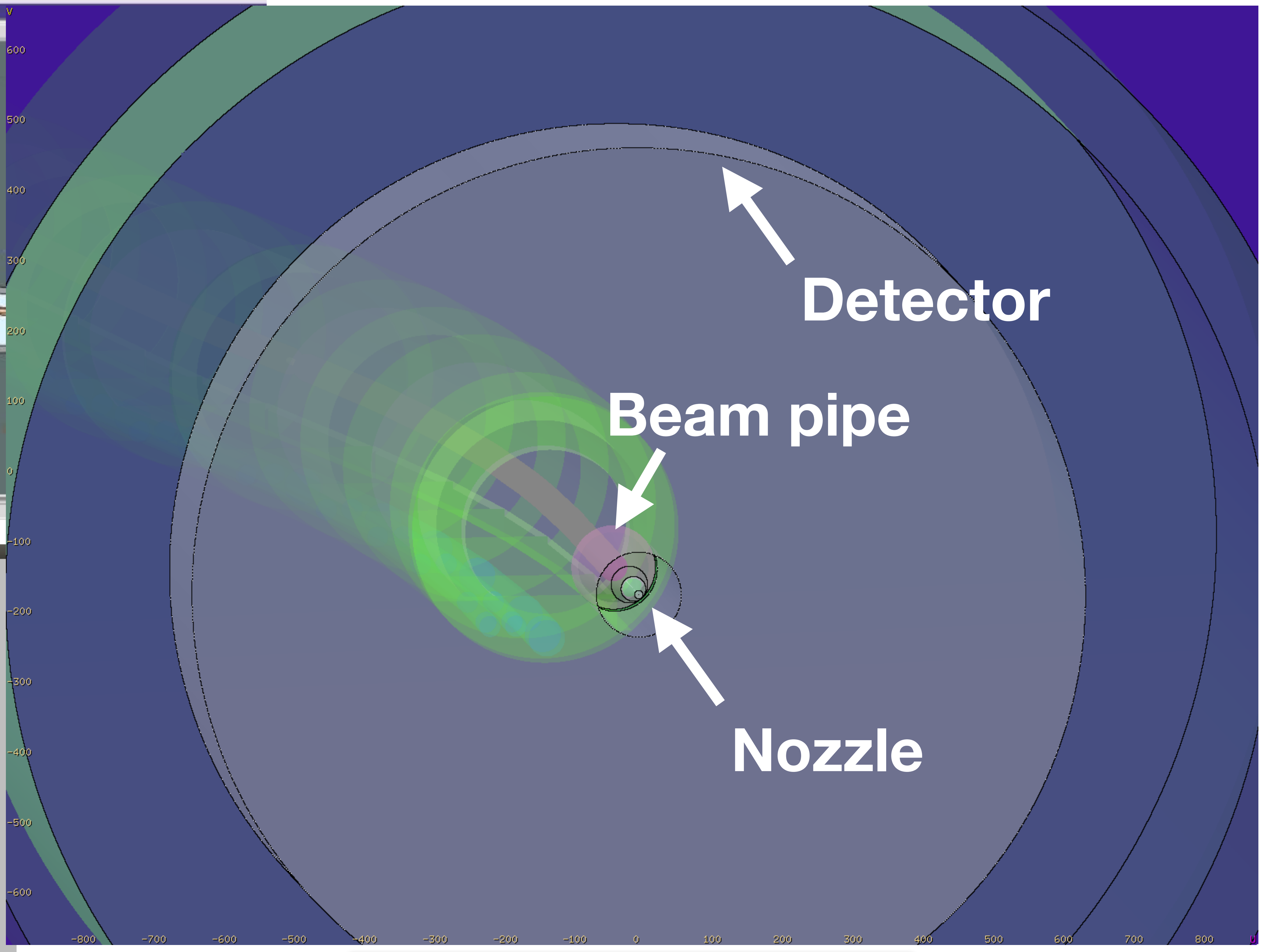
credits: A.Mereghetti @CERN

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



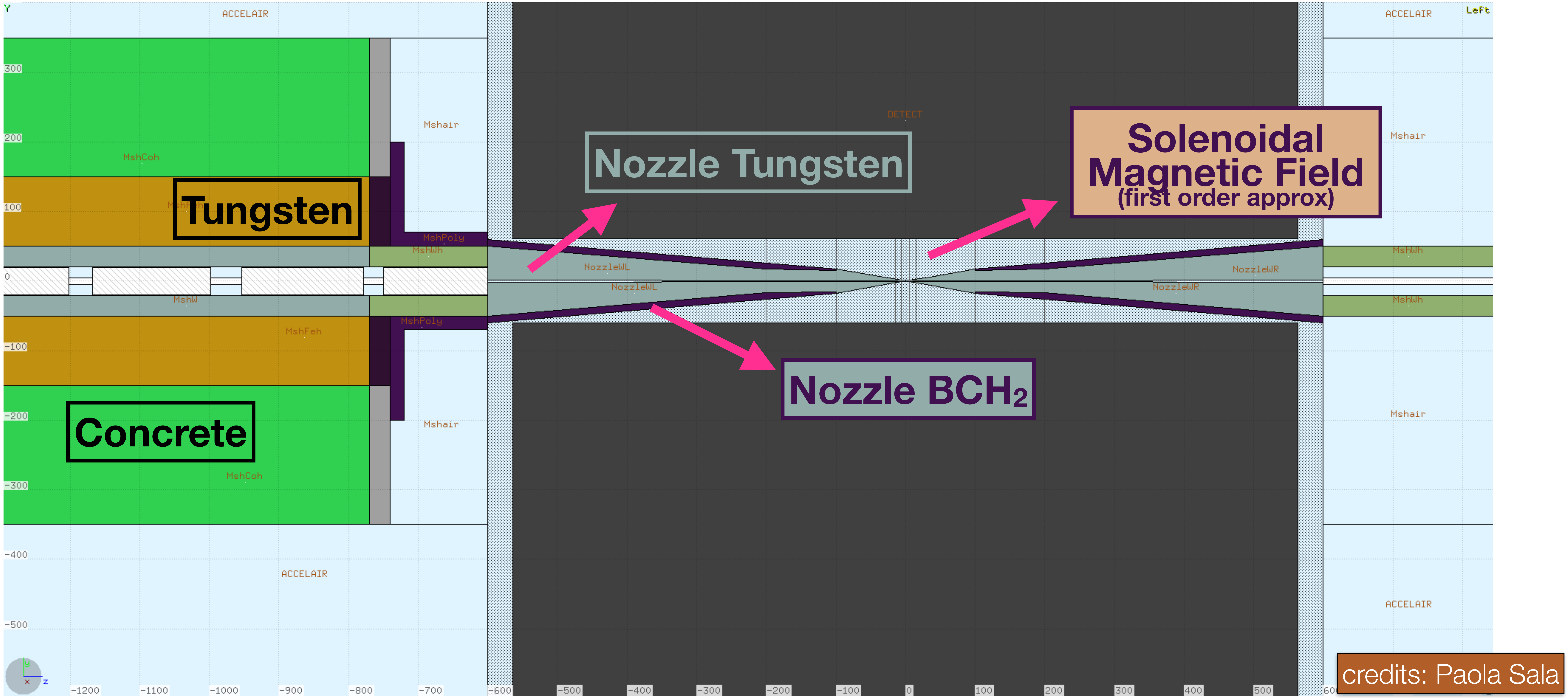
- A very first geometry of the whole muon collider (half ring) has been produced…





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

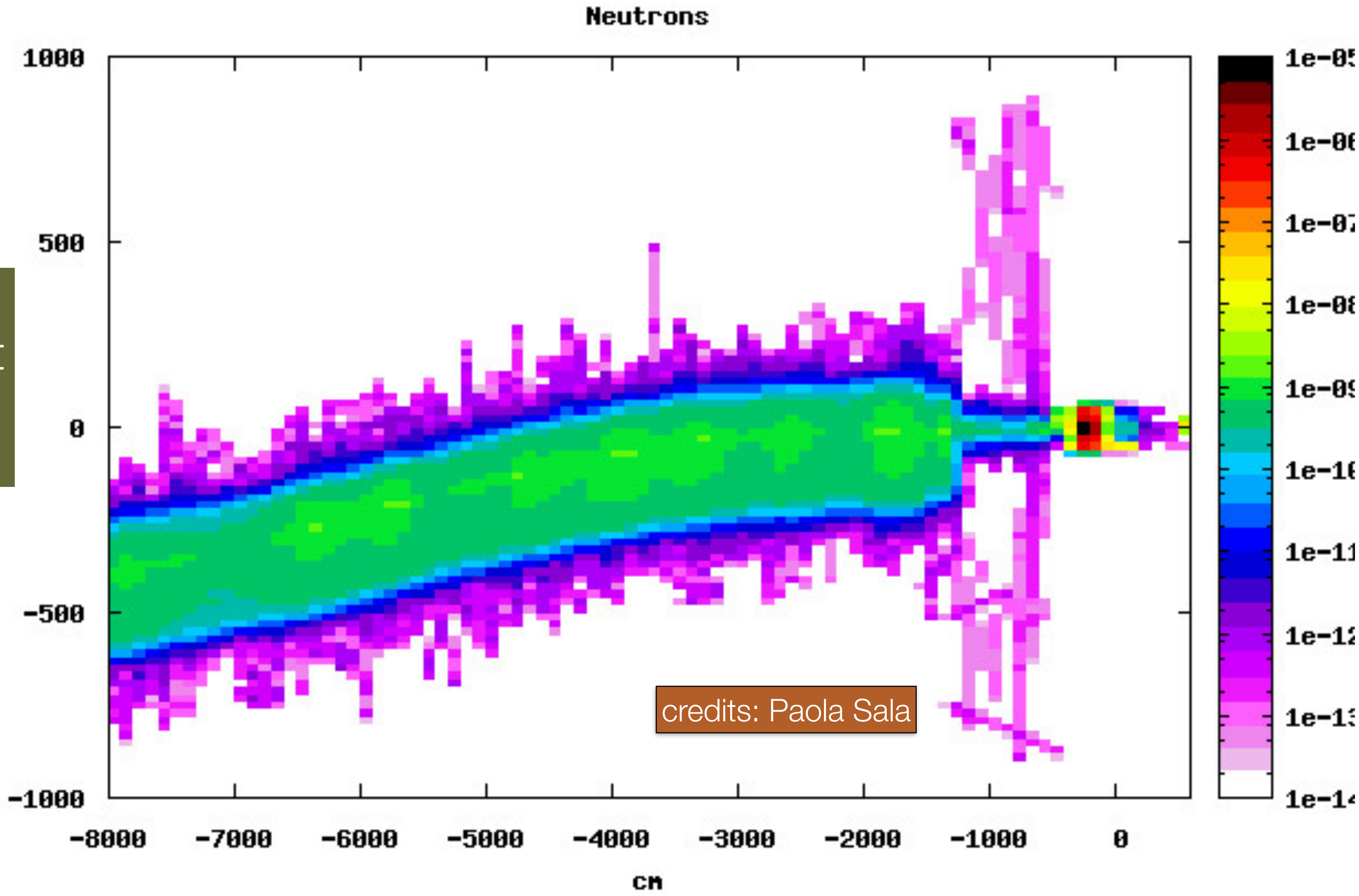
◉Machine Geometry: MDI



- We fire 750GeV μ^+ from the opposite IP, biasing μ decay in the last 100m to have good statistics

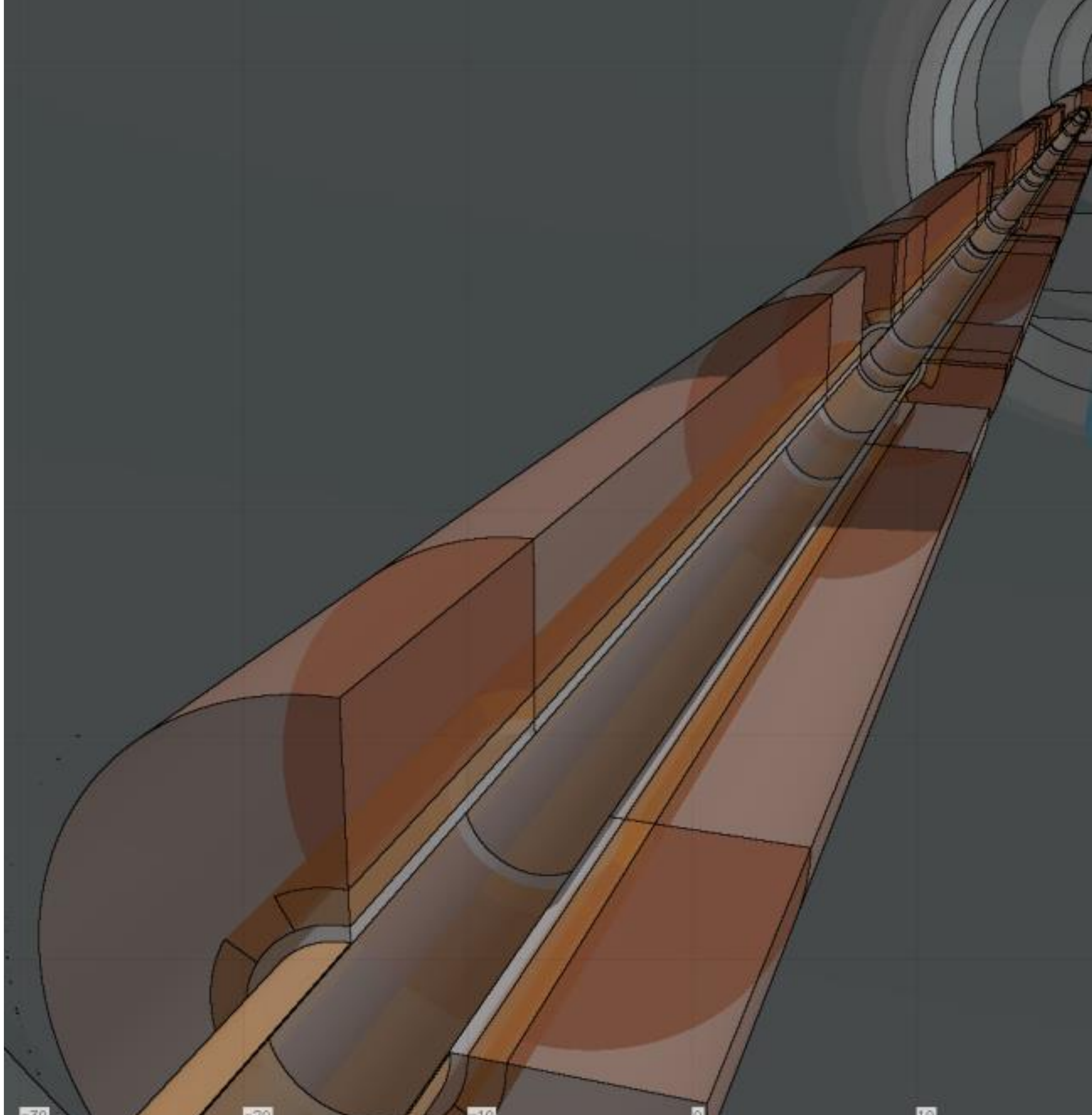
A DUMP output file is produced with all the relevant tracks information at the entrance of the detector

…to be fed to detector simulation



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 + FLUKA + Root analysis** has been chosen as approach and started to use with first descriptions for optics element and detector



Next Steps

- To complete the **1.5TeV** validation, we need:
  - A series of monitor plots (in progress..)
  - More **detailed** description of **magnets** used in MAP study
    - Actual shape, technology, material, aperture
  - More details about “passive elements” in the experimental **cavern**
    - Iron?, concrete?, return yoke?
- To proceed with the **3TeV** case
  - Machine optics for that energy
  - Accelerator physicists contribution

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For this benchmark to be useful we need the same exact geometry of MAP studies

FERMILAB-11-370-APC

Muon Collider Interaction Region Design*

Y.I. Alexahin, E. Gianfelice-Wendt, V. V. Kashikhin, N.V. Mokhov, A.V. Zlobin,
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Design of a muon collider interaction region (IR) presents a number of challenges arising from low $\beta^* <$ 1 cm, correspondingly large beta-function values and beam sizes at IR magnets, as well as the necessity to protect superconducting magnets and collider detectors from muon decay products. As a consequence, the designs of the IR optics, magnets and machine-detector interface are strongly interlaced and iterative. A consistent solution for the 1.5 TeV c.o.m. muon collider IR is presented. It can provide an average luminosity of 10^{34} cm^{-2}s^{-1} with an adequate protection of magnet and detector components.

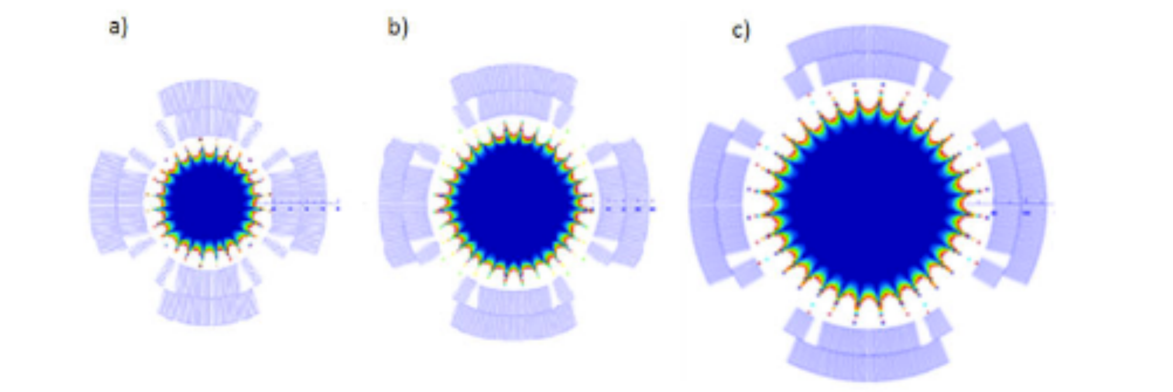

FIG. 4 (color). Cross-sections and a good-field region of Q1 (a), Q2 (b) and Q3-Q5 (c) quadrupoles. The dark blue color corresponds to the field error $|\delta B/B|<10^{-4}$.

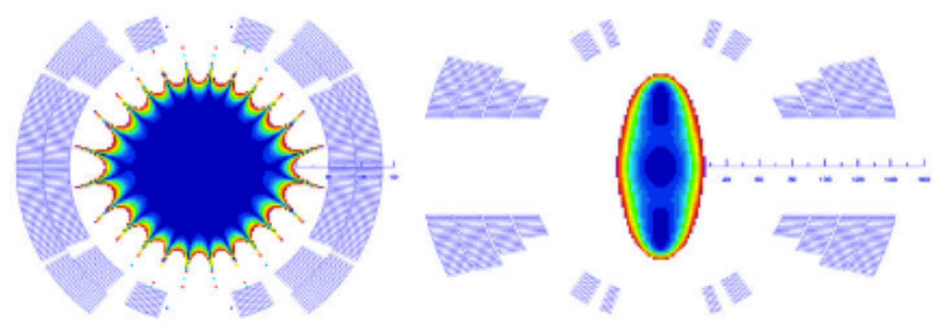

FIG. 5 (color). Cross-sections and a good-field region of the dipole B1 based on cos θ (left) and open mid-plane (right) coil design. The dark blue color corresponds to the field error of $|\delta B/B|<10^{-4}$.

Are these the magnets used in the MARS simulation?

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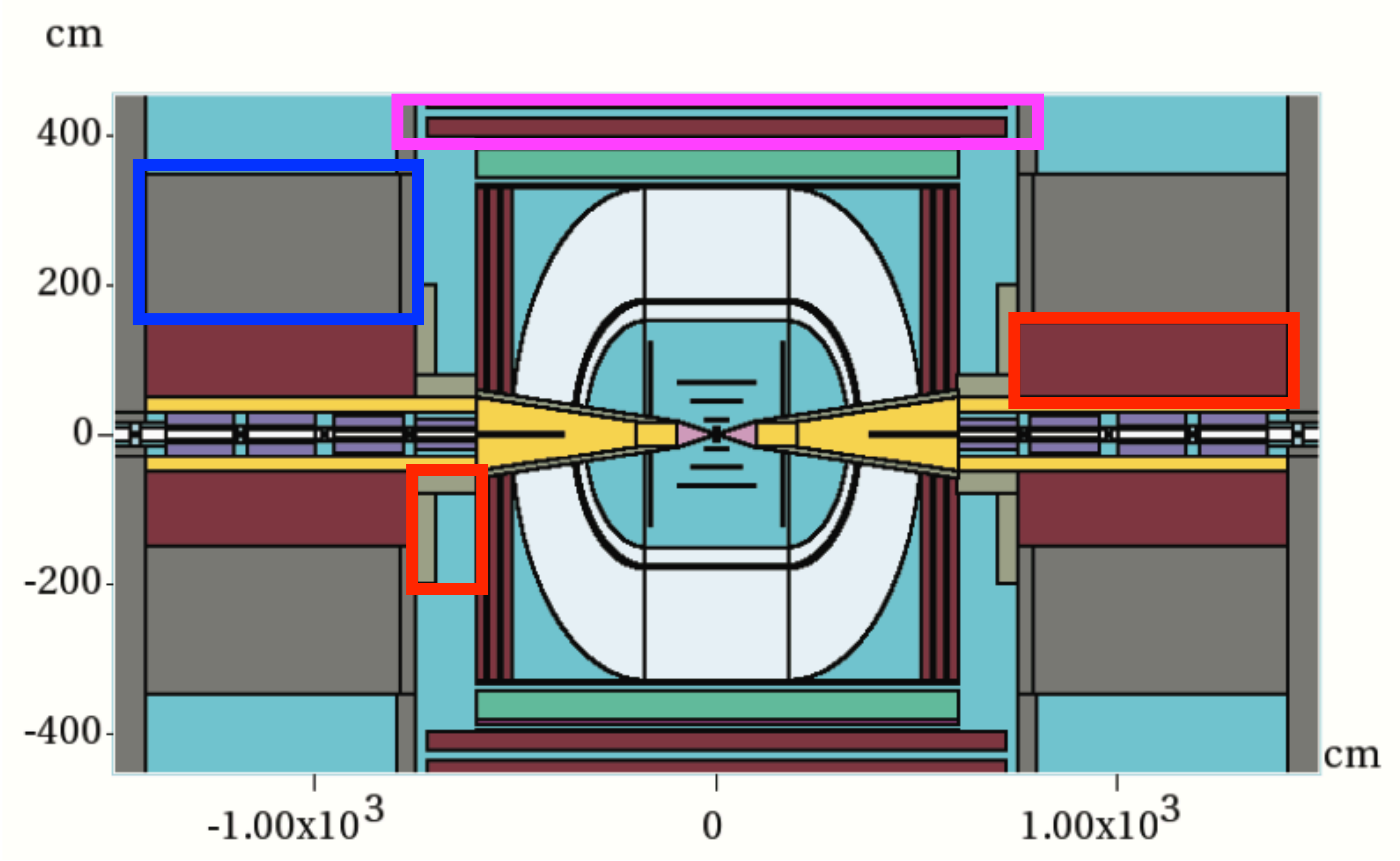

components [19], experimental hall and machine-detector interface. To protect SC magnets and detector, tungsten masks in the interconnect regions, liners in magnet apertures (wherever needed), and a sophisticated tungsten cone inside the detector [5] were implemented into the model and carefully optimized. The muon beam with parameters cited in Table 1 was assumed to be aborted after 1500 turns when the luminosity is reduced by a factor of ~6.

Next Steps

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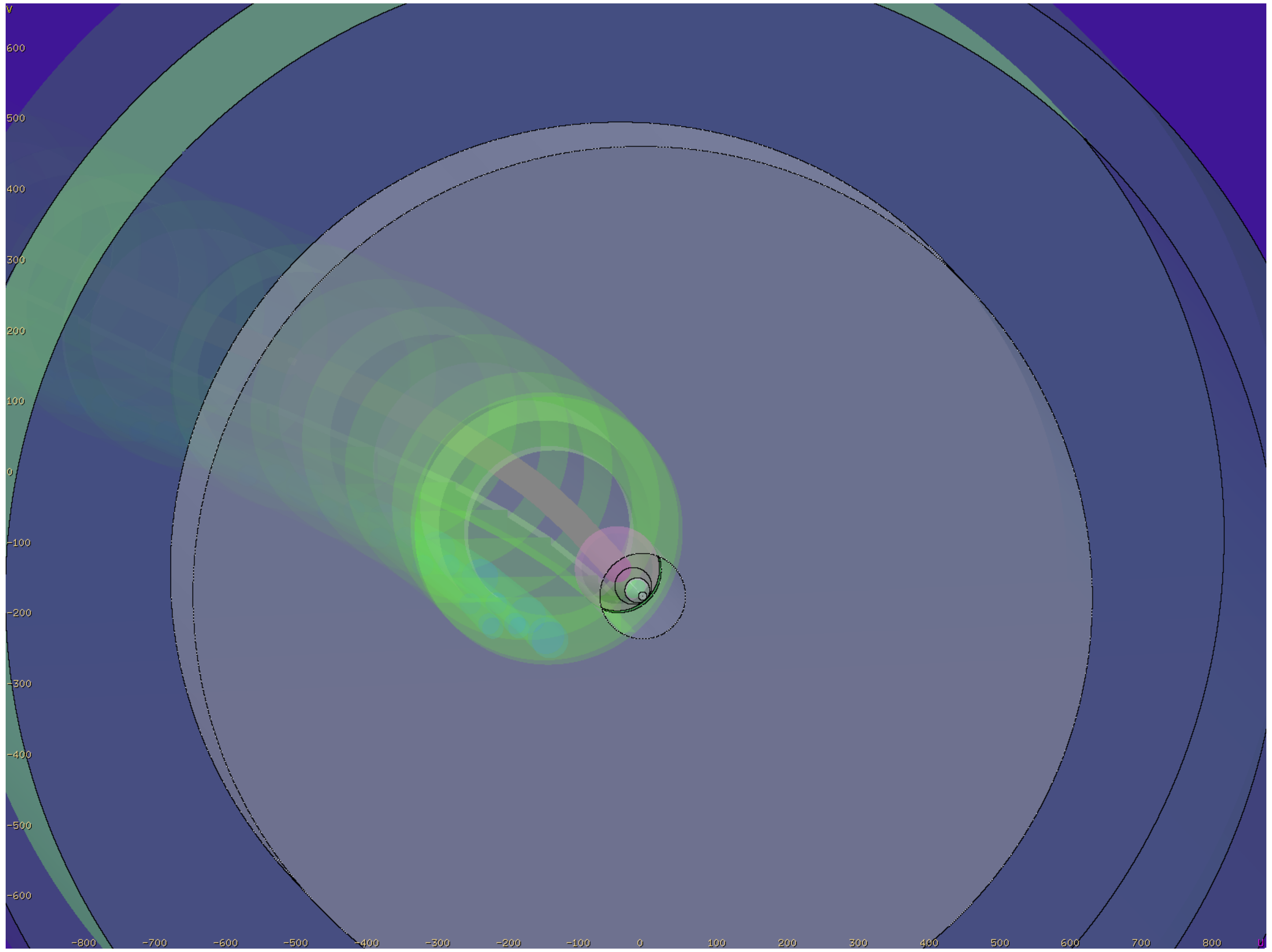

Very important!
Knowing both 1.5 and 3TeV cases allows to have **insights** on 10TeV!

Backup

Flux of produced particles (firing 750GeV mu+)

DISCLAIMER:
these results were obtained without proper cavern shiedling

credits: Paola Sala