Automatic Generation of FLUKA Input Files for Hydrodynamic Tunnelling Studies

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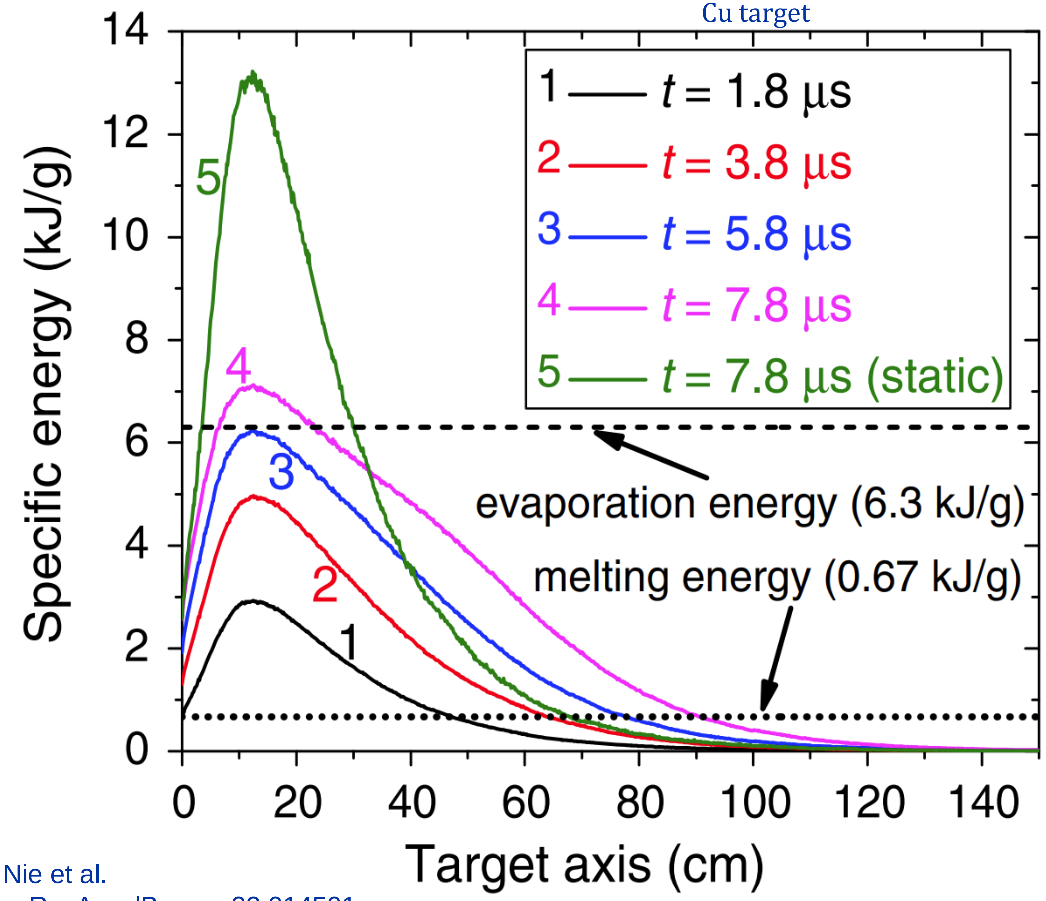
Penetration Depth from Energy Deposition at Constant Densities

Proton energy = 440 GeV
Bunch intensity = $1.5 \cdot 10^{11}$
rms beam size $\sigma_{x,y} = 0.2mm$
Bunch length = 0.5 ns
Bunch spacing = 50 ns
Cu target

Beam failure

- Static approximation
  - Total specific energy is obtained by multiplying dose per proton at t=0μs by total number of protons
    - Normally this is sufficient and only requires one-way coupling of an energy code (FLUKA) and hydrocode (e.g Ansys-Autodyn, BIG2)
- Difference in distribution of deposited energy
  - If considering the density change of the target material during the beam impact the penetration depth increases
    - This is known as hydrodynamic tunnelling



Y. Nie et al.
PhysRevAccelBeams.22.014501
doi: 10.1103/PhysRevAccelBeams.22.014501

Hydrodynamic Tunnelling

Beyond design failure

- **In case of entire beam being lost at one point**
  - No dilution case
  - Severe extraction failure
    - Incorrect field strength for extraction kick
      - Wrong energy from BETS

- **The penetration depth will be significantly longer than if assuming constant density throughout the impact.**
  - Validated in 2012 HiRadMat experiment with SPS beam
  - The time structure allows for the density of the material to change before the next bunch hits.
    - First bunches deplete density along the beam path and allows subsequent bunches to penetrate further.

Proton energy $= 440\ GeV$

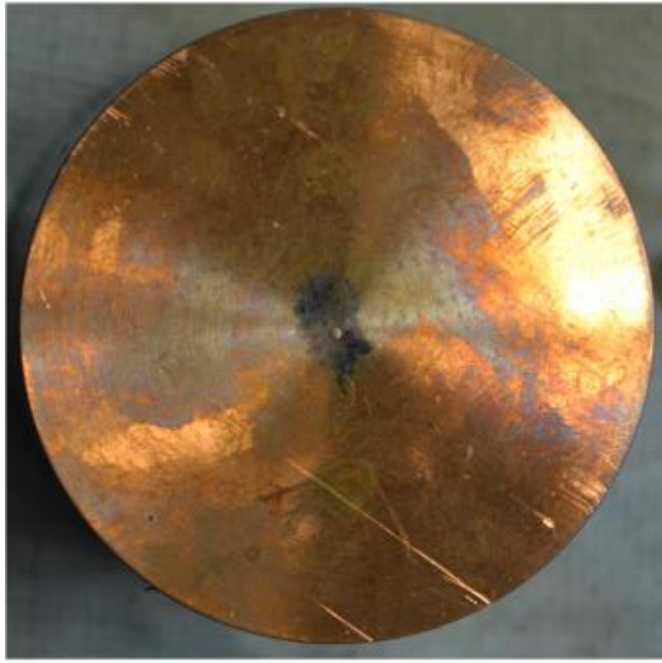
Bunch intensity $= 1.5 \cdot 10^{11}$

rms beam size $\sigma_{x,y} = 0.2mm$

Bunch length $=$ 0.5 ns

Bunch spacing $=$ 50 ns

Cu target



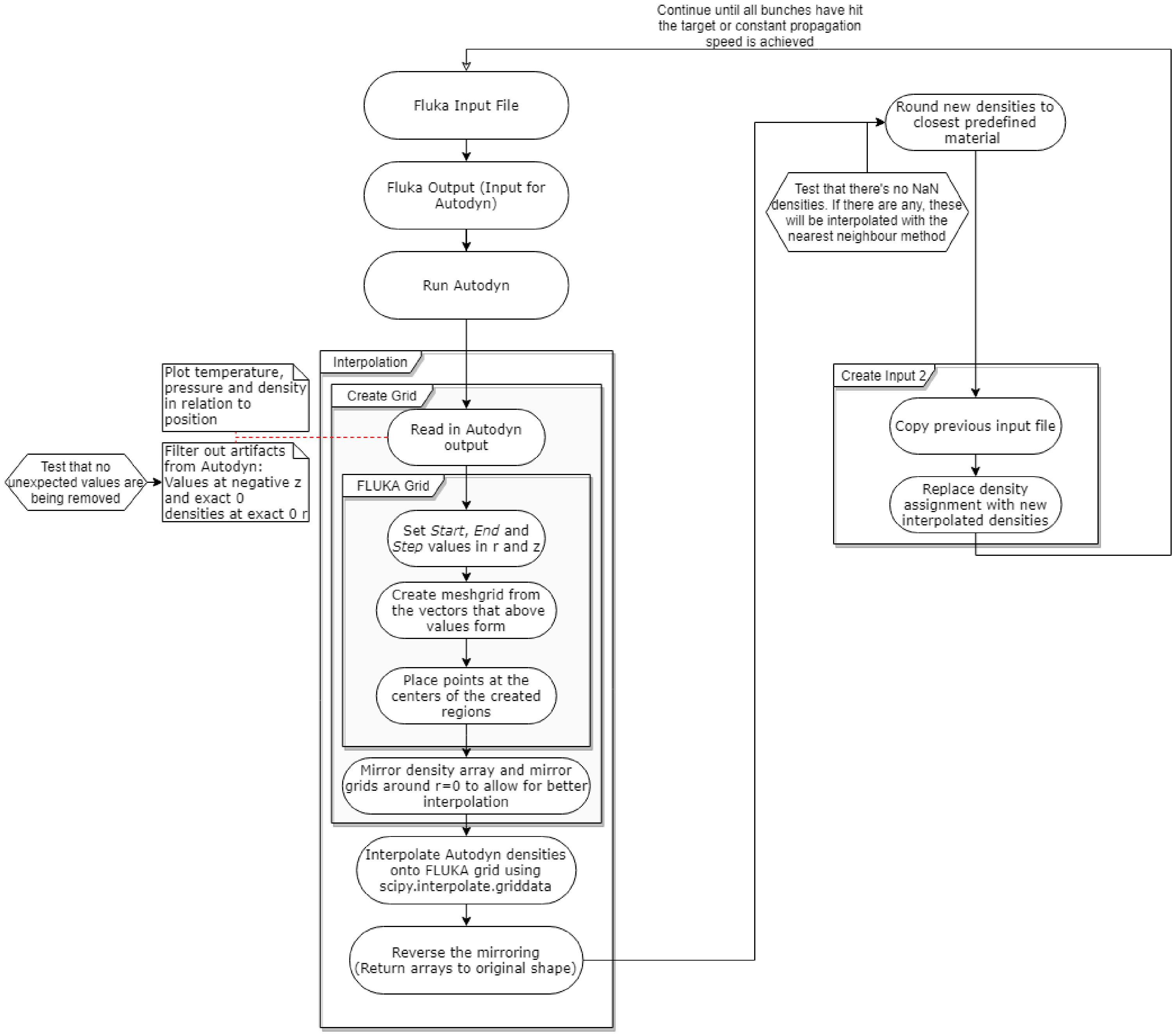
From HiRadMat test in 2012.

F. Burkart et. Al.
J. Appl. Phys. 118, 055902 (2015);
https://doi.org/10.1063/1.4927721

Continuation of Hydrodynamic Tunneling studies

- **Continue beyond design failure studies for LHC and HL-LHC**
  - Requires coupling of hydro and energy deposition codes (FLUKA and Autodyn)
- **Earlier Approach**
  - Energy depositions are simulated using FLUKA and hydrodynamics are simulated using ANSYS-Autodyn.
    - This was performed manually. Density output from Autodyn was interpolated onto the FLUKA geometry by means of averaging in Origin. After this was done a new FLUKA input file was created with the new densities.
      - New input file could then be run, and these steps would be repeated until all bunches had hit the target.
- **Automate the process**
  - Python script to achieve the above steps.
    - Find an efficient and reliable way to interpolate the densities from Autodyn onto the FLUKA regions
    - Including automatic checks and plotting
  - For benchmarking the HiRadMat12 case will be used, which was already studied by Y. Nie (*Phys. Rev. Accel. Beams* 22 (2019) 014501)

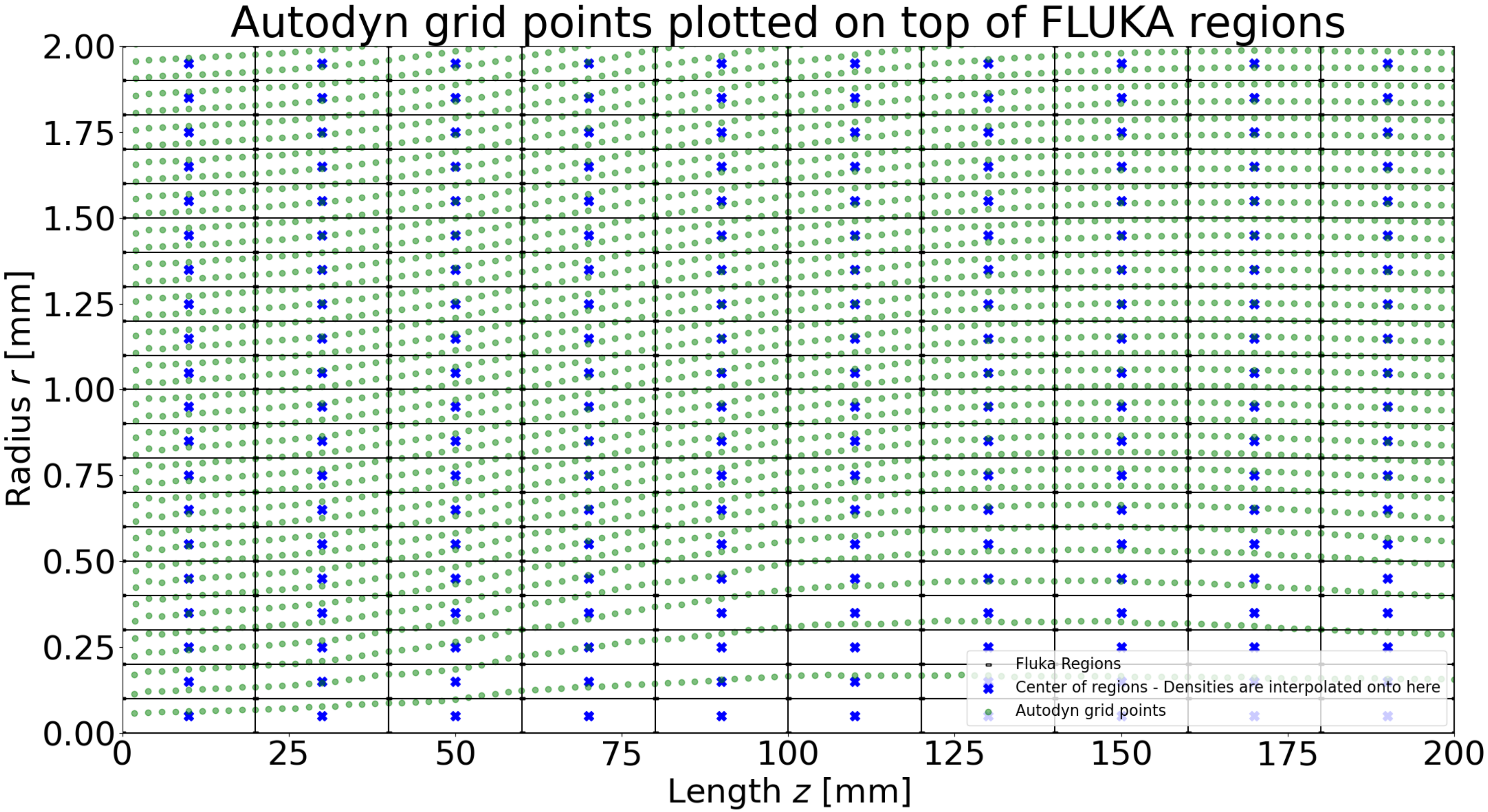
Workflow



Continue until all bunches have hit the target or constant propagation speed is achieved
Fluka Input File
Fluka Output (Input for Autodyn)
Run Autodyn
Interpolation
Create Grid
Read in Autodyn output
Plot temperature, pressure and density in relation to position
Filter out artifacts from Autodyn: Values at negative z and exact 0 densities at exact 0 r
Test that no unexpected values are being removed
FLUKA Grid
Set Start, End and Step values in r and z
Create meshgrid from the vectors that above values form
Place points at the centers of the created regions
Mirror density array and mirror grids around r=0 to allow for better interpolation
Interpolate Autodyn densities onto FLUKA grid using scipy.interpolate.griddata
Reverse the mirroring (Return arrays to original shape)
Round new densities to closest predefined material
Test that there's no NaN densities. If there are any, these will be interpolated with the nearest neighbour method
Create Input 2
Copy previous input file
Replace density assignment with new interpolated densities

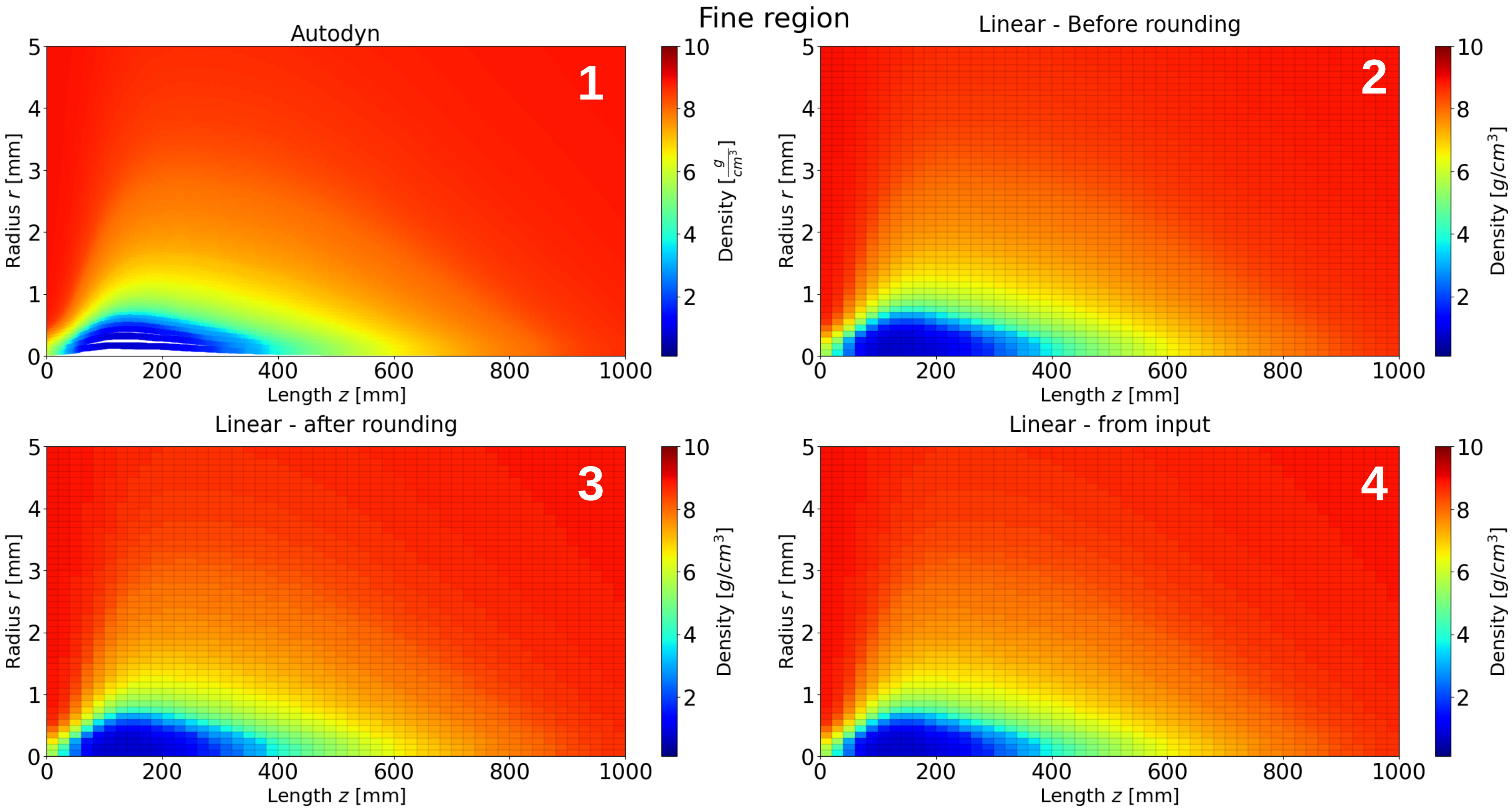
Mirroring and Interpolating

- Interpolating ~260,000 density points from Autodyn onto the 2500-point FLUKA grid
- Autodyn gave unphysical densities at r=0, which is why these points are filtered out
- To allow for the best inter-polation the radially symmetrical grid is mirrored around r



Results

After 144 bunches



Four stages

1. **From Autodyn**
2. **After interpolation**
3. **After downsampling**
4. **Read in from generated input file as a cross-check**

Automatically Generated FLUKA Input File

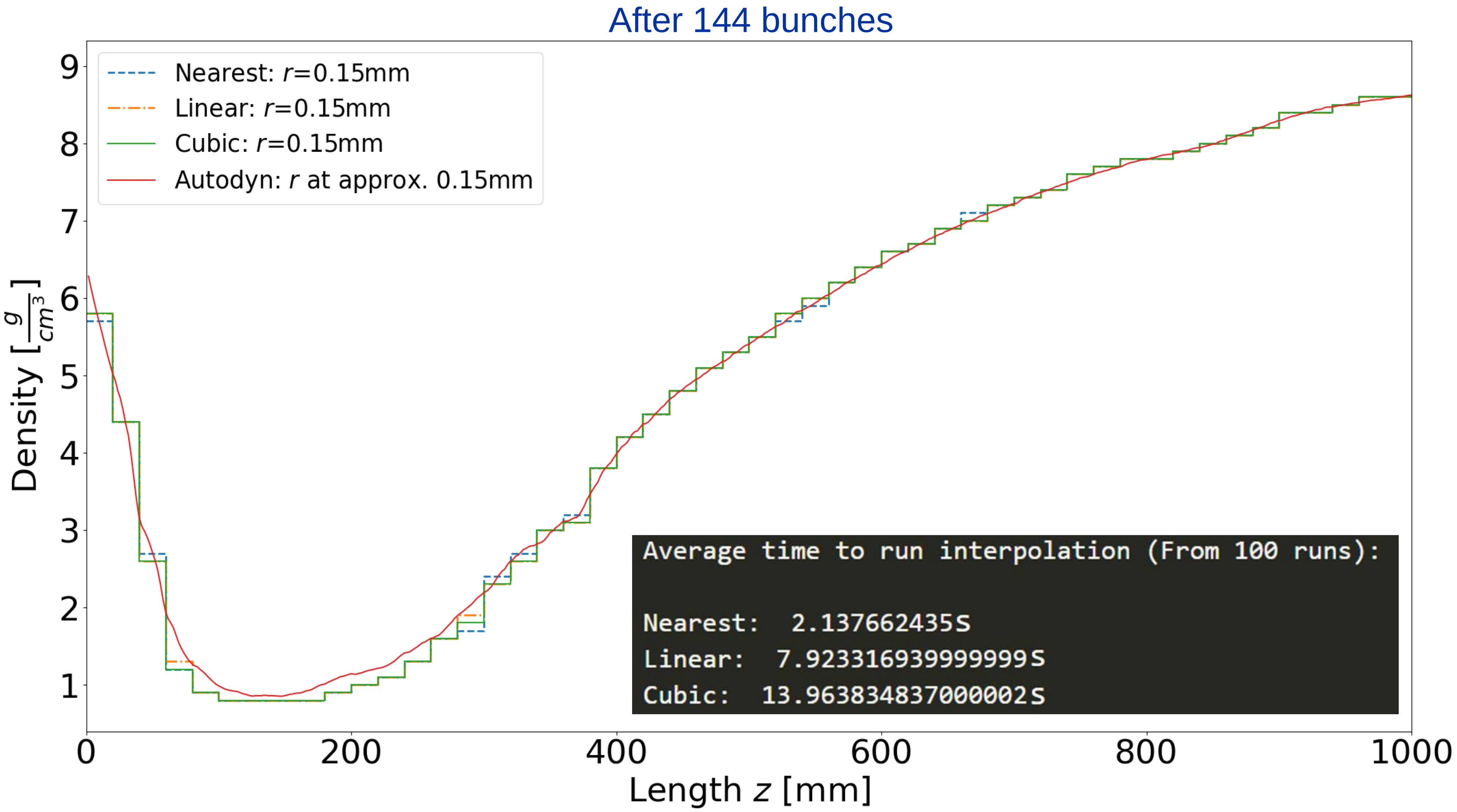
Reference File

```
TITLE
07hiradmat
GLOBAL        20000.
* Set the defaults for precision simulations
DEFAULTS                                                              PRECISIO
* Define the beam characteristics
BEAM          -440.0                        -0.0471   -0.0471         PROTON
* Define the beam position
BEAMPOS          0.0       0.0    -0.001
GEOBEGIN                                                              COMBNAME
    0    0          440 GeV proton in copper
ASSIGNMA    BLCKHOLE   BLKBODY
ASSIGNMA      VACUUM      VOID
ASSIGNMA       CU000   R150400
ASSIGNMA       CU066   R002001
ASSIGNMA       CU070   R002002
ASSIGNMA       CU075   R002003
ASSIGNMA       CU080   R002004
ASSIGNMA       CU085   R002005
ASSIGNMA       CU087   R002006
ASSIGNMA       CU088   R002007
ASSIGNMA       CU089   R002008
ASSIGNMA       CU089   R002009
ASSIGNMA       CU089   R002010
ASSIGNMA       CU089   R002011
ASSIGNMA       CU089   R002012
ASSIGNMA       CU089   R002013
```

Generated Input File

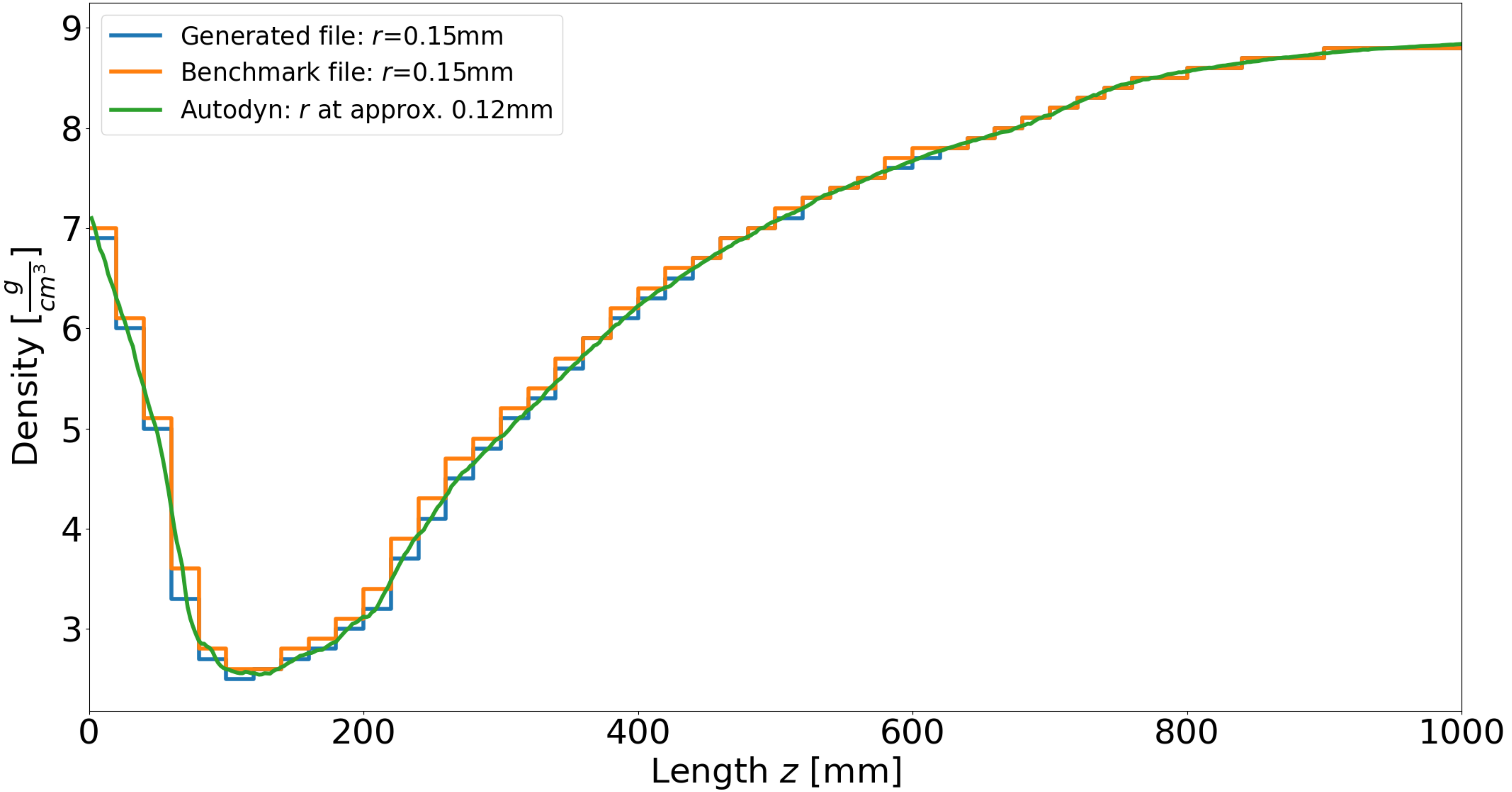
```
TITLE
newInputFile
GLOBAL        20000.
* Set the defaults for precision simulations
DEFAULTS                                                              PRECISIO
* Define the beam characteristics
BEAM          -440.0                        -0.0471   -0.0471         PROTON
* Define the beam position
BEAMPOS          0.0       0.0    -0.001
GEOBEGIN                                                              COMBNAME
    0    0          440 GeV proton in copper
ASSIGNMA    BLCKHOLE   BLKBODY
ASSIGNMA      VACUUM      VOID
ASSIGNMA       CU000   R150400
ASSIGNMA       CU066   R002001
ASSIGNMA       CU069   R002002
ASSIGNMA       CU074   R002003
ASSIGNMA       CU079   R002004
ASSIGNMA       CU085   R002005
ASSIGNMA       CU087   R002006
ASSIGNMA       CU088   R002007
ASSIGNMA       CU089   R002008
ASSIGNMA       CU089   R002009
ASSIGNMA       CU089   R002010
ASSIGNMA       CU089   R002011
ASSIGNMA       CU000   R002012
ASSIGNMA       CU000   R002013
```

Interpolation methods

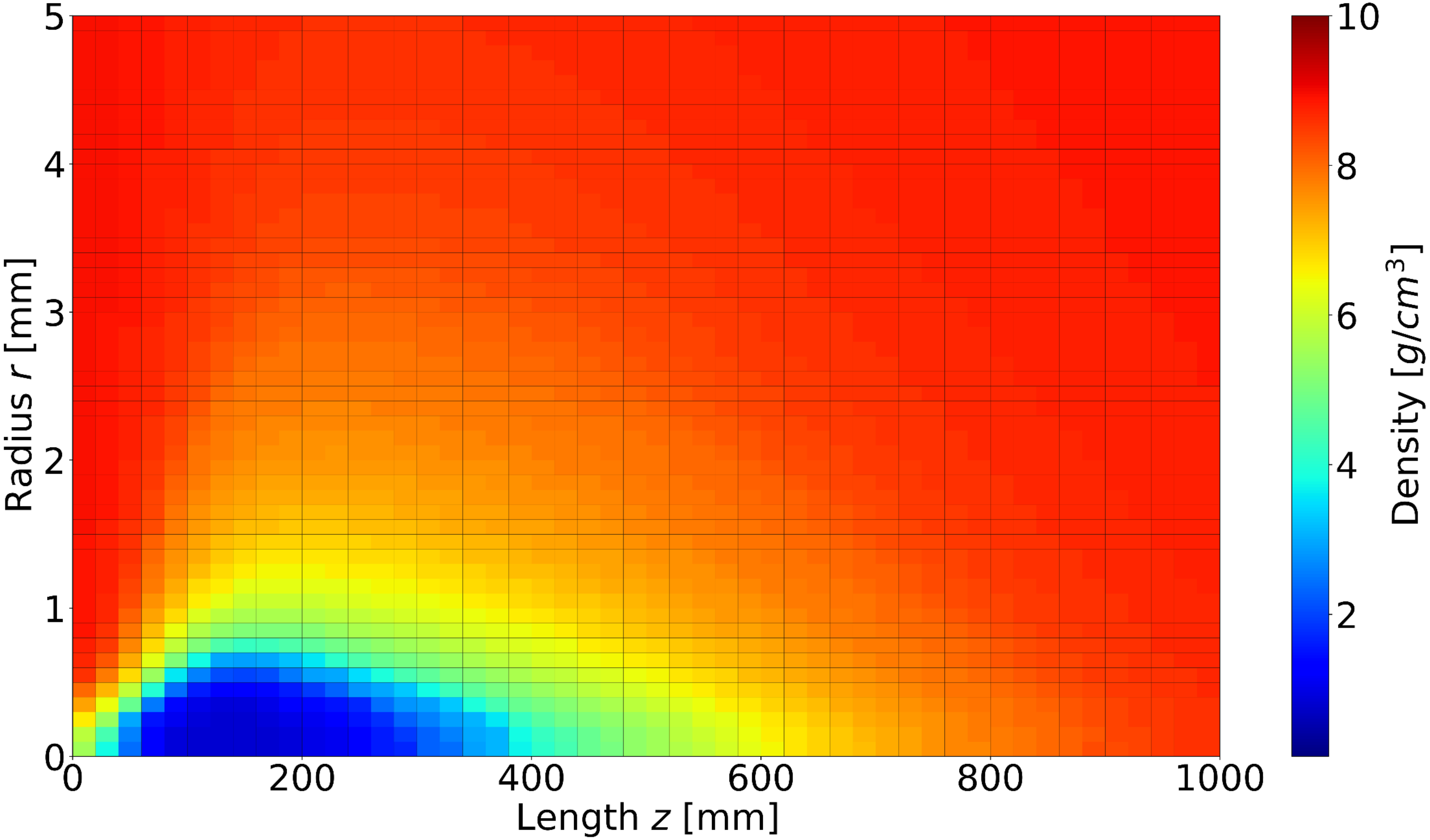


- **Scipy.interpolate.griddata**
- **Nearest neighbour**
- **Linear**
- **Cubic**
- **Linear as the default interpolation**
  - Timing

Comparison of generated input, benchmark input and Autodyn output file (After 92 bunches)



After 144 bunches
Data from Run011



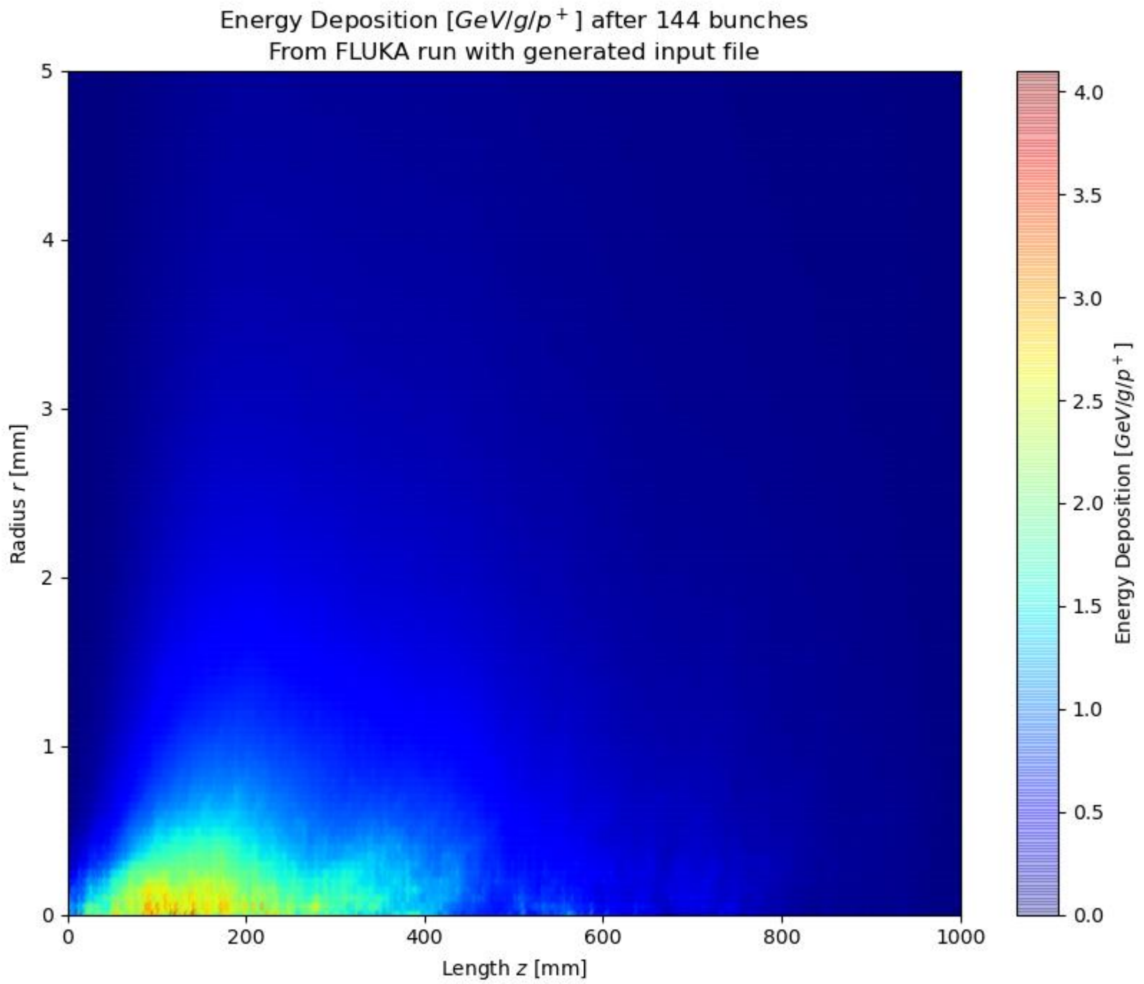
Conclusion

- **Automatic generation of FLUKA input files has been achieved using a newly developed python script**
  - Input files have been automatically produced for every Autodyn output file from the benchmark studies
- **Automatically generated input files have been used in FLUKA simulations to obtain energy depositions for the benchmark case**
- **Added functionality by having an automatic script**
  - Choice between nearest, linear and cubic interpolations (or several in same run)
  - Produces several plots along the different steps of the process
  - Creates log file with information - e.g., comparison of density changes, faulty data, failed interpolation etc.
  - Saves arrays, so the data can be accessed without having to run the whole script again

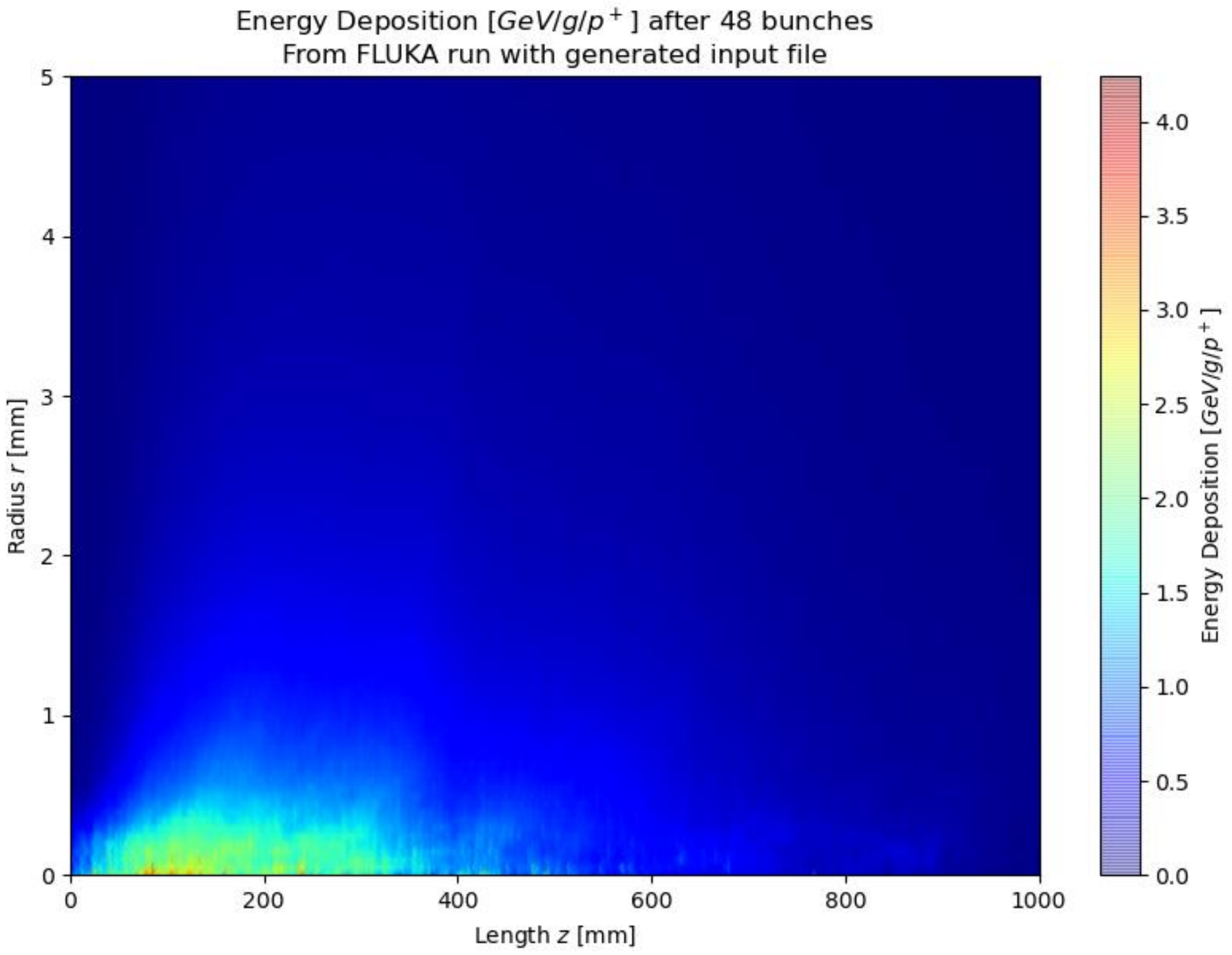
Thanks for your attention

home.cern

FLUKA run of generated input file After 48 bunches



FLUKA run of generated input file
After 48 bunches



FLUKA run of generated input file
After 60 bunches