P3M solver and plasma parameters in OPAL

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P3M solver in OPAL

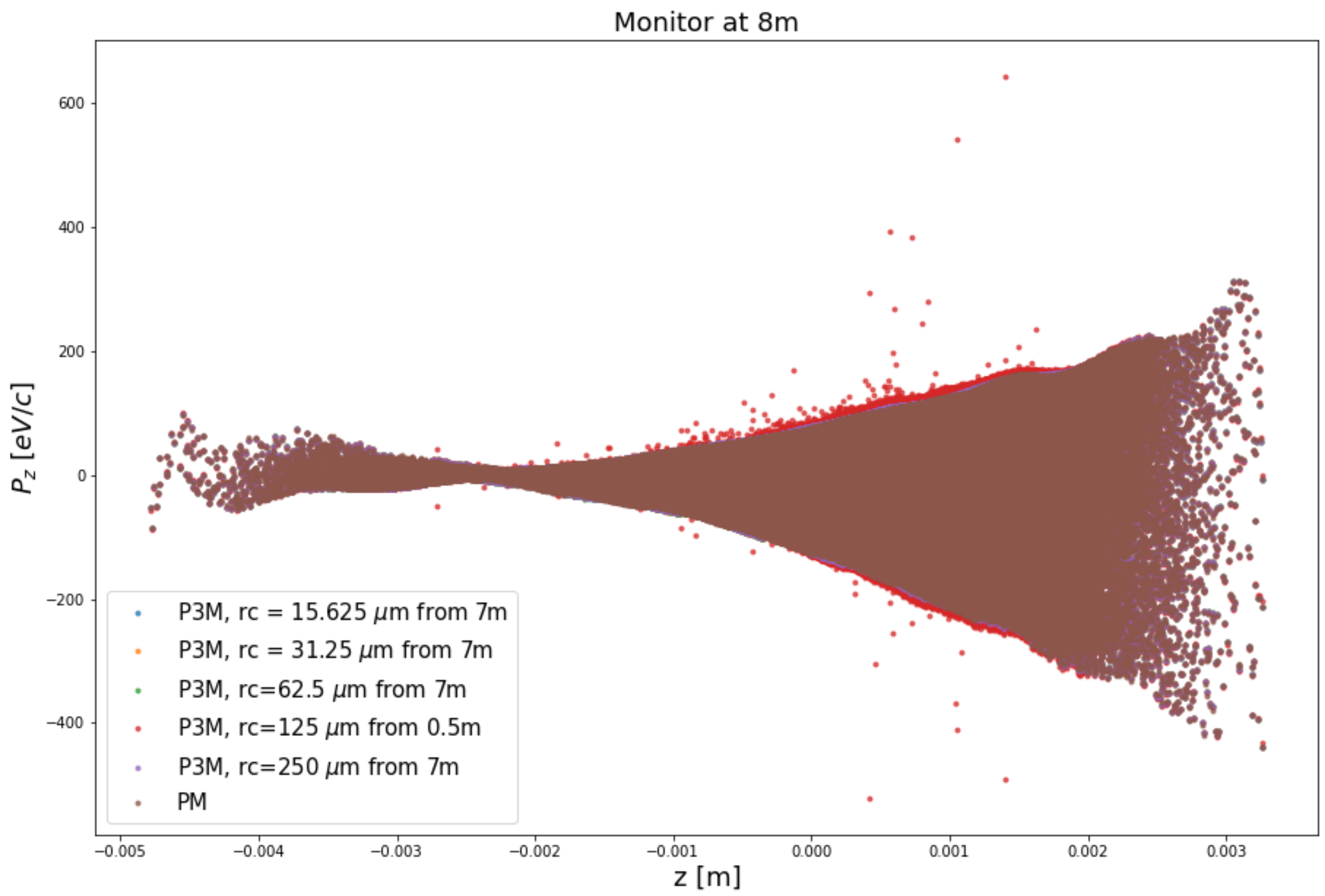
- To capture nearby particle-particle interactions which are not captured in the usual PIC (PM solver)
- Essential to capture intrabeam scattering (IBS) in FELs
- Based on the M.Sc. work of Benjamin Ulmer
- Currently not available for the binned version of the space charge calculations and hence cannot be used during emission

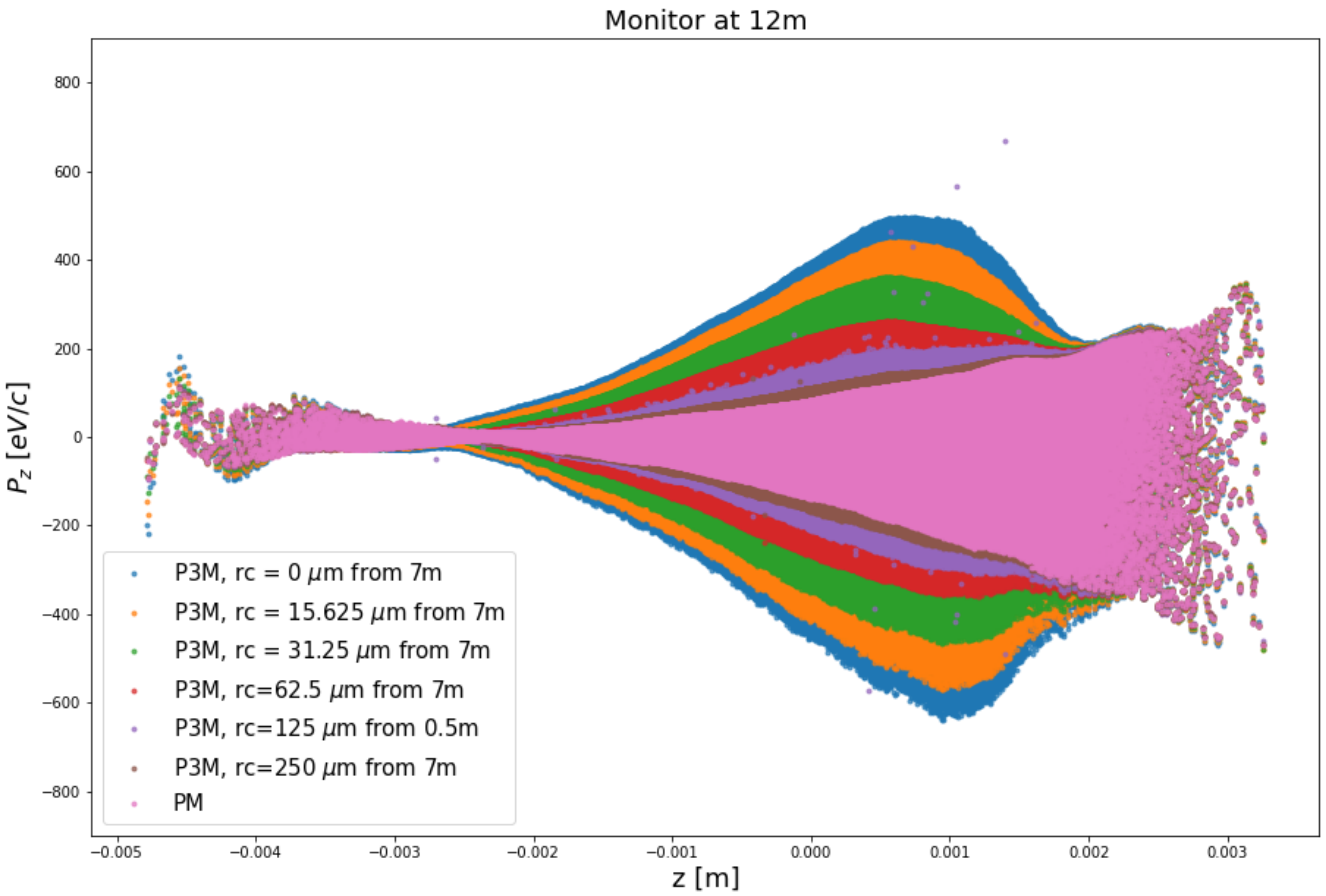
OPAL input file with P3M solver

First 7m PM solver and then switch to P3M solver

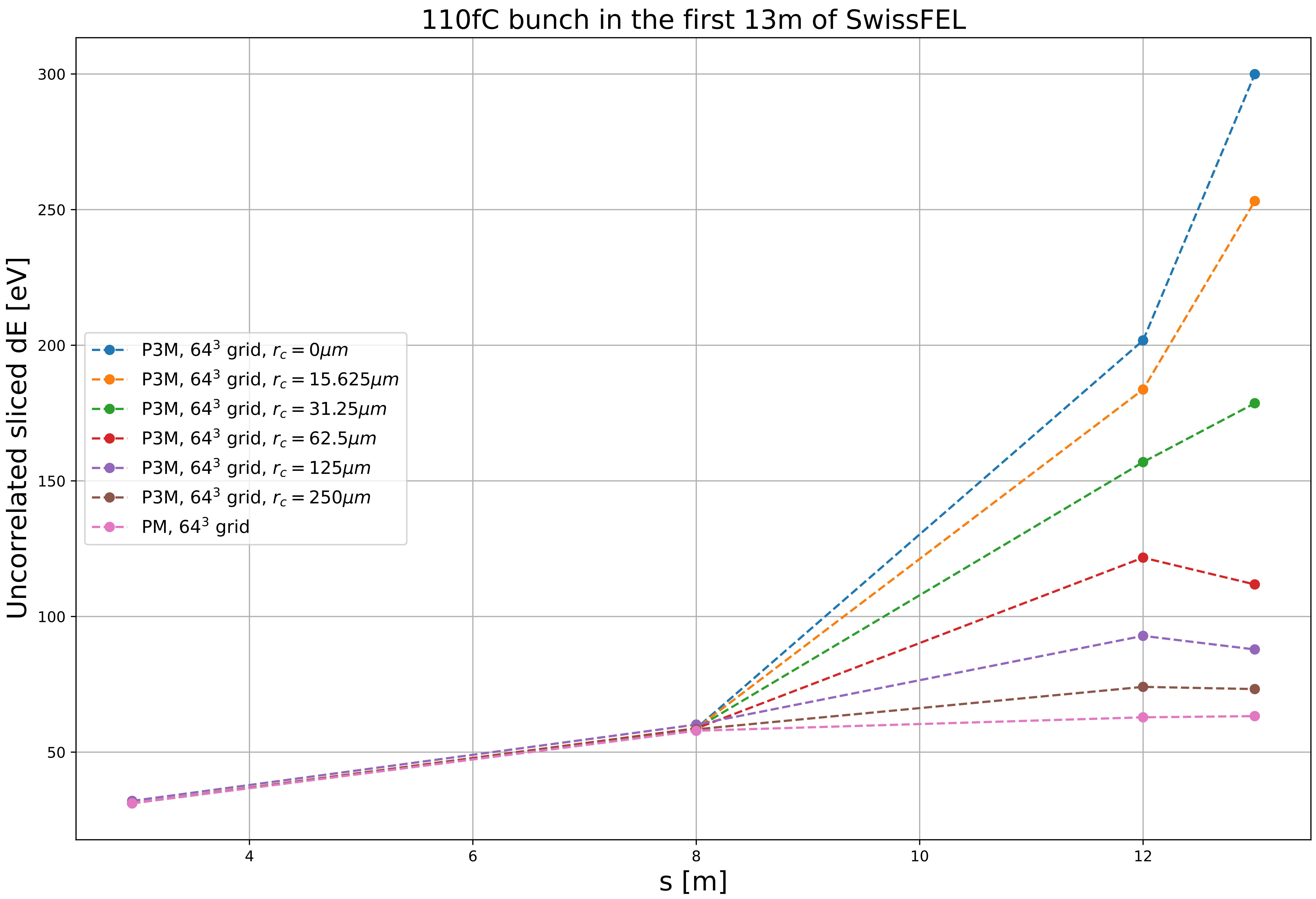
```
FS_PM: Fieldsolver, FSTYPE = FFT, MX = 64, MY = 64, MT = 64, PARFFTX = decx, PARFFTY = decy,
       PARFFTT = decz, BCFFTX = open, BCFFTY = open, BCFFTT = open , GREENSF = INTEGRATED;

FS_P3M: Fieldsolver, FSTYPE = "P3M", MX = 64, MY = 64, MT = 64, PARFFTX = decx, PARFFTY = decy,
       PARFFTT = decz, BCFFTX = open, BCFFTY = open, BCFFTT = open, RC=6.25e-5,
       ALPHA=32000, EPSILON=0, P3MTEST=false;

//-------------------------------------------------------------------------------------
BEAM1:  BEAM, PARTICLE = ELECTRON, pc = P0, NPART = n_particles, BFREQ = rf_freq,
        BCURRENT = beam_current, CHARGE = -1;
//-------------------------------------------------------------------------------------


//TRACK, LINE = SWISSFEL, BEAM = BEAM1, MAXSTEPS = 1900000, DT = {1.0e-13, 2.0e-12}, ZSTOP={0.20, 0.50};
TRACK, LINE = SWISSFEL, BEAM = BEAM1, MAXSTEPS = 1900000, DT = {2.0e-12}, ZSTOP={7.0};
RUN, METHOD = "PARALLEL-T", BEAM = BEAM1, FIELDSOLVER = FS_PM, DISTRIBUTION = Dist;
ENDTRACK;
TRACK, LINE = SWISSFEL, BEAM = BEAM1, MAXSTEPS = 1900000, DT = {2.0e-12}, ZSTOP={13.1};
RUN, METHOD = "PARALLEL-T", BEAM = BEAM1, FIELDSOLVER = FS_P3M, DISTRIBUTION = Dist;
ENDTRACK;

STOP;
```

Preliminary results for SwissFEL beam line





Uncorrelated sliced dE



Debye length calculation

If $\mathbf{p}$ is in units of $\beta\gamma$ where $\beta = \mathbf{v}/c$

$$\mathbf{v} = \frac{\mathbf{p}c}{\gamma}$$

$$\bar{v}_d = \frac{1}{N_p}\sum_{i=1}^{N_p} v_d$$

$$k_B T_e = \frac{1}{3} m_0 \frac{1}{N_p} \sum_{i=1}^{N_p} \sum_{d=1}^{3} ((v_d)_i - \bar{v}_d)^2$$

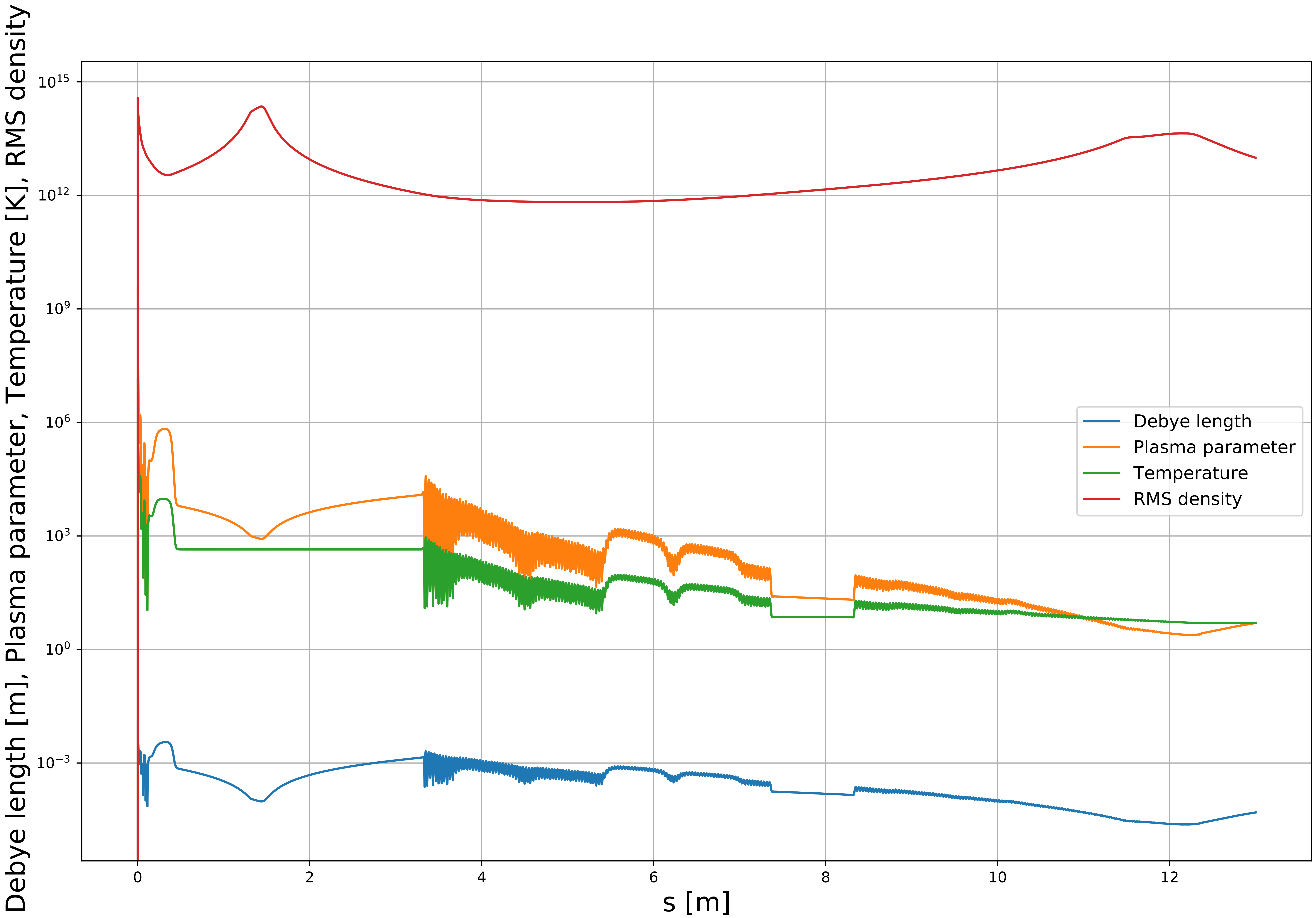
Debye length

$$\lambda_D = \sqrt{\frac{k_B T_e \varepsilon_0}{||n_e||e^2}}$$

Plasma parameter

$$\Lambda = \frac{4\pi}{3}\lambda_D^3 n_e$$

Here m_0 is the rest mass of an electron and e is the elementary charge



- Plasma parameter > 1: Collisions are not important
- Plasma parameter <= 1: Collisions are important
- The plasma is not in equilibrium here so we can maybe get only some guidance from these values and not interpret them literally
- These quantities are available in the stat file of OPAL

Ongoing work

- More tests with the P3M solver including one-one simulations of SwissFEL
- Regression test for P3M solver + unit test for plasma parameter calculations
- The MR P3M-solver should be ready soon for review and merging