FCC-ee Resonance Driving Terms Using MAD-NG Parametric Differential Maps.

FCC-ee Optics Tuning WG

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FCC-ee lattice

- **Pantaleo's lattice and optics V24.3_Z**
  - ➡ Converted from MAD8 to MAD-X by Ghislain.
  - ➡ MAD-NG extended to support MAD-X syntax of beam LINE.
    - MAD-NG will also be extended to directly read MAD8 lattices.
  - ➡ MAD-NG detected half a dozen of typos in the MAD-X file.

- **Optics Setup**
  - ➡ RF-cavities on.
  - ➡ No synchrotron radiation.

- **Lattice Structure**
  - ➡
```
KSF1 := KSFFAM1*1.0; KSF2 := KSFFAM2*1.0; KSF3 := KSFFAM1*1.0; KSF4 := KSFFAM2*1.0;
KSD1 := KSDFAM1*1.0; KSD2 := KSDFAM2*1.0; KSD3 := KSDFAM1*1.0; KSD4 := KSDFAM2*1.0;
```
  - ➡
```
FCCEE_P_RING: LINE=(4*(
-CCS_YR,-CCS_XR,-CELL_UFFR,-CELL_R3,-ARC_OCTANT,CELL_UR,CELL_SU,STRAIGHT_R,
-STRAIGHT_L,-CELL_US,-CELL_UL,ARC_OCTANT,CELL_L3,CELL_UFFL,CCS_XL,CCS_YL ));
```

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Comparison with MAD-X

- Survey: lengths differ by 3.2 mm (not so bad for a description by LINEs of 90 km).
- MAD-X missed **one typo** that changes the length by -0.4768 m and affects the optics.
  - `ANGFFL := ANGTFL/(1*B0FL*0.76 + 2*B0FL*1.1 + 1.B0FL*1.38 + 1*B1FL*1.68 + 2*B3FL*0.71 + 1*B4FL*1.37 + 1*B4FL*0.98 + 1*B4FL*0.98 + 1*B5FL*0.8 + 2*B6FL*0.72 + 2*B7FL*0.72);`
- Twiss Summary:

MAD-X with typo

length	alfa	gammatr
90659.0855	1.42746e-04	83.69860
q1	dq1	betxmax
198.1940015	2317.09	2998.454
q2	dq2	betymax
174.4623069	22095.24	6640.189

MAD-X without the typo

length	alfa	gammatr
90658.6087	2.89580e-05	185.83010
q1	dq1	betxmax
198.2000032	0.22	2948.094
q2	dq2	betymax
174.3000586	0.34	9193.870

MAD-NG

length	alfa	gammatr
90658.6054	2.89580e-05	185.83010
q1	dq1	betxmax
198.199999	0.23	2948.198
q2	dq2	betymax
174.299998	0.17	9196.073

MAD-X output from Ghislain

length	alfa	gammatr
90658.6087	2.89580e-05	185.83010
q1	dq1	betxmax
198.2000032	0.22	2948.094
q2	dq2	betymax
174.3000586	0.34	9193.870

Ghislain has used the correct lattice

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MAD-NG log

```
ex-fcc_ee-pantaleo % time ../mad ex-fcc_ee-pantaleo.mad
    ____  __   ______    ______     |   Methodical Accelerator Design
     /  \/  \   /  _  \   /  _  \   |   release: 0.9.9_P (OSX 64)
    /  __   /  /  /_/ /  /  /_/ /   |   support: http://cern.ch/mad
   /__/  /_/  /__/ /_/  /_____ /    |   licence: GPL3 (C) CERN 2016+
                                    |   started: 2024-05-07 19:[illegible].14

timing load/convert seq from file: 0.02 s
timing build seq fccee_p_ring: 0.23 s
beamline 'fccee_p_ring' converted (14514 elements, L=90658.6054 [m])
timing survey: 0.20 s
symplectic deviation:  2.70979617e-12
symplectified deviation:  3.424750117e-16
timing twiss fccee_p_ring: 1.82 s
timing build seq cell_u: 0.00 s
beamline 'cell_u' converted (59 elements, L=318.1995 [m])
timing twiss cell_u: 0.07 s
*** ring info ***
seq='fccee_p_ring', length=90658.60537
q1=198.19999, dq1=0.23, betxmax=2948.198, dxmax=0.77371
q2=174.29998, dq2=0.17, betymax=9196.073, dymax=0.00000
alpha=2.89580e-05, gammatr=185.83010
symplectic deviation:  2.70979617e-12
symplectified deviation:  3.424750117e-16
timing twiss fccee_p_ring: 16.28 s
timing twiss cell_u: 0.11 s
|f4000| =  2.309773e+02
|f3100| =  1.947545e+03
|f2020| =  2.332276e+03
|f1120| =  5.178961e+03
|f0040| =  7.769161e+03
ksffam1 =  0.2754240
ksdfam1 = -0.2714880
ksffam2 =  0.2464320
ksdfam2 = -0.1515000
timing twiss sector: 27.28 s
timing twiss cell_u: 1.27 s
50.95s user 1.03s system 136% cpu 40.877 total
```

Load MAD-X sequence file
Convert MAD-X to MAD-NG representation
Save MAD-NG representation in a file (580 lines)

0.02 sec

Convert BLine (tree of objects) to Sequence
Equiv. to MAD-X FLATTEN + USE, done once
14514 elements, L = 90658.6054 m

0.23 sec

Run Survey and save the table

0.20 sec

Run Twiss @ 2nd order, save the table (+ plots)

1.82 sec

Twiss “summary” extracted from Twiss table

Run Twiss @ 4th order with RDTs
save the table (+ plots)

16.28 sec

Twiss RDTs extracted from Twiss table @ ring$end

4 knobs used as parameters
2 sextupoles families

Run Twiss @ 5th order with parametric RDTs
save the table (+ plots)

27.28 sec

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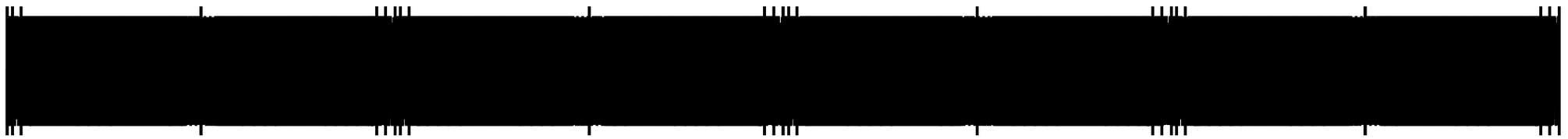
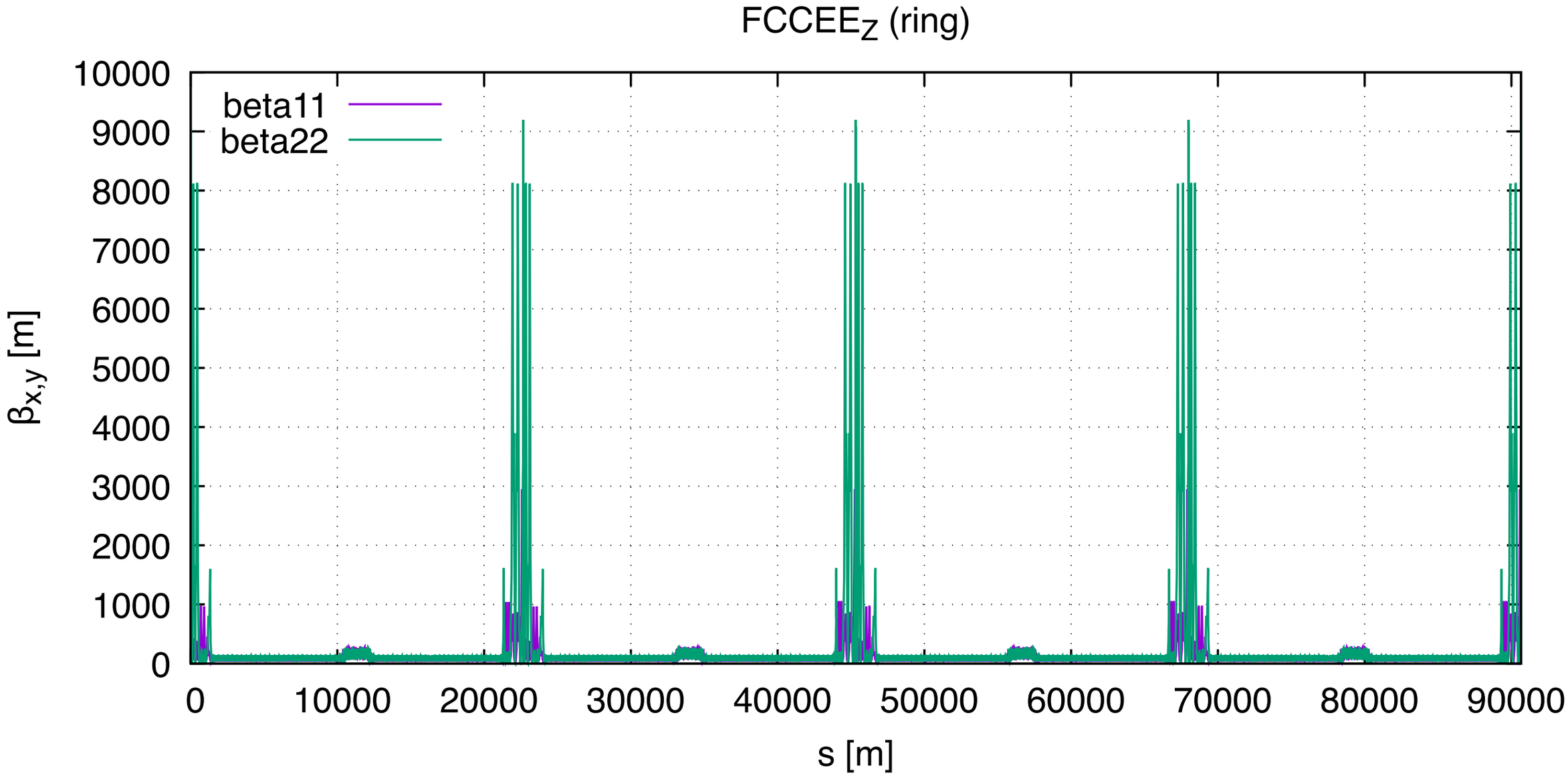
FCC-ee Betas (ring)





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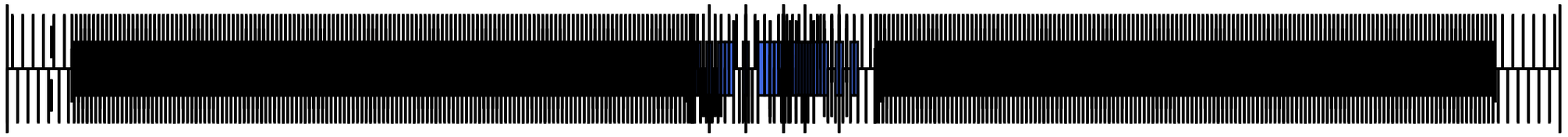
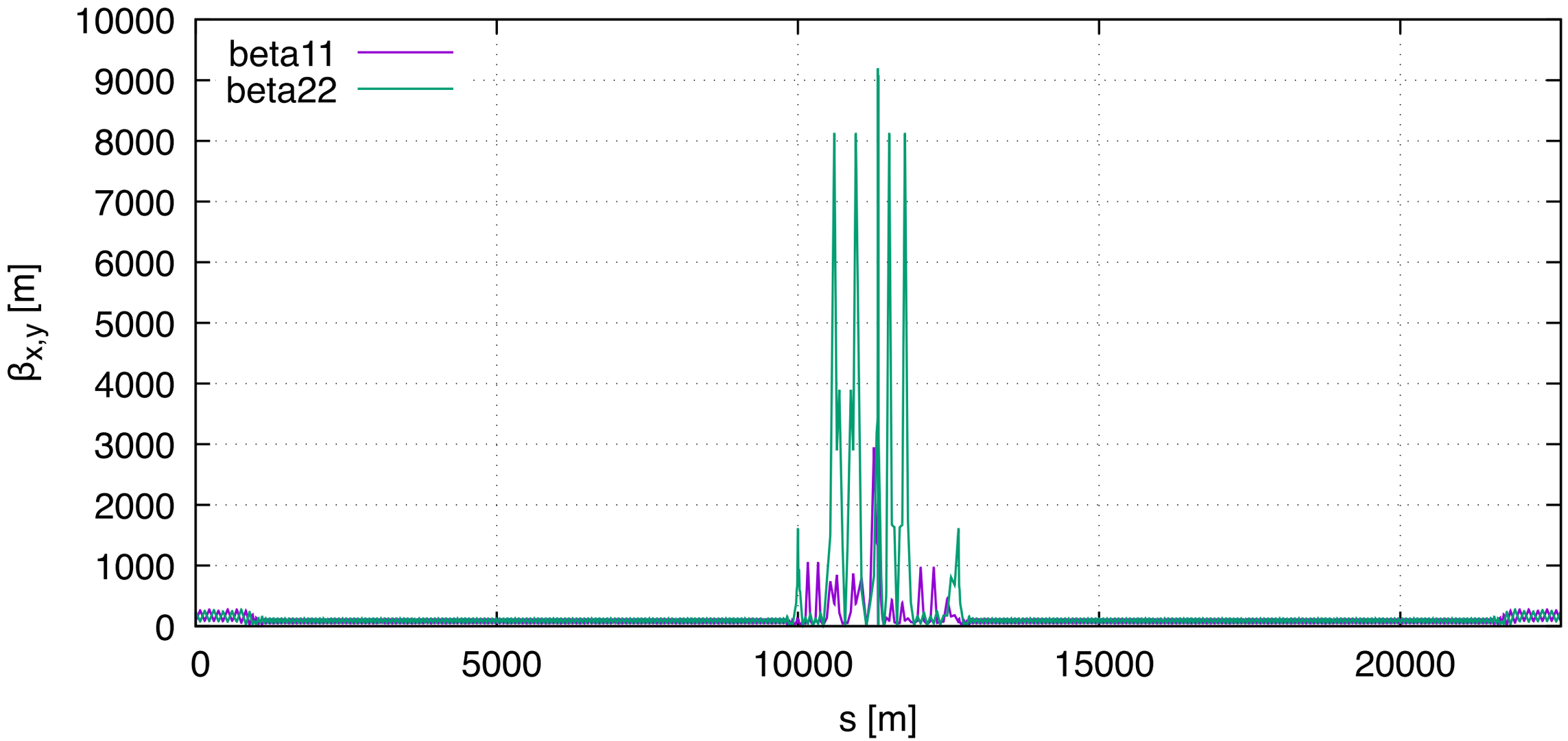
FCC-ee Betas (sector)





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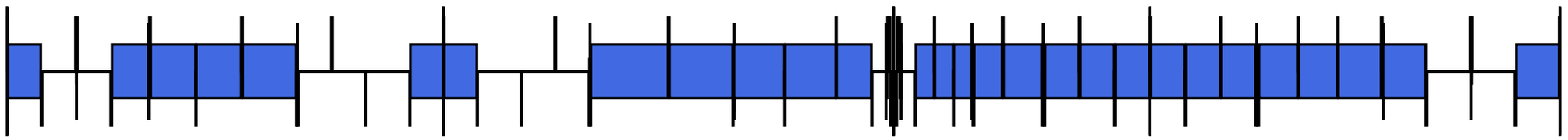
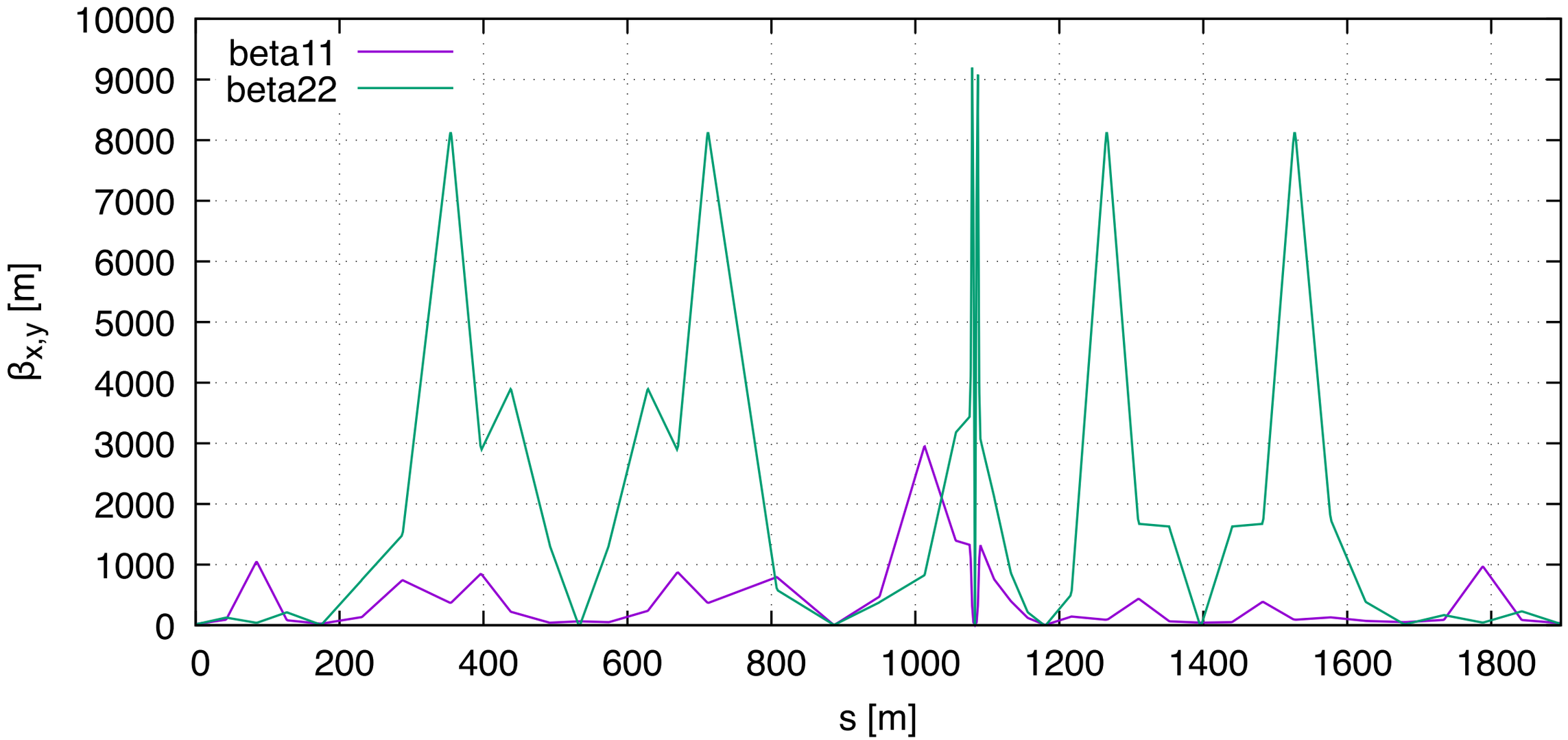
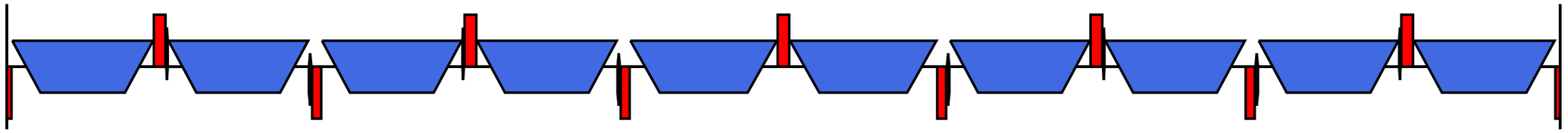
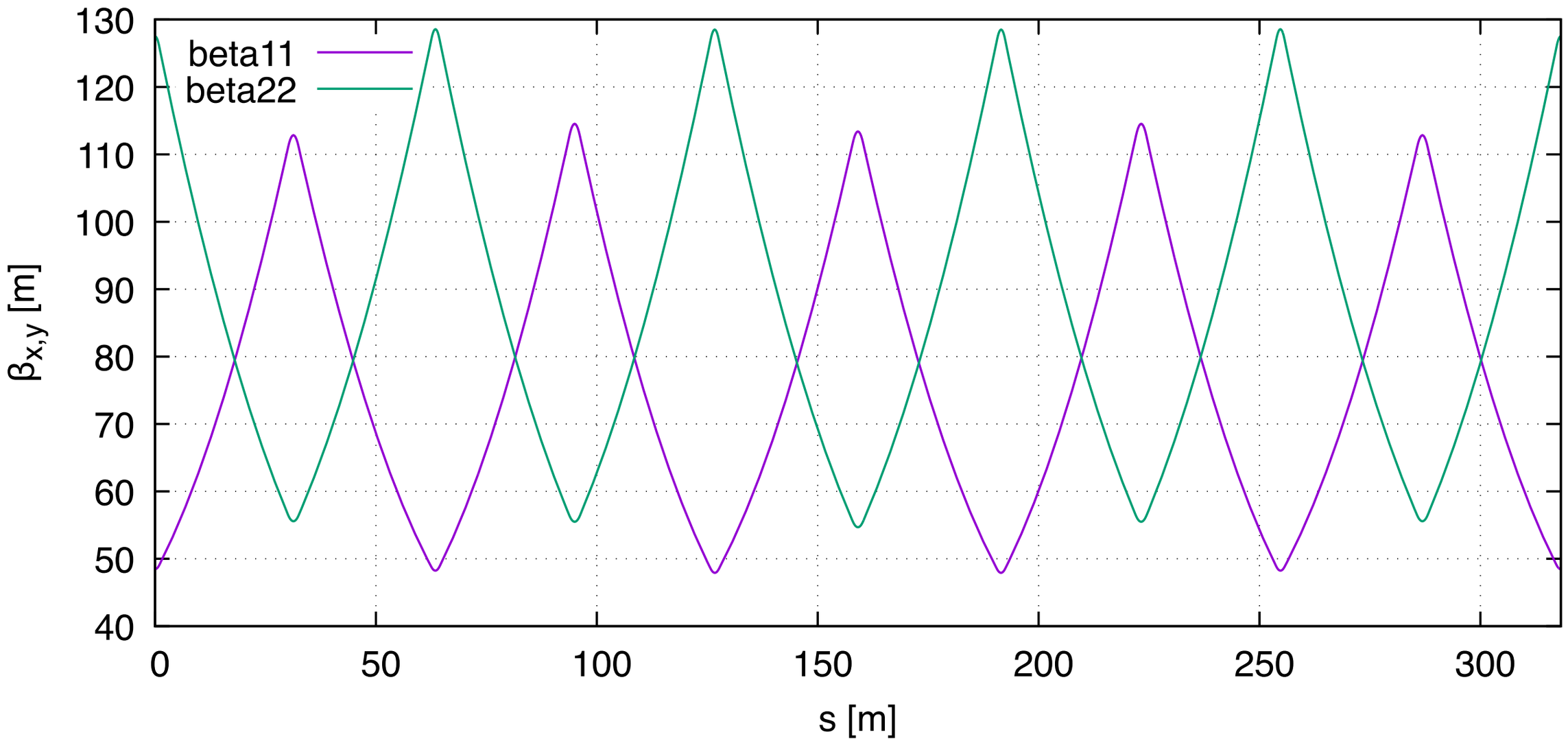
FCC-ee Betas (ip)





FCC-ee Betas (cell)





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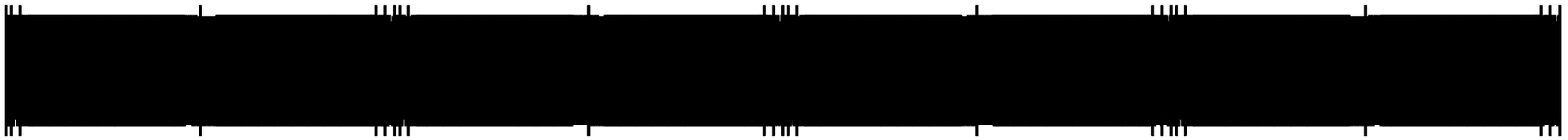
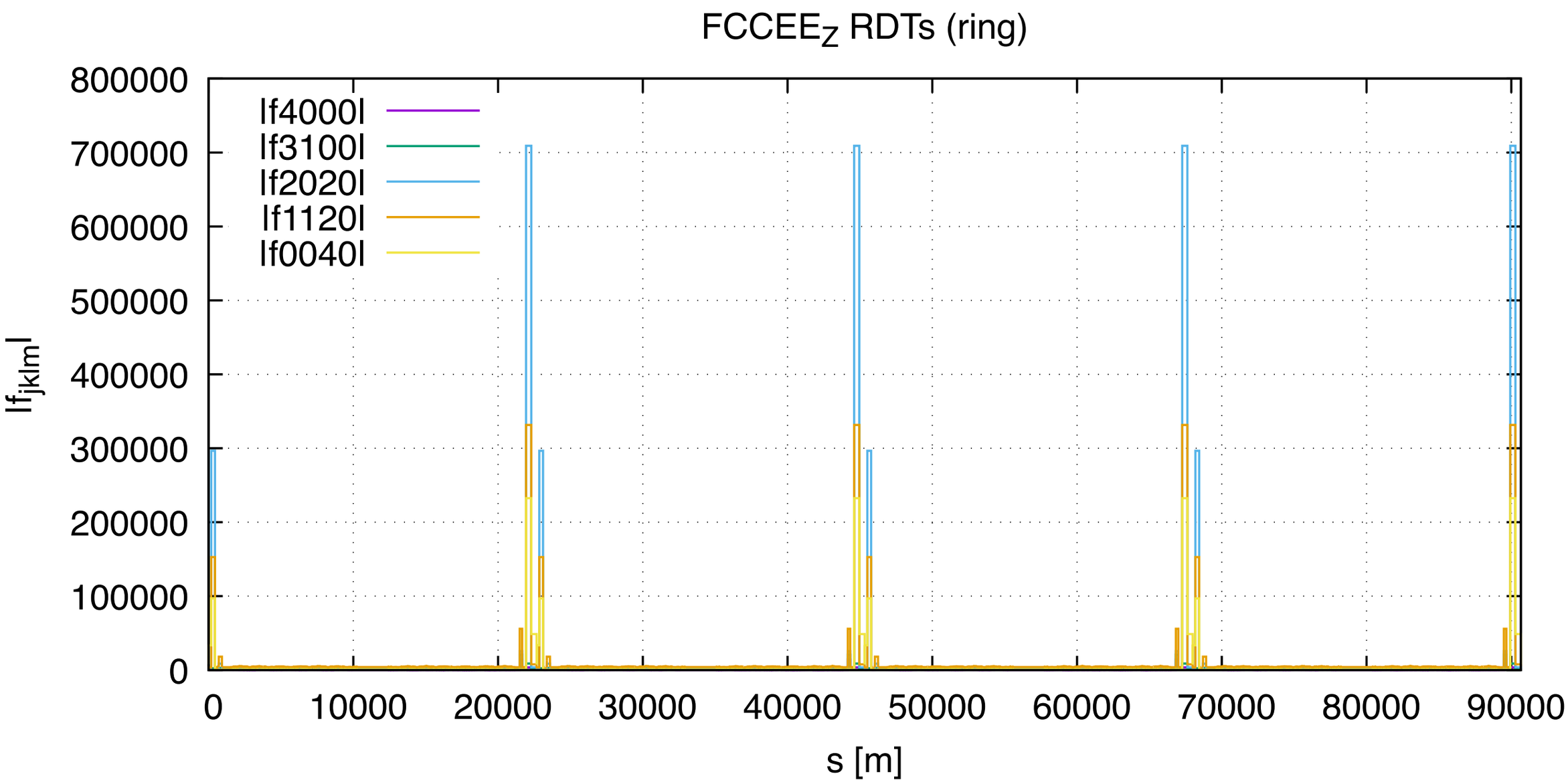
FCC-ee RDTs (ring)





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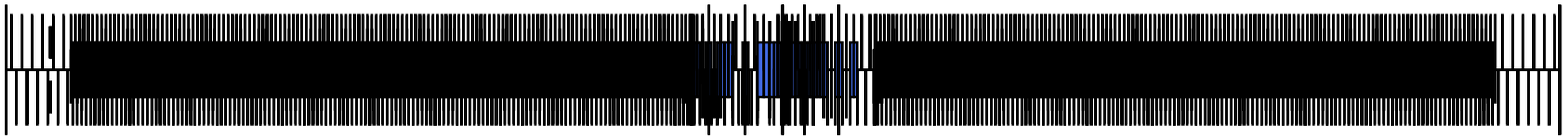
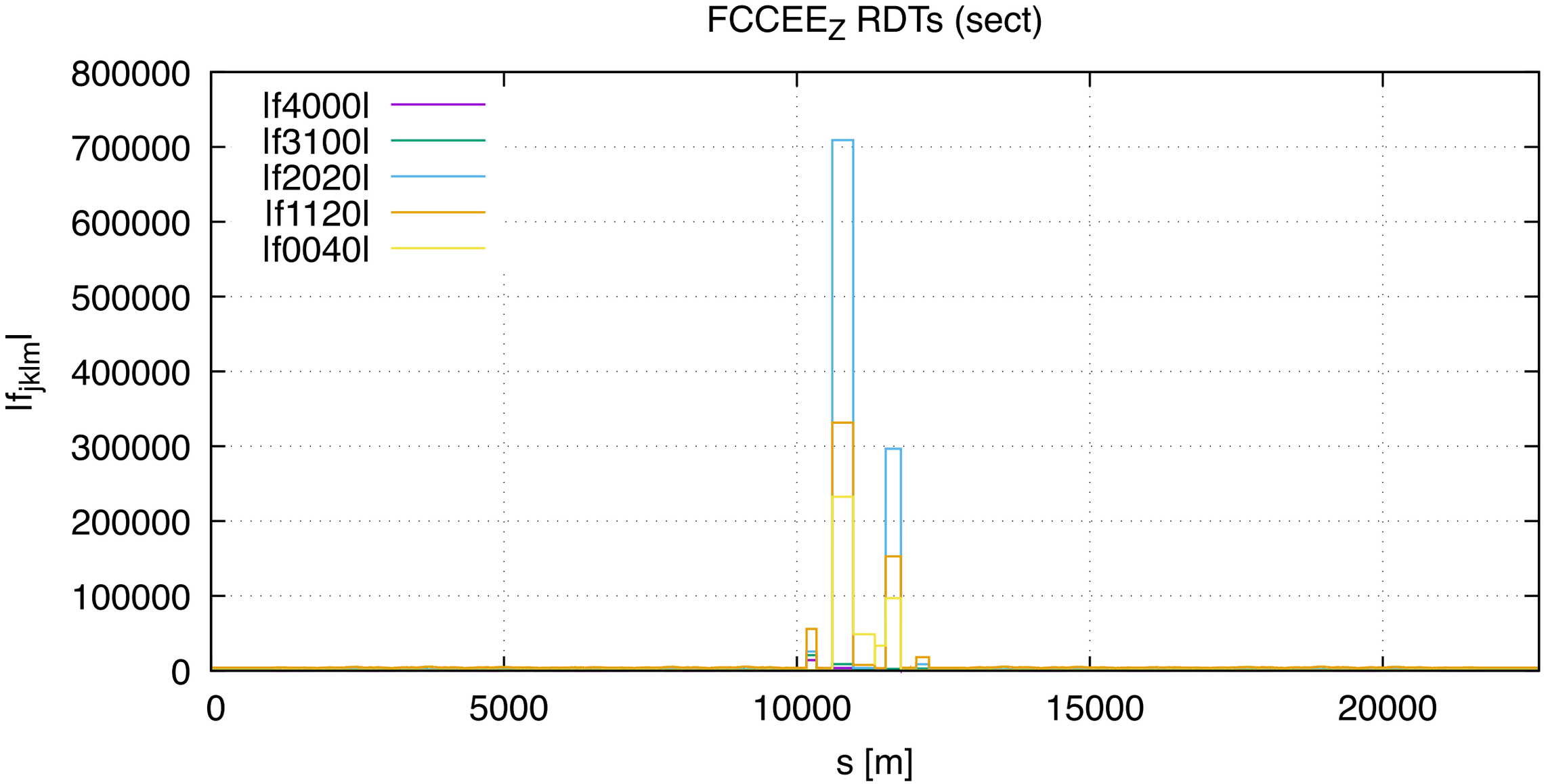
FCC-ee RDTs (sect)





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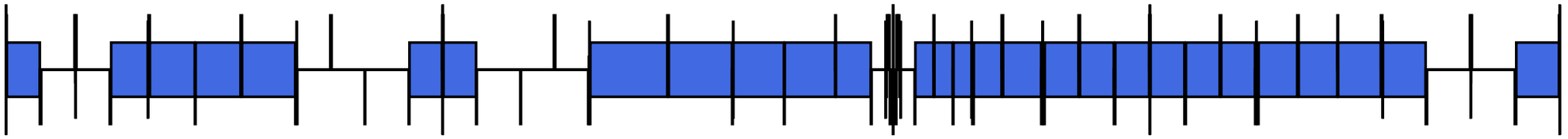
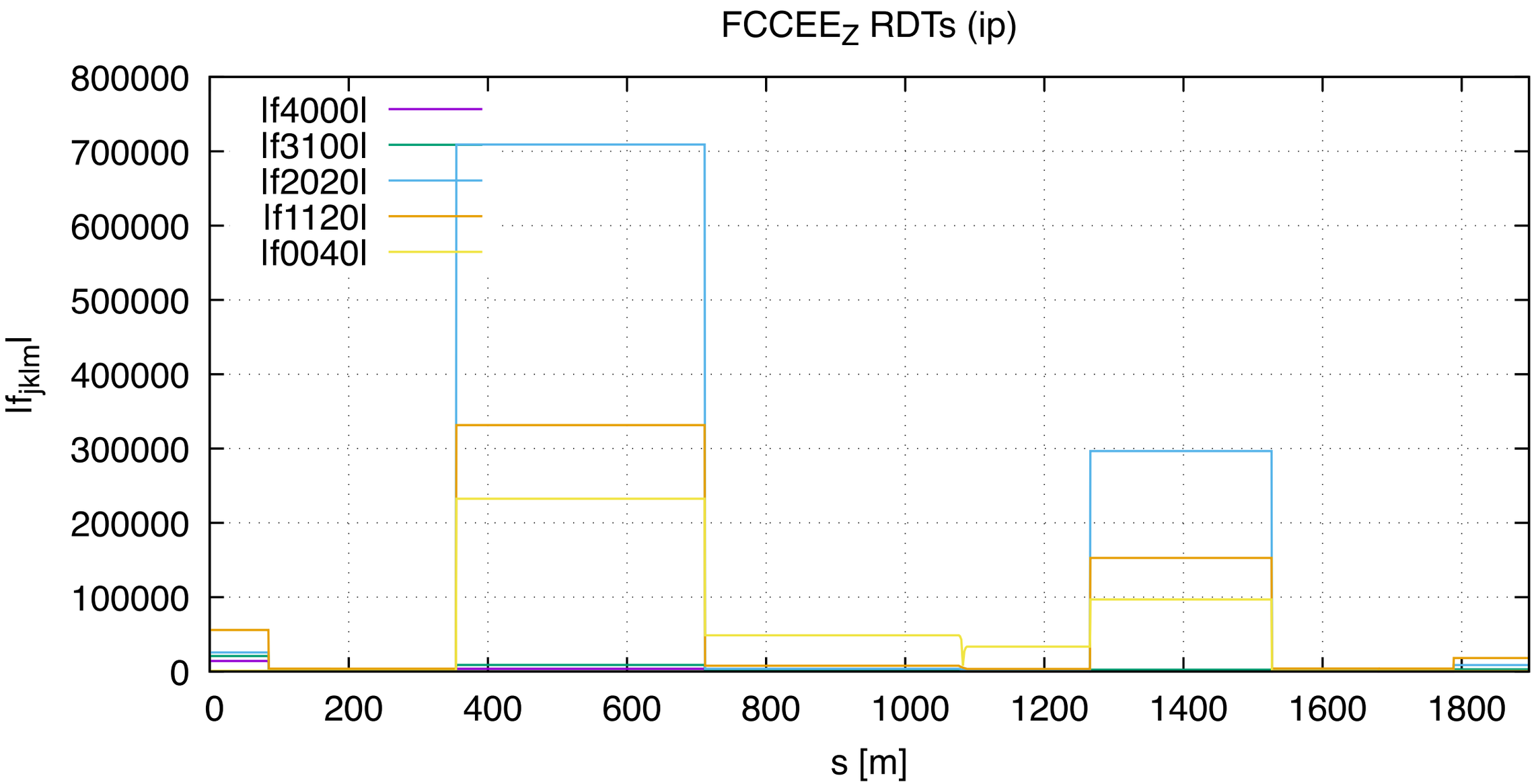
FCC-ee RDTs (ip)





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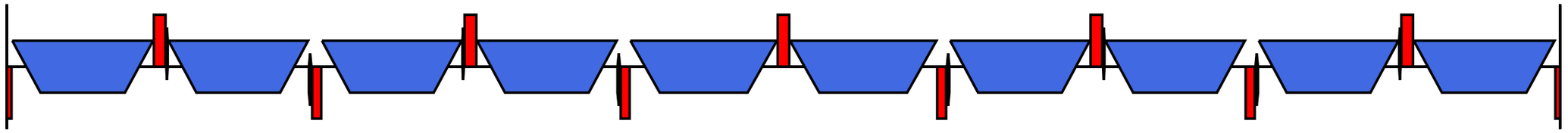
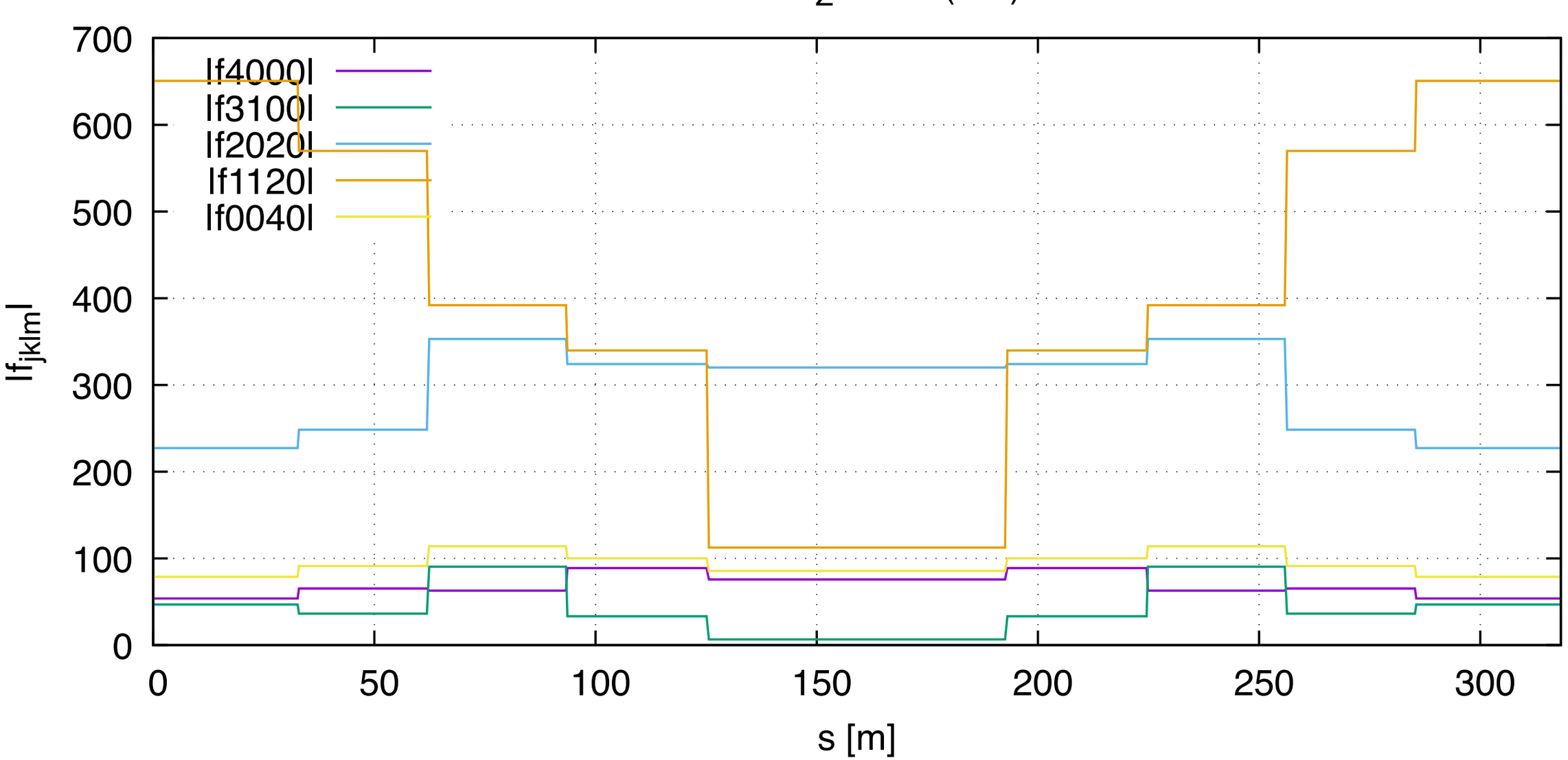
FCC-ee RDTs (cell)





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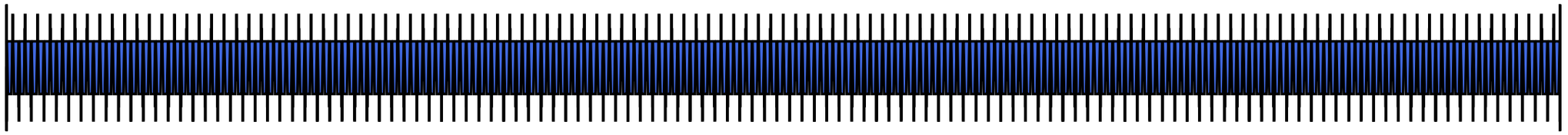
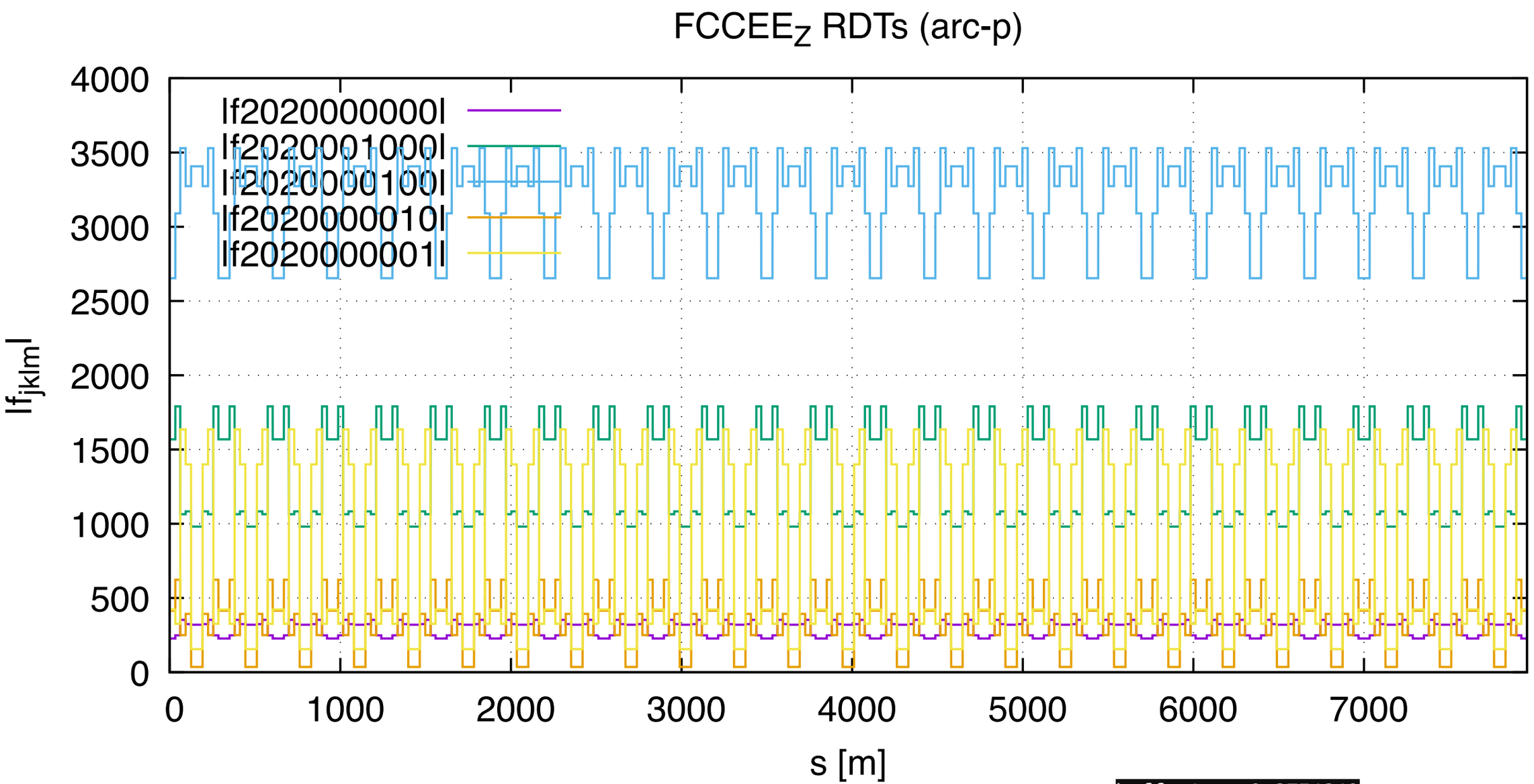
FCC-ee P-RDTs (octant-f2020)






```
ksffam1 =  0.2754240
ksdfam1 = -0.2714880
ksffam2 =  0.2464320
ksdfam2 = -0.1515000
```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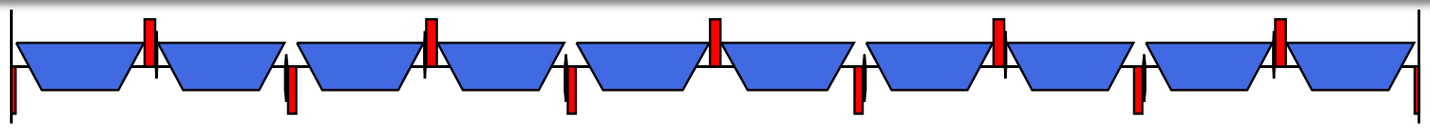
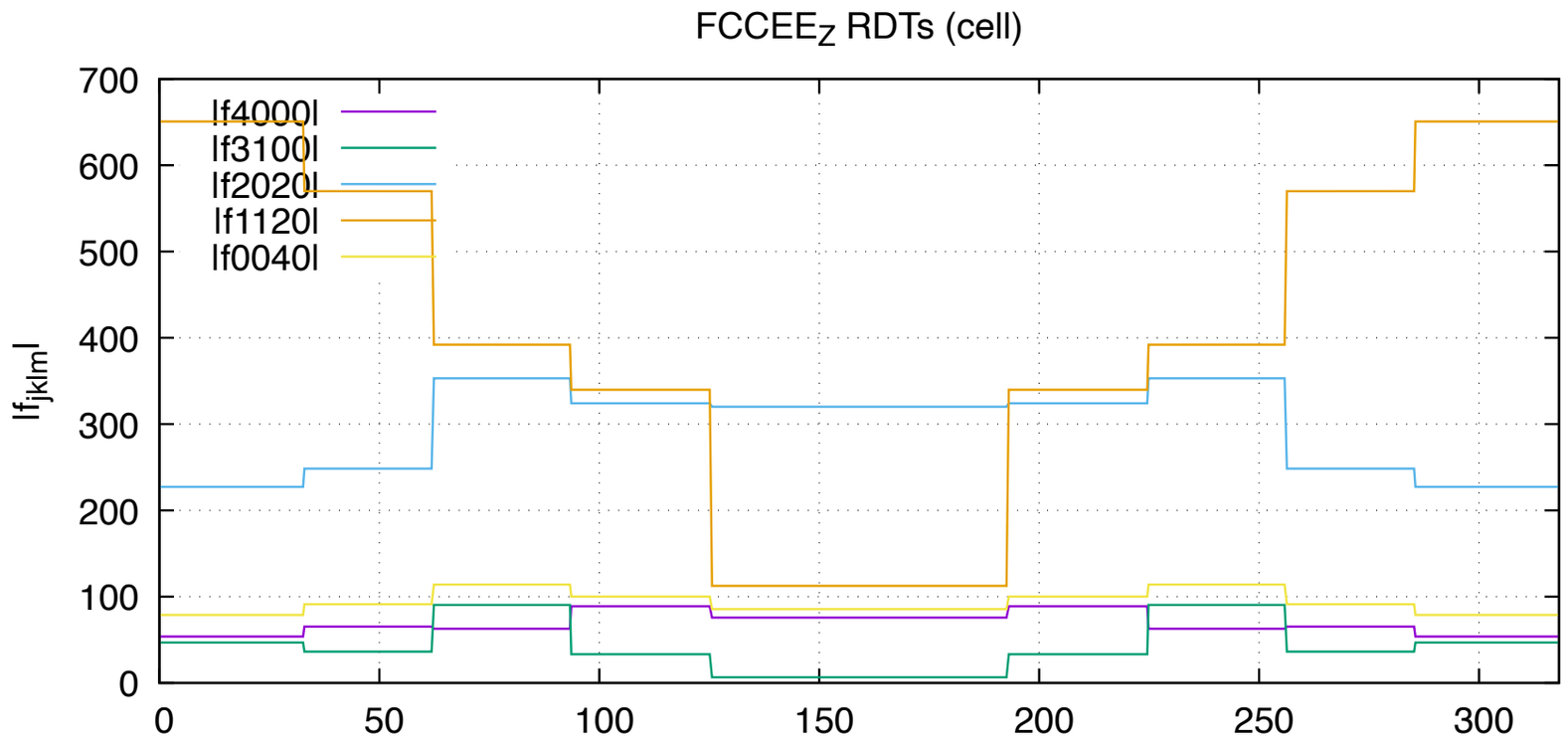
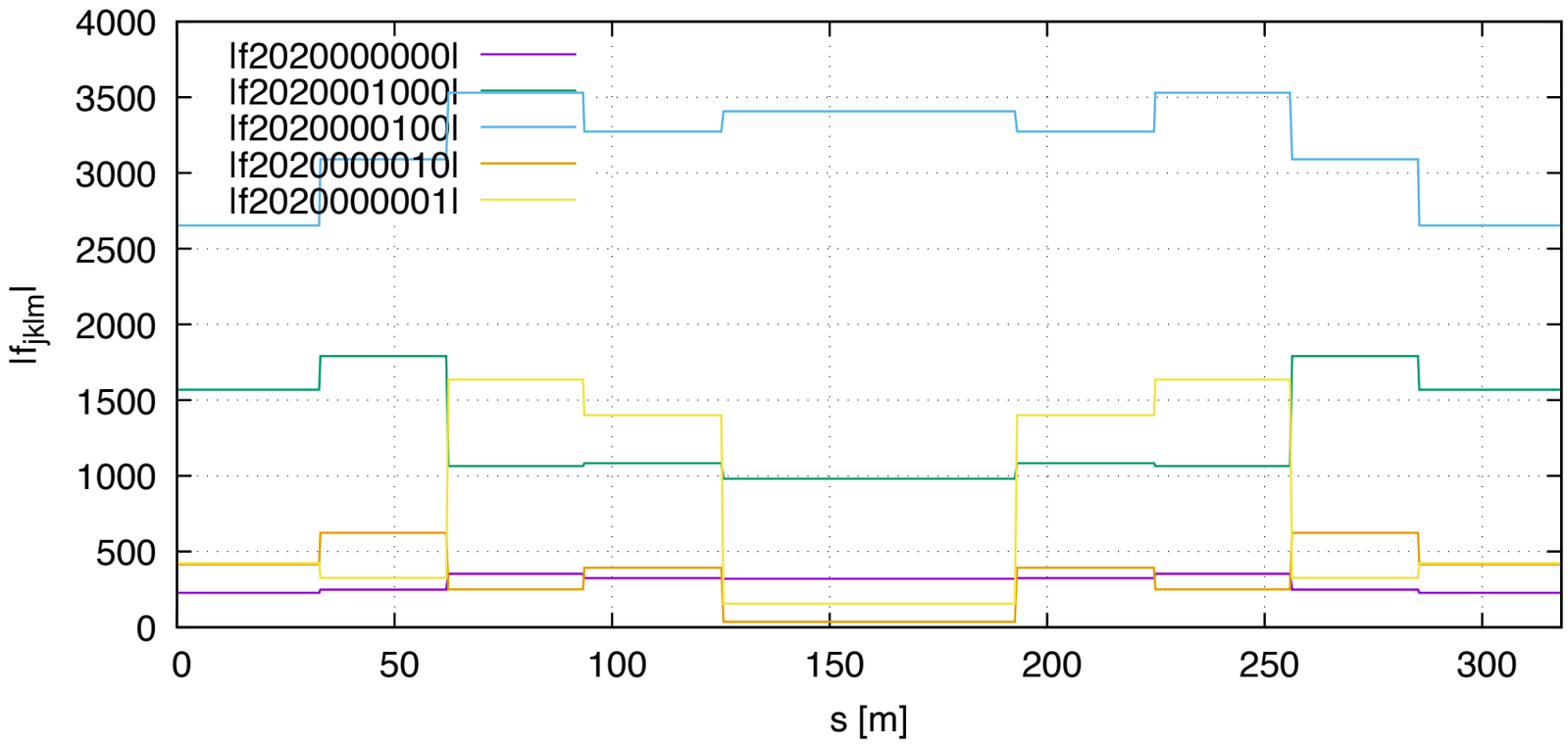
FCC-ee P-RDTs (cell-f2020)





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ksffam1 =  0.2754240
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```

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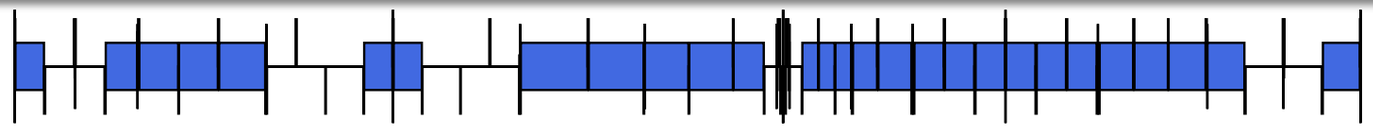
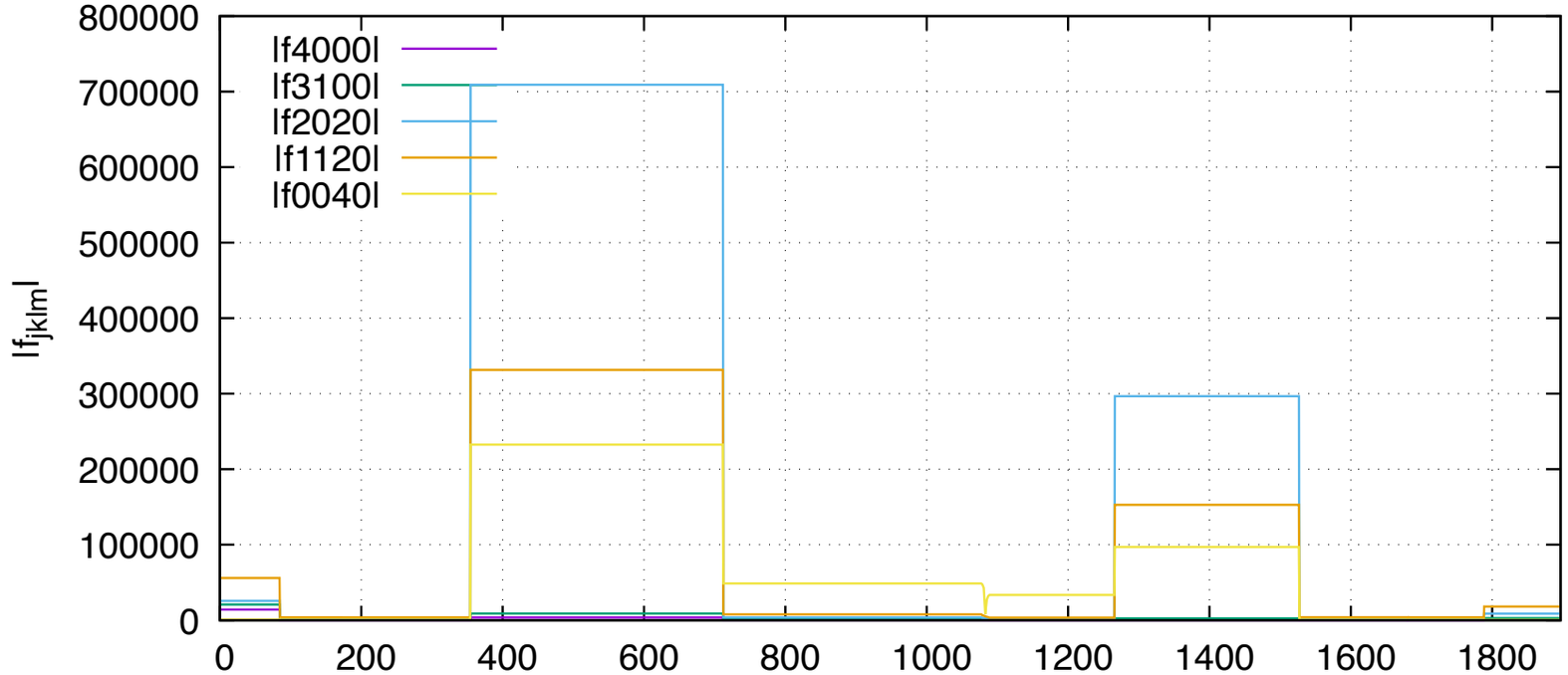
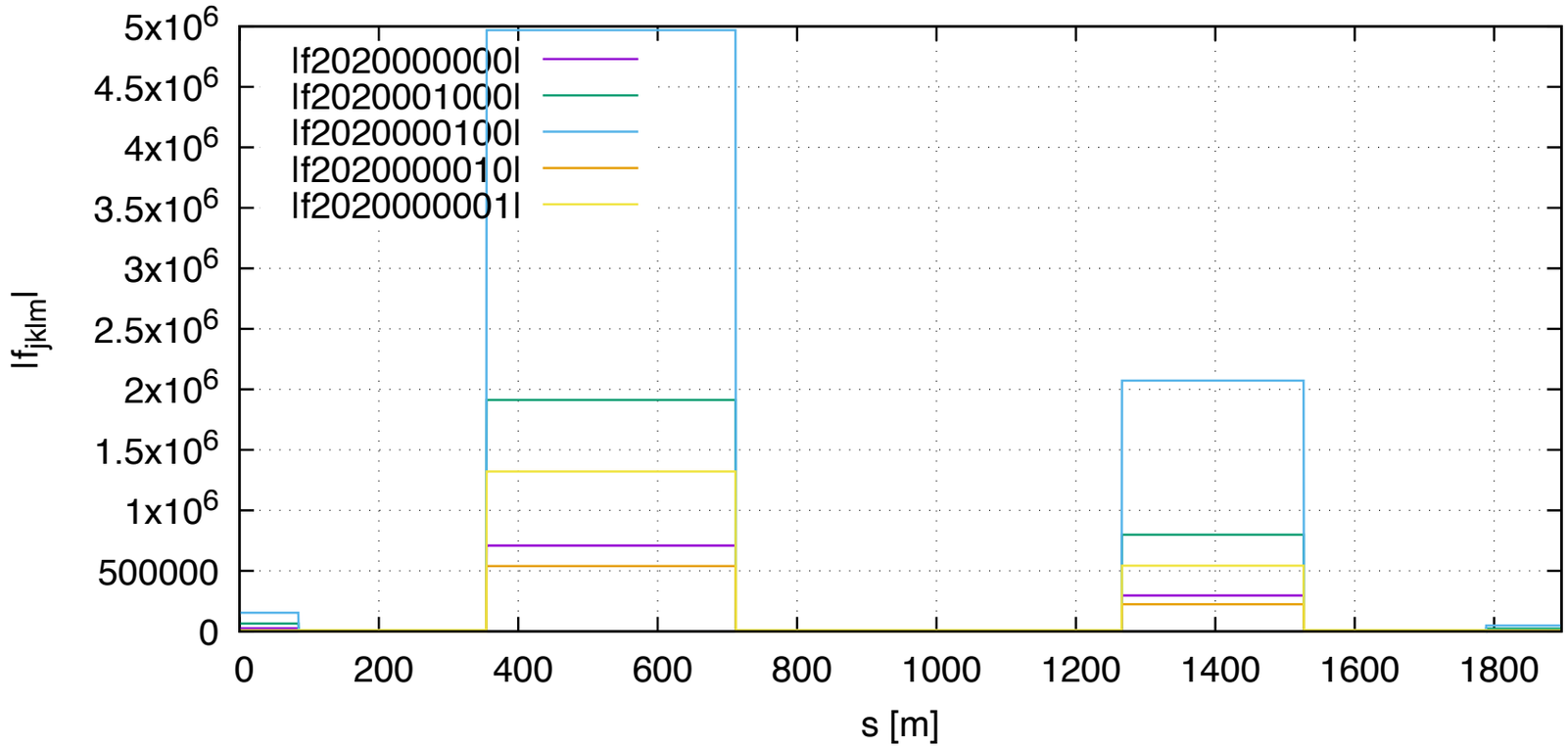
FCC-ee P-RDTs (ip-f2020)





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ksffam1 =  0.2754240
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ksdfam2 = -0.1515000
```


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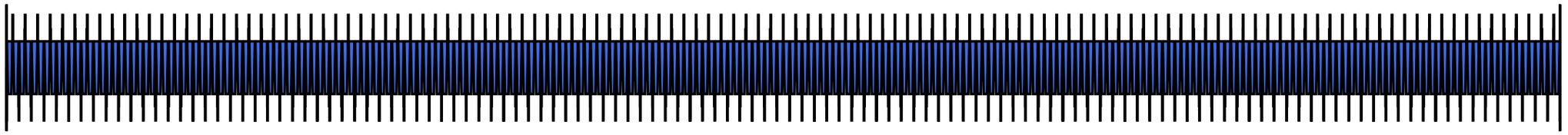
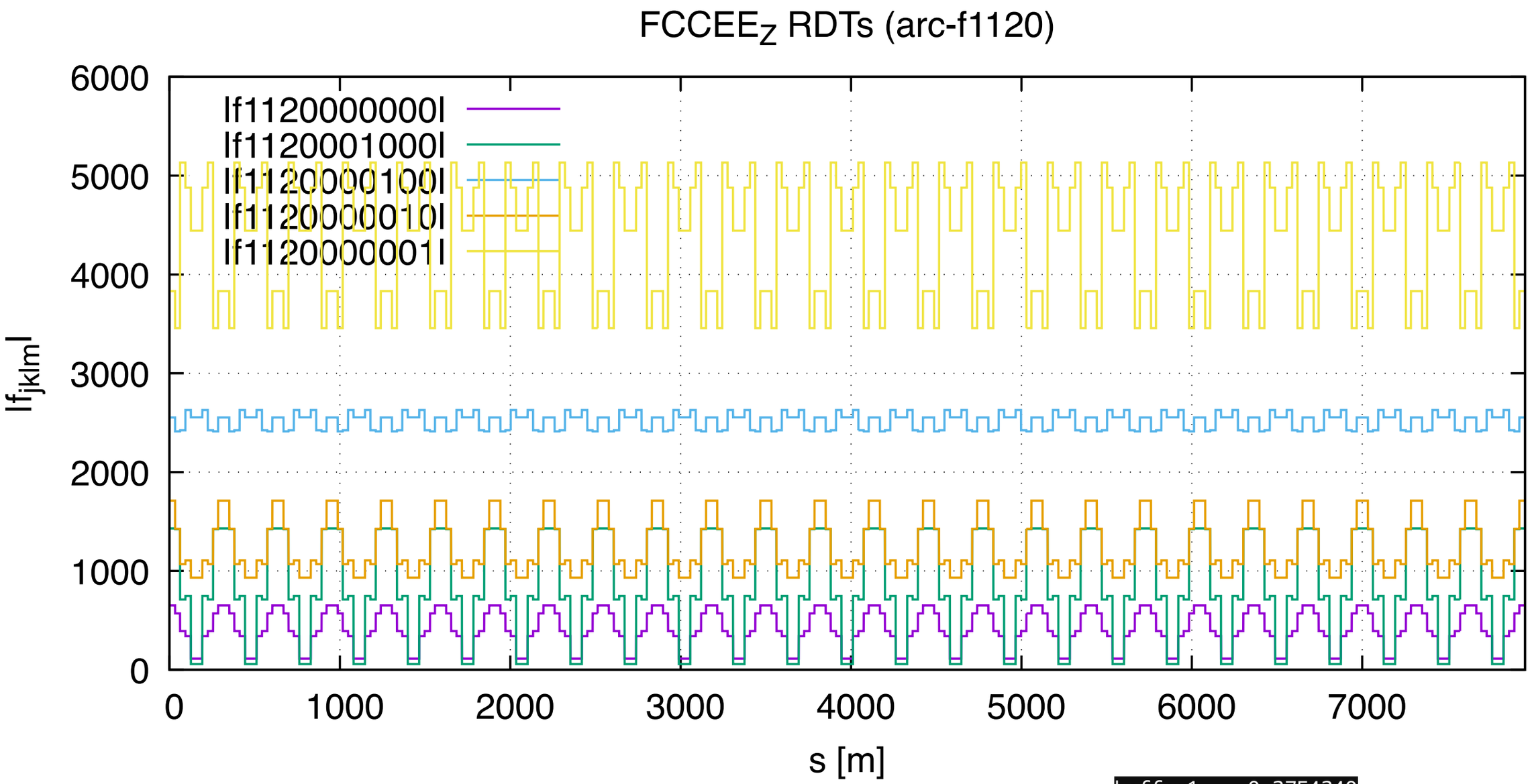
FCC-ee P-RDTs (octant-f1120)






```
ksffam1 =  0.2754240
ksdfam1 = -0.2714880
ksffam2 =  0.2464320
ksdfam2 = -0.1515000
```

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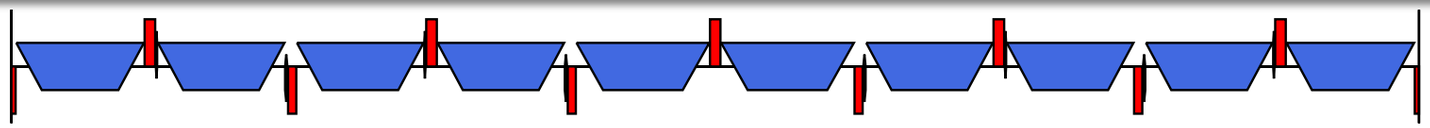
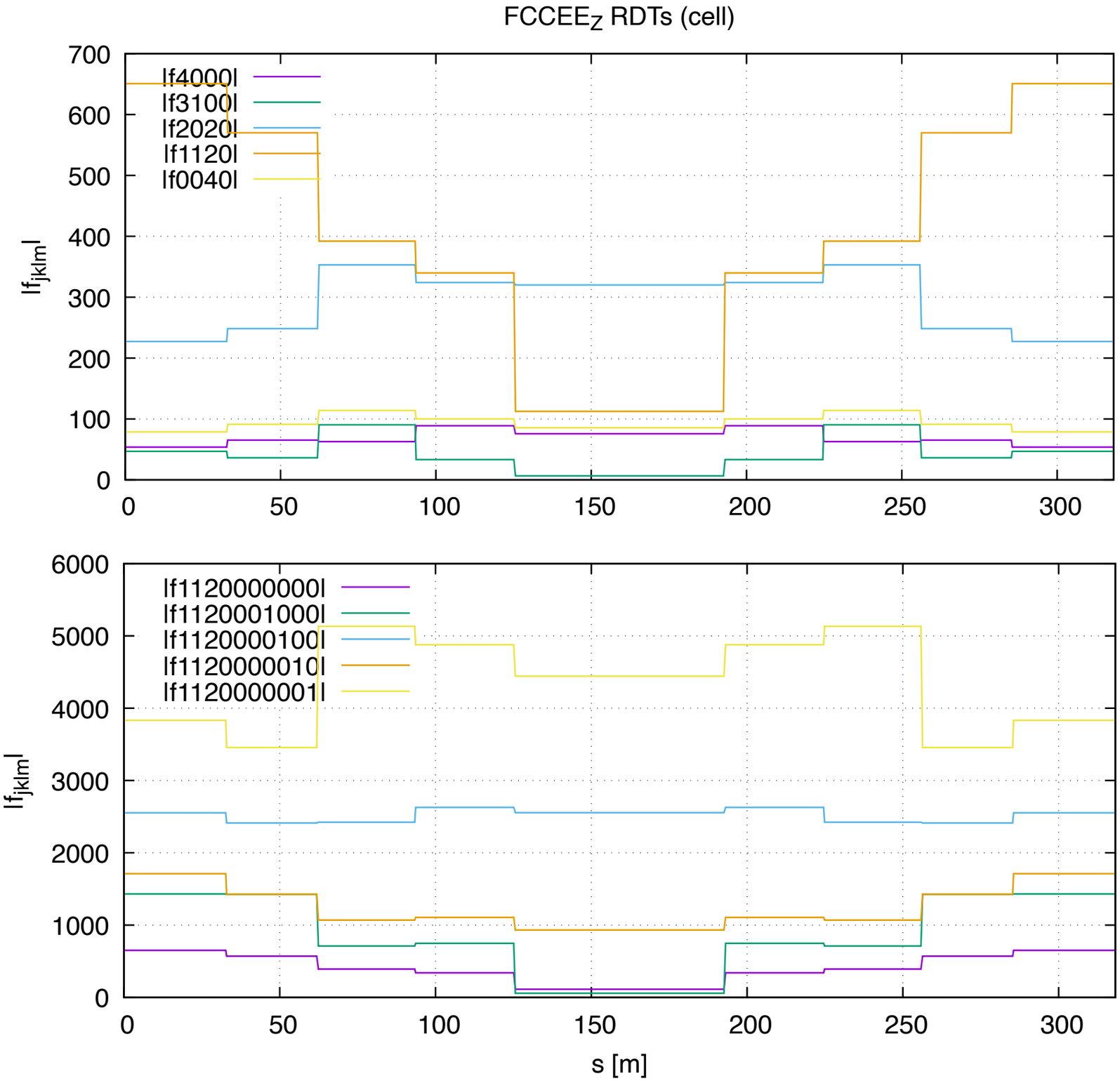
FCC-ee P-RDTs (cell-f1120)






```
ksffam1 =  0.2754240
ksdfam1 = -0.2714880
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ksdfam2 = -0.1515000
```

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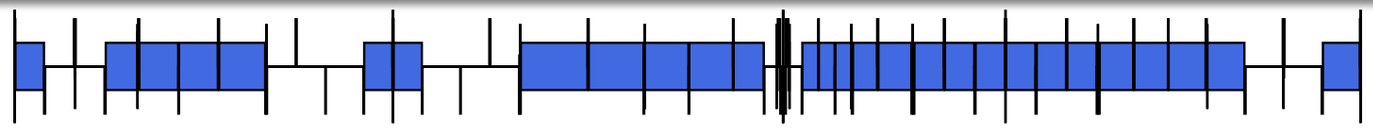
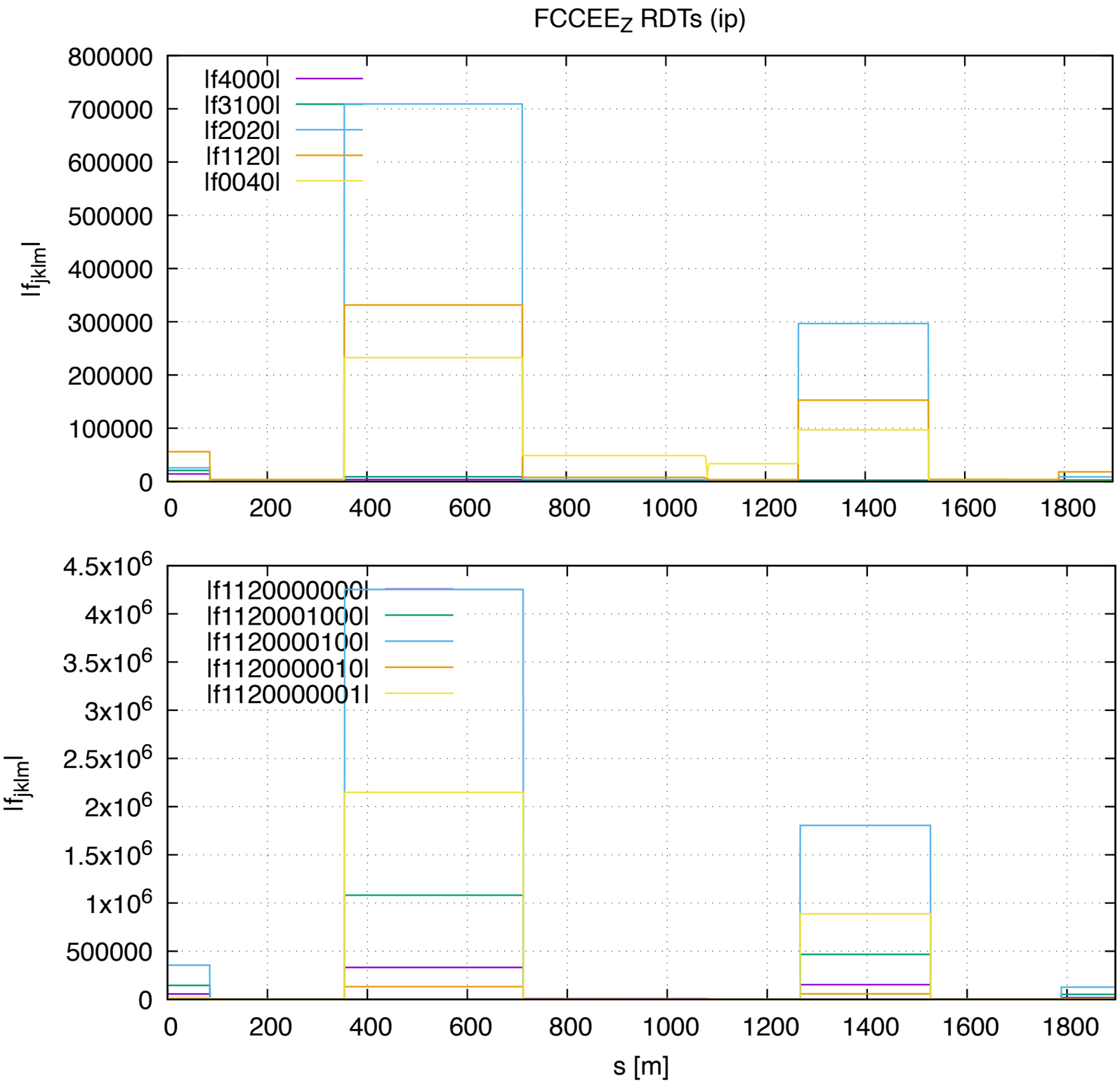
FCC-ee P-RDTs (ip-f1120)



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ksffam1 =  0.2754240
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ksdfam2 = -0.1515000
```


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Conclusions

- **Purpose of the work**
  - ➡ Give a quick & fun try to Pantaleo's FCCee optics provided by Ghislain.
  - ➡ This work was completed in a couple of hours with MAD-NG.
  - ➡ The LINE extension was also added and tested in one hour to MAD-NG parser.
- **Pantaleo's lattice and optics V24.3_Z**
  - ➡ Very compact and globally symmetric design (use LINE).
  - ➡ "Easy" to understand, maximise "cell" reuse, can switch from 2 to 4 sextupole families.
  - ➡ Arcs are very robust to 4^{th} order RDTs.
  - ➡ IPs are also good for 4^{th} order RDTs but quite sensitive.
  - ➡ 4^{th} order RDTs can be "optimised" almost everywhere by tuning sextupoles.
- **Further steps**
  - ➡ RF-cavities on (done) + synchrotron radiation — need more work and checks.
  - ➡ Add solenoid, cross-check with XSuite (same physics) — easy.
  - ➡ Add misalignments and check sensitivity to RDTs — easy.
  - ➡ Add ground waves oscillations — easy.
  - ➡ Give a try to optimise even better the RDTs when combined e.g. with misalignments.

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