HL-LHC: Towards updated baseline for Run4

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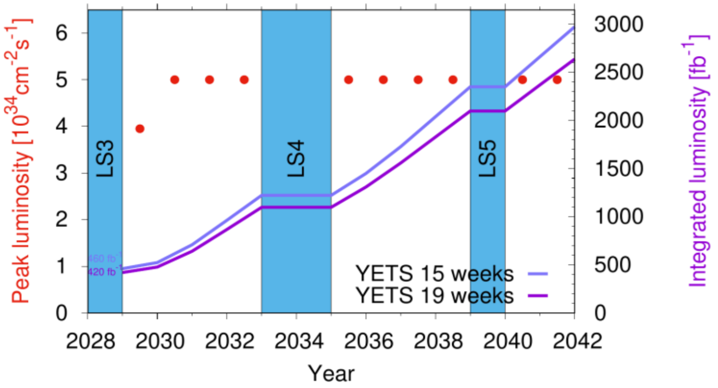
Baseline HL-LHC schedule and Run 4 ramp-up



Baseline HL-LHC schedule and performance for ATLAS/CMS. Heavy ion runs are considered at the end of each year.

Assuming 2748 bunches, 2.3 10^{11} ppb, 2.5h turn-around time, 50% operational efficiency* (or 40% stable-beam efficiency for 7h stable beam duration).

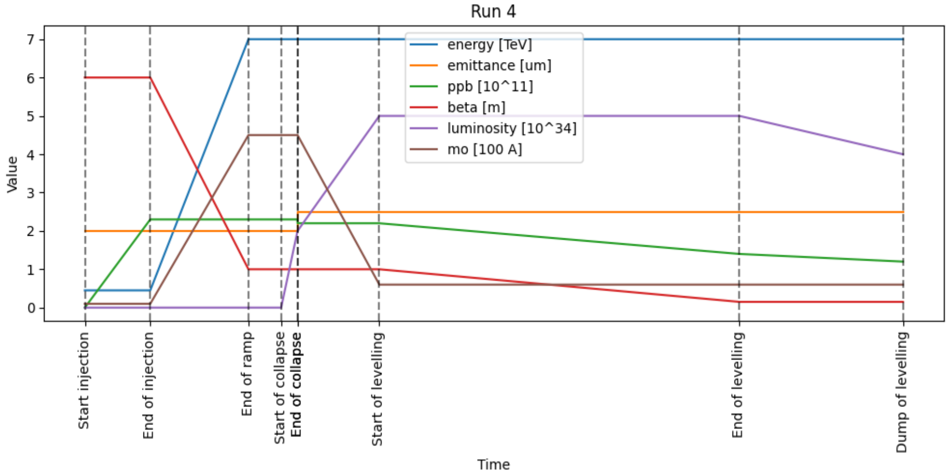
Run 4 aims at approaching 250 fb^{-1} in the last year after ramping up phase for a total of 750 fb^{-1}.

15 Weeks EYETS	pp	Yets	Commissioning	Scrubbing	Ion + comm.	Op. efficiency	∫ L dt	Pile-up
	[days]						[fb^{-1}]	
2029	90	105	80	10	34	0.4	64	120
2030	120	105	60	2	34	0.5	185	140
2031	160	105	25	2	34	0.5	254	132
2032	160	105	25	2	34	0.5	260	132
Run 5 avg	172	105	27	2.5	34	0.5	280	132
Run 6 avg	190	105	25	2.5	34	0.5	309	132

*Op. efficiency = ideal stable beam duration + turn-around/allocated time;
SB efficiency = ideal stable beam duration/allocated time

This table is being reviewed by taking into account the new schedule!

Run 4 scenarios



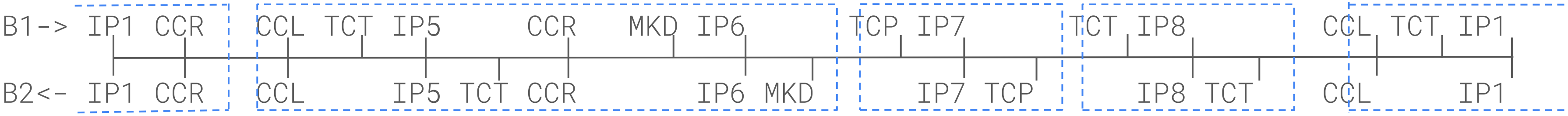
Example cycle evolution (not to scale).

The collapse process has a lot of uncertainties, therefore assume an unrealistic step function for ε and ppb to study a pessimistic collapse scenarios. At the same time we should also qualify the optimistic and middle case, to understand the extent of the margins.

News from previous baseline:

1) No e-lens:
   a) Point 4 optics not optimal anymore
   b) Improve Crab TCP phase advance
   c) Better tails for impedance
2) BETS upgrade:
   a) TCDQ gaps can change at flat top (like TCTs), no more tight constraints in TCDQ beta
3) Impedance unknowns: crab needs a comb filter (~+20 A) and if does not work (~+100A) to stabilize beam during collapse
   a) Need to use improved IR7 optics
   b) Need to decrease beta at crabs
   c) Be compatible with relaxed TCPs
4) MS10 in allows to consider larger ATS factor and flat optics to increase performance:
   a) Increase virtual lumi with flat beta* at the end of levelling
5) Proven effectiveness of phase advance optimization:
   a) Factor in lessons learned at injection and flat top.

Phase advance constraints



15 cm baseline [unit 2 pi]

CC-TCP	**B1 Left**	**B1 Right**	**B2 Left**	**B2 Right**
CC1 H	46.25	45.74	15.58	16.08
CC5 V	14.56	14.05	44.85	45.4
MKD-TCT	**B1 MKD.A**	**B1 MKD.0**	**B2 MKD.A**	**B2 MKD.0**
TCTH1	23.49	23.5	38.45	38.46
TCTH5	54.42	54.43	7.41	7.42
TCTH8	15.51	15.53	46.66	46.67
TCP-TCT	**B1 H**	**B1 V**	**B2 H**	**B2 V**
TCT1	16.07	15.77	46.23	44.91
TCT5	47	45.76	15.19	14.96
TCT8	8.09	7.72	54.44	52.77

Constraints

CC-TCP
Below 30° mod 180°

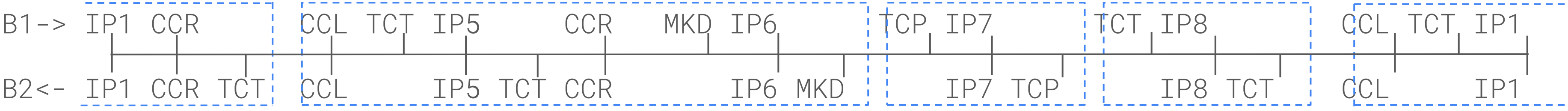
→ Particularly needed for tight settings

MKD-TCT
Below 20° mod 180°

TCP-TCT
Below 25° or in
70°-110° mod 180°

→ Particularly needed for relaxed settings

Phase advance constraints



15 cm baseline [unit degree]

CC-TCP	**B1 Left**	**B1 Right**	**B2 Left**	**B2 Right**
CC1 H	88.21	86.76	28.77	29.93
CC5 V	21.19	19.74	-52.65	-36.87
MKD-TCT	**B1 MKD.A**	**B1 MKD.0**	**B2 MKD.A**	**B2 MKD.0**
TCTH1	-4.85	1.35	-18.7	-14.74
TCTH5	-29.87	-23.67	-30.97	-27
TCTH8	3.55	9.74	57.16	61.12
TCP-TCT	**B1 H**	**B1 V**	**B2 H**	**B2 V**
TCT1	23.75	-81.71	81.78	-31.38
TCT5	-1.27	-85.69	69.52	-13.25
TCT8	32.14	77.75	-22.36	-82.54

Constraints

CC-TCP
Below 30° mod 180°

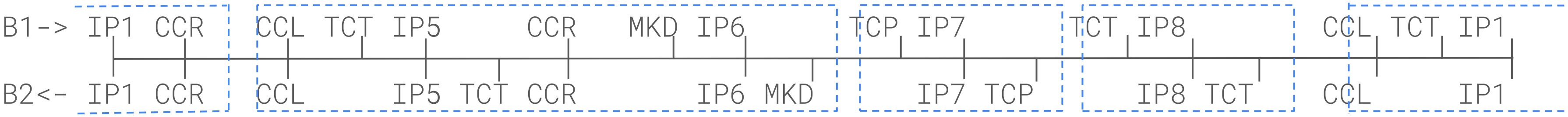
MKD-TCT
Below 20° mod 180°

TCP-TCT
Below 25° or in
70°-110° mod 180°

Freedom

- Arc 23,34, 67, 78
- IR 2, 8, 3, 4

Phase advance constraints



15 cm optimized [unit degree]

CC-TCP	B1 Left	B1 Right	B2 Left	B2 Right
CC1 H	16.21	14.76	13.87	15.02
CC5 V	21.19	19.74	6.16	7.55
MKD-TCT	B1 MKD.A	B1 MKD.0	B2 MKD.A	B2 MKD.0
TCTH1	-4.75	1.45	-18.67	-14.71
TCTH5	-29.77	-23.57	-30.94	-26.97
TCTH8	4.27	10.47	48.58	52.54
TCP-TCT	B1 H	B1 V	B2 H	B2 V
TCT1	-84.25	-81.71	-83.31	-75.79
TCT5	70.73	-85.69	84.42	-72.06
TCT8	-75.23	77.45	-16.07	50.96

Constraints

CC-TCP
Below 30° mod 180°

MKD-TCT
Below 20° mod 180°

TCP-TCT
Below 25° or in
70°-110° mod 180°

Freedom

- Arc 23, 34, 67, 78
- IR 2, 8, 3, 4

Using MQTF/D at <95 T/m

But without IR8, IR4, etc…

Beta* options

	Point 1 and 5 βx/βy* [m]			Point 8
Optics case	**Flat Option 1**	**Flat Option 2**	**Back-up**	
Injection	6	6	6	10
Collapse	0.7/2.8	0.9/1.8	1.1	1.5
End of levelling 2029	0.15/0.60	0.25/0.50	0.3	1.5
End of levelling 2030	0.10/0.40	0.15/0.30	0.2	1.5
End of levelling 2031-32	0.09/0.18	0.09/0.18	0.15	1.5
MD 2029-2030	0.075/0.18	0.075/0.18	0.15	0.5/1.5*
MD 2024-2025	0.3/0.72**	0.3/0.72**	0.6**	1.5
MD 2024-2025	2	2	2	0.5/1.5

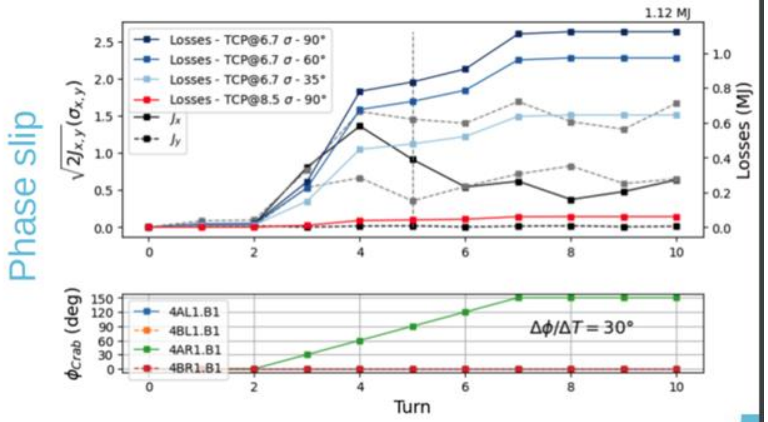
*if LHCb upgrade approved for Tun   ** same ATS factor as 0.075/0.18 cm (pre-squeeze 2m)

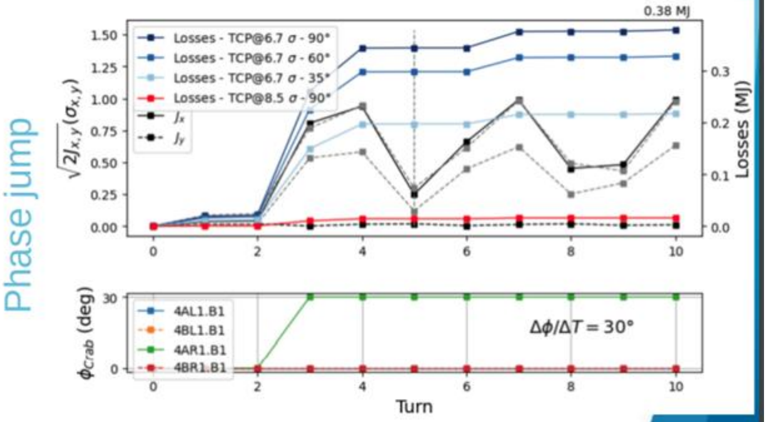
- Flat ratio and ATS factors choice pending DA results.
- Anti-ATS for the collapse is better to forward physics, but relies more on BETS upgrade.
- Further reduction of beta at the crab at collapse could be envisaged at the cost of initial changes of transport for forward physics. New IR7 optics to be added in the ramp.
- Tight settings probably needed for most pushed beta*, new aperture estimates on-going, ideally waiting from b.s. Production.
- Optics to be compatible both 6.8 TeV and 7 TeV (although we may miss some optimizations)

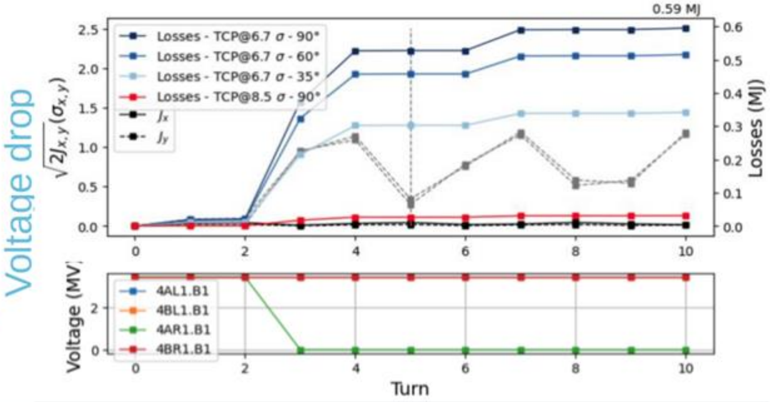
Back-up

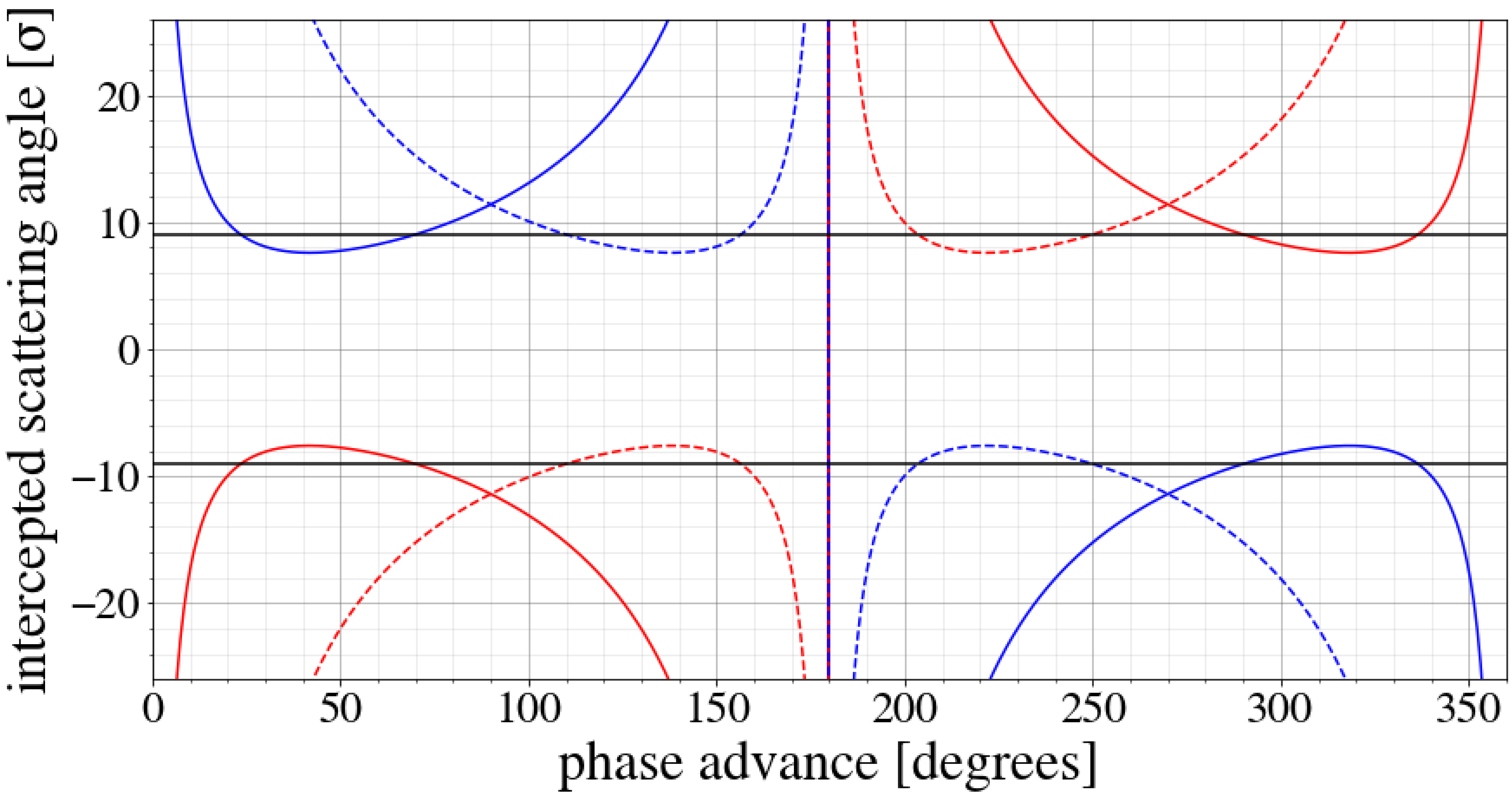
Crab Cavity failure: worst cases 4AR1.B1

- **Phase slip**
  - Phase change in one crab cavity over 5 turns by **30 degree per** turn (based on recent experience from the SPS test stand)
  - Shift of centre of bunch by **1.4 sigma** within two turns after the start of the failure
  - **Up to 1.12 MJ lost** after 10 turns (0.8 MJ after 3 turns)
- **Phase jump**
  - Phase change of **30 degree in one turn**
  - Shift of centre of bunch by **1.0 sigma** within two turns after the start of the failure
  - Up to 0.38 MJ lost within 10 turns (0.35 MJ after 3 turns)
- **Voltage drop**
  - Drop of voltage to **zero within one turn**
  - Up to 0.59 MJ lost within 10 turns (0.5 MJ after 3 turns)

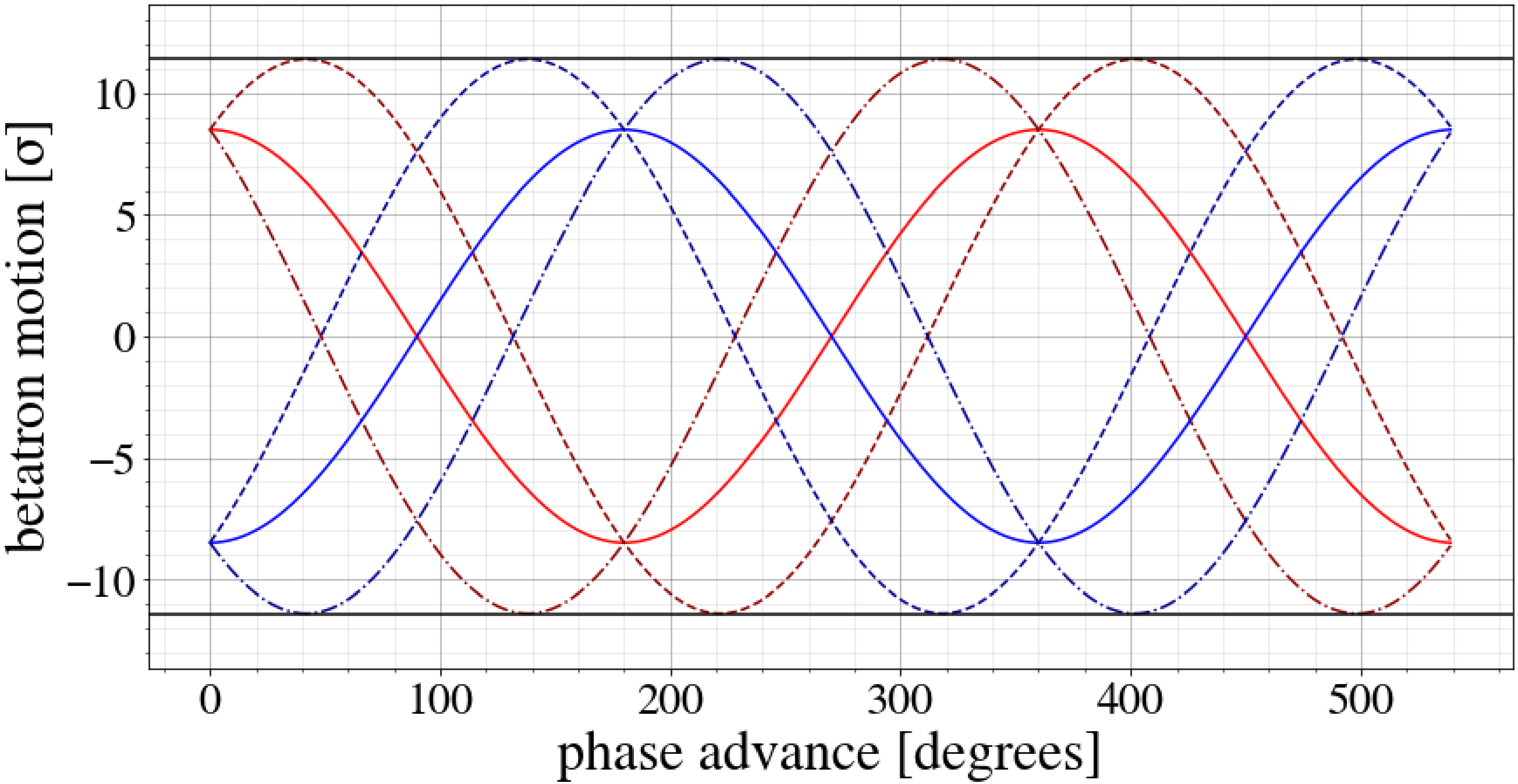








intercepted scattering angle [σ]
20
10
0
−10
−20
0
50
100
150
200
250
300
350
phase advance [degrees]



10
5
0
−5
−10
betatron motion [σ]
0
100
200
300
400
500
phase advance [degrees]