Collimation studies for Run IV

B. Lindström

Thanks to A. Abramov, R. Bruce, R. De Maria, J. Molson, P. Hermes , S. Redaelli, F. van der Veken

24th August 2021 – WP2/WP5 joint section meeting

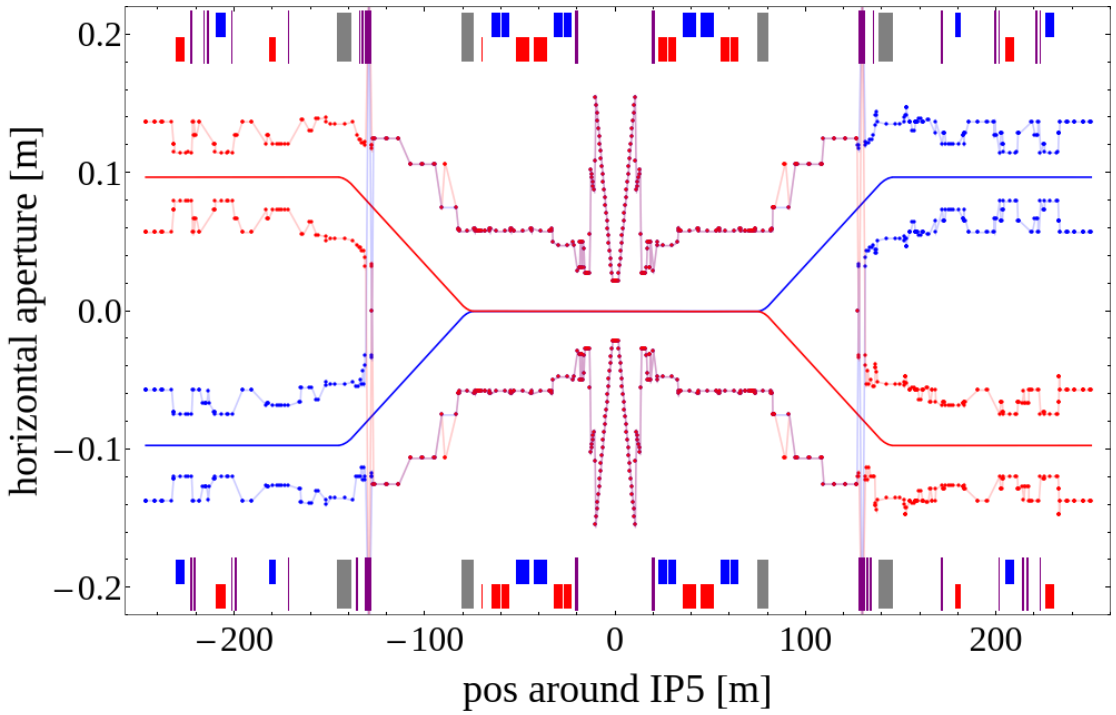
Introduction

- Previous HLLHC **beam loss** studies based on **v1.3 optics**
- **v1.5 (latest)** introduces several differences:
  - Optics
  - IR1/IR5 element positions up to half-cell 4
  - TCL.5R{1,5} and TCT.6L{1,5} positions
  - DFXJ, D2 lengths
  - 2x Crab cavities per beam/IP/side removed
  - D2 aperture
  - 11T dipole moved from cell 8 to 9
  - 1 MQWA in IR7 removed, pos of remaining changed
  - ...
- Aperture improved using **layout database***
- **Relaxed collimator settings** requested by WP2 for beam stability
  - Tentative settings under study
- **TCLD** most likely not available (runIV)
  - Must be confirmed that **DS quench limit** compatible with **relaxed collimator settings**
- Simulations discussed at ColUSM #143 (https://indico.cern.ch/event/1058294)

*layout.cern.ch

Aperture model

- Sources:
  - MAD-X files on AFS
  - Inherited file with VSS/BPM markers
  - Layout database



- ToDo:
  - LayoutDB requires some patches: inconsistent positions, aperture definitions, extensive yet incomplete
  - LHCb VELO+SMOG not available
  - ALICE experimental pipe aperture change not available

https://gitlab.cern.ch/collteam/generate_aperture/-/tree/master/HLLHC/v1p5

Collimator Settings ($\epsilon_n = 2.5\mu m \cdot rad$)

	TDR Baseline (tight settings)	Relaxed Settings		
	15 cm β*	15 cm β*	20 cm β*	100 cm β*
TCP IR7	**6.7**	**8.5**	8.5	8.5
TCS IR7	**9.1**	**10.1**	10.1	10.1
TCLA IR7	**12.7**	**14.0**	**13.7**	**13.7**
TCLD IR7	**16.6**	**n/a**	n/a	n/a
TCP IR3	17.7	17.7	17.7	17.7
TCS IR3	21.3	21.3	21.3	21.3
TCLA IR3	23.7	23.7	23.7	23.7
TCS IR6	**10.1**	**11.1**	**11.1**	**11.1**
TCDQ IR6	**10.1**	**11.1**	**11.1**	**11.1**
TCL IR1/5	14.2	14.2*	16.4*	38 – 44*
TCT IR1/5	**10.4**	**11.4***	**13.2***	**23 – 35***
Prot. Aperture IR1/5	**11.8**	**12.8**	**14.6**	**>24.4**
TCT IR2	43.8	43.8	43.8	43.8
TCT IR8	17.7	17.7	17.7	17.7
TDIS	park	park	park	park
TCLD IR3	park	park	park	park

* gap in mm is set to final (15 cm) value and kept constant throughout squeeze

See ”Run 4 proton operational scenario” (in preparation) for more details

Collimator Settings ($\epsilon_n = 2.5\mu m \cdot rad$)

	TDR Baseline (tight settings)		Run IV	
	15 cm β*	15 cm β*	20 cm β*	100 cm β*
TCP IR7	6.7	8.5	8.5	8.5
TCS IR7	9.1	10.1	10.1	10.1
TCLA IR7	12.7	14.0	**13.7**	**13.7**
TCLD IR7	16.6	n/a	n/a	n/a
TCP IR3	17.7	17.7	17.7	17.7
TCS IR3	21.3	21.3	21.3	21.3
TCLA IR3	23.7	23.7	23.7	23.7
TCS IR6	10.1	11.1	11.1	11.1
TCDQ IR6	10.1	11.1	11.1	11.1
TCL IR1/5	14.2	14.2*	**16.4***	**38 – 44***
TCT IR1/5	10.4	11.4*	**13.2***	**23 – 35***
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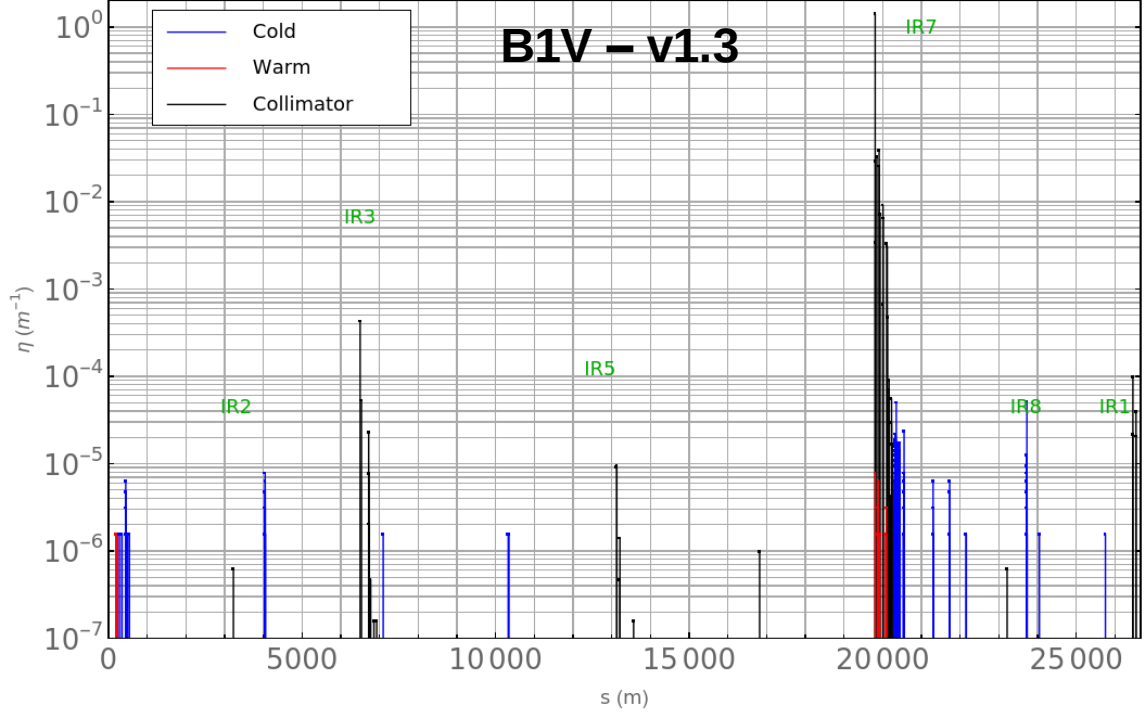
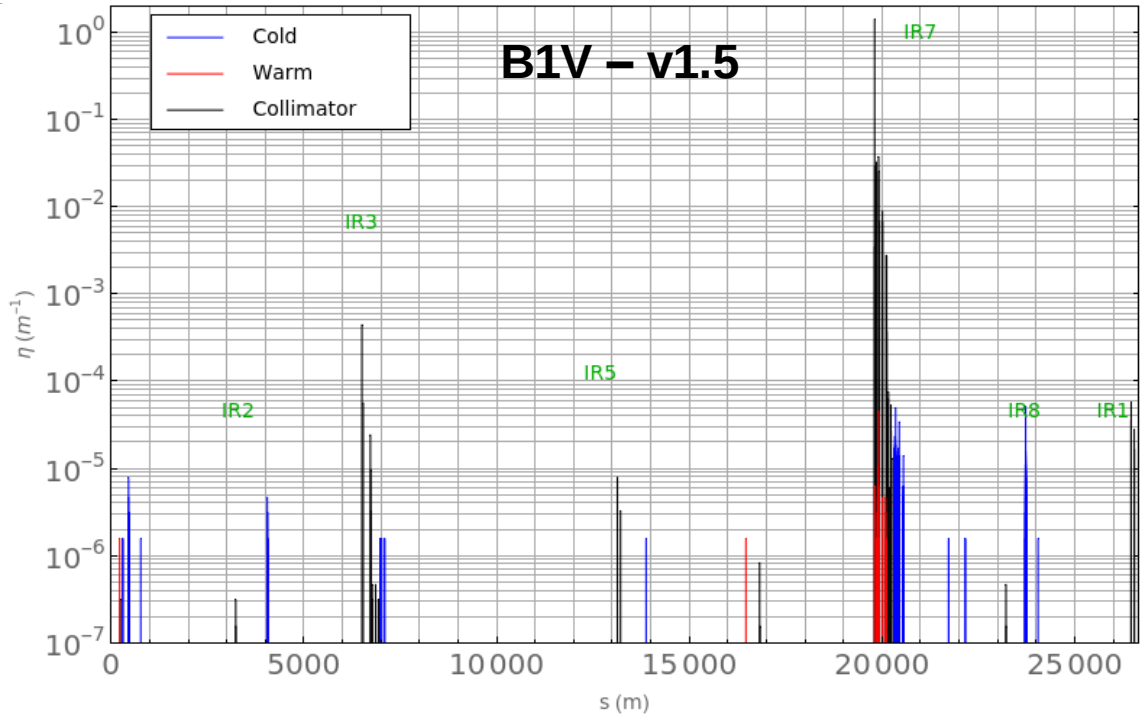
Optics version comparison – v1.3 vs v1.5





Present baseline with tight collimator settings

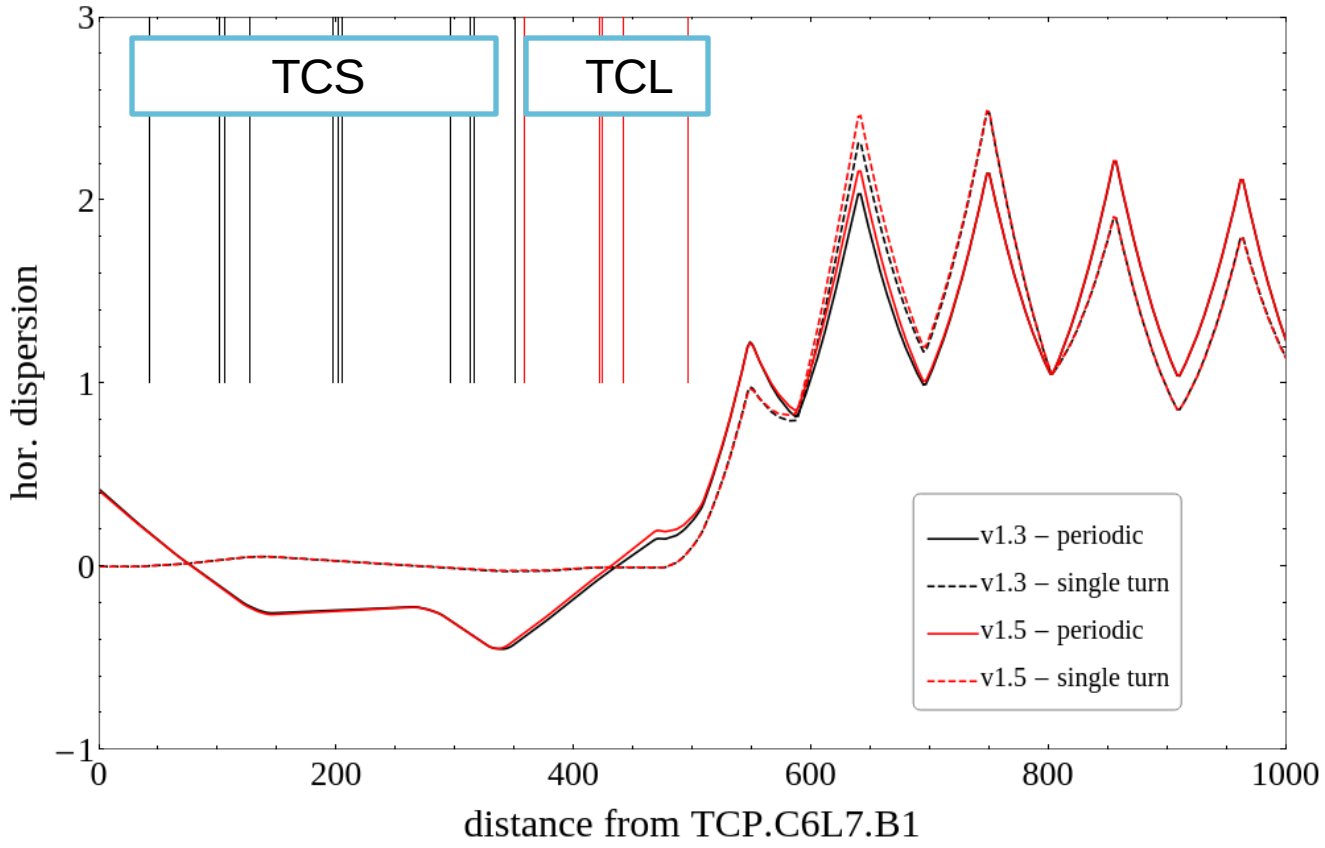
- Nominal optics (15 cm β*)
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

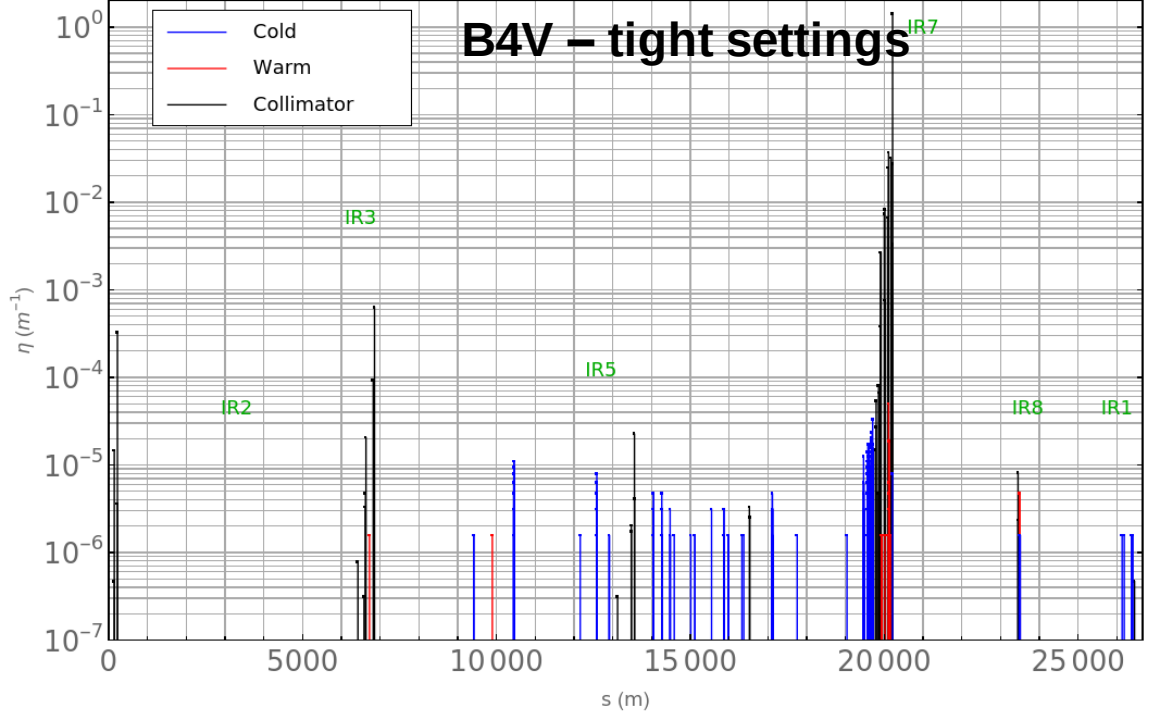
- Collimator loss distributions consistent, except for some TCT losses
- b1: ~15 % more DS losses in v1.5
  n.b. b2 is worse than b1 in v1.3 but similar in v1.5
- Max warm losses larger in v1.5, b1&b2
  - possibly due to more detailed aperture

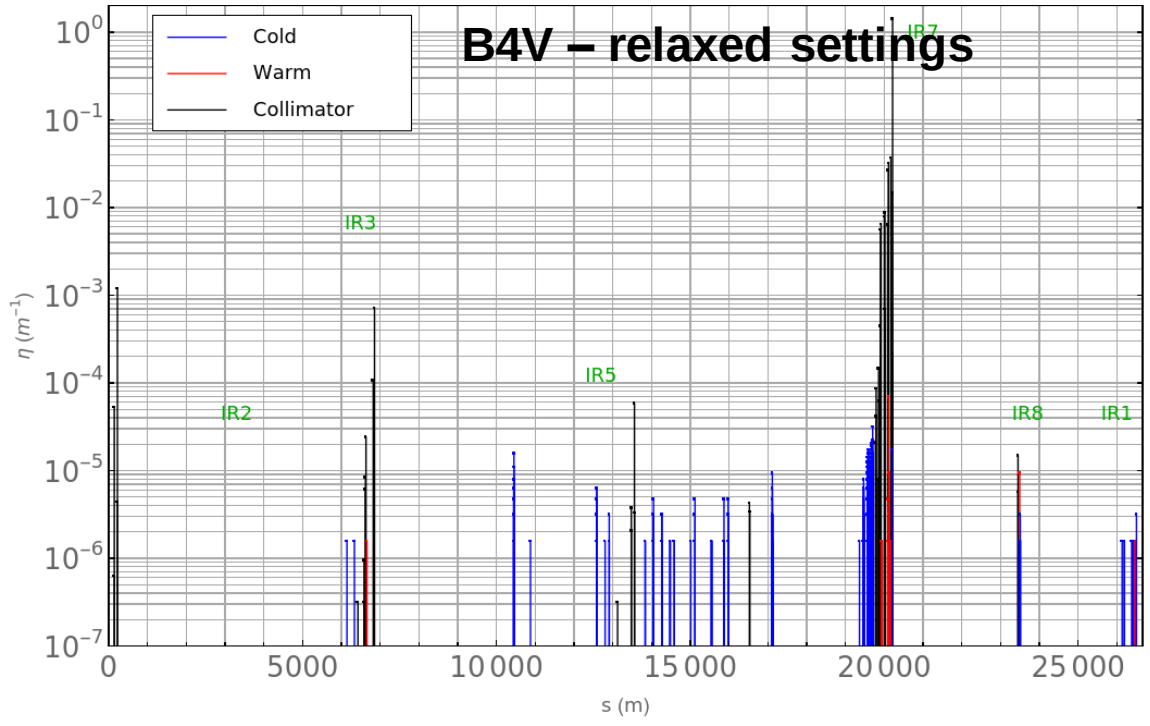
Increase of IR7 DS losses

- Larger dispersion in IR7 DS could explain increase – further validations ongoing
- Beta functions also different



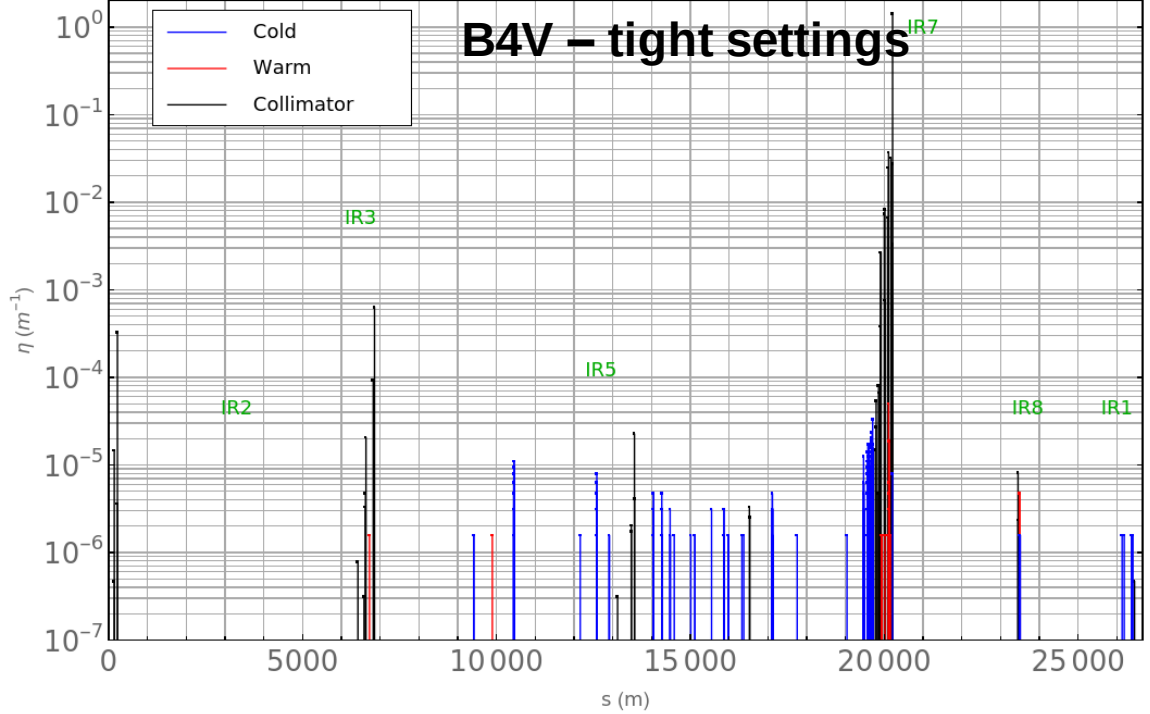
Collimator settings comparison – Tight Settings vs Relaxed Settings

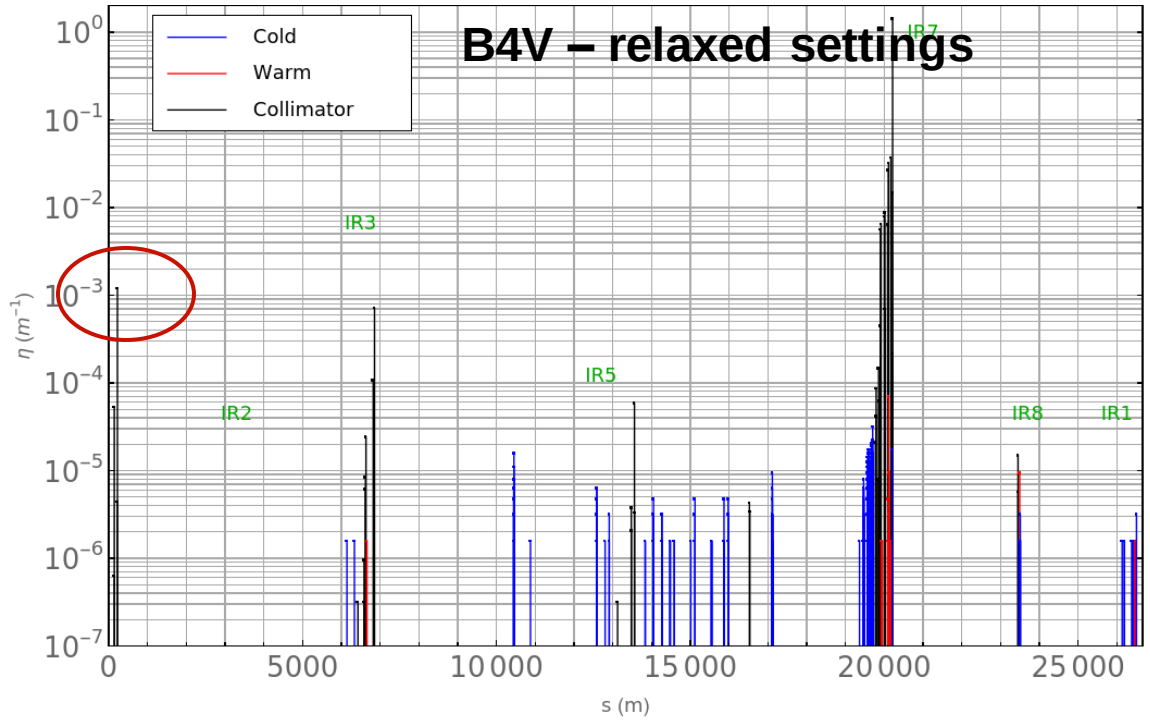




Tight vs Relaxed collimator settings

- Nominal v1.5 optics (15 cm β*), Impact: 4 µm, 6.4e6 particles / 200 turns
- ~10 % worse global inefficiency with relaxed settings
- ~7 % larger DS losses with relaxed settings



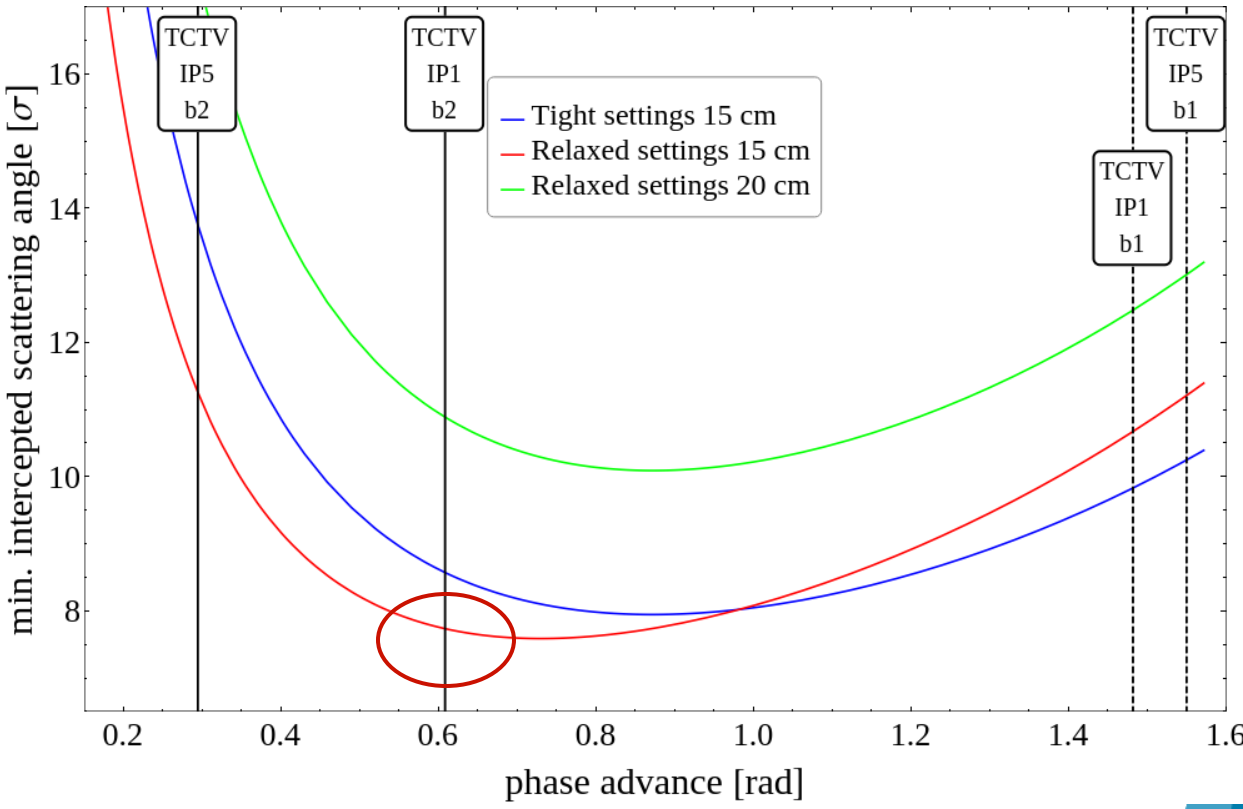


Tight vs Relaxed collimator settings

- Nominal v1.5 optics (15 cm β*), Impact: 4 µm, 6.4e6 particles / 200 turns
- ~10 % worse global inefficiency with relaxed settings
- ~7 % larger DS losses with relaxed settings
- **B4V TCT losses** in IR1 reach **1.2e-3**

Normalized cut on scattering angle

- TCP to IR1 TCT phase advance almost optimal with new collimator settings
- Not a concern at 20 cm

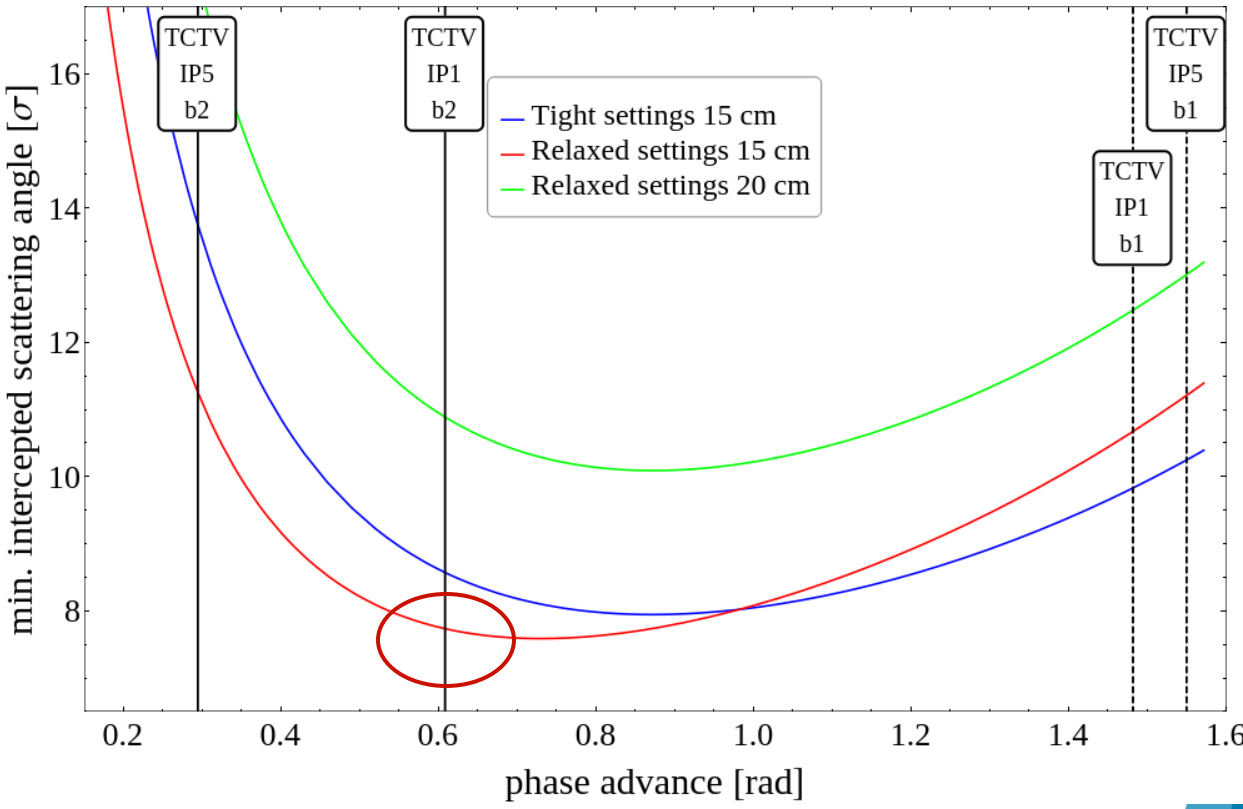


Normalized cut on scattering angle

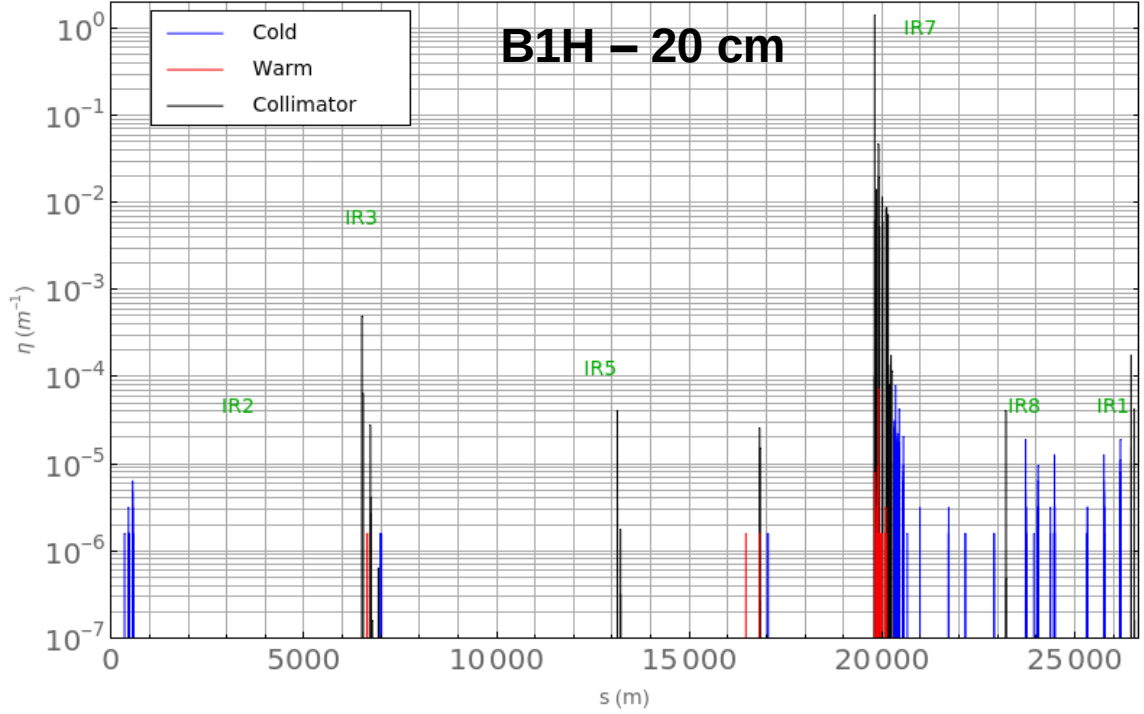
- TCP to IR1 TCT phase advance almost optimal with new collimator settings
- Not a concern at 20 cm

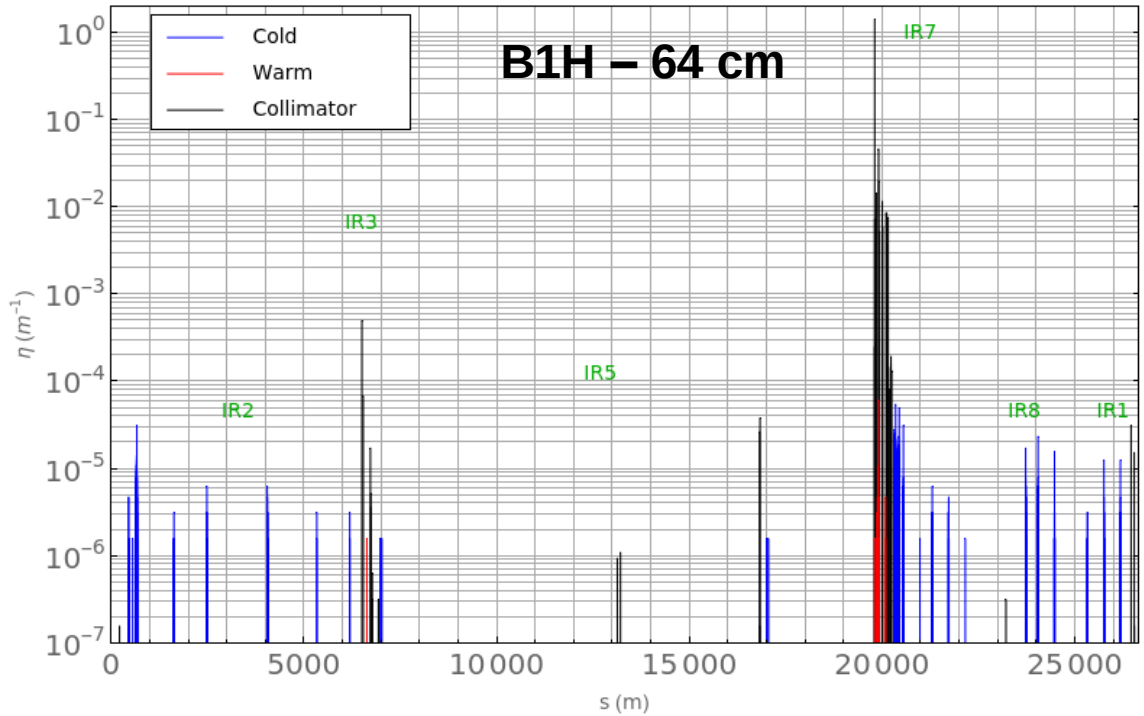
Solutions if relaxed settings to be used at 15 cm?

- Adjust phase advance?
- Retract TCTV in IR1 by 0.5 sigma (reduces margin in 15 cm optics)
- Insert TCP.D by 0.5 sigma (increases impedance)
- Insert TCS by 0.4 sigma (increases impedance)



20 and 64 cm β* with Relaxed Settings





Relaxed collimator settings

- v1.5 optics
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

- 20 cm results similar to 15 cm, except TCT losses
- 64 cm results similar to 20 cm, except TCT losses and inefficiency (~6 % worse)

Scenario	inefficiency [e-4]	MaxCold [e-5]	MaxWarm [e-5]	DS cl1 [e-6]	DS cl2 [e-6]	MaxTCT [e-4]
B1 v1.3 tight H/V	7.4 / 6.6	6.1 / 5.2	1.1 / 0.8	8.0 / 6.5	5.6 / 5.2	2.3 / 1.0
B1 v1.3 relaxed H/V	8.1 / 7.2	6.1 / 6.3	0.6 / 0.6	8.8 / 6.9	6.0 / 5.5	3.3 / 1.0
B2 v1.3 tight H/V	8.6 / 5.9	4.6 / 2.5	0.5 / 0.6	9.4 / 6.1	5.8 / 4.4	0.4 / 3.7
B2 v1.3 relaxed H/V	9.5 / 6.5	5.4 / 3.2	0.6 / 1.6	10. / 6.7	6.2 / 4.7	0.6 / **13**
B1 v1.5 tight H/V	8.6 / 7.1	6.9 / 5.2	5.0 / 4.5	9.2 / 6.7	6.8 / 6.0	2.3 / 0.6
B1 v1.5 relaxed H/V	9.3 / 7.7	6.9 / 6.7	9.0 / 6.6	9.9 / 7.2	7.2 / 6.4	4.0 / 0.8
B2 v1.5 tight H/V	8.8 / 6.8	4.9 / 3.3	6.7 / 5.0	9.2 / 6.5	6.4 / 5.1	0.4 / 3.2
B2 v1.5 relaxed H/V	9.9 / 7.2	5.6 / 3.2	7.3 / 7.0	10. / 6.8	7.0 / 5.5	0.6 / **12**
|---- TCP inserted V	8.1	3.8	5.9	7.4	6.5	**8.0**
|---- TCSG inserted V	6.2	1.9	5.1	5.5	4.9	**8.1**
|---- TCT relaxed V	7.3	3.8	6.0	6.7	5.7	**4.8**
B1 v1.5 relaxed TCLD	2.1 / 1.3	13. / 5.8	7.2 / 4.5	3.9 / 2.3	0.03/0.03	3.4 / 0.9
B2 v1.5 relaxed TCLD	2.0 / 1.3	14. / 8.9	6.9 / 7.6	3.4 / 2.0	0.02/0.02	0.6 / **12**
FLUKA B1 v1.5 tight*	/ 2.8	/ 3.5	/657	**/ 2.8**	**/ 2.3**	/ 0.7
FLUKA B1 v1.5 retract*	/ 3.1	/ 3.4	/699	**/ 3.0**	**/ 2.4**	/ 1.0
FLUKA B2 v1.5 tight	/ 2.4	/ 3.7	/499	**/ 2.5**	**/ 2.1**	/ 3.3
FLUKA B2 v1.5 retract	/ 2.8	/ 5.6	/572	**/ 2.3**	**/ 2.3**	/ **13**

* 1.5 µm impact parameter, the rest are 4 µm

** 15 cm beta*, results for 20 cm are similar except TCT losses

Scenario	inefficiency [e-4]	MaxCold [e-5]	MaxWarm [e-5]	DS cl1 [e-6]	DS cl2 [e-6]	MaxTCT [e-4]
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B2 v1.3 tight H/V	8.6 / 5.9	4.6 / 2.5	0.5 / 0.6	9.4 / 6.1	5.8 / 4.4	0.4 / 3.7
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B1 v1.5 tight H/V	8.6 / 7.1	6.9 / 5.2	5.0 / 4.5	9.2 / 6.7	6.8 / 6.0	2.3 / 0.6
B1 v1.5 relaxed H/V	9.3 / 7.7	6.9 / 6.7	9.0 / 6.6	9.9 / 7.2	7.2 / 6.4	4.0 / 0.8
B2 v1.5 tight H/V	8.8 / 6.8	4.9 / 3.3	6.7 / 5.0	9.2 / 6.5	6.4 / 5.1	0.4 / 3.2
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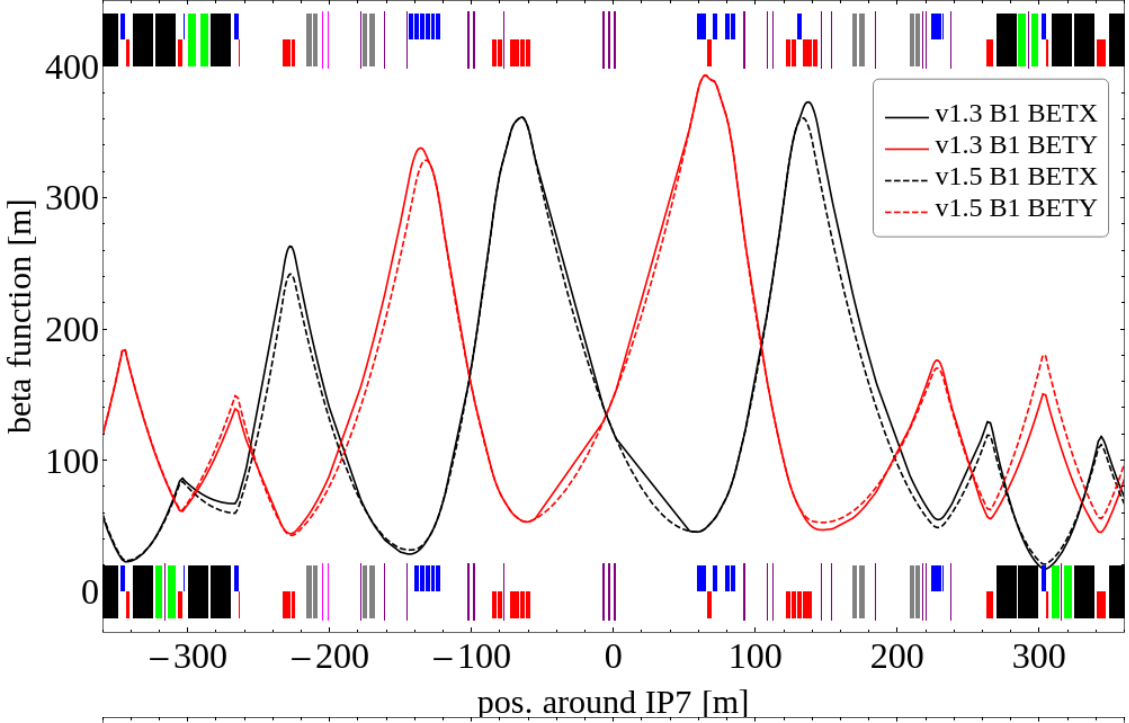
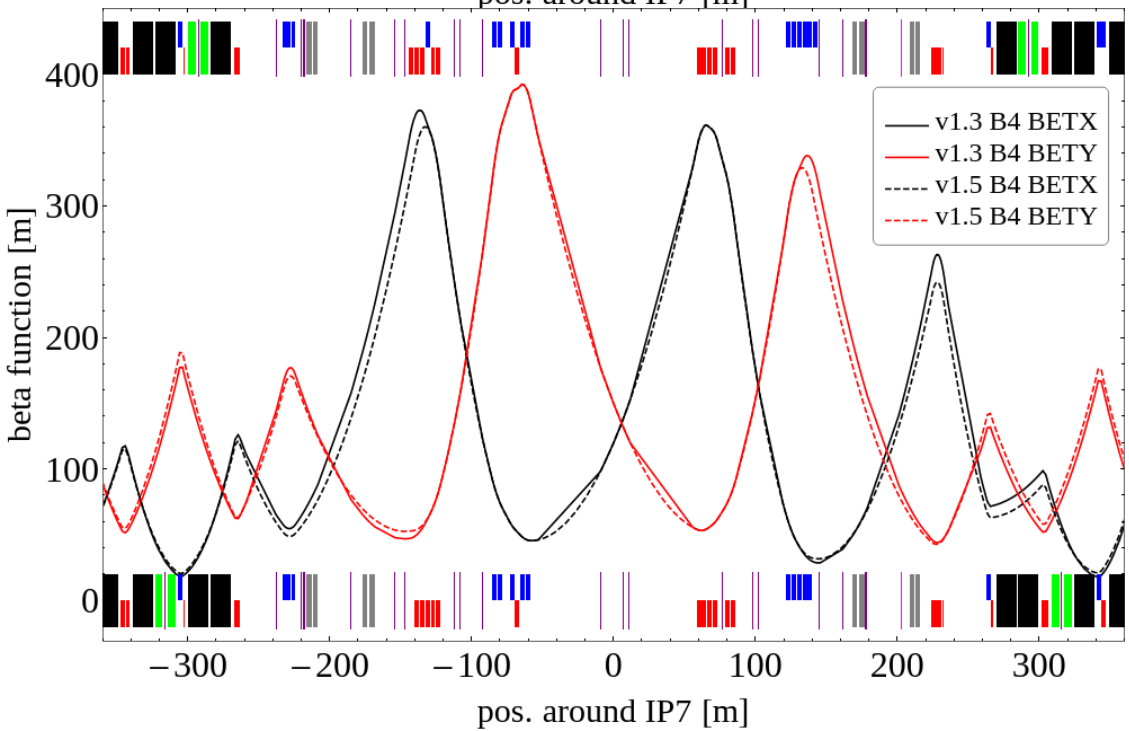
** 15 cm beta*, results for 20 cm are similar except TCT losses

Summary

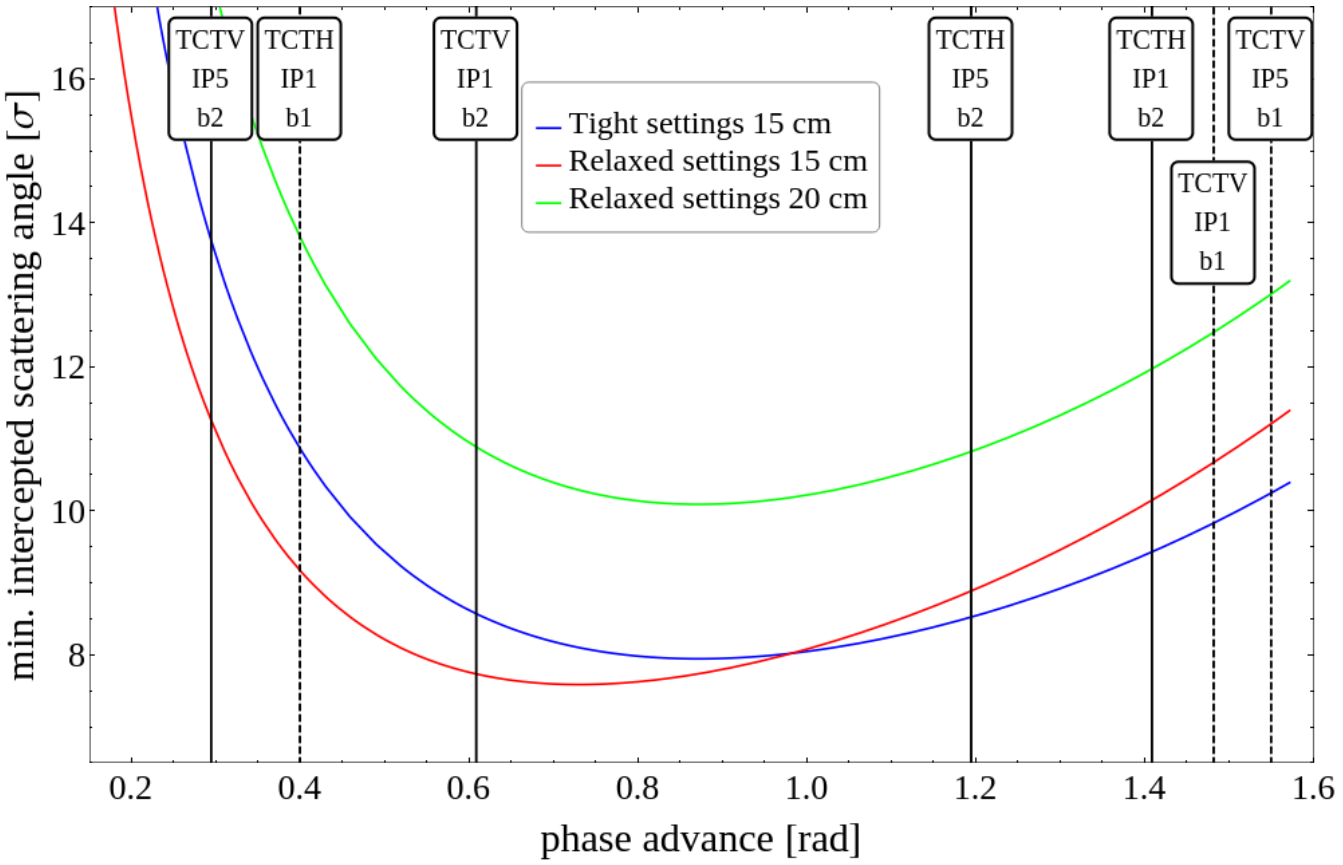
- Simulation model has been updated to v1.5 optics and a more detailed aperture has been included
  - Currently requires some patching of layoutDB aperture
  - ~15 % increase in B1 DS losses compared to v1.3 optics – under investigation
- Relaxed collimator settings have been requested and studied
  - ~7 % increase in DS losses
  - Higher TCT losses, in particular in IR1 for B4 vertical
    → solutions: retracting TCT by 0.5 sigma, inserting TCP by 0.5 sigma or inserting TCSG by 0.4 sigma
  - TCT losses are no concern for 20 cm
- Compared to v1.3 optics with tight settings, up to ~23 % increase in DS losses (B1H)
  - B1H DS losses are similar to B2H in v1.5
- Energy deposition simulations (FLUKA) should be performed before final validation

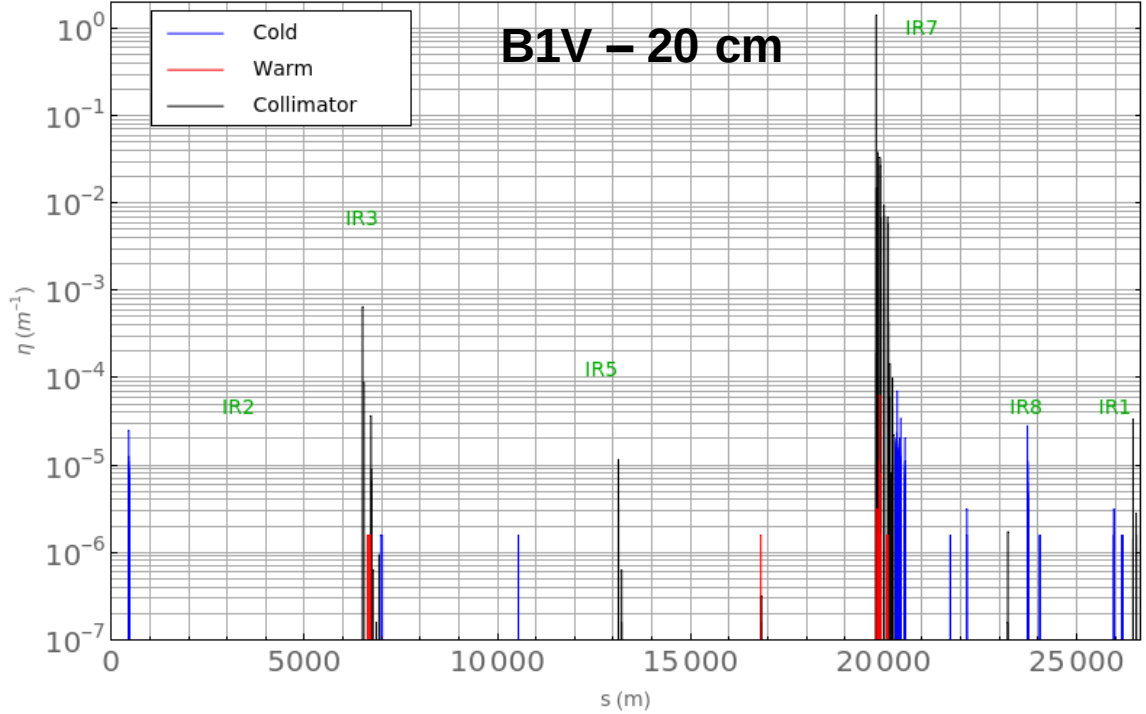
IR7 beta functions

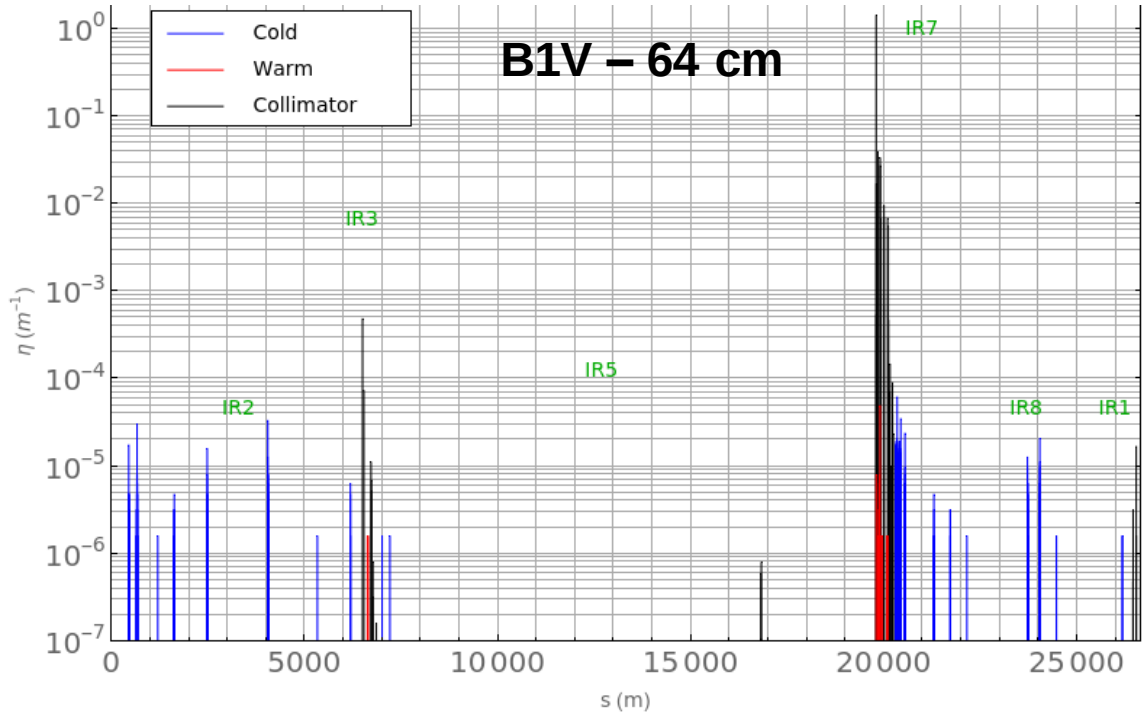




Normalized cut on scattering angle





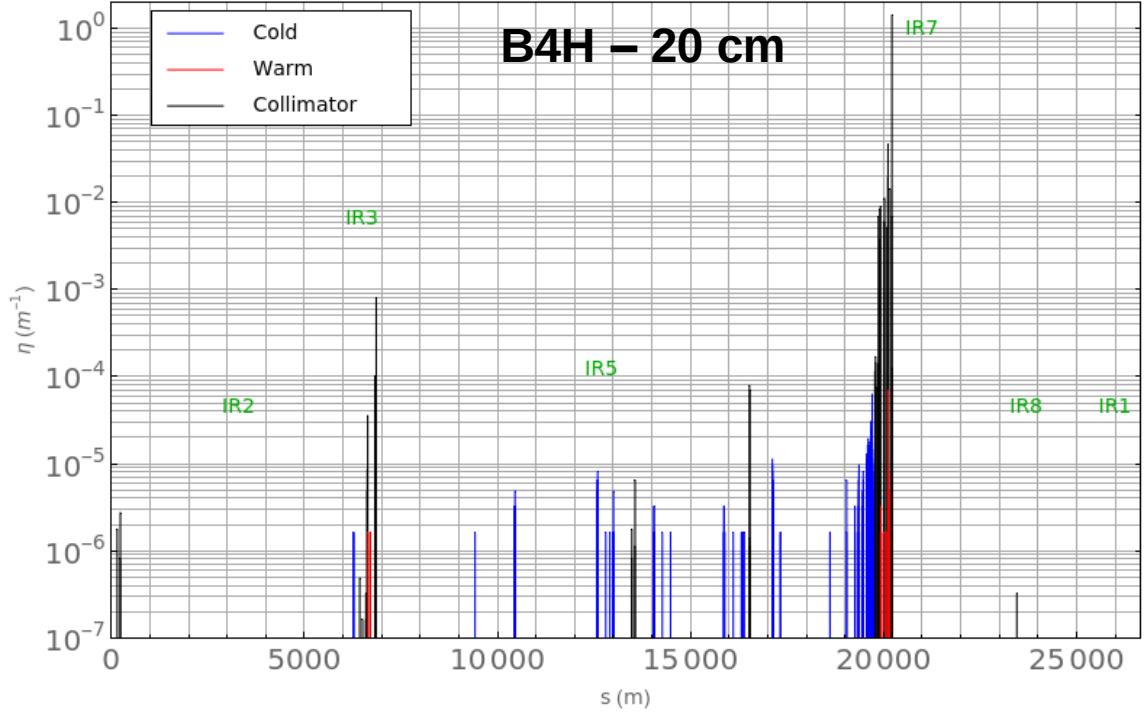


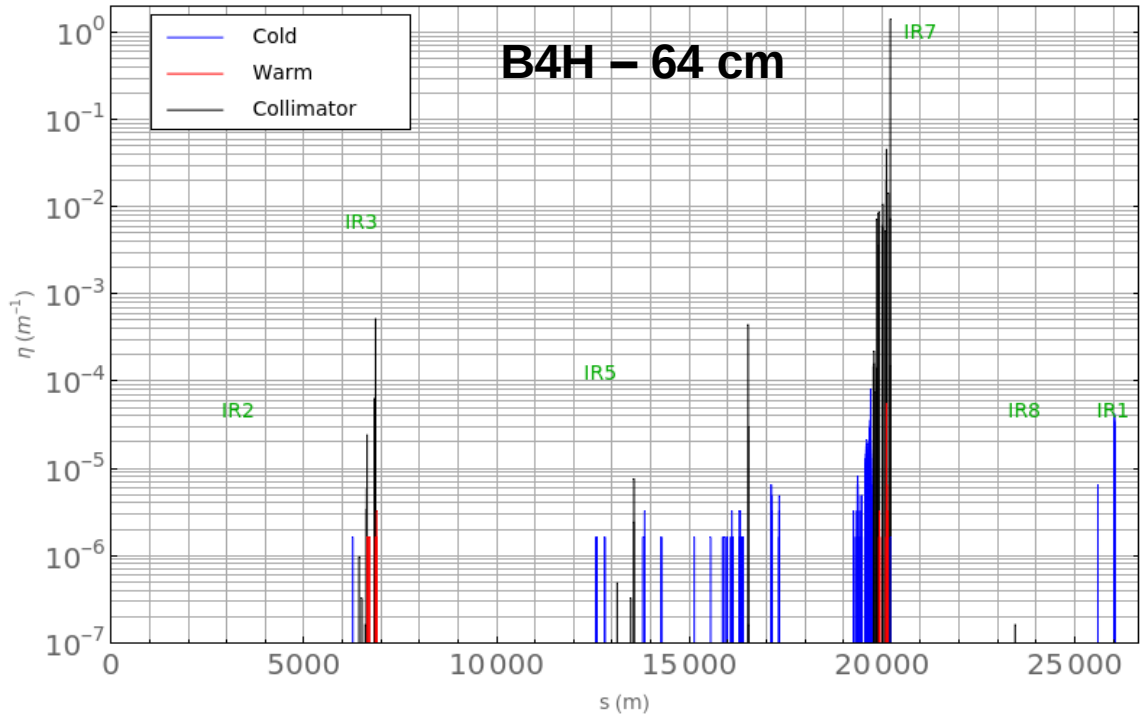
relaxed collimator settings

- v1.5 optics
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

- 20 cm results similar to 15 cm, except for TCT losses
- 64 cm results similar to 20 cm, except TCT losses and global inefficiency (~5 % worse)





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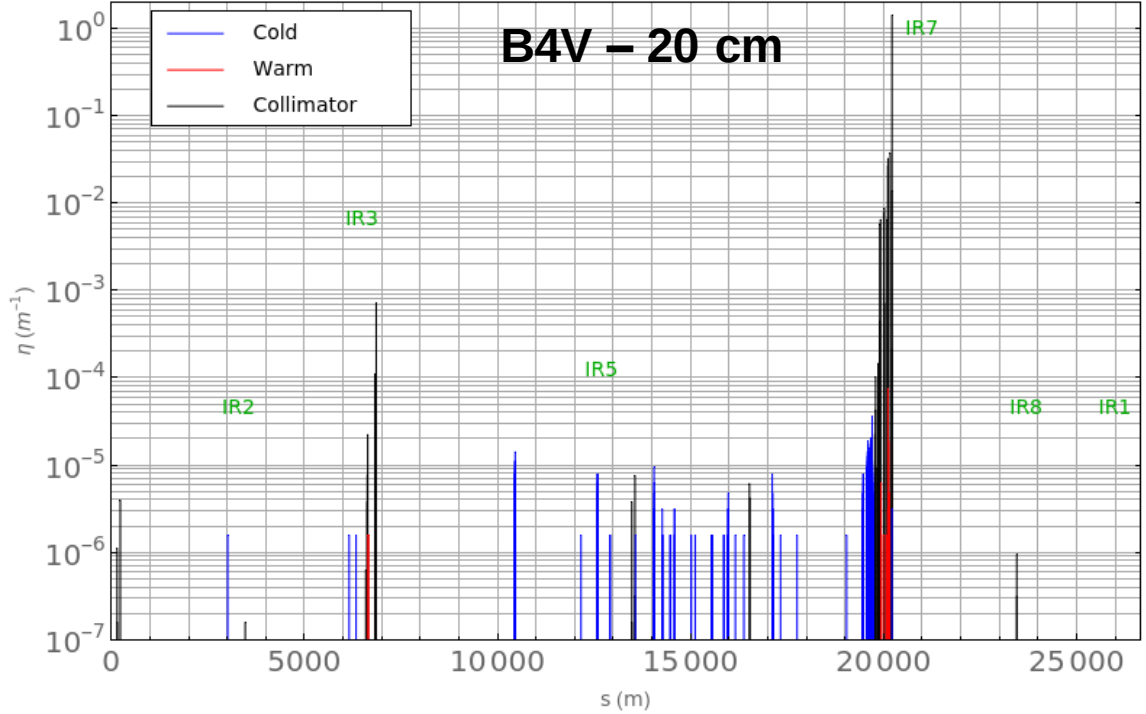

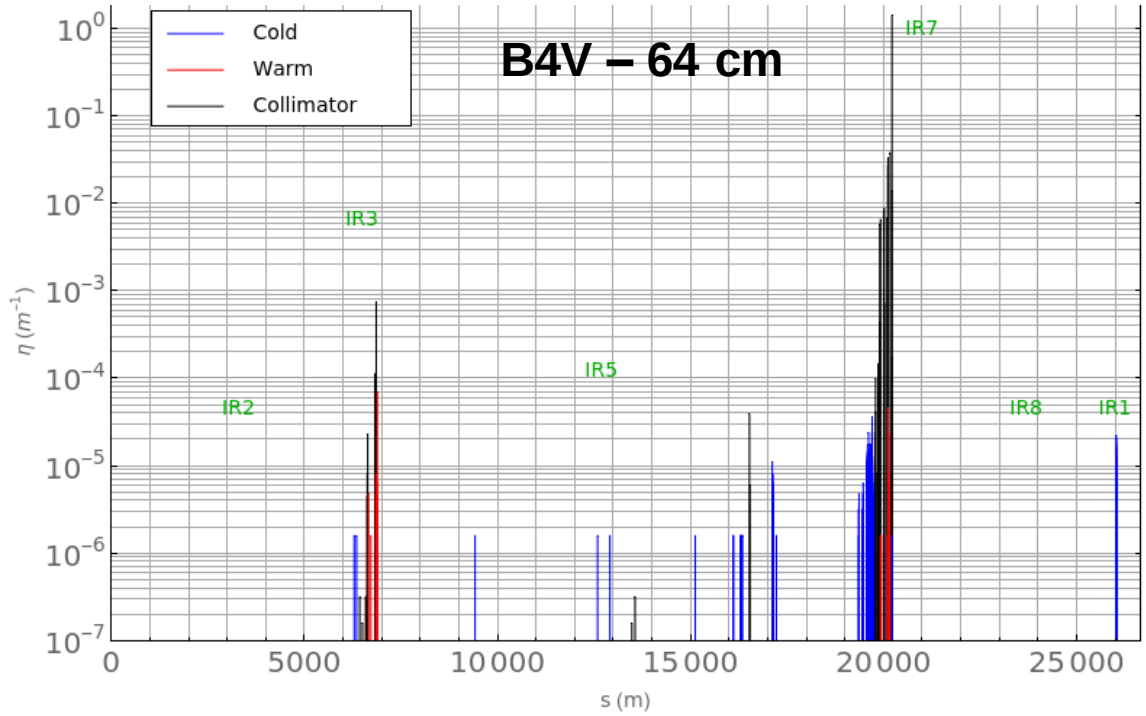

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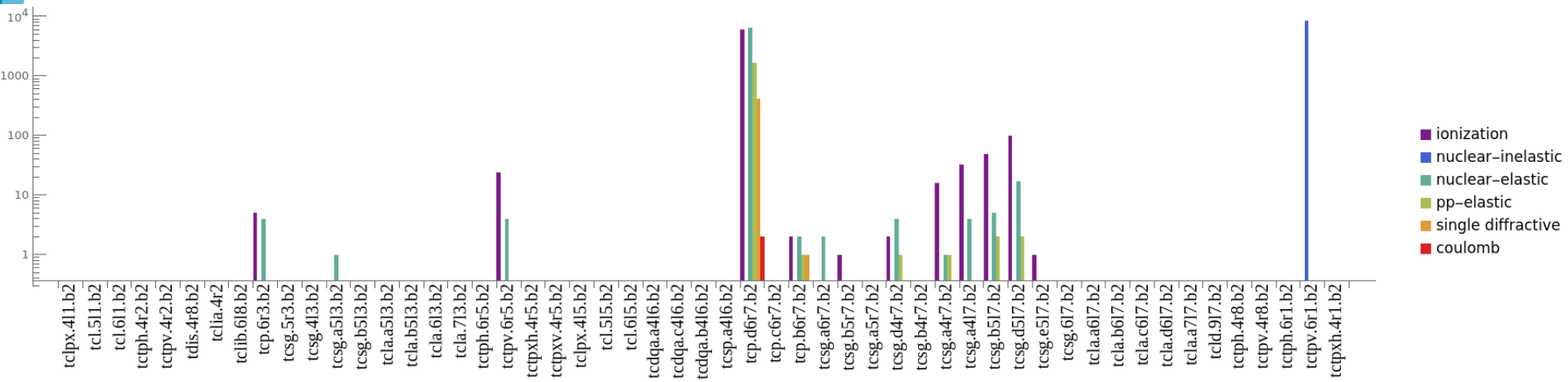
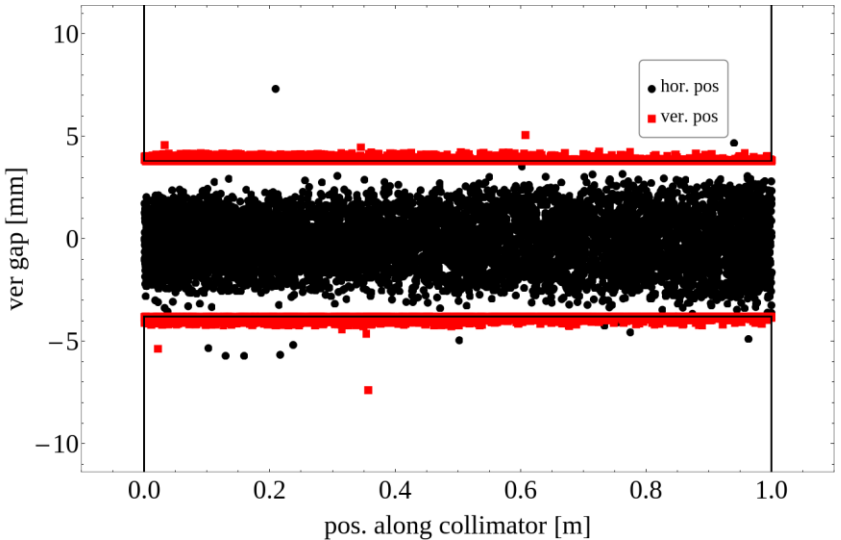
B4V – large TCT losses

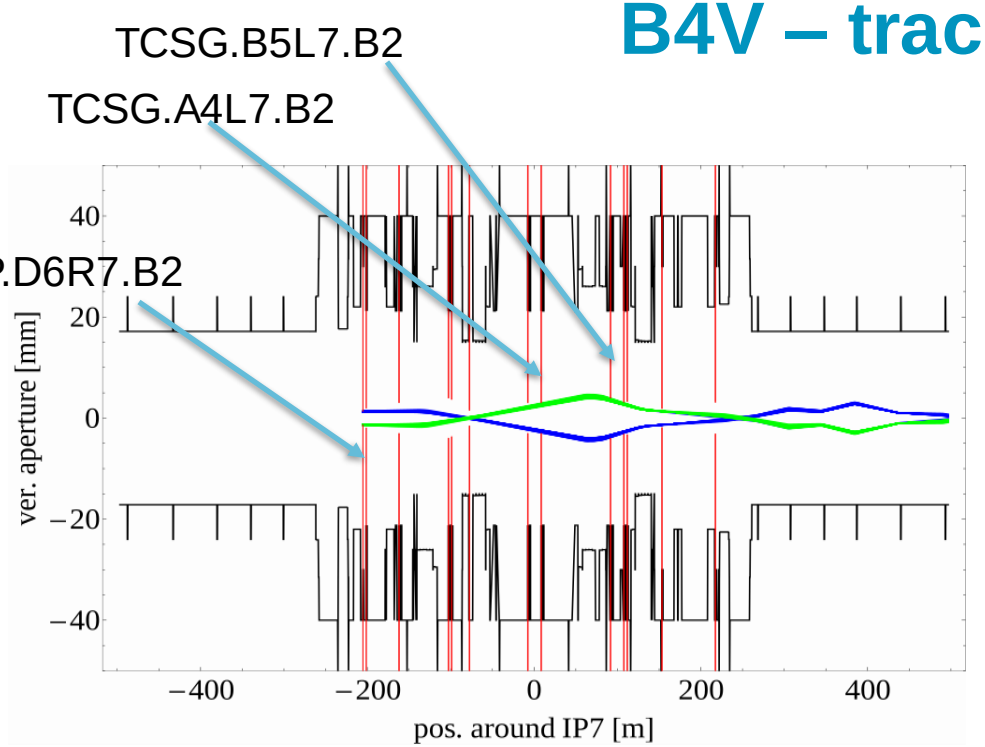
- Losses at 1.3e-3 in the TCTs could risk cause beam dumps, should be rectified
  - n.b. – in 20 cm optics, TCTs are at 13.2 sigma and losses are insignificant
- Mostly elastically scattered protons in TCP, betatron oscillations



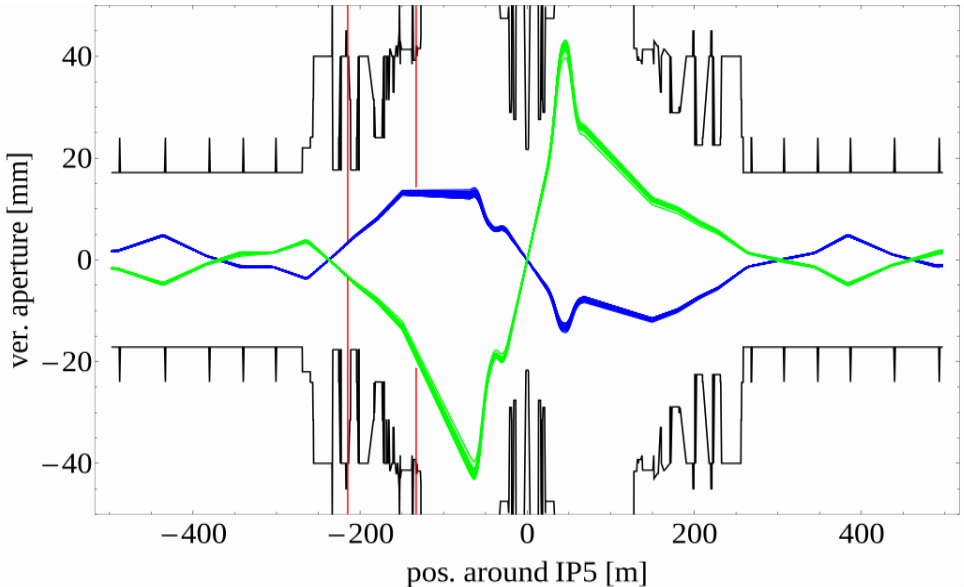
- Superficial hits on TCT
- 90 % particles within impact param 0.5 sigma

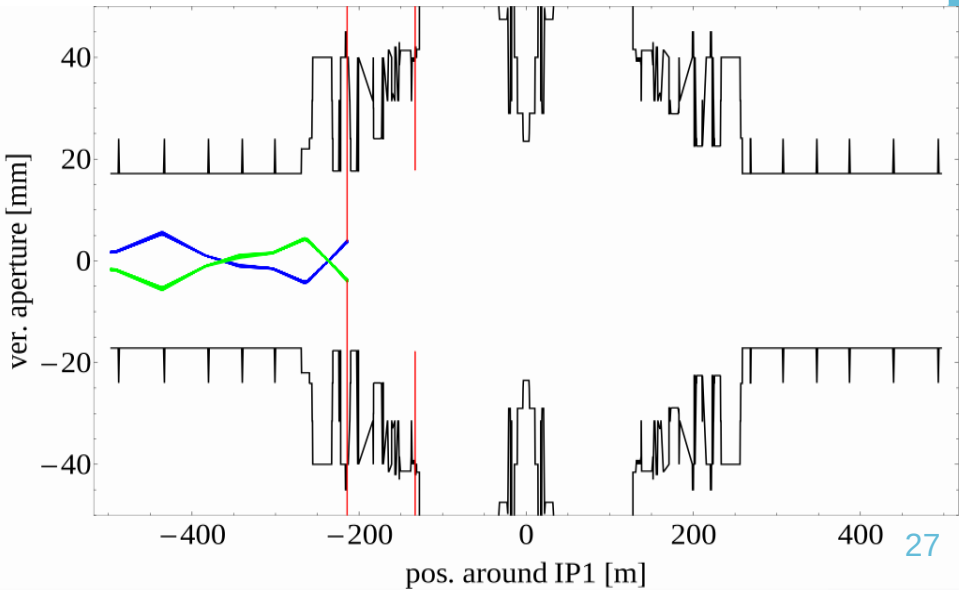


B4V – tracks

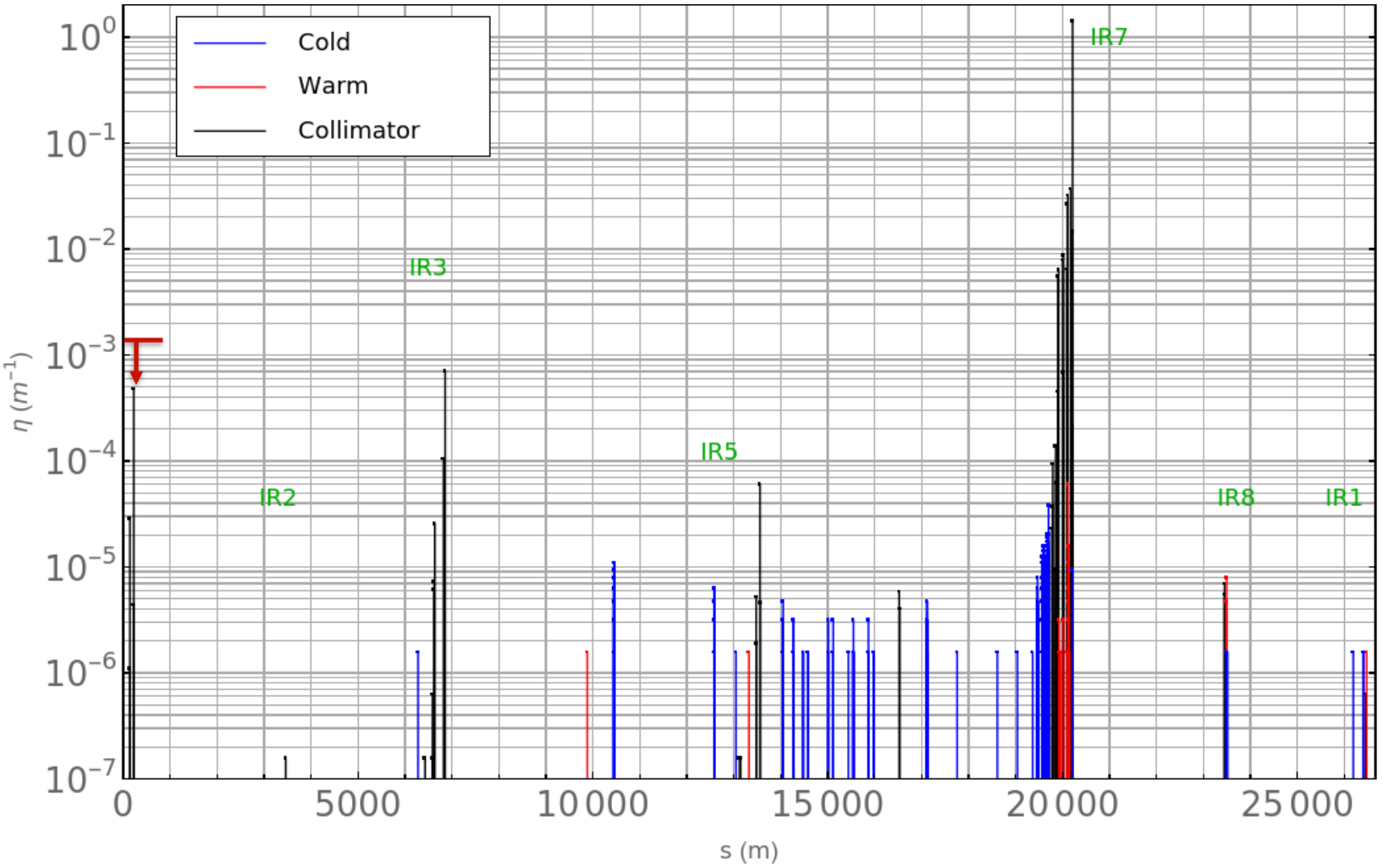


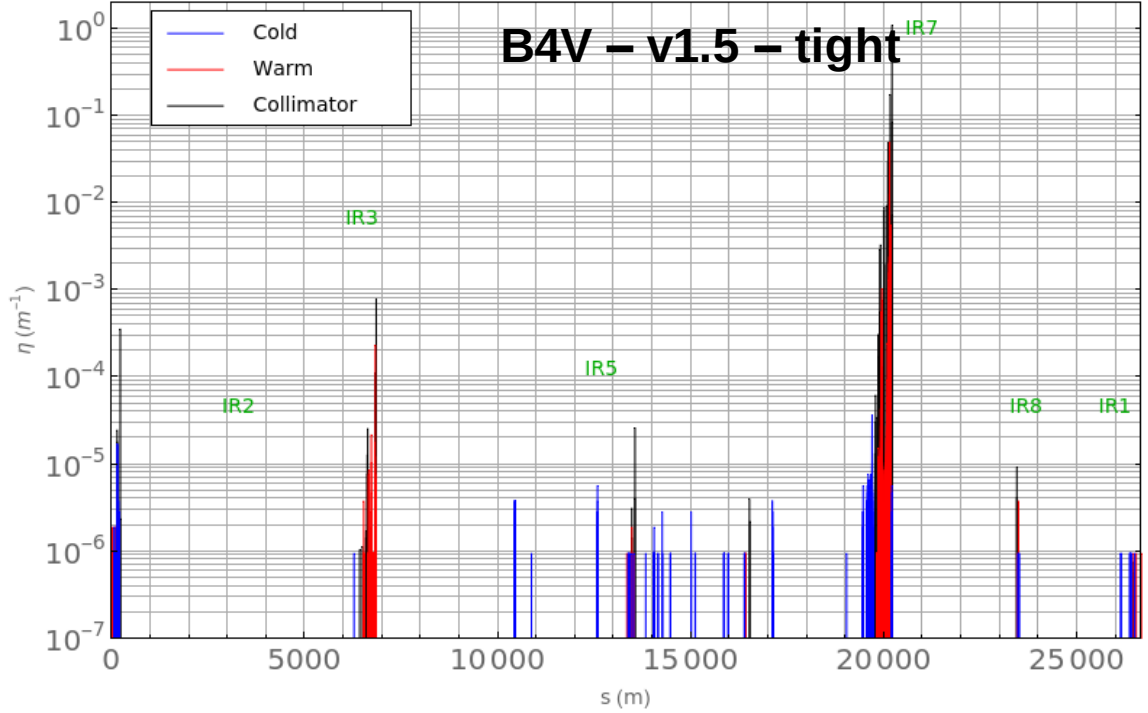
- Solutions?
  - Retract TCT1 by 0.5 sigma (reduces margin in 15 cm optics)
  - Insert TCP.D by 0.5 sigma (increases impedance)
  - Insert TCS by 0.4 sigma (increases impedance)

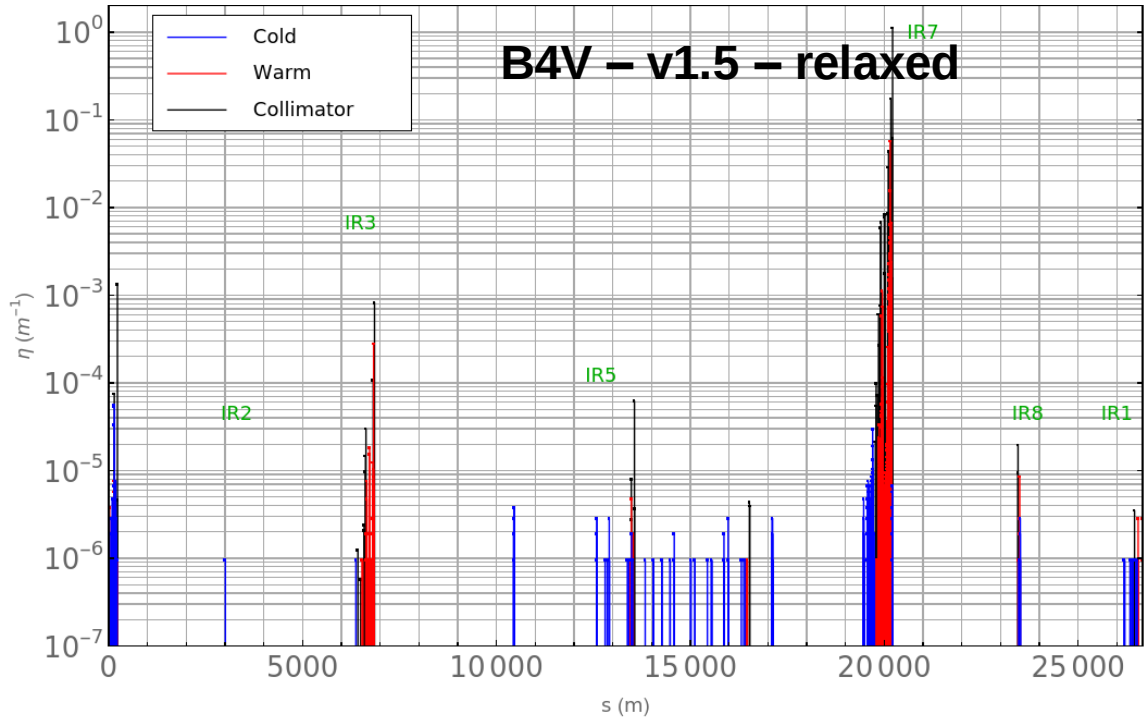




TCT relaxed 0.5 sigma







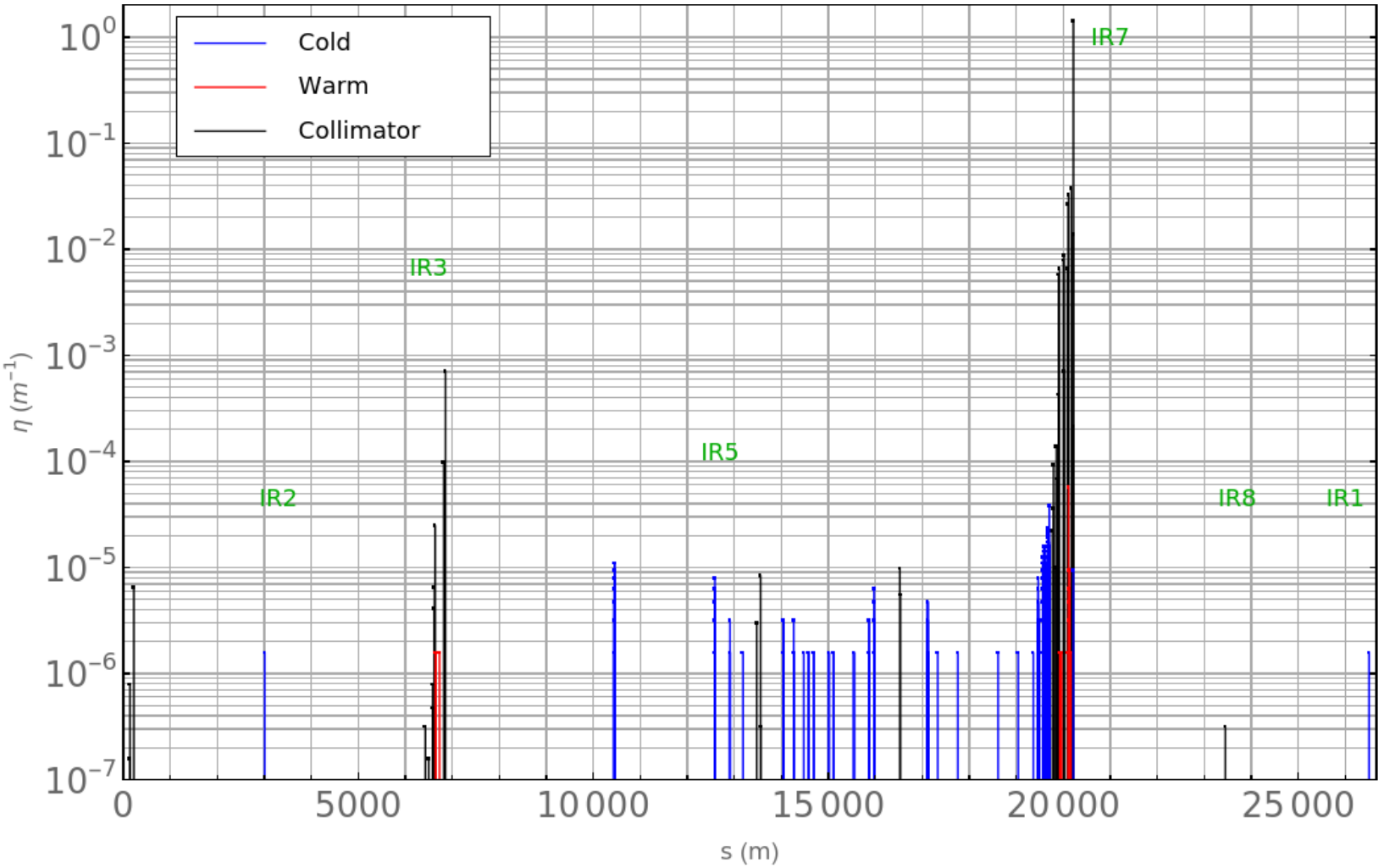
FLUKA coupling

- Nominal optics (15 cm β*)
- Impact: 4 µm
- 6.4e6 particles / 200 turns

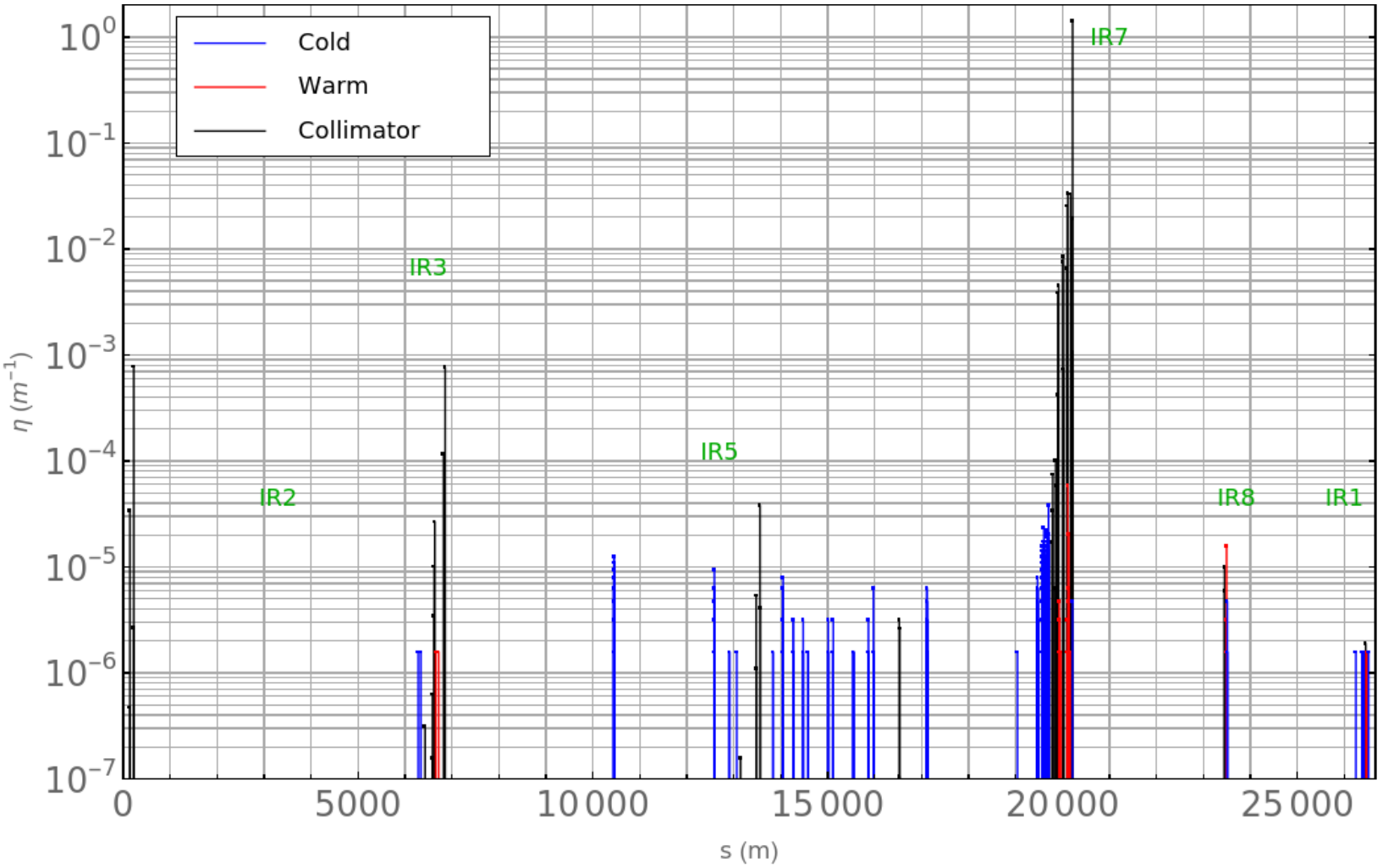
General notes:

- Differences due to the different collimator settings are similar to the k2 simulations
- Compared to k2 simulations, the DS losses and inefficiency are factor ~3 smaller
- Worsening due to relaxed settings is similar
- Warm losses are larger by two orders of magnitude

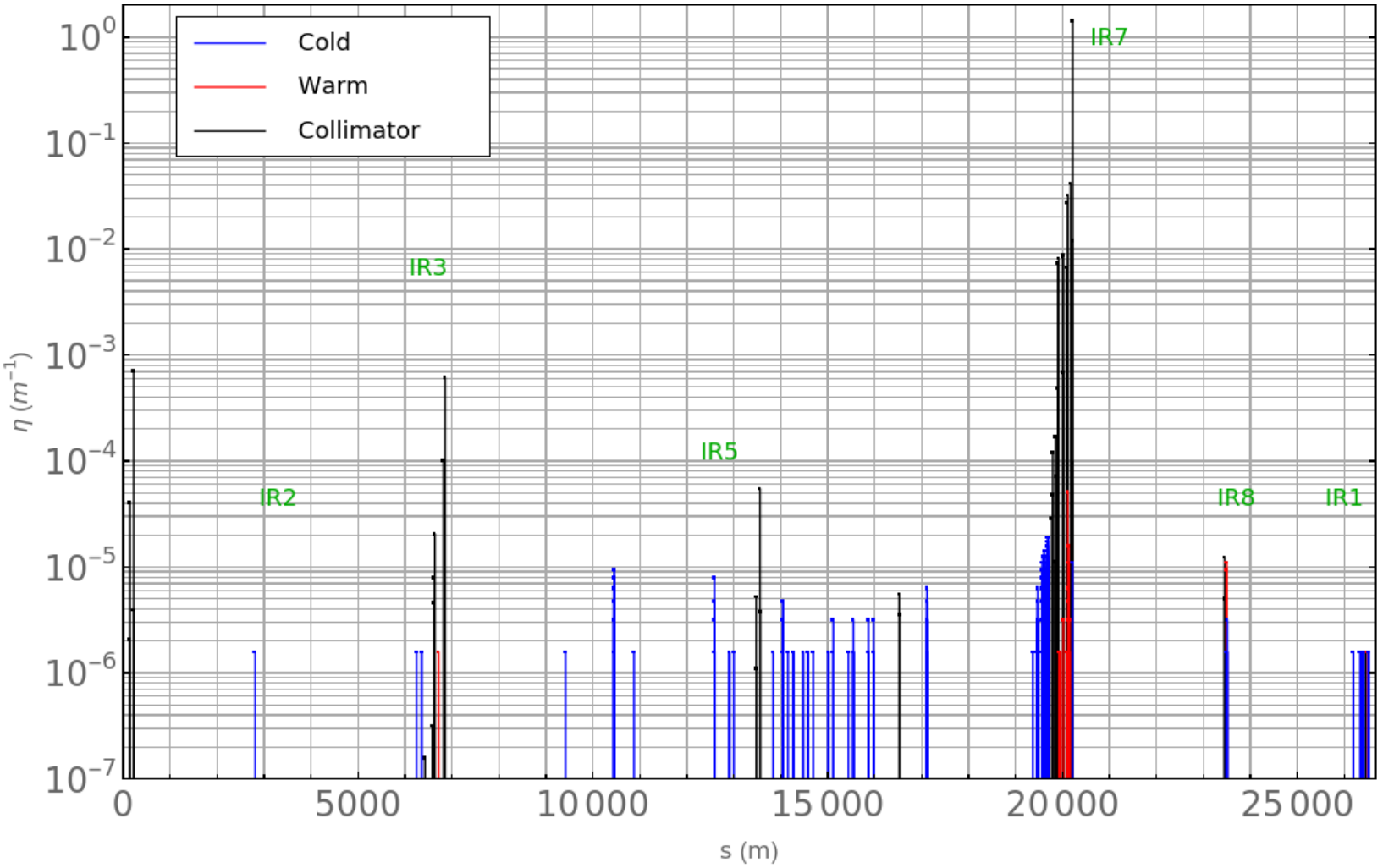
TCT relaxed to 13.2 sigma (corr. to 20 cm optics)



TCP inserted 0.5 sigma



TCS inserted 0.4 sigma

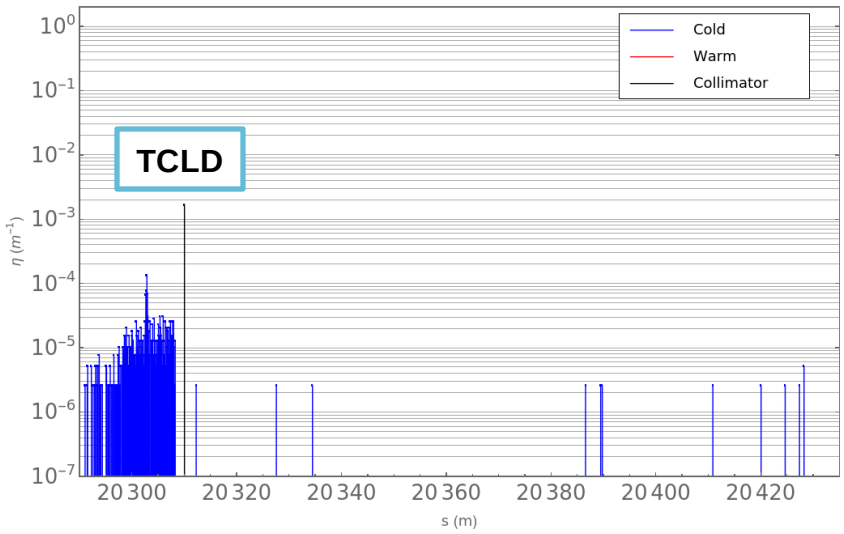


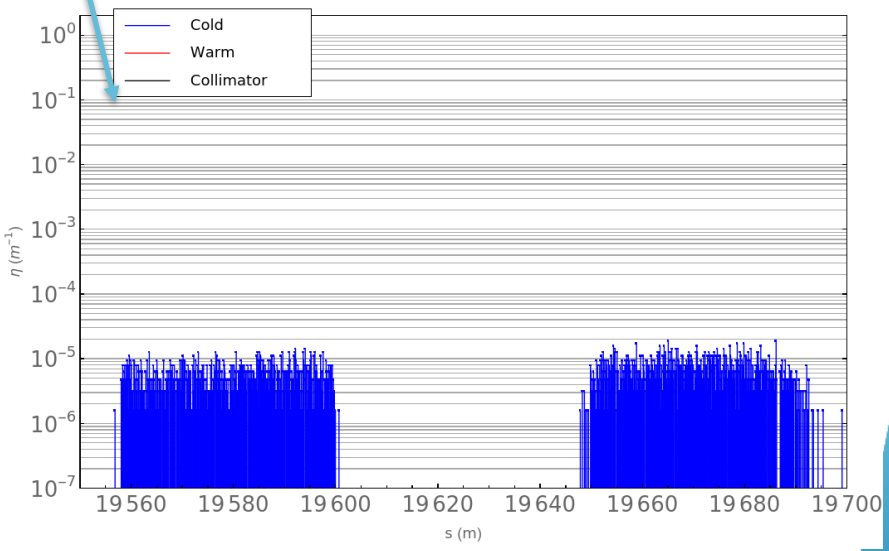
TCLD in IR7 dispersion suppressor

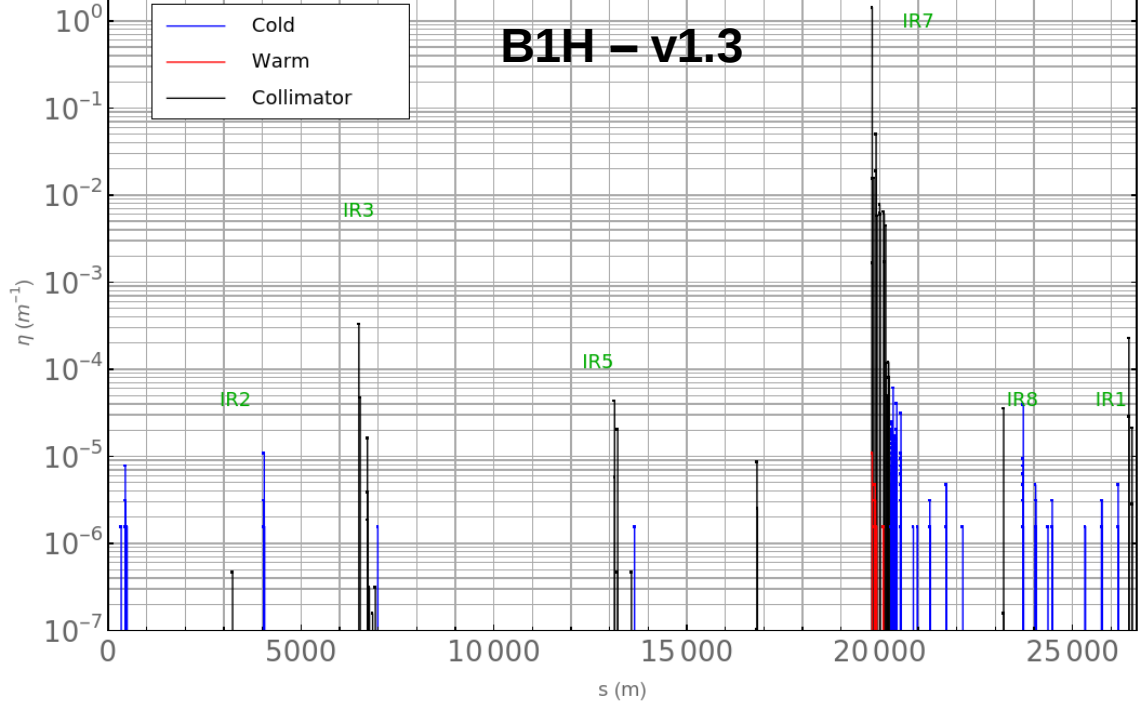
- Plan to exchange 1x main dipole with 2x 11T dipoles
- Provides space for the TCLD
- Installation postponed, unlikely to occur before RunIV

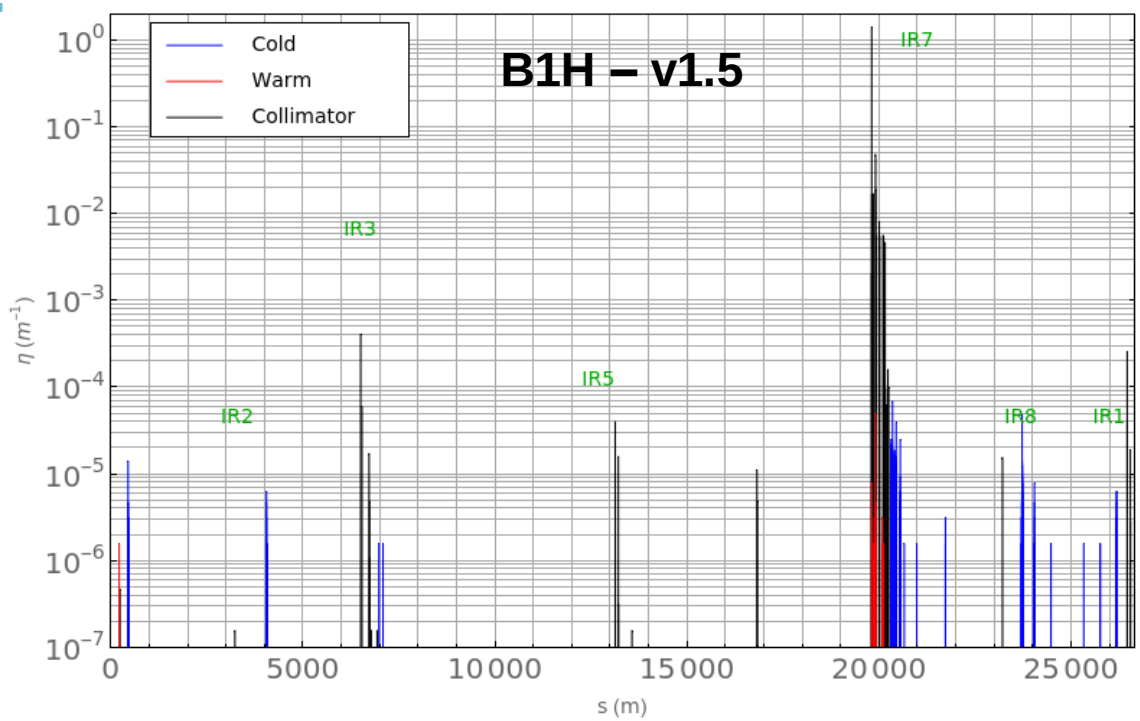
→ must **consider** configurations **without TCLD**

IR7 DS beam losses







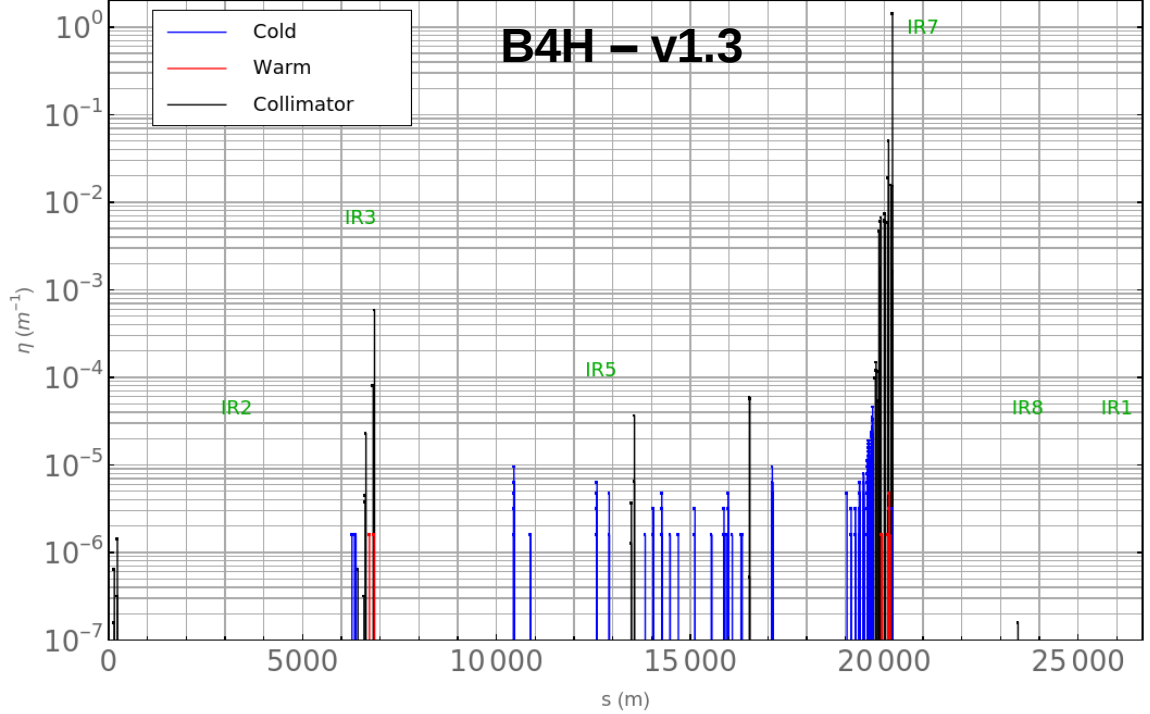


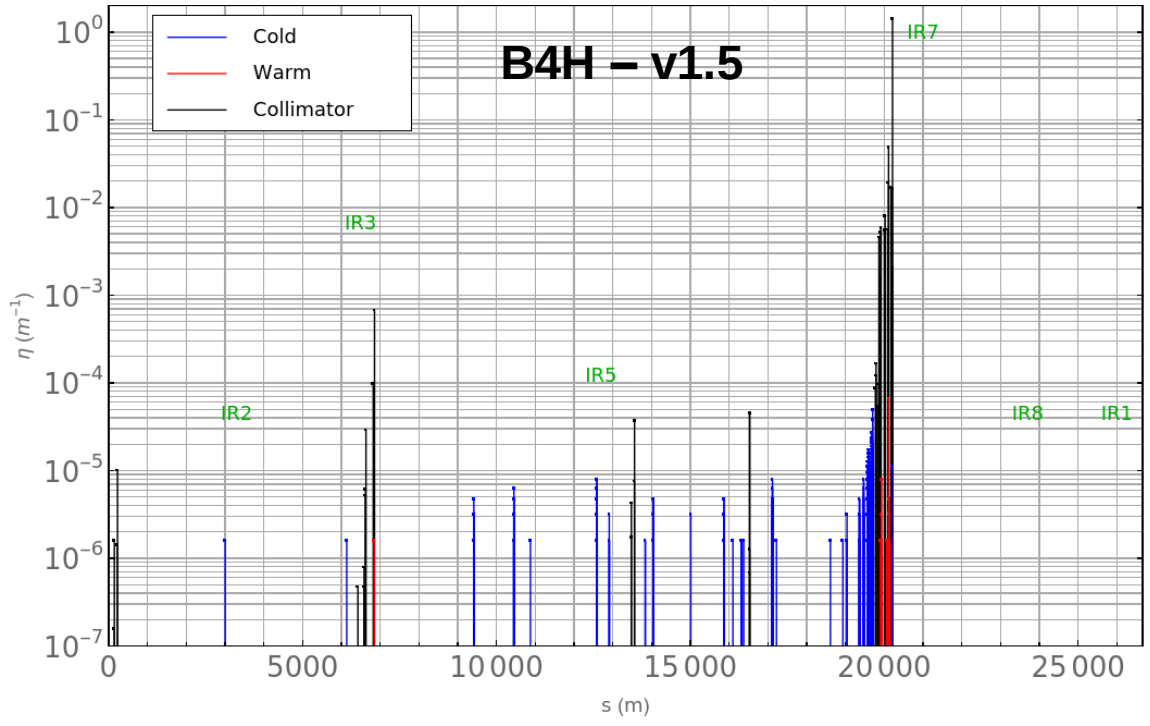
Comparison using old collimator settings

- Nominal optics (15 cm β*)
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

- Collimator loss distributions consistent, except for some TCT losses
- b1: up to 15 % worse global inefficiency in v1.5
- b1: up to 15 % larger DS losses in v1.5
- Max warm losses much larger in v1.5, b1&b2





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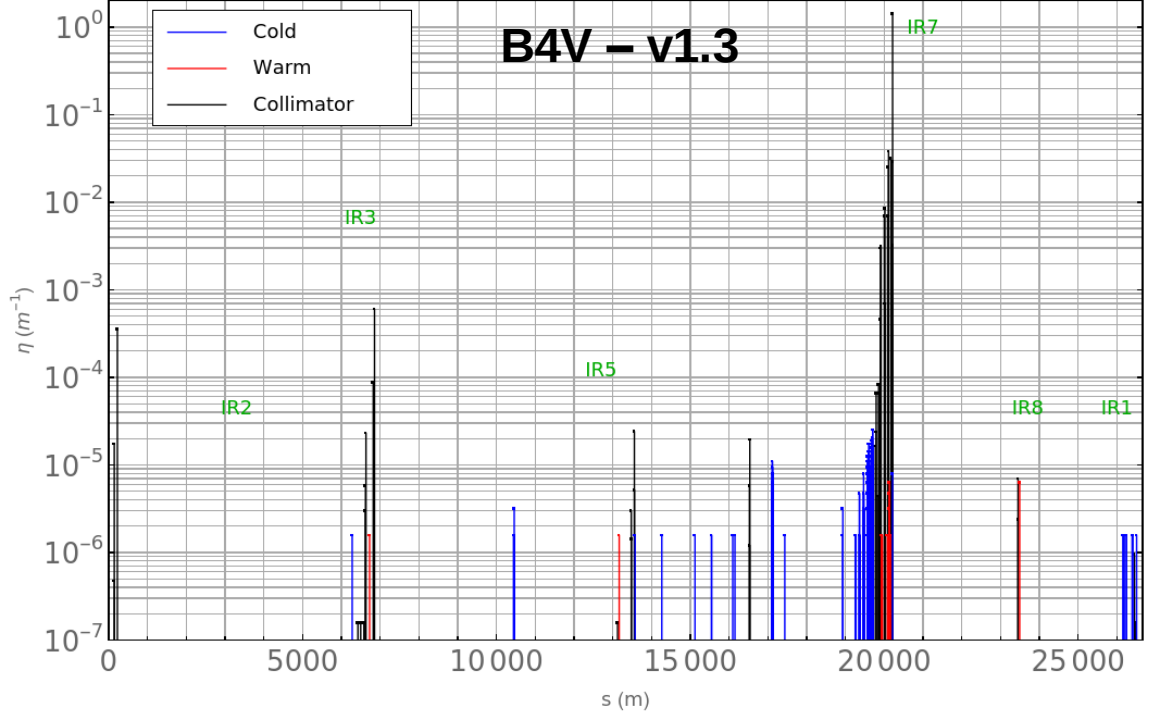
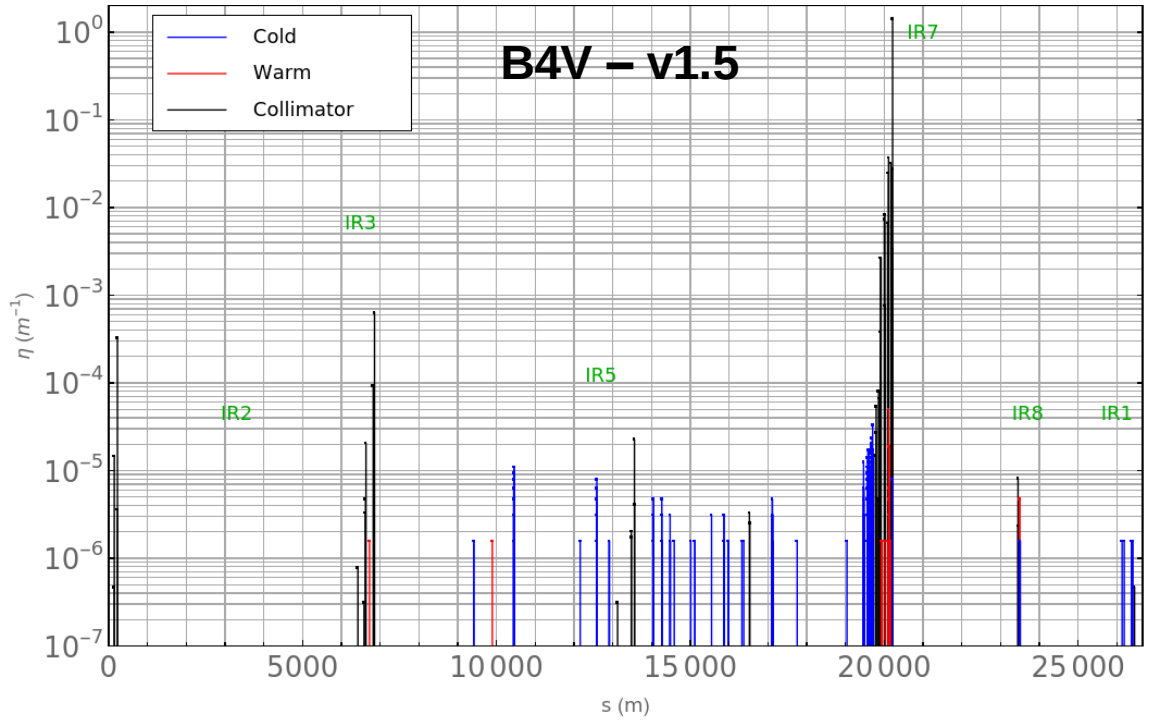
  → comes from change in single turn dispersive orbit

Comparison using old collimator settings





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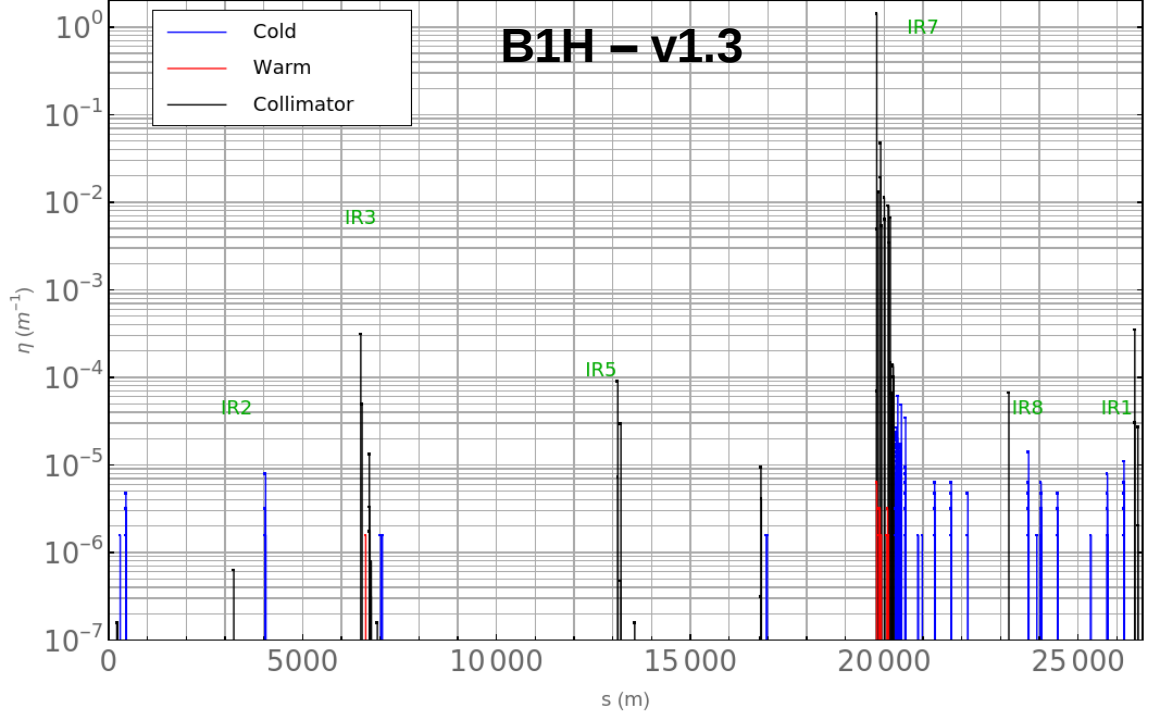
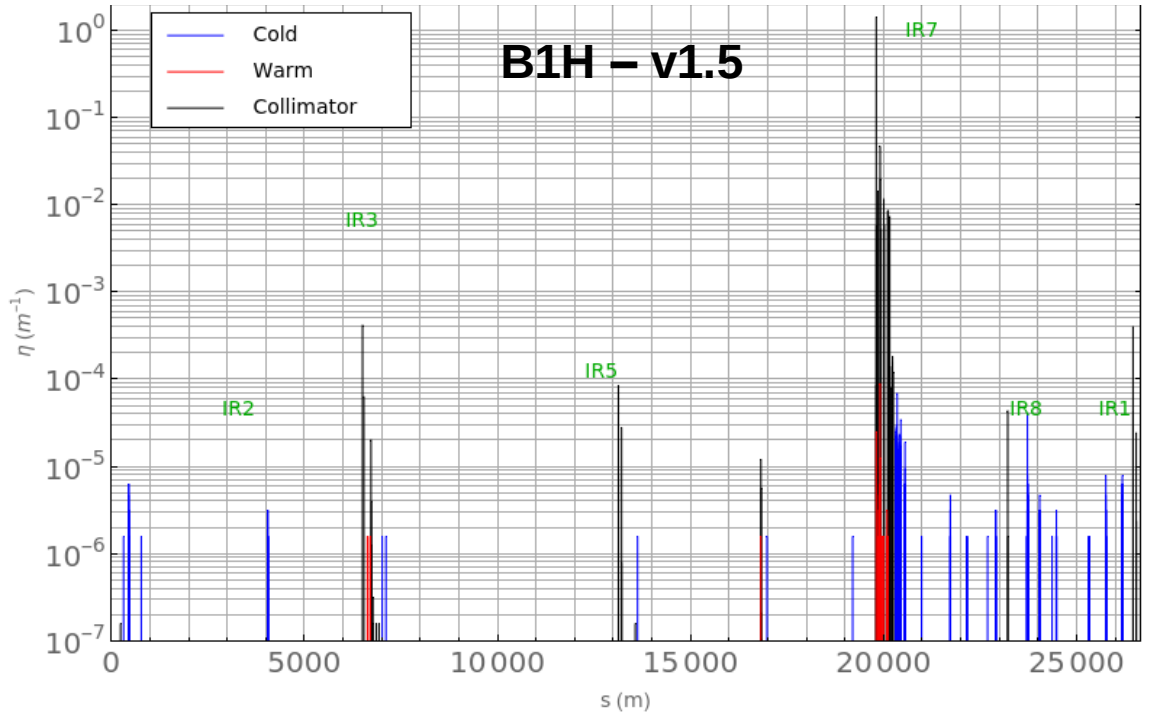




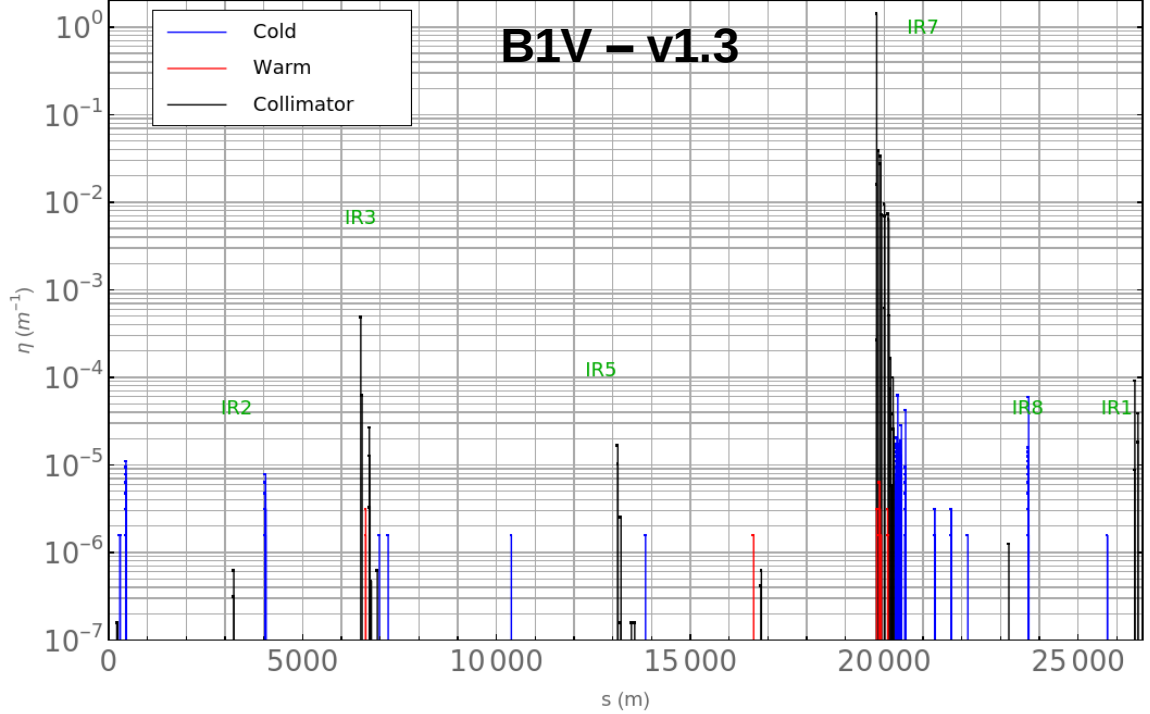
Comparison using new collimator settings

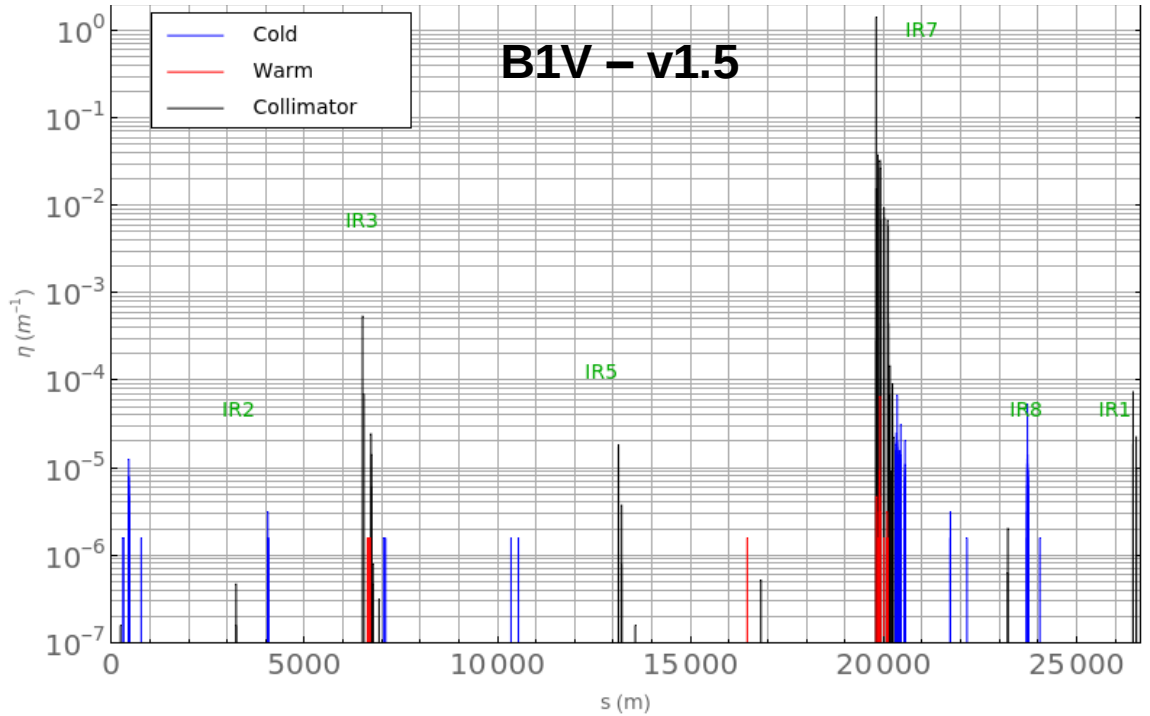
- Nominal optics (15 cm β*)
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

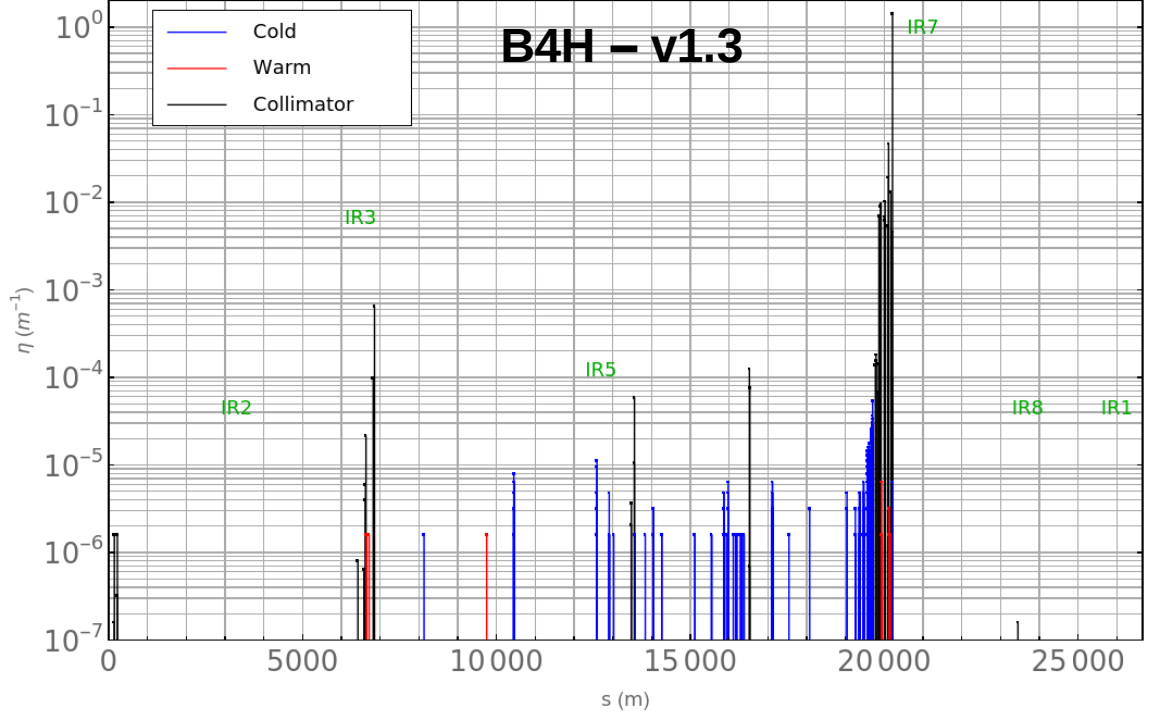
- Collimator loss distributions consistent
- b1: up to 15 % worse global inefficiency in v1.5
- b1: up to 15 % larger DS losses in v1.5
- Max warm losses much larger in v1.5, b1&b2

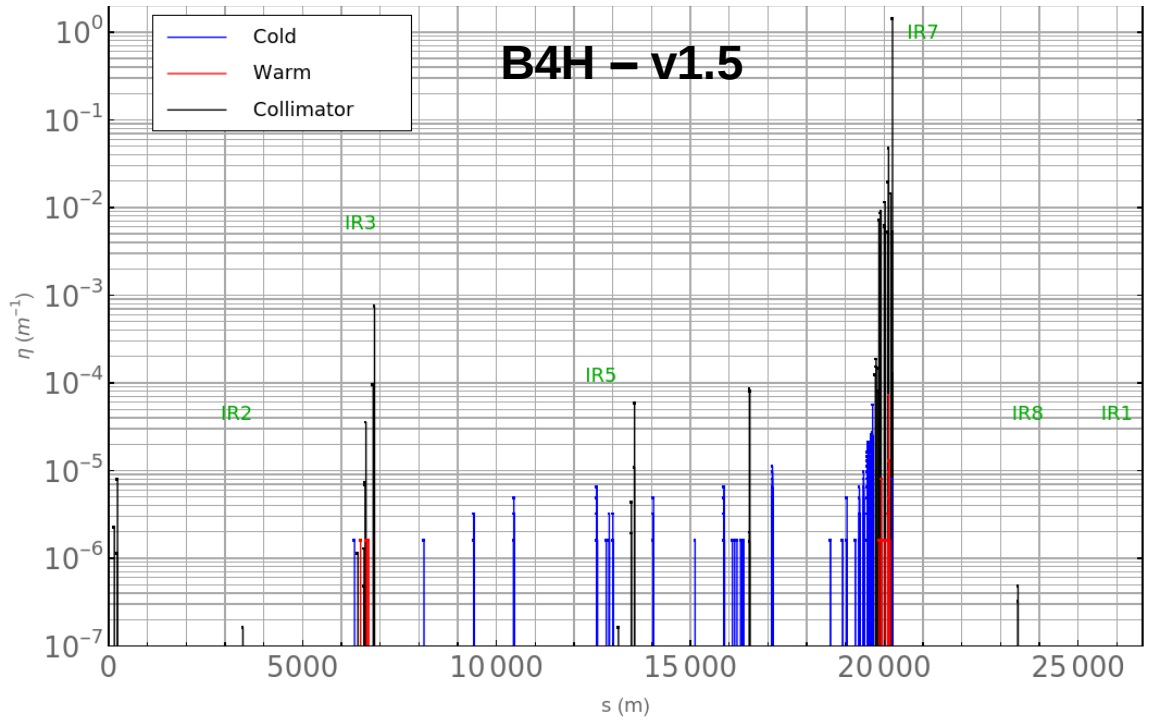
Comparison using new collimator settings





Comparison using new collimator settings





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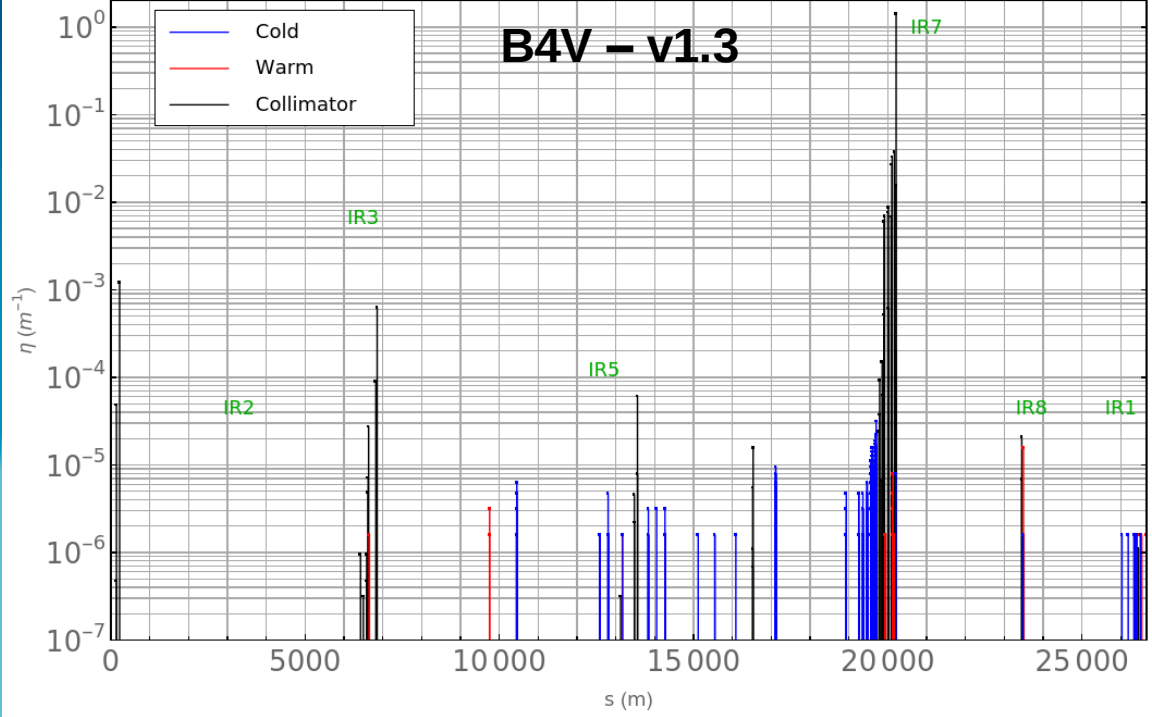
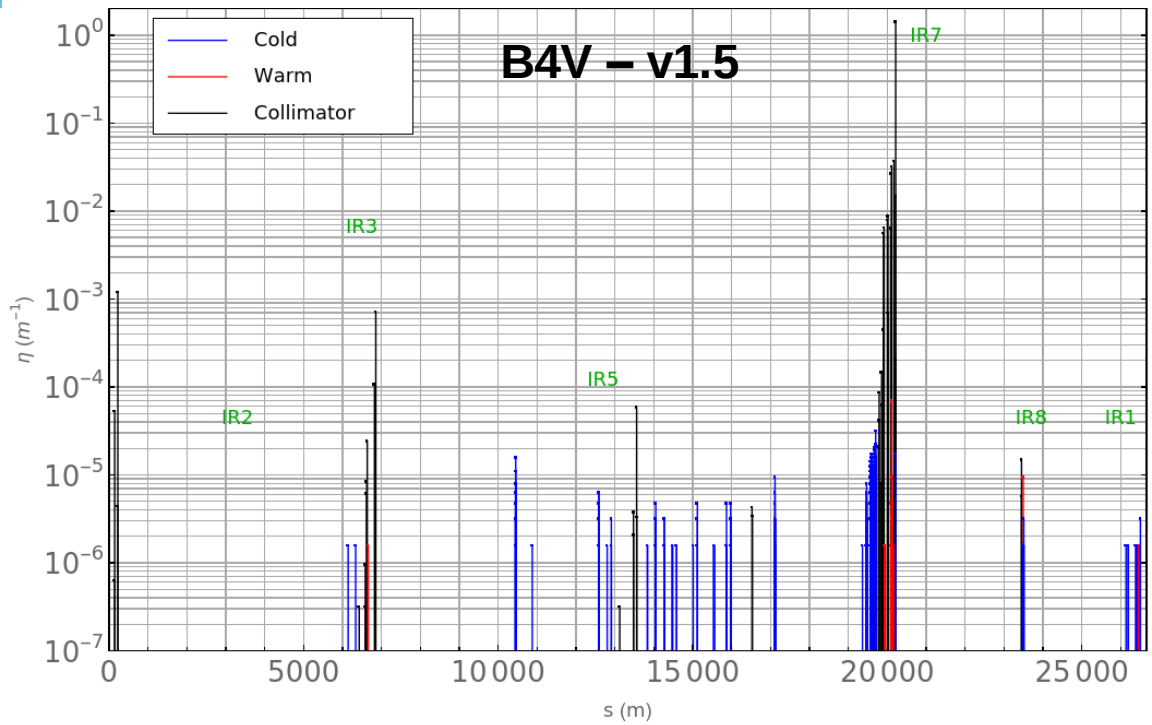
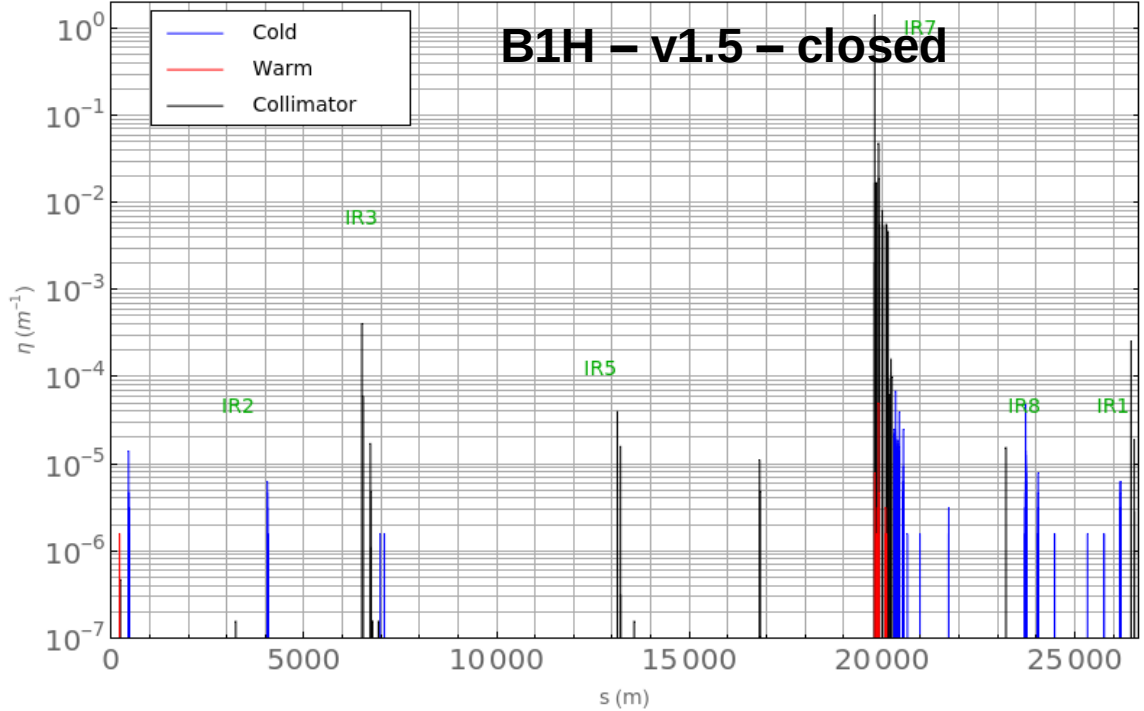
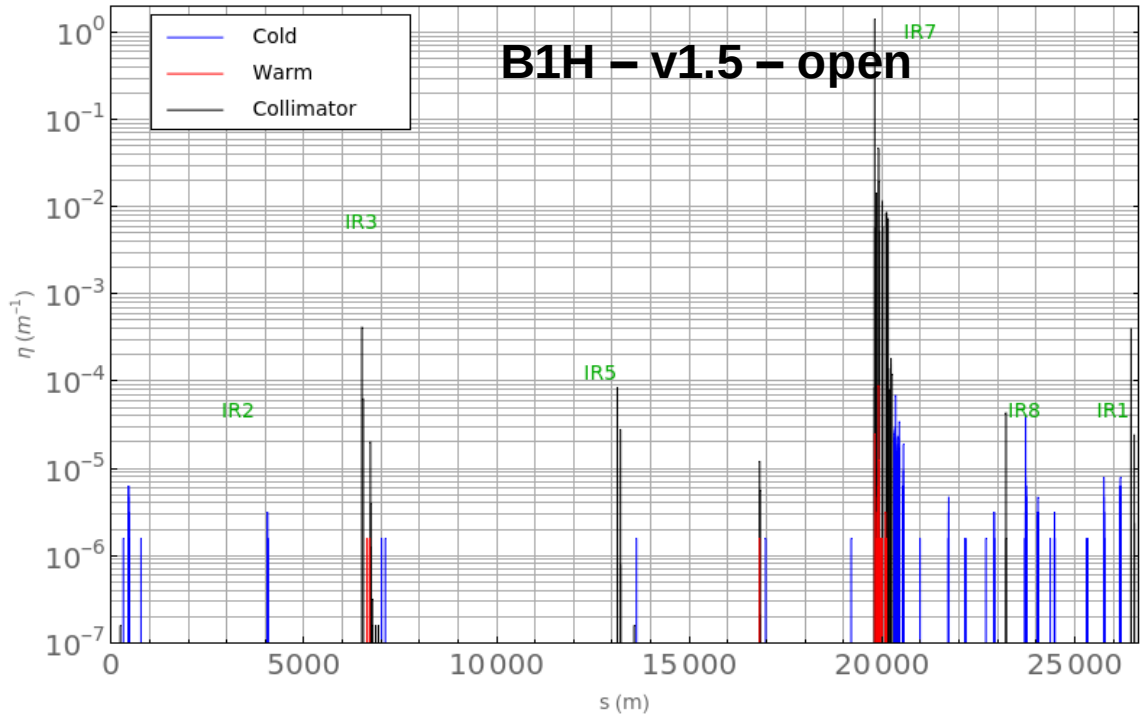


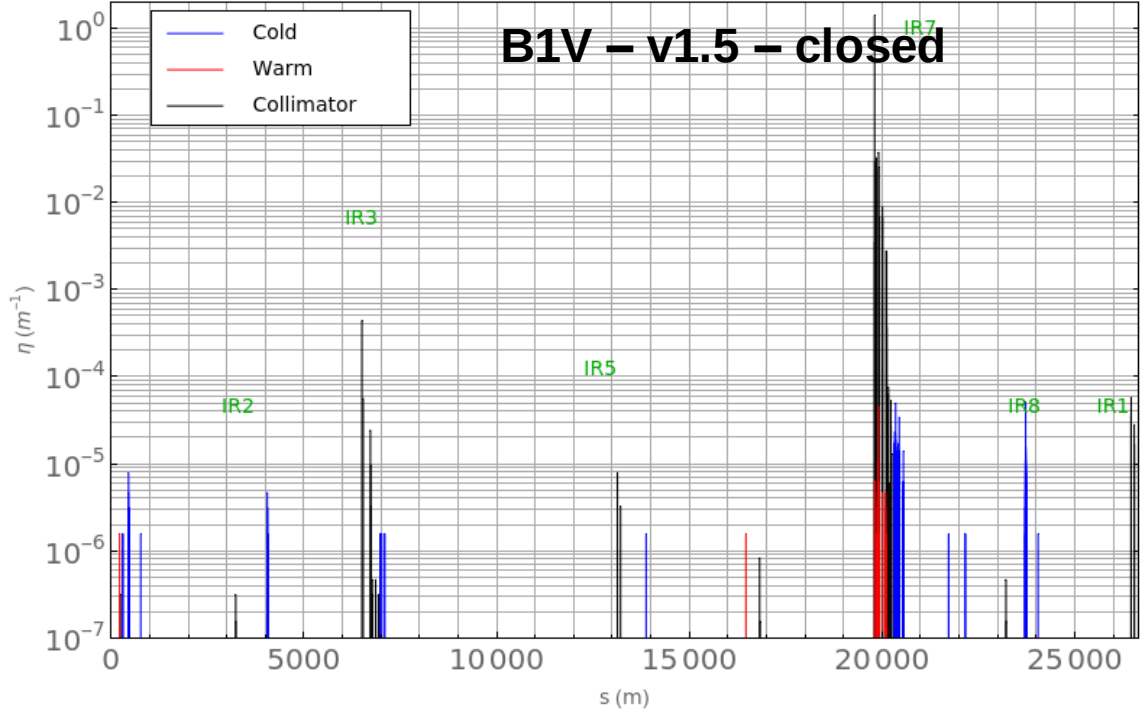


B1H


B1H – v1.5 – closed
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
$\eta\,(m^{-1})$
s (m)


B1H – v1.5 – open
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
$\eta\,(m^{-1})$
s (m)

B1V


B1V – v1.5 – closed
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
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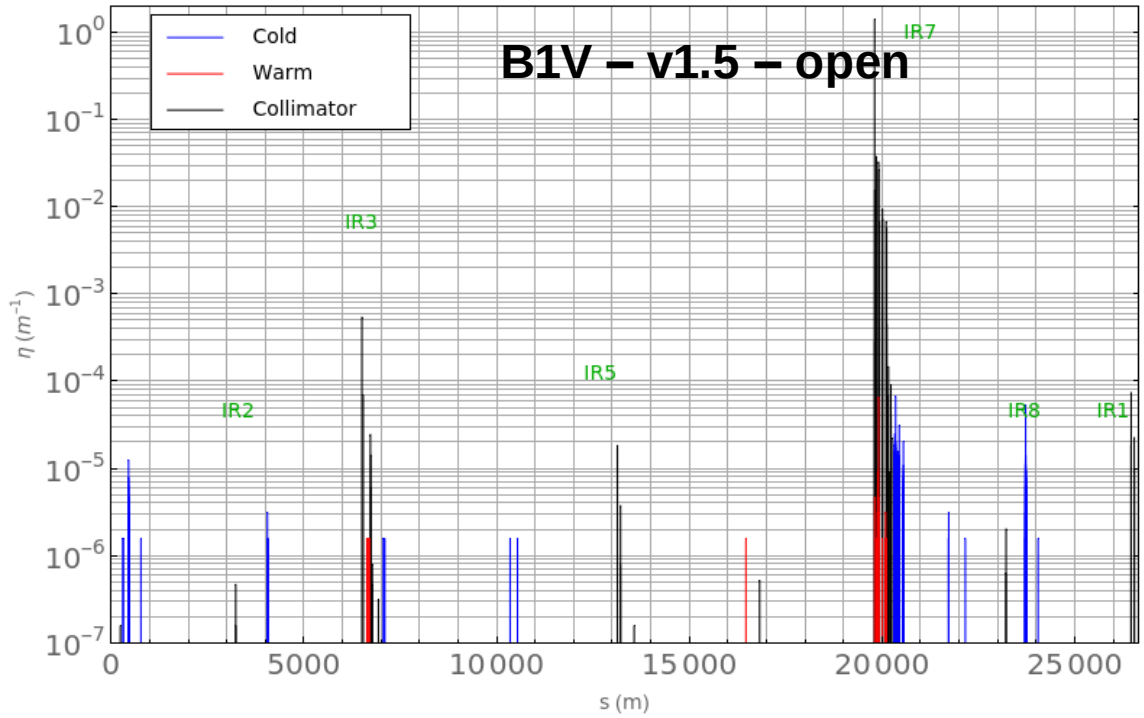
s (m)


B1V – v1.5 – open
Cold
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IR2
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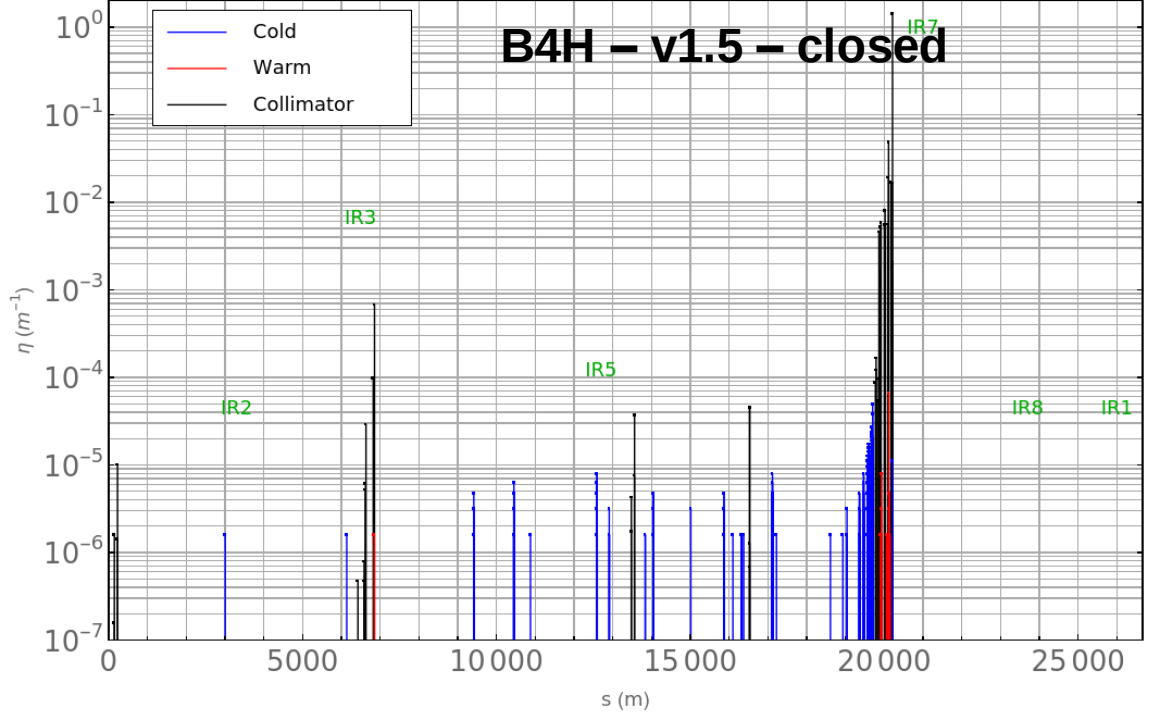
s (m)

B4H


B4H – v1.5 – closed
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
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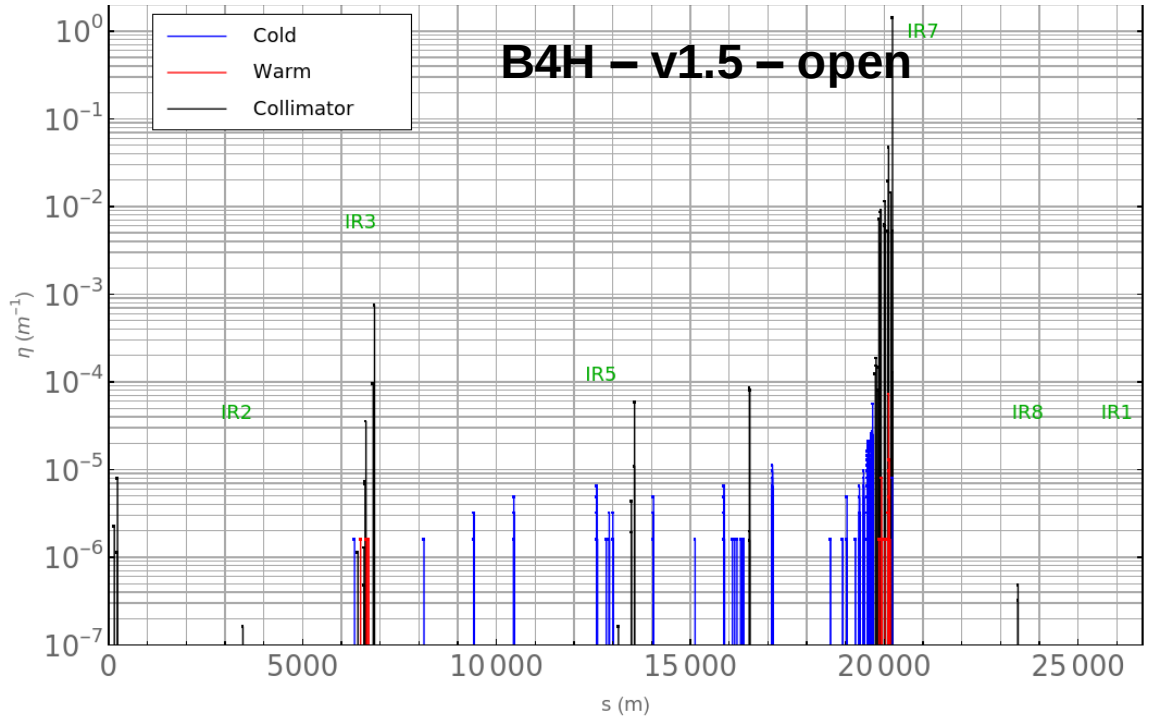
s (m)


B4H – v1.5 – open
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FLUKA coupling