Collimation updates for v1.5

B. Lindström

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

20th October 2021 – 11th HL-LHC Collaboration Meeting

Introduction

Previous HLLHC **beam loss** studies are ~three years old

- Significant changes in **optics** and **layout** since then (**v1.3** to **v1.5**)
- Operational scenario for **RunIV** has changed from the baseline
  - ”Run IV operational scenario” document under preparation by WP2*
- **Relaxed collimator settings** requested for beam stability

⟶ Collimation studies need update:

- Global cleaning efficiency
- IR7 dispersion suppressor losses
- Loss spikes/clusters in other cold sections
- TCT shower simulations (experiment backgrounds)
- Asynchronous beam dumps
- Beta beating and orbit errors

*R. Tomás – Update on Optics, Layout and Run4 operational scenario
https://indico.cern.ch/event/1079026/contributions/4544728

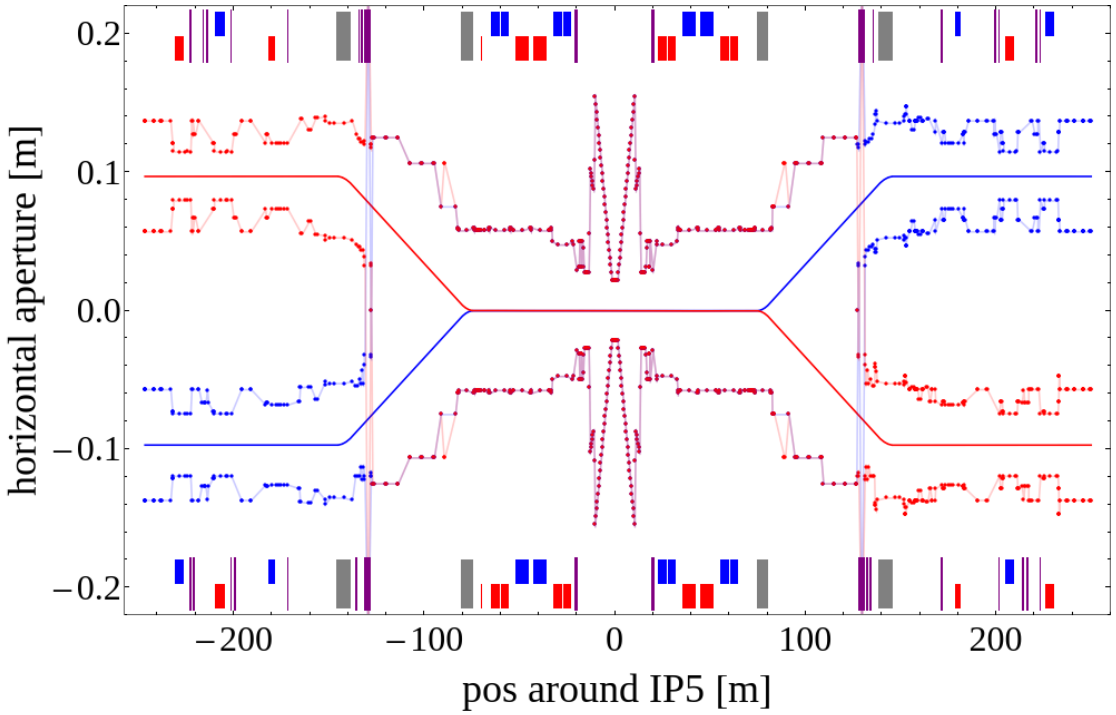
Layout Changes

- **v1.5 (latest)** introduces several differences from v1.3:
  - 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***
- **IR7 TCLD** likely not available for RunIV
  - → strong impact on cleaning efficiency

*layout.cern.ch

Aperture model

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



- Updates to do:
  - LayoutDB requires some patches: inconsistent positions, aperture definitions, extensive yet incomplete
  - LHCb VELO+SMOG not available

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

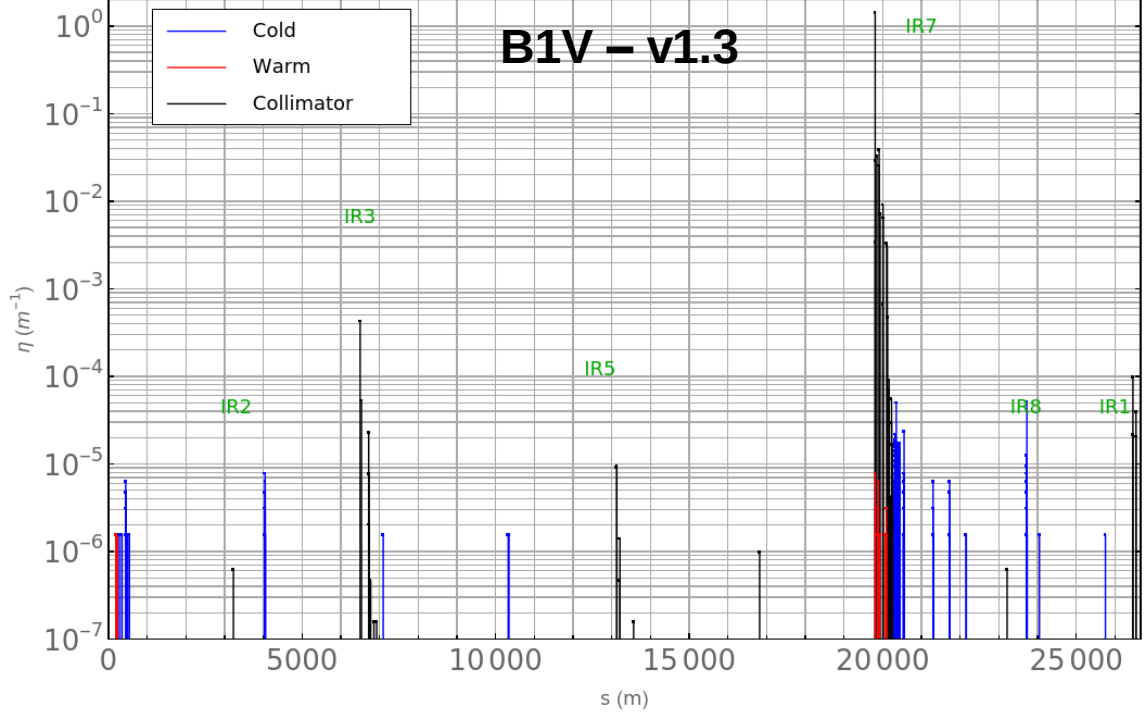
Collimator Settings ($\epsilon_n = 2.5\mu m \cdot rad$)

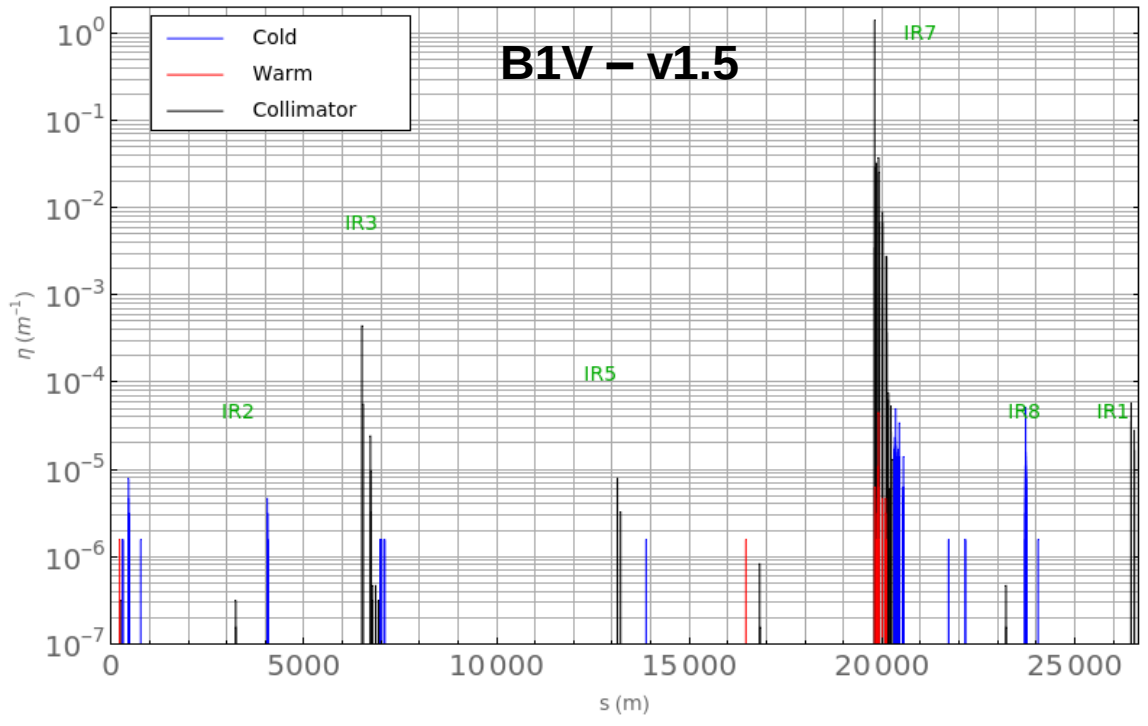
	TDR Baseline (tight settings)	Relaxed Settings		
		Run V	Run IV	
	15 cm β*	15 cm β*	20 cm β*	100 cm β*
TCP IR7	**6.7**	**8.5**	8.5	8.5
TCS IR7	**9.1**	**10.1**	10.1	10.1
TCLA IR7	**12.7**	**14.0**	**13.7**	**13.7**
TCLD IR7	**16.6**	**n/a****	n/a**	n/a**
TCP IR3	17.7	17.7	17.7	17.7
TCS IR3	21.3	21.3	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***
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 IR2	park	park	park	park

* gap in mm is set to final (15 cm) value and kept constant throughout squeeze
** likely n/a for runIV, status for runV to be confirmed

Optics version comparison – v1.3 vs v1.5

TDR baseline with tight collimator settings





- 15 cm β*
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

- Collimator loss distributions mostly consistent, except for some TCT losses

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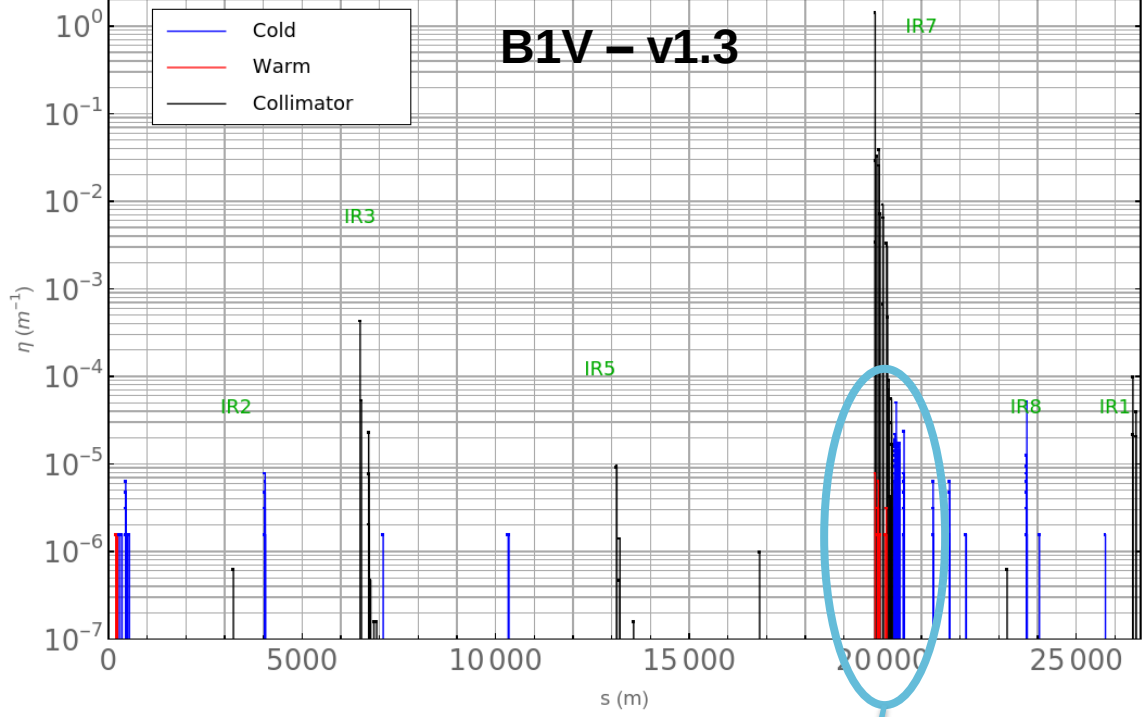
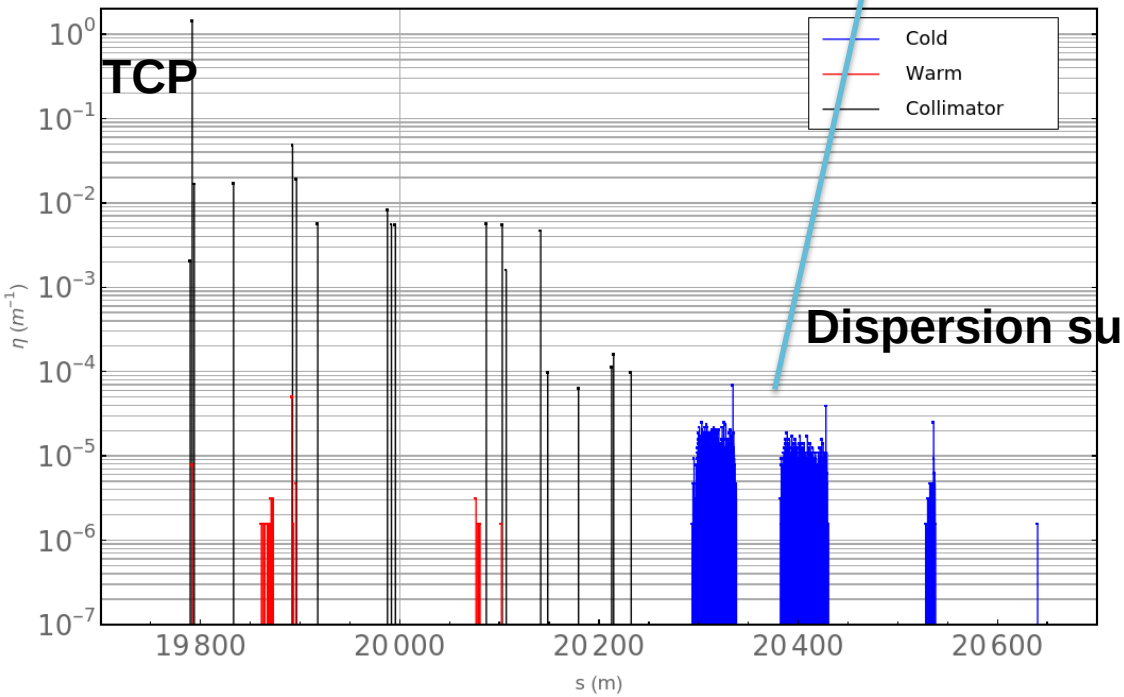




Dispersion suppressor (DS)

- 15 cm β*
- Impact: 4 µm
- 6.4e6 particles / 200 turns

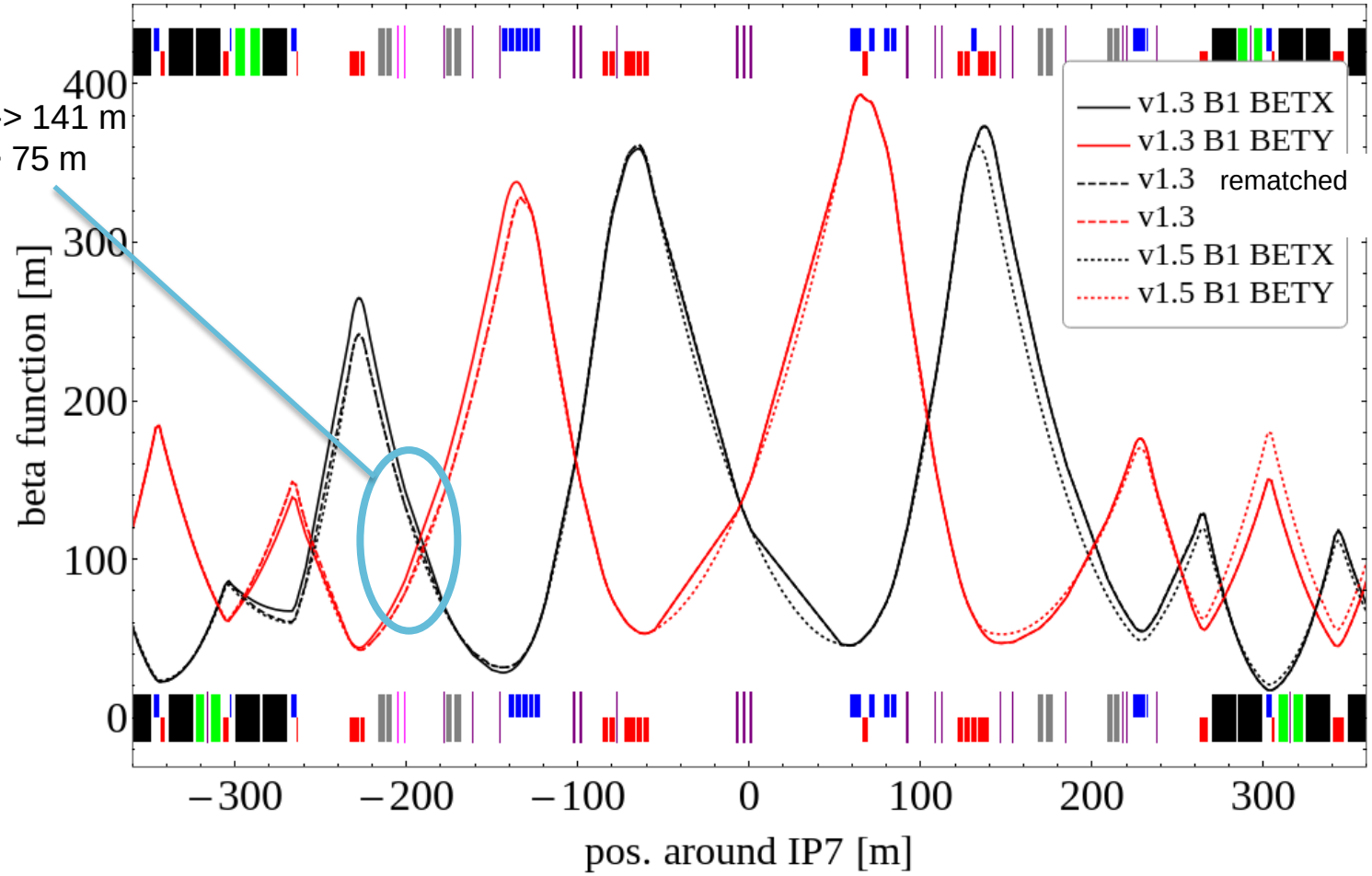
General notes:

- Collimator loss distributions mostly consistent, except for some TCT losses
- b1: ~15 % more DS losses in v1.5
- b2: ~5 % more DS losses in v1.5

TCP beta functions

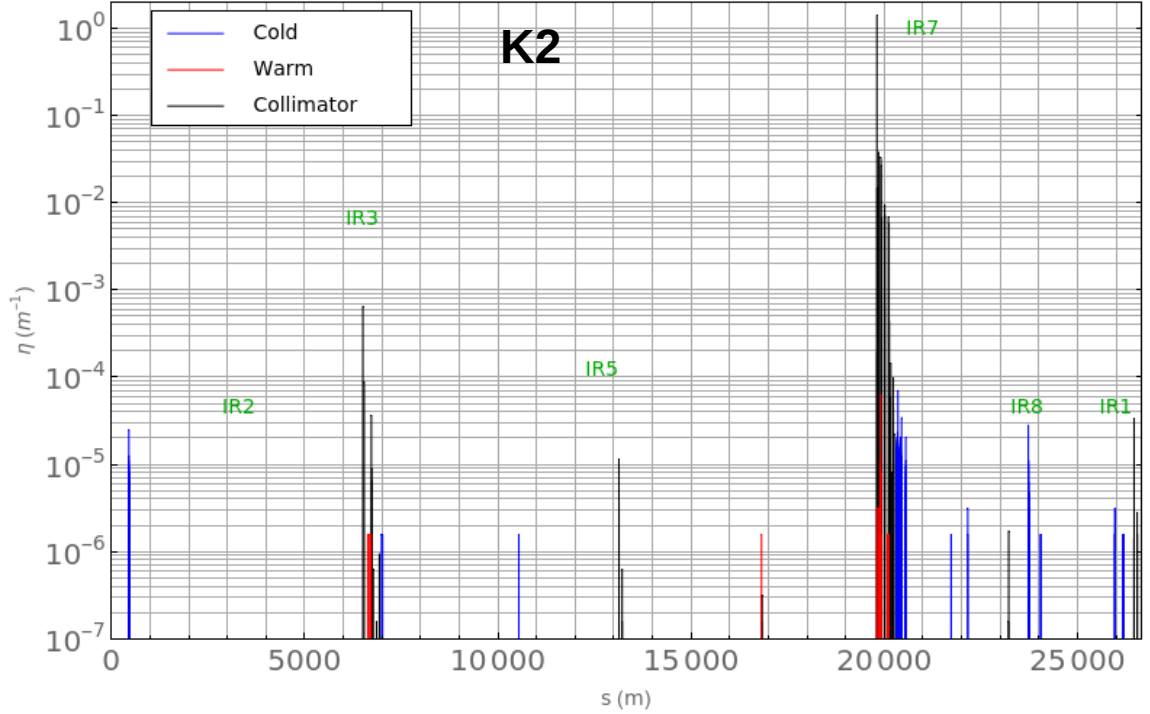
- Worsening of DS losses likely due to smaller TCP beta functions in v1.5 optics
- Matching the TCP beta functions in v1.3 to v1.5 reproduces worsened cleaning in both beams
- Restoring the v1.3 beta functions in v1.5 is feasible

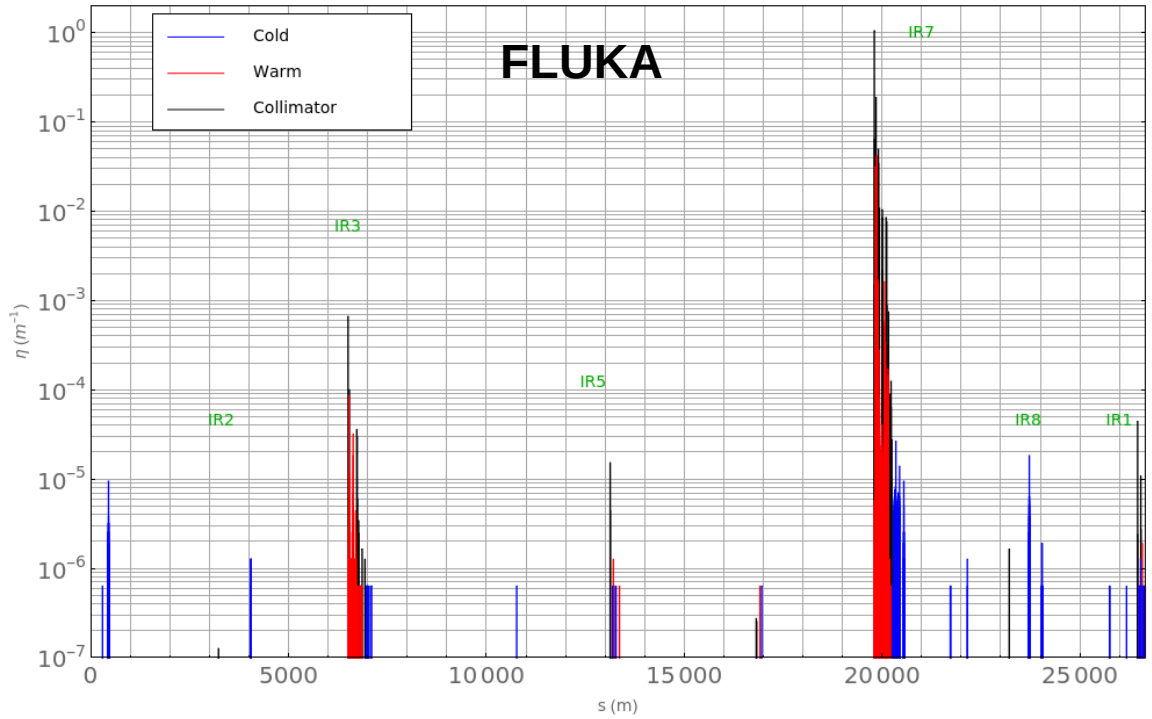
TCP betx: 150 -> 141 m
bety: 83 -> 75 m



Simulation method comparison – K2 vs FLUKA

K2 vs FLUKA





K2 is a built-in scattering module in SixTrack

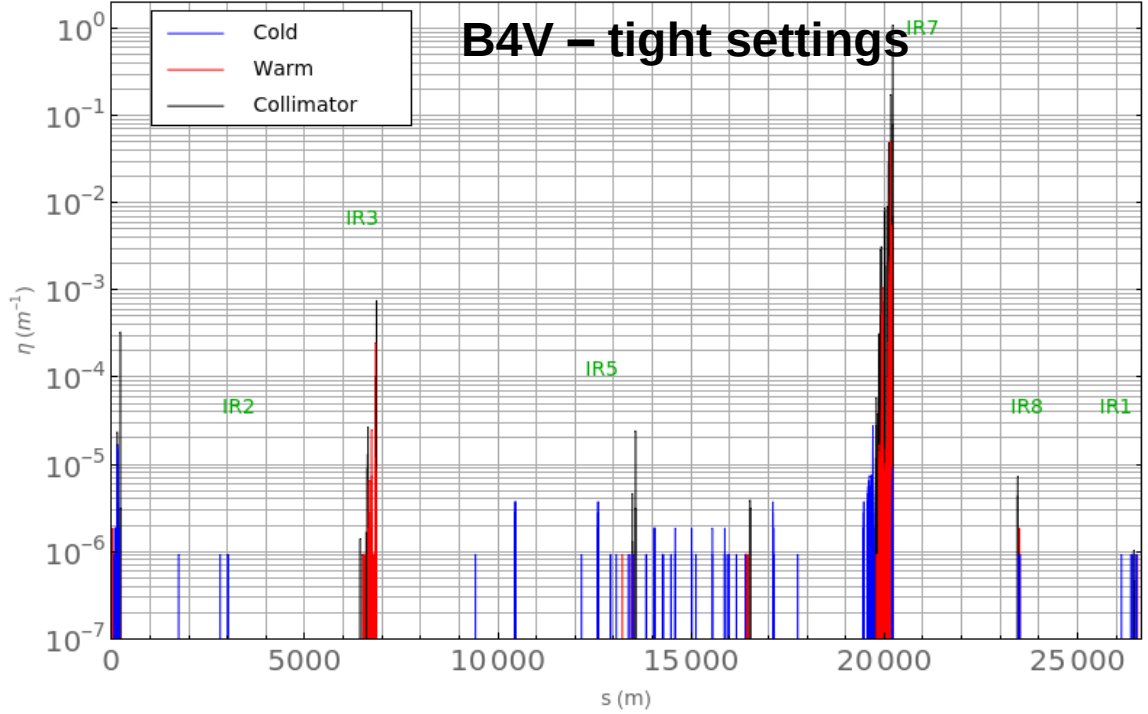
FLUKA is an extensive tool for simulating particle-matter interactions – can be coupled to SixTrack for collimator interactions

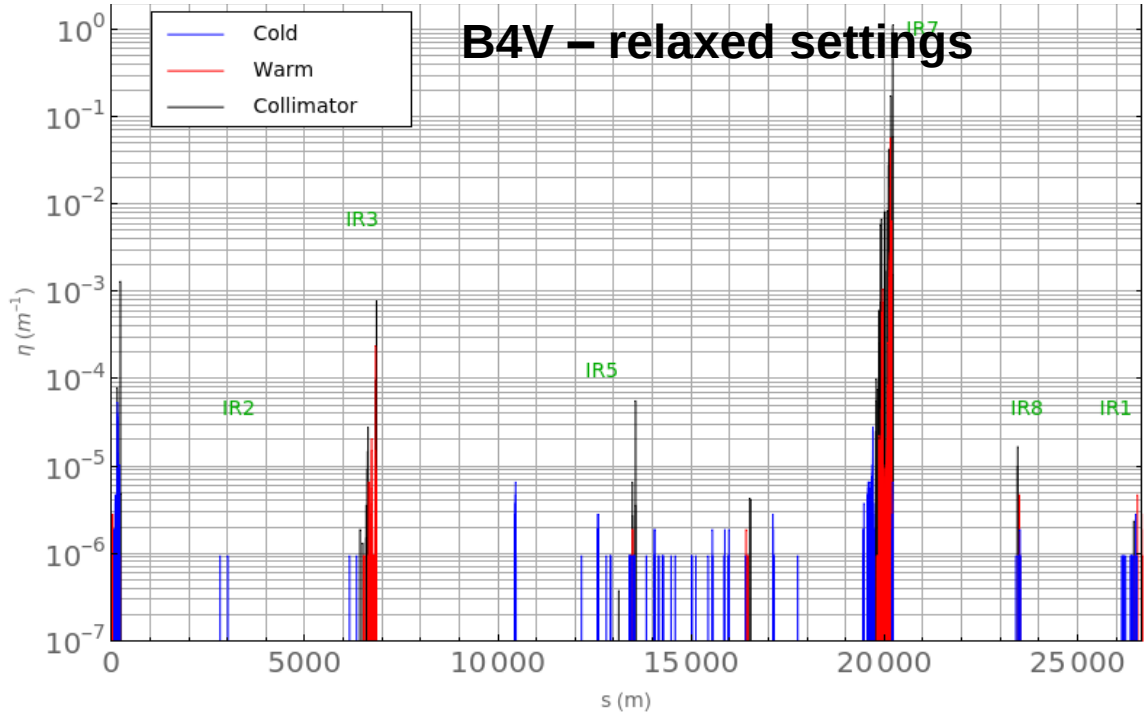
- B1V – v1.5 optics
- 20 cm β*
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

- Collimator loss distributions mostly consistent
- Increase in TCT4 losses
- Leakage from TCP is larger

Collimator settings comparison – Tight Settings vs Relaxed Settings



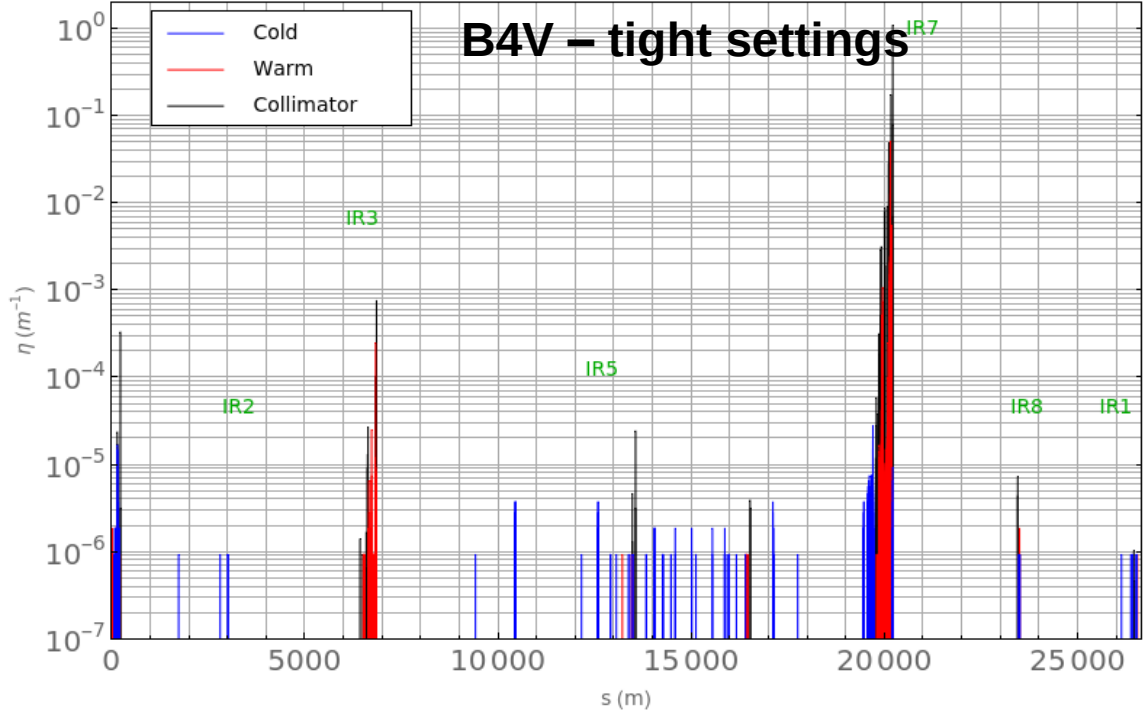


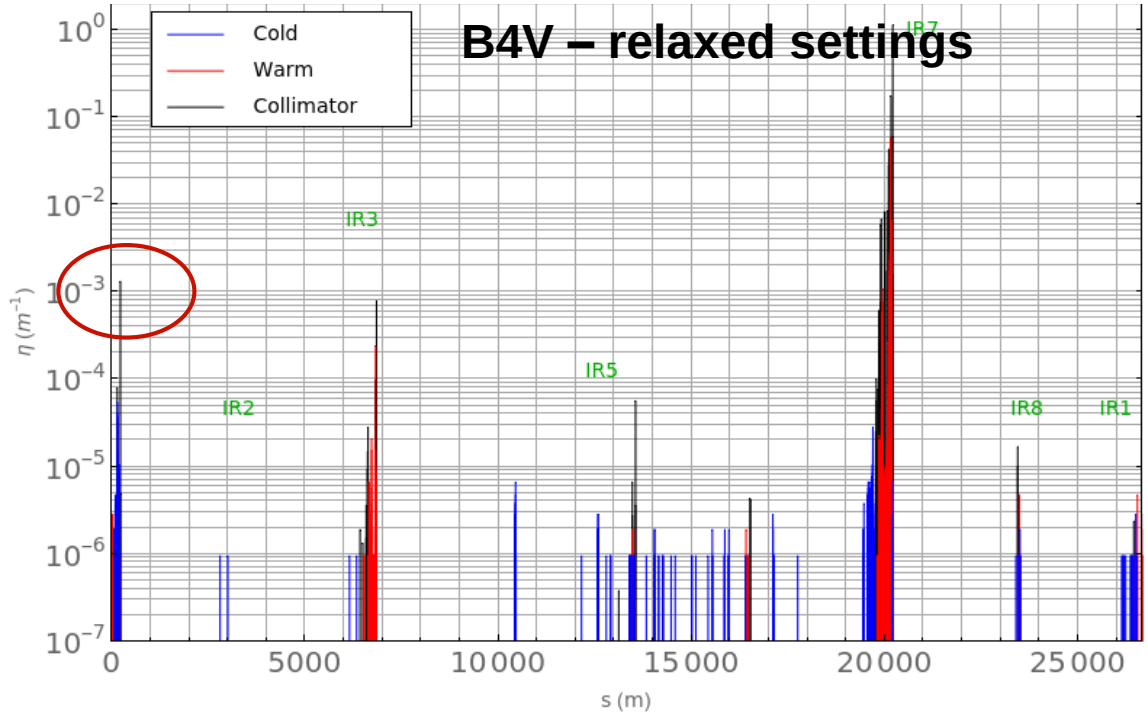
Tight vs Relaxed collimator settings

- **FLUKA**
- 15 cm β*
- Impact: 4 µm
- 10e6 particles / 200 turns

- ~10 % worse global inefficiency with relaxed settings
- ~7 % larger DS losses with relaxed settings

Tight vs Relaxed collimator settings





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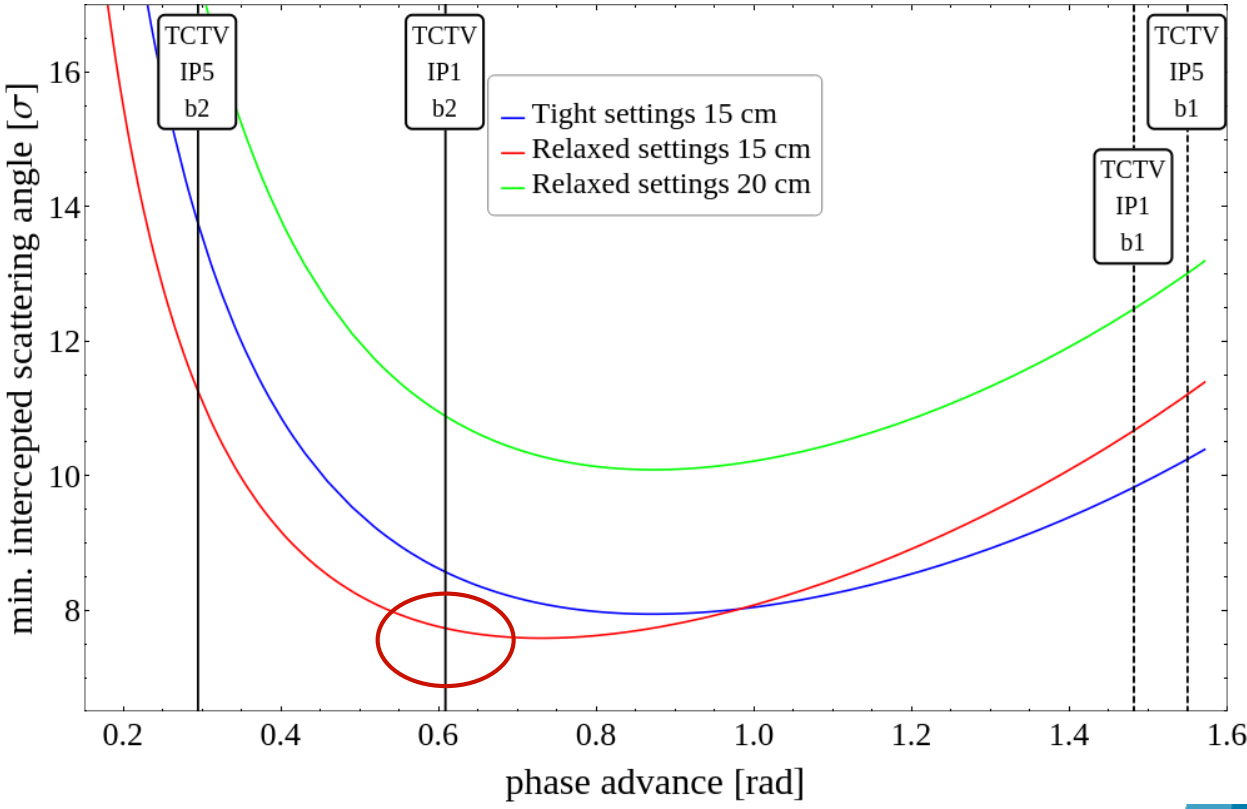
- **B4V TCT losses** in IR1 reach **1.2e-3**
  - **Could affect background in IP1**

Normalized cut on scattering angle

- **Minimum angle** that a particle can be scattered and **be absorbed** by a downstream collimator depends on **phase advance** and **collimator settings**
- **TCP** to IR1 **TCT phase advance** almost **optimal** with new collimator settings
- Not a concern at 20 cm (run IV)



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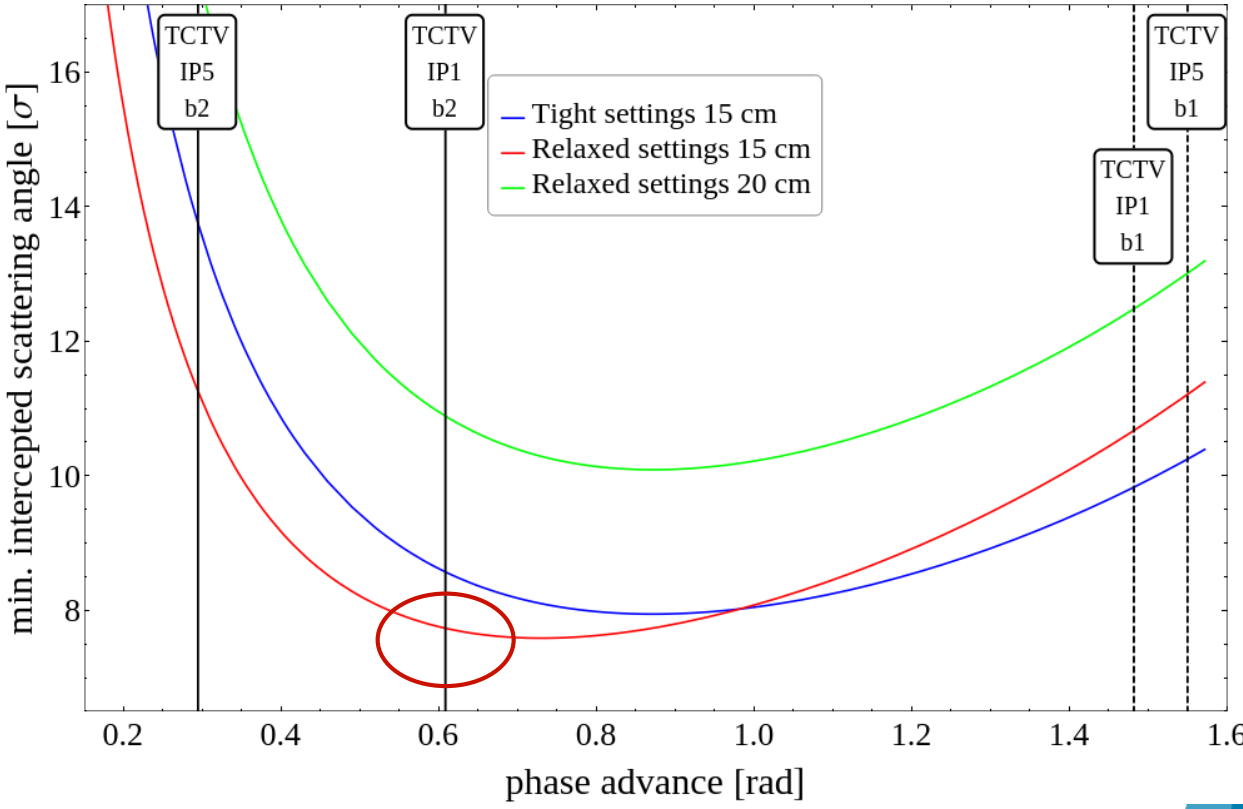
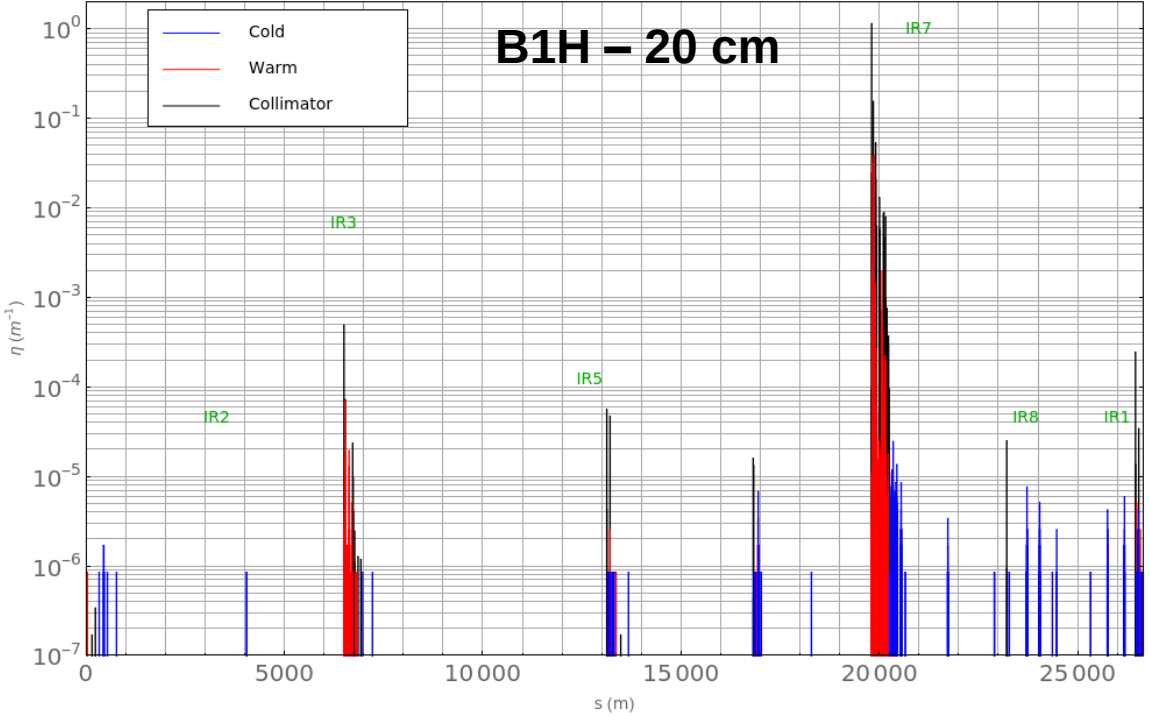
Solutions if relaxed settings to be used at 15 cm?

- 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)



more details, see presentation by R. Bruce, ”Studies of IR7 optics”: https://indico.cern.ch/event/828666

20 cm β* with Relaxed Settings

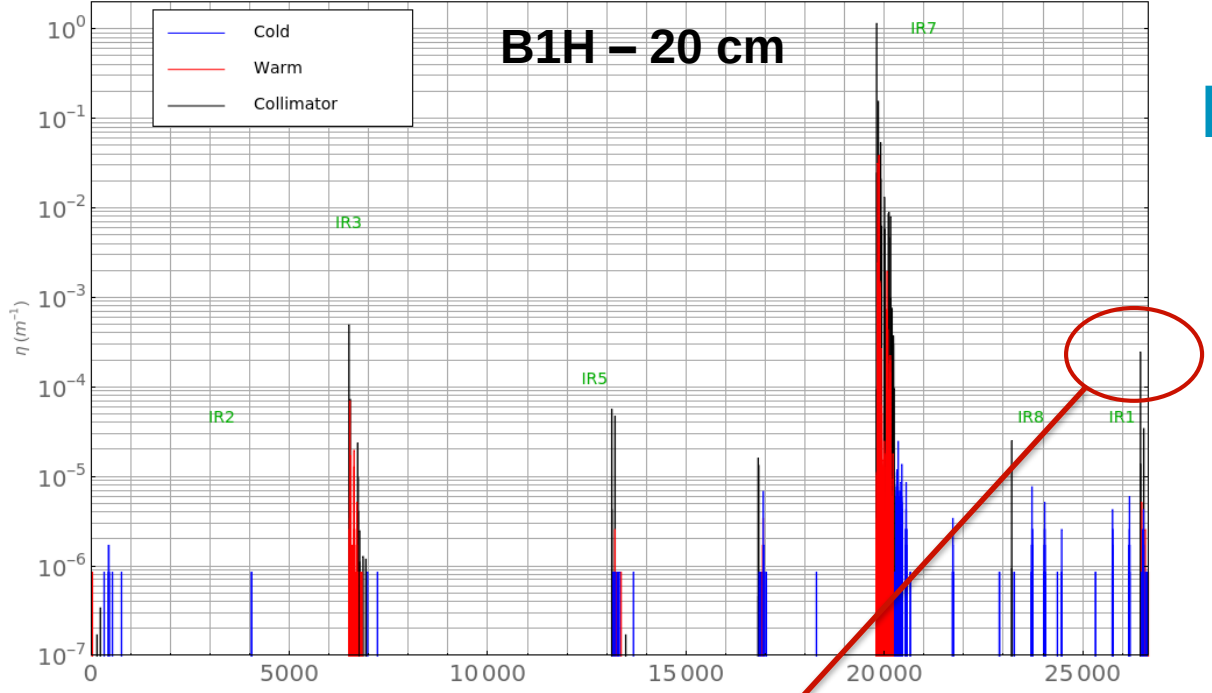


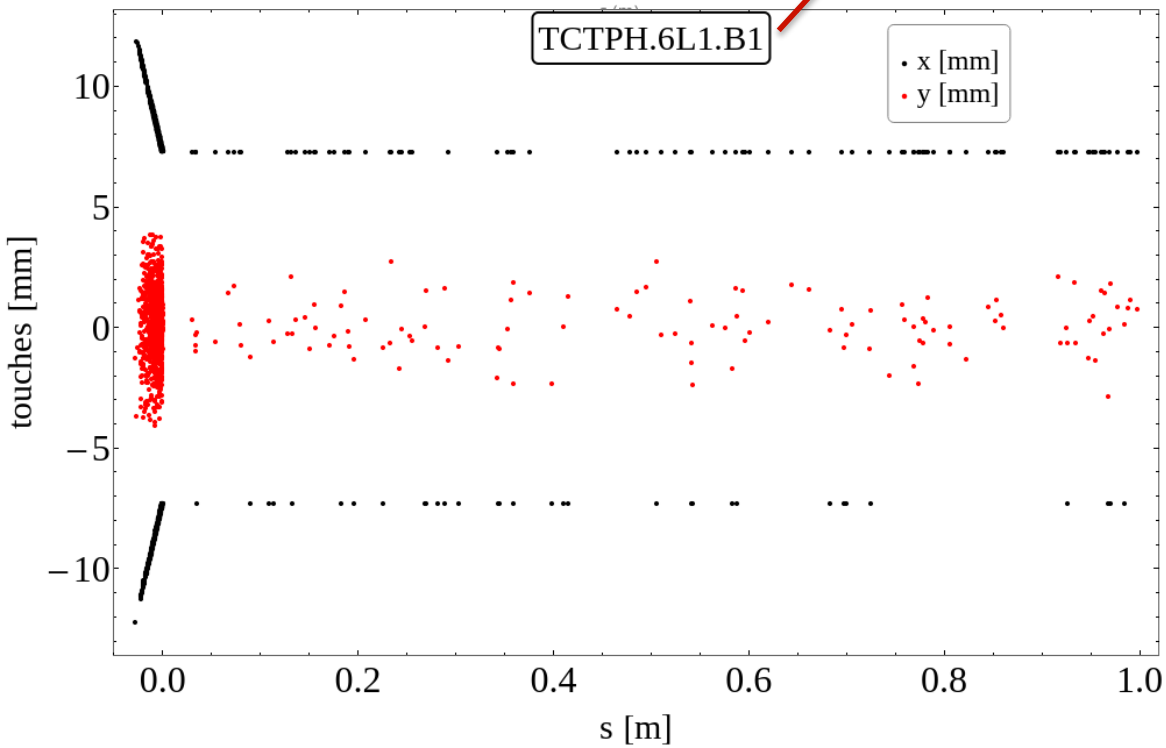
Relaxed collimator settings

- v1.5 optics
- Impact: 5 µm
- 10e6 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)





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TCT losses worst in IR1, for B1H

- Touch maps have been sent to FLUKA team for experiment background simulations

Summary

- Simulation model has been updated to **v1.5 optics** with a more **detailed aperture**
  - Aperture requires some **patching**
    → discussion ongoing with layout team
  - **15 % larger DS losses** in v1.5 optics
    → due to smaller TCP beta functions, can be corrected

- **Relaxed collimator settings** have been requested
  - 7 % larger DS losses
  - Higher TCT losses, in particular **IP1 for B4 vertical**
    → potential **solutions**: retracting TCT by 0.5 sigma, inserting TCP / TCSG by 0.5 / 0.4 sigma
  - **TCT losses not** expected to be an **issue** at **20 cm**
  - Input for **TCT shower simulations** has been sent to FLUKA team

- v1.5 optics, relaxed settings vs v1.3 tight, up to ~23 % increase in the DS losses (B1H)
  - B1H DS losses similar to B2H losses in v1.5
  - To be cross-checked with FLUKA simulations of power deposition in IR7 DS before new collimator settings are validated

Follow ups:

- consider using much larger beta functions at TCP for increased cleaning efficiency
  - see presentation by R. Bruce, ”Studies of IR7 optics”: https://indico.cern.ch/event/828666
- consider optics errors, failures

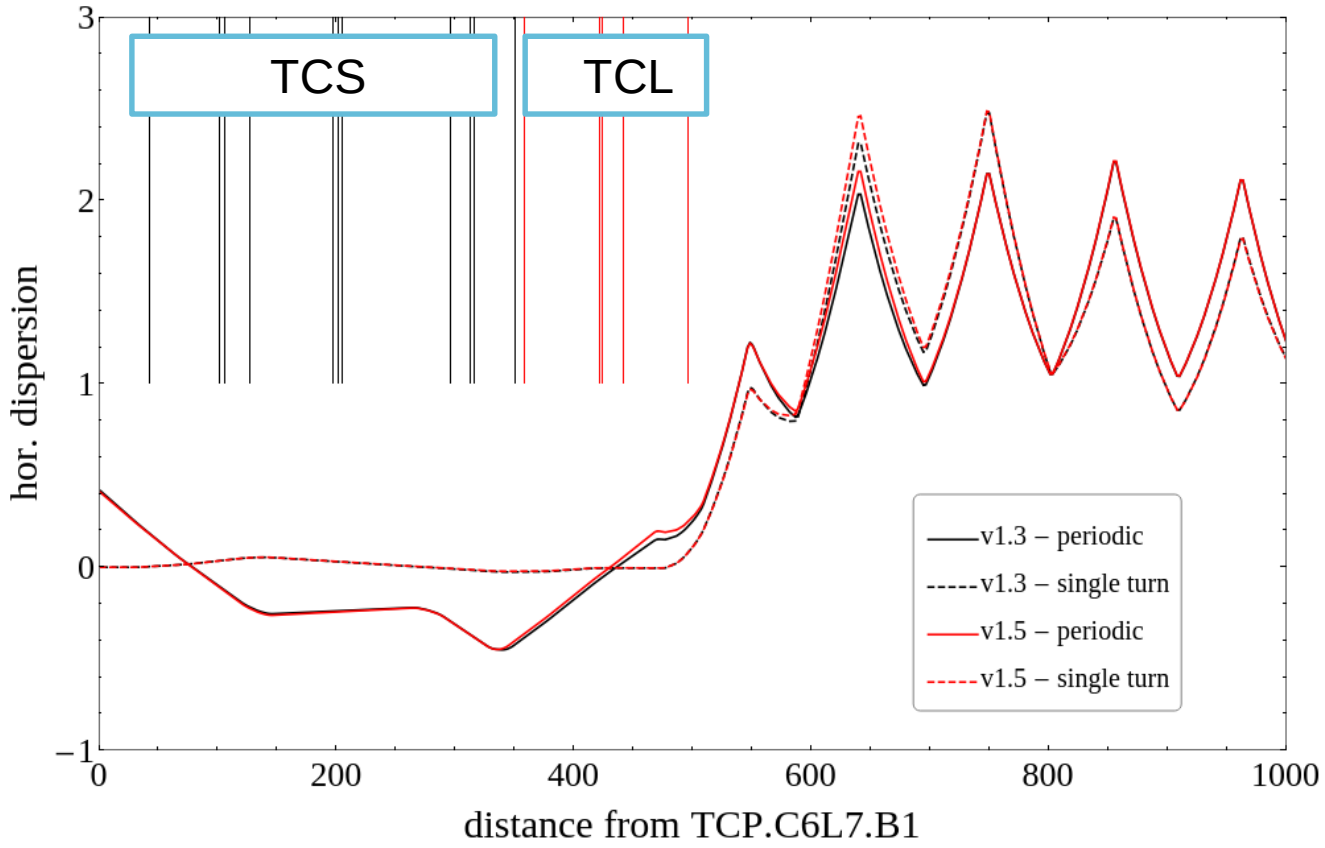
Scenario	inefficiency [e-4]	MaxCold [e-5]	MaxWarm [e-5]	DS cl1 [e-6]	DS cl2 [e-6]	MaxTCT [e-4]
B1 v1.3 tight H/V	7.4 / 6.6	6.1 / 5.2	1.1 / 0.8	8.0 / 6.5	5.6 / 5.2	2.3 / 1.0
B1 v1.3 relaxed H/V	8.1 / 7.2	6.1 / 6.3	0.6 / 0.6	8.8 / 6.9	6.0 / 5.5	3.3 / 1.0
B2 v1.3 tight H/V	8.6 / 5.9	4.6 / 2.5	0.5 / 0.6	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 relaxed*	/ 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 relaxed	/ 2.8	/ 5.6	/572	**/ 2.3**	**/ 2.3**	/ **13**

* 1.5 μm impact parameter, the rest are 4 μm

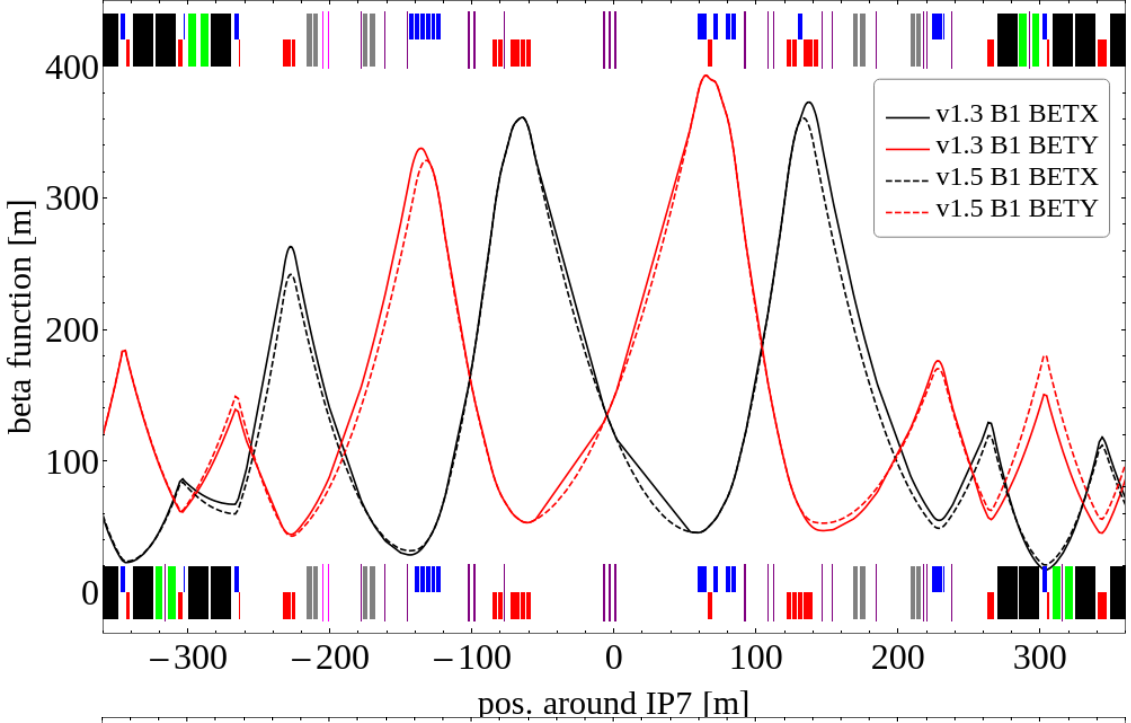
** 15 cm beta*, results for 20 cm are similar except TCT losses

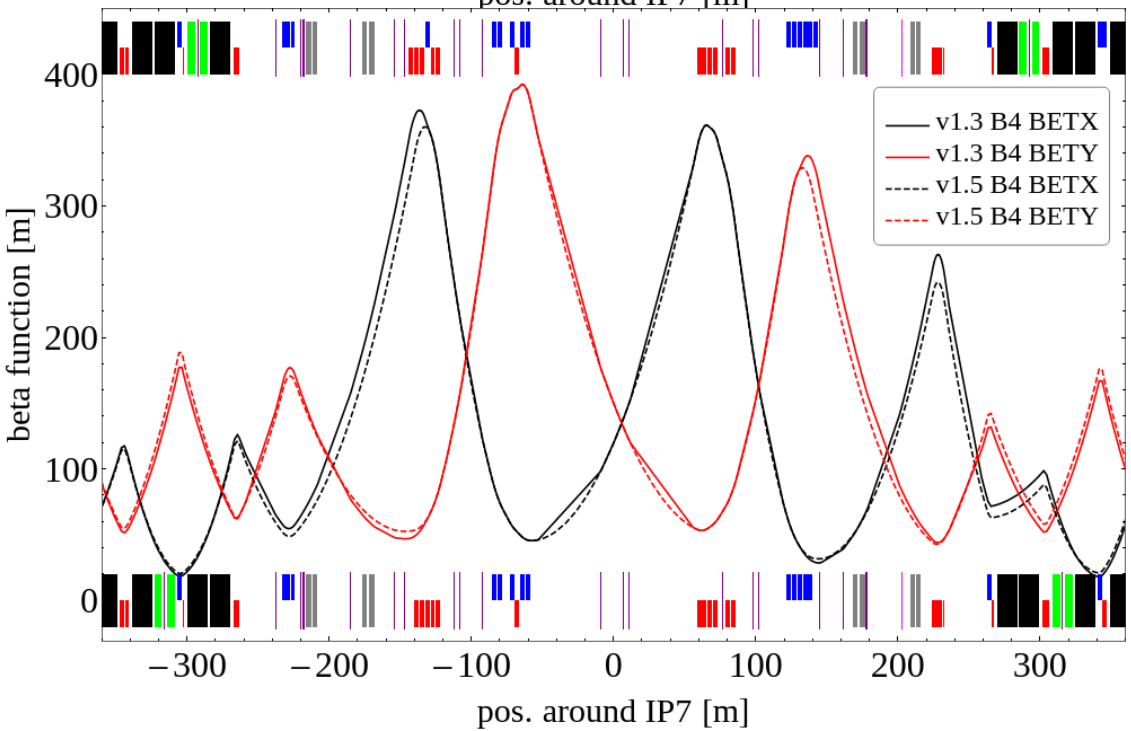
Increase of IR7 DS losses

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

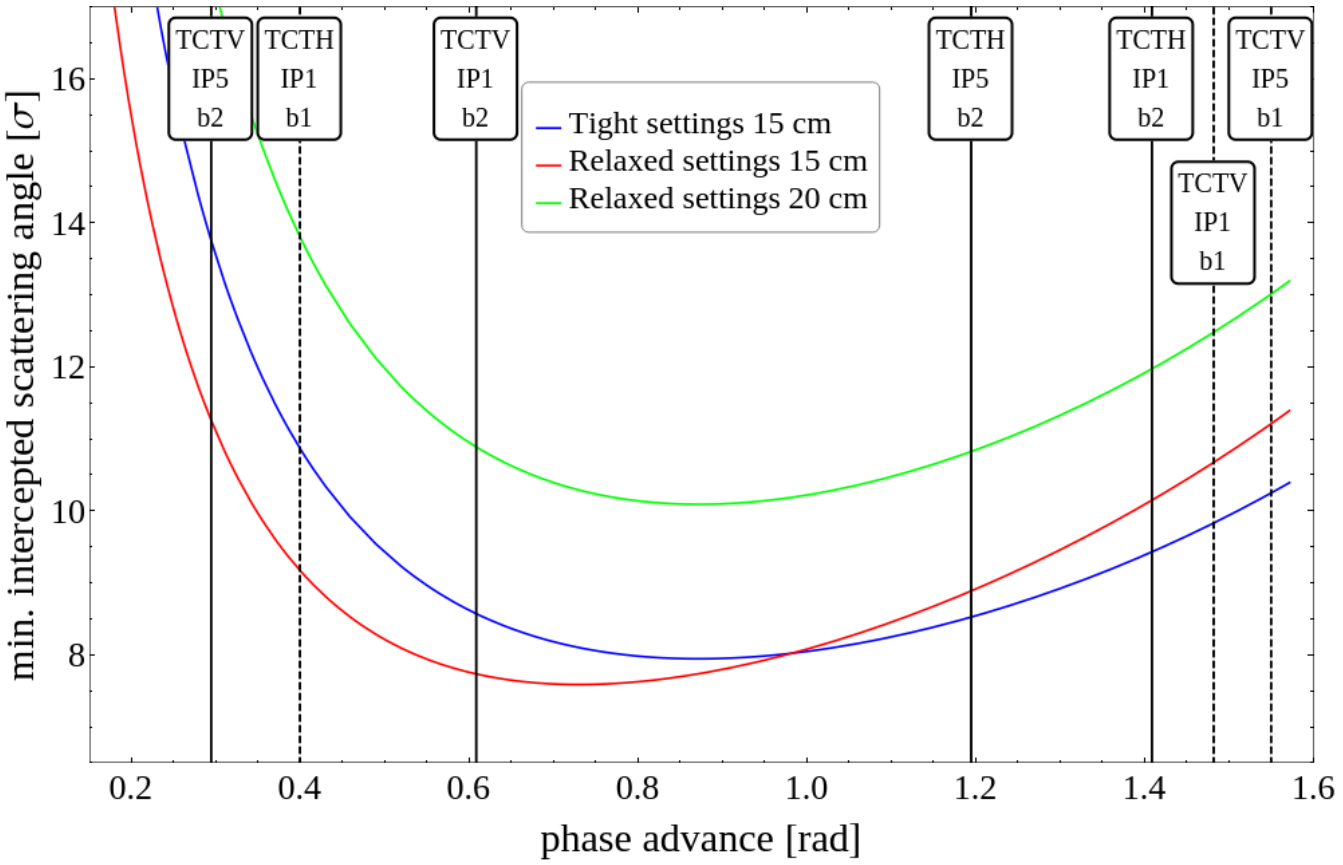


IR7 beta functions

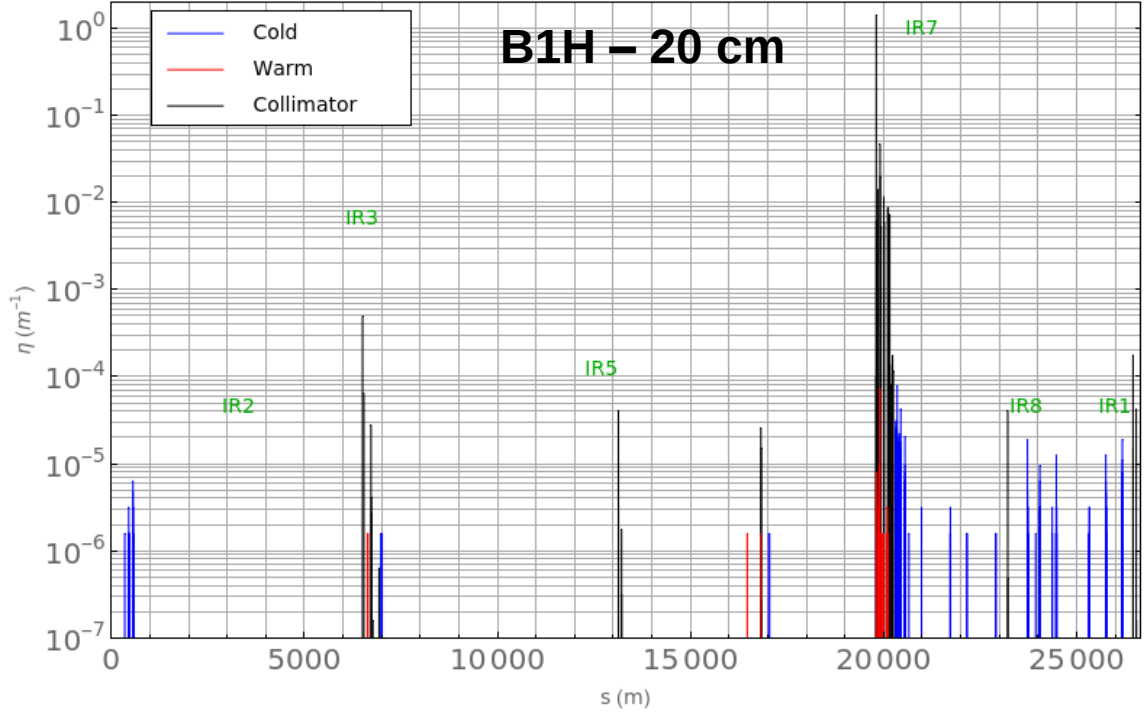


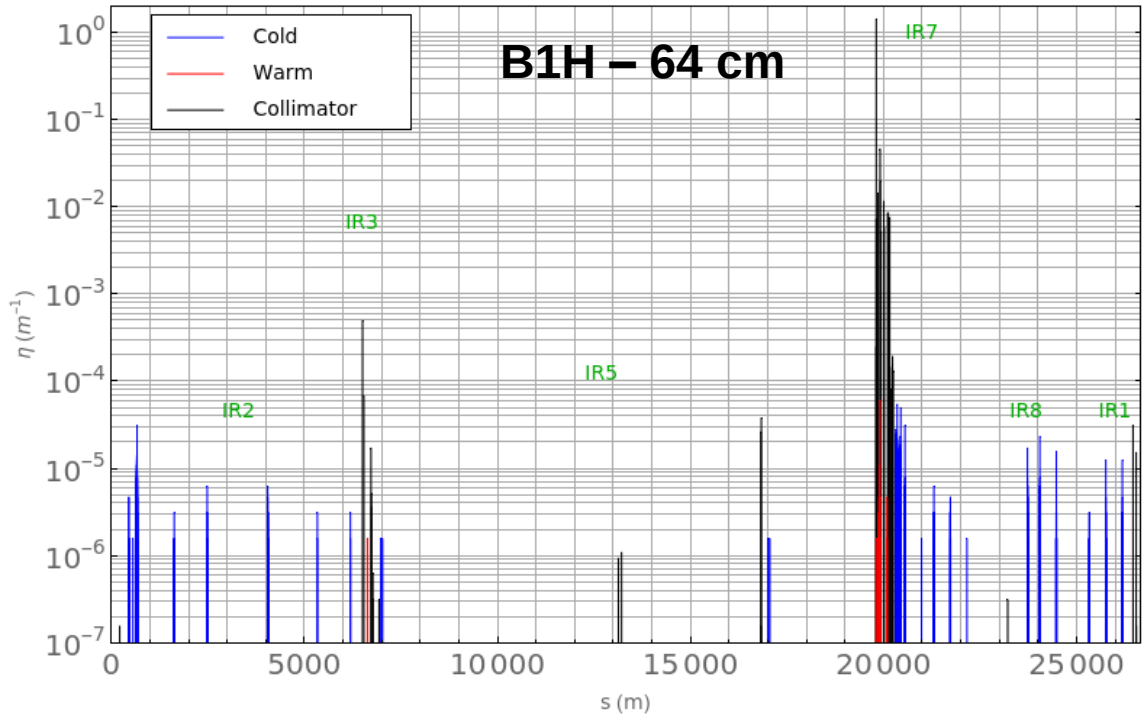


Normalized cut on scattering angle



v1.5 optics – relaxed settings at 20 cm and 64 cm





Relaxed collimator settings

- v1.5 optics
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General notes:

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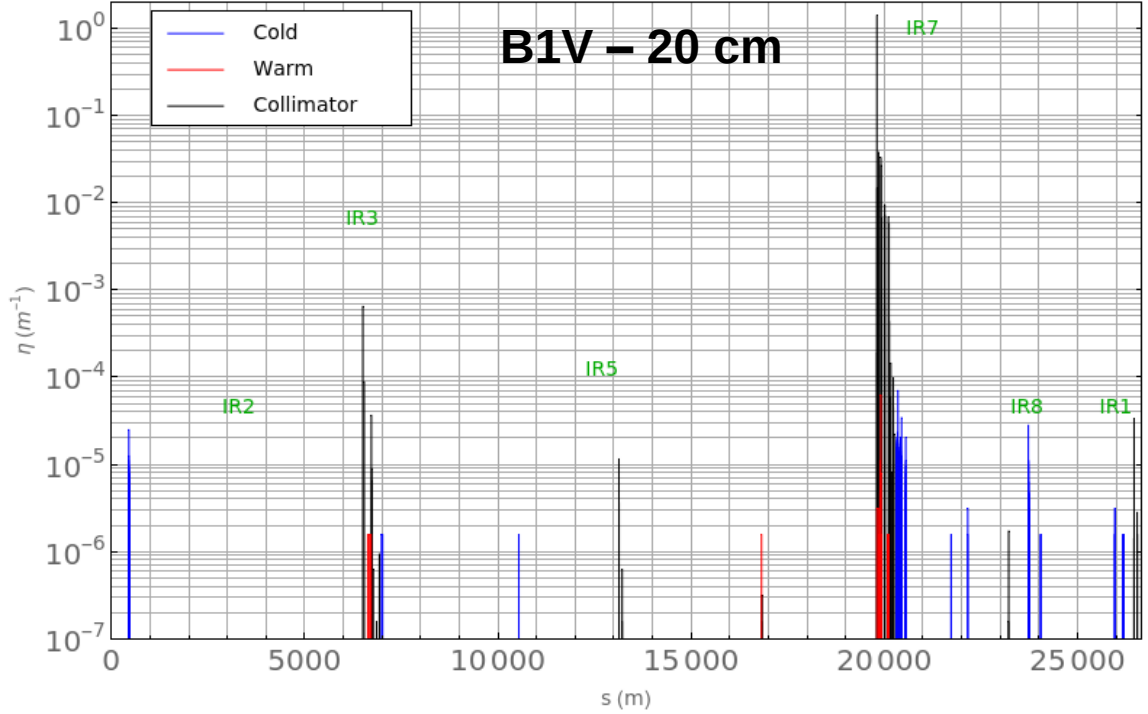

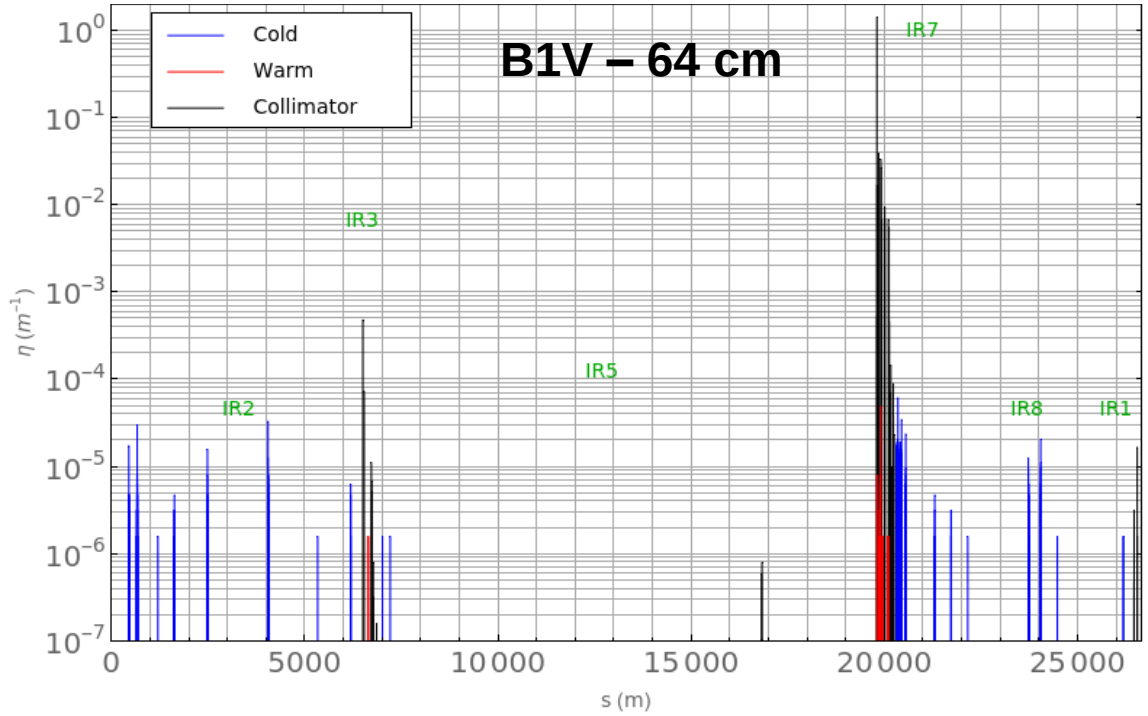

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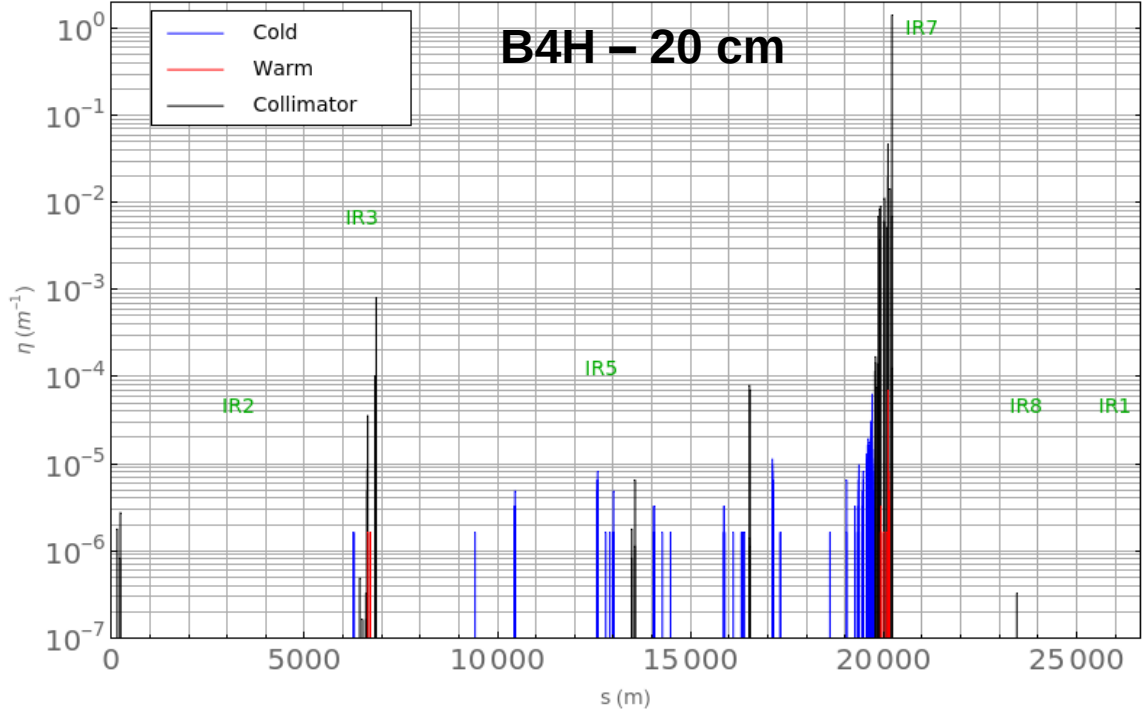

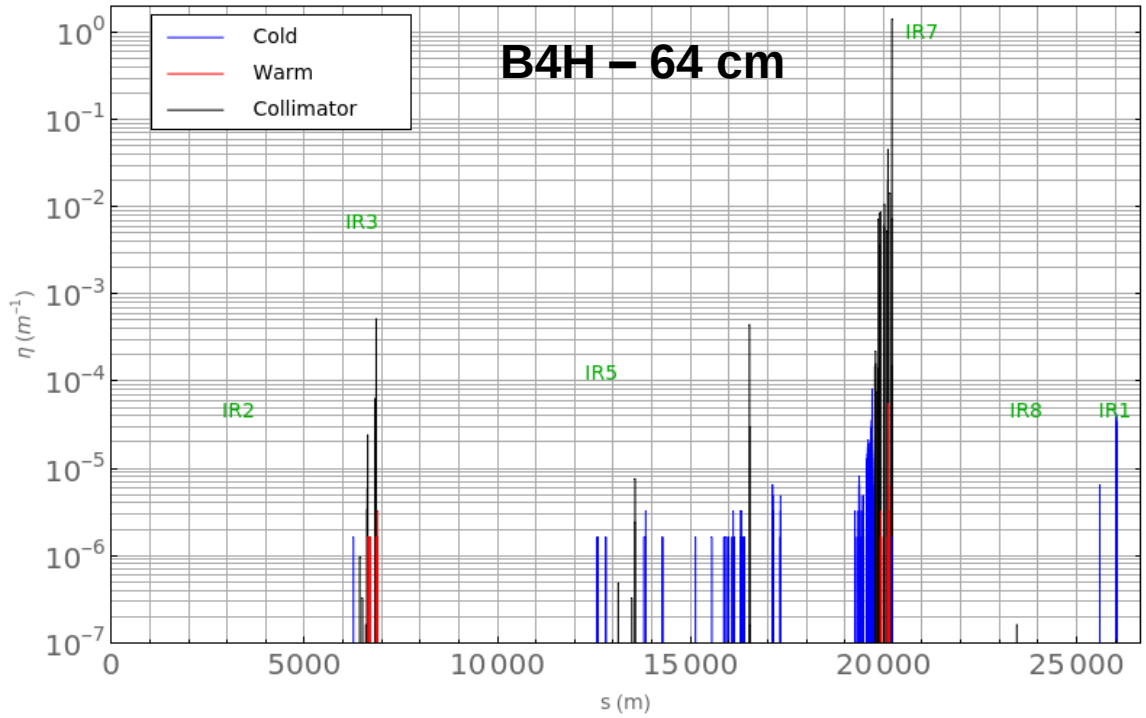

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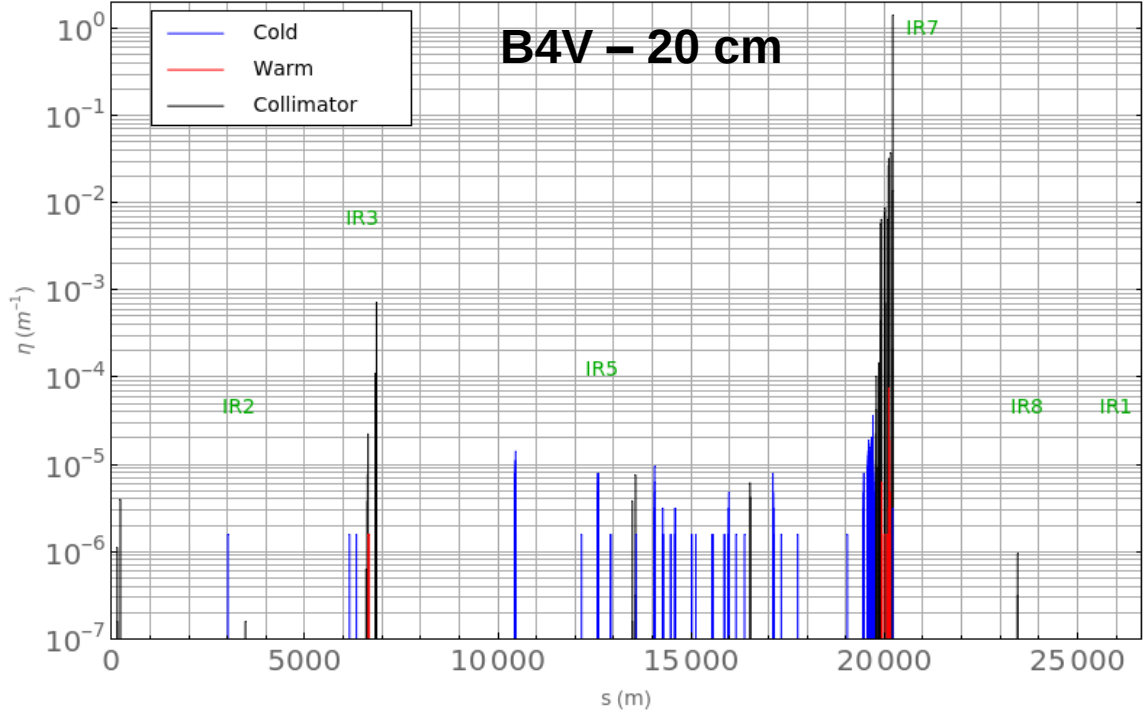

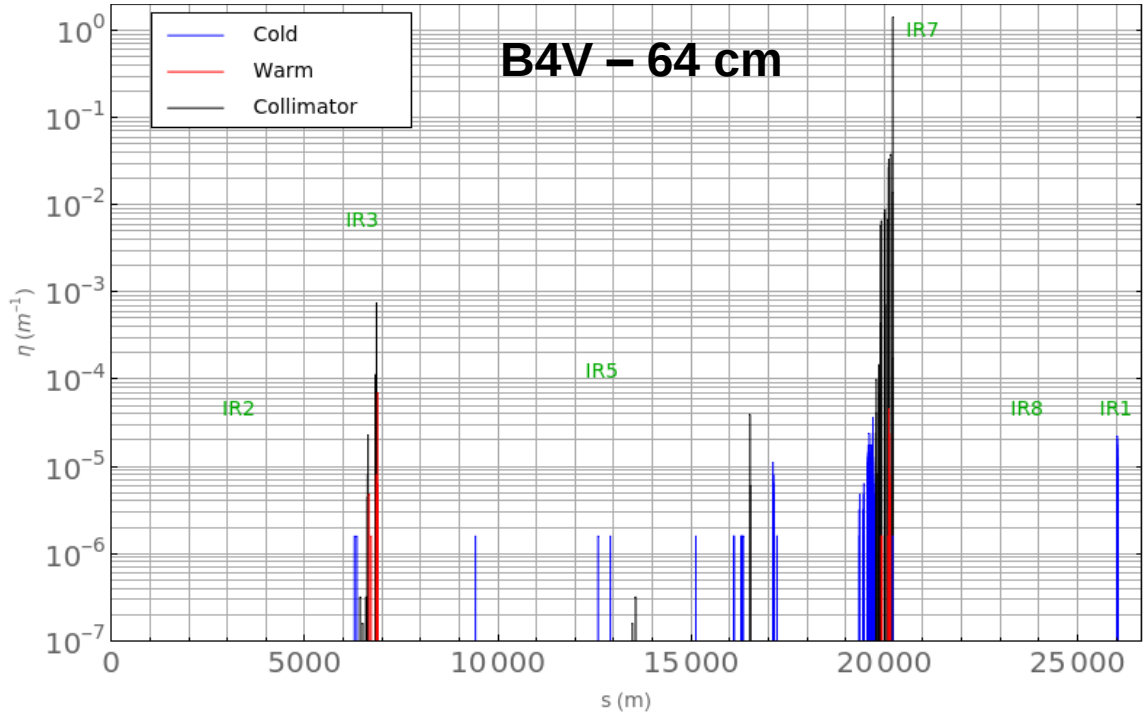

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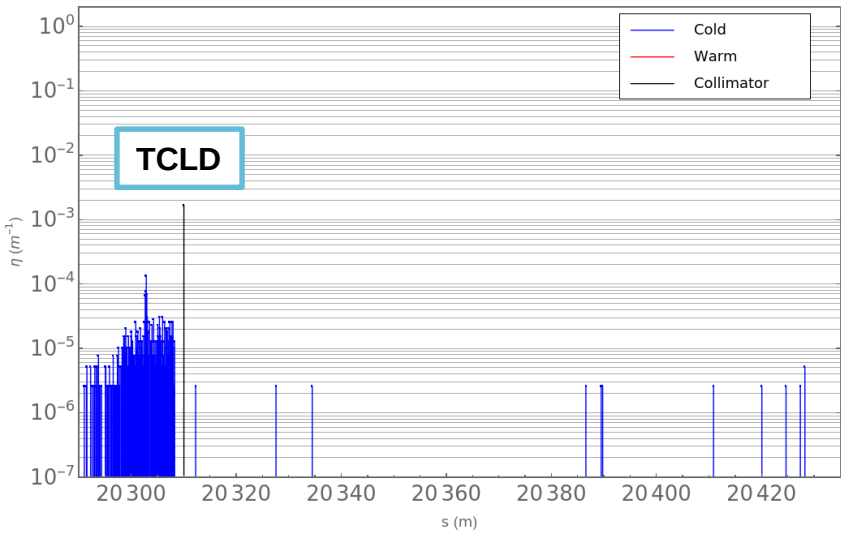
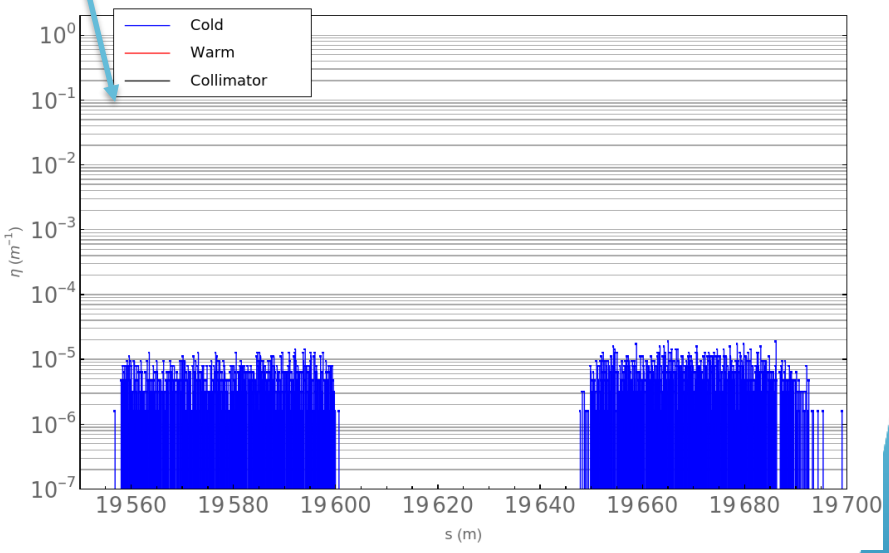
TCLD in IR7 dispersion suppressor

- 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

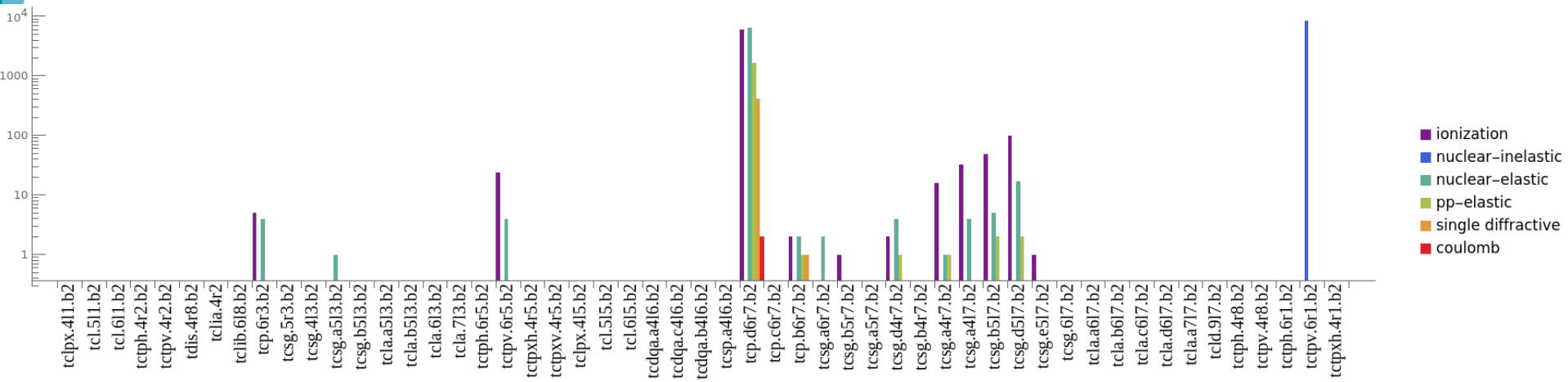




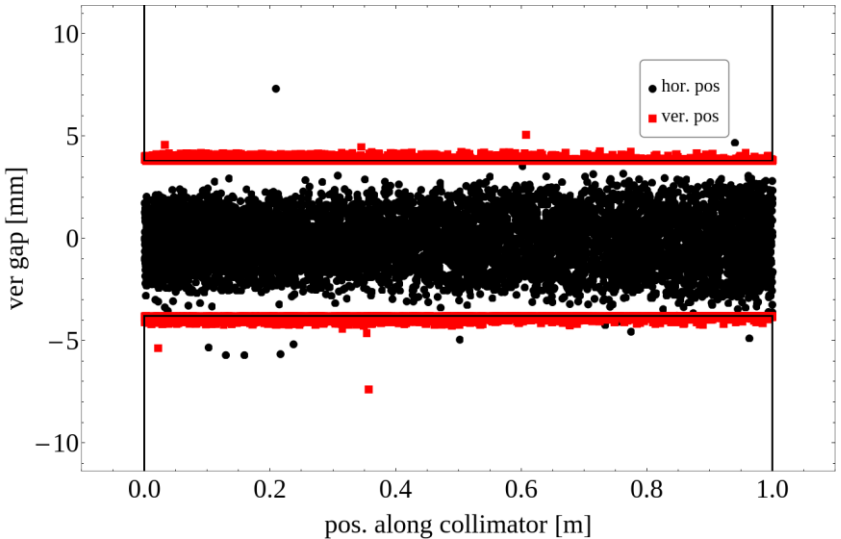
B4V large TCT losses – mitigations

B4V – large TCT losses

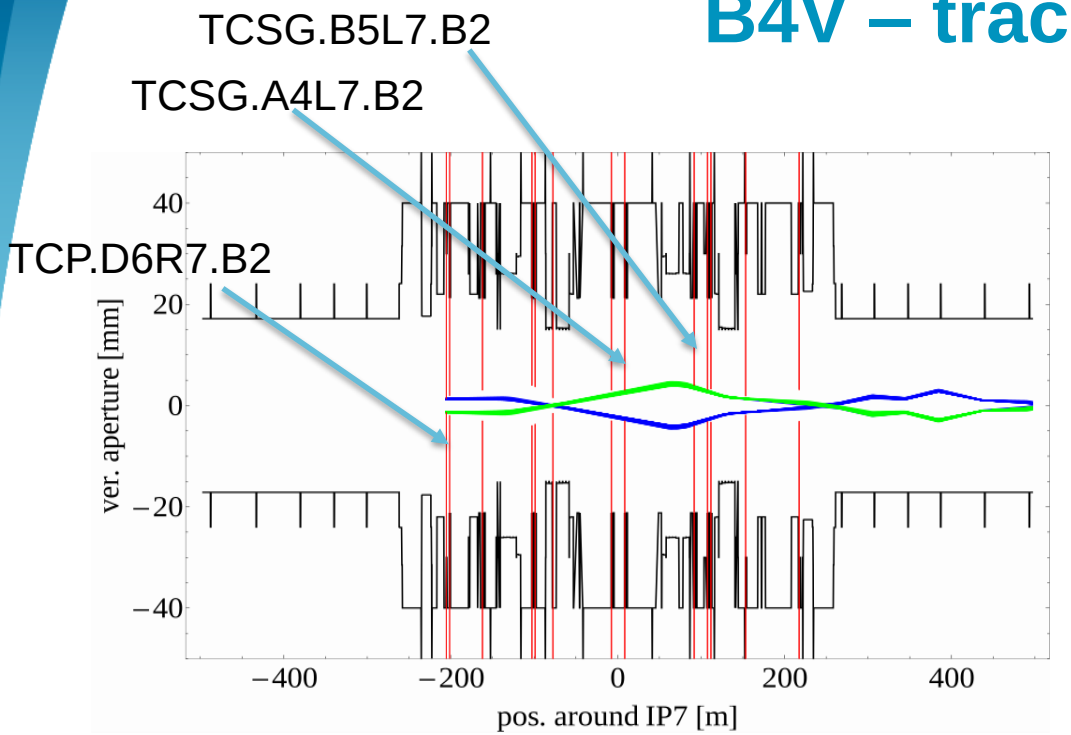
- Losses at 1.3e-3 in the TCTs could risk cause beam dumps, should be rectified
  - n.b. – in 20 cm optics, TCTs are at 13.2 sigma and losses are insignificant
- Mostly elastically scattered protons in TCP, betatron oscillations



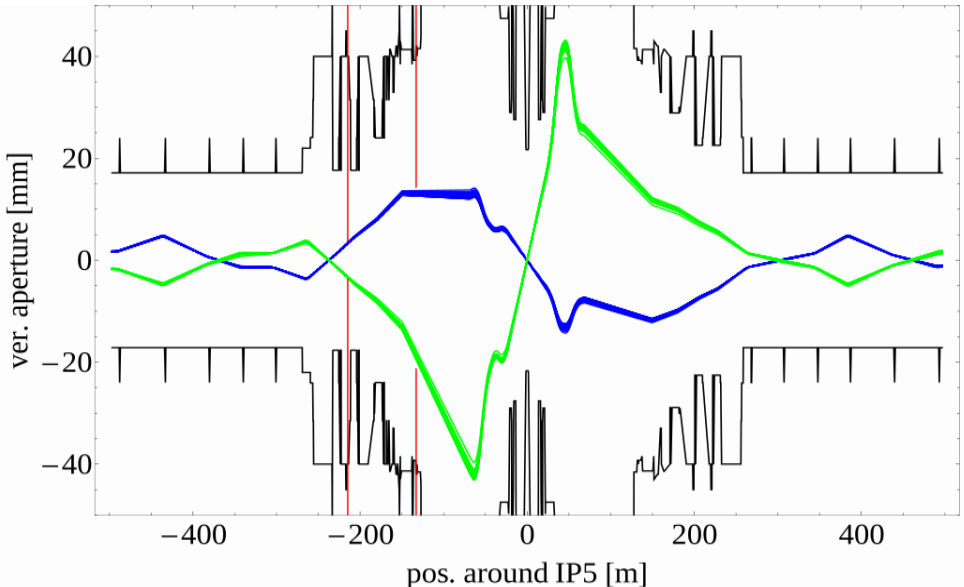
- Superficial hits on TCT
- 90 % particles within impact param 0.5 sigma

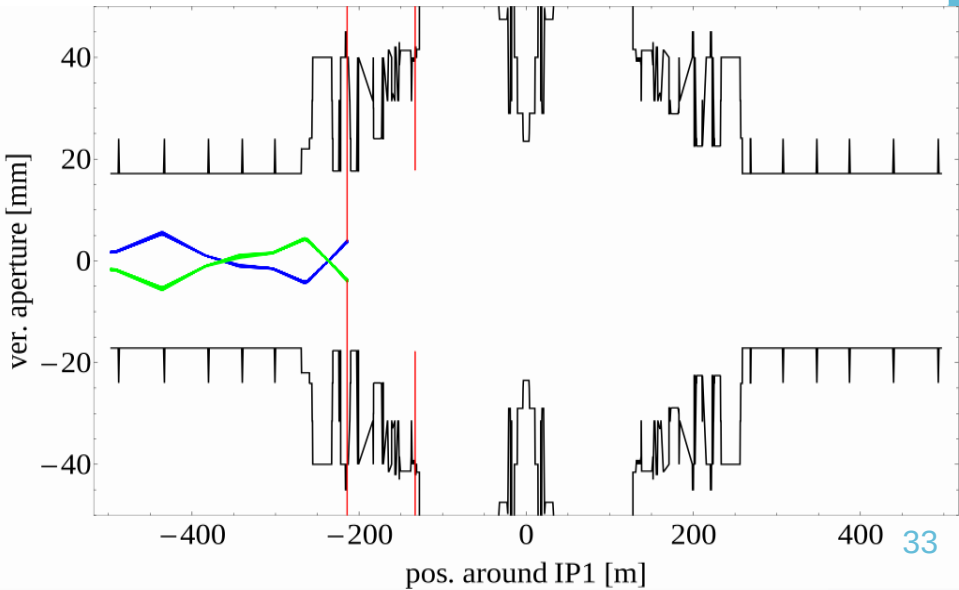


B4V – tracks

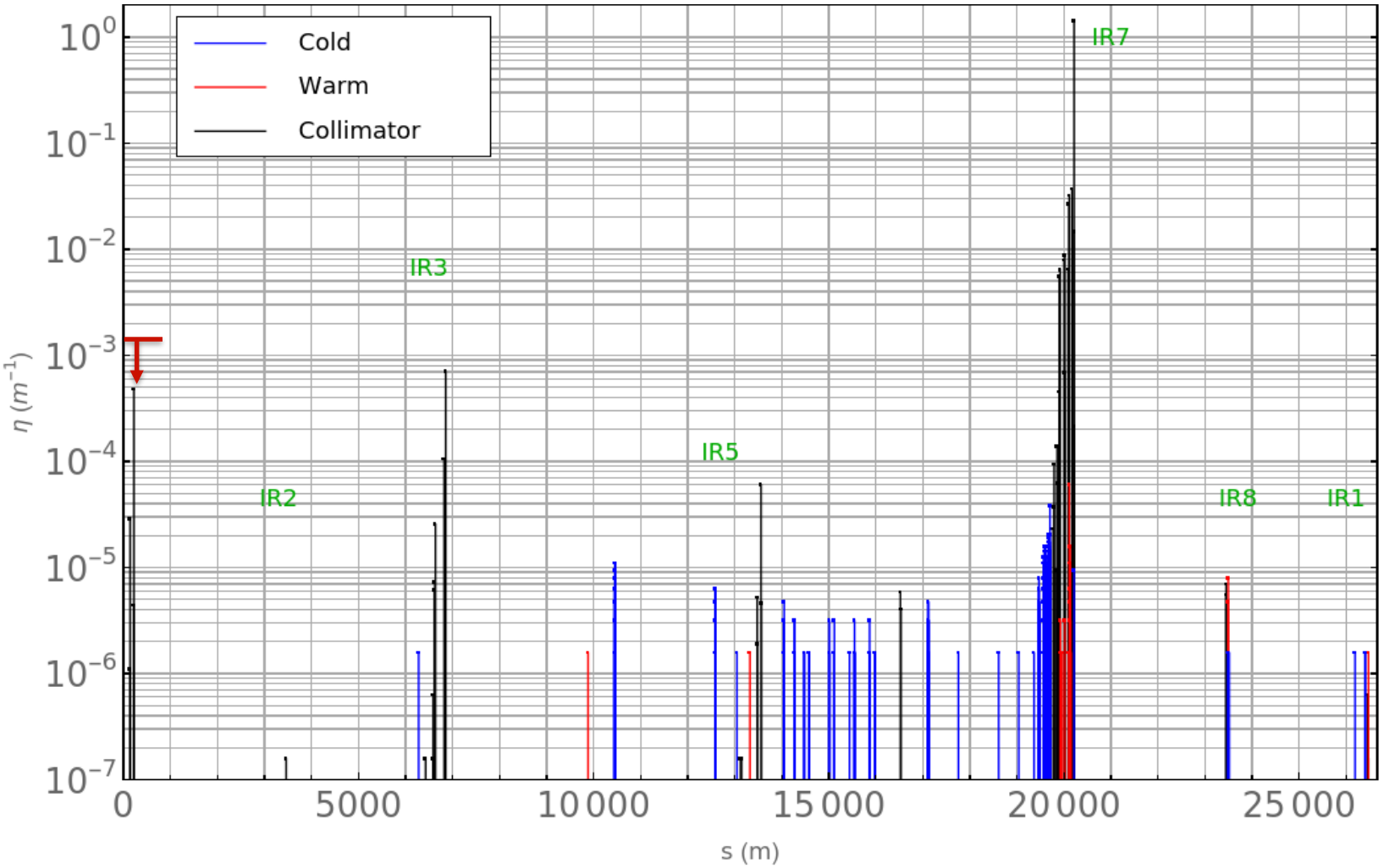


- Solutions?
  - Retract TCT1 by 0.5 sigma (reduces margin in 15 cm optics)
  - Insert TCP.D by 0.5 sigma (increases impedance)
  - Insert TCS by 0.4 sigma (increases impedance)

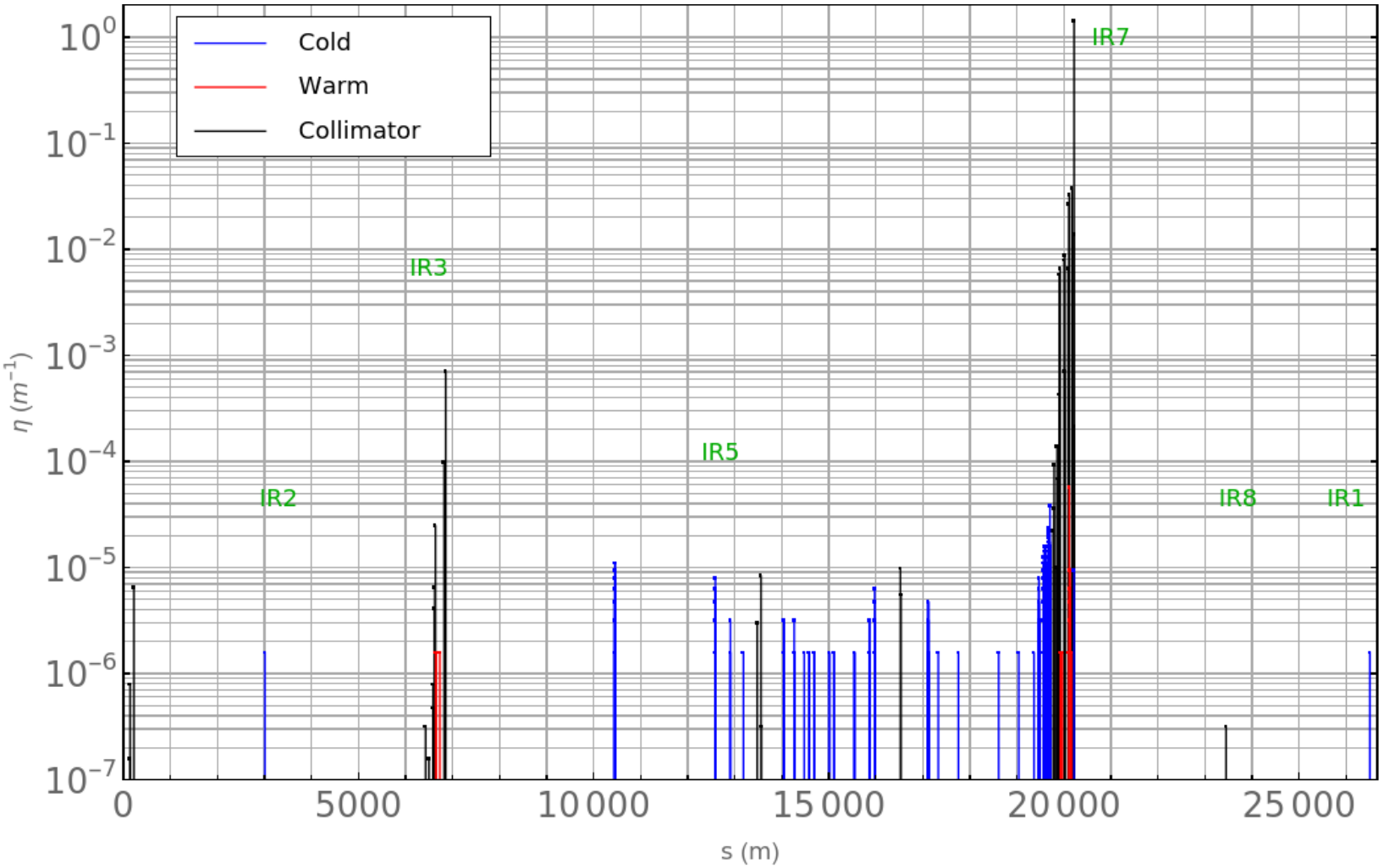




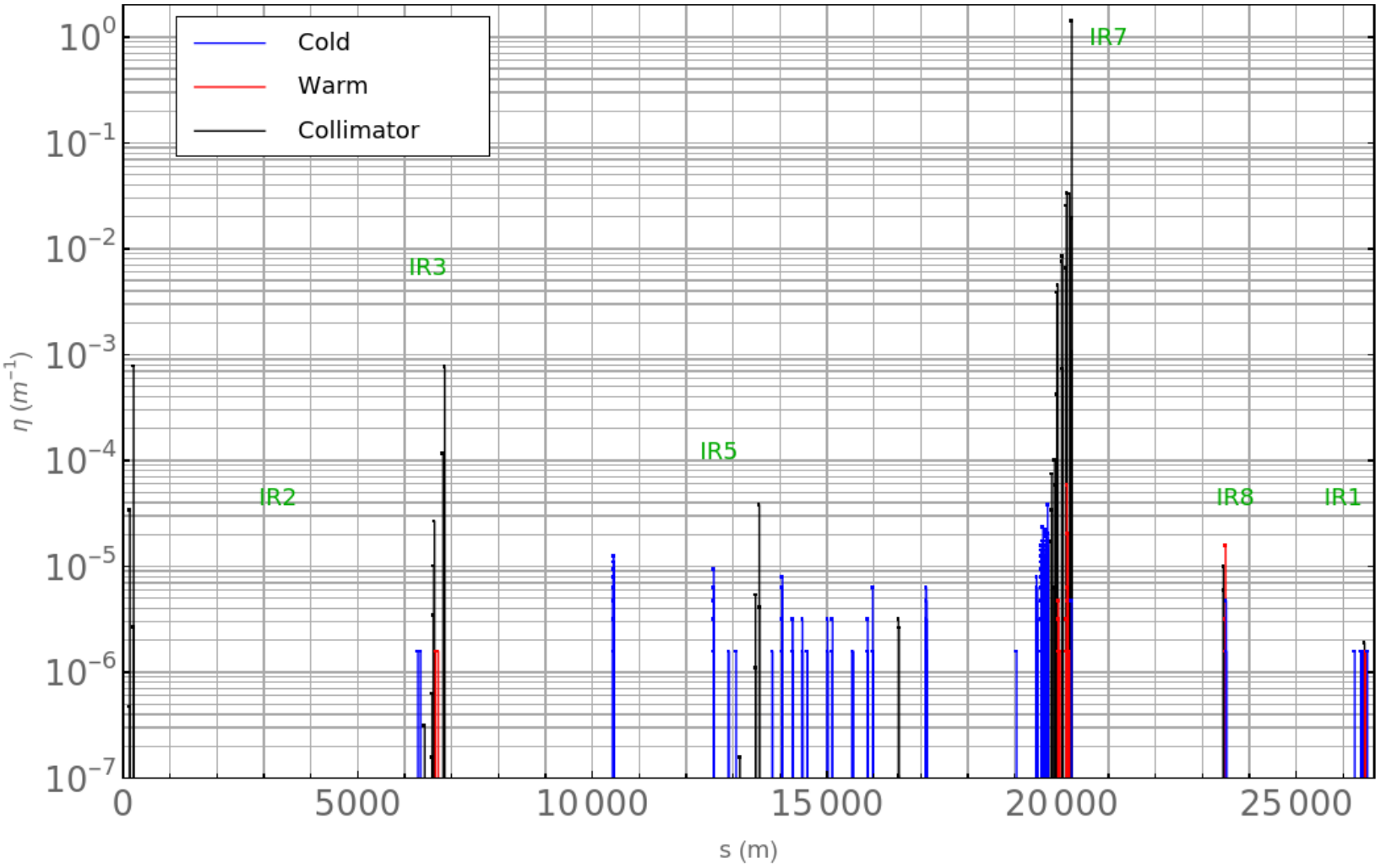
TCT relaxed 0.5 sigma



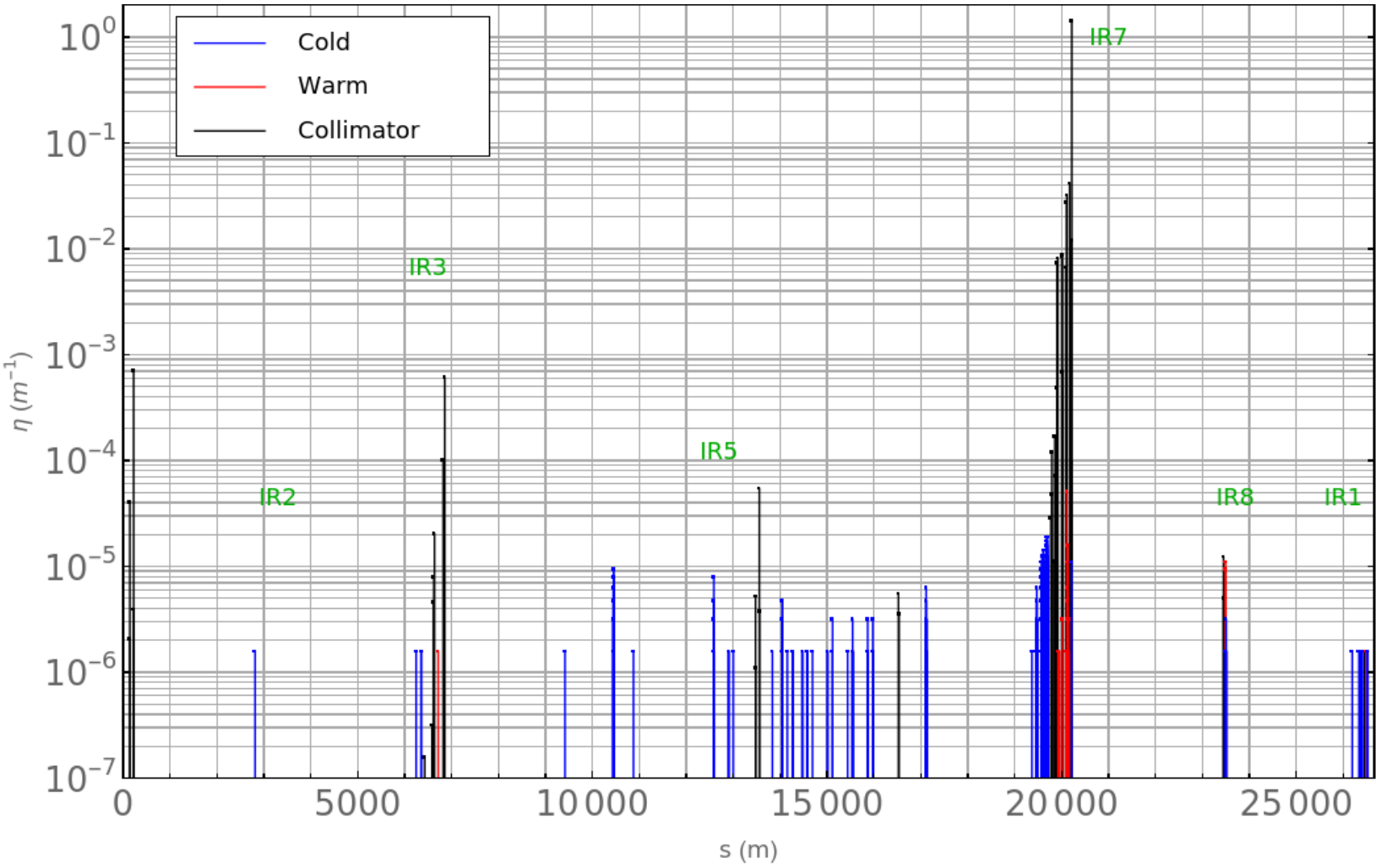
TCT relaxed to 13.2 sigma (corresponds to 20 cm optics)



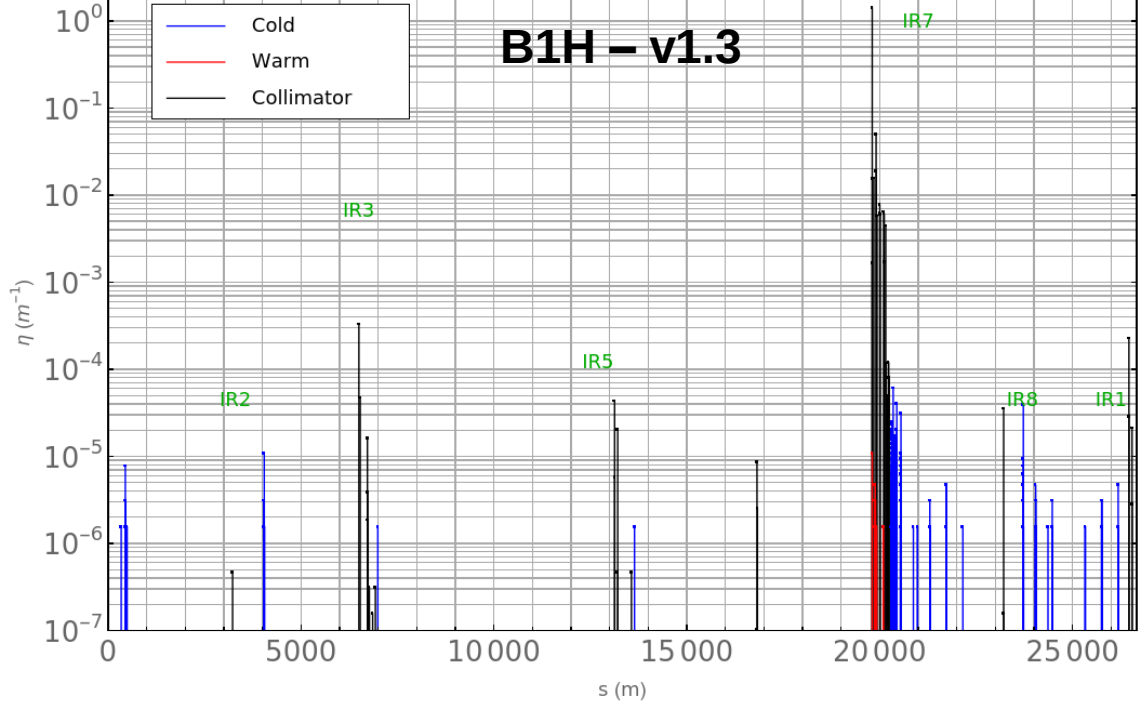
TCP inserted 0.5 sigma

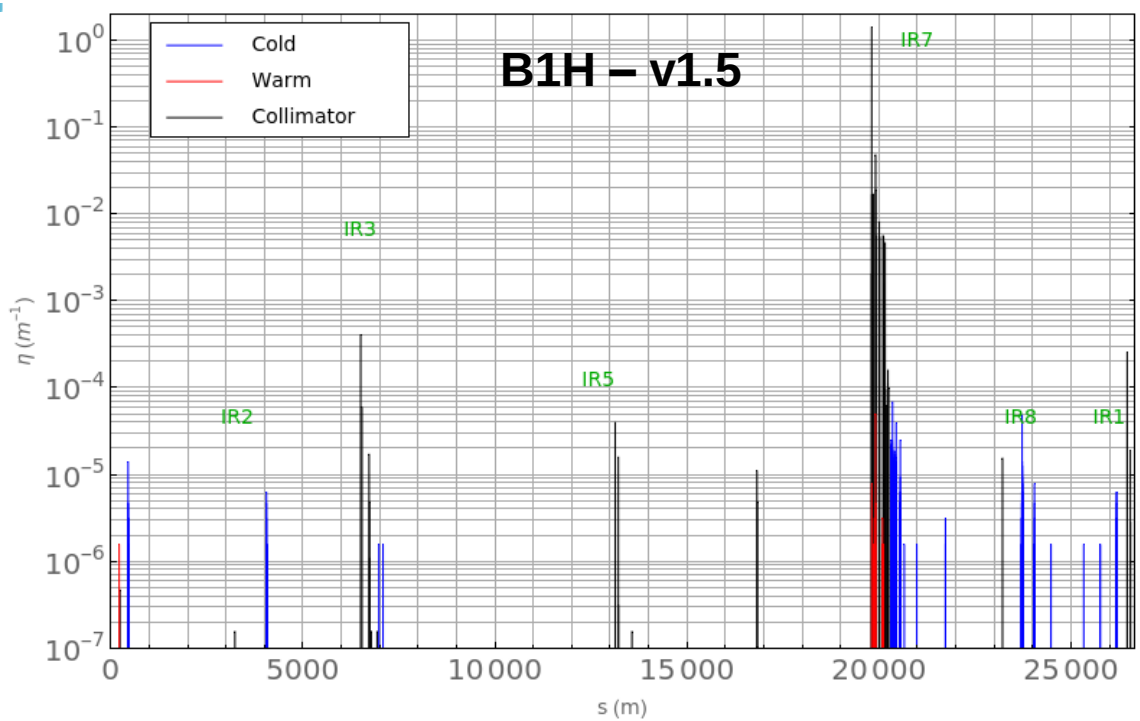


TCS inserted 0.4 sigma



v1.3 vs v1.5 comparison using tight collimator settings



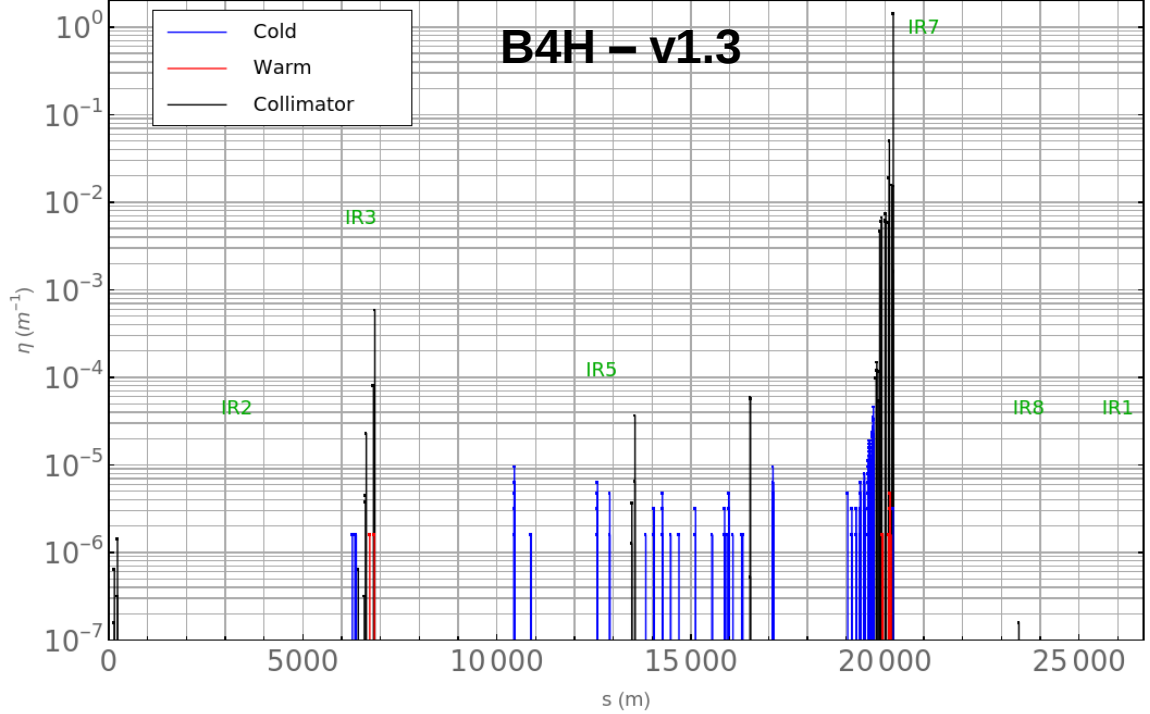


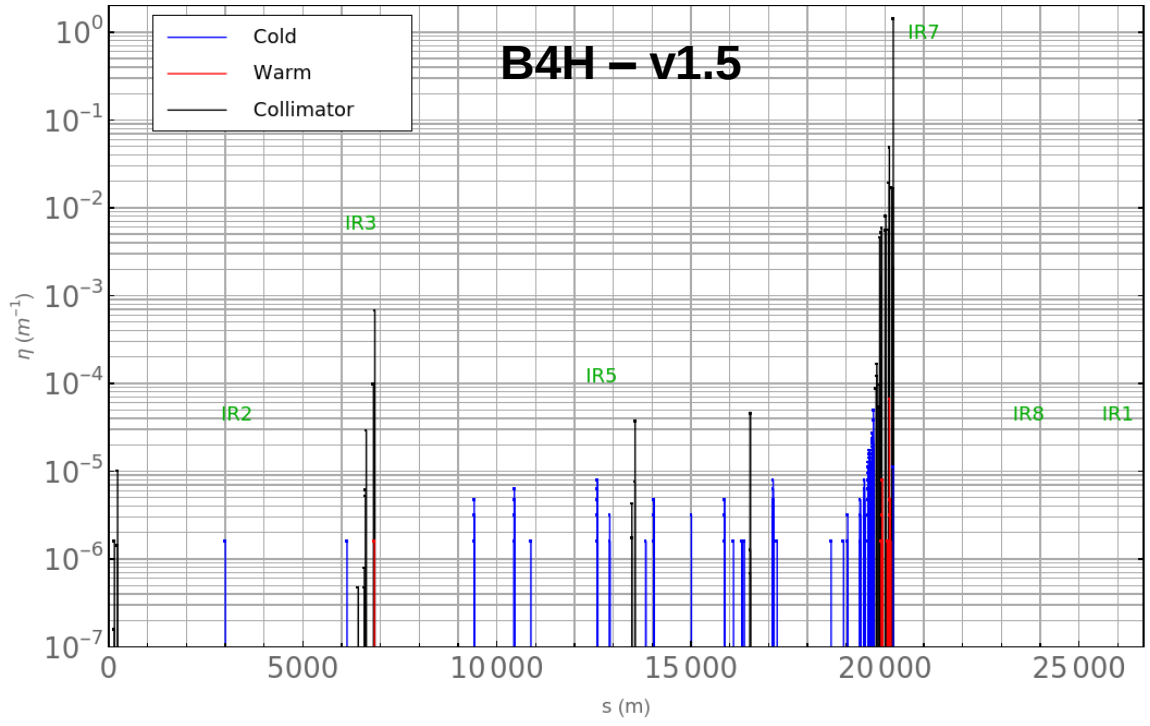
Comparison using old collimator settings

- 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





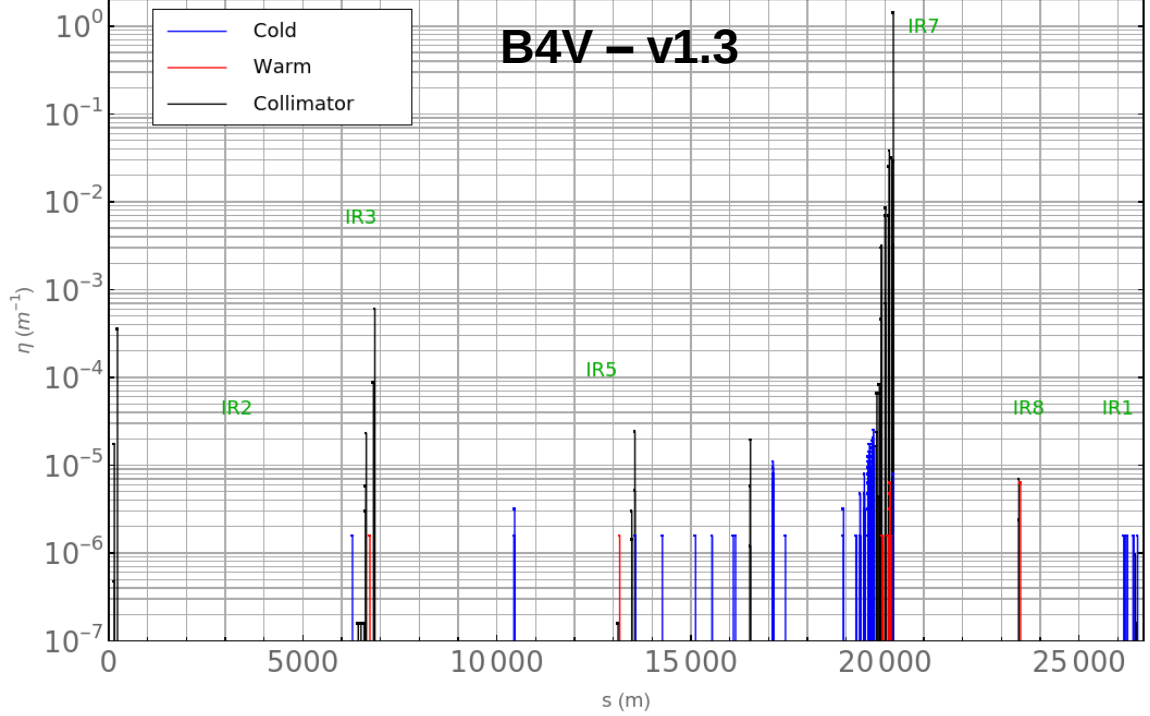
Comparison using old collimator settings

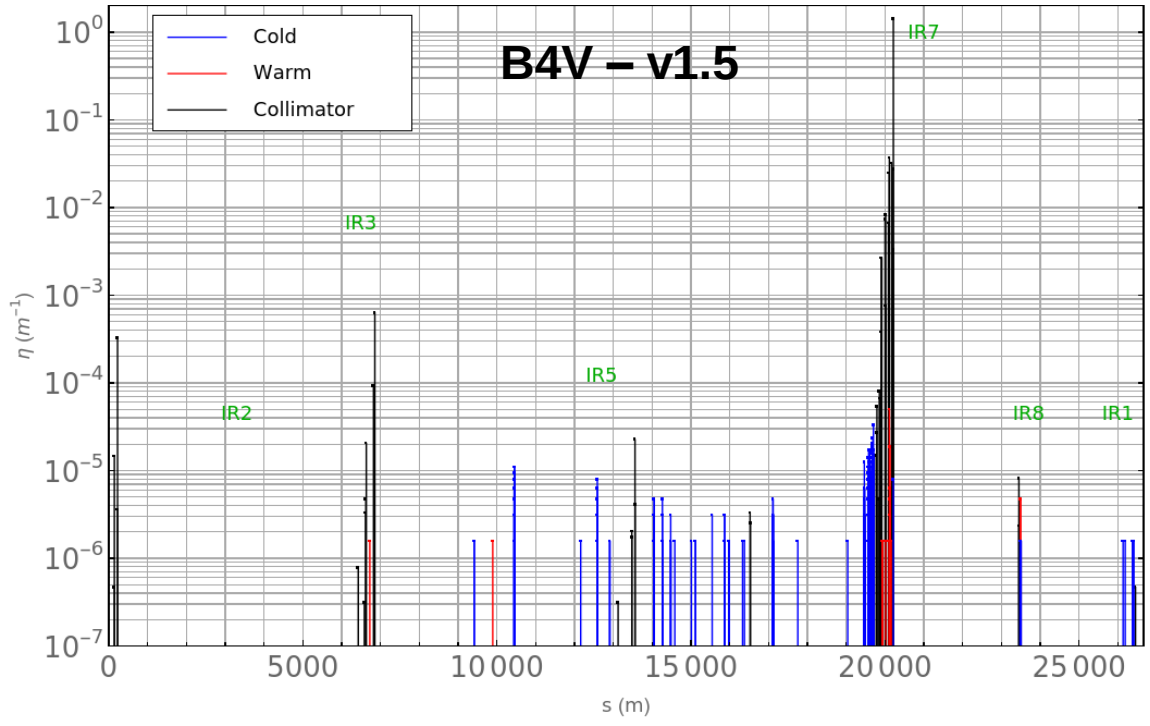
- Nominal optics (15 cm β*)
- Impact: 4 µm
- 6.4e6 particles / 200 turns

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

  → comes from change in single turn dispersive orbit





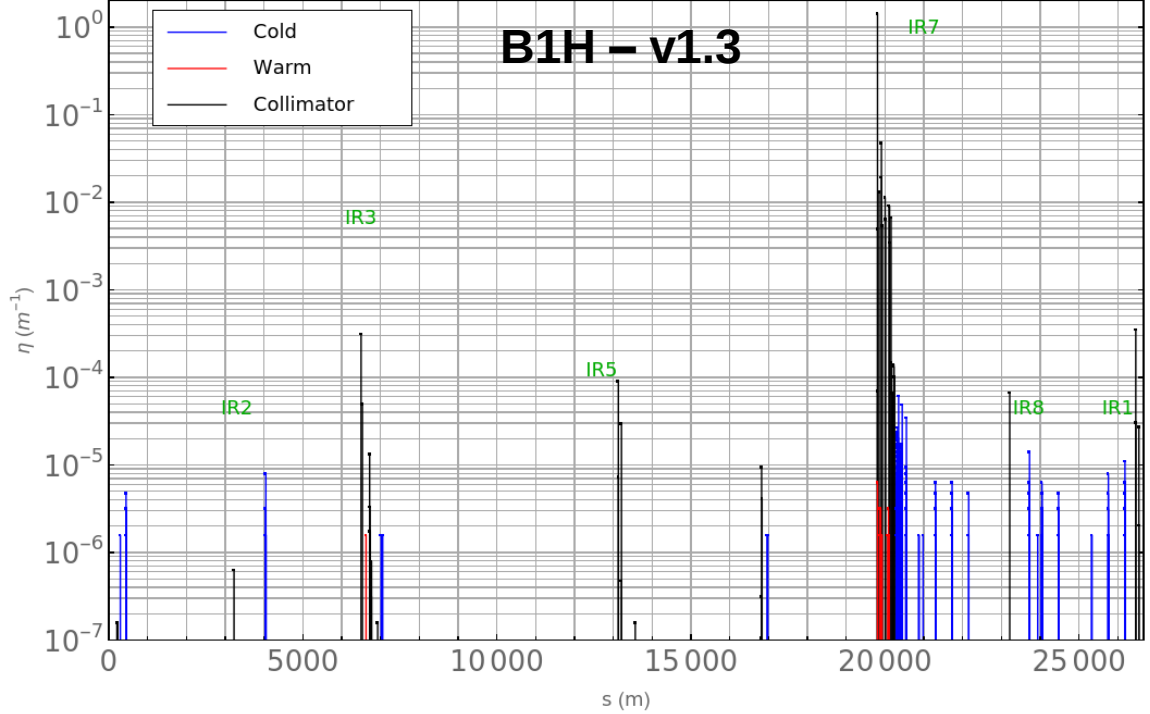
Comparison using old collimator settings

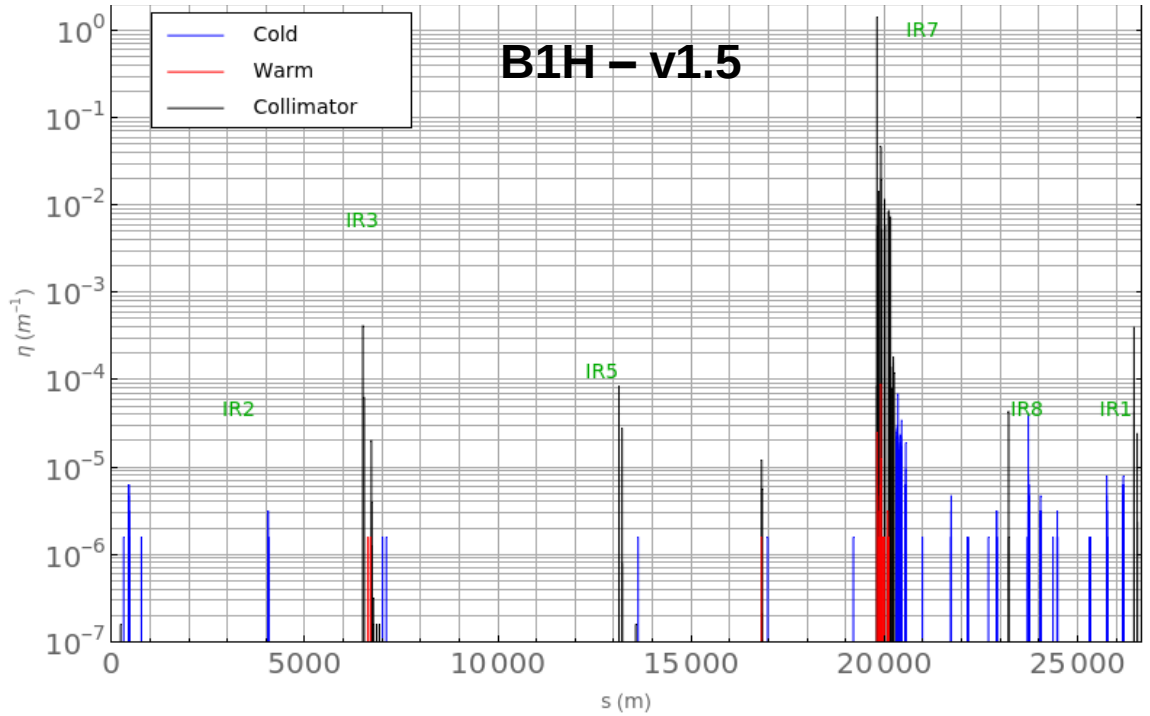
- Nominal optics (15 cm β*)
- Impact: 4 µm
- 6.4e6 particles / 200 turns

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

v1.3 vs v1.5 comparison using relaxed collimator settings





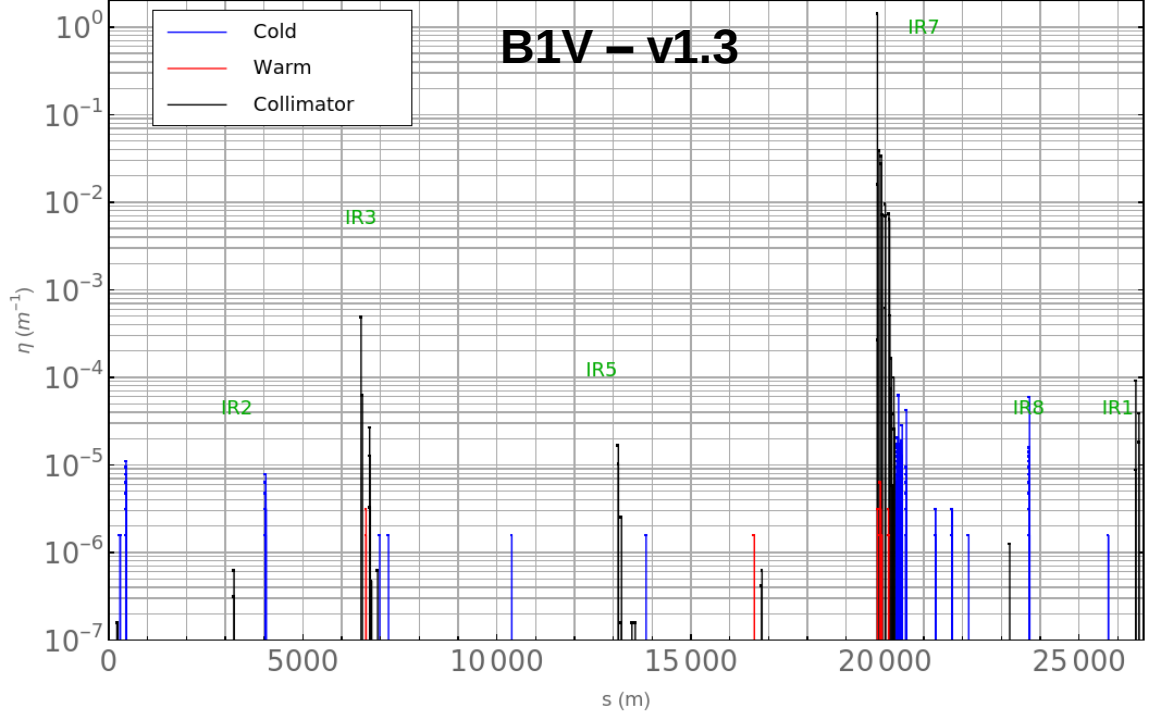
Comparison using new collimator settings

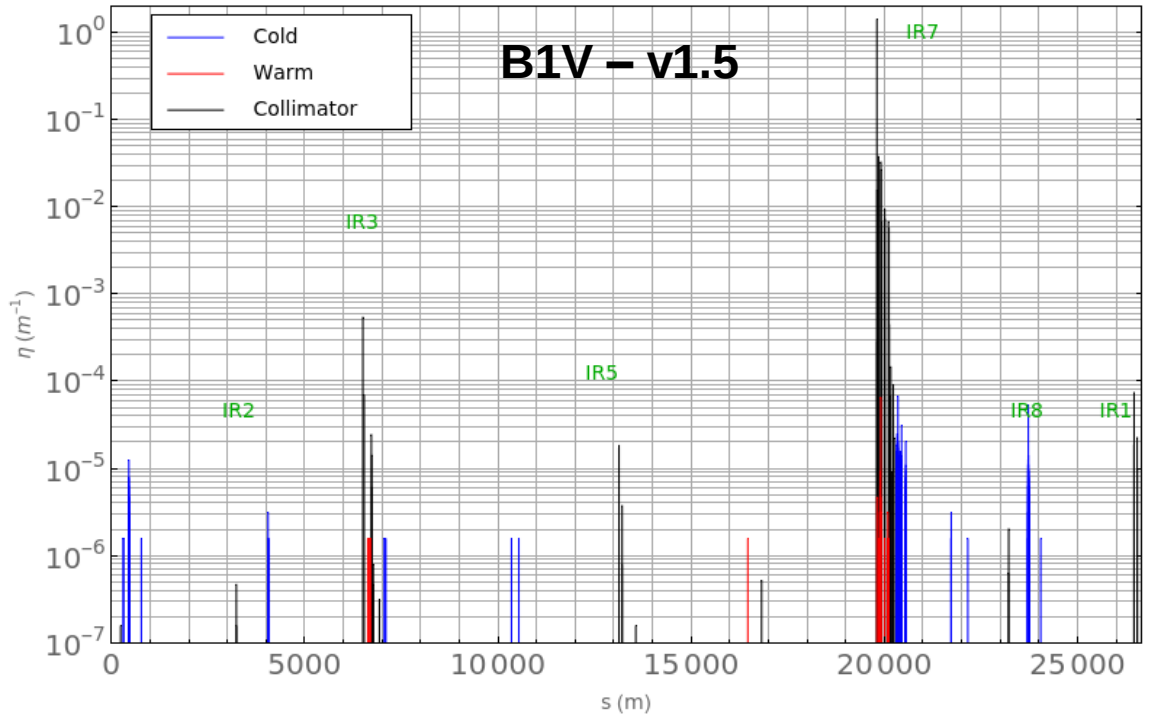
- Nominal optics (15 cm β*)
- Impact: 4 µm
- 6.4e6 particles / 200 turns

General notes:

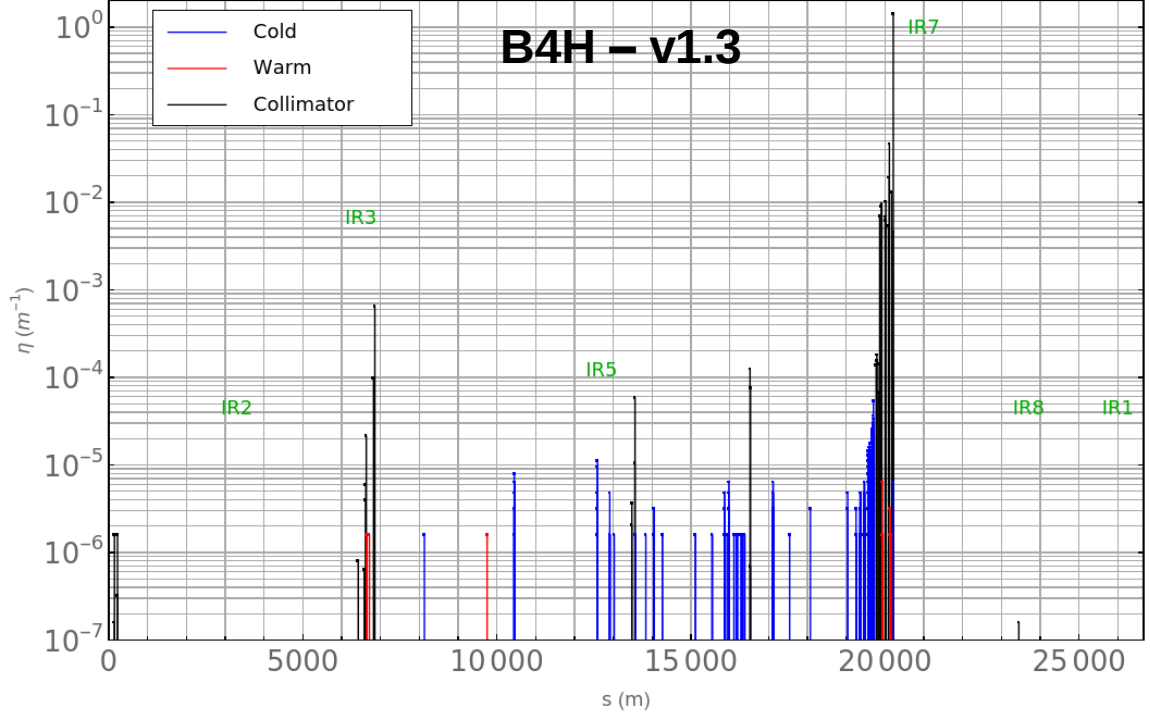
- Collimator loss distributions consistent
- b1: up to 15 % worse global inefficiency in v1.5
- b1: up to 15 % larger DS losses in v1.5
- Max warm losses much larger in v1.5, b1&b2

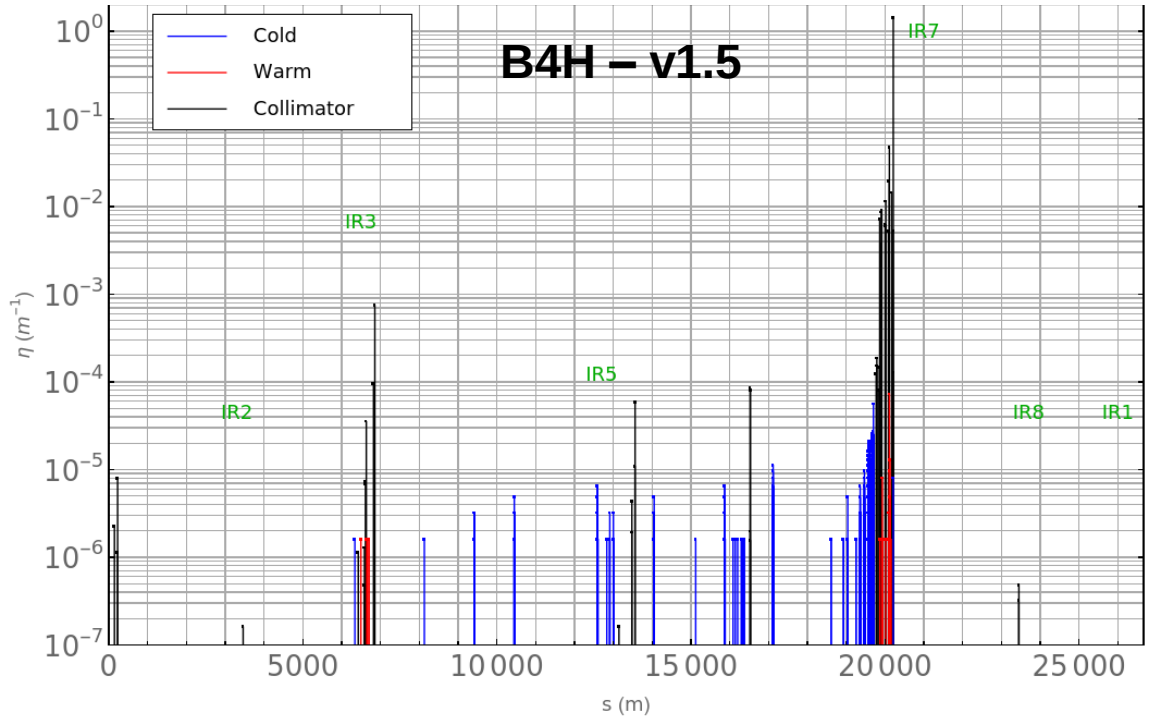
Comparison using new collimator settings



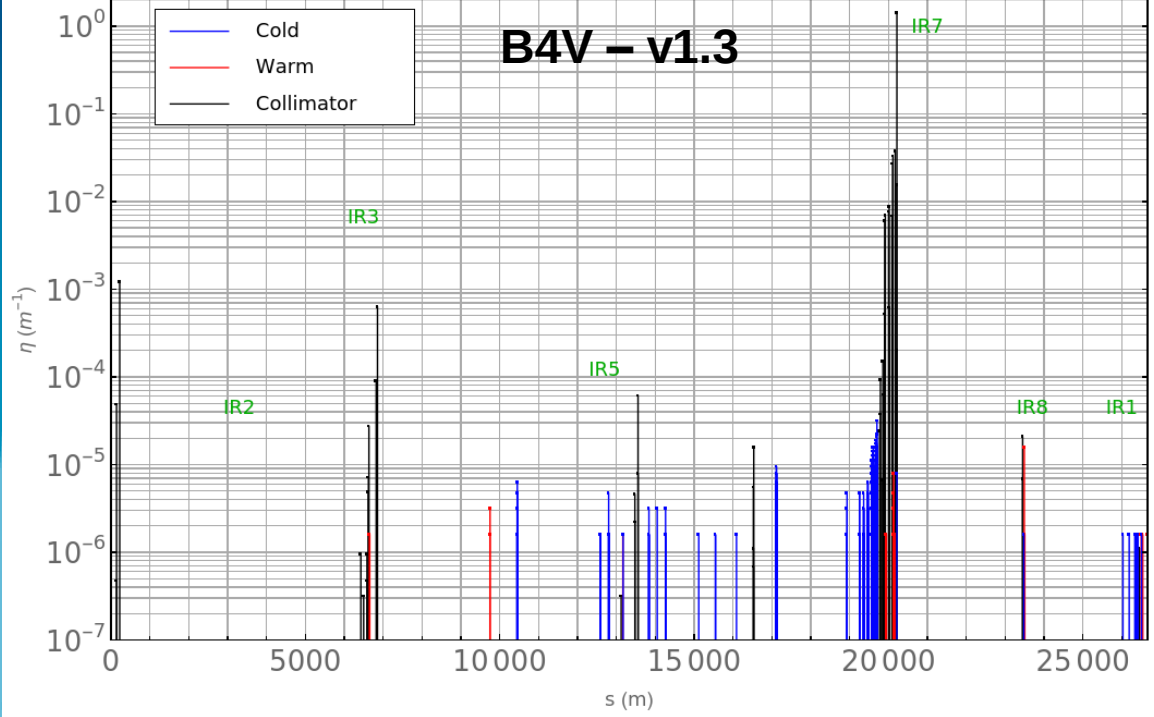


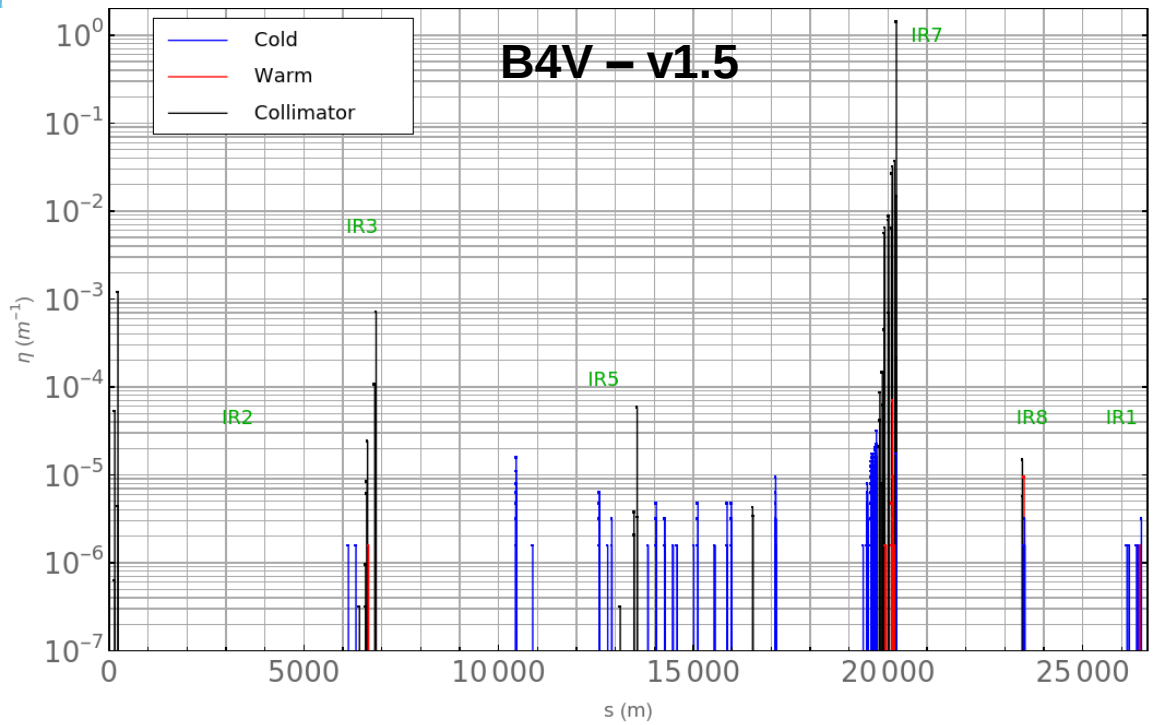
Comparison using new collimator settings





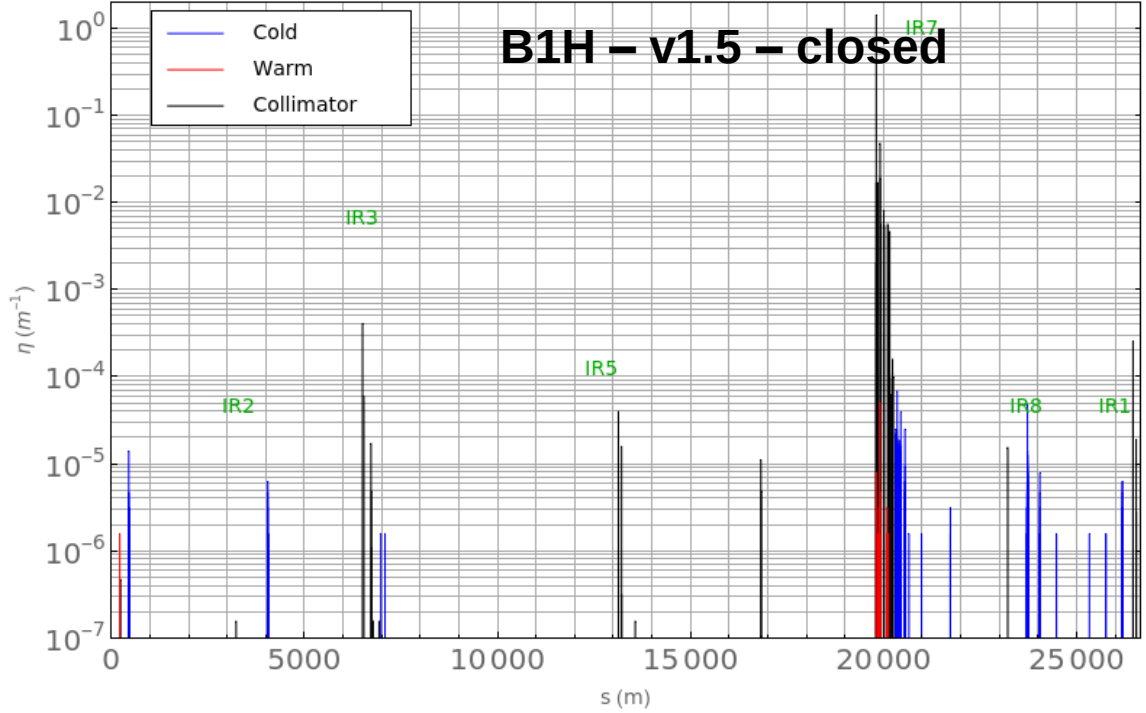
Comparison using new collimator settings

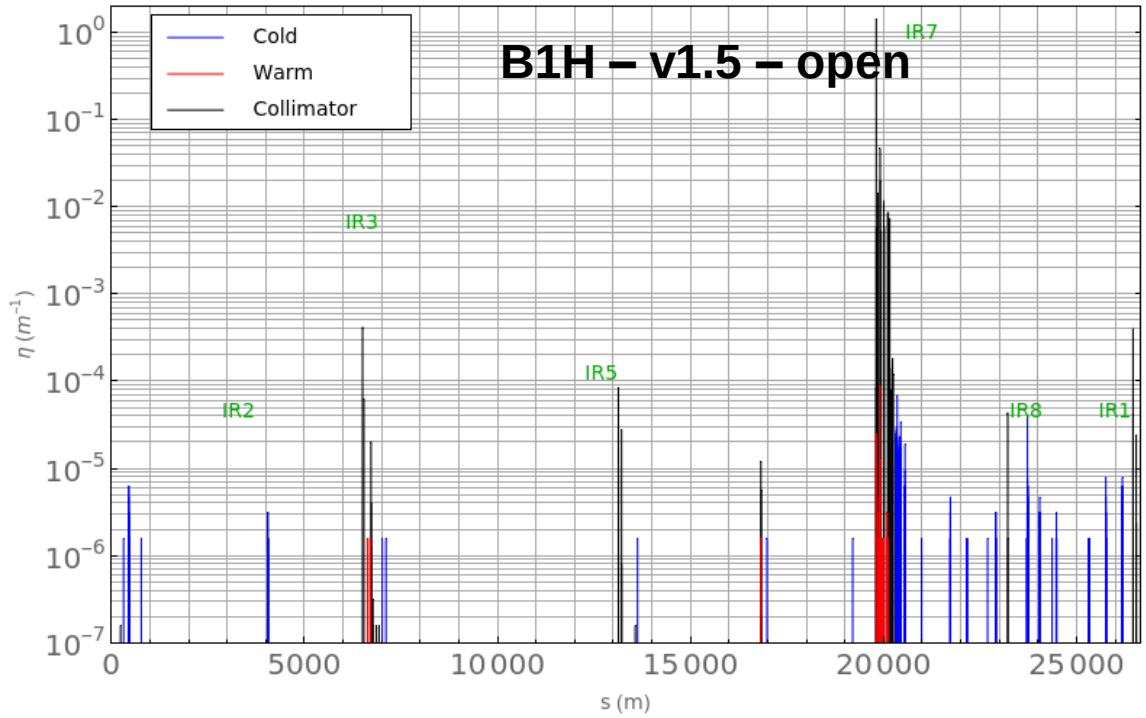




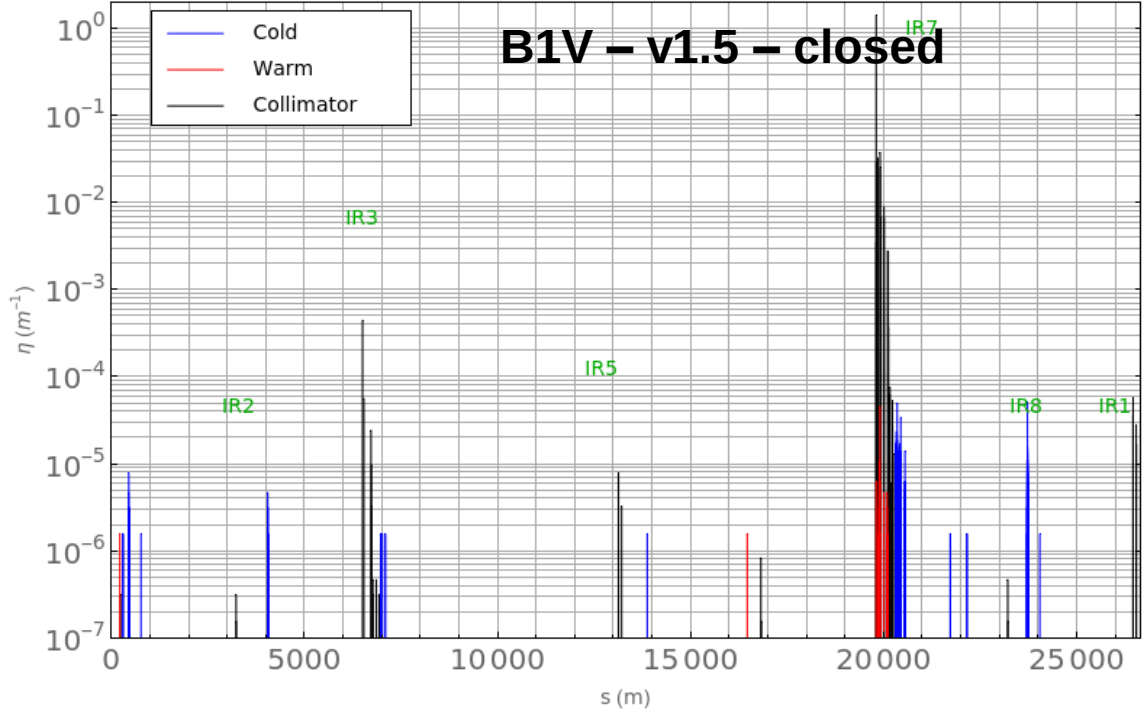
v1.5 – collimator comparison

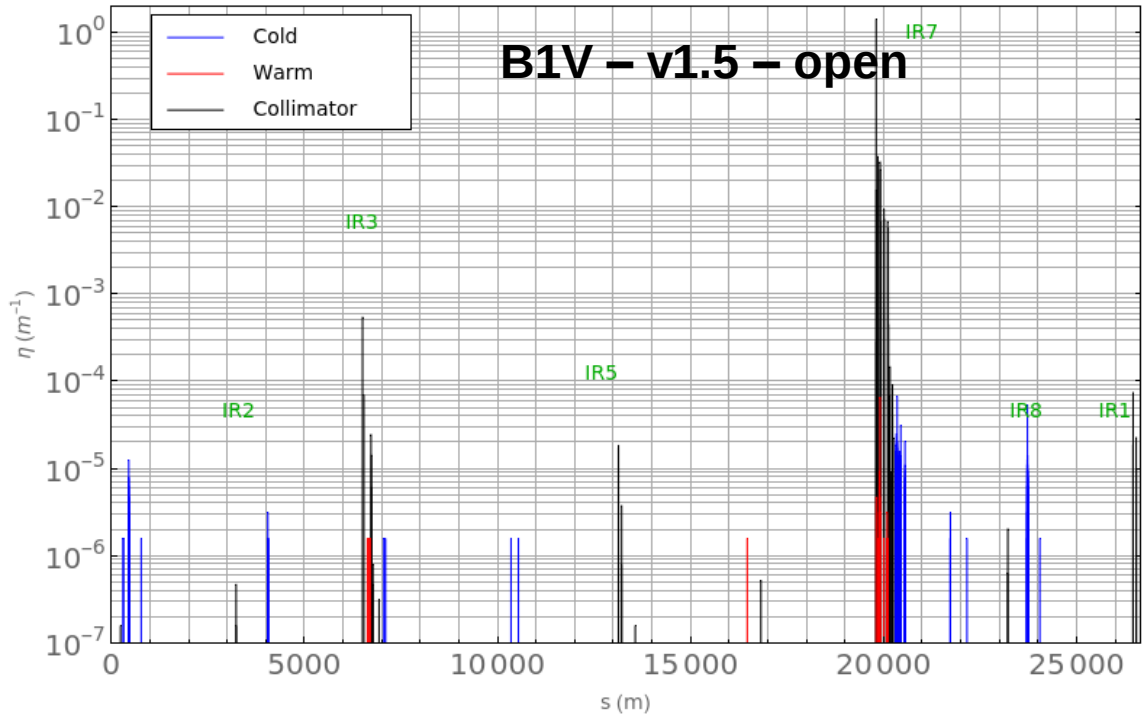
B1H

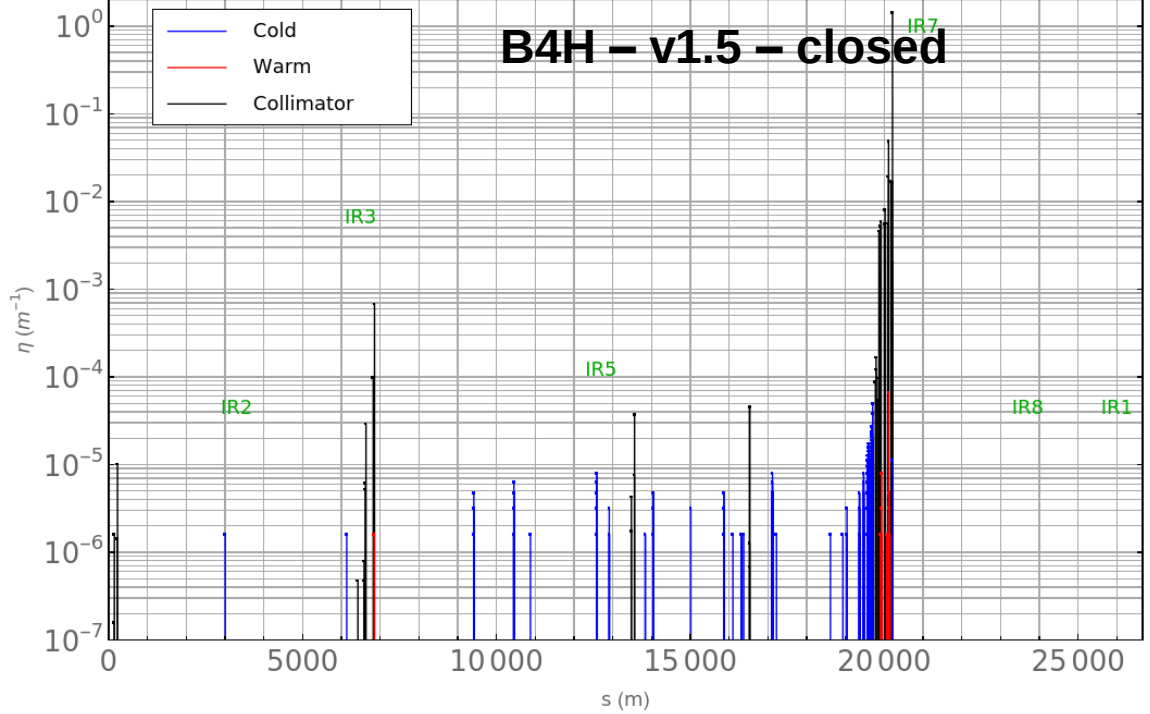

B1H – v1.5 – closed
Cold
Warm
Collimator
IR7
IR3
IR5
IR2
IR8
IR1
$\eta\,(m^{-1})$
s (m)

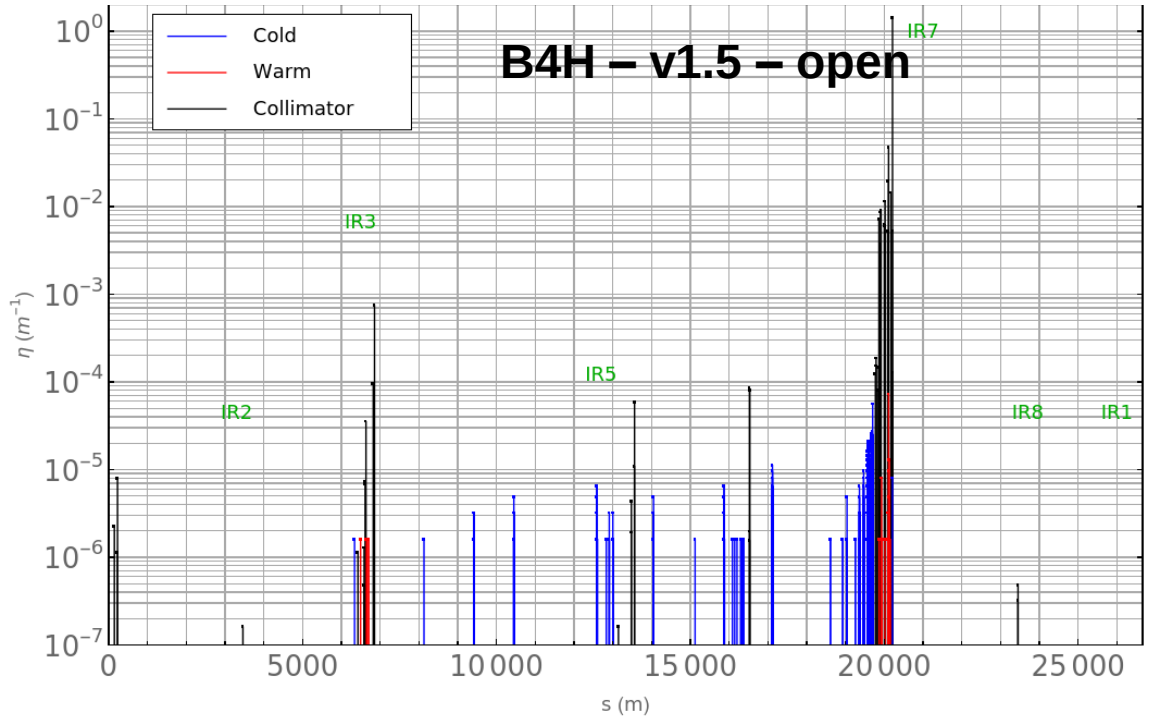

B1H – v1.5 – open
Cold
Warm
Collimator
IR7
IR3
IR5
IR2
IR8
IR1
$\eta\,(m^{-1})$
s (m)

B1V


B1V – v1.5 – closed
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
$\eta\,(m^{-1})$
s (m)


B1V – v1.5 – open
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
$\eta\,(m^{-1})$
s (m)

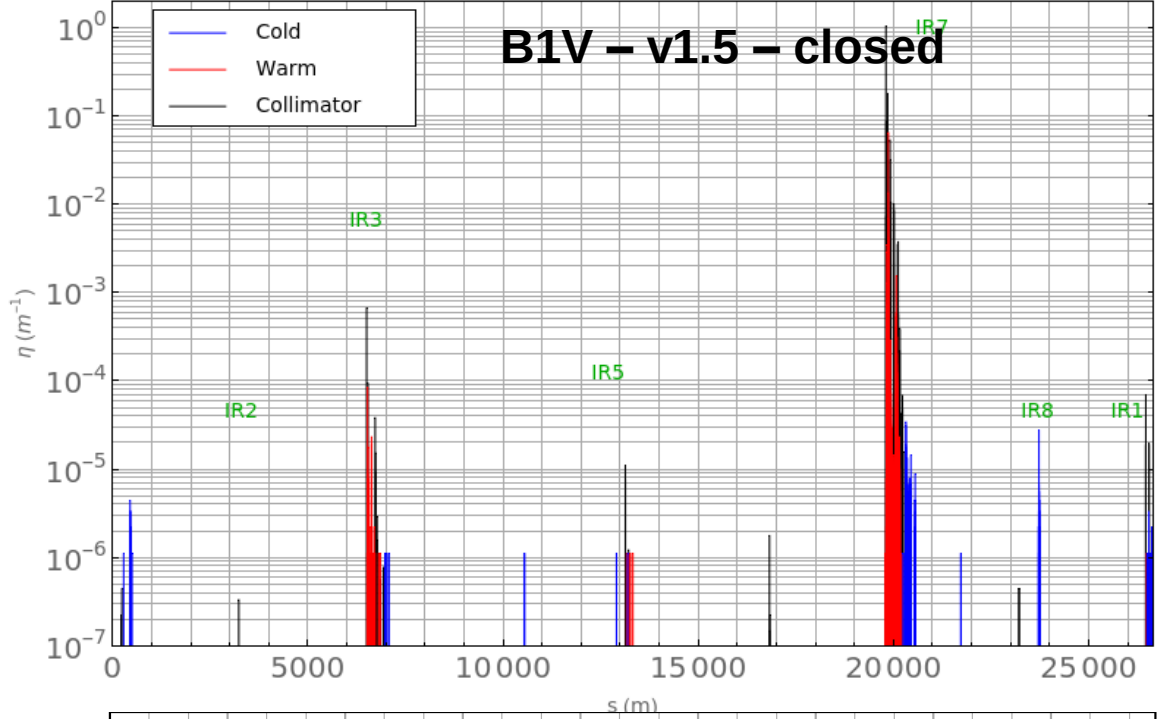

B4H – v1.5 – closed
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
$\eta\ (m^{-1})$
s (m)

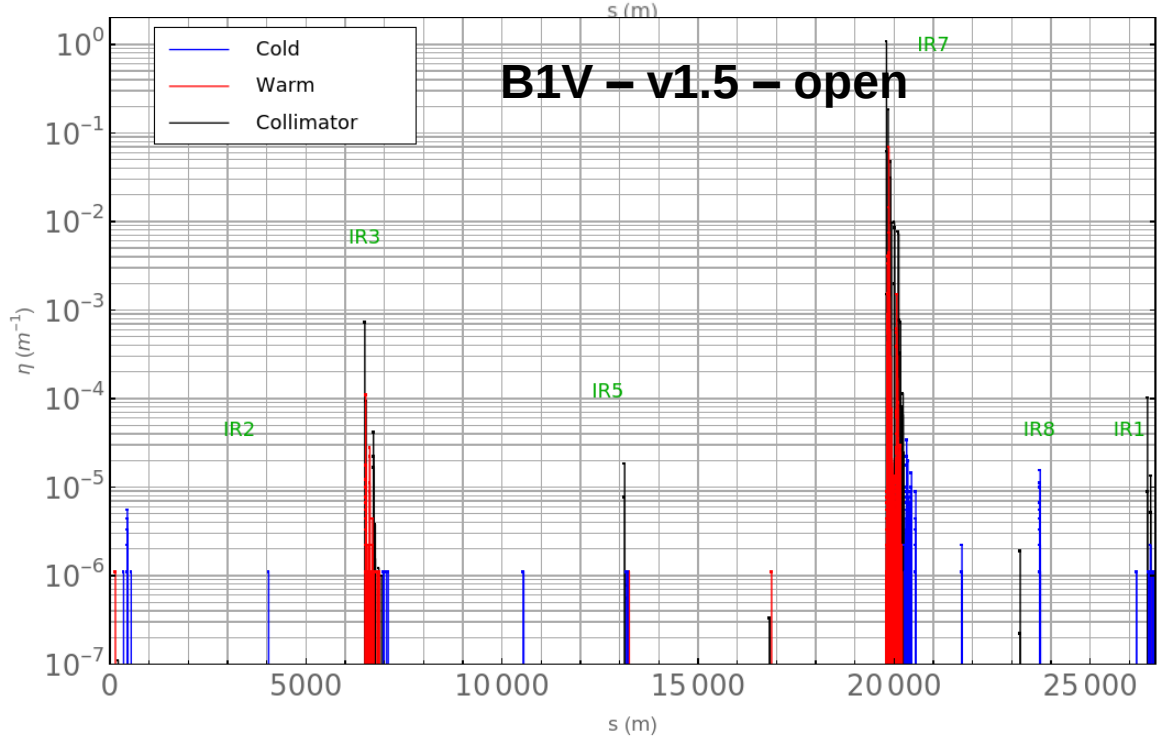

B4H – v1.5 – open
Cold
Warm
Collimator
IR2
IR3
IR5
IR7
IR8
IR1
$\eta\ (m^{-1})$
s (m)

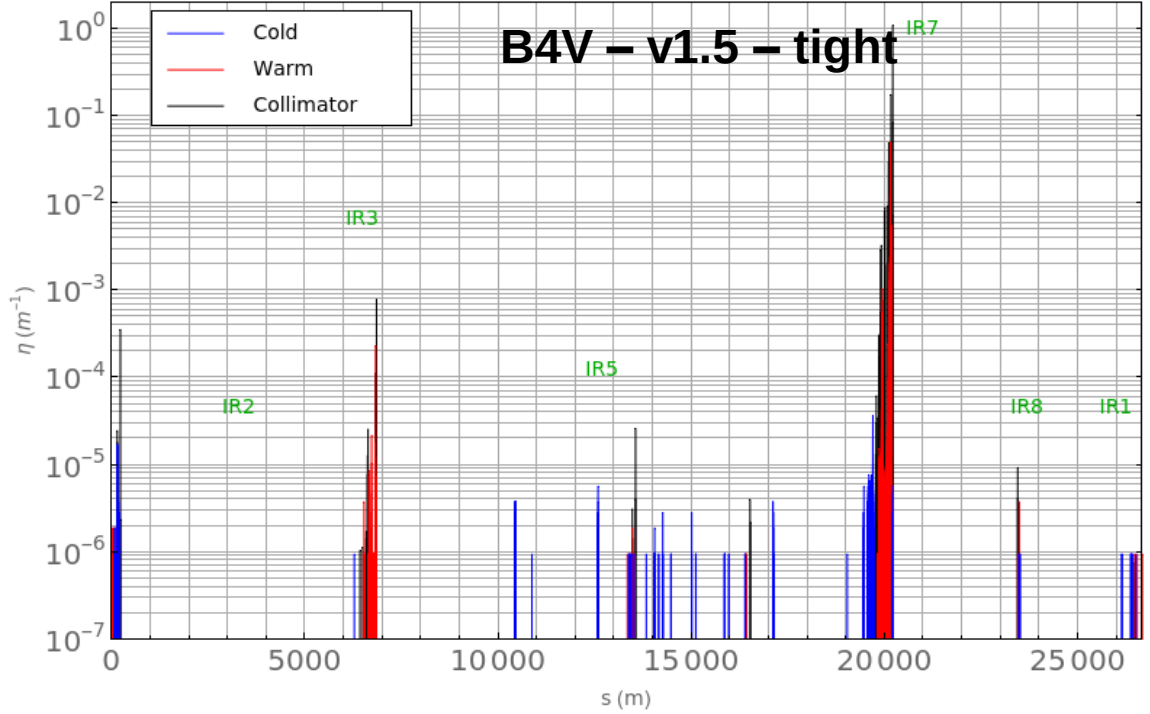
B4H

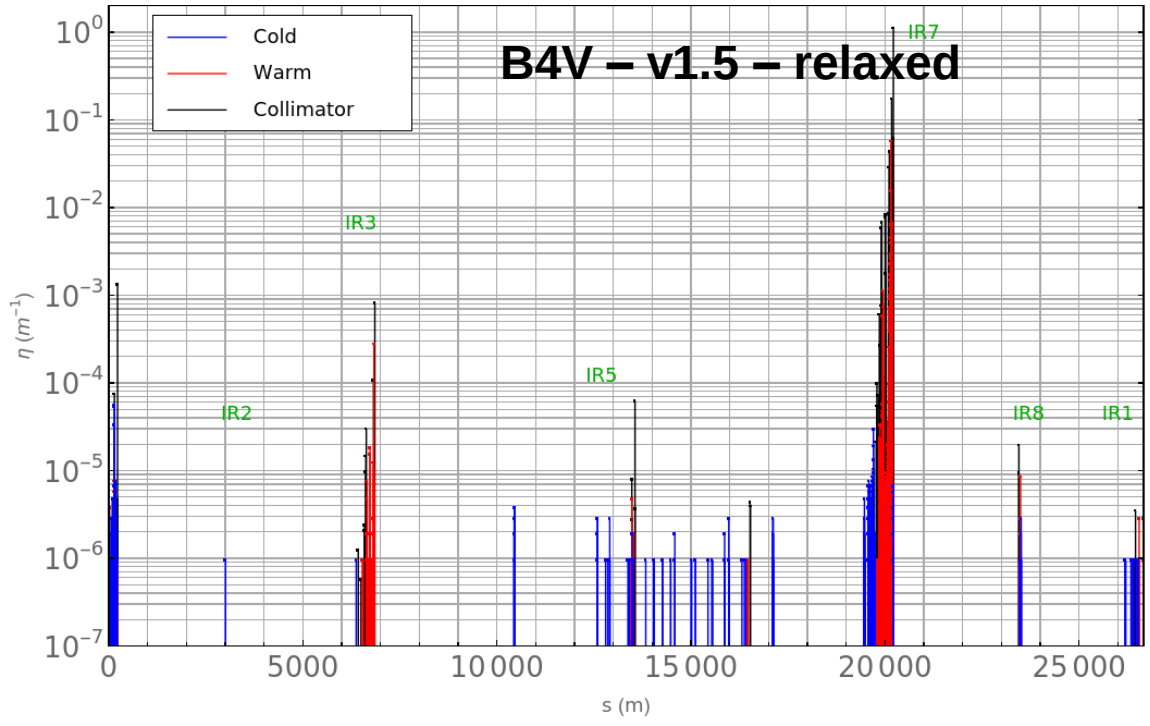
v1.5 – collimator comparison using FLUKA coupling

FLUKA coupling









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