HiLumi
HL-LHC PROJECT

Energy deposition from collimation losses in IR7 dispersion suppressor

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thanking the contributions of
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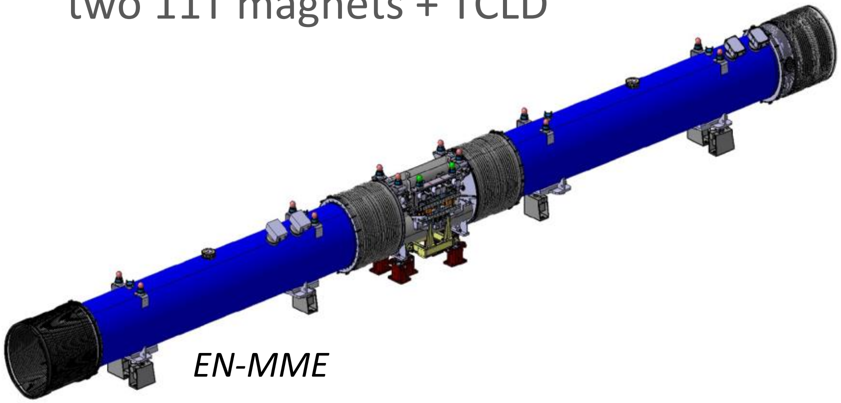
CERN FLUKA EN STI

Outline

- **Motivation & upgrade plans during LS2**
- Energy deposition studies using FLUKA
  - Normalization and other factors to consider
  - Optimization of collimator position
- Results
  - Peak power density
  - Total power to cryogenic cells
  - Total power to 11T coils
- Conclusions and outlooks

Motivation: IR7 DS losses and collimation

- In current LHC, **IR7 DS (cells 8-11)** is the **main bottleneck** of collimation losses both for protons and heavy ions
- In HL-LHC the **stored beam energy** will almost **double** → increased risk of magnet quench and beam dumps → downtime and **reduced machine availability**
  - Mitigation measure: collimators (**TCLD**) to be installed in LS2 both IR7 DS to alleviate losses
- Two existing dipoles will have to be removed and replaced by two ensembles of two 11T magnets + TCLD



Collimator position along the DS should be **optimized** for best cleaning balance during both proton and ion runs

Quench risk should be **evaluated** in all superconducting magnets involved

Energy deposition studies (FLUKA)

Energy deposition studies using FLUKA

Power deposition in magnets cannot be measured directly →

particle shower simulations (FLUKA) are essential

Information on beam losses
Spatial distribution of the particles (tracking simulations)

+

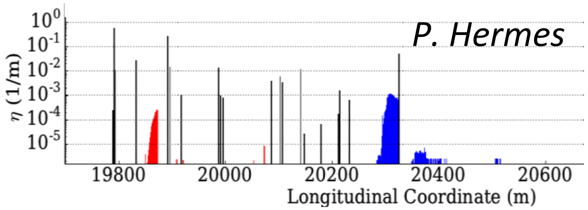
Creating a realistic geometry in FLUKA

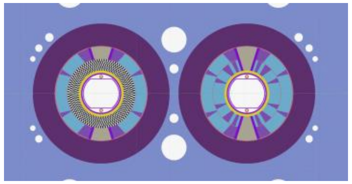
+

Selecting relevant quantities to calculate
Energy deposition in the magnet coils & cryogenic cells

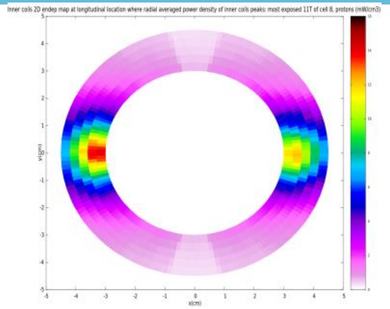
→ **Simulations (recreating experimental conditions)**

FLUKA results: energy deposition normalization
Peak power density in magnet coils
Total power deposited in the 11T coils
Total power in cryogenic cells





Mesh over inner coils
ΔR: 0.25 cm
$\Delta\phi$: 2°
Δz: 10 cm



Comparable with ↕

Quench level estimates (cryogenics & magnet teams)

Normalization of FLUKA results: BLT

Two beam life times (BLT) are considered: **12 min BLT**

	# bunches	# particles/bunch	Loss rates
Protons	2760	2.3e11	8.81e11 protons/s
Ions	1248	2.1e8	3.64e8 ions/s

BLT of 1h is just a rescaling (divided by 5) of 12 min BLT results.

*Heavy ion lifetime analysis 2015/16 (*D. Mirarchi CWG #232*)

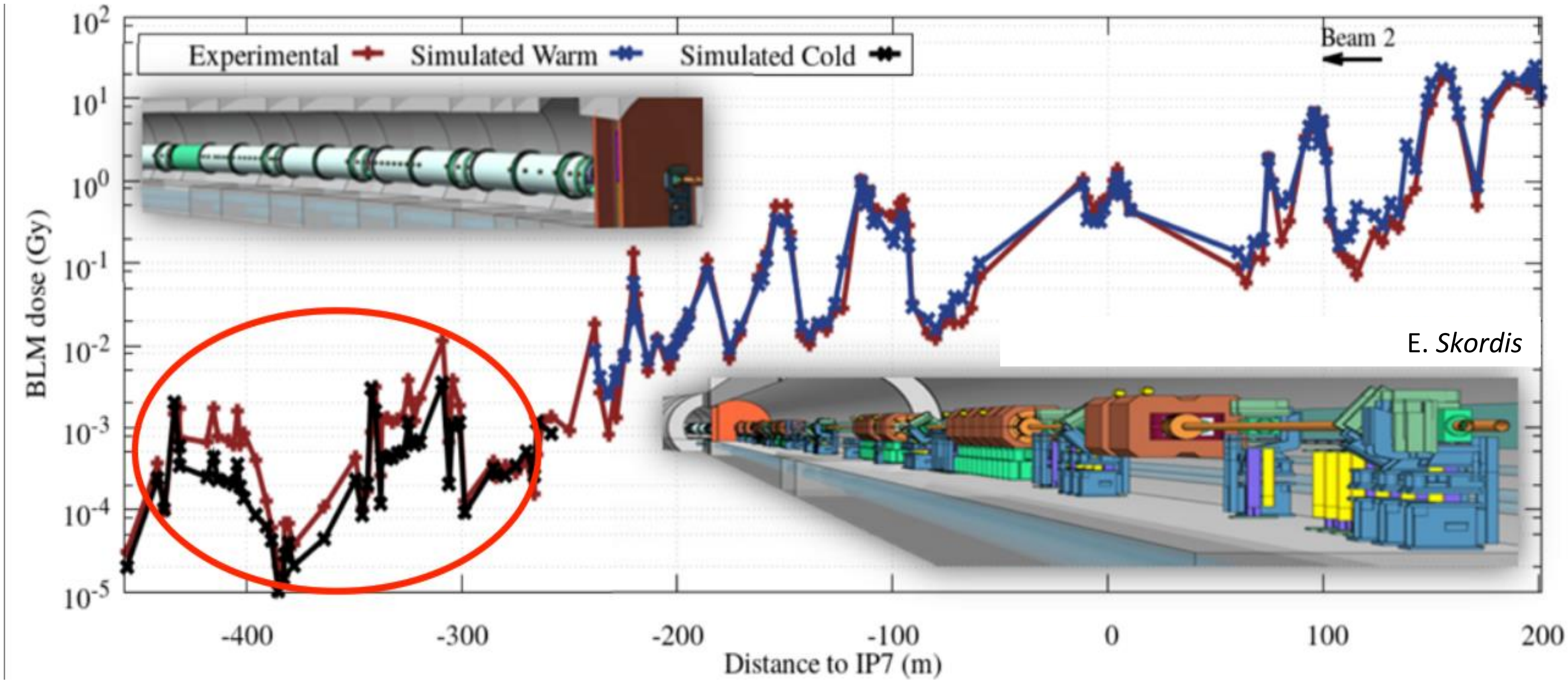
- 9 events of <12 min BLT in 2015 (47 fills in total)
- <1h BLT never longer than 1 minute

*Proton lifetime analysis (*B. Salvachua*, Review Hollow E-lens 2016 & *A.Mereghetti* Evian 2017)

- About 10 events <12 min BLT in 2017 (>200 proton fills)
- Mostly >1h BLT especially during 2016/2017 runs

Normalization of FLUKA results: factor 3

Factor of 3 added to simulation results: to account for **FLUKA underestimation of BLM measurements in the DS** found in previous benchmarks (between cell 8-11)

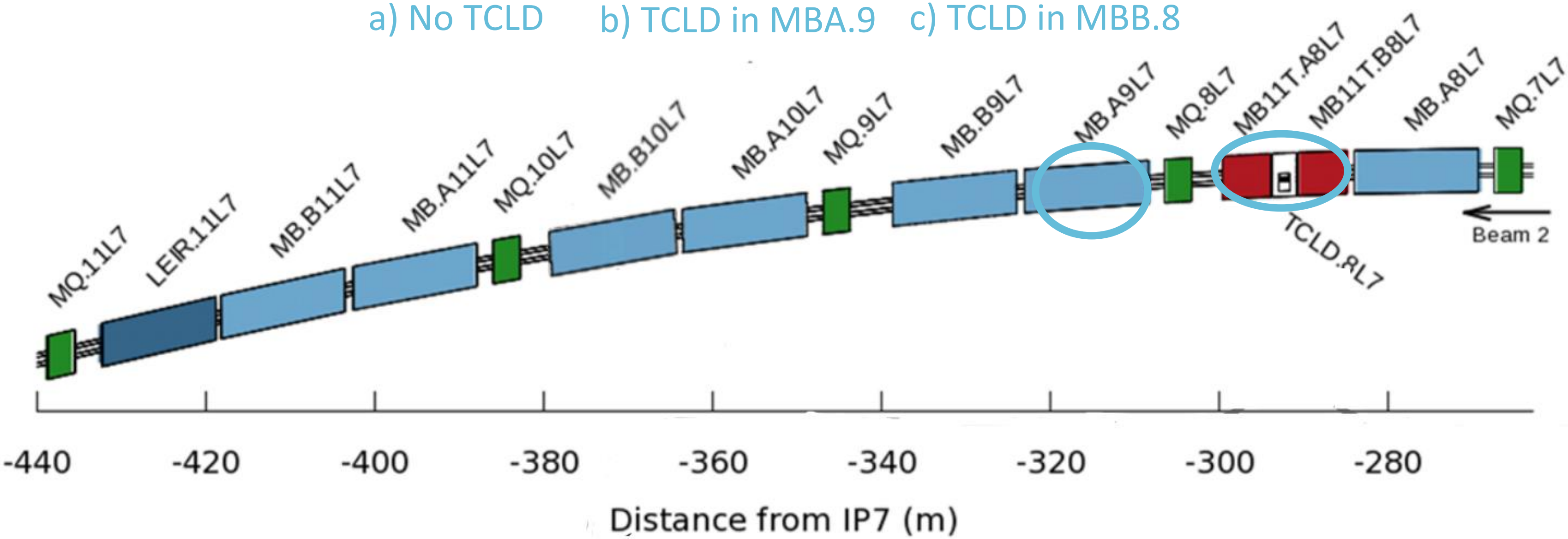


BLM signal benchmark in IR7 quench test

Optimization of collimator position

DS geometry: cells 8-11

a) No TCLD b) TCLD in MBA.9 c) TCLD in MBB.8



For each position, two scenarios:

1. Protons
2. Ions

For each position and scenario

I) **Peak power density** in most exposed superconducting magnets

II) **Total power in cryogenic cells** (half-cells 8 to 12)

When TCLD included

II) **Total power deposited in the 11T coils**

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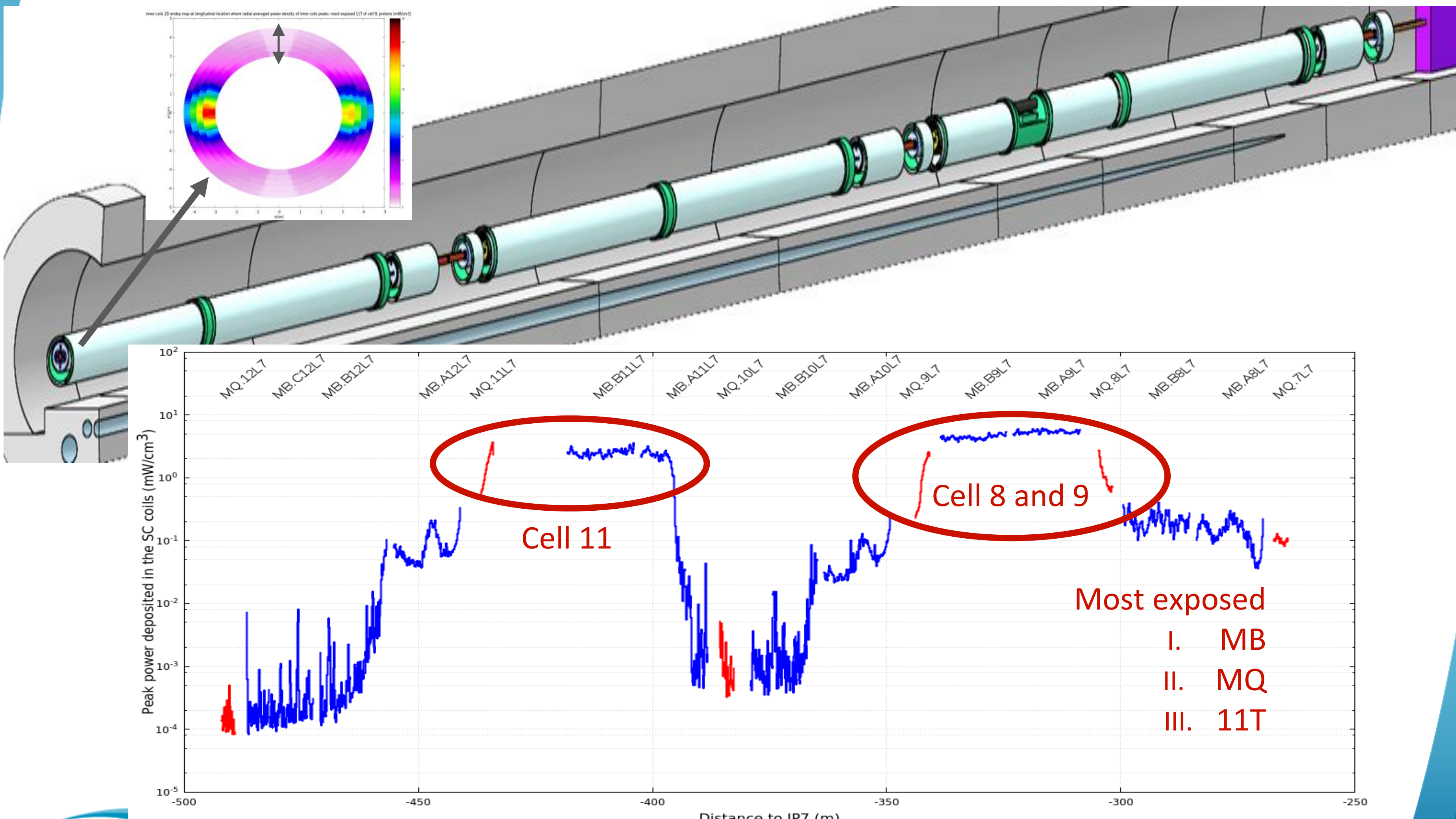
Peak power density

Peak has been radially averaged along the coils → steady state losses (not averaged factor of 2-3 higher)



Peak power density in SC coils (mW/cm^3)

TCLD position		PROTONS					IONS				
		Cell 8/9			Cell 11		Cell 8/9			Cell 11	
		*MB**	*MQ*	*11T*	*MB**	*MQ*	*MB**	*MQ*	*11T*	*MB**	*MQ*
No TCLD	0.2h	**21**	9.9	-	12	13	**57**	27	-	**57**	36
	1h	**4.2**	2	-	2.4	2.6	**11**	5.4	-	**11**	7.2
MBB.8	0.2h	6.6	8.1	11	8.7	13	5.4	15	21	**36**	33
	1h	1.3	1.6	2.2	1.7	2.6	1.1	3	4.2	**7.2**	6.6
MBA.9	0.2h	6.0	8.1	**48**	<0.3	<0.3	6.0	3.6	**33**	<0.003	<0.003
	1h	1.2	1.6	**9.6**	<0.06	<0.06	1.2	0.7	**6.6**	<0.0006	<0.0006

*Quench limit for MB could be ~20 mW/cm^3 for steady state losses at 6.37*Z* TeV)

MBA.9 position would be better for ions and for cell 11 cleaning, but implies higher peak power density in the 11T coils

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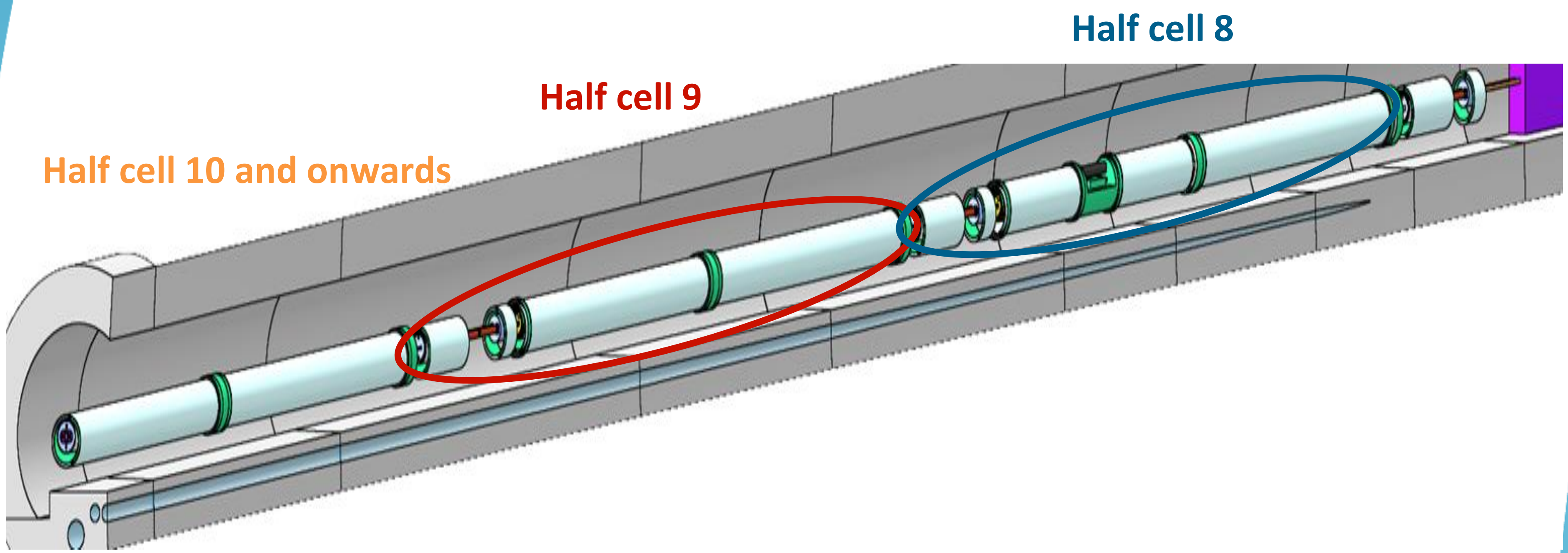
Total power to cryogenics cells (W)



Everything inside the shrinking cylinder was quantified other than the beam screen.

Total power in cryogenic cells (W)

		PROTONS						IONS					
		Half-cells						Half-cells					
TCLD position		*8*	*9*	*10*	*11**	*CC*	*12*	*8*	*9*	*10*	*11**	*CC*	*12*
No TCLD	0.2h	50	**740**	15	**280-310**	100	10	10	**985**	35	**910-1015**	270	25
	1h	10	**148**	3	**56-62**	20	2	2	**197**	9	**182-203**	54	5
MBB.8	0.2h	210	100	10	230-265	85	10	351	135	20	569-635	115	20
	1h	42	20	2	46-53	17	2	70	27	4	112-127	23	4
MBA.9	0.2h	51	475	3	2.1-2.2	<1	<1	9	758	<1	<1	<1	<1
	1h	10	95	<1	<1	<1	<1	2	152	<1	<1	<1	<1

*From Q11 on, FLUKA benchmarks show a better agreement between simulated and experimental BLM signals. For this reason, in cell 11 the total power is shown with and without the factor 3 applied to the Q11.
Cell 11 values don't include the Connection Cryostat which is shown separately

TCLD in cell 8 does not reduce much the load for cell 11 cluster. When in cell 9 it does but at the expense of more loads in first cluster (mostly on 11T)

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Total power in 11T coils (W)

TCLD position		PROTONS	IONS
MBB.8	0.2h	54	98
	1h	11	20
MBA.9	0.2h	93	162
	1h	19	32

- Only most exposed 11T shown (downstream from TCLD)
- Return coils included, beam screen not included

If placed in cell 9, 11T would take 70% more power to their coils during proton runs and 60% during ion runs compared to cell 8

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Conclusions and outlooks

- A **complete study of energy deposition** to evaluate the impact of TCLD + 11T installation in different positions was performed, **paving the way for a detailed quench risk analysis from magnet and cryogenics experts**.
- **Looking only at the peak power density**, **cell 9** position would be **better for ions and for cell 11 cleaning**, but implies **higher** peak power density **in the 11T coils** with respect to cell 8 position
- The **total power to the different cryogenics cells** indicates:
  - TCLD in **cell 8 does not** reduce much the **load for cell 11** cluster.
  - TCLD in **cell 9 vastly improves the loads in cell 11** cluster but at the expense of a **more loaded cell 9, with most of the load going to 11T**. This can be seen already from the 60-70% increase in the power to the 11T coils between both position.

Thank you for your attention

Back-up

DS simulation parameters

Protons and Pb ions

- 7Z TeV, HL-LHC optics

- B2, Horizontal case

Collimator materials in FLUKA model

TCP, TCSG in CFC

TCLA, TCLD (when used) in inermet 180

DS collimator settings

Proton studies

TCP 5.7 sigma
TCSG 7.7 sigma
TCLA 10 sigma
TCLD 14 sigma (when used)

2 sigma retraction (TCP–TCSG)

4.3 sigma retraction (TCSG–TCLA)

Ion studies

TCP 6 sigma
TCSG 7 sigma
TCLA 10 sigma
TCLD 14 sigma (when used)

1 sigma retraction (TCP–TCSG)

4 sigma retraction (TCP–TCLA)

Detailed heat load to the half-cell 8 (W)

TCLD cell 8

	PROTONS		IONS	
	BLT (12 min)	*BLT (1 h)*	*BLT (12 min)*	*BLT (1 h)*
MQ.8	5	1	10	2
MQTLI.8	2	0.4	5	1
MCBC.8	5	1	8	1.6
11T.A	170	34	327	65
11T.B	7	1.4	1	0.4
MB.A8	21	4	0.8	0.16
TOTAL	**210**	**42**	**351.8**	**70.16**

Sextupoles NOT included in the FLUKA model (MCS. A8 and MCS. B8)

Detailed heat load to the half-cell 9 (W)

no TCLD

	PROTONS		IONS	
	BLT (12 min)	*BLT (1 h)*	*BLT (12 min)*	*BLT (1 h)*
MQ.9	27	5	86	17
MQTLI.B9	15	3	56	11
MQTLI.A9	21	4	70	14
MCBC.9	19	4	59	12
MB.B9	335	67	609	122
MB.A9	377	75	155	31
TOTAL	**794**	**158**	**1035**	**207**

Sextupoles NOT included in the FLUKA model (MCS. A8 and MCS. B8)

Detailed heat load to the cold mass of most exposed 11 T (W): TCLD Cell 8

	PROTONS		IONS	
	BLT (12 min)	*BLT (1 h)*	*BLT (12 min)*	*BLT (1 h)*
Coils (return coils included)	54	11	98	20
Yoke	44	9	85	17
Collars	32	6	62	12
Spacers (between coils)	11	2	23	5
Vacuum vessel	4	1	7	1
Beam pipe	4	1	7	1
Shrinking cylinder	2	0.4	4	1
Other parts	19	4	44	9
TOTAL	**170**	**34**	**330**	**66**
TOTAL FOR MBA.9	**300**	**60**	**630**	**130**

Detailed heat load to the cold mass during 2015 quench tests

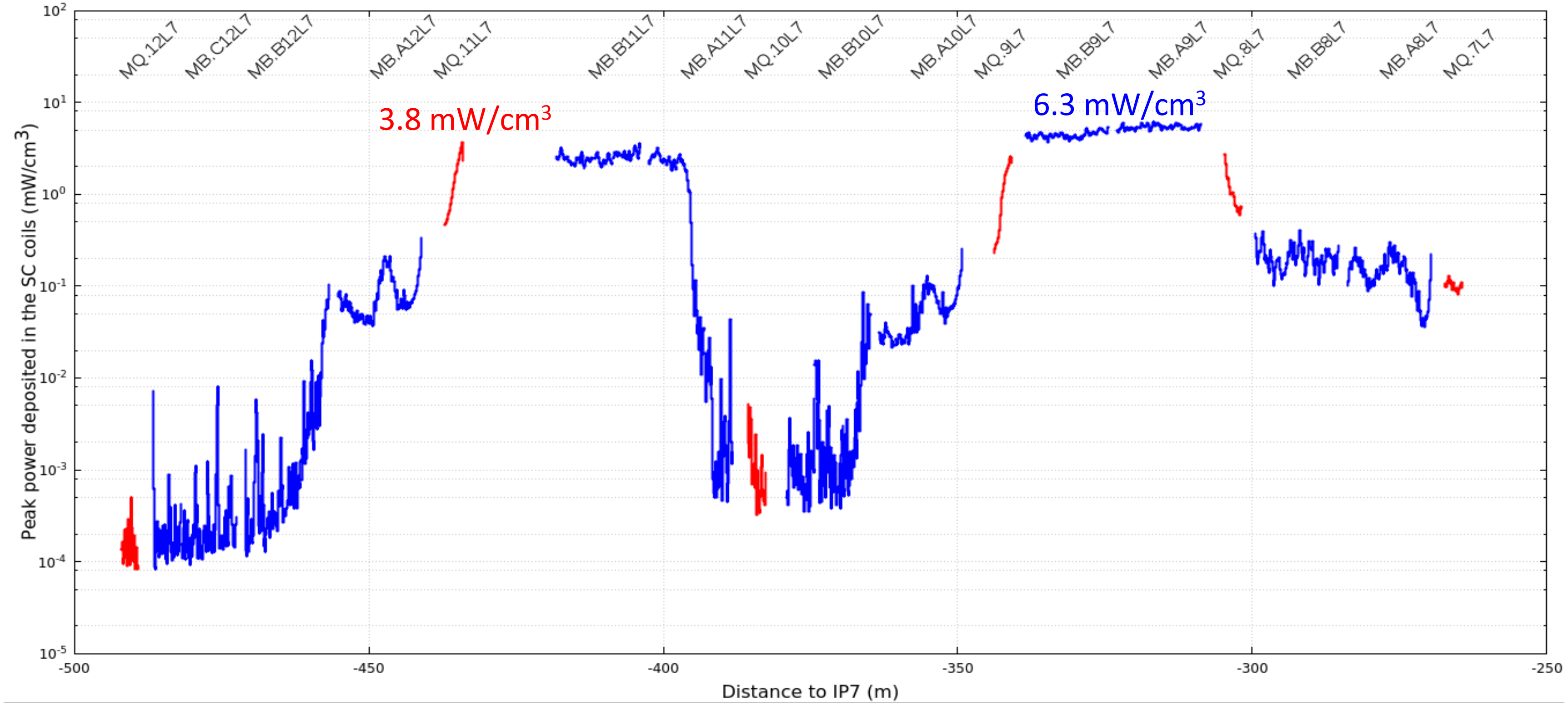
BFPP Quench Test heat load to the cold mass MB.B11L5 (W)	
Coils	17
Collars	13
Yoke	4
Beam pipe	2
All other parts inside shrinking cylinder (except beam screen)	1
TOTAL	**37**

Normalization:

Instantaneous luminosity of 2.3×10^{27} $cm^{-2}\ s^{-1}$ and BFPP cross section of $276 \times 10^{-24}\ cm^2$ at $6.37Z$ TeV

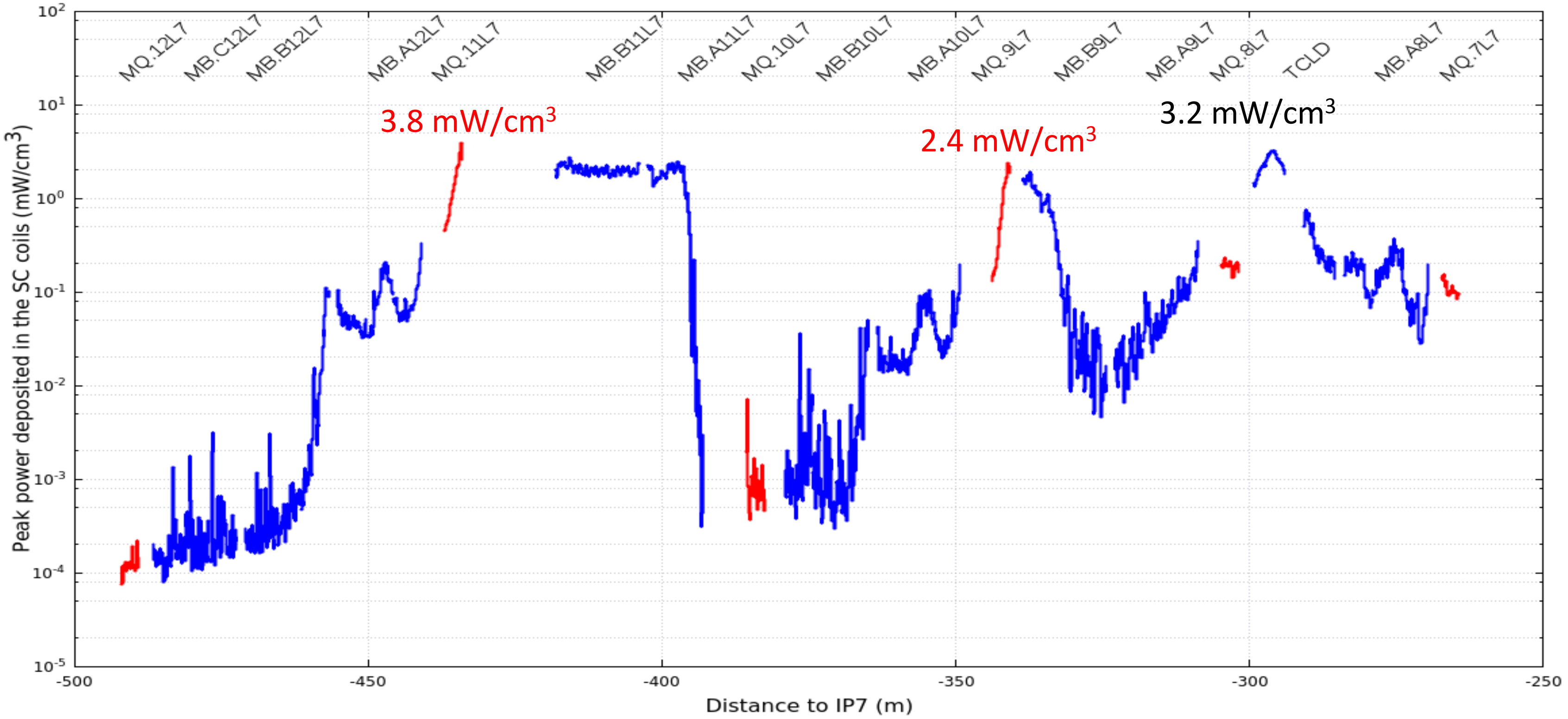
Protons: no TCLD

Factor of 3 not included



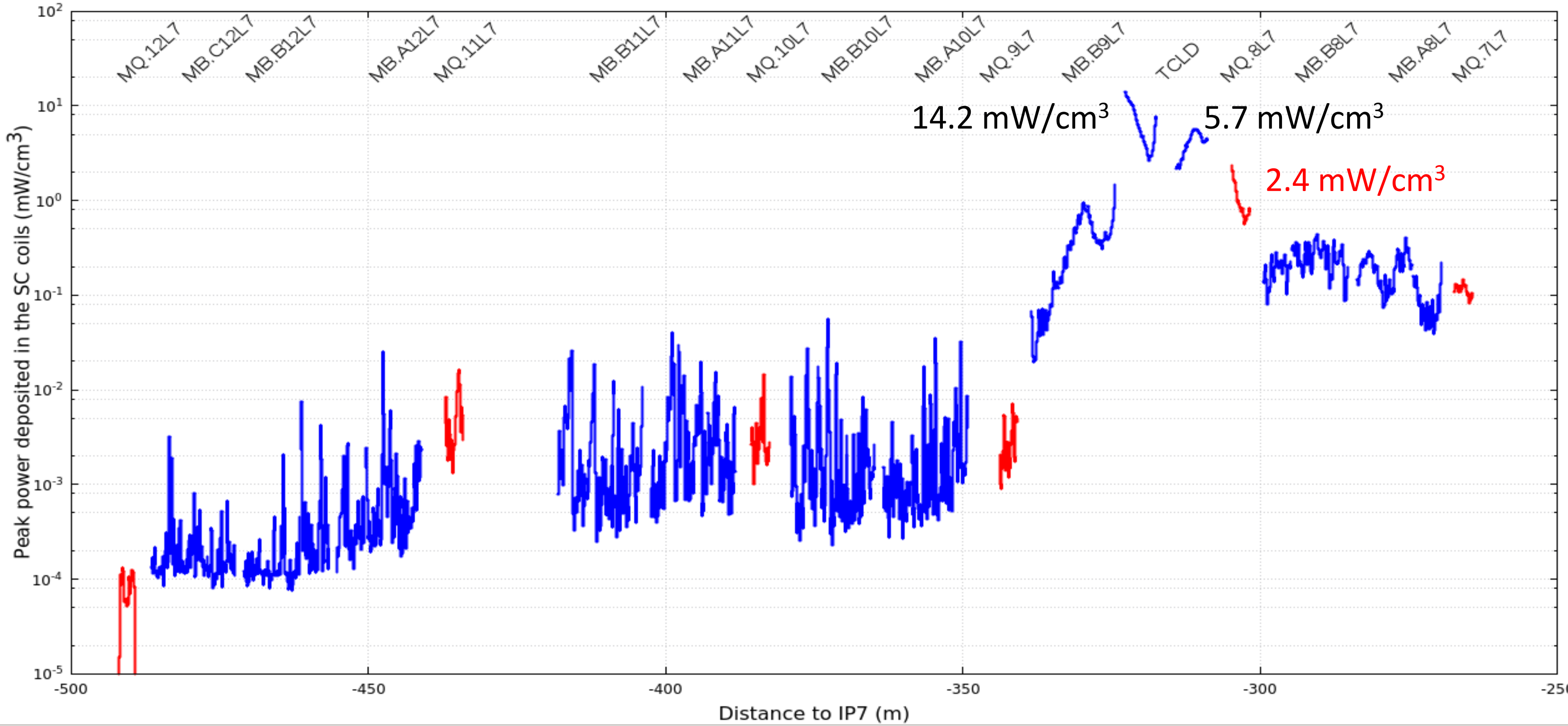
Protons: TCLD in MBB.8

Factor of 3 not included



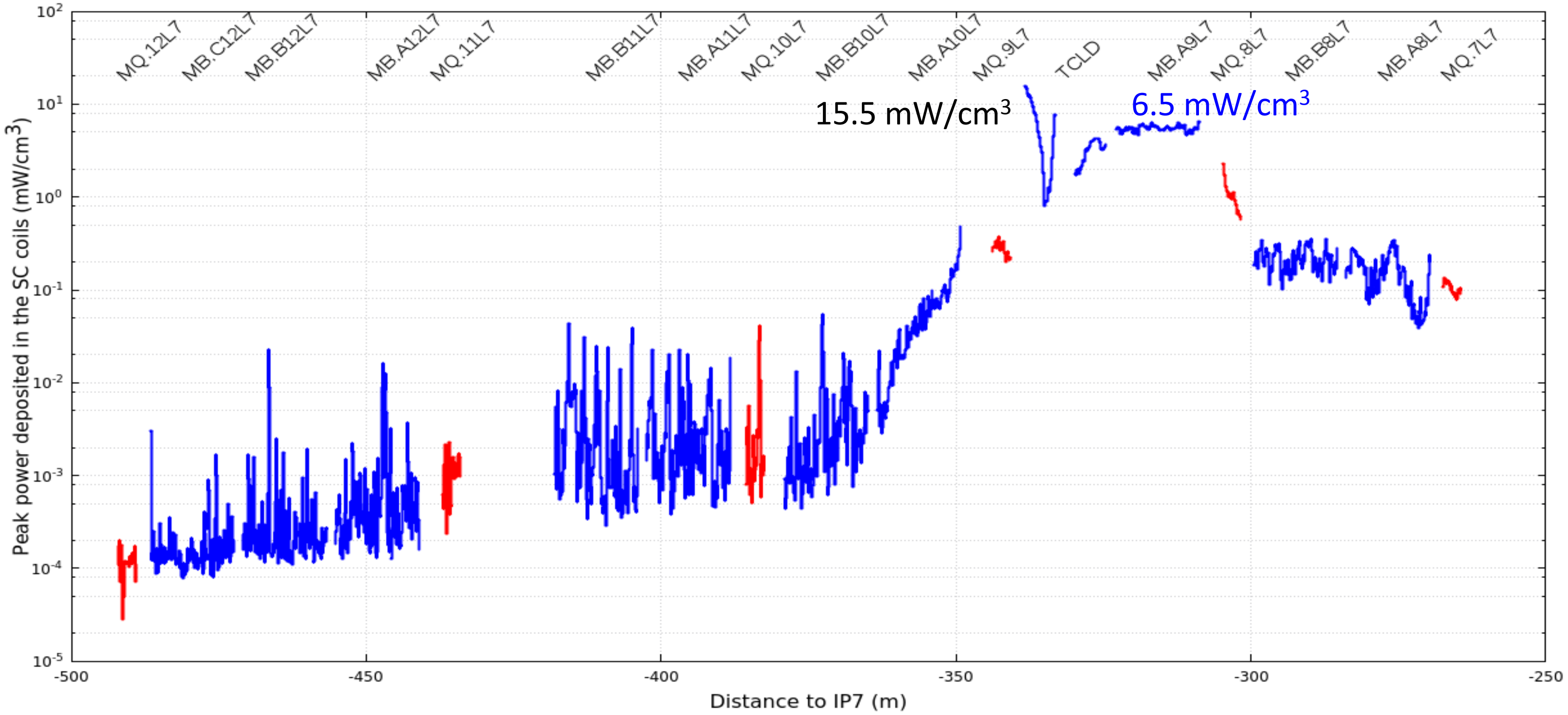
Protons: TCLD in MBA.9

Factor of 3 not included



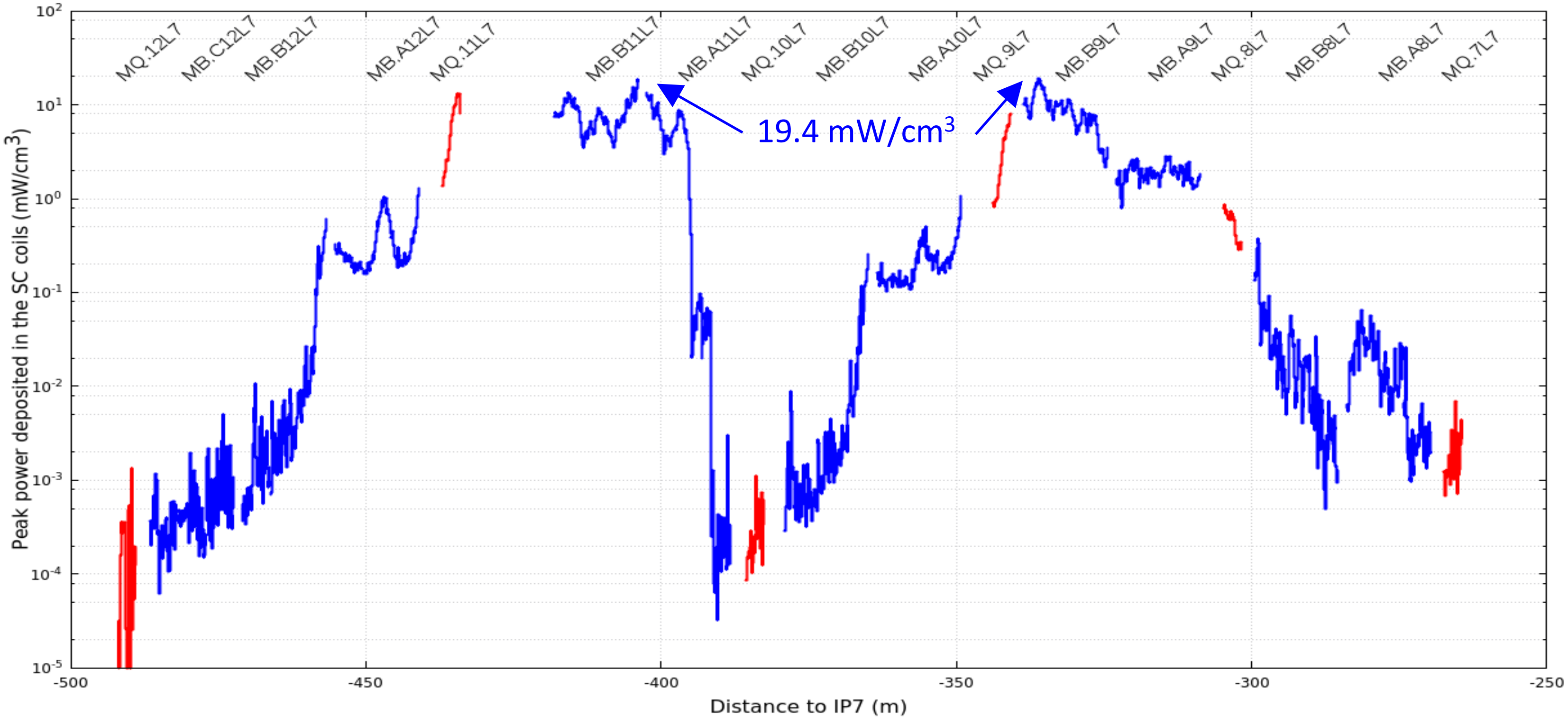
Protons: TCLD in MBB.9

Factor of 3 not included



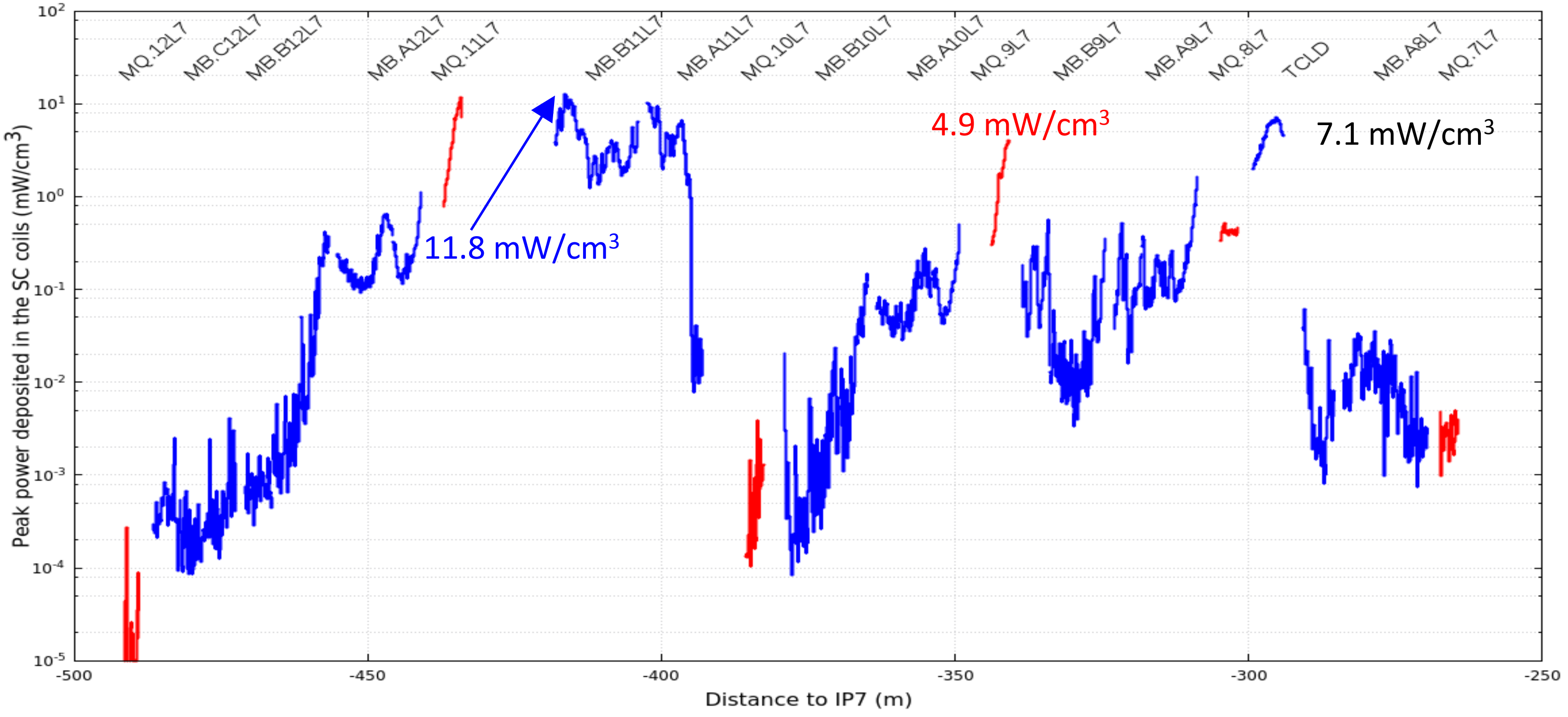
Ions: no TCLD

Factor of 3 not included



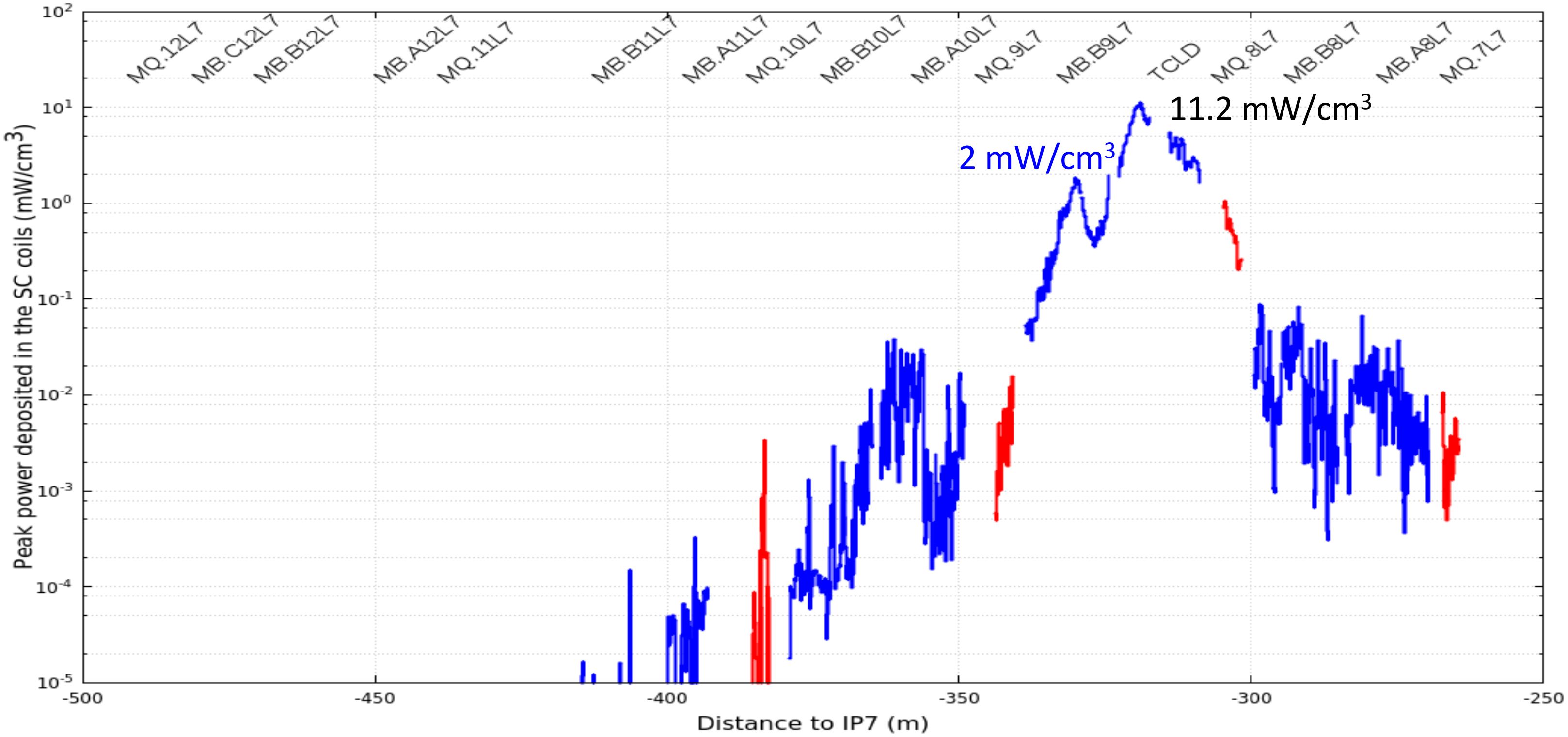
Ions: TCLD in MBB.8

Factor of 3 not included



Ions: TCLD in MBA.9

Factor of 3 not included



Ions: TCLD in MBB.9

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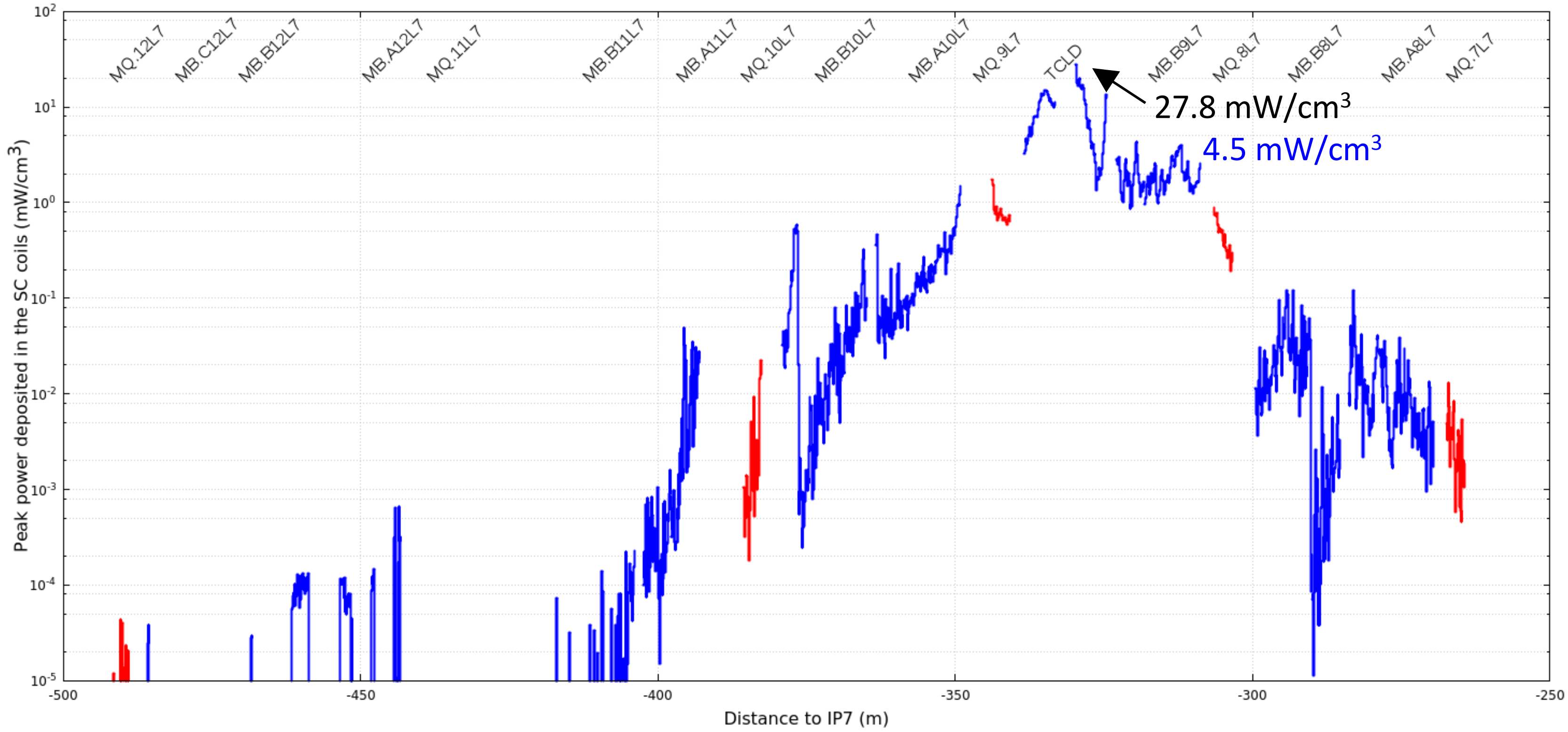
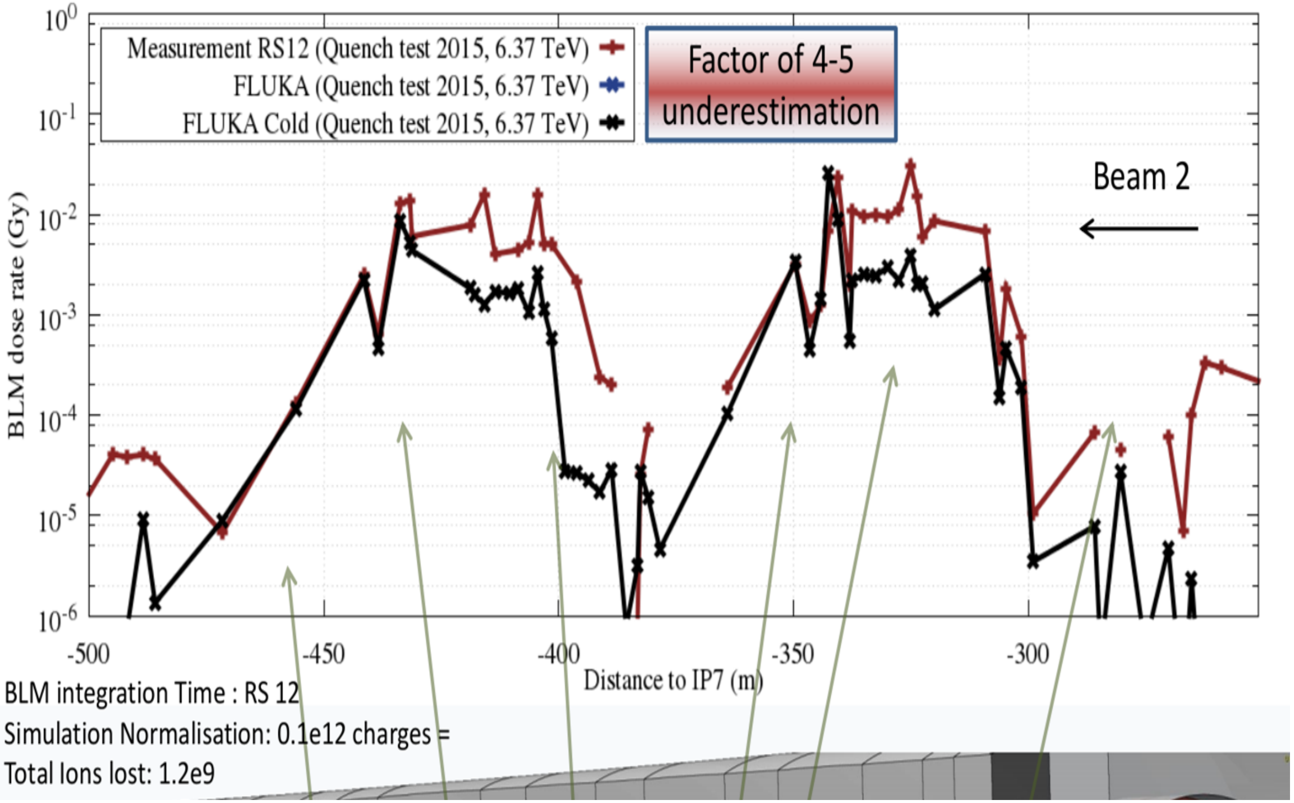


Impact parameter influence (TCP) in leakage to the DS during ion runs

Ion quench test 2015



No impact parameter scan performed (~2um)

Impact parameter scan now performed showed up to factor 2 difference in the energy density

Current i.p. 1um

Ion collimation quench test

6.37 Z TeV, 2015 optics

TCP 5.5 sigma

TCSG 8 sigma

TCLA 14 sigma