DRAFT ECR:

LIU UPGRADE OF TCDI COLLIMATORS FOR SPS-TO-LHC TRANSFER LINES (TI2/TI8)

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OVERVIEW

- Existing System and Introduction
- Reason for Change(s)
- Detailed Description:
    i. Integration
    ii. Change to optics
- Impact on Other Systems
- Impact on Utilities/Services
- Impact on Cost/Schedule
- Impact on Performance
- Impact on Operational Safety / Worksite Safety

EXISTING SITUATION AND INTRODUCTION

- The existing collimation system in the SPS to LHC transfer lines (TI2 and TI8) consists of a set of passive absorber blocks (graphite) with moveable jaws (TCDIs) and associated downstream stainless steel masks (TCDIMs).

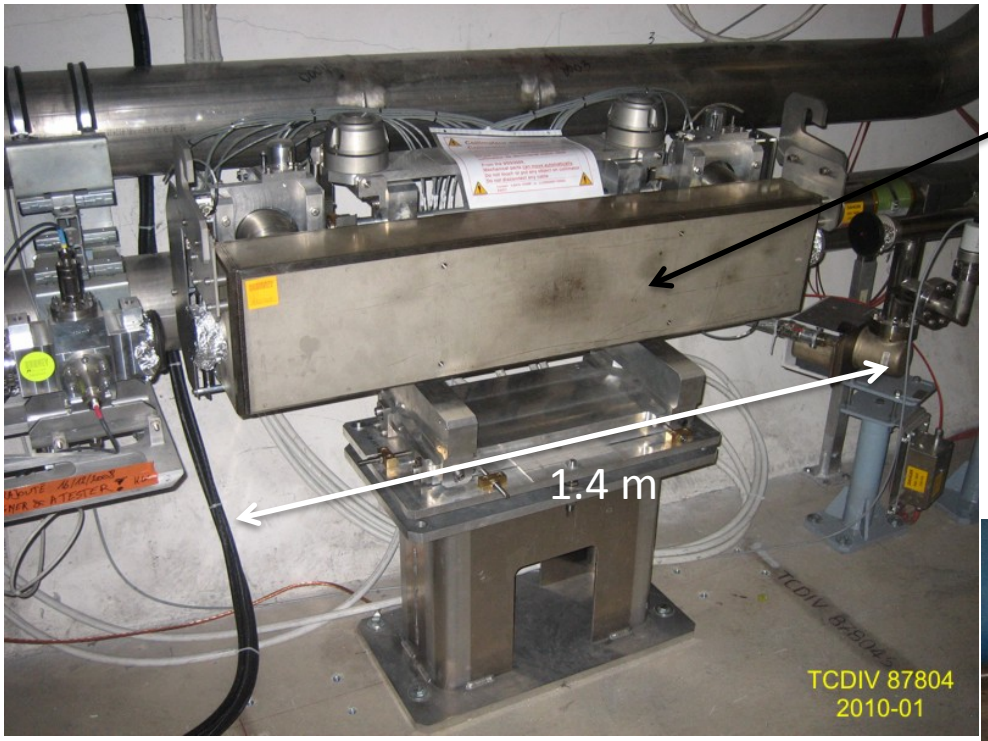
- Protects the LHC aperture and MSI (injection septum) in case of failures during the extraction process from SPS and in case of failures of the beam transfer line itself.

- Consists of 13 TCDIs (7 in TI2 and 6 in TI8) with 3 TCDIs spaced at 60° phase advance to give full phase-space coverage in both horizontal (TCDIH) and vertical (TCDIV) orientations. The TCDIs are located at the downstream end of both transfer lines close to the LHC injection region. An additional upstream TCDI is installed in TI2 for momentum collimation (this was never installed in TI8).

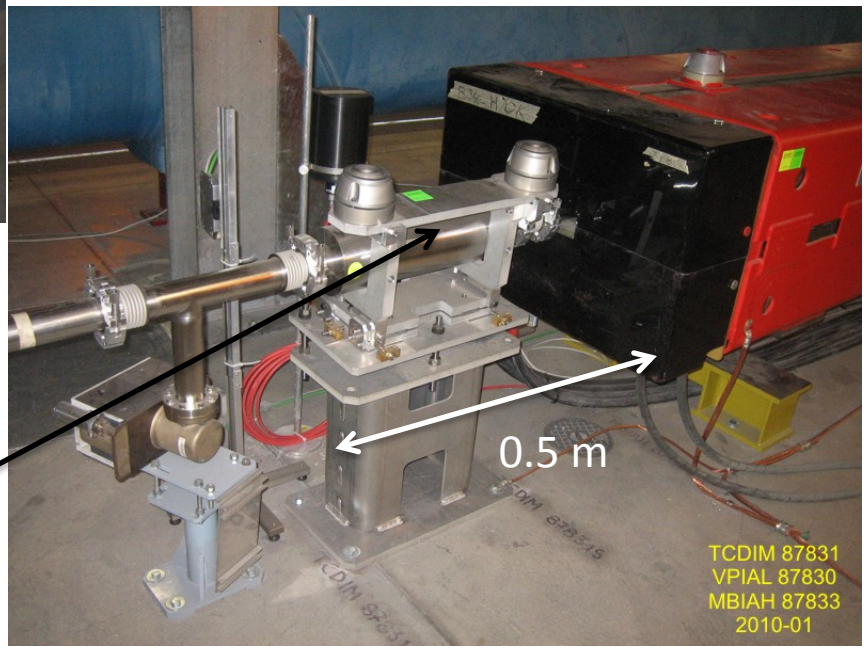
- Designed for impact of *ultimate* LHC beam parameters providing an attenuation factor of ~20, reducing energy deposition in beam line elements to a safe level.

- Most TCDI locations remain unchanged (e.g. in TI2 all positions are the same) but in TI8 3 TCDIs move significantly (~50 m) and optics needs re-matching with two additional power converters. TCDIM masks will remain installed and unchanged.

EXISTING TCDI AND TCDIM



Attenuates impact of proton beam.



Absorbs energy contained in secondary shower of particles created after proton beam impact on TCDI

REASON FOR CHANGE

- LIU project imposes an increase of beam intensity and a reduction of emittance, with respect to the ultimate LHC beam parameters:

Beam Parameter	***Ultimate* LHC**	***Standard* LIU**	***BCMS***
Proton energy [GeV]	450		
Emittance (rms, norm.) [mm mrad]	3.5	**2.1**	**1.3**
Emittance [nm rad]	7.3	**4.4**	**2.7**
Number of bunches	288	**288**	**288**
Number of protons per bunch	1.7×10^{11}	**2.3×10^{11}**	**2.0×10^{11}**

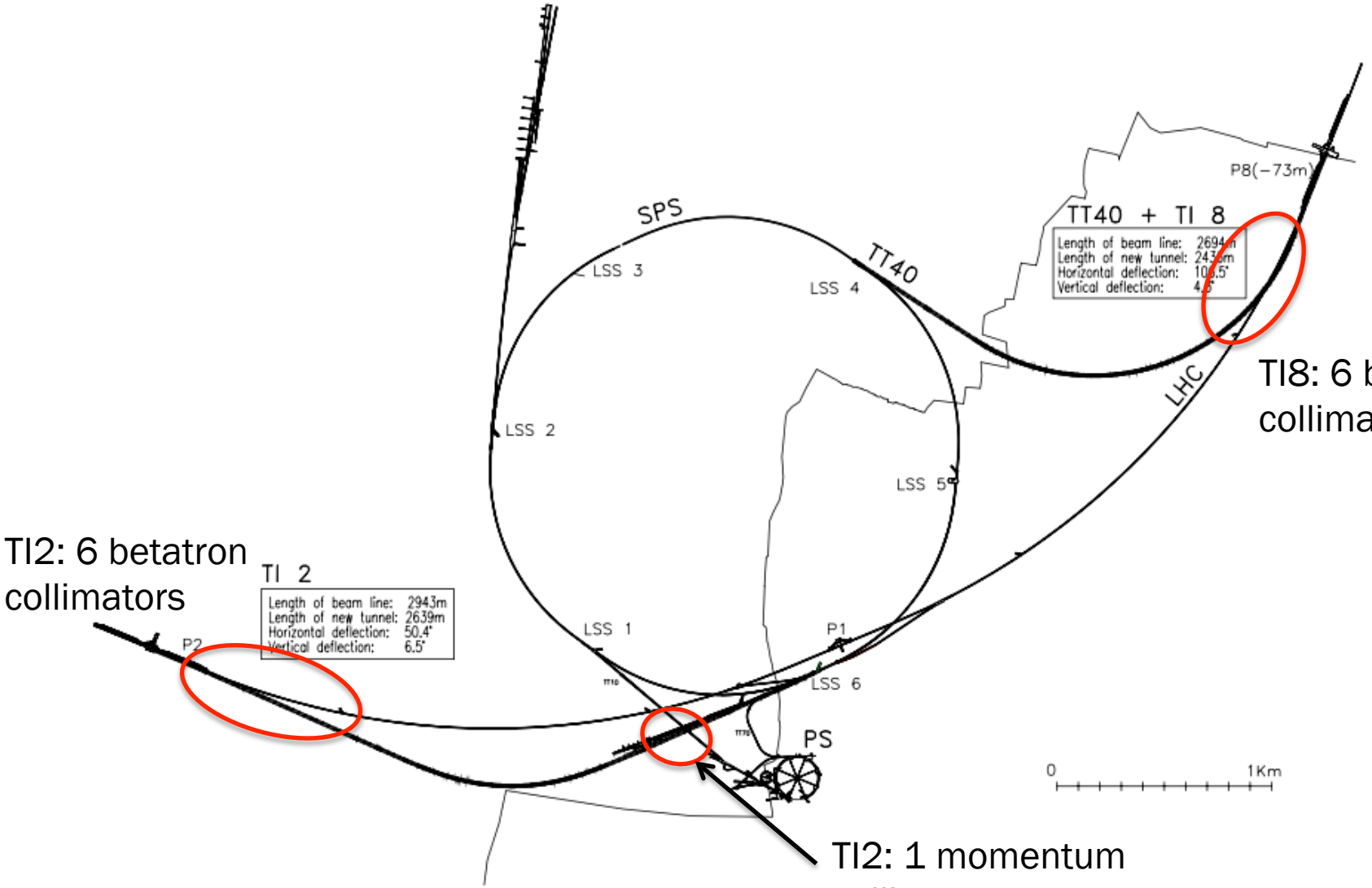
- The attenuation factor must be increased to ~70 and new, longer TCDIs will be installed in place of the existing collimators:

$$\frac{N_{\text{afterTCDI}}}{\varepsilon_{\text{afterTCDI}}} = \frac{1}{20} \times \frac{N_{\text{ultimate}}}{\varepsilon_{\text{ultimate}}} = \frac{1}{70} \times \frac{N_{\text{BCMS}}}{\varepsilon_{\text{BCMS}}}$$

- We have reserved 2.5 m of beam line for each TCDI position, which is compatible with a jaw length of up to 2.1 m.

- Optics in TI8 had to be re-matched to increase the beam size such that stresses in the collimator jaw are kept within the material strength.

TCDI LOCATIONS

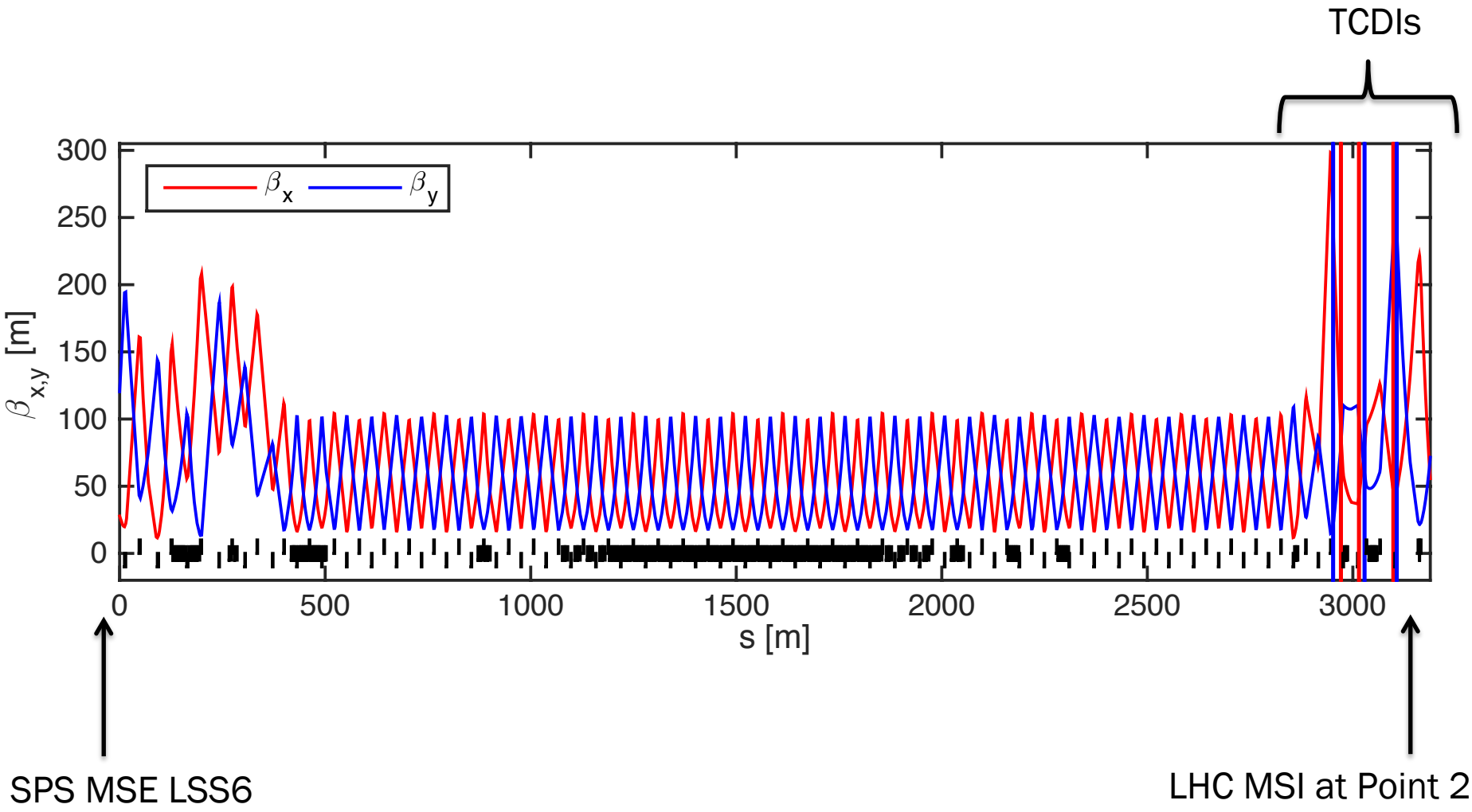


TI8: 6 betatron collimators

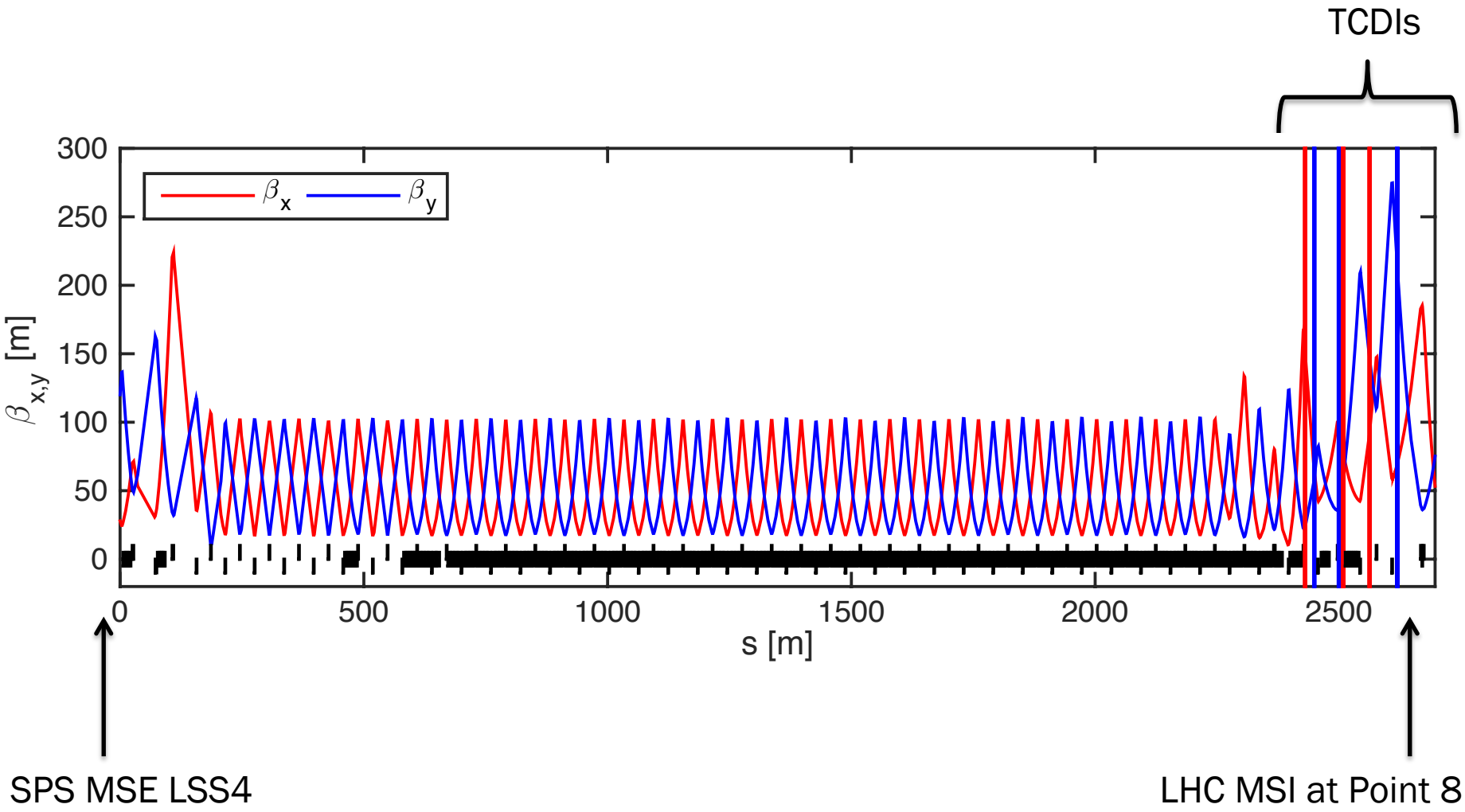
TI2: 6 betatron collimators

TI2: 1 momentum collimator

TCDI LOCATIONS: TI2



TCDI LOCATIONS: TI8



DETAILED DESCRIPTION

- A total of 12 collimators (3 horizontal and 3 vertical, per transfer line) will be removed and replaced with a longer version (< 2.5 m) based on the same design.

- Most TCDI locations are the same, however, the location of the 3 horizontal collimators in TI8 will change significantly.

- In TI2 there is no change of TCDI position, all TCDIMs stay in the same place.

New Collimator Name	Position s_{end} [m]	Length [m]	Downstream Mask	Position s_{end} [m]	Centre-to-centre Distance [m]
TCDIV.29011	2953.22	2.5	TCDIM.29059	2975.73	23.46
TCDIH.29049	2972.22	2.5	TCDIM.29059	2975.73	4.46
TCDIH.29206	3016.14	2.5	TCDIM.29241	3032.17	16.98
TCDIV.29233	3029.72	2.5	TCDIM.29241	3032.17	3.40
TCDIH.29464	3099.72	2.5	TCDIM.29472	3101.81	3.04
TCDIV.29508	3108.07	2.5	TCDIM.29527	3116.40	9.28

*The upstream momentum collimator not shown (TCDIV.20607) will stay installed.

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- In TI2 there is no change of TCDI position, all TCDIMs stay in the same place.
- In TI8 all 3 TCDIHs change positions, all TCDIMs stay in the same place:

Existing Collimator Name	Existing Position s_{end} [m]	New Collimator Name	New Position s_{end} [m]	Difference in Position [m]
TCDIH.87441	2387.665	TCDIH.87606	2432.032	+44.37
TCDIV.87645	2450.165	TCDIV.87644	2450.625	+0.50
TCDIV.87804	2499.965	TCDIV.87804	2501.125	+1.16
TCDIH.87904	2546.152	TCDIH.87822	2509.930	-36.22
TCDIH.88121	2619.837	TCDIH.87939	2564.460	-55.53
TCDIV.88123	2621.237	TCDIV.88121	2620.897	+0.34

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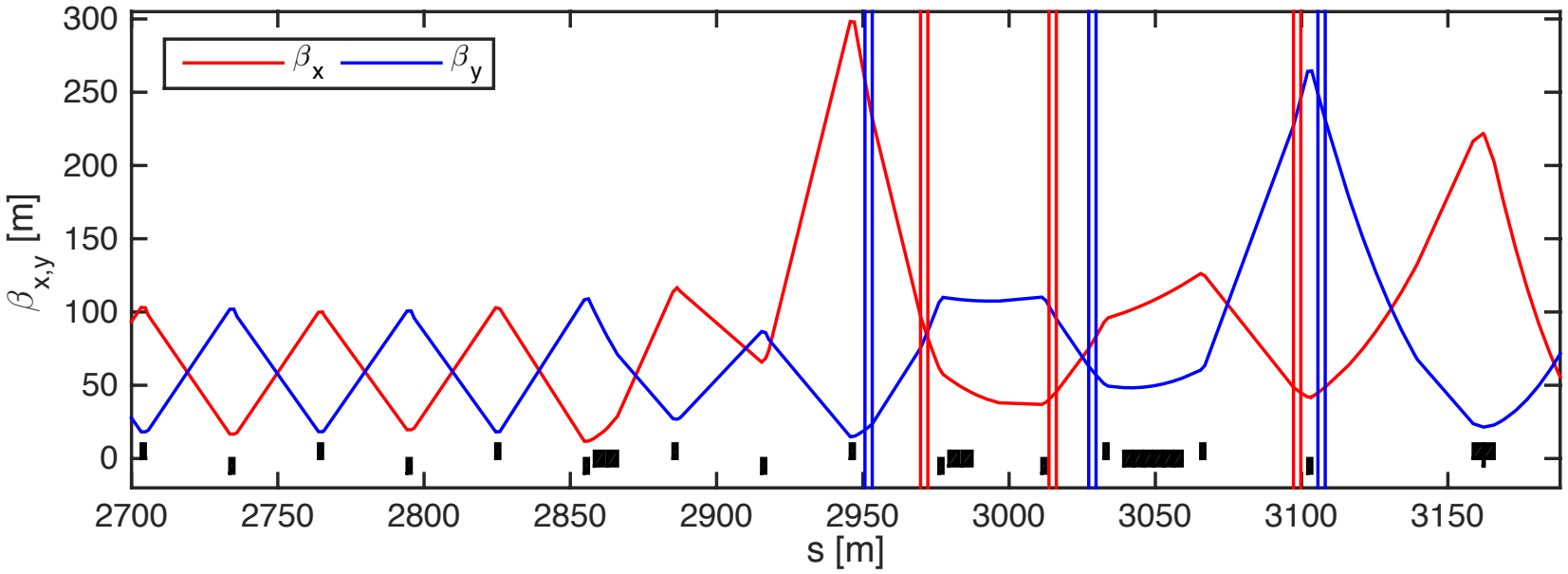
Collimator Name	Position s_{end} [m]	Length [m]	Downstream Mask	Position s_{end} [m]	Centre-to-centre Separation [m]
TCDIH.87606	2953.22	2.5	TCDIM.87658	2456.232	6.56
TCDIV.87644	2972.22	2.5	TCDIM.87658	2456.232	25.15
TCDIV.87804	2501.125	2.5	TCDIM.87831	2512.730	12.56
TCDIH.87822	2509.930	2.5	TCDIM.87831	2512.730	3.75
TCDIH.87939	2564.460	2.5	TCDIM.87966	2576.218	12.71
TCDIV.88121	2620.897	2.5	TCDIM.88132	2625.125	5.18

OPTICS: TI2

- Optics remains unchanged from the Q20 optics presently used.
- TCDIs are replaced but locations are unchanged.
- TCDIMs are unchanged.
- Only change foreseen is to remove two LEP (RB6) converters from SR2 and replace them with new COMET power converters (to be discussed).



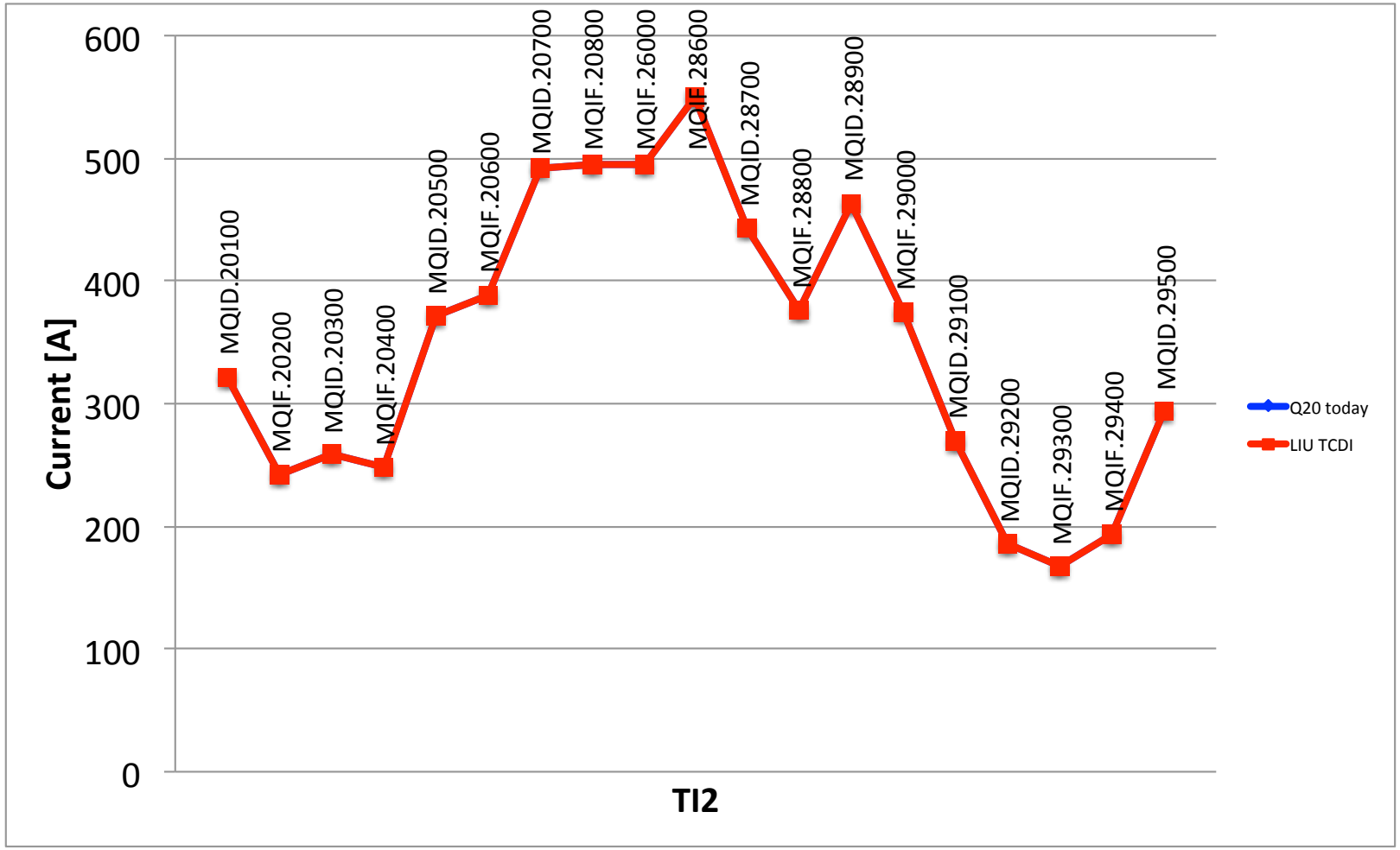
OPTICS: TI2

- Optics remains unchanged from the Q20 optics presently used.
- Emittance presented as 3.5 mm mrad

New Collimator Name	Position s_{end} [m]	β [m]		$\beta_x \times \beta_y$ [m^2]	D [m]		Δμ [deg]		σ=√βε [mm]	
		β_x	β_y		D_x	D_y	Δμ (from TCDI)	Δμ (to MSI)	σ_x	σ_y
TCDIV.29011	2953.22	232.2	20.6	5021	-3.60	0.11	-	-126.5	1.37	0.39
TCDIH.29049	2972.22	82.1	87.0	7331	-2.32	0.04	-	-138.6	0.84	0.74
TCDIH.29206	3016.14	45.4	95.4	4196	-1.21	0.01	56.8	-81.8	0.54	0.87
TCDIV.29233	3029.72	83.3	57.0	4720	-1.27	0.02	63.3	-63.2	0.74	0.68
TCDIH.29464	3099.72	45.0	245.9	11038	-0.44	0.08	59.0	-22.8	0.60	1.29
TCDIV.29508	3108.07	48.7	231.2	11175	-0.31	0.09	60.1	-3.1	0.57	1.35

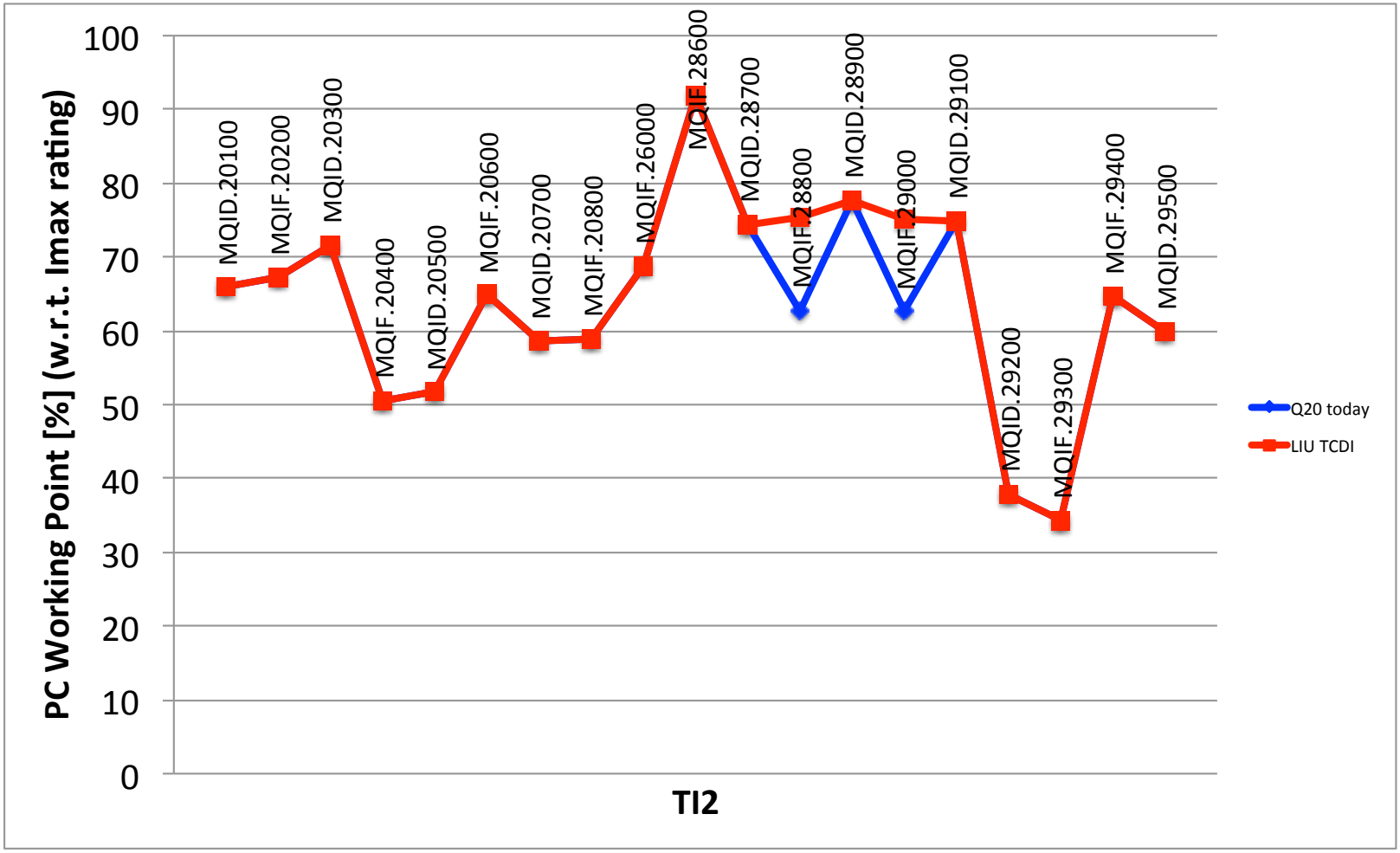
OPTICS: TI2

- Current required in the transfer line quadrupoles:



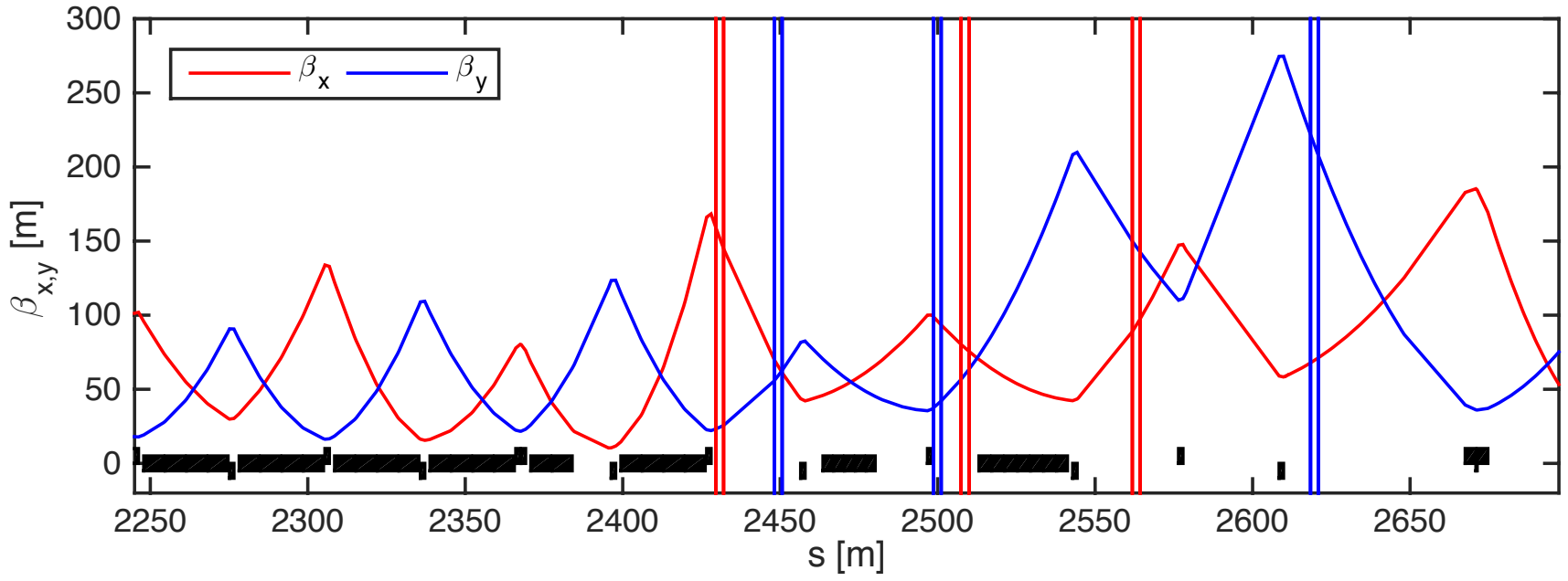
OPTICS: TI2

- Working point of power converters with 2 COMET power converters swapped in: the maximum current is rated 100 A lower:



OPTICS: TI8

- Optics has to change from the Q20 optics presently used because of the limited space available to place longer TCDIs.
- TCDIMs are unchanged.
- Two additional LEP (RB6) power converters taken from TI2 for MQIF.87000 and MQID.87100 in SR8, presently powered in series with circuits RQIF.80400 and RQID. 80500.



OPTICS: TI8

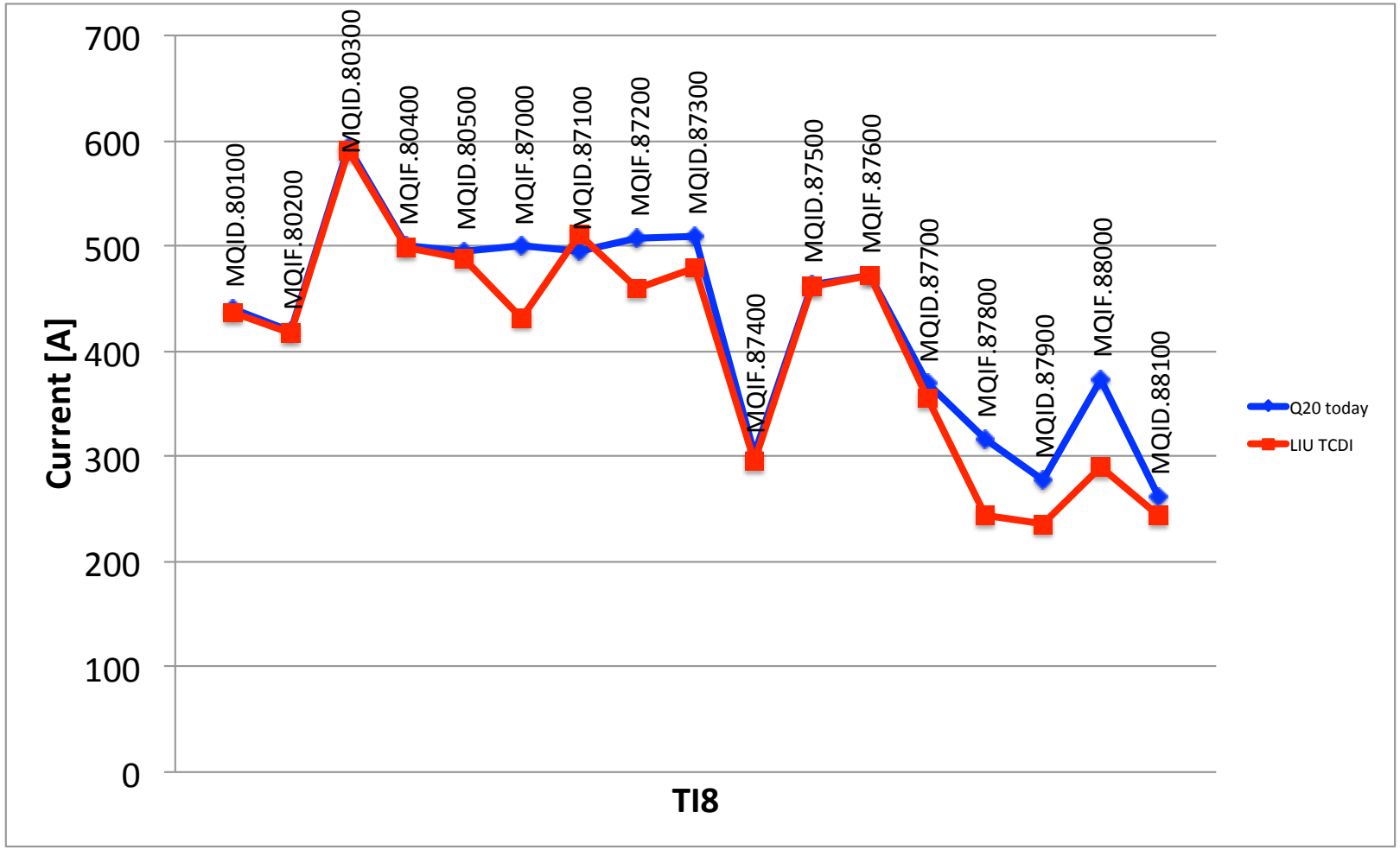
- Optics will change from the Q20 optics presently used, with two new independent quads.

- Emittance presented as 3.5 mm mrad

Collimator Name	Position s_{end} [m]	β [m]		$\beta_x \times \beta_y$ [m^2]	D [m]		Δμ [deg]		$\sigma=\sqrt{\beta\varepsilon}$ [mm]	
		β_x	β_y		D_x	D_y	Δμ (from TCDI)	Δμ (to MSI)	σ_x	σ_y
TCDIH.87606	2432.032	159.3	23.2	3700	2.27	-0.53	-	-161.8	1.08	0.41
TCDIV.87644	2450.625	69.9	55.7	3894	1.61	-0.45	-	-114.8	0.71	0.64
TCDIV.87804	2501.125	99.0	37.4	3706	1.67	-0.04	56.9	-57.8	0.85	0.52
TCDIH.87822	2509.930	80.3	56.6	4546	1.40	-0.02	64.2	-97.6	0.77	0.64
TCDIH.87939	2564.460	88.9	149.9	13331	0.84	0.05	55.7	-41.8	0.81	1.05
TCDIV.88121	2620.897	67.9	221.8	15052	0.28	0.09	55.8	-2.1	0.70	1.27

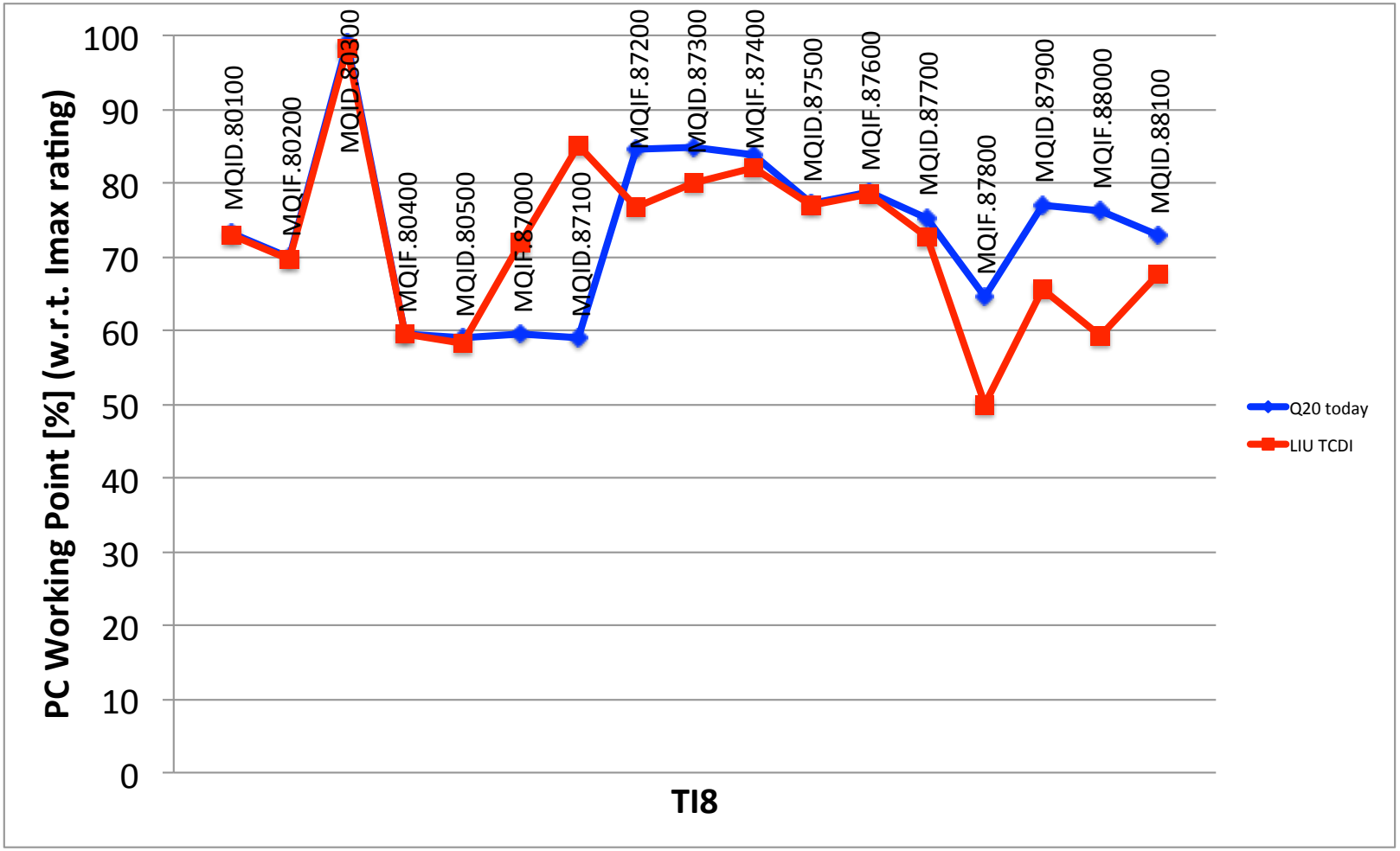
OPTICS: TI8

- Current required in the transfer line quadrupoles:



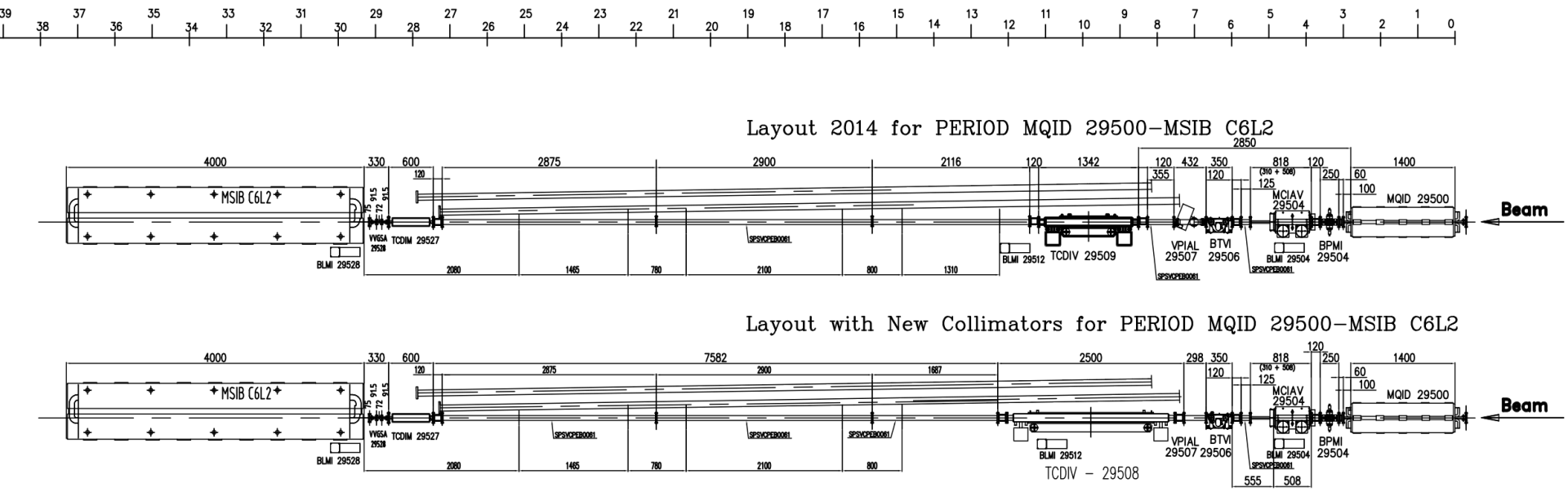
OPTICS: TI8

- Working point of power converters with 2 additional converters of the LEP (RB6) type, swapped from TI2:



EXAMPLE INTEGRATION DRAWING

- In most cases, the installation will be a similar procedure as for the original TCDIs.
- Frederic Galleazzi has prepared new drawings based on 2.5 m TCDIs and identified issues where installation is more complicated (TCDIH.87939 to be discussed later)
- As an example, the last TCDIV in TI2 swapped with a new collimator:



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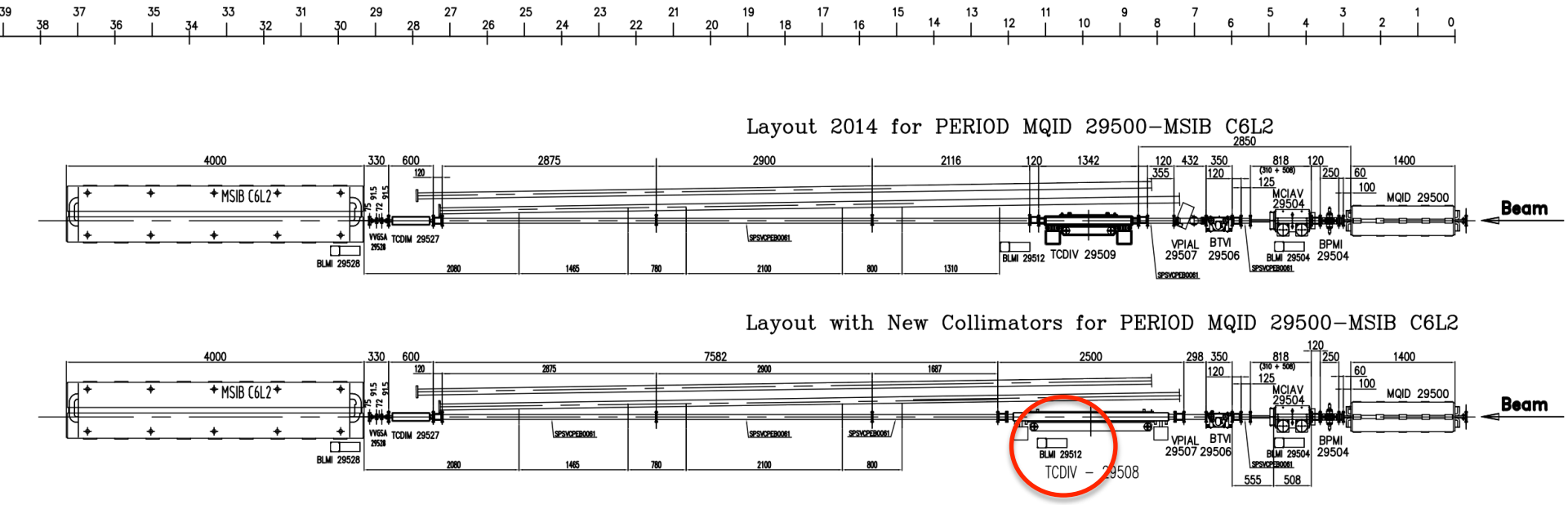
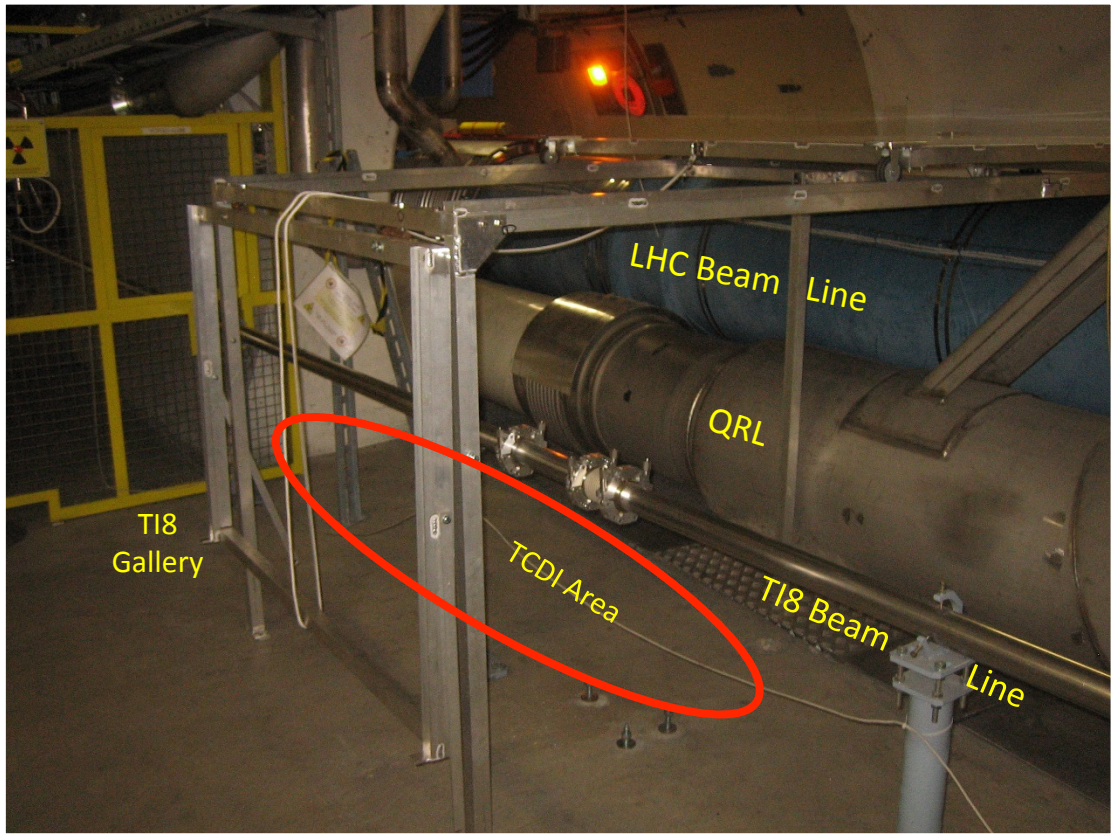


Comment: BLM positions need updating.

IMPACT ON OTHER SYSTEMS

- Passerelle/Plates-Formes for Patrol in Point 8 (LHC-HPMQ-EC-0001) :



- Frederic identified this issue. As I understand it, the passerelle will be dismounted and moved during LS2: an integration study is needed to find it new position.

IMPACT ON OTHER SYSTEMS

- **Power converters in SR2 for TI2 (still being validated with TE-EPC and EN-EL):**
- Still converging on this solution with Gilles Le Godec and Guillaume Gros:
- The specification for the two new power converters in TI8 was over 500 A, requiring a very large converter (APOLLO) rated at 900 A and requiring water-cooling… **this option has been ruled out.**
- As a compromise, we can procure smaller COMET converters rated at 500 A, and install them in TI2 at locations where LEP (RB6) converters rated at 600 A are being used with lots of margin. The LEP converters can be used in TI8.
- We propose to replace the TI2 LEP (RB6) converters on circuits RQIF.28800 and RQIF.29000, with no extra cabling required.

IMPACT ON OTHER SYSTEMS

- **Power converters in SR8 for TI8 (still being validated with TE-EPC and EN-EL):**
- Also converging on this solution with Gilles Le Godec and Guillaume Gros:
- The LEP converters from TI2 will be installed in SR8 for TI8, powering MQIF.87000 and MQID.87100 independently.
- MQIF.87000 and MQID.87100 will need disconnecting from their respective FODO circuits RQIF.80400 and RQID.80500.
- Still need to check the integration of the new LEP converters in SR8.
- Still need to check length of new cables that need pulling. The cable length is quite long demanding close to the maximum voltage provided by the LEP converters.

IMPACT ON OTHER SYSTEMS

- Beam Loss Monitors:

- Each TCDI is equipped with a dedicated BLM to aid the alignment of the collimator jaws with the beam.

- BLMs will need to be repositioned to take into account the extra length of the collimators, and in TI8 the movement of the three TCDIHs.

- The naming has not been updated:

Existing BLM Name	Existing Position s_{end} [m]	New Collimator Position s_{end} [m]	Approximate Change in Position [m]
BLMI.87441	2386.552	2432.032	+44.4
BLMI.87905	2545.382	2509.930	-36.2
BLMI.88122	2619.413	2564.312	-55.5

- This needs following up with Jonathan Emery.

IMPACT ON OTHER SYSTEMS

- TCDIM Masks:

- Each TCDI has a downstream mask made of stainless steel that surrounds the beam pipe to absorb the energy in the shower of secondary particles created if the proton beam hits the upstream TCDI. The masks are placed between the TCDI and next beam line element (MBI, dipole or MQI, quadrupole)

- In one case in TI2 the distance between TCDI and TCDIM mask is smaller than previous due to the extra length of the TCDI. FLUKA simulations have been carried out with the temperature rise computed and reported in the LIU-TCDI Functional Specification.

- Thermo-mechanical simulations are to be done by Francois-Xavier Nuiry who has just joined us.

IMPACT ON UTILITIES/SERVICES

- **Raw water:** No impact.
- **Demineralized water:** No impact.
- **Compressed air:** No impact.
- **Electricity, cable pulling:**

  i. **TCDIs:** no new services required, in principle. TCDI concept is the same: same sensors and motors etc. so should check compatibility with existing cables. In three cases the existing cables need extending (or new cables pulled) to account for the movement the TCDIHs in TI8.

  ii. **MQIs:** new cables will need pulling to independently power MQIF.87000 and MQID.87100. The new circuits will be called RQIF.87000 and RQID.87100.

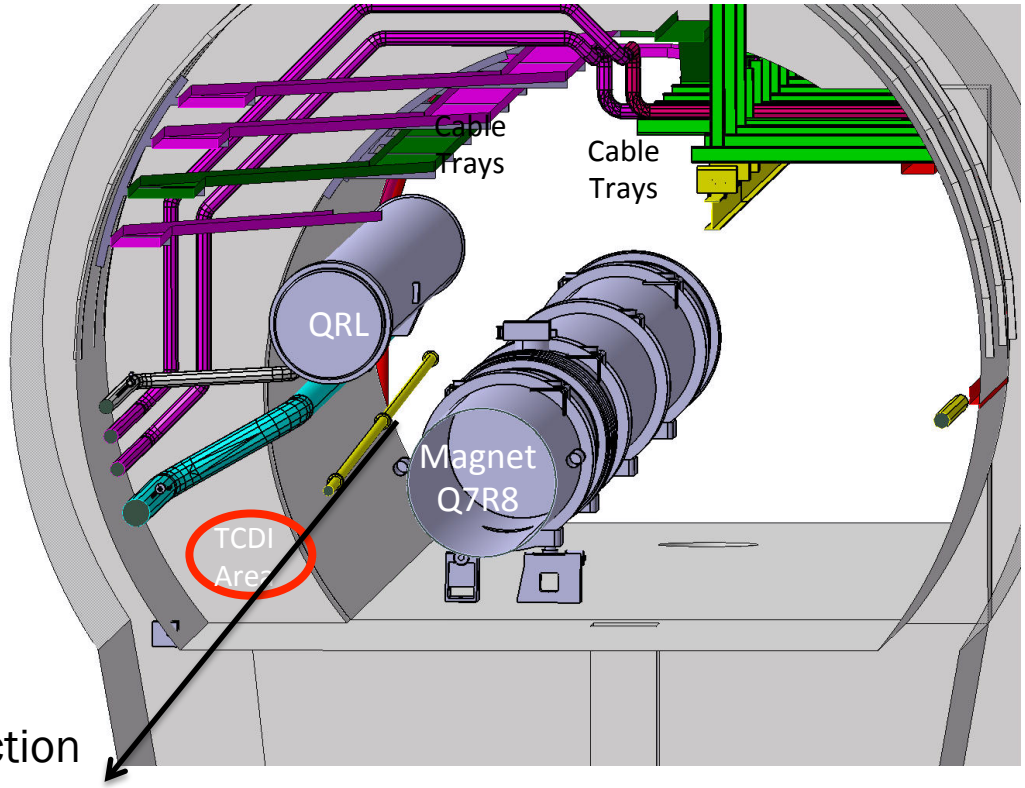
  iii. **BLMs:** to move with TCDIHs in TI8.

- **Vacuum (bake outs, sectorisation):** Vacuum chambers surrounding TCDIs will need modification to accommodate extra length of TCDIs.

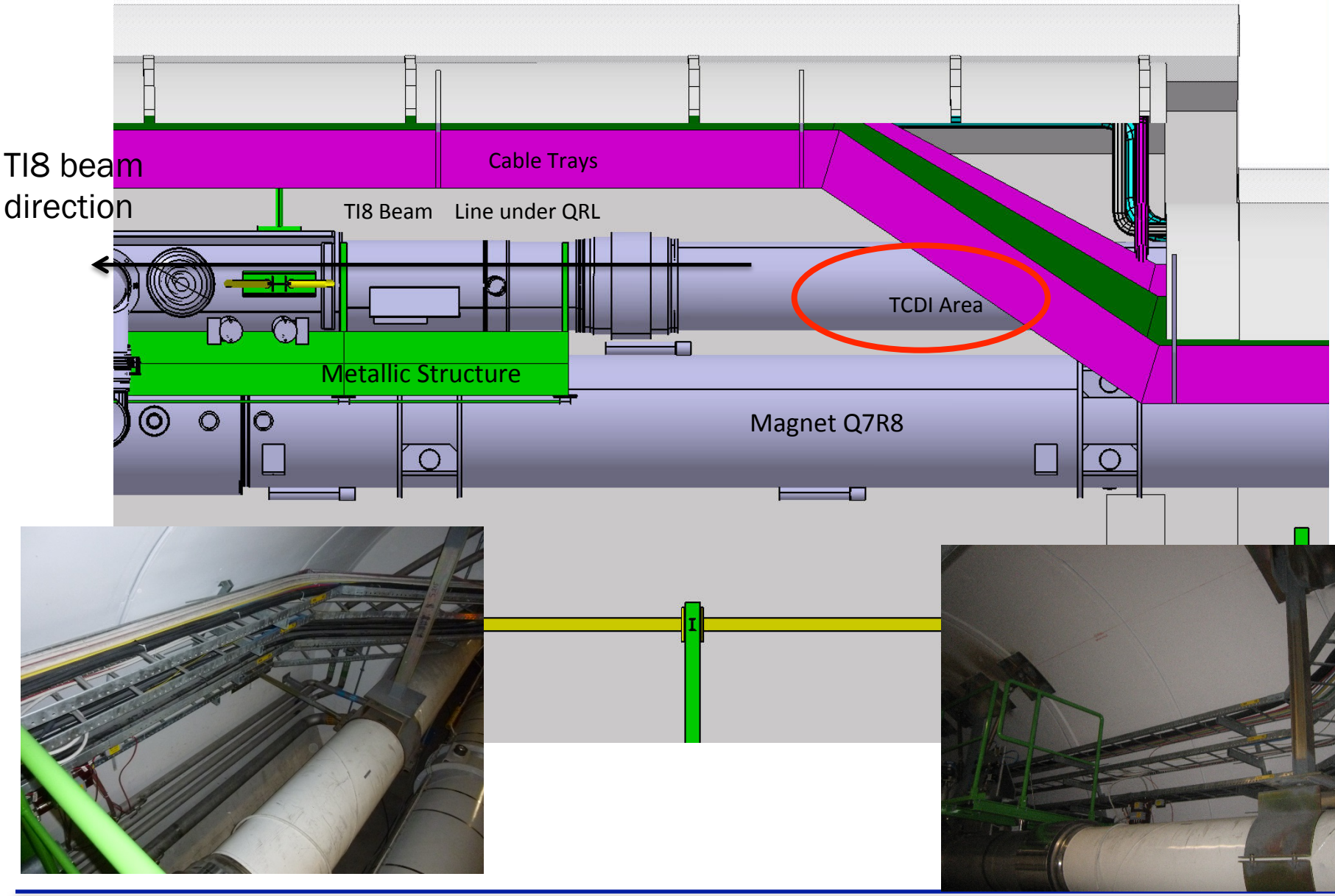
IMPACT ON UTILITIES/SERVICES

- **Special transport/handling:** the installation of TCDIs close to LHC (where space is restricted) will need special transport and handling, in particular for TCDIH.87939. Frederic Galleazzi has already investigated some options for installation, please see LIU-SPS BL, Pro., TL WG: https://indico.cern.ch/event/354946/

- Some special tooling/craning exists but certainly for TCDIH.87939 this should be followed up.



INSTALLATION TCDIH.87939



IMPACT ON UTILITIES/SERVICES

- **Temporary storage of conventional/radioactive components:** Although TCDIs have never taken a full beam impact, they are aligned close to the beam and will have some low level activation. To be followed up with Nadine Conan.

- **Survey:** The newly installed TCDIs wil need to be aligned after installation.

- **Scaffolding:** No impact.

- **Controls:**

  i. TCDI sensors/motors assumed compatible with existing control systems.
  ii. If the old momentum collimator TCDIV.20607 is kept installed and used for setup, it should be interlocked to be retracted during run to prevent it being insert with high intensity beams.
  iii. Interlocks for the new TCDIs should be compatible with the old system.
  iv. New power converters and circuits RQIF.87000 and RQID.87100 should be introduced to the interlock system.

- **Cryogenics/Contractors/Others:** No impact.

IMPACT ON COST/SCHEDULE

- **Detailed breakdown of the change cost:** Costs included as part of the LIU Project baseline. Cost analysis still to be done when jaw material is chosen. Power converter costing is straight forward.

- **Budget code:** 63122

- **Proposed installation schedule:** LS2

- **Proposed test schedule:** Dry runs possible without beam, TCDIs commissioned during transfer line tests as machine is recommissioned during Run 3 start-up.

- **Estimated duration:** For installation at least half a day is needed per TCDI. Considering a full day for the removal and installation of each TCDI we estimate about 12 days or 2.5 weeks for installation.

- **Urgency:** Required for Run 3 operation.

- **Flexibility on scheduling:** Must be competed during LS2.

IMPACT ON PERFORMANCE

- Impact on performance is detailed fully in Functional Specification now under review on EDMS:
  - SPU-T-ES-0001 https://edms.cern.ch/document/1458583
- **Mechanical Aperture:** reduced slightly in TI8.

Element Name	Position s_{end} [m]	Present Q20 Optics		Re-matched Q20 Optics for LIU	
		n_x	n_y	n_x	n_y
MBI.87507	2405.722	-	6.35	-	6.86
MQIF.87600	2428.052	9.12	-	8.75	-
MSIB.C6R8	2629.605	6.88	2.55	6.94	2.97

IMPACT ON PERFORMANCE

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  - SPU-T-ES-0001 https://edms.cern.ch/document/1458583
- **Mechanical Aperture:** reduced slightly in TI8.
- **Momentum Collimation:** no dedicated momentum collimator in TI2 or TI8. Will use the significant dispersion found at the end of the transfer lines to intercept off-momentum beams extracted from SPS. The first TCDIH in each line will double as both betatron and dispersion collimator. The level of dispersion collimation is slightly relaxed compared to today which is at the level of ~0.12 %.

Collimator Name	TI2		Collimator Name	TI8 (LIU Re-matched Optics)	
	$D_x/\sqrt{\beta_x}$ [$m^{1/2}$]	$\Delta p/p_0\|_{max}$ [%]		$D_x/\sqrt{\beta_x}$ [$m^{1/2}$]	$\Delta p/p_0\|_{max}$ [%]
TCDIH.29049	**-0.24**	**0.16**	**TCDIH.87606**	**0.18**	**0.22**
TCDIH.29206	-0.18	0.21	TCDIH.87822	8.75	0.25
TCDIH.29464	-0.06	>0.5	TCDIH.87939	6.94	0.43

IMPACT ON OPERATIONAL SAFETY

- **EIS:** No impact.

- **Other operational safety aspects:** The system is largely unchanged, except for length and position of TCDIs. The same procedures apply for this system as the current one.

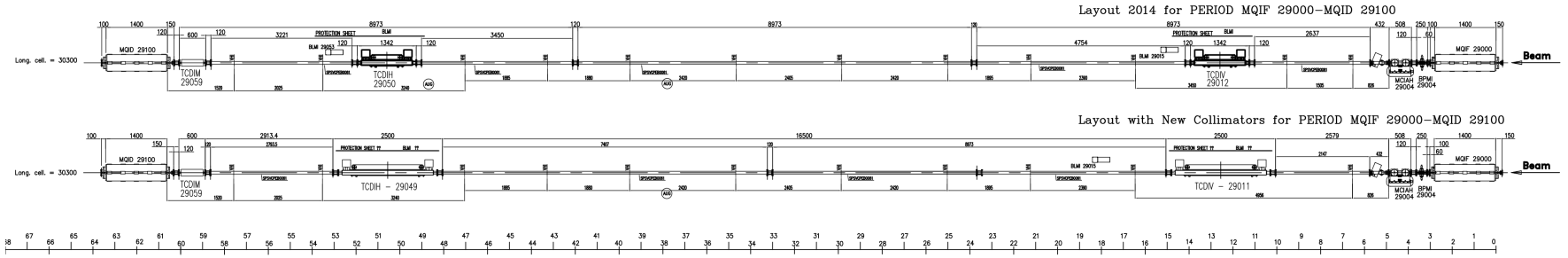
WORKSITE SAFETY

- To be worked out with Anne Funken.

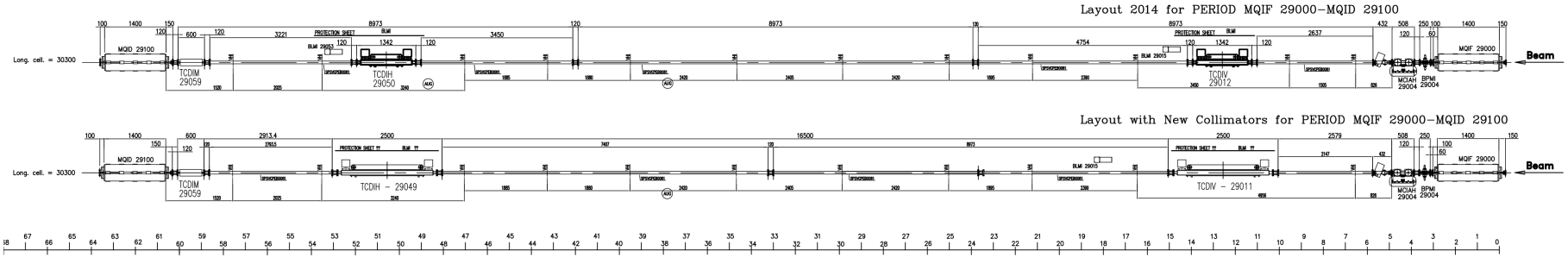
EXTRA SLIDES

TI2: INTEGRATION DRAWINGS (F. GALLEAZZI)

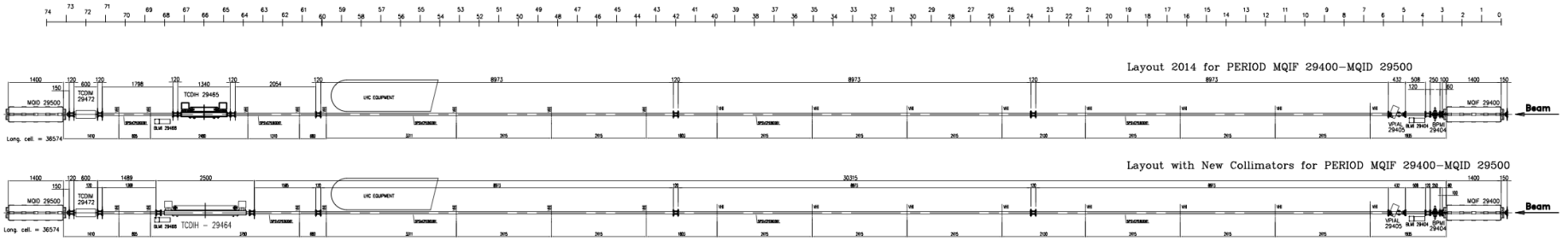
- TCDIV.29011 and TCDIH.29029



- TCDIH.29206 and TCDIV.29233

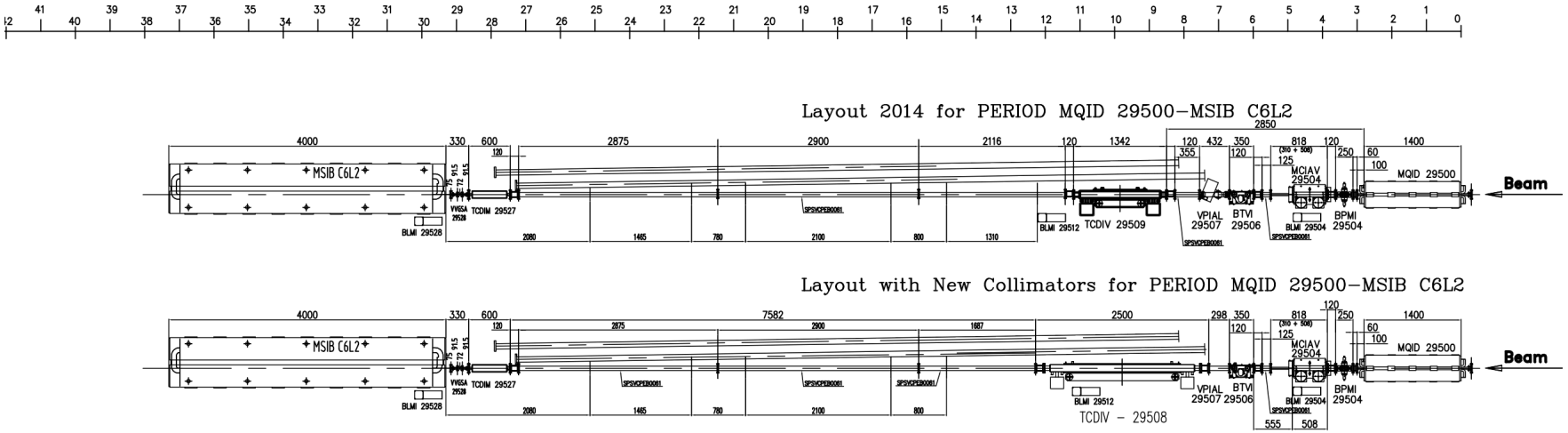


- TCDIH.29464:



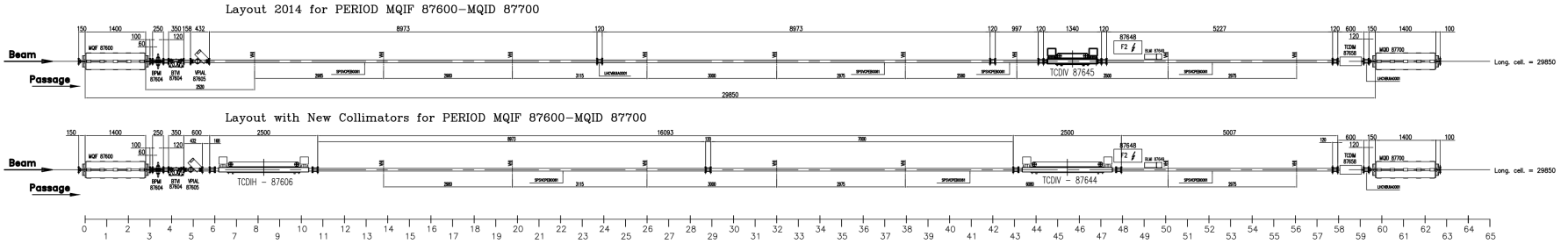
TI2: INTEGRATION DRAWINGS

- TCDIV.29508

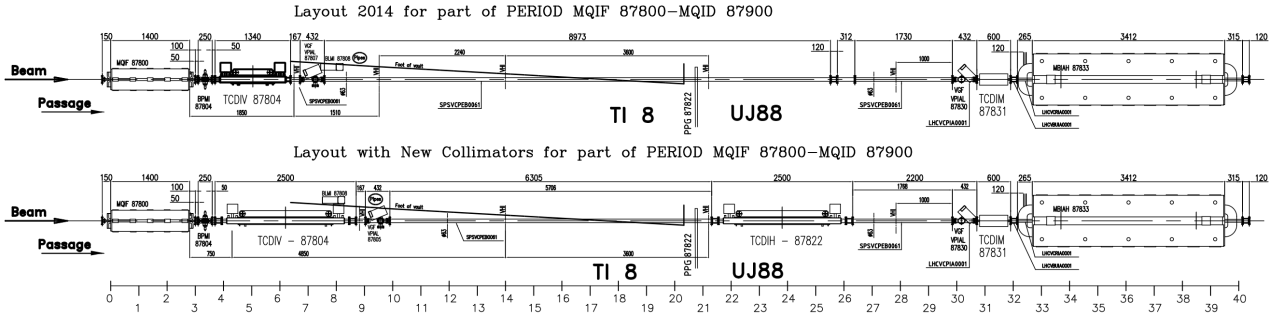


TI8: INTEGRATION DRAWINGS (F. GALLEAZZI)

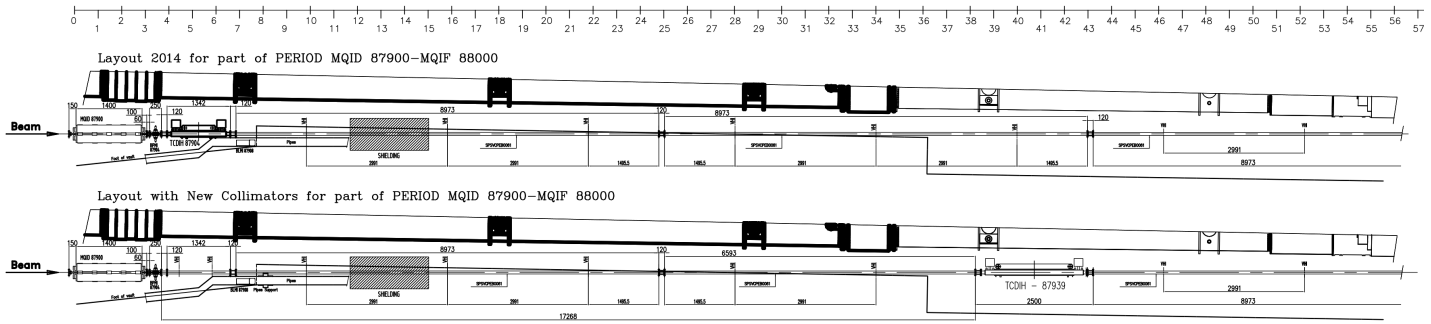
- TCDIH.87606 and TCDIV.87644



- TCDIH.87804 and TCDIV.87822



- TCDIH.87939:



TI8: INTEGRATION DRAWINGS

- TCDIV.88121: