Energy collimation studies

Yuri Alexahin (on behalf of FNAL – NIU team)
EuroCirCol meeting
9 October 2017

The Team

N. Mokhov & M. Syphers (NIU) – leaders,

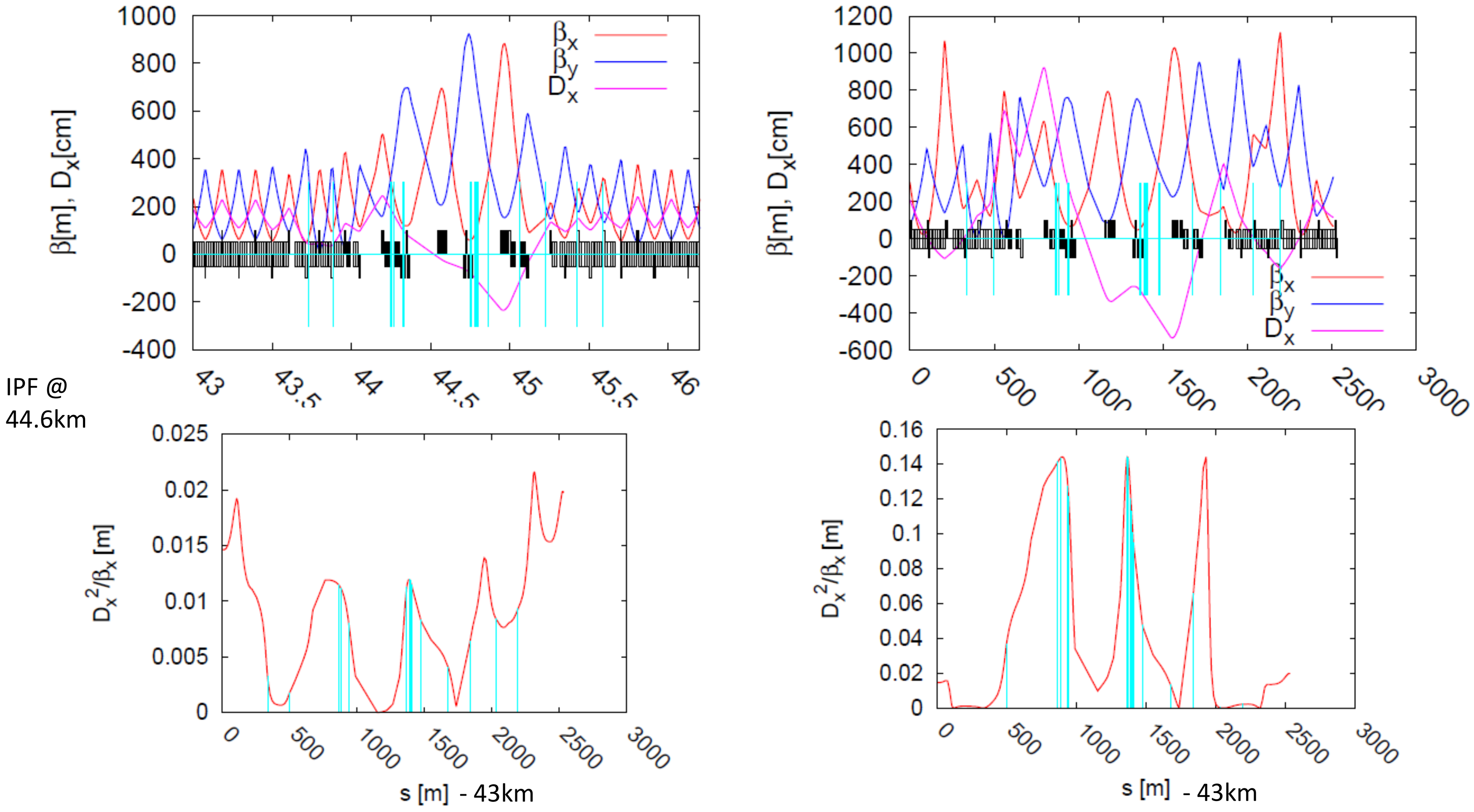
E. Gianfelice-Wendt – optics design

Y. Alexahin – optics & collimation arrangement design

I. Tropin – MARS simulations & collimation arrangement design

A. Narayanan (NIU PhD student) – G4beamline and MARS simulations

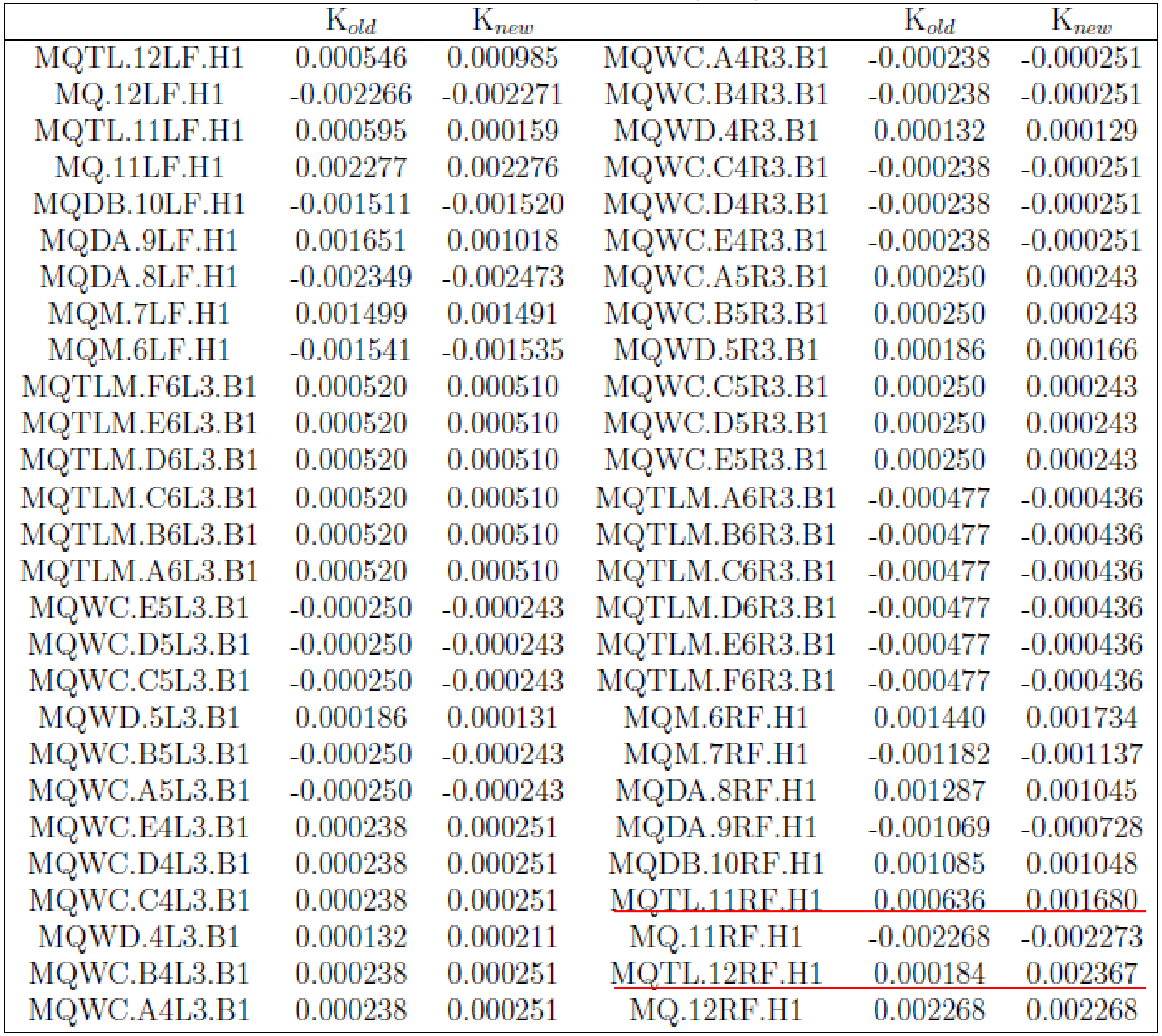
Optics Modifications



Left: The starting optics is Collider dev/fcc hh dev.seq as found back in June 2017

Right: Eliana's optics modification – the merit factor D_x^2/β_x increased by 7 times

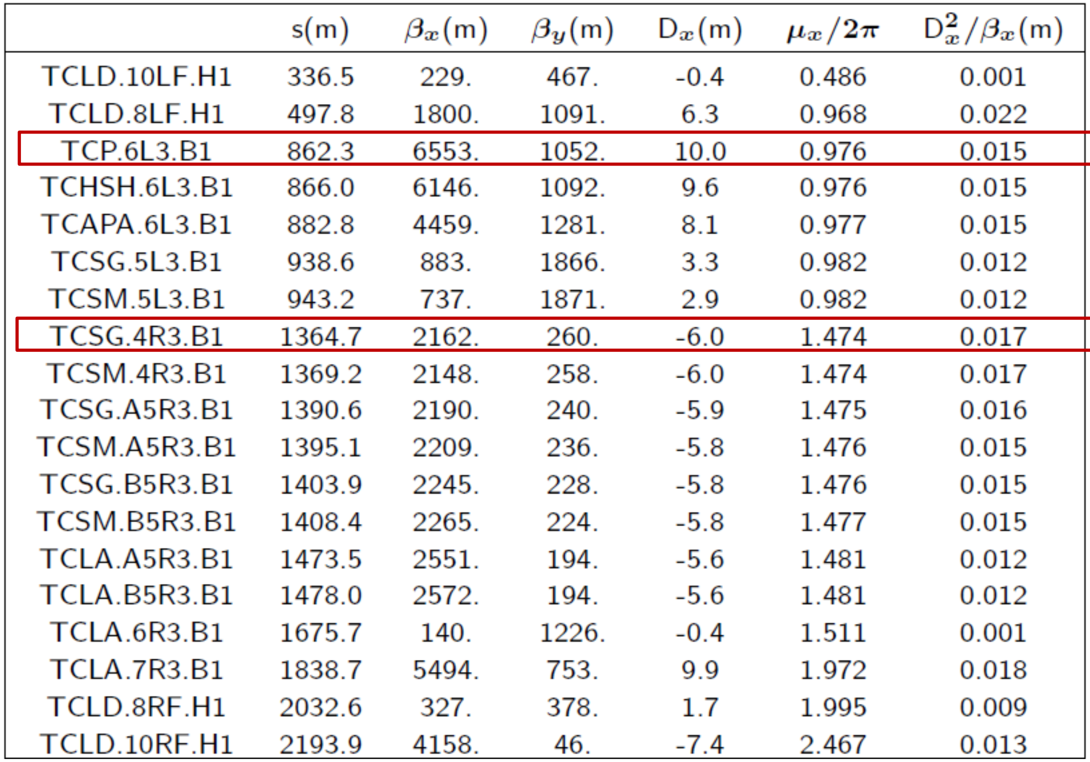
Quadrupole Strength Modification



	K_{old}	K_{new}		K_{old}	K_{new}
MQTL.12LF.H1	0.000546	0.000985	MQWC.A4R3.B1	-0.000238	-0.000251
MQ.12LF.H1	-0.002266	-0.002271	MQWC.B4R3.B1	-0.000238	-0.000251
MQTL.11LF.H1	0.000595	0.000159	MQWD.4R3.B1	0.000132	0.000129
MQ.11LF.H1	0.002277	0.002276	MQWC.C4R3.B1	-0.000238	-0.000251
MQDB.10LF.H1	-0.001511	-0.001520	MQWC.D4R3.B1	-0.000238	-0.000251
MQDA.9LF.H1	0.001651	0.001018	MQWC.E4R3.B1	-0.000238	-0.000251
MQDA.8LF.H1	-0.002349	-0.002473	MQWC.A5R3.B1	0.000250	0.000243
MQM.7LF.H1	0.001499	0.001491	MQWC.B5R3.B1	0.000250	0.000243
MQM.6LF.H1	-0.001541	-0.001535	MQWD.5R3.B1	0.000186	0.000166
MQTLM.F6L3.B1	0.000520	0.000510	MQWC.C5R3.B1	0.000250	0.000243
MQTLM.E6L3.B1	0.000520	0.000510	MQWC.D5R3.B1	0.000250	0.000243
MQTLM.D6L3.B1	0.000520	0.000510	MQWC.E5R3.B1	0.000250	0.000243
MQTLM.C6L3.B1	0.000520	0.000510	MQTLM.A6R3.B1	-0.000477	-0.000436
MQTLM.B6L3.B1	0.000520	0.000510	MQTLM.B6R3.B1	-0.000477	-0.000436
MQTLM.A6L3.B1	0.000520	0.000510	MQTLM.C6R3.B1	-0.000477	-0.000436
MQWC.E5L3.B1	-0.000250	-0.000243	MQTLM.D6R3.B1	-0.000477	-0.000436
MQWC.D5L3.B1	-0.000250	-0.000243	MQTLM.E6R3.B1	-0.000477	-0.000436
MQWC.C5L3.B1	-0.000250	-0.000243	MQTLM.F6R3.B1	-0.000477	-0.000436
MQWD.5L3.B1	0.000186	0.000131	MQM.6RF.H1	0.001440	0.001734
MQWC.B5L3.B1	-0.000250	-0.000243	MQM.7RF.H1	-0.001182	-0.001137
MQWC.A5L3.B1	-0.000250	-0.000243	MQDA.8RF.H1	0.001287	0.001045
MQWC.E4L3.B1	0.000238	0.000251	MQDA.9RF.H1	-0.001069	-0.000728
MQWC.D4L3.B1	0.000238	0.000251	MQDB.10RF.H1	0.001085	0.001048
MQWC.C4L3.B1	0.000238	0.000251	MQTL.11RF.H1	0.000636	0.001680
MQWD.4L3.B1	0.000132	0.000211	MQ.11RF.H1	-0.002268	-0.002273
MQWC.B4L3.B1	0.000238	0.000251	MQTL.12RF.H1	0.000184	0.002367
MQWC.A4L3.B1	0.000238	0.000251	MQ.12RF.H1	0.002268	0.002268

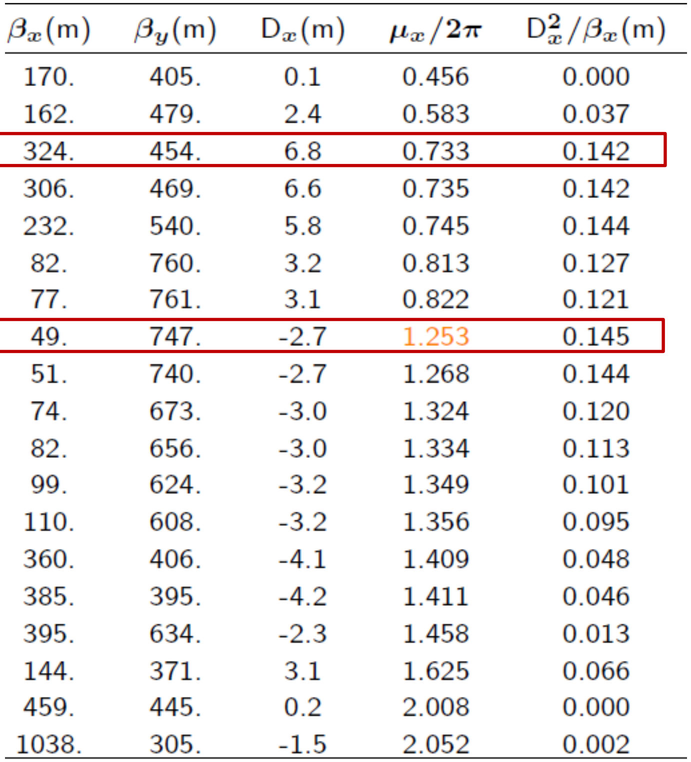
Optics Functions @ Collimators

Original design



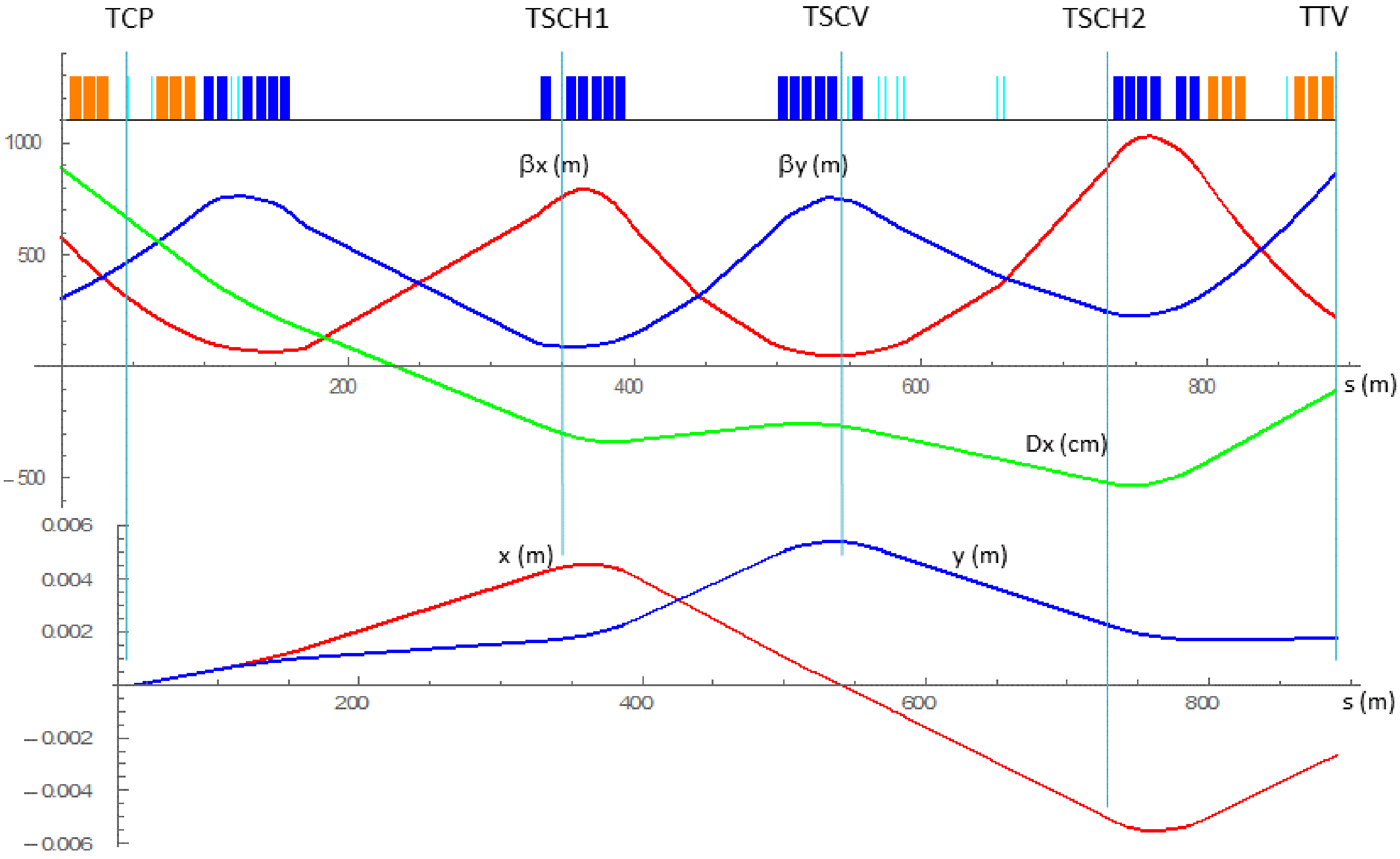
	s(m)	β_x(m)	β_y(m)	D_x(m)	$\mu_x/2\pi$	D_x^2/β_x(m)
TCLD.10LF.H1	336.5	229.	467.	-0.4	0.486	0.001
TCLD.8LF.H1	497.8	1800.	1091.	6.3	0.968	0.022
TCP.6L3.B1	862.3	6553.	1052.	10.0	0.976	0.015
TCHSH.6L3.B1	866.0	6146.	1092.	9.6	0.976	0.015
TCAPA.6L3.B1	882.8	4459.	1281.	8.1	0.977	0.015
TCSG.5L3.B1	938.6	883.	1866.	3.3	0.982	0.012
TCSM.5L3.B1	943.2	737.	1871.	2.9	0.982	0.012
TCSG.4R3.B1	1364.7	2162.	260.	-6.0	1.474	0.017
TCSM.4R3.B1	1369.2	2148.	258.	-6.0	1.474	0.017
TCSG.A5R3.B1	1390.6	2190.	240.	-5.9	1.475	0.016
TCSM.A5R3.B1	1395.1	2209.	236.	-5.8	1.476	0.015
TCSG.B5R3.B1	1403.9	2245.	228.	-5.8	1.476	0.015
TCSM.B5R3.B1	1408.4	2265.	224.	-5.8	1.477	0.015
TCLA.A5R3.B1	1473.5	2551.	194.	-5.6	1.481	0.012
TCLA.B5R3.B1	1478.0	2572.	194.	-5.6	1.481	0.012
TCLA.6R3.B1	1675.7	140.	1226.	-0.4	1.511	0.001
TCLA.7R3.B1	1838.7	5494.	753.	9.9	1.972	0.018
TCLD.8RF.H1	2032.6	327.	378.	1.7	1.995	0.009
TCLD.10RF.H1	2193.9	4158.	46.	-7.4	2.467	0.013

Eliana's design



β_x(m)	β_y(m)	D_x(m)	$\mu_x/2\pi$	D_x^2/β_x(m)
170.	405.	0.1	0.456	0.000
162.	479.	2.4	0.583	0.037
324.	454.	6.8	0.733	0.142
306.	469.	6.6	0.735	0.142
232.	540.	5.8	0.745	0.144
82.	760.	3.2	0.813	0.127
77.	761.	3.1	0.822	0.121
49.	747.	-2.7	1.253	0.145
51.	740.	-2.7	1.268	0.144
74.	673.	-3.0	1.324	0.120
82.	656.	-3.0	1.334	0.113
99.	624.	-3.2	1.349	0.101
110.	608.	-3.2	1.356	0.095
360.	406.	-4.1	1.409	0.048
385.	395.	-4.2	1.411	0.046
395.	634.	-2.3	1.458	0.013
144.	371.	3.1	1.625	0.066
459.	445.	0.2	2.008	0.000
1038.	305.	-1.5	2.052	0.002

Warm Section Optics



Optics functions in warm section (from *bpm.6l3.b1* to *bpmwc.6r3.b1*) and trajectories of particles scattered in the primary collimator by 10μrad

Collimators for Preliminary Study

name	collim. plane	length (m)	position from warm start (m)	jaw distance (mm) from centerline	jaw angle (μrad) w.r.t. centerline
TCP	h	2.5	43.75	10	-72.75
TSCH1	h	2.5	343.0	5	0
TSCV	v	2.0	545.47	3.6	0
TSCH2	h	2.5	732.82	9	0
TTV	v	1.5	888.65	2.5	0

Important Note:

Generally the contribution to the transverse impedance goes as $\beta_{x,y}/gap^3$, so for horizontal momentum collimator $Z_x \sim \beta_x / D_x^3$, while for the vertical $Z_y \sim 1/\beta_y^{1/2}$.

In Eliana's design both contributions are smaller!

G4beamline* Simulations

The goal of the study was to see if it is possible to eliminate protons with relative momentum deviation δ_p larger (by absolute value) than δ_{max}=0.0015 not allowing scattered protons with transverse amplitudes larger than 12σ at 50 TeV to escape.

A G4BL input file was built that includes warm magnets and collimators as described on slides 2-3 which act on dp/p < 0 part of the halo. The gaps were calculated for δ_{max}=0.0015

Three values of dp/p were chosen: -0.0016, -0.0015 and -0.0014

For each dp/p value an ensemble of 10^4 particles was built based on MADX values of optics functions at the warm section entrance as

$$x = D_x\delta + \sqrt{2\beta_x I_x}\cos(\psi_x), \quad x' = D_x'\delta - \sqrt{2I_x/\beta_x}[\sin(\psi_x) + \alpha_x\cos(\psi_x)],$$

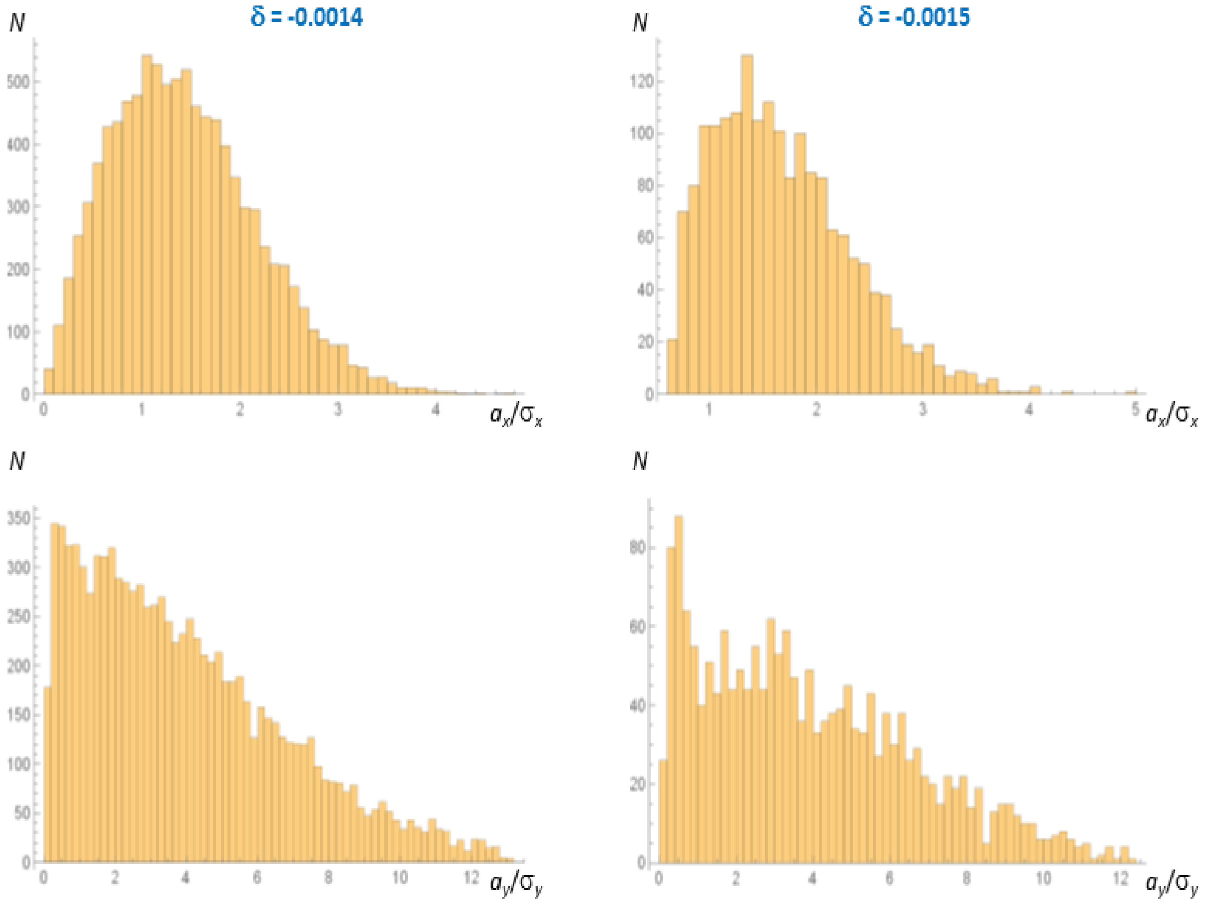
$$y = \sqrt{2\beta_y I_y}\cos(\psi_y), \quad y' = -\sqrt{2I_y/\beta_y}[\sin(\psi_y) + \alpha_y\cos(\psi_y)],$$

where the initial phases $\psi_{x,y}$ were randomly distributed in the interval (0, 2π), while action variables $I_{x,y}$ were distributed according to the exponential law with the average $\varepsilon_\perp = 4.1 \cdot 10^{-11}$m and truncation at 5$\sigma$ amplitude ($I_{x,y}$=12.5$\varepsilon_\perp$).

Protons that reached the end of the warm section were analysed.

*) T. Roberts, http://g4beamline.muonsinc.com

G4BL Tracking Results (30k protons total)



Distribution in the transverse amplitudes of surviving particles at the warm end, none survived of those with $\delta = -0.0016$

Next steps

Limitations:

Present shape and dimensions of collimators and magnets are too simplistic.

Magnets work as “black holes”: kill all particles entering iron.

No beamline enclosure, instead some disc absorbers put to kill off particles with large amplitudes.

Only 50 TeV case considered

To-do list with G4BL

More realistic configuration of collimators (may be shorter C + metallic?)

More realistic sizes of the magnet iron yokes (w/o “kill” option)

Additional absorbes for secondaries and low energy protons

Energy deposition in collimators and magnets (“totalEnergy” command)

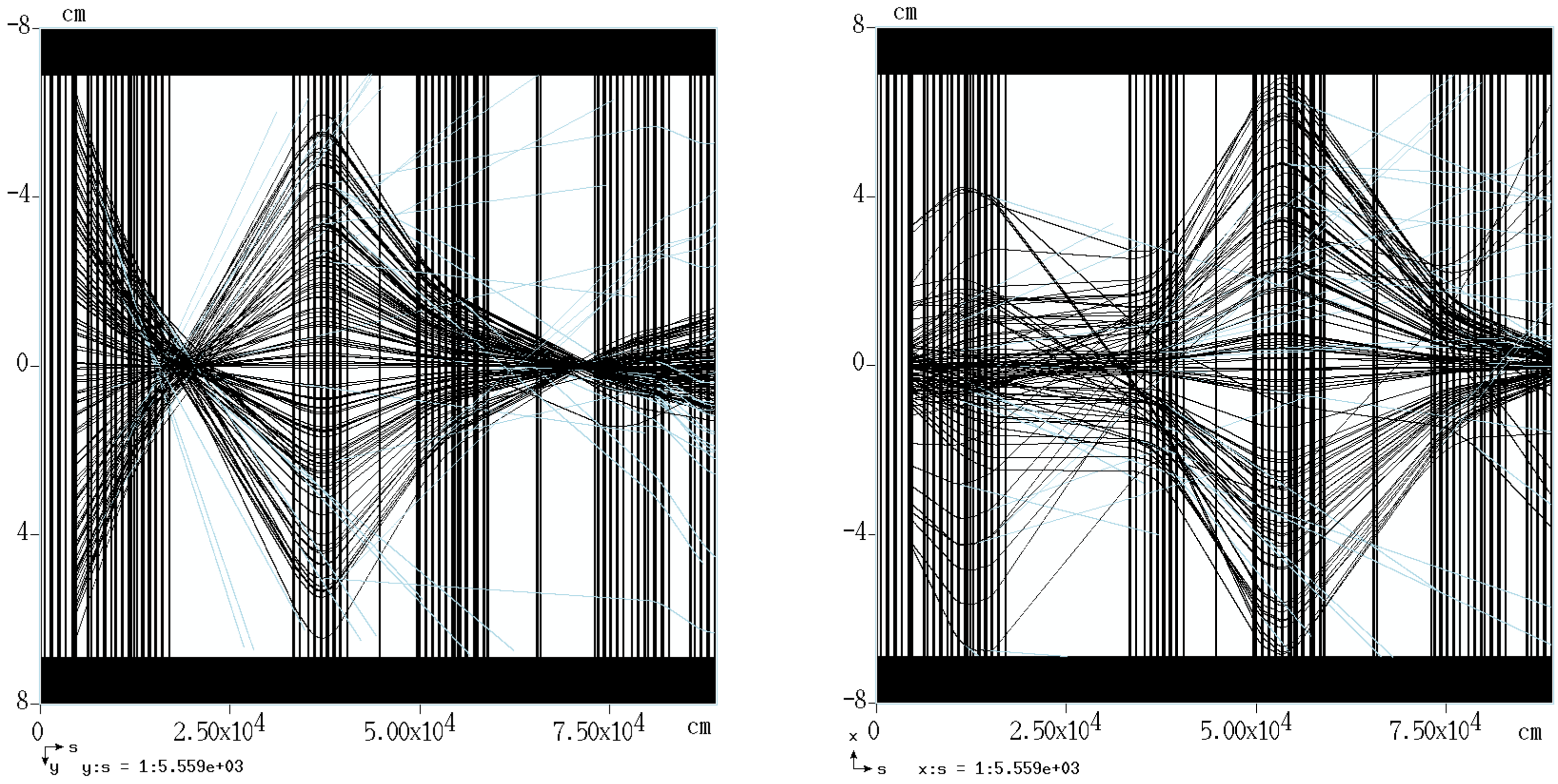
Injection energy case

Draft of the report

MARS model and simulations

MARS Unleashed!

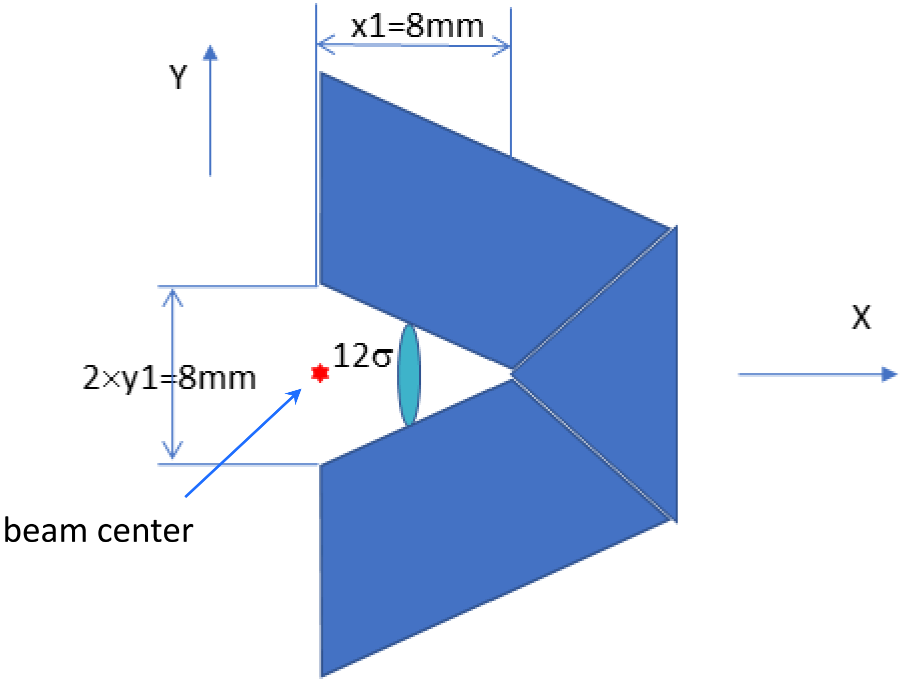
Lattice file for warm section was created and checked by tracking protons with original collimators (?)



Proton trajectories in horizontal (left) and vertical (right) plane. MARS notations differ from conventional x ↔ y

TSCV (the right half) used in G4BL simulations

Since there is no elliptic apertures in G4beamline I had to invent something that would produce smaller impedance and collimate particles with large |dp/p| tighter:



Schematic view of the cross-section of the right half of the TSCV collimator acting on protons with $\delta_p < 0$. The red star shows the beam center while the teal ellipse shows the 12σ envelope for $\delta_p = -0.0015$.