Design of the MYRRHA superconducting linac & beam delivery

Jean-Luc BIARROTTE
CNRS-IN2P3 / IPN Orsay, France
EURATOM FP7 MAX project coordinator

1.Introduction

2. Design of the MYRRHA SC main linac
3. The MYRRHA beam lines
4. Conclusion

ADS proton beam requirements

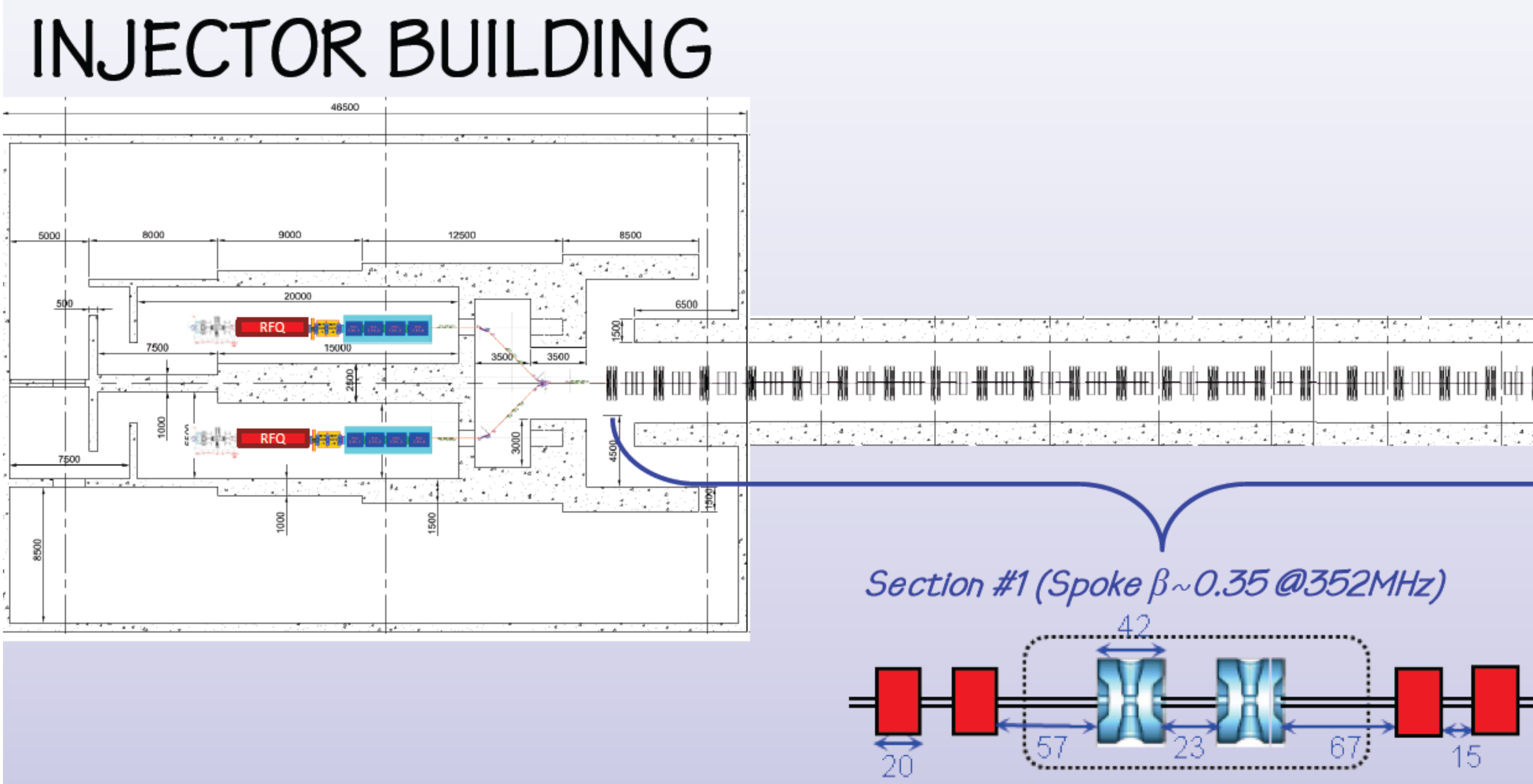
Proton beam general initial specifications within EUROTRANS

	Transmuter demonstrator (XT-ADS / MYRRHA project)	Industrial transmuter (EFIT)
Proton beam current	2.5 mA (& up to 4 mA for burn-up compensation)	~ 20 mA
Proton energy	600 MeV	800 MeV
Allowed beam trips nb (> 3 s)	~ < 10 per 3-month operation cycle	~ < 3 per year
Beam entry into the reactor	Vertically from above	
Beam stability on target	Energy: ±1% - Current: ±2% - Position & size: ±10%	
Beam time structure	CW (w/ low frequency 200μs beam "holes" for sub-criticality monitoring)	

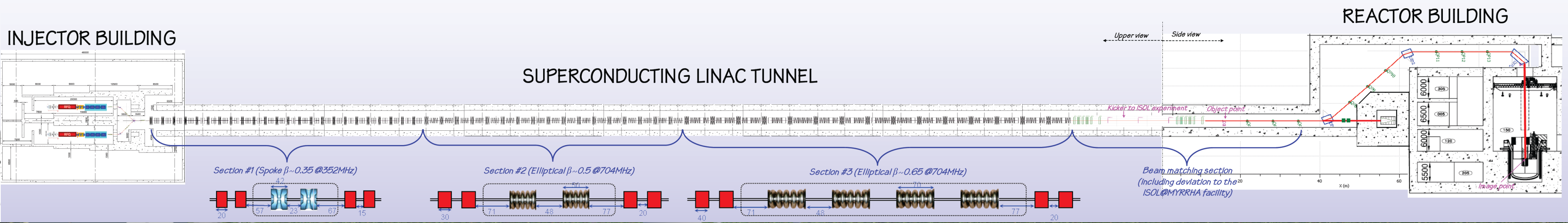
Extreme reliability level

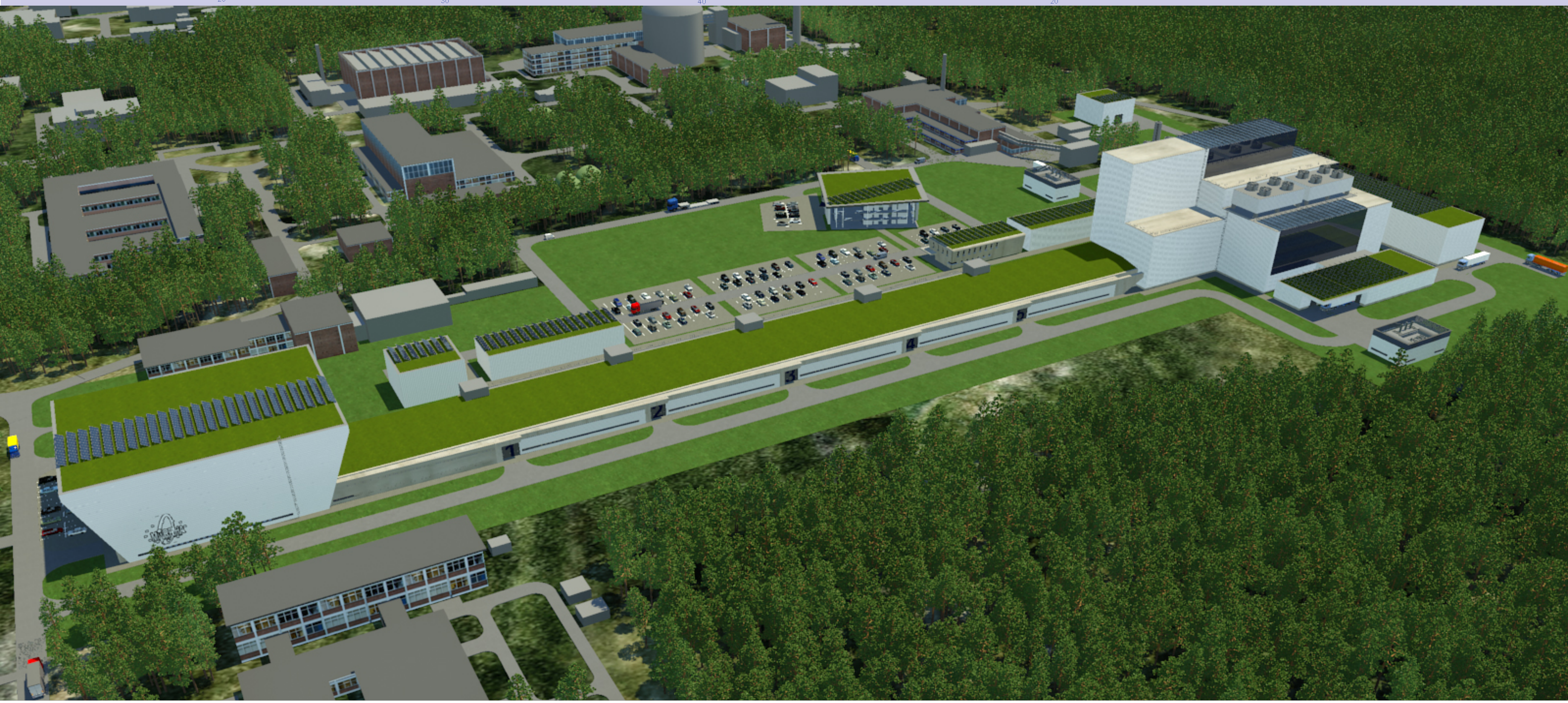
Multi MW class CW beams

Layout of the MYRRHA linac



Layout of the MYRRHA linac





1. Introduction

2. Design of the MYRRHA SC main linac

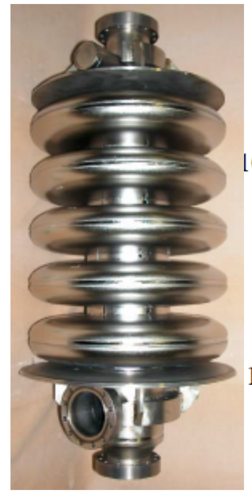
3. The MYRRHA beam lines

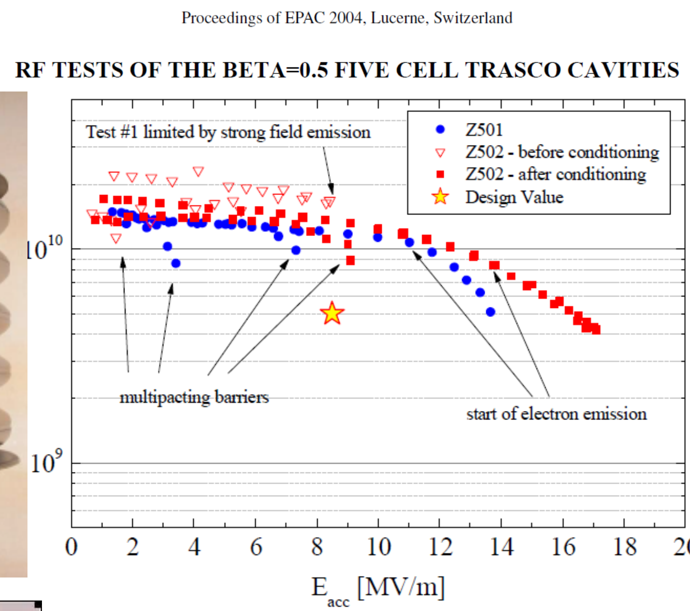
4. Conclusion

MYRRHA superconducting cavities

➢ 704.4 MHz elliptical cavities (CEA/CNRS/INFN)

E_{acc} given at β_{OPT}	β_{OPT}	E_{pk}/E_{acc}	B_{pk}/E_{acc}
5-cells β_g=0.47	0.51	3.34	5.50 mT/MV/m
5-cells β_g=0.66	0.70	2.49	4.65 mT/MV/m

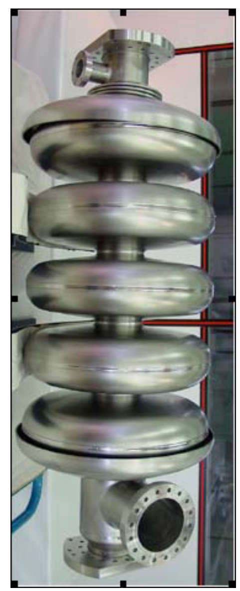




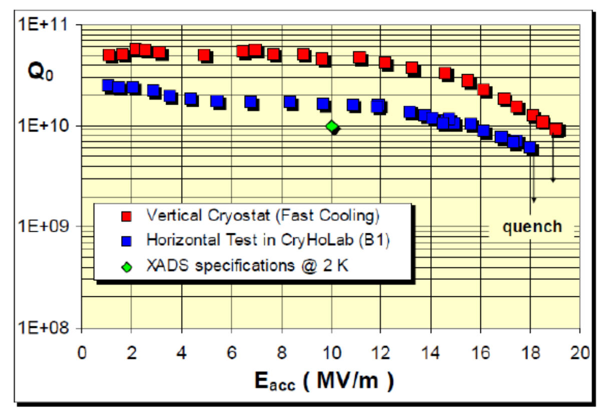
➢ 352.2 MHz spoke cavities (CNRS)

E_{acc} given at β_{OPT}	β_{OPT}	E_{pk}/E_{acc}	B_{pk}/E_{acc}	Wall-to-wall
1-spoke β_g=0.35	*0.37*	*4.7*	*12.8 mT/MV/m*	*≈36 cm*
2nd generation 1-spoke β_g=0.35	0.37	4.4	8.3 mT/MV/m	≈42 cm
2nd generation ESS 2-spoke β_g=0.5	0.50	4.5	7.0 mT/MV/m	≈78 cm

Keep in mind that very few spoke test results exist



Test results of 704 MHz, 5-cell, beta 0.65



"Performance Improvement of the Multicell Cavity Prototype for Proton LINAC Projects", B. Visentin et al., LINAC 2004

MYRRHA superconducting cavities

- **Choice of operation point**

→ analysis of SNS medium-beta SC cavities

- β_g 0.61 average operation: E_{acc_MEAN} = 12.5 MV/m
- corresponding to B_{pk}=72mT, E_{pk}= 34 MV/m

→ add 25% margins for MYRRHA fault-tolerance

- Nominal operation limited by E_{pk}= 27.5MV/m

→ Eacc_nom = 11.0 MV/m (@β_{OPT}) for β_g 0.65 cavities

→ Eacc_nom = 8.2 MV/m (@β_{OPT}) for β_g 0.47 cavities

→ Eacc_nom = 6.2 MV/m (@β_{OPT}) for spoke cavities

Beam Dynamics Studies for the Fault Tolerance Assessment of the PDS-XADS Linac Design

AIP Conf. Proc. 773, pp. 99-103; doi:http://dx.doi.org/10.1063/1.1949505 (5 pages)
HIGH INTENSITY AND HIGH BRIGHTNESS HADRON BEAMS: 33rd ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams
Date: 18-22 October 2004
Location: Bensheim (Germany)

Jean-Luc Biarrotte[1], Marta Novati[2], Paolo Pierini[2], Henri Safa[3], and Didier Uriot[3]
[1]CNRS / IN2P3 / IPNO, Orsay, France
[2]INFN / LASA, Milano, Italy
[3]CEA / DAPNIA, Saclay, France

Table 3: Optimised retuning parameters and corresponding beam dynamics behaviour for a few cavity fault conditions. In all cases, the transmission is 100%. Note that the optimisation level can be different depending on the cases.

# faulty cavity	section	Final energy	Emittance growth (%)		Number of retuned cavities (before + after)	Max ΔEacc (%)	Max E_{pk} (SP) or B_{pk} (EL)	Max ΔPower (%)	Nb of retuned quads (before + after)
			Transv.	Long.					
0	-	Nominal	+ 5 %	0 %	-	-	-	-	-
1	SP 0.15	Nominal	+ 7 %	+ 4 %	0 + 4	+ 67 %	19 MV/m	+ 67 %	0 + 4
2	SP 0.15	Nominal	+ 9 %	+ 12%	1 + 3	+ 90 %	19 MV/m	+ 68 %	0 + 4
3	SP 0.15	Nominal	+ 10%	+ 12%	2 + 3	+ 94 %	21 MV/m	+ 56 %	4 + 2
4	SP 0.15	Nominal	+ 9 %	+ 4 %	3 + 3	+ 46 %	15 MV/m	+ 35 %	2 + 4
19	SP 0.15	Nominal	+ 6 %	+ 6 %	2 + 3	+ 38 %	24 MV/m	+ 48 %	2 + 2
20	SP 0.15	Nominal	+ 9 %	+ 4 %	3 + 2	+ 37 %	26 MV/m	+ 58 %	2 + 2
35	SP 0.15	Nominal	+ 6 %	0 %	2 + 3	+ 20 %	32 MV/m	+ 27 %	2 + 2
36	SP 0.15	Nominal	+ 7 %	+ 4 %	3 + 3	+ 22 %	34 MV/m*	+ 32 %	2 + 2
37	SP 0.35	Nominal	+ 6 %	0 %	3 + 2	+ 22 %	35 MV/m*	+ 34 %	2 + 2
38	SP 0.35	Nominal	+ 7 %	+ 6 %	3 + 4	+ 29 %	31 MV/m	+ 26 %	2 + 2
39	SP 0.35	Nominal	+ 5 %	+ 5 %	4 + 2	+ 24 %	36 MV/m*	+ 35 %	4 + 2
61	SP 0.35	Nominal	+ 6 %	+ 2 %	2 + 3	+ 25 %	31 MV/m	+ 26 %	2 + 2
62	SP 0.35	Nominal	+ 6 %	0 %	2 + 2	+ 26 %	31 MV/m	+ 28 %	2 + 2
63	SP 0.35	Nominal	+ 5 %	+ 1 %	3 + 2	+ 25 %	31 MV/m	+ 27 %	2 + 2
94	SP 0.35	Nominal	+ 6 %	+ 2 %	3 + 3	+ 16 %	29 MV/m	+ 18 %	4 + 2
95	SP 0.35	Nominal	+ 7 %	- 1 %	3 + 3	+ 22 %	31 MV/m	+ 29 %	4 + 2
96	SP 0.35	Nominal	+ 5 %	+ 1 %	4 + 2	+ 21 %	30 MV/m	+ 25 %	4 + 2
97	EL 0.47	Nominal	+ 6 %	0 %	3 + 3	+18 %	59 mT	+27 %	4 + 2
98	EL 0.47	Nominal	+ 6 %	0 %	3 + 2	+ 23 %	62 mT	+ 31 %	4 + 2
109	EL 0.47	Nominal	+ 6 %	0 %	3 + 3	+ 20 %	60 mT	+ 28 %	4 + 2
110	EL 0.47	Nominal	+ 6 %	0 %	3 + 2	+ 20 %	60 mT	+ 29 %	2 + 2
123	EL 0.47	Nominal	+ 6 %	0 %	2 + 4	+ 20 %	60 mT	+ 26 %	4 + 2
124	EL 0.47	Nominal	+ 6 %	0 %	3 + 3	+ 19 %	60 mT	+ 28 %	4 + 2
125	EL 0.65	Nominal	+ 5 %	0 %	2 + 3	+ 18 %	59 mT	+ 27 %	4 + 2
126	EL 0.65	Nominal	+ 5 %	0 %	3 + 4	+ 21 %	61 mT	+ 20 %	4 + 2
127	EL 0.65	Nominal	+ 5 %	0 %	3 + 3	+ 21 %	61 mT	+ 25 %	4 + 2
146	EL 0.65	Nominal	+ 5 %	0 %	3 + 3	+ 18 %	59 mT	+ 22 %	4 + 2
147	EL 0.65	Nominal	+ 6 %	- 1 %	3 + 4	+ 19 %	60 mT	+ 22 %	4 + 2
148	EL 0.65	Nominal	+ 6 %	- 1 %	3 + 3	+ 20 %	60 mT	+ 22 %	4 + 2
173	EL 0.65	Nominal	+ 5 %	0 %	3 + 4	+ 17 %	59 mT	+ 19 %	4 + 2
174	EL 0.65	Nominal	+ 5 %	0 %	3 + 3	+ 18 %	59 mT	+ 22 %	4 + 2
175	EL 0.65	Nominal	+ 5 %	0 %	4 + 4	+ 17 %	59 mT	+ 18 %	4 + 2
176	EL 0.85	Nominal	+ 5 %	0 %	3 + 5	+ 18 %	59 mT	+ 22 %	4 + 2
177	EL 0.85	Nominal	+ 5 %	0 %	4 + 4	+ 18 %	59 mT	+ 20 %	4 + 2
178	EL 0.85	Nominal	+ 5 %	0 %	5 + 4	+ 18 %	59 mT	+ 19 %	4 + 2
179	EL 0.85	Nominal	+ 5 %	0 %	6 + 4	+ 17 %	59 mT	+ 16 %	4 + 2
184	EL 0.85	Nominal	+ 5 %	0 %	4 + 3	+ 17 %	59 mT	+ 29 %	2 + 2
185	EL 0.85	Nominal	+ 6 %	0 %	5 + 2	+ 19 %	60 mT	+ 30 %	2 + 2
186	EL 0.85	Nominal	+ 7 %	0 %	6 + 1	+ 21 %	61 mT	+ 33 %	2 + 2
187	EL 0.85	Nominal	+ 6 %	0 %	7 + 0	+ 25 %	63 mT	+ 37 %	2 + 2

* these values are exceeding the 33 MV/m maximum allowed value because the tuning acts on a cavity (#38) that is already working at 29 MV/m nominal conditions (this cavity is used for the transition matching between the 2 spoke sections)

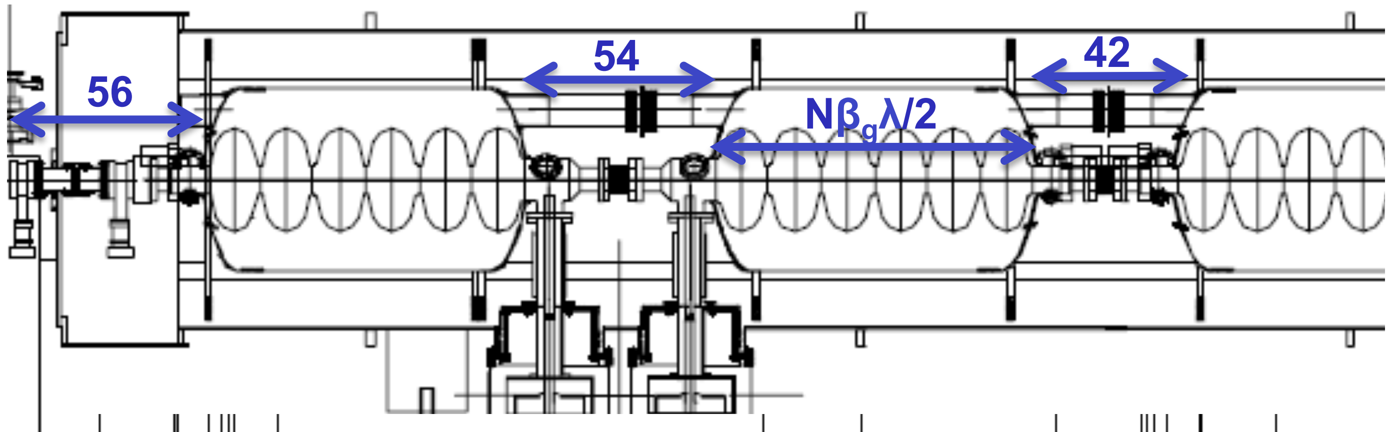
MYRRHA cryomodules

- **Strategy = short modules (<6m) w/ RT quad. doublets**

→ need for modularity, fast maintenance, beam diagnostics at regular locations

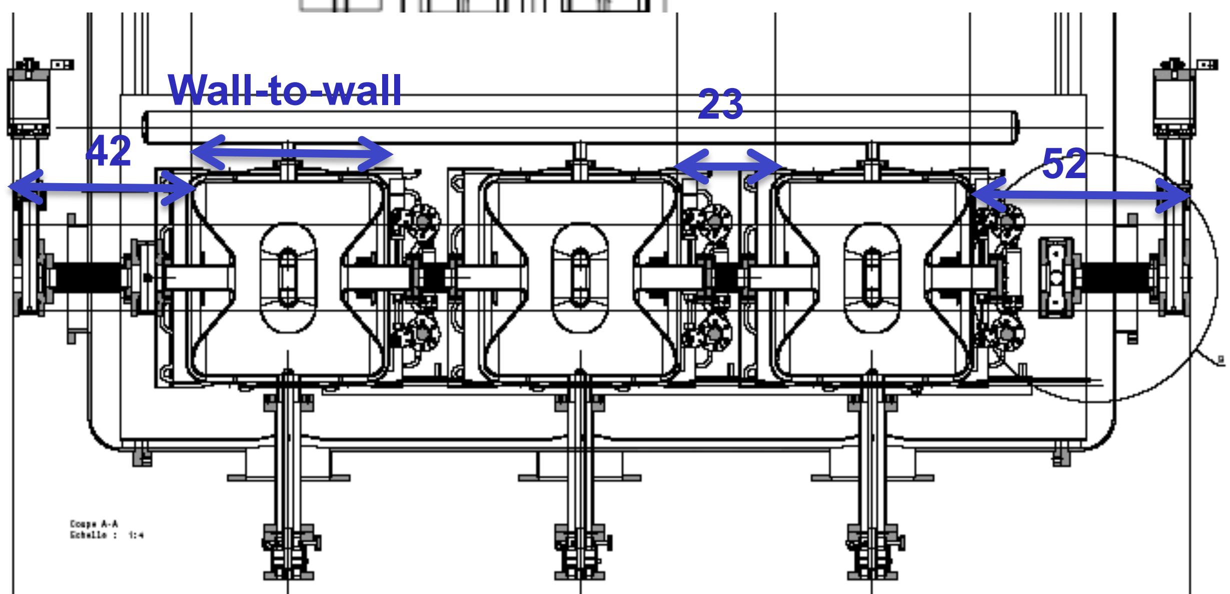
- **Elliptical 2K cryomodule**

→ SNS as a basis



- **Spoke 2K cryomodule**

→ New MAX preliminary designs as a basis

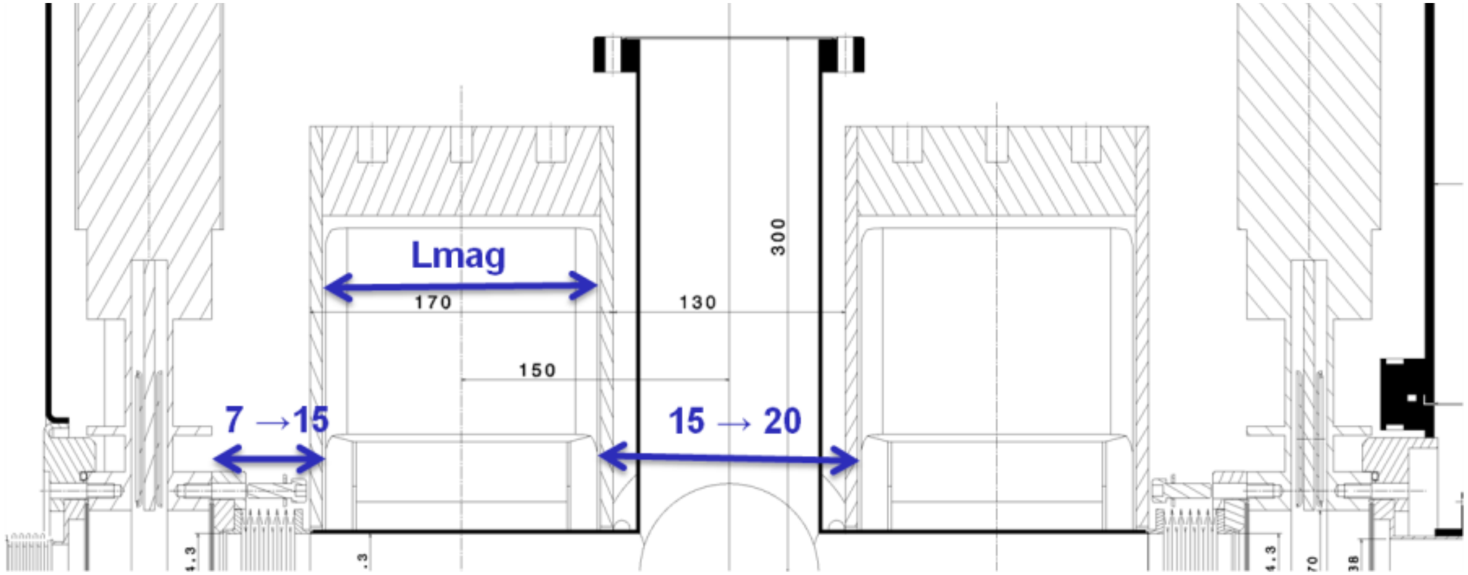


MYRRHA warm sections

- **Inter-module**

→ SPIRAL-2 as a basis

→ + margins



- **Quads**

→ Sufficiently long ($L_{mag} > 4\ R_{ap}$) to minimize fringe field effects

→ Low gradients to ensure $B_{pole} < 0.3T$, minimize NI ($\alpha\ B'R_{ap}^2$) and ensure reliable operation

→ 3 quadrupole families

- section #1: L_{mag}= 20 cm, ∅60 (∅56 for cav.) to ensure B' < 10 T/m (& even less)
- section #2: L_{mag}= 30 cm, ∅85 (∅80 for cav.) to ensure B' < 7 T/m
- section #3: L_{mag}= 40 cm, ∅95 (∅90 for cav.) to ensure B' < 6.3 T/m

Longitudinal beam dynamics

➢ **1. Keep phase advance at zero-current σ_{L0} < 90° / lattice**

→ GOAL = avoid SC-driven parametric resonances & instabilities in mismatched conditions

→ Implies limitations on E_{acc} (and L)

$$\sigma_{L0} = L\sqrt{-\frac{\omega q E_{acc} sin\phi_s}{m_0 c^3 \beta^3 \gamma^3}}$$

➢ **2. Provide high longitudinal acceptance**

→ GOAL = avoid longitudinal beam losses & easily accept fault conditions

→ Implies low enough synchronous phases (ϕ_s= -40° at input, keep ϕ_s< -15°)
& to keep constant phase acceptance through linac, especially at the frequency jump

➢ **3. Continuity of the phase advance per meter (< 2°/m)**

→ GOAL = minimize the potential for mismatch and assure a current independent lattice

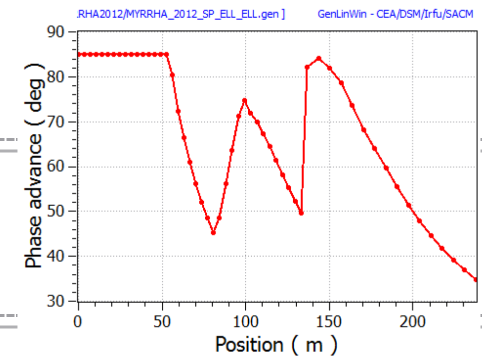
→ Implies especially limitations on E_{acc} at the frequency jump

Some LINAC optimisation results (w/ GenLinWin)

➢ **Results with 1-SPOKE35 + 5-ELLIPT47 + 5-ELLIPT65**

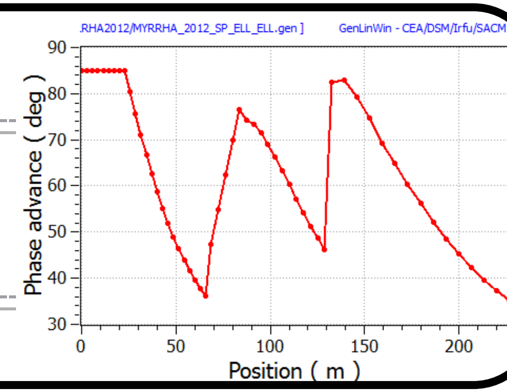
3cav/mod + 2cav/mod, + 4cav/mod (EUROTRANS scheme)

Sect:1 -> Cell/Cav: 2/ 72 Cav/Cryo: 3/ 24 Cryo/Per: 1/ 24 L: 84.2400 m ßg:0.493 ßtrans:0.400 Eo: 86.526 MeV
Sect:2 -> Cell/Cav: 5/ 28 Cav/Cryo: 2/ 14 Cryo/Per: 1/ 14 L: 52.6400 m ßg:0.470 ßtrans:0.530 Eo: 172.822 MeV
Sect:3 -> Cell/Cav: 5/ 64 Cav/Cryo: 4/ 16 Cryo/Per: 1/ 16 L:107.5200 m ßg:0.658 ßfinal: 0.795 Eo: 607.536 MeV
NSection: 3 --> NCav: 164 NCryo: 54 NLattice: 54 Length: 244.4 m Energy: 607.536 MeV



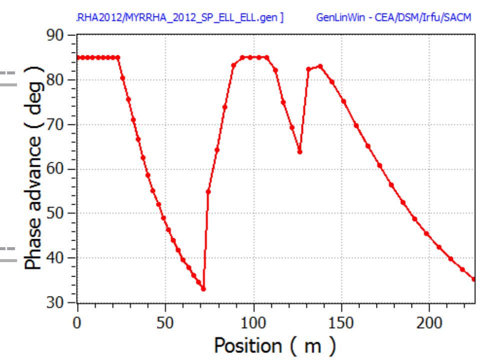
2cav/mod + 2cav/mod + 4cav/mod

Sect:1 -> Cell/Cav: 2/ 48 Cav/Cryo: 2/ 24 Cryo/Per: 1/ 24 L: 68.6400 m ßg:0.493 ßtrans:0.390 Eo: 80.819 MeV
Sect:2 -> Cell/Cav: 5/ 34 Cav/Cryo: 2/ 17 Cryo/Per: 1/ 17 L: 63.9200 m ßg:0.470 ßtrans:0.540 Eo: 183.868 MeV
Sect:3 -> Cell/Cav: 5/ 60 Cav/Cryo: 4/ 15 Cryo/Per: 1/ 15 L:100.8000 m ßg:0.658 ßfinal: 0.793 Eo: 602.421 MeV
NSection: 3 --> NCav: 142 NCryo: 56 NLattice: 56 Length: 233.36 m Energy: 602.421 MeV



2cav/mod + 3cav/mod + 4cav/mod

Sect:1 -> Cell/Cav: 2/ 52 Cav/Cryo: 2/ 26 Cryo/Per: 1/ 26 L: 74.3600 m ßg:0.493 ßtrans:0.400 Eo: 88.309 MeV
Sect:2 -> Cell/Cav: 5/ 36 Cav/Cryo: 3/ 12 Cryo/Per: 1/ 12 L: 56.8800 m ßg:0.470 ßtrans:0.540 Eo: 182.259 MeV
Sect:3 -> Cell/Cav: 5/ 60 Cav/Cryo: 4/ 15 Cryo/Per: 1/ 15 L:100.8000 m ßg:0.658 ßfinal: 0.793 Eo: 600.356 MeV
NSection: 3 --> NCav: 148 NCryo: 53 NLattice: 53 Length: 232.04 m Energy: 600.356 MeV

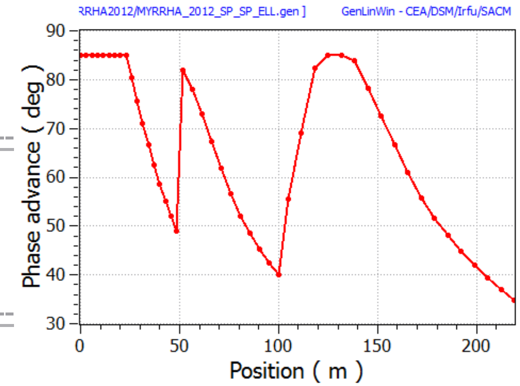


Some LINAC optimisation results (spoke options)

➢ Results with 1-SPOKE35 + 2-SPOKE50 + 5-ELLIPT65

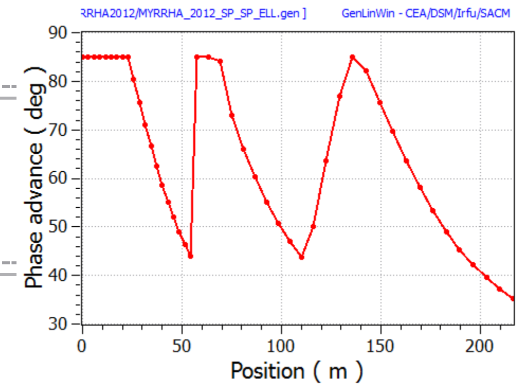
2cav/mod + 3cav/mod, + 4cav/mod

Sect:1 -> Cell/Cav: 2/ 36 Cav/Cryo: 2/ 18 Cryo/Per: 1/ 18 L: 51.4800 m ßg:0.493 ßtrans:0.330 Eo: 58.497 MeV
Sect:2 -> Cell/Cav: 3/ 33 Cav/Cryo: 3/ 11 Cryo/Per: 1/ 11 L: 53.2400 m ßg:0.611 ßtrans:0.521 Eo: 168.334 MeV
Sect:3 -> Cell/Cav: 5/ 72 Cav/Cryo: 4/ 18 Cryo/Per: 1/ 18 L:120.9600 m ßg:0.658 ßfinal: 0.794 Eo: 606.199 MeV
NSection: 3 --> NCav: 141 NCryo: 47 NLattice: 47 Length: 225.68 m Energy: 606.199 MeV



2cav/mod + 4cav/mod + 4cav/mod

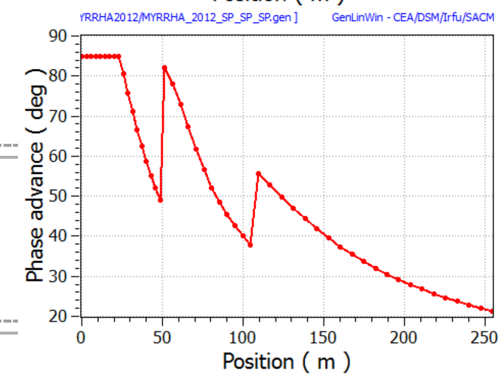
Sect:1 -> Cell/Cav: 2/ 40 Cav/Cryo: 2/ 20 Cryo/Per: 1/ 20 L: 57.2000 m ßg:0.493 ßtrans:0.350 Eo: 65.872 MeV
Sect:2 -> Cell/Cav: 3/ 40 Cav/Cryo: 4/ 10 Cryo/Per: 1/ 10 L: 58.5000 m ßg:0.611 ßtrans:0.556 Eo: 199.193 MeV
Sect:3 -> Cell/Cav: 5/ 64 Cav/Cryo: 4/ 16 Cryo/Per: 1/ 16 L:107.5200 m ßg:0.658 ßfinal: 0.793 Eo: 602.607 MeV
NSection: 3 --> NCav: 144 NCryo: 46 NLattice: 46 Length: 223.22 m Energy: 602.607 MeV



➢ Results with 1-SPOKE35 + 2-SPOKE50 + 3-SPOKE65

2cav/mod + 3cav/mod + 4cav/mod

Sect:1 -> Cell/Cav: 2/ 36 Cav/Cryo: 2/ 18 Cryo/Per: 1/ 18 L: 51.4800 m ßg:0.493 ßtrans:0.330 Eo: 58.497 MeV
Sect:2 -> Cell/Cav: 3/ 36 Cav/Cryo: 3/ 12 Cryo/Per: 1/ 12 L: 58.0800 m ßg:0.611 ßtrans:0.533 Eo: 179.309 MeV
Sect:3 -> Cell/Cav: 3/ 84 Cav/Cryo: 4/ 21 Cryo/Per: 1/ 21 L:152.2500 m ßg:0.846 ßfinal: 0.794 Eo: 604.977 MeV
NSection: 3 --> NCav: 156 NCryo: 51 NLattice: 51 Length: 261.81 m Energy: 604.977 MeV



Conclusions on longitudinal design

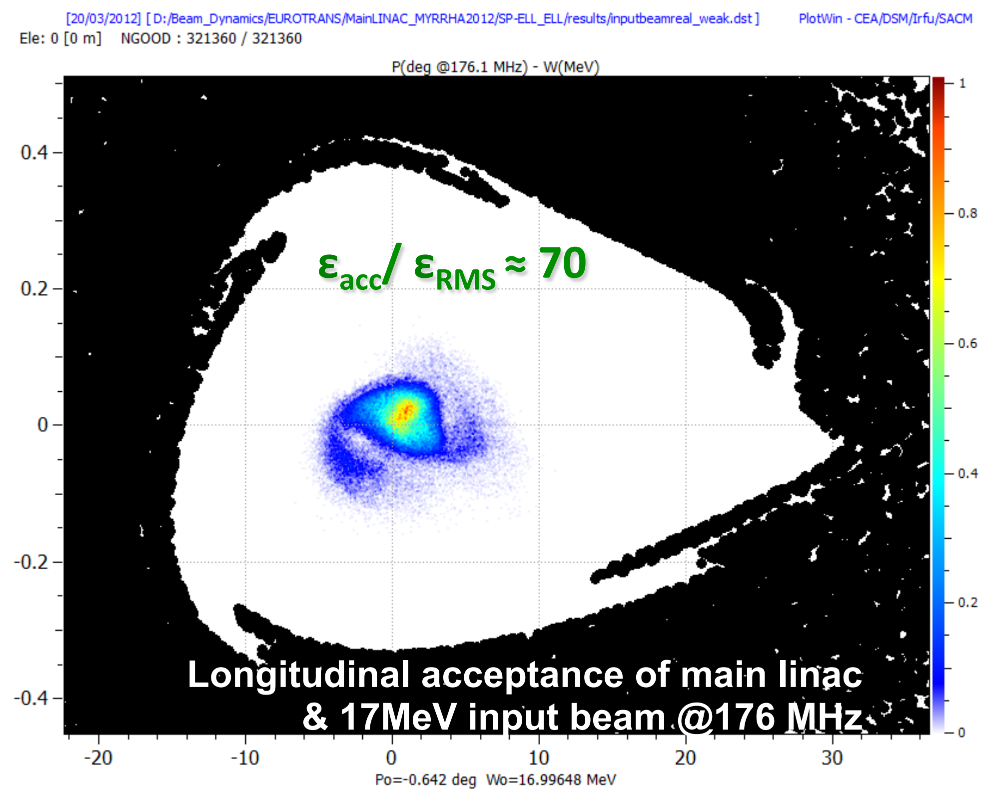
1-SPOKE35
2 cav/module

5-ELLIPT47 2 cav/module
2-SPOKE50 (ESS) is also a viable back-up candidate

5-ELLIPT65
4 cav/module

Section #	#1	#2	#3
E_{input} (MeV)	17.0	80.8	183.9
E_{output} (MeV)	80.9	183.9	600.0
Cav. technology	Spoke	Elliptical	
Cav. freq. (MHz)	352.2	704.4	
Cavity geom. β	0.35	0.47	0.65
Nb of cells / cav.	2	5	5
Focusing type	NC quadrupole doublets		
Nb cav / cryom.	2	2	4
Total nb of cav.	48	34	60
Nominal E_{acc} (MV/m)	6.2	8.2	11.0
Synch. phase (deg)	-40 to -19	-38 to -15	
Beam load / cav (kW)	1.5 to 7.5	2.5 to 17	14 to 32
Section length (m)	68.6	63.9	100.8

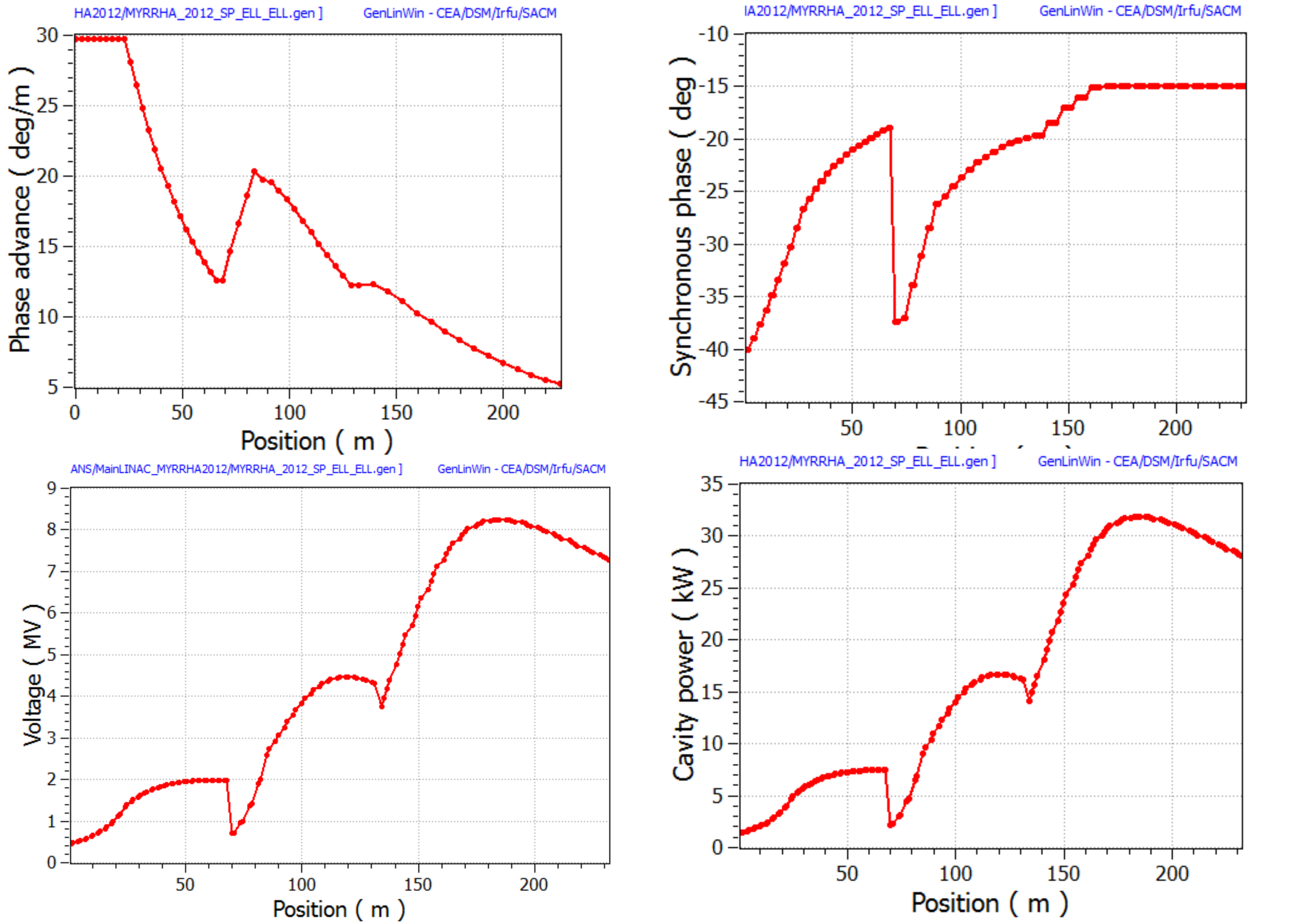
➤ **Overall linac: 233 metres & 142 cavities**



→ 3 sections is a clear choice for a 17-600 MeV SC linac

→ Playing around with cavity beta & nb cells does'nt change much the picture

MYRRHA linac longitudinal tunings

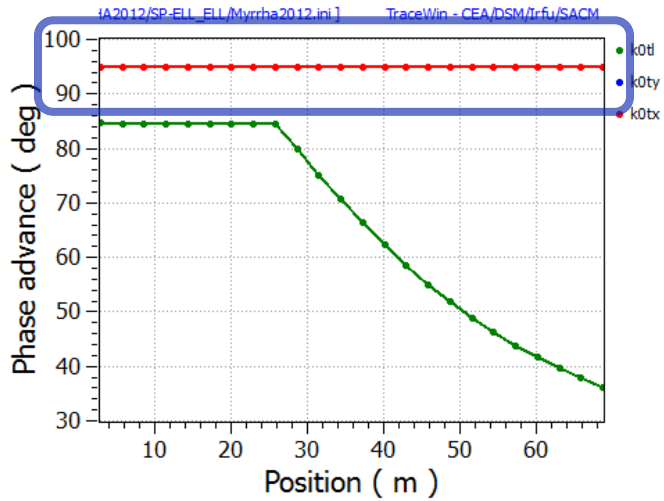


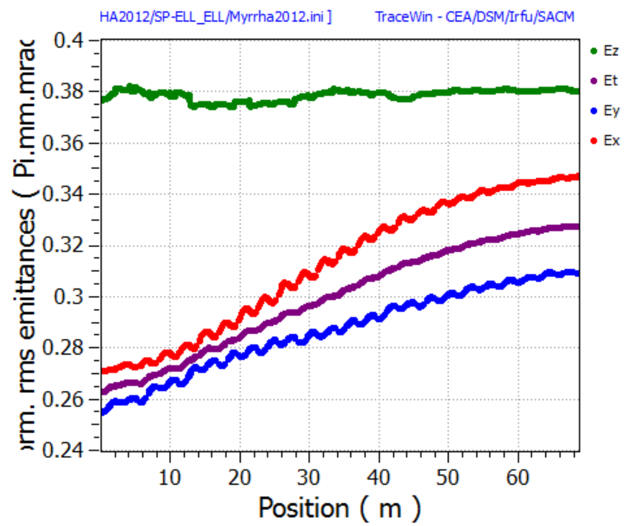
Rules for transverse beam dynamics

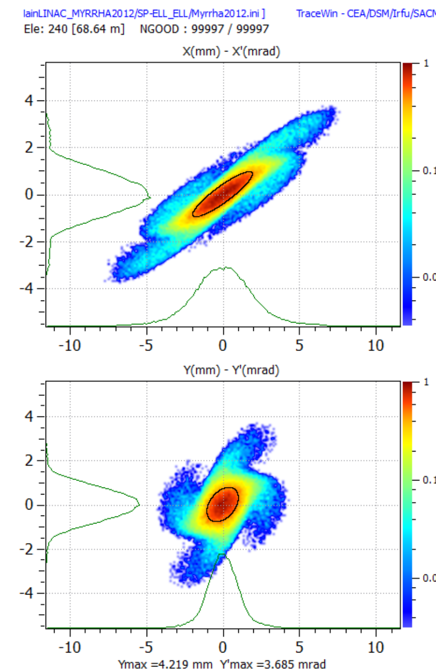
➤ **1. Keep phase advance at zero-current σ_{T0} < 90° / lattice**

Ex1:

σ_{T0} = 95°
I = 4mA

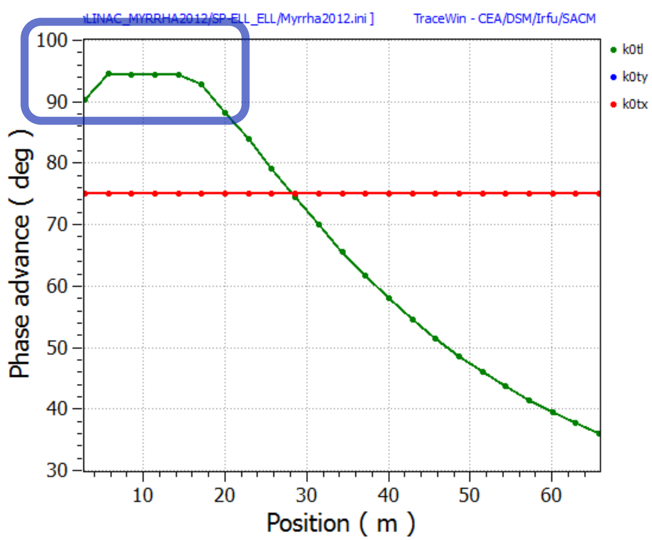


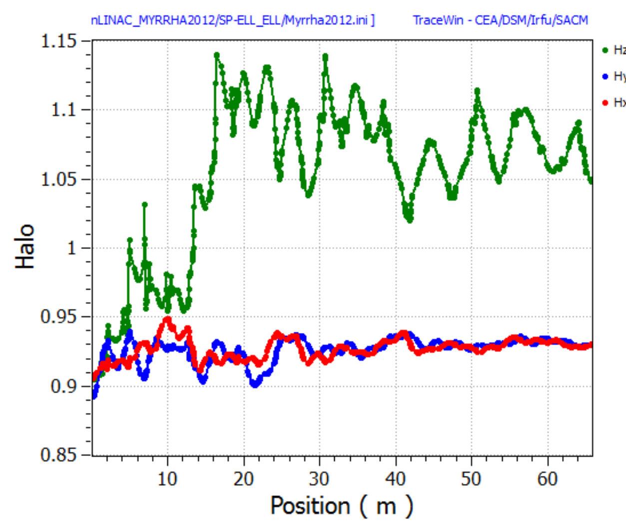


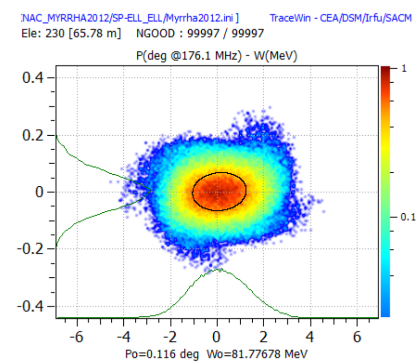


Ex2:

σ_{L0} = 95°
I = 4mA





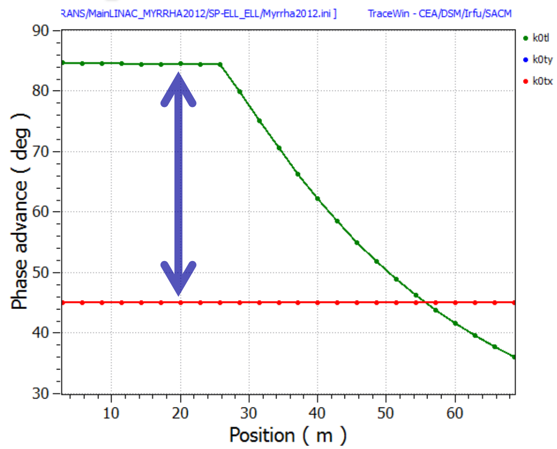


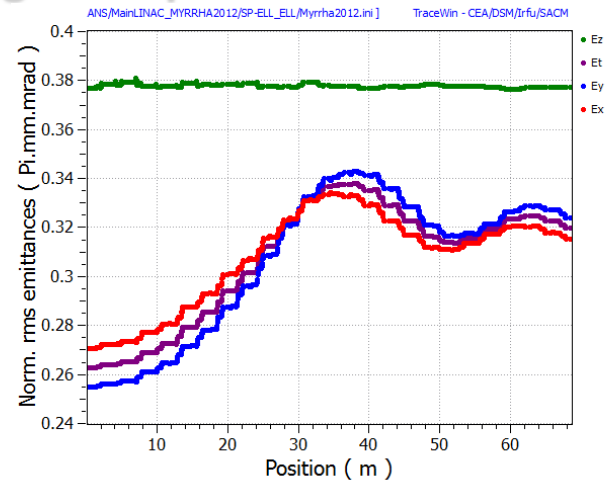
Rules for transverse beam dynamics

➢ **2. Keep $\sigma_T > 70\%\sigma_L$ to stay away from the dangerous parametric resonance $\sigma_T = \sigma_L/2$**

Ex:

$\sigma_{T0} = 45°$
I = 0mA

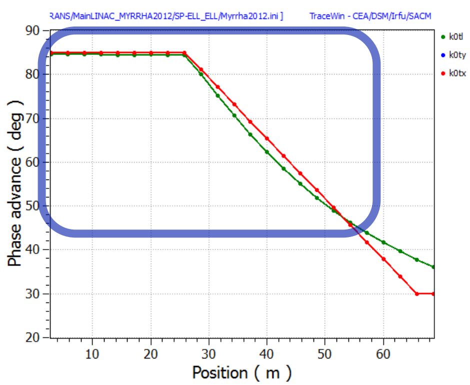


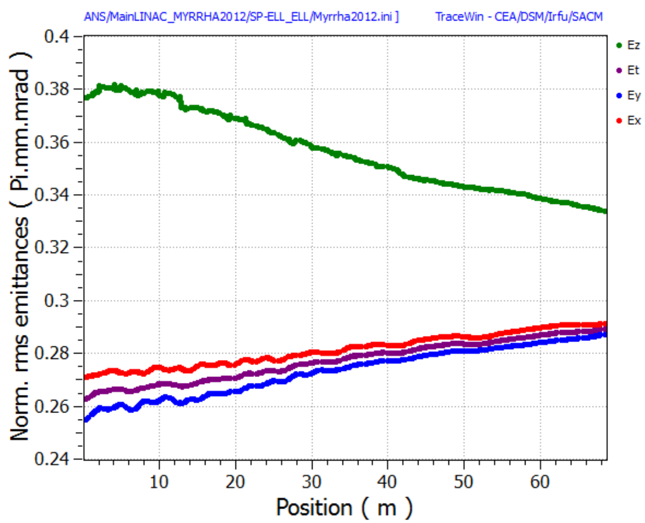


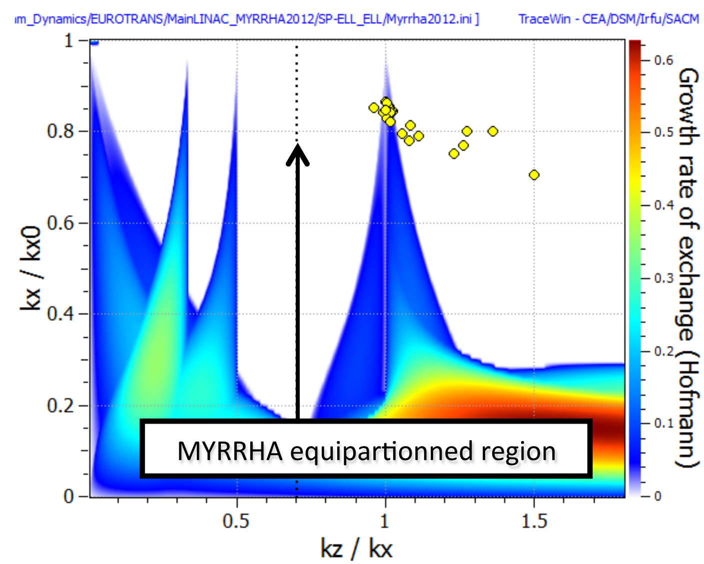
➢ **3. Avoid emittance exchange between T & L planes via SC-driven resonances**

Ex:

$\sigma_{T0} \sim \sigma_{L0}$
I = 4mA





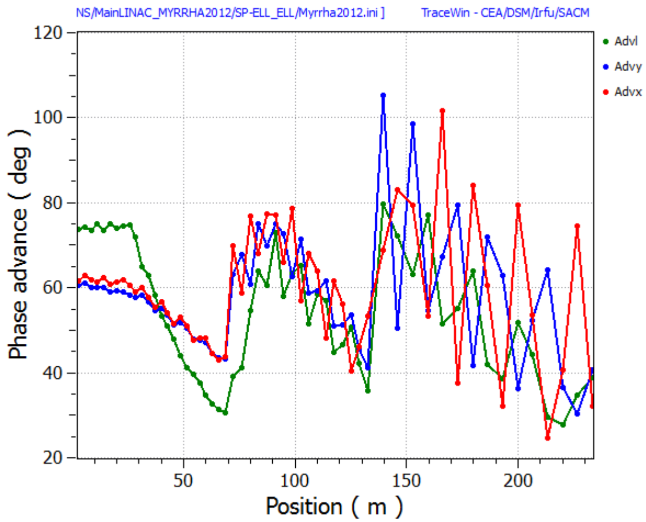


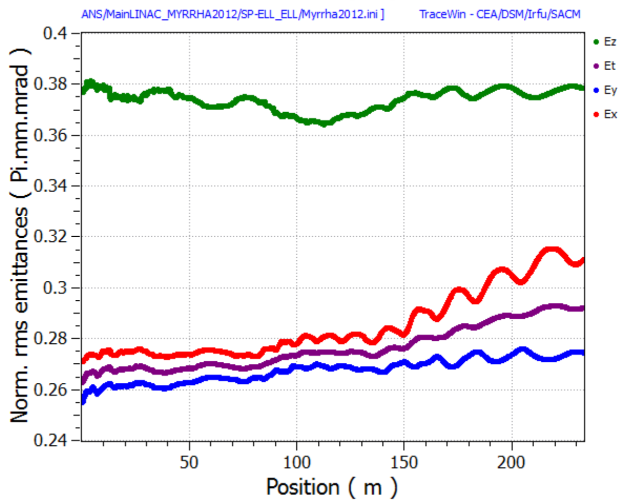
Rules for transverse beam dynamics

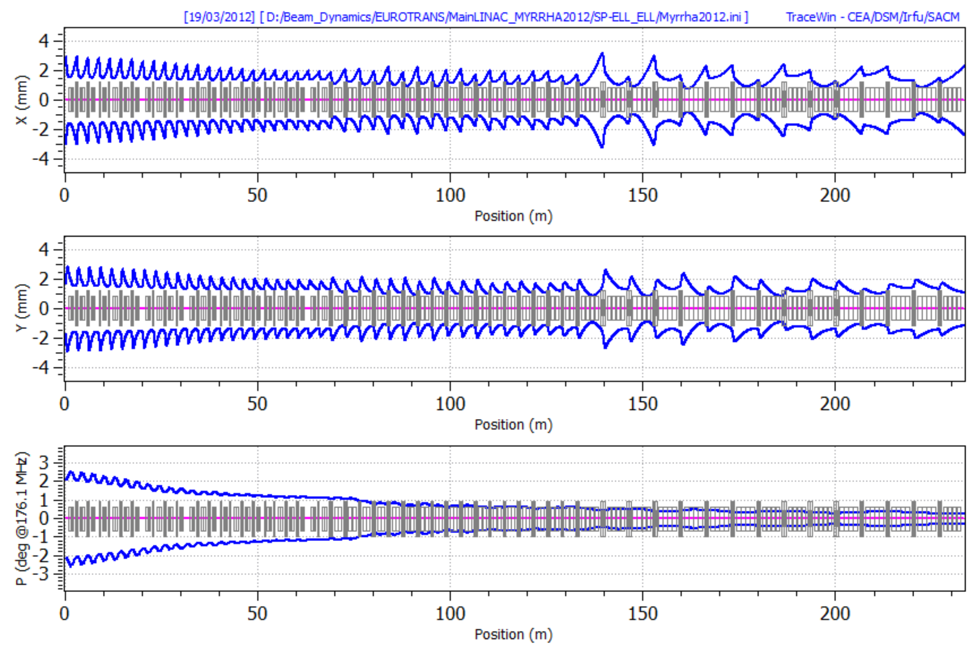
➢ **4. Provide clean matching between sections in all planes to minimize emittance growth**
(+ again, continuity of the phase advance per meter to minimize sensitivity to mismatch)

Ex:

Matched beam, but no matching btwn sections





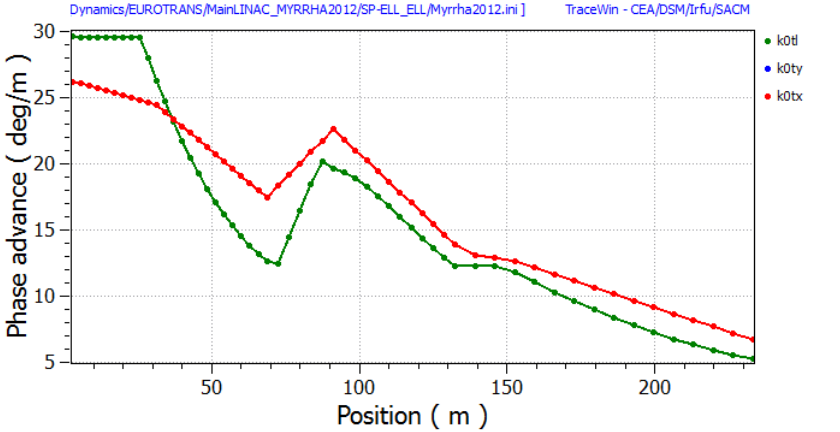


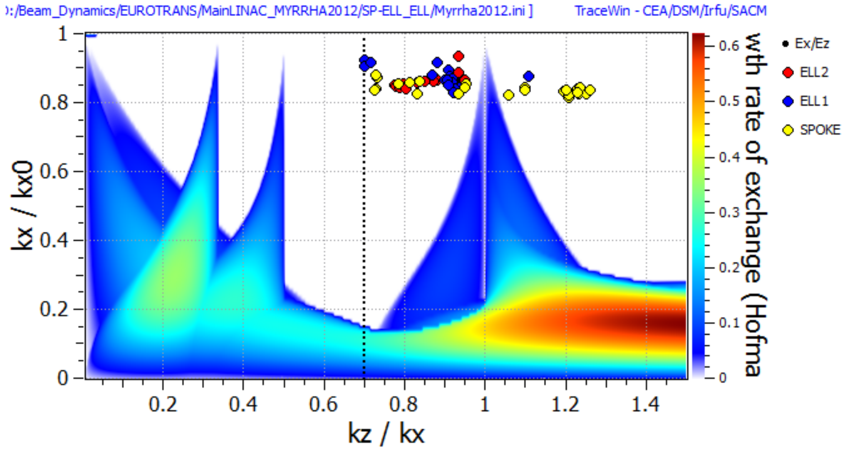
Choices for MYRRHA transverse tuning

- **OPTION 1: “Strong” focusing**

→ Optimal transverse acceptance

→ Close to equipartitioning

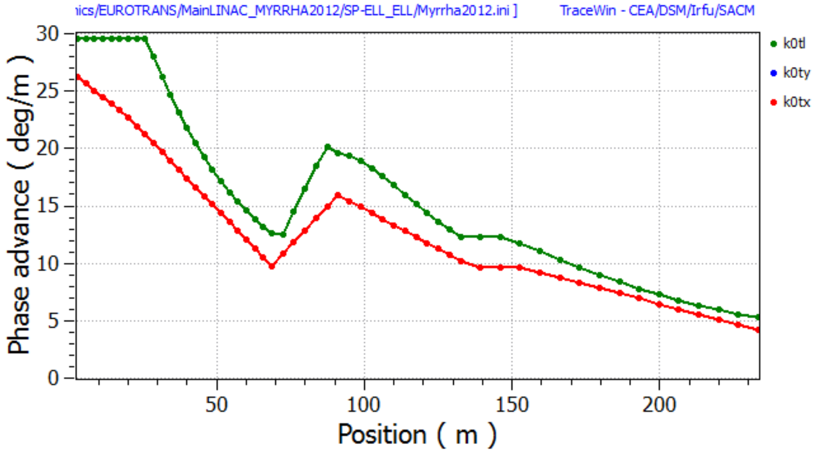


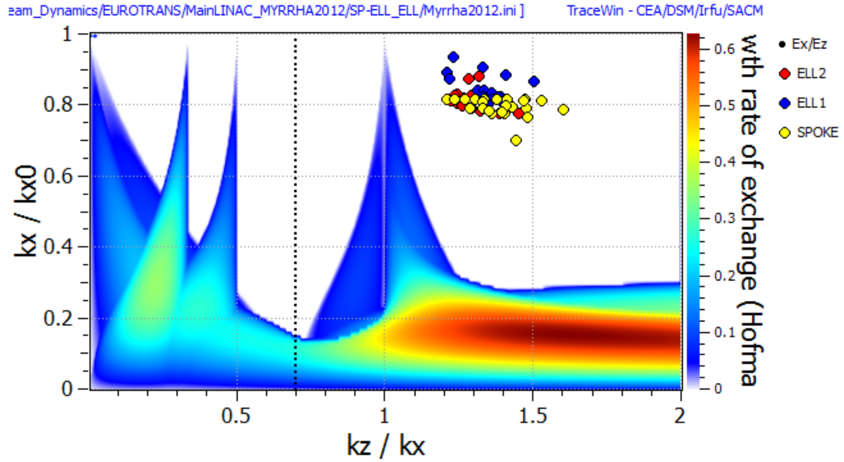


- **OPTION 2: “Weak” focusing**

→ No $\sigma_T=\sigma_L$ crossing

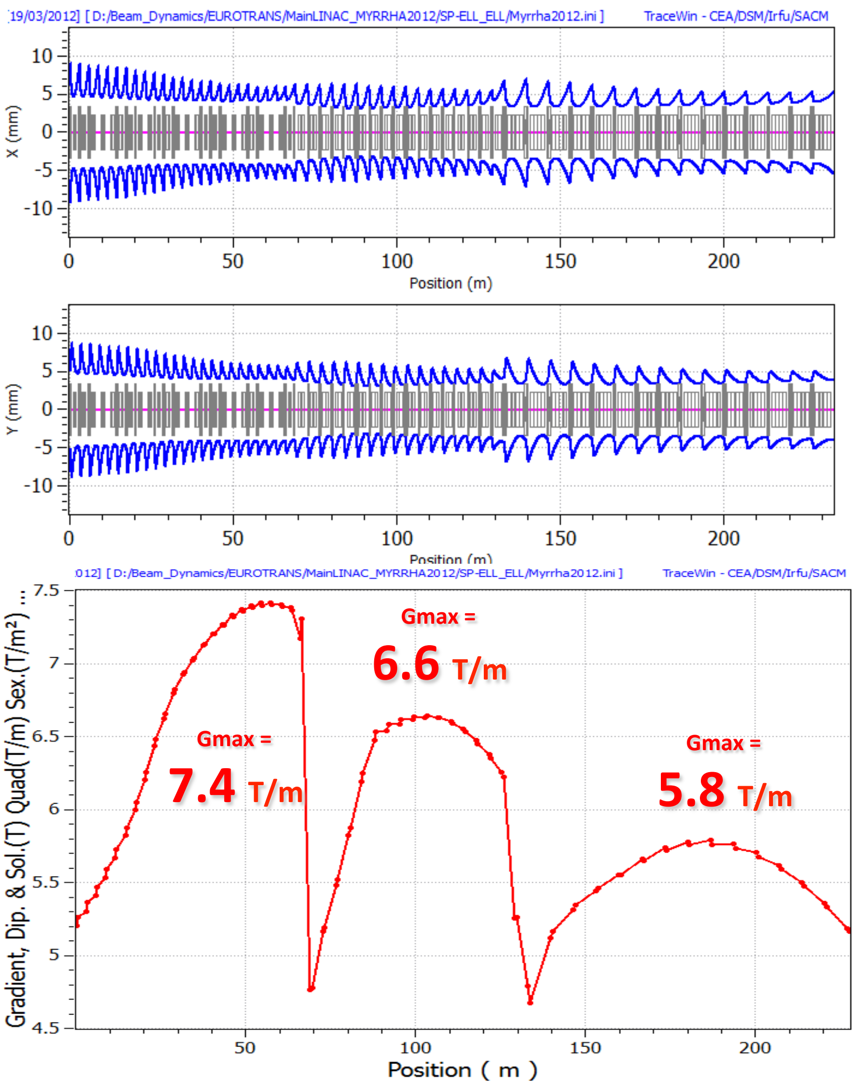
→ Reduced quad gradients



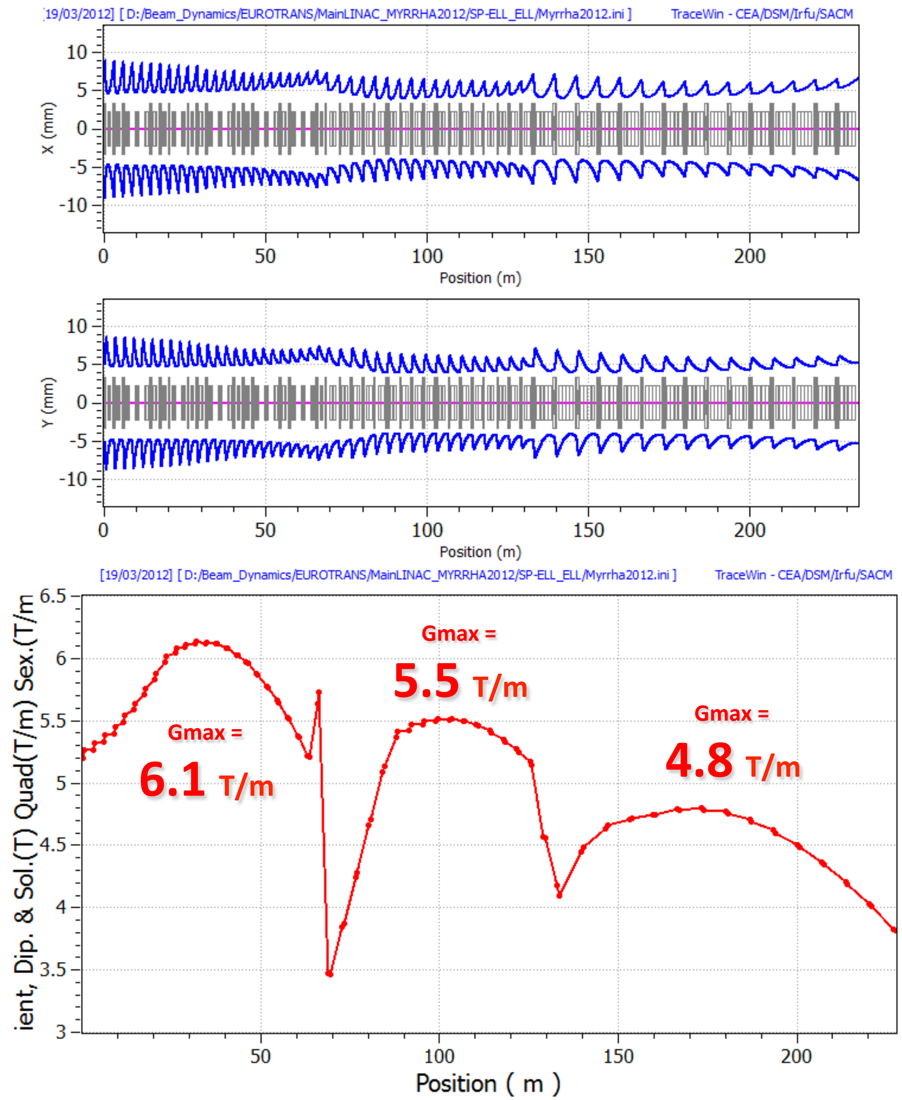


Beam envelopes & quad gradients

- **OPTION 1: “Strong” focusing**

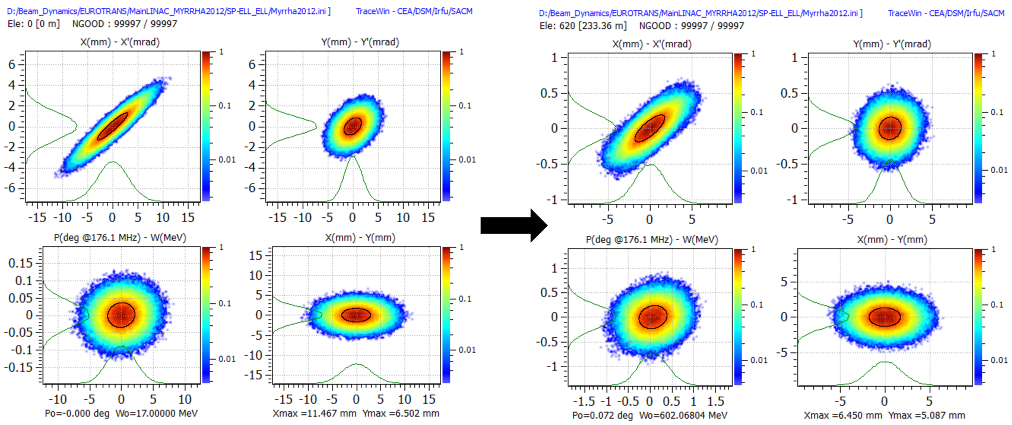


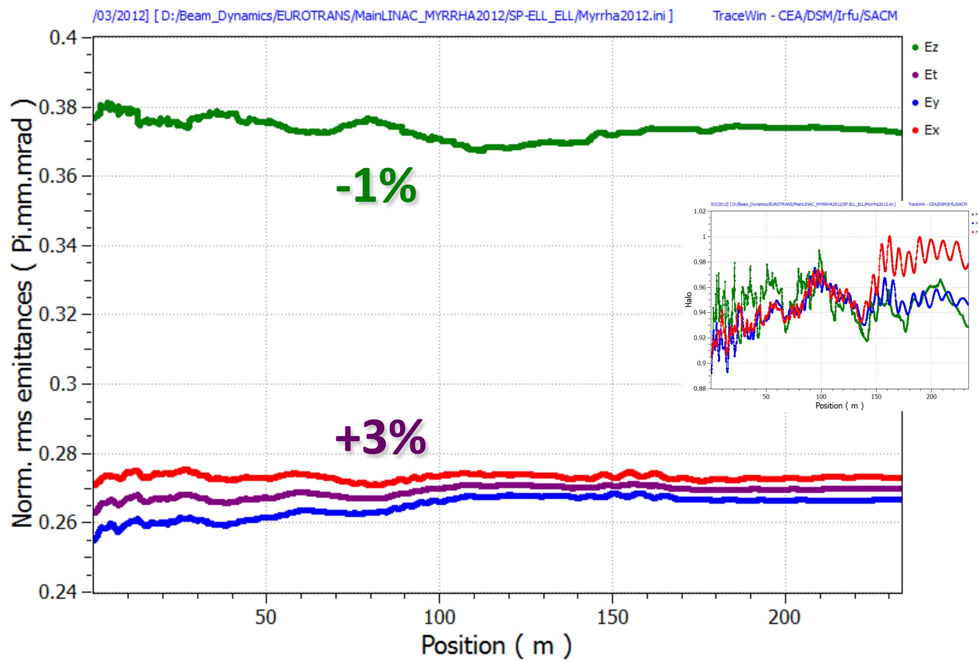
- **OPTION 2: “Weak” focusing**



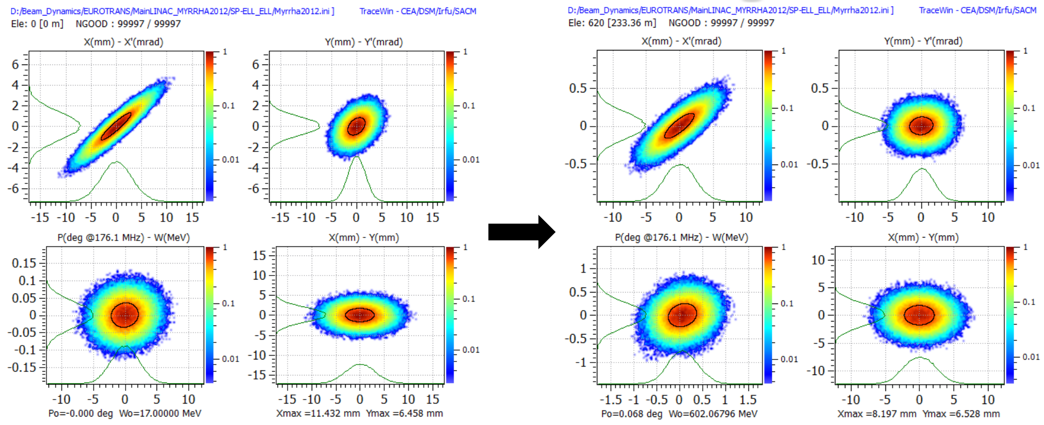
Emittance growth (4σ gaussian beam)

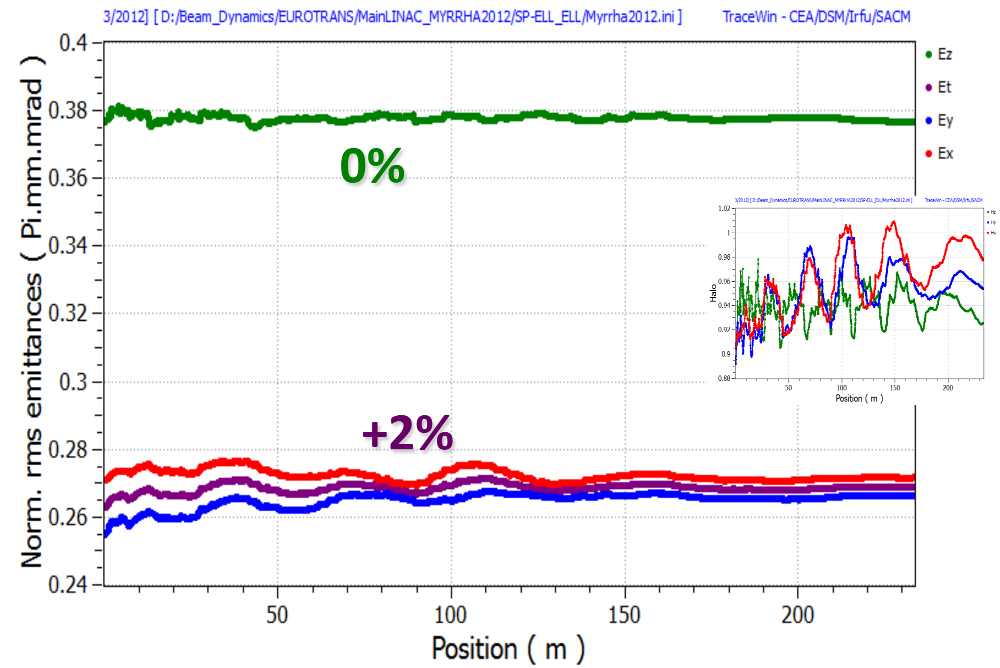
➢ OPTION 1: "Strong" focusing





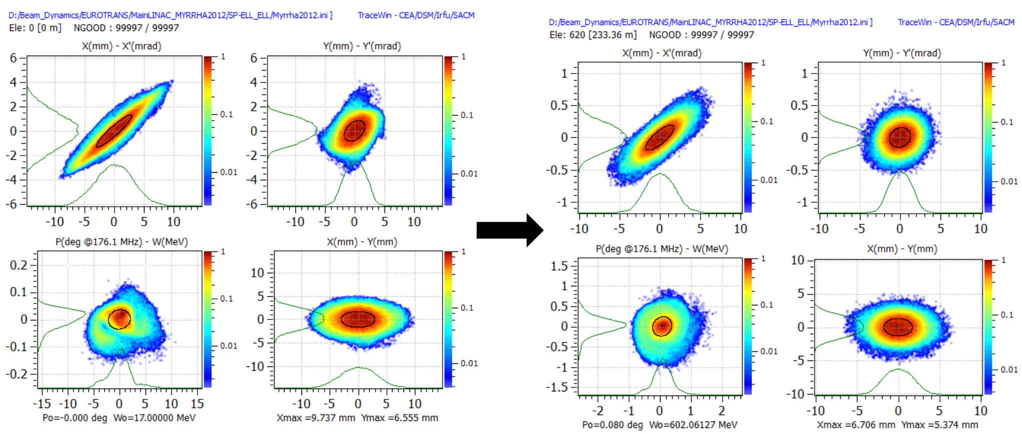
➢ OPTION 2: "Weak" focusing

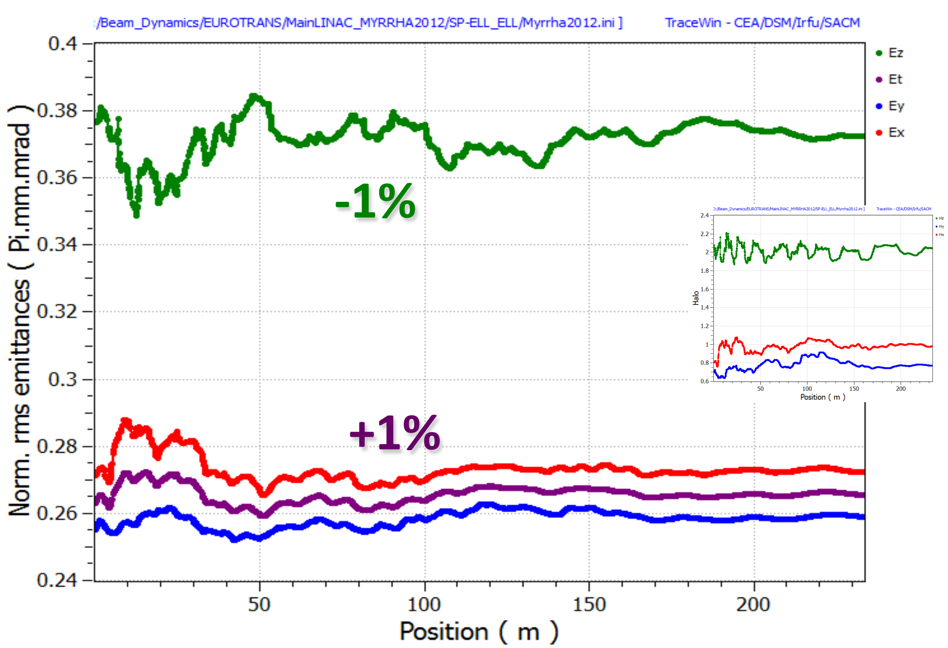




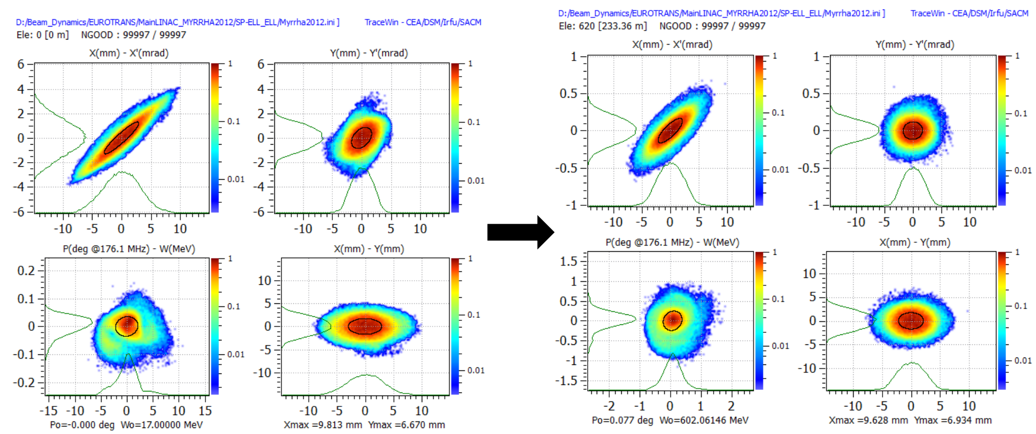
Emittance growth ("real" beam from injector simulation)

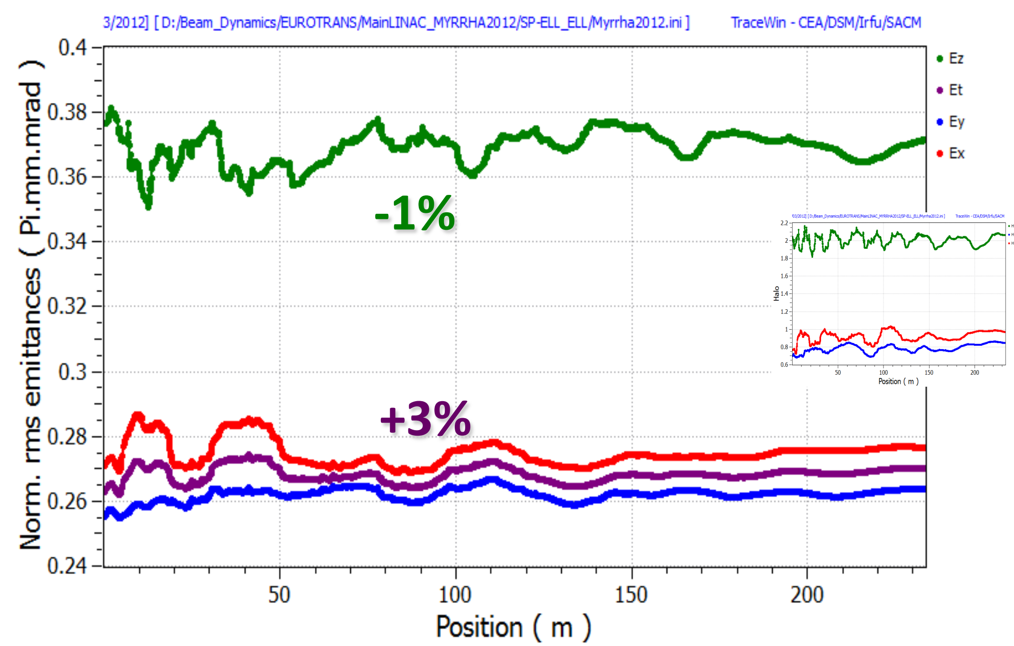
➢ OPTION 1: "Strong" focusing





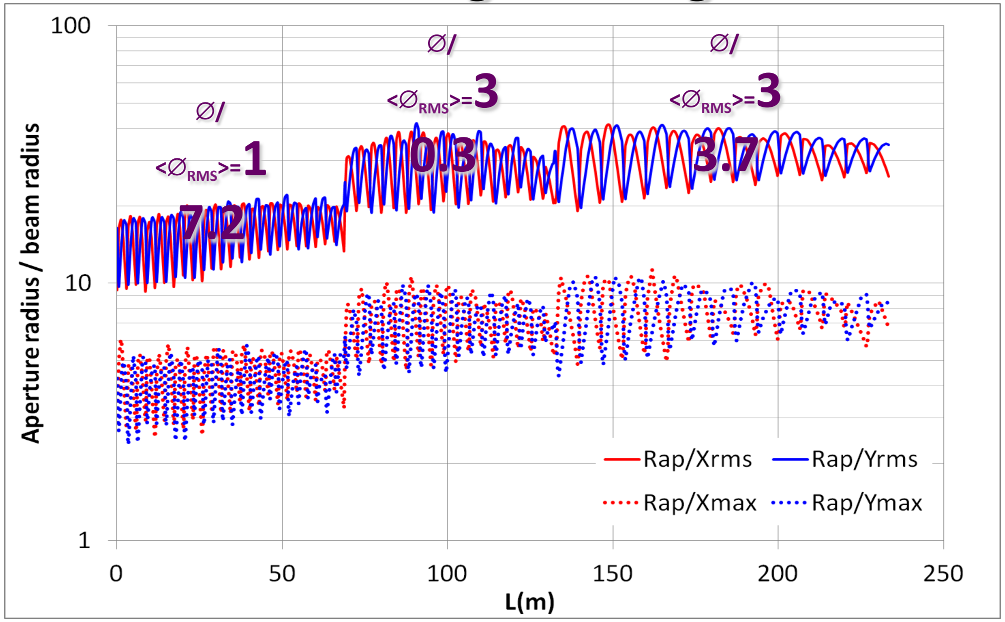
➢ OPTION 2: "Weak" focusing

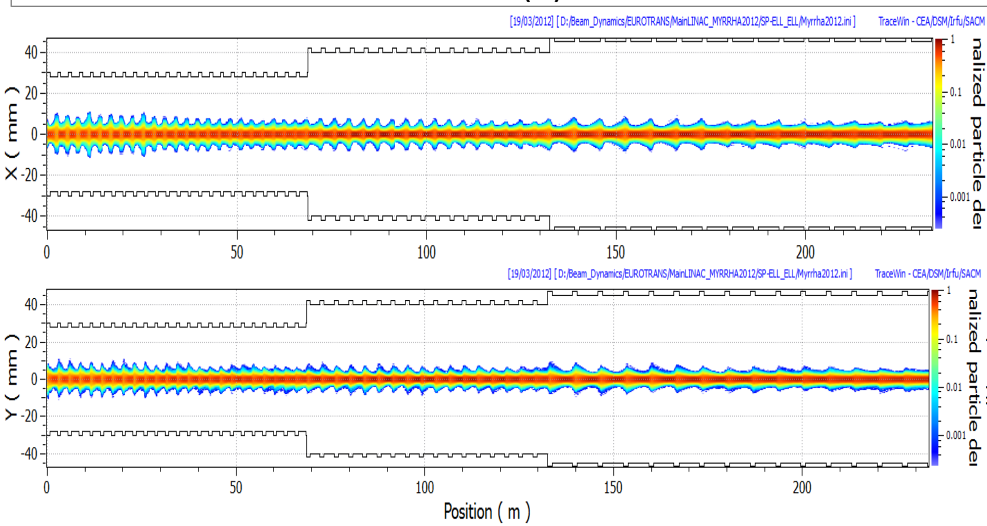




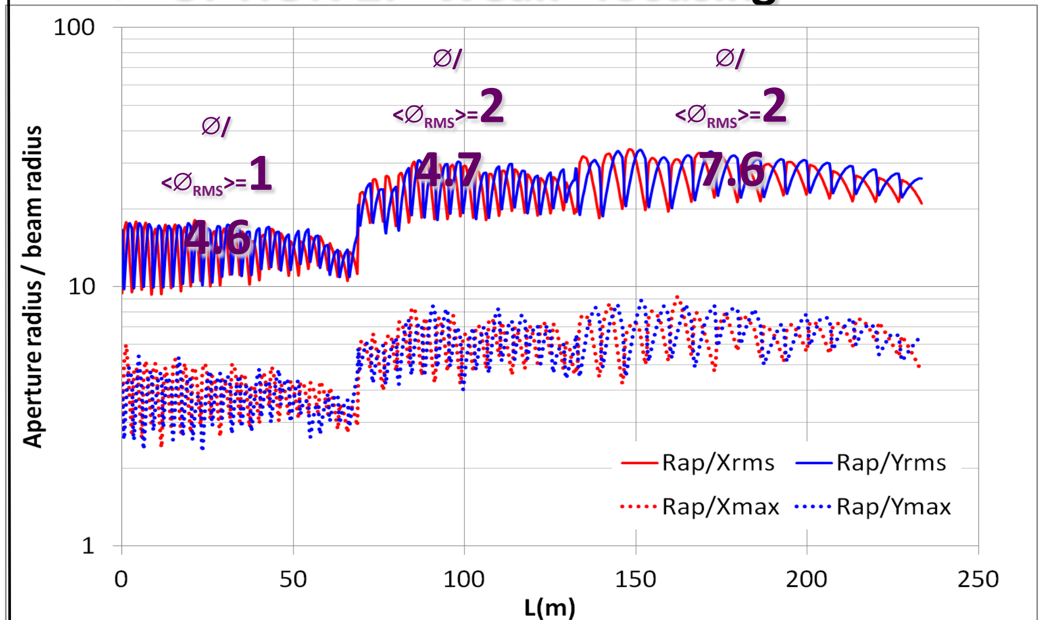
Transverse acceptance

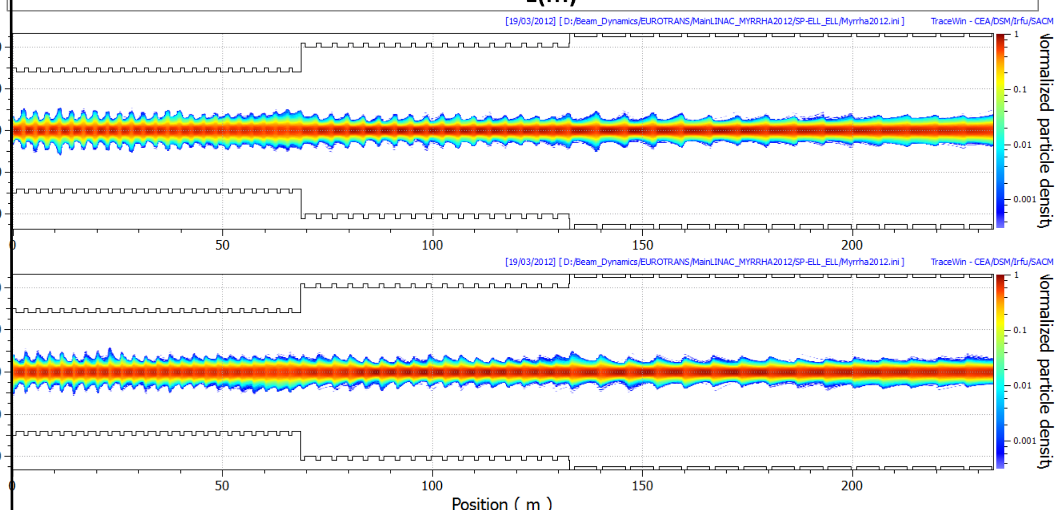
- **OPTION 1: "Strong" focusing**





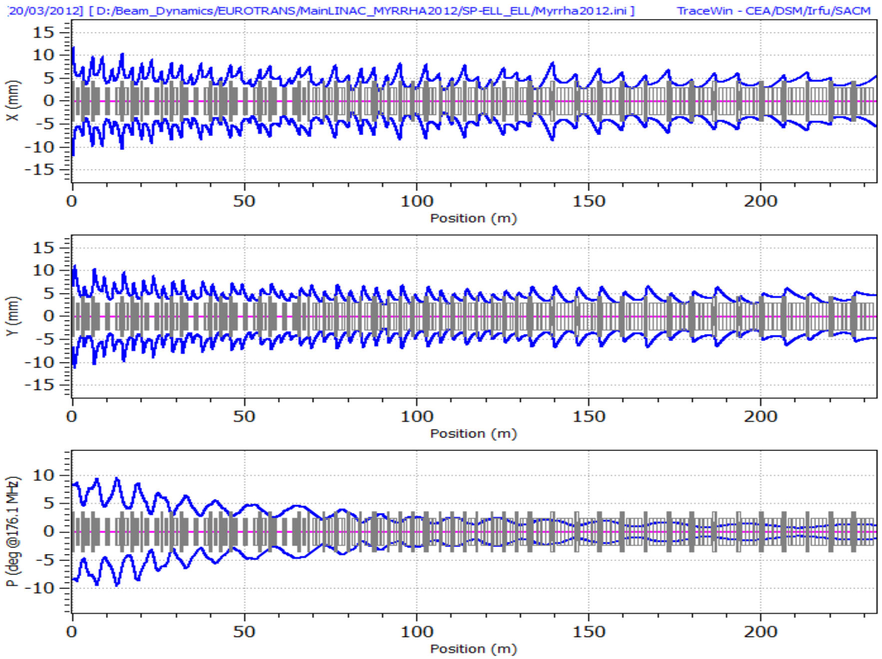
- **OPTION 2: "Weak" focusing**

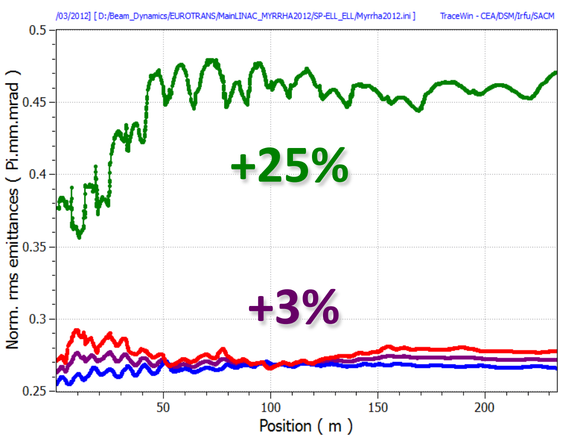


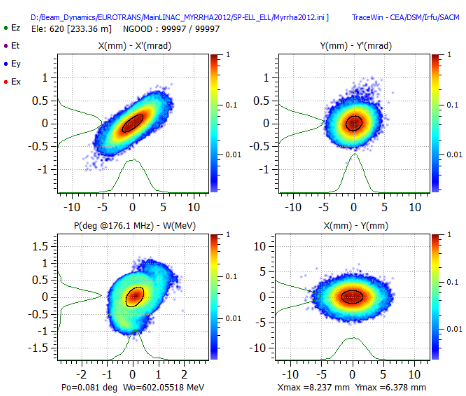


Tolerance to 30% mismatch +++

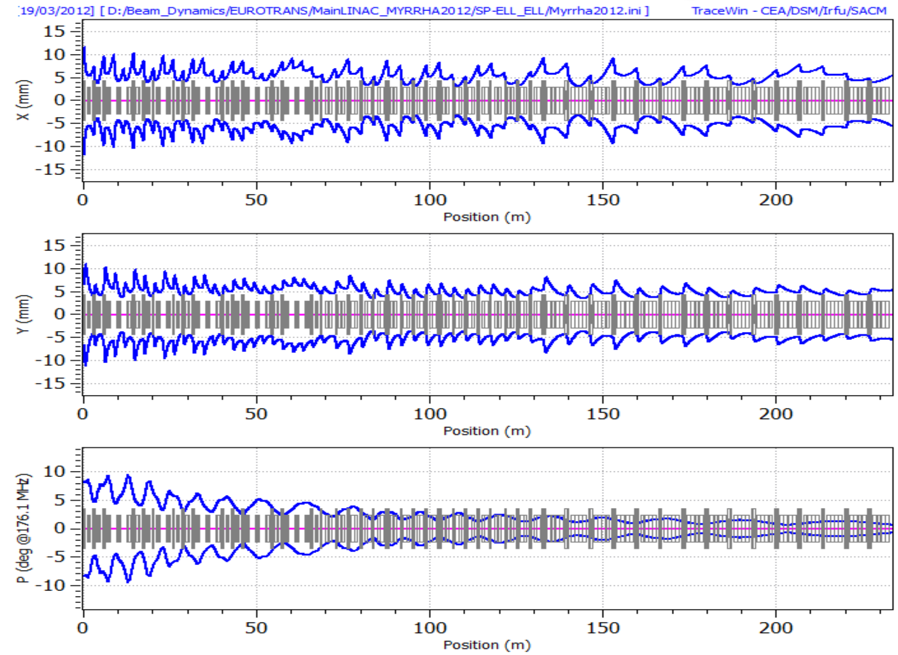
➢ OPTION 1: "Strong" focusing

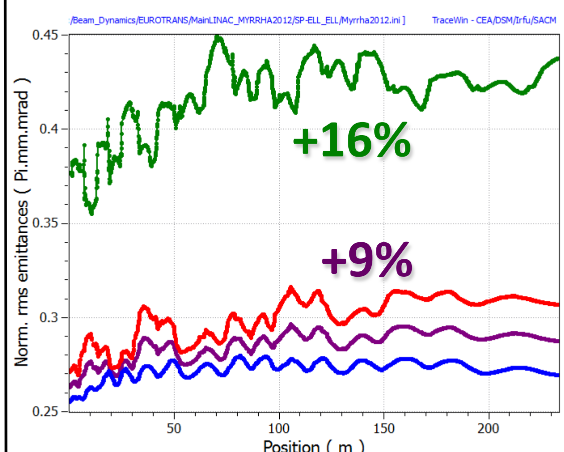


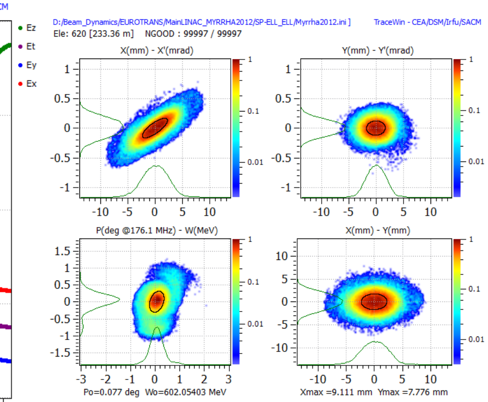




➢ OPTION 2: "Weak" focusing

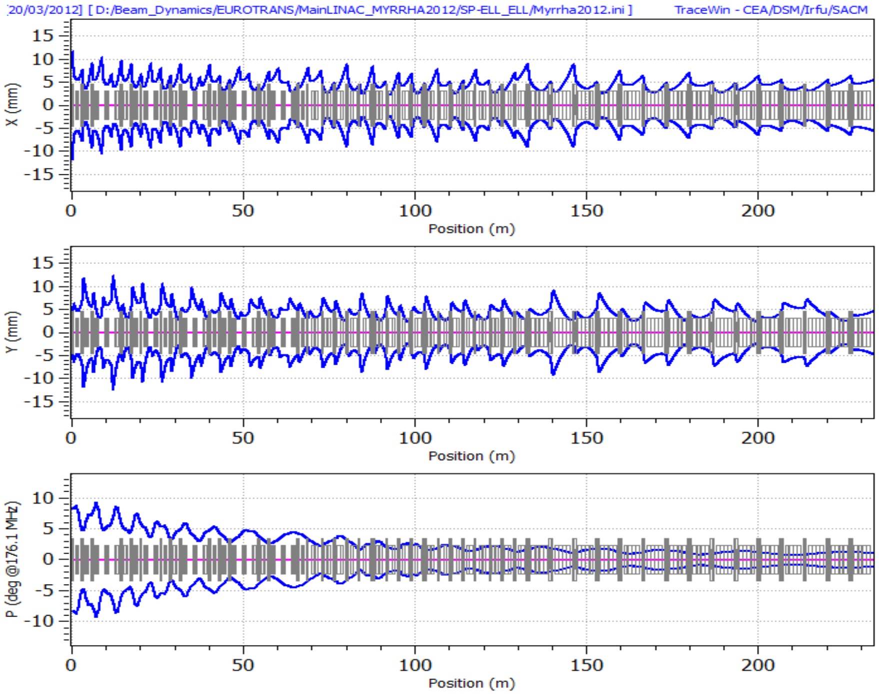


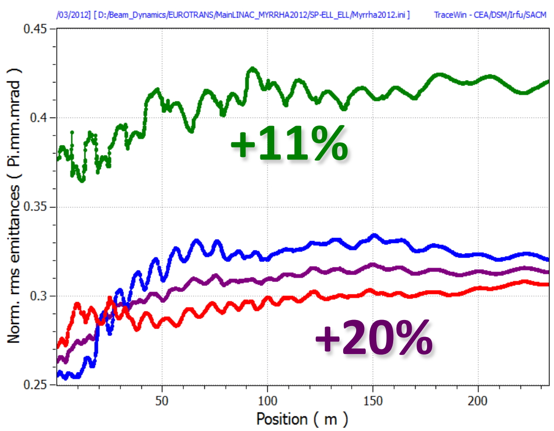


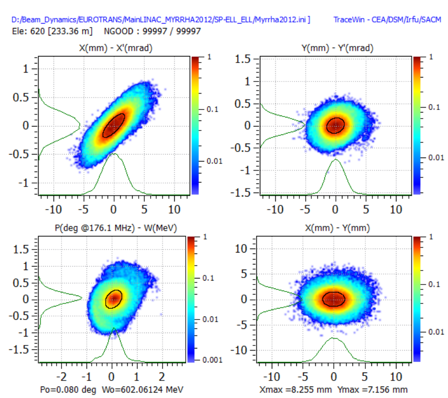


Tolerance to 30% mismatch +-+

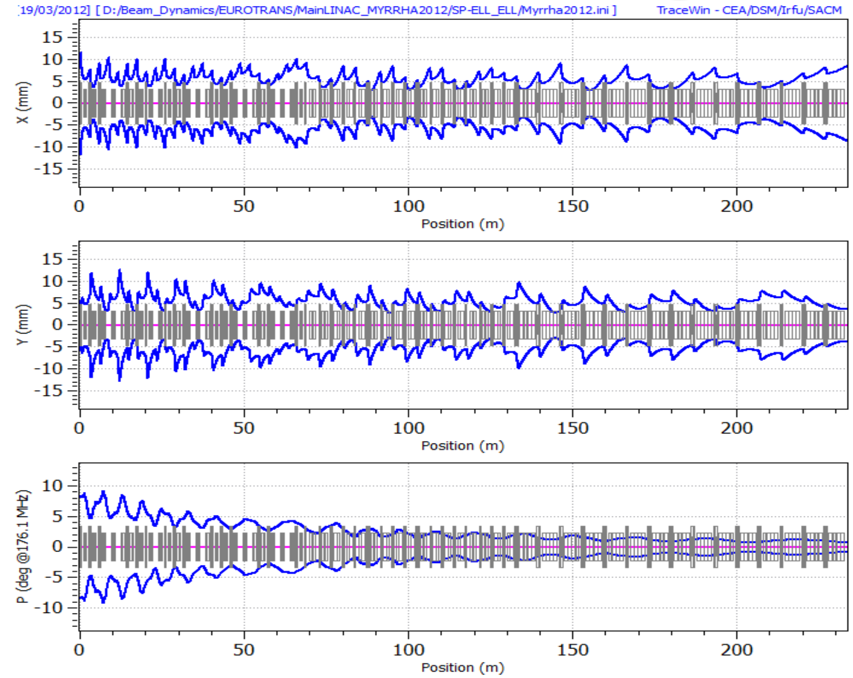
- **OPTION 1: "Strong" focusing**

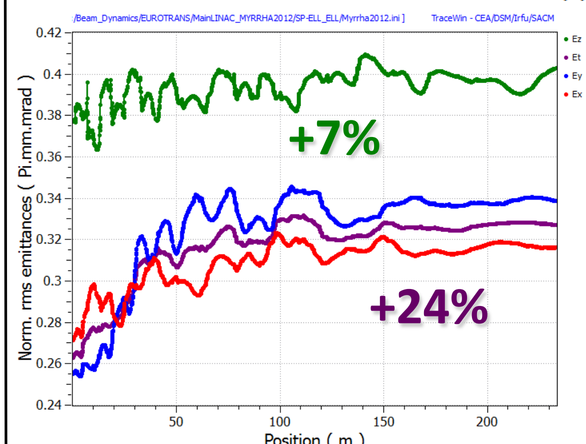


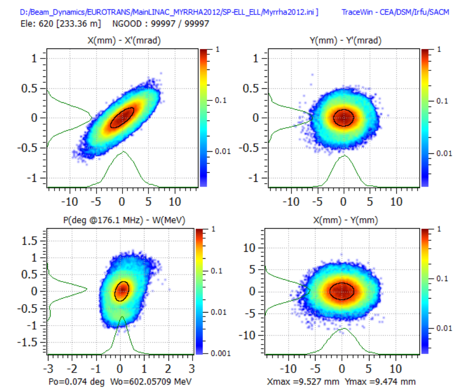




- **OPTION 2: "Weak" focusing**

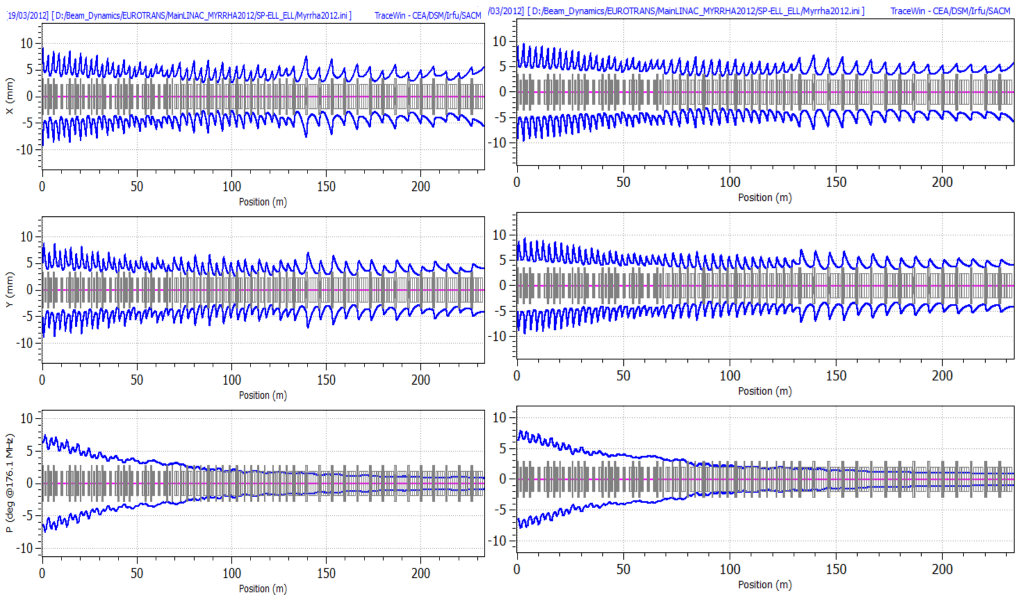




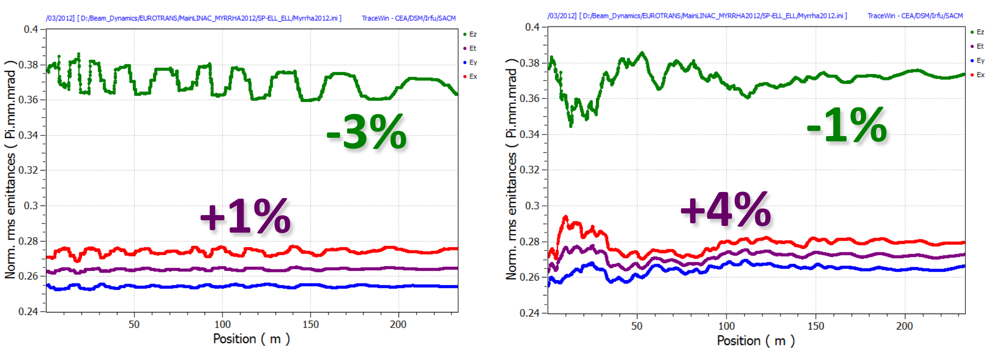


Sensitivity to current change

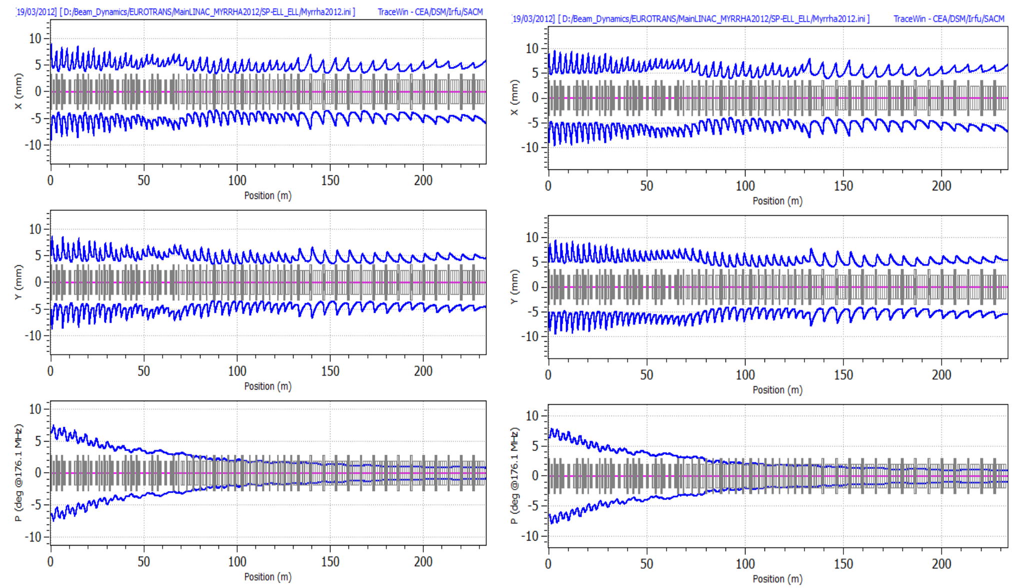
➢ OPTION 1: "Strong" focusing



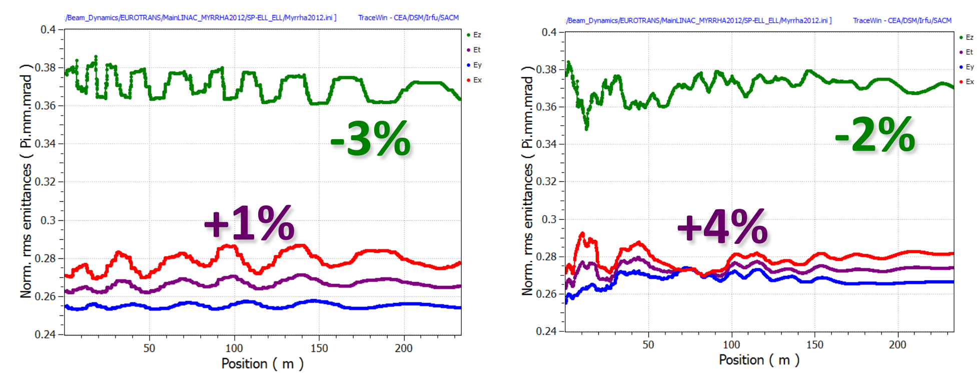
I = 0 mA **I = 6 mA**



➢ OPTION 2: "Weak" focusing



I = 0 mA **I = 6 mA**



Summary on SC linac design

- **MYRRHA longitudinal design**

→ 233 metres long & 142 cavities (1-SPOKE35, 5-ELLIPT47, 5-ELLIPT65)

→ ESS-type spoke cav. could be a back-up solution for fam #2 – R&D to be followed

→ Modular scheme & warm focusing

- **Beam dynamics is very robust**

→ Low sensitivity to mismatch and to beam current change

→ High acceptance even with the new 176 MHz input beam

→ Valid for both « weak » and « strong » transverse focusing schemes

- **NEXT STEPS...**

→ Add full 3D field-maps

→ Thorough analysis of fault cases (1 cavity, 1 cryomodule, diag needs...)

→ Monte-Carlo error studies in nominal and fault operation

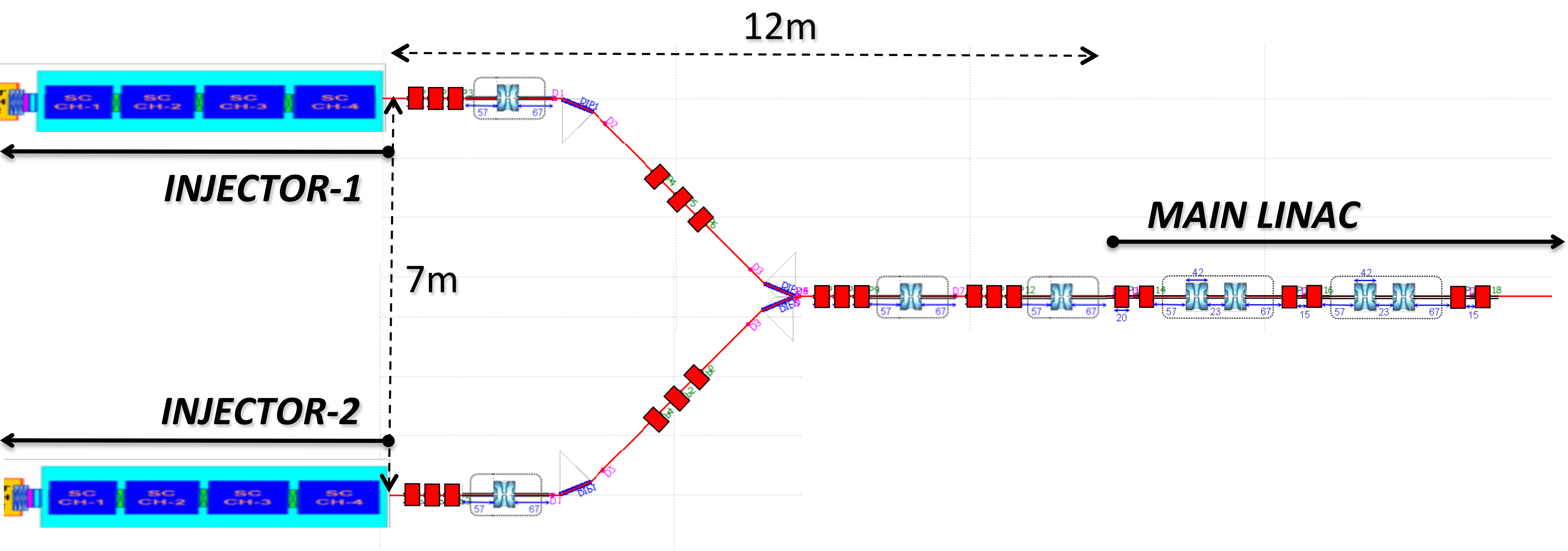
→ Look again at HOM analysis & BBU simulations (just to check)

1. Introduction
2. Design of the MYRRHA SC main linac

3. The MYRRHA beam lines

4. Conclusion

17 MeV MEBT preliminary design



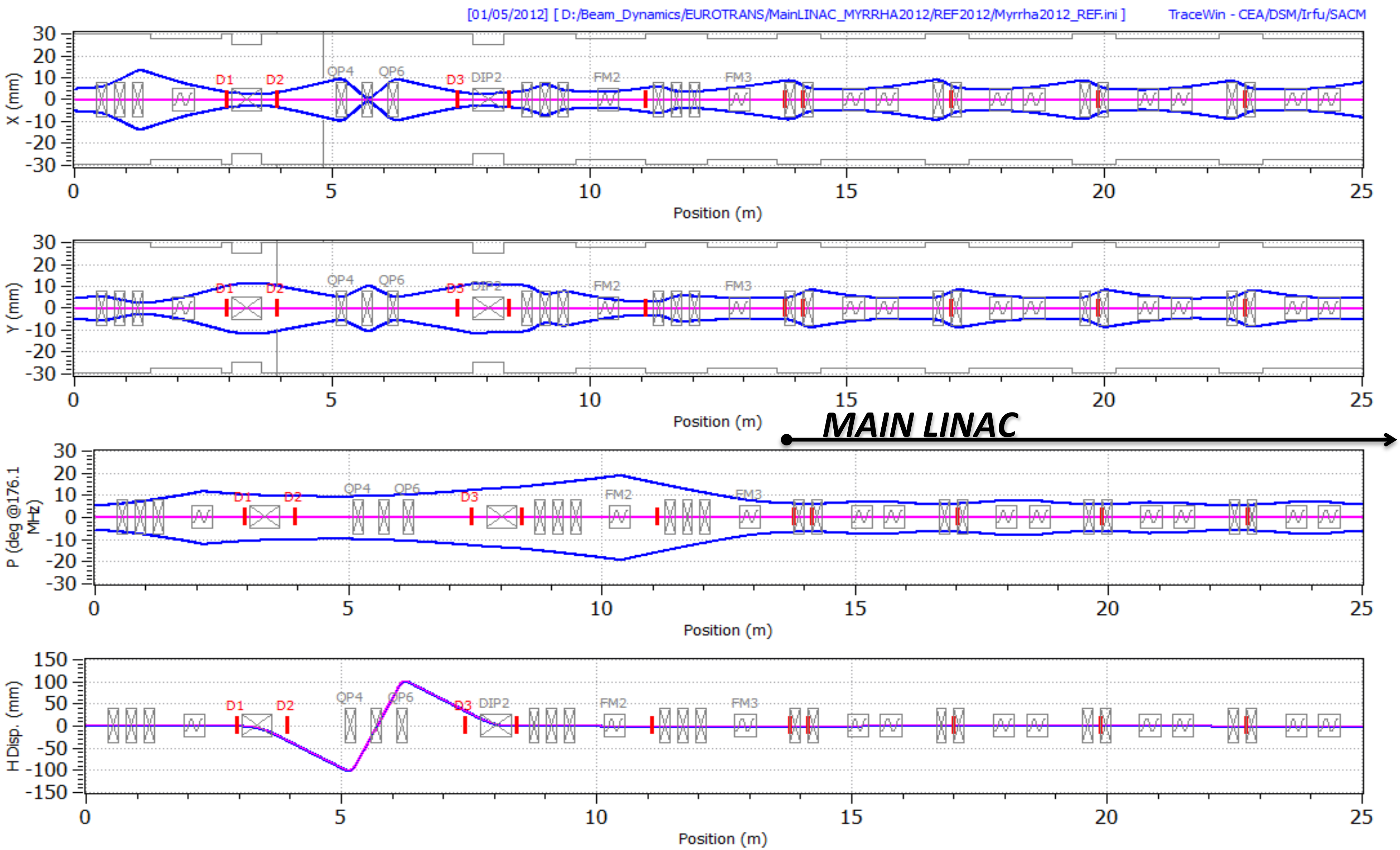
→ 2 dipoles 45° (ρ=0.75m, gap 50mm, 22.5° edges) & 1 switching 45° magnet

→ 15 or 18 quadrupoles (same as spoke linac)

→ 4 re-bunchers (up to 0.5MV voltage, probably SC spoke cavities)

→ Diagnostics (BPMs, WS, ToFs) & collimators / halo monitors (in the dispersive section)

17 MeV MEBT 99% beam envelopes

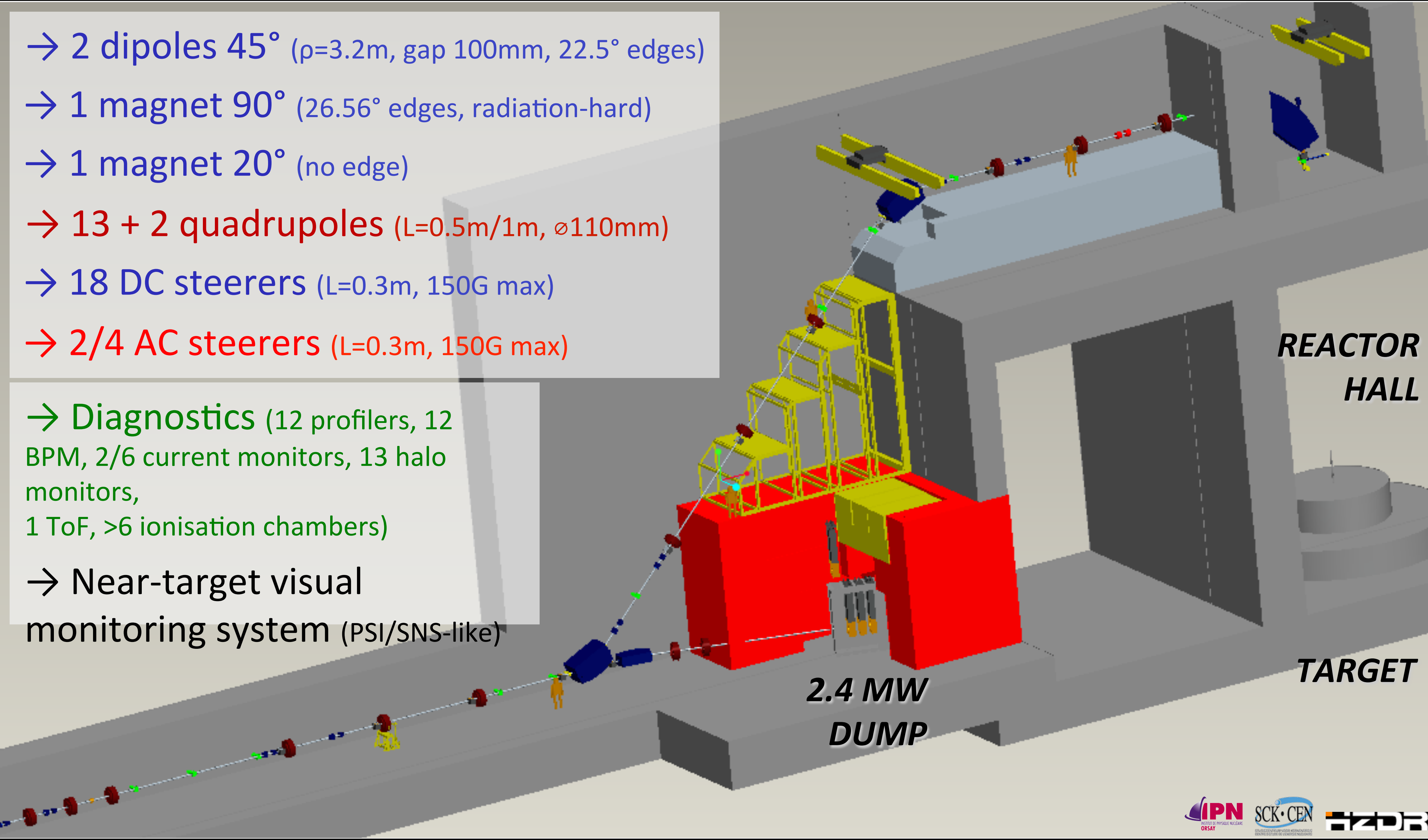


The MYRRHA final beam lines

- → 2 dipoles 45° (ρ=3.2m, gap 100mm, 22.5° edges)
- → 1 magnet 90° (26.56° edges, radiation-hard)
- → 1 magnet 20° (no edge)
- → 13 + 2 quadrupoles (L=0.5m/1m, ⌀110mm)
- → 18 DC steerers (L=0.3m, 150G max)
- → 2/4 AC steerers (L=0.3m, 150G max)

- → Diagnostics (12 profilers, 12 BPM, 2/6 current monitors, 13 halo monitors,
1 ToF, >6 ionisation chambers)

- → Near-target visual monitoring system (PSI/SNS-like)



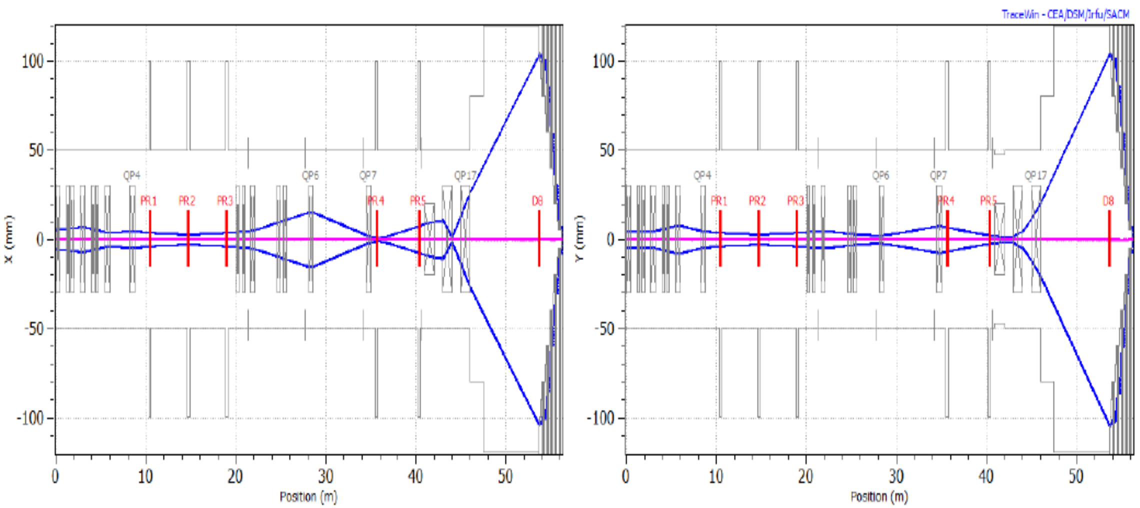
Beam line to dump

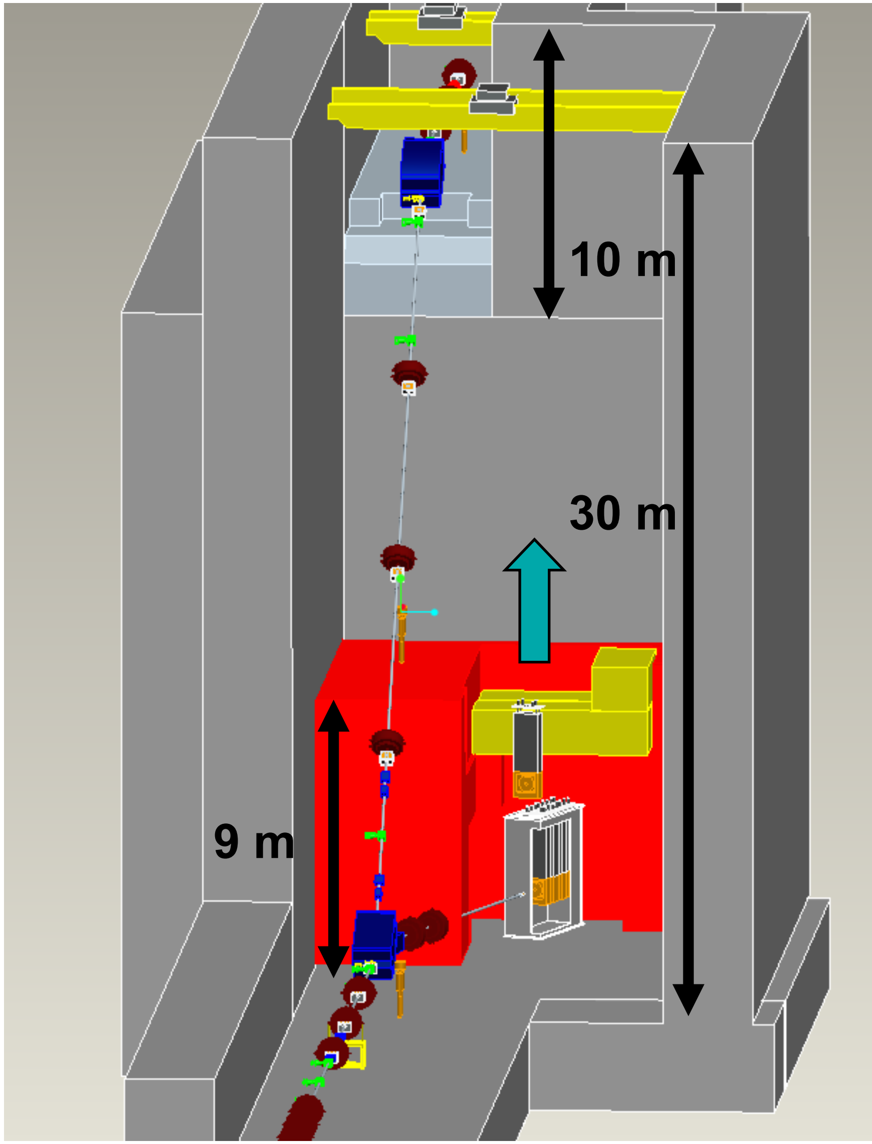
→ 20° dipole to avoid neutron backstreaming & ease maintenance

→ 2 quadrupoles to defocus the beam on dump

→ >5 metres thick casemate (from preliminary shielding & activation calculations results)

→ Preliminary dump design from the 1MW PSI copper dump



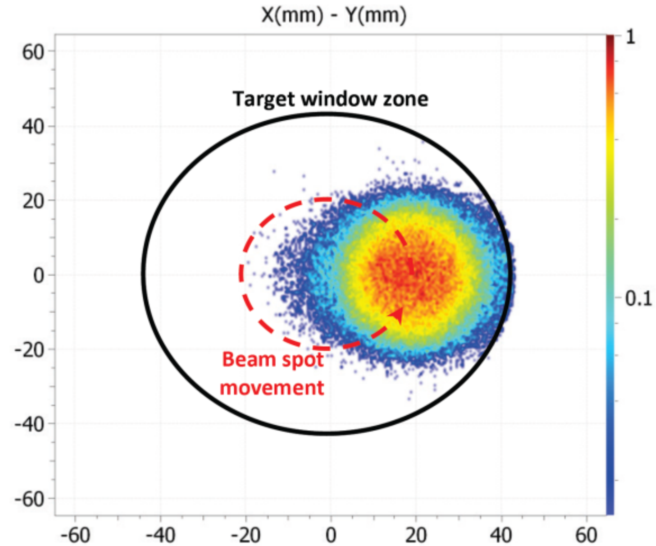


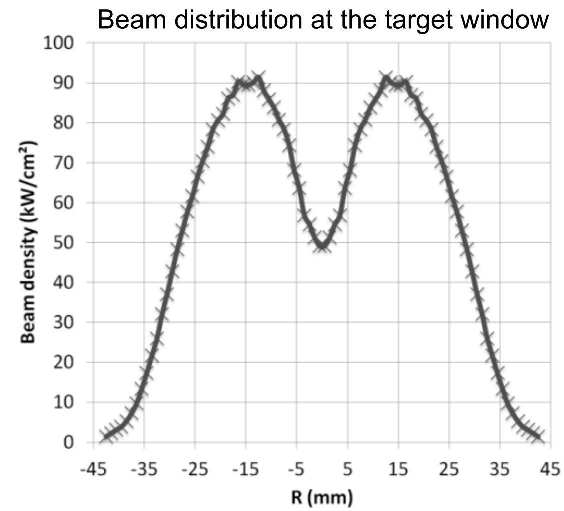
Beam line to reactor: main properties

→ Achromatic line

→ Telescopic properties
(size at target I is 9 times size at point 0)

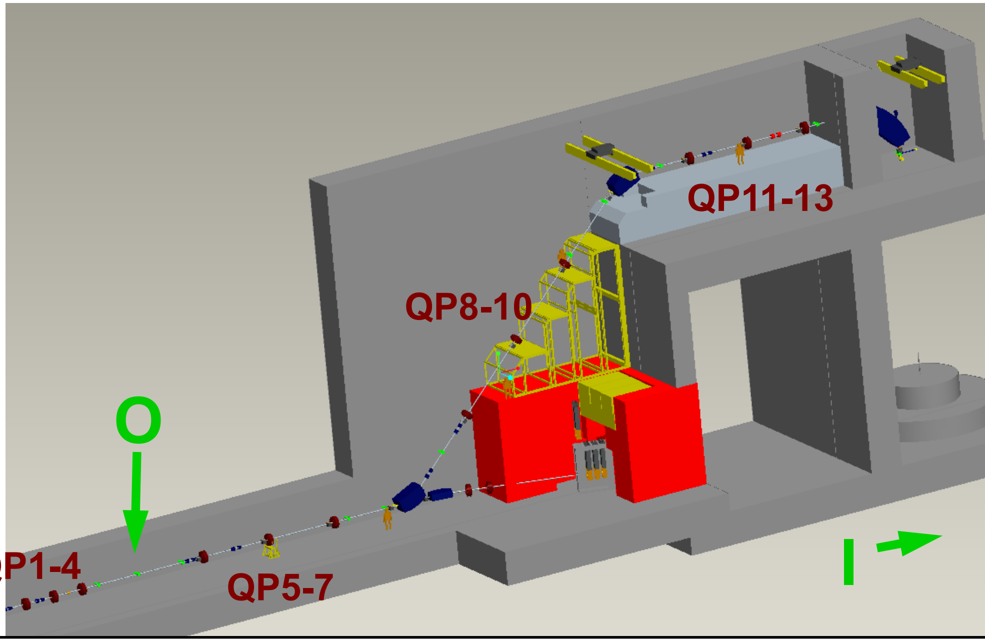
→ "Donut-shape" beam footprint by raster scanning
(non-linear beam expander was tested)



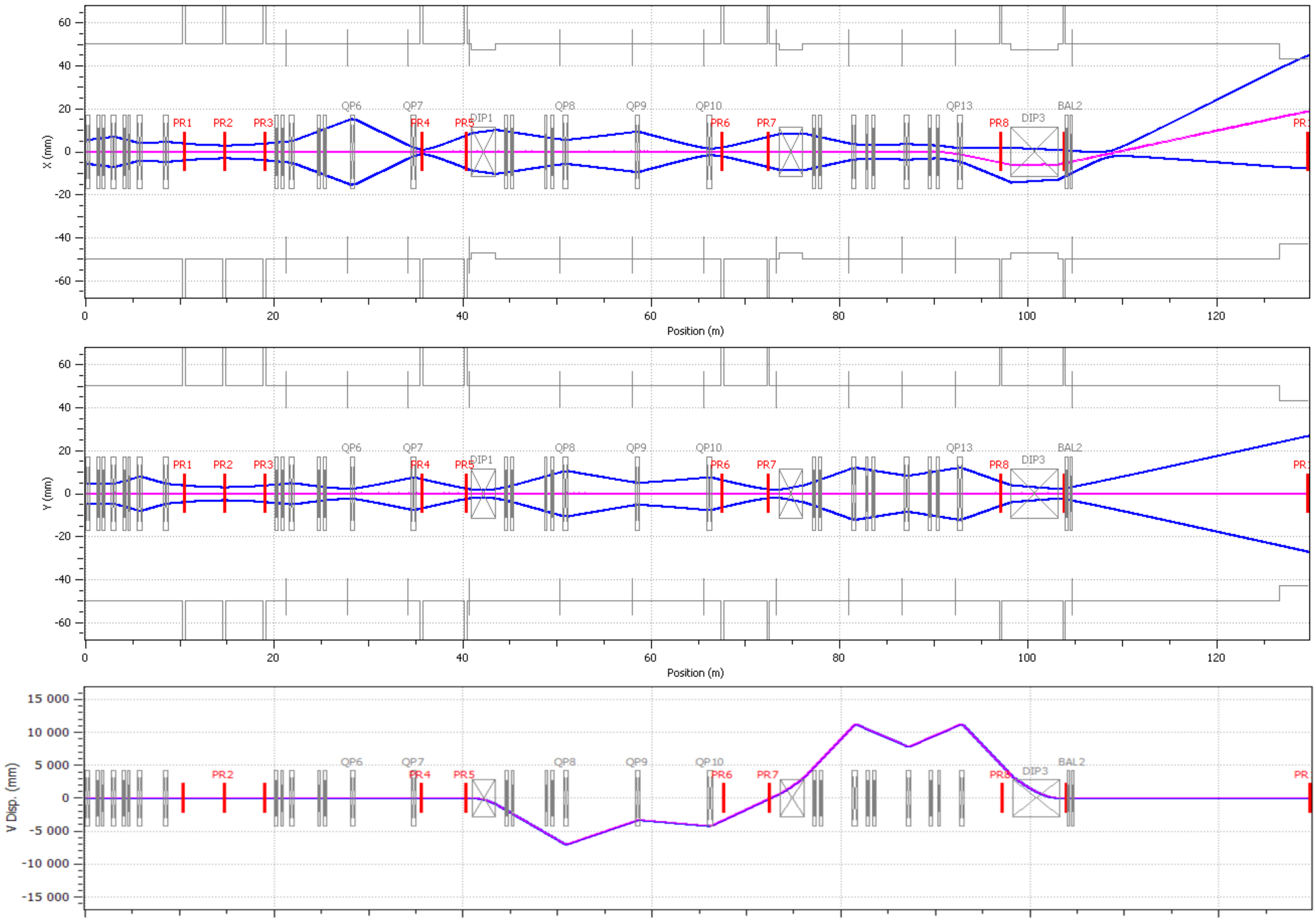


The tuning method is the following:

1. Magnets to theoritical value & low duty cycle beam
2. Adjust DC steerers for orbit correction (alignement)
3. Adjust QP1-4 => tune beam waist on 0 w/ 1mm rms
4. Adjust QP8-13 => optimize achromaticity
5. Adjust QP 5-7 => adjust size on target I (9mm rms)
6. Recheck alignement & switch on + tune AC steerers
7. Increase step by step the beam duty cycle



Beam line to reactor: 99% beam envelopes



Main pending issues in the beam line to reactor

- **No room presently for any passive safety elements near the target**

→ No passive collimator, we rely on halo monitors + near-target imaging system

→ No additional passive "cold" window, we rely on several fast valves

- **Reactor hall is a red zone 100% remote-handled**

→ no electronics, no water i.e. no magnets, nearly no instrumentation

- **27 metres long final naked drift to manage**

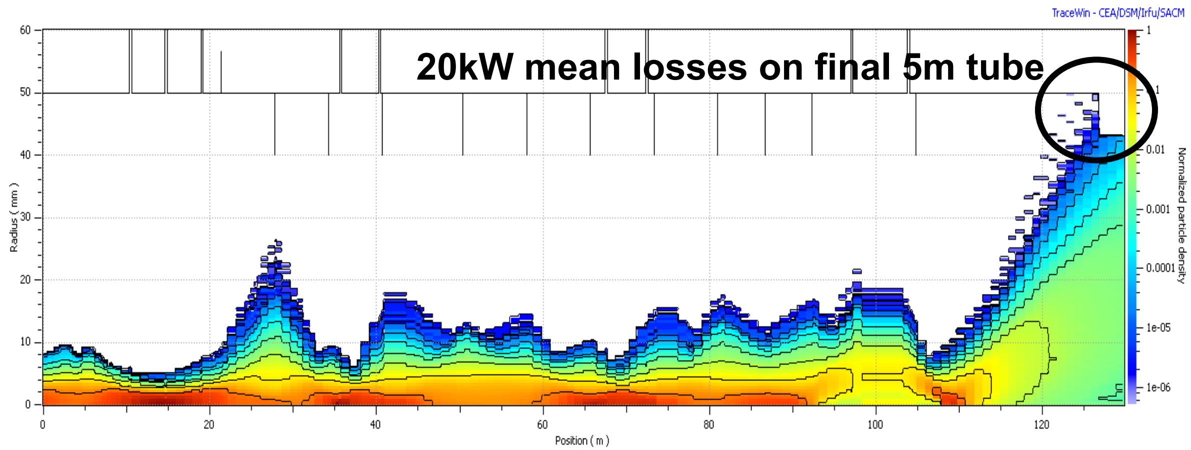
→ High optical sensitivity to errors & severe specs on dipole stability especially

→ Systematic beam halo losses (20kW) inside the reactor vessel before the target

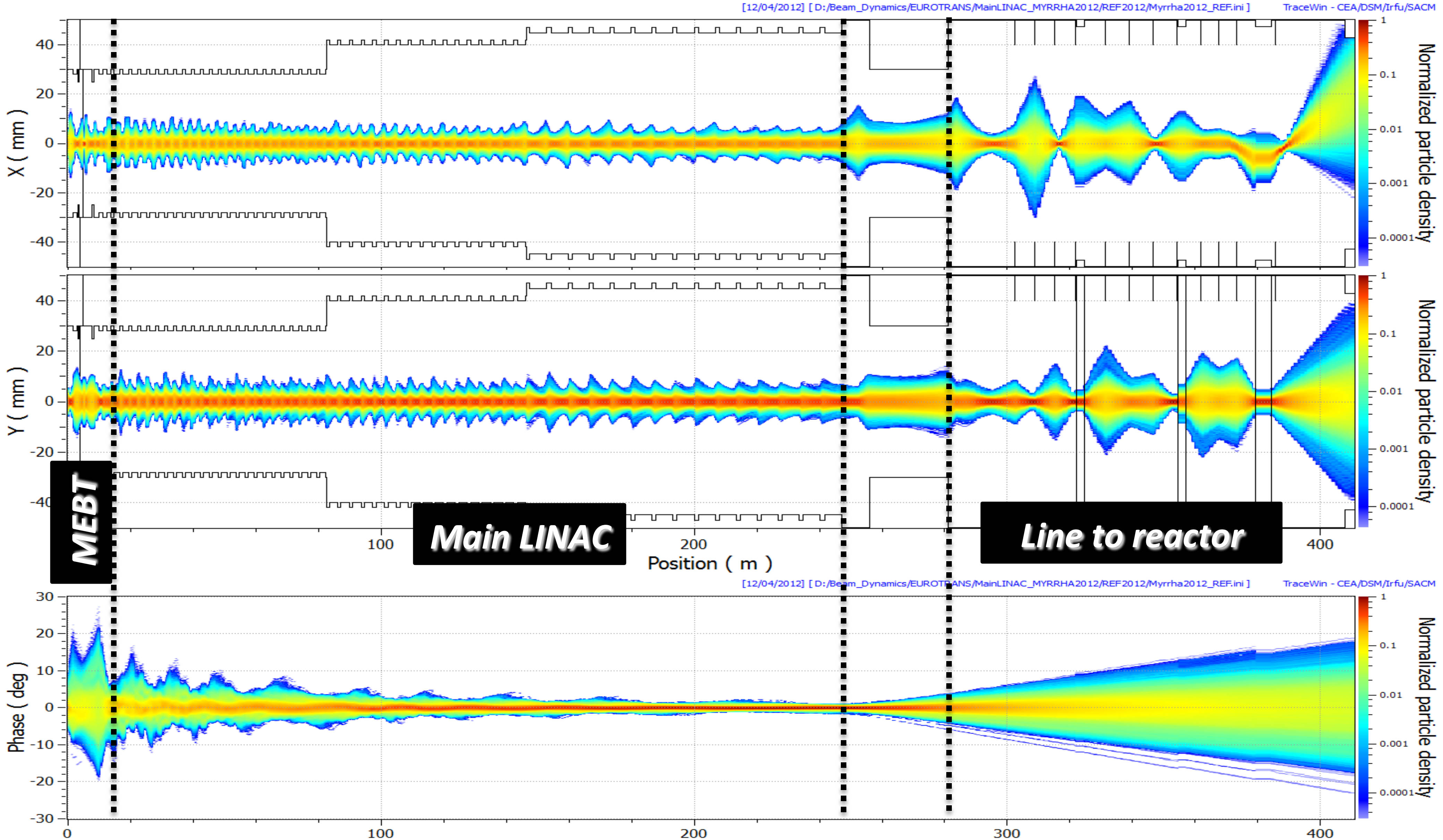
Magnets errors	*Static*	*Dynamic*
Dipole field	± 0.1 %	$\pm 2.10^{-5}$
Dipole displacement	± 0.3 mm	± 10 µm
Quad. gradient	± 1 %	± 0.1 %
Quad. displacement	± 0.3 mm	± 10 µm

Input beam errors	*Static*	*Dynamic*
Position	± 2.0 mm	± 0.1 mm
Divergence	± 0.2 mrad	± 0.01 mrad
Energy	-	± 1.0 MeV
Emittance	± 10%	± 1%
Mismatch factor	± 10%	± 1%
Intensity	± 50 µA	± 50 µA

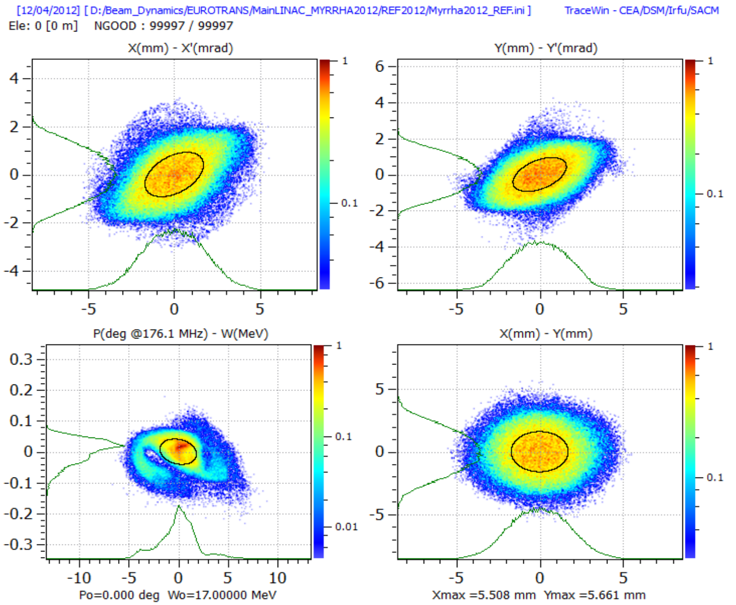
Measurement	*Accuracy*
Beam position (BPM, near-target device)	± 0.5 mm
Beam rms size (profilers, near-target device)	± 0.5 mm



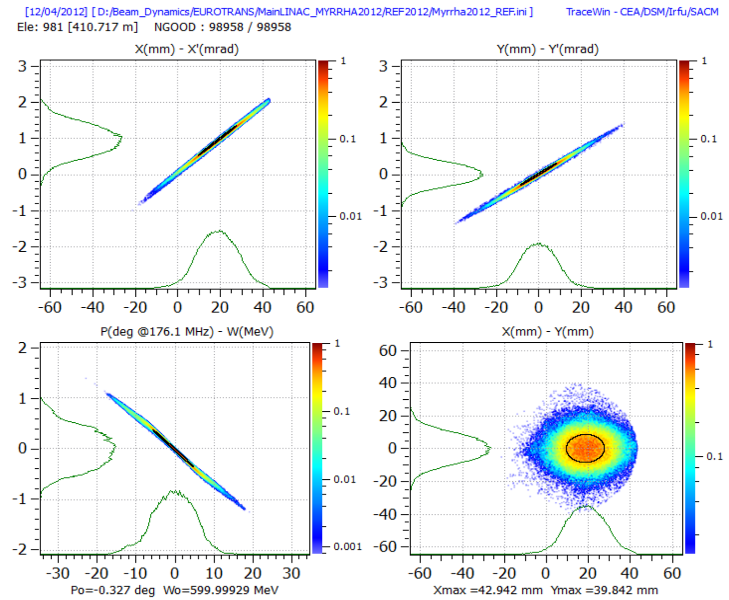
17 – 600 MeV STE simulation (first try)



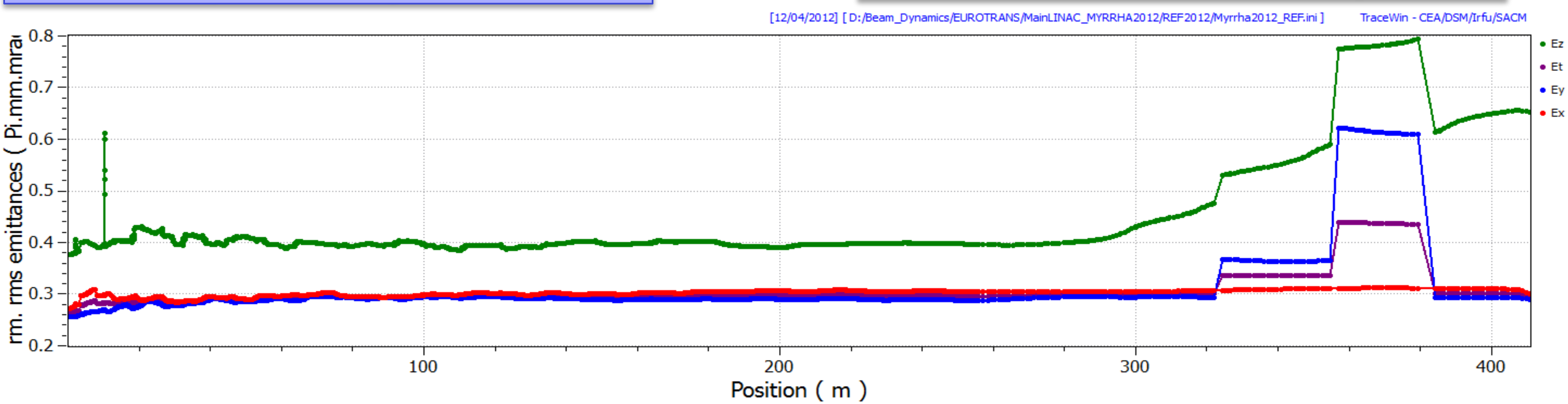
17 – 600 MeV STE simulation (first try)



17 MeV input beam from LORASR



600 MeV beam on target



1. Introduction
2. Design of the MYRRHA SC main linac
3. The MYRRHA beam lines

4. Conclusion

Summary

- **MYRRHA** = new large multi-purpose fast neutron research infrastructure, to be operational in 2024.

- At the end of the EURATOM FP7 projects, the goal is to reach a sufficient level of design to be able to launch a **construction phase in 2015**

- The overall MYRRHA **accelerator design** should be more or less frozen within the MAX project in 2014

- Next main steps are to consolidate the design, connect the injector and perform **extensive STE error studies in 2013** to validate the design

- **Many thanks to the main contributors to this on-going design work:**
F. Bouly, G. Olry, L. Perrot, H. Saugnac (CNRS), H. Klein, H. Podlech, C. Zhang (IAP), D. Uriot (CEA), D. Vandeplassche (SCK•CEN), R. Pires (ITN), A. Ferrari (HZDR) & all the FP7 MAX & CDT teams

Thank you & happy birthday Romuald !

Coordinator

http://ipnweb.in2p3.fr/MAX/

http://myrrha.sckcen.be/

CNRS IN2P3 Les deux infinis
SCK•CEN Studiecentrum voor Kernenergie Centre d'Etude de l'Energie Nucléaire
Goethe Universität Frankfurt am Main
INFN Istituto Nazionale di Fisica Nucleare
Empresarios Agrupados
CEA
Universitas Catholica Lusitana
Katholieke Universiteit Leuven
Accelerators and Cryogenic Systems
ADEX
Thales Electron Devices