Potential SPL architectures & beam dynamics

F. Gerigk & M. Eshraqi

SPL review meeting, 30 April 2008

Outline

- motivation: is 704 MHz still the right choice?
- review the layouts for 704 MHz, and explore alternatives at different frequencies,
- first beam dynamics simulations for the different options,
- impact of 704/1408 MHz on layout/beam dynamics.

why we chose 704 MHz, *part I*

1. maximum gradients in SC cavities are more related to the quality of the surface treatments (and to the geometric beta..), rather than to the frequency,
2. Linac4 had a 704 MHz section: continuing with 704 MHz in the SC linac simplified the RF system and simplifies longitudinal dynamics (no frequency jump) -> no longer true!

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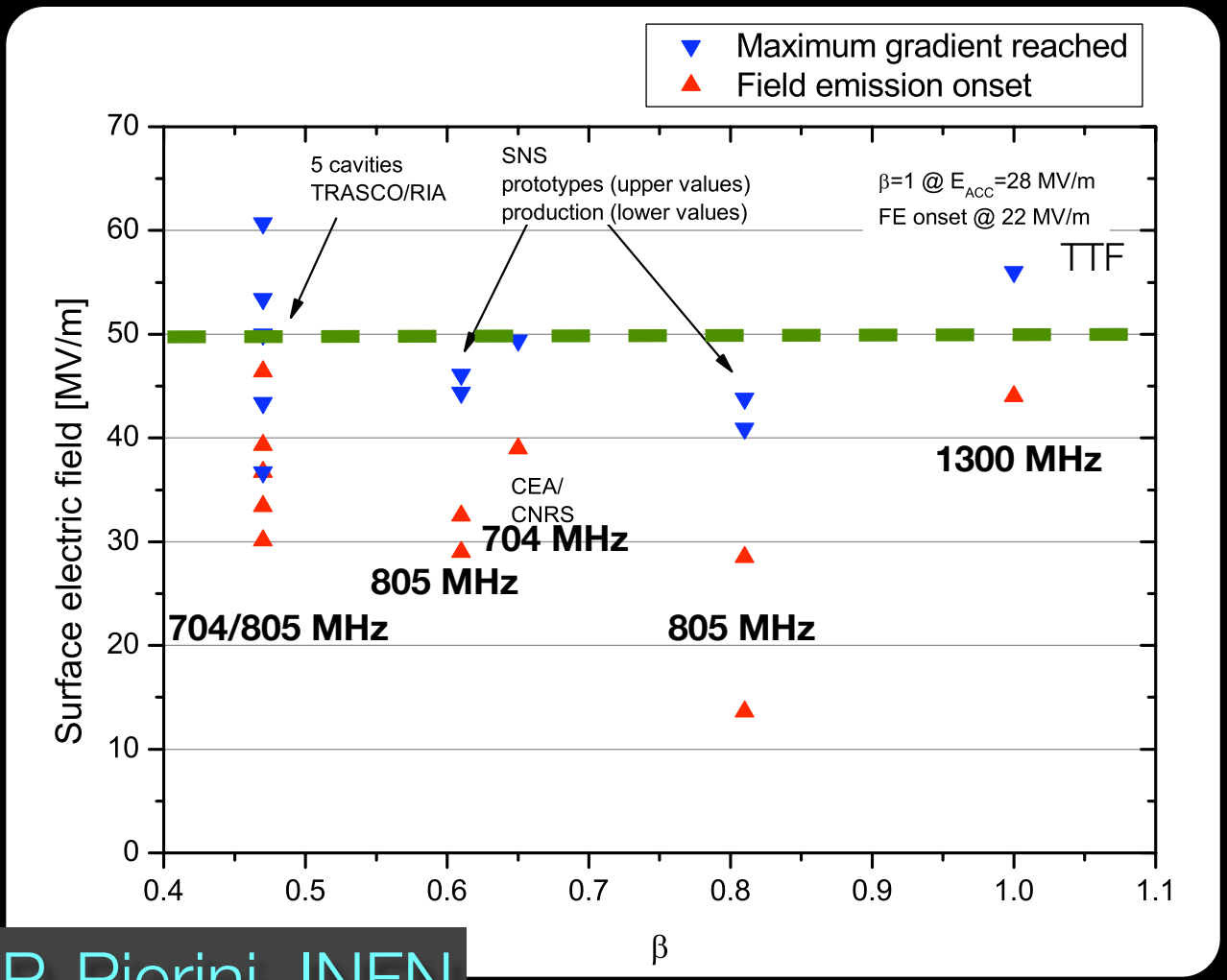
SC cavity gradients (CDR2)

peak surface fields (electric)



P. Pierini, INFN

- max. surface fields are based on measured cavity performance,
- surface fields: 50 MV/m and 100 mT are challenging but seem realistic for pulsed operation,
- **chosen gradients: 19/25 MV/m** for β=0.65/1

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why we chose 704 MHz, *part 2*

1. maximum gradients in SC cavities are more related to the quality of the surface treatments (and to the geometric beta..), rather than to the frequency,
2. Linac4 had a 704 MHz section: continuing with 704 MHz in the SC linac simplified the RF system and simplified longitudinal dynamics (no frequency jump) -> no longer true because Linac4 is now entirely at 352 MHz!

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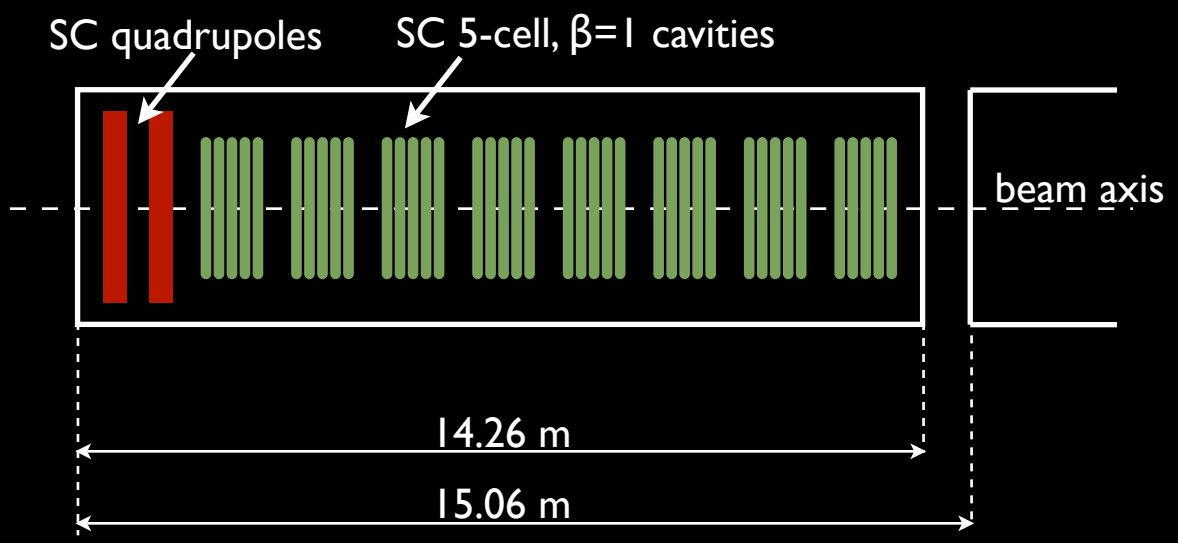
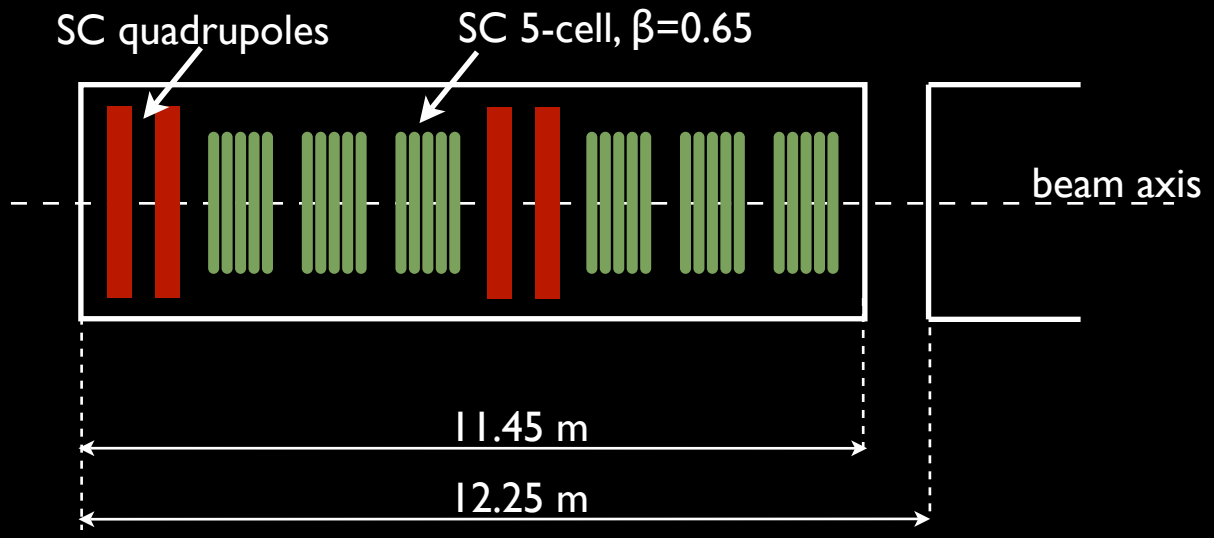
Base-line cryo-modules (CDR2)

high-beta section:
- 704.4 MHz, 25 MV/m,
- 668 - 5094 MeV,
- 25 periods, 200 cavities,
- 377 m



low-beta section:
- 704.4 MHz, 19 MV/m,
- 180 - 668 MeV,
- 14 periods, 42 cavities,
- 86 m



in total: 463 m, 242 cavities, 2 families, 704 MHz

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assumption

keep all inter-cavity distances the same for all scenarios!

- cavity to cavity: 0.5 m (incl. cut-off tubes and coupler ports), *(spoke: 0.3 m)*,
- quadrupole: 0.45 m, *(spoke: NC magnet: 0.2 m)*
- quad to cavity: 0.45 m *(spoke: 0.2 m)*,
- quad to quad: 0.45 m, *(spoke: 0.14 m)*,
- last element to period end: 0.40 m, (for transition between modules), *(spoke: 0.2 m)*

Start simple..

1. different linacs are created by combining different cavity families with different betas and cell numbers (cavity fields are modelled with a simple fit, including end-cell fields),
2. verification of some scenarios with beam dynamics simulations (matching of transitions, limiting the longitudinal phase advance per period, particle tracking, etc): M. Eshraqi

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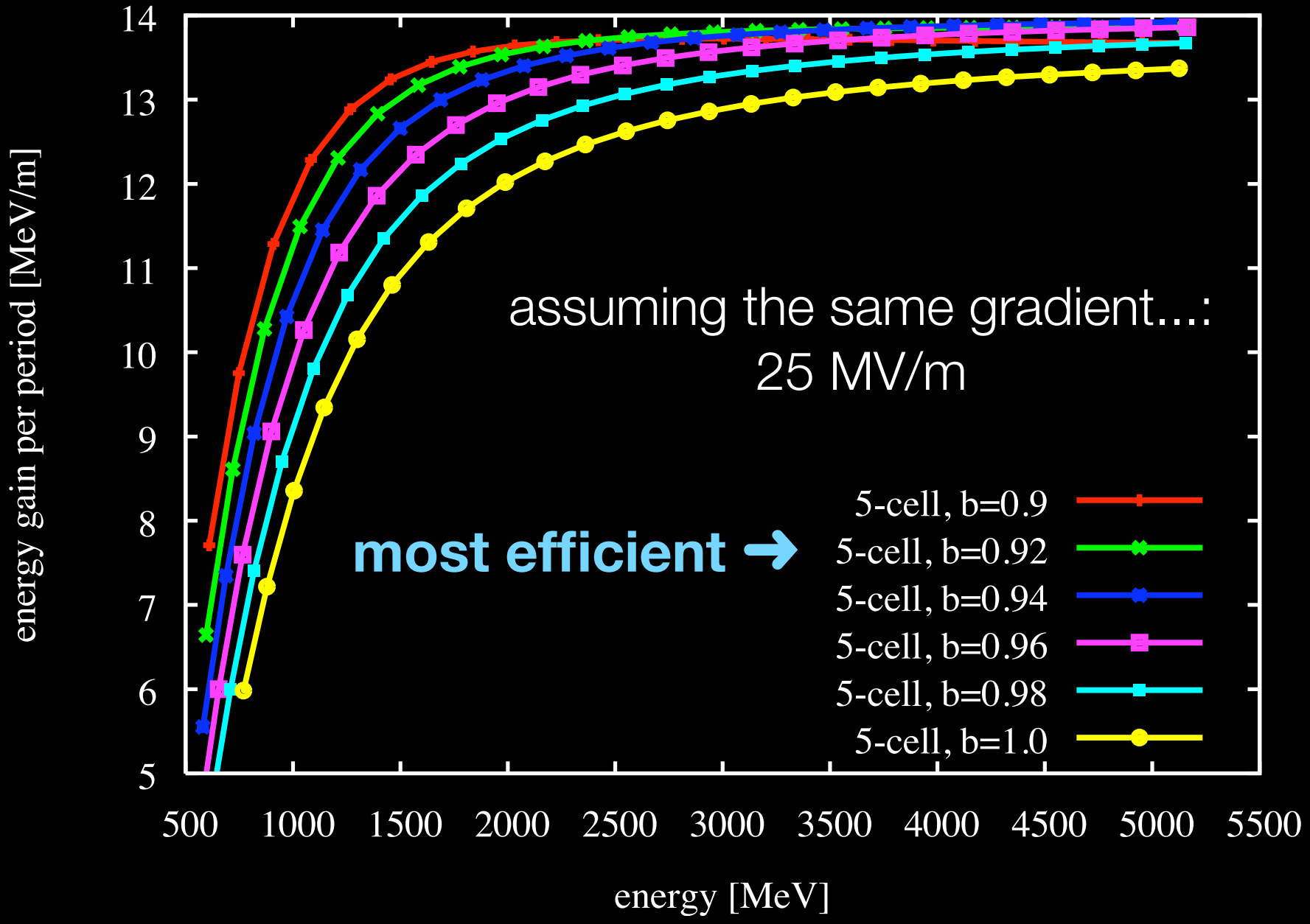
improving the nominal option



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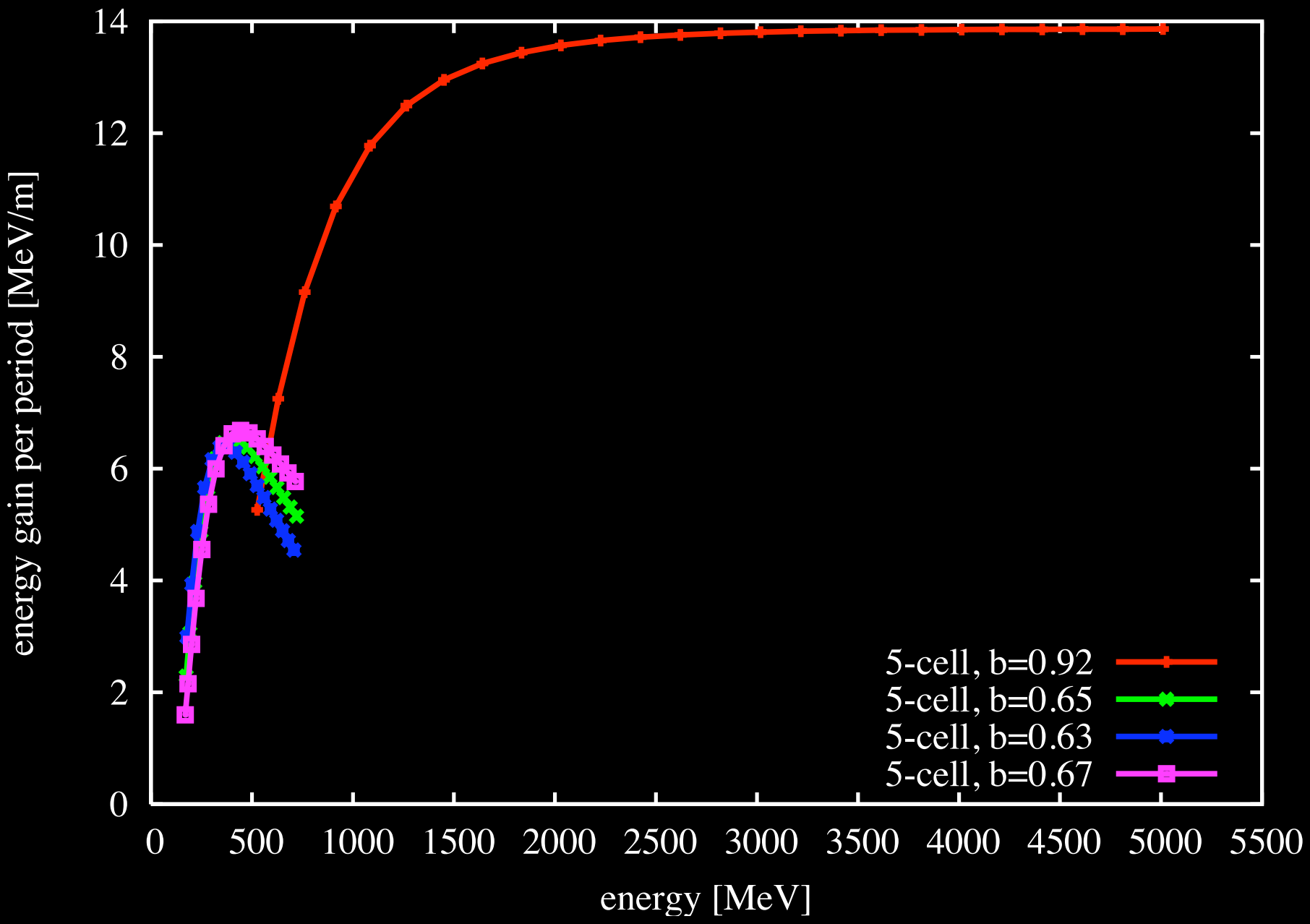
+ low beta section



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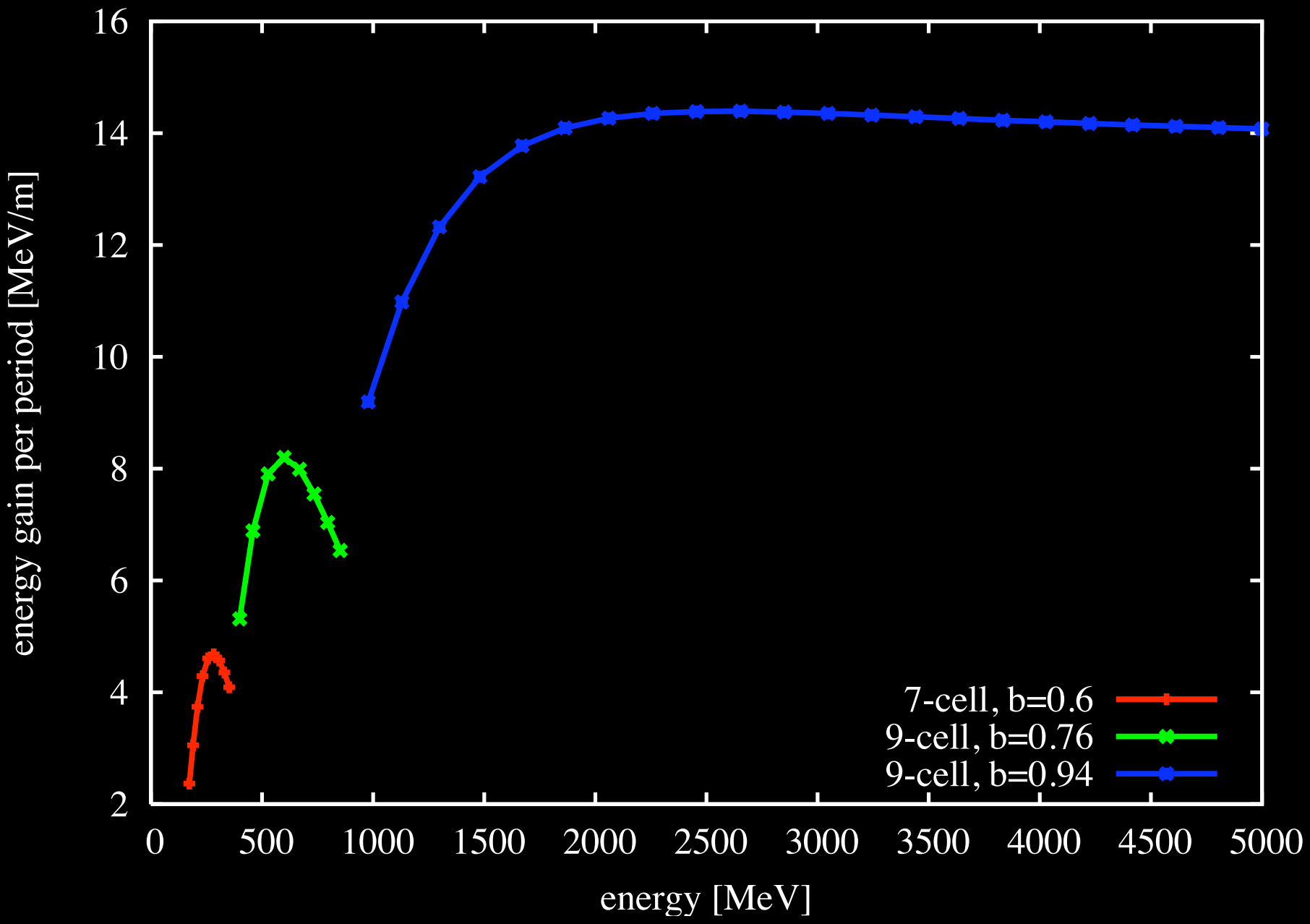
option I: 1408 MHz with elliptical cav.



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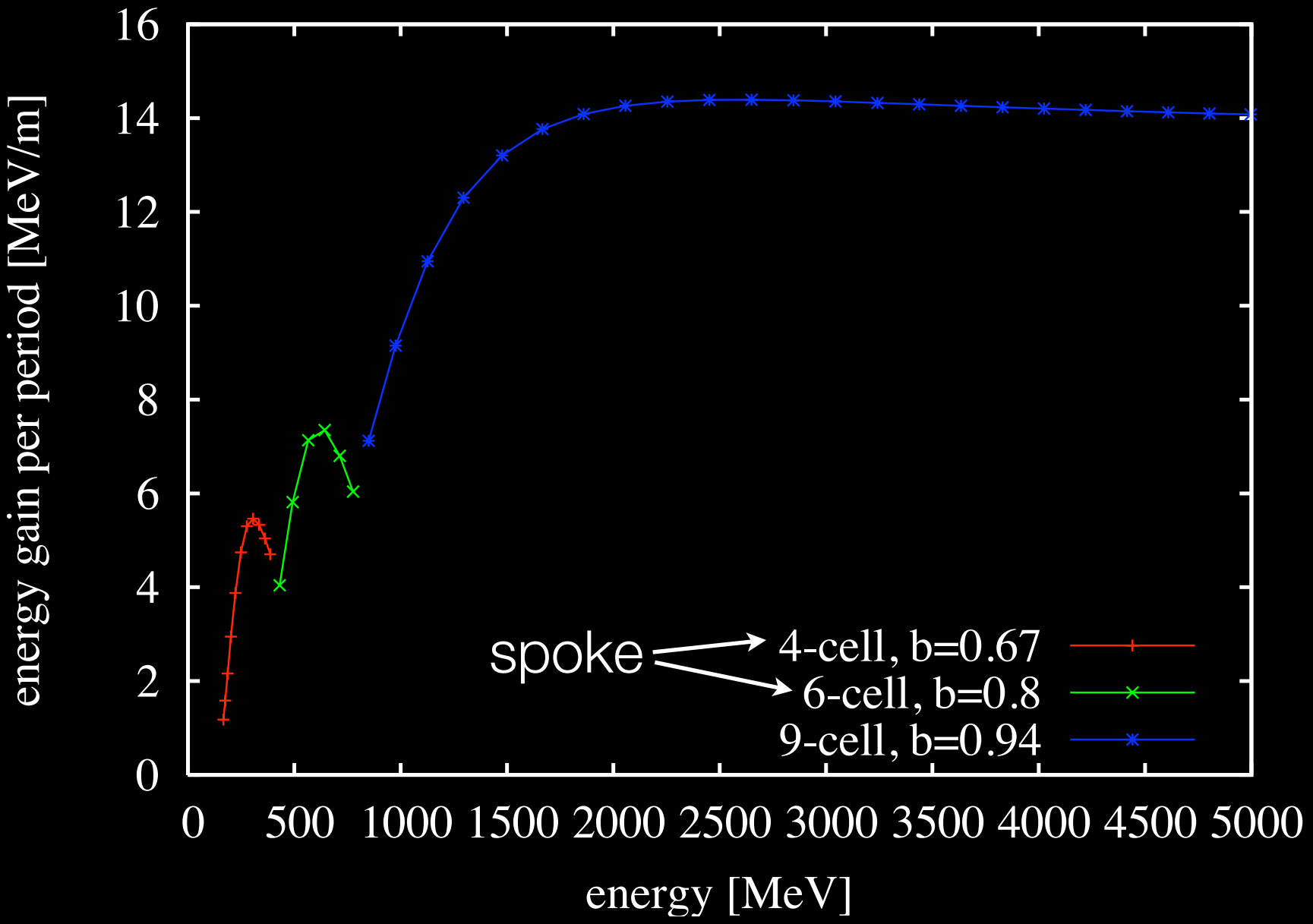
option 1b: 352 MHz spoke + 1408 MHz 9-cell



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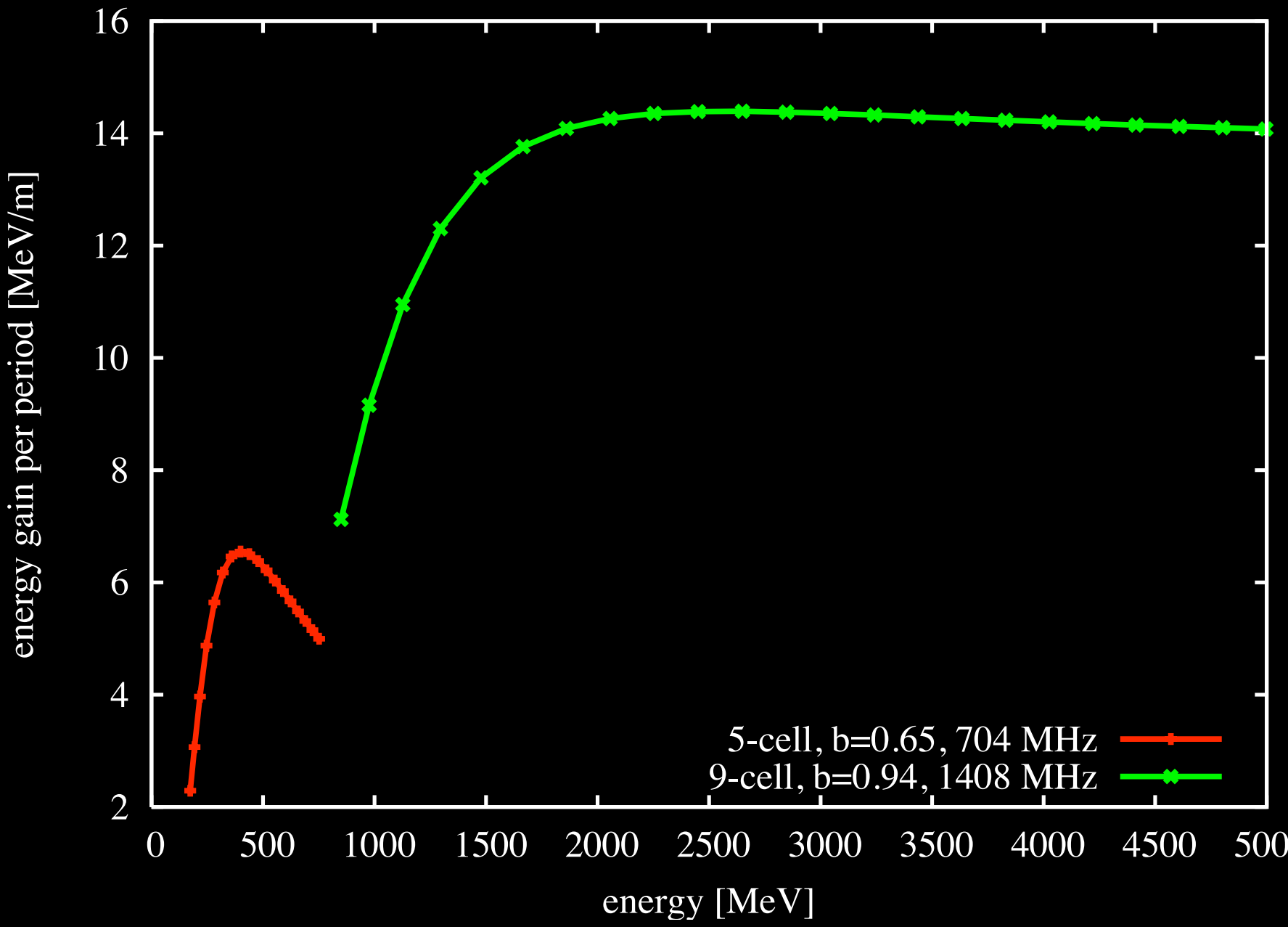
352 MHz spoke cavities:

2 families of spoke cavities:

- assume NC quadrupole doublets between the cryo-modules,
- continue with 352 MHz up to 743 MeV,
- β=0.64: triple spoke, 8.5 MV/m, 160 - 387 MeV,
- β=0.8: 5-spoke, 9.5 MV/m, 387 - 743 MeV,

option 2: 704 MHz + 1408 MHz



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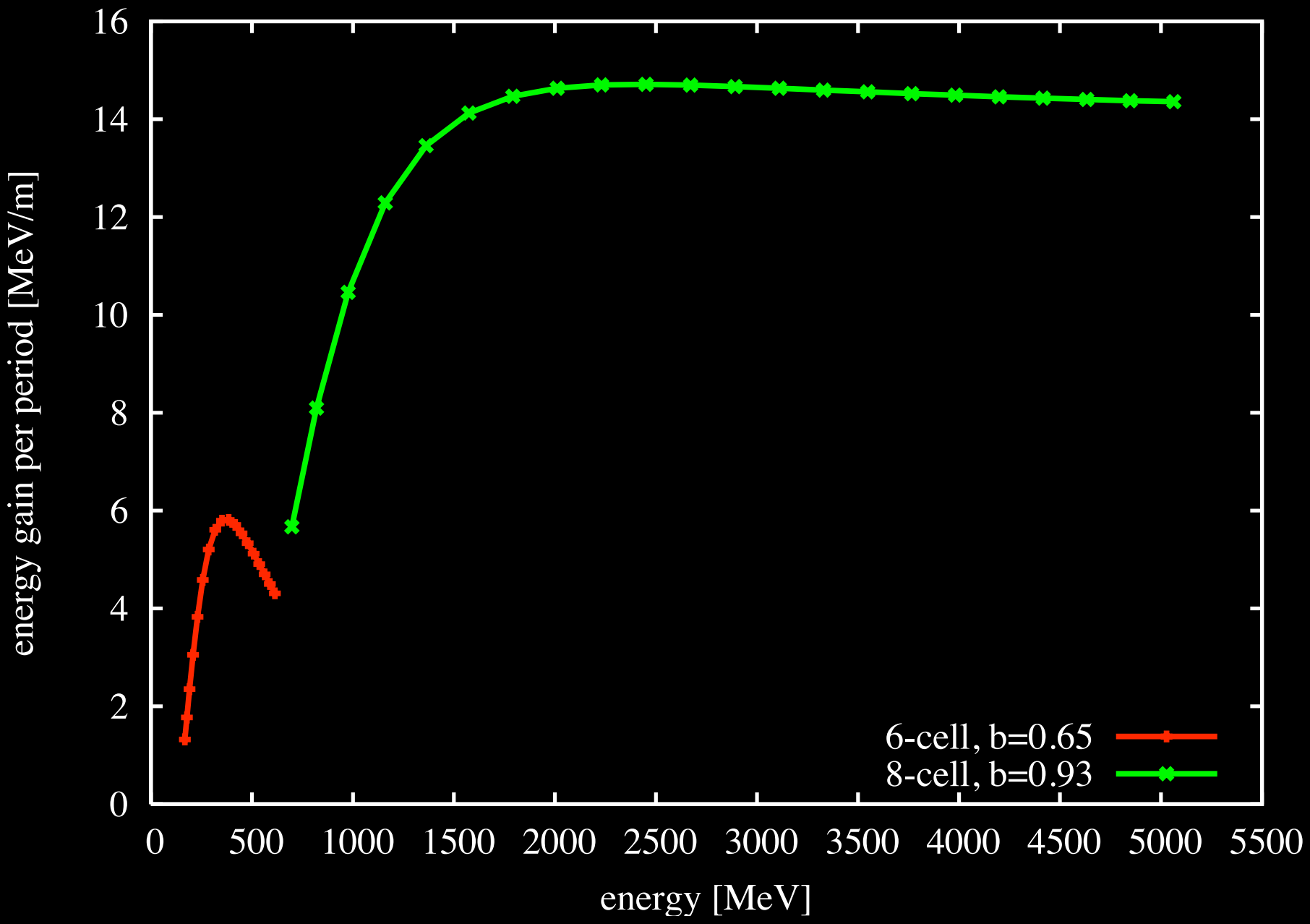
option 3: 1057 MHz



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SPL type	nominal	nominal improved	option I	I b	option II	option III
frequency [MHz]	704.4	704.4	1408.8	352/1408	704/1408	1057
beta families	0.65/1.0	0.65/0.92	0.6/0.76/0.94	0.67/0.8/0.94	0.65/0.94	0.65/0.93
cells/cavity	5/5	5/5	7/9/9	4/5/9	5/9	6/8
trans. energies [MeV]	180/668	160/589	160/358/876	160/387/743	160/752	160/613
output energy [MeV]	5094	5137	5090	4996	4996	5063
gradients [MV/m]	19/25	19/25	19.6/23.8/27.1	8.5/9.5/28	19/28	20/26.5
period length [m]	6.1/15.1	6.1/14.4	5.4/8.9/13.8	5.4/9.0/13.8	6.1/13.8	5.7/15.0
cavities p. period	3/8	3/8	3/5/8	3/4/8	3/8	3/8
cavities p. family	42/200	39/192	27/35/184	33/24/184	54/184	54/176
cavity/linac length [%]	52	51	48	57	47	50
cavities in total	**242**	**231**	**246**	**241**	**238**	**230**
length [m]	**463**	**425**	**426**	**430**	**428**	**433**

power per cavity < 1 MW, -15 deg synchronous phase

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beta families	0.65/1.0	0.65/0.92	0.6/0.76/0.94	0.67/0.8/0.94	0.65/0.94	0.65/0.93
cells/cavity	5/5	5/5	7/9/9	4/5/9	5/9	6/8
trans. energies [MeV]	180/668	160/589	160/358/876	160/387/743	160/752	160/613
output energy [MeV]	5094	5137	5090	4996	4996	5063
gradients [MV/m]	19/25	19/25	19.6/23.8/27.1	8.5/9.5/28	19/28	20/26.5
period length [m]	6.1/15.1	6.1/14.4	5.4/8.9/13.8	5.4/9.0/13.8	6.1/13.8	5.7/15.0
cavities p. period	3/8	3/8	3/5/8	3/4/8	3/8	3/8
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power per cavity < 1 MW, -15 deg synchronous phase

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beam dynamics design

making realistic lattices out of the "simple approach":

- using the beam out of Linac4,
- matching of transitions,
- adjusting the transverse and longitudinal focusing parameters (phase advance) for smooth beam evolution (avoiding resonances, etc),
- particle tracking.

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beam dynamics design

SPL type	nominal improved	option I	I b
frequency [MHz]	704.4	1408.8	352.2/1408.8
beta families	0.65/0.92	0.6/0.76/0.94	0.67/0.8/0.94
cells/cavity	5/5	7/9/9	4/5/9
trans. energies [MeV]	160/589	160/358/876	tbs
output energy [MeV]	5137	4992	tbs
gradients [MV/m]	19/25	19/20/28	tbs
cavities p. module	6/8	4/4/8	1/1/8
cavities p. period	3/8	2/4/8	tbs
cavities p. family	39/192	32/48/176	tbs
cavities in total	**231**	**256**	**tbs**
length [m]	**425**	**466**	**tbs**

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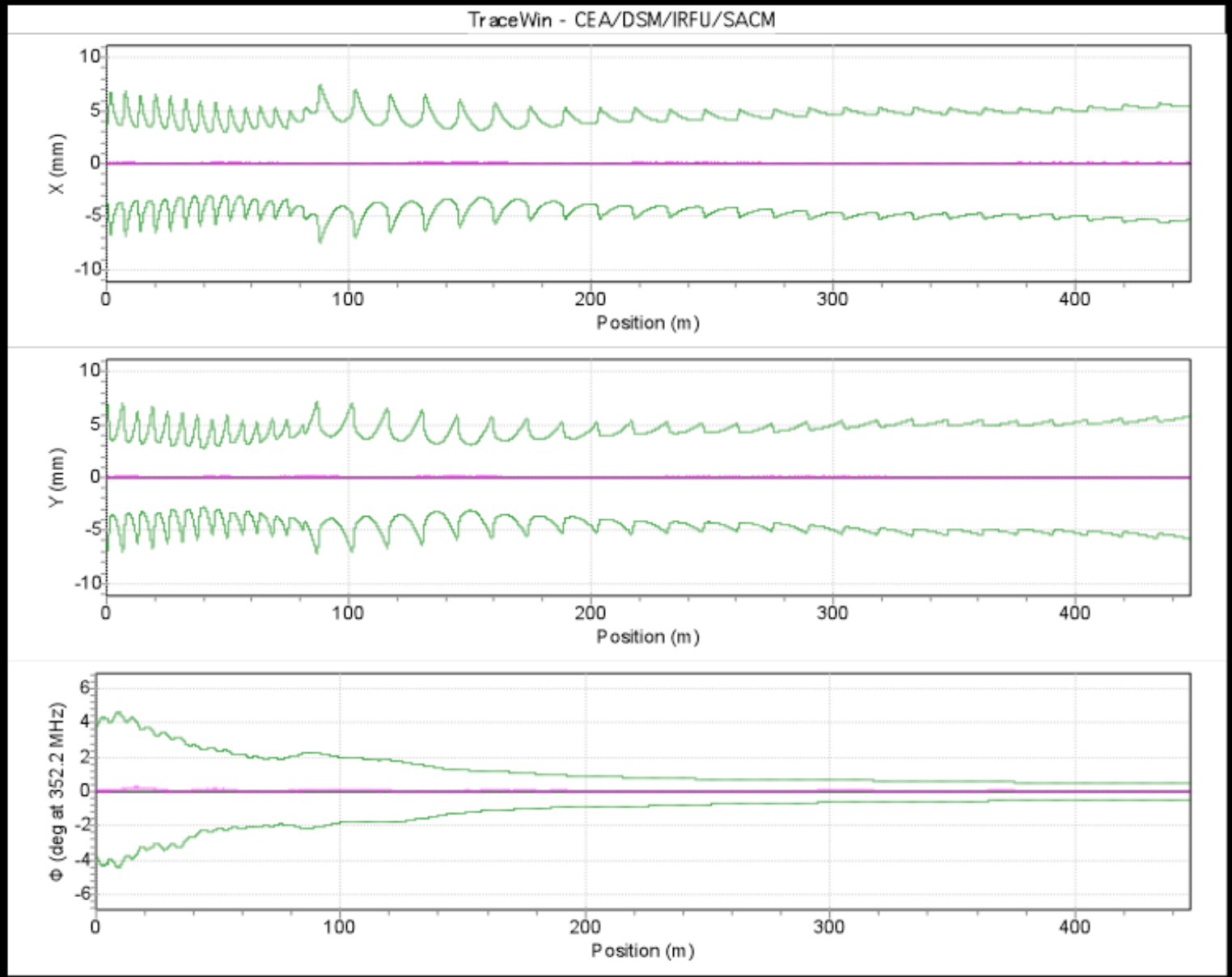
nominal improved: beam envelopes (5 rms)



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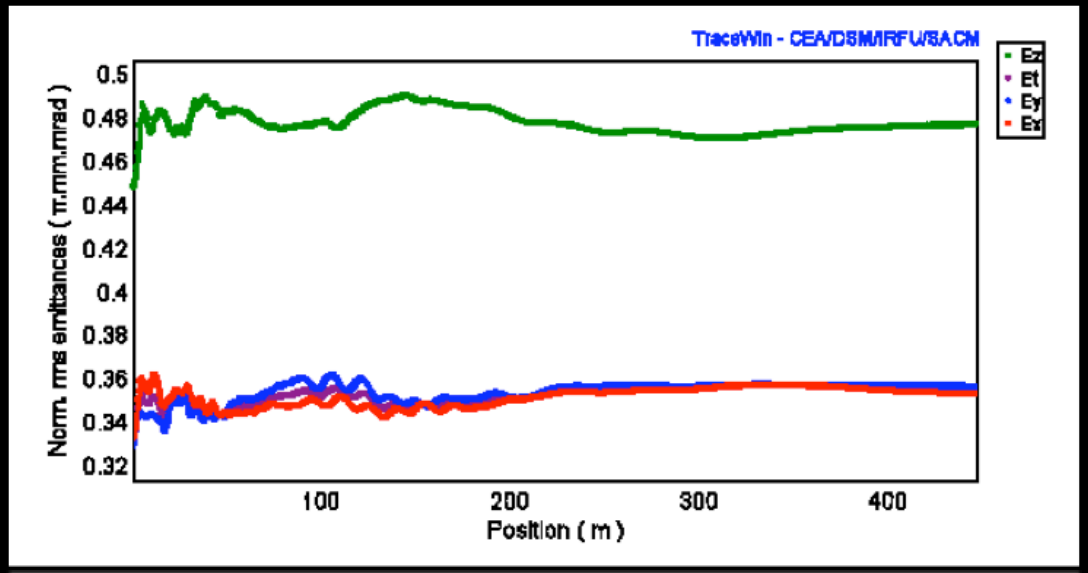
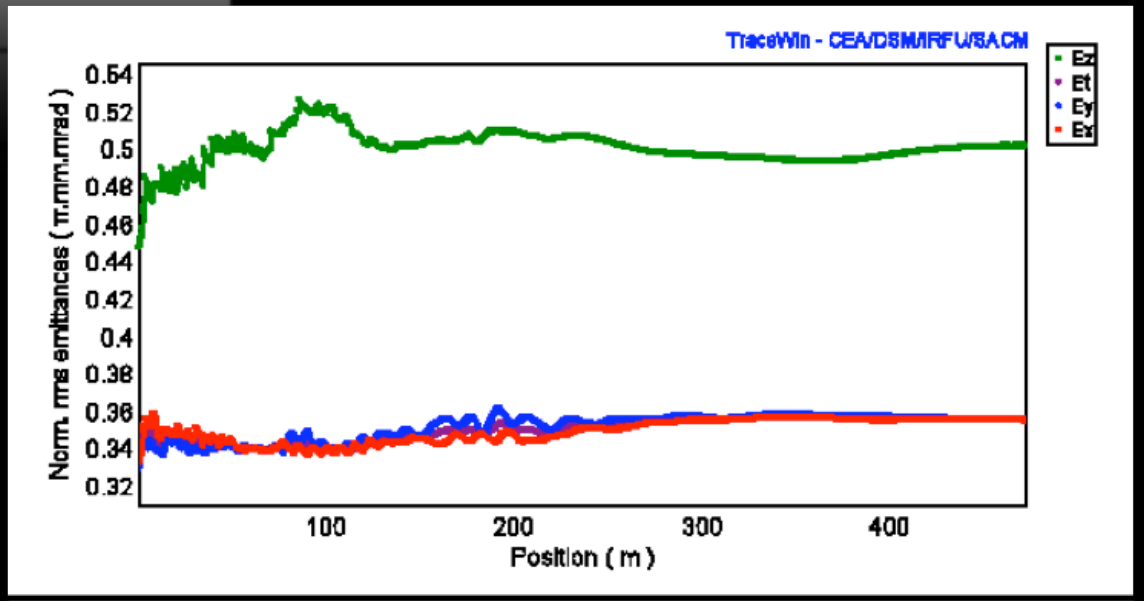
rms emittances



nominal improved

option 1 (1408 MHz elliptic cavities)



beam dynamics comparison

SPL type	nominal improved	option I	I b
frequency [MHz]	704.4	1408.8	352.2/1408.8
beta families	0.65/0.92	0.6/0.76/0.94	0.67/0.8/0.94
$\Delta\varepsilon_x$ [%]	5.6	6.3	tbs
$\Delta\varepsilon_y$ [%]	8.2	7.8	tbs
$\Delta\varepsilon_z$ [%]	6.8	12.1	tbs
Losses	-	-	tbs

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Beam loss I

detailed error studies are still missing, but we can make an educated guess:

- longitudinal ε-growth is 2 time larger, when jumping to 1408 MHz,
- rms beam radius <1.5 mm,
- transversely there is enough margin at all frequencies:

project	f_{RF} [MHZ]	cavity beta	R_{pipe} [mm]	$R_{pipe}/R_{beam(SPL)}$
SNS	805	0.8	50	33
TRASCO/CEA	704	0.47	40	27
CEA	704	0.65	45	30
TESLA	1300	1.0	35	23

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Beam loss II

...the educated guess:

- reducing the aperture due to higher frequency cavities (1408 MHz) is unlikely to influence transverse beam loss: beam pipe/ rms radius > 20,

➡ even for strong mismatch, the outermost halo particles are usually confined to beam pipe/rms radius < 12,

- longitudinal ε-growth in itself may not be a big problem, but the development of energy/phase jitter must be evaluated,

➡every frequency jump multiplies the jitter values: 4x jump ➜ 4x phase jitter ➜ increased energy jitter !!

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Preliminary conclusions: 704 vs 1408 MHz

- 1408 MHz layouts are comparable to 704 MHz, probably ~10% longer, 10% more cavities, optimisations still to be done,
- beam dynamics suggests that it is possible to use 1408 MHz, even from 160 MeV onwards,
- probably higher phase and energy jitter at 1408 MHz, and less jitter acceptance from the NC part, to be simulated..
- transverse losses unlikely to be affected by frequency choice,
- spoke + 1408 MHz still needs to be simulated.

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