Energy Consumption Considerations in the Beam Physics Design and Optimization of the ESS Linac

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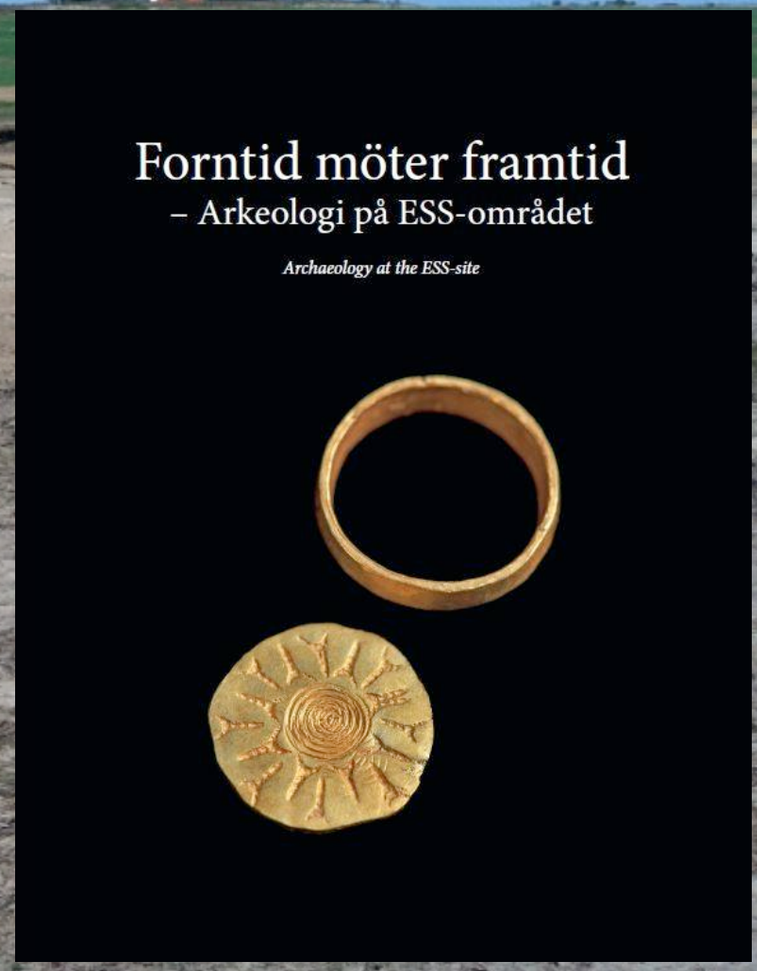
2019 November 28-29

5th Workshop on Energy for Sustainable Science and Research Infrastructures (ESSRI)

PSI, Villigen, Switzerland

From Largest Archaeology Site in Sweden

2013 September



… TO ESS SITE

2014 September

… TO ESS SITE

2019 September

Key Linac parameters

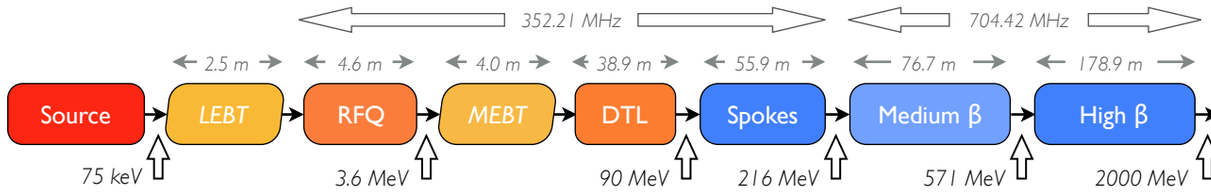
Energy	2.0 GeV
Current	62.5 mA
Repetition rate	14 Hz
Pulse length	2.86 ms
Losses	<1W/m
Ions	p

Controls

Control variables.	~1.6E6 PVs
MPS and PSS	
EPICS7	
µTCA.4	

Flexible/Upgradable design

Minimize energy consumption

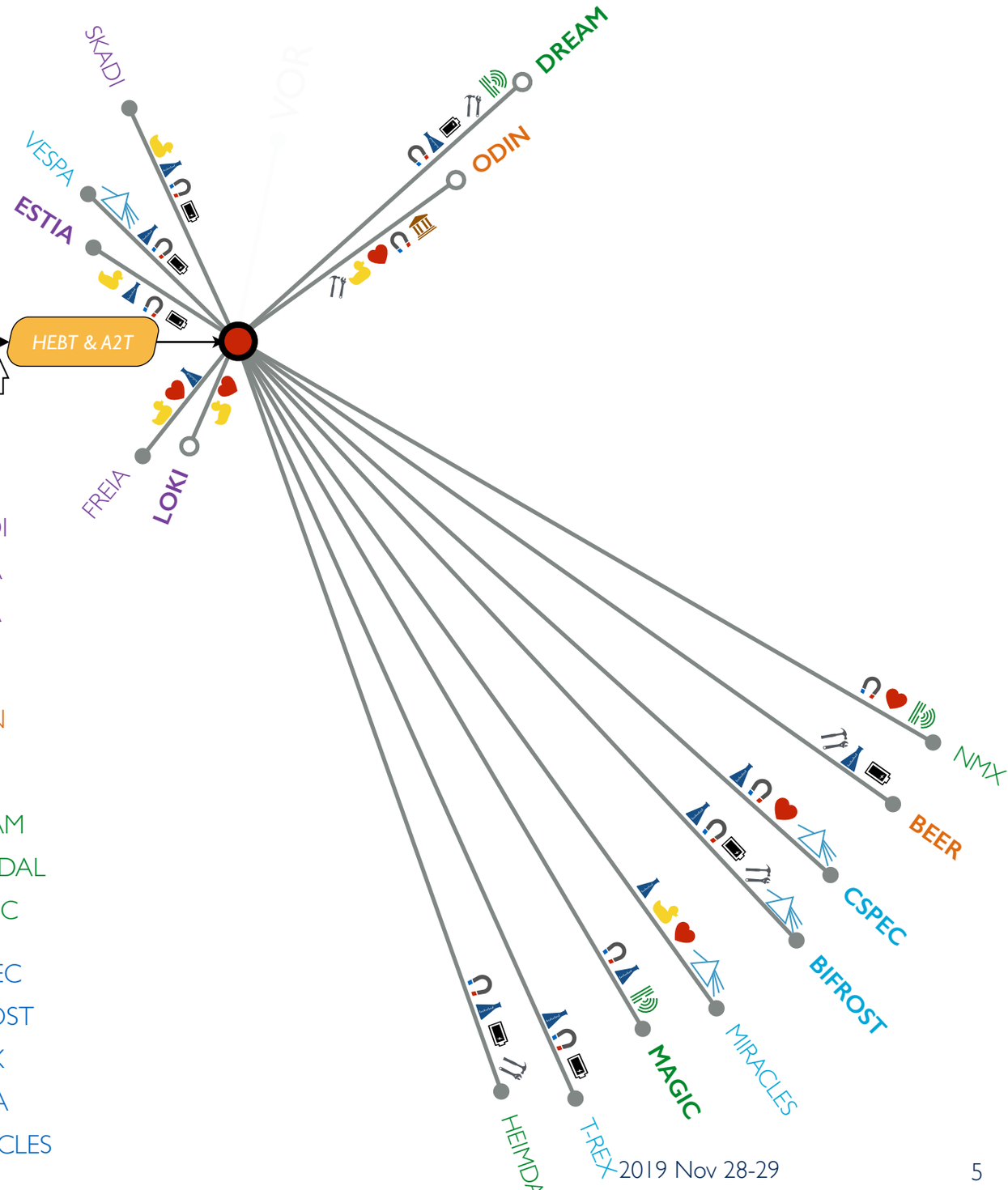


Rotating tungsten target

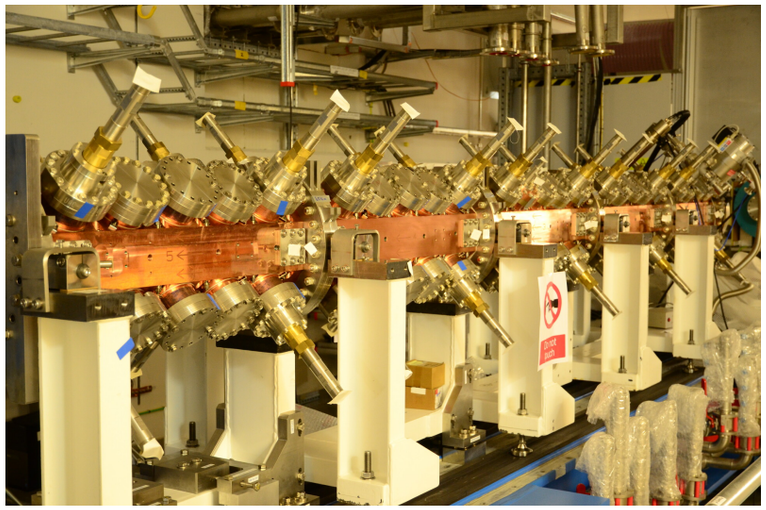
Target diameter	2.6 (0.45) m
Mass	11 (3) tons
	36 sectors
Rev. freq.	~0.4 Hz
Expected lifetime	5 years
Cooling	He gas
Beam ports	42
Peak flux	~30-100 x ILL
Cold moderator	Liquid H_2
	7 K
	30 mm
Thermal moderator	H_2O
	300 K
	30 mm

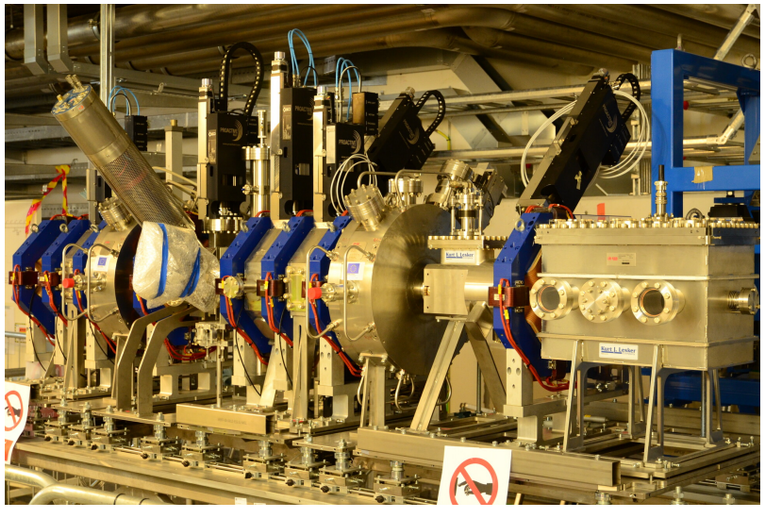
Instruments

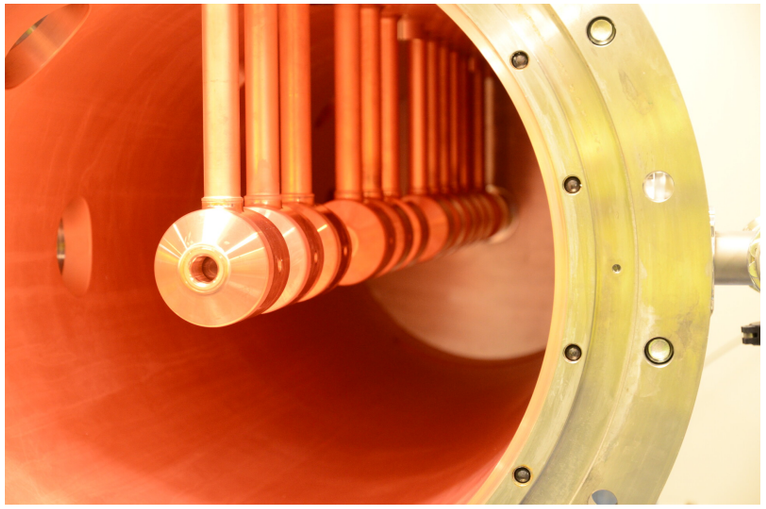
Large Scale Structures	LOKI
	SKADI
	ESTIA
	FREIA
Engineering	BEER
	ODIN
Diffraction	NMX
	DREAM
	HEIMDAL
	MAGIC
Spectroscopy	C-SPEC
	BIFROST
	T-REX
	VESPA
	MIRACLES



SOME UPDATES

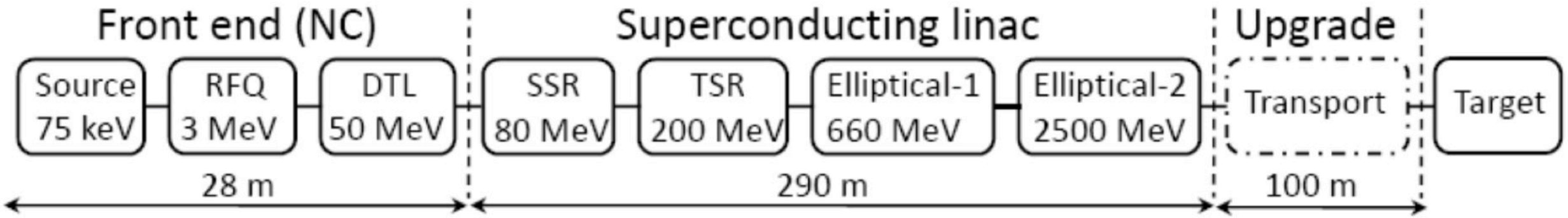






2012 COST SCRUBBING

< 2009_05_01



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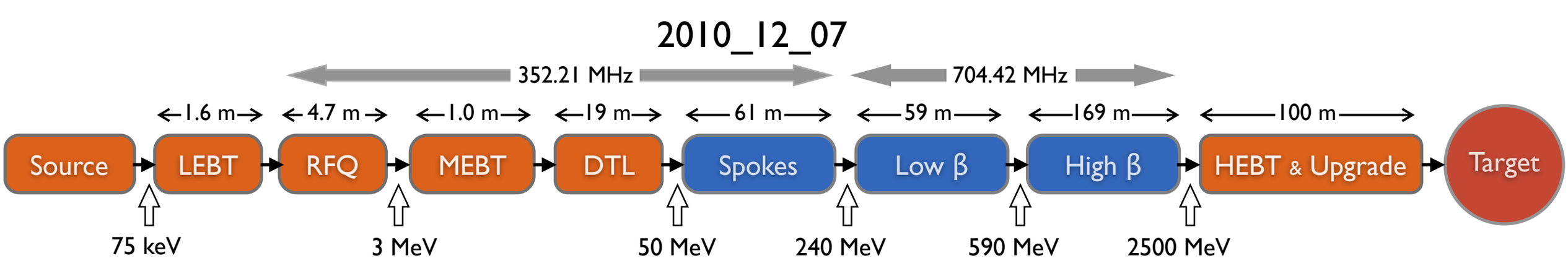

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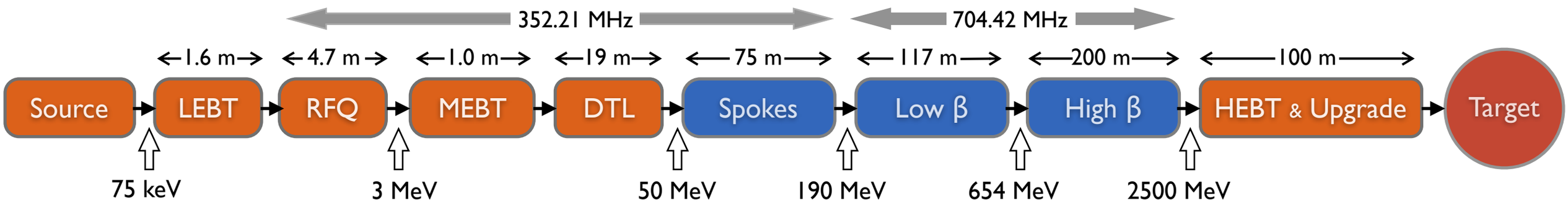
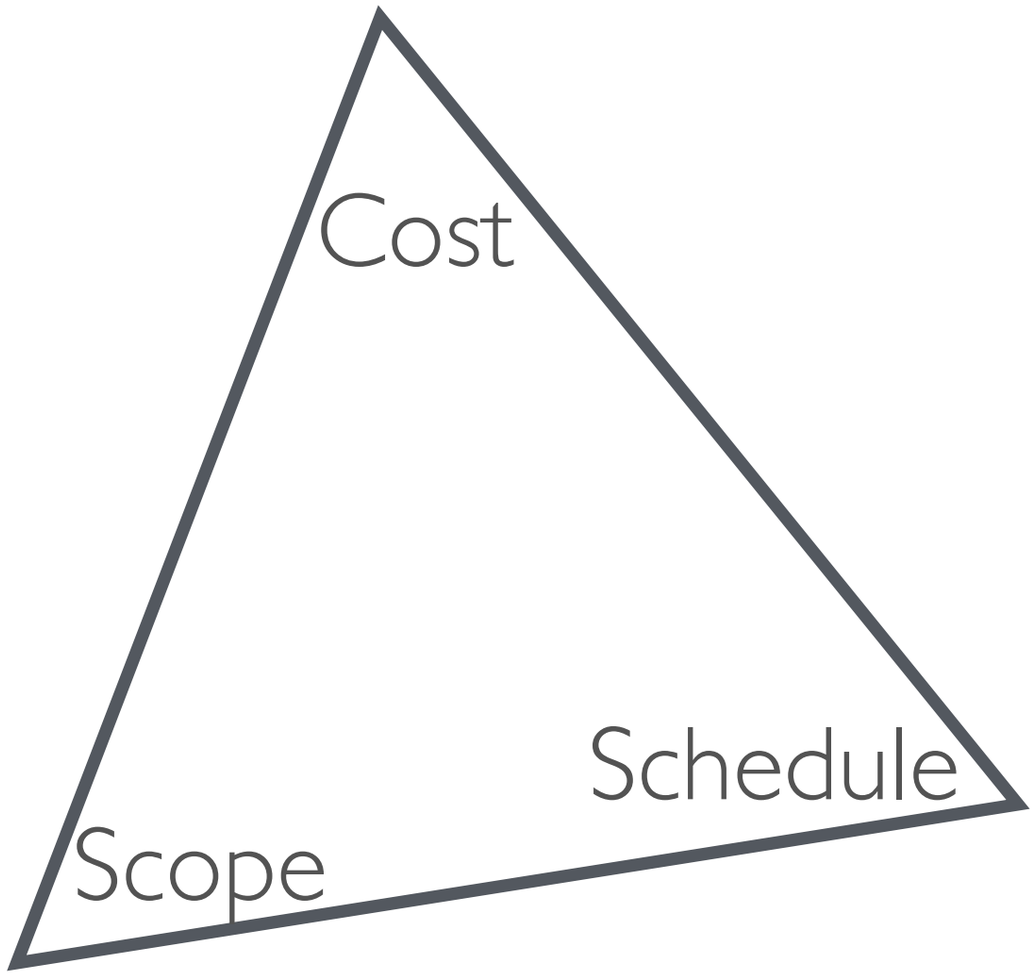


CONSTRAINTS



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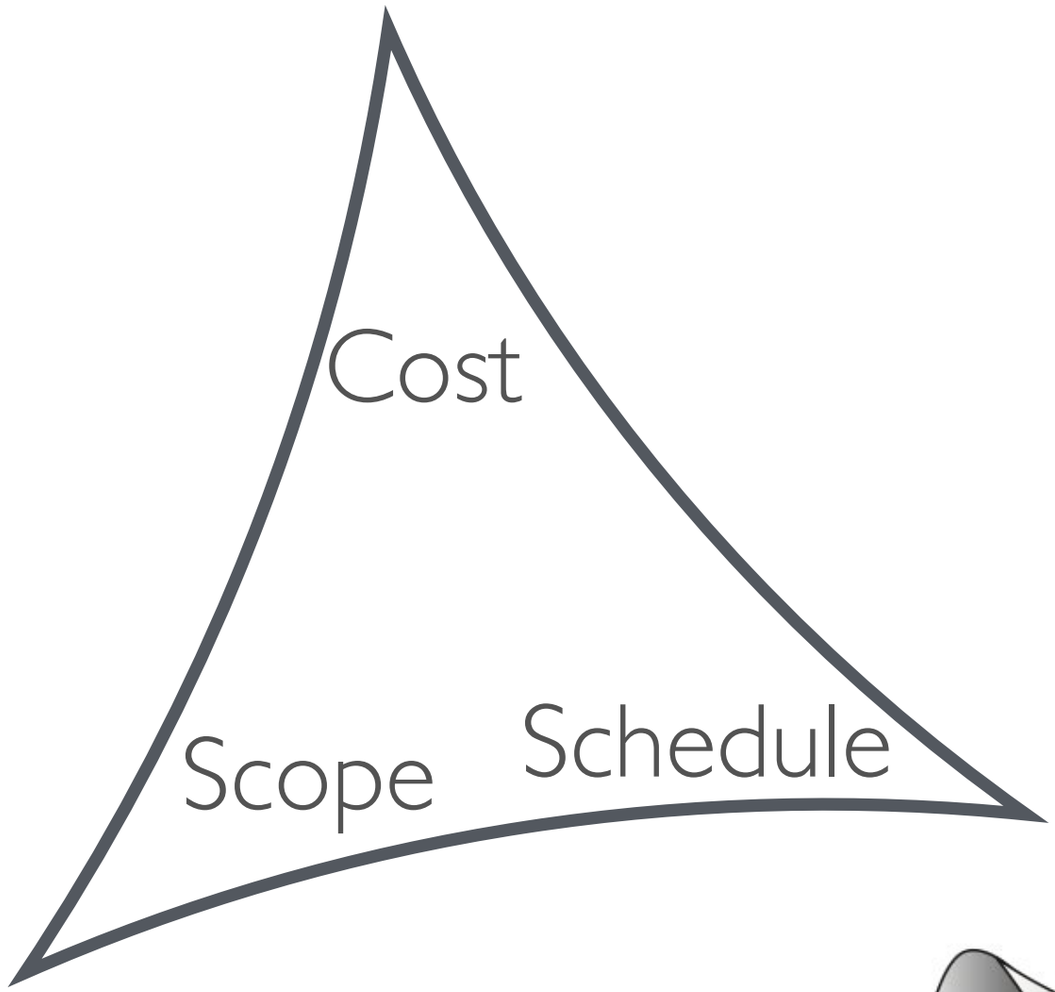

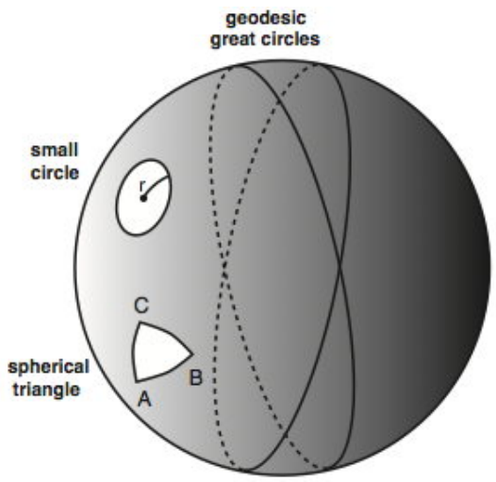

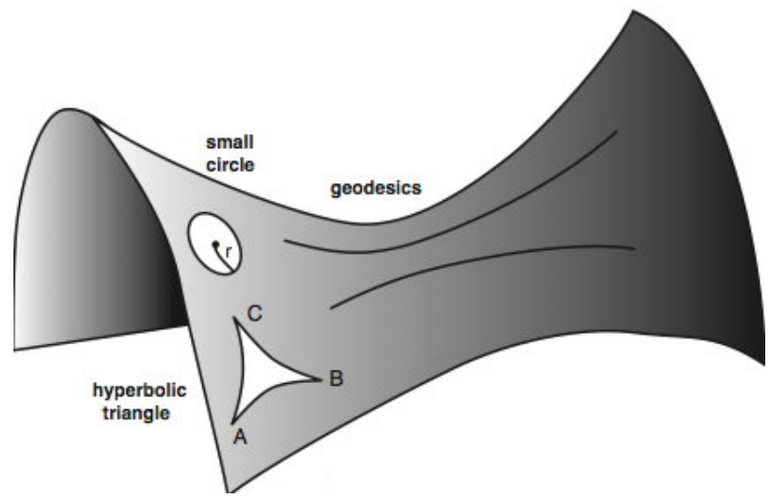

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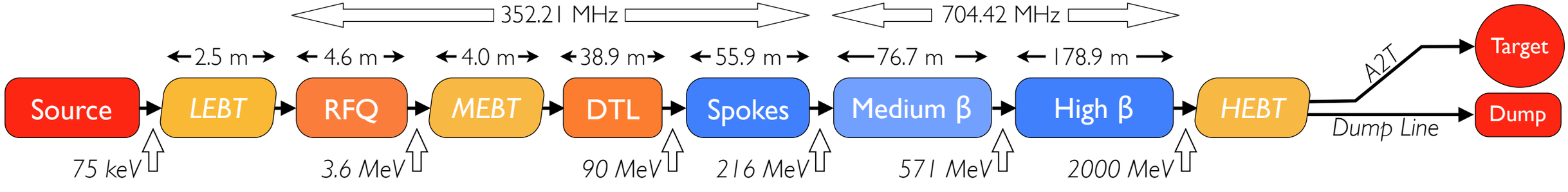
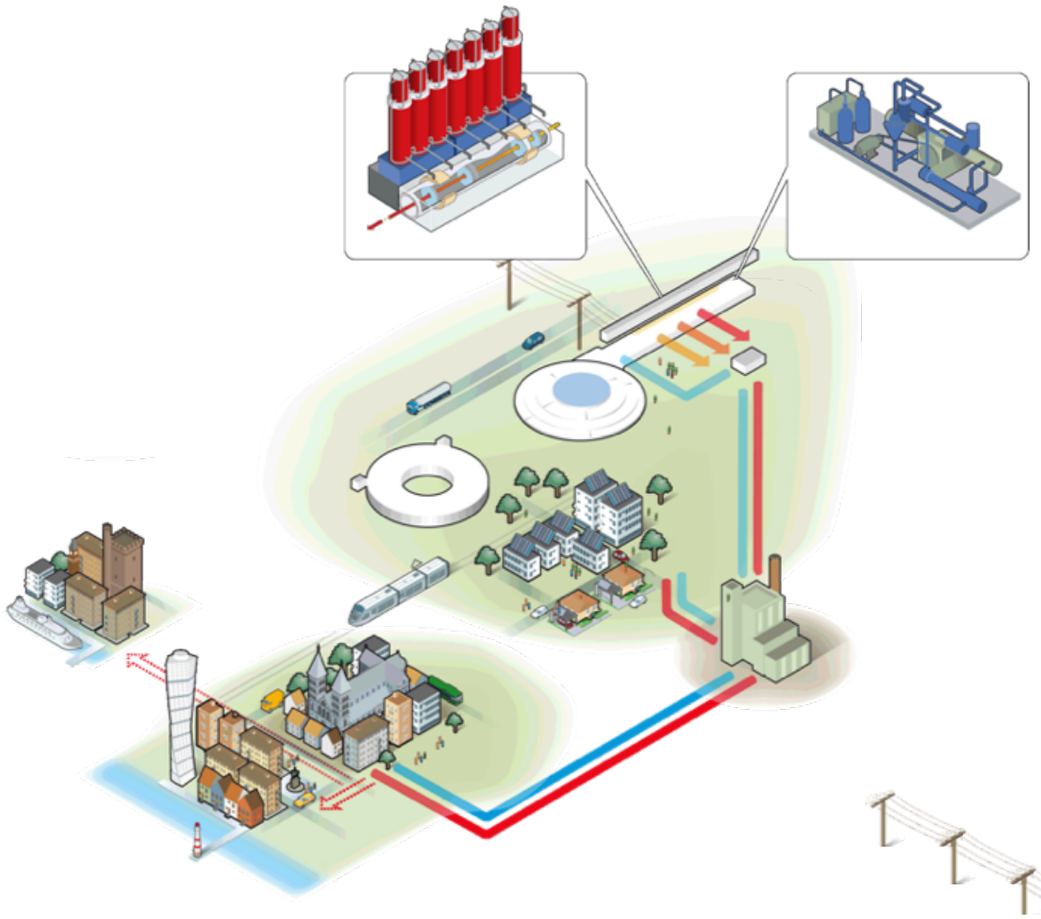
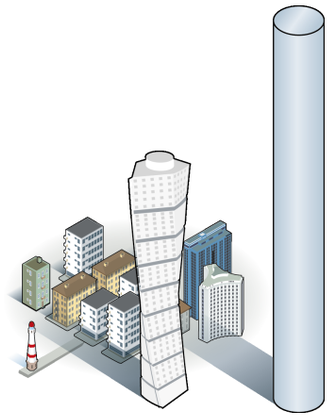
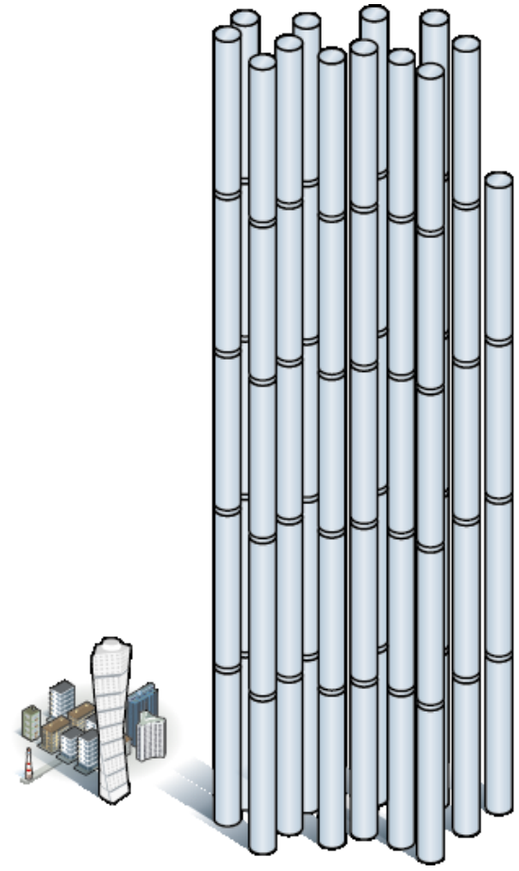


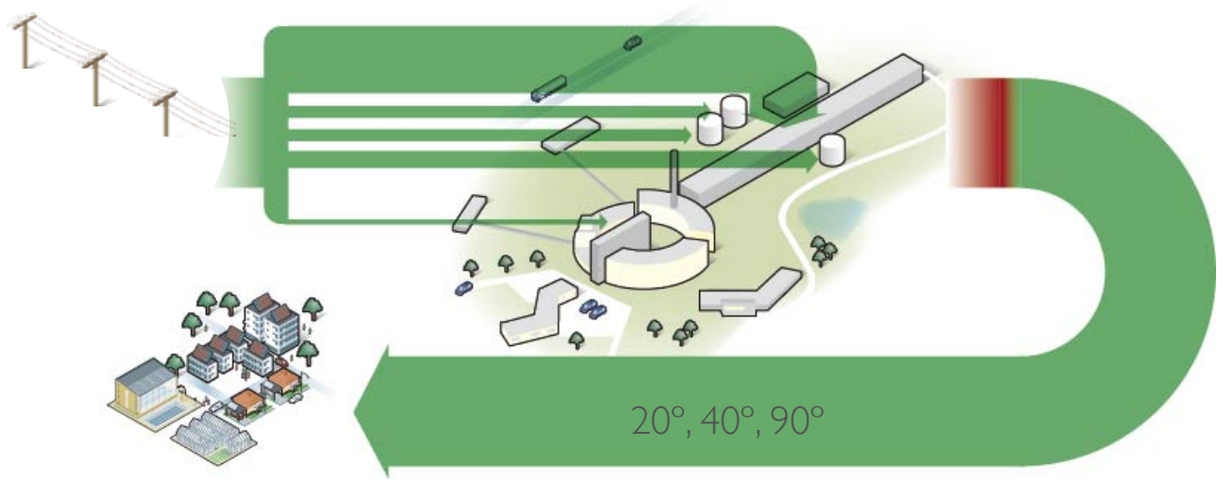
	Length	No. Magnet	No. Cavs	β Geometric	No. Sections	Power (kW)
LEBT (from Plasma)	2.7431	2 Solenoids	—	--	1	—
RFQ	4.545	—	1	--	1	1600
MEBT	3.986	11 Quads	3	--	1	15
DTL	38.881		5	--	5	2200
LEDP + Spoke	55.86	26 Quads	26	0.50 (Optimum)	13	330
Medium Beta	76.68	18 Quads	36	0.67	9	870
High Beta	178.920	42 Quads	84	0.86	21	1100
Contingency + HEDP	132.251	32 Quads	—	(0.86)	15	—
DogLeg	64.355	12 Quads + 2	—	—	1	—
A2T	44.743	6 Quads + 8	—	—	1	
	602.9641					

RESPONSIBLE, RENEWABLE, RECYCLABLE (RELIABLE)



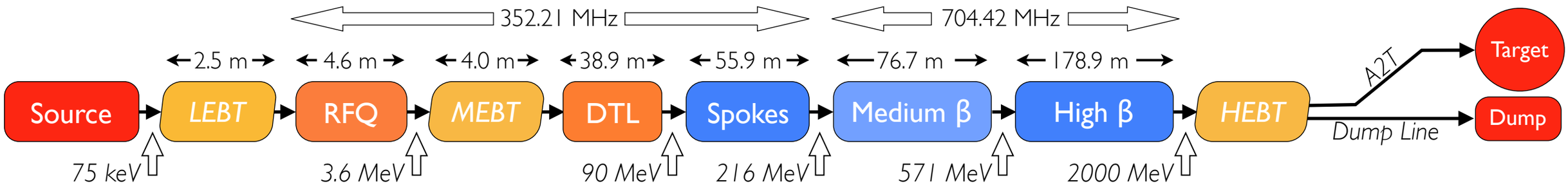






Colin Carlile, Thomas Parker

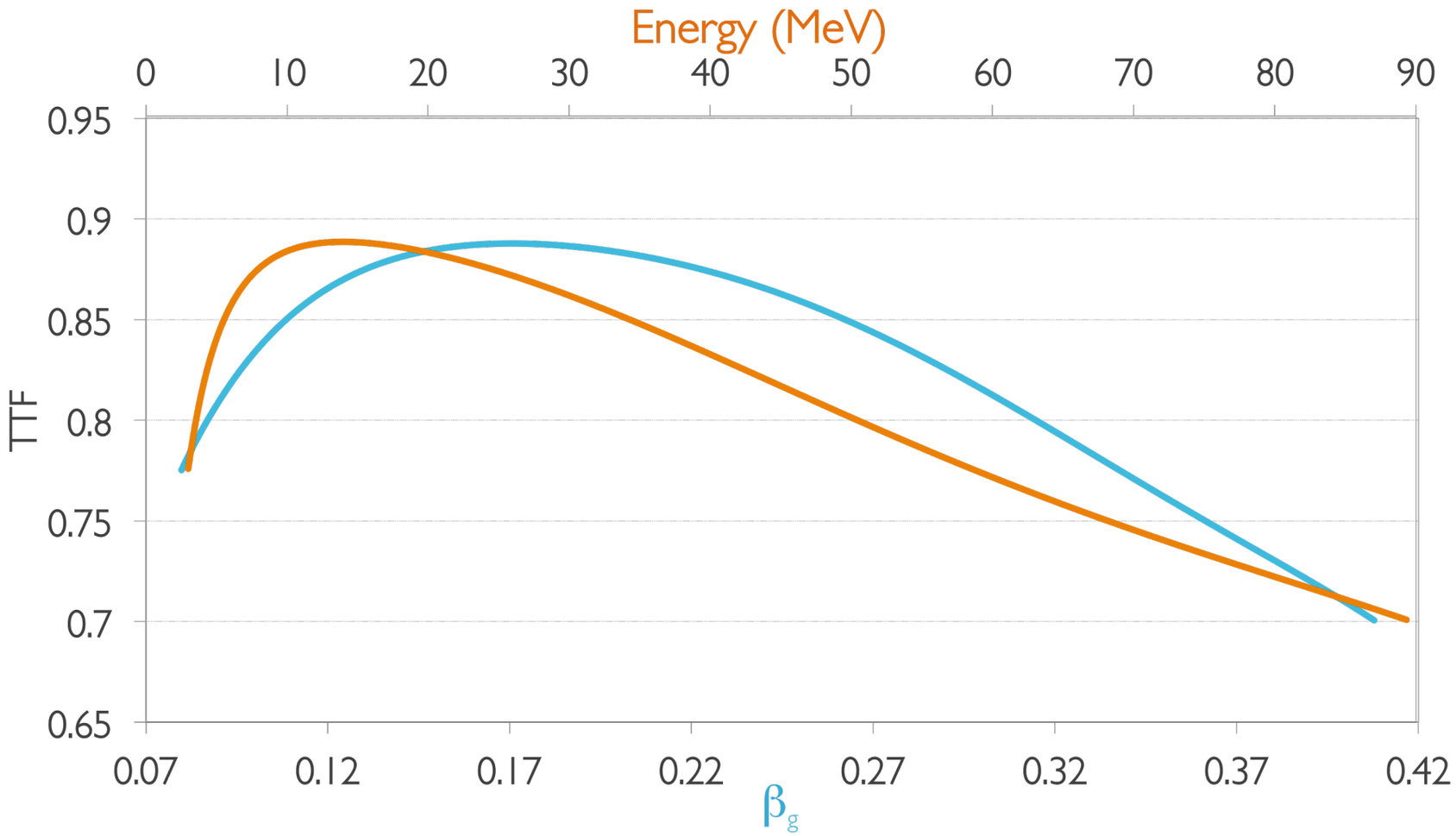
PAST ESSRIS



Front End Cooling	✗
Magnet and coupler cooling	✗
Klystron and load cooling	✗
LLRF, Modulator, Klystron and Load design	✗
Cryoplant	✗
Beam physics	✗

Transition Energies

- Each structure type is efficient over a certain velocity range, by choosing the right transition velocity (energy)



Transit time factor vs particle β and energy in DTL

A. France, "Advanced RF Design and Tuning Methods of RFQ for High Intensity Proton Linacs", IPAC14

NCL or SCL, The transition Energy

- A normal conducting structure delivers only a fraction of the energy to the beam, while a superconducting structure delivers almost all the energy to the beam (e.g. the ESS DTL delivers 50% of the power to the beam)
  - Then why don't ESS uses SC structures at lower energies?

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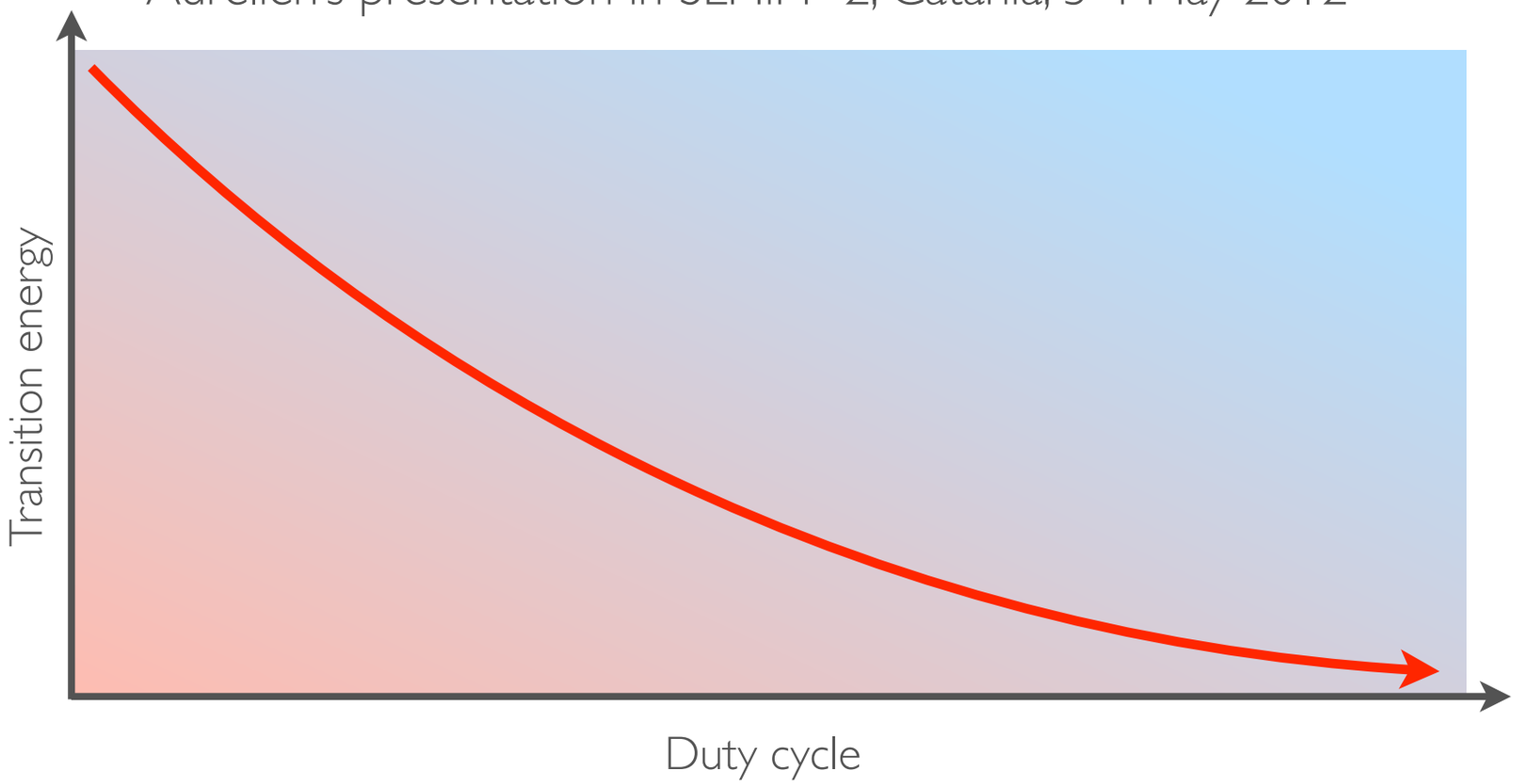
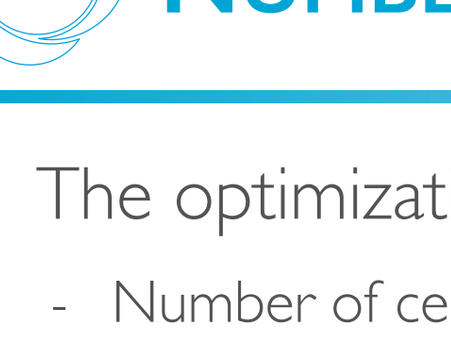
  - Then why don't ESS uses SC structures at lower energies?
    - Duty cycle and final energy are two of the main parameters to consider for choosing the right transition energy*

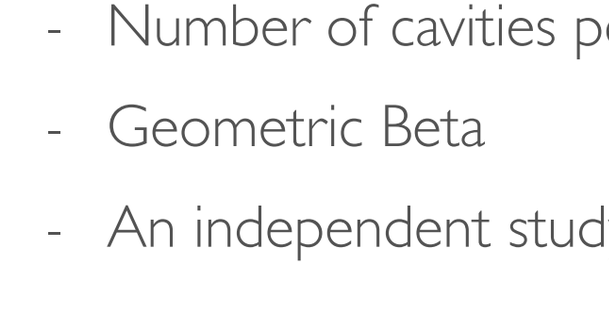


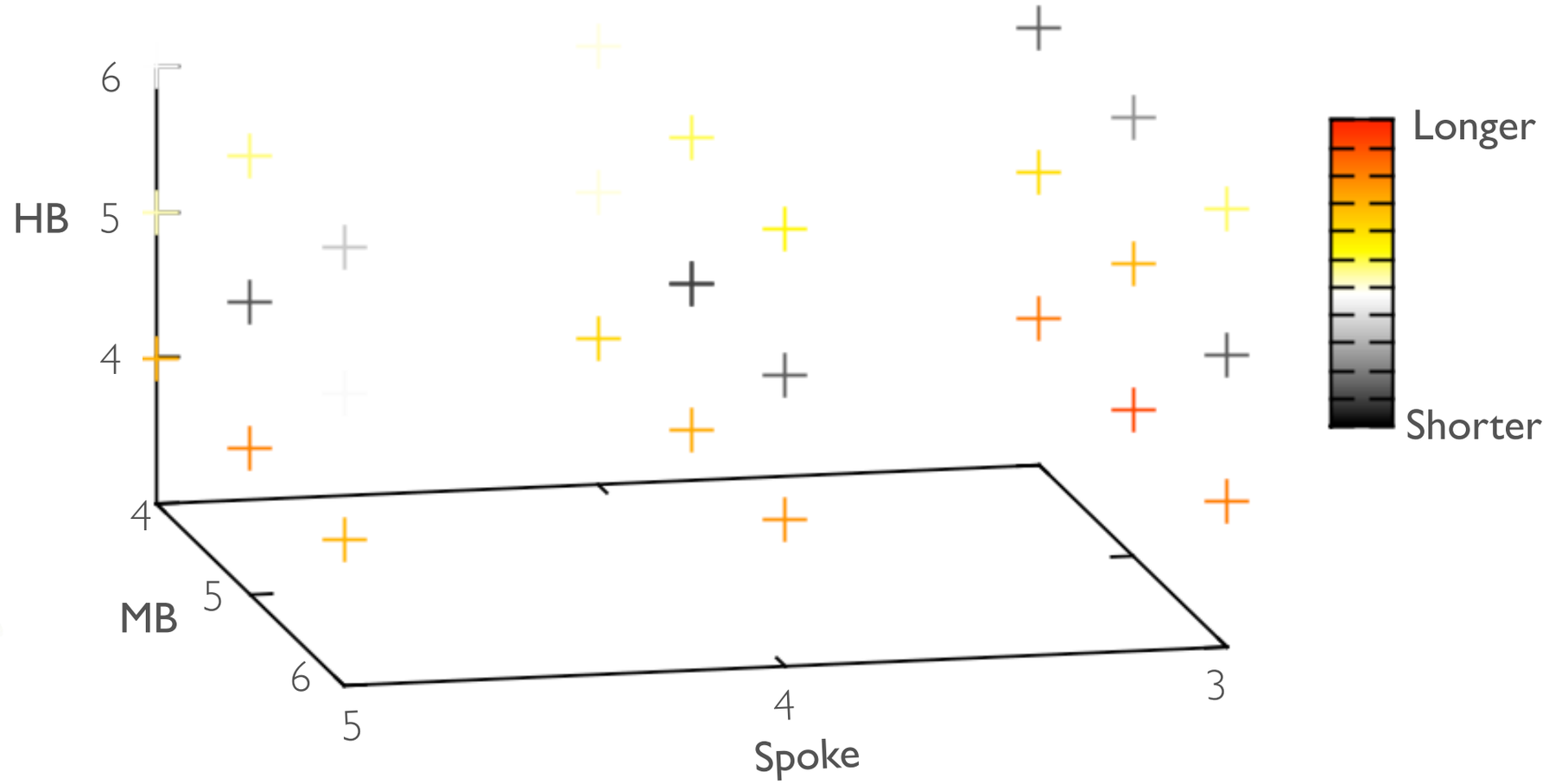
Aurélien Ponton, SLHiPP-2, Catania, 2012 May 3-4

Number of Cells

- The optimization was done on:
  - Number of cells
  - Number of cavities per cryomodule
  - Geometric Beta
  - An independent study on the number of spoke families



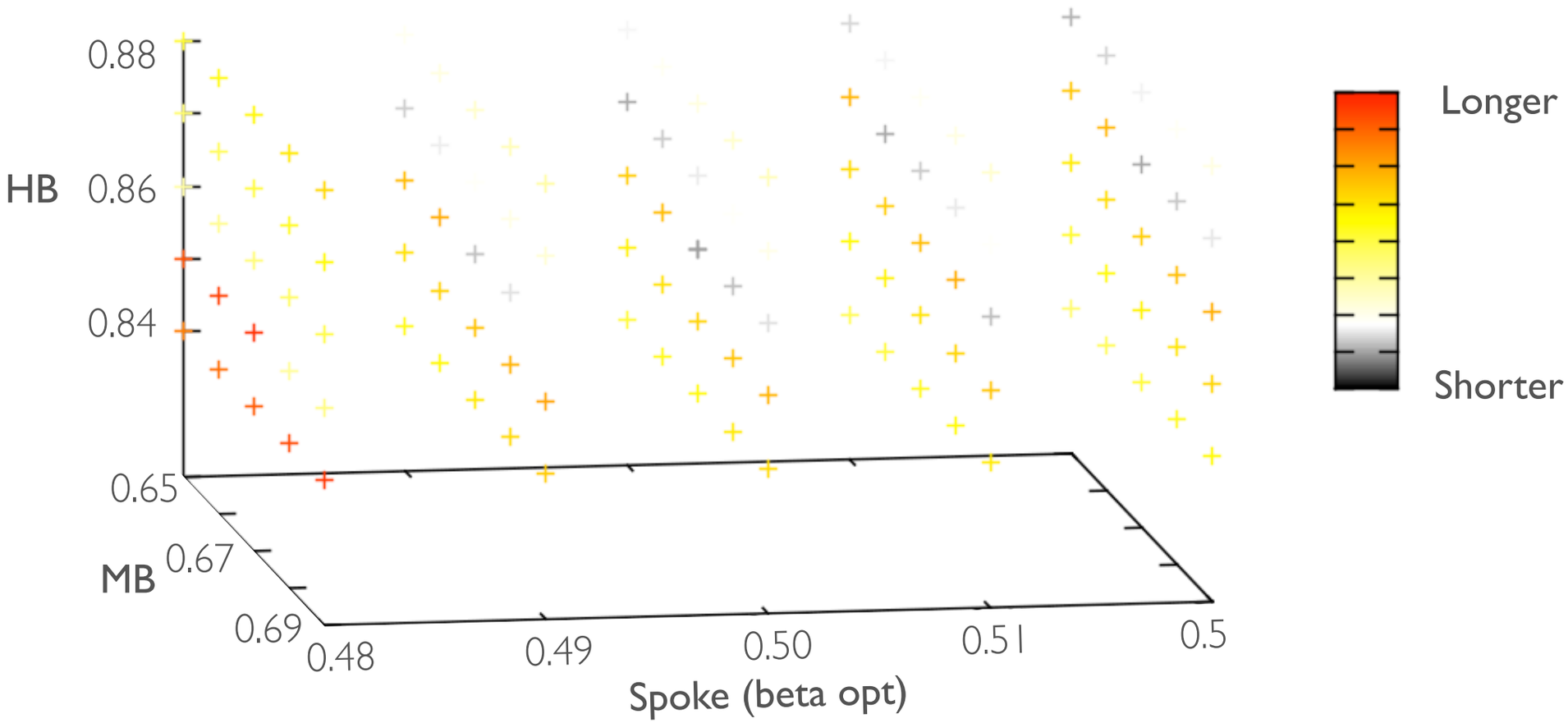


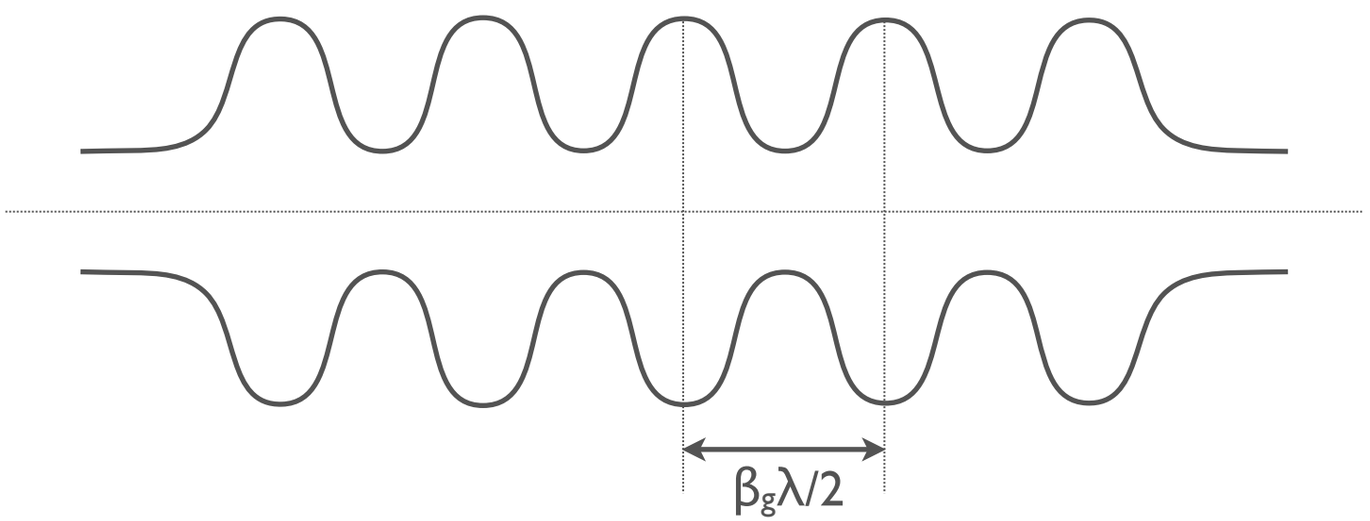


Design and Optimization of the ESS LINAC, IPAC11

Geometric Beta

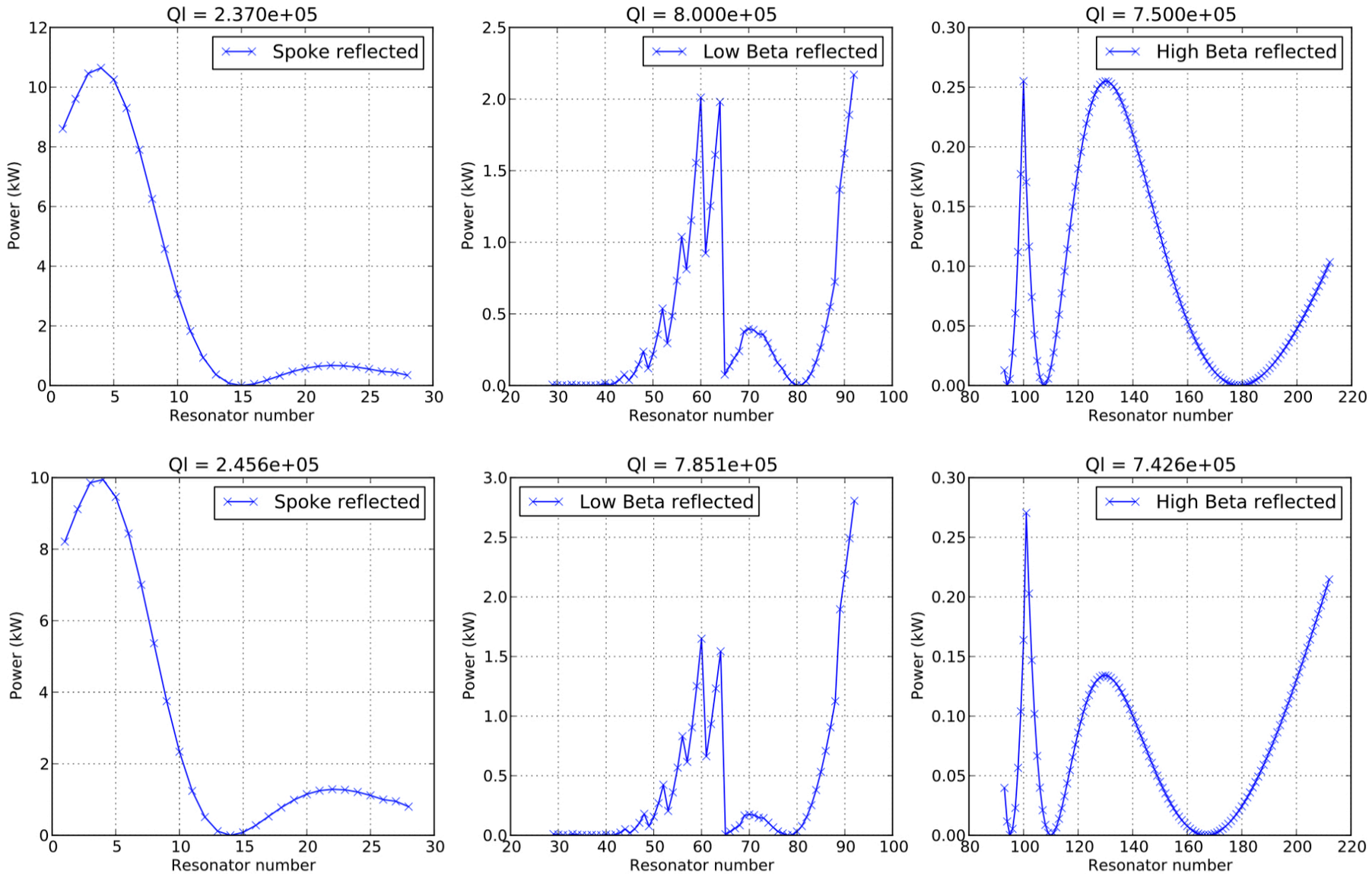
- Geometric betas of SC cavities have been optimized for the shortest linac.





COUPLING

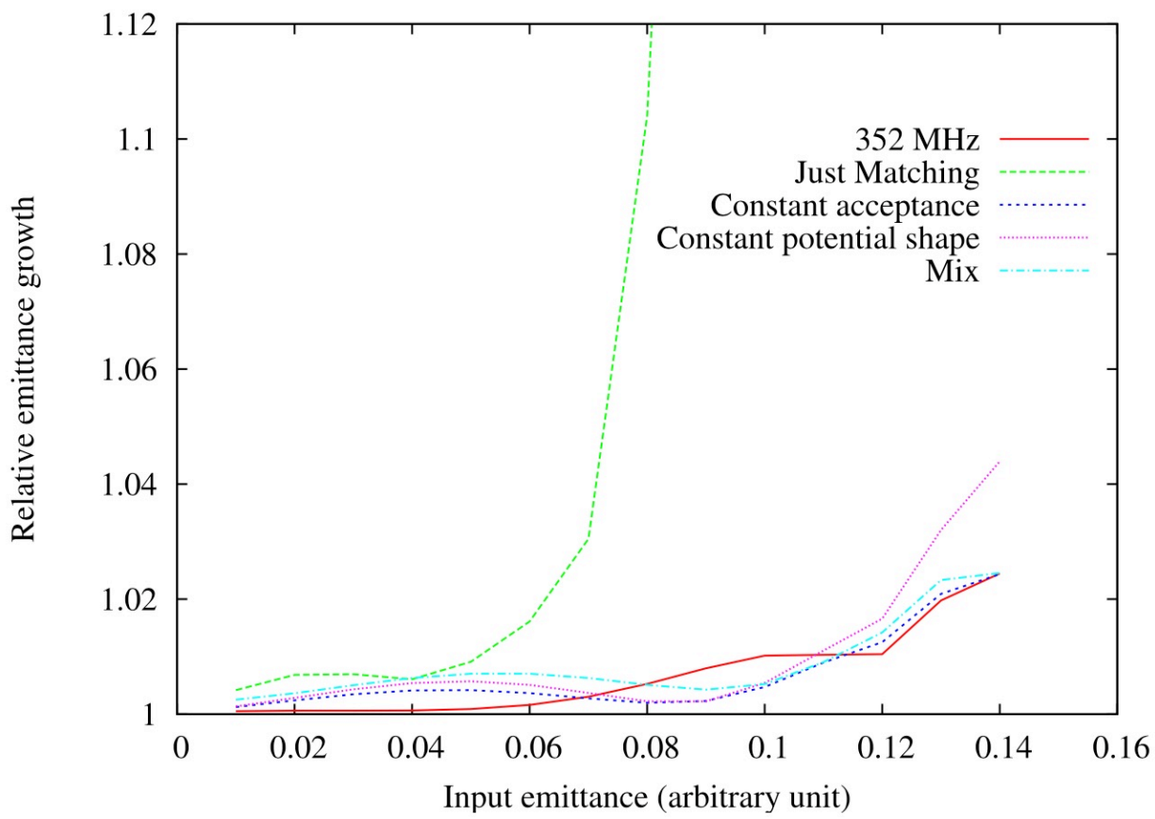
- Coupler's coupling optimization for reduced reflected power
  - Pre-2012 design



Stephen Molloy, Optimizing High-Power Input Coupler, Internal ESS Note, 2011 Nov 21

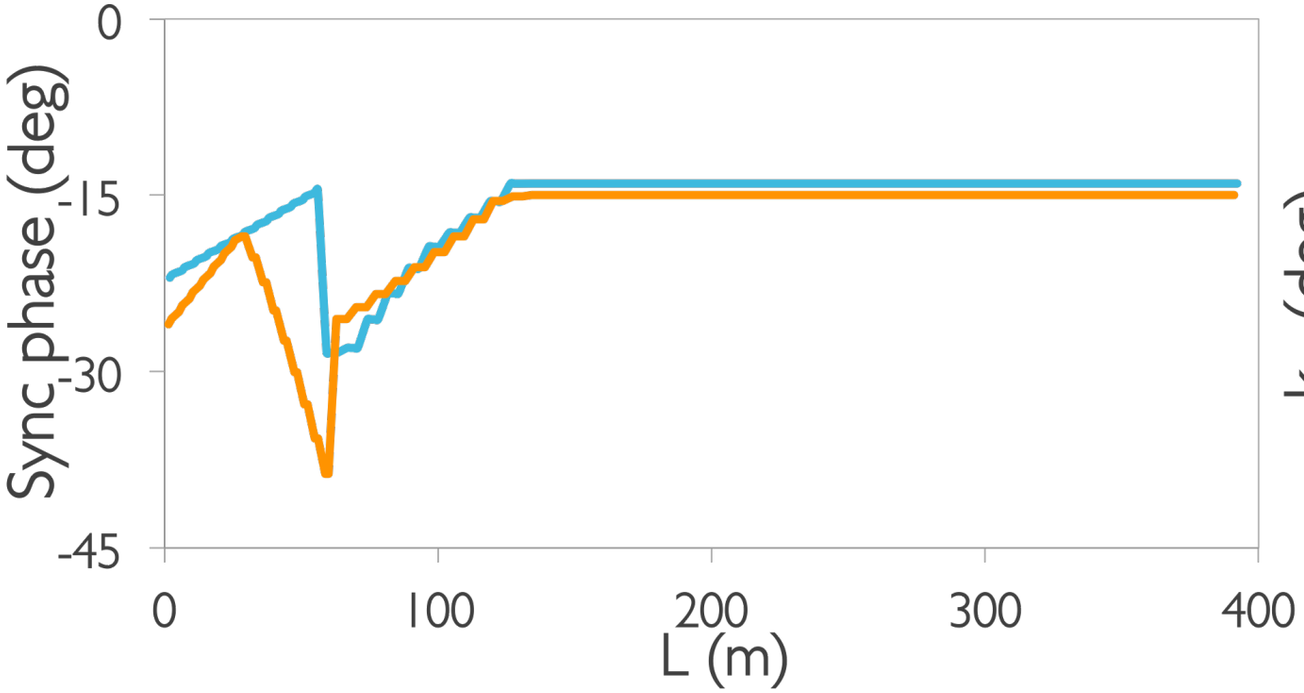
Frequency Jump

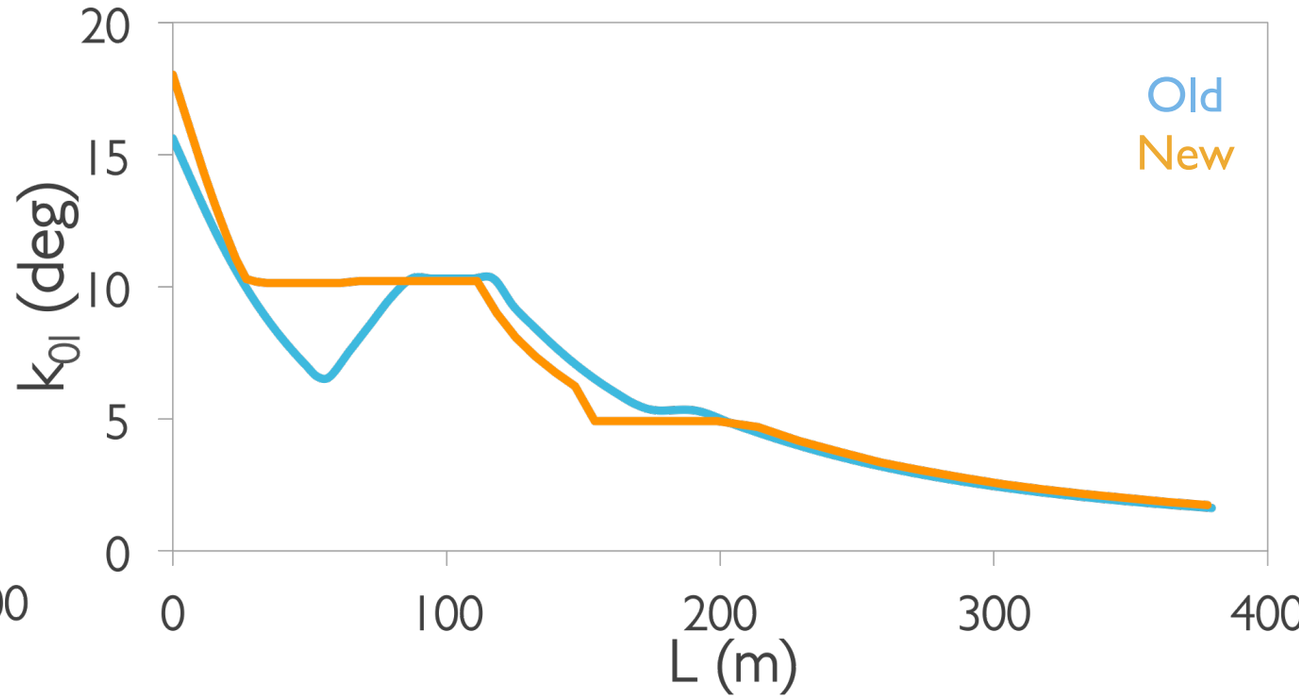
- Previous methods of handling the frequency jump in linacs*:
  - Local Matching
    - Adjusting the phase advance smoothness locally
  - Constant potential shape
    - Adjusting the sync phase and amplitude such that the potential well keeps the same shape
  - Constant acceptance
    - Adjusting the sync phase and amplitude such that the acceptance area stays the same
  - Constant acceptance in phase
    - Adjusting the sync phase and amplitude such that the acceptance in phase (not energy) is the same
- ESS high acceleration:
  - Phase advance smoothing starting in the upstream part



R. Duperrier, N. Pichoff and D. Uriot , Frequency jump in an ion linac, PRST-AB 10, 084201 (2007)

Frequency Jump II



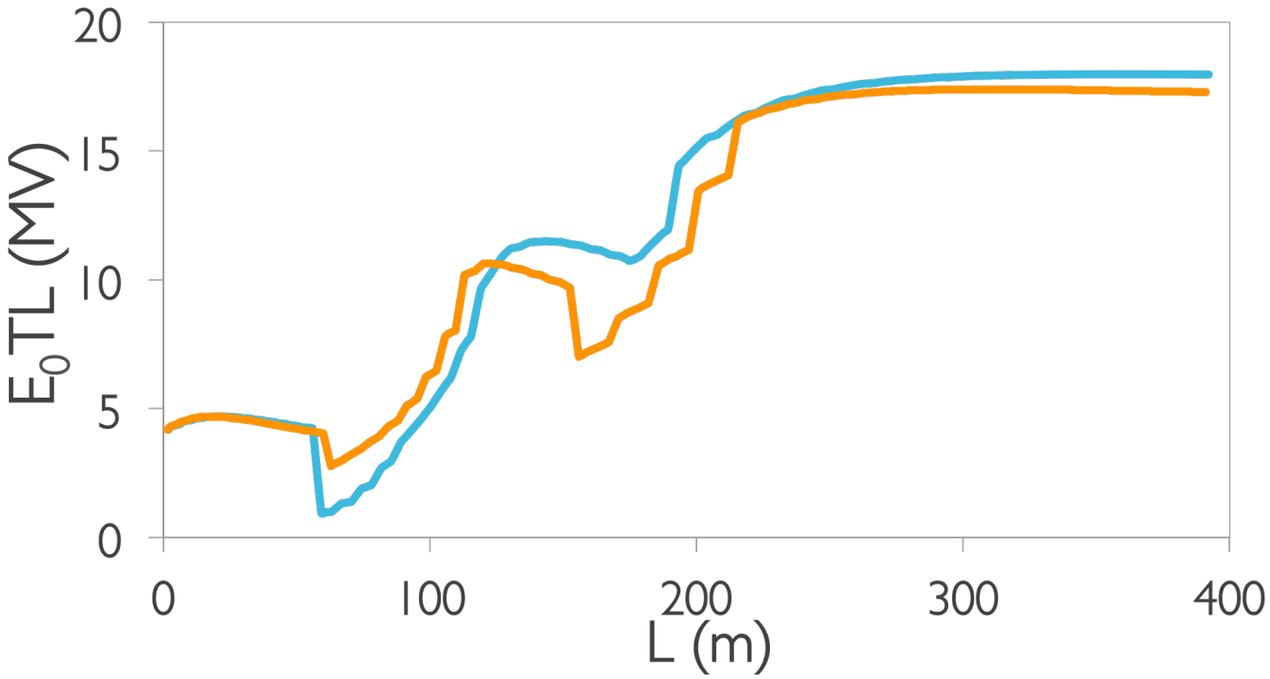


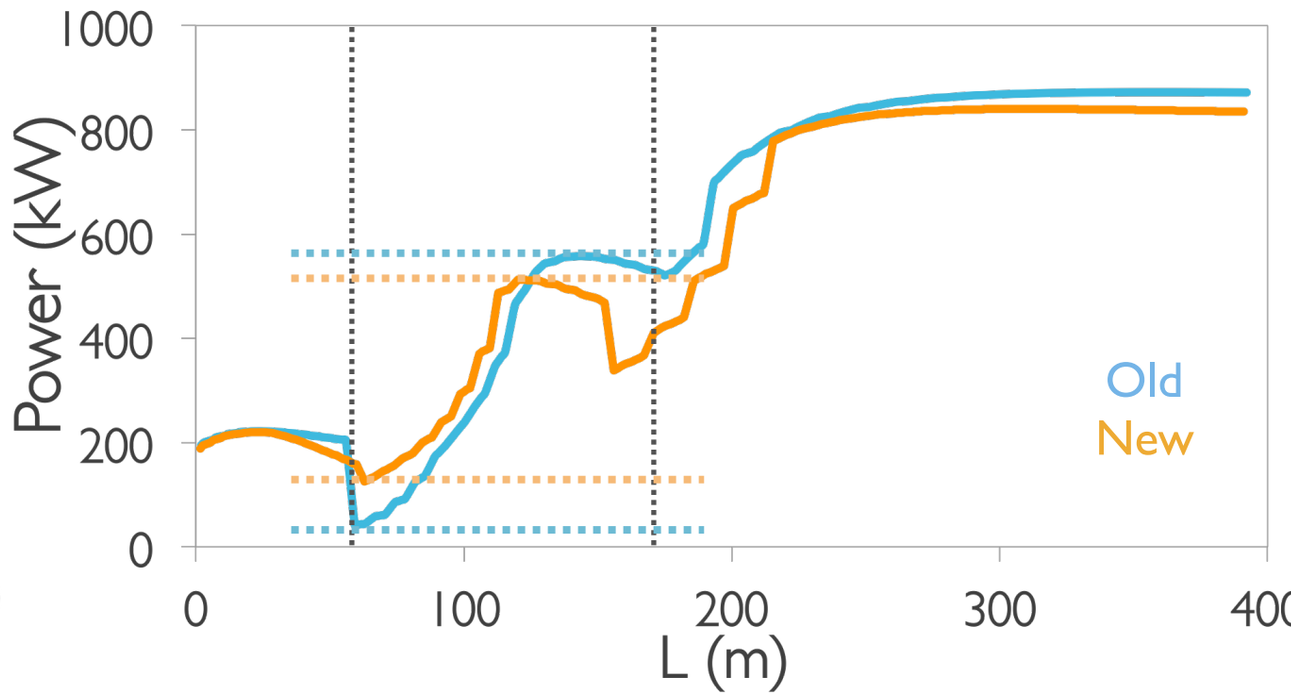
$$\phi_{704.42} = 2 \times \phi_{352.21}$$

$$\lambda_{704.42} = 0.5 \times \lambda_{352.21}$$

$$k_{0l}^2 = \frac{2\pi q E_{acc} T \sin(-\phi_s)}{mc^2 \beta_s^3 \gamma_s^3 \lambda}$$

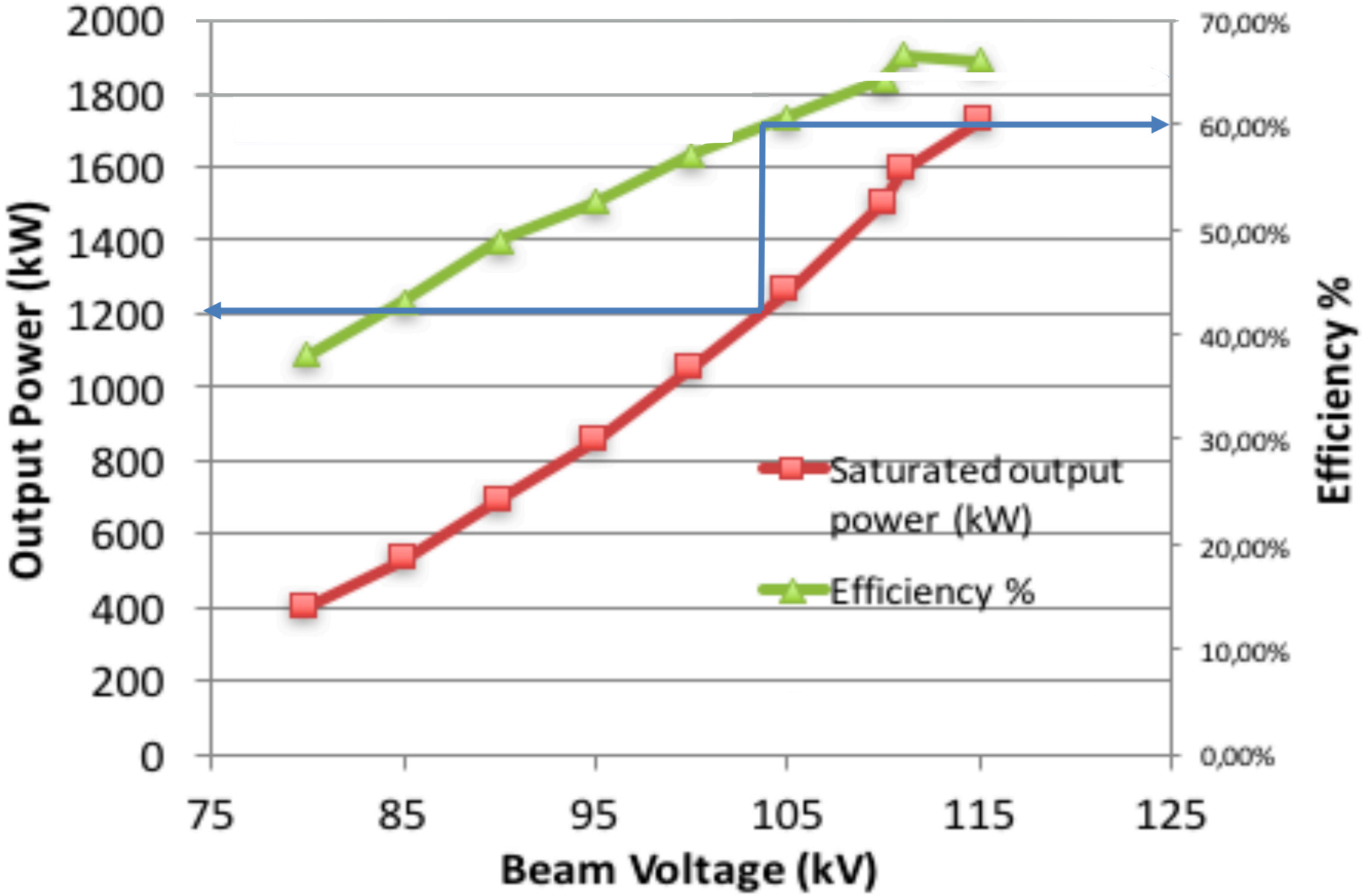
Frequency Jump III





Power ratio in MBL: ~4 vs. ~13

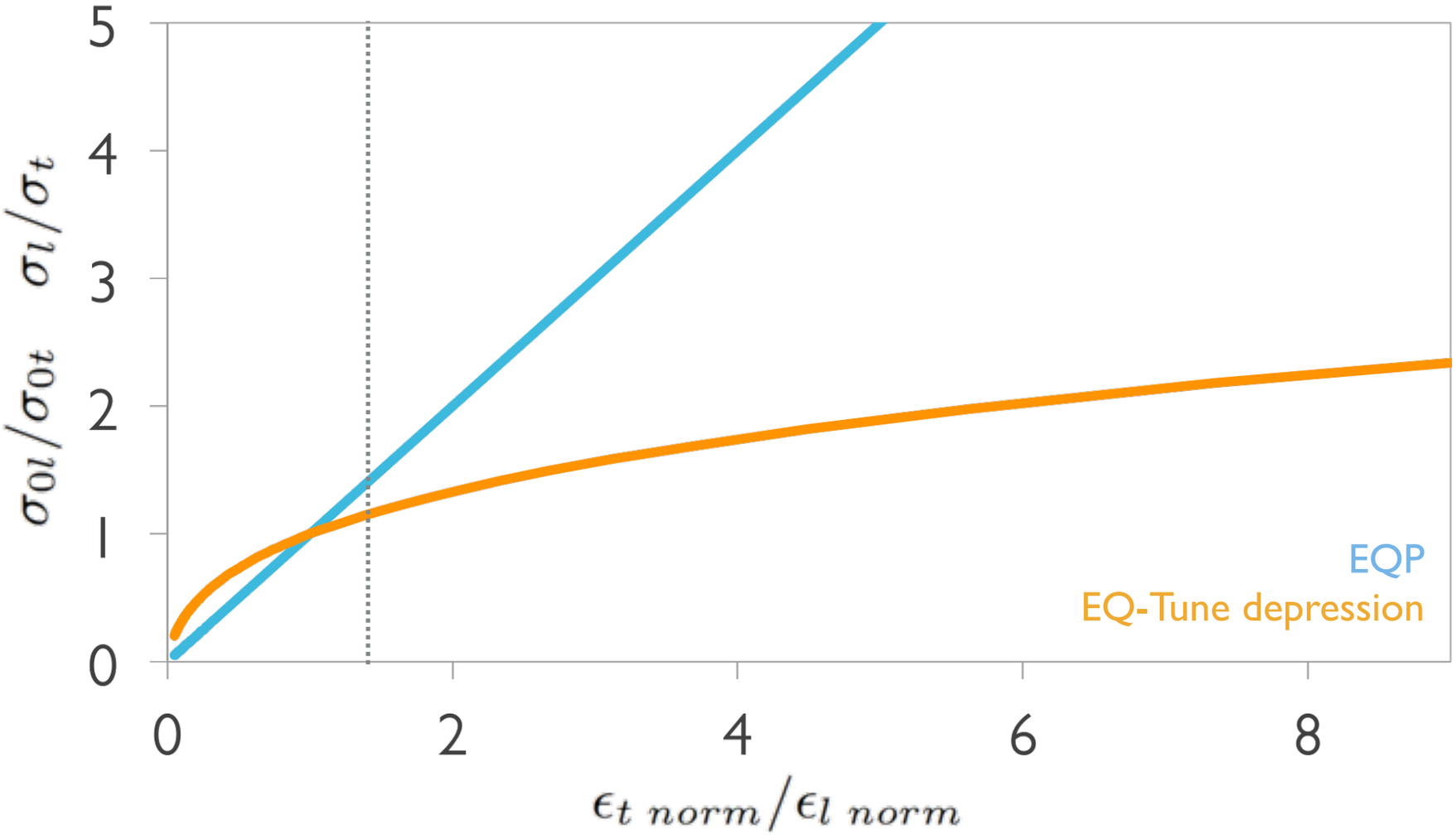
KLYSTRON EFFICIENCY



For more details please refer to the talk by Morten Jensen, 4th ESSRI

Optimized Beam Physics

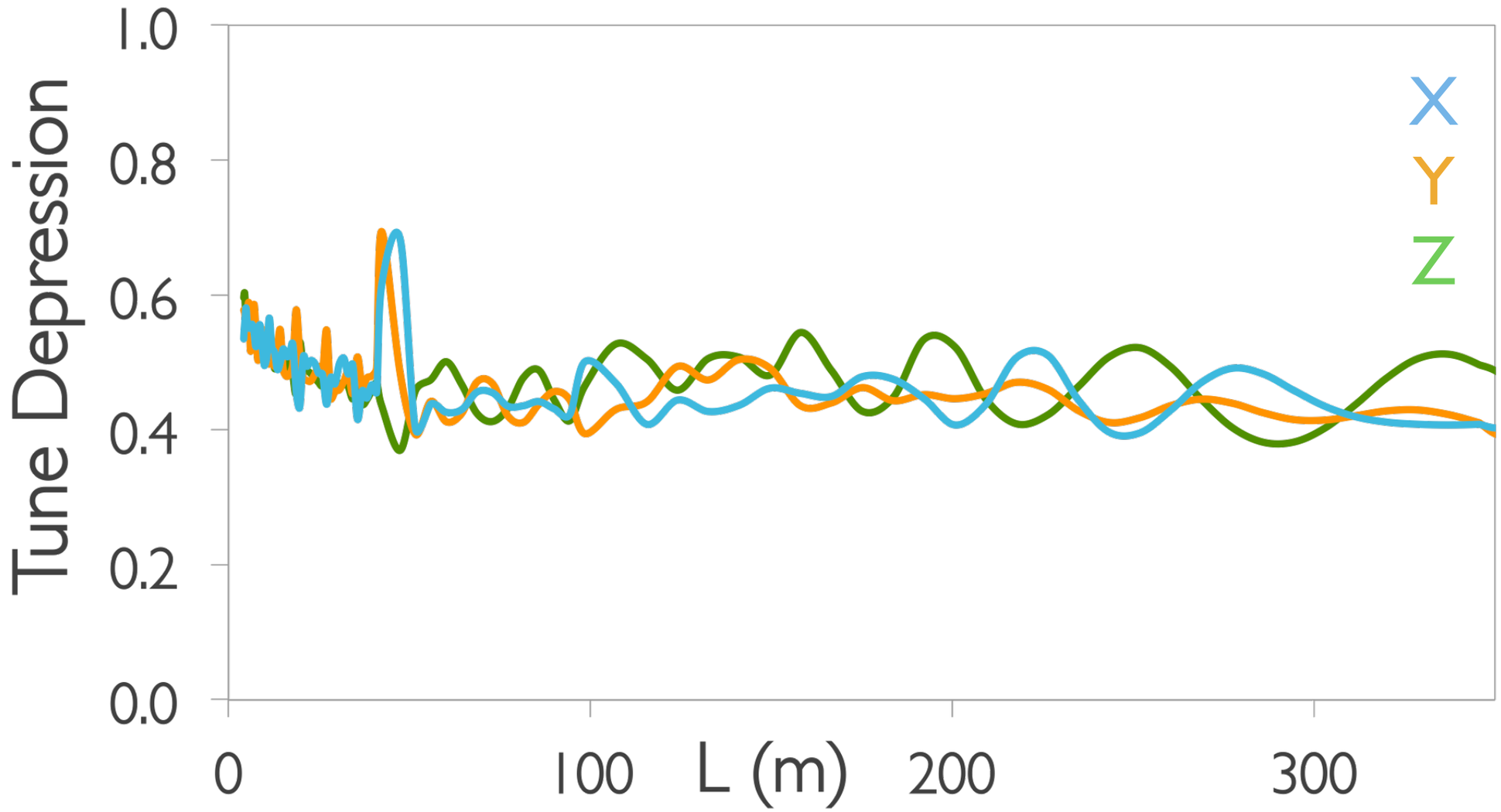
- At higher longitudinal emittance with EQT one needs lower longitudinal phase advance, i.e. one can have more acceleration



Equipartition vs. Equi-tune depression

M. Eshraqi, J-M, Lagniel, "On the Choice of Linac Parameters for Minimal Beam Losses", IPAC 2013

Effect on the Beam



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SUMMARY

- ESS started in a green field
  - Sustainability was part of the mandate
  - Sustainability was incorporated in the design from the beginning

- Major energy consuming components have been optimized for better energy management in close collaboration with local companies

- Even smaller energy savings have been implemented, saving also on the energy consumed for production

- Sustainability is bigger than our species

Thank you for your attention

https://showyourstripes.info