DESIGNING COST OPTIMIZED LINACS

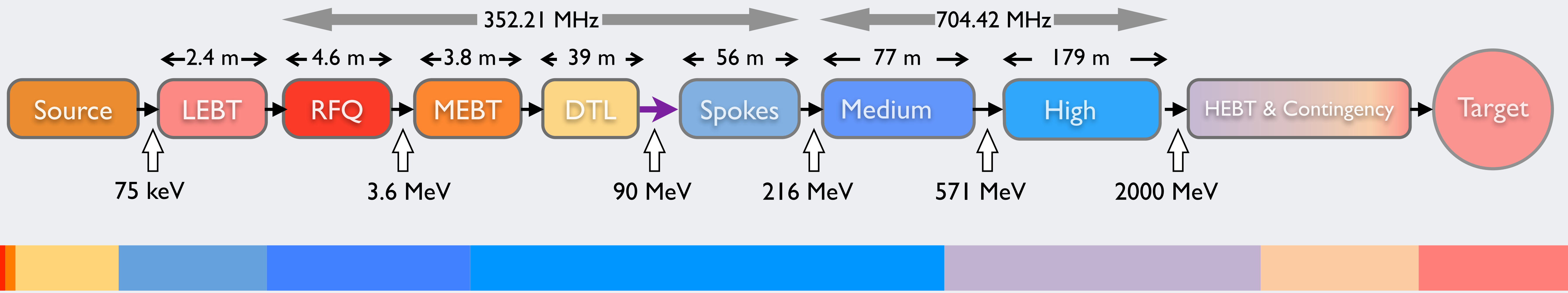
Mamad Eshraqi

LINAC 2014, Geneva, 2014 September 4

THE ESS

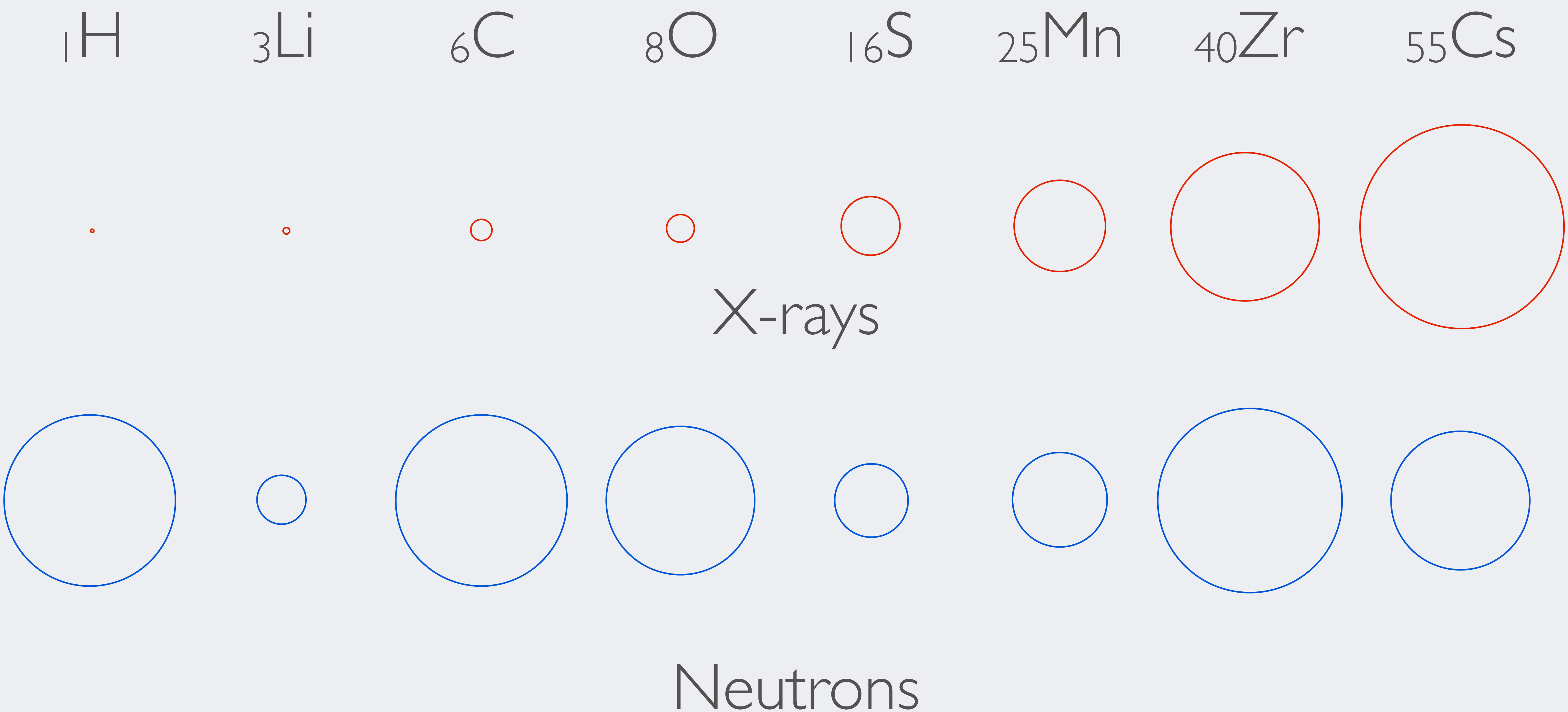
- **Power: 5 MW**
- **Energy: 2.0 GeV**
- **Current: 62.5 mA**
- **Repetition rate: 14 Hz**
- **Pulse length: 2.86 ms**
- **Duty cycle: 4%**
- **High reliability (>95%)**
- **Ions: p**

THE ESS LINAC

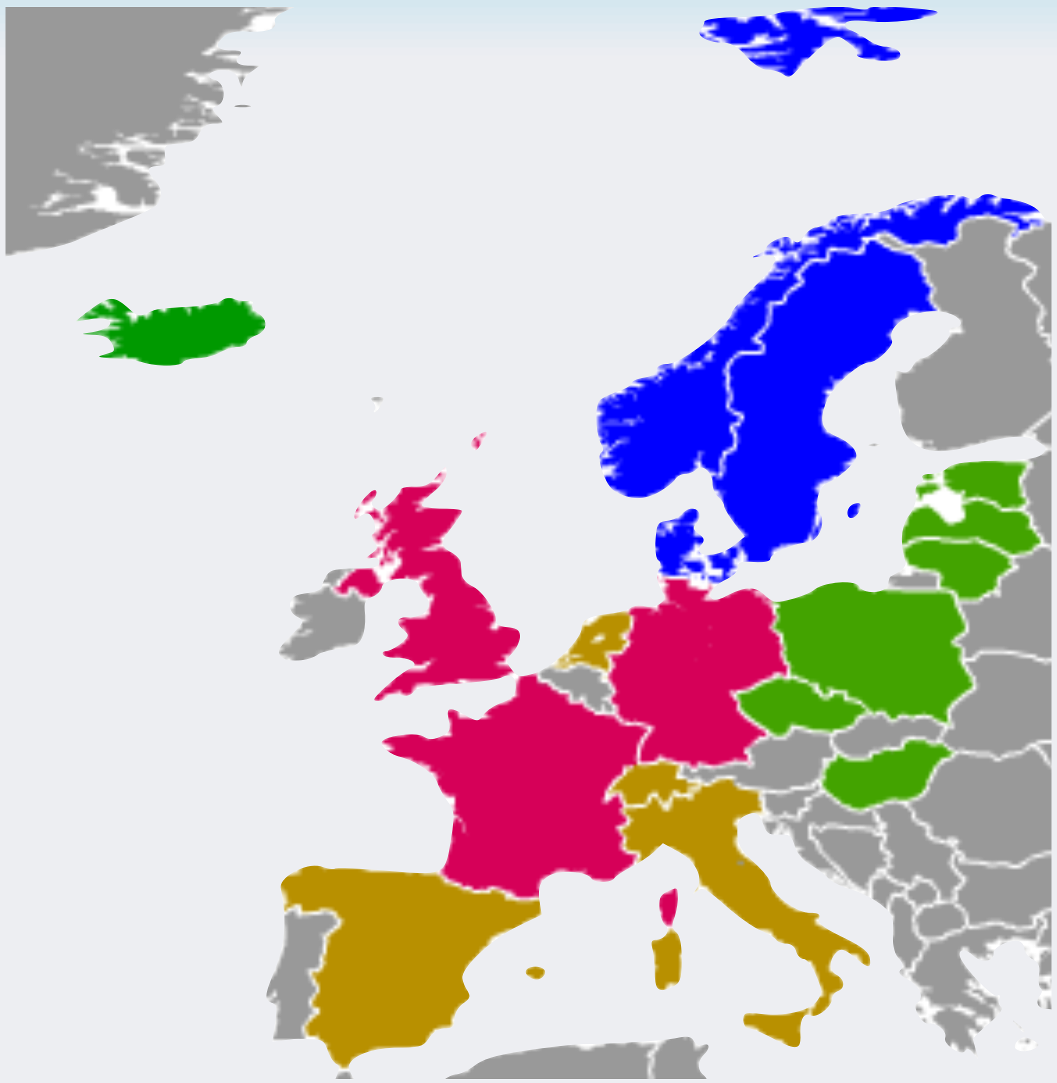


	Length (m)	W_in (MeV)	F (MHz)	β Geometric	No. Sections	T (K)
LEBT	2.38	0.075	--	--	1	~300
RFQ	4.6	0.075	352.21	--	1	~300
MEBT	3.81	3.62	352.21	--	1	~300
DTL	38.9	3.62	352.21	--	5	~300
LEDP + Spoke	55.9	89.8	352.21	0.50	13	~2
Medium Beta	76.7	216.3	704.42	0.67	9	~2
High Beta	178.9	571.5	704.42	0.86	21	~2
Contingency	119.3	2000	704.42	(0.86)	14	~300 / ~2

WHY NEUTRONS

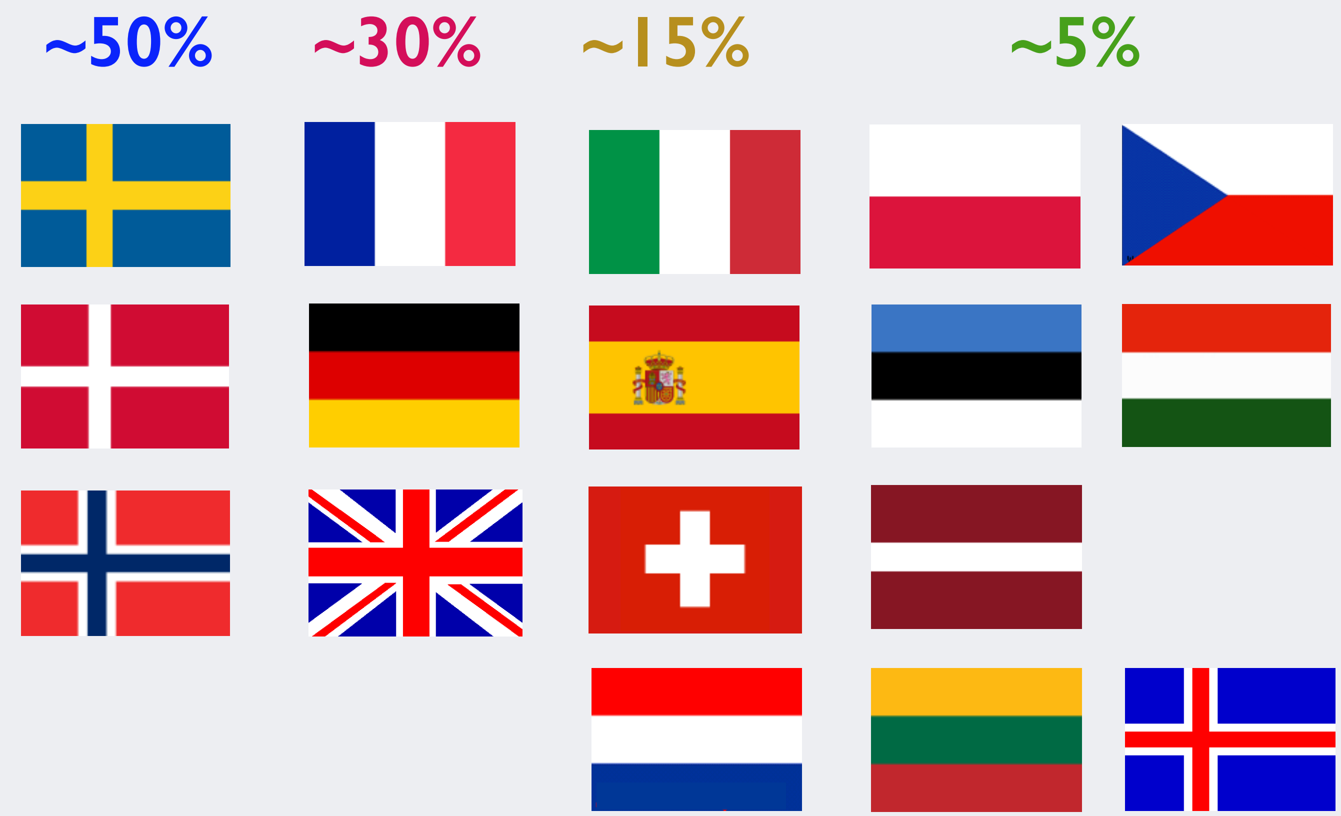


INTERNATIONAL COLLABORATION



17 Partners today

Investment: 1.843 G€ (indexed)
Operation: 140 M€
Decommissioning: 346 M€



Complete and operate the best and ***most powerful neutron source*** *in the world by the end of* ***the decade****.*

European Spallation Source

ESS GROUNDBREAKING

Jan Björklund (Swedish Research minister), Sofie Carsten Nielsen (Danish Research minister)
2014 September 2

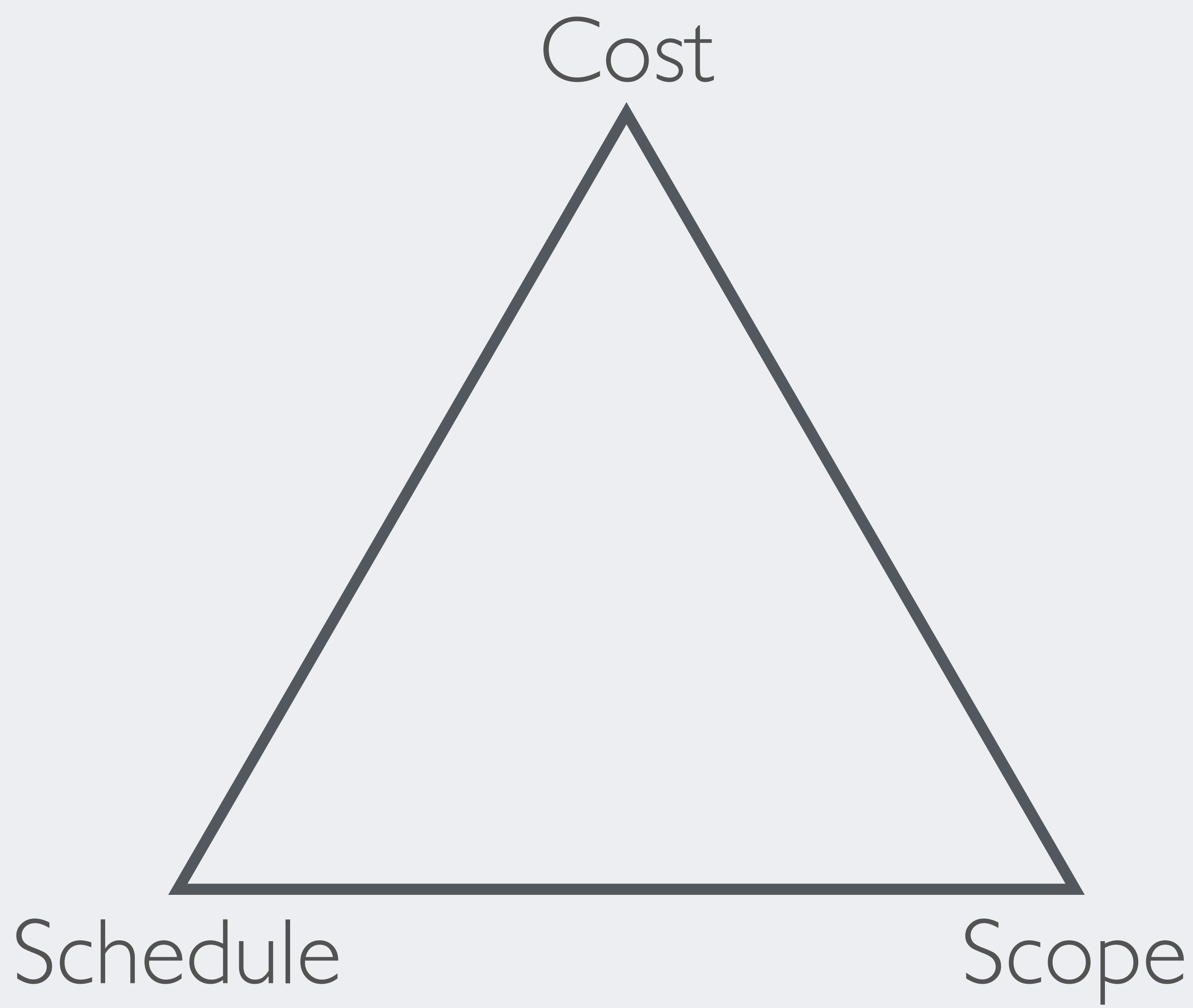
DEFINING THE GOAL

I believe that this nation should commit itself to achieving the goal, before ***this decade*** *is out, of* ***landing a man on the moon*** *and returning him safely to the earth.*

President Kennedy

Address to Congress on Urgent National Needs, 1961 May 25

CONSTRAINTS



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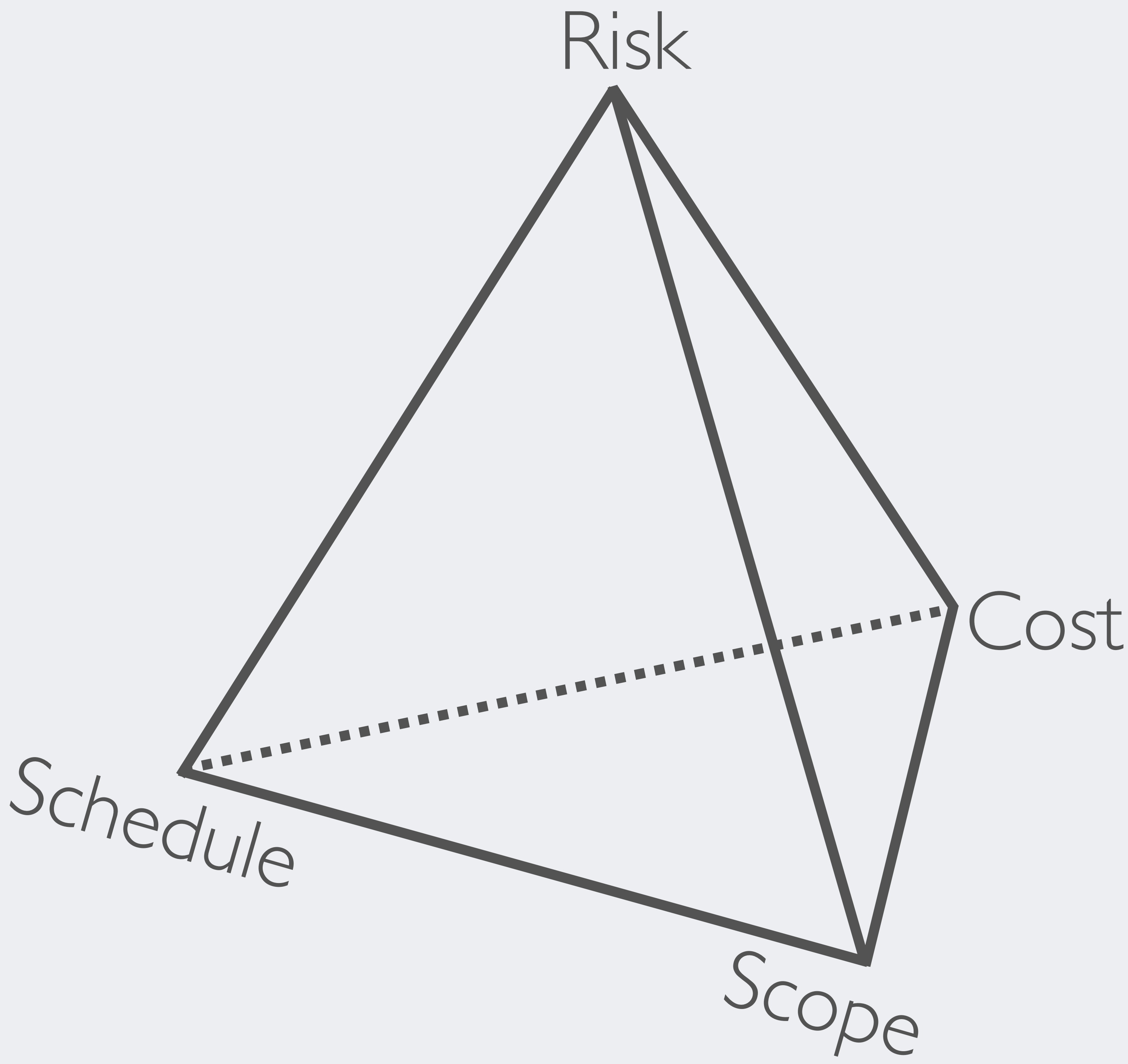


BEAM POWER

- Assuming a defined beam power:

$$P_b = I_b \cdot W_{linac}$$

$$I_b = I_{max} \cdot f_{pulse} \cdot L_{pulse} = I_{max} \cdot d.c.$$

$$W_{linac} = q \sum_i E_{acc_i}\ TTF_i\ L_i\ \cos(\phi_i)$$

ESS Accelerator's chief engineer Dave McGinnis

BEAM POWER

$$L_i = M_{cell_i} \cdot \frac{\beta_{g_i} \lambda_i}{n_i}$$

$$E_{acc_i} = E_{pk} \left(\frac{E_{acc}(\beta_g)}{E_{pk}} \right) = E_{peak} \cdot f_{acc}(\beta_g)$$

$$P_b = q \cdot I_{max} \cdot d.c. \cdot k \cdot E_{peak} \cdot \sum_i f_{acc}(\beta_g)\ T_i\ M_{cell_i} \cdot \frac{\beta_{g_i} \lambda_i}{n_i}\ \cos(\phi_i)$$

PARAMETERS TO PLAY WITH

$$P_b = q \cdot I_{max} \cdot d.c. \cdot k \cdot E_{peak} \cdot \sum_i f_{acc}(\beta_g)\ T_i\ M_{cell_i} \cdot \frac{\beta_{g_i}\lambda_i}{n_i}\ \cos(\phi_i)$$

E_{pk} : Peak electric surface field

I_{max} : Maximum current

$d.c.$: Duty cycle

β_g : Geometric beta

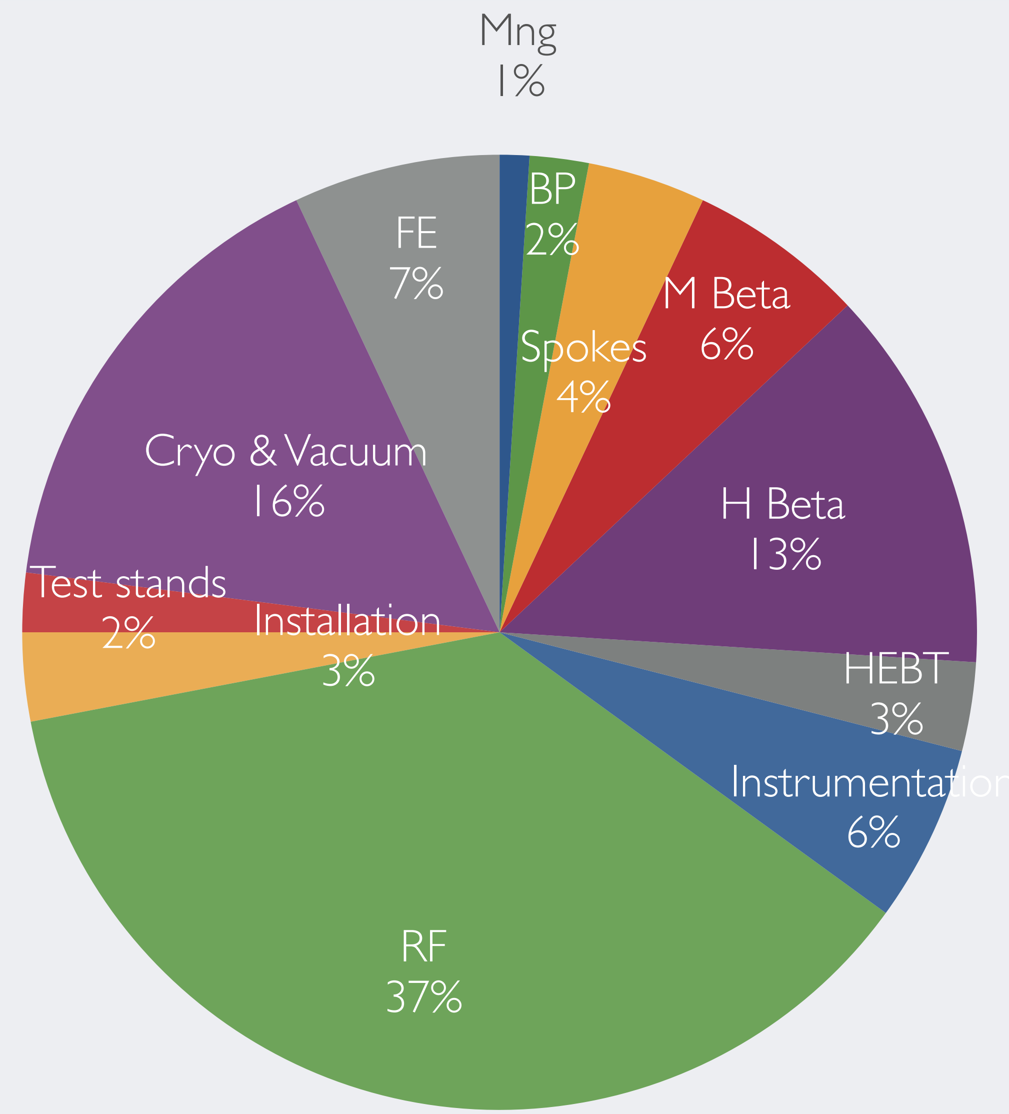
TTF : Transit time factor(by optimizing the geometric beta and transition energies)

ϕ_s : Synchronous phase

k : Scaling factor of the cavity fields wrt their max field.

COST CONTRIBUTORS

- Elliptical cryomodules occupy 19% of the cost
  - There are 45 elliptical cryomodules
  - The cryogenic plant absorbs 14% of the total cost.
- RF systems comprise 37% of the cost
  - The RF costs are distributed over five major systems
  - The elliptical section comprises 82% of the RF system cost
- For the elliptical section
  - 62% of the total cost of the linac
  - the klystrons and modulators comprise 80% of the RF system cost
  - 95% of the acceleration energy



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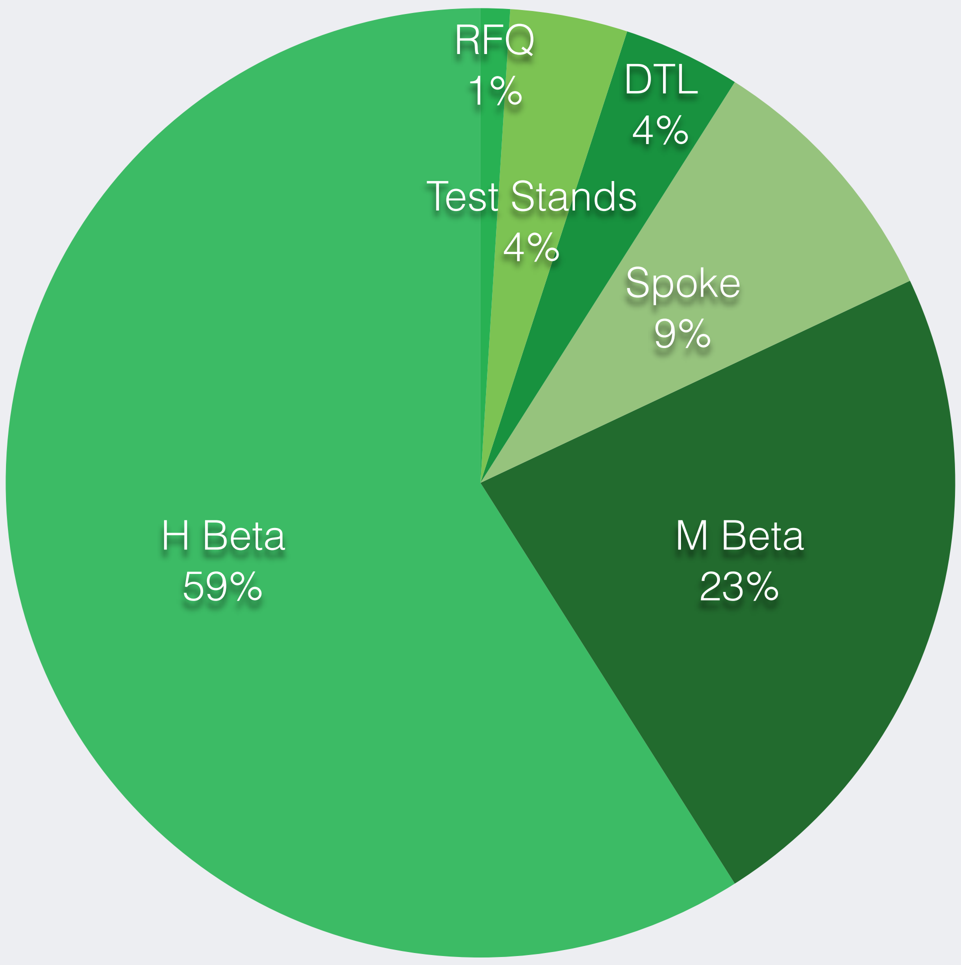
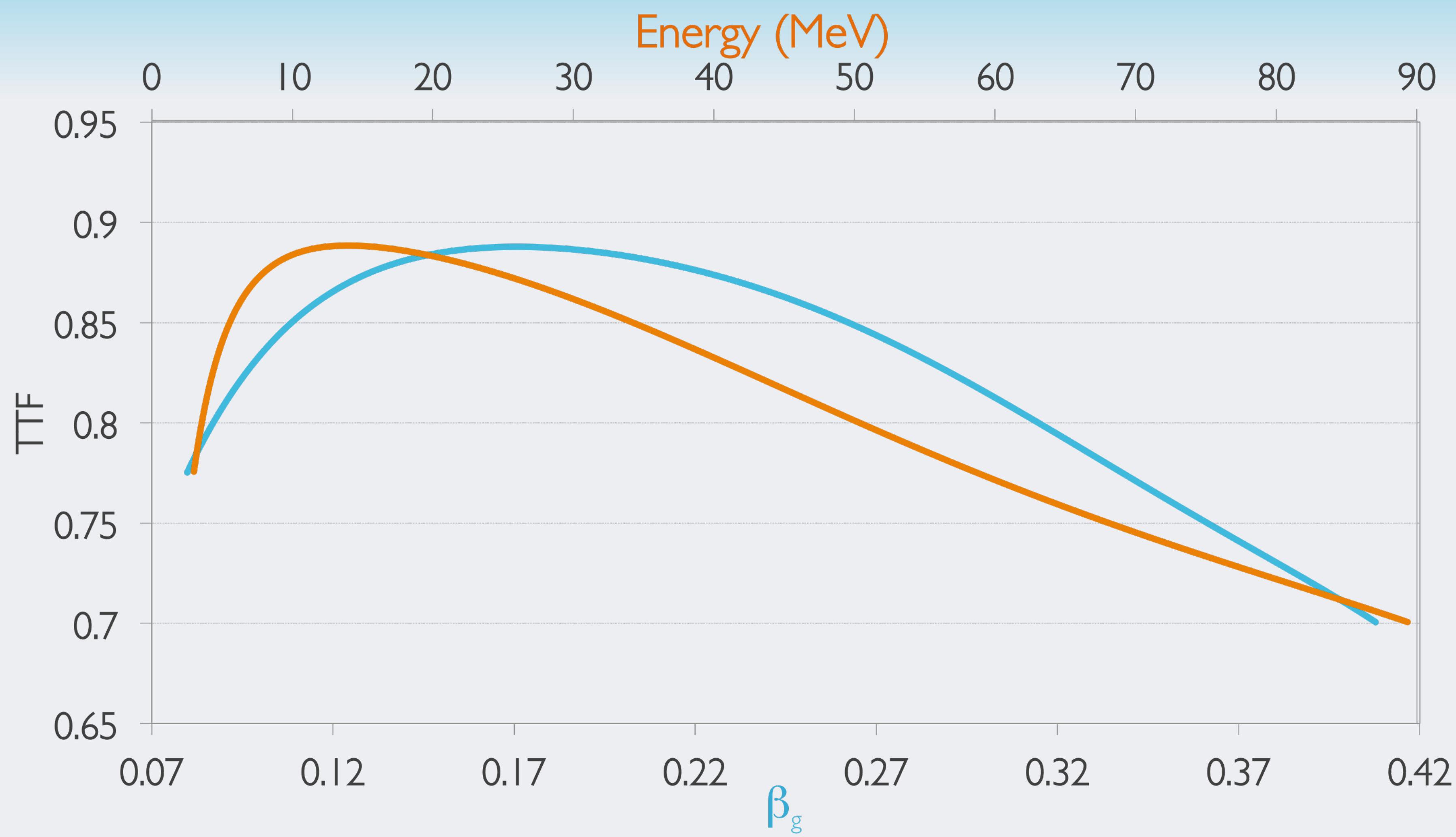


Dave McGinnis, “New Design Approaches for High Intensity Superconducting Linacs – The New ESS Linac Design”, IPAC 2014

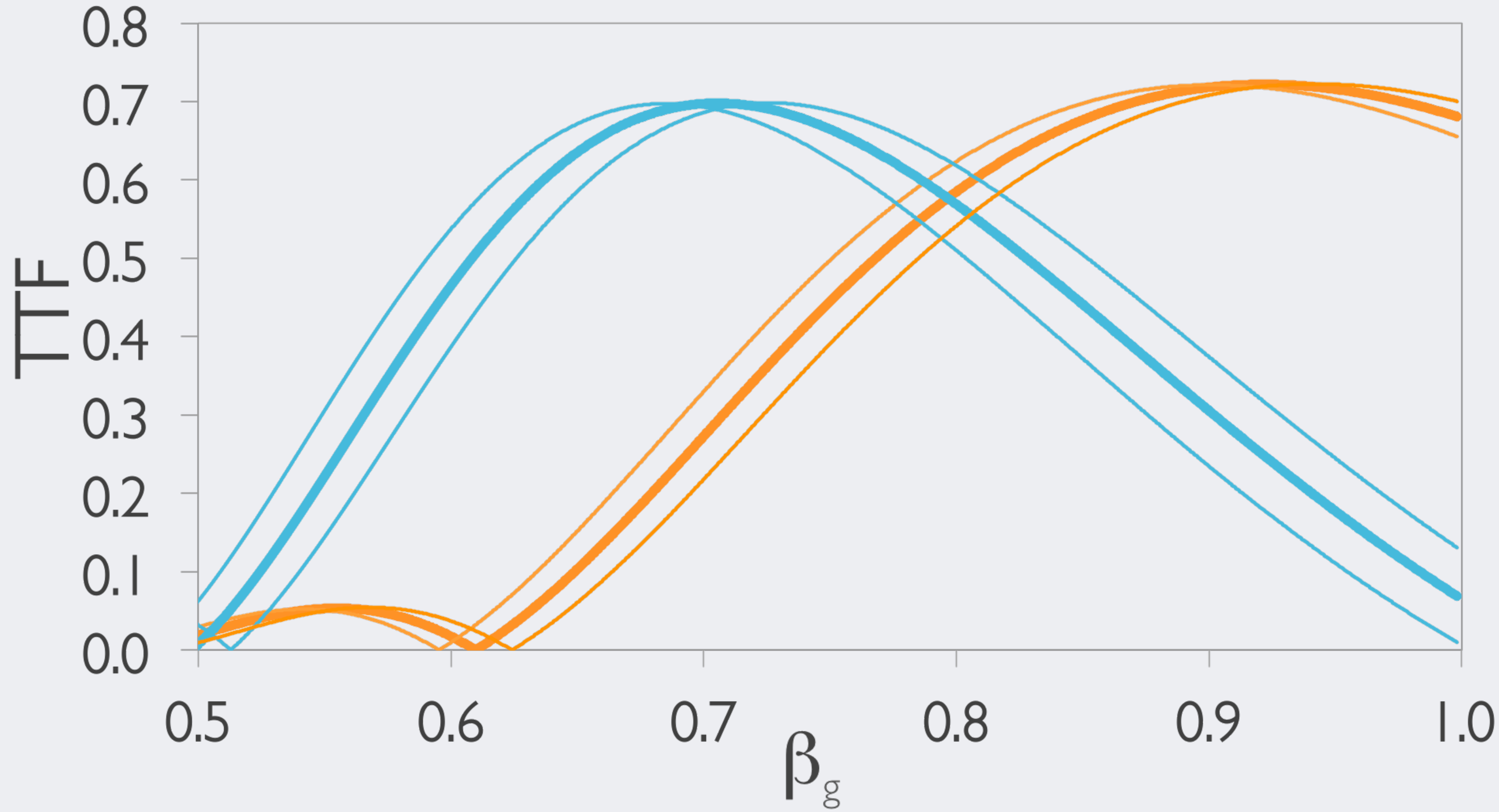
DTL TTF



Transit time factor vs particle β and energy in DTL

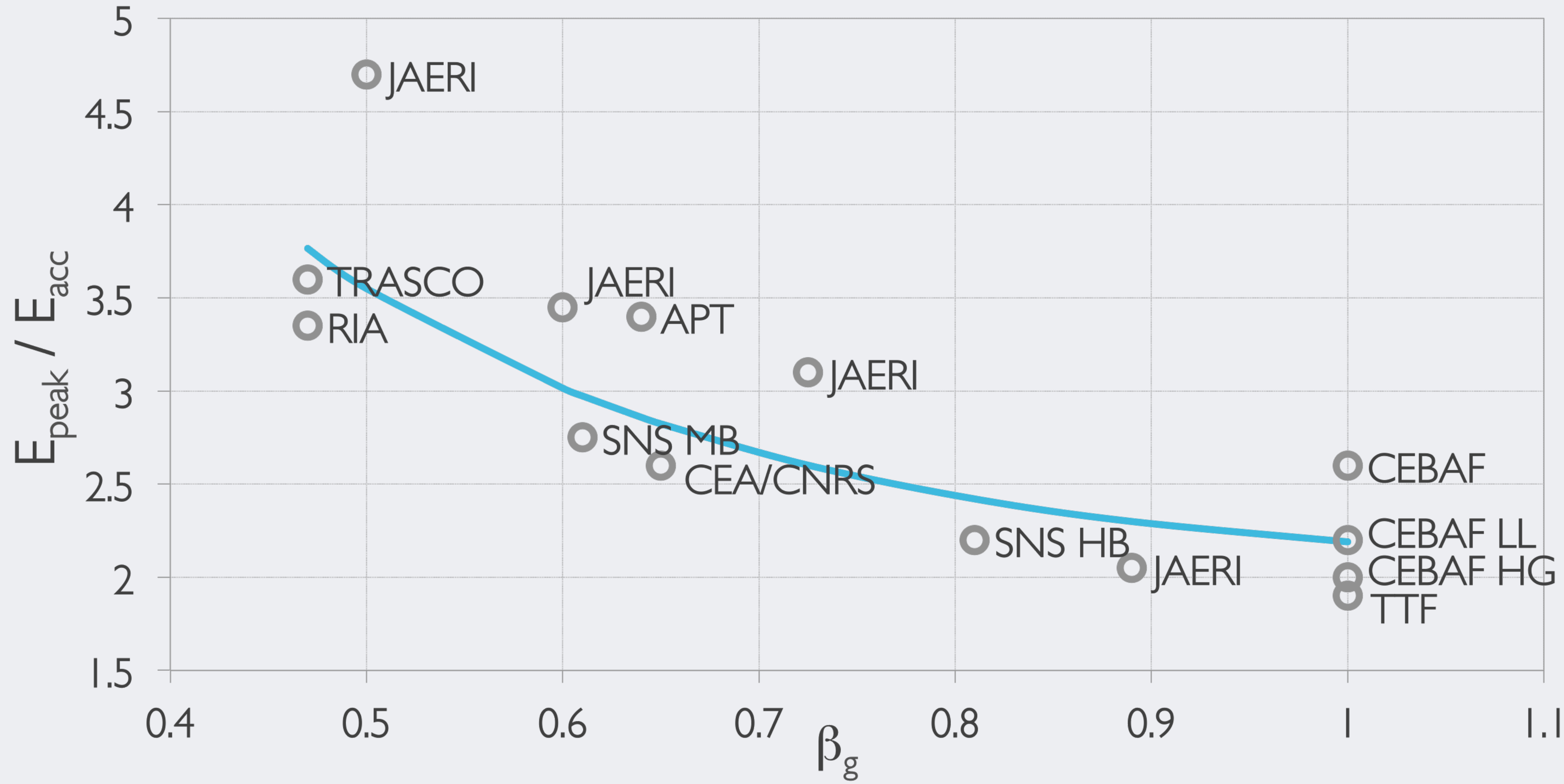
A. France, "Advanced RF Design and Tuning Methods of RFQ for High Intensity Proton Linacs", IPAC14

TTF AND TRANSITIONS



Transit time factor and the transition β between medium and high β section

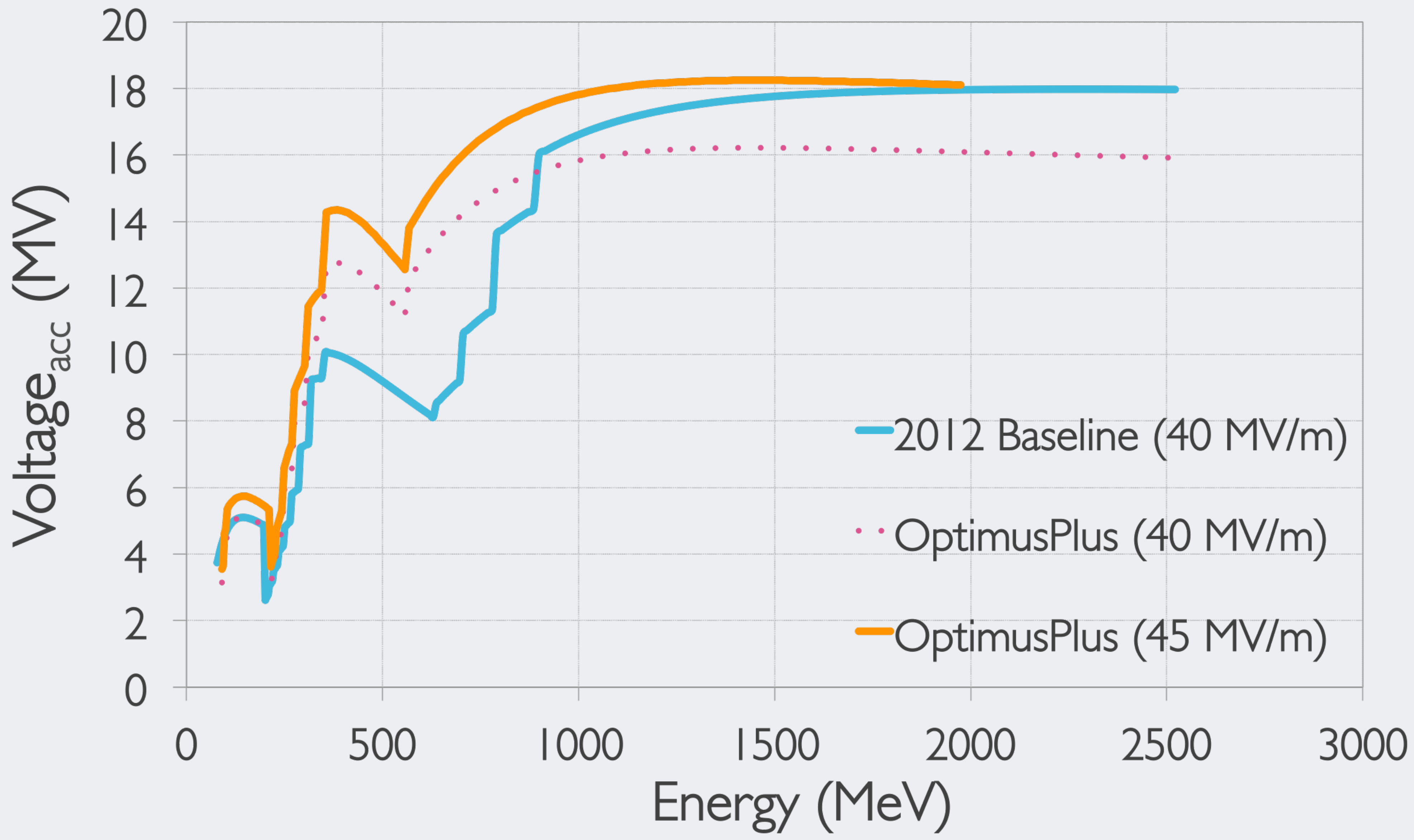
ACCELERATING FIELD



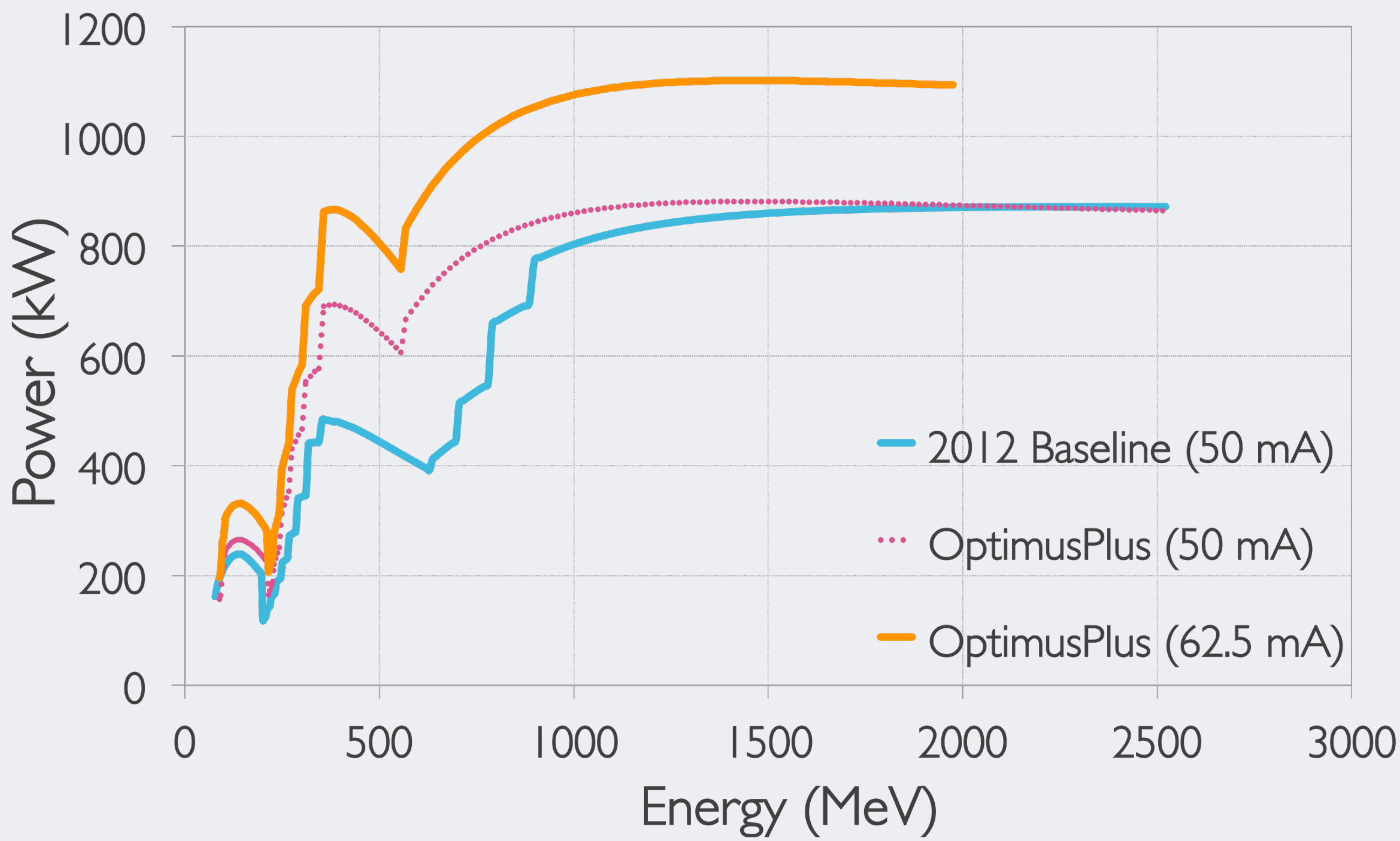
Surface electric field to accelerating field ratio as a function of β in superconducting elliptical cavities

Courtesy of Paolo Pierini

USING THE CAVITIES AT THEIR BEST

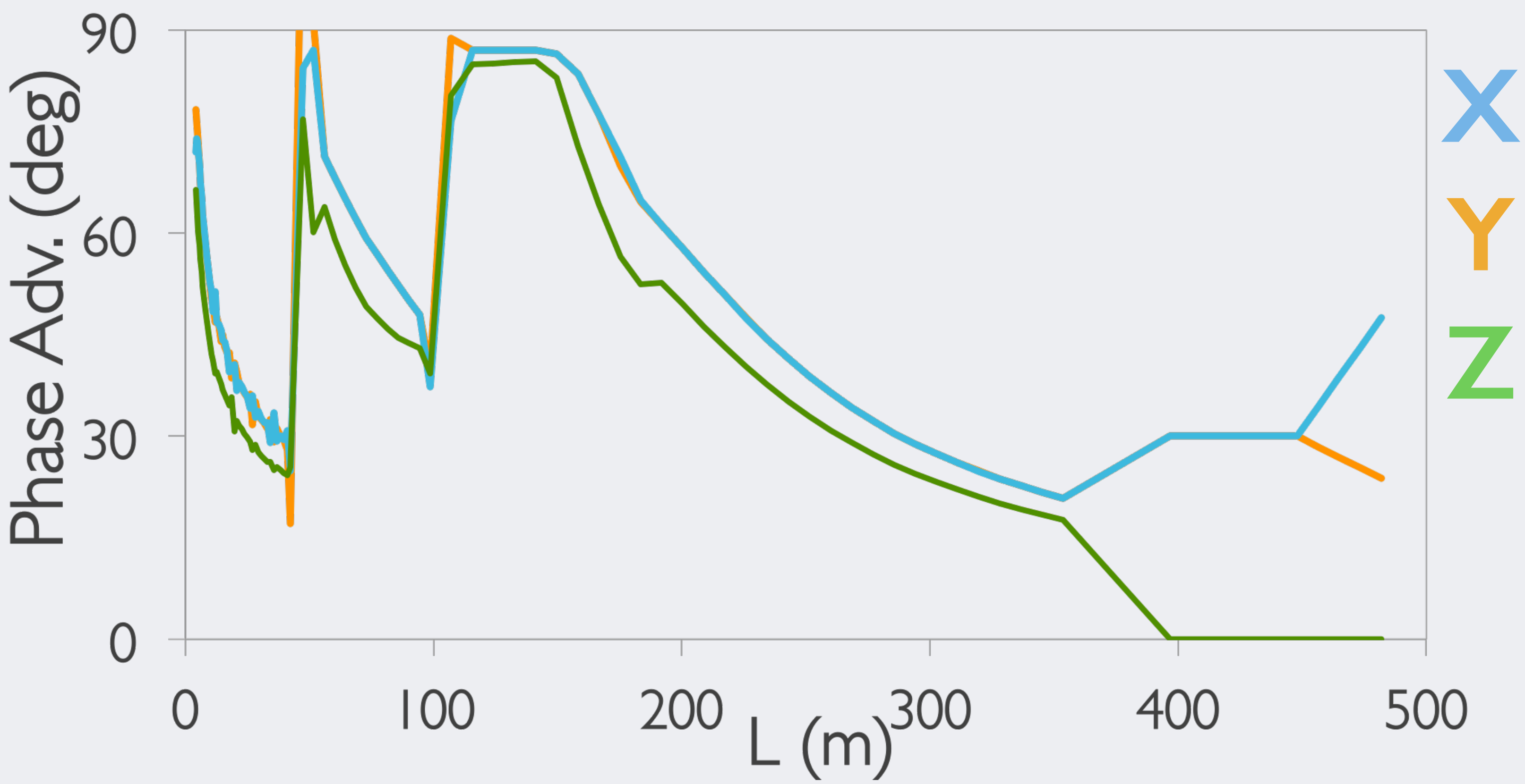


POWER PROFILE



RULES OF THUMB

- Phase advance per period < 90 degrees



- Smooth average phase advance
- Avoiding strong tune depression

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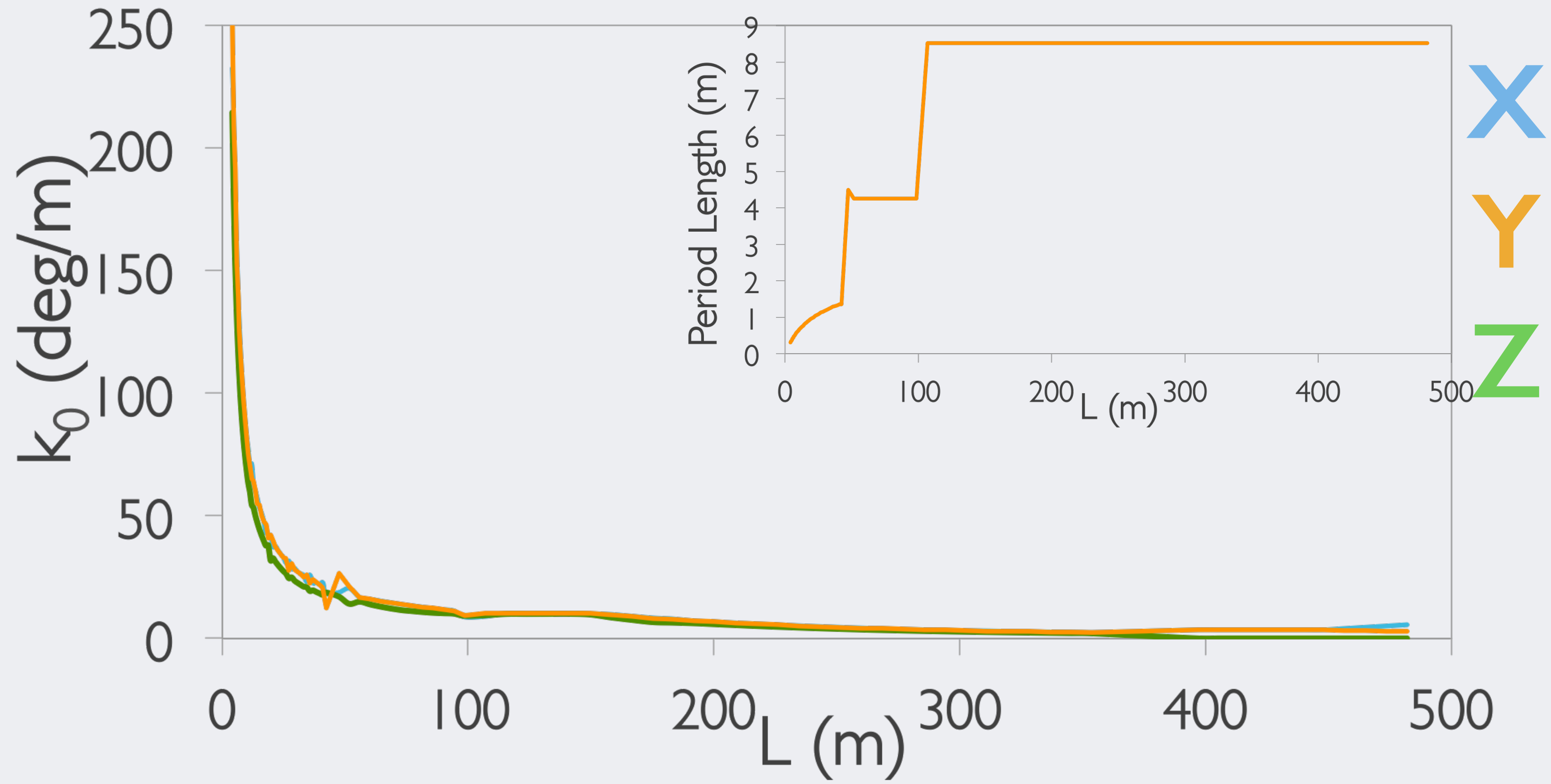

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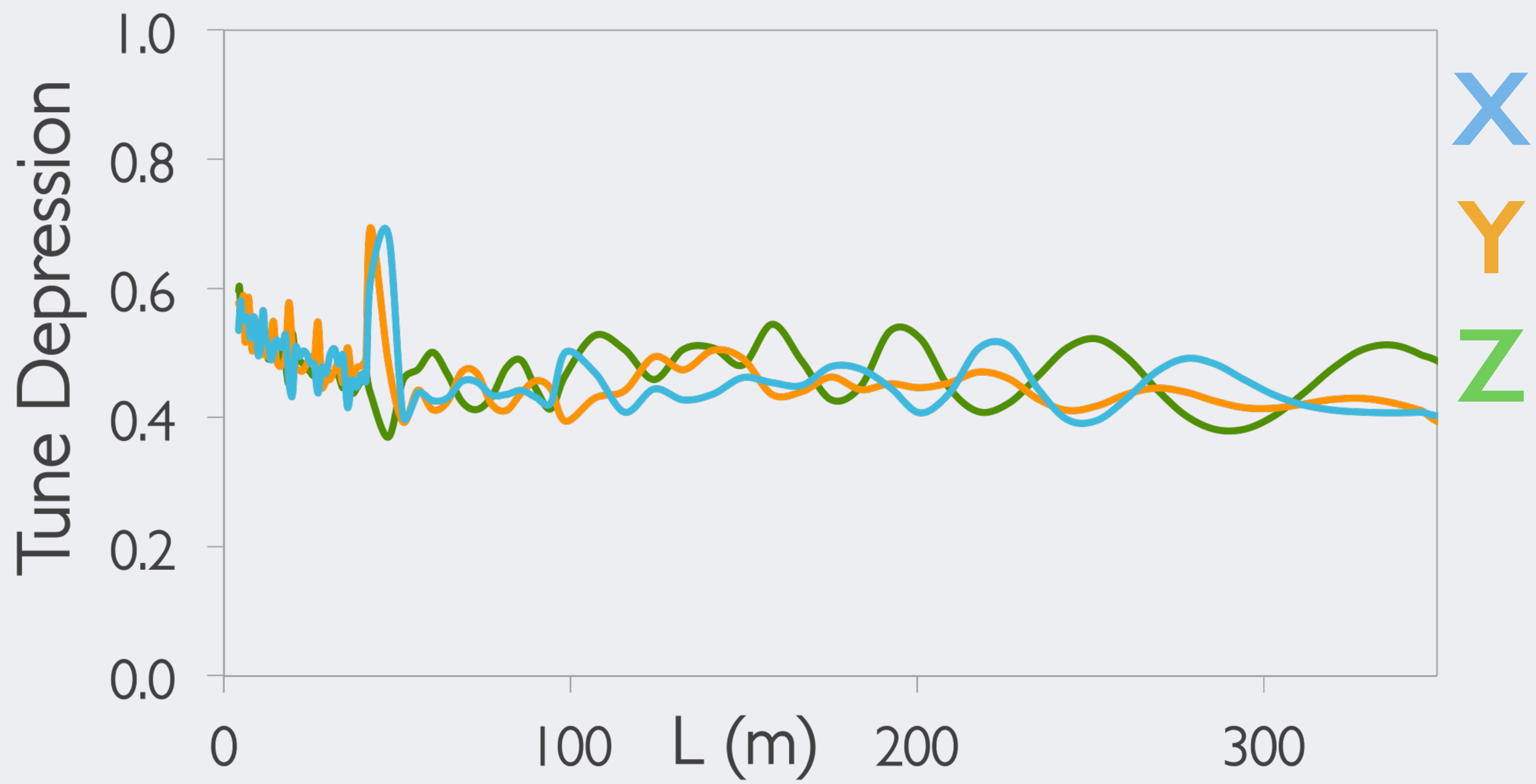
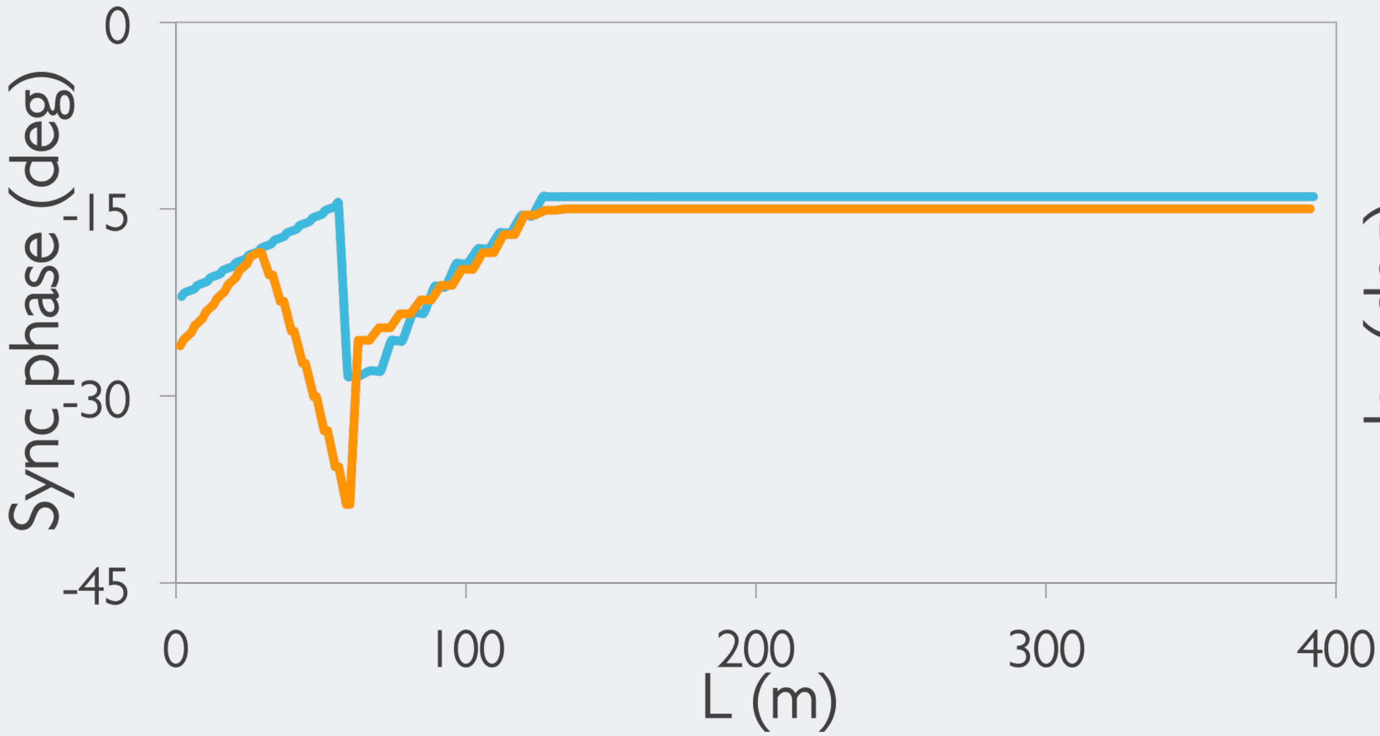
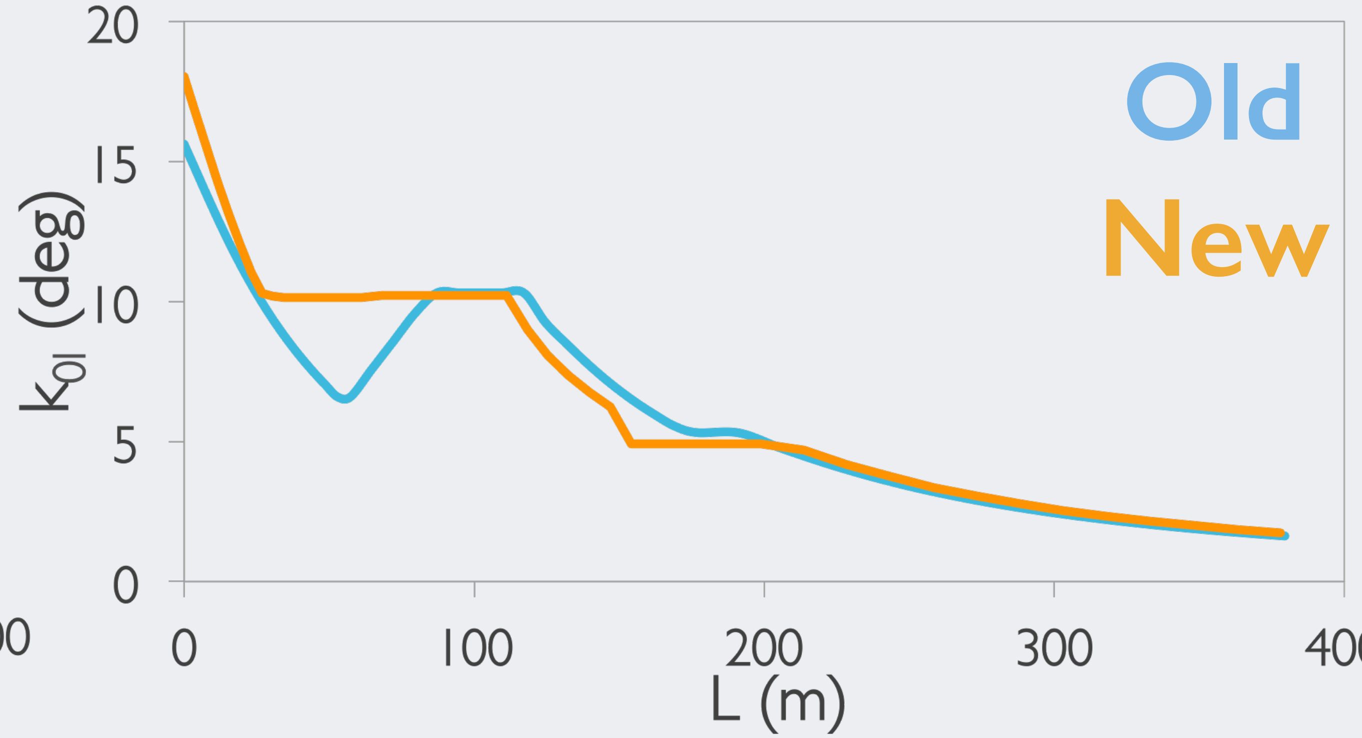


SYNC. PHASE & PHASE ADV.





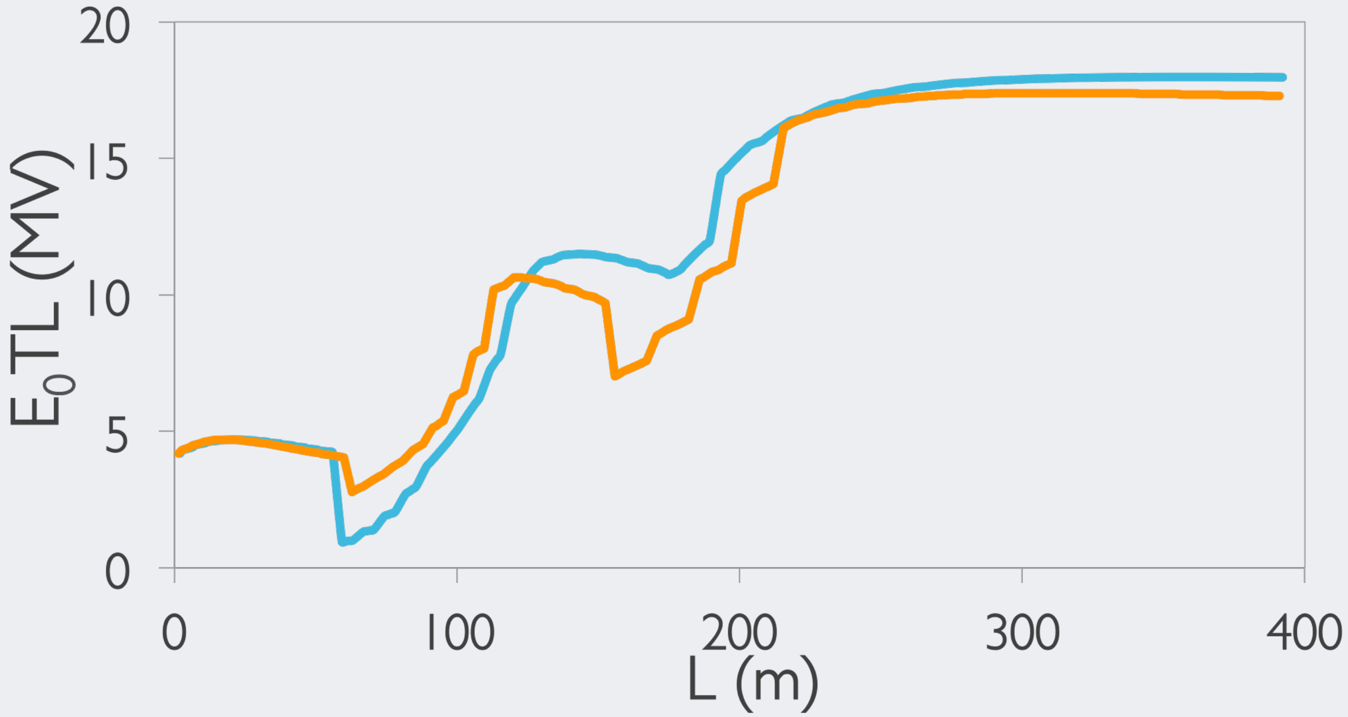
$$\phi_{704.42} = 2 \times \phi_{352.21}$$

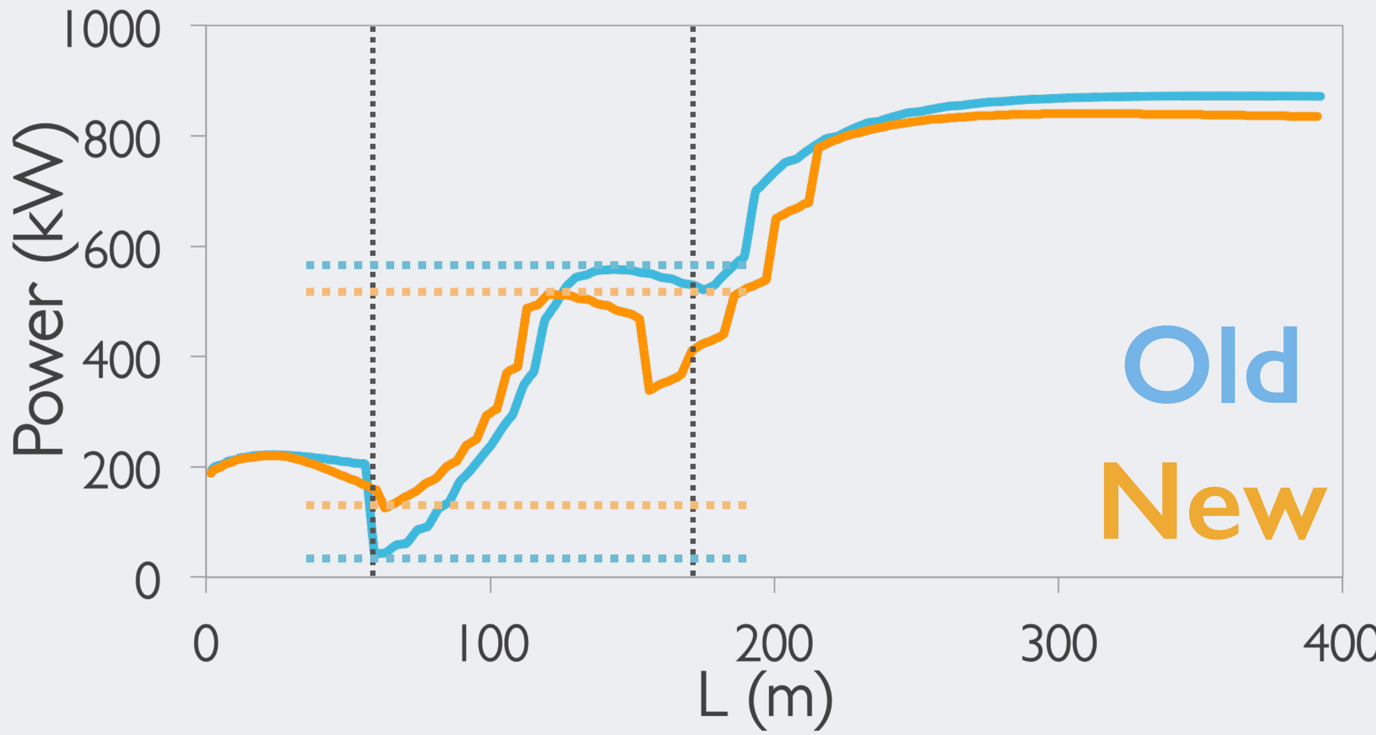
$$\lambda_{704.42} = 0.5 \times \lambda_{352.21}$$

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

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

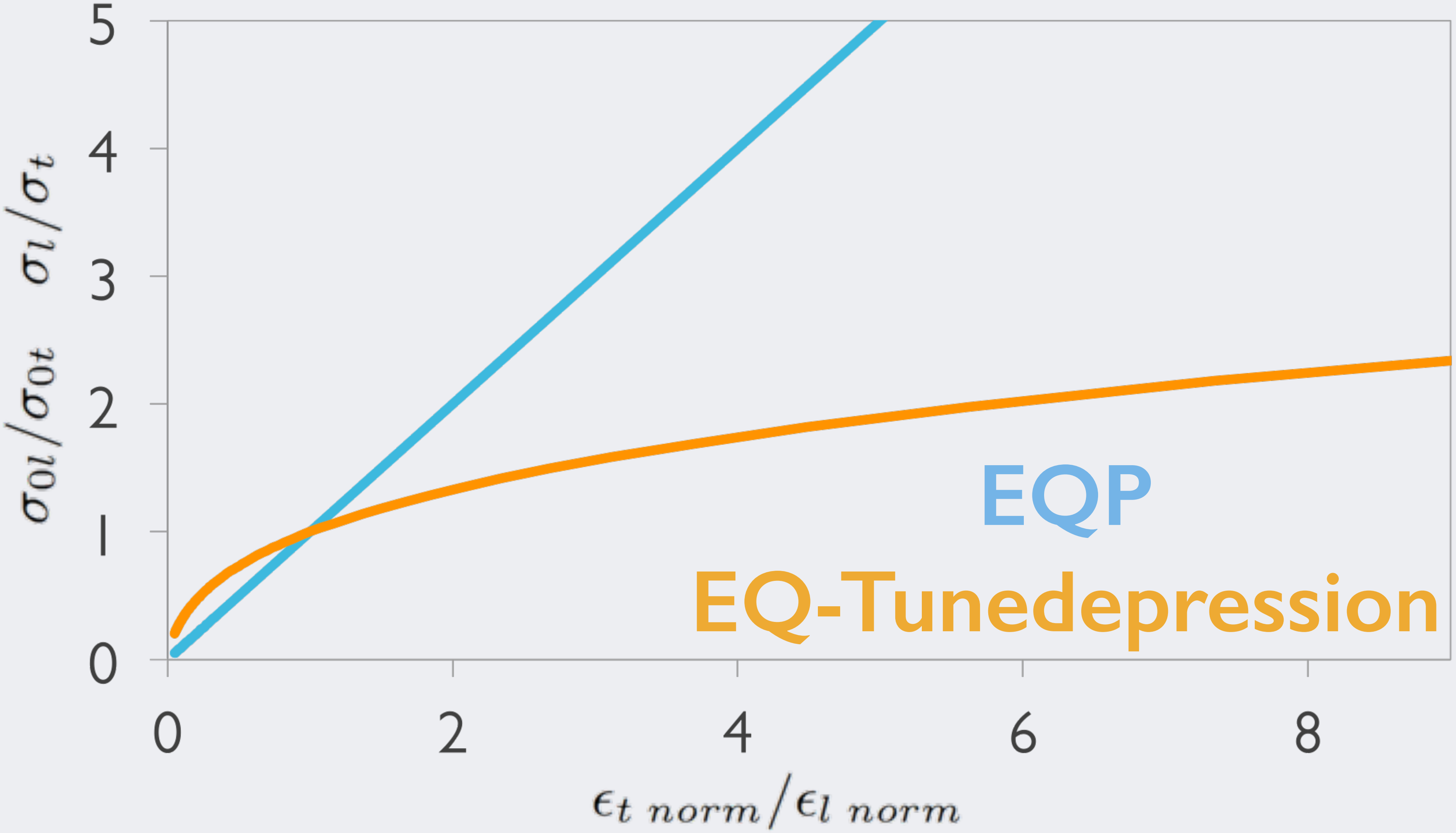
VOLTAGE & POWER





Power ratio: ~4 vs. ~13

OPTIMIZED BEAM PHYSICS

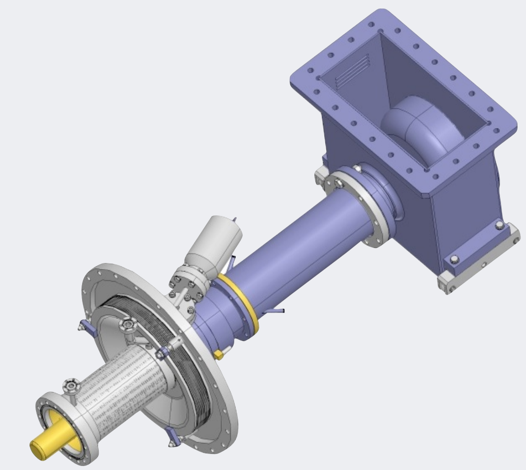


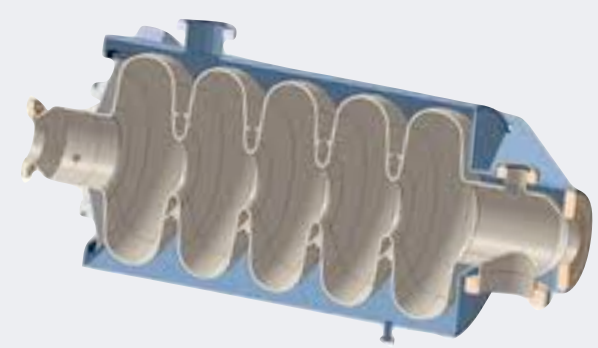
Equipartition vs. Equi-tune depression

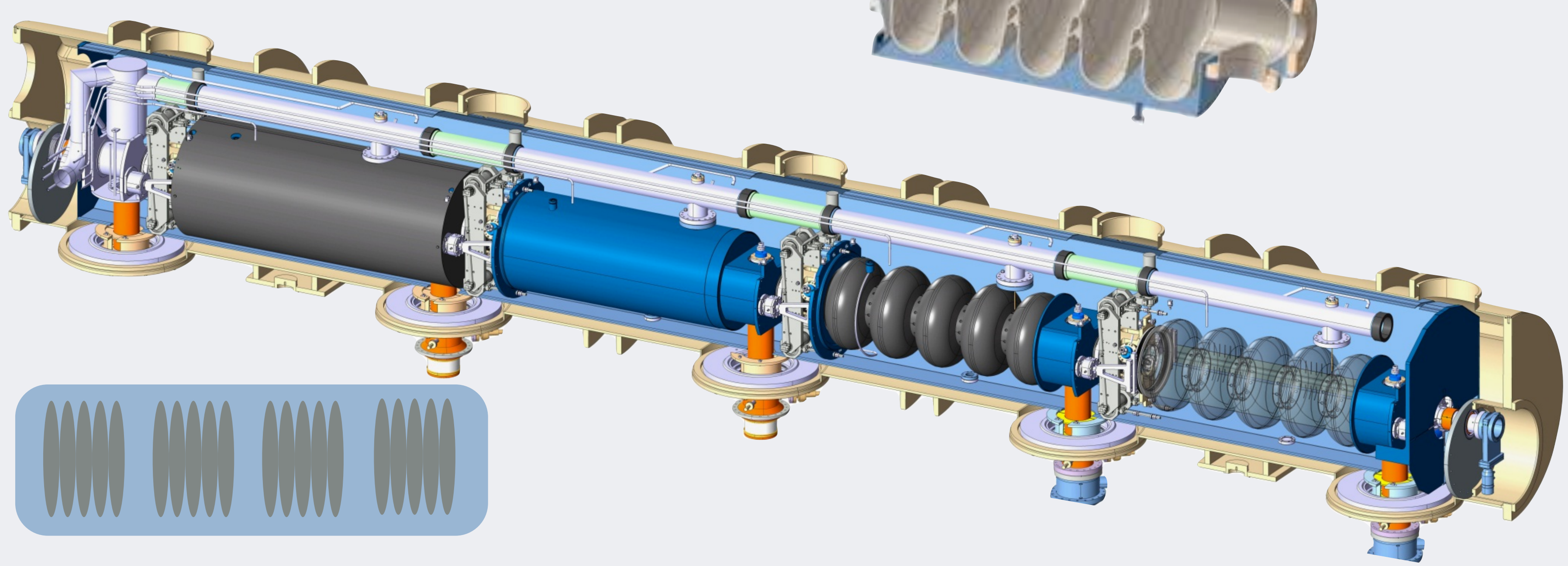
M. Eshraqi, J-M, Lagniel, "On the Choice of Linac Parameters for Minimal Beam Losses", IPAC 2013

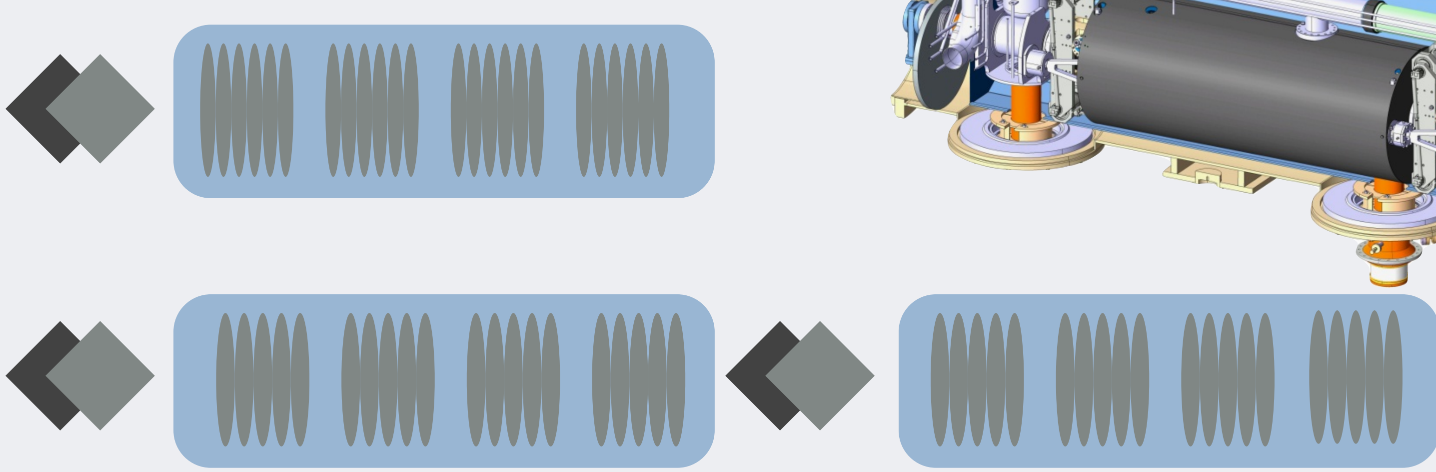
REDUCTION OF ENGINEERING

- The ESS case.
  - The number of cells in the medium beta section was increased to 6, to have the same length as the high beta cavities.
    - The same cryomodule design could be used
    - Two families of elliptical cavities accelerate the beam from 220 to 2000 MeV.









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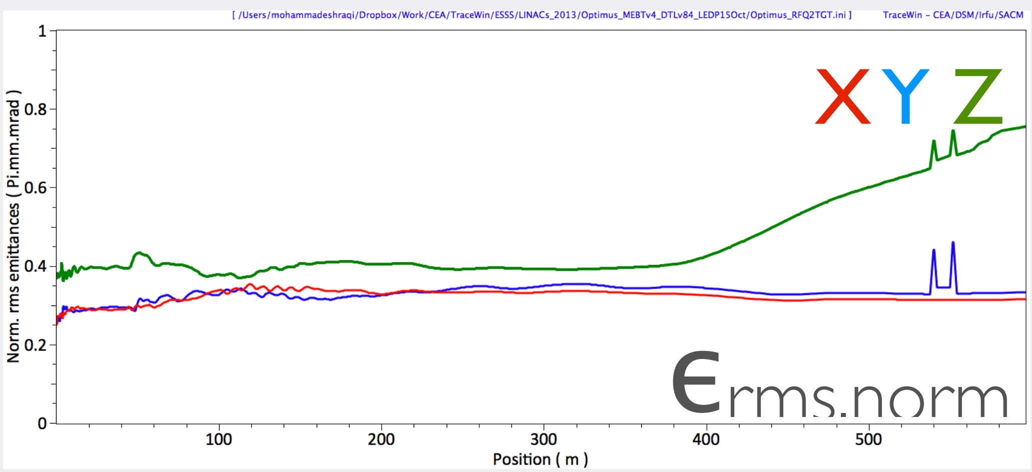
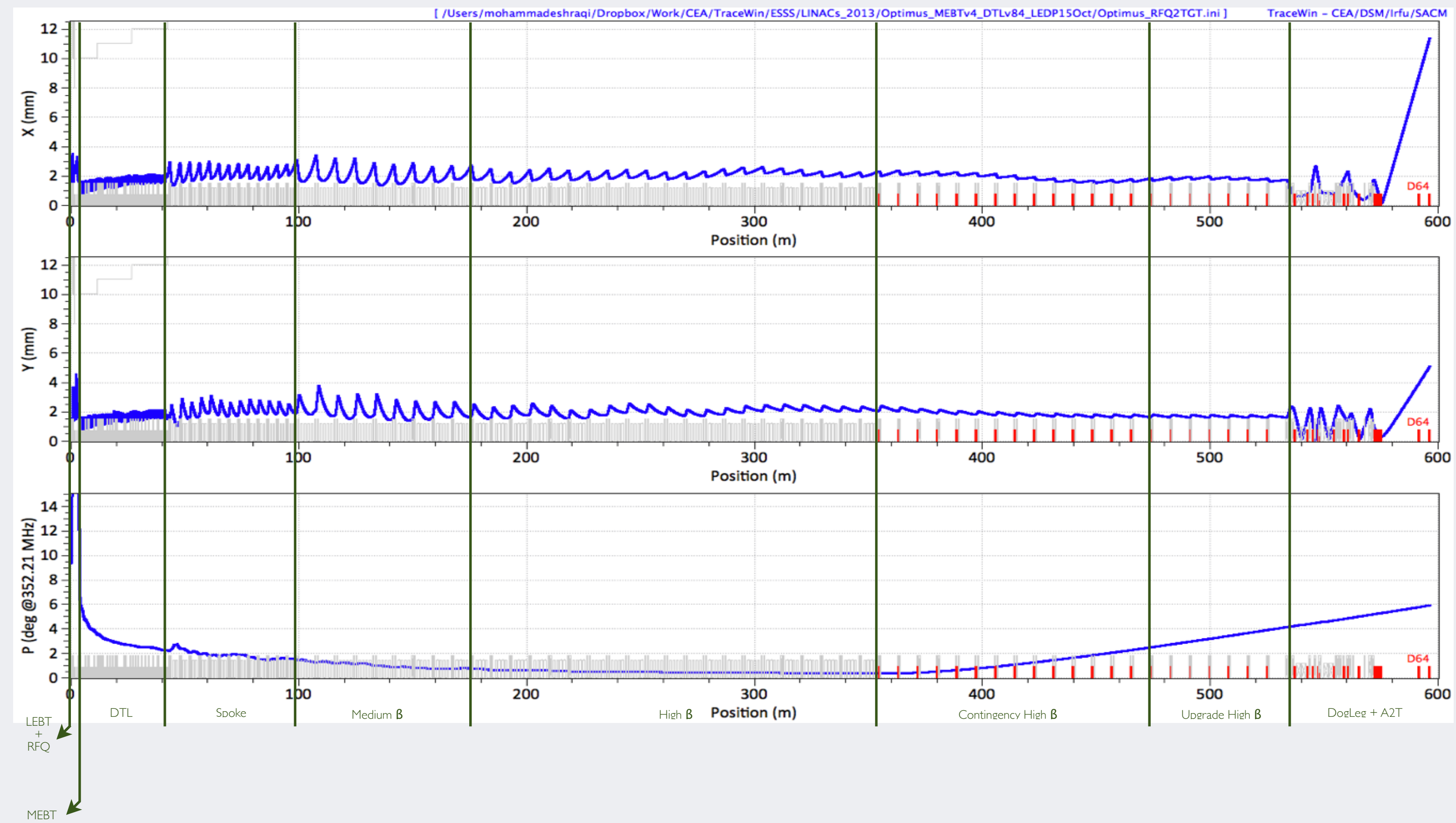
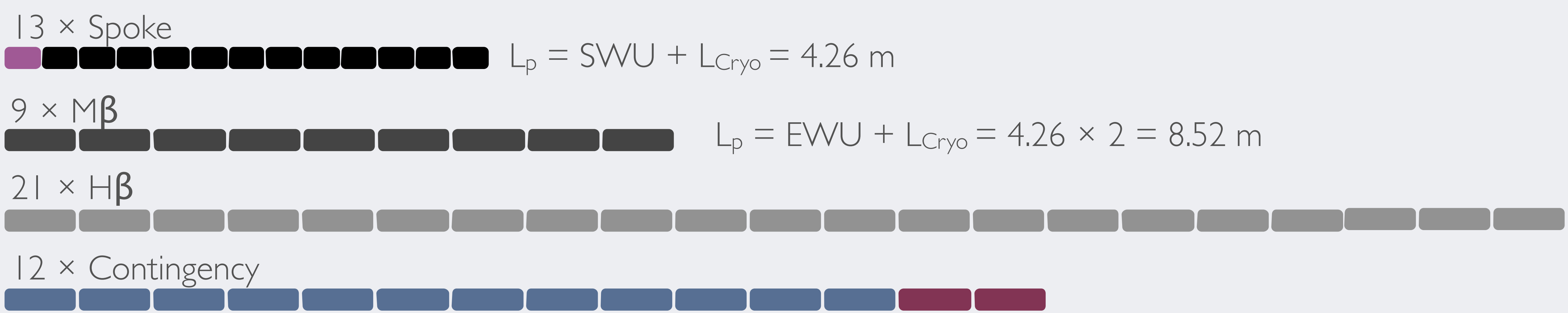




MITIGATING THAT RISK!

- The major risk of the new lattice is 25% increase in current and 11.25% increase in accelerating gradient.
  - In case of lower current (coupler/space-charge/loss limitations) the linac will still work, but at a lower power
- Free space at the end of the linac provides space for additional cryomodules to recover the lost energy/power
- Uniform Lattice would permit cryomodule replacement at the transitions



LOOK AT THE RINGS

- 352.21 MHZ
  - Several linacs (and rings) in Europe are designed at 352.21 MHz
    - Mainly to benefit from the available klystron and rf sources at this frequency range

- MAX IV and SOLARIS
  - Max IV and Solaris are using the same design for one of the rings.
    - This reduces the engineering costs
    - Ordering higher numbers results in cheaper pieces

SUMMARY

- Initially, after a series of linac designs and optimization, the linac is costed
- The main cost contributors are identified and by adjusting and re-optimizing the linac parameters and design the cost is reduced
- Minimizing the engineering reduces the cost and helps the schedule
    - R&D can also reduce cost; IOTs, Surface treatment of cavities
- The new design shall include the ability mitigate the risks
- Beam dynamics known rules could be revisited to find better solutions

Thank you for your attention

Special thanks to:

Dave McGinnis

Beam physics and Accelerator integration groups in ESS

Colleagues and collaborators

PLEASE LOOK AT OTHER ESS PAPERS

- High Power RF Sources for the ESS RF Systems, Morten Jensen (WEIOA05)
- Benchmark of the Beam Dynamics Code DYNAC using the ESS Proton Linac, E. Tanke (THPP043)
- ESS Normal Conducting Linac Error Studies, R. De Prisco (THPP042)
- Estimation of the thermal load and signal level of the ESS wire scanner, B. Cheymol (MOPP036)
- Conceptual design of the ESS DTL Faraday cup, B. Cheymol (MOPP037)
- Longitudinal Bunch Profile Monitoring at the ESS Linac, I. Dolenc Kittelmann (MOPP038)
- Dynamics of Bunches Partially Chopped with the MEBT Chopper in the ESS Linac, R. Miyamoto (MOPP039)
- Application investigation of High Precision Measurement for Basic Cavity Parameters at ESS, R. Zeng (MOPP040)
- Accuracy determination of the ESS MEBT emittance measurements, B. Cheymol (TUPP039)
- Preliminary Functional Analysis of ESS Superconducting Radio-Frequency Linac, C. Darve (TUPP040)
- Beam Current Monitor System of the European Spallation Source, H. Hassanzadegan (TUPP041)
- Identifying Appropriate Beam Mode for Phase Scan at ESS, R. Zeng (TUPP042)
- Design of the Phase Reference Distribution System for ESS, R. Zeng (TUPP043)
- The Accelerator Cryoplant at ESS, P. Arnold (THPP041)
- ESS Normal Conducting Linac status and plans, A. Ponton (THPP044)
- ESS Linac Beam Modes, E. Sargsyan (THPP045)
  - and plenty of other talks from our collaborators, just search for *space*ESS*space*!