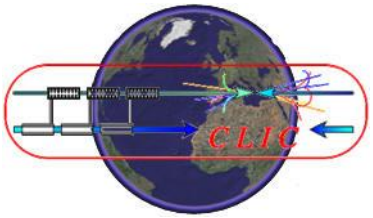
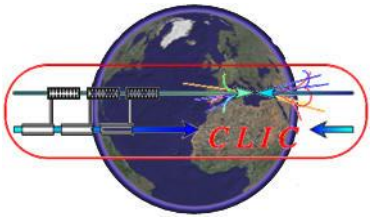


Klystron Modulators for the Drive Beam Accelerator

Daniel Siemaszko, David Nisbet

21.10.2010



Klystron parameters

Everything (for the modulator) starts here…

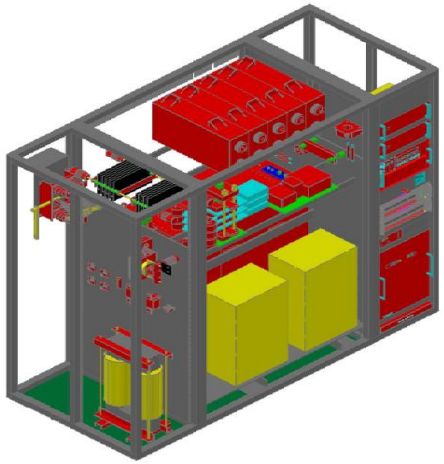
Peak power/klystron	15 MW
Train length after injection	140 μs
Repetition rate	50 Hz
Klystrons efficiency	65% (70% target)
Phase precision	0.05° @ 1 GHz
Nb of klystrons (DB linac)	2x 819 = 1638

CW and Pulsed Modulators

Why a pulsed modulator?



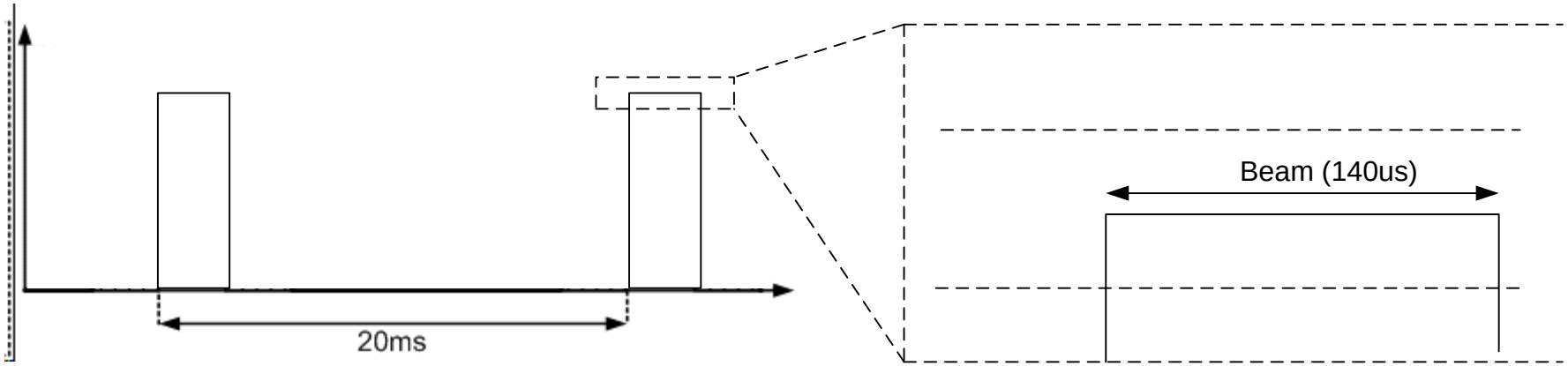

LEP 4MW CW Modulator: 350 m^3



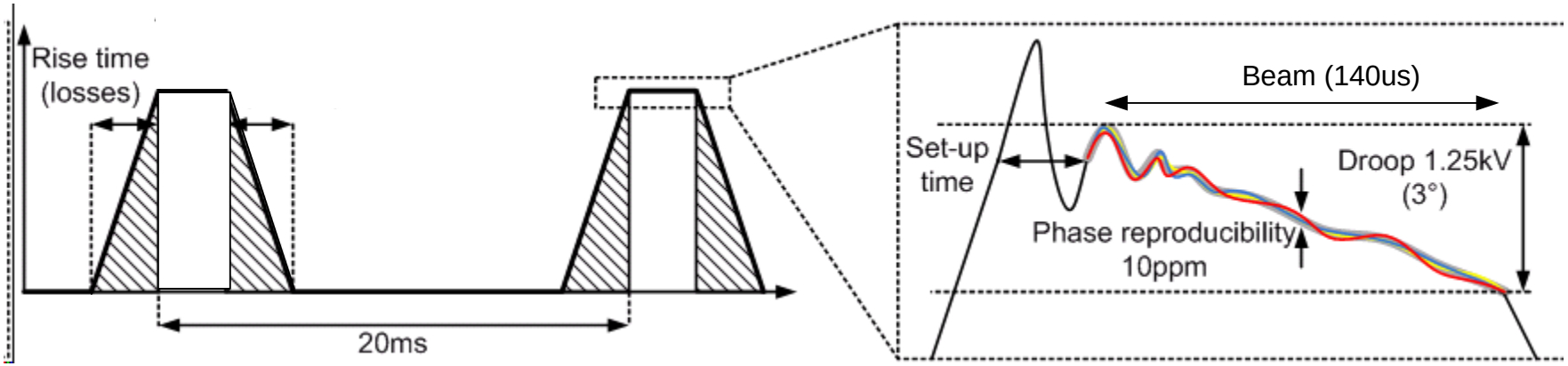
LINAC4 5MW Pulsed Modulator: 7 m^3

Pulse parameters

The perfect pulse



The real world

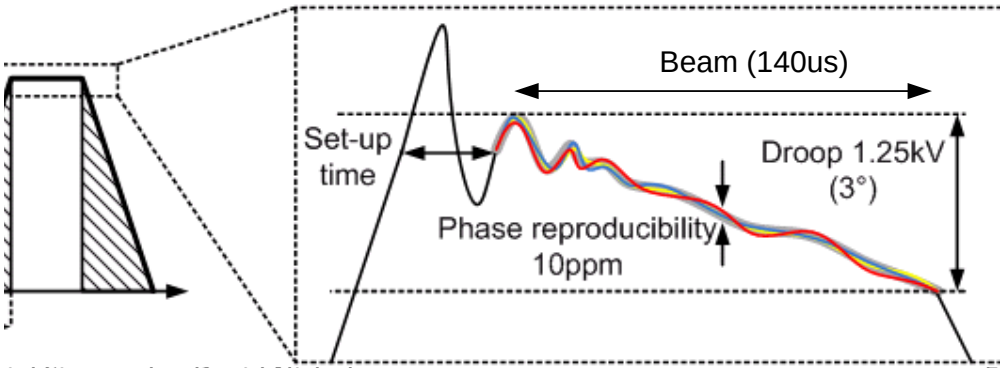


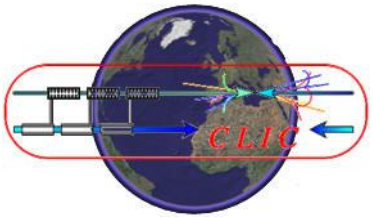
Klystron modulators

- Modulator requirements and characteristics

Peak power/modulator	23.1 MW (15MW@ 65% efficiency)
Output voltage	150 kV
Pulse to pulse reproducibility	10^{-5}
Droop (including harmonics)	3° (1.25 kV or <0.85%)
Pulse characteristics	20us rise/fall; 30us set-up; 140us beam
Average power/modulator	243.6 kW @ 90% efficiency

- Flat-top is 190us (50% to 50%)





Power consumption

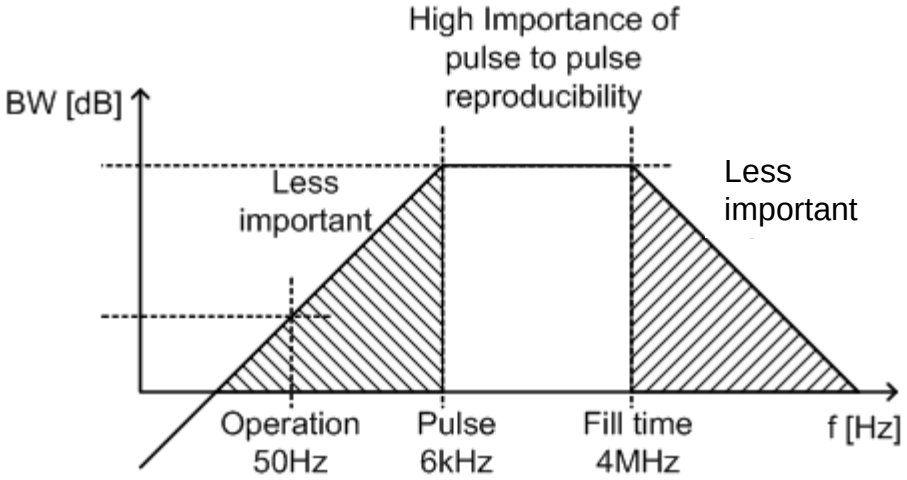
- A rise time and fall time of 20μs, and settling time of 30us, is assumed.
- Note that the baseline currently assumes 90% efficiency for modulator. This is realistic for energy conversion, but unrealistic if dynamics are considered
- Thus the power consumption is evaluated for a 15MW klystron assuming klystron efficiency of 65% (70%) and modulator efficiency of 90% (92%) and dynamic effects.

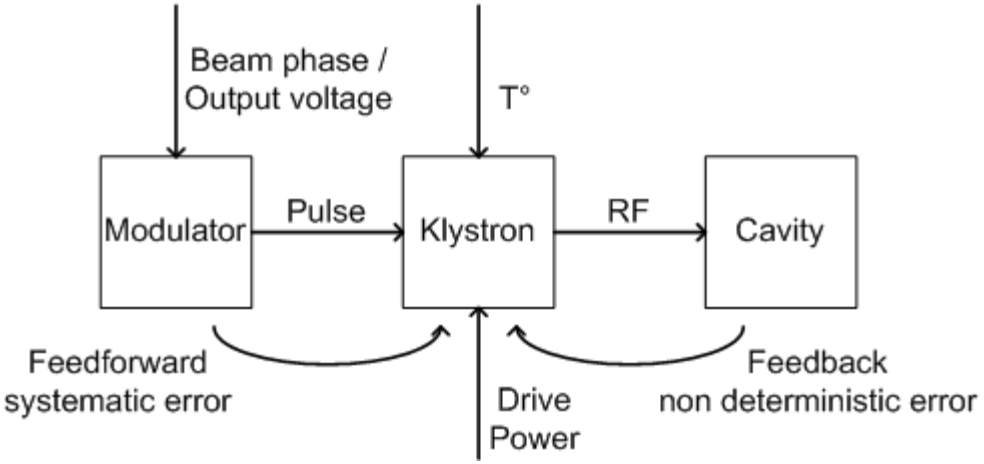
Modulator average input power	243.6kW (221.3kW)
Modulator quantity for DB	1638
Total consumption	399 MW (362.4MW)

- R&D required to reduce rise/fall times and settling times, to obtain >90% efficiency, and consume true constant power
- System level R&D for power management and grid effects when shutting down or failure modes of many modulators (the grid can only tolerate a gradual change at this power level).

System and bandwidth

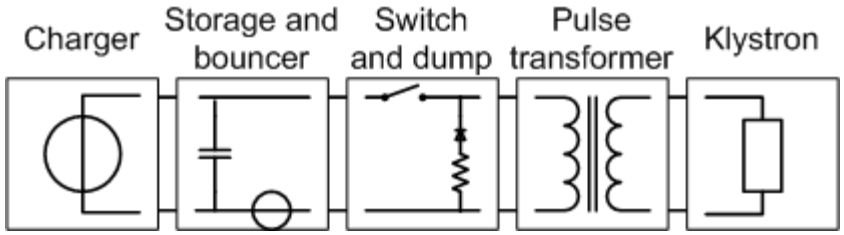
- Quality of RF is dependant on many inputs.
- RF feed-forward control takes care of modulator harmonics, voltage droop and other systematic errors.
- RF feed-back control takes care of other errors (eg temperature drift, calibration, etc)
- At lower frequencies, precision is less important due to RF feedback
- At higher frequencies, precision is less important due to natural machine filtering.
- 10^{-5} pulse to pulse reproducibility precision required between 6kHz and 4MHz.



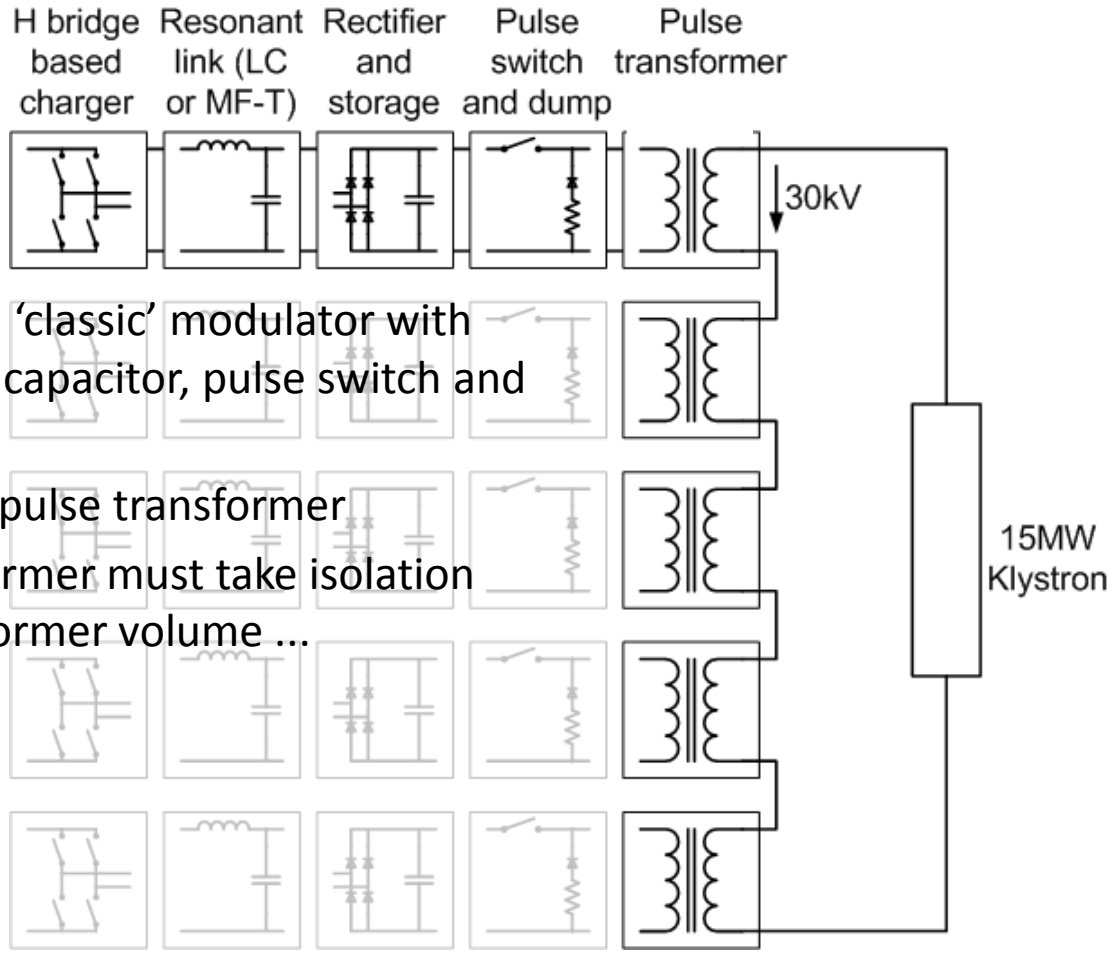


Classic approach

- Pulse transformer: The pulse is generated at high current lower voltage at the primary side of the pulse transformer. 150kV is reached at the secondary side.
- Switch: High voltage, high current solid state switch.
- Storage capacitor: The pulsed power is collected by an intermediate storage capacitor before being transmitted through the switch.
- Voltage droop compensation: Voltage compensator for the droop occurring in the storage capacitor during the pulse discharge.
- Charger: Classical resonant topology for charging the capacitor.

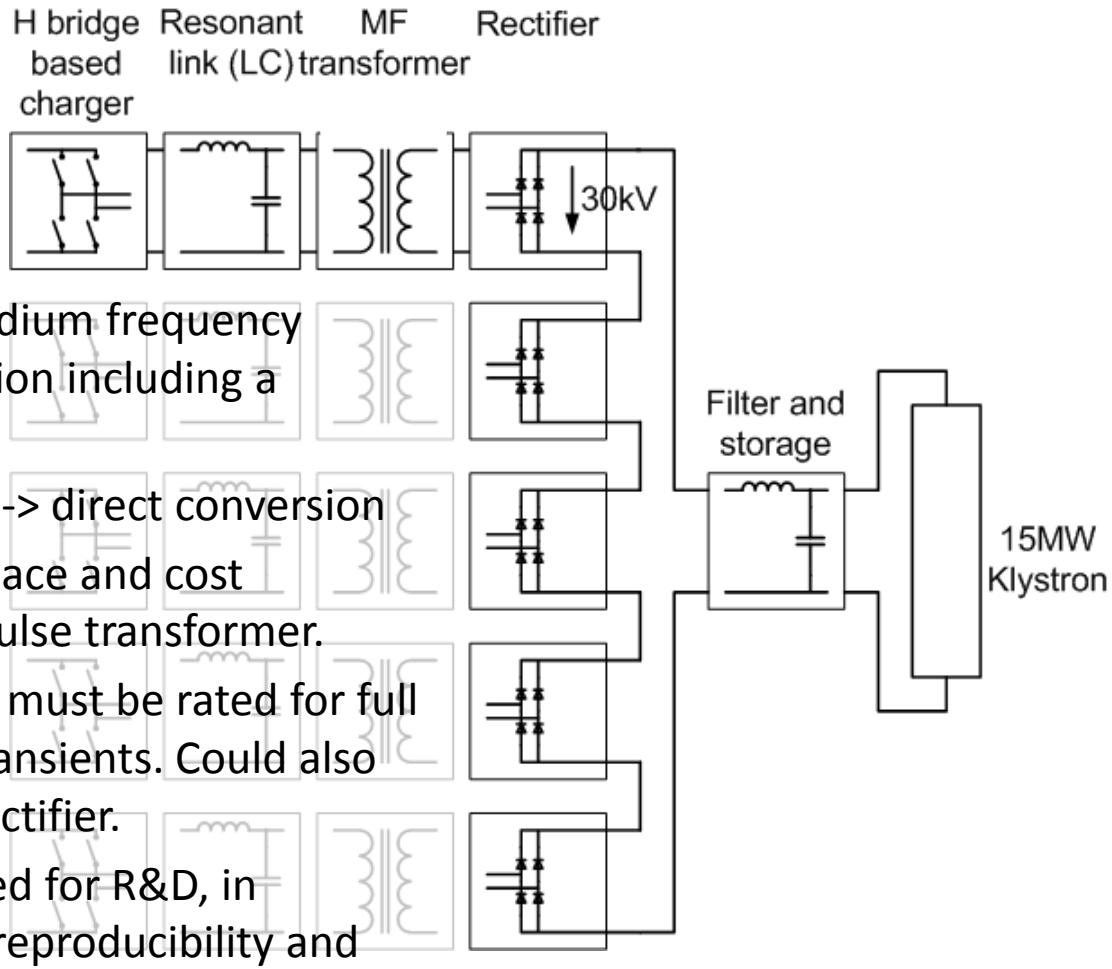


Modular approach (1)



- Modular approach based on a 'classic' modulator with charger, intermediate storage capacitor, pulse switch and pulse transformer.
- Need to design a fast enough pulse transformer
- Dimensioning of pulse transformer must take isolation voltage into account -> transformer volume ...

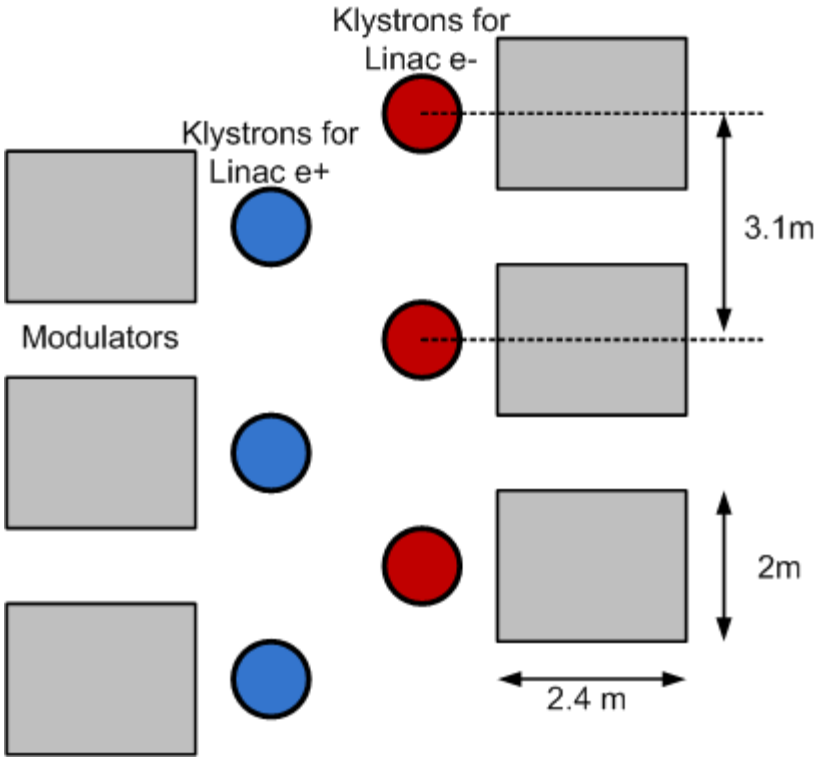
Modular approach (2)

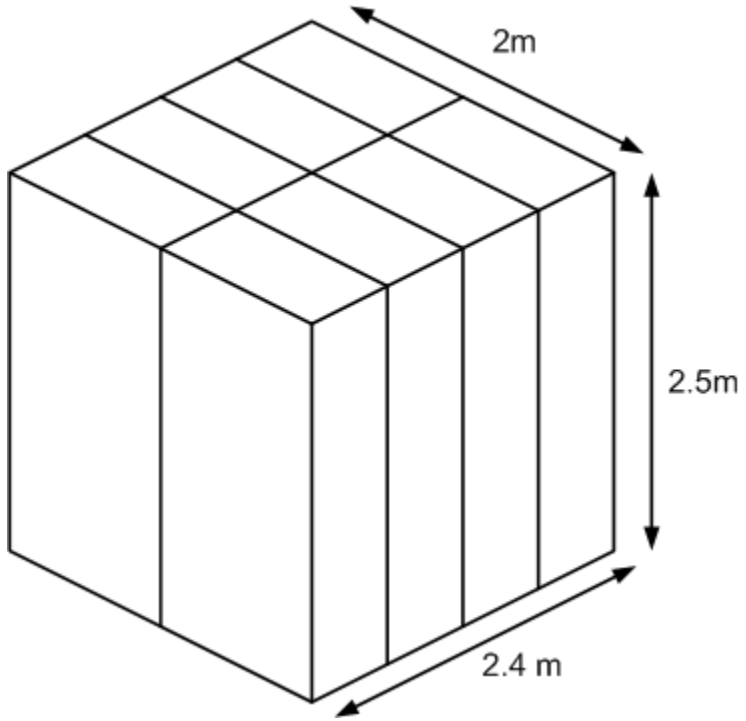


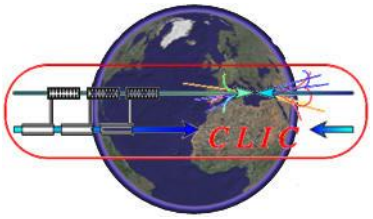
- Modular approach based on medium frequency transformer and direct rectification including a charger and an output filter.
- No intermediate energy storage -> direct conversion
- Use of MF transformer allows space and cost reductions when compared to pulse transformer.
- Passive components of the filter must be rated for full voltage and allow fast voltage transients. Could also be modular structure on each rectifier.
- Very interesting solution but need for R&D, in particular concerning rise time, reproducibility and transformer design.

Space requirements

- With a first estimation, the modulators would require ~8 standard racks per klystron.
- The two linacs are placed side by side every 3.1m (2.5km for the whole linac) .







Conclusions

- Cost, efficiency and reproducibility requirements are key parameters for the machine feasibility
- Design for pulse-to-pulse reproducibility of 10^{-5} at 150kV is a significant issue -> significant R&D in characterisation, measurement and feedback techniques
- Constant power consumption at modulator level, and power management strategies on a machine scale, will be required
- Modulator redundancy important to ensure sufficient availability of such a large number of systems

- Plenty of topics requiring further research!