HIGH POWER HADRON ACCELERATORS

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ESS

Design Drivers:

High average beam power	5 MW
High peak beam power	125 MW
High availability	>95 %

Key parameters:

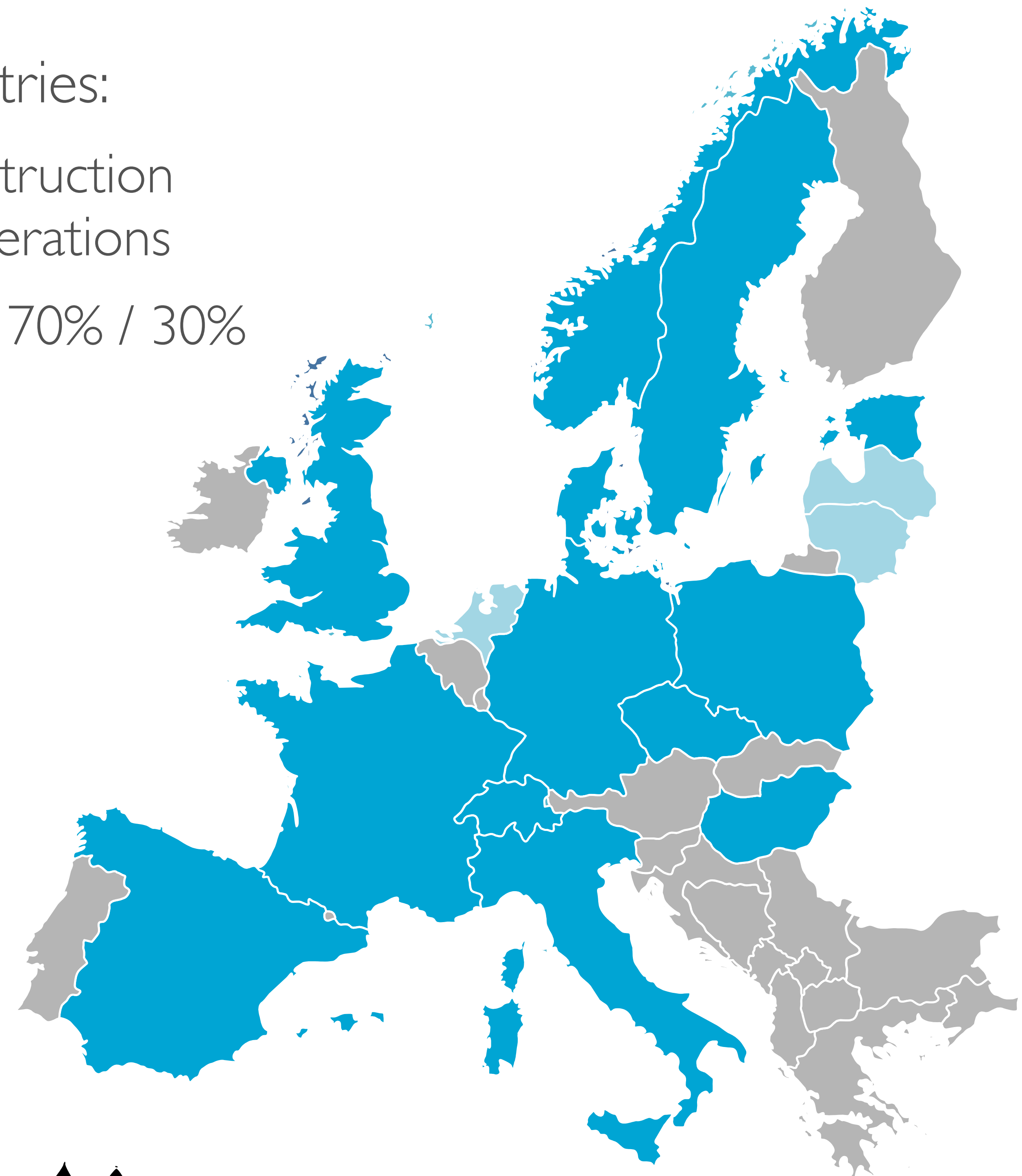
Energy	2.0 GeV
Current	62.5 mA
Repetition rate	14 Hz
Pulse length	2.86 ms
Losses	<1W/m
Ions:	p

Flexible/Upgradable design

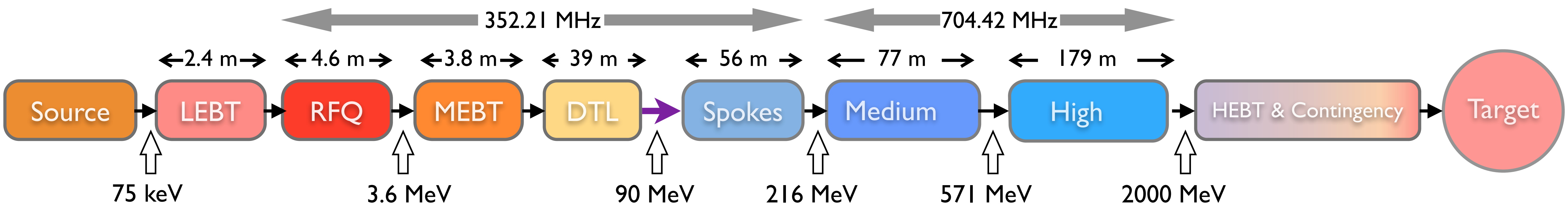
Minimize energy consumption

FUNDING AND PARTNERS

- Sweden and Denmark:
  - 47,5% Construction
    15-20% Operations
  - Cash ~100%
- Partner Countries:
  - 52,5% Construction
    80-85% Operations
  - IKC/Cash ~ 70% / 30%

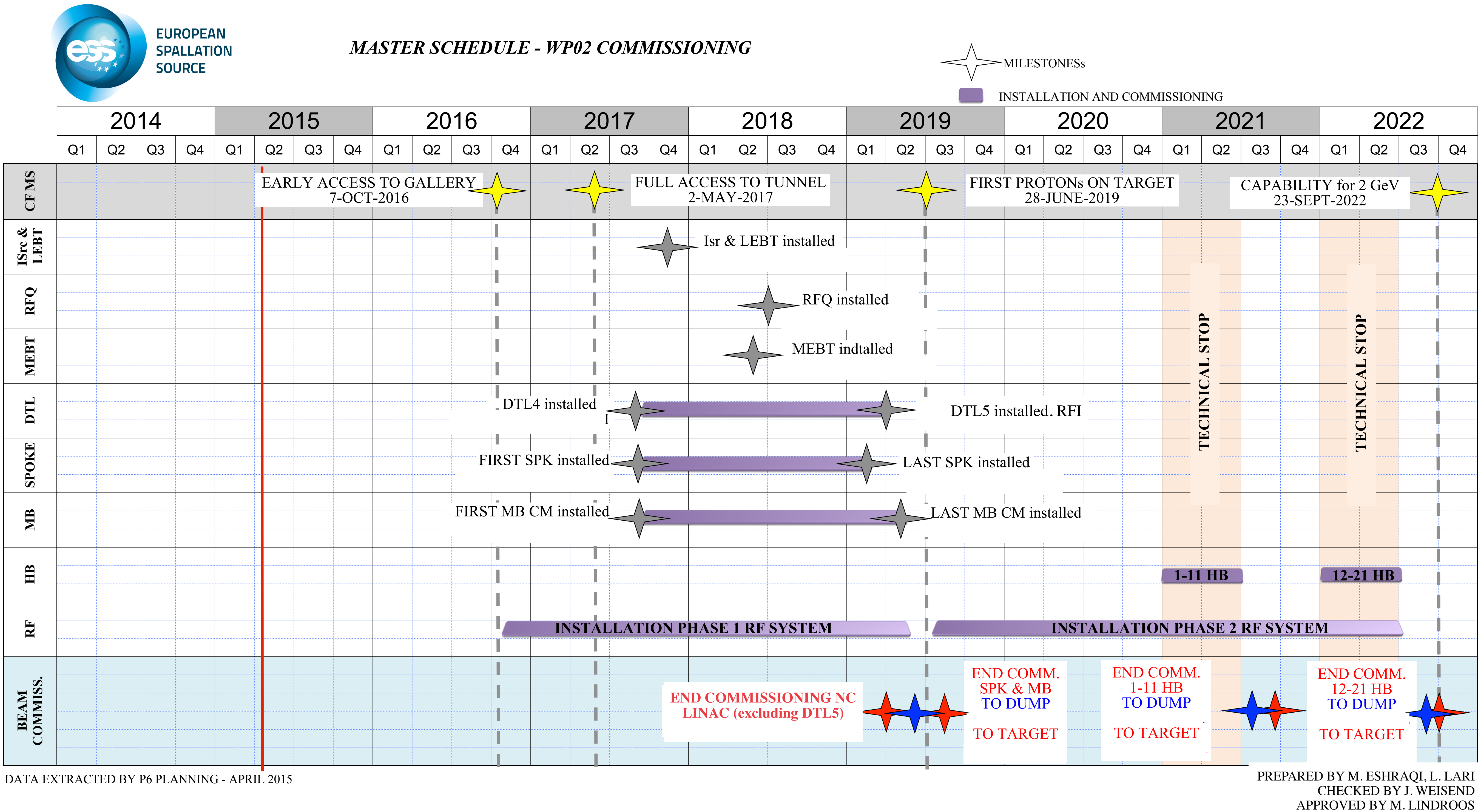


ESS PARAMETERS



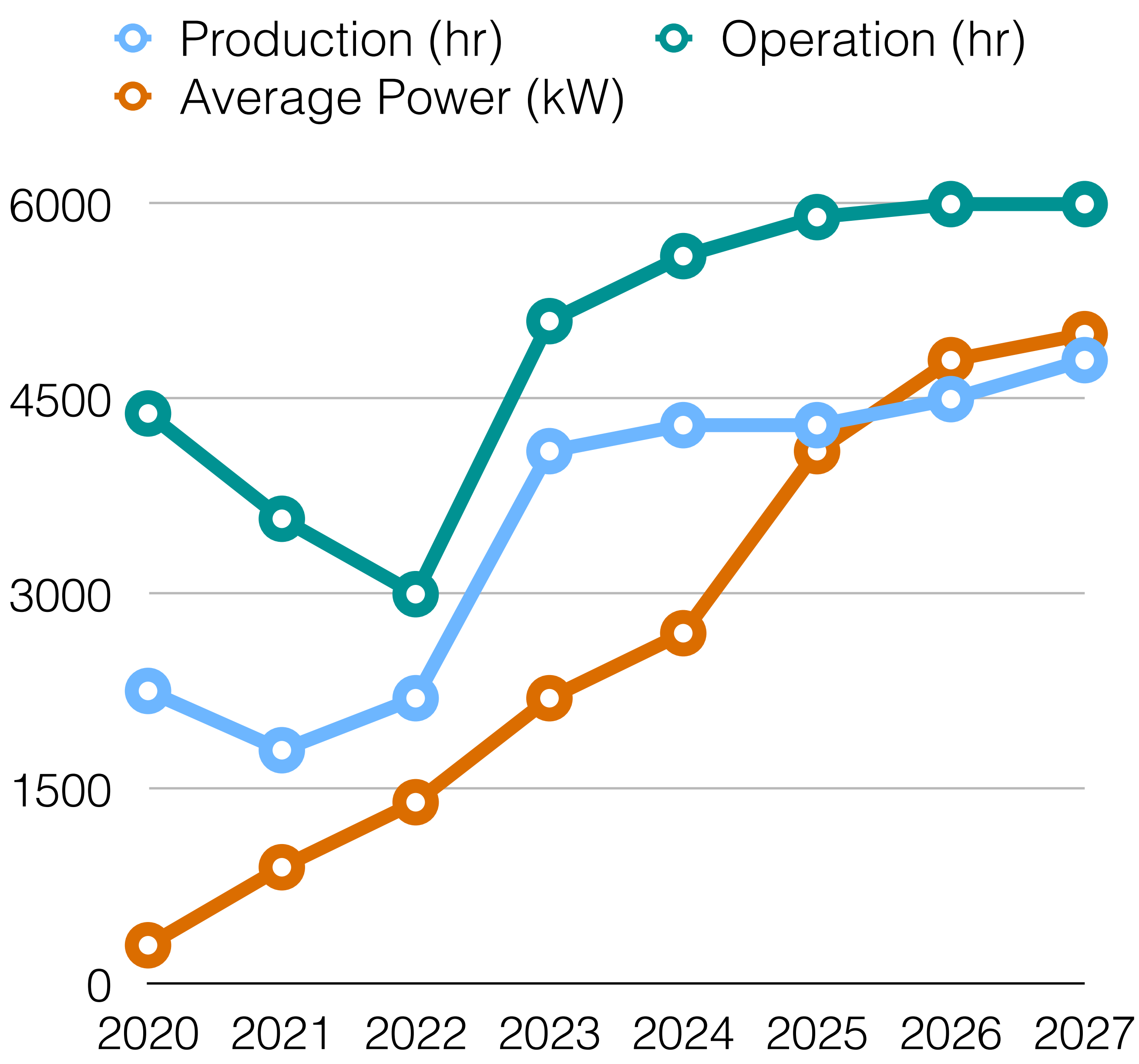
	Length	No. Cavs	No. Magnet	No. Steerers	β	No. Sections	Power (kW)
LEBT	2.38	—	2 Solenoids	2 x 2	--	1	—
RFQ	4.6	1	—	—	--	1	1600
MEBT	3.83	3	11 Quads	10 x 2	--	1	15
DTL	38.9	5	PMQs	15 x 2	--	5	2200
LEDP + Spoke	55.9	26	26 Quads	26	0.50	13	330
Medium Beta	76.7	36	18 Quads	18	0.67	9	870
High Beta	178.9	84	42 Quads	42	0.86	21	1100
Contingency + HEDP	130.4	—	32 Quads	32	(0.86)	15	—
DogLeg	66.2	—	12 Quads + 2 Dipoles	14	—	1	—
A2T	46.4	—	6 Quads + 8 Raster		—	1	

SCHEDULE


EUROPEAN SPALLATION SOURCE
MASTER SCHEDULE - WP02 COMMISSIONING
MILESTONESs
INSTALLATION AND COMMISSIONING
2014
2015
2016
2017
2018
2019
2020
2021
2022
Q1 Q2 Q3 Q4
CF MS
ISrc & LEBT
RFQ
MEBT
DTL
SPOKE
MB
HB
RF
BEAM COMMISS.
EARLY ACCESS TO GALLERY 7-OCT-2016
FULL ACCESS TO TUNNEL 2-MAY-2017
FIRST PROTONs ON TARGET 28-JUNE-2019
CAPABILITY for 2 GeV 23-SEPT-2022
Isr & LEBT installed
RFQ installed
MEBT indtalled
DTL4 installed
DTL5 installed. RFI
FIRST SPK installed
LAST SPK installed
FIRST MB CM installed
LAST MB CM installed
TECHNICAL STOP
TECHNICAL STOP
1-11 HB
12-21 HB
INSTALLATION PHASE 1 RF SYSTEM
INSTALLATION PHASE 2 RF SYSTEM
END COMMISSIONING NC LINAC (excluding DTL5)
END COMM. SPK & MB TO DUMP TO TARGET
END COMM. 1-11 HB TO DUMP TO TARGET
END COMM. 12-21 HB TO DUMP TO TARGET
DATA EXTRACTED BY P6 PLANNING - APRIL 2015
PREPARED BY M. ESHRAQI, L. LARI
CHECKED BY J. WEISEND
APPROVED BY M. LINDROOS

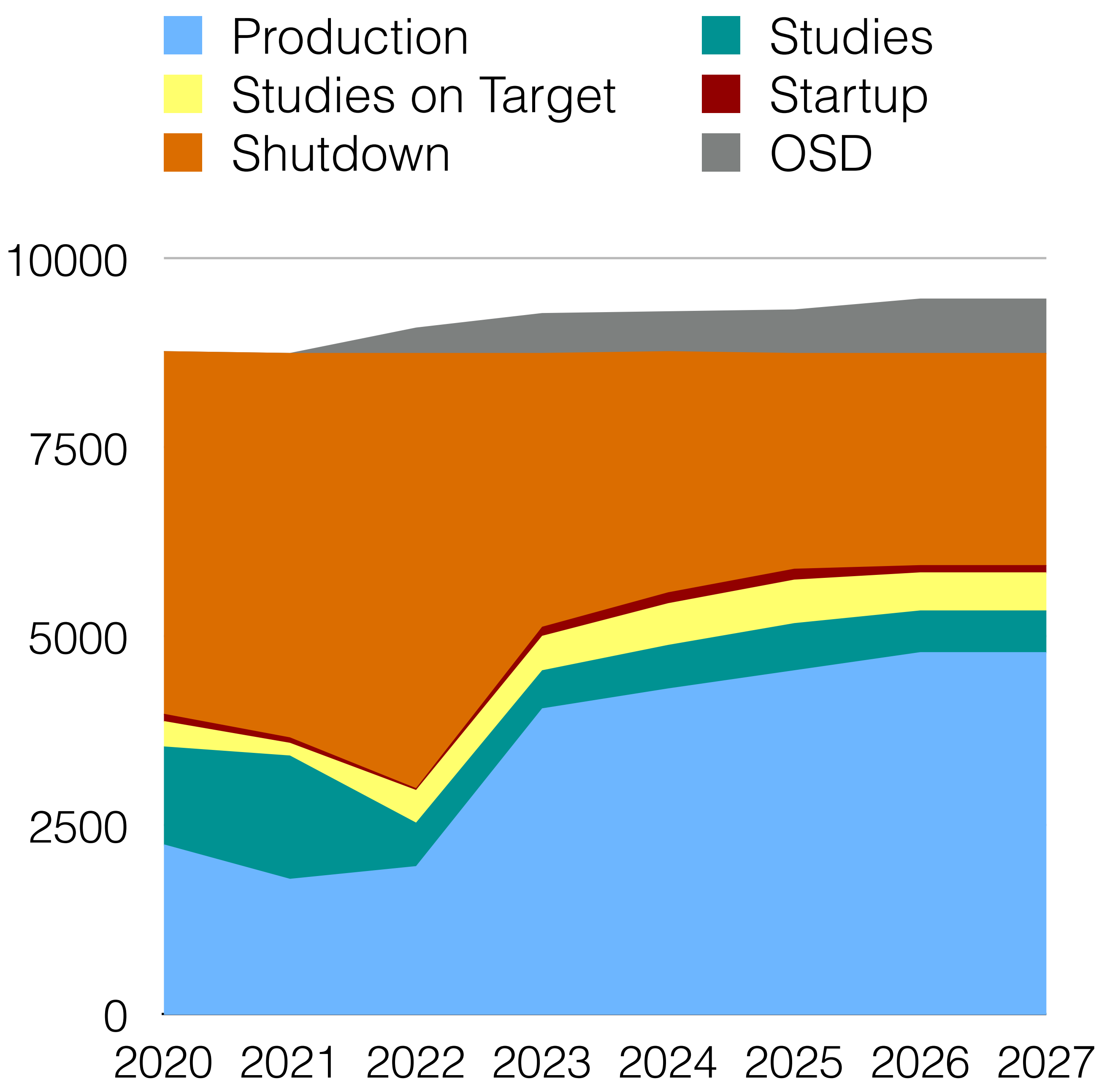
RAMP UP MILESTONES

- The planned (annual averaged) power ramp up increases monotonically from ~300 kW in 2019 to 5 MW in 2026.
- The power could be adjusted through changing the energy, beam current, pulse length and repetition rate.



OPERATION HOURS

- Two long shutdowns are foreseen for years 2021 and 2022, permitting the installation of high beta cryomodules in two phases.
  - In phase one the beam energy can reach 1370 MeV by installing 11 high beta cryomodules
  - In phase two the accelerator is fully installed and can bring the beam energy to 2 GeV

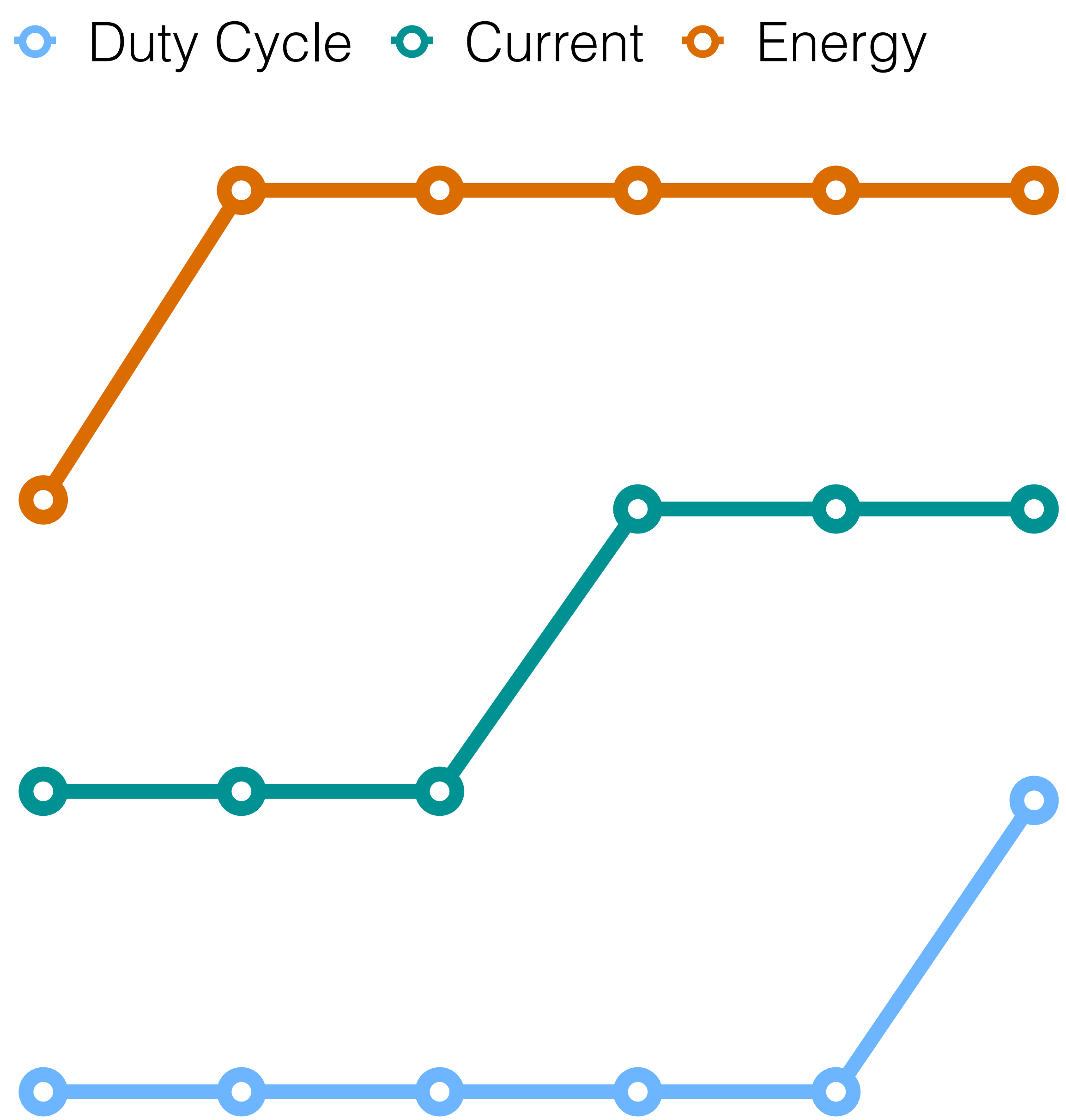


RAMP UP

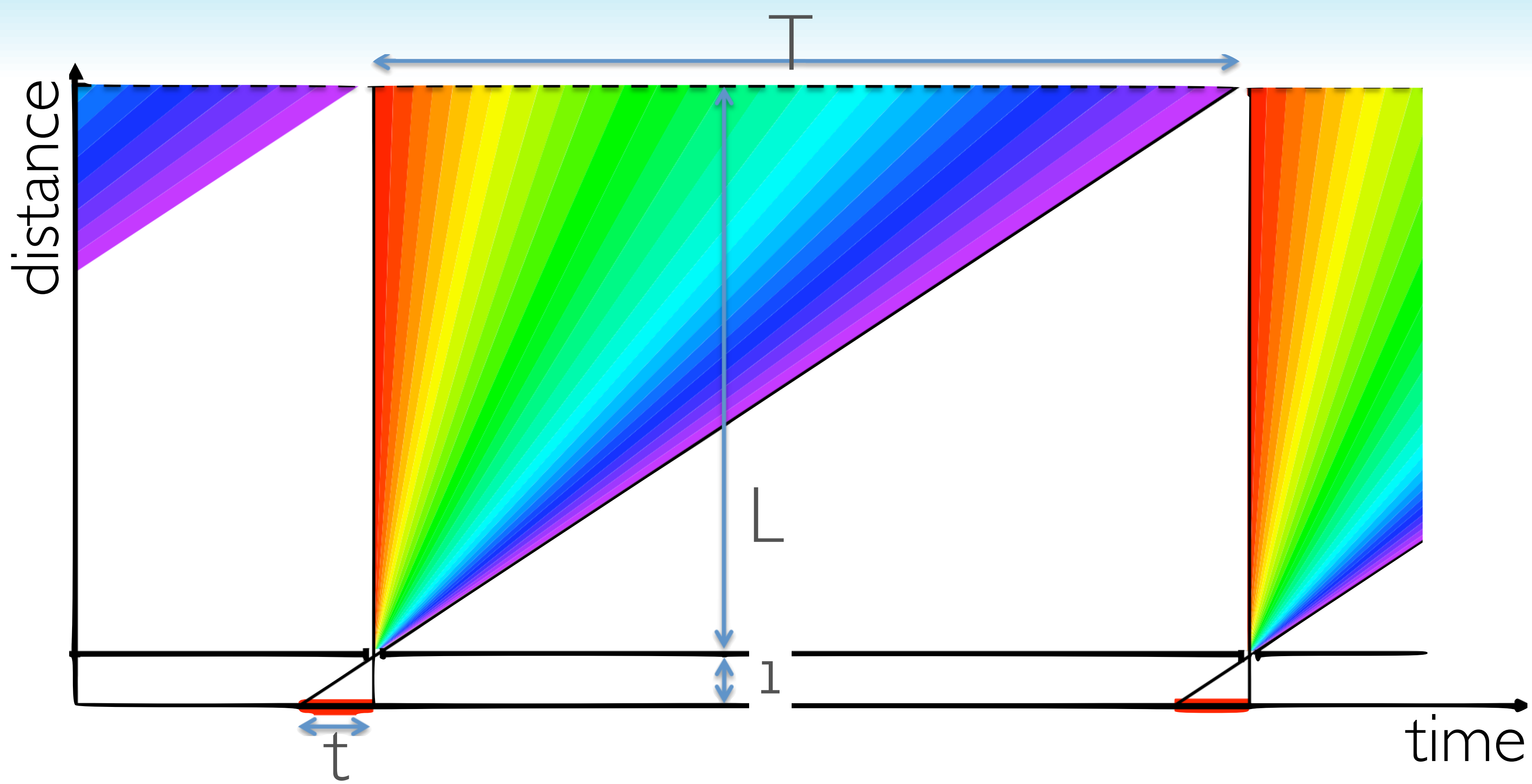
- Initially the cavities are ramped to their nominal (maximum possible), gradient to reach the max energy

- After a period of test the current will be increased to check the sensitivities to space charge and losses as a function of that

- Finally the rep rate is raised to increase the power

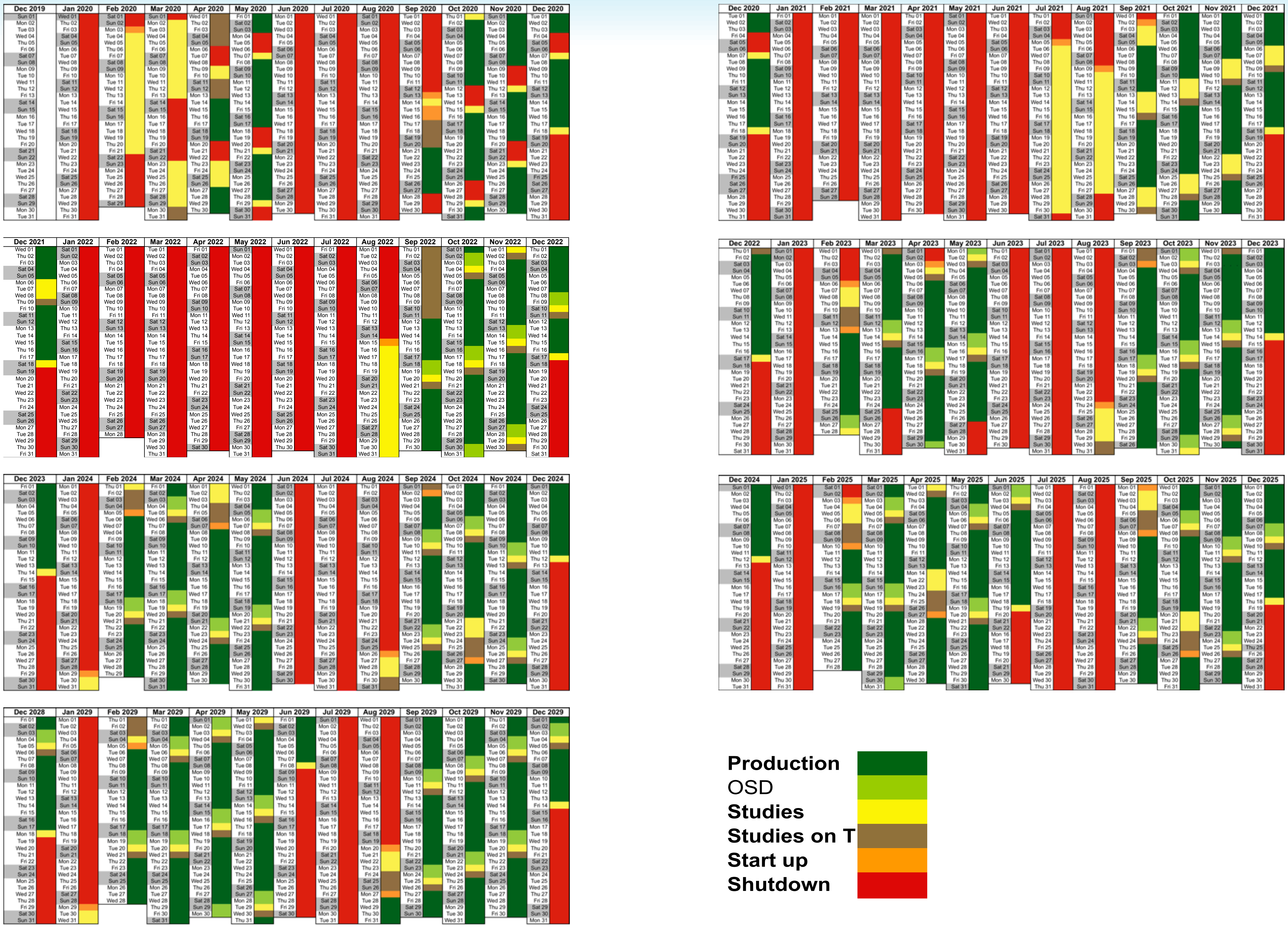


DUTY CYCLE



- Instruments require the full pulse length, however, one wants to ramp up the power gradually
- most efficient way is to ramp the rep rate instead of beam current

CONSTRUCTION TO OPERATION



AVAILABILITY

- How high availability affects losses
  - A defined number operating hours
    - Samples / Users
  - Fast repair and maintenance requirement
    - Activation of the components
    - Cool down time and hands-on maintenance

HIGH POWER ACCELERATORS

- ING: Intense Neutron Generator, 65 MW (1968)
- APT: Accelerator Production of Tritium, 200 MW (1991)
- CONCERT: A High Power Proton Accelerator Driven Multi-Application Facility, 25 MW (2000)

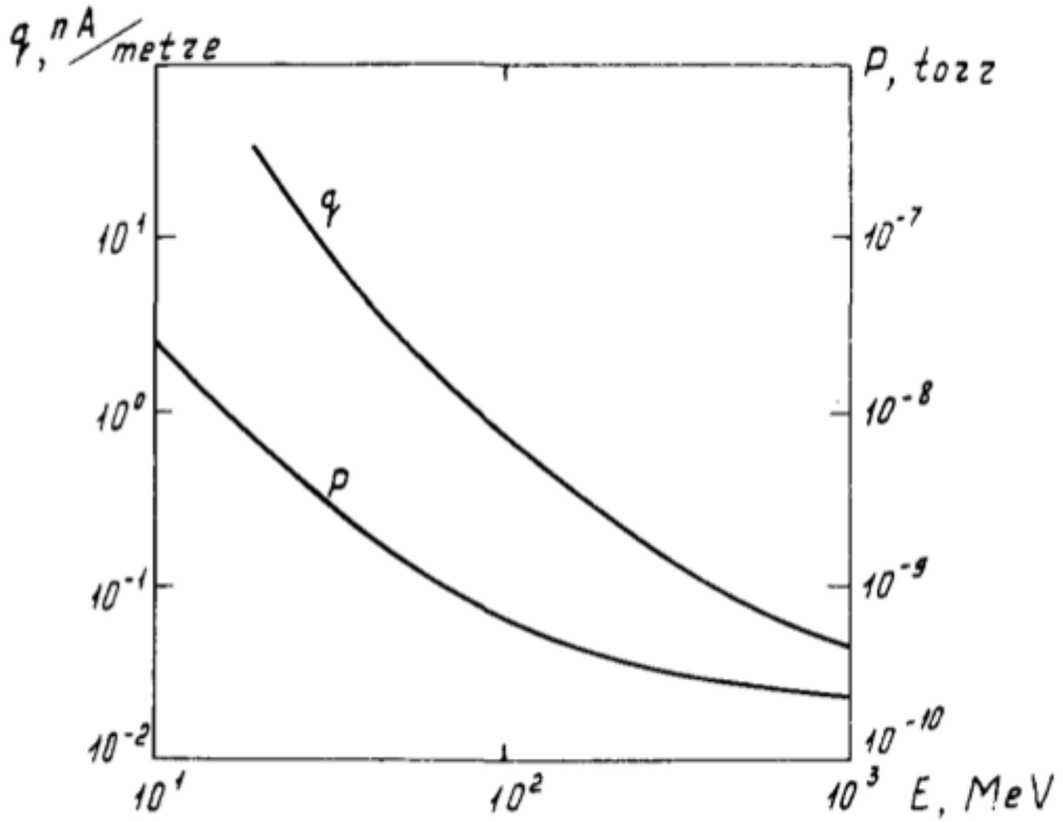
- ISIS: ——— , 350kW (1980)
- SNS: Spallation Neutron Source, 1 MW (1993) - [PSS]
- IFMIF: International Fusion Materials Irradiation Facility, 10 MW (1994)
- ESS: European Spallation Source, 5 MW (1988)

POWER

- At 5 MegaWatt:
  - 14 pulses a second
    - Has the same energy as a discus (2 kg) flying at ~2150 kph (Mach 1.76)
  - Has the same energy as a 1 ton car which travels at ~110 kph
  - Or you can melt +8 (+5) kg of copper (niobium) starting from room temperature

LOSSES

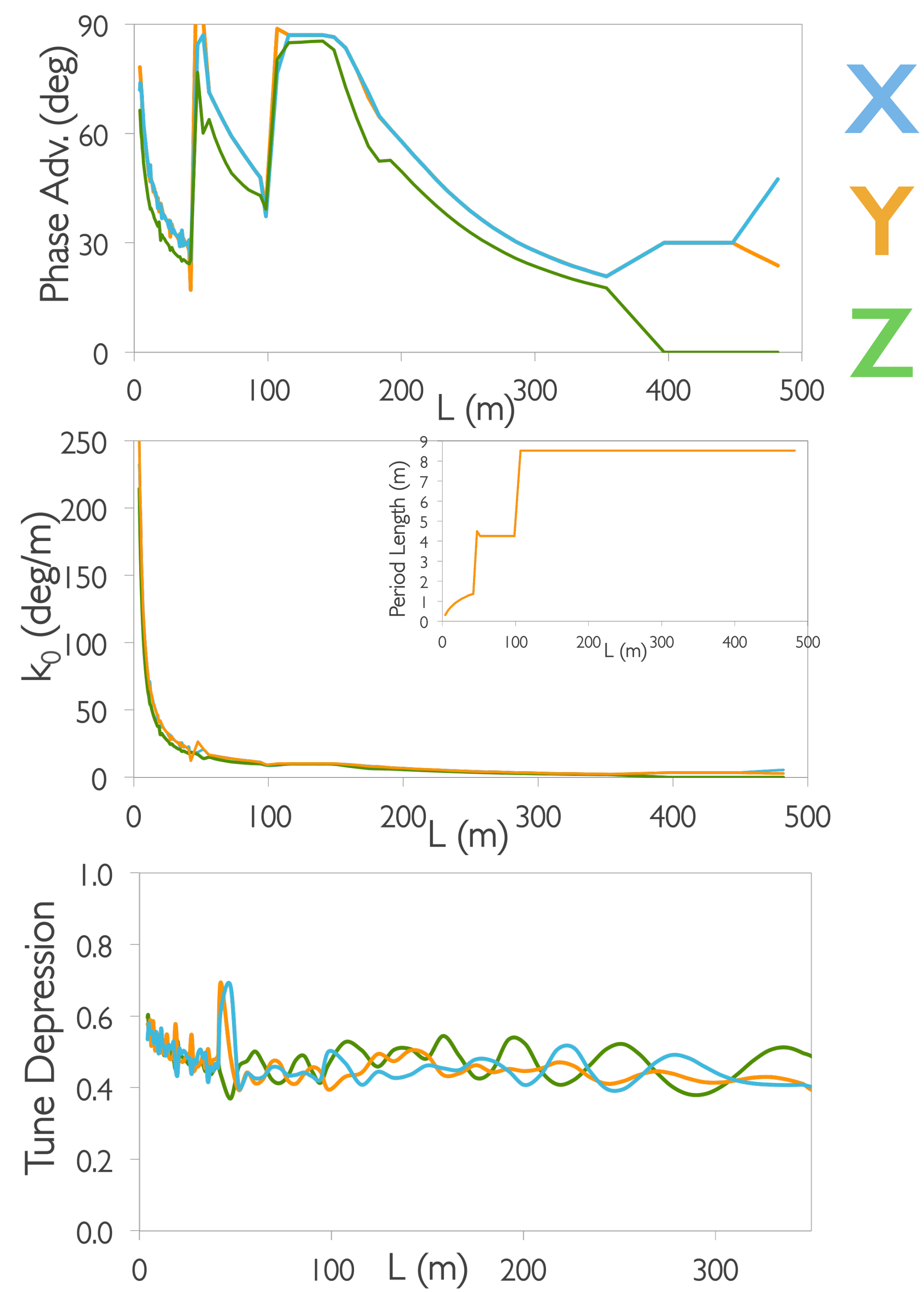
- *"The linac can be considered as radiation-free, provided that the gamma dose at one-metre distance from the linac does not exceed the professional dose of 28 μGy/hr one hour after the linac has been stopped after a long operation"* *A. P. Fedotov*
  - This translates to few tens of a watt/meter



- This value could be relaxed by looking at the linac few hours after such a shutdown, maybe that is where this 1 W/m comes from!

RULES OF THUMB

- Phase advance per period < 90 degrees
- Smooth average phase advance
- Avoiding strong tune depression



LINAC COMPONENTS

- Ion source: current stability
- RFQ: Phase and amplitude stability
  - The phase of the linac is dictated by RFQ

- Errors in phase and amplitude and static errors in the rest of the linac

LLRF FOR LLRF

- Phase and amplitude error in RFQ causes beam arrival error in the rest of the linac
  - This adds/creates additional errors - to be compensated(?) - by the LLRF
  - This adds to the power needed by the buncher cavities (if not compensated)
    - Since buncher cavities work at -90° (quadrature wrt beam), the power needed by this cavities in only to compensate the ohmic losses. A shift in the arrival time adds to the load.

APT REVIEW

- Transient behaviour of the linac is an issue that needs further study.
- A heavily beam loaded accelerator operating at such high power can only be operated with a complex set of sensors and multiple, interacting feedback and feedforward control loops.
- In particular, start-up and recovery from safety trips or routine klystron trips …

SUMMARY

- We are entering the era of – operational – high power accelerators, where beam losses should be controlled to few parts in 10E7.
- This is mainly caused by high availability demanded by users of this machines.
- Though a robust beam physics design could reduce the risk of beam losses, with such high power machines the LLRF is as important and plays a major rule in the success of the accelerator.

THANK YOU!