EUROPEAN SPALLATION SOURCE

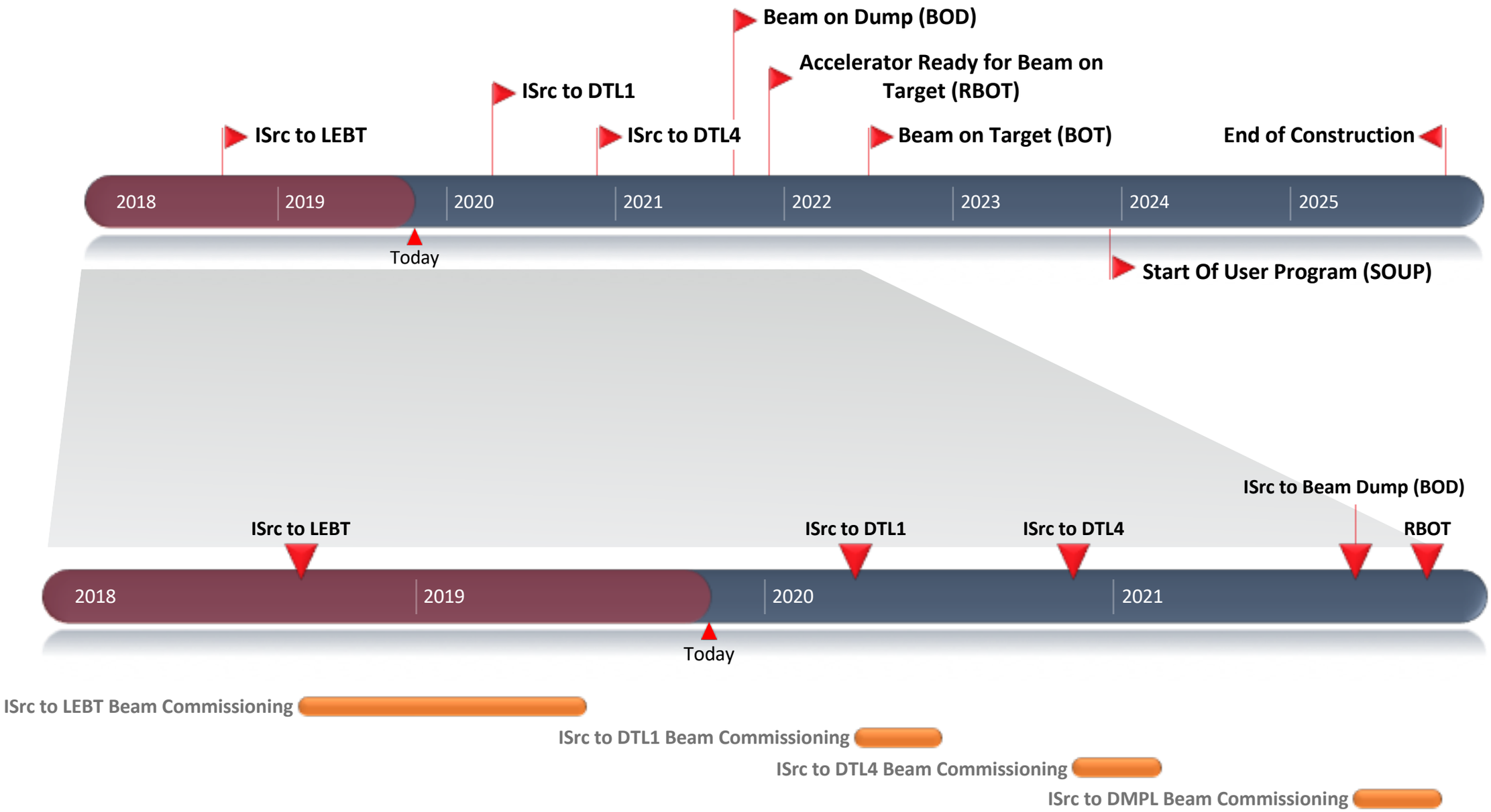
ESSnuSB Linac Report

Mamad Eshraqi for WP2

ESSnuSB Annual Meeting
2019 Oct 21-24

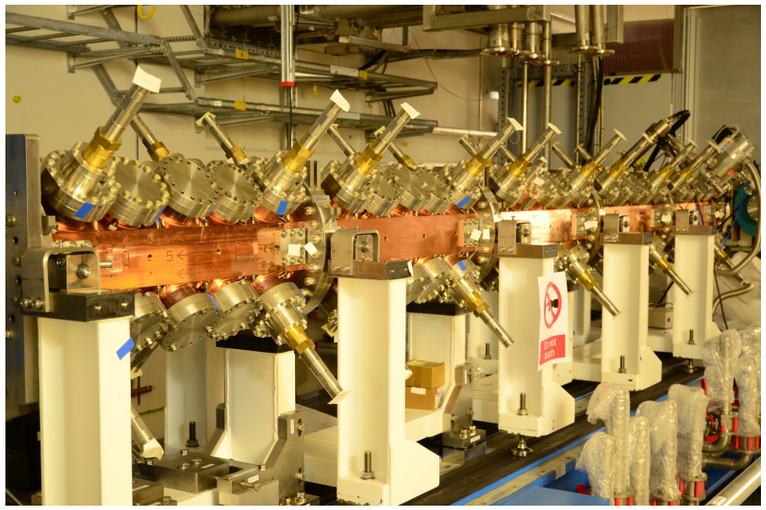
ESS Site

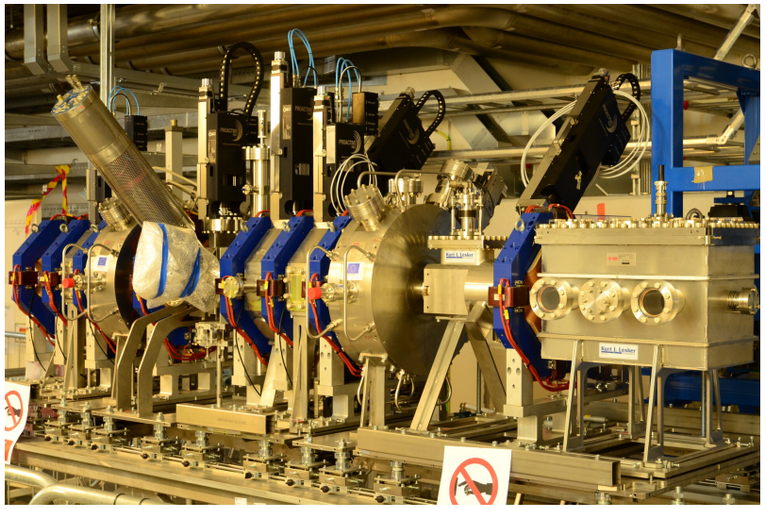
BIG PICTURE

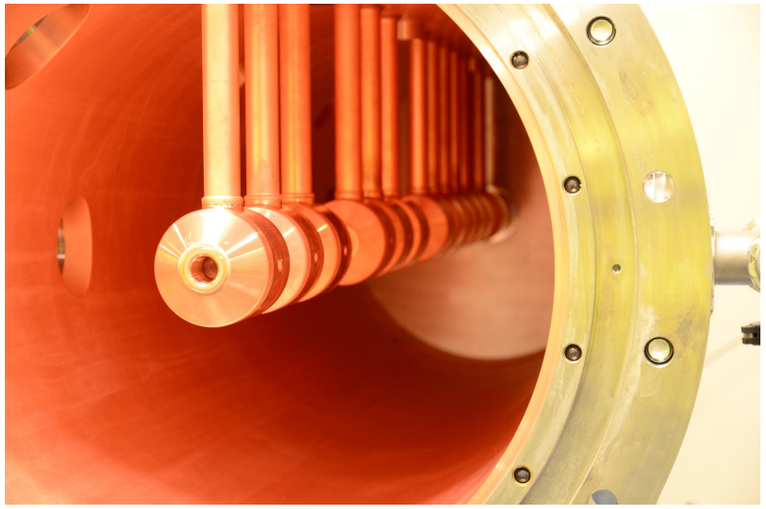


Ciprian Plostinar

SOME UPDATES







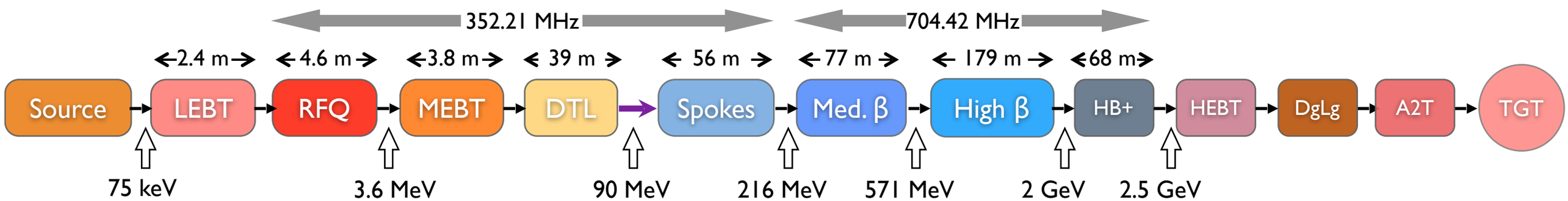
LUND TO GARPENBERG VIA ZINKGRUVAN

ESSnuSB has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777419

WP2 Members

- Mamad Eshraqi (ESS)
  - WP leader
- Roger Ruber (Uppsala University)
  - Deputy WP leader
- Björn Gålnander (ESS)
  - Accelerator scientist
- Aaron Farricker (CERN)
  - Accelerator scientist
- Ben Folsom (ESS)
  - PostDoc
- Open recruitment (ESS)
  - PostDoc (50% ESS, 50% ESSnuSB)
- Colleagues at ESS and UU

Areas of Change



H- source

Front End

SC cavities (couplers, cavities)

RF (Modulators, SSA, Tubes), LLRF

Beam physics (Halo, losses)

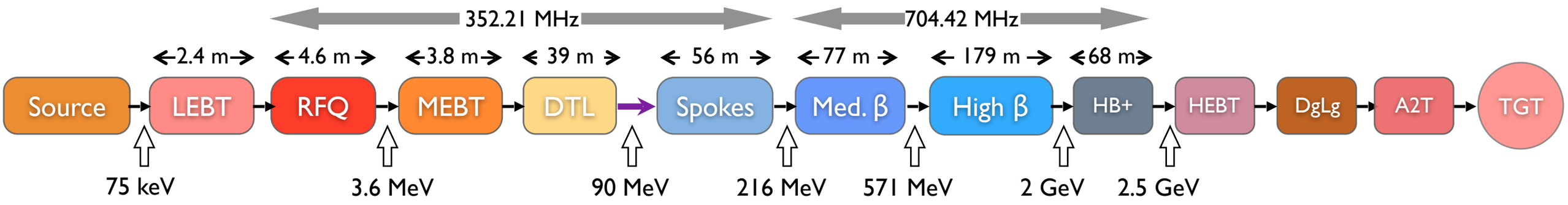
Operations, Reliability, Availability and Safety

L2R

Ring

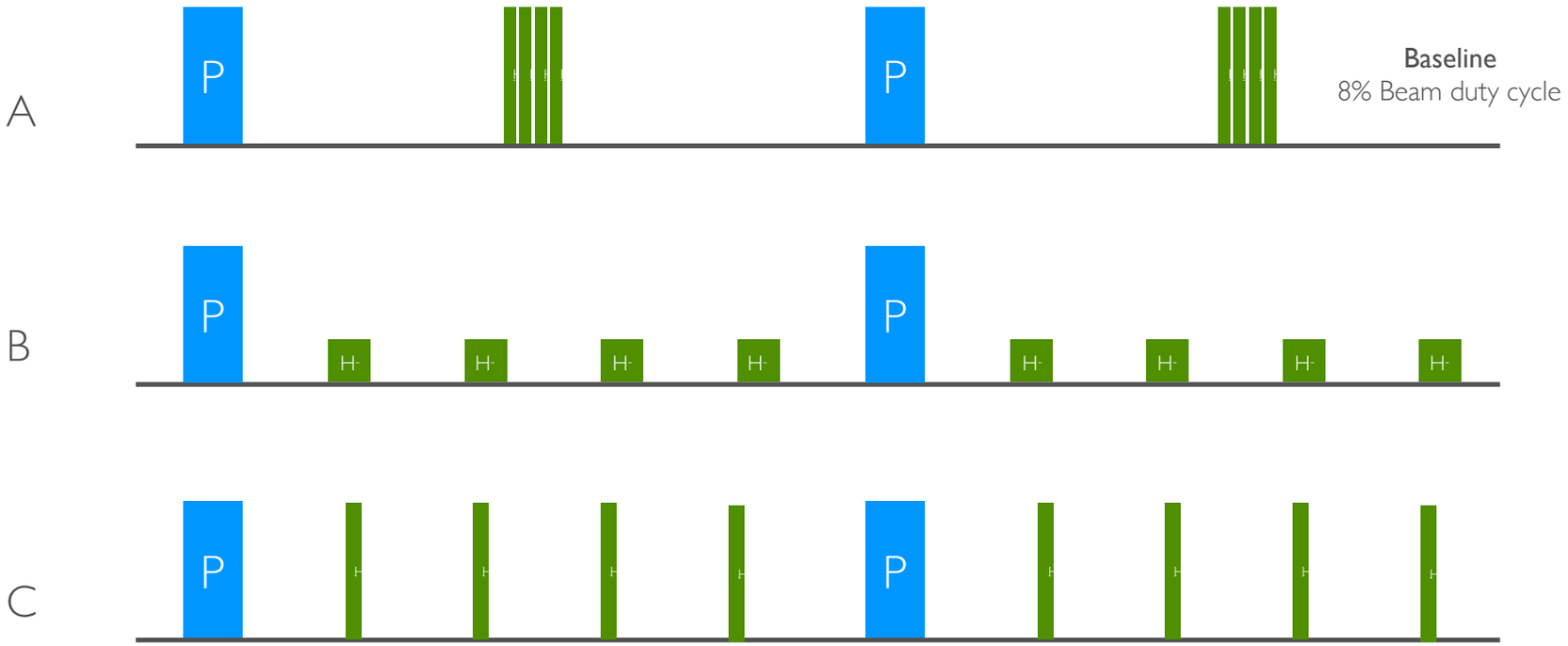
R2T

LINAC LAYOUT



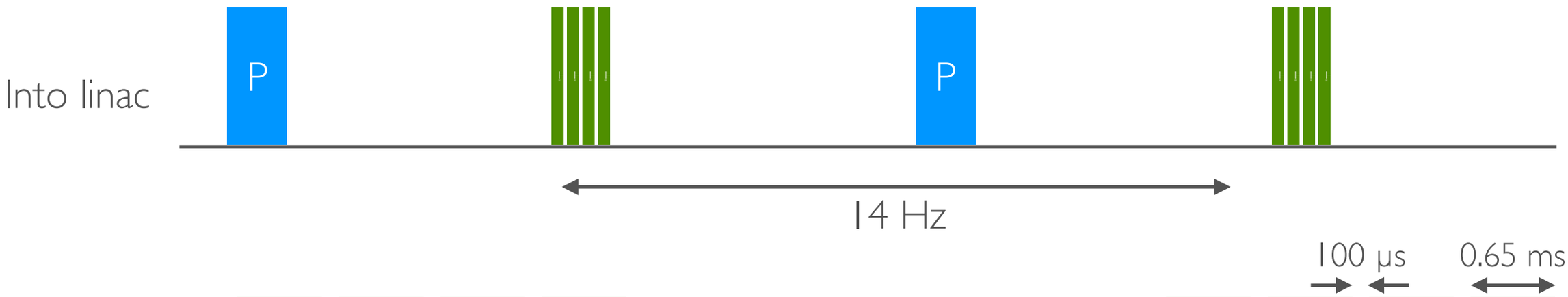
	Length (m)	W_out (MeV)	F (MHz)	β Geometric	No. Sections	T (K)
LEBT	2.38	0.075	—	—	1	~300
RFQ	4.6	3.62	352.21	—	1	~300
MEBT	3.83	3.62	352.21	—	1	~300
DTL	38.9	89.8	352.21	—	5	~300
LEDP + Spoke	55.9	216.3	352.21	0.50 (Opt)	13	~2
Medium Beta	76.7	571.5	704.42	0.67	9	~2
High Beta	178.9	2000	704.42	0.86	21	~2
HB+	68.2	2500	704.42	0.86	8	~2
HEBT	59.6	2500	—	—	7	~300
DogLeg	66.3	2500	—	—	6	~300
A2T	44.6	2500	—	—	1	~300

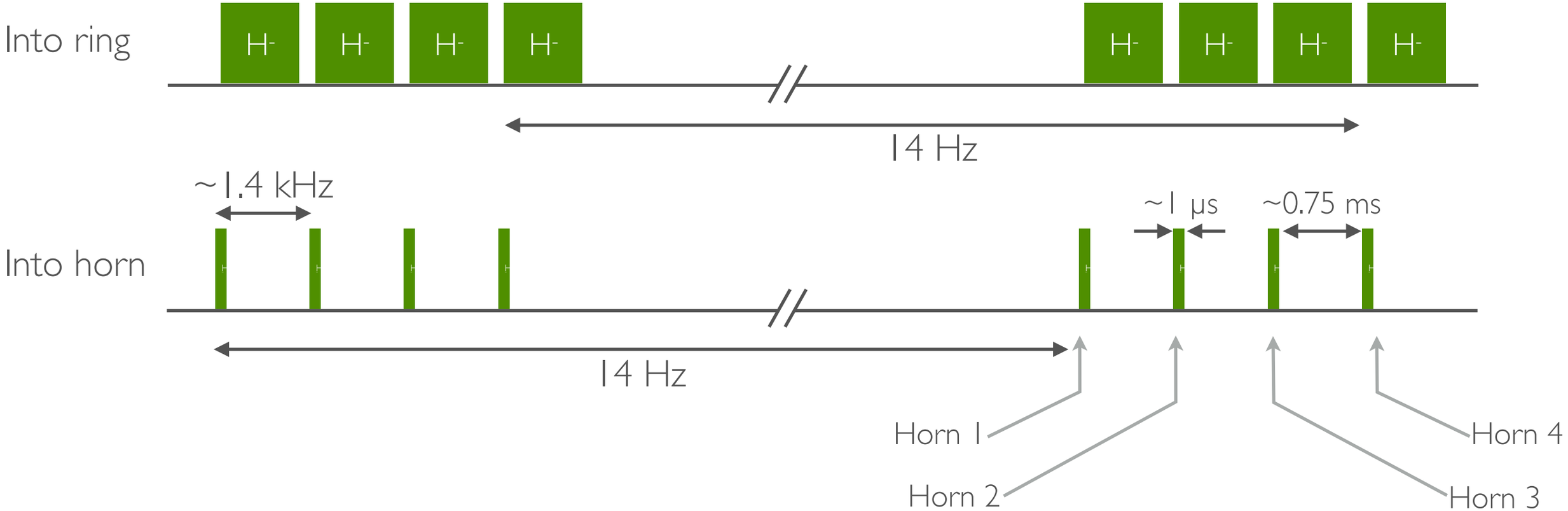
PULSING



Scenario	A	B	C
Sub-pulse length (ms)	0.65	~1.3*	0.77
Beam current# (mA)	60	~30	50
Frequency (Hz)	14	70	70
Time between pulses (ms)	72 (0.75)	14	14
Particles per batch	$2.23 \cdot 10^{14}$	$2.23 \cdot 10^{14}$	$2.23 \cdot 10^{14}$
Batches per macro pulse	4	4	4
Particles per macro pulse (72 ms /14 Hz)	$8.93 \cdot 10^{14}$	$8.93 \cdot 10^{14}$	$8.93 \cdot 10^{14}$

PULSING II


Into linac
P
P
14 Hz
100 µs
0.65 ms


Into ring
H-
H-
H-
H-
H-
H-
H-
H-
14 Hz
Into horn
~1.4 kHz
~1 µs
~0.75 ms
14 Hz
Horn 1
Horn 2
Horn 3
Horn 4

RAL AND SNS SOURCES

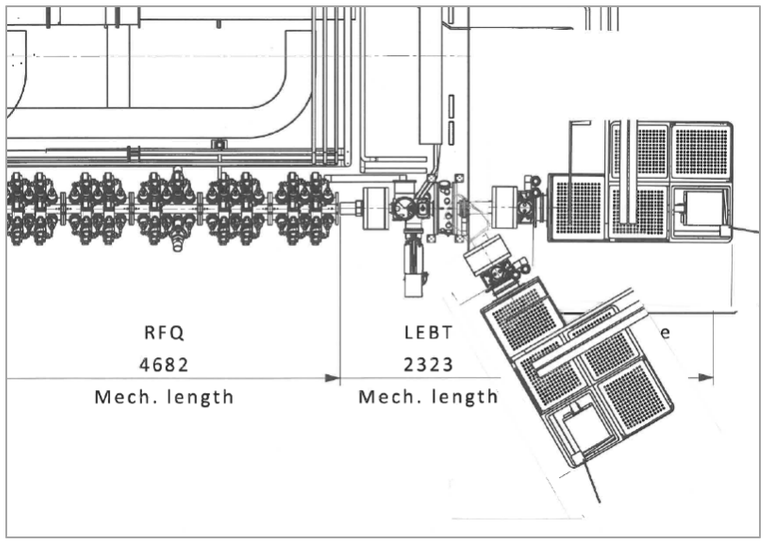
- Started to work with RAL and SNS on developments on their existing sources to make them meet the ESSnuSB needs

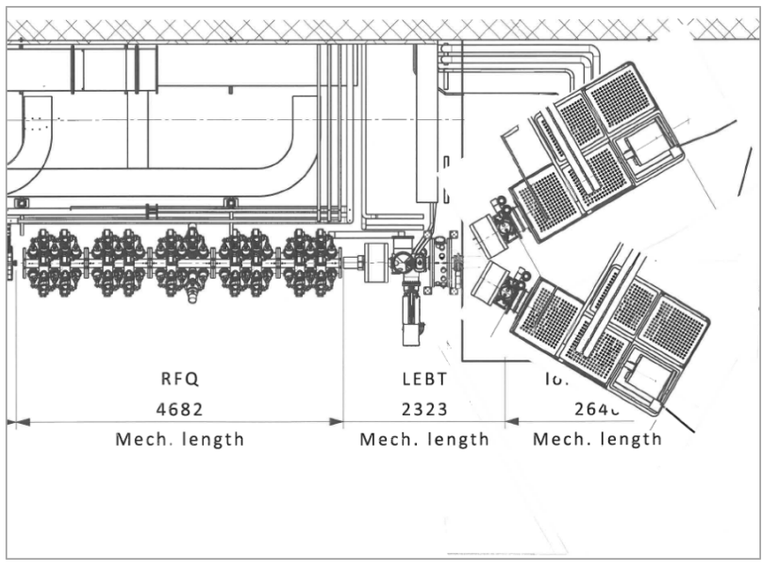
Parameter	RAL Penning 1X ISIS	RAL Penning 2X FETS	SNS, Oak Ridge, RF surface enhanced volume source
Beam pulse length (ms)	0.25 ms	2 ms	1 ms
Repetition frequency	50 Hz	50 Hz	60 Hz
Beam current	55 mA	100 mA	60 mA
Duty cycle	1.25 %	10 %	6 %
Lifetime	5 weeks	2 weeks	14 weeks
Cs consumption	~0.7 g/week	~3.5 g/week	~2 mg/week
Emittance rms norm	0.25 mm mrad	0.3 mm mrad	0.25 mm mrad
LEBT	Sector magnet 90 degrees bend plus Cs cold trap	Einzel lens, carbon Cs trap Magnetic LEBT	Electrostatic LEBT
Emittance rms norm after inital beam transport stage	0.7 mm mrad	0.3 mm mrad	N/A
Extraction voltage	18 (35) kV	18 (65) kV	65 kV

Björn Gålnander

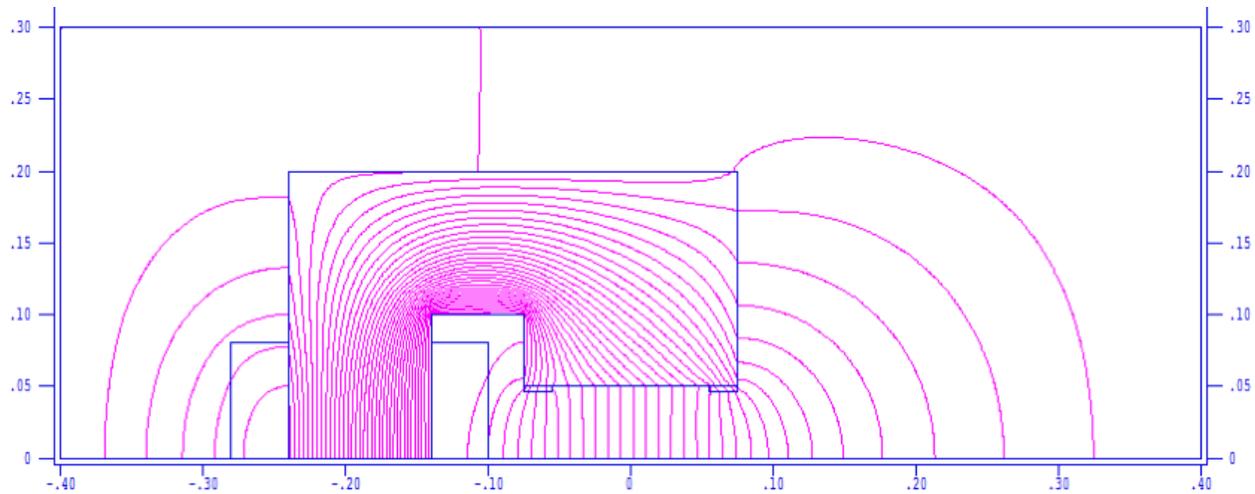
A PULSED DIPOLE

- Possibility of merging the two beams at 70 Hz (cases B and C).





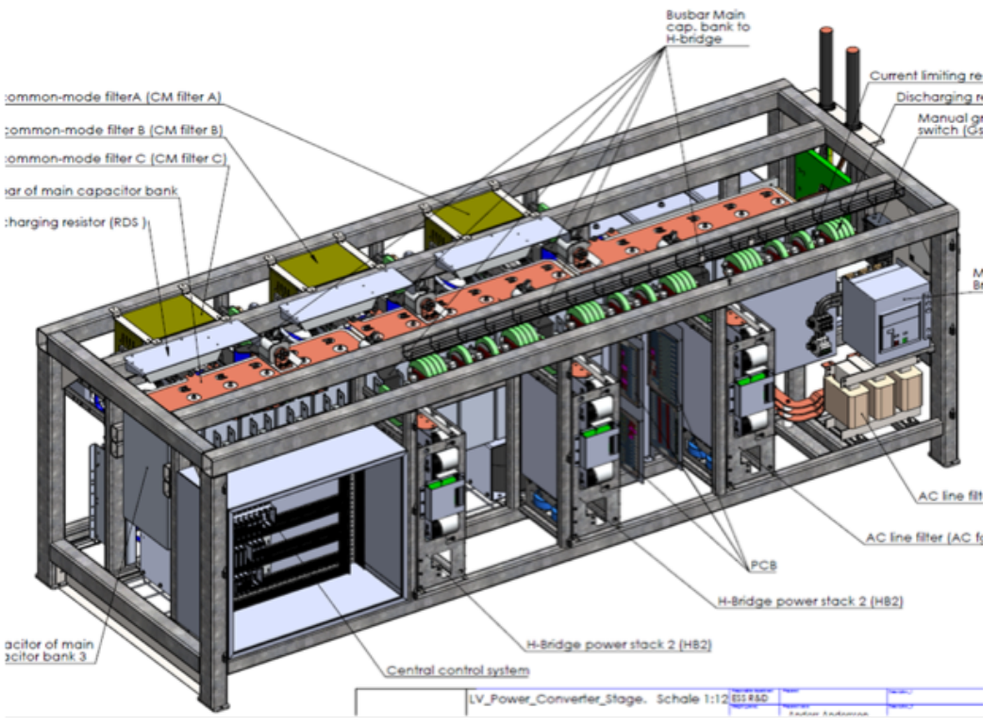
- B field: 0.1 T
- Bending radius: 400 mm
  - pole gap: 100 mm
- A coil with100 turns
  - Inductance: 17 mH
    - possible to switch at 70 Hz
- Power supply:
  - Current: 80 A
  - Voltage: 170 V

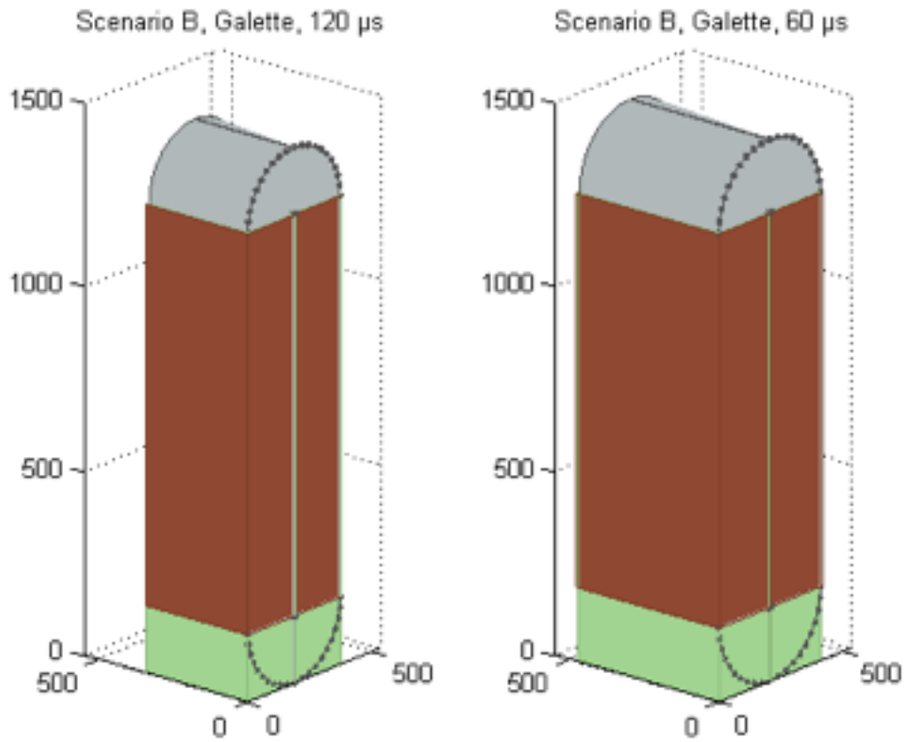


Björn Gålnander Håkan Danared

MODULATOR

- Two different power upgrades for the modulators have been studied:
  - Using the SML modulators of ESS and upgrading the capacitor chargers
  - Using the SML modulators of ESS and adding pulse transformers for the H- beam





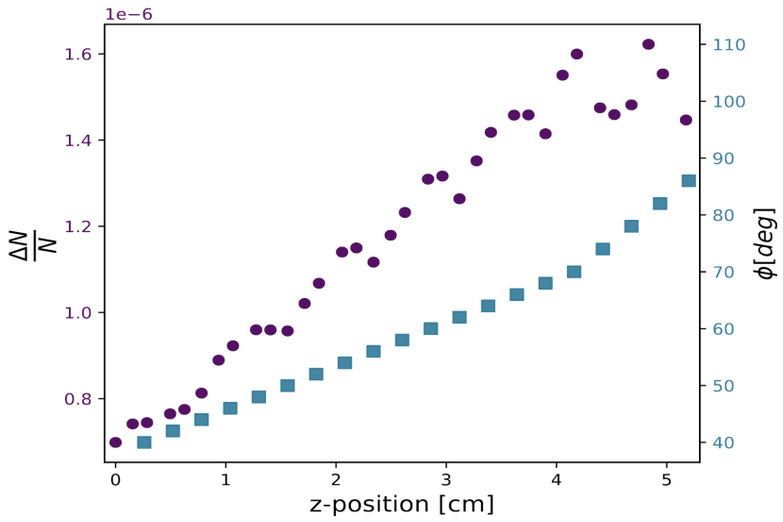
Max Collins and Carlos Martins

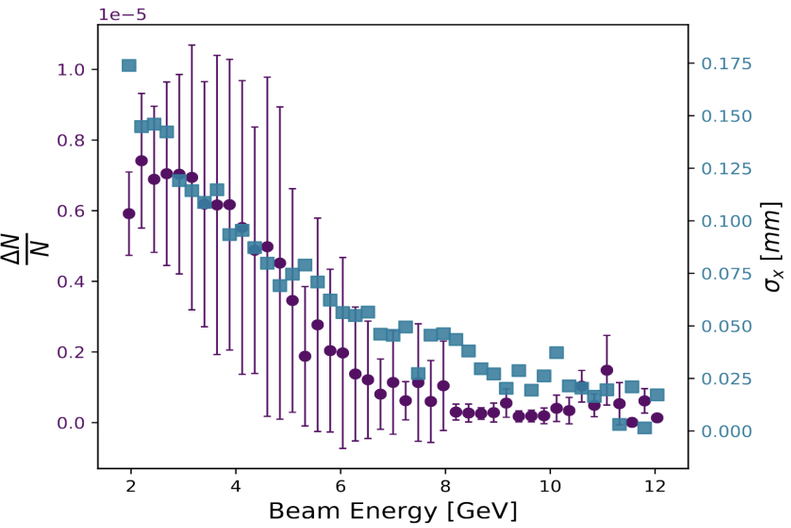
MODULATOR

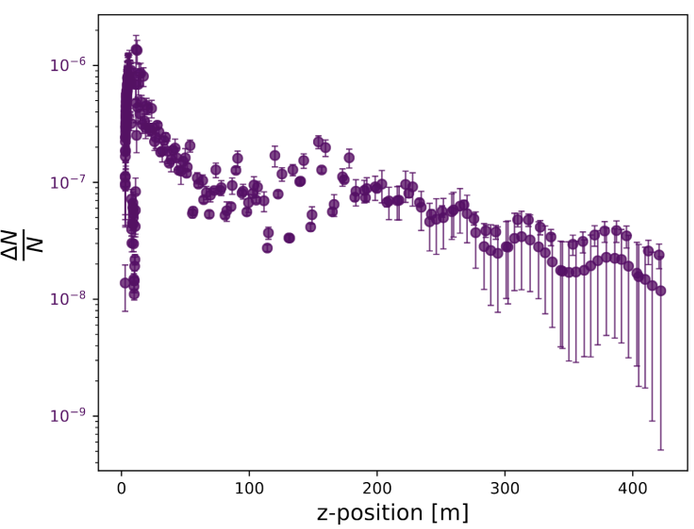
Scenario	Solution	Eta	Investment cost [M€]	Electricity cost per year [M€/y]	Increased system footprint [m²]	Total system height [m]	H^- pulse rise time [μs]
A	SML upgr.	0.82	13.4	14.6	0	3.1	< 120
B	SML upgr.	> 0.80	13.4	14.8	0	3.1	< 80
	SML + PT	> 0.80	26.3	14.8	< 2.5 x 1.5	2.4	60-120
C	SML upgr.	> 0.71	13.4	16.7	0	3.1	< 170
	SML + PT	> 0.72	26.6	16.5	< 2.5 x 1.5	2.4	50-120
Baseline	SML	0.82	N/A	7.30	N/A	2.6	N/A

Max Collins and Carlos Martins

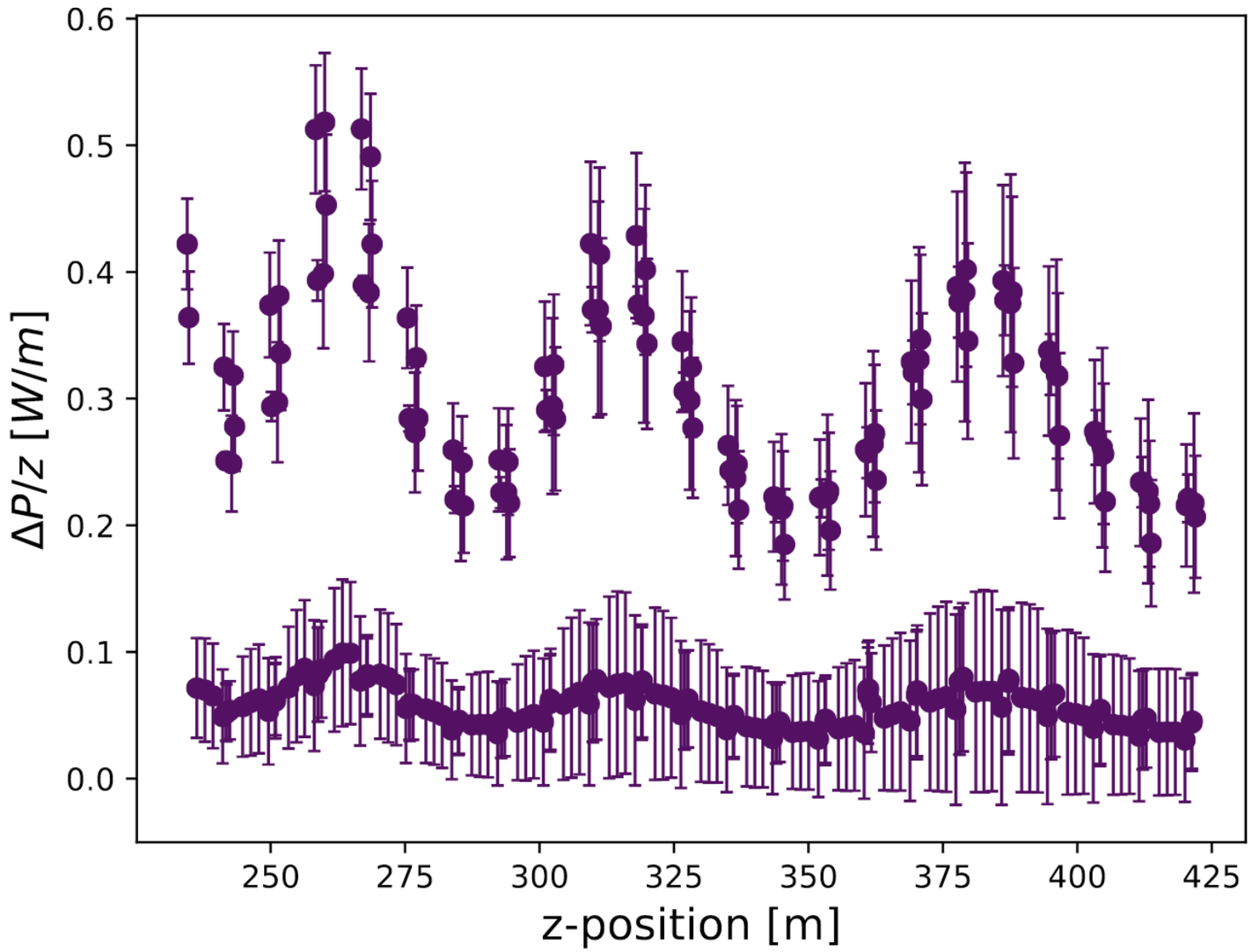
Intra Beam Stripping





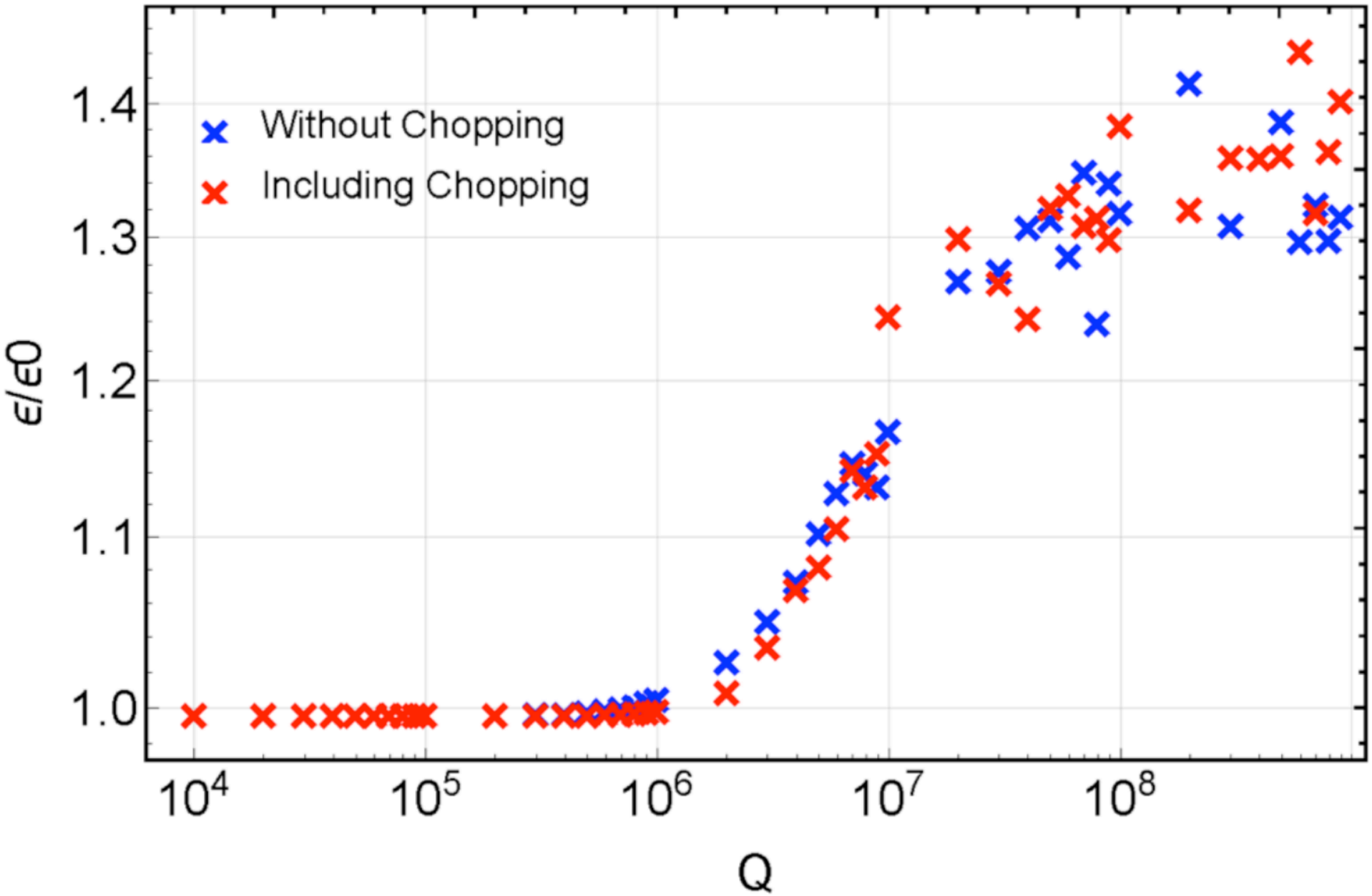


$$\frac{1}{N}\frac{dN}{dS} = \frac{N\sigma_t\sqrt{\gamma^2\theta_x^2 + \gamma^2\theta_y^2 + \theta_z}}{8\pi^2\gamma^2\sigma_x\sigma_y\sigma_z} F\left(\gamma\theta_x, \gamma\theta_y, \theta_z\right)$$



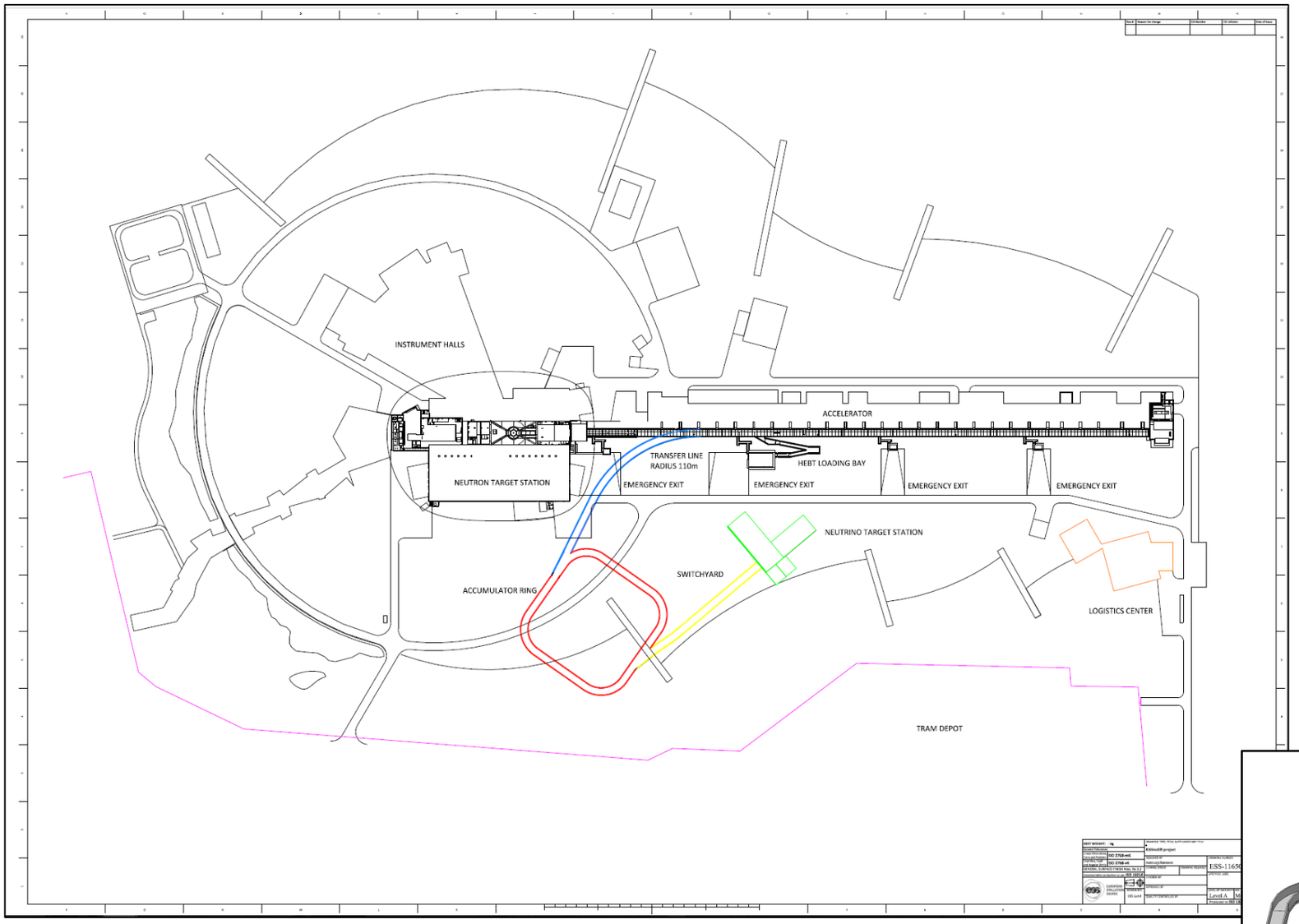
Ben Folsom

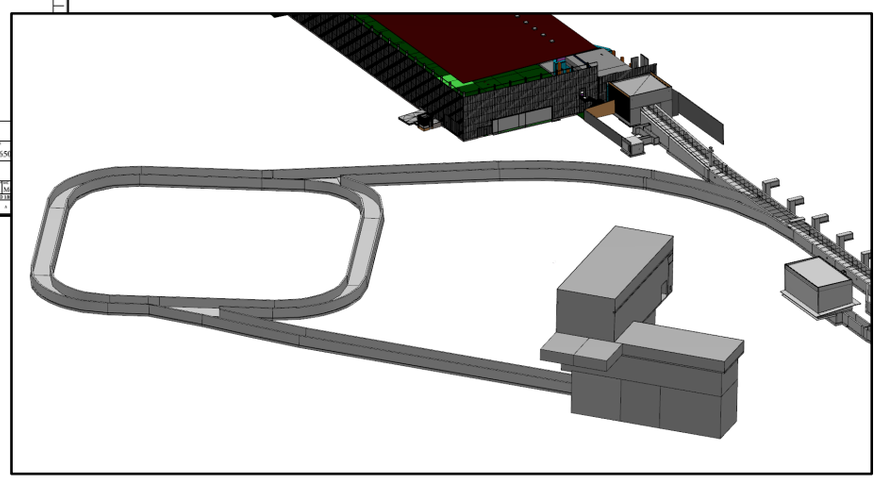
HOMs



Aaron Farricker

ESSnuSB Layout



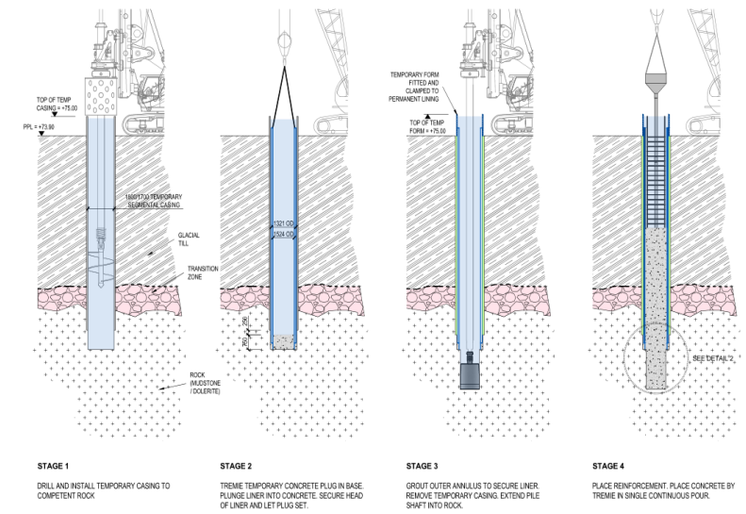


- Transfer line straight end.
- Longer possible switchyard length.
- Target station position flexibility increased.

Rasmus Johansson and Nick Gazis

Excavation and Construction

Diaphragm Wall



Lennart Stenman

EUROPEAN SPALLATION SOURCE

IAP Q&A

IAP Q&A I

- 1) Investigate the possibility to modify the linac tunnel after construction with minimum disruption to ESS operations. Similarly, also investigate how to modify the tunnel section where the H-minus beam is required to be extracted from the linac tunnel and transported to the accumulator ring.
  - Discussions have started with the conventional facilities on both the construction of the transferline, ring tunnel, and the target area as well as the connection of the transferline to the tunnel. This work is ongoing.

IAP Q&A II

- 2) Observe future global developments in H-minus ion sources. If the ESSnuSB requirements cannot be met in time, the project may need to consider a solution of two parallel H-minus sources.

  - Depending on the requirement of different pulsing options, 70 Hz or 28 Hz, the requirements of the beam current varies from about 40 mA at 1.3 ms and 70 Hz, up to 80 mA at 3 ms and 14 Hz.
  - The most demanding case is the long pulse at about 3 ms, and high current, and it is on the edge of the performance of the existing ion sources.
    - We summarize the present status of the H^- ion source development in a recent report [1].
  - The most promising sources available today are the Penning source used at RAL, STFC, and the RF ion source at SNS. For both ion sources it is believed that the most challenging beam requirements could be met with further developments.

IAP Q&A III

- 3) Pursue detailed study of the beam losses, and check whether the current linac design meets the safety requirements of the upgraded linac.
  - A study of H- specific losses is complete.
    - These fall into two categories:
      - mode-resonance losses in the linac due to chopping scheme required for extraction and stripping losses due to the unwanted loss of the outer electron in H-. There were not any high-order modes found to be problematic in the current linac design. Some single-order modes do lie close to resonances lines based on the preferred pulsing scheme, but simulations have shown negligible effect on emittance growth compared to an uncapped beam.
      - All the various known mechanisms for H- stripping have been considered and calculated with the current design parameters for the linac. Of these, intra-beam stripping is the most pressing concern and was tested in multi particle simulations. Throughout the high-energy sectors (>1 GeV), the average power loss is an acceptable 0.13 W/m, with a maximum estimated loss rate of 0.5 W/m in the HBL quadrupoles.

IAP Q&A IV

- 4) Since short gaps in the H-beam time structure might be problematic, consider studying the option of a linac RF repetition rate of 70 Hz, with one longer pulse for the proton beam and four shorter pulses for the H- beam. Compare cost estimates for the two RF options (70 Hz versus 2 x 14 Hz).
  - The 70 Hz pulsing case is being studied as an alternative for the 28 Hz pulsing. For both alternatives, two solutions are assessed; upgrade of the present SML (Stacked MultiLayer) modulators to handle the increased average power, adding separate modulators based on conventional pulse transformer technology. The conclusion is that both of the alternatives are technically feasible for both the 28 Hz and the 70 Hz case. Upgrading the SML modulators would require significantly less additional space (footprint) and is approximately two times less expensive than the PT pulse transformer type, and is therefore preferred.
  - The klystron collectors need to be upgraded to handle the higher power, and the lifetime will be shortened with a higher RF duty cycle, but at the time when ESSnuSB is built up the klystrons are at the end of the lifetime, and could be exchanged for upgraded versions.
  - The LLRF will be able to adapt to the 70 Hz case with some reprogramming of the firmware. The increased pulsing frequency will put a higher load on the fast cavity tuners, the piezo-tuners, and the cooling of these needs to be addressed as well as the additional heat load of the power couplers. With a higher repetition rate, there will be more ringing from the previous pulse at the start of the new pulse, and tests have to confirm that the tuning system is able handle this.

IAP Q&A V

- 5) Clarify whether the ESS proton beam will be 2.0 GeV or 2.5 GeV by the time of the planned ESSnuSB construction. 2.5 GeV would be preferred as it is less technically challenging and matched to the present physics potential studies.

  - All the parties have agreed to use the 2.5 GeV beam, this requires 8 additional cryomodules to be added to the ESS tunnel, along with the CDS, and the RF system.

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Thank you!