Nufact
RAL and CERN p-drivers

S. Gilardoni – CERN

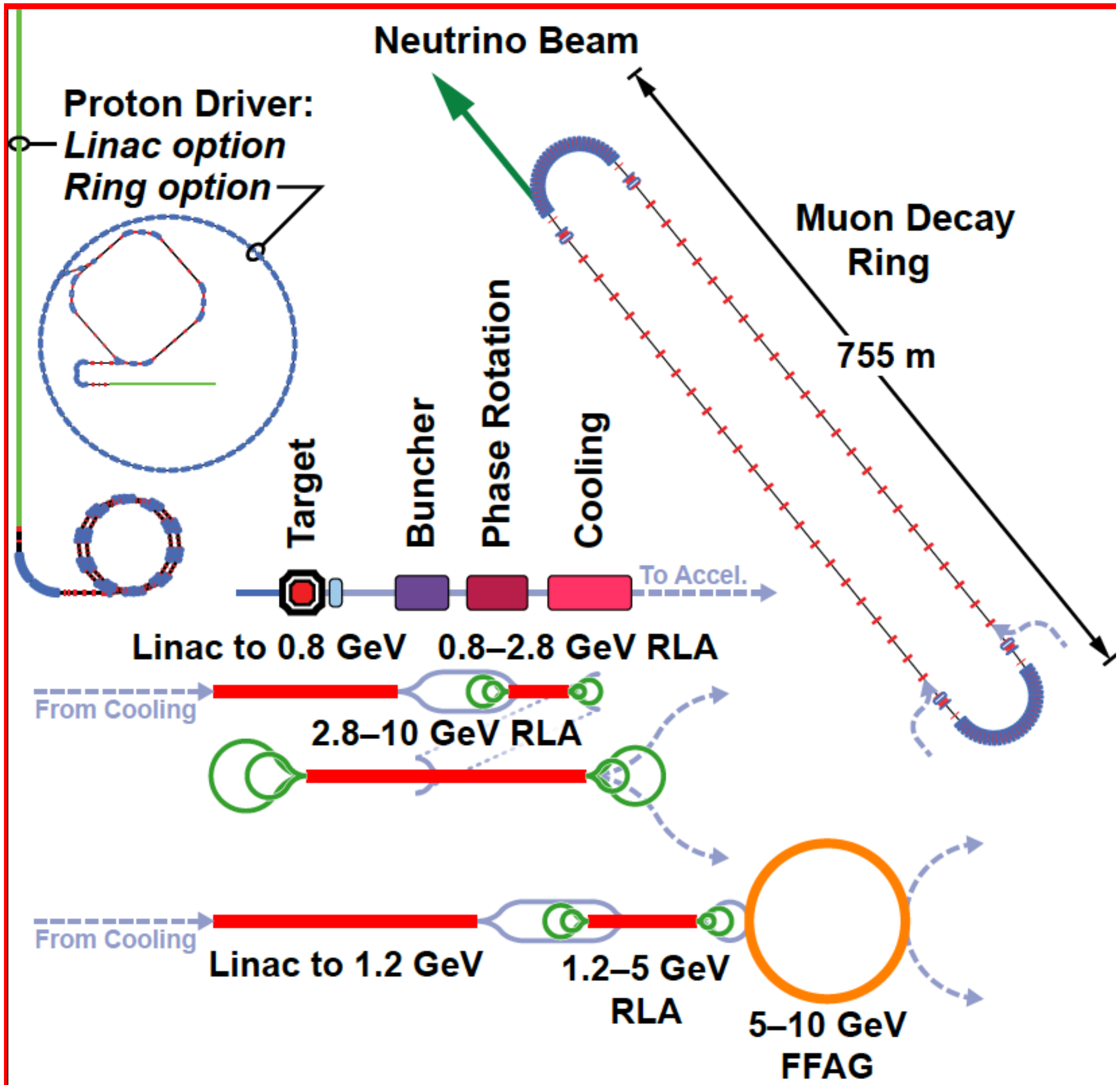
Based on contributions from:

J. Thomason, ISIS Accelerator Division
M. Aiba, E. Benedetto, R. Garoby and M. Meddahi, CERN

Multi-MW p-driver

Basic requirements:

- 4 MW power on target
- Energy between 5 – 15 GeV
- RMS bunch length 1 – 3 ns
- 50 Hz rep. rate.
- 3 bunches, spaced by more than 80 μs

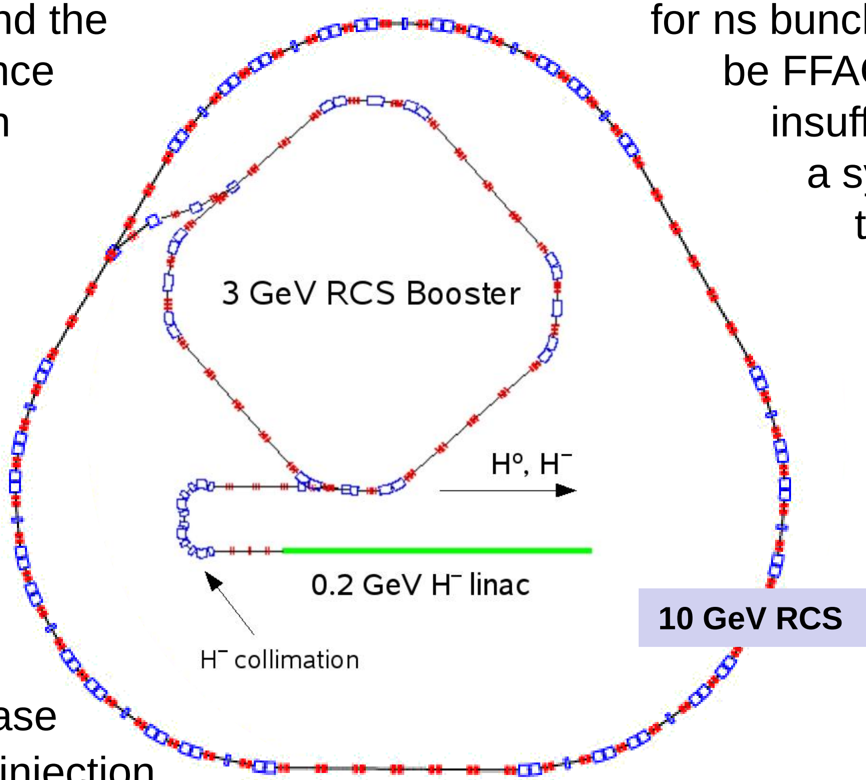


UK Green Field Solution

Chris Prior, Grahame Rees,
Shinji Machida (Science & Technology Facilities Council ASTeC)

Proton Driver for a Neutrino Factory

- Lower injection energies provide smaller bucket area in the ring and the small longitudinal emittance needed for final ns bunch compression. Studies show that 180 MeV is a realistic energy for NF
- Special achromat for collimation (longitudinal and transverse) and momentum ramping for injection
- Separate booster ring designed for low loss phase space painting for beam injection and accumulation. Synchrotron moving buckets give flexibility to capture all of the injected beam

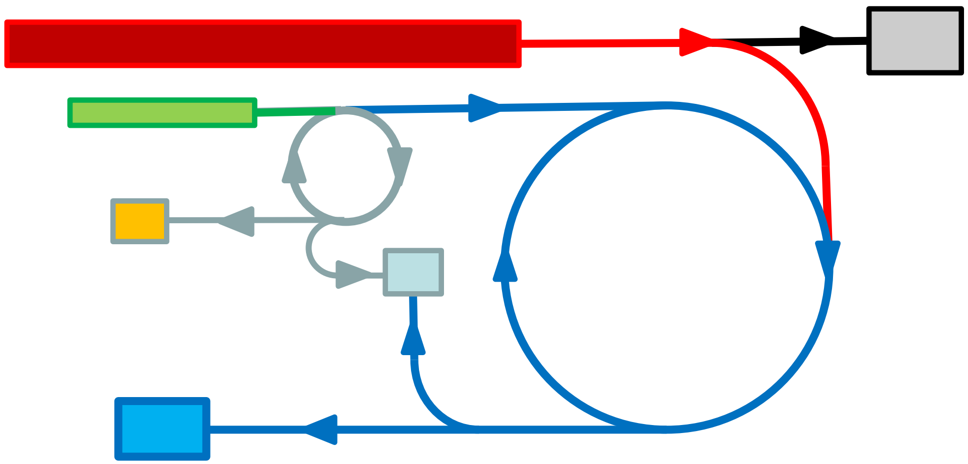


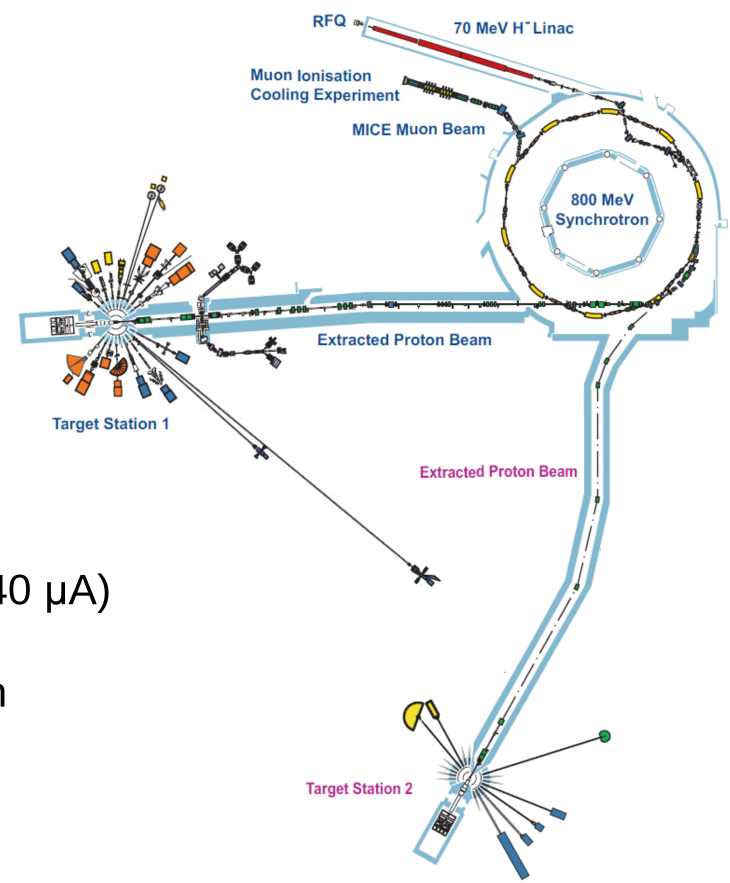
- Separate main ring with optics chosen for ns bunch compression. Could be FFAG (cheaper but insufficiently developed) or a synchrotron (reliable, tried and tested)
- Compressed bunches need to be held and sent to target at intervals of ~100 μs. Possible in FFAG and also synchrotron with flat top

ISIS Upgrade + NF Solution

Science & Technology Facilities Council
ISIS

ISIS Upgrades



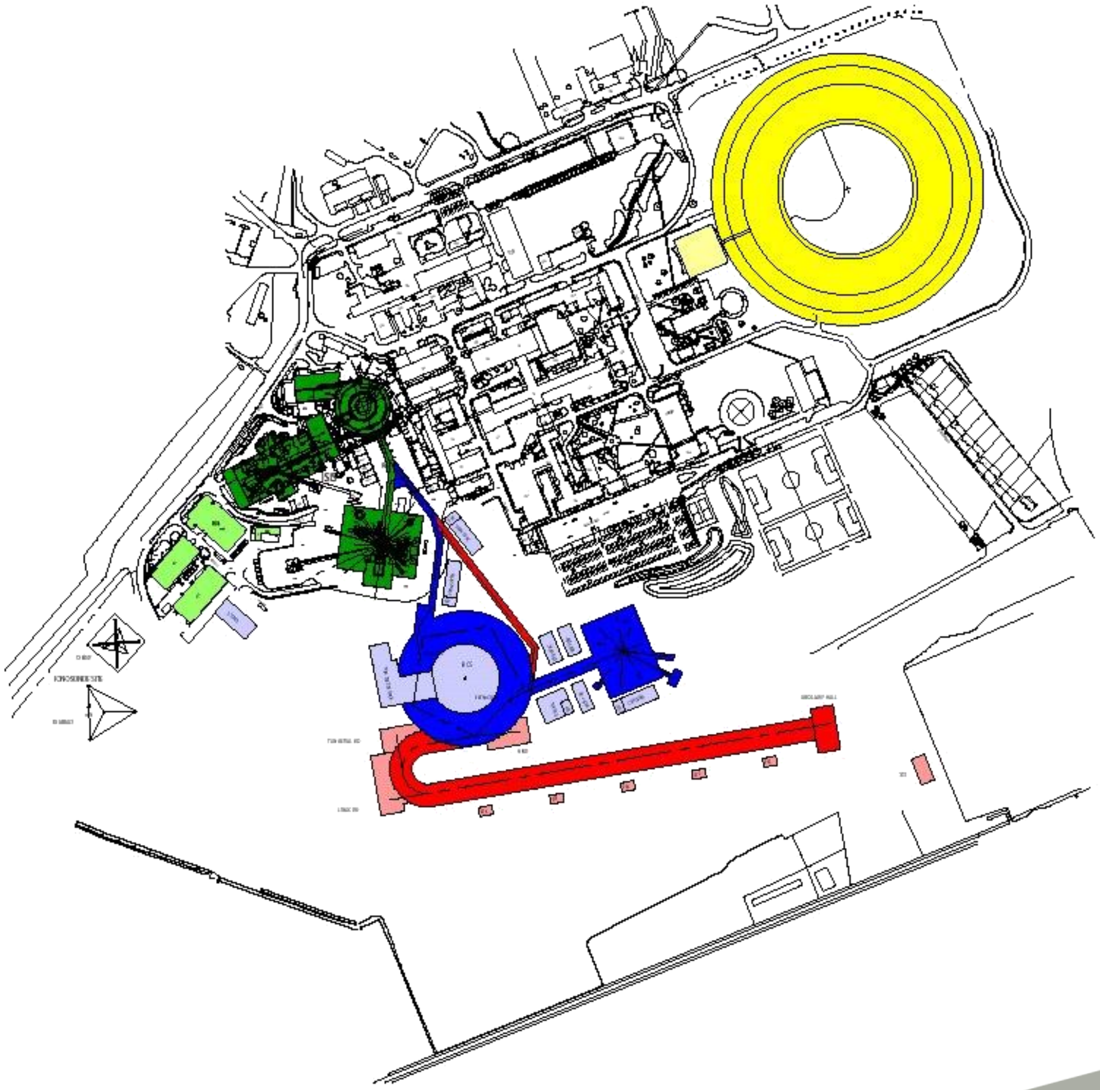


- Present operations for two target stations
  - Operational Intensities: 220 – 230 μA (185 kW)
  - Experimental Intensities of $3{\times}10^{13}$ ppp (equiv. 240 μA)
  - DHRF operating well: High Intensity & Low Loss
  - Now looking at overall high intensity optimisation

- Study ISIS upgrade scenarios
  - 0) Linac and TS1 refurbishment
  - 1) Linac upgrade leading to ~0.5 MW operations on TS1
  - 2) ~3.3 GeV booster synchrotron: MW Target
  - 3) 800 MeV direct injections to booster synchrotron: 2 – 5 MW Target
  - 4) Upgrade 3) + long pulse mode option

Overlap with NF proton driver

ISIS MW Upgrade Scenarios

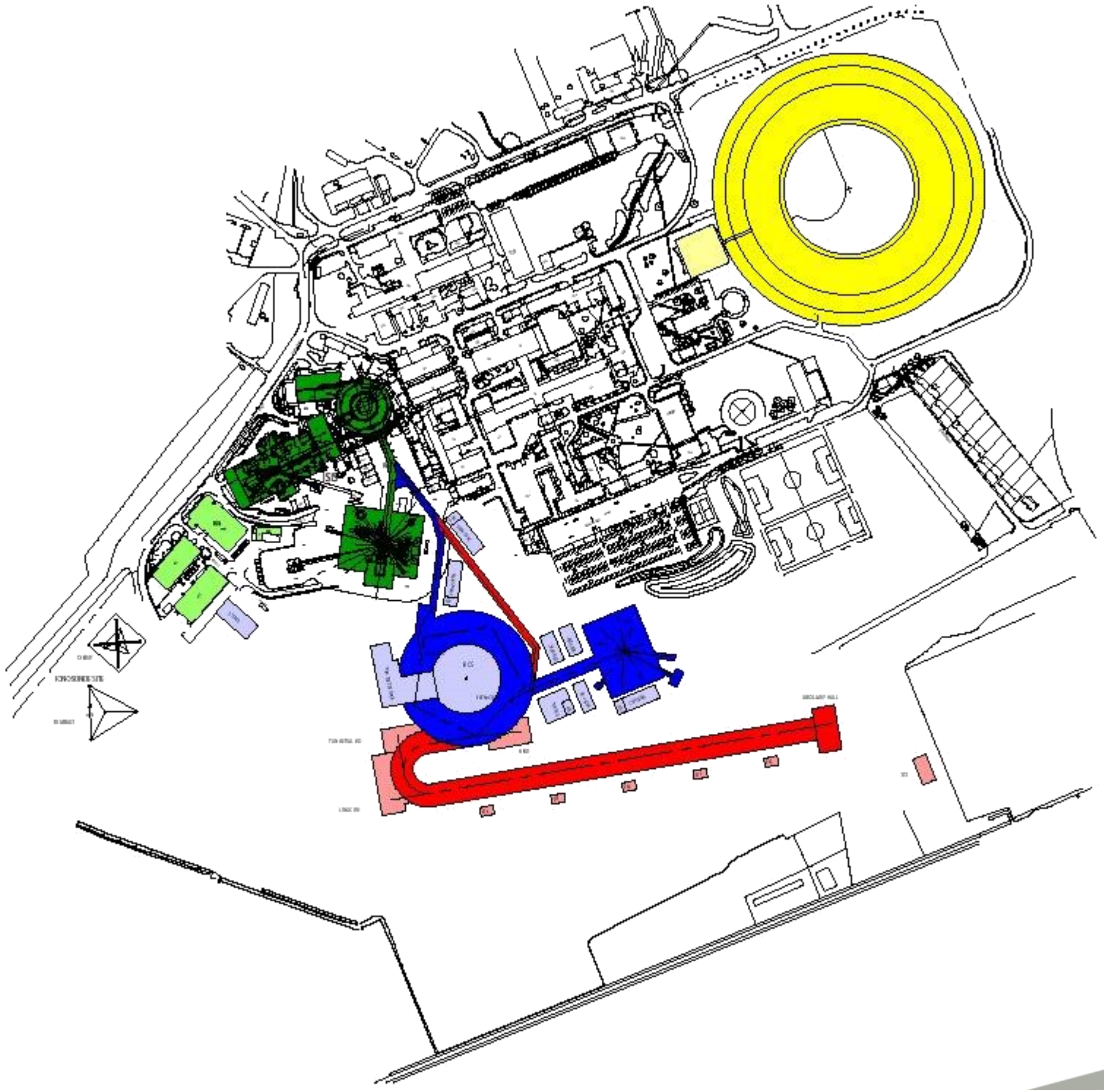


1) Replace ISIS linac with a new ≈ 180 MeV linac (≈ 0.5MW)

2) Based on a ≈ 3.3 GeV RCS fed by bucket-to-bucket transfer from ISIS 800 MeV synchrotron (1MW, perhaps more)

3) RCS design also accommodates multi-turn charge exchange injection to facilitate a further upgrade path where the RCS is fed directly from an 800 MeV linac (2 – 5 MW)

ISIS MW Upgrade Scenarios



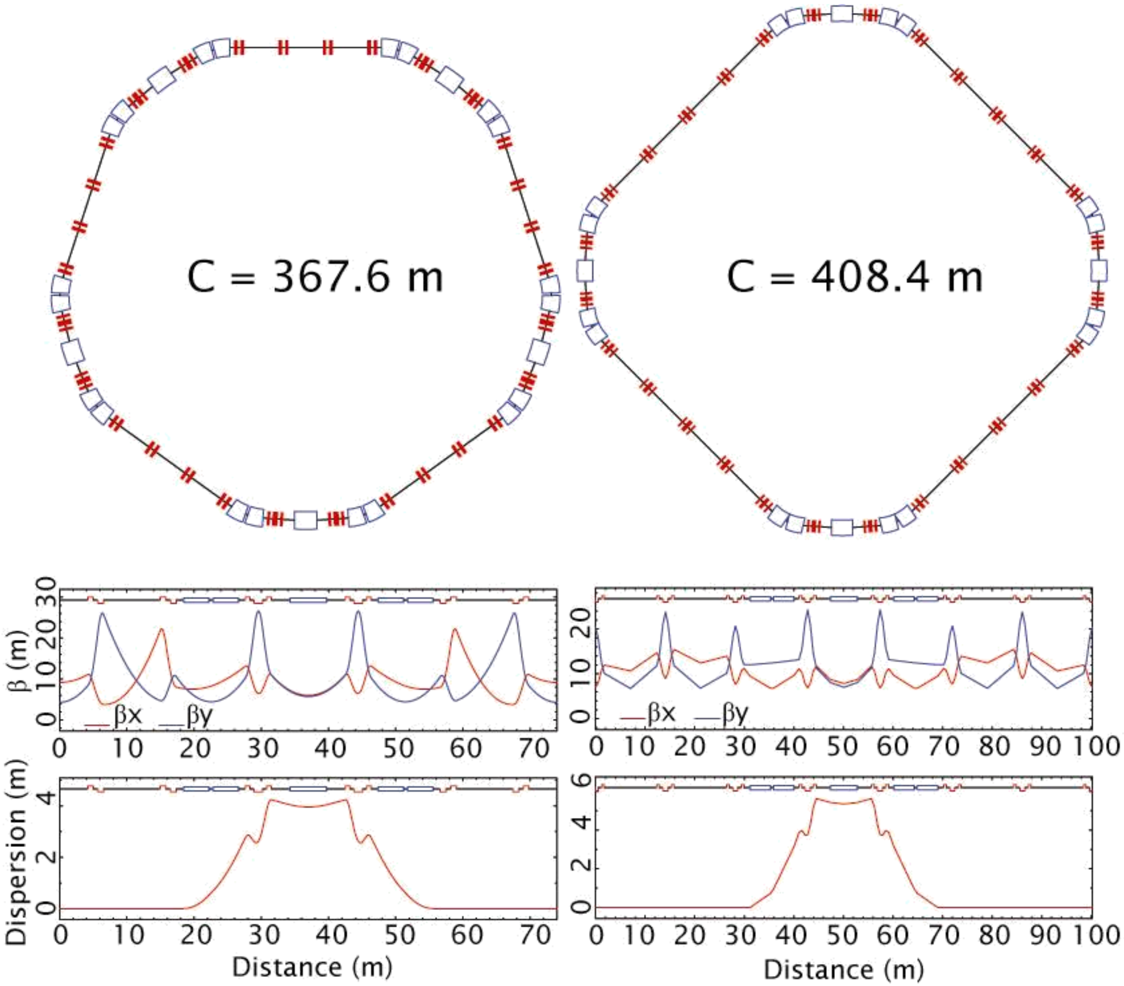
1) Replace ISIS linac with a new ≈ 180 MeV linac (≈ 0.5MW)

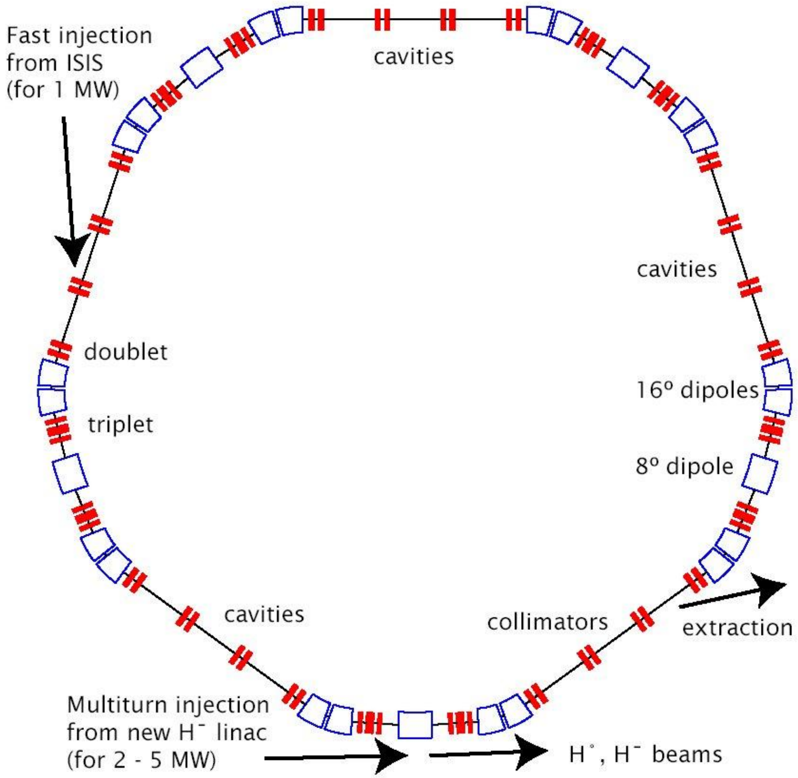
2) Based on a ≈ 3.3 GeV RCS fed by bucket-to-bucket transfer from ISIS 800 MeV synchrotron (1MW, perhaps more)

3) RCS design also accommodates multi-turn charge exchange injection to facilitate a further upgrade path where the RCS is fed directly from an 800 MeV linac (2 – 5 MW)

Science & Technology Facilities Council ISIS

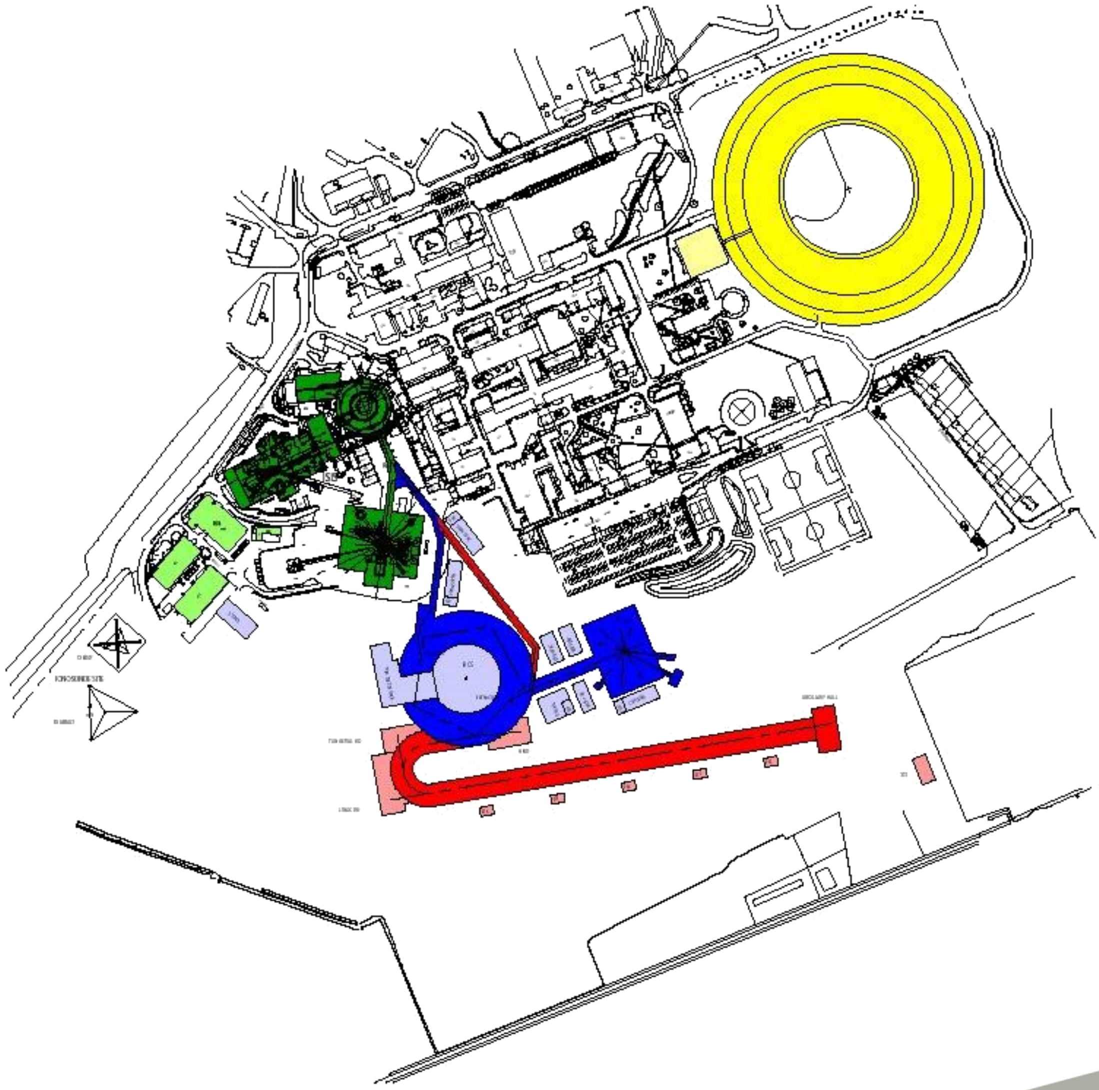
Possible ≈ 3.3 GeV RCS Rings





Energy	0.8 – 3.2 GeV
Rep Rate	50 Hz
C, R/R_0	367.6 m, 9/4
Gamma-T	7.2
h	9
f_{rf} sweep	6.1-7.1 MHz
Peak V_{rf}	≈ 750 kV
Peak K_{sc}	≈ 0.1
ε_l per bunch	≈ 1.5 eV s
$B[t]$	sinusoidal

ISIS MW Upgrade Scenarios



1) Replace ISIS linac with a new ≈ 180 MeV linac (≈ 0.5MW)

2) Based on a ≈ 3.3 GeV RCS fed by bucket-to-bucket transfer from ISIS 800 MeV synchrotron (1MW, perhaps more)

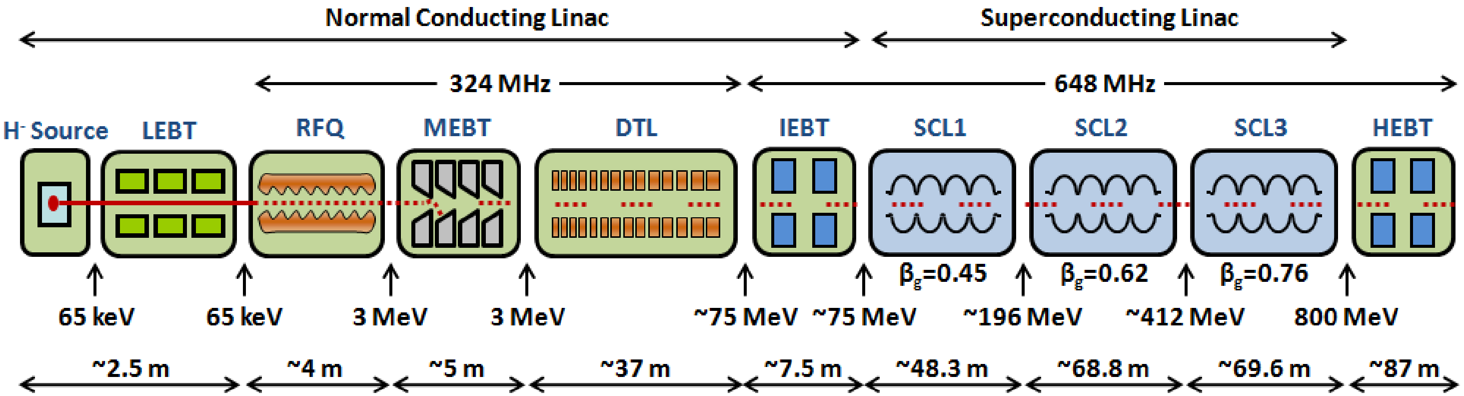
3) RCS design also accommodates multi-turn charge exchange injection to facilitate a further upgrade path where the RCS is fed directly from an 800 MeV linac (2 – 5 MW)

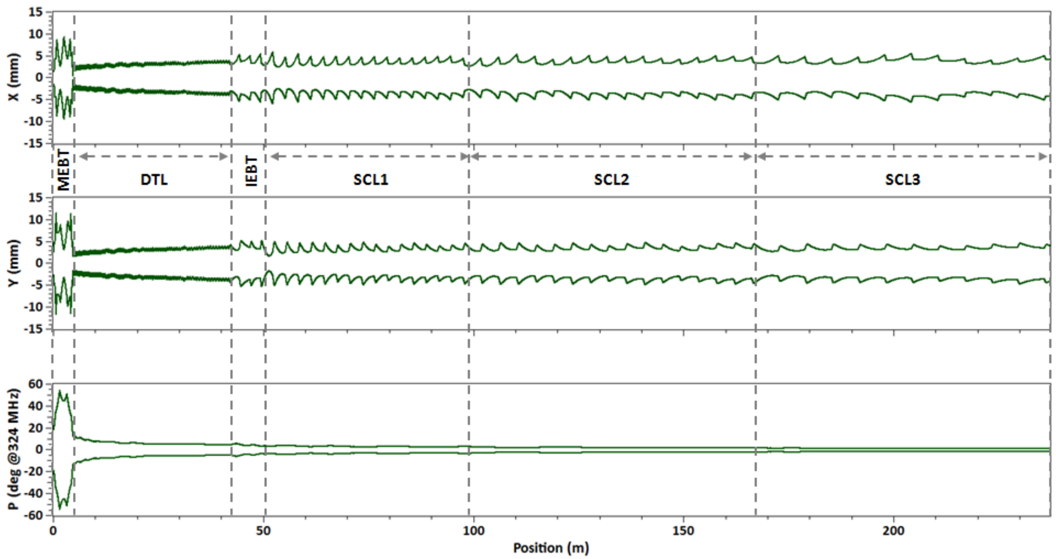
Grahame Rees,
Ciprian Plostinar (Science & Technology Facilities Council ASTeC)

800 MeV, H^- Linac Design Parameters

Ion Species	H^-
Output Energy	800 MeV
Accelerating Structures	DTL/SC Elliptical Cavities
Frequency	324/648 MHz
Beam Current	43 mA
Repetition Rate	30 Hz (Upgradeable to 50)
Pulse Length	0.75 ms
Duty Cycle	2.25 %
Average Beam Power	0.5 MW
Total Linac Length	243 m

Design Options

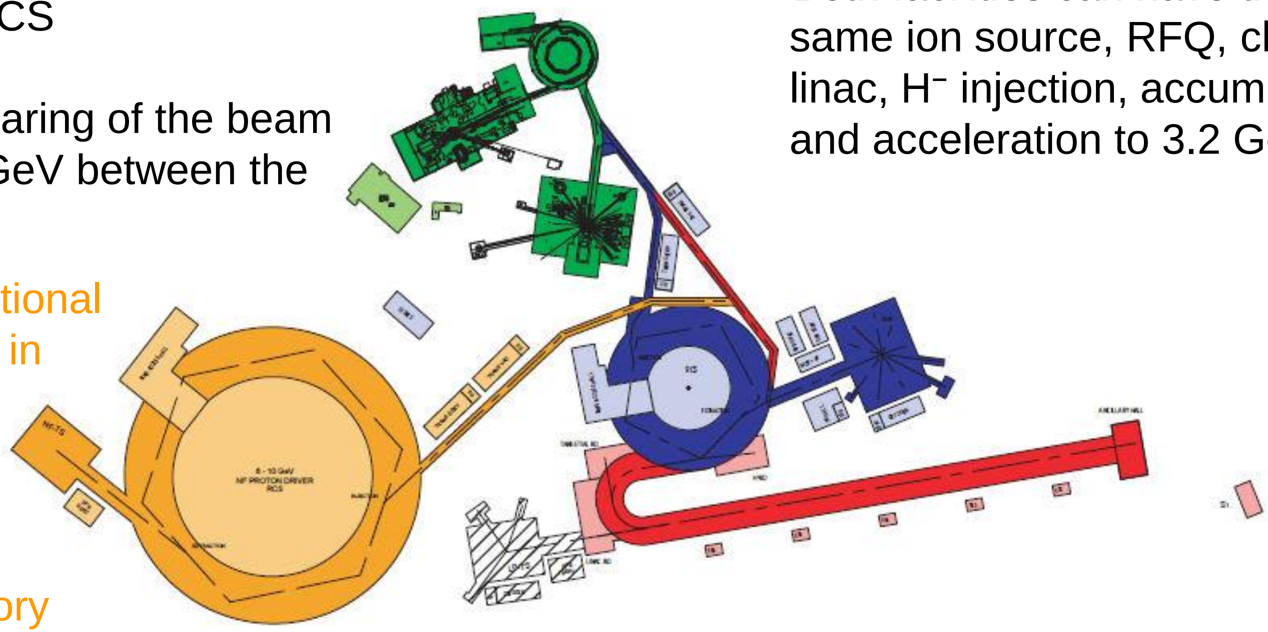




Science & Technology Facilities Council
ISIS

Common Proton Driver for the Neutron Source and the Neutrino Factory

- Based on MW ISIS upgrade with 800 MeV Linac and 3.2 (≈ 3.3) GeV RCS
- Assumes a sharing of the beam power at 3.2 GeV between the two facilities
- Requires additional RCS machine in order to meet the power and energy needs of the Neutrino Factory



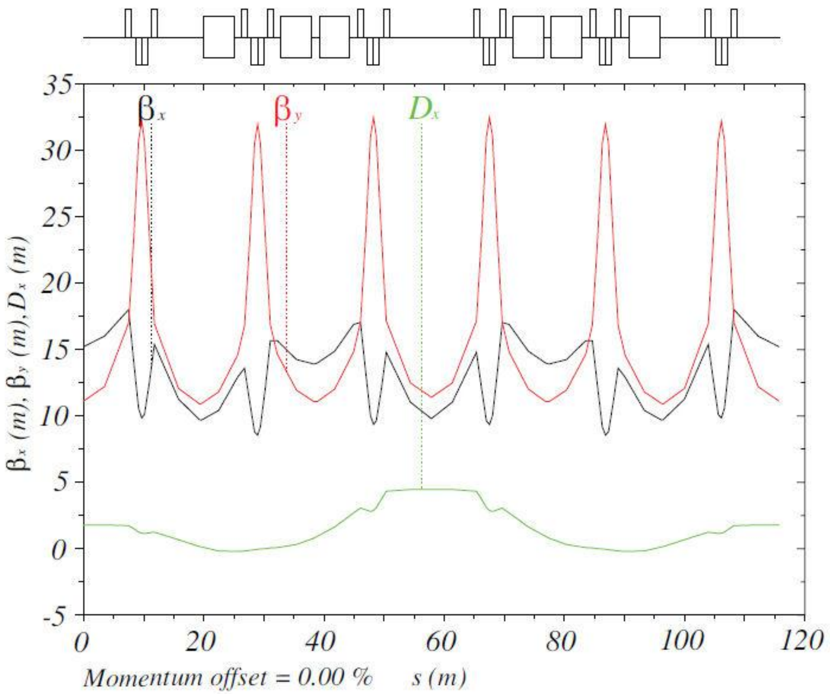
- Both facilities can have the same ion source, RFQ, chopper, linac, H^- injection, accumulation and acceleration to 3.2 GeV

- Options for the bunch compression to 1 – 3 ns RMS bunch length:
  - adiabatic compression in the RCS
  - ‘fast phase rotation’ in the RCS
  - ‘fast phase rotation’ in a dedicated compressor ring

Science & Technology Facilities Council
ISIS

Jaroslaw Pasternak, Leo Jenner
(Imperial College London , ISIS , Fermilab)

Preliminary design of the second RCS

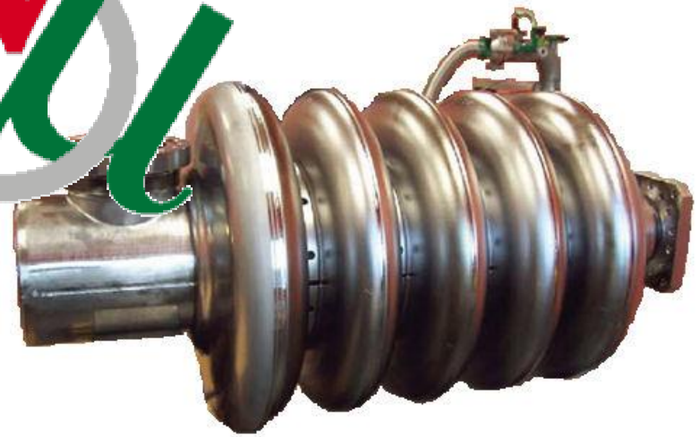


Parameters of 3.2 – 9.6 GeV RCS

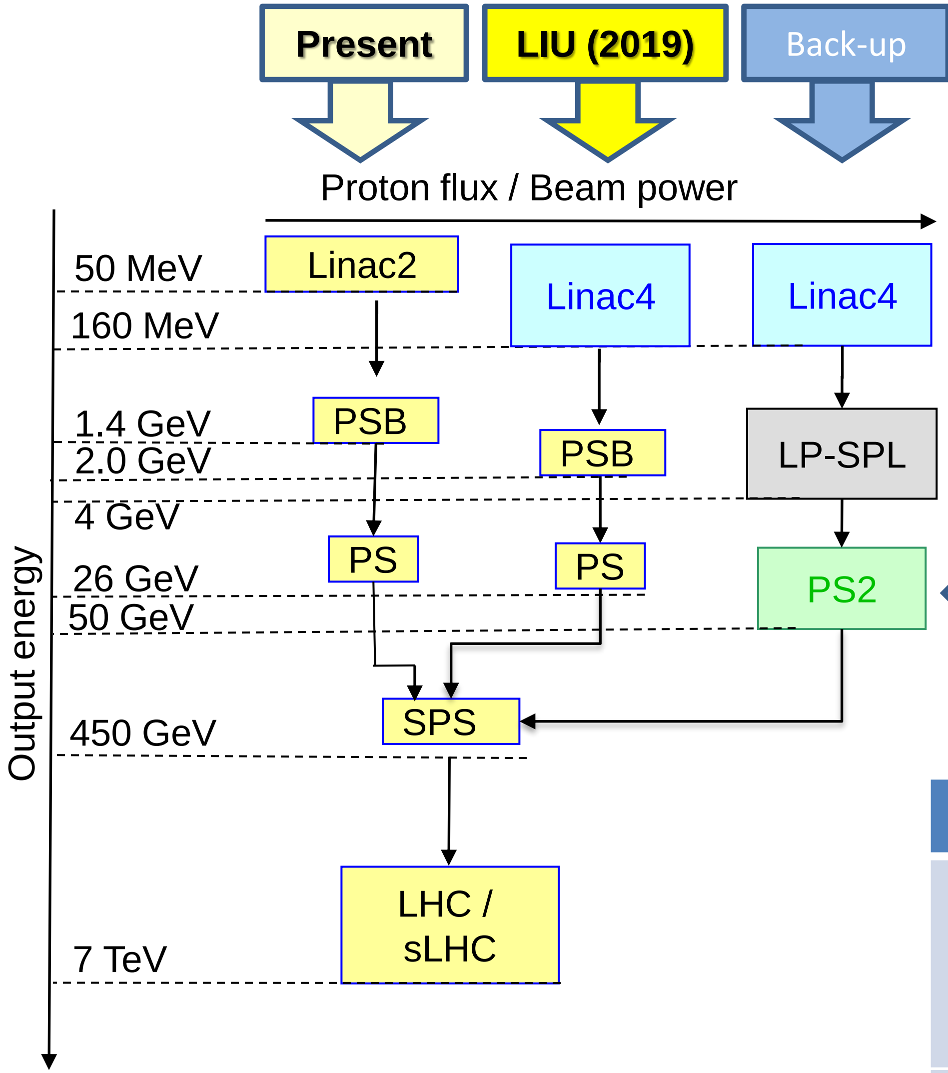
Number of superperiods	6
Circumference	694.352 m
Harmonic number	17
RF frequency	7.149 – 7.311 MHz
Gamma transition	13.37
Beam power at 9.6 GeV	4 MW for 3 bunches
Injection energy	3.2 GeV
Extraction energy	9.6 GeV
Peak RF voltage per turn	≈ 3.7 MW
Repetition rate	50 Hz
Max B field in dipoles	1.2 T
Length of long drift	14 m

- Present-day, cost-effective RCS technology
- Only three quadrupole families
- Allows a flexible choice of gamma transition
- Up to 3.7 MV/turn?

SPL-Based NF Proton Driver



Nearly Green Field Solution



LP-SPL: Low Power-Superconducting Proton Linac (4 GeV)

HP-SPL: Upgrade of infrastructure (cooling water, electricity, cryogenics etc.)

Replacement of klystron power supplies

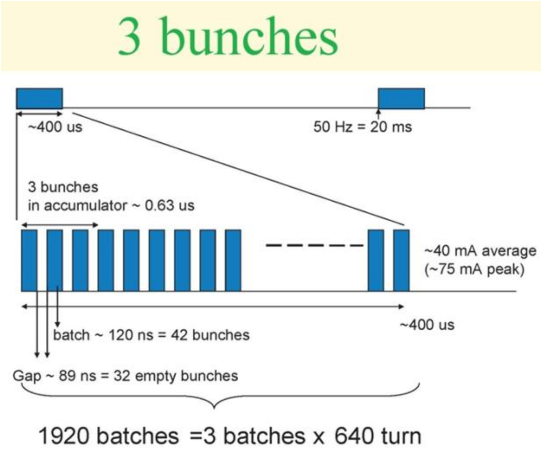
Addition of 5 high β cryomodules to accelerate up to 5 GeV

Main requirements of PS2 on its injector:

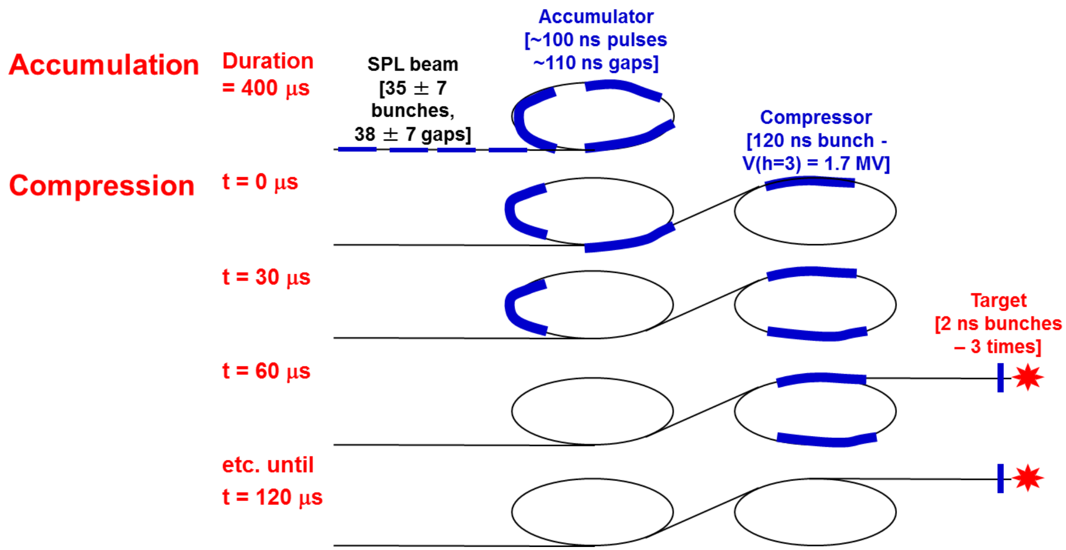
Requirement	Parameter	Value
2.2 x ultimate brightness with nominal emittances	Injection energy	4 GeV
	Nb. of protons / cycle for LHC (180 bunches)	6.7×10^{13}
Single pulse filling of SPS for fixed target physics	Nb. of protons / cycle for SPS fixed target	1.1×10^{14}

SPL-Based Proton Driver: Principle

- Accumulation of beam from the High Power SPL in a fixed energy Accumulator (5 GeV, 4MW beam power).
- Bunch compression («rotation») in a separate Compressor ring

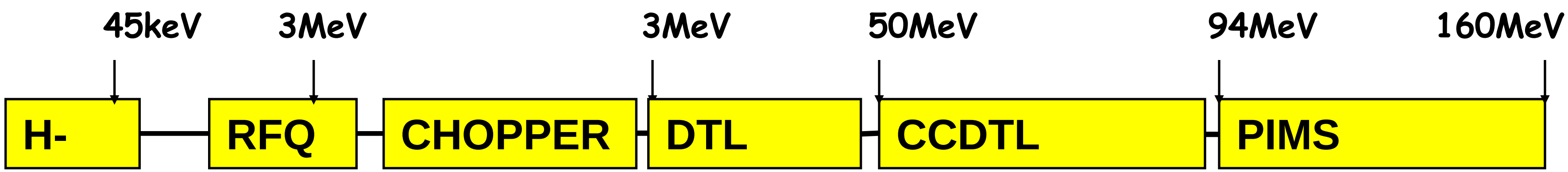


	3 bunches / 1 bunch
Accumulator	
circumference	185.8 m
no. of accumulation turn	640 / 1920
transition gamma	6.33 (isochronous)
no. of simultaneous bunches	3 / 1
Compressor	
circumference	200 m
rf voltage	1.7 MV
no. of compression turn	86
transition gamma	2.84
no. of simultaneous bunches	2 / 1
Beam on target	
bunch spacing	30 μs / -
burst duration	60 μs / -
bunch length	2 ns
beam energy	5 GeV
beam power	4 MW
repetition	50 Hz



SPL front end (Linac4): block diagram

Linac4: 80 m, 18 klystrons



RF volume source (DESY)	Radio Frequency Quadrupole	Chopper & Bunchers	Drift Tube Linac	Cell-Coupled Drift Tube Linac	Pi-Mode Structure
45 kV Extrac.	3 m 1 Klystron 550 kW	3.6 m 11 EMquad 3 cavities	18.7 m 3 tanks 3 klystrons 4.7 MW 111 PMQs	25 m 21 tanks 7 klystrons 7 MW 21 EMQuads	22 m 12 tanks 8 klystrons ~12 MW 12 EMQuads

Ion current:
40 mA (avg.),
65 mA (peak)

RF accelerating structures: 4 types (RFQ, DTL, CCDTL, PIMS)
Frequency: 352.2 MHz
Duty cycle: 0.1% phase 1 (Linac4), 3-4% phase 2 (SPL), (design: 10%)

Linac4 building Oct 2010

Linac4 Mar 2011

First user

HP-SPL: Main Characteristics

Ion species	H^-	
Output Energy	5	GeV
Bunch Frequency	352.2	MHz
Repetition Rate	50	Hz
High speed chopper (rise & fall times)	< 2	ns

Required for low loss in accumulator (Ion species)

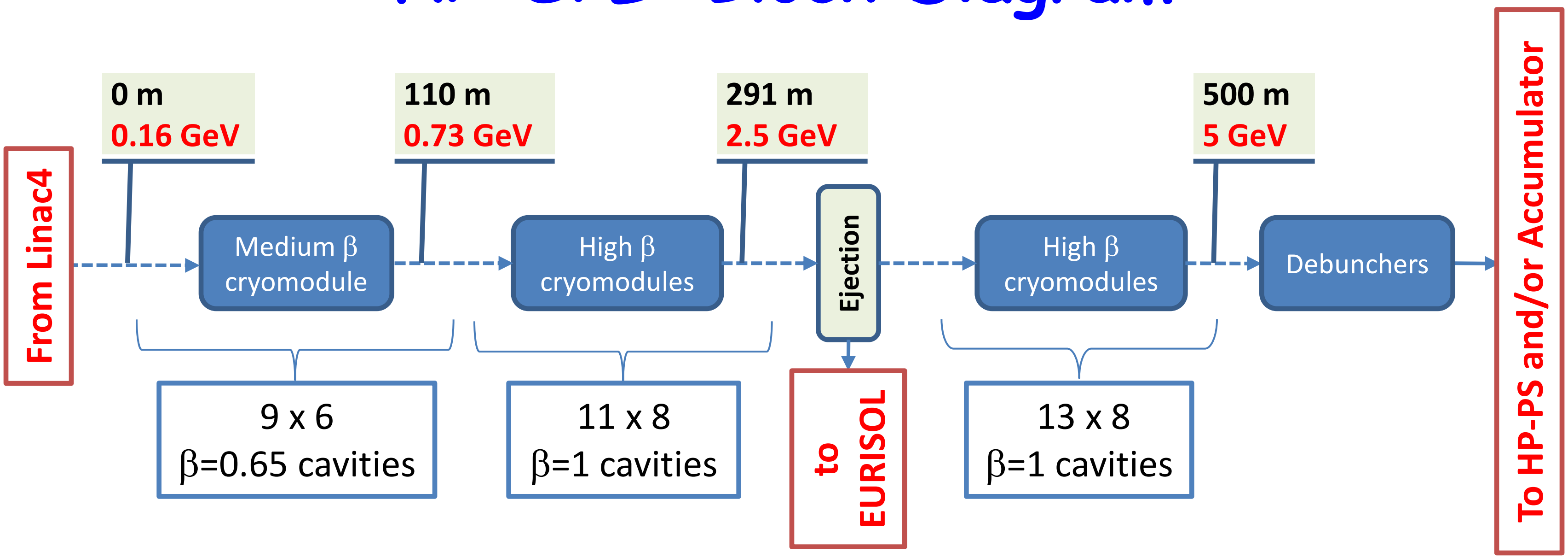
Required for muon production (Output Energy)

Required for flexibility and low loss in accumulator (High speed chopper)

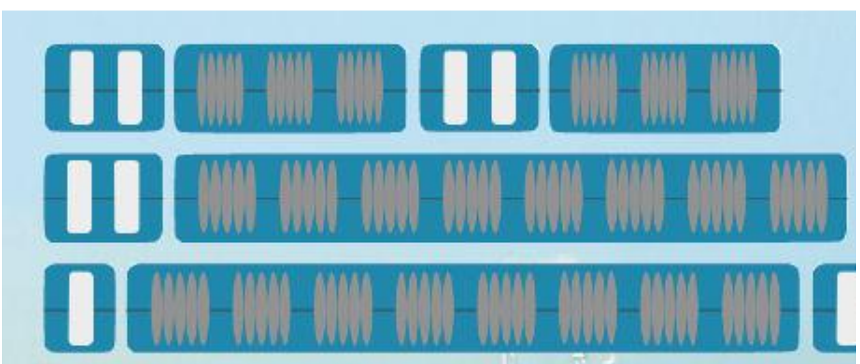
	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 MW (2.5 GeV) <u>or</u> 4.5 MW (5 GeV)	5 MW (2.5 GeV) <u>and</u> 4 MW (5 GeV)
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current (mA)	20	40
Pulse duration (ms)	0.9	1 (2.5 GeV) + 0.4 (5 GeV)

2 ´ beam current ⇒ 2 ´ nb. of klystrons etc .

HP-SPL: Block Diagram



Segmented cryogenics / separate cryo-line / room temperature quadrupoles:
-Medium β (0.65) – 3 cavities / cryomodule
-High β (1) – 8 cavities / cryomodule



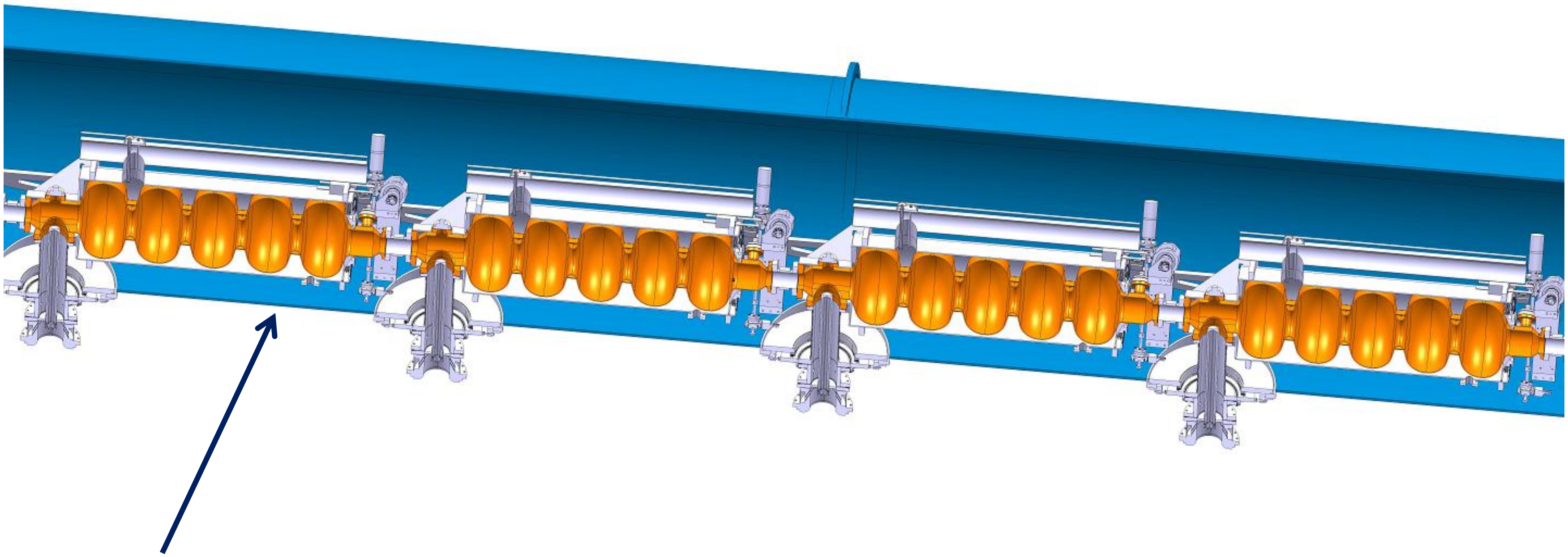
Low energy

Intermediate energy

High energy

HP-SPL: R&D Objective

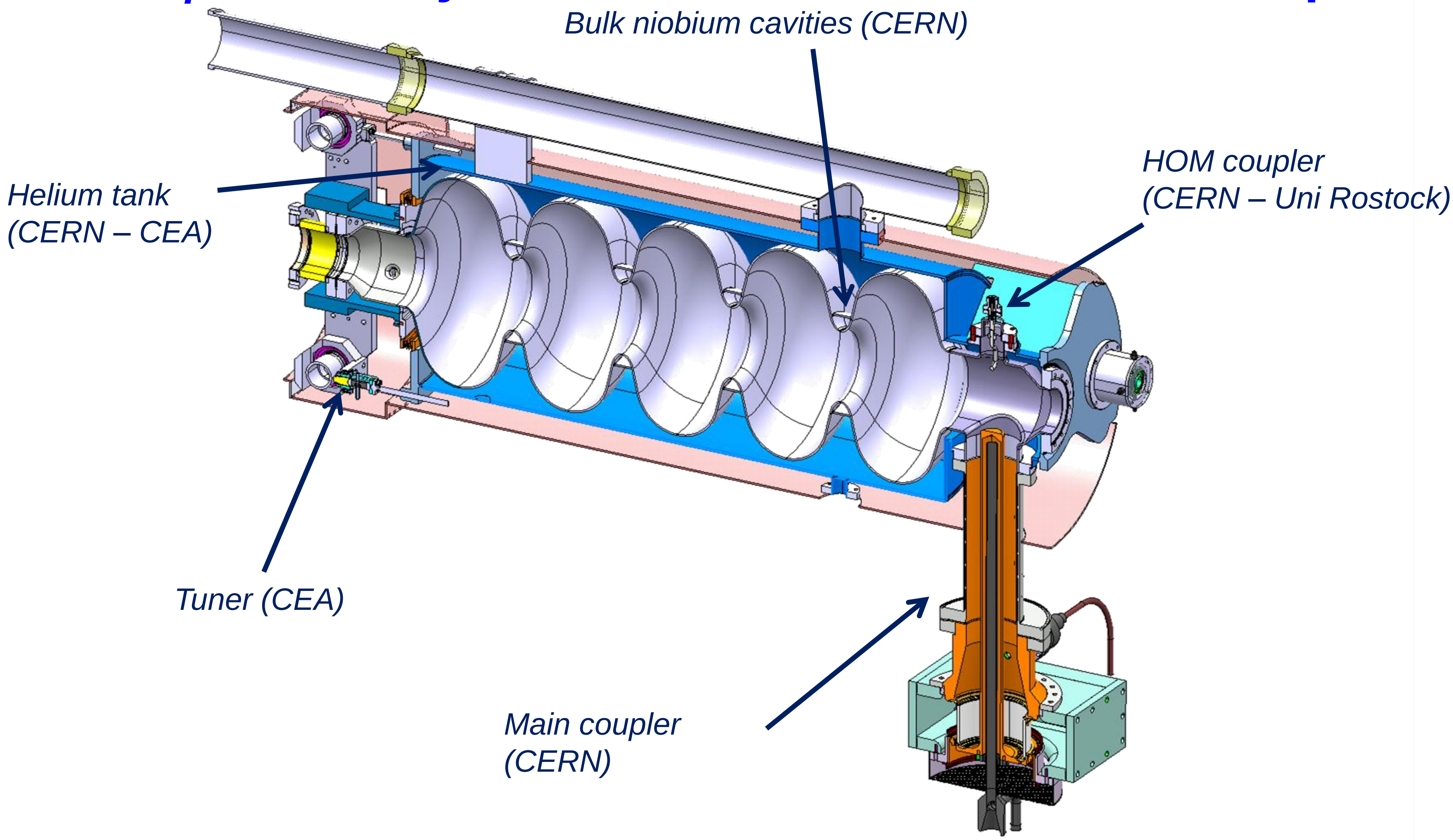
Design, construction and test of a string of 4 β=1 cavities equipped with main couplers & tuners inside a "short" prototype cryo-module before the end of 2014 tested in 2014.



Cryomodule
(CERN – CNRS)

HP-SPL: Cavity & Cryomodule Design

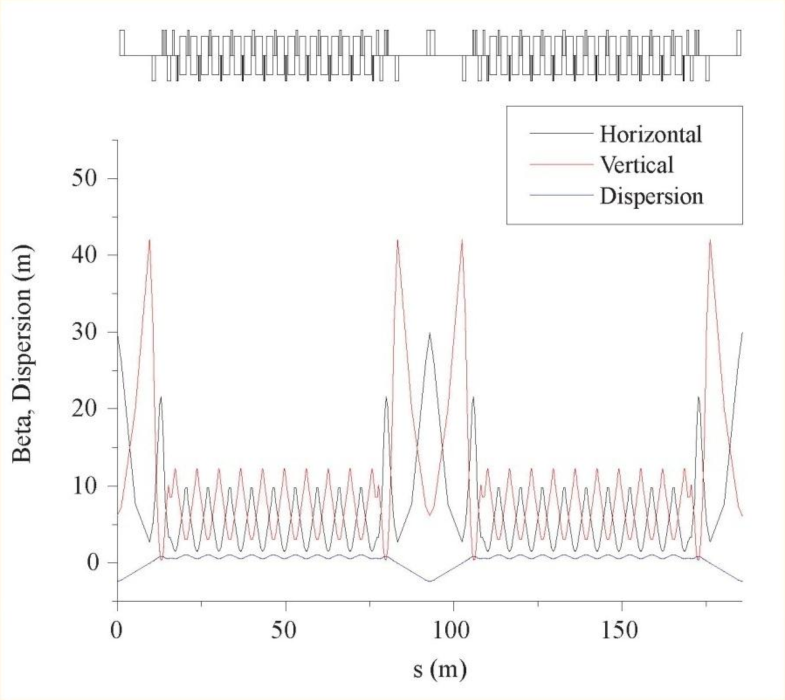
SPL $\beta = 1$ cavity + helium tank + tuner + main coupler



Accumulator/compressor lattices

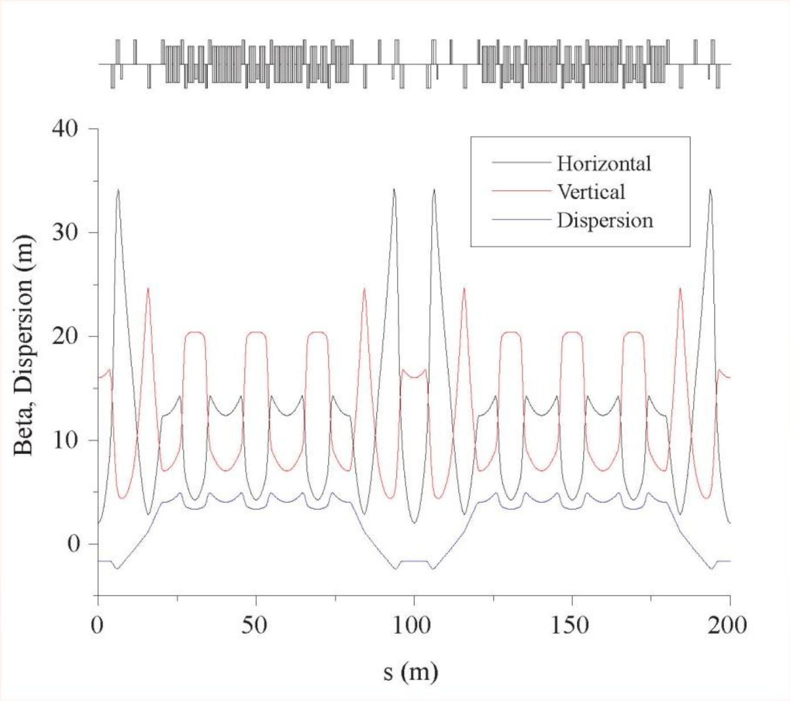
from M. Aiba

Lattice for 1 & 3 bunches



γ_{tr}=6.33 (isochronous)

Lattice for 1 & 3 bunches



γ_{tr}=2.8

HP-SPL: Cost Estimate (1/3/12)

sLHC-Project-Note-0037

2012-03-01

frank.gerigk@cern.ch

Cost estimate for the High Power SPL (HP-SPL)

F. Gerigk, CERN-BE-RF

Keywords: SPL, cost estimate

Abstract

This note gives a cost estimate for the construction of a 5 GeV, 4 MW High Power H^- Linac (SPL) on the CERN site.

1 Assumptions

This estimate is an extrapolation and update of a costing that was done in 2009 for the construction of a new LHC proton injector chain, consisting of a Low-Power SPL, PS2, and an upgrade of the SPS [1]. It is largely based on the basic parameters listed in Table 1 whose choice is detailed and motivated in [2].

Table 1: Parameters of the HP-SPL

Energy	5 GeV	
Beam power	4 MW	
Repetition rate	50 Hz	
Average pulse current	40 mA (20 mA)*	
Beam pulse length	0.4 ms (0.8 ms)*	
RF pulse length	0.8 ms (1.6 ms)*	
protons per pulse	$1 \cdot 10^{14}$	
Cavity bath temperature	2 K	
Cavity types	$\beta = 0.65$	$\beta = 1.0$
Number of klystrons	66	200
Cells per cavity	5	5
Cavities per cryo-module	3	8
Number of cavities	60	184
Re-buncher cavities	0	4
Spare cavities	6	12
Accelerating gradient	19.3 MV/m	25 MV/m
(R/Q)	275	566
Q in 10^9	6 (3)*	10 (5)*
Peak power per cavity	0.5 MW	1 MW

* worst case assumption for cryogenics design

HP-SPL cost estimate - sLHC-Project-Note-0037 (F. Gerigk, CERN-BE-RF, public)

- Cost estimate : 806.9 MCHF
- Very detailed
- Include services, tunnels, L4 upgrade, even T-line to PS2
- Does not include contingency
- Does not include Linac4 (~100 MCHF)