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Proton Driver Review

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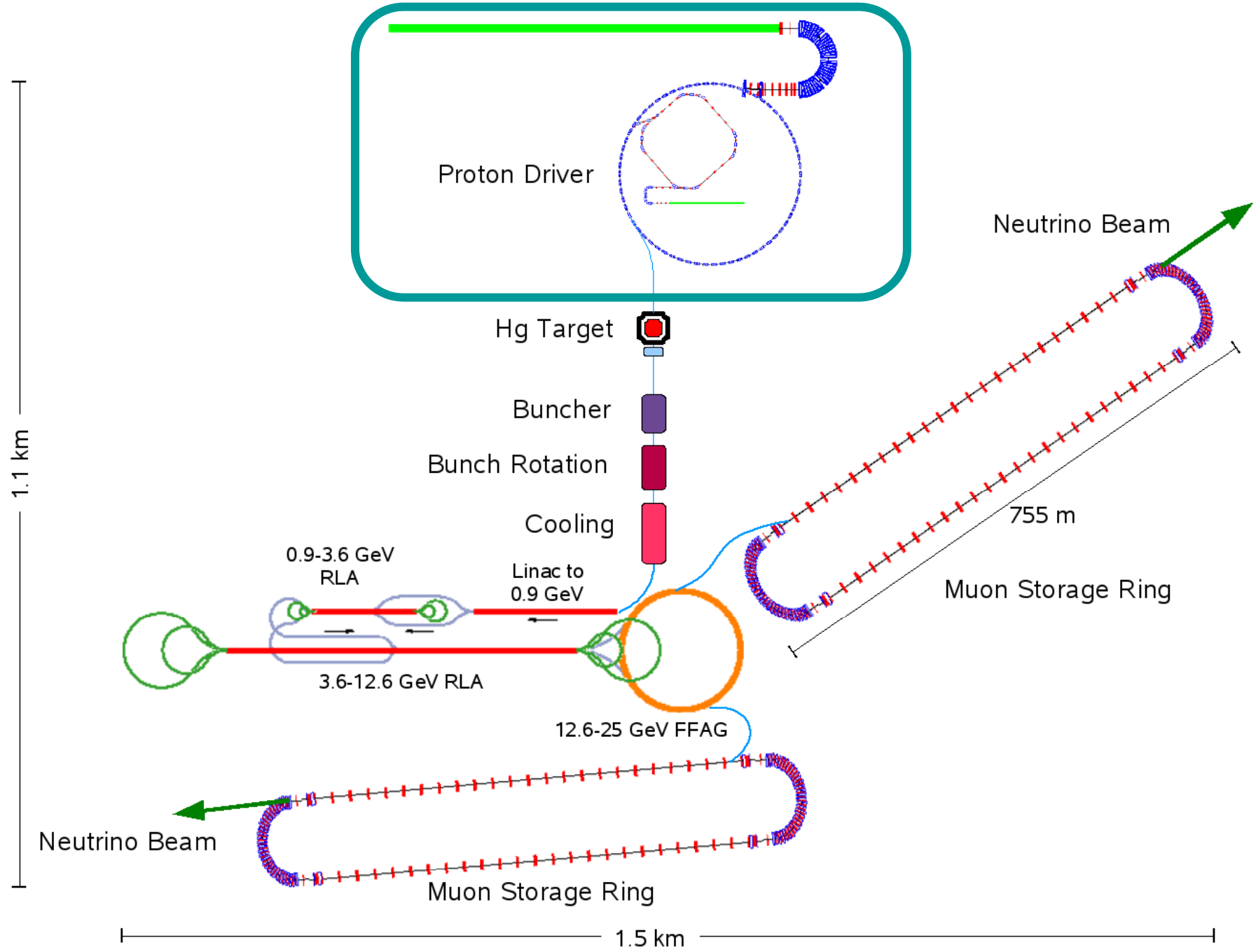
Overview

- Requirements for a Neutrino Factory (ISS)
- Proton driver developments
  - Construction projects
  - Theoretical models/proposals
- Requirements for a Muon Collider
  - Example driver


Proton Driver
Hg Target
Buncher
Bunch Rotation
Cooling
0.9-3.6 GeV
RLA
Linac to
0.9 GeV
3.6-12.6 GeV RLA
12.6-25 GeV FFAG
Neutrino Beam
Muon Storage Ring
755 m
Neutrino Beam
Muon Storage Ring
1.1 km
1.5 km

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ISS Recommendations

- Mean beam power 4 MW
- Pulse repetition rate 50 Hz
- Proton kinetic energy 5-10-15 GeV
- Bunch duration at target 1-3 ns rms
- Number of bunches per pulse 3 or 5
- Separated bunch extraction delay ≥ 17 μs
- Pulse duration:
  - liquid mercury target ≤ 40 μs
  - Solid metal target ≤ 70 μs

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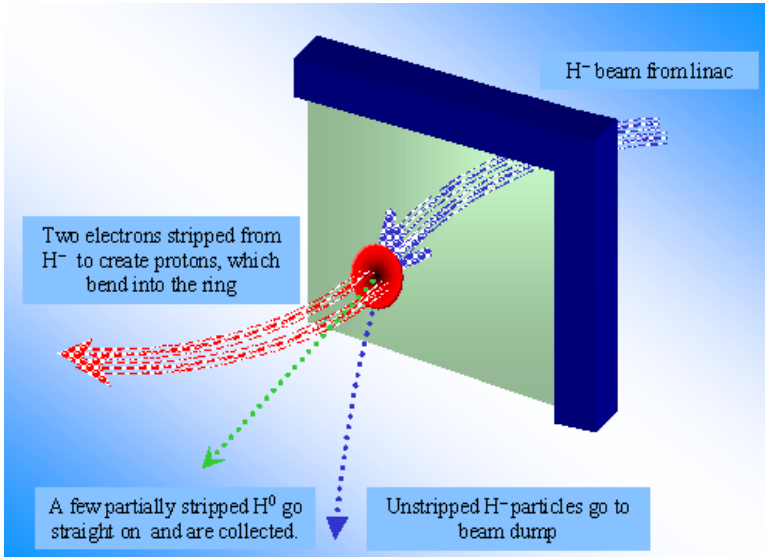
Possible Schemes

- H^- linac with pairs of 50 Hz booster and 25 Hz driver synchrotrons (RCS)
- H^- linac with 50 Hz booster RCS and 50 Hz non-scaling FFAG
- H^- linac with chain of 3 FFAGs in series
- H^- linac with 2 slower cycling synchrotrons and 2 holding rings
- Full energy H^- linac with accumulator and compressor rings - CERN, Fermilab

Main Problem Areas/Demands

- Low level of uncontrolled beam loss:
  - ~1 W/m
- High current H^- linac (40-70 mA)
- Very low loss charge exchange ring injection
  - Chopped beam
  - Achromatic arc
  - Phase space painting
- Bunch compression



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The Spallation Neutron Source

- Collaboration between six US National Laboratories
- Formal Project Completion in June 2006
- A short-pulse neutron source, driven by a full energy 1.4 MW proton accelerator

- Stepping stone to other high power facilities

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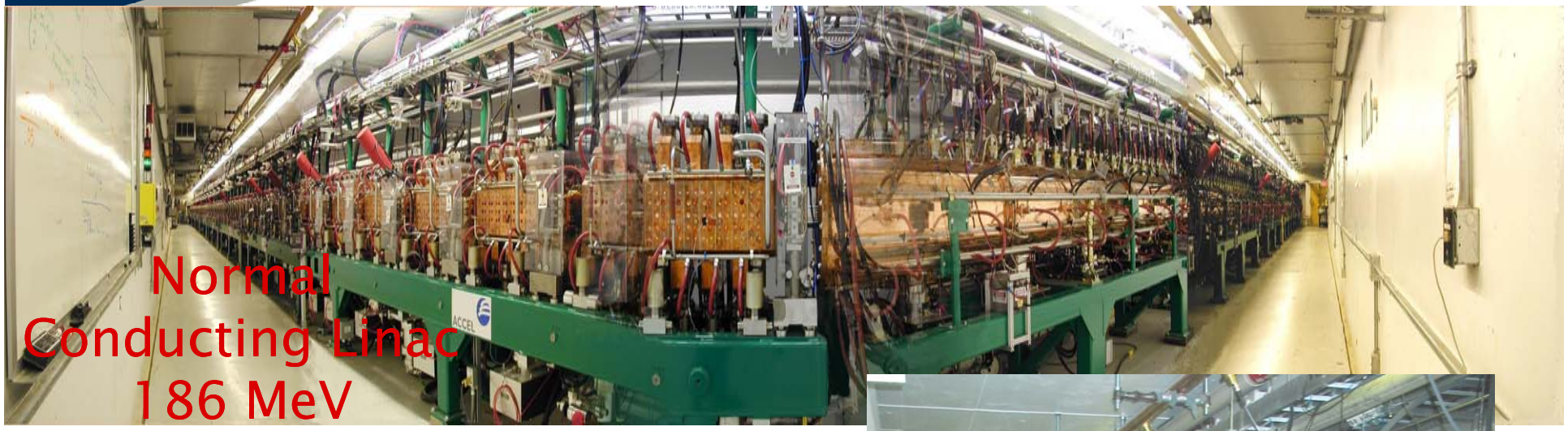
SNS Linac



- World's first high-energy superconducting proton linac
- 38 mA peak current, 68% chopping
- Design: 60 Hz rep.rate
  - achieved with beam to date:15 Hz
- Design energy: 1 GeV
  - max output energy to date 952 MeV

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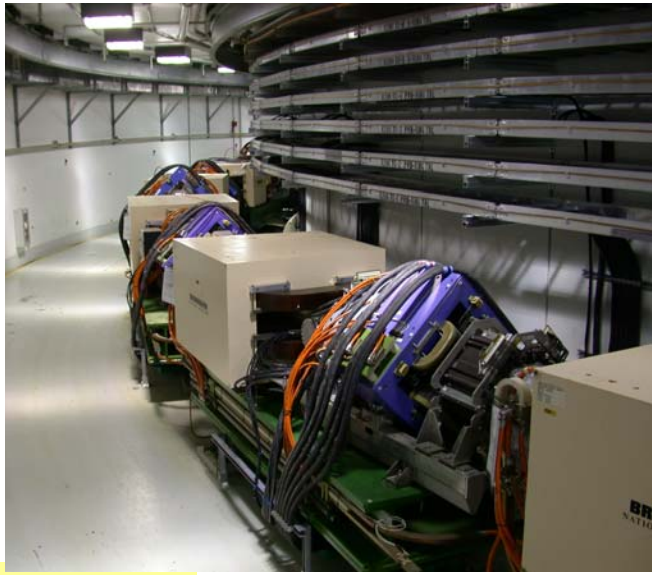
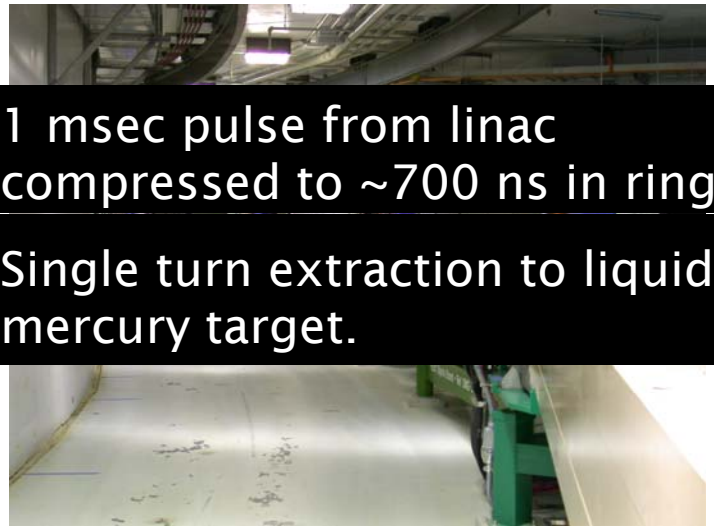
Accumulator Ring and Transport Lines

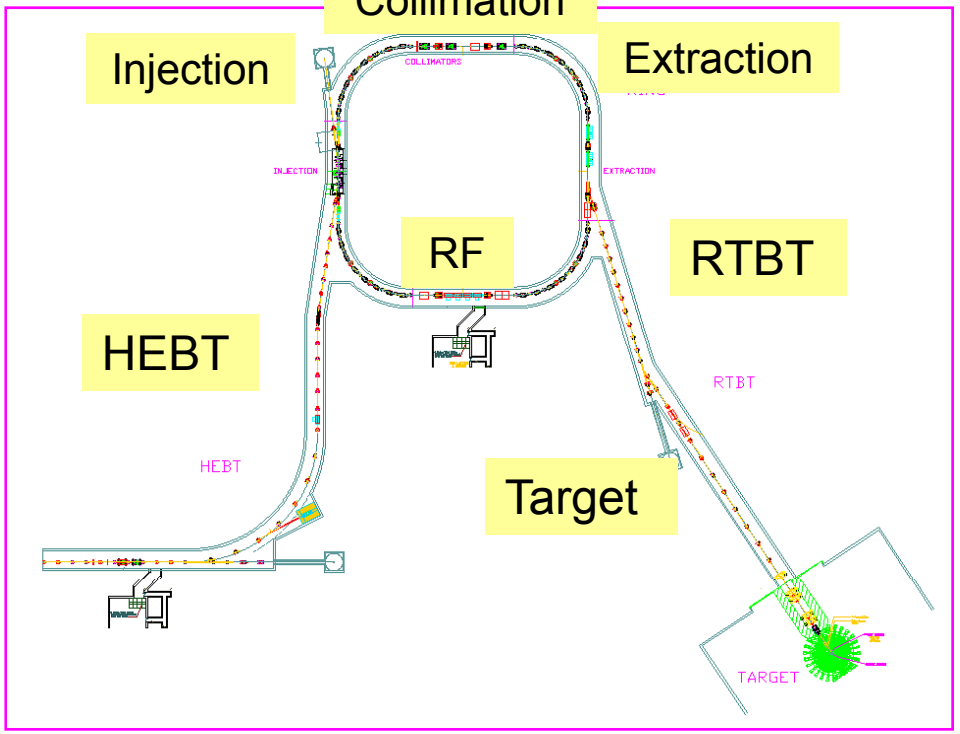


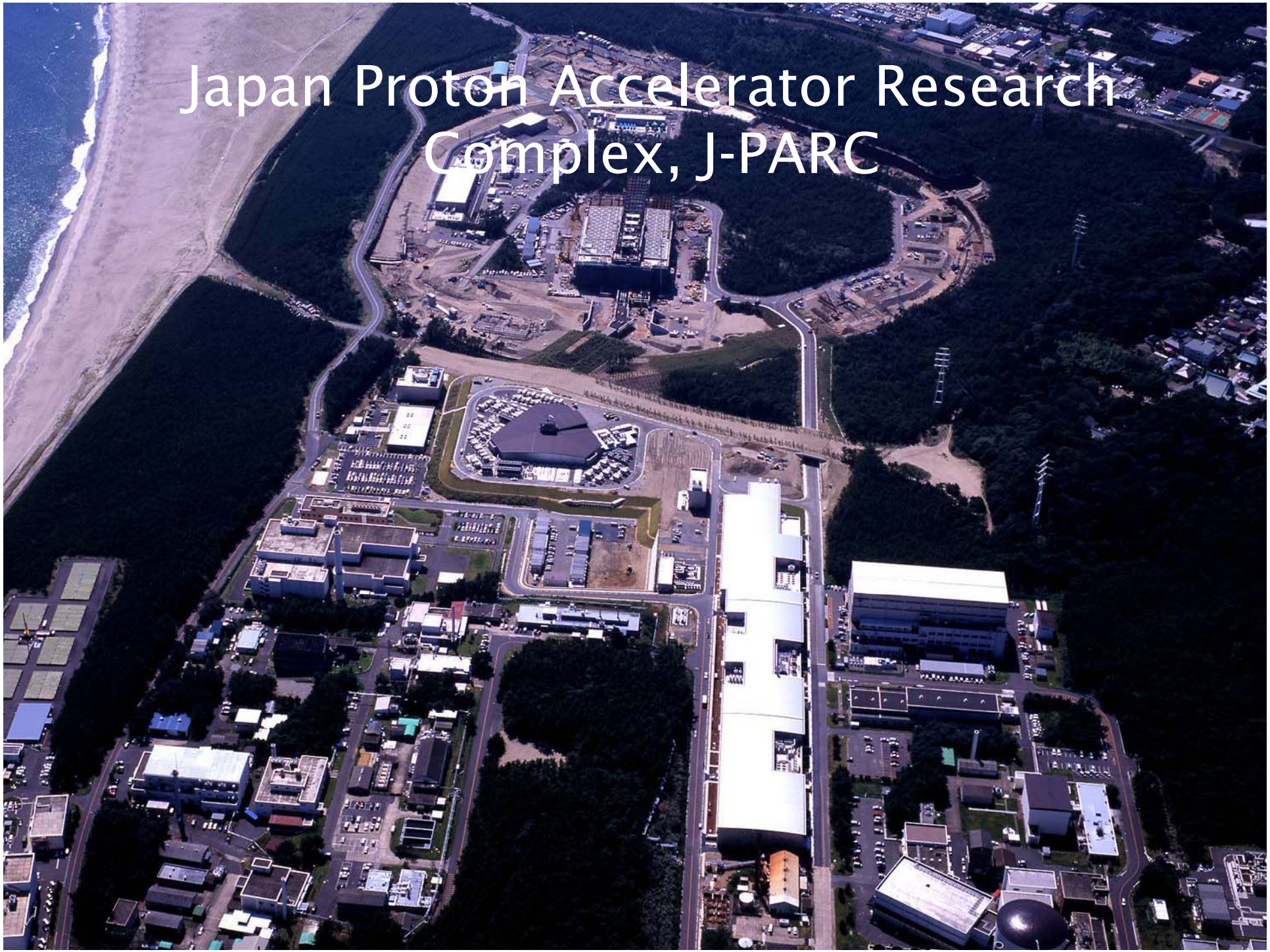
- Circumference 248 m
- Accumulated turns 1060
- Design Intensity 1.5×10^{14}
- Achieved intensity 0.4×10^{14}
- Power achieved **183 kW**



1 msec pulse from linac compressed to ~700 ns in ring.

Single turn extraction to liquid mercury target.




Japan Proton Accelerator Research Complex, J-PARC

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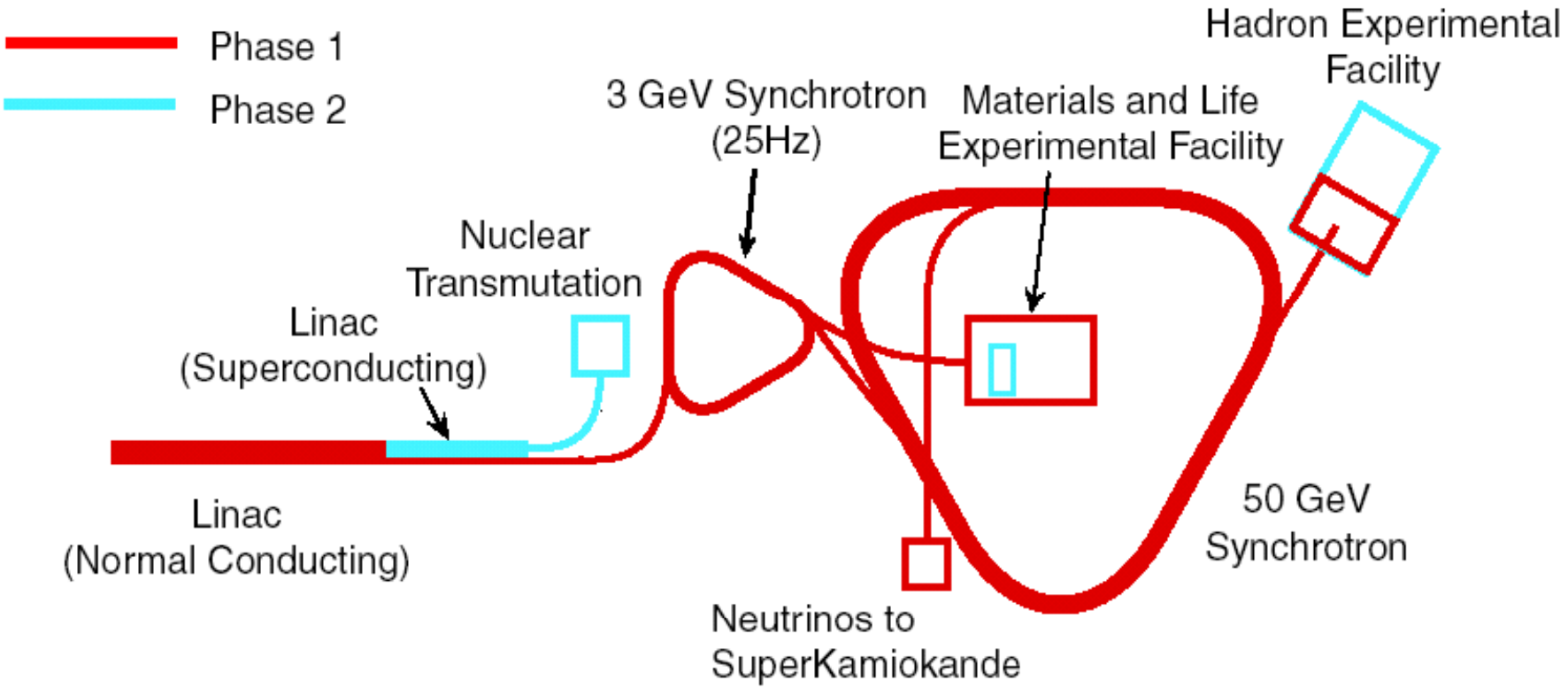
J-PARC Facility



KEK: High Energy Accelerator Research Organization
JAEA : Japan Atomic Energy Agency

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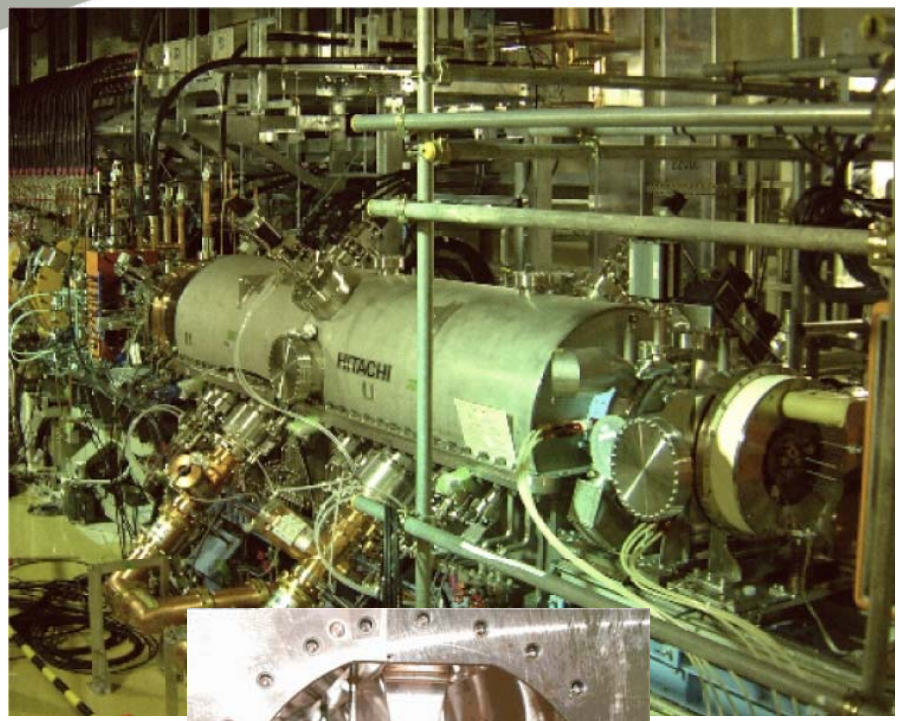
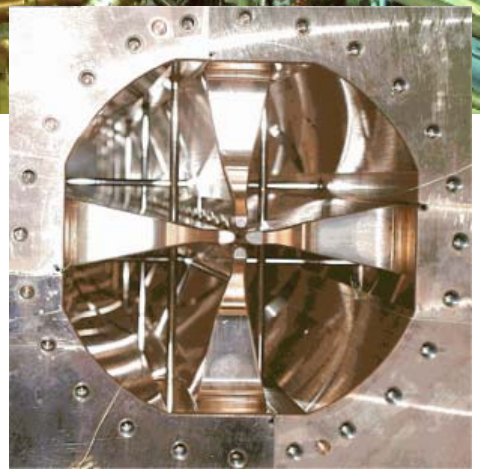
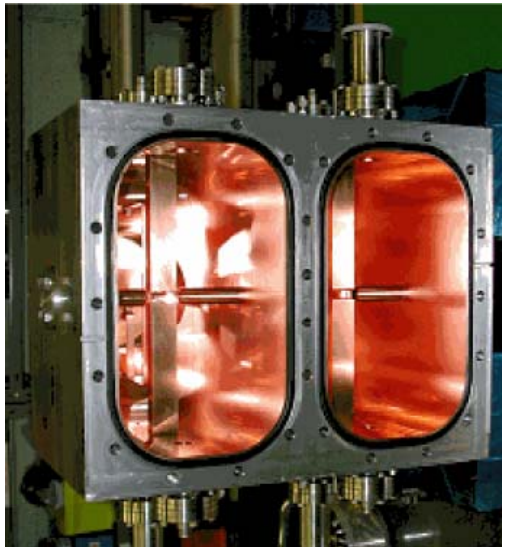
J-PARC Linac

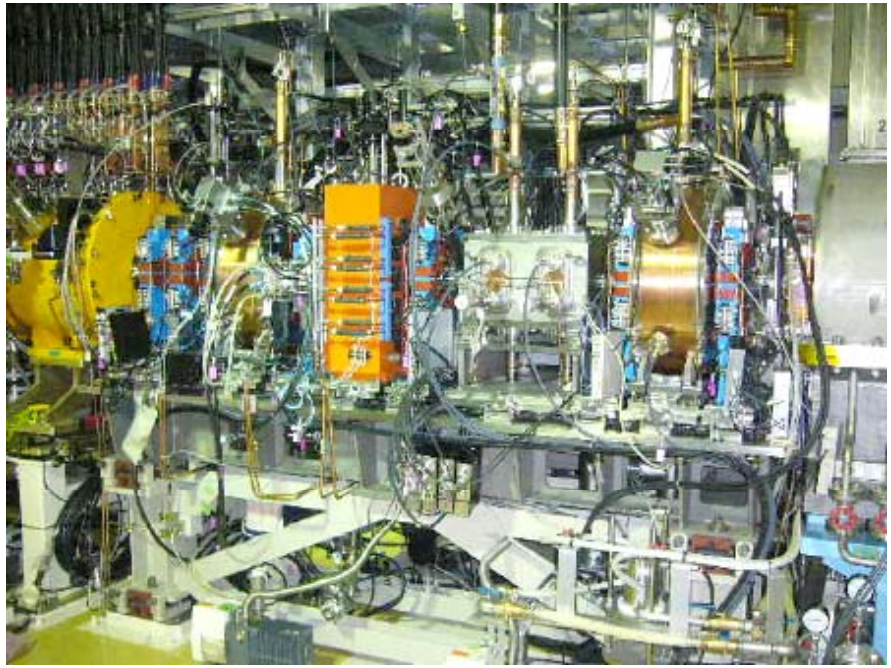
3 MeV RFQ







Chopper
and MEBT



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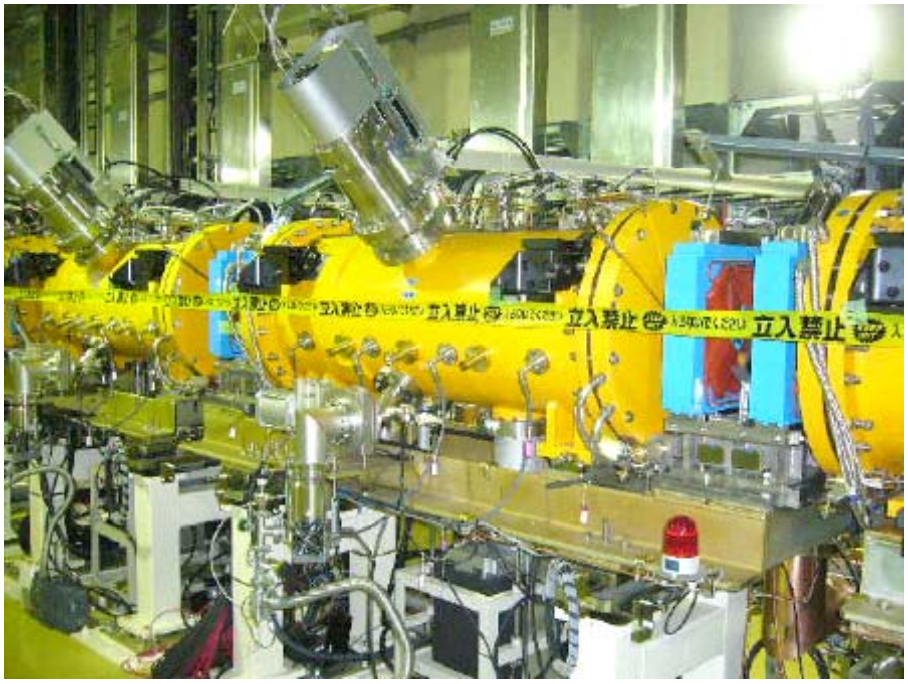
J-PARC Linac

Design: 50 mA, 400 MeV,
324 MHz

DTL

Linac commissioned June 2007
at design energy of 181 MeV,
peak current 26 mA.

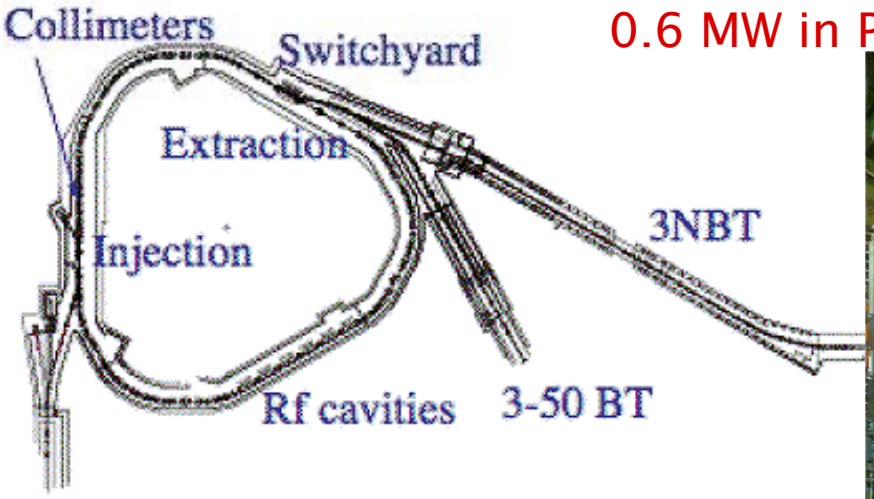
Separated-type DTL



Later additional structures to 400 MeV,
then superconducting to 600 MeV

3 GeV Rapid Cycling Synchrotron (RCS)

Design: 25 Hz, 1 MW, but
0.6 MW in Phase I



Beam commissioning starting now (Oct 2007)

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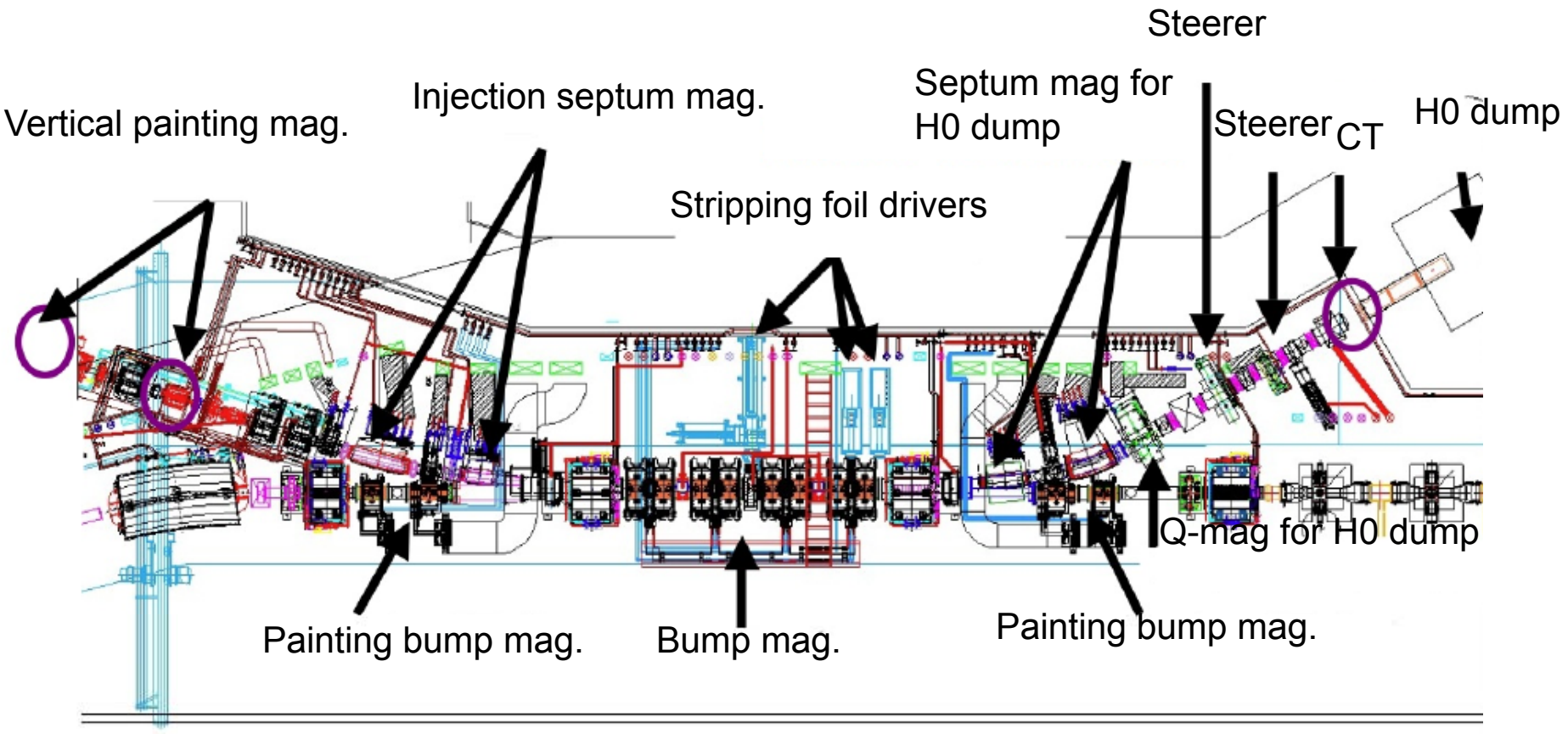
RCS Injection System



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J-PARC 50 GeV Main Ring

Slow cycling, 0.75 MW proton beam to hadron and neutrino beam facilities.

Beam commissioning to start May 2008. 40 GeV in Phase I.


Injection region (Jan. 4 2007)

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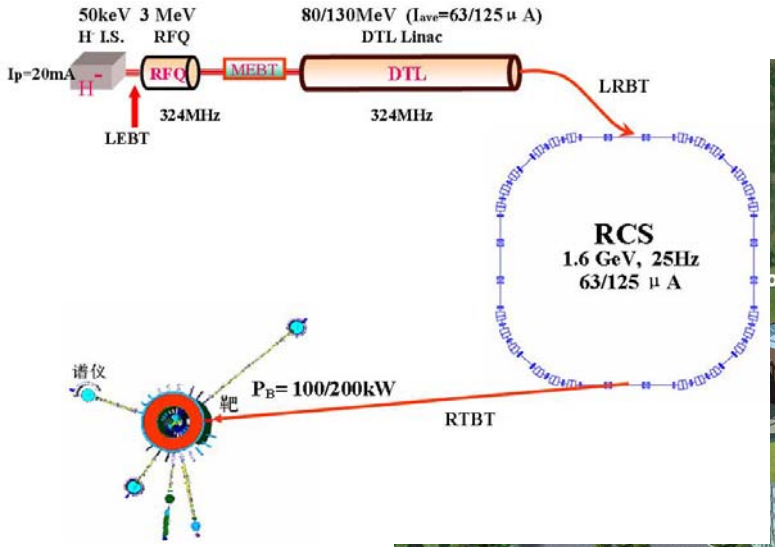
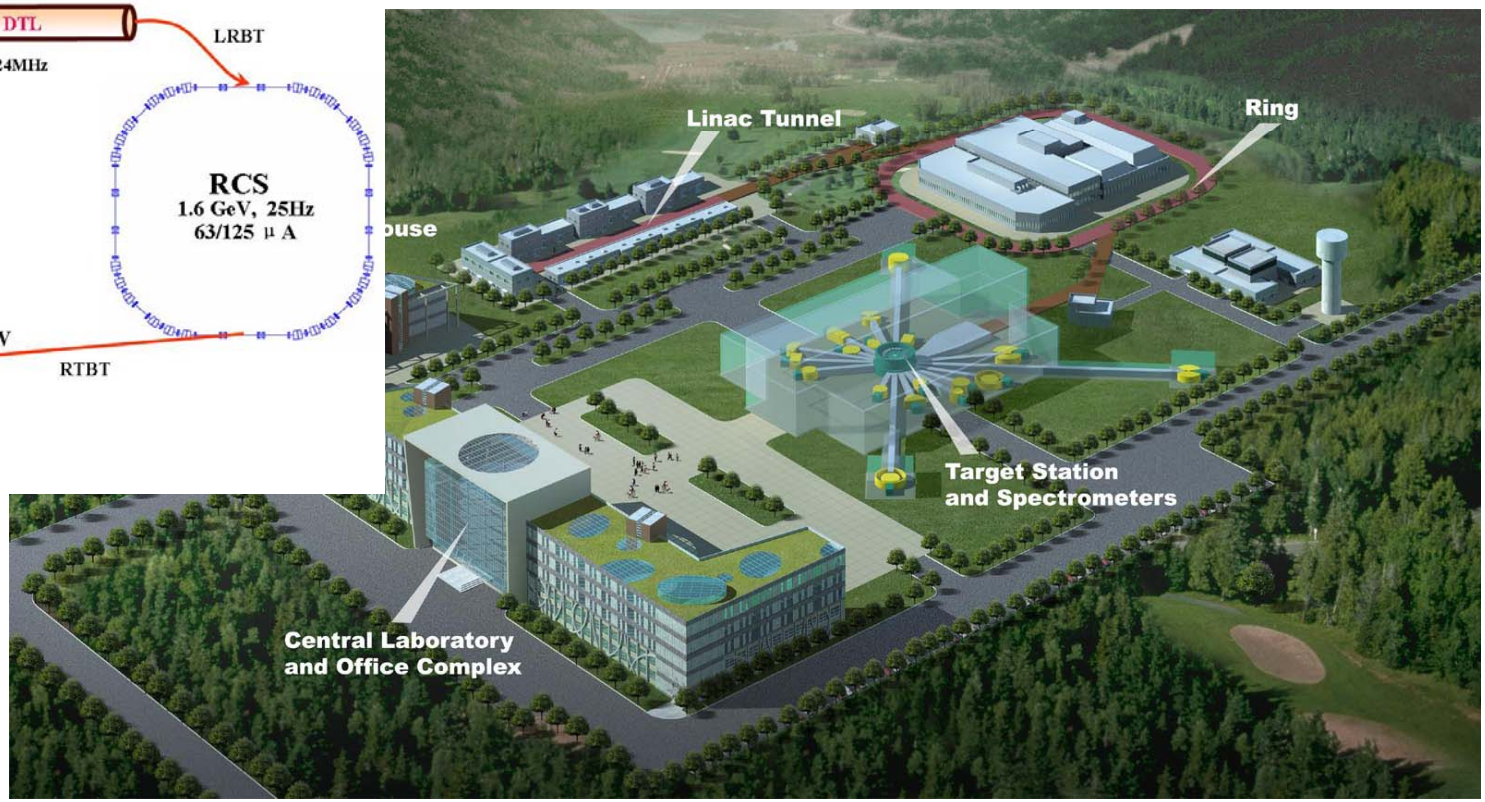
Chinese SNS, Dongguan

- Linac: H^- beam, 81 MeV (DTL) to 250 MeV (SCL)
- Rapid-cycling synchrotron: 1.6 GeV at 25 Hz





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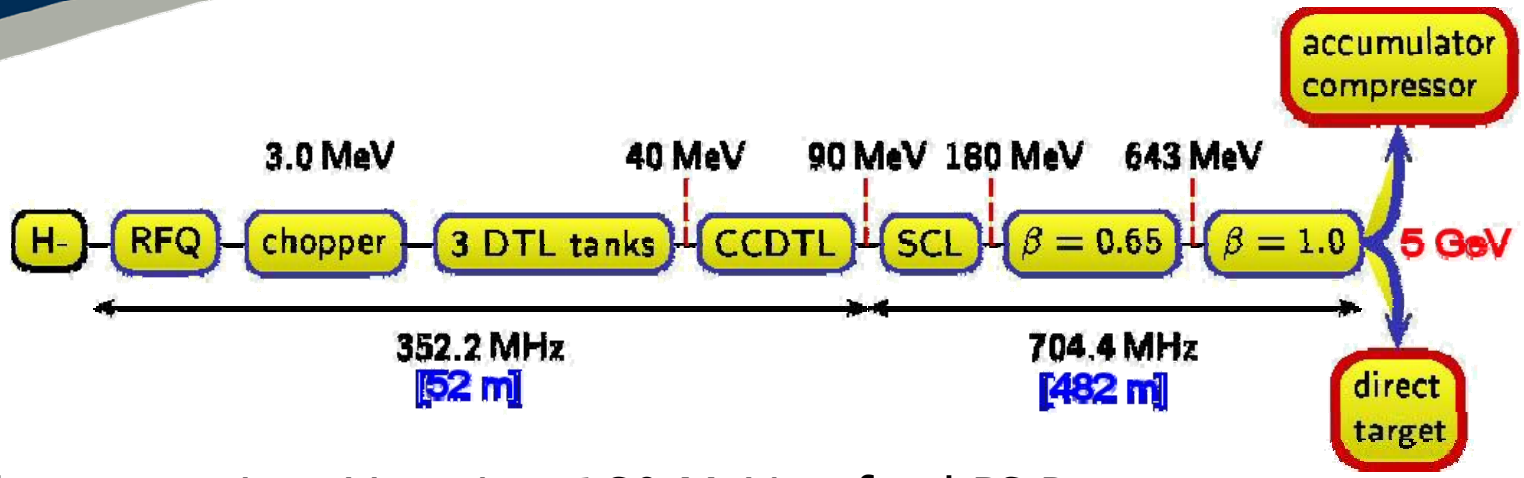
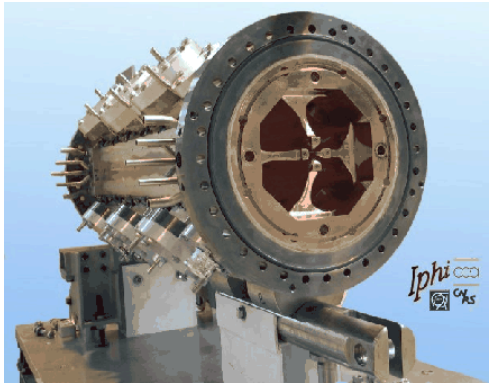
CERN Linac4 and SPL

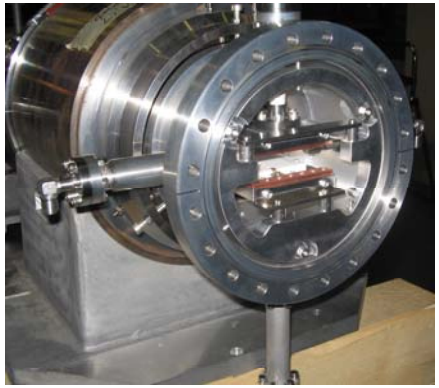


Phased construction: Linac4 to 160 MeV to feed PS Booster

Add ~350 m of SC RF to reach 3.5 GeV (possibly 5 GeV)



IPHI RFQ



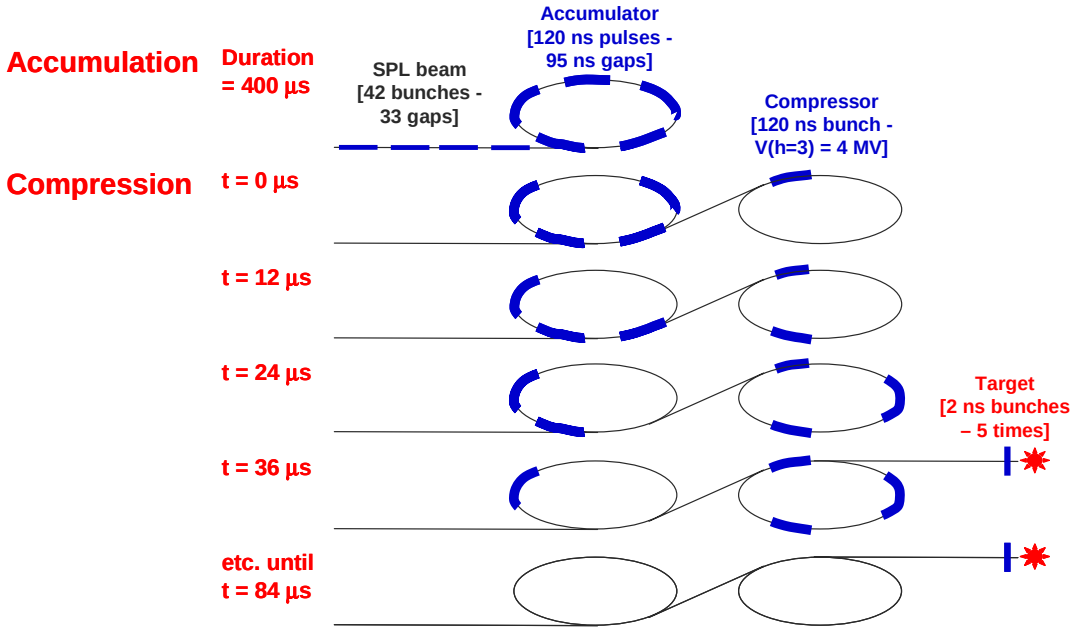
Chopper in Quad

CCDTL-BINP

Buncher Cavity

SPL as a Driver for NF

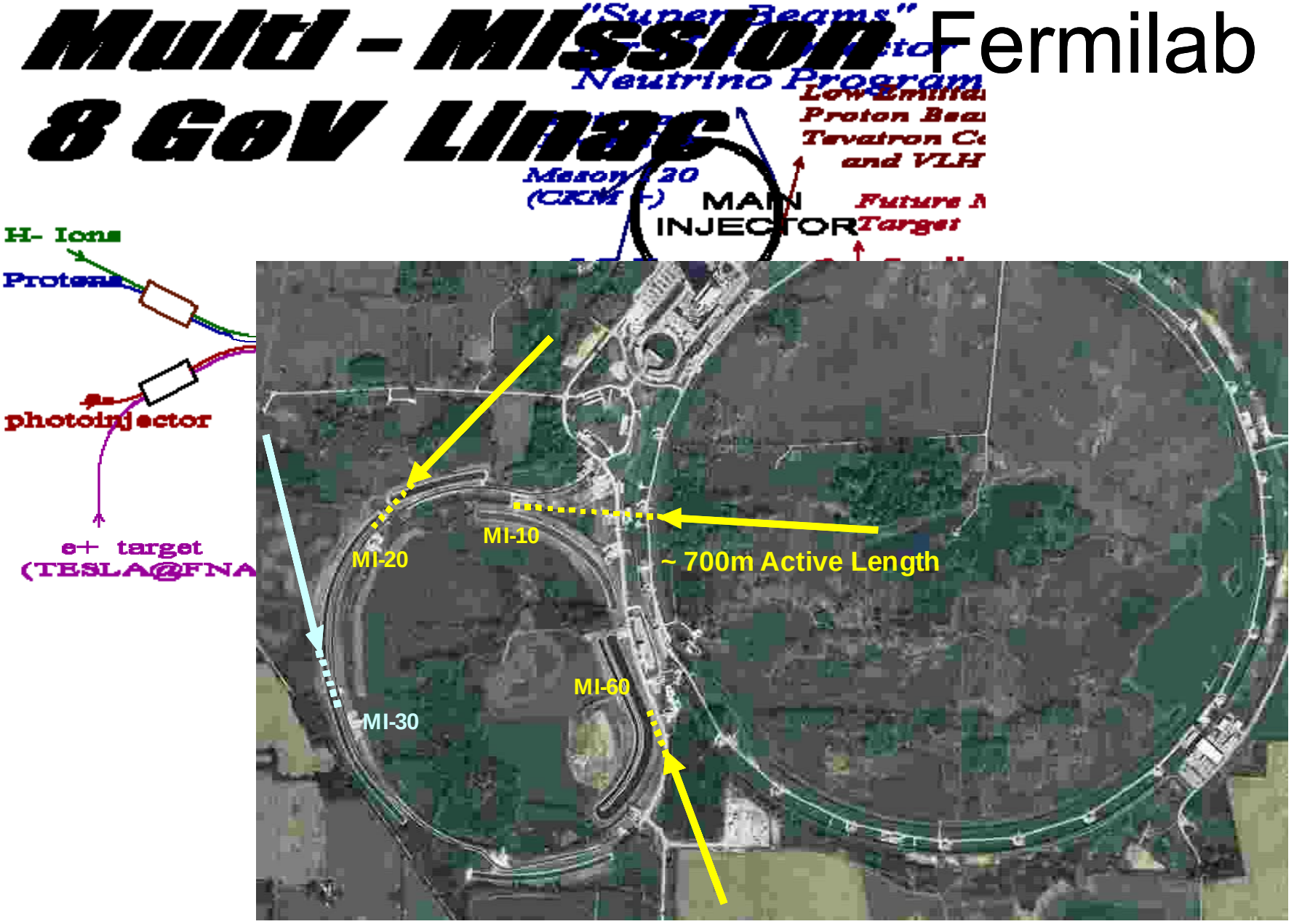
Ion	H^-	
Kinetic energy	5	GeV
Beam power	4	MW
Repetition rate	50	Hz
Mean current	40	mA
Pulse duration	0.4	ms
Bunch frequency	352.2	MHz
Linac length	534	m



	Accumulator		Compressor	
Mean radius (R_{Acc} = 185/183 R_{Comp})	50.546448	m	50	m
γ^2_T	~50		5.29	
Revolution frequency	0.932095	MHz	0.942288	MHz
VRF (h_{RF})	0 (h_{RF} =5)	V	4 (h_{RF} =3)	MV
Bunch length at ejection	120 (total)	ns	2 (rms)	ns
Number of protons per bunch	$2\ 10^{13}$		$2\ 10^{13}$	

Multi – Mission 8 GeV Linac

Fermilab



FNAL Proton Driver Parameters

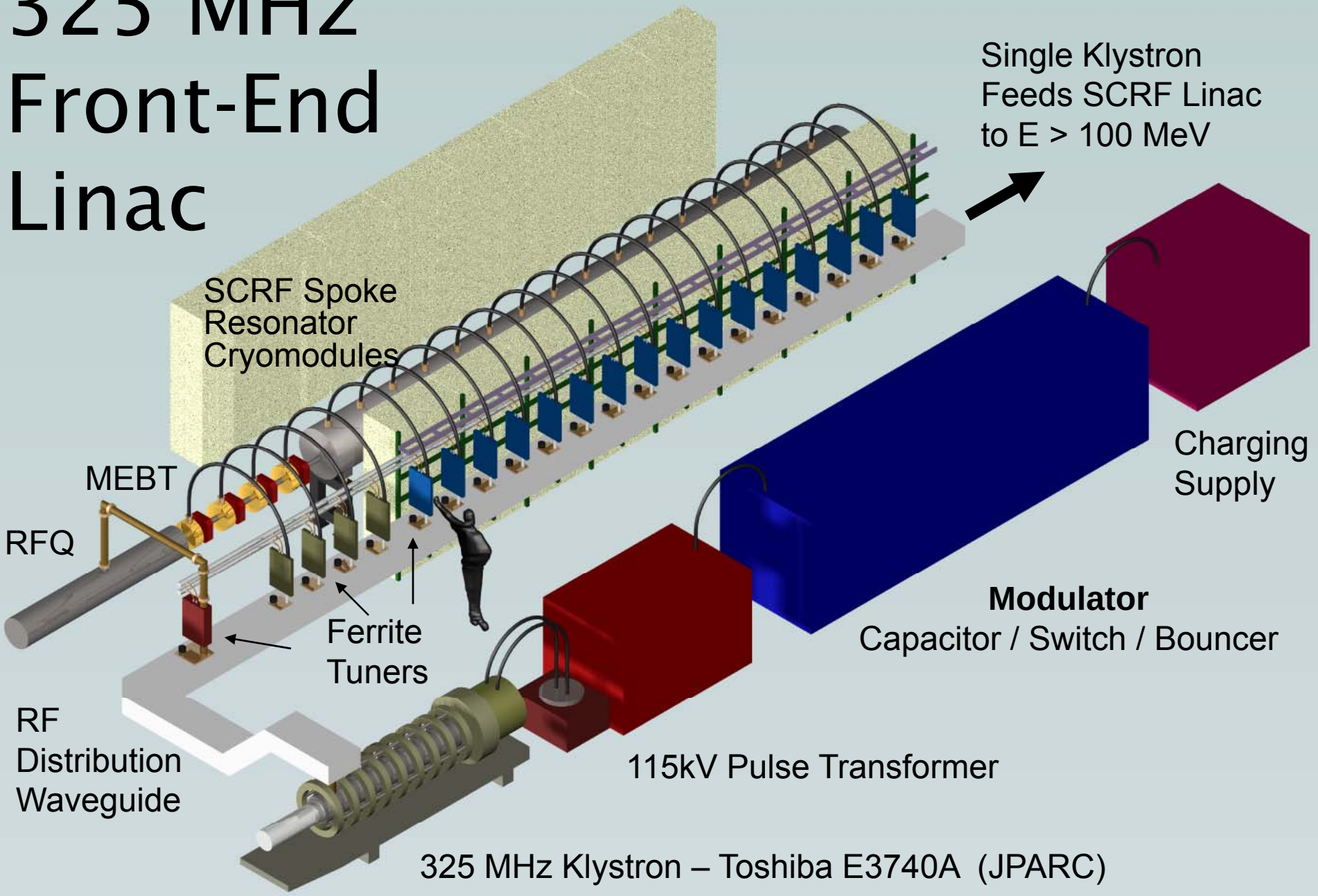
8 GeV LINAC

Energy	**GeV**	**8**	
Particle Type	H- Ions, Protons, or Electrons		
Rep. Rate	**Hz**	**10**	
Active Length	m	671	
Beam Current	mA	25	
Pulse Length	msec	1	
Beam Intensity	**P / pulse**	**1.5E+14**	(can also be H-, P, or e-)
	P/s	1.5E+15	
Linac Beam Power	MW avg.	2	
	MW peak	200	

MAIN INJECTOR WITH 8 GeV LINAC

MI Beam Energy	GeV	120	
MI Beam Power	MW	2.0	
MI Cycle Time	sec	1.5	filling time = 1msec
MI Protons/cycle		1.5E+14	5x design
MI Protons/hr	P / hr	3.6E+17	
H-minus Injection	turns	90	
MI Beam Current	mA	2250	

325 MHz Front-End Linac



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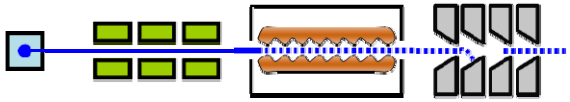
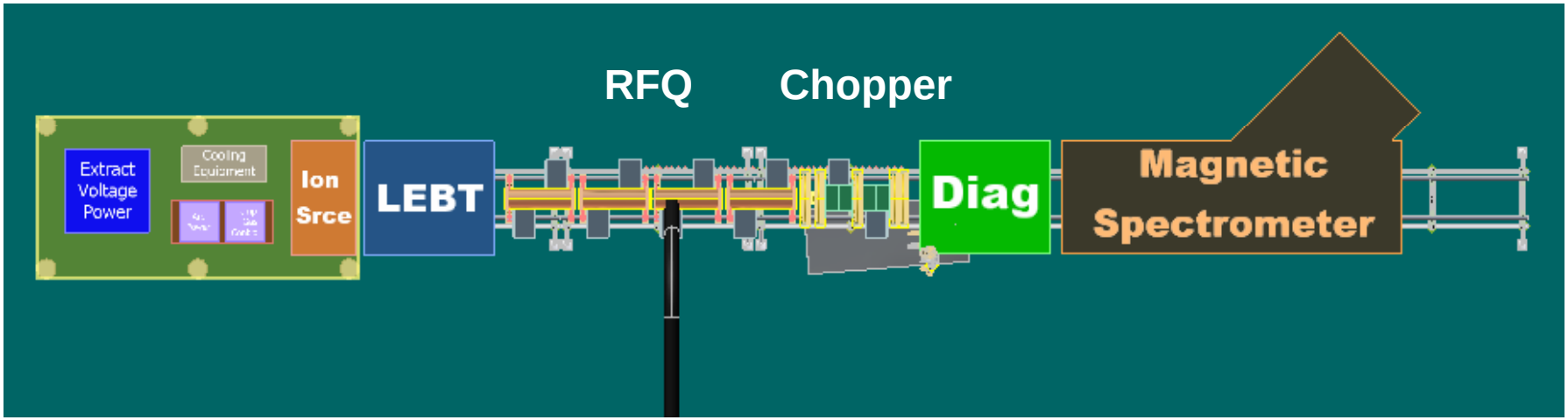


R&D Project: Front-End Test Stand at RAL (FETS)

FETS main components:

- High brightness H^- ion source.
- Magnetic Low Energy Beam Transport (LEBT).
- High current, high duty factor Radio Frequency Quadrupole.
- Very high speed beam chopper (3 MeV).
- Comprehensive diagnostics.

Essential part of any future high intensity, high power proton accelerator



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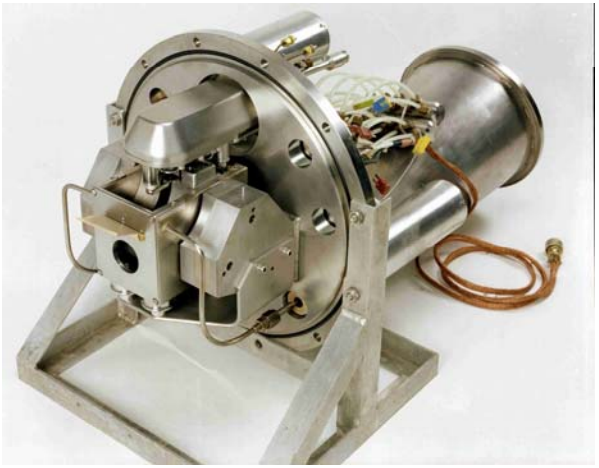
FETS Components

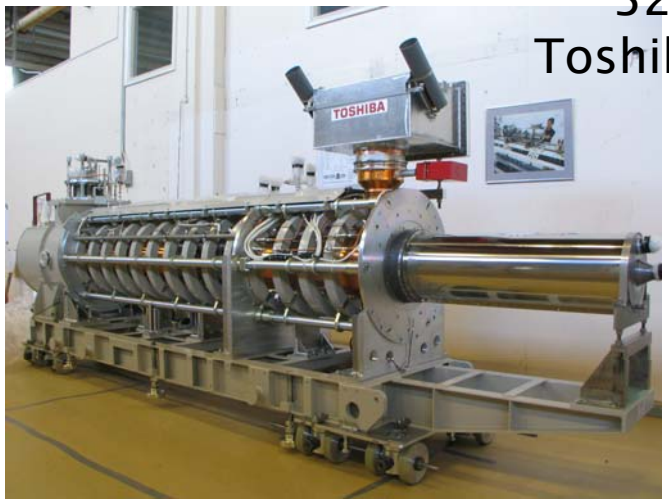
Ion Source Goals:

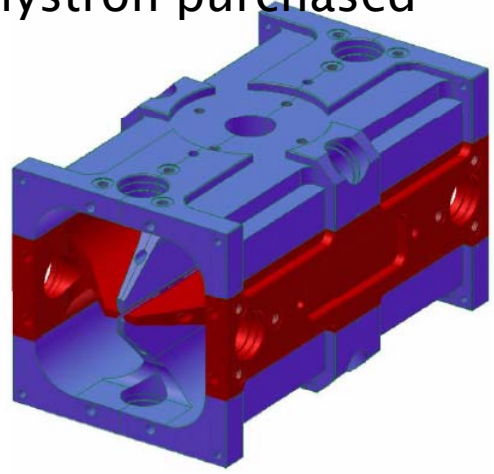
- Double output current:
  35 mA → 70 mA ☑
- Increase pulse length:
  200 μs → 2 ms ☑
- Improve emittance
  ε_{nrms}=0.2 π mm.mrad
- Maximize lifetime ≥10 weeks

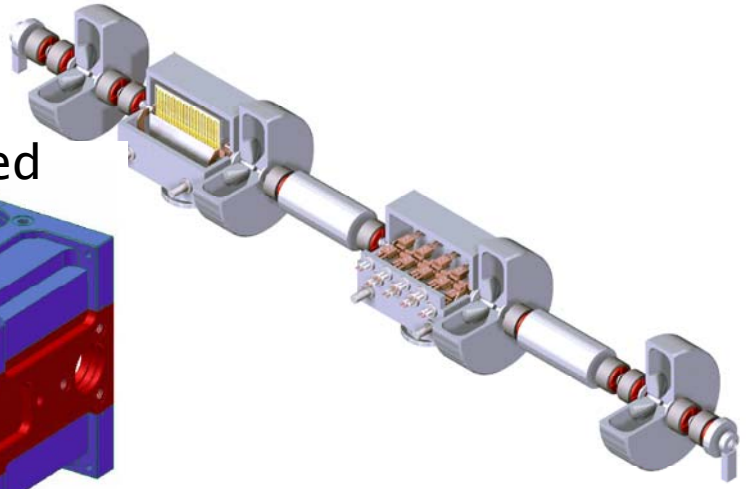


ISIS
Penning
ion source

Cold model built for
324MHz 4-vane RFQ.
Toshiba klystron purchased







Tandem fast-slow beam
chopper

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EU/CARE/HIPPI

- EU/FP6 funded study of High Intensity Pulsed Proton Injectors
  - Linacs up to 200MeV
- To support/improve infrastructure at CERN, RAL and GSI
- Major European institutions participating
  - CERN, RAL, CEA, IN2P3, INFN, FZJ, GSI, Univ. Frankfurt
- Work packages
  - Normal conducting linac structures
  - Super conducting linac structures
  - Fast beam Choppers
  - Beam dynamics, code development and benchmarking
  - Diagnostics

Annual CARE meeting, CERN, October 28-30, 2007

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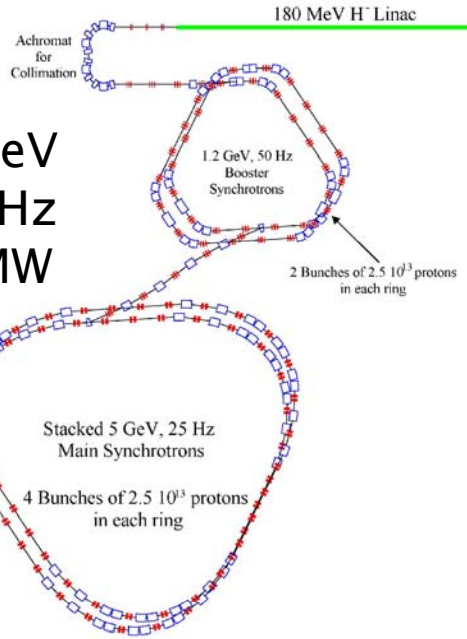
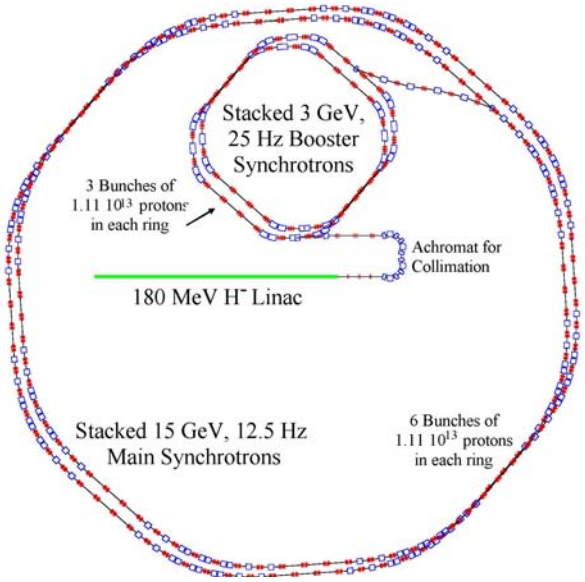
Theoretical Models

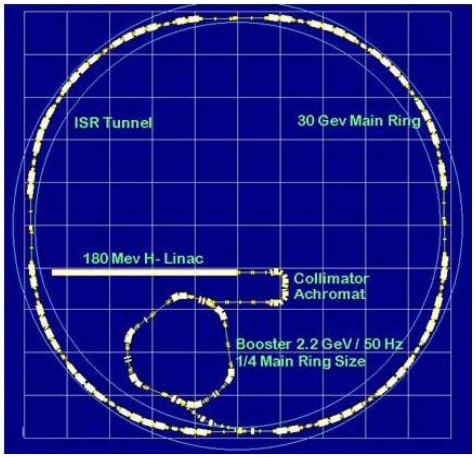
5 GeV
50 Hz
4 MW



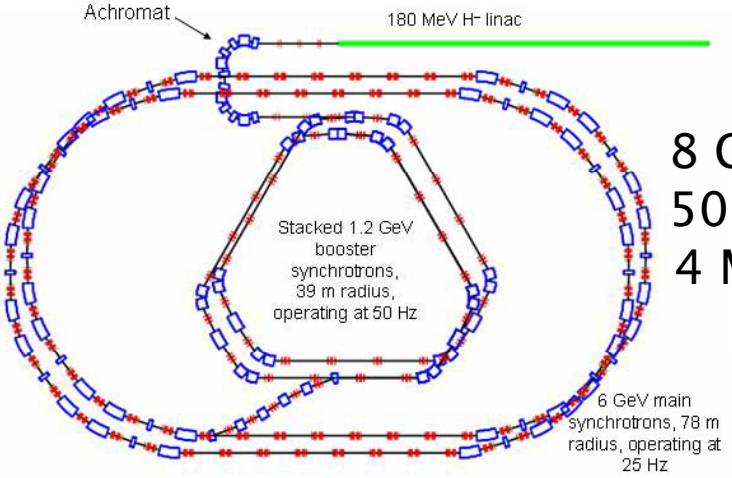
15 GeV
25 Hz
4 MW



30 GeV
8.33 Hz



8 GeV
50 Hz
4 MW



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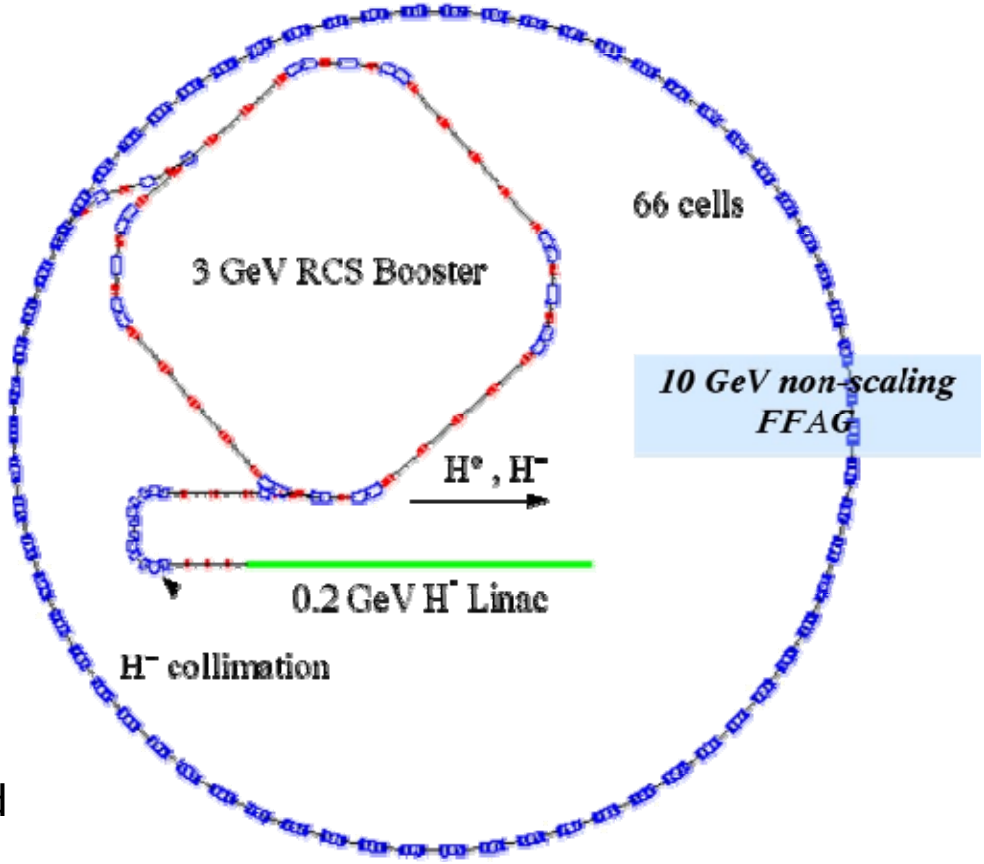
Proton Driver for a Neutrino Factory (ISS)

- High intensity ~10^{14} protons
  - Achieved with phase space painting in RCS booster
- 50 Hz rep rate
- Booster circumference 400 m
- Bunch area (h=3) 1.1 eV.sec
- ns bunch compression
  - Achieved with FFAG accelerator
  - 1.3 MV per turn for 3 ns rms
  - FFAG circumference ~800 m
- Delayed extraction of bunches to meet requirements of muon accelerators and decay rings
  - May be easier with FFAG than synchrotrons



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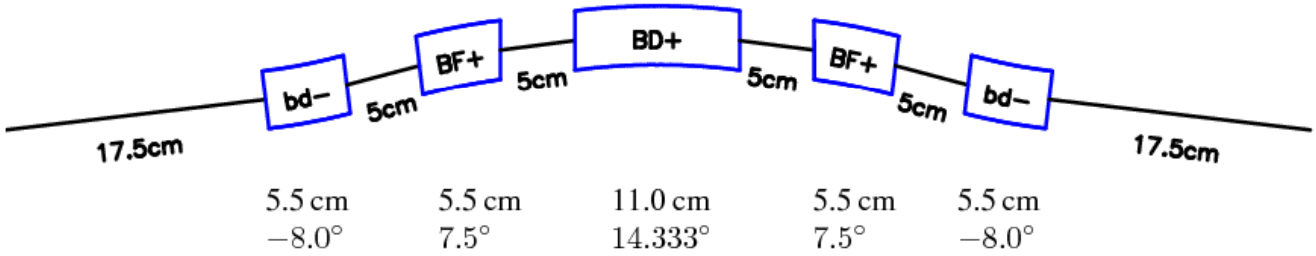
R&D Project: e-model of Proton FFAG



Pumplet lattice

27 cells

circumference ~24m

Energy range 3.0 to 5.45 MeV

Designed to test:

- Effects of non-linear magnetic fields
- Constancy of tunes at different energies
- Halo growth during acceleration
- Behaviour under space charge levels ΔQ=-0.1
- Range of momentum that can be accelerated
- Adiabatic bunch compression ~1ns (195 V needed)
- Longitudinal space-charge limitations

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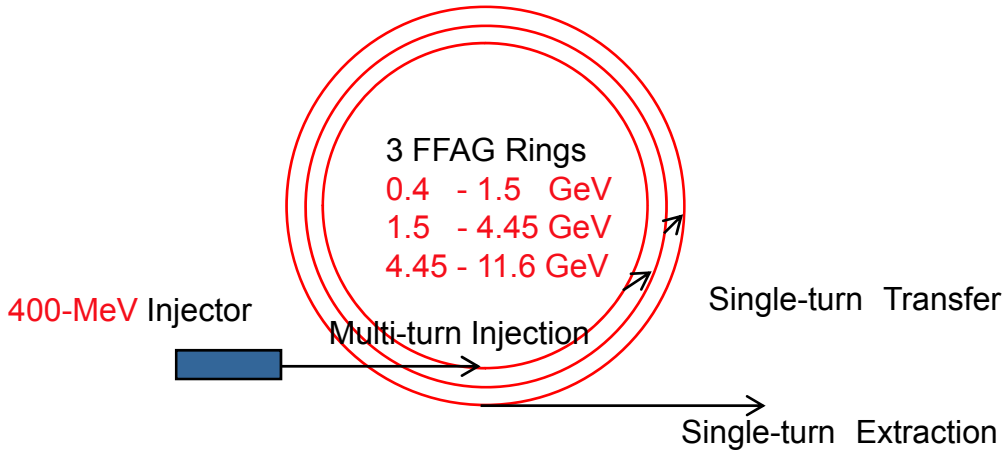
FFAG-based Proton Drivers

Project	*A*	*B*	*C*	*D*	*E*
Final Energy, GeV(/u)	1.5	12	12	1	0.40
Inj. Energy, MeV(/u)	400	400	400	50	15
Repetition Rate	2.5-5.0 Hz	50 Hz	CW	1 kHz-CW	1 kHz-CW
Ave. Power, MW	0.050	4	100	10	0.40
Ave. Current, mA(-ion)	0.033	0.33	8.5	10	0.0042
No. of Rings	1	3	3	2	2
Circumference, m	807	807	807	204	204



A: AGS upgrade

B: Driver for NF

C: CW driver for NF

D: low energy, high rep rate driver for energy production

E: acceleration U^{238} for rare isotope production

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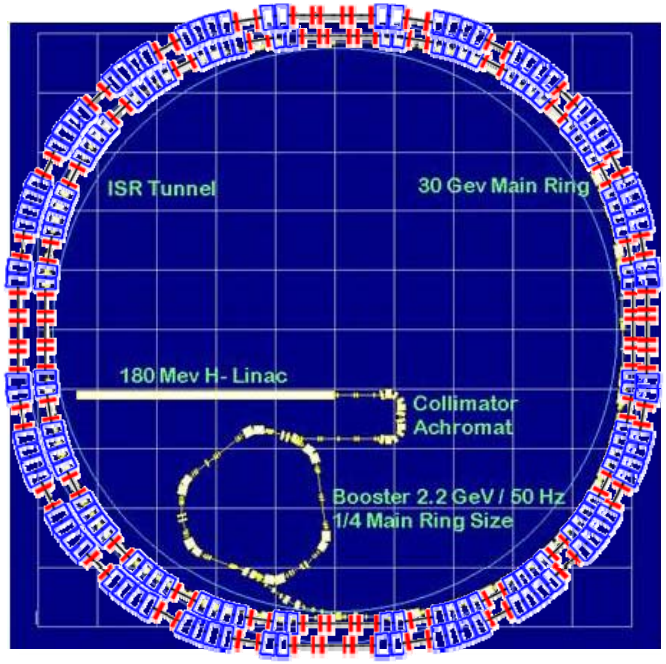
Table of Candidate Proton Accelerators

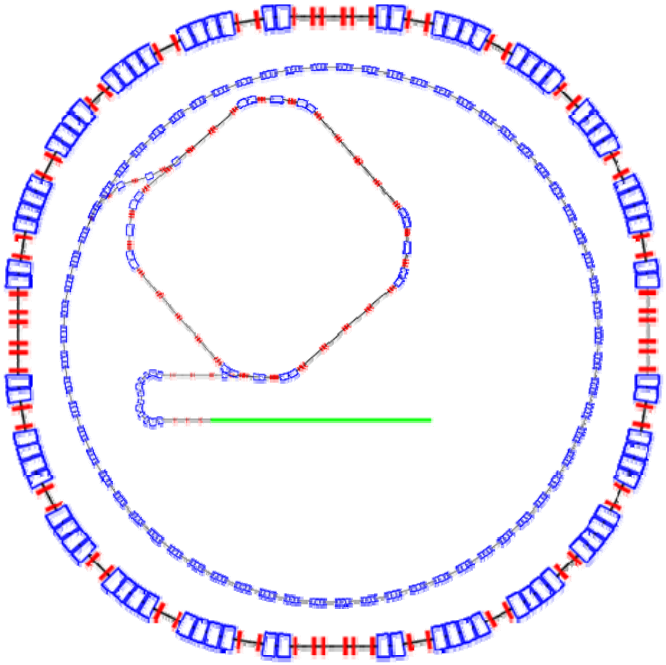
Driver	Power (MW)	Type	Energy (GeV)	Frequency (Hz)	Protons per pulse ($\times 10^{13}$)	Pulse structure τ_p (μs)	N_b	τ_b (ns)
BNL-AGS	1	Synch	28	2.5	9	720	24	3
	4	Synch	28	5	18	720	24	3
	4	Synch	40	5	12.5	720	24	3
FNAL	2	Synch	8	15	10	1.6	84	1
	2	Linac	8	10	15			
FNAL MI	2	Synch	120	0.67	15	10	330	2
CERN-SPL	4	LAR	2.2	50	23	3.2	140	1
	4	LAR	3.5	50	14	1.7	68	1
	4	LAR	5.0	50	10	50	5	2
J-PARC	0.75	Synch	50	0.3	31	4.6	8	6
RAL	4	Synch	5	50	10	1.4	4	1
	4	Synch	6–8	50	8.3	1.6	6	1
	4	FFAG	10	50	5	37	3	1
	4	Synch	15	25	6.7	3.2	6	1
RAL/CERN	4	Synch	30	8.33	10	3.2	8	1
KEK/Kyoto	1	FFAG	1	10^4	0.06	0.4	10	10
	1	FFAG	3	$3\,10^3$	0.06	0.5	10	10

Extending NF driver to Muon Collider

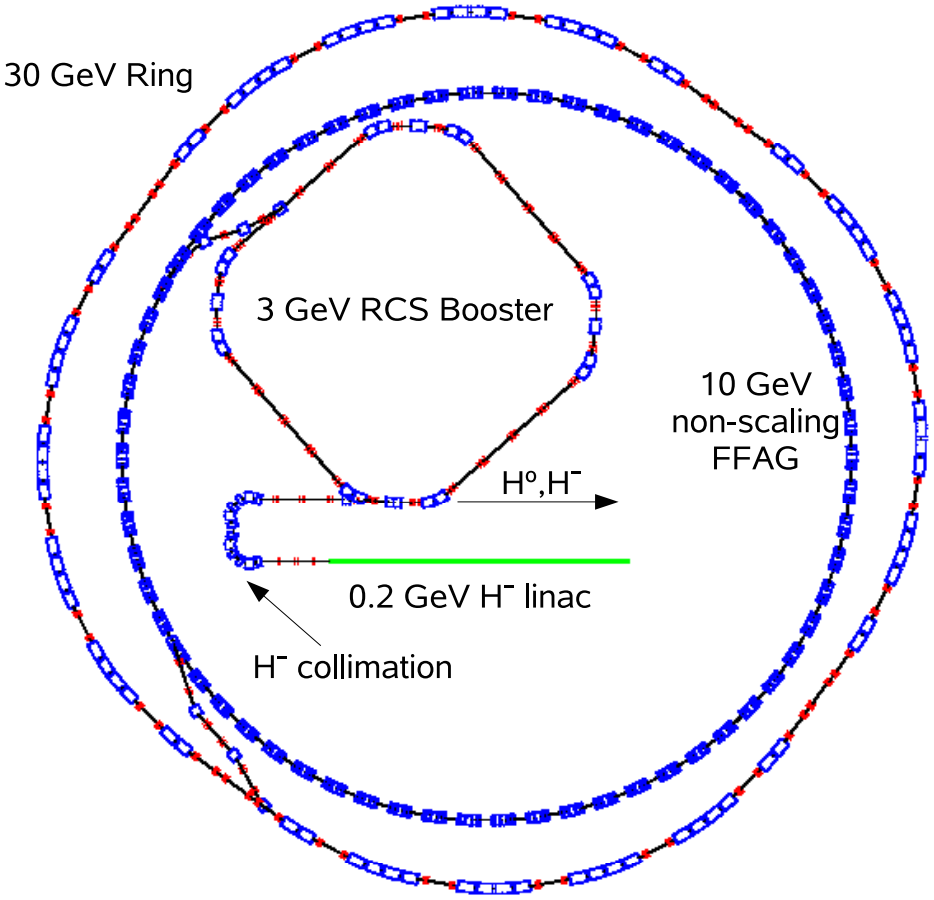
	Neutrino Factory	Muon Collider
Beam power (MW)	4	4
Number of bunches	3	1
Bunch duration (rms ns)	3	3
Bunch area (eV.s)	1.1	3.3
Repetition rate (Hz)	50	50/4 or 50/3
Kinetic energy (GeV)	10	40 or 30
Circumference (m)	800	1300 or 950
Protons per bunch (10^{13})	1.67	6.67 or 5.0

Idea is to add a further ring to 10GeV NF driver (adapted)


ISR Tunnel
30 Gev Main Ring
180 Mev H- Linac
Collimator
Achromat
Booster 2.2 GeV / 50 Hz
1/4 Main Ring Size



30 GeV Proton Driver for a Muon Collider



- 10 GeV NF driver modified
  - Single bunch
  - Rep rate 50/3=16.7 Hz
  - Bunch area x3
  - RCS h=3 to h=1
  - FFAG h=24 to h=8
  - RF reduced by factor 3
- 30 GeV RCS
  - Circumference 952 m
  - Peak voltage per turn for compression 1.4 MV
  - Compressed bunch 2.5 ns

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Discuss