Muon Collaboration

Prospects for Future Proton Drivers

APS Neutrino Study Group
Meeting

ANL

March 3-4, 2004

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Harold G. Kirk
Brookhaven National Laboratory

Need for Intense Secondary Beams

New physics opportunities are generating world wide interest in the development of new intense secondary beam.

- Neutron Sources
  - European Spallation Source
  - US Spallation Neutron Source
  - Japanese Neutron Source
- Kaons
  - RSVP at BNL
  - CKM at FNAL
- Muons
  - MECO and g-2 at BNL
  - SINDRUM at PSI
  - EDM at JPARC
  - Muon Collider
- Neutrinos
  - Beta Beams
  - Superbeams
  - Neutrino Factories

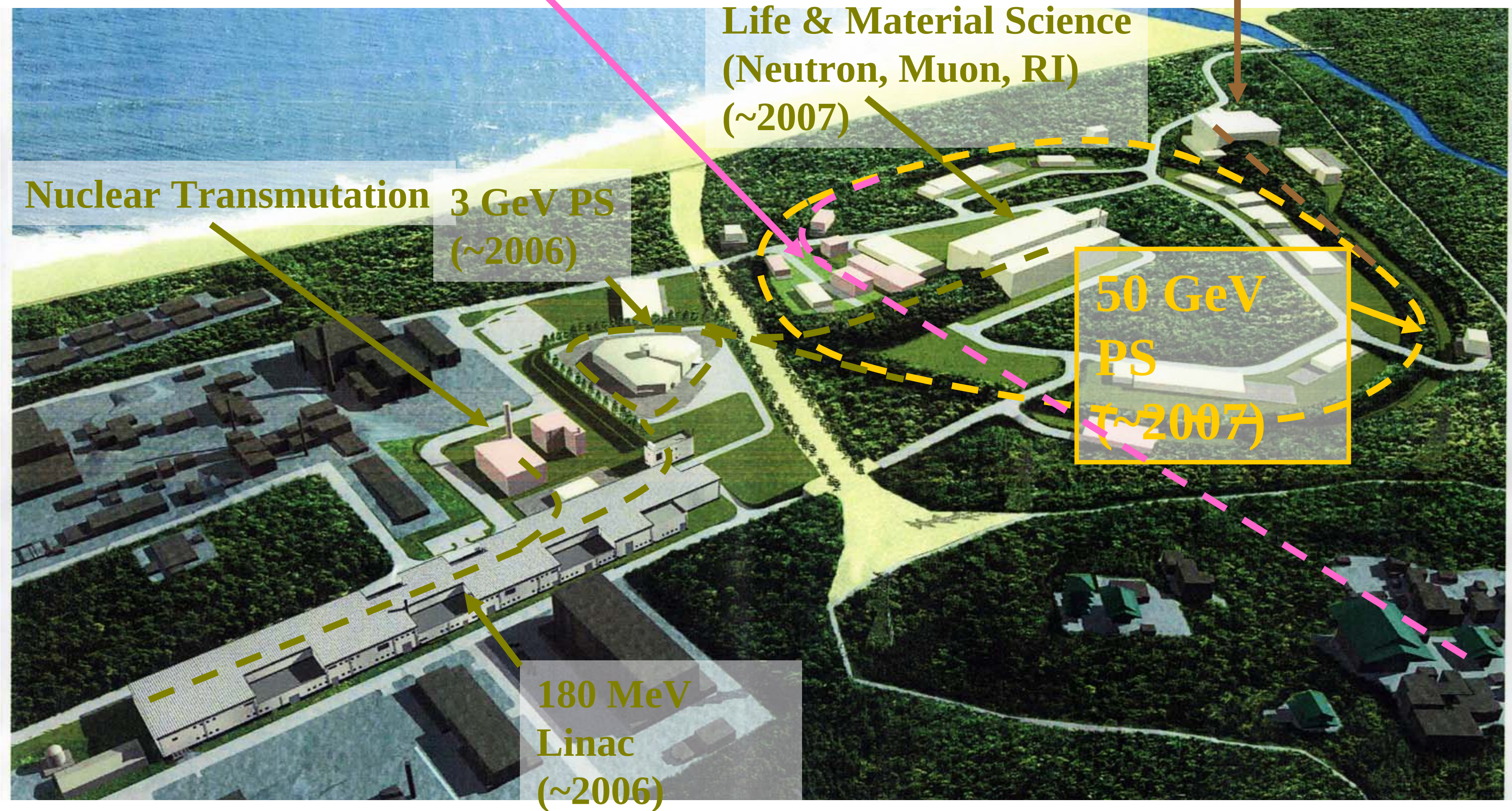
Multi-MW New Proton Machines

SNS at 1.2 MW	→	2.0 MW		
JPARC 0.7 MW	→	4.0 MW		
FNAL 0.4 MW	→	1.2 MW	→	2.0 MW
BNL 0.14 MW	→	1.0 MW	→	4.0 MW
CERN(PS) 0.1 MW	→	SPL 4.0 MW		

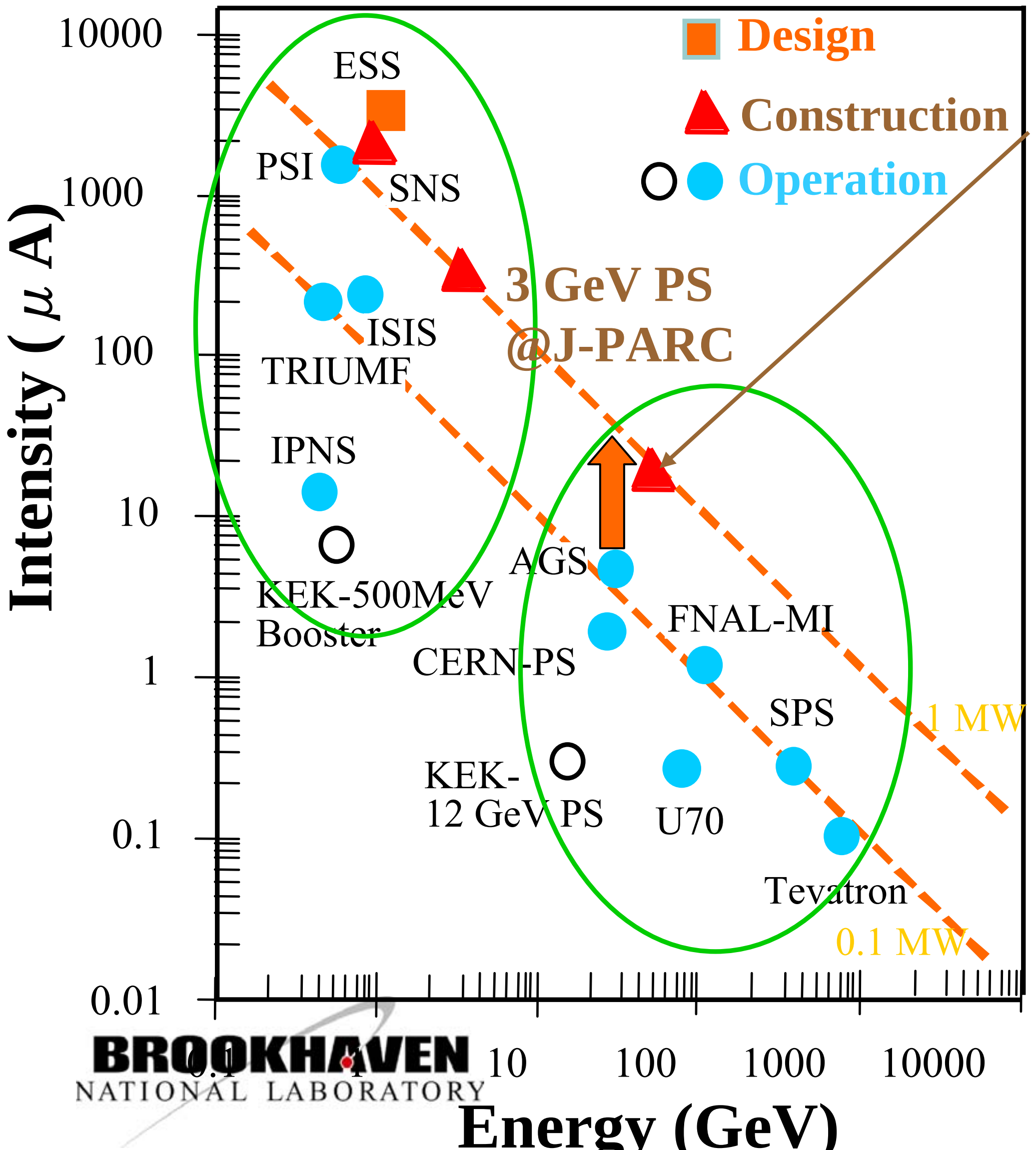
The JPARC Project

Facility for Neutrino Experiment (2004?~2008?)

Facility for Nuclear/Particle Physics experiment (~2007)



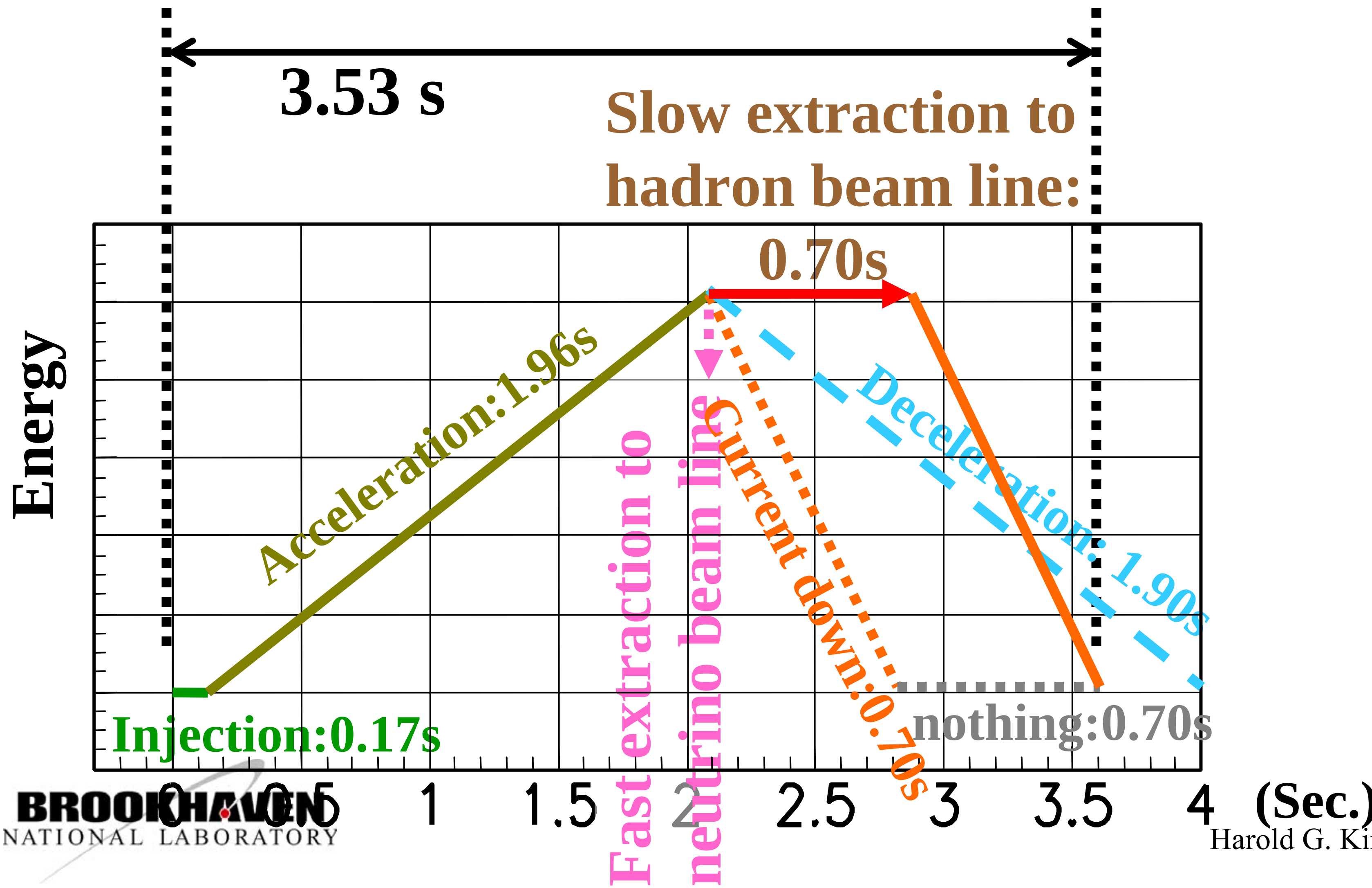
Machine power



50 GeV PS @J-PARC

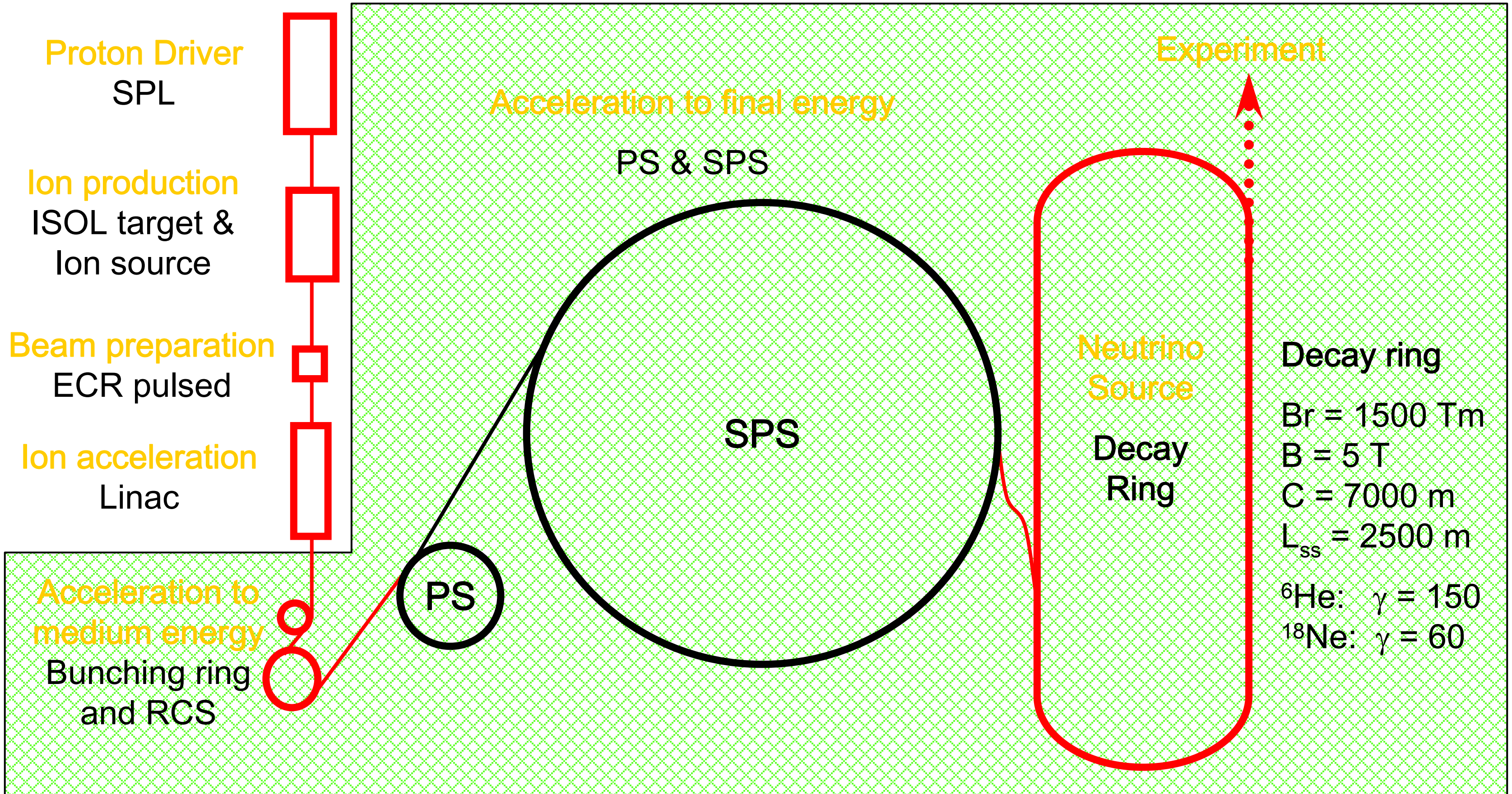
- **Beam Energy:**
  - **50GeV**
  - **(40GeV in Phase1-)**
- **Beam Intensity:**
  - **3.3×10^{14}ppp, 15 μ A**
  - **(2×10^{14}ppp, 9 μ A in Phase1-)**
  - **(18×10^{14}ppp, 80 μ A in future)**
- **Beam Power:**
  - **0.75MW**
  - **(0.36MW at Phase1-)**
  - **(4MW in future)**

Acceleration/extraction cycle

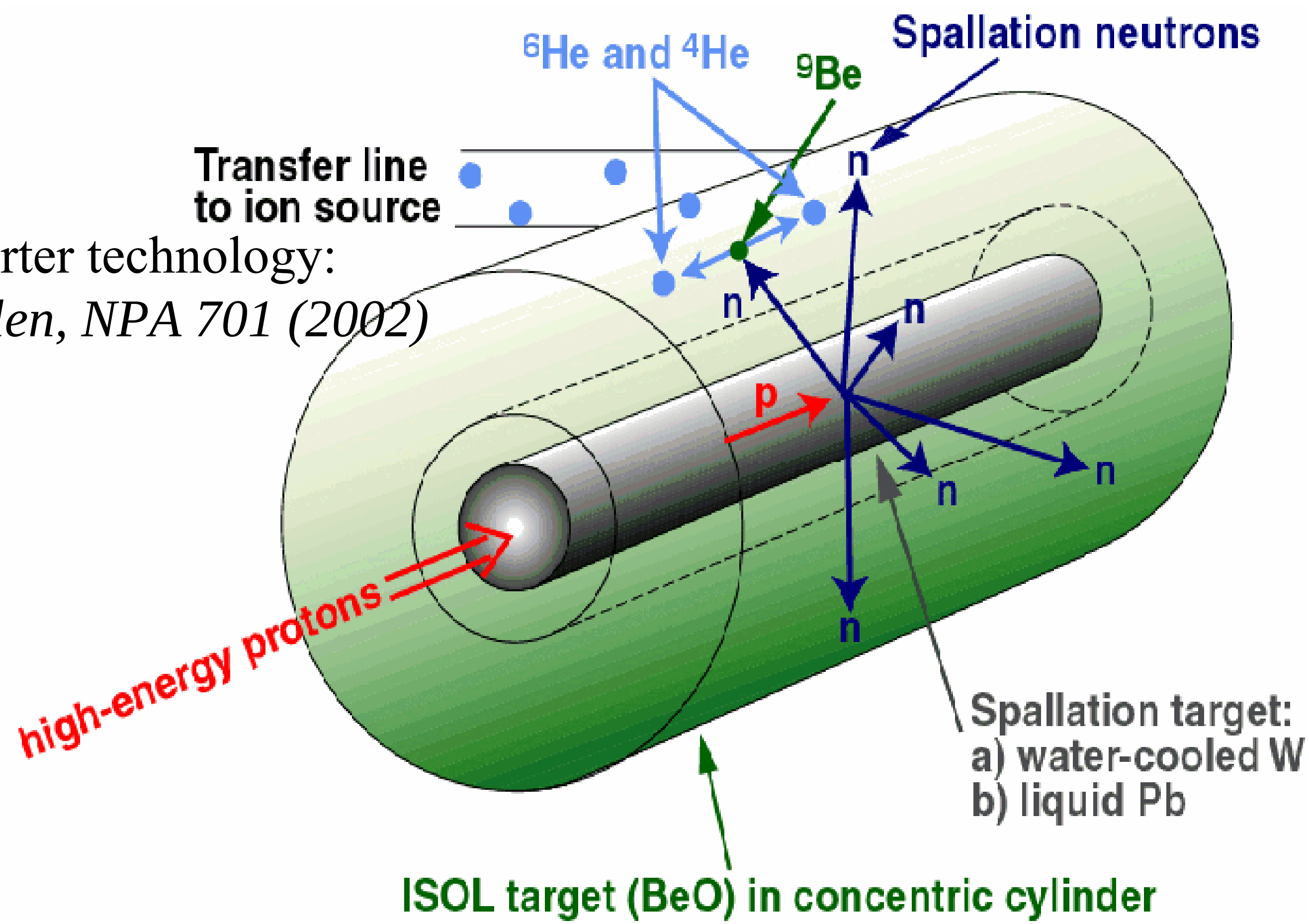


The European Beta-beam Scenario

Process begins with high-power proton driver



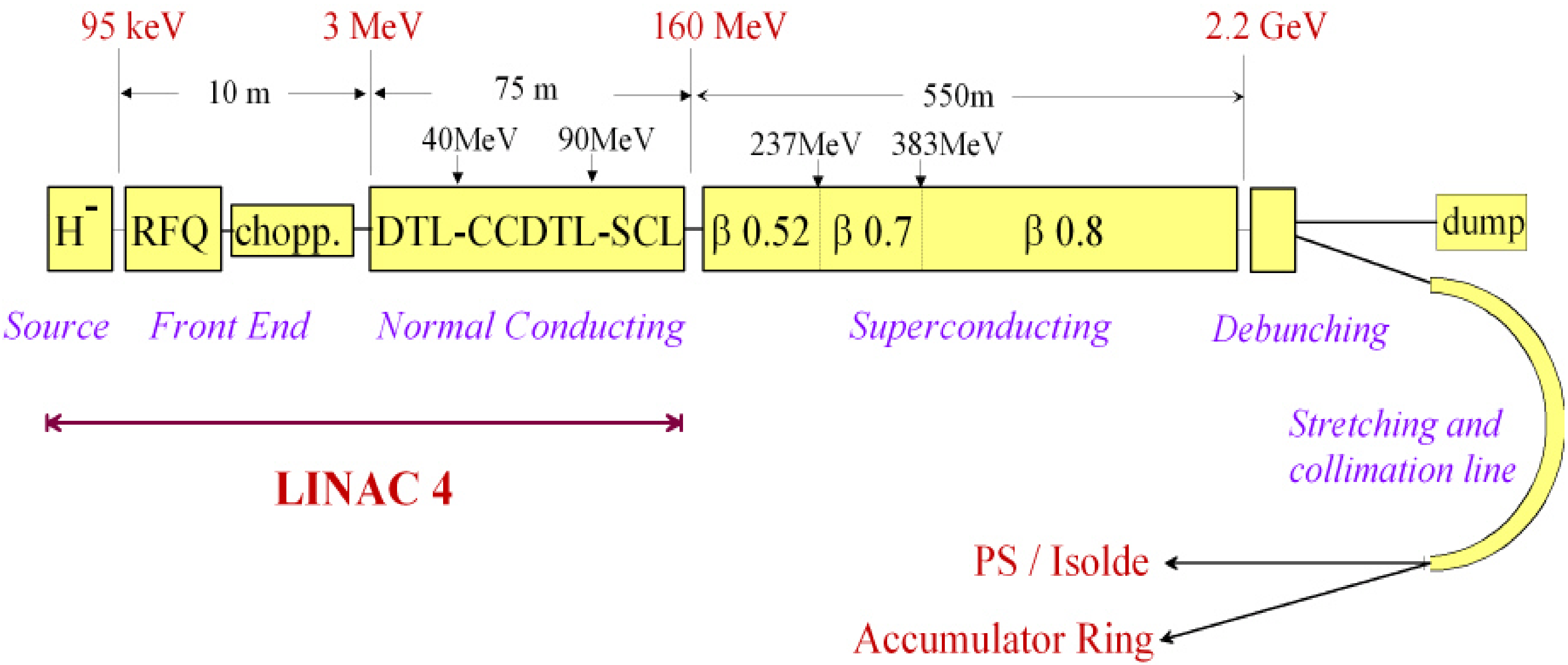
ISOL ^{6}He production by ^{9}Be(n,a)



Converter technology:
(J. Nolen, NPA 701 (2002) 312c)

Layout very similar to planned EURISOL converter target aiming for 10^{15} fissions per s.

The CERN SPL



95 keV
3 MeV
160 MeV
2.2 GeV
10 m
75 m
550m
40MeV
90MeV
237MeV
383MeV
H-
RFQ
chopp.
DTL-CCDTL-SCL
β 0.52
β 0.7
β 0.8
dump
Source
Front End
Normal Conducting
Superconducting
Debunching
LINAC 4
Stretching and
collimation line
PS / Isolde
Accumulator Ring

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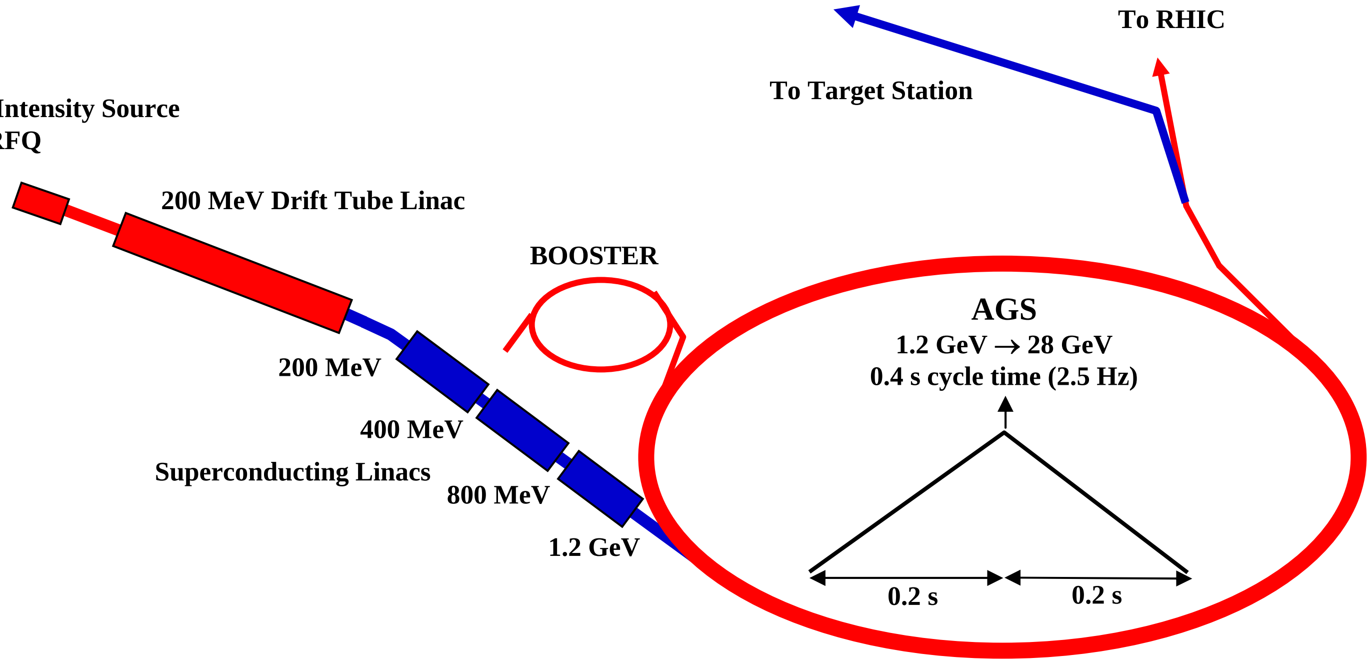
CERN SPL Parameters

Ion species	H-	
Kinetic energy	2.2	GeV
Mean current during the pulse	13	mA
Duty cycle	14.0	%
Mean beam power	4	MW
Pulse frequency	50	Hz
Pulse duration	2.80	ms
Duty cycle during the beam pulse	61.6	%
Maximum bunch current	22.7	mA
Bunch length (total)	0.5	ns
Energy spread (total)	0.5	MeV
Normalised rms horizontal emittance	0.4	π mm mrad
Normalised rms vertical emittance	0.4	π mm mrad
Longitudinal rms emittance (352 MHz)	0.3	π deg MeV

AGS Upgrade to 1 MW



- 1.2 GeV superconducting linac extension for direct injection of $\sim 1 \times 10^{14}$ protons

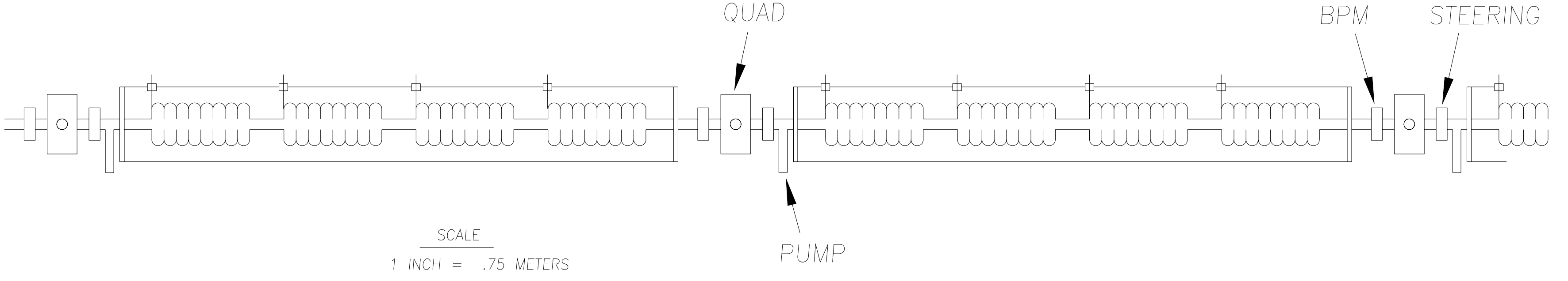
  low beam loss at injection; high repetition rate; possible further upgrade to 1.5 GeV and 2×10^{14} protons per pulse possible (x 2)

- 2.5 Hz AGS repetition rate

  triple existing main magnet power supply and magnet current feeds;
  double rf power and accelerating gradient further upgrade to 5 Hz possible (x 2)

1.2 GeV Superconducting Linac

Beam energy	$0.2 \rightarrow 0.4$ GeV	$0.4 \rightarrow 0.8$ GeV	$0.8 \rightarrow 1.2$ GeV
Rf frequency	805 MHz	1610 MHz	1610 MHz
Accelerating gradient	10.8 MeV/m	23.5 MeV/m	23.4 MeV/m
Length	37.8 m	41.4 m	38.3 m
Beam power, linac exit	17 kW	34 kW	50 kW



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AGS Injection Simulation

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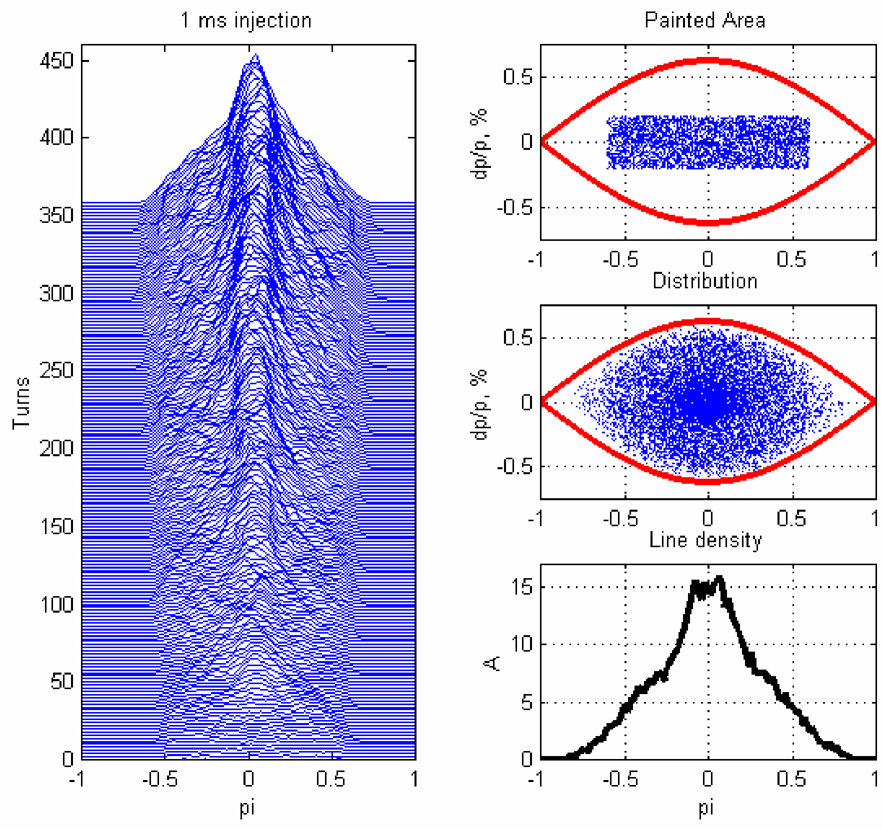
Injection parameters:

Injection turns	360
Repetition rate	2.5 Hz
Pulse length	1.08 ms
Chopping rate	0.65
Linac average/peak current	20 / 30 mA
Momentum spread	± 0.15 %
Inj. beam emittance (95 %)	12 π μm
RF voltage	450 kV
Bunch length	85 ns
Longitudinal emittance	1.2 eVs
Momentum spread	± 0.48 %
Circ. beam emittance (95 %)	100 π μm



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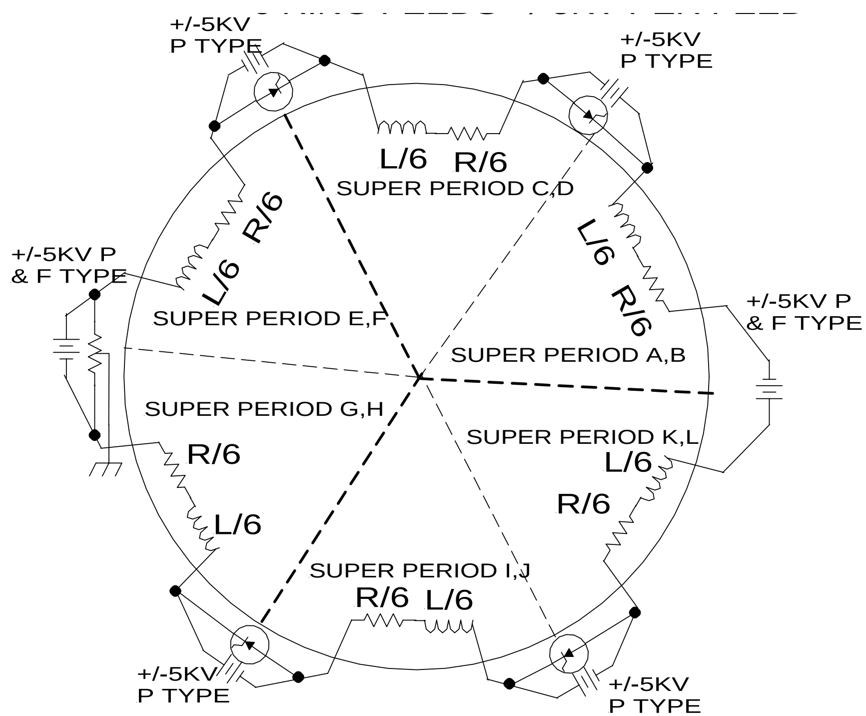
Path Towards 4 MW

	Upgrade I	Upgrade II	Upgrade III
Linac intensity/pulse	1.0×10^{14}	2.0×10^{14}	2.0×10^{14}
Linac rep. rate	2.5 Hz	2.5 Hz	5.0 Hz
Linac extraction energy	1.2 GeV	1.5 GeV	1.5 GeV
$\beta^2\gamma^3$	9.6	14.9	14.9
Beam power	54 kW	144 kW	288 kW
AGS intensity/pulse	0.9×10^{14}	1.8×10^{14}	1.8×10^{14}
AGS rep. rate	2.5 Hz	2.5 Hz	5.0 Hz
Rf peak power	2 MW	4 MW	8 MW
Rf gap volts/turn	0.8 MV	0.8 MV	1.5 MV
AGS extraction energy	28 GeV	28 GeV	28 GeV
Beam power	1 MW	2 MW	4 MW

New AGS Main Magnet Power Supply

		presently:
• Repetition rate	2.5 Hz	1 Hz
• Peak power	110 MW	50 MW
• Average power	4 MW	4 MW
• Peak current	5 kA	5 kA
• Peak total voltage	± 25 kV	± 10 kV
• Number of power converters / feeds	6	2



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AGS RF System Upgrade

Use present cavities with upgraded power supplies

	Upgrade	Present
• Rf voltage/turn	0.8 MV	0.4 MV
• RF voltage/gap	20 KV	10 KV
• Harmonic number	24	6 (12)
• Rf frequency	9 MHz	3 (4.5) MHz
• Rf peak power	2 MW	0.75 MW
• Rf magnetic field	18 mT	18 mT
• 300 kW tetrodes/cavity	2	1

Preliminary Cost Estimate of the BNL - SNBF

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A) Accelerator Systems

1.2 GeV SC Linac:	
Front End	$ 2.5 M
LE SC Linac	$ 38.3 M
ME SC Linac	$ 30.7 M
HE SC Linac	$ 28.1 M
AGS Upgrades:	
AGS Power Supply	$ 32.0 M
AGS RF Upgrade	$ 8.6 M
AGS Injection Channel	$ 3.7 M
Full Turn Extraction	$ 5.5 M
Shielding	$ 3.2 M
Direct Cost	**$156.8 M**

B) Neutrino Production Systems

Item	Cost
Proton Transport	$14.8 M
Target/Horn	$ 5.5 M
Shielding/Dump	$ 5.8 M
Decay Tunnel	$ 0.4 M
Hill. Construction	$13.0 M
Near Detector Vault	$ 7.3 M
Conventional Facility	$ 7.5 M
Other Construction	$ 2.2 M
Installation	$ 5.2 M
Direct Cost	**$61.7 M**

Total Direct Cost = $218.5 M$

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Preliminary Cost Estimate – Accelerator

Total Direct Cost = $156.8 M

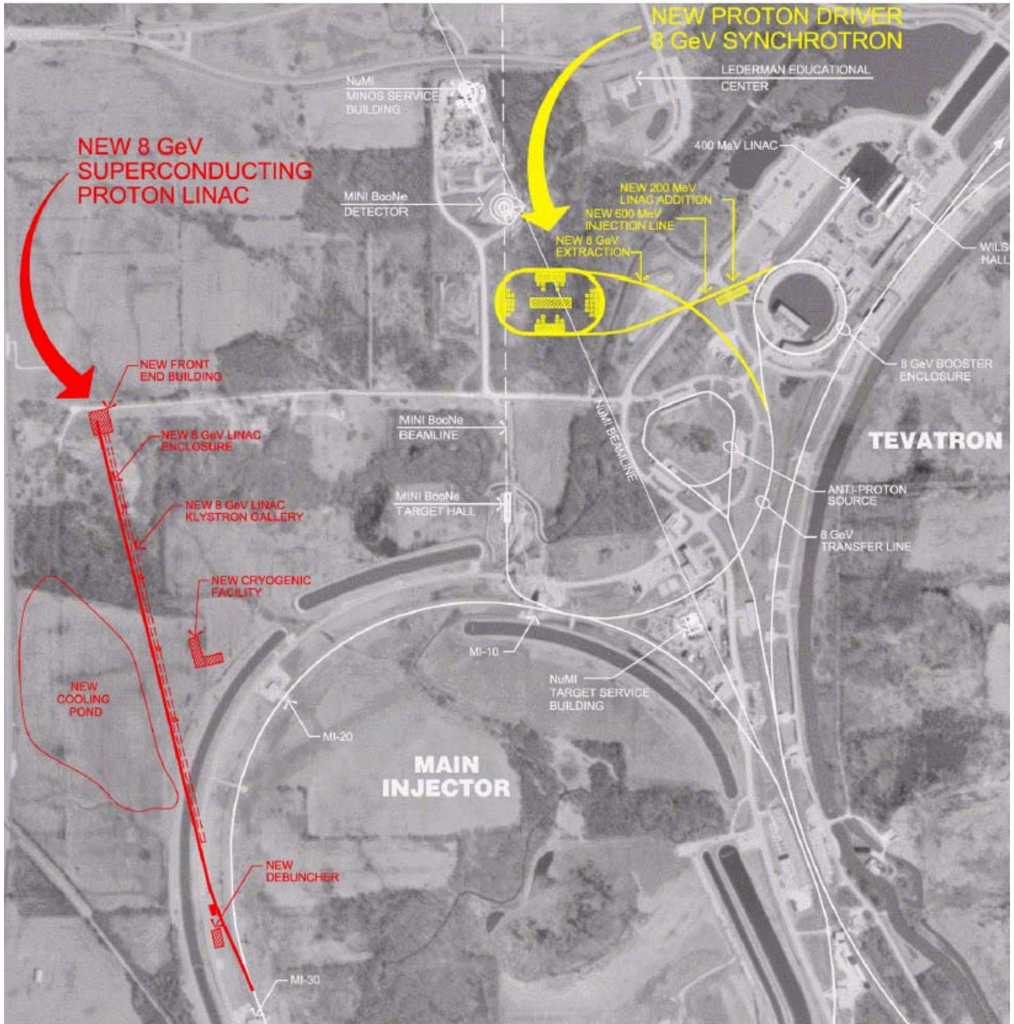
Add ED&I, 15%

Contingency, 30%

BNL Project Overhead, 13%

Total Estimated Cost = $265 M

FNAL Proton Driver Upgrades



Synchrotron Solution

- Sited West of the existing booster
- Twice the shielding of the current booster
- Large aperture magnets
- Collimators contain losses to avoid activation of equipment

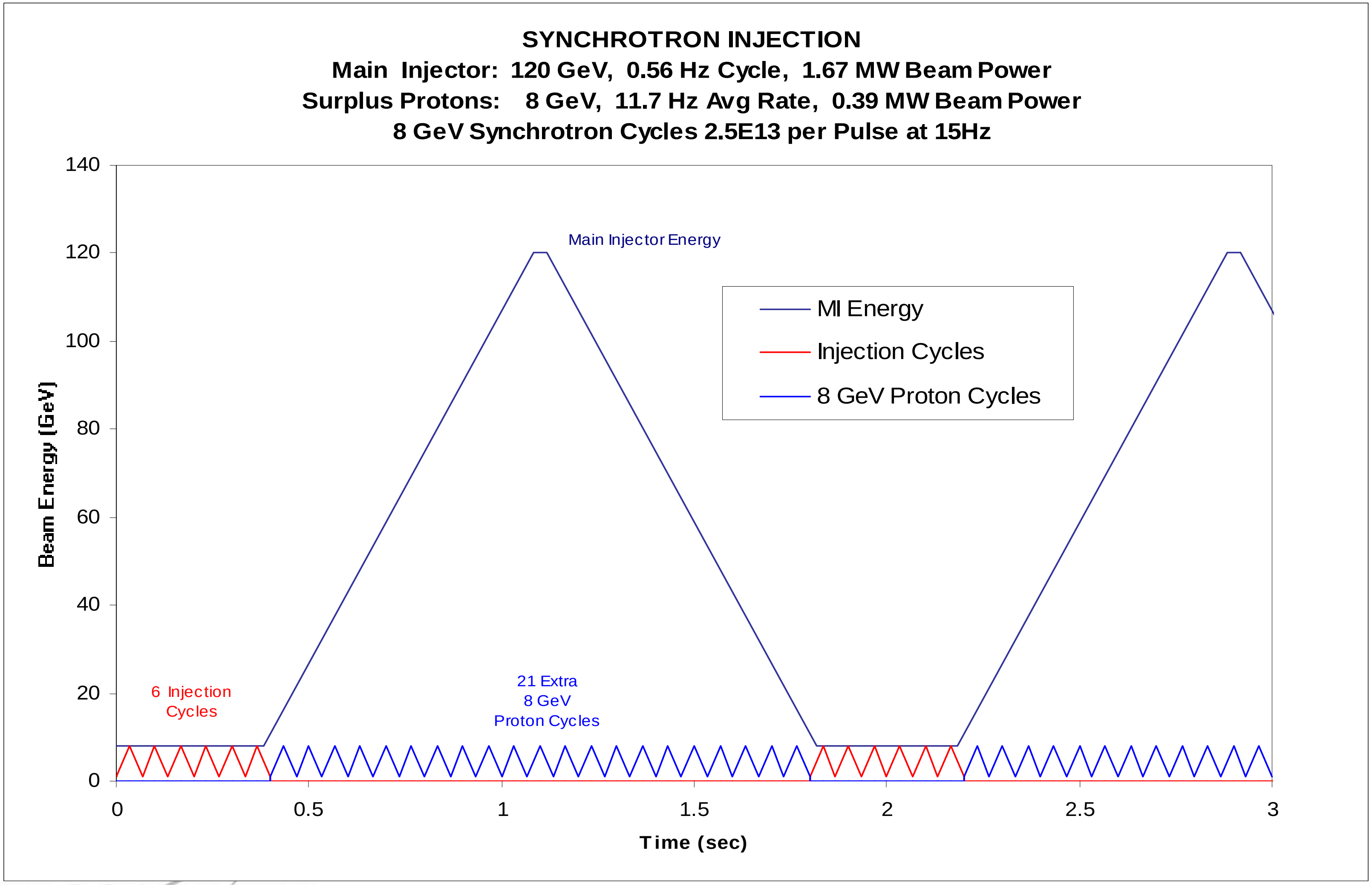
8 GeV Linac Solution

- SNS-like Linac to 1.2 GeV
- TESLA-like Linac to 8 GeV

FNAL 8 GeV Synchrotron Parameters

Parameters	Present Proton Source	Proton Driver (PD2)
Linac (operating at 15 Hz)		
Kinetic energy (MeV)	400	600
Peak current (mA)	40	50
Pulse length (μs)	25	90
H^- per pulse	6.3×10^{12}	2.8×10^{13}
Average beam current (μA)	15	67
Beam power (kW)	6	40
Booster (operating at 15 Hz)		
Extraction kinetic energy (GeV)	8	8
Protons per bunch	6×10^{10}	3×10^{11}
Number of bunches	84	84
Protons per cycle	5×10^{12}	2.5×10^{13}
Protons per hour	9×10^{16} (@ 5 Hz)	1.35×10^{18}
Normalized transverse emittance (mm-mrad)	15π	40π
Longitudinal emittance (eV-s)	0.1	0.2
RF frequency (MHz)	53	53
Average beam current (μA)	12	60
Beam power (MW)	0.033 (@ 5 Hz)	0.5

120 GeV Main Injector Cycle with 8 GeV Synchrotron



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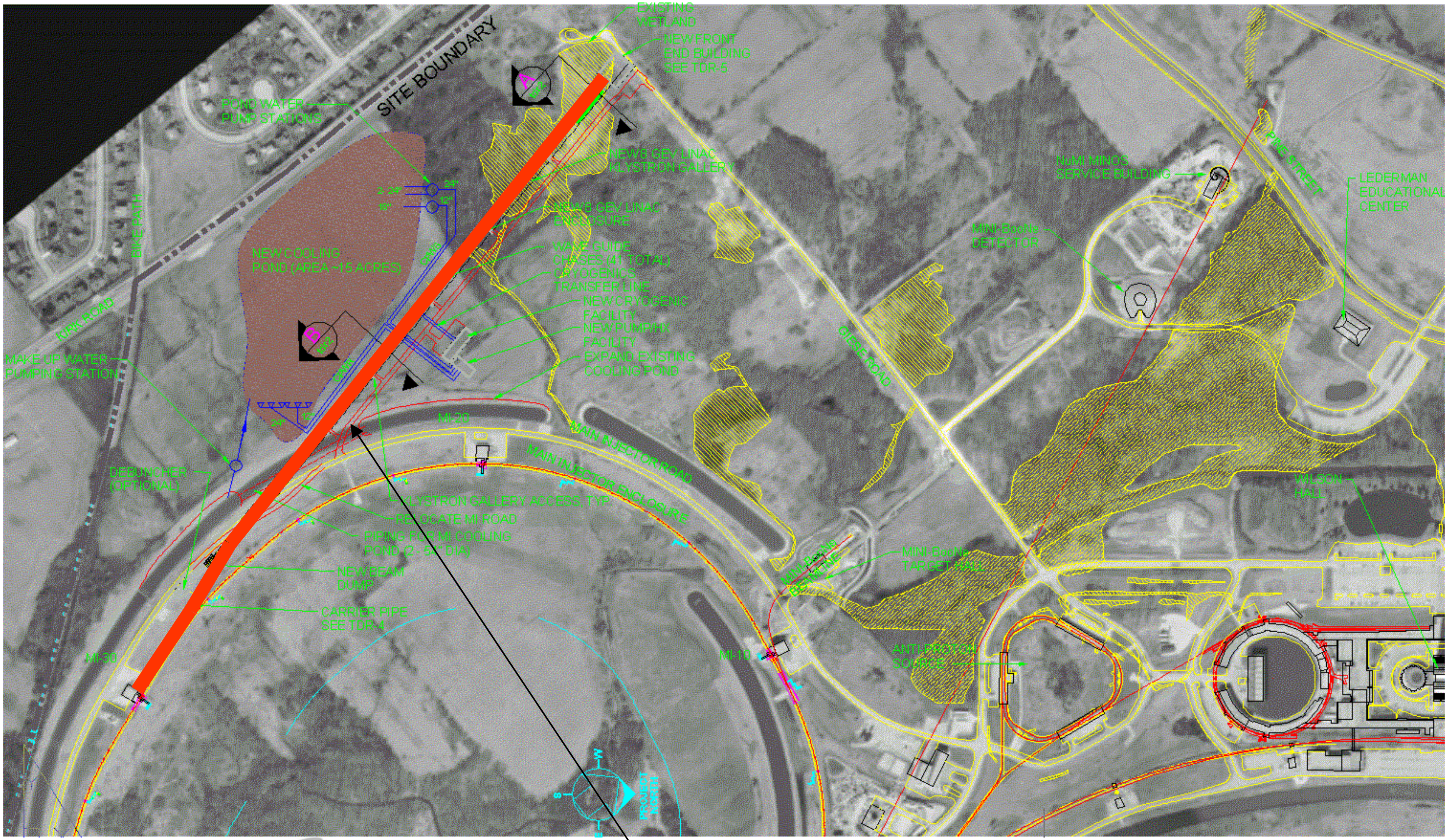
8 GeV Linac Siting for Design Study



•**Sited tangent to the Main Injector**

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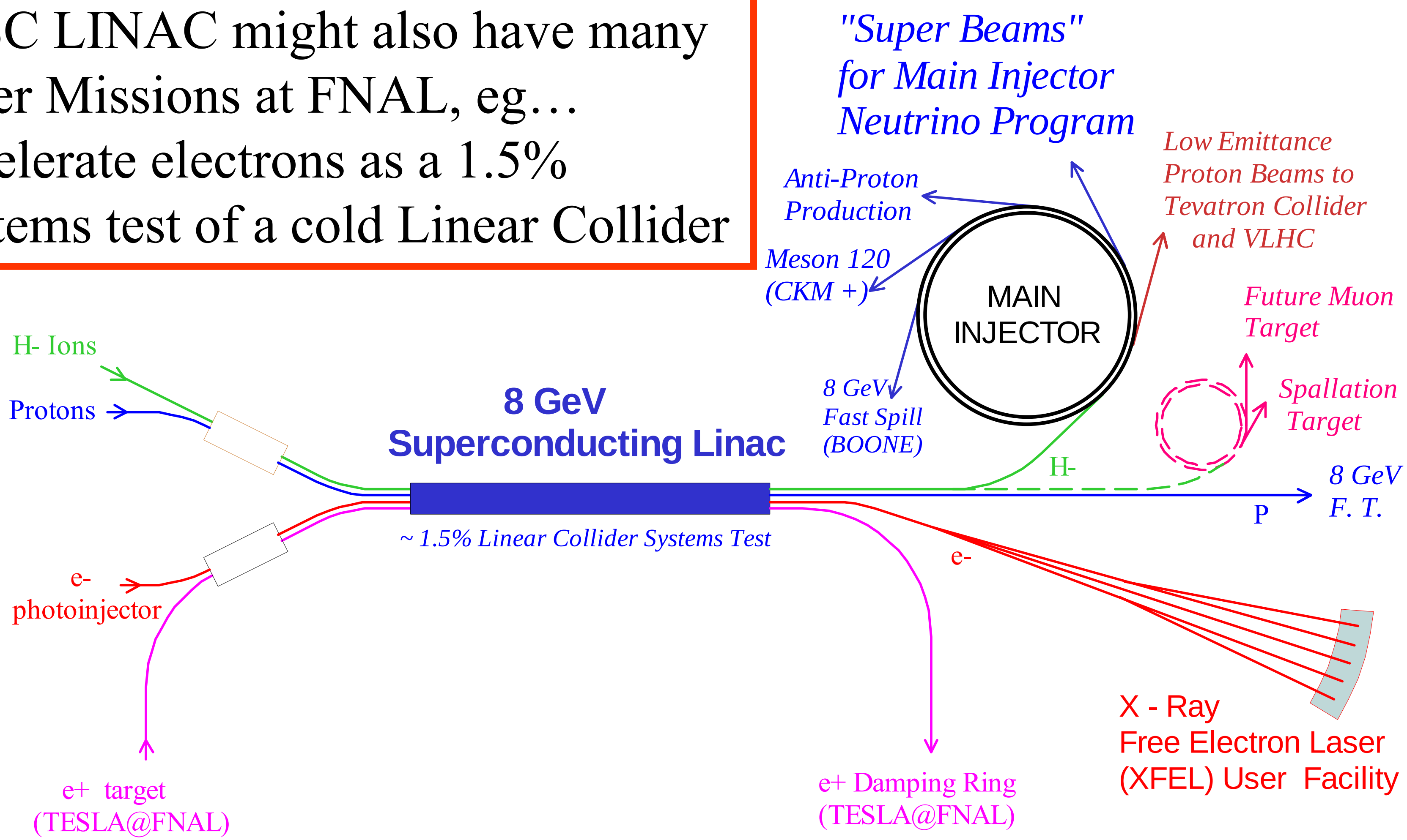
Multi-Mission 8 GeV Injector Linac

A SC LINAC might also have many other Missions at FNAL, eg… accelerate electrons as a 1.5% systems test of a cold Linear Collider



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Basic plan for 8 GeV SC Linac

Commercial 402.5 MHz RFQ & DTL up to 87 MeV

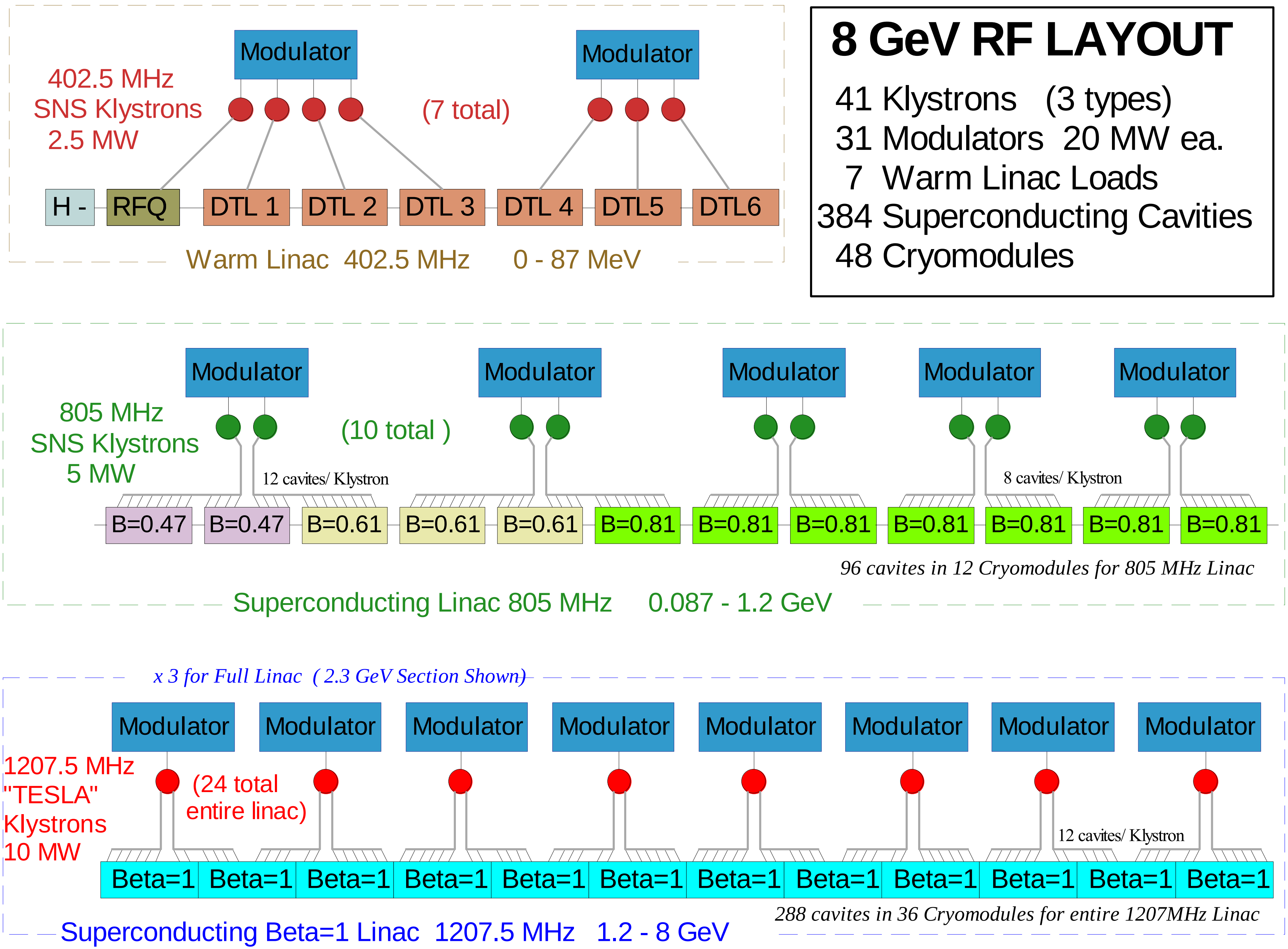
- Accelerator Physics design ~ cloned from SNS

805 MHz Superconducting Linac up to 1.2 GeV

- Three sections: Beta = 0.47, 0.61, 0.81
- Use cavity designs developed for SNS & RIA
- TESLA-style cryomodules for higher packing factor

1.2 GHz “TESLA” cryomodules from 1.2-8 GeV

- This section can accelerate electrons as well
- RF from one Klystron fanned out to 12 cavities
- Current design study assumed TESLA 500 gradients (25 MV/m) to achieve 8 GeV, if TESLA 800 gradients (35 MV/m) are practical ➔ can operate at 12 GeV or could reduce the cost accordingly



8 GeV RF LAYOUT
41 Klystrons (3 types)
31 Modulators 20 MW ea.
7 Warm Linac Loads
384 Superconducting Cavities
48 Cryomodules
Modulator
Modulator
402.5 MHz
SNS Klystrons
2.5 MW
(7 total)
H -
RFQ
DTL 1
DTL 2
DTL 3
DTL 4
DTL5
DTL6
Warm Linac 402.5 MHz 0 - 87 MeV
Modulator
Modulator
Modulator
Modulator
Modulator
805 MHz
SNS Klystrons
5 MW
(10 total)
12 cavites/ Klystron
8 cavites/ Klystron
B=0.47
B=0.47
B=0.61
B=0.61
B=0.61
B=0.81
B=0.81
B=0.81
B=0.81
B=0.81
B=0.81
B=0.81
96 cavites in 12 Cryomodules for 805 MHz Linac
Superconducting Linac 805 MHz 0.087 - 1.2 GeV
x 3 for Full Linac (2.3 GeV Section Shown)
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
1207.5 MHz
"TESLA"
Klystrons
10 MW
(24 total
entire linac)
12 cavites/ Klystron
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
Beta=1
288 cavites in 36 Cryomodules for entire 1207MHz Linac
Superconducting Beta=1 Linac 1207.5 MHz 1.2 - 8 GeV

8 GeV Linac Parameters

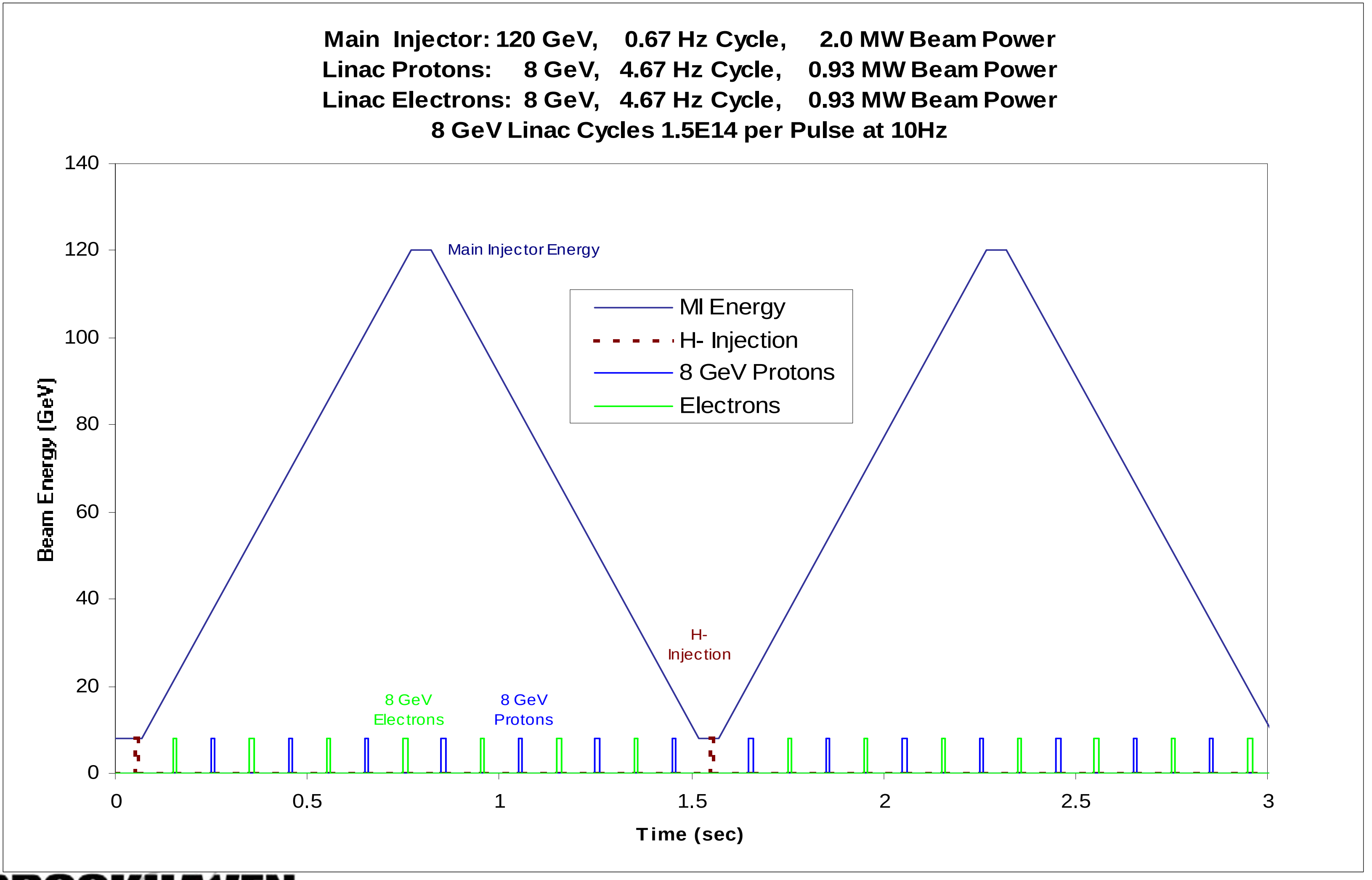
8 GeV LINAC

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 be H-, P, or e-)
	P/hour	5.4E+18	
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	SNS = 1060 turns
MI Beam Current	mA	2250	

120 GeV Main Injector Cycle with 8 GeV Linac, e- and P



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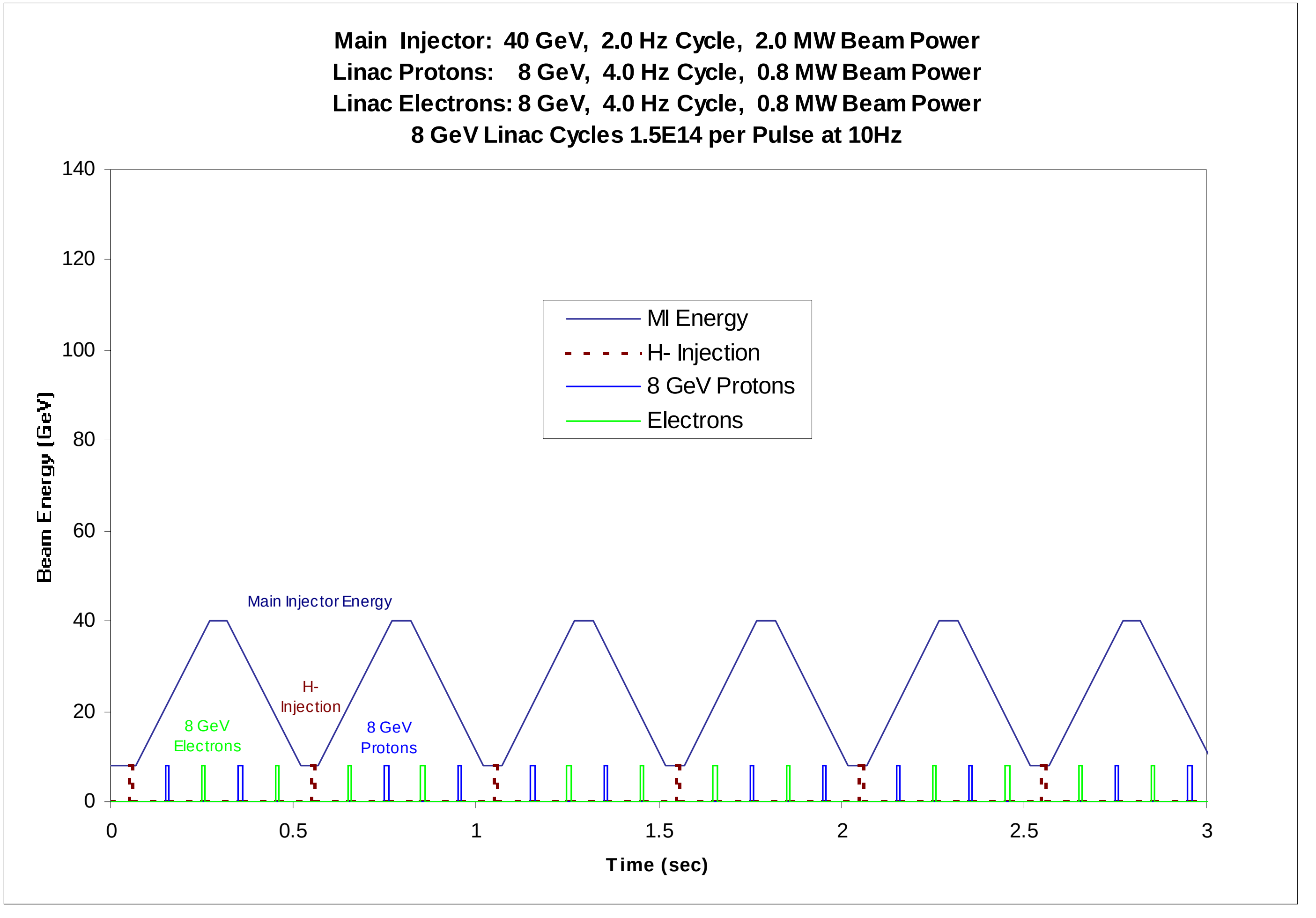
Linac Allows Reduced MI Beam Energy without Compromising Beam Power



MI cycles to 40 GeV at 2Hz, retains 2 MW MI beam power

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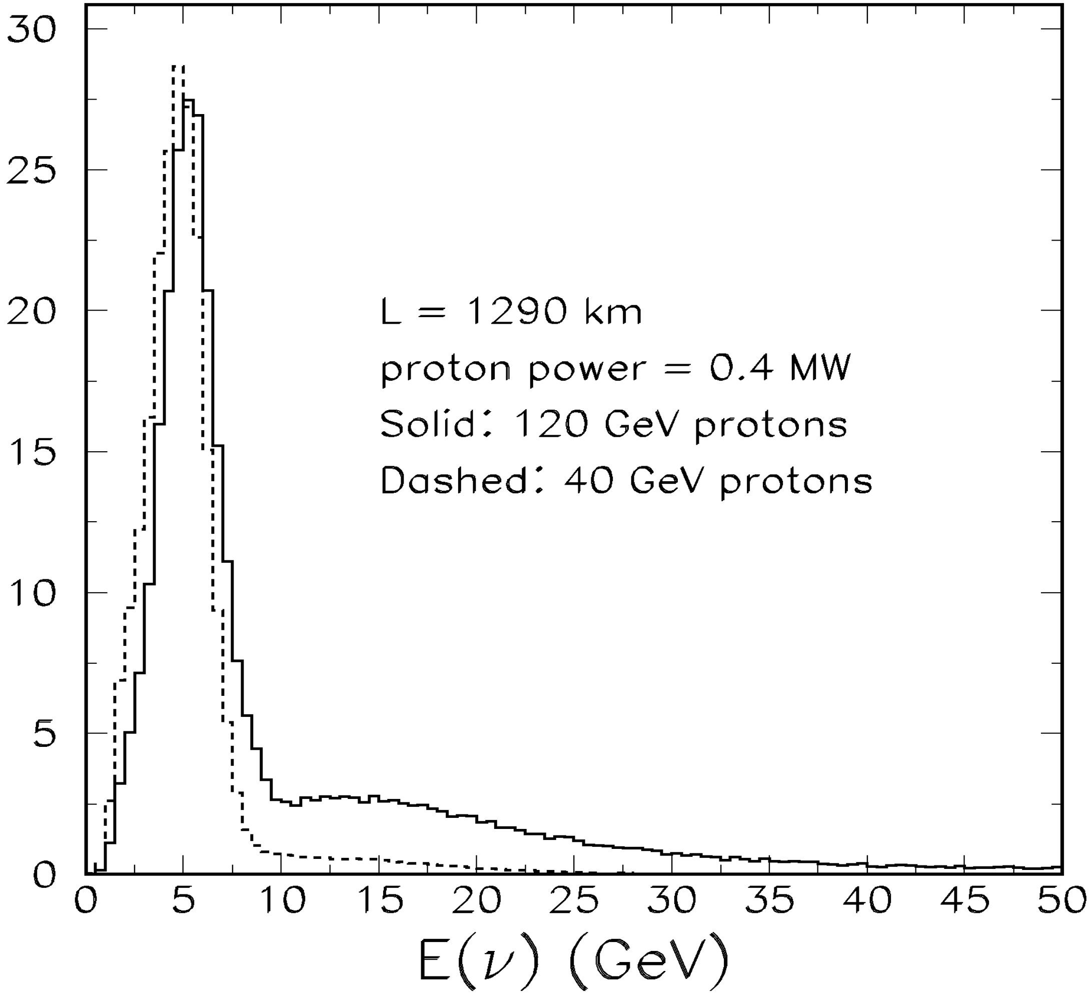
Running at Reduced Proton Energy Produces a Cleaner Neutrino Spectrum



Running at 40 GeV reduces tail at higher neutrino energies.

Same number of events for same beam power ➔ may be a useful operating mode

(Plot courtesy Fritz & Debbie)

FNAL 2-MW Main Injector Upgrade

- Increase beam intensity by a factor of 5
- Reduce cycle time by 20%
- Increase beam power by a factor of 6

	Present MI	Upgraded MI
Injection kinetic energy (GeV)	8	8
Extraction kinetic energy (GeV)	120	8 - 120
Protons per MI cycle	3×10^{13}	1.5×10^{14}
Cycle time at 120 GeV (s)	1.867	1.533
Beam power (MW)	0.3	1.9

SUMMARY

Multi-MW proton machines are on the way. All three neutrino scenarios will benefit.

Beta-beam

- Needs high-Z target for neutron production
- Needs DC primary proton beam

Super-beam

- Can utilize low-Z target for fast pion production
- Needs time-structured primary proton beam

Neutrino-factory

- Needs high-Z target for soft pion production
- Needs time-structured primary proton beam