AGS Upgrade and Super Neutrino Beam

DOE Annual HEP Program Review

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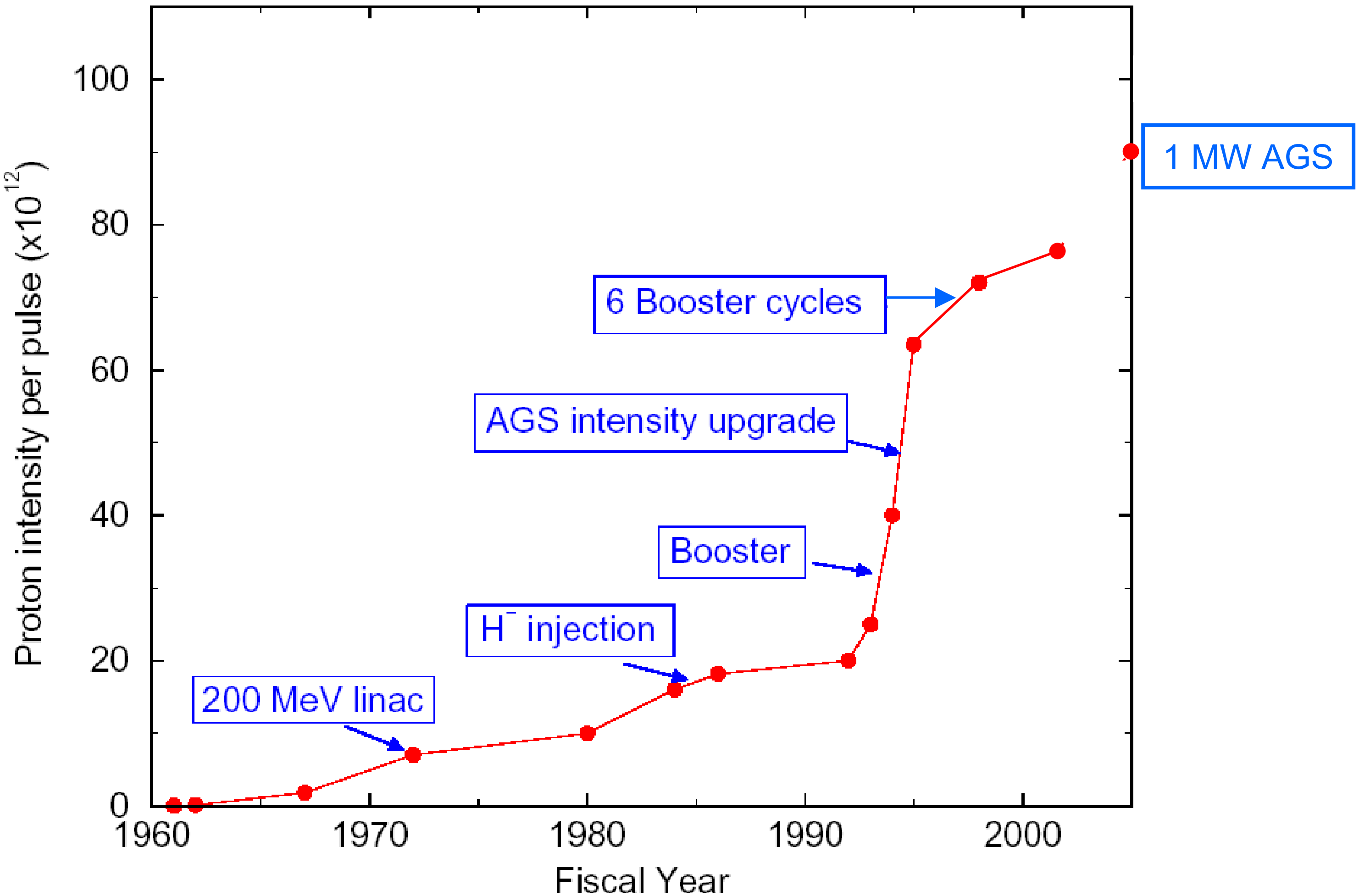
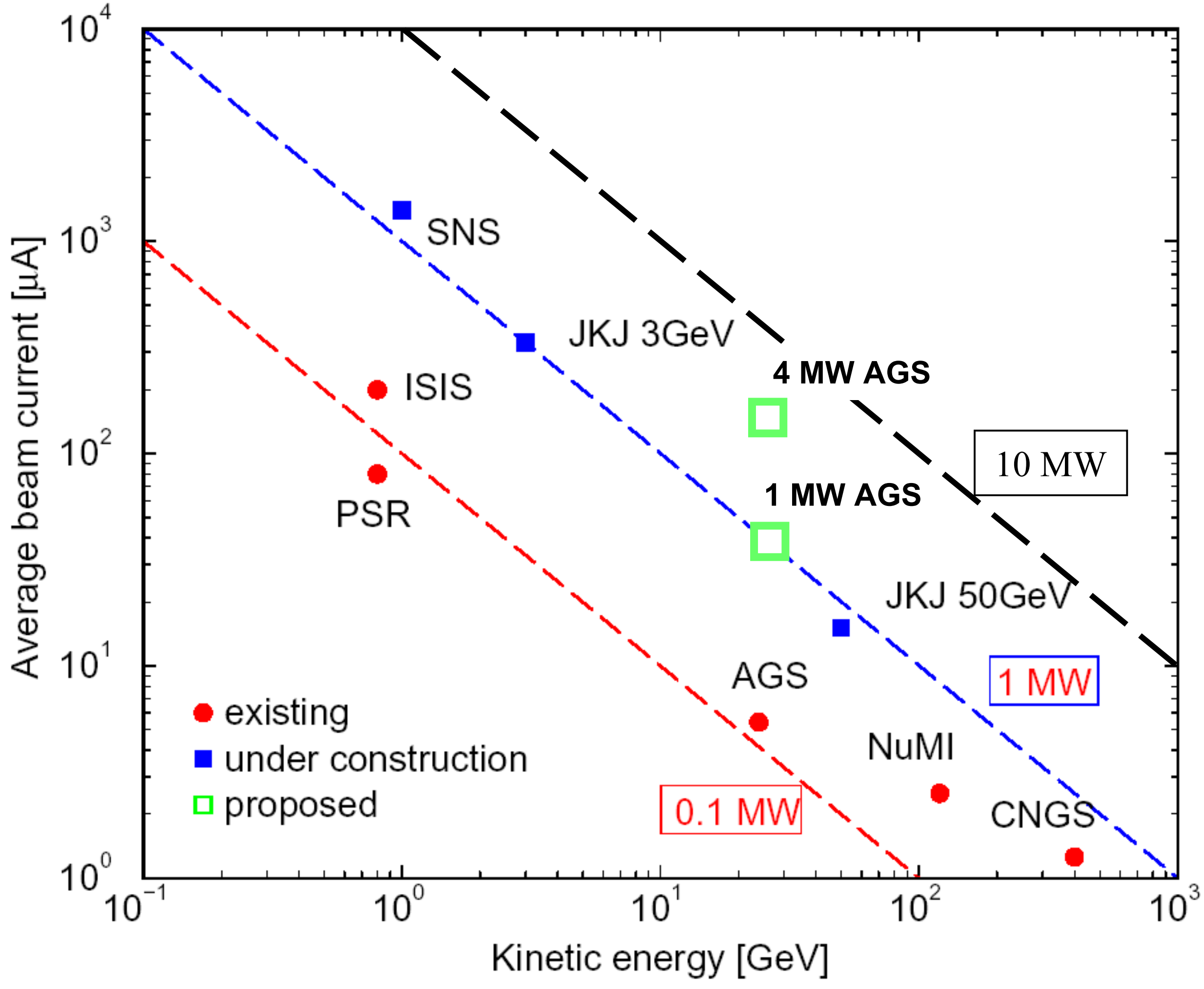
R&D Plan

- Long baseline neutrino experiments are a compelling next high energy physics initiative in the US.
- BNL (AGS) and Fermilab (MI) are the two possible sources of neutrinos that could satisfy the neutrino intensity and energy spectrum.
- The R&D effort focuses on a phase 1 delivery of 9 x 10^{13} protons / 0.4 sec (1.0 MW); 2.3 x 10^{21} protons/10^{7} sec
  - The AGS has previously delivered 7 x 10^{13} protons/ 2 sec (.14 MW); 3.5 x 10^{20} protons / 10^{7} sec
  - Ultimate possibility of 1.8 x 10^{14} protons /0 .2 sec (4 MW); 9 x 10^{21} protons / 10^{7} sec.

AGS Intensity History



High Beam Power Proton Machines



AGS Alternative Intensity Enhancement Paths

- Linac upgrade
  - Conceptual design in 2004 neutrino experiment proposal
- FFAG
  - An old concept with a new twist
  - Under investigation

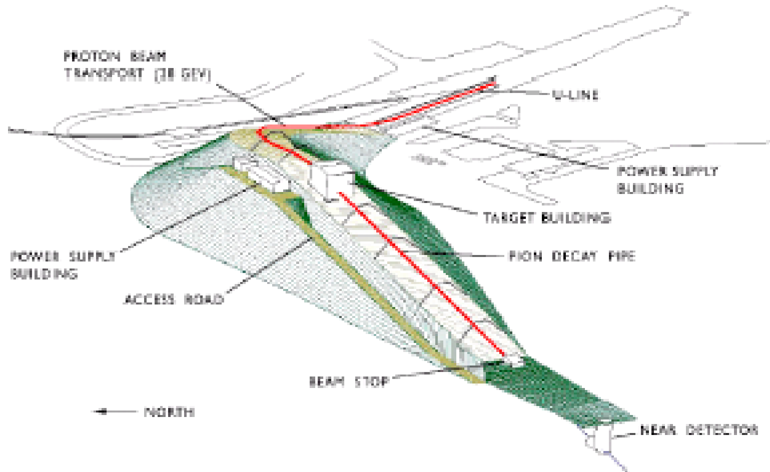
Path to increased intensity

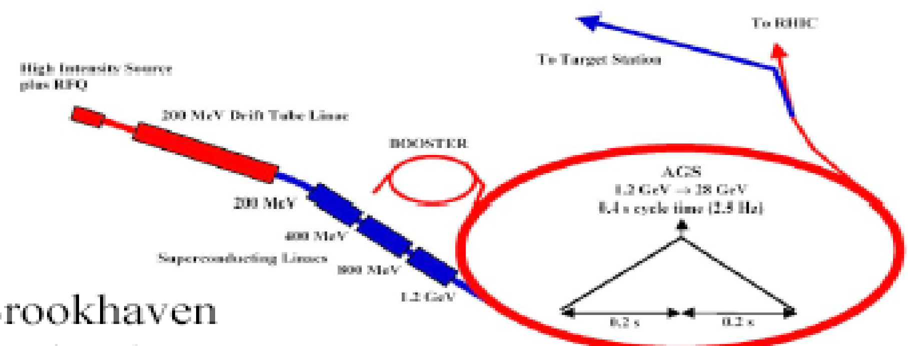
- Minimize space charge at injection to the Booster and the AGS

- Maximize AGS repetition rate

BNL-73210-2004-IR

The AGS-Based Super Neutrino Beam Facility
Conceptual Design Report





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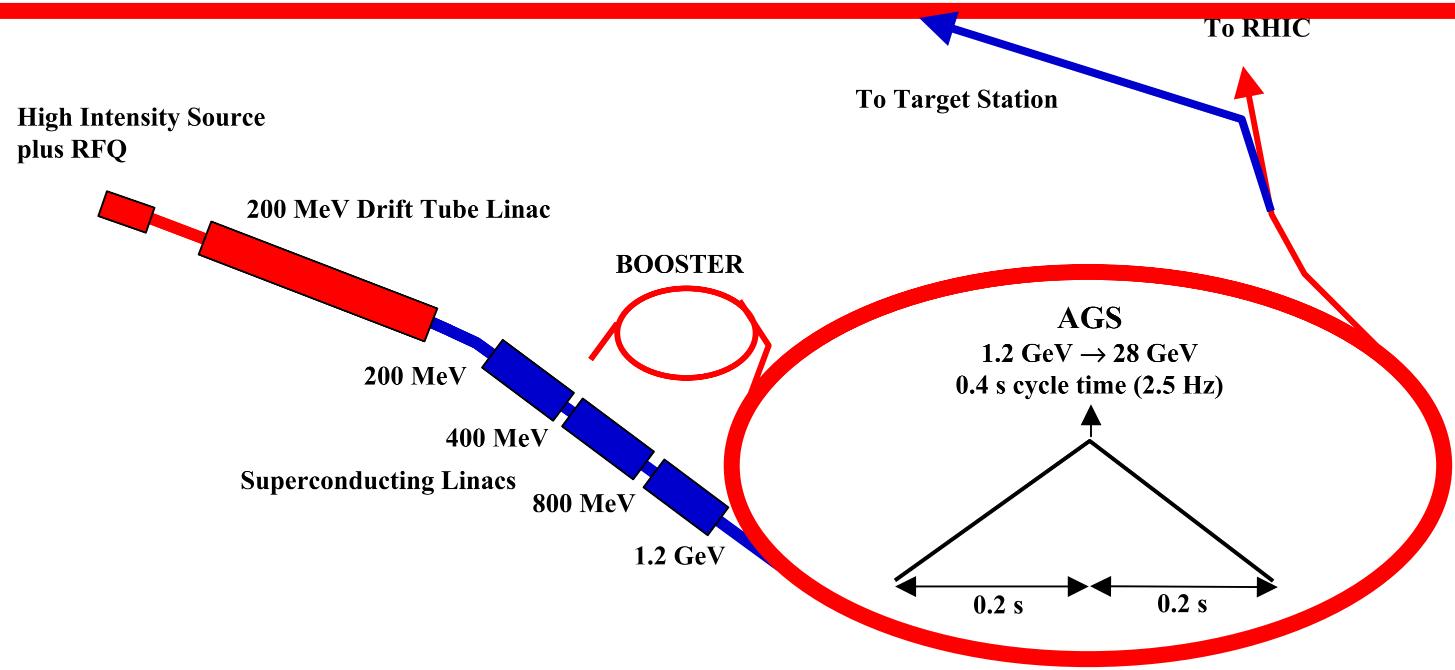
8 October 2004

AGS Proton Driver Parameters

	present AGS	**1 MW AGS**	**4 MW AGS**	J-PARC
Total beam power [MW]	0.14	1.00	4.00	0.75
Beam energy [GeV]	24	28	28	50
Average current [μA]	6	36	144	15
Cycle time [s]	2	0.4	0.2	3.4
No. of protons per fill	0.7×10^{14}	0.9×10^{14}	1.8×10^{14}	3.3×10^{14}
Average circulating current [A]	4.2	5.0	10	12
No. of bunches at extraction	6	24	24	8
No. of protons per bunch	1×10^{13}	0.4×10^{13}	0.8×10^{13}	4×10^{13}
No. of protons per 10^7 sec.	3.5×10^{20}	23×10^{20}	90×10^{20}	10×10^{20}

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)

Several of the items that were discussed in the October 2004 CDR will require R&D support.

A second approach has developed since the CDR.

Not everything has to be reinvented by a particular laboratory, so we will take full advantage of Fermilab's NuMi experience and future R&D efforts, BNL's and JLab's experience with the SNS.

1.2 GeV Superconducting Linac

Beam energy	0.2 → 0.4 GeV	0.4 → 0.8 GeV	0.8 → 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

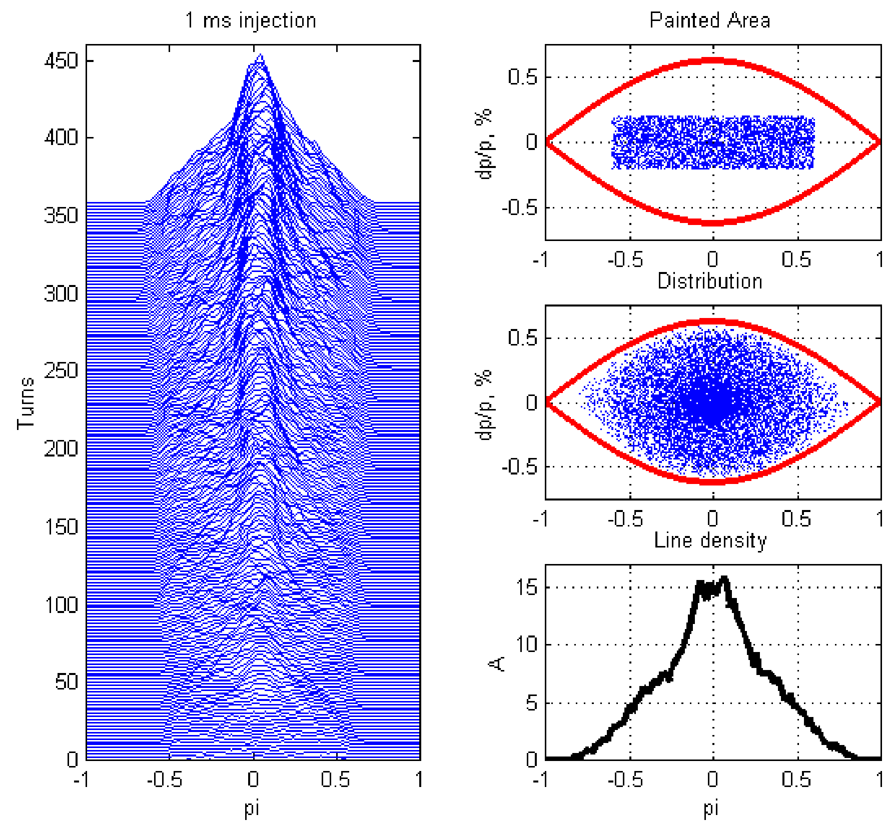
Some other areas that require further study

Beam Loss at H^- Injection Energy

	AGS Booster	PSR LANL	SNS	**1 MW AGS**
Beam power, Linac exit, kW	3	80	1000	50
Kinetic Energy, MeV	200	800	1000	1200
Number of Protons N_P, 10^{12}	15	31	100	100
Vertical Acceptance A, π μm	89	140	480	55
$\beta^2\gamma^3$	0.57	4.50	6.75	9.56
N_P / ($\beta^2\gamma^3$ A), 10^{12} / π μm	0.296	0.049	0.031	0.190
Total Beam Losses, %	5	0.3	0.1	3
Total Loss Power, W	150	240	1000	1440
Circumference, m	202	90	248	807
Loss Power per Meter, W/m	0.8	2.7	4.0	1.8

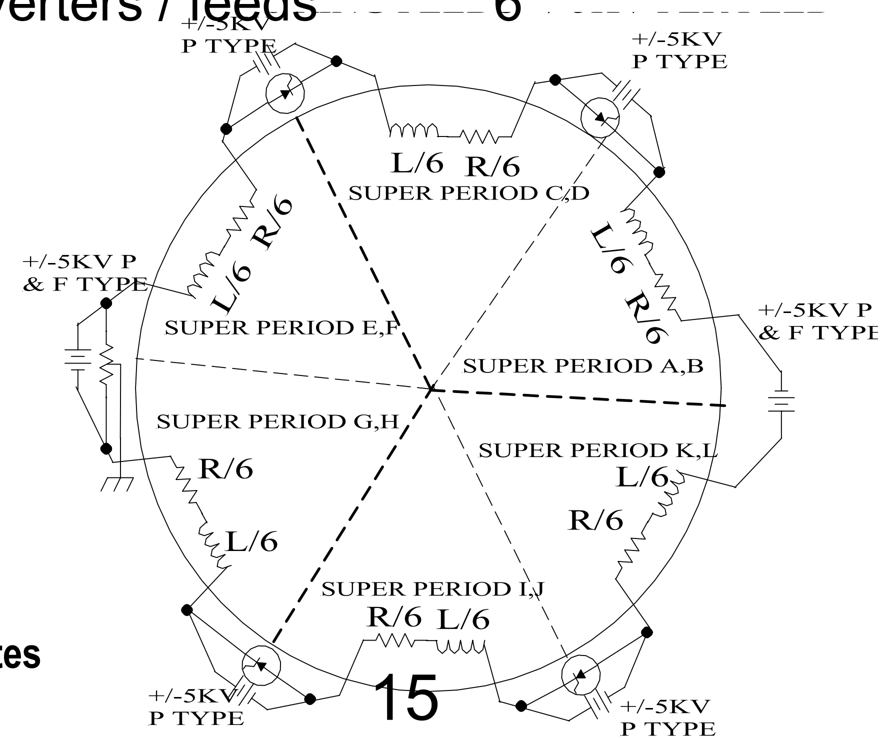
AGS Injection Simulation

RF voltage	450kV
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
Bunch length	85 ns
Longitudinal emittance	1.2 eVs
Momentum spread	± 0.48 %
Circ. beam emittance (95 %)	100 π µm

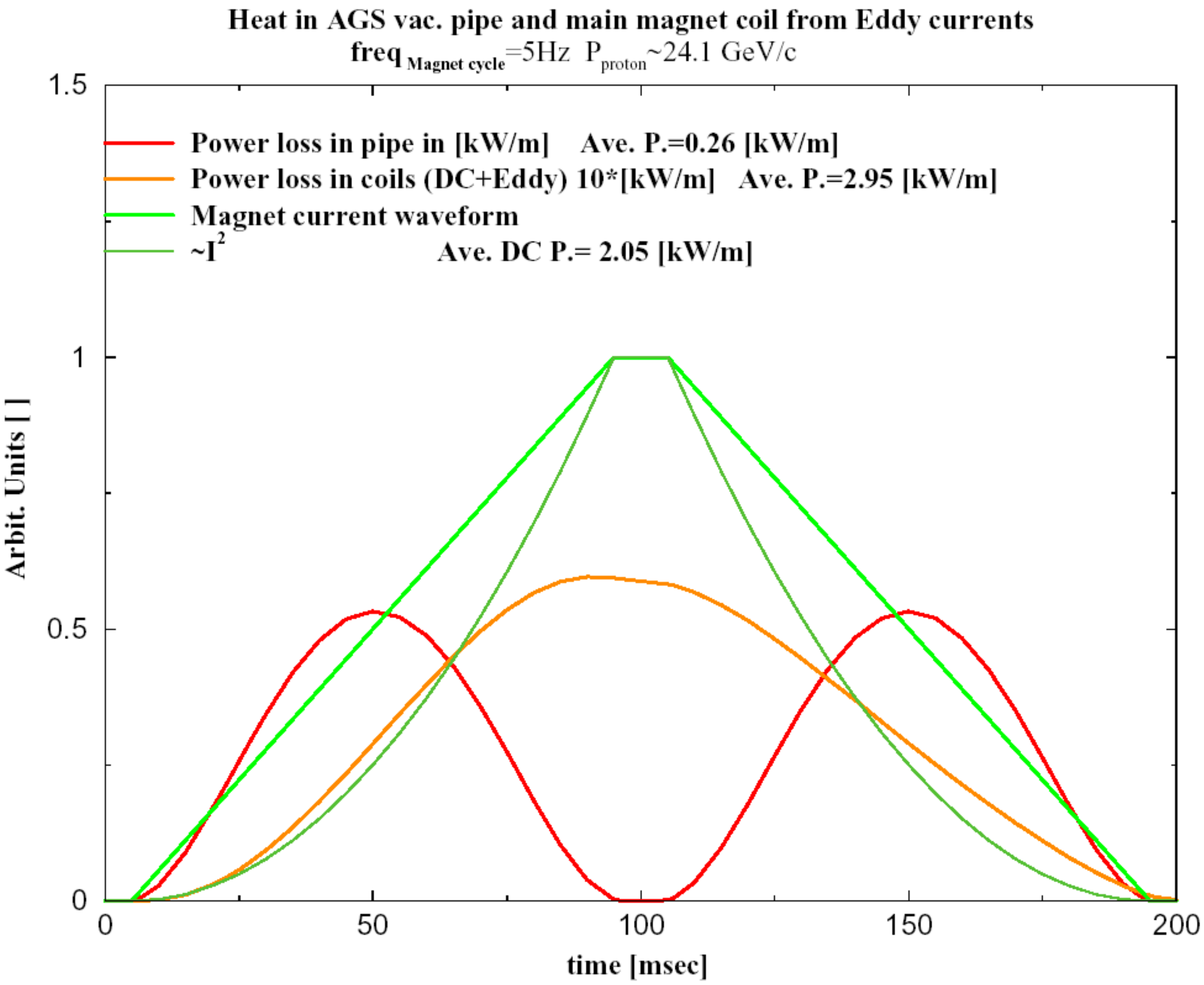


New AGS Main Magnet Power Supply

	Upgrade	Present
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



Eddy Current Losses in AGS Magnets



For 2.5 (5.0) Hz:

In pipe: 65 (260) W/m

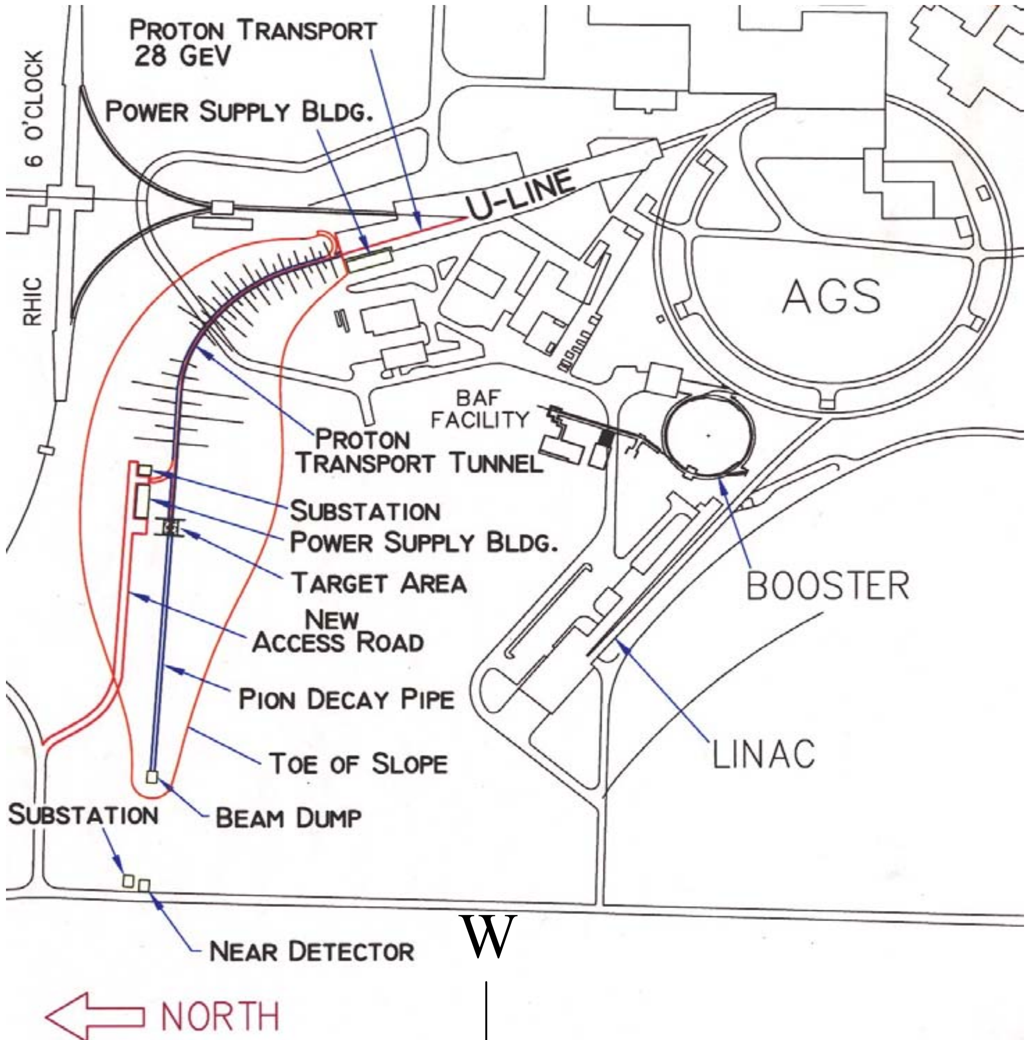
In coil: 225 (900) W/m

AGS RF System Upgrade

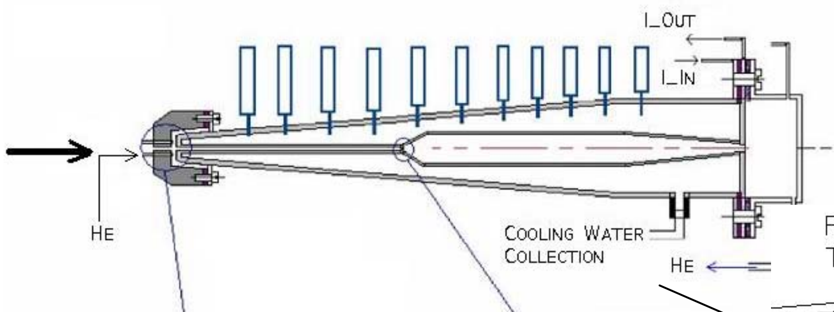
Use present cavities with upgraded power supplies (two 300 kW tetrodes/cavity)

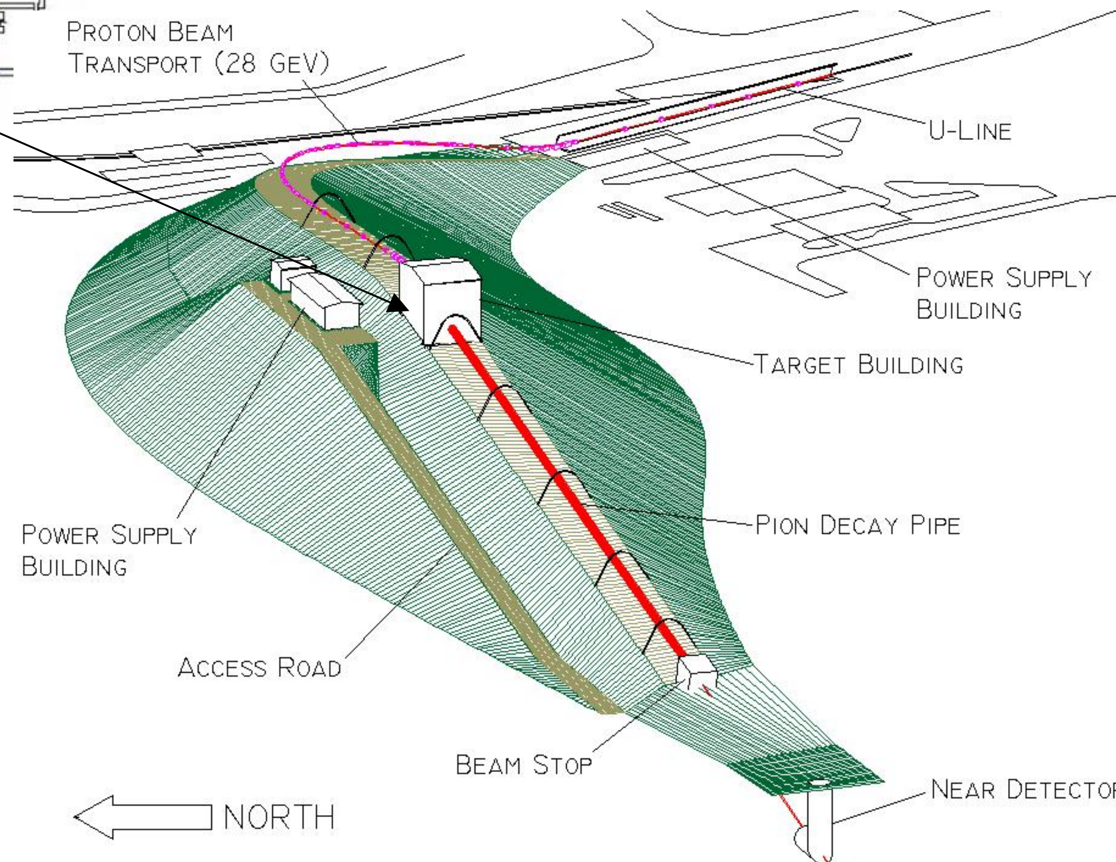
	Upgrade	Present
• Rf voltage/turn	0.8 MV	0.4 MV
• harmonic number	24	6 - 12
• Rf frequency	~ 9 MHz	3 - 4.5 MHz
• Rf peak power	2 MW	
• Rf magnetic field	18 mT	

Beam line to your favorite western mine



Neutrino Beam Production





- 1 MW He gas-cooled Carbon-carbon target
- New horn design
- Target on down-hill slope for long baseline experiment
- Beam dump well above ground water table to avoid water activation

Costs

- The October 2004 proposal has an initial estimated direct construction cost of $273M.
  - TEC of $407M (FY04$), including a 30% contingency and 14.5% overhead.
- The incremental AGS operations costs to HEP, concurrent with RHIC, is estimated to be the order of $25M (FY05$) for a 35 week per year operation.
  - Cost is dependent upon sharing beam time with other programs using the AGS at the time.

The resultant total direct cost of the 1 MW AGS super Neutrino Beam facility, is $ 273.4 M. The preliminary total estimated cost (TEC) is $406.9 M in FY04 dollars, including a contingency of 30% on all items plus the BNL construction project G&A overhead applied at 14.5%. The cost escalation factor cannot be estimated without a project start year.

Cost Estimate of the AGS Super Neutrino Beam Facility

Construction Phase - Direct FY04 Dollars

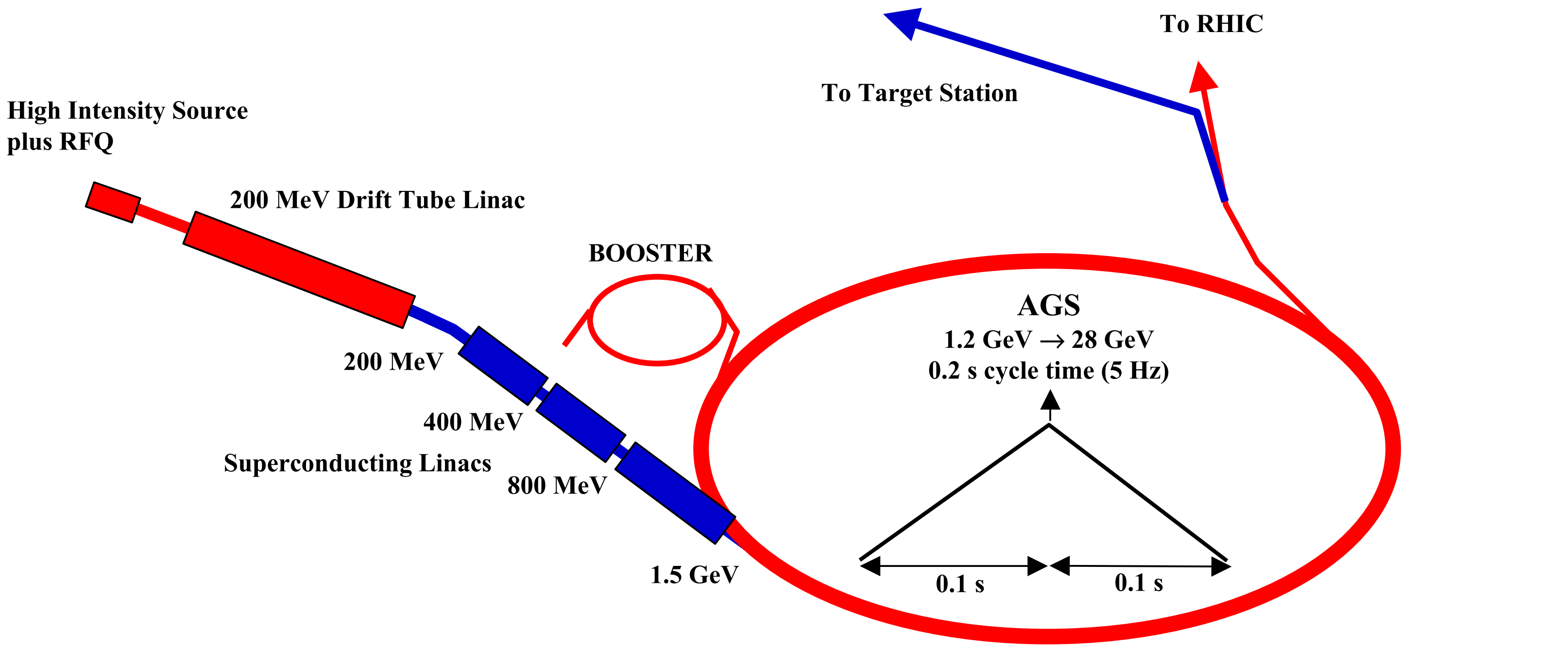
1.0 AGS Super Neutrino Beam Facility	EDIA	M&S	Labor	Total
1.1 The Linac System	6,079,116	98,558,970	16,703,762	122,219,040
1.1.1 Front End and RT Linac Upgrade	313,000	2,383,000	856,000	3,552,000
1.1.2 SCL Accelerating Cavity System	954,240	22,254,200	11,040,000	34,248,440
1.1.3 SCL RF Source	3,620,988	51,668,800	402,332	55,692,120
1.1.4 SCL Cryogenic System	370,000	13,700,000	2,200,000	16,270,000
1.1.5 SCL Vacuum System	641,598	3,474,570	1,148,378	5,264,546
1.1.6 SCL Instrumentation	460,957	1,390,400	409,061	2,260,418
1.1.7 SCL Magnet and Power Supply	518,332	3,686,000	727,991	4,932,324
1.2 The AGS Upgrade	10,496,245	53,619,159	6,472,500	70,587,904
1.2.1 AGS Main Magnet Power Supply	503,959	28,200,000	1,342,337	30,046,296
1.2.2 AGS RF System Upgrade	6,082,625	9,850,000	675,847	16,608,472
1.2.3 AGS Injection/Extraction	644,000	6,437,086	1,668,330	8,749,396
1.2.4 Beam Transport to Target	1,636,771	7,862,241	2,637,290	12,126,302
1.2.5 Control System	1,628,890	1,270,852	148,786	3,057,528
1.3 The Target and Horn System	664,742	3,417,152	1,208,338	5,290,232
1.3.1 The Target System	127,008	229,284	50,130	406,422
1.3.2 The Horn System	454,524	2,358,568	656,224	3,469,316
1.3.3 Shielding and Remote Handling	83,210	809,300	125,300	1,017,810
1.3.4 Target & Horn Physics Support	0	20,000	376,684	396,684
1.4 The Conventional Facility	7,550,300	60,090,300	1,210,700	68,851,300
1.4.1 Linac Tunnel/Klystron Gallery	2,253,000	11,529,000	230,000	14,012,000
1.4.2 AGS Power Supply Building	2,024,000	13,347,000	432,000	15,803,000
1.4.3 Beam Transport and Target Area	1,674,300	25,091,000	172,500	26,937,800
1.4.4 The Decay Tunnel and Beam Stop	184,000	1,225,300	115,200	1,524,500
1.4.5 Site Utilities & Roads	1,088,000	6,820,000	140,000	8,048,000
1.4.6 Modifications for AGS RF System	327,000	2,078,000	121,000	2,526,000
1.5 ES&H	104,652	275,211	437,355	817,218
1.5.1 ES&H	20,000	105,000	270,000	395,000
1.5.2 Access Controls,	84,652	170,211	167,355	422,218
1.6 Project Support	1,148,681	384,109	4,096,963	5,629,753
1.6.1 Project Management	0	100,000	1,178,000	1,278,000
1.6.2 Technical Support	1,148,681	214,109	2,146,963	3,509,753
1.6.3 Project Controls	0	70,000	772,000	842,000
AGS Super Neutrino Beam Facility Project Total	26,043,736	216,342,901	30,209,709	273,396,345

Figure 9.2: Cost estimate of the AGS Neutrino Superbeam Facility

Path Towards >1 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**

4 MW AGS Proton Driver Layout

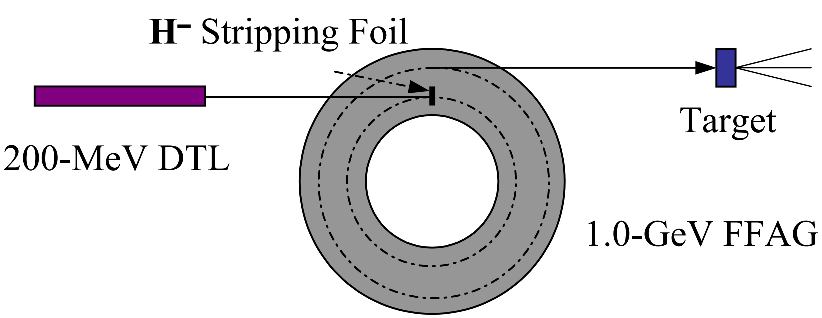


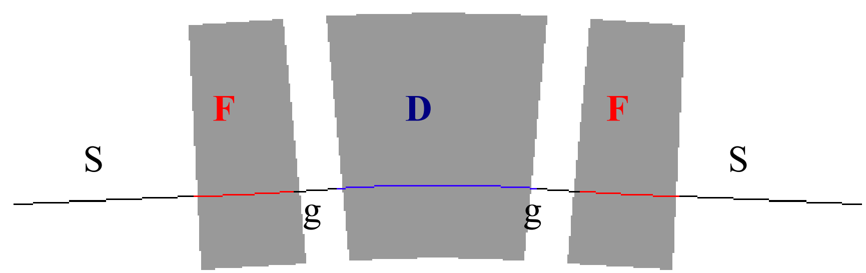
A new use of an old idea.

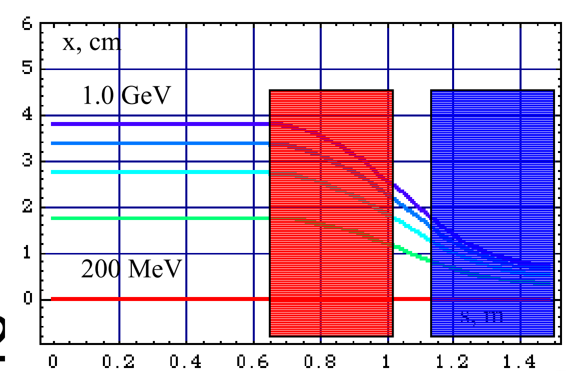
An FFAG injector to the AGS.

FFAG proton drivers

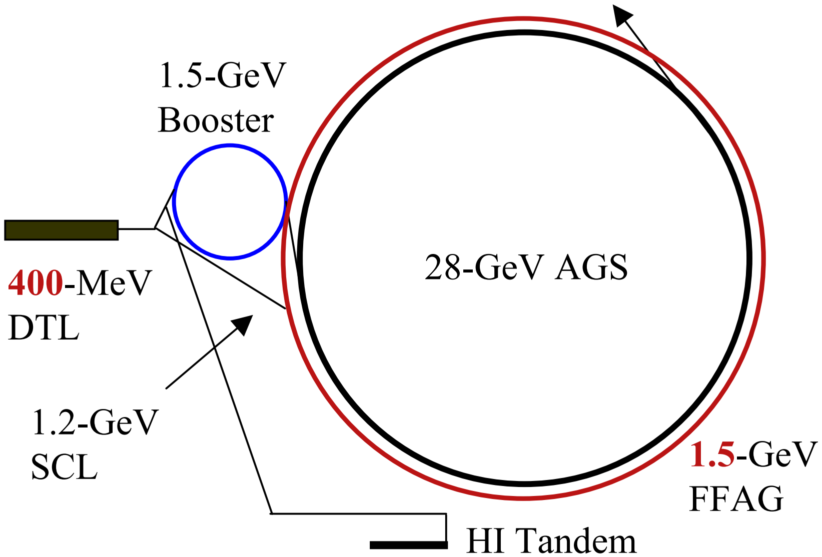
- Renewed interest in Fixed Field Alternate Gradient (FFAG) accelerators [F. Meot (Saclay)]
- Advantages: High repetition rate (~ kHz), final energy > 1 GeV
- Successful demonstration of scaling (fixed tune) FFAG [Y. Mori/S. Machida (KEK)]
- Non-scaling designs with small tune variation are being developed
- Example: Idea of a 10 MW proton driver: [A. G. Ruggiero (BNL)]
- 1 GeV, 10 mA , 10 MW, 1 kHz
- After FFAG: DF: ~ 3 x 10^{-4}, I_{peak} ~ 30 A
- Issues: High rf power, fast frequency tuning, complicated magnetic field profile







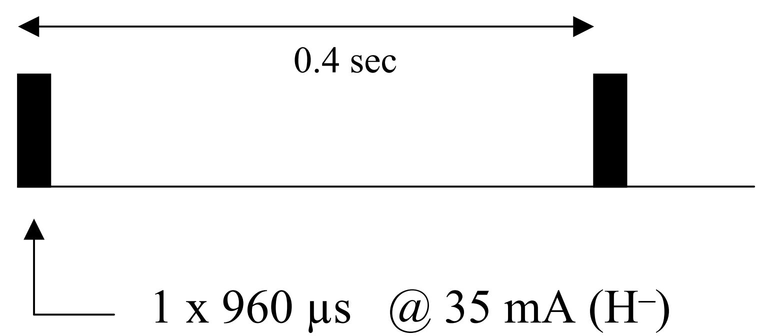
AGS Upgrade with 1.5-GeV FFAG



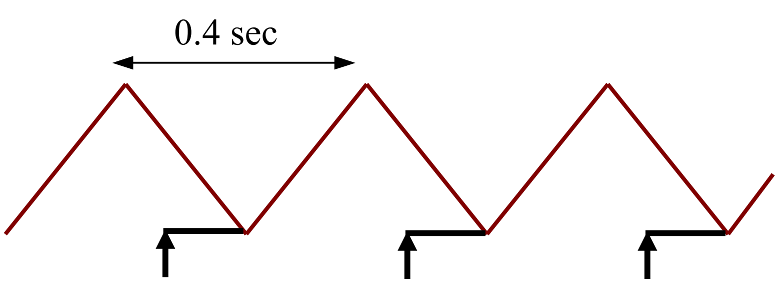
Performance

Rep. Rate	0.4	->	2.5 Hz
Top Energy	28 GeV		
Intensity ppp	0.70	->	1.0 x 10^{14}
Ave. Power	0.125	->	**1.0 MW**

DTL cycle for Protons with 1.5-GeV FFAG



AGS Cycle with 1.5-GeV FFAG



R&D funding request

- We are preparing an accelerator R&D funding request (FY06) to investigate cost saving and performance enhancing alternatives for the development of a next generation neutrino source, directed towards a long baseline experiment.
  - Simulating the space charge effects of high intensity beams.
  - Reducing the costs and improving the reliabilty of the proton source and the neutrino production target station.
  - Study the FFAG as an alternative to a high energy linac.

Conclusion

An upgraded AGS with 1 MW (further upgradeable to 2 and 4 MW) beam power is a cost effective and competitive proton driver for a neutrino super-beam long baseline experiment.