AGS Upgrade and Neutrino Super Beam

AGS High Intensity Performance

AGS Upgrade:

- Beam loss considerations
- 1.2 GeV Superconducting Linac
- 2.5 Hz AGS power supply and rf system
- Neutrino beam production
- Cost estimate

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Thomas Roser
DOE HEP review
April 23-24, 2004

Neutrino Working Group - AGS Super Neutrino Beam Facility

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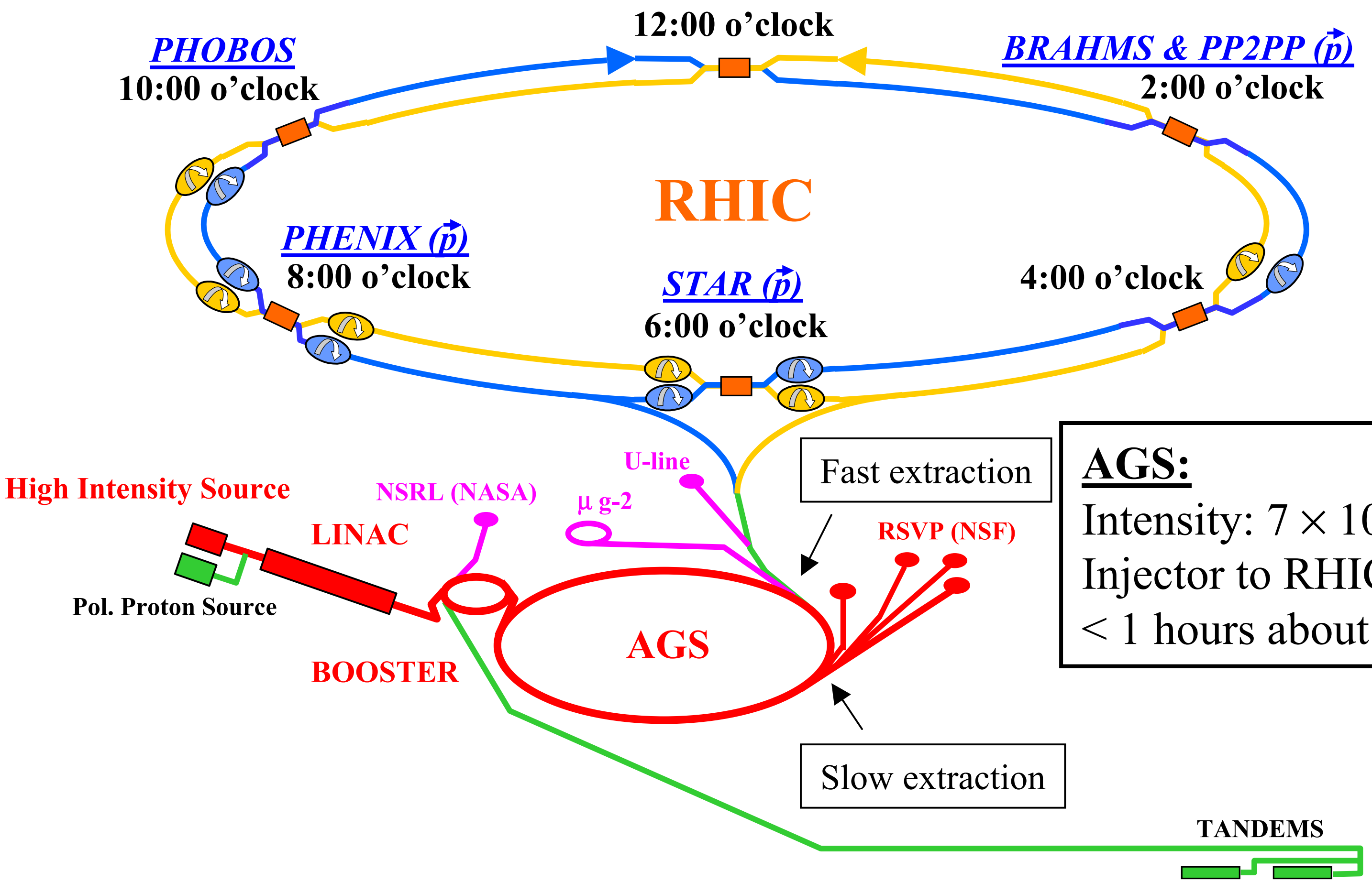
BNL → Homestake Long Baseline Neutrino Beam

Baseline Design:

- 28 GeV protons from the AGS
- 1 MW beam power from upgraded proton driver
- 500 kTon Water Cherenkov Detector
- Conventional Horn Focused beam

- Alternate detector sites such as the WIPP facility in New Mexico and the Henderson mine in Colorado would be acceptable. The Homestake site is used for purposes of calculation.

AGS/RHIC Accelerator Complex



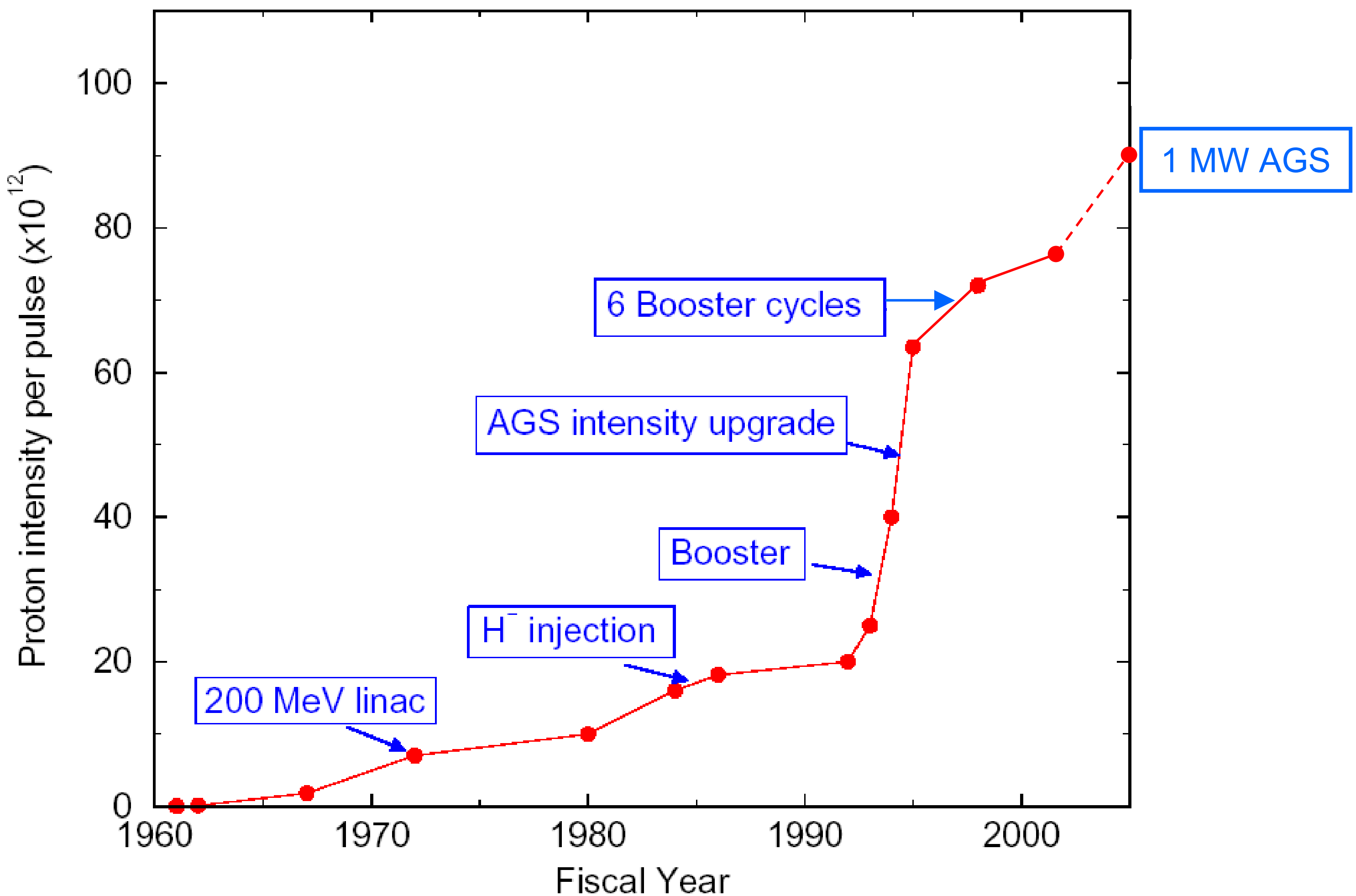
<u>AGS:</u>

Intensity: 7×10^{13} protons/pulse

Injector to RHIC:

< 1 hours about every 4 hours

AGS Intensity History



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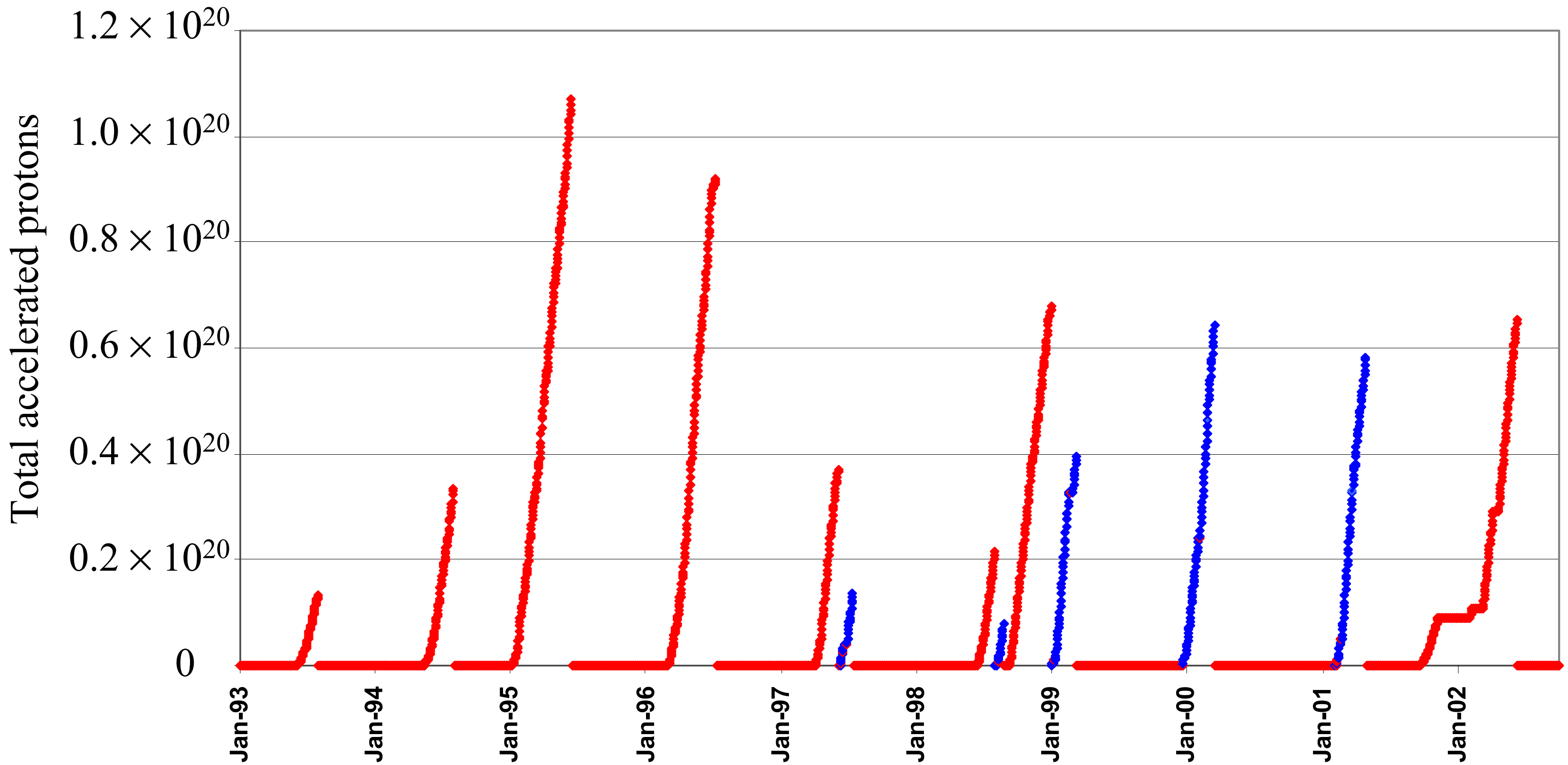
Total Accelerated Protons at the AGS



Slow extracted beam (Kaon decay)
Fast extracted beam (g-2)

Note: Lower total accelerated protons in later years due to much shorter running time

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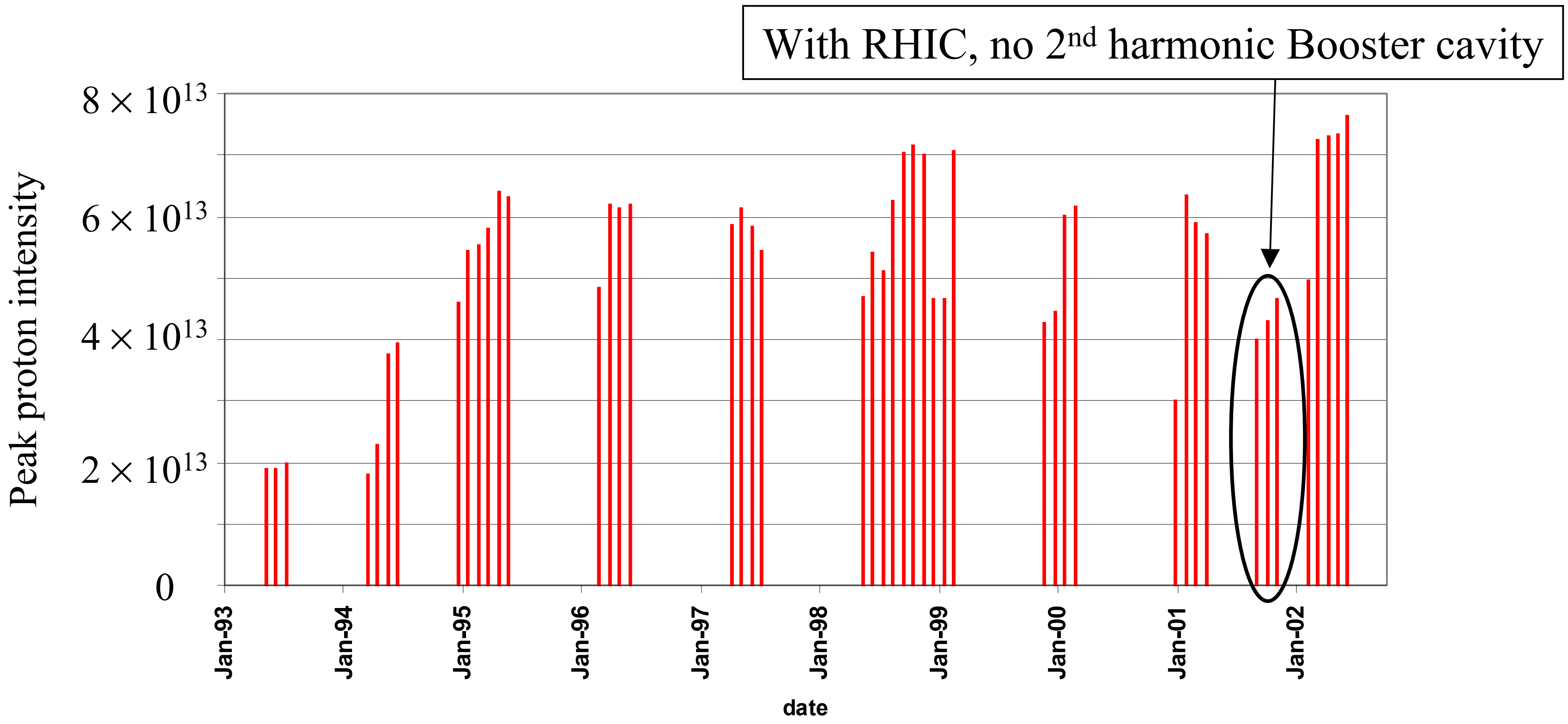
AGS Peak Proton Intensities



World record proton synchrotron intensity!

AGS high intensity/RHIC operation

AGS high intensity operation when RHIC is at store.

RHIC at store: presently ~ 85 hrs/week (50%), goal: ~ 100 hrs/week (60%)

Au – Au:

- Typical 4-hour store length determined by Intra-Beam-Scattering (IBS)
- With future luminosity upgrade (RHIC II) 4-hour store length determined by "burn-off"
- Minimum refilling time is 5 – 10 minutes, typically takes < 1 hour
- Fast injector switching between RSVP and RHIC mode beneficial

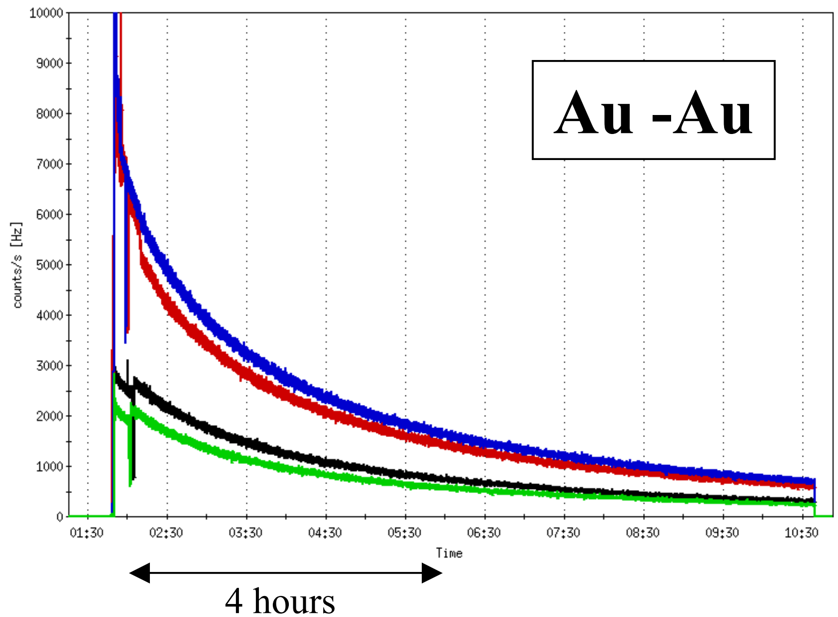
p – p:

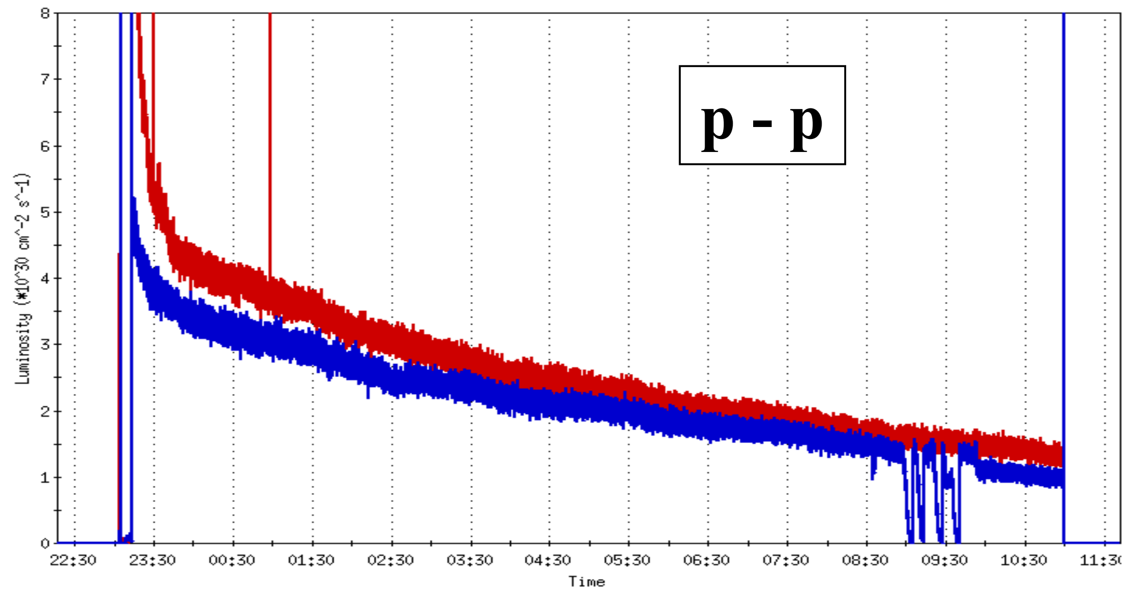
- Typical store length: 8 – 10 hours
- Slower injector switching possible and necessary to ramp super-conducting AGS Siberian snake

Only incremental costs for high intensity operation.

High intensity and RHIC operations is very beneficial for equipment reliability and development of expertise.

Typical RHIC stores





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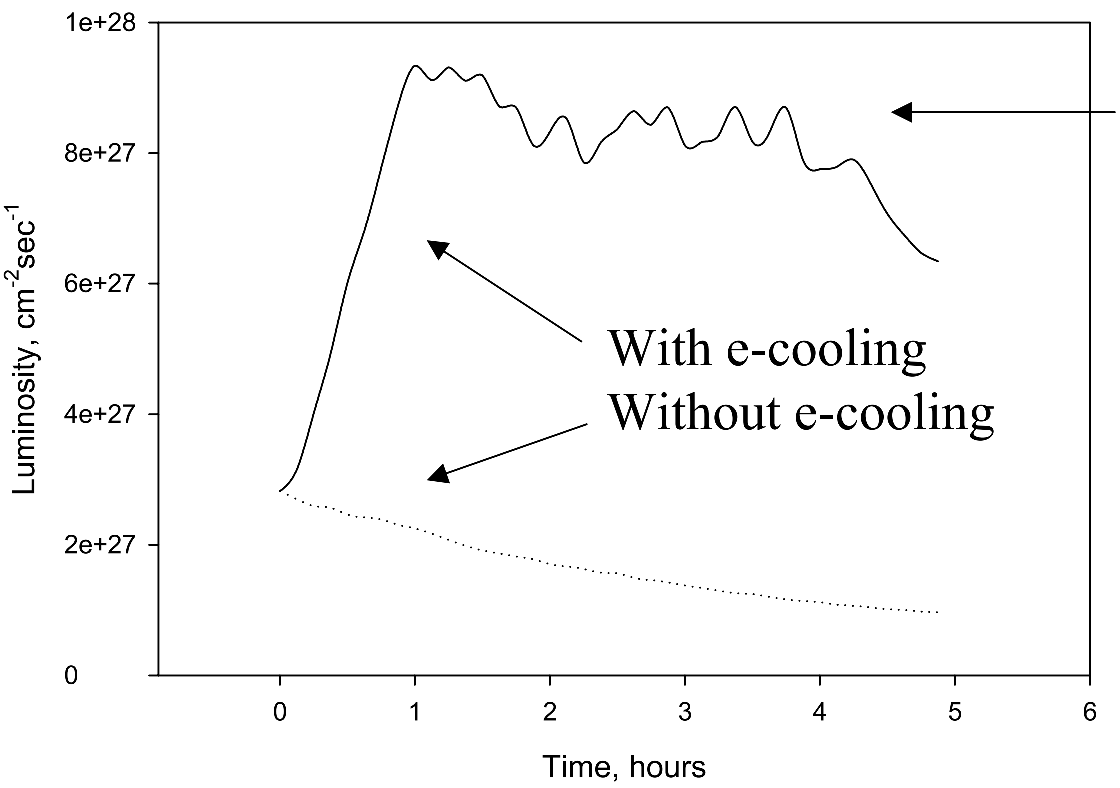
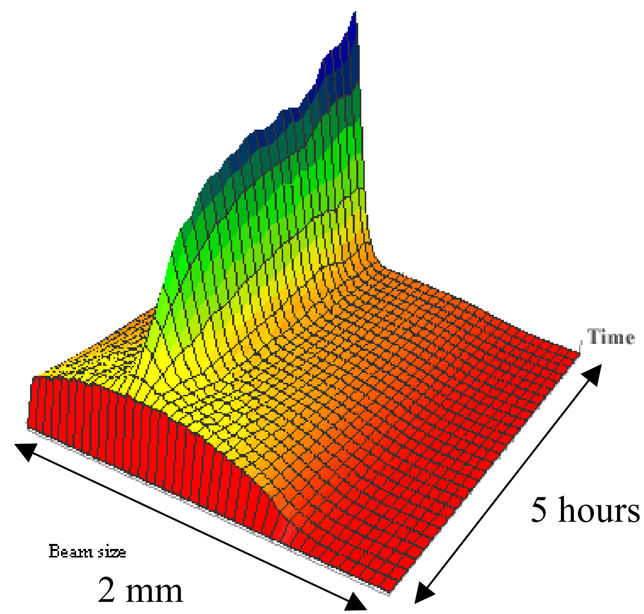
RHIC Luminosity with Electron Cooling (RHIC II)



Luminosity leveling through continuous cooling and beta squeeze
Store length limited by "burn-off"

Transverse beam profile during store



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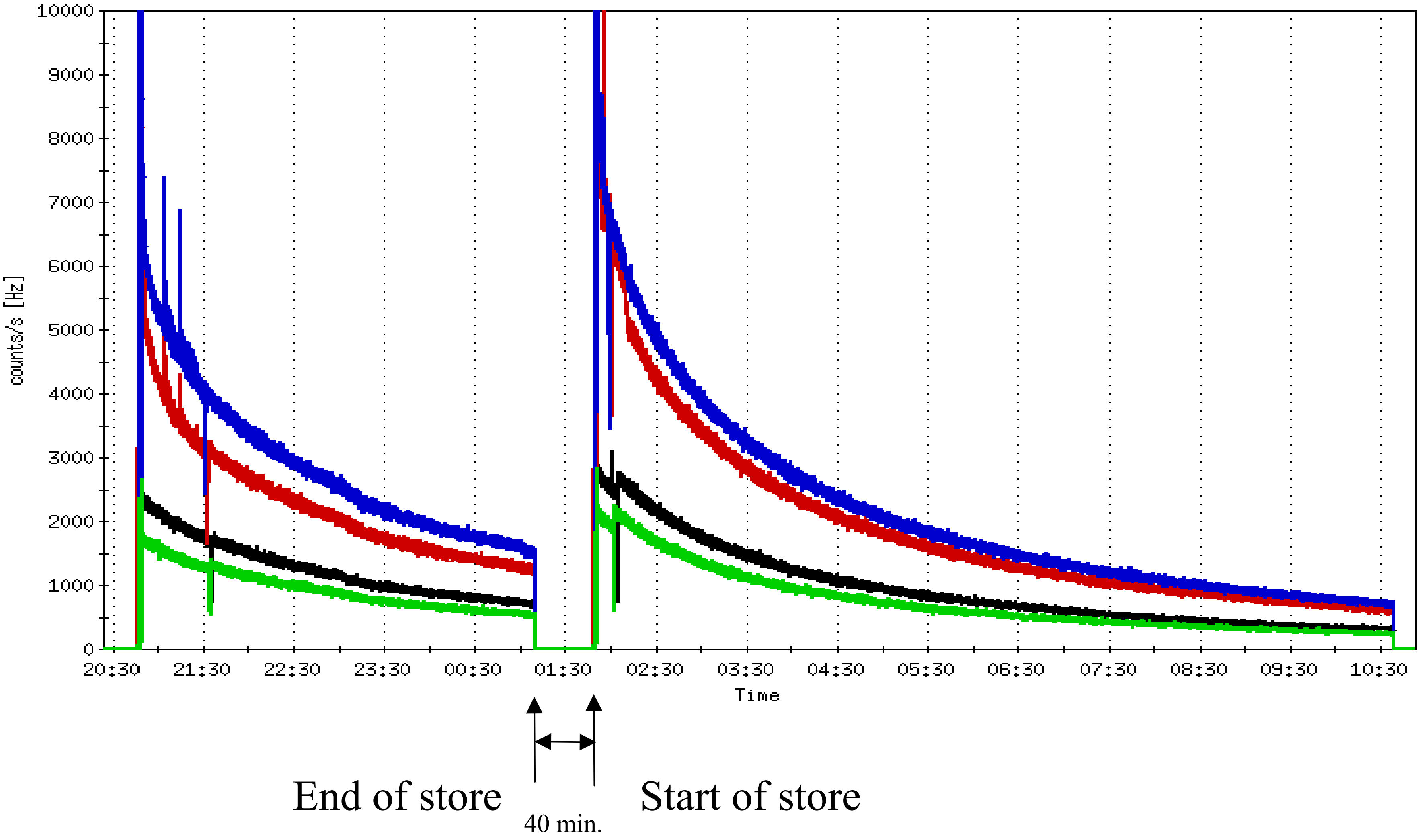
Refill of RHIC



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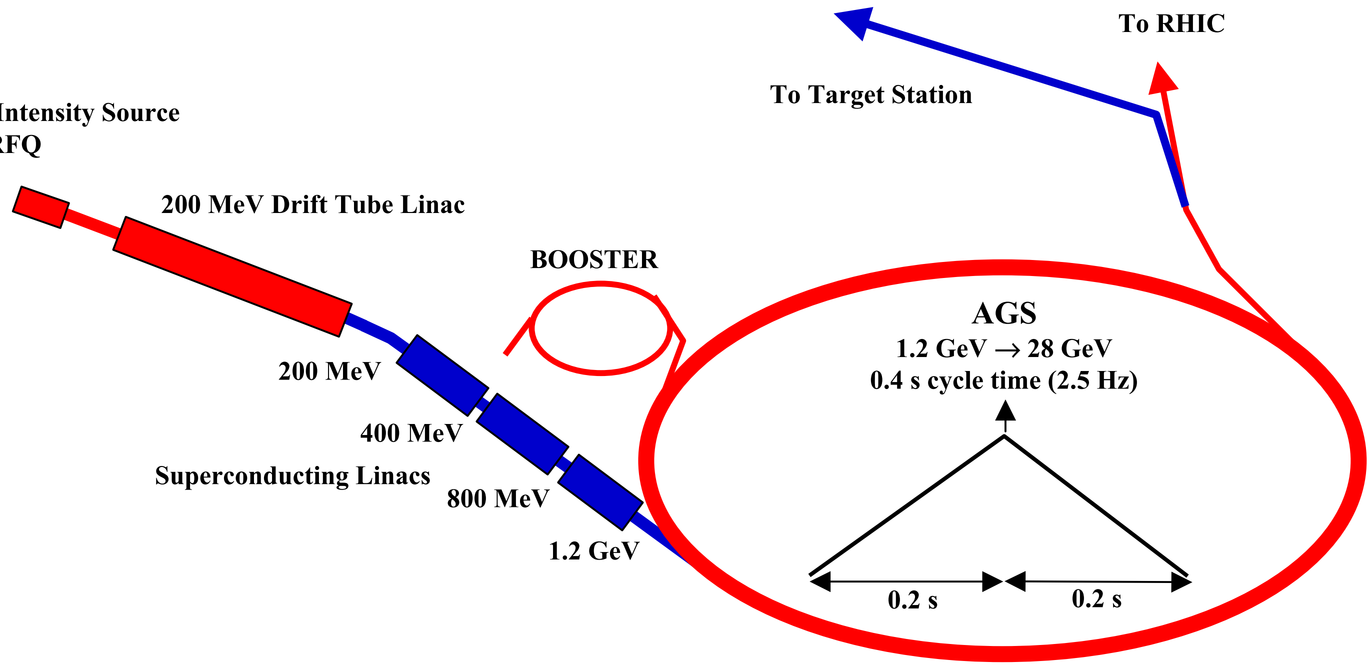
AGS Upgrade to 1 MW



- 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

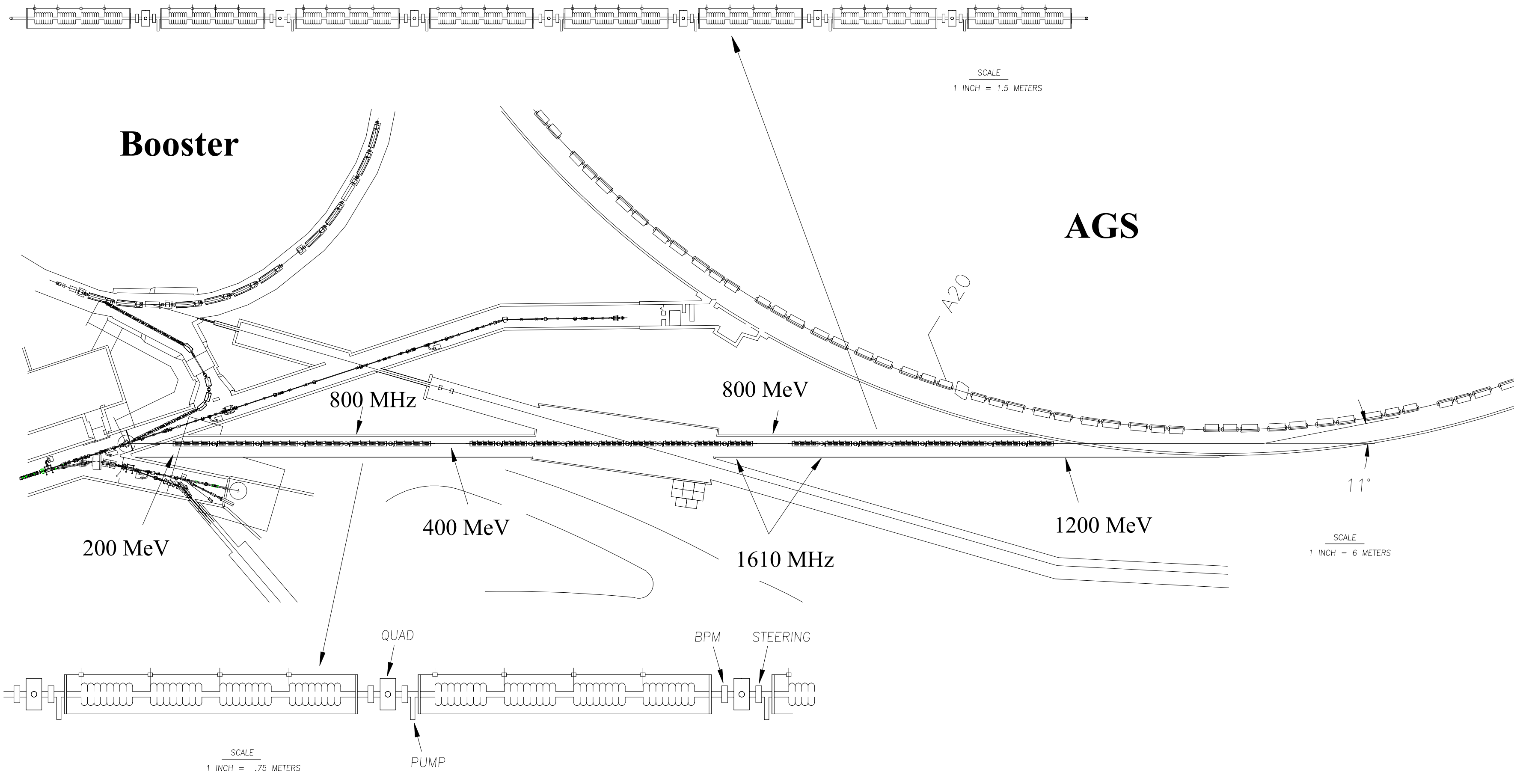
  double rf power and accelerating gradient

  further upgrade to 5 Hz possible (x 2)

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}

1.2 GeV Superconducting Linac



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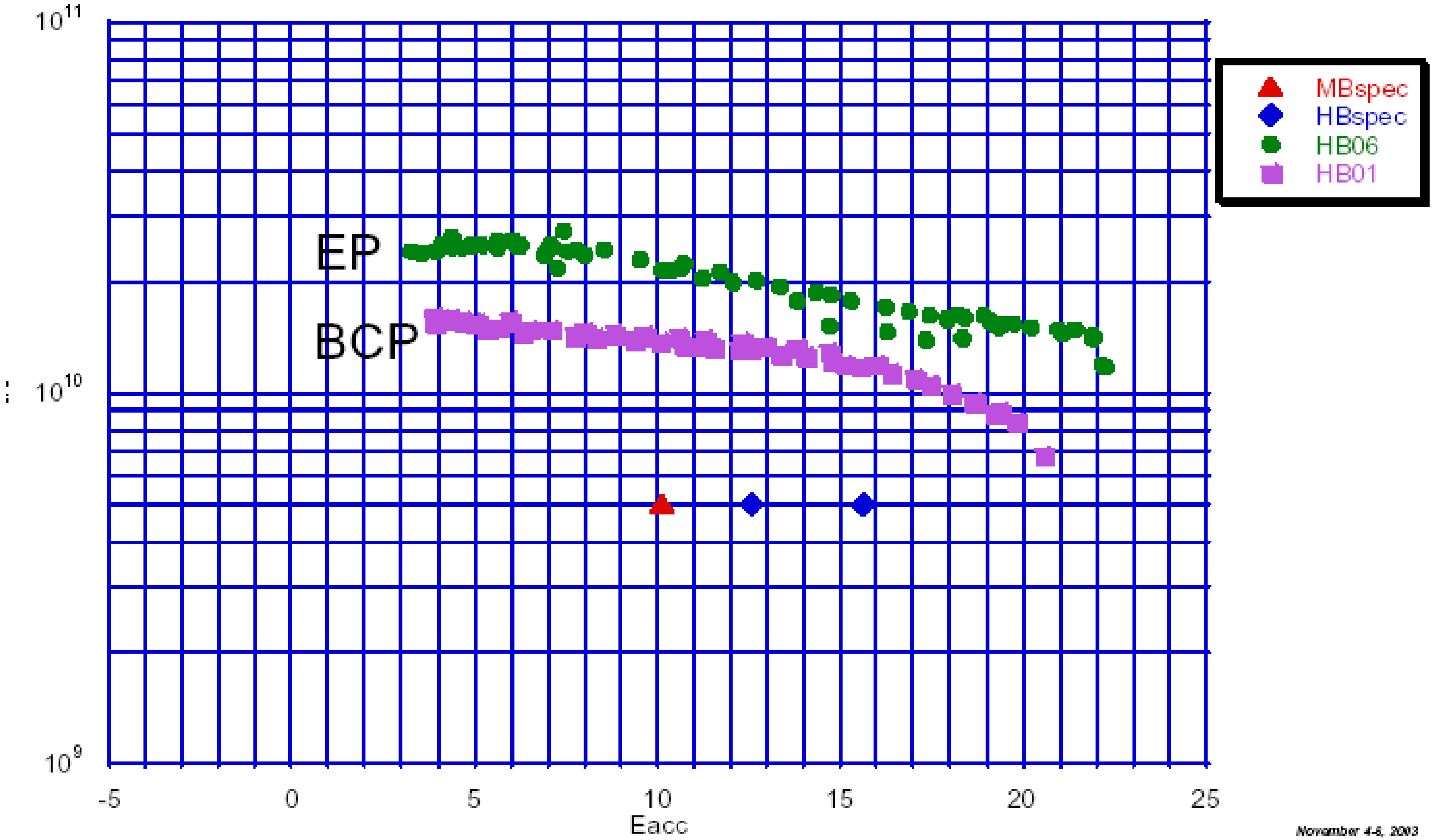
1.2 GeV Superconducting Linac

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	23.5 MeV/m
Length	37.8 m	41.4 m	38.3 m
Beam power, linac exit	17 kW	34 kW	50 kW

Based on SNS Experiences

SNS high beta cavity performance



R&D Activities

1. Beam Dynamics in the AGS
   - Injection Painting
   - Linac Emittance
   - Transition Crossing
   - Ring Impedances
   - Beam Loss and Collimation
2. AGS Magnet Test
3. New Power Supply Design
4. AGS RF Cavity/Ferrite Test
5. SCL Accelerating Cavity (Join the US SMTF Program)
6. LLRF for Beam Control
7. Design of the 1MW Target/Horn System
8. Target Material Testing (US/Japan Collaboration/BNL LDRD Program)

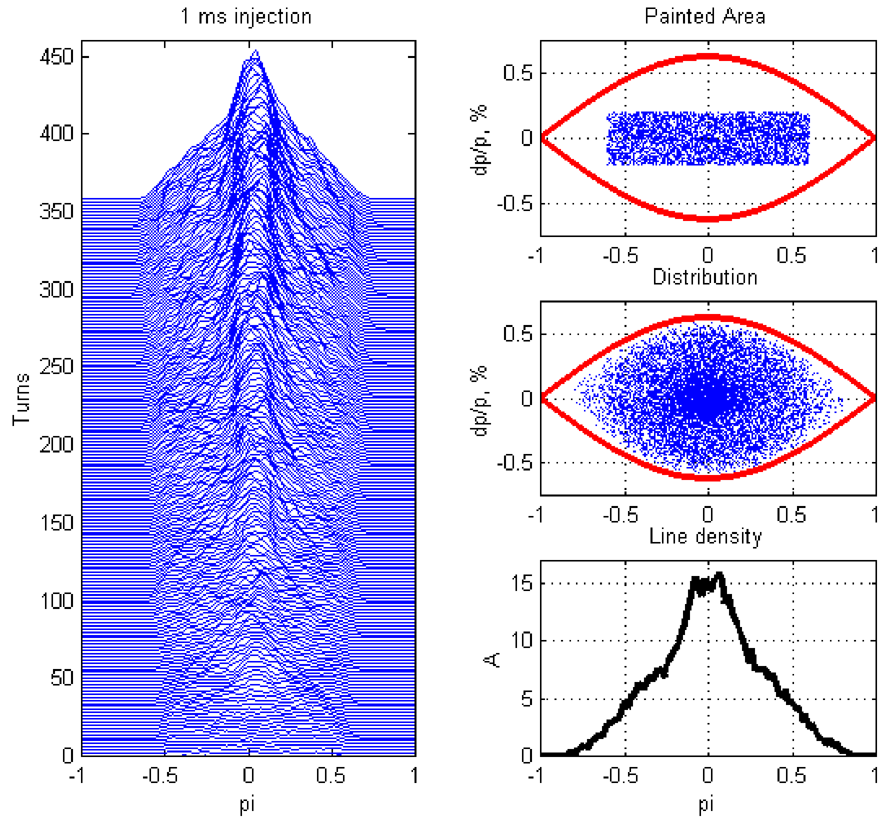
Beam Loss at H^- Injection Energy

	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

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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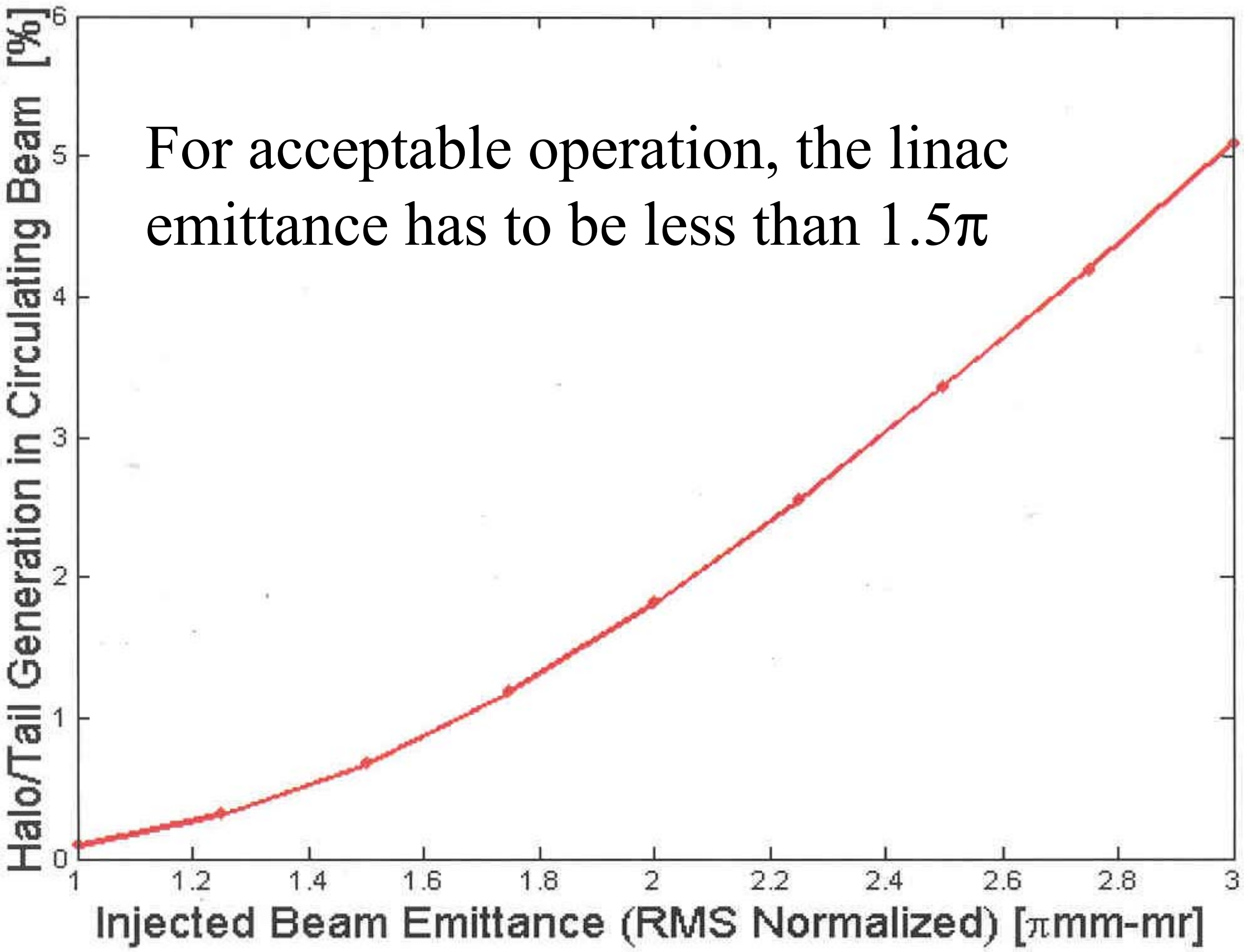
Halo in AGS as Function of Linac Emittance



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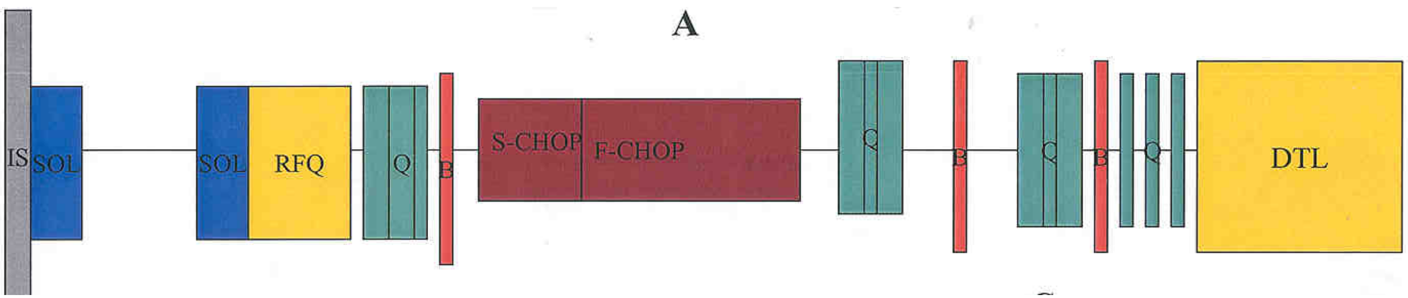
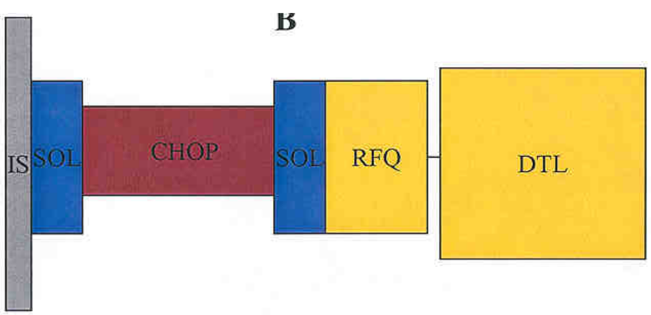
New RFQ to DTL matching

Present: 60% transmission, emittance growth: 5.5(x),6.0(y),4.5(z)

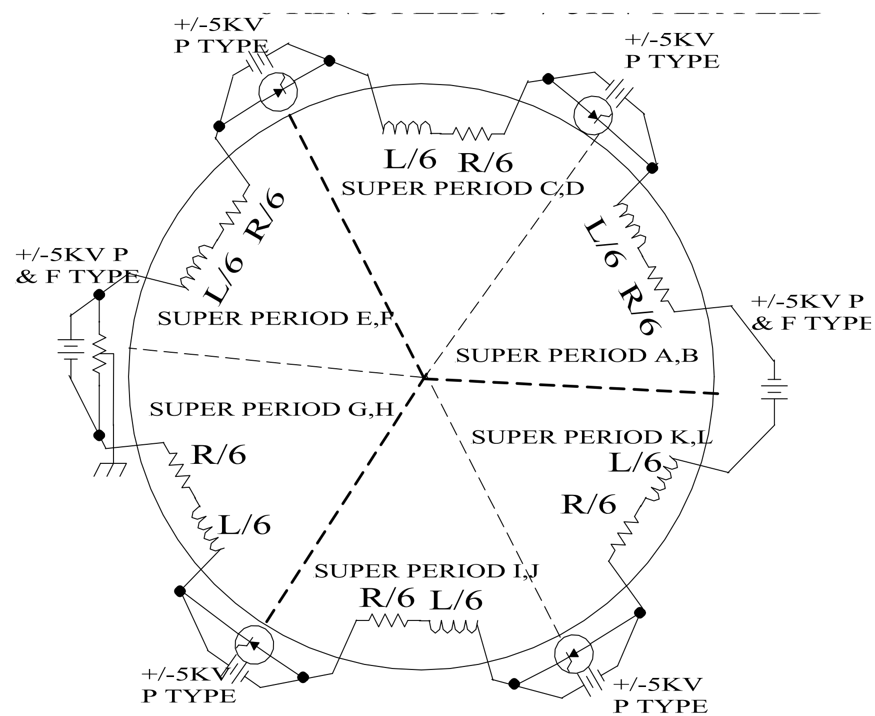


“No LEBT”: 100% transmission, emittance growth: 1.6(x),1.4(y),1.6(z)



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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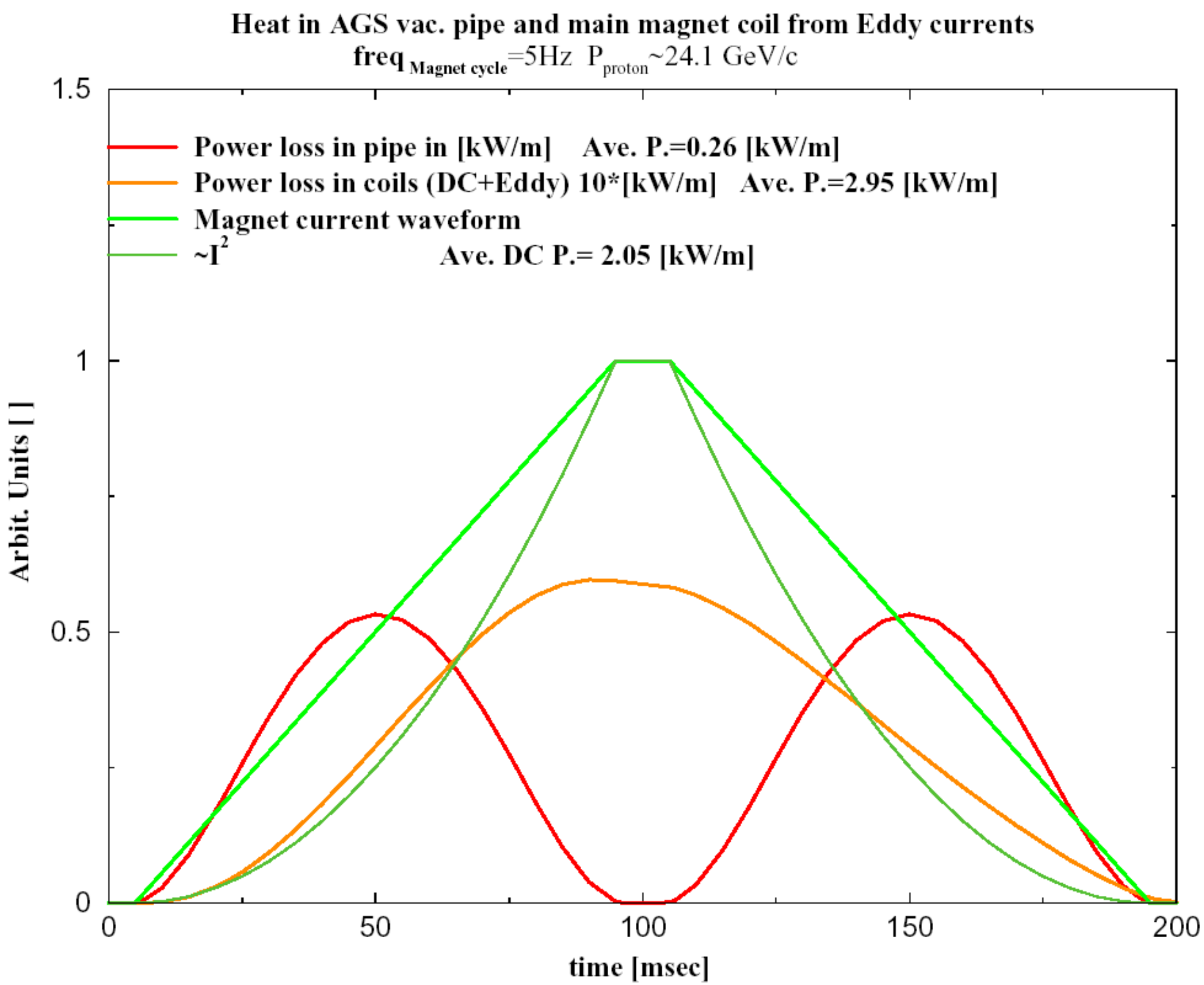
Eddy Current Losses in AGS Magnets



For 2.5 (5.0) Hz:
In pipe: 65 (260) W/m
In coil: 225 (900) W/m

Heat test performed on Spare AGS magnet with vacuum chamber.

OK up to 5 Hz cycle.

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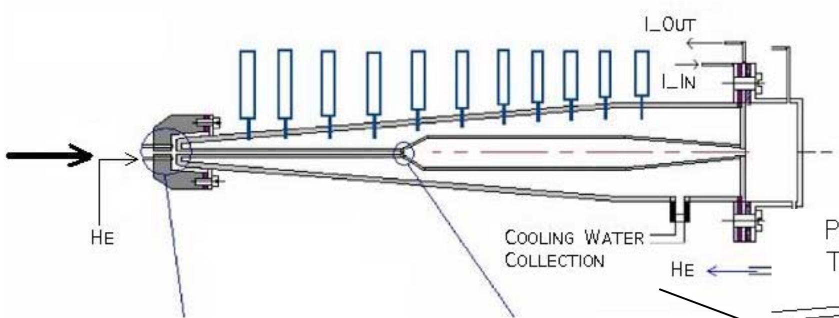
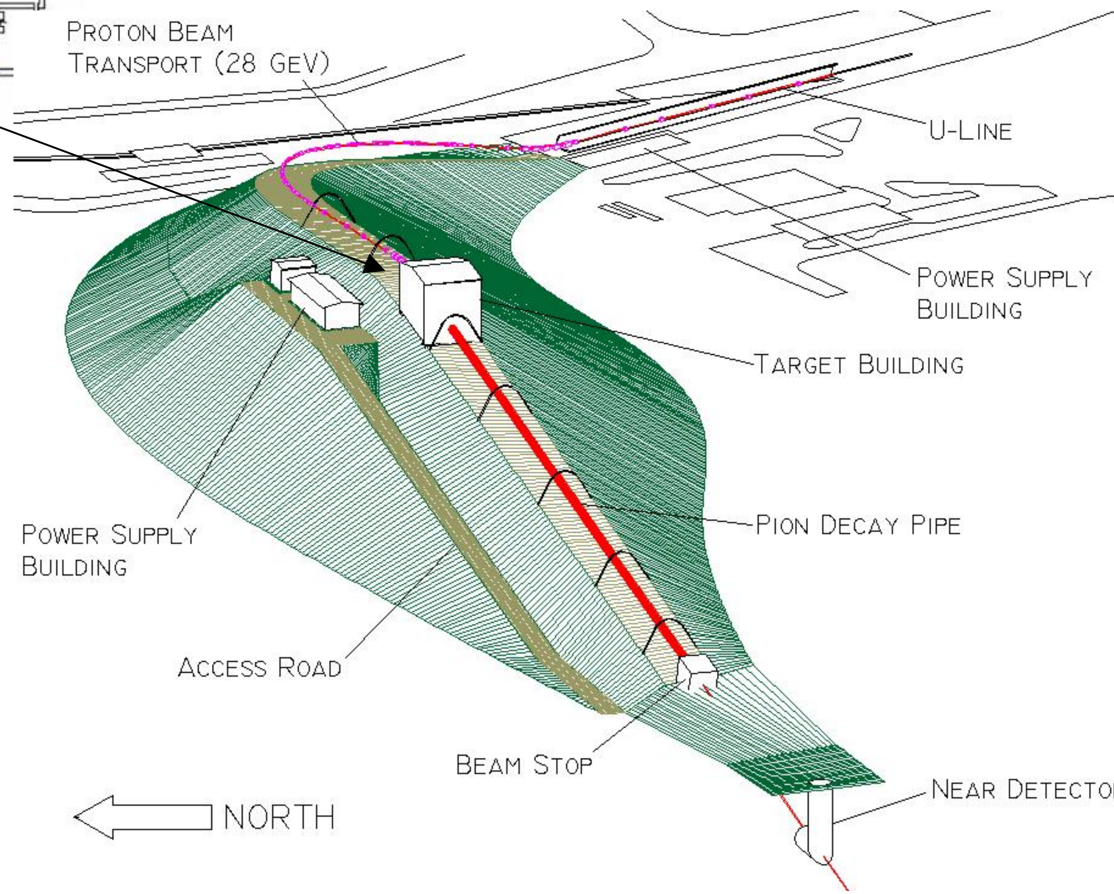
AGS RF System Upgrade

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

Neutrino Beam Production





- 1 MW He gas-cooled Carbon-carbon target
- New horn design
- Target on 11.3 degree down-hill slope to aim at Homestake mine
- Beam dump well above ground water table to avoid activation

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MATERIAL STUDIES FOR PULSED HIGH-INTENSITY PROTON BEAMS

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Kirk McDonald, Princeton U
K. Yoshimura, KEK
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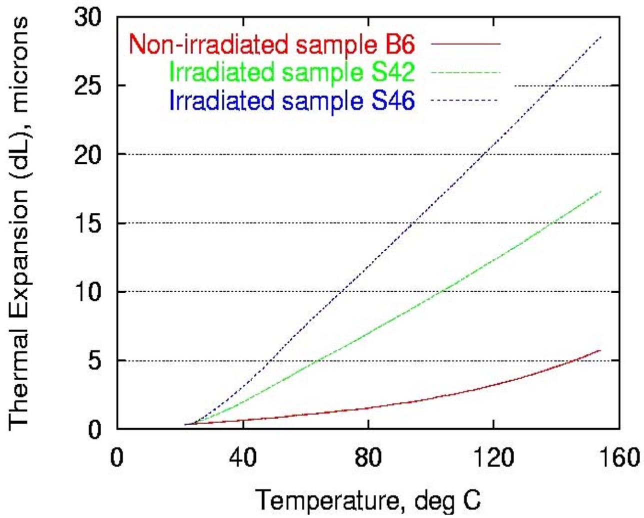
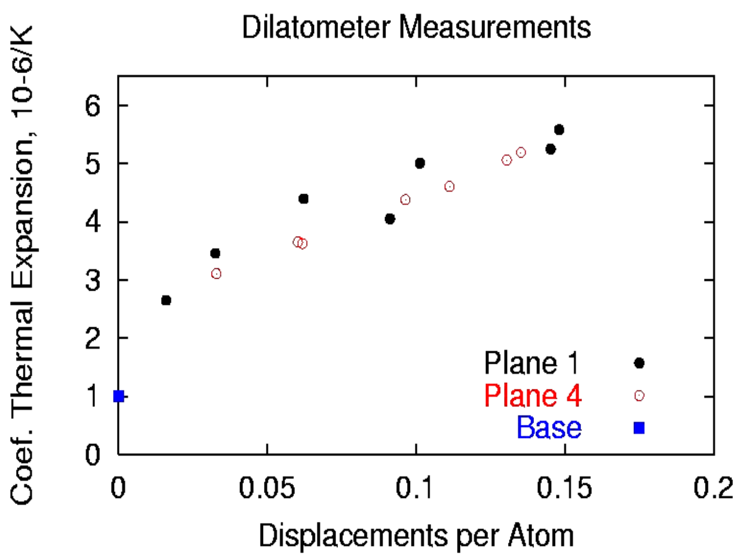
J. Hylen, FNAL

BLIP Irradiation Studies



Thermal expansion of Super-Invar as a function of atom displacements



We are in the process of irradiating possible target materials in the BLIP facility at BNL.

- The samples will receive exposures representative of the expected lifetime of the neutrino facility.

Target materials that will be examined (in the next few weeks) are

- Carbon-Carbon Composite
- Titanium Ti-6 Al-4V alloy
- Toyota *Gum Metal*
  - High strength, near-zero expansion coefficient
- Vascomax
- Beryllium
- AlBeMet
  - Aluminum-Beryllium alloy.

Horn material

- Nickel-plated T6062 Aluminum that is being used in the NuMI horn

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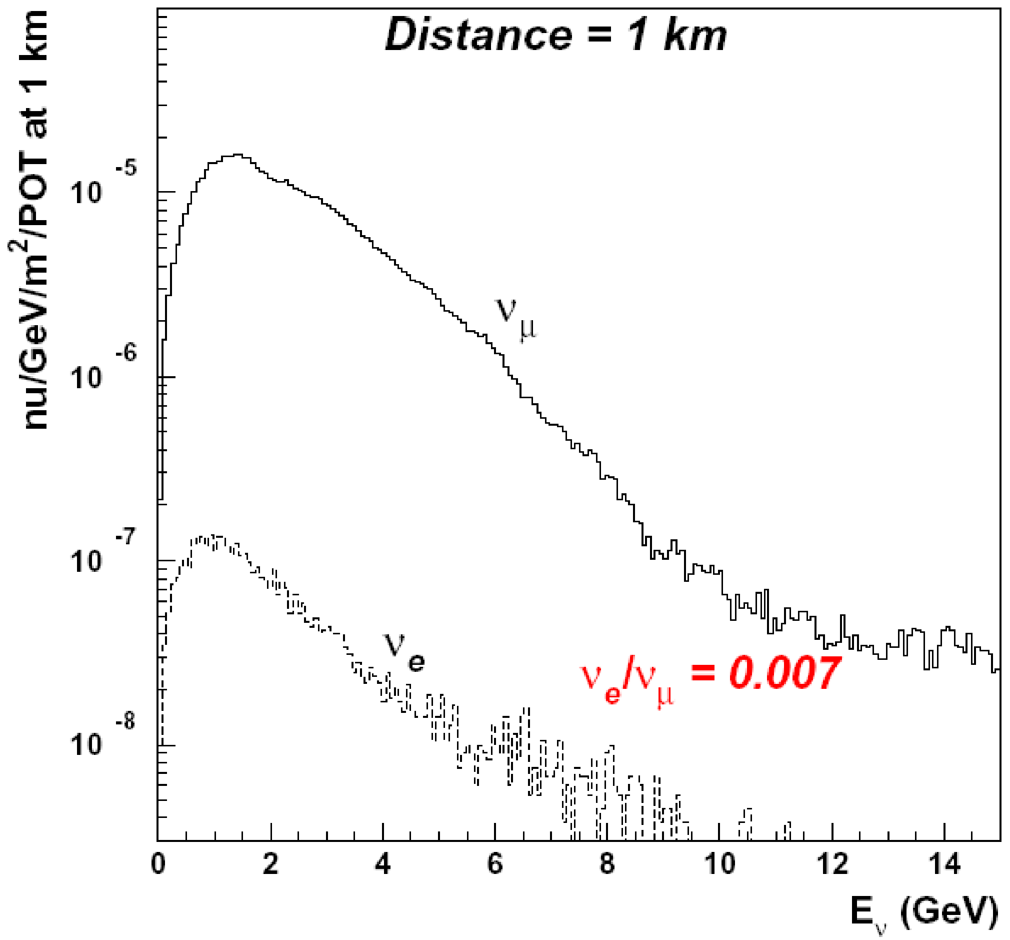
Neutrino Spectrum at 1 km

Low Z (Carbon) target seems feasible for 1 MW, 28 GeV proton beam.

Thin low Z target minimizes reabsorption which increases flux of high energy neutrinos



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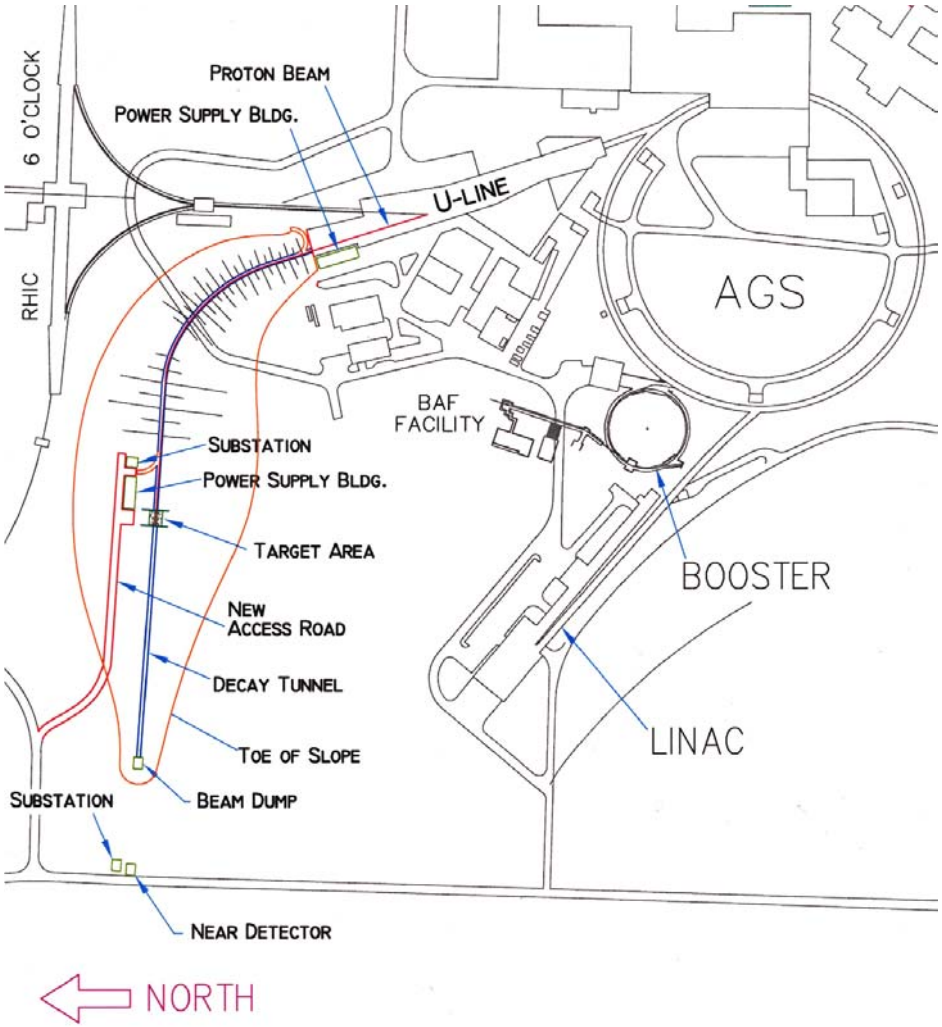
Super Neutrino Beam Geographical Layout



- BNL can provide a *1 MW capable Super Neutrino Beam*
- the neutrino beam can aim at any site in the western U.S.; the Homestake Mine is shown here
- there will be no environmental issues if the beam is produced atop the hill illustrated here and the beam dumped well above the local water table
- construction of the Super Neutrino Beam is essentially de-coupled from AGS and RHIC operations

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Preliminary Cost Estimate of the BNL - SNBF

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**

Summary of Preliminary Cost Estimates

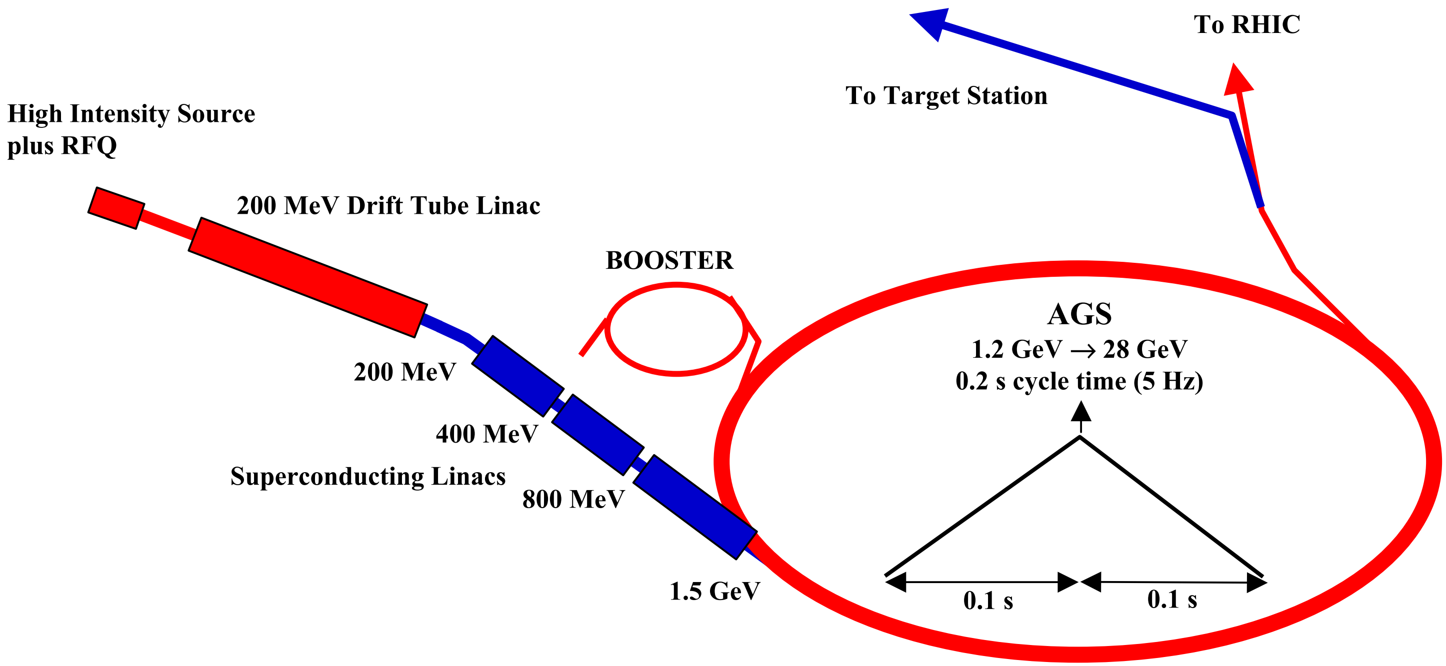
1.2 GeV Superconducting Linac	$ 99 M
AGS upgrade	$ 58 M
Neutrino beam production	$ 62 M
Total direct cost	$ 219 M
Total Estimated Cost (FY2003 $)	$ 369 M

(incl. 15% EDIA; 30% contingency;13% BNL project overhead)

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

4 MW AGS Proton Driver Layout



Conclusions

The feasibility has been demonstrated for a 1MW upgrade for the AGS

It is possible to further upgrade the AGS to 4 MW

Active R&D efforts are in progress to improve on the design and reduce cost.

Such a high power proton driver is essential for very long base-line neutrino experiment and also for a neutrino factory.