EFFECTS OF HALO ON THE AGS INJECTION FROM THE 1.2 GeV LINAC

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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

AGS/RHIC Accelerator Complex

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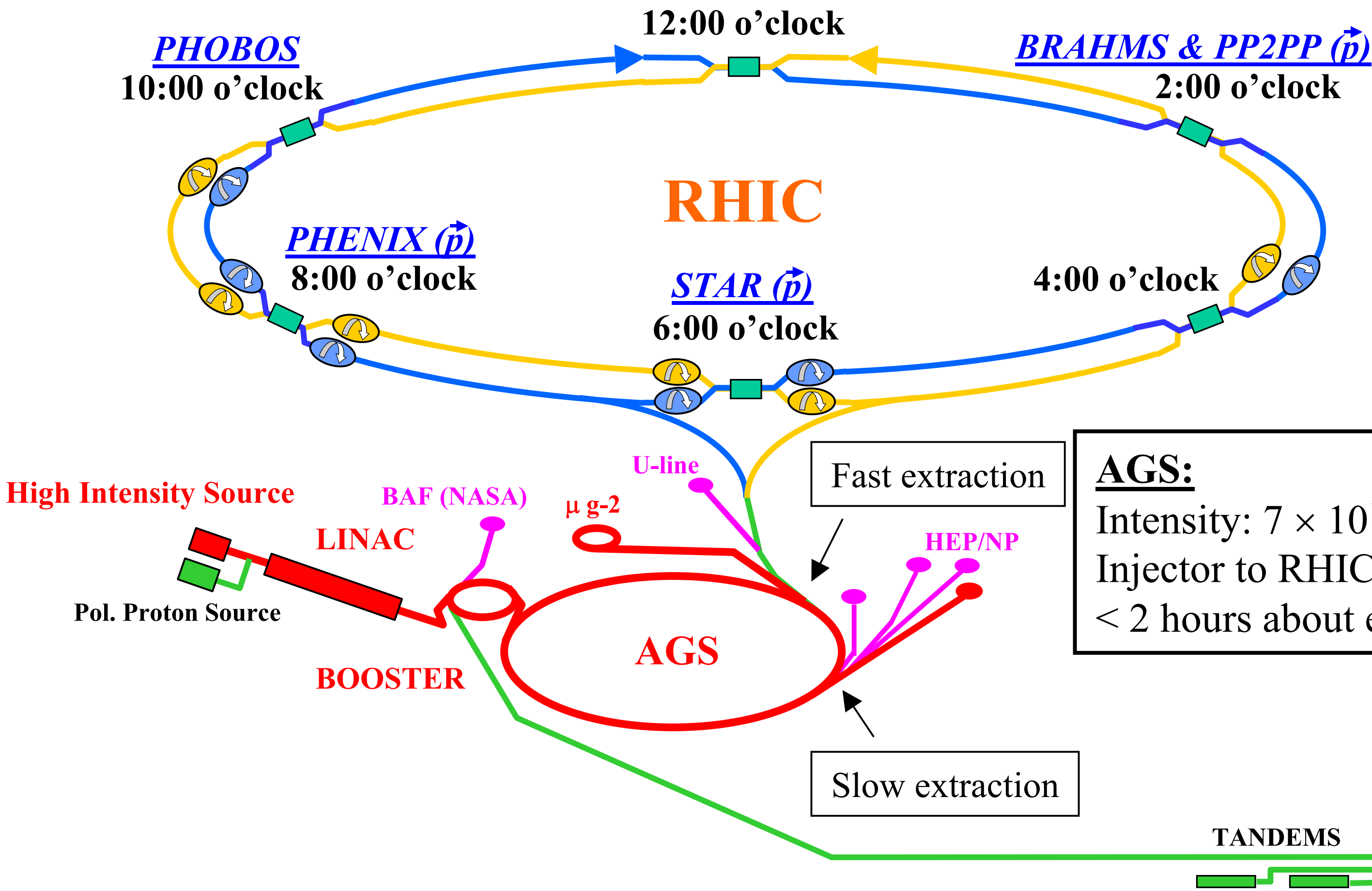
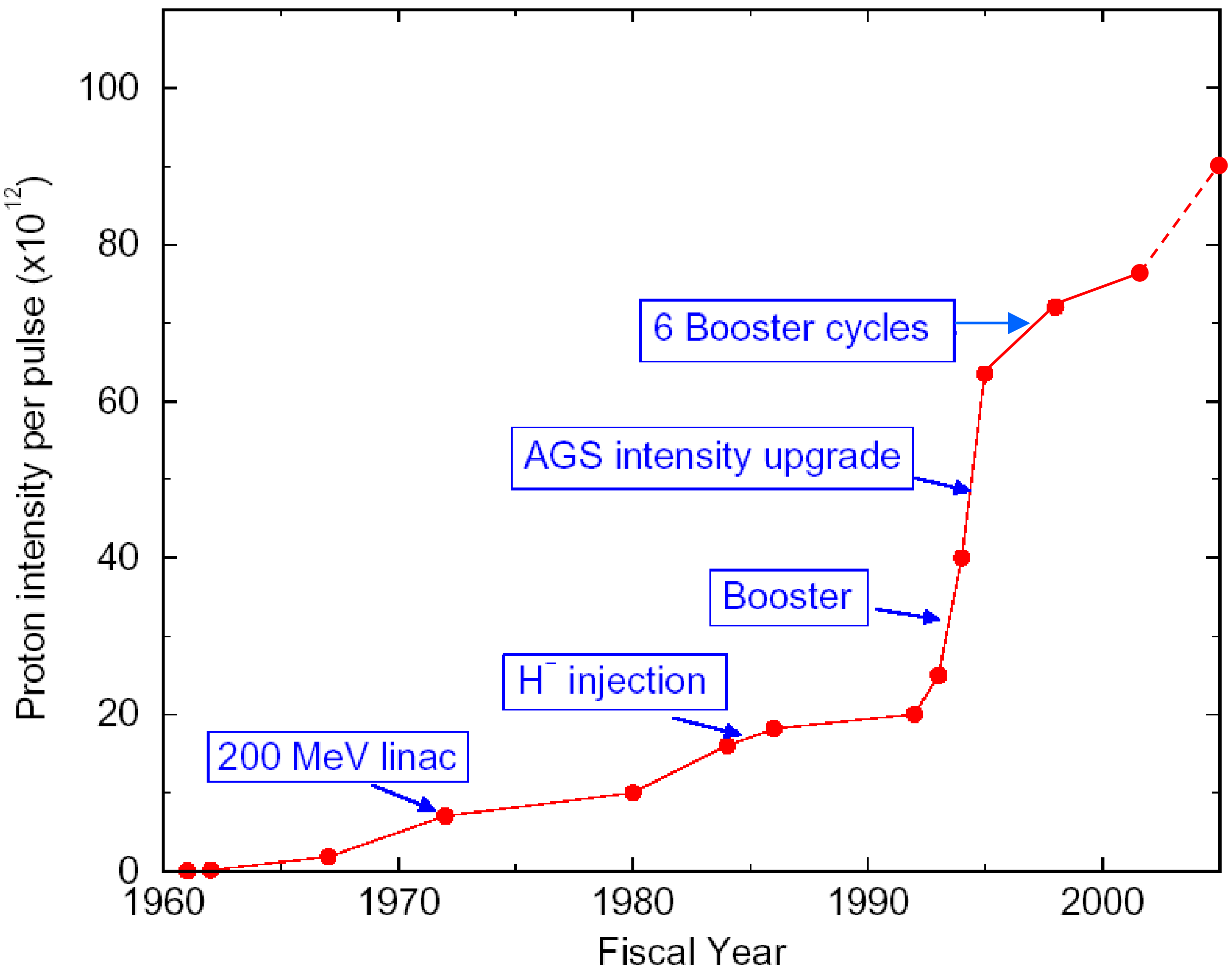


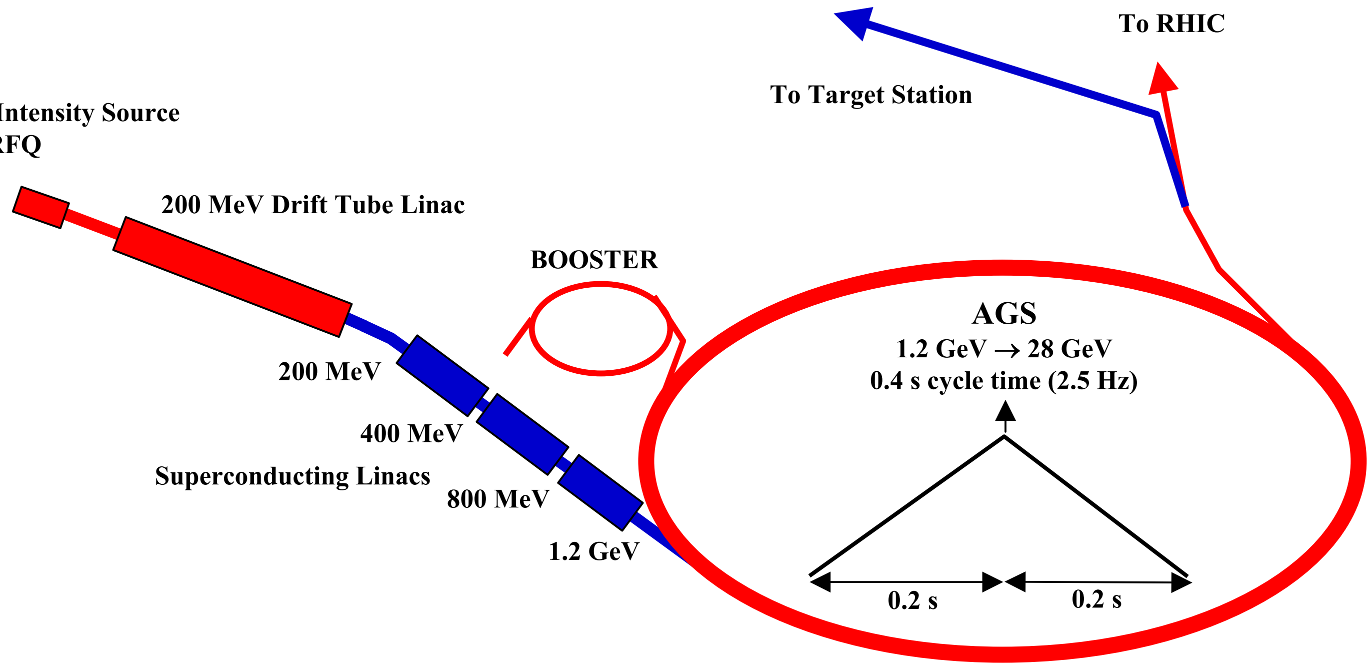
AGS:
Intensity: 7×10^{13} protons/pulse
Injector to RHIC:
< 2 hours about every 10 hours

AGS Intensity History



1 MW AGS

AGS Upgrade to 1 MW



- 1.2 GeV superconducting linac extension for direct injection of ~ 1×10^{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 [mA]	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}

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
$N_P / (\beta^2\gamma^3 A)$, $10^{12} / \pi\ \mu$m	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

1.2 GeV Superconducting Linac

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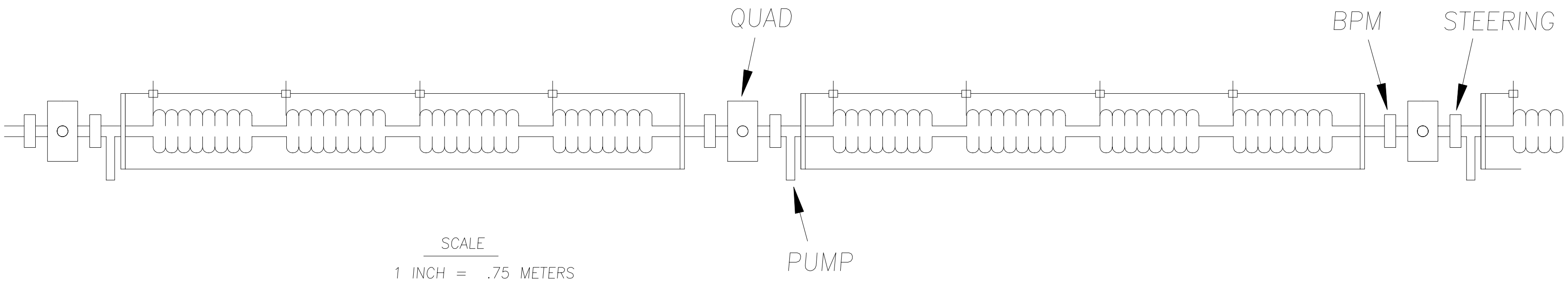
Beam energy	0.2 → 0.4 GeV	0.4 → 0.8 GeV	0.8 → 1.2 GeV
Rf frequency	805 MHz	1610 MHz	1610 MHz
Accelerating gradient	10.8 MeV/m	23.5 MeV/m	23.4 MeV/m
Length	37.8 m	41.4 m	38.3 m
Beam power, linac exit	17 kW	34 kW	50 kW



1.2 GeV Superconducting Linac

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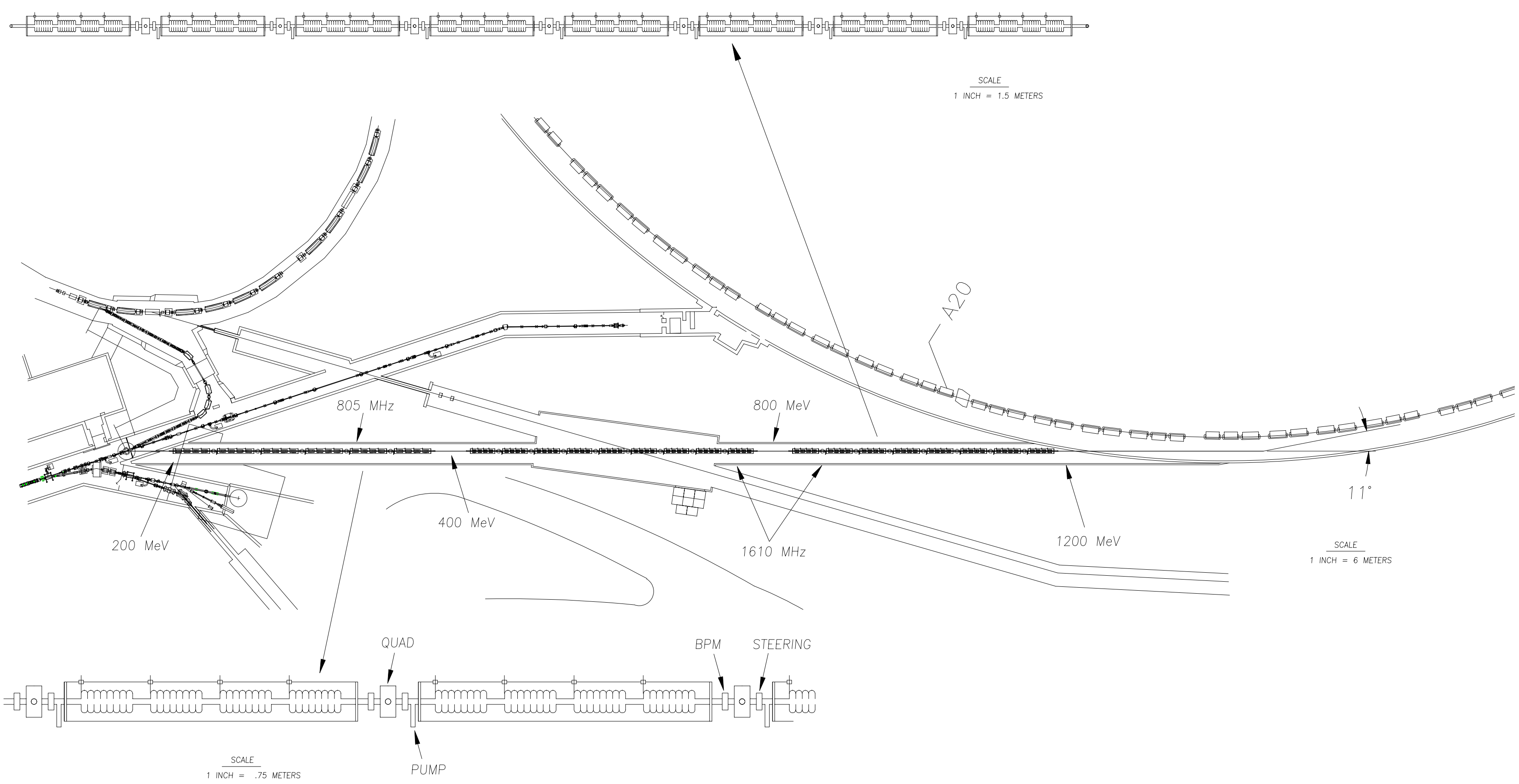
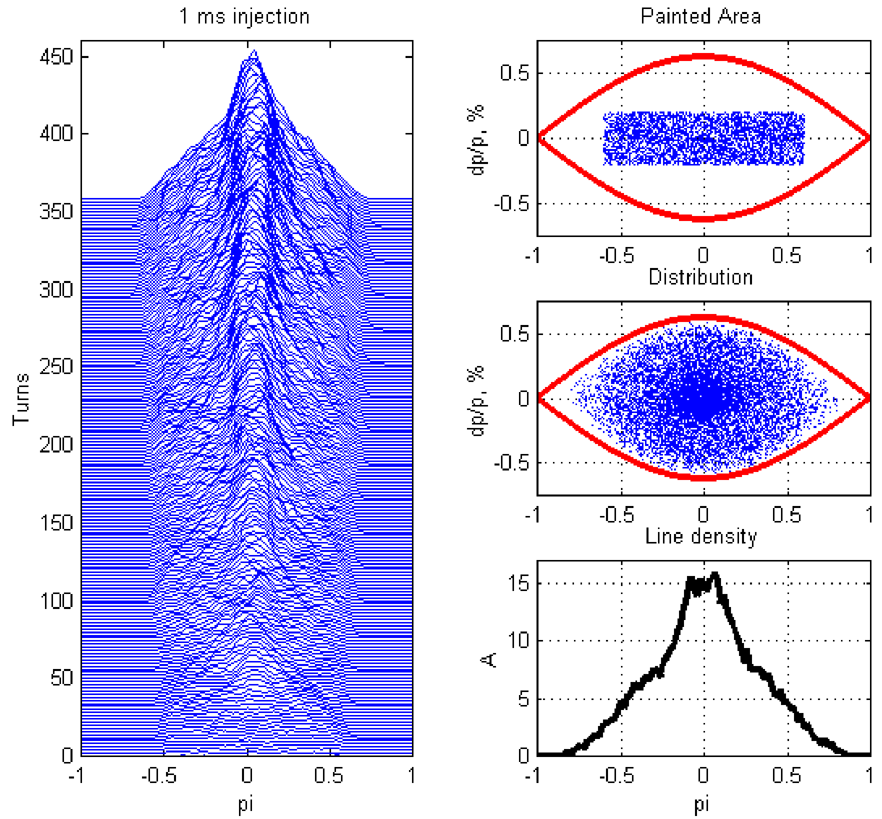


AGS Injection Simulation

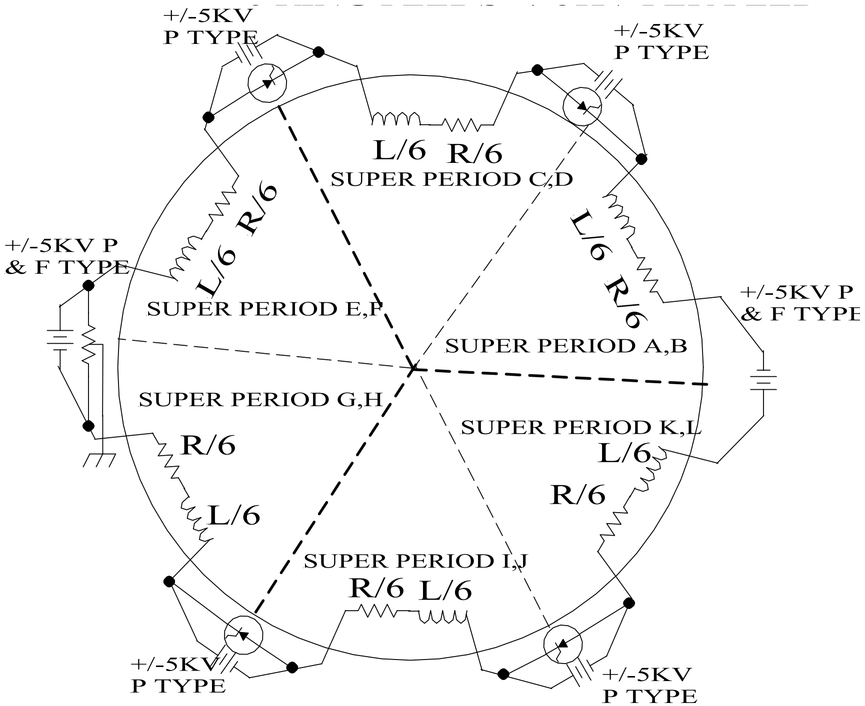
Injection parameters:

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



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



Eddy Current Losses in AGS Magnets

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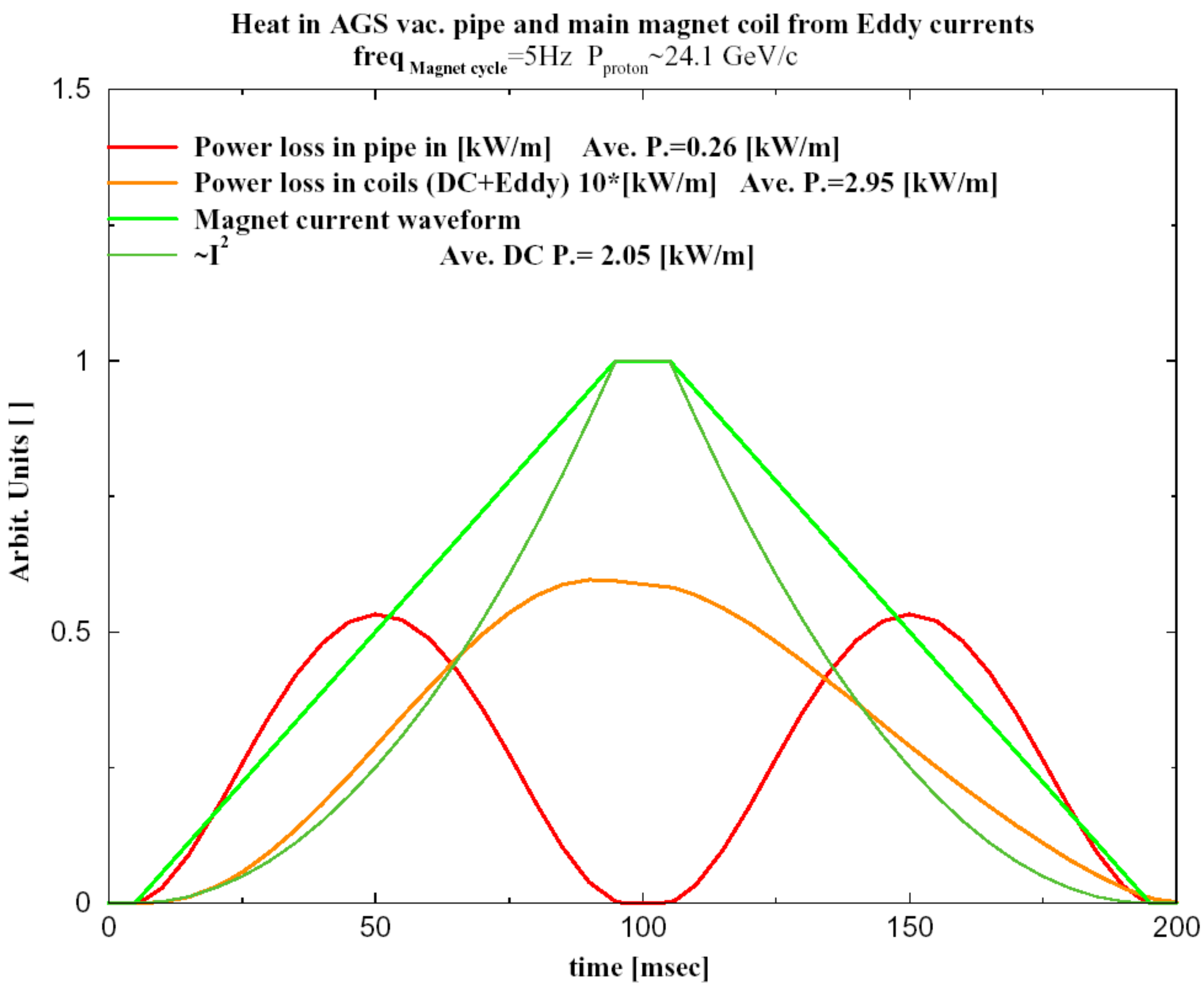

For 2.5 (5.0) Hz:

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)

		presently:
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	

Neutrino Beam Production

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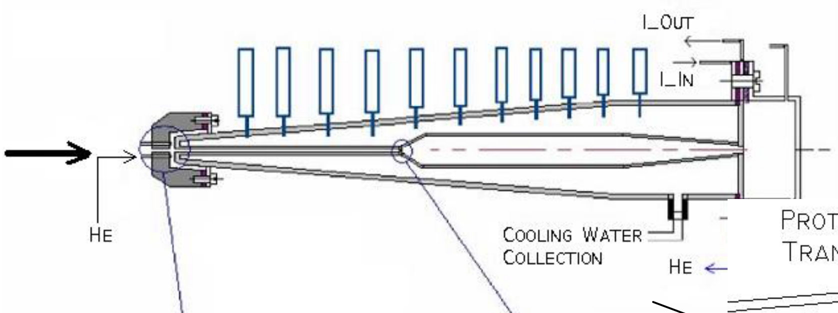
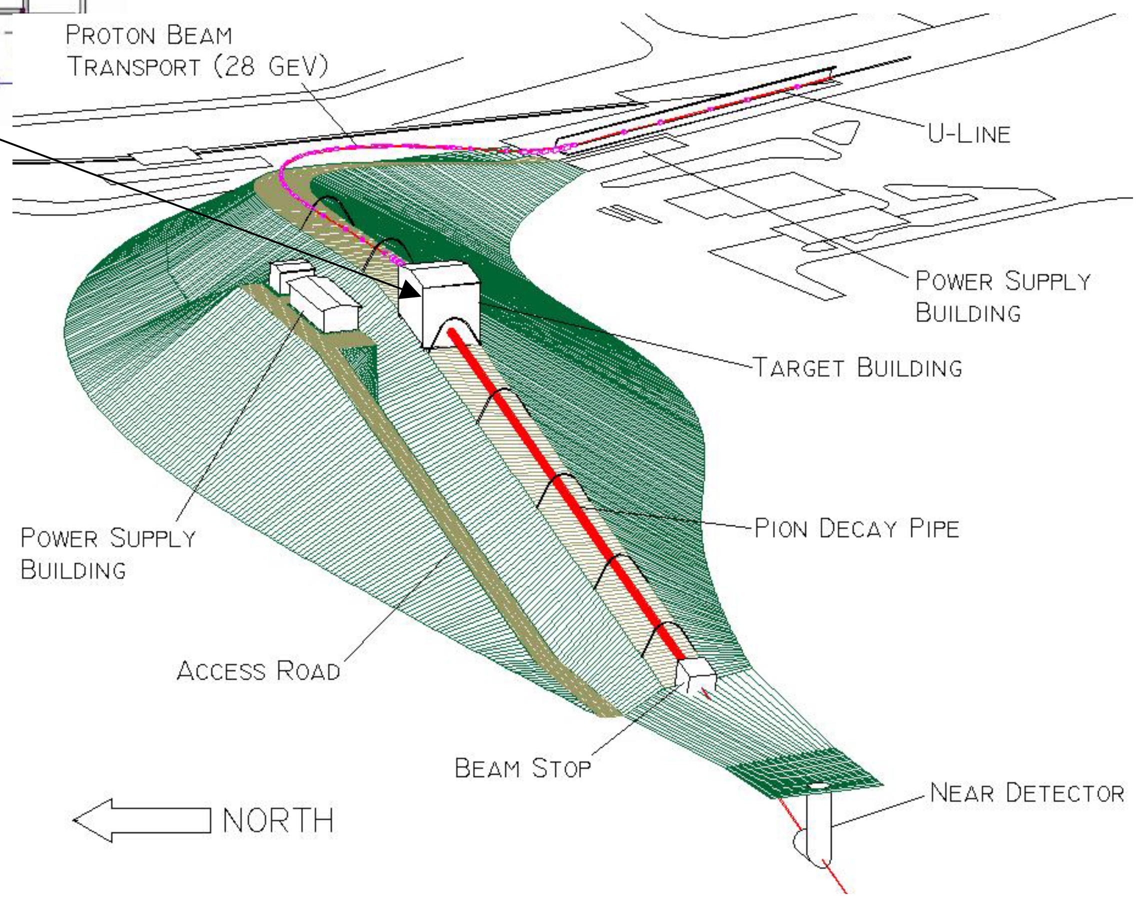


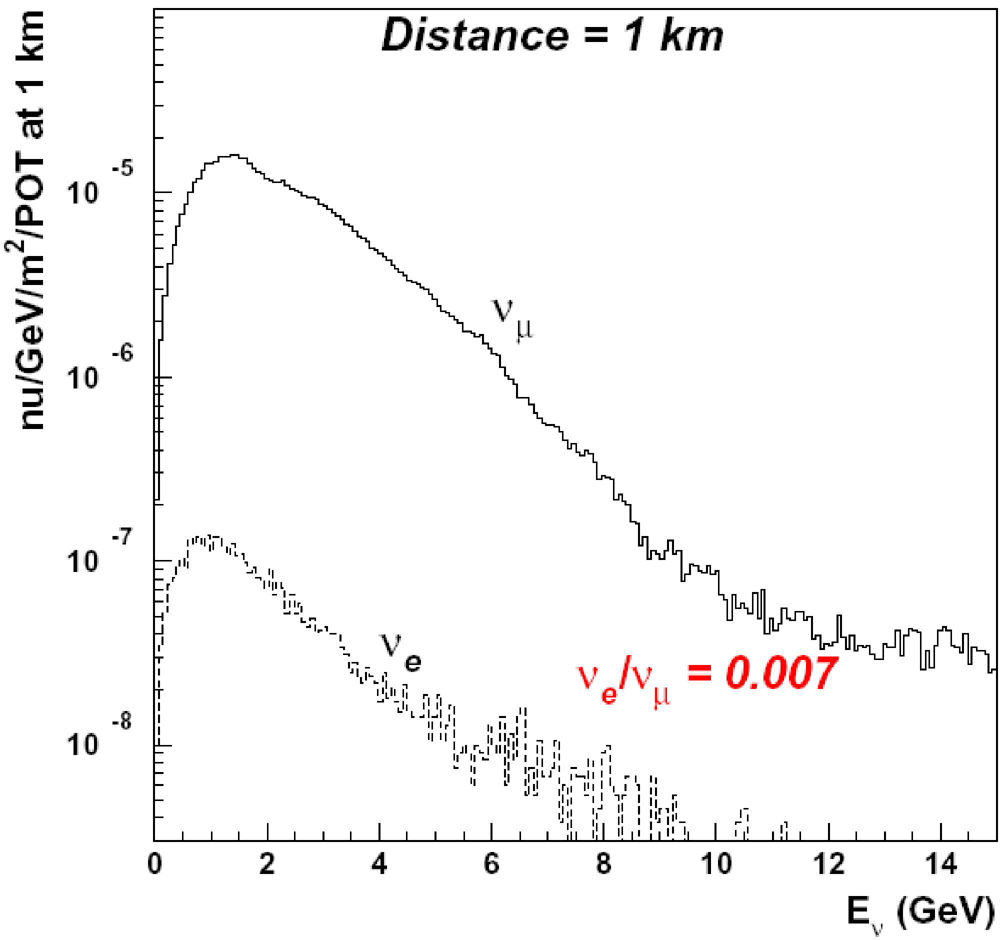


- 1 MW He gas-cooled Carbon-carbon target
- New horn design
- Target on down-hill slope for long baseline experiment
- Beam dump well above ground water table to avoid activation

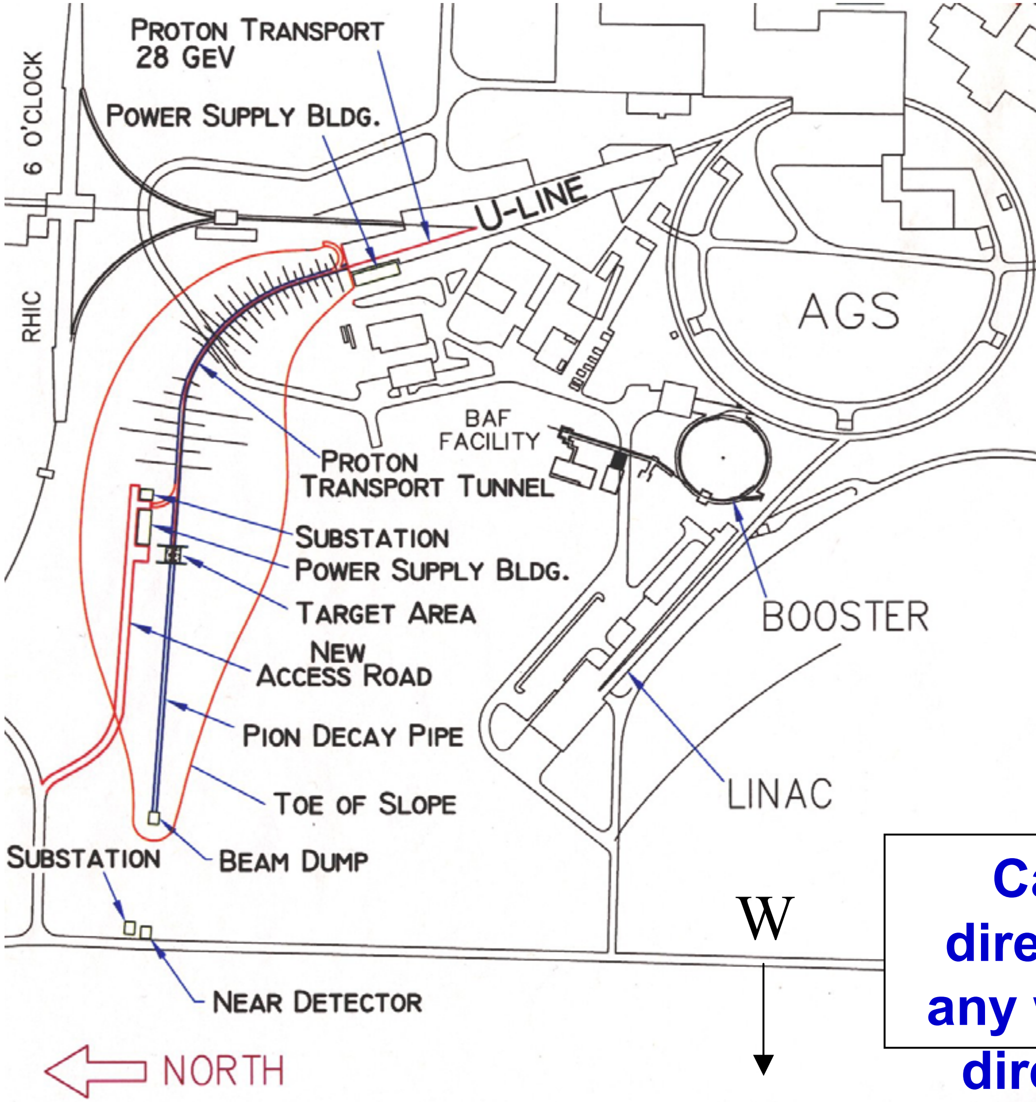
Neutrino Spectrum at 1 km

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

Thin low Z target minimizes re-absorption which increases flux of high energy neutrinos



Beam Line to Homestake Mine



Can be directed to any western direction.

H^- Stripping Injection

What happens at the injection:

- Two electrons are stripped off H^- through carbon foil.
- Phase space painting is necessary for AGS-NSF injection.

What is injection painting:

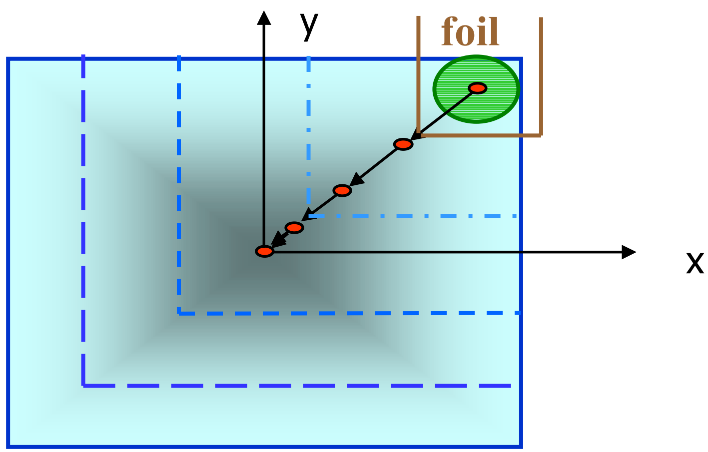
It is an injection with a controlled phase space offset between the centroid of injected beam and the closed orbit in the ring to achieve a different particle distribution from the injected beam.

Why injection painting:

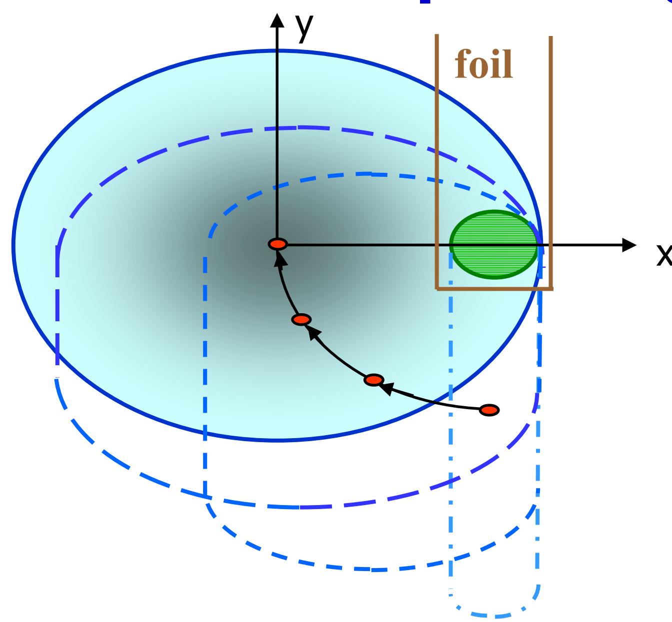
- to satisfy beam pipes and target requirements
- to reduce beam losses due to space charge
- to reduce foil hits (foil life-time, beam loss at foil)

Choice of Painting Schemes

Correlated painting



Anti-correlated painting



Correlated Painting is chosen for AGS-NSF considering the available aperture at the injection and beam halo/tail control.

Injection Bump Optimization

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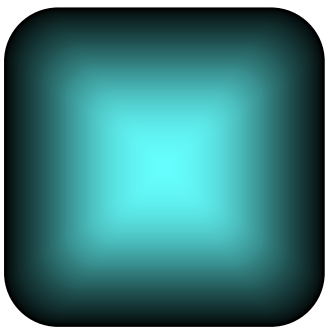
Work is in progress in developing injection bumps that optimize between the goals:

Beam profile without SC



Example bump function: exp(-t/τ) with τ=0.01msec

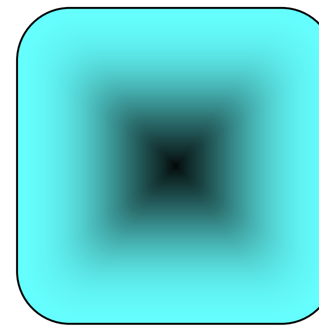
Meeting target requirement (←)

Reducing loss at primary collimator (→)

Reducing space charge tune shift (←)

Reducing foil-hitting rate (depends on details) (↔)

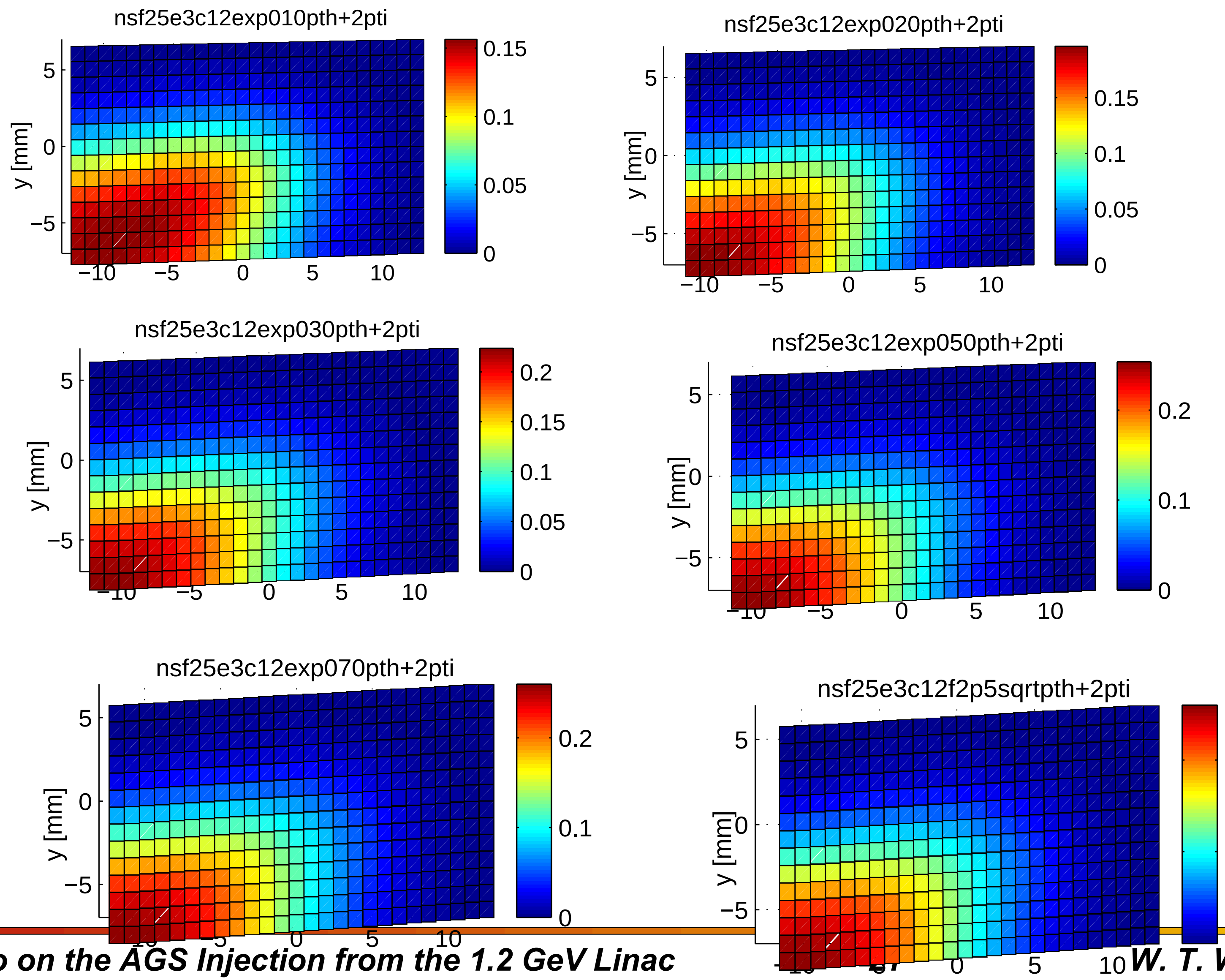
Beam profile without SC



Example bump function: Sq-root

0.01 msec ← τ (time constant) → 1.0 msec

Current density on Foil



Optimized Injection Painting

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Simulation Parameters

Horizontal beta at the injection	28.0 m
Vertical beta at the injection	8.0 m
Horizontal emittance of injected beam	2 pi-mm-mr
Vertical emittance of injected beam	2 pi-mm-mr
Horizontal beam size at injection, sigma_x	5.2293 mm
Vertical beam size at injection, sigma_y	2.7952 mm
Horizontal Foil size (2.5 sigma_x)	13.0731 mm
Vertical foil size (2.5 sigma_y)	6.9878 mm
Injection turns	230

Simulation Results

Average number of foil hits (/particle/pulse)	17.86
Foil missing rate	1.77%
designed emittance at the end of injection	49 pi-mm-mr
particles out side of the designed emittance	1.81%

Foil Hits & Beam Loss

Beam loss as a consequence of foil traversal through the following mechanism:

(1.2GeV proton, foil=300μg/cm^2, foil traversal rate=18hits/particle)

- **Nuclear Scattering**

  estimated fractional loss=2×10^{-4}

- **Particle loss in gap due to energy straggling**

  estimated fractional loss=8×10^{-6}

- **Transverse emittance growth due to multiple Scattering**

  estimated $\Delta\varepsilon$=0.1 πmm-mr

Radiation due to Nuclear Scattering

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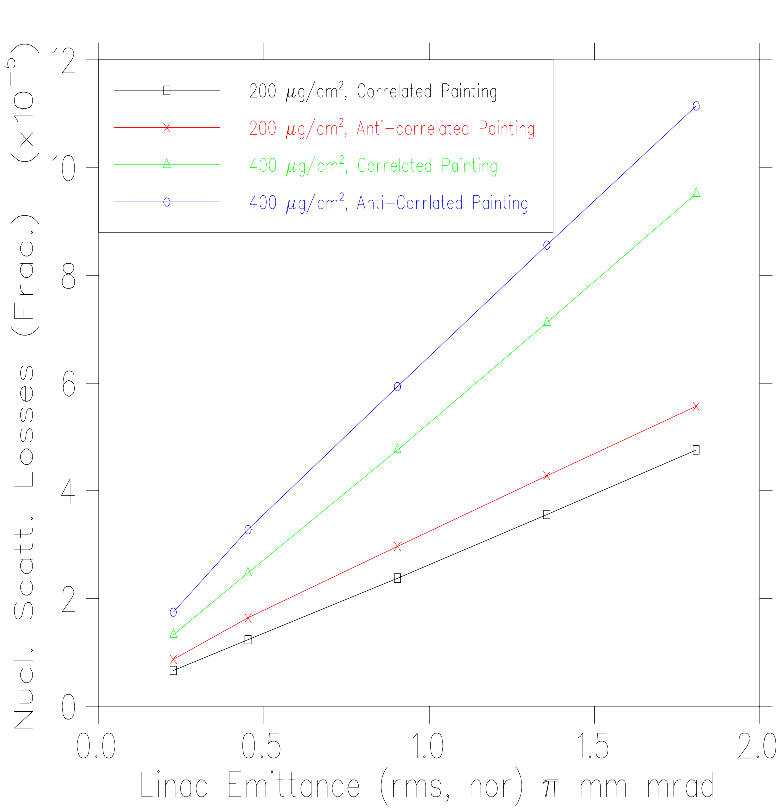
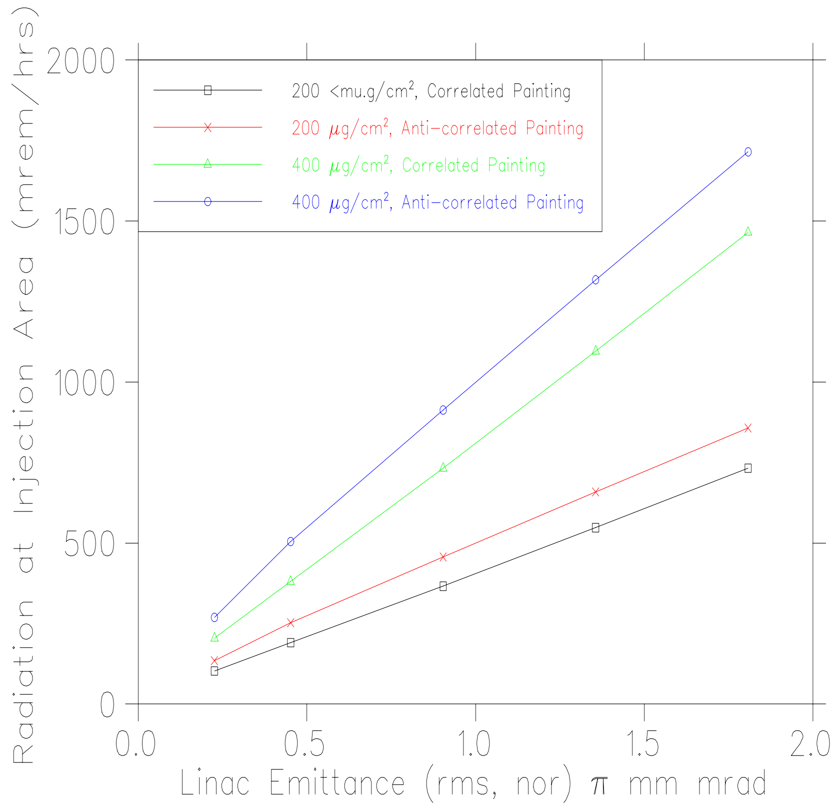
Particle Loss (Fraction)

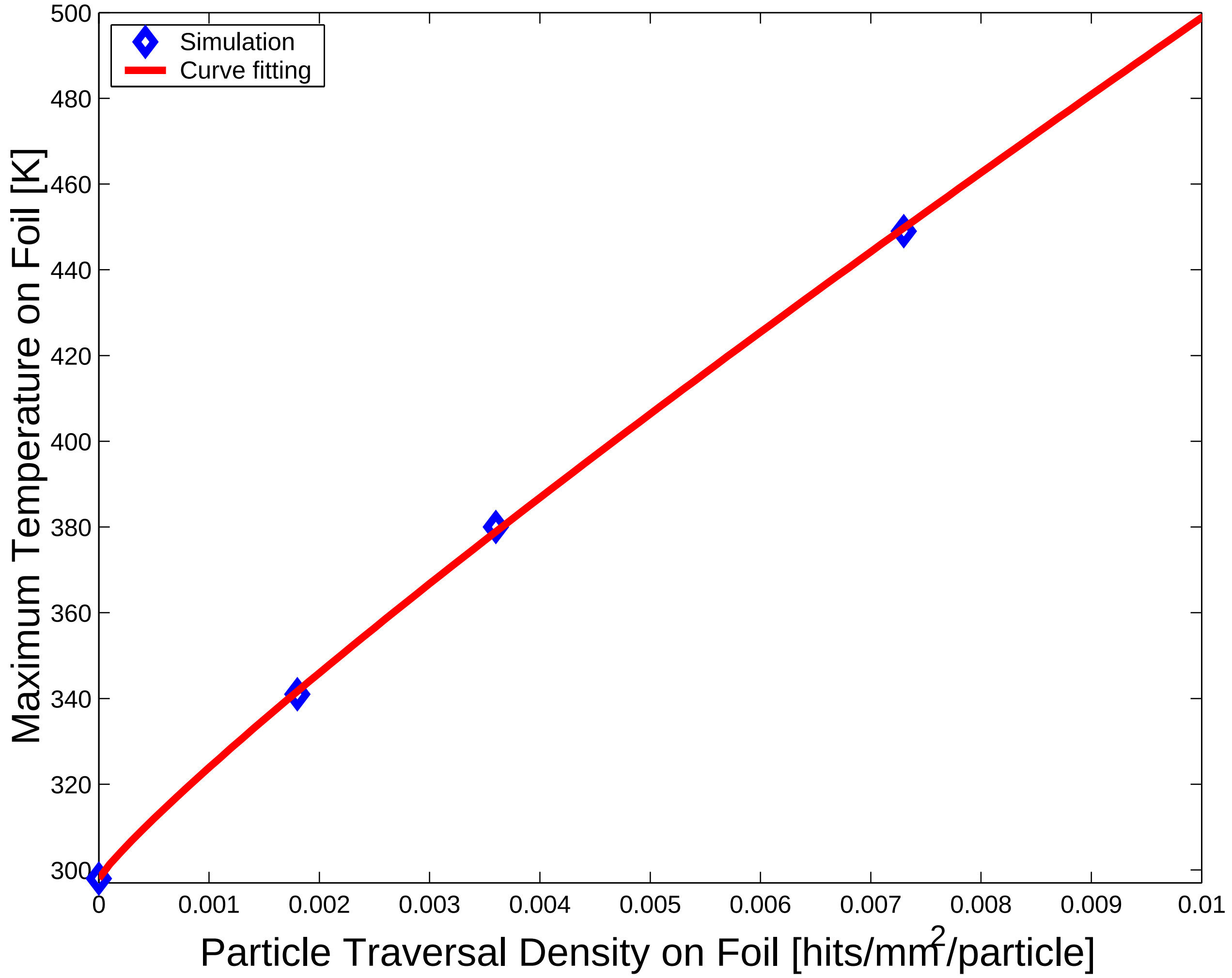


Radiation at Injection Area

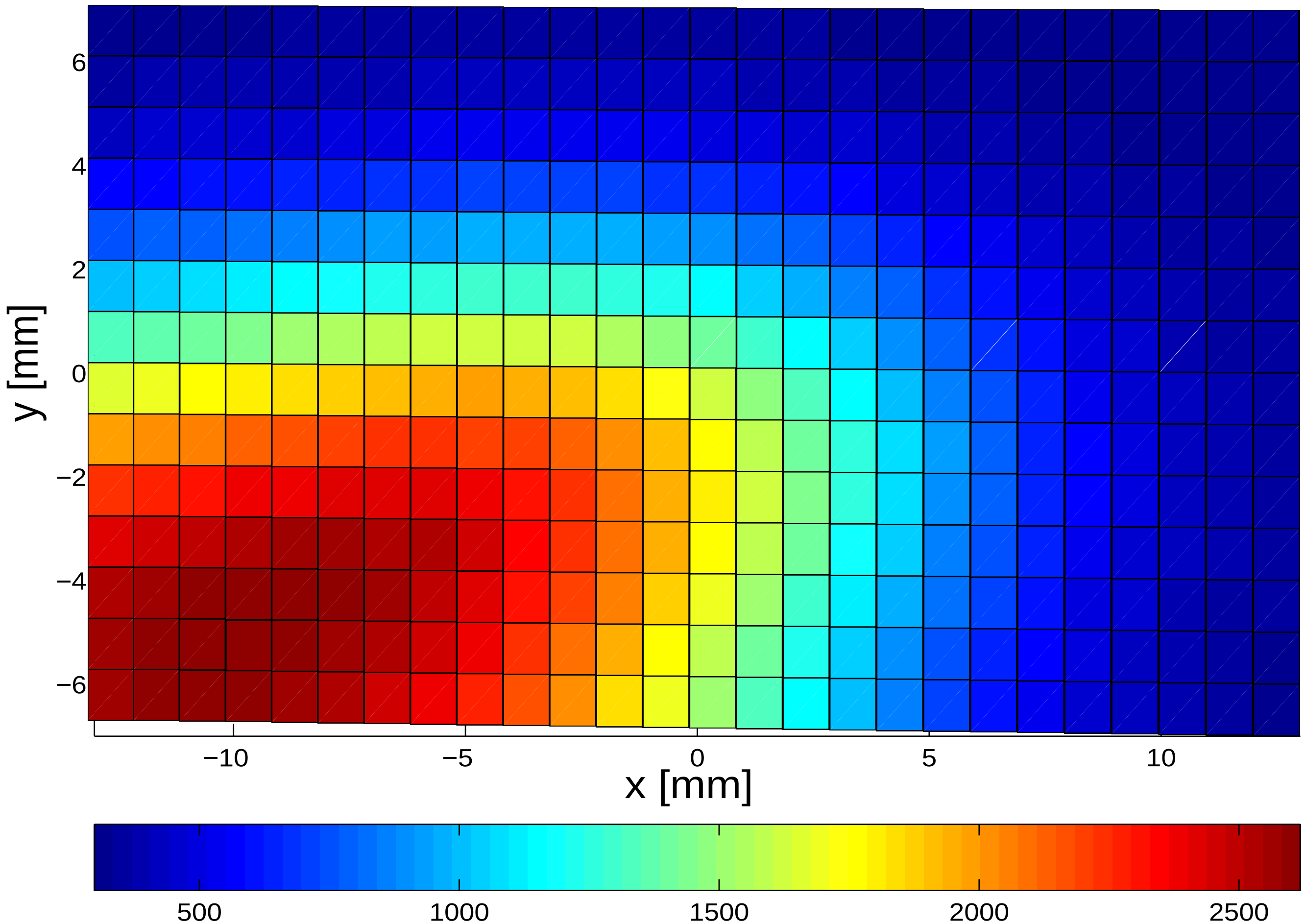


Simulations by Deepak Raparia for SNS project.
They can be scaled-up for AGS-NSF estimates.

Foil Temperature vs. Current Density



Foil Temperature Distribution



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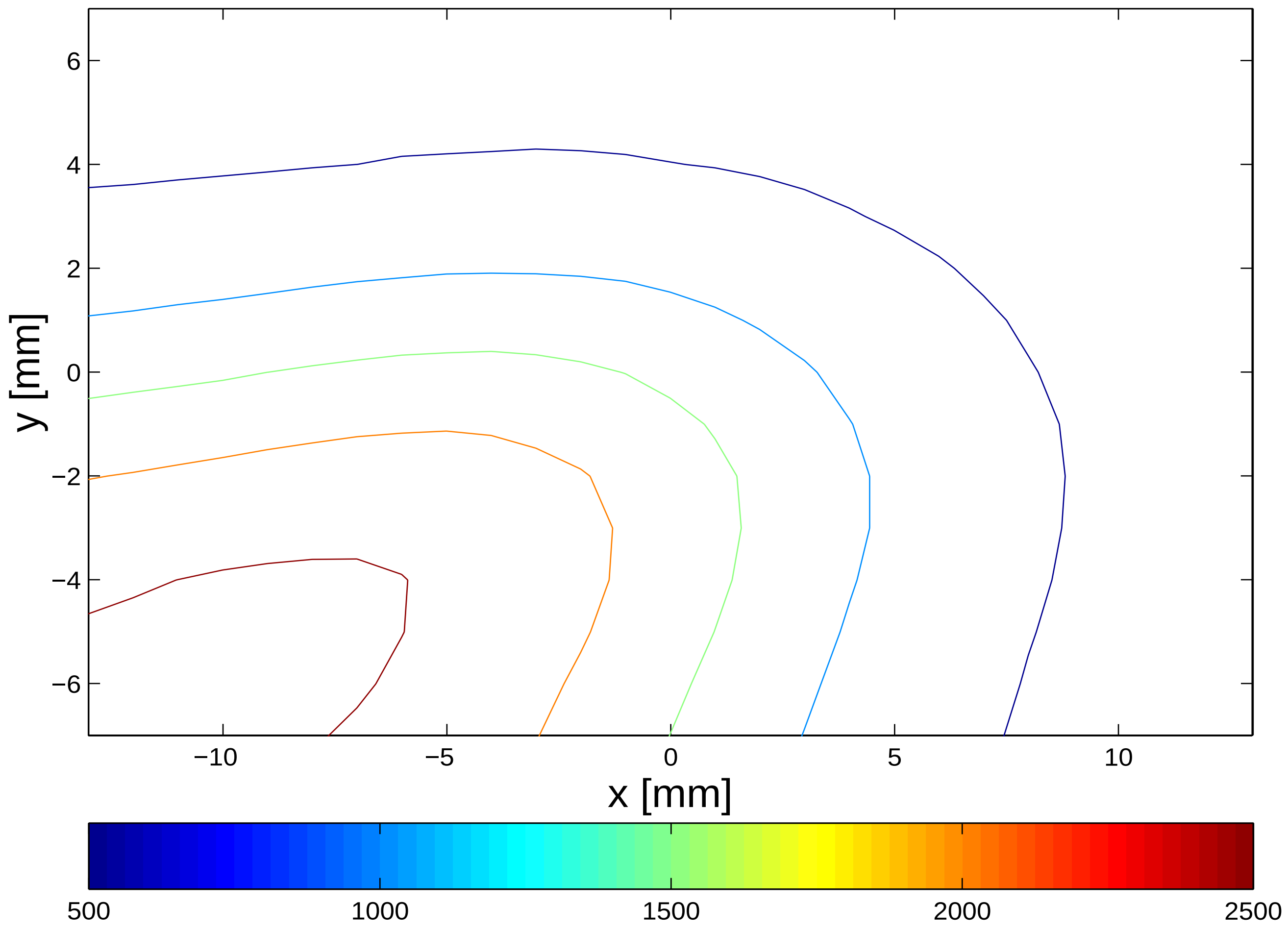
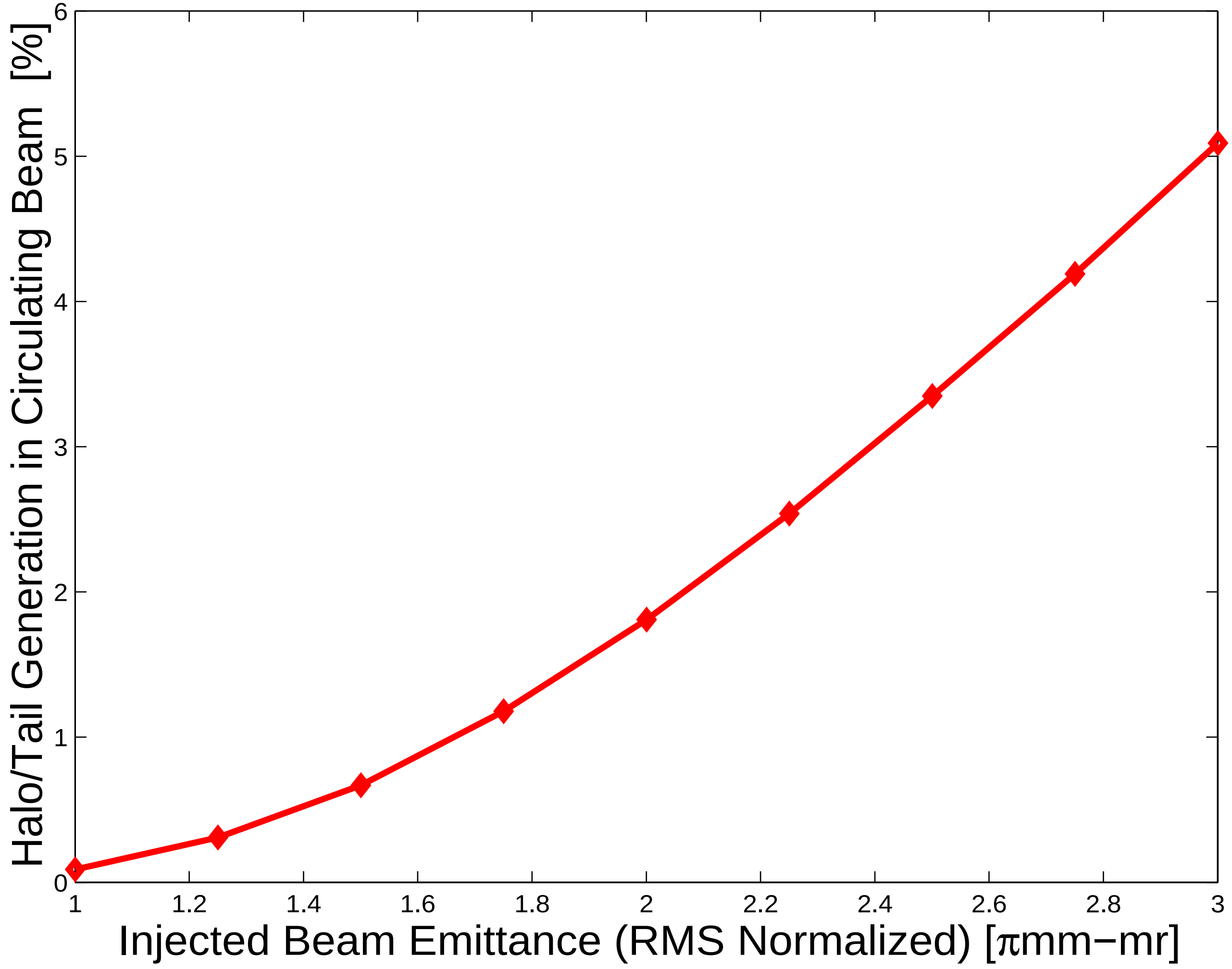


Impact of Injected Beam Emittance



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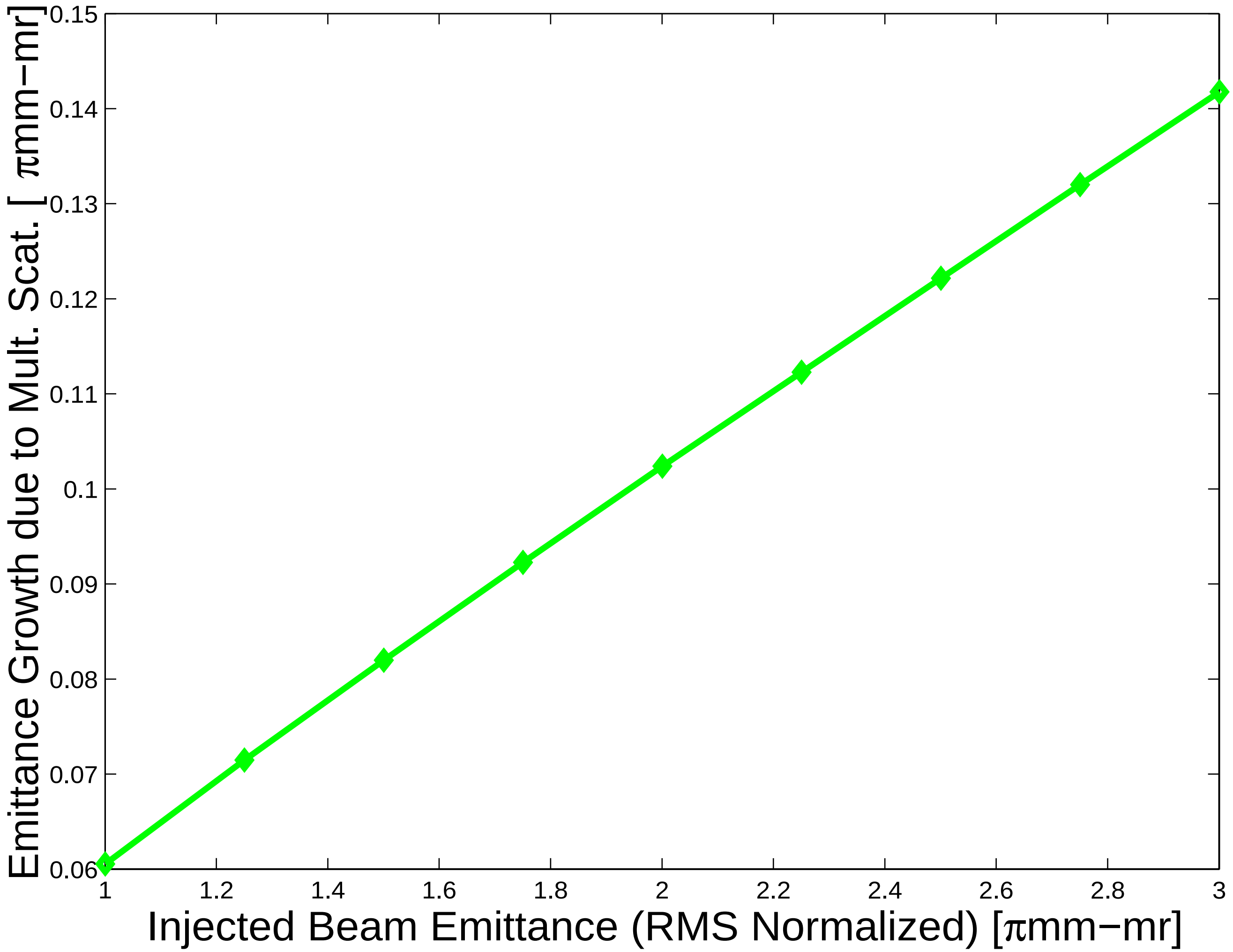

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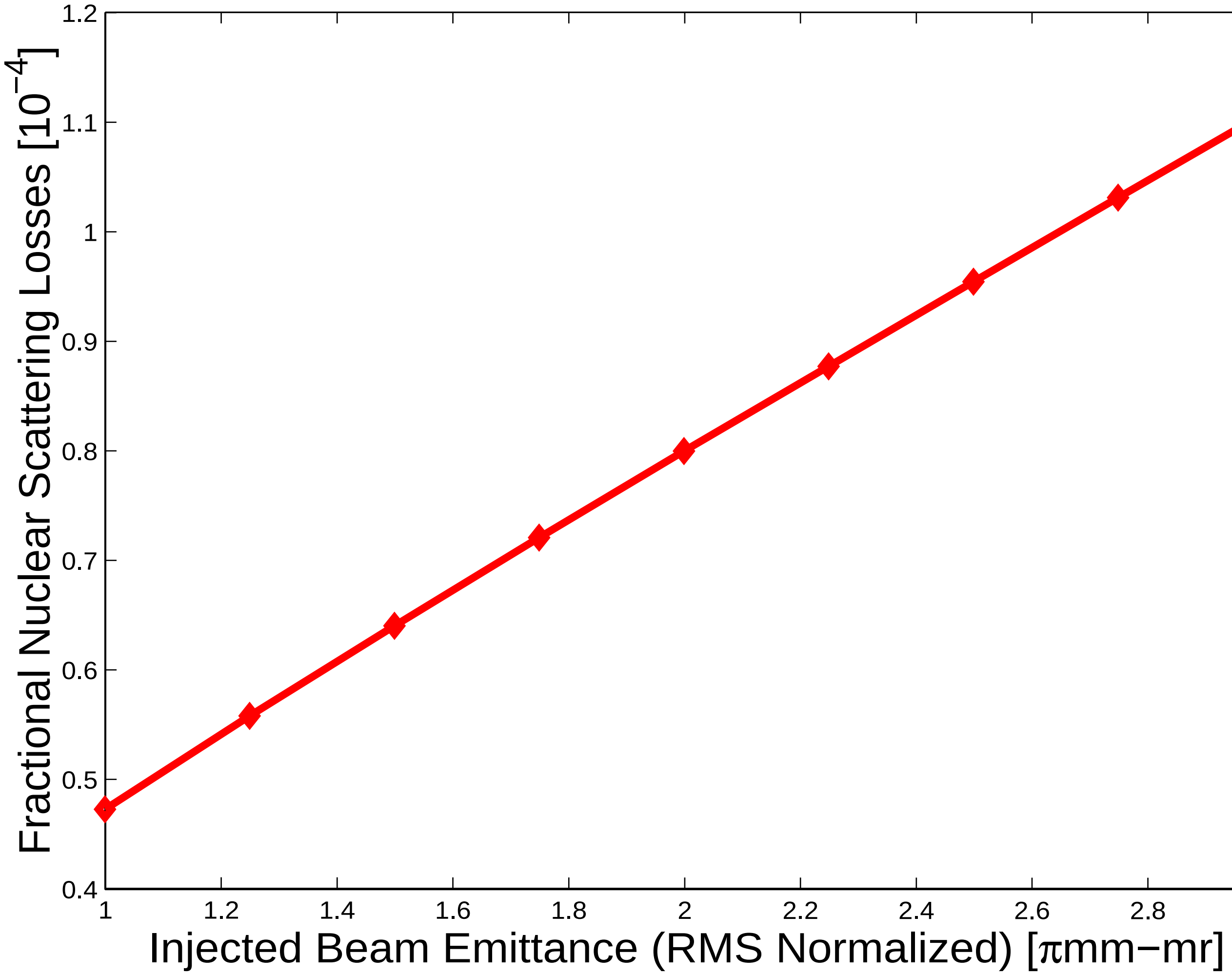

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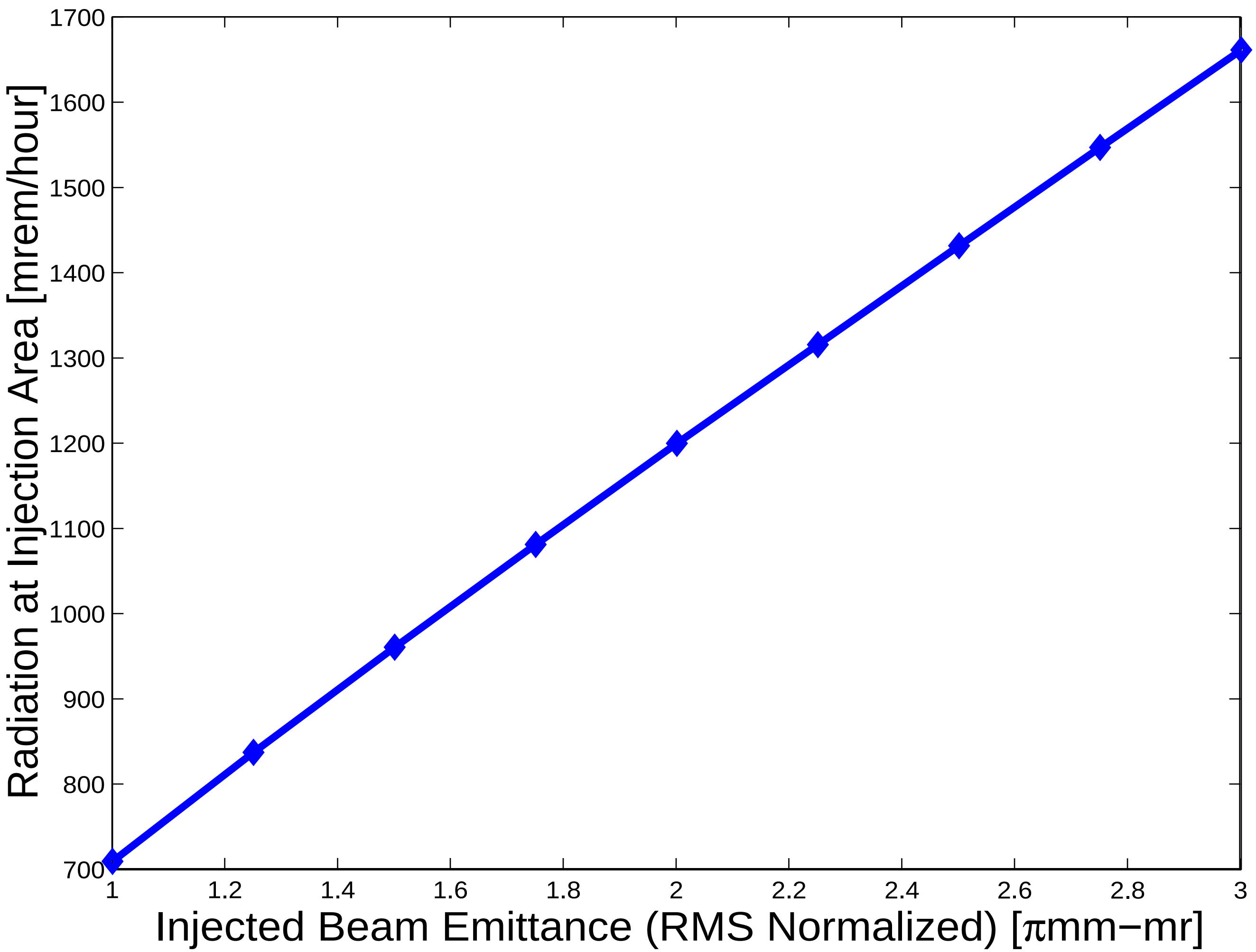

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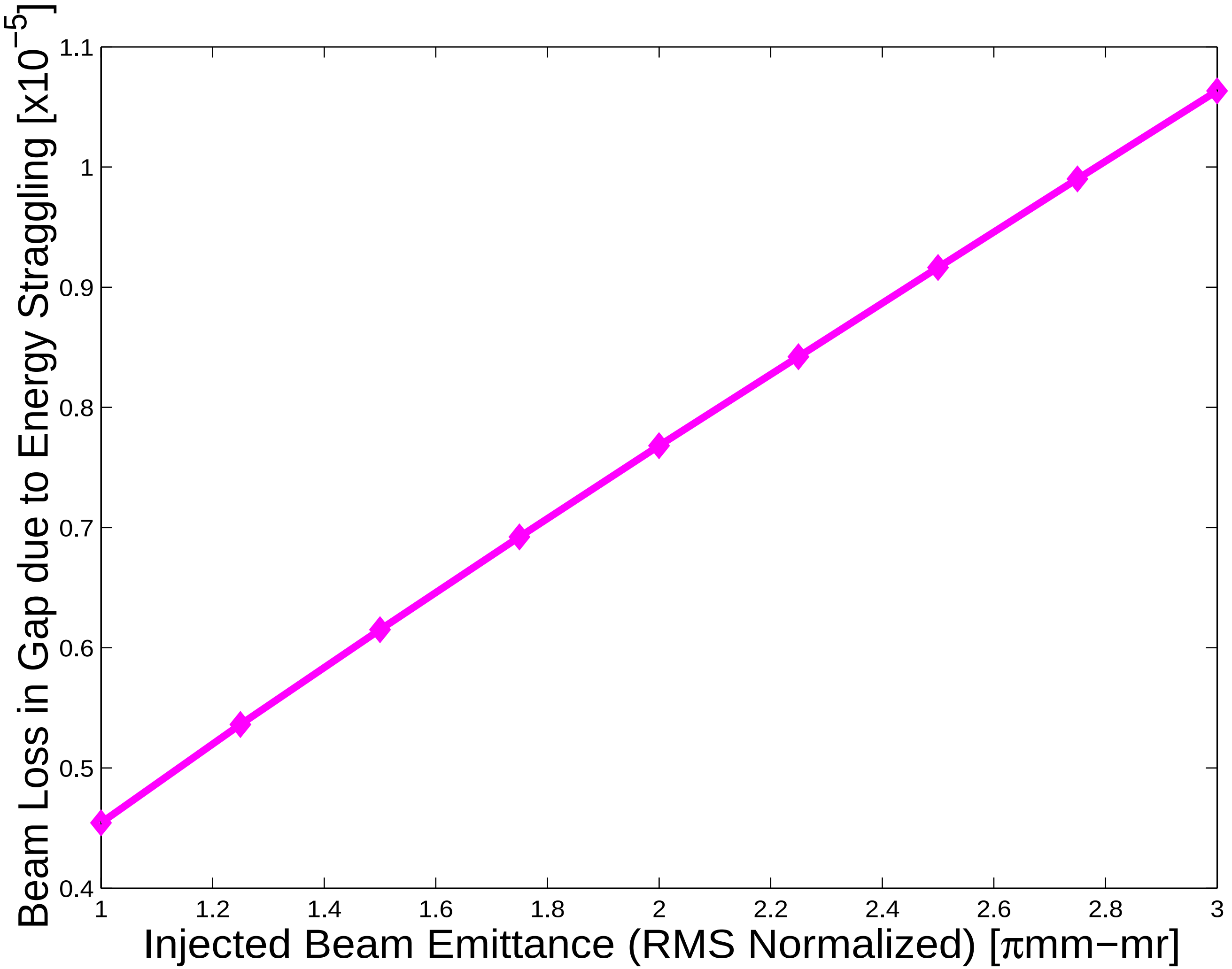

More Investigations

- Calculate/simulate the rate and the trajectory of un-stripped H^- and H^0 . Design injection beam dump correspondingly.
- Investigate the impact of LINAC emittance (Done)
- Investigate the impact of energy jitter and energy spread of LINAC beam
- Investigate the impact of injection mismatch
- Investigate foil heating and foil life-time (Done)

Additional Improvements

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- Move RFQ closer to ion source to control emittance growth
- 2nd harmonic cavity for the AGS to reduce space charge tune shift
- Better foil material