Ring and Transport System OVERVIEW

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Diagnostic Review

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Acknowledgments

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- **Acknowledgements:**

SNS AP and Diagnostic Groups

Introduction

BNL is responsible for three major accelerator systems:

- **High Energy Beam Transport (HEBT)**
- **Accumulator Ring (AR)**
- **Ring to Target Beam Transport (RTBT)**

Major function:

Take 1 GeV H^- beam of length 1msec and convert it into 0.6 microsecond beam.

Final beam has $2*10^{14}$ particles per pulse resulting in 2MW beam power at 60 Hz repetition rate.

Primary concern: *radio-activation*

- **High radio-activation at injection, extraction, collection**
  - **AGS: up to 10 mSv/hour at localized area**
- **High beam loss**
  - **FNAL Booster (30 - 40%): ramp tracking, debunching-recapturing, transition, aperture!**
  - **AGS/Booster (20 – 30%): pushing record intensity**
  - **ISIS (~15%): injection capture, initial ramp**
  - **PSR (0.3%! Full energy accumulation): injection loss**
- **Injection, initial ramping, transition, instability**

Sources of Beam Loss

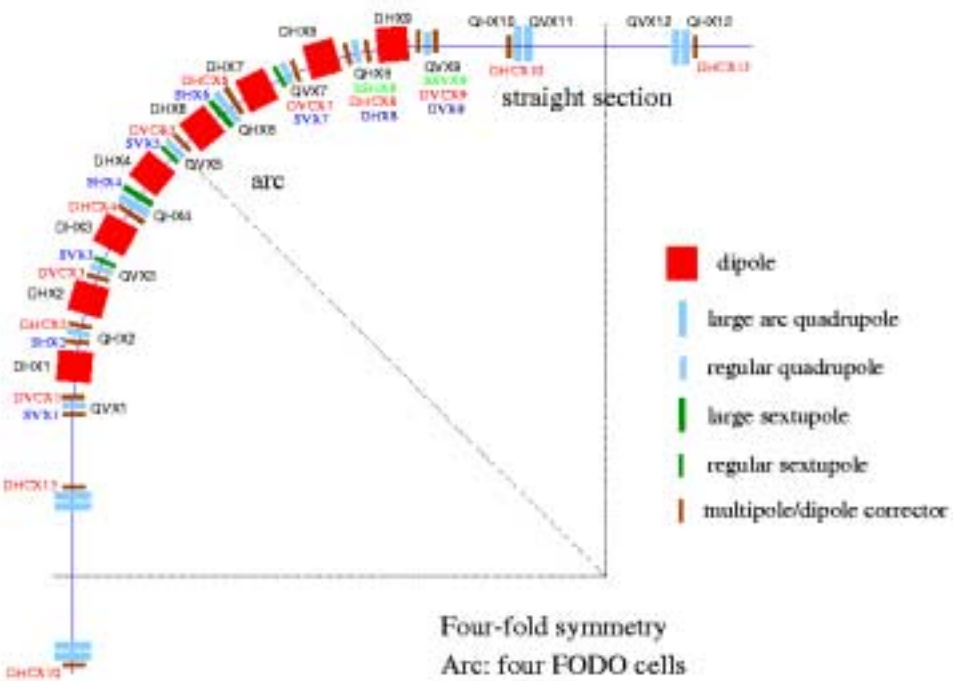
- radio-activation
  - 100 – 200 mrem / h average activation (30 cm, 4h down)
  - 1 – 2 W / m average beam power loss $\mapsto$ 0.02% of the total intensity @ 1GeV
- Sources of beam loss
  - Space charge: large tune-shift, crossing of resonances
  - Injection loss: Premature H^- and H^0 stripping, foil hits
  - Magnet errors: eddy-current & saturation, fringe fields
  - Instabilities: Head-tail, microwave, coupled bunch, electron cloud
  - Accidental loss: Ion source and linac malfunction, extraction kicker failure

Low-loss Design Philosophy

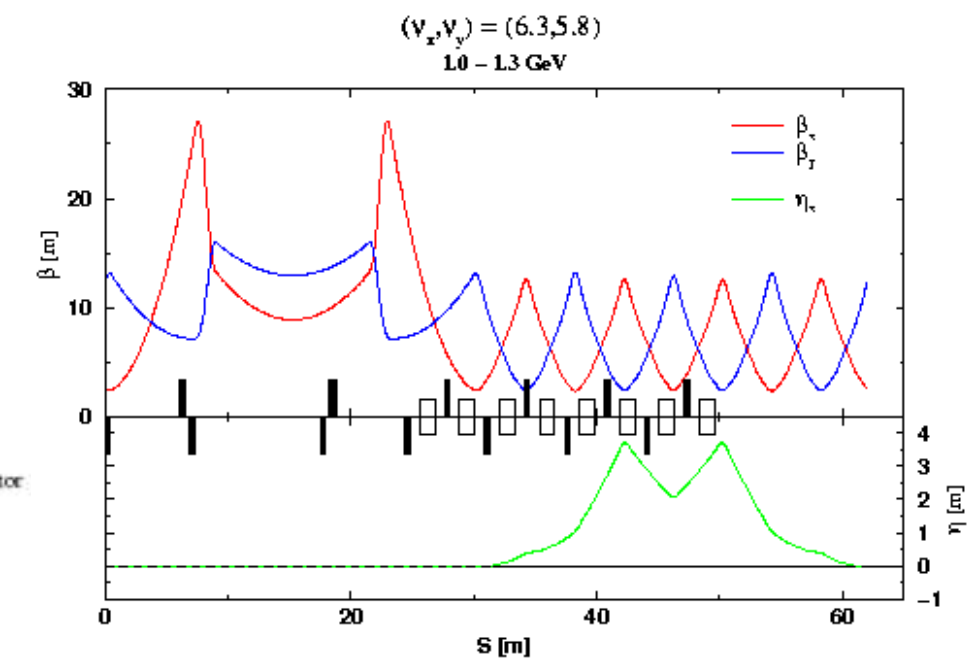
(Wei et al., PRST-AB, 2000)

- **Maximize acceptance (matching)**
- **Optimize injection process (stripping loss, foil hits, foil survival)**
- **Design a robust extraction system (two stages fast extraction)**
- **Improve magnet quality (multipole compensation), provide correction (chromaticity, amplitude detuning, resonances)**
- **Reduce space charge tune shift (painting)**
- **Control impedance & instabilities (chromatic sextupoles, energy spreader, tapering, TiN coating)**
- **Localize beam losses with collimators & Beam-In-Gap kicker**
- **Engineering issues (hardware shielding for an average 10^{-2} beam loss and up to two full pulses, quick removal of devices)**
- **Operational flexibility (tuning, painting schemes, adjustable collimation, interchangeable RF cavities)**
- **Off-normal condition protection (device failures, ground motion)**

Ring Lattice and Optics Functions

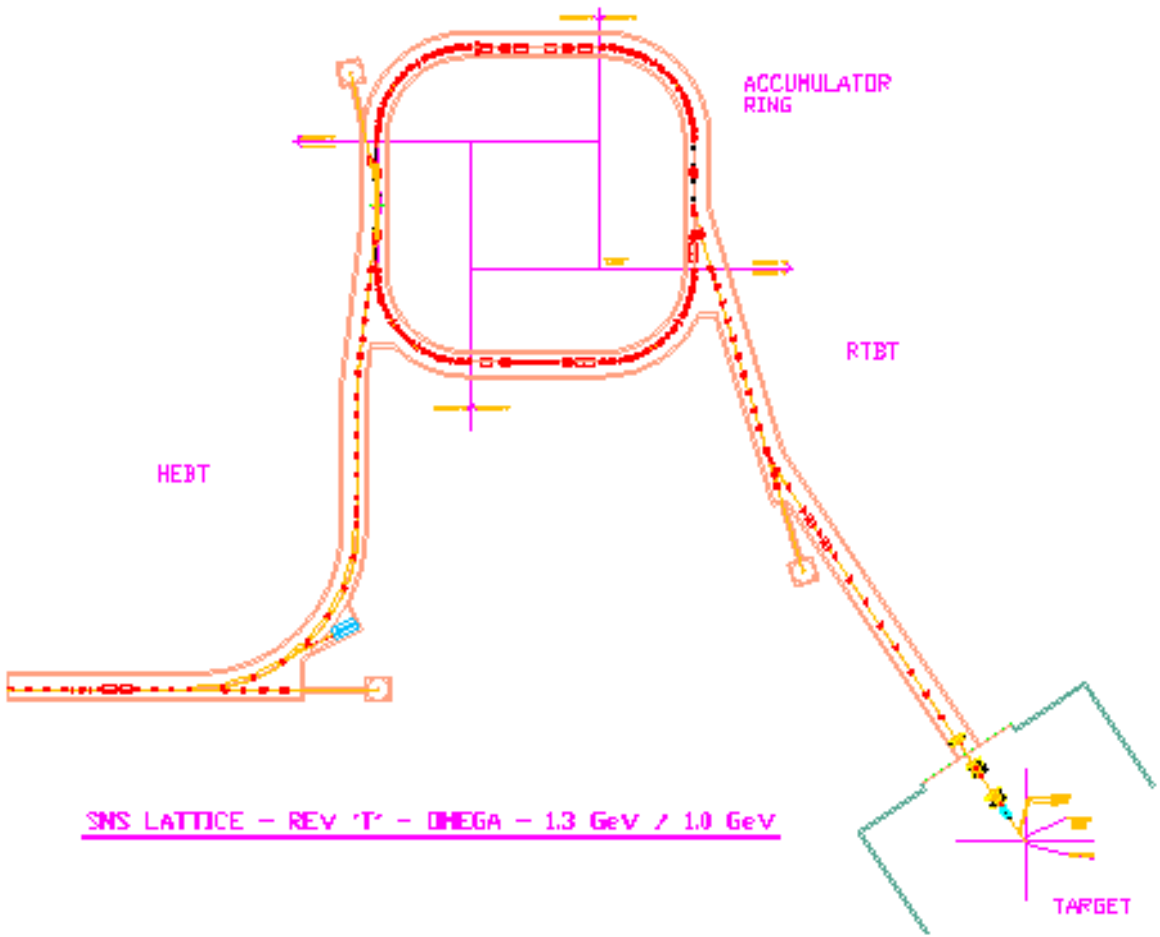


Four-fold symmetry
Arc: four FODO cells
S.S.: doublets



- **Perfect matching**
- **Arc achromats**
- **Zero dispersion in straights**

Ring & Transport System layout



Scope of Ring System

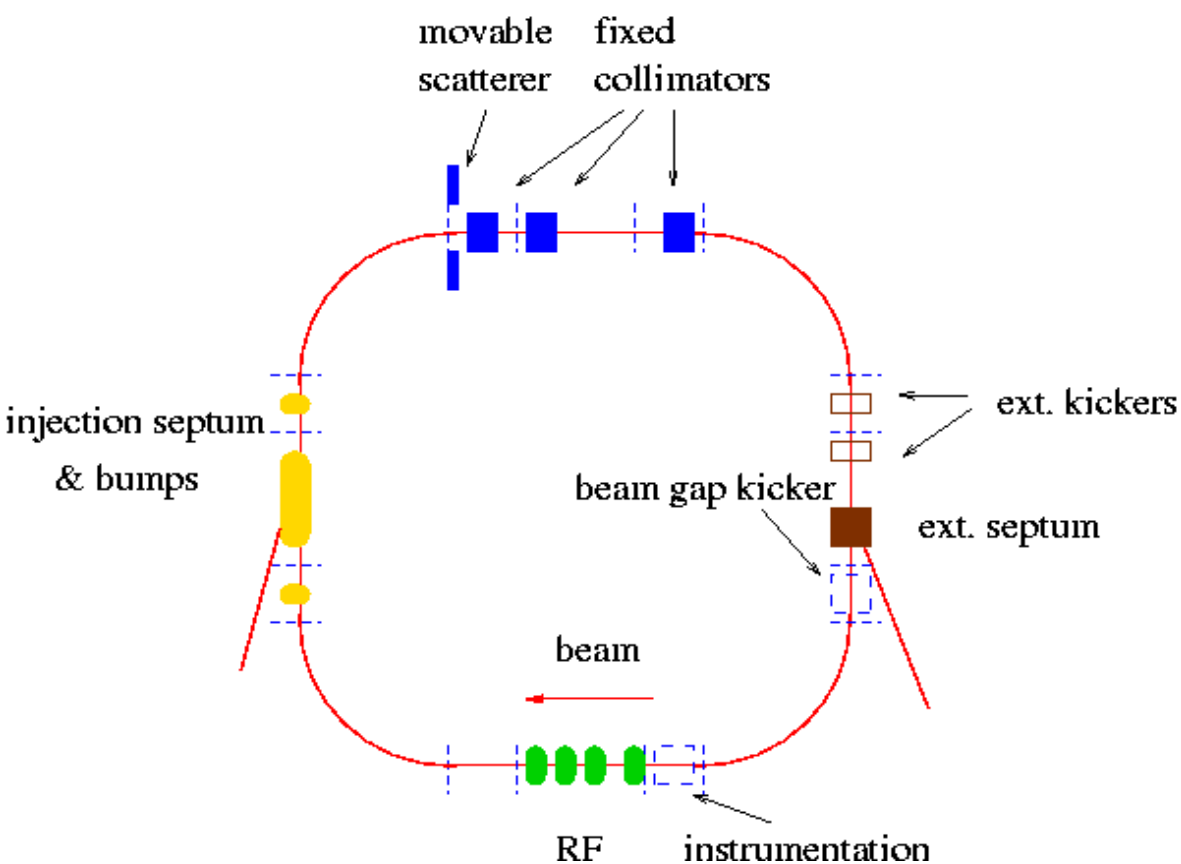
	HEBT	AR	RTBT
Length	169 m	248 m	151 m
Dipoles	9	32	2
Quads	41	52	32
Collimators	3+5 scrapers	3+4 scrapers	2
RF Stations	2	4	

Ring System is designed to cover energy range: 0.8-1.3GeV

Ring beam parameters

• Beam power	2MW
• Kinetic energy	1.0 GeV
• Transition Energy	5.25 GeV
• Number of protons	$2.08*10^{14}$
• Number of turns injected	1060
• Revolution period	945 ns
• Beam pulse length (inj)	650 ns
• Beam gap (inj)	295 ns
• Bunching factor	0.44
• Space-charge tune shift	0.2
• Uncontrolled beam loss	0.02%

Ring straight functions



- **Separate functions in each straight**
- **Four straights: 12.5 m; 2 x 6.85 m**
- **Injection modules**
- **Two-stage collimation**
- **3 (h=1)+1 (h=2) interchangeable RF cavities**
- **Beam-in-gap kicker**
- **Empty section for future use**

Ring features

Beam power of SNS – an order of magnitude higher than in existing machines.

Lowest beam loss achieved – PSR: 0.3%

We have to go up by 1 order of magnitude in power BUT need to go down in beam loss to only 0.02%

The ring accumulation is a dynamic process during which the beam intensity increases by more than 3 orders of magnitude and transverse beam radius increases by more than a factor of 10.

- **Diagnostic – becomes especially critical**

HEBT features

More Than a Transfer Line

- **Optical and Dispersion Matching to Linac and Ring**
- **Linac Energy Jitter Correction**
- **Increase Energy Spread**
- **Characterization of the beam (L-Dump)**
- **Cleans Halo, Protects Ring injection**
- **Cleans momentum tail from linac**

- **Diagnostic**

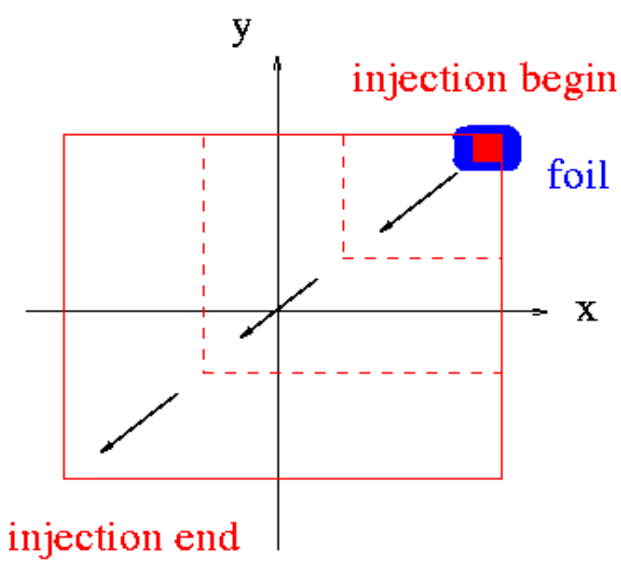
RTBT features

- Extraction (6 cells)
- Extraction Beam Dump (Two quads)
- Transport (6 cells)
- Beam Spreader (last 5 quads), beam spot on the target HxV: 200x70 mm
- Minimize Beam motion on the target in case of one or two kickers fails

- Diagnostic

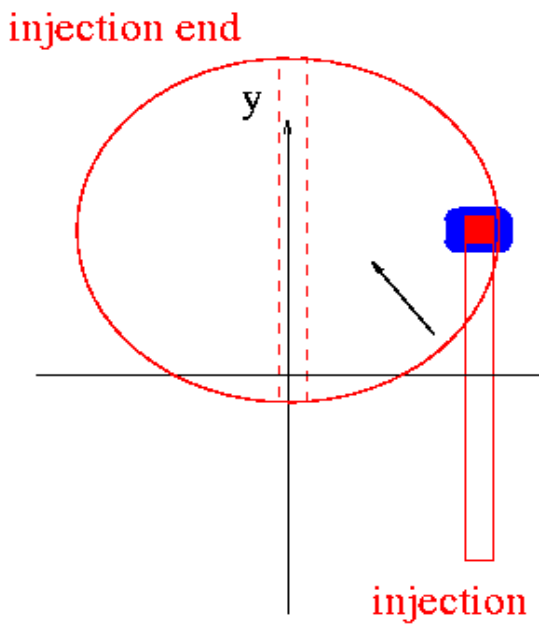
Ring injection options

Correlated



(a)

Anti-correlated



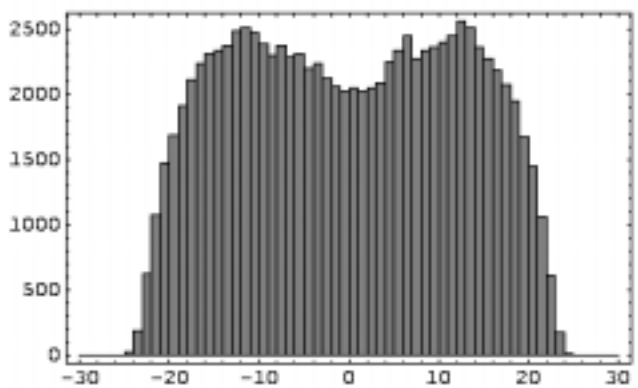
(b)

Example of final beam distribution (Ring)

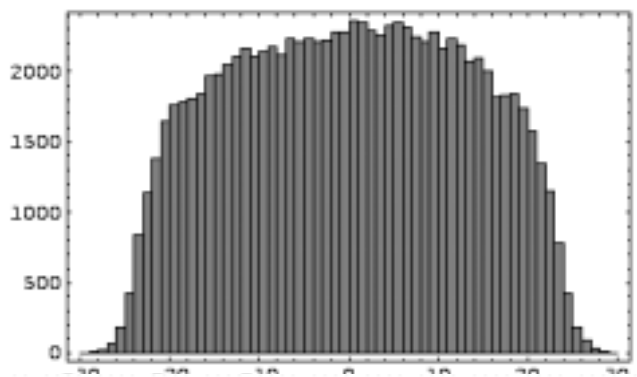
Correlated painting with & without space-charge (sqrt bump)

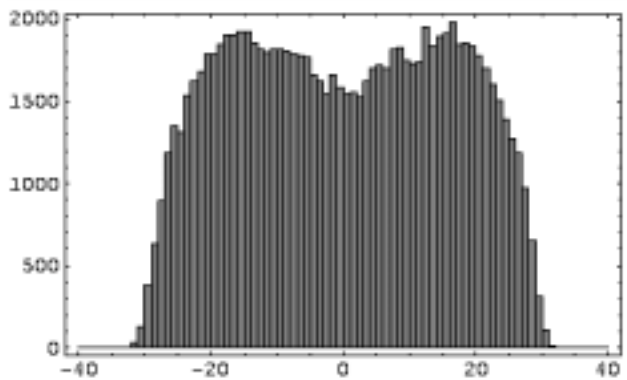
1D density plots without SC

1D density plots with SC

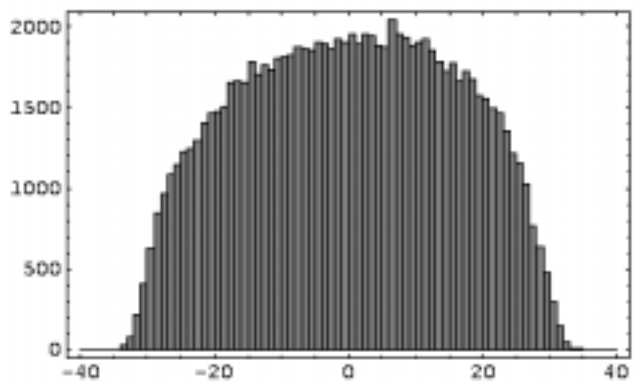


x





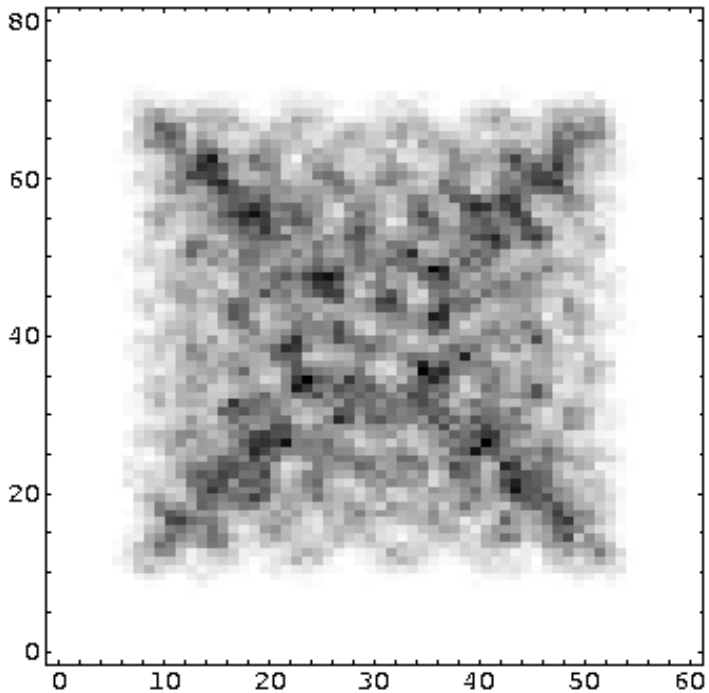
y



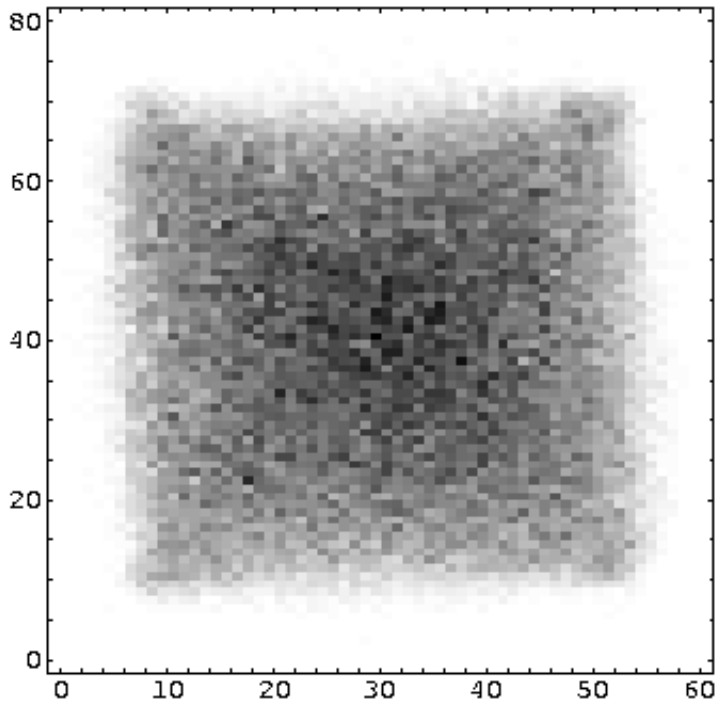
Example of final beam distribution (continued)

Correlated painting with & without space-charge (sqrt bump)

2D density plot without SC



2D density plot with SC

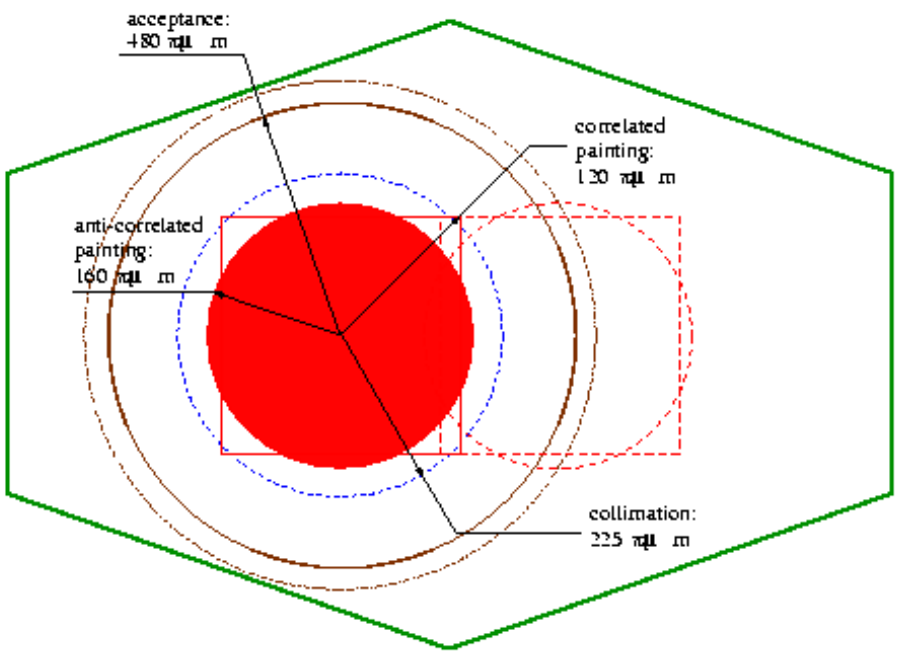


Major tune-spread contributions

Tune Spreads

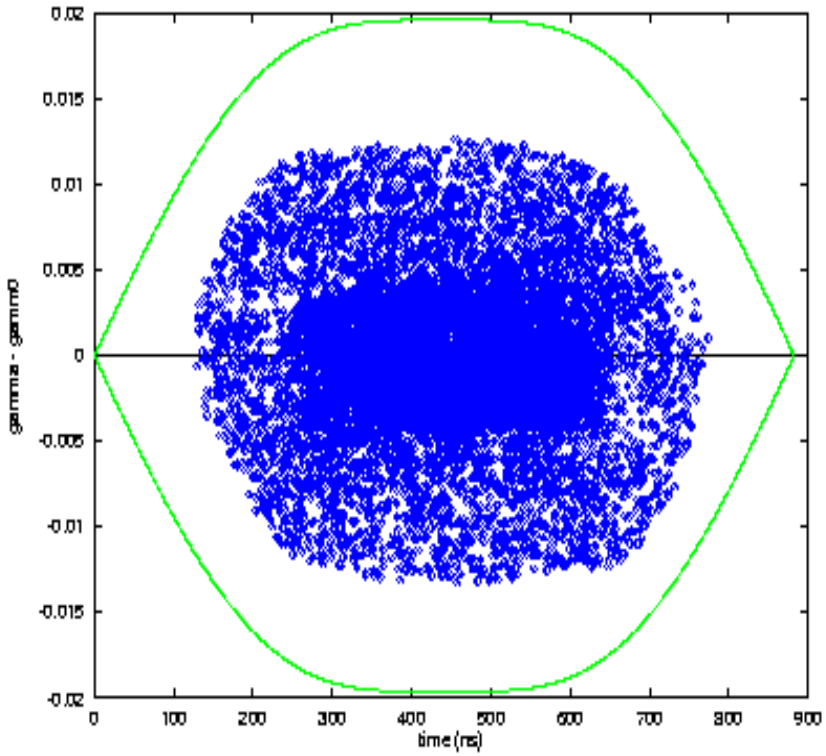
Mechanism	Full tune spread
Space-charge (2MW beam)	0.2
Chromaticity (1% mom. spread)	+/- 0.08
Fringe field 3D (at 480 pi mm mrad)	0.025
Uncomp. dodecapole fringe field (at 480 pi)	0.06
Compensated magnet errors	0.002
Kinematic nonlinearity (at 480 pi)	0.001

Ring transverse acceptance



- **Dipole chamber: (23x15 cm)**
- **Acceptance: 480 π mm mr ($\Delta p/p = \pm 1\%$)**
- **Beam emittance (full) 120-160 π mm mr**
- **Injection/extraction straight: 480 π mm mr ($\Delta p/p = \pm 1\%$)**
- **Arc: 480-600 π mm mr for $\Delta p/p = \pm 1\%$ depending on working points**

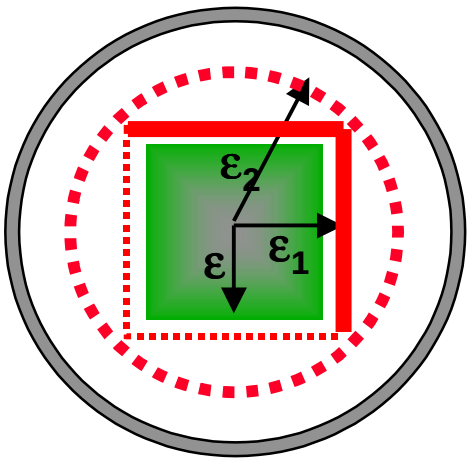
Ring longitudinal acceptance



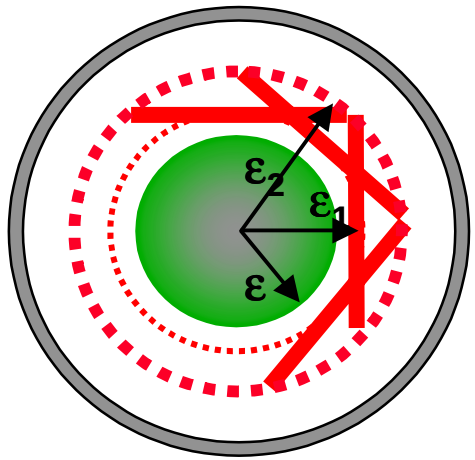
Beam Δp/p (full) spread	**±0.007**
RF acceptance	**±0.010**
Acceptance (full beam)	**±0.020**
Acceptance (0 amplitude)	**±0.036**
RF voltage (h=1)	**40-60 kV**
RF voltage (h=2)	**20 kV**
RF frequency (h=1)	**1.06-1.10 MHz**

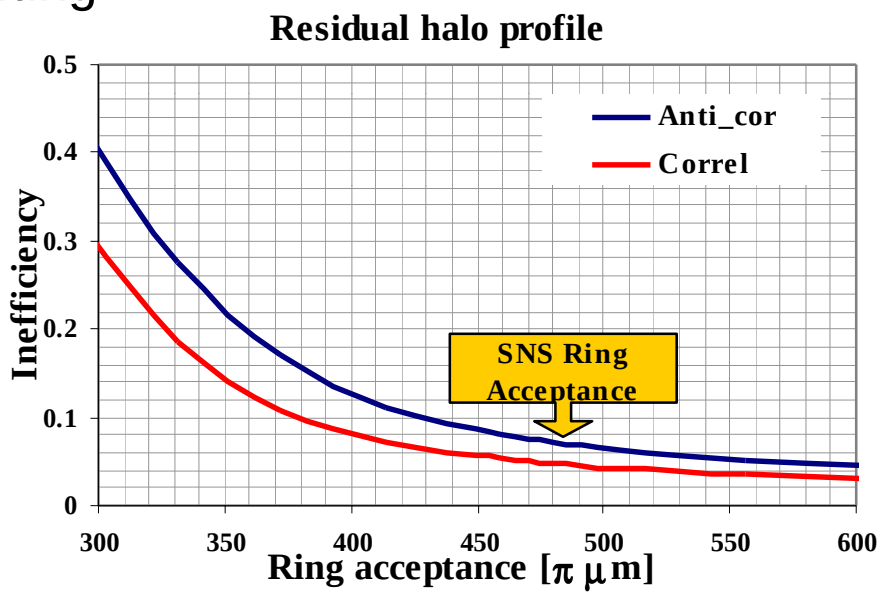
Collimation schemes for the 248m accumulator ring

Correlated painting



Anti-correlated painting





$\varepsilon_1 > \varepsilon = 120;\ \varepsilon_2 > 2\varepsilon_1$

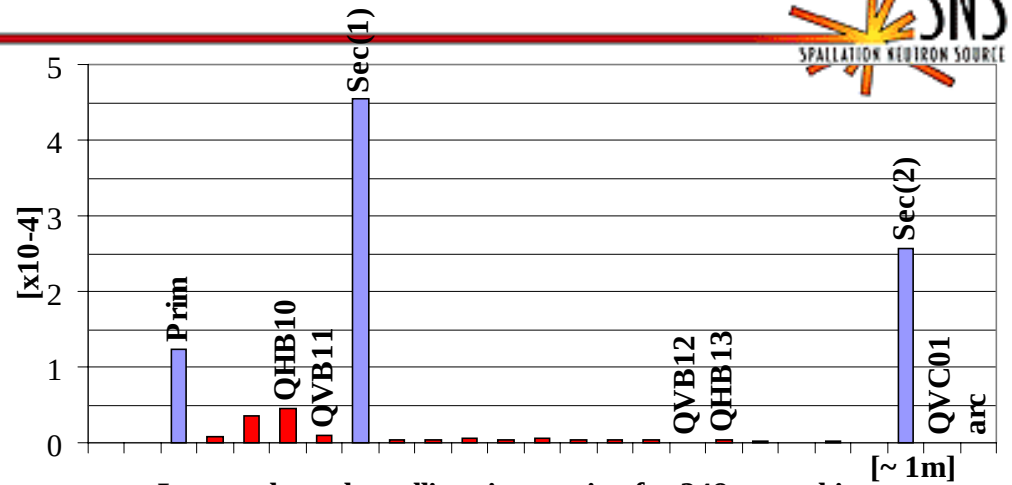
$\varepsilon_1 > \varepsilon = 160; \varepsilon_2 > \varepsilon_1$

$\varepsilon_1 = 140;\ \varepsilon_1 = 180;\ \varepsilon_2 = 300$

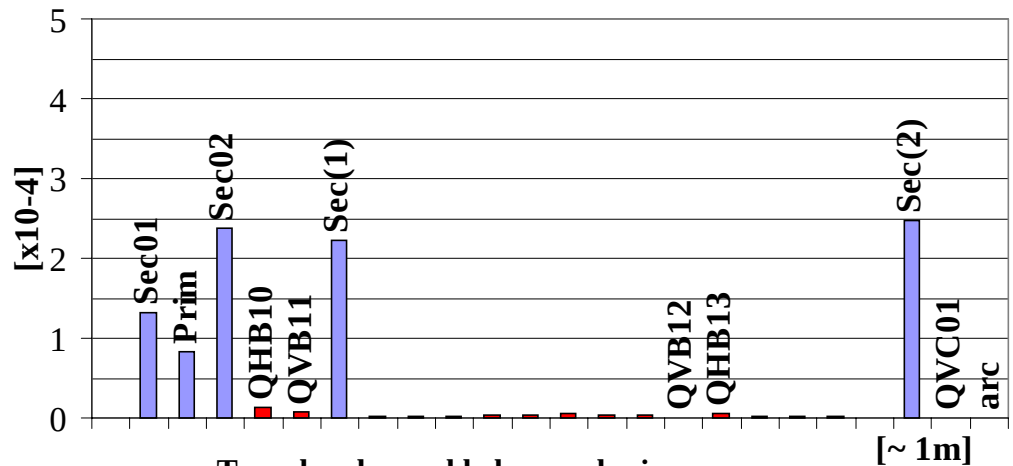
- **Flexible collimation for housing correlated and anti-correlated painting schemes**
- **Cleaning efficiency over 95%**

Loss distribution along the collimation section

- **Simulation results assuming 0.001 fractional loss**
- **Two absorbers added around the scraper reduce direct losses in downstream quadrupoles (~1/4)**
- **Residual radiation also reduced in a factor 2 to 4**
- **Cleaning straight section designed as a hot area**



Losses along the collimation section for 248m machine



Two absorbers added around primary scraper

Diagnostics

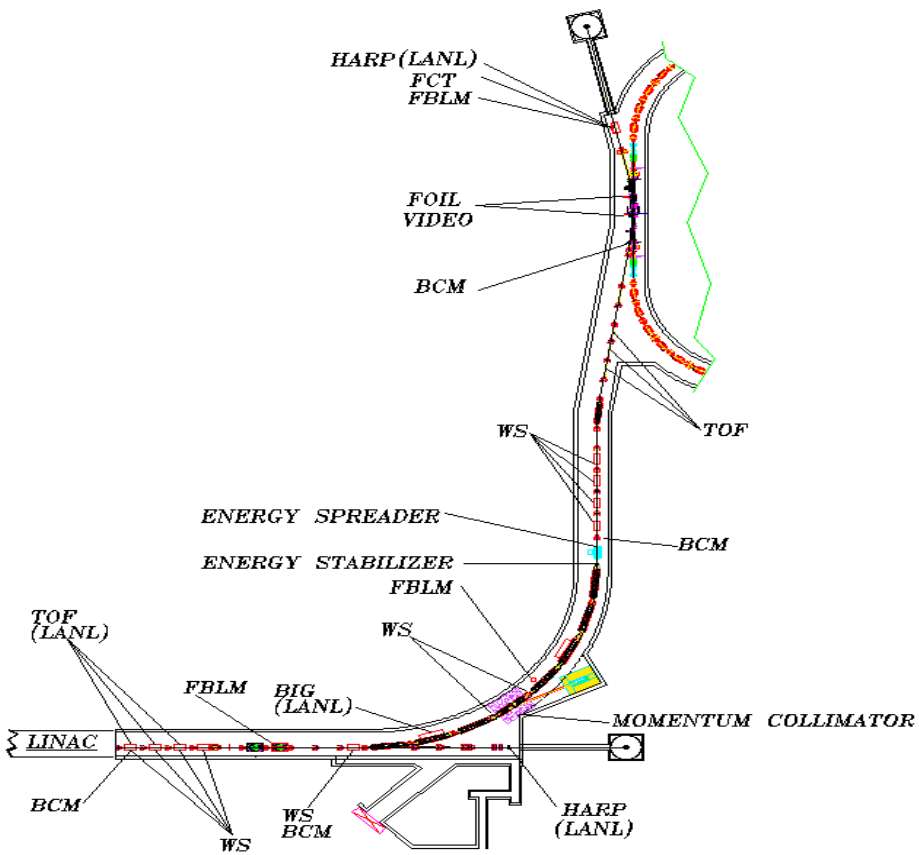
All of this requires Ring Diagnostic to be designed with a wide range of sensitivity and turn-by-turn capability to monitor:

- beam intensity (BCM)
- position, size, shape (BPM, WS)
- transverse and longitudinal profile (IPM, WCT)
- beam loss (BLM, FBLM)
- beam size and emittance (WS, IPM, Harp)
- tune (kick/PU, PPL, Quadrupole-Mode monitors)
- beam residual (BIG)
- electron cloud (e-detectors)

AP requirements on Ring System Diagnostic

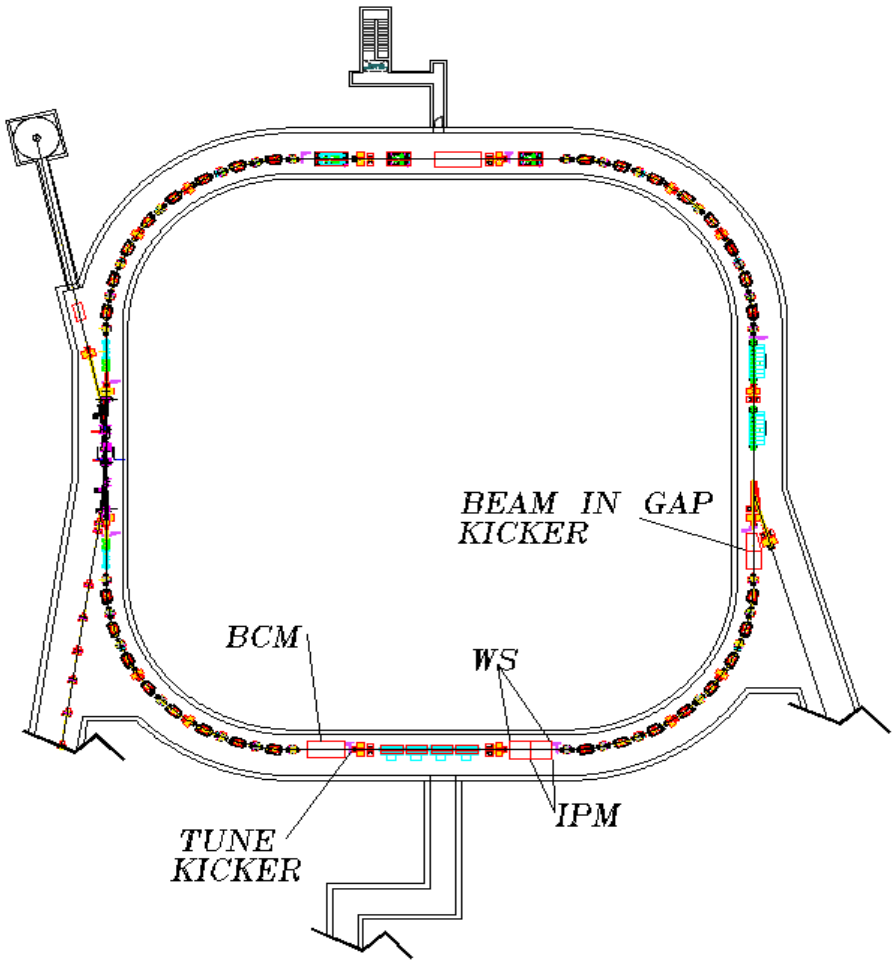
Ring System Diagnostics AP Requirements (12/2000)							
Device	Location	Intensity	Range	Accuracy	Resolution	Data structure	Comments
		[ppp]					
BPM	HEBT	5e10 - 2e14	+/- 20mm	+/-1 mm	0.15 mm		dual plane/high frequency
(position)	Ring-RTBT	5e10 - 2e14		+/-1 mm	0.15 mm	turn-by-turn	each quad/doublet, dual plane
BPM (TOF)	HEBT	5e10 - 2e14	+/- 180 deg	+/-2 deg	0.1 deg		402.5MHz
(phase)							
IPM	Ring	5e10 - 2e14	+/- 64mm	2mm	2mm	few per turn	three planes (H, V, 45 deg.)
Wire	HEBT		+/- 50mm		0.2mm		three planes
	Ring-RTBT	5e10 - 2e14	+/- 100mm		0.2mm	turn-by-turn steps	three planes
Harp	HEBT,RTBT					single shot	
Misc. profile	Ring						foil video
BLM (10 HZ)	Linac-Ring Sys	1e7 - 2e14	1-1000 rem/h	1%	0.6% (0.5 r/h)	average at 10Hz	of 1 W/m
BLM (35 KHZ)	Linac-Ring Sys	6e8 - 2e14	30-2.5e5 rem/h		30 rem/h	once/10 turns	
FBLM	SCL-to-HEBT		1-1000 rem/h			inside mini pulse	fast; not calibrated
	Ring		1-1000 rem/h			intra turn	fast; not calibrated
Current	MEBT-to-HEBT		15mA - 52 mA	1%	.1%	inside mini pulse	
	Ring-RTBT	5e10 - 2e14	15mA - 100A	1%	.1%	turn-by-turn	All are Fast Current Transf.
Tune	Ring			+/- 0.001			tune kicker/pick-up - coherent
							Phase Locked Loop (PLL)
							Quad. Monit. - incoherent
Beam-in-gap	HEBT		0 - 0.1mA	20%	.5mkA	each mini pulse	laser neutralization
	Ring		0 - 0.1 A	20%			BIG kicker/monitor
e - detectors	Ring		2e8 - 2e11 (e-)	5%	1e8 (e-)	turn-by-turn	conspicuous locations

HEBT Beam Instrumentation



Detectors	BNL	LANL
BIG	0	1
BPM	41	0
TOF	0	2
BLM	52	0
FBLM	3	0
BCM	5	0
WS	11	0
Foil Video	2	0
HARP	0	2

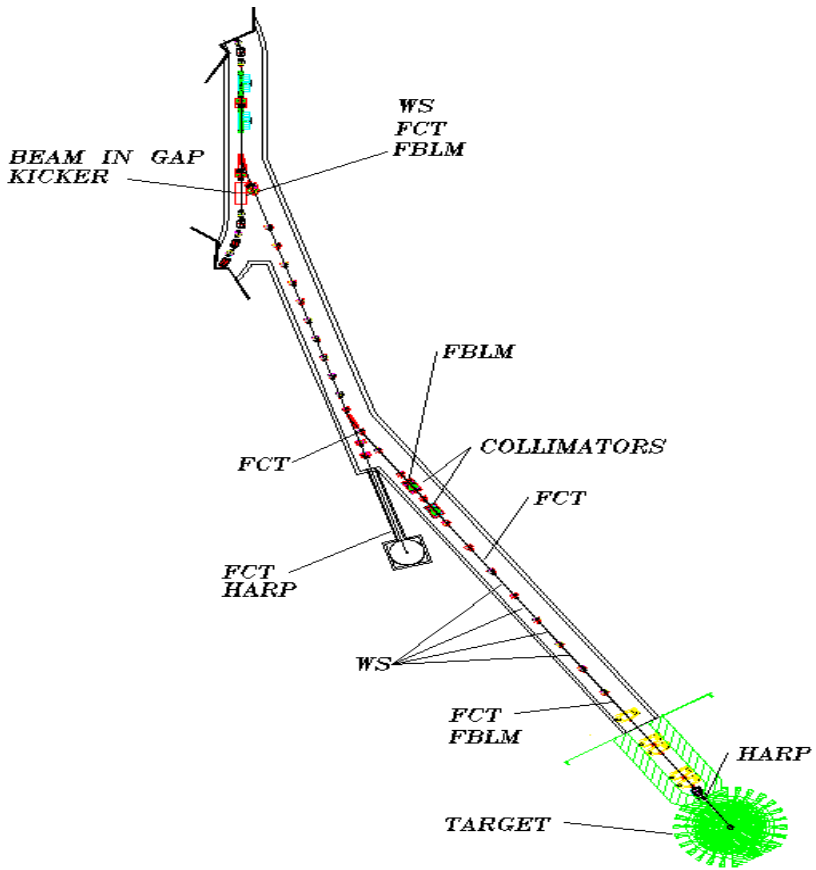
SNS Ring Instrumentation



Detectors	BNL	Comments
BPM	44	dual plane
BPM	2	RF radial loop
BLM	75	ion chamber
FBLM	12	photomultip.
BIG	1	kicker+PMT
IPM	2	H+V
WS	2	H+V
Coherent Tune	1	kick/PU
Incoherent Tune	2	PLL & QMM
BCM	1	FCT
WCM	2	including RF
E-detector	5	
High Moment	1	

RTBT Beam Instrumentation

Detectors	BNL	LANL
BPM	32	0
BLM	40	0
FBLM	3	0
HARP	0	2
WS	5	0
BCM (FCT)	5	0



Summary

Beam diagnostic is an essential constituent of any accelerator.

An accelerator is just as good as its diagnostic

With VERY strict requirement on beam loss (0.02%) we need to handle it MUCH better than in any existing high-intensity machine.

We will thus need the best possible diagnostic!