ACCELERATOR PHYSICS INTERFACE & INTEGRATION

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SNS/ORNL Accelerator Physics

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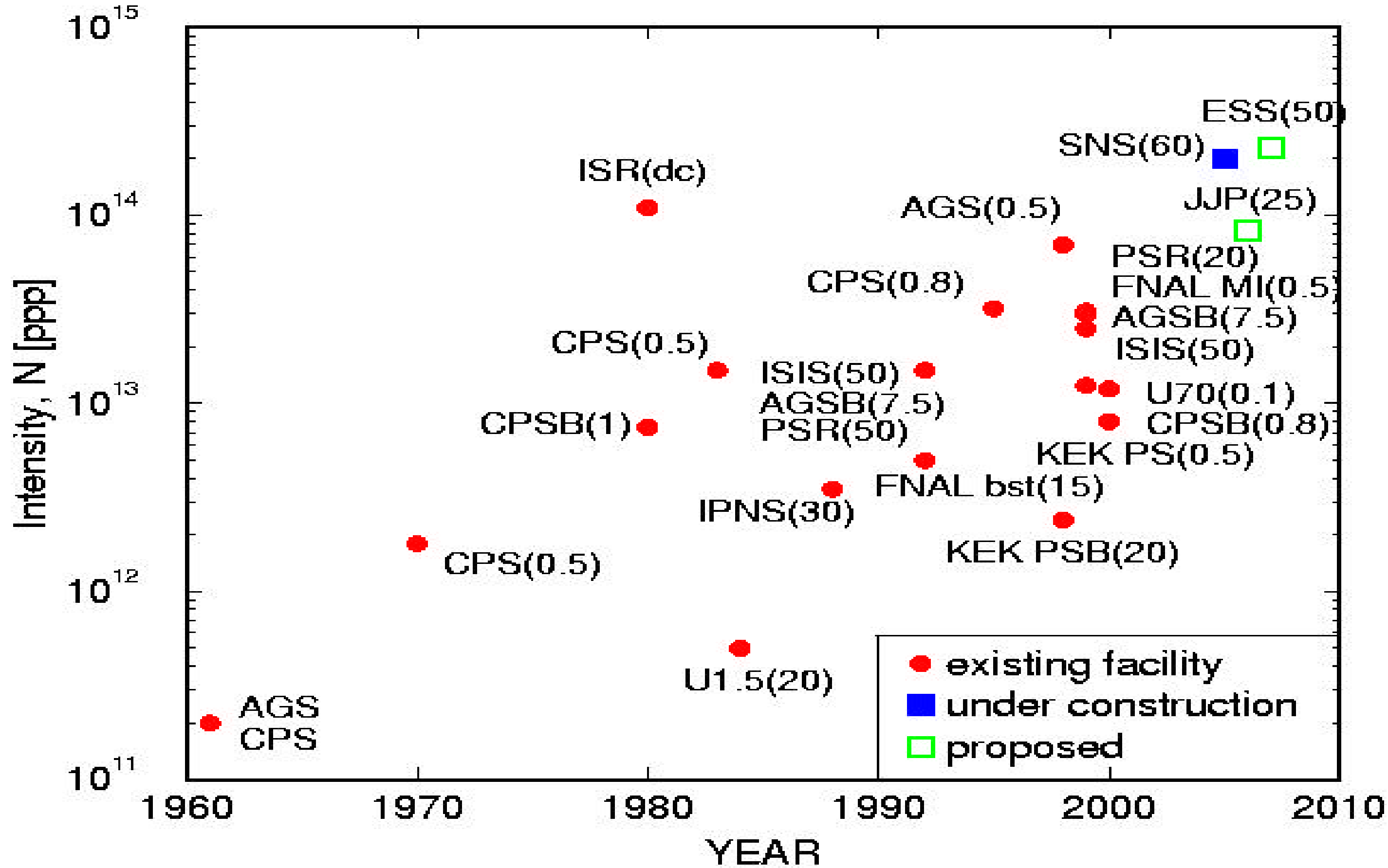
Outline

- Past activities, design & optimization philosophy
- End-to-end beam evolution & simulation
  - First-round parameter evolution & simulation
  - Independently studied subjects
- Interface issues
  - Linac / Ring interface; Ring / Target interface
- Challenges & attempts
  - Open issues, To-do list, R&D programs, integration efforts

SNS accelerator physics team

- LBNL Accelerator Physics:
  - R. Keller, J. Staples, R. Thomae, J. Reijonen …
- LANL Accelerator Physics
  - J. Stovall, S. Nath, H. Takeda, J. Billen, L.Young, S. Kurennoy …
- JLAB Accelerator Physics
  - R. Sundelin, P. Kneisel, J. Delayen, G. Krafft, L. Merminga, B. Yunn …
- BNL Accelerator Physics
  - J. Wei, D. Raparia, D.T. Abell, J. Beebe-Wang, M. Blaskiewicz, N. Catalan-Lasheras, A.V. Fedotov, C. Gardner, Y.Y. Lee, A. Luccio, N. Malitsky, W. Meng, Y. Papaphilippou, A. Shishlo, N. Tsoupas, S.Y. Zhang …
- ORNL Accelerator Physics
  - J. Wei, D. Raparia, A. Aleksandrov, S. Cousineau S. Danilov, M. Doleans, J. Galambos, J. Holmes, D. Jeon, S.H. Kim, N. Malitsky, E. Tanke, W. Wan
- Collaborators
  - K. Crandall (TechSource), C. Pagani, P. Pierini (INFN), S. Simrock (DESY), K. Bongardt (COSY), R. Ryne, J. Qiang, T. Wangler (LANL) …
  - G. Rees, C. Prior (ISIS) S. Machida (KEK), R. Macek (PSR), R. Talman (Cornell), R. Gluckstern (UMCP), S.Y. Lee (IUCF), D. Kaltchev (TRIUMF), J.B. Jeanneret , H. Schonauer (CERN), S. Tepikian, D. Trbojevic (BNL), …

Intensity evolution



Low-loss design philosophy

- A low-loss design -- (~ 1 W / m uncontrolled loss)
  - SC RF linac with large bore radius; moderate accelerating gradient
  - Accumulator ring design with adequate acceptance $A/\varepsilon>2$
  - Space charge minimization; Injection optimization
  - Magnet field compensation/correction; impedance/instability control
- Localize beam loss to shielded area
  - Multi-stage (LEBT, MEBT, ring) beam-gap cleaning
  - HEBT betatron/energy collimation; Ring 2-stage collimation; RTBT
- Flexibility
  - SRF linac flexible tuning & ring energy compatibility
  - Adjustable tunes; flexible injection; adjustable collimation
  - Programmable ramp & possible correction; foil & spare interchange
- Engineering reliability: design redundancy, heat/radiation resist.
- Accident prevention: immune to FE, linac & kicker malfunction

Project challenges (physical & technical)

- First storage ring requiring 10^{-4} uncontrolled beam loss
  - 1 -- 2 W / m beam loss for hands-on maintenance (LAMPF, AGS, Booster)
  - presently achieving 3×10^{-3} fractional beam loss at PSR
  - large aperture, robust injection, magnet field quality, instability control
  - collimation, beam-in-gap cleaning, activation & protection
- First proton linac using super-conducting RF cavities
  - important to control energy jitter and emittance for a proton beam
  - beam loading, Lorentz detuning, microphonics, complications for $\beta \ll 1$
- Mega Watt pulsed facility; stringent target requirements
  - eliminate ``hot spots'', control beam profile
- High peak current (65 mA IS) with specified emittance
  - Ion source lifetime & reliability
  - tuning & emittance preservation in MEBT

Linac design guideline (LANL/JLAB/ORNL)

- State-of-the-art design yet to match tight schedule
  - Moderate peak/accelerating field; room for upgrade
  - Confident RF control: one cavity per klystron for energy offset, Lorentz detuning, microphonics, beam loading/transient effects
- Maximizing acceleration gradient & beam energy
  - Optimized two cavity beta type: flexible for gradient upgrade, but large phase slip requires detailed error sensitivity analysis
  - Constant gradient & continuous focusing: maximizing field strength but compromising equipartition law; disputed but converging at a "moderate" momentum growth level
- Energy upgrade-ability
  - Extra space (6 cryo modules) for higher energy, power, second target

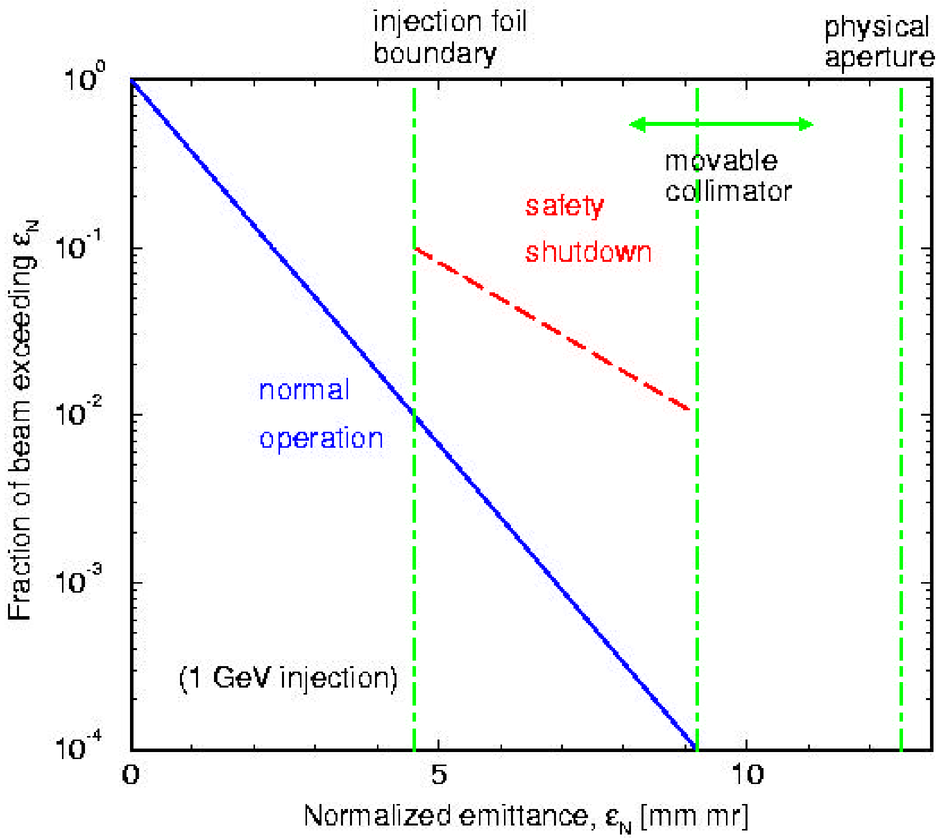
Linac activities (LANL/JLAB/ORNL/more)

- Output energy & power maximization
  - Nominal 1 GeV energy, 2 MW beam power
  - Minimum 0.8 GeV for 1 MW beam power
- Energy upgrade compatibility
  - Up to 1.3 GeV, total above 2.65 MW for second target
  - Space for 6 extra cryo reserved; compatible/adjustable ring
- Matching transverse & longitudinal; continuous focusing
- Error sensitivity
  - Steep reduction of transit time factor near low energy end
  - End-cell phase slip relatively large
- Other beam dynamics
  - Non-equipartition study; R. Ryne, J. Qiang (LANL) I. Hofmann (GSI)
  - 2D vs 3D space-charge comparison (LANL, INFN)
  - Cavity field modeling comparison (LANL, INFN)
  - Higher-order-mode analysis & beam break-up (ORNL/JLAB/LANL)

Emittance evolution

Device	Emittance (ε_N) rms [μm]	Centroid Jitter [mm]	Comments
IS/LEBT	0.09 / 0.2		Aberrations
RFQ	0.19 -- 0.21		
MEBT	0.22 -- 0.27		Transverse space-charge growth due to long chopper gap
Linac	0.34 -- 0.56	~ +/- 0.2	Transverse space-charge mismatch due to lattice & acc. gradient change; vibrations
HEBT	0.34 -- 0.59	~ +/- 0.2	Energy spread (chromatic)
Ring	(44+44)	~ +/- 0.2	Painting; space-charge/magnet error halo (Full ε_{UN} = 120+120 μm)
RTBT	(44+44)	~ +/- 0.2	Full ε_{UN} = 120+120 μm
Target	50 – 150 times		Window scattering

Linac/Ring interface (transverse)



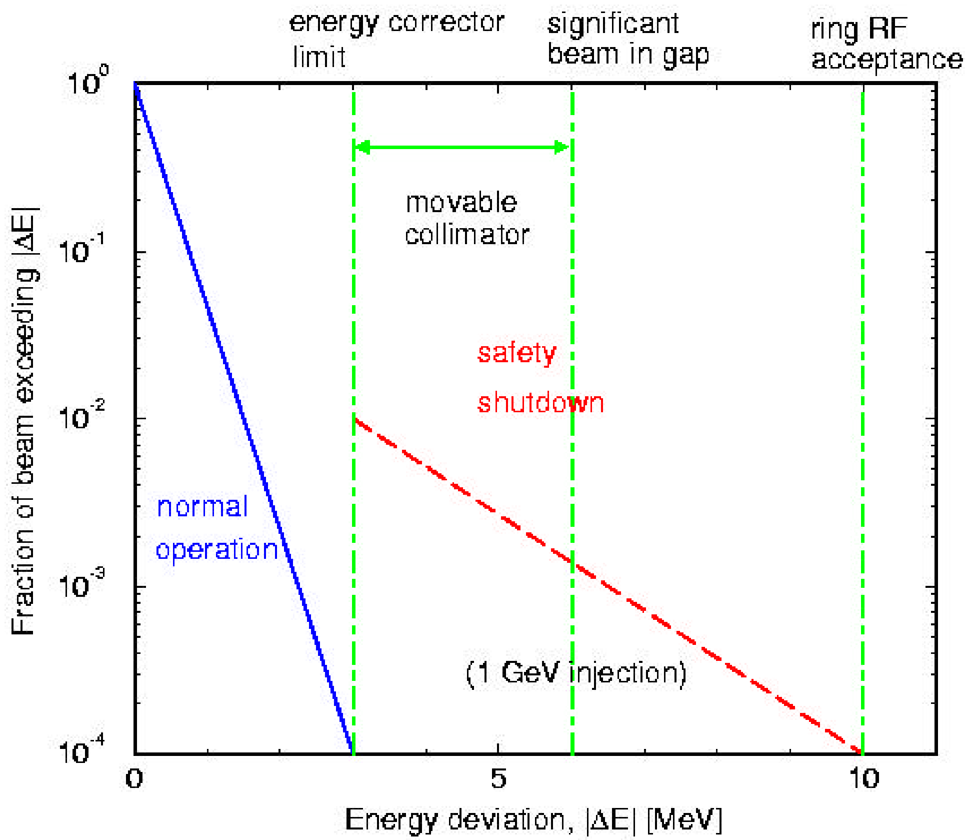
(equivalent; including jitter)

- Nominal norm. rms emittance ~ 0.4 mm mr
- Nominal jitter ~ 0.2 mm
- Larger emittance compromises power & loss/activation
- Injection dump accepts 10% power
- Movable transverse collimator for protection; takes 1% power
- Chamber aperture: HEBT rf cavity …

Energy spread evolution

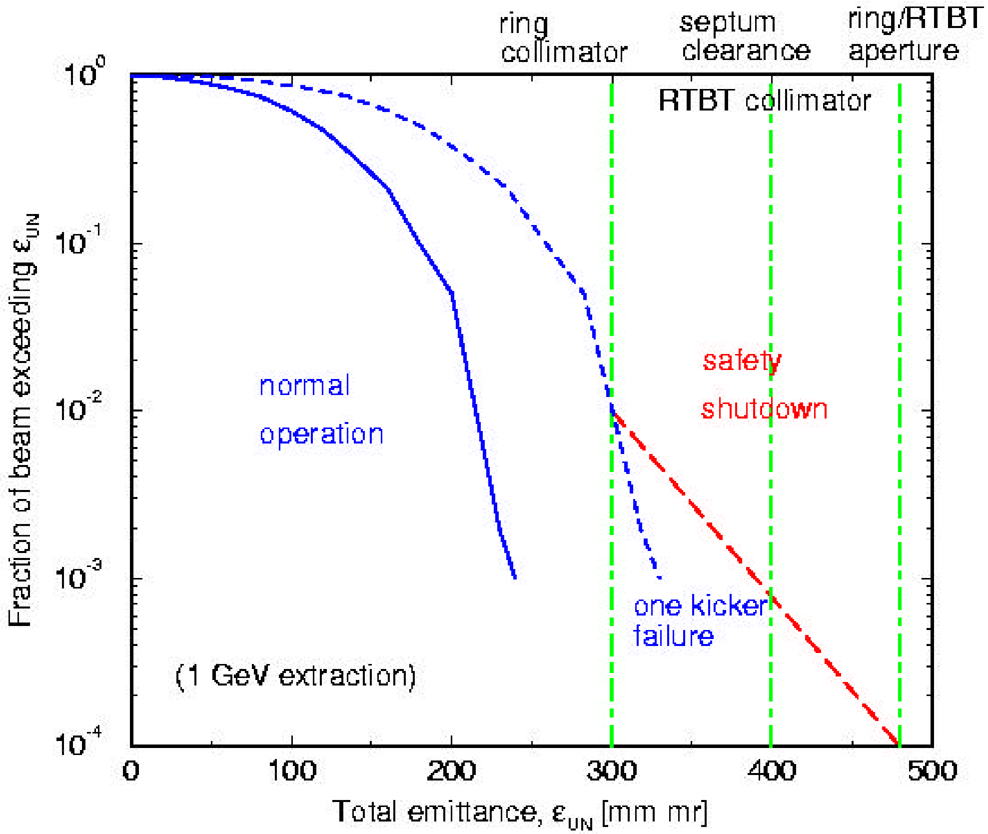
Device	Spread [MeV]	Centroid Jitter [MeV]	Comments
Linac	0.33 (rms)	+/- 1.6	0.5% amplitude, 0.5 deg. phase error (space charge, magnet errors, beam loading/transient, Lorentz detuning, microphonics, non-equipartition)
HEBT collimator	0.72 (rms)	+/- 1.6	space charge growth due to lack of RF
Energy corrector	1.3 -> 0.85 (rms)	+/- 1.6 -> +/- 0.25	space charge growth due to lack of RF; cavity corrects the energy error (jitter & spread)
Energy spreader	+/- 4 (full)		cavity broadens the energy core, without enhancing tail
Ring	+/- 10 (full)		gap cleanness versus beam stability

Linac/Ring interface (longitudinal)



- Nominal energy jitter limit: +/- 2.2 MeV
- Nominal rms energy spread: 0.3 MeV
- Impact of beam loading, Lorentz detuning, and microphonics (under study) 1-on-1 controlled
- Movable energy collimator; corrector limit & ring acceptance
- Two locations of energy corrector reserved (present & future)

Ring/Target interface

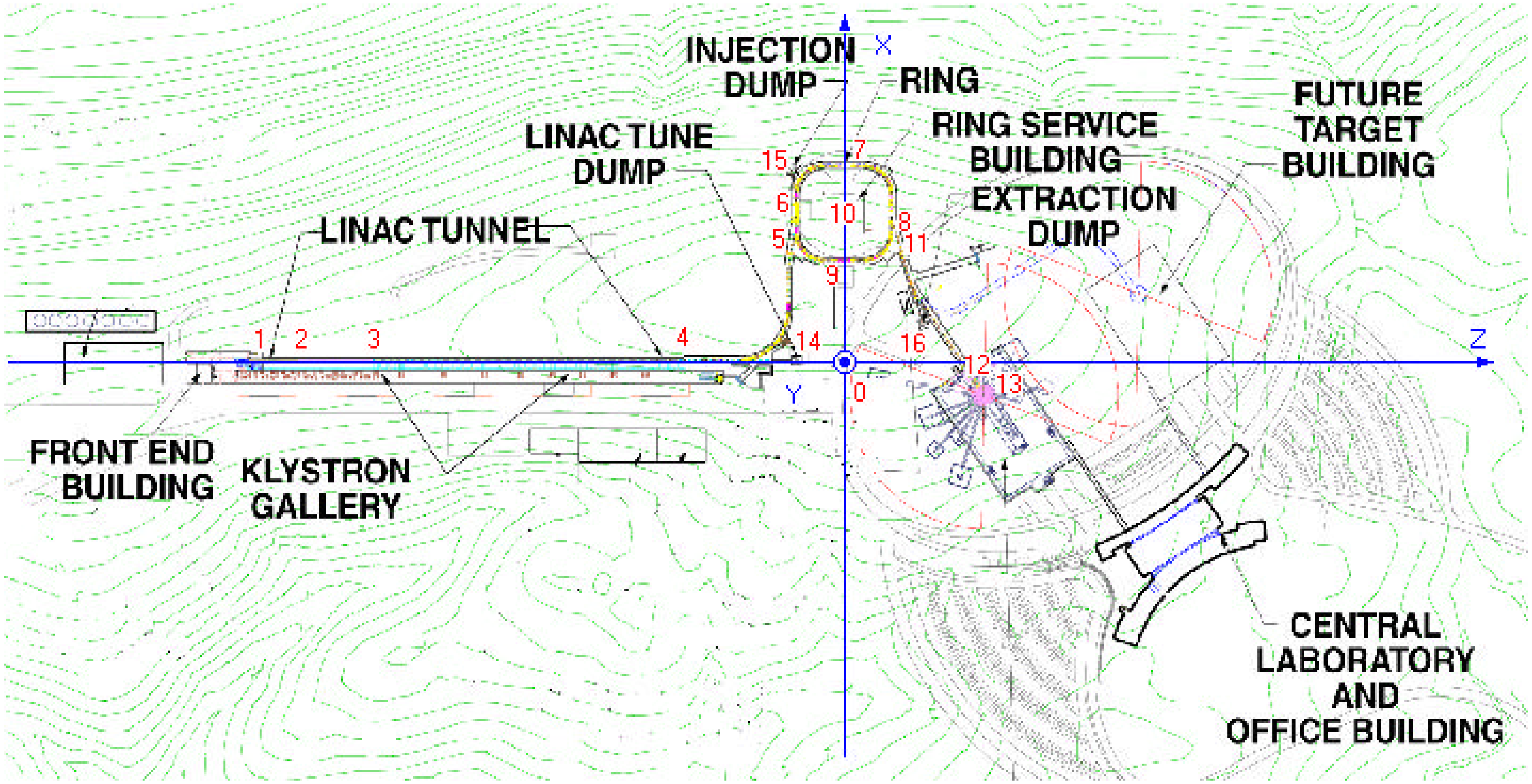


- Tolerable to one extraction kicker failure
- Beam position on target not moved upon kicker failure
- RTBT collimator for accident protection
- Accelerator-target interface involves many aspects: painting, halo, window scattering, collimation, ...

Project challenges (managerial)

- First six-lab collaboration on a large-scale accelerator
  - ANL, BNL, JLAB, LANL, LBNL, ORNL
  - individual laboratories are intellectual owners of component design
  - ORNL is the ultimate owner of the entire facility
- Integration & interface
  - ``horizontal'' integration, subject by subject, from front-end to target (diagnostics, loss & activation, simulation, software, applications & database, ground motion, installation, measurement, steering …)
  - interface between Front End/linac, Linac/HEBT, RTBT/Target
- One-team spirit
  - share source codes, working files; routine video & visits; joint beam/facility tests & machine machine studies
  - share resources, complement each other in work, joint publications
  - ORNL team to inherit the ``big team'' after commissioning

Definition of global key coordinates



SNS AP reference working tables

- Shared working parameters, files, codes from Front End to Target

SNS AP Reference Tables http://www.sns.gov/APGroup/refTables/reftables.htm

SNS Accelerator Physics Reference Working Tables

Contents:

SNS publications (example)

Abstracts

XX International Linac Conference

TUD22 (Poster)

Presenter: J. Stovall (LANL)
email: jstovall@lanl.gov
Status: Complete
FullText: ps or pdf

Superconducting-Linac for the SNS

J. STOVALL, S. NATH, H. TAKEDA, J. BILLEN, L.Young, M. Lynch, D. Rees (LANL), J. GALAMBOS, D. JEON, D. RAPARIA, J. WEI (SNS/ORNL), R. SUNDELIN (TJNAF), K. Crandall (TechSource), C. PAGANI, P. PIERINI (INFN)

The Spallation Neutron Source (SNS) linac is comprised of both normal and superconducting rf (SRF) accelerating structures. The SRF linac accelerates the beam from 186 to 1000 MeV through a series of ~100 low-b 'elliptical' multi-cell niobium cavities. This paper describes the SRF linac architecture, cavity design, rf power distribution topology, cavity field control philosophy, and the expected beam dynamics performance.

Open issues & to-do list (Overall)

– Detailed loss and activation distribution & protection
  - (project office, N. Catalan-Lasheras, instrumentation, …)
– AP diagnostics requirements and measurement procedure
– More coherent end-to-end simulation
– “standard” simulation codes from RFQ to Ring foil
  - (H. Takeda with D. Raparia & J. Staples)
– Impact of ground motion, settlement, misalignment, vibrations
– Target requirements (distribution, margin, protection)?
  - (D. Raparia, J. Beebe-Wang, Target group, …)
– Application software (J. Galambos, N. Malitsky, S. Sathe …)
– Common ring/line software (UAL / ORBIT) (N. Malitsky, A. Fedotov, J. Holmes, S. Danilov, S. Cousineau …)

Joint R&D programs:

- Collimator performance & codes benchmarking
  - Protvino U70 machine study; first collimation calibration near 1 GeV; scraper material, collimator geometry, adjustability
- PSR instability & e-p effects
  - PSR (LANL), SNS, Princeton, LBNL joint effort; PSR machine study
  - vacuum chamber coating, wide-band damper, loss reduction,
- Booster study & simulation codes benchmarking
  - AGS Booster & PSR space charge study; painting/steering scenario
  - calibration of loss and distribution versus space charge
- Injection foil manufacturing and test
  - establish foil manufacturing facility at ORNL; foil test at BNL
- Broad collaboration on SRF linac design & ring design
  - Linac: INFN/CEA, JAERI, DESY, LANL/GSI
  - Ring: ISIS, KEK, PSR, Protvino IHEP, AGS, CERN, Cornell

Reliability & design redundancy (overall)

- Controls:
  - Machine protection system limits integral dose
  - 1-pulse emergency shut-down for prevent damage
- Instrumentation
  - Redundant diagnostics (BPMs, wire scanners, harps)
- Vacuum
  - Operational at worse vacuum
- Spares
  - Spare magnets (main dipoles, quads, kickers, correctors) & PS

ORNL/AP staffing plan

- 16 physicists upon commissioning, in 3 teams
- Group leader: J. Wei; Deputy group leader/target interface: D. Raparia
- Ring/Transport line physics team: Leader: (J. Wei, acting – to be filled)
- S. Danilov (impedance calculation & measurement/collective effects/e-p/coating/shielding)
- J. Holmes (optics/machine tuning/space charge/RF support; BNL interface)
- W. Wan (ground motion/magnet analysis/compensation/correction, Survey interface)
- Ring physicist (activation/loss/collimation/alignment, transport/injection/extraction & Installation filled)
- S. Cousineau (student) (beam-in-gap, instability simulation & software implementation)
- Linac/Front end physics team: Leader: (D. Raparia, acting – to be filled)
- A. Aleksandrov (Front end / LBNL interface, instrumentation interface)
- J. Galambos (matrixed) (linac optimization, steering/tuning; LANL interface)
- D. Jeon (Linac/cavity beam dynamics)
- S. Kim (Cavity analysis/development/linac technology / JLAB interface)
- E. Tanke (RFQ, DTL, CCL testing/tuning, linac technology & operations interface)
- M. Doleans (student) (SC RF cavity design, test & analysis)
- Applications/Software team: Leaders: J. Galambos/N. Malitsky
- P. Chu (commissioning algorithm/operation physics support)
- Computer analyst (database, commissioning/operation support to be filled)
- Computer analyst (on-line infra-structure development/maintenance; to be filled)
- A. Shishlo (off-line simulation/documentation; presently at BNL)

Summary

- First-order physics design completed from FE to Target
  - IS / RFQ: first beam & tuning underway / prepared
  - SRF linac: geometry & design settled – physically comfortable
  - Accumulator ring: 1st article measurements & detailed analysis
- End-to-end simulation started
  - First-round parameter evolution & simulation completed
  - Detailed studies performed on individual subjects
  - Open issues identified & actively pursued; codes developed
- Interface issues identified & pursued
- Cold model test & magnet measurement analysis, database & application software development, and commissioning plan
- Greatly improved one-team spirit
  - Shared codes, resources, collaborators, publications