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Title: Short-bunch stacking mode for the PSR - an overview

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Short-Bunch Stacking Mode for The PSR – An Overview

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The overall upgrade involving a short-bunch PSR mode proceeds from the WNR-proposed-project main goals, namely greatly enhancing the ability of WNR to measure neutron cross-sections and reaction dynamics, in a wide neutron-energy range (from thermal to ~100 MeV.) Such measurements, with currently (and surprisingly) sparse data, are of strong interest to several areas of application including weapons physics, nuclear science and engineering, astrophysics, homeland defense, and isotope production. As well as accelerator enhancement, the project plans to enhance radiochemistry facilities, revive the shelved radioactive-species-isotope separator, create a new faster version (TANGO) of the DANCE detector used at LANSCE, and enhance the WNR target and data-taking infrastructure. The cost of all this has not been well established and funding (so far negligible) is needed to achieve a credible figure. A proposal has been sent to NNSA and is currently under review.

This document is limited to discussion of first-order considerations for a short-bunch mode at the PSR that is needed to achieve project goals. (Additionally, a brief venture into facility performance is given, since the proposal has not been distributed.) Such a mode is taken to mean the overlay of single LANSCE micropulses turn by turn into RF- capture buckets. (This mode has also been called a "pulse-stacking" mode, a misnomer since stacking is already done in the PSR long-bunch mode.) Topics noted briefly in this document are:

- Achievable beam parameters and consequences for WNR
- Devices in the ring needed to implement a short-pulse beam. These include
    - Bump magnets
    - Extraction kicker
    - RF bunching
- Beam dynamics for injection and storage
- RF stability and control
- Beam transport to WNR
- Issues and efforts needed (in Appendix A)

These topics are here treated briefly to provide an overview and list of conclusions to be formed or that have been investigated. In particular, the ring beam dynamics and buncher RF specifications have undergone substantial analyses that will be detailed in further documents. Many further considerations, requiring study but little R&D will be needed for a working accelerator design including beam diagnostics, control systems, shielding, personnel protection, power distribution, and simply fitting new equipment into existing areas. As usual, models of the RF cavities and their tuning are to be built and tested.

Beam Structure and Intensity

WNR requires short beam pulses with high intensity to produce a range of neutron energies upon target. The neutron energies are sorted by time-of-flight over 20 m to produce measurements, e.g., cross sections as a function of neutron energy. Hence a short proton pulse is needed for resolution as well as sufficient time between pulses to prevent frame overlap. The present mode of WNR neutron production relies on single short pulses (micropulse mode) selected by the chopper in the linac low-energy section. Each WNR micropulse consists of pre-bunched beam containing protons that would otherwise fit into three 201-MHz pulses, thus containing 6×10^{8} protons. This structure is to be continued for the short-bunch mode in filling the ring with injection of 1 such micropulse per ring bunch. Use of the short-pulse mode greatly increases performance measures over present operation and over associated measurements by LANSCE.

There are several indicators of maximum pulse intensity in the short-pulse mode. Tune-shift results indicate a maximum storage of $<1 \times 10^{11}$ protons/ns of pulse length. Other factors such as RF control and buncher power also enter into these considerations. For this study we considered three bunch time lengths, 1.5 ns, 5 ns, and 10 ns, presumed to bracket the range of tolerable pulse widths. Conservatively, we set the protons/pulse at 1×10^{11} and 3×10^{11}, and 6×10^{11} for the three pulse lengths, respectively. In turn, these pulse lengths correspond to the 180th, 52nd, and 26th ring harmonic (or buncher frequencies of 503.125, 145.347 MHz and 72.673 MHz for corresponding pulses with $\pm 3\pi/4$ phase widths.) To achieve these pulse intensities at the 6×10^{8} delivered micropulse intensity, injection would proceed over 500 turns for the 1.5 and 5 ns cases corresponding to an injection time of 180 μs for both pulse lengths[1]. The 10-ns case requires 1000 turns or 360 μs. Although some leeway in maximum intensities may be possible, first order considerations (including the Robinson and tune-shift instabilities) indicate that a factor-of-two increase is not possible. Higher-order instabilities as well as practical considerations may further limit the protons/pulse, but on the basis of the present analysis the above pulse intensities are readily achievable.

At the time of this writing the 10-ns pulse is adopted as a compromise between intensity and resolution. The long response time of the 73-MHz cavity as well as the higher intensity may, however, preclude use of this longer pulse. It is unlikely that more than one buncher frequency will be used, each frequency requiring a separate cavity. Additionally, a macropulse repetition rate of 120 Hz is assumed, presuming the planned LANSCE upgrade, with 20 Hz delivered to LANSCE. A 625 ms long macropulse is also assumed. Three modes of operation are envisioned with the 10-ns pulse:

Mode 1 – The ring delivers a single pulse containing 6×10^{11} protons every macropulse. This mode has the widest spacing between pulses, 8.3 ms, which allows measurement to the lowest neutron energy (without wrap around,) about 0.02 eV, with an average current of 9.8 μA.

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[1] It may seem surprising that both pulse lengths take the same injection time, but, as Jeff Kolski points out, the ring in the long pulse mode is operated at the 72.07 harmonic instead of the 72nd harmonic of the 201.25 MHz linac micropulse frequency in order to prevent overlapping of the injected pulses. (The ring nominal energy differs from that of the beam so that the injected micropulses walk along the bucket.) The spacing between pulses relative to the bucket center is 0.35 ns. Hence injection for the 503-MHz frequency takes three times as long as it would were the 72nd harmonic used. This is an advantage for our two lower-frequency cases in that the beam is longitudinally painted.

Mode 2 – Four pulses are stored in the ring and one extracted every 2 ms. This mode delivers the highest time-averaged neutron flux on sample, with an average current of 39 μA, allowing measurement down to 0.4 eV.

Mode 3 – Single pulses are formed in the ring with immediate extraction and immediate injection of a subsequent pulse. This mode delivers the maximum number of pulses. It is assumed that separation between pulses is limited by a 120-μs recharge time for the bump magnets in the PSR. If $2x10^{11}$ protons are accumulated in each pulse, 5 pulses can be delivered, with an average current of 16 μA and minimum neutron energy of 145 eV. This mode limits the neutrons/pulse, useful when instantaneous proton rate is limited by detector characteristics. It can also serve as a temporary backup mode if difficulty is encountered with long ring-storage times.

The number of pulses in the ring is *a priori* limited by extraction-kicker timing to four in number, each spaced 90° apart. Therefore, with the three frequencies, respectively, $4x10^{11}$, $1.2x10^{12}$, or $2.4x10^{12}$ protons/macropulse can be achieved with respective currents of 6.5, 19.3, or 39 μA at the envisioned 100-Hz macropulse repetition rate and in mode 2. Using WNR calculations, a gain of up to several orders of magnitude in neutron intensity over that of LANSCE occurs for neutron energies greater than ~1 keV, using the 10-ns pulse.

The gain in neutron-intensity performance with modes 1 and 2 is shown in Fig. 1.

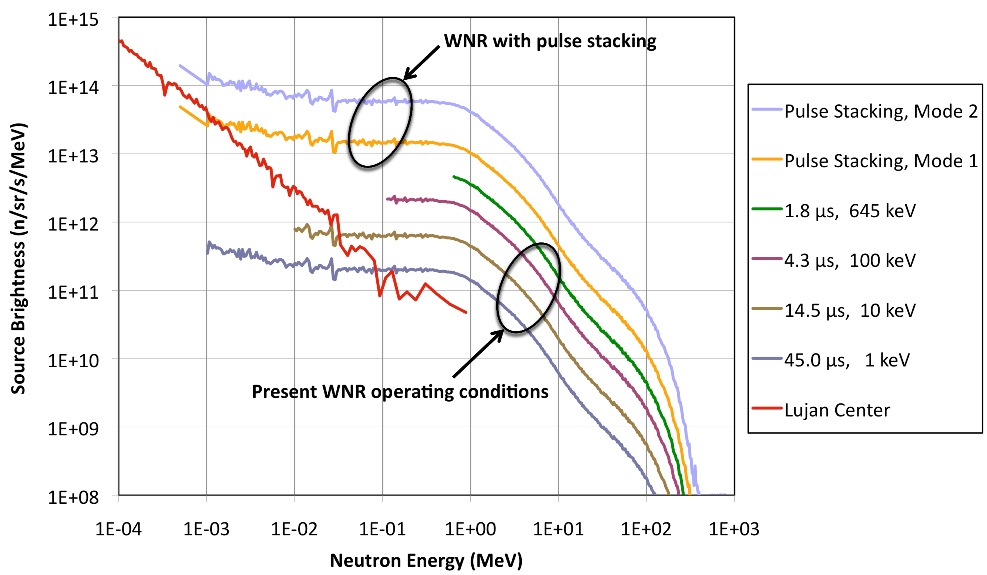


Fig. 1. Neutron source brightness vs. neutron energy for present WNR operation and with short-pulse stacking. Comparison with LANSCE performance (red trace) is also shown. The traces end at their useful range of operation except for the pulse stacking that can be extended to thermal energies. This Figure is provided by WNR.

The spacing between proton pulses determines the lowest-energy neutrons that don't overlap with the next frame. E.g., ~ 1 ms between pulses is required to prevent frame overlap for 1-eV neutrons, with time interval (non-relativistically) decreasing inversely with the square root of the energy, i.e., at 1 MeV only an ~1 μs interval is needed. To achieve low neutron energies with the micropulse mode, the proton beam intensity (pulse rate) is correspondingly lower. Thus, one major advantage of the short-pulse mode over present WNR operation is, for all but the highest energies, proton intensity independence on neutron energy. The limits imposed by frame overlap are reflected in the endpoints of the "Present WNR Operating Conditions" text in Fig. 1. As is seen for these latter conditions, a lower pulse rate extends the available low-energy range but decreases the proton intensity.

A further consideration is the neutron-energy resolution. Using WNR numbers for the target length and LANSCE moderator thickness with a 20-m flight path, Fig. 2 shows the rms resolution of the two facilities as a function of energy assuming a parabolic beam distribution in time and with the full 270-ns PSR beam at LANSCE.[2]

The lower-energy part of the plot is dominated by target (and in the case of LANSCE, moderator) scattering and is constant since the time-of-flight and scattering have inverse relations to the energy. At above ~1 keV the pulse width dominates. Hence, the short-pulse mode provides substantially better resolution than does LANSCE along with higher neutron brightness.

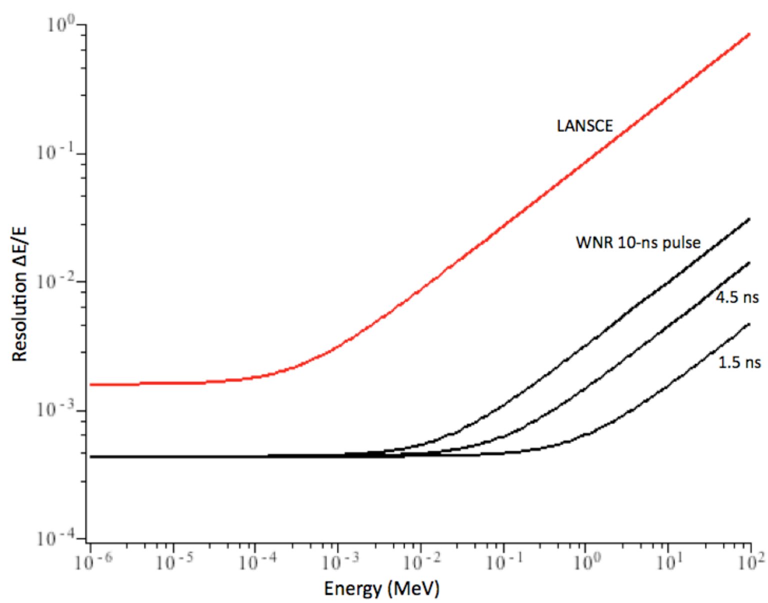


Fig. 2 Plot of the rms neutron-energy resolution for LANSCE and for WNR short-pulse stacking as a function of neutron energy.

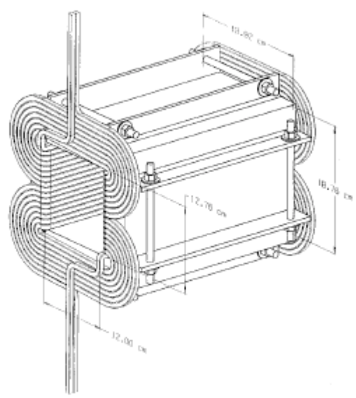
Bump Magnets

The present ring bump magnets [1] are likely inadequate for the pulse-stacking mode since the bump field must fall within 120 μs rather than the present 625. Fig. 3 shows a sketch of the bump magnet and a waveform trace. The magnet has a Mn-Zn ferrite yoke using Ceramic Magnetics MN60 that has moderately good high-frequency characteristics but relatively high loss especially for the alternative mode above. It may be necessary to use a low-loss ferrite; MN8CX has lower loss and better frequency response with otherwise similar characteristics. The beam pipe within the magnet is a thin (0.008"-thick) SS

[2] With differing assumptions about beam-pulse shape and widths, WNR calculations may differ from Fig. 2, which is my own result, but nonetheless indicative of the facility's performance.

bellows with an eddy current decay time of 15 μs that will appreciably distort the field waveform and will overheat for the alternative mode. This suggests use of a (conductively coated) glass or ceramic beam pipe (with some worrisome risk of breaking under vacuum.) We could not find information on measurements of the integrated field as a function of (pulsed) current for the present magnet as operated.

Additionally, changes to or replacement of the present modulators is required. Since the present magnet looks predominantly inductive (see Fig. 3) it may suffice to increase the voltage on the present supplies, if possible. On the other hand, it may be simplest to purchase new supplies that are easy to program. (A linear field fall does not produce a canonical beam charge distribution, further complicated by lack of horizontal bumping.) To remove the beam well away from the foil, as would be important for long storage times, a larger bump (or smaller diameter beam) may be required.



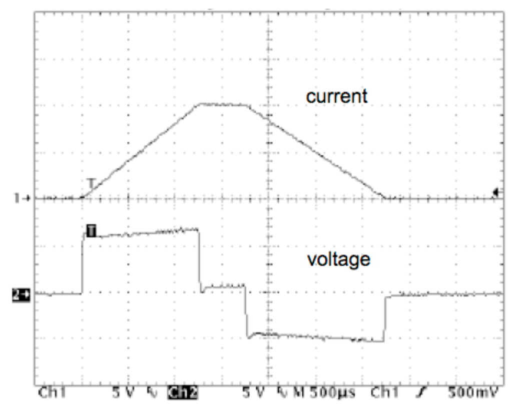


Fig. 3. Bump magnet (left) and operational waveform traces of the magnet current and voltage (right). The trace scales are 30 A/V and 10 V/V. Figures are from [1]

Extraction kicker

The two current PSR strip-line extraction deflectors [2] each have a fill time of 13 ns, but, since the EM wave must fill the structure before beam enters (for addition of the electric and magnetic fields on beam deflection) an additional 16-ns structure-transit time is to be added giving an effective rise time of 29 ns before emergence of the deflected beam. The present structure is adequate for the four-pulse scenario but a higher-performance modulator (±50 kV into 50 Ω) is needed. The present modulator uses a thyratron switch to discharge a (dual ferrite-isolated) Blumlein line that stores the pulse energy and the length of which determines pulse width. It is inadequate for pulse-stacking use since it needs 2.5 ms to recharge after a single extraction. It is also marginal in terms of pulse rise and fall with appreciable ringing after the pulse. Timing requirements are:

- pulse full rise time +13-ns fill time+16-ns beam transit through kicker+10-ns beam width+5-ns jitter, < 90-ns interval between pulses ⇒ < 46-ns rise time
- pulse full fall time+13 ns structure empty time+ 10-ns beam width+5-ns jitter, <90-ns interval between pulses ⇒ < 62-ns fall time

Substantial development has been done on a device known as an "inductive adder" that utilizes a large number of low-voltage paralleled transformer-primary drivers to induce a high voltage in a single secondary. This device was conceived and pursued with near success for the AHF kickers, implemented for low-duty factor use at DARHT, and, with the advent of modern components, particularly fast switches, is again pursued by AOT-RFE [3]. The concept is shown in Fig. 4.

Energy is stored in capacitors at each primary stage (yellow boxes) with the energy transferred by MOSFET switches (black) to the copper-plated primary winding (orange line) wrapped around a Metglass core. The secondary voltage is closely the sum of voltages generated by each stage. A worry is failure of some of the large number of components, but redundant stages can be switched in. The current specifications for stored energy allows a 6-pulse burst on our time scale with charging capability at 40 Hz, presumably extendable to our 4-pulse scenario at 100 Hz.

Successful implementation requires small after-pulse ringing, in part implying good impedance matching, perhaps requiring trimming of the present structure, alleged to be slightly misaligned. Rise and fall times <20 ns each (10 to 90%) and <90 ns cycle times (including a 30-ns flat top) are alleged by the developers, as is high reliability.

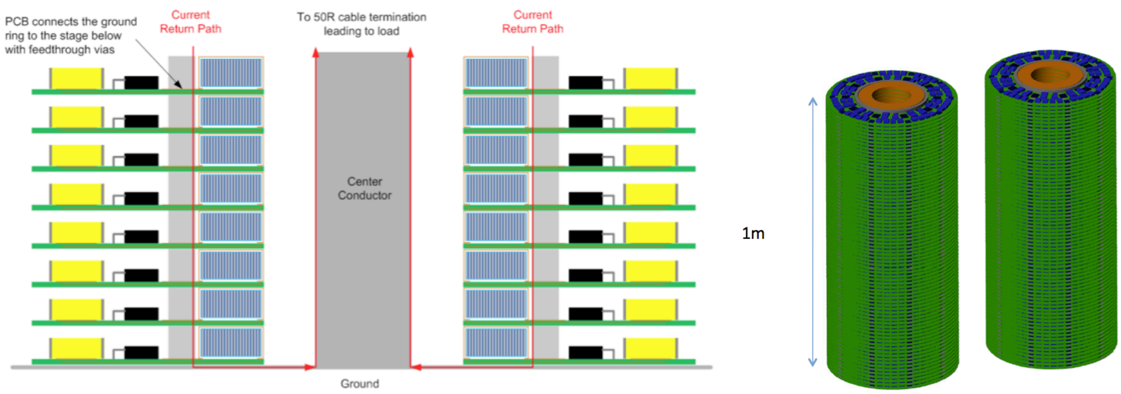


Fig. 4. Shows inductive adder stack of 8 modules (left) and their implementation for a ±50 kV supply (right) requiring 148 stages for each polarity. Figures from [3]

Beam dynamics

An analytical formalism has been developed to track particles in the fields of the RF buncher cavity and (non-self-consistent) bunch space-charge fields around the ring. The validity of the formalism is tested against predictions for the present long-bunch mode operation. Further improvement may be found from use of tracking codes such as ESME [4] that provide self-consistent bunch-charge distributions, albeit with very little additional physics. The analytic formalism used allows graphic expression of dynamic parameter dependencies and ballpark calculations of needed device settings. This formalism will be discussed more extensively in future publications.

The emergent figures for the buncher voltages (always at 90° in phase from the beam bunch centroid) during injection and storage are:

503 MHz – V= 1.1+0.46·n MV for a storage voltage of 1.57 MV

145 MHz – V= 0.40+0.12·n MV for a storage voltage of 0.52 MV

73 MHz – V= 0.15+0.06·n for a storage voltage of 0.21 MV

where n is the fractional number of particles injected relative to the final number, 1×10^{11} and 3×10^{11} and 6×10^{11} for the three frequencies, respectively, irrespective of injection rate to first order. (A linear variation in V with n is needed by our formalism to maintain a constant phase-space shape.) These figures are for the voltage seen by the beam and do not include transit-time factors (0.785, 0.98, and 0.11.) The corresponding cavity powers for storage, including transit-time factors, are 93, 29 and 11 kW for the currently designed cavities. The stated voltages are based on a first-order analysis for maintaining trajectories within the specified phase width; lower values, at around -20%, for the first figure in the above voltages show particle loss. The second figure (proportional to n) is adjusted to maintain bucket shape by maintaining a constant longitudinal kick to the particles as particles are injected.[3]

As a comparison and reality check, the corresponding (here derived) voltages for the PSR long-bunch mode are $V = 0.011 + 0.0057 \cdot n$ for a storage voltage of 0.017 MeV, injecting 4×10^{13} protons, similar to what is observed. However, in the long-bunch case, the cavity beam loading is small due to the low cavity impedance, untrue for the higher frequencies used here. Hence, the present assessment of voltages and other parameters will need to be modified by RF stability considerations. Nonetheless, the coefficient of n is determined by beam dynamics stability considerations and should remain invariant to RF considerations, while the constant term in the above formula can vary.

RF parameters and stability

Given the voltages in the previous section, we have shown that the RF-cavity frequency must be detuned to minimize generator power and, at high intensity, to prevent occurrence of the first-order (Robinson) instability. Detuning for minimization of power guarantees Robinson stability and maximizes the instability damping time, in each case maximally equal to the cavity response time ($\alpha = 2Q/\omega$ = 9.8, 22, and 94 μs.) The respective detuning angles at full current are -69, -79, and -58 degrees with respective frequency shifts of -42, -19, and -5.3 kHz. Methods for accomplishing this are noted briefly below. The required detuning must happen very quickly, particularly as each successive bunch is extracted. Strategies need to be developed to meet these requirements, e.g., overdriving the cavities and sequencing the RF before beam discontinuities. A more complete discussion of the RF stability and consequent beam stability will be given in future publications.

Note that the PSR long bunch does not require detuning for stability due to the feedback-induced-low buncher impedance. Only a 2° detune is needed for minimum generator power at 4×10^{13} protons.

RF buncher

A detailed design for 503-MHz bunching was begun at the inception of the PSR. In particular tuning provision was investigated and a novel perpendicularly biased fast-ferrite tuning cavity, coupled to the main cavity, was devised [5]. The arrangement differs from traditional ring cavities that are more slowly varied in frequency (mainly directed toward tuning beam rotation-frequency changes during acceleration,) that differ in the ferrite-biasing direction, the ferrite power loss, and the separation of ferrite from the main cavity.

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[3] A series of quick ESME runs by Jeff Kolski show that these calculated figures agreed approximately with code results, i.e., somewhat below the stated voltages, particle loss was noted.

Extensive testing of the tuning concept was carried out but a final prototype was not completed before the PSR was changed to a long-bunch mode. A related utilization of the concept was carried out at the Advanced Photon Source. A sketch of this proposed buncher is shown in Fig. 5.

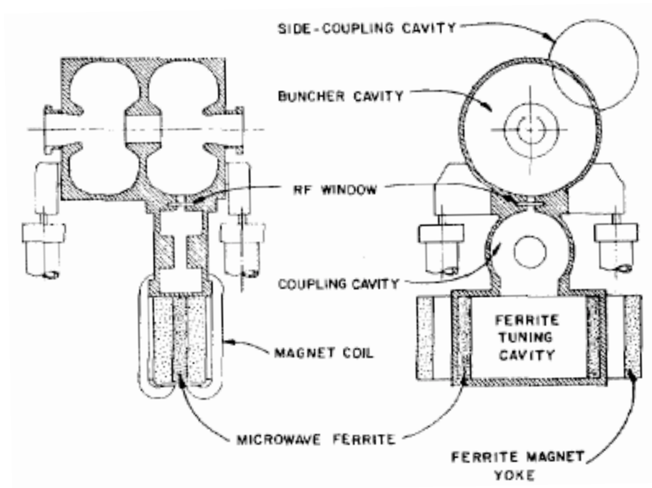

Fig. 5. Drawing of initially proposed 503-MHz buncher cavity with tuning cell attached from [5].

The original proposal was for four of these cavities to be located symmetrically in the ring. Space limitations may only allow two such structures in the PSR that will stress the cavity cooling (at over 76 kW peak power) for long storage times.

The configuration of Fig. 5 under the present scheme produces 1.5-ns beam pulses. For the 5- and 10-ns pulses a 145- and a 73-MHz cavity is, respectively, needed. This would provide a nominal pulse intensity of 3×10^{11} and 6×10^{11} protons, decrease RF power and tuning range, presumably require only a single cavity, but provide slower cavity response and lower synchrotron frequency. The 10-ns pulse is favored by WNR. Preliminary cavity design for these latter frequencies is available, but a tuning arrangement has not yet been designed.

Adequate RF sources exist [6] for our purpose within the frequency range considered (73 to 503 MHz). Specifically, we mention: the Diacrode-tetrode-TH781-based system for frequencies below 200 MHz that will be used for the LANSCE 201-MHz system, capable of 200 kW cw; Klystron sources, e.g., TH2167, for frequencies above 325 MHz and peak powers up to 300 kW; and an Inductive Output Tube for frequencies above 400 MHz, up to 90 kW cw.

Of course, 201 MHz, a more familiar frequency, could be an option giving a 3.75 ns pulse width, $\sim 2.2 \times 10^{11}$ protons/pulse, and possibly using a drift-tube cavity. By filling successive buckets a longer pulse could be alternatively obtained, at the expense of fill time and a requirement for an enhanced .

Since multiplexing the long- and short-pulse modes is required, the effect of each mode on the quiescent cavities of the other would be appreciable; mechanical shorting is not possible. Possible expediencies here include a passive (dissipative) coupler or active feedback to maintain zero voltage on the quiescent cavity.

Further details on the buncher topics will be given in future publications.

Beam transport

Beam transport of the short-pulse mode to WNR is simply stated as transferring the PSR beam to a beamline that leads to WNR target 4. The situation, however, is complex since the beam must be multiplexed (alternating pulses) between WNR and LANSCE. Additionally, there is little room for such a transfer in the present configuration because of its topology, the short drift spaces available, and the high density of elements. A further consideration is the differing currents in the three pathways existing in the line D tunnel, after the PSR injection line turnoff. These present pathways are (referring to Fig. 6):

1) Line D to 1LBM01 that can switch to 1L (line to LANSCE with 1LBM01 on) or through BYM04 (when it is off along with 1LBM01) going to WNR. This path (since somewhat modified) was the course for supplying the LANSCE or WNR with either a macropulse or a series of micropulses, both beams having the low space charge of a micropulse (~6×10^8 ppp.) Of course ROBM02 must be off. (Shown in the solid blue line in Fig. 6.) Multiplexed operation between the Lujan center and WNR is not possible using this path.
2) If the PSR long-pulse mode is running, The WNR micropulse beam can be diverted into line BY (when the pulsed magnet RIKI01 is off) by BYM01 to avoid being switched into 1L, since 1LBM01 and ROBM02 are on. BYBM01 and BYBM02 are on in this mode. This supplies WNR with micropulses and has the low space charge of a micropulse. (Path shown as a dashed blue line.) Thus WNR can receive micropulses and Lujan center can receive the PSR long-pulse beam, but not on the same macropulse.
3) For delivery of the long pulse to LANSCE, the red line is followed due to RIKI01 pulsed on and 1LBM01 on. This pathway has intense space charge several hundred times that of the micropulse after the PSR. To deliver PSR beam to WNR 1LBM01 and BYBM04 must be off (dashed red line.) Additionally, the focus of the red dashed line must be changed, taking considerable time. Thus multiplexed operation of the PSR beam between Lujan center and WNR is not possible.

The possibility of using the present lines for macropulse-to-macropulse multiplexed beam usage between WNR and LANSCE (given transport from the ring to ROBM02) was extensively explored [7] with the conclusion that this would be very difficult if not impossible because of space considerations (a sortie into line D is very convincing of this.) There are more fundamental problems to be overcome; the short-pulse beam intensity is very high with peak currents ~10 A, similar to the long pulse as compared to the micropulse peak of ~0.2 A. Additionally, the beam from the PSR to LANSCE has accumulated considerable dispersion (in both planes due to skew dipole ROBM02) from the PSR energy spread and passage through a series of bends that is only canceled at 1LBM01. The original solution to this transport, maintaining target spot size and low beam loss was hard to come by and seems to be unique. It seems unlikely that the current line to WNR could handle the proposed beam, even if transfer to the line were feasible. Should this work out, retuning of the line would be needed for a return to the micropulse mode, precluding multiplexing with the short-pulse-stacking mode.

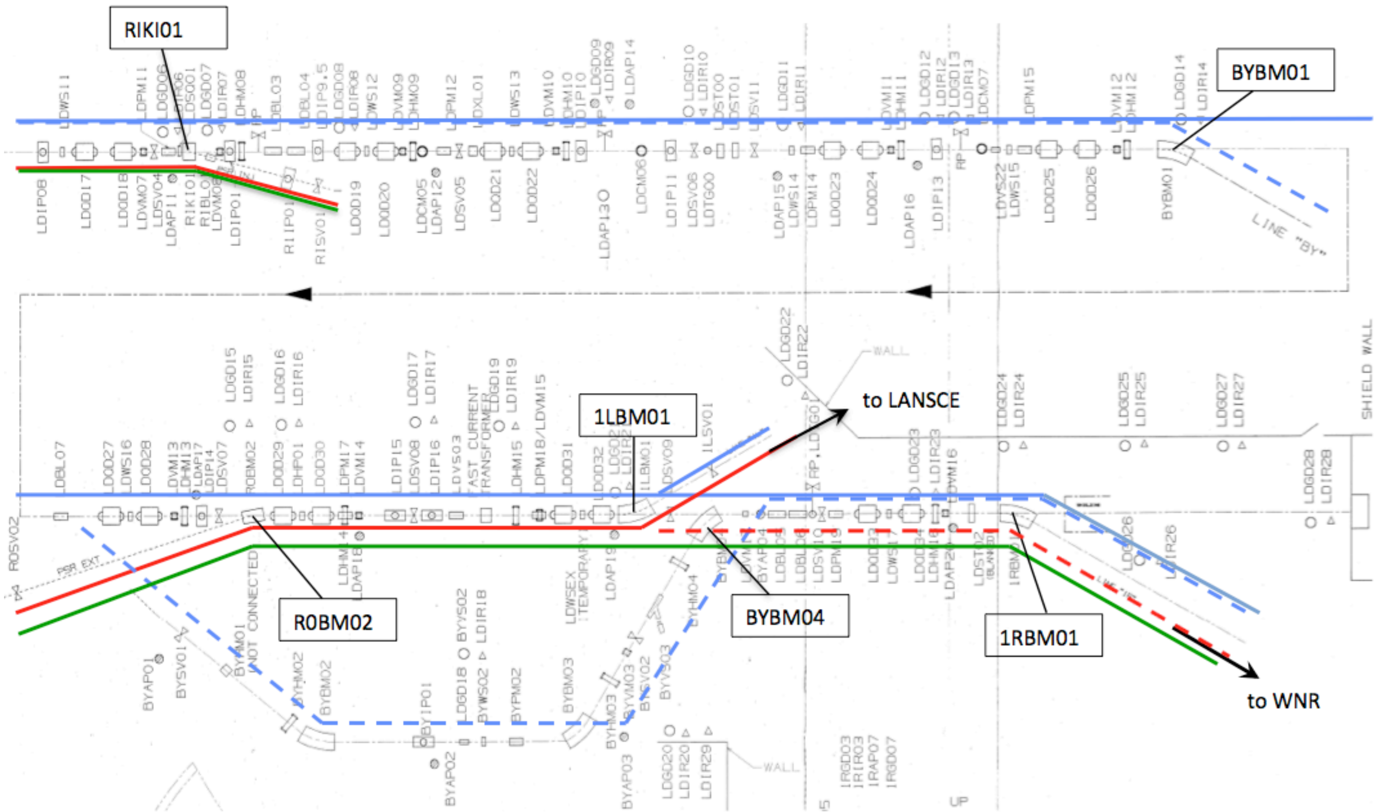

Fig. 6. Diagram showing the location of elements and beam pathways from the PSR injection kicker to the LANSCE and WNR turn offs. The red and blue traces show present pathways while the green trace shows a pathway for a possible new line.

An alternative to transfer in line D [8] was suggested some time ago for a neutrino/muon line, shown schematically in Fig. 7. The present (nearly periodic) transport line from the ring to line D has over 5-m spacing between quad doublets and, with the aid of septum quads and dipoles, could transport the short-pulses to the line D tunnel.

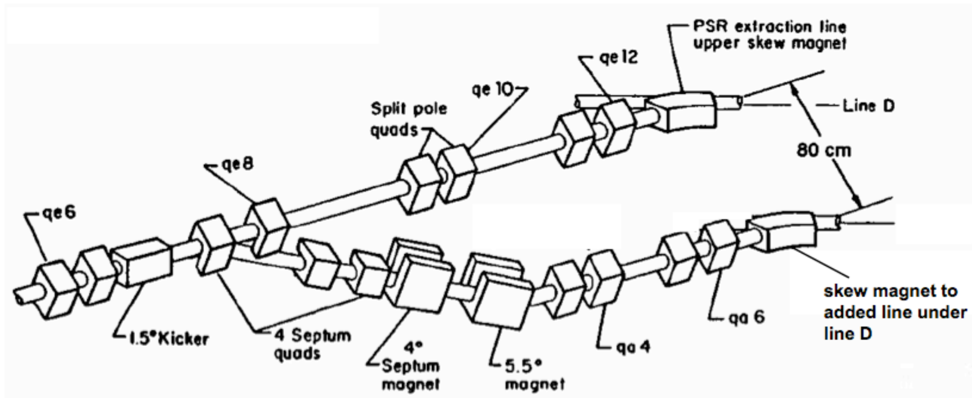

Fig. 7. A scheme for beam transfer between the PSR extraction line and a secondary line that could transport the short pulses of the pulse-stacking mode into line D. The concept shown is schematic and susceptible to many variations. Quad designations differ from the current naming with the diagram starting at ROQF03.

It may then be possible to transfer beam to line BY through BYBM02 and, with changes to the line optics, to use (an enhanced) present transport line to WNR. Alternatively, an additional line would keep the multiplexing and ensure a good optics configuration with dispersion cancellation at 1RBM01 or 1RBM02. Such a line would solve all multiplexing and optics issues and allow multiplexing of target 2 with target 4, but would be a challenge to fit in the tunnel. If tunnel widening is not possible, line location on the tunnel floor with a removable walkway on top of the line might be considered. The success of the present extraction line argues for such a course.

A more considered study of the transport to target 4 needs to be done, including schemes for beam transport through the Blue Room for maintenance of present capabilities. The changes to be made are extensive and will be the most expensive part of the project.

Summary

Conservative figures for the intensity of short-pulse beams are given as $1x10^{11}$, $3x10^{11}$, and $6x10^{11}$ protons/pulse with 1 or 4 pulses/macropulse based on beam-transverse considerations. This represents a gain several hundred over the present micropulse mode at low neutron energies and enhanced resolution over related LANSCE measurements by an order of magnitude.

Specifications for the bump magnet, extraction kicker, and buncher systems are given requiring substantial development for each system. Work is already underway for the kicker modulator [3] with quite adequate prognosticated characteristics.

Analytic formalisms have been developed for longitudinal injection and first-order stability that define parametric dependencies and yield values for needed parameters. The use of existing or writing of specialized accelerator codes may enhance accuracy of parameter numerical values. Further delving into instability analysis should be done; we have covered the first order considerations. The discussion presented here is superficial, with greater detail on this complex subject to be found in succeeding publications.

Beam transport to WNR is complex due to multiplexing requirements, beam optics considerations, and lack of space for beam transfer. Transfer of beam from the PSR extraction line into a new line dedicated to the short pulse mode is suggested.

References

1. C. R. Rose, et al., "Overview of the Bump-Magnet System at the LANSCE Proton Storage Ring," PAC 97, p93. Also discussions with Peter Walstrom. Also see J. F. Power, et al., "The evaluation of High-speed Bump Magnets for Direct Injection into Accumulator Rings," PSR Tech Note 94-016 for a discussion of magnet virtues.

2. John F. Power, et al., "The Los Alamos Proton Storage Ring Fast-Extraction kicker system," PAC 85, p1032.

3. Design review by Michael Bland, AOT-RFE, LANL, August 4, 2011. Electronic copies of his talk are available. See earlier pioneering work on an incomplete device by E. Cook and P. Walstrom, "A 50 kV solid state multi-pulse kicker modulator," PAC 2003. Also see sparse references for Ed Cook on the DAHRT kicker, e.g., "G. Behrmann, "XFEL IBFB kicker amplifier concept," XFEL BPM Workshop, Boettstein, Switzerland, 2008.

4. Web site for code source and overview of the latest ESME code versions may be found at http://www-ap.fnal.gov/ESME/. Jeff Kolski is the AOT contact for use of ESME.

5. L. Earley, et al., Rapidly Tuned Buncher Structure for the Los Alamos Proton Storage Ring (PSR)," PAC 1983, p 3511.

6. John Lyles, AOT-RFE, private communication.

7. D. Barlow and P. Walstrom, AOT-ABS and –RFE, private communication. Their unpublished drawings of investigated configurations are available.

8. A. Jason, "PSR-Muon Facility Transport Line" in "Proceedings of the Workshop on Muon Science and Facilities at Los Alamos" Los Alamos, 1982 LA-UR-9582-C, p 108.

Appendix A: Issues and efforts needed

The major issues, beyond routine engineering, that remain to be resolved are listed for each of the above topics.

<u>Bump magnets</u>: Can the present modulators be used? Does the ferrite type need to be changed? Can a ceramic or glass chamber be used in the PSR? There are no showstoppers here, but decisions and a development program needs to be established.

<u>Extraction kickers</u>: Can the pulse and timing requirements be met? Can the large stack of modules be maintained or is the failure rate daunting? Use of the present kicker, if possible, will reduce the intensity by a factor of four. There appears to be a development program underway, but funding and direction is needed. Success is then likely.

Buncher: Substantial development will be required with a prototype cold-cavity system after a design involving physics, mechanical engineering, and electrical engineering. Design and testing of a fast-tuning mechanism is non-trivial, to be tested on a hot model, likely including a pulsed wire for beam simulation. A formal plan for the work is needed. An estimated time for completion of a full-swing development to final product is ~2.5 years, if staffing is adequate and dedicated. Here no showstoppers are foreseen, but the path is difficult and new to accelerator technology.

The main challenge to the RF system involves creating sufficient flexibility in control to achieve stability, to be determined by interaction with stability analyses.

A corollary effort on buncher-mode interaction is needed and may extend into the commissioning period. No defined approach has yet been identified but active feedback is the likely course.

Beam dynamics: Codes involving macroparticle tracking are to be applied for an alternative analysis to determine bunching voltages and injection procedures. Sufficient flexibility in buncher voltage needs to be built in.

RF control and stability: Always a difficult thing to predict. First-order analysis has been accomplished. Classical instabilities such as the microwave or resistive wall require accurate knowledge of ring impedances to fit into current formalisms that, by experience, overestimate the danger. Application to our case requires substantial effort. Also needed are the analyses of bunch-to-bunch instability and RF control as bunches are injected and extracted (one by one,) as well as the electron-induced instability noted in the PSR.

At some beam intensity, an instability will be encountered, believed to be well above our conservative figures and likely involving the predicted first-order limits.

Beam transport: This system will readily work if a dedicated line is constructed. The issues then include fitting the system into line D and through WNR, as well as finding a beam optics solution that handles the high peak current and dispersion. Otherwise, feasibility of using parts of the current lines needs exploration. A transport-physics study is to be initiated in coordination with facility engineering.

Chopper and low-energy linac: The chopper and buncher systems are old and will need some upgrade to meet our requirements, but changes are perceived to be minor.

Dated postscript

After further work on the stability issues cited, the following documents were issued proffering further conclusions as to RF control and beam-dynamics interface.

Andrew. J. Jason, "First-order beam dynamics and RF parameters for the PSR short-bunch ("pulse stacking") mode," LA-UR-13-20497.
Andrew. J. Jason, "Stability and parameter determination for injection and extraction in the PSR short-bunch mode," LA-UR-13-20496.