Current Proton Driver Activities in the Accelerator Division

Accelerator Physics and Technology Seminar

Bob Webber
February 2, 2006
What is this Proton Driver?

- **8 Gev Superconducting Linac**
  - To provide basis for ILC Test Facility
    - Main Linac Prototype
    - 4-5 GeV Electron source for Damping Ring R&D
  - To serve as high intensity source of protons for Main Injector Neutrino Physics programs
What Makes It Unique?

- High speed (nsec) beam chopping at 2.5 MeV
- Spoke resonators and solenoidal focusing in room temperature section
- Low transition energy to superconducting accelerating structures (10 MeV)
- Superconducting spoke resonator RF structures in low beta sections
- ILC cavities and cryostats for beta=1 section
- Large number of cavities driven by few high power klystrons
**0.5 MW Initial 8 GeV Linac**
11 Klystrons (2 types)
449 Cavities
51 Cryomodules

**“PULSED RIA”**
Front End Linac
325 MHz
0-110 MeV

**β<1 LINAC**
1300 MHz
0.1-1.2 GeV
2 Klystrons
42 Triple Spoke Cavities
7 Cryomodules

**ILC LINAC**
1300 MHz
β=1
8 Klystrons
288 Cavities in 36 Cryomodules
Proton Driver Information

Project Site:

http://protondriver.fnal.gov

Design Study (Draft, 215 pg.)

http://protondriver.fnal.gov/SCRF_PD_V56.doc

Director’s Review:

Why Am I Talking About It?

- Bill Foster convinced Roger Dixon that, as of December 1, I should be replaced as Head of the Instrumentation Department
  (I hadn’t known that Bill was so concerned about the Instrumentation Department!)
- I am now assigned to organize and lead Proton Driver efforts within the Accelerator Division
Document the Technical Design & Cost
(J. Kerby, Project Office)
Document the Technical Design & Cost
(R. Webber, Accelerator Systems)
Document the Technical Design & Cost
(G. Apollinari, Beamline Components)
Three Main Foci at this Time

1. **Machine Design and Baseline**
   - Technical Baseline (linac, transport line, injection, acceleration, targetry)
   - Cost Range

2. **Meson Area Front-End Test R&D Program**
   - Beam test of RF Power Split w/Ferrite Vector Modulators
   - First beam through SRF Spoke Resonators

3. **Main Injector at Proton Driver Intensities**
   - Impedance calculations, measurements
   - New MI RF Cavity Prototype (*Inter-Lab Collaboration?*)
   - Beam demonstrations (fast ramping, RR stacking, e-cloud, etc.)
   - Upgrade system designs (momentum collimation, gamma-T, etc.)

- **Remainder of this talk will focus on Accelerator Division activities in support of items 1 and 2**
- **Alberto Marchionni is leading efforts for item 3**
Meson Test Facility Objectives

- **Provide 325 MHz power test facility**
- **Provide 325 MHz superconducting resonator test cryostat**
- **Construct and operate 10 MeV room temperature Linac section**
  - To demonstrate high power RF distribution and vector modulator control of multiple cavities with one klystron
  - To demonstrate performance of solenoidal focusing low energy linac
- **Construct and operate 325 MHz superconducting spoke resonator Linac sections up to ~100 MeV**
  - To demonstrate spoke resonator performance with beam and 3ms beam pulse length
325 MHz Front-End Linac

- 325 MHz Klystron – Toshiba E3740A (JPARC)
- SCRF Spoke Resonator Cryomodules
- RFQ
- MEBT
- Ferrite Tuners
- RF Distribution Waveguide
- 115kV Pulse Transformer
- Single Klystron Feeds SCRF Linac to E > 100 MeV
- Modulator Capacitor / Switch / Bouncer
- Charging Supply
Meson Floor Plan
Cleared Area for Proton Driver in Meson
Pulse Transformer in Meson
Bill, The tube is great; it was tested to our long pulse length and pulse rates requirements.
## RFQ SPEC in Procurement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>325 MHz at nominal RF power and 27°C ambient temp.</td>
</tr>
<tr>
<td>Input Energy</td>
<td>50 keV</td>
</tr>
<tr>
<td>Output Energy</td>
<td>2.5 MeV</td>
</tr>
<tr>
<td>Output Current (max)</td>
<td>40 mA</td>
</tr>
</tbody>
</table>

**Pulse Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial operation:</td>
<td>3 msec x 2.5 Hz @ 13 mA (duty factor 0.75%)</td>
</tr>
<tr>
<td>Final operation:</td>
<td>1 msec x 10 Hz @ 40 mA (duty factor 1%)</td>
</tr>
<tr>
<td>Input Transverse Emittance</td>
<td>0.24 p mm-mrad RMS Normalized</td>
</tr>
<tr>
<td>Output Transverse Emittance</td>
<td>0.26 p mm-mrad RMS Normalized</td>
</tr>
<tr>
<td>Output Longitudinal Emittance</td>
<td>Less than 150 p keV deg, rms</td>
</tr>
<tr>
<td>Output Twiss parameters</td>
<td>Axisymmetric: $\beta_x = \beta_y$, $a_x = a_y$ equal within +/-10%</td>
</tr>
<tr>
<td>Acceleration Efficiency</td>
<td>&gt; 85% of incoming beam exits at &gt;99% nominal energy</td>
</tr>
<tr>
<td>Power Consumption (max)</td>
<td>450 kW(structure) + 100 kW (beam)</td>
</tr>
<tr>
<td>Cooling Fluid Input Temp.</td>
<td>32 degrees Celsius</td>
</tr>
<tr>
<td>Sparking Rate</td>
<td>$&lt; 10^{-4}$ sparks/pulse</td>
</tr>
<tr>
<td>Design Lifetime</td>
<td>20 years</td>
</tr>
<tr>
<td>X-Ray Emission</td>
<td>Less than 5 mrem/h</td>
</tr>
</tbody>
</table>
325 MHz SRF Spoke Resonators 10-400 MeV

- Well Developed Technology for RIA, APT, TRASCO...
- Simulations indicate excellent beam dynamics
  \[\rightarrow\] Never yet tested with beam
- Runs Pool-Boiling at 4.5K – Simple Cryosystem
- R&D Demonstration (SMTF):
  \[\rightarrow\] beam properties with pulsed operation.
Meson Schedule 2006

• **325 MHz klystron delivery**
  – March 2006

• **Modulator completion**
  – April 2006

• **325 MHz RF power system commissioning**
  – May 2006

• **325 MHz Test Cryostat (now in final design) delivery**
  – August 2006

• **RFQ (now in procurement) delivery and power testing**
  – October 2006

• **2.5 MeV tests**
  – November 2006

• **325 MHz SC spoke resonator test in test cryostat**
  – November 2006
Klystron Modulator

- Dan Wolff, Howie Pfeffer, Chris Jensen et al.
Modulators
Modulator Choke

A modulator ahead of its time!
Ferrite Vector Modulator R&D

• Dave Wildman, Ding Sun, Iouri Terechkine, Steve Hays, Brad Claypool, etc.

• Provides fast, flexible drive to individual cavities of a proton linac, when using an ILC style fanout, 1 klystron feeds multiple cavities. Also needed if Linac alternates between e- and P.

• Coaxial at 325 MHz, either coaxial or waveguide at 1.3 GHz

Making this technology work is important to the financial feasibility of the 8 GeV Linac and potentially to ILC.
325 MHz RF System

Single Klystron
325MHz
3 MW

TOSHIBA E3740A

Pulse Transformer & Oil Tank

IGBT Switch & Bouncer

CAP BANK

Charging Supply
300kW

MODULATOR: FNAL/TTF Reconfigurable for 1,2 or 3 msec beam pulse

110 kV
10 kV

10kV

10 kW

400kW

WR2300 Distribution Waveguide

RF Couplers

Fast Ferrite Isolated I/Q Modulators

Cables to Tunnel

Radio Frequency Quadrupole

Medium Energy Beam Transport Copper Cavities

Cryomodule #1 Single-Spoke Resonators

Cryomodule #2 Double-Spoke Resonators
I/Q modulator box (stripline structure)

Box size: 24” x 20”
Ding Sun’s Hybrid Prototype
Dave Wildman’s Coaxial Phase Shifter

- Coax design is preferred at 325 MHz.
- In-house design tested to 660 kW at 1300 MHz.
- Tested at 300 kW at Argonne with APS 352 MHz Klystron.
- Fast coil and flux return should respond in ~50us.

3 ms, 50 kW pulse at 352 MHz

Bias Current (A)
High Power Ferrite Modulator Test at FNAL

1300 MHz Klystron

$T = 250 \mu\text{sec}$

$F = 5 \text{ Hz}$

Existing A0 Klystron was used for testing

Waveguide Version
HPVM Driver
Transfer Line and MI Injection Design

- **Dave Johnson and Dixon Bogert**
  - Following work by others for previous Proton Driver efforts
H- transport line and Main Injector injection

• Refinement and Optimization of work by A. Drozhdin, W. Chou, and others on the H- transport line and Main Injector injection which includes:
  - Inclusion of most recent information from $\beta=1$ Linac design.
  - Creation of independent achromats for +/- momentum collimation
  - Creation of injection achromat and matching section
  - Investigation of MI-10 injection insertion modifications
  - Optimization of site coordinates to minimize impact of construction on MI tunnel (cost and schedule impact)
• Baseline layout and design will include H- stripping by foil, but will not preclude a future upgrade for laser stripping
• Design will include options for PD beam to MiniBoone and injection into Recycler.
• Continued refinement of requirements and specifications for transport line collimators and injection absorber
• Design will build upon experiences of SNS
• Establish collaboration with experts at FNAL, BNL, and SNS
Revised H- Transport Line

Injection achromat and matching

Momentum Collimation sections

Betatron Collimation section

Linac Matching

Main Injector

Linac

60 degree phase advance

90 degree phase advance

H贬

Revised H- Transport Line
Revised Main Injector MI10 Injection straight

Advantages:
- Increases available space for injection devices
- Flexible injection optics
- Allows greater separation between circulating beam and foil after injection
- Removal of Quad from middle of injection devices

Disadvantages:
- Requires additional quad circuits for matching into MI
- Must keep vertical beta below 70 m in dipole section
Linac Simulations

• Jean-Paul Carniero
  – In support and check of Linac design work by Petr Ostroumov and his RIA group at Argonne
TRACK vs. ASTR for H-

H- Through Entire Beta = 1 Linac Section
Laser

511 MeV, ~5 kA, ~20 µs

RF Gun S.H. BC1 BC2

PD

BETA1 ACC1 ACC2 ACC3 ACC4

511 MeV, ~5 kA, ~20 µs

RF Gun + Proton Driver Beta=1 (37 cryomodules)

Laser

Long = 20 ps Flat Top + 3ps rise time
Trans = 3 mm diameter

RF Gun

40 MV/m, -2.8 deg w.r.t crest

Solenoids

0.163 T

ACC1

4 × 13.65 MV/m @ -25 deg w.r.t. on crest
4 × 22.22 MV/m @ -25 deg w.r.t. on crest

ACC234

20.22 MV/m @ -24.3 deg w.r.t. on crest

S. H. (3.9 GHz)

8 × 32.5 MV/m @ 160.6 deg w.r.t. on crest
Electron Simulation

Change from 2 to 1 Quadrupole per Cryomodule

Electrons Through Entire Beta = 1 Linac
Some Other Activities

- **Doug Moehs, Henryk Piekarz, Chuck Schmidt**
  - H- Ion Source development

- **Milorad Popovic**
  - 50 KeV beam transport

- **Paul Czarapata, Leon Beverly, Jim Steimel and the Meson Building Crew**

- **Jerry Leibfritz, Maurice Ball, Steve Wesslen and Rob Reilly in AD Mechanical Support**

- **Apologies to all I’ve failed to include**

- **12 Accelerator Division FTE’s effort in December !!!**
Some MI Investigations Under Alberto

- **Impedance Measurements & Pallatives**
  - Main Injector is ~7 yrs old
  - No Impedance Measurements Yet
  - Will key MI components need low-Z upgrades?
- **Gamma-T Jump Systems**
  - Main Injector
  - Booster
- **Collimation**
  - Main Injector (Momentum, & Betatron)
  - Recycler Stacking Collimators (Momentum & Betatron)

All these will be valuable independent of PD
Summary

• There is considerable Accelerator Division activity now on Proton Driver design and R&D
• It should be an exciting year to bring 325 MHz klystron and RFQ on-line to accelerate beam in the Meson Detector Building
• Much of the Proton Driver activity will support plans for ILC systems and ILC Test Facilities
  – Civil construction considerations
  – High power vector modulator and multiple cavity control development
• MI efforts will lead to improvements even for present program
8 GeV Superconducting Linac
With X-Ray FEL, 8 GeV Neutrino & Spallation Sources, LC and Neutrino Factory

- 8 GeV Linac
- ~700m Active Length
- Neutrino "Super-Beams"
- Main Injector @2 MW
- SY-120 Fixed-Target
- Damping Rings for TESLA @ FNAL With 8 GeV e+ Preacc.
- 8 GeV neutrino
- Anti-Proton
- Short Baseline Detector Array
- Neutrinos to "Homestake"
- X-RAY FEL LAB
- VLHC at Fermilab

Fermi National Accelerator Laboratory