TRIUMF

ANNUAL REPORT
SCIENTIFIC ACTIVITIES
2004

ISSN 1492-417X

CANADA'S NATIONAL LABORATORY
FOR PARTICLE AND NUCLEAR PHYSICS

OPERATED AS A JOINT VENTURE

MEMBERS:

THE UNIVERSITY OF ALBERTA
THE UNIVERSITY OF BRITISH COLUMBIA
CARLETON UNIVERSITY
SIMON FRASER UNIVERSITY
THE UNIVERSITY OF TORONTO
THE UNIVERSITY OF VICTORIA

ASSOCIATE MEMBERS:

THE UNIVERSITY OF GUELPH
THE UNIVERSITY OF MANITOBA
McMASTER UNIVERSITY
L'UNIVERSITÉ DE MONTRÉAL
QUEEN'S UNIVERSITY
THE UNIVERSITY OF REGINA
SAINT MARY'S UNIVERSITY

UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

OCTOBER 2005

The contributions on individual experiments in this report are outlines intended to demonstrate the extent of scientific activity at TRIUMF during the past year. The outlines are not publications and often contain preliminary results not intended, or not yet ready, for publication. Material from these reports should not be reproduced or quoted without permission from the authors.

CERN COLLABORATION

INTRODUCTION

TRIUMF's collaboration with CERN on producing accelerator components for the Large Hadron Collider (LHC) is now essentially complete with only a few small tasks continuing up to first collisions. For the period 1995–2005 the amount of this contribution that TRIUMF is coordinating on behalf of Canada is $41.5 million. The largest contribution has been the manufacture of 52 twin aperture quadrupoles, completed and shipped to CERN last year. These magnets are being field mapped at CERN and this work is expected to be completed by May, 2005.

The LHC injection kicker components designed and built at TRIUMF underwent some final long term high voltage testing using the CERN provided control system. High voltage measurements were carried out to demonstrate that the rise time, fall time, and pulse uniformity were within the required specifications. The PFNs are being shipped to CERN in a special shock-absorbing container and all components should arrive by June, 2005.

The remaining hardware project is the design and prototyping of the digital acquisition boards for the LHC beam pick-up monitors. This design has become a CERN standard and is now planned for use in the transfer lines and for the beam loss monitors. TRIUMF has manufactured prototypes of the latest version for testing at CERN. The series production will be carried out at CERN.

The two beam dynamics efforts continue to be supported. The first is a continuation of the beam tracking efforts taking into account field errors in the magnets, beam-beam interactions and misalignments to determine methods of correcting these non-linearities. The second study looks at beam-beam effects in the collision region and the potential instabilities that might be caused by the electric forces between the bunches. This task requires extensive computing power and makes use of the parallel processing available from WestGrid.

The LHC schedule presently calls for an injection test into an octant of magnets to take place in late 2006, with first collisions scheduled for July, 2008. More details of the TRIUMF LHC work can be found in the following sections.

BEAM DYNAMICS

Beam Optics and Collimation

After completion, in late 2003, of the tasks related to collimation set-up and optics, a request was made by the CERN beam-dynamics group for assistance in studies of LHC at collision. This is a part of an intensive tracking campaign planned by CERN for 2004–2005 aiming to optimize the machine parameters at collision and evaluate the realistically achievable luminosity.

During 2004, in collaboration with CERN, a tracking model was developed, which includes weak-strong beam-beam interactions, simulated alignment and field errors in both rings, and procedures for their correction. The resultant programming tools mostly consist of already existing modules. They were thoroughly tested at TRIUMF and, on several occasions, improvements were made.

The tracking job is built in several stages: preparation of optics for an imperfect machine, correction, short-term (1000 turns) tracking performed with the code MADX, and a million-turns tracking with Sixtrack to obtain the domain of stable trajectories (dynamic aperture). The short-term tracking allows us to observe the effect of non-linearities on the beam-beam tune footprint. The long-term jobs are built locally, but executed on dedicated clusters at CERN and worldwide. Being intended to assist the actual machine operation, the correction algorithm takes into account only measurable observables, i.e. such that can be accessed from the LHC control room.

The non-linear particle motion in an accelerator can be described by a symplectic 6-D map acting on initial coordinates. Using the well established theory of such maps, several programing tools were created allowing us to build the Lie-algebraic map of a beam line or a ring in either factorized, or Taylor form. Such maps were applied for the LHC triplet correction, where an analytical treatment was made, and on beam dynamics problems arising at TRIUMF – to reproduce the 7^{th} order Taylor map (COSY) of an FFAG cell. In perspective, such tools may serve to analyze the Linear Collider interaction region.

Beam Optics and Stability

Coherent beam-beam effects in the LHC

Our study of beam-beam interactions in the LHC seeks to identify potentially unstable coherent modes excited by the electric forces between counter-rotating bunches of protons as the two beams meet and cross in the collision regions. Large-scale multiparticle simulations are a principal tool in this type of investigation and our parallel beam-beam simulation code BeamX is one of the first to include a fully 3-dimensional model of the collision process.

In 2004 BeamX was migrated to three new computing platforms in order to evaluate their parallel performance and to establish resource criteria for supporting large-scale simulations that would allow the exploration of the beam-beam parameter space and help to predict and optimize LHC collision scenarios.

The systems used were: the WestGrid Lattice CLUMP (CLUster of MultiProcessors) system at the University of Calgary, the WestGrid Glacier facility at UBC, and the new Openlab cluster at CERN. This provided a diverse set of testbeds. The WestGrid-UBC and CERN clusters are based on dual 32- or 64-bit commodity processors in blade or rackmount configurations, respectively. In contrast, the CLUMP architecture uses specialized hardware and is designed to support rapid low-latency communication among small groups of processors in shared memory configurations.

To benchmark these systems, a series of full-scale BeamX runs (131078 simulated collisions), employing from 1 to 9 processors, were performed on each cluster. Consistently, the lattice CLUMP system was the clear leader, with performance at least a factor of 2 better than the commodity clusters, making it the preferred platform for BeamX in its current form. However, further developments in parallel beam-beam simulation for LHC will likely involve increasing numbers of processors, to handle multiple interaction regions and bunch trains, and this may swing the preference back to the larger commodity clusters.

We would like to acknowledge the support of WestGrid (funded by the Canadian Foundation for Innovation and other agencies) whose facilities were essential to the timely validation, scaling up, and benchmarking of our parallel code in collaboration with CERN.

CONTROLS AND INSTRUMENTATION

LHC Orbit System Components

The digital acquisition board (DAB64x) was redesiged to meet the latest LHC specification (LHC-BP-ES-0002 Rev 2.0). Five prototype boards were manufactured and assembled for preliminary hardware testing. Two modules were sent to CERN for beam loss monitor mezzanine development. Firmware development and hardware testing is ongoing. Software for DAB control and monitoring was rewritten to support the new power PC processor and the latest Lynx OS operating system.

Assistance was also provided in the production of 30 DABIII modules which were used for beam tests at CERN.

KICKER MAGNETS

Each of two LHC injection kicker magnet systems must produce a kick of 1.3 T m with a flattop duration variable up to 7.86 ms, and rise and fall times of less than 900 ns and 3 μs, respectively. A kicker magnet system consists of four 5 Ω transmission line magnets with matching terminating resistors, four 5 Ω pulse forming networks (PFN) and two resonant charging power supplies (RCPS). Six RCPS and nine PFNs, together with associated switch tanks, and dump switch terminating resistors have been built at TRIUMF and all have been tested at high voltage (60 kV) to ensure that the performance is within specification.

Each 5 Ω PFN is composed of two parallel 10 Ω lumped element delay lines; each line consists of a 28 cell, 4.36 m long precision wound coil, high voltage and high current capacitors and damping resistors in parallel with the coil. There is a thyratron switch tank at each end of the 5 Ω PFN.

Each PFN and associated thyratron switch tank was operated at 54 kV and 0.1 Hz for more than 24 hours. Detailed measurements were carried out with 54 kV on the PFNs: 54 kV was chosen as it is the expected operating voltage at CERN. Pulses of magnitude 27 kV are produced when a PFN is charged to 54 kV and discharged into a matched terminating resistor. CERN provided a terminating resistor and 10 RG220 cables to connect the main switch (MS) CX2003 thyratron to the main switch terminator (Fig. 246). The kicker pulse length is controlled by a dump switch (DS) CX2503 hollow anode thyratron that connects to a water-cooled DS terminating resistor. A total of 10 precision terminating resistors was built and tested at TRIUMF with a measured resistance of 4.74 Ω ± 0.01 Ω at 25°C at low voltage. The MS terminating resistance was measured at low voltage to be 4.96 Ω. The voltage dependence of the MS and DS terminating resistors is, according to HVR, −1.33%/(kV/cm). Each resistor consists of a stack of 10 resistor disks each 1 in. thick, thus the MS terminator resistor at 27 kV is 4.89 Ω, and the DS terminator resistance at 27 kV is 4.68 Ω.

Fig. 246. PFN test set-up at TRIUMF with RCPS, and 4 CERN controls racks.

Each PFN system was set up and controlled by a CERN computer control system consisting of 4 racks of electronics, that was set up at TRIUMF. Thus testing of the PFNs and thyratron switches and RCPS was controlled in a representative manner. The operational status of the kicker system located at TRIUMF could be monitored from CERN via an Internet connection. Several modifications to the controls and interlocks were made remotely from CERN during the initial setup phase.

The high voltage pulse measurements are in excellent agreement with the low voltage measurements and with PSpice predictions. The pulse waveforms, measured at the MS terminating resistor, were used to calculate the field in a PSpice simulation that includes the kicker magnet (Fig. 247). The 0.5% to 99.5% rise time for PFN2 is 800 ns (cf 900 ns) and the 99.5% to 0.5% fall time 2.4 ms (cf 3.0 ms). The fall time is 2.0 ms if the 0.6% undershoot at the tail of the pulse is neglected. The standard deviation of the magnetic field variation for PFN2 during the flat top is ±0.09%. The largest flat top standard deviation is ±0.16% for PFN9.

An important design consideration was the absolute precision of the PFN construction so that the PFNs are interchangeable with a minimum change in the relative calibration. All 9 PFNs were operated at a voltage of 54 kV: the high voltage was set by the CERN control system. The measurements were made in 2-month intervals over an 18-month period. The standard deviation in the relative calibration of the fields (Fig. 248) for the 9 PFNs is ±0.11%: this is a good indication of the long-term stability of the system as well as the precision of the PFN fabrication. Thus the overall system is well within the required specifications of ±0.5%. The maximum relative field calibration is 0.33%.

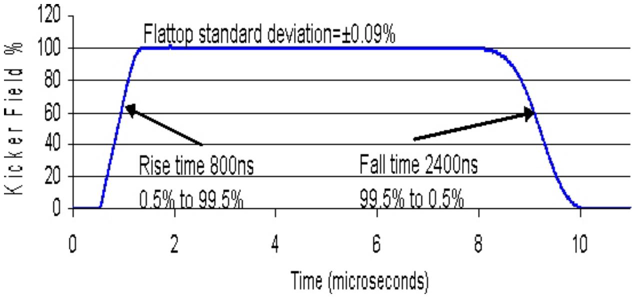

Fig. 247. Kicker magnet field calculated from PFN2 measured voltage pulse.

The TRIUMF shipping container, with special new shock absorbing frame, was used to ship 4 RCPS in 2003. One RCPS remains at TRIUMF and was used for all of the HV tests on the PFNs, switch tanks and terminating resistors. Special mounting brackets for clamping the PFNs to the shock absorbing frame were designed and installed in the spring, and there were 3 shipments of 2 PFNs each in 2004. There are 2 more shipments of the container scheduled for 2005, one shipment containing 2 PFNs to leave TRIUMF in February, and one shipment containing the final RCPS and PFN to leave TRIUMF in May. The CERN controls racks will be crated and sent separately in April. Thus all of these systems will be at CERN by June, 2005 for final testing and preparation for installation into the LHC tunnel.

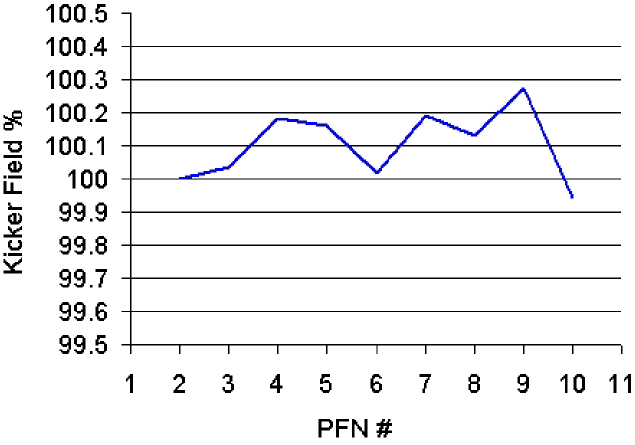

Fig. 248. PFNs (2 to 9) kicker fields normalized to PFN2.