Fermilab

Subject: Proton Improvement Plan - PIP

Project Quarterly Summary FY13 Q4

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Report # 5

Project Milestones

This quarter had only level 3 baselined milestones. Most of the milestones for this quarter were part of the Booster damper upgrade and Linac notch effort. Both of these two PIP task were impacted by budget changes to the original baseline plan. As noted in previous quarterly reports, a new RLS with the updated funding profile is being completed and will be used to generate a new milestone timetable.

Level	WBS	Name	Baseline Finish	Forecast Finish	Progress
3	1.01.02.03.05.03	MILESTONE: Linac Notch Laser Amplifier Technology Chosen	8/22/13	8/1/13	Done
3	1.02.03.02.01.02	MILESTONE: Specifications document for Booster longitudinal dampers complete	12/14/12	10/10/13	25%
3	1.02.01.01.02	MILESTONE: Specifications for Anode Power Supply Documented	1/10/13	10/25/13	25%
3	1.02.03.02.01.07	MILESTONE: Booster Damper prototype board for transverse system complete	3/5/13	11/14/13	5%
3	1.01.02.03.04.08	MILESTONE: Linac Notch Complete 1st 2 stage Fiber Amplifier	3/25/13	12/2/13	20%
3	1.01.02.03.06.09	MILESTONE: Linac Notch Optical Cavity Prototype Certification w/IR Optics	2/22/13	12/26/13	25%
3	1.01.02.03.06.10	MILESTONE: Linac Notch Prototype optical cavity certified (on bench)	2/22/13	12/26/13	0%
3	1.02.03.02.01.10	MILESTONE: Booster Damper prototype board testing complete	5/6/13	1/23/14	0%
3	1.02.03.01.01.03	MILESTONE: Booster BPM Specification Complete	3/1/13	2/5/14	5%

Figure 1 FY13 Q4 Milestone Report

In addition to funding RLS issues related to funding changes, there was some delay due to NOvA shutdown labor shortages and one due to vendor. Milestone 1.01.02.03.04 for Linac Notch had to be postponed until FY13 Q4 (2 months delay) due to vendor.

As stated above, Linac had one (1) L3 milestone: Linac Notch Laser Amplifier Technology chosen this quarter which was met. The laser chosen is a 1064 nm Nd:YAG amplifier offered by Northrop Grumman Cutting EdgetOptical (NGCEO). In the last quarter two (2) L3 milestones were reported as late for this project. Both were complete at the beginning of 4^{th} quarter.

Some additional M&S funding was provided to PIP this quarter. The additional funds were used to accelerate tasks that had been delayed by previous funding modifications. The WBS tasks below will mention the use of these funds if applied to that WBS. But an example would be the purchase of Booster Anode transformers. That task had been delayed several times until the funding became available.

PIP Highlights by WBS Section

WBS 1.1 Linac

The vulnerabilities associated with the LINAC are the 200 MHz accelerating system, including power amplifier tubes and other associated systems such as the modulator; utilities for power distribution and vacuum systems; need for reliable instrumentation along the Linac to improve beam transport and realistic machine model supported by real beam measurements. There are four largest elements of WBS Level 2 in Linac which are further subdivided at Level 3.

WBS 1.1.1 200 MHz RF Power System

The 200 MHz RF Power System represents approximately 40% of the total scope of the PIP project. There are 3 level 4 elements which will be described below.

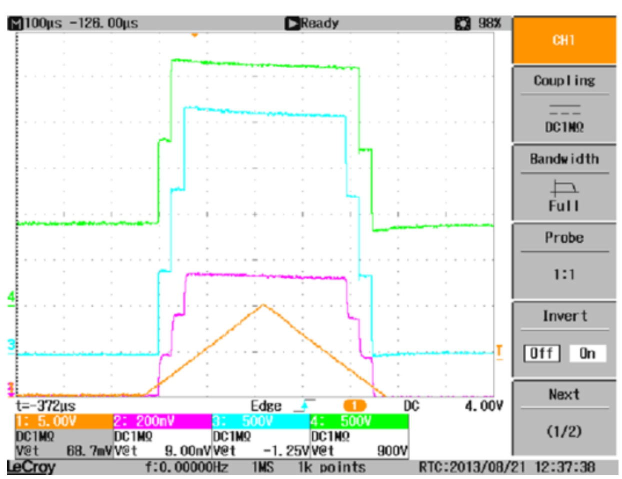
WBS 1.1.1.1 High Level RF

It was reported on the previous quarter report that the HLRF team was working close with business department to validate the bid awarded to CPI 13 months ago for a multi-beam klystron (MBK). However, CPI objected to the fixed price contract (FP) and offered Cost plus Fixed Fee (CPFF). This type of contract provides the contractor only a minimum incentive to control costs as the great risk falls on the laboratory. The laboratory business department initiated the necessary precautionary steps to understand our needs and work on a solution that could enable us to move forward with this unconventional type of contract here at the laboratory. A series of meetings were held between procurement personnel, legal advisors, laboratory internal audit head and PIP team. In the meantime, it was brought up to the PIP Project Manager attention that in recent past CPI offered a fixed price for a 200 MHz single beam klystron (SBK) for Los Alamos. Immediately the Project Manager contacted LANL to understand more about this situation while Craig Burkhart, (PIP consultant from SLAC) held a meeting with CPI engineers and inquired about this possibility. The response from CPI was positive, if PIP was willing to sacrifice peak power by developing a SBK device rather than a MBK, CPI would be willing to accept as a FP contract. A revision of the specifications was made to incorporate the necessary changes for a SBK and it was submitted to CPI whom, in the first order, agreed with the specifications. With CPI endorsement and a positive feedback from members of an internal review conducted by PIP team members, AD/RF experts and Dr. Burkhart, PIP team request another bid process to be generated for a 200MHz SBK. At the end of this quarter, the bid was in place and CPI requested an extension of the bid period, which was granted until early November.

WBS 1.1.1.2 Linac Modulator

<u>AD/EE Support Marx Modulator Design</u>

EE support spent most of this quarter testing the 3 cell system. Initially, some issues with the control board were addressed where the polarity of the cell status indication was inverted. After solving the controls issue, the 3 cells were tested, where it was learned that the bleeder resistors used to get the decay time to about 5 minutes would only hold off 300 volts per cell. New resistors were installed to run at a higher voltage. The cells were fired sequentially up and down, to a total of 900 Volts. The cells where tested again



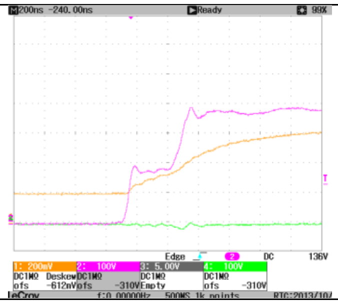
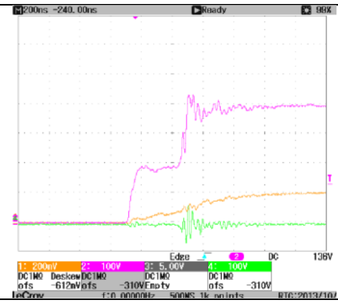
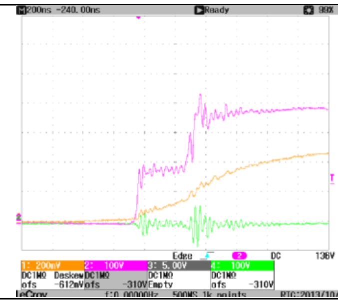
at 700 volts a cell (2100 Volts total), where some ringing was discovered. By changing two capacitors in the charging snubber network, the rising edge of the waveform steps was improved and ringing reduced. After changing the probing, the cells were run at 900 Volts, and a high frequency noise was discovered. These cell tests were done with a load resistance of 100 Ohms, which gives about 27 Amps of current through each cell. The load resistor value will be reduced to run the cells as a higher current (300 Amps), and therefore, at a higher power level. Presently all tests are done in single shot mode to reduce heating.

The above figure shows a picture of the 3 cell test that was conducted. One can see the capacitor droop due to the large energy draw from the cell capacitors for the length of the pulse. This was done at a load current of 50 ohm to increase the current drawn from each cell.

Another problem encountered was excessive ringing around 50 MHz. By changing the cell firing time close to each other the effect became more noticeable. By increasing the time between two cells firing the ringing was less significant. To determine where the ringing was coming from, the resistive load was switched to an inductive load which is pulsed, via another bouncer circuit, to any current level up to the full design current. The cells where then fired for less than 1 us at the inductor peak current time to show the ringing present in the cells. For this test, just two of the cells were fired into this inductive load. This enabled testing either one or two cells at any desired current to test the effect of the current through each cell. It was determined from these tests that the ring was likely caused by shutoff current required by the integrated free-wheeling diode on the main IGBT during switching.

When a downstream cell is turned on, the circuit path changes from the free-wheeling diode to the main storage capacitor. Some current is required to turn off this diode, which is suspected to cause the ringing. When tested at different currents, the ringing would get better or worse. Larger currents thought the cells obtained less ringing, as well as almost zero current, but a range of lower current, ringing was observed.

Now that the mechanism for the oscillations has been identified, further 2 & 3 cell testing will commence. This oscillation may need to be damped before the 9 cell prototype can be built and tested. More work on verifying these results will continue, with the goal of running a 3 cell prototype in the near future with a large range or output currents and without ringing as the cell firing times overlap. Once everything is working satisfactorily, then the building of the nine cell modulator starts.

		
Pink – Voltage Step 200 V Orange – Load Current 20 A Green – System Common No high frequency ringing	Pink – Voltage Step 200 V Orange – Load Current 0 A for cell one and 5 A for cell two. Green – System Common Starting with no current for cell one, but small amount of current through cell two starts ringing	Pink – Voltage Step 200 V Orange – Load Current 3 A for cell one and 13 A for cell two. Green – System Common Notice the ringing in both cells due to the small amount of current through each cell

WBS 1.1.1.3 7835 Procurement

With the supplemental money granted to PIP during this quarter, a procurement of one new 7835 tube was complete, which originally was schedule to happen at the beginning of FY14.

WBS 1.1.2 Accelerator Physics

WBS 1.1.2.1 Simulations and Studies

Small progress was achieved during this quarter for the Linac lattice.

WBS 1.1.2.2 *Not Used*

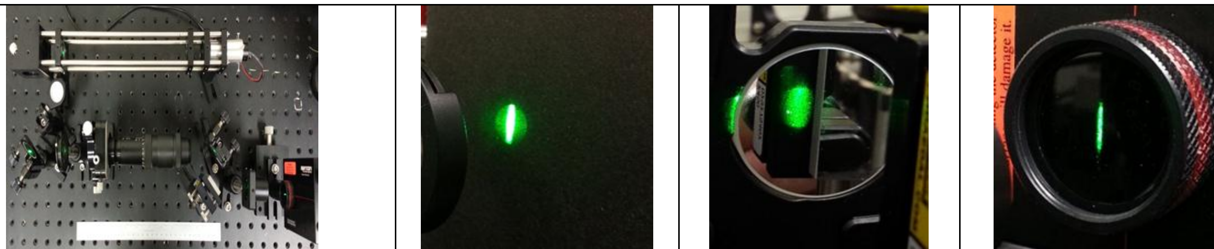
Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.1.2.3 Linac Notch Creation

The laser notch project had significant activities on several fronts during this quarter. The purchase of the waveform generator was finalized. This will allow the creation of the optical pulses, and procuring the final fiber amplifier which will feed the free-space amplifiers and beam shaping system.

During this quarter, the mechanical engineer (co-op), who designed the vacuum chamber and optical cavity to interface to the RFQ left in middle August, the model was transferred to ADMS Drafting where it is being optimized and fabrication prints being

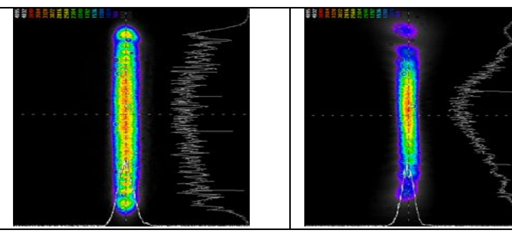
Effort continue to optimize the transverse beam shaping optics with the PiShaper, but the transport of the roof-type distribution over distances of interest is not as good as expected, so other techniques have been investigated to generate the roof-top profile. Figure 1 shows the optical set up and beam shapes at several points along the optics. Figure 2 shows the laser profile at two different distances from the optics.



A B C

Figure 1: Showing the laser beam shaping optical set up and results. (A) after the cylindrical telescope (input into PiShaper); (B) output of the PiShaper, and (C) output of the anamorphic prism pair on the face of the camera.

Figure 2: Laser profile of the roof-top beam at 5 cm from the prism (left picture) and 50 cm from the beam (right picture).



The prototype optical cavity design was 3D printed and used to test the design. Based upon the tests, several modifications to the design are being implemented to better optimize the operation and alignment. Figure 3 shows the 3D model and the alignment laser tests with the model.

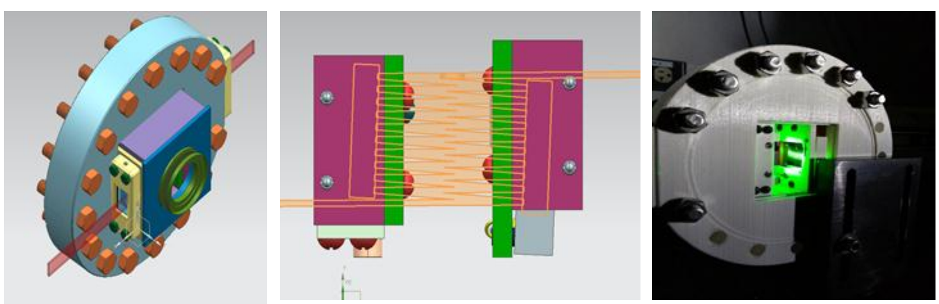


Figure 3: 3D model of vacuum chamber and cavity (left), a cut-away of the inside showing the mirrors and laser path (middle), and the 3D printed prototype being tested with green alignment laser (right).

Several waveform generators were tested for the production of the temporally uniform 201.25 MHz laser pulses to match the linac bunch structure and the Booster revolution period at injection. Due to the high gain of the final fiber amplifier the amplitude of the laser pulses are to be distorted such that the output will produce the required pulse structure for the solid-state amplifier. The arbitrary waveform generator (AWG) purchased will provide the flexibility needed in the generation of the laser pulse structure. Figure 4 shows the output of the AWG (yellow) and the laser pre-amplifier (green) for the various pulse f

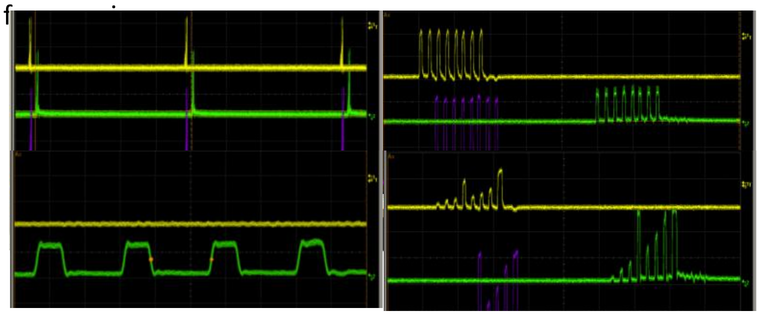


Figure 4: Output of AWG (yellow and laser pre-amplifier (green) at Booster revolution period (top, left), linac bunch frequency (top, right), uniform 201.25 MHz laser pulses (bottom, left), and the flexibility to pre-distort the laser pulses at the EOM (bottom, right).

Finally, as reported earlier, the Laser technology was chosen during this quarter. There were two options considered for the free-space amplifier: 1030nm amplifier wavelength based upon Snakecreek's cryogenic Yb:YAG technology or the 1064nm technology based upon Nd:YAG amplifier technology offered by Northrop Grumman Cutting Edge Optical (NGCEO). The chosen one was the ND:YAG technology because Snakecreek did not get the phase II SBIR. In addition NGCEO provides a robust OEM amplifier module system.

WBS 1.1.3 Instrumentation

WBS 1.1.3.1 Beam Position Monitors

First Linac Level-3 WBS completed (FY13-Q2).

WBS 1.1.4 *Not Used*

Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.1.5 Utilities

The Linac Utilities, such as power distribution and vacuum systems are composed of mostly 40 year-old equipment beyond its practical service life. There are two Level 4 elements in this WBS.

WBS 1.1.5.1 Power Distribution

Little progress was done during this quarter on the programming of the Motor Control Center PROFIBUS/SCADA system which was initiated. The reason is simply due to manpower restriction.

WBS 1.1.5.2 *Not Used*

Some numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established.

WBS 1.1.5.3 Vacuum System

With the slow startup for NOvA, there was an opportunity early August to install all the beam valves the 400 MeV area.

This particular task was another one which benefited from the additional money. All the roughing pumps that were pushed out to out-years were procured and received during this quarter.

WBS 1.2 Booster

Part of the PIP effort for the Booster Accelerator is to address the increase proton beam flux that will be demanded by the Fermilab program in the upcoming years. The increased flux will be achieved by providing beam on more/all of the Booster cycles; certain equipment will increase from an average 7.5 Hz to 15Hz. Overheating of old components is a major concern; several Booster PIP tasks are to upgrade/refurbish equipment to run at 15 Hz.

The aging original equipment and infrastructure of the Booster are vulnerable due to obsolescence and increase wear due to the increase of flux. Some of the PIP effort is to replace these possible reliability problems.

WBS 1.2.1 RF

WBS 1.2.1.1 Anode Supply

With the additional funding, transformers for the anode supplies have been purchased. This required some work on the specifications. Complete specifications are to be done early in FY14.

WBS 1.2.1.2 Bias Supply

Work on assembling the heat sinks will commence when manpower is made available to PIP. The retrofit of the first bias supply will begin when manpower is made available to PIP.

WBS 1.2.1.3 *Not Used*

Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.2.1.4 Cavity Test Stand

The cavity test stand task will not be done since there will be no benefit to PIP.

WBS 1.2.1.5 Cavity and Tuners Refurbishment

The refurbishment of the eighth cavity tuner set was completed this quarter. The time it takes to refurbish and test each set has averaged over the last three sets is a little more than ten weeks. Last quarter, the first cavity-tuner set had been removed since it was shown to have an RF leak. Additional manpower has been identified but has been called away several times to work on operational issues.

Figure 1 Milled bottom flange

Figure 2 Setup of cavity on milling machine

The above figures show recent progress in the resurfacing of the flanges of the rebuilt cavities and tuners. The rigging of a milling machine to grind down the additional material welded on the flanges has helped to produce a clean even surface. This also will help reduce dose rates the technicians receive for this process.

WBS 1.2.1.6 New Tuners

Previously, a high power test stand for ferrite cores showed that one of four different core sets (two different permeabilities from two vendors) was acceptable. The acceptable core samples have been implemented into a tuner and been certified. A purchase order for one set ferrite cores was done; delivery of these new cores occurred in FY13Q2. However, only four of the nearly sixty cores passed our high power test. The vendor made several batches of these ferrite cores and the cores that passed came from the same batch. The vendor believes that the chemistry/method of this particular batch is understood and has made a new set of cores according to this recipe. These have been delivered and been tested. We now have sixty low permeability cores which can be used. The vendor also believes that they can produce the high permeability ferrite core. A small order of five cores was delivered and tested. These did barely satisfy the permeability specification but were slightly the wrong physical dimensions. The vendor believes it can raise the permeability and will deliver another set of test ferrite cores early in FY14.

WBS 1.2.1.7 New Cavities

Comparison of a model developed for the current Booster RF cavities and the temperature measurements taken as part of the refurbishment task continues. Further tests of cooling rates will be done to be compared with the simulation. A preliminary look into making small improvements to the cavity-tuner design is being done. In addition, we are starting to investigate possible benefits of using a higher order harmonic cavity; in particular, for beam capture and initial acceleration.

WBS 1.2.1.8 Cavity 1013

This task requires the same manpower as the refurbishment task. Some resources were found for a short period and work has been done to do some assembly of the previously rejected cavity parts from the 1970's along with some newly manufactured components. The next step will be to vacuum certify the partial assembly.

WBS 1.2.2 Accelerator Physics

WBS 1.2.2.1 Simulations and Studies

Studies were done before the shutdown began. The main person doing the studies and analyses left at the end of FY12. The person was able to visit for several weeks at the end of second quarter and able to train/work with two individuals identified to be the main and secondary Booster optics. In FY13Q2, it was announced that the main Booster optics person would be stationed at CERN for a year. A new person from the Accelerator Physics Center has been assigned to work with a member of the Proton Source. They have been in email contact with the original person while they resurrect the codes, procedures and analyses.

The Booster was operational the entire quarter. Work is on-going to smooth the orbit to an ideal orbit (see WBS 1.2.2.2) and measure the optics.

WBS 1.2.2.2 Alignment and Aperture

No further magnet moves were done in FY13Q4. Areas have been identified where the alignment of components will be done in the future; it is possible that a minor move of a combined function magnet will occur next quarter. The centers of the apertures have been designated as the ideal orbit (see WBS 1.2.2.1).

WBS 1.2.2.3 Booster Notcher

The system was operational this quarter. Procurement of parts for upgraded notcher kickers and associated power systems finished in FY13. Assembly of the power systems has started. A completed short kicker magnet is to be tested in the near future.

WBS 1.2.2.4 Booster Cogging

Based upon the current cogging equipment, initial code development for the new magnetic cogging method-system is in progress.

WBS 1.2.2.5 Booster Collimation

The collimation task is to control Booster beam loss after implementing the above notcher and cogging systems.

WBS 1.2.2.6 Radiation Shielding

Beam studies concerning the beam loss profile and measurement of beam loss radiation through penetrations has been done. There are on-going discussions of the results of the studies and simulations. The analysis and write-up of the beam studies concerning beam loss radiation is nearly finished. The next step will to continue discussion with Accelerator Division ES&H. Once accepted by ES&H, they will write the Booster Shielding Assessment for the PIP proton flux goal.

WBS 1.2.3 Instrumentation

WBS 1.2.3.1 Beam Position Monitors

Design work for the Booster beam position monitor system will begin after completion of the Linac beam position monitor system.

WBS 1.2.3.2 Dampers

Studies to verify damper design choices are being done.

WBS 1.2.4 *Not Used*

Some WBS numbering is nonconsecutive at lower levels because of account closings and rearrangements after financial codes were initially established during the period of setting up PIP.

WBS 1.2.5 Utilities

WBS 1.2.5.1 Low Conductivity Water System

The task is done.

WBS 1.2.5.2 Power Distribution

With supplemental funding, a last power transformer has been ordered. The transformer will be identical to the two transformers previously purchased by PIP.

WBS 1.2.5.3 Vacuum System

The aged components will be replaced as opportunities present themselves with downtime of the Booster. Previously purchased vacuum equipment awaits opportunities for installation. Further purchases of vacuum equipment were done with additional funding.

WBS 1.2.7 Solid State Upgrade

The Booster RF solid state upgrade had been going on piecemeal for several years with purchasing of enough components to assemble the main elements of the solid state system: power amplifier, driver module and modulator for several stations. With the Proton Improvement Plan, we have been able to buy components in quantities. The East gallery of the Booster had been previously upgraded in FY12. The West Gallery upgrade was completed early in the FY13Q2. A few last spares spares were assembled at the end of FY13.

PIP Budget – Costs and Obligations Updates (FY13 Q4)

The previous Q3 report mentioned concern over FY12 carry over for several items. The decision has been made by laboratory management that PIP be allowed to now use those funds as originally planned. The carryover is currently reflected in both the OBL and RIP. Notwithstanding the carryover, the budget and spending for FY13 Q4 has been tracking the schedule. As mentioned in the previous quarterly report, tasks with significant cost and labor, such as new tuners, new Booster cavity and 201 MHz Klystron, will likely need to have schedule modifications in the outlying quarters. These items have experienced either vendor or budget issues as discussed in their respective WBS summary above. Another issue has been the balancing of labor due in part to the NoVA shutdown and then the startup and commissioning.

FY13 PIP OBL BUDGET K$	OBL BUDGET	YTD OBL	RIP	BUDGET BAL
M&S	6,027	2,624	2,395	1,008
Labor	3,946	3,919		27
FY13 Sums (End of Year)	9,973.3	6,543	2,395	1,036