DATA ACQUISITION AND ANALYSIS FOR THE FERMILAB COLLIDER RUNII

T. Bolshakov, K. Genser, K. Gounder, E. S. McCrory,
P. L. G. Lebrun [b] S. Panacek, V. Papadimitriou and J. Slaughter

Fermilab, P.O. Box 500, Batiavia, Ill., U.S.A.

[b] *e-mail contact: lebrun@fnal.gov*

Abstract

Operating and improving the understanding of the Fermilab Accelerator Complex for the colliding beam experiments requires advanced software methods and tools. The Shot Data Acquisition and Analysis (SDA) has been developed to fulfill this need. The SDA takes a standard set of critical data at relevant stages during the complex series of beam manipulations leading to $\sqrt{(}s) \approx 2$ TeV collisions.

Data is stored in a relational database, and is served to programs and users via Web based tools. Summary tables are systematically generated during and after a store. Written entirely in Java, SDA supports both interactive tools and application interfaces used for in-depth analysis. In this talk, we present the architecture and described some of our analysis tools. We also present some results on the recent Tevatron performance as illustrations of the capabilities of SDA.

Key words:
PACS: Data Acquisition, Data Processing, Accelerator

1 Introduction

Producing proton/anti-proton collisions for the Fermilab RunII program is a complex procedure involving the integrated operation of the Proton Source (Linac/Booster), the Anti-proton Source comprising the Debuncher and Accumulator rings, the Anti-proton Recycler, the 150 GeV Main Injector and the largest superconducting synchrotron currently in operation - the Tevatron [1]. One important tool for managing

⋆ This work was supported by the DOE of U.S.A

this complexity is the Shot Data Acquisition and Analysis (SDA) This paper gives an overview of SDA developed at Fermilab to meet this challenge.

Our goals are: (i) to develop, maintain and document an official, permanent repository for collider/shot data; (ii) assure the accuracy and the integrity of this data; (iii) build analysis tools for this data, thereby making it available to physicists and engineers. Finally, (iv) provide the primary intellectual guidance for new analysis of the shot data that will lead to a better understanding of the RunII accelerator complex and to improvements of its performance.

2 Acquisition, Analysis and Related Software Infrastructure

2.1 Data Acquisition

SDA is a dual use acronym, where the A stands for both "Acquisition" and "Analysis". These two distinct tasks are well integrated in part because the programming languages are identical (Java). Two distinct types of data are in use: data can either be "Sequenced" [1] or "Periodic". The former one is triggered and is taken when a significant change in the beam or machine condition occurs, for instance a beam transfer between the 150 GeV Main Injector and the Tevatron. Such carefully orchestrated state changes are controlled by the Sequencers.

The "Periodic" data is taken continuously at a fixed frequency (ranging from 1/300 to 1 Hz), no matter what happens in the complex. We also take periodic data at relatively high frequency ($\approx$ 100 Hz), during short periods, like during synchrotron's ramps, called Fast Time Plots(FTP), or beam aborts. The Front-End systems generate data asynchronously from each other, based on the state of the instruments they serve or the state of the machine. However, they all generate ACNET [2] data. An ACNET variable is either of scalar type or vector, indexed - for instance - against the number of bunches in a given machine. The Sequenced or Periodic data loggers handle only ACNET data via dedicated processes named OAC (Open Access Clients). This data is stored in relational databases. The block diagram shown on figure 1 reflects the complexity of this software infrastructure.

The Sequenced data is organized hierarchically. We introduced "Shots", "Cases" and "Sets", where a Shot resides at the highest level and refers to the collection of data for a Tevatron Collider Store, or, conversely, a Recycler refill. The Case refers to a significant change in the operating mode of a given machine, triggered

[1] The original means for "S" in SDA stood for "Sequenced" instead of "Shot". We later generalized the project to include integrated analysis of RunII collider operation

[2] This ACcelerator NETwork protocol has been internally developed at Fermilab several years ago

by the Sequencer. A typical example is a beam transfer between two machines. Such operations can be done multiple times in which case the "Case" has multiple "Sets". For instance, we inject 36 individual proton bunches to the Tevatron, one by one, from the Linac/Booster/Main Injector, which leads to 36 "Sets" in the "Inject Proton" "Case". A "Set" contains a list of ACNET variable values or FTPs.

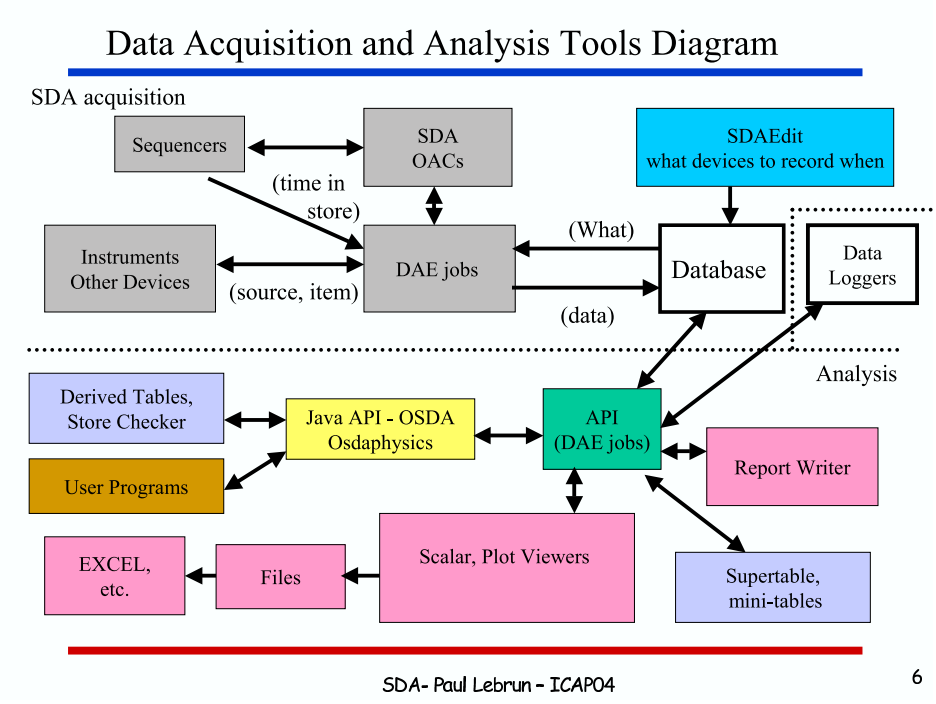

Fig. 1. Block Diagram of the Shot Data Acquisition and Analysis Software. The top part refers to the acquisition part and the bottom part to the analysis tools.

2.2 Analysis Tools

SDA data is of interest to RunII managers, accelerator physicists and engineers. We had to provide versatile data access and tools adapted to the capabilities - and taste - of the users. All the information (results as well as analysis code) is available from the Web. A great advantage of Java is the easy Web integration, and we certainly took advantage of this. We now briefly describe these tools, starting with the high level access to information, and ending up with expert tools [2].

- The "Supertable" summarizes the performance of the entire complex for a given store [3] The table consist of approximately 130 columns (and growing) and one

[3] A Tevatron store or shot consists of the proton/anti-proton injection, acceleration to 980 GeV, focusing the beams at the two experiments for collisions. A store duration is typically 20 hours

row per store. Beam properties are computed based on latest calibrations or lattice functions and properly averaged. Information on luminosity, beam intensities, lifetimes, transfer efficiencies, emittances, chromaticities and betatron tunes is available either in HTML or Excel. Macros to conveniently select particular set of columns have been written.

- Performance Plots and Table: The weekly and yearly integrated luminosities are monitored by a wide audience.
- The "Derived Tables". More details can be found in multiple tables with the the history of a particular bunch, from the source(s) to the Tevatron at low beta. Bunch intensity, lifetime and emittances (longitudinal and transverse) throughout the complex are computed.
- The "Store-Checker". As we reach collisions in the Tevatron, SDA data integrity is checked and an HTML table listing possible defects or problems is created. URL's are send via e-mail to interested parties.
- The Data browsers. The SDAViewer is a browser for the Sequenced data, organized in a tree following the SDA hierarchy ("Shots", "Cases" and "Sets") The Plot Viewer handles FTP's. The Periodic data can be accessed via a dedicated Web browser.
- An Application Programming Interfaces (API). The data browsers can generate flat ASCII files, or Excel sheets, that can be processed offline. However, detailed and systematic analysis often requires writing some dedicated code, and if so, a direct API is appropriate. We developed two Java packages osda and osdaphysics, to access to Sequenced and Periodic data access over the network and place it into advanced containers and optionally correct the data. These packages are also used in part of the tables described above.
- The Physics Analysis Tools: commercial (Origin7) [3], or freeware (Root) [4] JAS [5]) are used to do statistical tests, fits or simply to make plots.

Thoughout this implementation, we used several advanced utlities of the Java programming environment such as "servlets" based on Remote Method Invocation, Functors and several security mechanisms.

3 Two Analysises

Our intend is to illustrate the capabilities of the SDA and not to present a comprehensive report on the performance of the Tevatron.

3.1 The delivered luminosity, bunch by bunch

This simple example illustrates the degree at which we understand quantitatively our delivered instantaneous luminosity $\mathcal{L}$. It is directly measured by the experi-

ments, bunch by bunch. Since the Tevatron is equipped with intensity and emittance detectors, $\mathcal{L}$ for each proton/anti-proton pairs of bunches can be computed and compared to measurements shown on figure 2. It shows that (i) there are substantial variation among bunches with a solid correlation between expected and observed luminosities is observed (ii) the anti-proton bunch intensity is the dominating factor in this variability. This variability can be traced from the source, and the evolution of each bunch across the accelerator chain. (iii) A systematic overall scale factor of ≈ 1.2 needs to be applied. There are many possible causes for such a factor: uncertainties in the total $p\bar{p}$ cross-section or/and the emittance scale or the lattice functions at the interaction points.

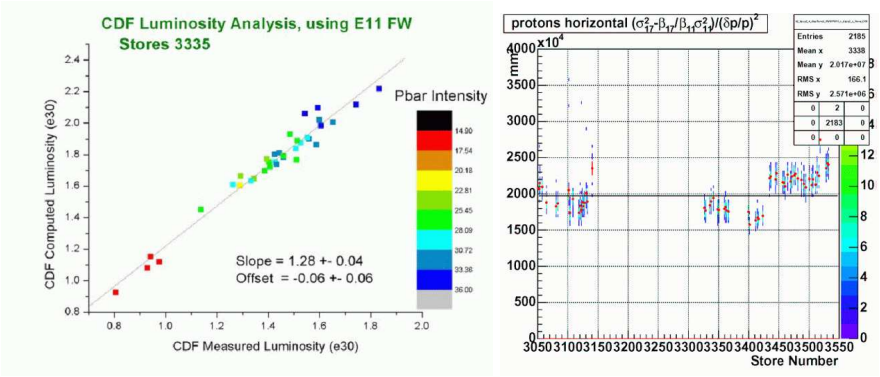

Fig. 2. Right: The expected Luminosity versus the CDF measured luminosity for each 36 bunch circulating in the Tevatron. Left:The lattice function k^2 versus the store number.

3.2 Tevatron Emittance Measurements and lattice stability

The Tevatron transverse emittances are measured by two distinct devices, the Synchrotron Light Monitor [6] and the Flying Wire system[7]. These have been compared to each other, allowing a cross check of the lattices and a better understanding of these instruments. In addition, we measure the horizontal emittance with flying wires at two distinct locations. Knowing the momentum spread $\delta P/P$ and the measured horizontal width of the beam at these two locations (σ_1 and σ_2), we derive the following quantity:

$$k^2 = (\sigma_1^2 - (\beta_2/\beta_1)\sigma_1^2)/(\delta P/P)^2 = D_2^2 - (\beta_2/\beta_1)D_1^2$$

where β_i and D_i are the horizontal beta function and dispersion, respectively. Thus, for a fixed lattice, k is a constant (figure 2, left side) Yet, subtle changes in this quantity are observed and correlates to lattice adjustments at other locations in the lattice (interactions points in particular). Such studies allow us to establish systematic errors on beam properties like transverse emittances, which is critical to optimize the accelerator complex.

4 Conclusions

SDA is a system for acquiring, archiving and analyzing RunII collider stores. The system allows us to study correlations of information from multiple data sources at specific times during the stores. SDA is also used to search for trend and to optimize the running conditions. It has been implemented and has been operational for at ≈ 3 years. We still make significant upgrades: for instance, we need to integrate the Recycler data within the SuperTable. This work is progressing well, without significant changes to either the data model or the core infrastructure.

References

[1] The Fermilab RunII Handbook, at http://www-ad.fnal.gov/runII/index.html

[2] http://www-ad.fnalgov/sda/ See also Fermilab Beam Document Database documents # 661, 662, 665 at http://beamdocs.fnal.gov/cgi-bin/public/DocDB/ShowDocument

[3] This package has been developed by OriginLab corporation at http://www.originlab.com/

[4] http://root.cern.ch/

[5] http://jas.freehep.org/

[6] H. W. K. Cheung, "Performance of a beam monitor in the Fermilab Tevatron using Synchrotron Light", PAC03 paper WPPB036, Oregon, May 2003

[7] W. Blockland, *et al* "A New Flying Wire System for the Tevatron", PAC97 Proceedings, vol 2, p. 2032, Vancouver, Canada, 1997.