DATA ACQUISITION AND ANALYSIS FOR THE FERMILAB COLLIDER RUNII

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

[a] *Fermilab, P.O. Box 500, Batiavia, Ill., U.S.A.*

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

Abstract

Operating and improving the Fermilab Accelerator complex for the colliding beam experiments requires advanced software methods and tools. The Shot Data Acquisition and Analysis system (SDA) has been developed to fulfill this need. The SDA system 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 automated 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 unique analysis tools. We also present some salient results on the recent Tevatron performance, as illustrations of the capabilities of SDA.

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

1 Introduction

The Fermilab Proton-Anti-proton Collider RunII program is based on a diverse set of accelerators, accumulator rings [1]. Operating this complex implies many beam transfers or manipulations in each machines, which range from a negative hydrogen ion Linear accelerator, three distinct anti-proton accumulator rings, to the Tevatron, largest superconducting synchrotron currently running in the world. Managing this complexity requires dedicated software and computing resources. This paper gives

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an overview of the Shot Data Acquisition and Analysis 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) make it available to physicists and engineers. That is, develop, maintain and integrate analysis tools that are easy to use and complete. Finally, one must also provide the primary intellectual guidance for new analysis of the shot data that will lead to a better understanding of the performance of the RunII accelerator complex and to improve 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". It also reflects the robust integration we achieved between these two tasks: the programming languages are identical (Java) and the basic data models are of course applicable for acquisition and analysis tasks. Two distinct types of data are in use: data can either be "Sequenced" 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 others, based on the state of the instruments they serve or the state of the machine. However, they all generate ACNET [1] 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

[1] This ACcelerator NETwork protocol has been internally developed at Fermilab for many years

refers to a significant change in the operating mode of a given machine, triggered by the Sequencer. 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). A "Set" contains a list of ACNET values (scalars or array (vectors)) or a FTPs.

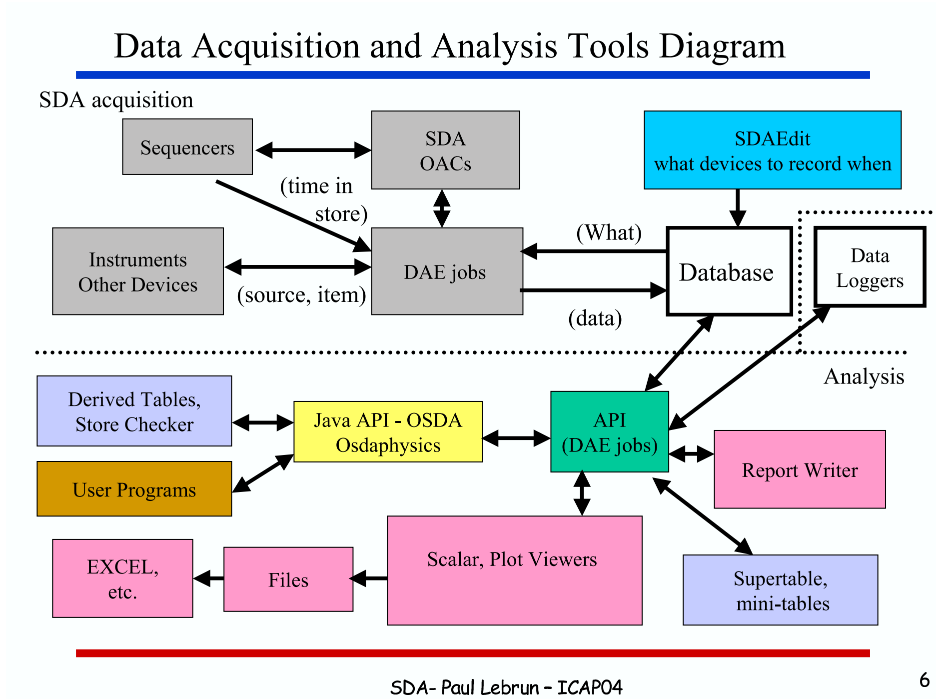

Fig. 1. Block Diagram of the Shot Data Acquisition and Analysis Software. The top part refers to the acquisition part and the bottom part to the analysis tools.

2.2 Analysis Tools

SDA data is of interest to RunII managers, accelerator physicists and engineers. This means that data access methods must be versatile, and the tools highly 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 integration to the Web, 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].

- Supertable: This table summarizes the performance of the entire complex achieved for a given store [2] The table consist of approximately 130 columns (and grow-

[2] A Tevatron store consists of the proton/anti-proton injection, acceleration to 980 GeV,

ing), one row per store. Beam properties are recomputed based on latest calibration, lattice values and properly averaged. Information on beam intensities, lifetimes, transfer efficiencies, emittances, betatron tunes is available either in HTML or Excel format. Macros to conveniently select particular set of columns have been written.

- Performance Plots and Table. The weekly and yearly integrated luminosities are obviously of great interest [3] .
- Derived Tables. More details can be found in multiple tables that can give the the history of a particular bunch, from the source(s) to the Tevatron at low beta. Bunch Intensity lifetime in the Tevatron are computed.
- 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 relevant members of the lab.
- Data browsers. The SDAViewer is Java based data 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.
- 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 quite handy. We develop two Java packages OSDA and OSDAPhysics, that allows access to Sequenced and Periodic data access over the network, place this data into more advanced containers and optionally correct the data. These packages are also used in computing some element of the tables described above.
- Finally, we use generic Physics Analysis Tools, commercial (Origin7) [3], or freeware (Root) [4] Jas [5]) to do statistical tests, fits or simply to make plots.

3 Two distinct analysis

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

3.1 The delivered luminosity, bunch by bunch

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

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focusing the beams at the two experiments for collisions. A store duration is typically 20 hours

[3] prompting occasional phone calls from DOE or lab officials, when they are unavailable for some reasons...

periments, 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 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 root-causes for such a factor: uncertainties in the total $p\bar{p}$ cross-section, the emittance scale or the lattice functions at the interaction points.

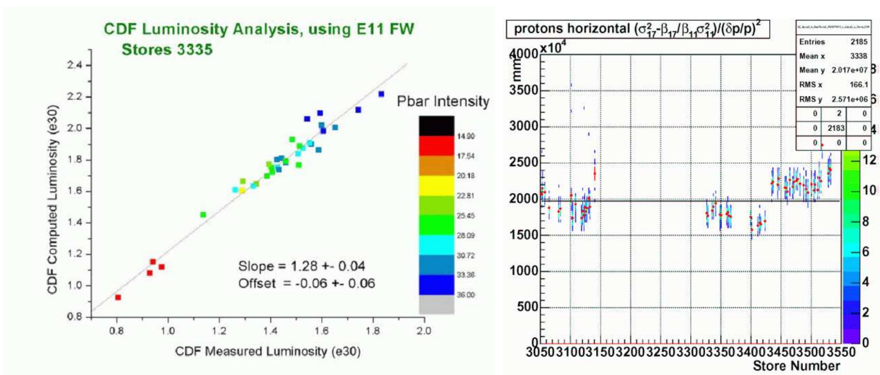

Fig. 2. Right: The expected Luminosity versus the CDF measured luminosity for each 36 bunch circulating in the Tevatron. Left:The lattice function k^2 is shown versus store number.

3.2 Tevatron Emittance Measurements and lattice stability

The Tevatron transverse emittance are measured by two distinct devices, the Synchrotron Light Monitor [6] and the Flying Wire[7]. These have been compared to each others, 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 in the Tevatron. Knowing the momentum spread $\delta P/P$ and the measured horizontal width of the beam at these two locations (σ_1 and σ_2), one can construct 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 data stores. The system allows us to study correlations of information from multiple data sources at specific times during the stores. SDA is also used for trending analysis and optimization of the running conditions. It has been implemented and has been running for at ≈ 3 years. Yet, we still are making significant upgrades: for instance, we need to integrate the Recycler data in the Collider shot 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

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