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The e-Science Paradigm for Particle Physics[1]

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1. Introduction

Research in the 21st century is increasingly driven by the analysis of large amounts of data within the e-Science paradigm. e-Science is the data centric analysis of science experiments unifying experiment, theory, and computing. According to Simon C. Lin and Eric Yen (Lin & Yen, 2009), e-Science or data-intensive science unifies theory, experiment, and simulations using exploration tools that link a network of scientists with their datasets. Results are analyzed using a shared computing infrastructure.

In this chapter, we use the concept of e-Science to combine experiment, theory and computing in particle physics in order to achieve a more efficient research process. Particle physics applications are generally regarded as a driver for developing this global e-Science infrastructure.

According to Tony Hey at Microsoft (Hey, 2006), thousands of years ago science focused on experiments to describe natural phenomena. In the last few hundreds of years, science became more theoretical. In the last few decades, science has become more computational, focusing on simulations. Today, science can be described as more data-intensive in nature, requiring a combination of experiment, theory, and computing. Attempts have been made to realize this e-Science concept. One e-Science application is the Worldwide Large Hadron Collider Computing Grid (WLCG), which realizes Ian Foster's definition of a grid (Foster et al., 2001). The grid is the combination of computing resources from multiple administrative domains to reach a common goal (Cho & Kim, 2009). As the global e-Science infrastructure is rapidly established, we must take advantage of worldwide e-Science progress. High-energy physics has advanced the e-Science paradigm by successfully unifying experiments, theory, and computing (Cho et al., 2011).

We apply the e-Science concept to particle physics and show an example of this paradigm. As shown in Fig. 1, we construct a unified research model of experiment-theory-computing in order to probe the Standard Model and search for new physics.

This is not a simple collection of experiments, computing, and theory, but a fusion of research in order to achieve a more efficient research process. We apply this concept to the

[1] This chapter is based on the paper titled "Collider physics based on e-Science paradigm of experiment-computing-theory" by K. Cho et al. in Computer Physics Communication Vol. 182, pp. 1756-1759 (2011).

Collider Detector at Fermilab (CDF) experiment in the USA and the Belle/Belle II experiment at High Energy Accelerator Research Organization (KEK) in Japan.

For computing-experiment, we construct and use the components of the e-Science research environment, including data production, data processing, and data analysis using collaborative tools. We also develop new computational tools for future experiments. In high energy physics, the goal of e-Science is to perform and/or analyze high energy physics experiments anytime and anywhere. We apply this system to the Belle II experiment at KEK. For data processing, WLCG is one of the original new research infrastructures that show how an effective collaboration might be conducted between users and facilities (Cho, 2007). The Asia Pacific area should develop both an e-Science platform and best practices for collaboration in order to fill the gaps in e-Science development between other continents. The Academia Sinica Grid Centre (ASGC), as the coordinator of the Asia federation under Enabling Grid in e-Science (EGEE), has worked closely with partners for region specific applications in data processing. For data analysis using collaborative tools, community building should be the foundation for collaboration rather than just offering technology. The e-Science research environment provides a trusted way to allow people, resources, and knowledge to connect and participate via a virtual organization. More and more countries will deploy a grid system and take part in the e-Science research environment. According to Simon C. Lin (Simon & Yen, 2009), we are widening the uptake of e-Science through close collaboration regionally and internationally.

For experiment-theory, we develop a combination of phenomenology and data analysis. Experiments give results and tools for theories and theories give feedback to experiments. We apply this system to the CDF, D0, and Belle experiments in order to probe the standard model and search for new physics. For theory-computing, we study lattice gauge theory and use the supercomputer at the Korea Institute of Science and Technology Information (KISTI).

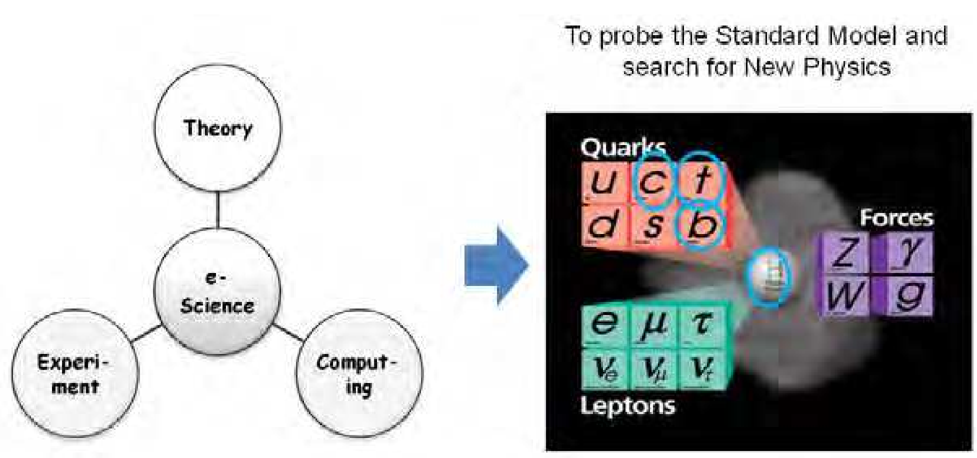

Fig. 1. The paradigm of e-Science in high energy physics, which is a fusion of experiment, computing, and theory research.

2. Main

We explain the results for computing-experiment, experiment-theory, and theory-computing for the analysis of particle physics. While many previous works have only used supercomputers, in our work computing results are combined with theory and experiment. We use a combination of supercomputers and an e-Science environment. The components of an e-Science environment are data production for remote shifts, data processing for grid farms, and data analysis using the Enabling Virtual Organization (EVO) collaborative tool.

2.1 For computing-experiment

2.1.1 e-Science research environment

We define a computing-experiment tool as an e-Science research environment. In order to study particle physics, we can access the environment anytime and anywhere even if we are not on-site an accelerator laboratory. A virtual laboratory enables us to perform research as if we were on-site (Cho, 2008). We apply e-Science components to the CDF experiment.

2.1.1.1 Data production

The purpose of data production is to take both on-line shifts and off-line shifts anywhere. On-line shifts have been conducted through the use of a remote control room at KISTI and off-line shifts have been conducted via the sequential access through metadata (SAM) data handling (DH) system at KISTI. The remote control room is built to help non-US CDF members to fulfill their shift duties as a Consumer Operator (CO) part of the CDF data taking shift crew. The remote control room facilitates various monitoring applications that the CO has to monitor for a given eight hour shift. We have been operating the CDF remote control room at KISTI since July 22, 2008. A real Data Acquisition (DAQ) has been recorded at the remote control room at KISTI between August 1 and August 8, 2008. The CDF detector is an experimental apparatus for recording electrical events produced by the accelerator at an enormous rate. This apparatus is comprised of several components that perform different functions including a detector with millions of data channels transmitted to a corresponding number of electronic readout devices. The operation of an apparatus with this degree of complexity needs to be collaboratively controlled by researchers. In general, each shift crew takes an eight hour shift so that three shift crews will cover 24 hours. In the CDF experiment, the shift crew consists of three people with different missions. First, the Science Coordinator (SciCo) is responsible for the entire shift session and must have a lot of experience. The second person is the Ace shifter, who is an expert on the control of all detector components and electronic readout devices. The third person is the CO who has been trained in interpreting the meaning of the data being monitoring. UNIX processes intercept the on-line data transmitted from the front-end readout electronics and generate various plots that represent the quality of the data taken by the detector. These plots help the CO to determine whether or not the data collection is continuing as expected. Accordingly, the CO advises the Ace shifter to interrupt the detector operation in order to correct any problems.

Although the CO's monitoring task involves on-line data collection, this can be performed in a remote location due to its mostly monitoring-related nature. These remote control rooms are located at the Pisa University in Italy, the University of Tsukuba in Japan, and KISTI in Korea. In Korea, there are about 30 collaborators from six institutions, most of which have to fulfill CDF duties by taking detector operation shifts. All the plots that the consumers generate are accessible via web browsers where all the monitoring can be done. The CO has to not only monitor any plots generated by consumers but also must monitor the consumers themselves. However, the policy imposed by the Department of Energy (DOE) in the United States prohibits any remote researcher outside of Fermilab from executing any control-related UNIX command. Instead, control-related execution must be initiated by a person on-site. At the same time, all transmissions of control commands have to be encrypted using Kerberos. Thus, we can solve this problem by having an on-site crew send a graphic user interface (GUI) named "consumer controller" to the remote monitor via the Kerberized secure shell port. The CDF II experiment has been taking data from June 30, 2001 to September 30, 2011. Fig. 2 shows the CDF main operation center and remote control room at KISTI. As shown in Fig. 3, we have taken remote shifts (24 days per year on average) successfully.

Fig. 2. The CDF main operation center and remote control room at KISTI.

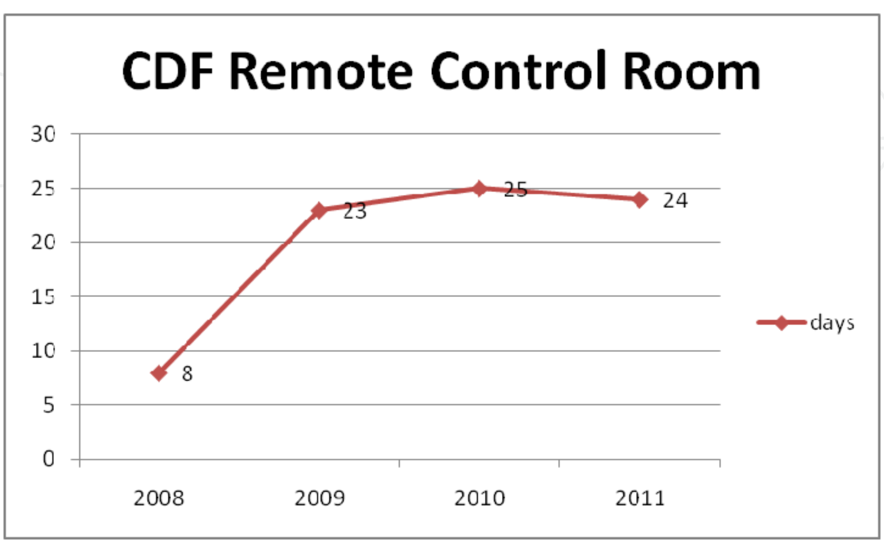

Fig. 3. The CDF remote control used at KISTI.

We perform another type of remote data handling shift at KISTI. Whereas the remote control room implements an on-line version of remote data handling, there is a second shift that implements an off-line version of remote data handling. This second type of shift is actually in the form of a SAM DH shift. This shift also occurs eight hours per day for seven days. These shifts do not need to cover the entire twenty four hours with three shifts per day since they are off-line. Furthermore, one can take the shift in the daytime of his or her time zone if participating in the shift schedule outside of the USA. The CDF SAM DH is called off-line since the data handled in this case includes data inbound to the tape from SAM stations in reconstruction farms and vice versa. The off-line data transfers in CDF are between SAM stations and mass storage system (MSS). In Fermilab, MSS consists of a Storage Resource Manager (SRM), dCache, and the Enstore system. The dCache software was the result of joint project between Fermilab in Batavia, USA and DESY (Deutches Elecktronen SYnchrotron laboratory) in Hamburg, Germany. dCache is a front-end for disk caching and provides end-users with the functionalities of reading cached files and writing files to and from Enstore indirectly via dCache. The Enstore system is a direct interface to files on tape for end-users. End-users can refer to SAM stations of CAF and farm machines. In the present context, the SAM stations in the CDF Analysis Farm (CAF) and farm clusters use an Application Programming Interface (API) provided by dCache to read files from and write files to the tapes via dCache and the Enstore systems. Thus, the mission of the CDF SAM shift includes monitoring the Enstore system, the dCache system, and SAM stations of the CDF analysis farm (CAF) and the CDF experiment farm.

2.1.1.2 Data processing

Data processing is accomplished using a High-Energy Physics (HEP) data grid. The objective of the high-energy physics data grid is to construct a system to manage and process high-energy physics data and to support the high-energy physics community (Cho, 2007).

For data processing, Taiwan has the only WLCG Tier-1 center and Regional Operation Center in Asia since 2005. ASGC has also been serving as the Asia Pacific Regional Operational Center to maximize grid service availability and to facilitate extension of e-Science (Lin & Yen, 2009). In Japan, a Tier-2 computing center supporting the A Toroidal LHC Apparatus (ATLAS) experiment has been running at the University of Tokyo. There is another Tier-2 center at Hiroshima University for the A Large Ion Collider Experiment (ALICE) (Matsunaga, 2009). At KEK, collaborating institutes operate a grid site as members of the WLCG. These institutes try to use their grid resources for the Belle and Belle II experiments. The Belle II experiment, which will start in 2015, will use distributed computing resources.

We explain the history of data processing for the CDF experiment. The CDF is an experiment on the Tevatron, at Fermilab. The CDF group ran its Run II phase between 2001 and 2011. CDF computing needs include raw data reconstruction, data reduction, event simulation, and user analysis. Although very different in the amount of resources needed, they are all naturally parallel activities. The CDF computing model is based on the concept of a Central Analysis Farm. The increasing luminosity of the Tevatron collider has caused the computing requirement for data analysis and Monte Carlo production to grow larger than available dedicated CPU resources. In order to meet demand, CDF has examined the possibility of using shared computing resources. CDF is using several computing processing systems, such as CAF, Decentralized CDF Analysis Farm (DCAF), and grid systems. The

Korea group has built a DCAF for the first time. Finally, we have constructed a CDF grid farm at KISTI using an LCG farm.

In 2001, we have built a CAF, which is a cluster farm inside Fermilab in the United States. The CAF was developed as a portal. A set of daemons accept requests from the users via kerberized socket connections and a legacy protocol. Those requests are then converted into commands to the underlying batch system that does the real work. The CAF is a large farm of computers running Linux with access to the CDF data handling system and databases to allow the CDF collaborators to run batch analysis jobs. In order to submit jobs we use a CAF portal with two special features. First, we can submit jobs from anywhere. Second, job output can be sent directly to a desktop or stored on a CAF File Transfer Protocol (FTP) server for later retrieval (Jeung et al., 2009).

In 2003, we have built a DCAF, a cluster farm outside Fermilab. Therefore, CDF users around the world enabled to use it like CAF at Fermilab. A user could submit a job to the cluster either at Central Analysis Farm or at the DCAF. In order to run the remote data stored at Fermilab in USA, we used SAM. We used the same GUI used in Central Analysis Farm (Jeung et al., 2009).

In 2006, we have built CDF grid farms in North America, Europe, and Pacific Asia areas. The activity patterns at HEP required a change in the HEP computing model from clusters to a grid in order to meet required hardware resources. Dedicated Linux clusters on the Farm Batch System Next Generation (FBSNG) batch system were used when CAF launched in 2002. However, the CAF portal has gone from interfacing to a FBSNG-managed pool to Condor as a grid-based implementation since users do not need to learn new interfaces (Jeung et al., 2009).

We have now adapted and converted out a workflow to the grid. The goal of movement to a grid for the CDF experiment is a worldwide trend for HEP experiments. We must take advantage of global innovations and resources since CDF has a lot of data to be analyzed. The CAF portal may change the underlying batch system without changing the user interface. CDF used several batch systems. The North America CDF Analysis Farm and the Pacific CDF Analysis Farm is a Condor over Globus model, whereas the European CDF Analysis Farm is a LCG (Large Hadron Collider Computing Grid) Workload Management System (WMS) model. Table 1 summarizes the comparison of grid farms for CDF (Jeung et al., 2009). Fig. 4 shows the CDF grid farm scheme (Jeung et al., 2009). Users submit a job after they input the required information about the job into a kerberized client interface. The Condor over Globus model uses a virtual private Condor pool out of grid resources. A job containing Condor daemons is also known as a glide-in job. The advantage of this approach is that all grid infrastructures are hidden by the glide-ins. The LCG WMS model talks directly to the LCG WMS, also known as the Resource Broker. This model allows us to use grid sites where the Condor over Globus model would not work at all and is adequate for grid job needs. Since the Condor based grid farm is more flexible, we applied this method to the Pacific CDF Analysis Farm (Jeung et al., 2009).

The regional CDF Collaboration of Taiwan, Korea and Japanese groups have built the CDF Analysis Farm, which is based on grid farms. We called this federation of grid farms the Pacific CDF Analysis Farm.

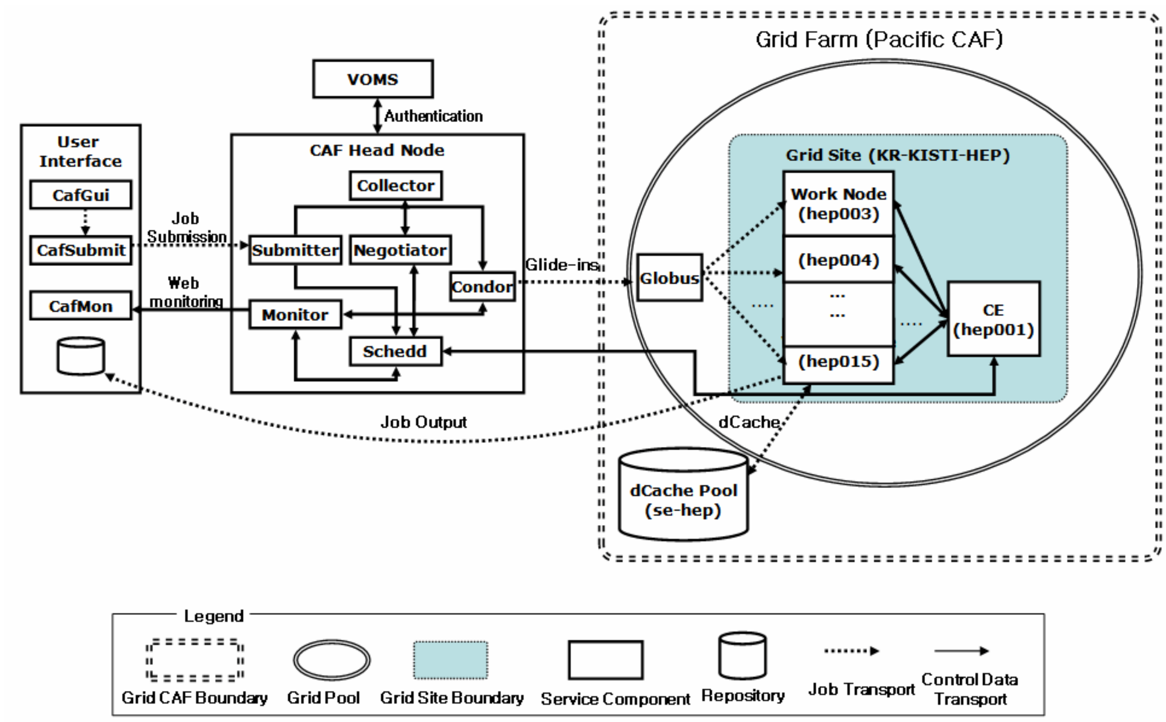

Fig. 4. The scheme of the Pacific CDF analysis farm.

Grid CDF Analysis Farm	Head node	Work node	Grid middle-ware	Method	VO (Virtual Organization)
North America CDF Analysis Farm	Fermilab (USA)	USSD (USA) etc	OSG	Condor over Globus	CDF VO
European CDF Analysis Farm	CNAF (Italia)	IN2P3 (France) etc	LCG	WMS (Workload Management System	CDF VO
Pacific CDF Analysis Farm	AS (Taiwan)	KISTI (Korea) etc	LCG, OSG	Condor over Globus	CDF VO

Table 1. Comparison of grid farms for CDF.

The Pacific CDF Analysis Farm is a distributed computing model on the grid. It is based on the Condor glide-in concept, where Condor daemons are submitted to the grid, effectively creating a virtual private batch pool. Thus, submitted jobs and results are integrated and are shared in grid sites. For work nodes, we use both LCG and Open Science Grid (OSG) farms. The head node of Pacific CDF Analysis Farm is located at the Academia Sinica in Taiwan. Now it has become a federation of one LCG farm at the KISTI in Korea, one LCG farm at the University of Tsukuba in Japan and one OSG and two LCG farms in Taiwan.

2.1.1.3 Data analysis using collaborative tools

A data analysis using collaborative tools is for collaborations around the world to analyze and publish the results in collaborative environments. We installed an operator EVO server at KISTI. Using this environment, we study high energy physics for CDF and Belle experiments. EVO is the next version of its predecessor, Virtual Room Videoconferencing System (VRVS). The first release of EVO was announced in 2007. The EVO system is written in the Java programming language. The EVO system provides a client application named "Koala." The Koala plays two client roles in order to communicate with two types of servers. The first type is a central server located in Caltech and handles videoconferencing sessions. Participants can use a Koala to enter a session that another participant created or book a new session. Once a participant is in a session, the Koala starts to play the role of another type of client that now communicates with one of the networked servers that handle the flow of media streams. The second type of server comprising a network is called "Panda." When a Koala is connected to a specific Panda, the Koala initiates a video tool called "vievo" and an audio tool called "rat," both of which have their origins in the "MBone" project. EVO has improved upon VRVS with the following new features: support for Session Initiation Protocol (SIP), including ad-hoc or private meetings, encryption, private audio discussion inside a meeting, and whiteboard. In 2007, we constructed the EVO system at KISTI since the Korean HEP community is large enough to have its own EVO Panda servers. The configuration of two servers by the Caltech group enables the first Korean Panda servers to run. Fig. 5 shows communications between KISTI Panda servers and other Panda servers in the EVO network. Since its introduction in 2007, KISTI Panda servers have served many communities such as the Korean Belle community and the Korean CDF community.

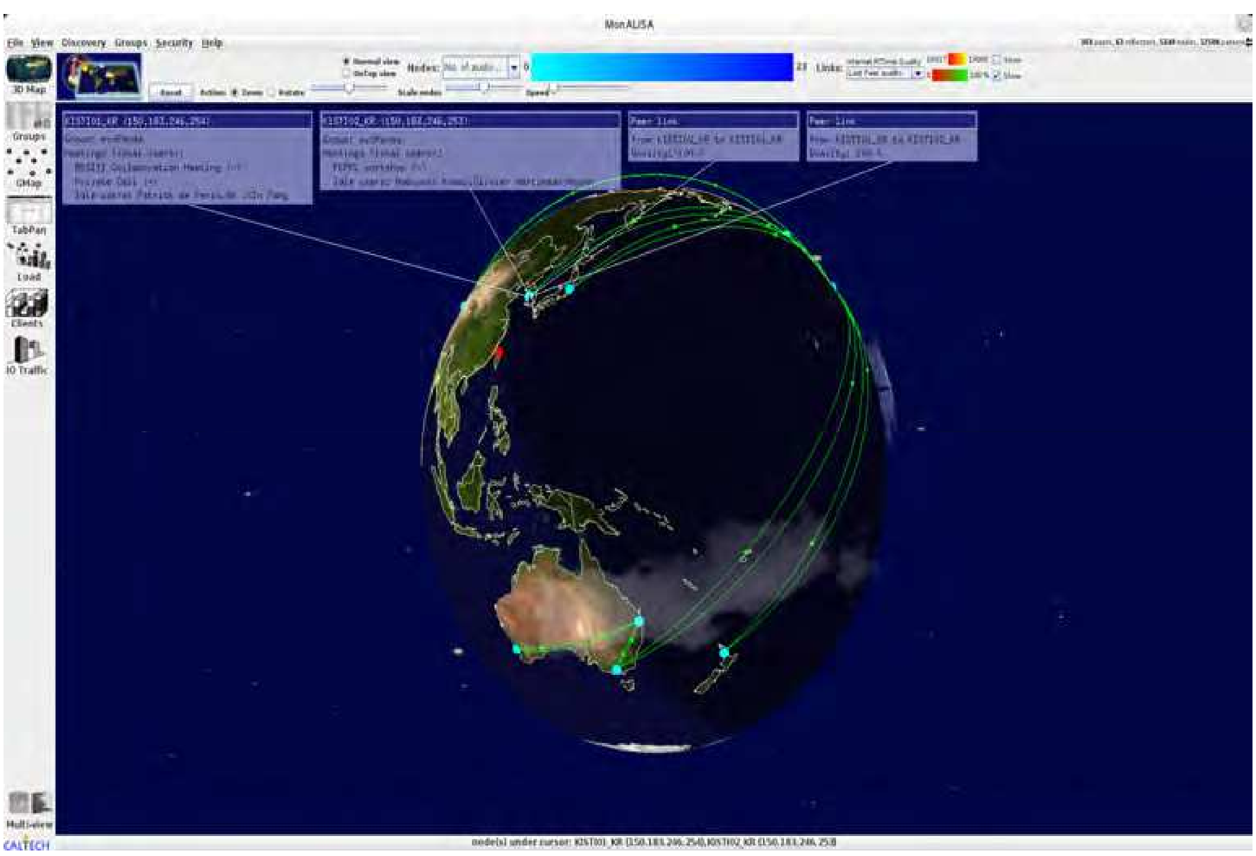

Fig. 5. Communications between KISTI "Panda" servers and other "Panda" servers in the EVO network.

2.1.2 New computing-experimental tools[2]

For new computing-experimental tools, we have worked on a Belle II data handling system. The Belle II experiment will begin at KEK in 2015. Belle II computing needs to include raw data reconstruction, data reduction, event simulation, and user analysis. The Belle II experiment will have a data sample about 50 times greater than that collected by the Belle experiment.

Therefore, we have very large disk space requirements and potentially unworkably long analysis times. Therefore, we suggested a meta-system at the event-level to meet both requirements. If we have good information at the meta-system level, we can reduce the CPU time required for analysis and save disk space.

The collider will cause the computing requirement for data analysis and Monte Carlo production to grow larger than available CPU resources. In order to meet these challenges, the Belle II experiment will use shared computing resources as the Large Hadron Collider (LHC) experiment has done. The Belle II experiment has adopted the distributed computing model with several computing processing systems such as grid farms (Kuhr, 2010).

In the Belle experiment (Abashian et al., 2002), we use a metadata scheme that employs a simple "index" file. This is a mechanism to locate events within a file based on predetermined analysis criteria. The index file is simply the location of interesting events within a larger data file. All these data files are stored on a large central server located at the KEK laboratory. However, for the Belle II experiment, this will not be sufficient as we will distribute the data to grid sites located around the world. Therefore, we need a new metadata service in order to construct the Belle II data handling system (Kim, et al. 2011; Ahn, et al., 2010).

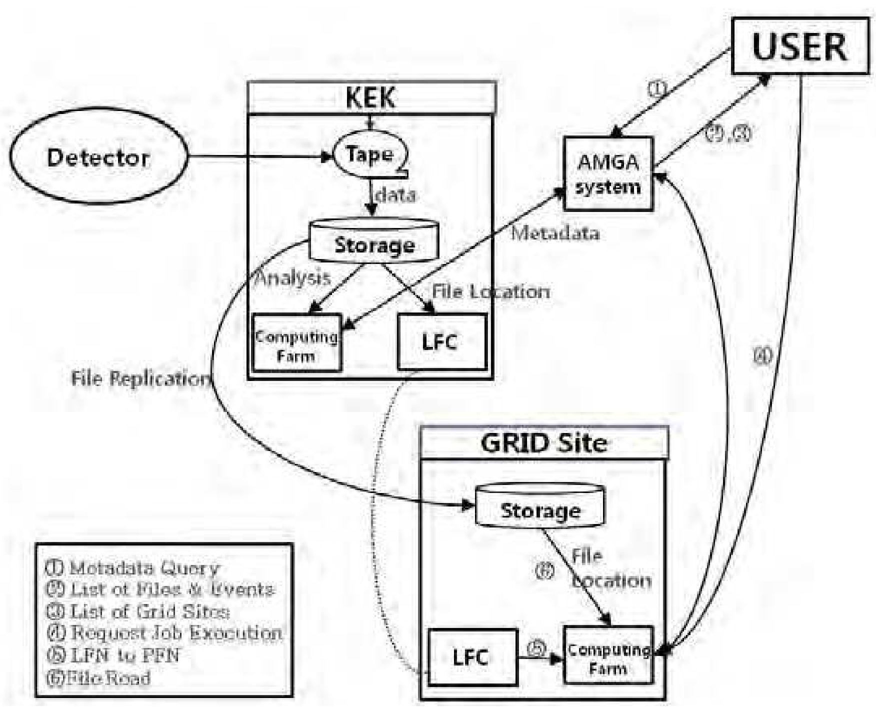

Fig. 6. Data handling scenario at the Belle II experiment.

[2] This section is based on the paper titled "The embedment of a metadata system at grid farms at the Belle II experiment" by S. Ahn et al. in Journal of the Korean Physical Society, Vol. 59, No. 4, pp. 2695-2701, (2011).

Fig. 6 shows the Belle II data handling system scheme. First, a user makes a metadata query to the server. Second, the server gives back a list of files and events. Third, the server may give a list of grid sites. Fourth, the user requests job execution at grid sites. Fifth, a logical file catalog (LFC) maps a logical file name (LFN) into a set of physical file names (PFN). Finally, the computing farms at the grid site read the requested physical file (Ahn, et al., 2011).

2.2 For experiment-theory

For experiment-theory, using the results of CDF and Belle experiments, we test phenomenological models of particle physics. Fig. 7 shows various physics topics for experiment-theory research, including Kaon Semi-leptonic form factor, rare B decay, mixing and *CP* (Charge Parity) violation on *Bs*→ *J/ψ Φ*, forward-backward asymmetry of top quarks, and *CP* violating dimuon charge asymmetry due to B mixing. Models for these physics topics include lattice gauge theory using staggered fermion, Left-Right models, and model-independent analysis. In this section, we introduce the left-right model and the forward-backward asymmetry of top quarks

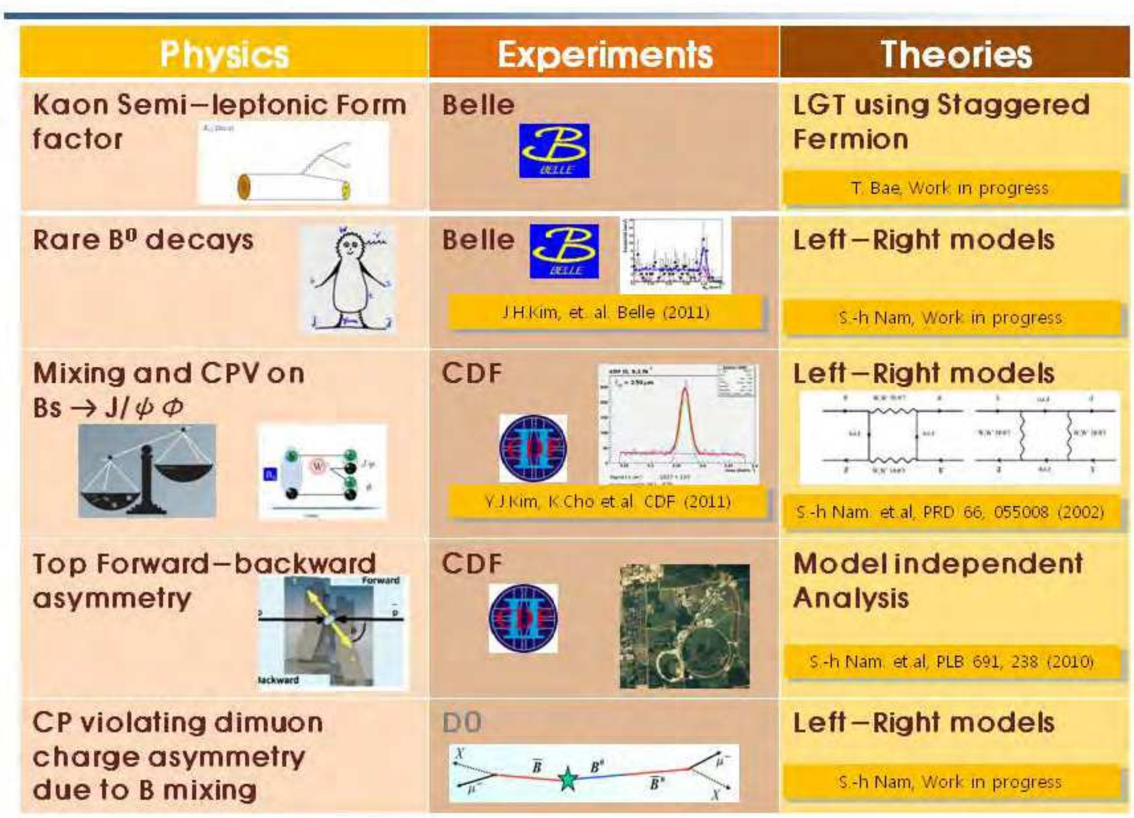

Fig. 7. Physics topics related to experiment and theory.

2.2.1 Left- right models

In CDF experiments, we study mixing and *CP* violation on *Bs*→ *J/ψ Φ* decay channels. For this analysis, we apply Left-Right models and compare the results. We also apply to the same model to the *CP* violating dimuon charge asymmetry due to *B* mixing. Fig. 8 shows the

Feynman diagram of Left-Right models for the analysis of *CP* violating dimuon charge asymmetry due to *B* mixing.

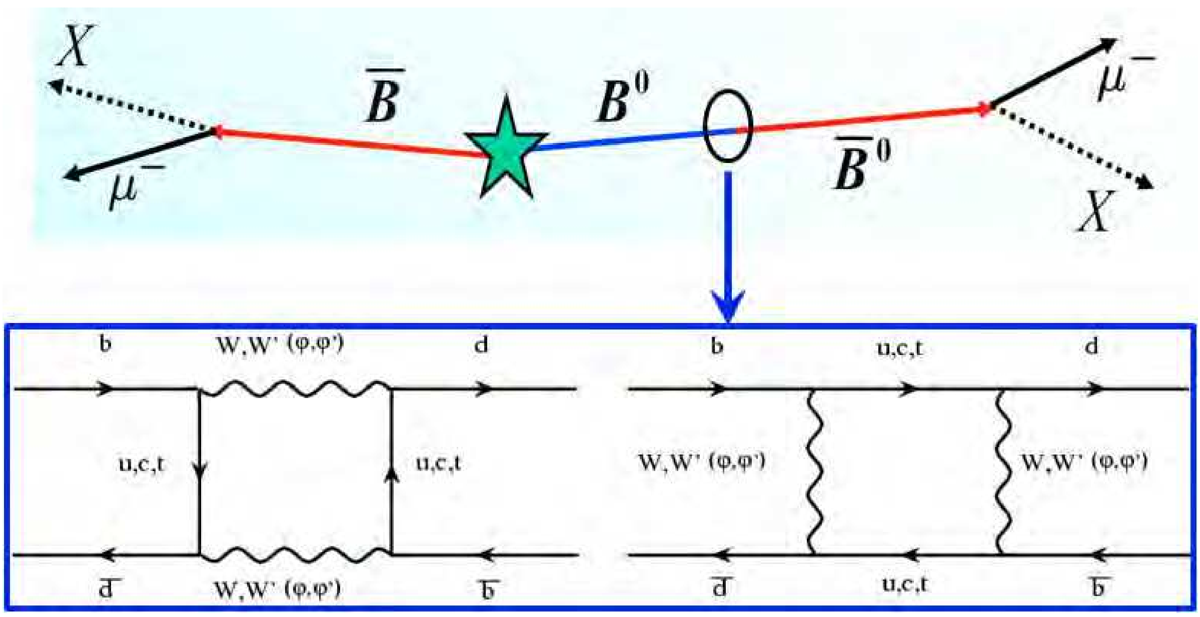

Fig. 8. The Feynman diagram of Left-Right models for the analysis of *CP* violating dimuon charge asymmetry due to B mixing.

2.2.2 The forward-backward asymmetry of top quark pairs

In 2008, CDF showed a possible anomaly in the forward-backward asymmetry of the top quark, where A_{FB} = 0.19± 0.07(stat.) ± 0.02(syst.) (Aaltonen et al., 2008). We have performed model independent analysis. Considering the s-, t-, and u- channel exchanges of spin-0 and spin-1 particles whose color quantum number is a singlet, octet, triplet or sextet, we study the region consistent with the CDF data at a one sigma level. We show the necessary conditions for the underlying new physics in a compact and effective way when those new particles are too heavy to be produced at the Tevatron. However, the results still affect the forward-backward asymmetry of top quark.

2.3 For theory-computing

For theory-computing, we study flavor physics based on lattice gauge theory, which enables large-scale numerical simulations on a supercomputer. The theory of strong interactions in the Standard Model is Quantum Chromo Dynamics (QCD). In phenomena related to the Cabibbo-Kobayashi-Maskawa (CKM) matrix, the theoretical values of the interaction amplitudes also have factors that cannot be obtained in a perturbative way since the strong coupling constant becomes strong at a low energy scale as QCD, as a non-abelian gauge theory, predicts. The only way that one can calculate the non-perturbative quantities with a controlled error is the lattice method, in which we put strongly interacting particles, quarks and gluons, on a lattice and calculate quantities directly from first principles. Fig. 9 shows the baryon based on lattice QCD.

We use the staggered fermions, which are one of the more popular lattice fermion schemes for full QCD lattice simulations. The staggered fermion scheme has the advantage that its

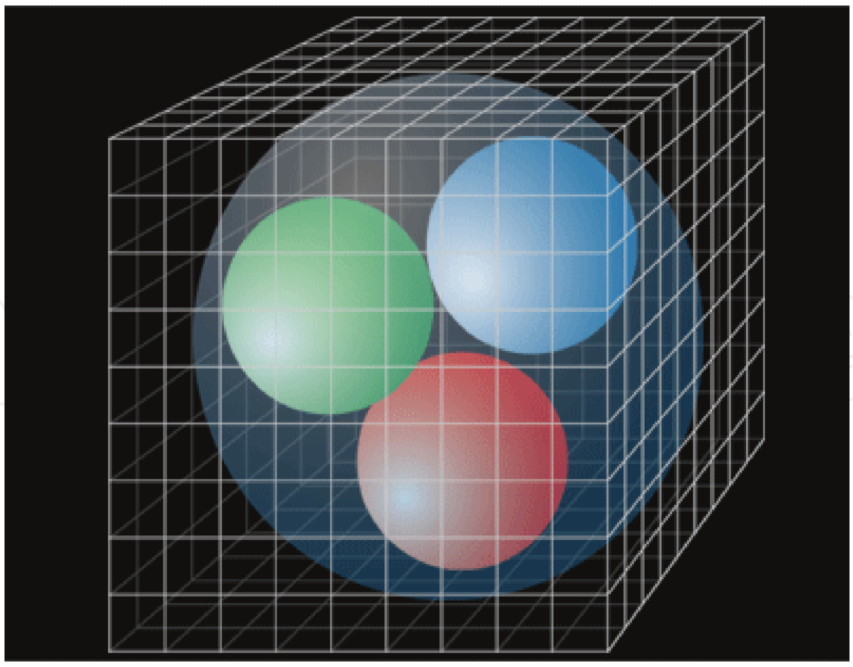

Fig. 9. Baryon based on lattice QCD.

computational cost is cheaper than other lattice fermion models while preserving remnant chiral symmetry. However, this scheme suffers from taste symmetry breaking in finite lattice spacing. Tastes are the remaining species that originate from the fermion doubling problem. Taste symmetry breaking complicates the analysis using lattice data. Thus, in order to reduce taste symmetry breaking effects, we use the HYP-smeared staggered fermions as valence quarks.

Lattice calculations cannot be done in the physical quark mass regime. In order to overcome this limitation, we calculate quantities with several non-physical quark masses and extrapolate the result to a physical regime. In this procedure, the staggered chiral perturbation theory guides the extrapolation.

This study can be extended to heavy flavor physics and other hadronic phenomena. In addition to physics research, we have developed new algorithms that enhance precision and utilize new hardware such as Graphic Processing Unit (GPU), which overcomes the limitation of CPU computing power.

2.3.1 Kaon semi-leptonic decay form factor

Fig. 10 shows the diagram for kaon semi-leptonic decay. The CKM matrix elements are quark mixing parameters, which can be determined by combining experimental weak decay widths of hadrons and their theoretical calculations. A traditional way to determine V_{us} is connected with the kaon semi-leptonic decay channels, which include $K^+ \rightarrow \pi^0 l^+ \nu_l$ (K^+_{l3}) and $K^0 \rightarrow \pi^- l^+ \nu_l$ (K^0_{l3}). Using these types of decays, we use the conserved vector current operator and the scalar density operator.

The decay rate of K_{l3} is written as the product of $|V_{us}|^2$ and $|f_+(0)|^2$. The vector form factor at zero momentum transfer, $f_+(0)$, is defined from the hadronic matrix element of the vector current between kaon and pion states. The matrix elements of the vector current can be extracted from the three-point correlation function whose interpolating operators are composed by the pseudo-scalar operator and the conserved vector current operator.

In this method, we have to generate quark propagators first. In order to create the desired meson states (kaon or pion) with non-zero spatial momenta, we use random U(1) sources with momentum phases. We also use the PxP operator insertion method (generally called sequential source) in order to create or annihilate the other meson state. Next, we contract these quark propagators properly and obtain three-point correlation function data.

From a Ward identity, we can convert the matrix elements of the vector current operator to those of the scalar density operator. This gives another method to calculate the form factor. The way to obtain correlation function data is similar to that found for the vector current method. Since the two methods are connected by a Ward identity, we can check if the data is consistent.

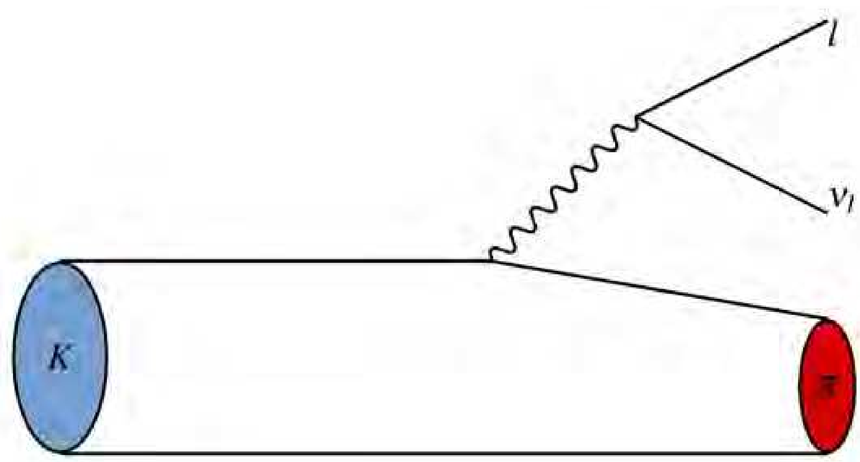

Fig. 10. Kaon semi-leptonic decay.

2.3.2 Kaon and pion decay constants

The kaon and pion decay constants can also be used to determine $V_{us.}$ Since the ratio f_K/f_π is related to V_{us}/V_{ub}, we can obtain V_{us} if V_{ub} is precisely known. From these quantities, we calculate the two point function of axial vector current and pseudo-scalar operator in the same way as the form factor.

3. Conclusions

We have introduced the concept of an e-Science paradigm for experiment-computing-theory for particle physics. Computing-experiment collaborative research offers not only an e-Science research environment including data production, data processing and data analysis, but also a data handling system for the Belle II experiment. The e-Science research environment enables us to research particle physics anytime and anywhere in more efficient way. Experiment-theory collaborative research provides a way to study the standard model and new physics. Theory-Computing collaborative research enables lattice gauge theory tools using supercomputing at KISTI.

In conclusion, we presented a new realization of e-Science paradigm of experiment, theory and computing in particle physics. Applying this concept to particle physics, we can achieve more efficient results to test the standard model and search for new physics.

4. Acknowledgment

I would like to express my thanks to the members of high energy physics team (Junghyun Kim, Soo-hyeon Nam, Youngjin Kim and Taegil Bae) at KISTI for the work.

5. A glossary of acronyms

ALICE: A Large Ion Collider Experiment
API: Application Programming Interface
ASGC: Academia Sinica Grid Centre
ATLAS: A Toroidal LHC Apparatus
CAF: CDF Analysis Farm
CDF: Collider Detector at Fermilab
CKM: Cabibbo-Kobayashi-Maskawa
CO: Consumer Operator
CP: Charge-Parity
DAQ: Date Acquisition
DCAF: Decentralized CDF Analysis Farm
DESY: Deutches Elecktronen SYnchrotron laboratory
DH: Data Handling
DOE: Department of Energy
GUI: Graphic User Interface
EGEE: Enabling Grid in e-Science
EVO: Enabling Virtual Organization
FBSNG: Farm Batch System Next Generation
FTP: File Transfer Protocol
GPU: Graphic Processing Unit
HEP: High-Energy Physics
KEK: High Energy Accelerator Research Organization in Japan
KISTI: Korea Institute of Science and Technology Information
LCG: Large Hadron Collider Computing Grid
LFC: Logical File Catalog
LFN: Logical File Name
LHC: Large Hadron Collider
MSS: Mass Storage System
OSG: Open Science Grid
PFN: Physical File Name
QCD: Quantum Chromo Dynamics
SAM: Sequential Access through Metadata
SciCo: Science Coordinator
SIP: Session Initiation Protocol

SRM: Storage Resource Manager
VRVS: Virtual Room Videoconferencing System
WLCG: Worldwide Large Hadron Collider Computing Grid
WMS: Workload Management System

6. References

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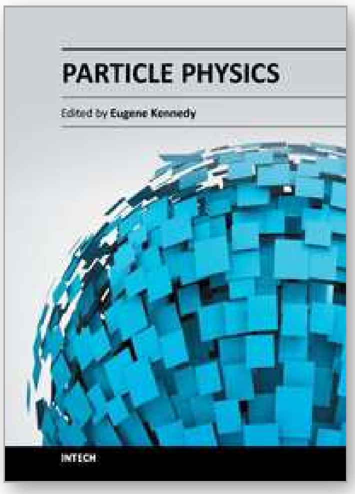

Particle Physics

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Stimulated by the Large Hadron Collider and the search for the elusive Higgs Boson, interest in particle physics continues at a high level among scientists and the general public. This book includes theoretical aspects, with chapters outlining the generation model and a charged Higgs boson model as alternative scenarios to the Standard Model. An introduction is provided to postulated axion photon interactions and associated photon dispersion in magnetized media. The complexity of particle physics research requiring the synergistic combination of theory, hardware and computation is described in terms of the e-science paradigm. The book concludes with a chapter tackling potential radiation hazards associated with extremely weakly interacting neutrinos if produced in copious amounts with future high-energy muon-collider facilities.

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