Osaka Symposium and New Accelerator Projects in Japan

(A Trip Report)

Jie Wei, Brookhaven National Laboratory

1. The Osaka Symposium

XVI RCNP Osaka Symposium on Multi-GeV High-Performance Accelerators

2. New/Proposed Accelerator Projects

Projects in Japan
Projects in China

3. Coolers and Beam Cooling

Newly proposed beam cooling methods
FOREIGN TRAVEL TRIP REPORT

Jie Wei, Scientist

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RHIC Project
Bldg. 1005 S
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P.O. Box 5000
Upton, New York 11973-5000
April 18, 1997

Dates Of Trip: March 1, 1997 to April 5, 1997

Destinations: Kyoto University, Kyoto, Japan
Research Center for Nuclear Physics, Osaka, Japan
Institute of High Energy Physics, Beijing, China
Tsinghua University, Beijing, China
Shanghai Institute of Nuclear Research, Shanghai, China

Statement of Purpose of trip:
As an invited speaker, present paper “The RHIC Project” in the XVI RCNP Osaka International Symposium, and give seminar at IHEP, Beijing and INR, Shanghai. Collaborate on beam cooling methods and beam crystallization. There is no revisions to the original itinerary.

Abstract:
To participate as an invited speaker to the XVI RCNP Osaka International Symposium on Multi-GeV High-Performance Accelerators and Related Technology, to collaborate with Kyoto University on laser cooling and beam crystallization projects, and to give seminars in Beijing and Shanghai on the Relativistic Heavy Ion Collider.
1. The Osaka Symposium

XVI RCNP Osaka Symposium on Multi-GeV
High-Performance Accelerators

Purpose:

• To celebrate the 50th anniversary of RCNP (Research Center for Nuclear Physics)

• To propose a new cooler-synchrotron-collider

• To review the performance and technology development of cooler rings, synchrotrons, and colliders.

March 11 - 14, 1997, Osaka, Japan

3 days, fully packed with talks

16 people from outside of Japan, all expenses paid

Panel review of the proposed RCNP project
Symposium Program:

- **Cooler Rings and Cooling Methods**
  - T. Tanabe (INS): Electron Cooler at TARN II
  - J. MacLachlan (FNAL): Electron Cooling
  - F. Caspers (CERN): Stochastic Cooling
  - B. Franzke (GSI): Diagnosis of Cooled H.I. Beams
  - D. Prasuhn (KFA, Juelich): Performance of COSY
  - D. Reistad (TSL): Performance of CELSIUS
  - L. Tecchio (Legnaro): The CRYSTAL Project
  - M. Grieser (MPI): Heavy Ion Storage Ring TSR

- **Colliders**
  - A.M. Sessler (LBL): The Development of Collider
  - J. Wei (BNL): The RHIC Project

- **Other multi-GeV Machines**
  - K. Sato (RCNP): Multi-GeV Machine at RCNP
  - Y. Yamazaki (KEK): 50-GeV Proton Synchrotron
  - W. Gu (IMP): HIRFL - CSR Project in Lanzhou
  - A. Goto (RIKEN): RIKEN RI Beam Factory
  - T. Katayama (INS/RIKEN): e⁻ & RI Collision
  - T. Tamae (Tohoku): 1.2 GeV Stretcher - Booster
  - A. Ando (Himeji): New SUBARU - Isochronous Ring
H. Sato (KEK): KEK 12 GeV-PS and Upgrade
P. Schwandt (IUCF): 20 GeV Synchrotron for Spin

• **Theories**

  B. Autin (CERN): Recent Trends in Lattice Design
  S.Y. Lee (IUCF): Nonlinear Dynamics
  Y. Batygin (RIKEN): Emittance preservation
  A. Garren (LBL): Lattice for $\mu^+ - \mu^-$ collider

• **Technologies**

  S. Wolff (DESY): Superconducting Magnets
  C. Ekstrom (TSL): Internal Targets
  M. Kumada (NIRS): Ultimate Power Supply
  K. Noda (NIRS): Slow Beam Extraction at HIMAC
Research and Development for Multi-GeV High-Performance Accelerator at RCNP

Kenji Sato
Research Center for Nuclear Physics (RCNP)
Osaka University

RCNP: Present accelerator facility

High-precision frontier of nuclear physics in the range of intermediate energies up to 420 MeV

AVF-Ring cyclotron cascade

RCNP: Future accelerator project

New high-precision frontier of quark-lepton nuclear physics in the range of multi-GeV energies

protons/light ions/electrons/polarized ions
cooler-synchrotron-collider

Contents

I. High-Performance Cyclotrons and Synchrotrons
II. Design Study of Cooler-Synchrotron
III. R&D Work for Synchrotron Components
IV. Summary
Proposal of "figure of 8" configuration synchrotron

Adaptation of "figure of 8"

In principle no intrinsic resonances of depolarization during acceleration of polarized ions

- opposite bending directions in both loops
- opposite spin precession motion in both loops
- no intrinsic resonances of depolarization

\[ C = 4.28 \text{ m} \]

\[ E \sim 5 \text{ GeV/u} \]

Request apart from his proposal

A "figure of 8" configuration based on a combination of two identical rings

Mode 1: "figure of 8" synchrotron

only need 5% partial

snakes
Requests for additional colliding mode

Design study for cooler-synchrotron-collider

(Merging point) \rightarrow \text{Colliding point}
Single ring characteristics

Unit cells of 45 degree arc

mirror symmetry of doublet lattice OFDBFBDFO
double achromat

Straight sections

double achromat
betatron phase advance of $2\pi$

Mode 2: two separated rings, collider
The Proposed RCNP Cooler Collider:

- Store/collide protons, light ions, electrons, polarized ions
  allow collision between different species
- Collision energy at multi-GeV range
  adjustable, around 5 GeV/u
- Various kinds of beam cooling for emittance preservation
  intrabeam scattering is strong for low energy ions
- Two independent rings, flexible modes for storage and collision
- “Figure of 8” configuration for depolarization minimization
Injection
  Multi-Turn Injection
  Slow Resonant Injection
  Charge Stripping/Charge Exchange Injection
  RF Stacking Injection
  Cooling Injection
  Single-Turn Injection with Fast Kicker
  Bunch to Bucket Injection

Acceleration

Extraction
  Slow Resonant Extraction
  Slow Resonant Extraction with RF Knock-Out
  Slow Stochastic Extraction
  Fast Extraction with Fast Kickers
  Fast Resonant Extraction
  Carbon Fiber Scattering Extraction
  Charge Stripping/Charge Exchange Extraction

Storage
Accumulation
Colliding
Merging

Cooling
  Electron Cooling
  Stochastic Cooling
  Laser Cooling
  Ionization Cooling
  Radiative Cooling

Other functions
  Insertions: Low Beta, Dispersion-Free
  Adjustments and Corrections: Tune, Chromaticity,
  COD, Non-Linearities

  **Focusing Mode Change:** e.g. between Q-Triplet and Q-Doublet
High Performance in HIMAC Synchrotron during both Acceleration and Slow Extraction

M. Kumada et al.,
"Towards an Ultimate Synchrotron Power Supply"

K. Noda et al.,
"Slow Beam Extraction at HIMAC Synchrotron"

Essentials of high-performance HIMAC synchrotrons

Very low ripple synchrotron magnet field

Very low ripple synchrotron power supply

Performance of HIMAC Q-magnet power supply with normal mode active filter

Frequency spectrum of normal mode output between positive and negative terminals

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Voltage (dB: measured)</th>
<th>Current ripple (relative: reduced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>-95</td>
<td>$1.4 \times 10^{-7}$</td>
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<tr>
<td>100</td>
<td>-76</td>
<td>$5.1 \times 10^{-7}$</td>
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<tr>
<td>150</td>
<td>-88</td>
<td>$0.9 \times 10^{-7}$</td>
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<tr>
<td>200</td>
<td>-81</td>
<td>$1.4 \times 10^{-7}$</td>
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<tr>
<td>300</td>
<td>-89</td>
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<tr>
<td>600</td>
<td>-77</td>
<td>$0.9 \times 10^{-7}$</td>
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<tr>
<td>1200</td>
<td>-85</td>
<td>$0.1 \times 10^{-7}$</td>
</tr>
</tbody>
</table>
3. Ripple suppression

![Diagram of a circuit with upper and lower coils and ground line.]

The potential develops at the neutral point of the power supply.

Normal mode current: Anti-Parallel current, \( I+J \)
Common mode current: Parallel current, \( I-J \)

Normal mode voltage:
Common mode voltage:

Normal mode impedance:
\[ Z_n = \frac{U+V}{I+J} \]

Common mode impedance:
\[ Z_c = \frac{U-V}{I-J} \]

Cancellation of "common mode" field

\( \Rightarrow \) ripple suppression
RECENT TRENDS IN LATTICE DESIGN

B. AUTIN

CERN, PS Division, 1211 Genève 23, Switzerland

Introduction

Lattice periods

FODO cell and scaling variables

Triplet cell, foci and principal planes

Quasi-isochronous period and orbit length

Betatron matching modules

Single lens

Doublet

λ/4 transformer

Afocal telescope

Inversor

BeamOptics

Conclusion
The program *BeamOptics*

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>FODO cell</td>
<td>FODO[f, ( \phi )] or FODO[Sin[( \mu/2 )], ( \phi )]</td>
</tr>
<tr>
<td>Triplet cell</td>
<td>Triplet[f, d, ( \phi )]</td>
</tr>
<tr>
<td>Isochronous period</td>
<td>IsoPeriod[n, MissingMagnet ( \rightarrow ) m, Resonance ( \rightarrow ) h]</td>
</tr>
<tr>
<td>Matching lens</td>
<td>MatchingLens[( \beta_x, \beta_y )]</td>
</tr>
<tr>
<td>Matching doublet</td>
<td>MatchingDoublet[( \beta, d )]</td>
</tr>
<tr>
<td>( \lambda/4 ) Transformer</td>
<td>Transformer[( \sigma_1, \sigma_2 )]</td>
</tr>
<tr>
<td>Afocal telescope</td>
<td>Telescope[f_1, f_3]</td>
</tr>
<tr>
<td>Inversor</td>
<td>Inversor[m]</td>
</tr>
</tbody>
</table>
COOLED HEAVY ION BEAMS IN THE ESR

DIAGNOSIS AND APPLICATIONS

B. FRANZKE, K. BECKERT, F. NOLDEN, H. REICH, A. SCHWINN, M. STECK, T. WINKLER

1. Heavy Ion Facilities at GSI

1.1 Accelerators UNILAC/SIS
1.2 Experimental Storage Ring ESR

2. Diagnostics for Cooled Ion Beams

2.1 Overview
2.2 Schottky diagnosis system

3. Results of Electron Cooling

3.1 Overview
3.2 Extremely low beam temperature

4. Applications

4.1 Schottky Mass Spectrometry
4.2 Bound-beta-decay
4.3 Di-electronic Recombination (DR)

5. Conclusion and Outlook
Consecutive Stripping and Electron Capture of a Single Stored Ion

Revolution Frequency of Ion [a.u.]
4. Applications

Novel experimental methods because of:
High resolving power of the Schottky diagnosis
High sensitivity with highly charged ions
Electron cooled beams
Relatively high stability of ring components

4.1 Schottky Mass Spectrometry

Procedure: exotic beams produced and pre-selected FRS
fragmentation,
electro-magnetic dissociation
fission of fast projectiles.
注射 to the ESR, electron cooled
Schottky diagnosis applied

Result: High accuracy: $\Delta m/m \leq 2 \times 10^{-7}$ attained
High redundancy by multi-component spectra
Nearly 150 new or essentially improved mass values

Limitation: Limited stability of ESR-components

4.2 Bound-beta decay of nuclei (BBD)

Komplex strategy for the measurement
BBD life time of nearly 33y for $^{187}\text{Re}^{75+} \rightarrow ^{187}\text{Os}^{75+}$

4.3 Di-electronic recombination (DR)

Energy resolution better than 0.01 eV!
$2s_{1/2} - 2p_{1/2}$-splitting precisely measured
Relevant for higher order QED
\[ \frac{\Delta p}{p} \quad \text{Spread} \]

**Emittances**

\( \varepsilon_x \) [\( \pi \text{ mm mrad} \)]

\( \varepsilon_y \) [\( \pi \text{ mm mrad} \)]

- \( \alpha N_i^{0.3} \)
- \( \alpha N_i^{0.5} \)

\[ I_{el} = 250 \text{ mA} \]

- \( \bullet \) U\(^{92+} \)
- \( \triangle \) Au\(^{79+} \)
- \( \square \) Xe\(^{54+} \)
- \( \triangledown \) Kr\(^{36+} \)
- \( \bullet \) Ti\(^{22+} \)

number of stored ions \( N_i \)
\( U^{92+} \ 360 \text{ MeV/u} \)

\( I_{el} = 250 \text{ mA} \)

Schottky noise power [a.u.]

storage time [min]

\( \delta p/p \)

storage time [min]
EXPERIENCE WITH STOCHASTIC COOLING
OF PARTICLE BEAMS

1. Introduction

2. Review of existing systems
   2.1 AAC
   2.2 LEAR
   2.3 FNAL
   2.4 TARN 1

3. Review of stochastic cooling systems under construction
   3.1 GSI Darmstadt (ESR)
   3.2 FZJ Jülich (COSY)

4. Bunched beam stochastic cooling (BBSC)
   4.1 SPS
   4.2 FNAL
   4.3 Experiments at AAC and LEAR

5. Some comments on theoretical aspects

6. A list of practical hints for design, setting up and trouble shooting

7. Conclusion
4.2 BBSC TEST IN THE TEVATRON

- A 4-8 GHz betatron BBSC system has been installed in the Tevatron (aim: reduction of emittance blow-up to increase luminosity lifetime).

- PU-kicker separation is about 60 m (= λβ/4). PU and kicker have movable plates with 16 co-planar loops each.

- The system uses fiber-optic delay lines for ps-timing level stability and as a high Q notch filter (photon storage ring).

- For BTF measurements "bucket gating" technique was used.

- The decrease in revolution harmonics power is much slower than predicted form a smooth Gaussian bunch shape.

- So far, observation of signal suppression when loop closed.

- As an important obstacle dynamic range limitation was identified (front end amplifier). To overcome this problem, presently a phase dispersive pulse stretcher (like a waveguide) is under construction in order to "smear out" the high peak signals without loss in bandwidth. After the last power amplifier a low loss pulse compressor cancels the phase distortion.
2. New/Proposed Accelerator Projects

New projects in Japan:

- SPRING-8
- Japanese B-Factory
- 50-GeV Proton Synchrotron
- New SUBARU - Isochronous Ring
- RIKEN RI Beam Factory
- Japanese Linear Collider
- RCNP (Osaka) Cooler Collider
- ...

<table>
<thead>
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<th>LOCATION</th>
<th>Electron Energy (GeV)</th>
<th>Notes</th>
<th>LOCATION</th>
<th>Electron Energy (GeV)</th>
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<td>Inst</td>
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* In construction
Status Report on the SPring-8

SPring-8 Accelerator Group, presented by M. Hara
JAERI-RIKEN SPring-8 Project Team
Kmigori-cho, Hyogo
678-12 Japan

Abstract

The SPring-8 is a high energy third generation synchrotron radiation source designed to deliver X-ray beam with a brilliance more than 10^{19} photons/sec/mm^2/mrad^2/0.1%bw. The facility consists of a 1 GeV linac, an 8 GeV booster synchrotron and an 8 GeV low emittance storage ring. The construction was started in 1990. Accumulated budget to date amounted to about a half of the total budget. Commissioning of the storage ring is expected in Feb. 1997.

1. INTRODUCTION

The SPring-8 is designed and constructed by Japan Atomic Energy Research Institute (JAERI) and The Institute of Physical and Chemical Research (RIKEN). After construction, Japan Synchrotron Radiation Research Institute (JASRI), which was established in 1990 as a nonprofit research institute, will be responsible for the management and operation in collaboration with JAERI and RIKEN. This is a user facility for SR researchers from universities, national laboratories, and industries not only in Japan but also from abroad. In Phase I, from '91 to '98, construction and commissioning of the accelerators and 10 beamlines are included. In Phase II, construction of beamlines will continue.

2. INJECTORS

2.1. Injector Linac

The SPring-8 linac has 26 accelerating columns. Each column is 2.835 m long and operated at the gradient of 16 MeV/m. The linac has space for electron/positron converter at 250 MeV, and can accelerate electron or positron up to 1.15 or 0.9 GeV. Main parameters of the linac is listed in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Parameters of linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Energy</td>
</tr>
<tr>
<td>Operation Rate</td>
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<tr>
<td>Radio Frequency</td>
</tr>
<tr>
<td>Type of Acc. Column</td>
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<tr>
<td>Length of Acc. Column</td>
</tr>
<tr>
<td>Number of Columns</td>
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<tr>
<td>Total Length</td>
</tr>
<tr>
<td>Klystron Max. Power</td>
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<tr>
<td>Emittance (1 GeV)</td>
</tr>
<tr>
<td>Energy spread</td>
</tr>
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</table>

The construction of the injector linac was started in 1991. The preinjector part of the linac has been operational in Tokai campus and the beam performance has already been evaluated. Measured emittance was about 5 mm-mrad(0 MeV), and the pulse width for short pulse mode was less than 1 nsec. All the accelerating columns have already been delivered in the site. The performance test for the first fabricated one was good enough to satisfy the specification. Construction of linac building will be completed in September '94. Detailed description is in reference [1].

2.2 Booster Synchrotron

The booster synchrotron has 2-fold symmetric 40 FODO cells. Two straight sections are used for injection, extraction and RF acceleration. Eight 5-cell cavities with inductive coupling slots are adopted and the RF power of 508.58 MHz is provided by Two 1.2-MW klystrons. Maximum RF voltage is 18.2 MVturn with 10 sec of quantum lifetime. The construction of the synchrotron was started in March 1993. All the components have been ordered to manufacturers and each preceding component (dipole, quadrupole, sextupole, cavity etc.) has manufactured and now under testing. Construction of the synchrotron building will be completed in March 1995.

<table>
<thead>
<tr>
<th>Table 2 Parameters of synchrotron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Energy</td>
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<td>Repetition Rate</td>
</tr>
<tr>
<td>Natural Emittance</td>
</tr>
<tr>
<td>Momentum Spread</td>
</tr>
<tr>
<td>Number of Cells</td>
</tr>
<tr>
<td>Nominal Tune ((v_x/v_y))</td>
</tr>
<tr>
<td>Radio Frequency</td>
</tr>
<tr>
<td>Radiation Loss(8 GeV)</td>
</tr>
</tbody>
</table>

3. STORAGE RING

3.1. Lattice and fundamental features

Design principles of the SPring-8 storage ring are as follows;
1) insertion device oriented ring,
2) the first harmonic undulator radiation from 10-20 keV with more than 10^{19} photons/sec/mm^2/mrad^2/0.1%bw.,
3) several very long straight sections for special insertion devices,
4) low emittance lower than 10 n m-mrad,
5) good photon beam stability,
6) good time structure.

To satisfy above requirements, energy of 8 GeV and Chasman-Green lattice structure was adopted. The ring has a 4-fold symmetric structure with 44 normal cells and 4 straight
cells, and total circumference is 1436 m. A normal cell has 2 dipole, 10 quadrupole, 7 sextupole magnets, and a 6.65 m long straight section, while a straight cell has no dipole magnets and can be changed to 30 m long straight section by rearranging Q and S magnets at a matured phase. This long straight section is one of the special merits of SPring-8[2,3]. Table 3 summarizes major parameters of the storage ring.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Energy</td>
<td>8 GeV</td>
</tr>
<tr>
<td>Current (multi-bunch)</td>
<td>100 mA</td>
</tr>
<tr>
<td>(single-bunch)</td>
<td>5 mA</td>
</tr>
<tr>
<td>Circumference</td>
<td>1435.95 m</td>
</tr>
<tr>
<td>Synchrotron Radiation Energy Loss per Turn</td>
<td>9.23 MeV/turn arc</td>
</tr>
<tr>
<td>Critical Photon Energy</td>
<td>12.4 MeV/turn with ID</td>
</tr>
<tr>
<td>Length of Straight Section</td>
<td>28.9 keV</td>
</tr>
<tr>
<td>Bending Radius</td>
<td>6.65 m normal</td>
</tr>
<tr>
<td>Natural Emittance</td>
<td>~30 m long</td>
</tr>
<tr>
<td>Synchrotron Frequency</td>
<td>39.727 m</td>
</tr>
<tr>
<td>Momentum Compaction</td>
<td>5.55 mm-rad.</td>
</tr>
<tr>
<td>Type of Lattice</td>
<td>0.010005</td>
</tr>
<tr>
<td>Number of Cells</td>
<td>1.46 × 10⁻⁴</td>
</tr>
<tr>
<td>Energy Spread</td>
<td>44 Normal cell</td>
</tr>
<tr>
<td>Harmonic Number</td>
<td>4 Straight cell</td>
</tr>
<tr>
<td>Harmonic Number</td>
<td>0.001094</td>
</tr>
<tr>
<td>Radio Frequency</td>
<td>2436</td>
</tr>
<tr>
<td>RF Voltage</td>
<td>508.58 MHz</td>
</tr>
<tr>
<td>Bunch Length σ</td>
<td>17 MV</td>
</tr>
<tr>
<td>Bunch Length σ</td>
<td>3.63 mm</td>
</tr>
</tbody>
</table>

3.2. Vacuum System

Vacuum system consists of two types of vacuum chamber, crotches, absorbers, and various components such as bellows, flanges and valves. One cell component (2 bending chambers, 3 straight chambers, crotches, absorbers, pumps and so on) have been assembled in a test bench with girders and magnets. In a test bench, various tests such as girders alignment, magnets set up and alignment, installing chambers and vacuum components (taking off the upper part of magnet), vacuum test, and baking, and so on, have already been performed. After the performance confirmation, construction of the rest 47 cells of chambers are to start.

3.3. RF system

The storage ring has 4 RF stations and each station has 8 single cell cavities which are powered by 1.2 MW klystron at 508.58 MHz. A klystron and a new type high voltage power supply for one of the four RF stations was installed in Dec. 1993, and the test of the power supply is in progress. Some of the RF components were tested with high power[4]. HOM property of the prototype cavity has been completed and 8 cavities for one RF station have been ordered and will be fabricated in 1995.
Original JHP was as follows:
1-GeV H⁻ Linac
(20 mA peak, 400 μs, 50 Hz, 400 μA average)
1-GeV Compressor, Stretcher Ring

The accelerator R&D group was organized in May, 1987.
During the course of eight years,
1. The KAON project at TRIUMF was canceled.
2. It was widely realized that the spallation neutron yield increases as the proton energy increases. (At first we believed that the optimum proton energy is around 1 GeV regarding the neutron yield.)
3. MW-class spallation neutron sources were strongly requested.

1. A few 10-GeV proton synchrotron was strongly requested by nuclear physicist community.
2. The cost should be optimized regarding the product of the current and the energy.
3. Upgradability.

The 3-GeV-class rapid cycle synchrotron can be an injector to a few 10-GeV synchrotron.
The proton linac should be able to cope with the future increase in the peak current at the ion source. For this the electromagnets have to be used in DTL. Then, the frequency should be lowered in order to contain the electromagnets in the drift tubes.
BEAM CURRENT (μA)

ACCELERATION ENERGY (GeV)
Proposed Time Profile of JHP

1997  New Organization

1998  Construction Start

1999  Neutrino Oscillation Experiment at 12-GeV PS

2000

2001  3-GeV Ring Installation into the 12-GeV PS Tunnel

2002  50-GeV Ring completion, First Beam
Accelerator Complex

- **200-MeV linac**
  - high brightness
  - accelerated particle: $H^+$ ion
  - peak beam current: $>30(50)$ mA (25Hz, 400μs)
  - structures: RFQ + DTL + ACS

- **3-GeV booster**
  - rapid cycling
  - intensity: $5 \times 10^{13}$ ppp
  - repetition rate: 25Hz
  - beam power: 0.6 MW
  - RF frequency: 1.99-3.43MHz
  - RF voltage: 389kV
  - circumference: 339.4m (KEK-PS tunnel)

- **50-GeV main ring**
  - transition free (negative $\alpha$)
  - intensity: $2 \times 10^{14}$ ppp
  - acceleration cycle: 0.3Hz
  - RF frequency: 3.43-3.51MHz
  - RF voltage: 270kV
  - momentum compaction: $\sim -10^{-3}$
  - circumference: 1442m (north site of KEK)
Japan B-factory  

Table 1. Parameters of TRISTAN-II B factory

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LER</th>
<th>HER</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>3.5</td>
<td>8.0</td>
<td>GeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>3018</td>
<td>3018</td>
<td>m</td>
</tr>
<tr>
<td>Tune shifts (x/y)</td>
<td>0.05 / 0.05</td>
<td>0.05 / 0.05</td>
<td></td>
</tr>
<tr>
<td>Beta at IP (x/y)</td>
<td>1.0 / 0.01</td>
<td>1.0 / 0.01</td>
<td>m</td>
</tr>
<tr>
<td>Beam current</td>
<td>0.52</td>
<td>0.22</td>
<td>A</td>
</tr>
<tr>
<td>Energy spread</td>
<td>0.078</td>
<td>0.073</td>
<td>%</td>
</tr>
<tr>
<td>Bunch length (1σ)</td>
<td>5</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>3.0</td>
<td>3.0</td>
<td>m</td>
</tr>
<tr>
<td>Bunch population</td>
<td>3.3</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Emittance (x/y)</td>
<td>19 / 0.19</td>
<td>19 / 0.19</td>
<td>nm.rad</td>
</tr>
<tr>
<td>Synchrotron tune</td>
<td>0.014</td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td>Betatron tune</td>
<td>~ 43</td>
<td>~ 39</td>
<td></td>
</tr>
<tr>
<td>Energy loss / turn</td>
<td>0.84</td>
<td>4.1</td>
<td>MeV</td>
</tr>
<tr>
<td>Momentum compaction</td>
<td>2.0×10^{-4}</td>
<td>1.0×10^{-3}</td>
<td></td>
</tr>
<tr>
<td>RF voltage</td>
<td>4.4</td>
<td>47</td>
<td>MV</td>
</tr>
<tr>
<td>RF frequency</td>
<td>508</td>
<td>508</td>
<td>MHz</td>
</tr>
<tr>
<td>Energy damping decrement</td>
<td>2.4×10^{-4}</td>
<td>5.1×10^{-4}</td>
<td></td>
</tr>
<tr>
<td>Bending radius</td>
<td>16.2</td>
<td>91.3</td>
<td>m</td>
</tr>
<tr>
<td>Length of bend magnet</td>
<td>0.85</td>
<td>2.56</td>
<td></td>
</tr>
</tbody>
</table>

The upgrade involves replacement of existing 30 MW klystrons with 60 MW types and installation of SLAC-style pulse compression systems (SLED) which will amplify the accelerating power. It will increase the accelerating gradient from 9 MeV/m to 25 MeV/m. With a modest extension of accelerating structures, the total energy of 8 GeV for electrons will be achieved. The positron target will be relocated so that the positrons will be produced by 4 GeV electrons, resulting in a factor 20 increase of positron intensity to 3.2×10^{10} / pulse.

To provide beams to the TRISTAN-II with improved stability and good optical matching, enhanced beam diagnostic tools and improved timing control systems will be built and implemented.

C. Ring Lattice

An important consideration in the lattice design is to maintain a sufficiently large dynamic aperture. This is to eliminate the need to alter the optics during injection, and to obtain a long beam lifetime during collisions. The very small β* would create a large chromaticity which needs to be compensated without much compromising the operability of the storage ring.
### Table 1.1

Linear Colliders: Overall and Final Focus Parameters – 500 GeV (c.m.)

<table>
<thead>
<tr>
<th></th>
<th>TESLA*</th>
<th>SBLC</th>
<th>JLC (S)</th>
<th>JLC (C)</th>
<th>JLC (X)</th>
<th>NLC</th>
<th>VLEPP</th>
<th>CLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial energy (c.of.m.)  (GeV)</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>RF frequency of main linac (GHz)</td>
<td>1.3</td>
<td>3</td>
<td>2.8</td>
<td>5.7</td>
<td>11.4</td>
<td>11.4</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>Nominal Luminosity ( \left( 10^{33} \text{ cm}^{-2}\text{s}^{-1} \right)^\dagger )</td>
<td>2.6</td>
<td>2.2</td>
<td>5.2</td>
<td>7.3</td>
<td>5.1</td>
<td>5.3</td>
<td>9.3</td>
<td>1.07-4.8</td>
</tr>
<tr>
<td>Actual luminosity ( \left( 10^{33} \text{ cm}^{-2}\text{s}^{-1} \right)^\dagger )</td>
<td>6.1</td>
<td>3.75</td>
<td>4.3</td>
<td>6.1</td>
<td>5.2</td>
<td>7.1</td>
<td>9.3</td>
<td>1.07-4.8</td>
</tr>
<tr>
<td>Linac repetition rate (Hz)</td>
<td>10</td>
<td>50</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>180</td>
<td>300</td>
<td>2530-1210</td>
</tr>
<tr>
<td>No. of particles/bunch at IP ( \left( 10^{10} \right) )</td>
<td>5.15</td>
<td>2.9</td>
<td>1.44</td>
<td>1.0</td>
<td>.63</td>
<td>.65</td>
<td>20</td>
<td>.8</td>
</tr>
<tr>
<td>No. of bunches/pulse</td>
<td>800</td>
<td>125</td>
<td>50</td>
<td>75</td>
<td>85</td>
<td>90</td>
<td>1</td>
<td>1-10</td>
</tr>
<tr>
<td>Beam separation (ns)</td>
<td>1000</td>
<td>16.0</td>
<td>5.6</td>
<td>2.8</td>
<td>1.4</td>
<td>1.4</td>
<td>-</td>
<td>.67</td>
</tr>
<tr>
<td>Beam power/beam (MW)</td>
<td>16.5</td>
<td>7.26</td>
<td>1.3</td>
<td>2.9</td>
<td>3.2</td>
<td>4.2</td>
<td>2.4</td>
<td>.3-3.9</td>
</tr>
<tr>
<td>Damping ring energy (GeV)</td>
<td>4.0</td>
<td>3.15</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.15</td>
</tr>
<tr>
<td>Main linac gradient, unloaded/loaded ( \text{MV/m} )</td>
<td>25/25</td>
<td>21/17</td>
<td>31/-</td>
<td>40/32</td>
<td>73/58</td>
<td>50/37</td>
<td>100/91</td>
<td>80/78</td>
</tr>
<tr>
<td>Total two-linac length (km)</td>
<td>29</td>
<td>33</td>
<td>22.1</td>
<td>18.8</td>
<td>10.4</td>
<td>15.6</td>
<td>7</td>
<td>8.8</td>
</tr>
<tr>
<td>Total beam delivery length (km)</td>
<td>3</td>
<td>3</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
<td>4.4</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>( \gamma_e/\gamma_{\gamma} ) (m.rad ( \times 10^{-8} ))</td>
<td>2000/100</td>
<td>1000/50</td>
<td>330/4.8</td>
<td>330/4.8</td>
<td>330/4.8</td>
<td>330/4.8</td>
<td>500/5</td>
<td>2000/7.5</td>
</tr>
<tr>
<td>( \beta_e^<em>/\beta_{\gamma}^</em> ) (mm)</td>
<td>25/2</td>
<td>22/0.8</td>
<td>10/0.1</td>
<td>10/0.1</td>
<td>10/0.1</td>
<td>10/0.1</td>
<td>100/0.1</td>
<td>10/0.18</td>
</tr>
<tr>
<td>( \sigma_e^<em>/\sigma_{\gamma}^</em> ) (nm) before pinch</td>
<td>1000/64</td>
<td>670/28</td>
<td>260/3.0</td>
<td>260/3.0</td>
<td>260/3.0</td>
<td>320/3.2</td>
<td>2000/4</td>
<td>247/4</td>
</tr>
<tr>
<td>( \sigma_{\gamma}^* ) (( \mu )m)</td>
<td>1000</td>
<td>500</td>
<td>120</td>
<td>120</td>
<td>90</td>
<td>100</td>
<td>750</td>
<td>200</td>
</tr>
<tr>
<td>Crossing Angle at IP (mrad)</td>
<td>0</td>
<td>3</td>
<td>6.4</td>
<td>6.0</td>
<td>6.1</td>
<td>20</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Disruptions ( D_e/D_{\gamma} )</td>
<td>0.56/8.7</td>
<td>.36/8.5</td>
<td>.29/25</td>
<td>.20/18</td>
<td>.096/8.3</td>
<td>.07/7.3</td>
<td>.4/215</td>
<td>.029/9.8</td>
</tr>
<tr>
<td>( \beta_D )</td>
<td>2.3</td>
<td>1.8</td>
<td>1.6</td>
<td>1.4</td>
<td>1.4</td>
<td>1.44</td>
<td>1.34</td>
<td>2.0</td>
</tr>
<tr>
<td>Upstream sub-zero</td>
<td>.02</td>
<td>.037</td>
<td>.20</td>
<td>.14</td>
<td>.12</td>
<td>.089</td>
<td>.059</td>
<td>.075</td>
</tr>
<tr>
<td>Upstream effective</td>
<td>.03</td>
<td>.042</td>
<td>.22</td>
<td>.144</td>
<td>.12</td>
<td>.090</td>
<td>.074</td>
<td>.075</td>
</tr>
<tr>
<td>( \delta_{\gamma} ) (%)</td>
<td>3.3</td>
<td>3.2</td>
<td>12.7</td>
<td>6.5</td>
<td>3.5</td>
<td>2.4</td>
<td>13.3</td>
<td>3.6</td>
</tr>
<tr>
<td>( n_{\gamma} ) (no. of ( \gamma's ) per ( \epsilon ))</td>
<td>2.7</td>
<td>1.9</td>
<td>2.2</td>
<td>1.5</td>
<td>.94</td>
<td>.8</td>
<td>5.0</td>
<td>1.35</td>
</tr>
<tr>
<td>( N_{\text{pairs}} ) (( p_{T_{\text{min}}}=20 \text{ MeV/c}, \theta_{\text{min}}=0.15 ))</td>
<td>19.0</td>
<td>8.8</td>
<td>31.6</td>
<td>10.3</td>
<td>2.9</td>
<td>2.0</td>
<td>1700</td>
<td>3.0</td>
</tr>
<tr>
<td>( N_{\text{hadrons}}/\text{crossing} )</td>
<td>0.17</td>
<td>0.10</td>
<td>0.98</td>
<td>0.23</td>
<td>0.05</td>
<td>0.03</td>
<td>45.9</td>
<td>0.05</td>
</tr>
<tr>
<td>( N_{\text{cells}} \times 10^{-2} ) (( p_{T_{\text{min}}}=3.2 \text{ GeV/c} ))</td>
<td>0.16</td>
<td>0.14</td>
<td>3.4</td>
<td>0.66</td>
<td>0.14</td>
<td>0.08</td>
<td>56.4</td>
<td>0.10</td>
</tr>
</tbody>
</table>

* Refer to Section 1.1 regarding possible TESLA parameter changes.

\( \dagger \) For the sake of uniformity, the nominal luminosity is simply defined as \( N^2/4\pi \sigma_e^* \sigma_{\gamma}^* \) times the number of crossings per second, and in all cases assumes head-on collisions, no hour-glass effect and no pinch. The actual luminosity incorporates all these effects, including crossing angle where applicable. NLC calculations assume crab-crossing.

\( \ddagger \) The loaded gradient includes the effect of single-bunch (all modes) and multibunch beam loading, assuming that the bunches ride on crest. Beam loading is based on bunch charges in the linacs, which are slightly higher than at the IP.
Fig. 1.6 JLC schematic layout.
new SUBARU project

1. Promote Industrial Activities in Hyogo Prefecture

   ① Micromachining; Extreme Ultraviolet Projection Lithography
      LIGA

   ② New Material

   ③ Development in Bio-technology

2. New Light Source; Coherent, Short pulse

   14m Long Straight Sections
   FEL
   Very Long Undulator
   Laser / External Beam & e-Beam Interaction

3. Isochronous & $\alpha_p < 0$
   Very Short Bunch $\sigma_z \Rightarrow 1\,\text{mm}$

   $\Rightarrow$ Deep Investigation of Beam Dynamics

   $\Rightarrow$ Beam Cooling
   Very Small Emittance in a Compact (Small) Ring
\[
\frac{\Delta T}{T} \Bigg|_{\text{rev}} = \sum \alpha_k \delta^k
\]

\[\alpha_p \Rightarrow 0\]

1. Higher Order Synchrotron Oscillation
   Stable Area of "

Second Islands at \( \delta = \Delta E/E \)

\[
\delta_\pm = \left[-\alpha_2 \pm (\alpha_2^2 - 4\alpha_1 \alpha_3)^{1/2}\right] / (2 \alpha_3)
\]

\[\Rightarrow -\alpha_2 / \alpha_3 \quad (\alpha_1 \rightarrow 0)\]

\[\Rightarrow -\alpha_1 / \alpha_2 \quad (\alpha_3 \rightarrow 0)\]

Overall control not only ordinary chromaticity but also \( \alpha_k \)'s
keeping enough dynamic aperture.

2. (Microwave) Instability
   Growth time \( \propto 1/|\alpha_p|\)
   Experimental Study

3. Touscheck Effects ----- How to overcome?

4. Technical Improvement
   Presice & Stable Control of power supplies, etc.

   * \( T(\text{synchrotron oscill}) > T(\text{radiation damping}) \)?
\( \alpha \) vs. \( \Delta p/p \)

Q Magnet Strength

\[ B'/(Bp) \text{ [1/m]} \]

\[ -0.005 \rightarrow -0.004 \rightarrow -0.003 \rightarrow -0.002 \rightarrow -0.001 \rightarrow 0 \]

Momentum Compaction \( \alpha \)

図2－5. チューンを固定し \( \alpha_p \) を変えたときの他パラメーターの変化（その5）
### Table 1: Main parameters of new SUBARU storage ring.

<table>
<thead>
<tr>
<th><strong>Fundamentals</strong></th>
<th><strong>Operation parameters</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection energy</td>
<td>1.5 GeV</td>
</tr>
<tr>
<td>Operation energy</td>
<td>1.5 GeV</td>
</tr>
<tr>
<td>Stored current</td>
<td>&lt;500 mA</td>
</tr>
<tr>
<td>Circumference</td>
<td>118.716 m</td>
</tr>
<tr>
<td>Revolution period</td>
<td>0.396 μ sec</td>
</tr>
<tr>
<td>Revolution freq.</td>
<td>2.525 MHz</td>
</tr>
<tr>
<td>Harmonic No.</td>
<td>198</td>
</tr>
<tr>
<td>RF frequency</td>
<td>500 MHz</td>
</tr>
<tr>
<td>Betatron Tunes</td>
<td>6.21/2.17 MHz</td>
</tr>
<tr>
<td>Chromaticity</td>
<td>-19/-7.5</td>
</tr>
<tr>
<td>$\alpha_p$</td>
<td>0.001</td>
</tr>
<tr>
<td>Straight sections</td>
<td>4m x4</td>
</tr>
<tr>
<td></td>
<td>14m x2</td>
</tr>
</tbody>
</table>

| **Natural emittance**     | 67 nm                    |
| **Coupling**              | 10 %                     |
| **Bending field**         | 1.55 T                   |
| **Critical photon**       | 0.53 nm                  |
| **Radiation / Turn**      | 176 keV                  |
| **Damping time**          |                          |
| Longitudinal X            | 3.42 msec                |
| Longitudinal Y            | 6.56 msec                |
| Energy spread             | 0.072 %                  |
| RF voltage                | > 250 kV                 |
| Bucket height             | > 0.83 %                 |
| Synchrotron tune          | 0.0021                   |
| Bunch length              | 7.76 mm                  |
| Touschek life             | > 10 hrs                 |
MUSES
-Multi USE Experimental Storage rings-
Scientific Research Objectives

Double Storage Rings (DSR)
1) RI + Electron  Collisions
2) RI + X-ray  Collisions
3) RI + RI  Merging
4) Ion + Ion  Collisions

Accumulator Cooler Ring (ACR)
1) RI + Internal Target  Collisions
2) Ions + Cooler Electron  Merging
3) Molecules + Cooler Electron  Merging
4) Micro RI beams production
MUSES PROJECT AT RIKEN

T. KATAYAMA
(INS, UNIV. OF TOKYO / RIKEN)

RIKEN
(INSTITUTE OF PHYSICAL AND CHEMICAL RESEARCH, BELONGS TO THE SCIENCE AND TECHNOLOGY AGENCY OF THE GOVERNMENT)

STARTED THE CONSTRUCTION OF HEAVY ION ACCELERATOR FROM 1997.

NAME OF THE PROJECT IS RI BEAM FACTORY

TOTAL BUDGET FOR CONSTRUCTION
~600 M$ FOR 10 YEARS

ACCELERATOR SYSTEM
INJECTOR
SUPERCONDUCTING RING CYCLOTRON

MUSES
(MULTIUSE EXPERIMENTAL STORAGE RINGS)
ACCUMULATOR COOLER RING(ACR)
BOOSTER SYNCHROTRON( BSR)
DOUBLE STORAGE RINGS(DSR)

OPTIONALLY HIGH CURRENT INJECTOR LINAC
MUSES (Multi USE Experimental Storage rings)

Booster Synchrotron Ring
Acceleration of ion and electron beams

Accumulator Cooler Ring
Accumulation and cooling of RI beams

Isotope Separator

Double Storage Rings
Various unique types of experiments
Key Issues of Accelerator Aspect of MUSES

1) RI beams production
   Peak Intensity, Emittance, Momentum/Phase spread

2) Accumulation of RI beams
   Multiturn injection, RF stacking

3) Fast beam cooling
   Electron cooling, Stochastic cooling

4) Acceleration/Deceleration of RI beams in ACR/BSR
   Ultra slow extraction

5) High current electron beam accumulation in DSR
   Low emittance electron beams for X-ray production

6) Beam-beam effects due to collisions/merging
   High Luminosity
Proposed projects in China:

- Synchrotron Light Source at Shanghai
  - 200 M $ equivalent
  - 3rd generation
- Tau-Charm Factory at Beijing
  - ?
- Heavy Ion Cooling Storage Ring at Lanzhou
  - ?
- Hefei Synchrotron Light Source Upgrade
  - √
The overall layout of HIRFL-CSR
3. Coolers and Beam Cooling
Methods of Beam Cooling:

- **Radiative Cooling**
  1956, Kolomenski and Lebedev
  natural in circular machines; 3D
  for electrons and other radiative particles; high energy

- **Electron Cooling**
  1967, Budker
  using cold electron beams; 3D
  for protons and ions; low to medium energy

- **Stochastic Cooling**
  1968, van der Meer
  using GHz pick-ups, amplifiers, and kickers; 3D
  for charged particles; any energy

- **Laser Cooling**
  1975, Wineland, Dehmelt, Hanchand, Schawlow
  based on velocity-selective transfer of photon momentum
  for partially stripped ions; longitudinal
  applied to ion beams by MPI Heidelberg group and Aarhus group; achieved 1 mK ($\Delta p/p \approx 4 \times 10^{-7}$)
• **Ionization Cooling**
  1980, Skrinsky
  based on energy loss by particles passing through a material medium
  for muons

• **Optical Stochastic Cooling**
  1993, Mikhailichenko, Zolotorev, Zholent,
  using wigglers for pick-ups and kickers, and wide-band lasers as amplifiers; $\sim 90$ GHz

• **Stimulated Radiation Cooling**
  1996, Bessonov and Kim
  using wide band lasers as a wiggler for damping for non-fully-ionized ions

• **Laser Cooling in 3D**
  1994, Okamoto, Sessler, Moehl
  using coupling cavities or dispersive location rf cavities on synchro-betatron resonance
  for laser cooling of ions in all 3 dimension

• **Tapered Cooling for Beam Crystallization**
  1995, Wei, Li, Sessler, et. al.
  forcing particles of different momenta to circulate at the same angular frequency
ITINERARY

Itinerary:

March 1, 1997   Depart New York
March 2        Arrive Kyoto, Japan
March 3 – 11   Collaboration, Kyoto, Japan
March 12 – 15  Attend Osaka Symposium, Osaka, Japan
March 16 – 21  Collaboration, Kyoto, Japan
March 22       Depart Kyoto, Arrive Beijing
March 23       Visit Tsinghua University, Beijing, China
March 24       Visit IHEP and give seminar, Beijing, China
March 25       Depart Beijing, Arrive Shanghai
March 26       Visit INP and give seminar, Shanghai, China
March 27 – April 3 Weekend time and vacation, Shenzhen, China
April 4, 5     Depart Shenzhen, China, Arrive New York

Persons contacted:

H. Okamoto, K. Noda, et. al., Kyoto University
A. M. Sessler, LBL
K. Hirata, KEK, Japan
I. Hoffman, GSI
M. Tigner, Y. Z. Wu, T. J. Deng, et. al., IHEP, Beijing
Y. P. Kuang, Y. P. Yi, Tsinghua University, Beijing
W. Q. Shen, X. F. Zhao, W. Q. Lai, et. al., INP, Shanghai

Participants at the Osaka Symposium including:

A. Ando, SUBARU
F. Caspers, B. Autin, CERN
B. Franzke, GSI
T. Katayama, INS/RIKEN
K. Sato, K. Hatanaka, RCNP
S. Y. Lee, IUCF
D. Reistad, TSL
W. Gu, Jin, Lanzhou, China

Literature acquired:

Copies of transperancies of the invited talks of Osaka Symposium
Papers by H. Okamoto, et. al., on laser beam cooling
Papers on proposed IHEP Tau-Charm Factory and INP synchrotron light source

Conclusion: A trip well worth the effort!