SPPC Study Status

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IAS Program for High Energy Physics
January 23-26, 2017, HKUST
Main topics

• Design goals
• Progress in preliminary conceptual design
• Studies on key technical issues
• Summary
DESIGN GOALS
SPPC Design Goal Evolution

• Pre-CDR
  – About 50 km in tunnel length, 20-T magnets to reach 70 TeV or above, high luminosity
  – Further development (together with CEPC): 61 km, longer long straight sections for collimation (partial double-ring for CEPC)

• CDR
  – 100-km tunnel
  – Different visions: 16T-100TeV, 20T-125TeV, 12T-75TeV/20T-125TeV
  – CDR SPPC design goals: First Phase: 12 Tesla, >70 TeV; Ultimate Phase: 20-24 Tesla, 125-150 TeV
# SPPC main parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>PreCDR</th>
<th>CDR</th>
<th>Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>km</td>
<td>54.4</td>
<td>100</td>
<td>100</td>
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<tr>
<td>C.M. energy</td>
<td>TeV</td>
<td>70.6</td>
<td>75</td>
<td>125-150</td>
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<tr>
<td>Dipole field</td>
<td>T</td>
<td>20</td>
<td>12</td>
<td>20-24</td>
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<td>Injection energy</td>
<td>TeV</td>
<td>2.1</td>
<td>2.1</td>
<td>4.2</td>
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<td>Number of IPs</td>
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<td>2</td>
<td>2</td>
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<tr>
<td>Nominal luminosity per IP</td>
<td>cm⁻²s⁻¹</td>
<td>1.2e35</td>
<td>1.0e35</td>
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<tr>
<td>Beta function at collision</td>
<td>m</td>
<td>0.75</td>
<td>0.75</td>
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<td>Circulating beam current</td>
<td>A</td>
<td>1.0</td>
<td>0.7</td>
<td>-</td>
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<tr>
<td>Bunch separation</td>
<td>ns</td>
<td>25</td>
<td>25</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Bunch population</td>
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<td>2.0e11</td>
<td>1.5e11</td>
<td>-</td>
<td></td>
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<tr>
<td>SR power per beam</td>
<td>MW</td>
<td>2.1</td>
<td>1.1</td>
<td>-</td>
<td></td>
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<tr>
<td>SR heat load per aperture @arc</td>
<td>W/m</td>
<td>45</td>
<td>13</td>
<td>-</td>
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PROGRESS IN PRELIMINARY CONCEPTUAL DESIGN
Main working topics

- General parametric design
- Collider accelerator physics
  - Layout and lattice design
  - Luminosity leveling
  - Collimation
  - Beam-beam effects
  - Injection/extraction
  - Instabilities
  - Bunch filling schemes
  - ....
- Schematic design on the injector chain
Parametric design

• General parameters
  – Maintaining parameter lists (according to the design goals)

• Layout designs
  – Eight arcs and long straight sections, and sufficiently long LSSs

C=61 km
LSS1/LSS5: 3.5 km
LSS3/LSS7: 1.04 km
Other LSS: 0.65 km
Lattice designs

• We have been studying the lattice for different SPPC layouts or design goals
  – Pre-CDR: 54 km, 71 TeV; CDR: 61 km, 71 TeV, 100 km, 100 TeV.
  – Will start on 100 km, 75 TeV, using 12-T magnets (present baseline)

• Design methods and constraints
  – Arc filling factor: >0.78
  – Dispersion suppression methods: half-bend (easy to match, uniform quads), full-bend (higher filling factor), LHC-like (compatible to CEPC, future direction)
  – Lattices for LSSs: IRs, collimation, separation and recombination
  – Different lattice at injection energy and during ramping: larger beta*
Some lattice design results

C=54, 61 km; Similar arc design

Dynamic aperture studies at collision energy
Luminosity Leveling

• Nominal luminosity defines the one at the collision starting, and it changes during the collision
• Integrated luminosity is more important for physics, so we exploit different schemes to maintain high instantaneous luminosity over collision period or average luminosity.
• Maximum luminosity is limited by the detector pile-up and beam-beam effects
• At SPPC, methods to increase instantaneous luminosity:
  – As emittance shrinks quickly due to synchrotron radiation, we can control the emittance heating to allow modest emittance damping
  – Changing beta* with smaller emittance
  – Allowing beam-beam effect to go up to 0.03
• Other measures
  – Smaller bunch spacing (5 or 10 ns instead of 25 ns) to reduce pile-up
  – Shorter turnaround time to increase average luminosity
Different luminosity leveling schemes
a) Constant B-B; b) Maximum B-B 0.03; c) Maintaining nominal lumi.;
d) 10 ns spacing; e) beta* changing; f) 5 ns spacing

C.M. energy: 100 TeV
Beam Collimation

- Beam collimation is extremely important and difficult for SPPC *(Stored energy: 6.3 GJ @ PreCDR)*
  - Heavy beam losses: beam-beam interactions, transverse and longitudinal diffusion, residual gas scattering, instabilities and so on *(peak loss: MW level)*
  - Quench protection of SC magnets
  - Machine protection
  - Hands-on maintenance
  - Cleaning of physics debris
  - Reducing experiment background
- Key issues: lattice, methods, materials
- New idea: Transverse and longitudinal collimation in the same LSS almost proved by simulations *(FCC is also studying the scheme)*
Collimation scheme for SPPC

- Single Diffractive Effect: energy loss at transverse collimators, more important at higher beam energy
- Very long straight sections to host both transverse and longitudinal collimators

Lattice for the collimation section

Beam losses by MERLIN Tracking
Bunch filling scheme

- Bunch filling scheme: important for bunching filling factor, related to injector chain, main ring injection

Version for 100km-100TeV

BT: a p-RCS batch with 112 bunches
- 112*25ns=2.8μs;
- t1: p-RCS extraction kicker rise time 400ns;
- t2: MSS injection kicker rise time 0.9μs;
- t3: MSS extraction kicker rise time 1.5μs;
- t4: SS injection/extraction kicker rise time 0.9μs;
- t5: SPPC injection kicker rise time 0.88μs;
- t6: SPPC beam dump kicker rise time 3.0μs
Other accelerator physics studies

- Instabilities: mainly on electron cloud effects, and also impedance issues related to beam screen.
- Beam-beam effects: phenomenon study, simulations just started; both incoherent and coherent effects; PACMAN effects.
- Injection: multiple injections from SS to SPPC in one SS cycle, to reduce the beam-stored energy less than 5-10 MW
- Extraction: very important for machine protection; very high reliability; beam dilution method at the dump
Impedance and Instabilities

• Analysis on key impedance contributions: beam screens and collimators
• Study on wall impedance for multilayer chamber: analytical and simulations
  – Beam screen: stainless steel (0.6mm) with coating copper (50um), now also HTS
  – Injection protection collimator: hBN (hexagonal boron nitride) coating with Ti (5 um)
  – Others
• Electron cloud study in different sections; characteristics measurements (with a NSFC fund)
Injectors Chain Design Concept

- Injector chain by itself is a very complicated and powerful accelerator system, large enough by a single stage
- Rich physics programs for each stage
- No close reference accelerators (scaled up by large factors)
  - Totally new, different from LHC or Tevatron (building-up by steps)
- Design work on each accelerator started: scheme, lattice and even more details (not only feeding the collider but also independent physics program)
- Key technical challenges should be identified, so needed R&D program can be pursued.
Injector chain
(for proton beam, 2.1 TeV)

- p-Linac: proton superconducting linac
- p-RCS: proton rapid cycling synchrotron
- MSS: Medium-Stage Synchrotron
- SS: Super Synchrotron

Ion beams have dedicated linac (i-Linac) and RCS (i-RCS)
### Major parameters for the injector chain

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Unit</th>
<th></th>
<th>Value</th>
<th>Unit</th>
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<td><strong>p-Linac</strong></td>
<td>MSS</td>
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<td>Energy</td>
<td>1.2</td>
<td>GeV</td>
<td>Energy</td>
<td>180</td>
<td>GeV</td>
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<tr>
<td>Average current</td>
<td>1.4</td>
<td>mA</td>
<td>Average current</td>
<td>20</td>
<td>uA</td>
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<td>~300</td>
<td>m</td>
<td>Circumference</td>
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<td>m</td>
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<td>RF frequency</td>
<td>325/650</td>
<td>MHz</td>
<td>RF frequency</td>
<td>40</td>
<td>MHz</td>
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<td>Repetition rate</td>
<td>50</td>
<td>Hz</td>
<td>Repetition rate</td>
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<td>Hz</td>
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<td>Beam power</td>
<td>1.63</td>
<td>MW</td>
<td>Beam power</td>
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<td>MW</td>
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<td><strong>p-RCS</strong></td>
<td>SS</td>
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<td></td>
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<tr>
<td>Energy</td>
<td>10</td>
<td>GeV</td>
<td>Energy</td>
<td>2.1</td>
<td>TeV</td>
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<tr>
<td>Average current</td>
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<td>mA</td>
<td>Accum. protons</td>
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<tr>
<td>Beam power</td>
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<td>MW</td>
<td>Protons per bunch</td>
<td>2.0E11</td>
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<tr>
<td>Dipole field</td>
<td></td>
<td></td>
<td></td>
<td>8.3</td>
<td>T</td>
</tr>
</tbody>
</table>

Will use high-Q ferrite-loaded RF cavities for RCS and MSS.
SS – Super Synchrotron

- Layout and preliminary lattice design: race-type lattice
- Dynamic aperture calculations
- Extraction considerations: multiple extractions, 10 Hz
- Fast ramping issue: 30-s cycling time, 8.3-T SC magnet, very challenging
STUDIES ON KEY TECHNICAL ISSUES
• Although there are many technical challenges in building SPPC and the injector chain, most of them can be waited to be solved a few years before construction. Actually we have identified two key technologies for long-term and early R&D:
  – High-field SC magnets: extremely challenging, needing very heavy R&D efforts with global collaboration
  – Beam screen: potential show-stopper, very complicated (vacuum, beam instability, mechanical support, cryogenics, magnet aperture), needing to develop special structure and material coating

• Recently adjusted SPPC goals
  – Reducing magnetic field but requiring all-HTS technology
  – 12-T/75-TeV: four times lower synchrotron radiation load per meter
R&D plan of the 20-T magnet technology

• 2015-2020
  Development of a 12-T operational field Nb$_3$Sn twin-aperture dipole; Fabrication and test of 2~3 T HTS (Bi-2212 or YBCO) coils in a 12-T background field, and basic study on tape superconductors for accelerator magnets (field quality, fabrication method, quench protection).

• 2020-2025
  Development of 15-T Nb$_3$Sn twin-aperture dipole and quadrupole with 10$^{-4}$ field uniformity; Fabrication and test of 4~5 T HTS (Bi-2212 or YBCO) coils in a 15-T background field.

• 2025-2030
  Nb$_3$Sn coils + HTS coils (or only one of them) to realize the 20-T dipole and quadrupole with 10$^{-4}$ field uniformity; Development of the prototype SPPC dipole/quadrupole and infrastructure build-up.
R&D plan of the 20-T magnet technology

(2015-2020)

Magnetic & mechanical design study: coil configuration, field quality, stress management, ...

**Cos-theta dipole**
High efficiency, complicated ends with hard-way bending

**Common coil dipole**
Simplest structure with large bending radius, low efficiency

**Block type dipole**
Simpler structure with hard-way bending, low efficiency

**Canted cos-theta dipole**
Lowest stress level in coil, low efficiency
Magnet design, prototyping and infrastructure

• Work is focused on:
  – Design Study of the SPPC Dipole Magnet
  – R&D Steps for the SPPC Dipole Magnet
  – Development of Nb3Sn Rutherford Cable
  – R&D of High Field ReBCO Tape by SSTC
  – R&D of Bi-2212 Superconductor by NIN
  – Preparation for the Model Magnet R&D

• Very slow building-up of infrastructure
• Domestic and international collaborations
Promoting collaboration on HTS technology

- SPPC high-field superconducting magnets: HTS has a great potential for future superconducting magnets, especially with expectation of a large reduction in cost.
- China has a good ground in high-temperature superconductors, both in basic research and applications. We use SPPC as a driving force to unify domestic institutions to develop HTS, especially iron-based HTS. A collaboration has been established.
Beam screen and vacuum

- Synchrotron radiation poses critical challenges to the cryogenic vacuum in next-generation pp colliders. Beam screen (shielding the light) is seen a potential stopper of the colliders.
- Screen structure under study: ante-chamber for absorbing photos, HTS coating to reduce impedance, high-temperature 45-65 K to reduce cryogenic load.
• **Beam instrumentation and controls**
  – Very fast and reliable beam instrumentation and controls for both machine protection and sophisticated beam manipulations (emittance blow-up, luminosity leveling etc.)

• **Machine protection**
  – It is tough to deal with 6.3 GJ energy at max in beam, and also huge energy stored in magnets. A workable and reliable machined protection system is critical for operating the machines

• **RF systems**
  – It is interesting to develop high-Q ferrite-loaded RF cavities for two fast ramping synchrotrons: p-RCS and MSS

• **Cryogenics**
  – Efficiency is important for super-large scale cryogenic system.
Summary

• We have been making progress on SPPC study steadily, covering the scope and many challenging topics.
• Study with newly defined SPPC goals will start soon.
• Strong domestic collaboration on HTS technology will support the SPPC magnet development.
• SPPC chapter in the CDR report will be ready by end 2017.
• Much welcome international experts join SPPC study.
THANKS FOR ATTENTION!