STATUS OF THE BINP SCTF PROJECT

Ivan Logashenko

BINP/NSU

Joint Workshop on Future charm-tau Factory,

Sep 24-28, 2019, Moscow
Existing and future flavor factories
Super Charm-tau factory @BINP

- Symmetric $e^+e^-$ collider, $2E = 2 \div 6 \text{ GeV}$
- Luminosity $10^{35} \text{ 1/cm}^2\text{s}$
- «Crab Waist» beam collision
- Longitudinal $e^-$ polarization

Factory of $c, \tau, J/\psi$
Brothers, sisters and cousins…

**BES-3**

- Very similar
- 1% luminosity

**BELLE-2**

- B-factory (10.58 GeV)
- 5-10x luminosity

**LHCb**

- pp collisions

Previous generation:

**BELLE**

**BaBar**

**CLEO-c**
One year at SCTF

1 year at $10^{35}$ $1/cm^2s$

$10^{12} J/\psi$

$10^{10} \tau\tau$

$10^9 D\bar{D}$

$10^8 D_s\bar{D}_s$

$10^8 \Lambda_c^+\Lambda_c^-$
Physics program

- Strong phase measurements in $D$-decays.
- Search for very suppressed $c$-quark decays.
- Search for CPV.
- ...

QCD

- Strong excited quarkonium physics.
- Molecular states.
- Threshold baryon interactions.
- Search for glueballs in $J/\psi$ and $\Psi'$ decays.
- ...

SCTF advantages

- Threshold production.
- Well determined initial state.
- Quantum correlated production of neutral $D$ meson pairs.
- Double tag technique.
- Low multiplicity (4-5).
- Longitudinal beam polarization.
- ...

- Precise measurements of $\tau$-lepton parameters.
- Michel parameters.
- Lepton Universality tests.
- Precise measurements of $\tau \rightarrow$ hadrons decays.
- Search for CPTV in $\tau$-decays.
- ...
Physics program

• The physics program of Super Charm-Tau factory was discussed in details at previous meetings:
  • December 2017, Novosibirsk
  • March 2018, Beijing
  • May 2018, Novosibirsk
  • December 2018, Orsay
• and continue to be discussed at this meeting with particular focus on beam polarization:
  • Andrzej Kupsc, *Hyperon physics at SCT with polarized beams*
  • Denis Epifanov, *Measurement of Michel parameters in tau decays at the Super Charm-Tau factory with polarized electron beam*
  • Denis Epifanov, *Search for CPV in $\tau \rightarrow K\pi\nu$ at $e^+e^-$ colliders, effect of the polarized electron beam*
  • Emilie Passemar, *CPV in tau decays with polarization*
  • …
SCTF and B-factories

There is strong competition/synergy between $c - \tau$ and $B$ factories:

- LHCb will have more $D$’s
- Belle-II will have more $D$’s and $\tau$’s

But statistics is not everything – SCTF has potential for higher systematic accuracy (e.g. $\tau \rightarrow \mu \gamma$)

Today:

- LHCb: 5 fb$^{-1}$
- B-factories: 1 ab$^{-1}$
- BES-III: ~100 fb$^{-1}$

Tomorrow:

- LHCb: 50/300 fb$^{-1}$ (Run 3/4)
- Super KEK-B: 50 ab$^{-1}$
- Super C-tau factory: ~10 ab$^{-1}$

Now there is delicate balance between the experiments

Super $c - \tau$ factory will allow to maintain the balance in future

There are ongoing MC studies of SCTF performance for various cases
Brief history of $c\tau$-factories

- 1993, Dubna JINR ($E_{cm} = 2$ GeV, $L = 9.4 \times 10^{32}$ cm$^{-2}$s$^{-1}$)
- 1994, Argonne National Laboratory ($E_{cm} = 3 - 5$ GeV, $L = 10^{33}$ cm$^{-2}$s$^{-1}$)
- 1995, BINP, round beams ($E_{cm} = 2 - 4.2$ GeV, $L = 10^{33}$ cm$^{-2}$s$^{-1}$)
- 1996, Spain & France ($E_{cm} = 4$ GeV, $L = 10^{33}$ cm$^{-2}$s$^{-1}$)
- 1997, Beijing IHEP ($E_{cm} = 2.0 - 4.2$ GeV, $L = 10^{33}$ cm$^{-2}$s$^{-1}$)
- 2006: Crab waist collision scheme (P.Raimondi):
  \[10^{33} \rightarrow 10^{35}\]
Collider conceptual design (2011)

<table>
<thead>
<tr>
<th>Energy</th>
<th>1.0 GeV</th>
<th>1.5 GeV</th>
<th>2.0 GeV</th>
<th>2.5 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>780 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emittance hor/ver</td>
<td>8 nm/0.04 nm @ 0.5% coupling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damping time hor/ver/long</td>
<td>30/30/15 ms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bunch length</td>
<td>16 mm</td>
<td>11 mm</td>
<td>10 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Energy spread</td>
<td>10.1·10^{-4}</td>
<td>9.96·10^{-4}</td>
<td>8.44·10^{-4}</td>
<td>7.38·10^{-4}</td>
</tr>
<tr>
<td>Momentum compaction</td>
<td>1.00·10^{-3}</td>
<td>1.06·10^{-3}</td>
<td>1.06·10^{-3}</td>
<td>1.06·10^{-3}</td>
</tr>
<tr>
<td>Synchrotron tune</td>
<td>0.007</td>
<td>0.010</td>
<td>0.009</td>
<td>0.008</td>
</tr>
<tr>
<td>RF frequency</td>
<td>508 MHz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harmonic number</td>
<td>1300</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particles in bunch</td>
<td>7·10^{10}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of bunches</td>
<td>390 (10% gap)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bunch current</td>
<td>4.4 mA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total beam current</td>
<td>1.7 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam-beam parameter</td>
<td>0.15</td>
<td>0.15</td>
<td>0.12</td>
<td>0.095</td>
</tr>
<tr>
<td>Luminosity</td>
<td>0.63·10^{35}</td>
<td>0.95·10^{35}</td>
<td>1.00·10^{35}</td>
<td>1.00·10^{35}</td>
</tr>
</tbody>
</table>

- 104 accelerating elements
- 52 klystrons
- 440 meters of linear accelerators
Updated conceptual design (2018)

The project continued to evolve. 2018: smaller ring, more robust and realistic design

<table>
<thead>
<tr>
<th></th>
<th>1 GeV</th>
<th>2 GeV</th>
<th>3 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Pi$ [m]</td>
<td>475.768</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2\theta$ [mrad]</td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>$N_{part}$ [$10^{10}$]</td>
<td>5.5 (2.1)</td>
<td>5.2</td>
<td>13 (7)</td>
</tr>
<tr>
<td>$N_{bunch}$</td>
<td>400 (500)</td>
<td>420</td>
<td>280 (150)</td>
</tr>
<tr>
<td>$I$ [A]</td>
<td>2.2 (1)</td>
<td>2.2</td>
<td>2</td>
</tr>
<tr>
<td>$\beta_x^<em>/\beta_y^</em>$ [cm]</td>
<td>5/0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varepsilon_x$ [nm]</td>
<td>20 (15)</td>
<td>6.5</td>
<td>11</td>
</tr>
<tr>
<td>$\varepsilon_y/\varepsilon_x$ [%]</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$\mathcal{L}$ [$10^{35}$]</td>
<td>0.5 (0.14)</td>
<td>1</td>
<td>1.9 (1)</td>
</tr>
<tr>
<td>$V_{RF}$ [MV]</td>
<td>1</td>
<td>0.7</td>
<td>2</td>
</tr>
</tbody>
</table>
Updated conceptual design (2018)

The project continued to evolve in 2018: smaller ring, more robust and realistic design.

The design continue to be improved/detailed.

See talks on Thursday by:

- Anton Bogomyagkov, *Status of Novosibirsk SCTF*
- Dmitry Shatilov, *Luminosity and beam-beam effects for Novosibirsk SCTF*
- Alexey Petrenko, *Status of injection facility for Novosibirsk SCTF*
- Ivan Koop, *Longitudinal polarization*
- Sergey Sinyatkin, *Machine-detector interface*
- Ivan Okunev, *Superconducting magnets of the final focus*

<table>
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<tr>
<td>$\mathcal{L} [10^{35}]$</td>
<td>0.5 (0.14)</td>
<td>1</td>
</tr>
<tr>
<td>$V_{RF} [\text{MB}]$</td>
<td>1</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Detector concept and requirements

Physics requirements:

- Good $\frac{dE}{dx}$ for charged particles.
- Good symmetry and hermeticity;
- Soft track detection;
  - Inner tracker to work with rate of charged tracks $\geq 10^4 \frac{\text{tracks}}{\text{cm}^2 \cdot \text{s}}$;
- Good $\mu/\pi/K$-sep. up to 1.5 GeV/c;
  - Good $\frac{dE}{dx}$ resolution;
  - Specialized PID system for $\mu/\pi$ and $\pi/K$-separation;
- Good $\pi^0/\gamma$-separation and $\gamma$ detection with $E_\gamma=10\div3000$ MeV;
  - EM calorimeter with $\sigma_E$ as close as possible to physics limit;
  - Fast calorimeter ($\sigma_t \leq 1$ ns and small shaping time) to suppress beam background and pileup noise;
- DAQ rate $\sim 300$ kHz at $J/\psi$-peak.
Inner tracker

- Resolution similar to drift chamber (~100 μ)
- Sensitive to particles with low momentum (~50 MeV/c)
- Able to handle high particle flux
- Compatible with final focus constraints
- Approximate size: Ø (40-400) x 600 mm

Talk by Andrey Sokolov on Wednesday, *Inner tracker options for SCTF: status and perspectives*

Simulation of π⁺ momentum distribution in e⁺e⁻ → DD*
Drift chamber

Measurement of momentum and dE/dx (PID)

- Spatial resolution $\sim 100 \, \mu$
- Small cell
- Minimal material (reduce MS)
- Approximate size: $\varnothing (400-1600) \times 1800$ mm

<table>
<thead>
<tr>
<th>“Traditional” option</th>
<th>“TraPid” option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Babar, BES-3, Belle-2</td>
<td>KLOE, MEG-2, IDEA</td>
</tr>
<tr>
<td>Axial and stereo superlayers</td>
<td>Full stereo</td>
</tr>
<tr>
<td>Traditional dE/dx</td>
<td>dE/dx by cluster counting</td>
</tr>
<tr>
<td>Feed-through wiring</td>
<td>Robotic wiring</td>
</tr>
</tbody>
</table>

| BINP                          | INFN (Lecce)             |

Talk by Korneliy Todyshev on Wednesday, *Drift chamber R&D progress in Novosibirsk*

TraPid development is part of CREMLIN+ working package 5
Particle identification

Requirements for PID system

• $\pi/K$ separation $> 4\sigma$ up to 2.5-3.0 GeV/c
  - TOF (BES-3): $3\sigma$ at 0.9 GeV/c, DIRC (BaBar): $4\sigma$ at 2.5 GeV/c
  - ASHIPH (KEDR): $4\sigma$ at 1.5 GeV/c
• $\mu/\pi$ suppression $\sim 1/40$ for to 0.5-1.2 GeV/c
• good $\mu/\pi$ separation at low momentum

Several option are being considered: FARICH, ASHIPH, TOF

Talks on Wednesday:

• Sergey Kononov, **FARICH PID system option: prototyping and simulation results**
• Mustafa Schmidt, **DIRC options for the SCTF Detector**
Calorimeter

Baseline option:
   BELLE/BELLE-2-like electromagnetic crystal calorimeter

Scintillator:
   CsI(Tl) has large light yield, “cheap”, very popular – but slow
   LSO, LYSO, etc. – have large LY, very fast – but very expensive
   (x10)
   pure CsI – good compromise: reasonable LY, 30 ns component, reasonable price

Other options being considered:
   LXe calorimeter, combined LXe + pCsI calorimeter (CMD-3: LXe+Csl(Tl))

Talk by Ivan Bulyzhenkov on Tuesday, *Progress in simulation of SCT calorimeter*
Talk by Sergey Oreshkin on Wednesday, *Status of the R&D on the calorimeter based on pure CsI crystals for the Super Charm-Tau factory*
Two options considered:

- **Outside calorimeter**
  - “thick” design
  - Al-stabilized coil, established technology
  - Similar to PANDA magnet
  - Baseline option

- **Just outside drift chamber**
  - “thin” design, $0.1 \times X_0$
  - CMD-3 and KEDR experience

Talk by Aleksey Bragin on Wednesday, Thin solenoid option proposal
Muon system

- detect muons
  - mult.scat. of O(1cm)
- $\mu/\pi$ separation
- $K_L$ detection

Baseline option:
scintillator strips + WLS fiber + SiPM
(BELLE-2, CMD-3)
8-9 layers inside iron yoke
~1500 m²
DAQ and data analysis/storage

**Requirements**

- **Maximum input data rate:** 10 GB/s
- **Total storage system capacitance:** ~300 Pbytes
- **Computing power:** ~1 Pflops

Can be realized with commercial solutions
Simulation and analysis software

The full scale simulation of experiments at SCTF is rapidly developed.

Aurora framework
  • widely used HEP tools (ROOT, Geant4, …)
  • Gaudi and Athena-inspired build and config system
  • FCCSW (DD4Hep, PODIO, …)
  • SCTF modules

Talk by Andrey Sukharev on Tuesday, Software for SCT detector: status

Dedicated RSF grant for development of SCTF software and design of data analysis hardware infrastructure
Status of project

- 2011: selected as one of six mega-science projects to be built in Russia
- There are roadmap, conceptual design, preliminary civil engineering design
- CERN, IHEP, INFN, KEK and other organizations expressed their interest in the project
- In 2017 SCTF was included in the 2017-2019 plan for the implementation of the first phase of the Russian Strategy for Science and Technology Development. 2019: expected to submit updated CDR to government
- SCTF is discussed in the framework of the Update of the European Strategy for Particle Physics
The collaboration

**Working groups**

- Inner tracker
- Drift chamber
- PID
- Calorimeter
- Muon system
- Magnet
- Physics and simulations
- Computing
- DAQ and trigger
- Beam background
- Engineering

- International advisory committee

- Dedicated international workshops
  - May 2018, BINP
  - December 2018, Orsay
  - November 2019, Moscow

- Collaboration in growing.
Conceptual Design Report

- First release in 2011
- Includes physics program, collider and detector conceptual design
- Revised in 2018
- Authors from 19 institutions (10 from Russia)

Available at https://ctd.inp.nsk.su/c-tau/
CREMLIN+ project proposal is about European-Russian scientific and technical collaboration in the field of research infrastructures.

Working package 5:

"Joint technology development around SCT and future lepton colliders"

- Task 5.1: Fostering internationalization and visibility of the SCT project, support of outreach activities related to SCT (BINP, CERN, INFN)
- Task 5.2: Development of collider technologies and fostering synergy between SCT, CLIC, and FCC-ee collider projects (CERN, BINP, LAL-CNRS)
- Task 5.3: Development of software for the design of an SCT detector (BINP, CERN)
- Task 5.4: Development and design of Inner Tracker for the SCT detector (BINP, INFN LNF/Ferrara)
- Task 5.5: Development and design of Central Tracker for the SCT detector (BINP, INFN Lecce/Bari)
- Task 5.6: Development and design of a Particle Identification system for the SCT detector (BINP, JLU)
Conclusion

• Super charm-tau factory has rich physics program, which is complementary to Belle II and LHCb.
• There are conceptual designs of the collider and the detector and they continue to be improved and detailed by the international collaboration
• R&D for the Super charm-tau factory is partially supported by Russian government, Russian science fund, European Commission
• We are open to collaboration proposal.
Backup slides
Drift chamber: traditional option

- ~40000 wires
  - 11k sensitive, W-Rh(Au)
  - 29k field, Al(Au)
- Hexagonal cell, 6.3-7.5 mm
- 41 layers
- 60% He + 40% C$_3$H$_8$
- 330 ns drift time (1.5 T)

\[
\frac{\sigma_{p_t}}{p_t} \approx \sqrt{0.21\%^2 p_t^2 + 0.31\%^2} \\
\approx 0.4\% \text{ at } 1 \text{ GeV}
\]

\[
\frac{\sigma_{dE/dx}}{dE/dx} \approx 6.9\%
\]
Drift chamber: TraPid

- ~141000 wires
  - 23k sensitive, W
  - 117k field, Al
- Square cell, 7.2-9.1 mm
- 64 layers
- 90% He + 10% iC$_4$H$_{10}$

\[
\frac{\sigma_{p_t}}{p_t} \approx \sqrt{0.078\%^2 p_t^2 + 0.18\%^2} \\
\approx 0.2\% \text{ at } 1 \text{ GeV}
\]

\[
\frac{\sigma_{dE/dx}}{dE/dx} \approx 3.6\% 
\]

Measurement of individual clusters improves time and $dE/dx$ resolution

Robotic wiring

With room for improvement!
PID options

FARICH: focusing aerogel
$O(10^6)$ readout channels!
Test beam:
- $\pi/K$: 7.6$\sigma$ at 4 GeV/c
- $\mu/\pi$: 5.3$\sigma$ at 1 GeV/c

ASHIPH: threshold Cherenkov counter with WLS+PMT readout
Two n values
Low cost:
- 30000 readout channels
- $\pi/K$ from 0.5 to 2 GeV/c
- $\mu/\pi$ from 0.4 to 0.9 GeV/c

dE/dx + TOF for lower momenta, muon system for higher momenta

TOF (TOP) counters, $\sigma_t \approx 30$ ps:
- $\pi/K$ up to 2.5 GeV/c
- $\mu/\pi$ from 0.25 to 0.5 GeV/c
Calorimeter: pCSi option

- 7424 crystals
  - 5248 in barrel
  - 2176 in endcap
- 5.5 x 5.5 x 30(34) cm
- pCSi+WLS+4 APD

\[
\frac{\sigma_E}{E} \approx \left( \frac{1.9\%}{\sqrt[4]{E(GeV)}} \right) + \left( \frac{0.33\%}{\sqrt{E}} \right) + \left( \frac{0.11\%}{E} \right)
\]

This option is being prototyped and optimized