Physics Summary

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Physics talks:

1）Tau Physics with future tau-charm factory - Antonio Pich
   - Tau Lepton flavor violation - Lorenzo Calibbi
   - Updated determinations of $V_{us}$ with tau data - Alberto Lusiani

2）Charm Physics with future tau-charm factory - Svjetlana Fajfer
   - Decays of charmed hadrons - Xiao-Rui Lyu
   - Prospects of charmonium(+like) states study - Galina Pakhlova
   - Is there any Physics from 5 to 7 GeV? - Pavel Pakhlov
   - Status and perspective on $g-2$ of charm - Emi Kou

3）Status of detector and physics simulations at HIEPA & SCT
   - Xiaorong Zhou & Andrey Sukharev
   - Simulation of physics background in SCT detector - Lev Shekhtman
   - Belle2 beam background simulations and measurements - Hiroyuki Nakayama
   - Software for detector development studies and production - André Sailer
Two major aims of physics at STCF:

1. Search for New Physics beyond Standard Model

2. Hadron spectroscopy to explore how quarks & gluons construct hadrons with strong QCD
1. Search for New Physics beyond Standard Model from tau & charm decays
\( \tau \) Data Samples

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Counts</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALEPH</td>
<td>(3.3 \cdot 10^5)</td>
<td>reconstructed (\tau) decays</td>
</tr>
<tr>
<td>BaBar / Belle</td>
<td>(1.4 \cdot 10^9)</td>
<td>(\tau^+\tau^-) pairs</td>
</tr>
<tr>
<td>Belle-II</td>
<td>(4.6 \cdot 10^{10})</td>
<td>(\tau^+\tau^-) pairs</td>
</tr>
<tr>
<td>s(\tau)cF</td>
<td>(2.1 \cdot 10^{10})</td>
<td>(\tau^+\tau^-) pairs ((10^8) near threshold)</td>
</tr>
</tbody>
</table>

Luminosity \((10^{35} \text{ cm}^{-2} \text{ s}^{-1})\) is important. Systematics also!

Advantages of the threshold región:

- Ability to measure backgrounds \(\text{running below threshold}\)
- Free of heavy quark backgrounds
- Single-Tagging \(\rightarrow\) Precise measurement of absolute branching fractions
- Monochromatic spectra for two-body decays \((\pi, K)\)
### LEPTONIC DECAYS

\[
\Gamma (\tau \rightarrow \nu_\tau l \bar{\nu}_l) = \frac{G_F^2 m_\tau^5}{192 \pi^3} f\left(\frac{m_l^2}{m_\tau^2}\right) \left(1 + \delta_{RC}\right)
\]

\[
f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x
\]

\[
B_e = \frac{B_\mu}{0.972561 \pm 0.000004} = \frac{\tau_\tau}{(1632.7 \pm 0.5) \times 10^{-15} \text{s}}
\]

\[
\left(\frac{B_\mu}{B_e}\right)_{\text{exp}} = 0.9762 \pm 0.0028
\]

- Non-BF: \(0.9725 \pm 0.0039\)
- BaBar '10: \(0.9796 \pm 0.0039\)

\[
B_e^{\text{univ}} = (17.815 \pm 0.023)\%
\]
HADRONIC TAU DECAY

Only lepton massive enough to decay into hadrons

\[ R_\tau \equiv \frac{\Gamma(\tau^- \rightarrow \nu_\tau + \text{Hadrons})}{\Gamma(\tau^- \rightarrow \nu_\tau \, e^- \, \bar{\nu}_e)} \approx N_C \quad ; \quad R_\tau = \frac{1 - B_e - B_\mu}{B_e} = 3.637 \pm 0.011 \]

\[ R_\tau = \frac{1}{B^{\text{univ}}_e} - 1.97256 = 3.6407 \pm 0.0072 \quad ; \quad R_\tau = \frac{\text{Br}(\tau^- \rightarrow \nu_\tau + \text{Hadrons})}{B^{\text{univ}}_e} = 3.6349 \pm 0.0082 \]
Updated determinations of $|V_{us}|$ with tau data

$|V_{us}|$ from tau, HFLAV 2017 + *BaBar* ICHEP 2018

- $K_{l3}$, PDG 2016
  - $0.2237 \pm 0.0010$
- $K_{l2}$, PDG 2016
  - $0.2254 \pm 0.0007$
- CKM unitarity, PDG 2016
  - $0.2258 \pm 0.0009$
- $\tau \to s$ incl., HFLAV Spring 2017
  - $0.2186 \pm 0.0021$
- $\tau \to s$ incl.
  - $0.2195 \pm 0.0019$
- $\tau \to K\nu / \tau \to \pi\nu$
  - $0.2241 \pm 0.0016$
- $\tau$ average
  - $0.2222 \pm 0.0014$

- $\tau \to s$ inclusive vs. CKM unitarity discrepancy: $-3.0\sigma$
- No significant change, $|V_{us}|$ increased a bit, uncertainty reduced
**CP Asymmetry**

$$A_\tau \equiv \frac{\Gamma(\tau^+ \rightarrow \pi^+ K_S \bar{\nu}_\tau) - \Gamma(\tau^- \rightarrow \pi^- K_S \nu_\tau)}{\Gamma(\tau^+ \rightarrow \pi^+ K_S \bar{\nu}_\tau) + \Gamma(\tau^- \rightarrow \pi^- K_S \nu_\tau)} = (-3.6 \pm 2.3 \pm 1.1) \cdot 10^{-3} \quad \text{BaBar'11} \quad \left( \geq 0 \pi^0 \right)$$

$$A_{\tau}^{\text{SM}}(\tau^+ \rightarrow \pi^+ K_S \bar{\nu}_\tau) = (3.6 \pm 0.1) \cdot 10^{-3} \quad \text{Bigi-Sanda, Grossman-Nir} \quad 2.8 \sigma \ \text{discrepancy}$$

**Belle does not see any asymmetry at the 10^{-2} level**

$$A_{i}^{\text{CP}} \simeq \left\langle \cos \beta \cos \psi \right\rangle_{i}^{\tau^-} - \left\langle \cos \beta \cos \psi \right\rangle_{i}^{\tau^+}$$

bins (i) of \( W = \sqrt{Q^2} \)

\( \beta = K_s \) direction in hadronic rest frame

\( \psi = \tau \) direction

**BaBar signal incompatible (with EFT)**

with other sets of flavour data

Cirigliano-Crivellin-Hoferichter, 1712.06595

A. Pich  \( \tau \) Physics  26
Why are we searching for CLFV?

\[
\frac{\Gamma(\ell_\alpha \to \ell_\beta \gamma)}{\Gamma(\ell_\alpha \to \ell_\beta \nu \bar{\nu})} = \frac{3\alpha}{32\pi} \left| \sum_{k=1,3} U_{\alpha k} U_{\beta k}^* \frac{m_{\nu_k}^2}{M_W^2} \right|^2
\]

\[
\frac{\Gamma(\ell_\alpha \to \ell_\beta \gamma)}{\Gamma(\ell_\alpha \to \ell_\beta \nu \bar{\nu})} \sim \frac{1}{G_F^2 m_\text{SUSY}^4}
\]

- Unambiguous signal of New Physics
- Stringent test of NP models
- It probes scales far beyond the LHC reach

Borzumati Masiero '86; Hisano et al. '95

Tau Lepton Flavour Violation

Lorenzo Calibbi (ITP)
CLFV has been sought for more than 70 years...
Comments on tau physics:

Nice place for new physics searches

For these benchmark channels, high competition from Belle2 & LHCb

Qualitatively, threshold production at STCF may have some advantages

But quantitatively, can STCF really compete with Belle2 and LHCb?

We need serious Monte Carlo simulation as well as checking from BESIII data and Belle data
Charm Physics with future tau-charm factories

Search for New Physics

Solution by New Physics

Tests of Lepton flavour universality

B meson puzzles

$(g-2)_\mu$ discrepancy SM prediction and experimental result

How about charm?

- CP violation in the up sector;
- Charm offers tests of possible NP in up sector at low-energies;
- If NP couples to weak doublets of quarks, CKM connects it with charm sector. 
- Can one see NP in charm decays not being present in B meson?
Charged current charm meson decays and New Physics

\[ \mathcal{L}_{SM} = \frac{4G_F}{\sqrt{2}} V_{cs} \bar{s}_L \gamma^\mu c_L \bar{\nu}_l \gamma_\mu l \]

PDG 2018

\[ f_{D^+} = 211.9(1.1) \text{ MeV} \]
\[ f_{D_s} = 249.0(1.2) \text{ MeV} \]
\[ \frac{f_{D_s}}{f_{D^+}} = 1.173(3) . \]

\[ |V_{cs}| = 0.997 \pm 0.017 \]

Electro-magnetic correction 1-3%

\[ \mathcal{L}_{NP} = \frac{2}{\Lambda_c^2} \bar{s}_L \gamma^\mu c_L \bar{\nu}_l \gamma_\mu l \]

1% error in

\[ \Gamma(D^+_s \rightarrow l^+ \nu_l) \]

\[ \Lambda_c \sim 2.5 \text{ TeV} \]

Message:
Even if there is NP at 3 TeV scale the effect on charm leptonic decay can be \sim 1%!
Is charm physics sensitive on NP explaining B puzzles?

Can some NP be present in charm and not in beauty mesons?

New physics explaining B anomalies, leads to rather small effects in charge current transitions;

Vector LQ(3,1,5/3)

\[ \mathcal{L} = Y_{ij} \left( \bar{\ell}_i \gamma_\mu P_R u_j \right) V^{(5/3)\mu} + h.c. \]

(for loop effects in B
Camargo-Molina, Celis, Faroughy
1805.04917)

not present in B physics at tree level!

\[ D^0 - \bar{D}^0 \]

Svjetlana Fajfer
Charm Physics

- $4 \times 10^9$ pairs of $D^{\pm,0}$ and $10^7 \sim 10^8 D_s$ pairs per year
  - $10^{10}$ charm from Belle II/year
- **Competition to Belle II**
  - The multiplicity of final state is lower by a factor of 2
  - Threshold effect, clear, double tagging
  - Produce in QM coherent state, $J^{PC}=1^{-}$ for DD, $J^{PC}=0^{++}$ for $\gamma DD$
- **Highlighted Physics programs**
  - Precise measurement of leptonic, semi-leptonic decay ($f_D, f_{Ds}$, CKM matrix…)
  - $D^0 - \bar{D}^0$ mixing, CPV
  - Rear decay (FCNC, LFV, LNV…)
  - Excite charm meson states $D_J, D_{sJ}$ (mass, width, $J^{PC}$, decay modes)
  - Charmed baryons ($J^{PC}$, Decay modes, absolute BF)
  - Light meson and hyperon spectroscopy studied in charmed hadron decays
Features in studying charm hadron decays

<table>
<thead>
<tr>
<th>Feature</th>
<th>STCF</th>
<th>Belle(-II)</th>
<th>LHCb</th>
</tr>
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<tbody>
<tr>
<td>Production yields</td>
<td>★★★</td>
<td>★★★★</td>
<td>★★★★★</td>
</tr>
<tr>
<td>Background level</td>
<td>★★★★</td>
<td>★★</td>
<td>★★</td>
</tr>
<tr>
<td>Systematic error</td>
<td>★★★★</td>
<td>★★★</td>
<td>★★</td>
</tr>
<tr>
<td>Completeness</td>
<td>★★★★</td>
<td>★★★</td>
<td>★</td>
</tr>
<tr>
<td>(Semi)-Leptonic mode</td>
<td>★★★★</td>
<td>★★★</td>
<td>★</td>
</tr>
<tr>
<td>Neutron/K$_L$ mode</td>
<td>★★★★</td>
<td>★★</td>
<td>★☆</td>
</tr>
<tr>
<td>Photon-involved</td>
<td>★★★★</td>
<td>★★★★★</td>
<td>★☆</td>
</tr>
<tr>
<td>Absolute measurement</td>
<td>★★★★</td>
<td>★★★</td>
<td>★☆</td>
</tr>
</tbody>
</table>

- Most are precision measurements, which are mostly dominant by the systematic uncertainty
- STCF has overall advantage
Vcs and Vcd

**Future BESIII:**
- Vcd: ~1.5% (stat. dominant)
- Vcs: ~1.5% (syst. dominant)

**STCF:** <0.2% (syst. dominant)
Systematic control is challenging

### SM fit
- PDG18: 0.22438 ± 0.00004

### CLEO/Belle/BaBar/BESIII
- PDG18: 0.214 ± 0.003 ± 0.009

### CLEO
- PRD75, 052003: 0.218 ± 0.009 ± 0.003

### BESIII
- PRD89, 051104: 0.215 ± 0.0065 ± 0.0020

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**by 2025**

- B physics
- Indirect
- Direct
- Nucleon & Kaon

**CKM**

- Excluded area has CL > 0.95
Summary for charm decays

- **STCF** is one of the crucial **precision frontier**: threshold production data is unique to carry out the measurements of the charmed hadron decays
- **Important playground for studying non-perturbative QCD and search for new physics**
  - CKM matrix, Decay constants ($f_D/f_{D_s}$), form factors
  - Neutral D mixing and strong phase
  - Charmed baryon decays
- Complementary to Belle II and LHCb in understanding the QCD/EW models and searching for new physics
2. Hadron spectroscopy to explore how quarks & gluons construct hadrons with strong QCD

atomic spectrum $\rightarrow$ atomic quantum theory
nuclear spectrum $\rightarrow$ shell model, collective motion
hadron spectrum $\rightarrow$ ? Important discovery

$X(3872)$ $\rightarrow$ top cited paper for Belle
$Zc(3900)$ $\rightarrow$ top cited paper for BESIII
$Pc$ states $\rightarrow$ top cited paper for LHCb
1) Key problem in hadron spectroscopy:

Unquenching dynamics: gluons $\rightarrow$ $\bar{q}q$

crucial for quark confinement & hadron structure
Charmoniumlike states (before PDG2018 naming scheme)

2002-2016 Discovery of two dozens exotic charmonium states
All of them above open charm threshold

Multiquark states
Tetraquark
tightly bound four-quark state
Molecular state
two loosely bound charm mesons

Charmonium hybrids
States with excited gluonic degrees of freedom

Hadrocharmonium
Specific charmonium state “coated”
by excited light-hadron matter

Threshold effects
Virtual states at thresholds
Charmonium states with masses shifted by nearby $D_{(s)^*}D_{(s)^*}$ thresholds

Galina Pakhlova
Predictions for the lowest $\Omega^*$ by various models:

$\Omega^*(x/2^-) \text{ as } sss \ (L=1) : \sim 2020 \text{ MeV}
\text{Chao, Isgur, Karl, PRD38(1981)155}$

$\Omega^*(1/2^-) \text{ as } \bar{K}\Xi \text{ bound state: } \sim 1805 \text{ MeV}$
\text{W.L.Wang, F.Huang, Z.Y.Zhang, F.Liu, JPG35 (2008) 085003}

$\Omega^*(x/2^-) \text{ as } \bar{u}u\bar{s}s \ (L=0) : \sim 1820 \text{ MeV}$
\text{Yuan-An-Wei-Zou-Xu, PRC87(2013)025205}

$\Omega^*(3/2^-) \text{ as } sss - \bar{u}u\bar{s}s \text{ mixture : } \sim 1780 \text{ MeV}$
\text{by instanton/NJL interaction}
\text{An-Metsch-Zou, PRC87(2013)065207; An-Zou, PRC89 (2014) 055209}

STCF: $e^+e^- \rightarrow \bar{\Omega} \Omega^*$
$\rightarrow \Omega^*(1800) ?!
2) my favorite strategy for hadron spectroscopy:

\[
\begin{align*}
\bar{c}c\text{uud} & \quad \bar{c}c\text{uds} \rightarrow \text{sss} - \bar{q}q\text{sss} \rightarrow \text{cqq} - \bar{q}q\text{cqq} \\
& \quad \rightarrow \text{hyperons} \rightarrow \text{light baryons} \\
\bar{c}c\text{ ud} & \quad \bar{c}s\text{ ud} \rightarrow \bar{c}c - \bar{q}q\text{ cc} \rightarrow \bar{c}q - \bar{c}q\text{ qq} \\
& \quad \bar{c}s - \bar{q}q\text{ cs} \rightarrow \text{K mesons} \rightarrow \text{light mesons} \\
s & \rightarrow c & \rightarrow b
\end{align*}
\]

charm & beauty meson  
charm & beauty baryon
All these kinds of hadrons can be studied at STCF XYZ states as well as various baryon states.

**Two-body baryonic cross section**

\[ e^+e^- \rightarrow \Lambda_c^+\Lambda_c^- \] near threshold bump surprised everybody, and still not understood.

There are many more such charmed ground state baryons, that have a pair production in 5-7.3 GeV region.

It is interesting to compare cross section behavior at threshold for \( \Xi_c^{0+}\Xi_c^{0+} \), \( \Omega_c^0\Omega_c^0 \) and doubly charmed baryon pairs.

\[
\begin{align*}
M(\Xi_c^{0/+}\Xi_c^{0/+}) &= 4.936/4.940 \text{ GeV} \\
M(\Omega_c^0\Omega_c^0) &= 5.390 \text{ GeV} \\
M(\Xi_{cc}^{0/+}\Xi_{cc}^{0/+}) &= 7.242 \text{ GeV}
\end{align*}
\]

And many more final states with excited baryons...
an ideal isospin and low spin filter from $\bar{c}c$ annihilation
No contamination from $t/u$-channel scattering as in $\pi N$ and $\gamma N$
high statistics extension to $\psi', \chi_{cJ}, \eta_c$
Observation of “missing” $N^*$ above 2 GeV with low spin

$J/\psi \rightarrow \bar{p}n\pi^+ \& \bar{n}\pi^-p$  

BESII Collaboration, PRL97 (2006)062001

The first experiment “seeing” $N^*(1440)$ in $\pi N$ mass spectrum

BESII $M = 1358 \pm 17$, $\Gamma = 179 \pm 56$ MeV
PDG06 $M = 1365 \pm 15$, $\Gamma = 190 \pm 30$ MeV
Observation of Two New $N^*$ Resonances in the Decay $\psi(3686) \rightarrow p\bar{p}\pi^0$

$N^*(2300)\frac{1}{2}^+, \ N^*(2570)\frac{5}{2}^-$

BESIII, PRL110(2013)022001

For $\pi N$ scattering at 2.2 GeV,
$L = r \times p = 1 \text{ fm} \times 900 \text{ MeV} = 4.5$
$J = \frac{7}{2} \text{ or } \frac{9}{2}$

For $\bar{c}c \rightarrow \bar{N}N^*(2300)$,
$L = r \times p = 0.3 \text{ fm} \times 400 \text{ MeV} = 1$
$J \leq \frac{5}{2}$

Low spin filter
Summary for physics at STCF:

1. Tau & Charm decays provide nice playground to search for New Physics beyond Standard Model
   high competition from Belle2 & LHCb
   Monte Carlo simulation as well as checking from BESIII & Belle data are needed

2. A leading role for Hadron spectroscopy with many new hadron states to be discovered.
Thank you for your attention!