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A physics program of charmed baryon studies at the Super tau-charm

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HSE

Workshop on future Super c-tau factories

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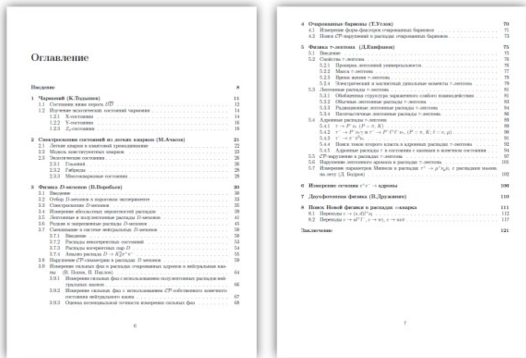
Physics program: published

Physics program: 2022 revision (in Russian)



- 2021: ≈ 40 pages
- 2022: ≈ 120 pages
- Editors:
  - G.Pakhlova (LPI)
  - A.Bondar (BINP)

Available at ctd.inp.nsk.su

Shorter (extracted) version prepared as a white paper for Snowmass

Physics program: UFN paper (2024)

Experiments at the Super Charm-Tau factory

M.N. Achasov [1,2], **V.E. Blinov** [1,2], **A.V. Bobrov** [1,2], **D.A. Bodrov** [3], **A.E. Bondar** [1,2], **V.S. Vorobiev** [1], **D.S. Gorbunov** [4], **V.P. Druzhinin** [1,2], **D.A. Epifanov** [1,2], **A.S. Kuzmin** [1,2], **I.B. Logashenko** [1,2], **D.V. Matvienko** [1,2], **A.V. Nefediev** [5], **P.N. Pakhlov** [3,5], **G.V. Pakhlova** [5], **V.E. Popov** [6], **T.V. Uglov** [5,*]

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The review discusses the physical program of a new experiment at the Super Charm-Tau factory, the basis of which will be a powerful electron-positron collider with a luminosity of $\sim 10^{35}$ cm^{-2} s^{-1} and an energy in the center of mass system in the range from 3 to 5 GeV. A modern detector located around the beam collision point will provide a new level of measurement accuracy. The longitudinal polarization of the electron beam, along with record luminosity, will allow the unique experiment to successfully compete with the existing Super B-factories Belle II and LHC*b*. The extensive physical program includes the study of the properties and measurement of physical parameters of charmed hadrons, the τ-lepton, the charmonium, and exotic states, as well as the study of the production of light hadrons in e^+e^--annihilation and in two-photon processes. In addition to testing the Standard Model and precisely measuring its parameters, a comprehensive search for New Physics beyond its boundaries is planned.

Keywords: e^+e^--collider, polarized beams, quantum chromodynamics, τ-lepton, physics of charmed hadrons, New Physics

PACS numbers: **12.38.–t, 12.60.–i,** 29.20.db

Bibliography — 199 references
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Uspekhi Fizicheskikh Nauk **194** (1) 60 – 76 (2024)
Physics – Uspekhi **67** (1) (2024)

A review of the SCTF physics program has just been published in the Russian top physics journal "Physics-Uspekhi."

Feasibility studies with realistic detectors and background descriptions are crucial to the further development of a physics program.

https://doi.org/10.3367/UFNe.2023.10.039583

See I. Logashenko's talk "SCTF* Overview"

Conceptual Design Report

Accelerator

To be published at the end of this year

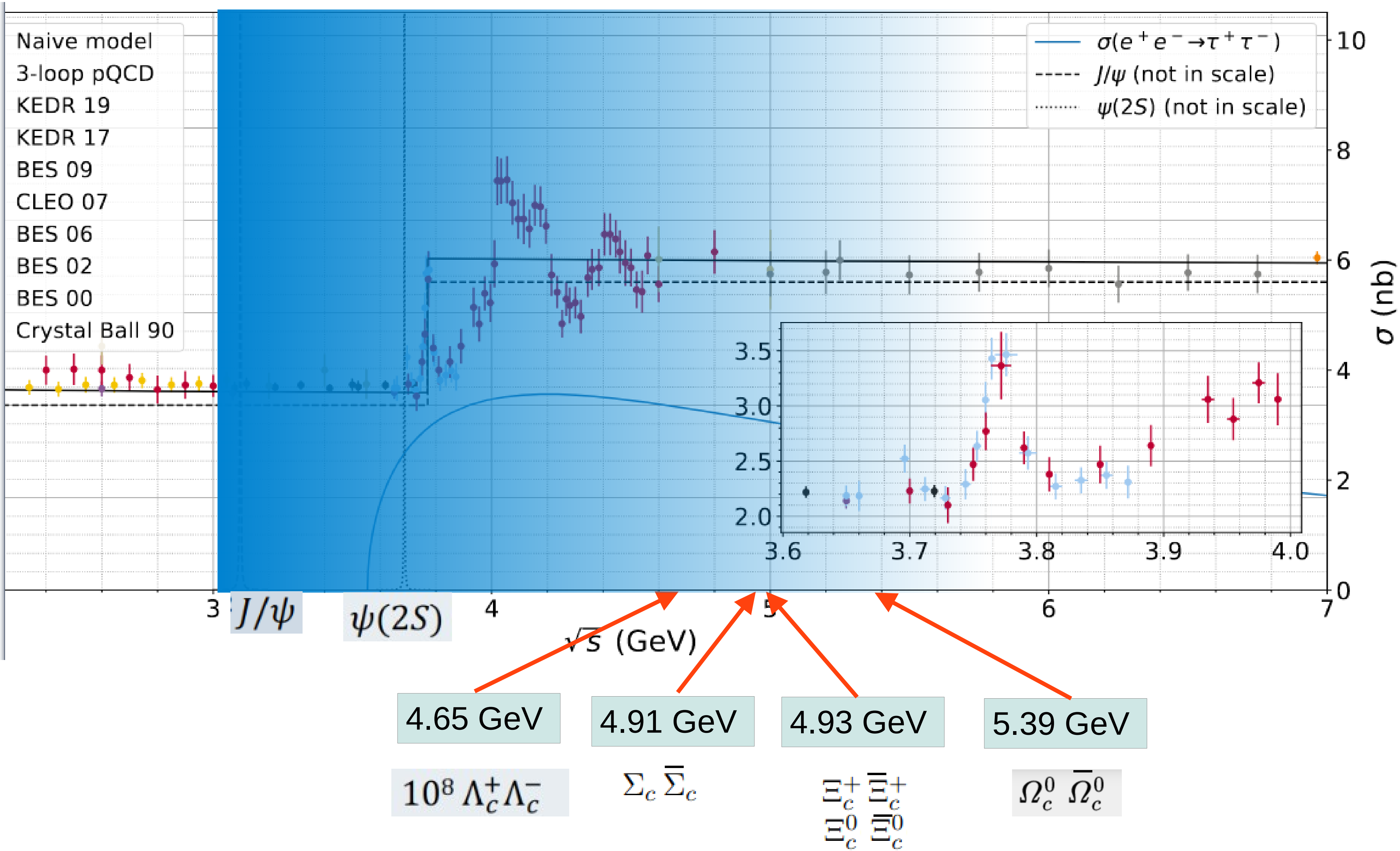
82 institutions, 453 authors

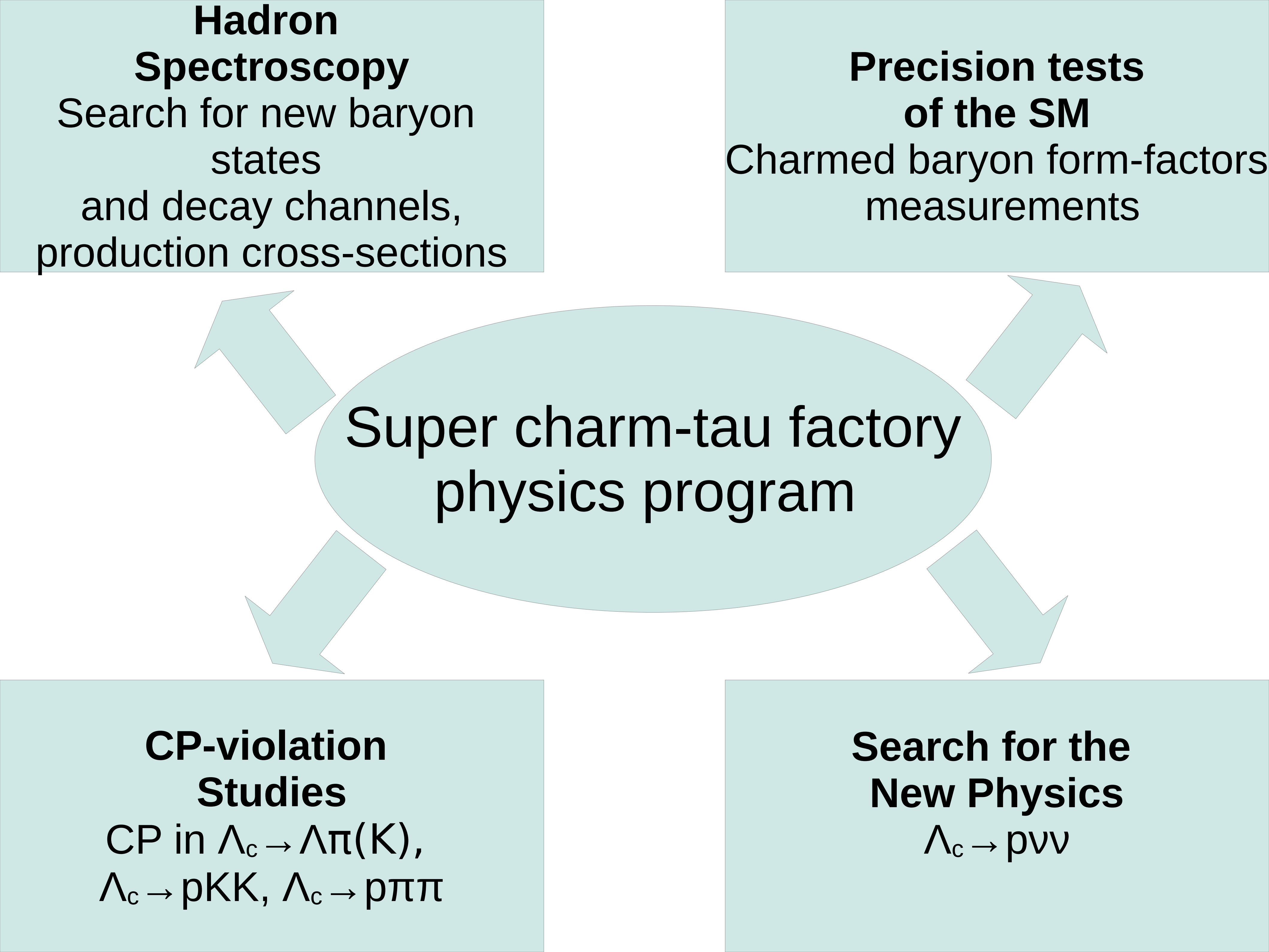
https://arxiv.org/abs/2303.15790

https://journal.hep.com.cn/fop/EN/10.1007/s11467-023-1333-z

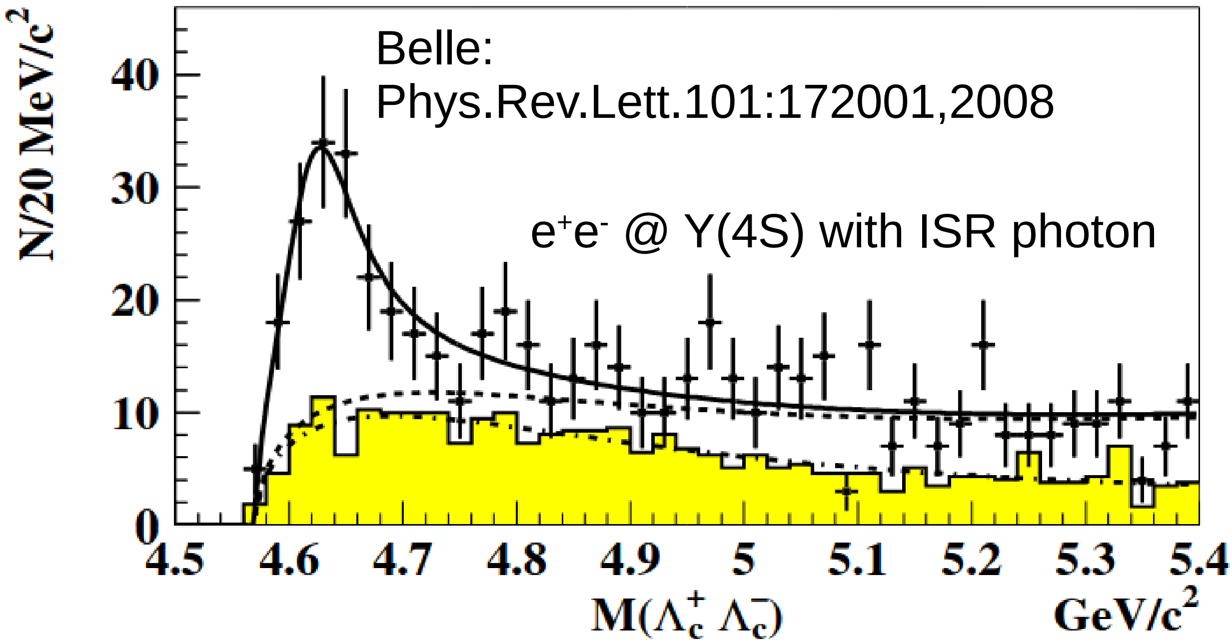
See H. Peng's talk "Overview of STCF project"

Energy range




Hadron Spectroscopy
Search for new baryon states and decay channels, production cross-sections
Precision tests of the SM
Charmed baryon form-factors measurements
Super charm-tau factory physics program
CP-violation Studies
CP in $\Lambda_c \to \Lambda\pi(K)$, $\Lambda_c \to pKK$, $\Lambda_c \to p\pi\pi$
Search for the New Physics
$\Lambda_c \to p\nu\nu$

Production cross-section in e^+e^- annihilation

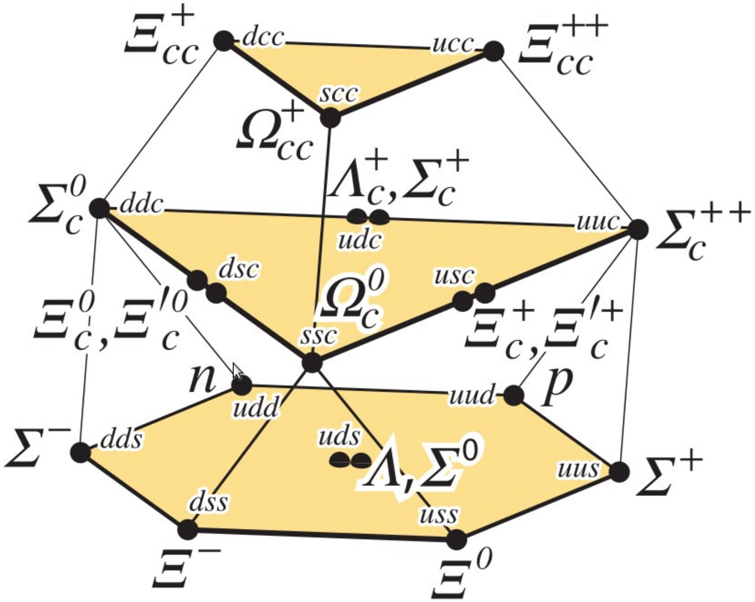


$\sigma(e^+e^- \to \Lambda_c\overline{\Lambda}_c) \sim 0.5\,\mathrm{nb}\;@\;4.65\,\mathrm{GeV}$ (possible resonant enhancement)

<10 pb without resonances (predicted)

No data for the other charmed baryons

Charmed baryon spectroscopy



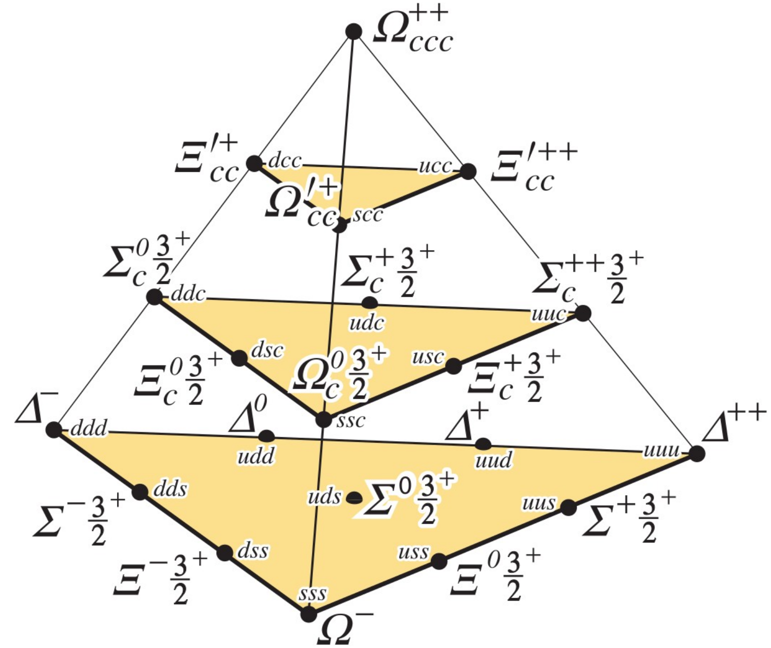
$$3 \times 3 = \bar{3}_A \oplus 6_S$$

q=u,d,s (q q) c ↓↑↑ (q q) c ↓↓↑

Spin 1/2: $\Lambda_c^+, \Xi_c^+, \Xi_c^0 \quad \Sigma_c^{++,+,0}, \Xi_c^{\prime +}, \Xi_c^{\prime 0}, \Omega_c^0$

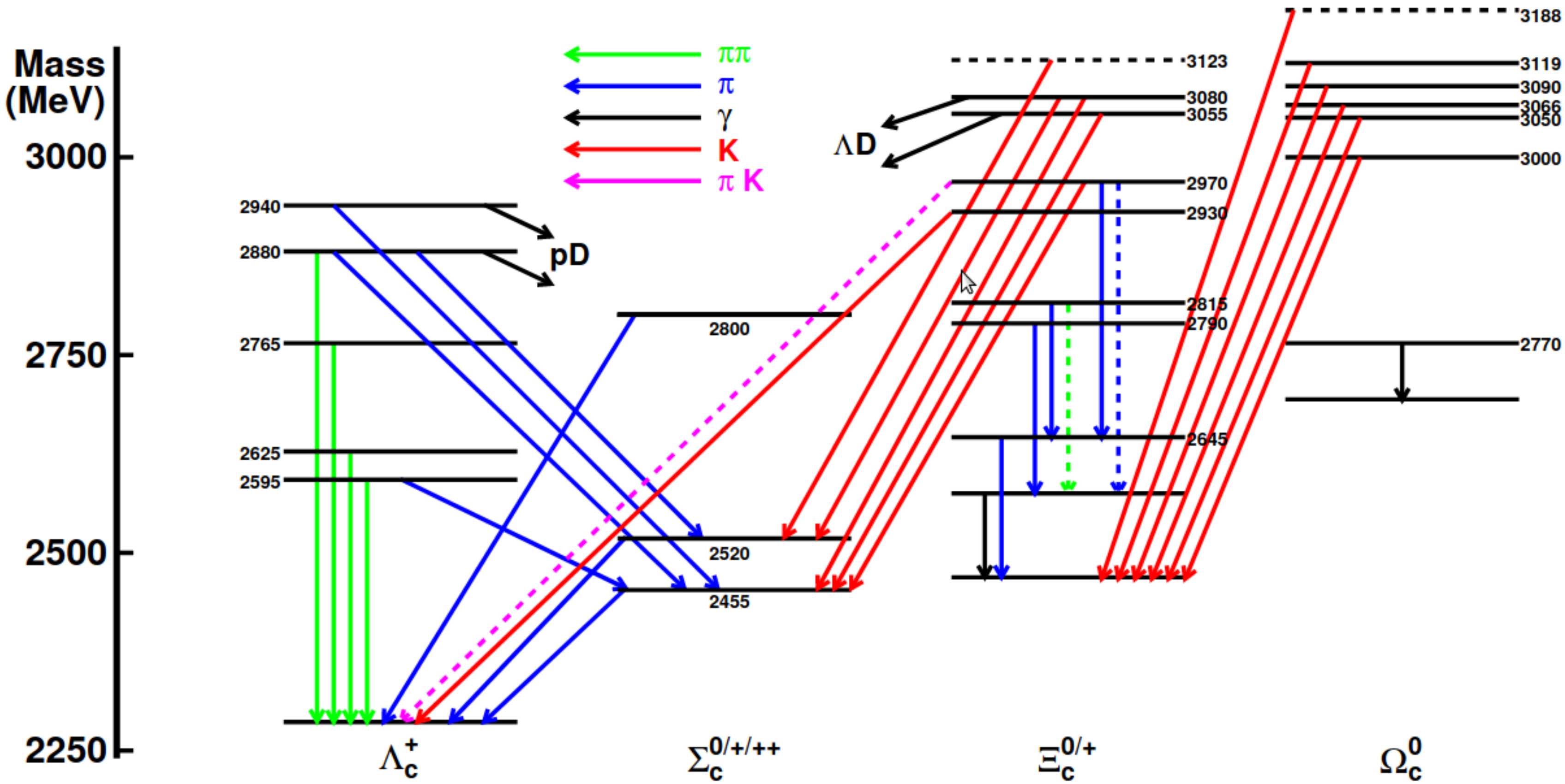
(q q) c ↓↓↓

Spin 3/2: $\Sigma_c^{*++,+,0}, \Xi_c^{*+}, \Xi_c^{*0}, \Omega_c^{*0}$



P-wave excitations: 63 states

Charmed baryon spectroscopy



Excited charmed baryon states and its decays

Polarized beam simplifies quantum number determination

Charmed baryons' masses and widths

		J^P	Mass	Width	Dominant decay channel
Λ_c^+	udc	$(1/2)^+$	2286.46 ± 0.14	(200 ± 6) fs	Weak
Ξ_c^+	usc	$(1/2)^+$	$2467.8^{+0.4}_{-0.6}$	(442 ± 26) fs	Weak
Ξ_c^0	dsc	$(1/2)^+$	$2470.88^{+0.34}_{-0.8}$	112^{+13}_{-10} fs	Weak
Σ_c^{++}	uuc	$(1/2)^+$	2454.02 ± 0.18	2.23 ± 0.30 MeV	$\Lambda_c^+\pi^+$
Σ_c^+	udc	$(1/2)^+$	2452.9 ± 0.4	< 4.6 MeV	$\Lambda_c^+\pi^0$
Σ_c^0	ddc	$(1/2)^+$	2453.76 ± 0.18	2.2 ± 0.4 MeV	$\Lambda_c^+\pi^-$
$\Xi_c'^+$	usc	$(1/2)^+$	2575.6 ± 3.1	—	$\Xi_c^+\gamma$
$\Xi_c'^0$	dsc	$(1/2)^+$	2577.9 ± 2.9	—	$\Xi_c^0\gamma$
Ω_c^0	ssc	$(1/2)^+$	2695.2 ± 1.7	(69 ± 12) fs	Weak
Σ_c^{*++}	uuc	$(3/2)^+$	2518.4 ± 0.6	14.9 ± 1.9 MeV	$\Lambda_c^+\pi^+$
Σ_c^{*+}	udc	$(3/2)^+$	2517.5 ± 2.3	< 17 MeV	$\Lambda_c^+\pi^0$
Σ_c^{*0}	ddc	$(3/2)^+$	2518.0 ± 0.5	16.1 ± 2.1 MeV	$\Lambda_c^+\pi^-$
Ξ_c^{*+}	usc	$(3/2)^+$	$2645.9^{+0.5}_{-0.6}$	< 3.1 MeV	$\Xi_c\pi$
Ξ_c^{*0}	dsc	$(3/2)^+$	2645.9 ± 0.5	< 5.5 MeV	$\Xi_c\pi$
Ω_c^{*0}	ssc	$(3/2)^+$	2765.9 ± 2.0	—	$\Omega_c^0\gamma$

Properties are studied mainly by B-factories (~10^7 Λ_c^+) and BES III

Charmed baryons' branching ratios

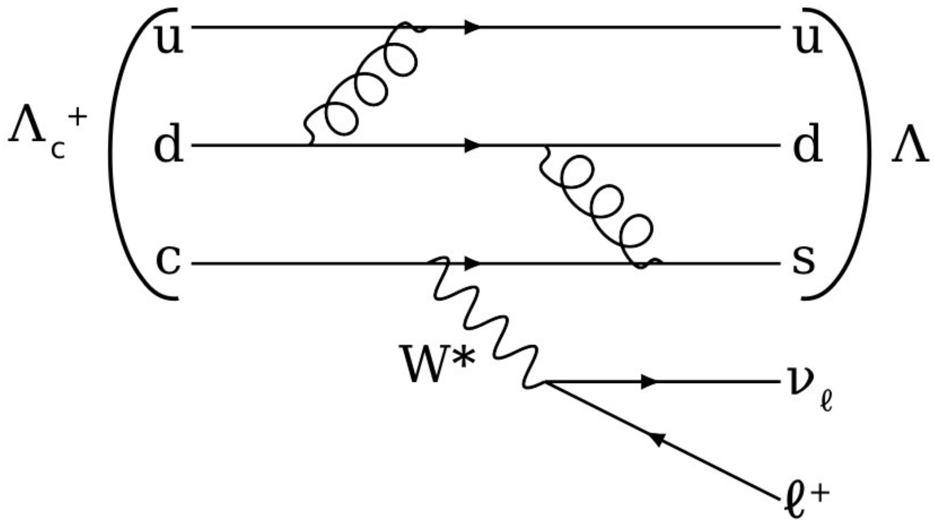
Decay	$\mathcal{B}$	Decay	$\mathcal{B}$	Decay	$\mathcal{B}$
$\Lambda_c^+ \to \Lambda\pi^+$	1.30±0.07	$\Lambda_c^+ \to \Lambda\rho^+$	4.06 ± 0.52	$\Lambda_c^+ \to \Delta^{++}K^-$	1.08 ± 0.25
$\Lambda_c^+ \to \Sigma^0\pi^+$	1.29±0.07	$\Lambda_c^+ \to \Sigma^0\rho^+$		$\Lambda_c^+ \to \Sigma^{*0}\pi^+$	0.65 ± 0.10
$\Lambda_c^+ \to \Sigma^+\pi^0$	1.25±0.10	$\Lambda_c^+ \to \Sigma^+\rho^0$	< 1.7	$\Lambda_c^+ \to \Sigma^{*+}\pi^0$	0.59 ± 0.08
$\Lambda_c^+ \to \Sigma^+\eta$	0.44±0.20	$\Lambda_c^+ \to \Sigma^+\omega$	1.70±0.21	$\Lambda_c^+ \to \Sigma^{*+}\eta$	1.05 ± 0.23
$\Lambda_c^+ \to \Sigma^+\eta'$	1.5±0.6	$\Lambda_c^+ \to \Sigma^+\phi$	0.38±0.06	$\Lambda_c^+ \to \Sigma^{*+}\eta'$	
$\Lambda_c^+ \to \Xi^0 K^+$	0.55±0.07	$\Lambda_c^+ \to \Xi^0 K^{*+}$		$\Lambda_c^+ \to \Xi^{*0}K^+$	0.43±0.09
$\Lambda_c^+ \to pK_S$	1.59±0.08	$\Lambda_c^+ \to p\bar{K}^{*0}$	1.96±0.27	$\Lambda_c^+ \to \Delta^+\bar{K}^0$	

Absolute branchings are normalized to Br($\Lambda_c^+ \to pK^-\pi^+$)= 6.28±0.32 %

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (1.80 \pm 0.50 \pm 0.14)\%, \quad \mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (2.86 \pm 1.21 \pm 0.38)\%.$$

No measured absolute branching for Ω_c

Form-factor measurement



Check and justify effective theories (like HQET) and lattice calculations (LQCD)

$$\Lambda_c^+ \to \Lambda l^+ \nu_l \ (l = e, \mu)$$

In HQET charm and beauty baryons' form-factors are connected

⇨ measurement of the Λ_c^+ semileptonic form-factor gives input to $|V_{cb}|$ and $|V_{us}|$ measurements with Λ_b^0 decays

Form-factor measurement

For arbitrary semileptonic baryon decay: $B_1(p_1, M_1) \to B_2(p_2, M_2) + l(p_l, m_l) + \nu_l(p_{\nu_l}, m_{\nu_l} = 0)$

$$\langle B_2| j^V_\mu |B_1\rangle = M^V_\mu = \overline{u}_2\left[F^V_1(q^2)\gamma_\mu + \frac{F^V_2(q^2)}{M_1}\sigma_{\mu\nu}q^\nu + \frac{F^V_3(q^2)}{M_1}q_\mu\right]u_1,$$

$$\langle B_2| j^A_\mu |B_1\rangle = M^A_\mu = \overline{u}_2\left[F^A_1(q^2)\gamma_\mu + \frac{F^A_2(q^2)}{M_1}\sigma_{\mu\nu}q^\nu + \frac{F^A_3(q^2)}{M_1}q_\mu\right]\gamma_5 u_1,$$

Assuming that:

- Lepton mass is small
- There are no T-odd effects
- HQET works for $c \to s l^+ \nu_l$ transition

  only two parameters survives: M_{pole} and $R(q^2) = f_2(q^2)/f_1(q^2)$

$$\langle \Lambda| J_\mu |\Lambda^+_c\rangle = \overline{u}_\Lambda\left[f_1(q^2)\gamma_\mu(1-\gamma_5) + f_2(q^2)\hat{v}_{\Lambda_c}\gamma_\mu(1-\gamma_5)\right]u_{\Lambda_c};$$

$$F^V_1(q^2) = -F^A_1(q^2) = f_1(q^2) + \frac{M_\Lambda}{M_{\Lambda_c}}f_2(q^2);$$

$$F^V_2(q^2) = -F^A_2(q^2) = f_2(q^2).$$

CLEO:
PRL 94 191801

$$M_{pole} = [2.21 \pm 0.08 \pm 0.14]\,\text{GeV}$$

$$R = -0.35 \pm 0.05 \pm 0.04$$

CPV in Λ_c decays

$$A_{CP}^{\mathrm{dir}} = \frac{\Gamma(\Lambda_c^+ \to f) - \Gamma(\bar{\Lambda}_c^- \to \bar{f})}{\Gamma(\Lambda_c^+ \to f) + \Gamma(\bar{\Lambda}_c^- \to \bar{f})}$$ = $(-58.5 \pm 4.9 \pm 1.8)\%$ (Belle), $\Lambda c \to \Lambda K$

$\Delta A_{CP} = (0.30 \pm 0.91 \pm 0.61)\%$ (LHCb), $\Lambda_c^+ \to pK^+K^-$ and $\Lambda_c^+ \to p\pi^+\pi^-$

Multibody final states $\Lambda_c^+ \to pK_S\pi^+\pi^-$ $\Lambda_c^+ \to pK^-\pi^+\pi^0$, $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$

Estimated sensitivity@ SCTF $(0.25–0.5)\%$

Summary

SCTF is an ideal laboratory for charm baryon study

10^8 $\Lambda_c\overline{\Lambda}_c$ pairs per year is one of the world larges (and cleanest) dataset

Near the threshold no momentum tag is needed

With polarized beams Λ_c^+ is produced with known polarization → no tag needed

Baryon studies contributes to all highlights of the SCTF (or STCF) physical program