Precision experiments at Super Charm-Tau Factory

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On behalf of the SCT community

SNOWMASS21-RF1_RF7_BINP-019

Snowmass Town Hall Meeting

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Physics program

ctd.inp.nsk.su

- ✓ Measurement of the strong phases of D decay amplitudes
- ✓ Measurement of absolute branching fractions
- ✓ Searches for rare and forbidden decays of the charm quark
- ✓ CP violation in charm
- ✓ …

Input for B meson studies at LHCb and Belle II

charm

QCD

tau

- ✓ Physics of highly-excited quarkonium
- ✓ Molecular states
- ✓ Baryon interaction at threshold
- ✓ Search for glueballs in decays of J/ψ and $\psi(2S)$
- ✓ …

- ✓ Precision measurement of the τ lepton properties
- ✓ Michel parameters, tests of lepton universality
- ✓ Precision measurement of hadronic τ decays
- ✓ Search for CP and T violation in τ decays
- ✓ …

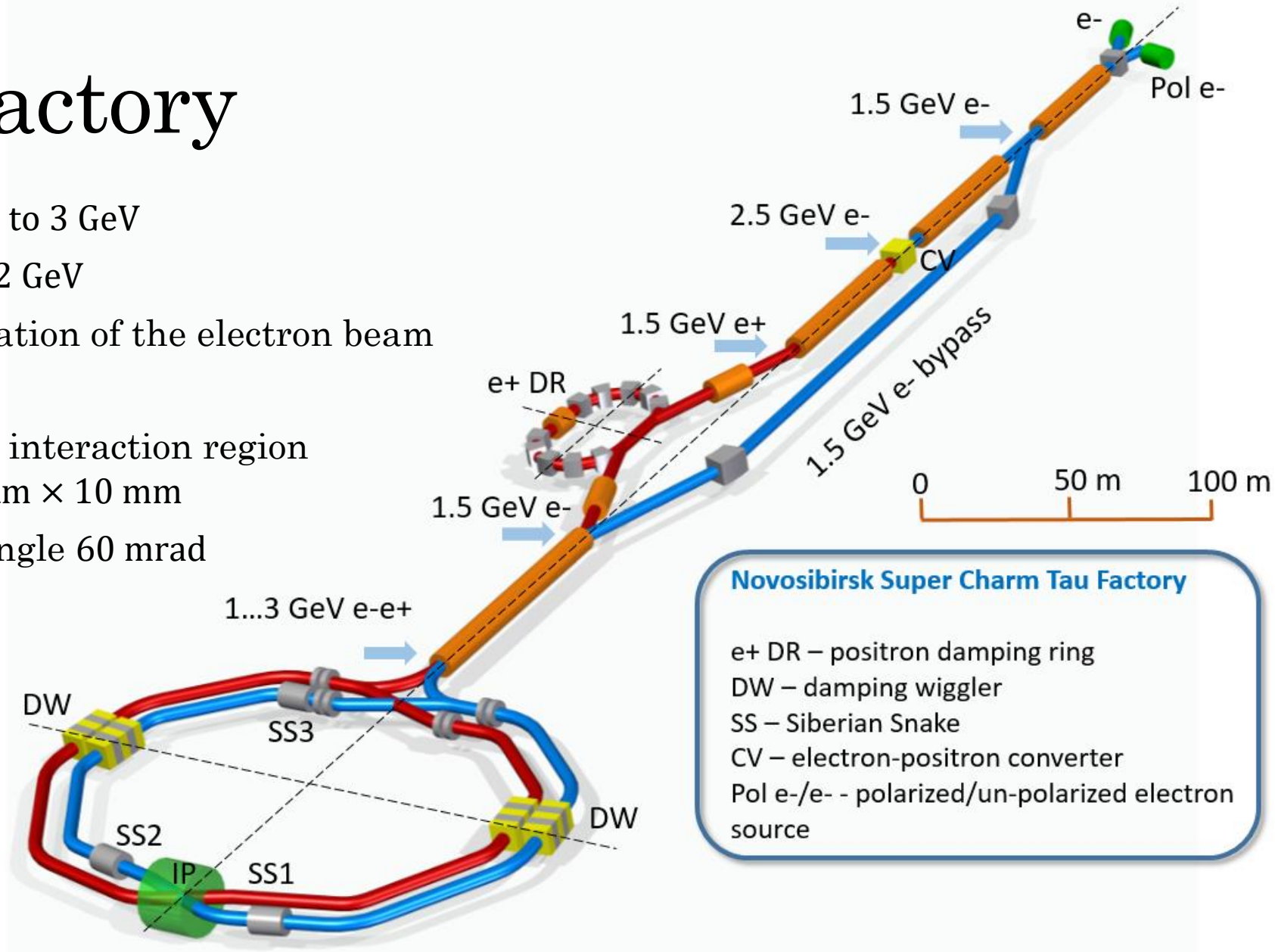
Test of the electroweak sector of the SM

QCD, α_s, V_{us}. Test of the electroweak model, searches for non-standard contributions

SCT Factory

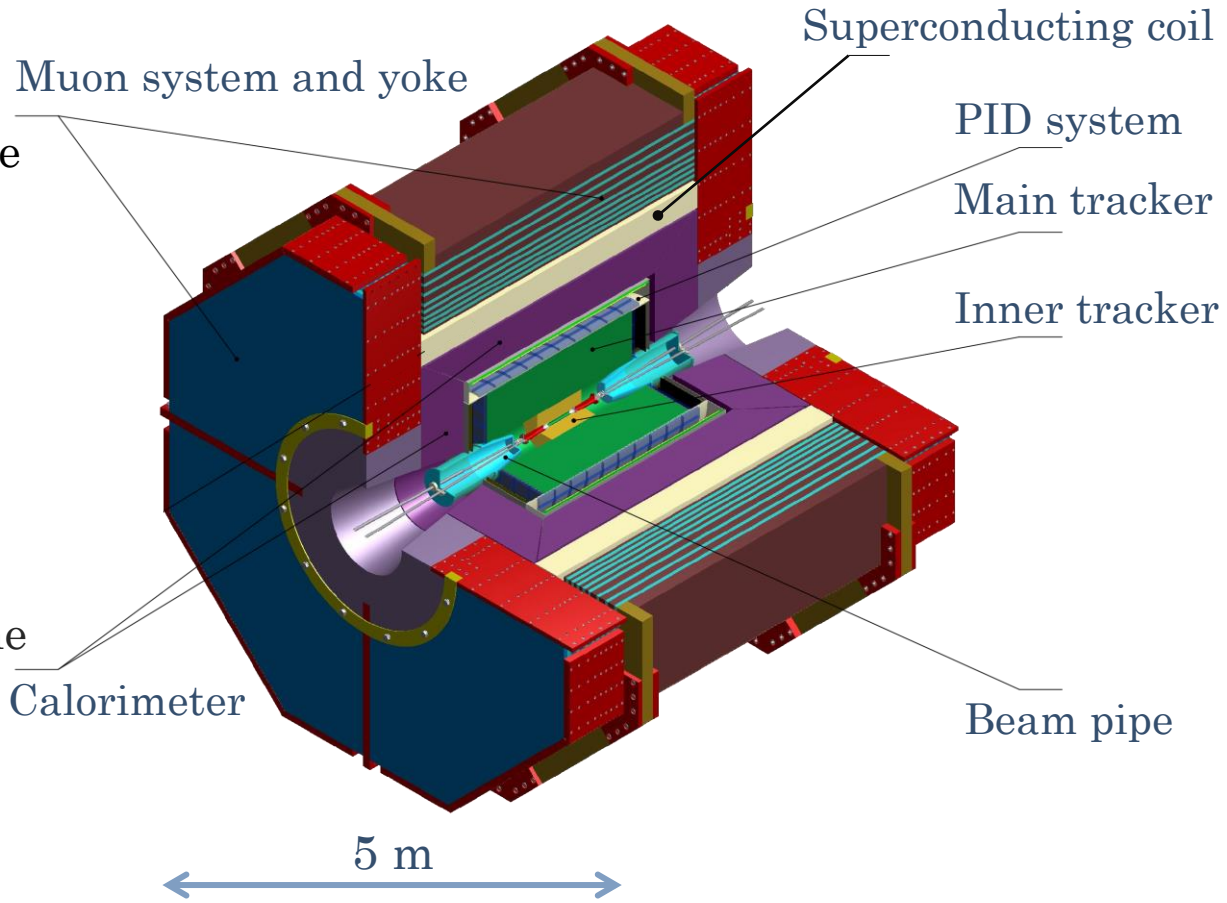
- Beam energy: from 1 to 3 GeV
- $\mathcal{L} = 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ @ 2 GeV
- Longitudinal polarization of the electron beam
- Crab-waist collisions
  - Beam size in the interaction region
    $20\ \mu\mathrm{m} \times 0.2\ \mu\mathrm{m} \times 10\ \mathrm{mm}$
  - Beam crossing angle 60 mrad

SCT website
ctd.inp.nsk.su



Detector concept

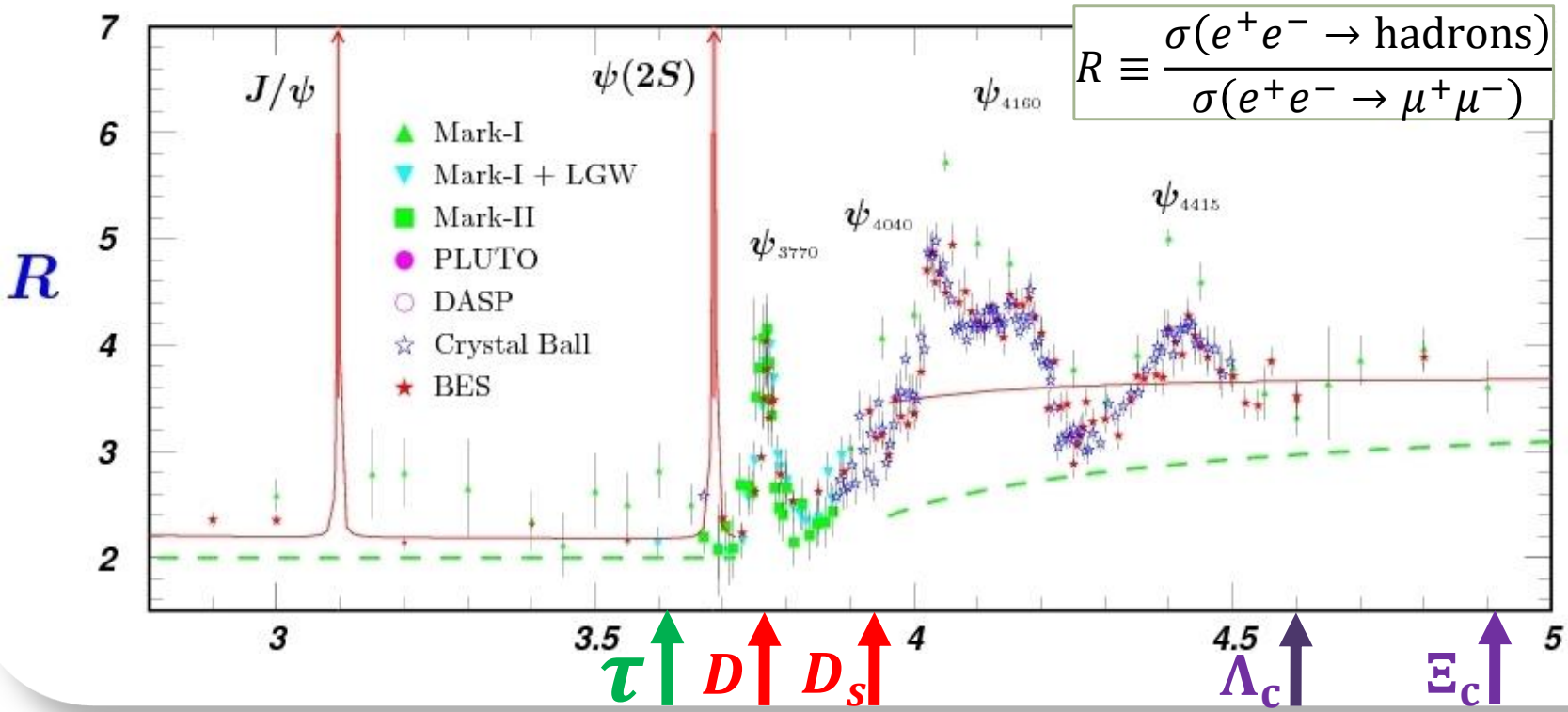
- Physics requirements
  - Momentum resolution: ≈ 0.3%
  - CP symmetry and hermeticity ≈ 95% of the full solid angle
  - Soft track detection with $p_t \gtrsim 50$ MeV
  - Excellent $\mu/\pi/K/p$ separation up to 1.5 GeV
    - dE/dx in tracking system
    - Cherenkov light detector for PID
    - The importance of μ/π separation
  - Good π^0/γ separation and γ detection in the energy range from 10 MeV to 3000 MeV
    - Good energy resolution in calorimeter
    - Fast calorimeter ($\sigma_t < 1$ ns)
  - DAQ rate ~300 kHz @ J/ψ peak



SCT yield

$\sqrt{s}$ from 2 GeV to 6 GeV

The production of non-relativistic particles near the threshold makes it possible to study them in detail



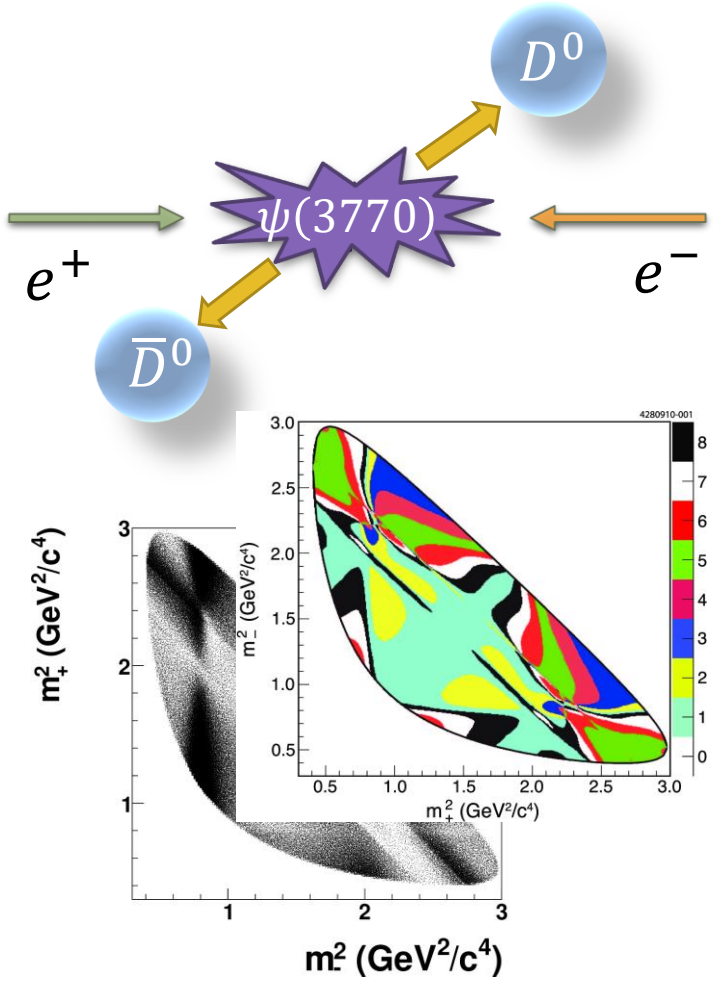
$\mathcal{L} = 10^{35}\ \text{cm}^{-2}\text{s}^{-1}$

$2E$, GeV	Annual yield
3.1	$10^{12}\ J/\psi$
3.69	$10^{11}\ \psi(2S)$
3.77	$10^{9}\ D\bar{D}$
4.17	$10^{8}\ D_s\bar{D}_s$
$3.55 \div 4.3$	$10^{10}\ \tau\,\tau$
4.65	$10^{8}\ \Lambda_c^+\Lambda_c^-$

Entangled $D^0\overline{D}^0$ state as a powerful tool

… a powerful tool to study charm and QCD

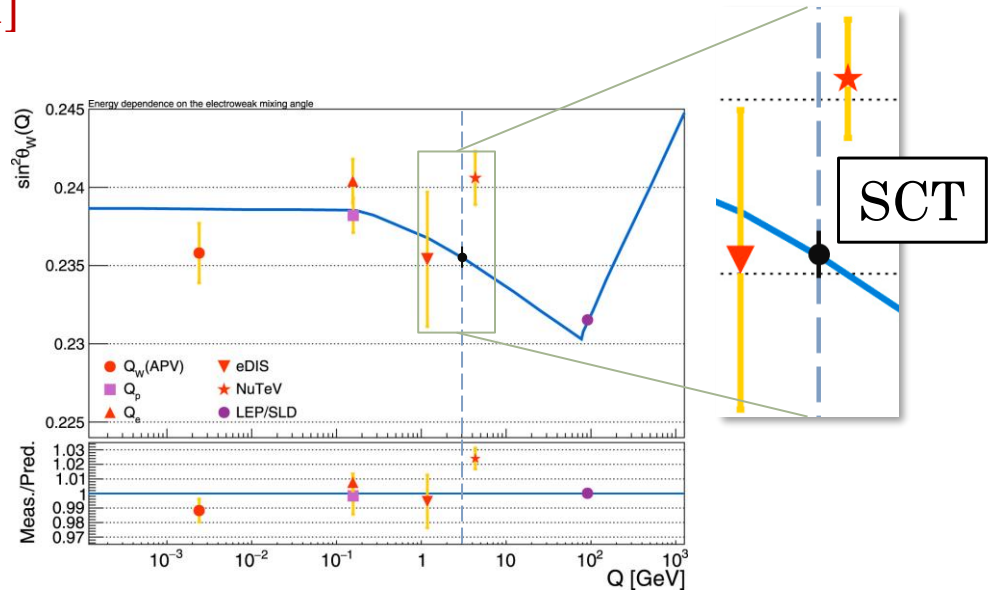
- Entangled $D^0\overline{D}^0$ pairs are produced at threshold
  - The unique phenomenology
- Measuring charm mixing and CPV in charm
  - In a unique way: quantum correlations in action! [1, 2]
  - Precision comparable to Belle II
  - The best environment for the decays with final-state neutrals
- Measurements of the D^0 decay amplitude phases
  - $\delta_{K\pi}$, $\delta_{K\pi\pi^0}$, … [3]
  - Model-independent Dalitz analysis of $D^0 \to K^0_S\pi^+\pi^-$
  - Essential input for the CKM phase γ measurements at Belle II and LHCb



[1] V.V. slides at HIEPA2018
[2] PRD 82 (2010) 034033
[3] PRD 73 (2007) 034024

Experiments with polarization

1. Left-right $e^+e^- \to J/\psi$ cross section asymmetry [1]
   - Measuring the Weinberg angle at 0.3%
   - Testing weak interaction of charm
   - Sensitivity to heavy Z'
2. Baryons (light and charmed)
   - Formfactors: calibration of lattice QCD calculations
   - CP and T violation in decays
3. Tau physics
   - Lorentz structure of lepton decays
     - No need of spin-spin correlations of $\tau^+\tau^-$. Great simplification of the analysis procedure → better systematics and statistics
   - CP violation in τ production: EDM
     - Current experimental limit: $|d_\tau| \lesssim 10^{-17}\ e \cdot cm$
     - With 10^{10} tau pairs at SCT: $\sigma(d_\tau) \sim 10^{-20}\ e \cdot cm$ [2]
   - CP violation in decays, e.g.: $\tau \to K\pi\nu_\tau$ [3]

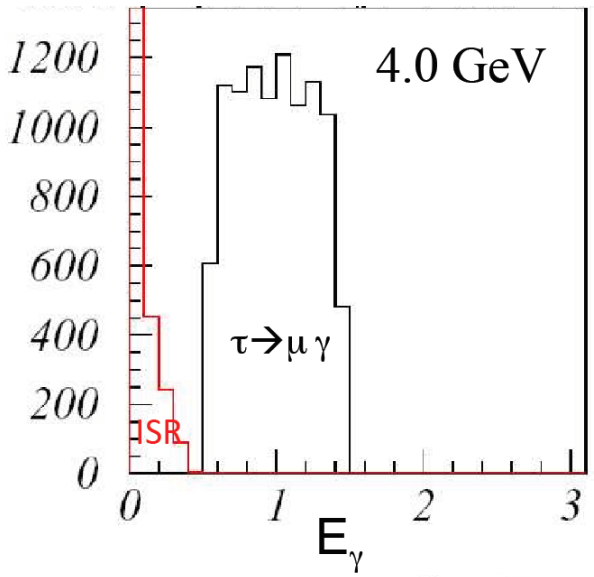


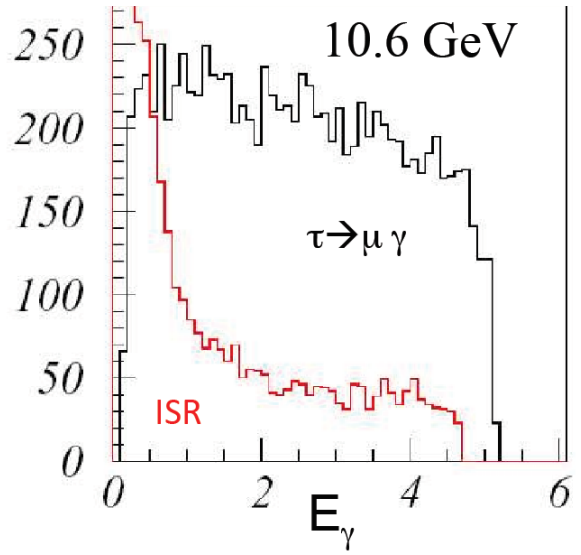
[1] JHEP 2020 (2020) 76
[2] PRD 51 (1995) 5996
[3] PLB 437 (1998) 191

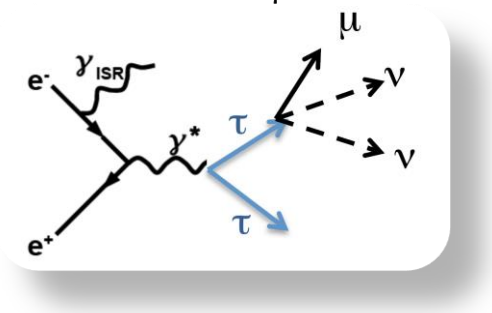
Experiments with τ leptons

- Controlling systematic uncertainties is crucial for τ measurements.
- Threshold kinematics
  - Additional kinematic constraints for τ decays reconstruction
  - Easy background sample (data below threshold)
  - Monochromatic particles from two-body decays
  - Ideal for $\tau \to \mu\gamma$ search
- Precision weak interaction test with polarized τ

ISR photon background for $\tau \to \mu\gamma$: B- vs. $c\tau$-factory
[Bondar, Bobrov (BINP)]



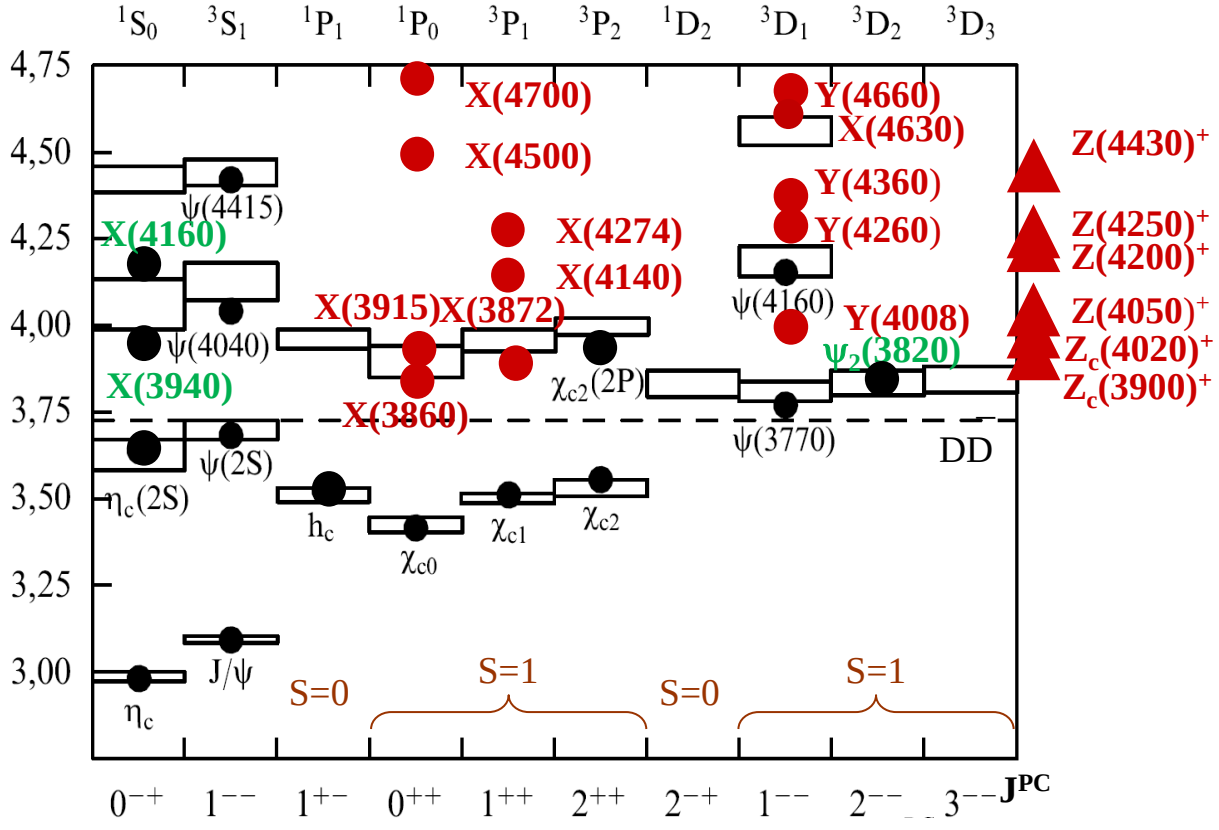




See A. Pich talk [pdf]

From «nuclear chemistry» to nuclear physics of quarkonium

- We have entered the era of «nuclear chemistry»
  - Various hadronic molecular states observed and continue to appear
  - No systematic description yet
- An exciting laboratory for QCD
  - QCD beyond perturbation theory
  - Not a new physics, but new phenomena interesting by themselves
- We should come back to nuclear **physics** at some point



Towards contributing papers

1. SCT physics program is discussed in SCT CDR (last revision - 2018). We are constantly elaborating the physics program. We started several dedicated feasibility studies for the most interesting proposed measurements (some were published)

2. We plan to summarize the SCT physics program in several contributing papers for Snowmass. We would like to prepare these papers as join effort with USTC colleagues (to be discussed). The possible titles are:
   - Review of the physics program of future charm-tau facilities
   - Experiments with polarized beams at the future charm-tau facilities
   - Tau physics at the future charm-tau facilities

Conclusions

1. SCT physics program is broad
   - Synergy with Belle II and LHC*b* experiments
2. SCT project is mature and we are open for collaboration
   - CDR is available [download page]
   - Regular workshops [Novosibirsk 2018, Orsay 2018, Moscow 2019]
   - R&Ds are in progress [Sept. 2020 meeting]
3. Support of the globe scientific community is essential for the internal Russian discussion on the SCT project funding

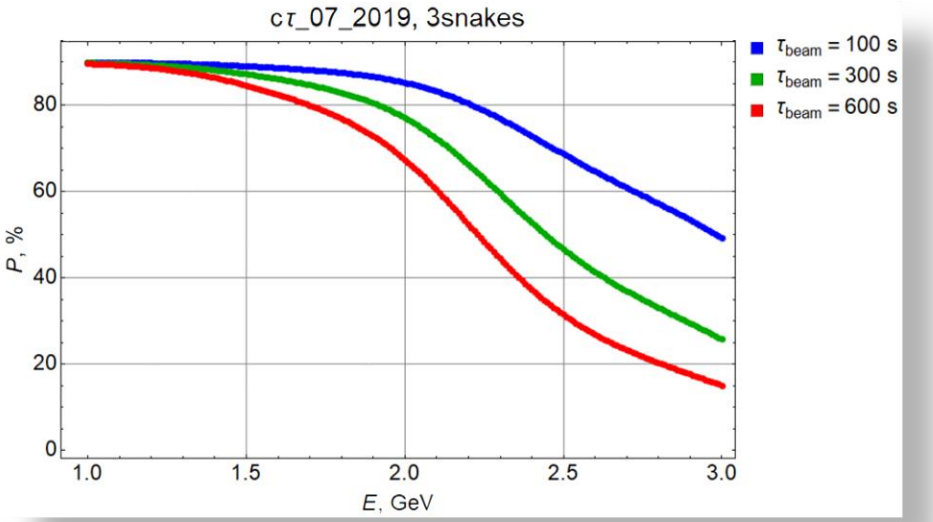
Thank you!

Back-up

SCT Collider parameters

Circumference	478.092 m				
2θ	60 mrad				
β_x^*/β_y^*	50 mm / 0.5 mm				
F_{RF}	349.9 MHz				
E_{beam} (GeV)	**1***	**1**	**1.5**	**2**	**3**
I (A)	1	1	2.2	2.2	2
N_{bunch}	500	500	490	420	290
ε_x (nm)	11.3	16.3	8.8	7	10.9
L_{peak} ($\text{cm}^{-2}\text{s}^{-1} \times 10^{35}$)	**0.21**	**0.14**	**0.8**	**1.3**	**1.1**

Electron beam polarization with 3 Siberian Snakes



* With two $B_w = 3.5$ T wigglers that suppress intrabeam scattering

SCT CDR

More details can be found here: https://c-tau.ru/indico/event/3/contributions/200/

The balance of charm

Experiment setup	Today	Tomorrow	
LHCb	9 fb^{-1} @ Runs 1 and 2	50/300 fb^{-1} @ Run 3/4	x5/30
B factory	1 ab^{-1} @ Belle & BaBar	50 ab^{-1} @ Belle II	x50
c-τ factory	~100 fb^{-1} @ BESIII	~10 ab^{-1} @ SCT	x100

- Each approach has its pros and cons
- There is a delicate balance between the experiments now
- SCT will maintain the balance in future

- Threshold production advantages
  - ✓ Threshold kinematics
  - ✓ Clear initial state
  - ✓ Quantum-correlated $D^0\bar{D}^0$ pairs
  - ✓ Double-tag technique
  - ✓ Low multiplicity (4-5)
  - ✓ Longitudinal beam polarization
  - ✓ Optimal for final states with neutrals
  - ✓ …