The project of the Super Charm-Tau Factory in Novosibirsk

A. Barnyakov for SCTF collaboration

Detection Systems and Techniques in Nuclear and Particle Physics 2019,
Messina (Italy)

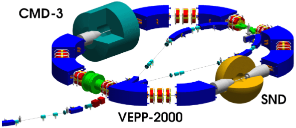
11^{th} of September 2019

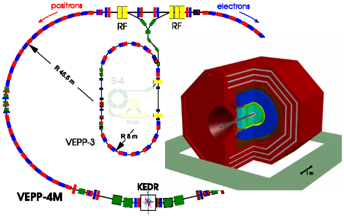
1. Introduction: colliding beam experiments at BINP
2. Physics program for Super CTF project (short overview)
3. SCTF: collider key parameters
4. Detector concept
5. Summary: status of the project

Location of colliding beam experiments

Recently only 6 colliders were under operation in the world.
Two of them are in BINP.
Since 1971 at list one collider is in operation at BINP!

Collider experiments at Budker INP



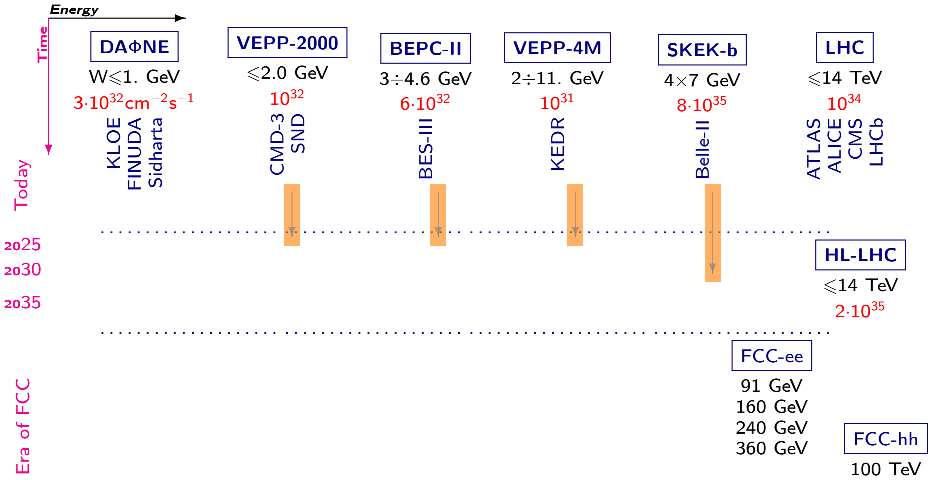


- CMD-3 and SND detectors
- C. m. energy range from 0.3 to 2 GeV
- Round beams
- In operation since 2009

- KEDR detector
- C. m. energy range from 2 to 10 GeV
- Precise energy measurement (res. dep. method)
- Physics program started in 2003

The Super Charm-Tau Factory in Novosibirsk could be the next collider experiment at BINP.

Colliding beam experiments landscape



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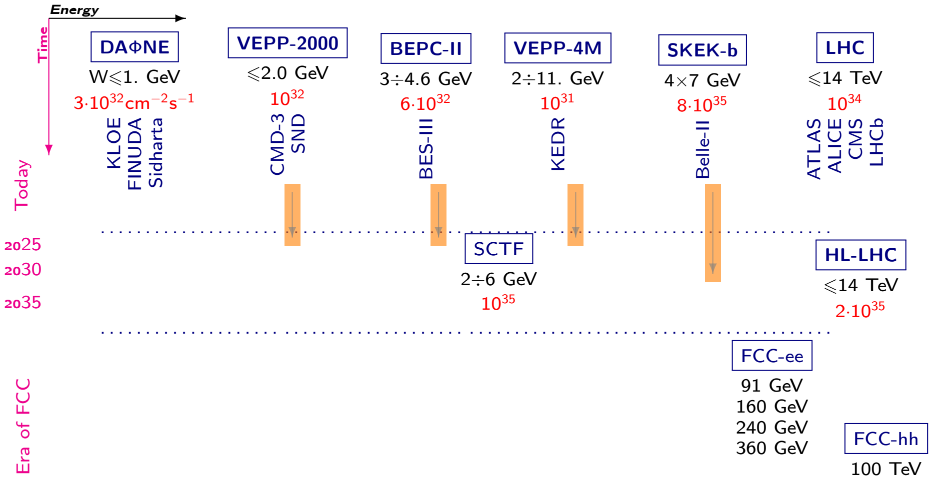
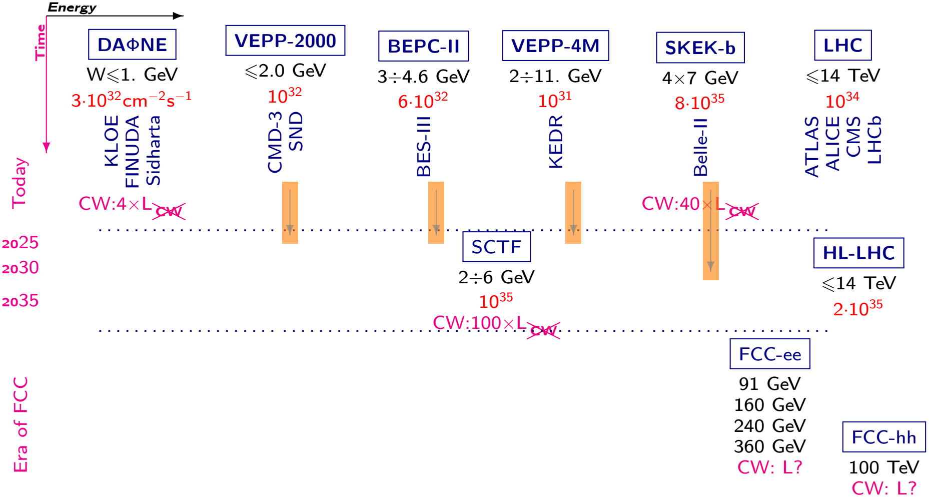


- The NP has not found at the extra large energy domain, precise tests of SM and NP search are very demanded today;
- Physics in the energy W=2÷6 GeV will complement the *B*elle-II and LHC*b* experiments;

Colliding beam experiments landscape



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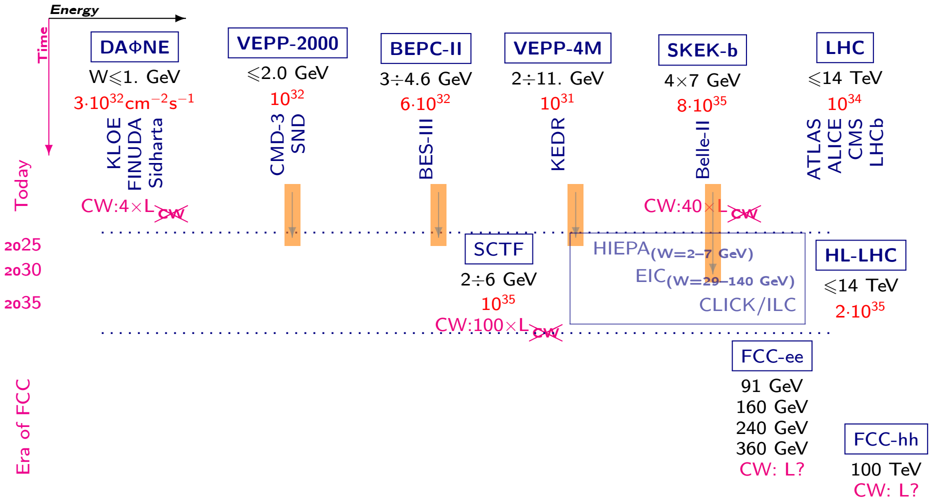
- A new project with incredible high luminosity in the field of energy, which is fruitful by physics processes, will be a good facility to grow a "new generation" of physicists!!!

Colliding beam experiments landscape



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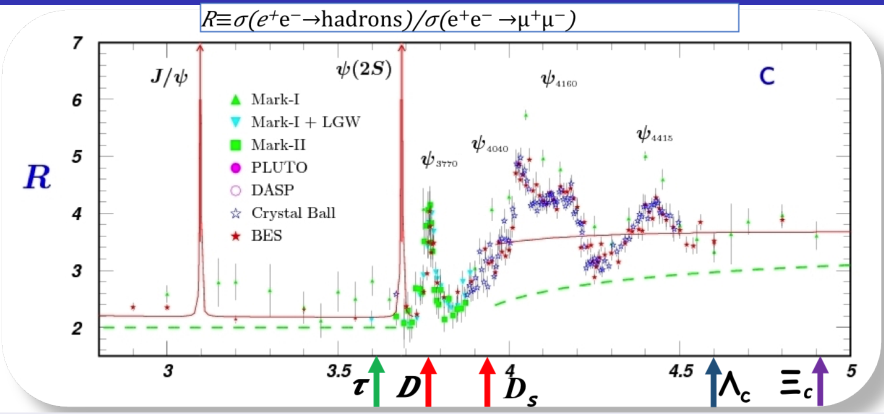
Energy region of SCTF



– The energy range, which cover all charm hadron pair production thresholds and almost untouched regions of Ξ_c and Ω_c could give a lot of physics results with new accuracies.

– Incredible luminosity (100 times better than BES-III has), the sufficient energy resolution ($\sim 1 \div 2$ MeV) and longitudinal beam polarization will help in the searches of New physics!

Physics program

c

- 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/ψ and Ψ' decays.
- ...

- Light hadron states study

τ

- Precise measurements of τ–lepton parameters.
- Michel parameters.

Lepton Universality tests.

- Precise measurements of $\tau \to$ hadrons decays.
- Search for CPTV in τ-decays.
- ...

Physics with polarized beams

- Weinberg angle measurement
- Baryon form-factor measurements
- ...

Expected statistics

Expected integrated $L \approx 1000\ fb^{-1}$

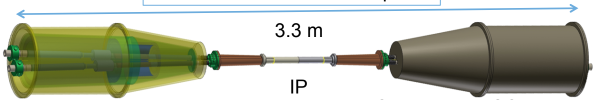
Energy, GeV	L, fb^{-1}	
3.096	300	J/ψ rare decays light hadr. spectroscopy
3.554	50	$e^+e^- \to \tau^+\tau^-$ (threshold)
3.686	150	$\psi(2S)$ J/ψ-spectroscopy light hadr. spectroscopy
3.770	300	$\psi(3770)$ (D-meson study)
4.170	100	$\psi * 4160)$ (D_s-meson study)
4.650	100	$e^+e^- \to \Lambda_c^+\Lambda_c^-$ (maximum)

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

Super Charm-Tau Factory (Accelerator complex)

Super Charm-Tau (CT) Factory is a double ring e+e- collider to be operated in the center-of-mass energy range from 2 to 6 GeV, with peak luminosity of $\approx 1 \div 2 \cdot 10^{35}$ cm^{-2}s^{-1} (Crab Waist collision) and with longitudinally polarized electrons at the IP.

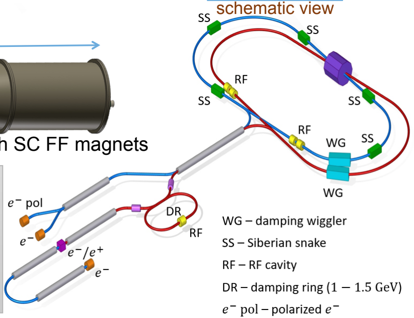
Artistic view of interaction point



Status of accelerator in 2019:

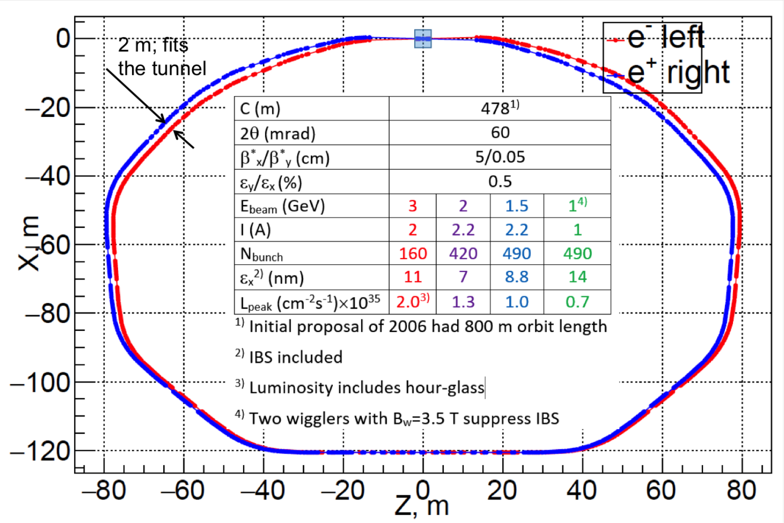
- Max beam energy increased from 2.5 GeV to 3 GeV
- Max peak luminosity at 3 (1) GeV is 2.0 (0.7)×10^{35} cm^{-2}s^{-1}
- Three Siberian Snakes provide longitudinally polarized e-
- Collider conceptual design is completed; no showstoppers are found

Novosibirsk SCTF schematic view



Sketch and key parameters

Collider rings



C (m)	478[1]			
2θ (mrad)	60			
β^*_x/β^*_y (cm)	5/0.05			
$\varepsilon_y/\varepsilon_x$ (%)	0.5			
E_{beam} (GeV)	3	2	1.5	1[4]
I (A)	2	2.2	2.2	1
N_{bunch}	160	420	490	490
ε_x[2] (nm)	11	7	8.8	14
L_{peak} ($cm^{-2}s^{-1}$)$\times10^{35}$	2.0[3]	1.3	1.0	0.7

[1] Initial proposal of 2006 had 800 m orbit length

[2] IBS included

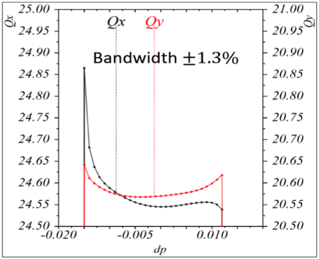
[3] Luminosity includes hour-glass

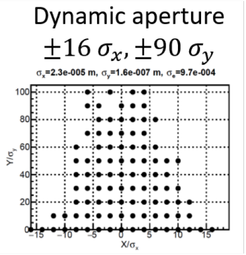
[4] Two wigglers with B_w=3.5 T suppress IBS

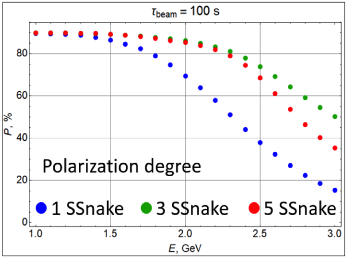
Configuration and parameters

Beam parameters

All essential beam physics issues were considered (optics, nonlinear beam dynamics, longitudinal polarization, IBS, etc.). No showstoppers are revealed.

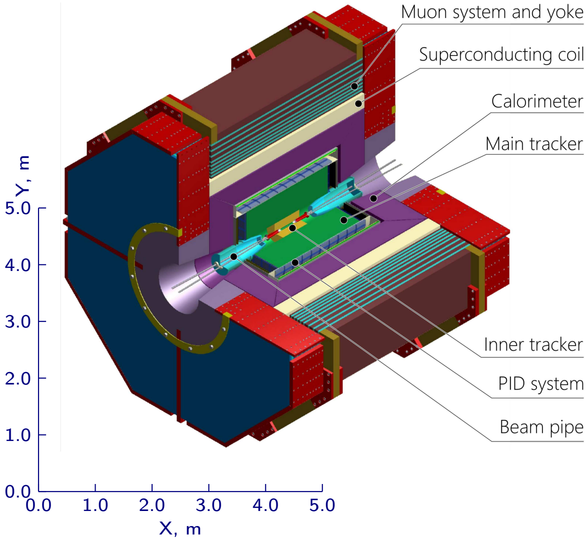






Beam dynamics and polarization

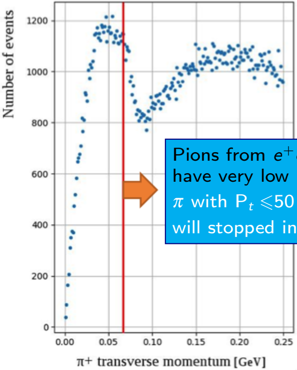
Detector concept and requirements



Physics requirements:

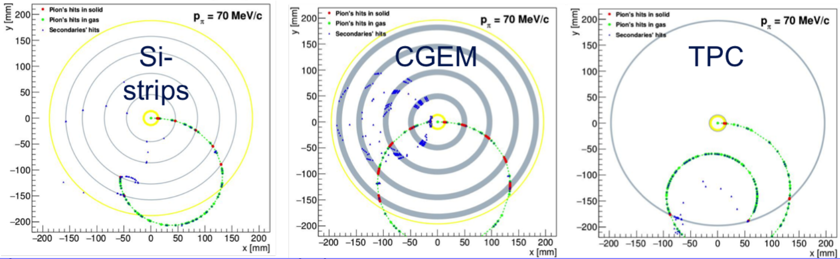
- Good $\frac{\sigma_P}{P}$ for charged particles.
- Good symmetry and hermeticity;
- Soft track detection;
  - Inner tracker to work with rate of charged tracks $\geqslant 10^4 \frac{\textbf{tracks}}{cm^2 \cdot s}$;
- Good $\mu/\pi/K$-sep. up to 1.5 GeV/c;
  - Good $\frac{dE}{dx}$ resolution;
  - Specialized PID system for μ/π and π/K-separation;
- Good π^0/γ-separation and γ detection with E_γ=10÷3000 MeV;
  - EM calorimeter with σ_E as close as possible to physics limit;
  - Fast calorimeter ($\sigma_t \leqslant$1 ns and small shaping time) to suppress beam background and pileup noise;
- DAQ rate ~ 300 kHz at J/ψ-peak.

Inner Tracker



Pions from $e^+e^- \to DD^*$ have very low momenta; π with $P_t \leqslant 50$ MeV/c will stopped in beam-pipe;

- The TPC is more attractive option:
  - More hits per track,
  - more reliable dE/dx – measurements.
- TPC capability to reconstruct the tracks in expected experimental conditions will be checked with full simulation soon.



Drift Chamber

Traditional DC optimization:

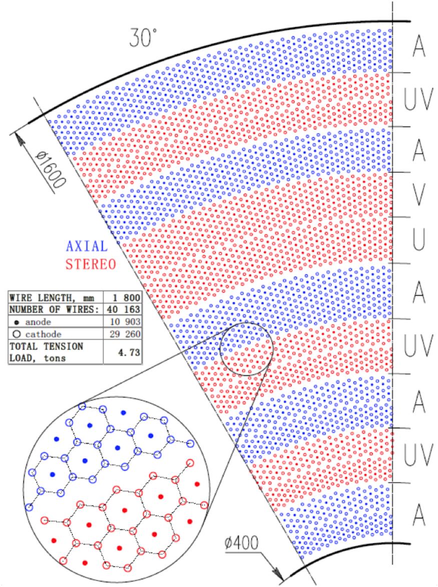
- Hexagonal cell, size ~0.8÷1.2 cm.
- 41 layers: 5 stereo and 5 axial super-layers.
- 10903 – anode wires.
- He/C_3H_8(60%/40%).
- ⋆ $\sigma_x \leqslant 90\ \mu$m.
- ⋆ $\frac{\sigma_P}{P_t}$(1GeV/c) ~0.38%.
- ⋆ $\frac{\sigma_{dE/dx}}{\left\langle \frac{dE}{dx} \right\rangle} \leqslant 7\%$.

Prototyping is going.

Alternative approach:

- Ultra-Low mass DC.
- Full stereo.
- Cluster counting.
- ⋆ $\sigma_{dE/dx}$ in 2 times smaller! π/K-separation at 3σ-level up to 0.9 GeV/c.
- ! More expensive.

Prototyping and beam tests are carrying out in INFN–Lecce.

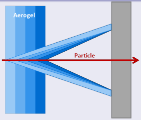


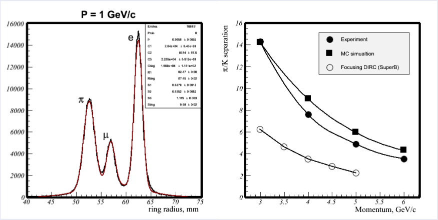
PID system: FARICH

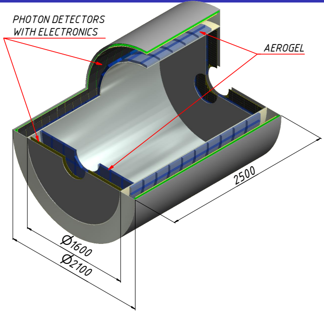
FARICH method

- Increase N_{pe} w/o σ_{Θ_c} increase;
- μ/π-sep.$\sim 5\sigma$ at 1 GeV/c

was obtained in beam tests;







Status & perspectives:

No any showstopers have been found yet, but there are several challenges:

- ! Mass-production of the multilayer focusing aerogel.
- ! 1.5 million of SiPMs and their radiation hardness.
- ! Big data flow in DAQ system.

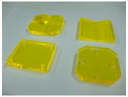
FARICH system parameters:

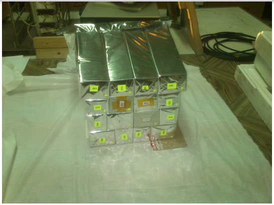
- Focusing aerogel with $n_{\mathbf{max}}$=1.05(1.07?), 4 layers, total thickness 35 mm
- Aerogel area: 14 m^2
- Photon detectors (3×3 mm^2):
  - Barrel – SiPMs (16 m^2)
  - Endcap – MCP PMT (5 m^2)
- $1\div2\cdot10^6$ channels (it depends on pitch)
- Load 0.5÷1.0 MHz/channel
- Cooling system ($\leqslant$-30°C) is needed
- R&D for read out electronics is required.

EMCalorimeter based on pure CsI

CsI(pure):

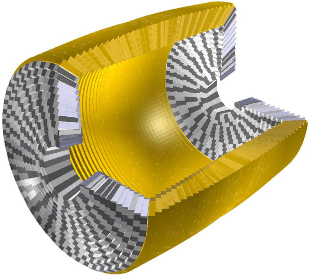
- $\tau \approx 30$ ns.
- Using of WLS(NOL-9) coupled with CsI(pure) crystal($6 \times 6 \times 30$ cm^3) and 4 APDs (Hamamatsu S8664-55) increase LO in 6 times.
- Prototype consisting of 16 crystals, 64 APDs and all necessary readout electronics are ready for beam tests at BINP in 2019.
- ENE=330±30 keV is obtained with cosmic muons.





BINP has a team experienced in constructuion and operation of crystal based calorimeters: SND (NaI), CMD-3 (CsI(Tl) and BGO), KEDR (CsI(Tl)) and Belle-II (CsI(Tl)).

Calorimeter geometry



Described in DD4HEP

CsI(pure) calorimeter for SCTF:

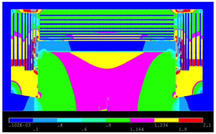
- Thickness $16/18X_0$ – 30/34 cm.
- 7424 crystal, total weight: 36/43 tons.
- 29696 APDs + 7424 WLSs or 7424 Photopentodes.

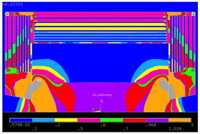
Muon system & Magnet system

Magnet system

Base option:

- B=1÷1.5 T;
- Volume with field ~30 m^3;
- W~28 MJ;
- Access to the detector systems ~12÷24 h.





Thin solenoid option:

- ⋆ B=1÷1.5 T;
- ⋆ Thick ~ 0.1 X_0;
- ⋆ Volume with field ~8 m^3;
- ⋆ W~7.5 MJ;
- ! Impact to σ_E is going to be considered with full detector simulation.

Muon system

Belle-II KLM system as a base option:

There are 9 and 8 gapes in the barrel and end-cap parts of the yoke correspondingly;

Active elements are scintillator strips which readout with help of WLS fibres coupled with SiPM (as Belle-II KLM system);

R&D and Belle-II experience adaptation is carrying out in LPI (Moscow).

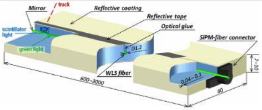


Fig. 1. Schematic view of the scintillator strip. Dimensions are in mm.

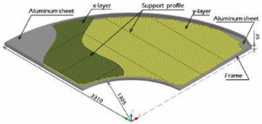
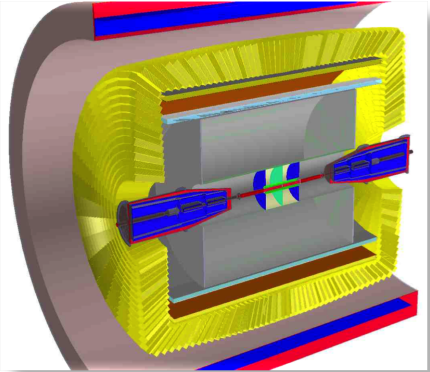


Fig. 2. Schematic view of one superlayer formed by scintillator strips. Sizes are given in mm.

Sketch of active element for Belle-II KLM

Detector software & simulation: status



Detector geometry in DD4HEP

- Parametric simulation is ready to use;
- DD4HEP package is used for detector geometry description;
- Aurora framework is under active developing now. It is based on:
  - Gaudi and FCCSW;
  - build & config system inspired by ATLAS Athena;

SUMMARY

- There is a good base to start the SCTF project in BINP!
  - There are two colliders (VEPP-4M and VEPP-2000) with three detectors (KEDR, CMD-3 and SND) under operation in BINP.
  - Technical documentation for construction of infrastructure objects are ready.
  - Tunnel for Linac and half tunnel for circular accelerator part have already made.
  - The physicist from BINP&NSU are engaged in all HEP colliding beam experiments in the world: KLOE, BES-III, Belle-II, ATLAS, CMS, ALICE, LHCb.
- The physics program of the SCTF project attracts a lot of physicist from all over the world:
  - NSU, LPI, INP, JINR, TSU, IHEP (Russia), . . . ;
  - CERN, KEK (Japan), INFN (Italy), GSI, Gissen Univ. (Germany), IHEP, USTC, UCAS (China), LAL (France), . . .
- Precise measurements and search for "New Physics" in easy achievable and fruitful energy region, which cover all charm hadron pair production thresholds and almost untouched regions of Ξ_c and Ω_c have to be done before start of FCC construction.

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- Three international Workshops on the project were held during previous two years (2017–2018);

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- Next round of Russian government consideration of this Mega-Science project is going to be held in fall of 2019;
- Three international Workshops on the project were held during previous two years (2017–2018);
- Join now to make sure that detector and the machine to be optimized for the physics you like!

See you in Moscow 24–27 September 2019 (https://c-tau.ru/)!

BACK UP

Longitudinal beam polarization and some Physics cases

"New Physics" search

- CPV in $\tau \to$ hadrons decays. (sufficient decrease of systematic uncertainties is expected)
- Michel parameters measurements with τ-lepton decay. ($\sim$1.6 times better accuracy for ρ and η than Belle-II experiment expectation)
- Weinberg angle measurements by spin asymmetry in $e^+e^- \to J/\psi$ production. (only with polarized beams)
- LFV: search for $\tau \to \mu\gamma$ decay. (some background suppression is expected)

Other polarized beam application at SCTF project

- All non-zero spin states can be studied with new systematic uncertainties.
- Baryon (Λ, Λ_c, Ω_c, Ξ_c, ...) FF measurements.
- ...

Quantitative analysis of the polarized beams advantages over non-polarized is now undergoing for these and other cases[1].

[1] The detailed discussion will be held at SCTF Workshop in Moscow 24-27/09/2019 (see `https://c-tau.ru`)

Physics program

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

Very demanded for NP search in B-meson decays

c

τ

QCD

- Strong excited quarkonium physics.
- Molecular states.
- Threshold baryon interactions.
- Search for glueballs in J/ψ and Ψ' decays.
- ...

- Precise measurements of τ–lepton parameters.
- Michel parameters.

Lepton Universality tests.

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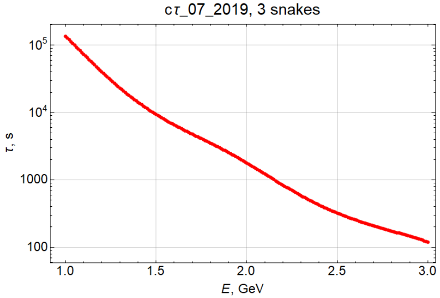
- ...

SM test in E-W sector

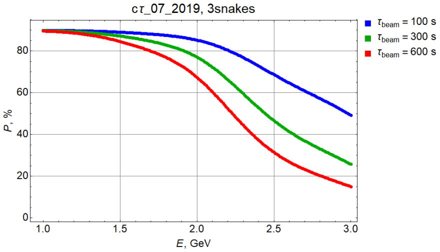
$\sim$1.6 times better accuracy than at Belle-II due to beam polarization (P=80%)

QCD, α_S, V_{us}, search for E-W model deviation

Beam polarization parameters

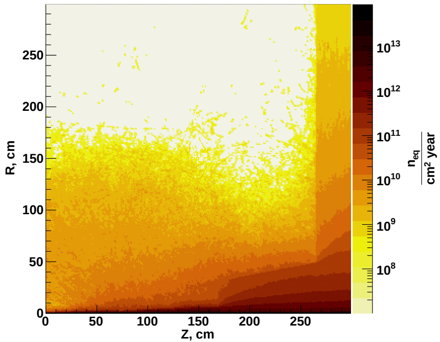


Dependence of polarization life-time on energy

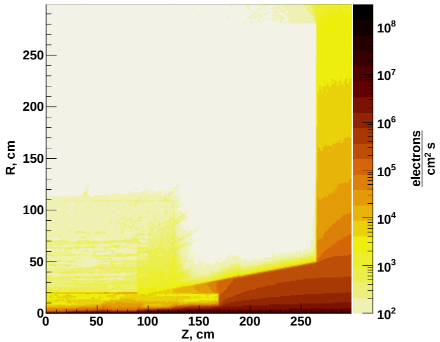


Dependence of beam polarization degree on energy for different time of beam doping

Physics background



1 MeV equivalent neutron dose for silicon



Electrons flux per second

First simulation of Physics background

Two major processes were taken into account:
- radiative BhaBha scattering ($\sigma \approx 1.7$ mb for $2E = 7$ GeV and $\Theta \geqslant 5^{\circ}$);
- two photon $e^{+}e^{-}$ production ($\sigma \approx 6.0$ mb for $2E = 7$ GeV).

Implement beam background at IP:
- IBS? (touschek scattering);
- SR (synchrotron radiation).