Overview of PID options for experiments at the Super-Charm-Tau-Factory (SCFT)

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Schloss Rauischholzhausen (Germany)

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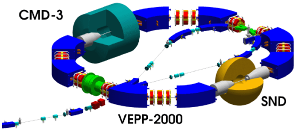
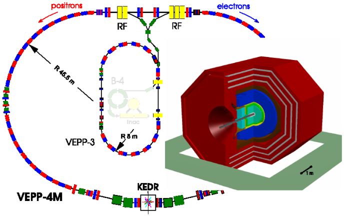
1. **Introduction: colliding beam experiments at BINP**
2. **Physics program for Super CTF project (short overview)**
3. **SCTF: collider key parameters**
4. **Detector concept**
5. **PID system options: FARICH, DIRC, ASHIPH, ToF+ToP**
6. **Summary**

Collider experiments at Budker INP





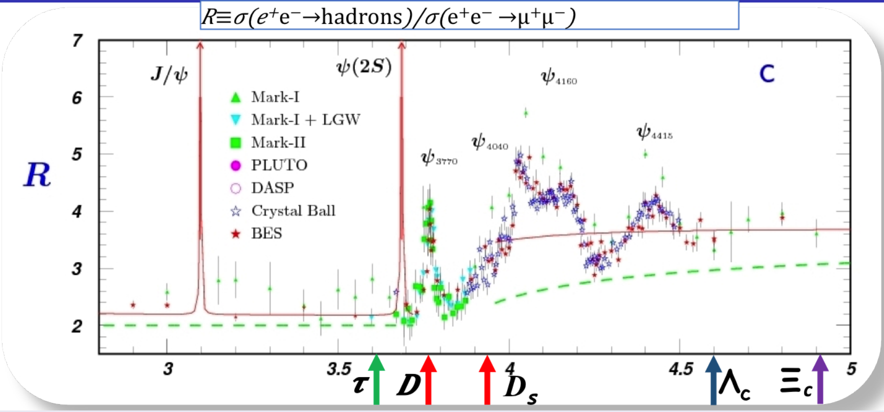
- CMD-3 and SND detectors
- C. m. energy range from 0.3 to 2 GeV
- Round beams
- In operation since 2009

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

Since 1971 at list one collider is in operation at BINP!

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

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÷2 MeV) and longitudinal beam polarization will help in the searches of New physics!

Physics program

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

C

τ

QCD

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

- Light hadron states study

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

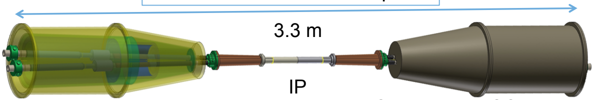
Energy, GeV	L, fb^{-1}	
3.096	300	J/ψ rare decays light hadr. spectroscopy
3.554	50	$e^+e^- \to \tau^+\tau^-$ (threshold)
3.686	150	$\psi(2S)$ J/ψ-spectroscopy light hadr. spectroscopy
3.770	300	$\psi(3770)$ (D-meson study)
4.170	100	$\psi * 4160)$ (D_s-meson study)
4.650	100	$e^+e^- \to \Lambda_c^+\Lambda_c^-$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

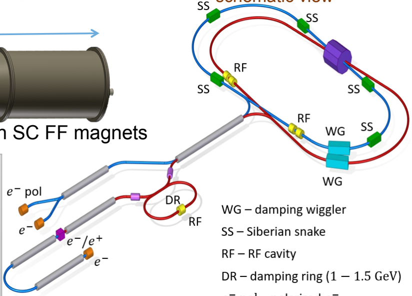
Artistic view of interaction point



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

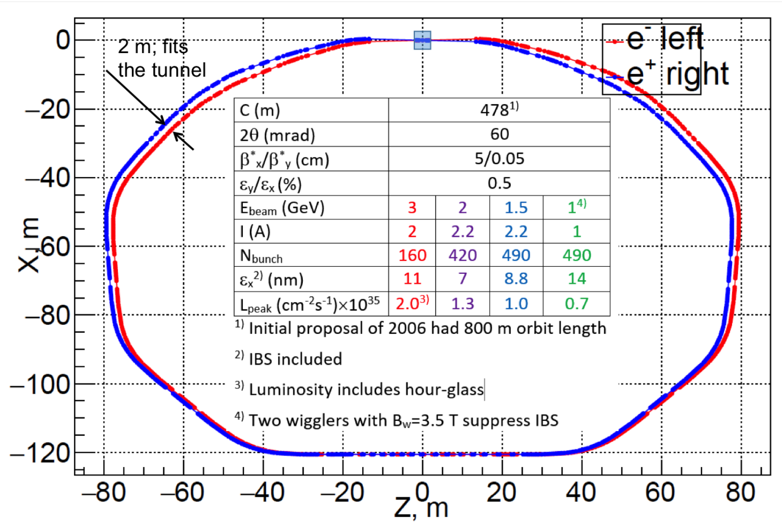
Novosibirsk SCTF schematic view



WG – damping wiggler
SS – Siberian snake
RF – RF cavity
DR – damping ring (1 — 1.5 GeV)
e^- pol – polarized e^-

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} $(cm^{-2}s^{-1})\times 10^{35}$	2.0[3]	1.3	1.0	0.7

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

[2] IBS included

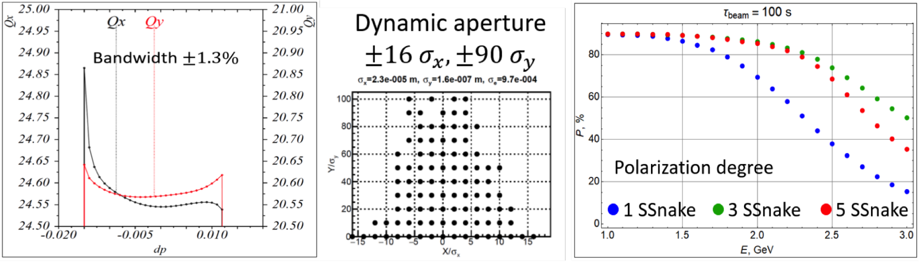
[3] Luminosity includes hour-glass

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

Configuration and parameters

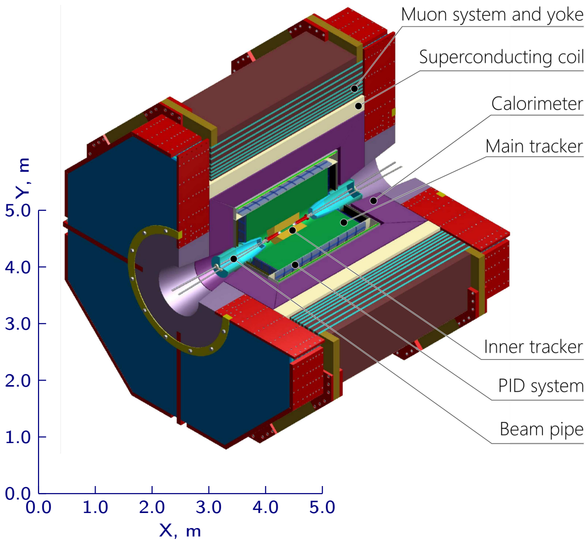
Beam parameters

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:

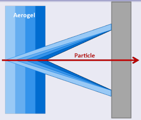
- Good $\frac{\sigma_P}{P}$ for charged particles.
- Good symmetry and hermeticity;
- Soft track detection;
  - Inner tracker to work with rate of charged tracks $\geqslant 10^4 \frac{\textbf{tracks}}{cm^2 \cdot s}$;
- Good $\mu/\pi/K$-sep. up to 1.5 GeV/c;
  - Good $\frac{dE}{dx}$ resolution;
  - Specialized 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 $\sim$ 300 kHz at J/ψ-peak.

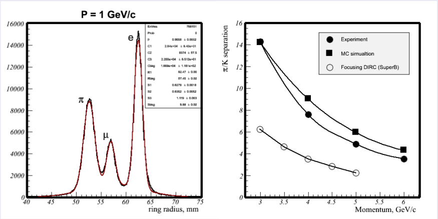
PID system: FARICH

FARICH method

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

was obtained in beam tests;

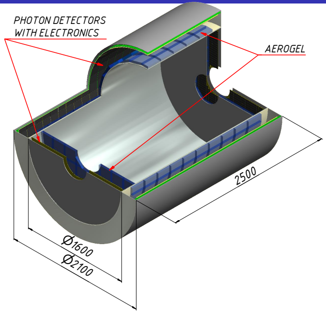




Status & perspectives:

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.

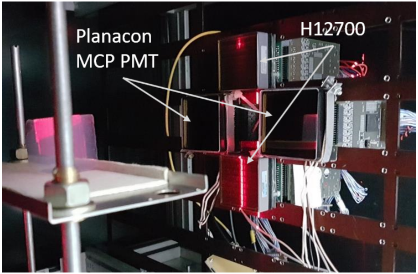


FARICH system parameters:

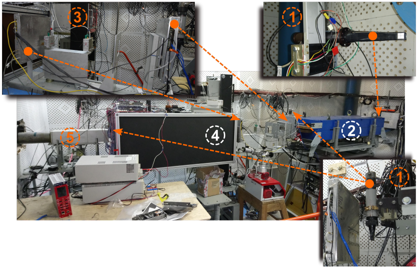
- Focusing aerogel with $n_{\mathbf{max}}$=1.05(1.07?), 4 layers, total thickness 35 mm
- Aerogel area: 14 m^2
- Photon detectors (3×3 mm^2):
  - Barrel – SiPMs (16 m^2)
  - Endcap – MCP PMT (5 m^2) LAPPD?
- 1÷2·10^6 channels (it depends on pitch)
- Load 0.5÷1.0 MHz/channel
- Cooling system ($\leqslant$-30°C) is needed
- R&D for read out electronics is required.

2018: 3rd prototype generation

- Determine critical moments in focusing aerogel production;
- Define optimal photon detector type and producer for SCTF;
- Find solution for readout electronics.



Photon detectors plane



MaPMTs 8×8 pixels □6 mm

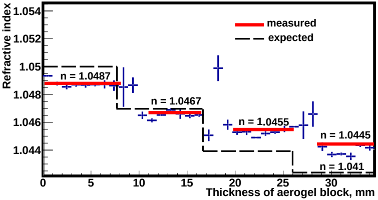
SiPM arrays 4×4 pixels □3 mm;

Tracker based on GEMs $\sigma_x \sim 70\mu$m;

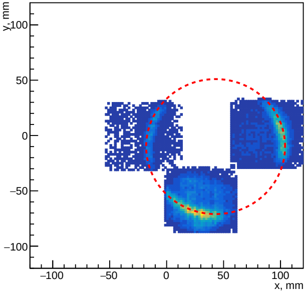
Readout electronics based on PaDiWa (discriminator) and TRB3 (TDC) from GSI.

- e^- with E=3 GeV;
- Only central tracks are selected (20x16 mm area);
- Time window $\sim$ 25 ns;
- Cut on energy deposited in NaI is aplied;

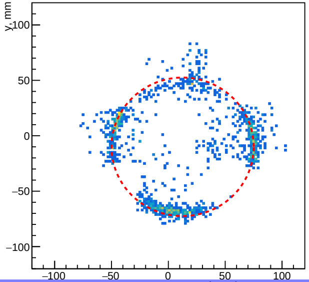
2018: Results of test beam



Refractive index: measured and expected.



Cherenkov rings: □6 mm (↑) and ø1 mm (↓).



Main results:

- Measurements and MC simulation are in good agreements.
- Measured resolution:
  $\sigma_R^{\mathbf{1ph}}(\square 6)$=2.9 mm → $\sigma\Theta_{\mathbf{Ch}}^{\mathbf{1ph}}$ ~14.5 mrad;
  $\sigma_R^{\mathbf{1ph}}(ø1)$=1.9 mm → $\sigma\Theta_{\mathbf{Ch}}^{\mathbf{1ph}}$ ~9.5 mrad;
- Expected for ideal 4-layer aerogel:
  $\sigma_R(\square 6)$=2.0 mm → $\sigma\Theta_{\mathbf{Ch}}^{\mathbf{1ph}}$ ~10.0 mrad;
  $\sigma_R(ø1)$=1.07 mm → $\sigma\Theta_{\mathbf{Ch}}^{\mathbf{1ph}}$ ~5.4 mrad.
- We need to improve aerogel to get better Cherenkov angle resolution

Alternative PID options

Why we need to find alternatives to FARICH

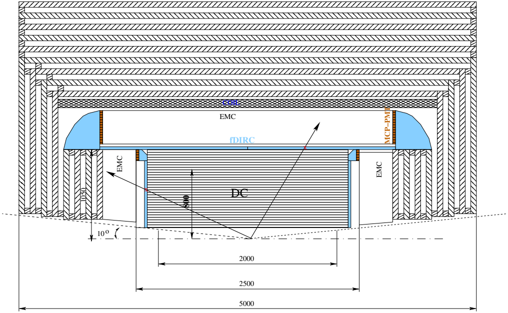
- μ/π-separation below 400 MeV/c;
- The aerogel RICH with largest radiator area. $\rightarrow$ Multilayer aerogel production is very challenge issue!
- 16 m^2 of SiPMs with 10^6 pixels:
  - Radiation hardness and cooling system which lead to increase material budget before EMC is a complex engineering task;
  - Such amount of the SiPMs with appropriate parameters is a rather large batch for one manufacturer (Hamamatsu, FBK, KETEK, SensL?!).
- 5 m^2 of MCP-PMTs. The very good approach is to use LAPPD with 20$\times$20 cm^2 size, but readout system should be optimized for our task to obtain the spatial resolution $\leqslant$1 mm in both directions.
- The total estimated coast of the FARICH system $\approx$ EMC of the detector.

DIRC option

The detailed consideration will be presented in next topic of M.Schmidt!

Few comments to DIRC option

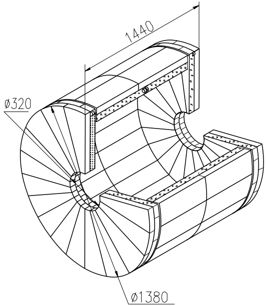
- Sufficient change of yoke geometry and calorimeter is needed.
- DIRC is very compact system in barrel part, therefore it is possible to increase DC or decrease the EMC volume.
- Good enough μ/π-separation is provided up to 700 MeV/c $\rightarrow$ we need to use something else to separate μ and π up to 1.2 GeV/c.



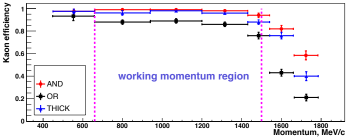
Schematic location of the DIRCs.

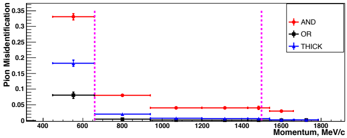
ASHIPH systems at BINP

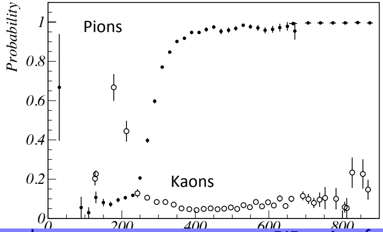
Aerogel Cherenkov ASHIPH counters



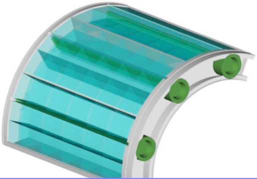
KEDR:
- 160 counters (2 layers)
- n=1.05 (1000l)
- WLS (BBQ)
- MCP PMT øPC=18 mm
- 0.97x4π
- 24% X_0







SND:
- 9 counters (1 layer)
- n=1.13 (9l)
- WLS (BBQ)
- Thickness ~ 30 mm
- MCP PMT øPC=18 mm
- 0.6x4π



ASHIPH with SiPM

MCP PMT → SiPM

Pros:

	MCP PMT	SiPM
PDE=QE*CE	25*0.6≈15%	30-45%
Magnetic field imm.	Axial	Any direction
Power supply	2÷4 kV	<100V

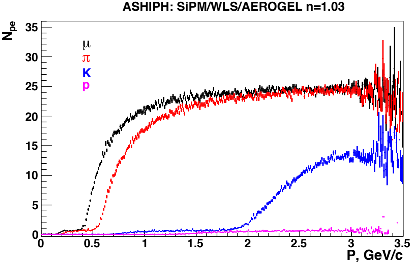
Cons:

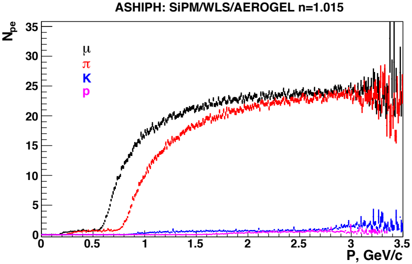
- High level of noise → New specific FEE → Cooling system
- Radiation tolerance is still low.

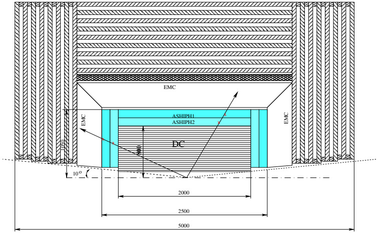
It is possible to upgrade KEDR and SND ASHIPH systems right now.

For Super Cτ (B)- Factories SiPM radiation tolerance study is needed.

ASHIP with SiPM for μ/π-separation







ASHIPH with SiPM

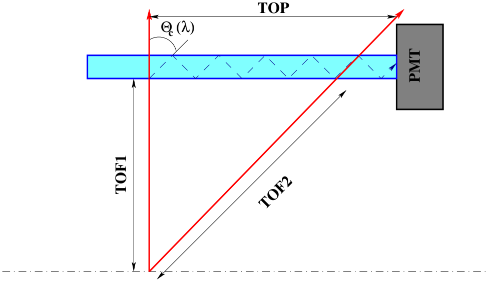
- π/K-separation from 500 to 2000 MeV/c
- μ/π-separation from 400 to 900 MeV/c
- Preliminary design:
  - 6000 l of aerogel in three layers: n=1.03 (8 cm) and n=1.015 (8+8 cm)
  - 1400 counter with sizes $\sim$ 18$\times$30$\times$8 cm
  - Amount of material $\sim$ 15%X_0
  - Light collection – WLS(BBQ) and 28000 SiPMs 3$\times$3 mm^2

ToF + ToP

• The record time resolution (∼5 ps) was obtained with quartz radiator coupled to MCP PMT.
• The best accuracy of TOF measurement achieved in currently operating colliding beam experiment is about 80 ps (BESIII).
• The time resolution of about 30 ps is considered for future upgrade of the CMS detector.
• The time resolution of about 15 ps is the aim of TORCH project — a time-of-flight detector.
• Recent progress in time-of-flight technique allows us to consider the TOF system with intrinsic time resolution better than 30 ps.
Time resolution mainly is determined by:

- refractive index dispersion
- time of light collection
- photon detector & electronics jitter

It is possible to use TOP information in addition to TOF.



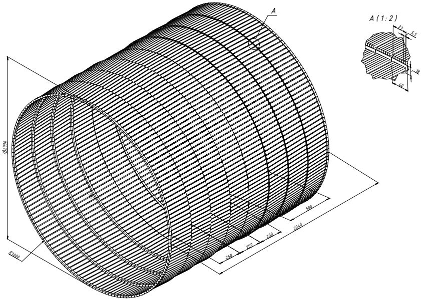
TOF & TOP

For perpendicular tracks with $\beta \geqslant \frac{1}{\sqrt{n(\lambda)^2-1}}$

$$\mathrm{TOP} \sim \frac{L}{c/n(\lambda)} \cdot \frac{\beta \cdot n(\lambda)}{\sqrt{n(\lambda)^2\beta^2-1}} = \frac{L}{c} \cdot \frac{n(\lambda)^2\beta}{\sqrt{n(\lambda)^2\beta^2-1}}$$

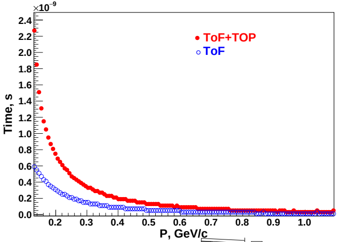
Time of Propagation (ToP) can improve the Time of Flight (ToF).

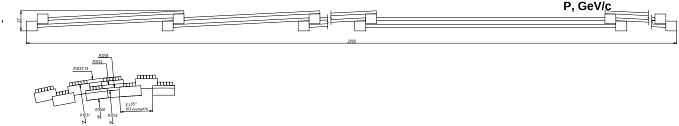
ToF+ToP option for SCTF barrel part



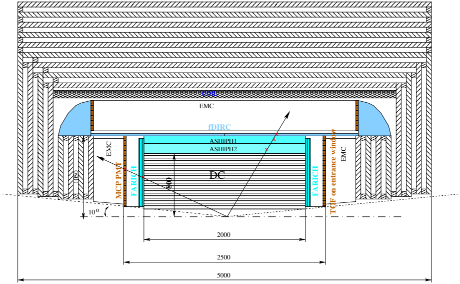
Main parameters

- π/K-separation from up to 2500 MeV/c
- μ/π-separation from 250 to 500 MeV/c
- Preliminary design:
  - Quartz bars 5×5×250÷500 mm – 10000 pcs
  - 1648 – MCP PMTs ∼40×20 mm with 12 anodes
  - Amount of material ∼ 7%X_0

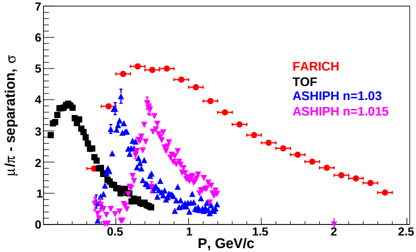




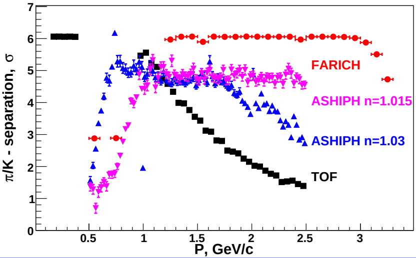
Different options for PID comparison



Combination of PID options



Particle separation power parametric simulated

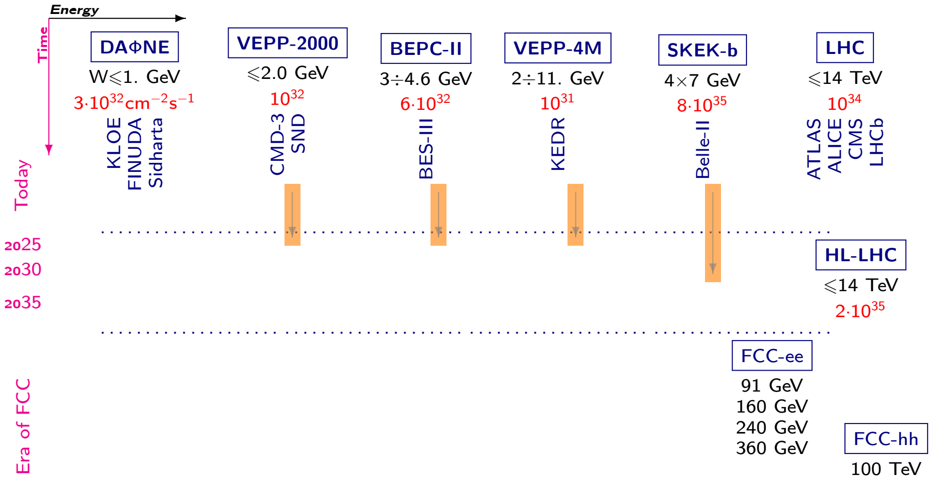


SUMMARY

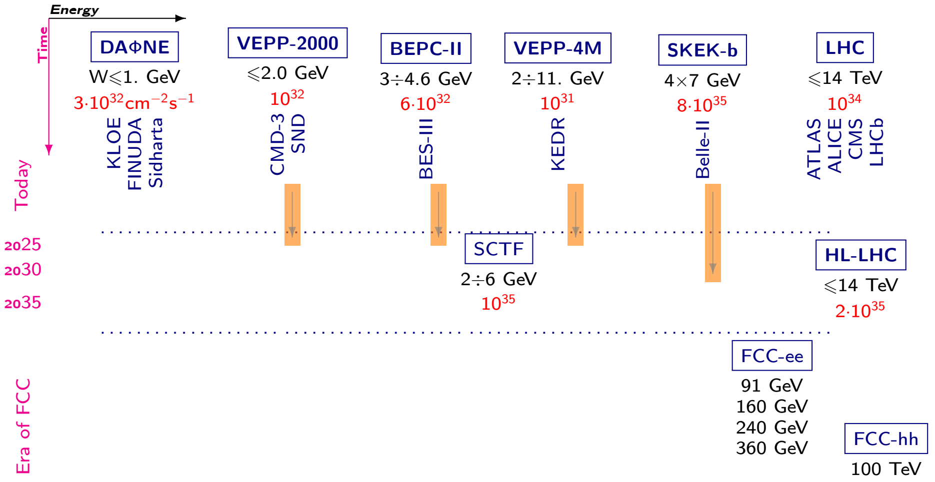
- The SCTF project in Novosibirsk is going now:
  - Next round of Russian government consideration of this Mega-Science project is going to be held in fall of 2019;
  - Three international Workshops on the project were held during previous two years (2017–2018) and the next one will be held in Moscow 24–27 September 2019 (https://c-tau.ru/)
  - Financial support for detector R&D from CREMLIN+ PROJECT have been obtained for 2020-2024.
- PID system is a key system for successful realization of physics program. All the best approaches should be considered and compared with help of parametric simulation for several physics processes:
  - FARICH;
  - fDIRC (will be soon implemented in ParSim of SCTF);
  - ASHIPH based on SiPMs;
  - ToF and ToF+ToP;
  - Combination of the several approaches.

BACK UP

Colliding beam experiments landscape

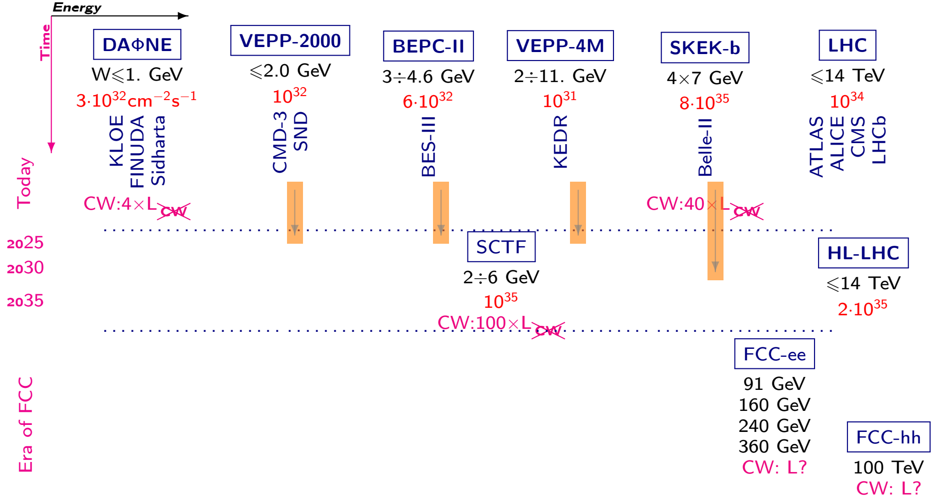


Colliding beam experiments landscape



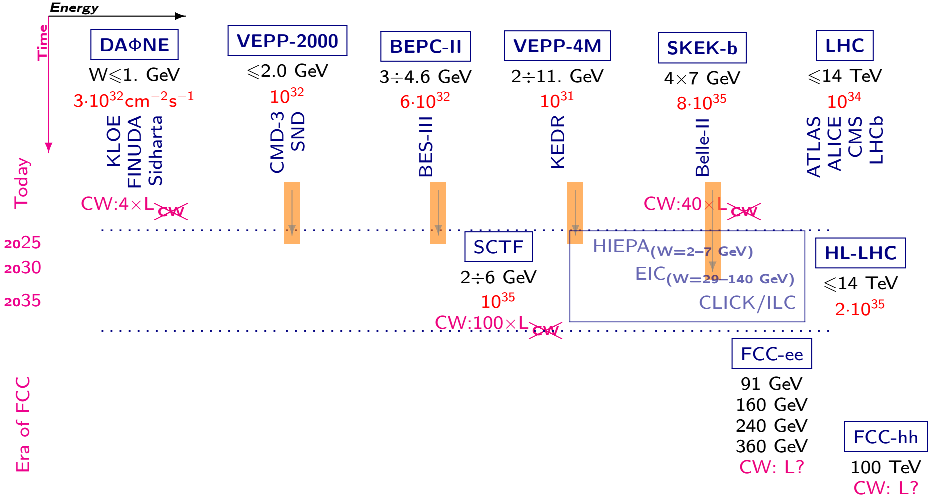
- The NP has not found at the extra large energy domain, precise tests of SM and NP search are very demanded today;
- Physics in the energy $W=2\div6$ GeV will complement the *B*elle-II and LHC*b* experiments;

Colliding beam experiments landscape



- 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;
- 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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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

QCD

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

τ

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

Lepton Universality tests.

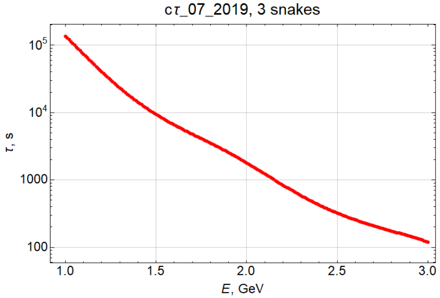
- Precise measurements of $\tau \to$ hadrons decays.
- Search for CPTV in τ-decays.
- ...

SM test in E-W sector

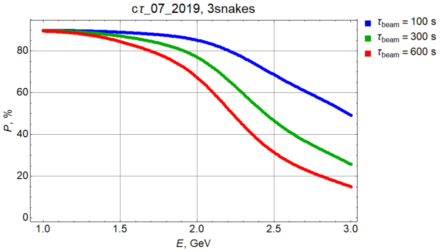
$\sim$1.6 times better accuracy than at Belle-II due to beam polarization (P=80%)

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

Beam polarization parameters

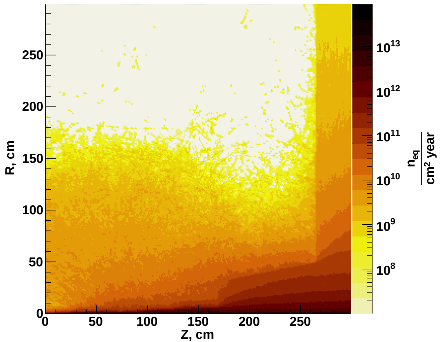


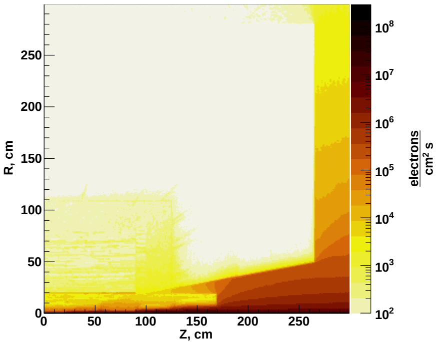
Dependence of polarization life-time on energy



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).