The SCT factory project

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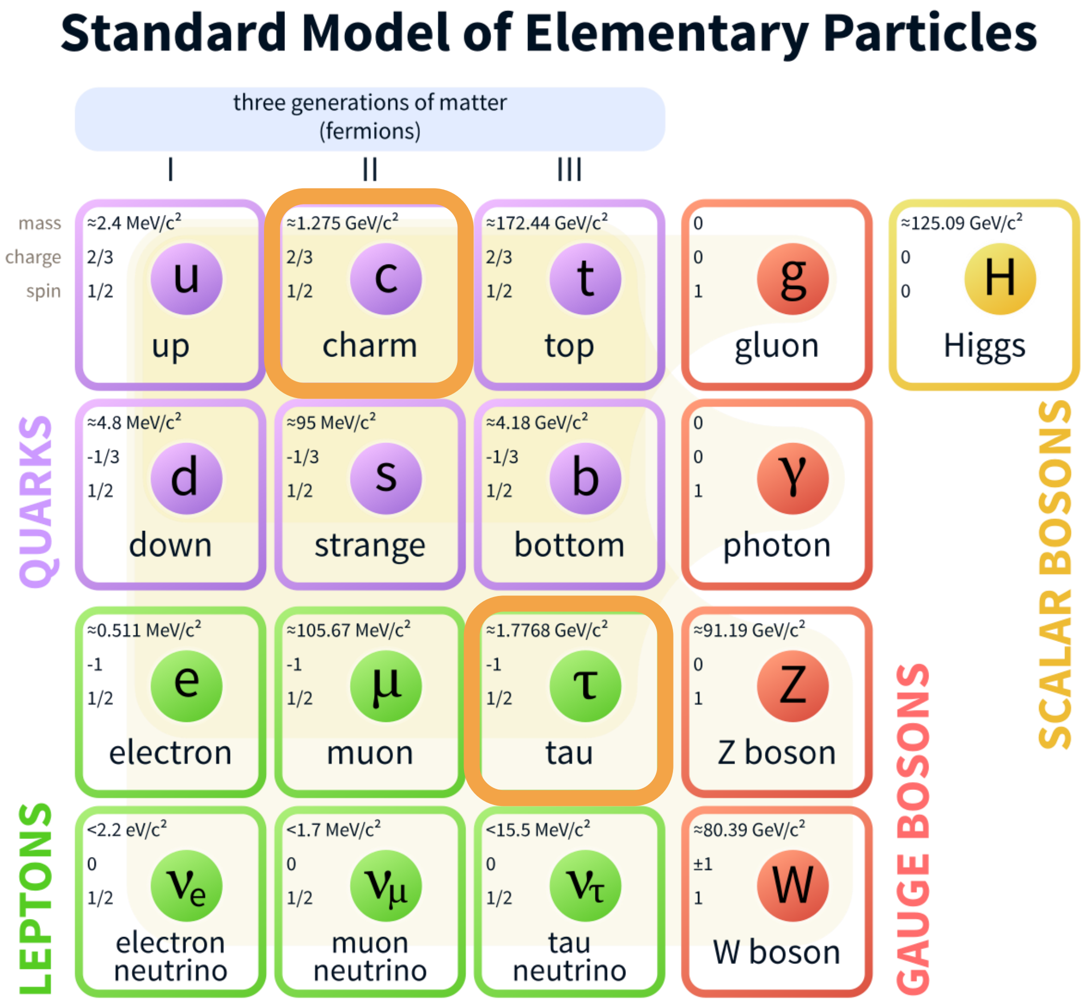
BINP, NSU

«BINP – IHEP meeting»

December 16th, 2019, BINP, Novosibirsk

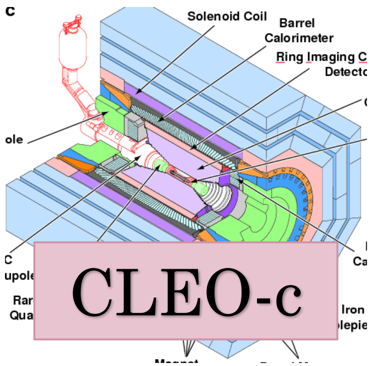
Charm quark and tau lepton

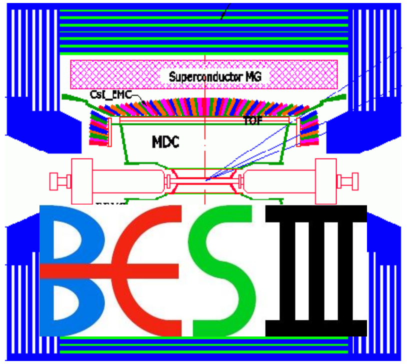
- Charm quark
  - The only heavy up-quark forming hadron systems
  - Open charm
    - Mesons: $D^{0,+}(c\bar{q})$ with $q \in \{u, d\}$, $D_s(c\bar{s})$
    - Baryons: $\Lambda_c^+(udc)$, $\Xi_c^+(usc)$, …
  - Hidden charm
    - Charmonia: η_c, J/ψ, …
    - Charmonium-like states: X, Y, Z
    - Pentaquarks $P_c(4450)^+$ and $P_c(4380)^+$ [Phys. Rev. Lett. 115 (2015) 072001]
- Tau lepton
  - Heaviest lepton
  - Tens of decay channels
  - The only lepton decaying into hadrons



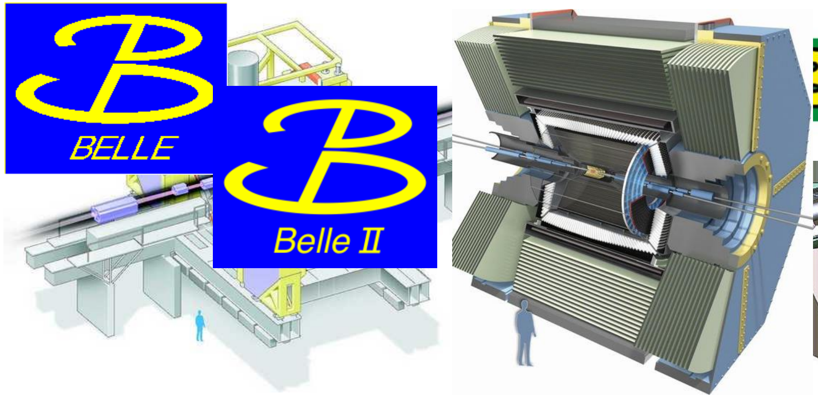
Colliders for charm (and tau)

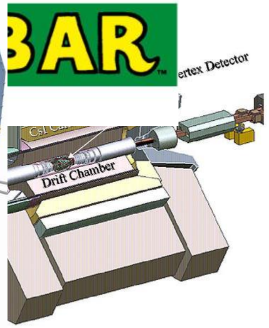
Threshold production



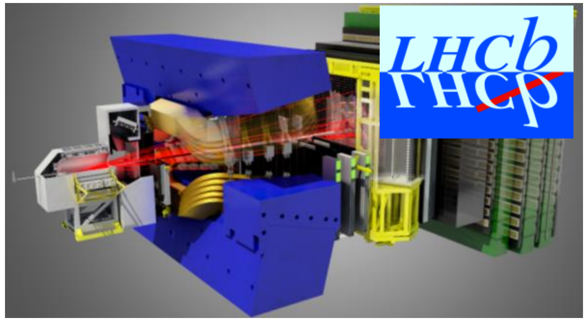


Asymmetric e^+e^- @ $\Upsilon(4S)$





Proton collisions



Q: Do we need a new generation threshold experiment?

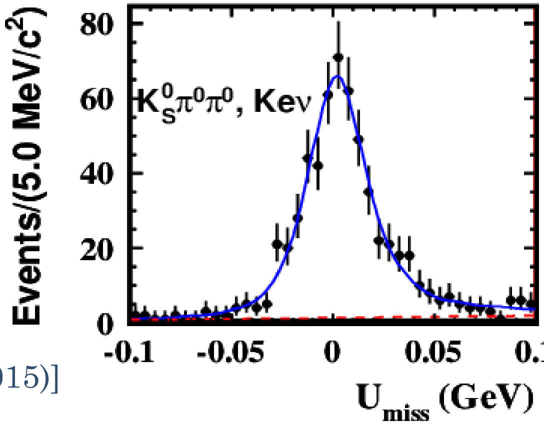
A: Yes.

The balance of charm

Experiment setup	Today	Tomorrow	
LHC*b*	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 experimental approach has its pros and cons
- There is a delicate balance between the experiments
- SCT will maintain the balance in future

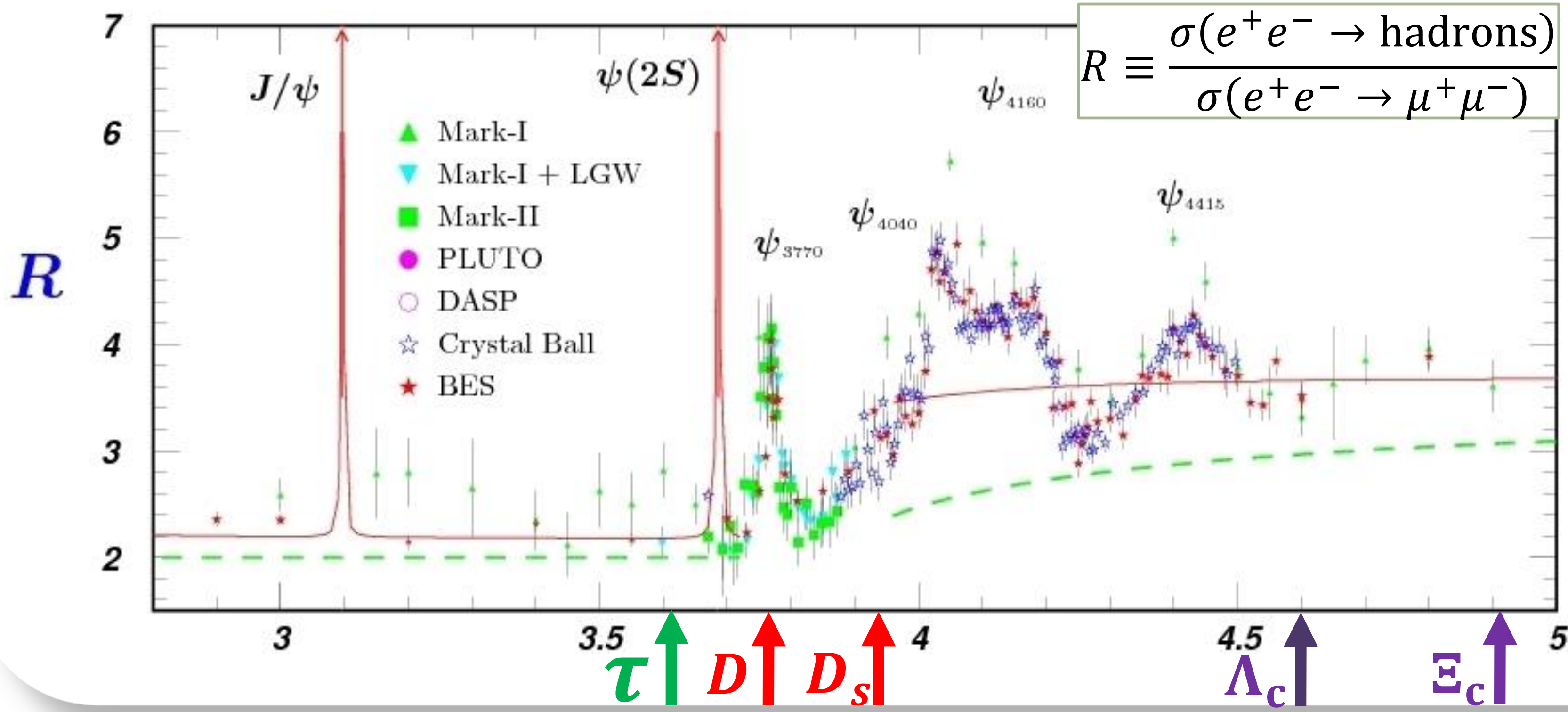
- Advantages of threshold production
  - ✓ Threshold kinematics
  - ✓ Well-determined initial state
  - ✓ Quantum-correlated $D^0\overline{D}^0$ pairs
  - ✓ Double-tag technique
  - ✓ Low multiplicity (4-5)
  - ✓ Longitudinal beam polarization
  - ✓ Optimal for final states with neutrals
  - ✓ …



[BESIII, Phys. Lett. B744, 339 (2015)]

SCT energy range

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



$$R \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

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

Annual yields

$2E$, GeV	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 ÷ 4.3	$10^{10}\ \tau\ \tau$
4.65	$10^{8}\ \Lambda_c^+\Lambda_c^-$

V. Vorobyev for BINP-IHEP meeting, December 16th 2019

Physics program


ФАНО России
Федеральное государственное бюджетное учреждение науки
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ имени Г.И. Будкера
Сибирского отделения Российской академии наук
(ИЯФ СО РАН)

Супер Чарм – Тау фабрика

КОНЦЕПТУАЛЬНЫЙ ПРОЕКТ
ЧАСТЬ ПЕРВАЯ
(физическая программа, детектор)

Новосибирск – 2017

ctd.inp.nsk.su

charm

Input for B meson studies at LHCb and Belle II

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

QCD

- ✓ Physics of highly-excited quarkonium
- ✓ Molecular states
- ✓ Baryon interaction at threshold
- ✓ Search for glueballs in decays of J/ψ and ψ'
- ✓ …

tau

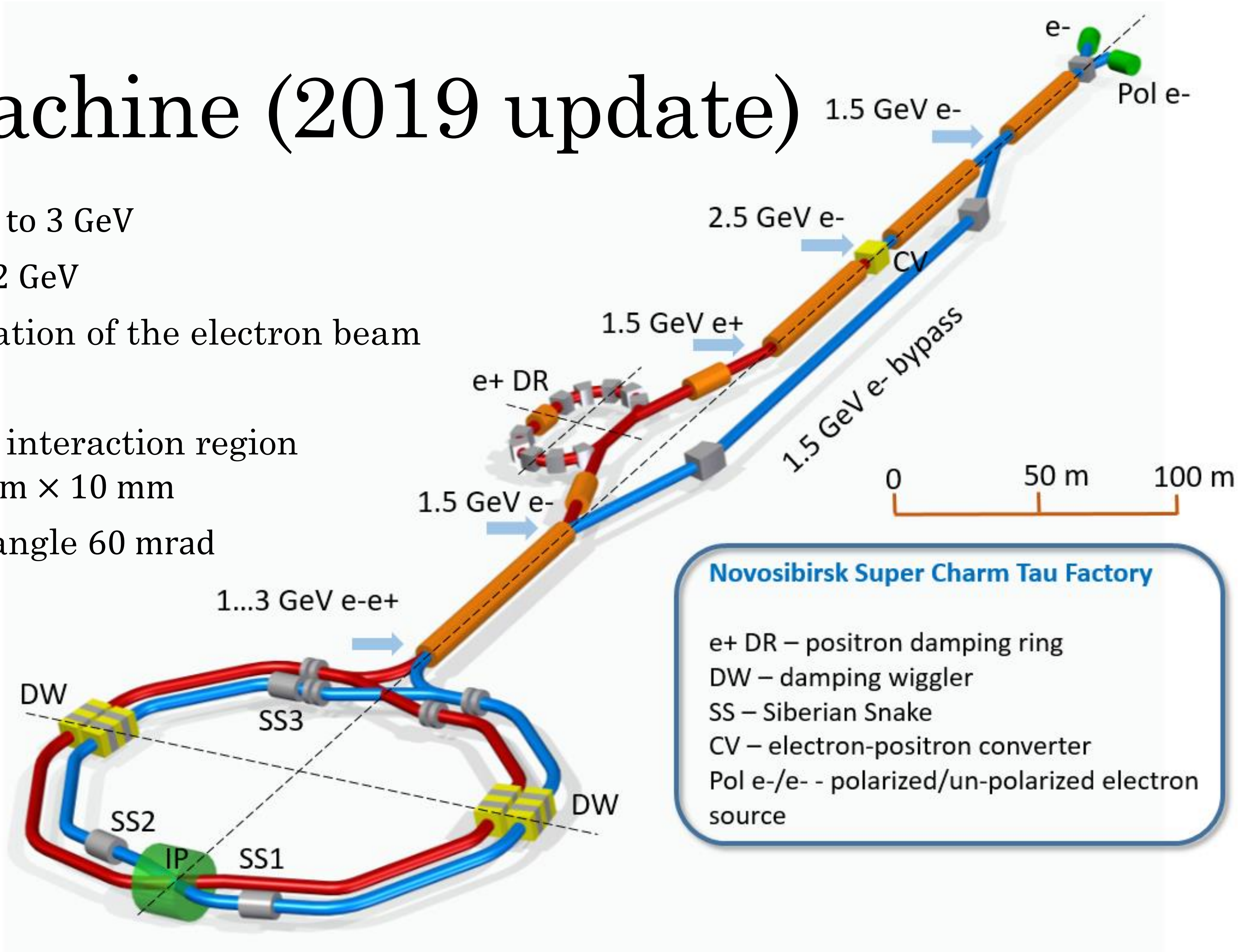
- ✓ Precision measurement of the τ lepton properties
- ✓ Michael parameters, tests of lepton universality
- ✓ Precision measurement of hadronic τ decays
- ✓ Search for CP and T violation in τ decays
- ✓ …

Test of the electroweak sector of the SM

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

The machine (2019 update)

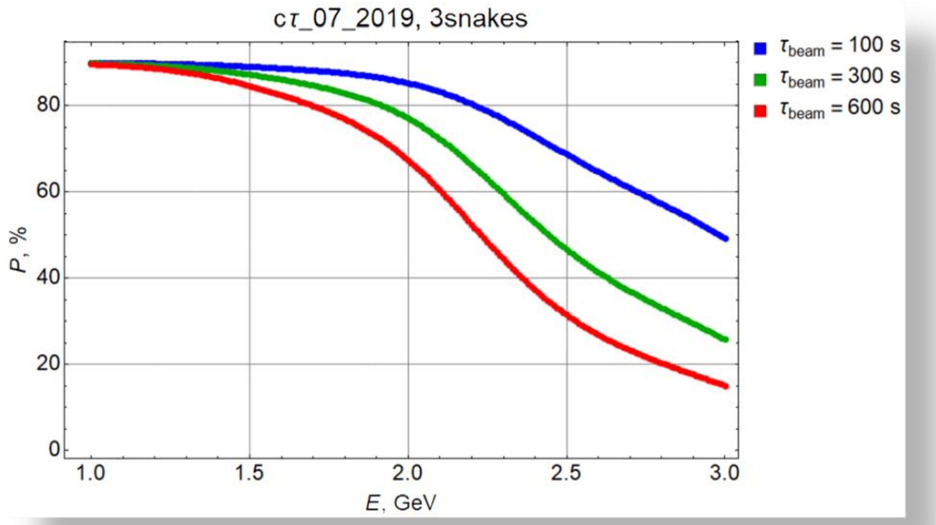
- Beam energy: from 1 to 3 GeV
- $\mathcal{L} = 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ @ 2 GeV
- Longitudinal polarization of the electron beam
- Crab-waist collisions
  - Beam size in the interaction region
    20 μm × 0.2 μm × 10 mm
  - Beams crossing angle 60 mrad



Collider parameters

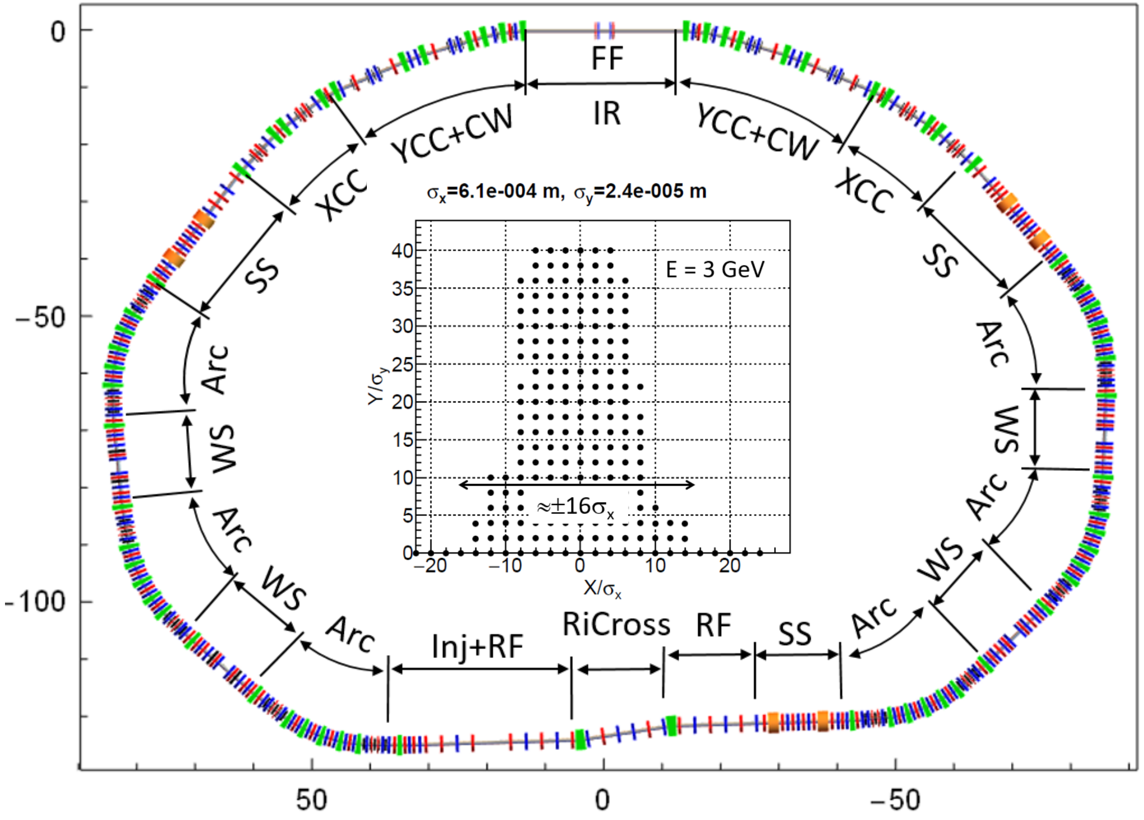
Circumference	478.092 m				
2θ	60 mrad				
β_x^*/β_y^*	50 mm / 0.5 mm				
F_{RF}	349.9 MHz				
E_{beam} (GeV)	**1***	**1**	**1.5**	**2**	**3**
I (A)	1	1	2.2	2.2	2
N_{bunch}	500	500	490	420	290
ε_x (nm)	11.3	16.3	8.8	7	10.9
L_{peak} ($\text{cm}^{-2}\text{s}^{-1} \times 10^{35}$)	**0.21**	**0.14**	**0.8**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

Electron beam polarization
with 3 Siberian Snakes

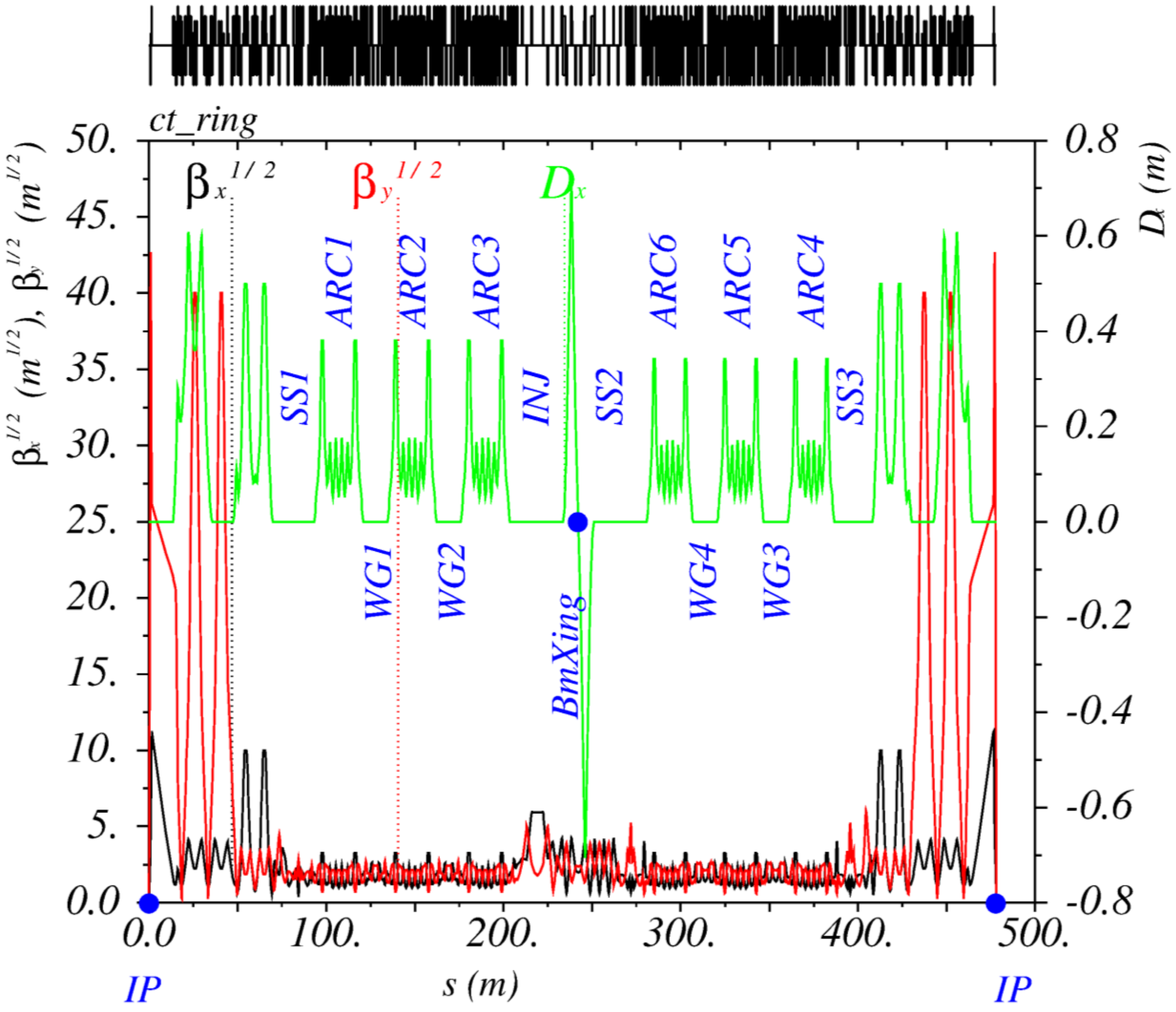


* With two $B_w = 3.5$ T wigglers that suppress intrabeam scattering

Lattice

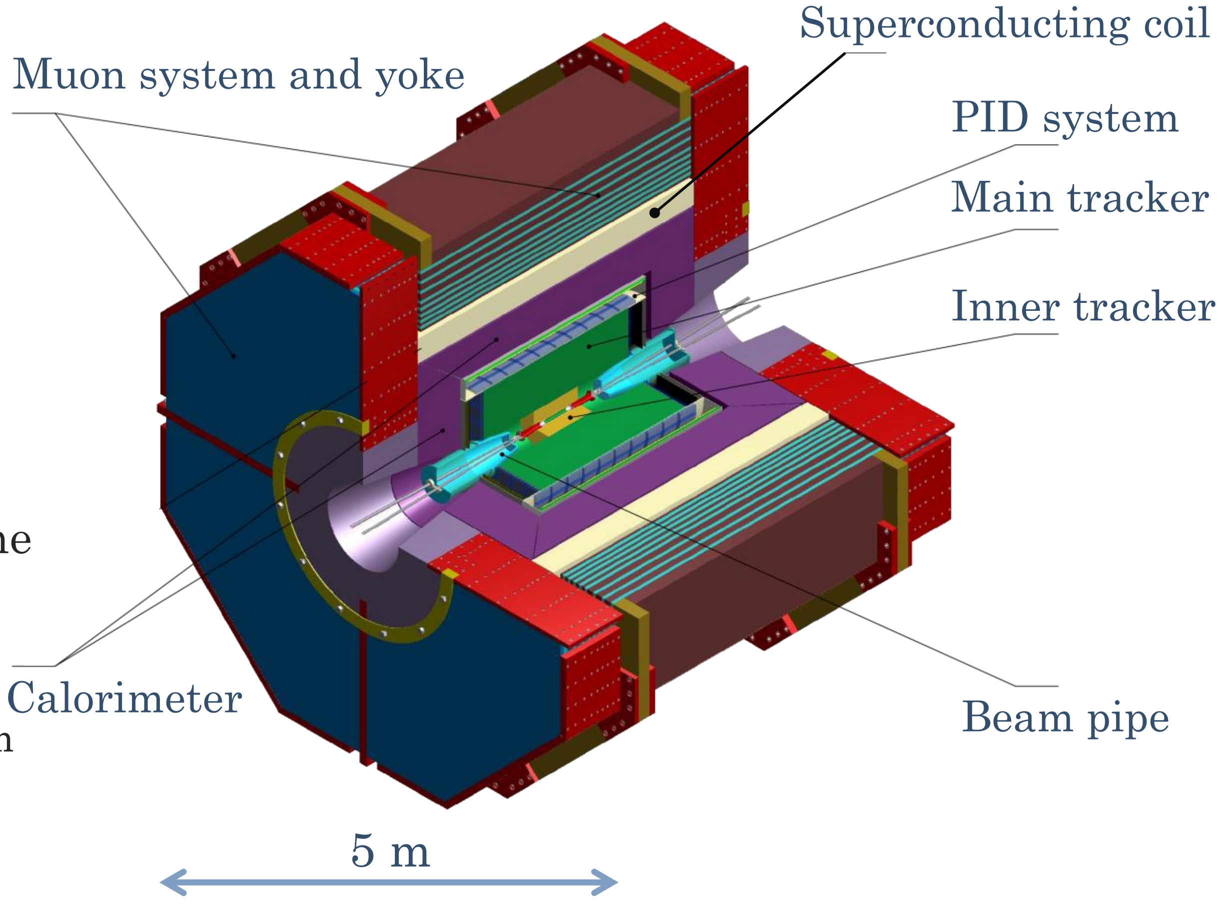


Analysis of nonlinear dynamics is performed (quadrupole fringes, kinematic terms, crab sextupoles)



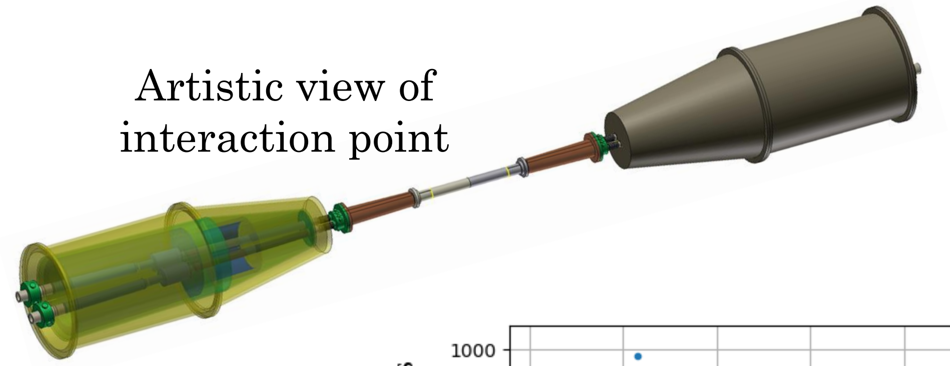
Detector concept

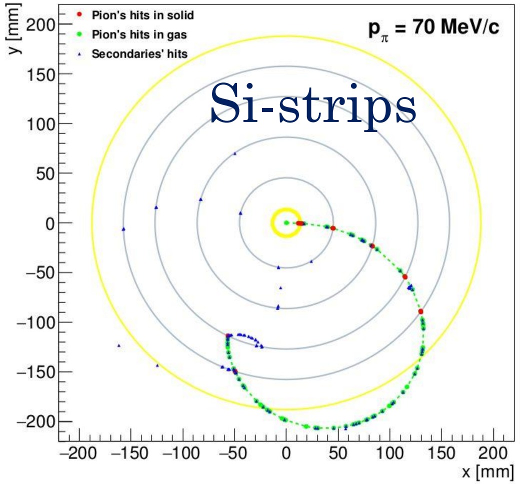
- Physics requirements
  - Good momentum resolution
  - Good CP symmetry and hermeticity
  - Soft track detection with $p_t \gtrsim 50$ MeV
  - Good $\mu/\pi/K/p$ separation up to 1.5 GeV
    - dE/dx in tracking system
    - Dedicated subsystems for μ/π and π/K separation
  - Good π^0/γ separation and γ detection in the energy range from 10 MeV to 3000 MeV
    - Good energy resolution in calorimeter
    - Fast calorimeter ($\sigma_t < 1$ ns) to suppress beam background and pileup noise
  - DAQ rate ~300 kHz @ J/ψ peak

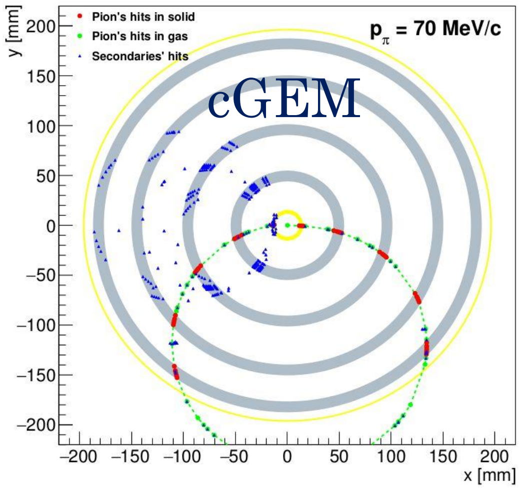


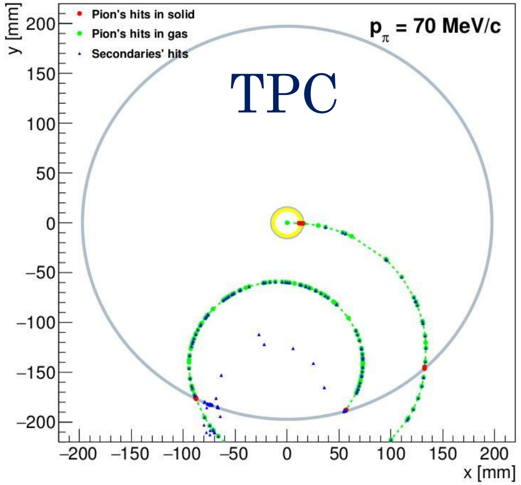
Inner tracker

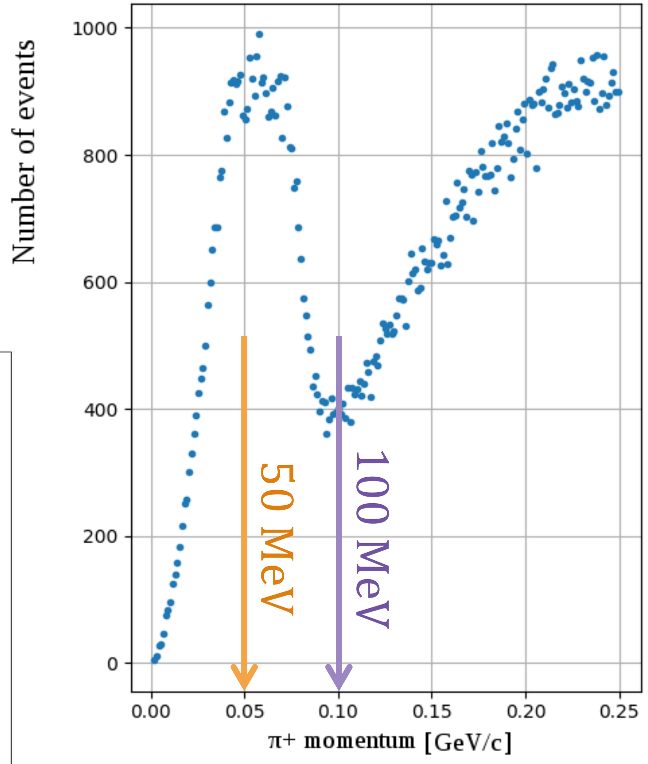
- Resolution similar to drift chamber (~100 μm)
- Sensitive to soft tracks (p_t ~ 50 MeV)
- Able to handle high particle flux
- Compatible with final focus constraints
- Approximate size: Ø (40 – 400) × 600 mm











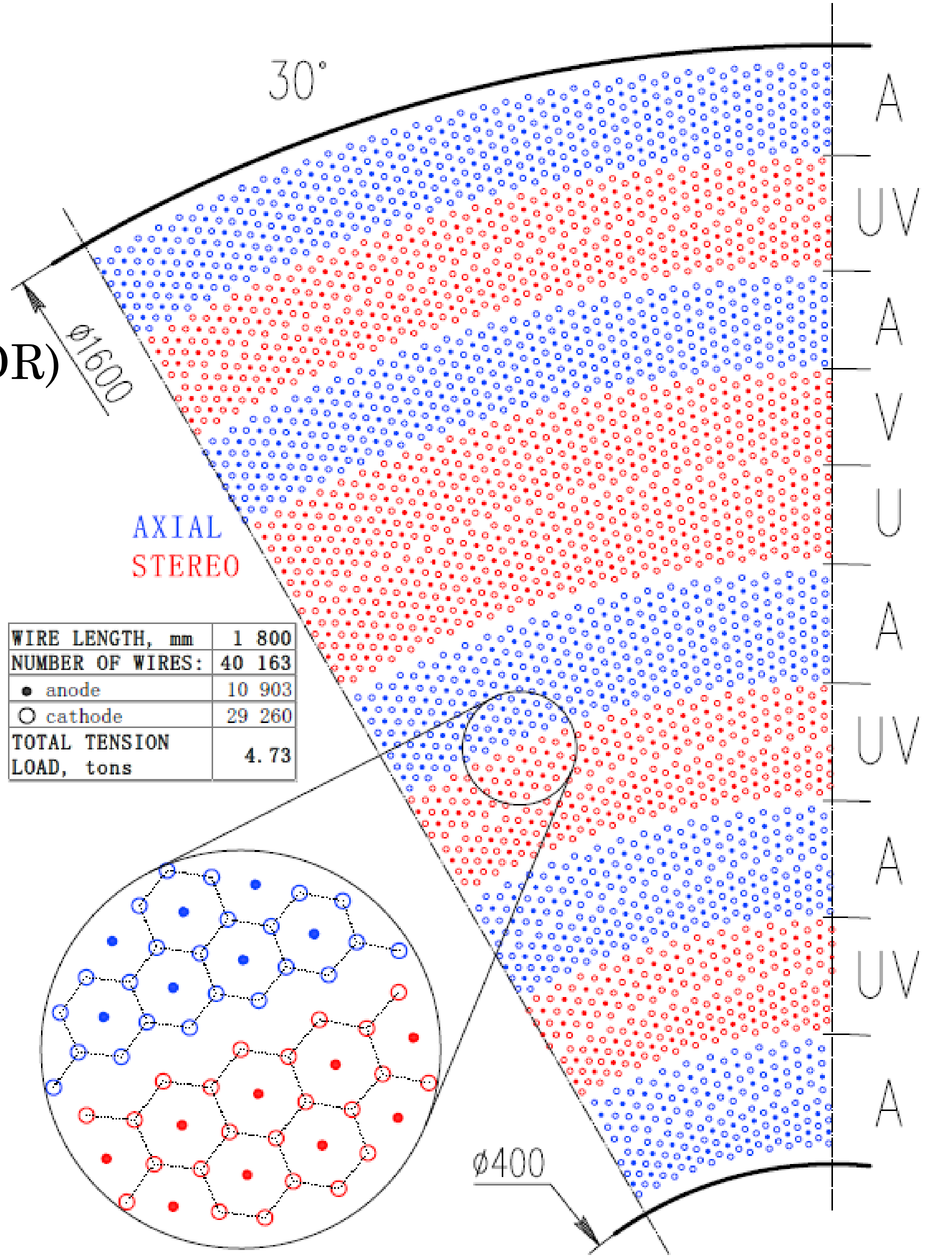
π^+ momentum distribution in $e^+e^- \to D^-[D^{*+} \to D^0\pi^+]$

Drift chamber

- Well-known robust solution (CLEO, BaBar, Belle, KEDR)
  - Hexagonal cell
  - 41 layers, 10903 sensitive wires
  - Gas mixture with 60% He and 40% propane
- Average spatial resolution in a cell better then 90 μm
- Momentum precision of 0.4% (at 1 GeV)

$$\frac{\sigma_{p_t}}{p_t} \approx \sqrt{0.21\%^2 p_t^2 + 0.31\%^2}$$

- dE/dx precision better then 7%



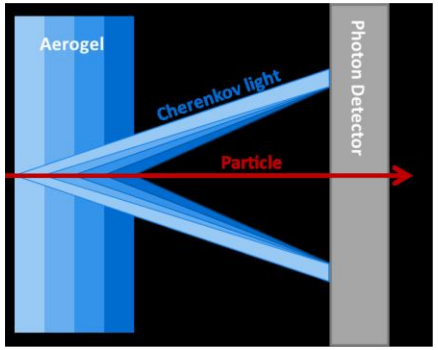
An alternative proposal «TraPId»

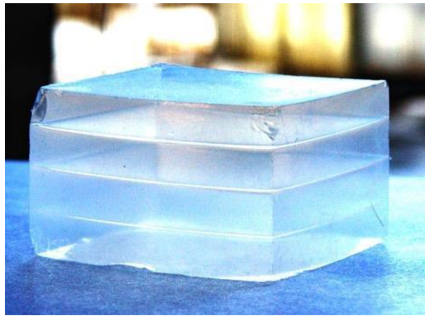
(INFN – Lecce)

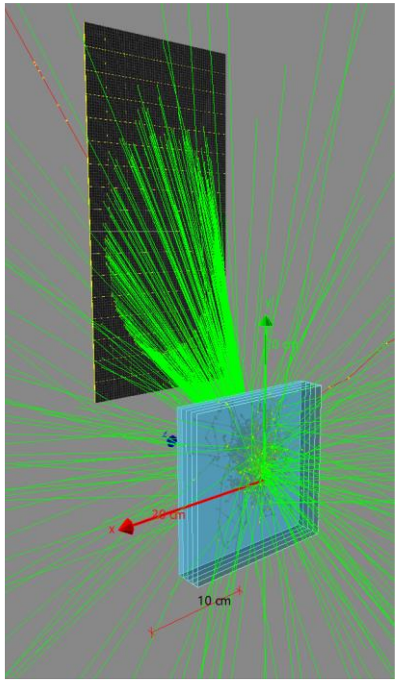
Ultra-low mass, cluster counting, full stereo

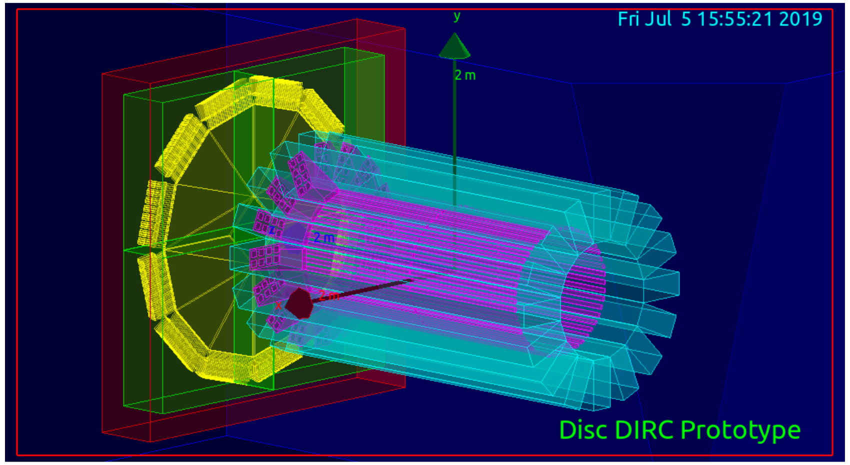
Particle identification

- Quality of particle identification is critical for physics performance of a high-statistics experiment
- Several options are under consideration:
  - Focusing Aerogel RICH (FARICH)
    - R&D with prototypes and test beam
    - Geant4 simulation
  - DIRC
    - Experience from BaBar and $\overline{\text{P}}$ANDA
    - Geant4 simulation
  - Time-of-flight
    - Parametric simulation









More details can be found at a recent charm-tau workshop page
c-tau.ru/indico/event/3/timetable/

Calorimeter

Baseline option

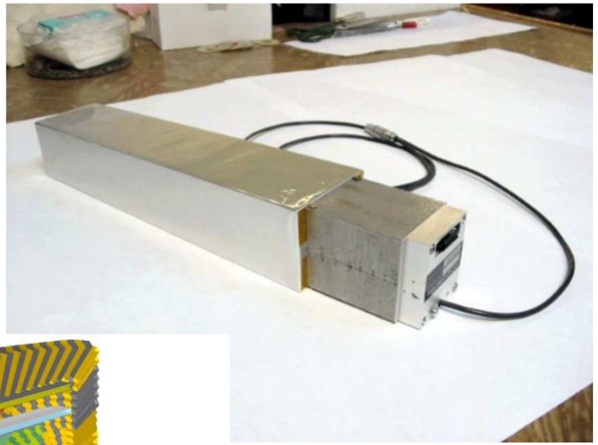
- Belle, Belle II-like electromagnetic crystal calorimeter

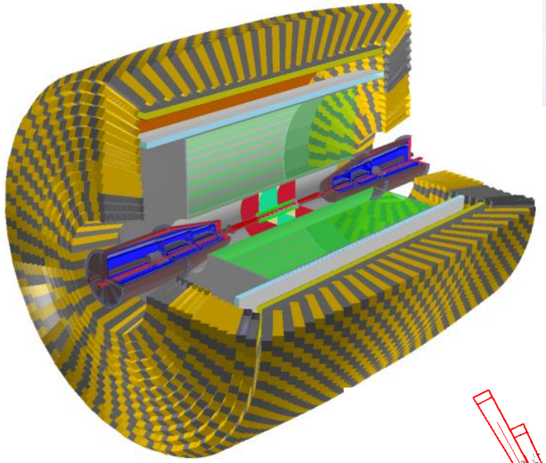
Scintillator

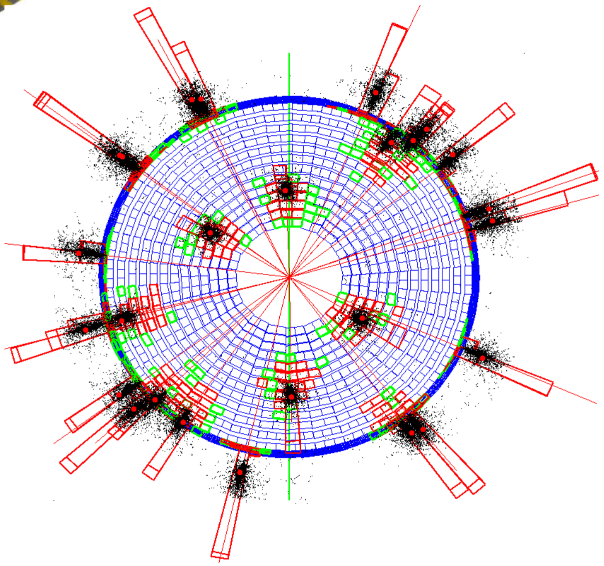
- CsI(Tl) has large light yield, “cheap”, very popular, but slow
- LSO, LYSO, etc. – have large LY, very fast, but very expensive (x10)
- **Pure CsI is a good compromise: reasonable LY, 30 ns component, reasonable price**

$$\frac{\sigma_E}{E} \approx \frac{1.9\%}{\sqrt[4]{E(GeV)}} \oplus \frac{0.33\%}{\sqrt{E}} \oplus \frac{0.11\%}{E}$$

- Active R&D is being performed including prototype test and Geant4 simulation





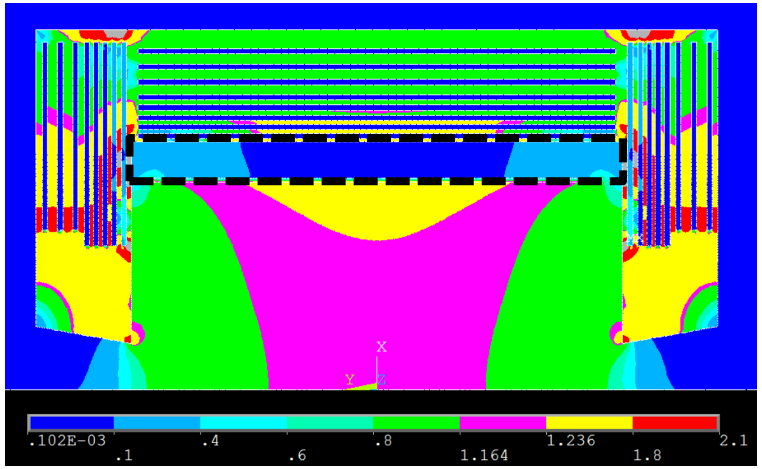


Magnet

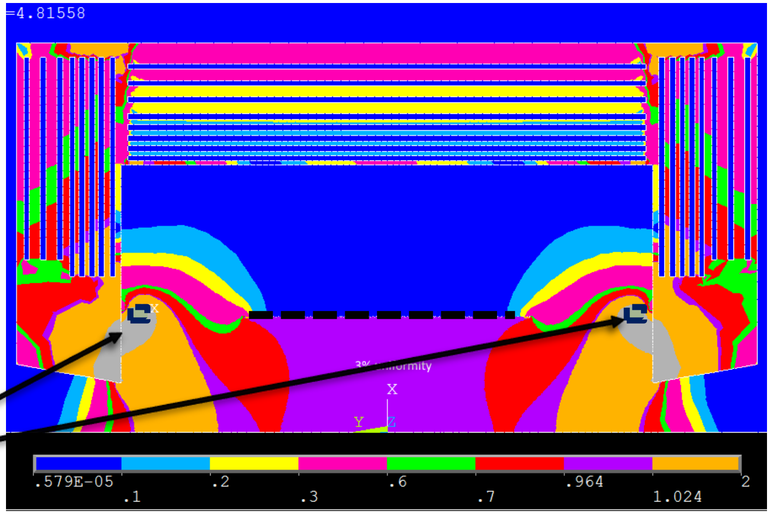
Two options under consideration

1. Outside calorimeter
   - “thick” design
   - Al-stabilized coil, robust technology
   - Similar to PANDA magnet
   - Baseline option
2. Just outside drift chamber
   - “thin” design, 0.1 X_0!
   - CMD-3 experience
   - Pros and cons are under investigations

Baseline option



Thin solenoid option



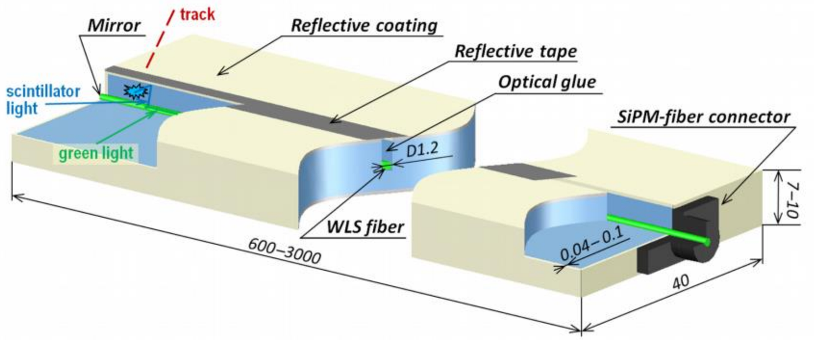
Correcting coils

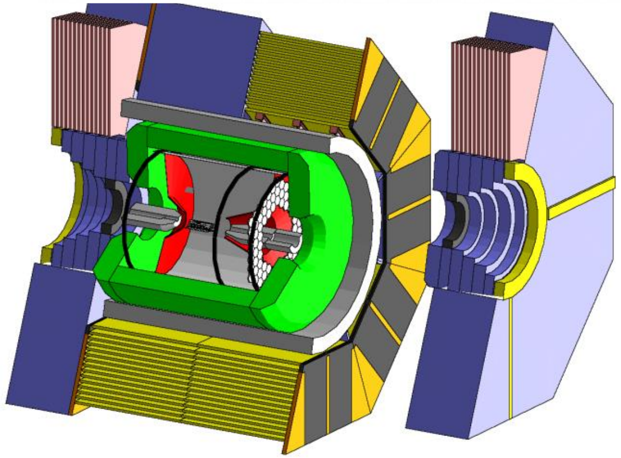
Muon system

- Purpose
  - To detect muons (note mult. scat. of $\mathcal{O}(1\text{ cm})$
  - μ/π separation
  - K_L detection

Baseline option

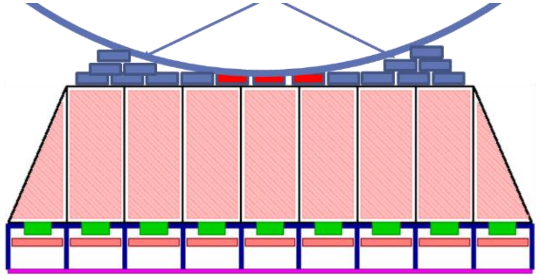
  - Scintillator strips + WLS fiber + SiPM
  - Similar to Belle II and CMD-3
  - 8-9 layers inside iron yoke to be able to stop K_L mesons
  - Total surface of ~1500 m^2



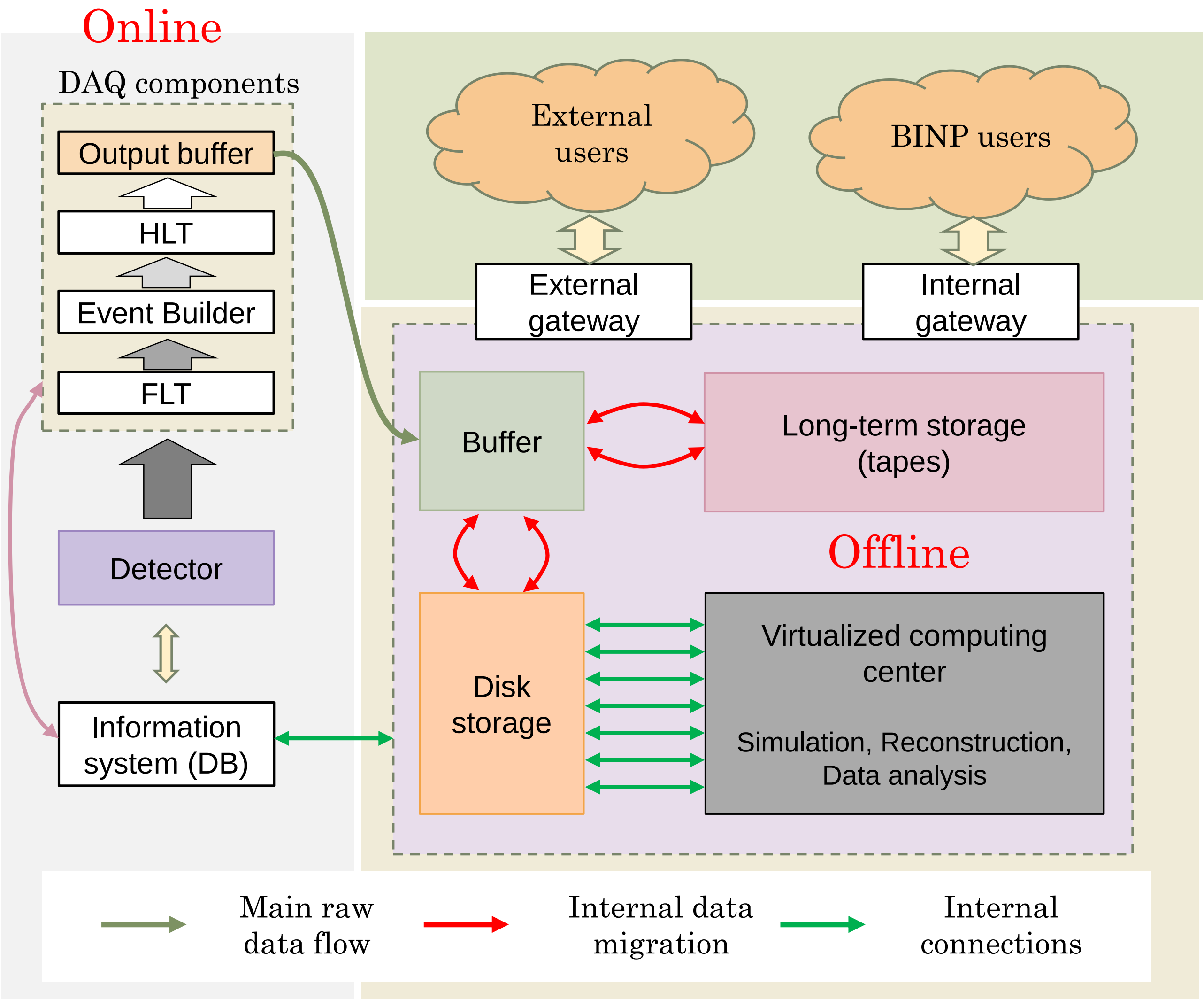


Belle II

CMD-3



DAQ and data analysis/storage



Requirements

- Maximum input data rate
  20 GB/s
- Total storage system capacitance
  ~300 Pbytes
- Computing power
  ~1 Pflops

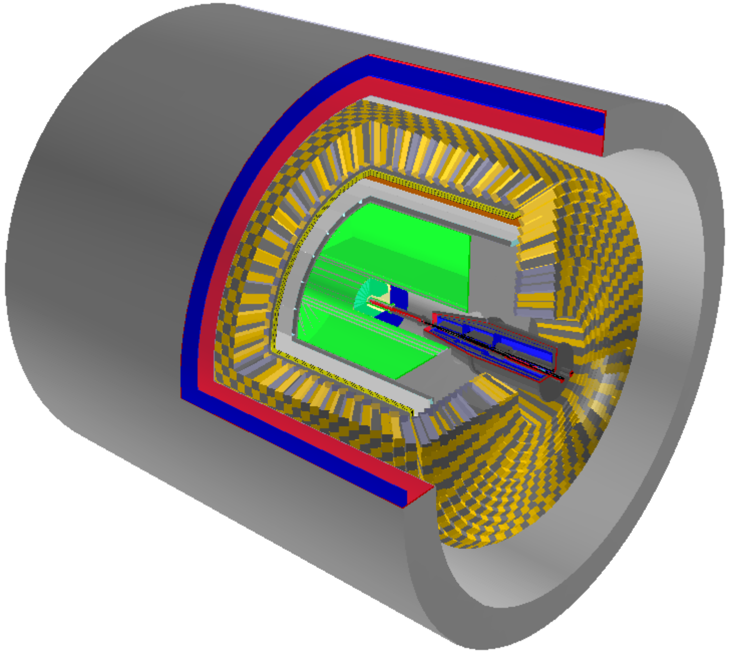
Can be implemented with commercial solutions

Simulation and analysis software

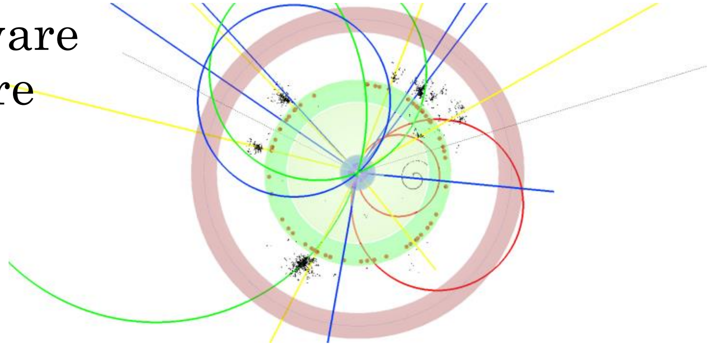
The full-scale simulation of the SCT experiment is being rapidly developed

SCT detector software framework Aurora

- Widely used HEP tools (ROOT, Geant4, …)
- Gaudi and Athena-inspired build and config system
- Event data model based on PODIO
- Detector geometry based on DD4Hep
- Specific SCT modules are being developed



- Dedicated RSF grant for development of SCT software and design of data analysis hardware infrastructure



Status of the project

- 2011: selected as one of six mega-science projects to be built in Russia
- There are
  - Roadmap
  - Conceptual design (ctd.inp.nsk.su)
  - Preliminary civil engineering design
- CERN, IHEP, INFN, KEK and other organizations expressed their interest in the project
- SCT was included in the 2017 – 2019 plan for the implementation of the first phase of the Russian Strategy for Science and Technology Development
- 2019: machine layout updated and refined leading to a CDR update
- 2020: SCT is expected to be mentioned in the updated European Strategy for Particle Physics

Collaboration

- Working groups
  - Inner tracker
  - Drift chamber
  - PID
  - Calorimeter
  - Muon system
  - Magnet
  - Physics and simulations
  - Computing
  - DAQ and trigger
  - Beam background
  - Engineering

- International advisory committee
- Dedicated international workshops
  - May 2018, BINP
  - December 2018, Orsay
  - September 2019, Moscow
  - Fall 2020 in China
- Monthly online meetings with colleagues working on the HIEPA project

WGs are open for international participation

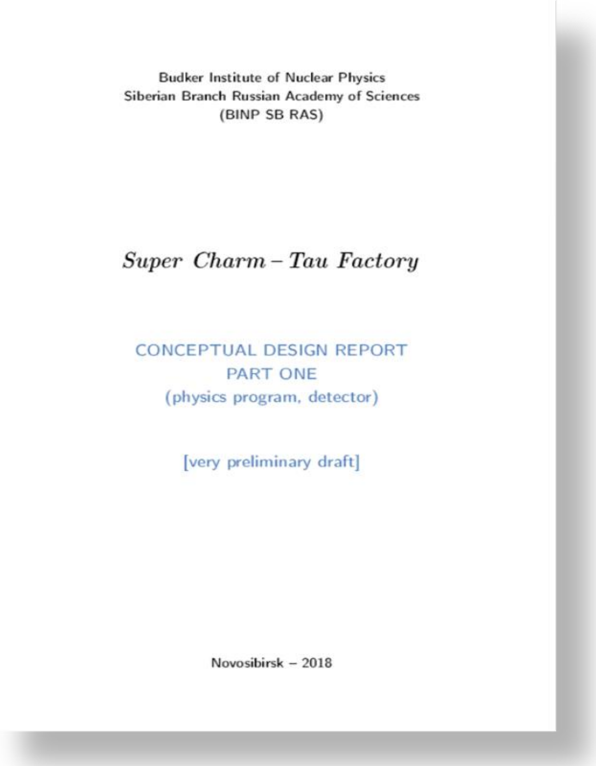
Conclusions

1. SCT physics program is broad and diverse. It is complementary to the Belle II and LHC*b*
2. There are conceptual designs of the collider and the detector and they continue to be improved and detailed by the international collaboration
3. R&D for the SCT factory project is partially supported by Russian government, Russian science fund, and European Commission

Thank you!

Back-up

SCT Physics program of Super c-τ factory


Budker Institute of Nuclear Physics
Siberian Branch Russian Academy of Sciences
(BINP SB RAS)

Super Charm – Tau Factory

CONCEPTUAL DESIGN REPORT
PART ONE
(physics program, detector)

[very preliminary draft]

Novosibirsk – 2018

Conceptual design report
ctd.inp.nsk.su

Charmonium
- Spectroscopy
- Decays
- Light states in J/ψ decays

Charm mesons
- Spectroscopy
- Decays
- Charm mixing
- $\mathcal{CP}$ symmetry violation

Charm baryons
- Spectroscopy
- Decays
- $\mathcal{CP}$ symmetry violation

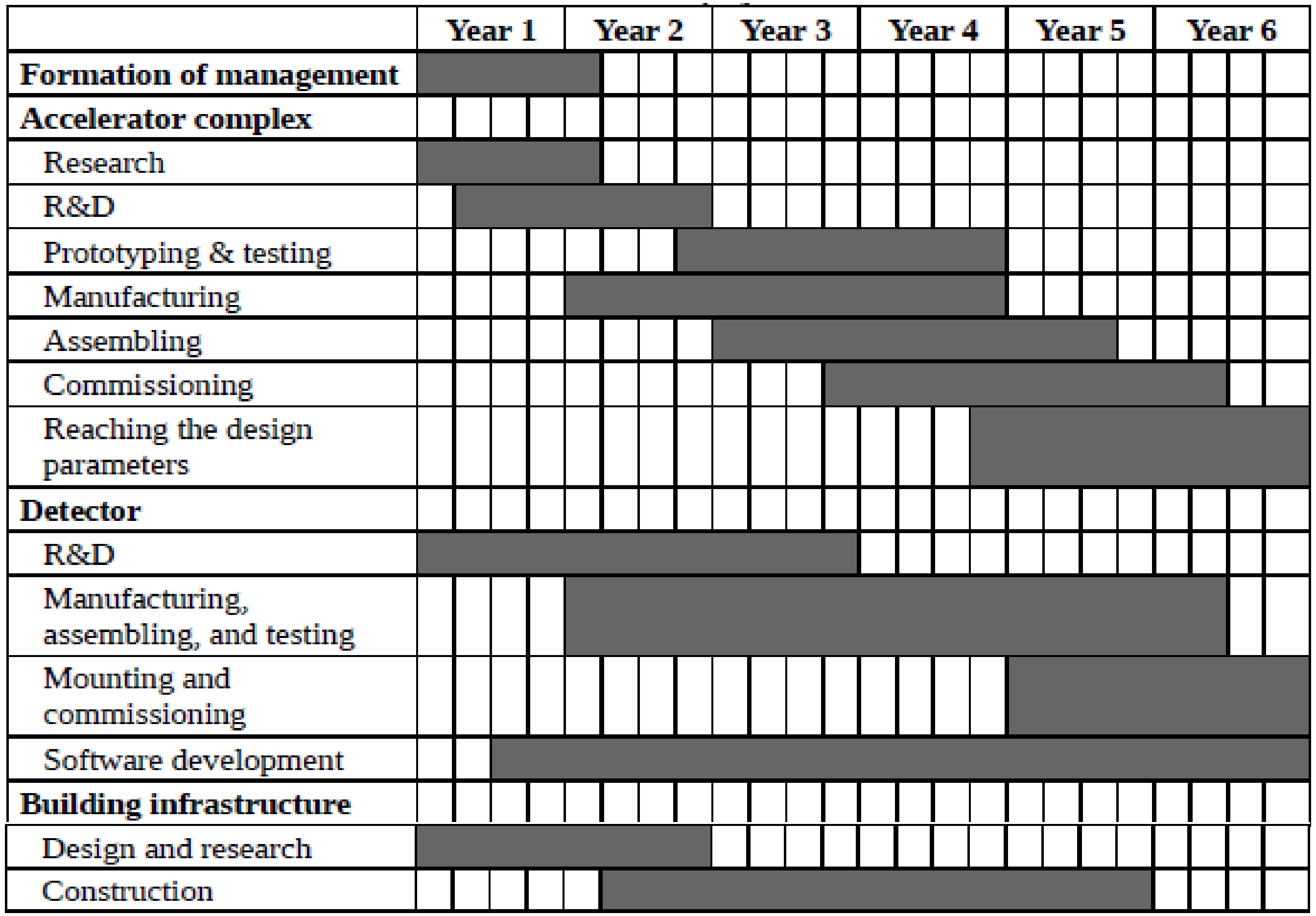
τ lepton
- Michel parameters
- Spectral functions
- $\mathcal{CP}$ symmetry violation
- Lepton number conservation test
- Lepton flavor universality test

Two-photon physics
- Search for $\mathcal{C}$-even resonances
- $\sigma(\gamma\gamma \to \text{hadrons})$

$\sigma(e^+e^- \to \text{hadrons})$

Status of the Super c-τ factory project

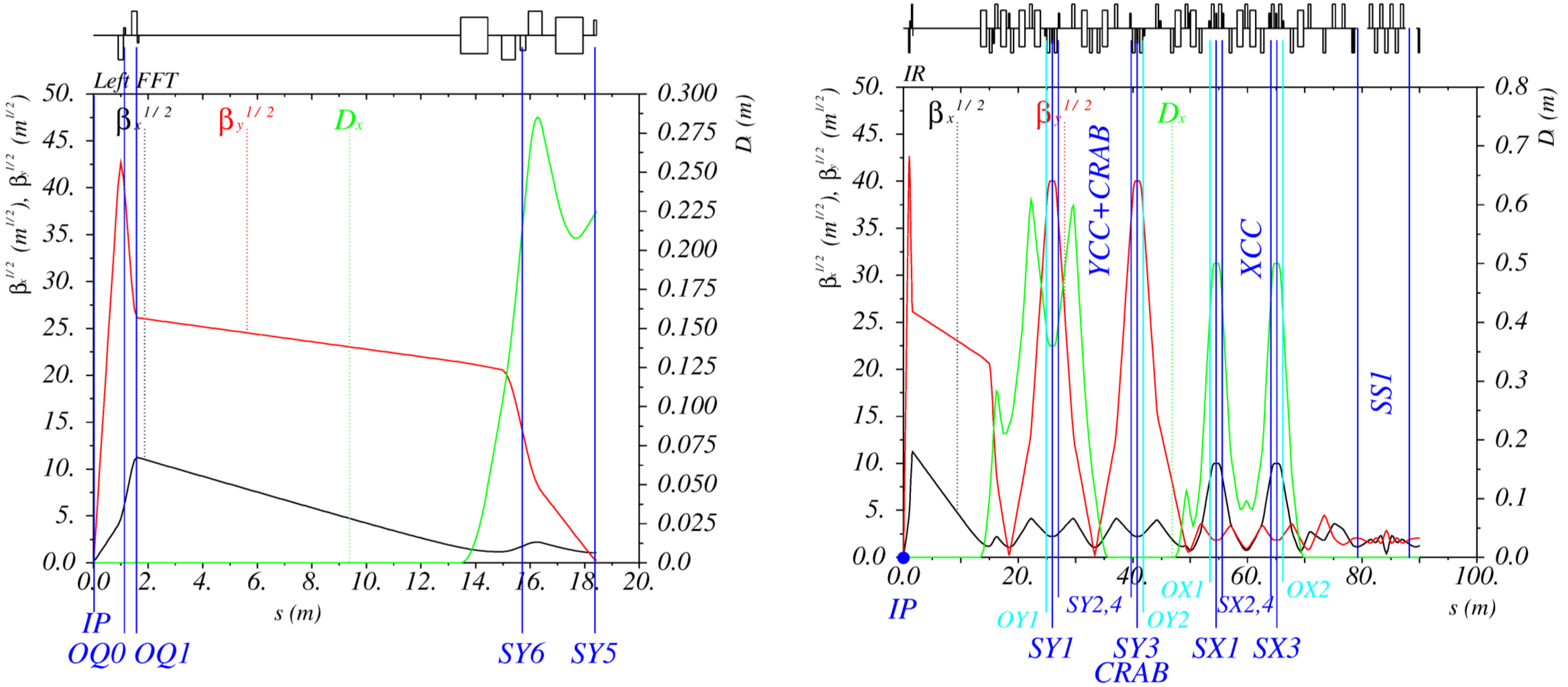
- In June 2017, the SCT project is included in the plan for the implementation of the first phase of the Strategy for Scientific and Technological Development of the Russian Federation
- In August 2017, the Russian Ministry of Education and Science and Budker Institute signed an agreement for an amount of about 0.25 bln. Rbls, which foresees the development and upgrade of the accelerator complex of BINP and the creation of scientific and technical groundwork for the implementation of the SCT



Collider parameters

E(MeV)	1000*	1000	1500	2000	3000
Π(m)	478.092				
F_{RF}(MHz)	349.9				
q	558				
2θ(mrad)	60				
κ (%)	0.5				
β_x^*(mm)	50				
β_y^*(mm)	0.5				
$\alpha \times 10^4$	9.77				
I(A)	1	1	2.2	2.2	2
$N_{e/bunch} \times 10^{-10}$	2.1	2.1	4.5	5.2	7
N_b	500	500	490	420	290
U_0(keV)	11.7	11.7	59.3	187.4	948
V_{RF}(kV)	1000	1000	600	1000	2000
ν_s	0.0093	0.0093	0.0059	0.0065	0.0072
δ_{RF}(%)	3.4	3.4	2	2	1.7
$\sigma_e \times 10^3$	1	1.2	0.9	0.8	9.6
σ_s(mm)	7.9	9.5	11	8.8	10
ε_x(nm)	11.3	16.3	8.8	7	10.9
$L_{HG} \times 10^{-35} (cm^{-2}s^{-1})$	0.21	0.14	0.8	1.3	1.1
HG (%)	76	72	79	82	77
ξ_x	0.0042	0.0029	0.0031	0.0042	0.003
ξ_y	0.06	0.04	0.07	0.085	0.054
φ	10	10	16	14	13
τ_L (s)	3245	4968	1803	1080	1197

Interaction region



TraPId: A proposal for SCTF

$R_{in} - R_{out}$ [mm]		200 – 800
active L – service area [mm]		1800 – 200
inner cylindrical wall		
C-fiber/C-foam sandwich	2×80 μm / 5 mm	0.036 g/cm² – 8×10^{-4} X/X_0
outer cylindrical wall		
C-fiber/C-foam sandwich	2×5 mm / 10 mm	0.512 g/cm² – 1.2×10^{-2} X/X_0
end plate		
gas envelope	160 μm C-fiber	0.021 g/cm² – 6×10^{-4} X/X_0
instrumented wire cage	wire PCB, spacers, HV distr. and cables, limiting R, decoupling C and signal cables	0.833 g/cm² – 3.0×10^{-2} X/X_0

cell	
shape	square
size [mm]	7.265 – 9.135
layer	
8 super-layers	8 layer each
64 layer total	
stereo angles	66 – 220 mrad
n. sense wires [20μm W]	23,040
n. field wires [40/50μm Al]	116,640
n. total (incl. guard)	141,120
gas + wires [600 mm]	
90%He – 10%iC_4H_{10}	4.6×10^{-4}
W + 5Al → Ti + 5 C	$(13.1 \rightarrow 2.5)\times10^{-4}$