SUPER C-TAU FACTORY: PROJECT STATUS

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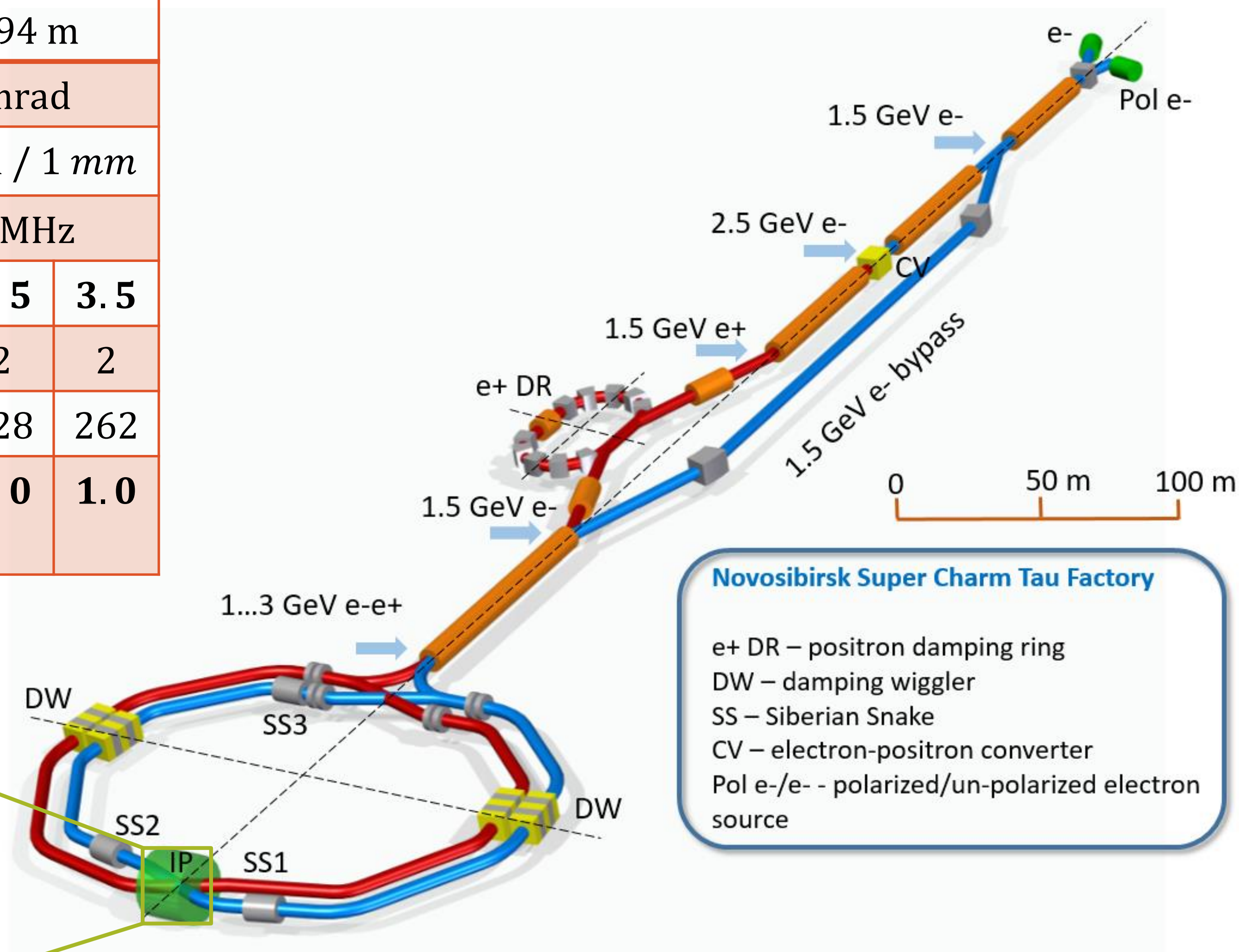
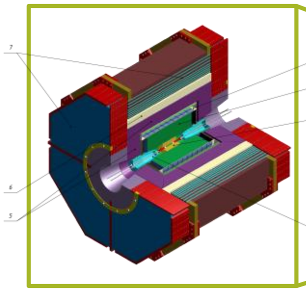
The overview

Super c-tau factory (SCTF) =
e^+e^- collider with c.m. energy from 3 to 7 GeV
+ detector

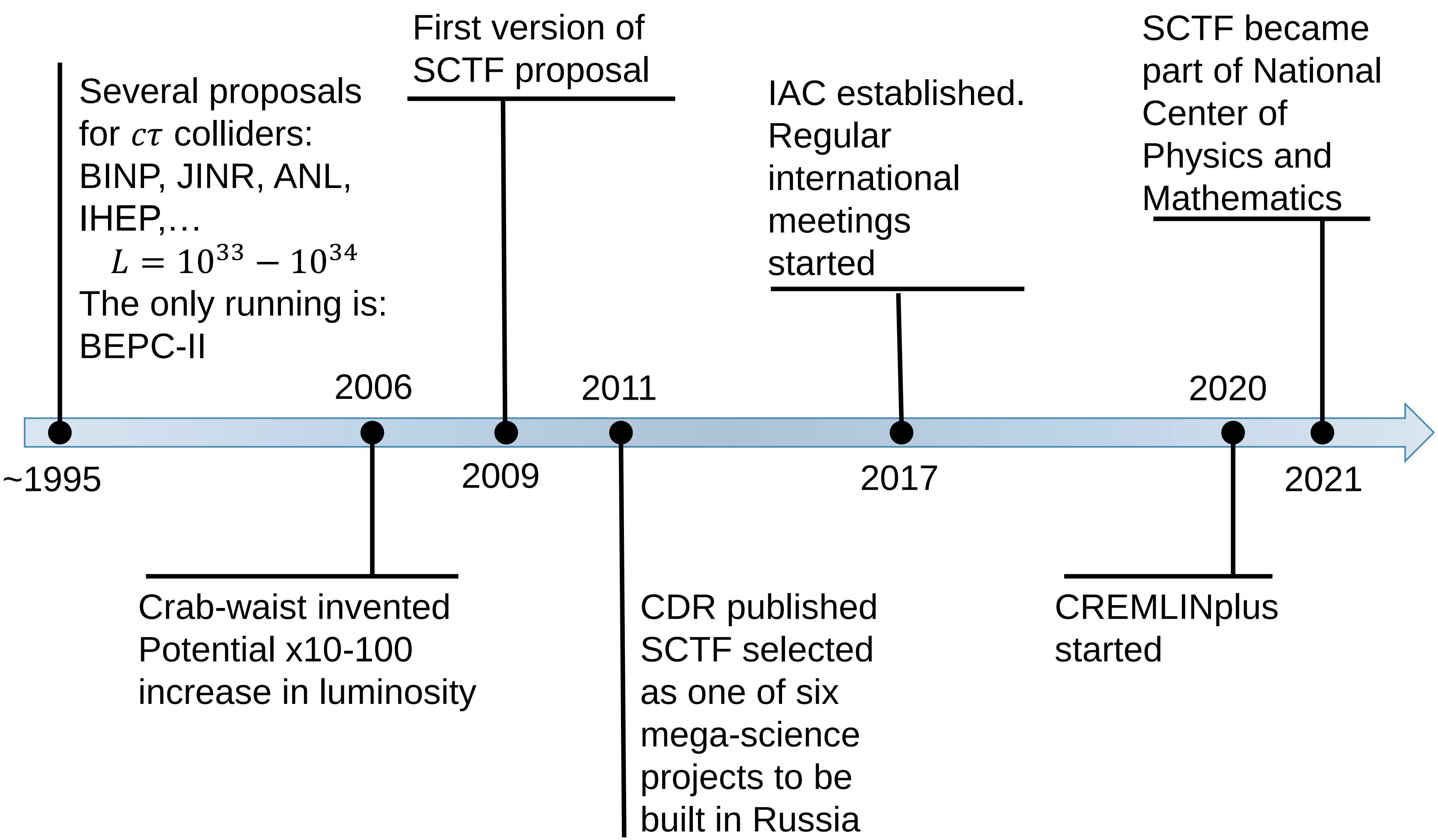
Perimeter	632.94 m		
2θ	60 mrad		
β_x^*/β_y^*	100 mm / 1 mm		
F_{RF}	350 MHz		
E_{beam} (GeV)	**1.5**	**2.5**	**3.5**
I (A)	2	2	2
N_{bunch}	292	328	262
$L_{\text{peak}} \times 10^{35}$ $(\text{cm}^{-2}\text{s}^{-1})$	**0.8**	**1.0**	**1.0**

Parameters as of 2021





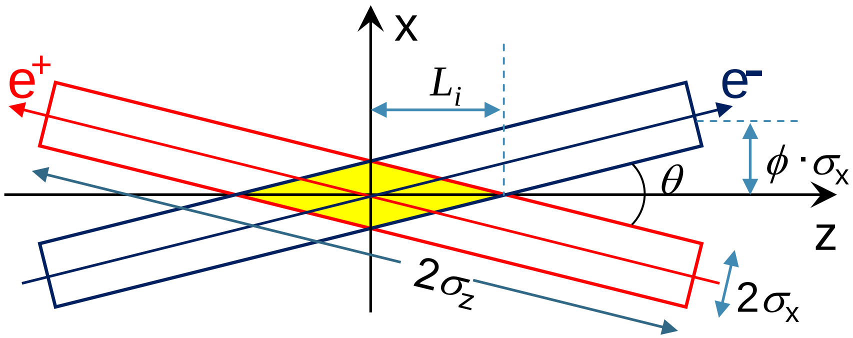
Timeline


Several proposals for $c\tau$ colliders: BINP, JINR, ANL, IHEP,…
$L = 10^{33} - 10^{34}$
The only running is: BEPC-II
~1995
First version of SCTF proposal
2006
Crab-waist invented
Potential x10-100 increase in luminosity
2009
2011
CDR published
SCTF selected as one of six mega-science projects to be built in Russia
IAC established.
Regular international meetings started
2017
2020
CREMLINplus started
SCTF became part of National Center of Physics and Mathematics
2021

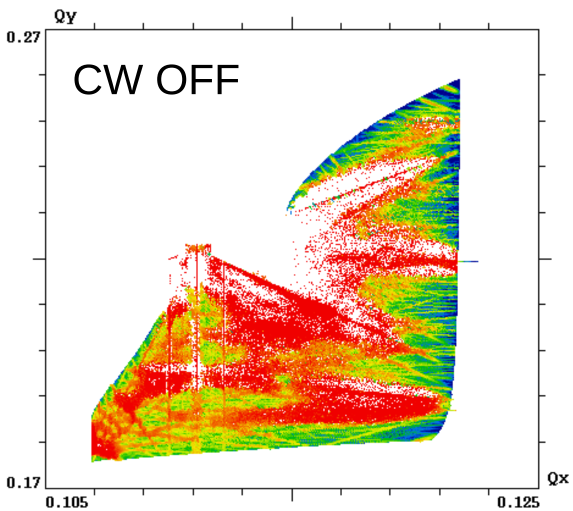
Crab waist collision scheme

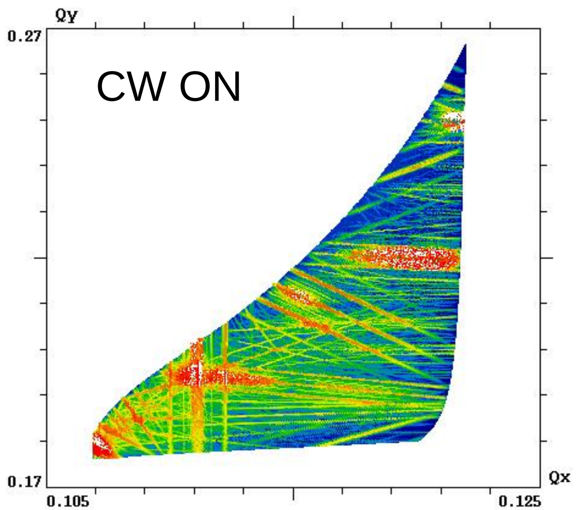
Crab waist (P.Raimondi, 2006):

- Collision at large Piwinski angle
  $\phi = \frac{\sigma_z}{\sigma_x}\tan\left(\frac{\theta}{2}\right)$
- "Crab" sextupoles to suppress resonances



Tested at DAFNE:

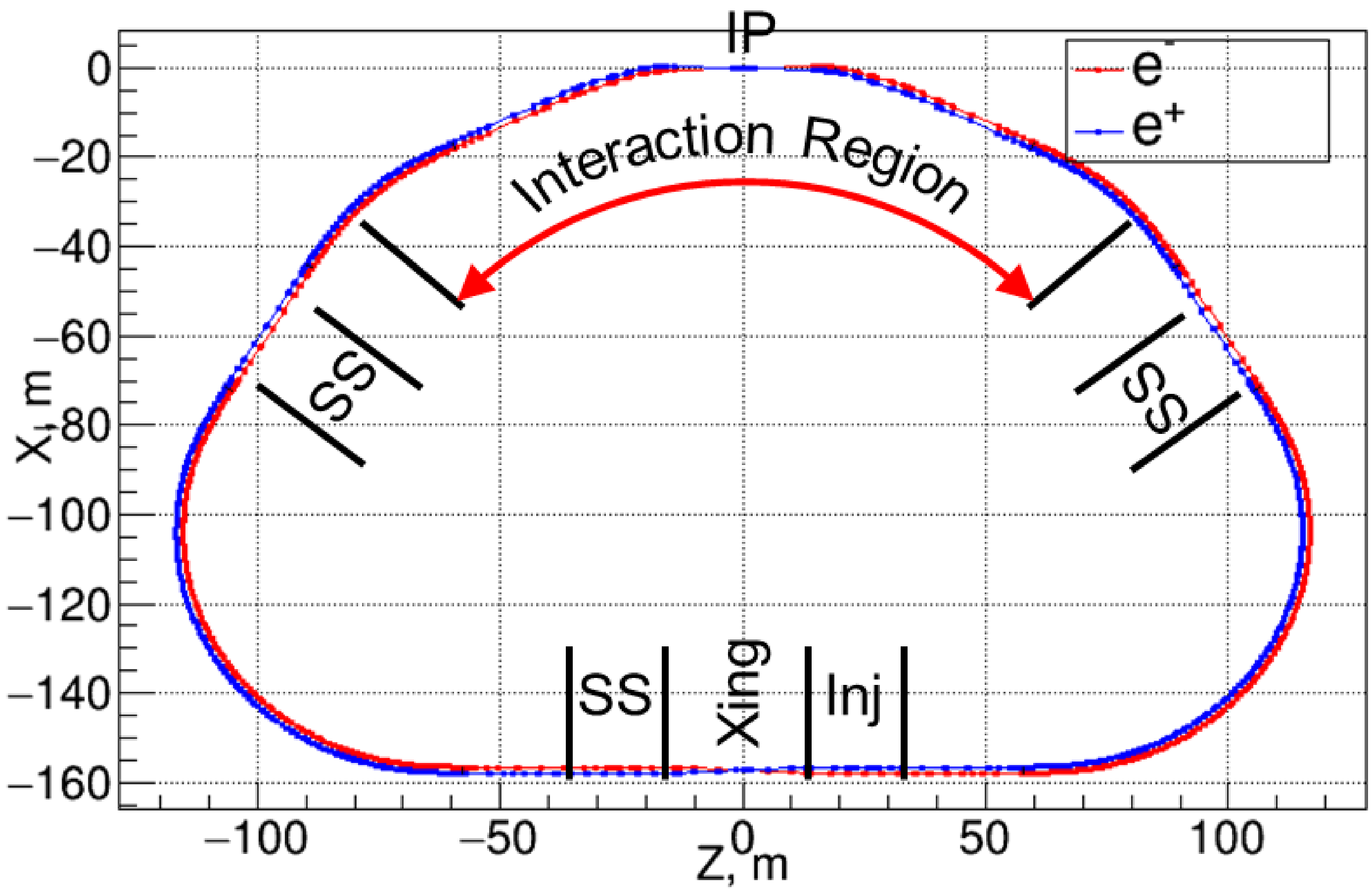




Key element of all high-luminosity colliders:

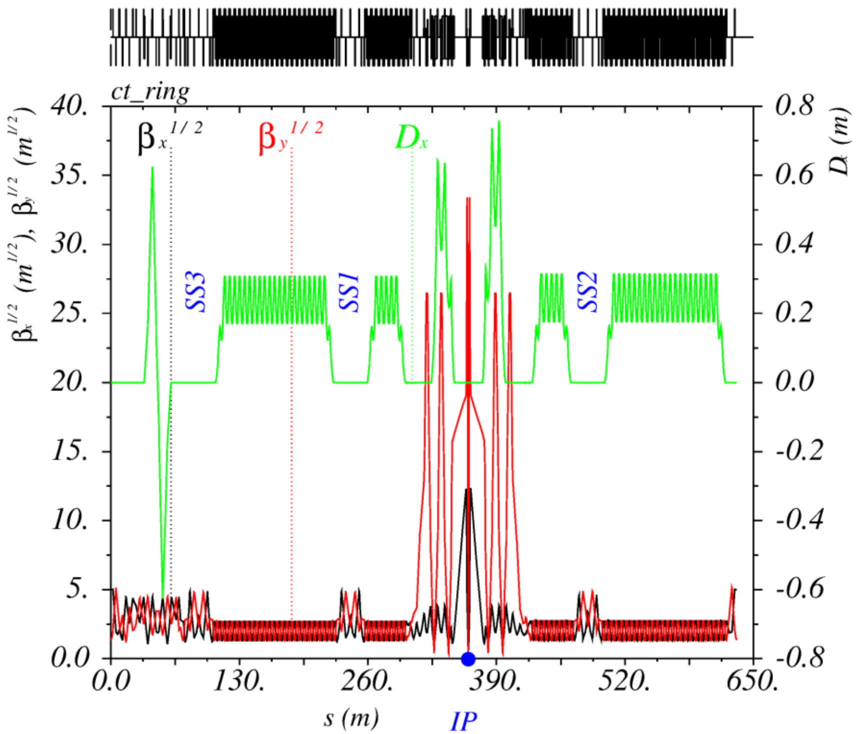
- Super KEK-B
- FCC-ee
- CEPC
- SCTF

Lattice and layout 2021

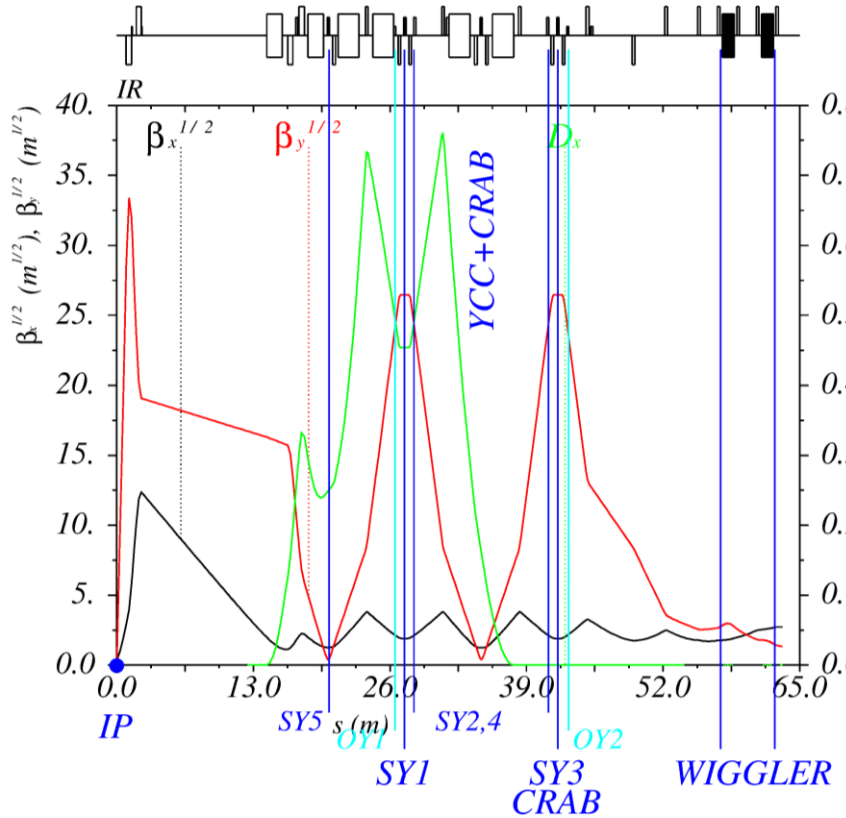


Lattice and layout 2021

Full ring



Interaction region



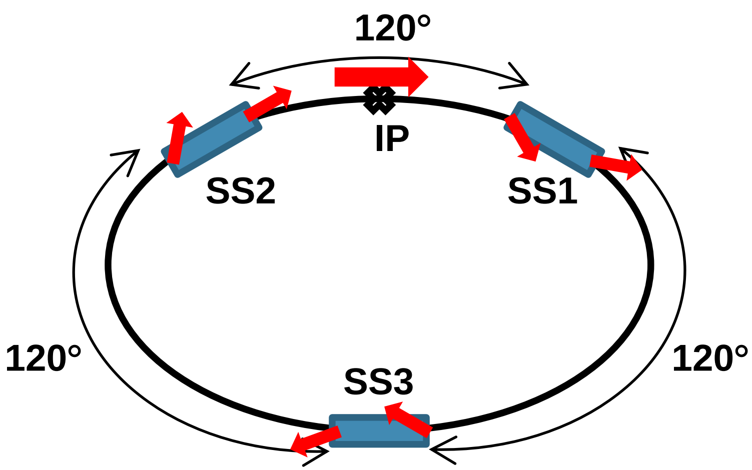
Synergy with FCC-ee, CEPC, SKIF,…

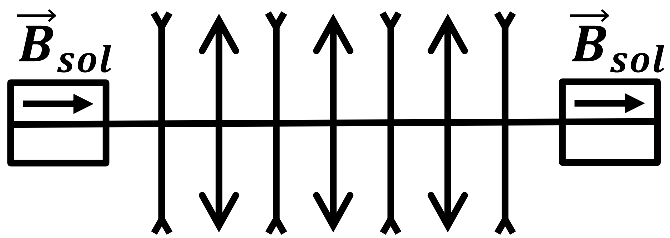
Parameters 2021

E(MeV)	1500	2000	2500	3000	3500
Π(m)	632.94				
F_{RF}(MHz)	350				
q	740				
2θ(mrad)	60				
$\varepsilon_y/\varepsilon_x$(%)	0.5				
β_x^*/β_y^* (mm)	100/1				
α	2.1×10^{-3}				
I(A)	2	2	2	2	2
$N_{e/bunch} \times 10^{-10}$	9	9	8	9	10
N_b	292	292	328	292	262
U_0(keV)	130	260	465	773	1220
V_{RF}(kV)	1600	2000	2500	3500	5000
ν_s	0.0164	0.0159	0.0158	0.017	0.019
δ_{RF}(%)	1.9	1.8	1.7	1.7	1.9
$\sigma_e \times 10^3$ (SR/IBS+WG)	0.28/1	0.4/1.1	0.5/1.1	0.6/1.1	0.7/1.1
σ_s(mm) (SR/IBS+WG)	4/15	7/15	7/15	10/15	12/14
ε_x(nm) (SR/IBS+WG)	2.7/8.8	5/5.5	7/4.6	10/5.8	14/8.1
$L_{HG} \times 10^{-35} (cm^{-2}s^{-1})$	0.8	1	1	1	1
ξ_x	0.007	0.005	0.003	0.003	0.004
ξ_y	0.15	0.14	0.10	0.09	0.08
$\tau_{\mathrm{Touschek}}/\tau_L$ (s)	1600/2000	1800/1600	2300/1670	4000/1600	8300/1600

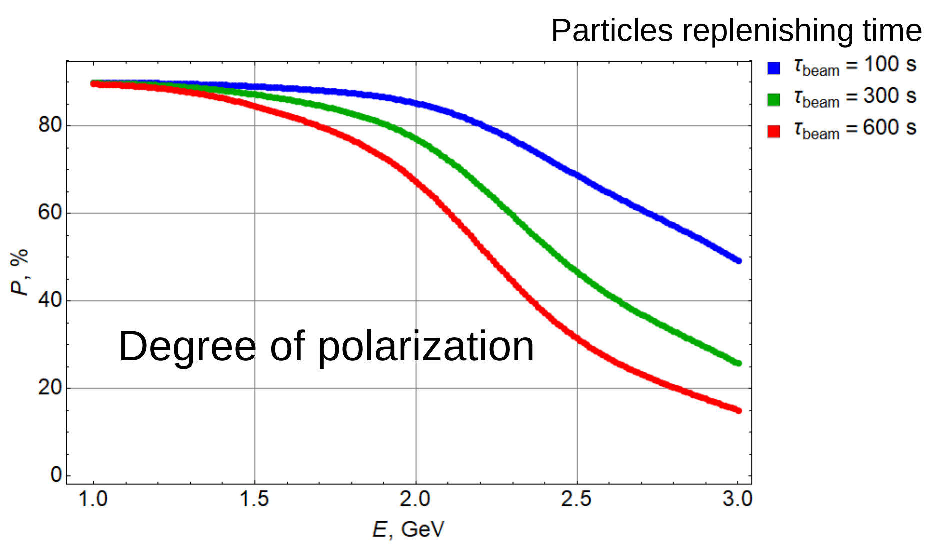
Polarization of electron beam

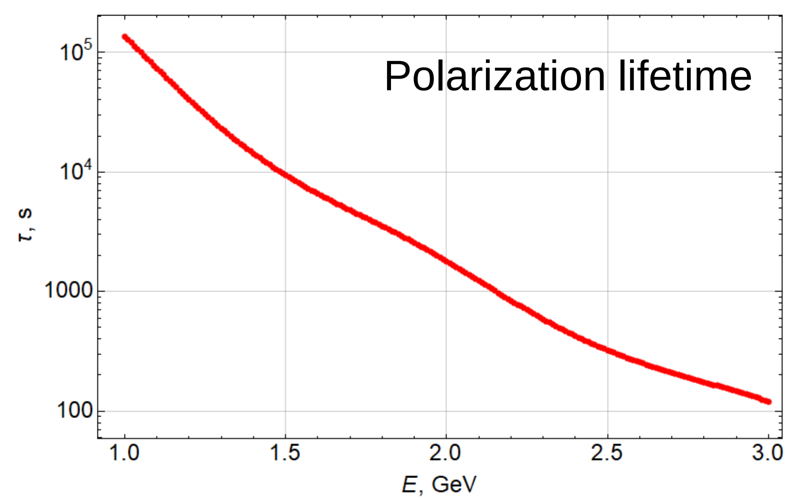
Three Siberian snakes are used to provide longitudinal polarization of e^- beam at IP





To decouple $R_x = -R_y$, 7 quadrupoles needed
Solenoid spin rotation angle is $\pi/2$
$B_{sol} = 7$ T at $E_{beam} = 3.5$ GeV, $L = 2.6$ m

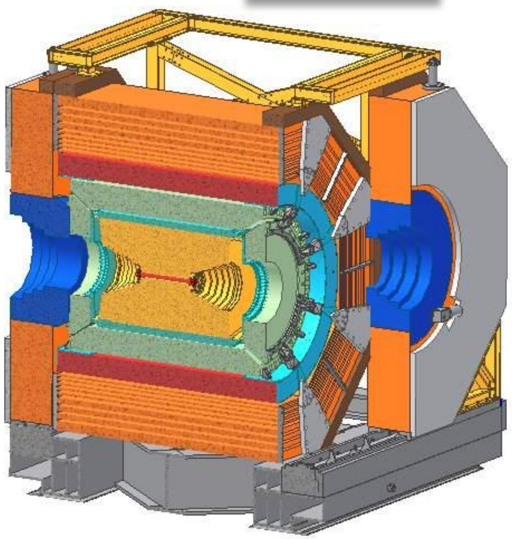




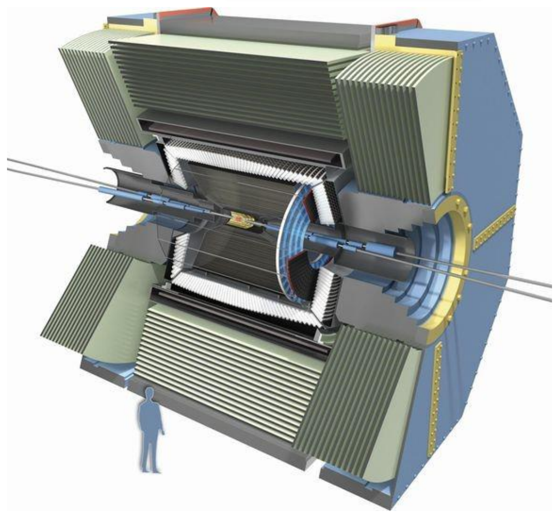
The detector

Brothers, sisters and cousins…

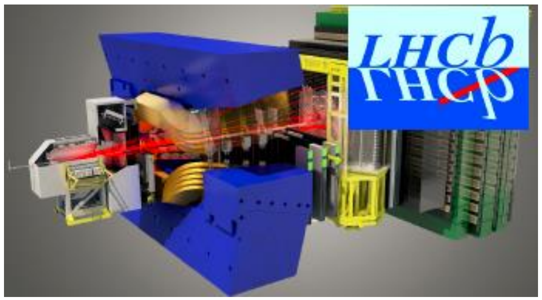
BES-3



BELLE-2



LHCb

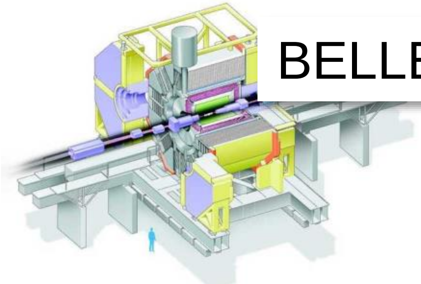


Very similar
1% luminosity

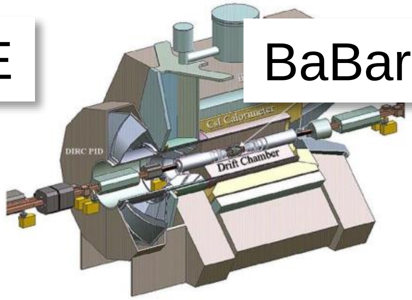
Super B-factory (10.58 GeV)
5-10x luminosity

pp collisions

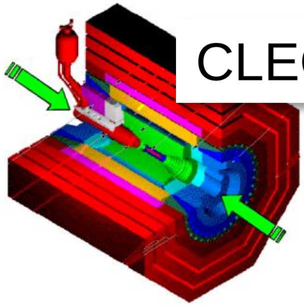
Previous generation:



BELLE

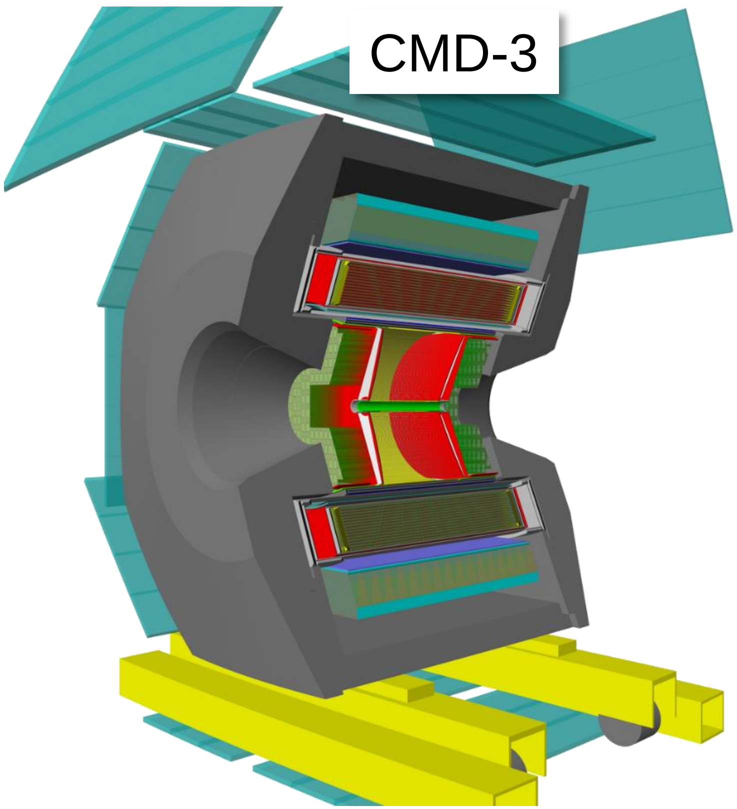


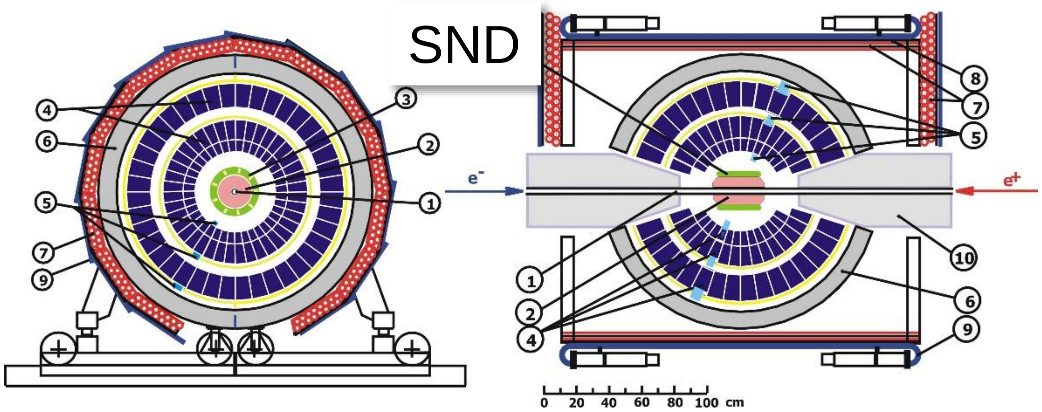
BaBar

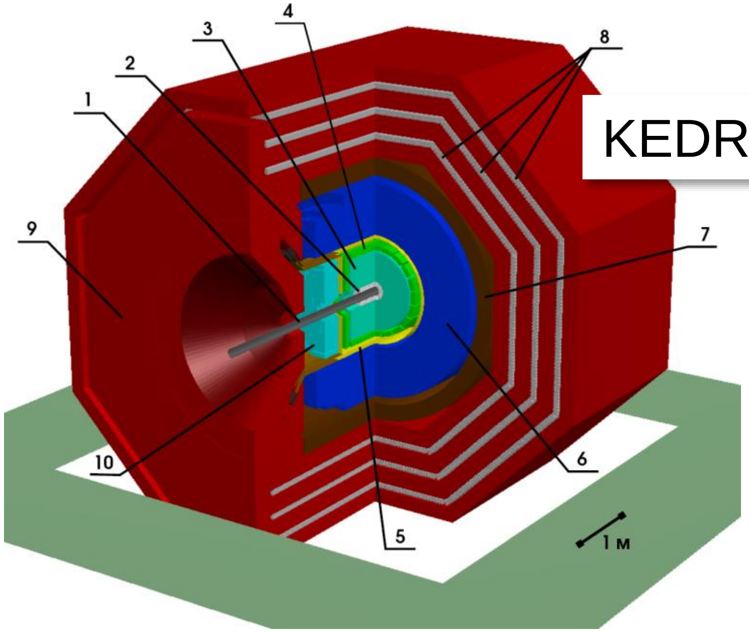


CLEO-c

In-house (Novosibirsk) cousins



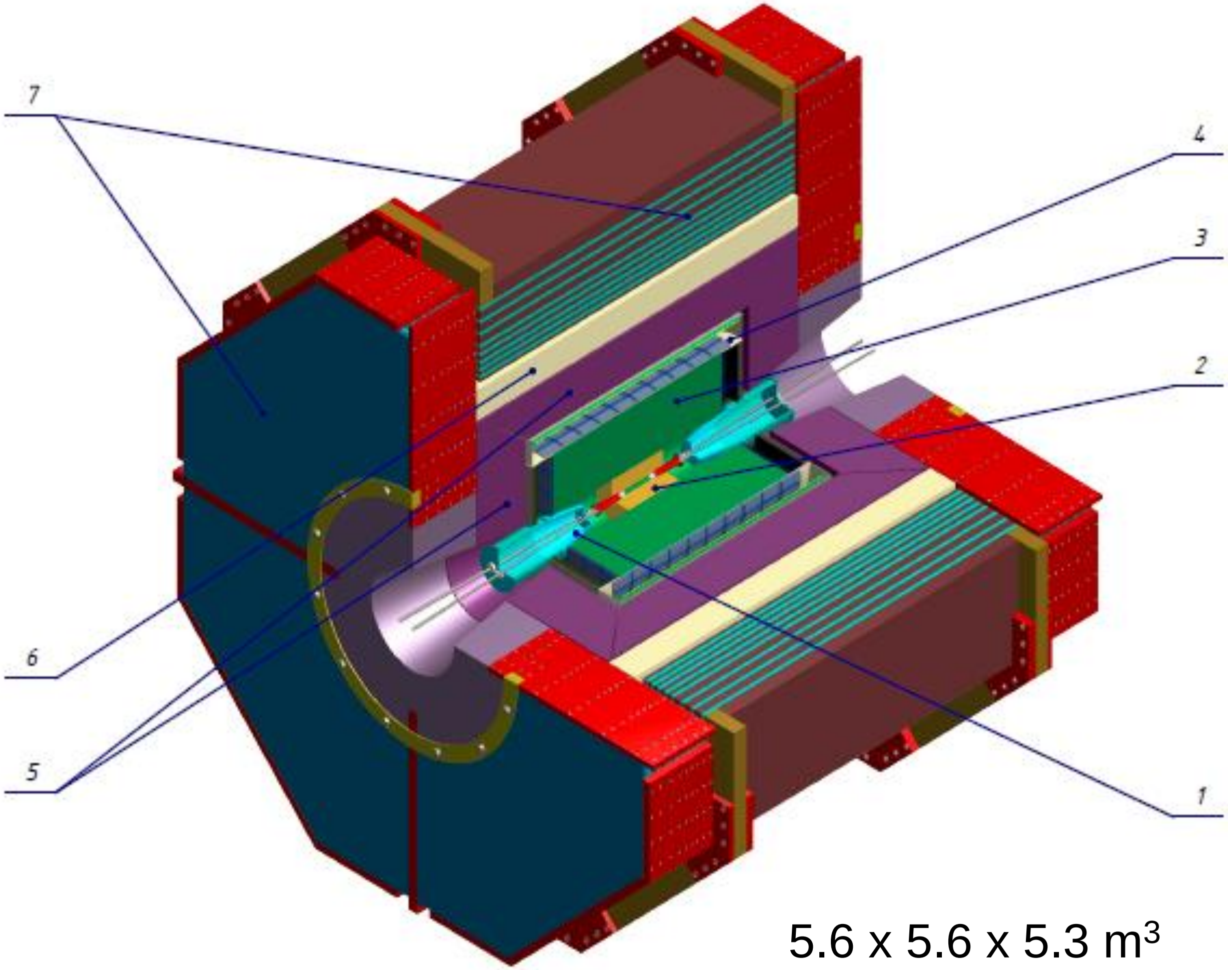




Detector requirements

- Momentum resolution $\sigma_p/p \leq 0.4\%$ at 1 GeV
- Very symmetric and hermetic
- Able to detect soft tracks ($p_t \geq 50\ MeV/c$)
  - Inner tracker should be able to handle 10^4 tracks/cm^{2}s
- Very good particle identification: $e/\mu/\pi/K$
  - π/K in the whole energy range, e.g. for $D\bar{D}$ mixing
  - μ/π up to 1.5 GeV, e.g. for $\tau \to \mu\gamma$ search
  - dE/dx better than 7%
- Able to detect γ from 10 MeV to 3 GeV, good π^0/γ separation
  - Calorimeter energy resolution $\sigma_E/E \leq 1.8\%$ at 1 GeV
  - Calorimeter time resolution $\sigma_t \leq 1$ ns
- Efficient "soft" trigger
- Ability to operate at high luminosity, up to 300 kHz at J/ψ

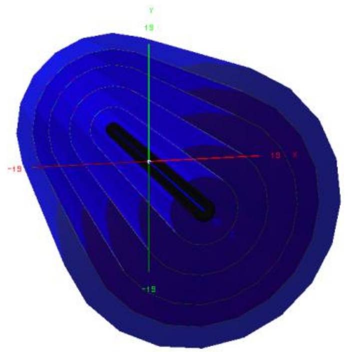
General layout



5.6 x 5.6 x 5.3 m^3

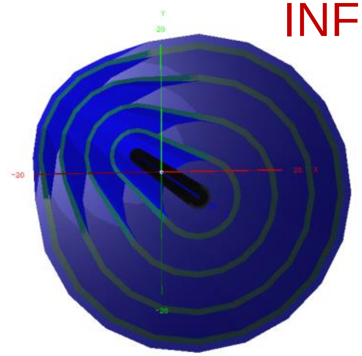
1. Vacuum pipe
2. Inner tracker
3. Drift chamber
4. PID
5. Calorimeter
6. SC magnet
7. Muon system

Inner tracker options



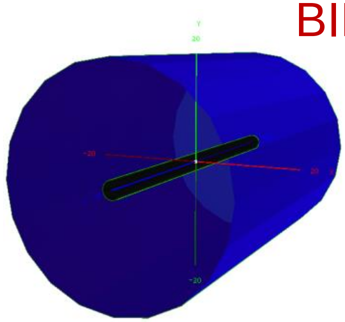
4-layer Si-strip

INFN



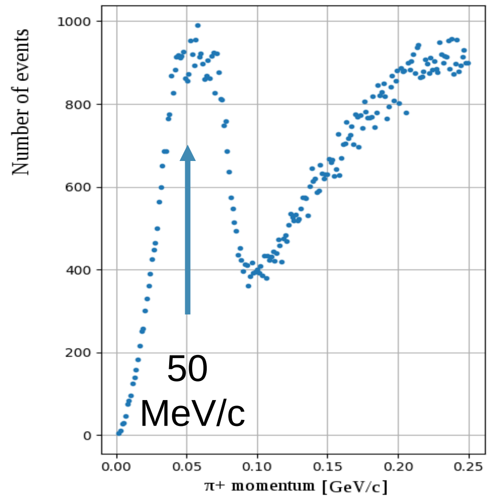
Cylindrical MPGD

BINP



Time Projection Chamber (TPC)

- Resolution similar to drift chamber ($\sim 100\ \mu$)
- Sensitive to particles with low p (~ 50 MeV/c)
- Compatible with final focus constraints
- Able to handle high particle flux
- Approximate size:
  Ø (40-400) x 600 mm



$p(\pi^+)$
in $e^+e^- \longrightarrow DD^*$

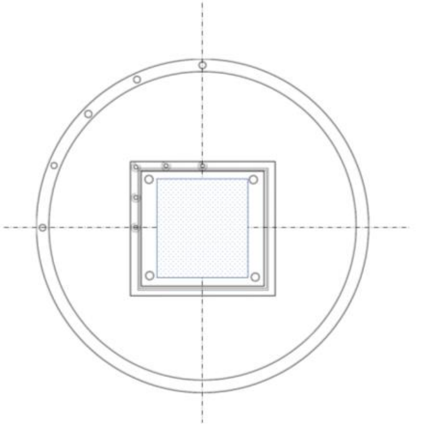
Inter tracker: TPC (BINP)

TPC advantages:

- Highest number of hits per track
- Great dE/dx measurement

Ability to operate in high flux (including reconstruction) have to proved

On the way to first prototype



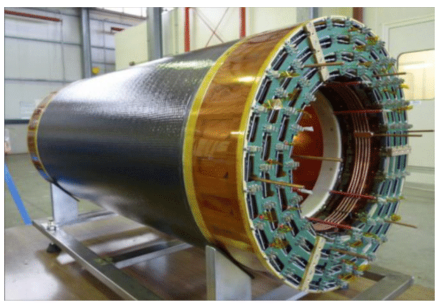
Inner tracker: CMPGD (INFN – Ferrara, Frascatti)

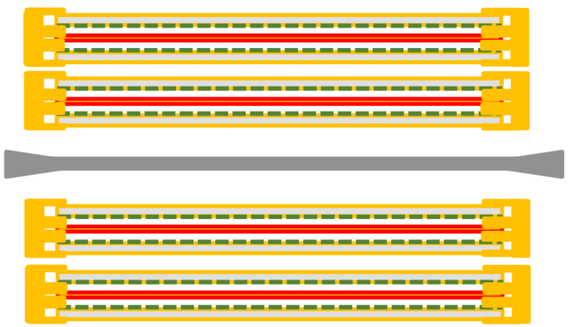
preliminary

- N. 4 independent C+layers → 1.9÷2.5% X0
- 1 cm gas gap/layer
- 4 cm global sampling gas

- N.2 small gap B2B C+layers → 1.5÷1.9% X0
- 2 × 1 cm gas gap/B2B device
- 4 cm global sampling gas

- N.1 large gap B2B C+layers → 0.75÷0.95% X0
- 2 × 5 cm gas gap/B2B device
- 10 cm global sampling gas





Operation of large gas gap radial TPC to be verified

Material budget estimated taking into account different material choices for the mechanics, cathode and faraday cage.
All these layouts require the design, construction and test of a C+RWELL prototype.
The prototype under discussion is based on the innovative concept of the **modular roof-tile shaped detector.**

A Radial Time Projection Chamber for α detection in CLAS at Jlab, R. Dupré et al., 10.1016/j.nima.2018.04.052

CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

4

Several sub-options are being developed. Parallel activity: endcap tracker disks for CMD-3 detector, based on micro-RWELL technology.

Main tracker: drift chamber

Measurement of momentum and dE/dx (PID)

- Spatial resolution ~100 μ
- Small cell
- Minimal material (reduce MS)
- Approximate size: Ø (400-1600) x 1800 mm

“Traditional” option BINP	**“Beyond-traditional” option** INFN
Babar, BES-3, Belle-2	KLOE, MEG-2, IDEA
Axial and stereo superlayers	Full stereo
Traditional dE/dx	dE/dx by cluster counting
Feed-through wiring	Robotic wiring

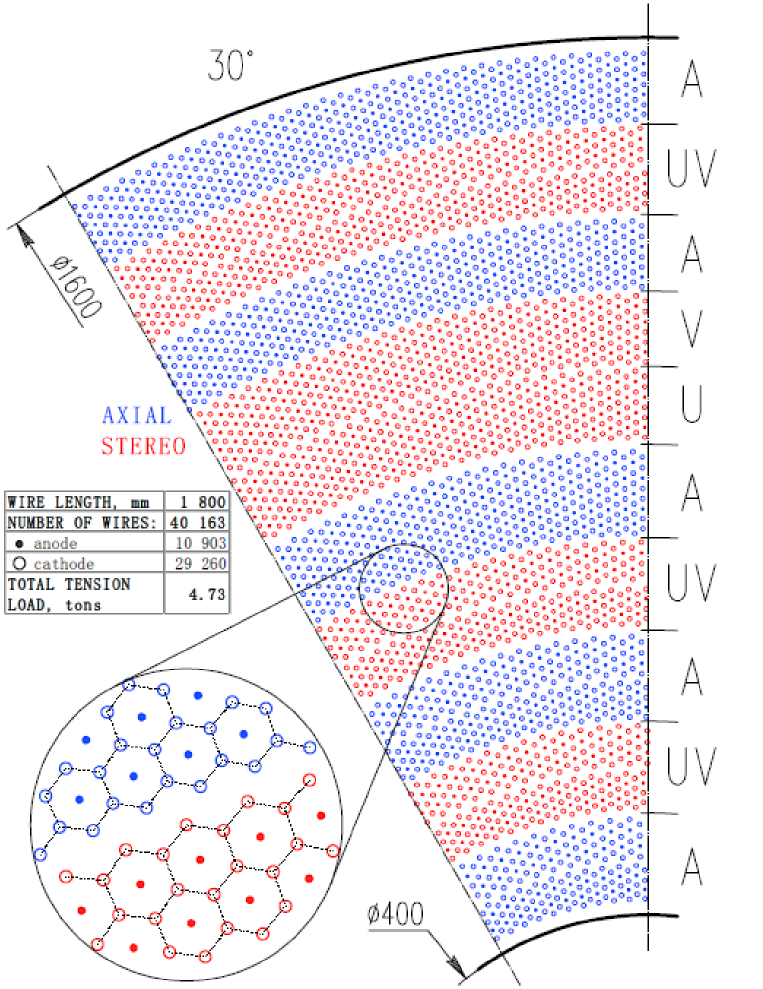
Drift chamber: “traditional” option (BINP)

- ~40000 wires
  - 11k sensitive, W-Rh(Au)
  - 29k field, Al(Au)
- Hexagonal cell, 6.3-7.5 mm
- 41 layers
- 60% He + 40% C_3H_8
- 330 ns drift time (1.5 T)

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

≈0.4% at 1 GeV

$$\frac{\sigma_{dE/dx}}{dE/dx} \approx 6.9\%$$

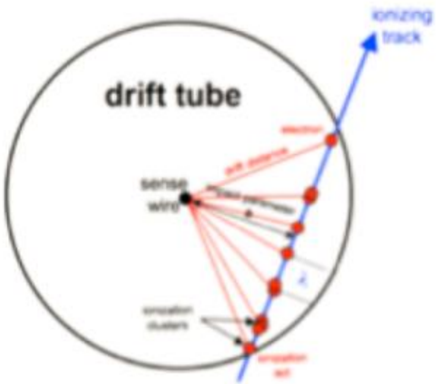


WIRE LENGTH, mm	1 800
NUMBER OF WIRES:	40 163
● anode	10 903
O cathode	29 260
TOTAL TENSION LOAD, tons	4.73

I.Yu.Basok et al., NIM A1009 (2021) 165490

Drift chamber: TraPid option (INFN)

- ~141000 wires
  - 23k sensitive, W
  - 117k field, Al (→ C)
- Square cell, 7.2-9.1 mm
- 64 layers
- 90% He + 10% iC_4H_{10}



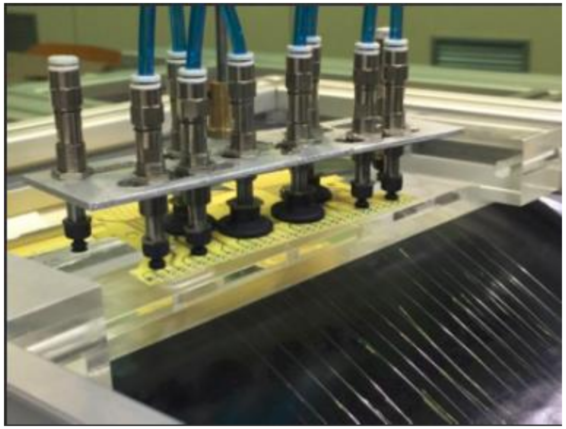
Measurement of individual clusters improves time and dE/dx resolution

$$\frac{\sigma_{p_t}}{p_t} \approx \sqrt{0.078\%^2 p_t^2 + 0.18\%^2}$$

≈0.2% at 1 GeV

$$\frac{\sigma_{dN/dx}}{dN/dx} \approx 3.6\%$$

With room for improvement!



Robotic wiring developed for MEG-2

Drift chamber: TraPid option (INFN)

INFN teams

INFN Bari

M. Abbrescia
R. Aly
N. De Filippis
D. Diacono
G. Donvito
W Elmetanawee
G. Iaselli
M. Maggi
I. Margjeka

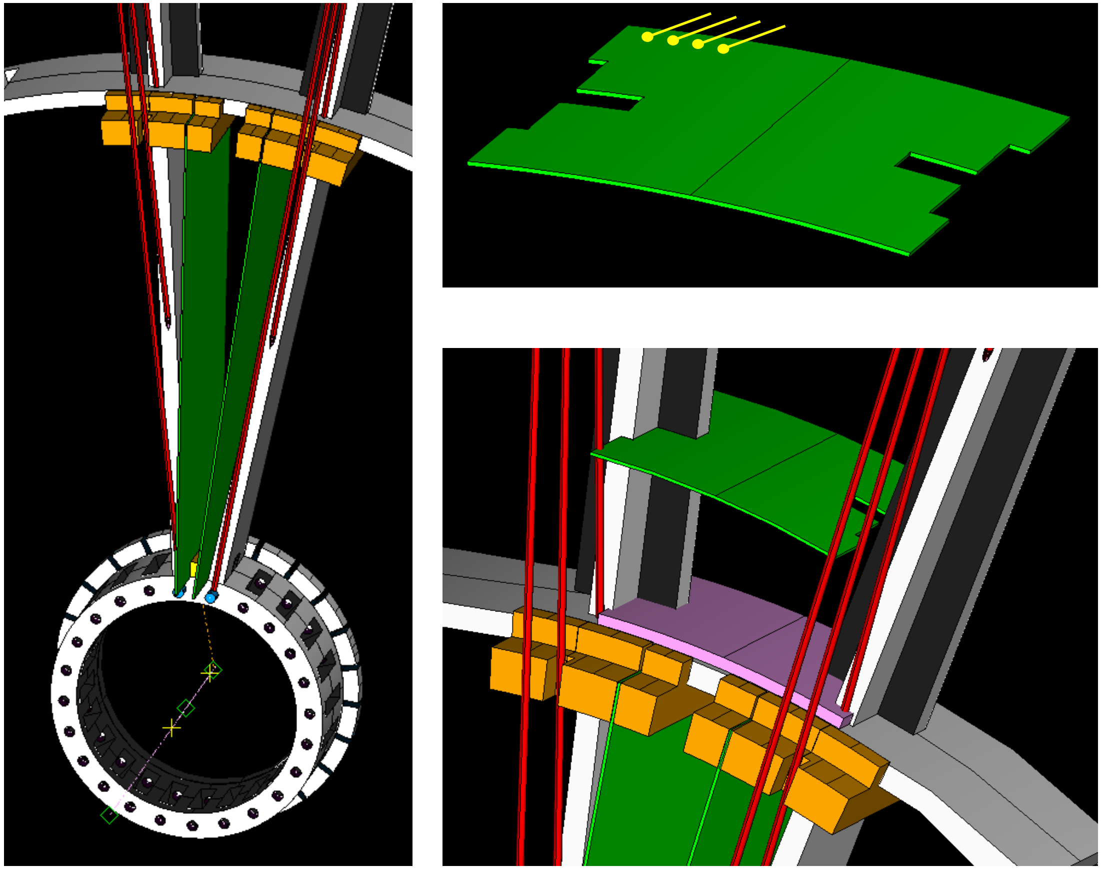
INFN Lecce

A. Corvaglia
G. Chiarello
F. Cuna
E. Gorini
F. Grancagnolo
A. Miccoli
M. Panareo
M. Primavera
G. Tassielli
A. Ventura

Mechanics, wiring, test beam, simulations…

BINP

Preamp ASIC, wire coating, simulations,…



Plan to create smaller-size DC for CMD-3 as a prototype

Particle identification

Requirements for PID system

- π/K separation $> 4\sigma$ up to 2.5-3.0 GeV/c

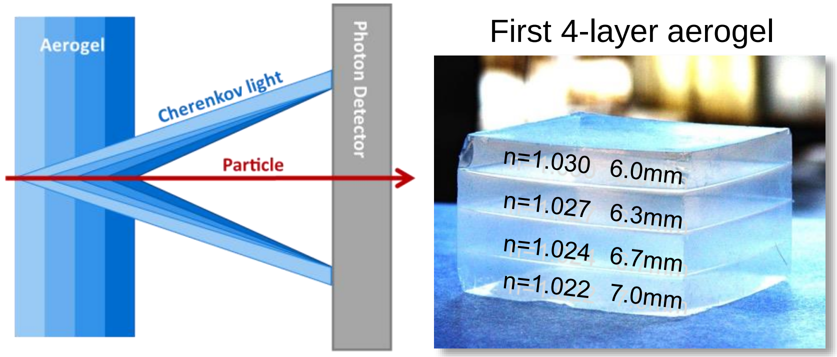
  TOF (BES-3): 3σ at 0.9 GeV/c, DIRC (BaBar): 4σ at 2.5 GeV/c

  ASHIPH (KEDR): 4σ at 1.5 GeV/c
- μ/π suppression ~1/40 for to 0.5-1.2 GeV/c
- good μ/π separation at low momentum

Several option are being considered:

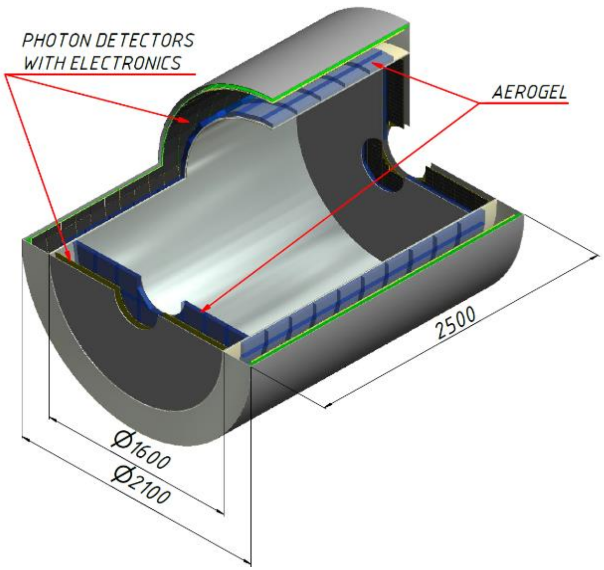
FARICH, ASHIPH, TOF, DIRC

PID: FARICH option (BINP)



Variable n allows to increase N_{pe} using thicker radiator without compromising $\sigma_{\Theta c}$

First detector: Belle-II (ARICH)



T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70
A.Yu. Barnyakov, et al., NIM A 732 (2013) 35

- Proximity focusing RICH
- 4-layer or gradient aerogel radiator n_{max} = 1.05 (1.07?), thickness 35 mm
- 21 m^2 total photon detector area
  - SiPMs in barrel (16 m^2)
  - MCP PMTs in endcaps (5 m^2)
- ~10^6 pixels with 4 mm pitch

2012 test beam: μ/π separation ≥3σ at P=1 GeV/c is demonstrated

PID: FDIRC options (JLU, Giessen)

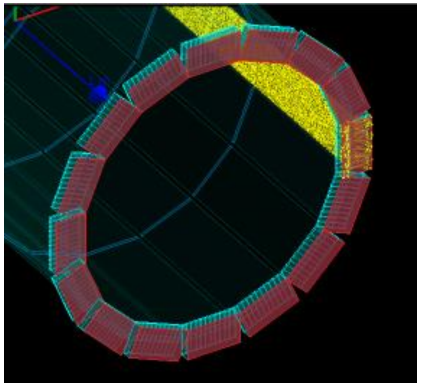
FDIRC option

- Inspired by design from BaBar, SuperB, Belle II, and PANDA
- For PANDA $\sigma_{\Theta_c} \approx 2.1$ mrad/track is achieved for π/K with 3σ@4 GeV/c
- For SCTF $\sigma_{\Theta_c} \approx 0.7$ mrad/track is required for μ/π with 3σ@1.5 GeV/c

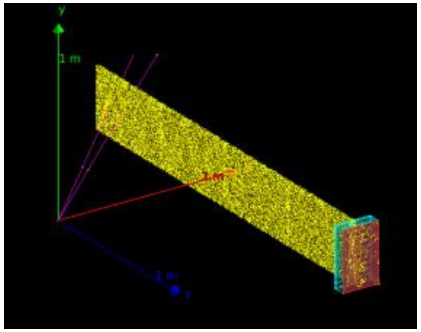
Main parameters:

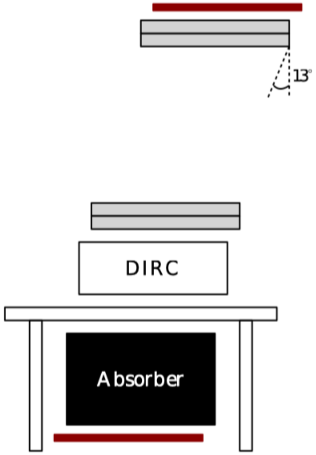
- Synthetic fused silica:
  Barrel: 2×16 plates $110\times32\times1.5$ cm
  Endcap: 2×4 sectors $1\div2$ cm thick
- Focusing optics: innovative rad-hard 3-layer spherical lens
- MCP-PMT or SiPM with $\sigma_t \leqslant 100$ ps
  Barrel:
  - $\square 2\div3$ mm pixel
  - $2.56\div1.14\cdot10^5$ readout channels

  Endcap:
  - 16×0.5 mm pixel
  - $2.88\cdot10^4$ readout channels

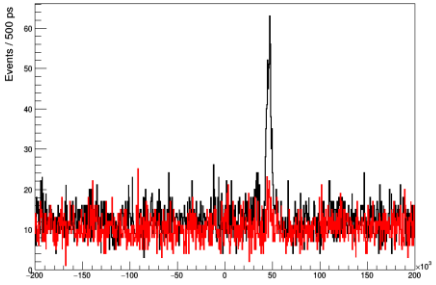


2×16 plates $110\times32\times1.5$ cm^3 and 2×16 expansion volumes $32\times20\times10$ cm^3

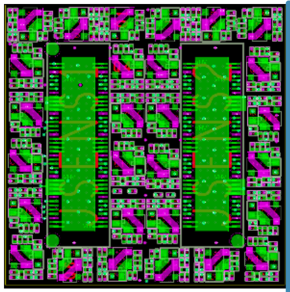




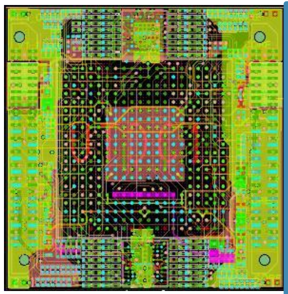
Giessen cosmic station (GCS)



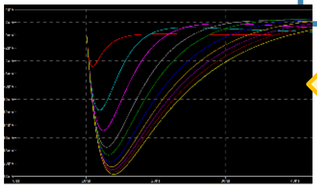
Compact FEE for FARICH/DIRC



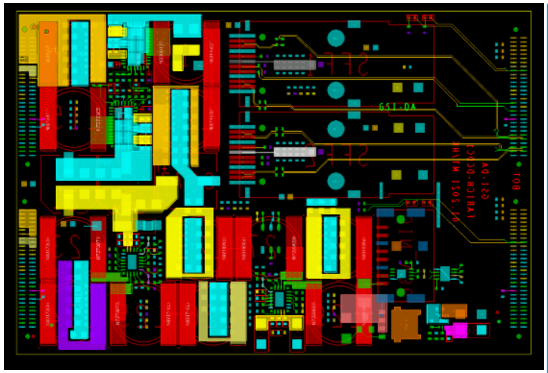
Amplifier board
- 27×27 mm^2 size
- 14-layer PCB
- 30x gain, 64 channels
- couples to KETEK 8×8 SiPM array



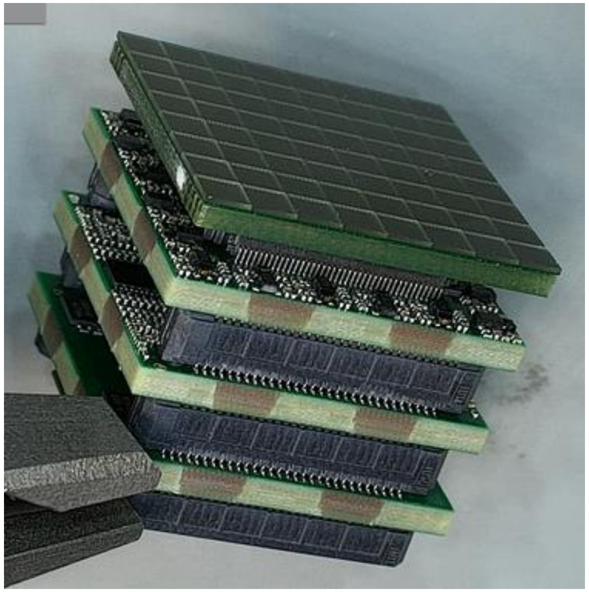
TDC board
- 64 channels
- 2 TDC + 4 threshold FPGAs
- 10ps precision



Simulated single photon pulse shapes from amplifier for different input resistance. ~ 22mV amplitude can be achieved.

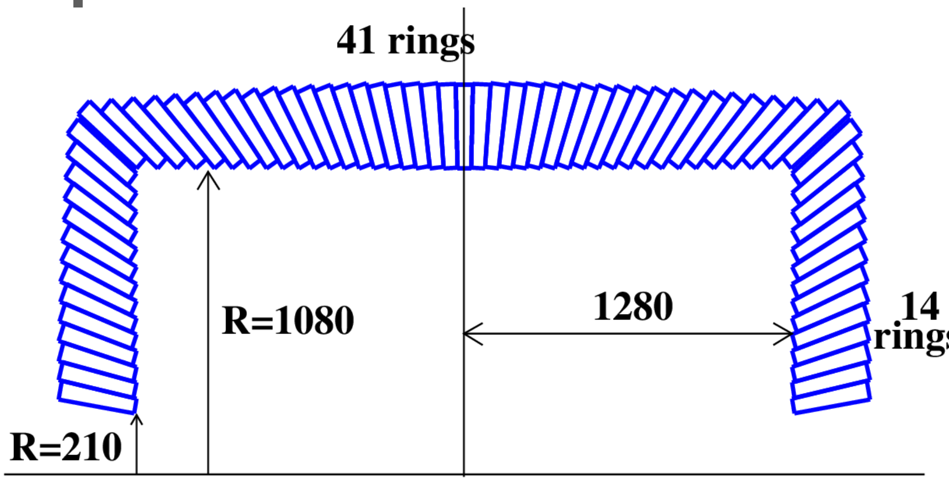


DC-DC convertor board
- goes behind the backplane
- 51×84 mm^2 size
- provides power to SiPMs, amplifiers, FPGA
- uses air inductive coils to operate in the detector magnetic field
- power, trigger & clock connectors

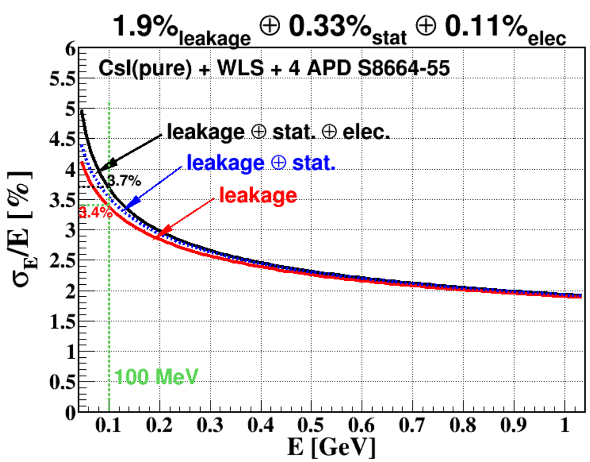


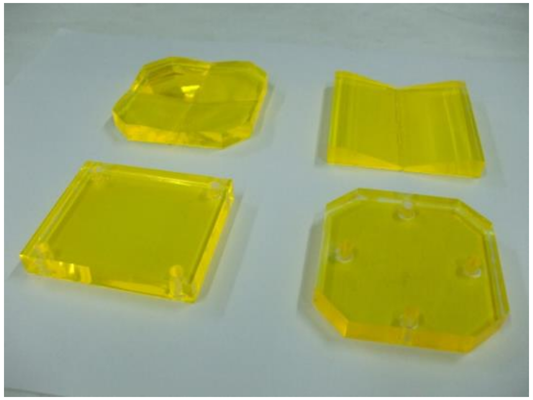
Calorimeter: pCsI option

- 7424 crystals, 16/18 X_0
  - 5248 in barrel
  - 2176 in endcap
- 5.5 x 5.5 x 30(34) cm
- pCsI+WLS+4 APD



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

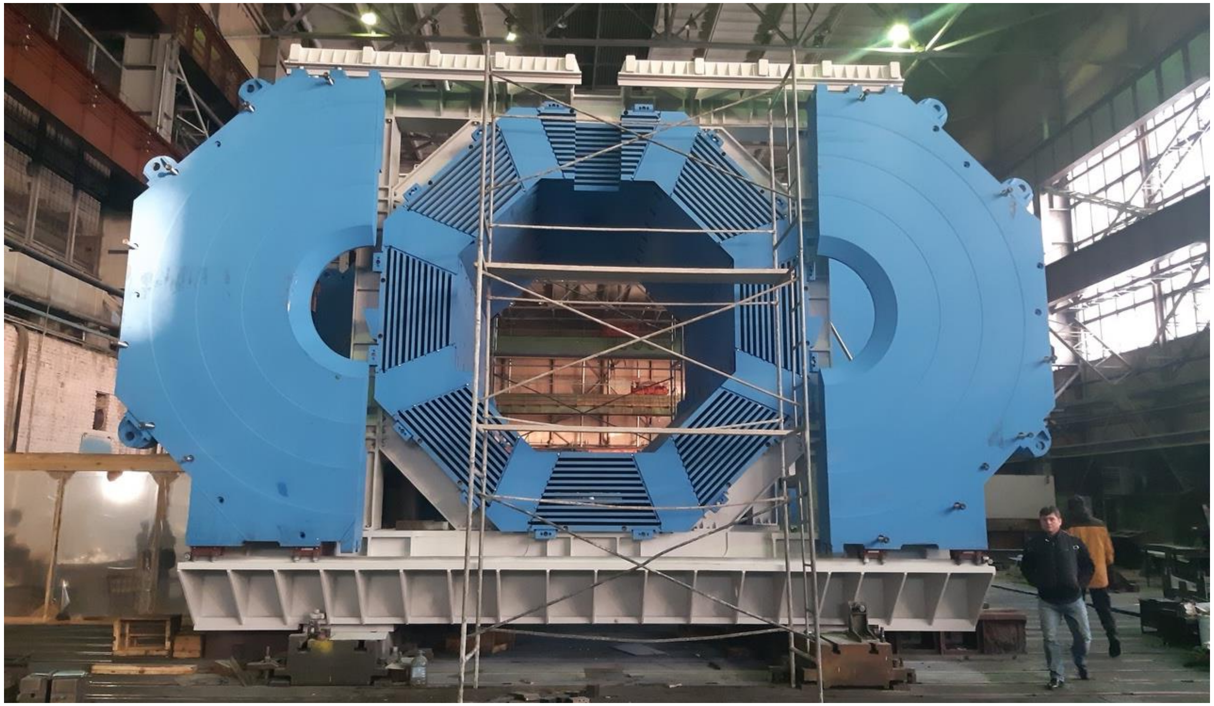




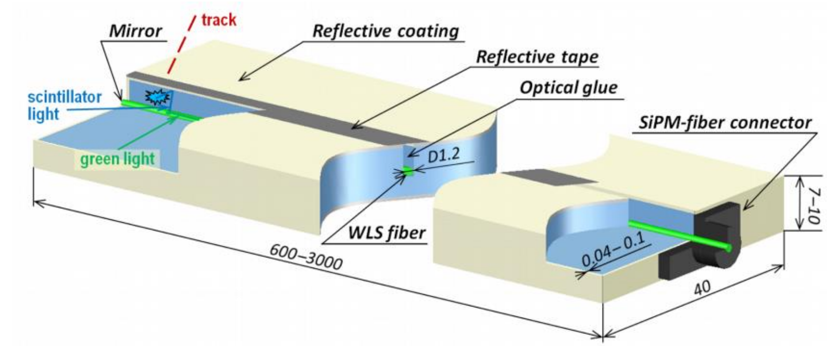
This option is being prototyped and optimized

Magnet

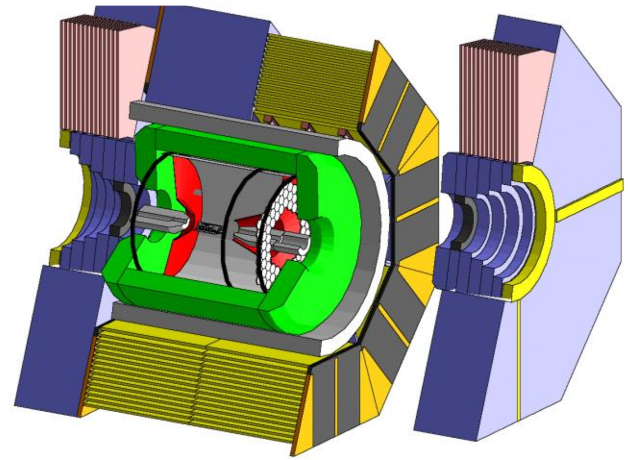
- BINP is now building SC magnet for PANDA detector
  - Yoke is finished
  - Technology for cable production is being developed (in Russia)
- SCTF magnet is very similar in size and design



Muon system



- detect muons
  - mult.scat. of O(1cm)
- μ/π separation
- K_L detection



BELLE-2

Baseline option:

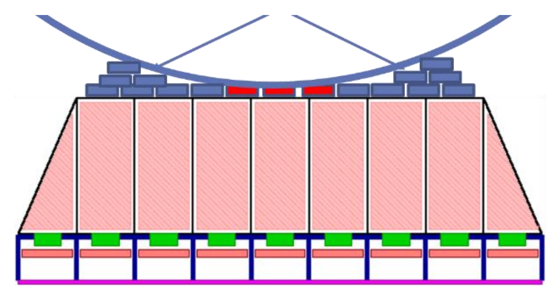
scintillator strips + WLS fiber + SiPM

(BELLE-2, CMD-3)

8-9 layers inside iron yoke

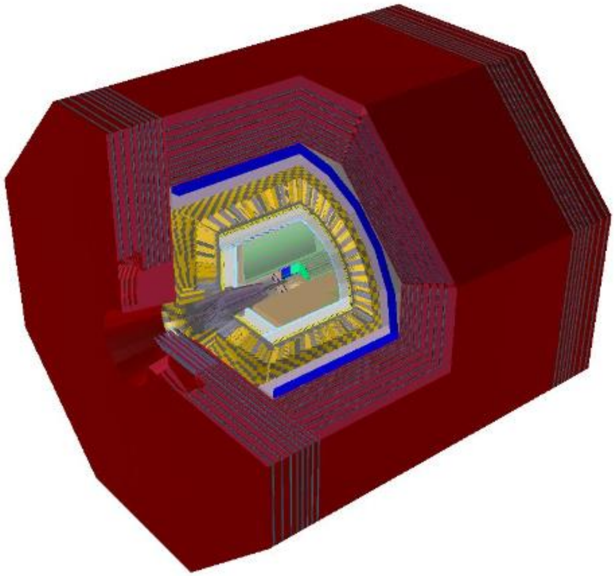
~1500 m^2

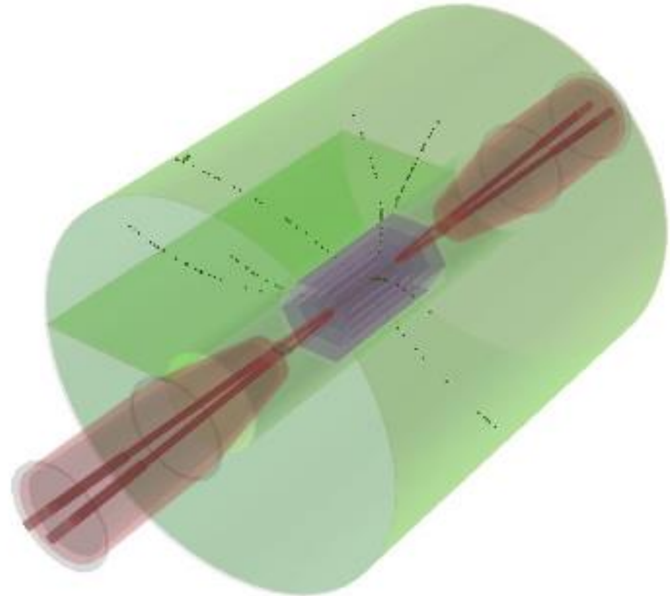
CMD-3

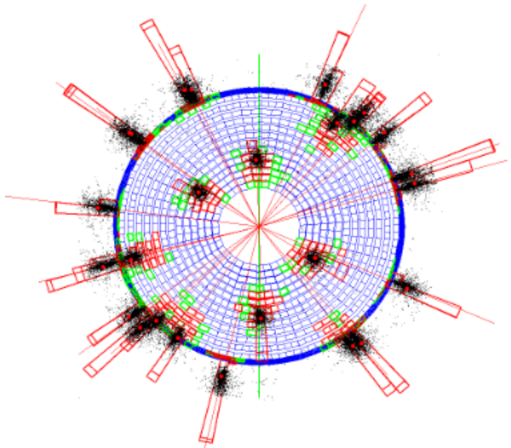


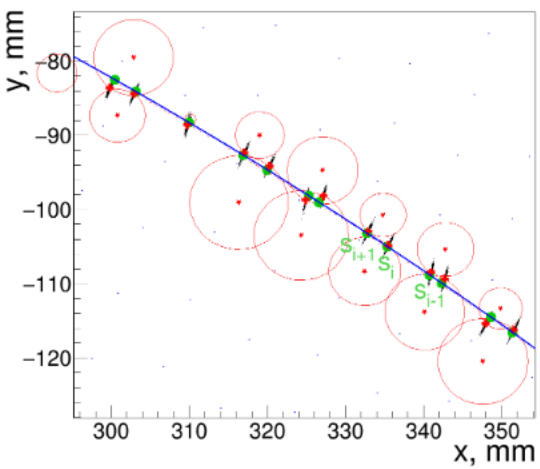
Simulations

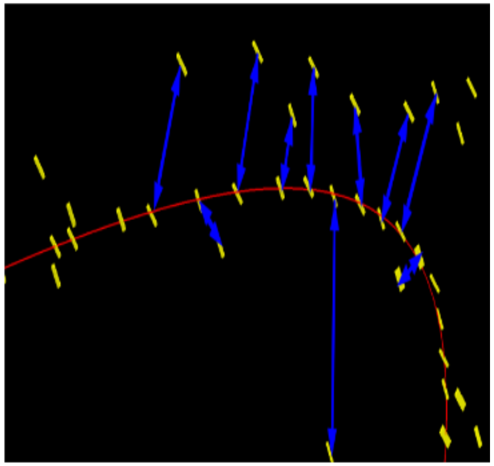
vCHEP 2021: https://indico.cern.ch/event/948465/contributions/4324160/
GRID 2021: https://indico.jinr.ru/event/1086/contributions/13280/









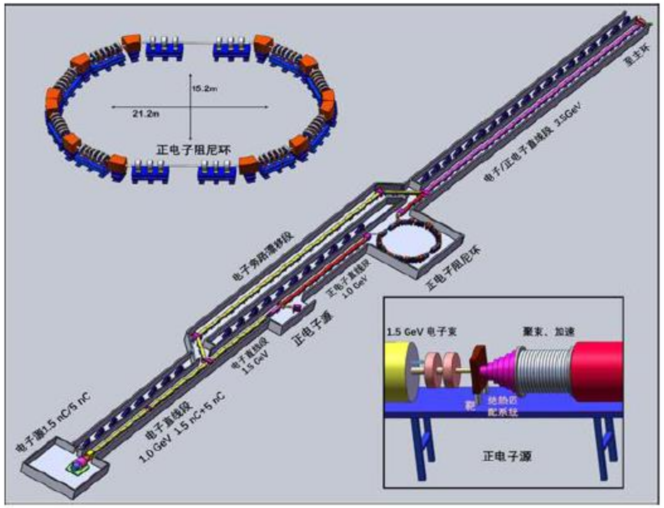


Super Tau-Charm Facility (STCF) in China

Possible locations:

- USTC, Hefei
- IMP, Huizhou

- Peaking luminosity >0.5×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2-7 GeV
- Potential to increase luminosity and realize beam polarization
- A nature extension and a viable option for China accelerator project in the post BEPCII/BESIII era



1 ab^{-1} data expected per year

2

There is regular communication between SCTF and STCF

Making SCTF a reality

Building the collaboration

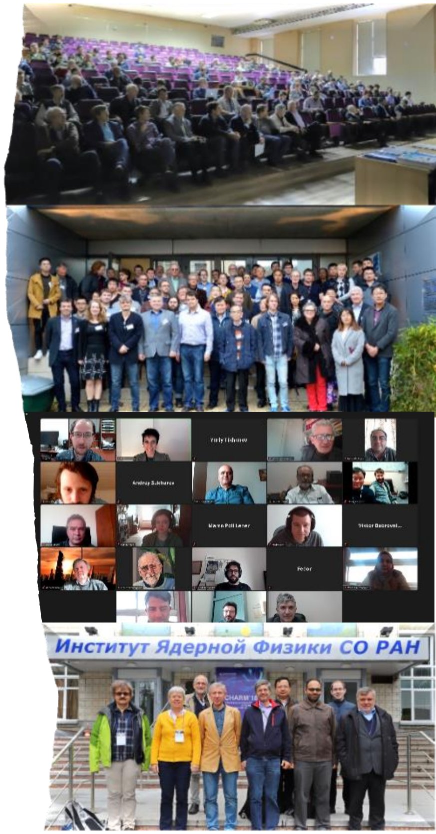
Working groups

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

- International advisory committee
  (from 2017, 13 experts, Italy, CERN, USA, Russia, China, Spain, Germany, Mexica, Poland)

- Dedicated international workshops
  - December 2017, Novosibirsk
  - March 2018, Beijing
  - May 2018, Novosibirsk
  - December 2018, Orsay
  - November 2019, Moscow
  - November 2020, Hefei (online)
  - Fall 2021, Novosibirsk (online)

Collaborators are very welcome!



CDR and other info: http://ctd.inp.nsk.su

By the end 2021 we plan to establish a more formal proto-collaboration

CREMLINplus

CREMLIN PLUS
Connecting Russian and European Measures for Large-scale Research Infrastructures

- Grant within Horizon 2020
- From 2020 to 2024
- SCTF development is one of the working packages
  - Internationalization
  - Collider development
  - Software development
  - Detector development
- Partners:
  1. CERN
  2. INFN (Ferrara, Bari, Lecce, Frascati)
  3. IJCLab (Orsay)
  4. JLU (Giessen)
  5. BINP

SCTF in the global particle physics landscape

Eurostrategy

- 2020: update of European Strategy in particle physics
- Role of SCTF in flavour sector is discussed in Physics Briefing book: arXiv:1910.11775 [hep-ex]

Snowmass2021

- Snowmass 2021 Letter of Interest was submitted
- Signed by physicists from 38 organizations (10 from Russia)
- We are working on contributed papers (together with updating CDR)

Location: Sarov

Super c-tau factory is now planned to be located near Sarov as the key megascience research infrastructure of the new National Center for Physics and Mathematics

- National Center for Physics and Mathematics was established near Sarov at the end of 2020
- Sarov Branch of Moscow State University is already created
- Russian Research Institute for Experimental Physics (ВНИИЭФ) and BINP are working with related government agencies and officials to get the official start of the project

Conclusion

- There is rich physics program of experiments at Super c-tau factory
- Super c-tau factory is deeply integrated in the global landscape of particle physics
- The project is well developed
- SCTF is proposed to be built near Sarov as the part of recently established National Center of Physics and Mathematics
- International collaboration is vital for the success of the project

We hope to interest some of you to join the collaboration!

Backup slides

Machine-detector interface