PID system based on Focusing Aerogel RICH for Super c-τ Factory.

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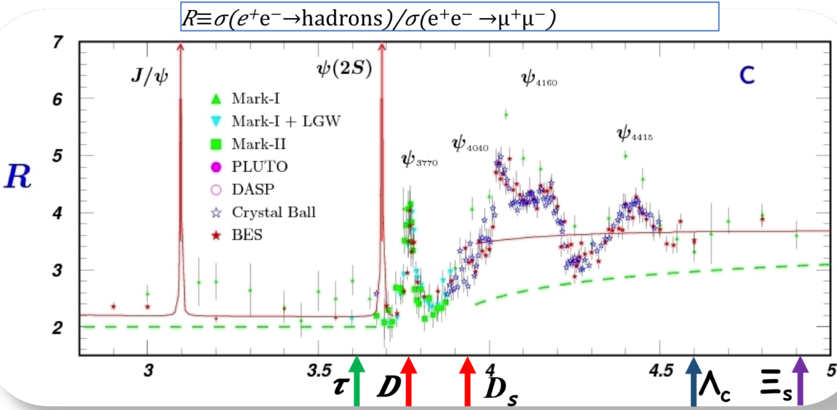
1. SCTF project
2. PID system requirements
3. Aerogel
4. FARICH method
5. Protoypes & beam tests results
6. Summary



R≡σ(e⁺e⁻→hadrons)/σ(e⁺e⁻→μ⁺μ⁻)
R
J/ψ
ψ(2S)
ψ3770
ψ4040
ψ4160
ψ4415
C
Mark-I
Mark-I + LGW
Mark-II
PLUTO
DASP
Crystal Ball
BES
2
3
4
5
6
7
3
3.5
4
4.5
5
τ
D
Ds
Λc
Ξs

Charmonia

- Spectroscopy
- Decays
- Light hadron states study

Charmed mesons

- Spectroscopy
- Decays
- *CP*-violation

Charmed baryons

- Decays
- *CP*-violation

$$\sigma(e^+e^- \to hadr)$$

$\gamma\gamma$-physics

- Search for C-even resonance
- $\sigma(\gamma\gamma \to hadr)$

τ-lepton

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- LFV
- Check of lepton universality

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Requirements to Collider

- Luminosity at least in 50 times more than at BES-III
- Energy spread (σ_E) ~1 MeV
- Energy range 2÷5 (7?) GeV
- Longitudinal e^- polarization at IP

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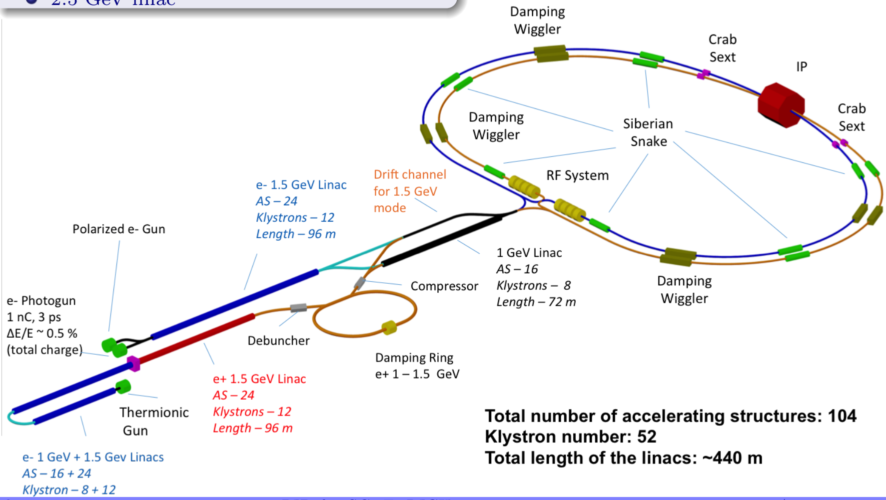
Requirements to Detector

- Good energy and momenta resolution
- High efficiency of soft track detection
- High PID quality (π/K, μ/π-separation is needed)
- Minimal *CP*-asymmetry
- Capability to work with load ~ 300 kHz of physics events

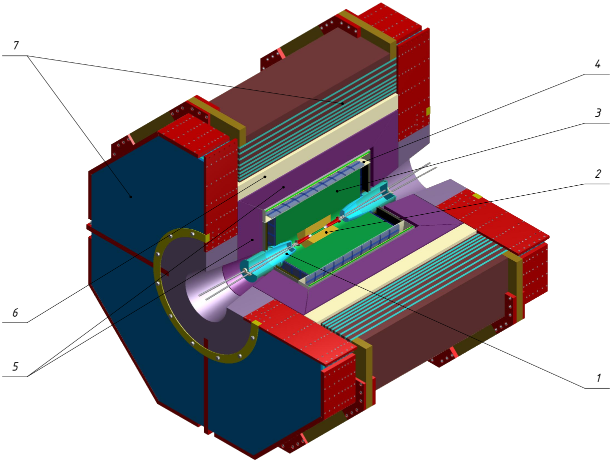
Main solutions

- Double ring collider
- Crab waist collisions
- 5 Siberian Snakes →~80% Pol.Lev.
- 2.5 GeV linac



Total number of accelerating structures: 104
Klystron number: 52
Total length of the linacs: ~440 m

Energy	1.0 GeV	1.5 GeV	2.0 GeV	2.5 GeV
Circumference	813.1 m			
Emittance hor/ver	8 nm/0.04 nm @ 0.5% coupling			
Damping time hor/ver/long	50/50/25 ms	30/30/15 ms		
Bunch length	21 mm	12 mm	10 mm	10 mm
Energy spread	$8.7\cdot10^{-4}$	$11\cdot10^{-4}$	$9.3\cdot10^{-4}$	$7.2\cdot10^{-4}$
Momentum compaction	$8.73\cdot10^{-4}$	$8.81\cdot10^{-4}$	$8.82\cdot10^{-4}$	$8.83\cdot10^{-4}$
Damping wiggler field	50 kGs	50 kGs	35 kGs	10 kGs
Synchrotron tune	0.007	0.012	0.009	0.008
RF frequency	499.95 MHz			
Harmonic number	1356			
Particles in bunch	$7\cdot10^{10}$			
Number of bunches	406 (10% gap)			
Bunch current	4.2 mA			
Total beam current	1.7 A			
Beam-beam parameter	0.135	0.135	0.121	0.097
Luminosity	$0.6\cdot10^{35}$	$0.9\cdot10^{35}$	$1.0\cdot10^{35}$	$1.0\cdot10^{35}$



1. CVC
2. Inner tracker
3. Drift chamber
4. PID system
5. Calorimeter
6. SC coil (B$\sim$1 T)
7. Yoke and MU system

Requirements

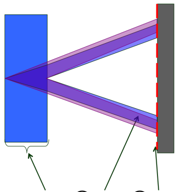
- π/K-separation from 0.6 to 2.5 GeV/c
- μ/π-separation from 0.4 up to 1.5 GeV/c

π/K-separation

Threshold Cherenkov aerogel counters (n~1.03÷1.05) or TOF ($\sigma_t \lesssim 50$ ps) are adequate for energy region of SCTF.

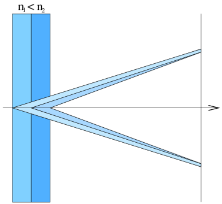
μ/π-separation

It is possible to provide separation for momenta below 900 MeV/c with help of combination of TOF counters (with 30 ps time resolution and extra light aerogel (n~1.008) threshold Cherenkov counters. For momenta above 900 MeV/c Muon system provides some μ/π-separation. More brilliant idea is to use proximity Focusing Aerogel RICH!



$$\sigma_{\theta,1\gamma} = \sigma_{ep} \oplus \sigma_{ch} \oplus \sigma_{px}$$

Proximity focusing single layer RICH



Proximity focusing multilayer RICH

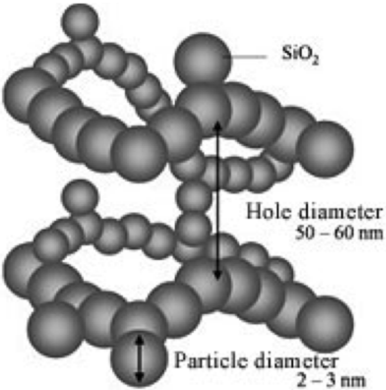
Lower refractive index provides more $\Delta\Theta_c$.
It leads to lower number of photons.
To increase N_{phot} without angle resolution degradation focusing is needed.

Main aerogel properties:

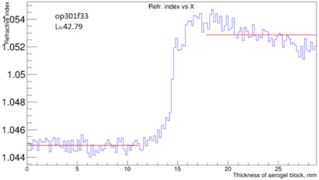
- Refraction indices 1.006÷1.20;
- Inner surface 800 m^2/g;
- L_{abs}(400nm)=5÷7 m;
- L_{sc}(400nm)=4÷6 cm;

Aerogel production in Novosibirsk

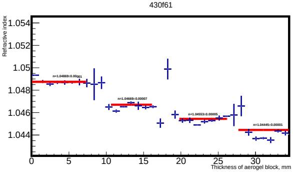
- It started in 1986 (IC&BINP);
- Aerogel for threshold counters:
  - n=1.008 for DIRAC-II (PS–CERN);
  - n=1.05 for KEDR (VEPP-4M);
  - n=1.13 for SND (VEPP-2000).
- Aerogel for RICH counters:
  - n=1.03 for LHCb (LHC-CERN);
  - n=1.05 for AMS-02 (ISS) & CLAS-12 (J-Lab);
- Modern production activity:
  - Blocks dimensions 200×200×30(20) mm;
  - L_{sc} ⩾4.5 cm;
  - 2 m^2/year aerogel;
  - Multilayer (20÷30) monolithic samples have been producing since 2004.



Aerogel structure

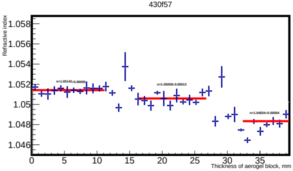


2-layers aerogel with “focus” at 20 cm

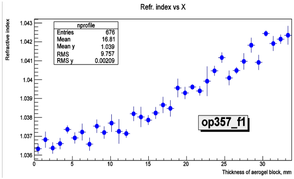


4-layers aerogel with “focus” at 20 cm

The distribution of refractive index inside the aerogel tile is measured by means of digital x-ray radiography.



3-layers aerogel with “focus” at 60 cm



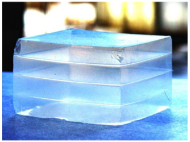
“Gradient” focusing aerogel

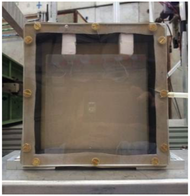
Beam test at CERN PS/T10 in 2012

- Positive polarity: e^+, μ^+, π^+, K^+, p
- Momentum: 1÷6 GeV/c
- Trigger: a pair of sc. counters 1.5×1.5 cm^2 in coincidence separated by ~3 m
- No external tracking, particle ID, precise timing

Aerogel

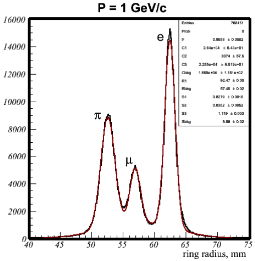
- 4-layer
- $n_{max} = 1.046$
- Thickness 37.5 mm
- Focal distance 200 mm

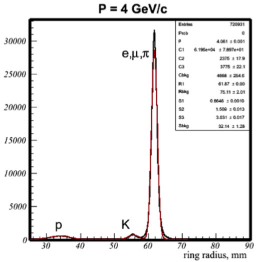


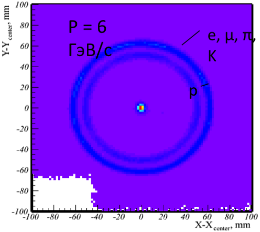


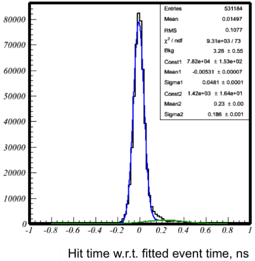
DPC matrix 20×20 cm

- Sensors: DPC3200-22-44
- 3×3 modules = 6×6 tiles = 24×24 dies = 48×48 pixels
- 576 time channels
- 2304 amplitude (position) channels
- Operation temperature is -40°C to suppress dark count rate
  - Dead time is 720 ns
  - DCR(+25°C)≈10 Mcps/sensor single photon detection is not feasible!
  - DCR(-40°C)≈100 kcps/sensor inefficiency is 7%

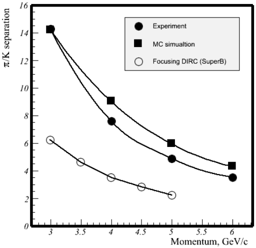




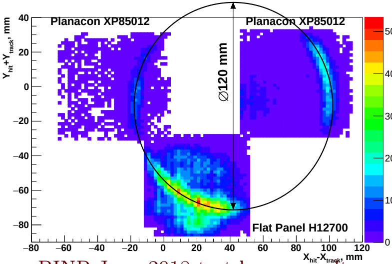




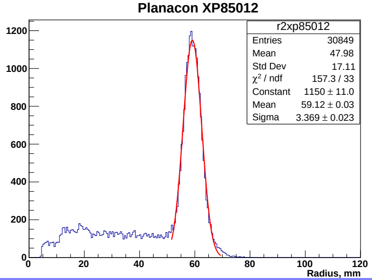
- $S(\pi/K) = \frac{R_\pi - R_K}{\sigma_{R\pi}}$
  - π/K: 7.6σ at 4 GeV/c;
  - μ/π: 5.3σ at 1 GeV/c;
- N_{pe}=12;
- σ_t=48 ps for single photon;

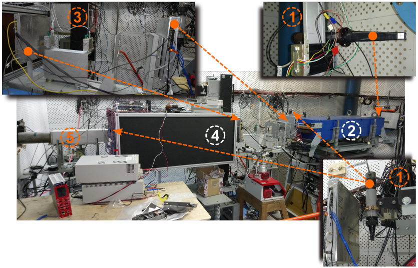


- Determine critical moments in focusing aerogel production;
- Define optimal photon detector type and producer for SCTF;
- Find solution for readout electronics.



BINP June 2018 test beam results



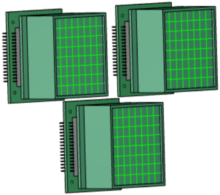


3×64 anodes PMTs with 6 mm pixel;

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 calorimeter is aplied;

Impact to angle resolution from pixel size ~1.7 mm.
To avoid this impact it is possible to use mask:



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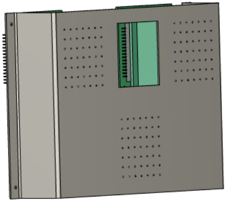

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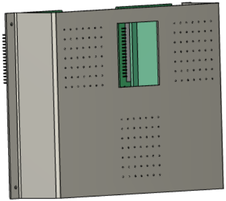
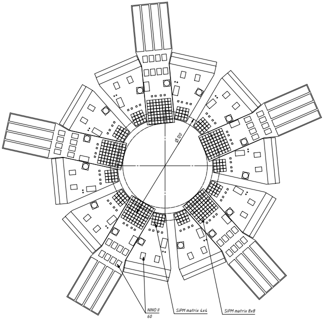
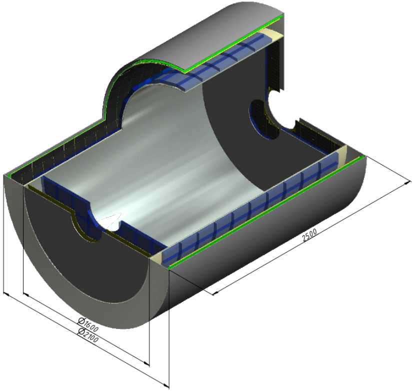




- For prototype based on analogue SiPMs we have 10 matrixes ArrayJ-30035-16P-PCB and 4 matrixes ArrayJ-30020-64P-PCB (SensL).
- Readout board based on NINO-II chip is under development.
- The 32-channel TDC based on Altera Cyclone III FPGA is developed in BINP.

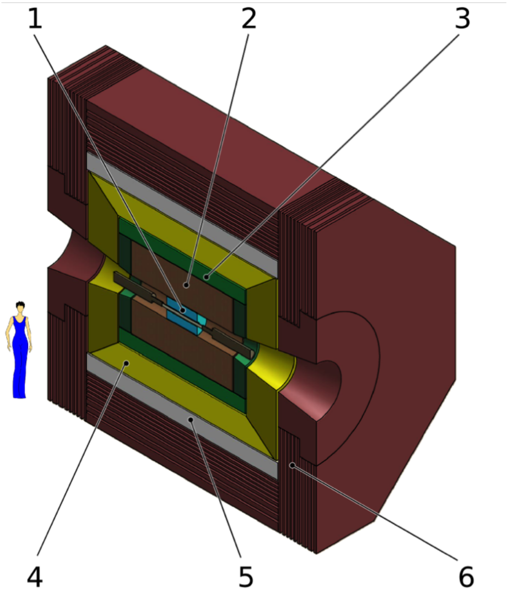


System sketch

Main parameters:

- Focusing aerogel with $n_{\max}$=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 – SiPM, MCP PMT? (5 m^2)
- 1÷2·10^6 channels (it depends on pitch)
- Load 0.5÷1.0 MHz/channel
- Cooling system is needed
- To read out the system it is necessary to develop new specific electronics: good time resolution, compactness with minimal power consumption.

- π/K-separation $\geqslant 4\sigma$ up to 6 GeV/c and μ/π-separation $\geqslant 5\sigma$ at 1 GeV/c were obtained with prototype based on 4-layer aerogel and 20×20 cm pixel matrix from DPC Philips in 2012.
- SiPM have good tolerance to magnetic fields but radiation tolerance could be not enough for SCTF.
- MCP PMTs could be good candidate to photon detector for endcaps of the system.
- We need to estimate radiation flux to make right chose of photon detectors.
- FARICH prototype based on PMTs H12700 to investigate of critical moments in focusing aerogel production processes is under operation now. First test beam results are under processing.
- First prototype FARICH based on analogue SiPM matrixes is under development.



Collider limitations

- $W = 2 \div 5$GeV
- l_{bunch} – 1÷1.8 cm
- Δt^{bunch} – 6 ns
- CVC: ø 30/l=300 mm
- FF: ±10°
- L: $10^{35}\text{cm}^{-1}\text{s}^{-1}$
  $\rightarrow 50 \div 300$ kHz event rate

1. Vertex detector
2. Drift chamber
3. PID system
4. Calorimeter
5. SC coil (B∼1 T)
6. Yoke and MU chambers

Tasks:

- π/K-separation for P$\geqslant$0.6 GeV/c
- μ/π-separation up to P$\approx$1.2 GeV/c

Modern state of art

π/K-separation

- TOF: BES-III (MPD NICA) – $\sigma_t \sim$100 ps$\rightarrow 3\sigma$/0.9(1.5) GeV/c
- DIRC(BaBar)$\sim 4\sigma$ up to 2.5 GeV/c
- ASHIPH(KEDR)$\sim 4\sigma$ up to 1.5 GeV/c

μ/π-separation at P$\approx$1 GeV/c

- Belle$\sim 2.5 \div 2.8\sigma$

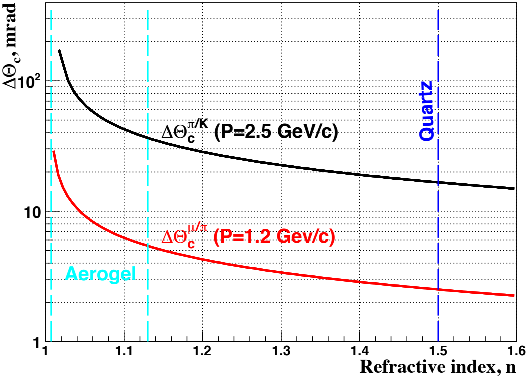
Perspectives:

π/K-separation

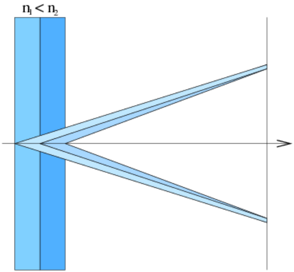
- TOF: $\sigma_t \sim$50 пс $\rightarrow 3\sigma$ up to 1.8(3.0) GeV/c
- fDIRC $\sim 3\sigma$ up to 4.25 GeV/c
- FARICH $\geqslant 3\sigma$ up to 6 GeV/c

μ/π-separation at P$\approx$1 GeV/c

- FARICH $\sim 5\sigma$



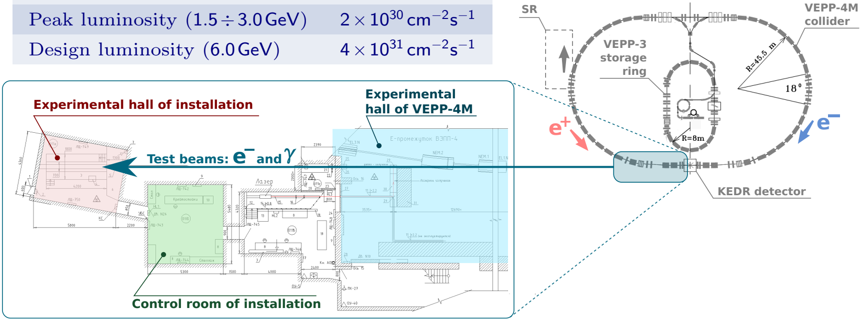
FARICH motivation

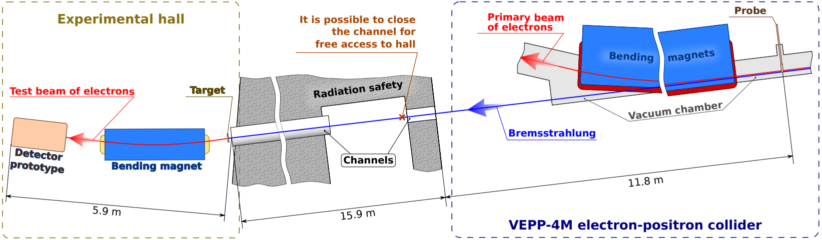


FARICH idea

- Detectors for High Energy Physics are developed in steps, including testing of detector prototype on specialized test beams.
- For this purpose an installation for generation of test beams of electrons and gammas was designed at Budker Institute of Nuclear Physics SB RAS (BINP).
- The installation uses the infrastructure of VEPP–4M electron–positron collider.

VEPP–4M main parameters	
Perimeter	366 m
Beam energy	$1.5 \div 5.5\,\mathrm{GeV}$
Number of bunchs	2×2
Peak luminosity ($1.5 \div 3.0\,\mathrm{GeV}$)	$2 \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Design luminosity ($6.0\,\mathrm{GeV}$)	$4 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

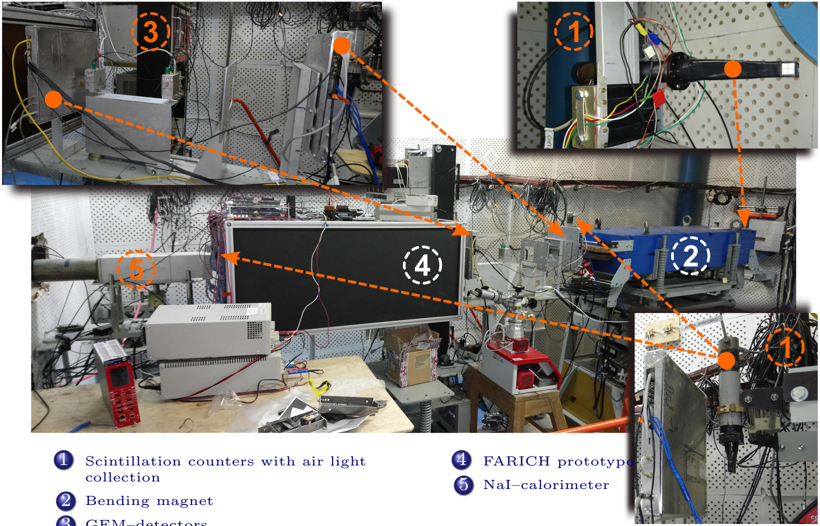




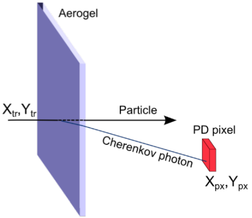
1. A special probe is moved into the halo of a primary electron beam of the VEPP–4M collider for generation of Bremsstrahlung gammas.
2. These gammas are converted to electron – positron pairs on a lead target at the entrance to the experimental hall.
3. Electrons with a certain momentum are selected using a bending magnet.

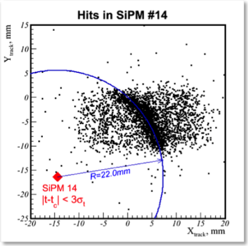
The beam parameters	
Energy range	$0.1 \div 3.5\,\mathrm{GeV}$
Intensity	$50 \div 100\,\mathrm{Hz}$
Energy spread	7.8% for 0.1 GeV and 2.6% for 3.0 GeV

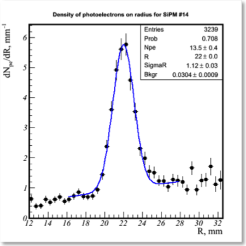
Example disposition of equipment in experimental hall (15/03/2018)



1. Scintillation counters with air light collection
2. Bending magnet
3. GEM–detectors
4. FARICH prototype
5. NaI–calorimeter

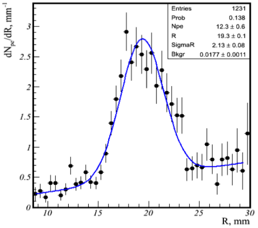




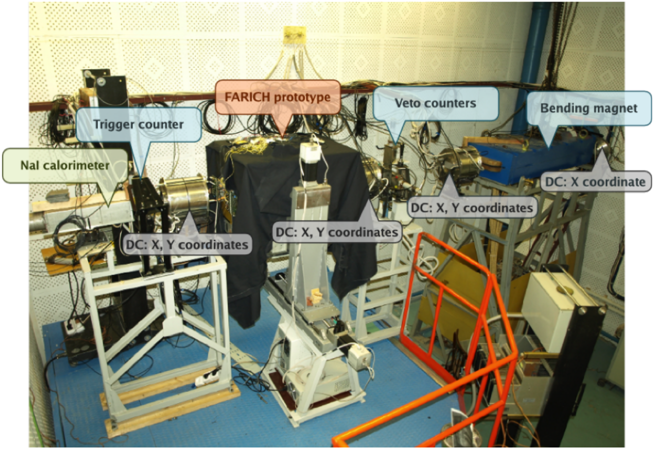


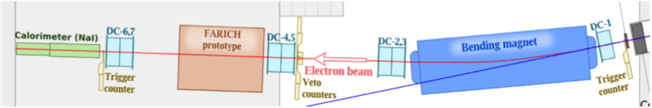
Main results

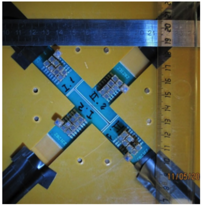
- Effect of focusing was demonstrated:
  - σ_R=1.1 mm for 4-layer aerogel t=30 mm;
  - σ_R=2.1 mm for 1-layer aerogel t=20 mm;



Prototype with CPTA MRS APDs BINP e^- test beam in 2011







32 CPTA MRS APDs with active pixel size 2.1x2.1mm^2

4-layer aerogel focusing at 62 mm

n_1=1,050 t_1=6,2mm

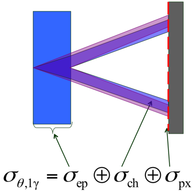
n_2=1,041 t_2=7,0mm

n_3=1,035 t_3=7,7mm

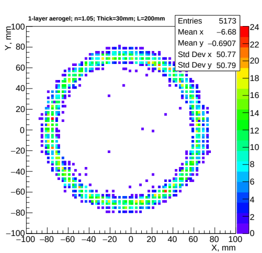
n_4=1,030 t_4=9,7mm

Size: 100x100x31mm^3

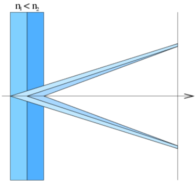
L_{sc}(400nm) = 43mm



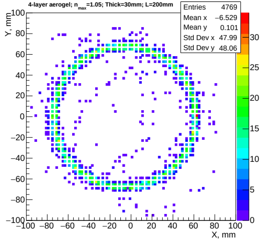
Proximity focusing single layer RICH



Simulation results: n=1.05, thickness 3 cm, L=20 cm, QE(MPPC, Hamamatsu), pixel 3×3 mm, pitch 3.2mm.



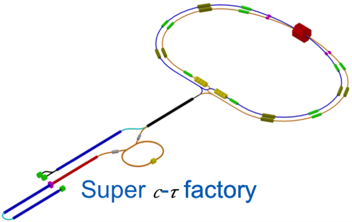
Proximity focusing multilayer RICH

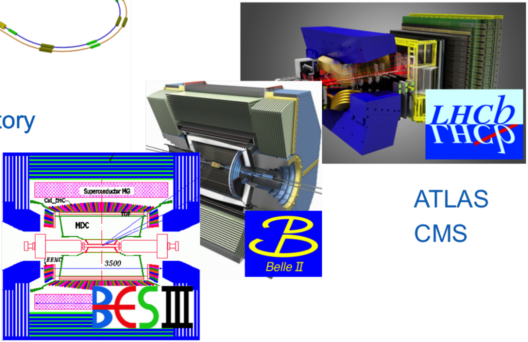


Simulation results: n_{max}=1.05, thickness 3 cm, L=20 cm, 4-layer aerogel.

CMD3
SND
KEDR

DAΦNE





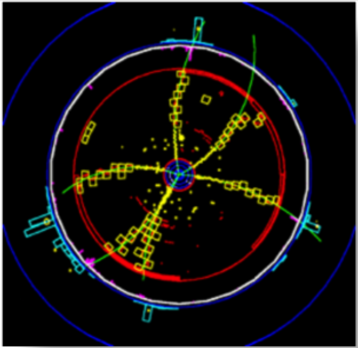
ATLAS
CMS

Super C-τ-Factory

What is the role and place of SCTF at this field?!

Unique advantages of the SCTF

- Threshold production
- Quantum correlated production of neutral D meson pairs
- Double tag technique
- Low multiplicity



CLEOc event topology

Complementarity to LHCb and Belle II

Crucial results from SCTF as input for LHCb and Belle II:

- Absolute branching ratios of charmed hadrons and τ-lepton
- The parameters measured with quantum correlations

Physics cases

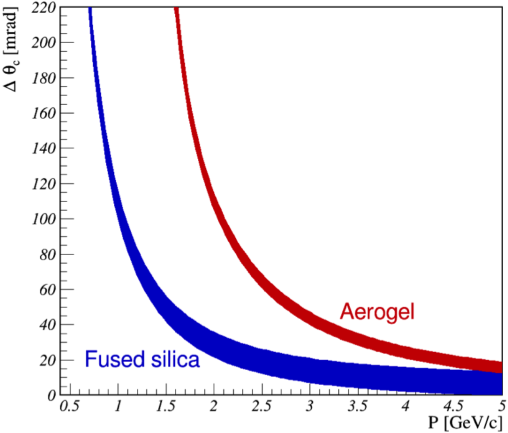
- Charm mixing
- Charmed and light hadrons spectroscopy
- Lepton flavour and lepton number violation ($\tau \to \mu\gamma$)
- CP symmetry breaking in charmed hadrons and τ-lepton decays
- Rare charmonia decays
- Exotic states: multiquark bound states, glueballs, hybrids, . . .

Refractive index

$n \downarrow \rightarrow \Delta\Theta_c \uparrow$

Chromatic Dispersion (D_n)

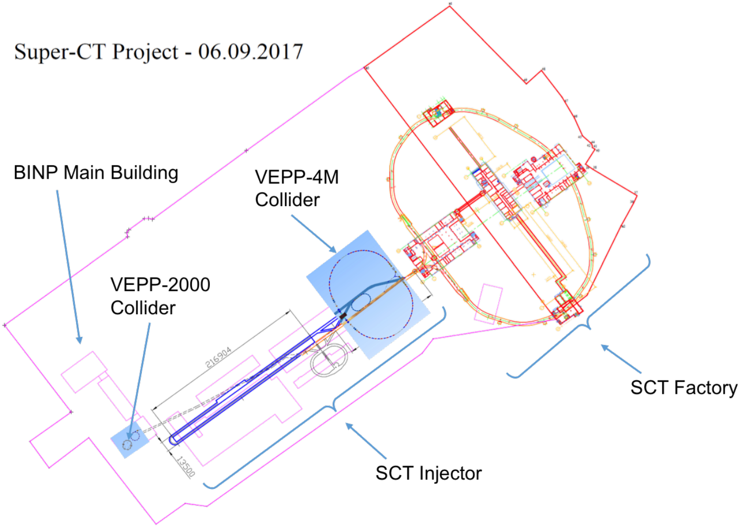
$D_n \downarrow \rightarrow \sigma(\Theta_c) \downarrow$



$\Delta\Theta_c$ for π and K.

Bands correspond to chromatic dispersion in 350÷700 nm.

Lower refractive index lead to lower number of Cherenkov photons.
To increase N_{phot} without angle resolution degradation focusing is needed.
Proximity focusing approach with multilayer aerogel (FARICH) is suggested.


Super-CT Project - 06.09.2017
BINP Main Building
VEPP-4M
Collider
VEPP-2000
Collider
216904
13500
SCT Factory
SCT Injector