Status of the Super Charm-Tau project at Novosibirsk

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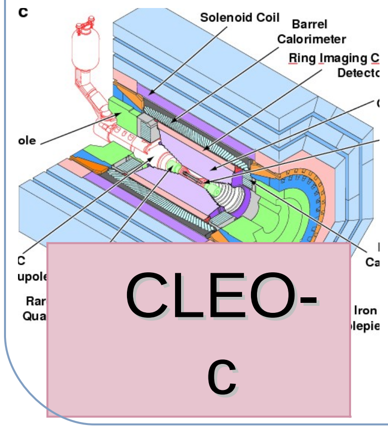
Novosibirsk State University
*THE REAL SCIENCE

Outline:

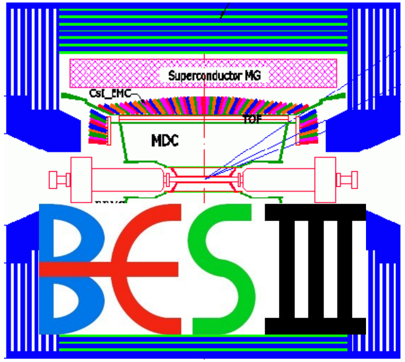
- Introduction
- Collider & detector
- Physics program
- Status of the project
- Summary

Current and legacy experiments

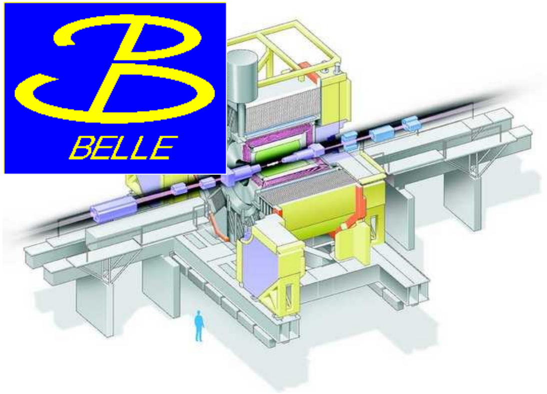
c factories

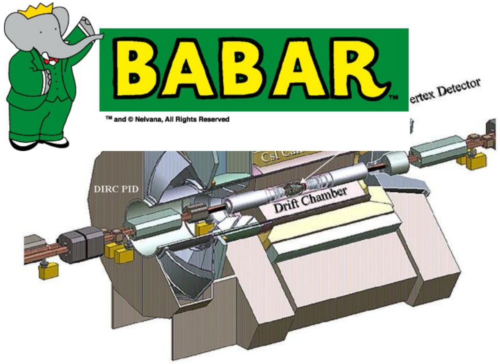


CLEO-c

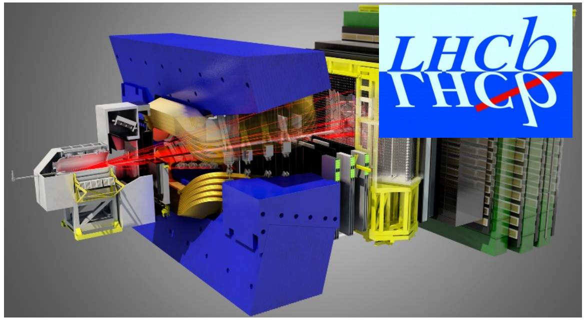


b factories



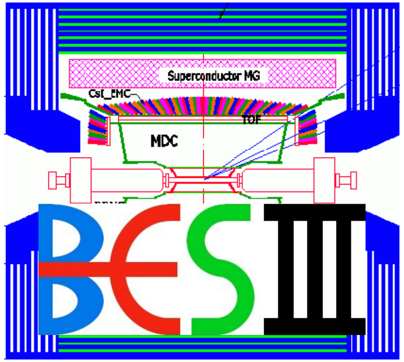


LHC

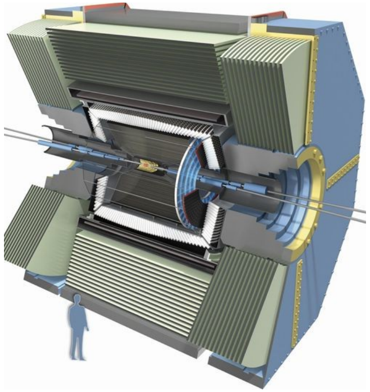


Current and future experiments

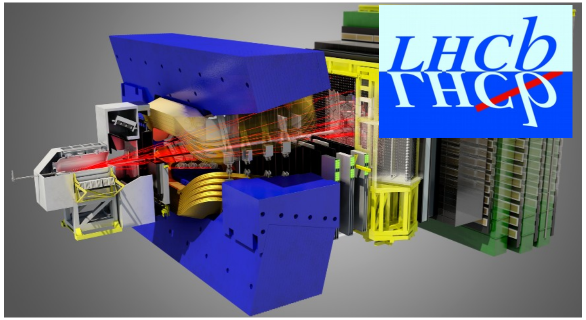
c factory

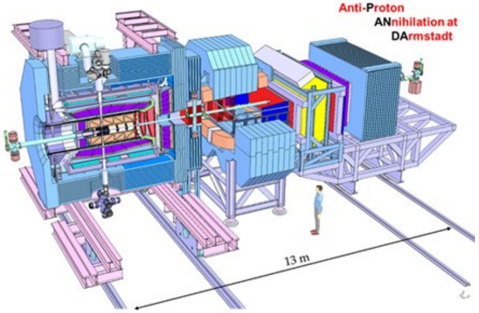


Super b factory



LHC phase 2
LHC HL

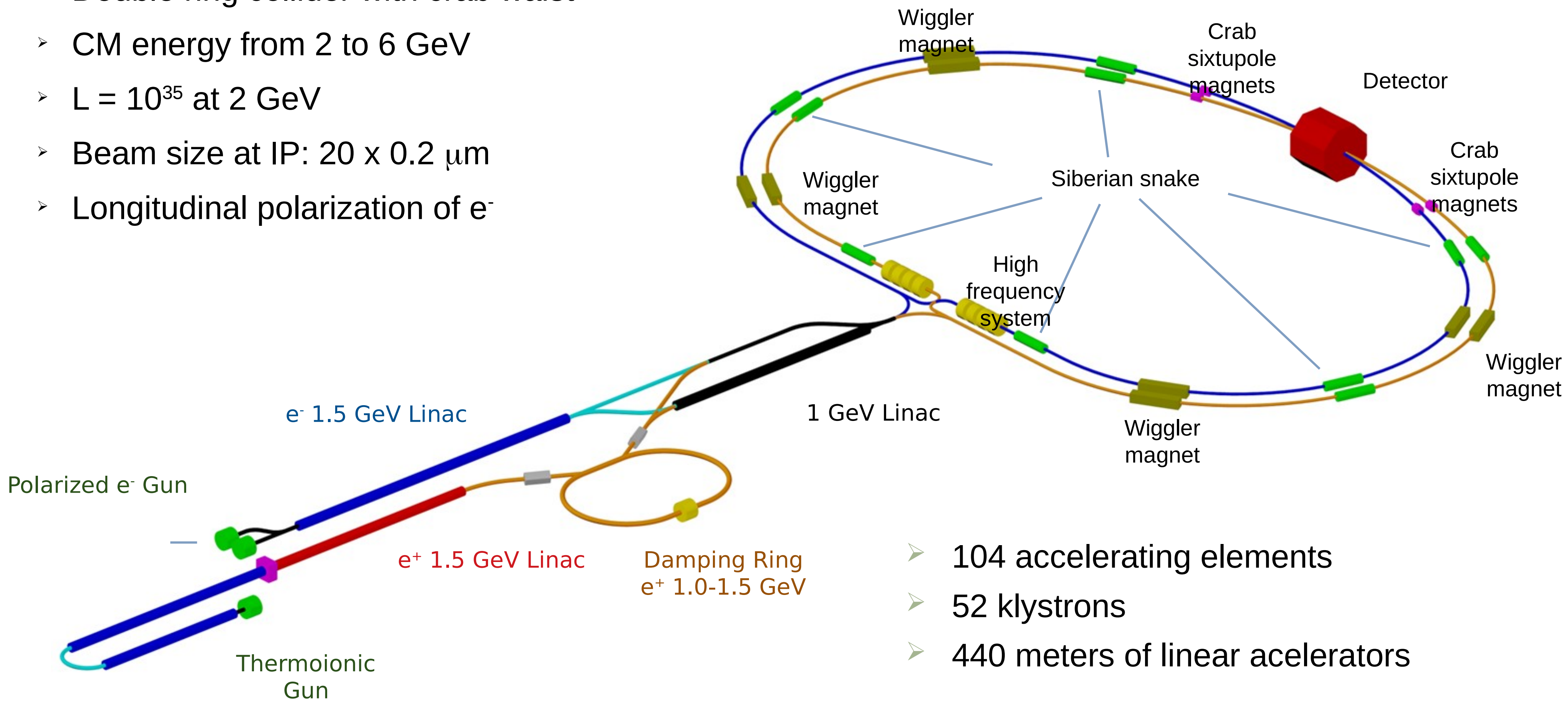




PANDA

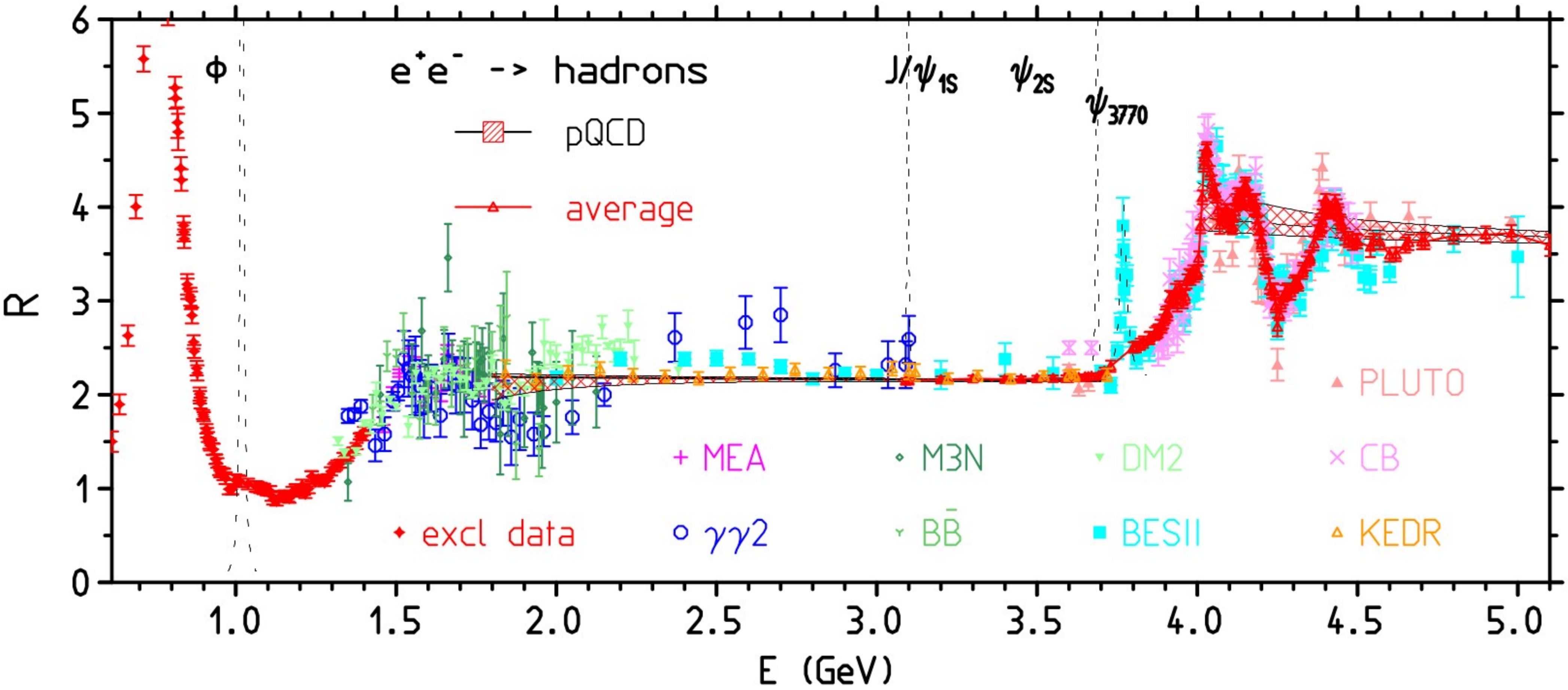
Super c-τ collider

- Double ring collider with crab waist
- CM energy from 2 to 6 GeV
- $L = 10^{35}$ at 2 GeV
- Beam size at IP: 20 x 0.2 μm
- Longitudinal polarization of e^-



- 104 accelerating elements
- 52 klystrons
- 440 meters of linear acelerators

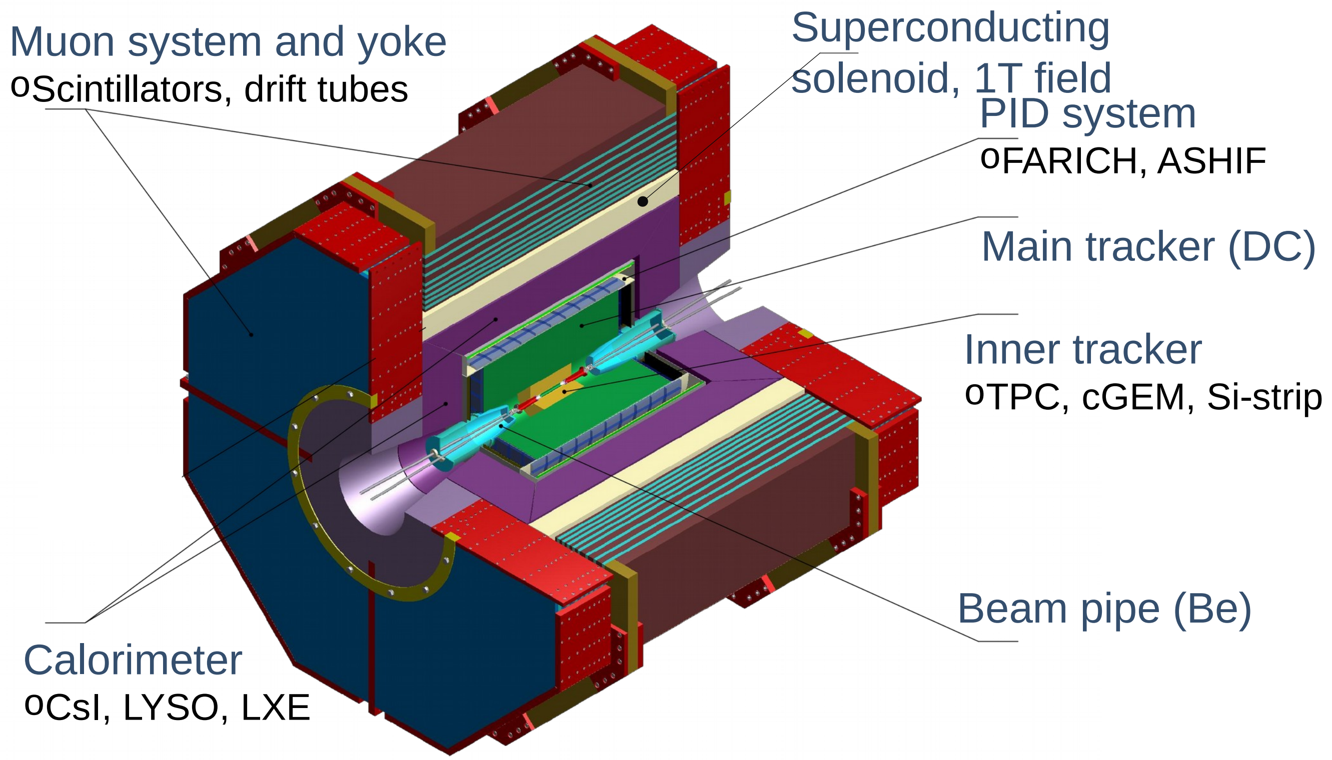
Energy range



Detector

Requirements

- Occupancy up to 300 kHz
- Good energy and momentum resolution
- High reconstruction efficiency to soft tracks
- Perfect π/K and π/μ separation
- Minimal $\mathcal{CP}$ detector asymmetry



Inner tracker

Requirements

- Reconstruction of K_S^0 and Λ
- Increase a solid angle of the detector up to 98 %
- Detection of particles with momentum from 50 MeV/c
- Dimensions: R_{inner} ≥2.5 cm, $R_{external}$ ≤20 cm, L ≤60 cm

TPC + GEM endcap redout

- 80% Ar , 20% CO_2 → 30 clusters / cm
- σ_{XY} ~ 50–100 μm
- σ_Z ~ 300 μm
- $\sigma_{dE/dx}$ ~ few %
- E = 300–400 V / cm → V_{dr} ~ 5cm / μs
- $P(\pi)_{min}$ ~ 55 MeV/c

Cylindrical GEM

- Material budget ~ 1.5% X_0
- σ_{XY} ≤ 100 μm / layer
- σ_T ≤ 7 ns
- No $\sigma_{dE/dx}$ information
- $P(\pi)_{min}$ ~ 55 MeV/c

Si-tracker

- 4 layers
- Material budget ~ 2.4% X_0
- $P(\pi)_{min}$ ~ 80 MeV/c

Straw tubes

- σ_{XY} ≤100 μm
- $P(\pi)_{min}$ ~ 55 MeV/c
- Rate ~ 10^4-10^5 track / (cm^2s)

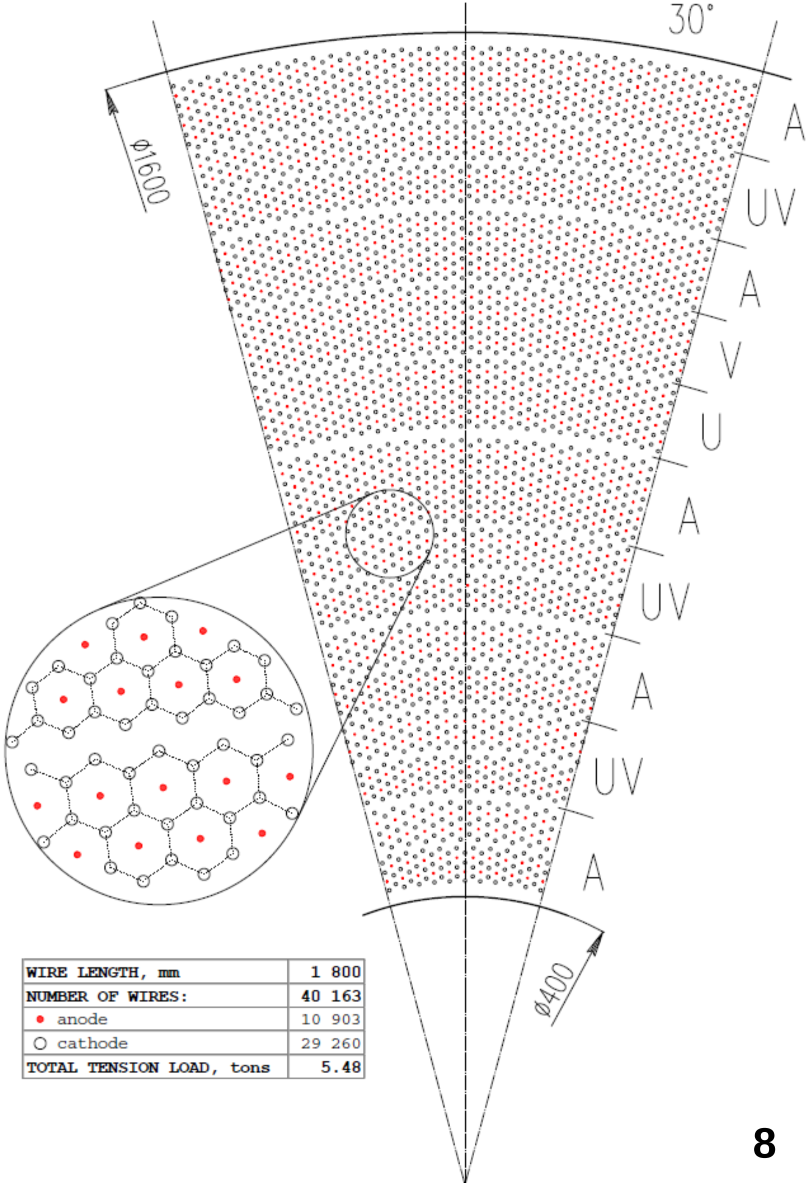
Drift Chamber

Tasks

- Tracks reconstruction
- Momentum measurements
- PID by dE/dx

Parameters

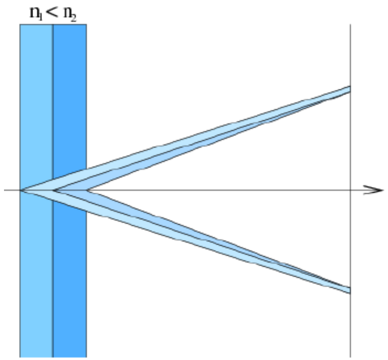
- Dimensions; $R_{in\,/\,ext}$ = 20 / 80 cm, L = 180 cm
- Small cell, drift distance < 8mm
- 10 903 cells, 29 260 field wires
- 60% He, 40% C_3H_8 or 50% He, 50% C_2H_6
- U ~ 2 kV
- τ_{drift} ~ 0.3 μs
- σ_R ~100 μm
- Material budget ~ 0.7% X_0



Particle Identification

Tasks

- π / K separation for P ≥ 0.6 GeV/c
- μ / p separation for P ≤ 1.2 GeV/c



FARICH idea

Modern state of art

π / K separation

- TOF: BES-III (MPD NICA) – σ_T ~ 100 ps → 3σ at 0.9(1.5) GeV/c
- DIRC(BaBar) ~ 4σ up to 2.5 GeV/c
- ASHIPH(KEDR) ~ 4σ up to 1.5 GeV/c

μ / π - separation

- Belle: 2.5÷2.8σ at P ~ 1 GeV/c

Perespectives

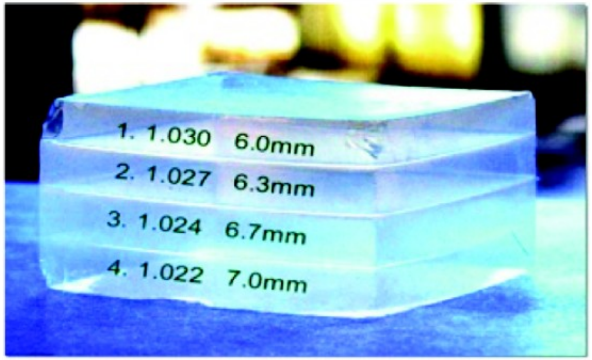
π / K separation

- σ_T ~ 50 ps → 3σ at 1.8(3.0) GeV/c
- fDIRC ~ 3σ up to 4.25 GeV/c
- FARICH ≥ 3σ up to 6 GeV/c

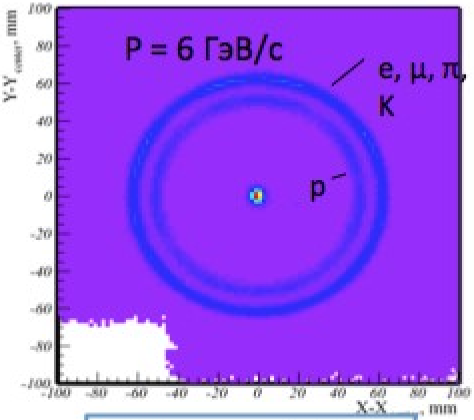
μ / π - separation

- FARICH ~ 5σ at P ~ 1 GeV/c

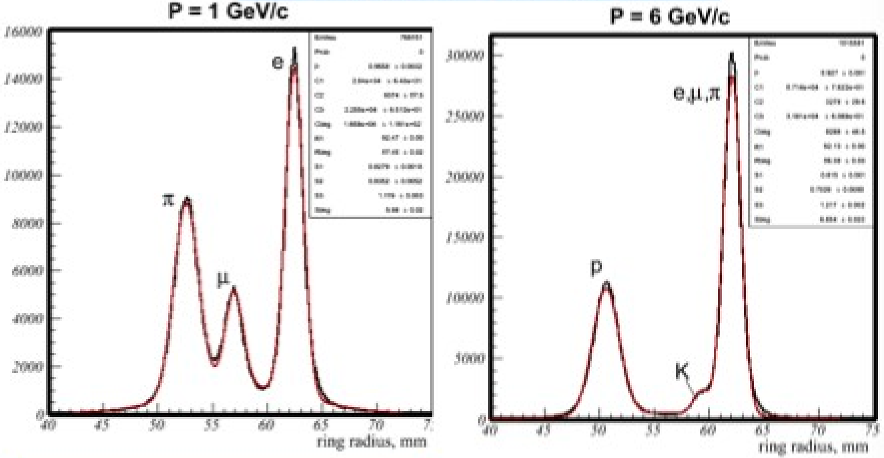
Focusing Aerogel RICH



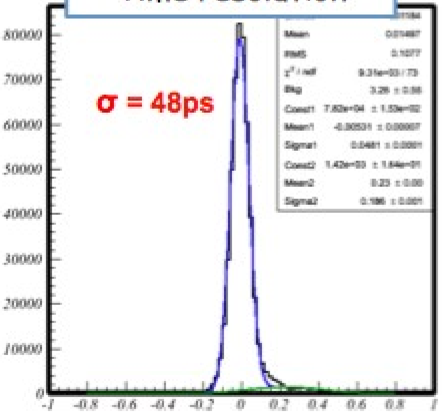
Hit positions



Ring radius distributions



Time resolution

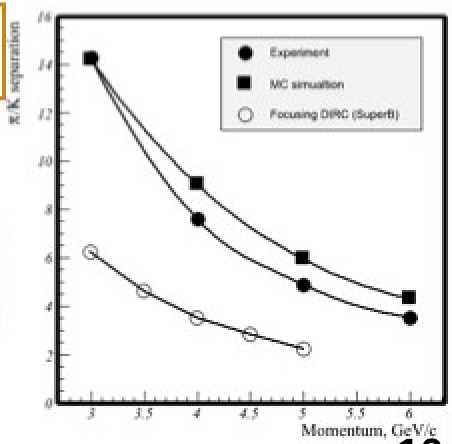


4-layer monolithic aerogel; thickness 30 mm; n_{max}= 1.046

$$S(\pi/K) = \frac{R_\pi - R_K}{\sigma_\pi}$$

π /K : 7.6σ @ 4 GeV/c
μ /π : 5.3σ @ 1 GeV/c

A.Yu. Barnyakov, et al., NIM A 732 (2013) 352



- Photon detectors (3×3 mm^2):
  - Barrel – SiPMs (16 m^2)
  - Endcap – SiPM, MCP PMT?, HAPD? (5 m^2)
- $1\div2\cdot10^6$ channels (it depends on pitch)
- load $0.5\div1.0$ MHz/channel
- Cooling system is needed

Calorimeter

Tasks

- Detection of γ from 1 MeV to 2 GeV
- Good energy and spatial resolution
- Separation of electrons and hadrons
- Trigger formation

Expected parameters (pure CsI)

- σ_E/E =1.8% at 1 GeV
- $\sigma_Z \sim 6mm / \sqrt{E(GeV)}$
- 16-18 X_0 → 30-34 cm
- t ~ 30ns (1μs for CsI(Tl))
- 5248 crystals → 26-31 tones
- Photodetectors: Photopentodes, APD or SiPM (+ WLS)

	ρ, g/cm^3	X_0, cm	λ_{em}, nm	n(λ_{em}, nm)	N_{ph}/MeV	T, ns
CsI(Tl)	4.51	1.85	550	1.8	52000	1000
pCsI	4.51	1.85	305	2	2000-5000	20
LSO (Lu_2SiO_5)	7.4	1.14	440	1.87	25000	40
LYSO ($Lu_2Y_2SiO_5$)	7.4	1.10	430	1.82	31000	40
GSO (Cd_2SiO_5)	6.7	1.38	375	1.87	8000	50

Muon ID (μ / π-separation)

Parameters

- Barrel – 9 layers in the yoke (64% of 4π)
- Endcap – 8 layers in the yoke (30% of 4π)
- $S_{total} \sim 1000\ m^2$

Gas tubes

- Used by CMD-3, KEDR, PANDA
- ageing? Rate capability?

RPC

- Used by BaBar, Belle
- Ageing, complex electronic required

Current detectors, μ / π-separation

- BaBar 64% efficiency, 2% π fake rate at 0.5 – 2 GeV/c
- BaBar 90% efficiency, 2% π fake rate for P > 1 GeV/c
- KEDR 95% efficieincy, 5% π fake rate for P > 1 GeV/c

Pion fake rate must be suppressed by factor 100. It is necessary to use an additional system, e.g. FARICH, TOF with σ_T < 30 ps.

Charming 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

http://ctd.inp.nsk.su

Charmonia

- Spectroscopy
- BR`s
- Light mesons on J/ψ decays

Charm mesons

- Spectroscopy
- BR's
- Mixing
- $\mathcal{CP}$ violation

Charm baryons

- Spectroscopy
- Br`s
- $\mathcal{CP}$ violation

τ lepton

- Michel parameters
- Spectral functions
- $\mathcal{CP}$ violation
- Lepton flavour violation
- Lepton universality

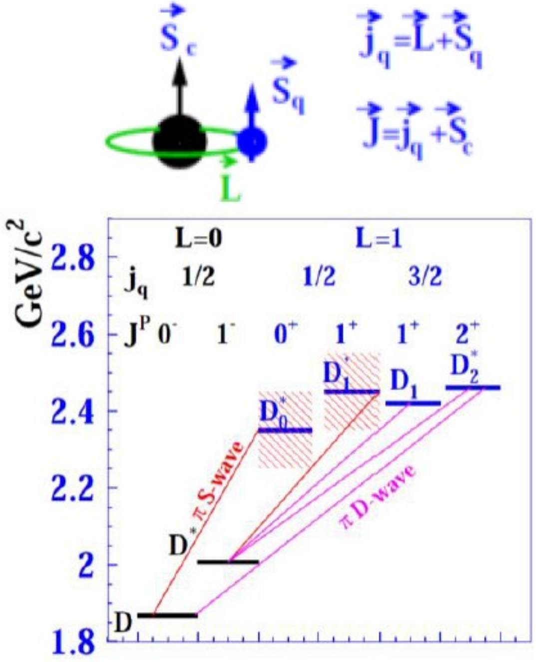
Two-photon processes

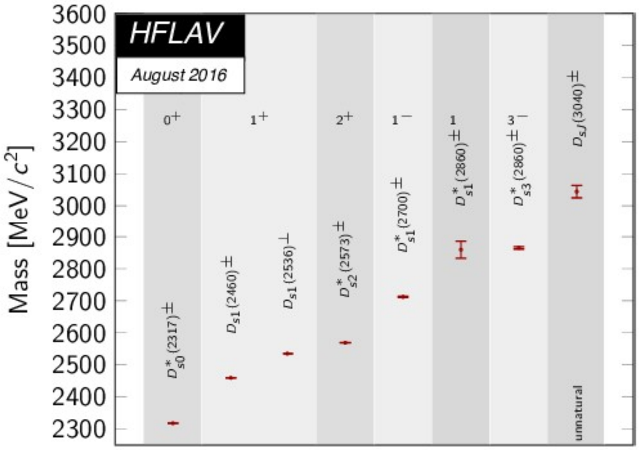
- Search for C-even states
- $\sigma(\gamma\gamma \to \text{hadrons})$

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

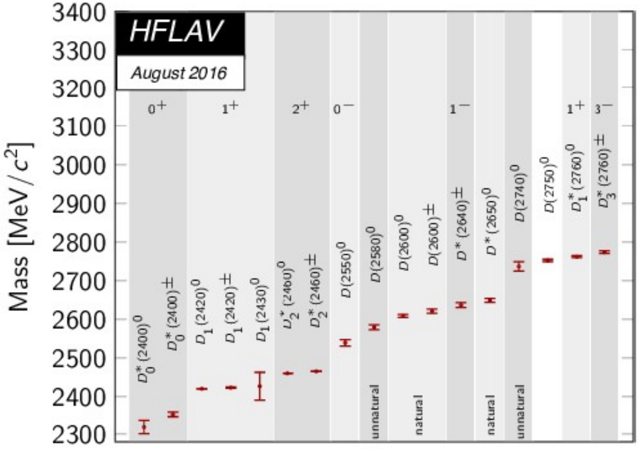
Spectroscopy of Charm Mesons

- Observables
  - Exclusive and inclusive cross-sections
  - Decay branching fractions
- Example: $D_{s0}^*(2317)$ и $D_{s1}(2460)$
  - Masses are about 50 MeV lower then predicted by potential models
  - Decays with final-state neutrals (not accessible for LHCb)
  - Nature of these states is still not clear





(a)



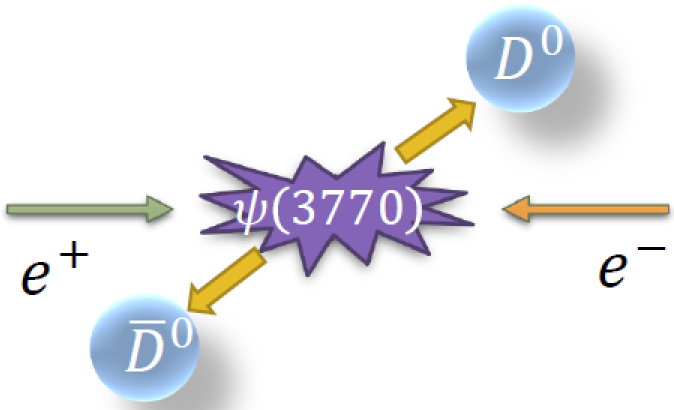
(b)

Mixing and CP violation in charm

- Quantum correlations in action

$$\Gamma(K^-\pi^+, K^+\pi^-) \propto |A_{K\pi}|^4(1 - r_{K\pi}^2)^2$$
$$\Gamma(K^-\pi^+, X) = |A_{K\pi}|^2[1 + 2yr_{K\pi}\cos\delta_{K\pi} + r_{K\pi}^2]$$

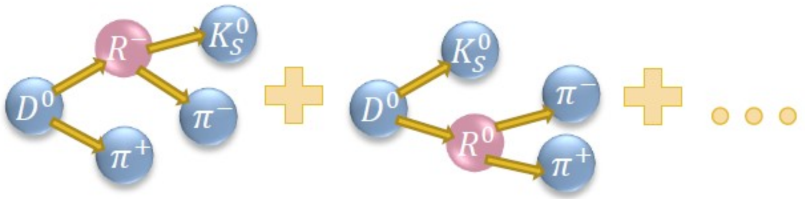
  - Many more relations with $\mathcal{CP}$-specific and multibody D^0 decays (see PRD 73 (2006) 034024)
  - This approach allows one to measure charm mixing together with phase $\delta_{K\pi}$
- There are other methods to measure charm mixing at Super c-τ factory
- Super c-τ factory is competitive with Belle II and LHCb in measurement of charm mixing



$$r_{K\pi} \cdot e^{i\delta_{K\pi}} \equiv \frac{\mathcal{A}(\overline{D}^0 \to K^-\pi^+)}{\mathcal{A}(D^0 \to K^-\pi^+)}$$
$$\mathcal{A}(D^0 \to K^-\pi^+) \equiv A_{K\pi}$$

Charm mesons multibody decays

$D^0 \to K_S^0 \pi^+ \pi^-$



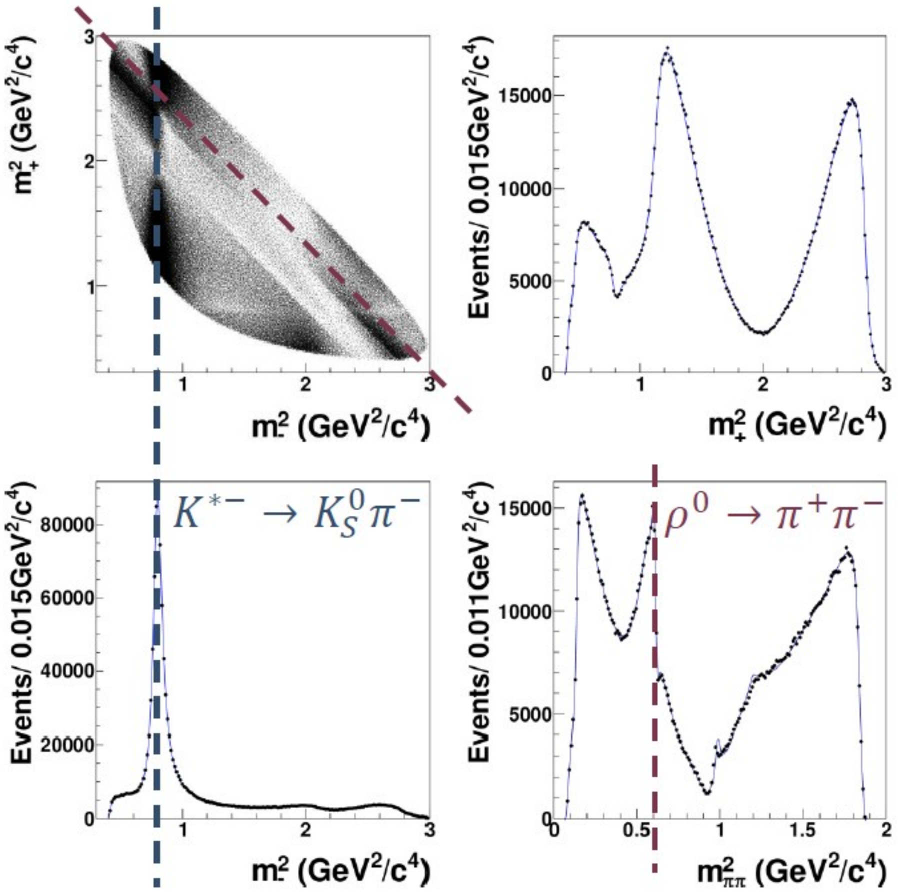
- Only probability density $|A(m_+^2, m_-^2)|^2$ is observable
- Isobar approach for amplitude parameterization

$$A(m_+^2, m_-^2) = \sum a_i F_i(m_+^2, m_-^2)$$

$$F_j(L, s,) = \boxed{R_j(s)} \times \boxed{F_D \times F_R} \times \boxed{T_j(L, \vec{p}_D, \vec{p}_R)}$$

Resonance term (Breit-Wigner) — Formfactors — Angular distribution

- The amplitude model obtained can be used in other measurements (ex. CKM phases β and γ, charm mixing)



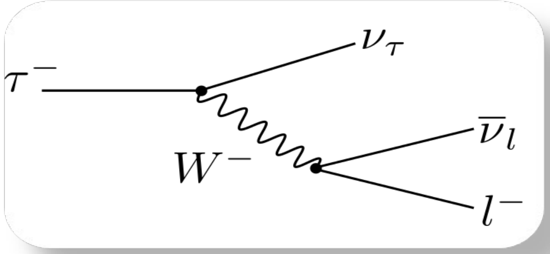
Measurement of Michel parameters

$$\frac{d\Gamma(\tau^{\mp})}{d\Omega dx} \propto x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x) \mp P_\tau \cos\theta_l\, \xi \sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\delta\left(4x - 4 + \sqrt{1 - x_0^2}\right)\right],$$

$$x \equiv \frac{E_l}{E_{\max}}, \qquad x_0 \equiv \frac{m_l}{E_{\max}}$$

$\tau \rightarrow l\nu\nu$ decay amplitude is defined by Michel parameters.
In SM (V-A charged weak current) their values are:

$$\rho = \frac{3}{4}, \qquad \eta = 0, \qquad \xi = 1, \qquad \delta = \frac{3}{4}$$



On b-factory Michel parameters are measured by spin-spin correlations on $\tau^+\tau^-$ pair

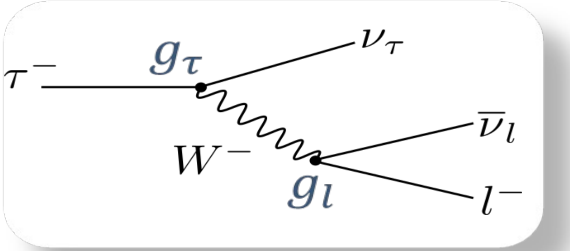
Super c-τ factory with polarized e^- beam would allow to measure it in single τ decay.

Check for LFU in τ decays

$$\tau^- \to l^- \bar{\nu}_l \nu_\tau$$

$$\Gamma(\tau^- \to \nu_\tau l^- \bar{\nu}_l) = \frac{G_\tau G_l m_\tau^5}{192\pi^3} f\left(\frac{m_l^2}{m_\tau^2}\right) r_{\mathrm{EW}}$$

$$r_{\mathrm{EW}} \approx 0.9915,\ f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x\,,\ \ G_l = \frac{g_l^2}{4\sqrt{2} m_W^2}$$



Parameter	SM prediction	Measurement
$\frac{\mathcal{B}(\tau^- \to \nu_\tau \mu^- \bar{\nu}_\mu)}{\mathcal{B}(\tau^- \to \nu_\tau e^- \bar{\nu}_e)}$	0.972564 ± 0.000010	$0.9796 \pm 0.0016 \pm 0.0036$ [BaBar, PRL 105 (2010) 051602]

Super c-τ factory can significantly reduce systematic uncertainty

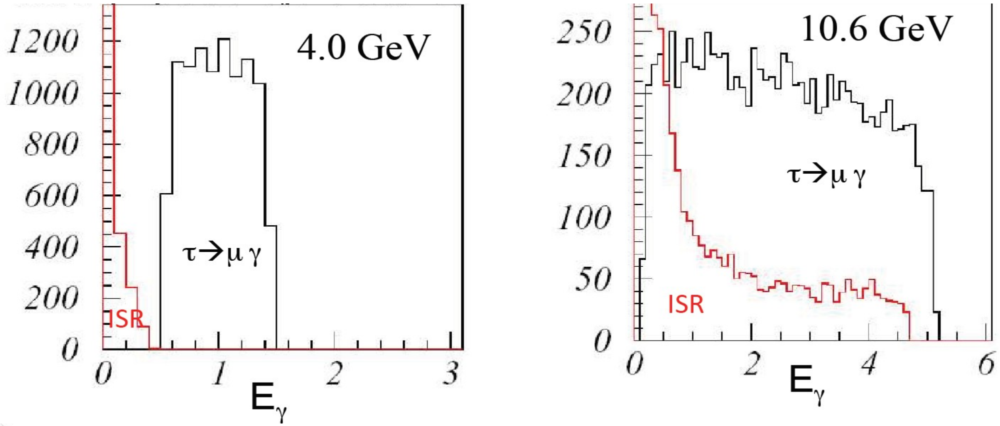
Search for LFV decay $\tau \to \mu\gamma$

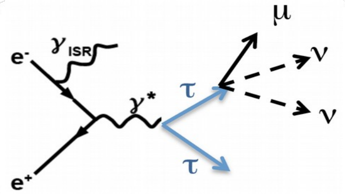
Allowed in some NP models

Main background sources:

- $\tau \to \mu\nu\nu$ + ISR photon
- $\tau \to \mu\gamma\nu\nu$
- $\tau \to \pi\nu$ + ISR or beam photon

ISR background [arXiv:1206.1909 (hep-ex)]



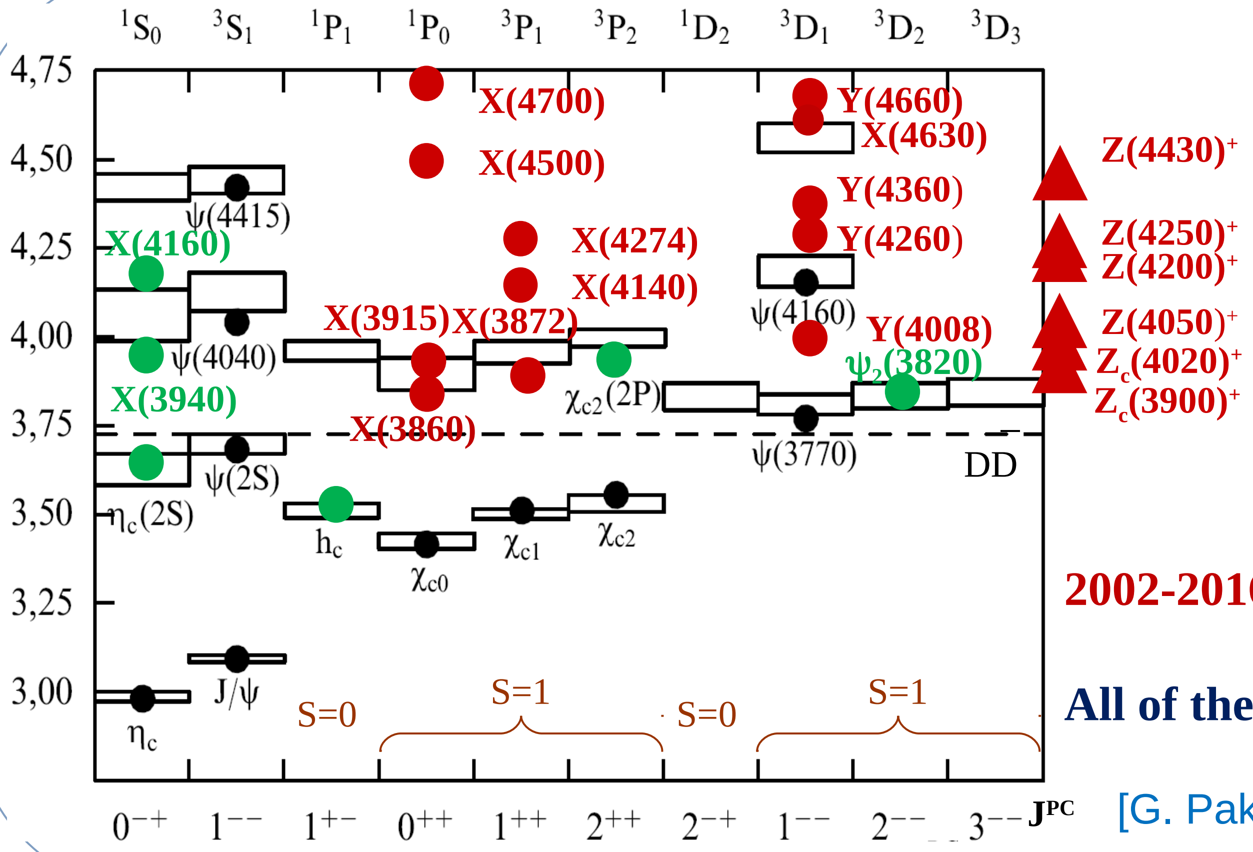


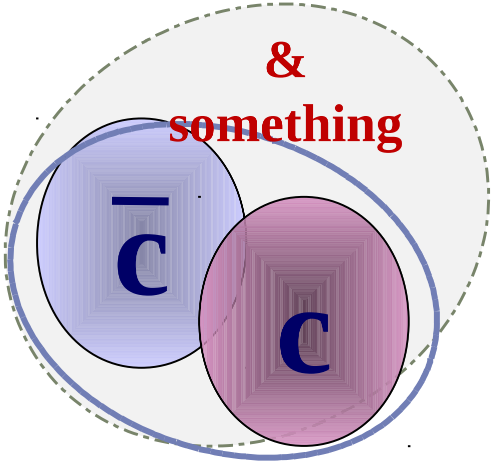
Expected limits on $B(\tau \to \mu\gamma)$

Belle II: $O(10^{-9})$

Super c-τ: $O(10^{-10})$

$c\bar{c}$ spectroscopy





2002-2016 Discovery of

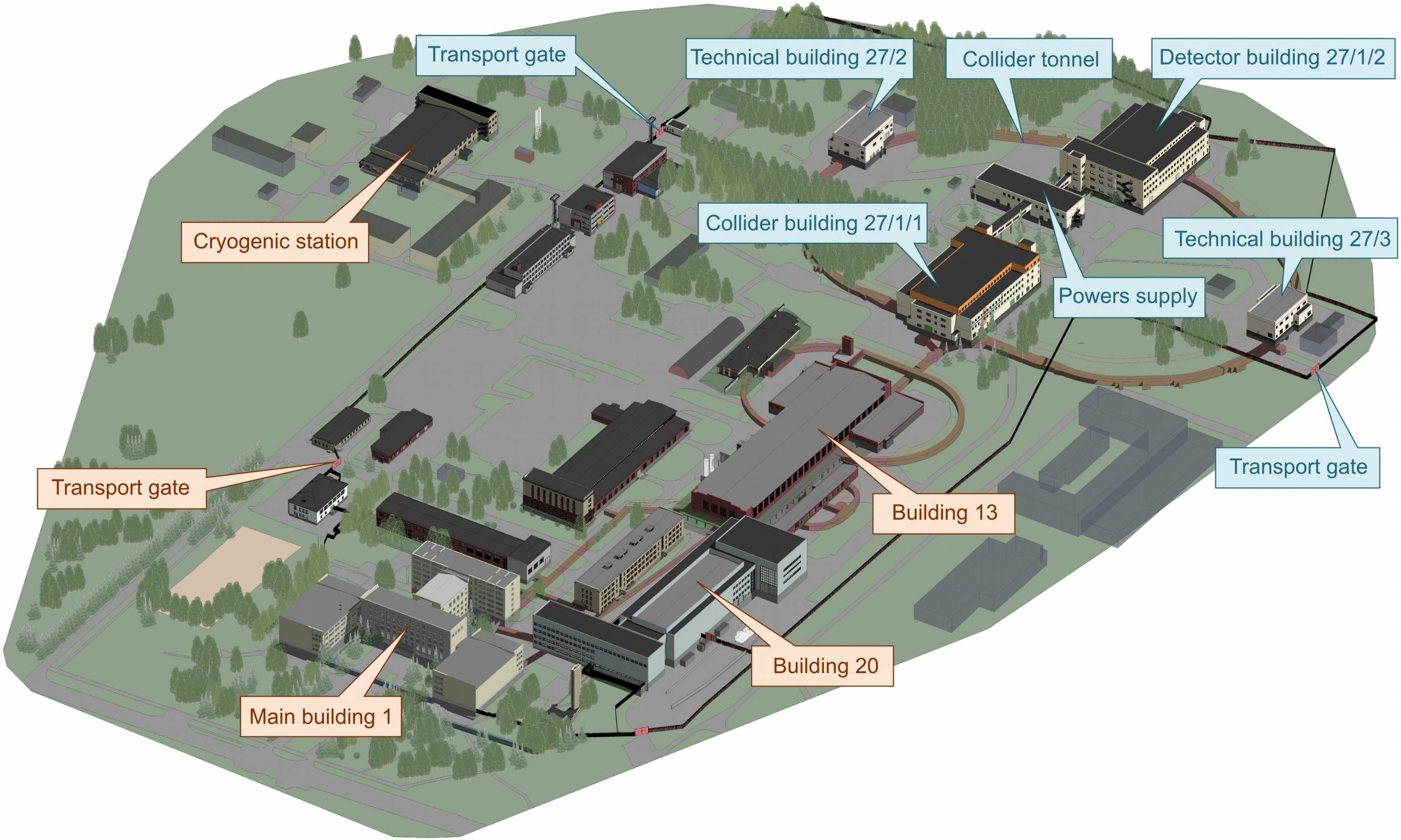
18 exotic charmonium states

All of them above open charm threshold

[G. Pakhlova, 19 december 2017, BINP]

Status of the project

- Detailed physics program is developed.
- CDR was issued in 2011 and updated in 2017.
- R&D for accelerator and detector is in progress.
- Preliminary civil engineering and infrastructure design is completed.
- Computing requirements are identified.
- CERN, IHEP, INFN, KEK and other organizations expressed their interest in the project.
- The project is included in the plan for the implementation of the first phase of the Russian Strategy for Science and Technology Development.

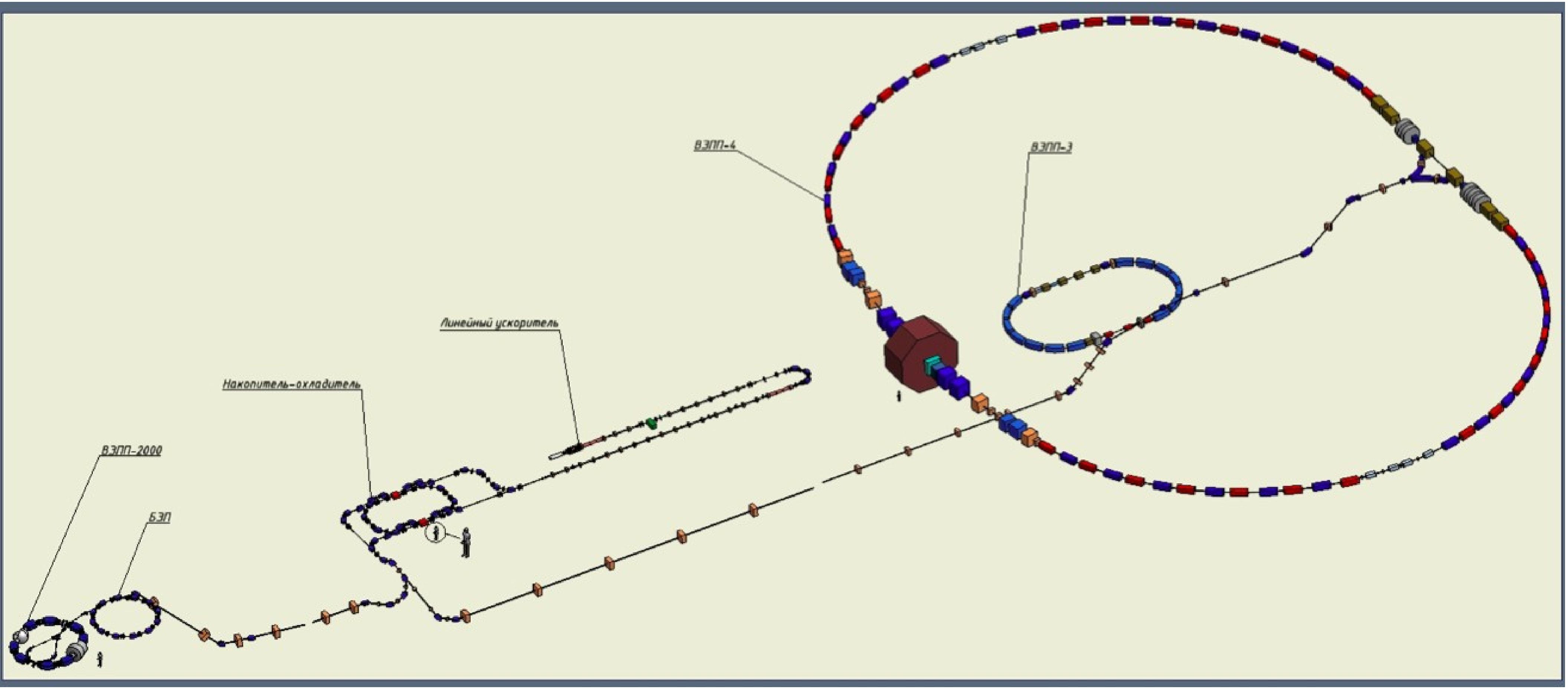

Transport gate
Technical building 27/2
Collider tonnel
Detector building 27/1/2
Cryogenic station
Collider building 27/1/1
Technical building 27/3
Powers supply
Transport gate
Building 13
Transport gate
Building 20
Main building 1

Conclusion

- Experiment on Super c-τ factory has rich physics program.
- Super c-τ physics program is complementary to Belle II and LHCb.
- BINP has long history in producing and operating colliders and detectors for local and international experiments.
- Project is supported by Russian government, first R&D started.
- We are open to collaboration proposal.

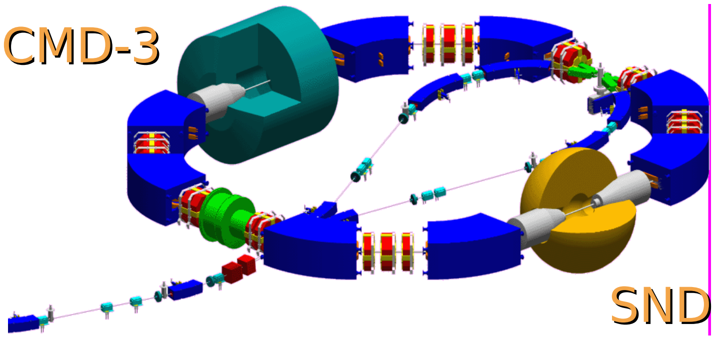
Backup

BINP colliders



BINP colliders

VEPP-2000



In operation from 2009

Round beams, $\sqrt{s}$ = 0.3 – 2.0 GeV

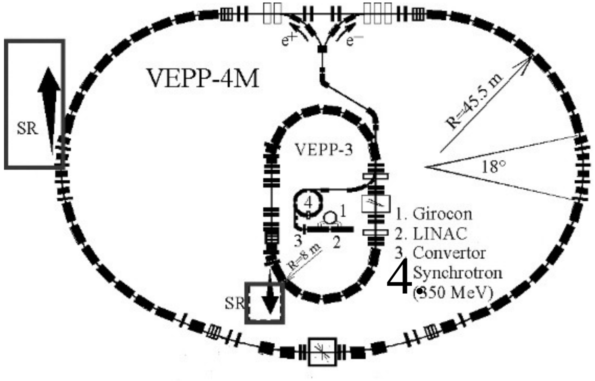
L = 5 10^{31} $cm^{-2}s^{-1}$@ 2 GeV

Two detectors:

CMD-3

SND

VEPP-4M



In operation from 2003

$\sqrt{s}$ = 2 – 10 GeV

L = 2 10^{30} $cm^{-2}s^{-1}$@ 2 GeV

L = 8 10^{31} $cm^{-2}s^{-1}$@ 10 GeV

Detector KEDR

Physics program

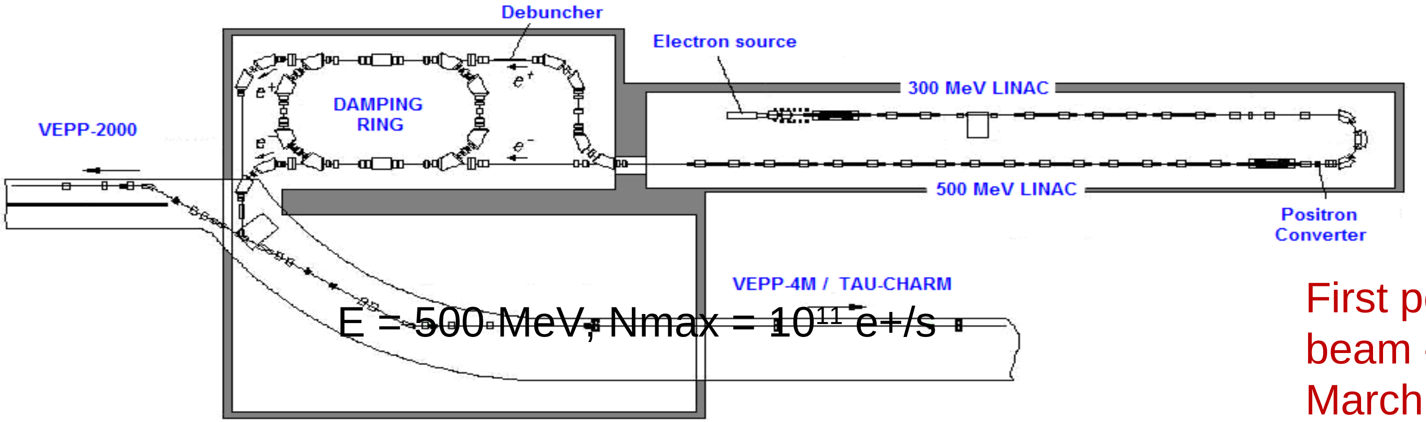
VEPP-2000

- Measure cross section and dynamic of $e^+e^- \rightarrow nh$ (h =π, K, η, …)
- Precise measurement of $R \equiv \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$
- Spectroscopy of light mesons (r,w,…)
- Measurement of nucleons form-factor

VEPP-4M

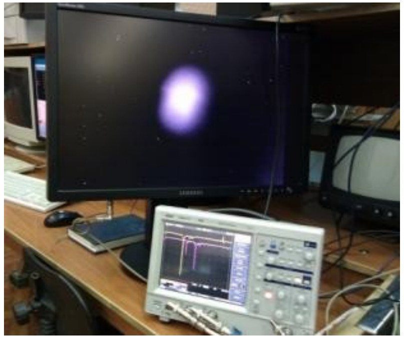
- Priciest measurement of mass: J/ψ, ψ' …, Y(nS), D, τ
- R Measurement at [2 – 7] GeV
- $c\bar{c}$ and $b\bar{b}$ spectroscopy
- Two photon physics

Injection system (VEPP-5)



$E = 500$ MeV, $N_{max} = 10^{11}$ e+/s

First positron beam - March 2013

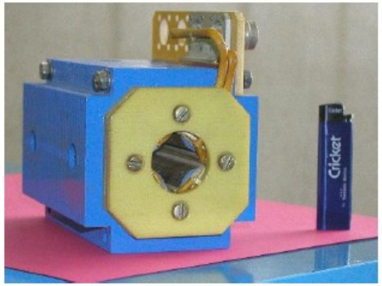


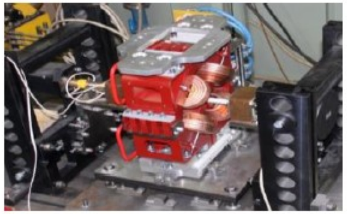
500 MeV Linac

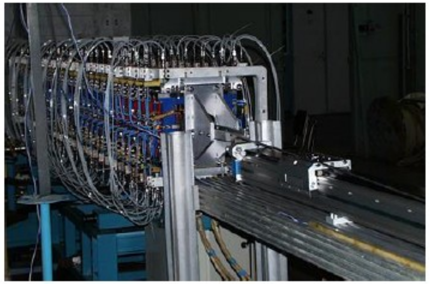
Damping ring

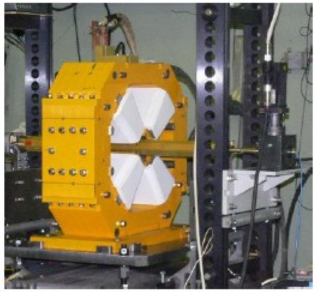
Transfer line

Made in BINP









Collider parameters

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	$0.6\cdot10^{35}$	$0.9\cdot10^{35}$	$1.0\cdot10^{35}$	$1.0\cdot10^{35}$