The e+e- experiments in the BINP and the super c-tau factory project

Fedor Ignatov
BINP, Novosibirsk

Pisa, Italy
26 June 2018

Budker Institute, Siberia

is located in Academgorodok (science town) of Novosibirsk
It is the biggest academic Institute in the Russian Academy of Science

Academician Gersh Budker
(1918-1977)

Budker INP is the Research Center of the Russian Academy of Sciences.

The Institute of Nuclear Physics (Novosibirsk, Russia) was founded in 1958 on the basis the Laboratory for new acceleration methods, then headed by academician Gersh Budker. The Lab was part of the Institute of Atomic Energy (Moscow) headed at that time by academician Igor Kurchatov.

this year we celebrated its 60th BINP anniversary, and also 100 years of G.Budker

Colliders History

1961	AdA	Frascati	Italy
1965	Princeton-Stanford(e-e-)	Stanford	USA
1965	VEP-1(e-e-)	Novosibirsk	USSR
1966	VEPP-2	Novosibirsk	USSR
1967	ACO	Orsay	France
1969	ADONE	Frascat	Italy
1971	CEA	Cambridge	USA
1972	SPEAR	Stanford	USA
1974	DORIS	Hamburg	German
1974	VEPP-2M	Novosibirsk	USSR
1976	DCI	Orsay	France
1977	VEPP-3	Novosibirsk	USSR
1978	VEPP-4	Novosibirsk	USSR
1978	PETRA	Hamburg	Germany
1979	CESR	Cornell	USA
1980	PEP	Stanford	USA
1981	Sp-pbarS	CERN	Switzerland
1982	p-pbar	Fermilab	USA
1987	TEVATRON	Fermilab	USA
1989	SLC	Stanford	USA
1989	BEPC	Beijing	China
1989	LEP	CERN	Switzerland
1992	HERA	Hamburg	Germany
1994	VEPP-4M	Novosibirsk	Russia
1999	DAFNE	Frascati	Italy
1999	KEKB	Tsukuba	Japan
1999	PEP-II	Stanford	USA
2001	RHIC	Brookhaven	USA
2008	BEPCII	Beijing	China
2009	LHC	CERN	Switzerland
2010	VEPP-2000	Novosibirsk	Russia.
2018	SuperKEKB	Tsukuba	Japan

(Physics start date)

1961: AdA was the first matter antimatter storage ring with a single magnet (weak focusing) in which e+/e- were stored at 250 MeV

Touschek effect (1963); first e+e– interactions recorded – limited by luminosity ~ $10^{25} cm^{-2} s^{-1}$

SLAC & Novosibirsk VEP-1 works independently

1965: First physics at collision with e-e- scattering

(QED radiative effects confirmed)

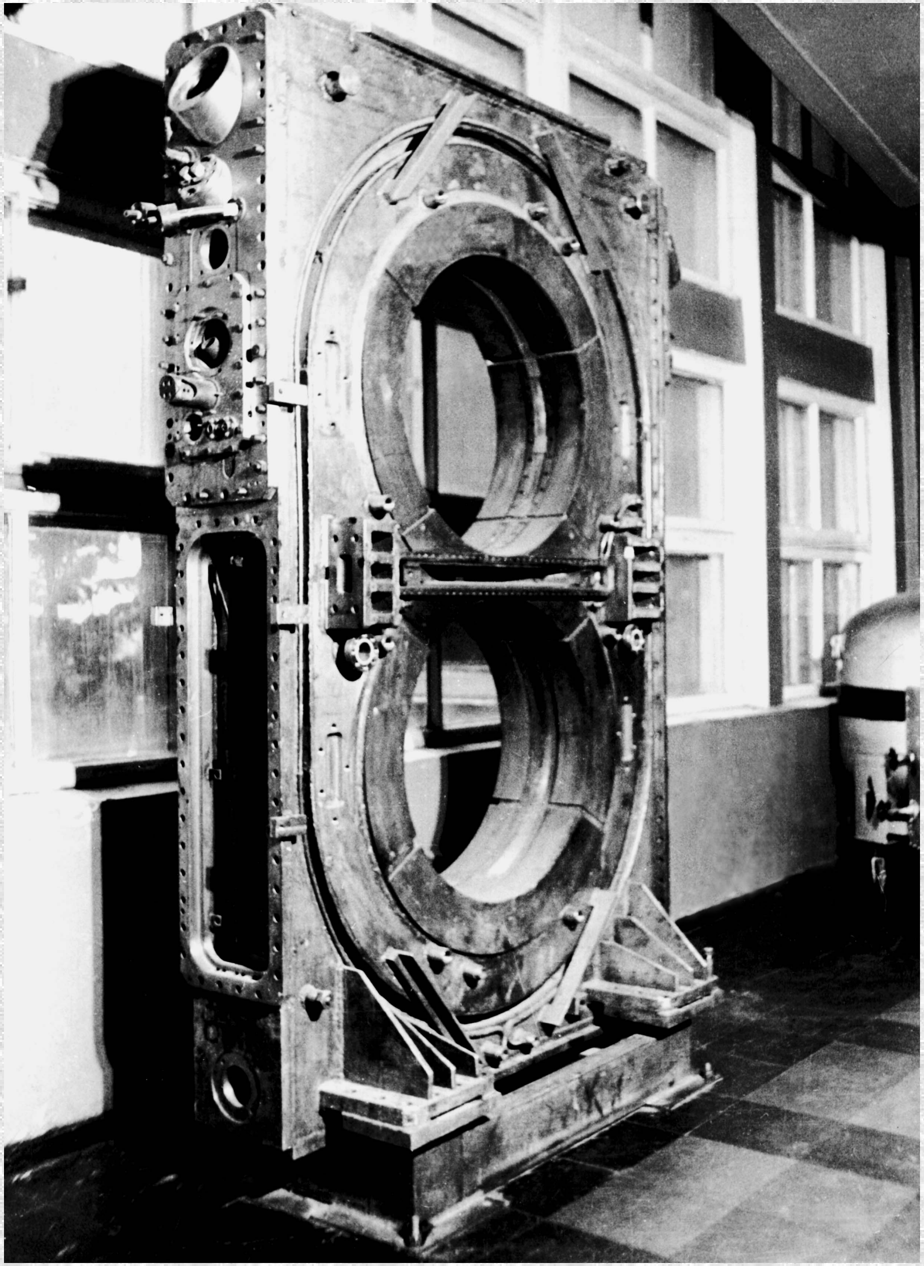
1967: VEPP-2 First e+e- → hadron production

$L \sim 10^{28} cm^{-2} s^{-1}$

AdA, VEP-1

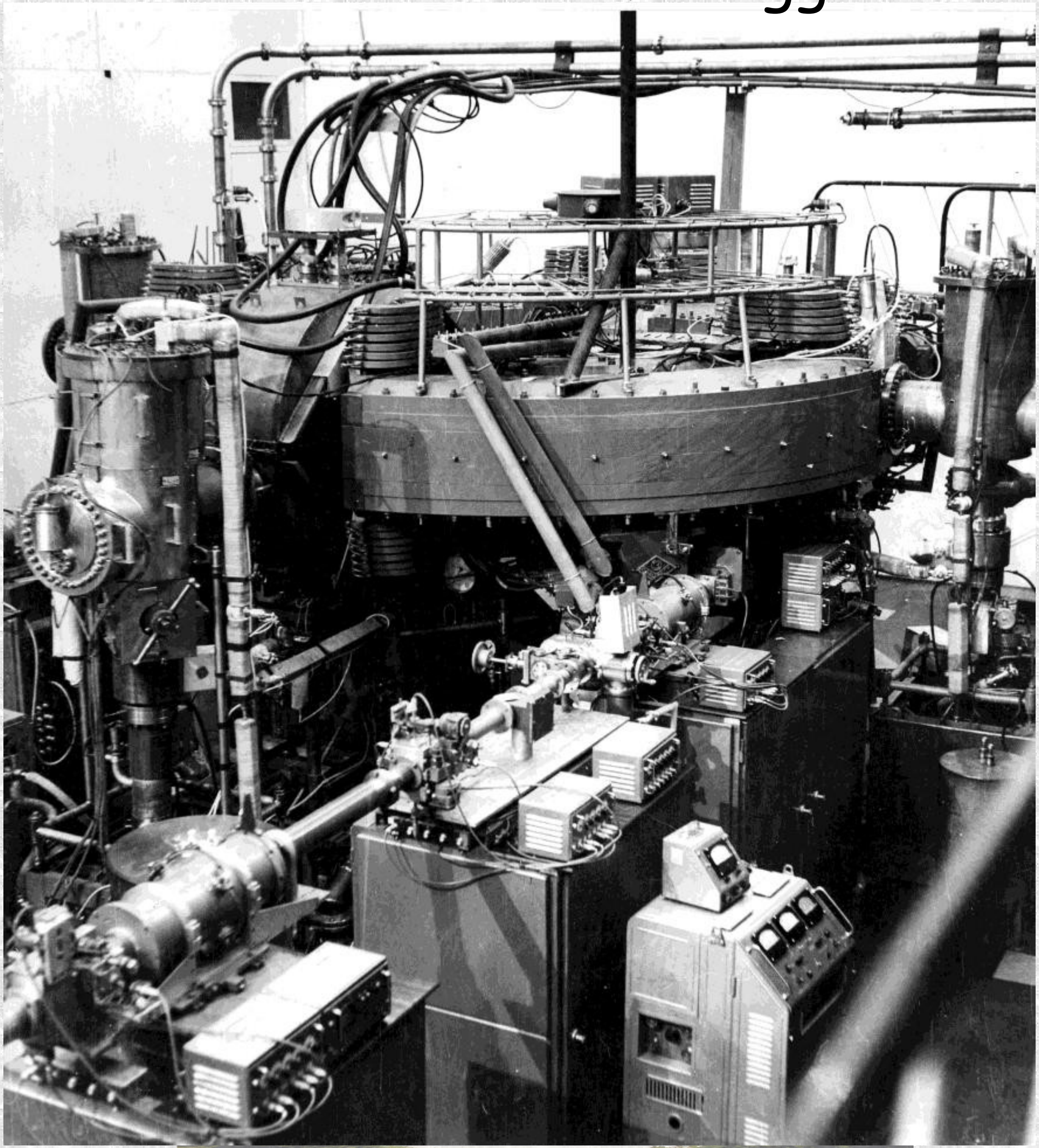
AdA
1961-1964

VEP-1
1964 - 1968



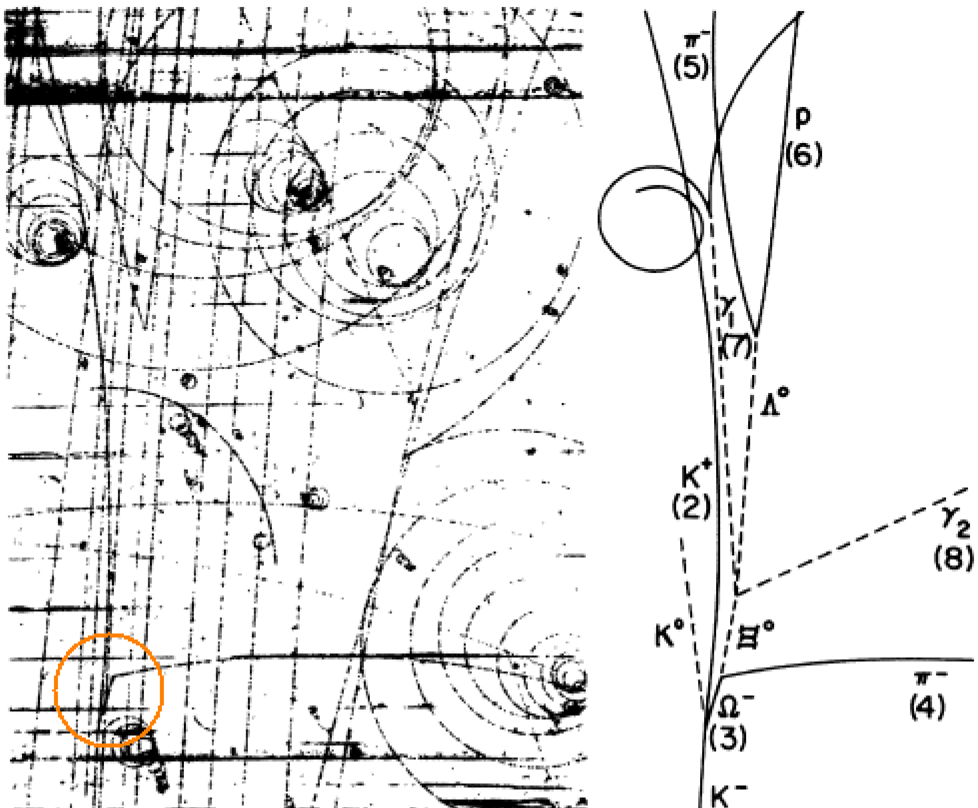
e+ e- collider VEPP-2 (1966-1970)

Colliders became bigger



Before colliders – fixed target experiments

Pions(etc) was produced by proton beams
Detection by
the wilson chamber(supersaturated vapor),
Scintillation crystals as counter
The bubble chambers(superheated liquid)



Ω^- discovery in 1964 at BNL

particle reactions were analyzed by scanning and measuring photographs, done by both skillful assistants and machines

<u>1952 – Discovery of resonances (Δ - baryon)</u>

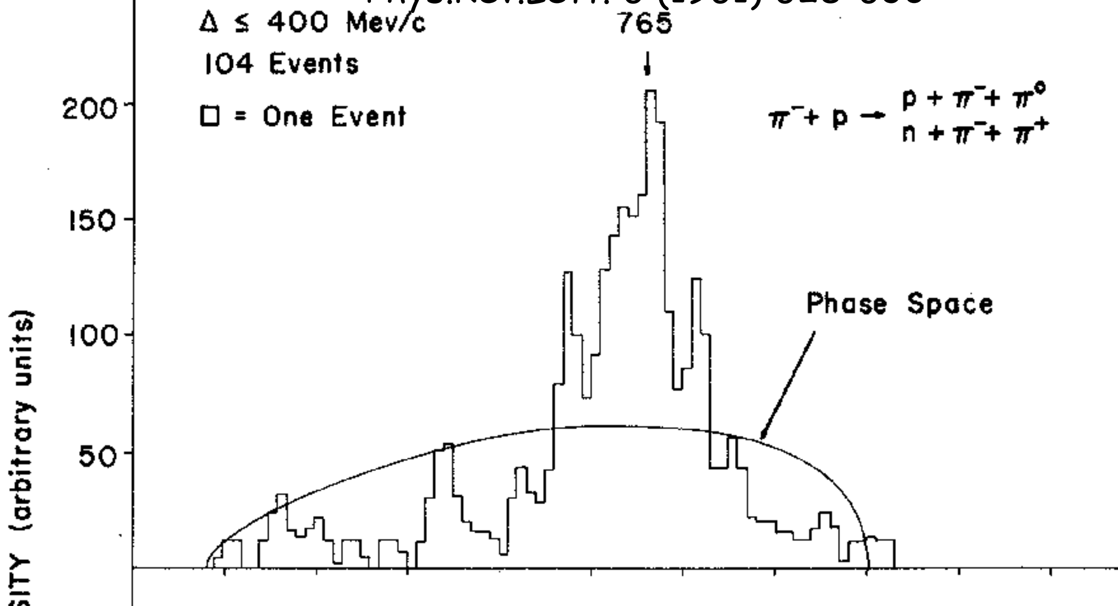
The first resonance in particle physics was discovered by E. Fermi's team working at the Chicago Cyclotron in 1952.

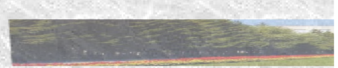
H. L. Anderson, E. Fermi, E. A. Long, and D. E. Nagle, Phys. Rev. 85, 936

<u>1961 - Discovery of rho</u>

This ππ resonance, the ρ, was observed by A. R. Erwin et al. using the 14-inch hydrogen bubble chamber.
π- beam was produced by the proton beam from "the Cosmotron" - proton synchrotron, BNL

Evidence for a ππ Resonance in the I = 1, J=1 State
Phys.Rev.Lett. 6 (1961) 628-630





First hadron production at colliders

Volume 25B, number 6 PHYSICS LETTERS 2 October 1967

INVESTIGATION OF THE ρ-MESON RESONANCE WITH ELECTRON-POSITRON COLLIDING BEAMS

V. L. AUSLANDER, G. I. BUDKER, Ju. N. PESTOV, V. A. SIDOROV, A. N. SKRINSKY and A. G. KHABAKHPASHEV
Institute of Nuclear Physics, Siberian Branch of the USSR Academy of Sciences, Novosibirsk, USSR

Received 1 September 1967

Preliminary results on the determination of the position and shape of the ρ-meson resonance with electron-positron colliding beams are presented.

When experiments with electron-positron colliding beams were planned [1, 2] investigation of the process

$$e^- + e^+ \rightarrow \pi^- + \pi^+$$

$$e^- + e^+ \rightarrow K^- + K^+$$

<u>1 September 1967</u>

Start of e+e- → hadrons measurements

Phys.Lett. 25B (1967) no.6, 433-435

ρ-meson produced at VEPP-2 collider

Detector was made from different layers of Spark chambers,
readouts by photo camera

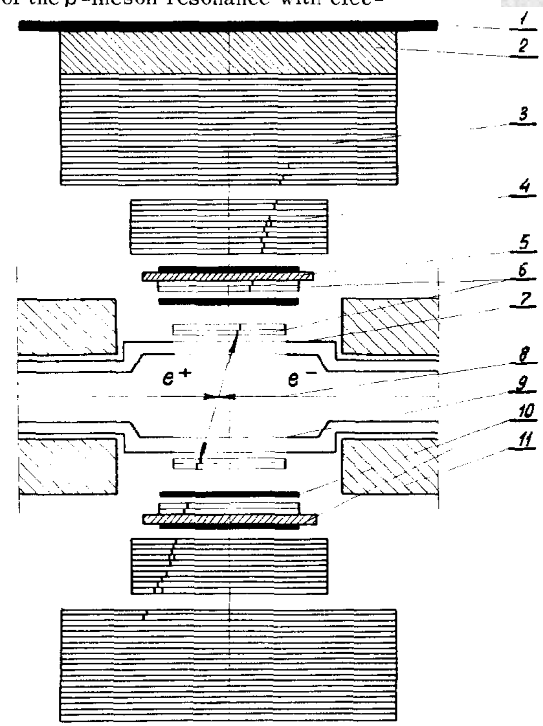


Fig. 1. Spark chambers system:
1) Anticoincidence scintillation counter
2) Lead absorber 20 cm thick
3) "Range" spark chamber
4) "Shower" spark chamber
5) Duraluminium absorber 2 cm thick
6) Thin-plate spark chambers

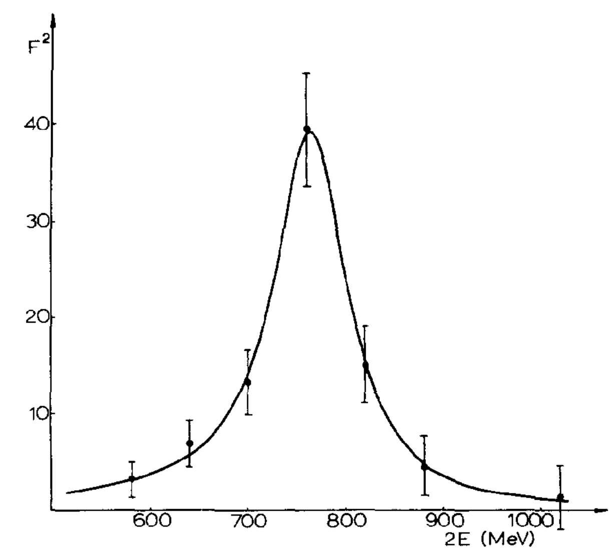
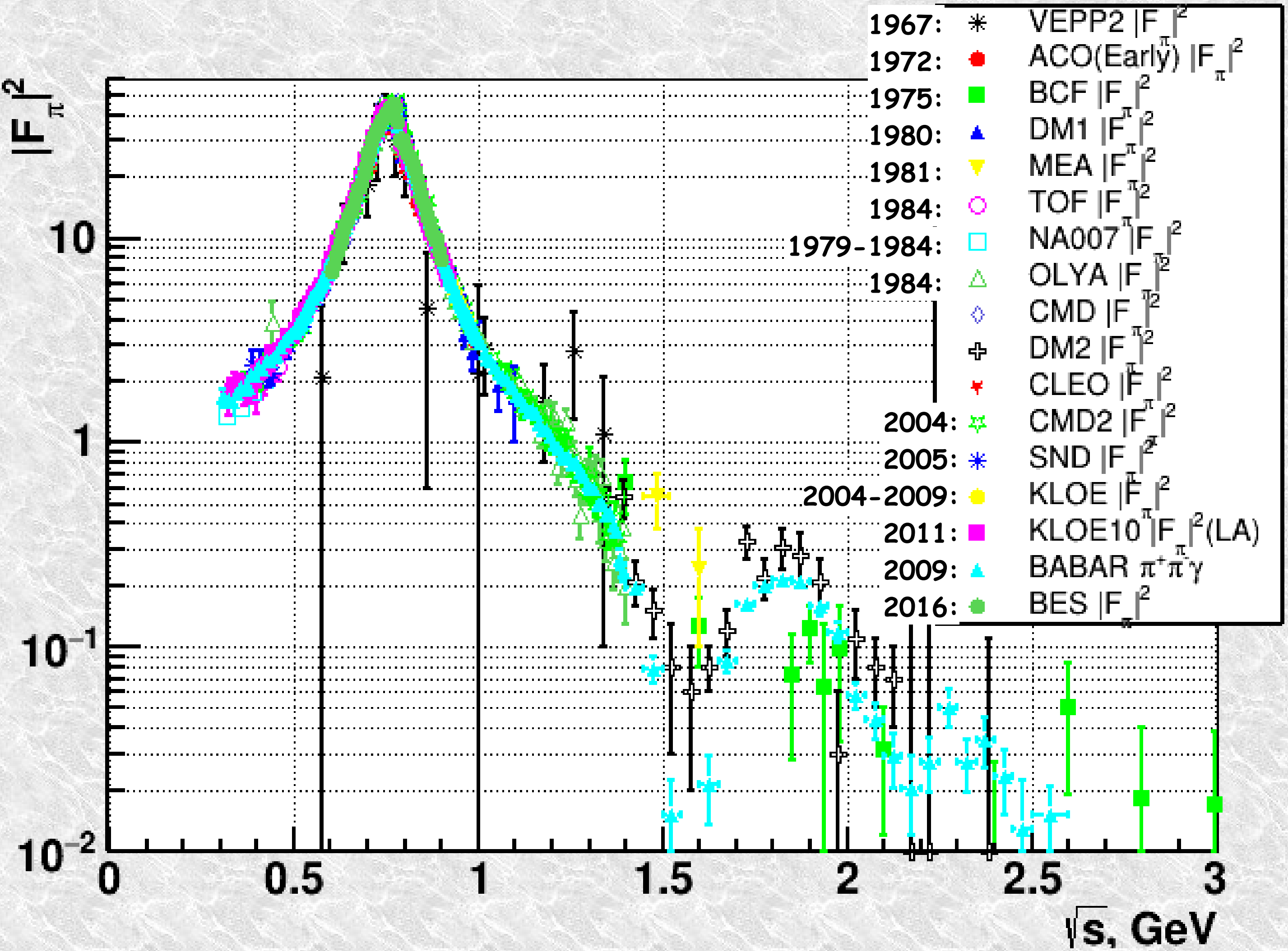


Fig. 2. Experimental values of F^2 (E) approximated by the Breit-Wigner formula.

ment geometry and F- modulus of the form factor for pion pair production [1]. In the case of QED with no other forces F=1. If the particles are produced at the angle 90° with respect to the beam axis then a=18. Integration over the solid angle gives a=20.4.

Rho meson this days



Before 1985

Low statistic precision

Systematic >10%

NA007 Few points with >1-5%

1985 - VEPP-2M

with more detail scan

OLYA systematic 4%

CMD 2%

2004 with CMD2 at VEPP-2M

was boost to systematic: 0.6%

The uncertainty in a_μ(had) was improved by factor 3 as the result of VEPP-2M measurements

New ISR method

e+e- → γ + hadron:

KLOE: 0.8%

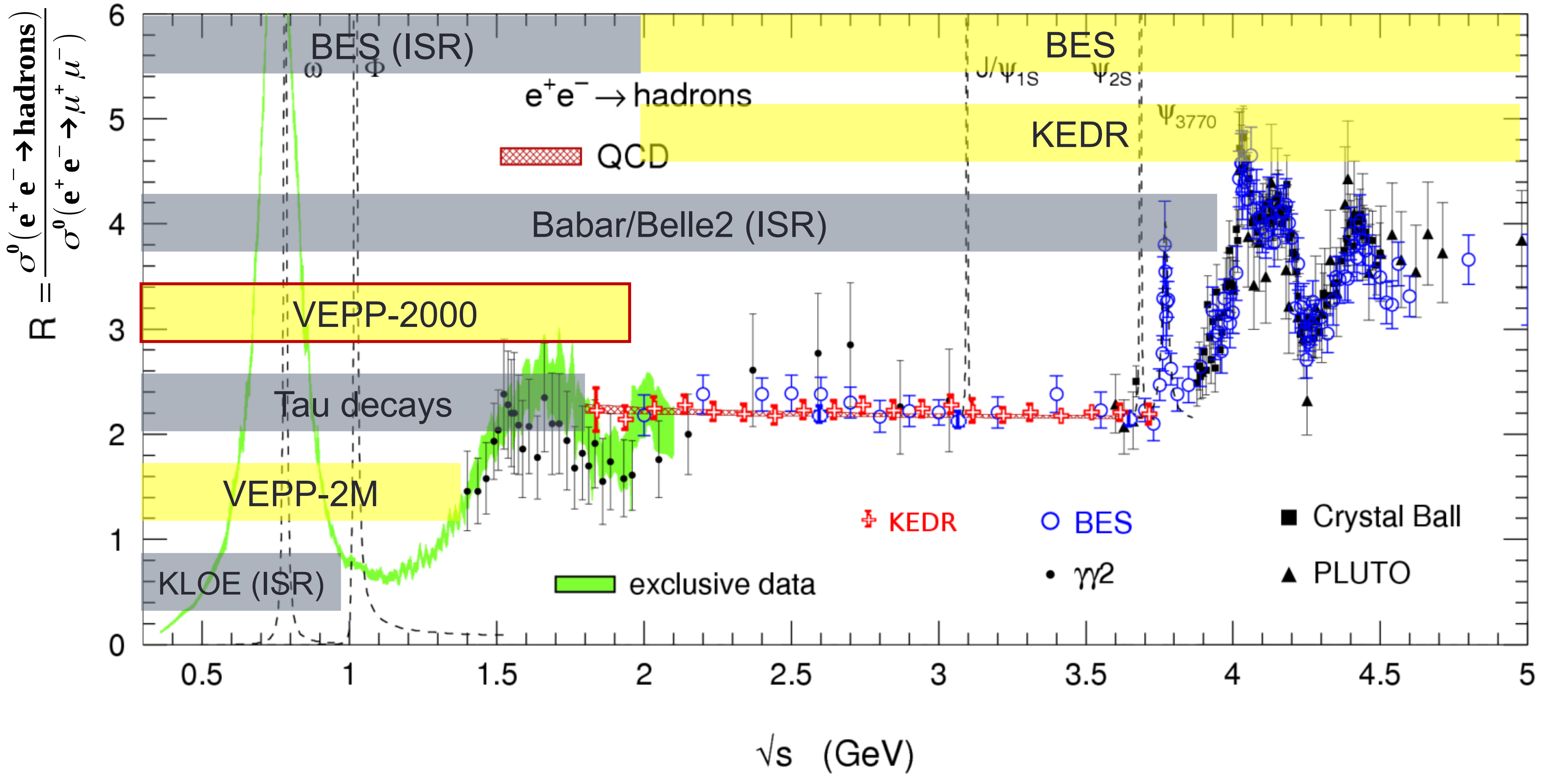
BaBar: 0.5%

BES: 0.9%

2π channel gives main contribution to theoretical precision of muon g-2

New g-2 experiments and future e+e- as ILC require summed precision ~0.2%

e+e → hadrons at √s < 5 GeV



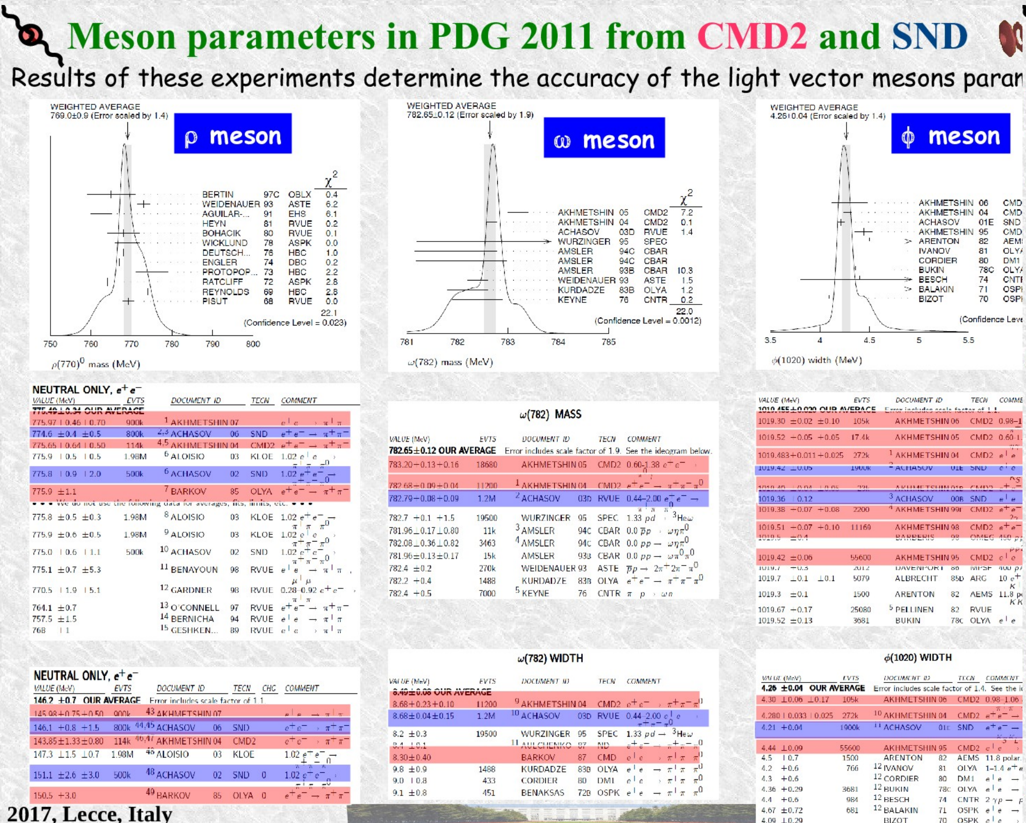
VEPP-2000: direct exclusive measurement of σ (e+e- → hadrons)
Only one working this days on scanning √s < 2GeV
World-best luminosity below 2 GeV (except at 1 GeV where KLOE outperfom everybody)

Physics at VEPP-200

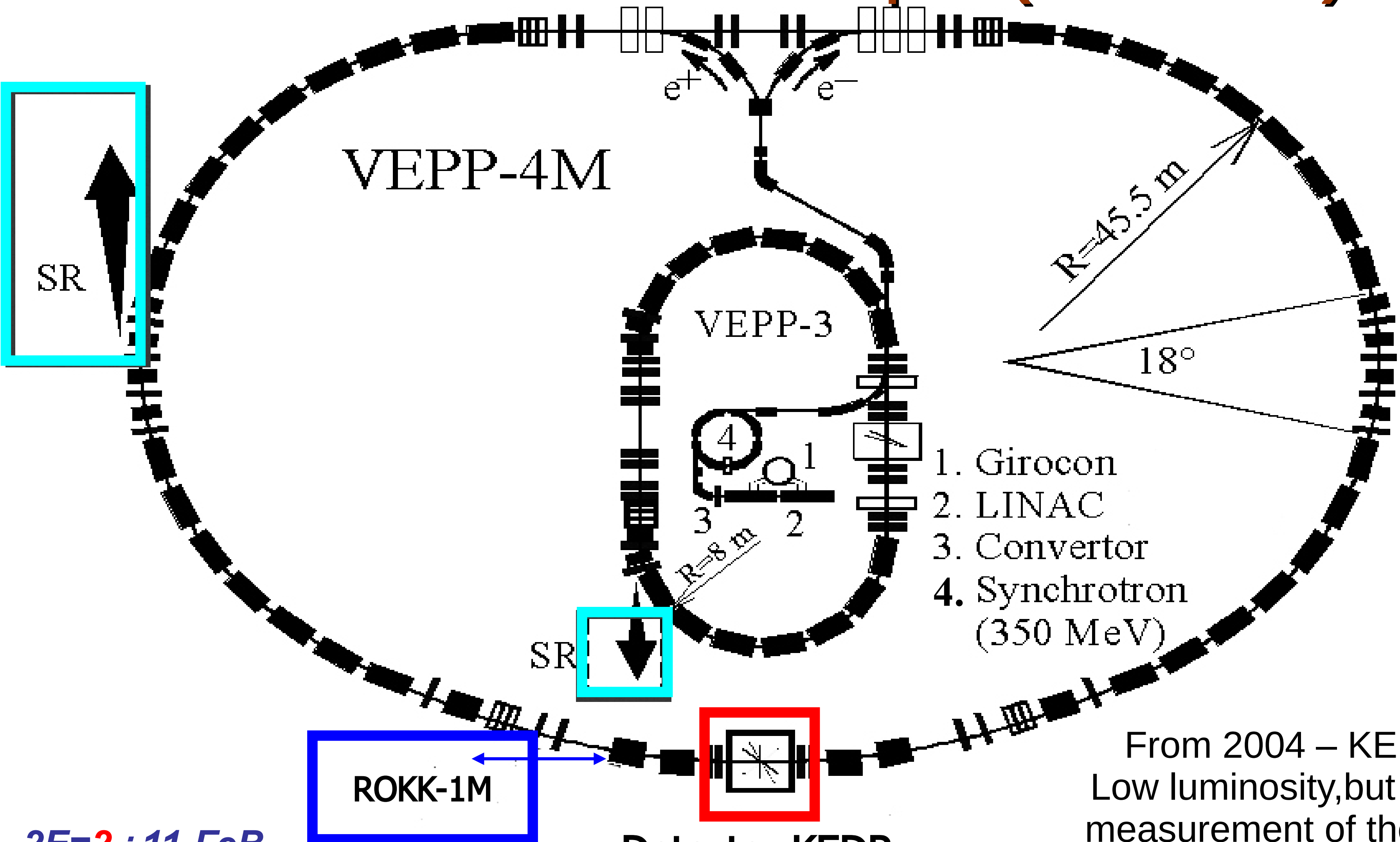
We are doing as precise measurement of total R(s) = hadron production cross-section at low energies(by sum of exclusive channels), which is used in many theoretical predictions (via dispersive integrals) : **$(g-2)_\mu$(had), $\alpha_{QED}(M_Z)$, …**

But also we do study of production dynamics, properties of light vector mesons, their decays, search of exotics, and so on….

Properties of light vector mesons in the PDG mostly comes from Novosibirsk measurements



VEPP-4M Collider Complex (1994- 202?)



From 2004 – KEDR experiment
Low luminosity,but high precision
measurement of the beam energy

2E=2÷11 ГэВ

J/ψ δm/m ~ 2e-6 (only 6 particles known better)

*L=2x10**30 см-2с-1*
*L= 8x10**31 см-2с-1*

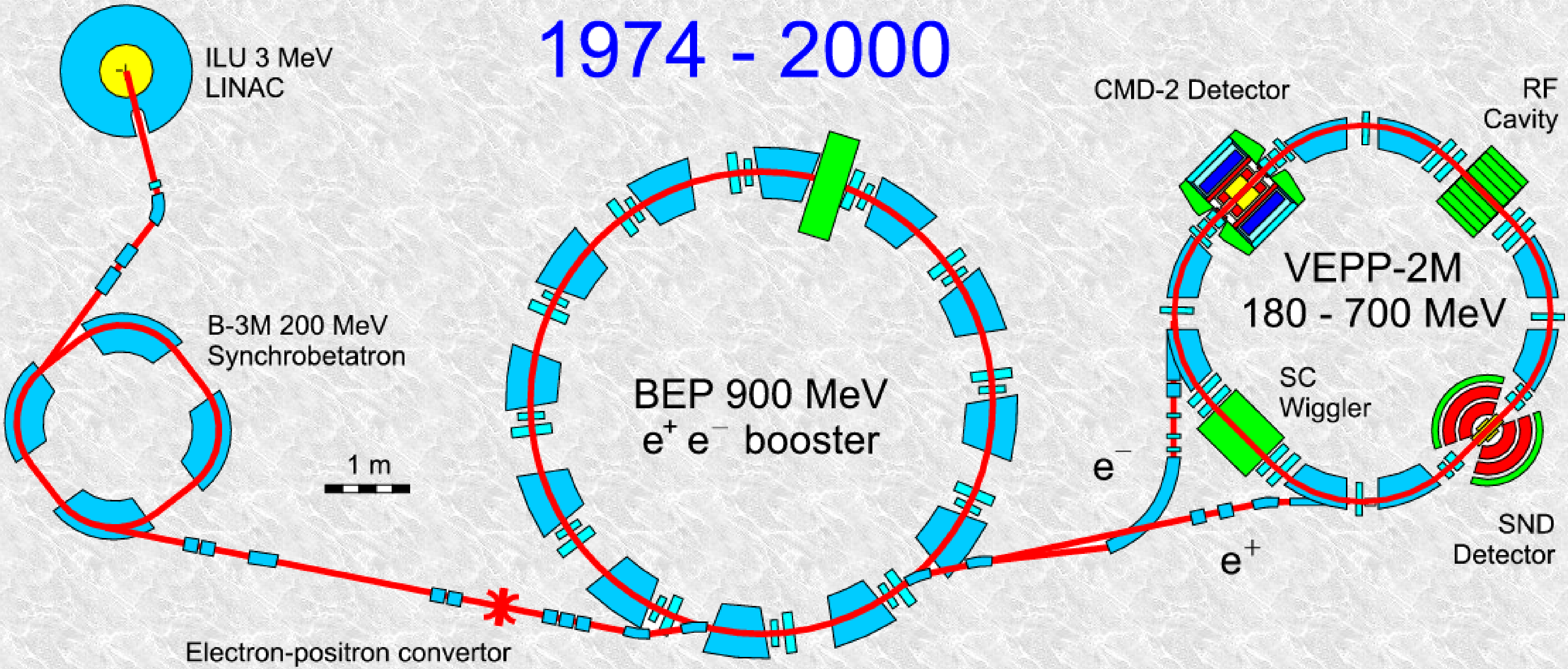
Best measurement of inclusive R(s), 2E<3.7 GeV

with ~2% systematic precision

Few more years to do scan above charm region

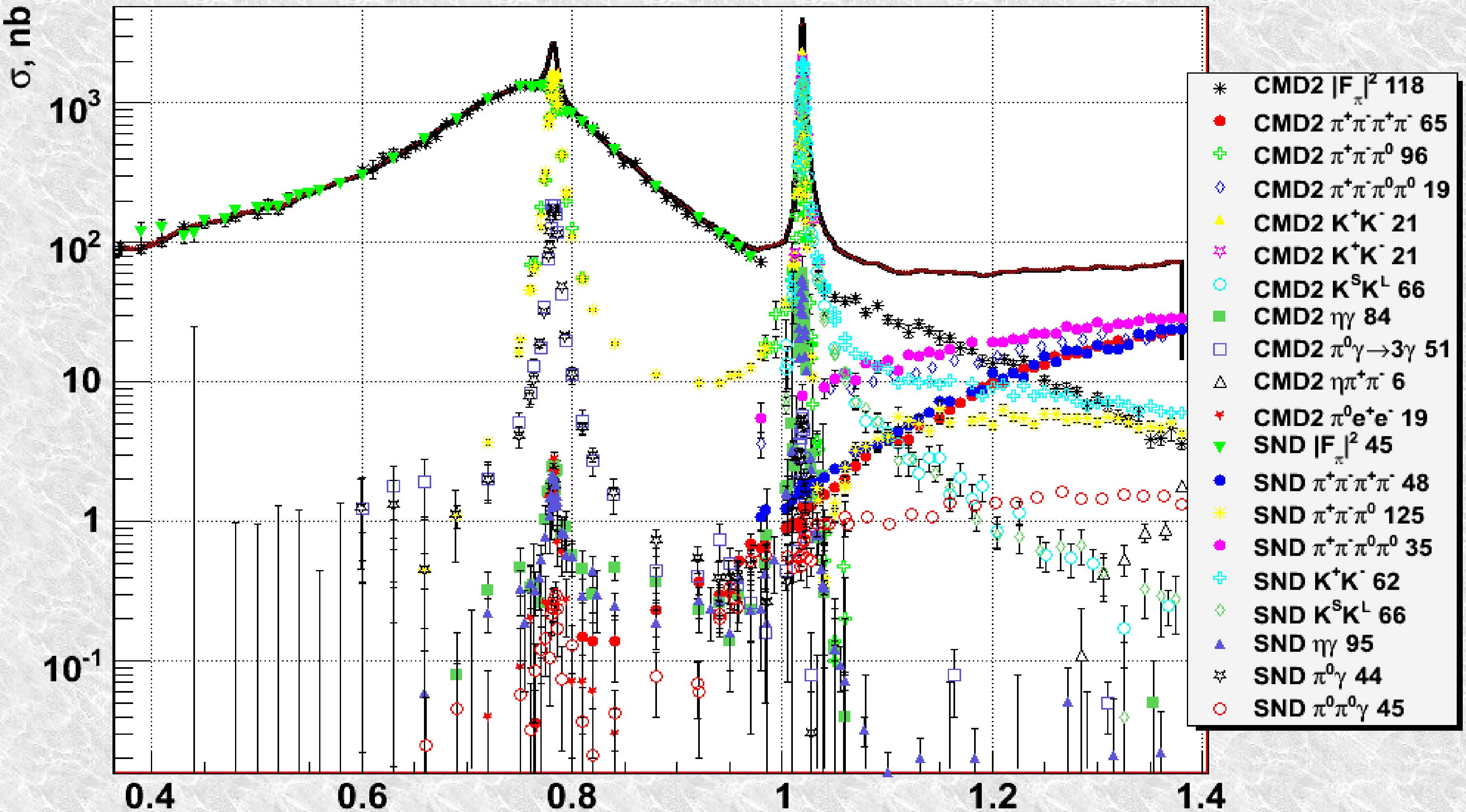
There was VEPP-2M

1974 - 2000



- VEPP-2M collider: 0.36-1.4 GeV in c.m., $L \approx 10^{30}$ $1/cm^2s$ at 1 GeV
- Detectors CMD-2 and SND: $\int Ldt \approx 60\ pb^{-1}$ collected in 1993-2000
- Precise energy: $\Delta E/E \sim 10^{-4}$ with depolarization method;
  10^{-3} from field in magnets
- All major hadronic modes were measured:
  $e^+e^- \to 2\pi, 3\pi, 4\pi, KK, ..$
  $e^+e^- \to \rho, \omega, \varphi$

Cross-section measurements at VEPP-2M



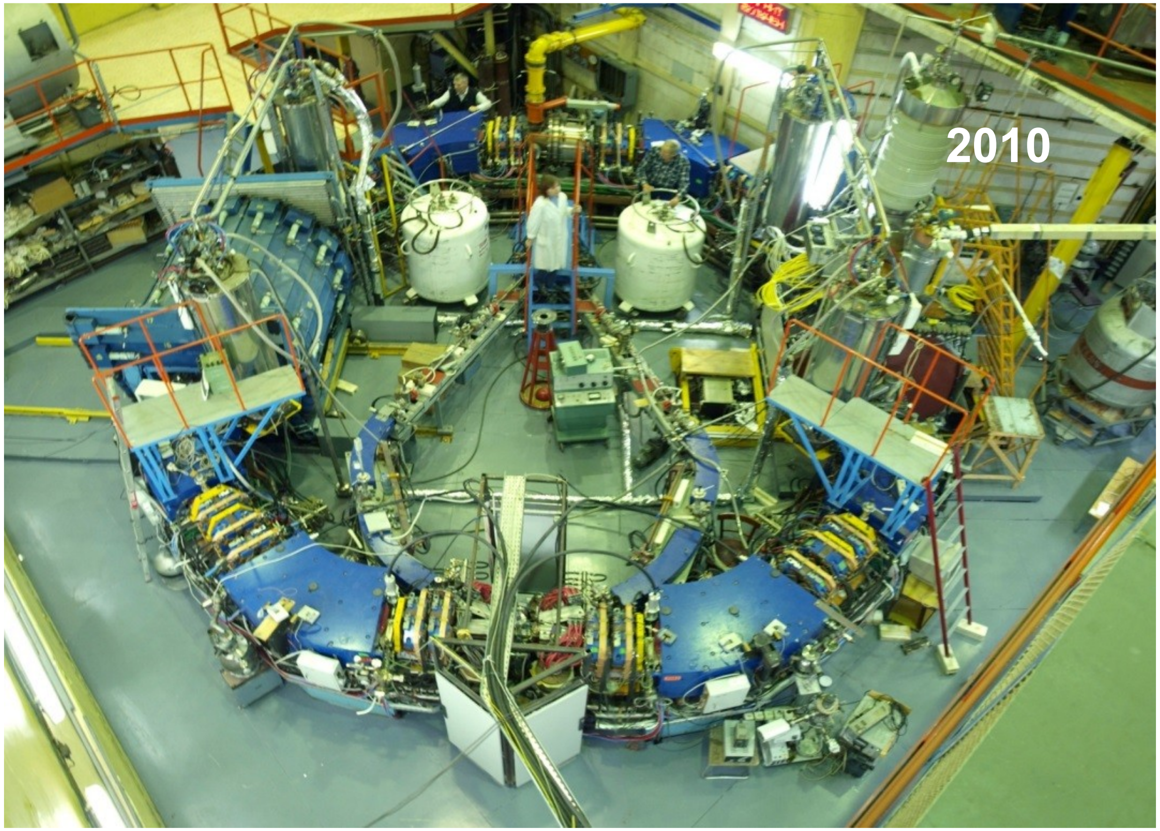
Combined precision of R(s) from CMD2&SND

Systematic error:	~0.6-0.7%	1.0%	0.6%	1.5%	1.5 -- 3.5 %
Total error:	~ 6 -- 1%	1.5%	1--2%	2.0%	2.5 -- 3.5 %

The theoretical uncertainty of $(g-2)_\mu$ was improved by factor 3 as the result of VEPP-2M measurements

From VEPP-2M to VEPP-2000

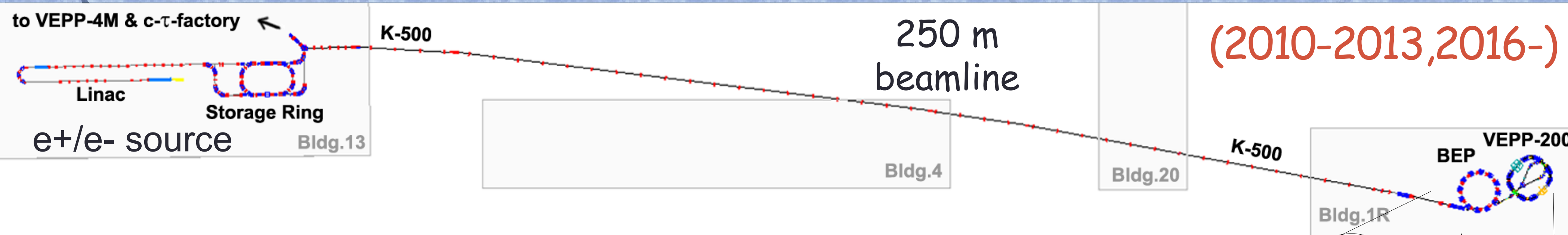
2001	VEPP-2M decommissioned
2010	first engineering run at VEPP-2000 collider with 2 new detectors: CMD-3 and SND



Main VEPP-2000 advantages:

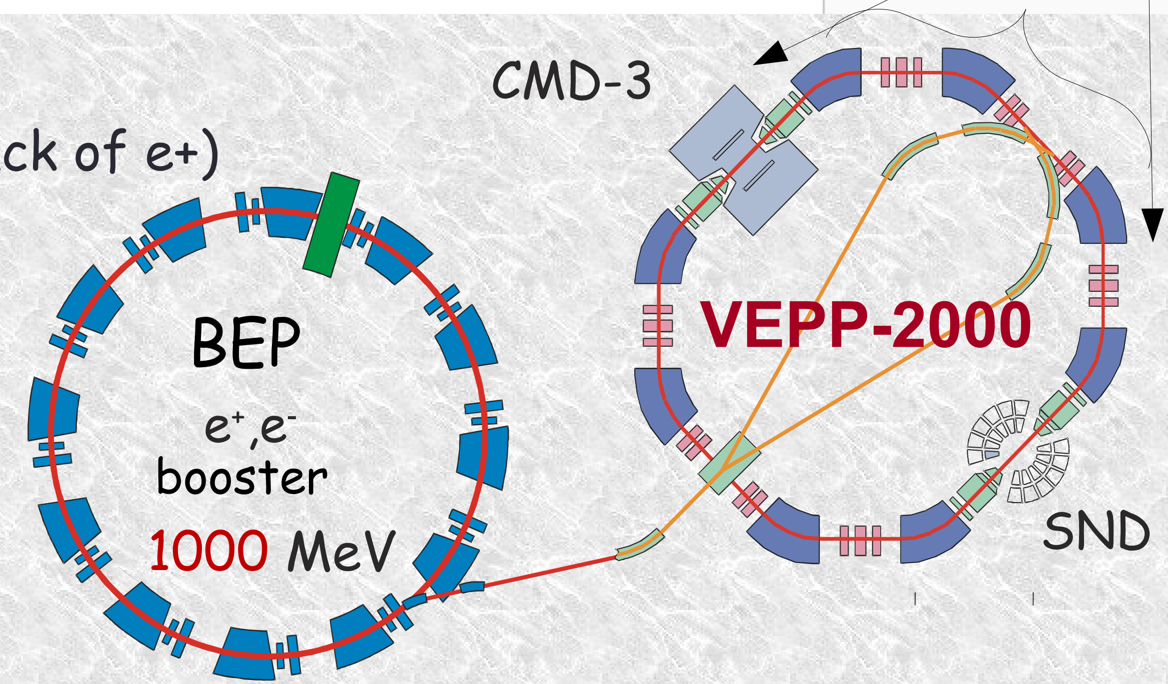
- maximum energy up to 2 GeV
- x10 higher luminosity

VEPP-2000 e+e- collider (2E<2 GeV)



- New positron source from 2016
  (no luminosity limitation due to lack of e+)

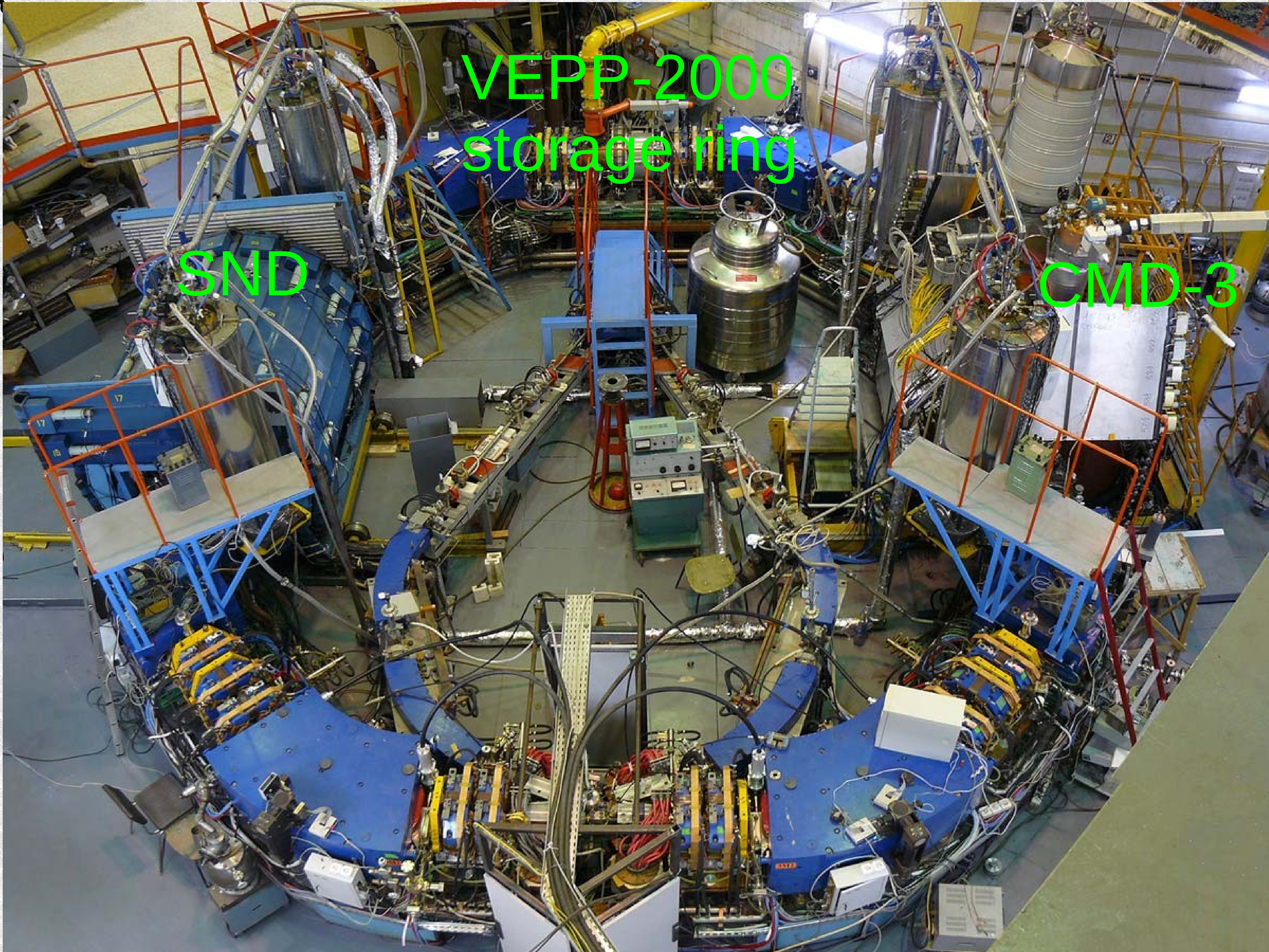
	before	after upgrade
e + /sec	2×10^7	3×10^8
e − /sec	10^9	10^{11}
BEP E max , МэВ	825	1000



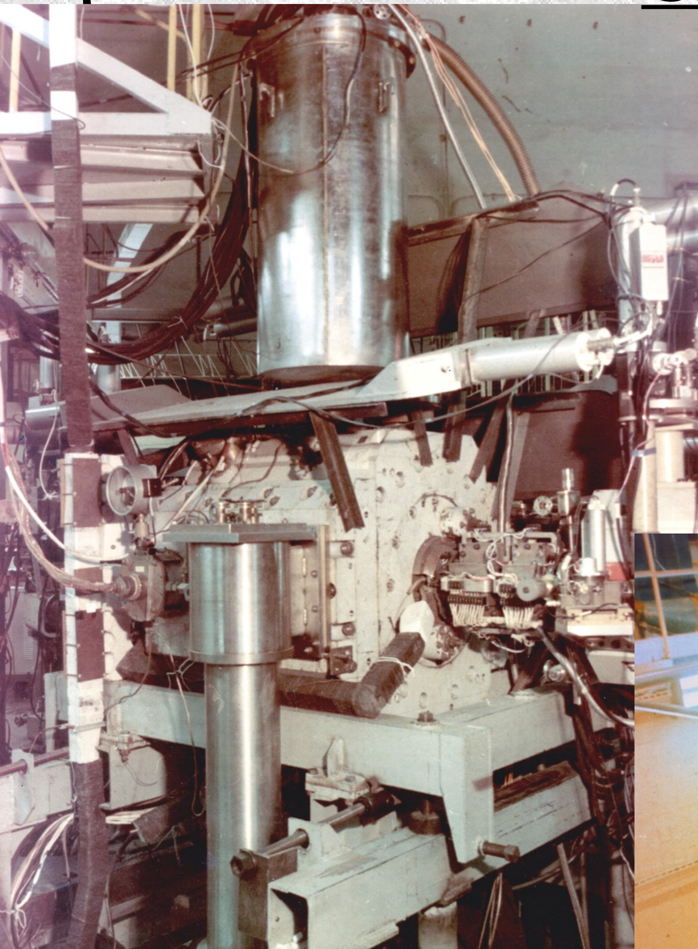
Maximum c.m. energy is 2 GeV, project luminosity is L = 10^{32} $cm^{-2}s^{-1}$at 2E= 2 GeV

Unique optics, "round beams", allows to reach higher luminosity

Experiments with two detectors, CMD-3 and SND, started by the end of 2010


VEPP-2000
storage ring
SND
CMD-3

Cryogenic Magnetic Detector's Family

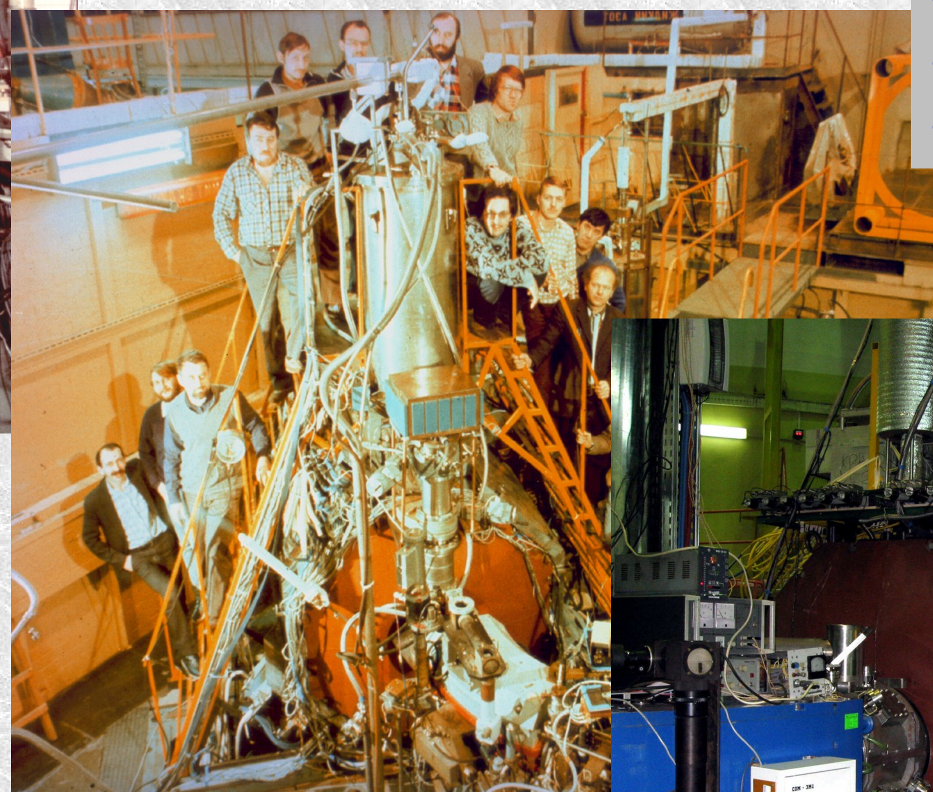


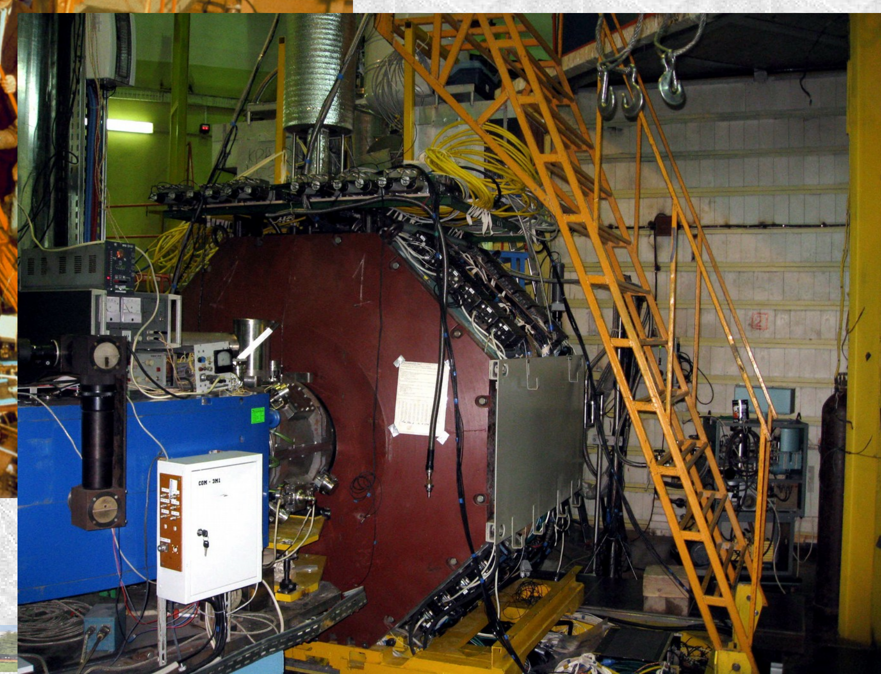
CMD-2 1989-2000

- SC Solenoid 10 kGs
- Drift Chamber
- MWPC Z-chamber
- Barrel CsI EMC
- End cap BGO EMC

CMD-3 2010-

- SC Solenoid 13 kGs
- Drift Chamber
- MWPC Z-chamber
- Barrel LXe EMC
- Barrel CsI EMC
- End cap BGO EMC



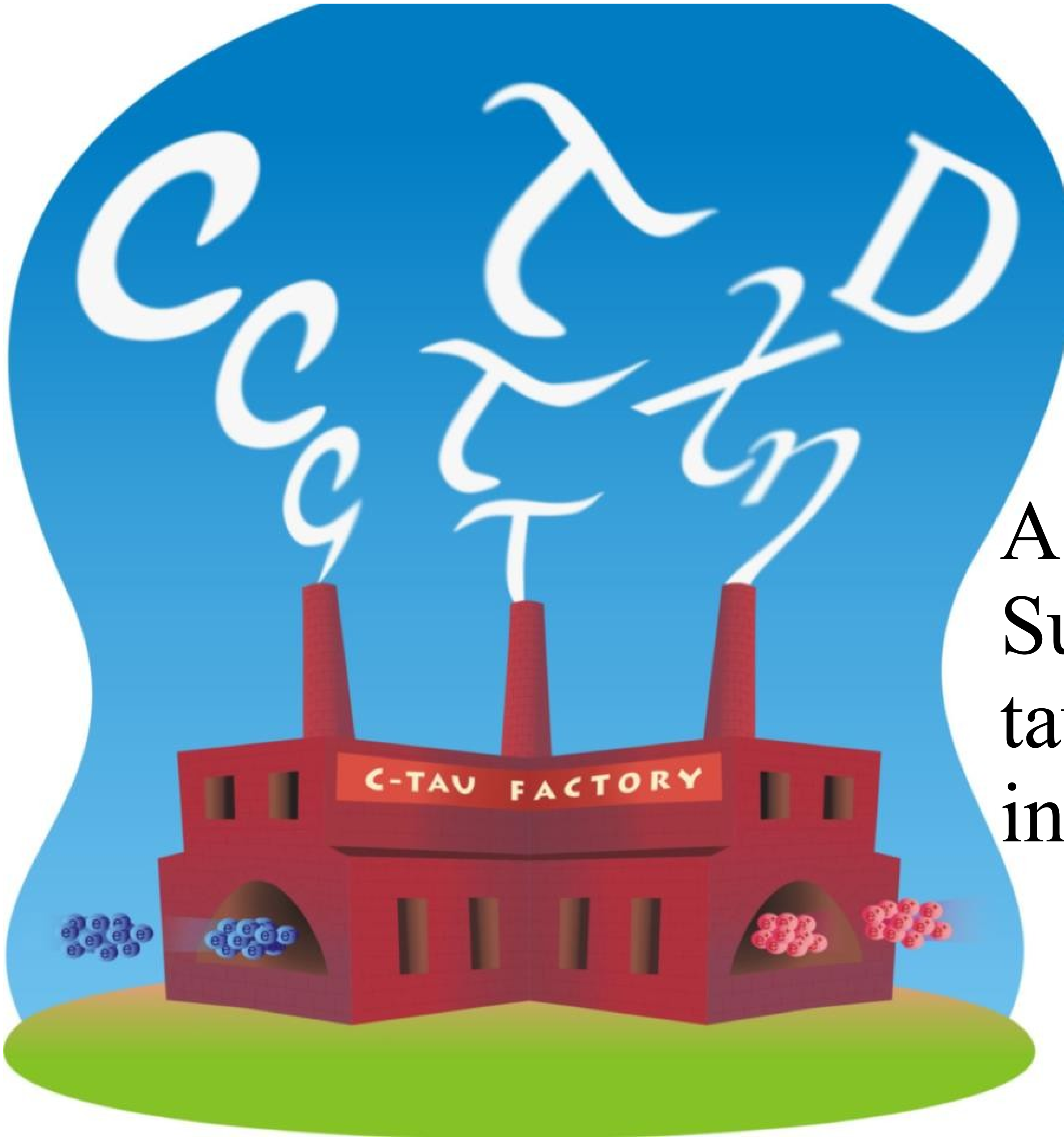


CMD 1979-1984

- SC Solenoid 32 kGs
- Optical spark chamber at 160 K with 50 μm spatial resolution
- MWPC

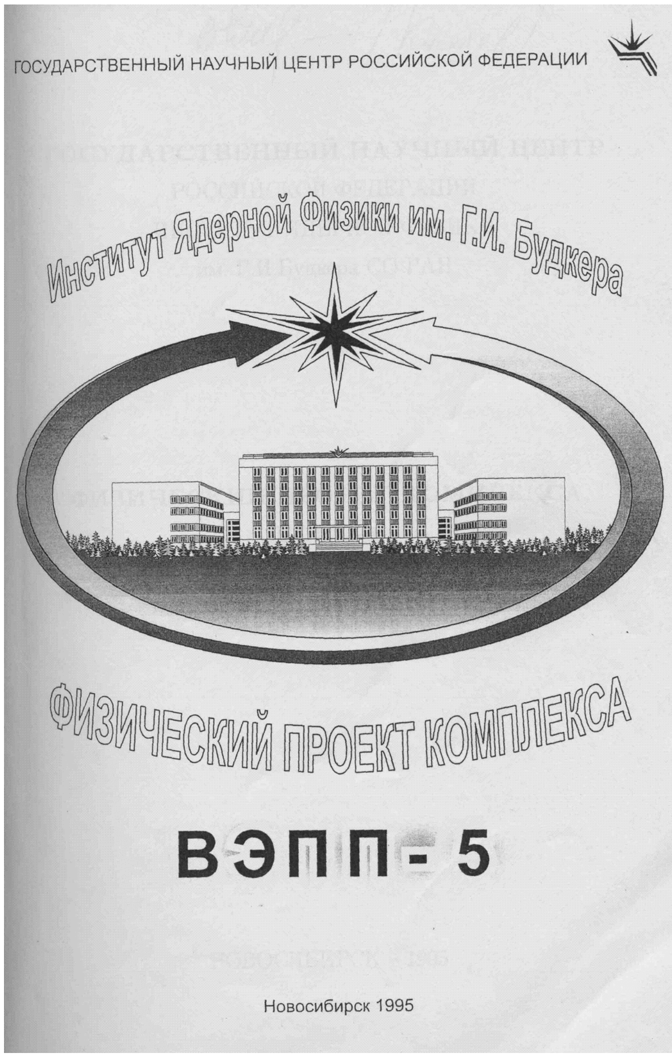
What is Next

VEPP-4M will be working for next few years
VEPP-2000 ~ additional 5-10 years of data taking



A project of
Super charm-
tau factory
in Novosibirsk

Super-c-tau
First proposal in Novosibirsk at 1995



- E = 700 – 2500 MeV
- Round beams $L = 10^{34}$ $cm^{-2}s^{-1}$
- Monochromatization

  $L \sim 10^{32}$ $cm^{-2}s^{-1}$
- Long. Polarization

  $L \sim 10^{34}$ $cm^{-2}s^{-1}$
- Transverse polarization for precise energy calibration

Many proposals was at that time this energies with $L \sim 10^{33}$ $cm^{-2}s^{-1}$

Dubna, Argonne NL, Spain&France, Beijing

Super Tau-Charm factory

$L = 10^{35}\ cm^{-2}s^{-1}$

The interest to such machine re appeared at 2000th after new crab waist scheme was proposed in the LNF with factor x10 higher luminosity.
The activity on SCTF was intensified with very pushing forward at ~ 2010

project status at begins of 2010th

- Project was preliminary approved by Russian Government (2011)
- CDR –has been completed (**2012**)
- Road map –is ready (**6 years for realization**)
- Very positive statement of ECFA (2012)
- Design of the building has been completed (2013)
- Conception model for computing is ready (2013)
- R@D for machine and detector in progress
- Injection complex construction in progres
- Very positive reply of EU review Committee (2013)
- Funding decision and construction ?

Super Tau-Charm factory

2011 – ctau one of 6 selected MegScience projects by Ministry of Science:

NICA – approved, under construction
<u>Super C-tau – highest rating by external experts</u>
XCELS - Exawatt Center for Extreme Light Studies
SSRS-4 – synchrotron center of 4th generation
IGNITOR - compact fusion reactor on the magnetic confinement - ~~canceled~~
PIK reactor facility – highest neutron source – under construction

Since 2013, ….. Bad economical situation,….

January 2017 – was hired new vice minister Grigorij Trubnikov, responsible for science part, ex vice director of Dubna, accelerator person
2018 – was new president election, many promises were made before during election campaign
(as result new 0.5B euro synchrotron machine was approved in the BINP)

Current Status

• SCTF was approved by Russian Government as one of the six mega-sciences projects.

• In June 2017, the SCT project was included in the plan for the implementation of the first phase of the Strategy for Scientific and Technological Development of the Russian Federation

• The Government requested final documents by the end of 2019 for the decision on project financing (we hope).

• Preliminary Design Report, Conceptual Design Report, Civil Construction Design Report and Road Map are ready(june 2017 renewed CDR version).

• SCTF officially supported by ECFA.

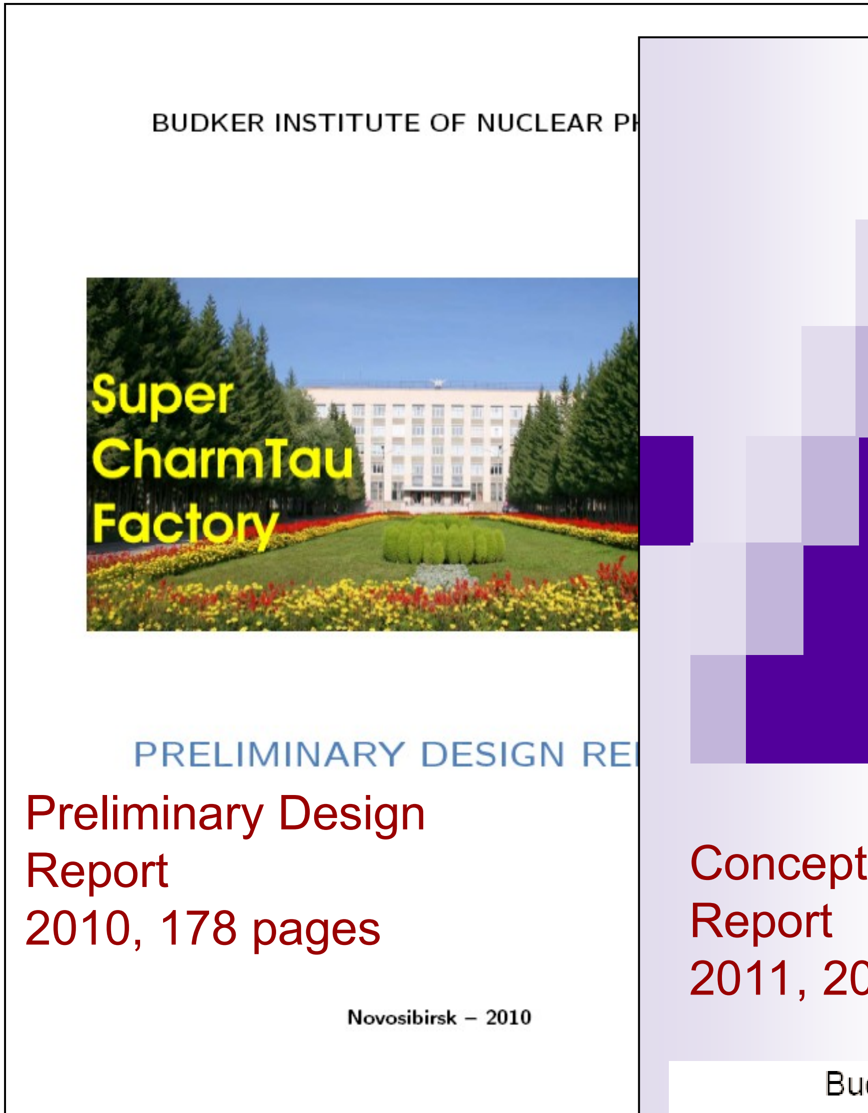
• European Commission Expert Group has supported SCTF (Russian Mega Science projects – evaluation of the potential for cooperation with Europe Experts meeting in Brussels 19 June 2013).

• MoUs with CERN, KEK, INFN, JINR, John Adams Institute, etc. are signed.

• First Meeting of International Advisory Committee – May, 26-27, 2018

• Next Join Meeting of the BINP and Hefei project, Orsay, 4-7 Dec 2018

Documentation



Preliminary Design Report
2010, 178 pages

Conceptual Design Report
2011, 202 pages

Road Map,
2011, 112 pages

International review

ECFA approval:

Your presentation clearly demonstrated that high precision tau and charm physics is important not only in itself, but also will provide crucial information for the interpretation of measurements by the flavour physics experiments at the LHC and the Super B Factories. Furthermore, the unique advantage of working at the tau/charm threshold was compellingly shown. For these reasons, the Committee members are all convinced by the physics case of a Tau-Charm Factory.

Prof. T.Nakada

Two experts were invited at 2011 by Russian Ministry of Science (Steve Mayers and Robert Aymar) to estimate the Novosibirsk Tau-Charm factory.

ECFA EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

Prof. A. Skrinsky
Director of the Budker Institute of Nuclear Physics, Novosibirsk
and
Prof. A. Bondar
Dean of the Physics Department of the Novosibirsk State University

Geneva, 7 April 2011

Dear Colleagues,

Thank you very much for your presentation on the physics potential and machine design for a Tau-Charm Factory to the Restricted session of European Committee for Future Accelerator in Vienna that took place on 12th of March 2011.

Your presentation clearly demonstrated that high precision tau and charm physics is important not only in itself, but also will provide crucial information for the interpretation of measurements by the flavour physics experiments at the LHC and the Super B Factories. Furthermore, the unique advantage of working at the tau/charm threshold was compellingly shown. For these reasons, the Committee members are all convinced by the physics case of a Tau-Charm Factory.

The Committee is very impressed by the well-advanced machine design study performed by the Novosibirsk group. We also note that the strategy to achieve high luminosities by storing small emittance beams is common to the Super B Factories. Therefore, many accelerator research and development programmes could be shared and done in collaboration with those groups working on the Super B Factories, generating synergy among accelerator groups in different regions.

We consider that the long and well-established tradition and expertise in accelerator science and the available accelerator infrastructure in Russia makes this proposal realistic and valuable. Construction of such a machine would further enhance the international role of Russia and attract a worldwide interest.

Thanks again for your effort in informing us about the project and the Committee is looking forward to hearing about the progress of the project in the future.

Yours Sincerely

T. Nakada

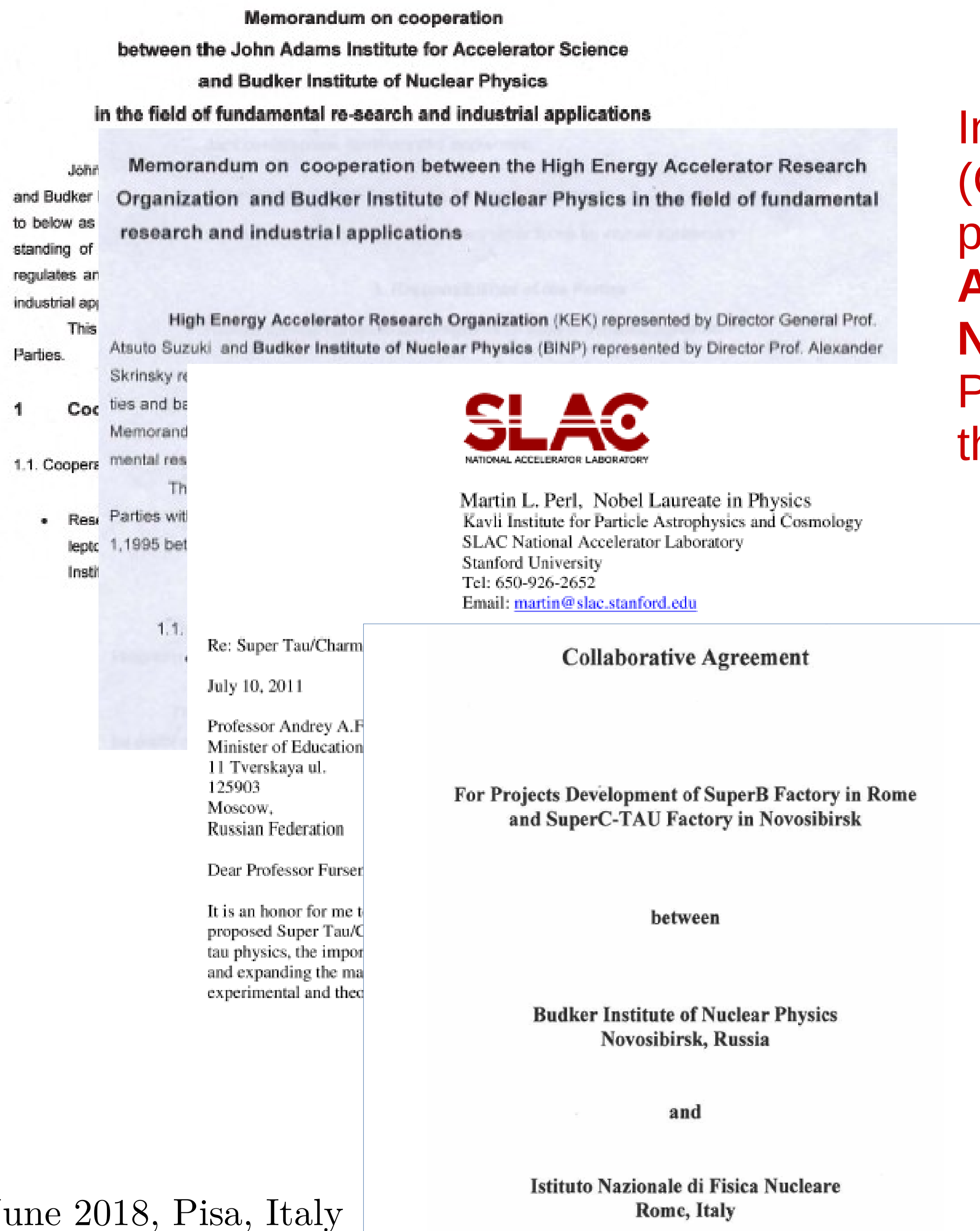
Professor T. Nakada

Chairman of the European Committee for Future Accelerators
Professor of Elementary Particle Physics,
Swiss Federal Institute of Technology Lausanne (EPFL)

ECFA Secretariat
CERN - DG
CH - 1211 Geneva 23

Tel: (41 22) 767 39 83
Fax: (41 22) 782 30 11
E-mail: sylvia.martakis@cern.ch

Collaboration and support



Memorandum on cooperation
between the John Adams Institute for Accelerator Science
and Budker Institute of Nuclear Physics
in the field of fundamental re-search and industrial applications

Memorandum on cooperation between the High Energy Accelerator Research Organization and Budker Institute of Nuclear Physics in the field of fundamental research and industrial applications

High Energy Accelerator Research Organization (KEK) represented by Director General Prof. Atsuto Suzuki and Budker Institute of Nuclear Physics (BINP) represented by Director Prof. Alexander Skrinsky

SLAC NATIONAL ACCELERATOR LABORATORY

Martin L. Perl, Nobel Laureate in Physics
Kavli Institute for Particle Astrophysics and Cosmology
SLAC National Accelerator Laboratory
Stanford University
Tel: 650-926-2652
Email: martin@slac.stanford.edu

Re: Super Tau/Charm

July 10, 2011

Collaborative Agreement

For Projects Development of SuperB Factory in Rome and SuperC-TAU Factory in Novosibirsk

between

Budker Institute of Nuclear Physics
Novosibirsk, Russia

and

Istituto Nazionale di Fisica Nucleare
Rome, Italy

International scientific organizations (CERN, JINR) and authoritative and prominent scientists (among them – **Atsuto Suzuki, Rolf Heuer, Tatsuya Nakada**, and Nobel Prize Winner in Physics **Martin Perl**) have expressed their support for the SCT.

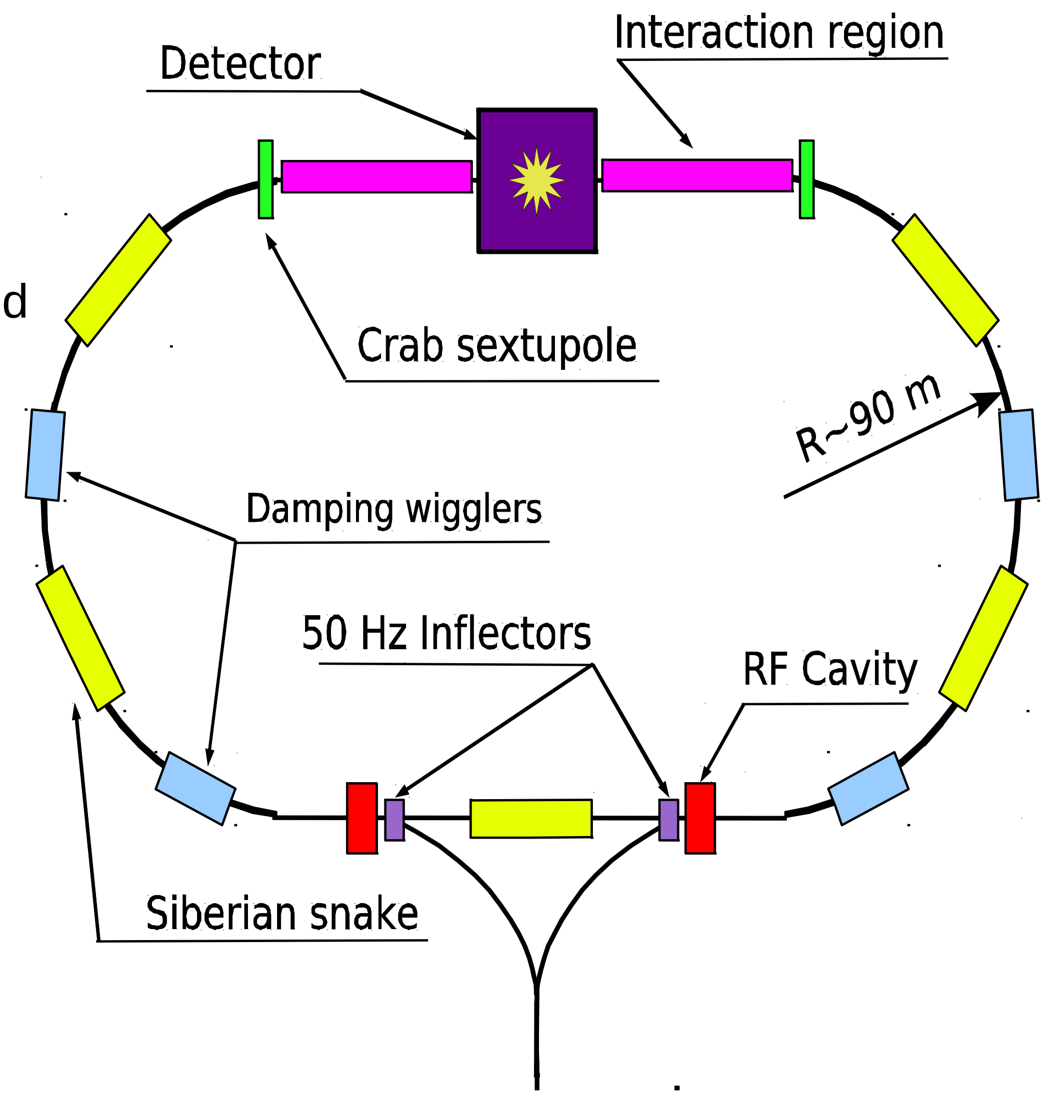
Agreements/memorandums are signed with CERN, KEK, INFN, JAI, JINR (Dubna), etc.

SCTF machine

Main accelerator specs:

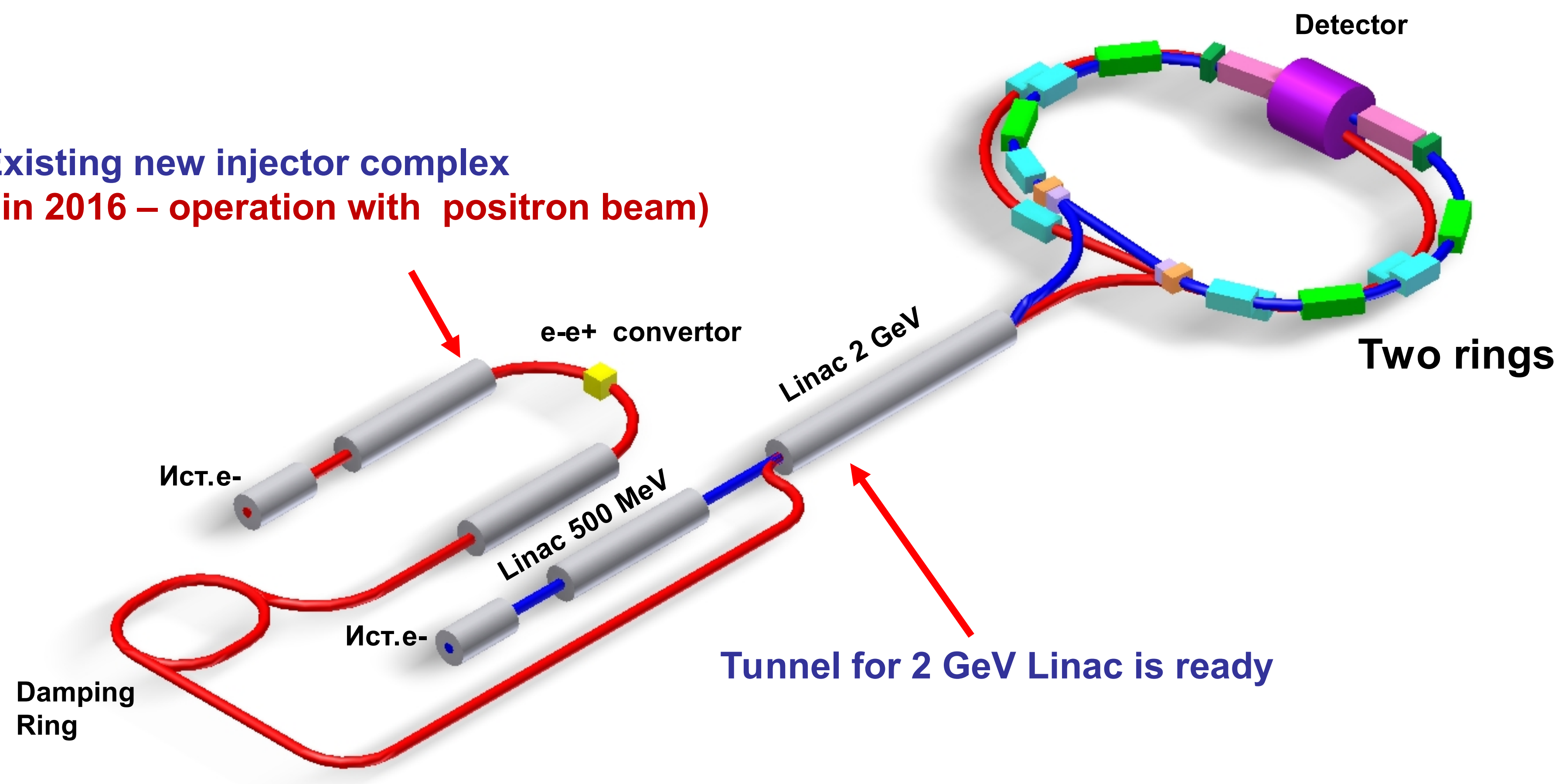
- 2E = 2. – 5. GeV
- Two rings with Crab Waist collision scheme and single interaction point
- Peak luminosity at 2 GeV of 10^{35} cm^{-2} s^{-1}
- Longitudinal polarization of electron beam
- No transverse polarization. Energy calibration by Compton backscattering (~$3x10^{-5}$)
- Symmetric beam energy at collision
- No collision monochromatization
- Positron production rate >= 1 x 10^{11} e+/c
- 2.5 GeV full energy linac

Main ring scheme



Super Charm-Tau Factory

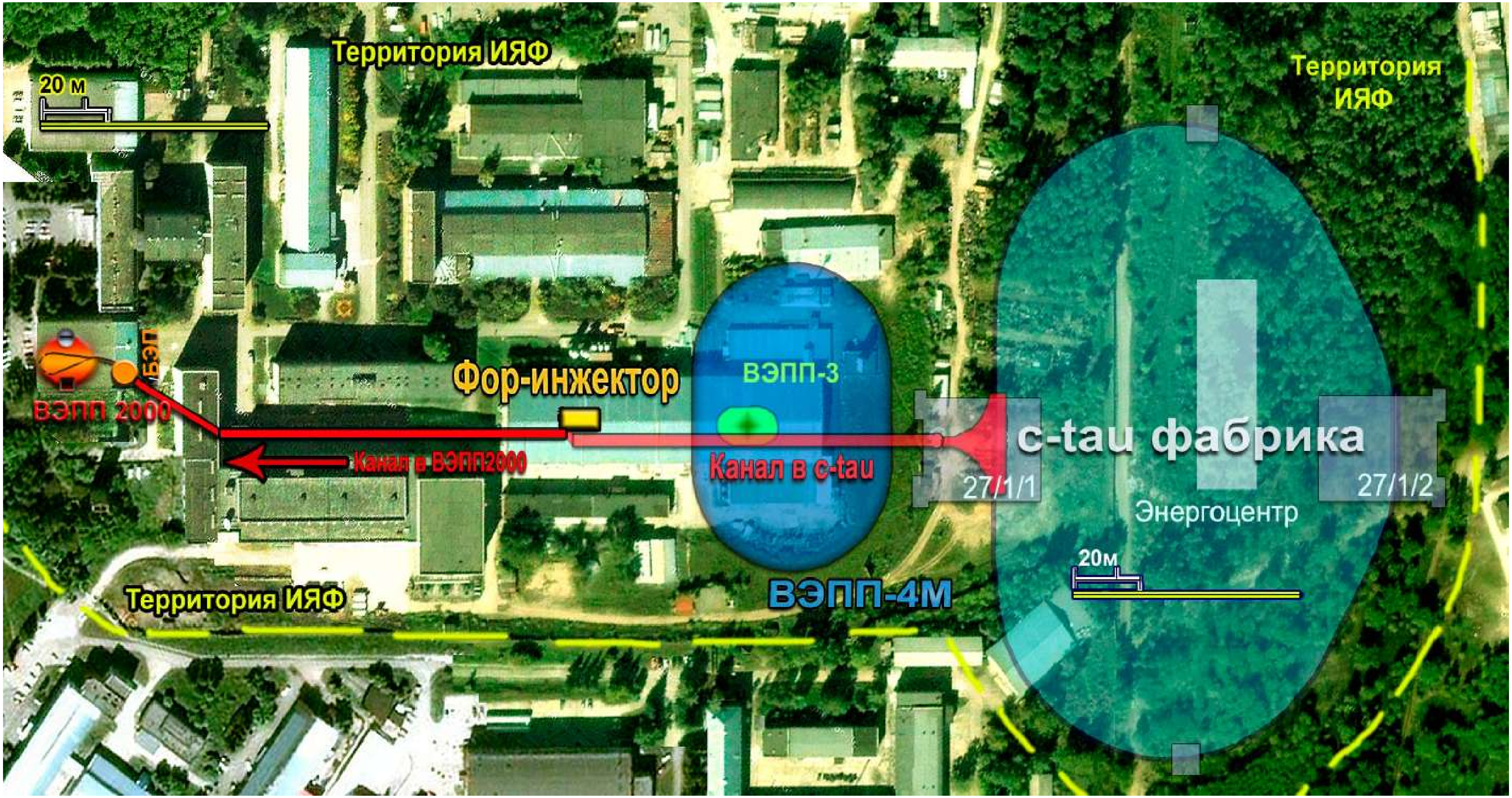
Existing new injector complex
(in 2016 – operation with positron beam)



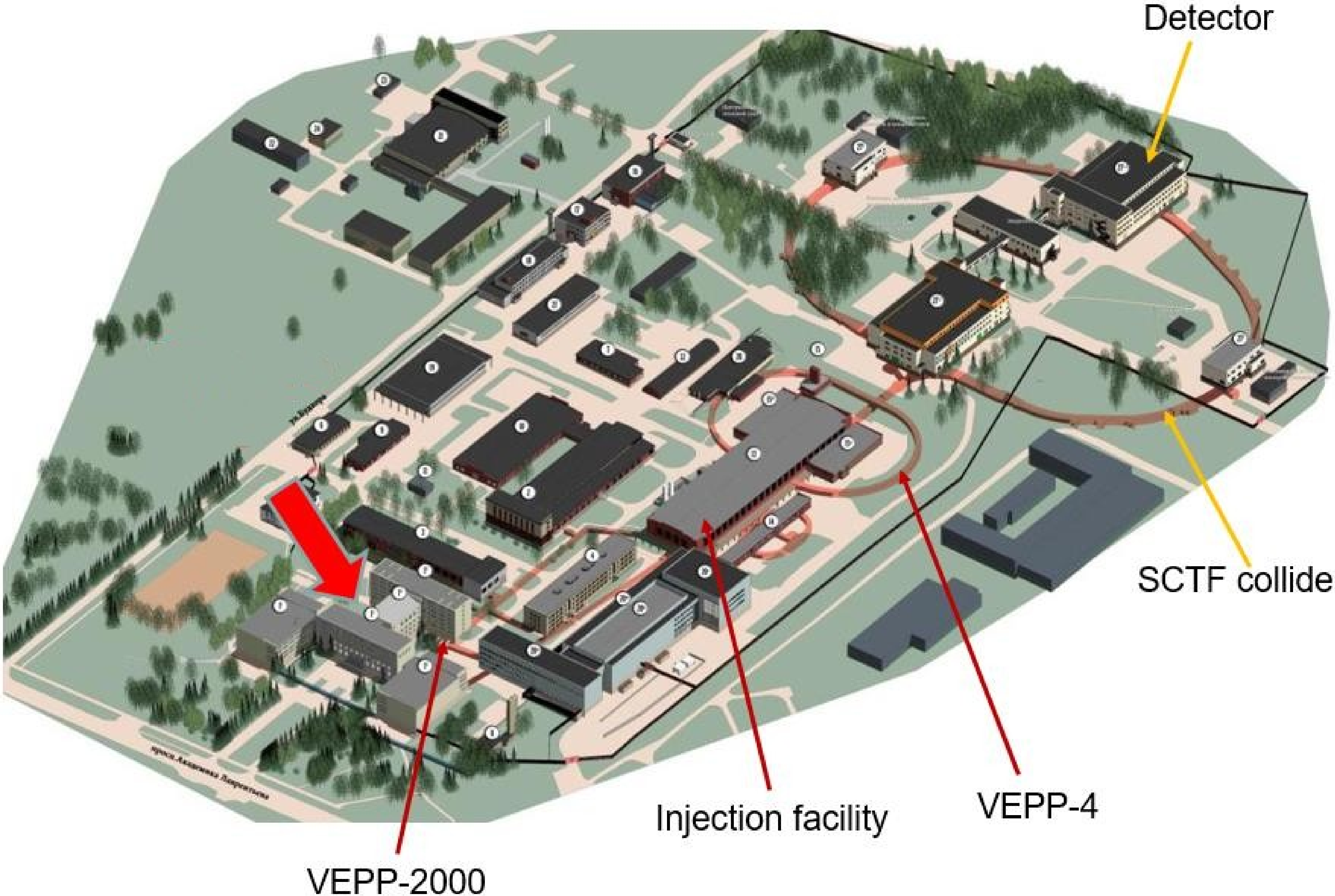
Tunnel for 2 GeV Linac is ready

- Two rings
- Crab waist
- L = 1×10**35 cm-2s-1,
- Variable energy Ecm= 2 – 5 GeV
- Longitudinal polarization

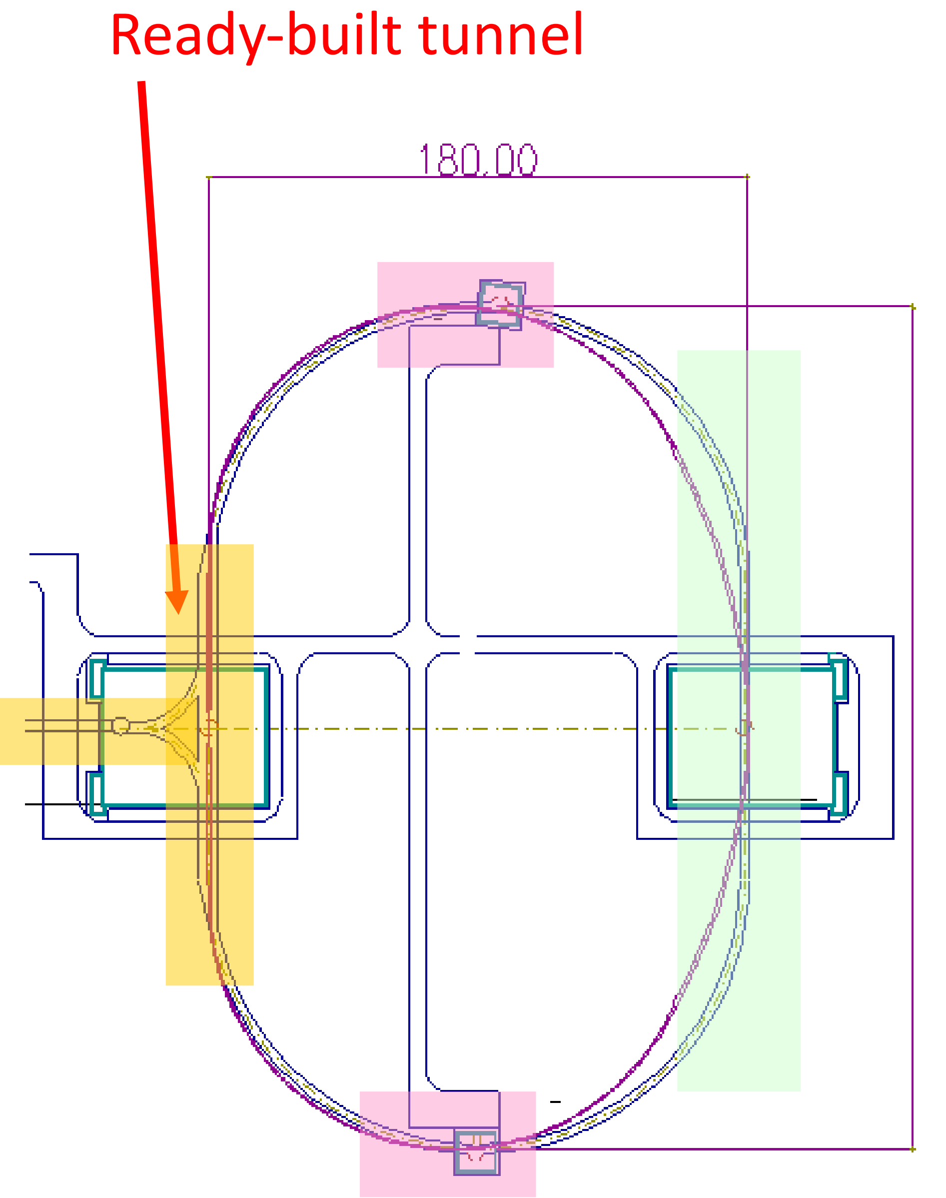
Super c-tau factory



SCTF location



Super-c-tau: construction cite



FF region

Technical reg. (RF and injection)

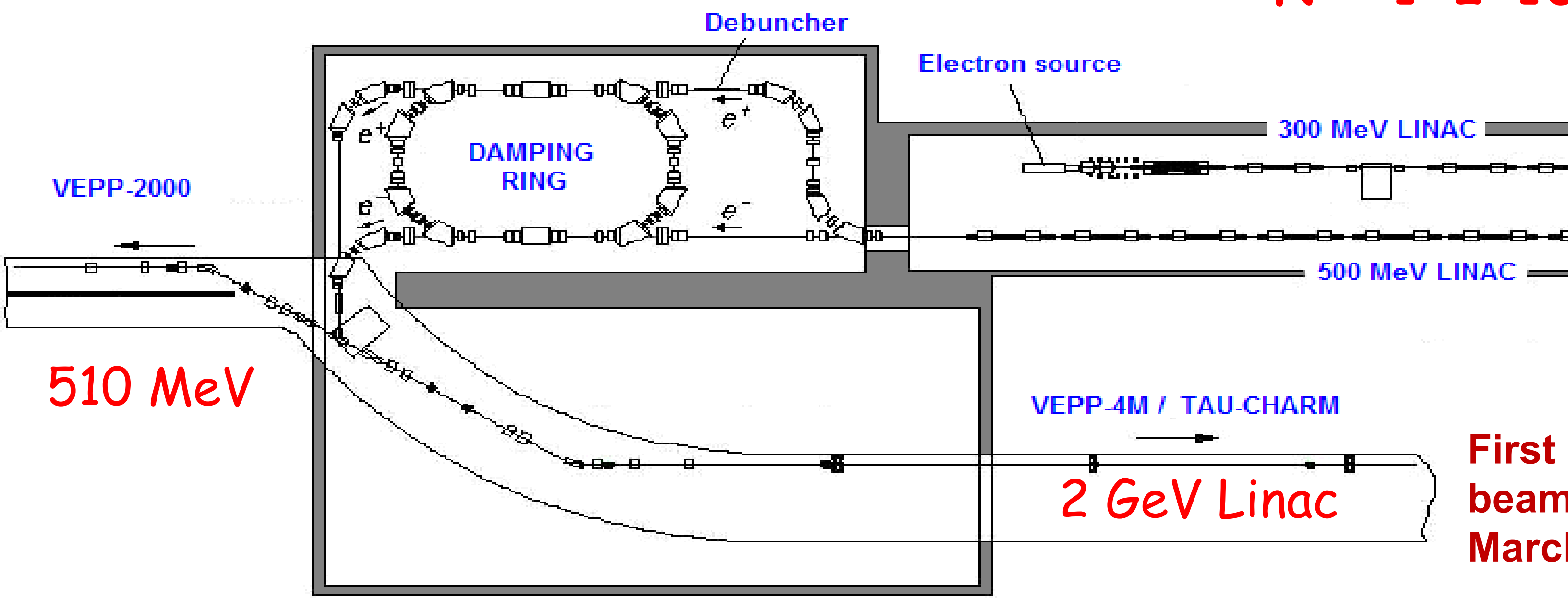
Damping wiggler sections

New injection complex

(is used now for VEPP-2000, VEPP-4M and can be used for Super Charm-Tau)

50 Hz Extraction

N = $1 \div 2 \cdot 10^{11}$ e+/sec



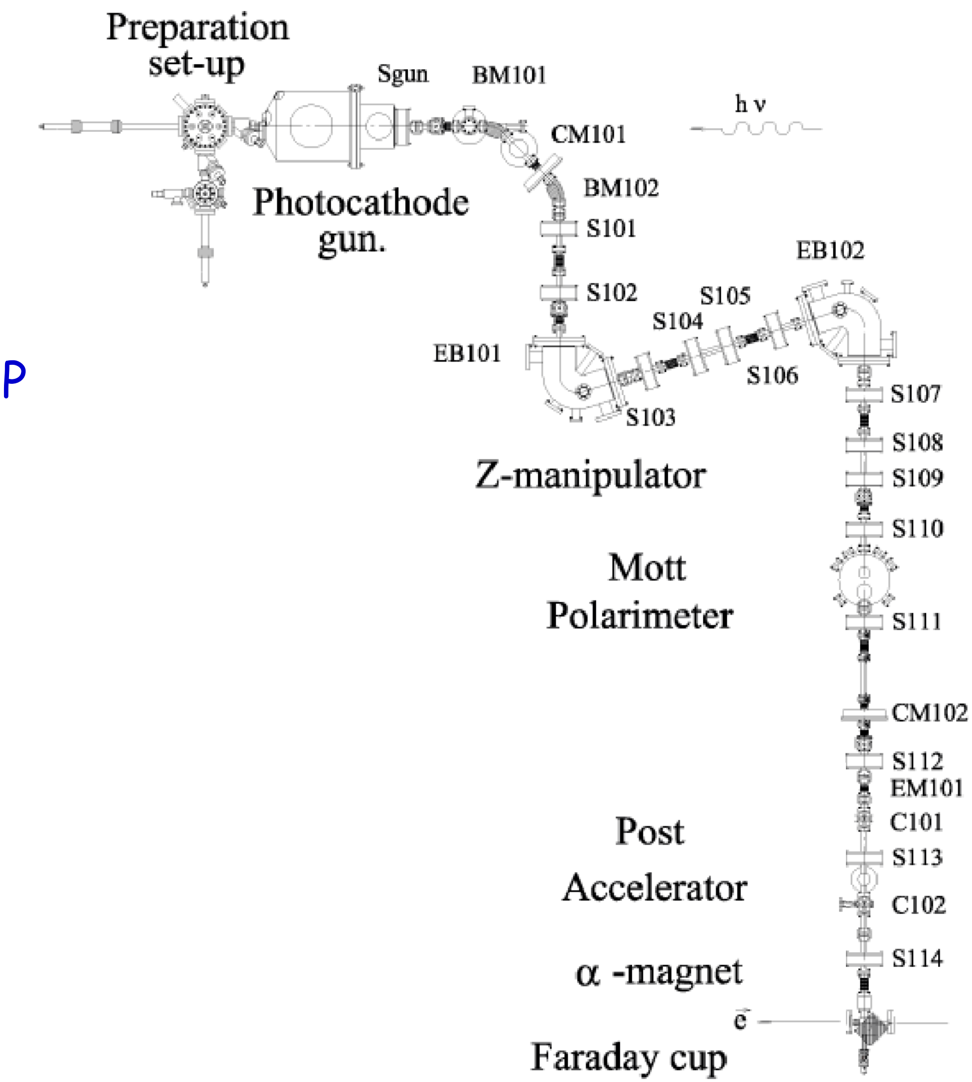
510 MeV

2 GeV Linac

First positron beam - March 2013

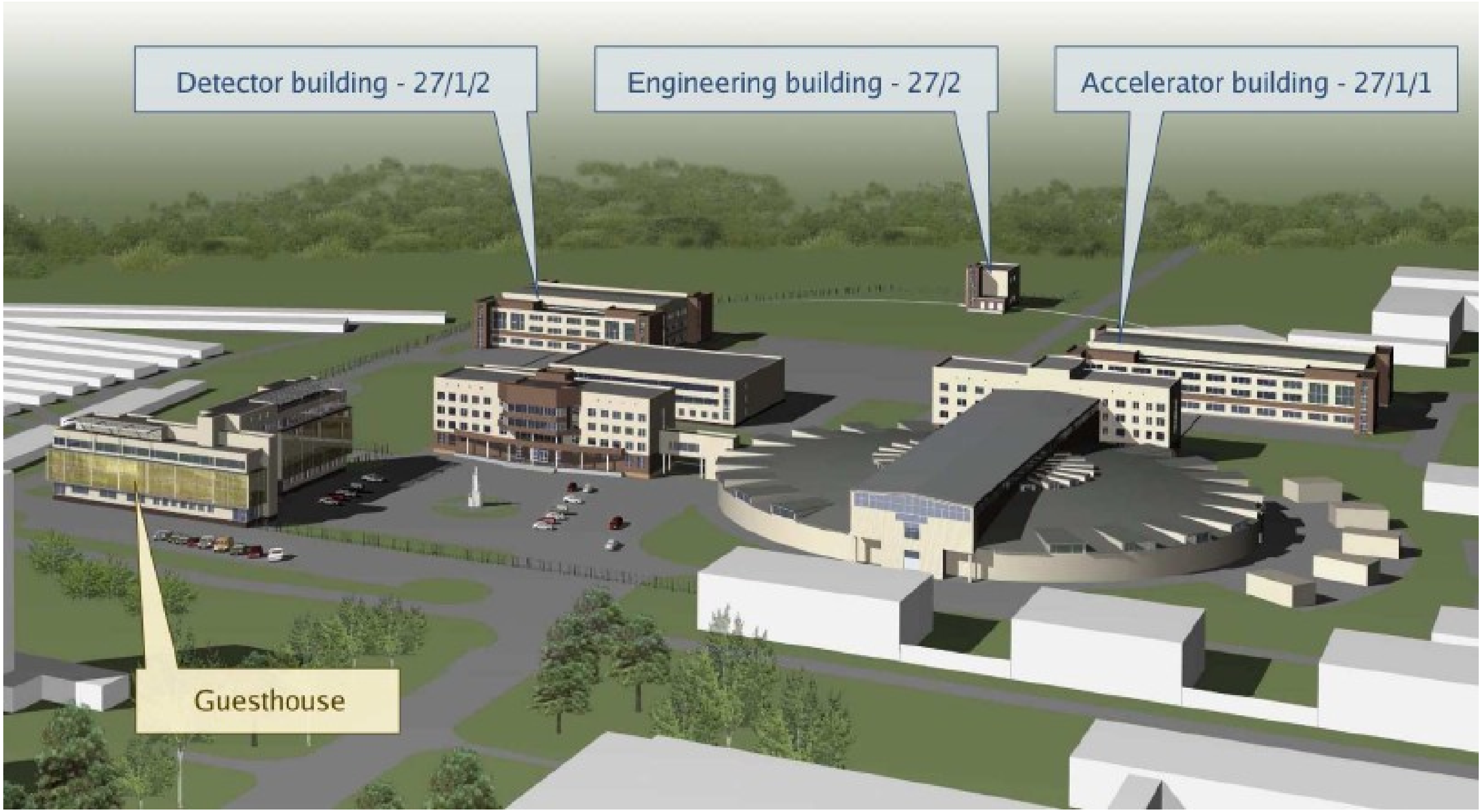
The pulsed polarized electron source

- Beam polarization 60-80% (90%)
- Cathode voltage 100 kV
- Photocathode type Strained InGaAsP
- Laser type Ti-Sapphire
- Light wavelength 700-850 nm
- Laser power in a pulse 200 W
- Pulse duration 2.1 μs
- Repetition rate 1 Hz (50 Hz)
- Max. current from a gun 150 mA
- Operational current 15-20 mA
- Photocathode lifetime 190-560 hours



Polarized electron source produced by BINP
for nuclear physics experiment at the NIKHEF accelerator facility AmPS

Artistic view of future Charm-tau factory



- **Accelerator Complex** **210 MEuro**
- **Detector** **90 MEuro**
- **Buildings infrastructure –** **100 MEuro**
- **BINP has already invested 37 MEuro in the capital construction and injection complex**

Mostly Ten years after initial design

- At BES III and LHCb experiments are in progress.
- Super KEKB has commissioned.
- Chinese project HIEPA is under consideration.
- Extremely low emittance light sources are in construction.
- New Crab Waist projects (FCC-ee, CEPC) are under way.

All this gives a basis for improvement of Novosibirsk SCTF performance.

By configuration each ring of SCTF is a synchrotron light source with a long straight section for collision. For the last decades many useful accelerator technologies were developed for synchrotron light sources (low emittance, chromaticity correction, DA optimization, effective injection, coupling correction, etc.) and all of them can be applied to SCTF.

Machine Parameters under modernization

- Beam energy increase at least up to 3 GeV according to request from experimentalists. (HIEPA promises 3.5 GeV)
- Realistic design of the FF/MDI area
 L * = 0.6 m -> 0.9 m.
- Short chromatic correction section (designed by Katsunobu Oide for FCC-ee).
- Damping wigglers removing (or reduction of their number).
- Slightly strengthen parameters and additionally increase luminosity.

E (MeV)	1000	2000	3000
П (m)	634		
F_{RF} (MHz)	354.1		
q	750		
θ (mrad)	±30		
κ (%)	0.5		
β_x^* (cm)	5		
β_y^* (mm)	0.5		
I (A)	2.18	2	2.2
$N_{e/bunch}\times10^{10}$	8	7	6.5
N_b	360	390	450
U_0 (keV)	10	160	808
V_{RF} (kV)	560	460	1200
$\nu_s\times10^{-3}$	4.05	2.5	2.9
δ_{RF} (%)	4.3	2	1.6
$\sigma_E\times10^{-3}$	0.3/2.3	0.6/1.1	0.97/0.97
σ_s (mm)	3/14.5	6/11.3	7.2/8.2
ε_x (nm)	0.3/14	1.1/3.3	2.6/2.6
$L_{HG}\times10^{35}$ ($cm^{-2}s^{-1}$)	0.8	1.9	3.3
HG (%)	74	89	90
$\xi_x\times10^{-3}$	4.8	3.4	4.1
ξ_y	0.11	0.13	0.12
ϕ	16	26	22
τ_L (s)	2610	960	630

Beam crossing at 2θ = 60 mrad, polarized electron beam
~ 6 nsec between beam crossing,
390 bunches followed by ~ 260 nsec empty gap

Luminosity

	CLEO-C		BES-III/год	C-τ
J/ψ	-	-	10×10^9	$\times100$
$\psi(2S)$	54 пб$^{-1}$	27×10^6	3×10^9	
$\psi(3770)$	818 пб$^{-1}$	5×10^6 D-пар	3×10^7	
4.17 ГэВ	586 пб$^{-1}$	7×10^5 D_s-пар	2×10^6	
$\tau^+\tau^-$		4×10^6	2×10^7	10^{10}
$\Lambda_c^+\Lambda_c^-$				5×10^8

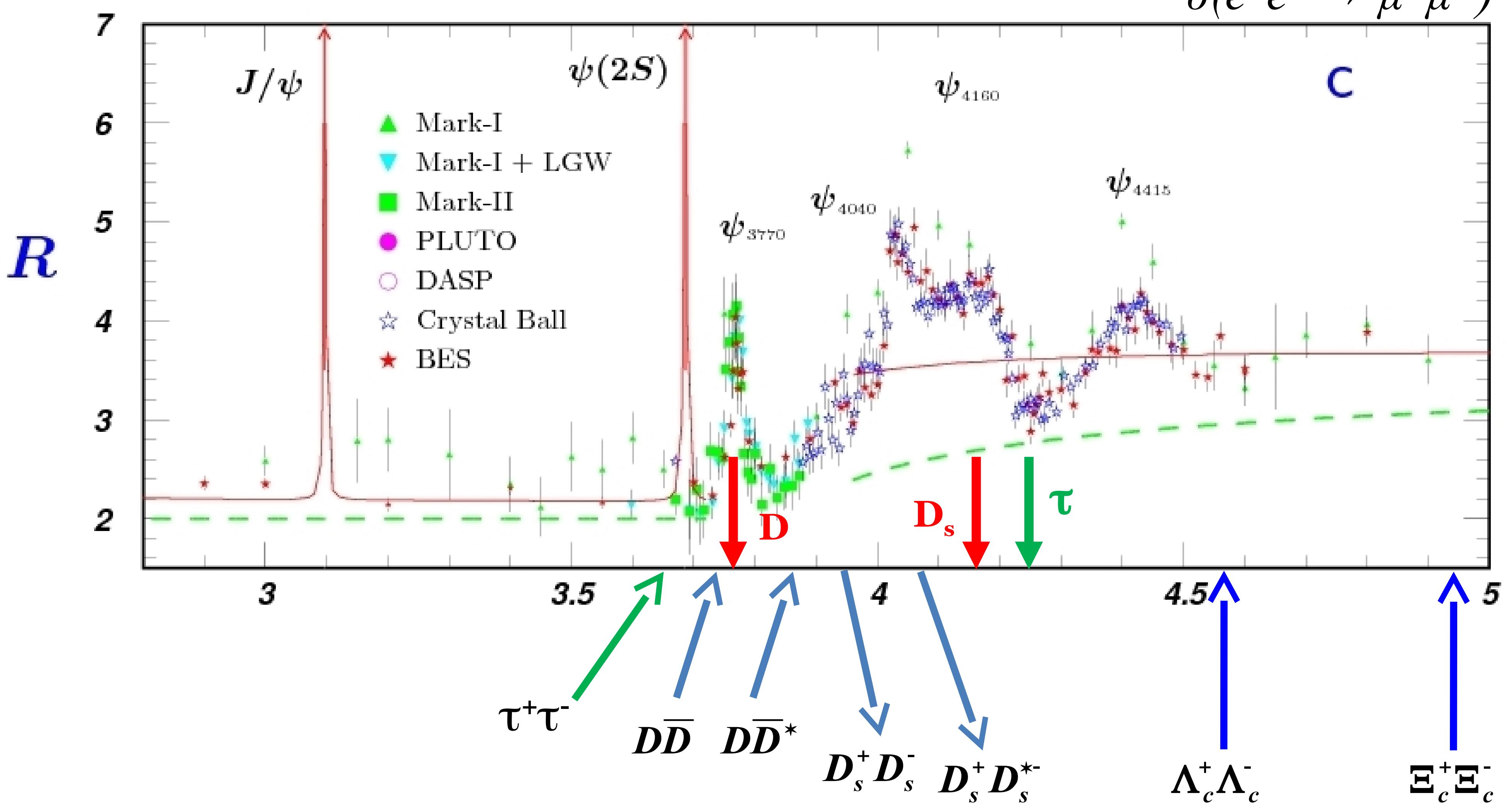
B-factories already produced 10^{10} charm hadrons and 10^9 pair τ-leptons

C-τ factory: $10^{33} \rightarrow 10^{35}$ cm^{-2}s^{-1}

B factory: $10^{34} \rightarrow 10^{36}$ cm^{-2}s^{-1}

Super-c-tau: scientific case

$$R = \frac{\sigma(e^+e^- \rightarrow hadrons)}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$



Super-c-tau: scientific case

Physics CDR, ver 2017
http://ctd.inp.nsk.su

Charmonium
- Spectroscopy, BFs
- Light hadron states
- J/ψ rare decays
- …

Tau
- Michel parameters
- Spectral functions, BFs
- Lorentz structure
- CP violation
- LFV decays
- …

Charm mesons
- Spectroscopy
- (Semi)leptonic decays
- Rare decays
- Mixing
- CP violation
- …

Charm baryons
- BFs
- Semileptonic decays
- CP violation
- …

γγ - physics
- Search for C-even resonance
- σ(γγ→ hadrons)

σ(e+e-→ hadrons)
- Direct and via ISR

- ✗ **Rare and forbidden charm decays**
- ✗ **D-Dbar mixing**
- ✗ **CP violation searches in charm and τ leptons decays**
- ✗ **Standard Model tests in τ leptons decays**
- ✗ **Searches for lepton flavor violation $\tau\to\mu\gamma$**
- ✗ **Exotic states: multiquark bound states, glueballs, hybrids**

Requirements: $L > 10^{35}$ cm^{-2} s^{-1}, longitudinal polarization, General Purpose Detector with perfect PID

The Importance of Charm

new physics

(1) Of the flavored hadronic systems with mixing — K(s), D(c), B(b) — the D system is the only system involving heavy up-type quarks:

$\Rightarrow$ ***it provides sensitivity to different new physics phenomena***

(2) Mixing (found) and CP violation (not found) are small in the charm system:

$\Rightarrow$ ***deviations from SM expectations could be dramatic***

weak physics

(3) Flavor physics relies on global constraints derived from all systems *(e.g., the CKM matrix elements, and inputs from one system into another)*:

$\Rightarrow$ ***charm is an essential piece of a larger flavor physics program***

strong physics

(4) Weak physics and strong physics can be separated in charm leptonic and semi-leptonic decays:

$\Rightarrow$ ***charm decays offer opportunities for precision QCD***

(5) Many rare decays have backgrounds from "long-distance" hadronic processes:

$\Rightarrow$ ***a spotlight is placed on less-understood aspects of QCD***

Advantages of near threshold production

10^9 pairs of $D^{\pm,0}$ and $2 \cdot 10^7$ D_s mesons can be collected
in the reaction $e+ e- \rightarrow D^+ D^-$, $D^0 \bar{D}^0$, $D_s^+ D_s^-$

- More precise results can be expected compared to produced at the Υ(4S):

- The multiplicity of final particles is lower by a factor of 2 than at 10.6 GeV
- Clean $D\bar{D}$ events are produced near threshold, additional kinematic constraints are possible, double-tagging: one D is fully reconstructed and for the other D absolute Br are measured
- At threshold D and $\bar{D}$ are produced in quantum coherent state, in $e+e- \rightarrow D\bar{D}$ ($J^{PC} = 1^{--}$) making possible studies of $D - \bar{D}$ mixing, CP violation, with determination of strong phase shifts and probabilities for decays to CP -pure states

The statistics of LHCb and Belle II will be formidable...
... a super τ-charm factory would be formidable in a complementary way!

τ Physics at STCF

STCF operation ~ 2.1×10^{10} τ pairs will be produced,
Belle-II ~ 4.6×10^{10} τ pairs

Since the accuracy of many τ physics measurements is limited by systematics, clean STCF running at the production threshold can improve drastically outcome results:

- In $\tau^+ \tau^-$ threshold production, the full kinematics can be reconstructed, so triple product asymmetries can be Inferred (CPV).
- At threshold, hadrons would be monochromatic in two-body tau decay:

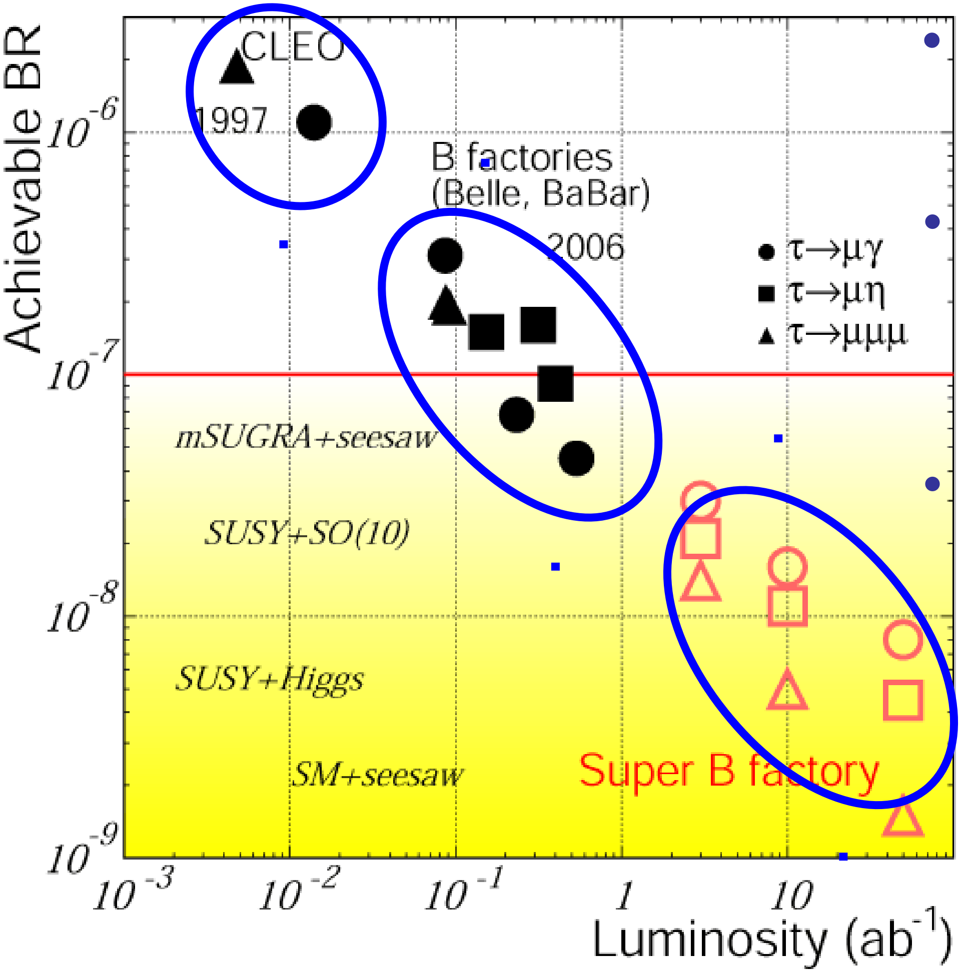
  precision in $\tau^- \to (\pi/K)^- \nu_\tau$ (LU).

Polarization may increase sensitivity by several times!
If even one beam polarized, τ almost 100% longitudinally polarized near the threshold - which is a key advantage compared to B-factories.

- **Michel parameters (lorentz structure of $\tau \to l\nu\nu$)**
- **CP-violation in τ-decays**

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

Super-B, 75 ab^{-1}
7×10^{10} τ-pairs



Current best limit:

4.4×10^{-8} by BaBar with 5×10^{8} τ pairs

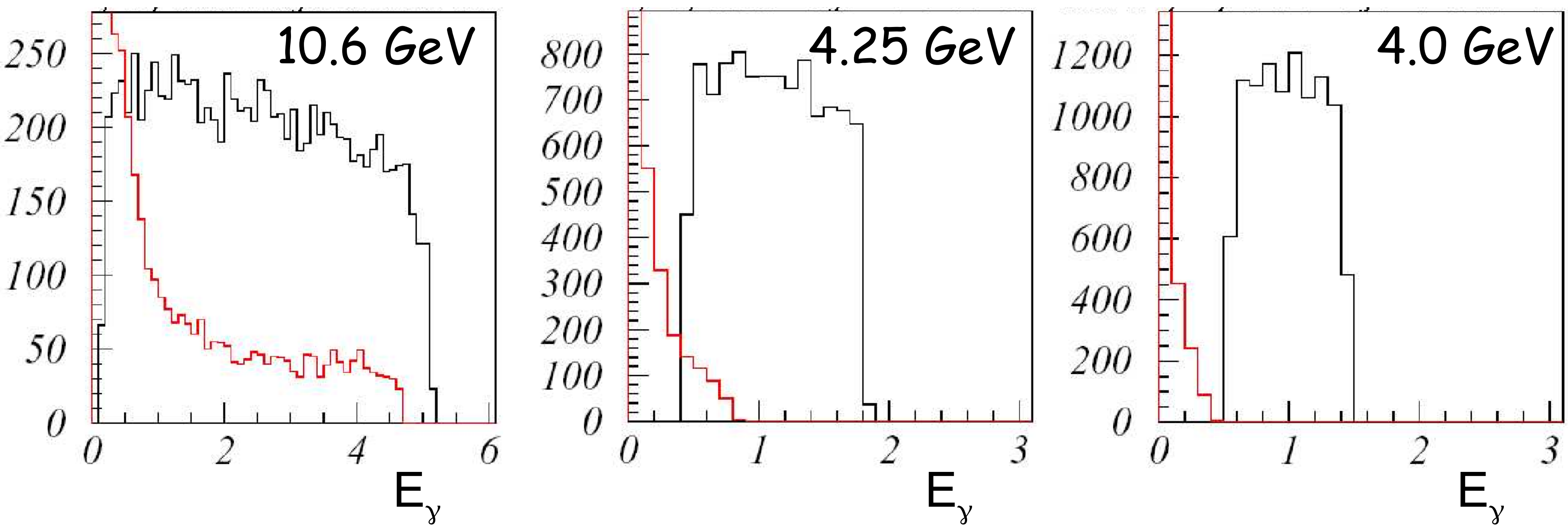
Super-B: 7×10^{10} τ-pairs $\to$ $(2\div4)\times10^{-9}$

- ISR background from $e^+e^-\to\tau^+\tau^-\gamma$
- Upper Limit $\propto 1/\sqrt{L}$

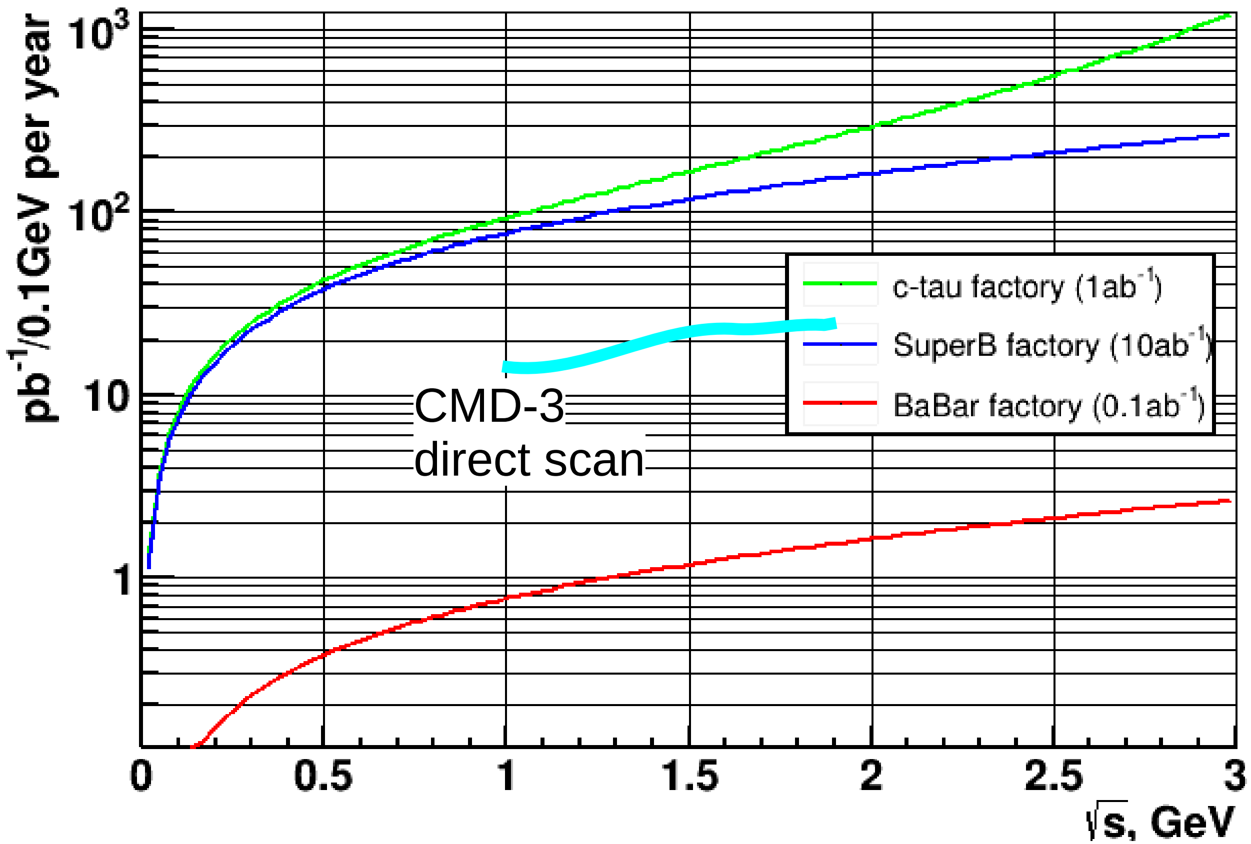
tau-charm factory with 3×10^{10} τ pairs may has better sensitivity

$\tau\to\mu\gamma$: background sources

The process $e^+e^-\to\tau^+\tau^-\gamma$, dominant background source at $\Upsilon(4S)$ does not contribute below $2E \approx 4m_\tau/\sqrt{3} \approx 4.1$ GeV



ISR measurement
e+e- → hadrons at √s<3 GeV



effective Luminosity for ISR is same or higher than at Belle2

SCTF advantages:
smaller momentums of final particles
And μ/π/K PID in full momentum range

Event rates

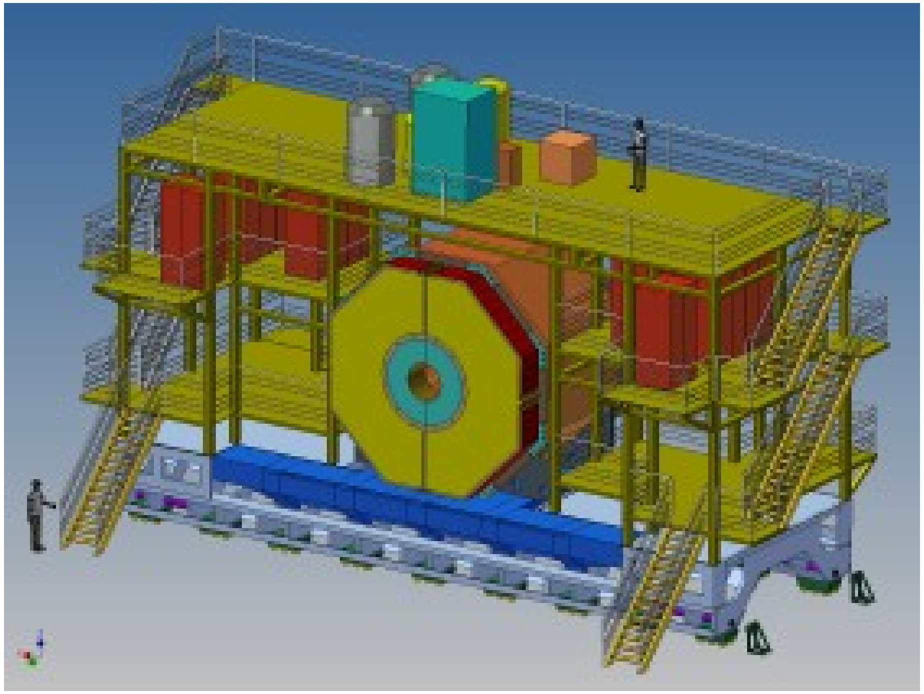
	J/ψ	$\psi(2S)$	$\tau\bar{\tau}$	$\psi(3770)$	$\tau\bar{\tau}$	$\Lambda_c\bar{\Lambda}_c$
E_{cm} [МэВ]	3097	3686	3700	3770	4250	4650
σ [нбн]	$\sim$1450	$\sim$400	2.5	$\sim$6	3.5	0.5
f [кГц]	140	40	2.5	6	3.5	0.5

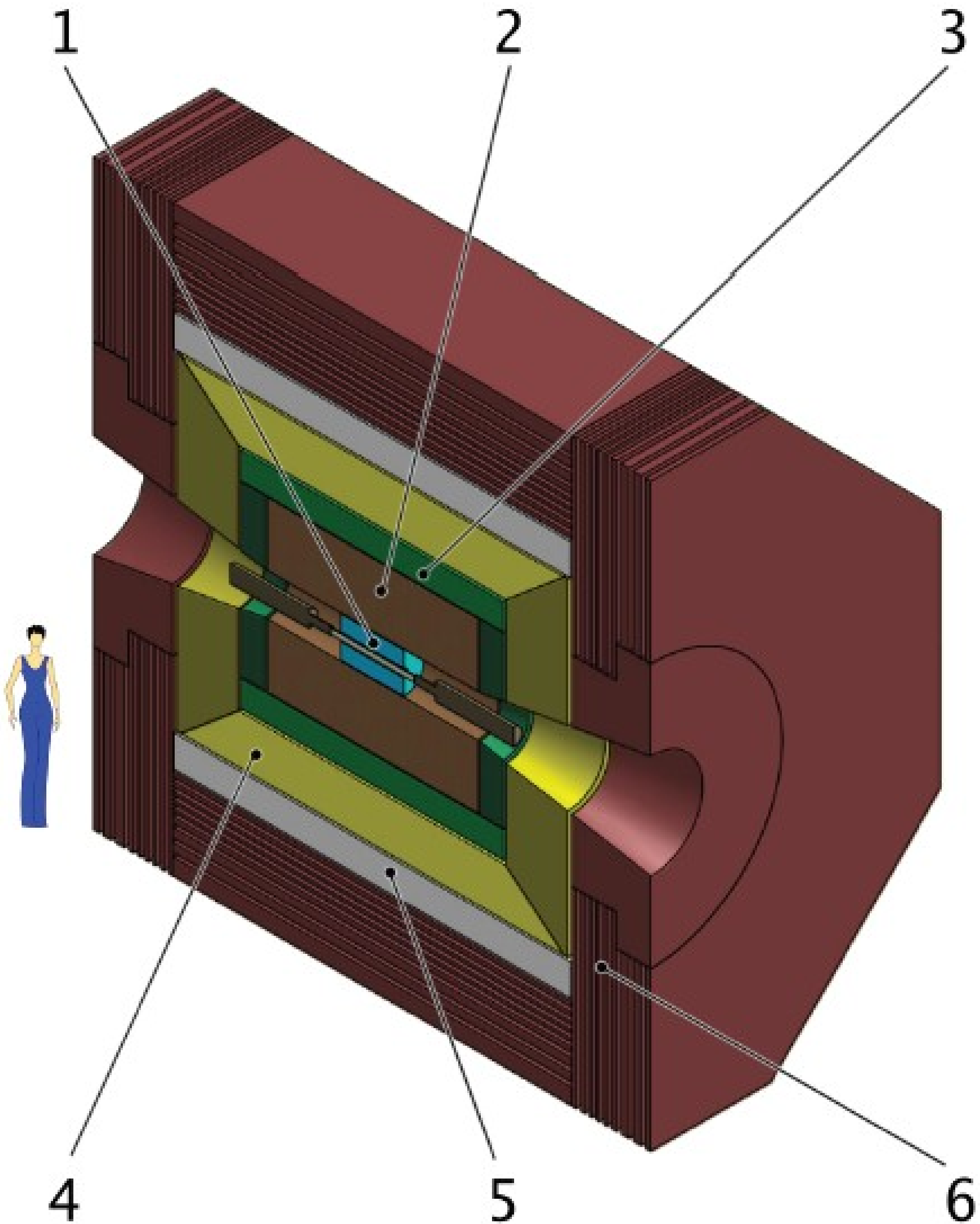
Background process

Cosmic [кГц]	$\sim$2					
Hadrons [кГц]	$\sim$19	$\sim$17	$\sim$17	$\sim$16	$\sim$14	$\sim$12
Bhabha [кГц]	$\sim$90	$\sim$80	$\sim$80	$\sim$80	$\sim$60	$\sim$50

- **At peak of** J/ψ - resonance full physical event rates $\sim$ 250 kHz

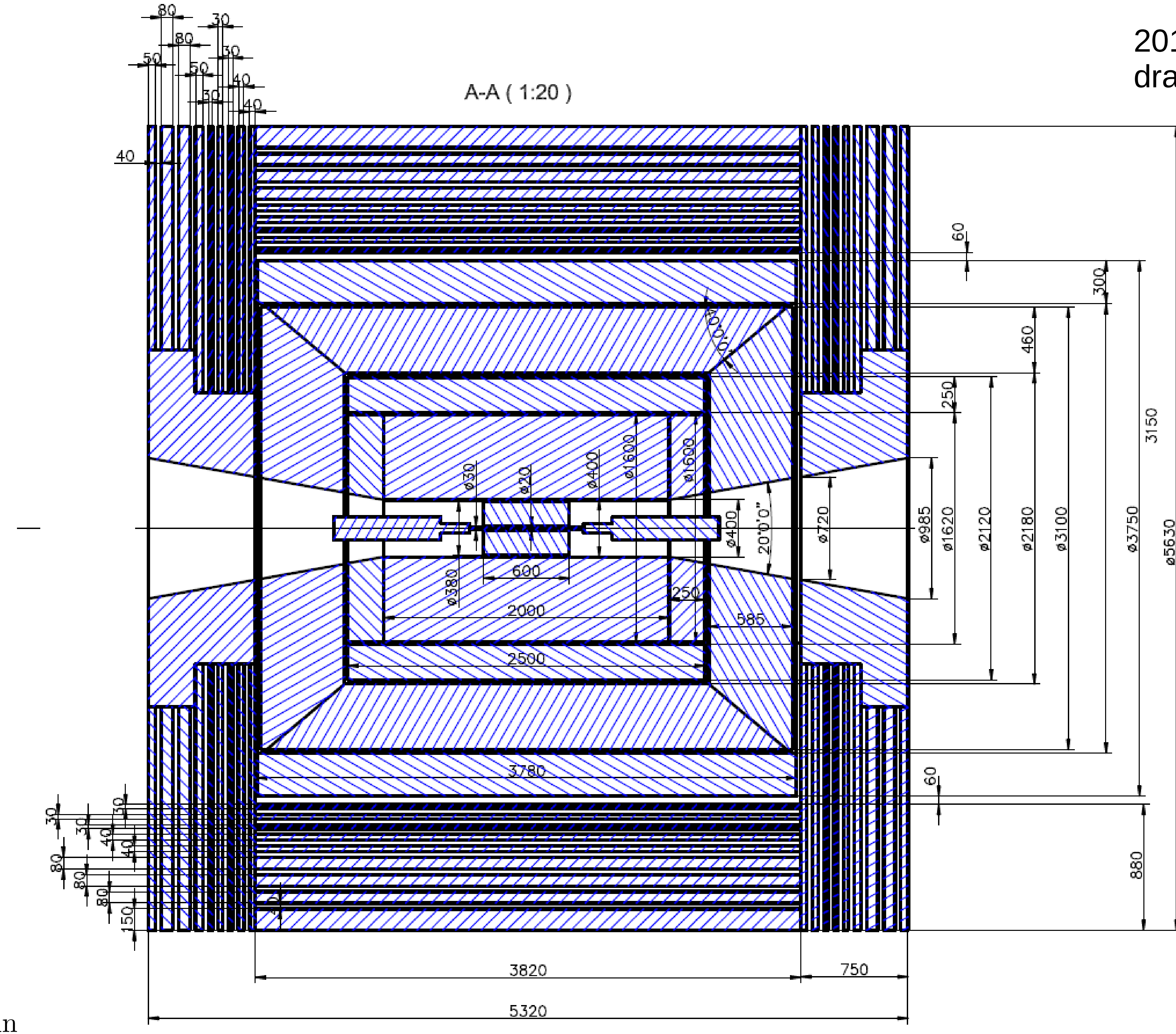
Detector for Super Charm-Tau factory



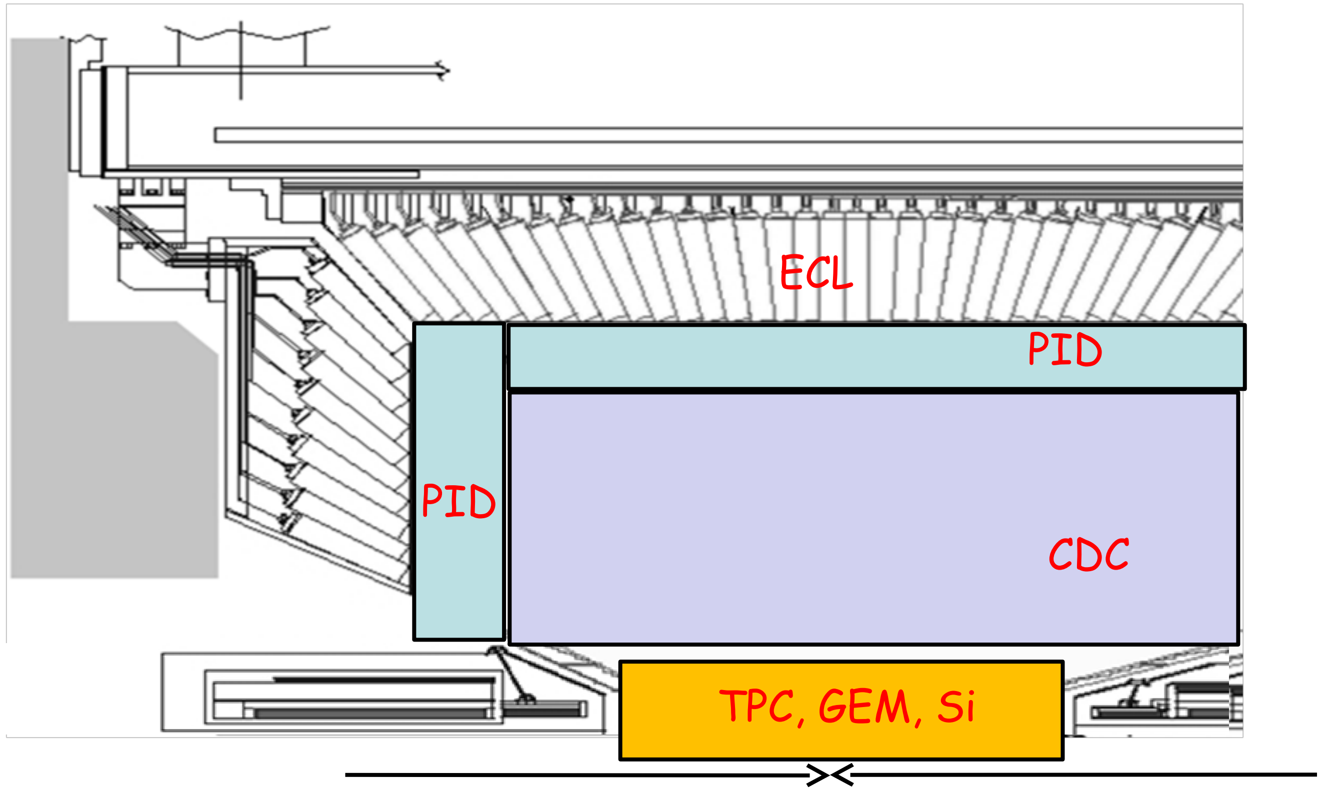


1- Vertex detector (?)
2- Drift Chamber
3- Particle Identification (FARICH)
4- Calorimeter (Pure CsI)
5- SC solenoid (~1 T)
6- Magnet yoke and muon system

2017 size drawing



Detector



- Ultimate Hermeticity
- PID $e/\mu/\pi/K$ separation up to 2GeV/c
- Momentum resolution
- Low p_T track efficiency
- ECL energy resolution
- Low energy (~20MeV) photons efficiency

Vertex precision requirement

Beam size : σ_x = 18. μm , σ_y = 0.18 μm, σ_z = 1 cm (E_{beam} > 1.5 GeV)

Beam angle crossing, 2 x θ : 60 μrad

Interaction point: σ_x =13 μm, σ_y =0.13 μm, σ_z ~300 μm

Time of flight: D^+ meson (e+e- -> D^+D^-) at 2E=3.77 ГэВ - 41 μm

D^+ meson (e+e- -> $D^{+*}D^-$) at 2E=4.05 ГэВ - 92 μm

D^0 ~ half of D^+

D_s meson ($e^+e^- \rightarrow D_s^*D_s$) at 2E=4.16 ГэВ - 30 μm

Time of flight tau at 2E=3.77 ГэВ - 31 μm

tau at 2E=4.16 ГэВ - 53 μm

84% of tau decay are only with one charged particle

Vertex precision at BABAR & Belle ~ 60-70 μm,

Belle II expect ~ 20 μm

Not clear physics case of dedicate silicon vertex detector

For Vertex detector: Most probably it can be separate inner DCH, or GEM, ….

Main purpose of the Inner Tracker:

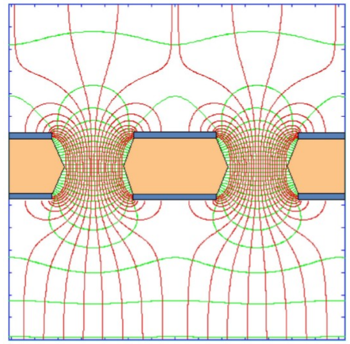
- ❑ Continue tracks from the Drift Chamber to Inner region
- ❑ Tracking of low momentum particles

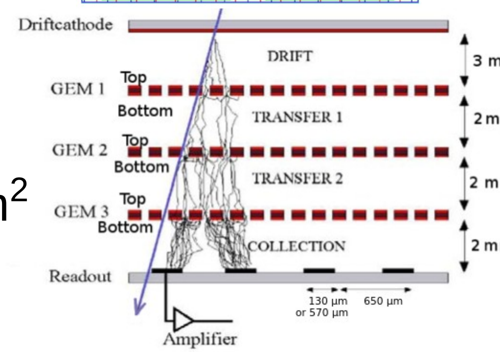
IT options

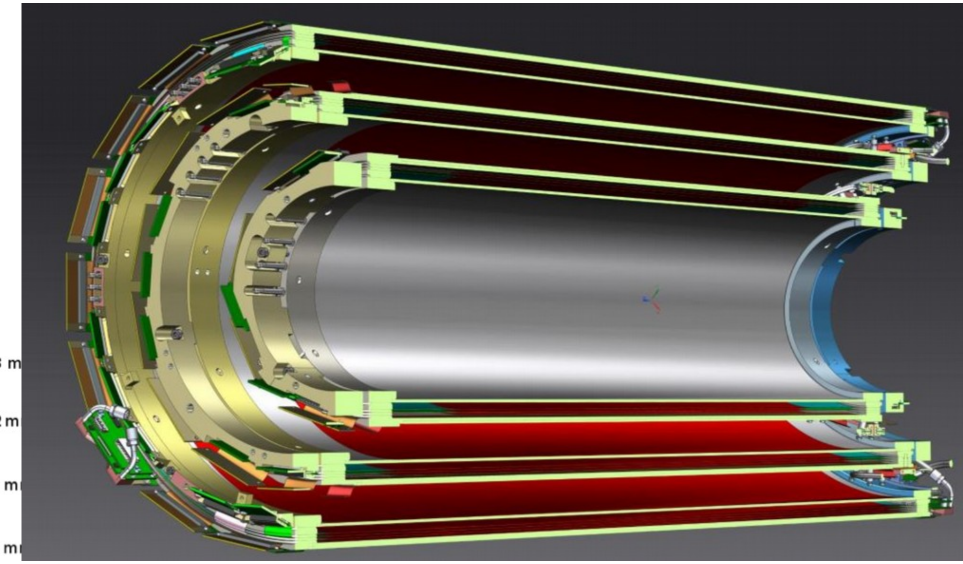
	Material budjet	Resolution	Electronics	Collaboration
TPC	1%X0	100-150 μm	CSA+shaper+an.memory for 10-30 μs+buffer & on-line tracking	TUM (ALICE TPC)
Si-strips	0.6%X0 per layer = 2.4% X0	10-20 μm	CSA+shaper+an.memory for ~1μs	?
Cyl.GEM	0.3%X0 per layer = 1.2%X0	100μm	CSA+shaper+an.memory for ~1μs	INFN Frascatti+… (CGEM KHLOE2)

Inner Tracker (vertex detector)

BES3 option (like KLOE2)







Cylindrical GEM

- ✗ Material budget ~ $1.2X_0$
- ✗ readout charge+time:
  σ_{XY} ~130 μm/layer
  σ_t ~5 ns
- ✗ no dE/dx
- ✗ Rate capability >1 MHz/mm^2

μ-RWELL technology (G. Bencivenni et al)

Very simplified construction/assembly

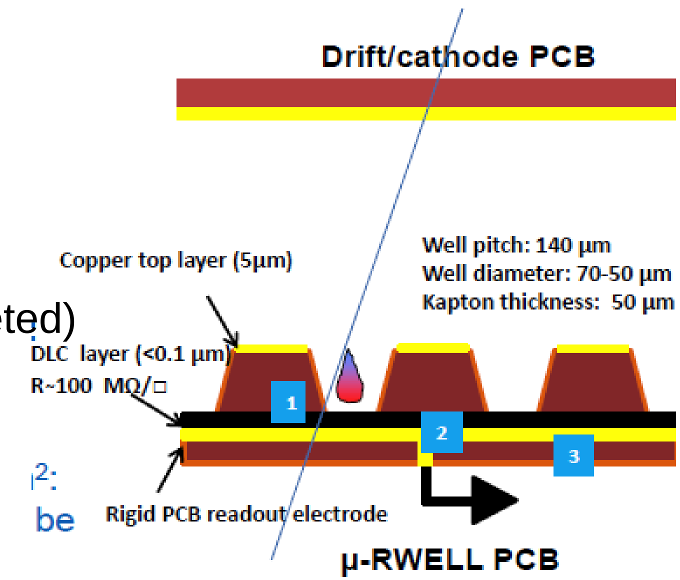
- ✗ σ_{XY} <100 μm/layer, σ_t ~5 ns
- ✗ Rate capability:

Single resistive layer : <0.1 Mhz/mm^2

small and large area prototypes built and extensively tested (R&D completed)
technology are ready for industrial production

Double resistive layer : >1 Mhz/mm^2

several layouts under study showing very promising performance
The engineering/industrialization of the double-resistive layer is difficult

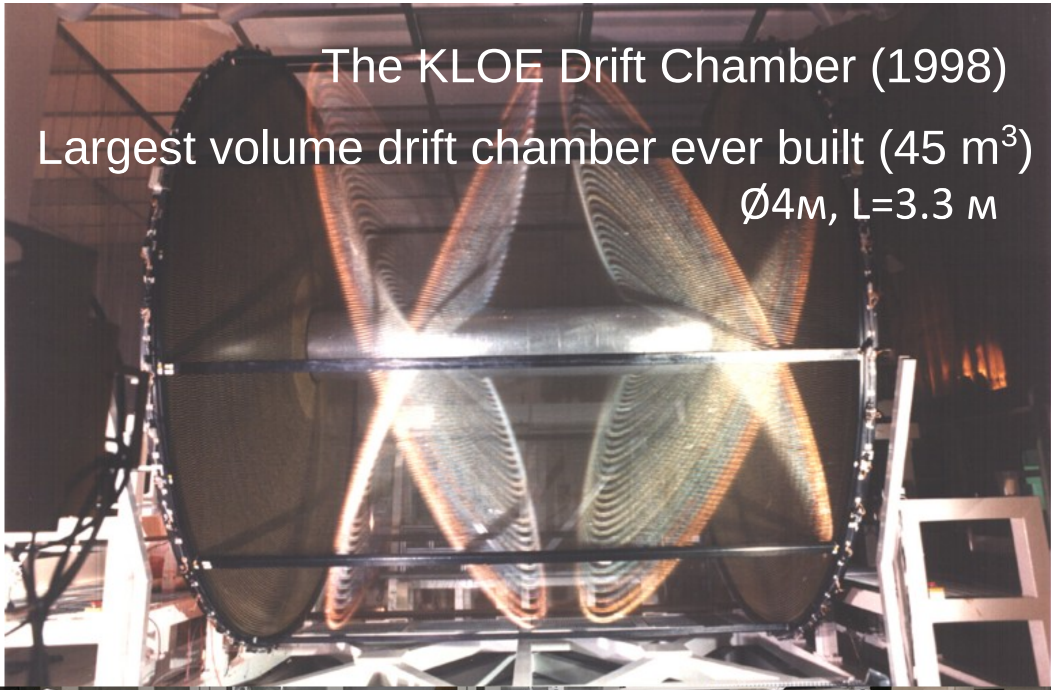


G. Bencivenni et al., 2015_JINST_10_P02008

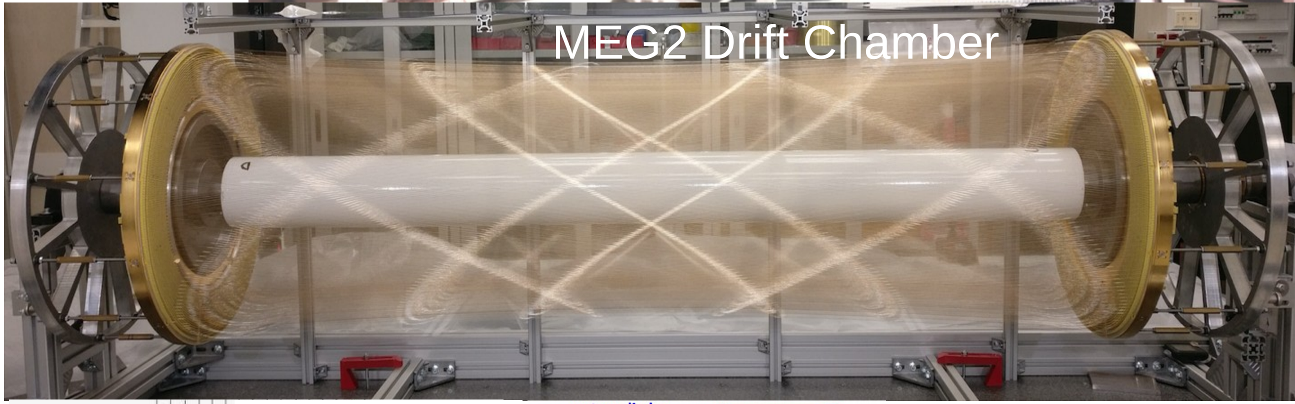
Drift chamber for SCTF

Can be conventional DCH
(like recent BES3, Belle2, COMET)
Wiring by crimping in pins

- Full stereo
- Ø1800:500 мм, L=2000 мм
- He/iC4H10 (80/20)
- $\sigma_{r\text{-}\phi}$ ~125 мкм
- $\sigma(P_T)/P_T = 0.13\% \cdot P_T + 0.45\%$
- $\sigma(dE/dx)/(dE/dx) \leq 7.5\%$

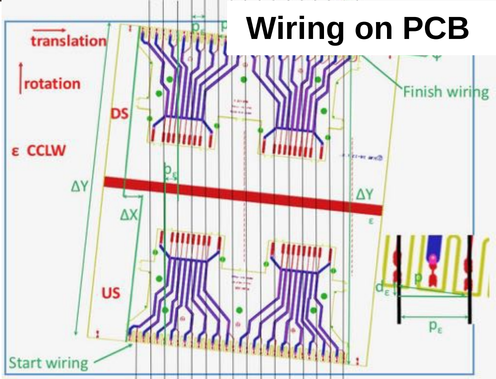


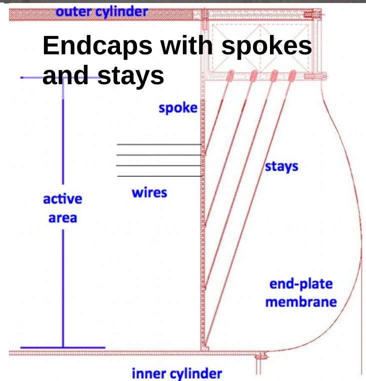
Utra-low mass drift chamber
TraPId: Tracking Performance
Proposal by Franco Grancagnolo
(like as built for MEG2,
or proposal for FCC-ee, CEPC)

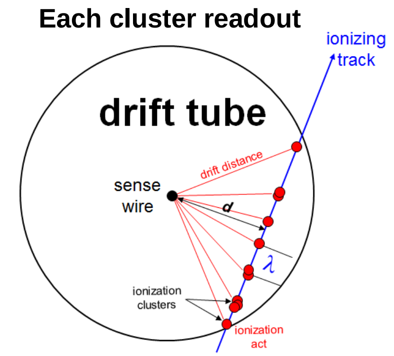


- ✗ Wiring by soldering on PCB
- ✗ Lightweight design of endcaps as was for Mu2e proposal ($0.04X_0$)
- ✗ Cluster counting readout $\sigma(dE/dx)/(dE/dx)$ ~ 3.%

(Cons: More complex electronics is necessary for real experiment.)







Calorimeters

(created with BINP contribution)

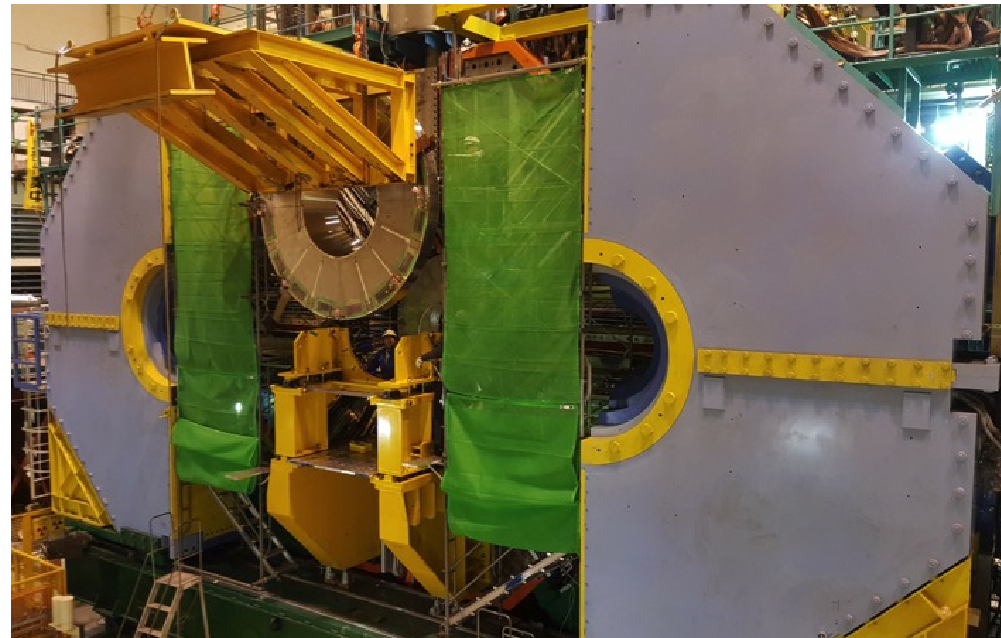
Based on liquid noble gases:

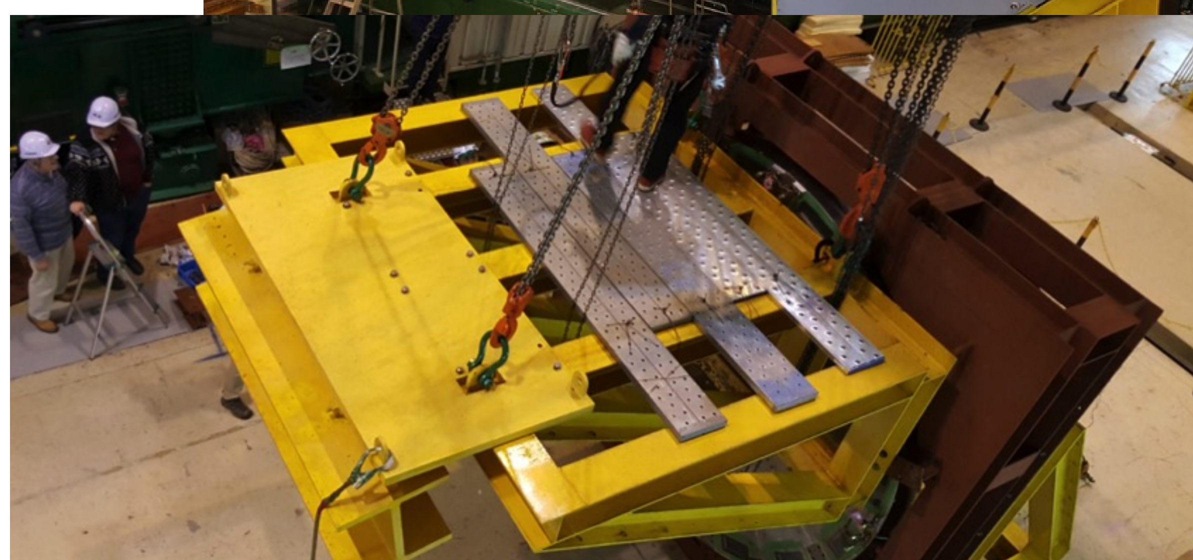
- LKr – KEDR
- LXe – CMD-3
- LAr – ATLAS

crystal:

- NaI(Tl) – SND
- CsI(Tl) – KEDR
- CsI(Tl) – CMD-3
- CsI(Tl) – Belle II
- BGO – CMD-3
- LSO & GSO – technology development of crystal production in NIIC SB RAN

Installation of endcap CsI-calorimeter of Belle II





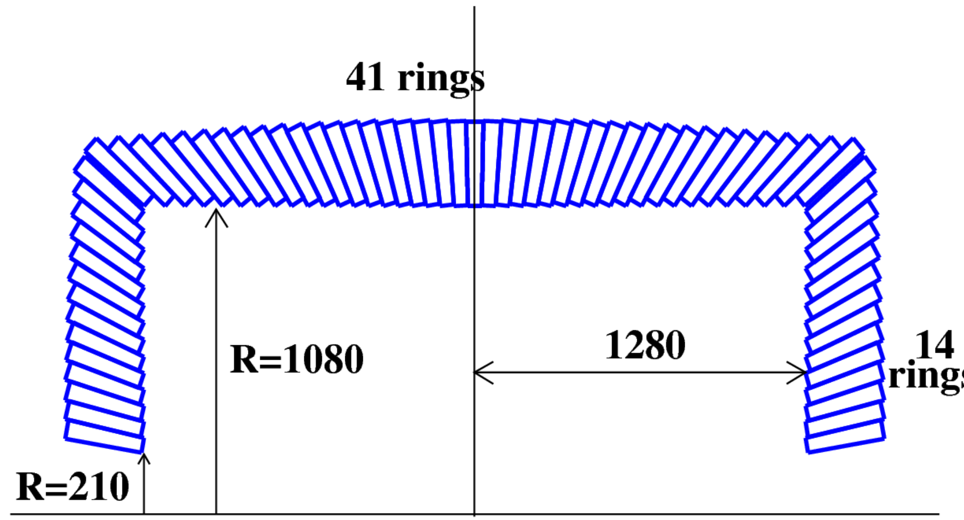
Scintillating crystals

	ρ, g/cm^3	X_0, cm	$\lambda_{em,}$ nm	n($\lambda_{em,}$ 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

- CsI(Tl) has the largest LY, slow scintillation decay time and modest price (~3$/cm^3). It is used in the electromagnetic calorimeters of modern particle detectors: Belle, Belle II, BaBar, BES-III, CMD-3.
- Lu_2SiO_5 (LSO), $LuAlO_3$, LYSO are very good (and much faster than CsI(Tl)), however they are essentially more expensive ((15 – 30)$/cm^3), COMET (2000 LYSO crystals).
- Pure CsI has still notable LY, fast decay time component of 30 ns and acceptable price (~5$/cm 3). The are several crystal-growing companies which are able to produce needed number of large size crystals (~40 tons): AMCRYS(Ukraine), Saint Gobain (France), HPK (Japan-China) → attractive variant for the Super Flavor factories.

Super C-Tau calorimeter layout

- To detect photons and measure their energy and coordinates from 10 MeV upto 2 GeV
  - Thick enough active material to have good energy resolution in wide energy range
  - Fast scintilator to have small pile-up noise
  - Good time resolution to suppress beam background
  - As thin passive material in front of the calorimeter as possible
- e/hadron-separation

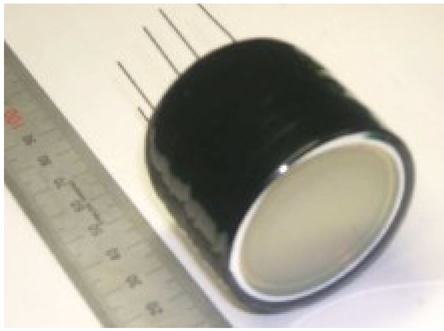


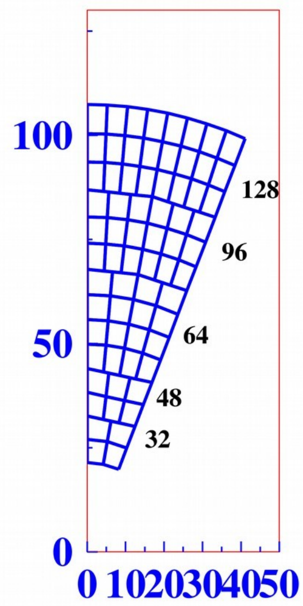
Pure CsI crystals
truncated pyramidal form with small facet
~ 5.5 x 5.5 cm^2 and length ~ 34 cm (18 X_0)

In barrel: 5248 counters = 41 θ-rings x 128 counters
weight ~ 26/31 tons

Endcap parts: 2176 counters = 2 x 16 sectors x 68 ,
weight ~ 10/12 tons

Hamamatsu
Photopentodes readout





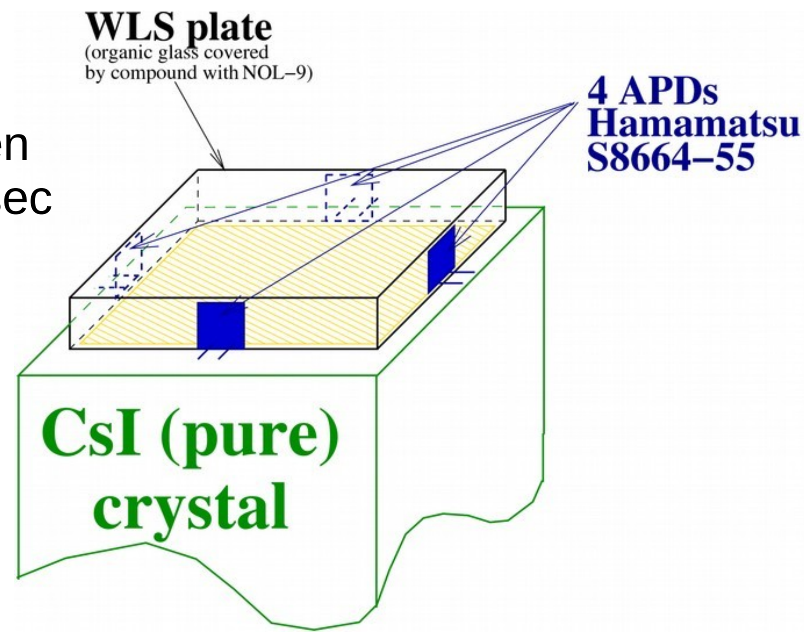
The whole calorimeter: 7424 counters
the total weight 43 tons → 47 M$
Photopentodes : 7424 → 7 M$
Electronics : 7424 → 4 M$
Total price : 58 M$

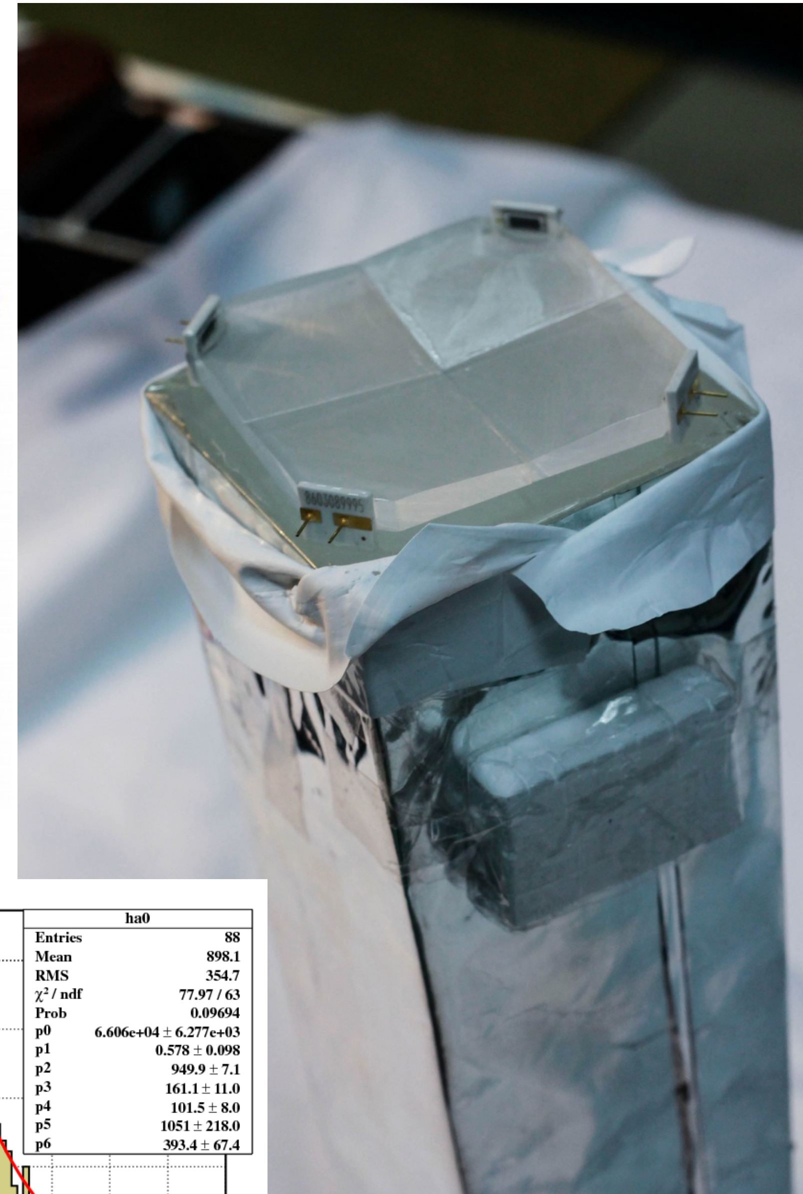
CsI(pure) + WLS + 4APD option

Photopentode option(low noise): no redundancy, strong dependency on magnetic field

Si APD readout(high noise, low light collection): is under R&D, 16 crystal prototype is under way to construct and to do testbeams

Can be additional SiPM readout for even better timing ~ 0.1 nsec (instead of 1nsec)





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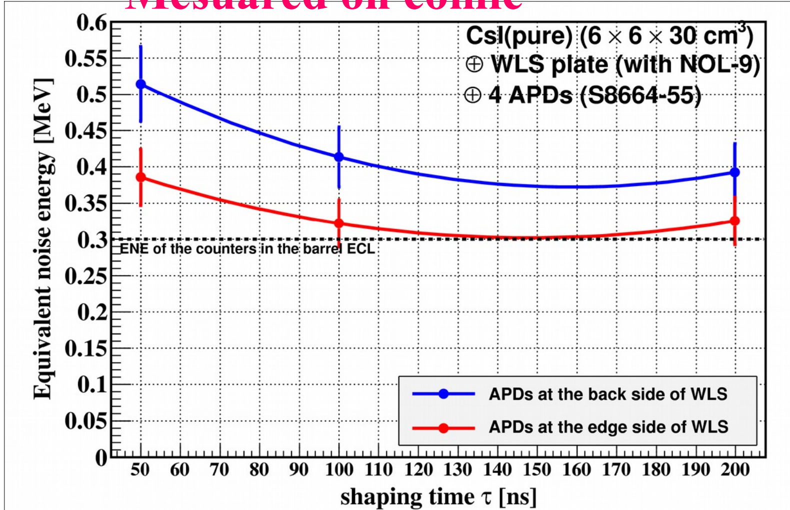
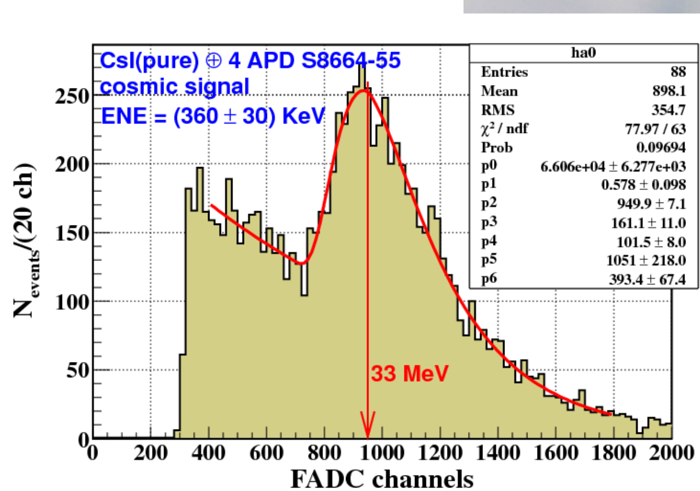


Gain =50



Facility to grow crystal scintillators in Nikolaev Institute of Inorganic Chemistry (Siberian Branch of Russian Academy of Sciences)

Test facility for growing of GSO crystals

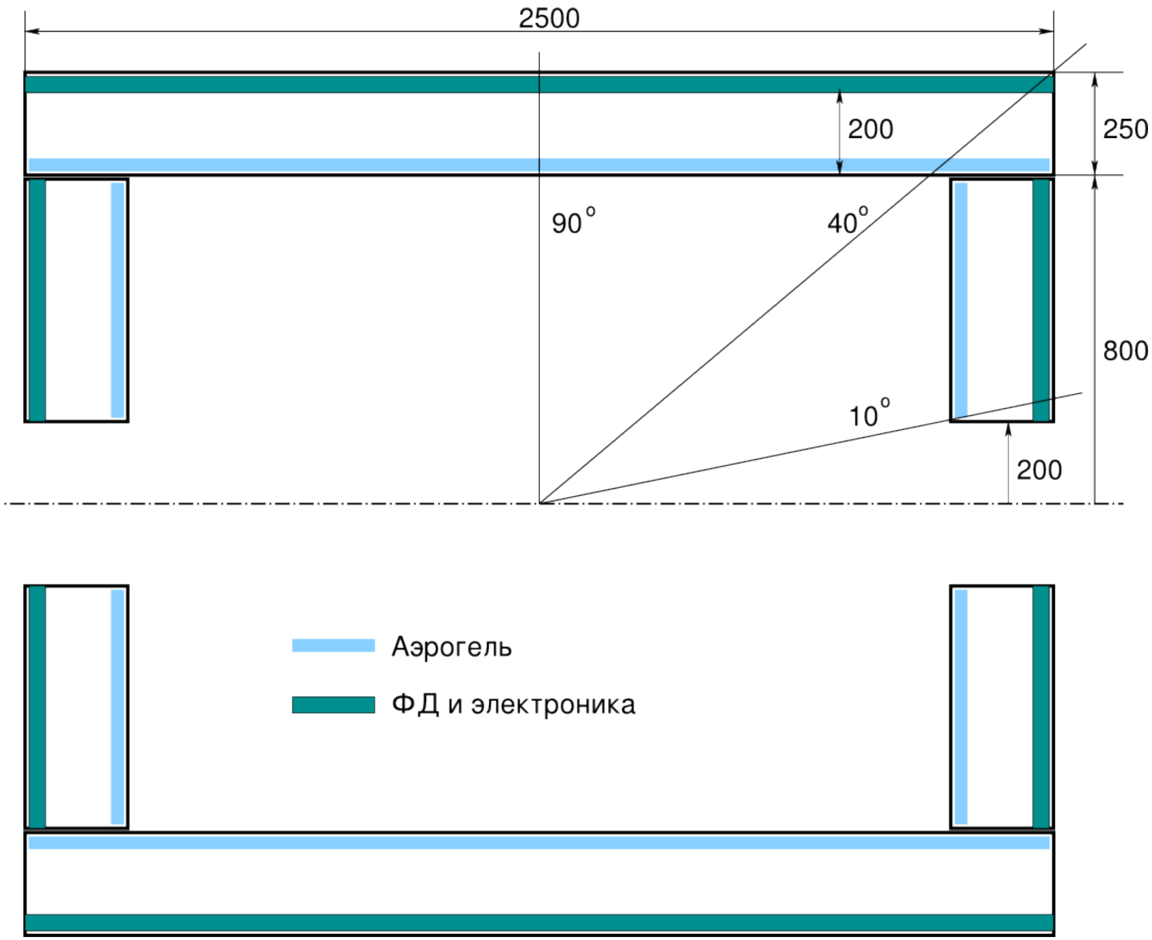
NIIS is able to produce BGO crystals with mass up to 75 kg, CdWO4 (20kg) ….

It was special grant to develop production of orthosilicate crystal:

- new test facility to grow GSO crystal up to 1 kg by low-thermal gradient Chozchralski was created
- **~2017-2018 was expected to obtain first GSO crystal**
- **2018 - … – LSO, LYSO,…**

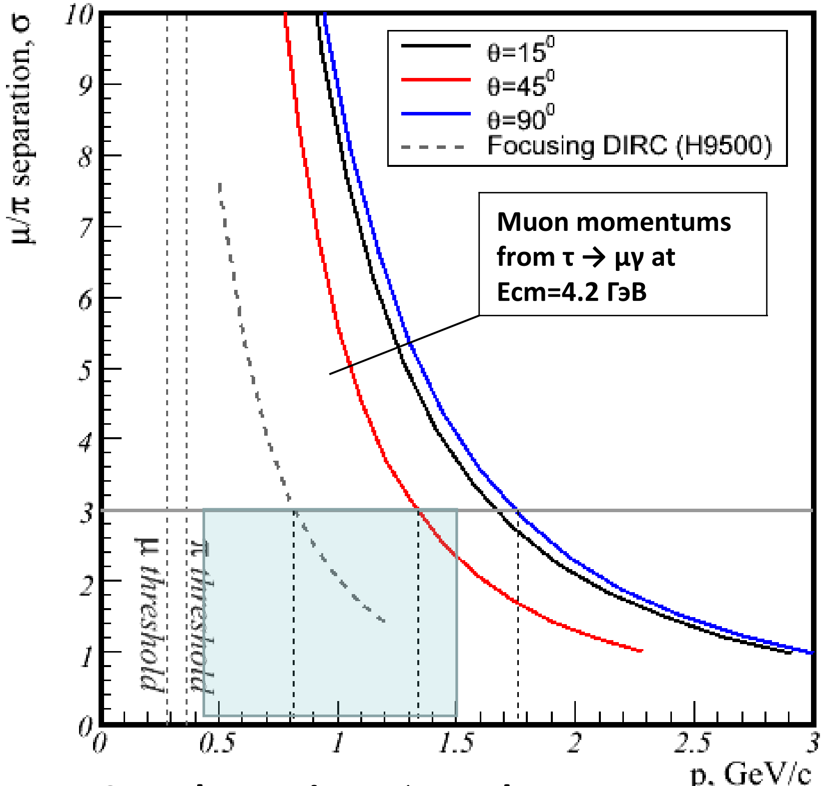
PID is a key system for Detector at Super Charm-Tau factory

FARICH – Focusing Aerogel RICH



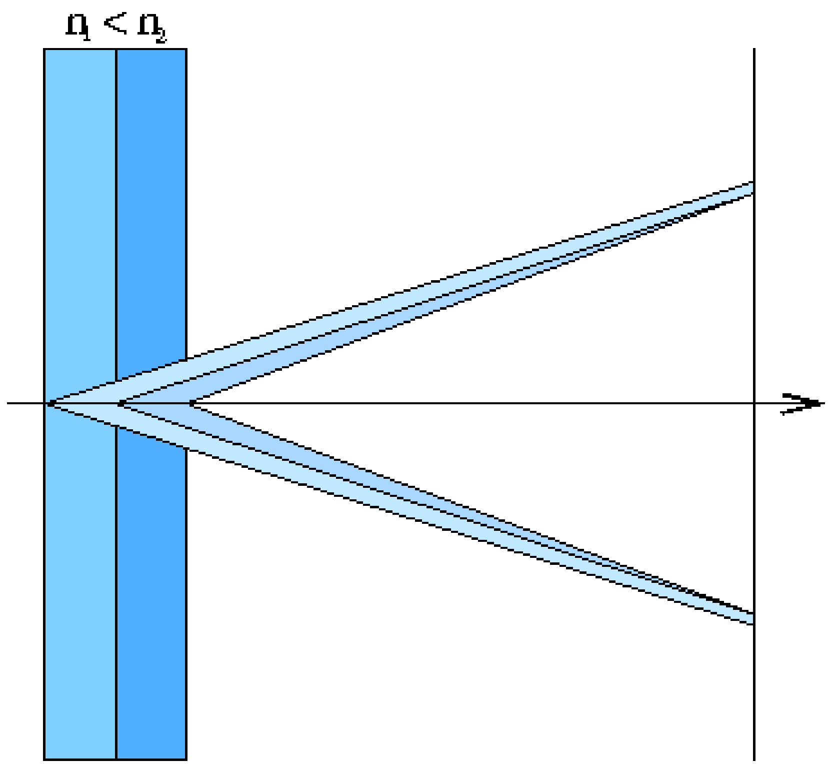
- **S= 21 м²**
- **SiPM for photon detection**

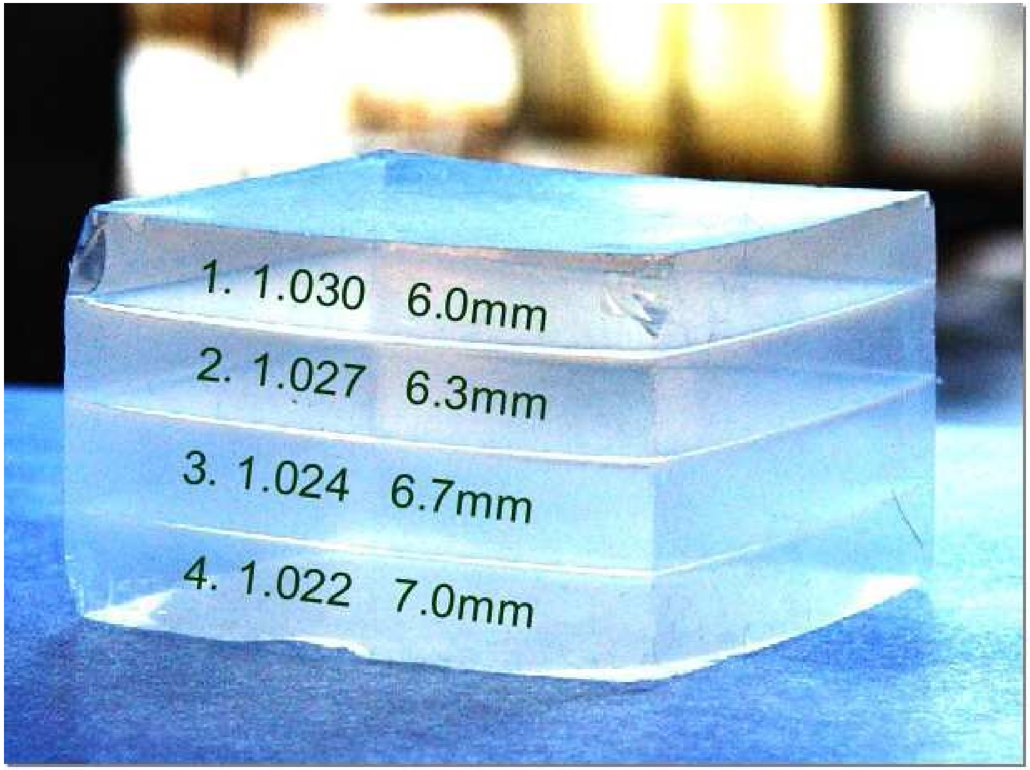
μ/π-separatiоn



- **Search LFV in τ → μγ decay (μ/π-разделение)**
- **Tagging of τ -leptons, D- mesons and etc.**

FARICH – Focusing Aerogel RICH





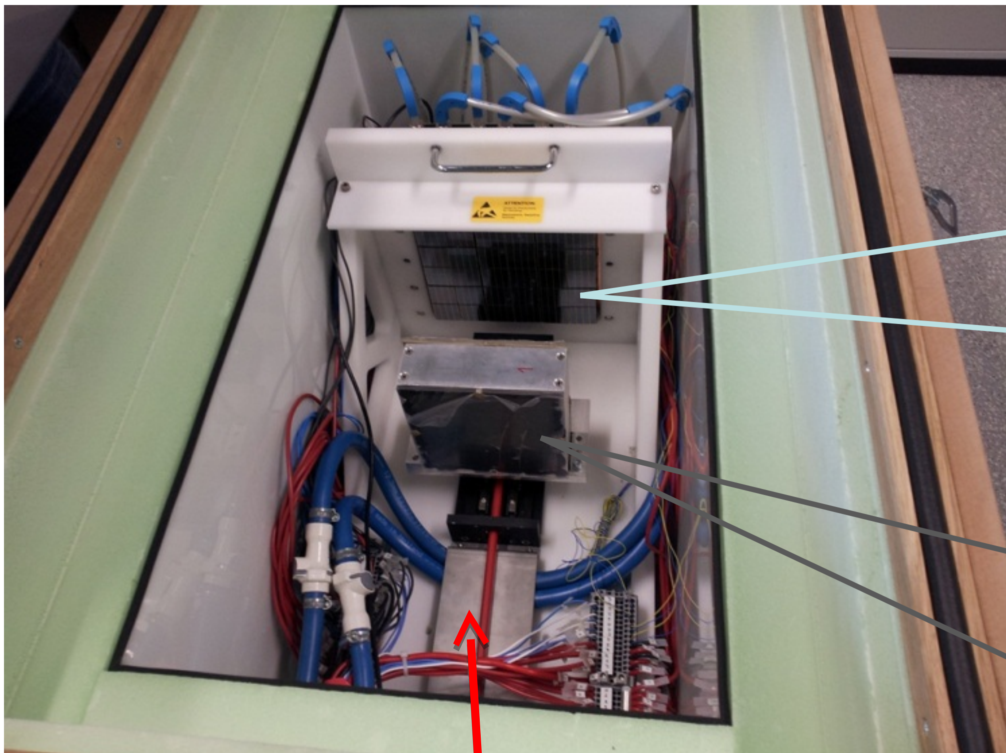
FARICH was suggested by BINP group and BELLE Collaboration in 2004 .

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

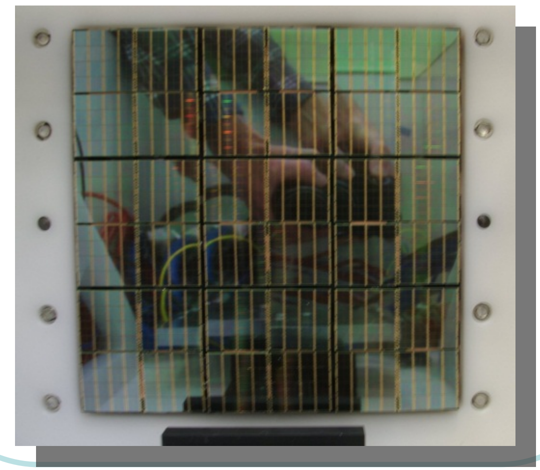
Technology of multi layers aerogel fabrication was developed by BINP and IC of SB RAS

Test of FARICH prototypes at CERN (2012) and at BINP (2013)

SiPM- for photon detection



Matrix dSiPM 20x20cm²
48x48 pixels (4x4mm²)



Focusing
4 layers aerogel
n_{max}=1.046
Thickness 37mm
Focus length 200мм

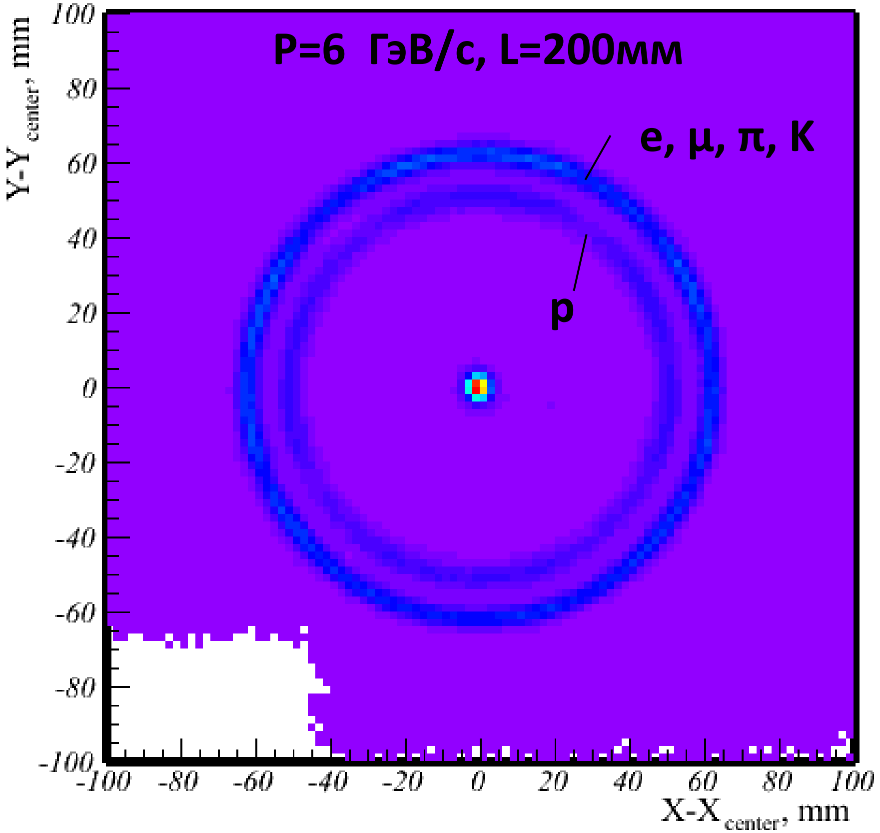
- **Philips Matrix DPC: 2034 pixels , 20x20 см²**
- **Cooling down to -40°C**
- **4- layers aerogel**
- **Focus 200 mm**

Pions and protons
P=2-6 ГэВ/с

Test of FARICH prototypes at CERN (2012) and at BINP (2013)

SiPM- for photon detection

~14 ph.el/mip

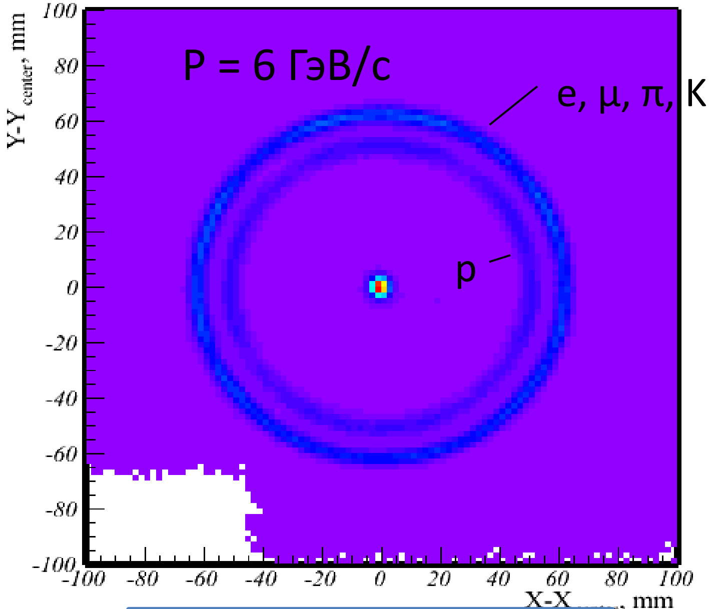


- Philips Matrix DPC: 2034 pixels , 20x20 см²
- Cooling down to -40°C
- 4- layers aerogel
- Focus 200 mm

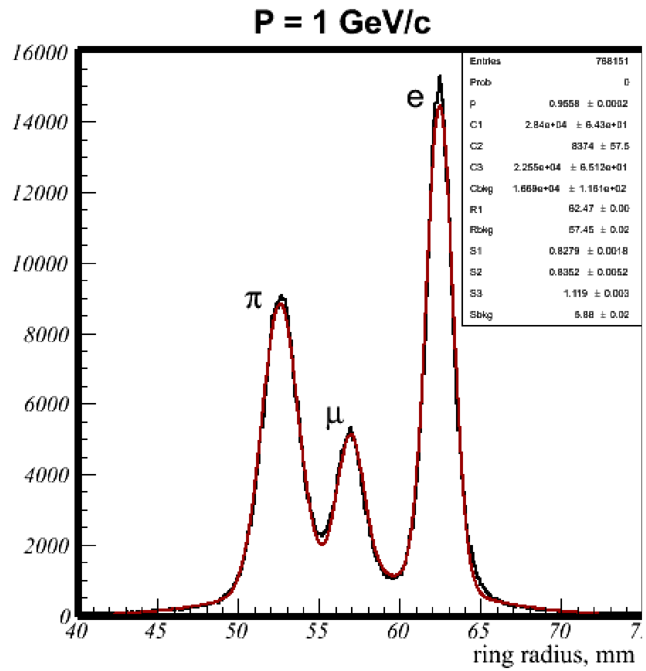
π /K: 7.6σ @ 4 GeV/*c*
μ/π: 5.3σ @ 1 GeV/*c*

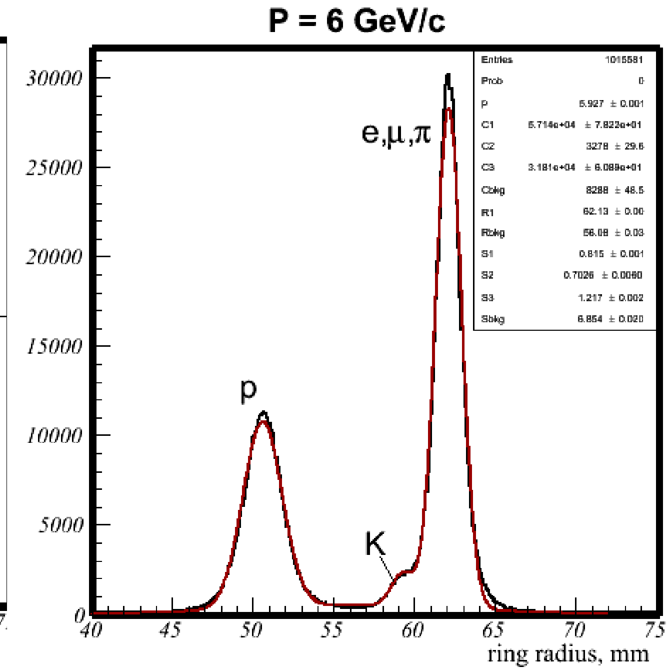
FARICH: testbeam results

Hit positions

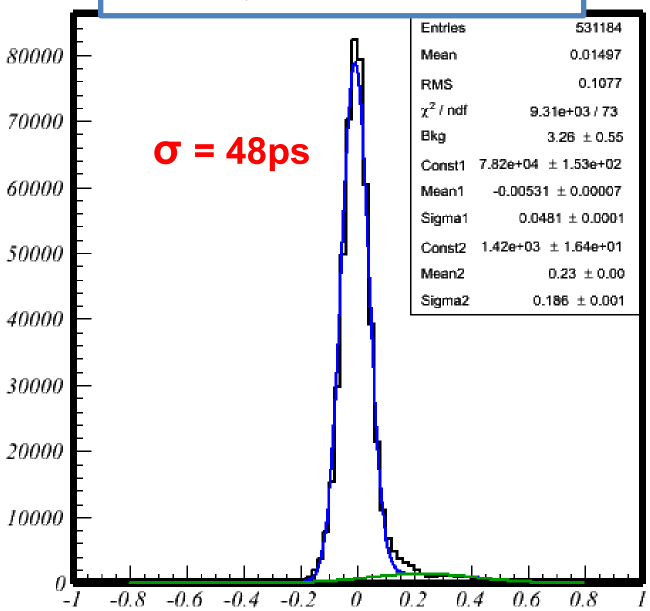


Ring radius distributions





Time resolution

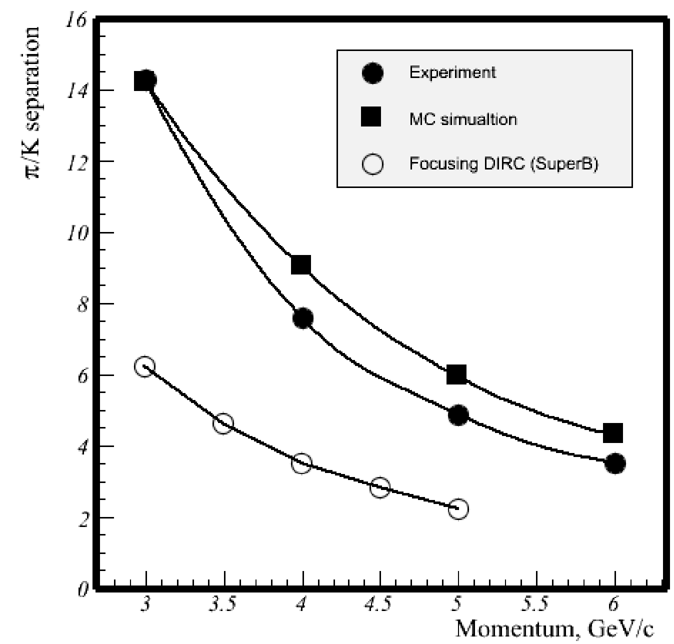


4-х слойный блок; 30 мм; n_{max}=1.046;

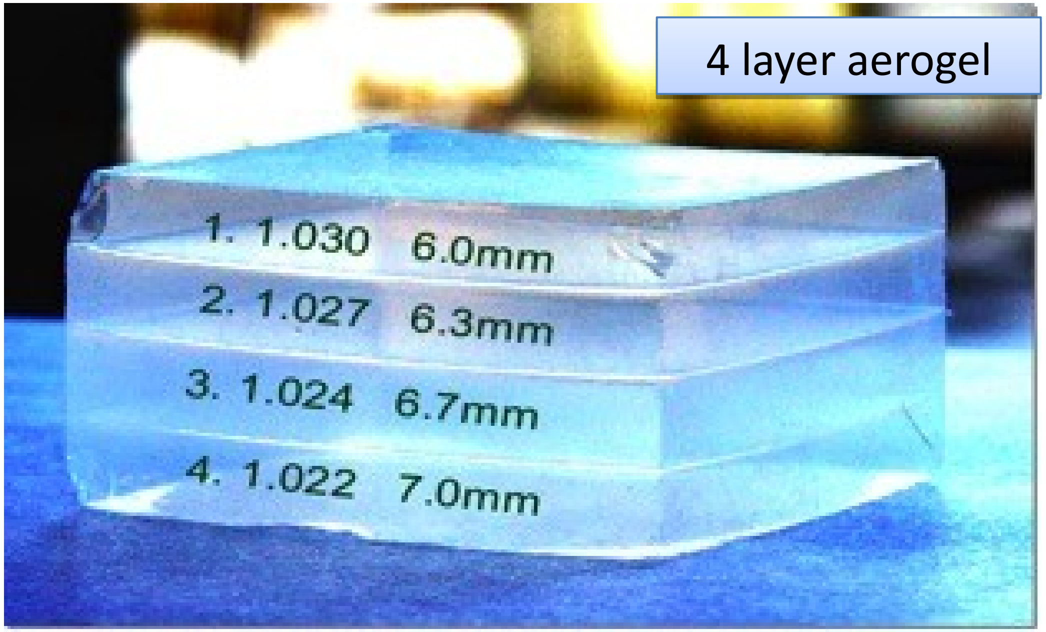
$$S(\pi/K) = \frac{R_\pi - R_K}{\sigma_\pi}$$

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

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

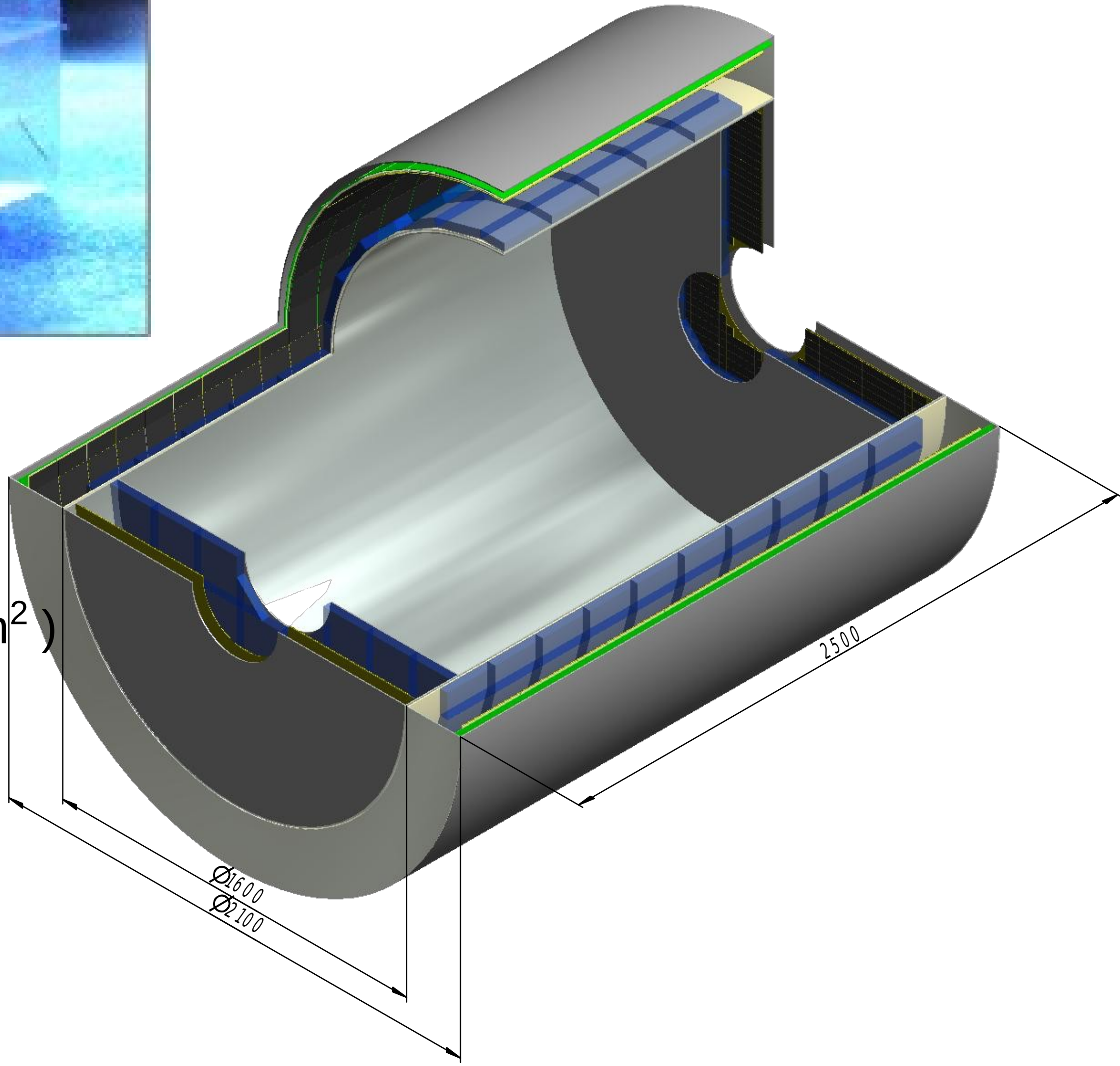


FARICH system



Main parameters:

- Focusing aerogel with n max =1.07, 4
- layers, total thickness 35 mm
- Aerogel area: 17 m^2



- Photon detectors (pixel 3x3 mm^2):

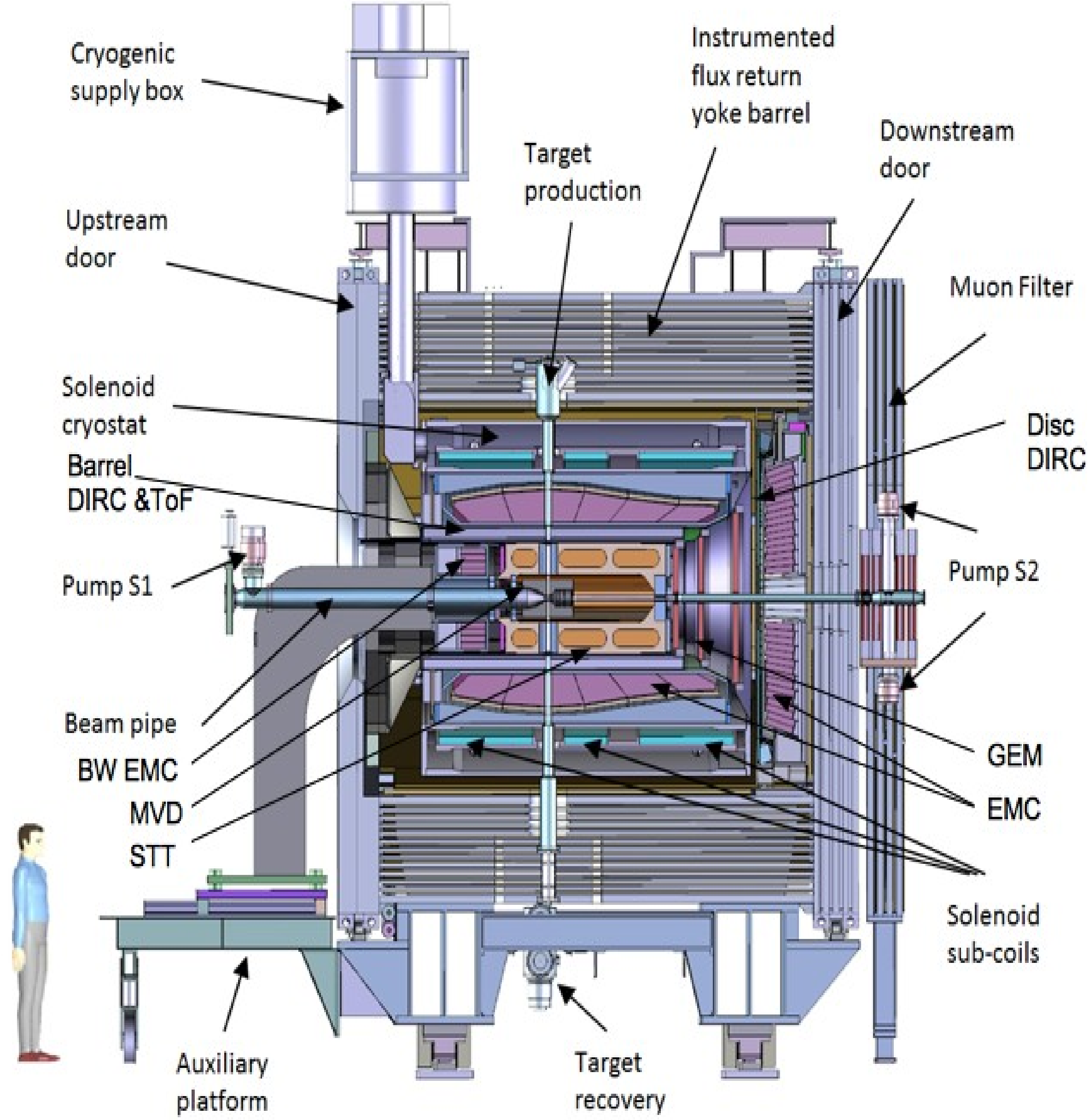
– Barrel – SiPMs (16 m^2)

– Endcap – SiPM, MCP PMT?, HAPD? (5 m^2)

- $1 \div 2 \cdot 10^6$ channels (it depends on pitch)
- load 0.5÷1.0 MHz/channel
- Cooling system is needed

PANDA solenoid magnet as a prototype for SCTF detector

The PANDA solenoid is designed to provide a magnetic field of 2 T with a uniformity of ± 2% and radial magnetic field integral in the range 0 to 2 mm over the central tracking region. The magnet is characterized by a warm bore of 1.9 m diameter, a free length of 4 m and 22.4 MJ of stored energy.



PANDA solenoid

B = 2 T

Ø 1.9 m, L = 4 m

E= 22.4 MJ

SCTF

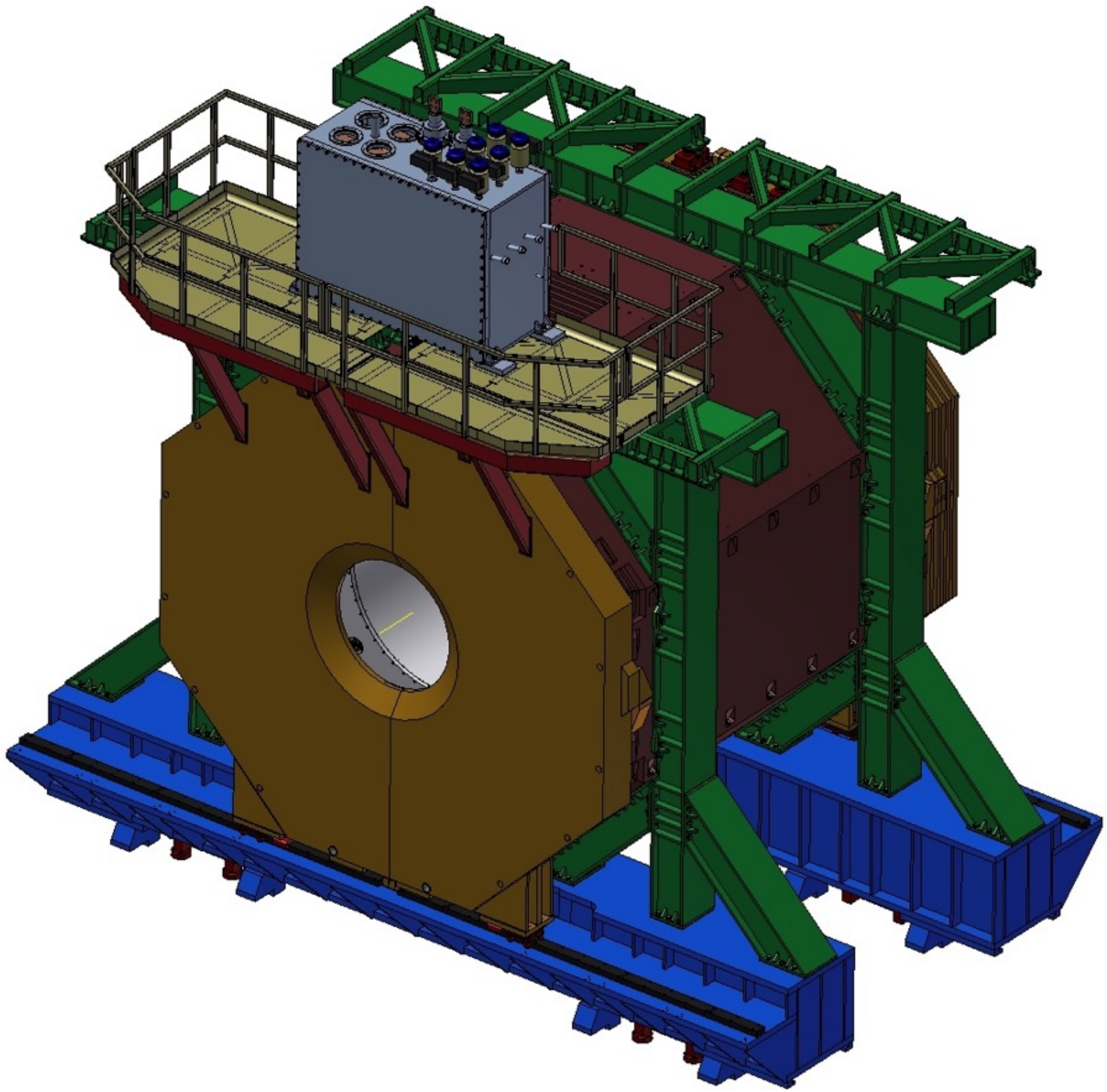
B = 1.-1.2 T

Ø 3.2 m, L = 4 m

E=28.8 MJ

Design: CERN+BINP. **BINP is responsible for construction.**

Solenoid, Yoke, Platform (PANDA)



Summary

- ✗ The SCT experiment is in many aspects complementary to other collider experiments like Belle II, LHCb
- ✗ We have same or better performance for charm, tau physics for less invested money
- ✗ We hope that funding of the project can start in 2020.
- ✗ Internationalization of the project is essential requirement from Russian Government. (more formal collaboration, international management board)
- ✗ Modernization of the CDR(collider, detector, physics) is ongoing.

PID system

Tasks:

- p/K-separation for P>0.6 GeV/c
- μ/p-separation up to P≈1.2 GeV/c

Modern state of art

p/K-separation

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

μ/p-separation at P≈1 GeV/c

- Belle ~ 2.5÷2.8σ

Perspectives:

p/K-separation

- TOF:
  σ_t ~50 пс → 3σ up to 1.8(3.0) GeV/c
- fDIRC ~ 3σ up to 4.25 GeV/c
- FARICH >3σ up to 6 GeV/c

μ/p-separation at P ≈1 GeV/c

- FARICH ~5σ

Muon system

Tasks & Parameters:

- $\mu/hadr$-separation
- μ/p-separation
  - Barrel – 9 layers in the yoke (64%↠4p)
  - Endcap – 8 layers in the yoke (30%↠4p)
- S_{total} ↑ $1000 m^2$

μ/p-separation

- BaBar: 64%/2% for P=0.5÷2 ГэВ/с
- Belle: 90%/2% for P>1 ГэВ/с
- КЕДР: 95%/5% for P>1 ГэВ/с

Pions suppression factor 100 is needed. It is necessary to use additiona systems (FARICH?, TOF with s_t 6 30 ps?, . . .).

Gas tubes (strimmer or drift tubes mode)

- ageing?, rate capability?, . . .
- KEDR, CMD, $\overline{P}$ANDA, . . .

RPC

- Good spatial and time resolution
- ageing, more complex electronics
- Belle (KEK), BaBar (SLAC), . . .

Scintillatrs + WLS + MaPMT

- Very simple in operation
- MINOS (FNAL)

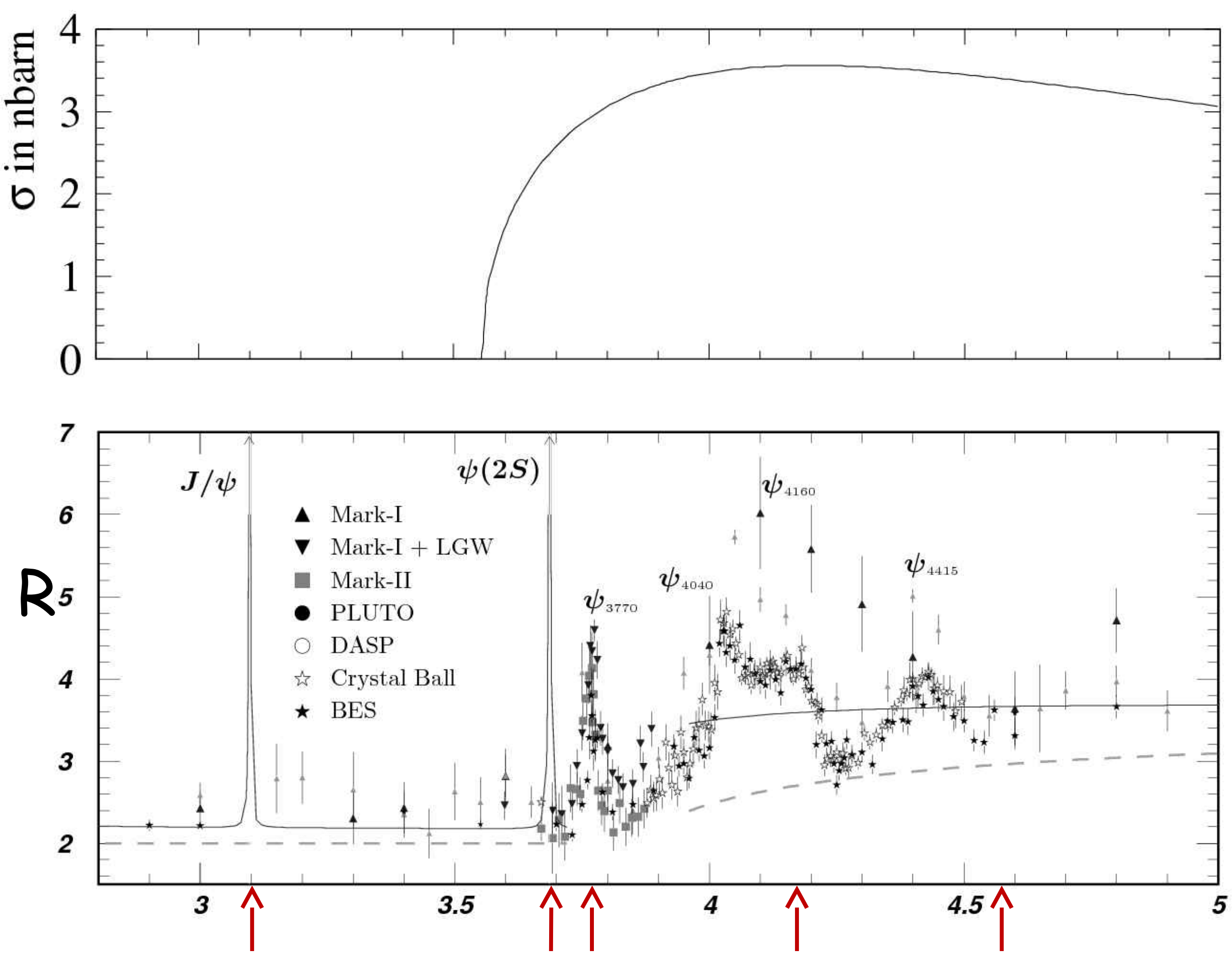
Magnetic system

Requirements to the system

- Solenoid length – 4 m
- Inner ⌀– 3.2 m
- Inside the solenoid (tracking system, PID, calorimeter)
- B ⇡ 1÷1.2 T
- Accumulated energy – 28.8 MJ
- Rise time 6 4 hours
- Time for acceptance to systems 12÷24 hours
- Yoke: 9 gapes in barrel and 8 gapes in endcaps are placed for MU system

There are several magnets fits for these requirements: PANDA, Belle-II, BES-III.

τ-lepton statistics



Data (10 ab^{-1}) will be collected mainly in the energy points:

- J/ψ - 3.1 GeV
- $\psi(2S)$ – 3.69 GeV
- D – 3.77 GeV
- D_s – 4.17 GeV
- Λ_c – 4.65 GeV

The expected number of produced τ pairs is about 3×10^{10}.

B factories: $\sigma(e+e- \to \tau+\tau-) \approx 0.9$ nb ⇒ 10^9 τ pairs
Super B factory: 7×10^{10} τ pairs

Long time ago...

- 1993, Dubna JINR (E_{cm}= 2 GeV, L=9.4×10^{32} cm^{-2} sec^{-1})
- 1994, Argonne National Laboratory (E_{cm}=3-5 GeV, L= 10^{33} cm^{-2} sec^{-1})
- 1995, BINP, round beams (E_{cm}= 2.0-4.2 GeV, L= 10^{33} cm^{-2} sec^{-1})
- 1996, Spain & France (E_{cm}= 4 GeV, L= 10^{33} cm^{-2} sec^{-1})
- 1997, Beijing IHEP (E_{cm}= 2.0-4.2 GeV, L= 10^{33} cm^{-2} sec^{-1})