Optical dissector for measurement of longitudinal beam profile

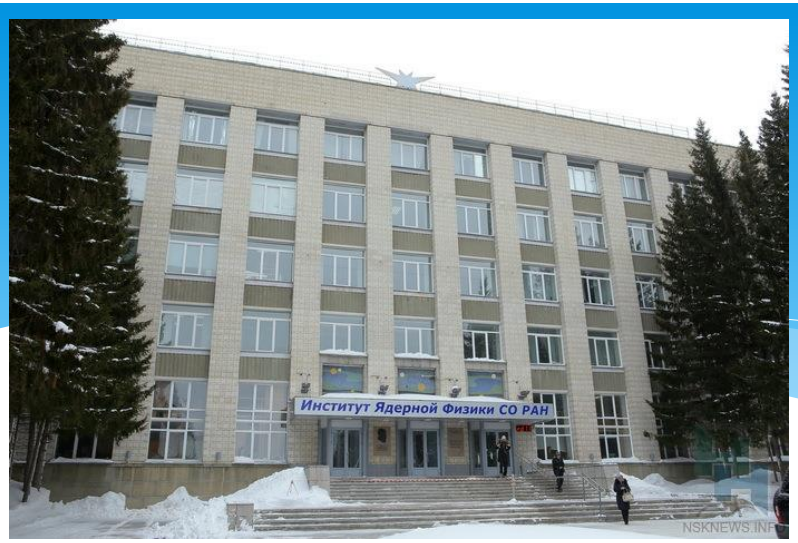
O. Meshkov

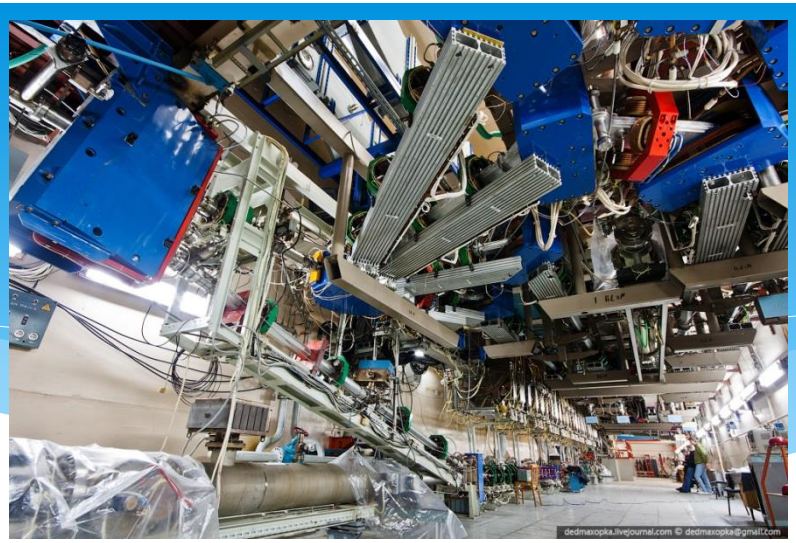
Budker Institute of Nuclear Physics SB RAS,

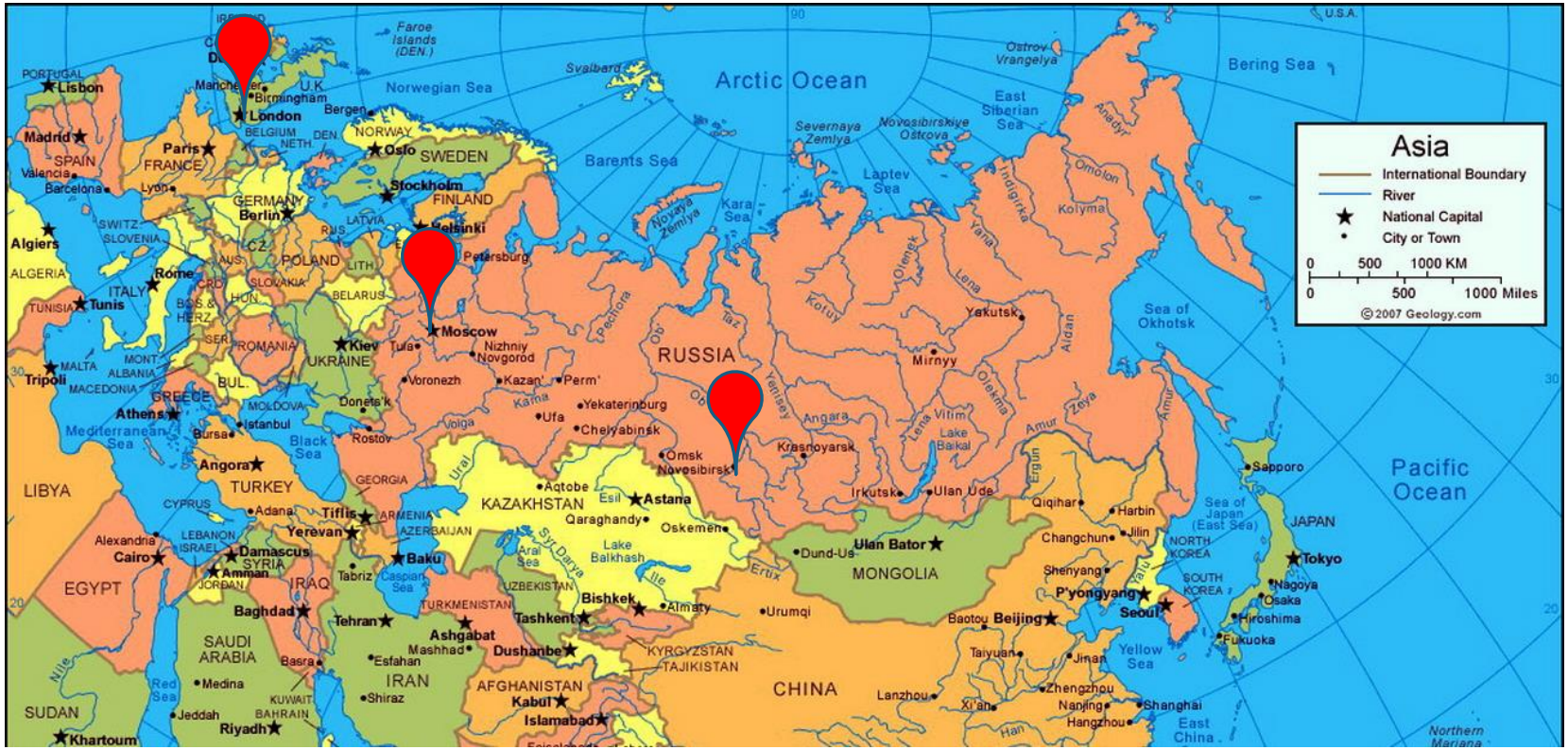
Novosibirsk, Russia

Content

1. Installations at the BINP and application of the dissector on them
2. The new dissector and the experiments at the MLS storage ring (Berlin)
4. The nearest plans
5. Conclusion

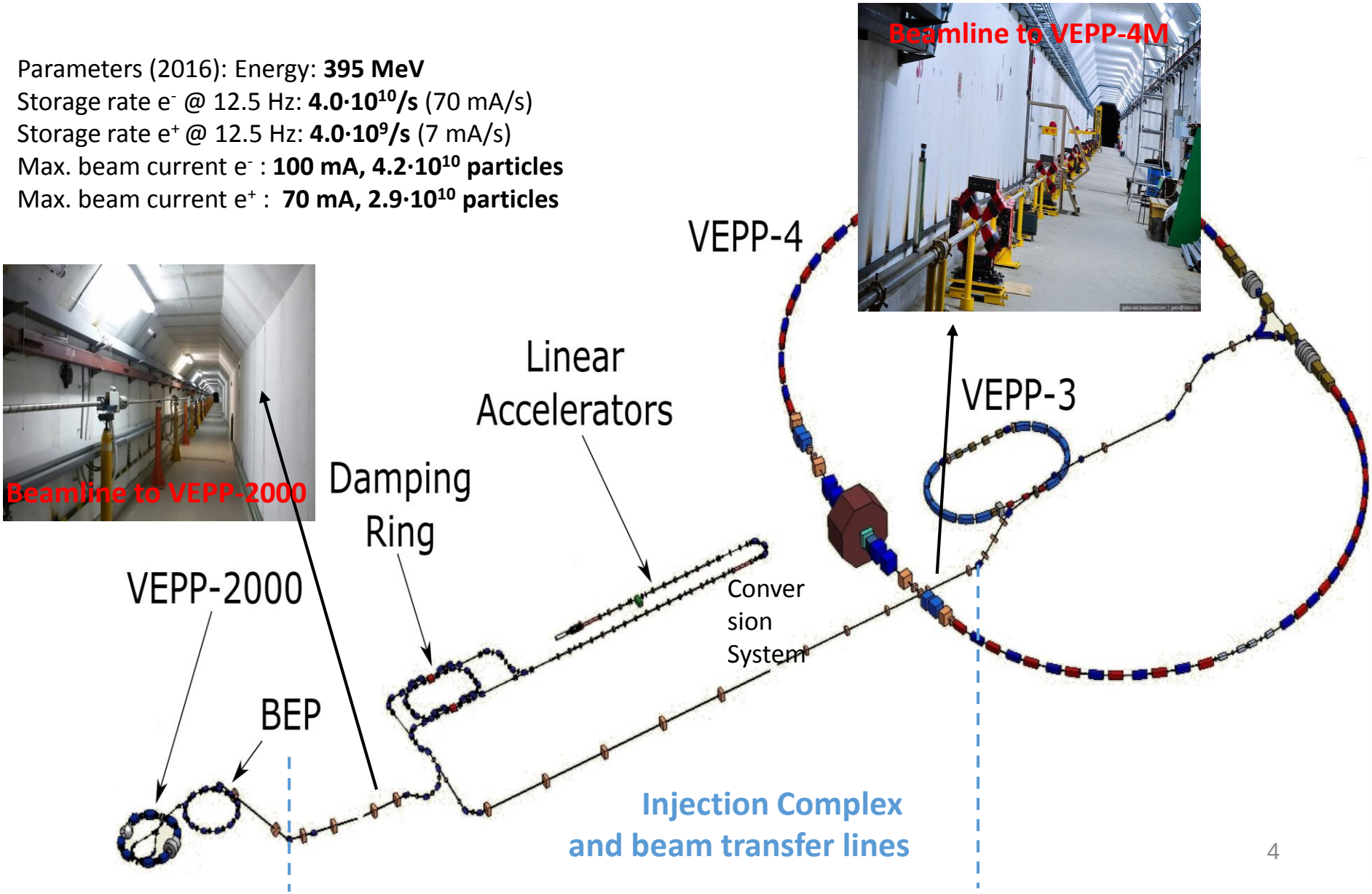

Институт Ядерной Физики СО РАН
NSKNEWS.INF


dedmaxopka.livejournal.com © dedmaxopka@gmail.com

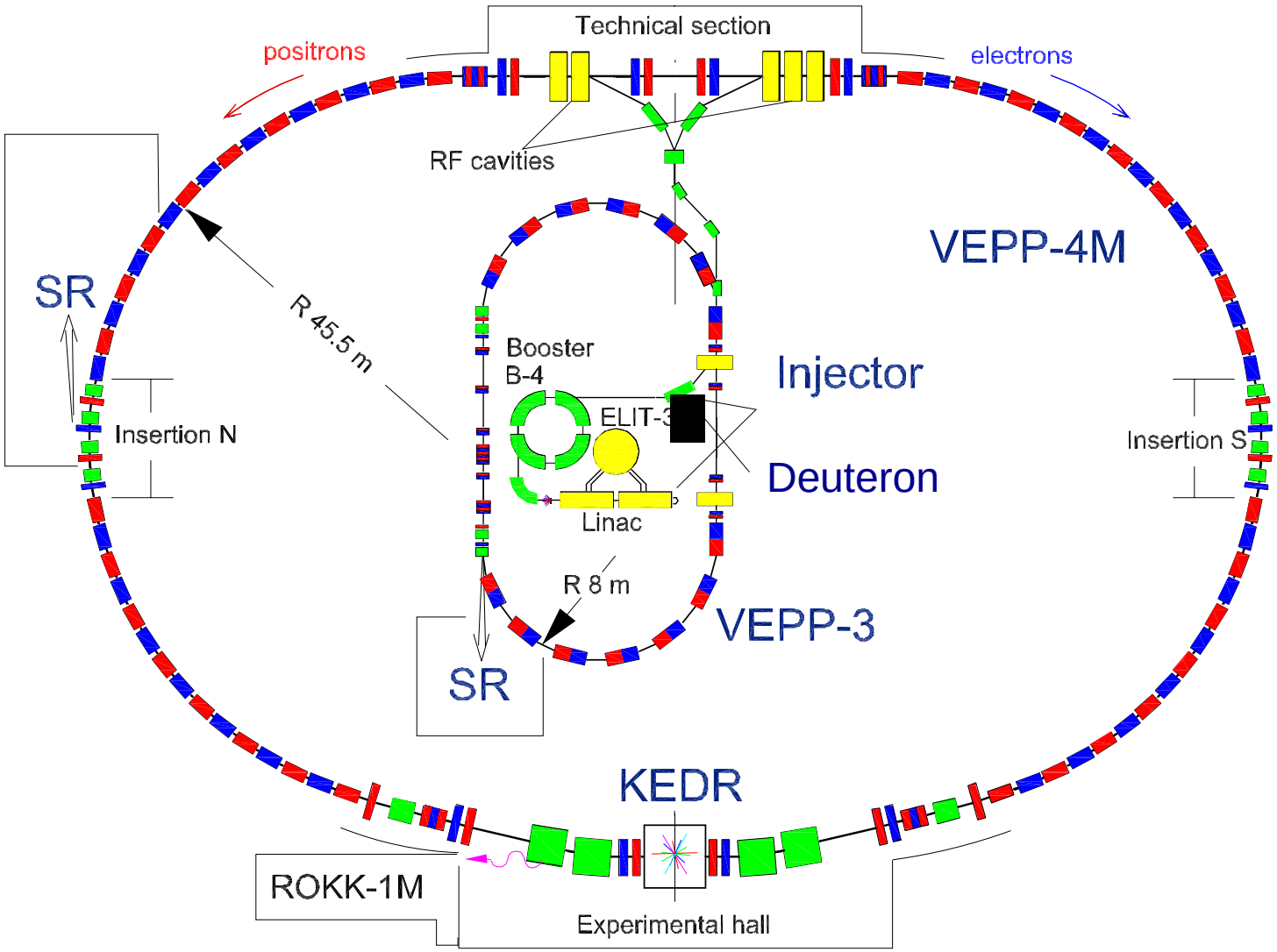

Asia
International Boundary
River
National Capital
City or Town
0 500 1000 KM
0 500 1000 Miles
©2007 Geology.com
Arctic Ocean
Bering Sea
Pacific Ocean
Norwegian Sea
Barents Sea
Kara Sea
Laptev Sea
East Siberian Sea
Sea of Okhotsk
Sea of Japan (East Sea)
Yellow Sea
Mediterranean Sea
Black Sea
Caspian Sea
Aral Sea
Lake Balkhash
Lake Baikal
RUSSIA
KAZAKHSTAN
MONGOLIA
CHINA
IRAN
IRAQ
SAUDI ARABIA
AFGHANISTAN
TURKEY
LIBYA
EGYPT
SUDAN
JAPAN
NORTH KOREA
SOUTH KOREA
Moscow
Petersburg
London
Paris
Berlin
Rome
Madrid
Lisbon
Athens
Istanbul
Kiev
Minsk
Oslo
Stockholm
Helsinki
Tokyo
Seoul
Beijing
Pyongyang
Ulan Bator
Astana
Tashkent
Bishkek
Dushanbe
Kabul
Islamabad
Tehran
Baghdad
Riyadh
Cairo
Khartoum
Tripoli
Algiers
Tunis
Ankara
Tbilisi
Yerevan
Baku
Damascus
Amman
Ashgabat
Yekaterinburg
Novosibirsk
Omsk
Krasnoyarsk
Irkutsk
Yakutsk
Vladivostok
Sapporo
Osaka
Nagoya
Hiroshima
Fukuoka
Shanghai
Hong Kong

Injection Complex VEPP-5 providing both BINP colliders VEPP4M and VEPP-2000 with the electron and positron beams

Parameters (2016): Energy: **395 MeV**
Storage rate e^- @ 12.5 Hz: **$4.0 \cdot 10^{10}$/s** (70 mA/s)
Storage rate e^+ @ 12.5 Hz: **$4.0 \cdot 10^{9}$/s** (7 mA/s)
Max. beam current e^- : **100 mA, $4.2 \cdot 10^{10}$ particles**
Max. beam current e^+ : **70 mA, $2.9 \cdot 10^{10}$ particles**



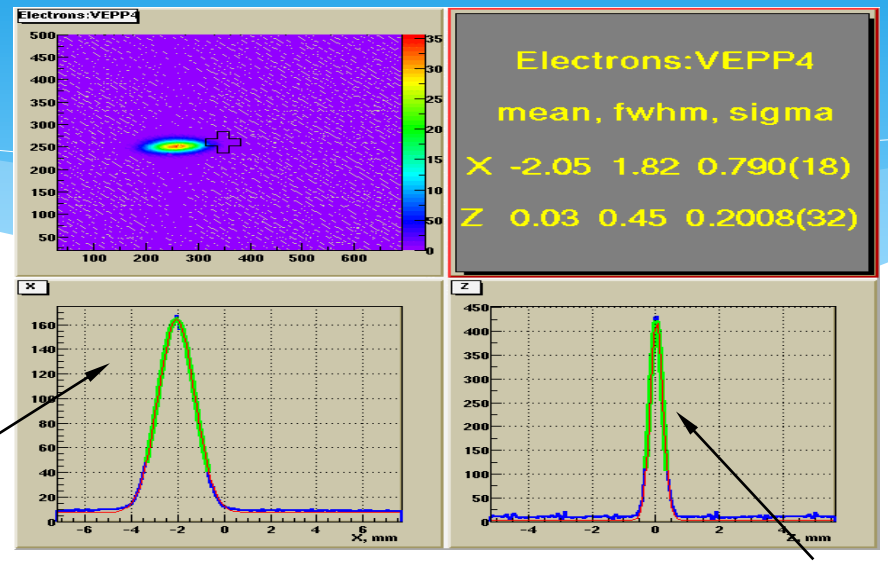
VEPP-4M electron-positron collider



VEPP-4M PARAMETERS

Energy	0.925 ÷ 4.75 (5.2)					
Circumference	366.075					m
Number of bunches	$2e^+$ x $2e^-$					
Harmonic number	222					
Betatron tunes, h/v	8.54/7.57					
Compaction factor	0.0168					
Coupling	0.05%					
Bunch length (σ_z)	5					cm
Beam Energy	1.5	1.8	3	4.7	5.2	GeV
Emittance	16	25	67	167	200	nm·rad
Energy Spread	2.5	3.0	4.9	7.8	8.5	$\cdot 10^{-4}$
Beam Current	1.6	3.0	12	25	25	mA
Luminosity	0.9	2.0	14	44	25	$\cdot 10^{30}$ $cm^{-2} \cdot s^{-1}$

Typical Bunch Dimensions at BINP cyclic Accelerators



Bunch dimensions at the VEPP-4M electron-positron collider (E = 1900 MeV):

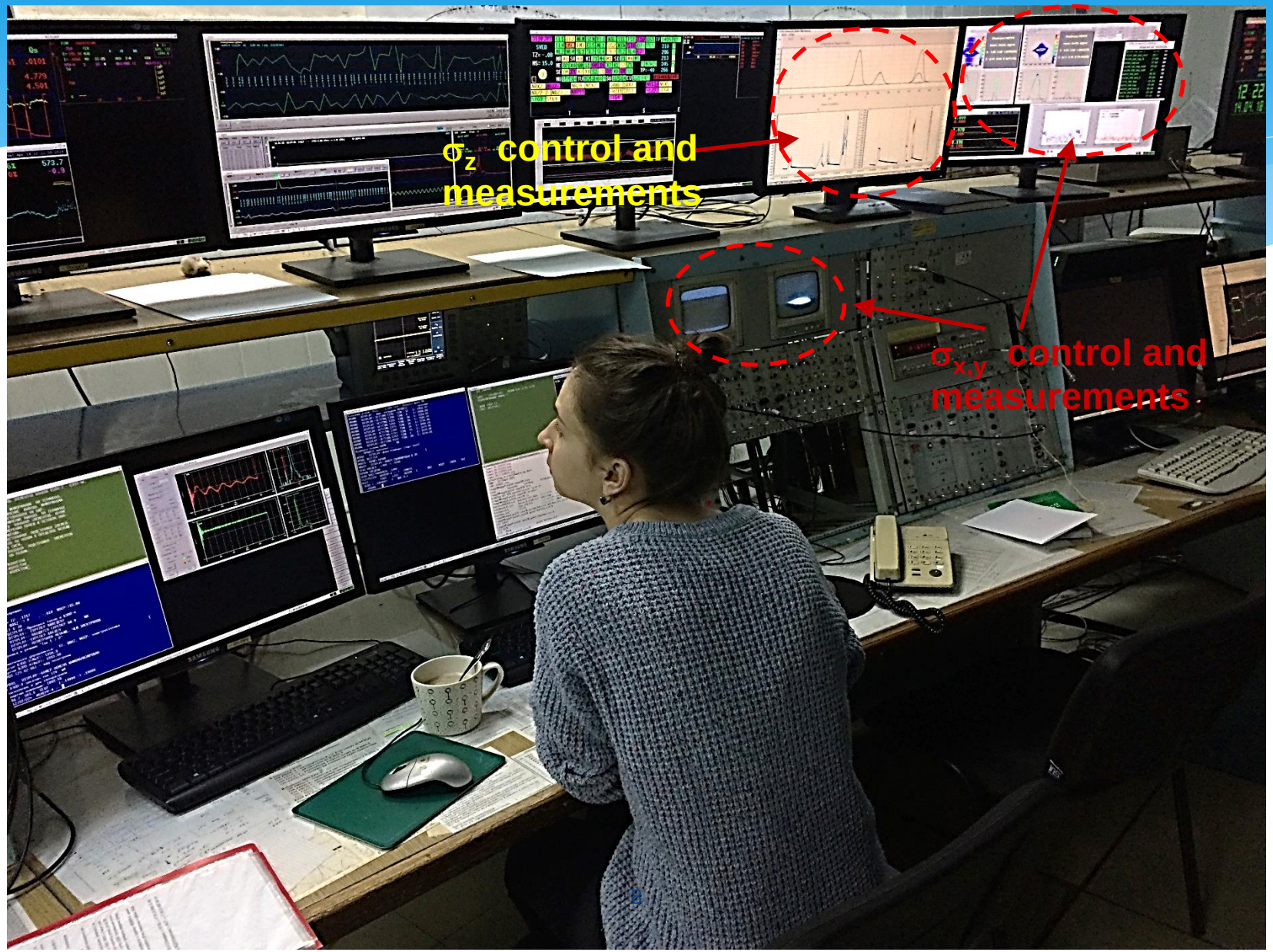
$\sigma_y \sim 140 \div 250\ \mu m$

$\sigma_x \approx 800\ \mu m$

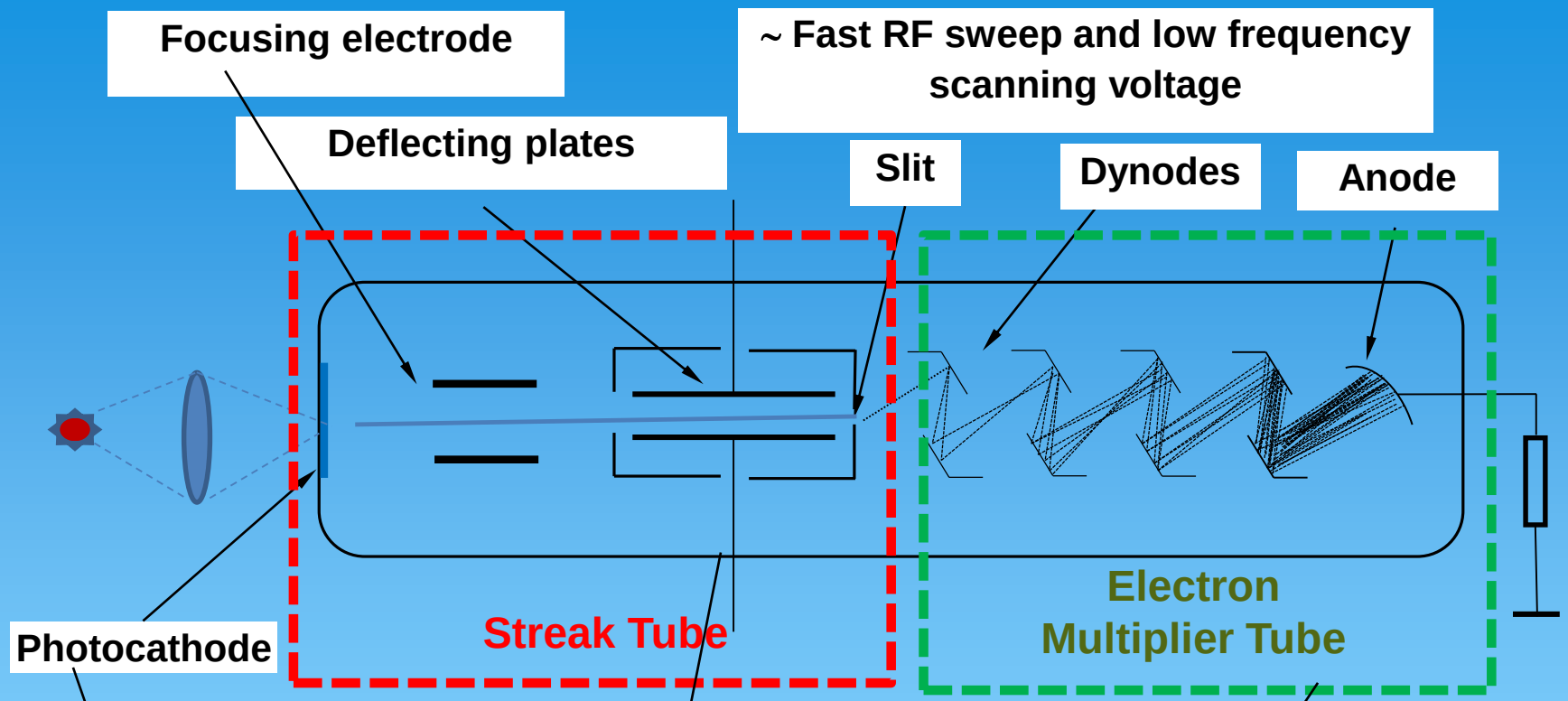
$\sigma_z \sim 4$ cm (120 picoseconds)

2×2 bunches of e^+ e^-, 5×5 mA

VEPP-4M Control Room



Streak Camera transformed into Dissector



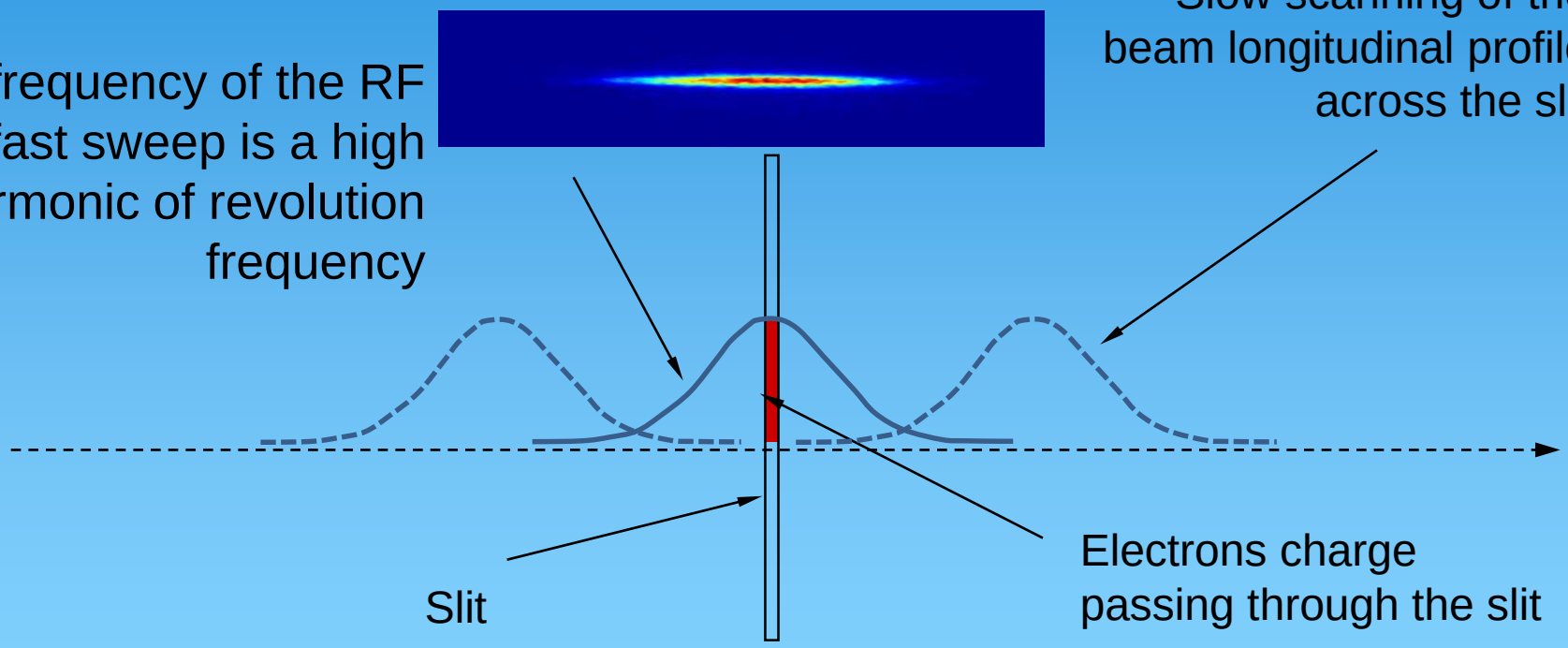
The simplified layout of the dissector

Streak Camera transformed into Dissector

Beam longitudinal profile *Q(x)* obtained at the slit aperture with RF fast sweep

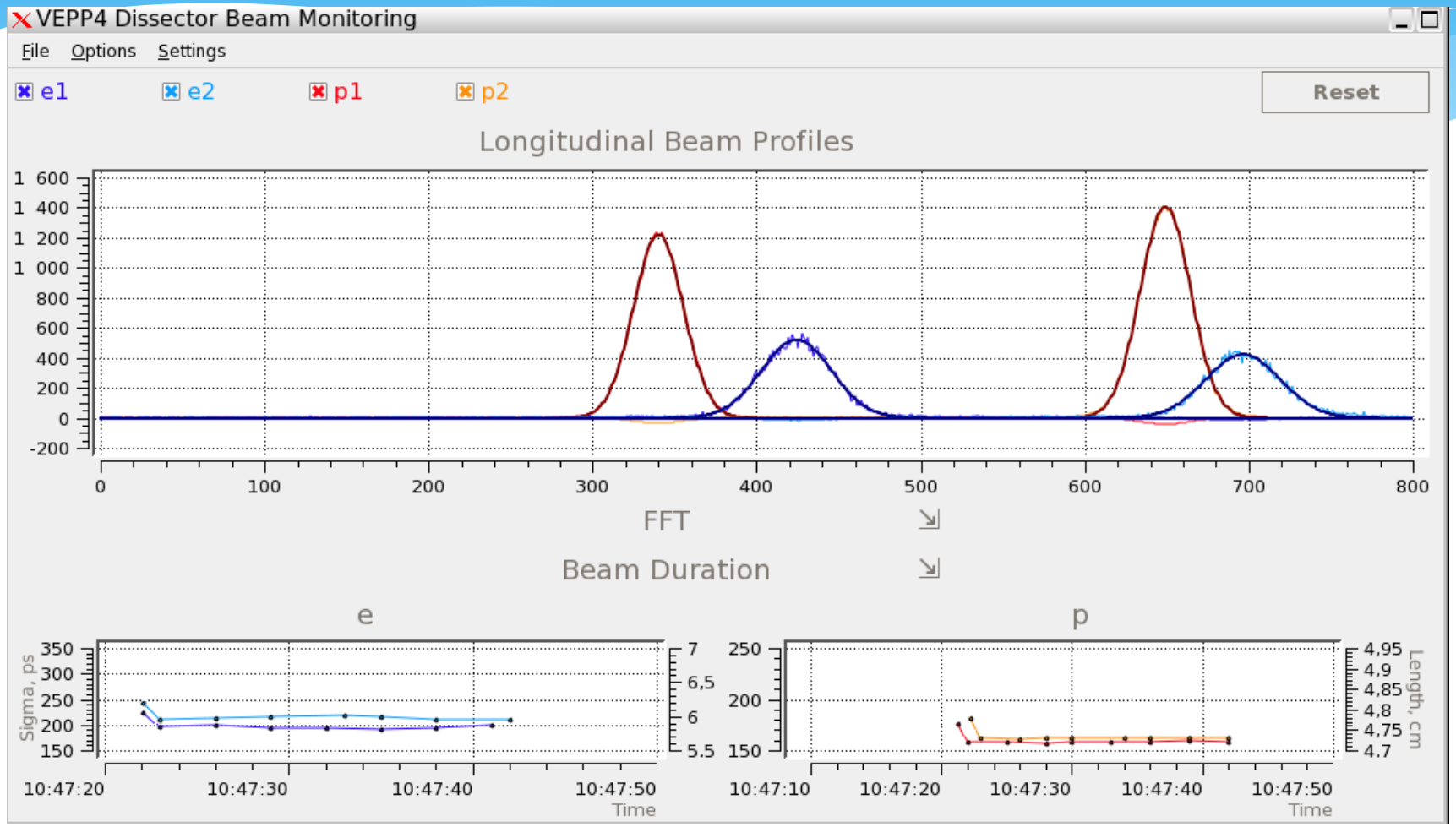
A frequency of the RF fast sweep is a high harmonic of revolution frequency

Slow scanning of the beam longitudinal profile across the slit

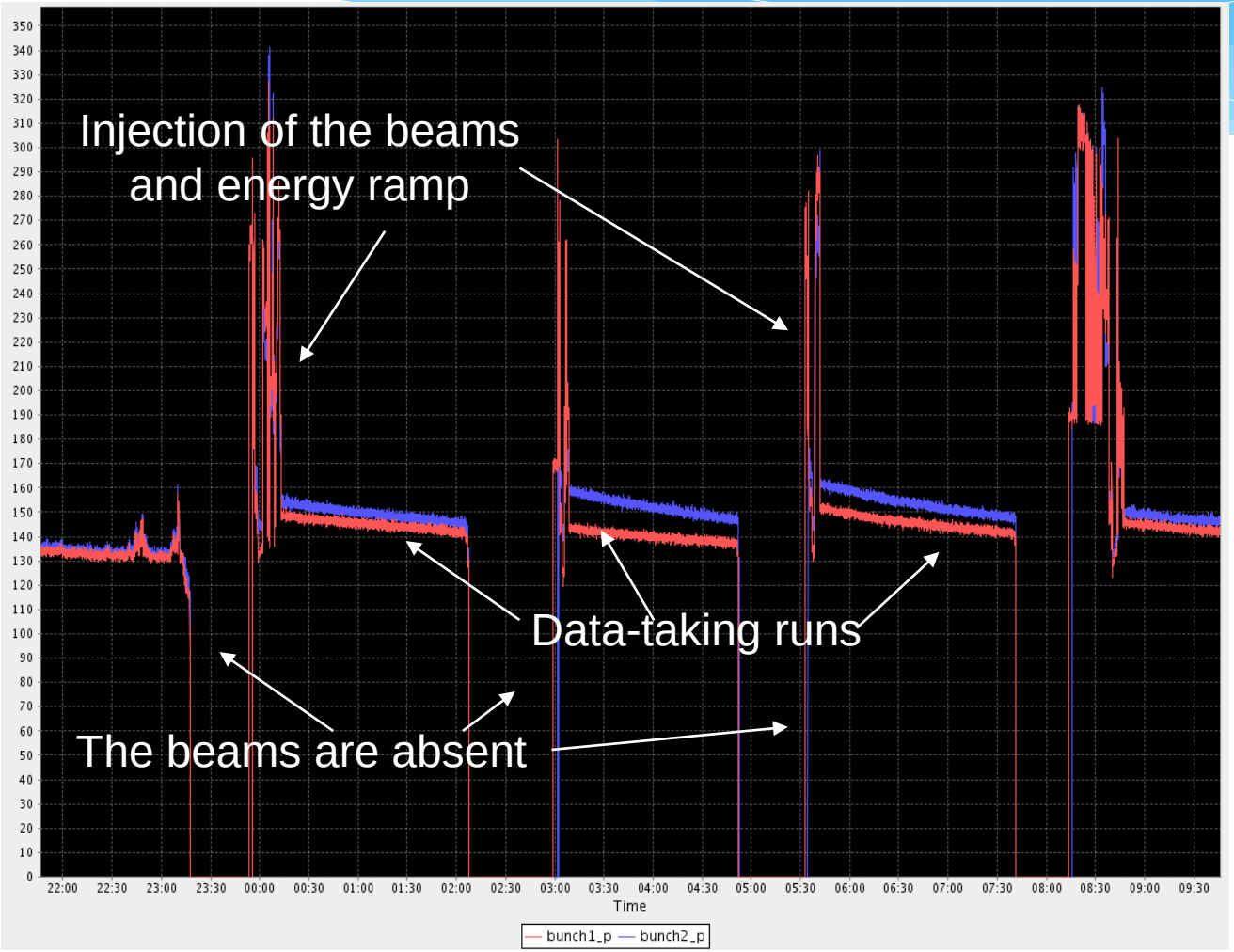


The electrons passing through the slit are amplified by the Electron Multiplier Tube. The anode signal of the EMT is recorded by the ADC

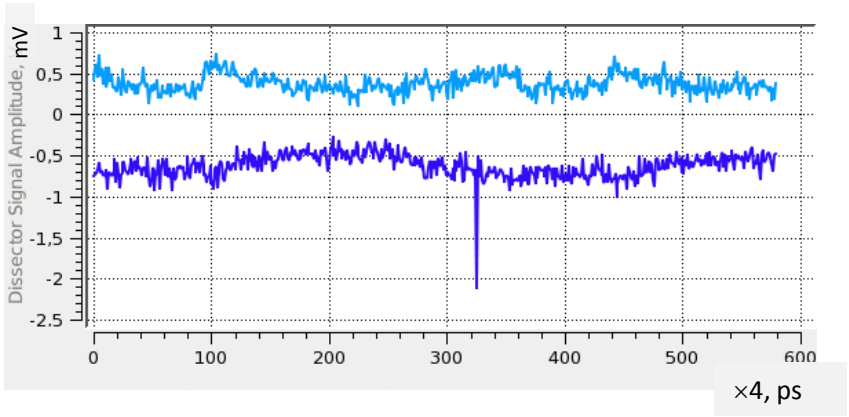
The software for processing of the dissector signals



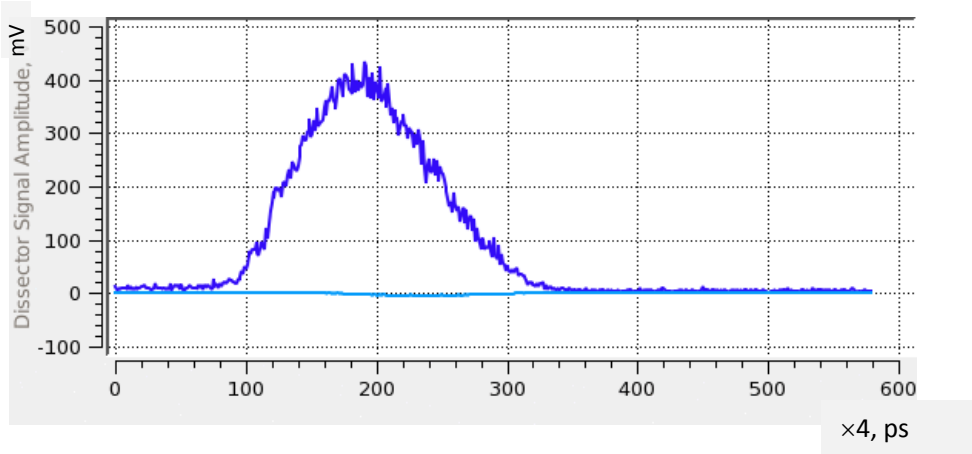
The record of positron bunches lengths, saved in the data base of the VEPP-4M during 12-hours shift



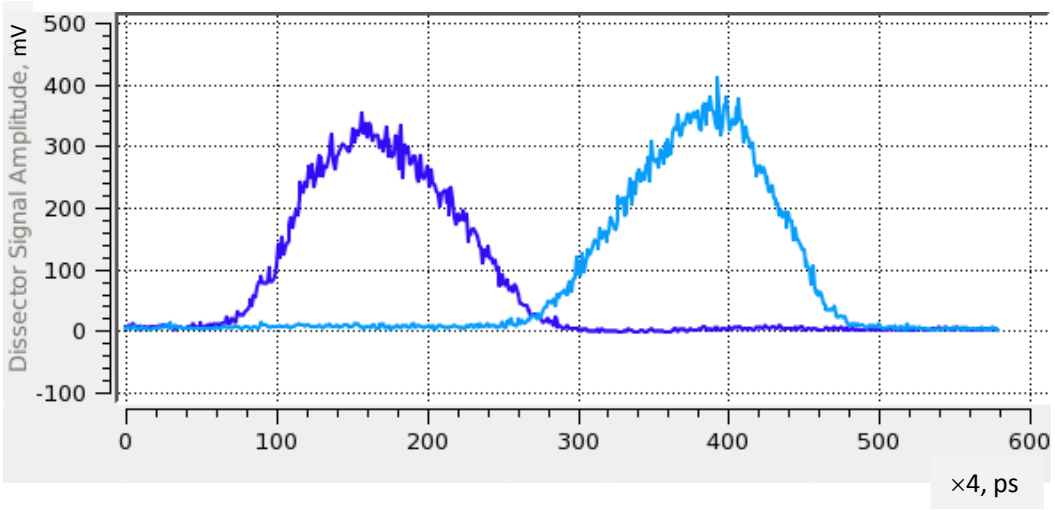
The behavior of the longitudinal profiles of the bunches during beam storage and acceleration in the VEPP-3 (the booster of the VEPP-4M collider)



The storage of the beam in the booster at the energy E = 354 MeV



The phase oscillations of the bunches during storage process



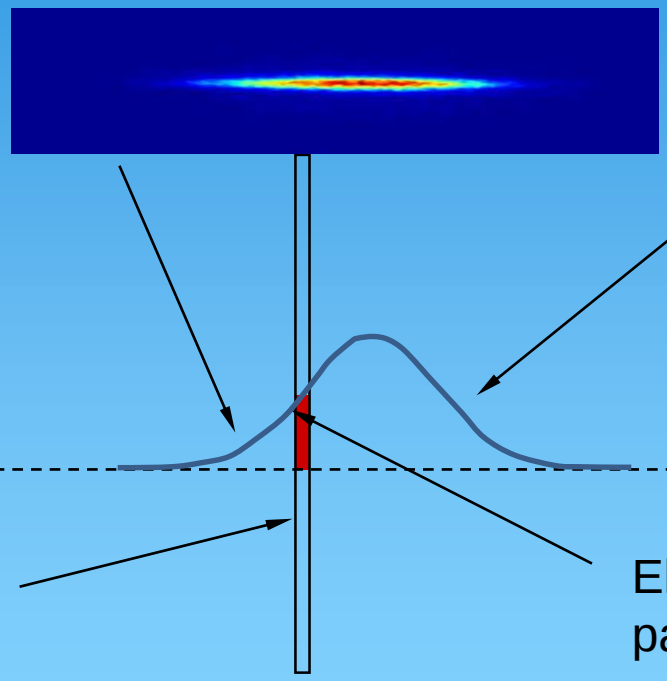
The acceleration of the beam to E = 1892 MeV. The acceleration frequency switches from 8 MHz to 72 MHz at the E = 600 MeV. It leads to well-seen decrease of the bunches length.

The repetition rate (slow scan frequency) is 50 Hz

Dissector operating in the mode of «phase slit»

Beam longitudinal profile *Q(x)* obtained at the slit aperture with RF fast sweep

Slow scanning of the profile across the slit is switched off.

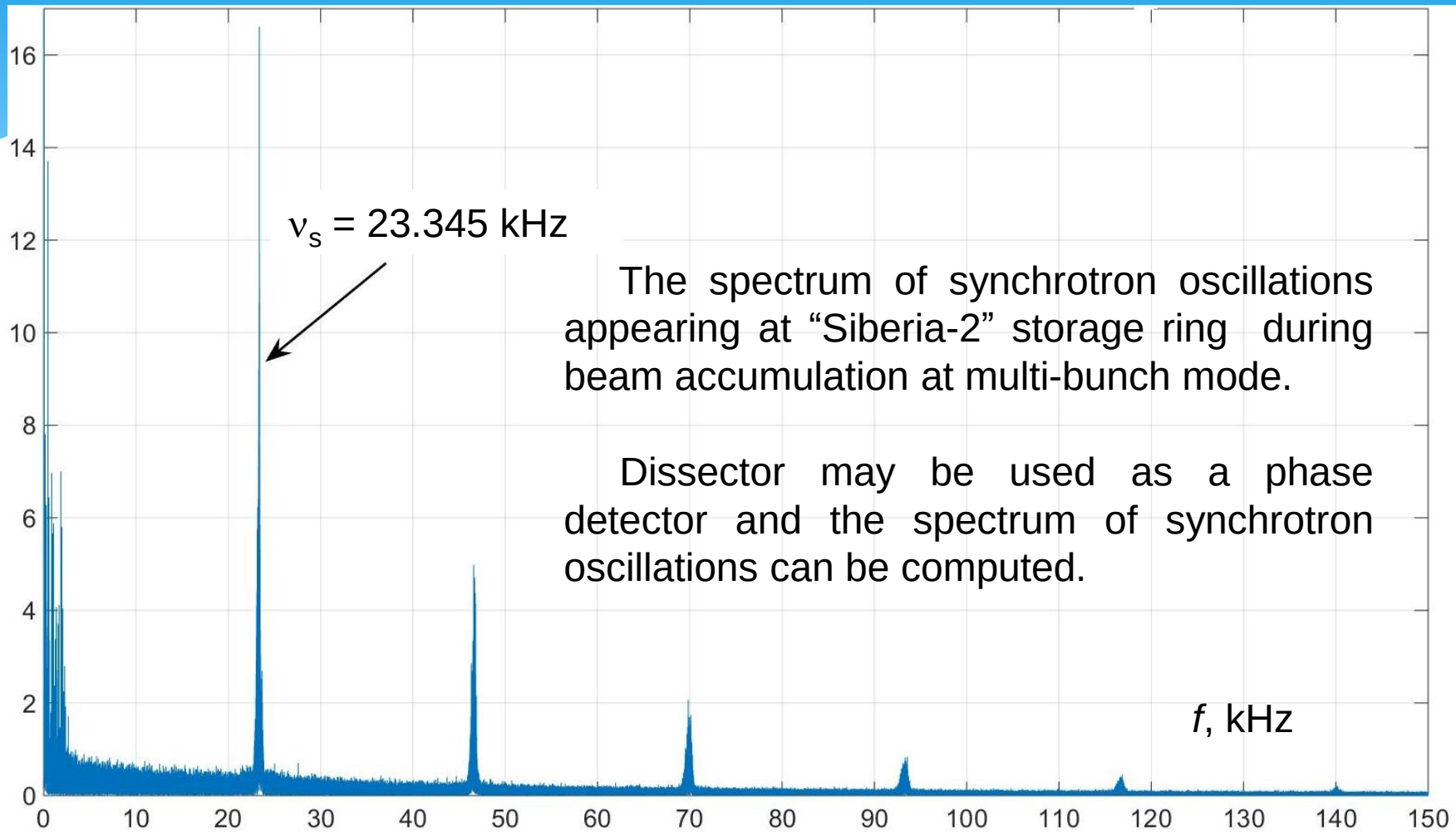


Slit

Electrons charge passing through the slit

The dissector records the dipole oscillations of the beam and any distortions on the longitudinal profile of the beam at the point of a beam profile, which was placed on the slit.

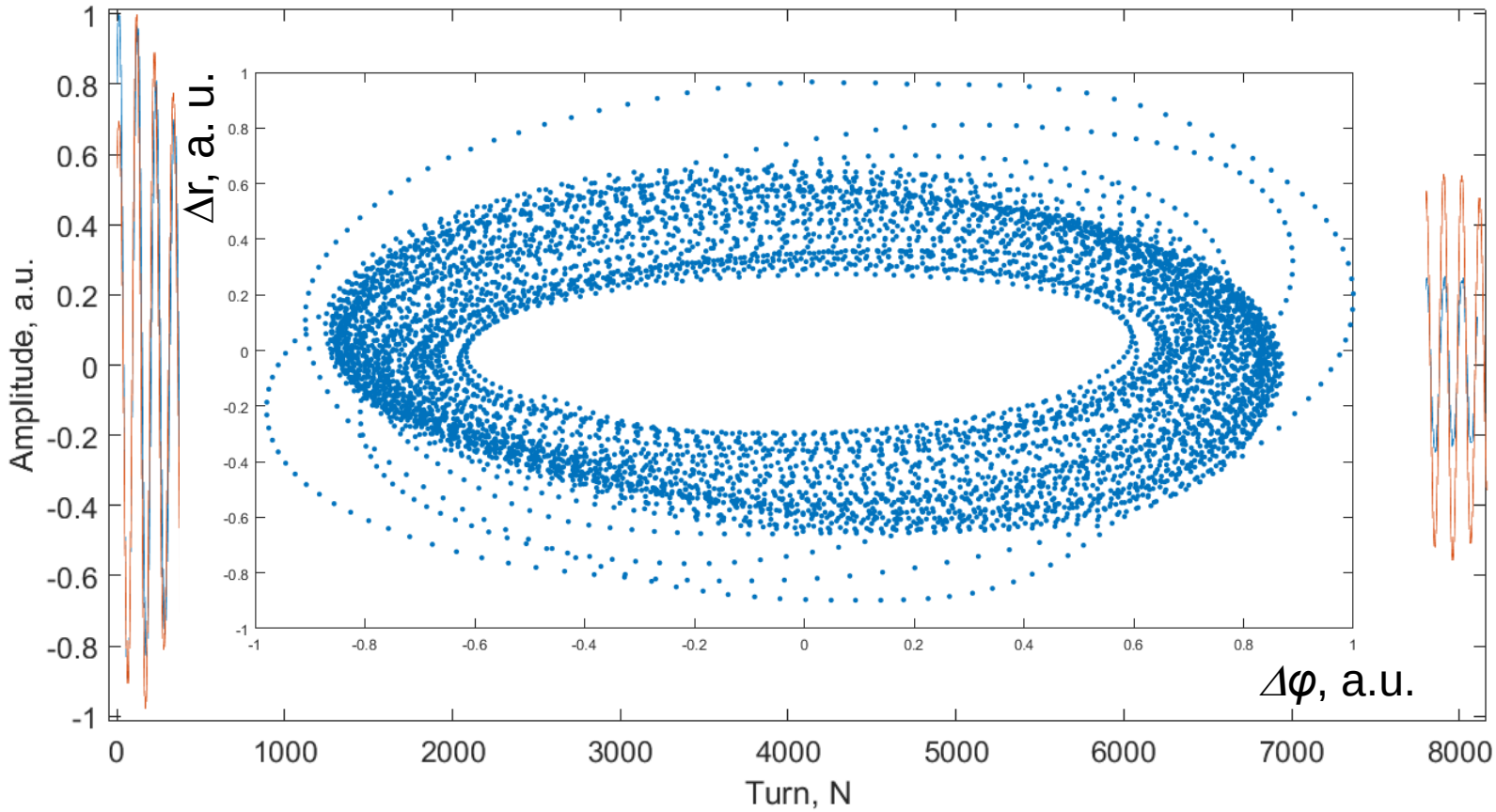
Synchrotron Oscillations (Siberia-2)



The spectrum of synchrotron oscillations appearing at “Siberia-2” storage ring during beam accumulation at multi-bunch mode.

Dissector may be used as a phase detector and the spectrum of synchrotron oscillations can be computed.

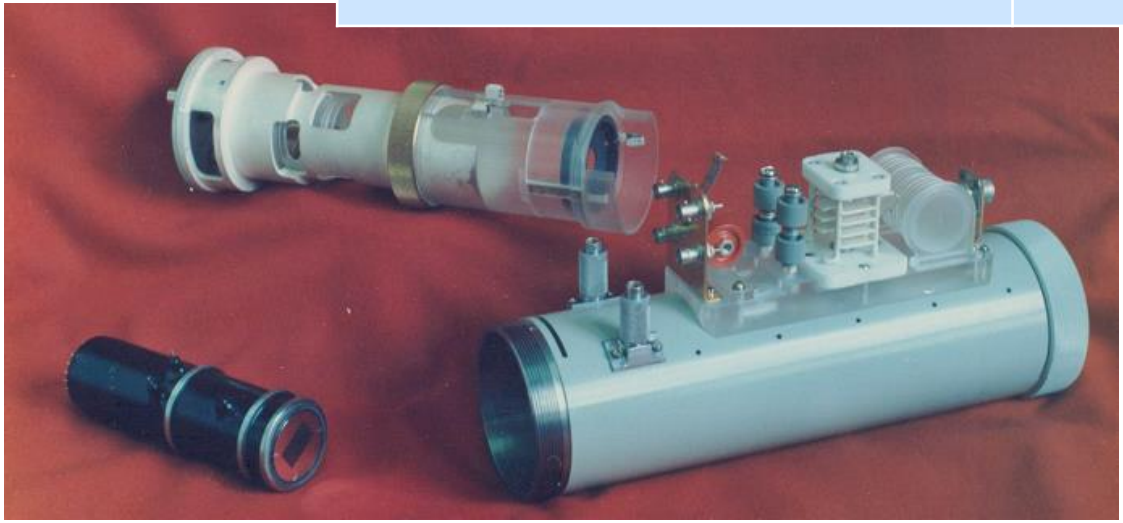
Beam injection from the VEPP-3 into the VEPP-4M



The radial (blue line) and longitudinal (red line) oscillations of a beam after injection from the VEPP-3 into the VEPP-4M. The dissector operates in the «phase slit» mode. The motion of the beam in the phase space can be computed.

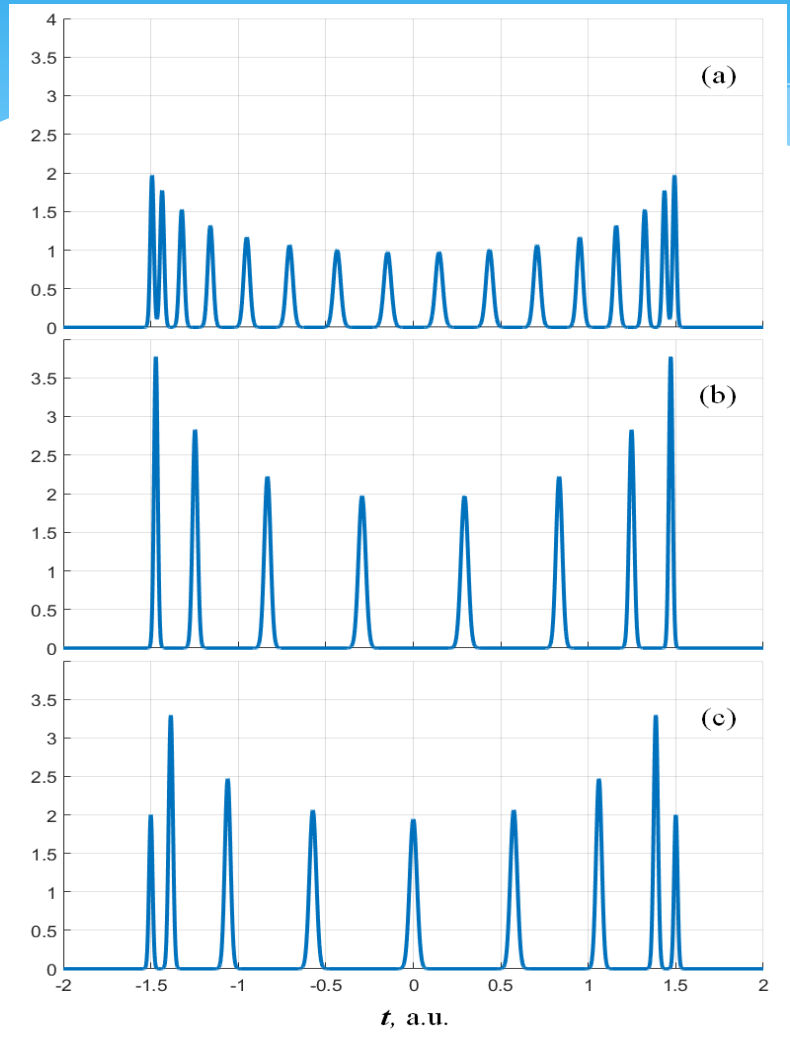
LI-602 the dissector: advantages and disadvantages

Advantages	Disadvantages
Very reliable. Actually, the device is working daily during tens of years all the time when the beam is present in an accelerator.	The last dissector was produced at the end of 1980-th
	Moderate temporal resolution (20-30 ps FWHM). This value can not be improved.
	Has some problems for application with multi-bunched beam



All the presented examples were obtained with LI-602 dissector. This device was designed and produced in the BINP by Dr. E. Zinin.

Operation of the dissector with a multi-bunched beam

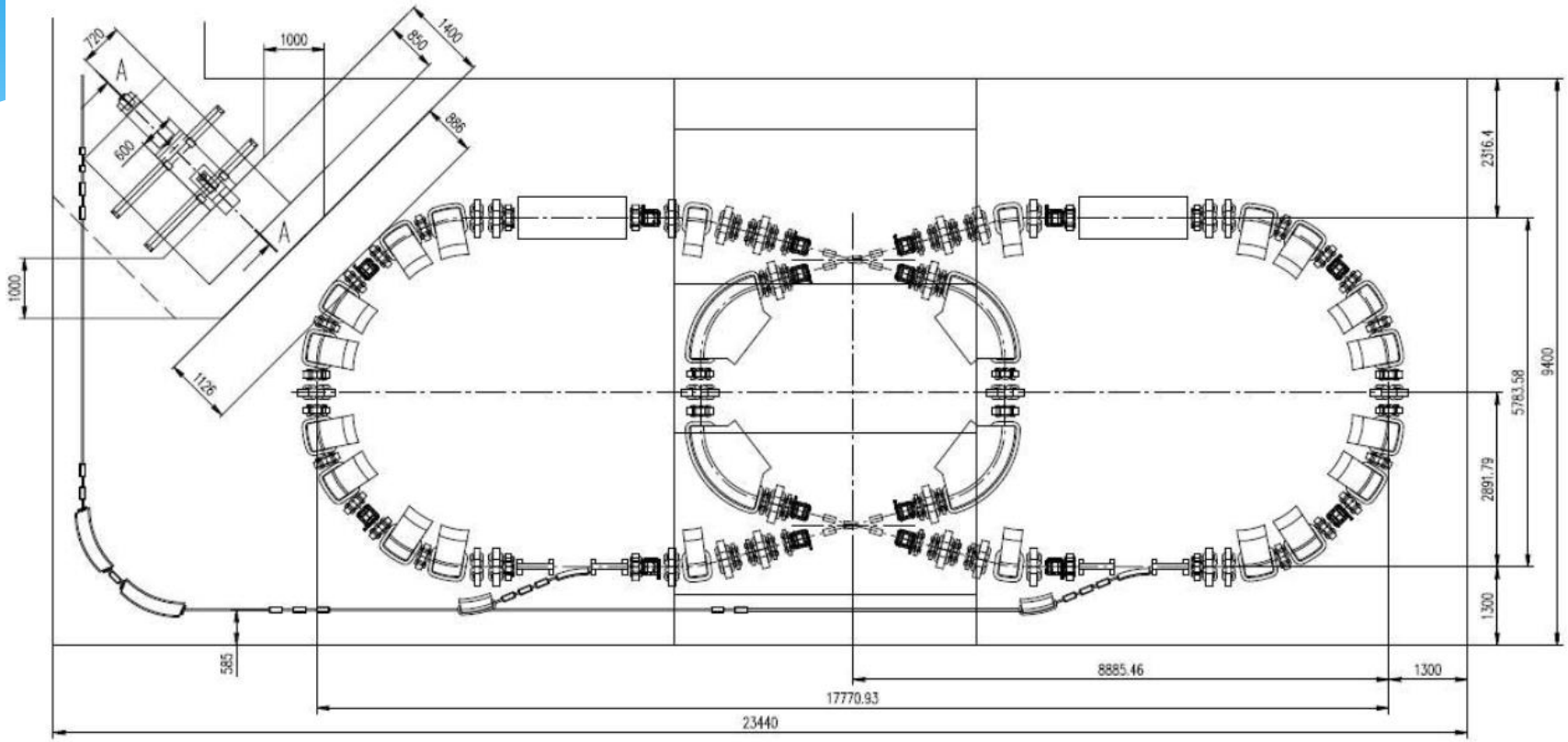


Oscilloscope image, 16 bunches are seen (a), each two overlap (b) and each two overlap except side ones (c).

So, each recorded profile is a sum of profiles of several bunches in a case of a multi-bunched beam.

The bunches from different RF buckets are overlapped at the plane of the slit of the dissector. It is an intrinsic feature of the operation principle of the device.

The very new two reasons to develop this kind of the beam diagnostics in the BINP

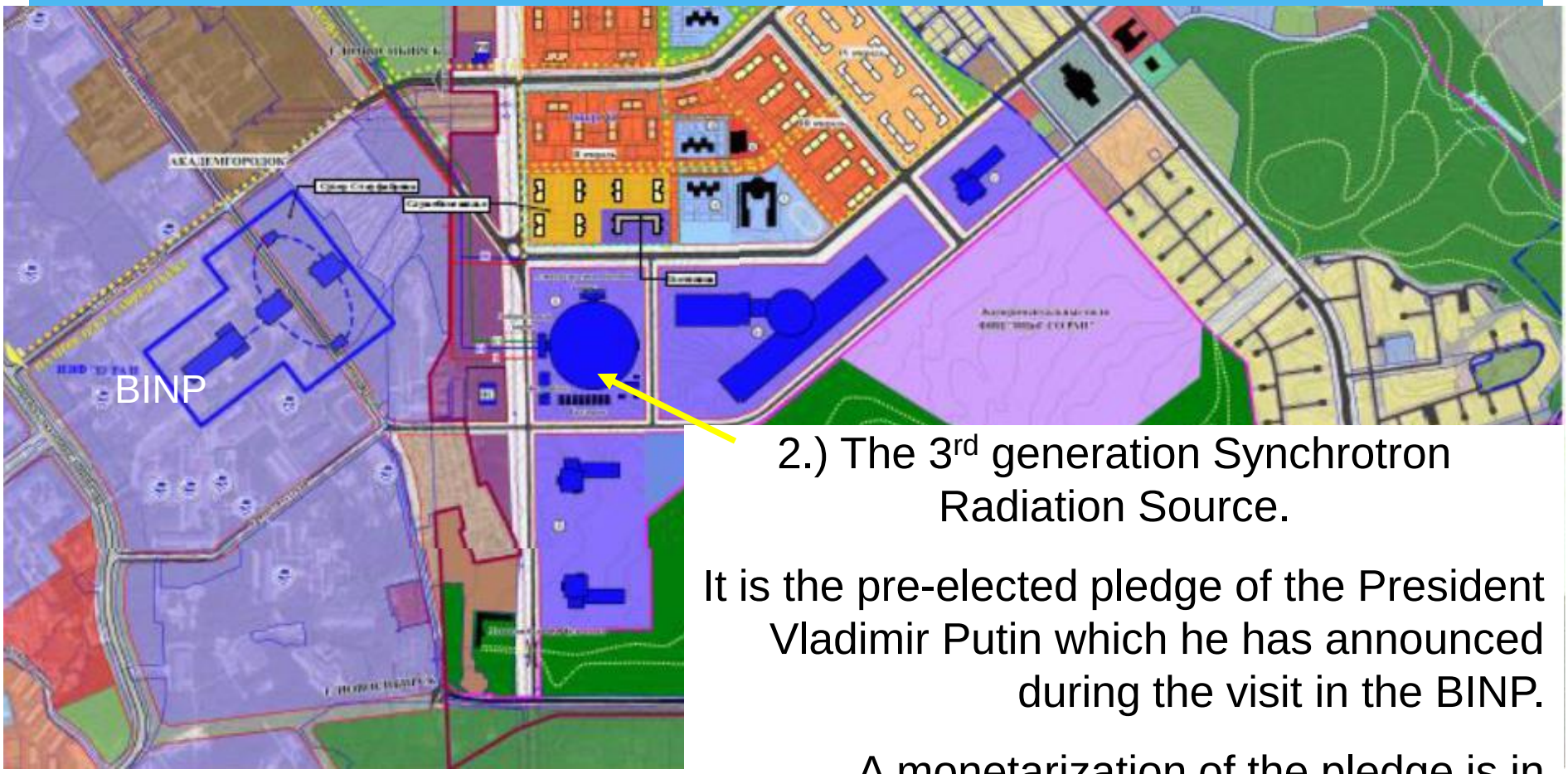


1.) The e+/e- collider on the energy 211 MeV – the stand for developing of technologies which BINP must have if going to build the super cτ-factory.

The scientific goal of the installation is a search of μ+μ- atoms.

The project is approved by Ministry of Science and Education of RF

The very new two reasons to develop this kind of the beam diagnostics in the BINP

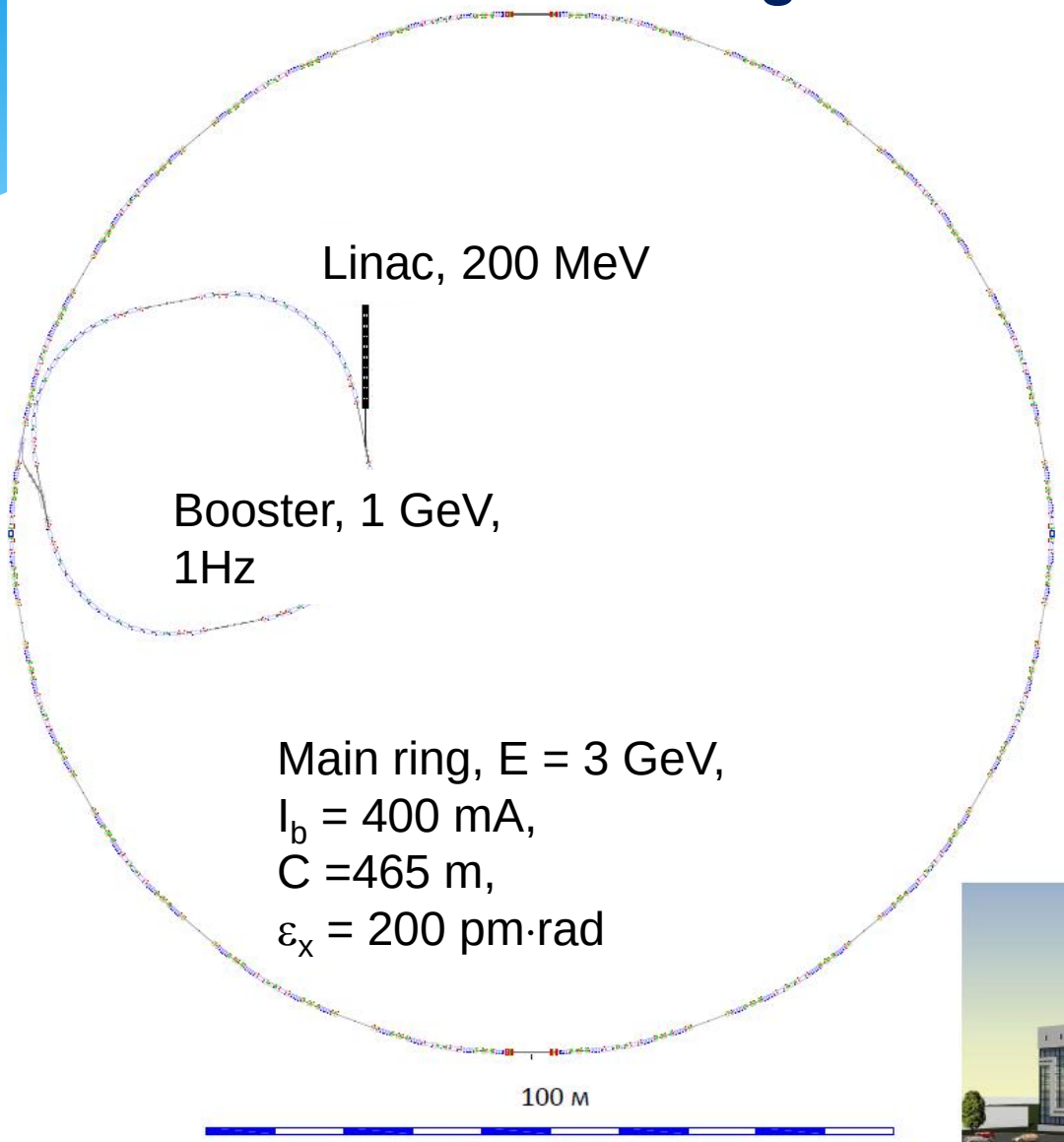


2.) The 3rd generation Synchrotron Radiation Source.

It is the pre-elected pledge of the President Vladimir Putin which he has announced during the visit in the BINP.

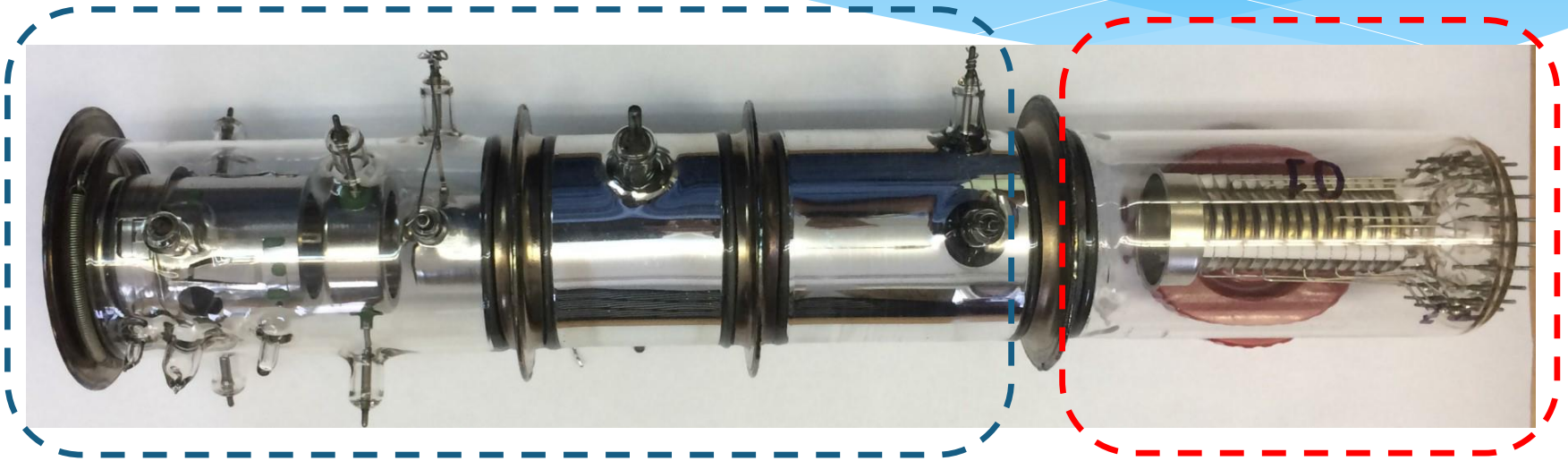
A monetarization of the pledge is in progress.

The very new two reasons to develop this kind of the beam diagnostics in the BINP



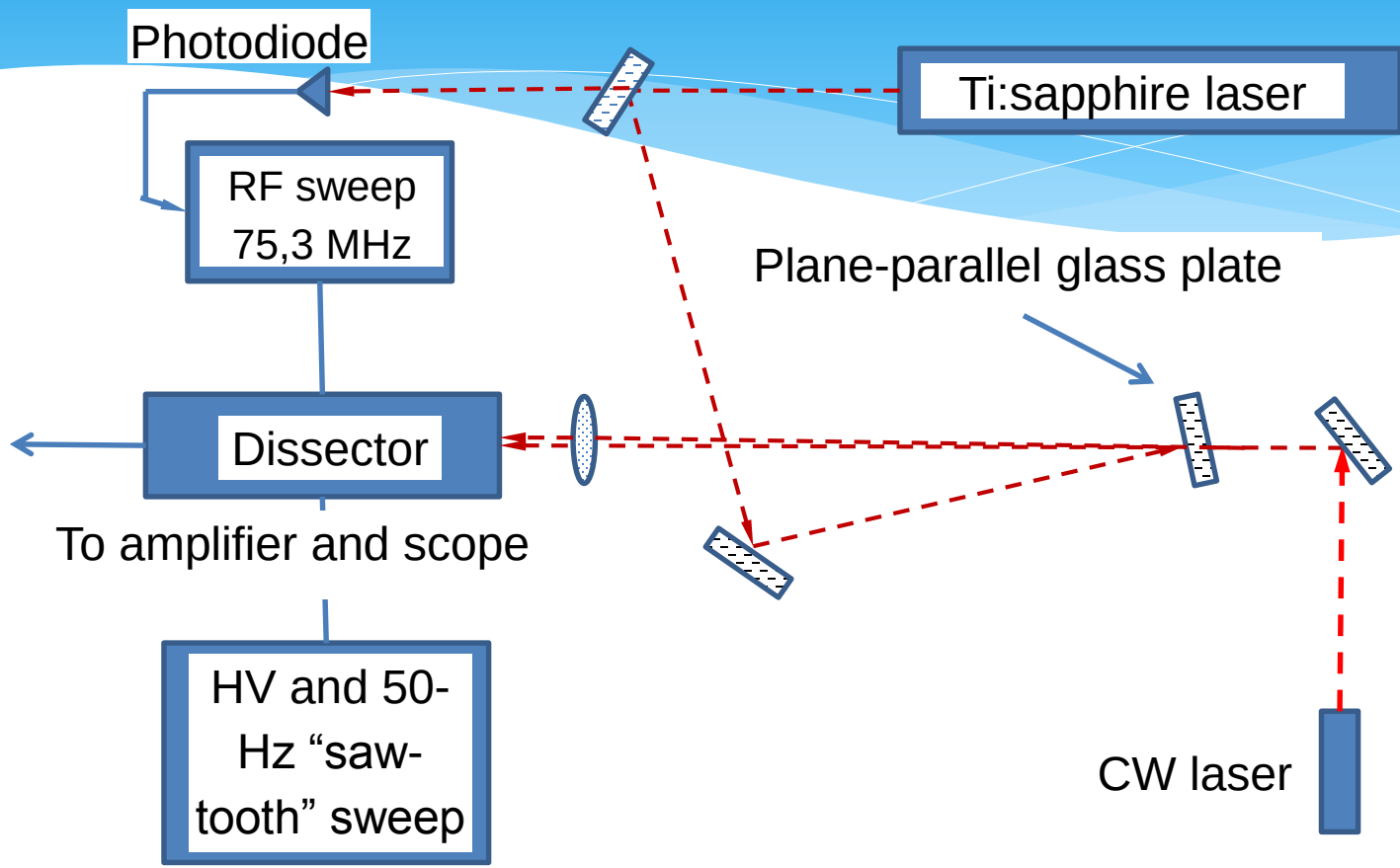
Энергия	3 ГэВ
Ток в пучке	До 400 мА (1.5 мА в каждом сгустке)
Магнитная структура	Гибридный мульибенд-ахромат (7 магнитов в ячейке)
Эмиттанс пучка	200 пкм рад
Тип инжекции	На полной энергии
Длина орбиты	~ 470 м
Генераторы СИ	15 вигглеров или ондуляторов
ВЧ	180 MHz

PIF-1D/S20(S1) - the next generation of the dissector



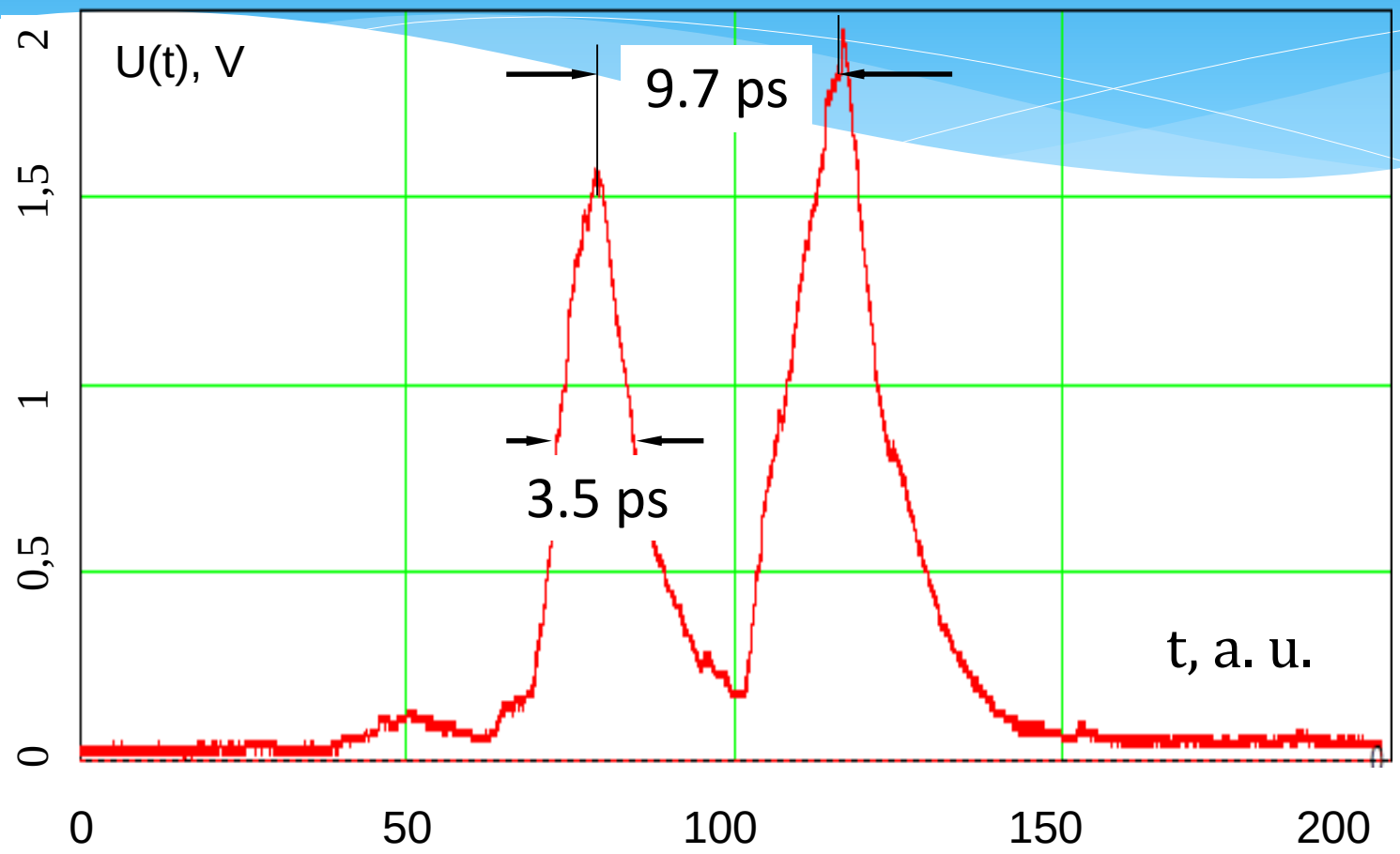
This device was created in cooperation between BINP and Prokhorov Institute of General Physics (Moscow). The “head” of the streak-tube PIF-1/S20(S1) was combined with an Electron Multiplier Tube. The streak-tube has a temporal resolution about 1 ps and a shutter on the exit for separation of the pulses.

Direct Measurement of the temporal Resolution of the Dissector



Measurements of the dissector temporal resolution were carried out at the Ti:sapphire laser generated light pulses at the wavelength of 0,81 microns with a 30-femtosecond duration at the frequency of 75,3 MHz.

The two Laser Pulses separated by a 10-ps Time Interval, which were recorded by the Dissector.



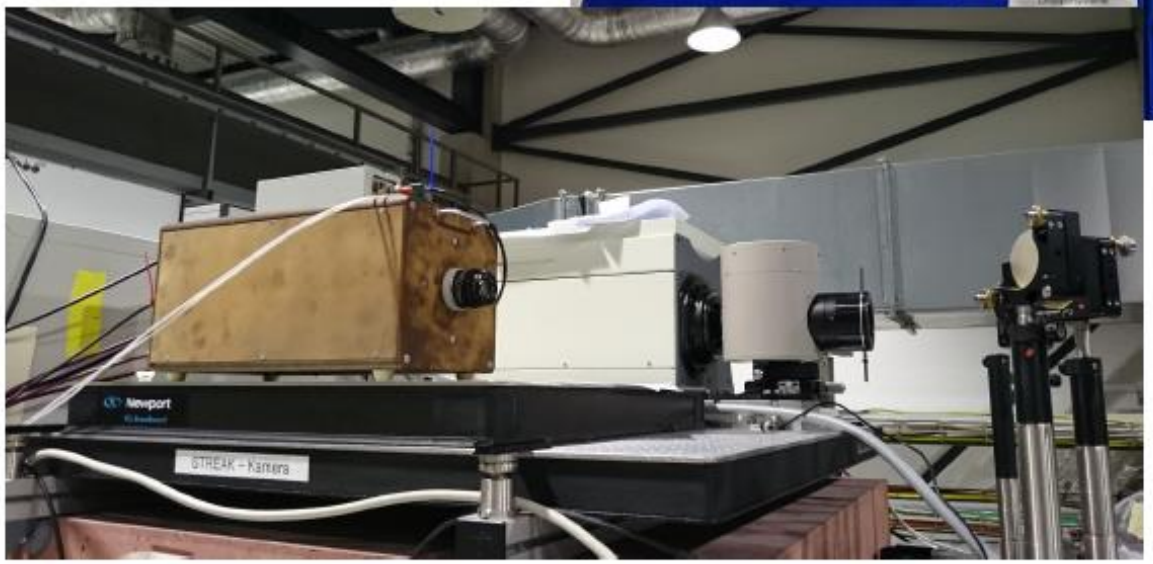
Very recently we have achieved the temporal resolution of 1.5 ps.

The experiments at the MLS (Berlin)

Installation at MLS

Dissector electronics:

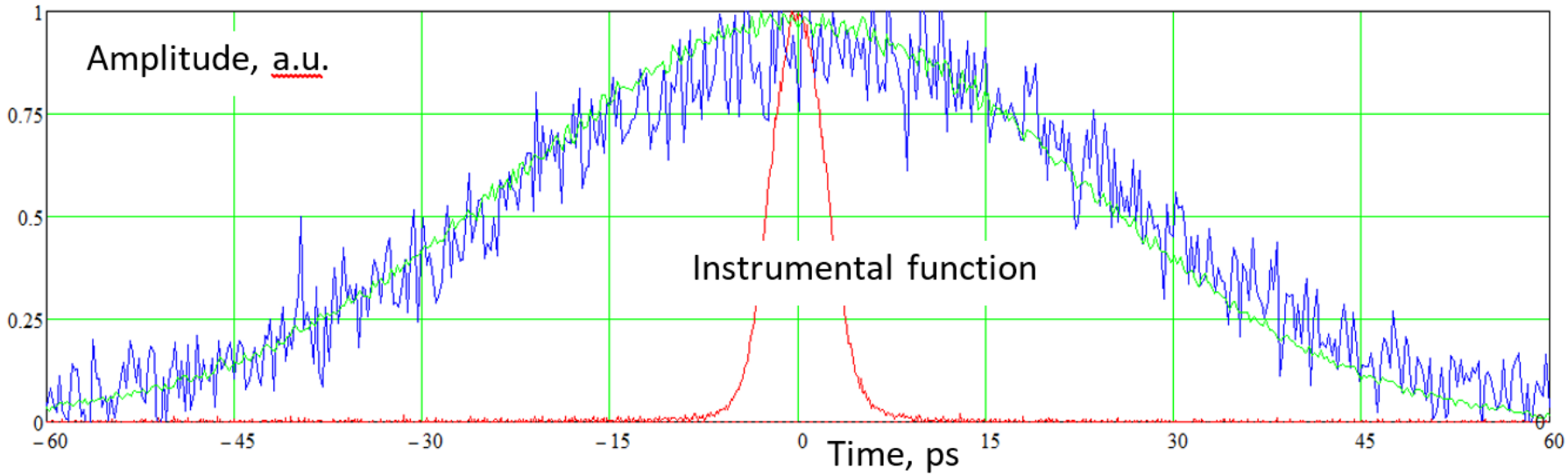
- RF power supply,
- high voltage power supply



Dissector and streak camera at the MLS:

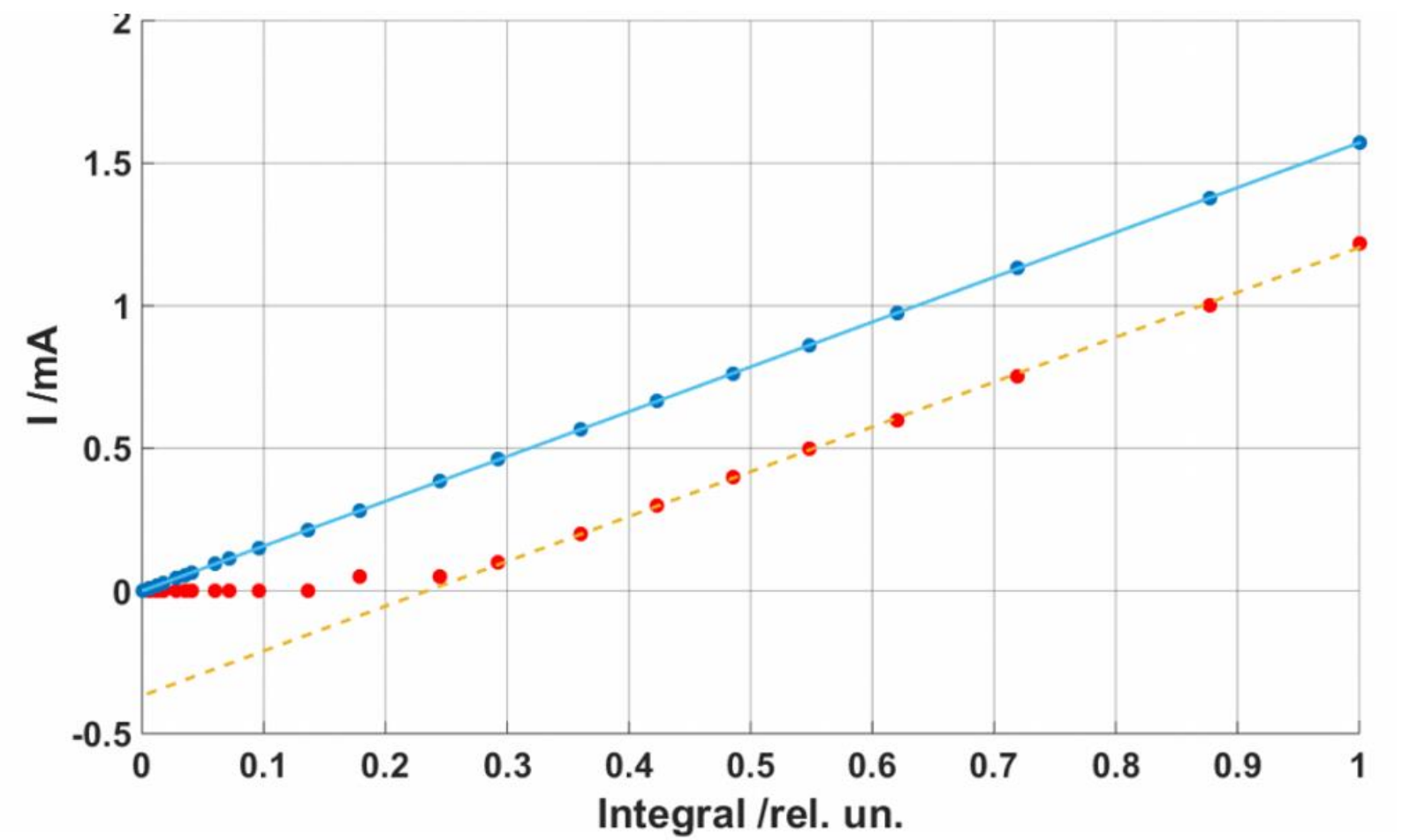
Synchrotron light is shared between both devices by a mirror edge.

The experiments at the MLS (Berlin)



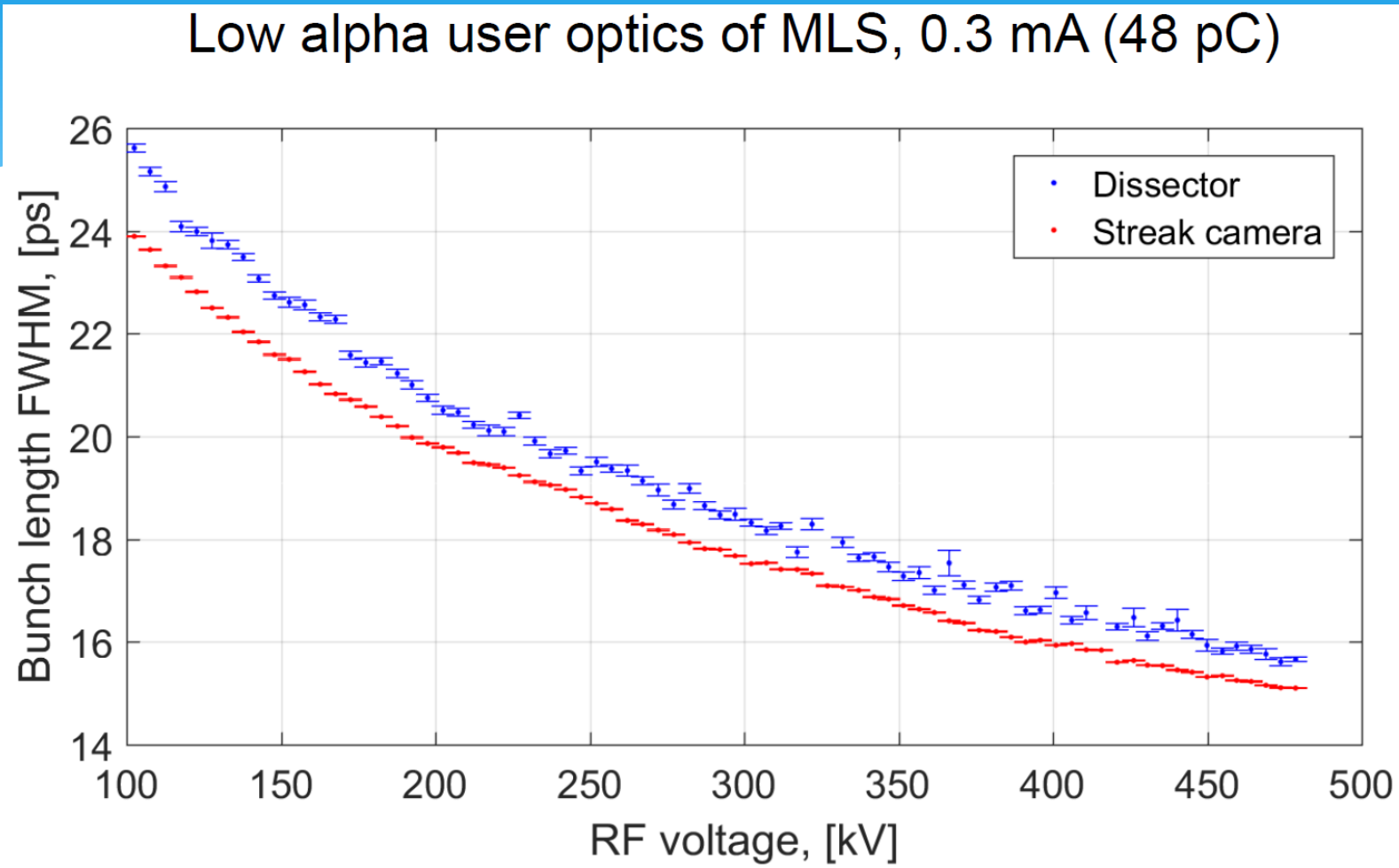
Longitudinal bunch profiles for two beam currents: the green curve corresponds to 0.35 mA, the blue curve corresponds to 0.02 mA and the red one is the instrumental function.

The experiments at the MLS (Berlin)



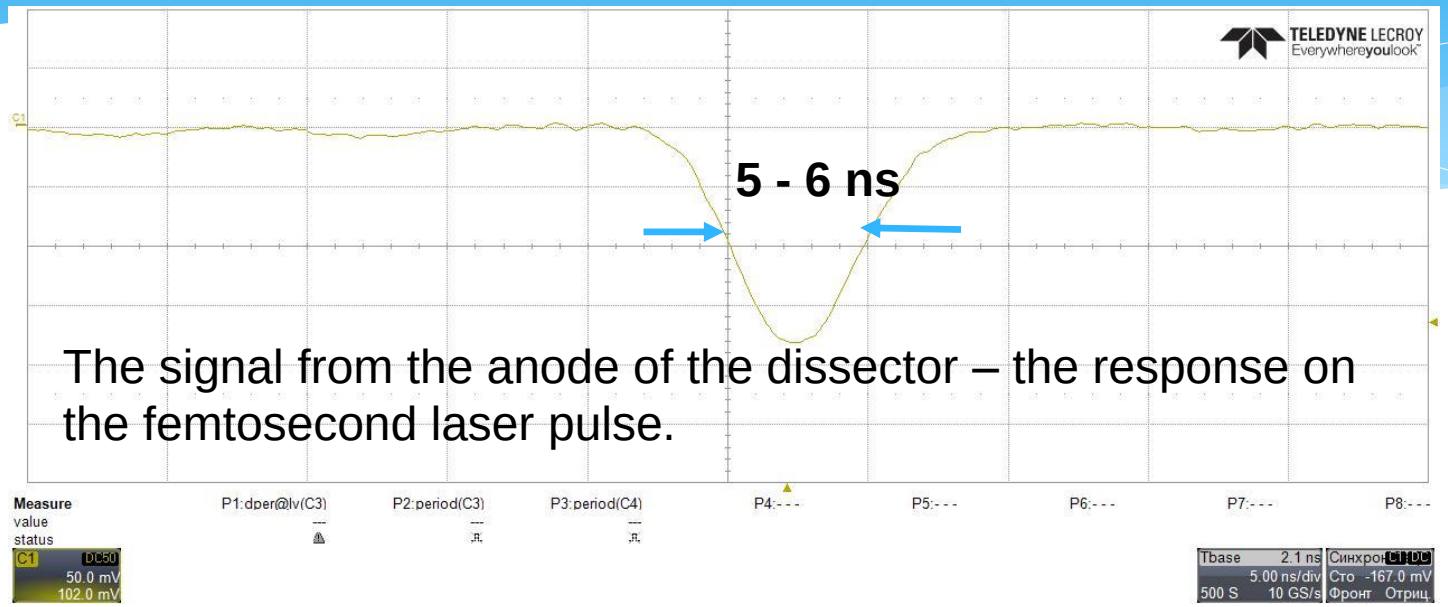
The beam current calibration procedure. The relation between integrated signal of the dissector and beam current is presented. The red points represent the values of the beam current measured with the MLS integrating current transformer.

The experiments at the MLS (Berlin)



The measured bunch lengths are in good agreement for the range from 70 ps down to 15 ps (point spread function needs to be taken into account).

The multi-bunched mode of the dissector operation. How to measure a length of the each bunch in the beam?



We can select the bunch using the temporal resolution of the EMT. The response of the dissector on the single SR pulse is presented in the Figure.

The design of the PIF-1D dissector contains the shutter which can be applied for selection of odd or even bunches.

The proof-of - principle experiment with 75-MHz laser is in progress.

The nearest plans

* The new dissector is a «raw» device yet. We want to get more experience with it at the VEPP-4M collider.
* The experiments at the MLS were done with sweep frequency of 93 MHz. We want to increase this value to 181 MHz (accelerating frequency of the VEPP-4M) and to rise the slow scanning frequency up to 1 kHz.
* The operation of the dissector in multi-bunched mode can be tested at the Siberia-2 storage ring (Moscow). This accelerator has 75 bunches in the beam and the same RF frequency as the VEPP-4M has.

Conclusion

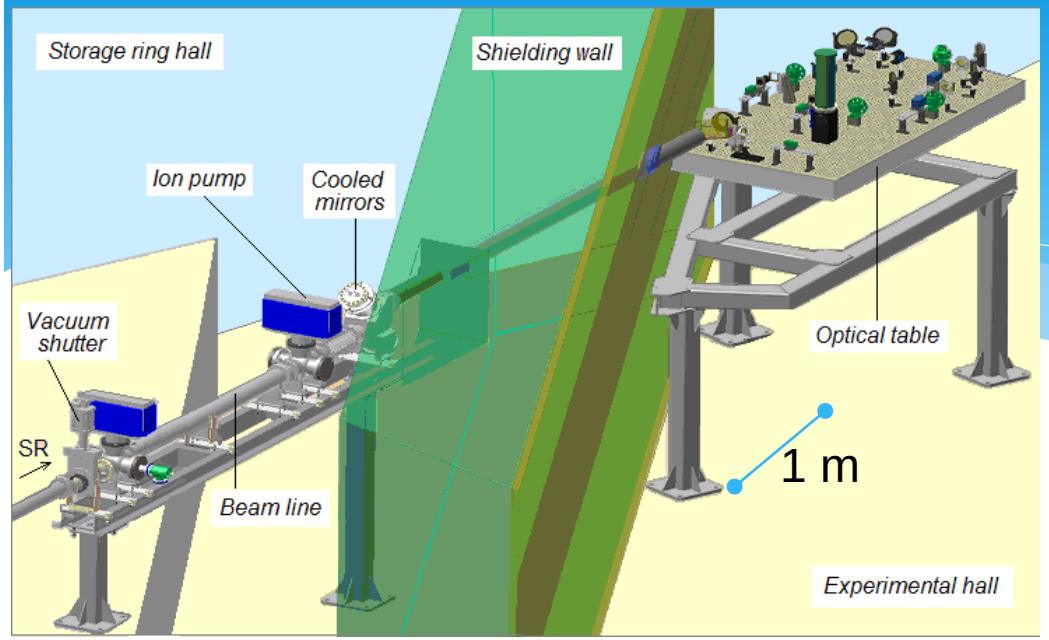
- The temporal resolution of PIF-1D dissector is about several ps.
- BINP develops the diagnostics which allows permanently measure the longitudinal beam profile of the selected bunch in a multi-bunched beam.

BUDKER INSTITUTE OF NUCLEAR PHYSICS

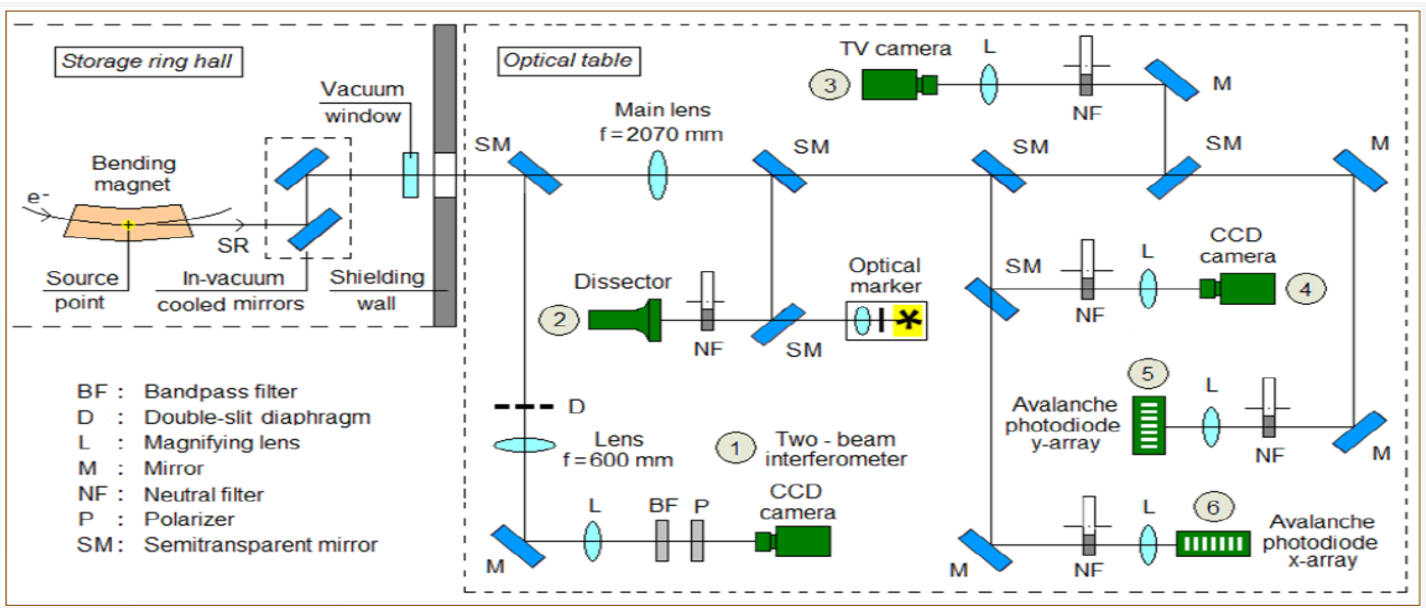
Thank you for attention!

Optical Diagnostics of Siberia-2 Storage Ring

Optical Diagnostics of Siberia-2 Storage Ring

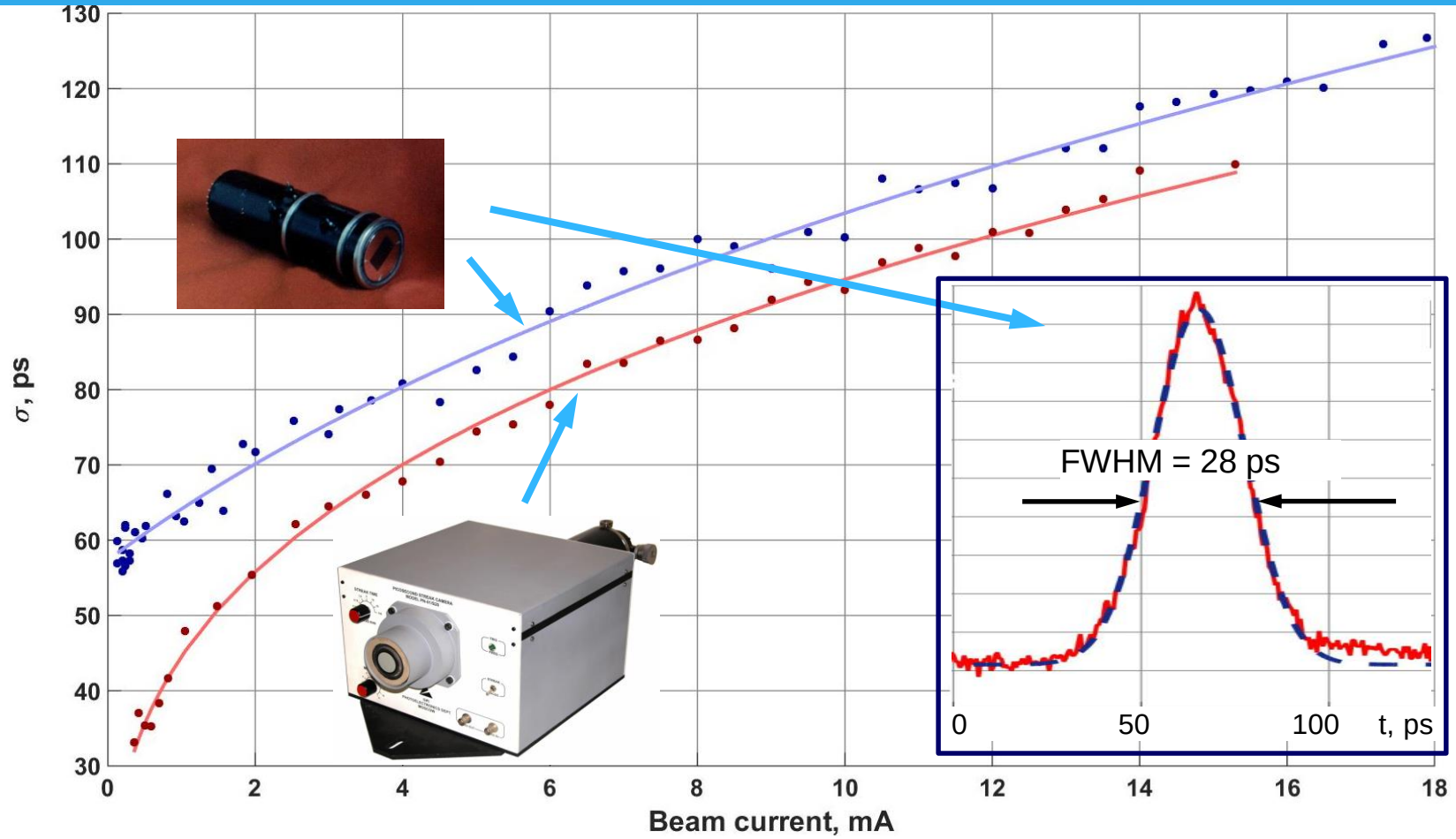


SR beam line and the optical diagnostics of a beam at Siberia-2 storage ring (KCSR, Moscow)



Layout of the optical diagnostics at Siberia-2 storage ring

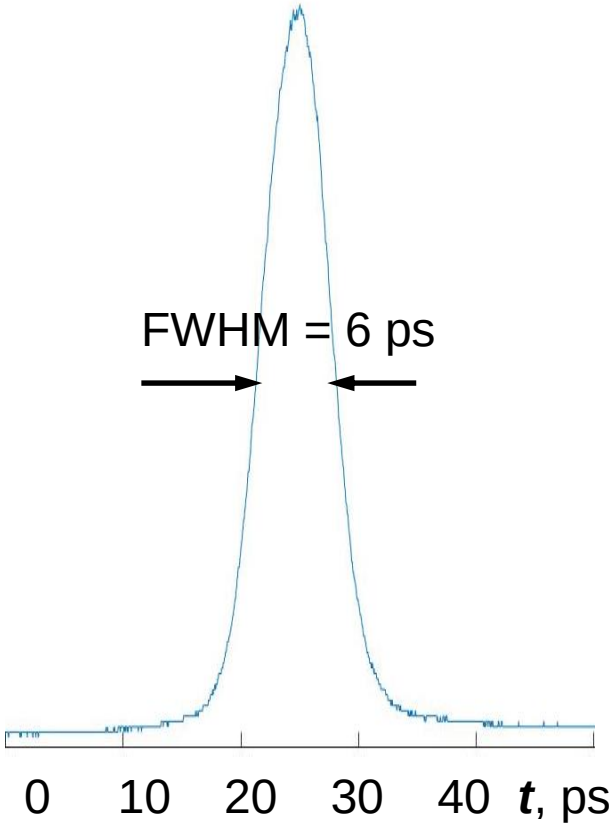
Experimental Results (Siberia-2)

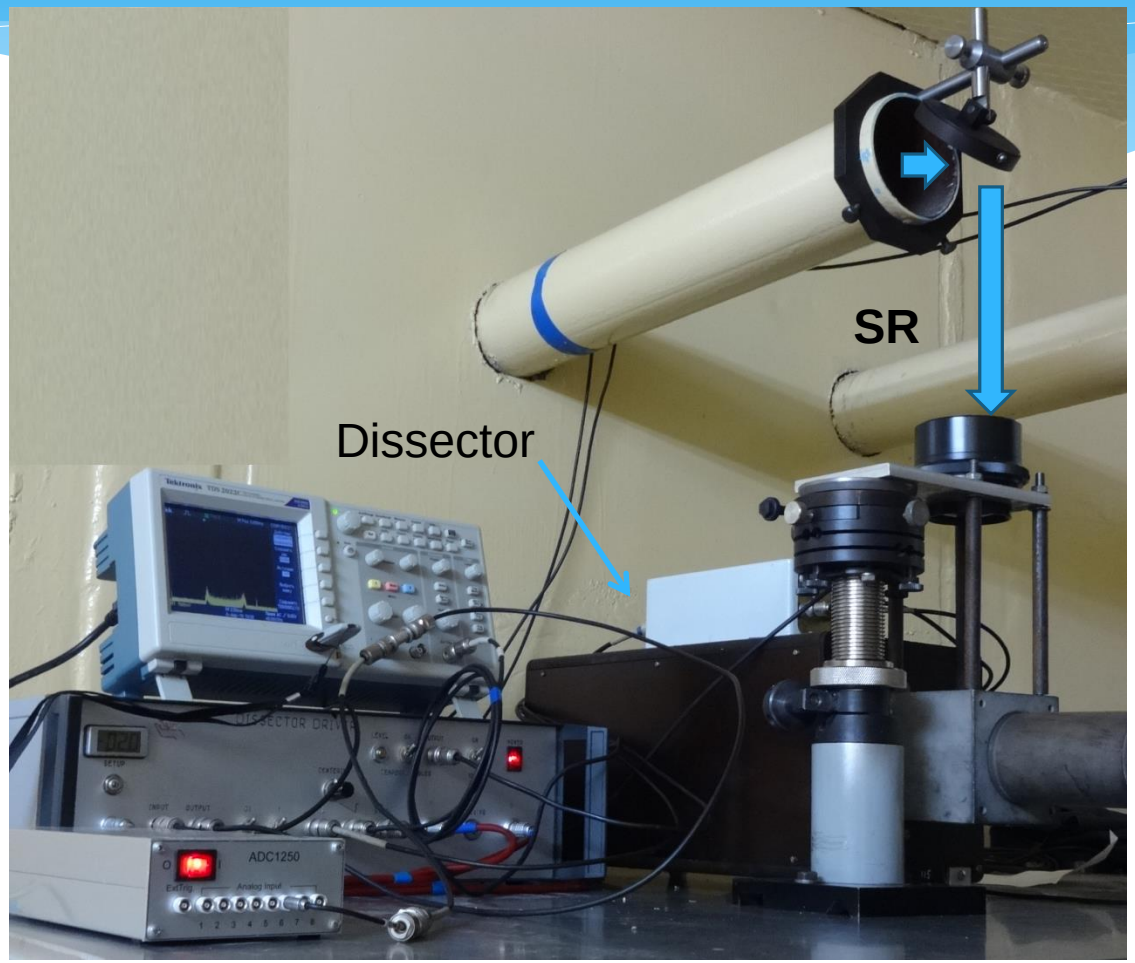


Bunch length *vs* bunch current measured by “old” dissector and streak camera PS-1/S1

Experimental Results: Application of the new Dissector at Damping Ring

Damping Ring, E = 450 MeV,
C = 28 m, ν_{RF} = 700 MHz





Experimental results (Damping Ring)