Progress towards realization of the Nuclotron-NICA project

A.Sidorin, on behalf of the team

PP PAC, JINR, Dubna, 16 January 2017

Contents

- **Nuclotron operation**
- **Preparation for BM@N**
- **HILac commissioning**
- **Preparation for Booster construction**
- **Progress in NICA collider design**

Nuclotron operation

- **Statistics of runs #52, 53**
- **Machine development**
- **Nearest plans**

Statistics of operation

Run #52 “technological” 02.06 - 30.06.2016 (650 h)

RFQ fore-injector commissioning (first stage)

Optimization of SPI regimes

Test of polarimeters:
after LU-20, at Internal target, at extracted beam

Test of the Booster power supply prototypes at SC load

Test of White Rabbit segment at BM@N

Improvement of beam line current stability

Statistics of operation

Run #53 26.10-25.12.2016 (1400 h)

SPI optimization, polarimetry

Spin physics experiments

Test of BM@N and MPD elements

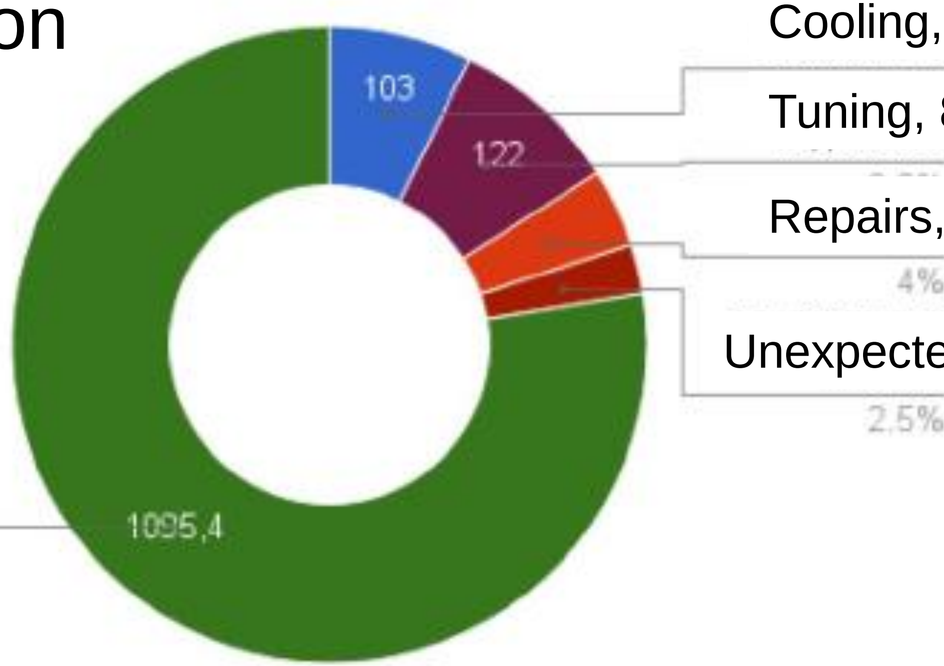
Test of the Booster power supply prototypes
with beam acceleration

Stochastic cooling, diagnostics, adiabatic capture

Run #53

A.Alfeev

Time distribution



Cooling, 7.3%

Tuning, 8.7%

Repairs, 4%

Unexpected losses, 2.5%

Machine development NICA R&D (24%), Experiments

77.6%

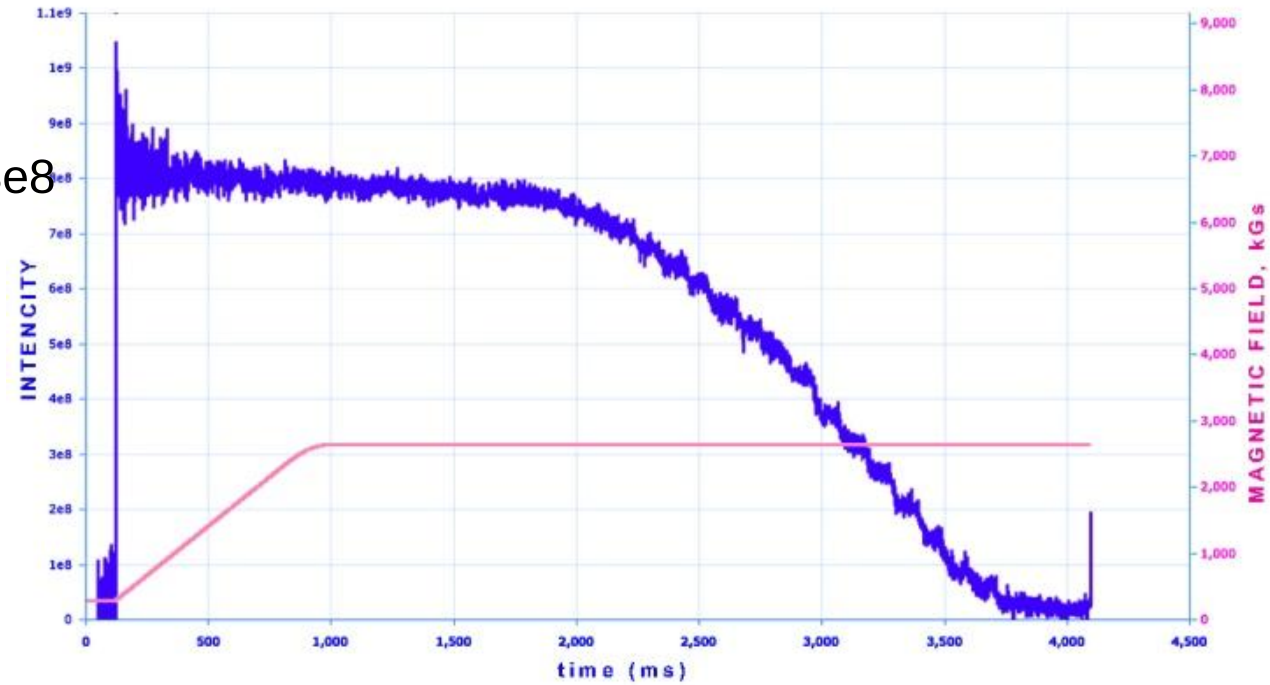
Polarized, unpolarized deuterons, maximum energy of extracted beam 4.6 GeV/u

Run #53

Routine operation of SPI and new fore-injector

Polarized deuteron acceleration:

Intensity 2÷5*10^8

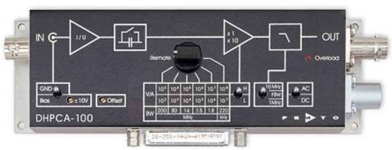


Deuteron Spin Structure experiment, internal target

Diagnostics: Q-meter

V.Volkov
E.Gorbachev
D.Monakhov

Amplifiers,
Filters,
Detectors



FlexRIO
Digitizer
ADC 18 bit
input

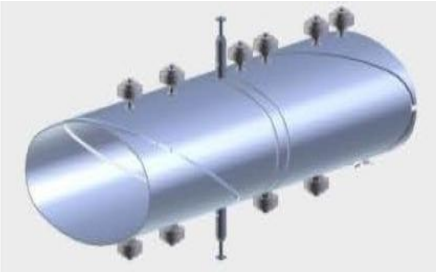
FlexRIO
Digitizer
DAC 14 bit
output

RF Amplifier AR 800A3A

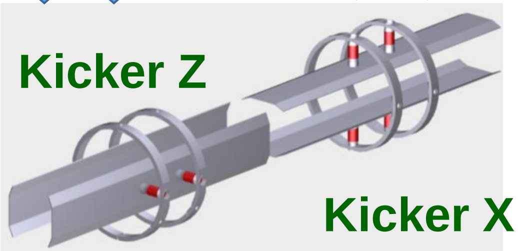
NI PXIe-1085 crate (PXI system)
with modules:

- FlexRIO Digitizer (developed at JINR)
- NI PXIe-7975R FlexRIO module
- PXI-6733 High-Speed Analog Outputs
- NI PXIe-8135 2.3 GHz Quad-Core PXI Express Controller

Impedance
transformers

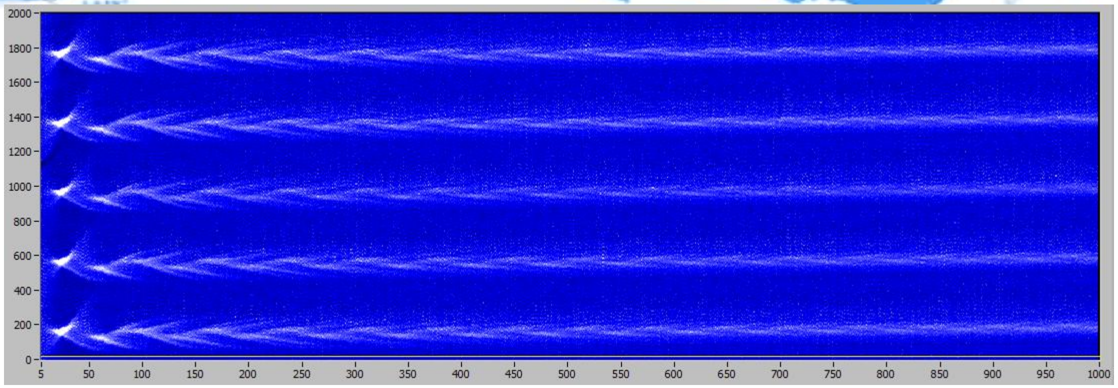


Pick-up electrodes
X and Z

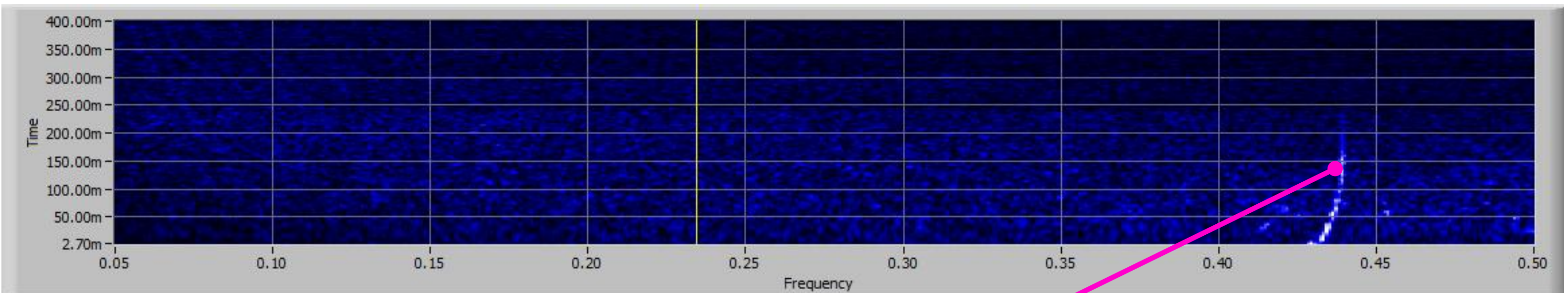


Q-meter: Measurements

V.Volkov
E.Gorbachev
D.Monakhov

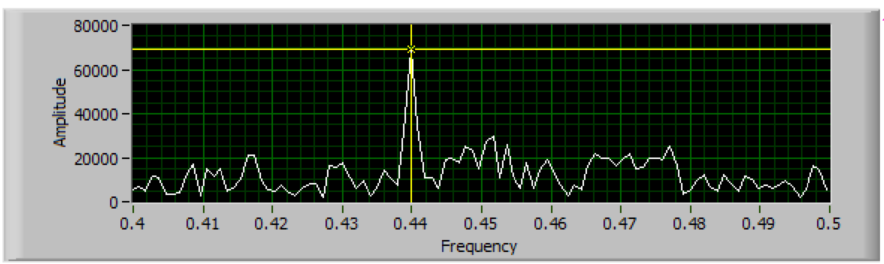


Σ signal after injection, 5 bunches



Q measurements

Δ spectrogram, X plane



Δ spectrum, X plane

Run #53

Q-meter

V.Volkov
E.Gorbachev
D.Monakhov

RF and Pick-up signal synchronization

Single-bunch excitation and measurements

3D (Direct Diode Detection)

Sensitivity down to 1e8 elementary charges

Accuracy $\Delta Q < 0.0025$

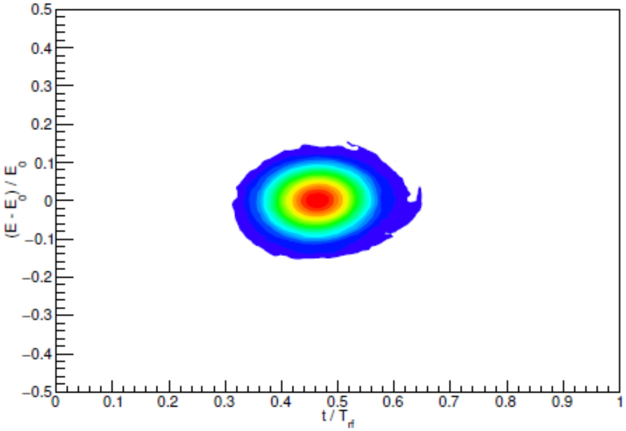
Diagnostic kicker

Diagnostics: bunch tomography

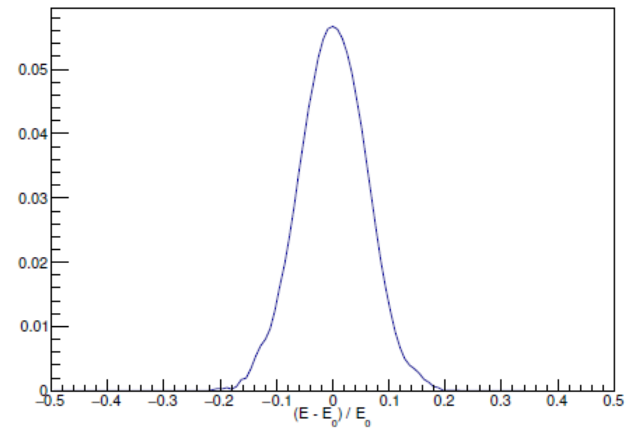
V.Zhabitsky

The particle distribution in the longitudinal phase plane

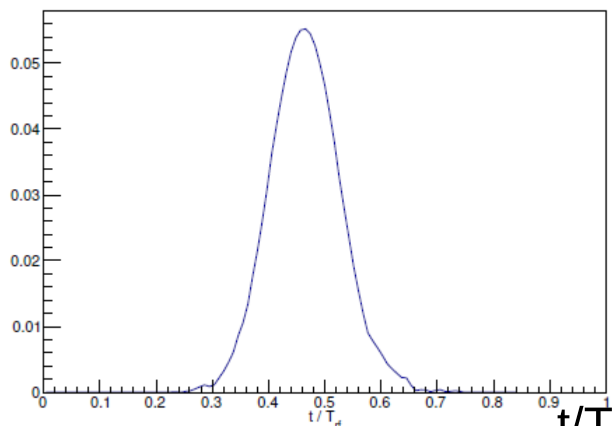
$\Delta E/E$



$t_{\rm init} = 40$ ms



$\sigma_{\rm E} = 0.06$



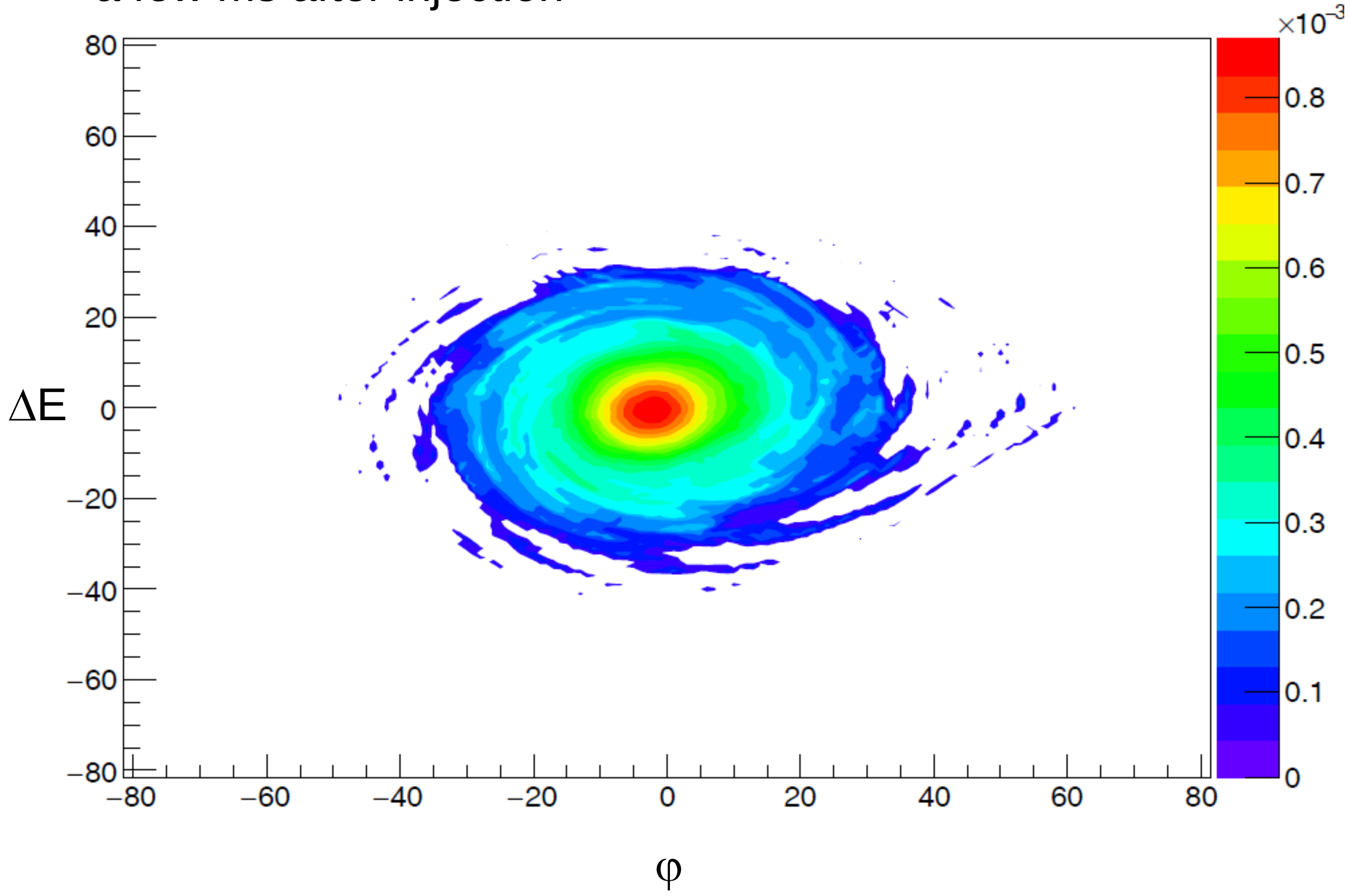
t/T_{RF}

$\sigma_{\rm t}/T_{\rm rf} = 0.063$

Diagnostics: bunch tomography

V.Zhabitsky

The particle distribution in the longitudinal phase plane
a few ms after injection



Plans

2017:

Preparation for the Booster construction
Start of BM@N experiment

Two Nuclotron runs
-February – March
(SPI - polarized d (p), laser source Li, C)

-November – December
(KRION source, Kr, Ar)

2018:

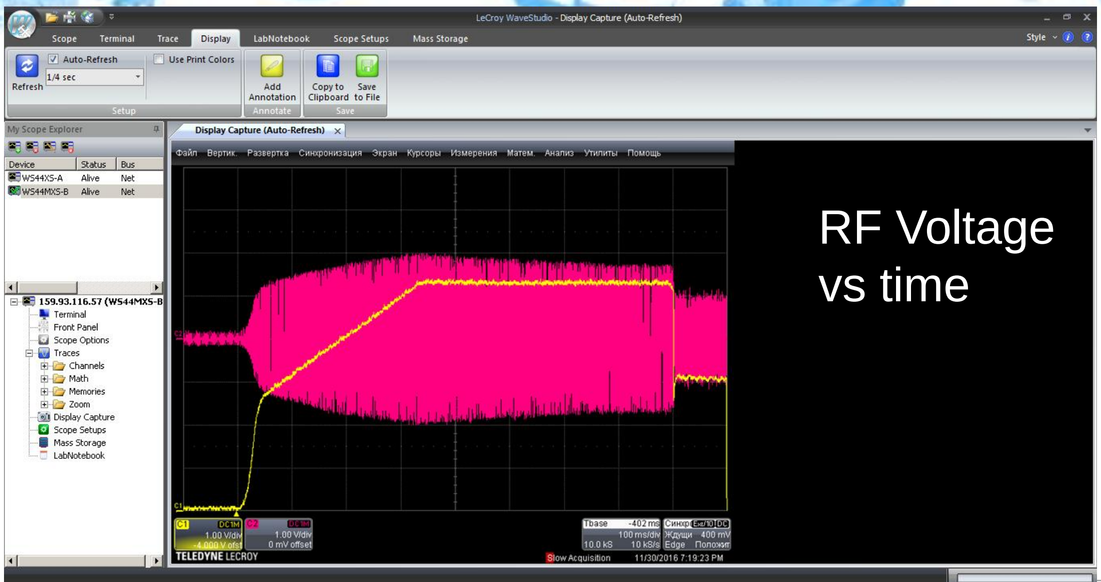
Booster assembly and commissioning

Preparation for BM@N

- Installation of buncher at LU-20 fore-injector
  (under RF test at ITEP)
- Adiabatic capture
- Improvement of the beam line current stability
- Test of White Rabbit (R&D for NICA synchronization system)

Adiabatic capture

A.Eliseev,
O.Brovko,
V.Slepnev

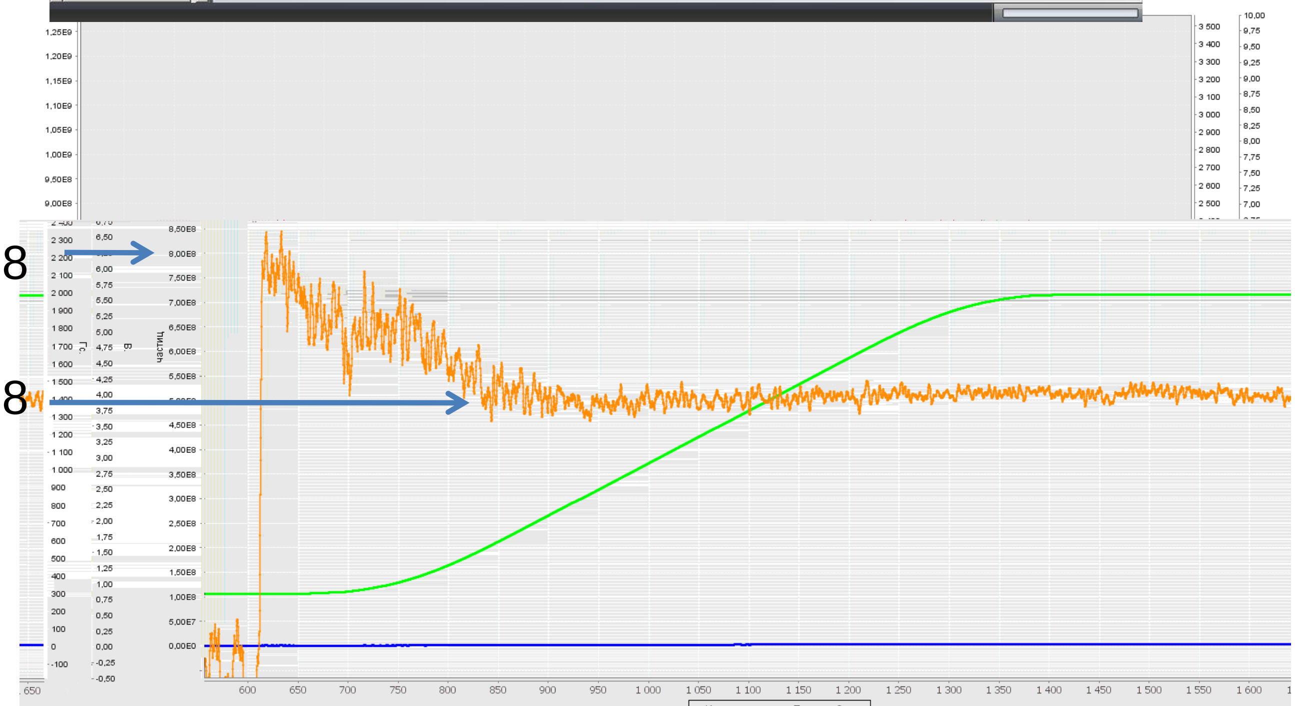


RF Voltage vs time

Capture efficiency ~ 70%

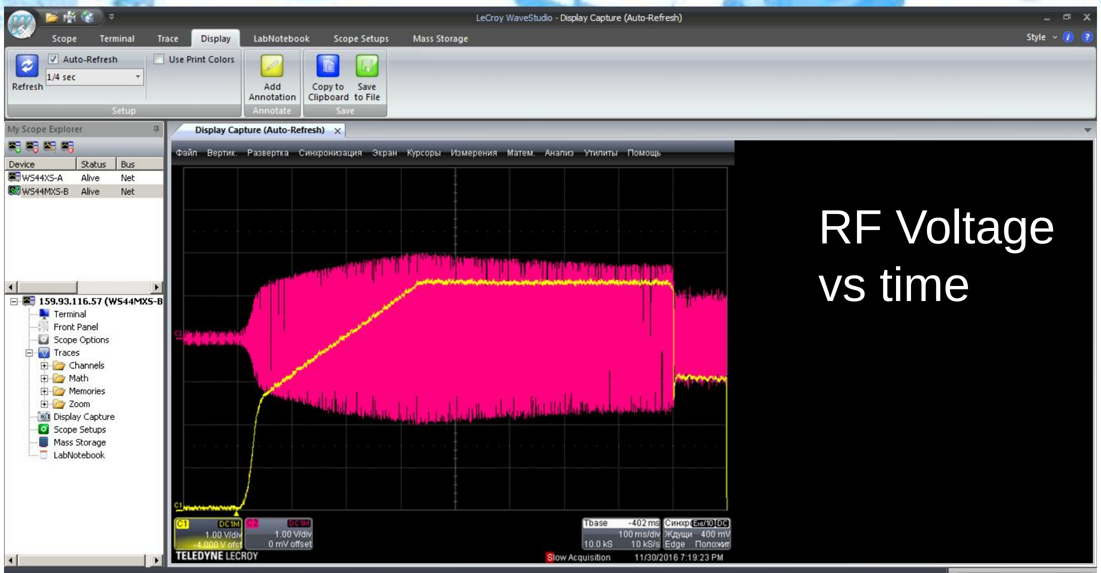
8e8

6e8



Adiabatic capture

A.Eliseev,
O.Brovko,
V.Slepnev

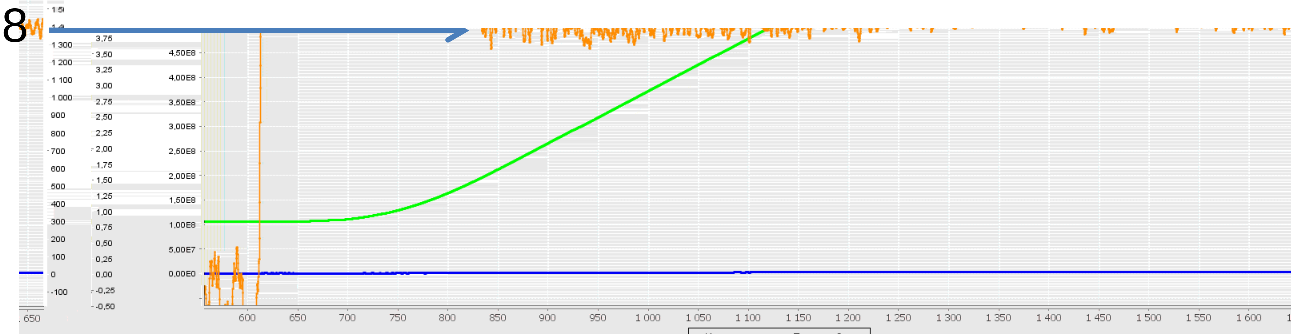


Capture efficiency ~ 70%

Routine operation during a few shifts with injection at magnetic field plateau + adiabatic capture

8e8

6e8



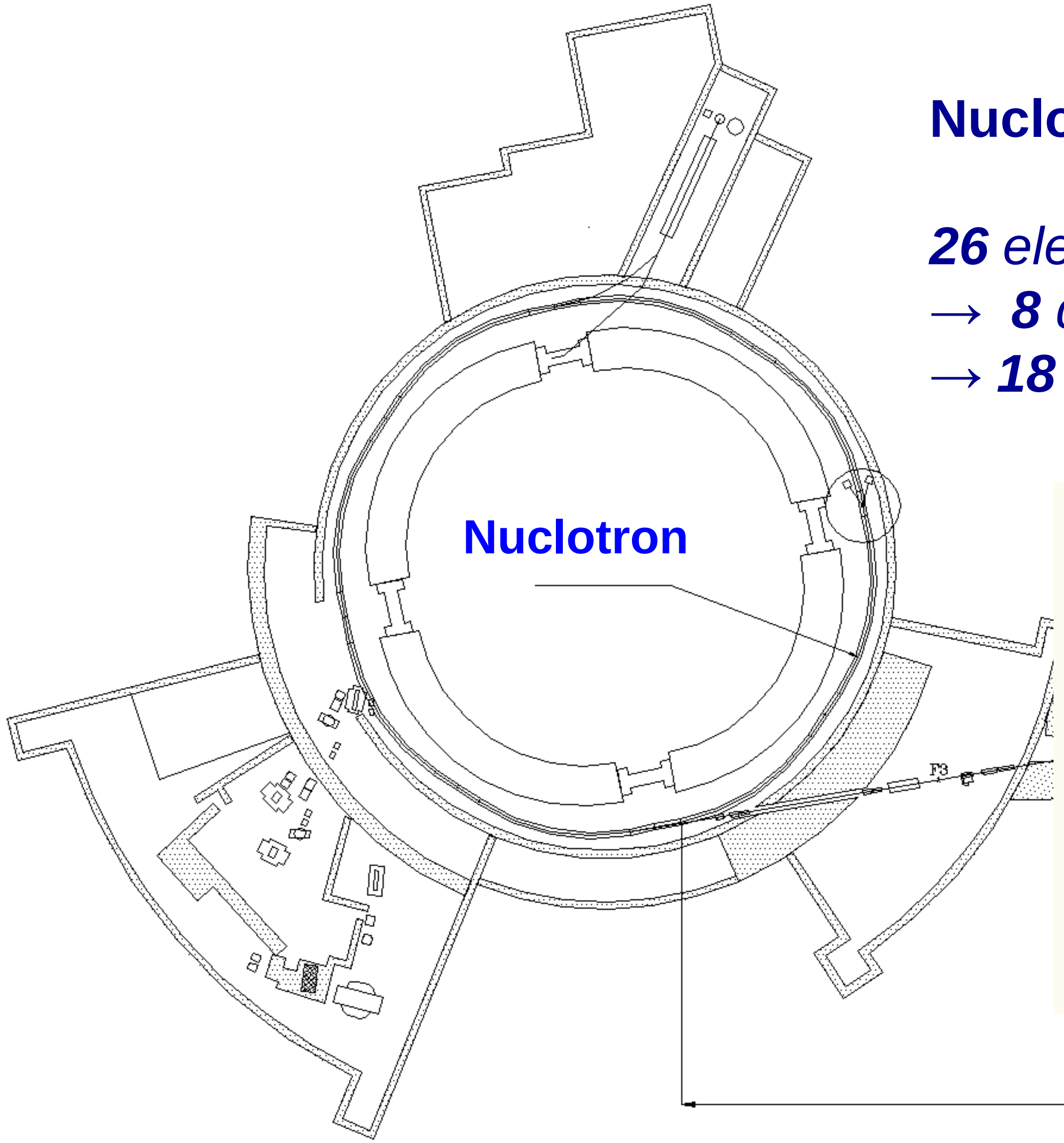
Preparation for BM@N, beam lines

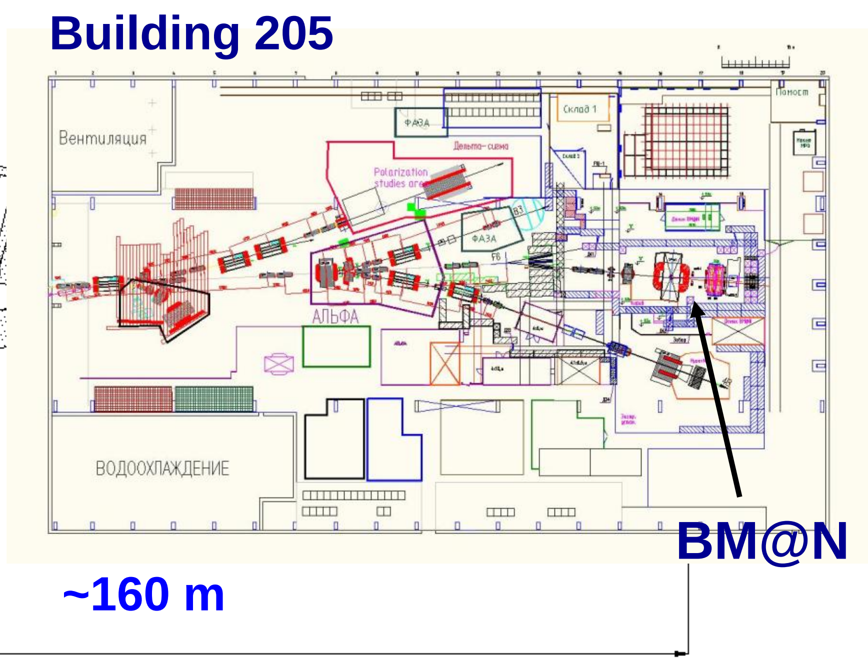
Nuclotron to BM@N beam line:

26 *elements of magnetic optics:*

→ ***8*** *dipole magnets*

→ ***18*** *quadruple lenses*





Improvement of the beam line current stability

V.Karpinsky

Run #52

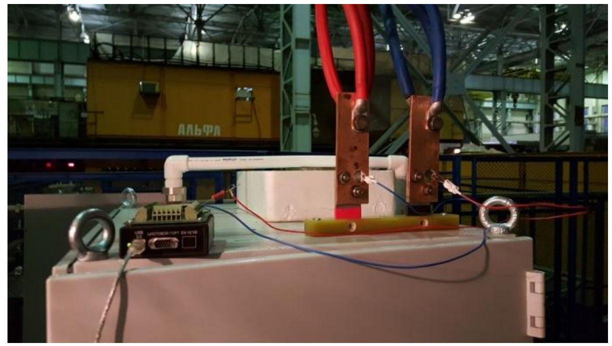
Prototype of the current control unit

Long-range relative current stability of 50 КВ source **is better than 10^{-3}.**
Ripple at 300 Hz 0.5…1% (depending on output current). (Run #52)

New source at the beam line

V.Karpinsky

Run #53

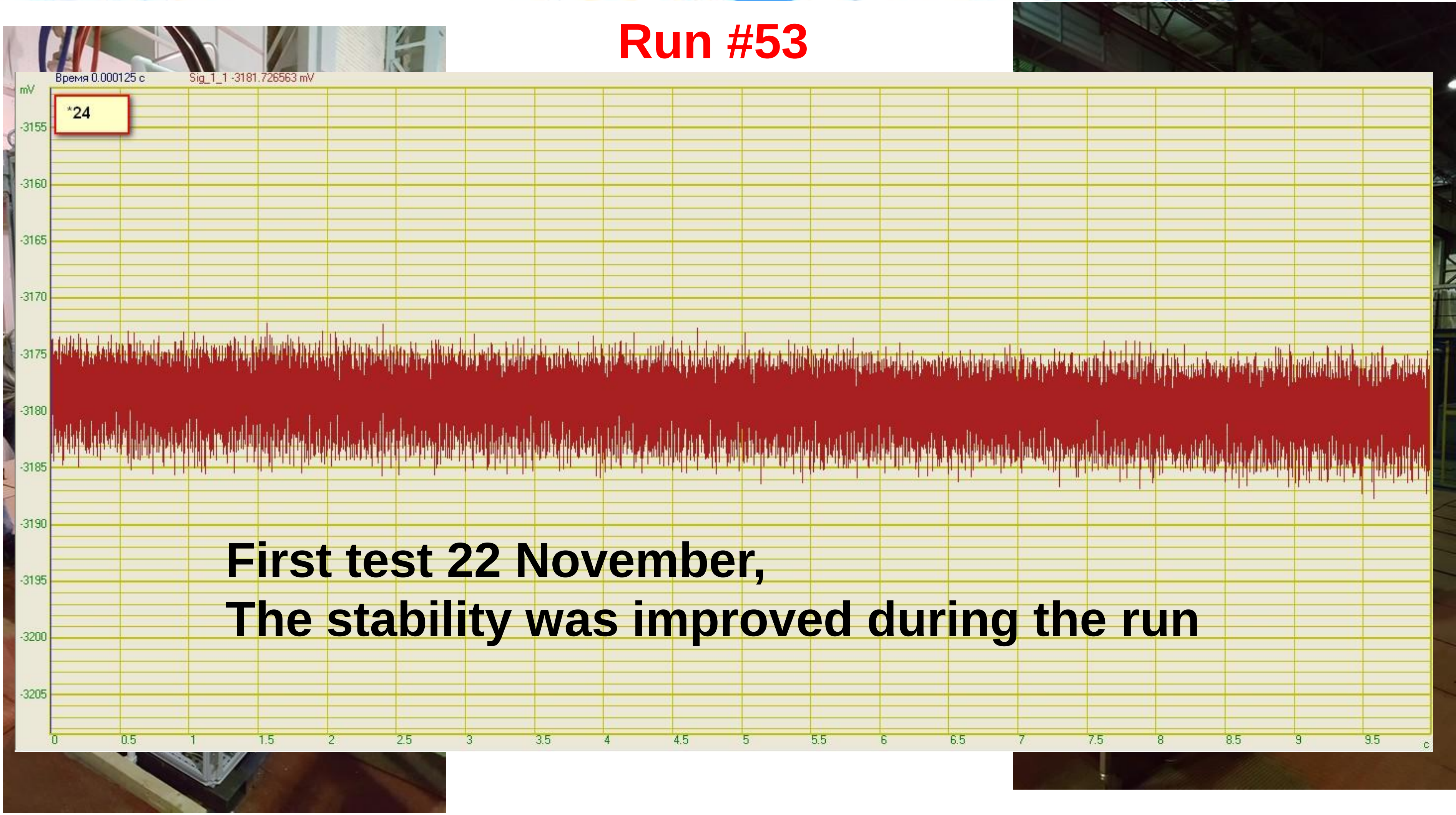


BM@N dipole magnet
(СП 57)

ИП-600-180 **LM Invertor (Moscow)**
600 A, 180 V, ripple 10^{-4}

New source at the beam line

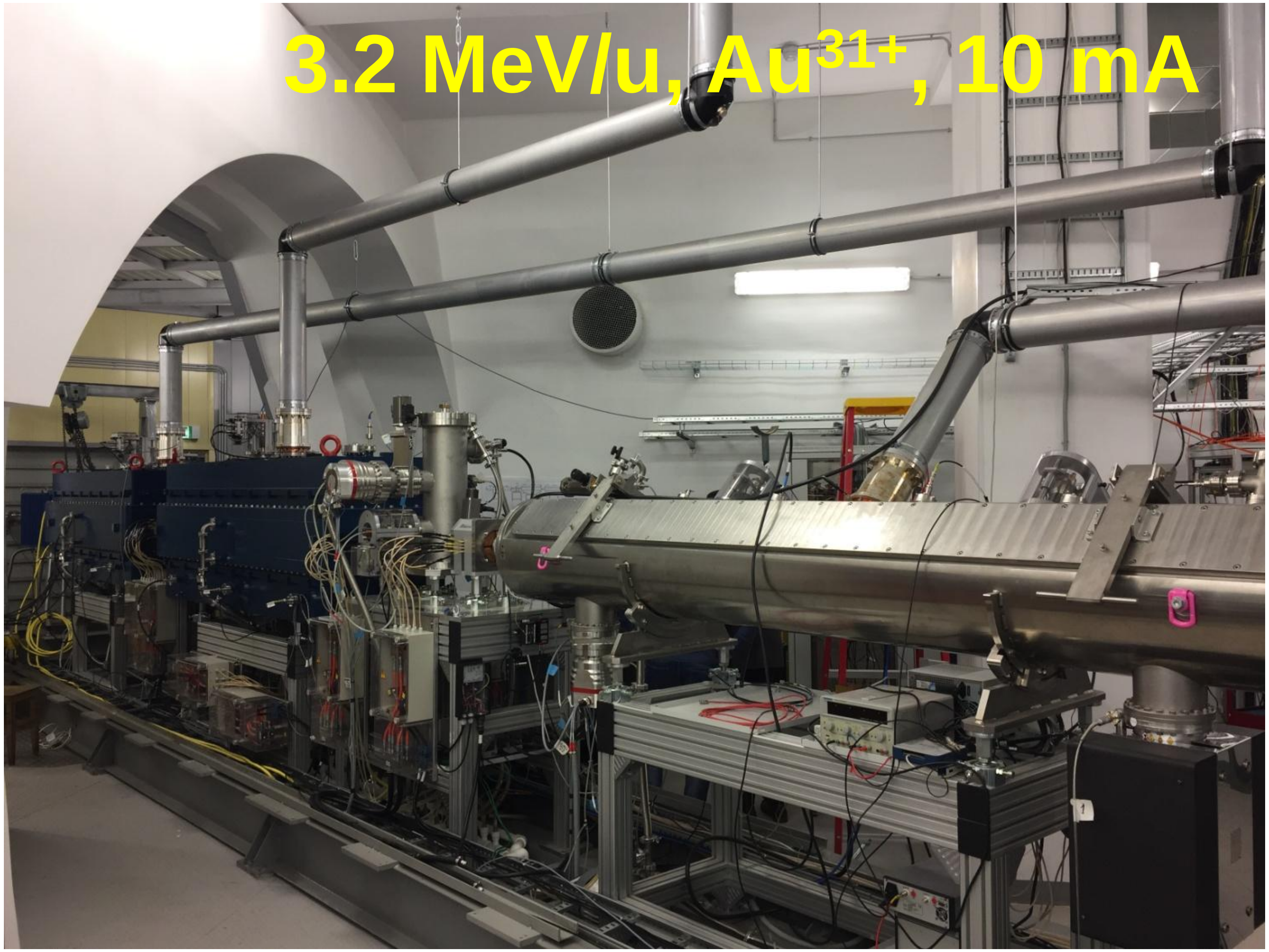
Run #53



ИП-600-180 **LM Invertor (Moscow)**
600 A, 180 V, ripple 10^{-4}

HILac commissioning

V.Butenko,
A.Govorov,
V.Monchinsky



October 2016 –
carbon beam from laser source was accelerated up to design energy

Acceleration structure
BEVATECH (Germany)

Power amplifier
TOMCO (Australia)

Low level RF
ITEP

Diagnostics
INR RAS

Vacuum system
Vaccum Praha

Building preparation,
Ion source,
LEBT,
Lens power supply, …
JINR

Preparation for Booster construction

- **Status of manufacturing the magnets**
- **Power supply system**

Design of the NICA booster magnets

The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the NICA Booster.

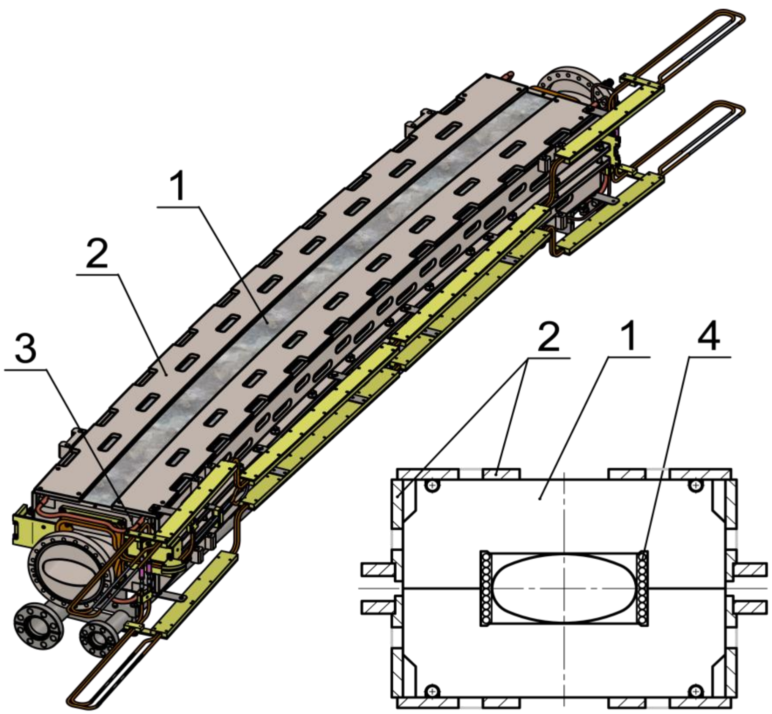


Figure 1: View of the dipole magnet. 1 – lamination, 2 - side plate, 3 - end plate, 4 – SC coil.

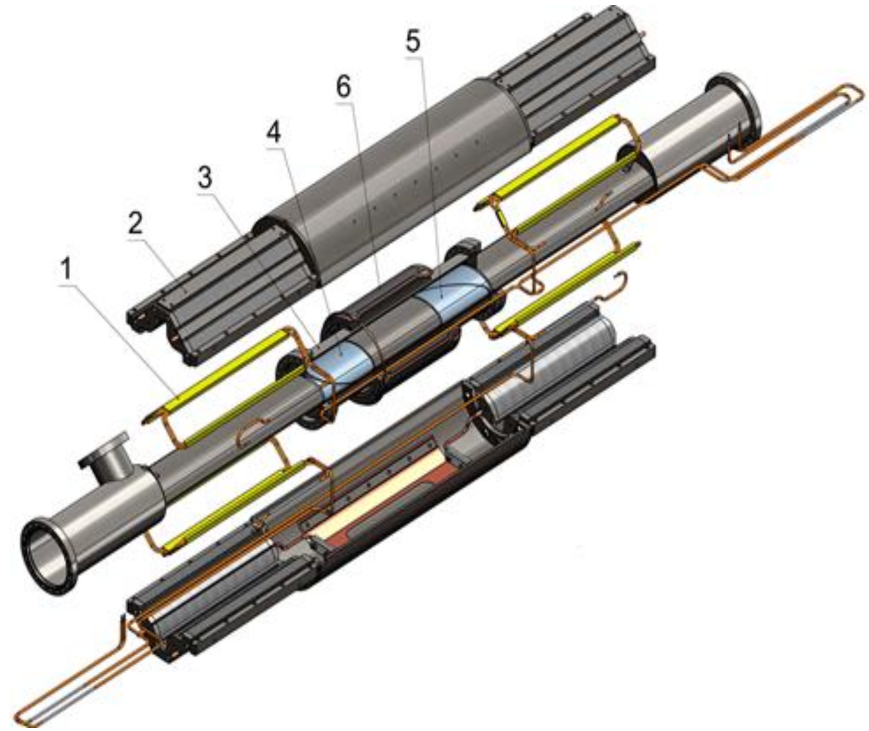


Figure 2: View of the doublet of the lenses. 1 – half-coil, 2 – half-yoke, 3 – beam pipe, 4, 5 – beam position monitors, corrector magnet

Main characteristics of the magnets

Characteristic	Dipole	Lens
Number of magnets	40	48
Max. magnetic field (gradient)	1.8 T	21.5 T/m
Effective magnetic length	2.2 m	0.47 m
Beam pipe aperture (h/v)	128 mm/ 65 mm	
Radius of curvature	14.09 m	-
Overall weight	1030 kg	110 kg

Facility for SC Magnets Assembling and Cryogenic Tests

H.Khodzhibagiyan
A.Kostromin

The facility for assembling and cryogenic tests of superconducting magnets for NICA and FAIR projects was commissioned 28 November 2016.

Status of Manufacturing the Magnets

H.Khodzhibagiyan
A.Kostromin

- Yoke of the Dipole Magnets – 27 or 68%
  Coil of the Dipole Magnets - 16 or 40%
- Yoke of the Quadrupole Magnets – 48 or 100%
  Coil of the Quadrupole Magnets - 38 or 79%
- Yoke of the Corrector Magnets – 8 or 25%
  Coil of the Corrector Magnets - 2 or 6%
- Cryostat for magnets – 71 or 100%

We plan to have 75% magnets at the end of 2017

The Booster power supply system

V.Karpinsky

Consists of three powerful units:

-**Main source** 180 V, 12 kA
-**Additional sources for quadrupole lenses**
25 V, 400 A and 15 V, 300 A

Three companies participate in the tender:

-**LM Invertor (Moscow)**
-**EVPUas (Slovak Republic)**
-**Frako-term (Poland)**

The Booster power supply system

V.Karpinsky

Prototypes were tested

Run #52: Operation on SC load

Run #53: Beam acceleration:

-**LM Invertor**

-**EVPUas**

Frako-term unit is transferred

to Facility for SC Magnets Assembling and Cryogenic Tests

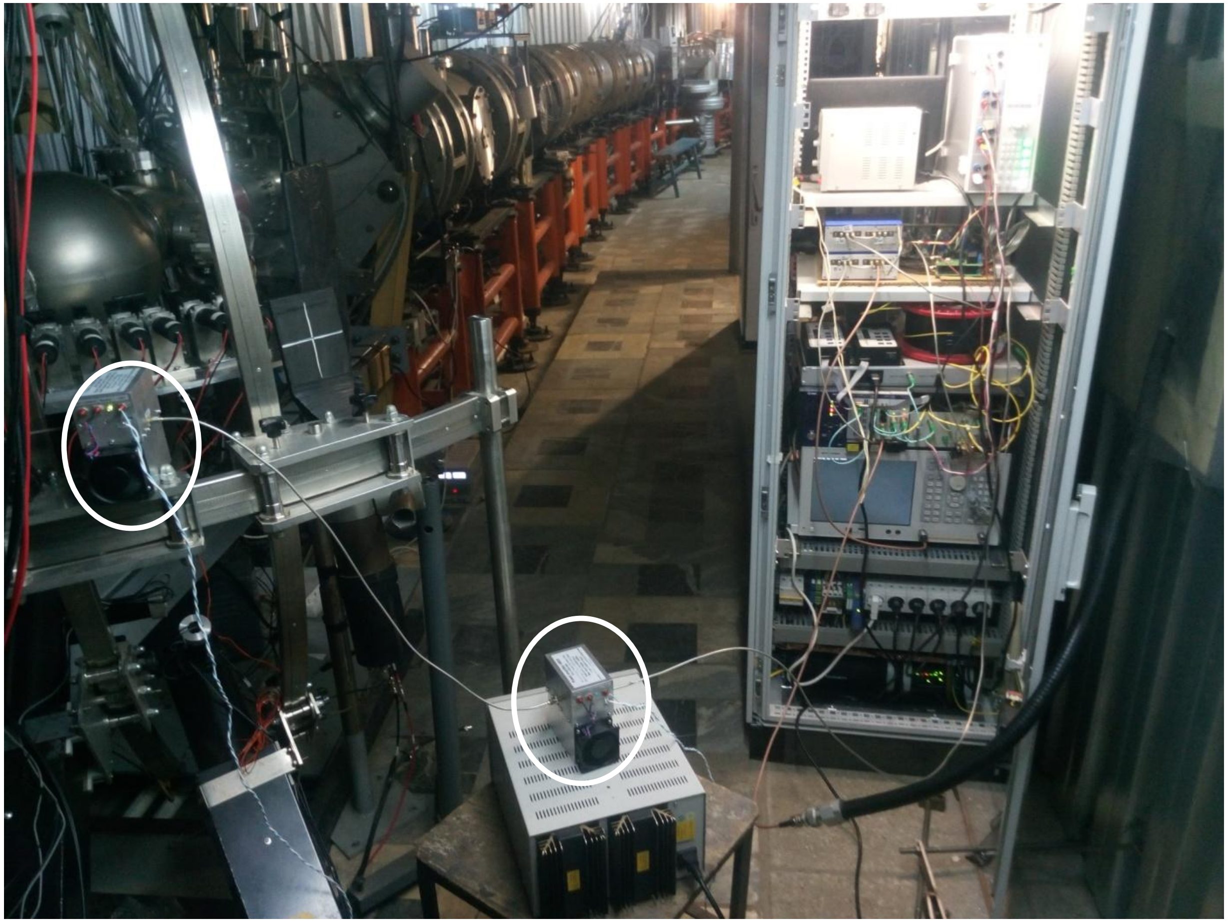
Progress in the NICA collider design

- R&D for stochastic cooling
- NICA synchronization system (Test at BM@N)
- Dynamics optimization

Stochastic cooling (Run #53)

I.Gorelyshev,
N.Shurkhno

Prototypes of amplifiers



2 - 4 GHz
30 W
$\Delta\varphi < \pm 5^0$

Sukhoy Gomel State University
Belorussia

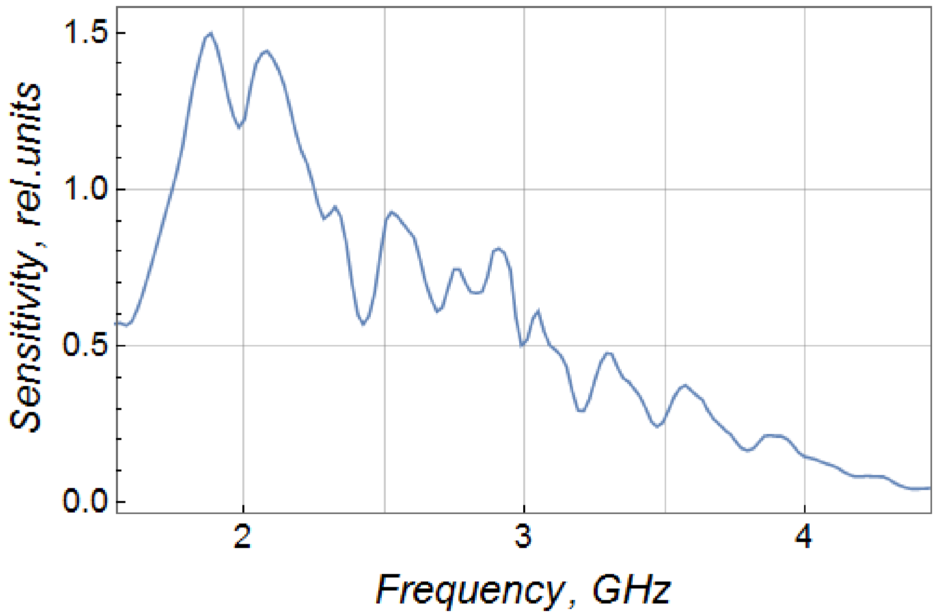
Stochastic cooling

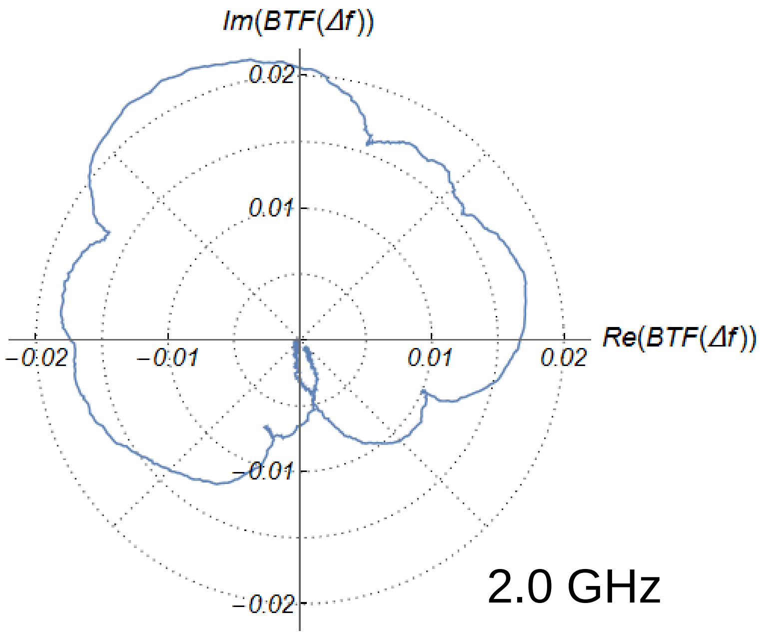
I.Gorelyshev,
N.Shurkhno

2.5 GeV/u, beam intensity ~4e8,
Magnetic field plateau duration 30 – 300 s

Time-of-flight cooling

Pick-up sensitivity





2.0 GHz

One of 8 plates, 200 harmonics

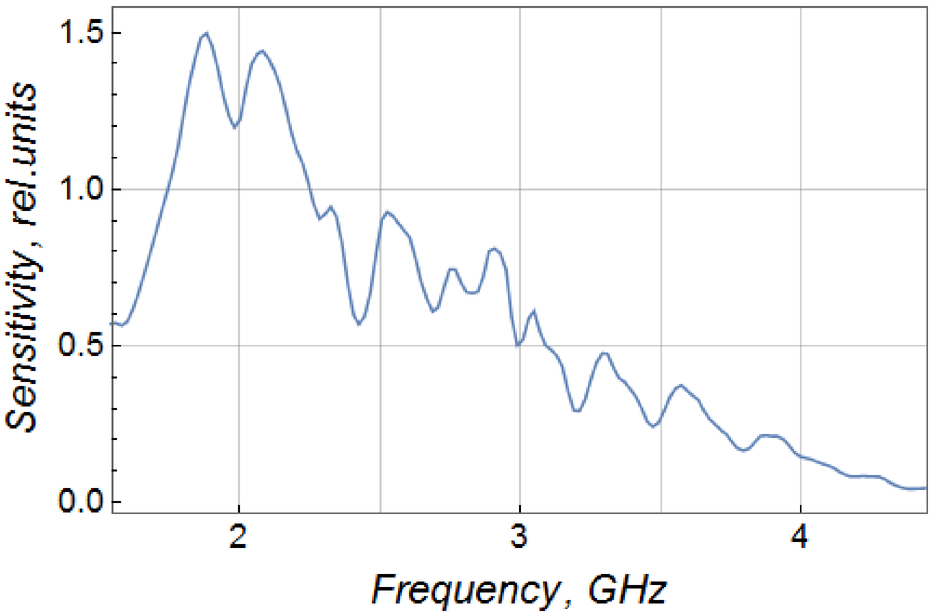
Stochastic cooling

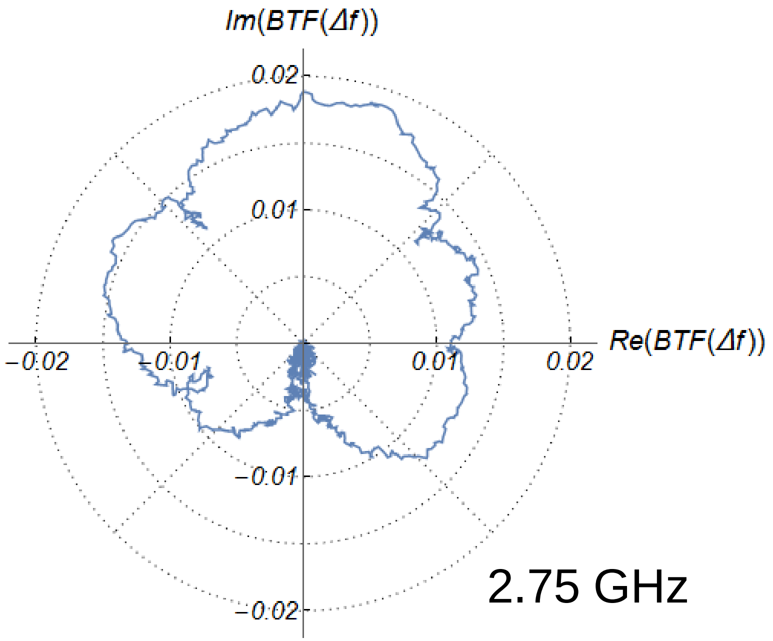
I.Gorelyshev,
N.Shurkhno

2.5 GeV/u, beam intensity ~4e8,
Magnetic field plateau duration 30 – 300 s

Time-of-flight cooling

Pick-up sensitivity





2.75 GHz

One of 8 plates, 200 harmonics

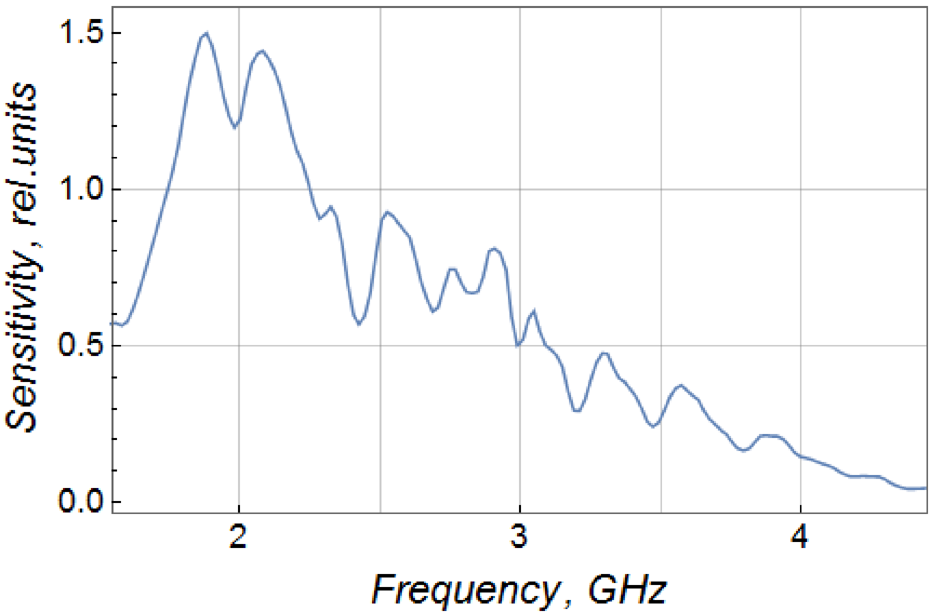
Stochastic cooling

I.Gorelyshev,
N.Shurkhno

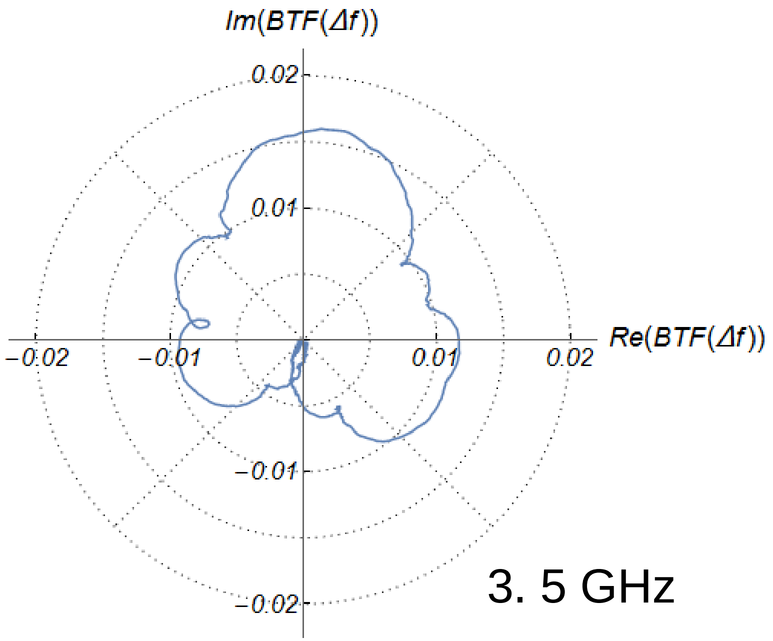
2.5 GeV/u, beam intensity ~4e8,
Magnetic field plateau duration 30 – 300 s

Time-of-flight cooling

Pick-up sensitivity



One of 8 plates, 200 harmonics



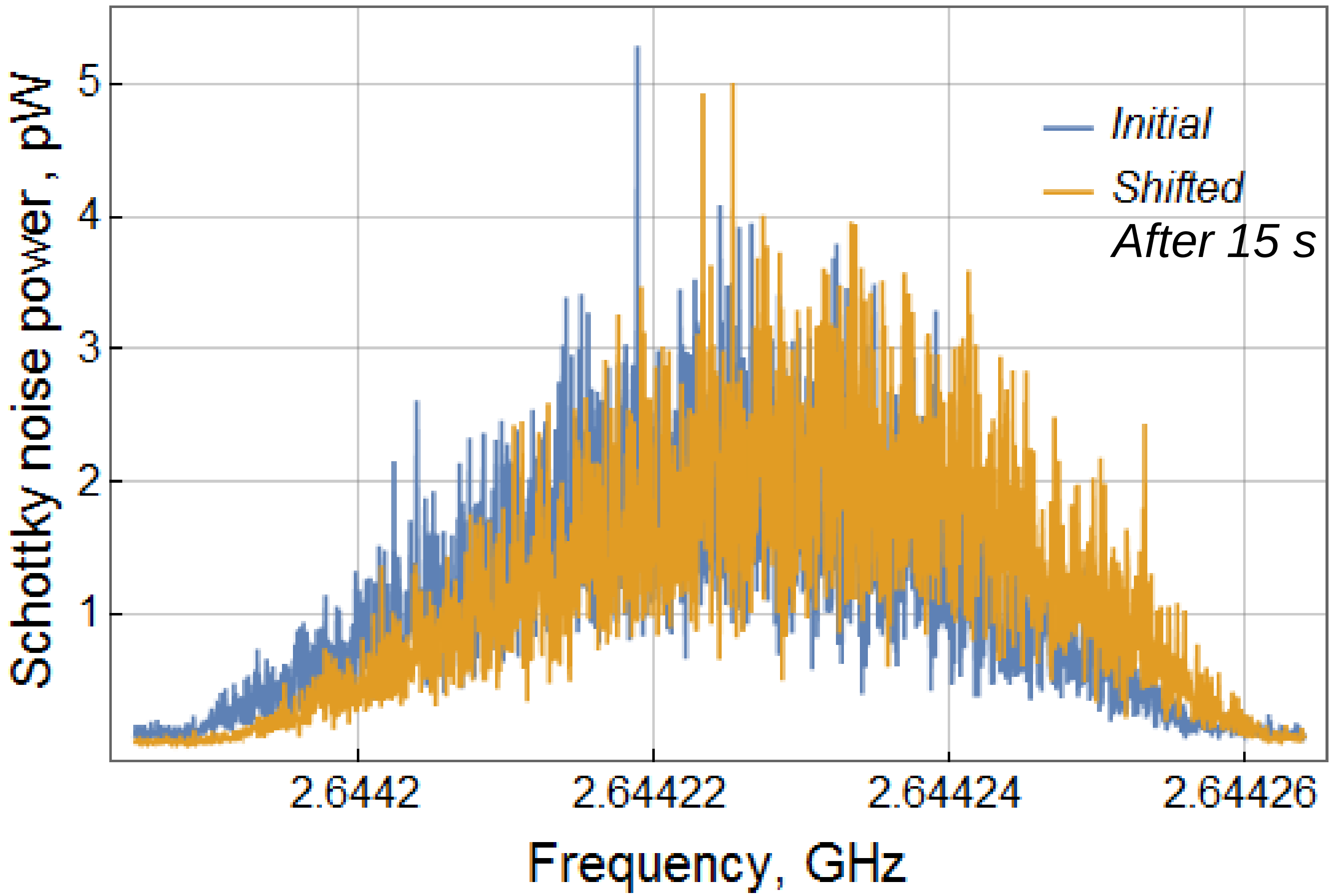
3. 5 GHz

41 harmonics were measured

Stochastic cooling

I.Gorelyshev,
N.Shurkhno

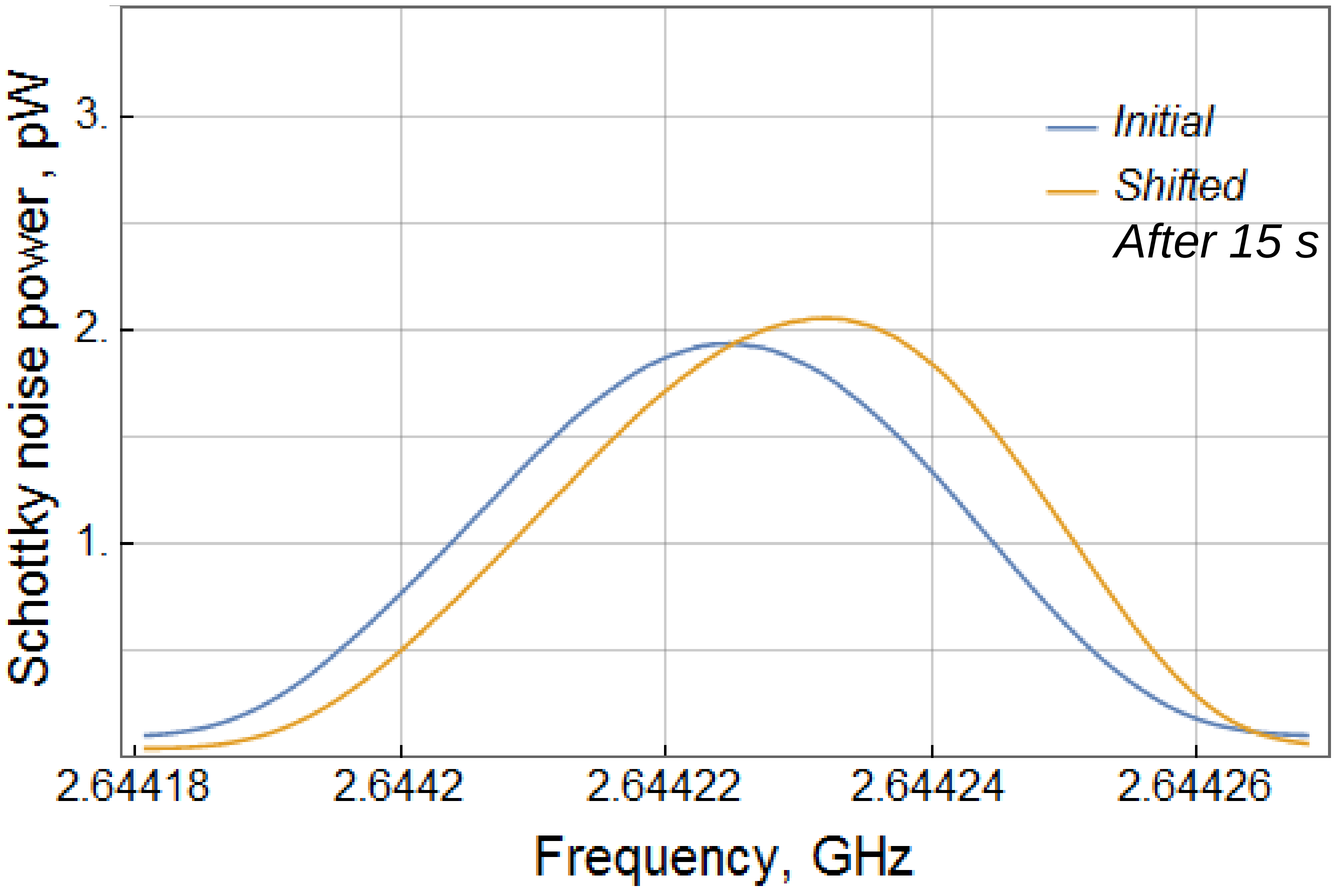
Initial spectrum



Stochastic cooling

I.Gorelyshev,
N.Shurkhno

Smoothed (Gaussian filter)



The gain << optimal

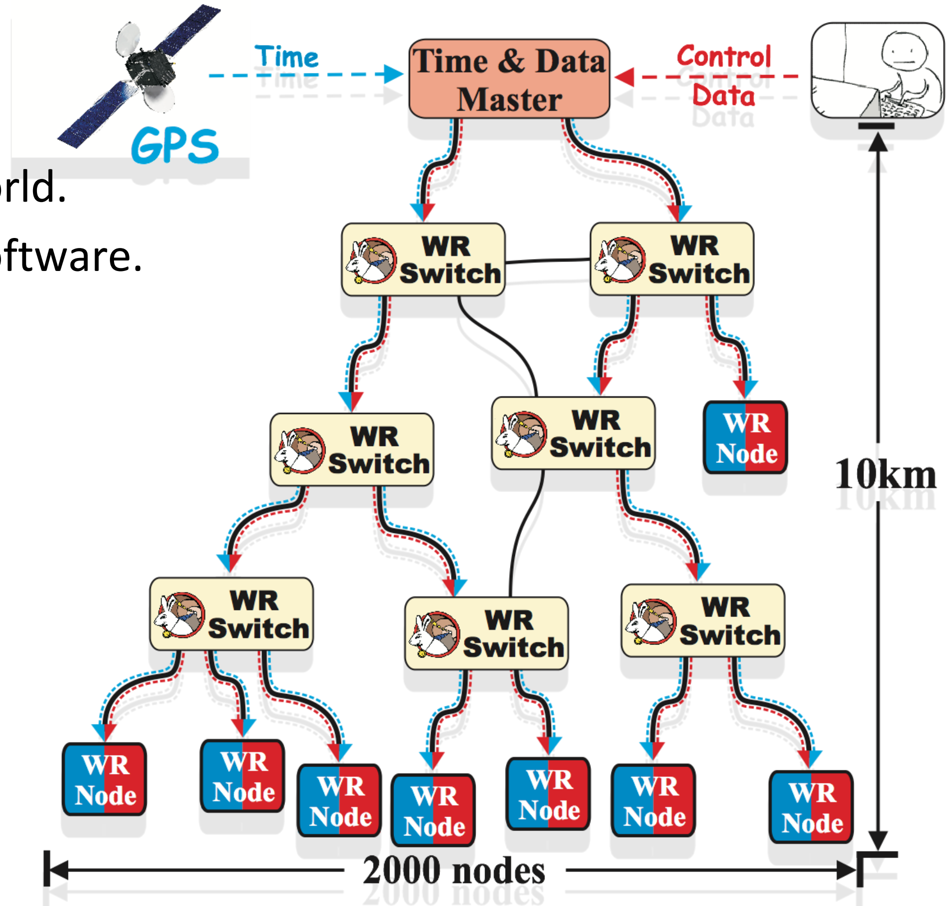
Diffusion is negligible

Investigations of
coherent term
(friction force)
as function of
the system delay
and beam energy

NICA synchronization system

V.Slepnev

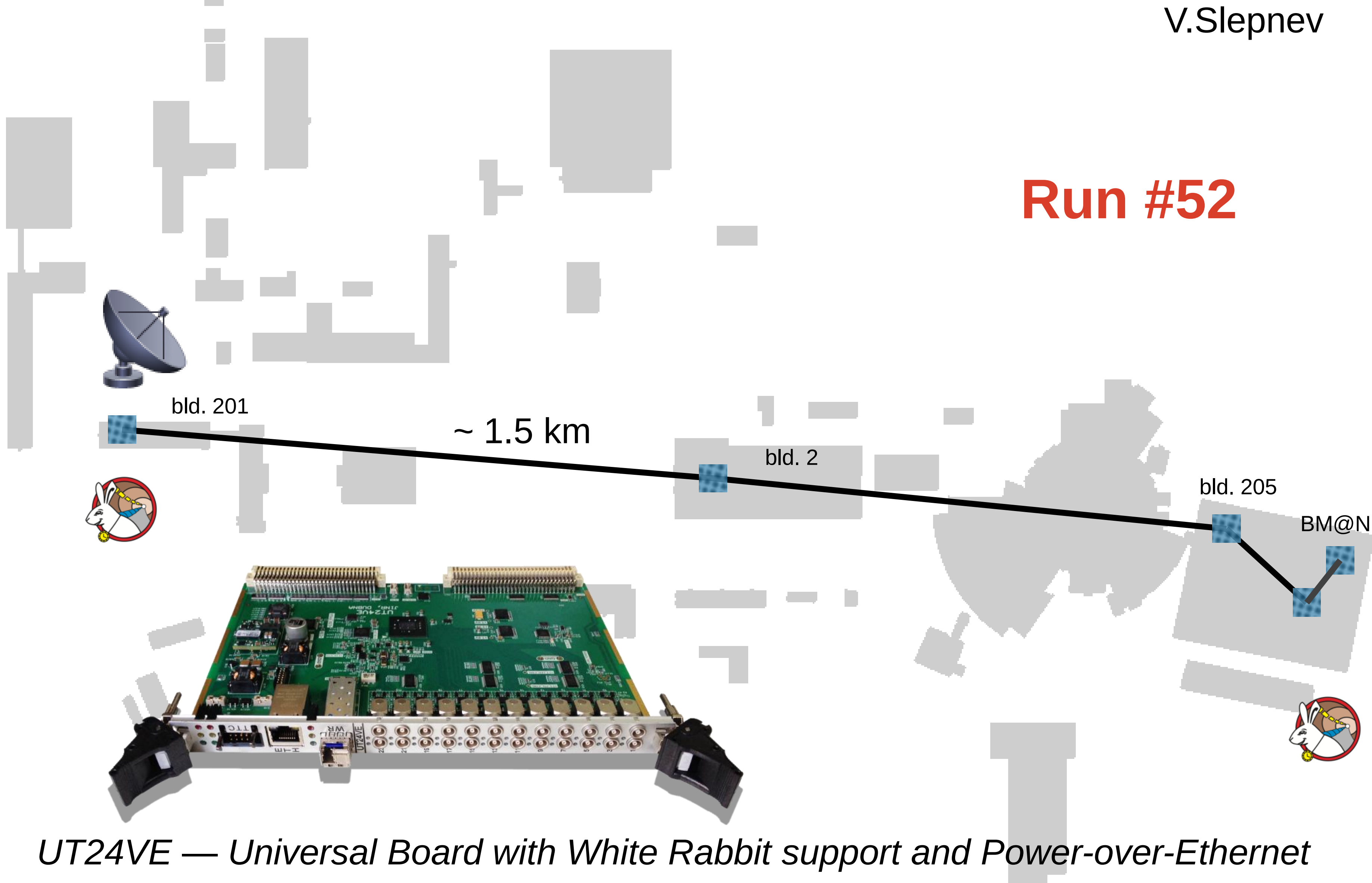
White Rabbit project was started to develop next generation control and timing network for CERN.
Later **FAIR** facility joined the project.
Currently, the project is a collaboration of many institutes and companies around the world.
The project is both, open hardware and opens software.
The projects aims at creating an Ethernet-based network with:
low-latency,
deterministic data delivery and network-wide,
transparent,
high-accuracy timing distribution.
The White Rabbit Network (WRN) is based on existing standards, namely Ethernet, Synchronous Ethernet and PTP.



Sub-nanosecond accuracy

Synchronization: test at BM@N

V.Slepnev



UT24VE — Universal Board with White Rabbit support and Power-over-Ethernet

Dynamics optimization

I.Meshkov,
B.Levichev,
T.Kulevoy

At Russian Particle Accelerator Conference RuPAC 2016
25 of November was provided special satellite meeting
dedicated to particle dynamics in the NICA collider.
As result a distributed scientific group
including specialists from **JINR, BINP, ITEP**
was established

Detail plan of nearest works

23.12.2016

Ближайшие задачи исследовательских и проектных работ по ускорительному комплексу NICA

1. Расчётно-аналитические задачи динамики пучков ионов в Коллайдере NICA

Закончить формирование оптики ФОДО-503м [1)]
Выбор рабочей точки (см. п. 5.2 также). [1) 2) 3)]
Схема коррекции хроматичности. [1) 2) 3)]
Расчет ДА с учетом [1) 2) 3)]
4.1. работа системы коррекции хроматичности [1) 2) 3)]
4.2. ошибок параметров элементов [1) 2) 3)]
4.3. нелинейностей краевых полей квадрупольных линз [1) 2) 3)]
4.4. эффектов пространственного заряда сгустка и эффектов встречи пучков. [2) 4)]
Компенсация влияния на ДА нелинейностей краевых полей с помощью
5.1. октупольных корректоров [1) 2) 3)]
5.2. выбора рабочей точки [1) 2) 3)]
5.3. увеличения β^* до 0.6 м [1) 2) 3)]
Влияние на работу MPD перехода с β^* = 0.35 м (исходный проект) на β^* = 0.6 м[1)], влияние на работу MPD распределения светимости по длине участка встречи L(s)
Влияние работы ВЧ-системы на динамику частиц в Коллайдере [5) ?) 8)]
Перенастройка β^* с 2.0 м (режим накопления) на 0.35 и 0.6 м (режим встречных пучков); [1) 2) 3)]
Коррекция x-y связи при помощи skew-квадруполей в прямолинейных секциях[1) 2) 3)]
Локализация потерь перезаряженных и рассеянных частиц [1) ?)]
Устойчивость интенсивных ионных пучков в Коллайдере [4) ?)] и импеданс вакуумной камеры Коллайдера [?)]
Когерентные неустойчивости[3), ?)] и feed-back систем [?)]
Специфика динамики частиц при использовании систем охлаждения [1) 6)]
Долговременная стабильность динамики частиц и светимости в Коллайдере [4) 6) ?)]
Вакуум в Коллайдере и проблема электронных облаков [6) 7) 8) ?)]
Поляризованные пучки протонов и дейтронов в Коллайдере [9) ?)]

2. Инженерно-физические и технические задачи ускорительного комплекса NICA

2.1 Оптимизация компоновки/конфигурации оборудования колец коллайдера, переходы «Тепло-Холод» на стыках СП и «тёплых» элементов, участки встречи/разведения пучков, инжекции и сброса пучков
2.2. Система управления и синхронизации [10)]
2.3. Режимы работы ускорительного комплекса NICA, согласование с MPD и SPD
2.4. Оптимизация семейств источников питания
2.5. Инфраструктура комплекса (криогеника, электро- и водоснабжение)

Dynamics optimization

I.Meshkov,
B.Levichev,
T.Kulevoy

At Russian Particle Accelerator Conference RuPAC 2016
25 of November was provided special satellite meeting
dedicated to particle dynamics in the NICA collider.
As result a distributed scientific group
including specialists from **JINR, BINP, ITEP**
was established

Responsible persons

Ответственные исполнители, ведущие численное моделирование и аналитические расчёты, подготовку (коррекцию) физического проекта:
1) О.С.Козлов, С.А.Костромин – ОИЯИ
2) С.Глухов – ИЯФ СО РАН
3) А.Е.Большаков, П.Р.Зенкевич – ИТЭФ
4) Д.Шатилов, С.А.Никитин – ИЯФ СО РАН
5) А.В.Елисеев – ОИЯИ
6) А.В.Смирнов – ОИЯИ
7) С.А.Краснов - ИЯФ СО РАН
8) А.В.Филиппов – ОИЯИ
9) Специалисты ИЯФ СО РАН
10) В.И.Волков, Е.В.Горбачёв, В.М.Слепнёв – ОИЯИ

Руководители и координаторы направлений (кроме перечисленных выше)
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Thank you for attention