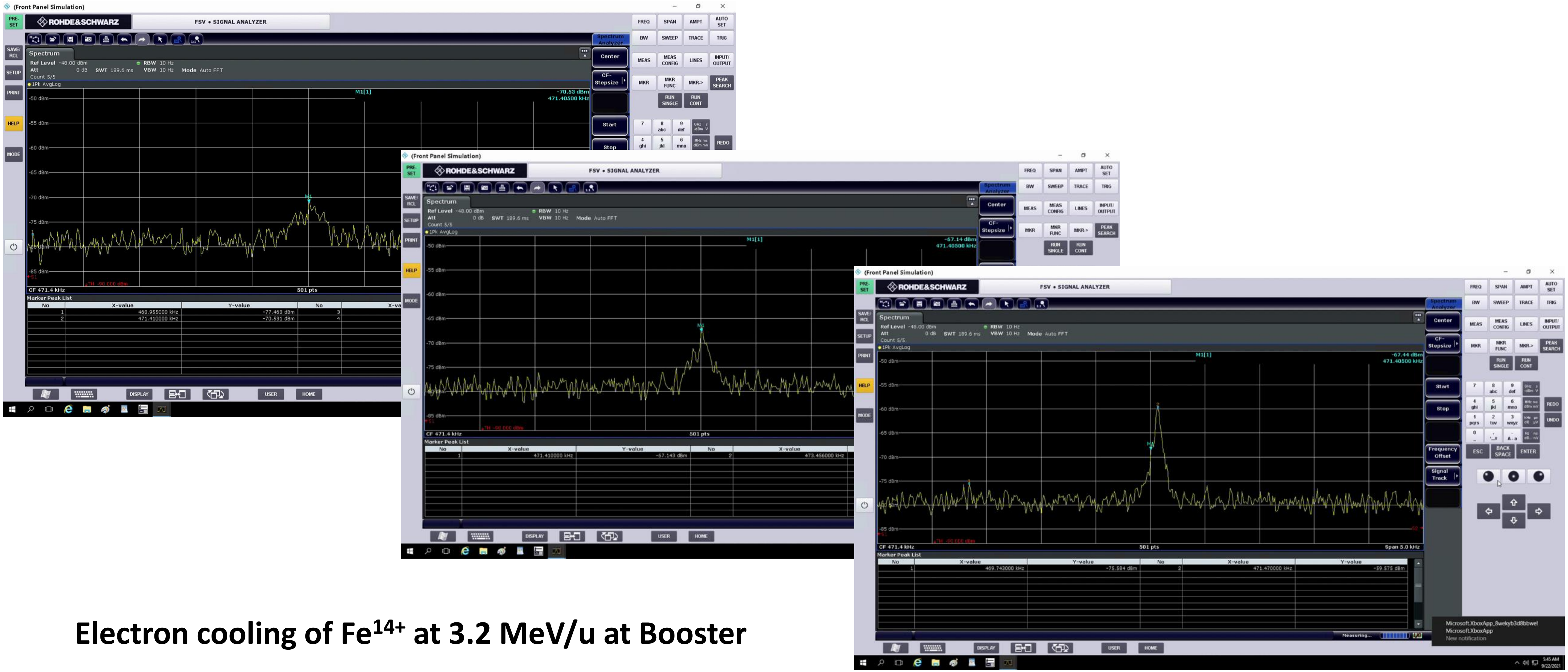
Beam cooling and dumping at NICA collider

Anatoly Sidorin on behalf of NICA team



Electron cooling of Fe^{14+} at 3.2 MeV/u at Booster

Schottky spectra at 4-th harmonics

Contents

Beam cooling division:

Leader:
Andrii Kobets

Researchers:
Ivan Gorelyshev – stochastic cooling simulation
Konstantin Osipov – RF structures and electronics for SC and feed-back
Sergei Melnikov – Impedance simulations and instability analysis

Engineers:
Anton Sergeev – Assembly, test and operation of EC
Sergei Semenov – Assembly, test and operation of EC
Vladimir Filimonov: technology of fabrication

Electron cooling system

A.Kobets

Mission: beam storage, luminosity preservation in SC dominated regime

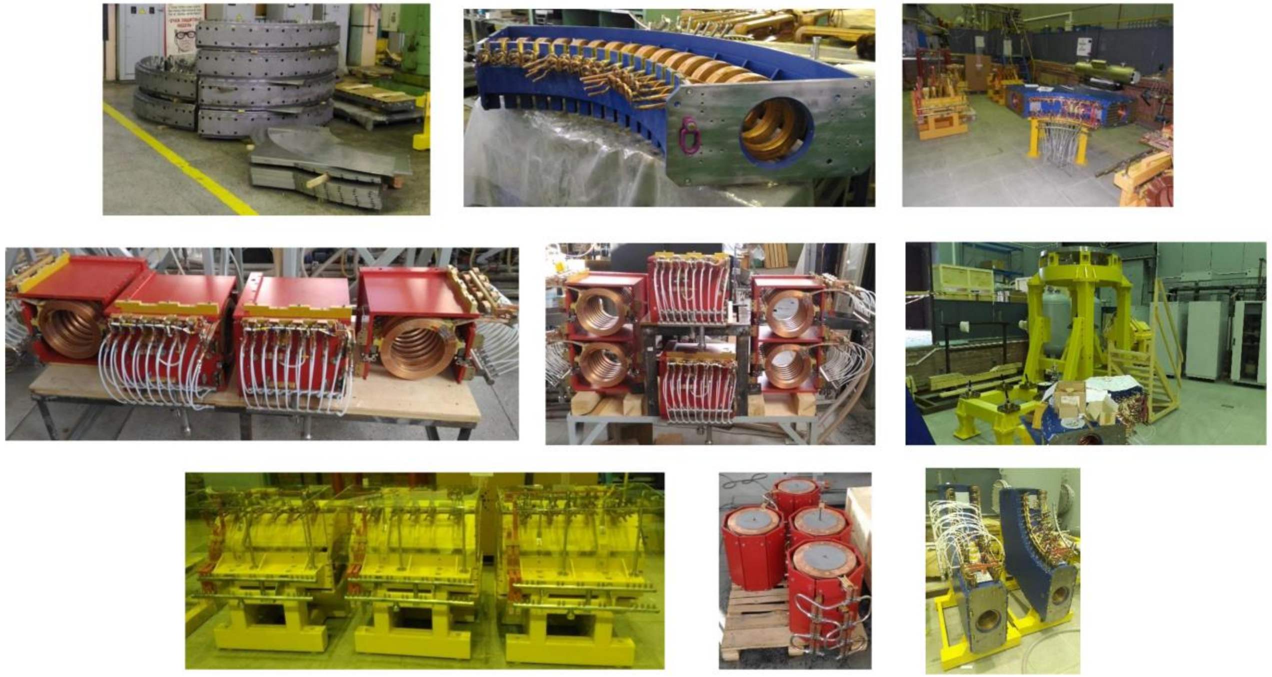
Parameter	Value
Energy range, MeV	0.2÷2.5 MeV
High voltage stability (ΔU/U)	$\leq 10^{-4}$
Electron current, A	0.1÷1
Diameter of the electron beam in the cooling section, mm	5÷20
Length of the cooling section, m	6
Bending radius of electrons in transport channels, m	1÷1.3
Magnetic field in the cooling section, kGs	0.5÷2
Vacuum pressure in the cooling section, mbar	10^{-11}
Beta-function in cooler (horizontal/vertical), m	(11 ÷ 13)/(13 ÷ 14)
Transversal temperature of electrons, eV	50
Longitudinal temperature of electrons, meV	5,0

Electron cooling system

A.Kobets

Under construction at BINP

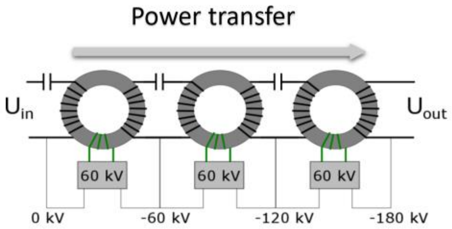
Hall for HV-E Cooler commissioning in BINP

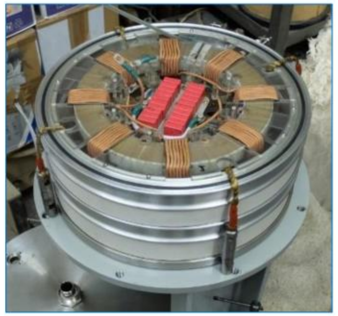


Construction of E-Cooler magnetic system

Electron cooling system

A.Kobets





Cascade transformer


High current (IST) PS


Cascade transformer PS


Low current (corrector) PS

E-Cooler power supplies

Delivery to Dubna – 2022
Start of operation - 2023

Stochastic cooling

I.Gorelyshev

Mission:

1. Counteract to IBS at collisions

Energy, GeV/u	3.0	3.8	4.5
IBS time, s	520	1130	1900

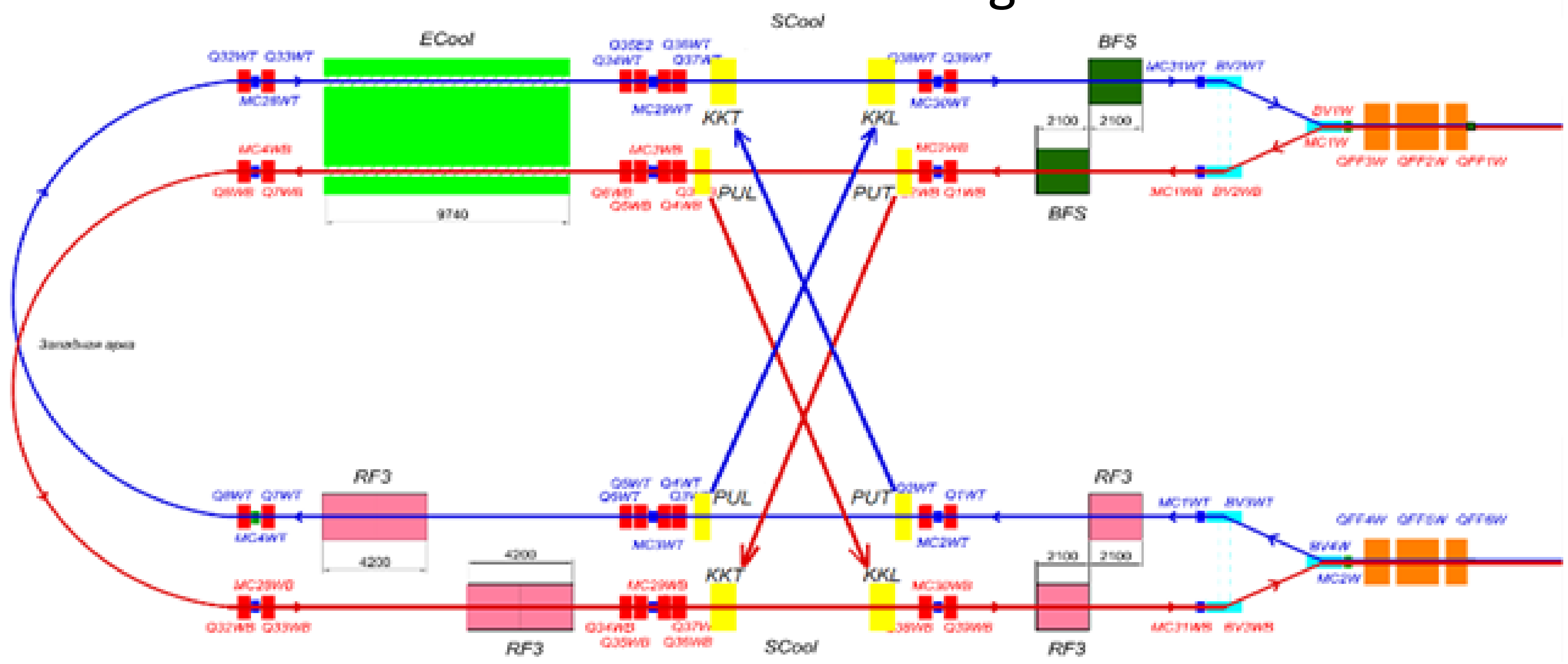
2. Support of beam storage and bunch formation

Configuration	Cooling method	Channel	Pickup	Kicker	ToF P→K, ns	Min. delay, ns
Start-up	Longitudinal Filter	L	Sum	Sum	635 – 645	405
Full	Horizontal	T	Combined	Combined	635 – 645	405
	Vertical				635 – 645	405
	Longitudinal Filter	L	Sum	Sum	635 – 645	405

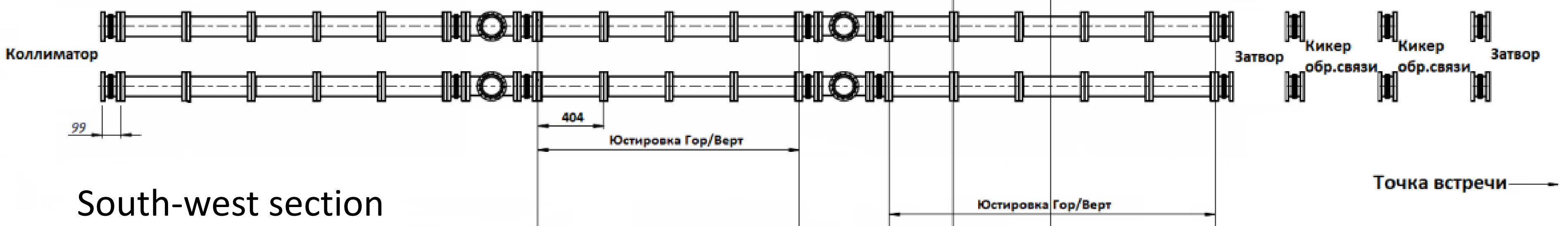
Stochastic cooling

I.Gorelyshev

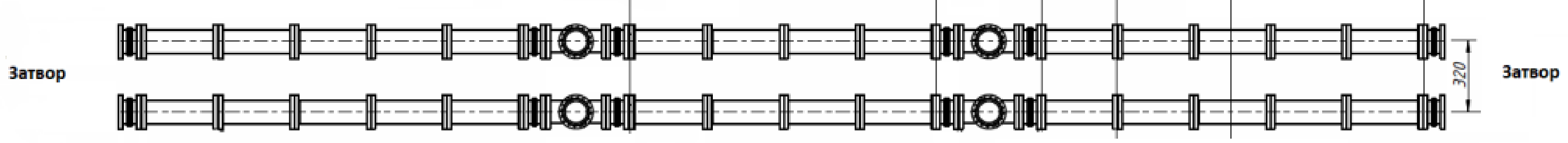
Location in the ring



Nord-west section



South-west section



Stochastic cooling

I.Gorelyshev

The concept is based on cut pick-up/kicker structures with ceramic chamber inside (proposed for MAC in 2018).

Shift of the band from 2-4 GHz to 1-3 GHz permits to use filter method for the longitudinal cooling.

Division of the total band by the sub-bands permits to optimize PU/Kicker impedance.

The ceramic vacuum chamber permits to achieve the required vacuum conditions and separate systems of two rings.

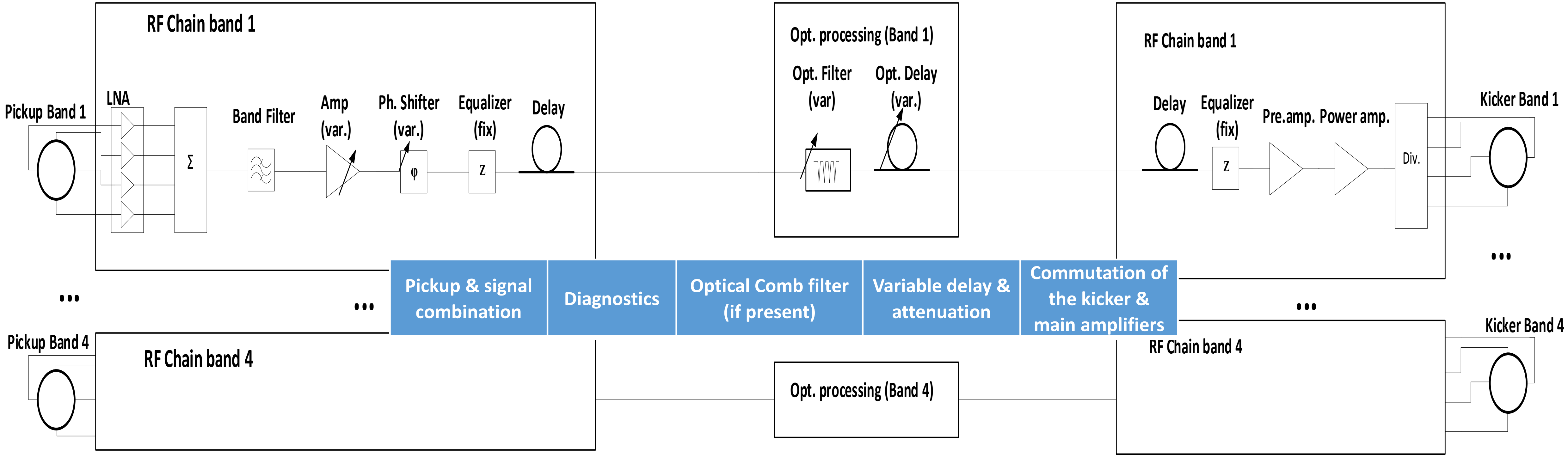
The development of the concept was presented for MAC in 2019.
Main problem of this concept was to provide required band and impedance of pickups and kickers.

The solution of this problem presented for MAC 2020 is the newly proposed band width 1~3 GHz, division of the band by 4 sub-bands, and design of PU/KK providing (in simulations) required parameters.

August 5, 2020 Video meeting among following members:
F.Caspers (CERN), T.Katayama (Nihon University), R.Stassen (FZJ),
I.Gorelyshev, S.Kostromin, I.Meshkov, K.Osipov, A.Philippov, A.Sidorin, G.Trubnikov (JINR).

I.Gorelyshev, K.Osipov

Four independent Sub-Bands:

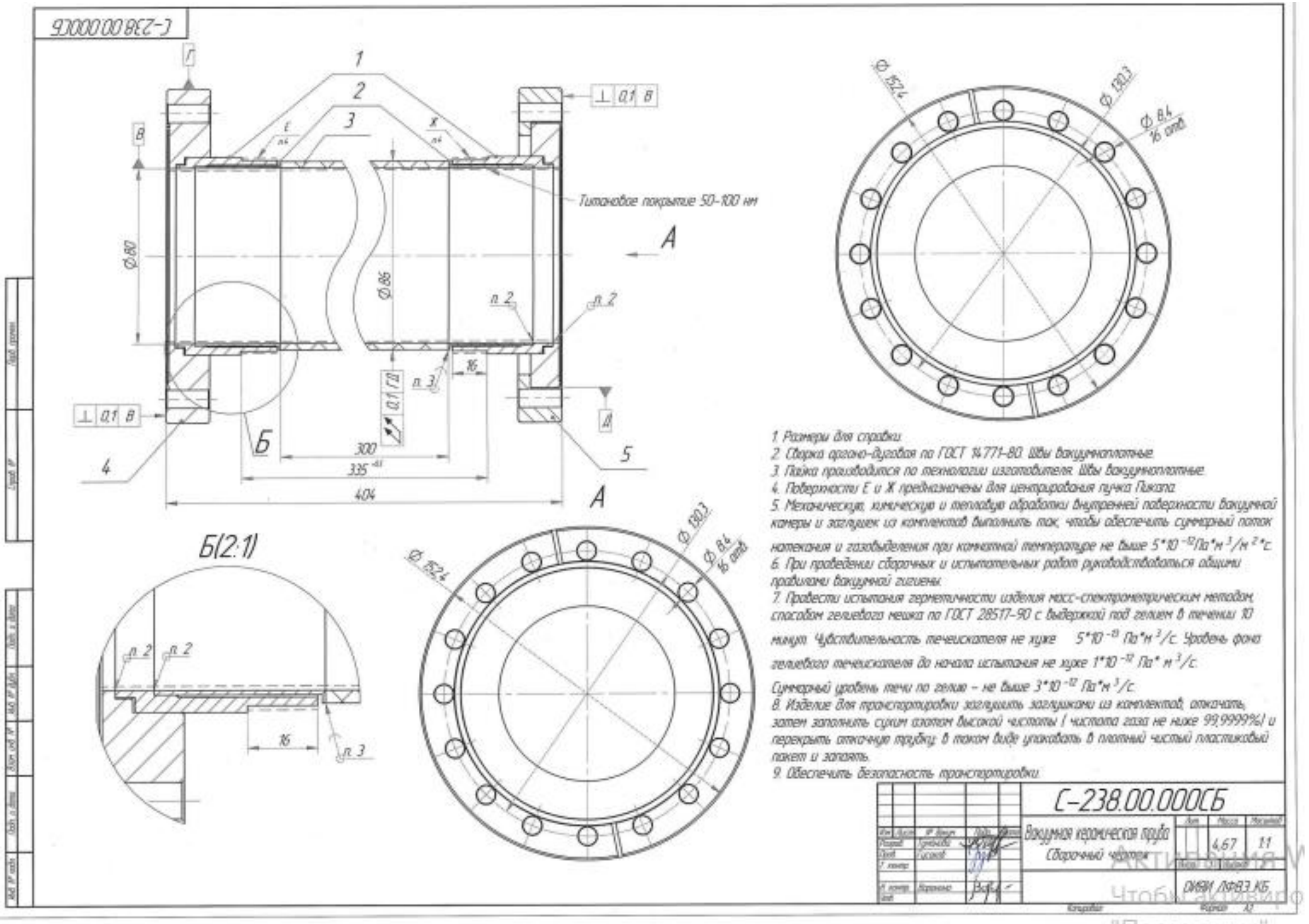


Passband, GHz	0.7 - 1.0	1.0 - 1.5	1.5 - 2.2	2.2 - 3.2
Min Pickup Impedance, Ω	300	210	220	160
Max Peak Pickup output power, nW	290	380	510	640
Min Kicker Impedance, Ω	1200	840	880	640
Max Peak power at the kicker, W	200	200	200	200
Gain(without losses), dB	97	109	107	105

Stochastic cooling

V.Filimonov

Ceramic Vacuum chambers



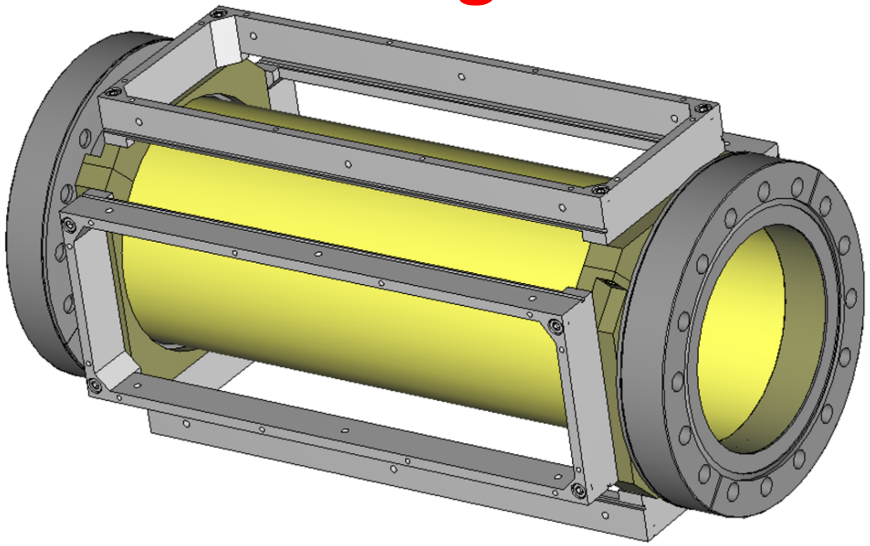
Tender procedure with four competitive companies

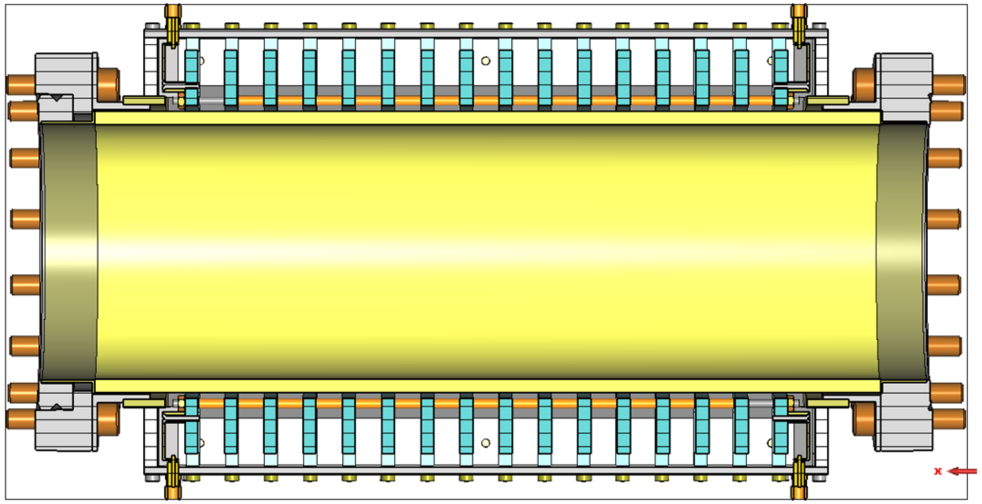
Term of delivery: 6 month after signature of contract

Stochastic cooling

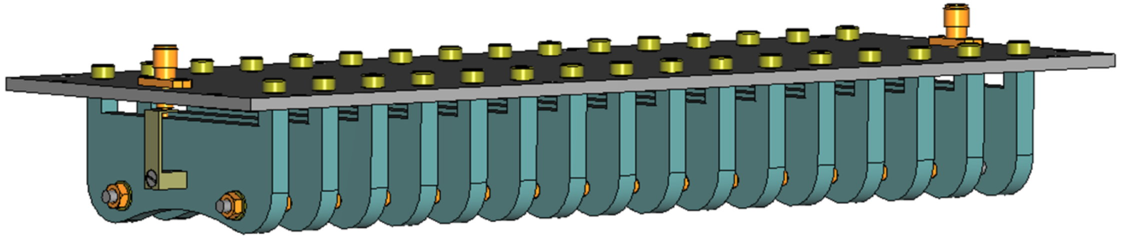
Pick-up/kicker

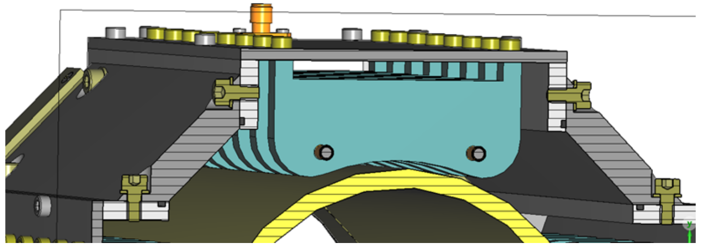
K.Osipov



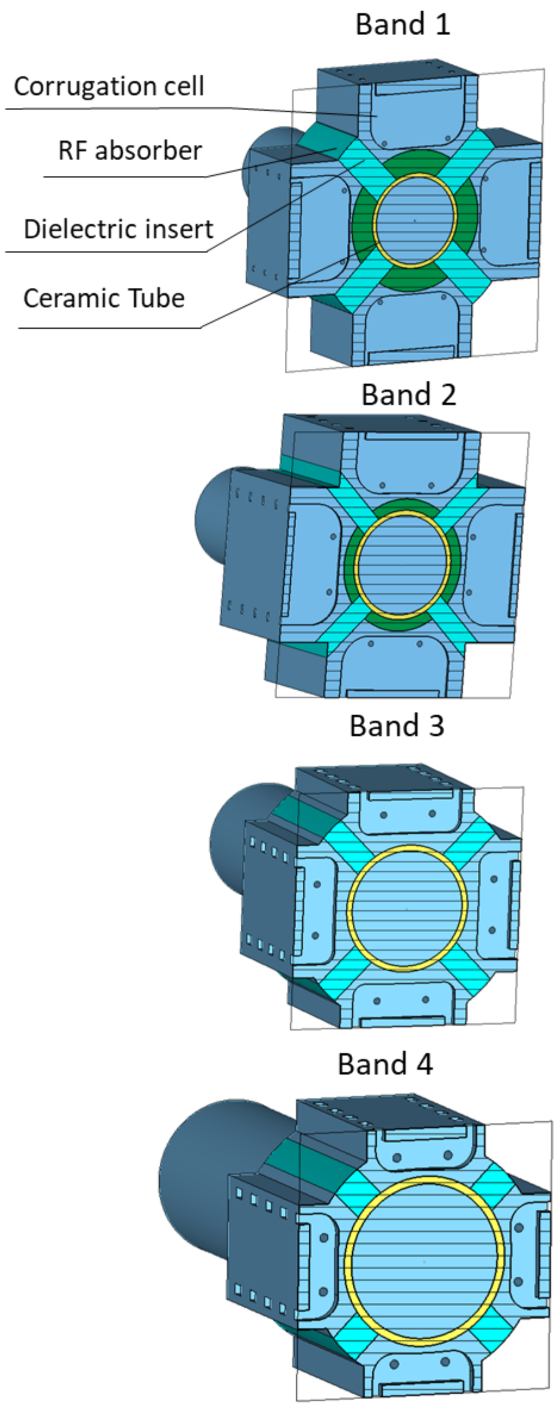


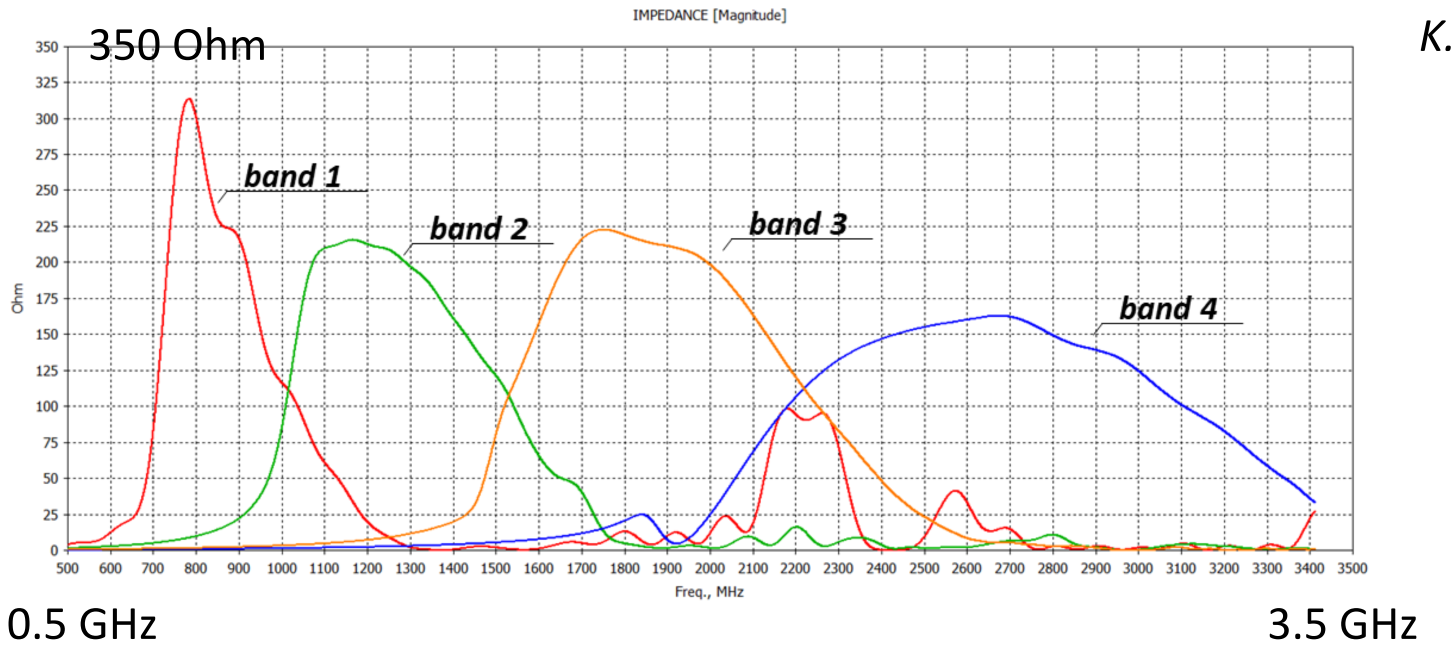
- Uses surface wave in corrugated waveguide.
- Can be adopted for all 4 bands
with different width of the dielectric inserts.
- Smooth and wide width Impedance response,
flat Phase response.
- Impedance level and width can be controlled
with the shape of corrugation plate.
- Impedance curve spikes can be damped
with RF absorber.
- Simple to fabricate design. Replaceable sensors.

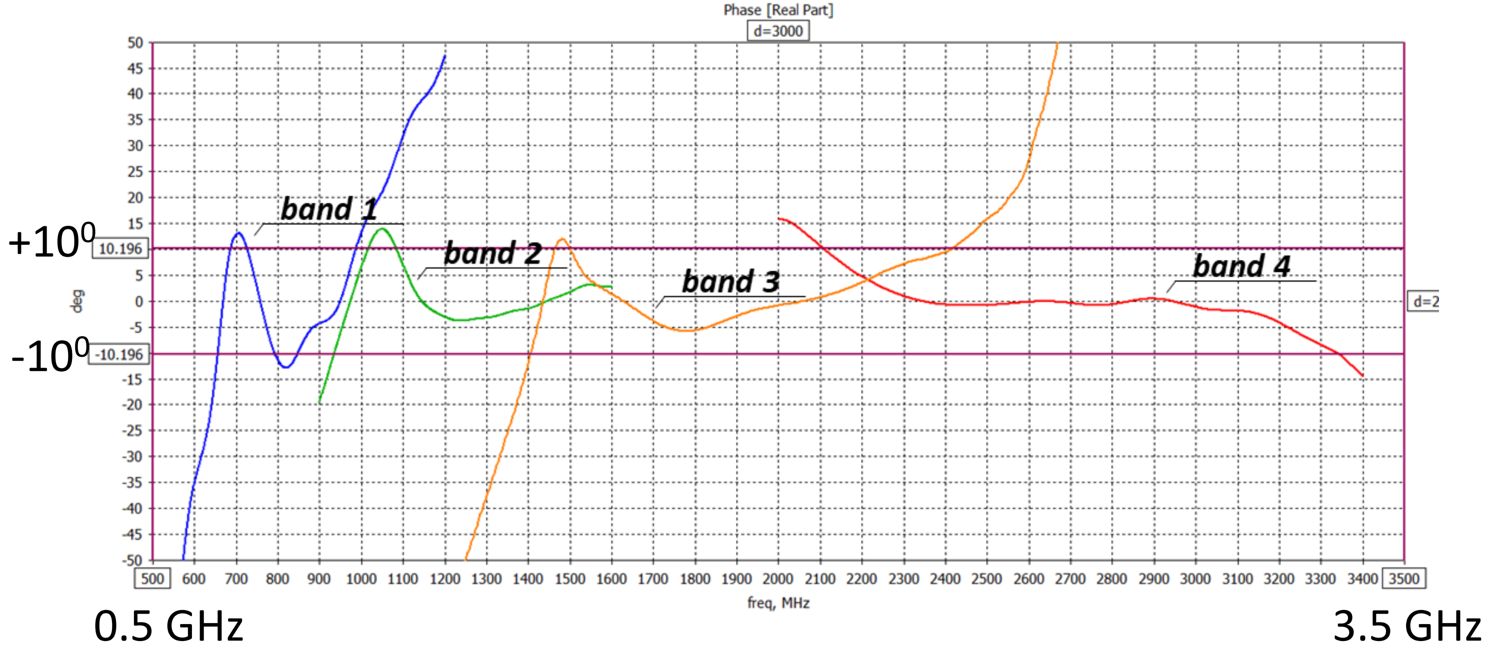




K.Osipov

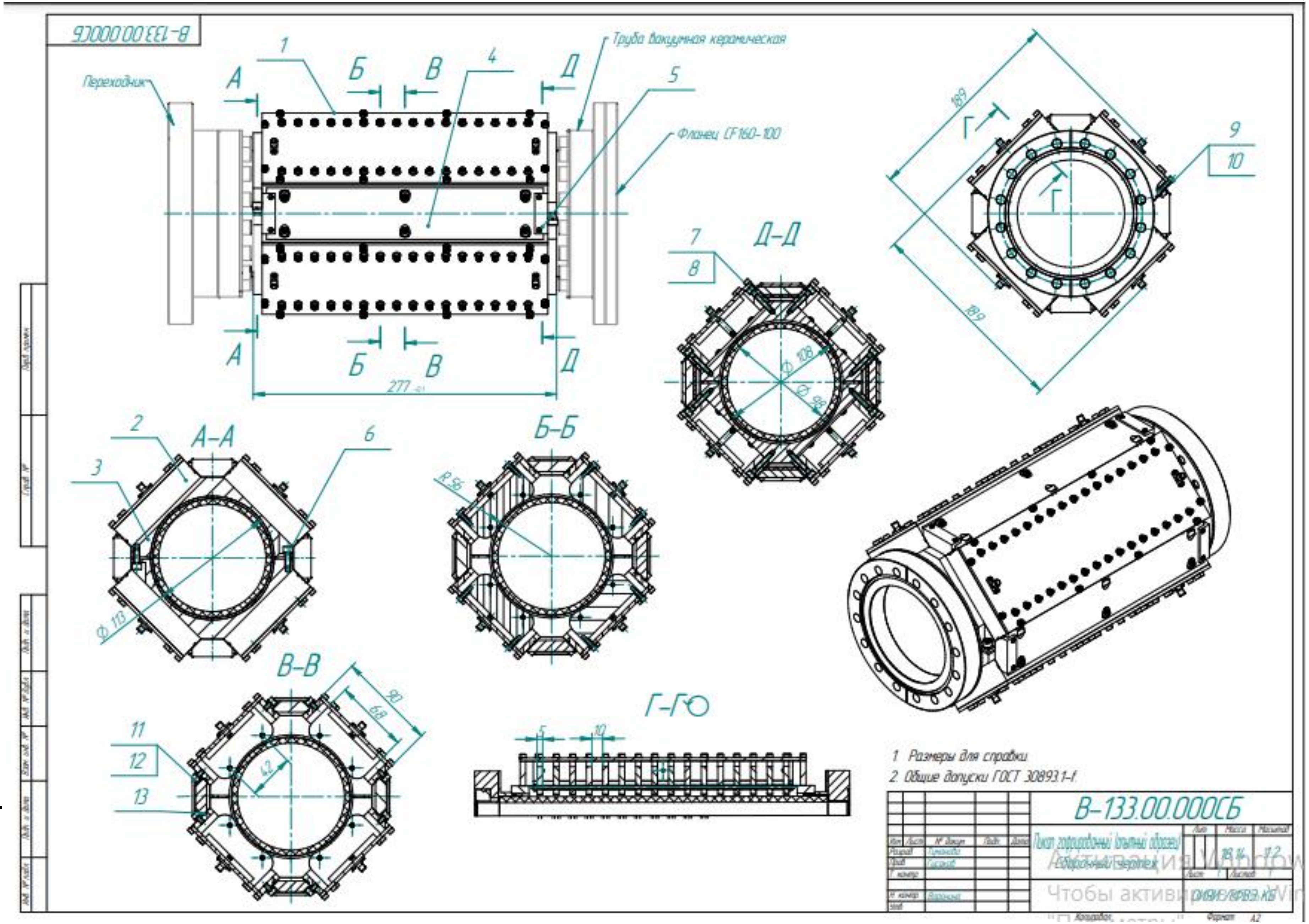

Band 1
Corrugation cell
RF absorber
Dielectric insert
Ceramic Tube
Band 2
Band 3
Band 4


IMPEDANCE [Magnitude]
350 Ohm
Ohm
band 1
band 2
band 3
band 4
Freq., MHz
0.5 GHz
3.5 GHz


Phase [Real Part]
d=3000
+10⁰
-10⁰
10.196
-10.196
deg
band 1
band 2
band 3
band 4
freq, MHz
0.5 GHz
3.5 GHz

Stochastic cooling

K.Osipov



Expected fabrication – End of this year

Stochastic cooling

Powerful amplifiers

Main parameters	Requirements (long./trans.)	
model	-	R&S BBA150 –D200 (R&S)
Frequency band	1-3 GHz	0.69-3.2 GHz
Pout	200Watt (30Watt)	200Watt
Gain	>40 dB (>40dB)	55dB
Pin	<15 dBm	-3.4 dBm
Connector	N-type	N-type

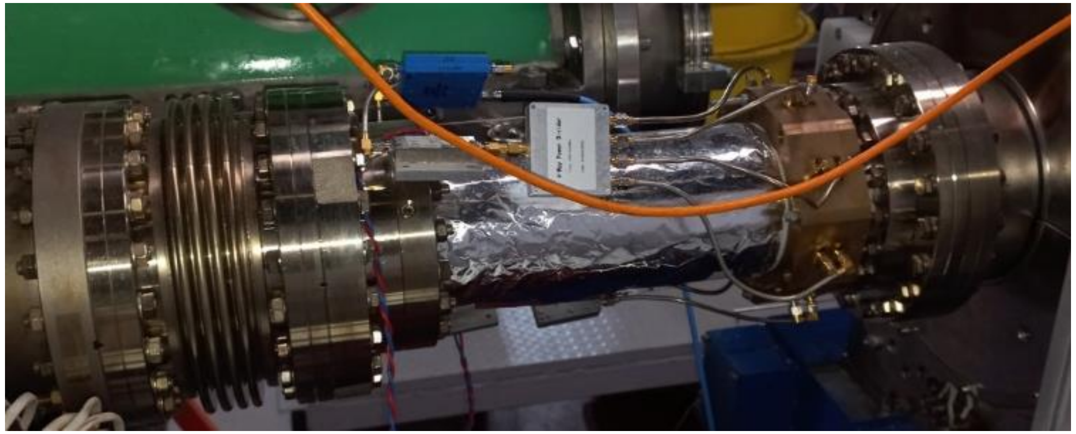
Under contract with GSI - first part this month
(test in the run at the Nuclotron SC)

Room for temporary storage and test of the equipment

Comb filters

Negotiations with GSI

Stochastic cooling



Test of pick-up at Booster – nearest run
(it depends on achievable ion energy)

Kicker of the Nuclotron SC
will be replaced by ceramic chamber:

Tests of PU
Cooling with kicker using existing PU

Start in the next year

September run:
Vacuum chamber,
two rings, preamplifiers, combiner were installed
(design $\beta = 0.9$)

Stochastic cooling

Stages of realization:

- Assembly of the vacuum chambers at the rings – June 2022
- Start of operation of the first sub-band end 2022
- Sub-band by sub-band commissioning first half 2023

Transverse feed-back system

Mission:

- Dumping of coherent oscillations due to injection errors,

- Dumping of the transverse coherent instability,

- Q- meter, excitation of the transverse oscillations for transverse dynamics investigations.

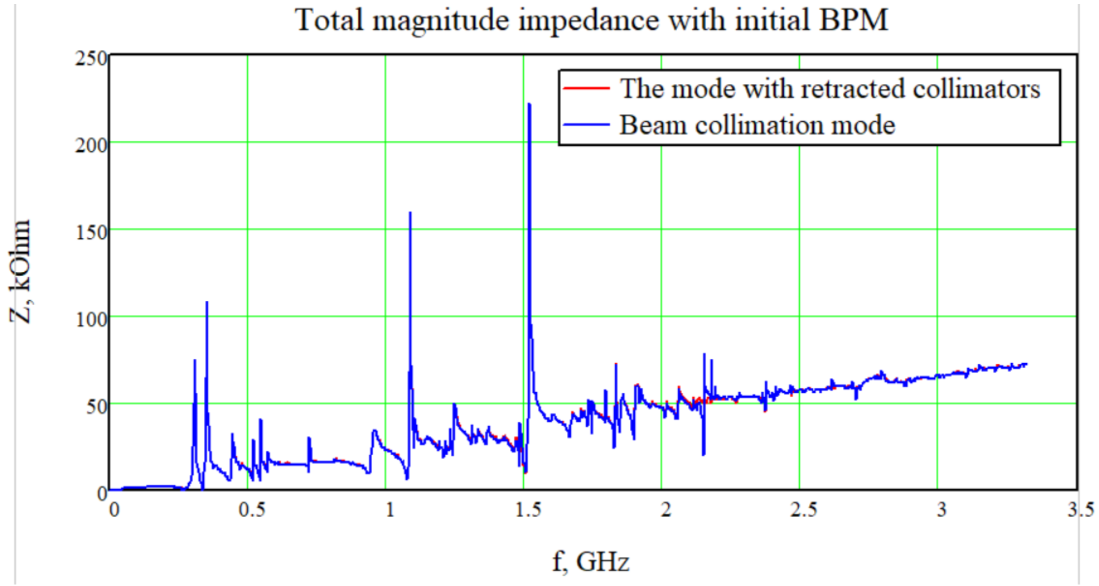
Transverse feed-back system

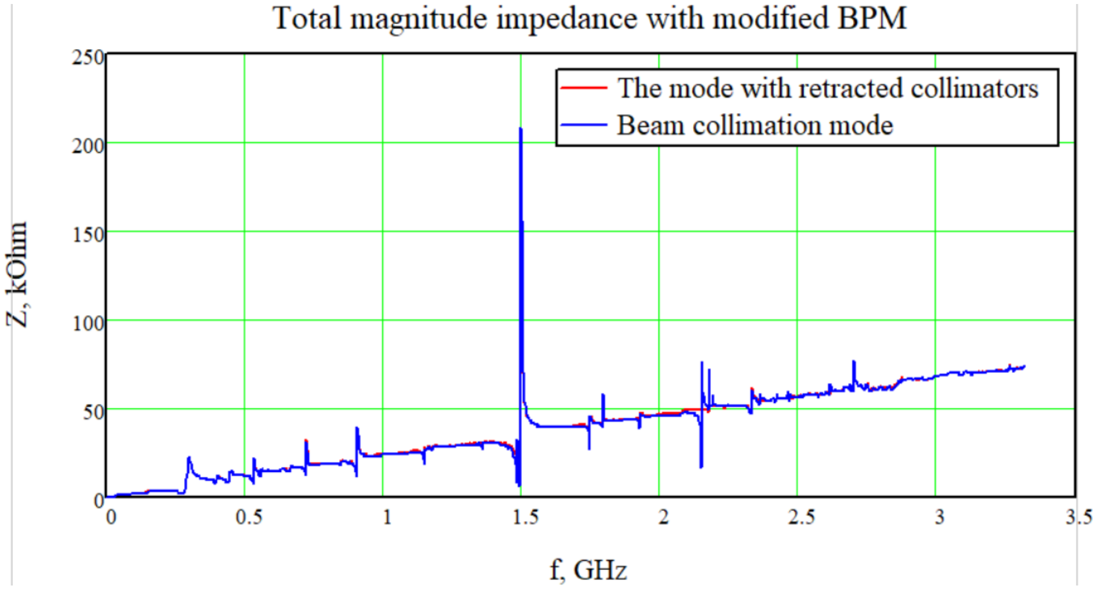
Parameter			Value
Revolution frequency	f_{rev}	kHz	522,1/587,1
Beam r.m.s dimensions horizontal (β_{av} = 8.48 м) vertical (β_{av} = 8.49 м) For estimations at injection(β_{inj} = 17 м)	 σ_x σ_y σ_{inj}	 mm mm mm	 2,83/1,59 2,44/1,38 3,5
Betatron tune	Q_x/Q_y		9,44/9,43
Injection errors (β_{inj} = 17 м) static (orbit displacement) dynamic (injection kicker)	e_{inj}		$\pm 2\sigma_{inj}$ $\pm 0{,}8\sigma_{inj}$ $\pm 1{,}2\sigma_{inj}$
Decoherence time	τ_{dec}/T_{rev}		800
Time of instability development (P.Zenkevich)	τ_{inst}/T_{rev}		400
Characteristic dumping time	τ_d/T_{rev}		100
Decrement	τ/T_{rev}		114
Minimum frequency	f_{min}	kHz	50
Maximum frequency	f_{max}	MHz	7
Frequecy (-3. dB)		MHz	2,8

Example of the impedance (longitudinal) optimization

S.Melnikov

- The total longitudinal impedance of the NICA collider ring is represented by figures below for 2 operating modes – the beam collimation mode (collimators are put in working position) and the mode when collimators are in retracted position. For both modes, **the results are presented for energy 3 GeV/u for the initial and shielded design of BPM, all other elements of the ring presented in the modified design. (**Collimator unit - absorber and scraper, Kicker of the feedback system, Strip-line monitor, MPD Detector beam tube, Electronic cooling section beam tube**)**

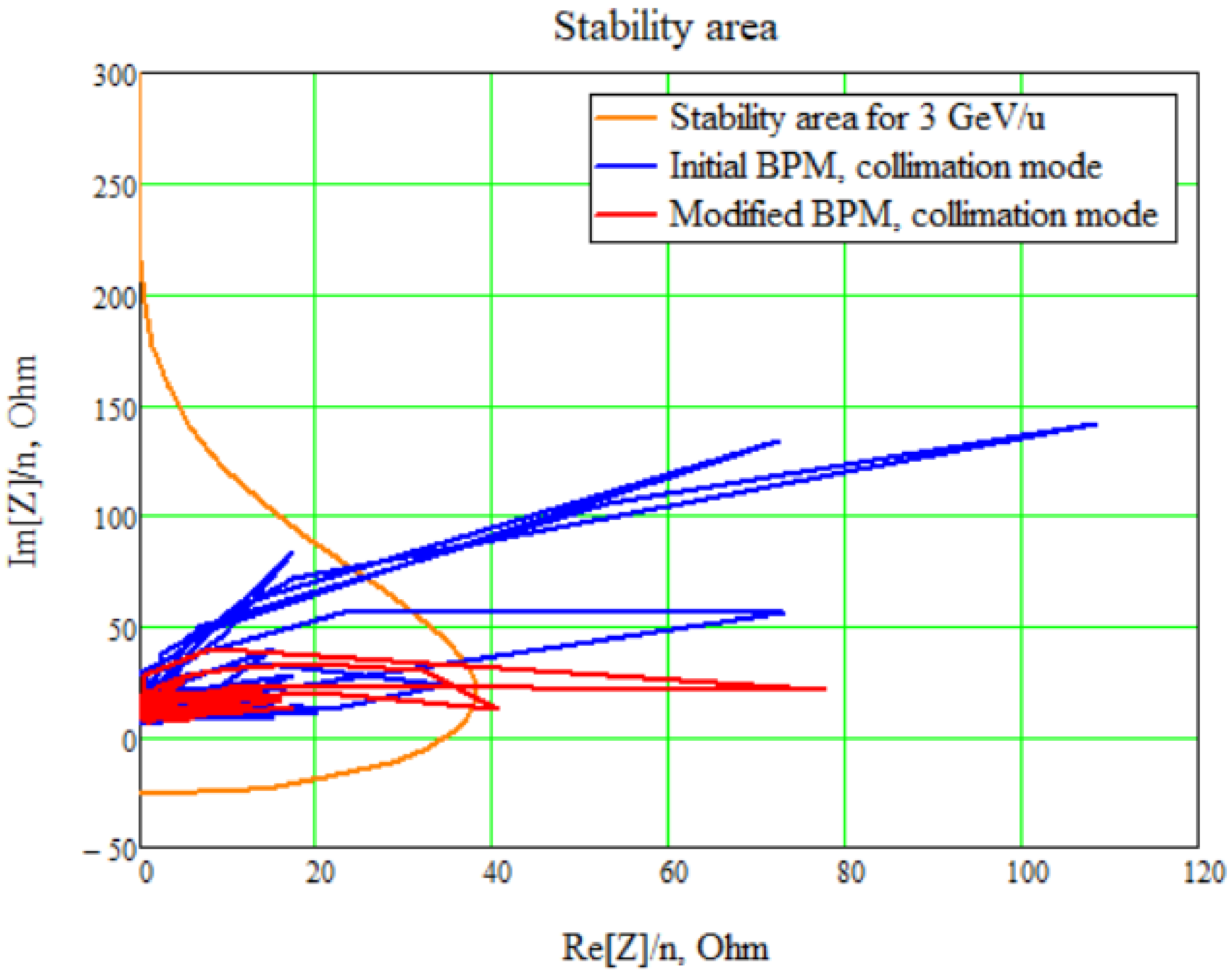




Total magnitude impedance with initial (left) and modified BPM for the mode with retracted collimator (red curve) and beam collimation mode (blue curve).

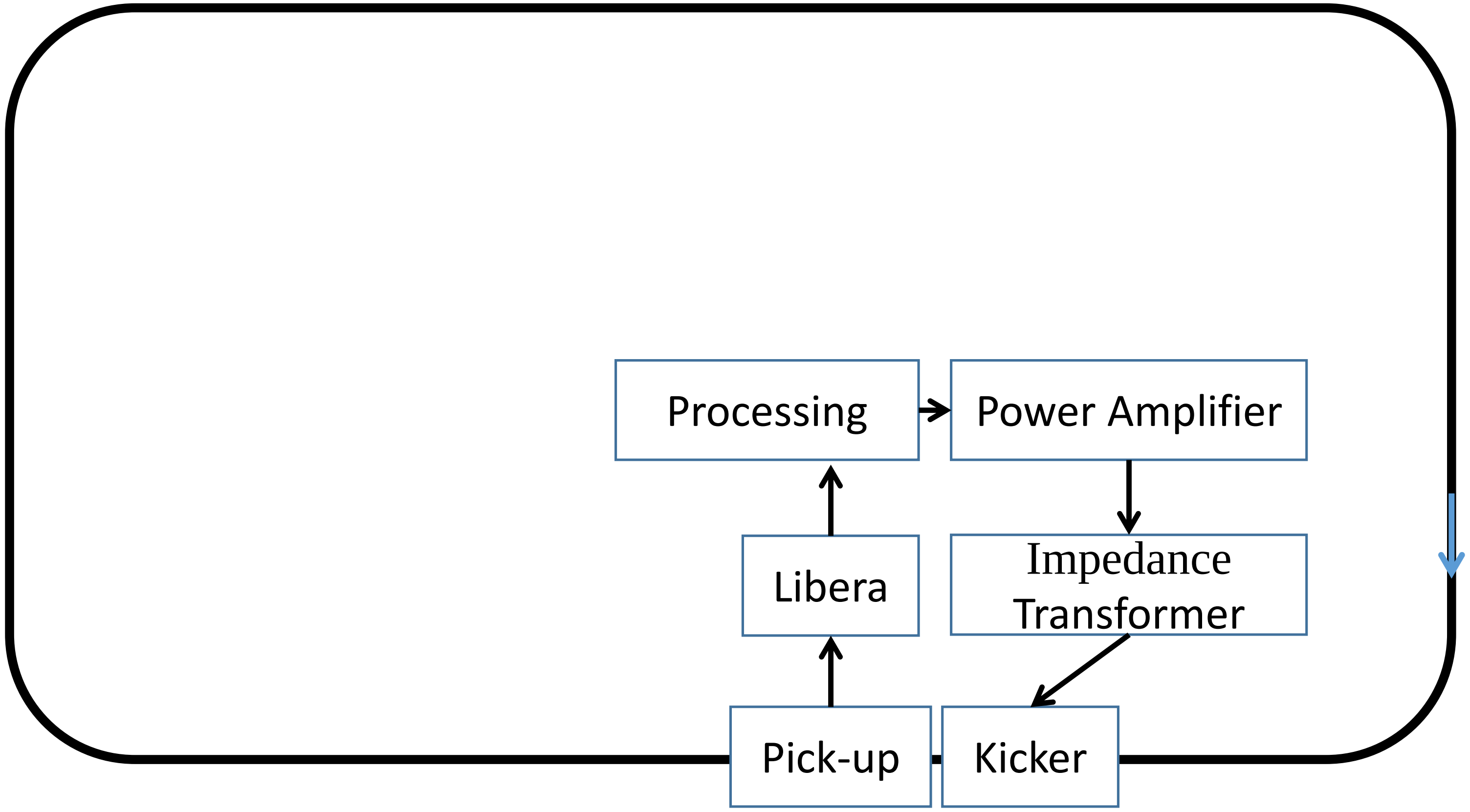
As can be seen from the figures, the main contribution to the total impedance is given by BPM and there is practically no difference between the collimation mode and the mode with retracted collimators

I.Meshkov, S.Melnikov



Stability area for 3 GeV/u (orange curve) and ring impedance divided by harmonic number
Blue curve – unshielded cavities
Red curve – shielded ones.

Transverse feed-back system



Kicker			value
Angular deviation per turn	$\Delta x'_k$	urad	9,1
Plates (β_k = 20 m): aperture/length	D_k/L_k	mm	100/1000
Maximum Voltage	V_k	mV	3,4

Structure of one chain

Pick-up – nearest BPM

Libera hadrons:

Digital signal Δ/Σ,
Proportional to displacement of the beam center.

Processing:

Optimum Phase shift,

Delay,

Correction of phase-frecuency dependence

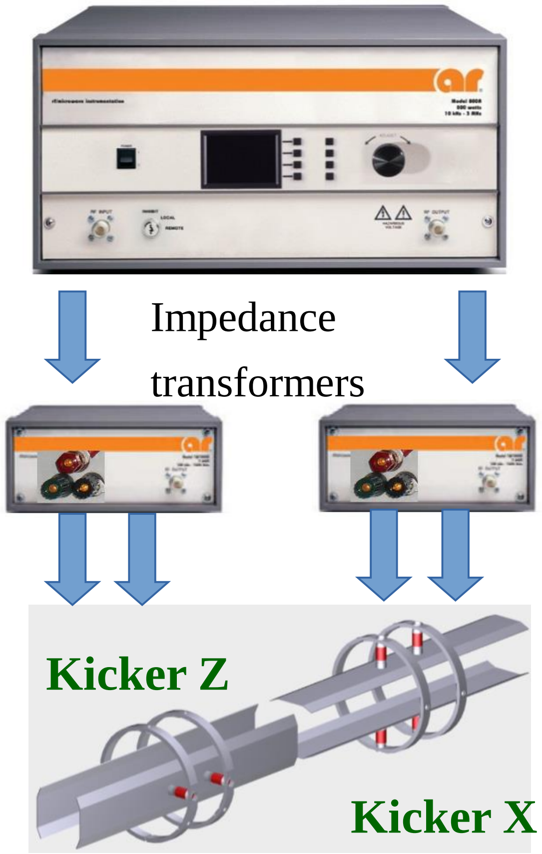
At the exit – analog signal.

Power amplifier:
0.1 – 7 (2.8) МГц

Transverse feed-back system

Nearest prototype: the Nuclotron Q-meter

RF Amplifier AR 800A3A



Transverse feed-back system

E.Gorbachev

Test bench for the BPM

Transverse feed-back system

E.Gorbachev

Libera Hadron system:

Specifications:

- 16 input channels (4 per module)
- 16 bit ADC
- 250MS/s
- 6.5Gbps Rocket I/O
- 4GB memory per module

Output data:

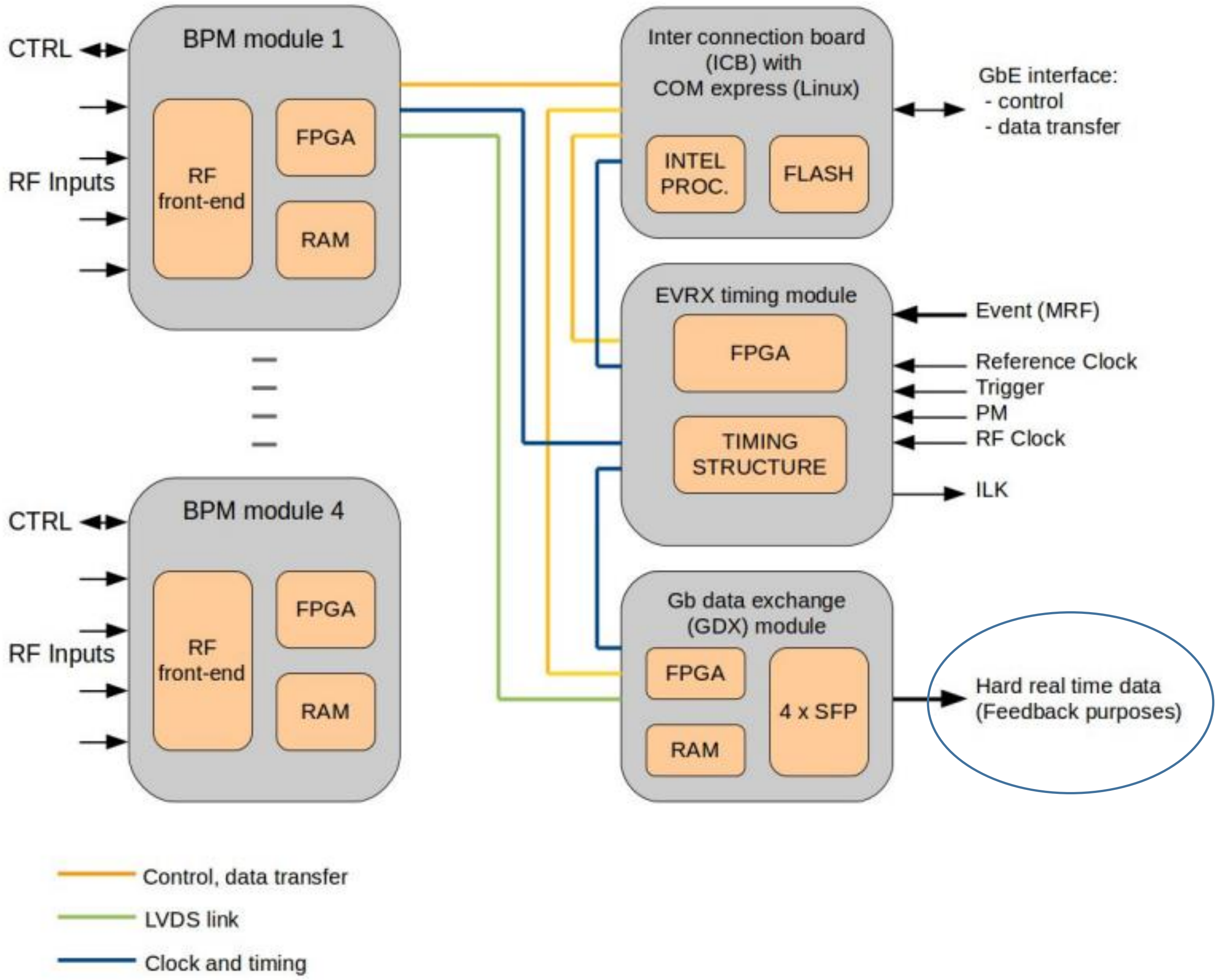
- Raw(A,B,C,D)
- calculated beam position (X,Y)
- Charge(SUM)
- FFT, FFT peak

Data paths:

- Broadband data (ADC@250MHz) -270MS (>1s of data), 4 channels
- Bunch-by-bunch data – 200MS (>66s of data @1MHz bunch rep rate)
- Slow data stream (10 S/s)
- Fast data stream (10kS/s)

Libera Hadron system:

E.Gorbachev



Transverse feed-back system

K.Osipov

Power amplifier + Impedance transformer

Nearest prototype
Amplifier of the Nuclotron Q-meter

Negotiations with

China companies
Triada (Novosibirsk)
Belorusian companies

800 watts CW. 10 kHz - 3 MHz.

Rated Output Power	800 watts
Input For Rated Output	1.0 milliwatt max.
Power Output @ 3dB compression	
Nominal 800 watts	Min. 700 watts, 10 kHz - 2 MHz Min. 600 watts, 2 - 3 MHz
Power Output @ 1dB compression	
Nominal 500 watts / Min. 400 watts	
Flatness	± 1.0 dB max.
Frequency Response	10 kHz - 3 MHz instantaneously
Gain (at max. setting)	60 dB min.
Gain Adjustment (continuous range)	23 dB min.
Input Impedance	50 ohms, nominal

Output Impedance (switch select; manual)
12.5, 25, 50, 100, 150, 200, 400 ohms nominal
(10 kHz - 3 MHz) on front panel

Mismatch Tolerance*
Will operate without damage or oscillation with any magnitude and phase of source and load impedance. 100% of rated power without foldback up to 6.0:1 mismatch above which may limit to 400 watts reflected power. May limit at rated output.

Modulation Capability
Will faithfully reproduce AM, FM, or pulse modulation appearing on the input signal. AM peak envelope power limited to specified power.

Harmonic Distortion
Minus 20 dBc max. at 400 watts power output

Connectors

RF Input	Type N female on front panel
RF Output	Type N female on front panel

Remote Control
IEEE-488/RS-232, USB ability to remote control and power an external impedance transformer.

RF Power Display
0 - 1000 watts full scale. Directional power monitor allows separate display of forward and reflected power.

Power Monitor
BNC: 0 - 10V forward and reverse power

Cooling	Forced air (self contained fans)
Primary Power	Universal, 85 - 137 / 180 - 300 VAC, 47 - 63 Hz, 2500 watts max.
Weight (max.)	36.4 kg (80 lb)

Size (WxHxD)
50.3 x 34 x 55.1 cm / 19.8 x 13.4 x 21.7 in

For external impedance transformer options, see specification sheet for IT2000 Series impedance transformers.

Transverse feed-back system

I.Gorelyshev

Kickers

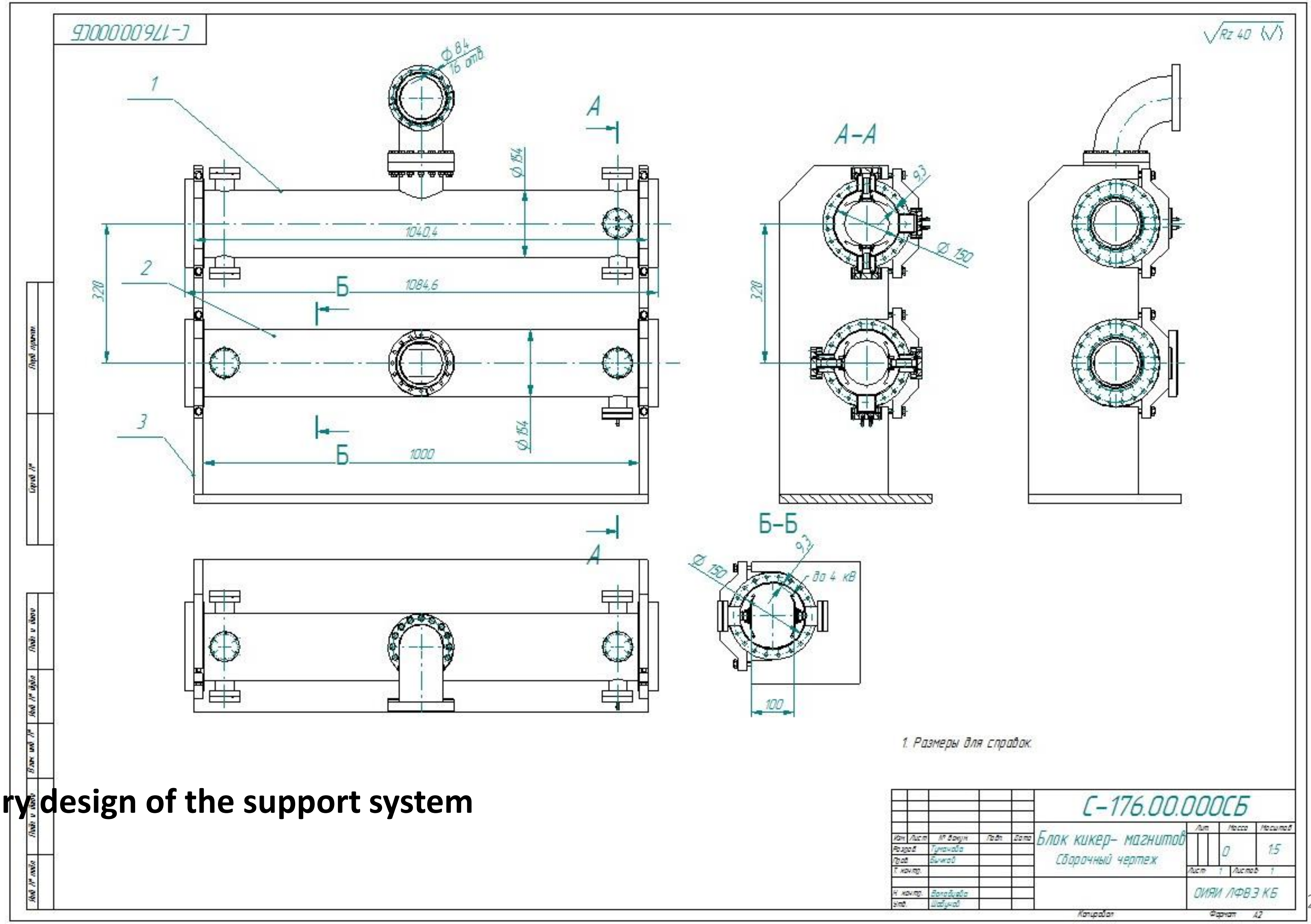
Feed back system includes 4 kickers:
(Horizontal and vertical for both rings).

The kickers are located at room temperature straight section
One upon other.

Each kicker – cylindrical vacuum chamber with two plates insulated from the ground.

Maximum design Voltage at the plates	4 kV.
Length of the plates	1000 mm.
Vacuum chamber diameter	150 mm.
Residual gas pressure	10^{-11} Topp.

Kickers

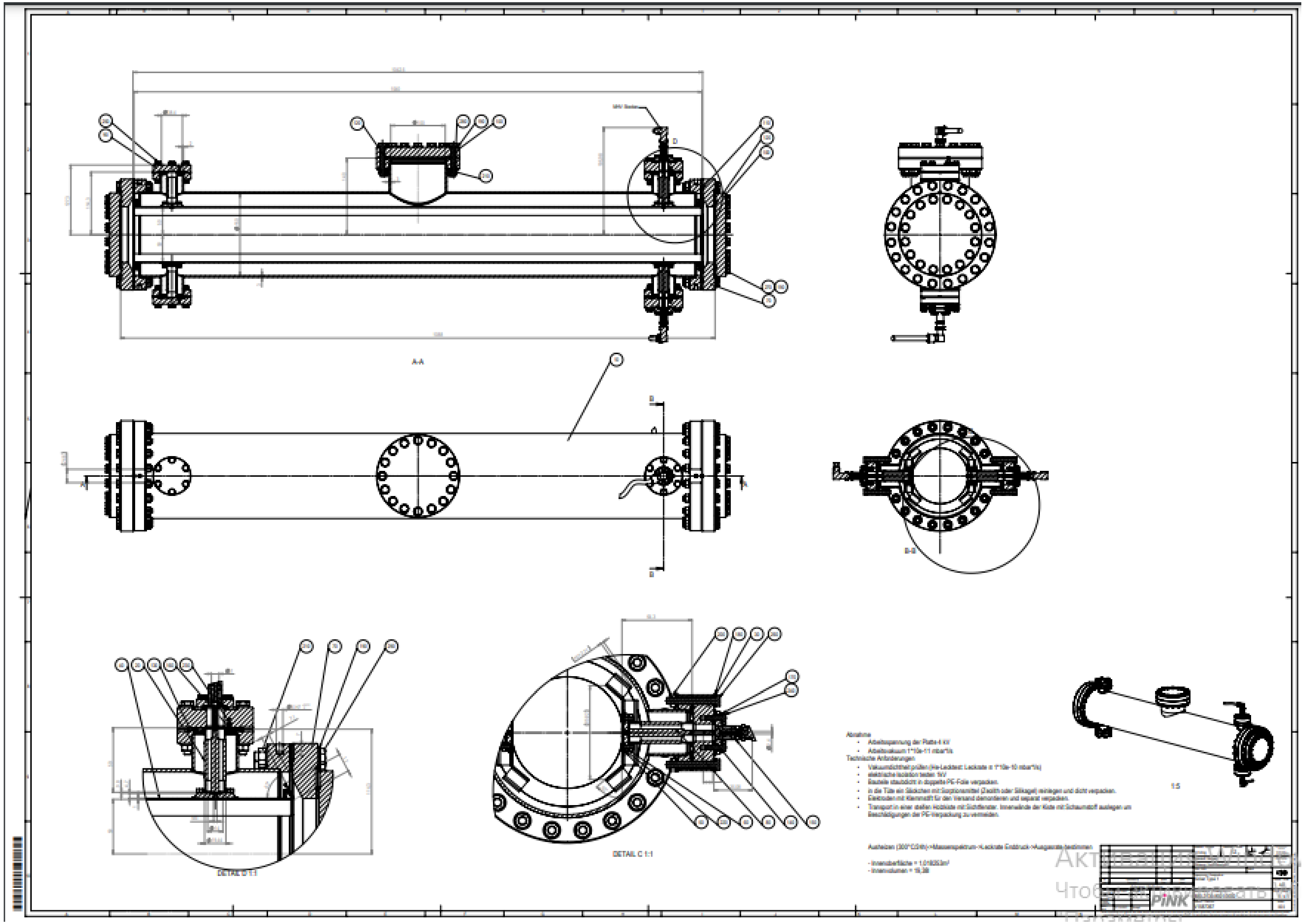


Preliminary design of the support system

Kickers

Under fabrication by BEVATECH GmBH

Delivery to Dubna: March 2022



Transverse feed-back system

Stages of realization:

- Test of the kickers at test bench	summer 2022
- Assembly of the kickers at the ring	end 2022
- Start of the Q-meter operation	end 2022
- Transverse feed-back	full configuration

Thank you for your attention