NATIONAL RESEARCH CENTRE
«KURCHATOV INSTITUTE»

INSTITUTE FOR HIGH ENERGY PHYSICS

Russia 142281, Moscow region, Protvino, Nauki sq., 1

Muon cooling demonstration with MICE at IHEP ?

48th MICE Collaboration Meeting
Institute of Physics Belgrade, Serbia 28th June 2017

A.Zaitsev

Formulation of the problem

- At the end of 2016, V. Shiltsev, FNAL, asked the Director of the NRC KI IHEP, S.Ivanov , to evaluate the feasibility of implementing the MICE program at the U-70 accelerator complex.

- In this report the results of initial study are presented. This study relies on the technical specifications provided by K.Long and C. White, for which we[1] are very grateful.

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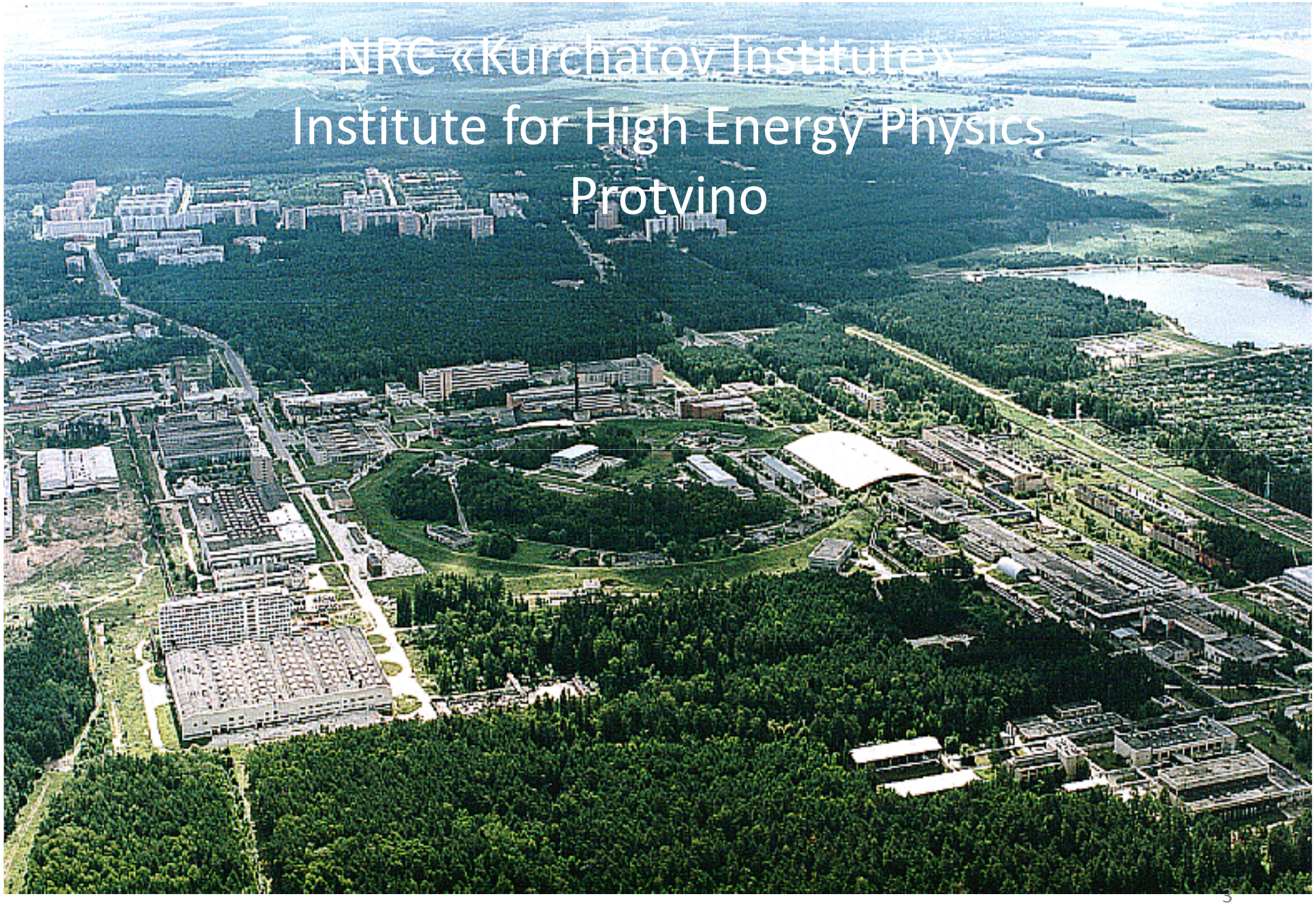
[1] V. Garkusha, F. Novoskoltsev, R. Sinyukov, A.Zaitsev


NRC «Kurchatov Institute» -
Institute for High Energy Physics
Protvino

IHEP LINEAR ACCELERATORS

	URAL-30	I-100	
Type	RFQ DTL	Alvarez DTL	
Energy, E	0.1–30	0.7–100	MeV
Length, L	25.3	79.4	m
Radio frequency, f_{RF}	148.5	148.5	MHz
Pulsed current, I	70	100	mA
Pulse length, t_p	1–10	12–40	μs
Cycle period, T	0.060	1–5	s
Sectioning	5	3	tanks

IHEP PROTON SYNCHROTRONS

PROTON SYNCHROTRONS

	U-1.5	U-70	
Energy, E	0.030–1.32	1.32–70	GeV
Orbit length, L	99.16	1483.699	m
Magnet rigidity, $B\rho$	0.80–6.87	6.87–237	T·m
Intensity, N	$2–9\cdot10^{11}$	$1.4\cdot10^{13}$	ppp
Cycle period, T	0.060	9.77	s
Radio frequency, f_{RF}	0.75–2.75	5.52–6.06	MHz
RF voltage, V_{RF}	6–60	190–300	kV
Lattice cell	MFDFM	FODO	
No. of cells/superperiods	12/12	60/12	

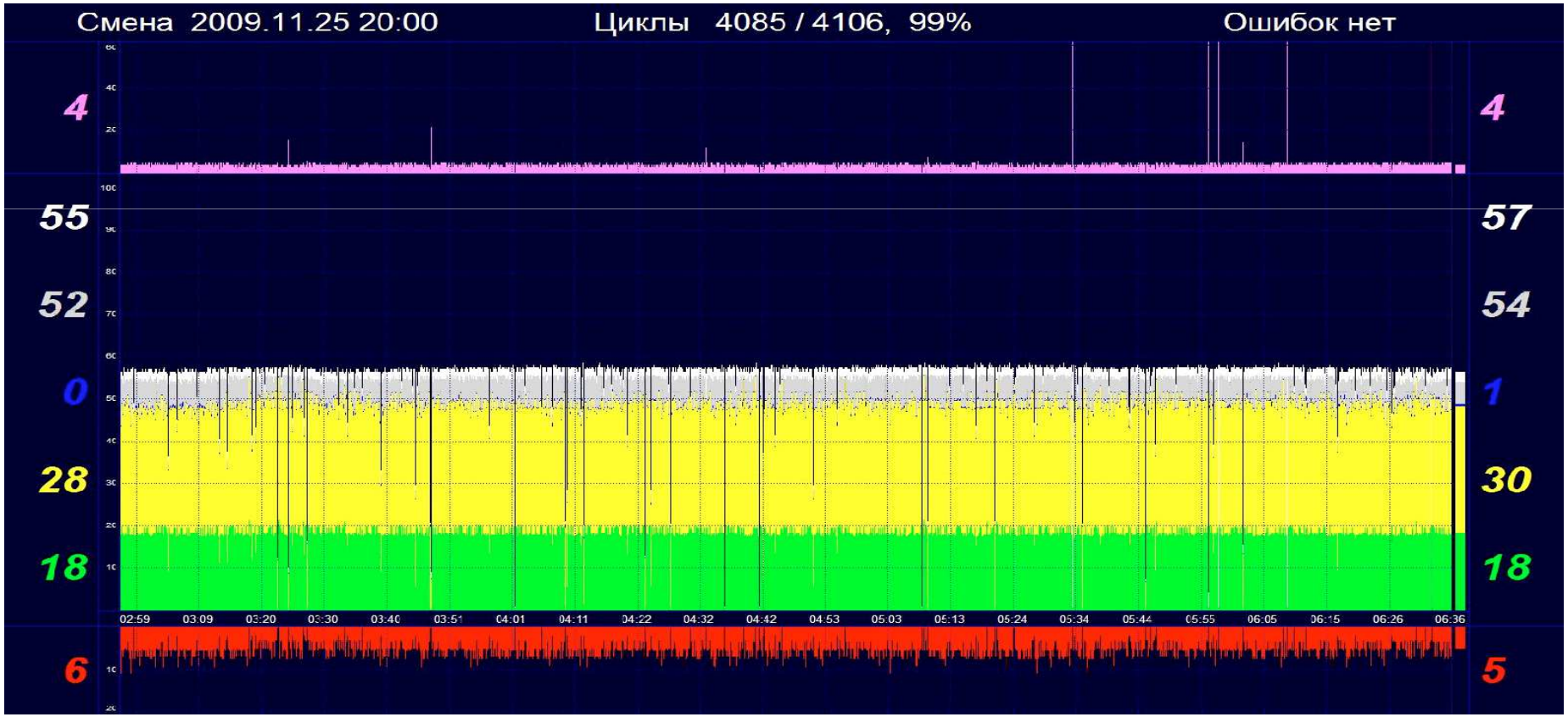
TYPICAL U-70 OPERATION

Statistics:

Two runs per year, 1000–1500 hours operation per run

50-70 GeV proton energy

90% beam availability for physics



3 hour of operation, 1000 cycles

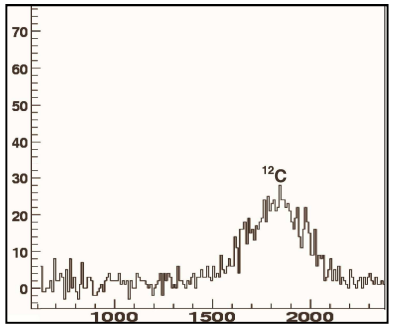
ACCELERATION OF LIGHT IONS

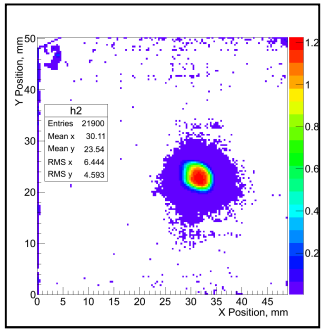
Modes of the U70 operation:

- Proton 50-70 GeV *URAL*30-*U*1.5-*U*70
- Light-ion (*d*, C) *I*100-*U*1.5-*U*70

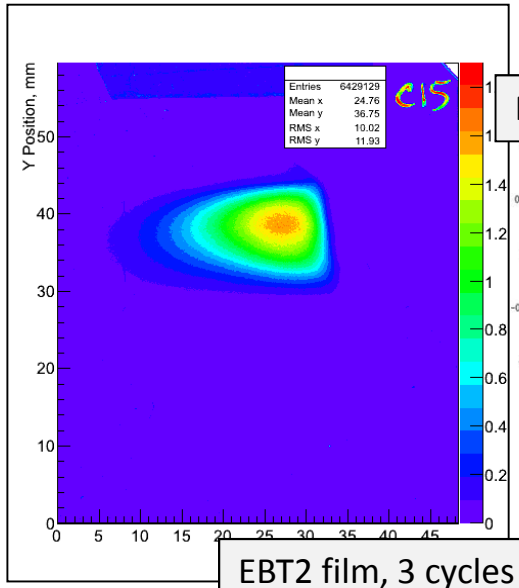
Light-ion:

- high energy 24.1-34.1 GeV/u
- intermediate energy 453-455 MeV/u

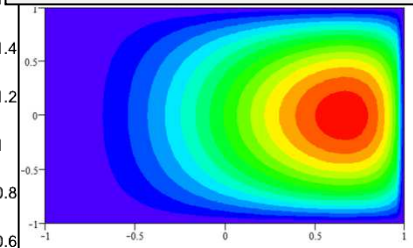




Amplitude spectrum of 300 GeV (full-*E*) carbon beam.
Ready for relativistic nuclear physics

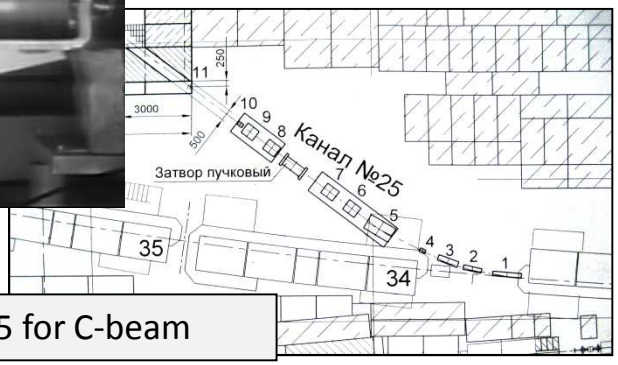


Foresight, calculations



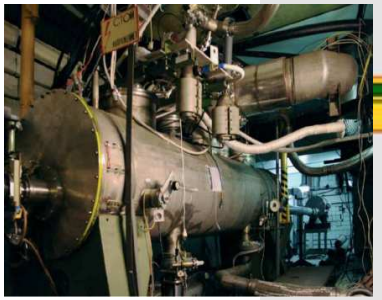
EBT2 film, 3 cycles of C beam, experimental footprint

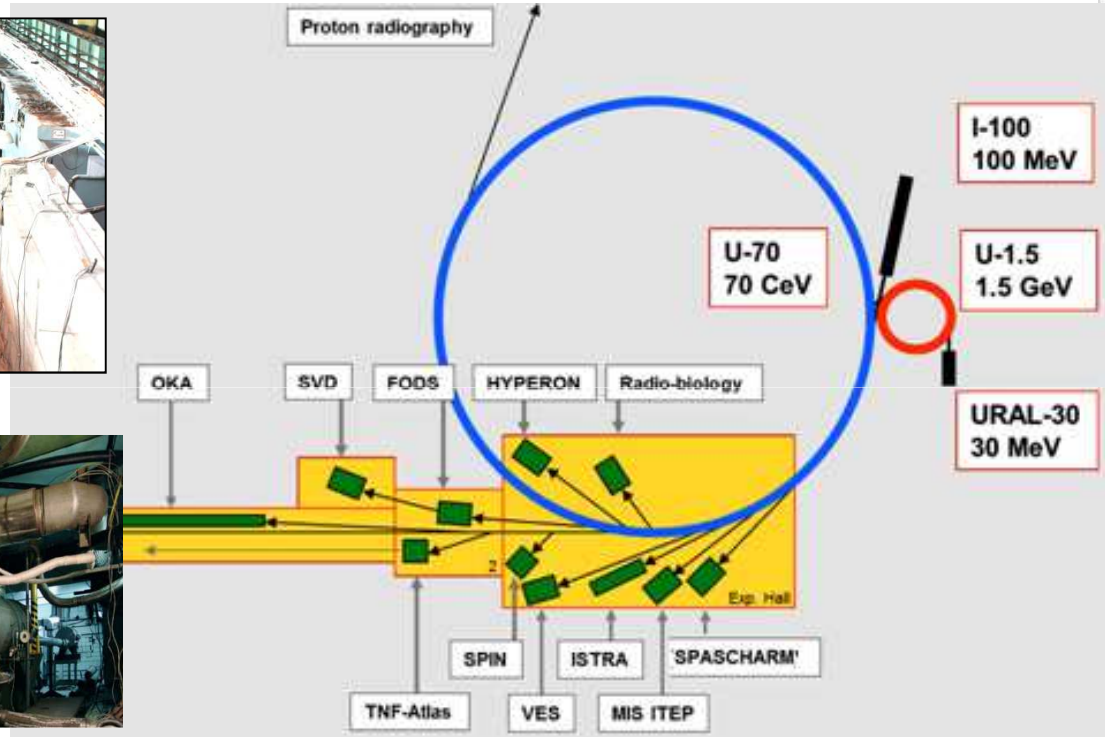
C beam Bragg's range in a sci. block

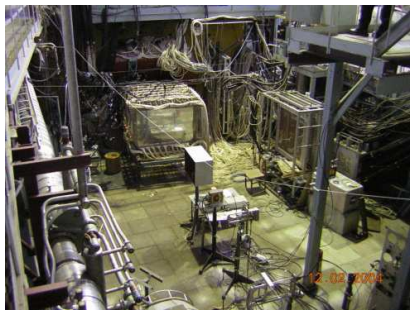


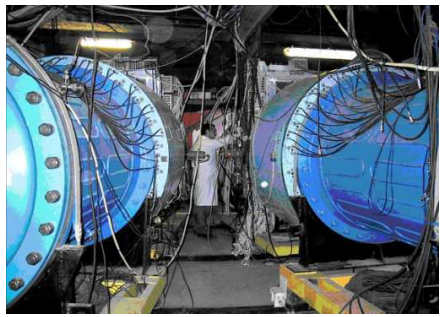
New BTL #25 for C-beam

Layout of IHEP accelerators and research facilities









E=70 GeV, (50 GeV)
I=1.7•10^{13} ppp (1.0•10^{13} ppp)
Beams : π+-, K+-, p, p̄, e+-, ^{12}C

- Fast extraction
- Slow extraction
- Extraction by crystal
- Internal targets

Research directions:

- hadron spectroscopy
- rare kaon decays
- spin asymmetries
- baryon matter
- multyboson systems
- nuclear physics
- ……
- proton radiography
- radiobiology
- radiation hardness
- beam optics with crystals
- R&D on detectors
- …….

R@D

Scintillators

Photomultipliers

Muon tomography

GaAs detectors

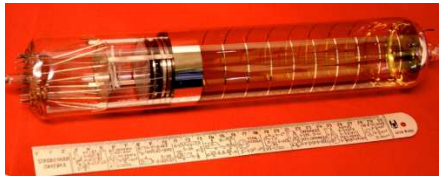
RFQ development

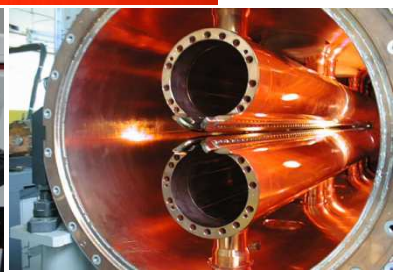
Beam optics

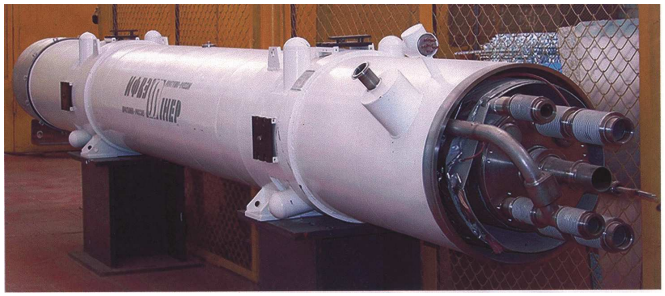
Superconducting systems

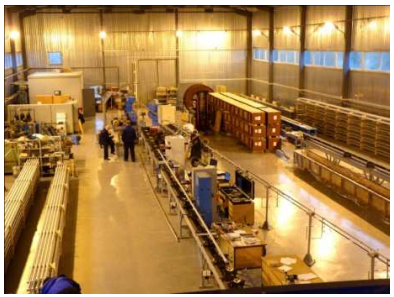
Superconducting cables

…….





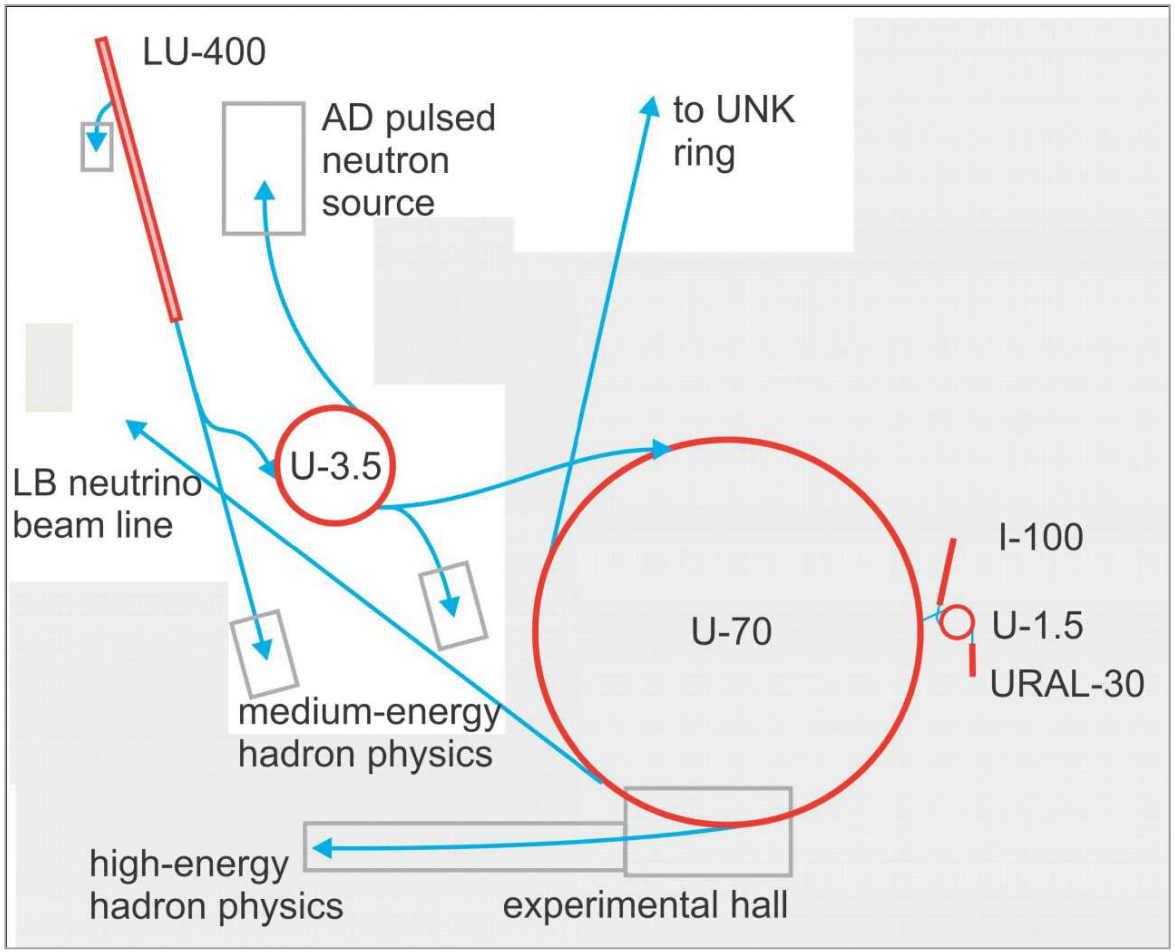




International collaborations

- USA
  - FNAL D0, MU2e
  - BNL PHENIX, STAR
- EUROPE
  - DESI XFEL , HERMES
  - FAIR PANDA
- CERN
  - LHC machine
  - ATLAS
  - CMS
  - LHCb
  - ALICE
  - COMPASS
  - DIRAC
  - NA 62
  - NA 64
- JAPAN
  - BELLE, BELLE II

FACILITY FOR INTENSE HADRON BEAMS (THE OMEGA PROJECT)



IHEP has put forward the design proposal "Facility for Intense Hadron Beams" (the OMEGA project).
This proposal aims a construction of a multipur-pose world-class accelerator facility with megawatt power proton beams in the energy range of 0.1 - 70 GeV to carry out a wide program of fundamental and applied researches.

Why MICE

The mounting a cooling demonstration with MICE at IHEP could be attractive for the laboratory:

- Modern facility
- International collaboration
- Diversification of an IHEP program
- Some potential for further development (6d etc)
- Scientific interest

Use of Ionization Friction in the Storage of Heavy Particles,

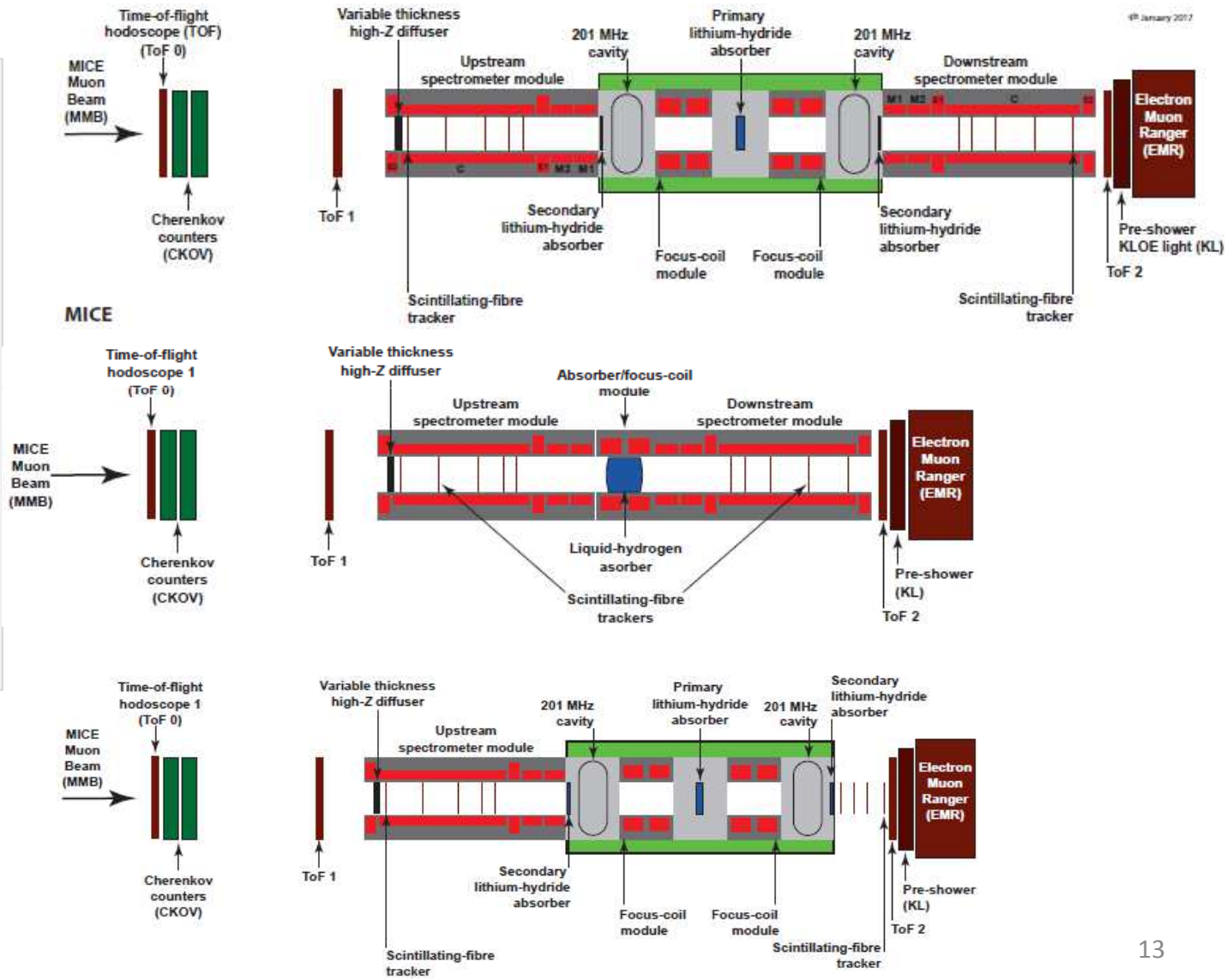
Yu.M. Ado and V.I. Balbekov, IHEP, *Sov. Atomic Energy 31, 731 (1971).*

The first published analysis to conclude that ionization cooling might actually work -- particularly if liquid hydrogen is used as the absorber.

Technical specifications

Requirements:

- Low energy muon beam
- Infrastructure to accommodate various variants of MICE facility



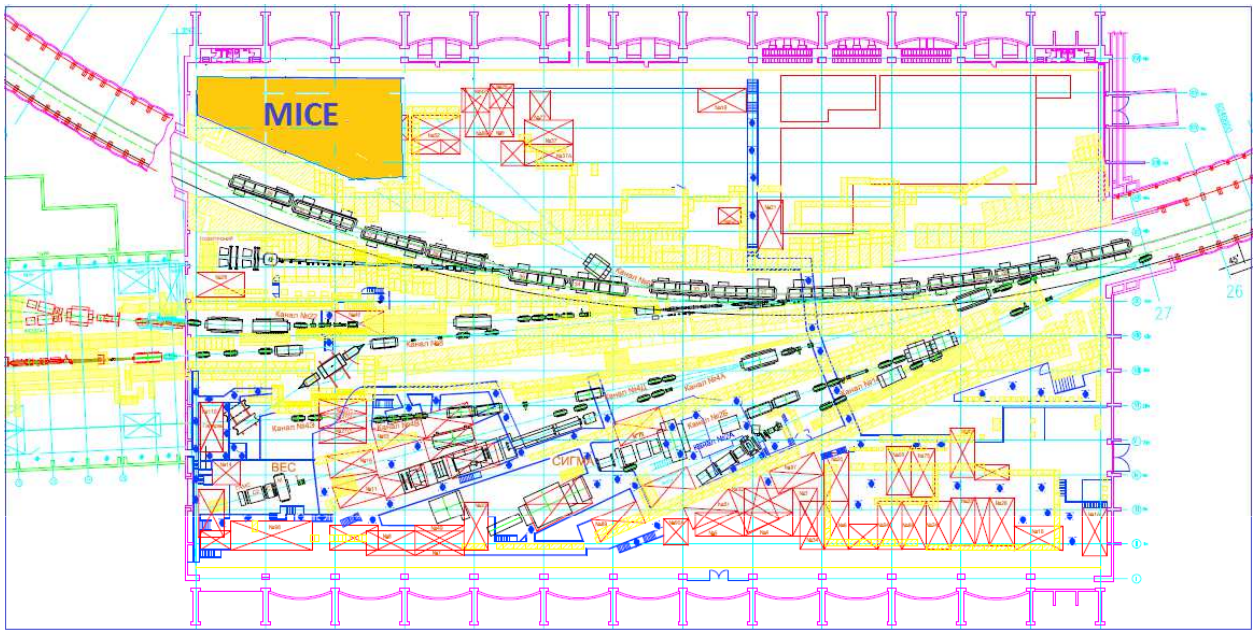
Principal parameters

Parameter	Unit	Value or comment
Δp	MeV/c	20
Vertical angular spread	rad	0.02–0.05
Horizontal angular spread	rad	0.02–0.05
Vertical emittance	mm	2–3
Horizontal emittance	mm	2–3
Intensity	μ/s	30–50 (depending on momentum)

Component	Power consumption	Comment
MICE Muon Beam	200 kW	Nominal
Cryo-coolers	200 kW	Nominal
Helium fridge	100 kW	
Air conditioning	350 kW	Five units, each of 70 kW
Roof mounted chiller/air blast cooler	350 kW	500–1000 l/min
Secondary chiller	175 kW	500 l/min
Pumps, heaters and services	100 kW	

Component	Weight	Comment
Soft iron magnetic flux return	30 t	
Spectrometer solenoid	8 t	Two off, weight per module
Focus coil magnet	4 t	Two off, weight per module
RF module	2 t	Two off, weight per module
Cryo compressor	0.1 t	20 off, weight per compressor

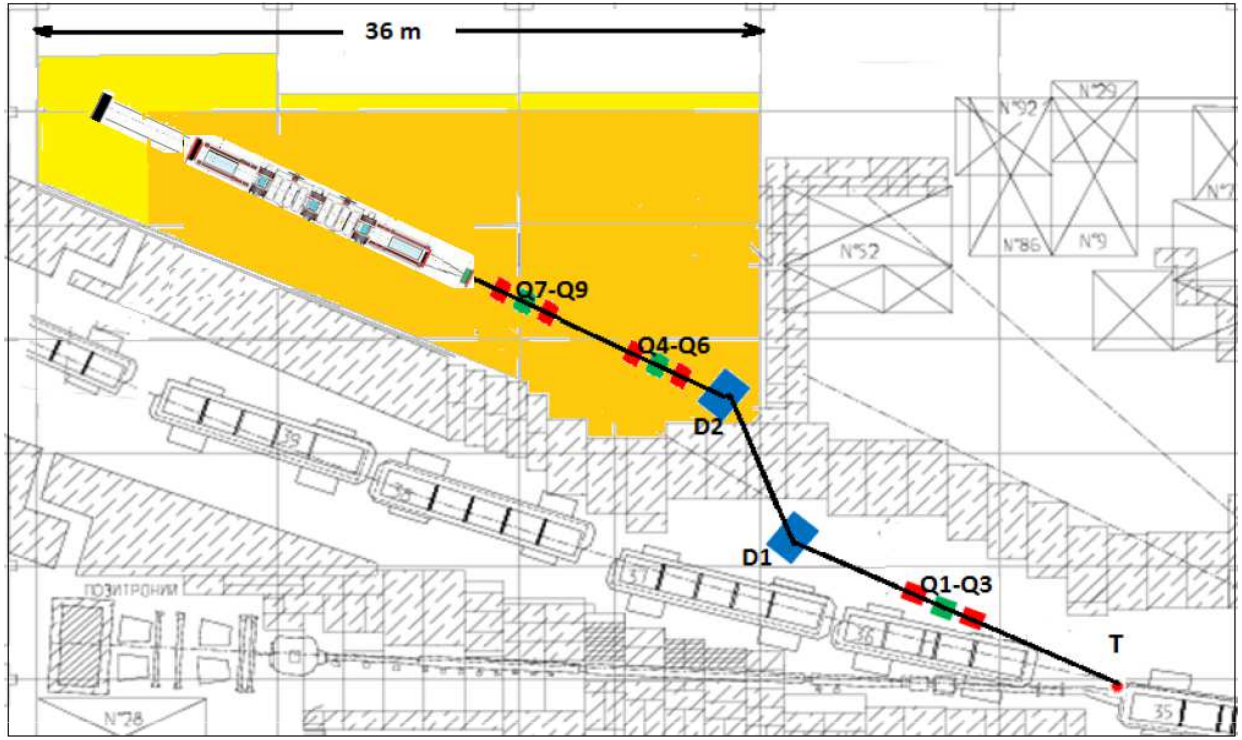
Layout



The area of the hall 156 · 90 m^2. The accelerator is covered with thick concrete shielding.
In the southern part of the hall there are channels of secondary particles from internal targets, channels for extracted proton beams, as well as part of experimental facilities. In the northern part there are two low energy channels.

The installation is proposed to be placed in the northwestern part of the hall. This choice is driven by following arguments:
–this area is sufficiently spacious to accommodate the MICE facility
–it is convenient for construction a low-energy muon channel
–the internal target can work in “shadow” mode in parallel with another users
–this area is “background free”
–currently, there is a moderate installation in this zone, which can be dismantled if necessary
– this zone is provided with the necessary infrastructure (cran, electrical power, LiH safety?).

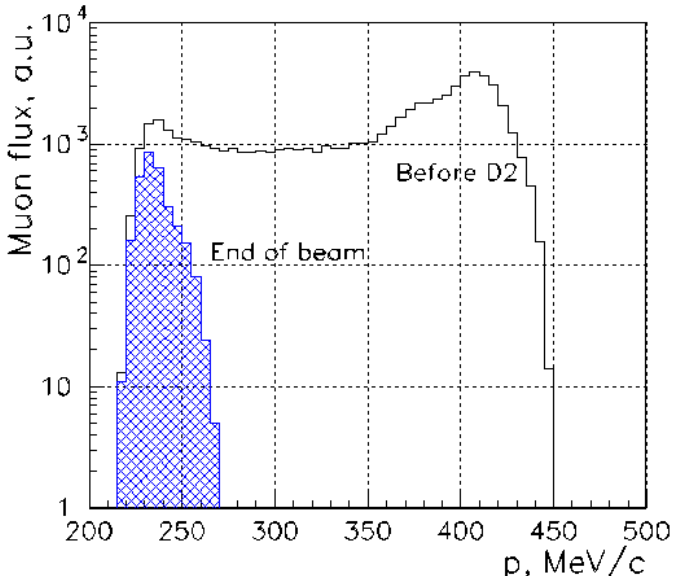
MUON BEAM



T : internal target,
Direction of the channel axis: 15°
Q1-Q3, Q4-Q9, D1, D2: equipment of the present MICE channel
Rotation angles in D1 and D2: 45^0
Distances: T -> D1 = 18.4 м, D1 -> D2 = 8.5 м, D2 -> EXP = 16 .1 м, T -> EXP = 43.0 м.
The solenoid is not used due to the complexity of its placement inside the thick shield

To calculate the spectra of secondary particles, we used the RTS&T-2004 code (*I.I. Degtyarev et al. Oct 2004. Prepared for Conference: C04-10-04.1, p.480-482]*).
For p_π = 410 MeV/c , θ = 15° it gives: $\frac{d^2N(\pi^+)}{dpd\Omega} = 7\times10^{-10}(\mathrm{MeV/c})^{-1}\mu\mathrm{sr}^{-1}(\mathrm{int.proton})^{-1}$

Specifications of a muon beam



p_π = 410 MeV/c

p_μ = 240 MeV/c, r.ms. = 8.4 MeV/c

$I_{\mu+} = 1.2\times10^{-8}$ μ/interacting proton

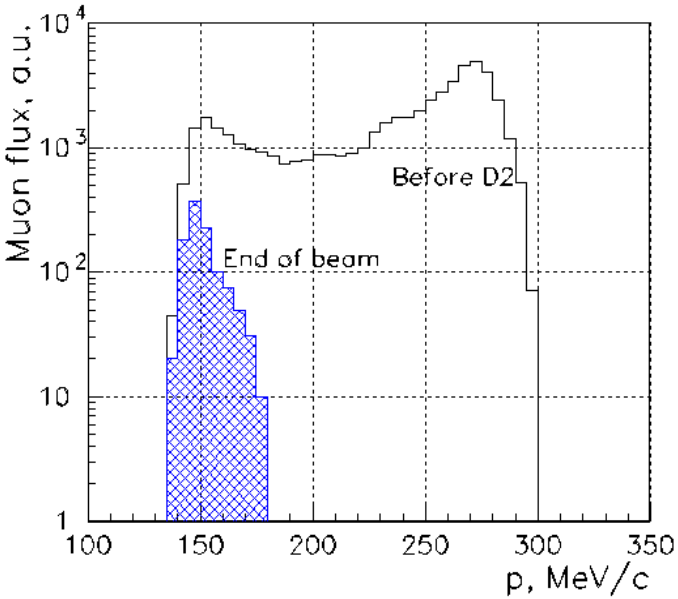
It leads to following intensity:

$I_{\mu+} = 5\times10^{3}$ μ/cycle in "active" mode

$I_{\mu+} = 1\times10^{3}$ μ/cycle in a "shadow" mode

$\varepsilon_H = 4.5\ \pi$ мм, $\varepsilon_V = 1.2\ \pi$ мм

r.m.s. $_H$ × r.m.s. $_V$ =47 × 43 mm^2



p_π = 270 MeV/c

p_μ = 151 MeV/c, r.ms. = 8.1 MeV/c

$I_{\mu+} = 0.3\times10^{-8}$ μ/interacting proton

It leads to following intensity:

$I_{\mu+} = 1.2\times10^{3}$ μ/cycle in "active" mode

$I_{\mu+} = 3\times10^{2}$ μ/cycle in a "shadow" mode

$\varepsilon_H = 4.4\ \pi$ мм, $\varepsilon_V = 1.1\ \pi$ мм

r.m.s. $_H$ × r.m.s. $_V$ =50 × 45 mm^2

Interactions with FA and other bodies

We reported to NRC KI, our head organization, about our interest in implementing the MICE project at IHEP. The information is taken into account.

We proposed to include the MICE project in the list of joint projects with CERN for implementation in Russia. The proposal was accepted by the Ministry of Education and Science and presented to CERN in April 2017. This and other proposals are scheduled for consideration in October 2017.

Conclusion

- Cooling demonstration with MICE at IHEP could be attractive for the laboratory
- There is a suitable area for placing the installation in the main experimental hall
- Basic infrastructure parameters satisfy the requirements of the experiment
- The parameters of the muon beam satisfy the experimental requirements
- Decision bodies tend to positive reaction
- The preparation of a zone and the installation of a channel will take about one and a half years and budget some 250 kEuro