Current progress in the NICA project

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VBLHEP of JINR, Dubna, Russia

(News after the middle of the 2017 year)

Content

1. **Introduction:** ***(to remind: what is the NICA project?)***
2. **Status of the main collaborations**
3. **Progress in works on the NICA Civil Construction**
4. **Progress in the machine upgrade**
5. **Progress with beams for users**
6. **Progress with detectors and with the first physical data taking (within the NICA project) …**
   a) **BM@N**
   b) **SRC at BM@N** ***(new experiment)***
7. **Summary and a remark…**

Introduction

(to remind: what is the NICA project?)

Relativistic Heavy Ion Physics is a high priority task in many scientific centers (BNL, CERN, GSI) since last few decades

This physics is under discussion in Japan (J-PARC) and in China (HIAF project) as well;

as an example - one recent event :

the JINR-IMP CAS Workshop on NICA and HIAF Projects took place an VBLHEP of JINR *(May 14-15, this year)*.

The present JINR plan includes:

start in the coming 2÷4 years experimental studies of hot and dense, strongly interacting QCD matter

as well as

search (in heavy ions collisions) for possible manifestations of the "mixed phase" and the critical endpoint at the phase diagram.

The instrumental basis for these studies:

NICA Collider **(including modes with polarized *d* and *p* beams) with multipurpose detectors *MPD* and *SPD*,**

Nuclotron-M **(including modes with polarized *d* and *p* beams, extracted to the *BM@N* and other "fixed target" spectrometers),**

external facilites **at CERN (SPS, LHC), RHIC, FAIR etc.**

Main directions of studies with the relativistic heavy ions:

Probing of different regions of the phase diagram for hot *and dense* hadronic matter:

- **Phase transitions**
  - **Baryonic to hadronic and QCD (quark-gluon) matter**
  - **Critical endpoint (exists or not); mixed phase**
  - **Liquid-to-fog (at the condensing-hadronization stage 3)**
- **Exotic nuclei (hypernuclei ; stabilizing role of strangeness implemented into a nuclear matter)**

Other physics within the NICA: *Spin and polarization phenomena*

- **nucleon structure, phenomenology of the nucleon-nucleon interactions**
- **few nucleon systems at short distances (probe of sub-nucleonic aspects; multinucleon forces etc.)**

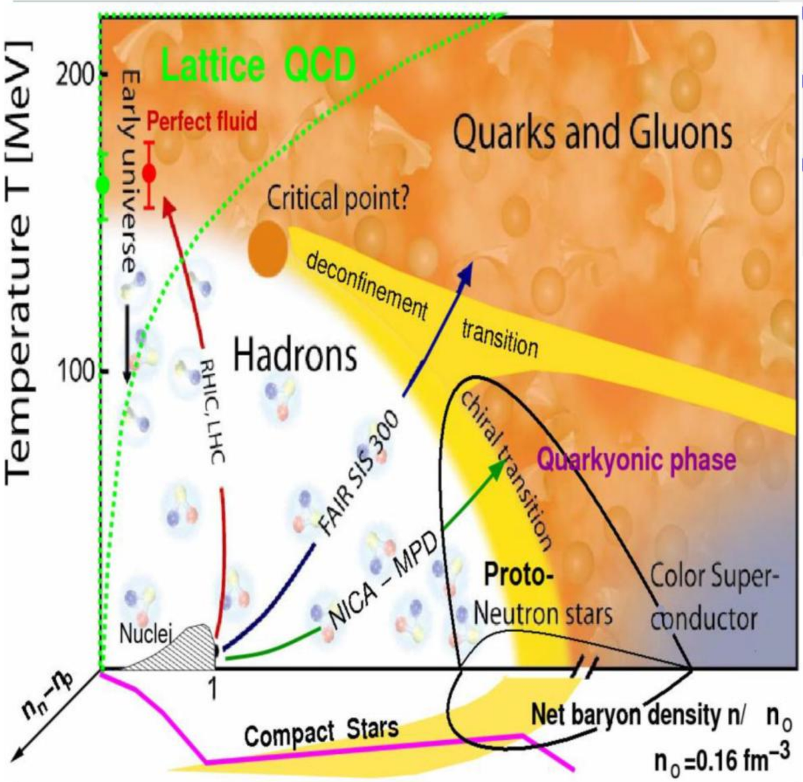
***Flavour physics*, i.e.**

***Fundamental symmetries* and mechanisms of their violation**

***Particle structure* (constituents, quark content) in empty space and in the strongly interacting medium, exotics)**

***Particle properties in medium* (cold and normal/sparse; hot and dense)**

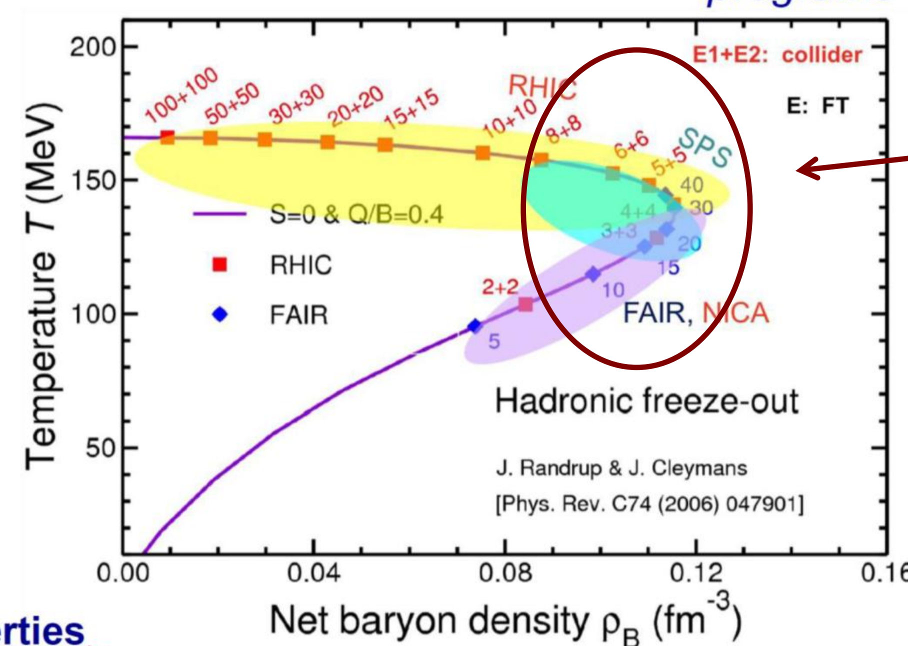
Physics



QCD matter at NICA :

- *Highest net baryon density*
- *Energy range covers onset of deconfinement*
- *Complementary to the RHIC/BES, FAIR and CERN experimental programs*

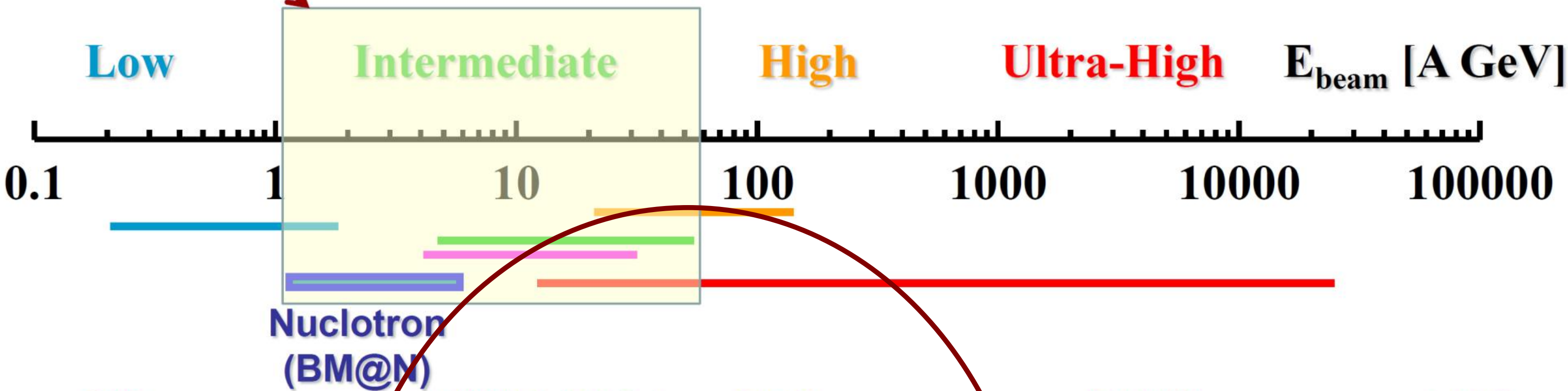
Freeze-out conditions



- **Bulk properties, EOS** - *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement (chiral), phase transition at high ρ_B** - *enhanced strangeness production*
- **QCD Critical Point** - *event-by-event fluctuations & correlations*
- **Strangeness in nuclear matter** - *hypernuclei*

NOTE: a particle must live "long enough" inside the medium!

NICA Heavy Ion Collision experiments

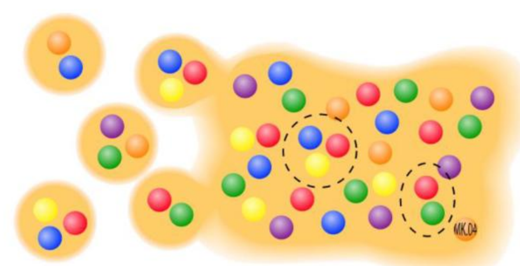


SIS | FAIR NICA | SPS | RHIC | LHC

Baryonic matter
||
Meson and baryon spectroscopy
In-medium effects
EoS

‚Mixed' phase: hadrons (baryons, mesons) + quarks and gluons
||
In-medium effects
Chiral symmetry restoration
Phase transition to sQGP
Critical point in the QCD phase diagram

QGP: quarks and gluons
||
Properties of sQGP



The NICA Project: recent review papers

See also

https://ufn.ru/en/articles/2016/4/

Physics – Uspekhi **59** (4) 383 – 402 (2016)

60th ANNIVERSARY OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH (JINR) PACS numbers: **11.80.–m**, 13.85.Dz, 14.20.Dh

Relativistic nuclear physics at JINR: from the synchrophasotron to the NICA collider

N N Agapov, V D Kekelidze, A D Kovalenko, R Lednitsky, V A Matveev, I N Meshkov, V A Nikitin, Yu K Potrebennikov, A S Sorin, G V Trubnikov

DOI: 10.3367/UFNe.0186.201604c.0405

and Eur. Phys. Journal A "Hadrons and Nuclei", 52 N8 (2016), ed. by D.Blaschke, J.Aichelin, E.Bratkovskaya et al (special issue).

Physics: program and suggestions see in

http://theor0.jinr.ru/twiki-cgi/view/NICA/WebHome

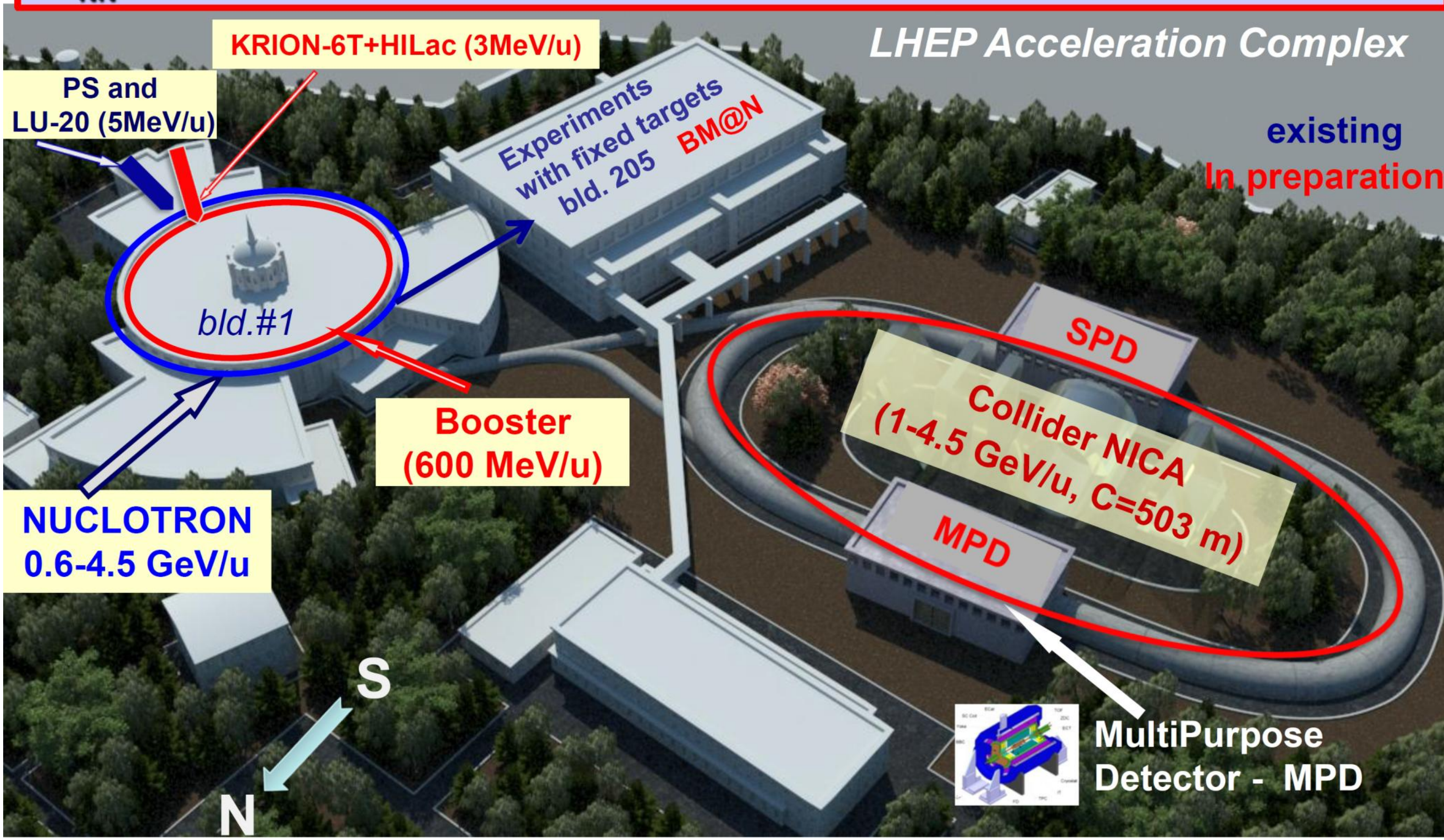
NICA White Paper – International Effort

NICA complex

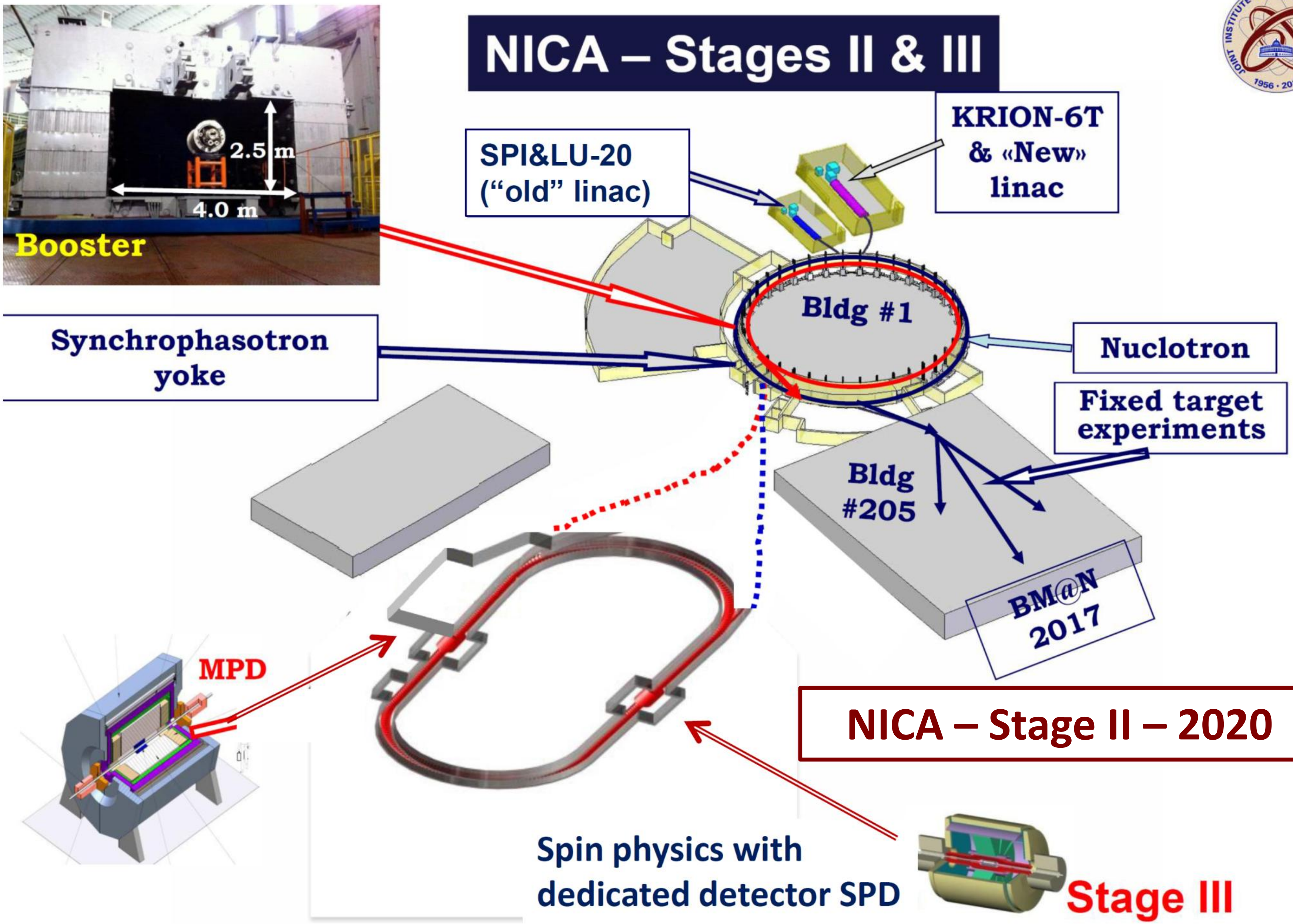
(reminder)

Collider basic parameters:

$\sqrt{s_{NN}}$ = **4-11** GeV; ***beams**: from* **p** to **Au**; **L**~10^{27} cm^{-2} c^{-1} (Au), ~10^{32} cm^{-2} c^{-1} (p)



Introduction *(reminder)*

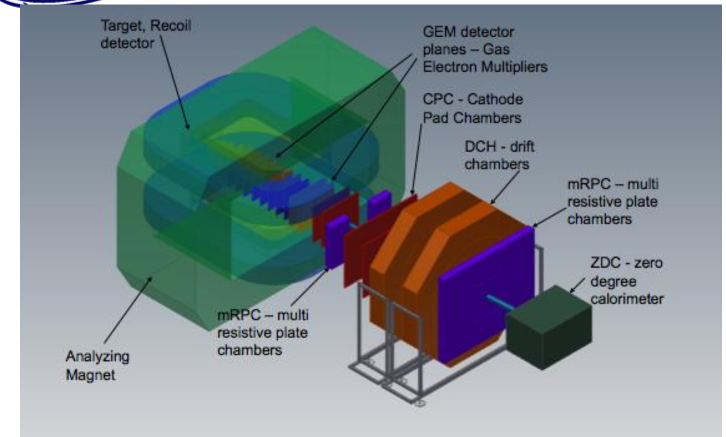


Complementarity between the collider-type and fixed-target type experiments

Simple kinematical consideration immediately shows,
that close to extremes (extremal multiplicities, extremal 4-momentum transfers, extremal missing masses),
any collider experiment cannot provide answers in principle:
only well planned "fixed target" experiments
can produce relevant data!
(see my talk at 11-th APCTP-BLTP Workshop in 2017, Peterhof)

Therefore the experiments with fixed targets
(the BM@N first of all)
at extracted Nuclotron beams
are important parts of the NICA project.

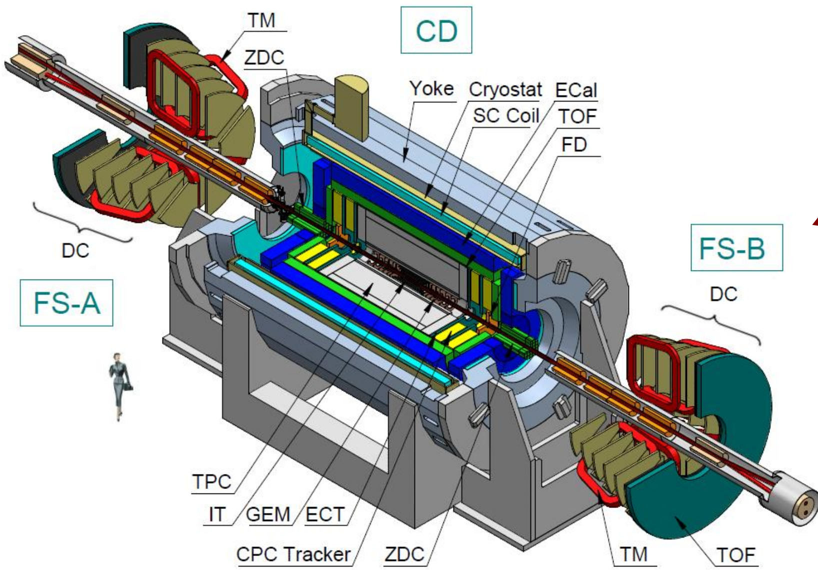
NICA Collider DETECTORS



Baryonic Matter at Nuclotron (BM@N)

the fixed target experiment at the Nuclotron

start of Stage I - 2017-/ 2018



MultiPurpose Detector (MPD)

at the Collider

start of Stage I - 2020

Spin Physics Detector (SPD) start of Stage I **- after 2023 (?)**

project is under preparation for submission to the JINR PAC in 2019

(II)

Status of the main collaborations

"Results of the first collaboration meeting of MPD and MB@N experiments at NICA"

Talk by V.D. Kekelidze at 49th meeting of the PAC for Particle Physics (June 2018)

The kick-off meeting on formation of the MPD and BM@N Collaborations

took place in Dubna on 11-13 April, 2018.

detailed information about the meeting can be found at:
https://indico.jinr.ru/conferenceDisplay.py?confId=385

Participants

192** participants form **18** countries (incl. **155** from **Russia**); **110** – from **JINR.

***Number** of organizations:*

BULGARIA	**1**	**MEXICO**	**1**
CHILE	**1**	**MOLDOVA**	**1**
CHINA	**3**	**POLAND**	**4**
CZECH REPUBLIC	**2**	**RUSSIA**	**13**
FRANCE	**1**	**SLOVAKIA**	**1**
GEORGIA	**1**	**SOUTH AFRICA**	**1**
GERMANY	**3**	**SWITZERLAND**	**1**
ISRAEL	**2**	**UKRAINE**	**2**
KAZAKHSTAN	**1**	**USA**	**1**

*Later on **two** more organizations expressed an interest:*
from **EGYPT** *and* **ARMENIA**

Participating organizations joined to the collaborations:

Baku State University, National Nuclear Research Center, ***Azerbaijan;***
University of Plovdiv, ***Bulgaria;***
University Tecnica Federico Santa Maria, Valparaiso, ***Chili;***
Tsinghua University, Beijing, ***China;***
USTC, Hefei, ***China;***
Huizhou University, Huizhou, ***China;***
Shandong University, Shandong, ***China;***
Institute of Nuclear and Applied Physics, CAS, Shanghai, ***China;***
Central China Normal University, ***China;***
Institute of High Energy Physics, Beijing, ***China;***
University of South China, ***China;***
Palacky University, Olomouc, ***Czech Republic;***
Nuclear Physics Institute CAS, Rez, ***Czech Republic;***
Tbilisi State University, Tbilisi, ***Georgia;***
Tubingen University, Tubingen, ***Germany;***
Tel Aviv University, Tel Aviv, ***Israel;***
Institute of Physics and Technology, Almaty, ***Kazakhstan;***
UNAM, Mexico City, ***Mexico;***
Institute of Applied Physics, Chisinev, ***Moldova;***
Warsaw University of Technology, Warsaw, ***Poland;***
National Center for Nuclear Research, Otwock – Swierk, ***Poland;***
University of Wroclaw, Wroclaw, ***Poland;***
Jan Kochanowski University, Kielce, ***Poland;***
INR RAS, Moscow, ***Russia;***
MEPhI, Moscow, ***Russia;***
PNPI, Gatchina, ***Russia;***
Skobeltsin Institute of Nuclear Physics MSU, Moscow, ***Russia;***
SPSU - Dept. of NP, St. Petersburg, ***Russia;***
SPSU – Dept. of HEP, St. Petersburg, ***Russia;***
Kurchatov Institute National Research Center, Moscow, ***Russia;***
MIT, Cambridge, ***USA;***

JINR, Dubna*.*

Progress in works on the NICA Civil Construction

NICA Collider area (Jan. 2017)

NICA Collider area (May 2017)

NICA Collider area (June 2017)

NICA Collider area (August 2018)

Reminder:

Some last year news, concerning realization of the NICA project (fixed targets part), had been reported at the previous APCTP-BLTP Workshop (in Peterhof):

(1) Renewal of the polarized deuteron beam at the LHEP of JINR (result of the year 2016)

(2) JINR has got the relativistic polarized proton beam, accelerated in the Nuclotron up to 2 GeV kin. energy

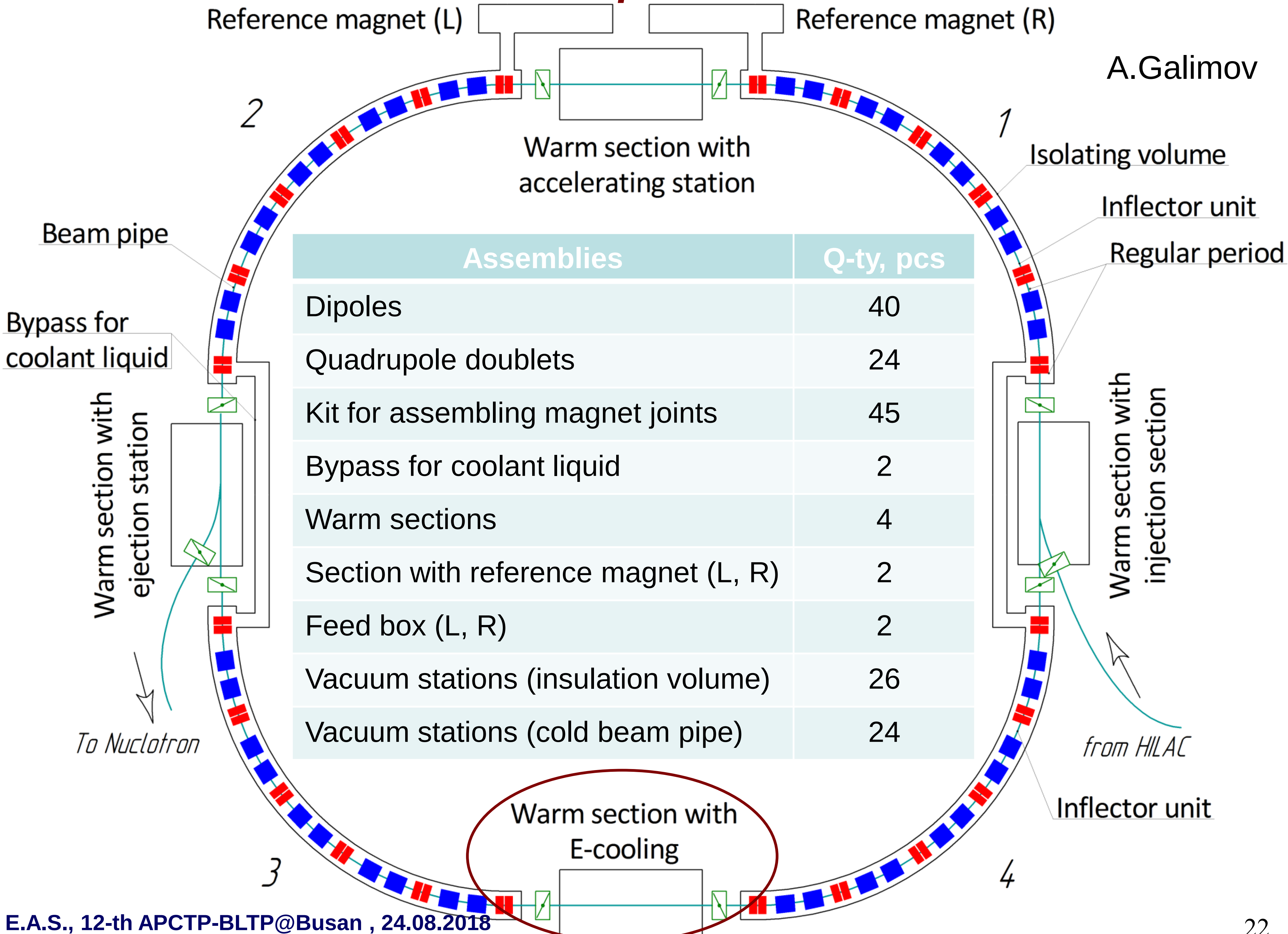
(*the result of the year 2016; such beam of polarized protons JINR has got at first time in its history* …)

Progress in the machine upgrade

(Booster, Injector complex etc.)

From talks by A.O.Sidorin, at PP PAC, JINR (January 2018 and June 2018)

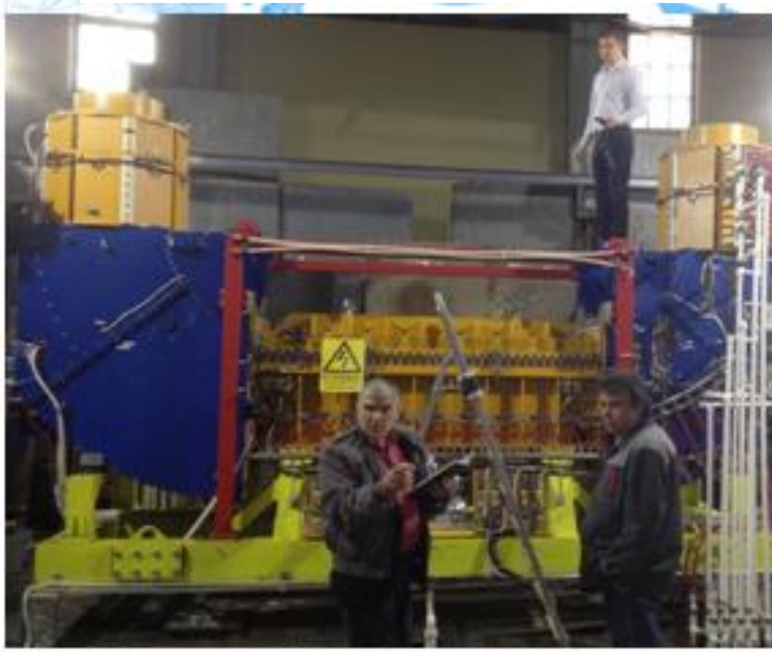
Scheme of the booster

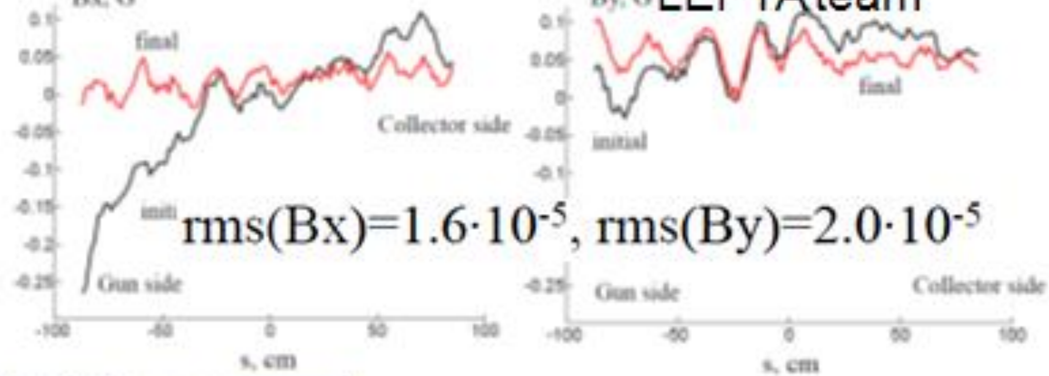


Assemblies	Q-ty, pcs
Dipoles	40
Quadrupole doublets	24
Kit for assembling magnet joints	45
Bypass for coolant liquid	2
Warm sections	4
Section with reference magnet (L, R)	2
Feed box (L, R)	2
Vacuum stations (insulation volume)	26
Vacuum stations (cold beam pipe)	24

Comissioning of the Electron Cooling System

V.Parkhomchuk,
B.Reva (BINP)
A.Smirnov,
LEPTA team





$$rms(Bx)=1.6\cdot10^{-5},\ rms(By)=2.0\cdot10^{-5}$$

Vacuum pressure, Pa	3×10^{-9}

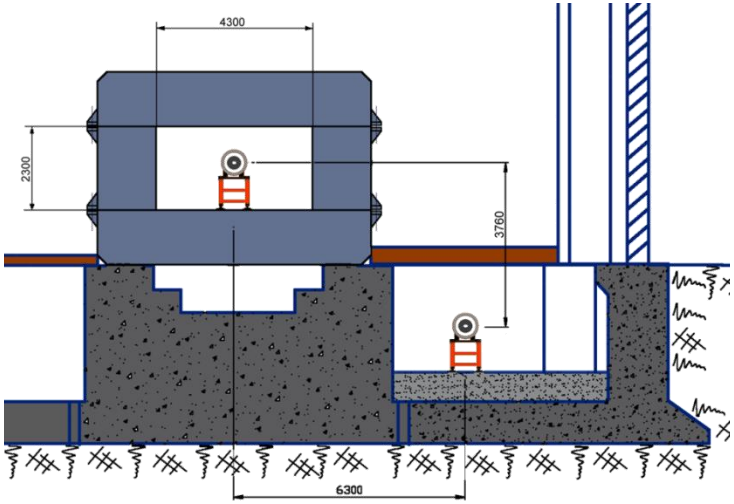
Preparation for the Booster assembly

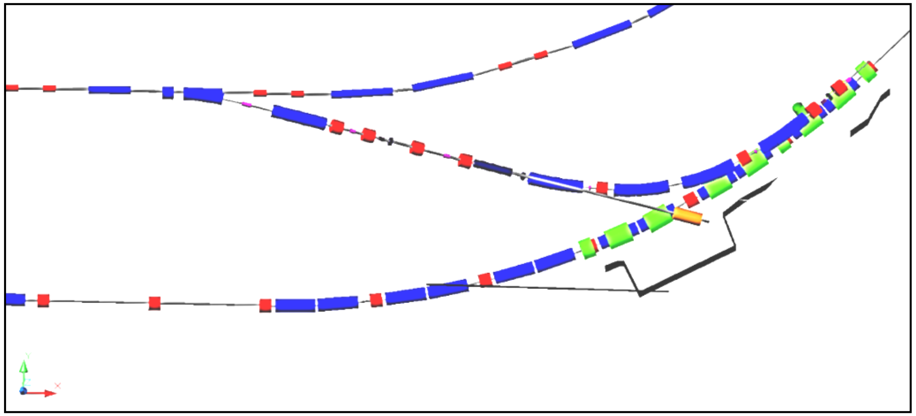
From talk by A.O.Sidorin at PP PAC, JINR, Dubna, 18 June 2018

-Serial production of the magnets for the NICA booster *is completed*

-All of the dipole magnets for the NICA booster *have been passed* successfully *the Cryogenic tests* and can be installed in the tunnel of the accelerator

-Completing the cold tests and start of installation of the booster elements in the designed places *is scheduled for the Fall of 2018*.

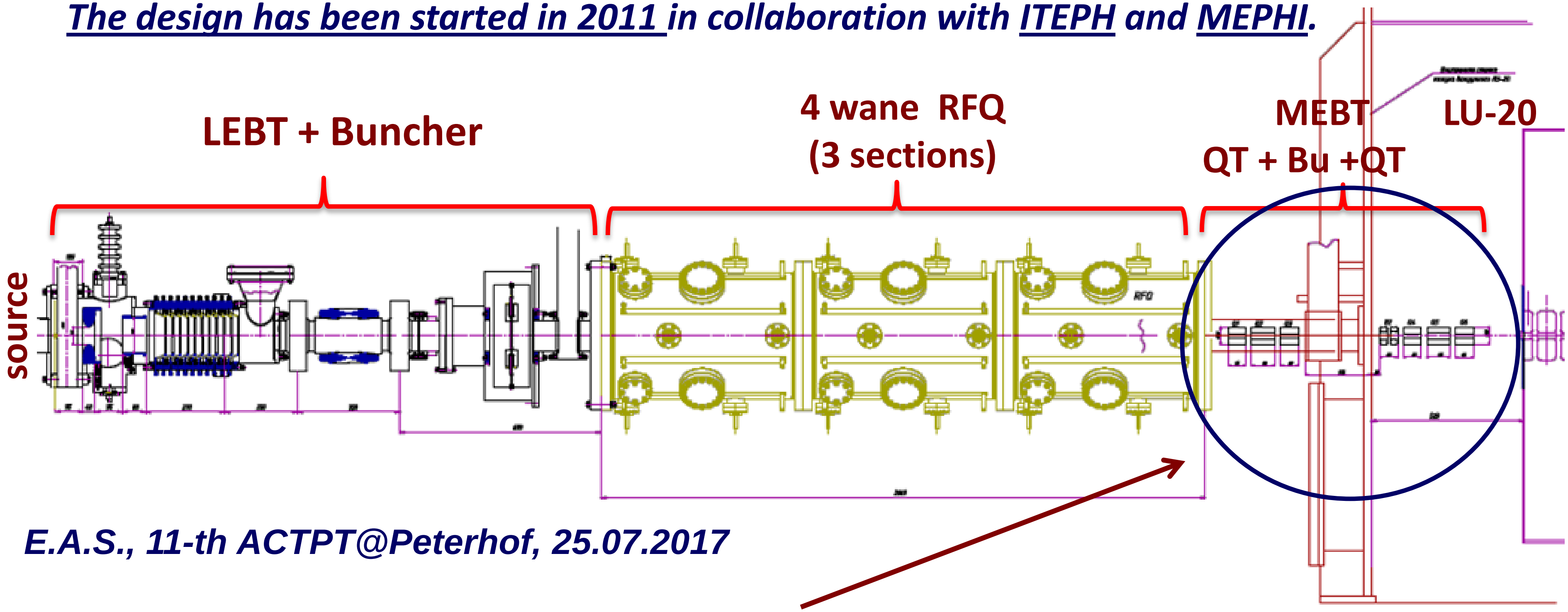




Commissioning – December 2019

New fore-injector for LU-20

<u>The design has been started in 2011</u> in collaboration with <u>ITEPH</u> and <u>MEPHI</u>.



E.A.S., 11-th ACTPT@Peterhof, 25.07.2017

The LEBT, RFQ and Medium energy beam transport (MEBT) were assembled in March – May 2016

The MEBT includes two triplets of quadrupole lenses and the *Buncher*

The new High-Voltage platform was assembled

In the configuration of the 1-st quarter of 2017 y.,
the Buncher was absent (Transmission ~ 20%)

Tuning of the ion source and the injection chain

A.Sidorin, at PP PAC, JINR, Dubna, 18 June 2018

Tuning of the KRION-6T at test bench

E.D.Donets, E.E.Donets

From April of 2017 to the October: optimization of the string formation for generation of the Ar^{16+} and Kr^{26+} ions; from October of 2017 – start of tuning the source at its place (at LU20)…

Buncher tuning and installation (April 2017)

ITEP, Chernogolovka, A.Butenko, A.Govorov

From June to September: LU-20 run with the laser source

Use of *the buncher* allowed to increase the Ar beam Intensity (at the injection point to the Nuclotron) by a factor of about 5 !…

Progress with beams for users
(after the Nuclotron Run in 2018)

Run 55 of the Nuclotron

22.02.2018 – 05.04.2018

total duration: 1018 hours

Beams: C, Ar, Kr from the KRION-6T source.

Data taking:

- ***"SRC at BM@N" project***
- ***BM@N project***
- ***In the "second priority" mode and in the parasitic mode: R&D of other users***

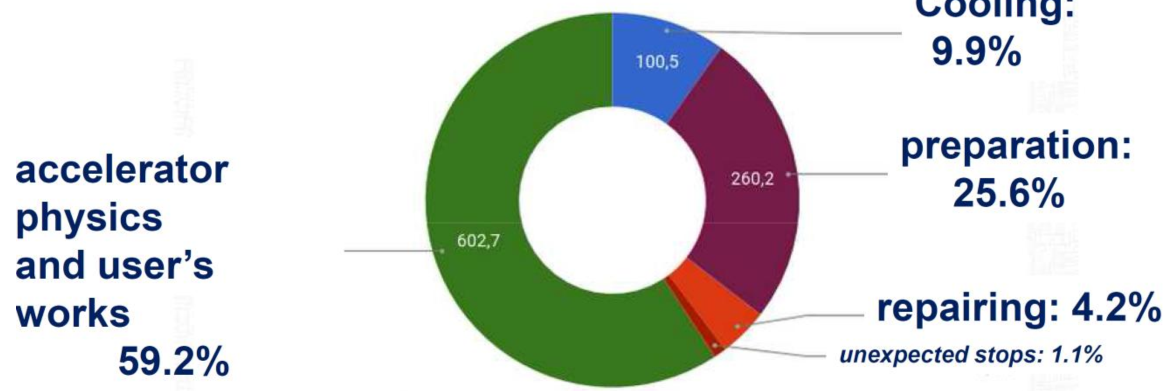
Within the BM@N (Kr) physics part:

works for radiation biology (by LRB of JINR)

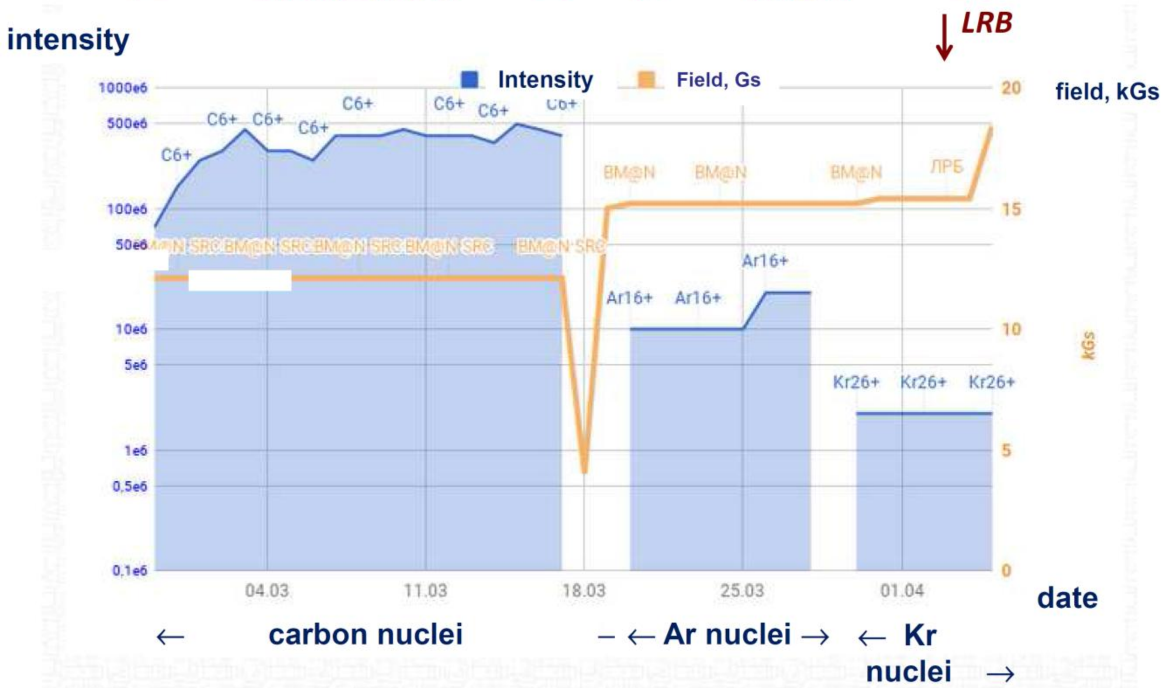
From talks by E.A.S., A.O.Sidorin, M.N.Kapishin and E. Piasetzky at PP PAC, JINR (January 2018 and June 2018)

Run 55 of the Nuclotron (22.02.2018 – 05.04.2018)

The total run duration: 1018



← SRC at BM@N → ← BM@N →



At the JINR PP PAC (June 2018):

BM@N results have been presented in the talk by M.Kapishin;

SRC at BM@N results have been presented in the talk by E.Piasetzky.

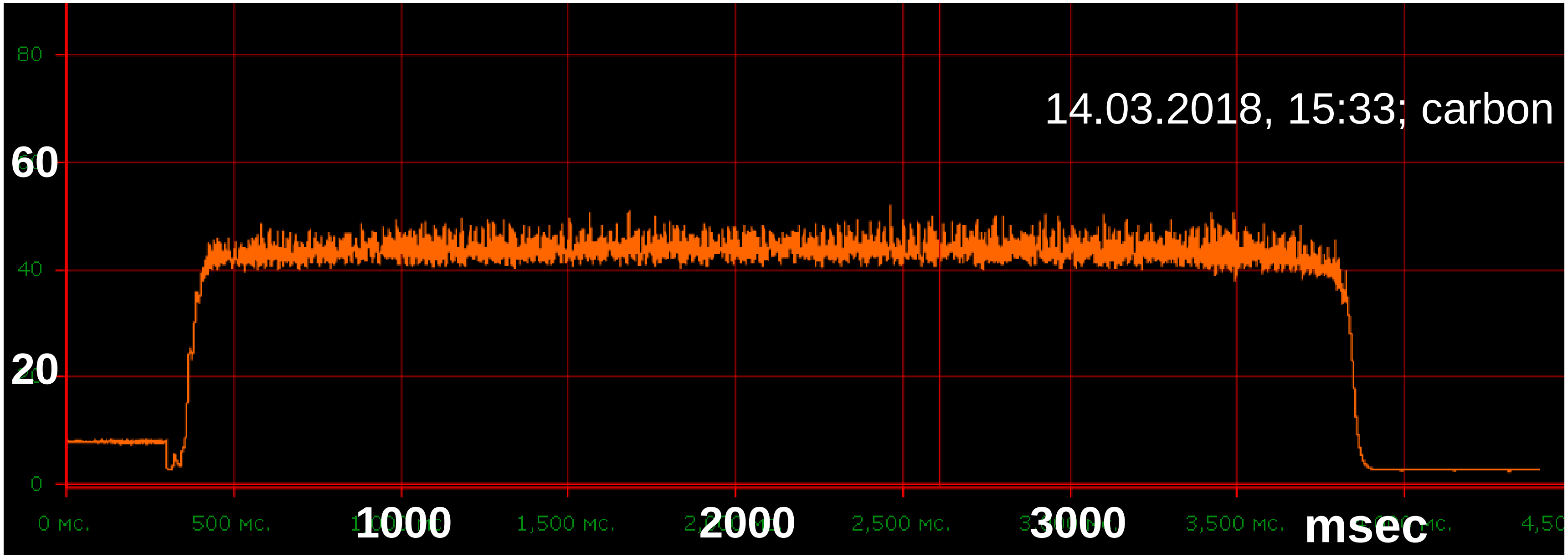
In total, users are satisfied by the machine work.

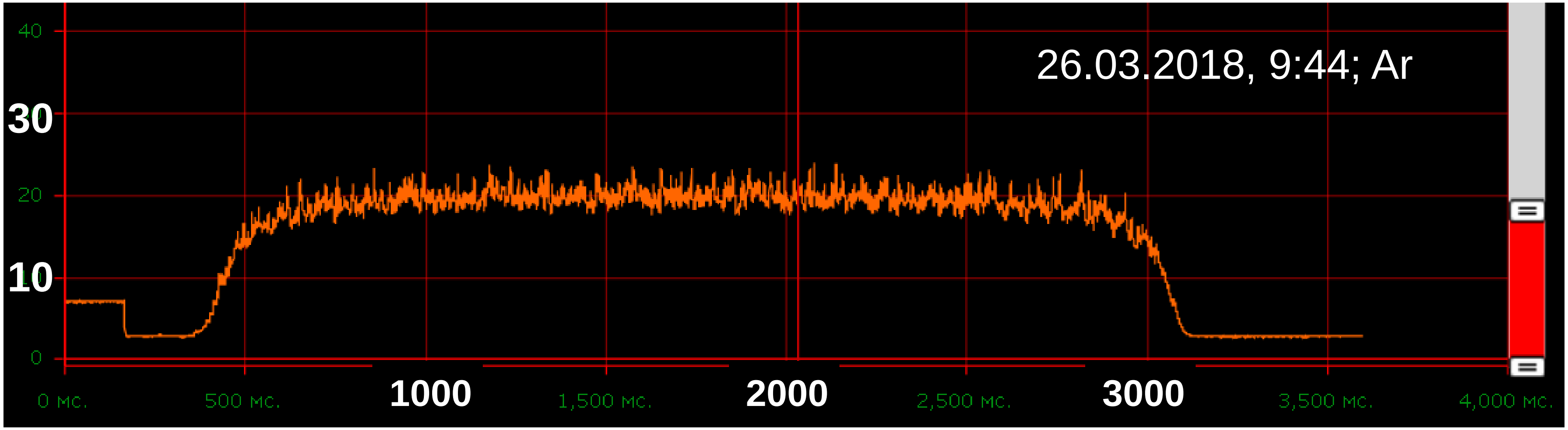
Users are especially satisfied by the very good result, obtained by our accelerator physicist, improved significantly the time structure of the beam spill.

(see next few slides)

All this became was realized by hard works on adjusting at high intensity the beam injection, adiabatic capture, orbit corrections and the beam acceleration; some newly developed machine diagnostics tools were used as well.

Present time structure of the extracted beam spill (a)



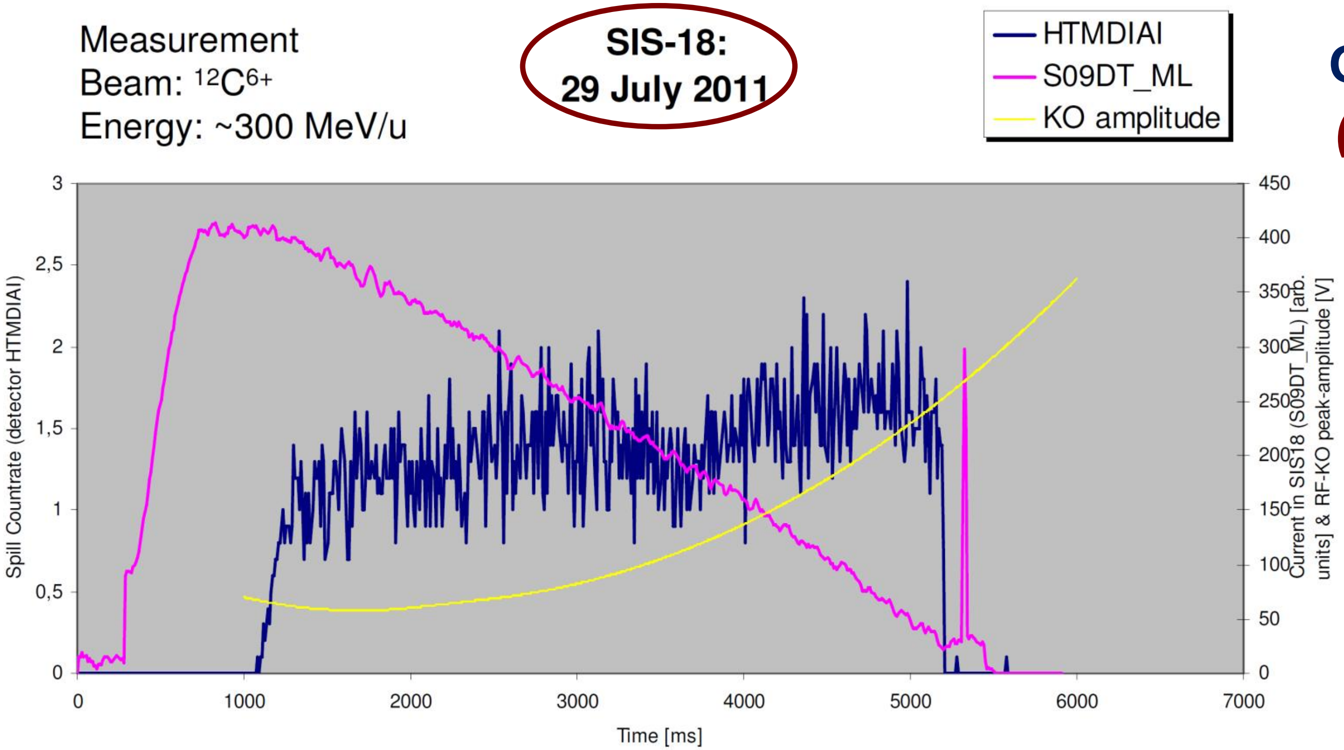


For comparison: see what was before …

Time structure of the extracted beam spill (b)

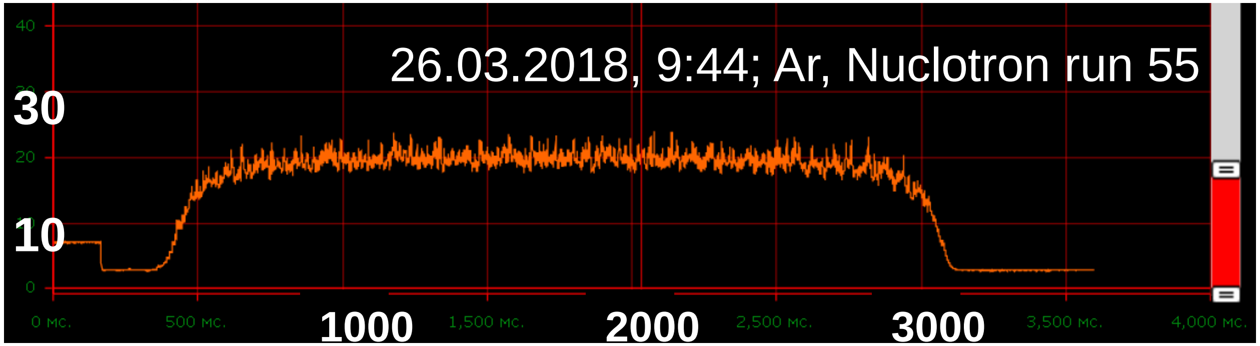
from: M. Kirk, Beschleuniger Palaver, GSI, 19th Jan 2012

Beam Intensity Control – Feedforward

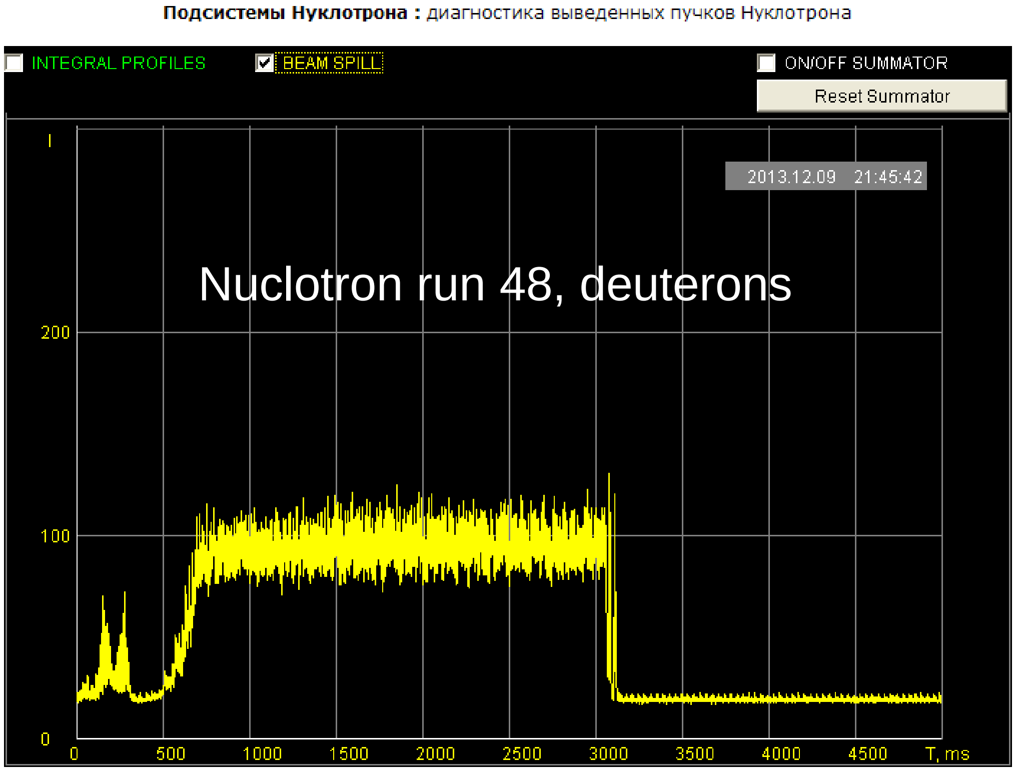


Other machines
(GSI, 2011 year)

Nuclotron,
March of 2018 year



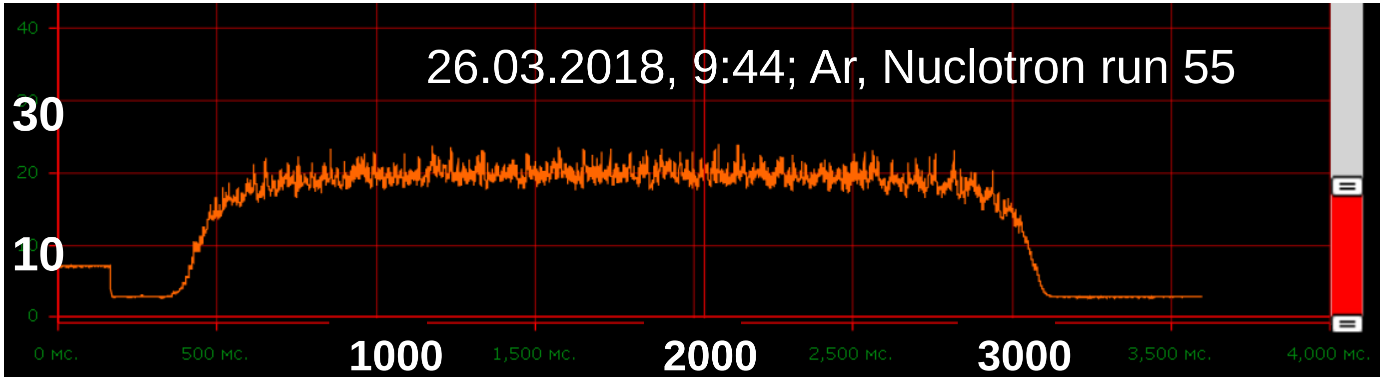
Past and present time structure of the extracted beam spill (c)



Screen-shot from: 09.12.2013; 21:45

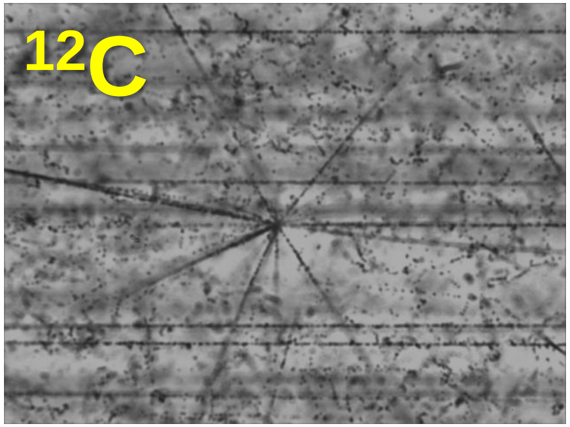
Nuclotron, Dec. of 2013 year

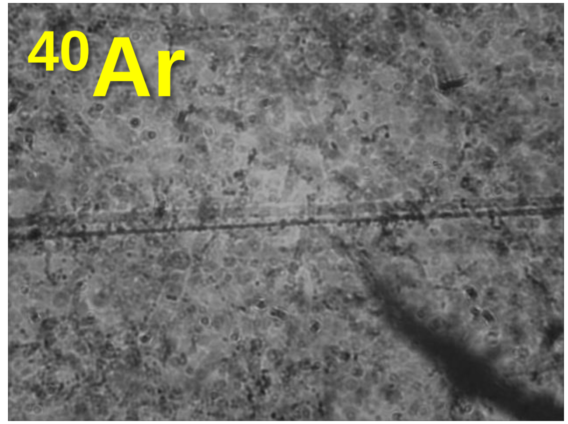
Nuclotron, March of 2018 year

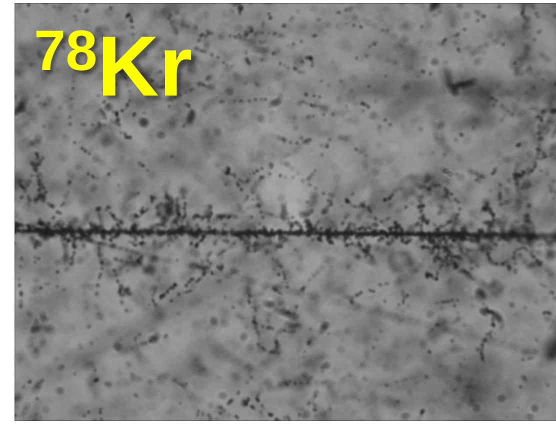


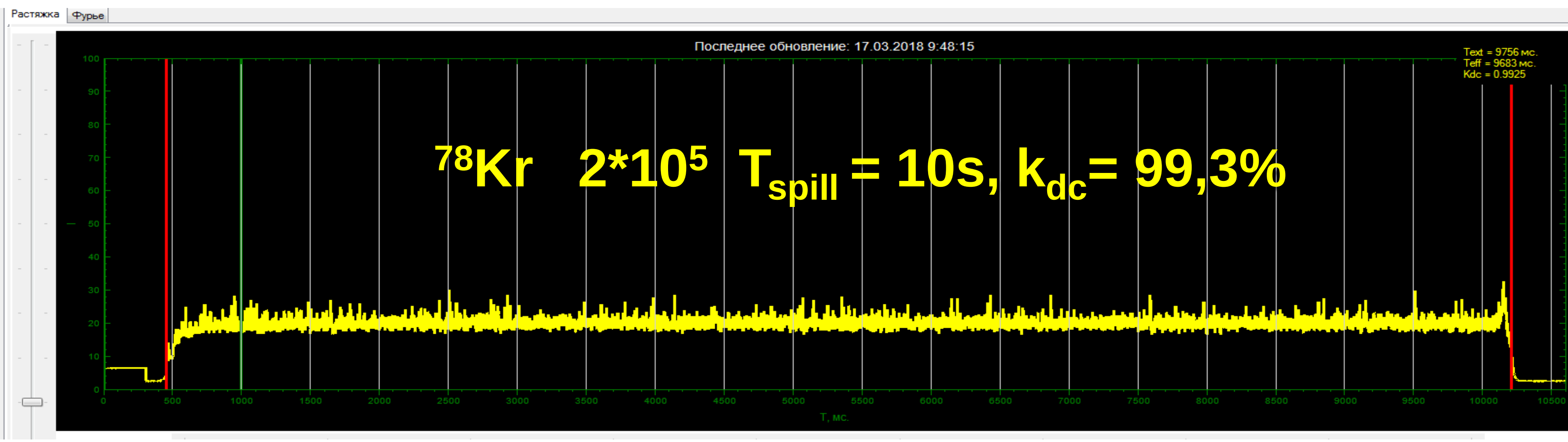
Progress towards realization of the Nuclotron-NICA project

From talk by A.O.Sidorin, at PP PAC, JINR (June 2018)







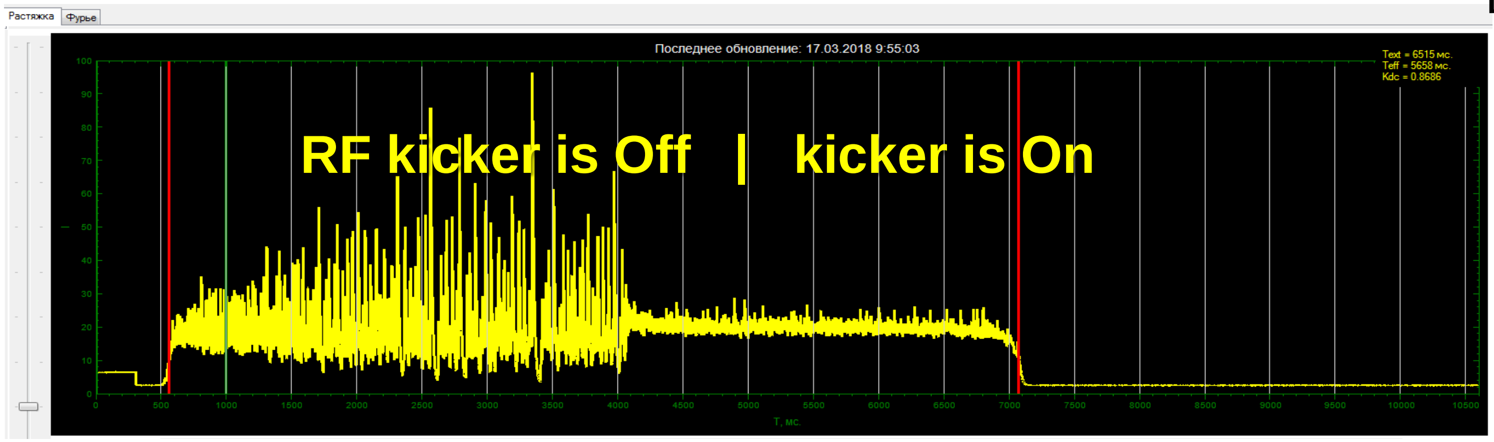


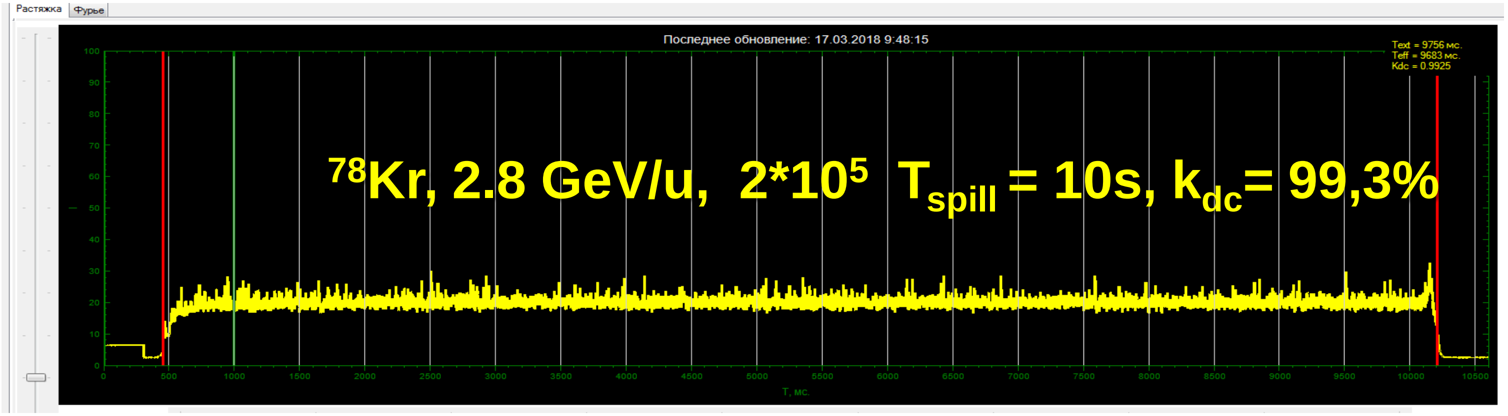
Slow extraction development

Run #54 – test of uncontrolled stochastic slow extraction (RF nock-out) using diagnostic kicker of the Q-meter.

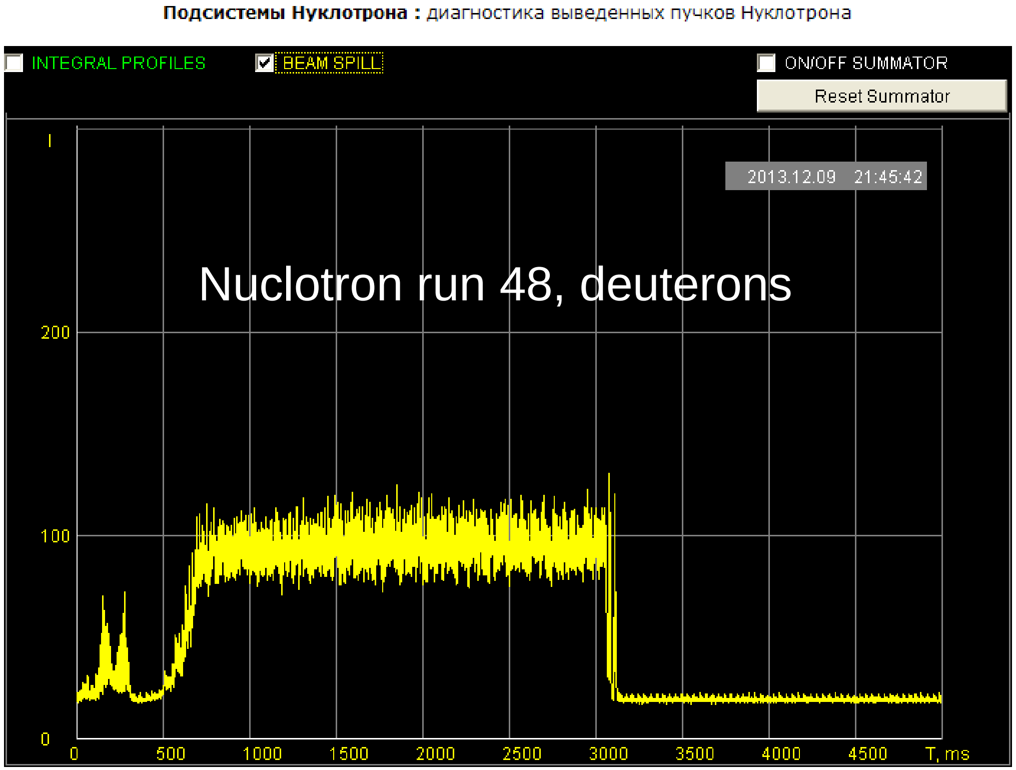
Run #55 **– routine operation of combined method**: controlled displacement of working point into 1/3 resonance + RF nock-out

A.Butenko,
V.Volkov,
E.Gorbachev





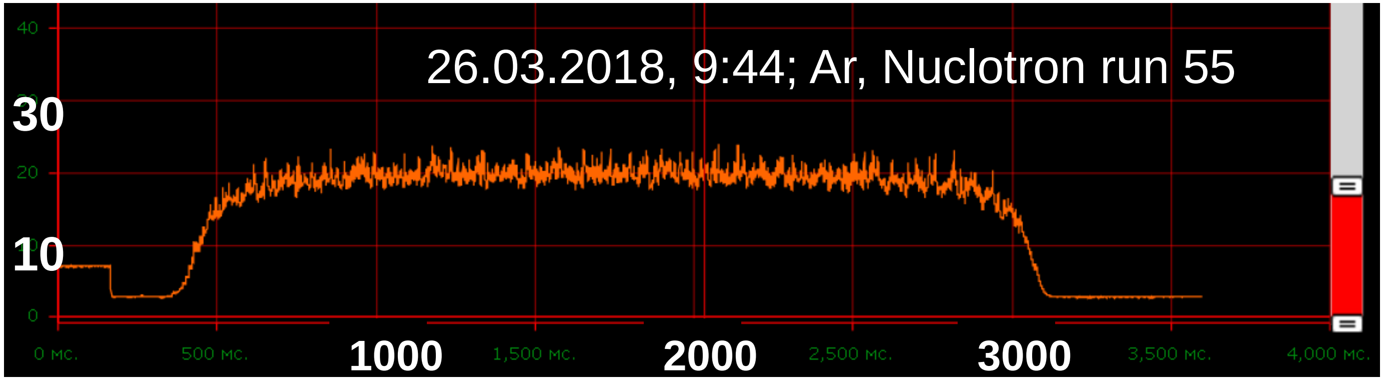
Results (for users) have been shown (slide #32)



Nuclotron,
Dec. of 2013 year

Screen-shot from: 09.12.2013; 21:45

Nuclotron,
March of 2018 year



(VI)

Progress with detectors and with the first physical data taking

(within the NICA project) …

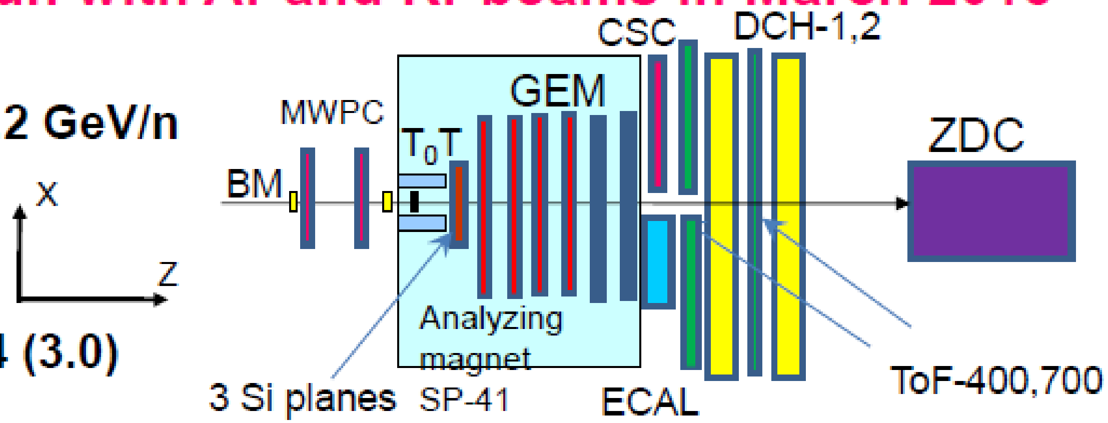
(after the Nuclotron Runs: in 2018 and before…)

From talks by M.N.Kapishin and E. Piasetzky
at PP PAC, JINR (January 2018 and June 2018)

BM@N run with Ar and Kr beams in March 2018

Ar beam, T_0= 3.2 GeV/n

Kr beam, T_0= 2.4 (3.0) GeV/n



- Central tracker inside analyzing magnet → 6 GEM detectors 163 x 45 cm^2 and forward Si strip detectors for tracking
- ToF system, trigger detectors, hadron and EM calorimeters, outer tracker

Program:

- Measure inelastic reactions Ar (Kr) + target → X on targets Al, Cu, Sn, Pb

→ Hyperon production measured in central tracker (Si + GEM)
→ Charged particles and nuclear fragments identified with ToF
→ Gamma and multi-gamma states identified in ECAL
→ 130 M events in Ar beam, 50 M events in Kr beam
+ SRC program in Carbon beam with Liq H_2 target (talk of E.Piasetzky)

+ analyze data from previous technical runs with Deuteron and Carbon beams of 3.5 - 4.6 GeV/n

Present status and next plans

- BM@N technical runs performed with deuteron and carbon beams at energies T_0 = 3.5 - 4.6 AGeV and recently with Ar beam of 3.2 AGeV and Kr beam of 2.4 AGeV
- Measurement of Short Range Correlations performed with inverse kinematics: C beam + H_2 target
- Major sub-systems are operational, but are still in limited configurations
- Algorithms for event reconstruction and analysis are being developed, signals of Λ hyperon decays are reconstructed
- First meeting of BM@N / MPD experiments held in April to form Collaborations

Major BM@N plans for Au+Au to start in 2020:

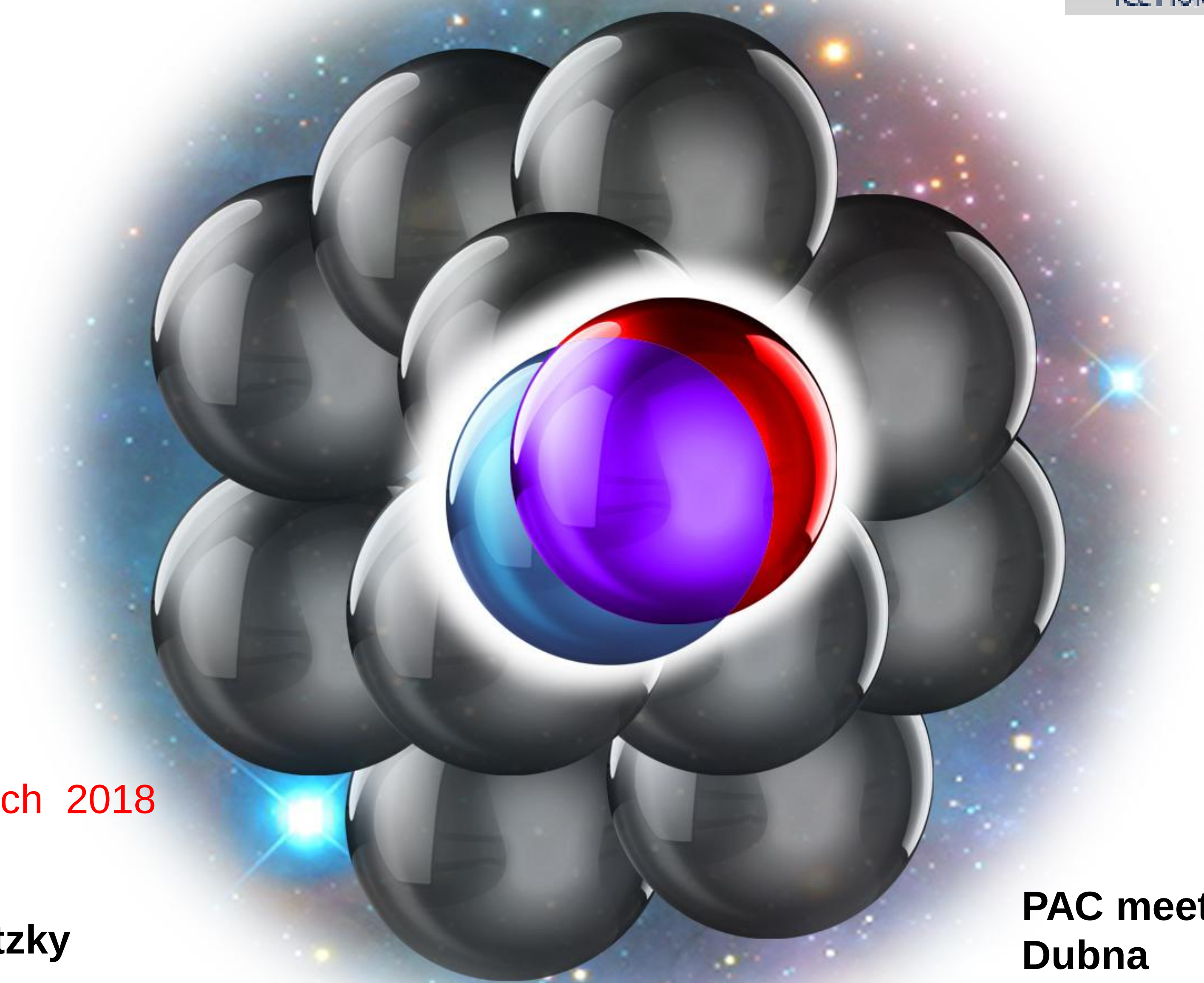
- Collaborate with CBM to produce and install large aperture STS silicon detectors in front of GEM setup
- Extend GEM central tracker and CSC outer tracker to full configuration
- Implement vacuum / helium beam pipe through BM@N setup

Beam parameters and setup at different stages of BM@N experiment

Year	2016	2017 spring	2018 spring	2020	2021 and later
Beam	d(↑)	C	Ar,Kr, C(SRC)	Au	Au,p
Max.intensity per spill	0.5M	0.5M	0.5M	1M	5M
Trigger rate, Hz	5k	5k	10k	10k	20k→50k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 small Si planes	7 GEM full planes + small + large Si planes	7 GEM full planes + small + large Si planes
Experimental status	technical run	technical run	technical run+physics	stage1 physics	stage2 physics

(VI.b)

Report on SRC @ BM@N: One Plus One is not Two



10 days:
4 – 17 March 2018

Eli Piasetzky

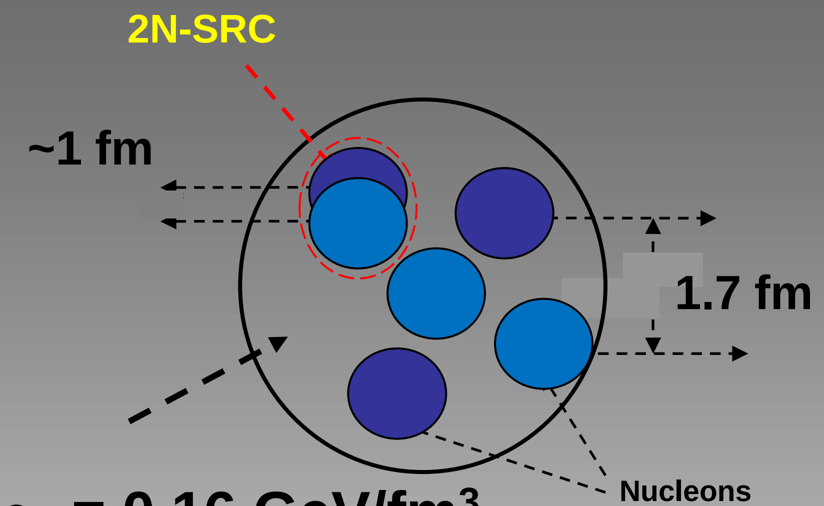
PAC meeting Dubna

Tel Aviv University, Israel

18 June 2018

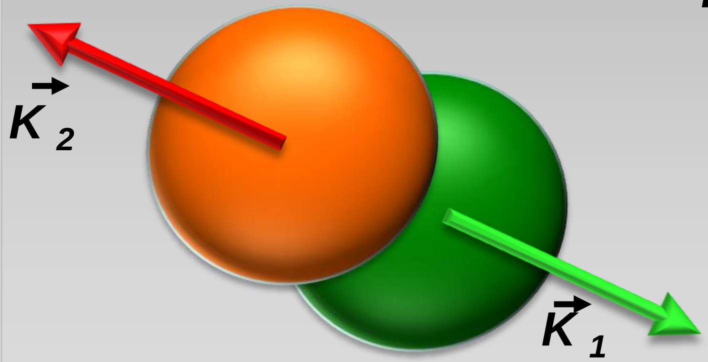
What are Short Range Correlations in nuclei ?

SRC ~R_N LRC ~R_A



ρ_o = 0.16 GeV/fm^3

In momentum space:



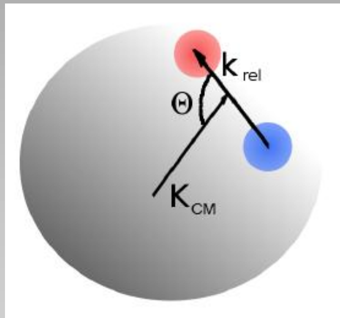
$\vec{K}_1 \cong \vec{K}_2$

$K_1 > K_F$,

$K_2 > K_F$

$$K_{rel} > K_F$$

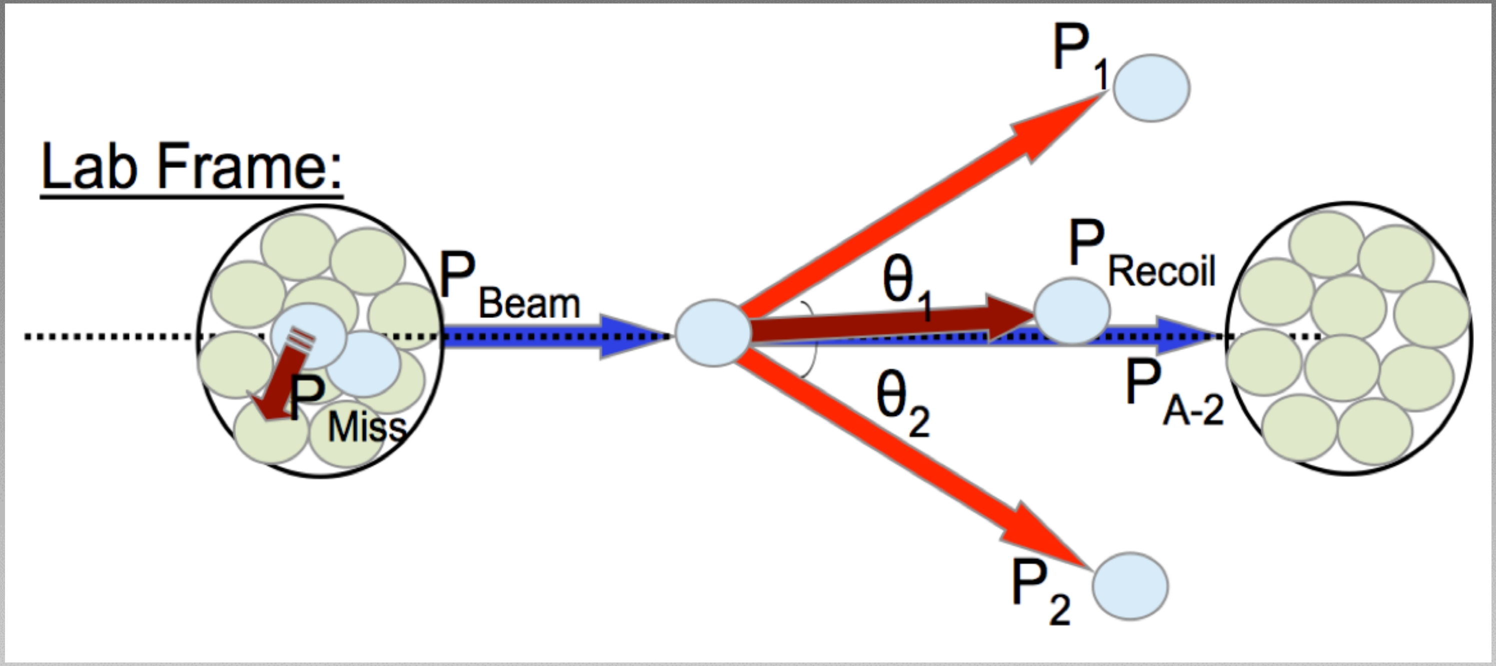
$$K_{CM} < K_F$$



$$k_F \approx 250 \text{ MeV/c}$$

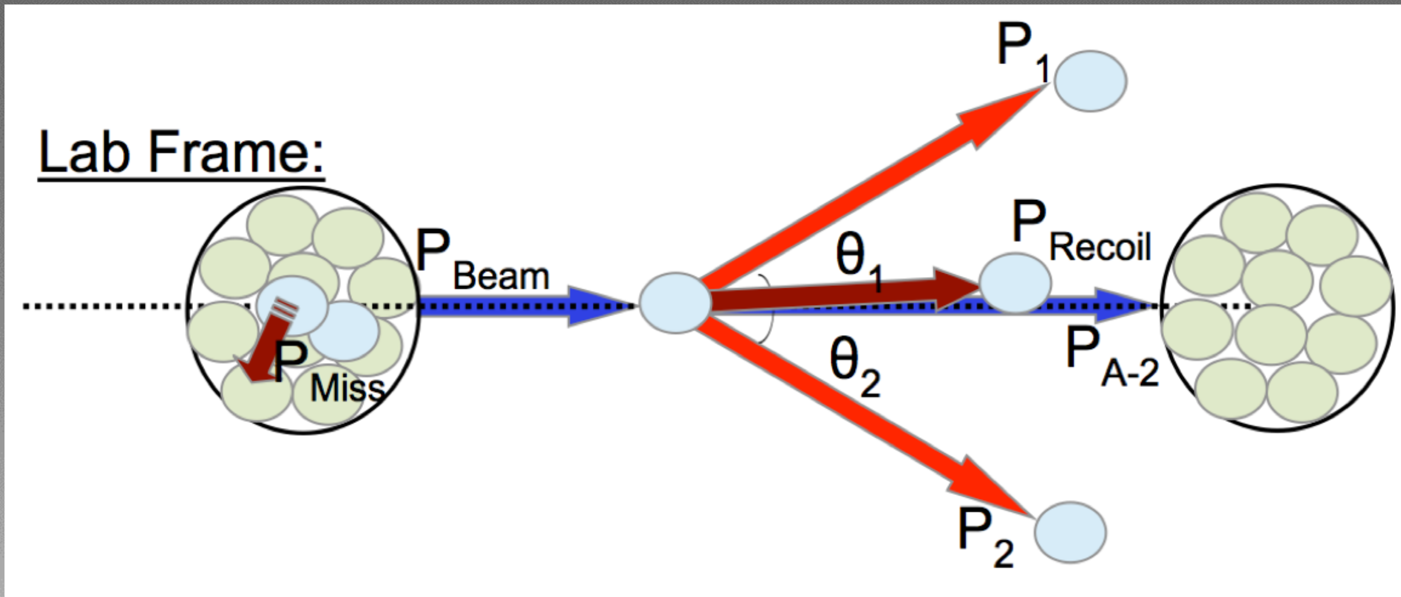
A pair with large relative momentum between the nucleons and small CM momentum.

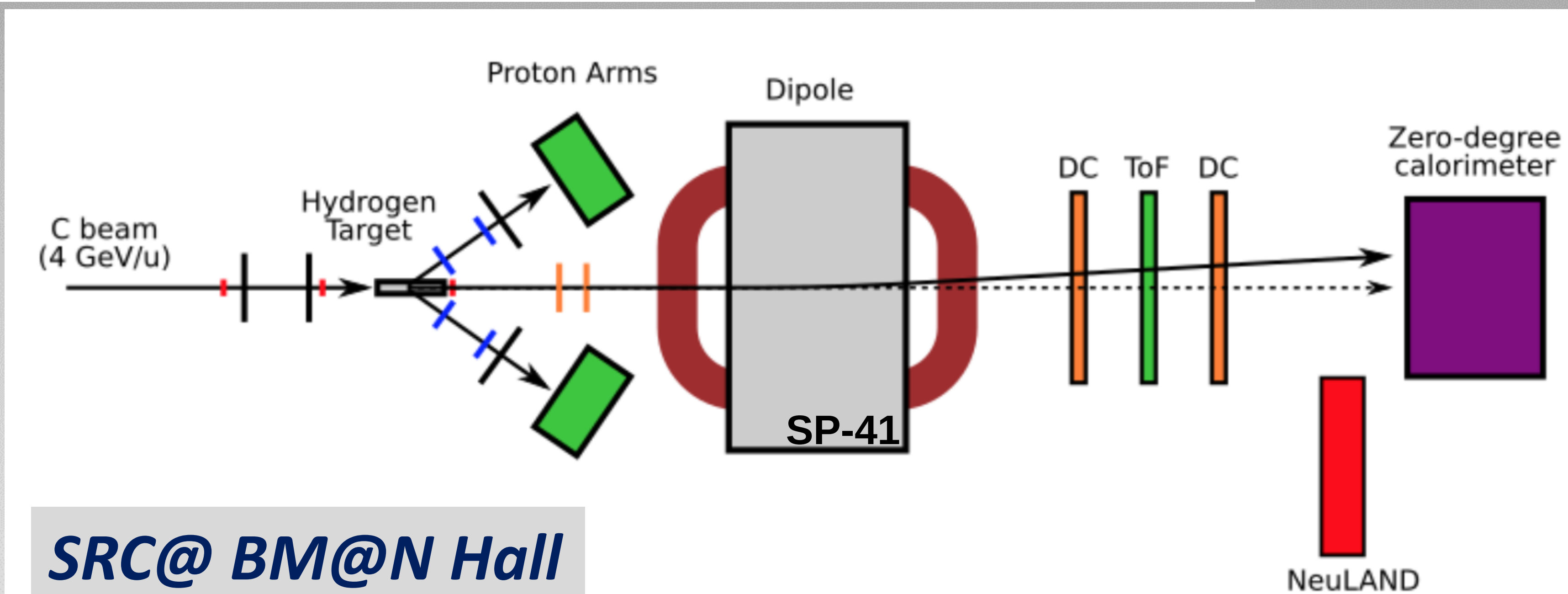
How we study SRC at JINR ?



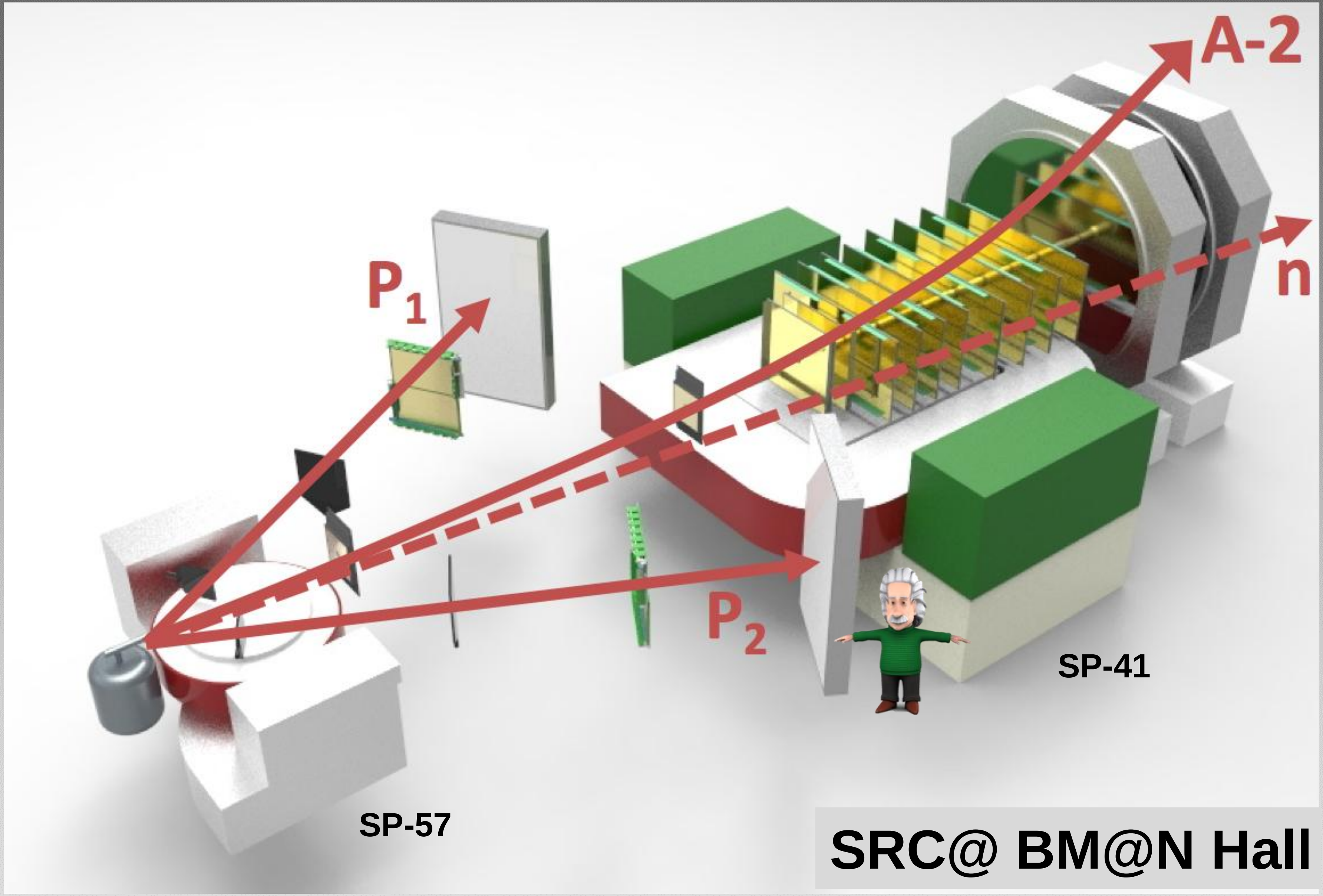
Hard scattering in the "Inverse" kinematics

Kinematics → Experimental setup

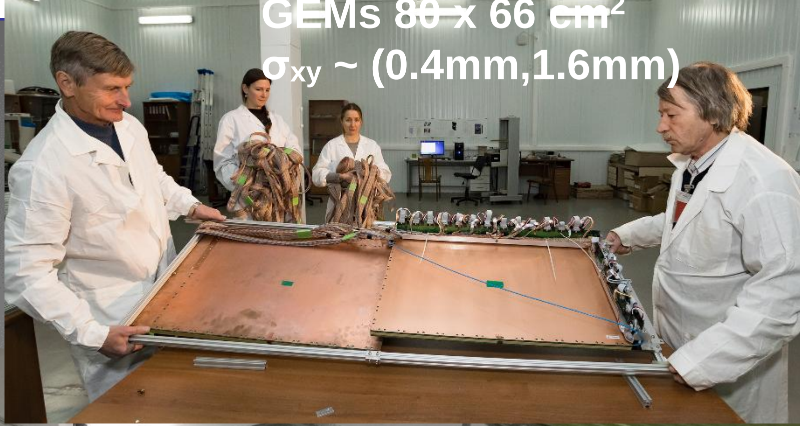


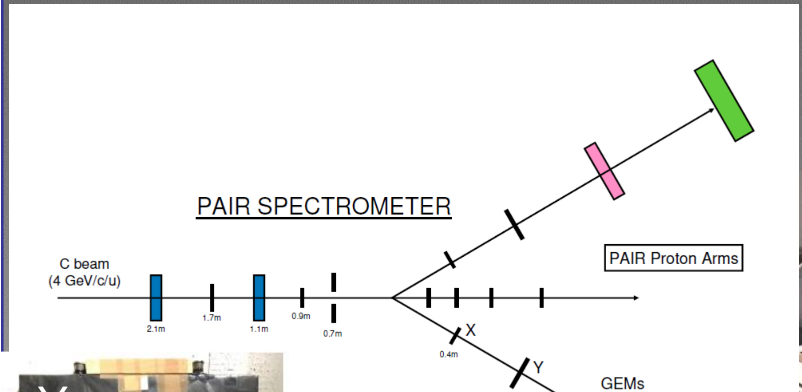


Experimental setup



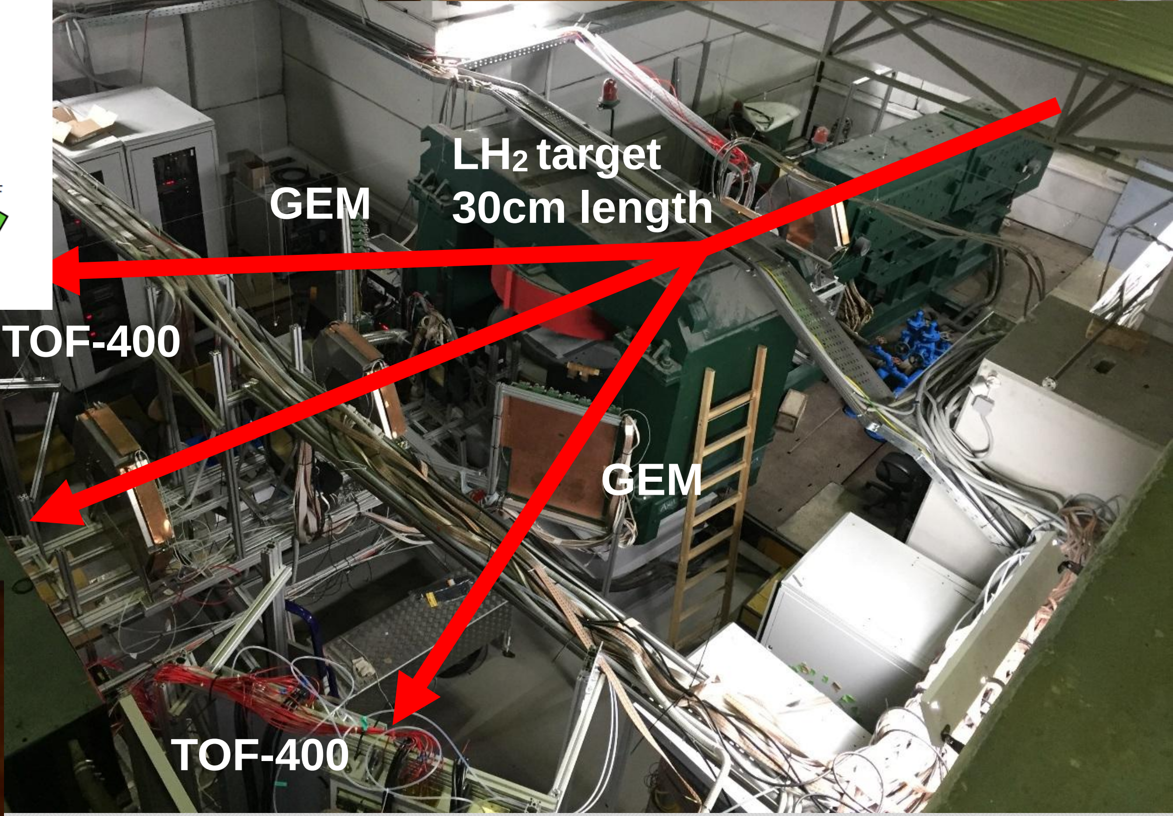
Proton Pair spectrometer

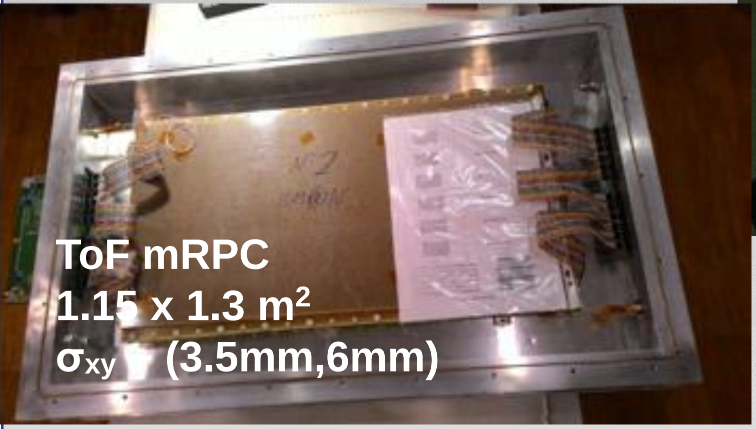




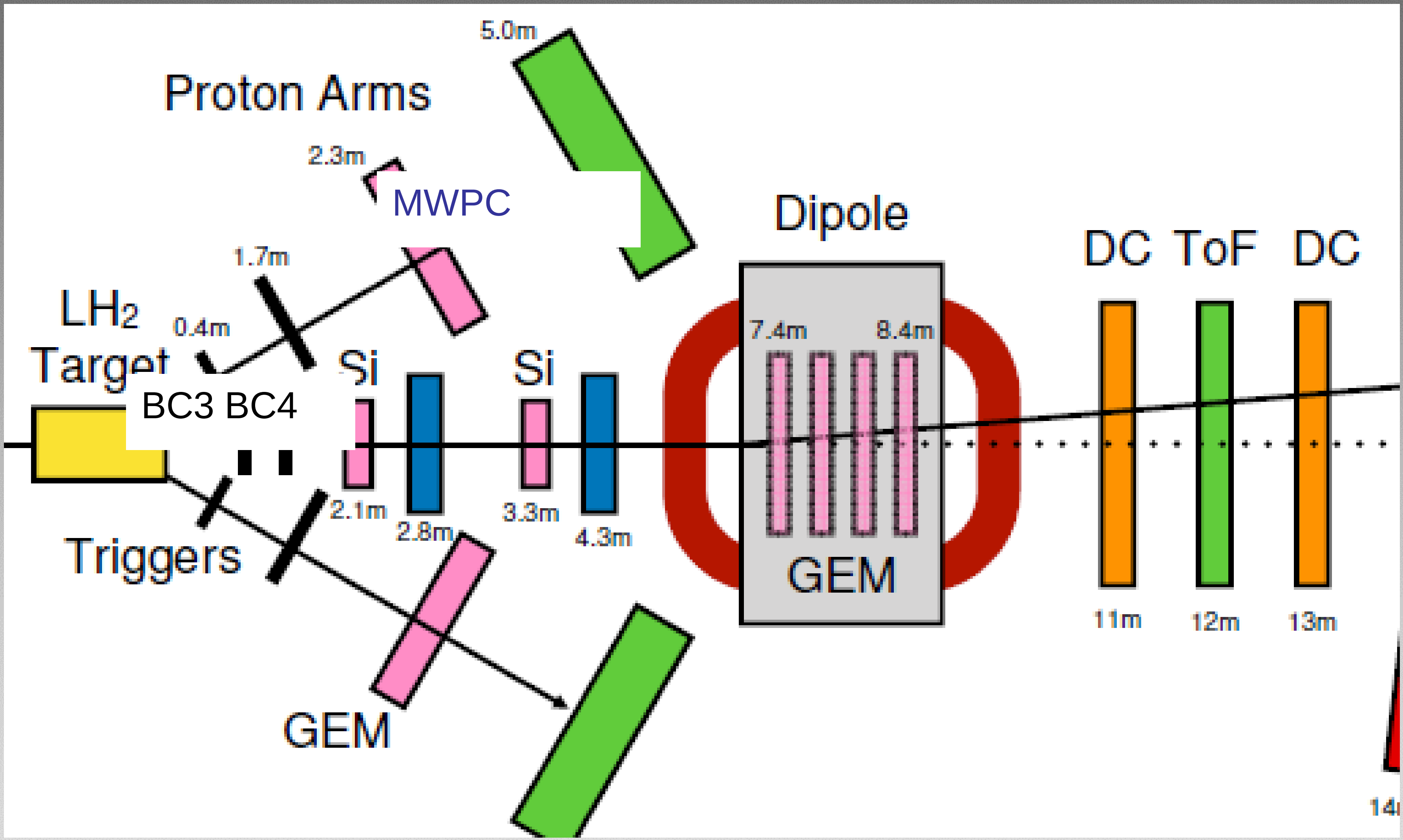
Y: 500 x 500 x 20 mm^3
2 ET9954KB PMT

X: 150 x 150 x 10 mm^3
2 pieces optically-separate
R7724-100 PMT





A-2 detection system



LAND – Large Area Neutron Detector

5 planes, 20 paddles each

Active area 2 m^2

200 cm x 10 cm x 10 cm of plastic scintillator and iron converter

σ_t = 250 ps ; $\sigma_{x,y,z}$ **= 3 cm**

Efficiency ~ 80%
for energies > 400 MeV

“Physics” Expected from the March 2108 data

TEL AVIV UNIVERSITY

Incident beam: about 5M

$$^{12}C + p \rightarrow {}^{11}B + p\ p$$ QE few 10^3

$$^{12}C + p \rightarrow {}^{10}B + p\ p$$ np-SRC few 10^2

$$^{12}C + p \rightarrow A^{*} + p\ p$$

Not enough statistics to look for:

pp-SRC , 4-fold coincidence

Plans for the period after the Booster construction

Better time resolution.
Better pair spectrometer.

Enough statistics for study of pp-SRC and Super exclusive SRC (4 fold) measurement.

Energy scan to improve understanding of reaction dynamics (important for SRC studies with beams of unstable nuclei.

Year	Activity
2018/19	Analysis and publication of test beam data. Preparations for 2020 data taking.
2020/21	data analysis and publication High-statistics data-taking with ^{12}C beam.
2021/22	data analysis and publication. data-taking with heavier nuclei beam.

SUMMARY (VII)

(1) Renewal of the polarized deuteron beam at the LHEP of JINR (result of the year 2016) (*reported in 2017 in Peterhof)*

(2) JINR has got the relativistic polarized proton beam, accelerated in the Nuclotron up to 2 GeV kin. energy (*the result of the year 2016; reported in 2017 in Peterhof).*

(3) Data taking for physics started at BM@N spectrometer with beams of C, Ar, Kr:

- *according the BM@N present program,*
- *according the new project "SRC at BM@N".*

(4) Quality of beams of relativistic nuclei for users was improved drastically.

Commissioning – December 2019

(5) Works on the Booster and beam transfer lines assemblings (Booster→ Nuclotron, Nuclotron→ NICA Rings) are being started.

(6) MPD and BM@N Collaborations are in the final stage of their formal establishing (Charts, Collaboration Boards, Spokesmen etc.)

(7) Civil Construction of the NICA Collider buildings is going well.

(reminder)

Final remark

It should be taken into account, that
interest to the intermediate energy physics problems is being renewed; new experimental opportunities are being opened for polarization phenomena studies (JINR, first of all) and are suggested for meson beams …

Eur. Phys. J. A (2015) **51**: 129 DOI 10.1140/epja/i2015-15129-5

Physics opportunities with meson beams

William J. Briscoe, Michael Döring, Helmut Haberzettl, D. Mark Manley, Megumi Naruki, Igor I. Strakovsky and Eric S. Swanson

Many talks given at the Meson-2018 Conference (Krakow, June 2018) well illustrate very significant importance of the meson beams of intermediate energies.

Thank you very much
for your attention!

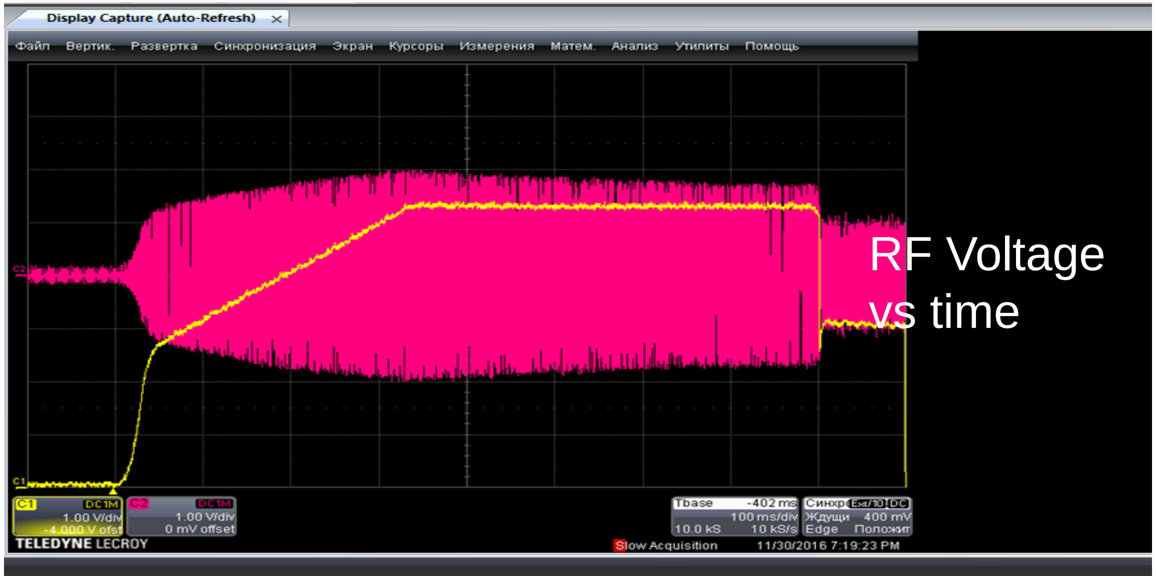
Backups

Progress in the machine upgrade

(Booster, Injector complex etc.)

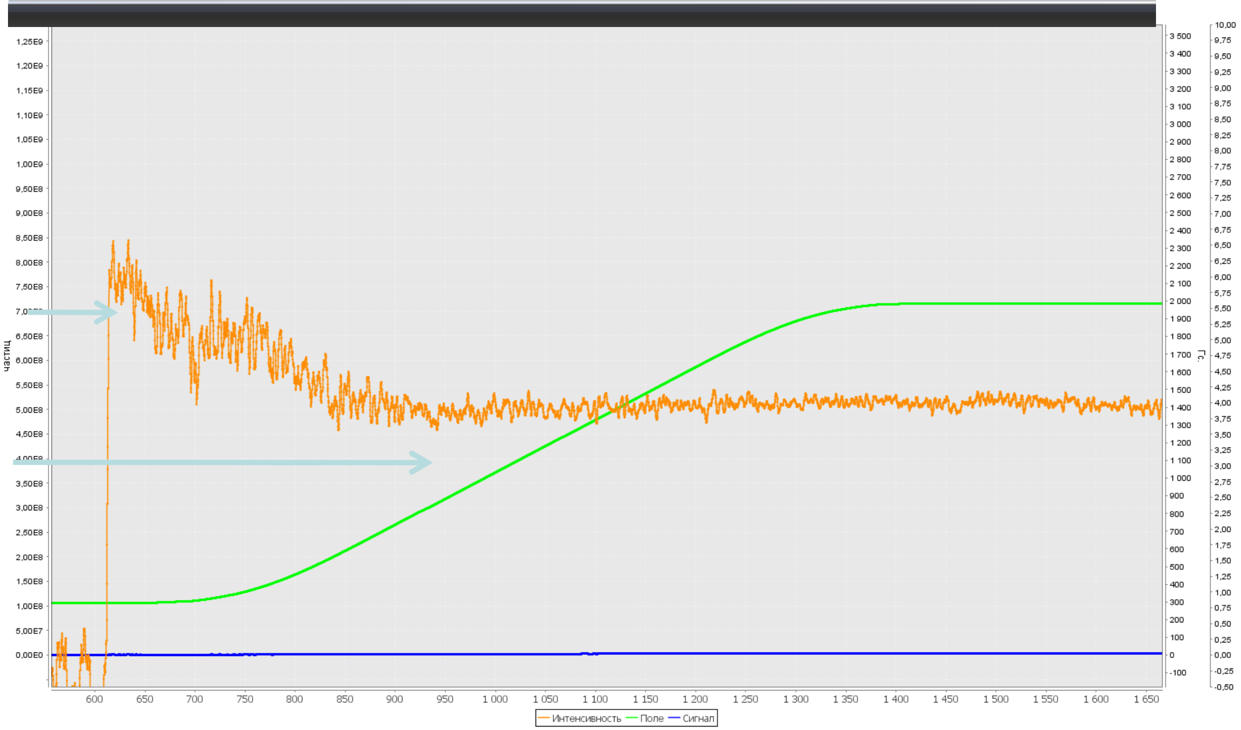
From talks by A.O.Sidorin, at PP PAC, JINR (January 2018 and June 2018)

Adiabatic capture



8e8

6e8



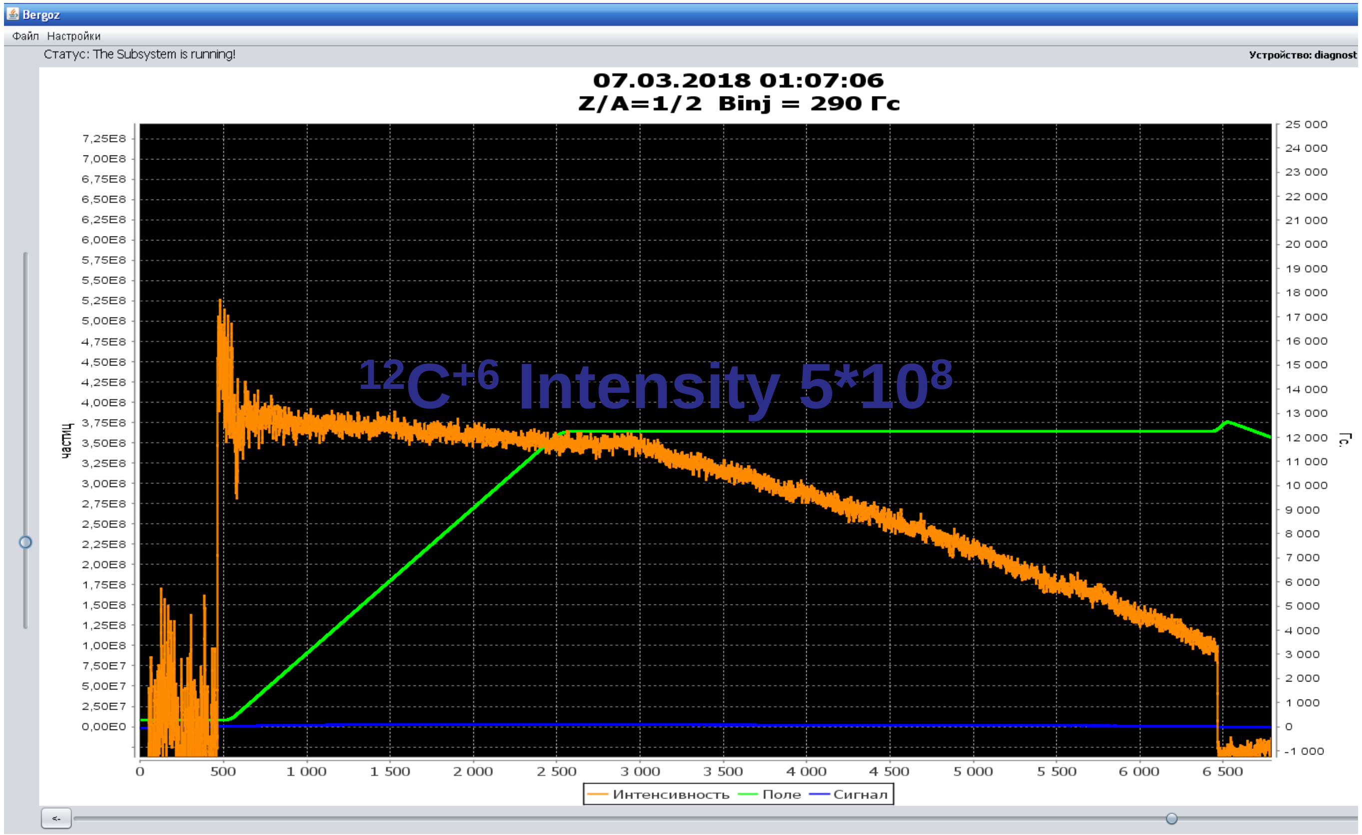
A.Eliseev,
A.Butenko,
V.Slepnev,
O.Brovko

RUN 54
routine regime
with injection
at magnetic field plateau

Efficiency of the capture: 70 – 80 %

Tuning of the Nuclotron

$^{12}C^{+6}$ beam acceleration (3,5 GeV/u)



Beam injection, adiabatic capture, orbit correction and beam acceleration were adjusted at high intensity using standard, as well as some newly developed machine diagnostics tools

Slow extraction at low intensity (past)