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"Relativistic Nuclear Physics & Quantum Chromodynamics"

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External beams at the Nuclotron facility: status and nearest tasks

P. Rukoyatkin

Veksler and Baldin Laboratory of High Energy Physics
Joint Institute for Nuclear Research
Dubna, Russia

External beams at the Nuclotron facility : outline

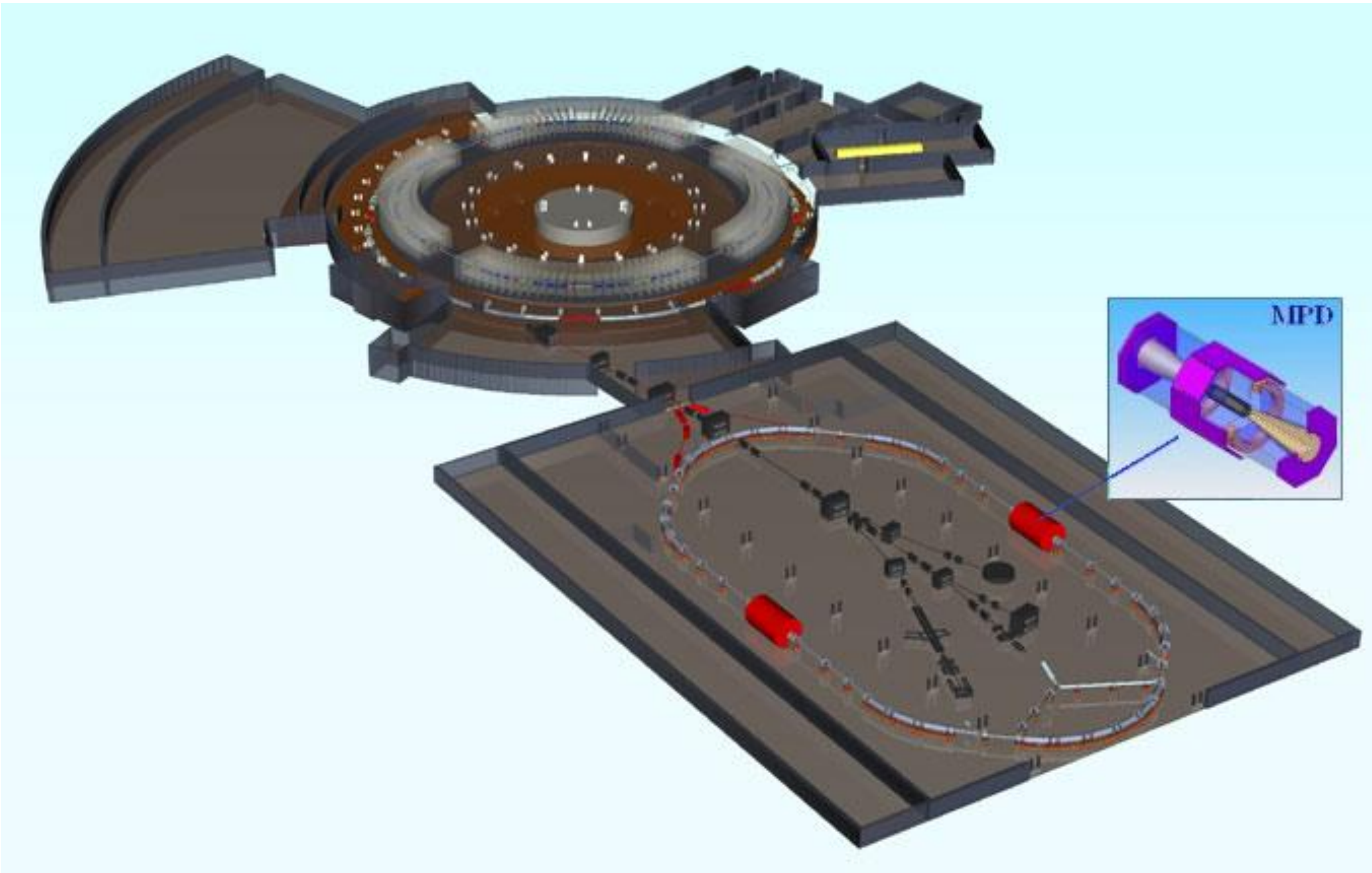
- As introduction: NICA project and external beam lines, Nuclotron M, slow extraction, transporting and distributing over experimental areas of the primary extracted beams.

- Secondary fragment beams.
  - Polarized (unpolarized) neutrons – the neutron beam line and secondary polarized protons.
  - Secondary beams of light unstable nuclei.

- Development of diagnostics instruments for the external beam lines in the Nuclotron M project frames.

- Nearest actual task

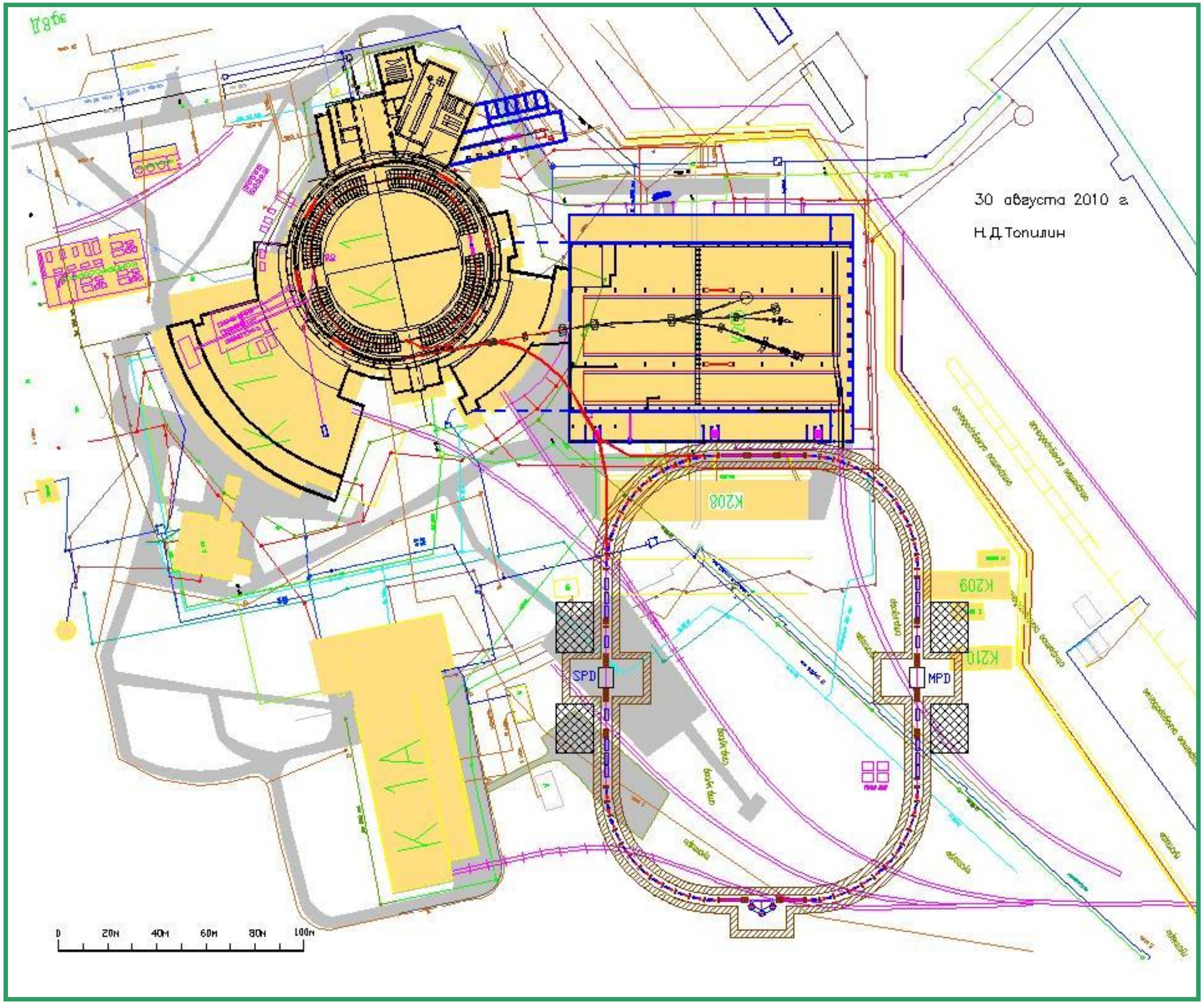
NICA location in the existing buildings*



* Design and Construction of Nuclotron-based Ion Collider fAcility (NICA), CDR, Draft 2.01.08

Preliminary drawing of the NICA elements location at VBLHEP site

In: "Advance in the NICA Collider Concept ", report for the MAC, Dubna 2010, editors I.Meshkov, A.Sidorin, G.Trubnikov



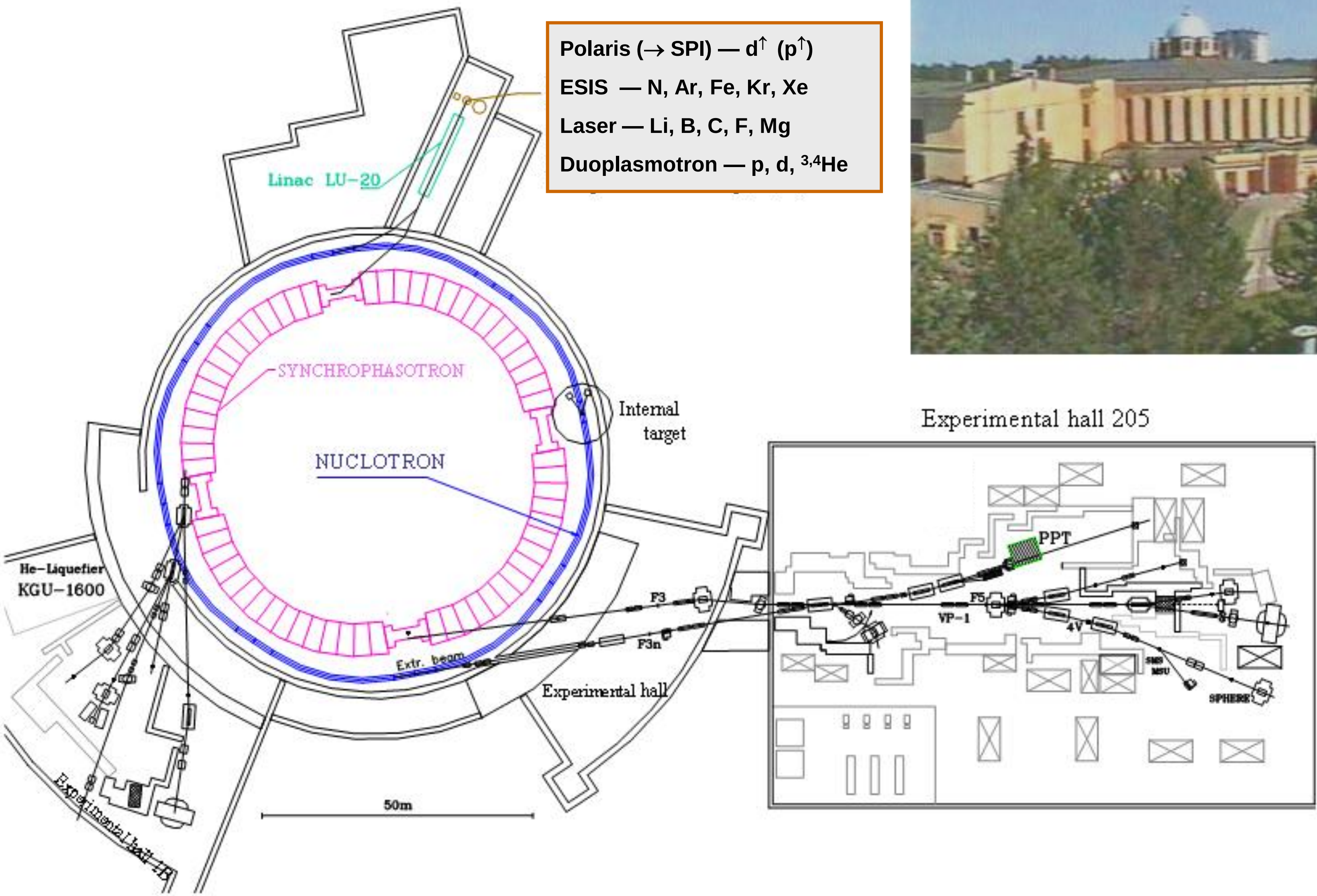
Accelerator facilities of LHEP

Polaris (→ SPI) — d$^{\uparrow}$ (p$^{\uparrow}$)

ESIS — N, Ar, Fe, Kr, Xe

Laser — Li, B, C, F, Mg

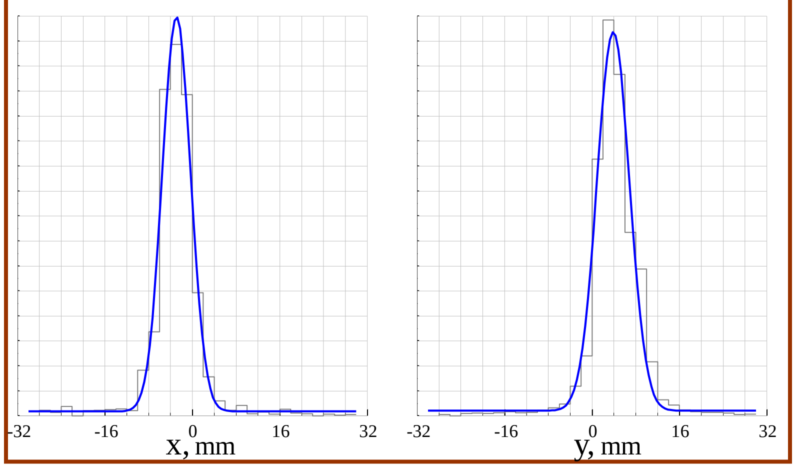
Duoplasmotron — p, d, ^{3,4}He



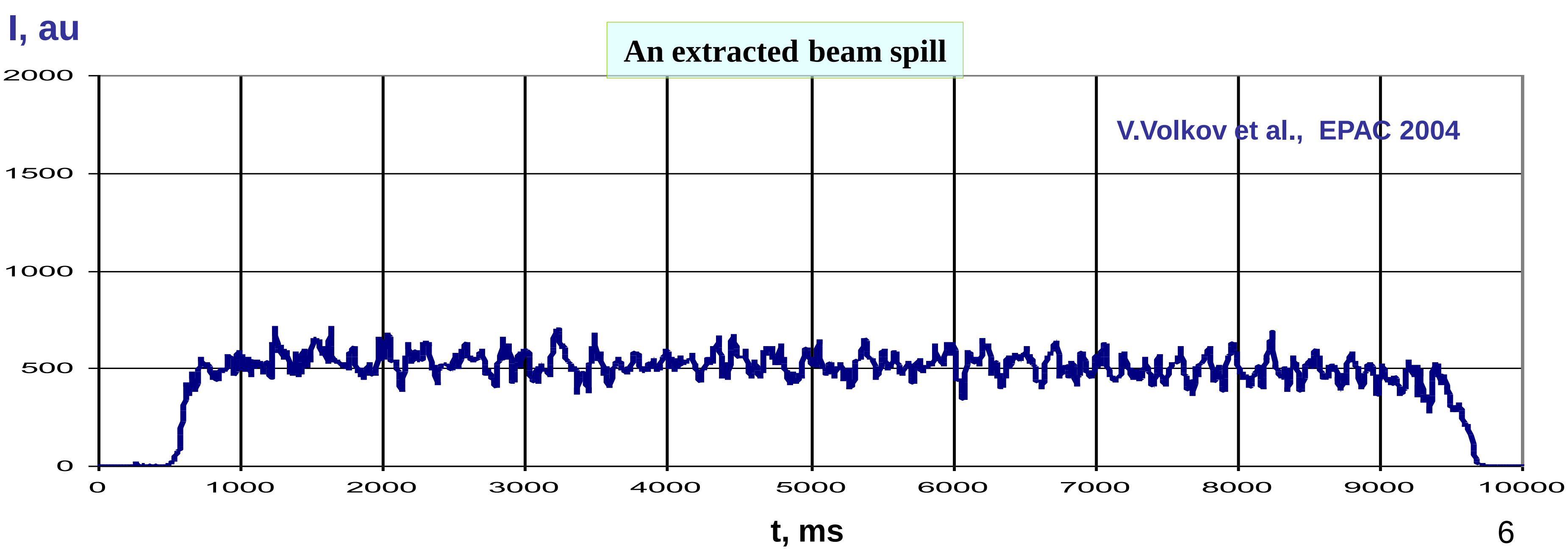
Nuclotron slow extraction

Parameter	@	Units	Value
Momentum range	Z/A = ½	Gev/c/amu	0.6 – 6.8
Momentum spread, σ		%	0.04 – 0.08
Extraction time		sec	10
Beam emittance	P_{max}	mm·mr	2π
Beam size in a waist, σ	P_{max}	mm	≤ 1
Extraction efficiency		%	> 90

Beam profiles at the F_5 focus.
Deuterons, p_{beam} = 4.3 GeV/c, σ_x = 2.6 mm, σ_y = 3.0 mm



An extracted beam spill

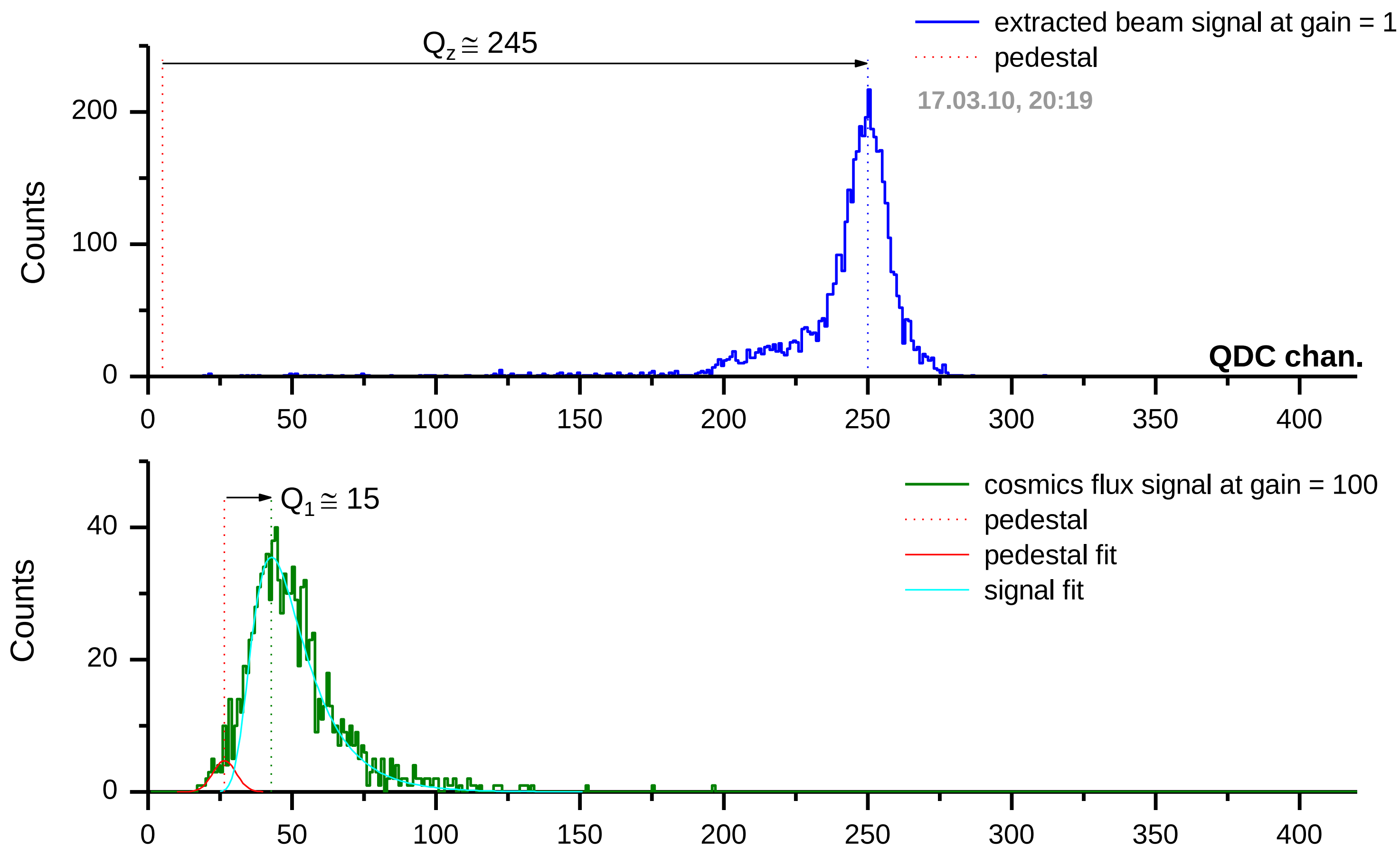


	Current	Src. type
p	$5{\cdot}10^{10}$	Duoplasmotron
d	$5{\cdot}10^{10}$	--- # ---
^{4}He	$3{\cdot}10^{9}$	--- # ---
d↑	$2{\cdot}10^{8}$	ABS ("Polaris")
^{7}Li	$4{\cdot}10^{9}$	Laser
$^{11,10}B$	$1{\cdot}10^{9,8}$	--- # ---
^{12}C	$2{\cdot}10^{9}$	--- # ---
^{24}Mg	$1{\cdot}10^{8}$	--- # ---
^{14}N	$1{\cdot}10^{7}$	ESIS ("Krion-2")**
^{24}Ar	$2{\cdot}10^{7}$	--- # ---
^{56}Fe	$1{\cdot}10^{6}$	--- # ---
^{131}Xe	$\sim 10^{3}$	--- # ---

Run #41, March 2010

Experimental estimation of extracted nuclei charge

- Nuclotron run #41, acceleration of the $^{42}Xe_{124}$ ions from the Krion source
- Slow extraction at t = 1 GeV/n → $^{54}Xe_{124}$
- Detector: scintillator, d = 2mm, FEU-85 PMT, 1.5 m downbeam exit flange

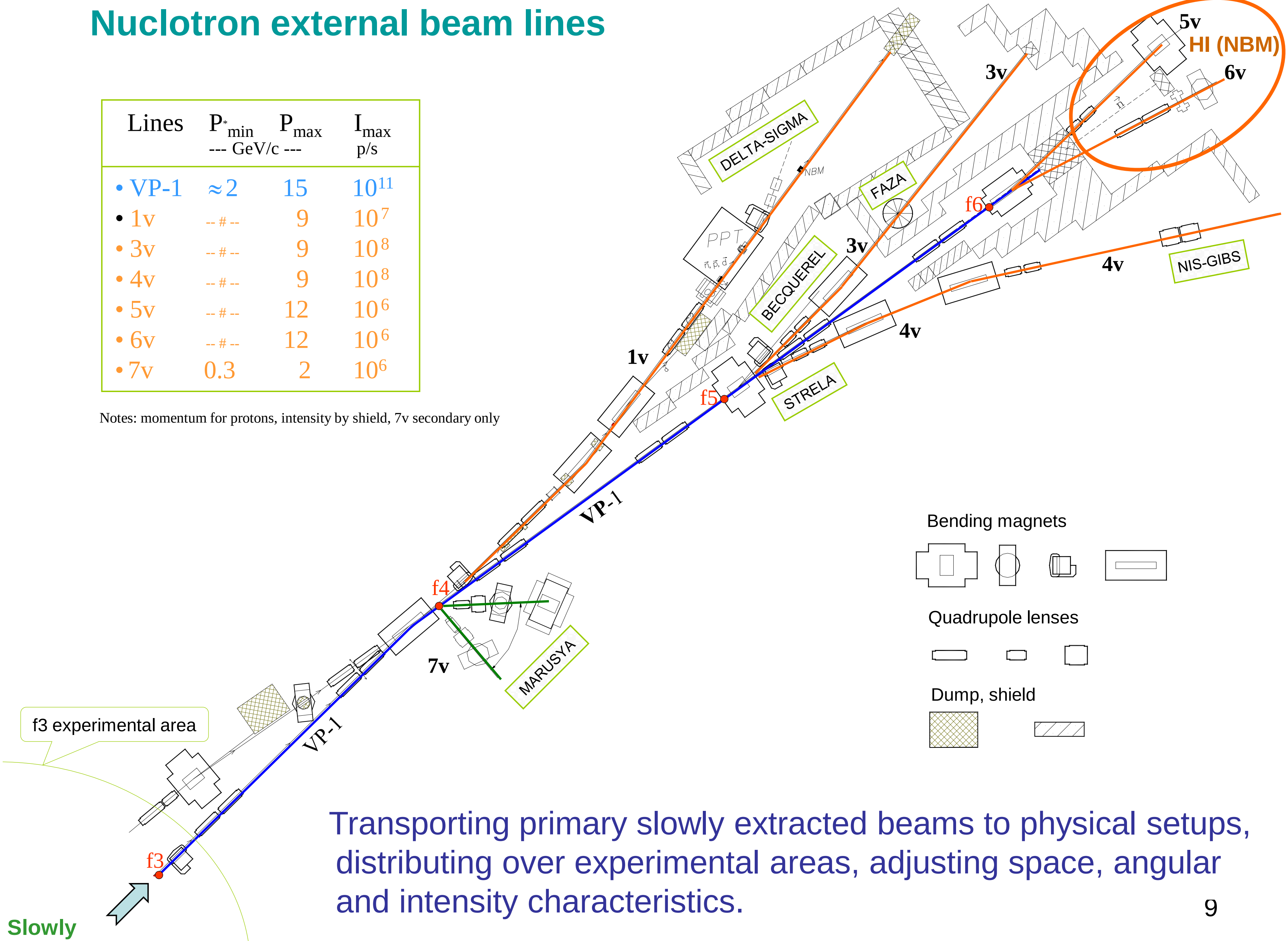


$z_{extr.} > 40$

Nuclotron external beam lines

Lines	P^{*}_{min} --- GeV/c ---	P_{max}	I_{max} p/s
• VP-1	≈ 2	15	10^{11}
• 1v	-- # --	9	10^{7}
• 3v	-- # --	9	10^{8}
• 4v	-- # --	9	10^{8}
• 5v	-- # --	12	10^{6}
• 6v	-- # --	12	10^{6}
• 7v	0.3	2	10^{6}

Notes: momentum for protons, intensity by shield, 7v secondary only



Transporting primary slowly extracted beams to physical setups, distributing over experimental areas, adjusting space, angular and intensity characteristics.

External beams at the Nuclotron facility

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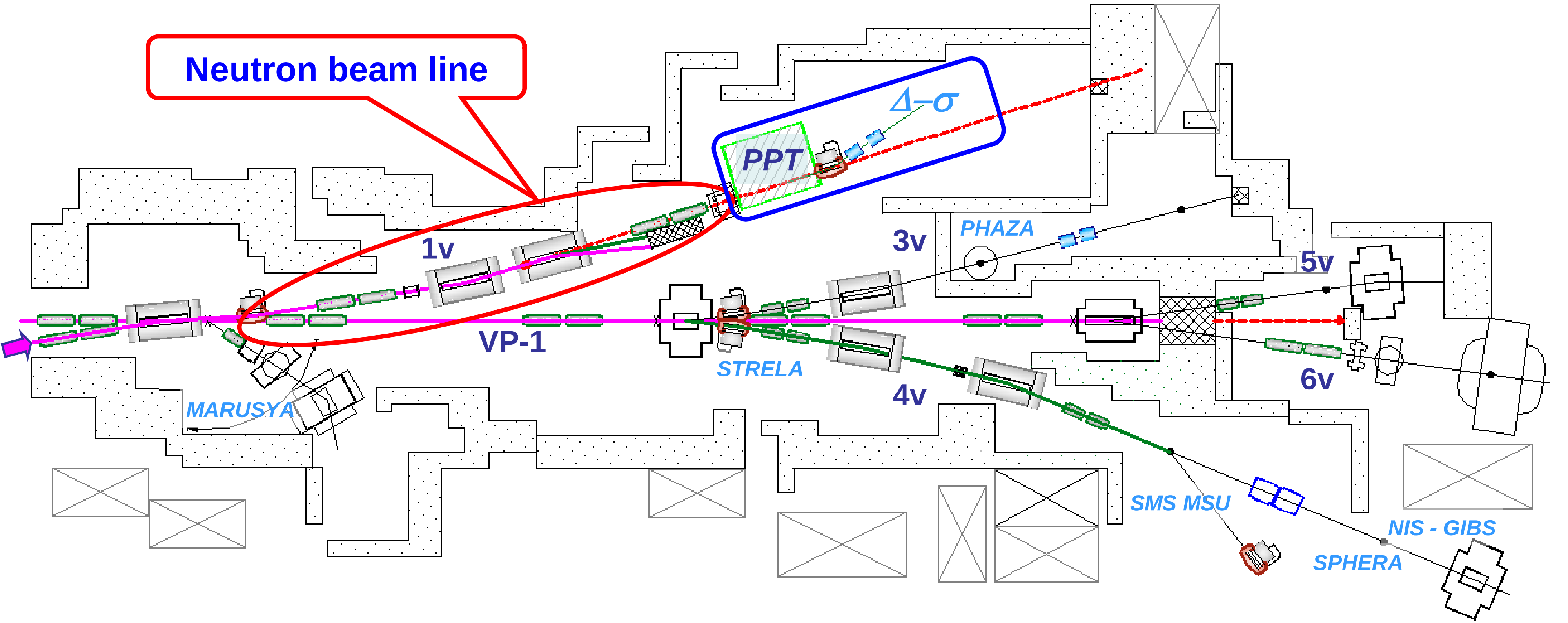
- Development of diagnostics instruments for the external beam lines in the Nuclotron M frames.

- Nearest actual task

Beam lines and setups layout in an extracted beam experimental area



Slowly extracted beams input

Primary polarized deuteron traces at secondary polarized beams forming

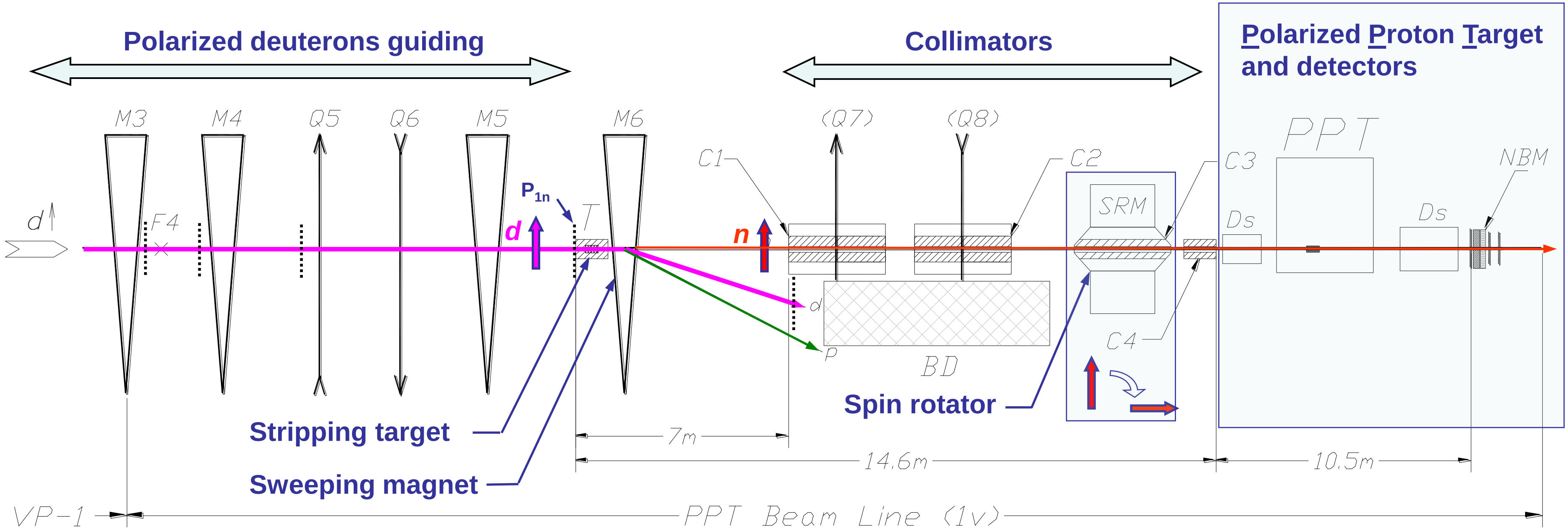
Neutron beam lines

Sec. polarized protons

PPT – Polarized Proton Target

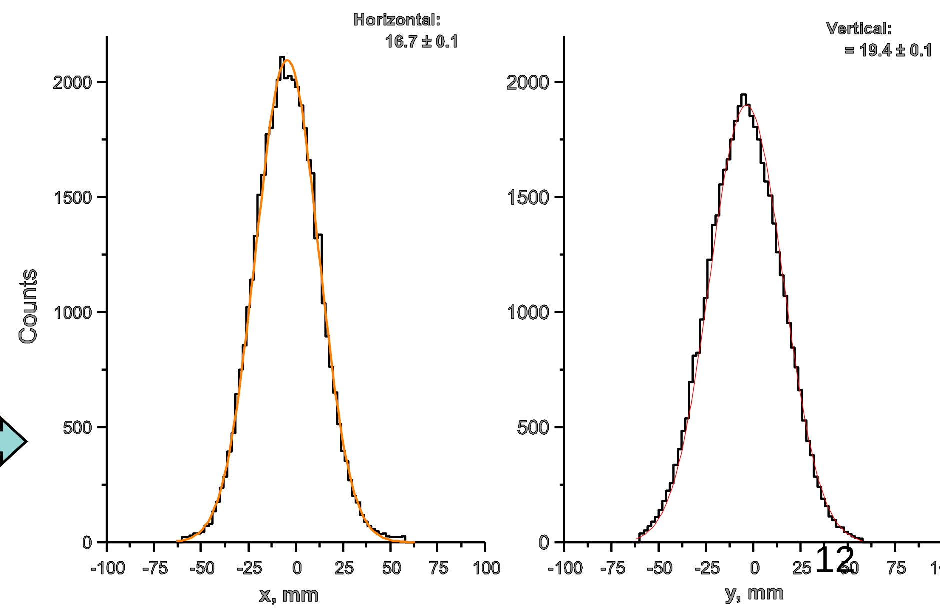
Δ–σ, NIS … – setups

Neutron beam line to the PPT



M – dipole magnets,
Q – quadrupoles,
SRM – spin rotating magnet, $(B \cdot L)_{max}$ = 2.7 T·m,
P – deuteron beam profilemeters,
NBM – neutron beam monitor,
BD – beam dump,
PPT – Polarized Proton Target.

Fig.: Example of neutron beam profiles from NBM



Polarized neutron beams at PPT

Table: Polarized neutron beams parameters

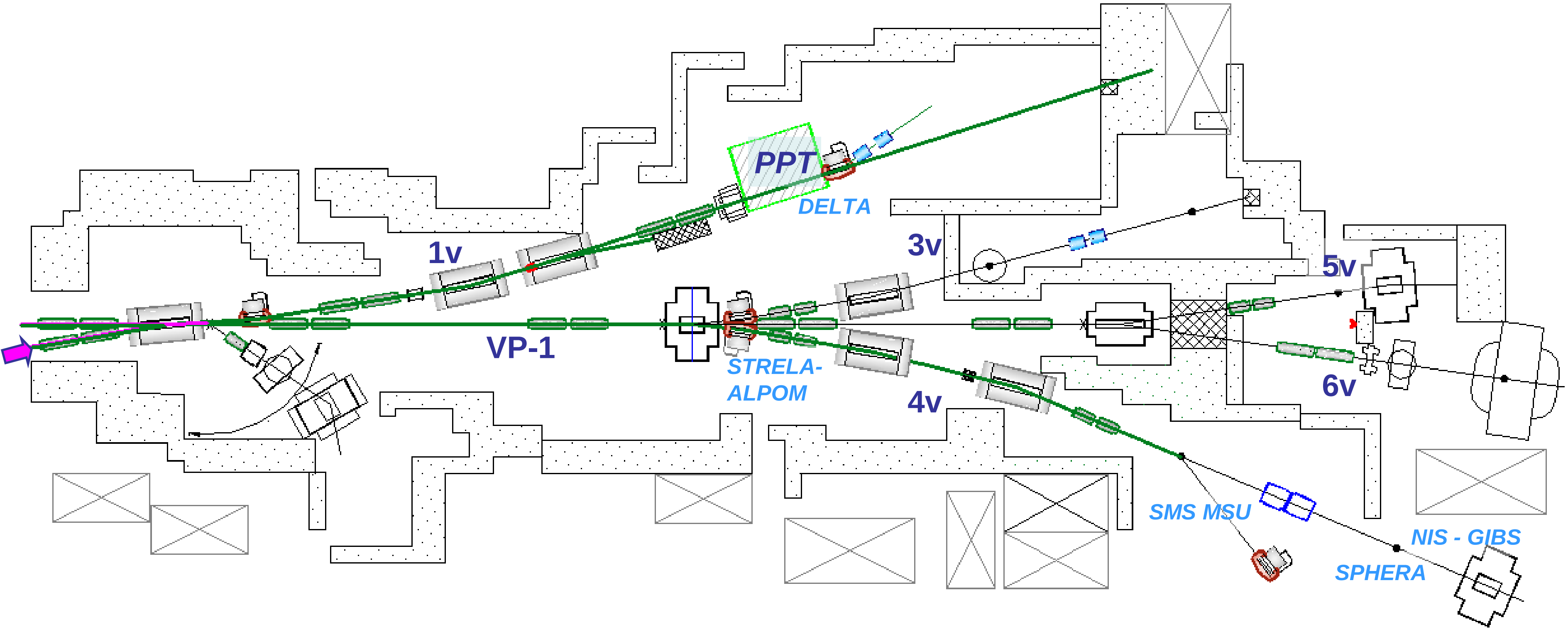
Parameter	Units	I	II
Momentum range	GeV/c	≅ 1 – 4.5	≅ 1 – 6.5 (6.8)
Intensity at p_{max}	ppc	$2 - 4 \cdot 10^6$	$2 - 4 \cdot 10^7$
Polarization		≅ 0.55	≅ 0.90
Momentum spread (FWHM)	%	≅ 5	≅ 5
Angular spread (σ)	mr	1 – 1.5	1
Full beam size at PPT	mm	≤ 30	≤ 30

I - Synchrophasotron + Polaris

II- Nuclotron-M + SPI

$(P^2 I)_{II} / (P^2 I)_{I} \cong 25$

Secondary polarized proton beams forming: d↑ + A → p↑ + …



- **Measuring proton-nucleus analyzing power *↑p + C, ↑p + CH_2* (SMS MSU, SPHERE), *↑p + CH2* (ALPOM) - carried out experiments.**
- **Search for the spin-dependent phenomena of π^0- and η-meson production in *↑p + ↑p, ↑n + ↑p* collisions (using polarized nucleon beams at PPT) – DELTA experiment, ready to take data setup.**
- **Measurement of the energy dependence of the spin correlation parameter A_{00nn} in quasi-elastic *↑p ↑p* scattering at angles close to $\theta_{cm} = 90^\circ$ - pp SINGLET experiment, proposal.**

References and discussions on the problems are in the review: F. Lehar, Part. & Nucl. 36, (2005)

Estimated parameters of polarized proton beams at the PPT for the Nuclotron-M + SPI beam

	Scheme, initial conditions $\varepsilon=5\pi$ mm·mr, I_d = 10^{10}, p_d = 9 GeV/c	
1	Target position: **f4** Q_5 - Q_8 lenses polarities: **FDDF** Primary beam X,Y*: **1.0, 2.0**	$Y_p = \mathbf{1.3} \cdot 10^8$ $h_p = 0.0\ \%$ $\sigma_x = 4.1$ mm $\sigma_y = 2.5$ mm $\sigma_p = 0.6\ \%$
2	Target position **f3** Q_5 - Q_8 lenses polarities : **FDFD** Primary beam X,Y*: **1.0, 2.5**	$Y_p = \mathbf{4.0} \cdot 10^8$ $h_p = 0.4\ \%$ $\sigma_x = 4.2$ mm $\sigma_y = 3.7$ mm $\sigma_p = 1.3\ \%$

* Sizes, mm

Y_p - proton yield estimation from 20 cm beryllium target

h_p - beam halo (particles, not incoming into the PPT working volume)

$\sigma_{x,y}$, σ_p - r.m.s. beam sizes and momentum spread

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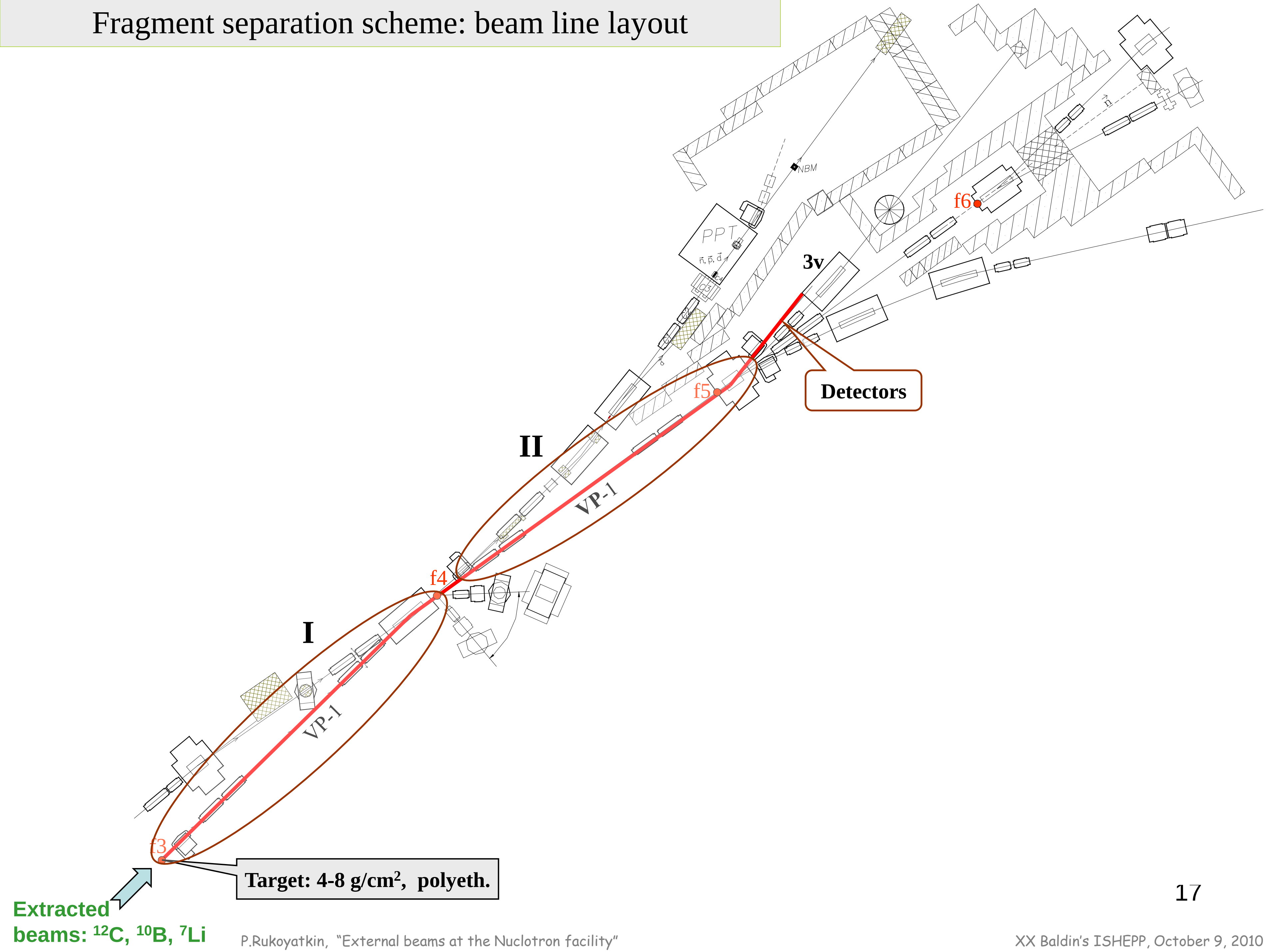
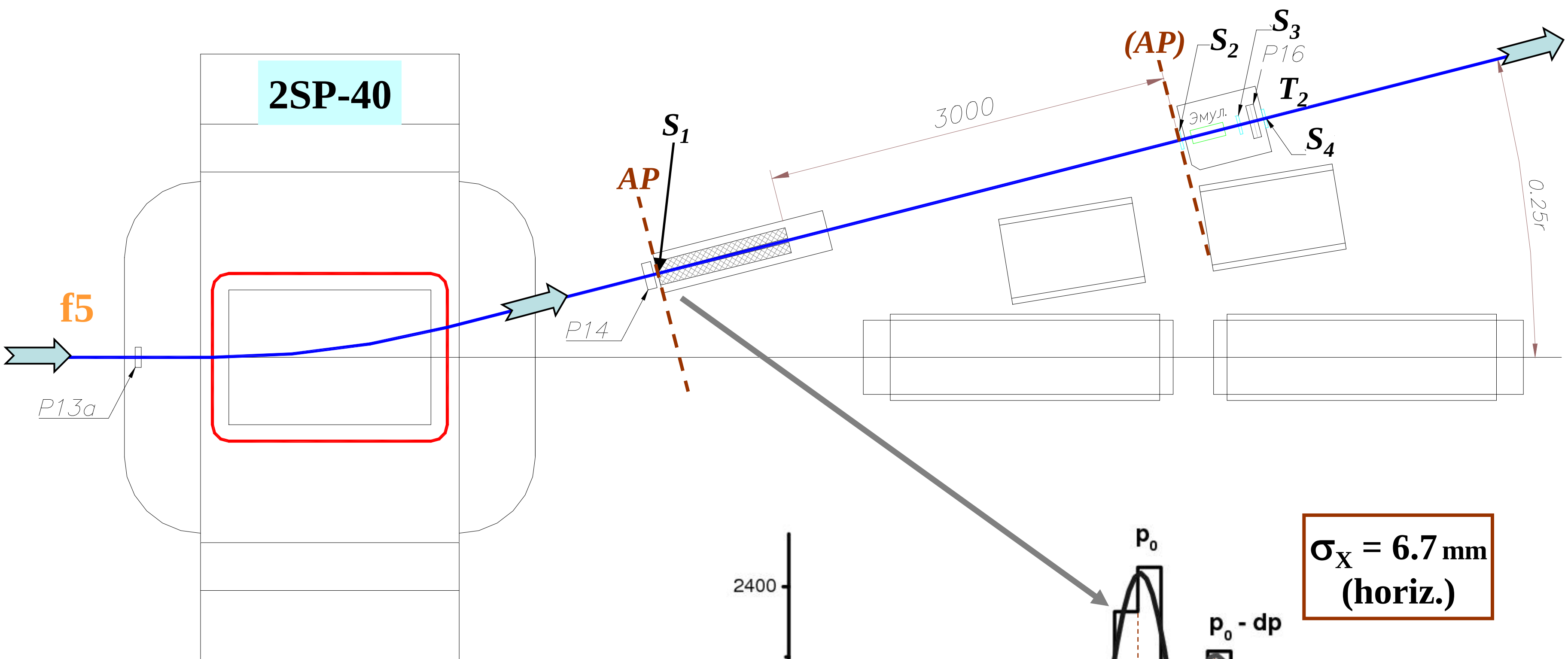
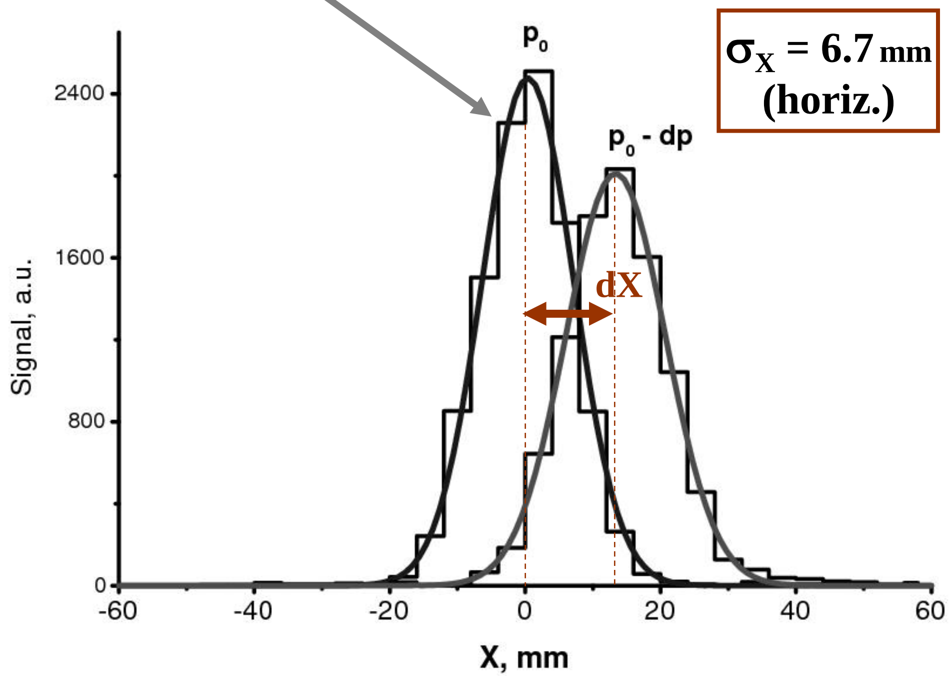
- Nearest actual task

Fragment separation scheme: beam line layout



Fragment separation scheme: detector layout



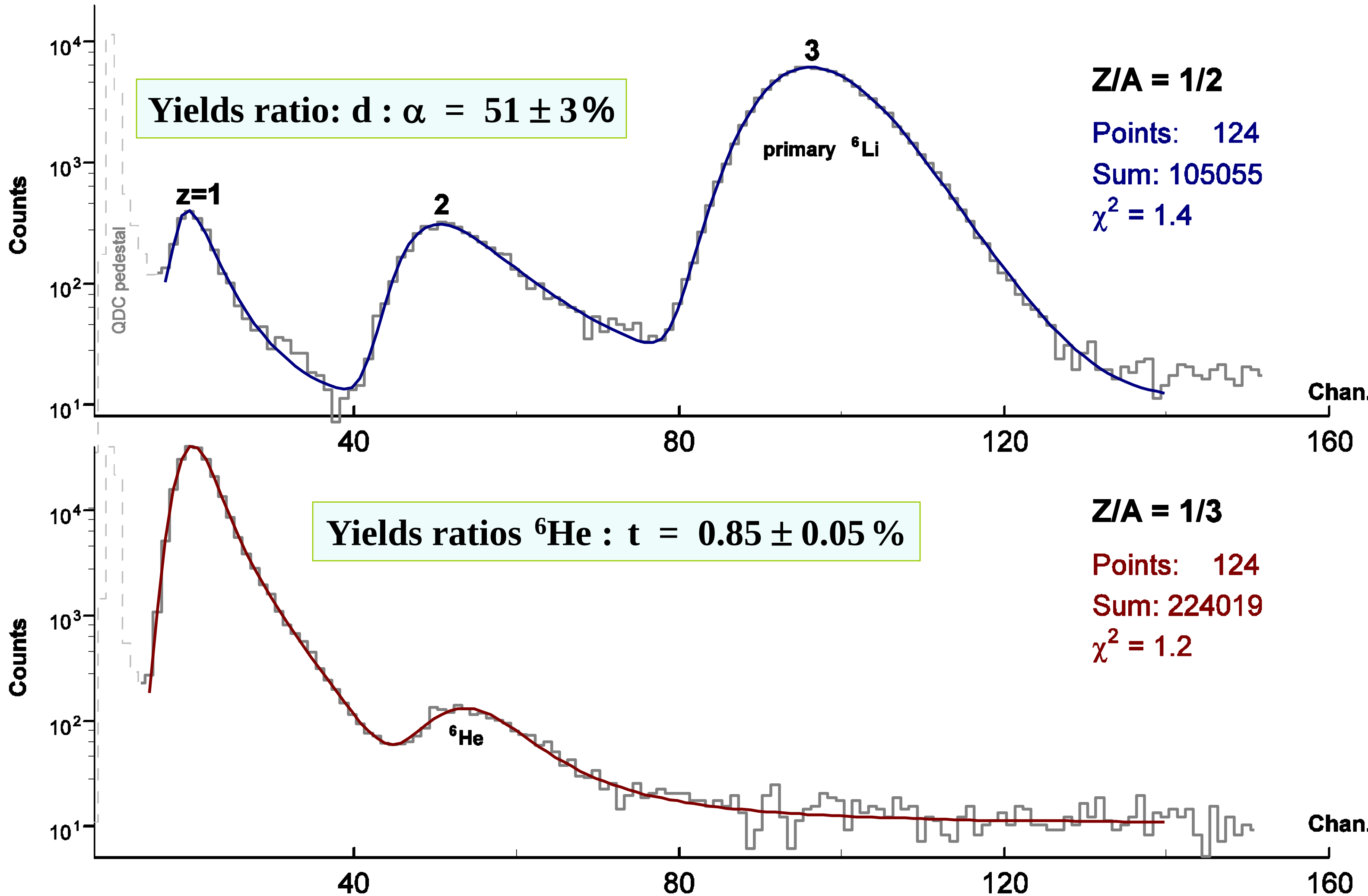


- **Multiwire ionization profilemeters (P13a, P14, P16)**
- **Scintillation counter (S_i, T_i)**

$$R_{exp} = dX/(2\sigma_X \, dP_{deg}) \cong 80,$$

($dP_{deg} \cong 1.3\%$ itrodused by a degrader)

Beam by reactions ^{6}Li + A → Nucleus + …



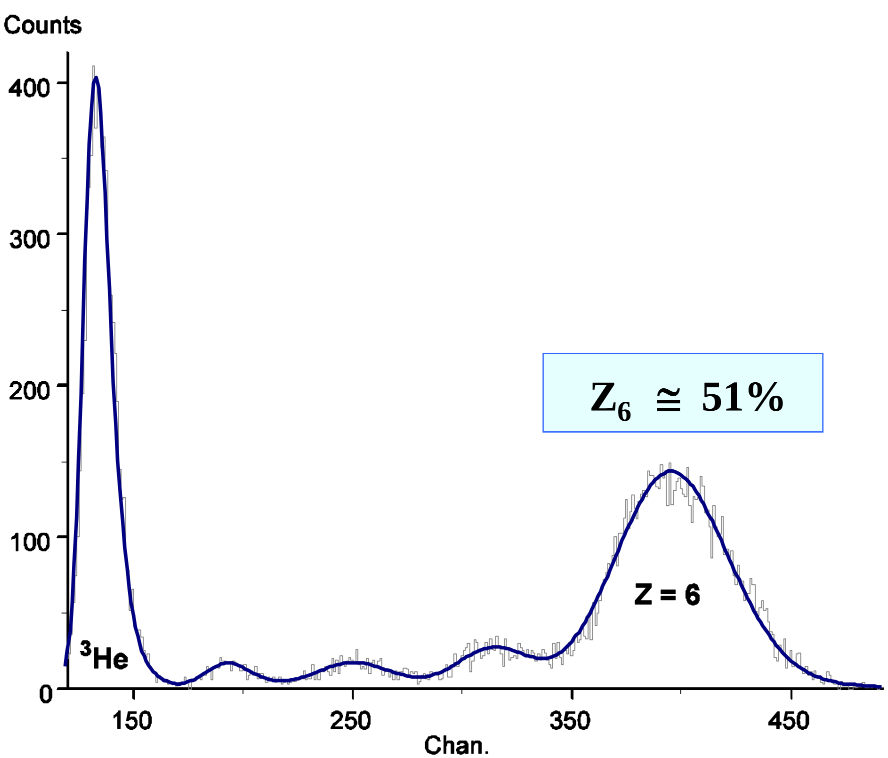
Fit: $$f(x,\mathbf{p}) = \frac{1}{\sqrt{2\pi}\sigma}\int \sum_{i=1}^{m} S_i\, v_i(x-t)\, e^{-t^2/2\sigma^2}\, dt + y_0$$

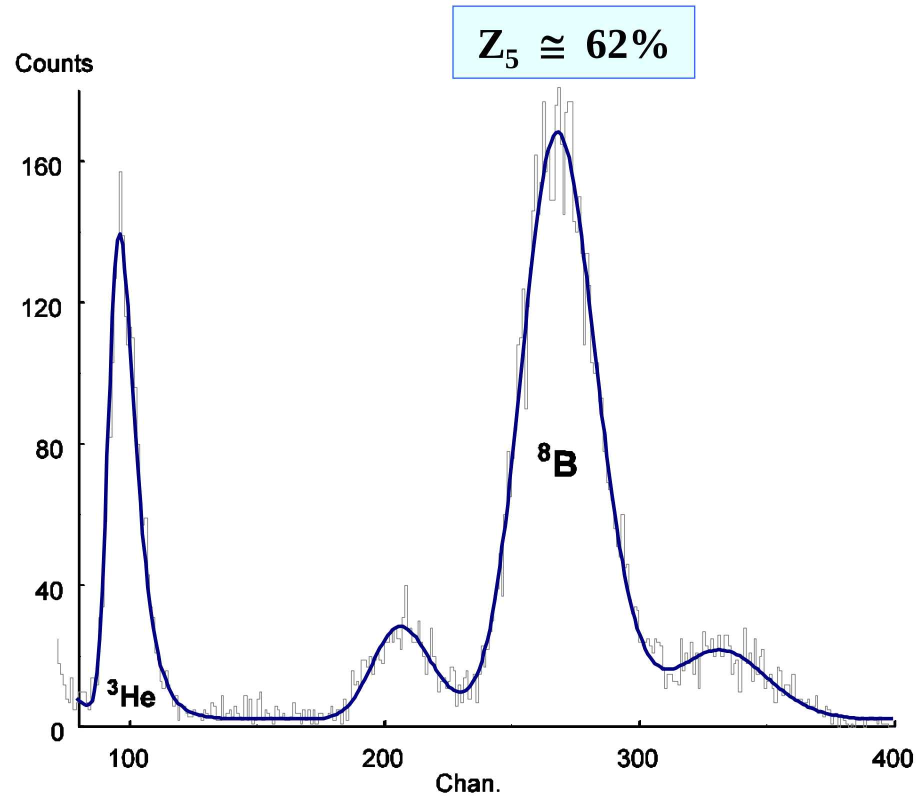
$v_i = v((x-x_i)/w_i, k_i, \beta^2)$ – Vavilov functions

$p = (S_1, x_1, w_1, \ldots, S_m, x_m, w_m, \sigma, y_0)$ – 4m+2 fit param.

Secondary fragments beams: $^{12}C + A \rightarrow {}^{9}C + \ldots,\quad {}^{10}B + A \rightarrow {}^{8}B + \ldots$

Primary beam momentum:	Target:	Separation scheme:	Analyzer:
p_0 = **2.0** GeV/c/nucl.	• Polyethylene, **8 g/cm²** • Placing – F3 focus	• VP-1, f3 – f5 + 2SP-40, • φ_{2SP-40} = 0.22 r	• Plastic scintillator, d=5 mm



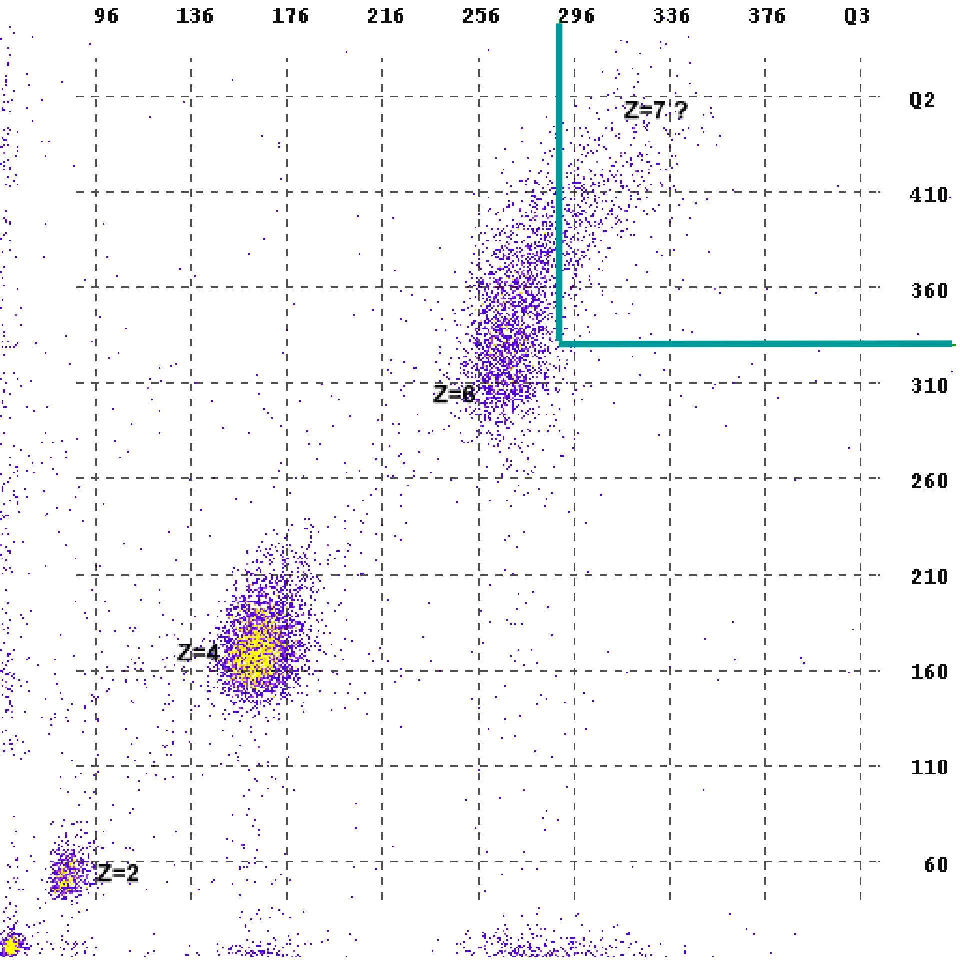


Secondary beam: $^{12}C + A \rightarrow {}^{12}N + \ldots$ ($p_0 =$ 2.0 GeV/c/nucl)

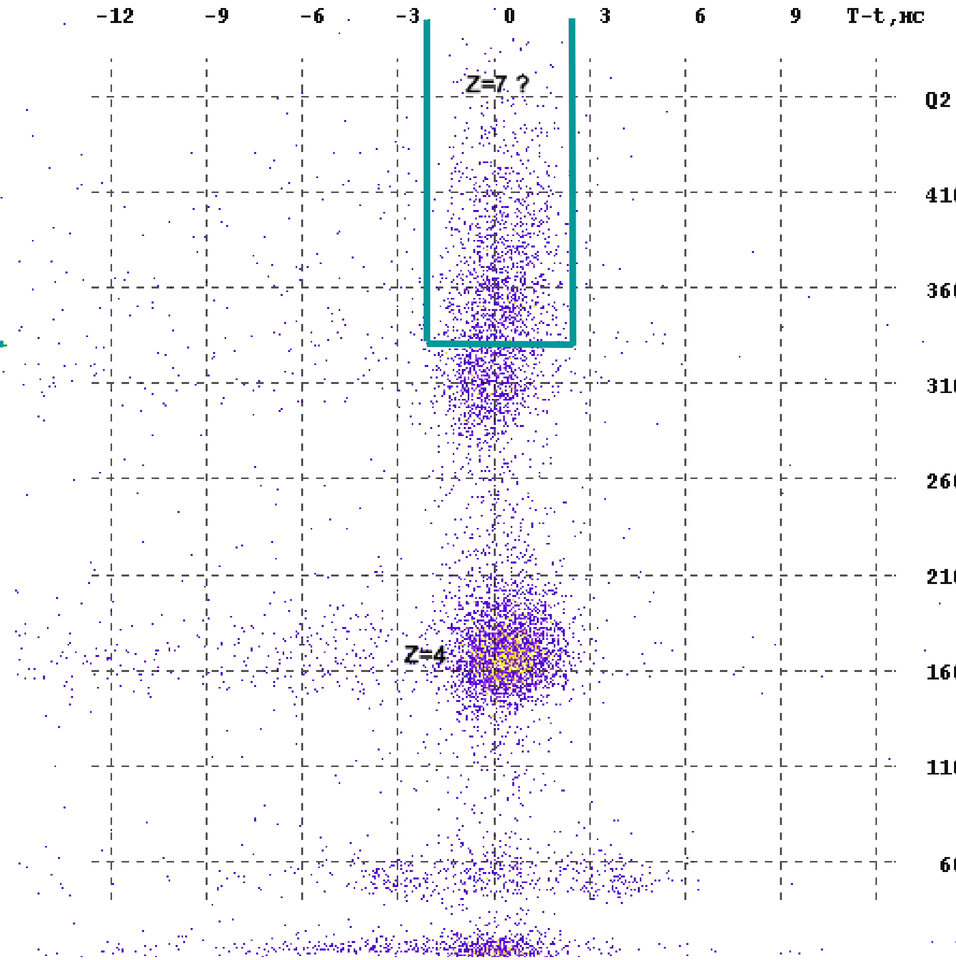
^{12}N: $T_{1/2} = 11$ ms

Correlation plots

$Q_3 - Q_2$

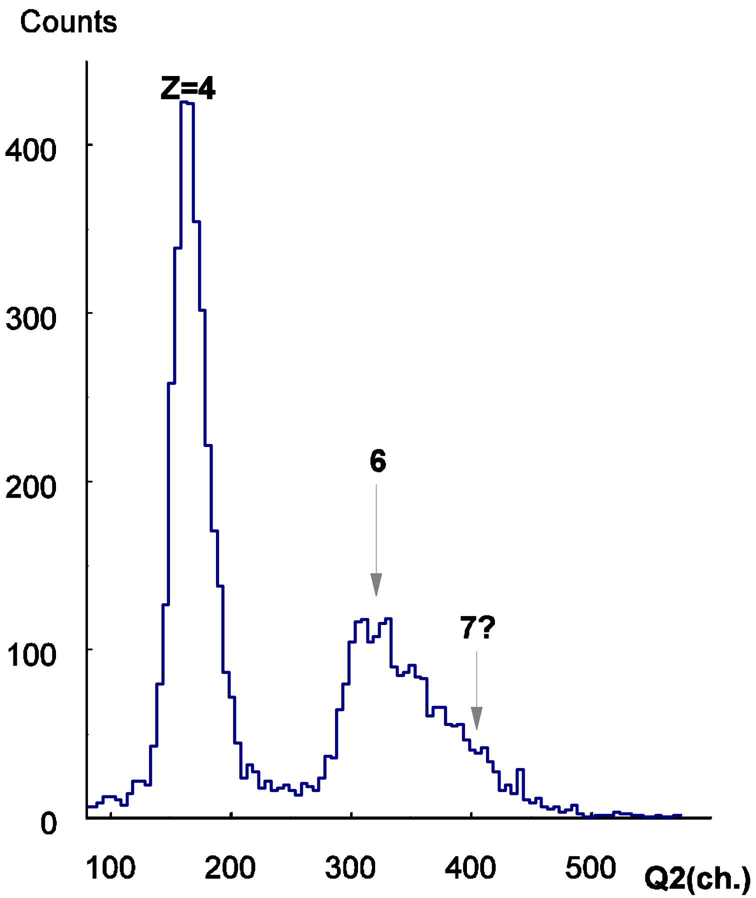


TOF – Q_2

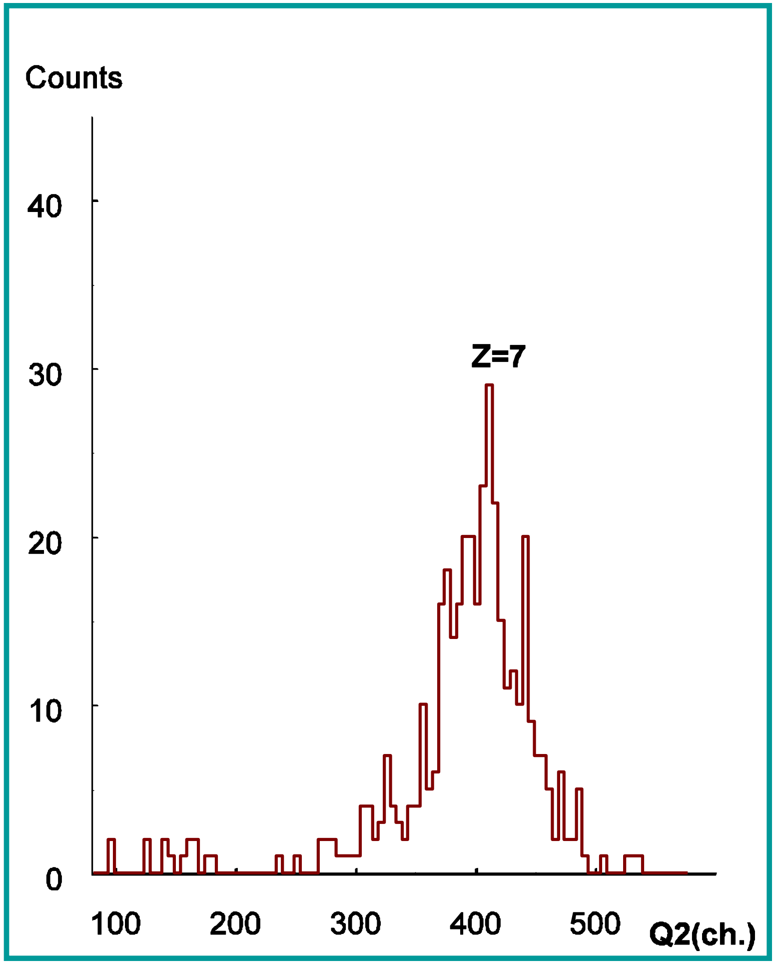


Secondary beam: $^{12}C + A \rightarrow$ ^{12}N + … (p_0 = 2.0 GeV/c/nucl)

Energy losses spectrum in the S_2 analyzer (5 mm)



on the cut sample



Summary

	p_0, $A\ GeV/c$	$Proj.$	$Sec.^a$	Registered components fractions, %						
				Z=1	2	3	4	5	6	7
1	2.7	^6Li	^6He	> 99	**0.85**					
2	1.7	^7Li	^7Be	$2 <$	28.3	$\simeq 5$	**64.7**			
3	2.0	^{10}B	^9Be		5.6	19.2	**66.8**	8.4		
4	2.0	^{10}B	^8B		19.8		9.1	**61.6**	9.5	
5	2.0	^{12}C	^9C		37.3	2.2	4.0	5.6	**50.9**	
6^b	2.0	^{12}C	^{12}N		$\simeq 10$		53		34	$\simeq$ **3**
7^b	2.0	^{12}C	^7Be		$\simeq 5$		**32**		63	
8^b	2.0	^{12}C	^9Be		$\simeq 3$	31	**29**	37		

[a]Nominal beam line momentum corresponds to the fragment
[b]Preliminary

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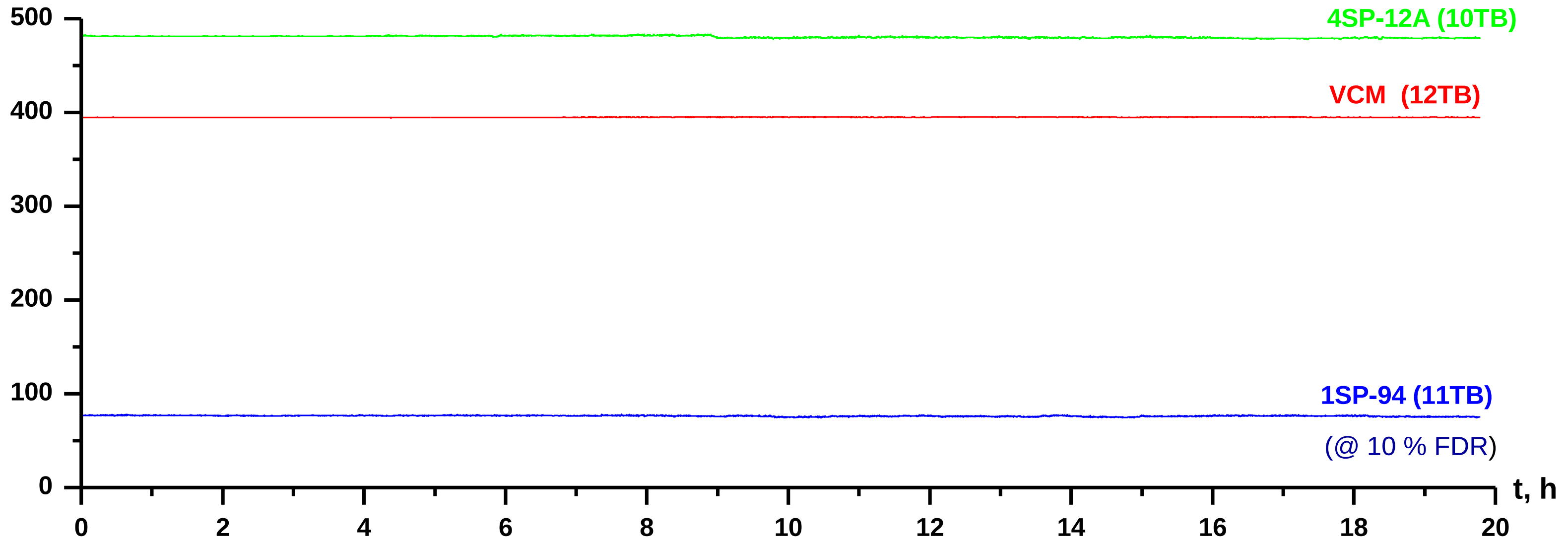
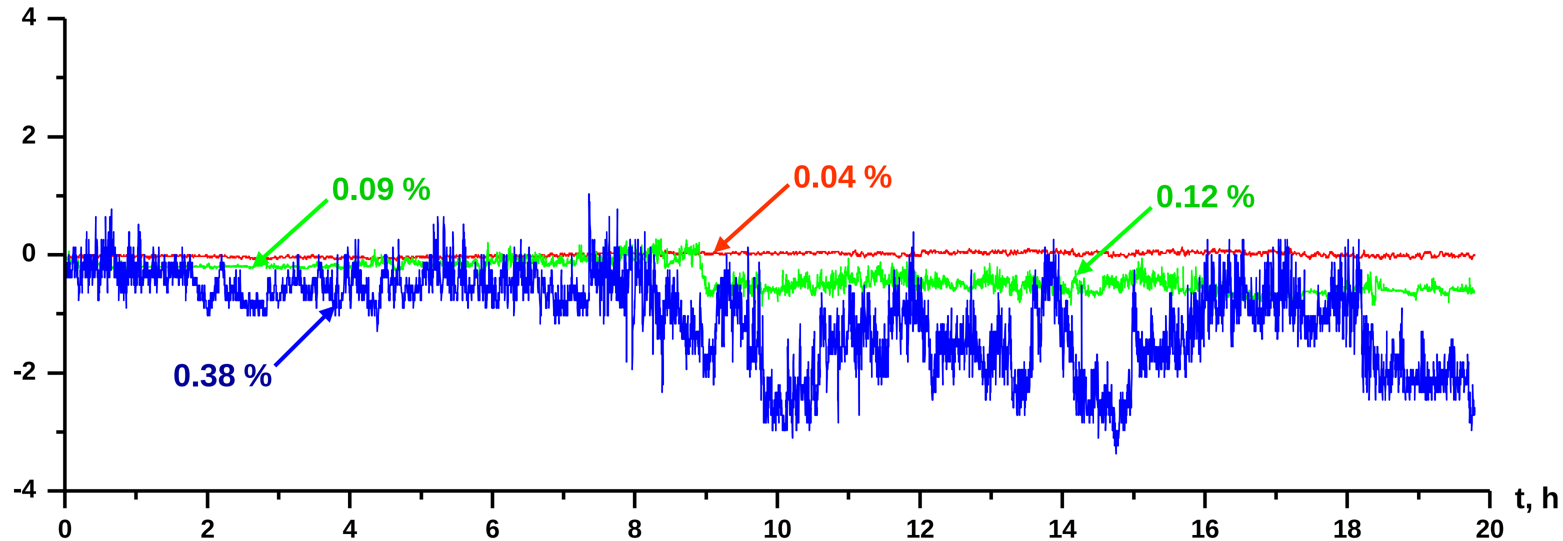
- Development of diagnostics instruments for the external beam lines in frames of the Nuclotron M project.

- Nearest actual task

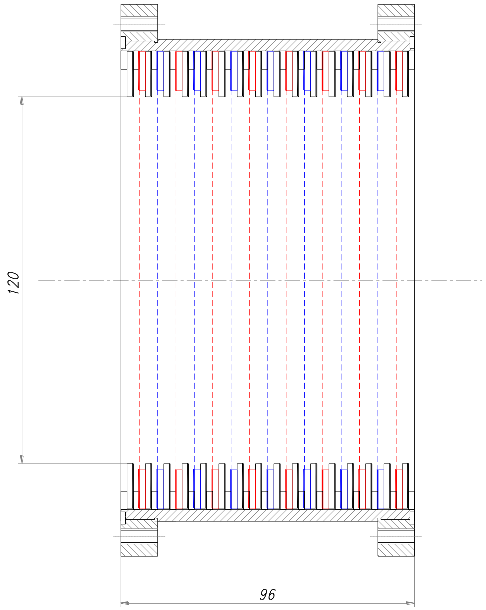
- A new industrial DAQ board based system for monitoring of lines elements currents have been put into operation.

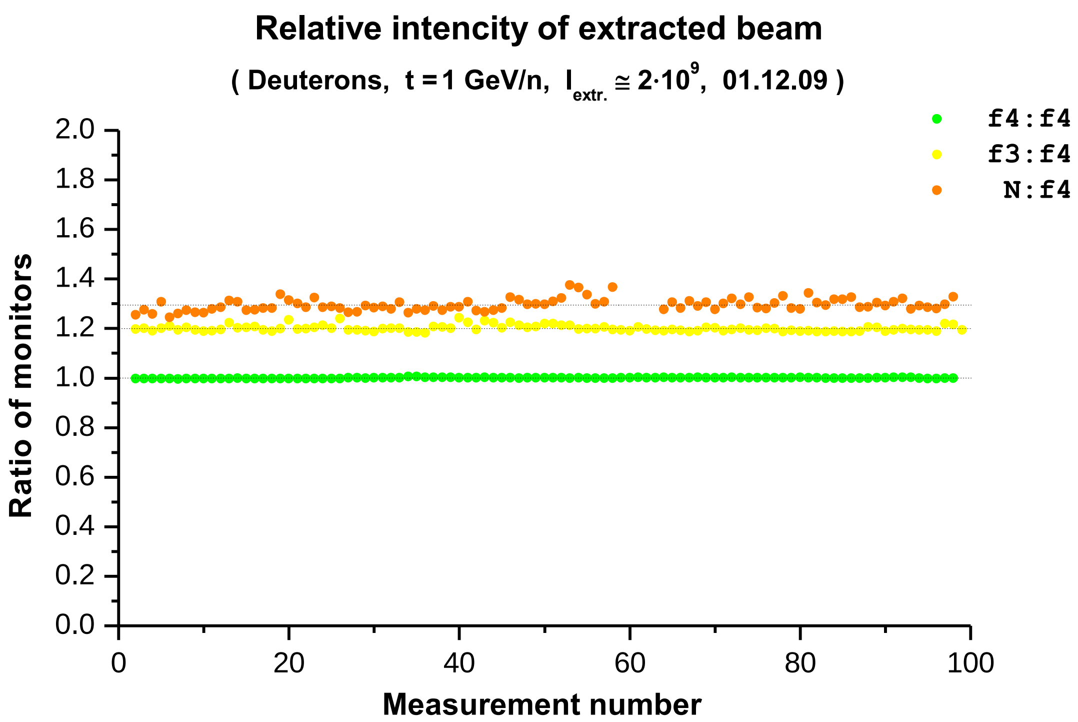




Monitoring interval: 00:51 - 20:38, 18-06-09

IC arrangement





- **Thin Mylar windows (20 μm)**
- **Constant blow-through by Ar**

External beams at the Nuclotron facility

Nearest actual task:

- Increase magnetic rigidity in “weak” parts (4 – 5 elements) of the lateral beam lines : narrowing bending magnet gaps, changing magnets type, installing additional 1-2 units. Development and realize “soft” focusing beam transporting schemes taking into account low emittance values of the extracted beams at high energies.

- Parasitic matter minimizing/eliminating from the beam line traces: thinner separating membranes, minimal (or no) air gaps, low matter diagnostics detectors.

- Modernization of the power supply of the beam lines including developing of a modern control system of the system.

- Creating new additional diagnostics instruments.

Conclusions:

The Nuclotron beam lines operation during the NICA facility creation gives opportunities to

- **Complete/extend current experimental program;**
- **Realize of a large scale heavy ions fixed target experiment;**
- **Perform R&D and test of MPD, SPD and other detector systems;**
- **Get experiences for new generation of experimentalists for further participation in NICA.**

Thank for your attention