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Accelerator Complex U70 of IHEP-Protvino: Status and Upgrade Plans

(report 4.1-1)

Sergey Ivanov,
on behalf of the U70 staff

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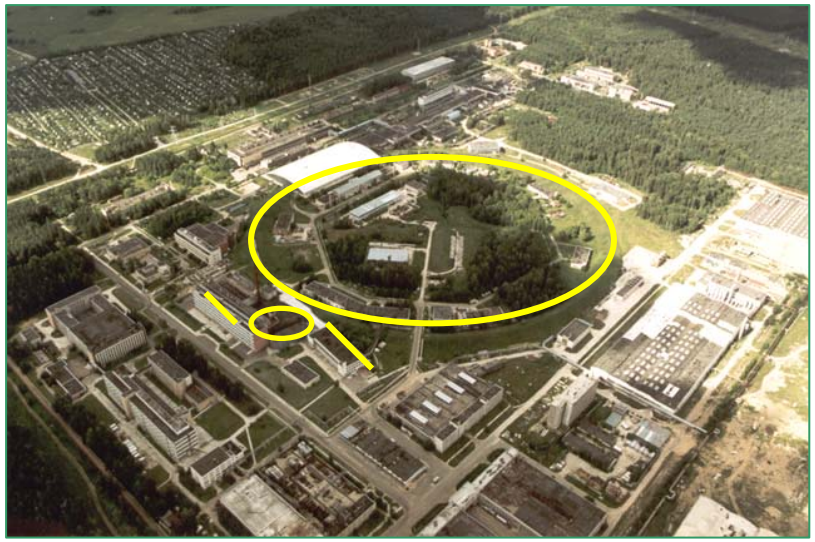
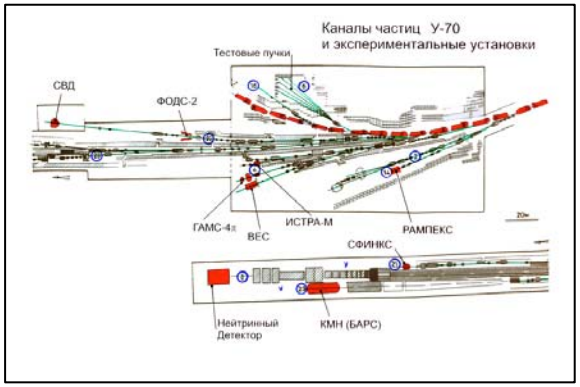
Layout of accelerator complex *U70*



experimental area



October 14, 2007
40 years to *U70*

4 machines:
- 2 *p*-linacs
- 2 *p*-synchrotrons

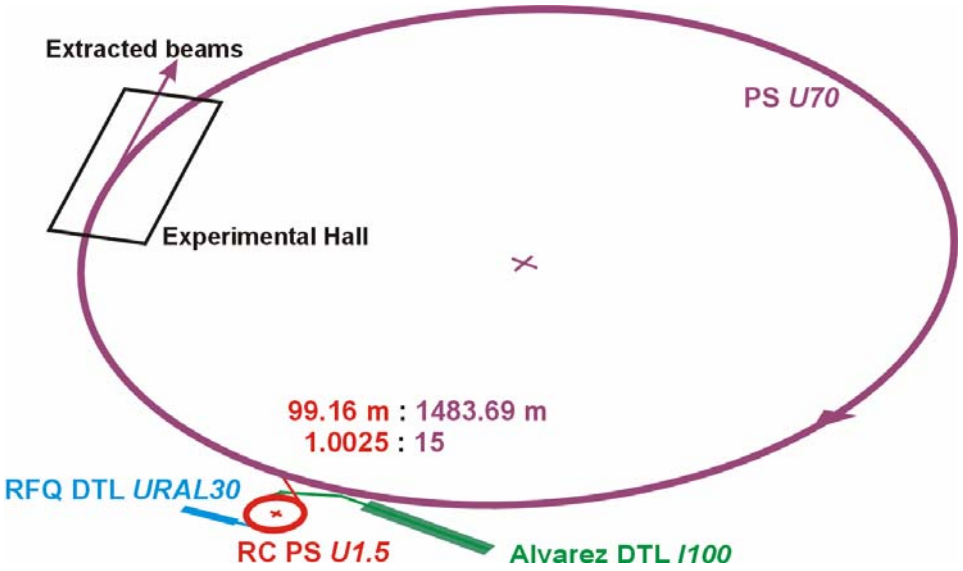
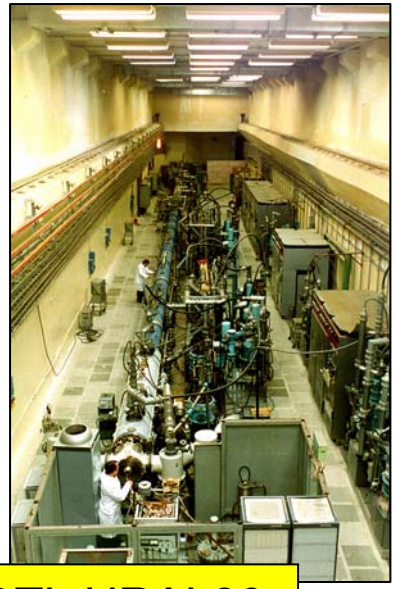


Photo album of machines



RFQ DTL URAL30

Alvarez DTL *I*100

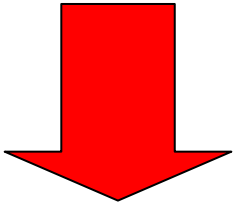
RC PS *U*1.5

PS *U*70

Goals of activity

3 goals:

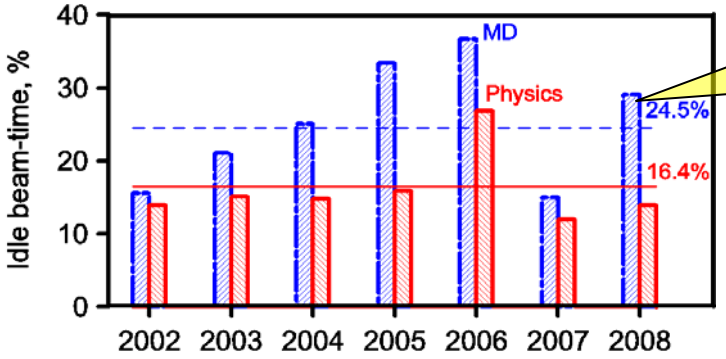
- Regular runs: stable operation and high beam availability
- Improve *p*-beam quality (lower ε, higher *N*, up to $3 \cdot 10^{13}$ p p p)
- Implement light-ion program, $q/A = 0.4–0.5$



Convert the U70 complex into
a universal hadron accelerator (& storage ring)
for applied and basic fixed-target research

Routine operation

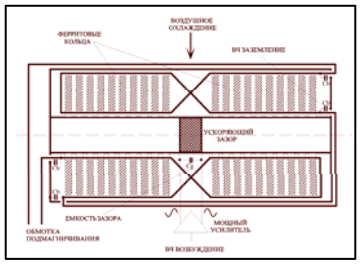
Statistics:
- Once or twice a year
- 1000–1500 hr long run
- 1 week long MD pre-session
- 50 GeV (–20% in overall power consumption w. r. t. 70 GeV)
- Beam availability 83–84% for experimental physics

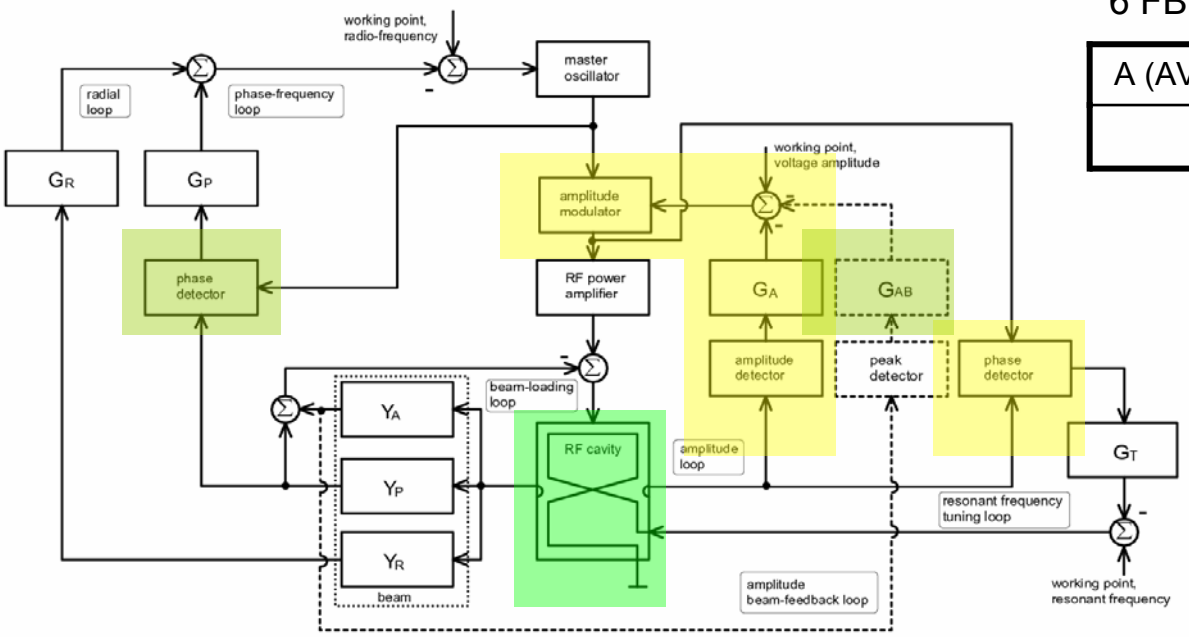


1st attempt to accelerate *d* through *I*100 and *U*1.5

Longitudinal feedbacks (1)

Accelerating system GRAPHITE, 40 ferrite-loaded 1-gap cavities, RF 5.52–6.06 MHz, 10 kV/gap





6 FB loops:

A (AVC)	T (AFC)	BL	R	P	AB
× 40			× 1		

Longitudinal feedbacks (2)

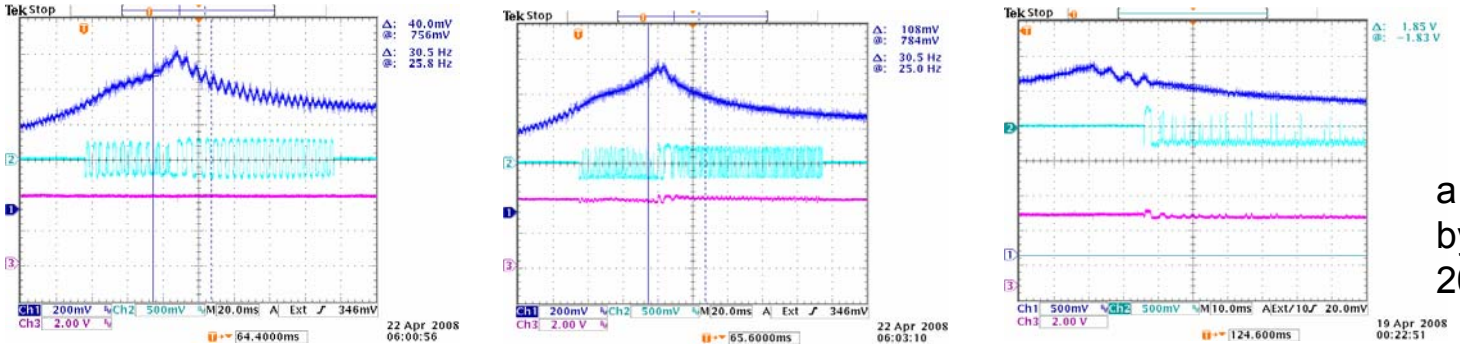
Loops A and T:
- Up-to-date circuit and hardware solutions
- More robust control over voltage and frequency programs
- Extended dynamic tuning range
- Reliability of operation

Details in a poster @ RuPAC-2008:

C8-5 *Markin A.M. et al.* ***Upgrade of Feedback Loops in Accelerating Cavities of U70***

Amplitude control:
- Dynamic range 0.2–10 kV instead of 1–10 kV
- Base-band AM bandwidth from 3 to 50 kHz at –3 dB
  (for reference, synchrotron frequency 1.4 kHz ($\gamma < \gamma_{tr}$), 100 Hz ($\gamma > \gamma_{tr}$))

Closing the AB loop, 1st run of 2008



a 2-channel option by the 2nd run of 2008

Loop P:
- Elimination of a cross-talk “bunch peak current → RF phase detector read-outs”

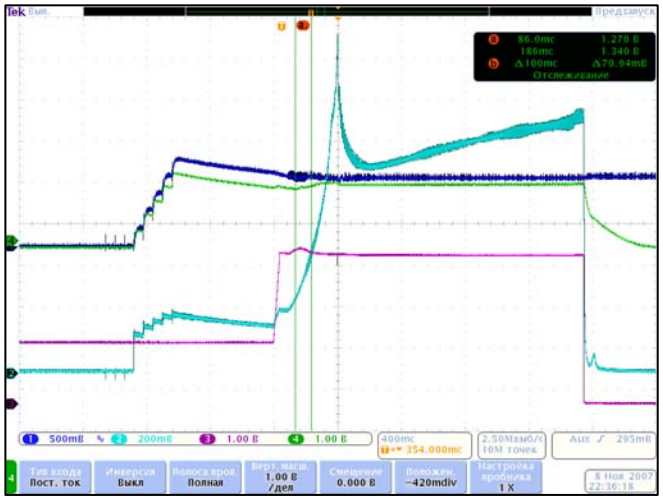
Beam quality, longitudinally

DC CT

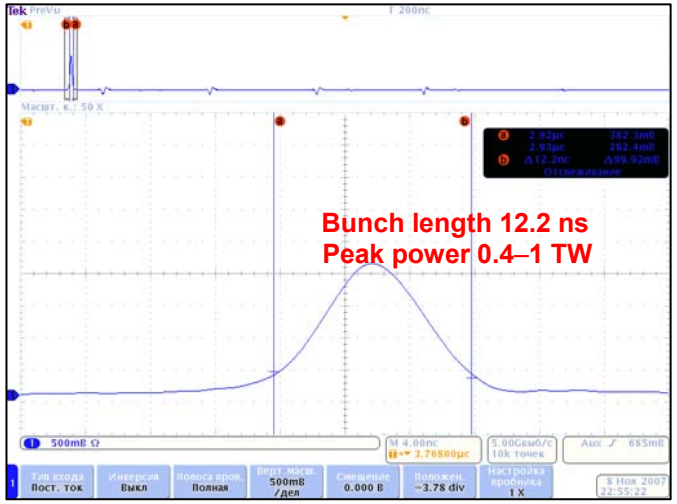
PU

V_{RF}

peak D



without 200 MHz spill cavity below γ_{tr}



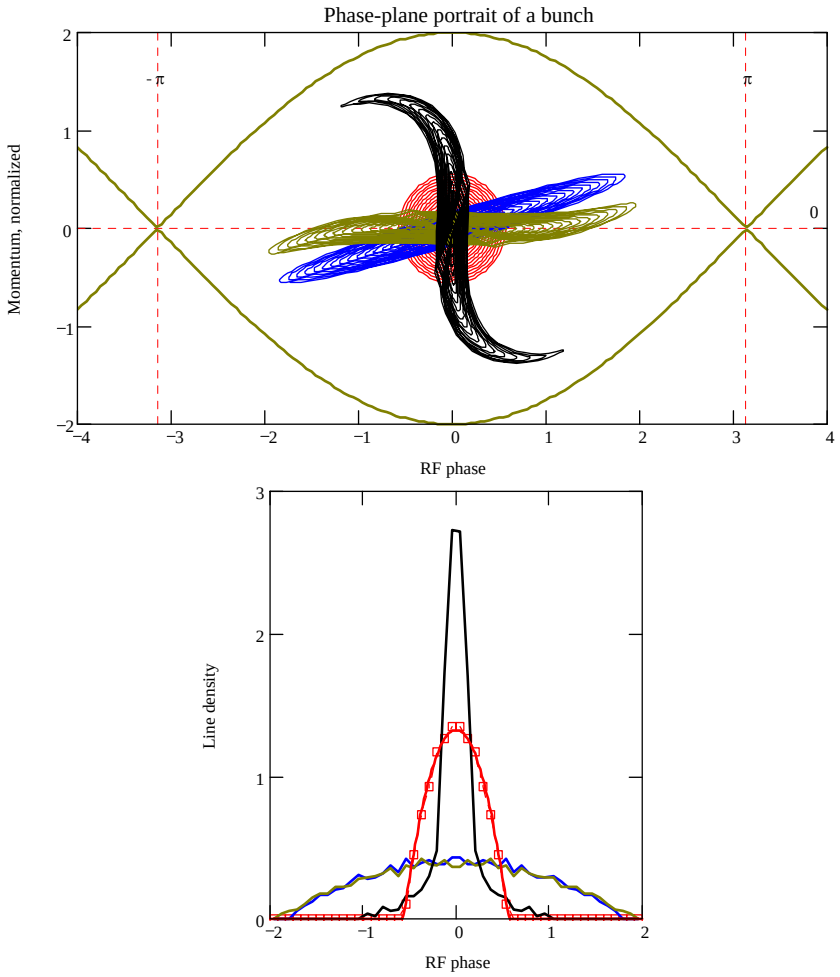
@ 50 GeV

	≤ 2006	2007–8
Bunch length (FW@0.9)	36 ns	12–15 ns
Momentum spread $\Delta p/p$	$\pm 1 \cdot 10^{-3}$	$\pm 4–5 \cdot 10^{-4}$

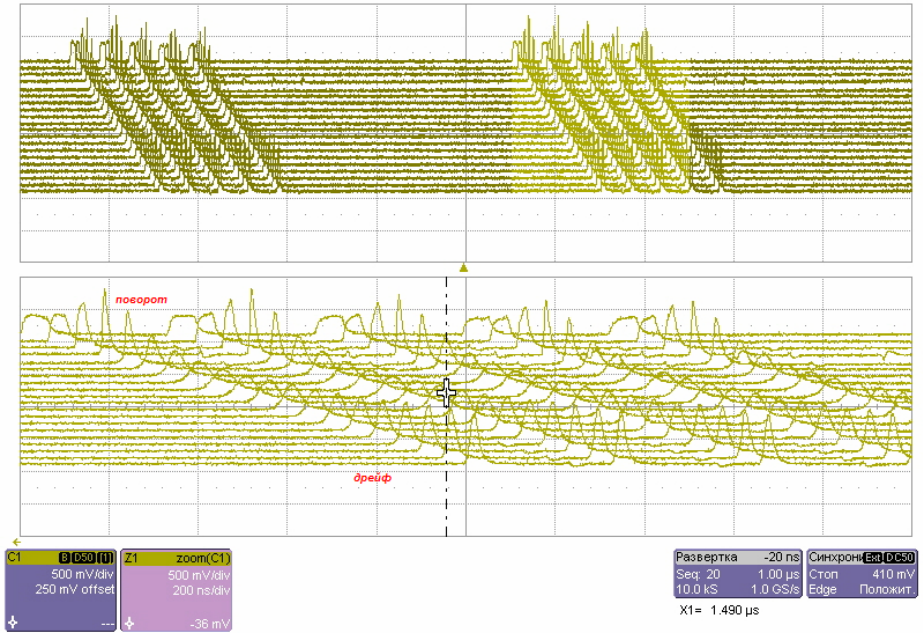
NEW PROBLEMS:

- Bunched beam circulation at 50 GeV
- Efficacy of SE (SSE) of around 80%
- Vertical size/stability of beam

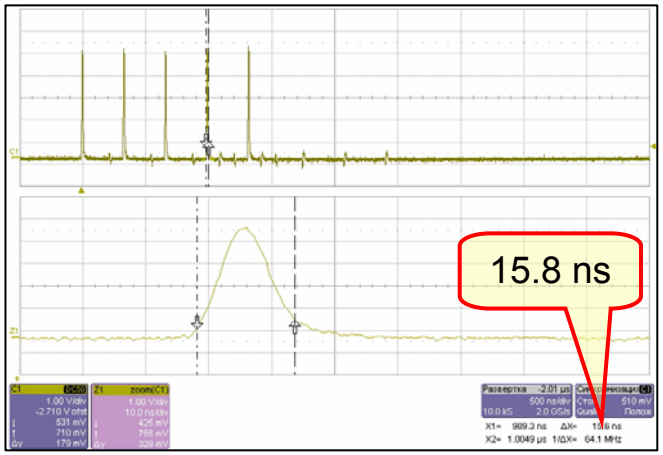
RF gymnastics (1)

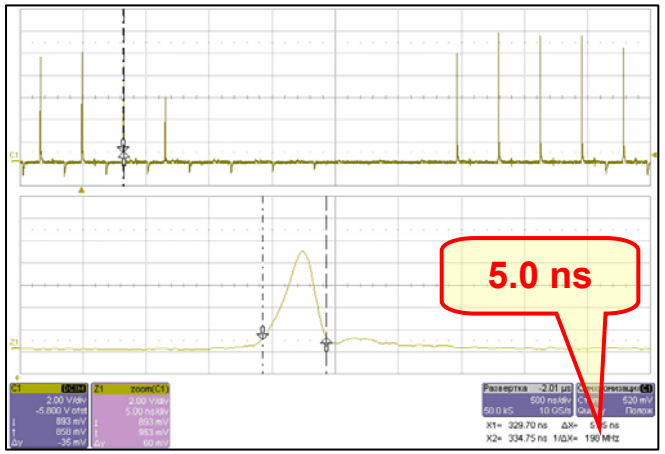


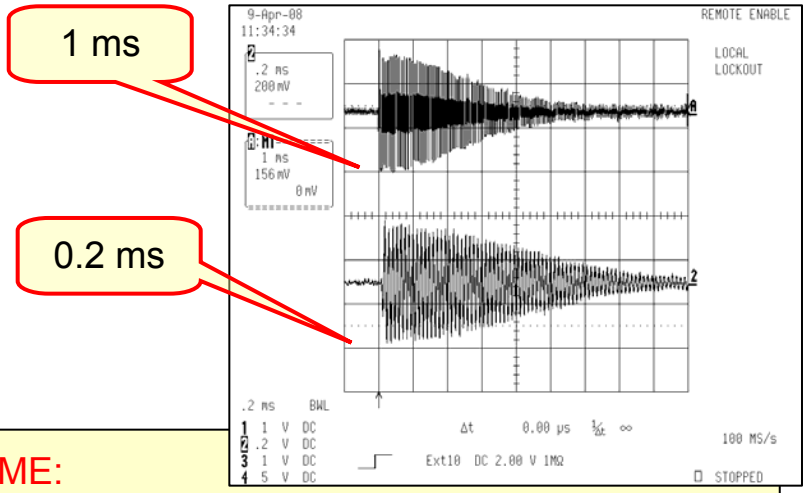
Computation vs. beam observation:
synchrotron frequency = 100 Hz,
bunch = 30 ns,
drift = 5 ms,
rotation *1* = 0.5 ms,
rotation *2* = 3 ms,
scan-to-scan = 0.5 ms



RF gymnastics (2)





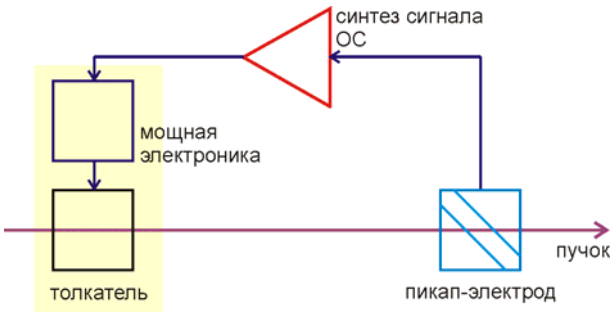


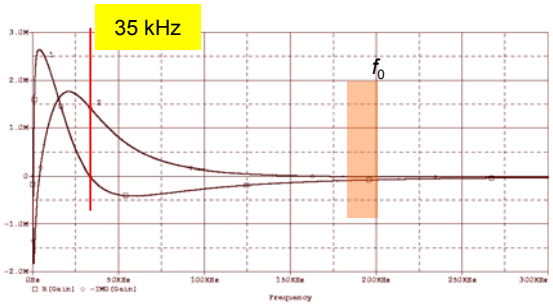
OUTCOME:

- a smooth control via VCO in 5.5–8 ms over $A = A_0 \cdot (K – 1/K)$, $\Delta p/p = \Delta p/p_0 \cdot (1/KK)$ with $K = 2–3$
- optional bunch length for a fast 1-turn extraction
- safely, >1 TW of peak beam power transported
- optional $\Delta p/p$ of a de-bunched (test) beam
- de-bunching time at extraction flat-top
- a straightforward hardware implementation:
- $t_{on+40kHz}$, $t_{off+40kHz}$, $t_{FE}/t_{off6MHz}$
- a built-in option foreseen in a new VCO design (protons + ions)

Transverse (local) feedback

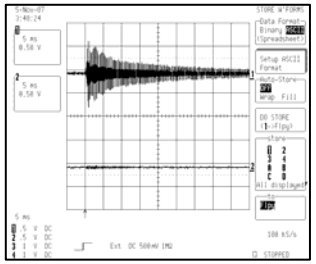
ESK @ SS2	0 – 0.2 MHz	±35.0 kV	PU @ SS2 (+ @SS116)

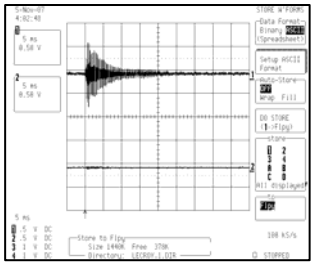


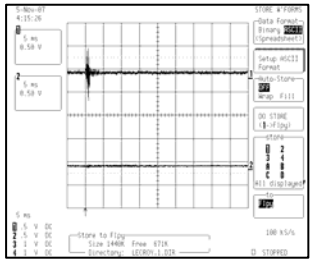


H: 14.7–72.3 kHz, ±45°

V: 29.4–43.2 kHz



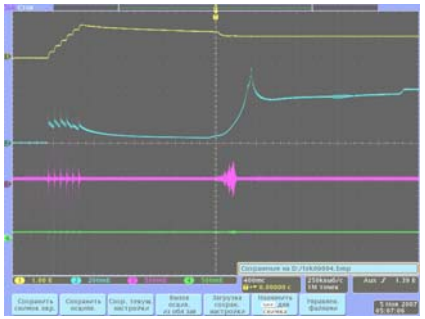


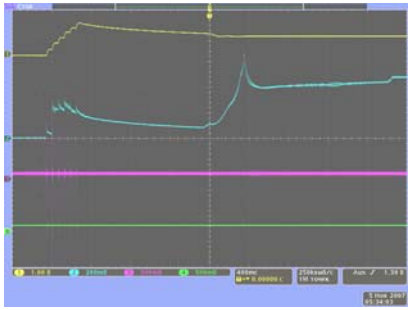


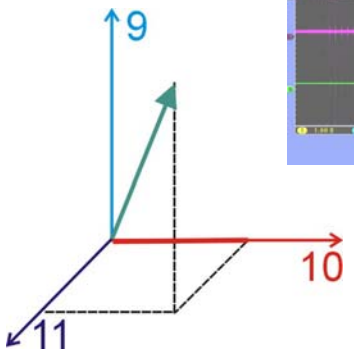
Damping factor = 100 w. r. t. natural

Details in a poster @ RuPAC-2008:

A3-8 *Lebedev O.P. et al.* **Narrow-Band Feedback System to Damp Transverse Coherent Oscillations of Beam in U70**





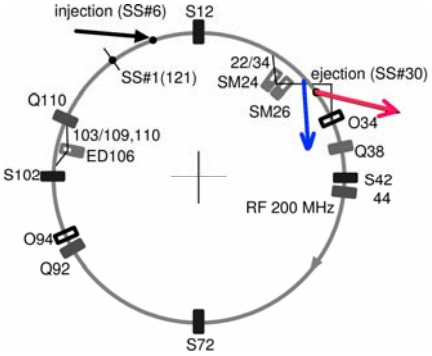


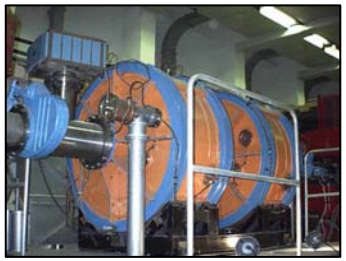
Extraction systems

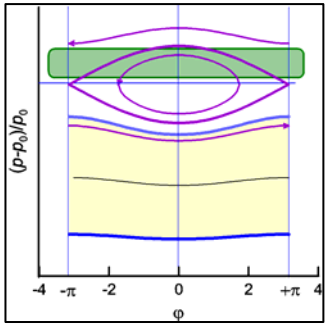
- **Fast single-turn**, 1–29 *p*-bunches, up to 1.1–1.2·10^{13} p p p, about 90% efficiency
- **Slow resonant**, up to 5·10^{11}–1·10^{13} p p p, spill to 2–3.5 s @ 50 GeV
  - Conventional, actuation via magnetic optics, lens Q38
  - Stochastic, actuation via RF noise @ 200 MHz, since 2006
- Secondary particles from **internal targets**
- **Bent crystal** (Si) deflectors, 1·10^{6}–1·10^{12} p p p, about 85% efficiency

Details in an oral talk @ RuPAC-2008 :

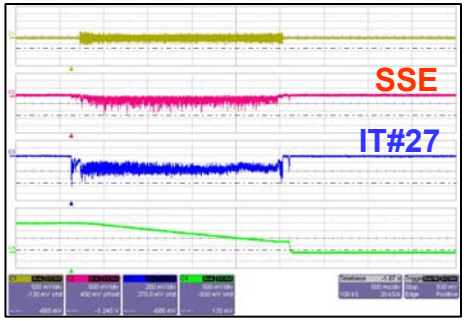
3.2-3 *Chesnokov Yu. et al.* **Review of Studies and Application of Bent Crystals for Beam Steering at U70**



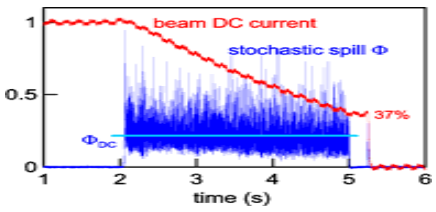


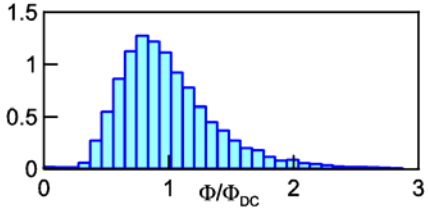


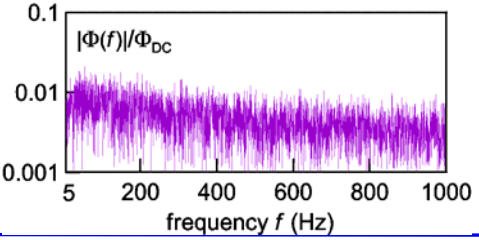
2.3 s long parallel slow extraction



Extraction of 63% in 2.9 s. σ = 0.40, duty factor ⟨Φ⟩^{2}/⟨Φ^2⟩ = 0.87. No lines of mains harmonics





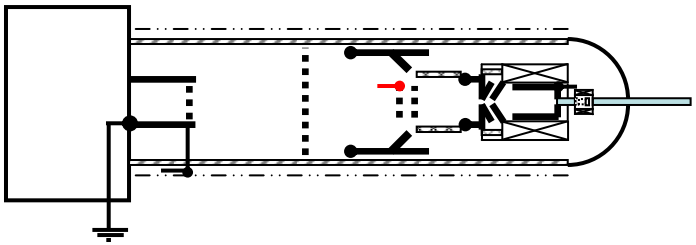


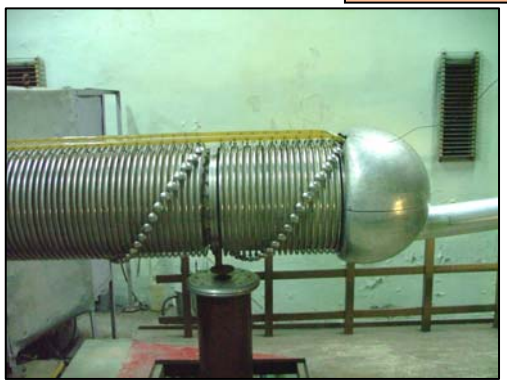
Light ions: *I*100 (ion gas source)

Details in a poster @ RuPAC-2008 :

B4-1 *Antipov Yu.M. et al.* **Deuteron Beam Acceleration at Linac I-100 and IHEP Booster**

p, *d* ion gun (duoplasmatron)
+ fast chopper

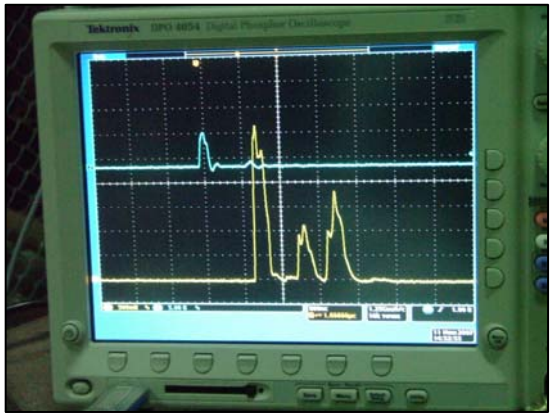




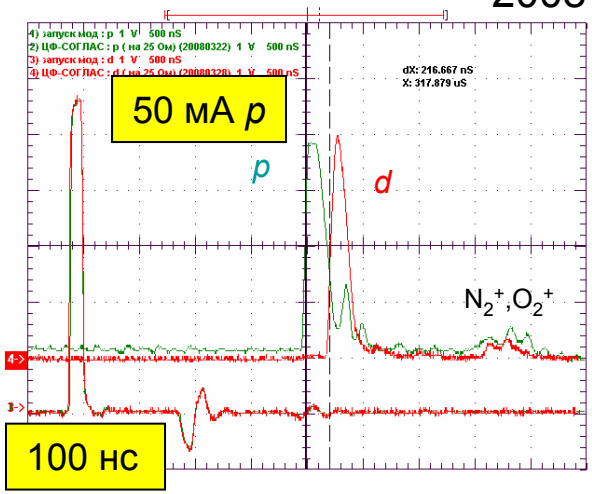
HV platform to +750 kV

control over *q*/*A* content

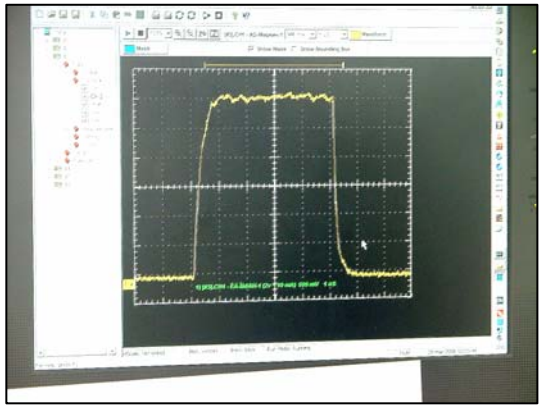
2008



p | N^+, O^+ | N_2^+,O_2^+

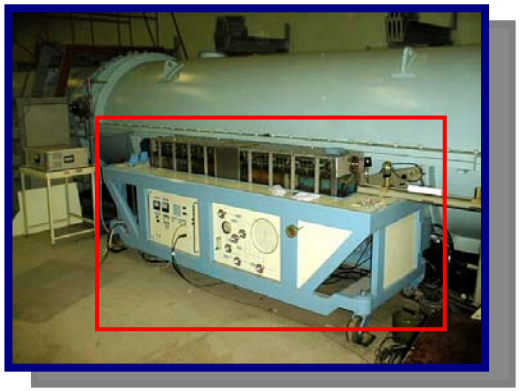


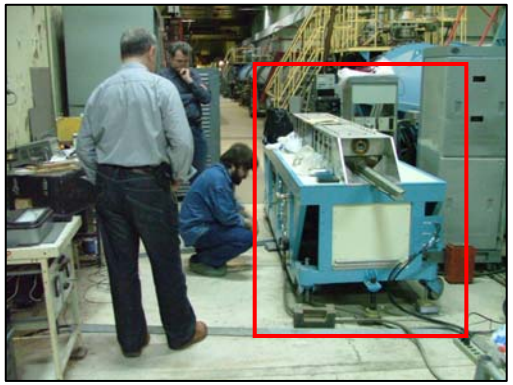
2008



15 мА *d* 5 μs 16.7 MeV/u

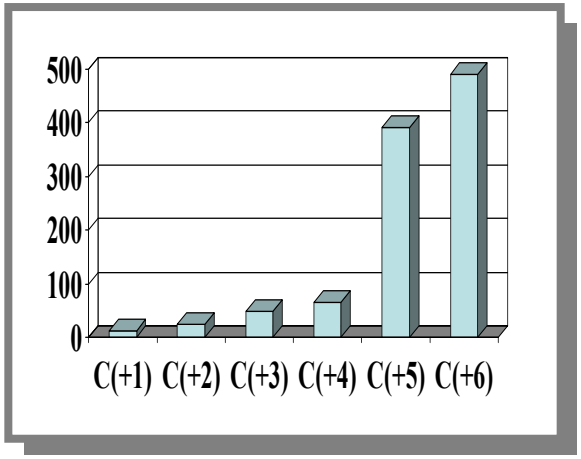
Light ions: /100 (laser SS C ion source)

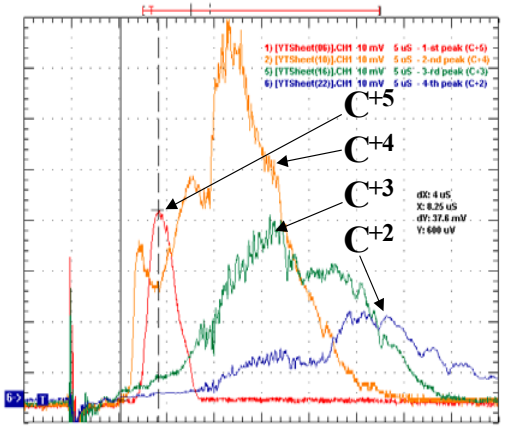


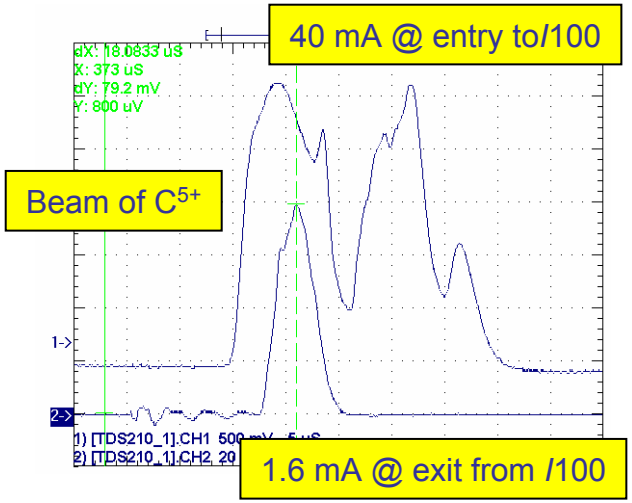


IHEP laser (CO_2, 2.7 J, 10 μm, 0.25 Hz)

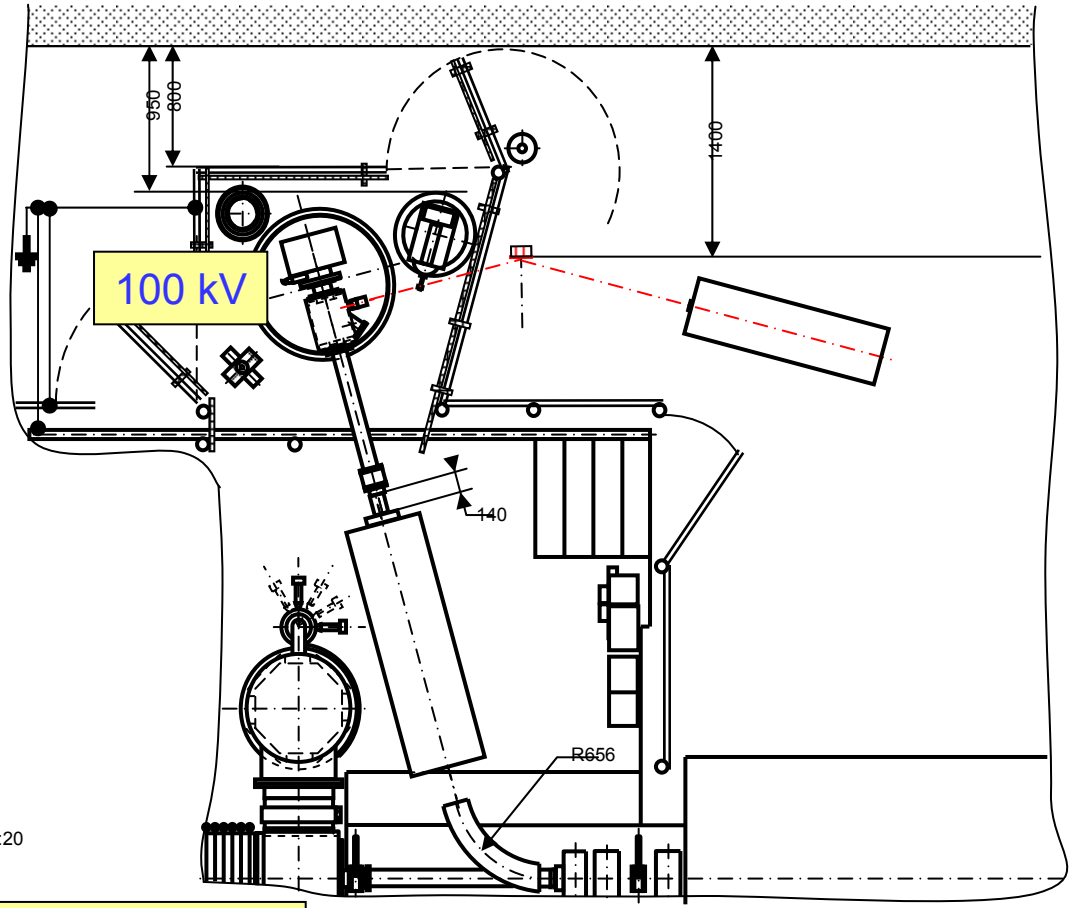
IGP of RAS laser (…, 10 Hz)





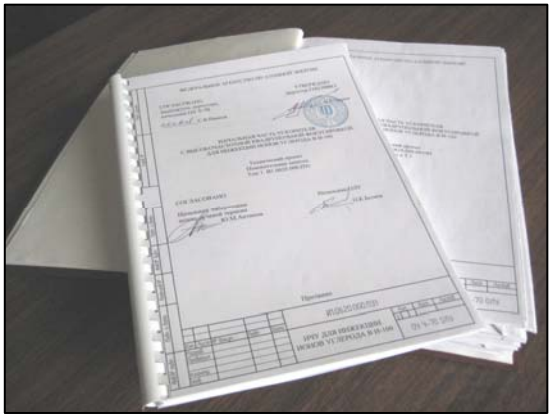


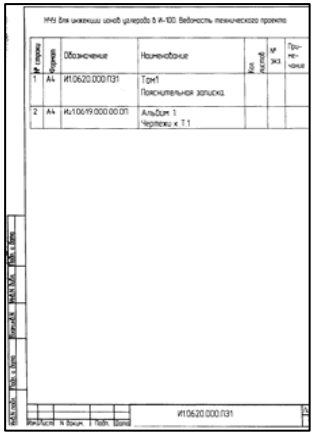
Light ions: /100 (RFQ fore-injector)



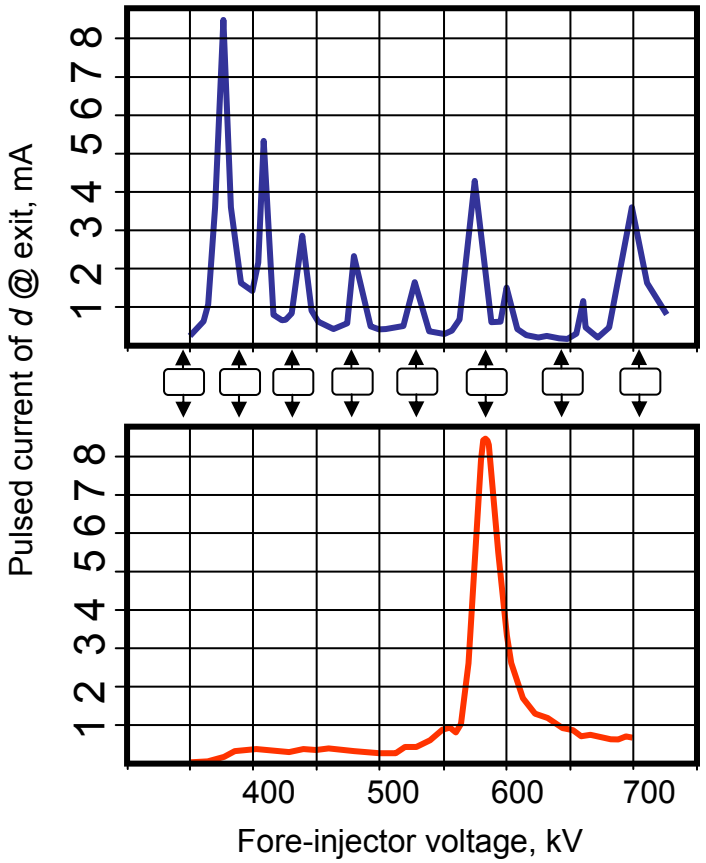
570 (to 750) kV

286 keV/u

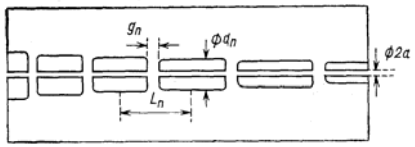




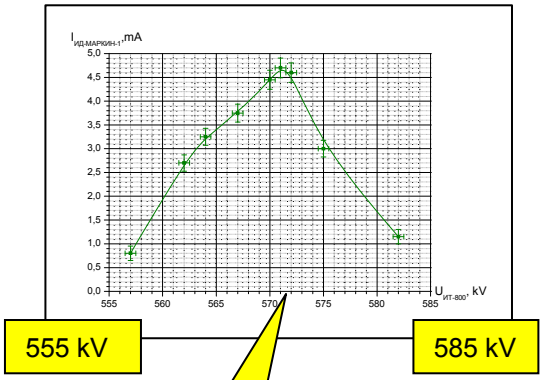
Light ions: /100 proper



period = βλ (2βλ, …)



Ускоряющая структура Альвареца



555 kV

585 kV

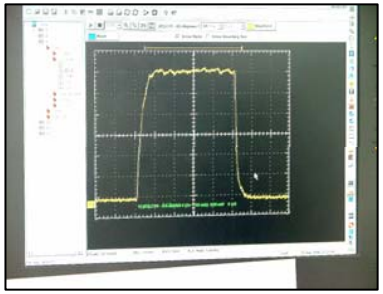
570 kV

2π-mode, p ($h = 1$)
4π-mode, d, C ($h = 2$)

$\beta_h = \beta_1/h$
$G_h = G_1/(h \cdot q/A)$
$(Vg)_h = (Vg)_1/(h^2 \cdot q/A)$
$(Vg)_h = V_h \cdot g_h$

$1/3 < q/A < 1/2$

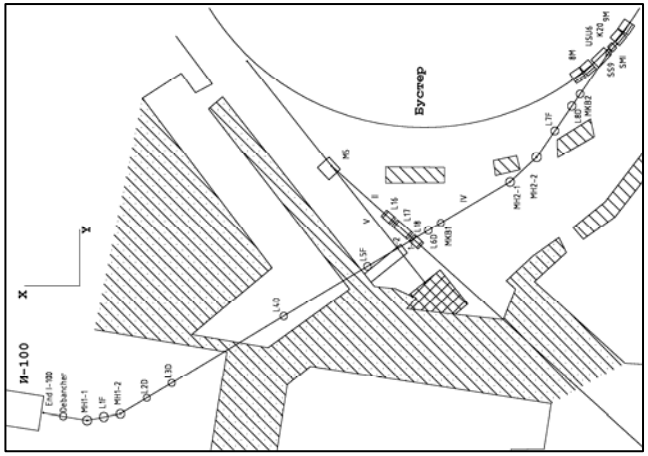
1st MD run of 2008

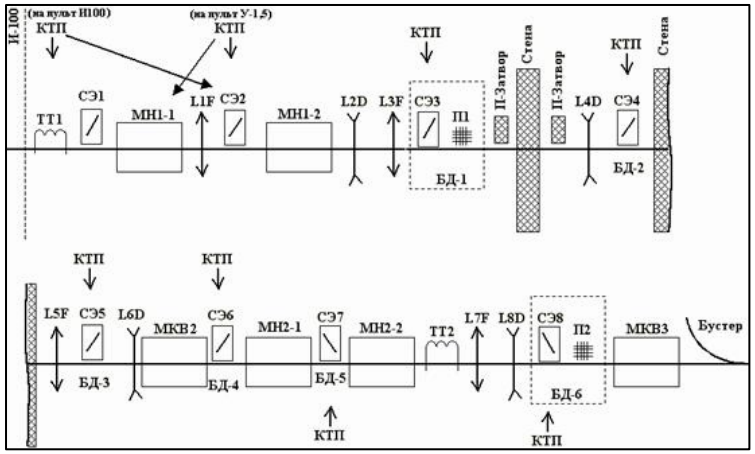


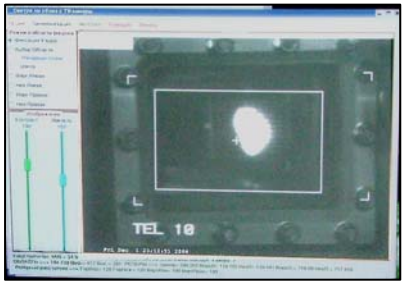
15 мА d 5 μs 16.7 MeV/u

Light ions: BTL *I*100 - *U*1.5

43 m long
4 bends
8 quads
3 H/V-correctors
beam diagnostics

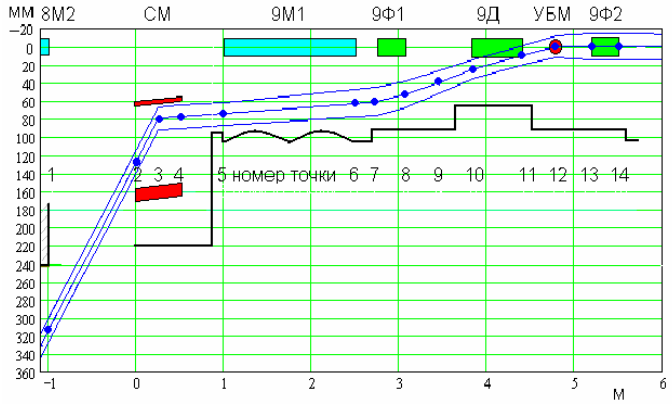






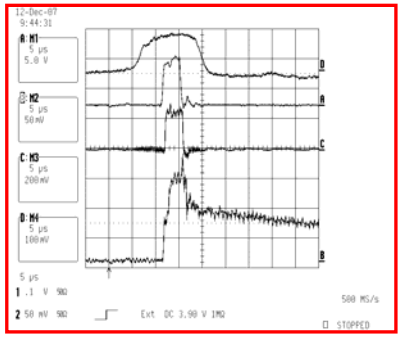
Commissioned with 72.7 MeV *p* (17.11.06) and 16.7 MeV/u *d* (01.12.06)

Light ions: *U*1.5 (1)



Reassemble SS#9 of *U*1.5 and update other equipment:

- A wider dipole
- New vacuum chamber
- Away 1 RF cavity of 9 (now, a spare unit)
- 177 mrad septum magnet with its PSU
- 23 mrad kicker magnet with its PSU
- The other ancillary equipment
- New RF master oscillator
- Extra capacitive loads to 8 RF cavities
- Improved (though, partially) beam diagnostics, …

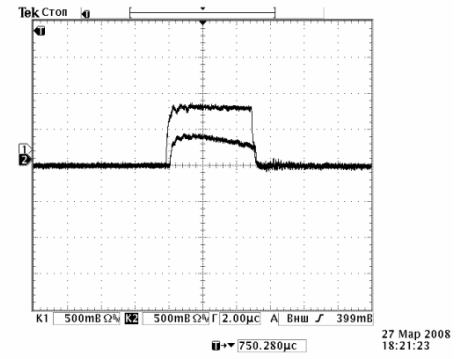


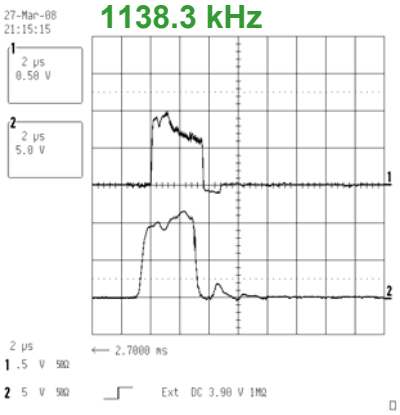
10–12.12.07; *p;* 72.7–1320 MeV; $3 \cdot 10^{10}$ ppb; 35% through *U*1.5

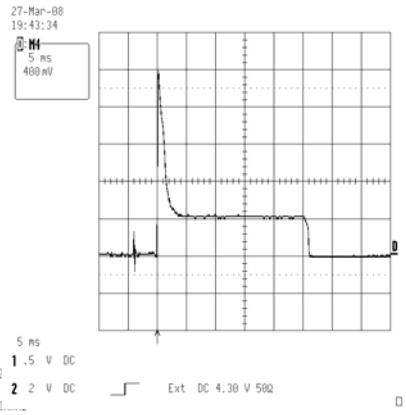
Light ions: *U*1.5 (2)

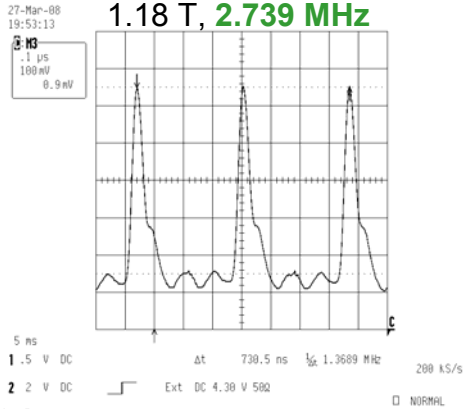
29–30.03.08; *d*; 16.7– 455 MeV/u; $3 \cdot 10^{10}$ ppb; 34% through *U*1.5

p

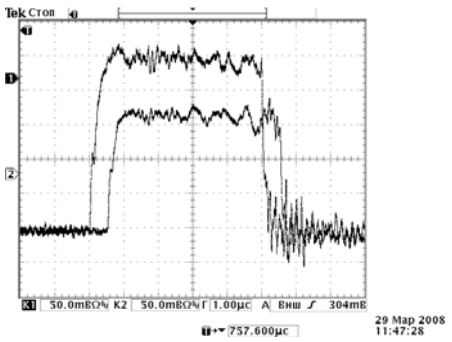


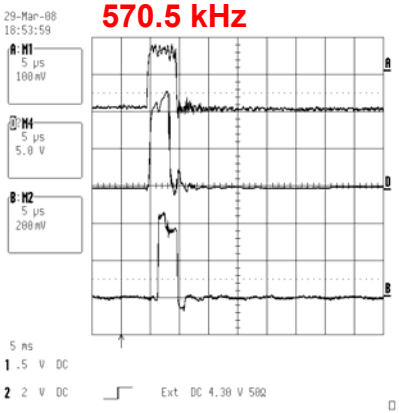


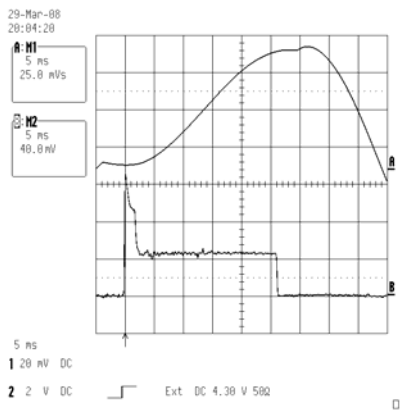


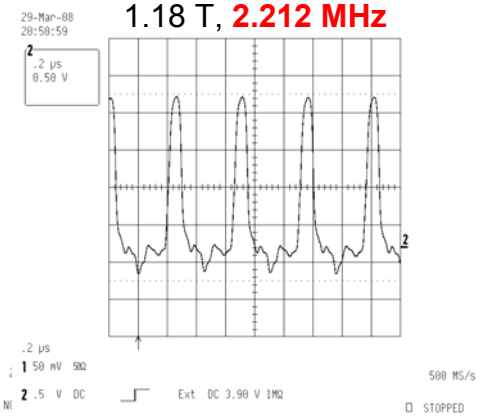


d









Overall: from *I*100 to *U*1.5

1st MD run of 2008

	Exit from *I*100	Exit from BTL	1st turn	Circulation	Start of acceleration	Extraction
p, 72.7 – 1320 MeV	48 mA	20 mA	15 mA	$8.2 \cdot 10^{10}$	$6.7 \cdot 10^{10}$	$1.5 \cdot 10^{10}$
TOTAL:	$3.0 \cdot 10^{8}$ $p_{U1.5}$/mA$_{I100}$, IN-OUT$_{U1.5}$ = 18%					
d, 16.7 – 455 MeV/u	15 mA	9.6 mA	8 mA	$8.8 \cdot 10^{10}$	$8.1 \cdot 10^{10}$	$3.0 \cdot 10^{10}$
TOTAL:	$2.0 \cdot 10^{9}$ $d_{U1.5}$/mA$_{I100}$, IN-OUT$_{U1.5}$ = 34%					

OUTCOME:

- Quality *p* from *I*100 yet to be improved
- Good quality of *d* beam
- Further improvement of fast injection kicker magnet PM3 is required
- 2-turn injection scheme for *d*, C should be assessed
- Beam capture efficiency and excessive momentum spread (a de-buncher cavity)

Towards light ions in *U*70 (1)

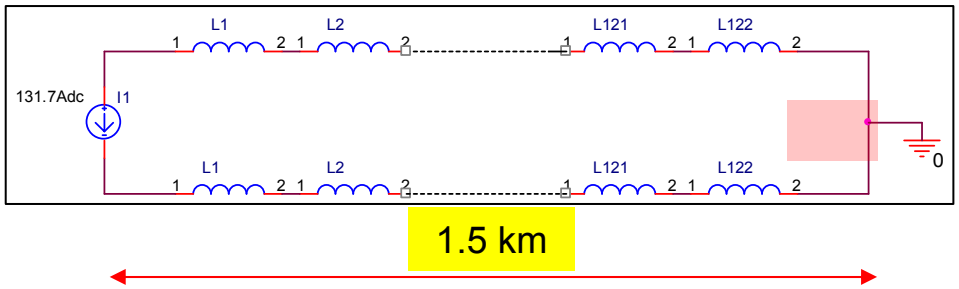
1st MD of 2008: beam test with a stand-alone DC power supply unit for the *U*70 ring magnet

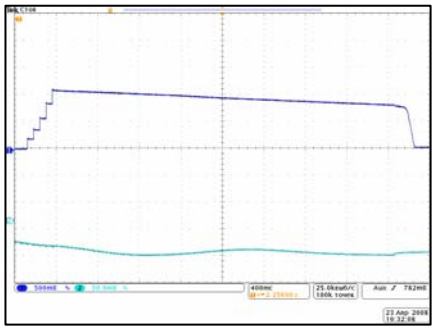
Goal:
- cheap MD runs (1.32 GeV *p*, 0.45 GeV/u *d*, C);
- storage/stretcher ring of light ions 450 MeV/u;
- medical applications of C beams

Preliminary job: long-line impedance measurements, two competitive DC PSUs

2 PSU: building #10, 131.7 A and (*building #175, 129.8 A*)

Experimental studies: 07.03 and 23.04.08





354 ± 0.05 Gauss

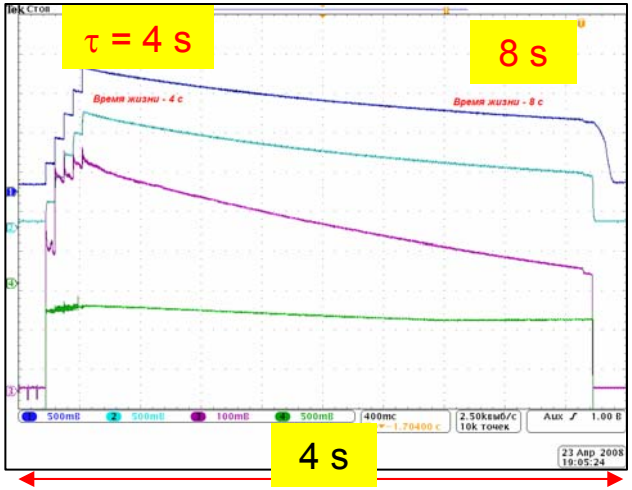
Towards light ions in *U70* (2)

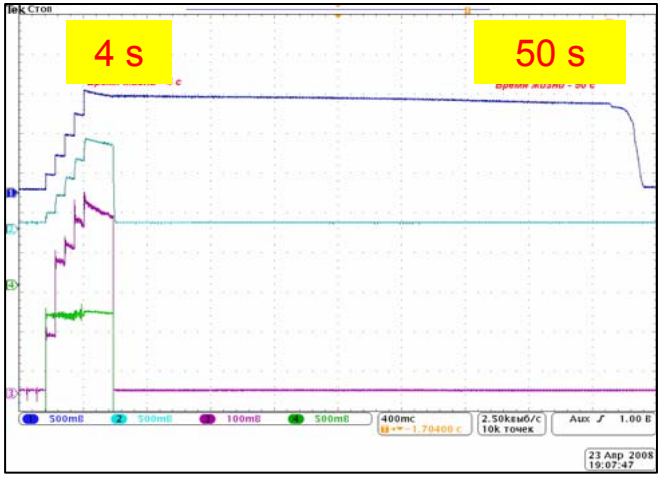
DC CT

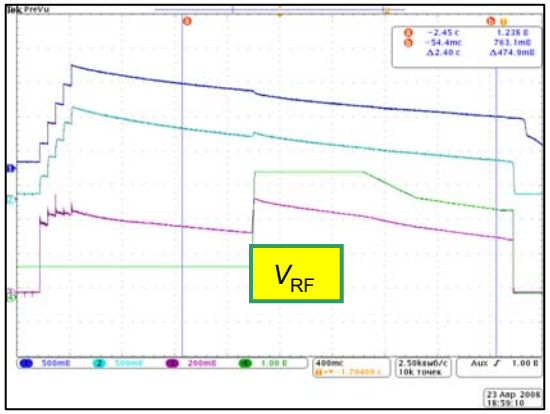
PU

peak D

φ D







- Significant difference in τ of bunched vs. un-bunched beams
- Vacuum conditions are better than expected
- Dynamical reasons of shortening τ:
  - Coulomb betatron tune shift, effect of local beam charge density, $30/5 \times 2 \times 1.5 = 18$
  - Synchro-betatron resonances, $mQ_x + nQ_y + (pQ_s) = k$
  - Dynamic aperture (distortions of the CO, WP, etc) …

PROBLEMS: residual D field due to G and S correction circuits

Conclusion

Accelerator complex *U*70 of IHEP-Protvino

- readily ensures running the fixed-target physics program,
- is subject to ongoing upgrade program,
- has noticeably improved quality of proton beam,
- on a way towards accelerating light-ions to 34 GeV per nucleon.

Accelerator side of light-ion program well advances: by the 1st half of 2008, 455 MeV/u deuterons were made available from *U*1.5