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Accelerator Complex U70 of IHEP-Protvino: Status and Prospects for Upgrade

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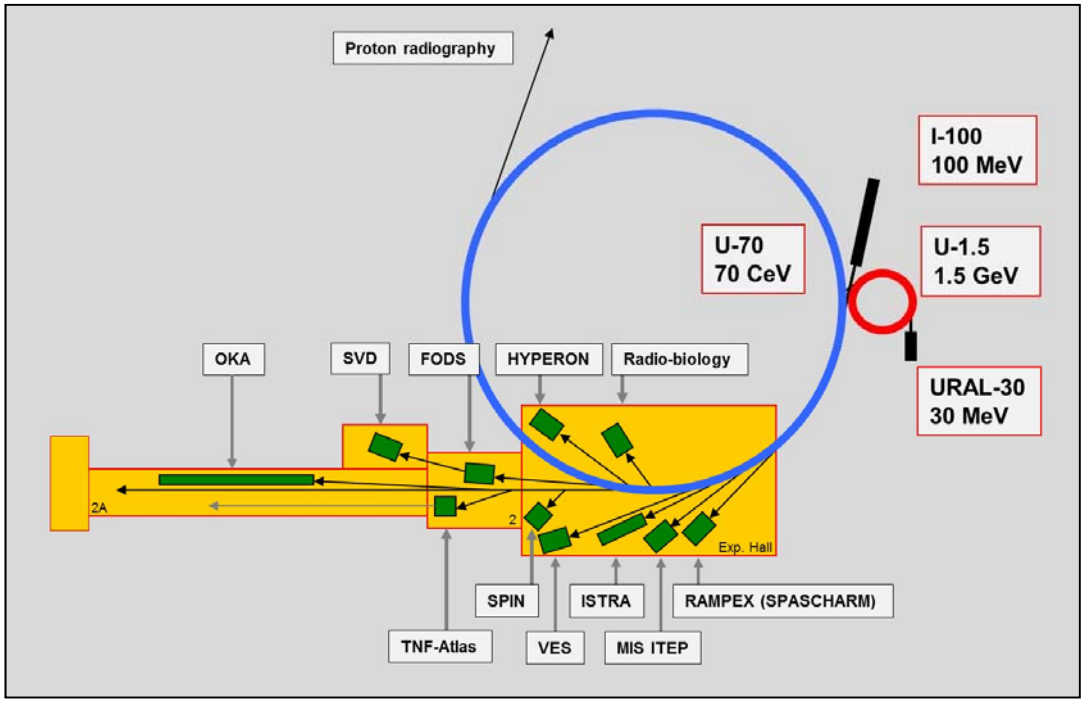
16th Lomonosov Conference on Elementary Particle Physics
August 22-28 2013, Moscow, Moscow State University

Outlook

- Generalities
- Routine operation, runs
- Machine upgrades
- Light ions
- Prospects (options) for future development
- Conclusion

Layout, AC U70 vs the U70 proper



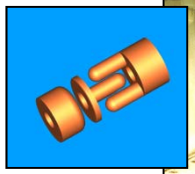
4 machines (since Oct 2007):
- 2 linacs
- 2 synchrotrons

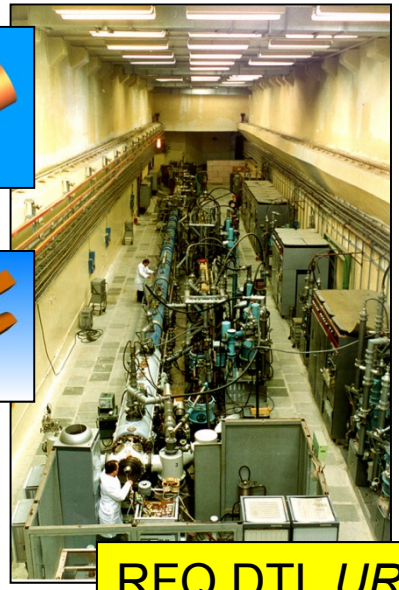
Modes:
- *p* (default, 50-70 GeV) *URAL*30-*U*1.5-*U*70
- light-ion (*d*, C) *I*100(2 of 3)-*U*1.5-*U*70

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

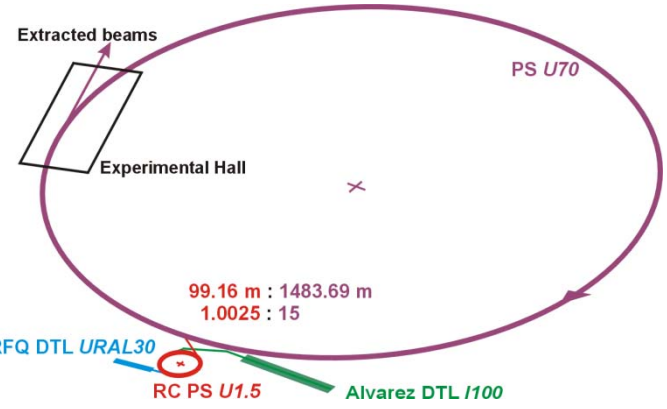
In a SIS-18, SIS-100 name convention:
- LIS-233 [T·m]
- LIS-6.9 [T·m]

Photo album of machines

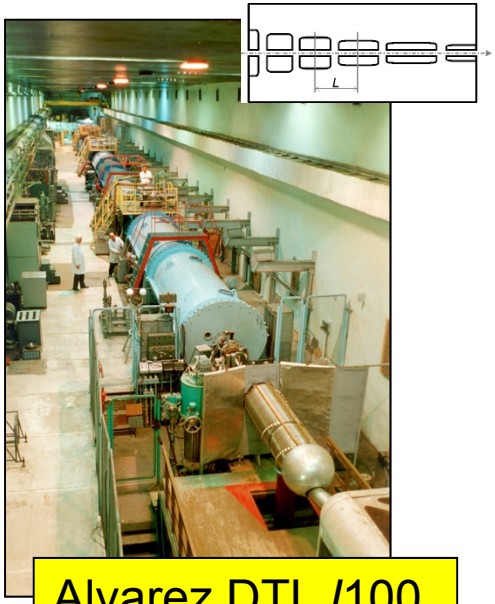




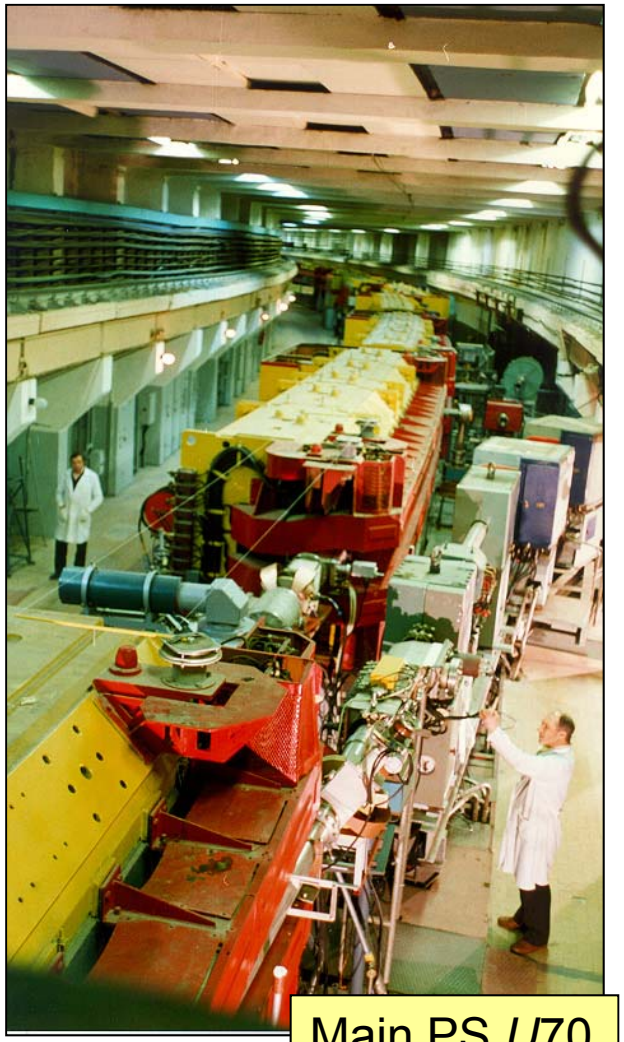
RFQ DTL *URAL*30



RC PS *U*1.5

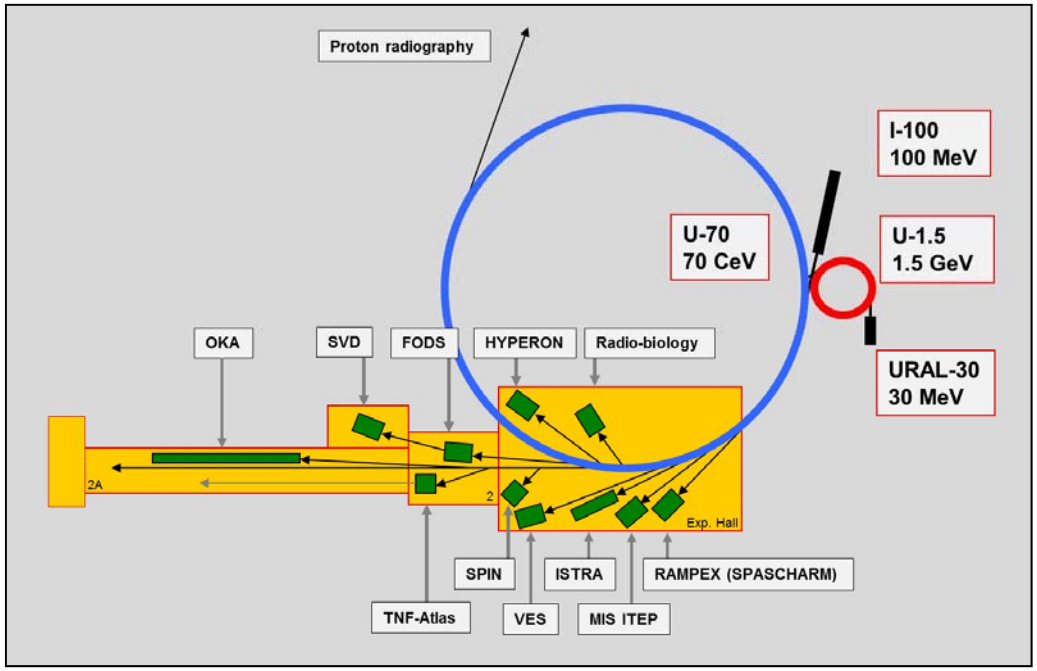


Alvarez DTL *I*100



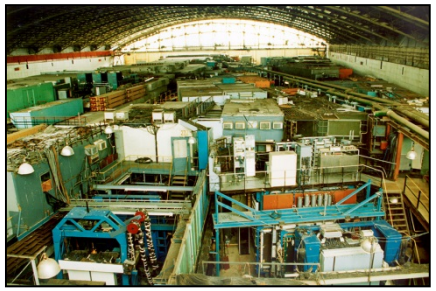
Main PS *U*70

Fixed-target physics and BTL network



Beams of
p, π, *K*, *e*, ν, *C*

Field of research:
- *h* spectroscopy
- spin physics
- rare *K*-decays
- *h*-*A* interactions
- [ν physics]
- [nuclear physics]
- …



90 m

Collaborators:
IHEP, ITEP, JINR,
INR, St.-PbNPI, SINP MSU,
MEPhI, CERN, FNAL, …

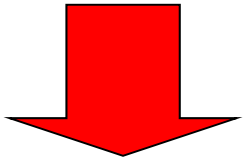
to note: OKA (#21), FODS (#22), stretcher (#25)

Up to 9 HEP experiments per a run, up to 7 beam users per a cycle

Goals of activity

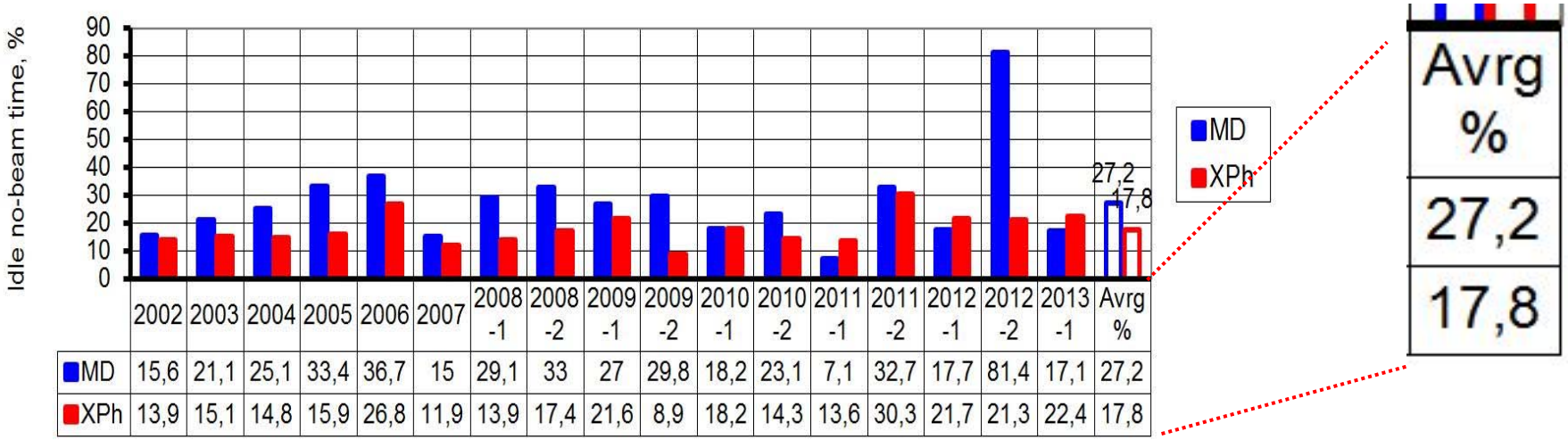
3 [4] goals:

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



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

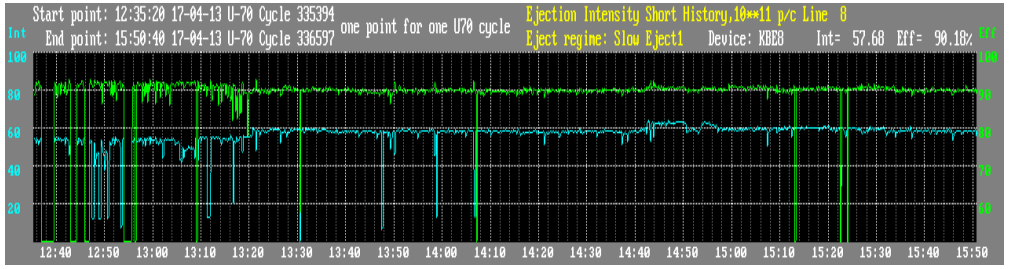
Statistics



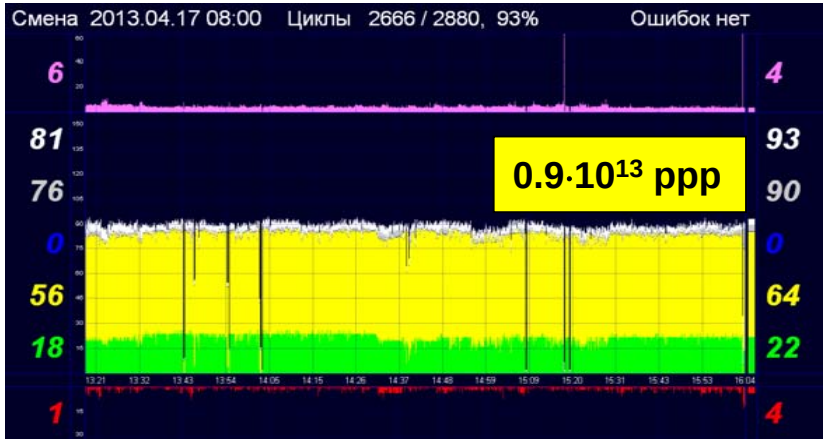
	2002	2003	2004	2005	2006	2007	2008 -1	2008 -2	2009 -1	2009 -2	2010 -1	2010 -2	2011 -1	2011 -2	2012 -1	2012 -2	2013 -1	Avrg %
MD	15,6	21,1	25,1	33,4	36,7	15	29,1	33	27	29,8	18,2	23,1	7,1	32,7	17,7	81,4	17,1	27,2
XPh	13,9	15,1	14,8	15,9	26,8	11,9	13,9	17,4	21,6	8,9	18,2	14,3	13,6	30,3	21,7	21,3	22,4	17,8

2 runs (7/24) per year:
- short (XPh 10 days ca) 2 MD(*p*) + ions
- long (XPh 30 days ca) 3 MD(*p*) + ions

Run



90-94% 1-6.5·10^{12} ppp



← **3 hr, or 1000 cycles** →

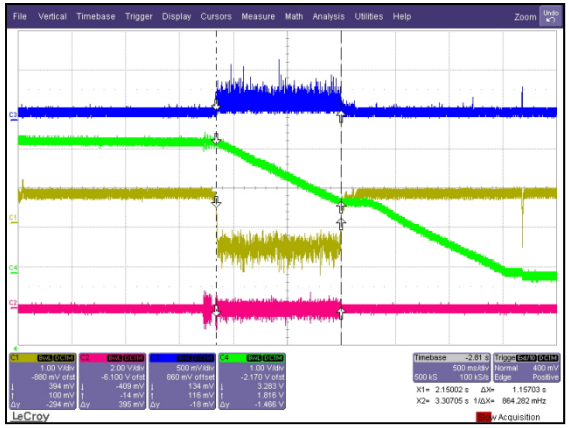
Extraction (fixed target, multi-user)

Inventory:

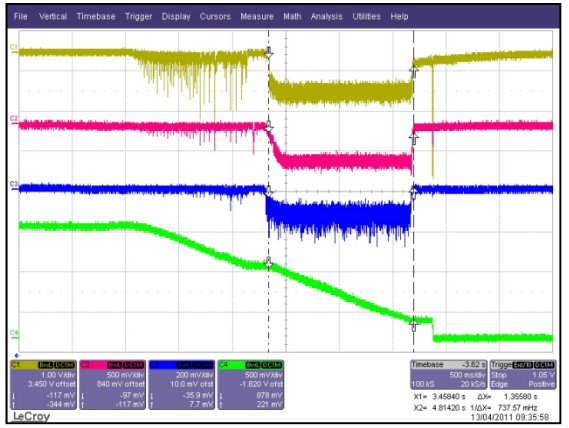
- 1-turn/1-bunch FE
- SRE (Q38 & SSE (new))
- IT
- bent Si-CD SE (new)
- flat-bottom (S)SE (new)

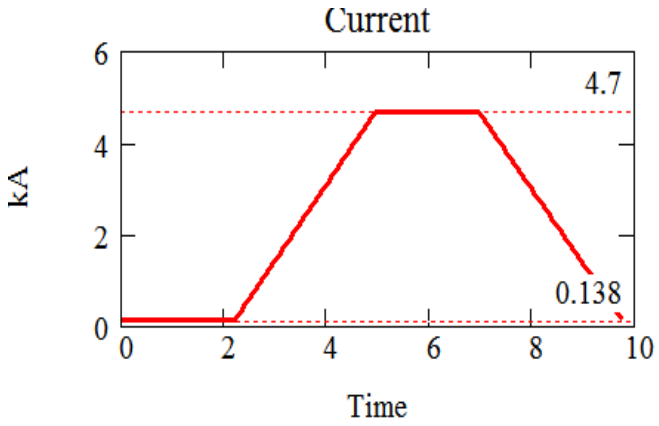
Sequential and parallel flattop sharing

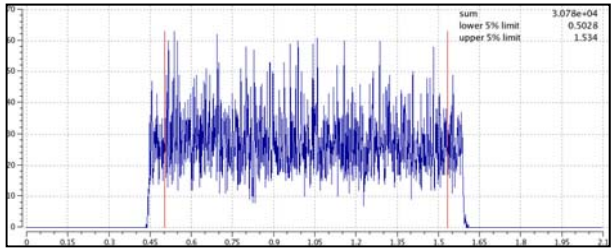
1st ½ of flattop, SSE

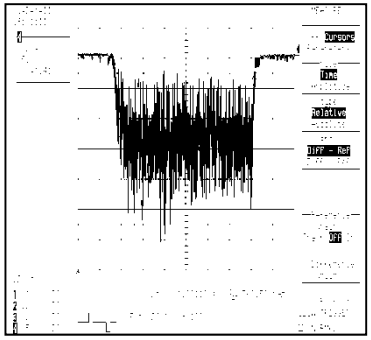


2nd ½ of flattop, IT & CD



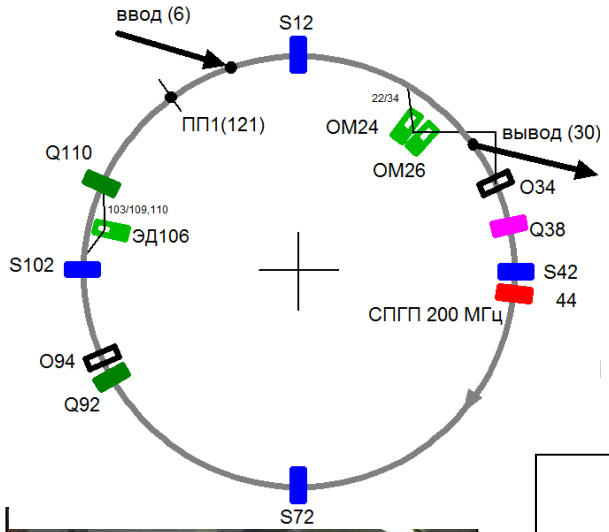


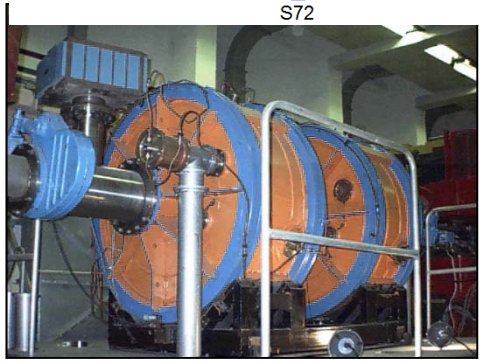




duty factor $\langle\Phi\rangle^2/\langle\Phi^2\rangle$ = 0.94.
No lines of mains harmonics

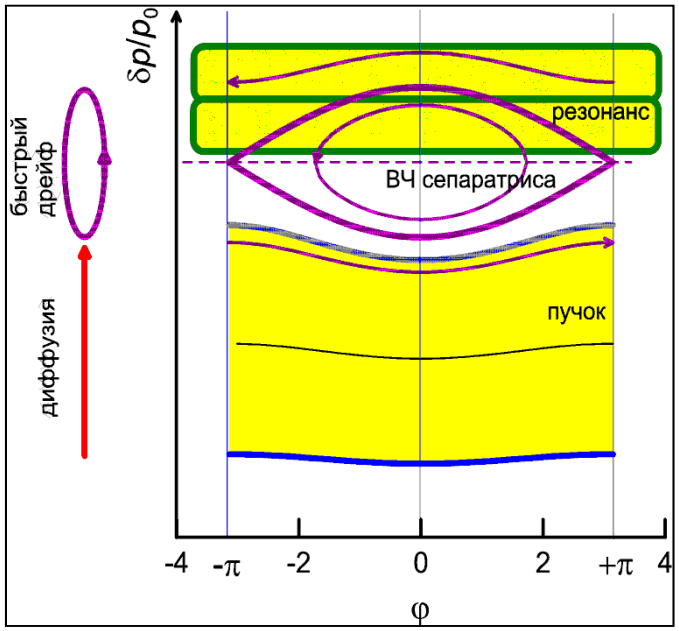
Slow stochastic extraction





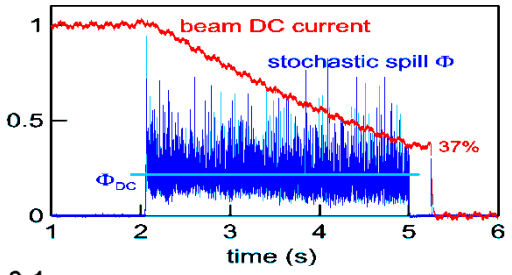
200 MHz RF system

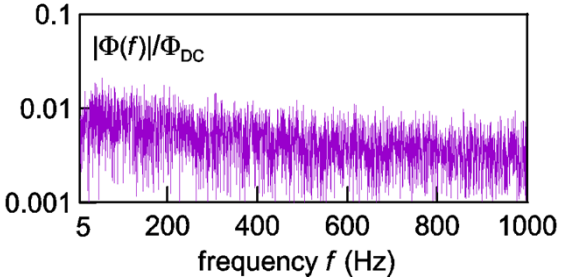
integer horizontal resonance $3Q_x = 29$

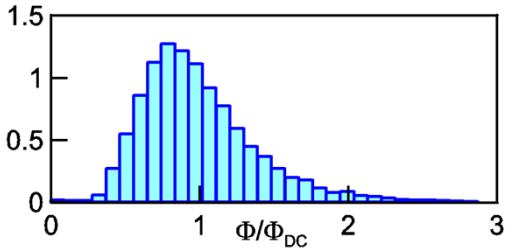


CERN Courier vol 47 no 2 March 2007:

63% in 2.9 s. σ = 0.40, duty factor $\langle\Phi\rangle^2/\langle\Phi^2\rangle$ = 0.87. No lines of mains harmonics



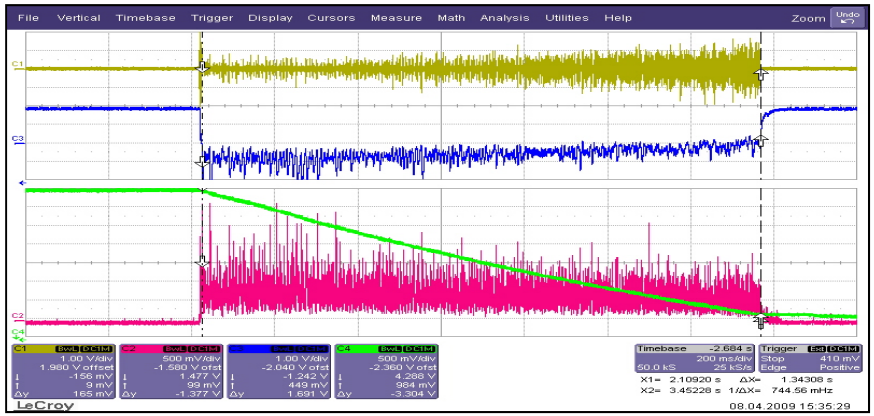




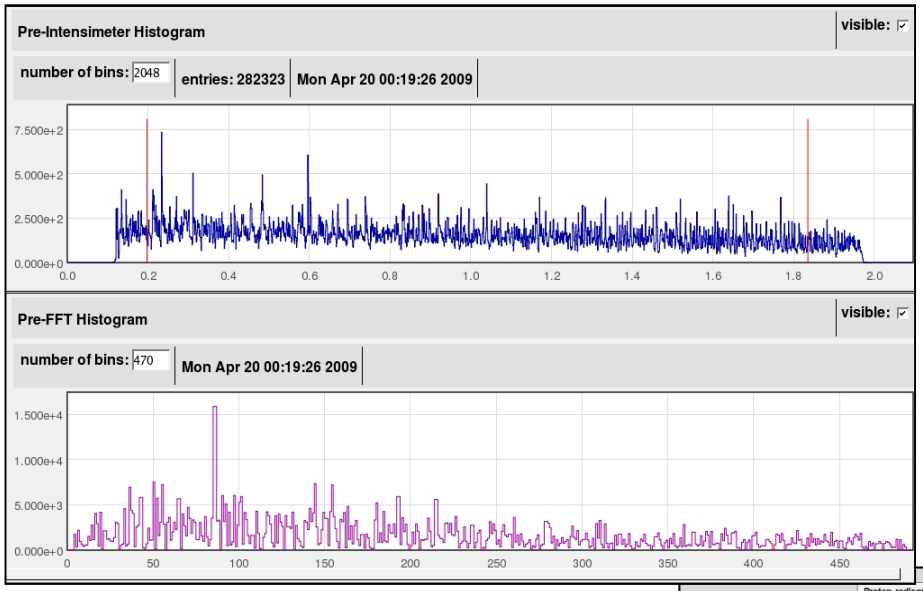
Slow extraction & the OKA experiment

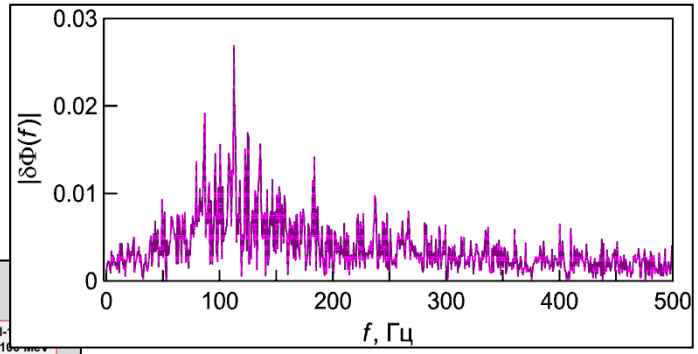
Data: run 2009/1

Technological data from *U*70



Data from OKA facility counters

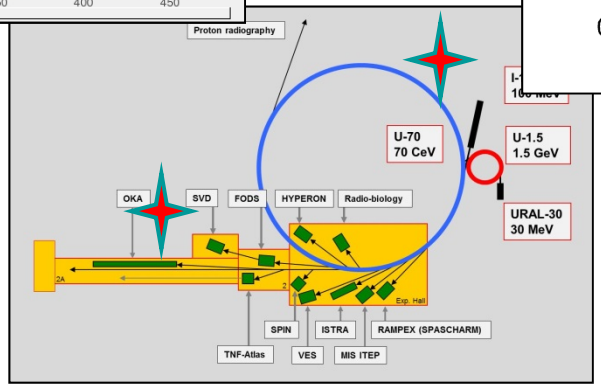




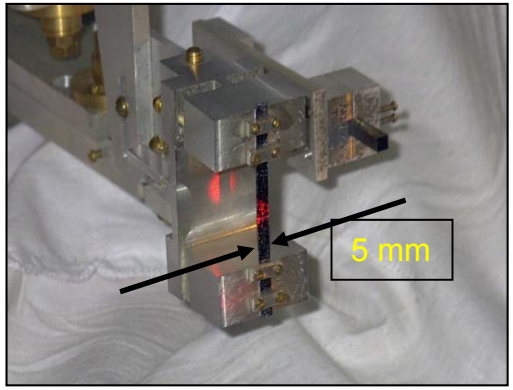
Spill 1.85 s long

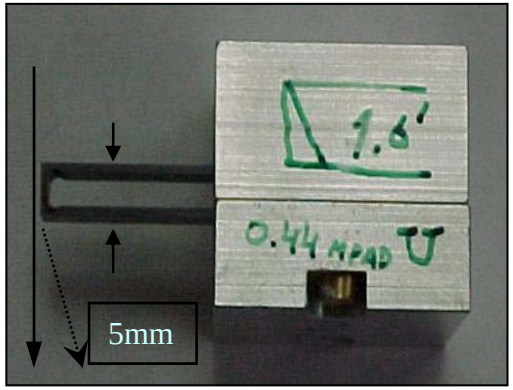
$0.95 \cdot 10^{13}$ *p* per a spill

50 GeV

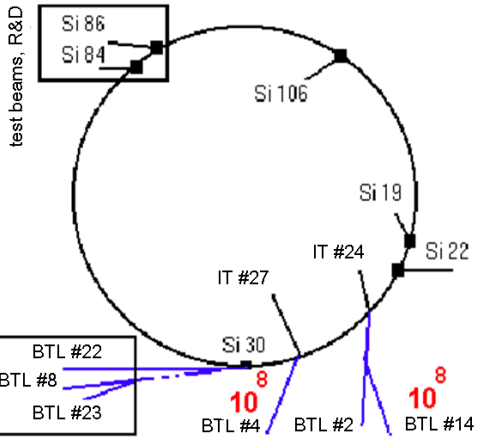


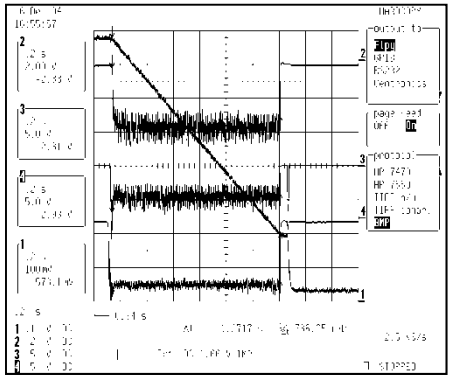
Bent-(Si)crystal deflectors





Run2007: 3 CD(19, 24, 30)
6 experiments

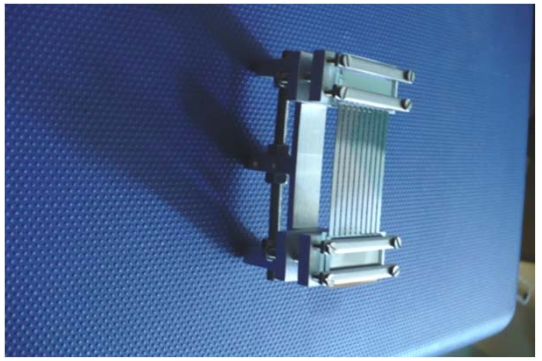




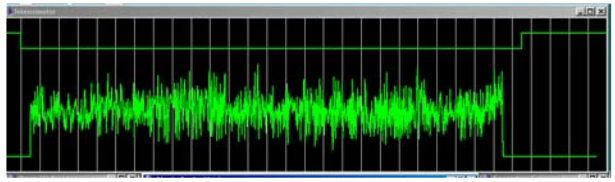
CD19

IT24

IT27

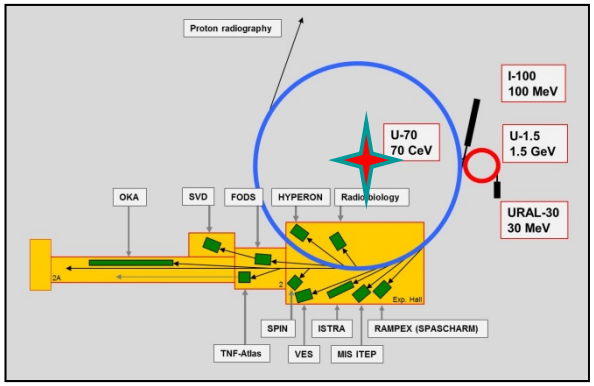


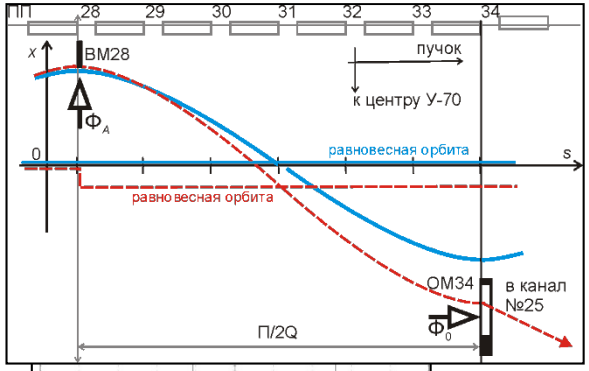
Beam to IHEP-CERN experiment
on radiation sustainability of liquid Ar

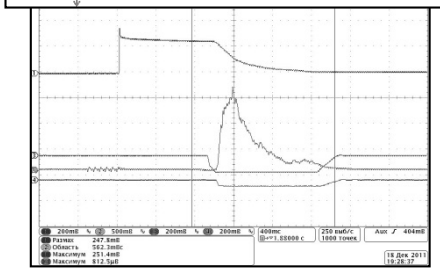


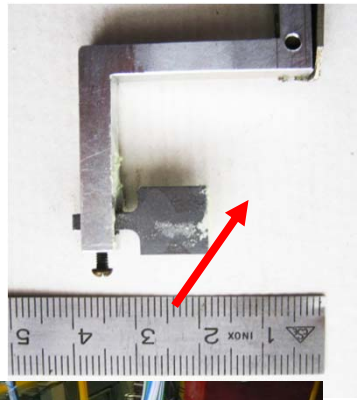
Flat-bottom S(S)E

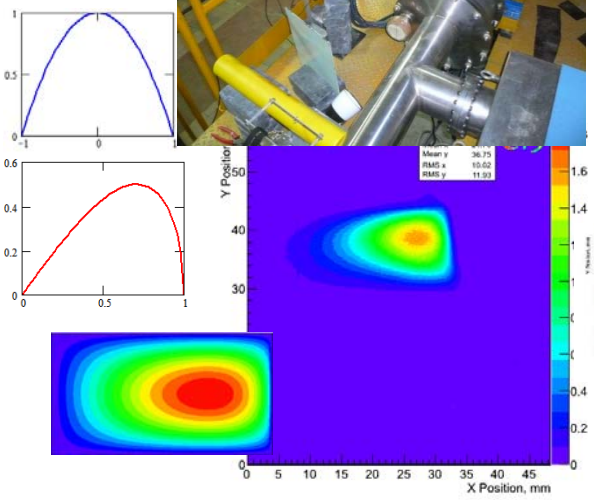
352 Gs, 1.32 GeV (*p*, test beam) 455 MeV/u (*C*)



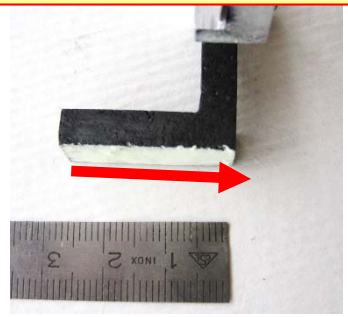


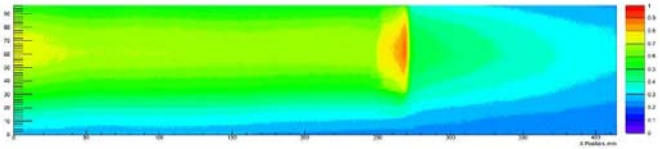






Graphite 30 mm (*p* 1.32 GeV)
Be 4 mm (C 455 MeV/u)

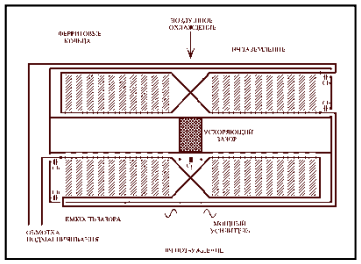


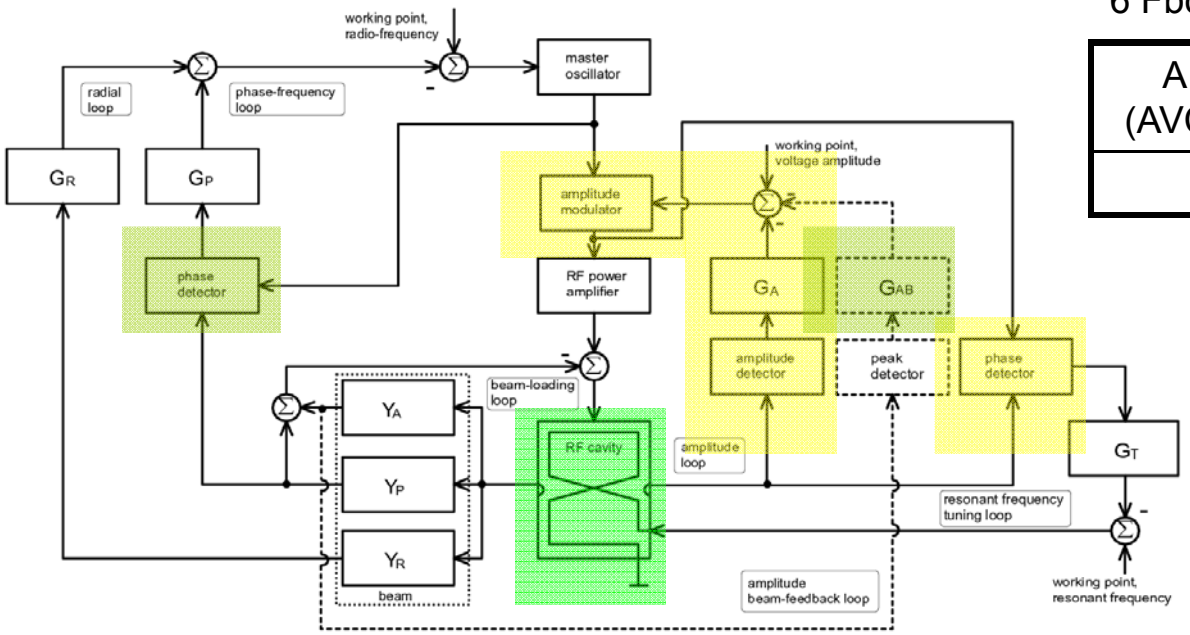


Bragg's peak in a water phantom

Longitudinal feedbacks

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





6 Fbck loops:

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

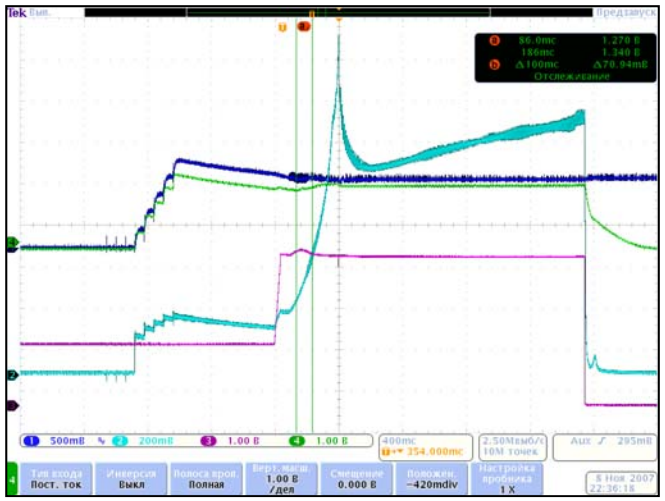
Beam quality, longitudinally

DC CT

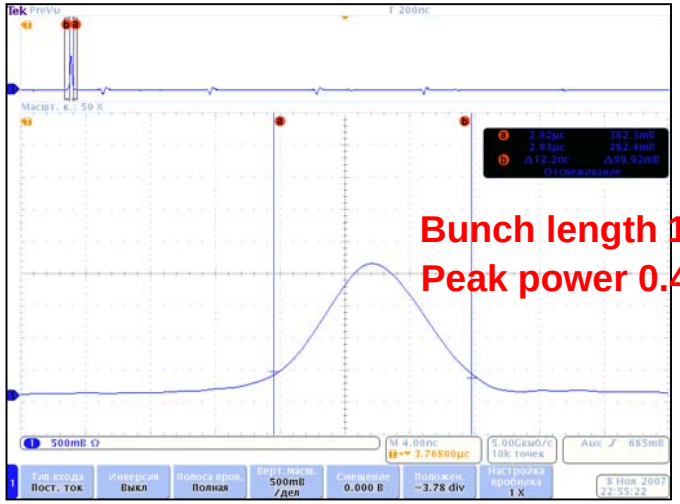
PU

V_{RF}

peak D



without 200 MHz spill cavity below γ_{tr}



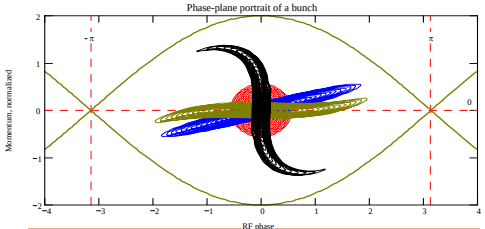
Bunch length 12.2 ns
Peak power 0.4–1 TW

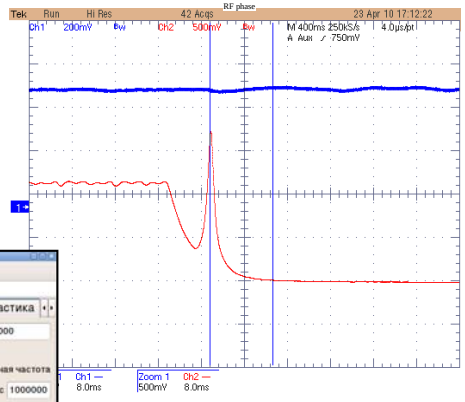
@ 50 GeV

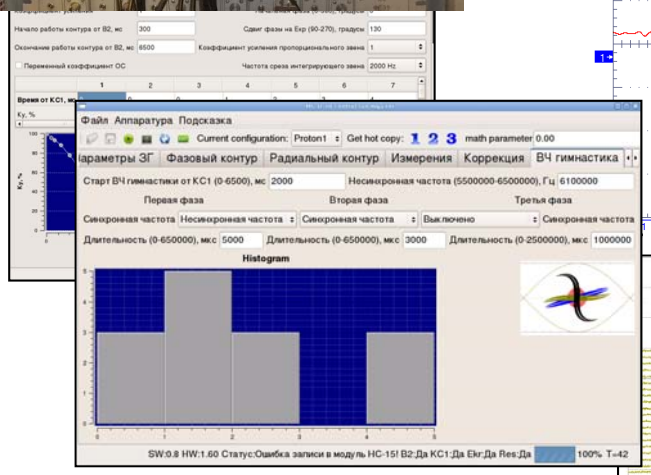
	≤ 2006	> 2007–8
Bunch length (FW@0.9)	36 ns	12–15 ns
Momentum spread $\Delta p/p$	$\pm 1 \cdot 10^{-3}$	$\pm 4–5 \cdot 10^{-4}$

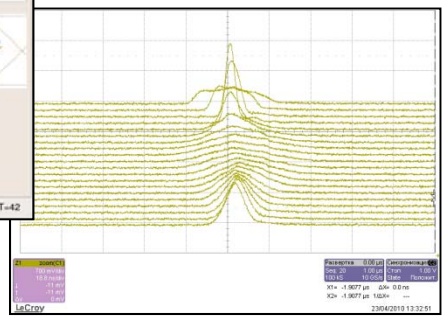
DDS RF MO

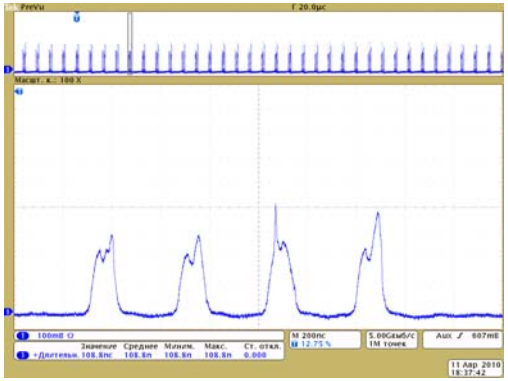
New digital MO in RF of the U70

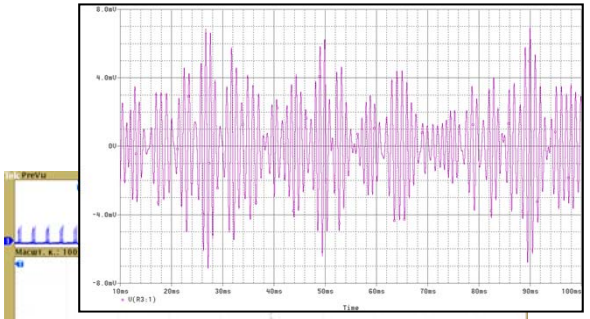


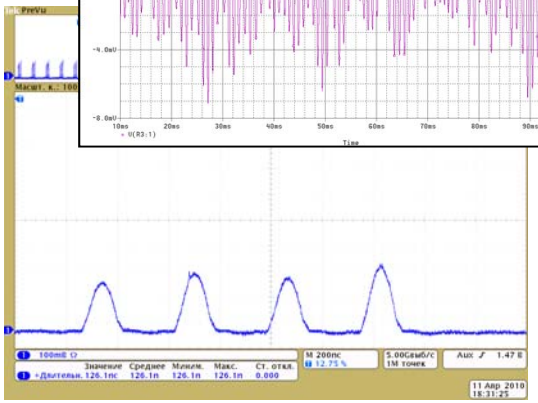






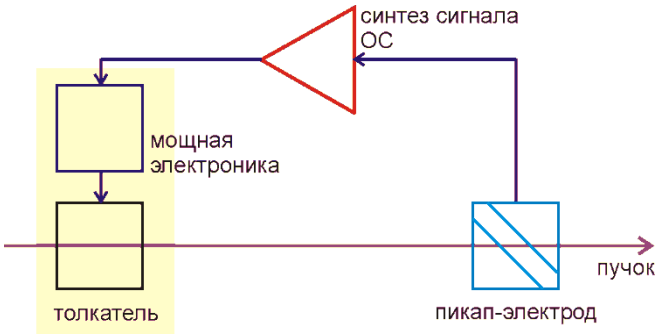


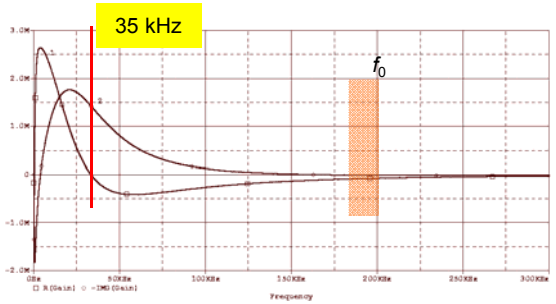




Transverse (NB, local) feedback

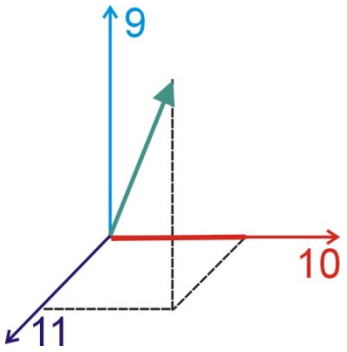
ESK @ SS2	0 – 0.2 MHz	±35.0 kV	PU @ SS2 (+ @SS116)



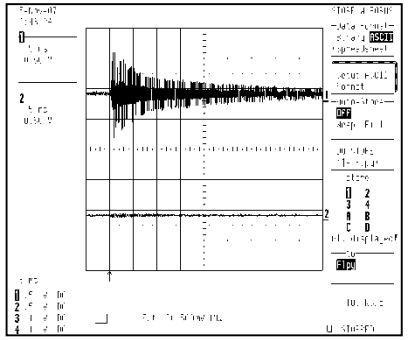


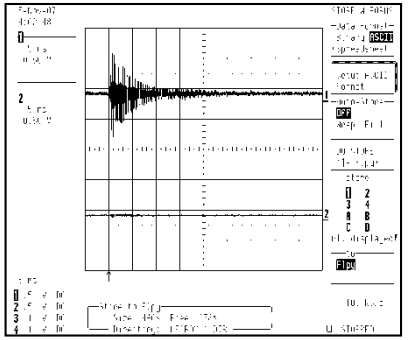
H: 14.7–72.3 kHz, ±45°

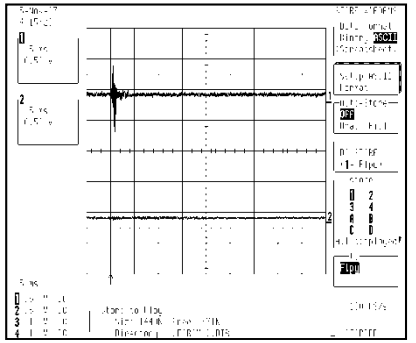
V: 29.4–43.2 kHz



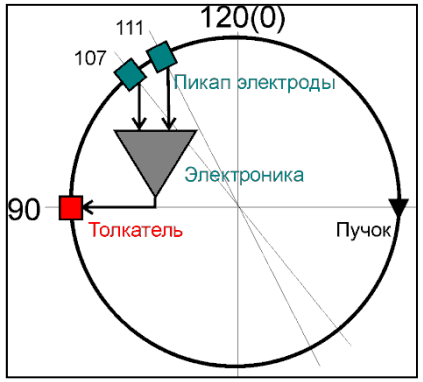
Damping factor =
100 w. r. t. natural



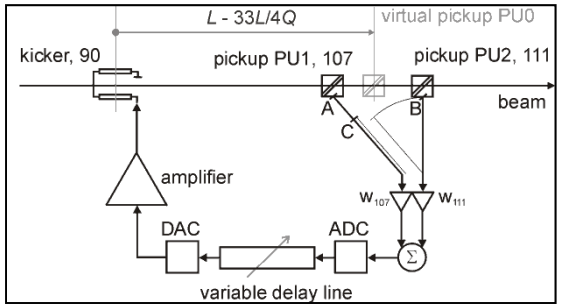


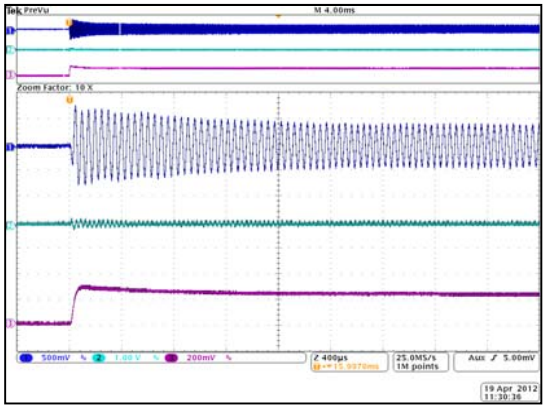


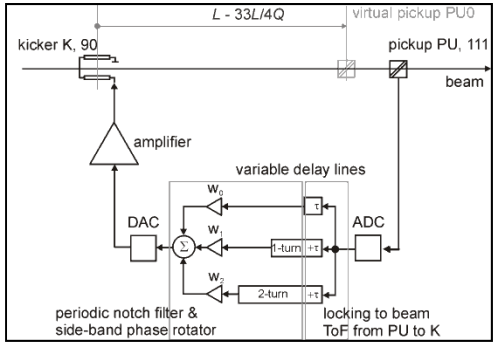
Digital transverse (WB) feedback

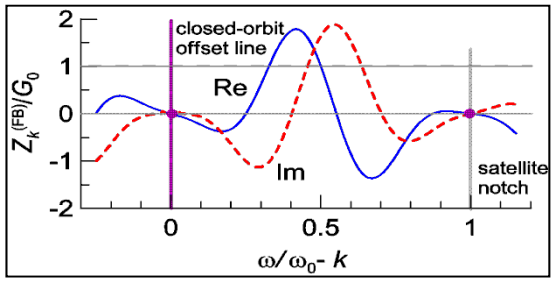


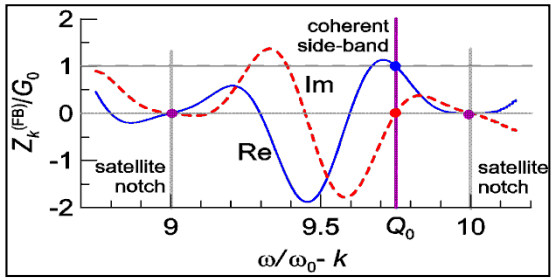
EMK @ SS90	0.2 – 15 MHz	±10.7 kV	PU @ SS107 + 111



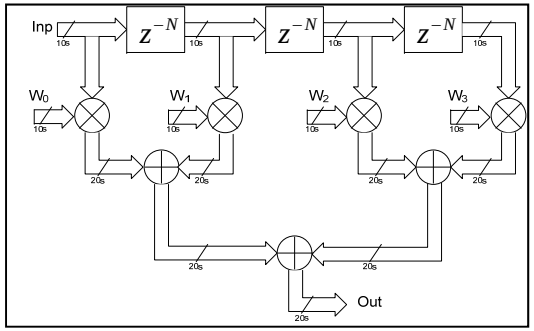


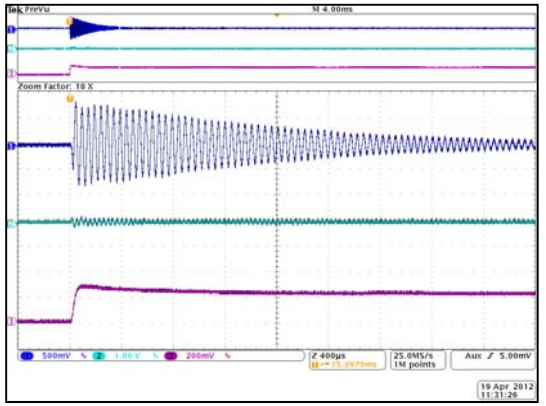






FIR-3 & FIR-4 options





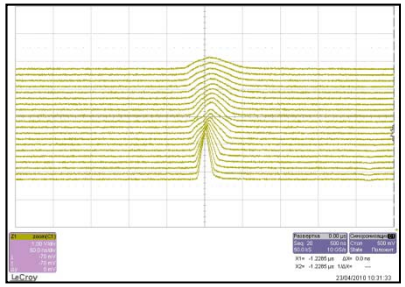
Instabilities

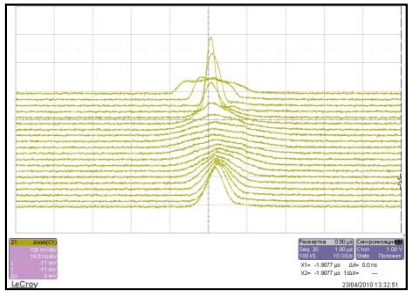
Back to factory default freq range of RF system, 2.6 (4.5)-6.1 MHz instead of o 5.5-6.1 MHz

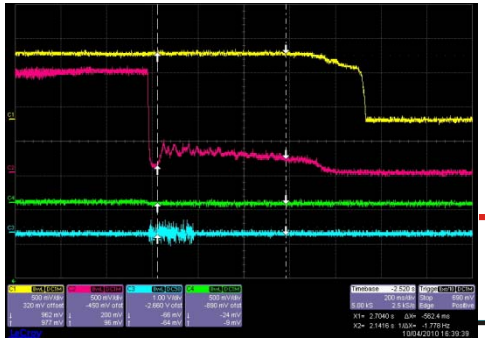
$$\left|\frac{Z(k\omega_0)}{k}\right| < \frac{1}{\Lambda}\frac{\beta^2|\eta|E}{eJ_0}\left(\frac{\Delta p}{p}\right)^2$$

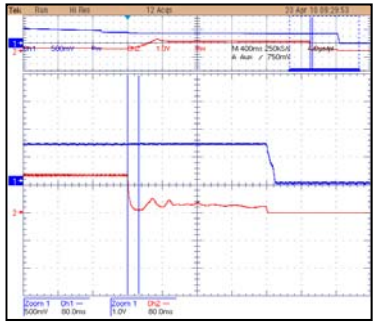
Cures:

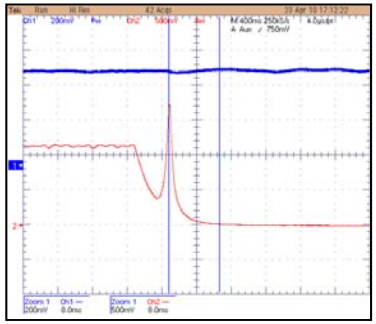
- Momentum spread, RF gymnastics
- Distribution function [momentum spread] RF noise

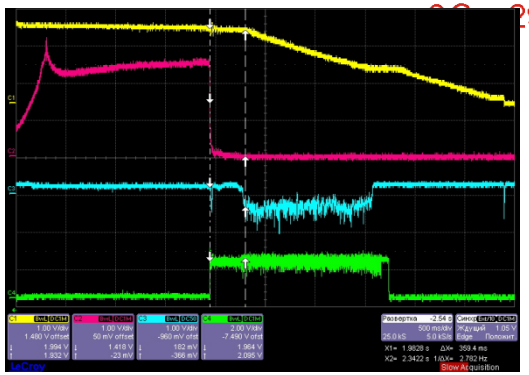


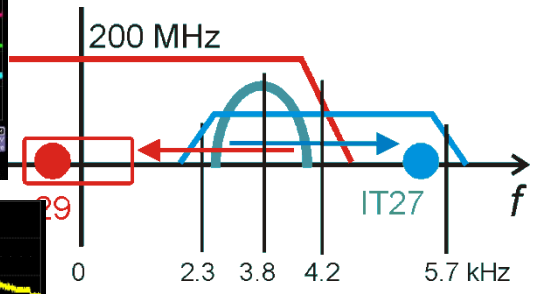












Strategy of light ion program

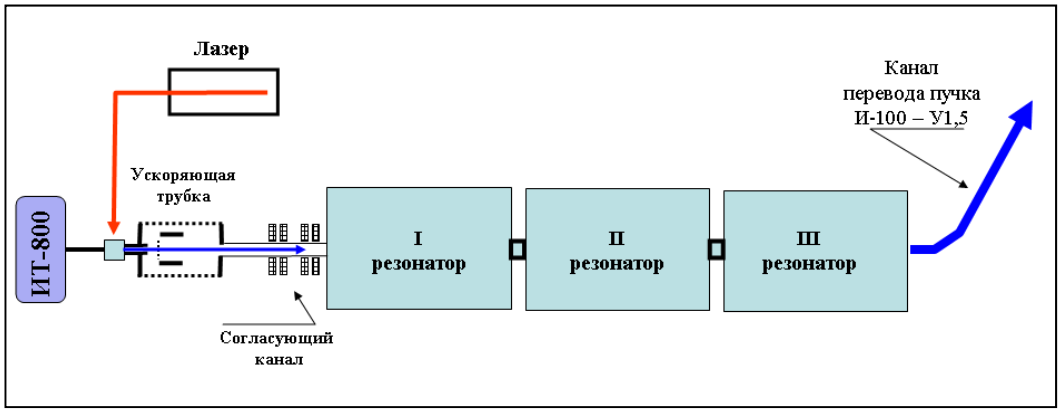
Incremental:

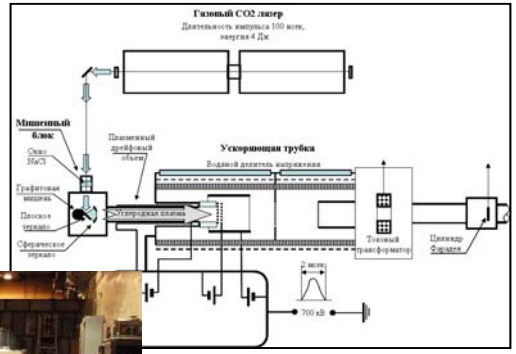
- ion species — *p* – *d* – *C*
- along cascade — [*I*100 - BTL] - *U*1.5 - BTL - *U*70 flat bottom circulation (DC PSU, RMG) - *U*70 fixed-field variable-RF acceleration - *U*70 transition crossing – *U*70 ramping to flattop field
- intensity [qpp] — 1 – 1/10 – 1/50 & low-*N pilot p*-beams prior to *d*, *C*-beams

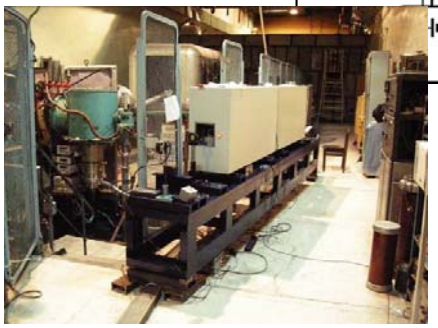
Reference ions $q = Z$, $q/A = 1/2$		*I*100, 2 cav of 3		*U*1.5		*U*70		
		IN	OUT	IN	OUT	IN	OUT	
p, *pilot* beam	β		0.3724		0.9000		0.9999	
	$B\rho$, T·m		*1.2558*		6.8659		233.38	
	T, MeV		72.71		1 323.8		69 032	49 0
d	β		0.1862		0.7392		0.9996	
	$B\rho$, T·m		*1.1856*		6.8659		233.38	
	T, MeV/u		16.691		454.56		34 057	23 6
C	β		0.1862		0.7414		0.9996	
	$B\rho$, T·m		*1.1776*		6.8659		233.38	
	T, MeV/u		16.678		456.53		34 063	24.1--34 1

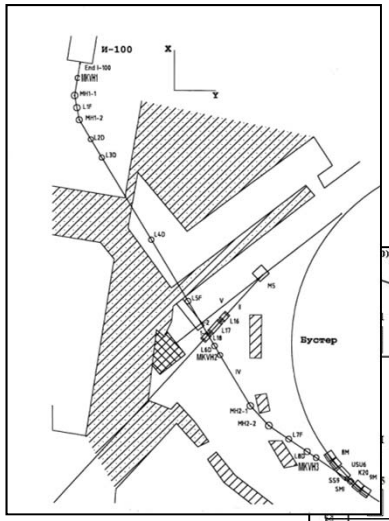
I100 DTL as C-injector

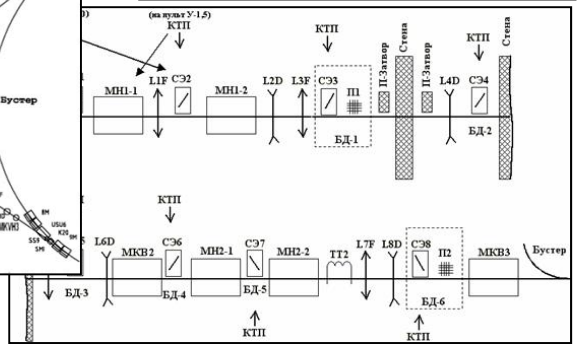
Stand-alone runs of I100





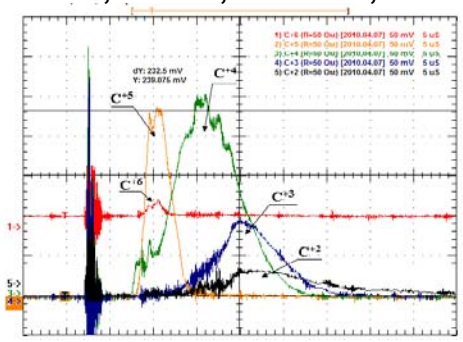






43 m long
4 dipoles
8 quads
3 H/V-correctors
Beam diagnostics

InfraLight SP, PhIC GPhI RAS, Troitsk
2 modules, CO2, N2 и He, λ=9.6–11 μm
2 Hz, 4.5 J, almost, COTS

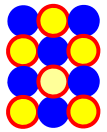


10–12 mA 4000 cycles

(former 800), i.e. >8 hr.

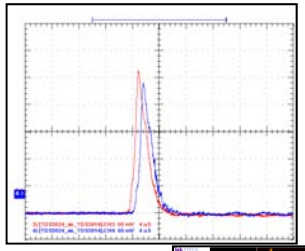
Milestones

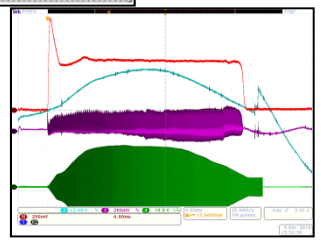
d: *q*=1,
A=2,
q/*A*=1/2

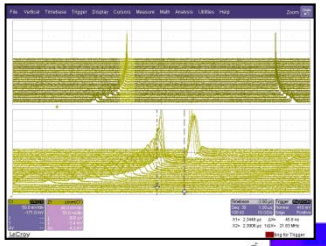


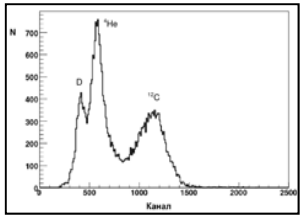
C: *q*=6,
A=12,
q/*A*=1/2

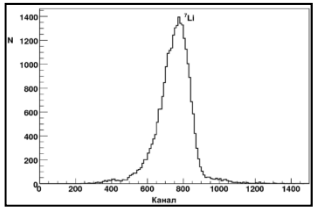
	Deuterons $^{2}H^{1+}$	Carbon $^{12}C^{6+}$
U1.5	16.7–448.6 MeV/u March 30, 2008	16.7–455.4 MeV/u December 08, 2010
U70	23.6 GeV/u April 27, 2010	34.1 GeV/u April 24, 2011
		SE @ 455 MeV/u April 24, 2011
		24.1 GeV/u in BTL#22 & FODS April 27, 2012

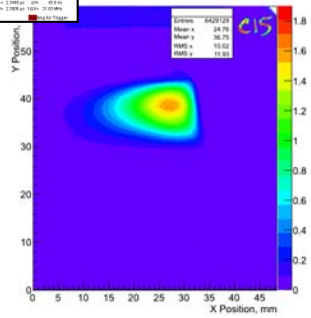












All H-E extractions with C

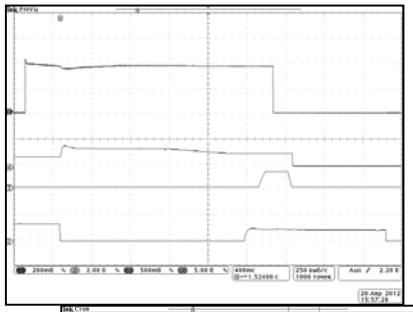
April 24, 2012. C 24.1 GeV/u (flattop 0.859 T) $5 \cdot 10^9$ ipp (8 s).

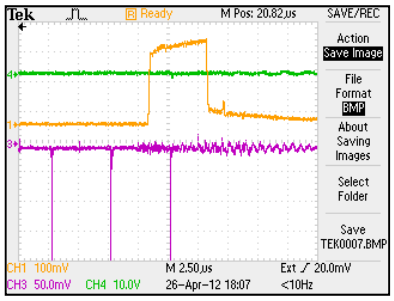
1st ever tests all HE extractions with the C beam

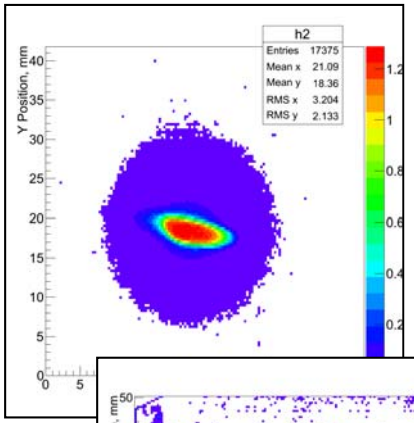
FE

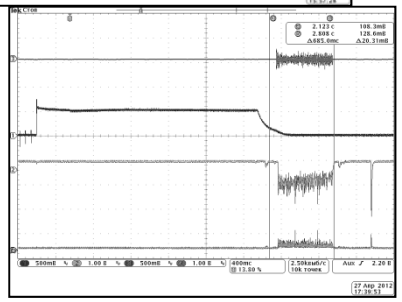
SE

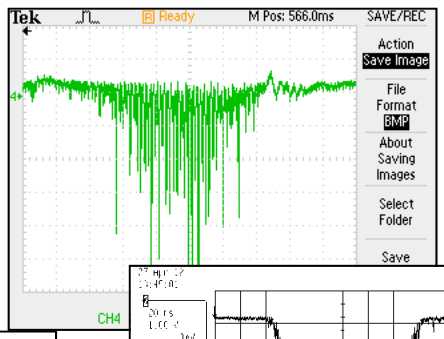
CD#22

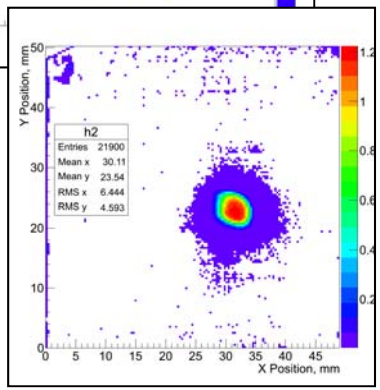


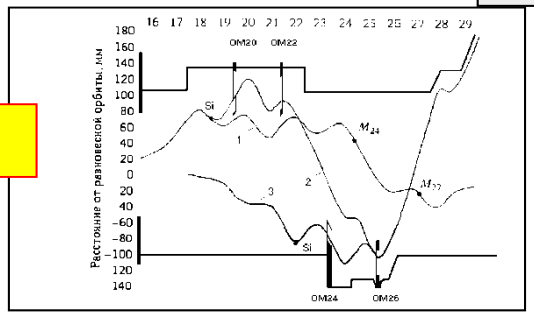


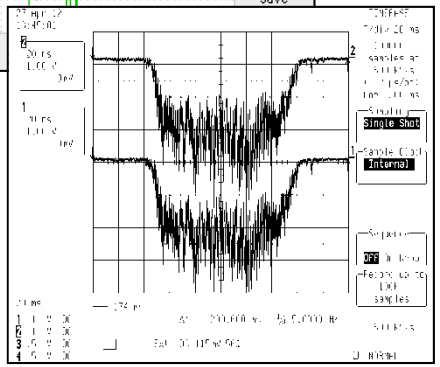








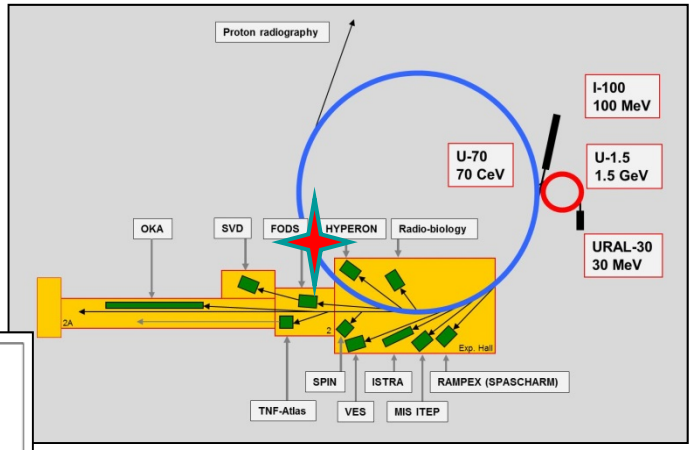




1st experimental NPh events

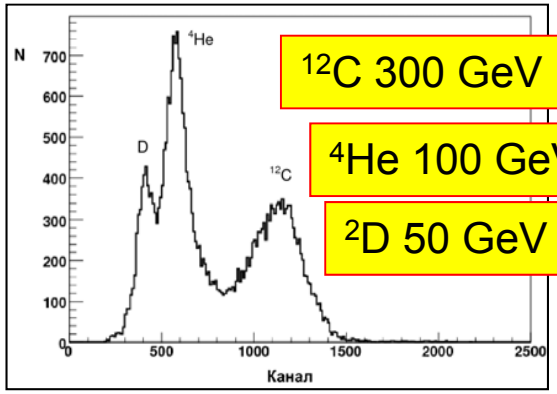
April 27, 2012. 1st ever extracted C beam in 190 m BTL#22 = **FRS** & FODS (a FOcussing 2-arm Spectrometer) experimental facility

24.1 GeV/u or 300 GeV full E



BTL#22 50 GeV/c (p),
25 Gev/c/u q/A=1/2

Hadron calorimeter

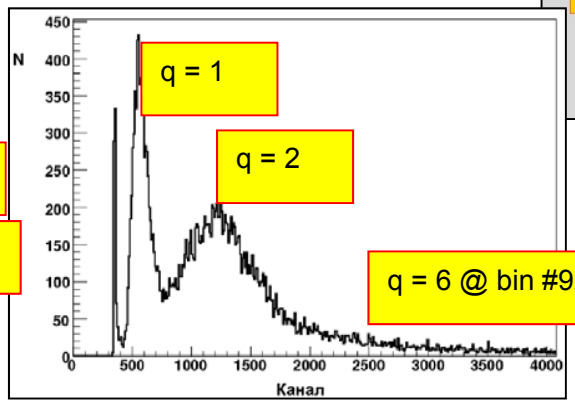


^{12}C 300 GeV

^{4}He 100 GeV

^{2}D 50 GeV

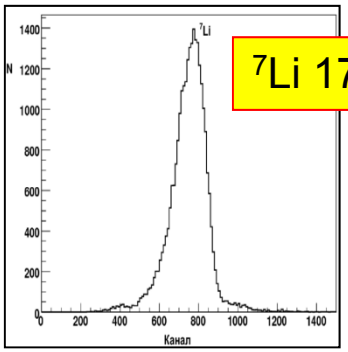
Scintillator counters



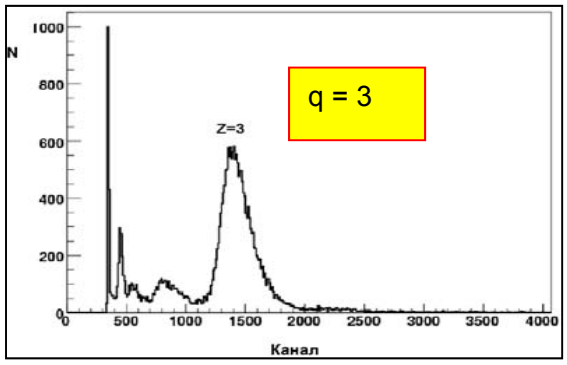
q = 1

q = 2

q = 6 @ bin #9250



^{7}Li 175 GeV



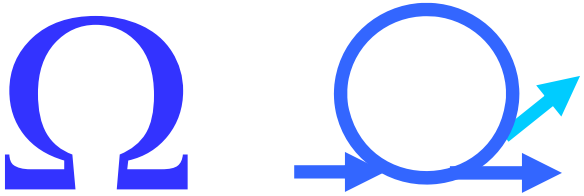
q = 3

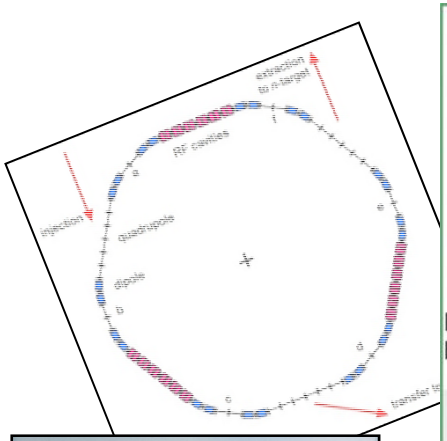
BTL#22 60 GeV/c (p) \pm 1%

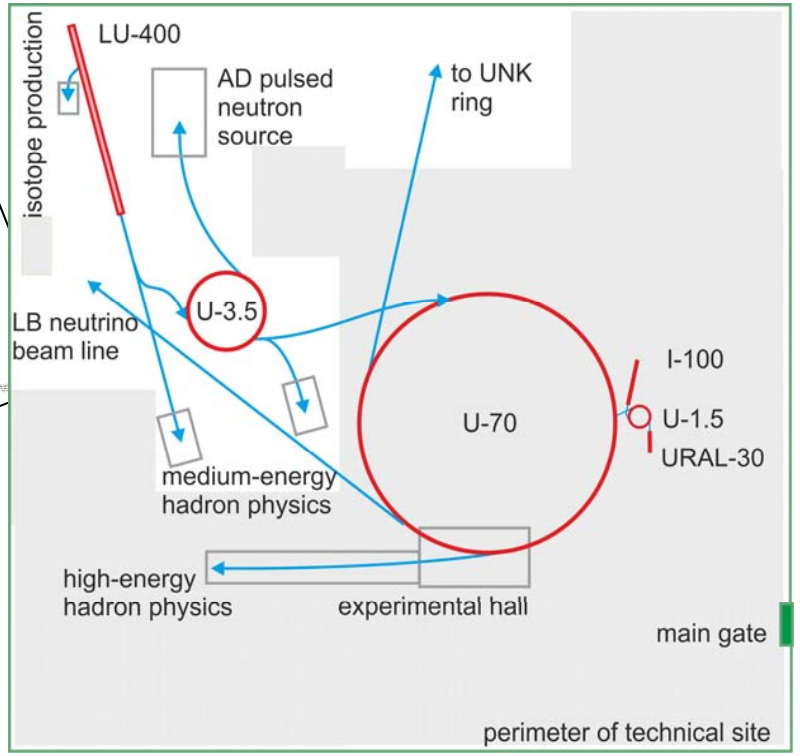
a FRS

25.7 Gev/c/u q/A=3/7

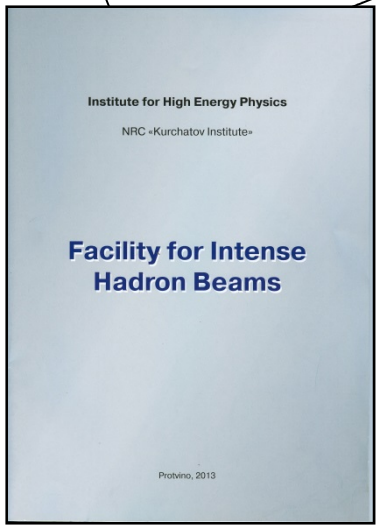
The OMEGA Project



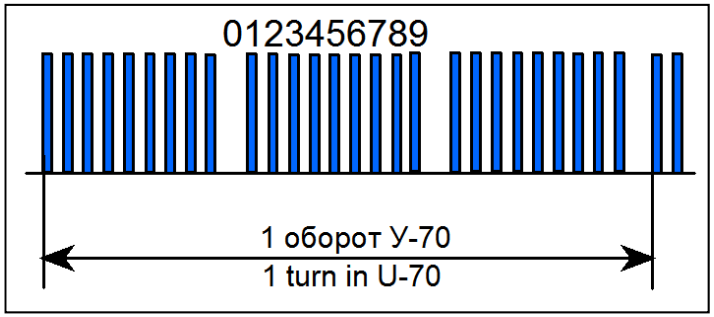




http://www.ihep.ru/ihep/news/IHEP-2-9-10_fin-c.PDF



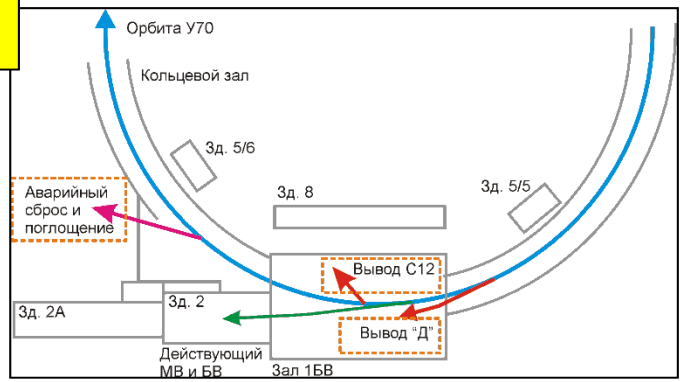
the extended LoI, 37p, June 2013



FE to LAGUNA LBNE

2-nd junction

4 deg H
5 deg V
23 T·m



$$P = \frac{N \cdot T}{\left(\frac{n}{f} + t_U + t_D\right)}$$

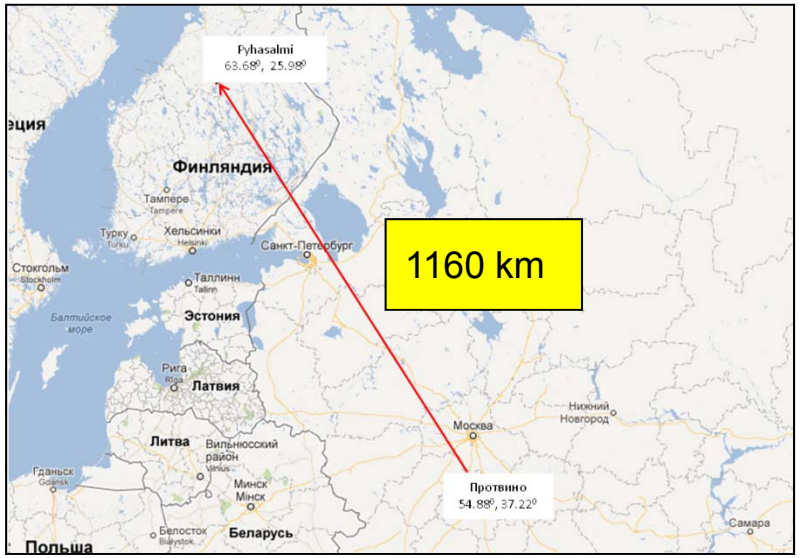
Table 1: The UNK option of U70

N, p.p.p.	*T*, GeV	*n*	*f*, Hz	*P*, kW
$5{\cdot}10^{13}$	69.0	29	16 2/3	75

Table 2:The OMEGA option of U70

N, p.p.p.	*T*, GeV	*n*	*f*, Hz	*P*, rW
$3{\times}7.5{\cdot}10^{13} = 2.25{\cdot}10^{14}$	69.0	3	25	450

Near detector @ 700-750 m, on the site



1160 km

Conclusion

Accelerator Complex *U*70 of IHEP-Protvino:

- comprises 4 machines (*URAL*30, *I*100, *U*1.5, and *U*70 itself),
- readily ensures running the fixed-target physics program,
- is subject to ongoing upgrade program,
- has noticeably improved quality of proton beam,
- is on a way towards a routine acceleration of light ions to 24-34 GeV per nucleon for high-energy nuclear physics
- now has slow extraction of 455 MeV per nucleon of $^{12}C^{6+}$ beam
- *U*1.5 and *U*70 now belong to PS and (L)IS categories
- open for a few promising options for future development