



**INSTITUTE FOR HIGH ENERGY PHYSICS (IHEP)**  
Protvino, Moscow Region, 142281, Russia

# Status of U70

Sergey Ivanov

on behalf of the U70 staff

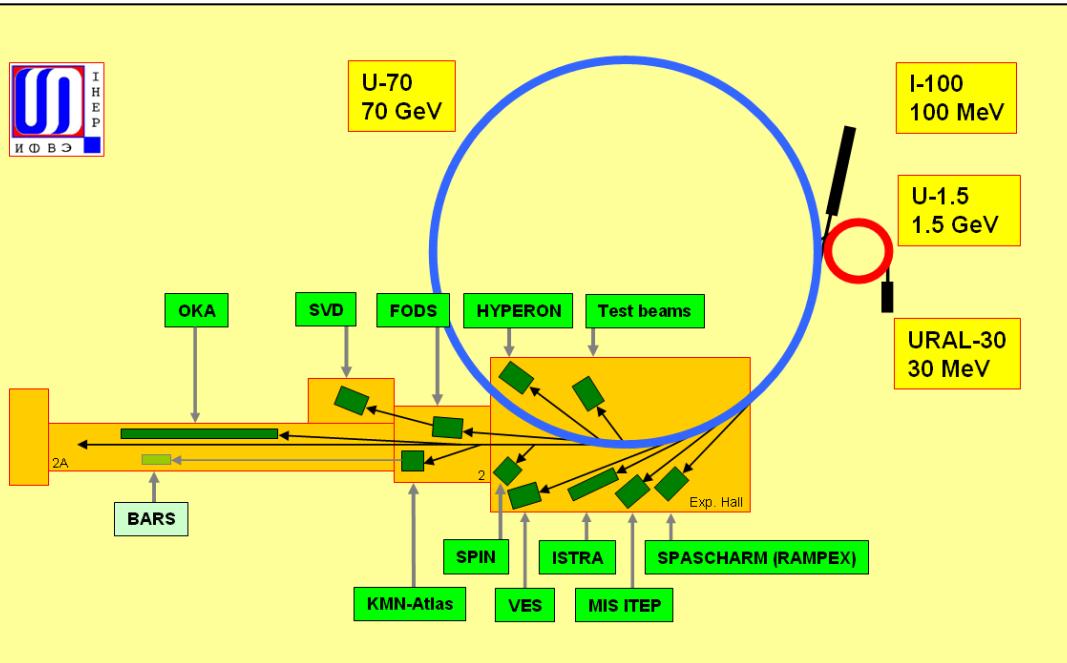
WS LHC on the March

November 20-22, 2012, *IHEP Protvino*

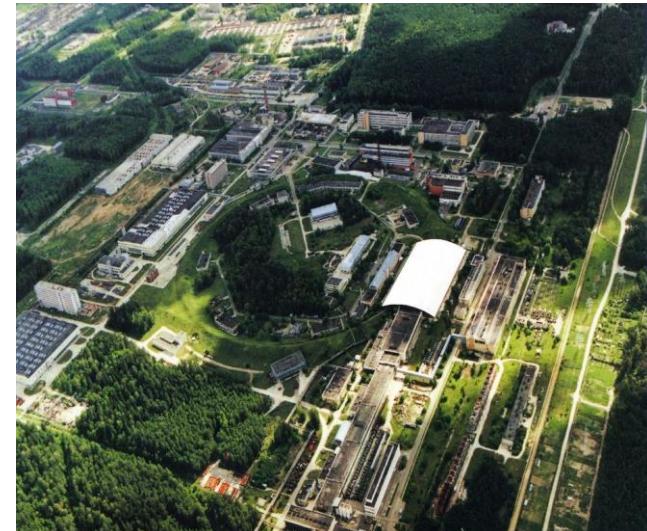
# Outlook

- Generalities
- Routine operation
- Upgrade of the facilities
- Light-ion program
- Prospects (possibilities) of long-term development
- Conclusion

# Layout, AC U70 vs the U70 proper



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



## Modes:

- proton (default) URAL30-U1.5-U70
- light-ion ( $d$ ,  $C$ ) I100(2 of 3)-U1.5-U70

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

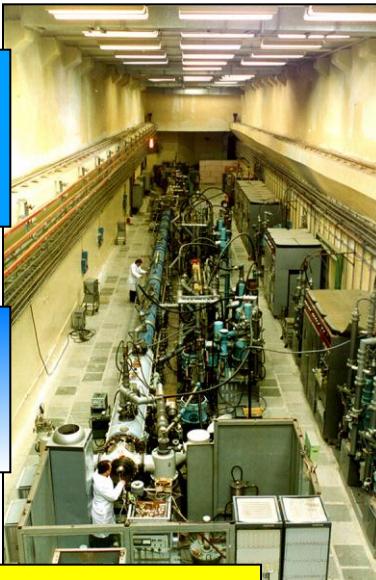
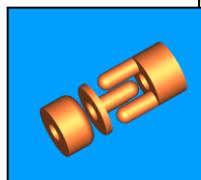
## Light-ion:

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

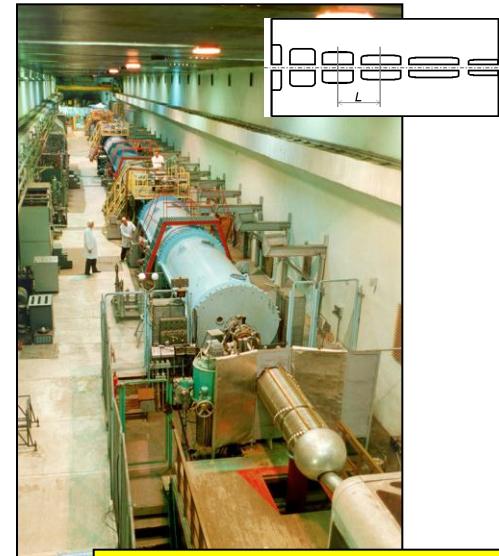
In a SIS-18, SIS-100 name convention:

- LIS-233 [T·m]
- LIS-6.9 [T·m]

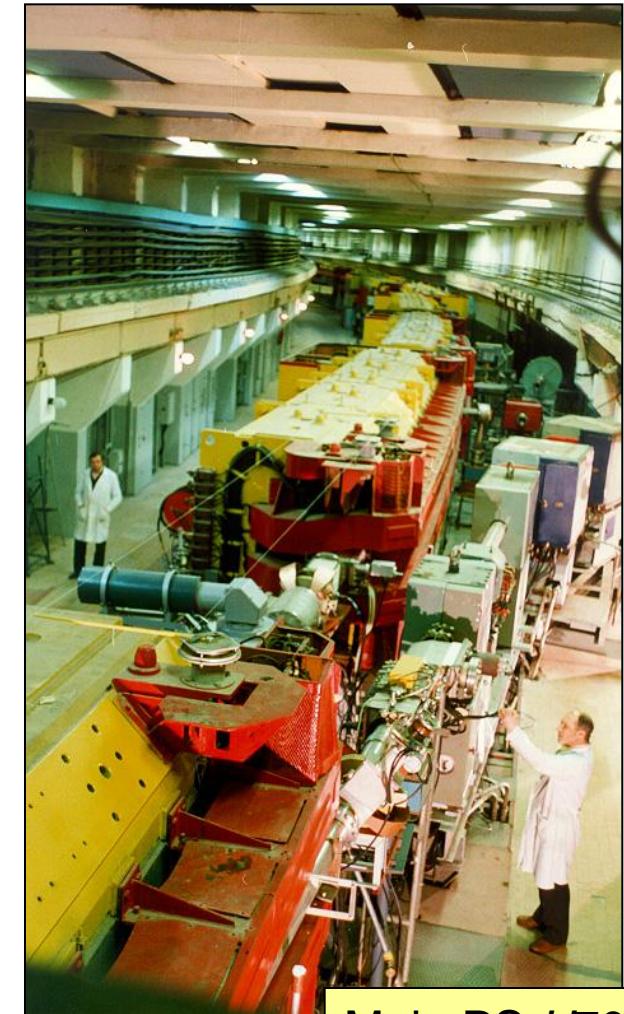
# Photo album of machines



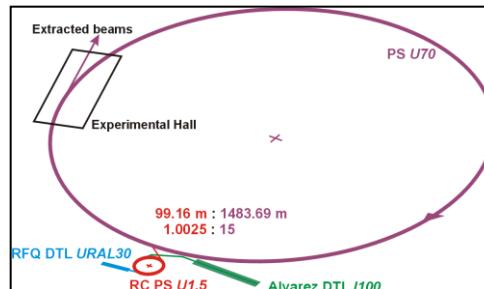
RFQ DTL *URAL30*



Alvarez DTL /100

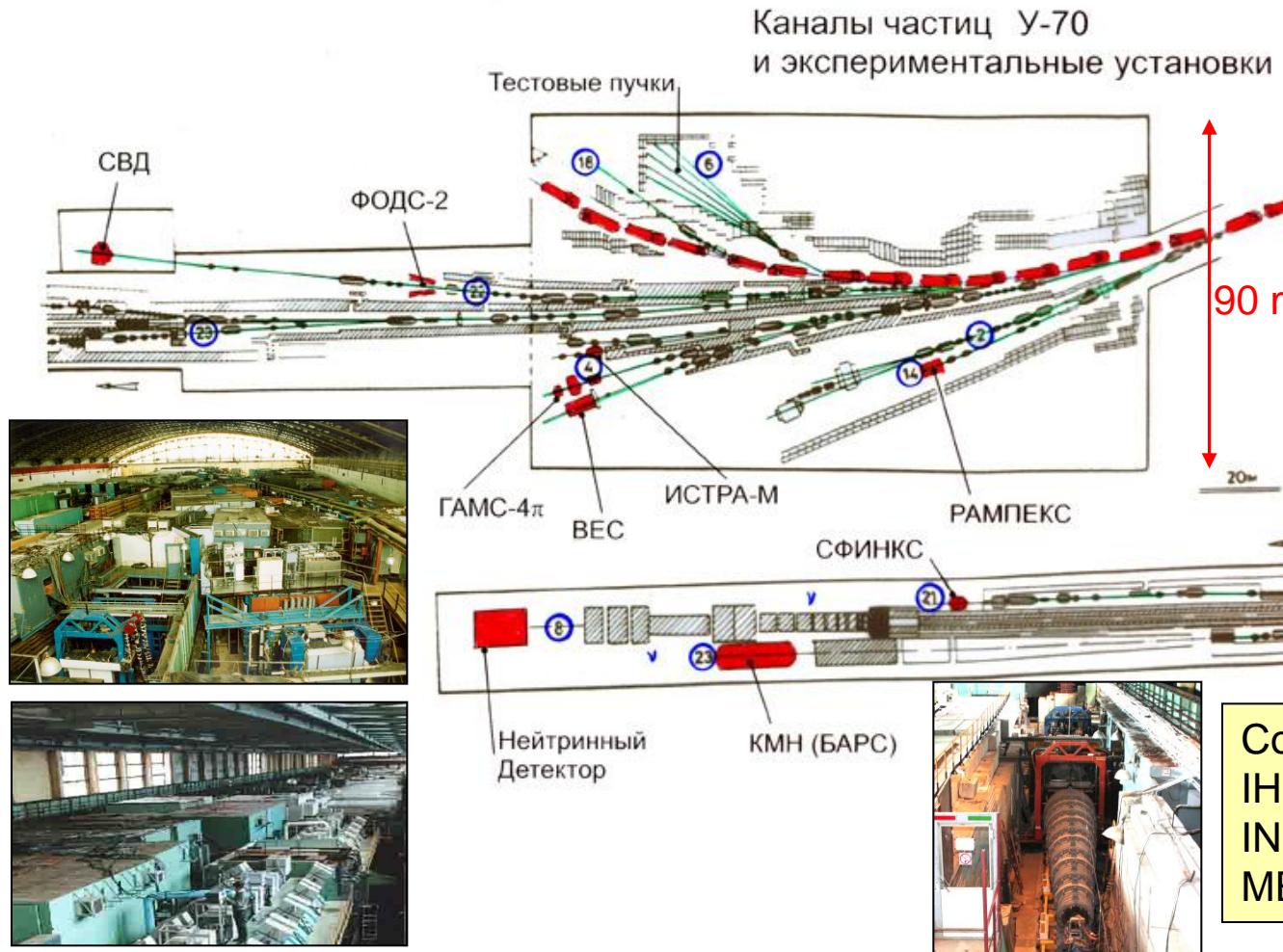


Main PS *U70*



RC PS *U1.5*

# Fixed-target physics and BTL network

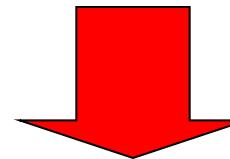


Up to 9 HEP experiments per a run, up to 7 beam users per a cycle

# Goals of activity

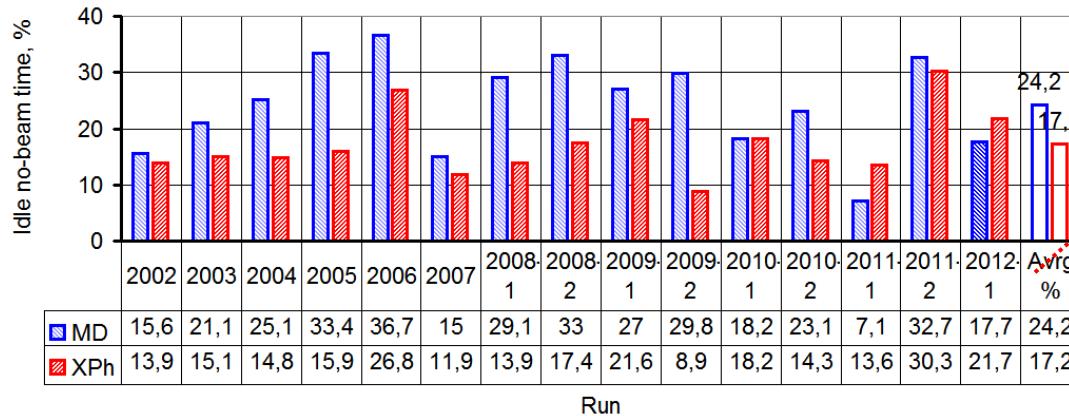
3 [4] goals:

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



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

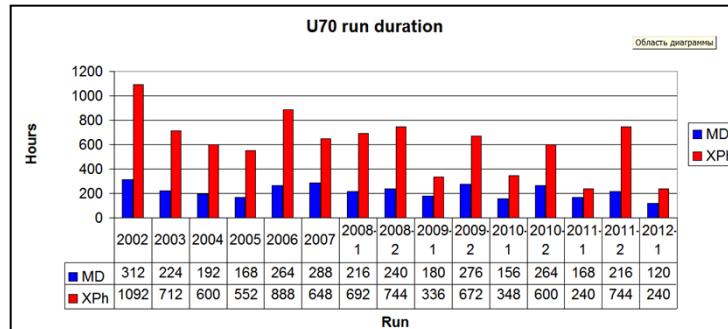
# Statistics



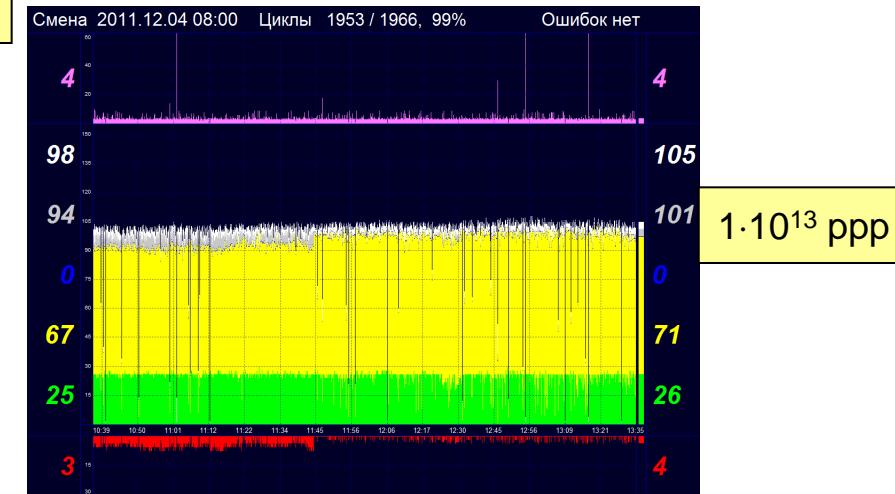
	2012	Avg
	1	%
	17,7	24,2
	21,7	17,2

2 runs (7/24) per year:

- short (XPh 10 days ca) 2 MD( $p$ ) + ions
  - long (XPh 30 days ca) 3 MD( $p$ ) + ions

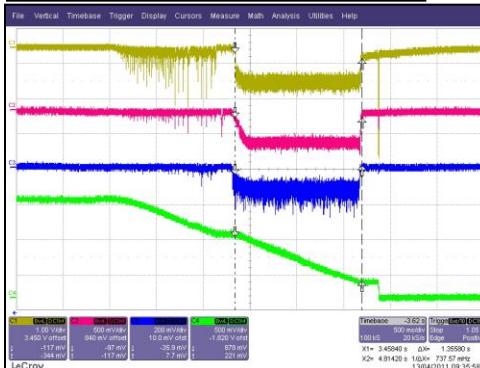


3 hr, 1000 cycles

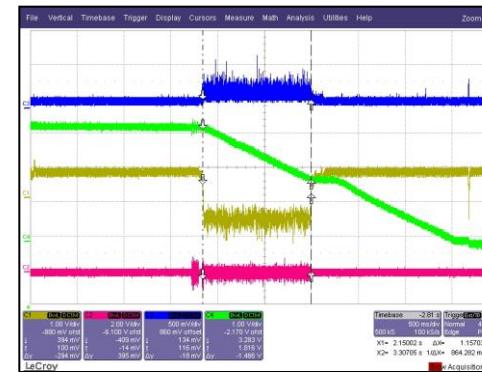


## Extraction (fixed target)

## 2<sup>nd</sup> ½ of flattop, IT & CD

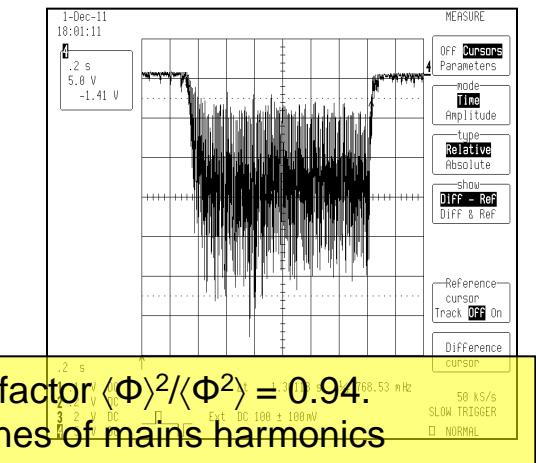


## 1<sup>st</sup> ½ of flattop, SSE

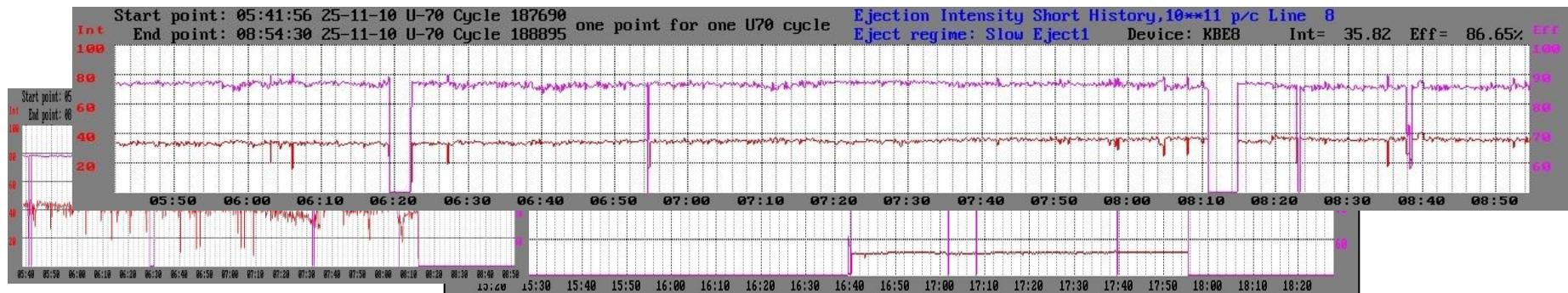


## Inventory

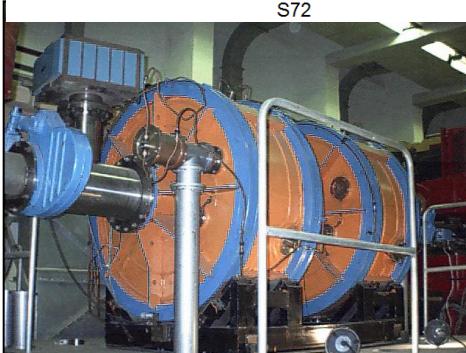
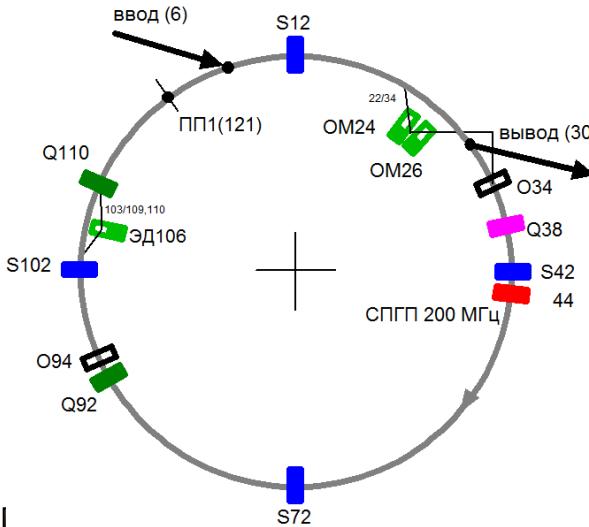
- 1-turn FE
  - SRE (Q38 & SSE)
  - IT
  - bent Si-CD SE
  - flat-bottom (S)SE



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

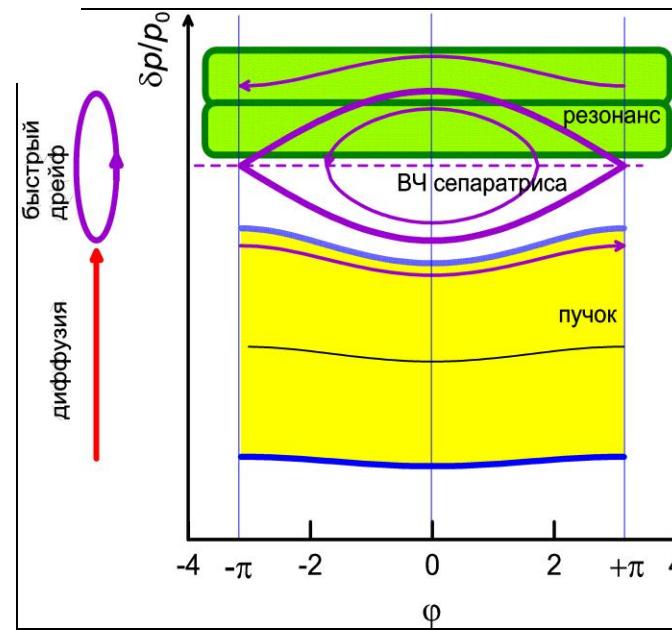


# Slow stochastic extraction



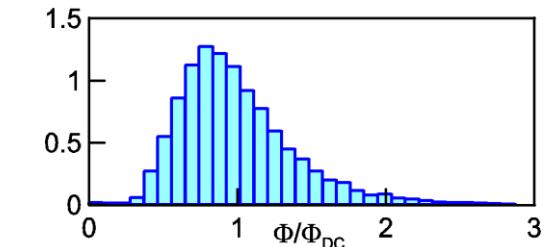
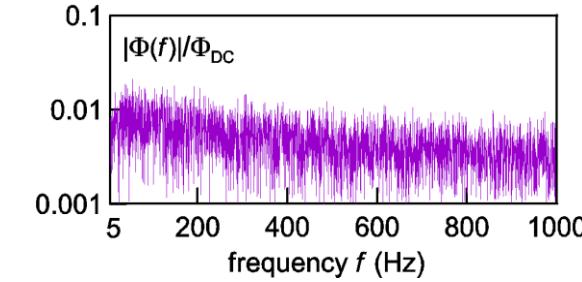
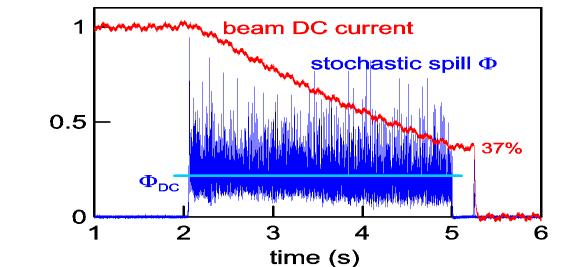
200 MHz RF system

integer horizontal resonance  $3Q_x = 29$



CERN Courier vol 47 no 2 March 2007:

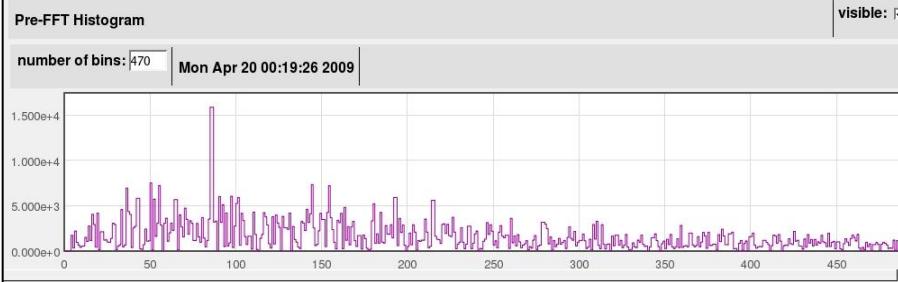
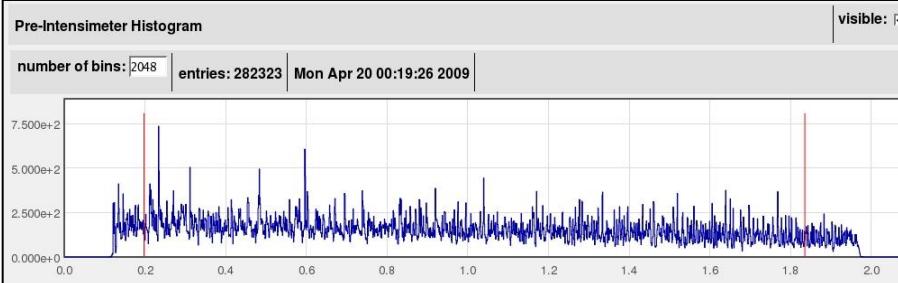
63% in 2.9 s.  $\sigma = 0.40$ ,  
 duty factor  $\langle \Phi \rangle^2 / \langle \Phi^2 \rangle = 0.87$ . No lines of mains harmonics



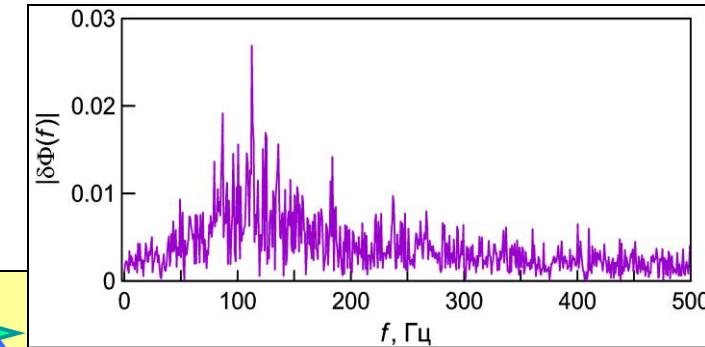
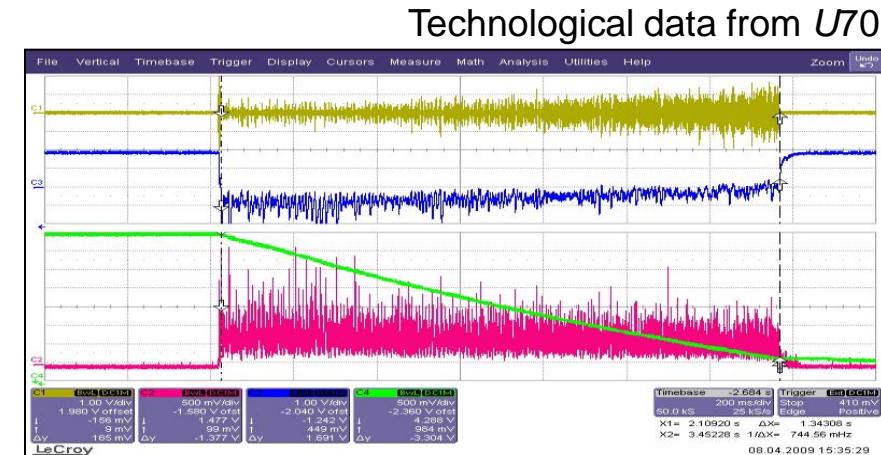
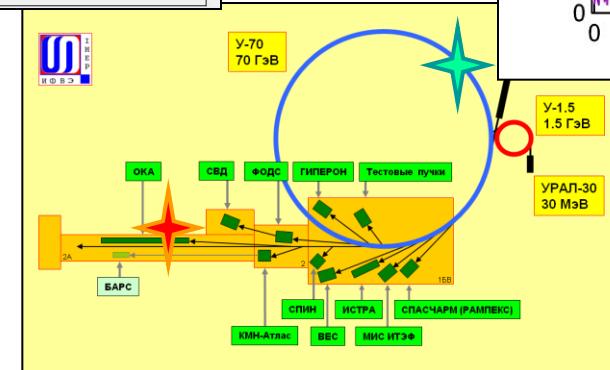
# Slow extraction & OKA experiment

Data: run 2009/1

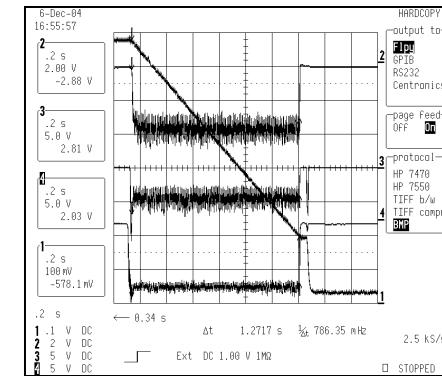
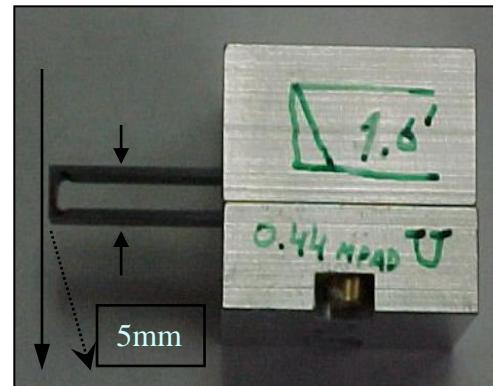
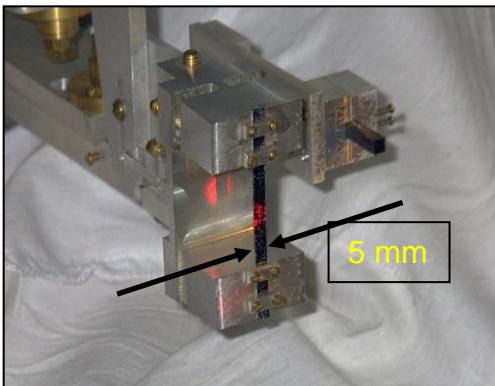
Data from OKA facility counters



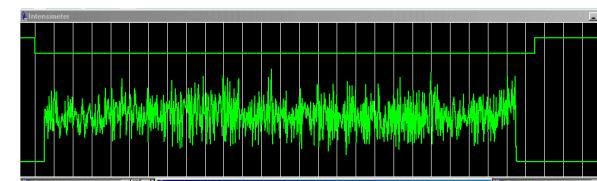
Spill 1.85 s long  
 $0.95 \cdot 10^{13}$  p per a spill  
 50 GeV



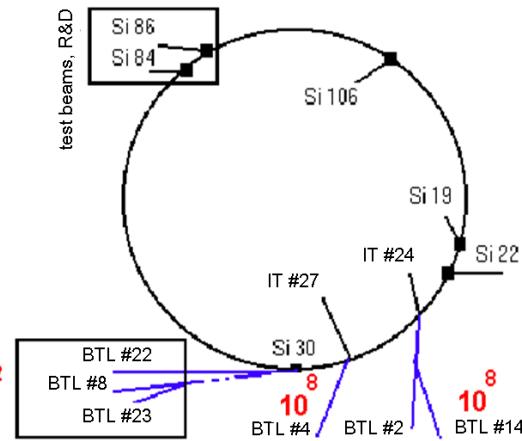
# Bent-crystal deflectors



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

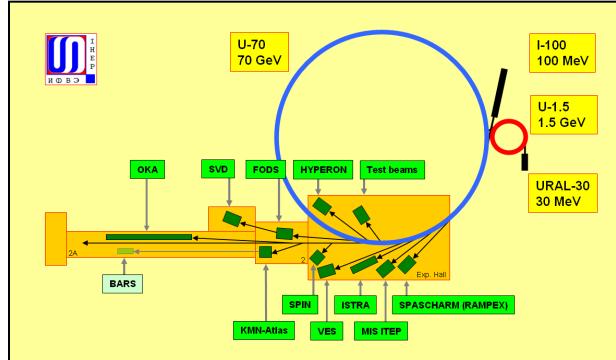


Run2007: 3 CD(19, 24, 30)  
6 experiments

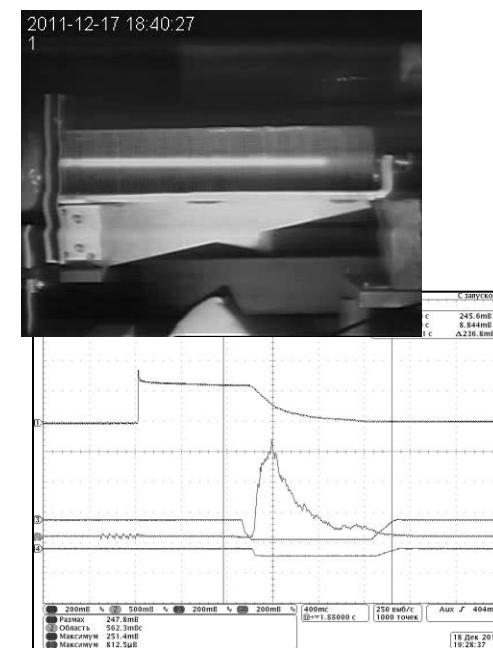
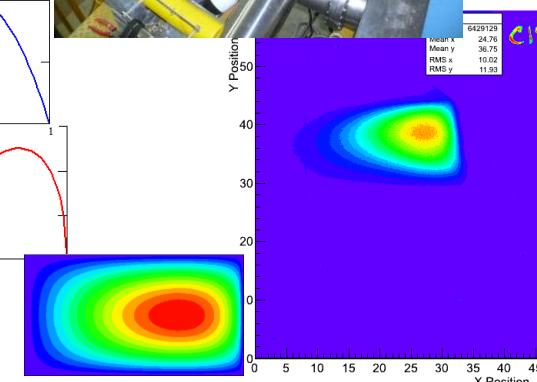
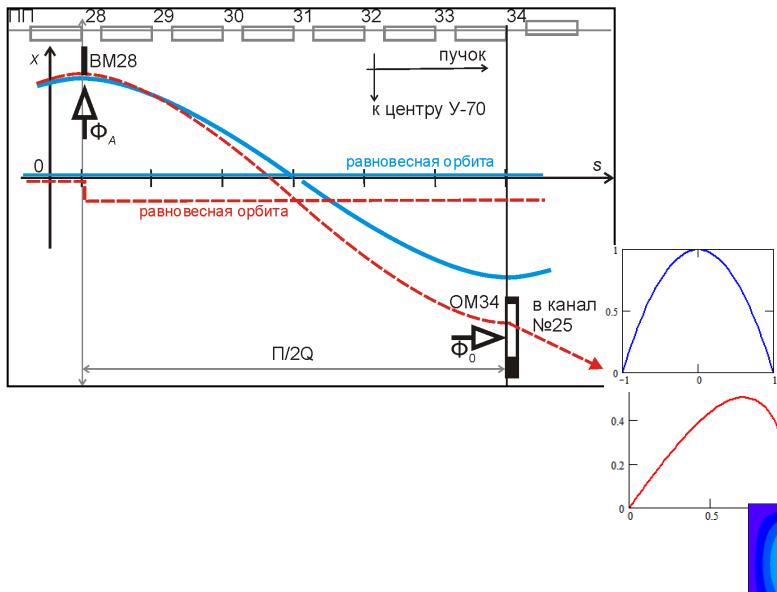
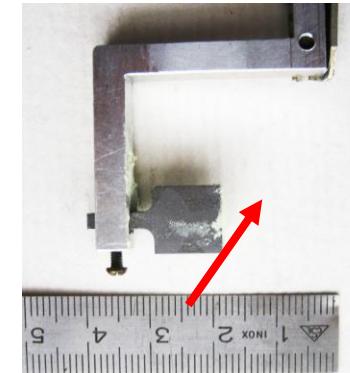


# Flat-bottom S(S)E

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

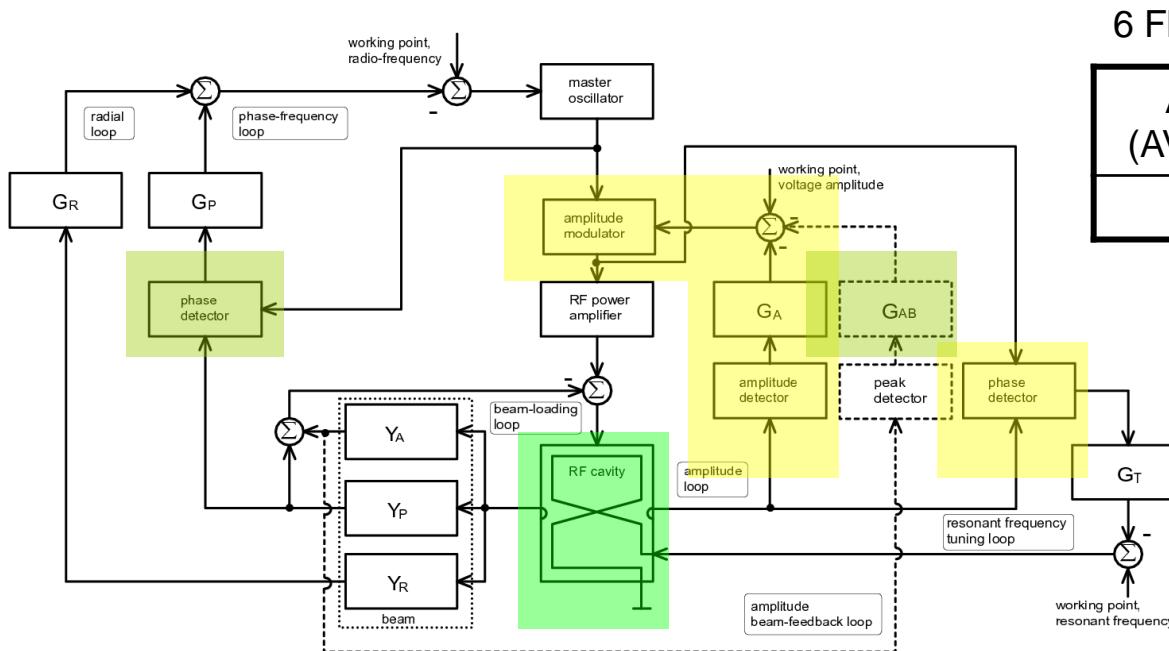
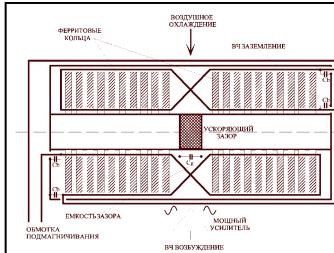


Graphite 30 mm ( $p$  1.32 GeV)  
Be 4 mm (C 455 MeV/u)



# Longitudinal Fbck

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



6 Fbck loops:

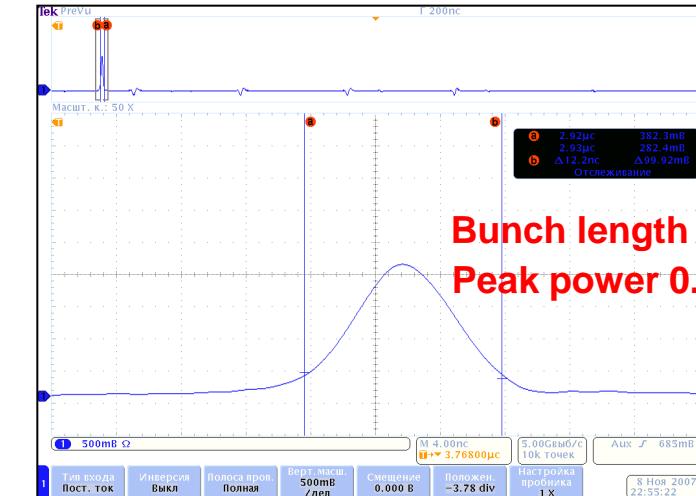
A (AVC)	T (AFC)	BL	R	P	AB
$\times 40$				$\times 1$	

# Beam quality, longitudinally

DC CT  
PU  
V<sub>RF</sub>  
peak D



without 200 MHz spill cavity below  $\gamma_{tr}$

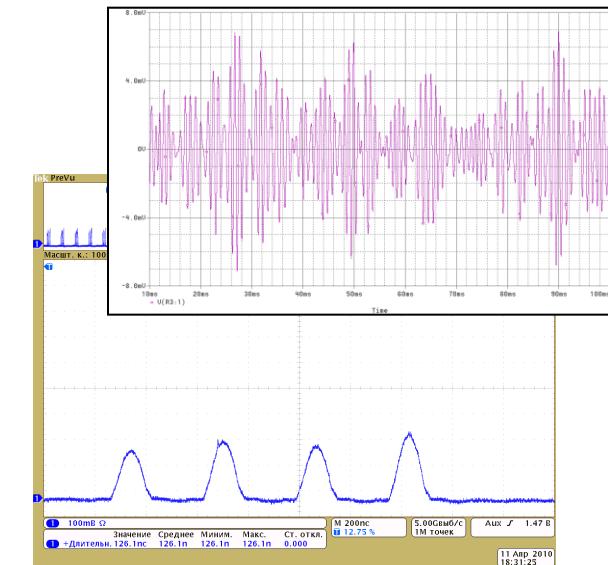
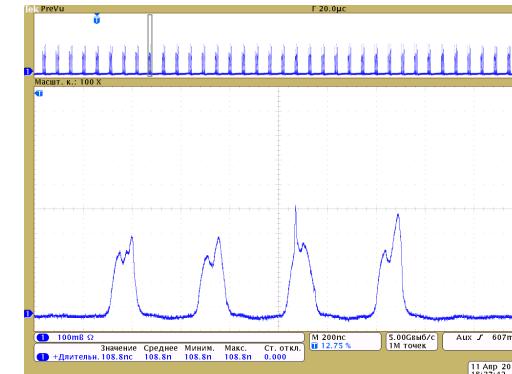
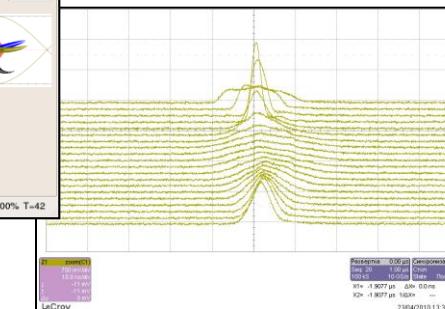
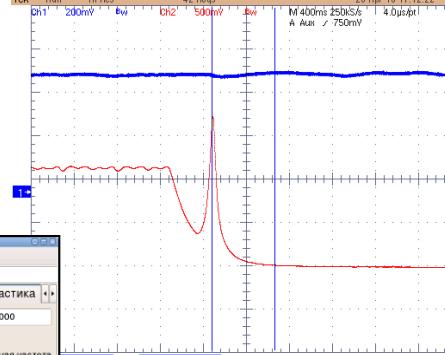
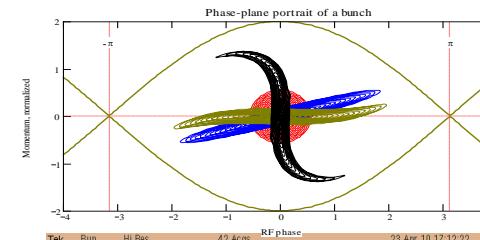
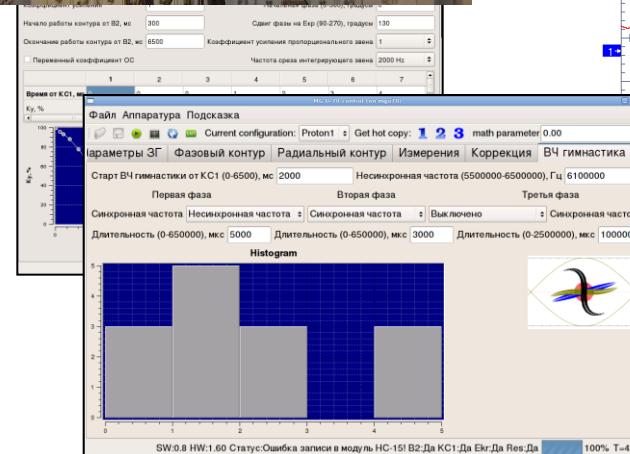


@ 50 GeV

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

# DDS RF MO

New digital MO in RF of the U70



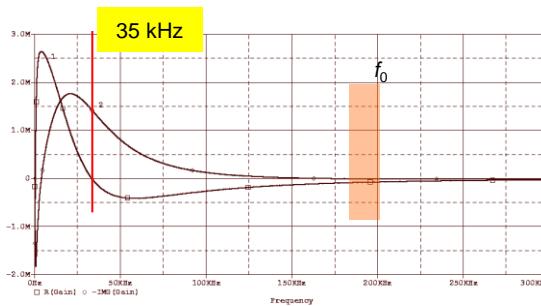
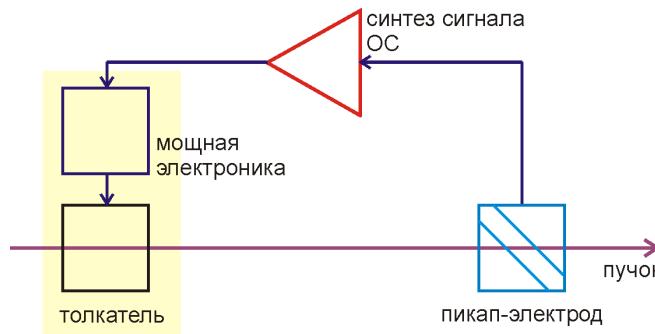
# Transverse (NB, local) Fbck

ESK @ SS2

0 – 0.2 MHz

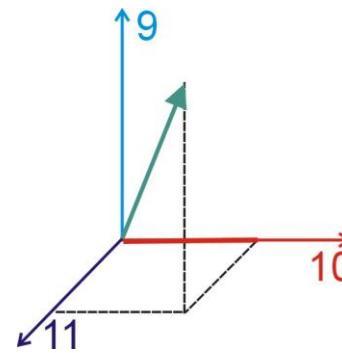
$\pm 35.0$  kV

PU @ SS2 (+ @SS116)

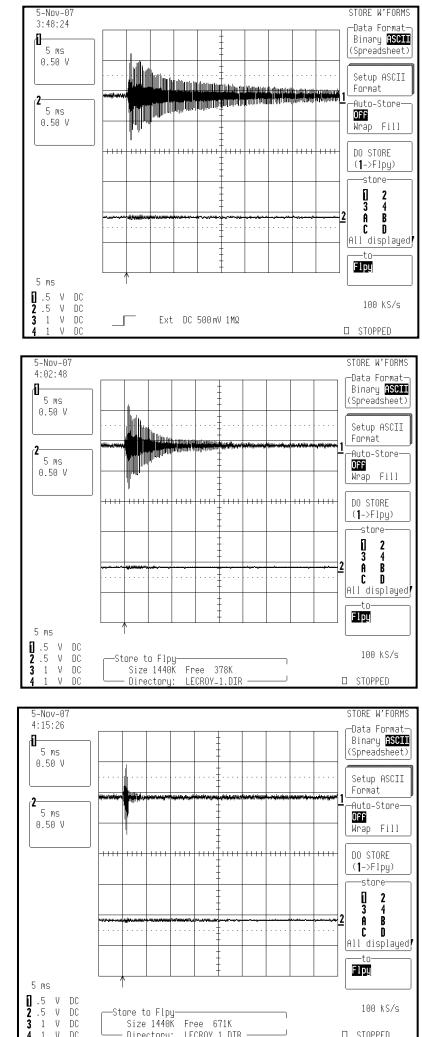


H: 14.7–72.3 kHz,  $\pm 45^\circ$

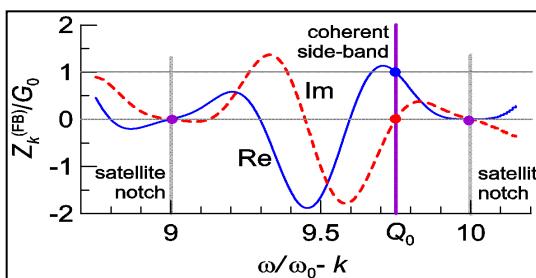
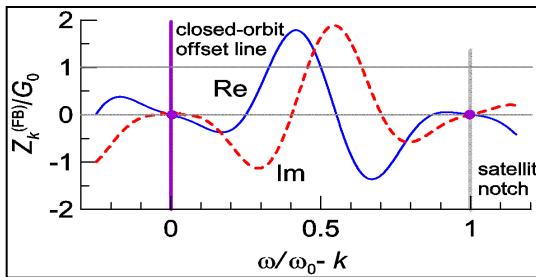
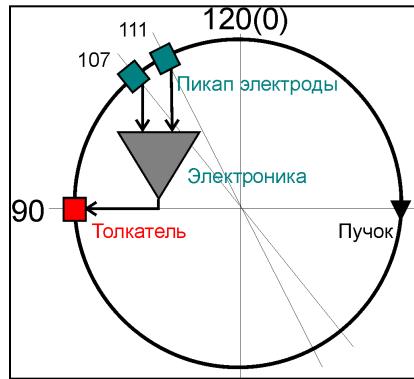
V: 29.4–43.2 kHz



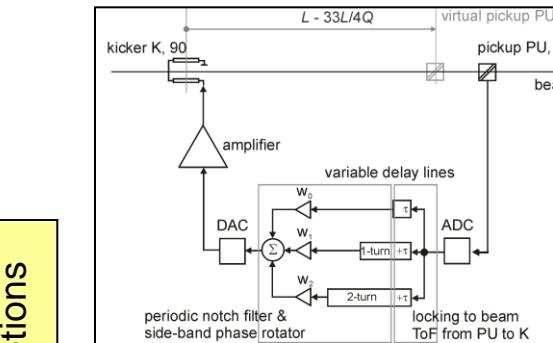
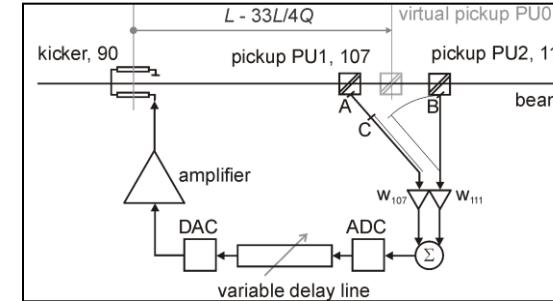
Damping factor =  
100 w. r. t. natural



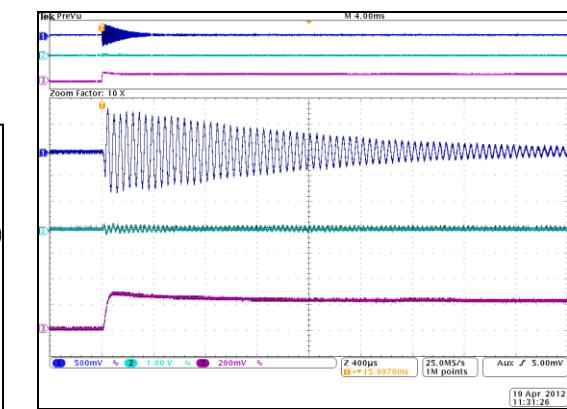
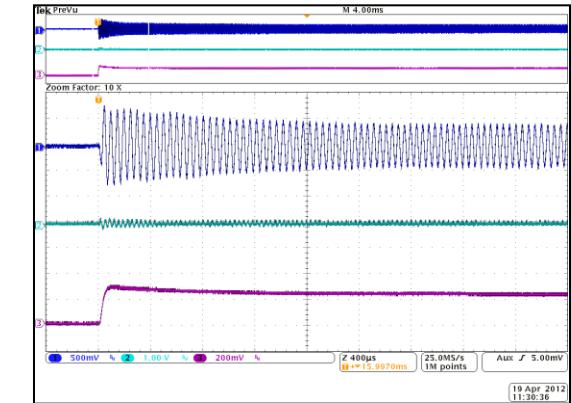
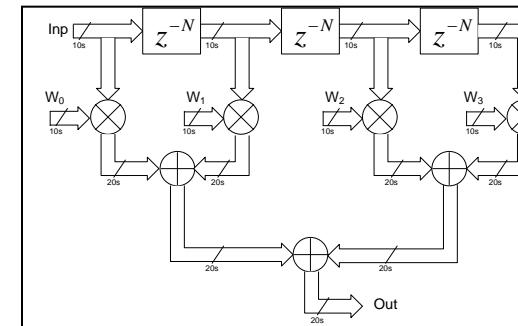
# Digital transverse (WB) Fbck



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



FIR-3 & FIR-4 options



# Instabilities

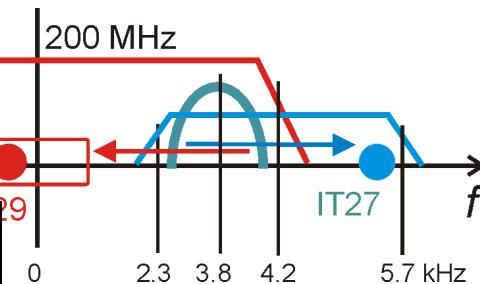
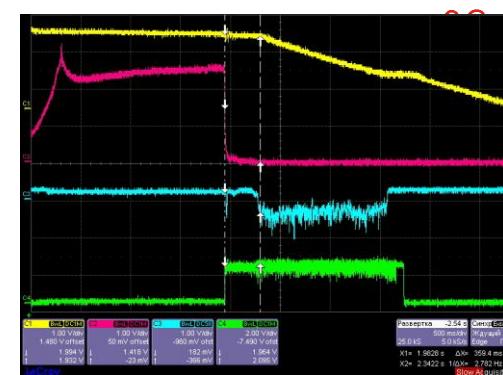
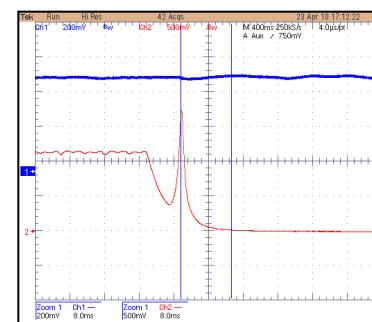
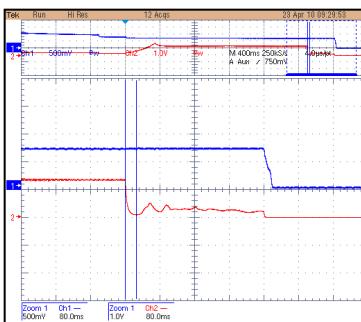
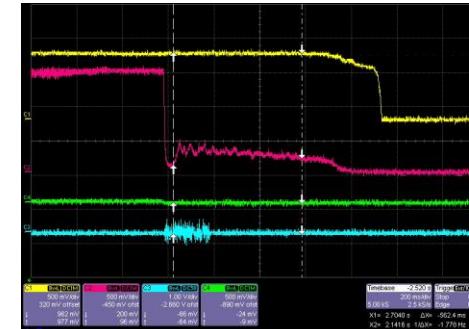
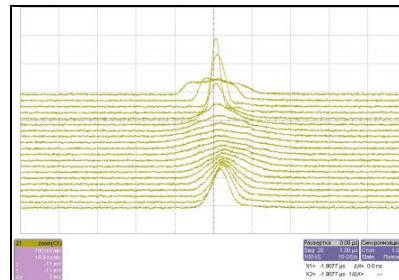
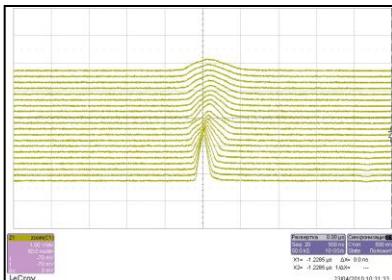
Back to factory default freq range of RF system, 2.6 (4.5)-6.1 MHz instead of o 5.5-6.1 MHz

$$\left| \frac{Z(k\omega_0)}{k} \right| < \frac{1}{\Lambda} \frac{\beta^2 |\eta| E}{e J_0} \left( \frac{\Delta p}{p} \right)^2$$

Cures:

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

RF noise



# Strategy of light ion program

Incremental:

- ion species
- along cascade
- intensity [qpp]

$p - d - C$

[/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  
 $1 - 1/10 - 1/50$  & low- $N$  pilot  $p$ -beams prior to  $d$ ,  $C$ -beams

Reference ions $q = Z$ , $q/A = 1/2$		/100, 2 cav of 3		$U_{1.5}$		$U_{70}$	
		IN	OUT	IN	OUT	IN	OUT
$p$ , pilot beam	$\beta$		0.3724		0.9000		0.9999
	$B_p$ , T·m		1.2558		6.8659		233.38
	$T$ , MeV		72.71		1 323.8		69 032
$d$	$\beta$		0.1862		0.7392		0.9996
	$B_p$ , T·m		1.1856		6.8659		233.38
	$T$ , MeV/u		16.691		454.56		34 057
$C$	$\beta$		0.1862		0.7414		0.9996
	$B_p$ , T·m		1.1776		6.8659		233.38
	$T$ , MeV/u		16.678		456.53		34 063

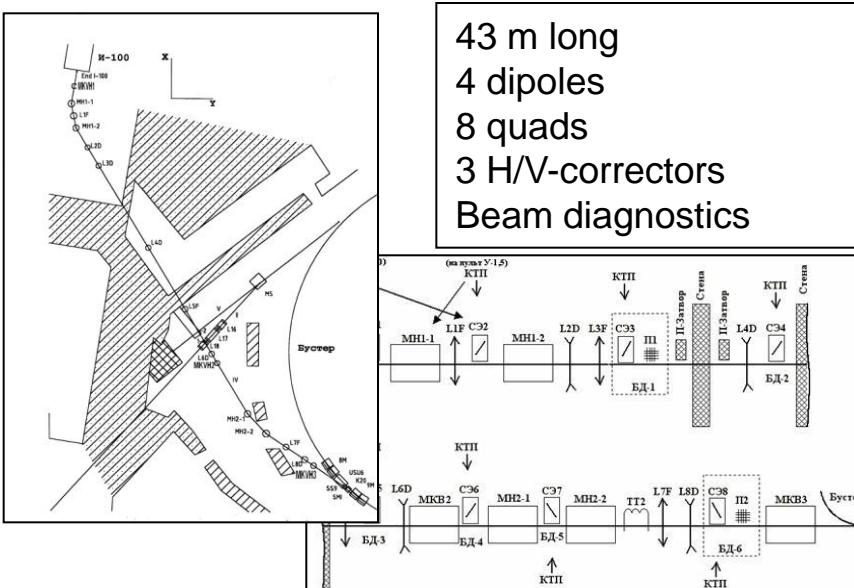
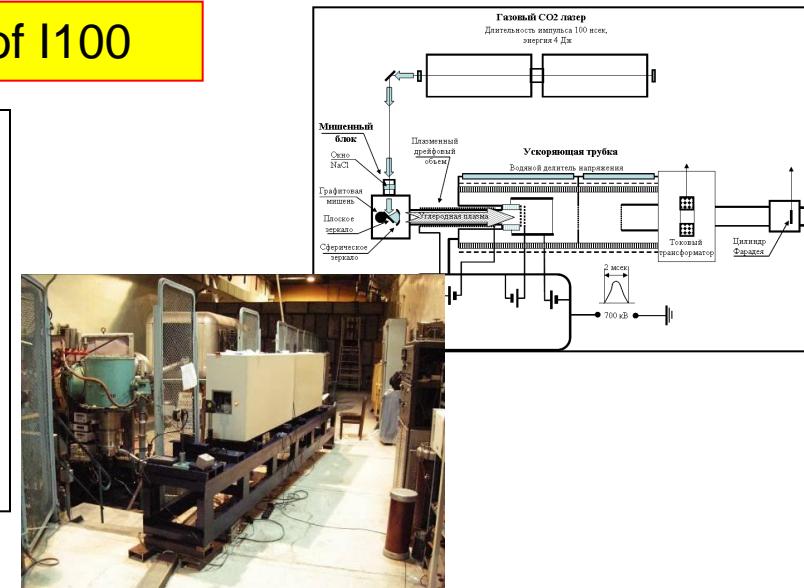
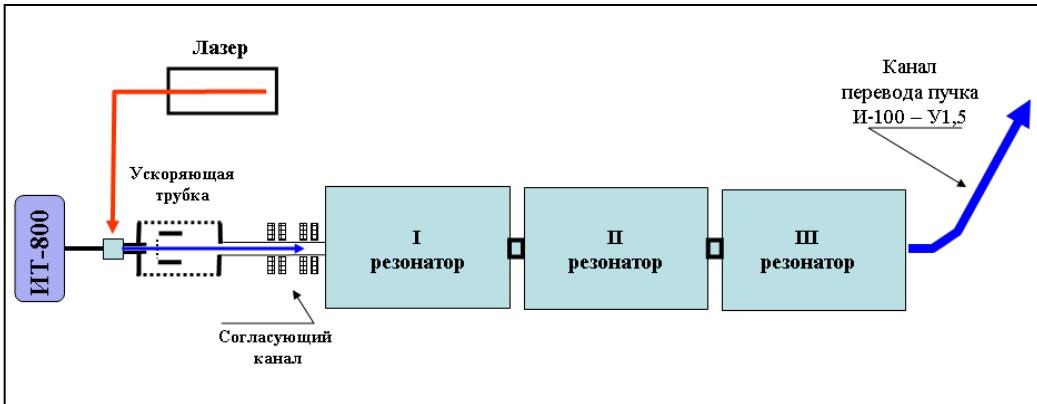
49 0

23 6

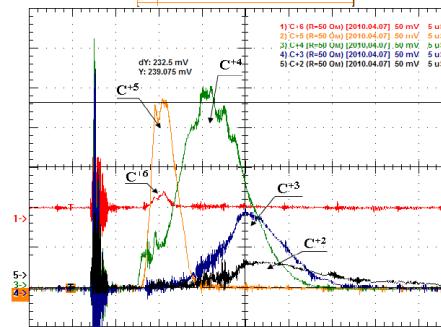
24.1--34 1

# I100 DTL as C-injector

Stand-alone runs of I100



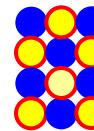
InfraLight SP, PhIC GPhI RAS, Troitsk  
 2 modules, CO<sub>2</sub>, N<sub>2</sub> и He,  $\lambda=9.6\text{--}11\text{ }\mu\text{m}$   
 2 Hz, 4.5 J, almost, COTS



10–12 mA 4000 cycles  
 (former 800), i.e. >8 hr.

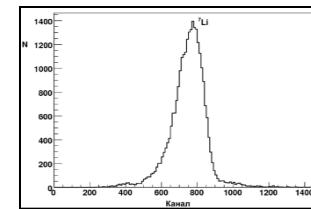
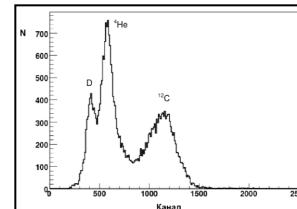
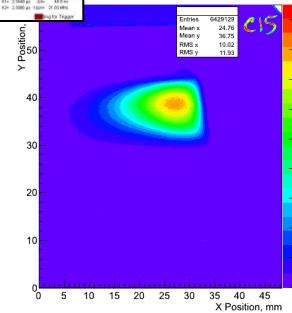
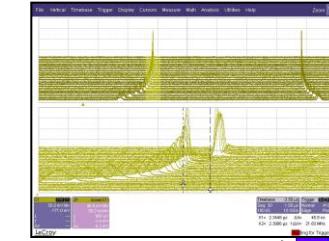
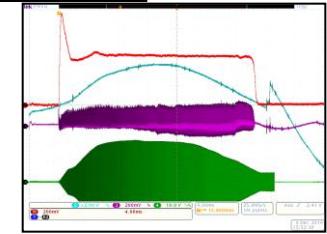
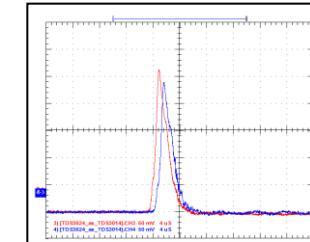
# Milestones

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



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

	Deuterons $^2\text{H}^{1+}$	Carbon $^{12}\text{C}^{6+}$
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

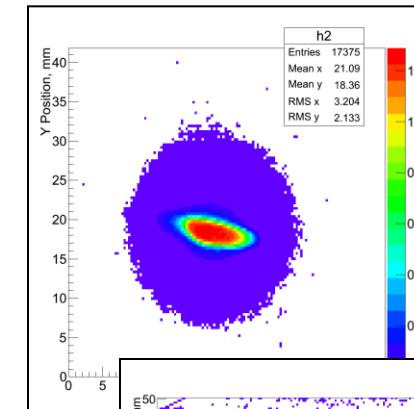
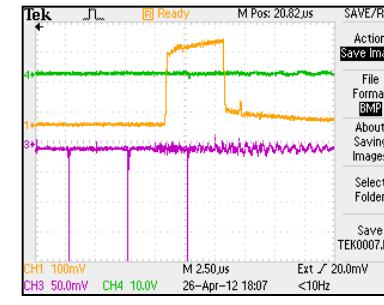
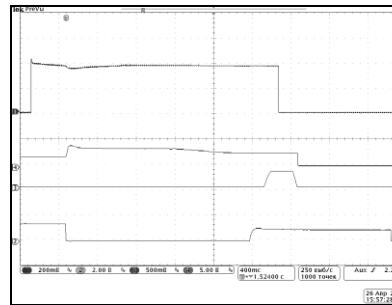


# All HE extractions with C

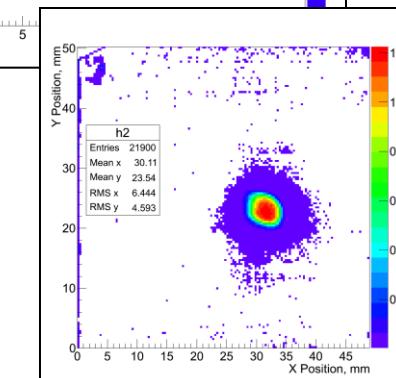
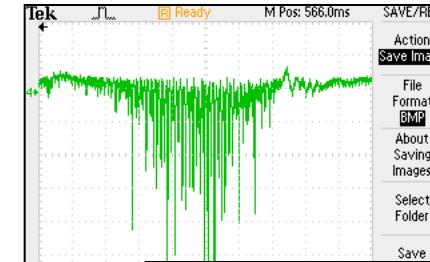
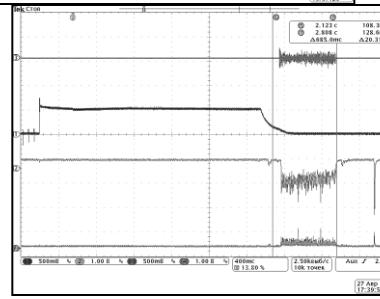
April 24, 2012. C 24.1 GeV/u (flattop 0.859 T)  $5 \cdot 10^9$  ipp (8 s).

1<sup>st</sup> ever tests all HE extractions with the C beam

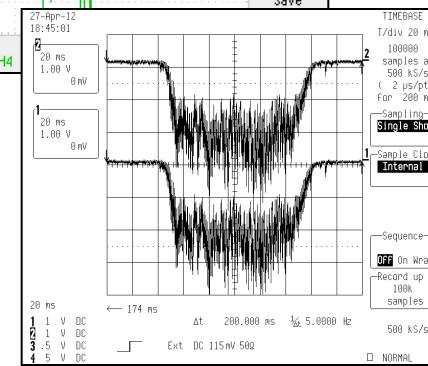
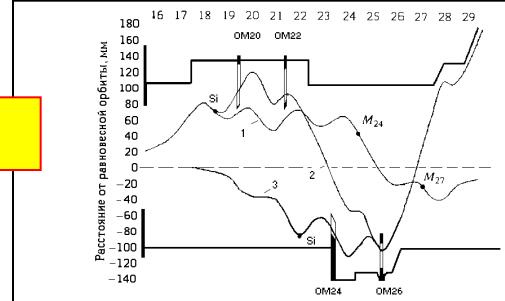
FE



SE



CD#22

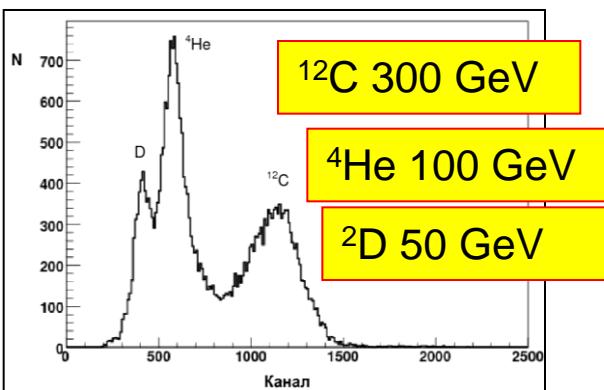


# 1st experimental NPh events

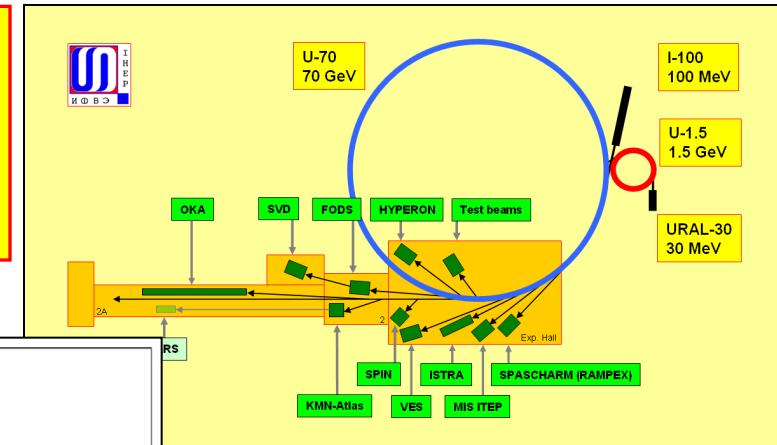
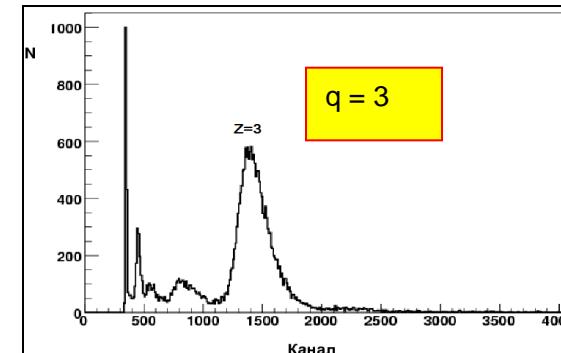
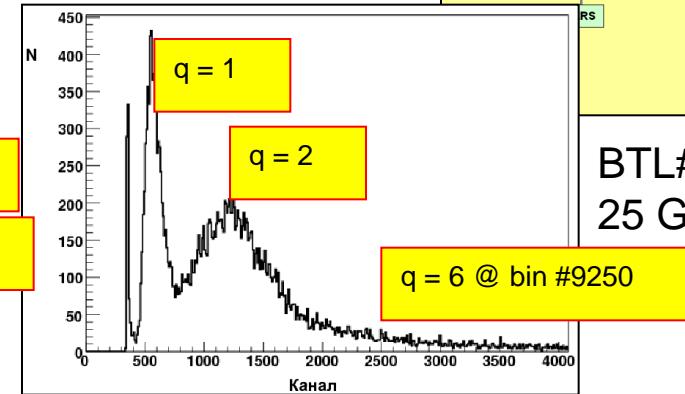
April 27, 2012. 1<sup>st</sup> ever extracted C beam in 190 m  
 BTL#22 = **FRS** & FODS (a FOcussing 2-arm  
 Spectrometer) experimental facility

24.1 GeV/u or 300 GeV full E

Hadron calorimeter



Scintillator counters



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

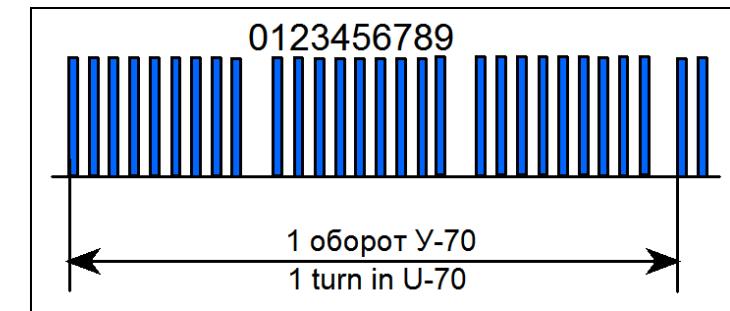
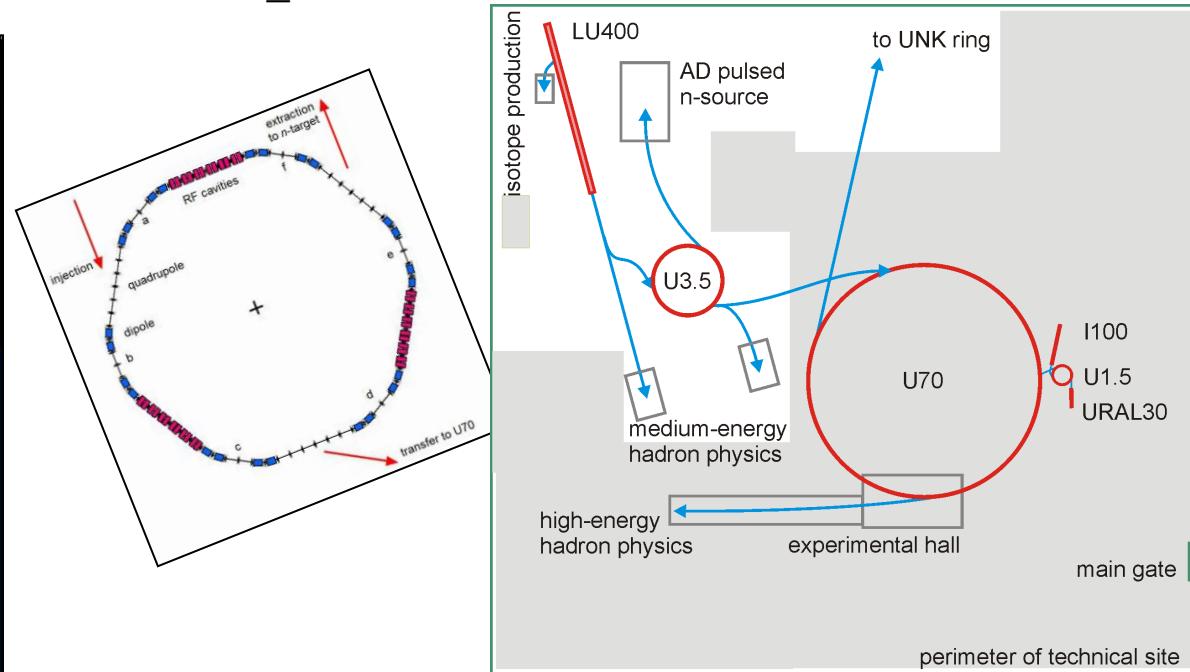
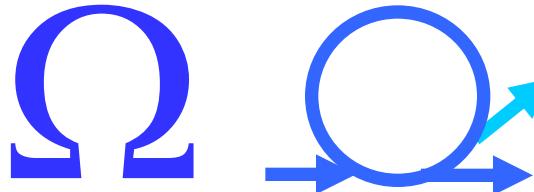
BTL#22 60 GeV/c (p) \pm 1%

a FRS

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

# OMEGA Project

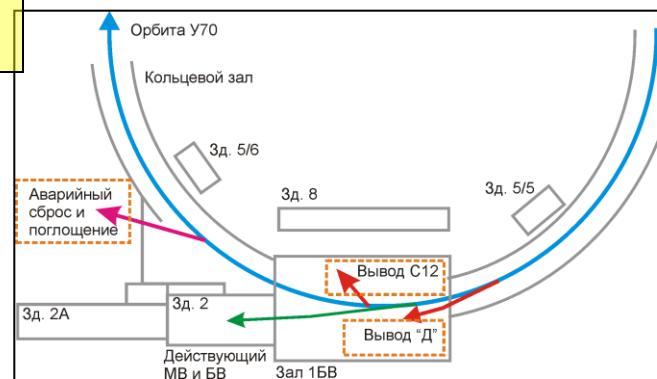
[http://www.ihep.ru/ihep/news/IHEP-2-9-10\\_fin-c.PDF](http://www.ihep.ru/ihep/news/IHEP-2-9-10_fin-c.PDF)



# FE to LAGUNA LBNE

2-nd junction

4 deg H  
5 deg V  
23 T·м



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

Таблица 1: Вариант УНК

$N$ , р.р.р.	$T$ , ГэВ	$n$	$f$ , Гц	$P$ , кВт
$5 \cdot 10^{13}$	69.0	29	16 2/3	75

Таблица 2: Вариант ОМЕГА

$N$ , р.р.р.	$T$ , ГэВ	$n$	$f$ , Гц	$P$ , кВт
$3 \times 7.5 \cdot 10^{13} = 2.25 \cdot 10^{14}$	69.0	3	25	430



# Conclusion

Accelerator Complex *U70* of IHEP-Protvino:

- comprises 4 machines (*URAL30*, *I100*, *U1.5*, and *U70* 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 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  $^{12}\text{C}^{6+}$  beam
- *U1.5* and *U70* now belong to PS and (L)IS categories
- open for a few promising options for future development