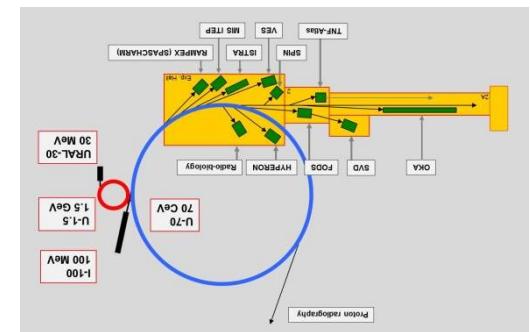




СТАТУС У-70

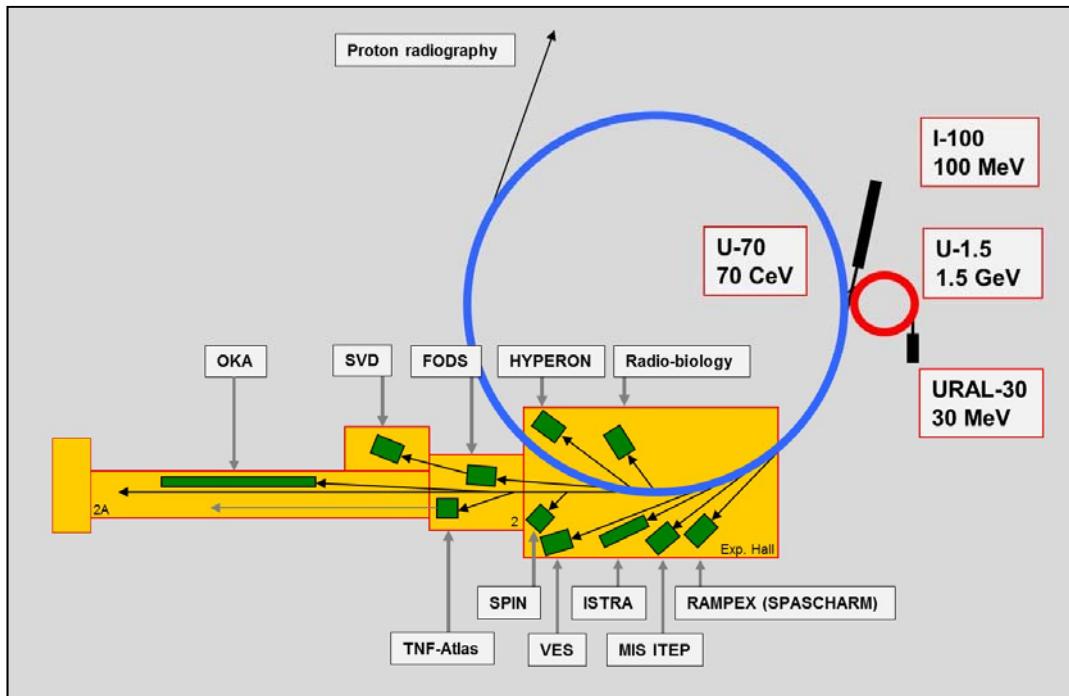
Сергей Иванов



Международная сессия-конференция СЯФ ОФН РАН
5-8 ноября 2013, Протвино, ГНЦ ИФВЭ

- Общие положения
- Работа в сеансах
- Модернизация установок
- Программа ускорения легких ионов
- Перспективы (возможности) развития
- Заключение

Layout, AC U70 vs the U70 proper



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



Modes:

- p (default, 50-70 GeV) **URAL30-U1.5-U70**
- light-ion (d , C) **I100(2 of 3)-U1.5-U70**

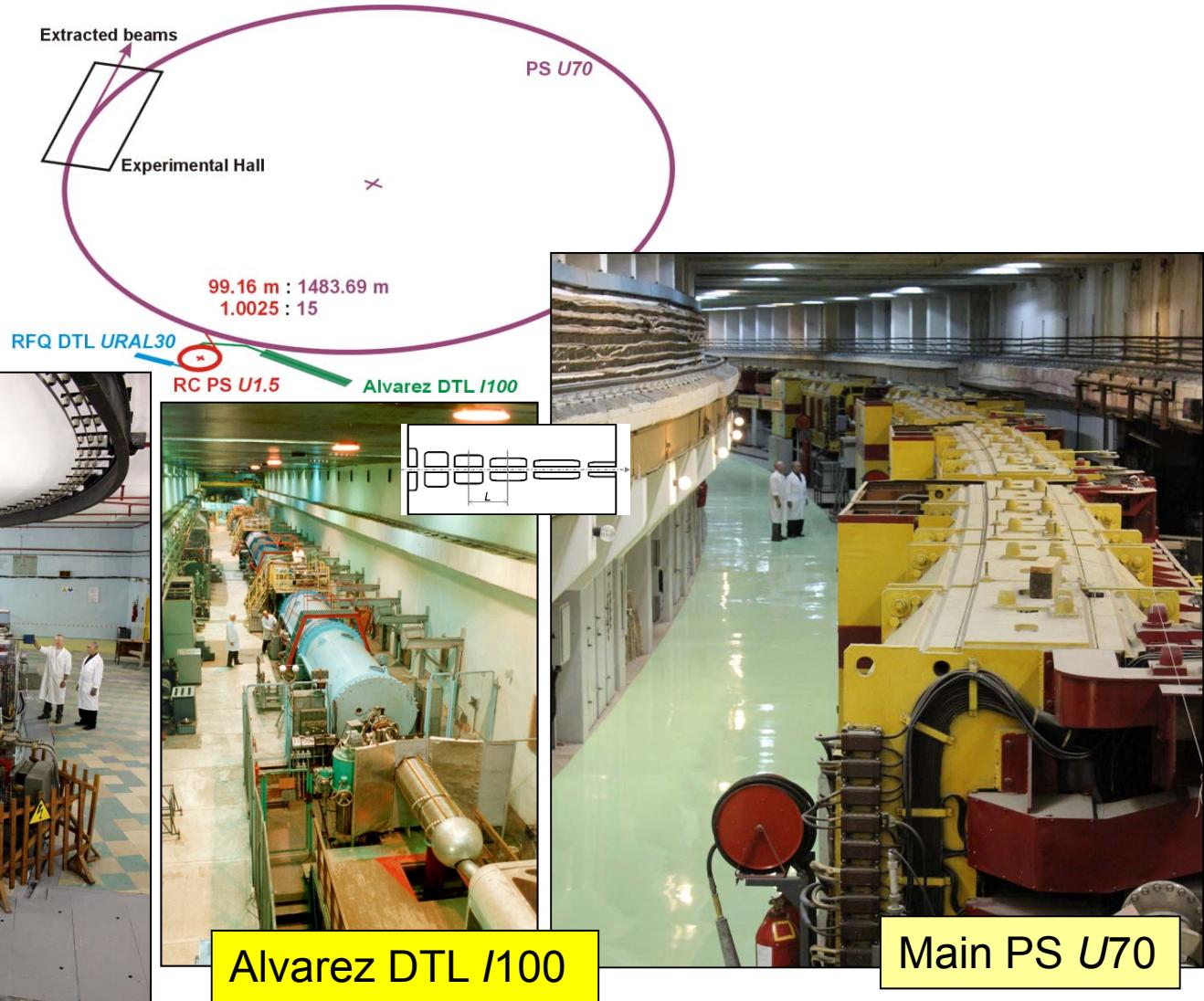
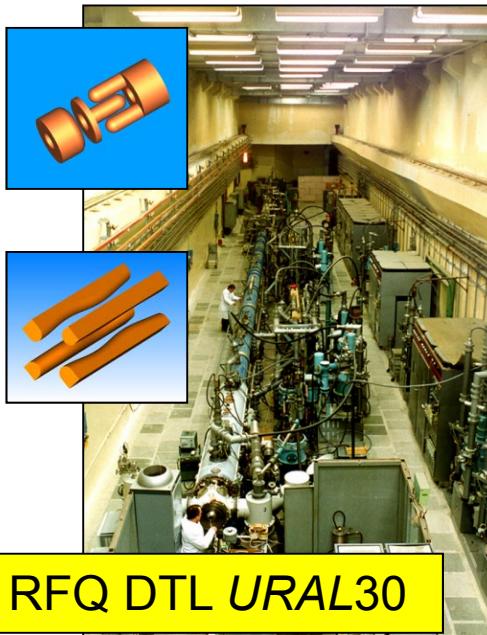
Light-ion (C):

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

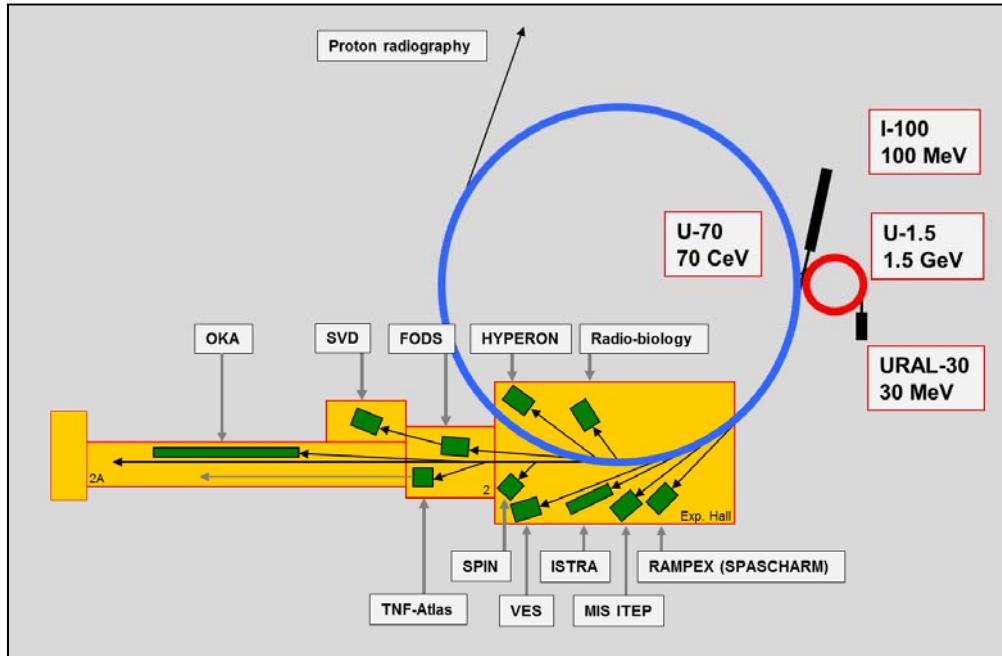
In a SIS-18, SIS-100 name convention:

- LIS-233 [T·m]
- LIS-6.9 [T·m]

Photo album of the machines



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]
- ...



span 90 m

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

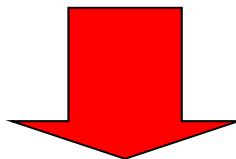
to note: OKA (#21), FODS (#22), stretcher (#25)

Up to 9 HEP experiments (= No of setups) per a run, up to 7 beam users per a cycle

Goals of activity with accelerators

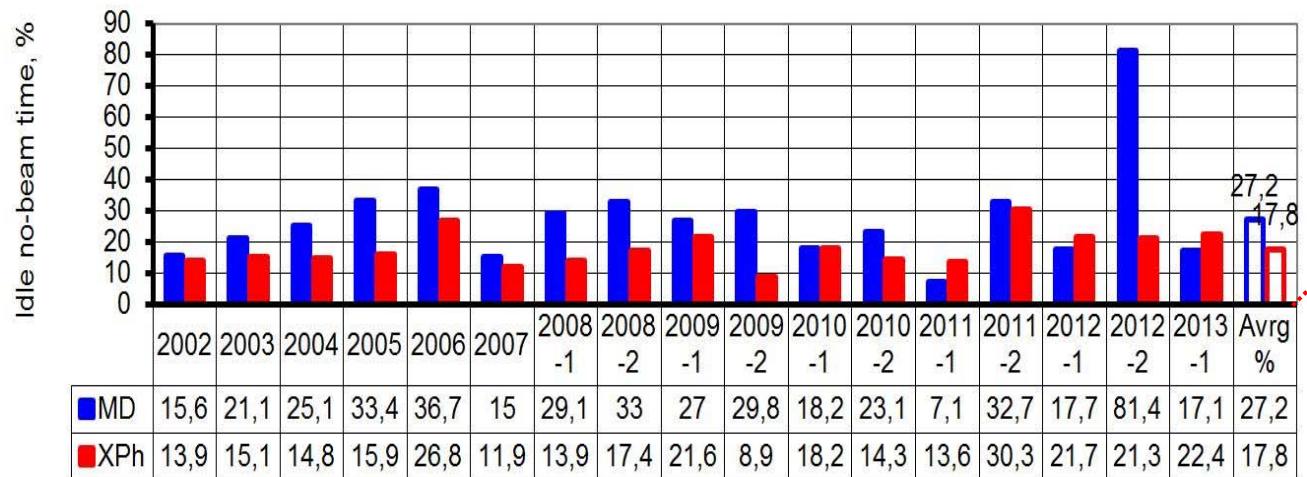
3 [4] goals:

- 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, $q/A = 0.4\text{--}0.5$
- [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

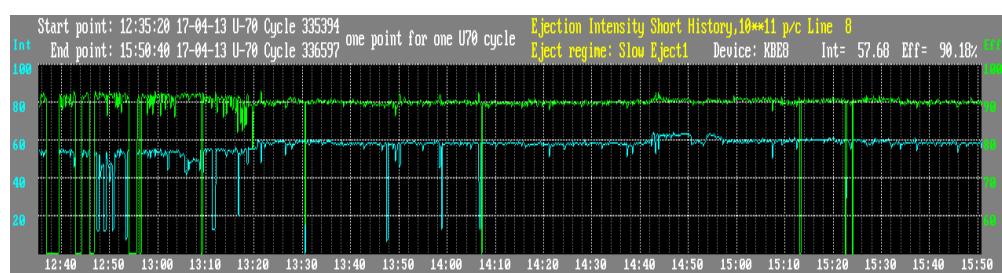


| | |
|-----|------|
| MD | 27,2 |
| XPh | 17,8 |

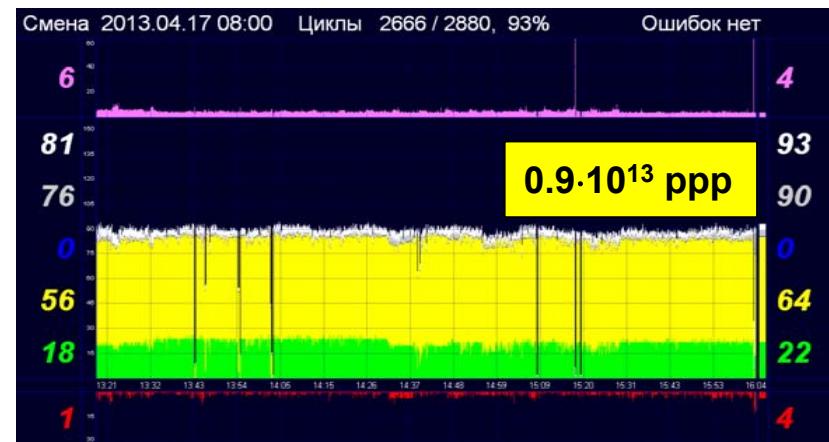
Run

2 runs (7/24) per year:

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



90-94% $1-6.5 \cdot 10^{12}$ ppp

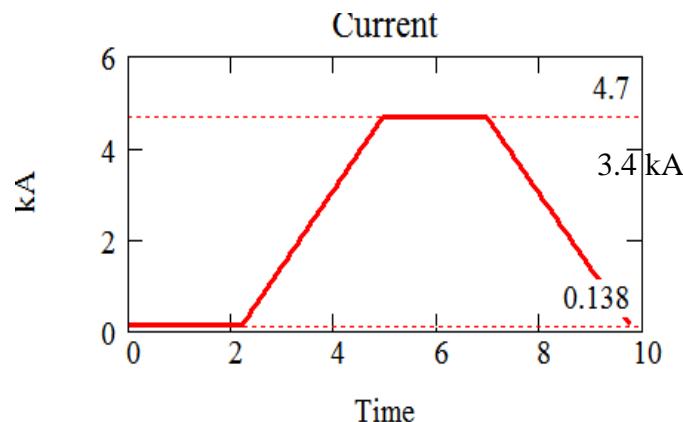


← 3 hr, or 1000 cycles →

Extraction (fixed target, multi-user)

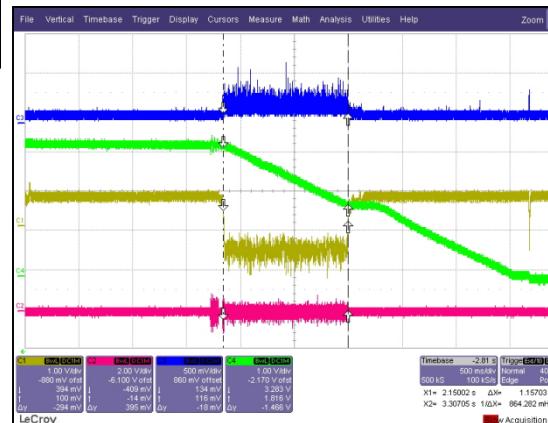
Inventory:

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

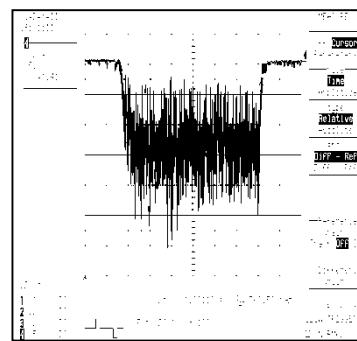
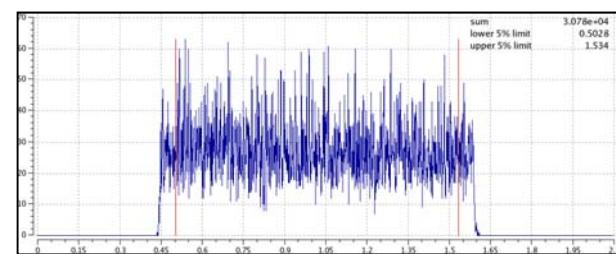
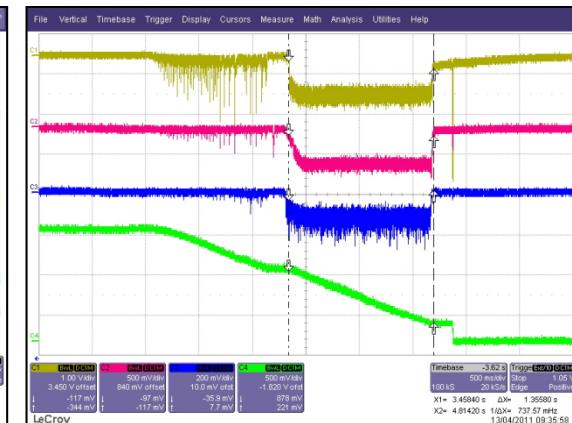


Sequential and parallel flattop sharing

1st ½ of a flattop, SSE

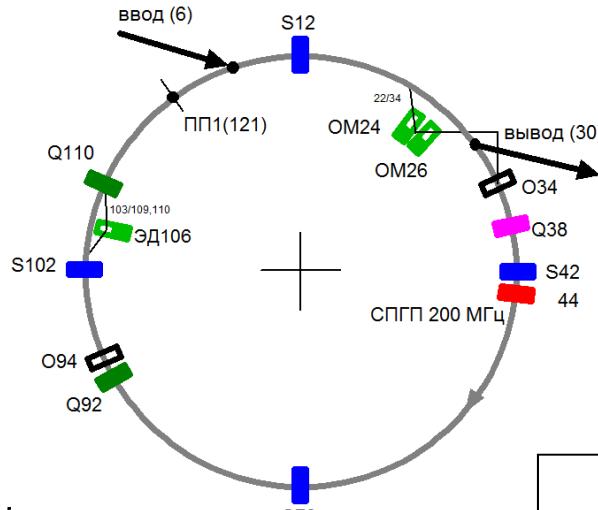


2nd ½ of a flattop, IT & CD

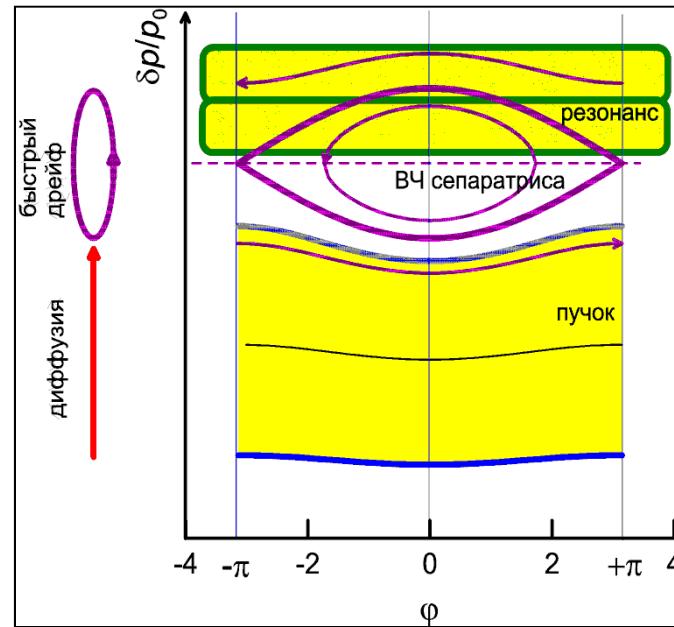


duty factor $\langle \Phi \rangle^2 / \langle \Phi^2 \rangle$ to 0.94.
No lines of mains harmonics

Slow stochastic extraction

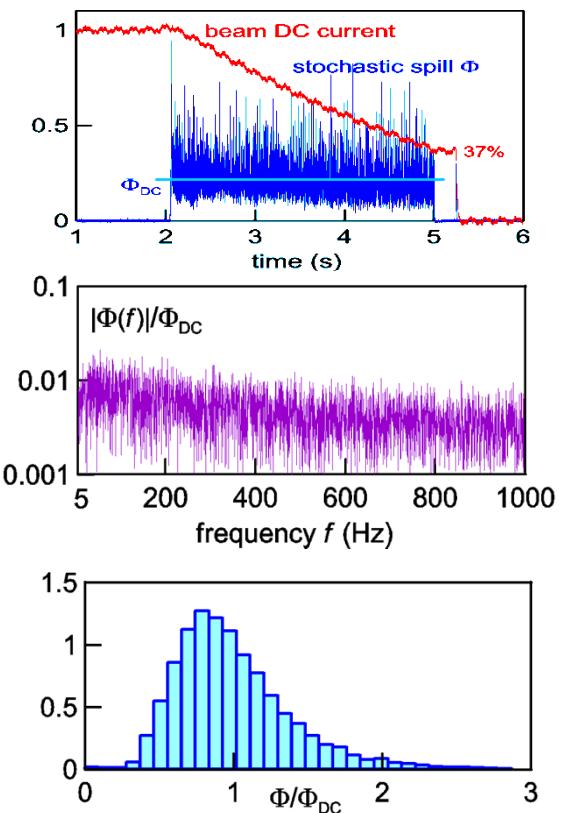


200 MHz RF system



CERN Courier vol 47 no 2 March 2007:

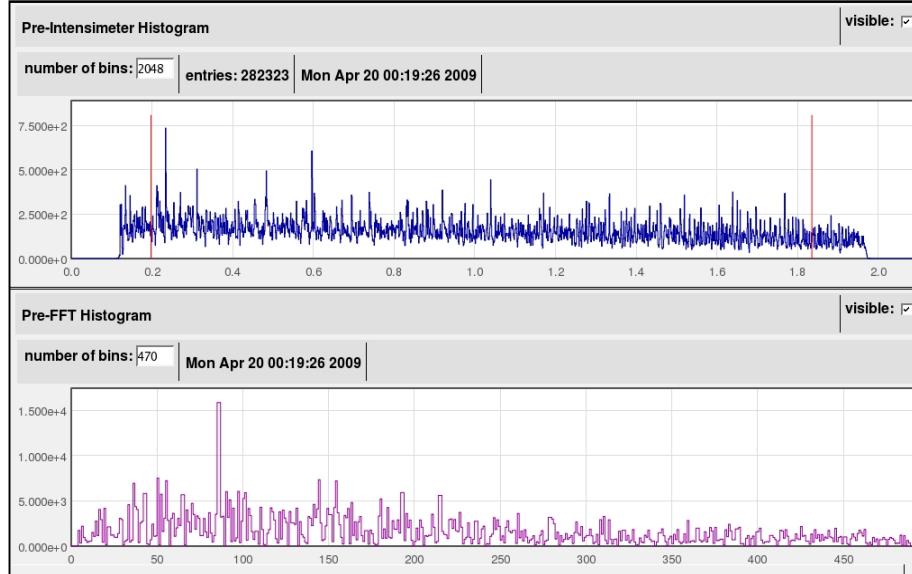
63% in 2.9 s. $\sigma = 0.40$,
duty factor $\langle \Phi \rangle^2 / \langle \Phi^2 \rangle = 0.87$. No lines of mains harmonics



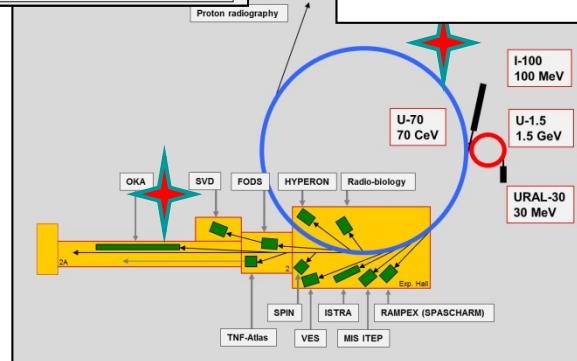
Slow extraction & the OKA experiment

Data: run 2009/1

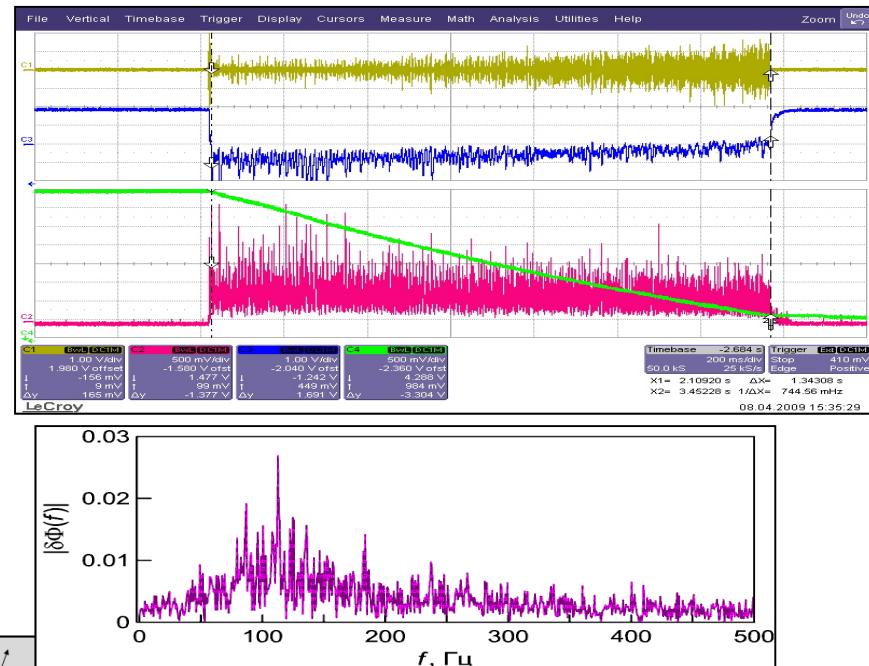
Data from the OKA facility counters



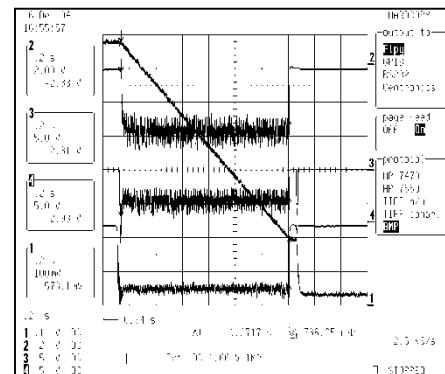
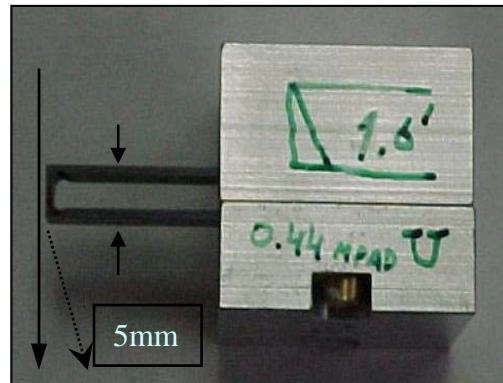
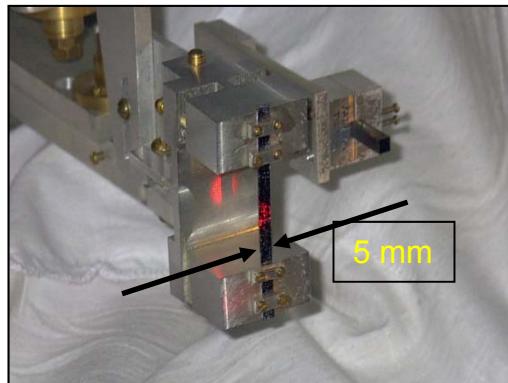
Spill 1.85 s long
 $0.95 \cdot 10^{13}$ p per a spill
 50 GeV



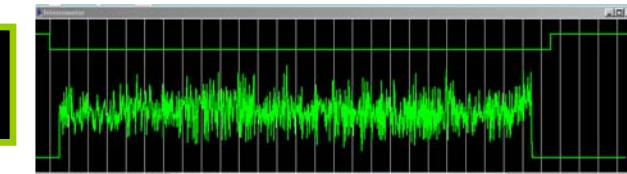
Technological data from the U70



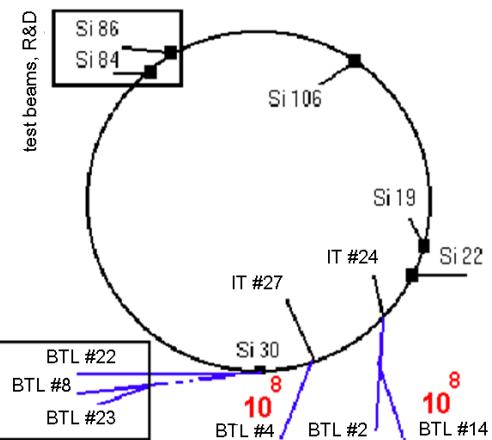
Bent-(Si)crystal deflectors



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

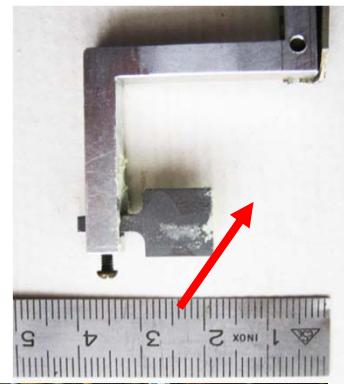
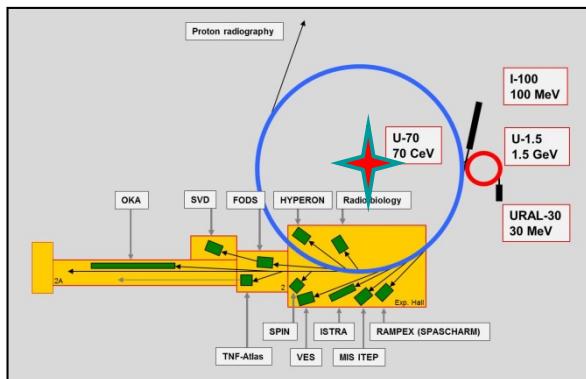


Run2007: 3 CD(19, 24, 30)
6 experiments

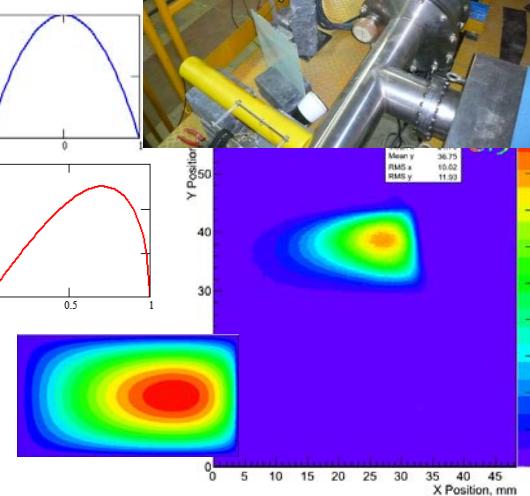
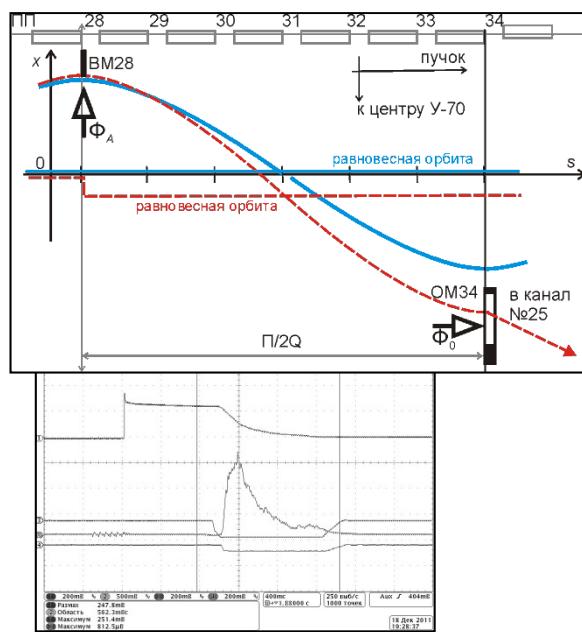
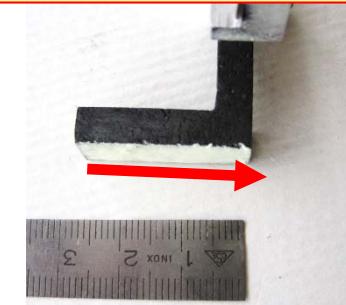


Flat-bottom S(S)E

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



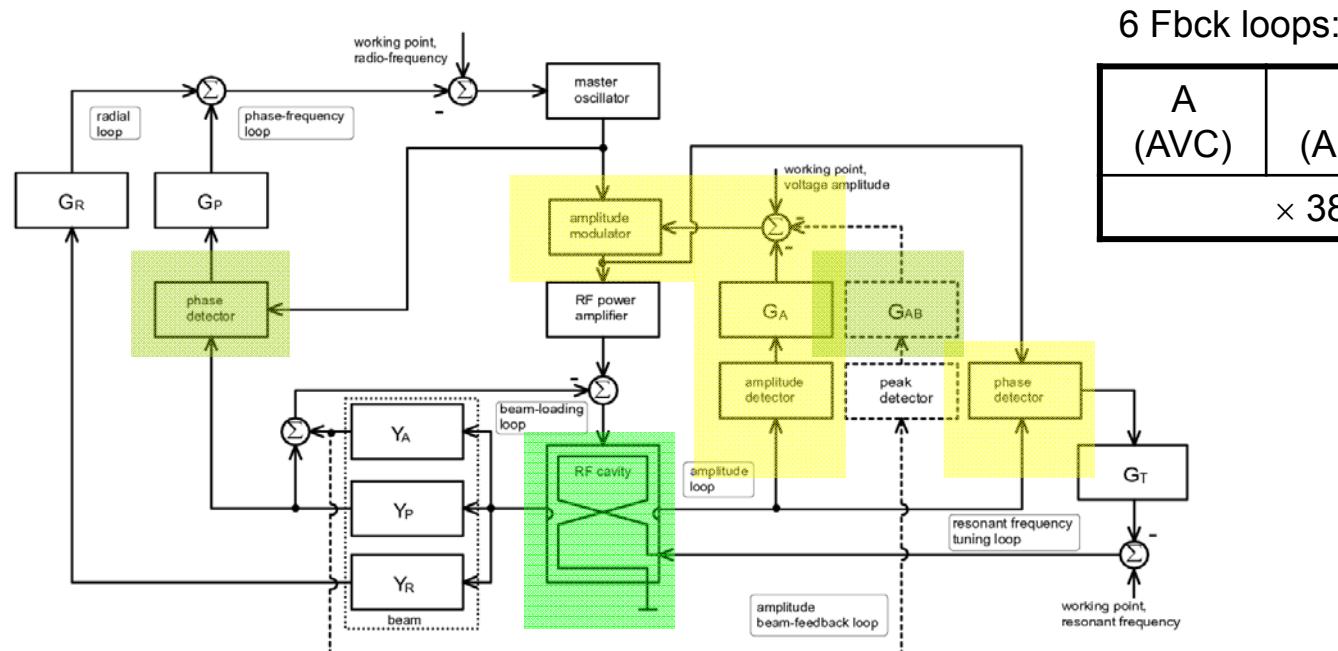
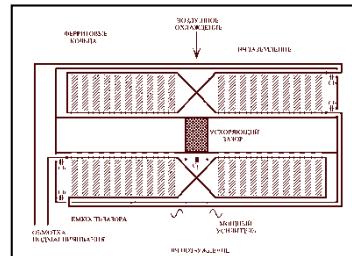
Graphite 32 mm (p 1.32 GeV)
Be 4 mm (C 455 MeV/u)



Bragg's peak in a water phantom

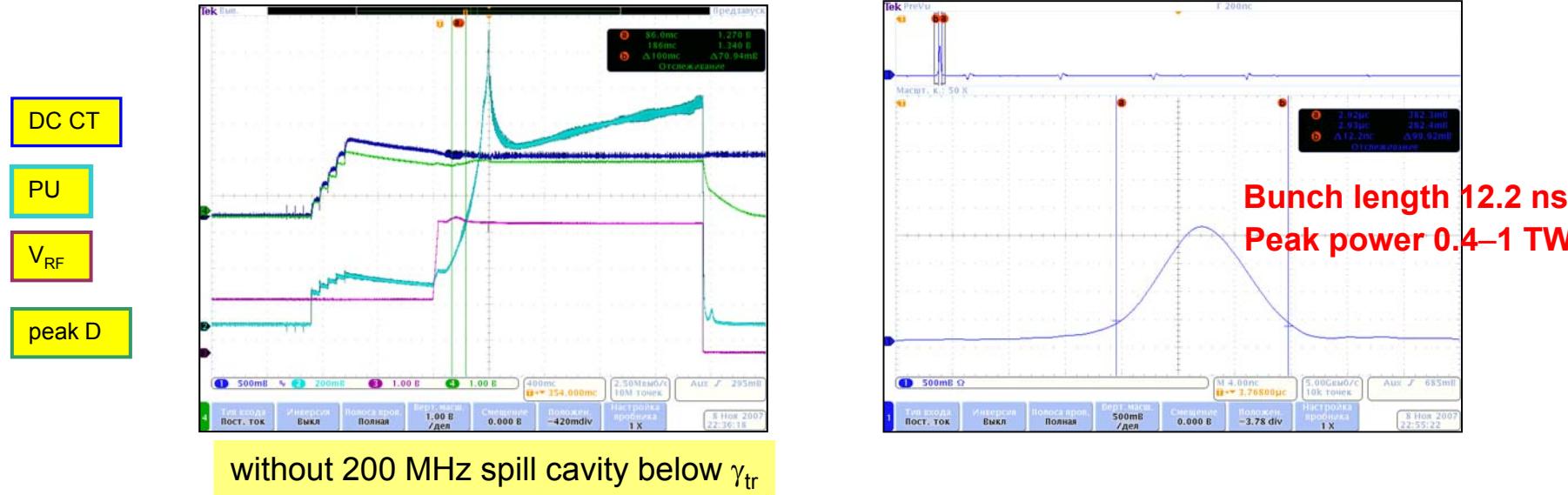
Longitudinal feedbacks

Accelerating system GRAPHITE, 38 ferrite-loaded 1-gap cavities, RF 5.52–6.06 MHz, 10 kV/gap



| | | | | | |
|-------------|------------|----|---|------------|----|
| A (AVC) | T (AFC) | BL | R | P | AB |
| $\times 38$ | | | | $\times 1$ | |

Beam quality, longitudinally

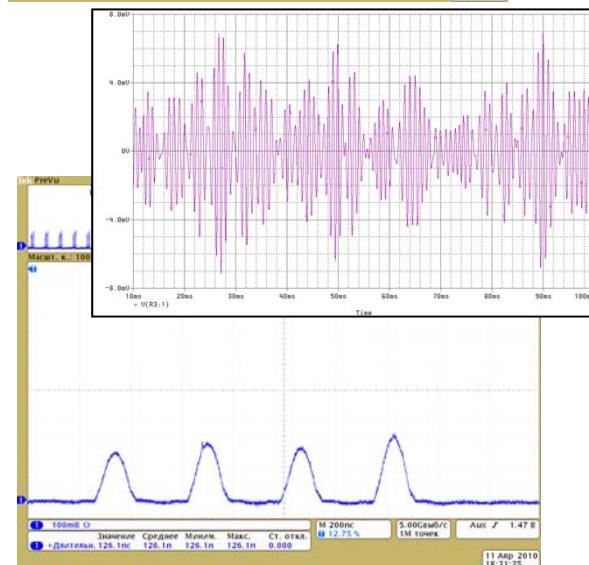
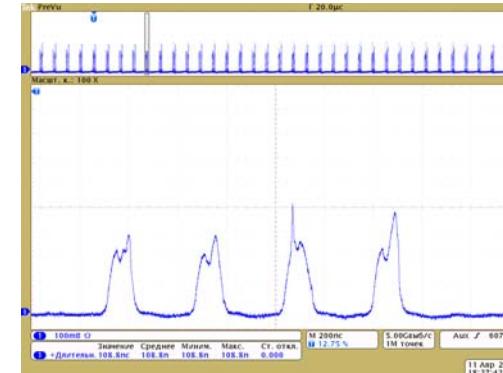
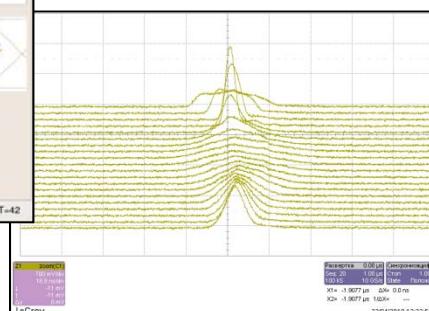
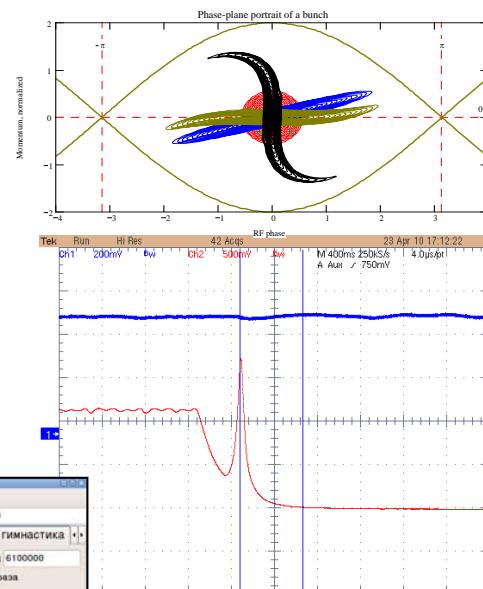
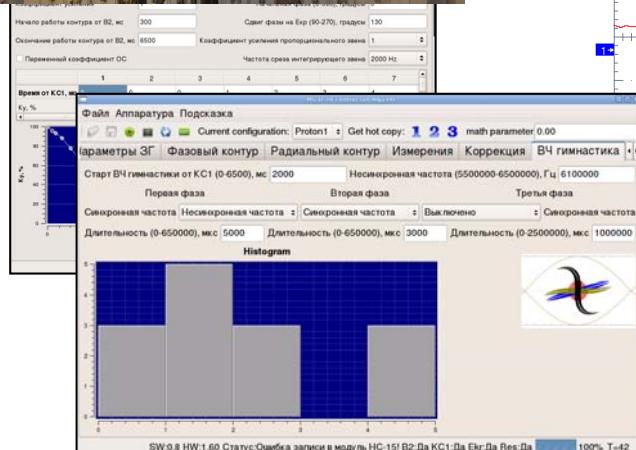


@ 50 GeV

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

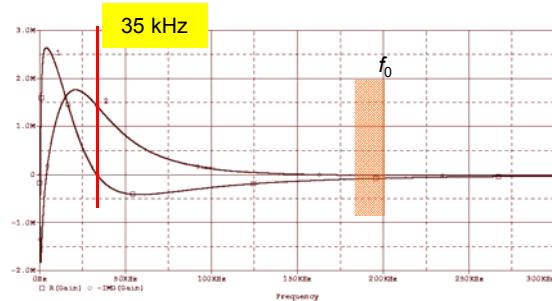
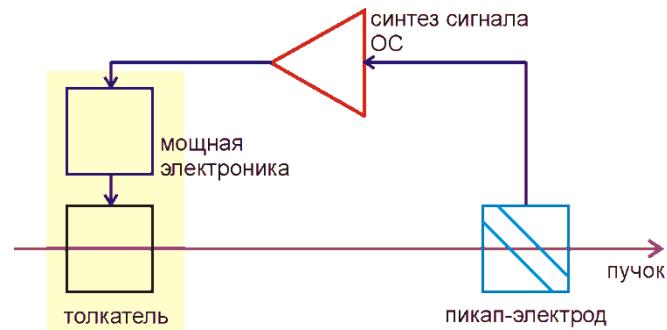
DDS RF Master Oscillator

New digital MO in RF of the U70

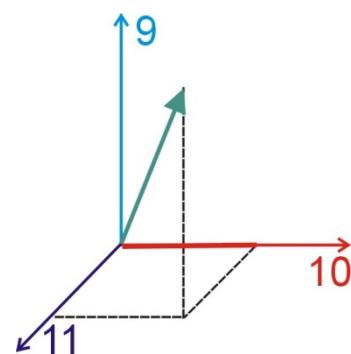


Transverse (NB, local) feedback

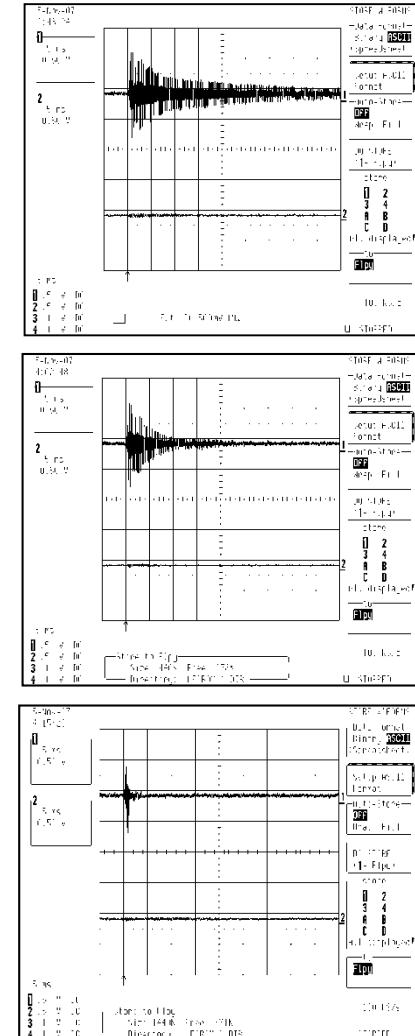
| | | | |
|-----------|-------------|---------------|---------------------|
| ESK @ SS2 | 0 – 0.2 MHz | ± 35.0 kV | PU @ SS2 (+ @SS116) |
|-----------|-------------|---------------|---------------------|



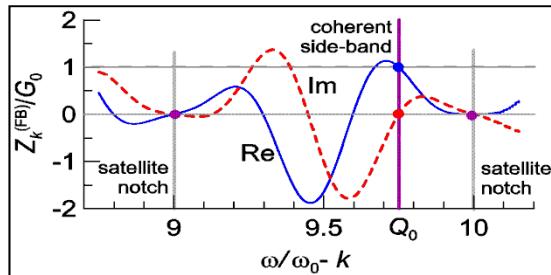
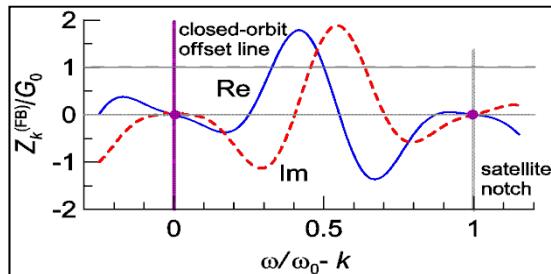
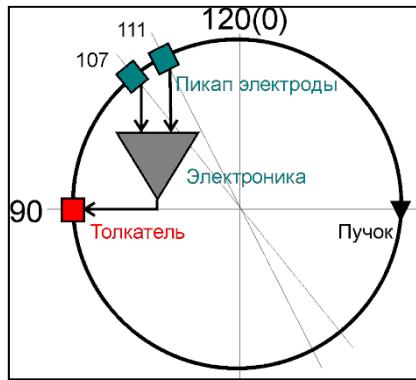
H: 14.7–72.3 kHz, $\pm 45^\circ$
 V: 29.4–43.2 kHz



Damping factor =
 100 w. r. t. natural

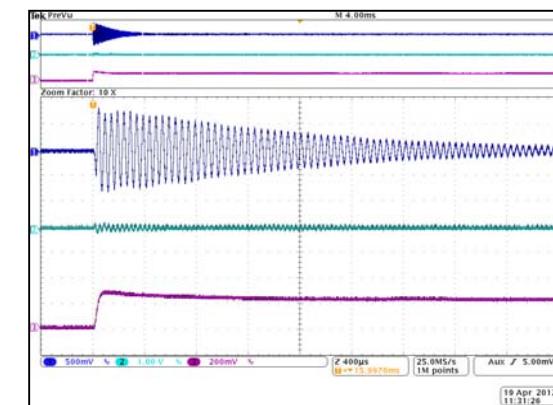
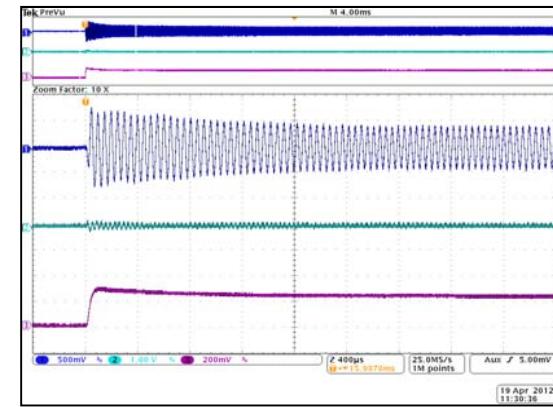
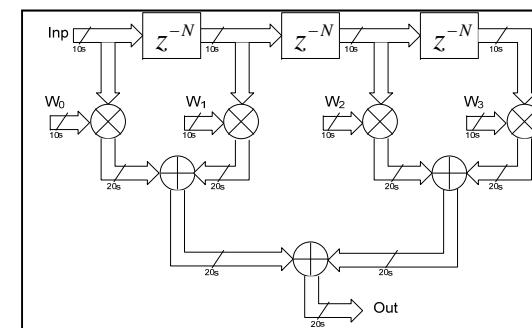
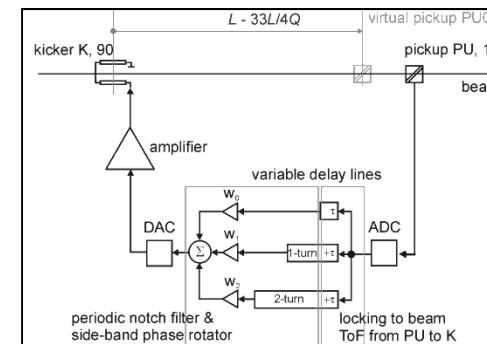
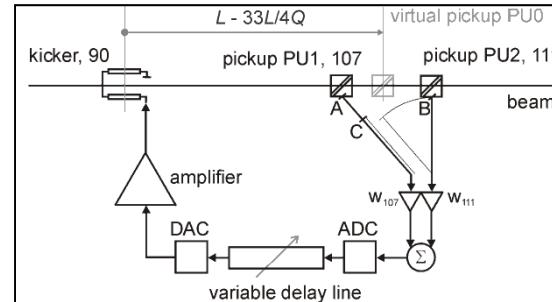


Digital transverse (WB) feedback



FIR-3 & FIR-4 options

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



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

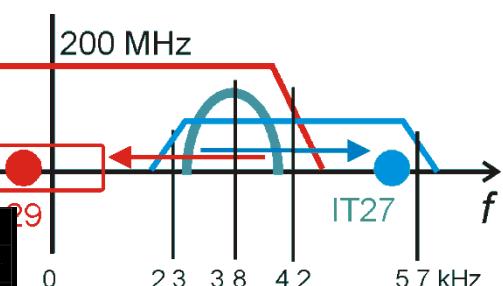
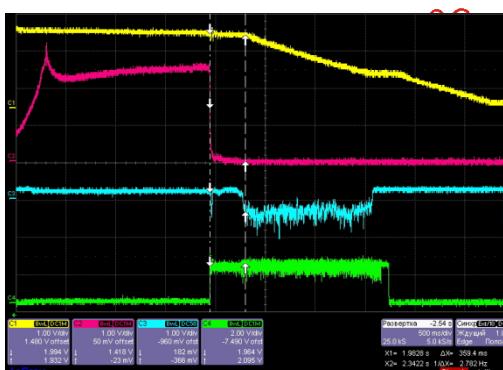
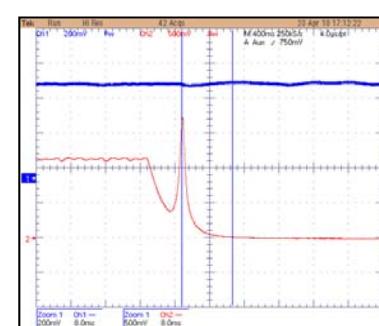
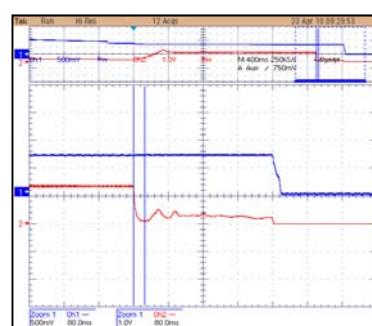
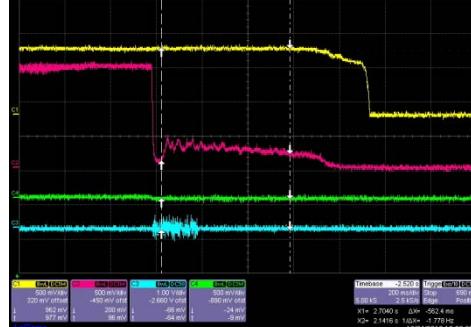
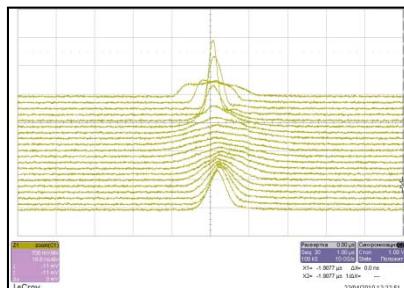
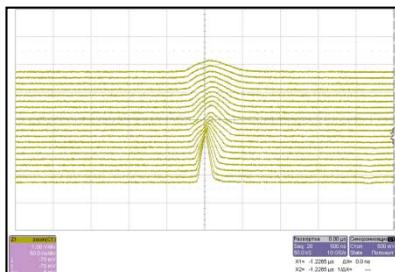
$$\left| \frac{Z(k\omega_0)}{k} \right| < \frac{1}{\Lambda} \frac{\beta^2 |\eta| E}{eJ_0} \left(\frac{\Delta p}{p} \right)^2$$

Cures:

- Momentum spread,
- Distribution function [& momentum spread]

RF gymnastics

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 | β | | 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 | β | | 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 | β | | 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 |

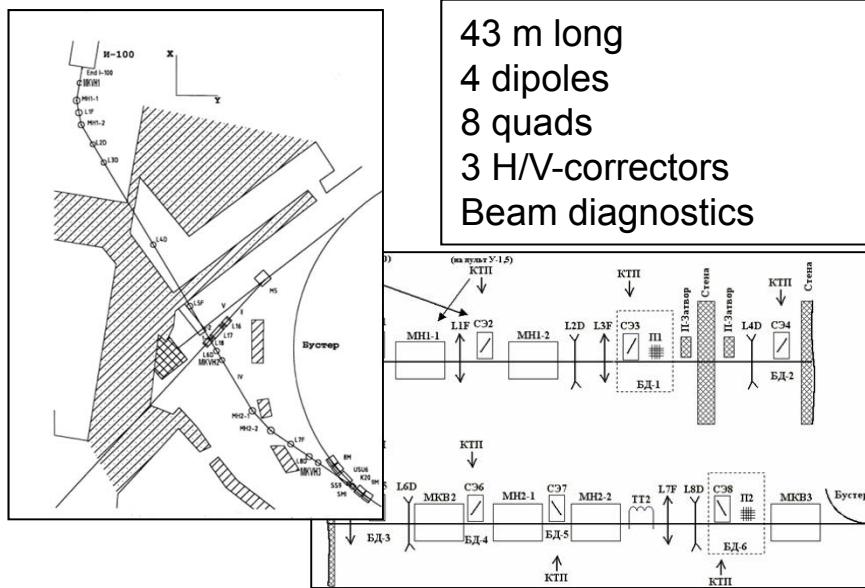
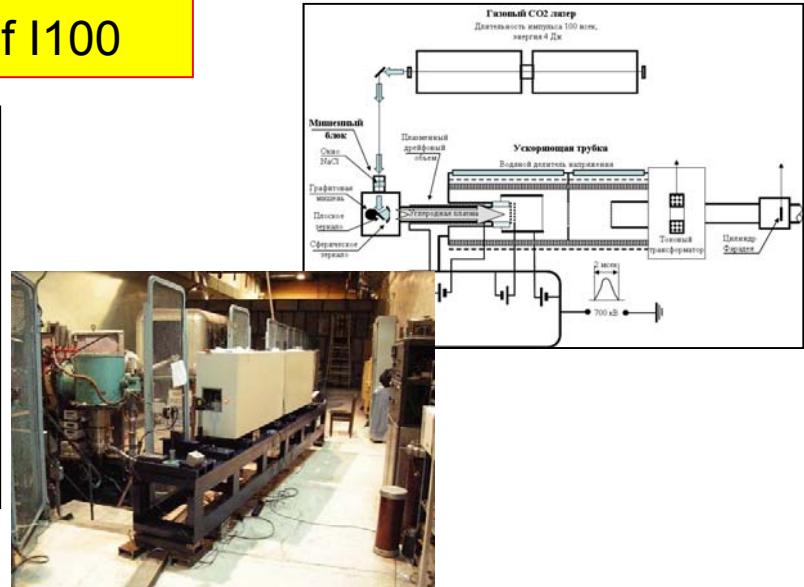
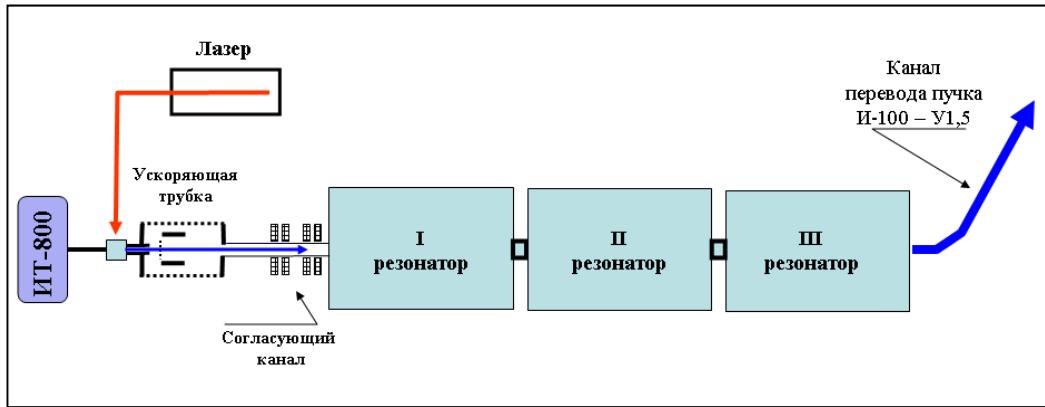
49 0

23 6

24.1–34 1

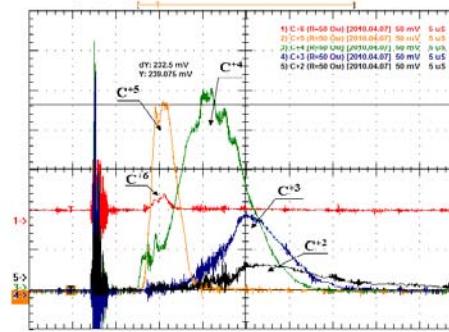
I100 DTL as a C-injector

Stand-alone runs of I100



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

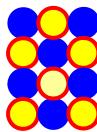
InfraLight SP, PhIC GPhI RAS, Troitsk
2 modules, CO₂, N₂ и He, $\lambda=9.6\text{--}11 \mu\text{m}$
2 Hz, 4.5 J, almost, COTS



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

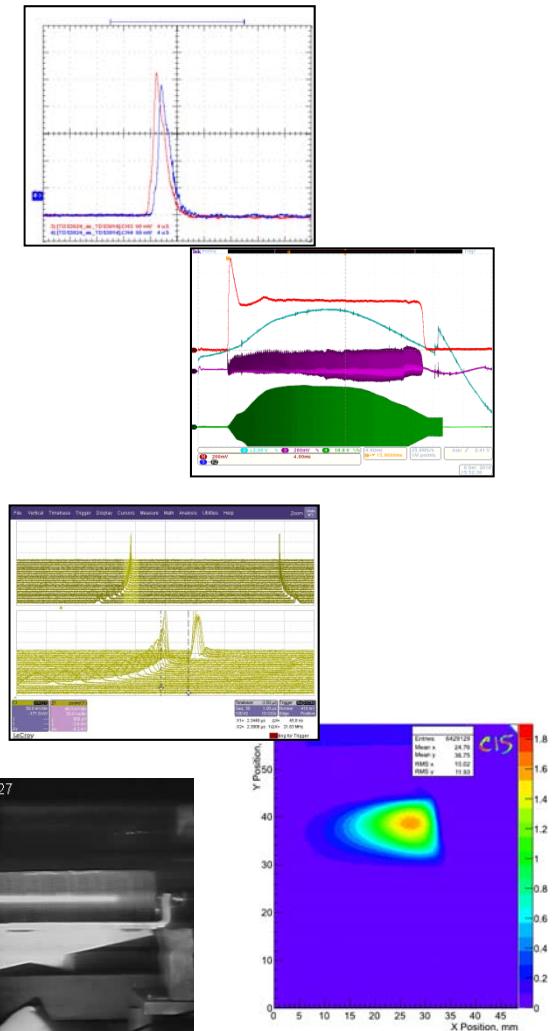
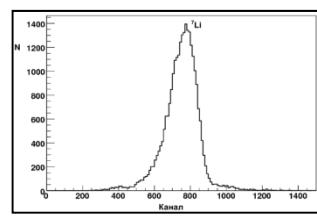
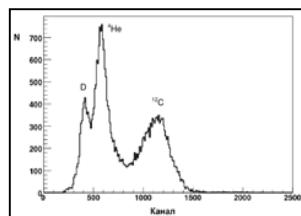
Milestones

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 |
| | | |

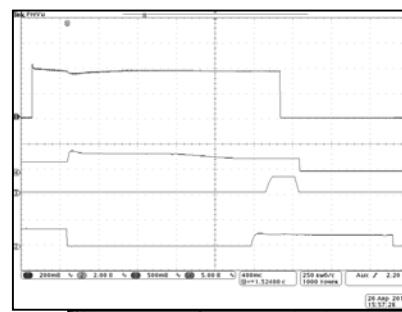


All H-E extractions with C

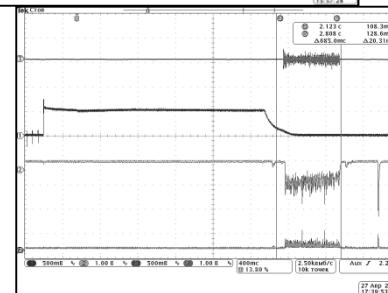
April 24, 2012. C 24.1 GeV/u (flattop 0.859 T) $5 \cdot 10^9$ ipp (8 s).

1st ever tests all HE extractions with the C beam

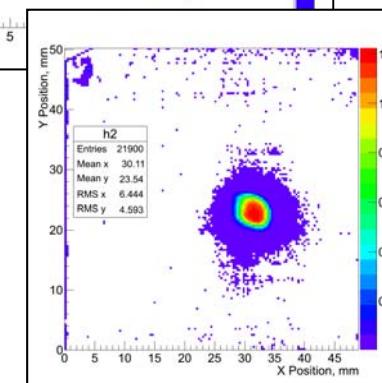
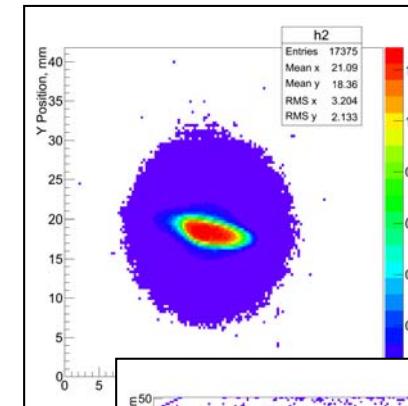
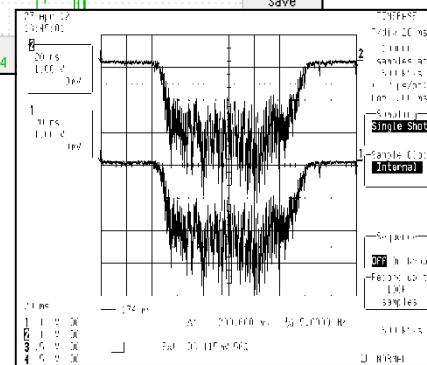
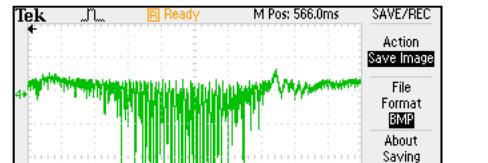
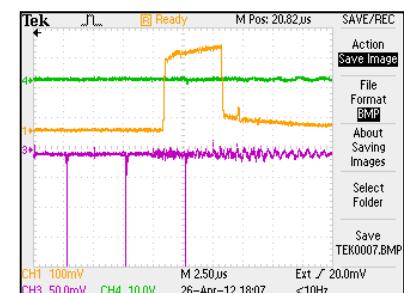
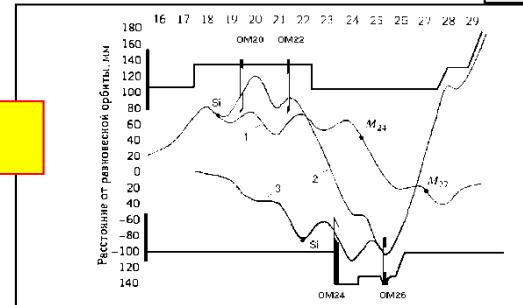
FE



SE

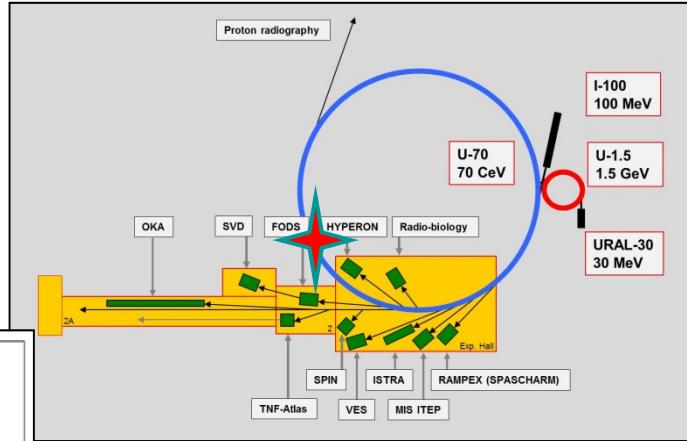


CD#22

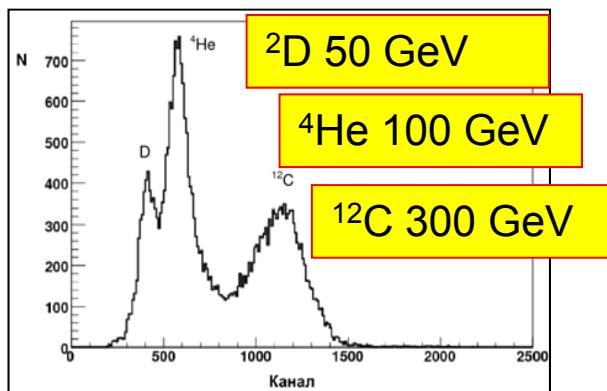


1st experimental NPh events

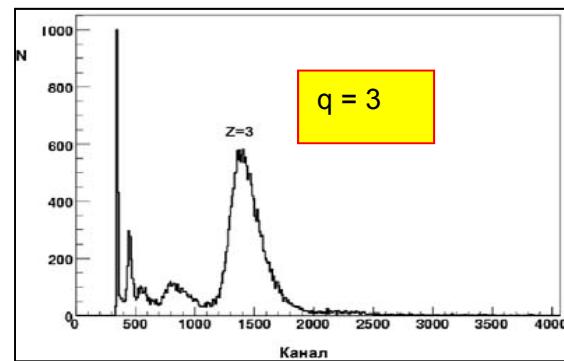
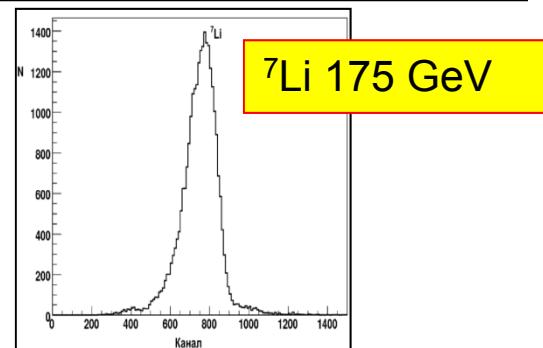
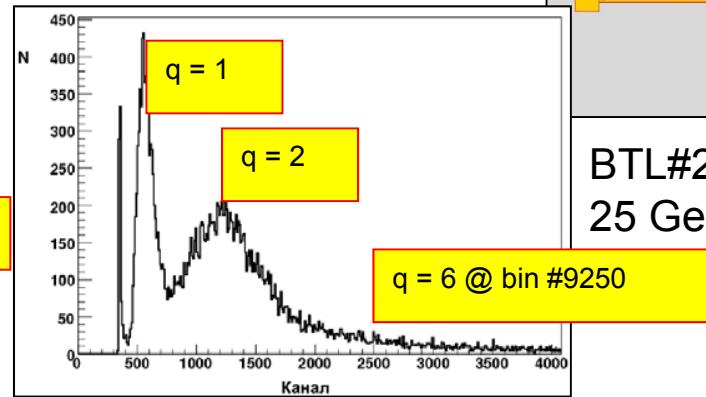
April 27, 2012. 1st ever extracted C beam in 190 m
 BTL#22 = **FRS** & FODS (a FOcussing 2-arm
 Spectrometer) experimental facility
 24.1 GeV/u or 300 GeV full E



Hadron calorimeter



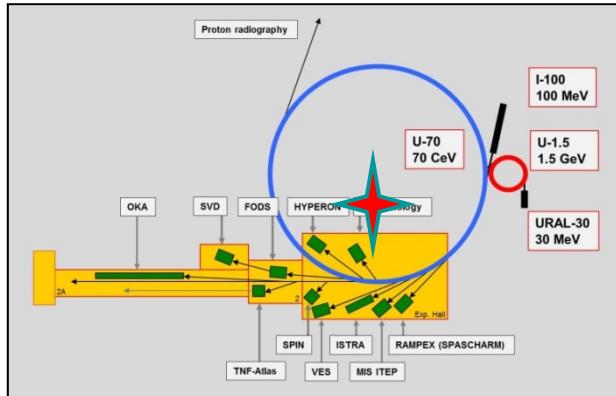
Scintillator counters



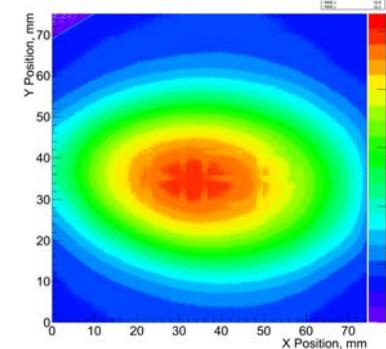
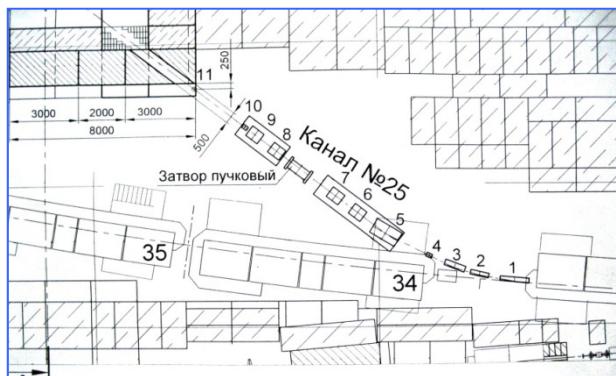
BTL#22 50 GeV/c (p),
 25 GeV/c/u q/A=1/2

BTL#22 60 GeV/c (p) \pm 1%
 a FRS
 25.7 Gev/c/u q/A=3/7

Applied R&D, towards radio-biology

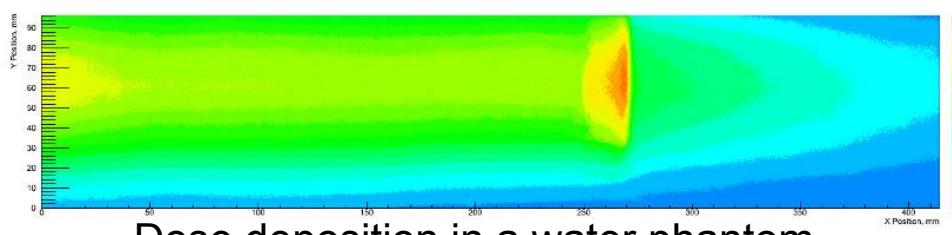


Front-end section of BTL #25 (18 m, 3D, 4Q, 2DCV)



Data: run 2013/1

C-beam footprint @ exit 7 x 5 cm²



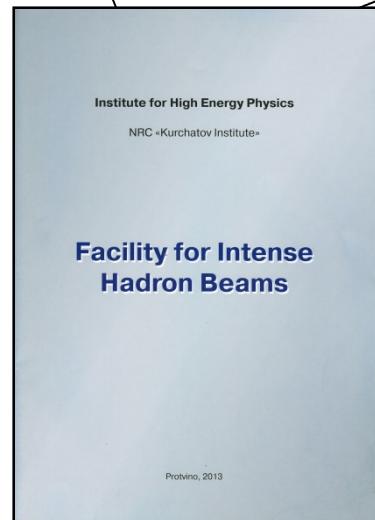
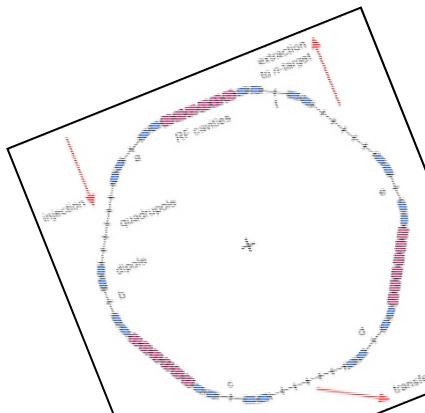
Dose deposition in a water phantom



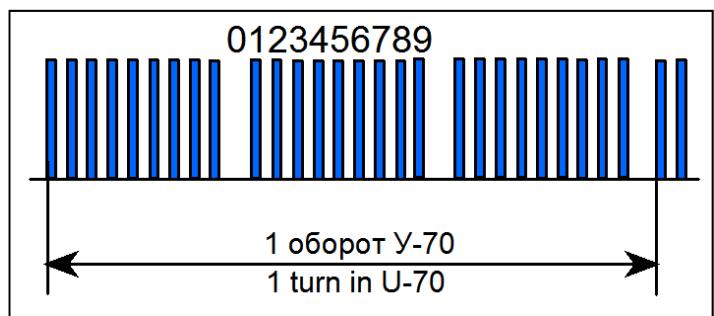
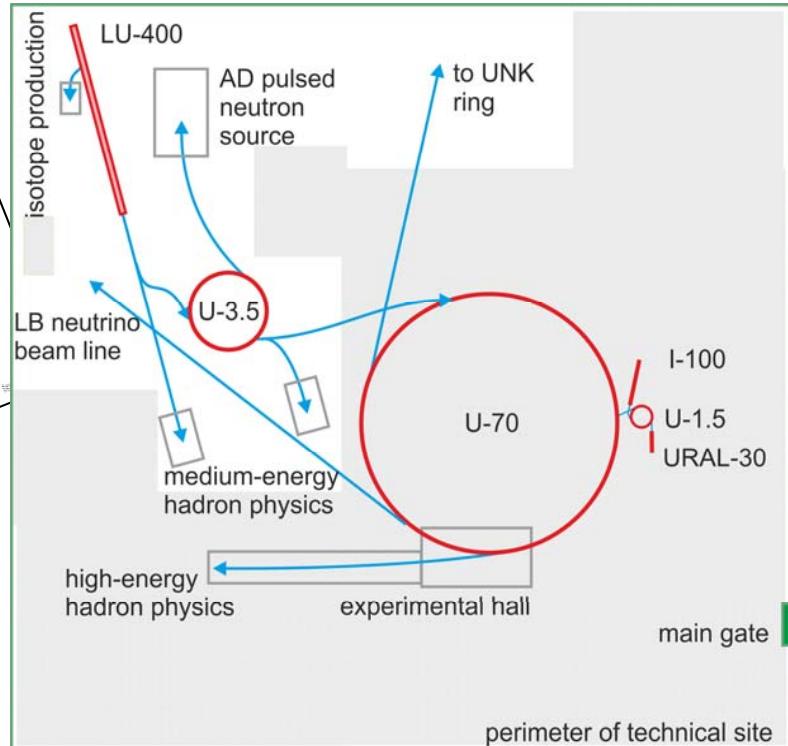
The OMEGA Project



[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)



the extended Lol,
37p, June 2013



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