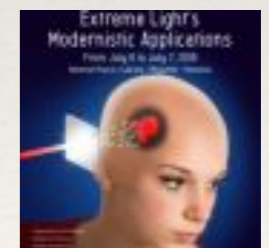




A. Soloviev, M. Starodubtsev, K. Burdonov, A. Ereemeev,
V. Ginzburg, A. Kuzmin, I. Shaykin, I. Yakovlev, A. Shaykin, A. Sladkov,
A. Sergeev (IAP RAS, Nizhny Novgorod, Russia)
N. Evteeva, A. Maslennikova (NNSMA, Nizhny Novgorod, Russia)
J. Fuchs, S. Chen, G. Revet (Ecole polytechnique, Palaiseau, France)

**Medical applications
development using laser-
driven protons generated at
the high-power PEARL facility**

Extreme Light's Modernistic
Applications



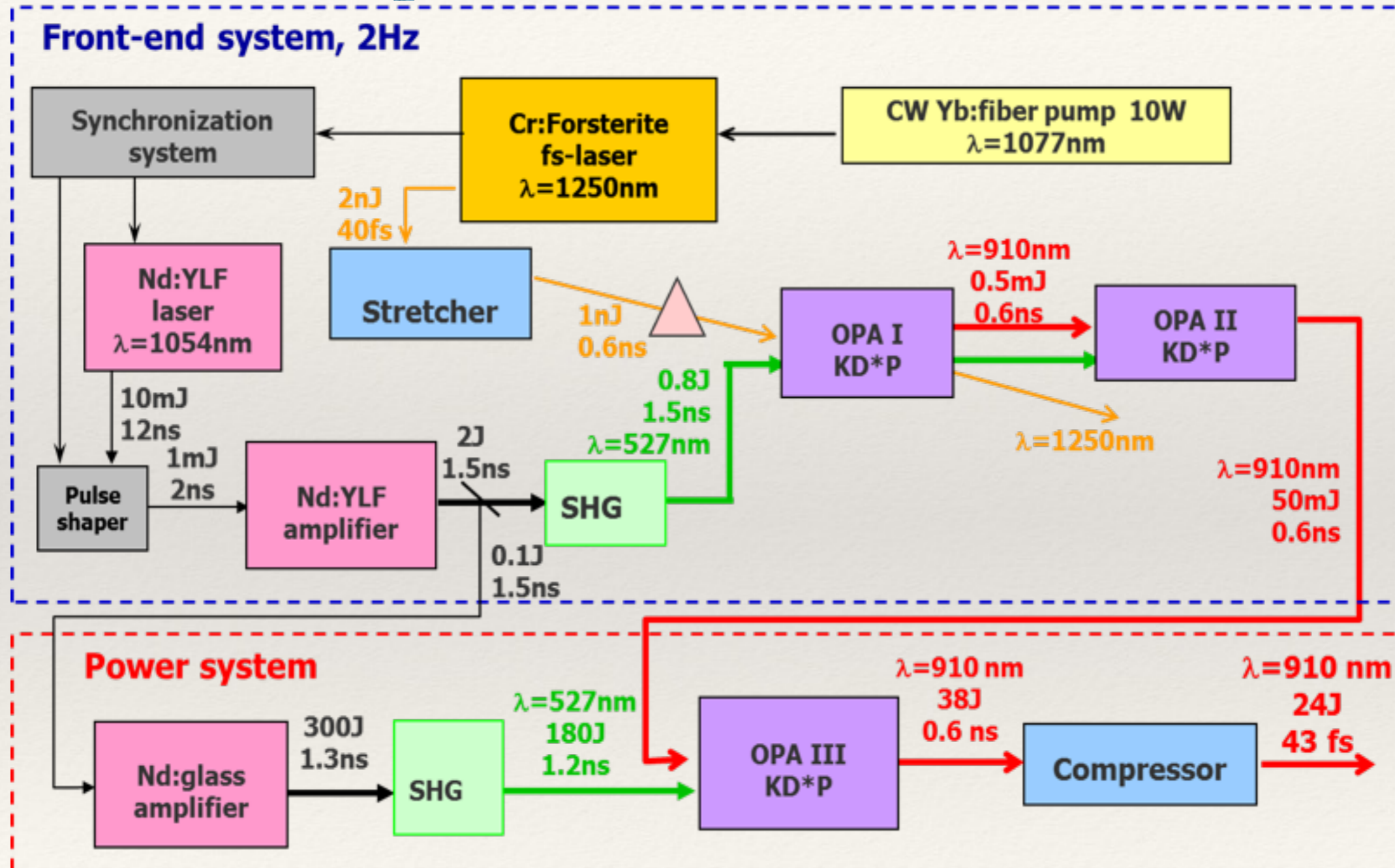
6-7 July 2016
ELI-NP Magurele - Romania

Outlook of the talk

- ❖ PEARL - possible applications
- ❖ The experiments have been conducted
 - ❖ LWFA
 - ❖ Proton acceleration
 - ❖ LabAstro
- ❖ Proton exposure of the bio-cells
 - ❖ Scheme of the biomedical experiment at PEARL
 - ❖ Experimental results
 - ❖ Ways to improve
- ❖ Summary

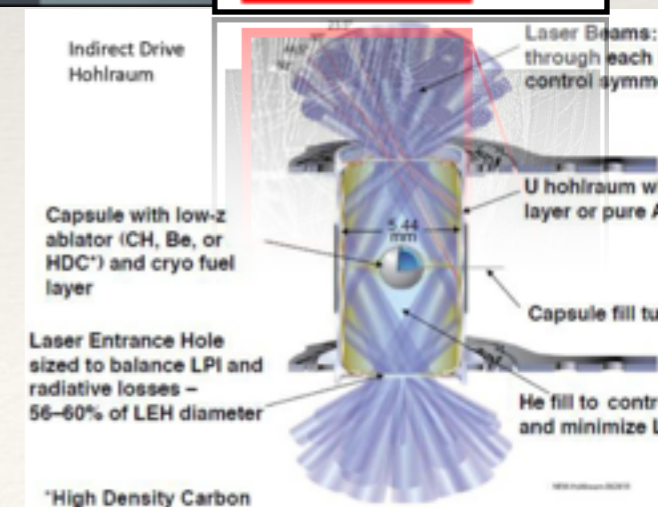
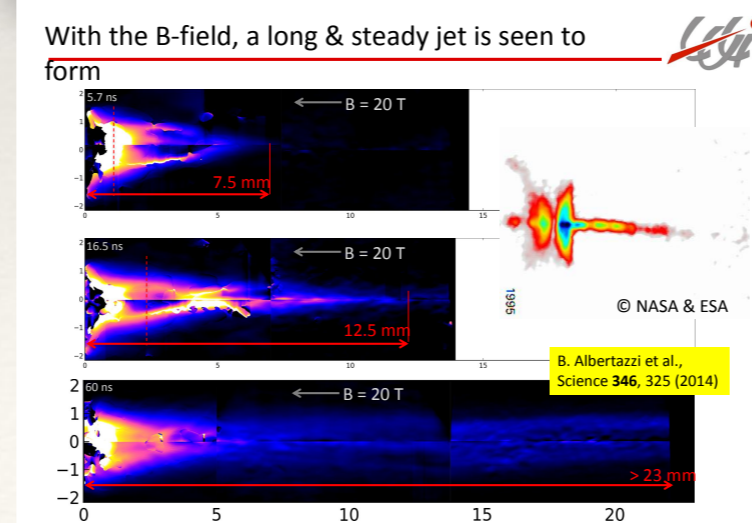
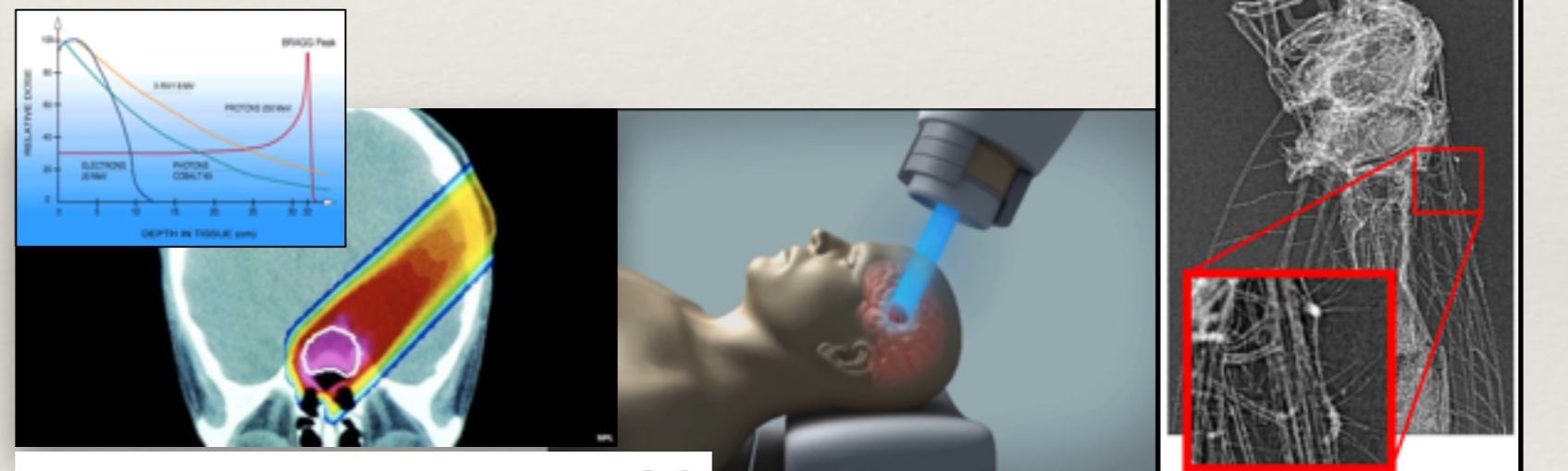
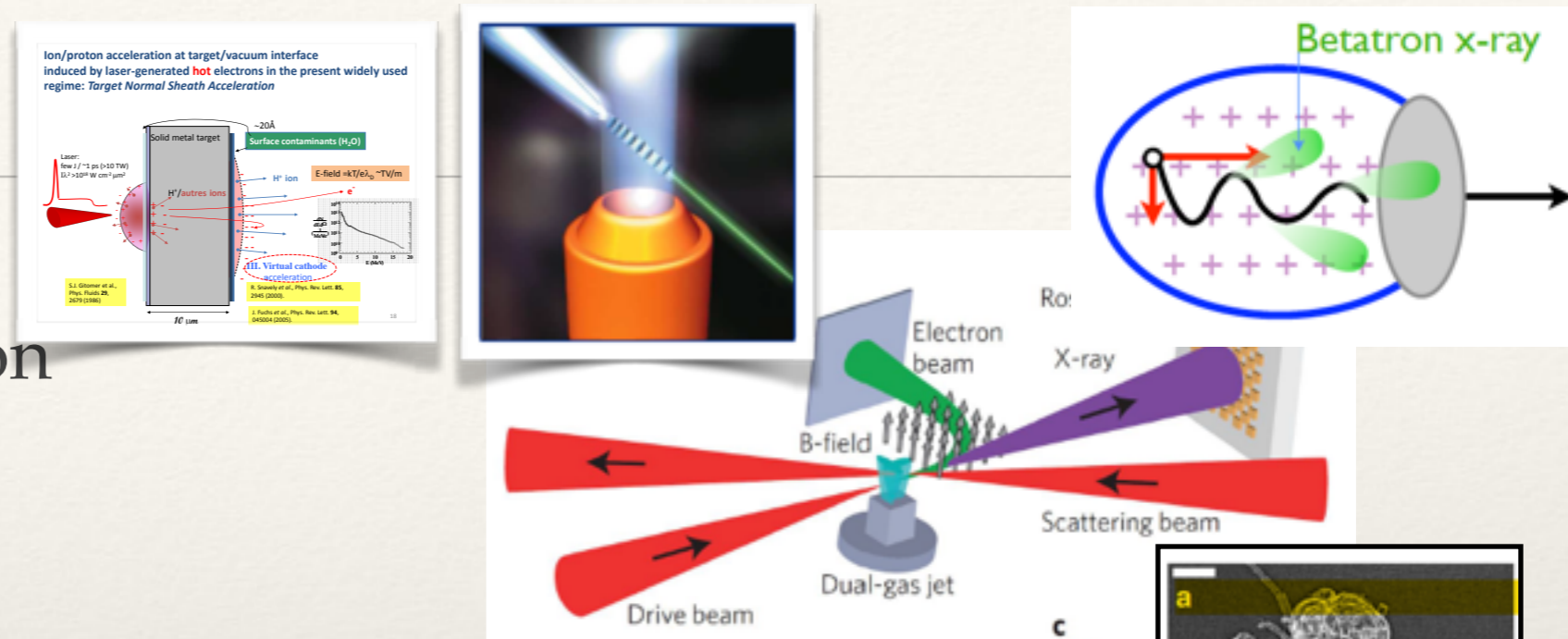
Sub-PW OPCPA-based PEARL laser facility

1



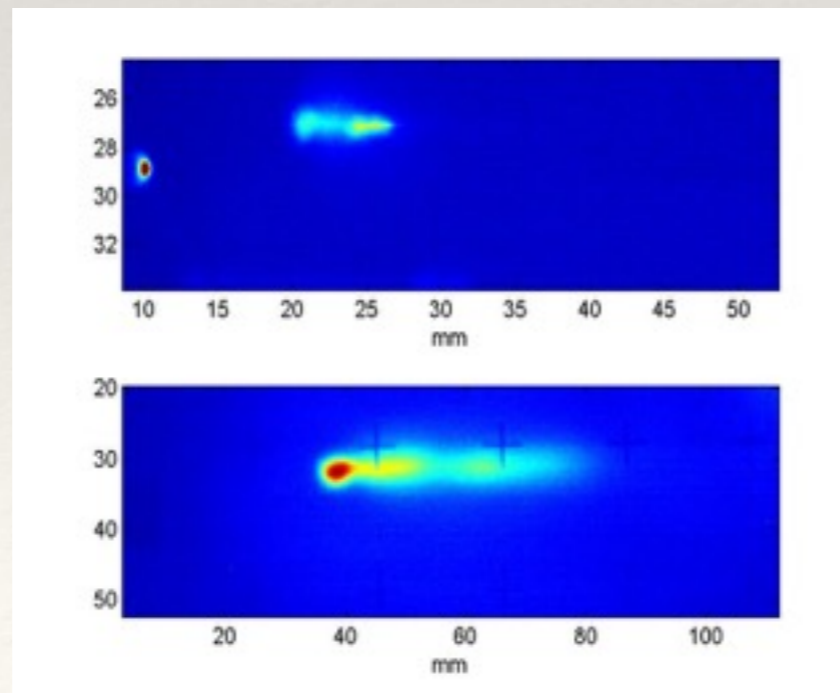
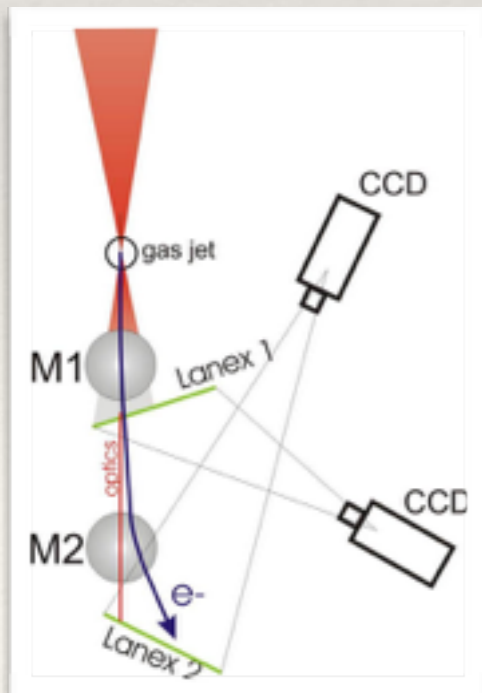
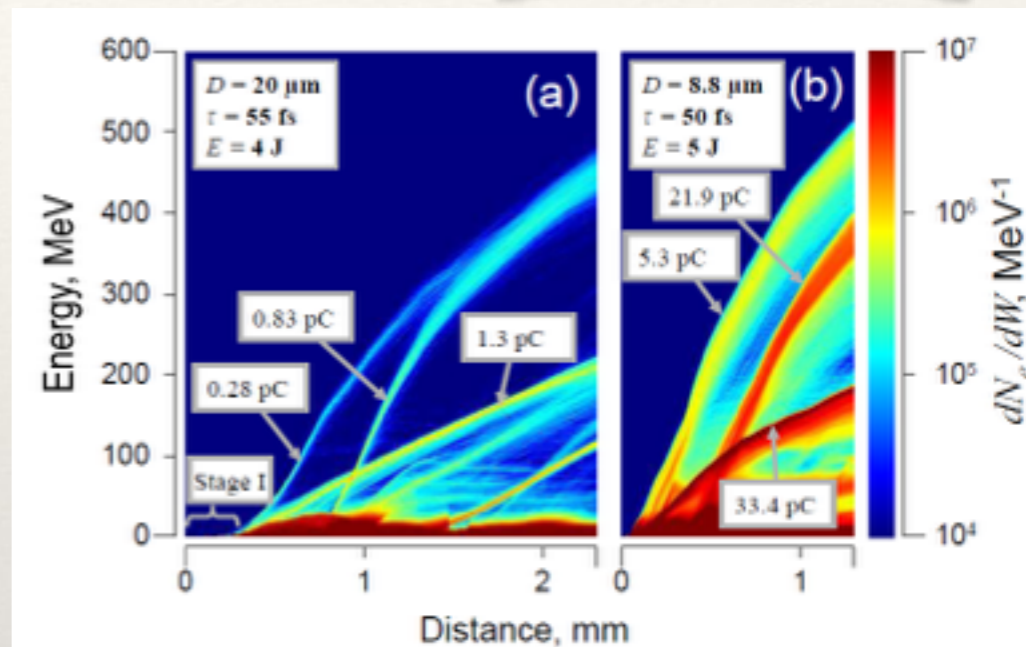
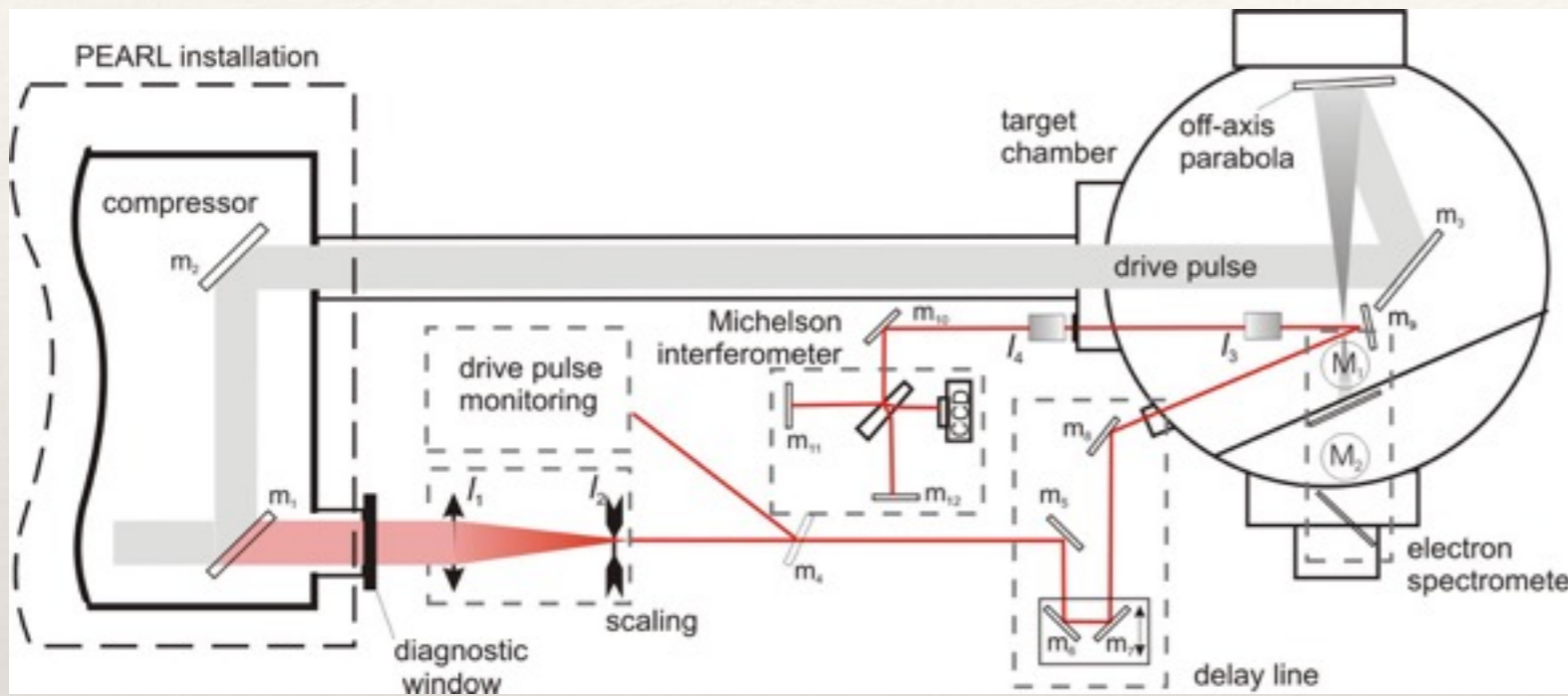
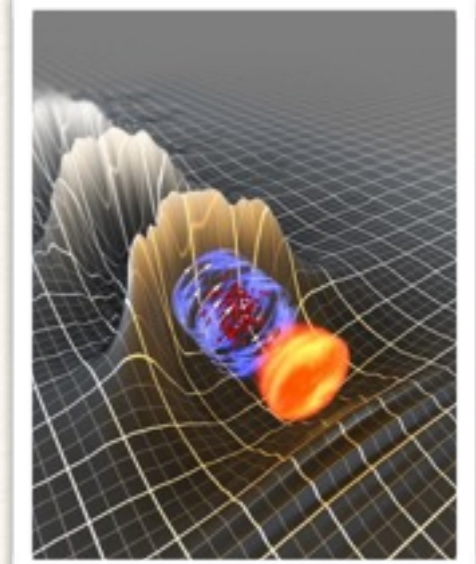
PEARL - possible applications

- ❖ Laser driven acceleration
 - ❖ Particles acceleration
 - ❖ X-ray generation.
- ❖ Applications
 - ❖ Radiotherapy
 - ❖ Bio-imaging
- ❖ HED physics
 - ❖ LabAstro
 - ❖ ICF

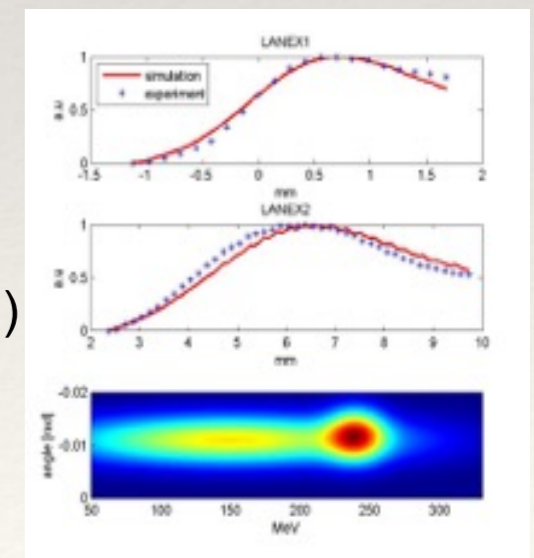


Accomplished experiments

Laser wakefield acceleration



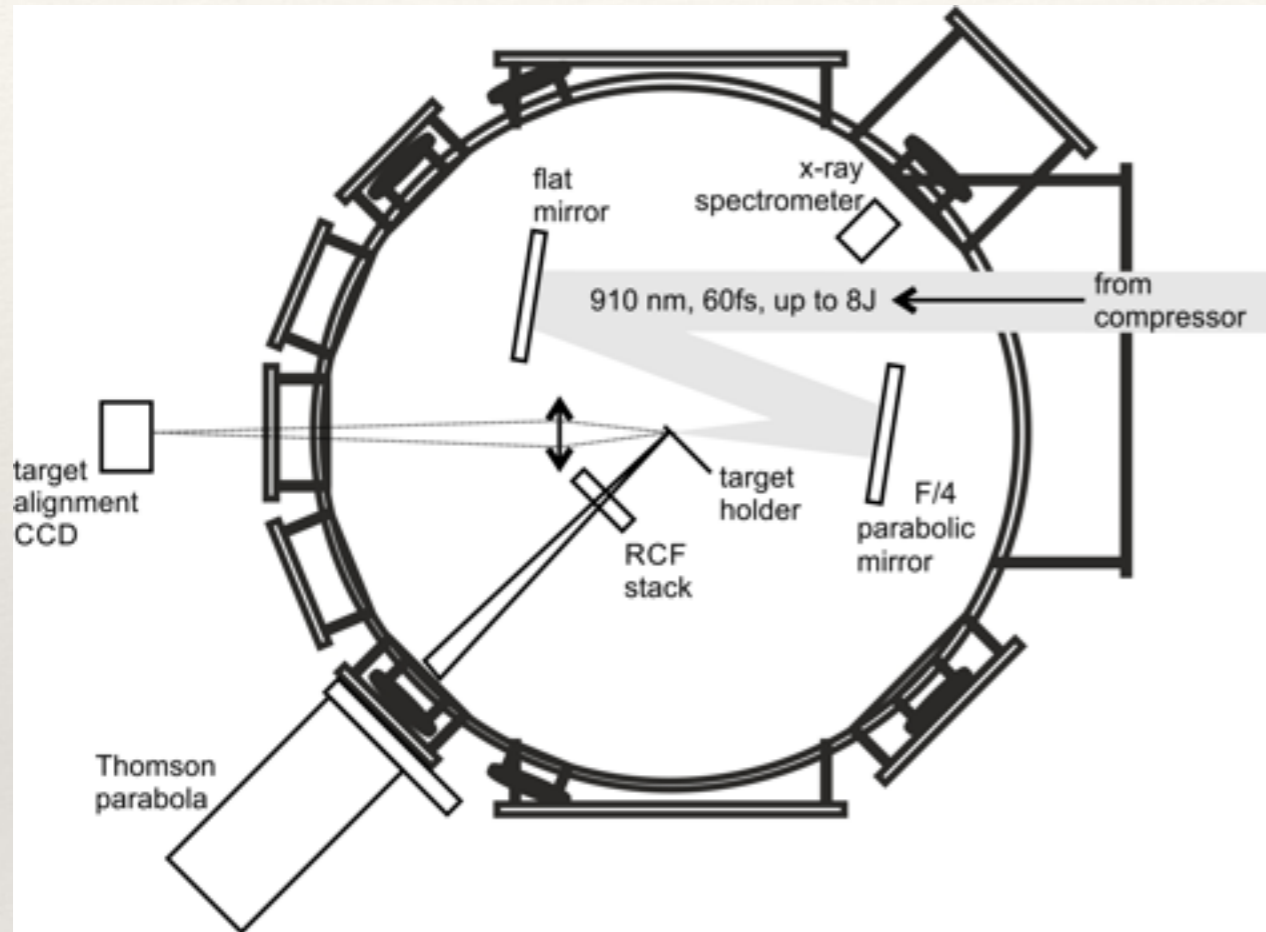
Launch angle = -0.011
 Angular size = $4,6 \text{ mrad}$
 $W = 260 \text{ MeV} (\pm 20 \text{ MeV})$
 $dW = 18 \text{ MeV} (\pm 10 \text{ MeV})$
 18 pC



Soloviev et al. *Rev. Sci. Instrum.* **82**, 043304 (2011)

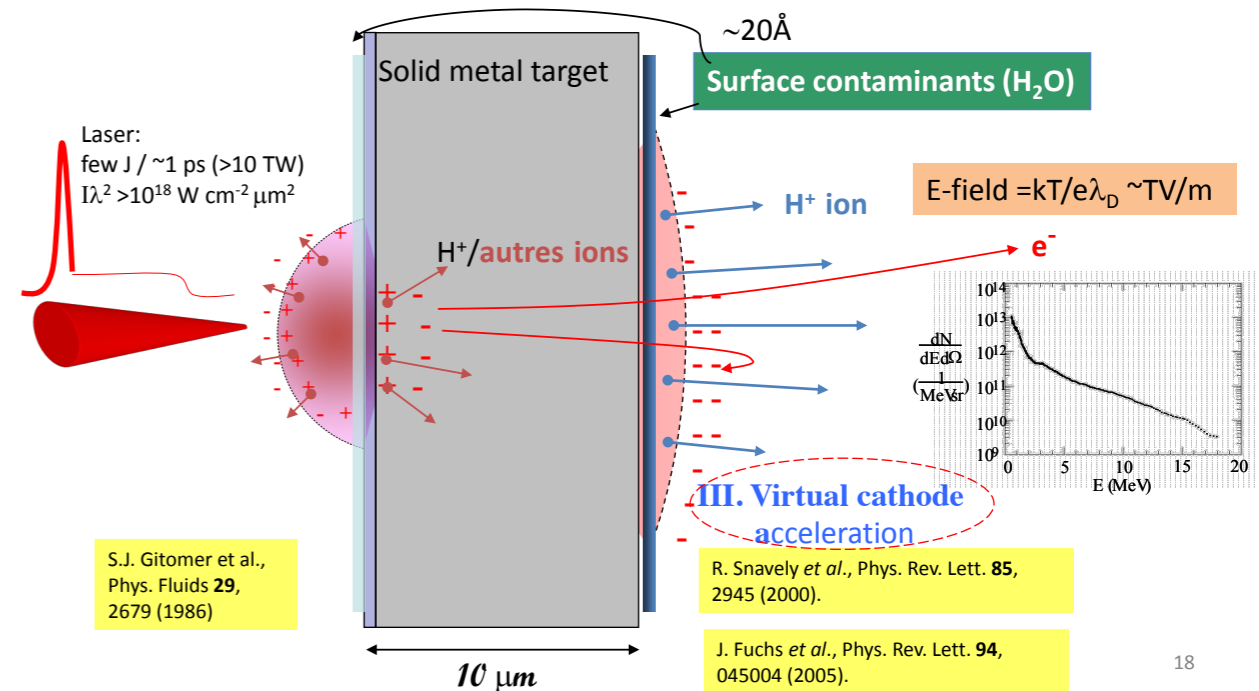
Soloviev et al. *NIMA*, Volume 653, Issue 1, 11 (2011)

Ion acceleration

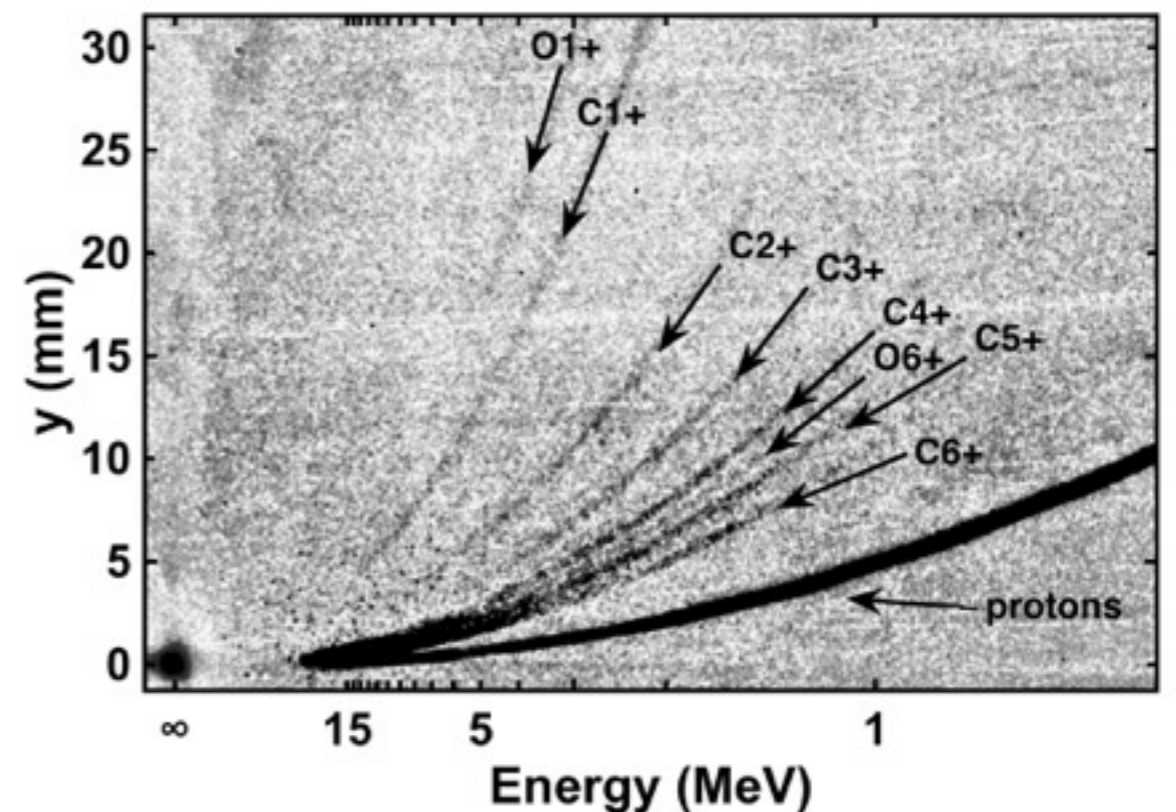


$\lambda_0 \approx 910 \text{ nm},$
 $\tau \approx 60 \text{ fs},$
 $E \approx 10 \text{ J},$
 $P \approx 160 \text{ TW}$
 $D \approx 100 \text{ mm},$
 $F/4.2,$
 $I \approx 3 \times 10^{20} \text{ W/cm}^2$
 $C \approx 2 \times 10^8 \text{ (1 ns)}$

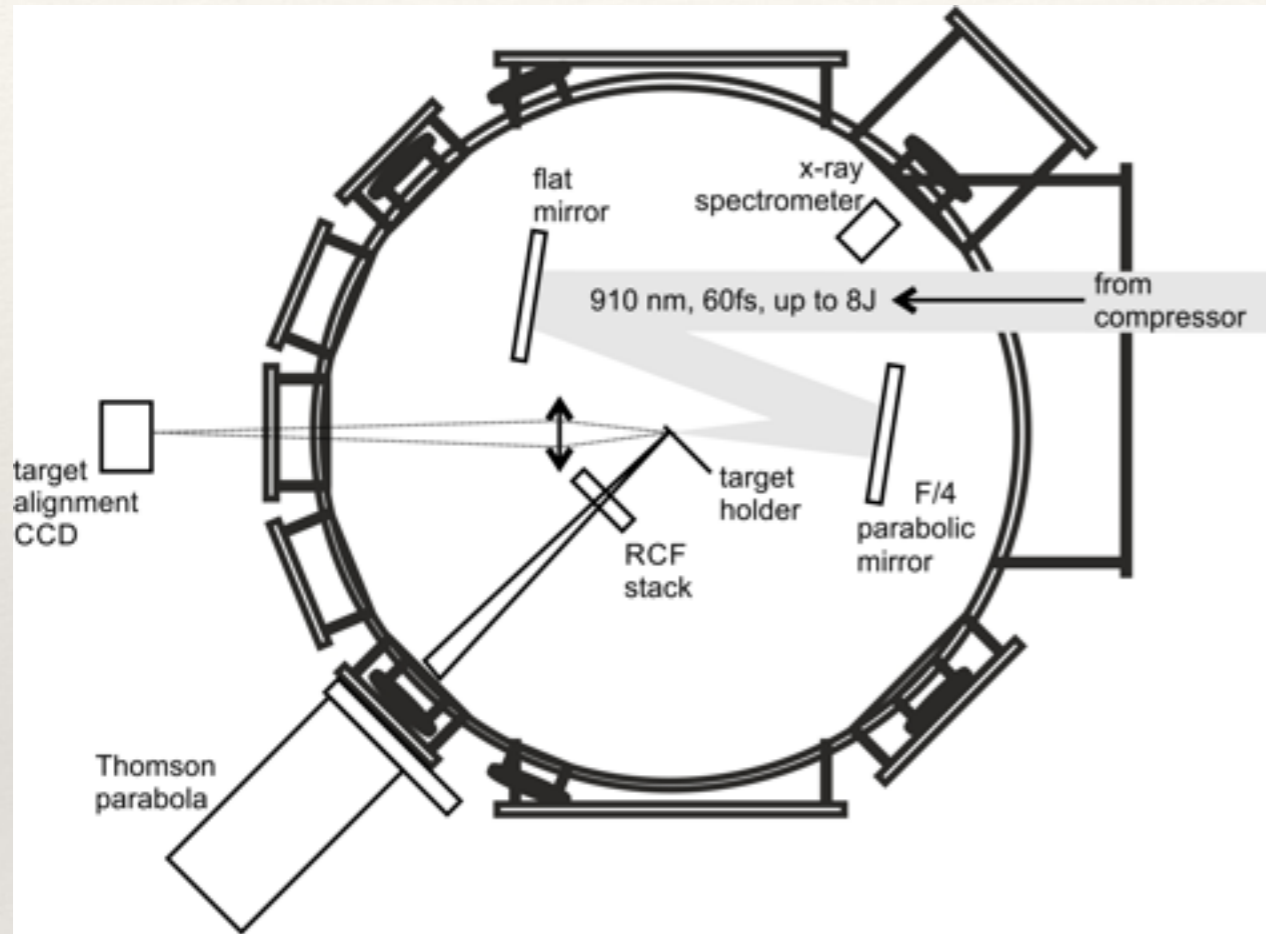
Ion/proton acceleration at target/vacuum interface induced by laser-generated hot electrons in the present widely used regime: *Target Normal Sheath Acceleration*



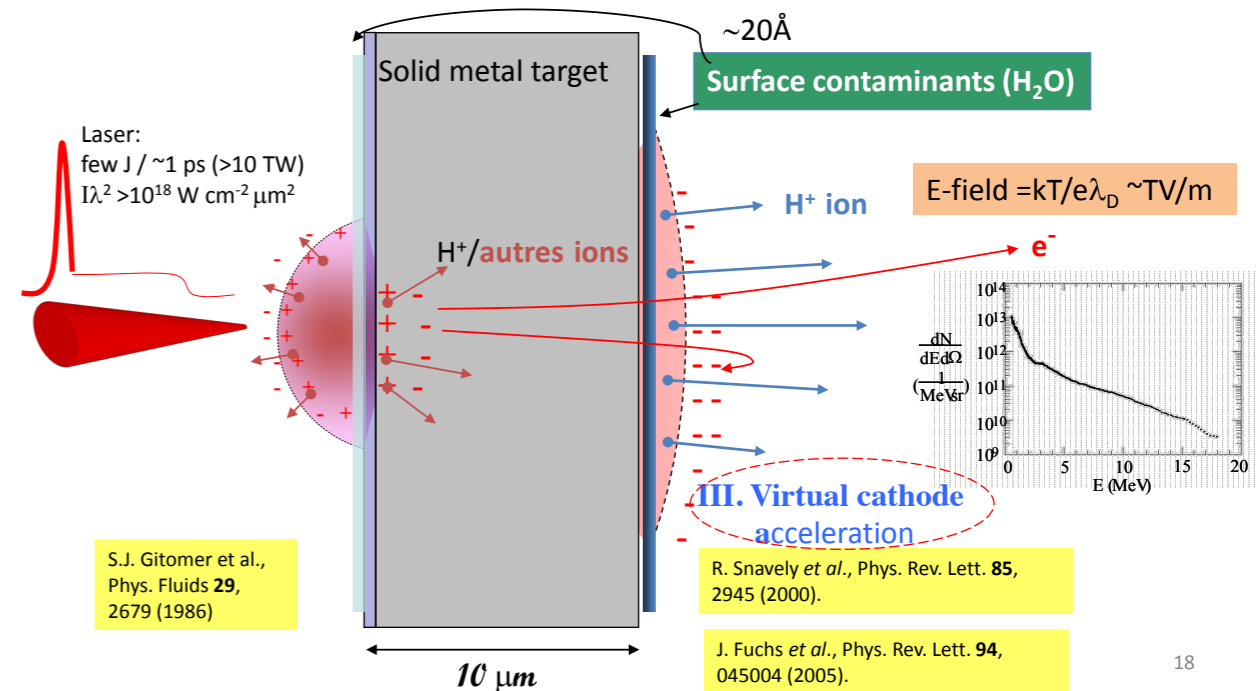
Experimental data:



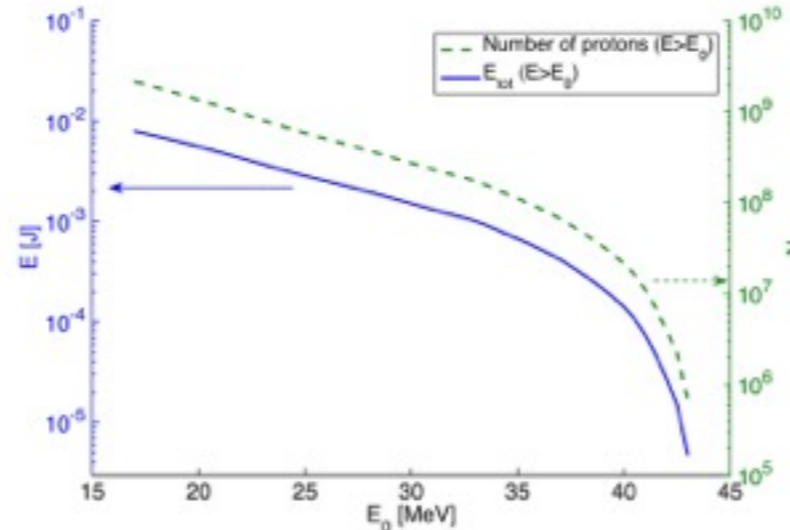
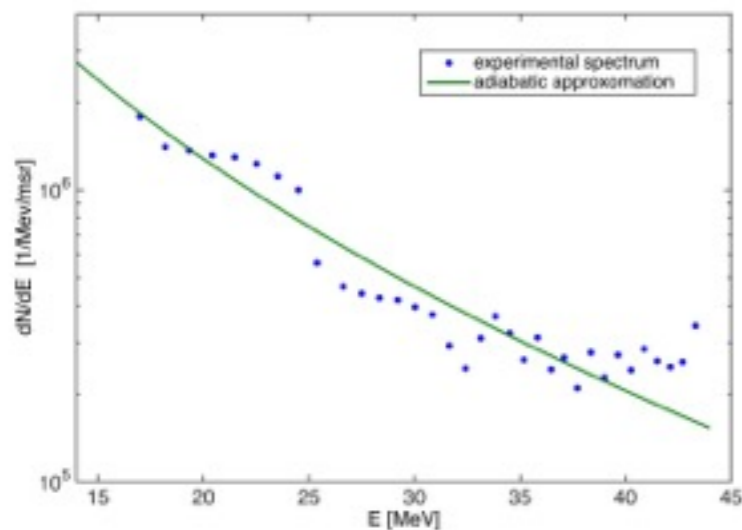
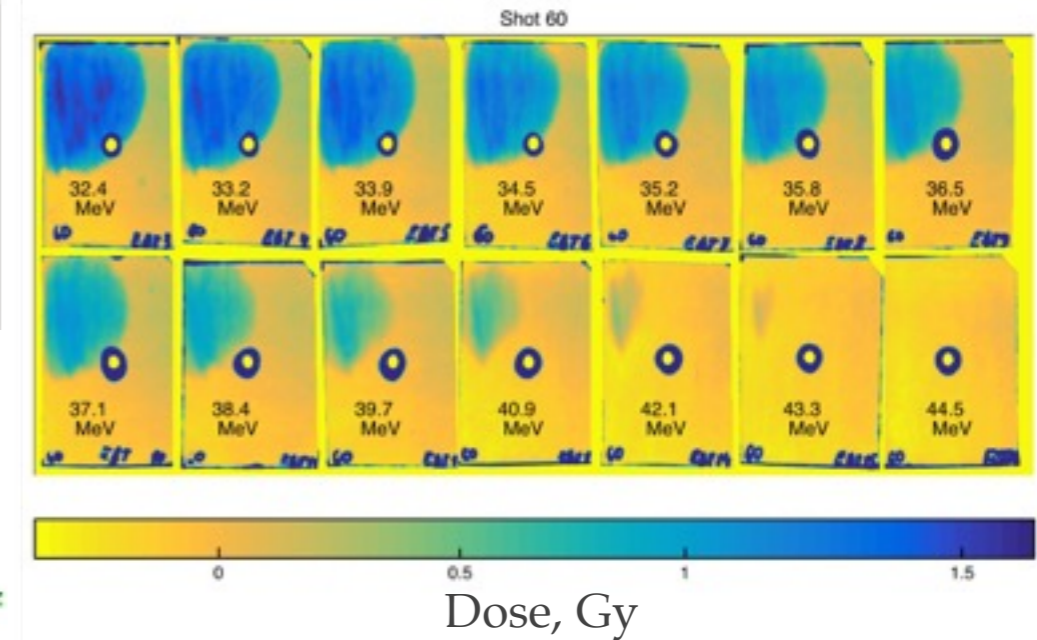
Ion acceleration

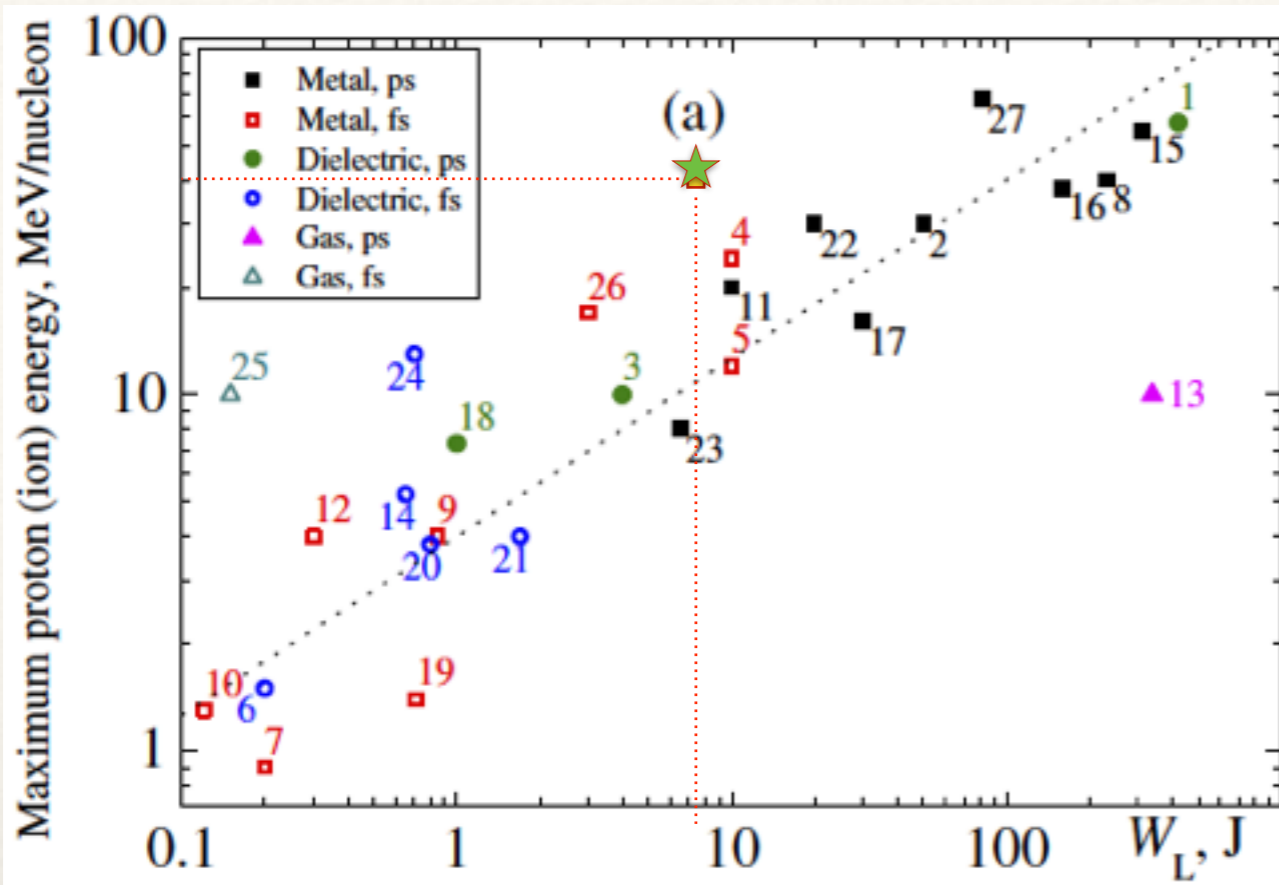


Ion/proton acceleration at target/vacuum interface induced by laser-generated **hot** electrons in the present widely used regime: *Target Normal Sheath Acceleration*



Experimental data:





■ Koichi Ogura et al. OPTICS LETTERS / Vol. 37, No. 14 / July 15, 2012

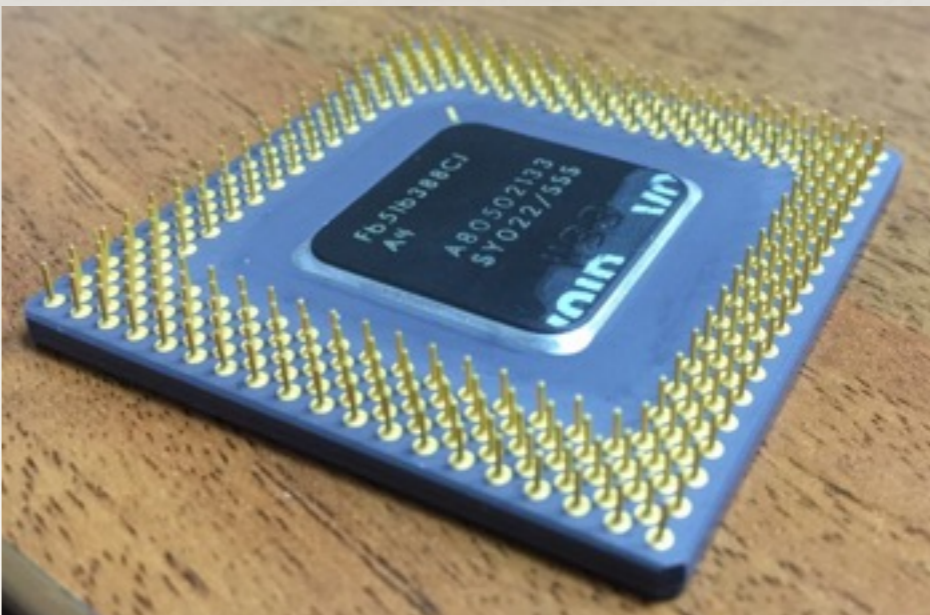
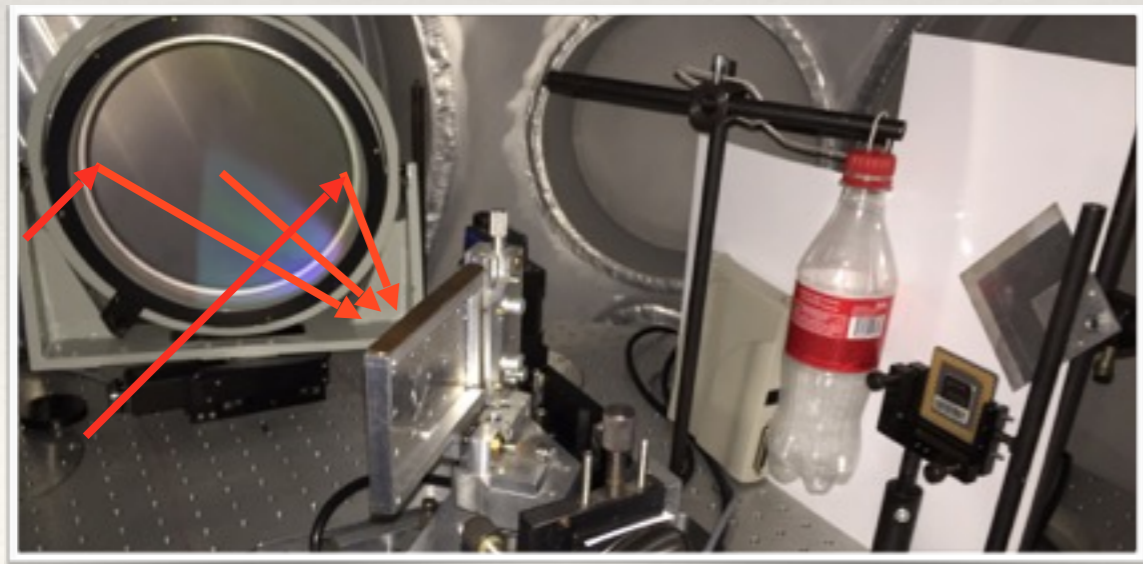
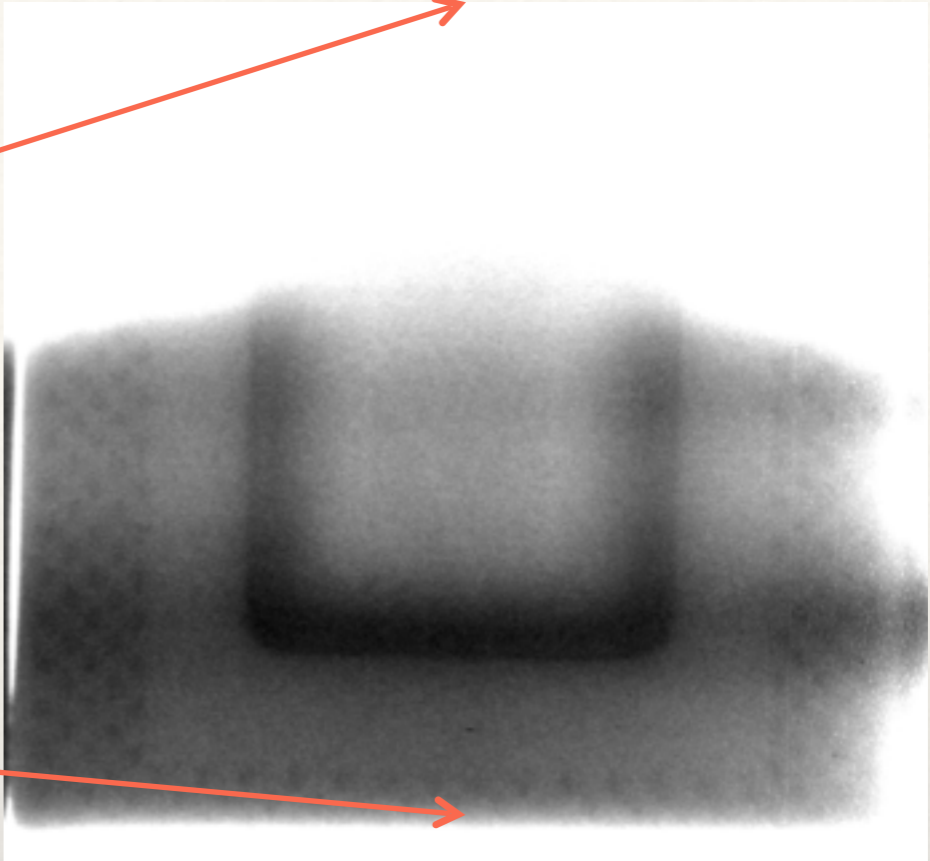
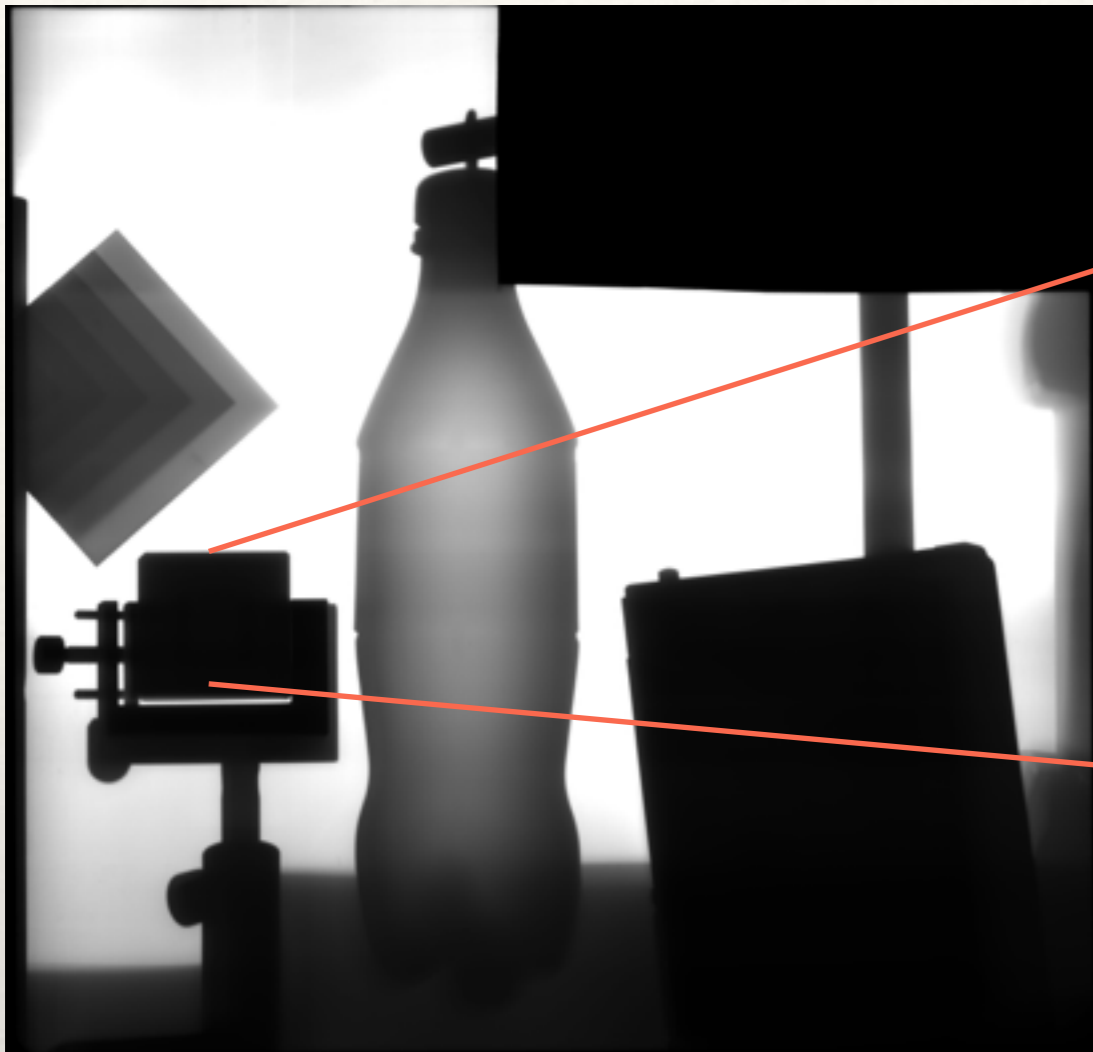
E=7.5J,
 Contrast = 1/10¹⁰,
 I=10²¹ Wcm⁻²)

★ IAP RAS (Summer 2015)

E=7.5J
 Contrast = 1/10⁸ ?
 I=3*10²⁰ Wcm⁻²)

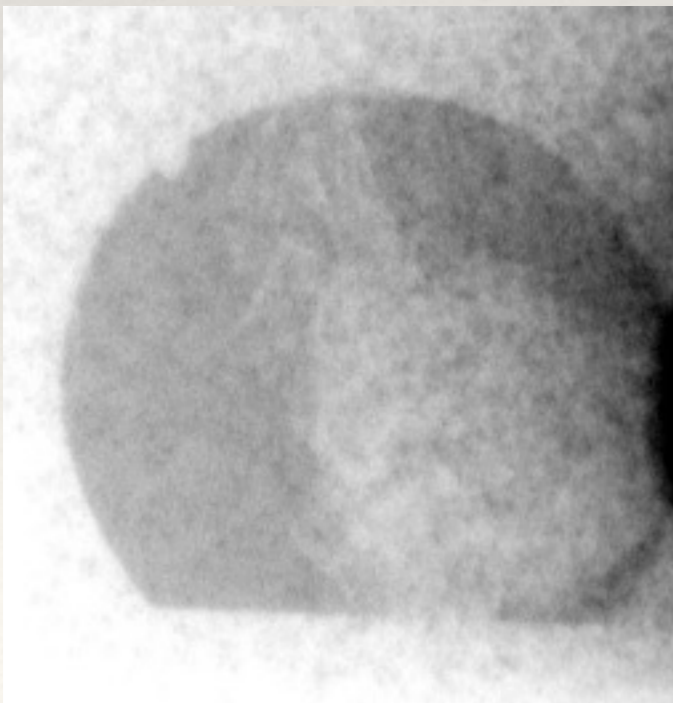
No.	Reference	Pulse energy W _L (J)	Pulse duration τ (fs)	Irradiance I ₀ (W cm ⁻²) ^a	Contrast	Target and thickness (μm)	Incidence angle (°)	Proton/ion energy ε _{p(i)} , (MeV/nucleon)
1	Snavely et al (2000)	423	500	3 × 10 ²⁰	1 × 10 ⁴	CH 100	0	58
2	Krushelnick et al (2000b)	50	1000	5 × 10 ¹⁹		Al 125	45	30
3	Nemoto et al (2001)	4	400	6 × 10 ¹⁸	5 × 10 ⁵	Mylar 6	45	10
4	Mackinnon et al (2002)	10	100	1 × 10 ²⁰	1 × 10 ¹⁰	Al 3	22	24
5	Patel et al (2003)	10	100	5 × 10 ¹⁸		Al 20	0	12
6	Spencer et al (2003)	0.2	60	7 × 10 ¹⁸	1 × 10 ⁶	Mylar 23	0	1.5
7	Spencer et al (2003)	0.2	60	7 × 10 ¹⁸	1 × 10 ⁶	Al 12	0	0.9
8	McKenna et al (2004)	233	700	2 × 10 ²⁰	1 × 10 ⁷	Fe 100	45	40
9	Kaluza et al (2004)	0.85	150	1.3 × 10 ¹⁹	2 × 10 ⁷	Al 20	30	4
10	Oishi et al (2005)	0.12	55	6 × 10 ¹⁸	1 × 10 ⁵	Cu 5	45	1.3
11	Fuchs et al (2006)	10	320	6 × 10 ¹⁹	1 × 10 ⁷	Al 20	0 and 40	20
12	Neely et al (2006)	0.3	33	1 × 10 ¹⁹	1 × 10 ¹⁰	Al 0.1	30	4
13	Willingale et al (2006)	340	1000	6 × 10 ²⁰	1 × 10 ⁵	He jet 2000		10
14	Ceccotti et al (2007)	0.65	65	5 × 10 ¹⁸	1 × 10 ¹⁰	Mylar 0.1	45	5.25
15	Robson et al (2007)	310	1000	6 × 10 ²⁰	1 × 10 ⁷	Al 10	45	55
16	Robson et al (2007)	160	1000	3.2 × 10 ²⁰	1 × 10 ⁷	Al 10	45	38
17	Robson et al (2007)	30	1000	6 × 10 ¹⁹	1 × 10 ⁷	Al 10	45	16
18	Antici et al (2007)	1	320	1 × 10 ¹⁸	1 × 10 ¹¹	Si ₃ N ₄ 0.03	0	7.3
19	Yogo et al (2007)	0.71	55	8 × 10 ¹⁸	1 × 10 ⁶	Cu 5	45	1.4
20	Yogo et al (2008)	0.8	45	1.5 × 10 ¹⁹	2.5 × 10 ⁵	Polyimide 7.5	45	3.8
21	Nishiuchi et al (2008)	1.7	34	3 × 10 ¹⁹	2.5 × 10 ⁷	Polyimide 7.5	45	4
22	Flippo et al (2008)	20	600	1.1 × 10 ¹⁹	1 × 10 ⁶	Flat-top cone Al 10	0	30
23	Safronov et al (2008)	6.5	900	1 × 10 ¹⁹		Al 2	0	8
24	Henig et al (2009b)	0.7	45	5 × 10 ¹⁹	1 × 10 ¹¹	DLC 0.0054	0	13
25	Fukuda et al (2009)	0.15	40	7 × 10 ¹⁷	1 × 10 ⁶	CO ₂ +He cluster jet 2000		10
26	Zeil et al (2010)	3	30	1 × 10 ²¹	2 × 10 ⁸	Ti 2 μm	45	17
27	Gaillard et al (2011)	82	670	1.5 × 10 ²⁰	1 × 10 ⁹	Flat-top cone Cu 12.5	0	67.5

X-RAY IMAGING



X-ray imaging

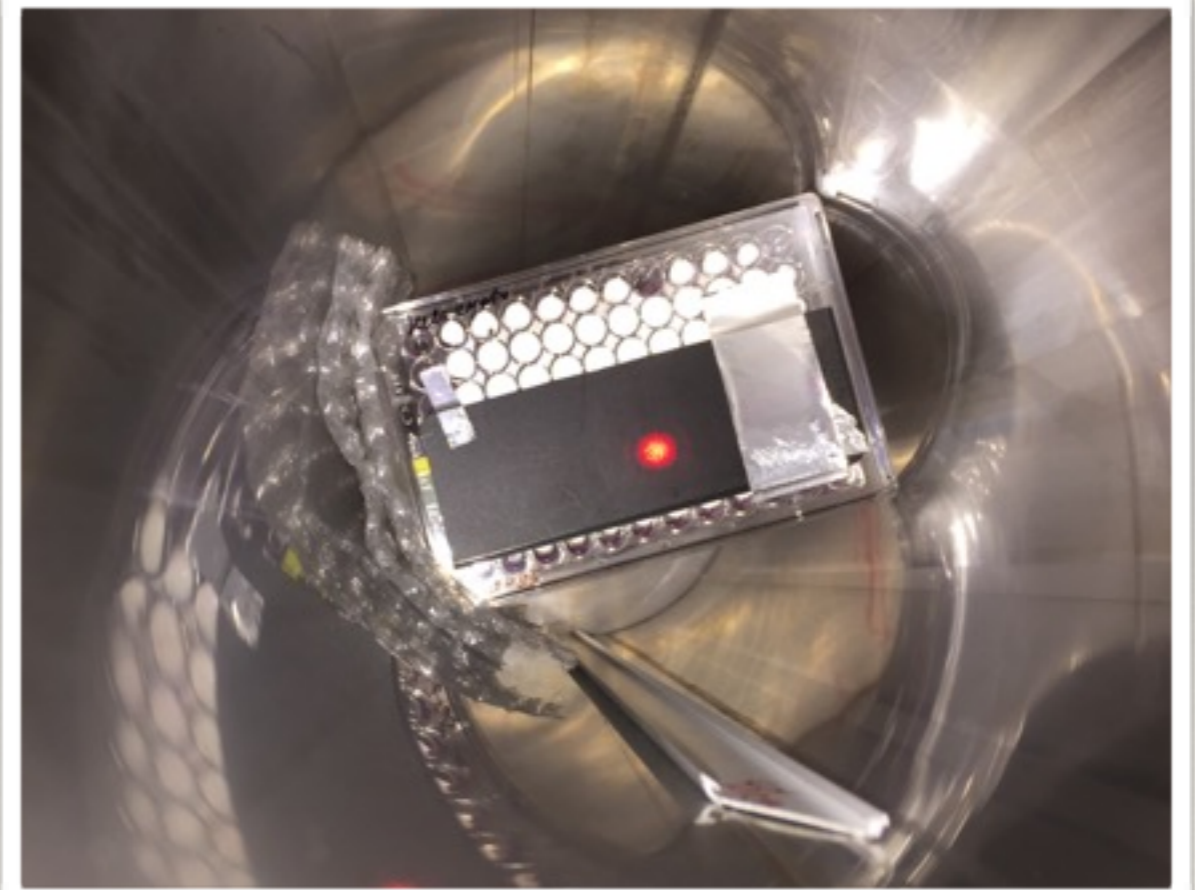
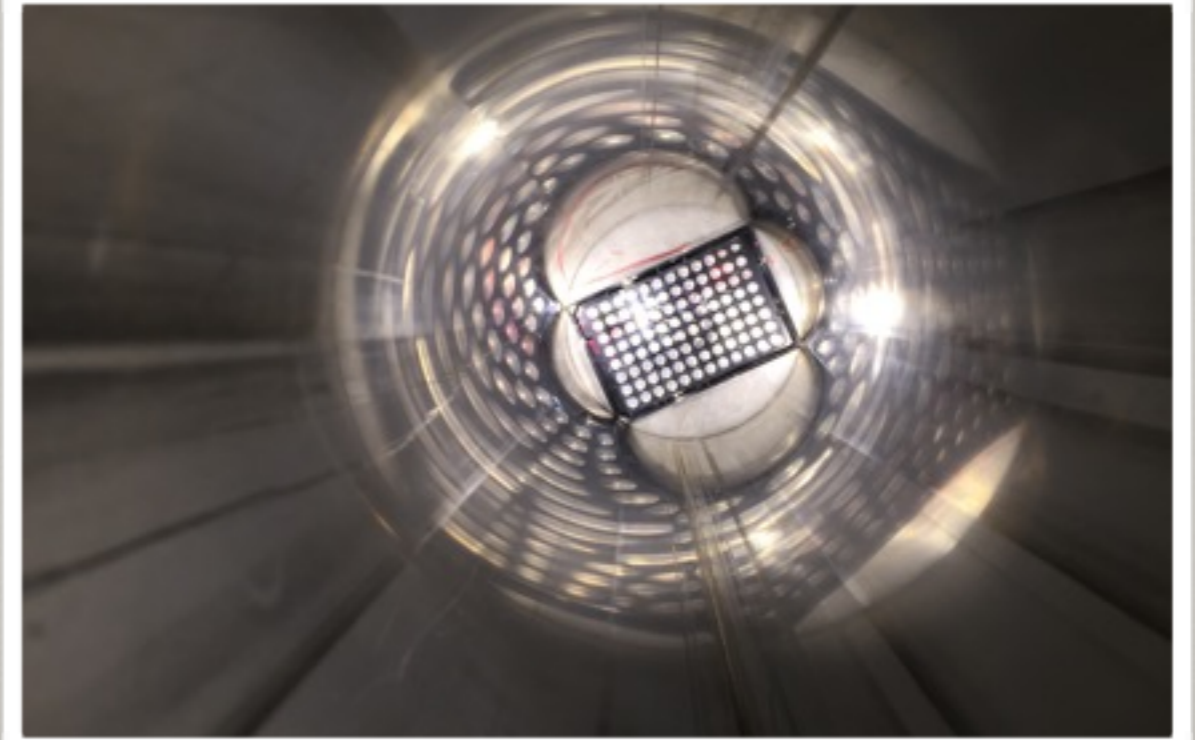
МИГРАФИЯ

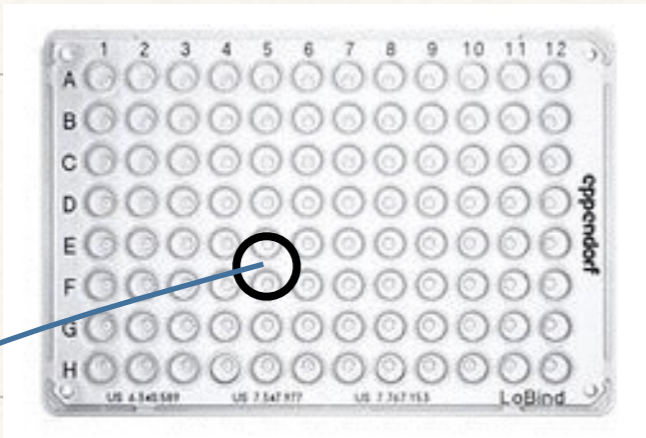




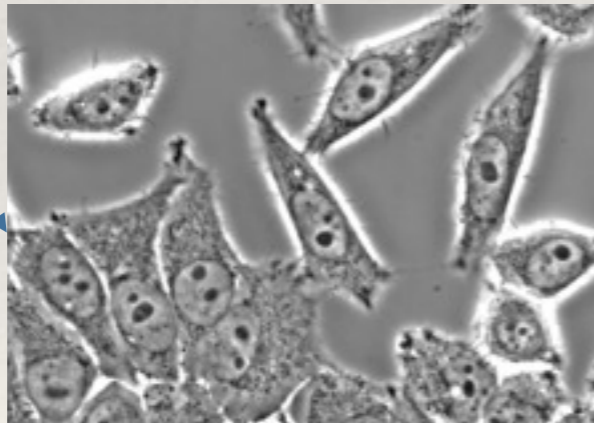
RADIOTHERAPY
OFFERS REAL HOPE

Photo...





Culturing in DMEM with
glutamine,
10% whey and antibiotics,
in the atmosphere with 5% CO₂
at 37°C
(3k cells per hole)

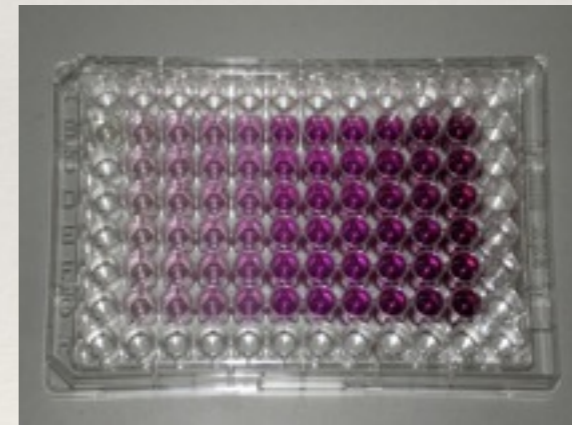


HeLa Kyoto (human cervical
cancer)

→
24 hours

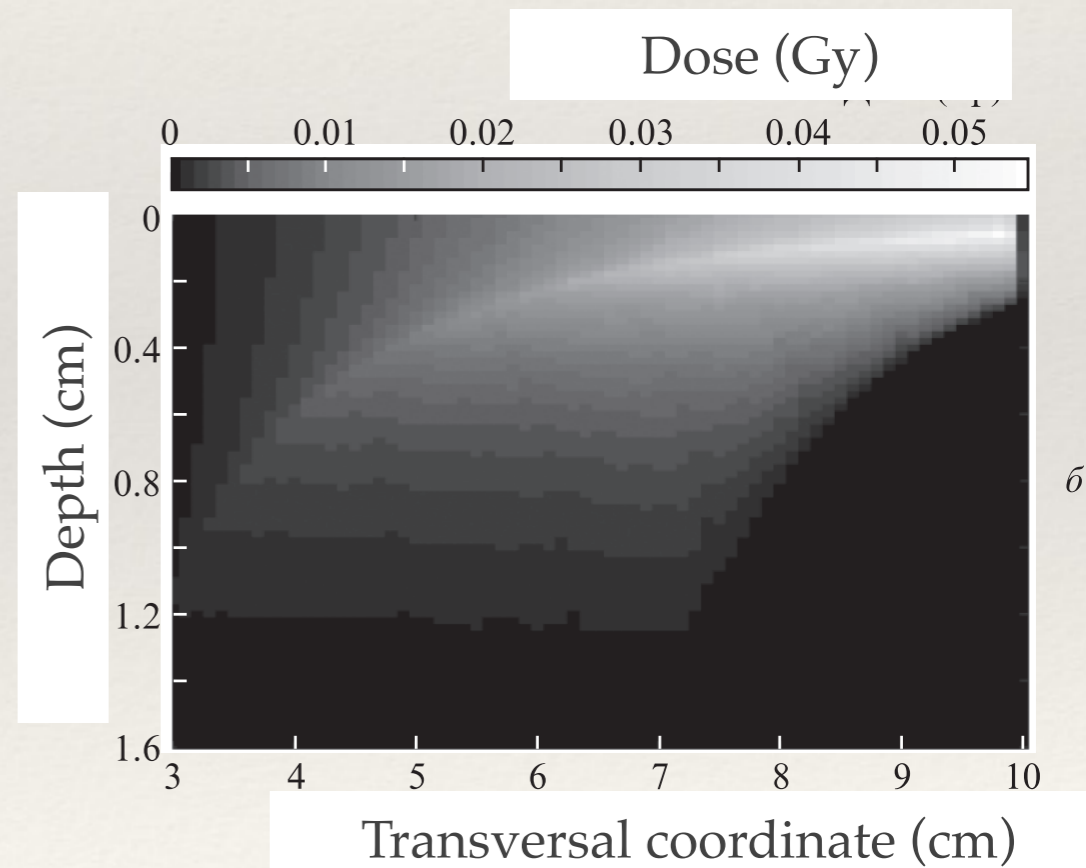
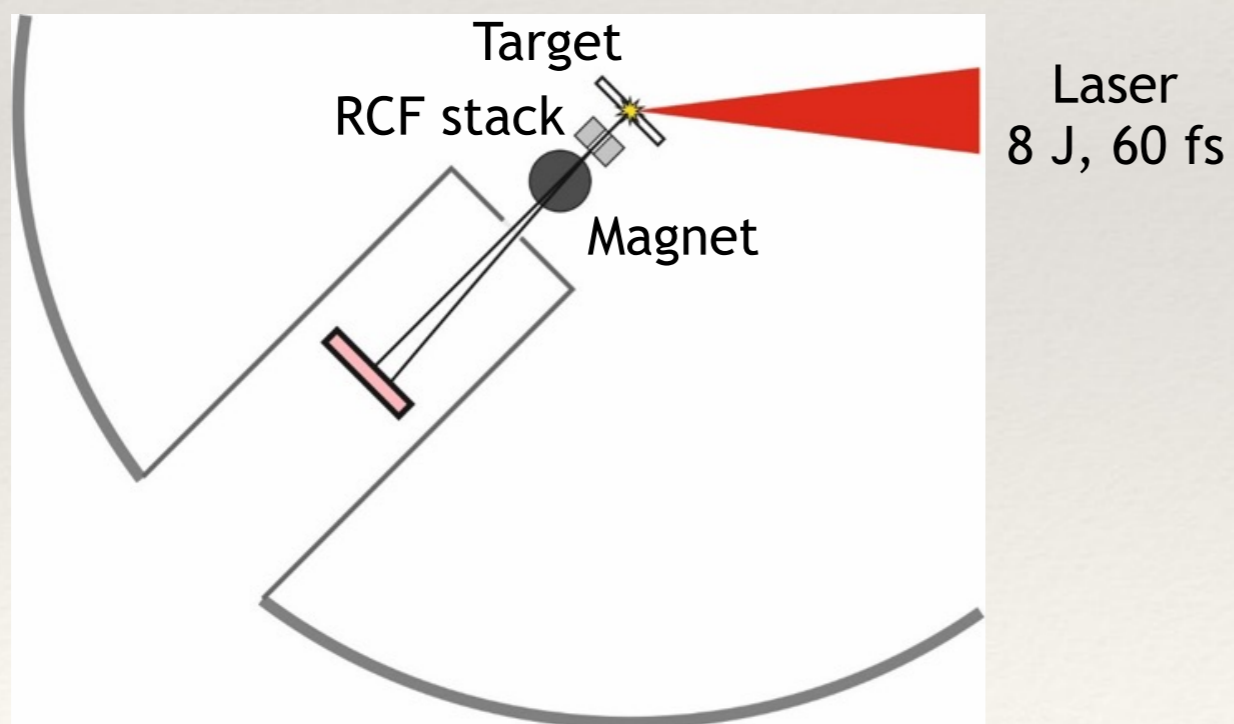
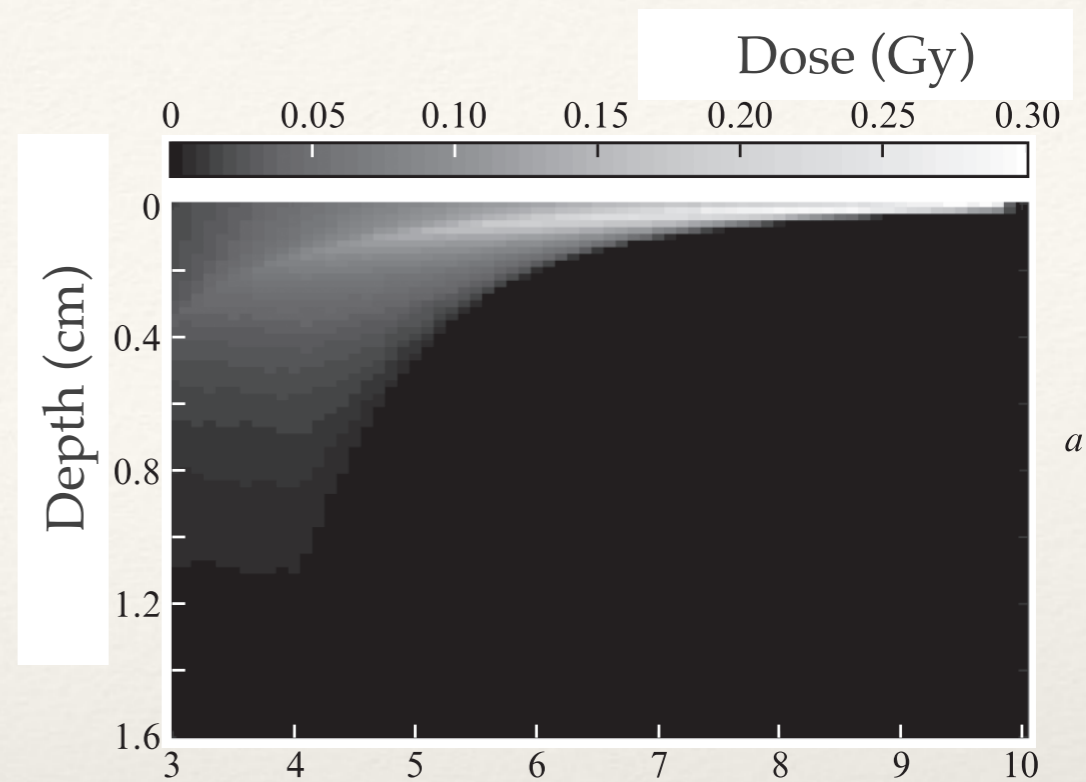
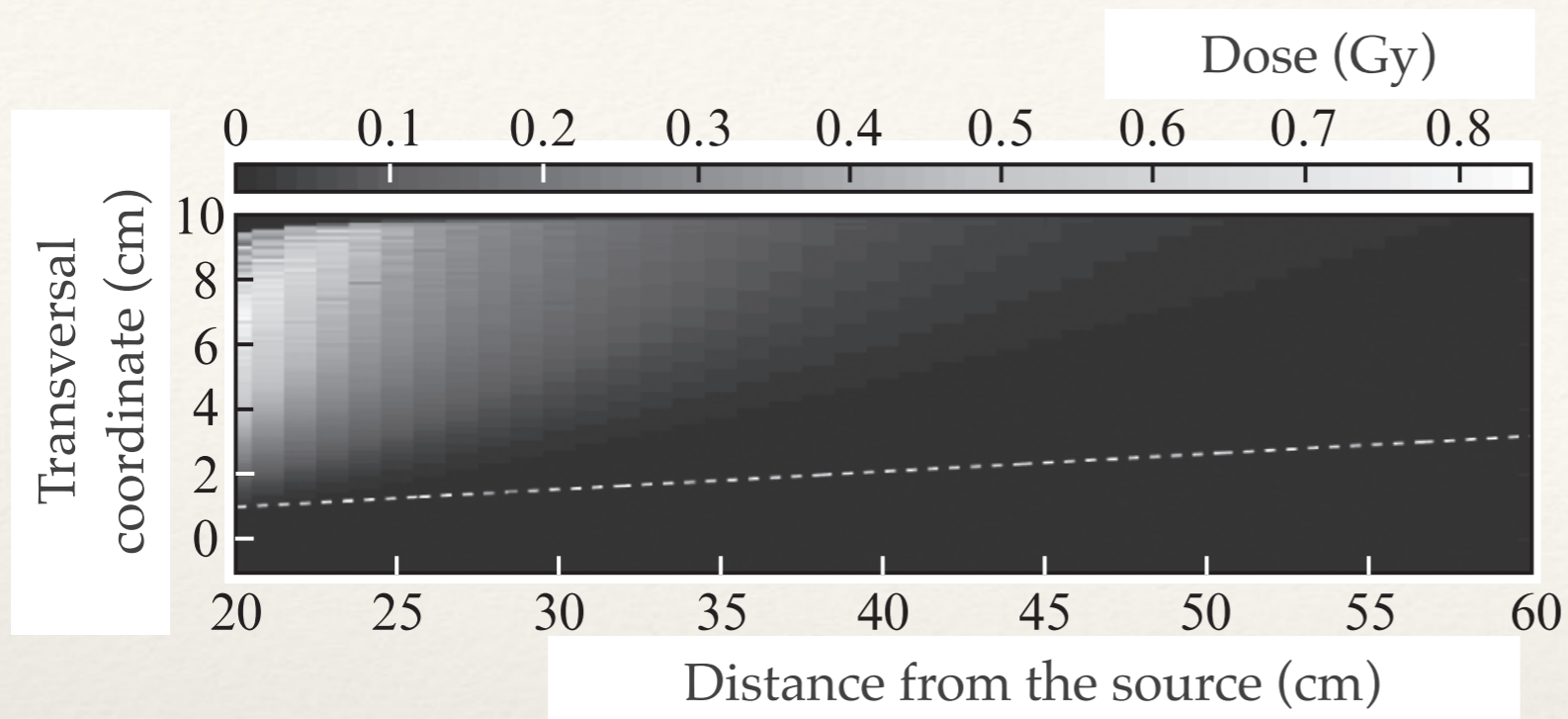
Proton exposure

↓
24 hours



MTT-test after 24
hours

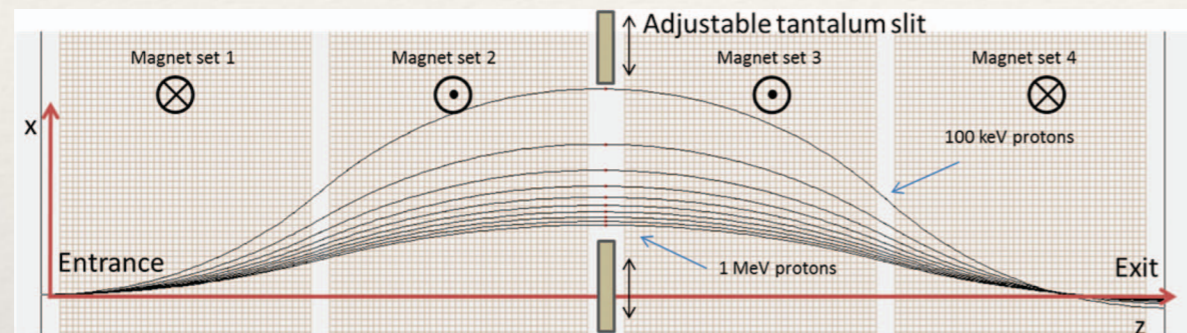
Dose estimations



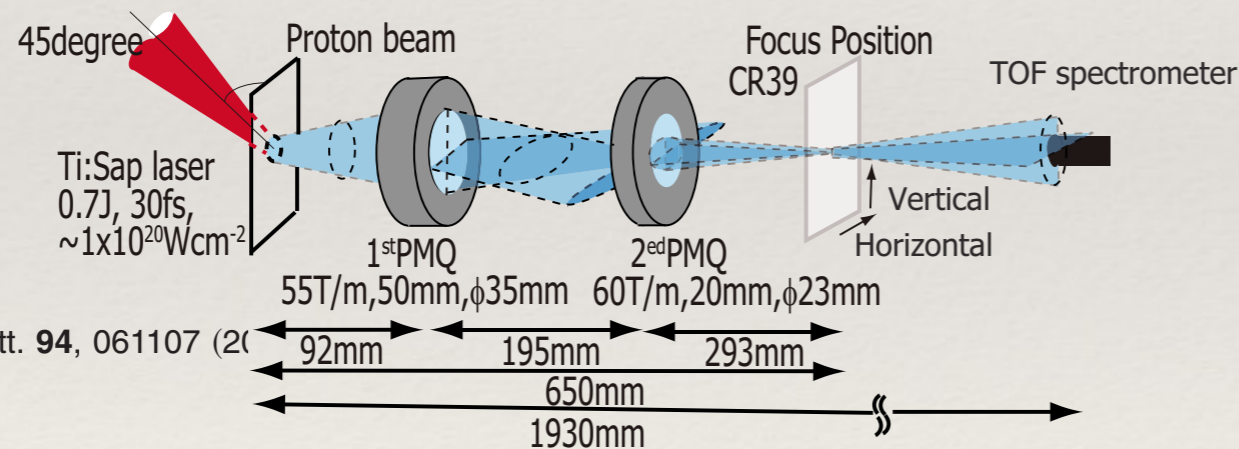
The goals for the further experiments

❖ Transport-Focusing system development

1)

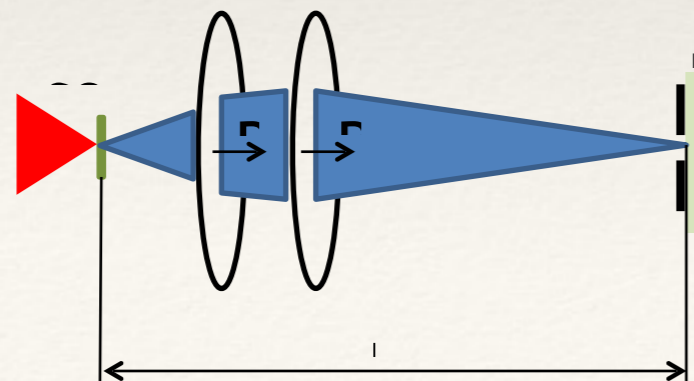


2)



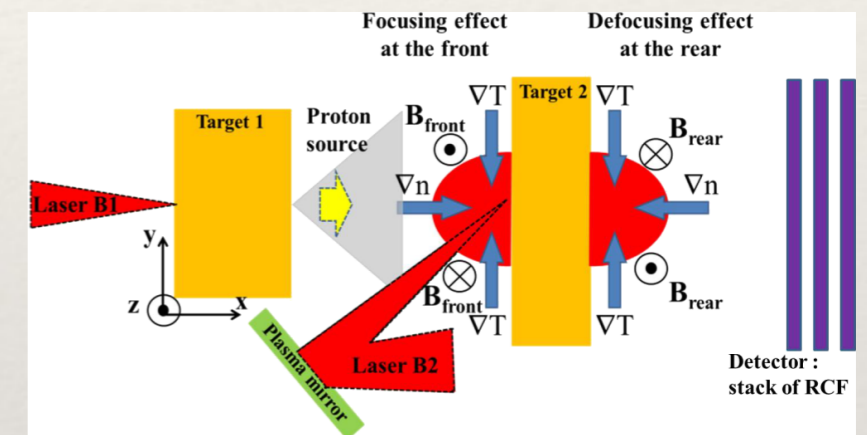
Appl. Phys. Lett. **94**, 061107 (2008)

3)

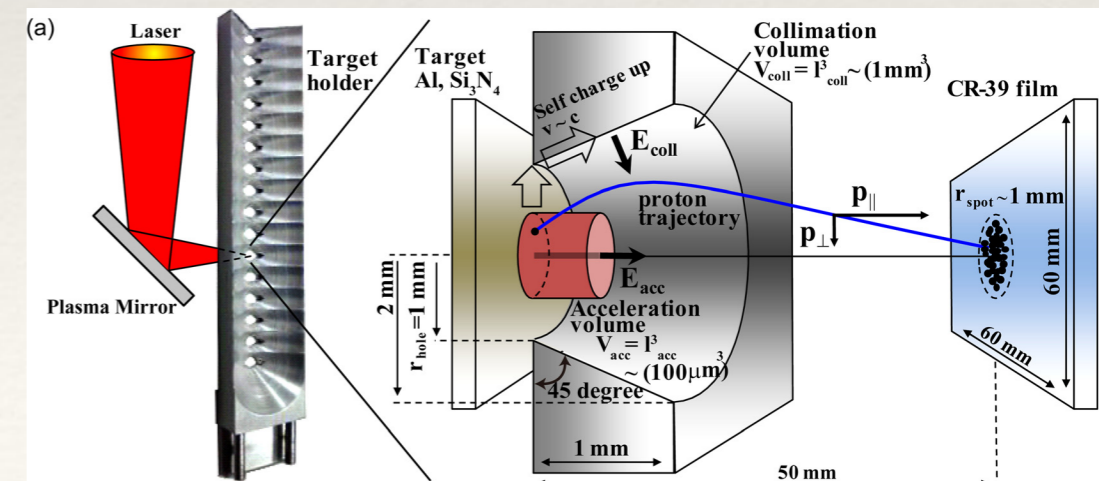


4)

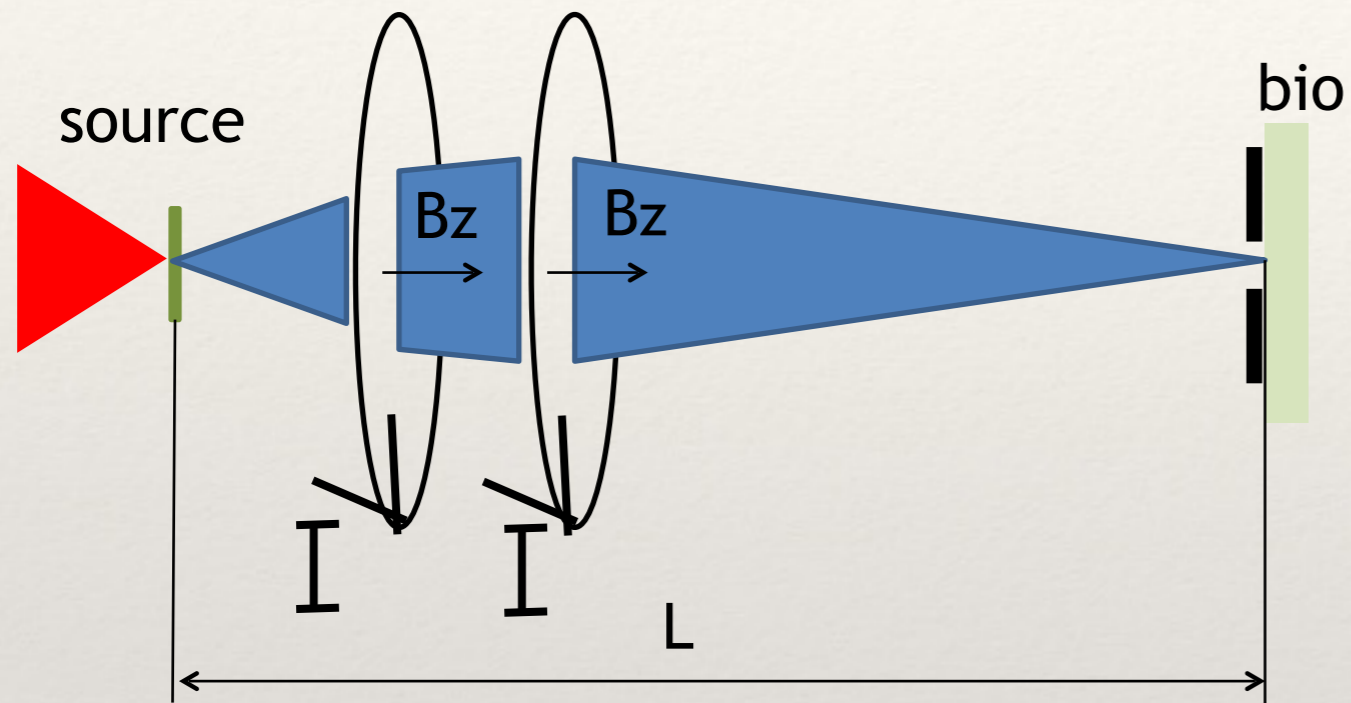
Albertazzi *et al.* Rev. Sci. Instrum. **86**, 043502 (2015)

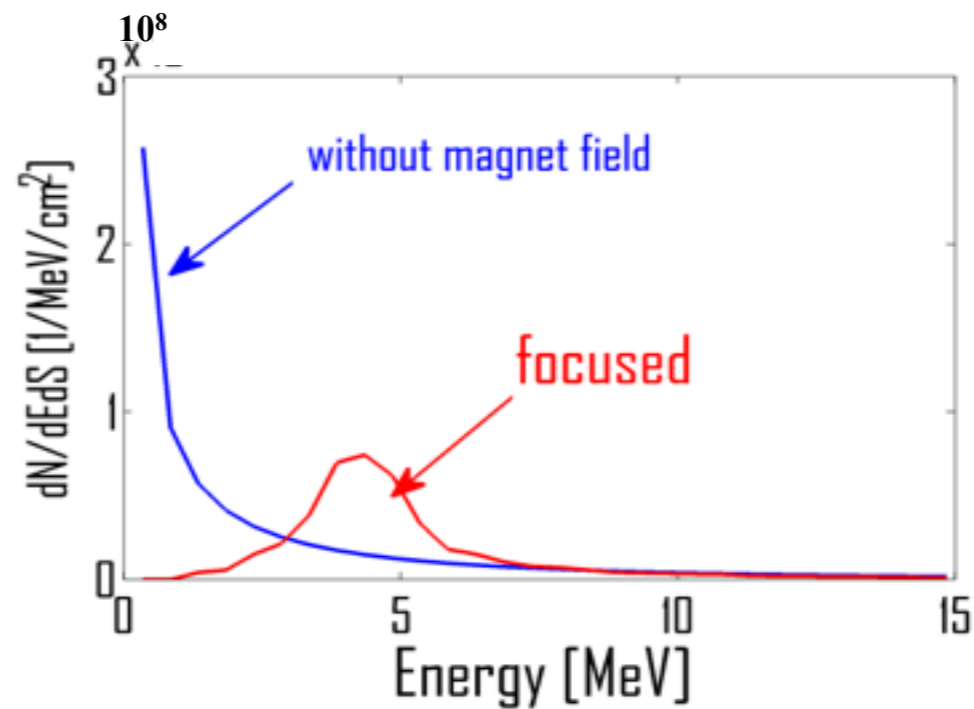
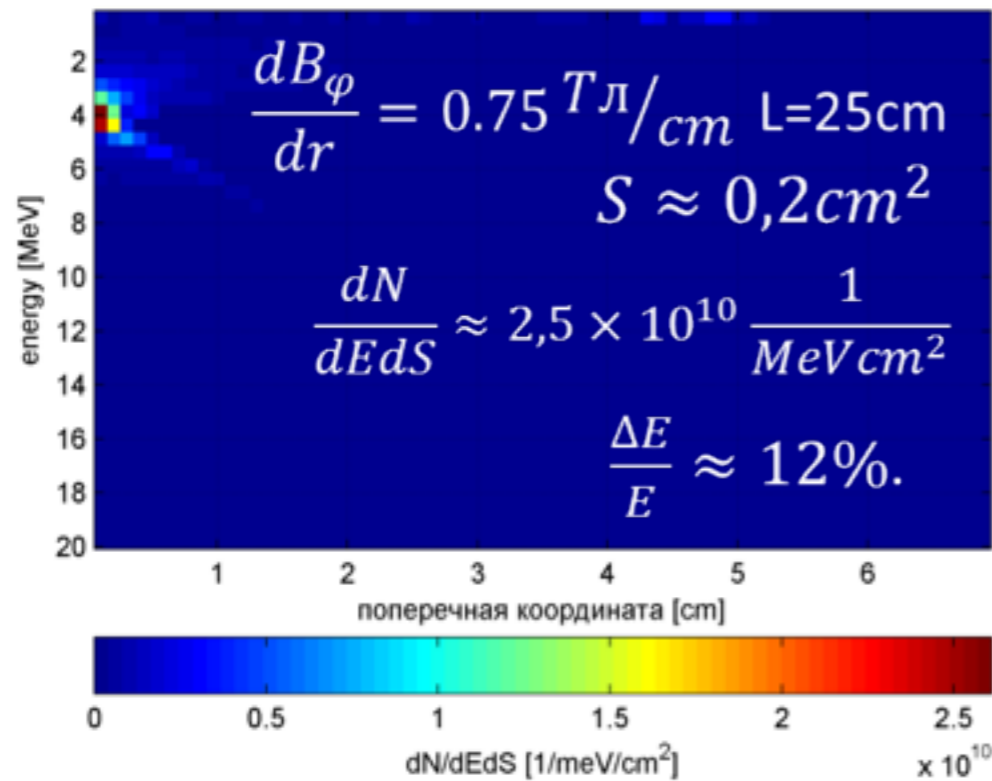
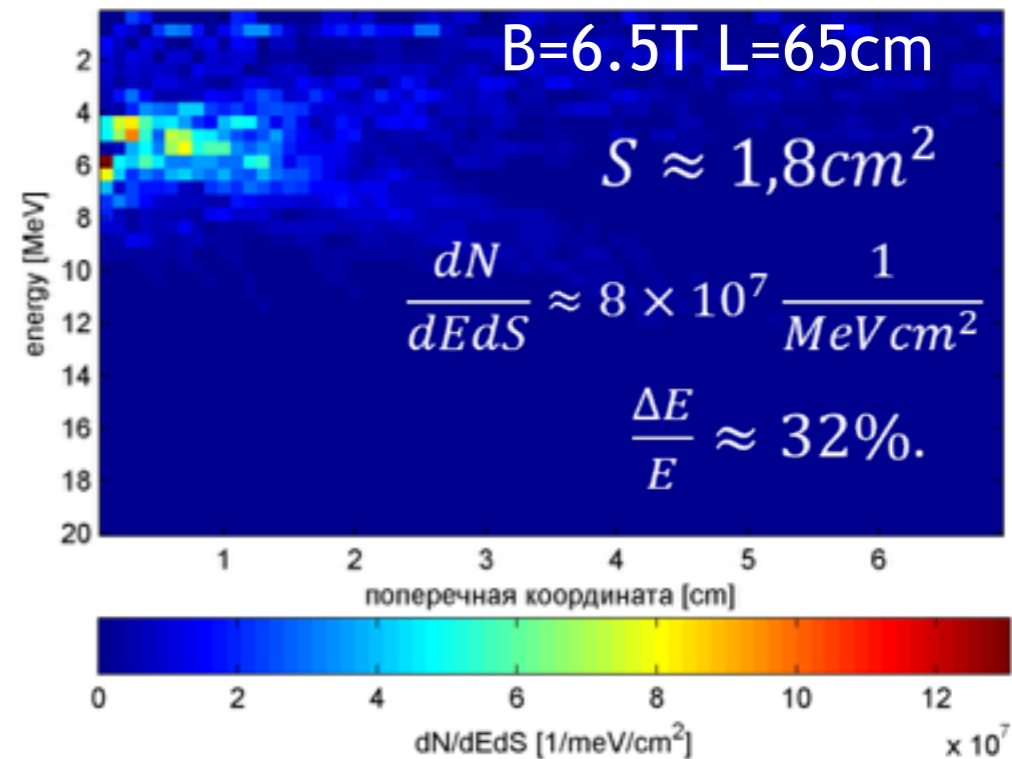
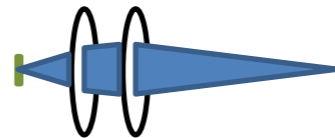
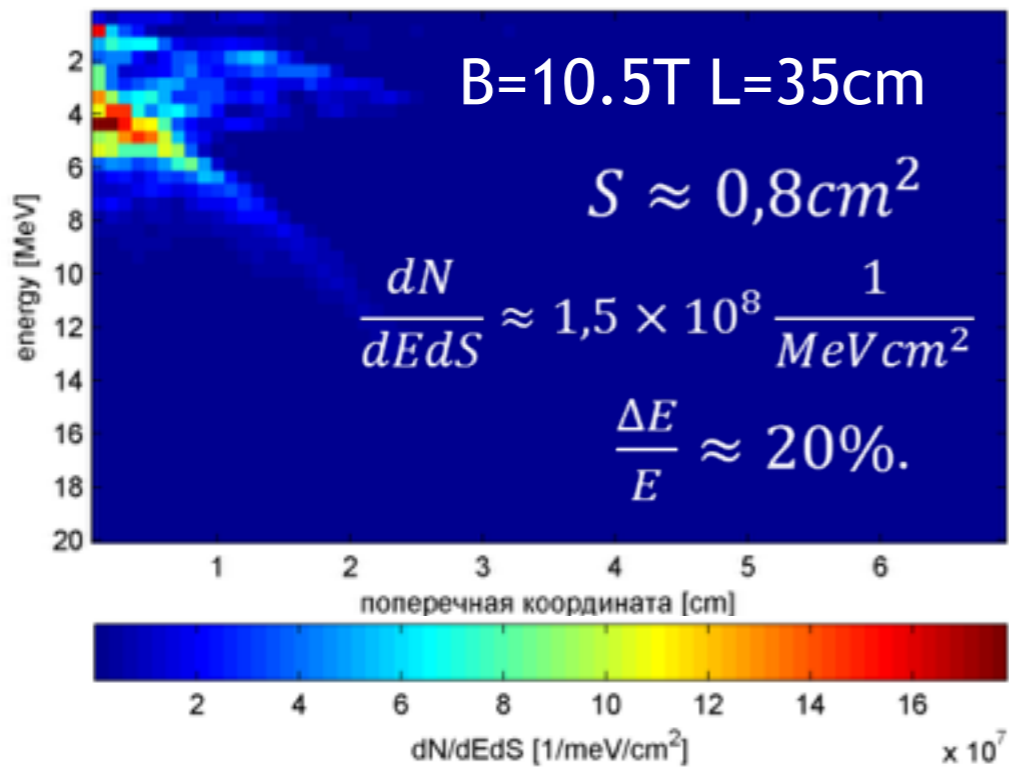


Nishiuchi *et al.* Phys. Plasmas **19**, 030706 (2012)



Cartoon of the focusing system





Summary

- ❖ We have accelerated protons up to the energies of ~ 43 MeV
- ❖ We have performed the very first radiobiological experiments at PEARL facility
- ❖ It is possible to modify the experimental scheme with adding magnetic separation and collimation system for energetic proton beams
- ❖ To obtain more energetic proton beams it is necessary to upgrade the laser facility

Temporal contrast measurement

Проблема временного контраста

Third order autocorelator:

The near contrast at $\tau=1$ ps is 10^4

The far contrast $\tau=500$ ps is 10^8

2007г. (Миронов, Гинзбург,
Ложкарёв...)

Direct parametric
luminescence measurement
gives also $2 \cdot 10^8$

