Sub-micrometer spheres for laser driven ion acceleration

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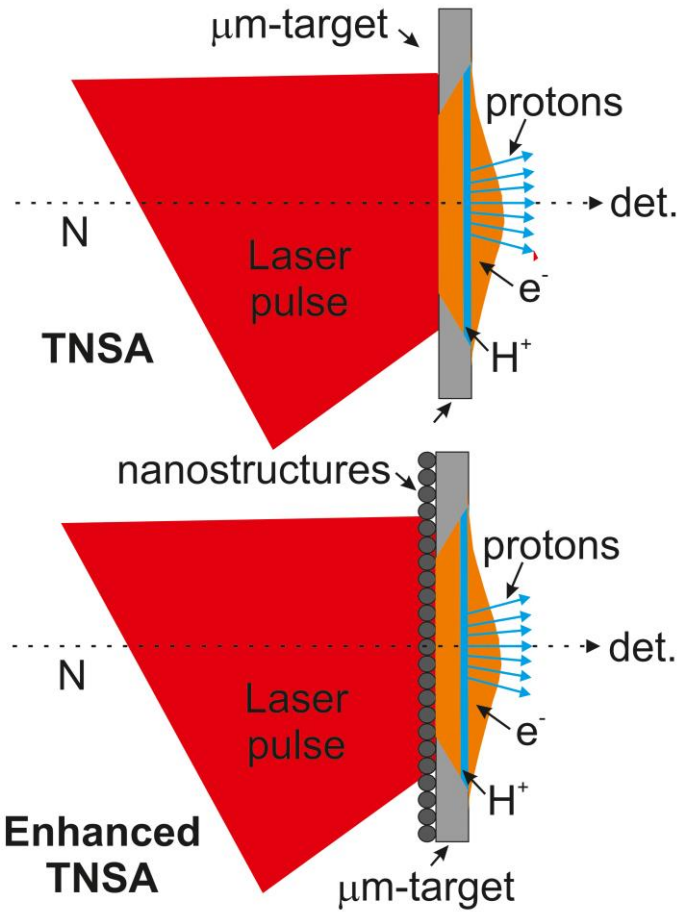
Prague, Czech Republic

MAP, 9-10 October 2013, Munich

Proton Acceleration by Enhanced-TNSA

- Experimental results with **100 TW-class** laser @ CoReLS-APRI
- Recent experiment with **1 PW-class** laser @ CoReLS-APRI
- Perspectives at **higher power** (and higher intensity!)
- Targetry, **ELIMAIA** @ ELI-Beamlines & ELIMED

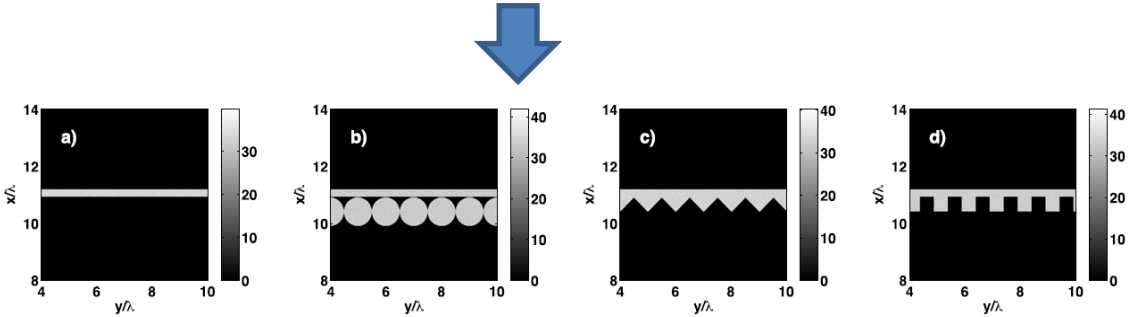
TNSA vs. enhanced-TNSA



Increase of **photoelectron** generation (low laser intensity):
M. Raynaud and J. Kupersztych, Phys. Rev. B 76 (2007) 241402

Increase of **X-ray** emission:
H.A. Sumeruk et al., Phys. Rev. Lett. 98 (2007) 045001

Increase of **proton acceleration** efficiency (*PIC simulations*):
Y. Nodera, S. Kawata et al, Phys. Rev. E 78 (2008) 046401
O. Klimo et al., New J. of Phys. 13 (2011) 053028

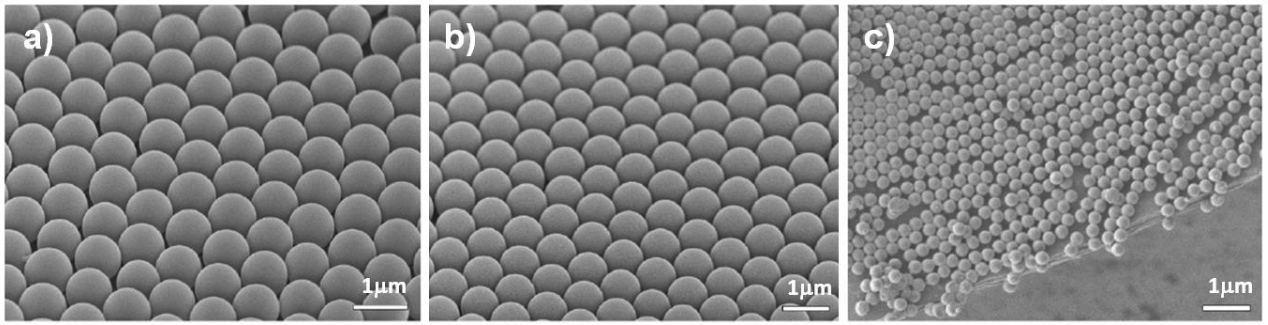


Increase of hot electron temperature (**stochastic heating**) in sub-micron clusters:
Boris N. Breizman Phys. Plasma 12 (2005) 056706

Target geometries

Target morphology

- monolayer of closely packed polystyrene spheres
- 1 μm mylar substrate
- self assembly in water *(@ CTU in Prague)*

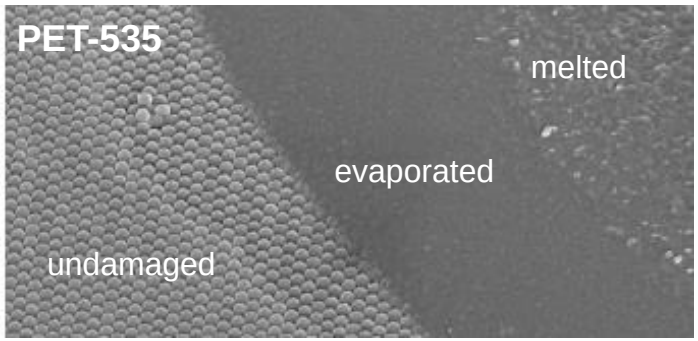


a) PET-266: 1 μm mylar + 266 nm polystyrene spheres
b) PET-535: 1 μm mylar + 535 nm polystyrene spheres
c) PET-920: 1 μm mylar + 920 nm polystyrene spheres
d) PET: 1 μm mylar (planar target)

Laser damaging threshold

✓ ns-regime: no damage for $I_L < 3 \times 10^9$ W/cm^2
✓ fs-regime: no damage for $I_L < 10^{11}$ W/cm^2

D. Margarone et al., Appl. Surf. Sci. (2012)



Experimental setup @ CoReLS-APRI

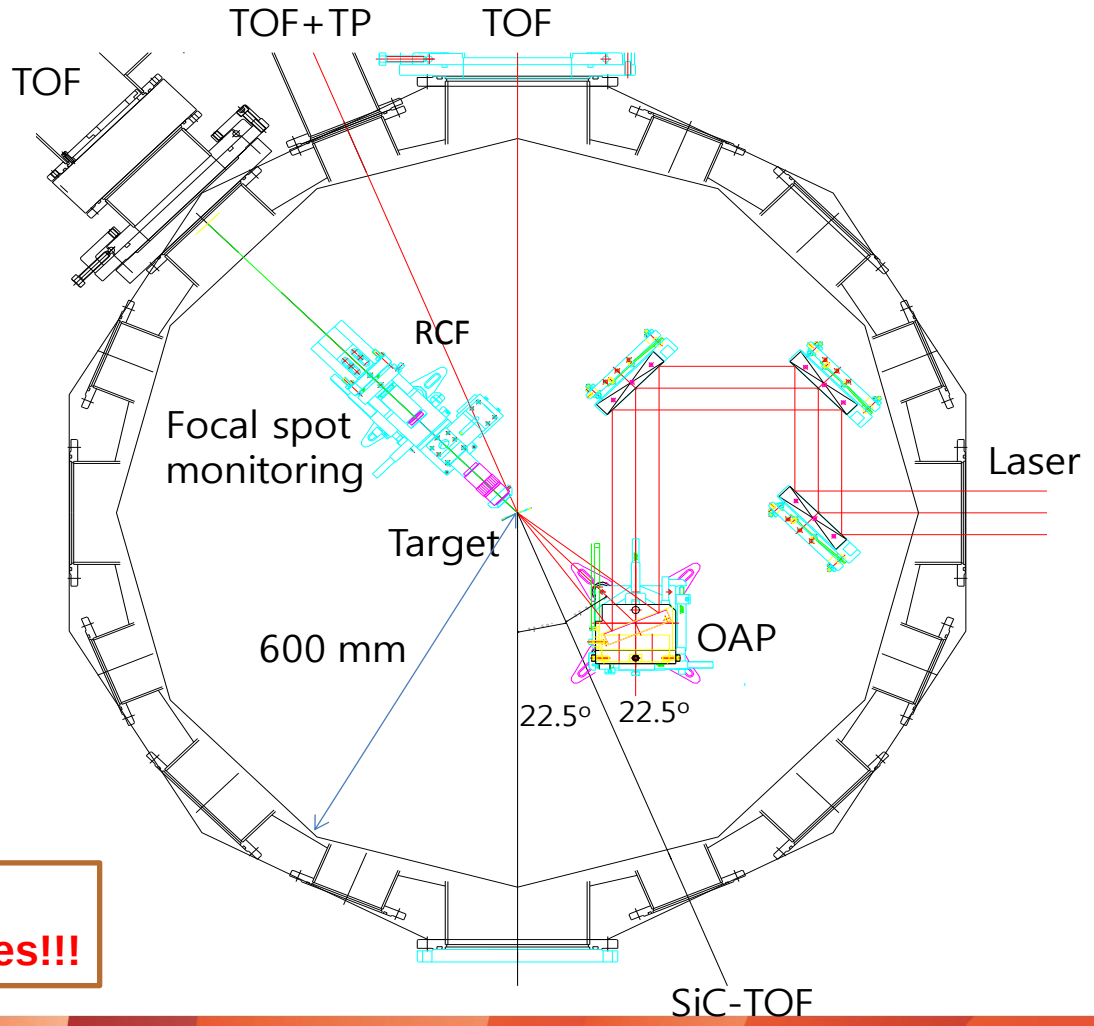
T. M. Jeong et al., J. Korean Phys. Soc. 50 (2007) 34

Laser parameters

- Max. laser energy/power/intensity:
  - without PM → 2J, **70 TW**, 10^{20} W/cm^2
  - with DPM → 1J, 35 TW, **5x10^{19}** W/cm^2
- Pulse duration : **30 fs**
- Wavelength: 805 nm
- Polarization: p
- Standard spot diameter: 5 μm (FWHM)
- main/pedestal contrast:
  - without PM → ~10^7 @ 6 ps
  - with DPM → ~**5x10^{11}** @ 6 ps

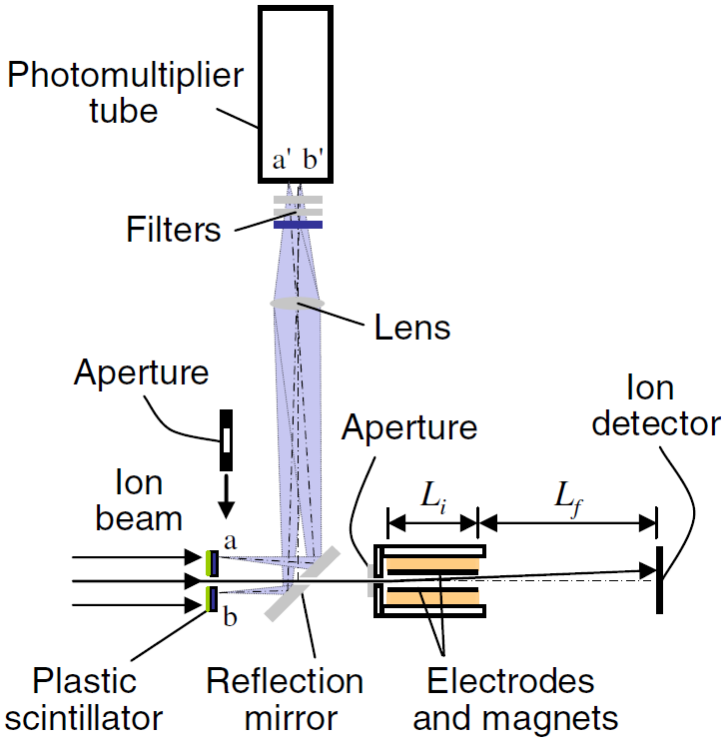
Pedestal intensity ~**10^8 W/cm^2**

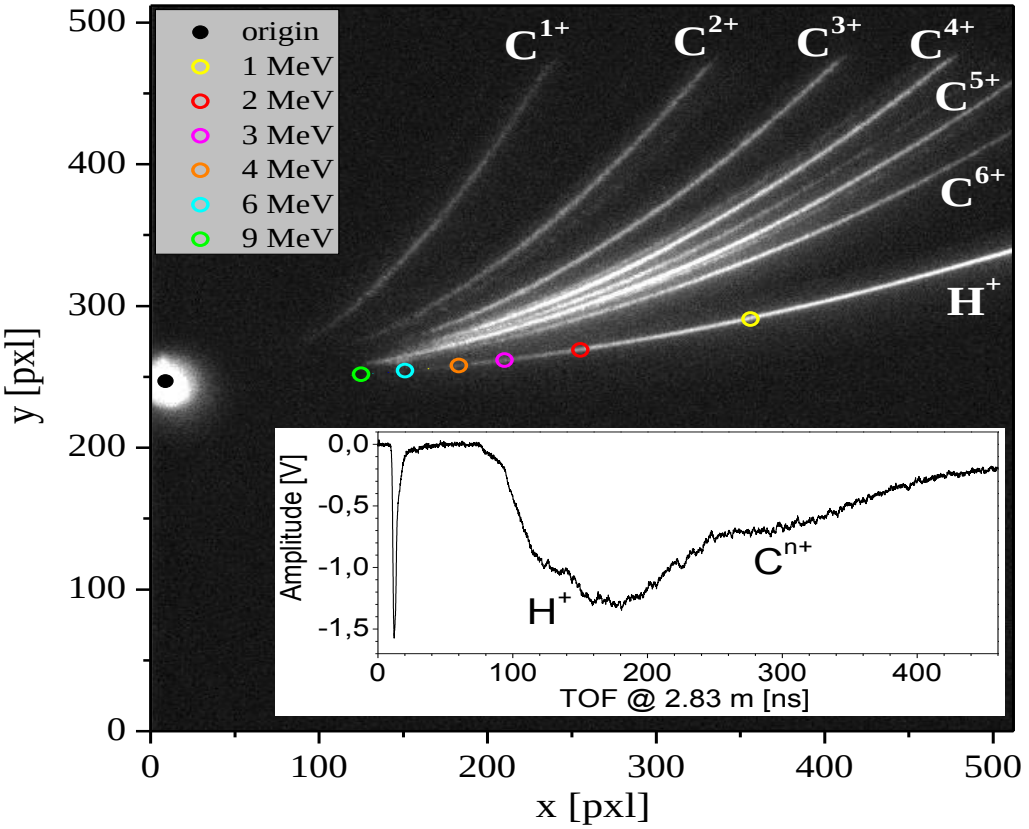
No laser damage for our nanostructures!!!



Proton/ion beam diagnostics

Thomson Parabola spectrometer & **TOF** measurements (simultaneous) + **RCF**





I.W. Choi et al., Rev. Sci. Instr. 80 (2009) 053302

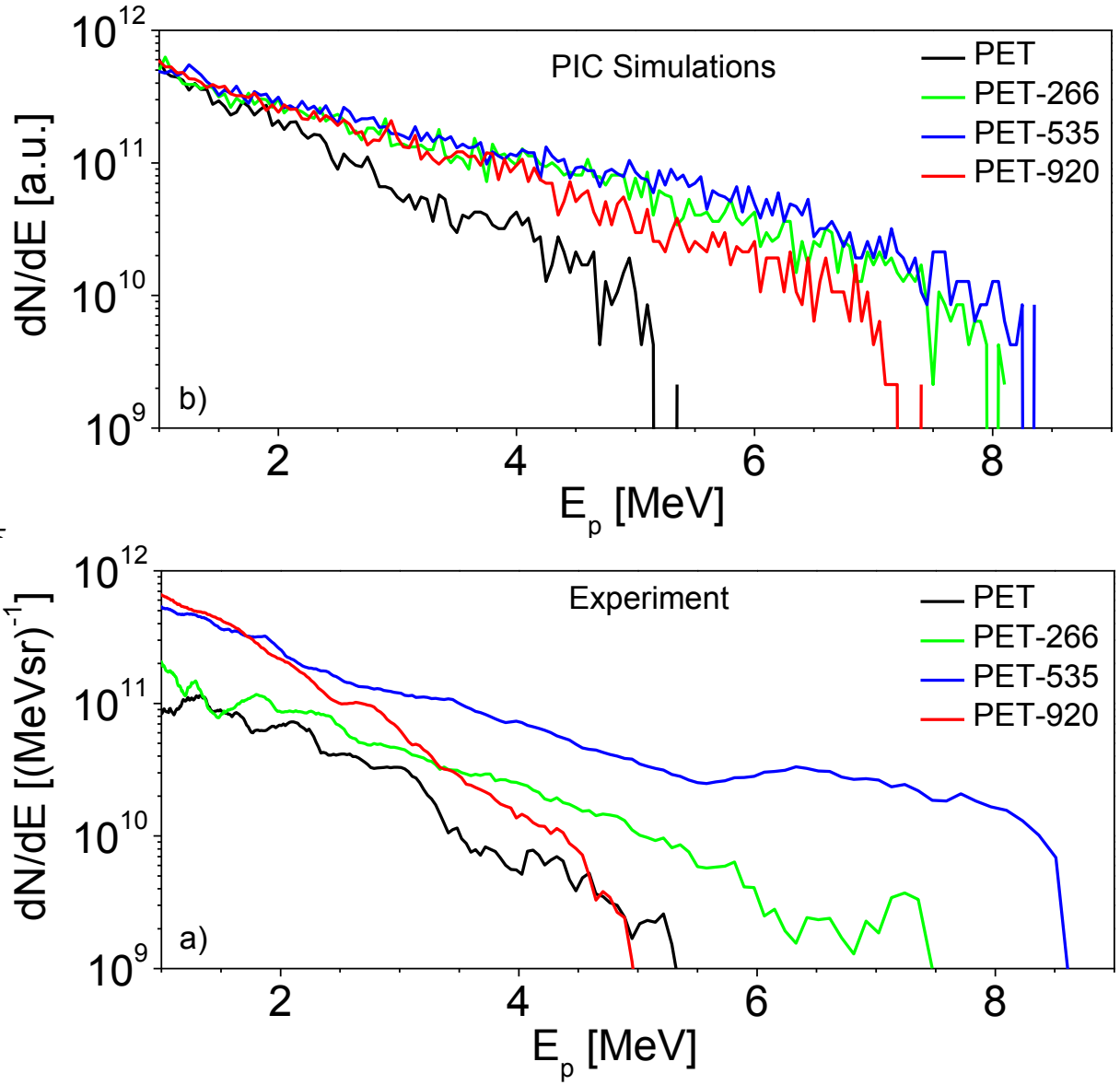
Proton beam energy distributions

Numerical simulations
(J. Limpouch's team at CTU)

- PIC 2½-dimensional
- Target: 1:1 mixture of C^{4+} and p^+, $n_e=40n_c$ (1.72×10^{21} cm^{-3})
- laser: same intensity, wavelength, duration, polarization and incidence angle

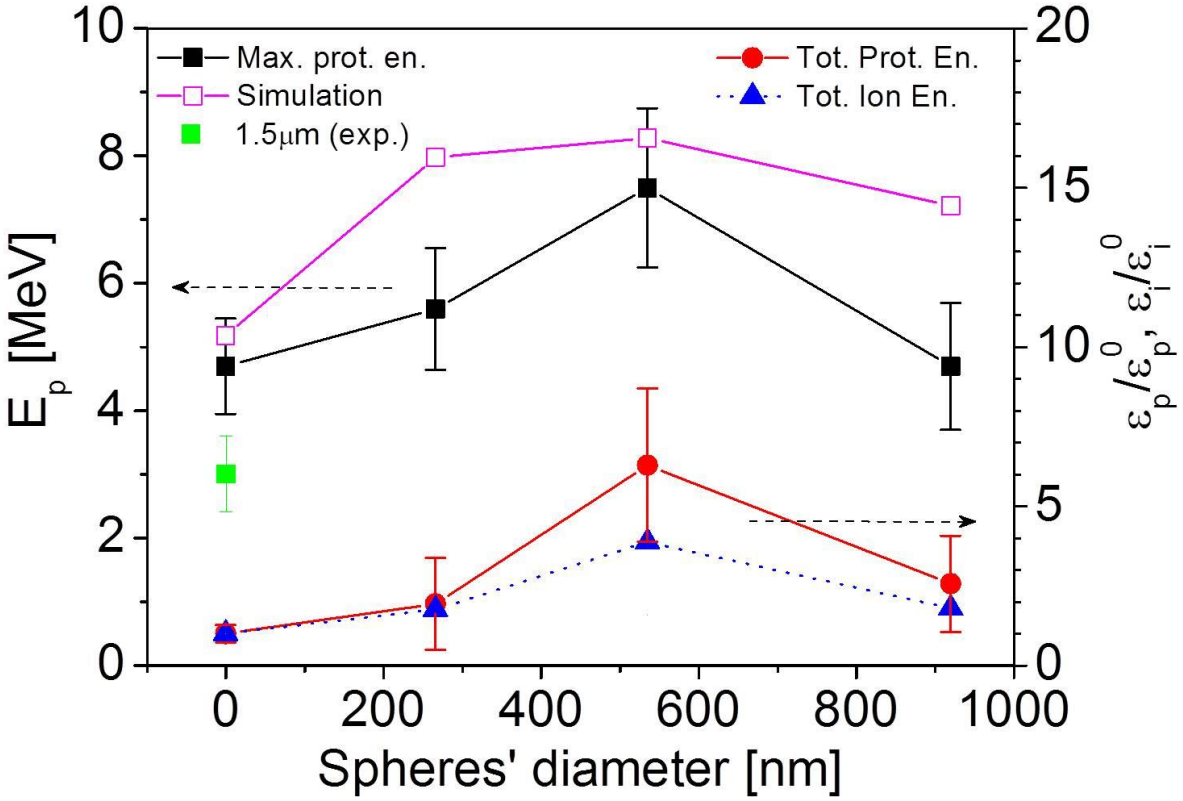
J. Psikal et al., Czech. J. Phys. 56 (2006) B515

Our **experimental results** @ CoReLS-APRI (GIST), Gwangju, South Korea



Fyzikální ústav
Akademie věd ČR, v. v. i.

Nanospheres size optimization



PRL **109,** 234801 (2012) PHYSICAL REVIEW LETTERS week ending 7 DECEMBER 2012

Laser-Driven Proton Acceleration Enhancement by Nanostructured Foils

D. Margarone,[1] O. Klimo,[1,2] I. J. Kim,[3] J. Prokůpek,[1,2] J. Limpouch,[1,2] T. M. Jeong,[3] T. Mocek,[1] J. Pšikal,[1,2] H. T. Kim,[3] J. Proška,[2] K. H Nam,[3] L. Štolcová,[1,2] I. W. Choi,[3] S. K. Lee,[3] J. H. Sung,[3] T. J. Yu,[3] and G. Korn[1]

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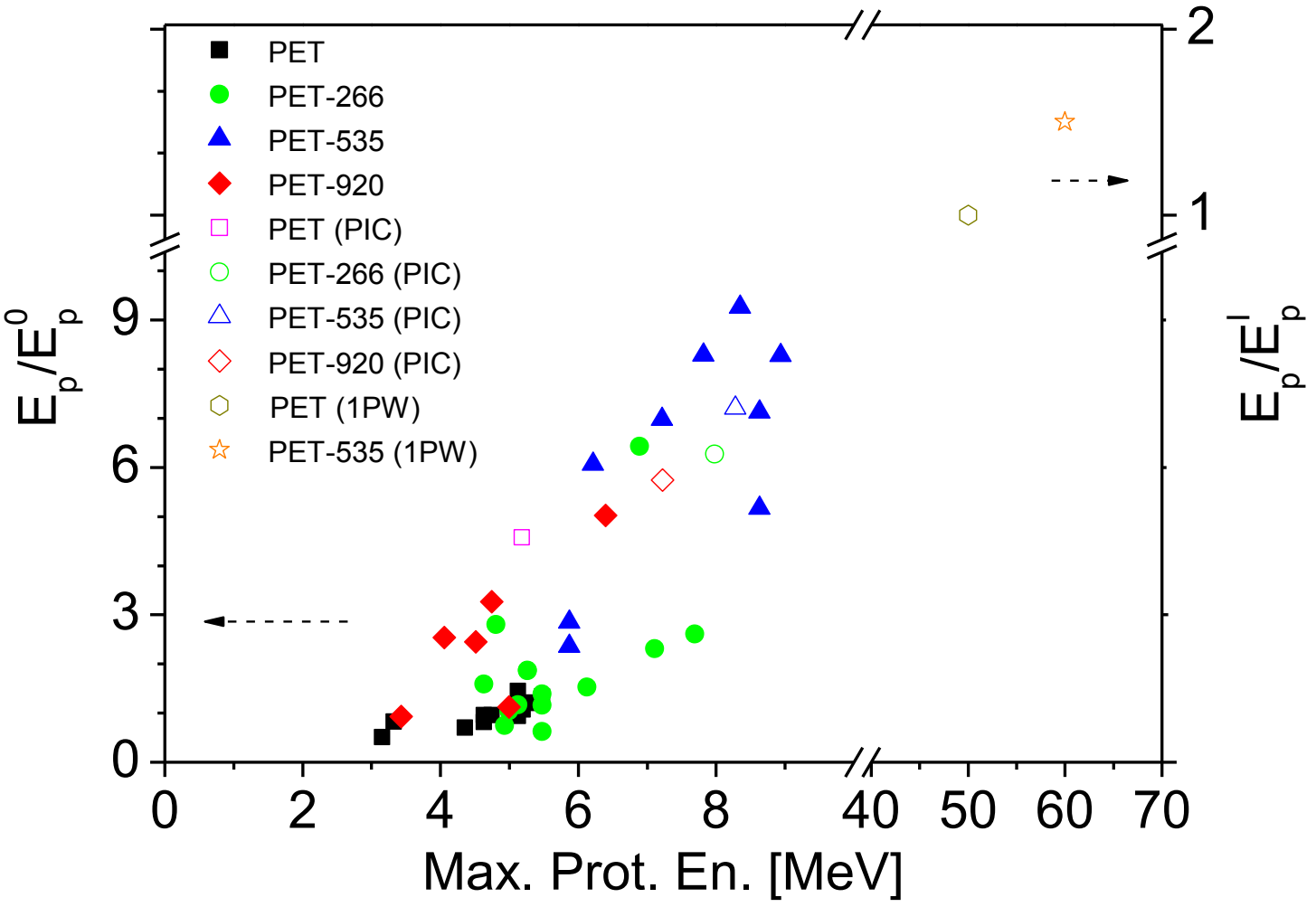
[2]*Czech Technical University in Prague, FNSPE, Brehova 7, 115 19 Prague, Czech Republic*
[3]*Advanced Photonics Research Institute, GIST, 1 Oryong-dong, Buk-gu, Gwangju 500-712, Republic of Korea*
(Received 3 June 2012; published 3 December 2012)

Maximum energy vs. total energy

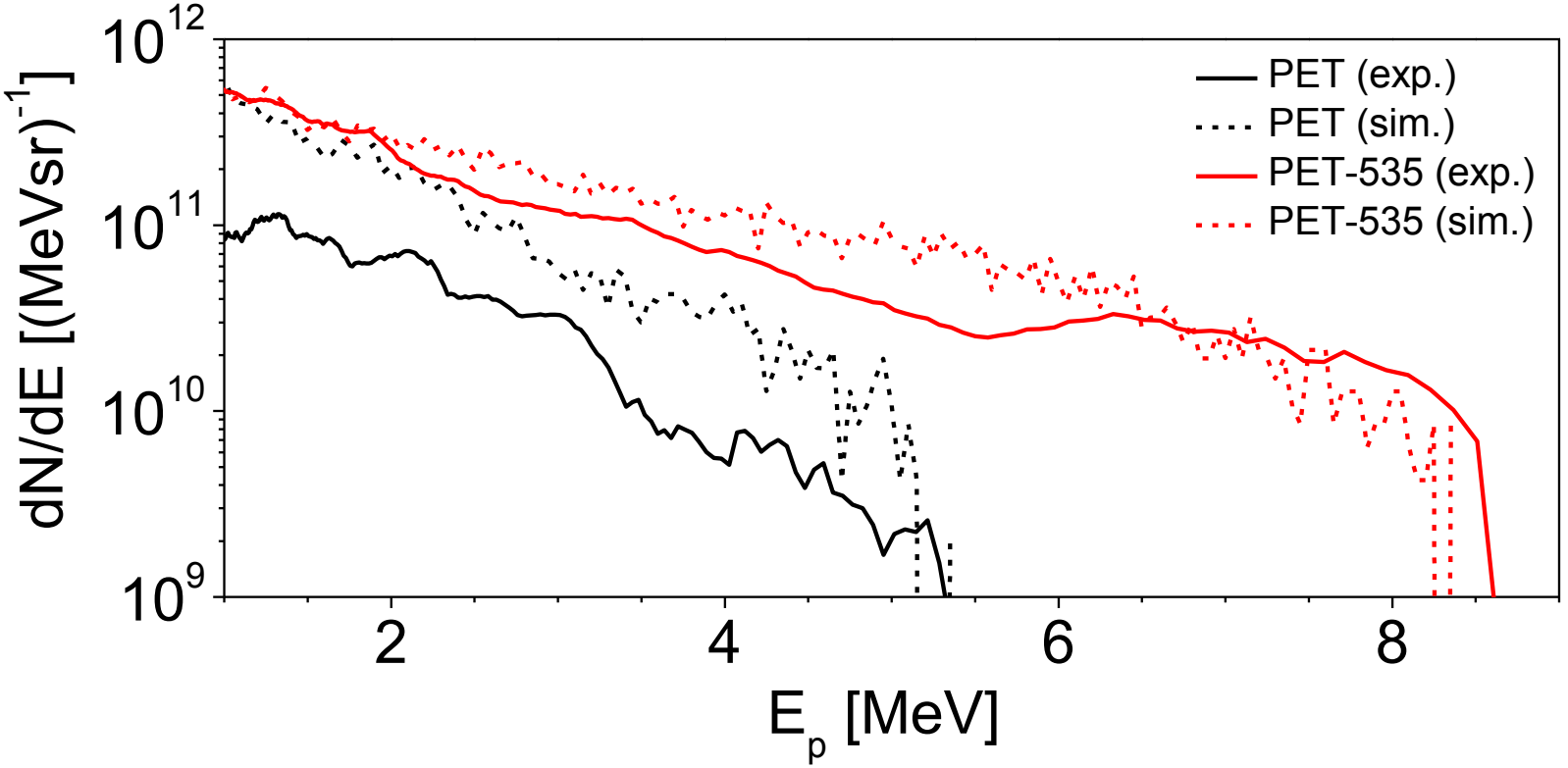


Main achievements

- Max. proton energy
  - PET: **5.3 MeV**
  - PET-535: **8.6 MeV**
  - energy increment: **62%**
- Relative proton accel. conv. efficiency
  - $\eta_{PET-535}/\eta_{PET}$: **6.9** (1-9 MeV)
  - $\eta_{PET-535}/\eta_{PET}$: **10.8** (4-5 MeV)

  efficiency estimation: 1.4% (PET), 9.4% (PET-535)

Stealth target for ion acceleration!



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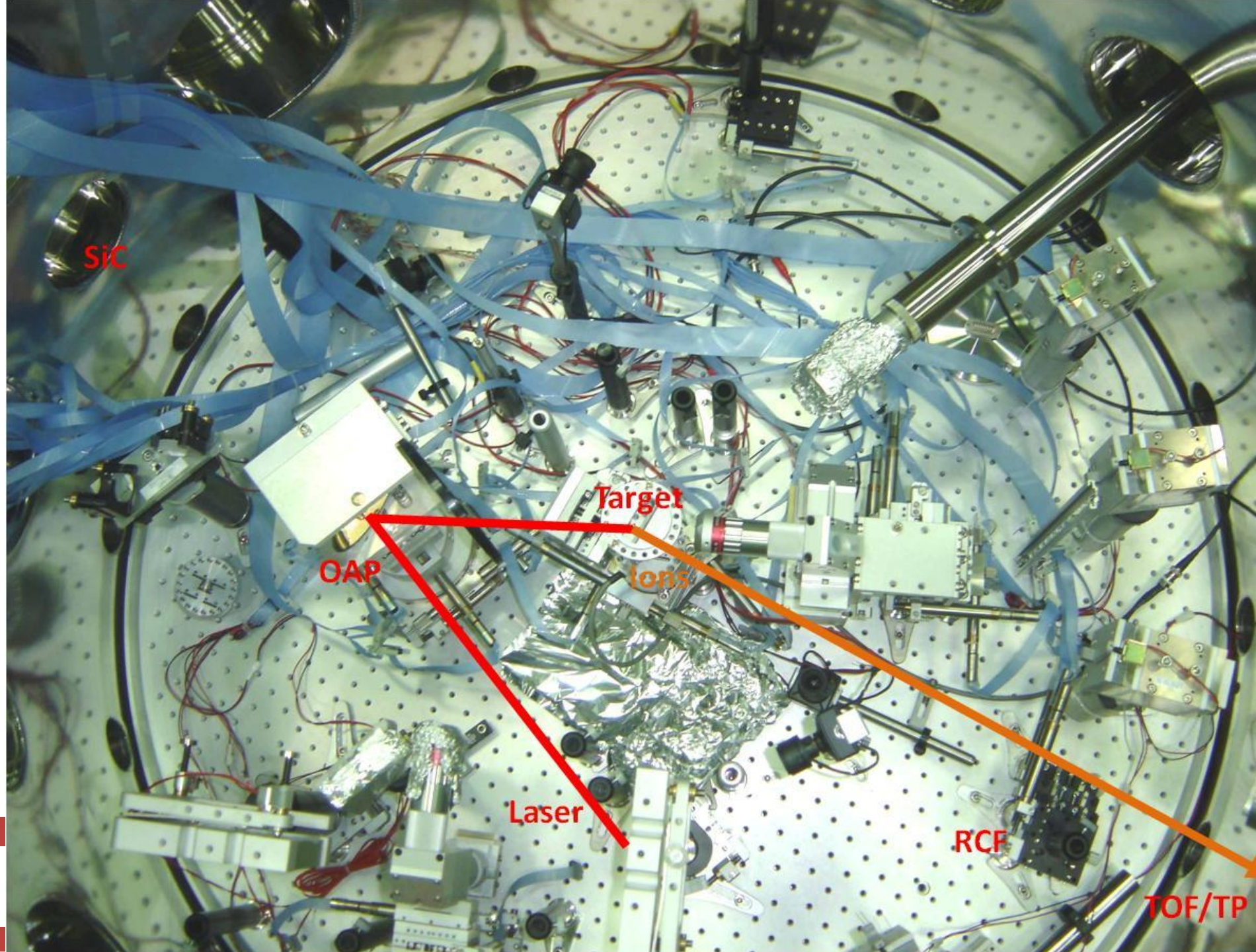
SiC
Target
OAP
Ions
Laser
RCF
TOF/TP

Proton/ion beam diagnostics

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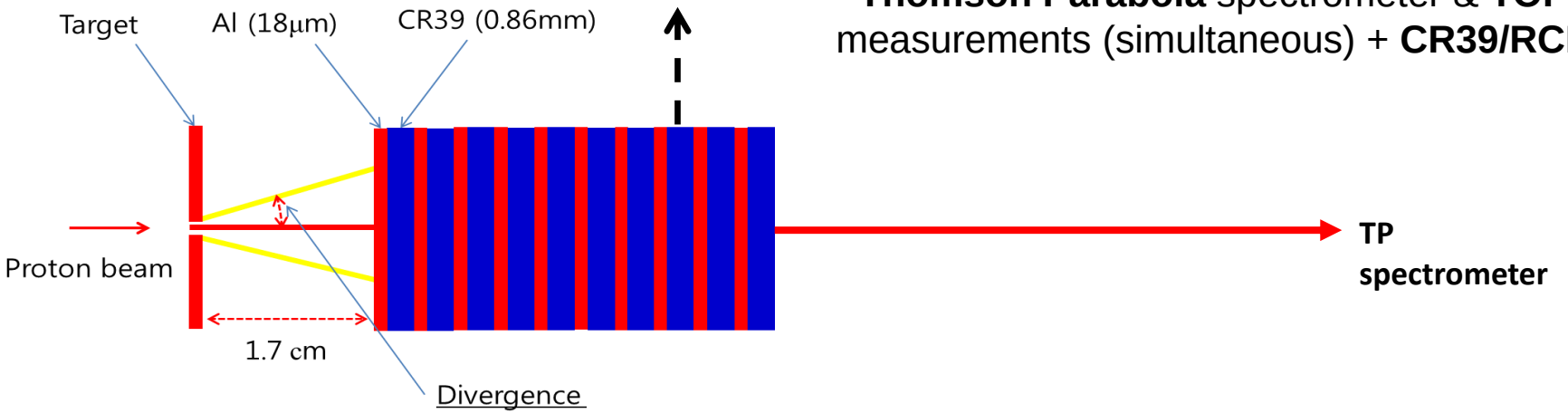
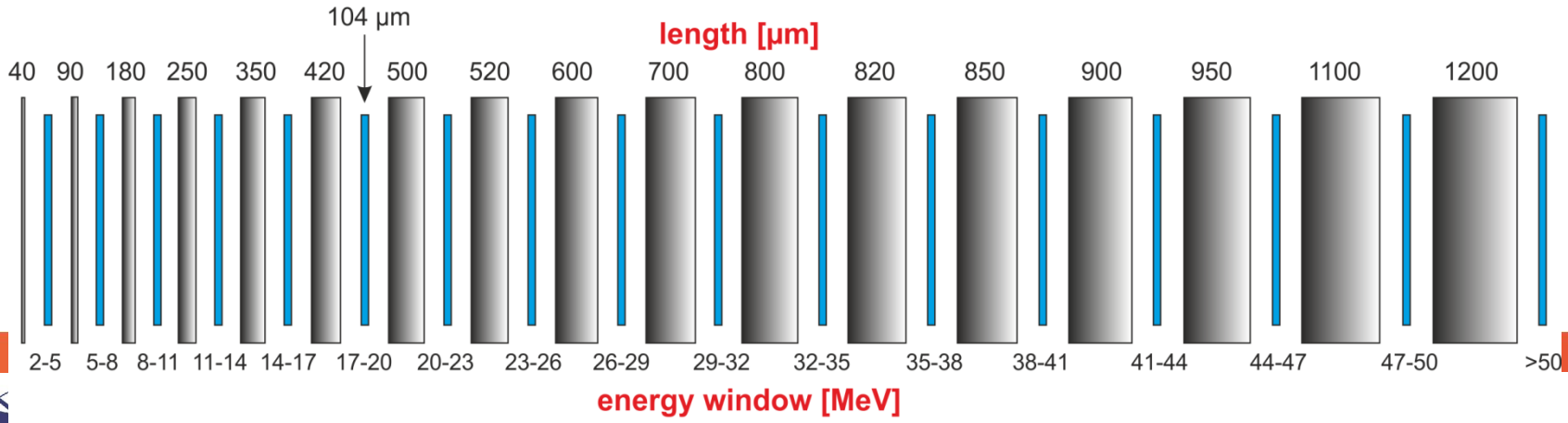
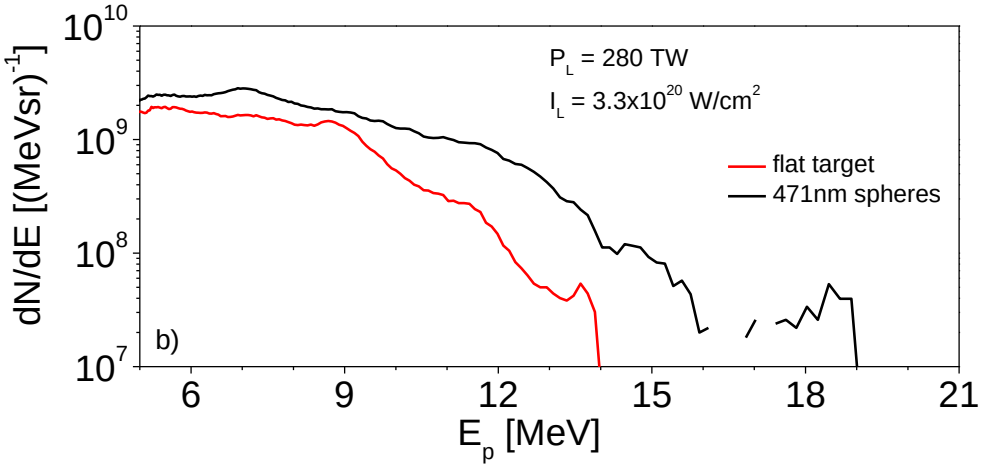


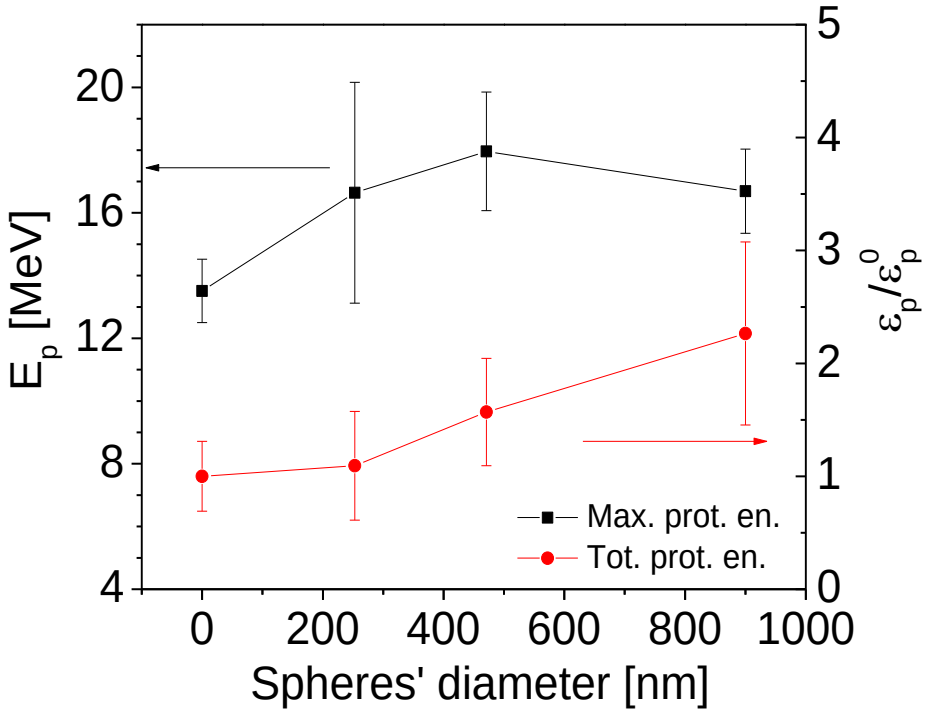
3 MeV energy steps, 17 films



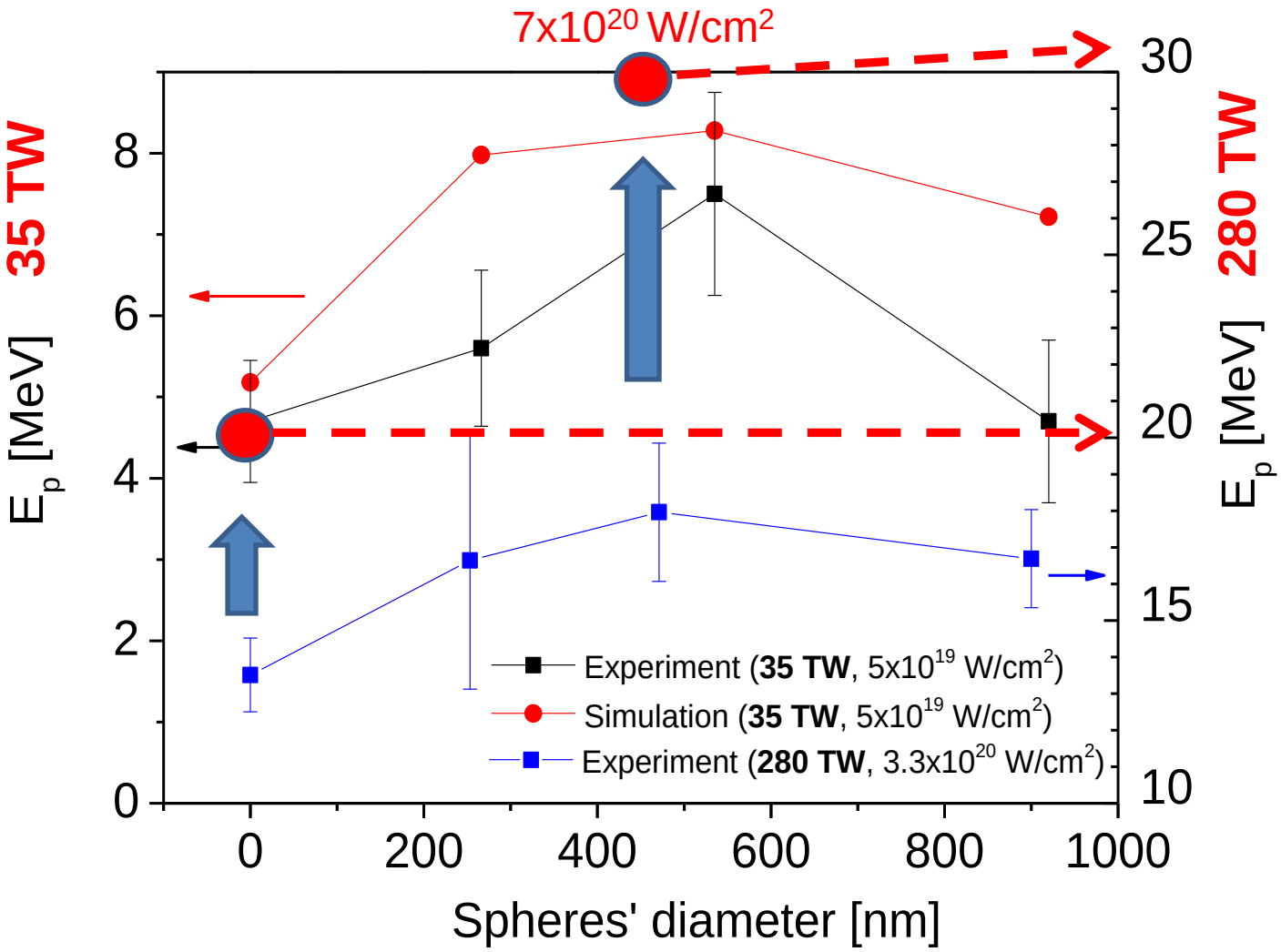
Nanospheres optimization @ 280 TW

P_L = 280TW
I_L ~ 3x10^{20}





Recent results at higher intensity…



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Enhanced-TNSA @ 500 TW (?)
Different structures (?)

P_L = 280TW; I_L ~ $7x10^{20}$ → P_L = 500TW; I_L ~ $7x10^{21}$

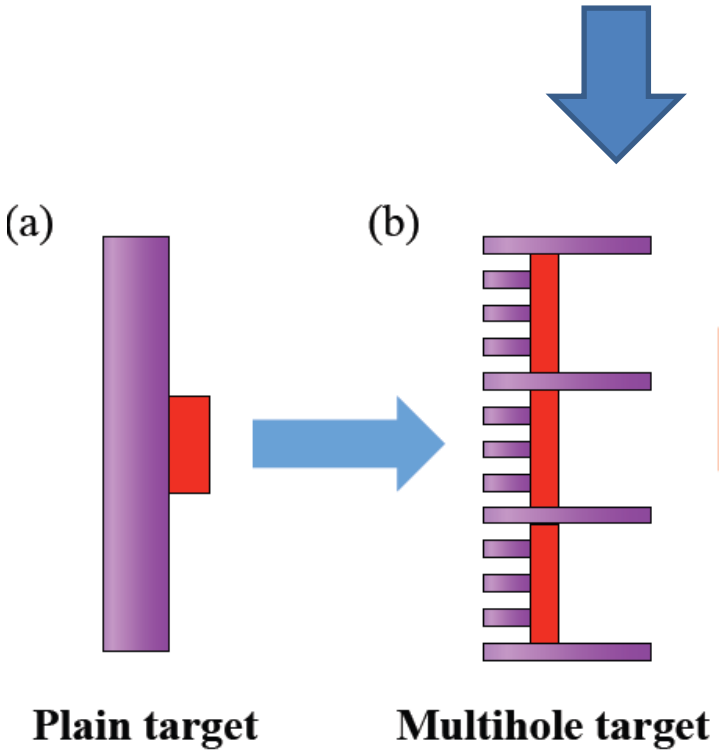
2D PIC simulations, 15 J, 30 fs, 3 μm (FWHM), CH_2 (200 n_c electrons density), normal incidence

	max. energy	proton number (28.5; 31.5) MeV	proton number (57; 63) MeV
Planar 1 μm thick	85 MeV	$7.7x10^9$	$1.4x10^9$
530nm spheres 1 μm thick	95 MeV	$2.2x10^{10}$	$5.3x10^9$
1.6 μm grating 1 μm thick	140 MeV	$1.1x10^{10}$	$9.4x10^9$

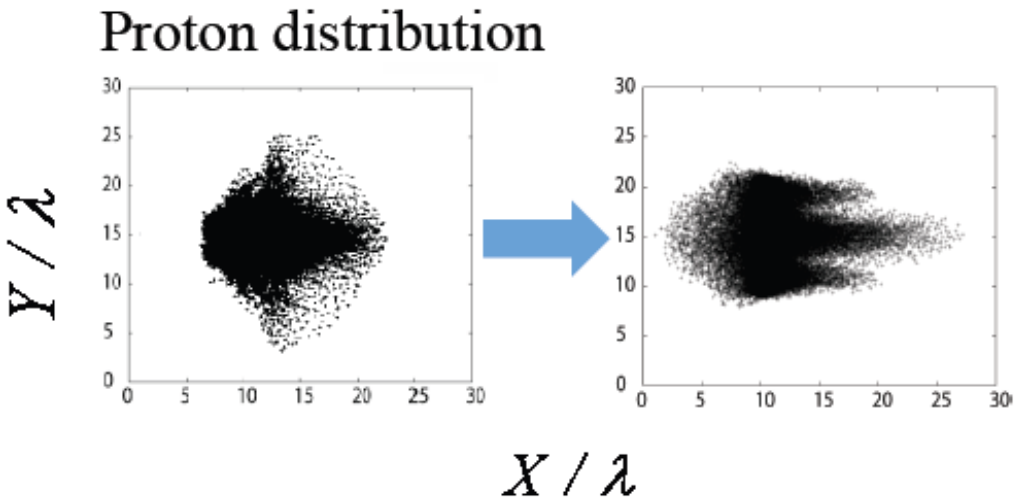
Courtesy of J. Psikal

Decreasing beam divergence (?)

Micron-size structures on the target rear-side (!)



Courtesy of S. Kawata



K. Takahashi et al., Phys. Plasma 10 (2012) 0931102

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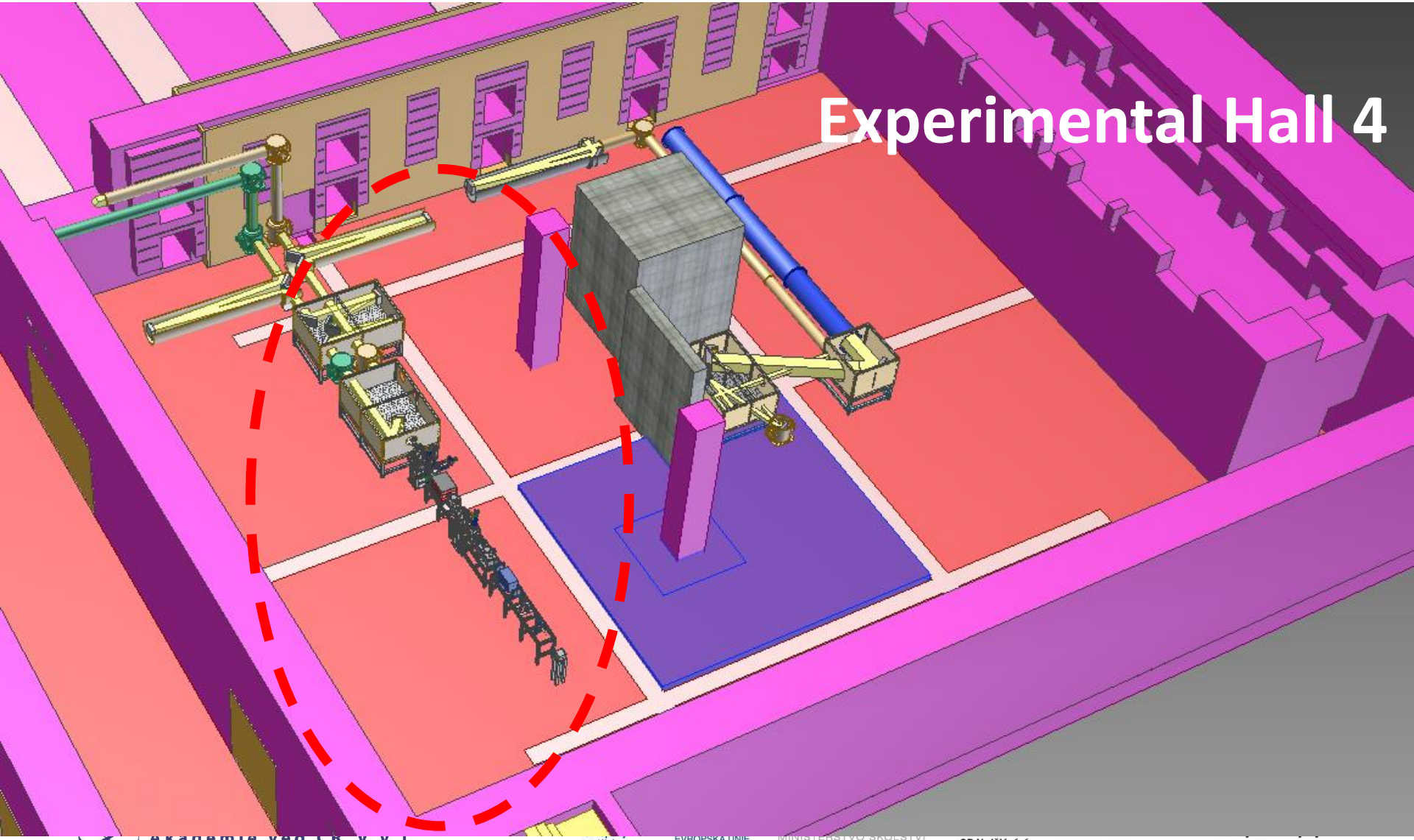
The ELIMAIA beamline: ELI Multidisciplinary Applications of laser-Ion Acceleration



ELIMAIA goals

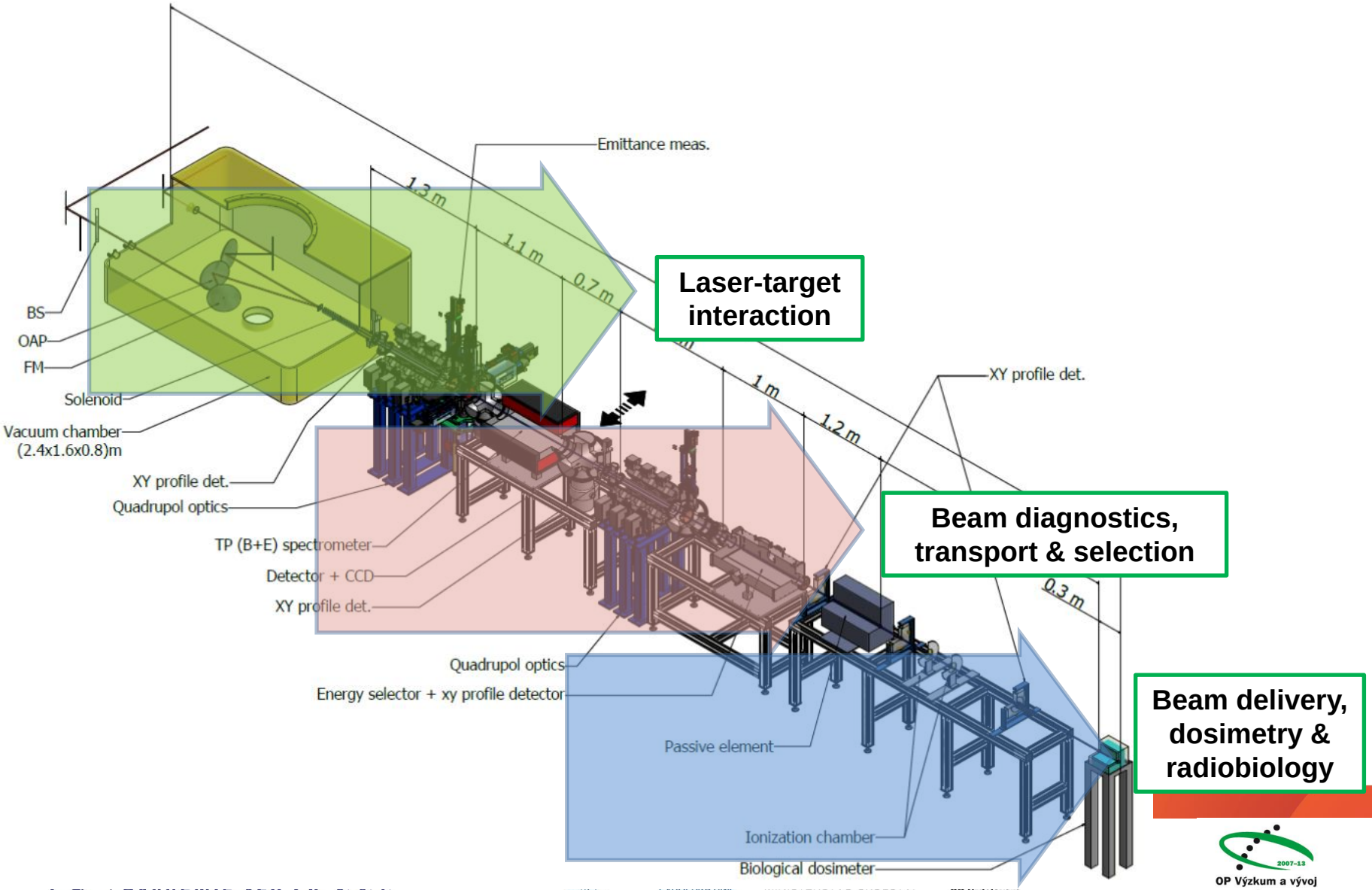
Realization of a multidisciplinary facility by laser-driven ion beams

- Irradiation of biological and other samples
- Radiation damage on different components
- Demonstration of new irradiation modalities for radiotherapy
- Detectors characterization
- Pump probe investigations
- Proof-of-principle experiments towards future hadrontherapy facilities

What users generally require:

- Wide energy and fluence range
- Homogeneous lateral beam distribution
- Stability in terms of energy and fluence distributions
- Variable beam spot size (from 2 mm up to 40 mm)
- Beam control (diagnostic and dosimetry) with < 5% errors
- Possibility of in-air irradiation
- Different ion species

The ELIMAIA Beamline



The ELIMED international cooperation

TÉCNICO LISBOA

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

SAPIENZA UNIVERSITÀ DI ROMA

Queen's University Belfast

KPSI Kansai Photon Science Institute

FONDAZIONE

Berkeley UNIVERSITY OF CALIFORNIA

Fyzikální ústav Akademie věd ČR, v. v. i.

eli beamlines

2nd ELIMED Workshop and Panel, 18-19 October 2012 @ INFN-LNS, Catania

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Volume 1546

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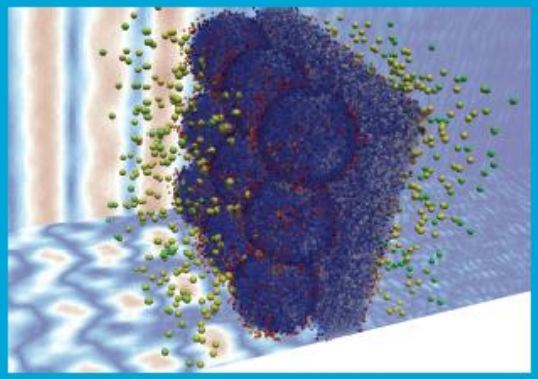

Catania, Italy
18-19 October 2012

Editors
Daniele Margarone, Pablo Cirrone, Giacomo Cuttone and Georg Korn

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A successful international collaboration...

- Institute of Physics of the ASCR (ELI-Beamlines and HiLASE projects), Prague:
  D. Margarone, J. Prokupek, T. Mocek, T. Levato, N. Pathak, M. Krus, J. Kaufman, G. Korn
- Czech Technical University in Prague:
  O. Klimo, J. Psikal, J. Proska, L. Stolcova, J. Limpouch
- CoReLS-APRI:
  I.J. Kim, H.T. Kim, K.H. Nam, I.W. Choi, J.H. Sung, S.K. Lee, T.J. Yu, T.M. Jeong

Thank you for your kind attention!