Spatial profile modulation of a proton beam generated by laser interacting with micro-structured targets

Lorenzo Giuffrida

The 3rd ELIMED Workshop MEDical and multidisciplinary applications of laser-driven ion beams at ELI-Beamlines. 7-9 September 2016 Laboratori Nazionali del Sud of INFN, Catania (Italy)

EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research, Development and Education
MINISTRY OF EDUCATION YOUTH AND SPORTS

Collaborations

Institute of Physics ASCR, v.v.i (FZU), ELI-Beamlines project, Prague, Czech Republic

J. Psikal, D. Margarone, P. Lutoslawski, J. Kaufman, V. Scuderi, T. Lastovicka, T. Wiste and G. Korn.

Department of Physics, Lund University, Lund, Sweden

K. Svensson, I. Gallardo Gonzalez, H. Ekerfelt, M. Dalui, O. Lundh, A. Persson, C.-G. Wahlström.

Laboratory Nazionali del Sud, INFN, Catania, Italy

G. Milluzzo, G.A.P. Cirrone and M. De Napoli

Micro-Nano Facility, Fondazione Bruno Kessler, Trento, Italy

A. Picciotto, A. Bagolini, M. Crivellari and P. Bellutti

Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

J. Magnusson and A. Gonoskov

Department of Functional Materials. Institute of Physics of the ASCR

L. Klimša and J. Kopeček

Summary

- **<u>Nanosphere targets</u>**:
  - Previous achievements;
  - Our experiment @ LLC

- **<u>Grating targets</u>**:
  - Experimental results vs PIC simulations

- Conclusions

- **<u>Nanosphere targets</u>**:
  - ➢ Previous achievements;
  - ➢ Our experiment @ LLC
- **<u>Grating targets</u>**:
  - ➢ Experimental results vs PIC simulations
- Conclusions

EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research,
Development and Education
MINISTRY OF EDUCATION
YOUTH AND SPORTS

Previous achievements:
Experiment @ APRI GIST (Korea) up to 280 TW

Laser parameters (with PM)

- power/intensity:
  → up to 280 TW, **7x10^{20}** W/cm^2
- Pulse duration : **30 fs**
- Wavelength: 805 nm
- Polarization: p
- Spot diameter: 5 μm (FWHM)
- main/pedestal contrast:

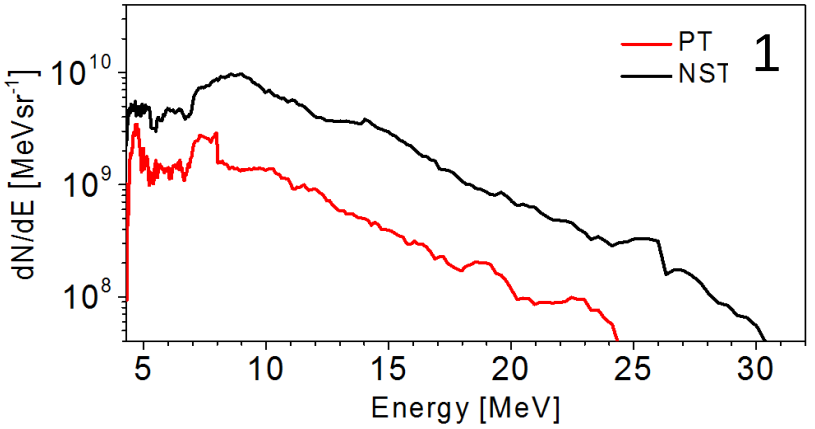
→ ~**5x10^{11}** @ 6 ps

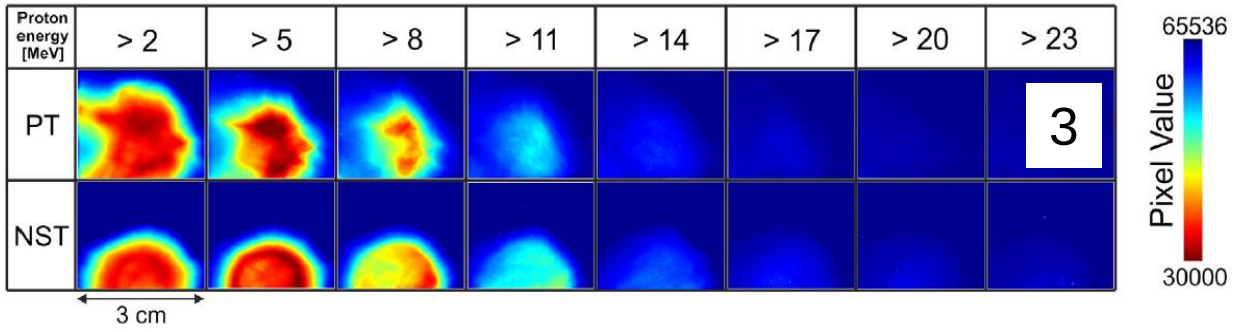
Main achievements of NS targets:

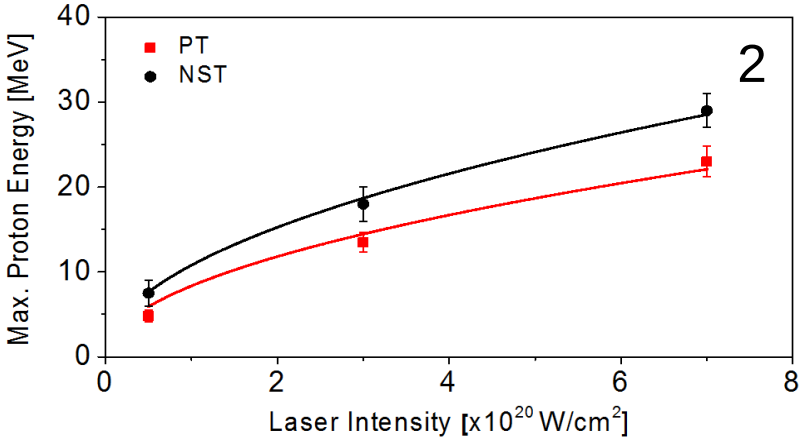
1. Enhancement of the max energy;

2. Enhancement of the number of protons;

3. Better homogeneity







For more information read:

- D. Margarone et al. PRL 109, 234801 (2012)
- D. Margarone et al. PRST 18, 017304 (2015)

- **Nanosphere targets**:
  - Previous achievements;
  - Our experiment @ LLC
- **Grating targets**:
  - Experimental results vs PIC simulations
- Conclusions

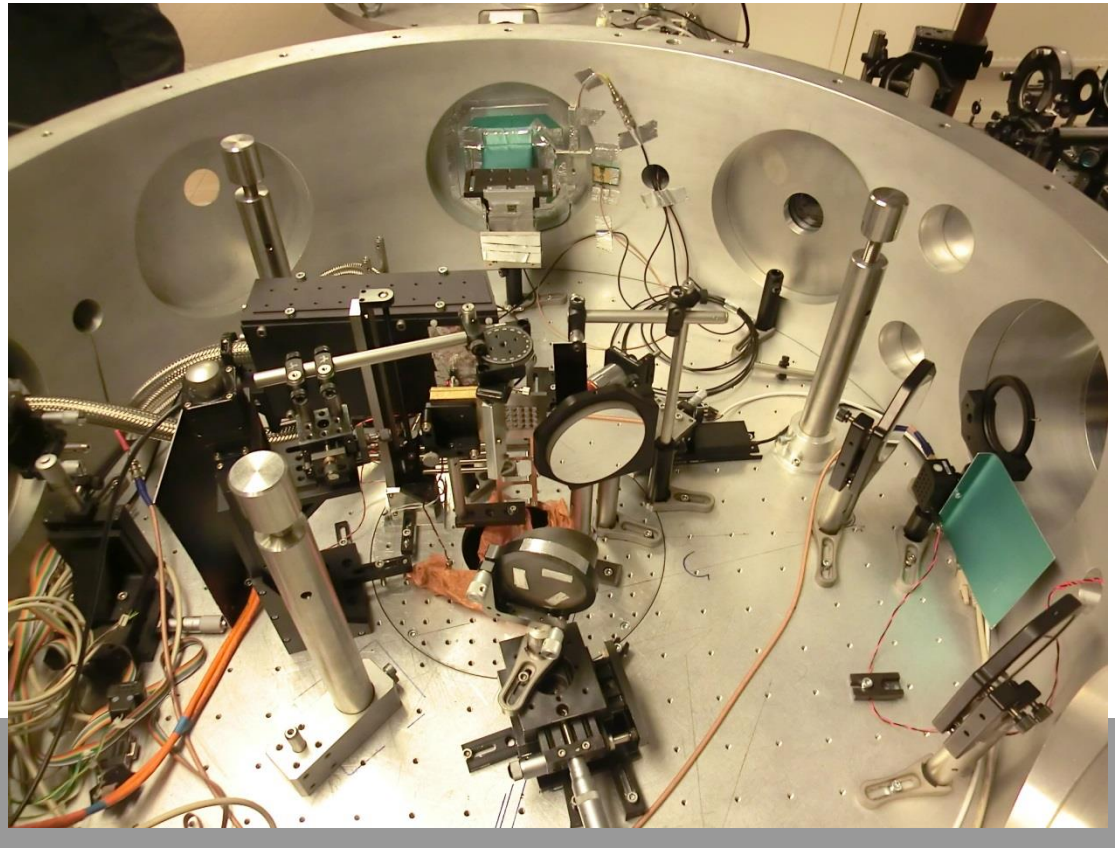
EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research,
Development and Education
MINISTRY OF EDUCATION
YOUTH AND SPORTS

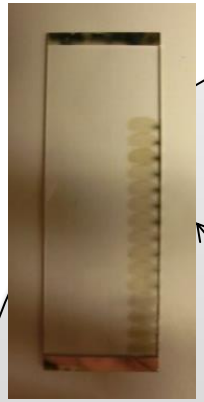
Experiment @ LLC

Laser Lab experiment, LLC0002134. PI: Lorenzo Giuffrida

Laser parameters

- E_L (before compression) = 2 J
- E_L (on target, after PM) = 475 mJ
- Time duration: 38 fsec
- Laser contrast (w/o PM): 10^9 at ps level
- Laser spot (FWHM) = 3,5 μm
- Intensity on target: $4*10^{19}$ W/cm^2





Plasma Mirror

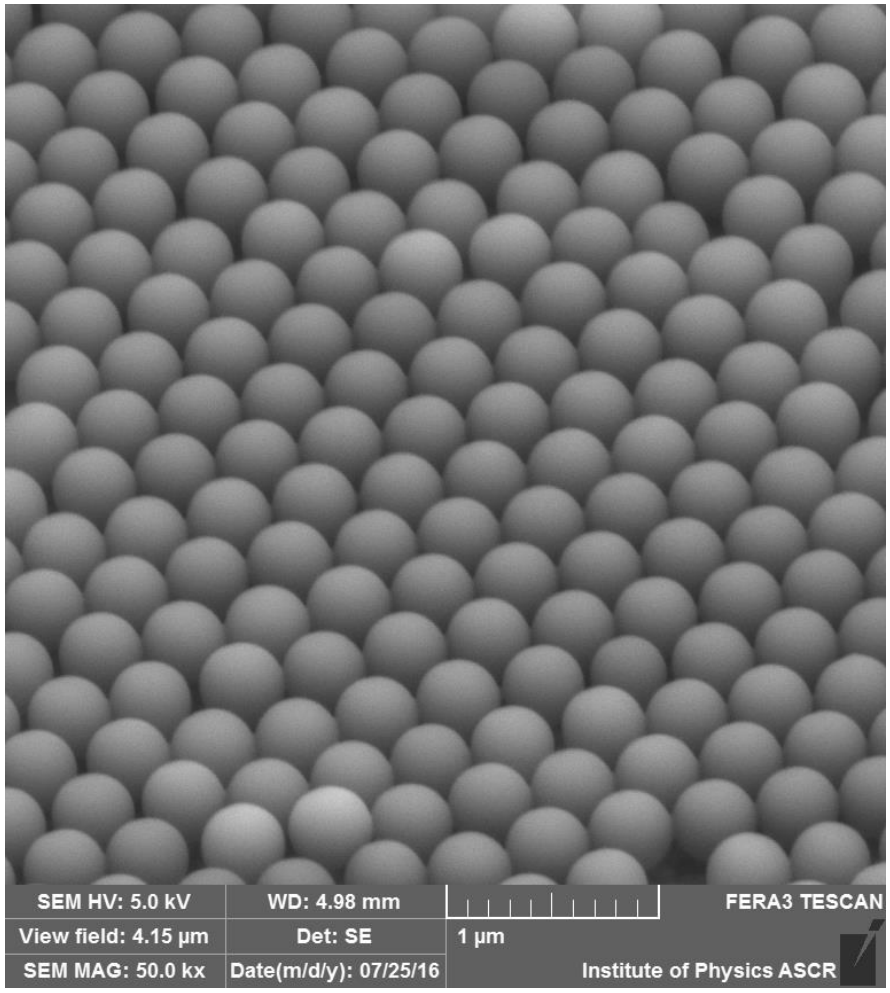
Energy spectrometer and CVD detector

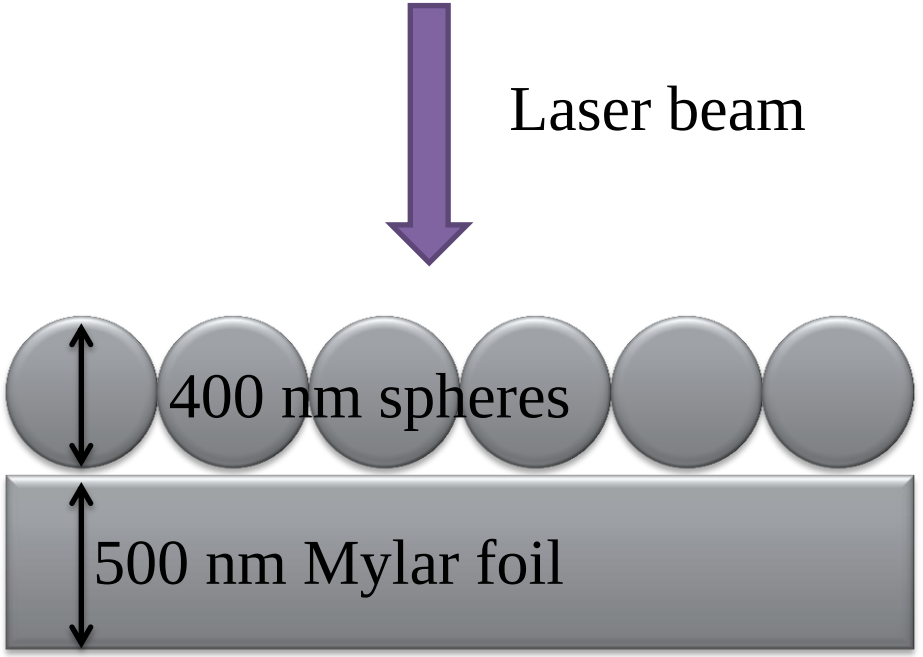
For energy measurements

RCF

For spatial profile measurements

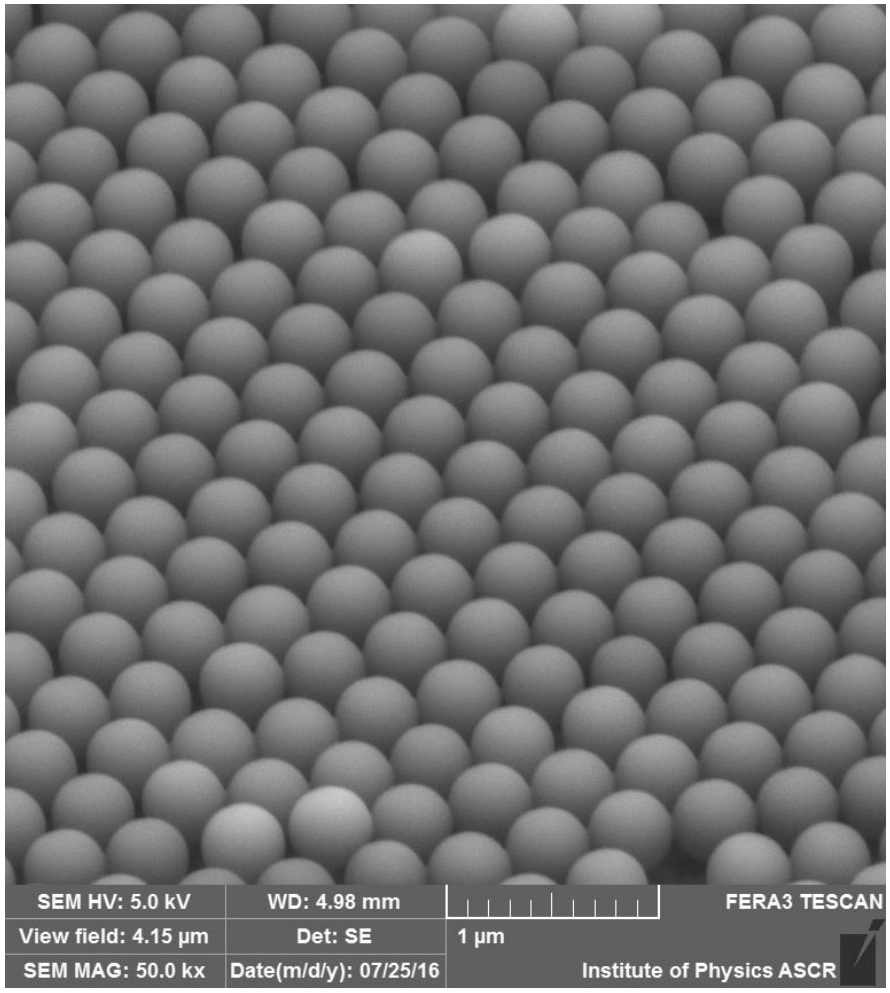
Experiment @ LLC
Nanospheres targets

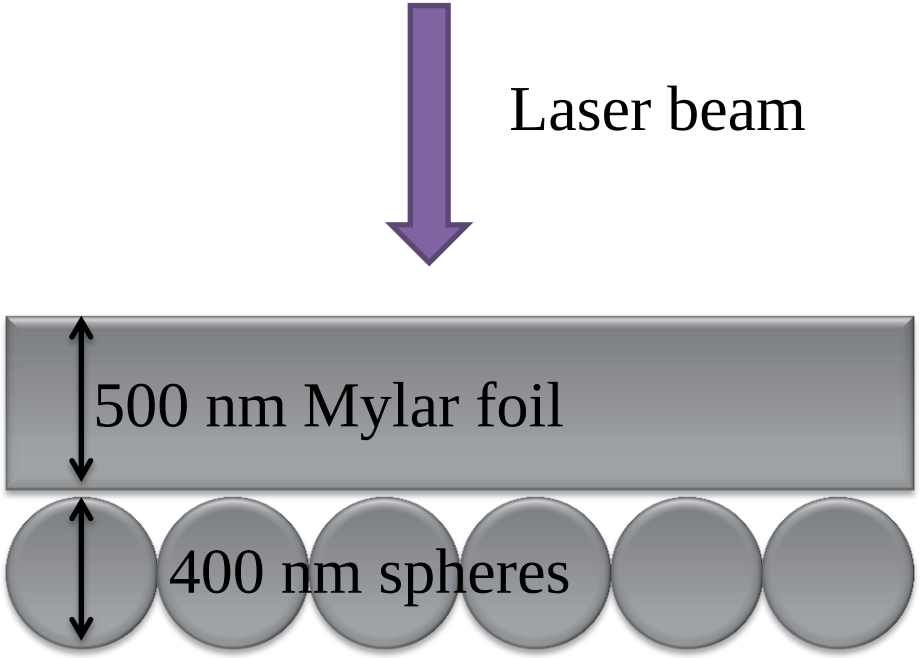




NS on the front surface of the target

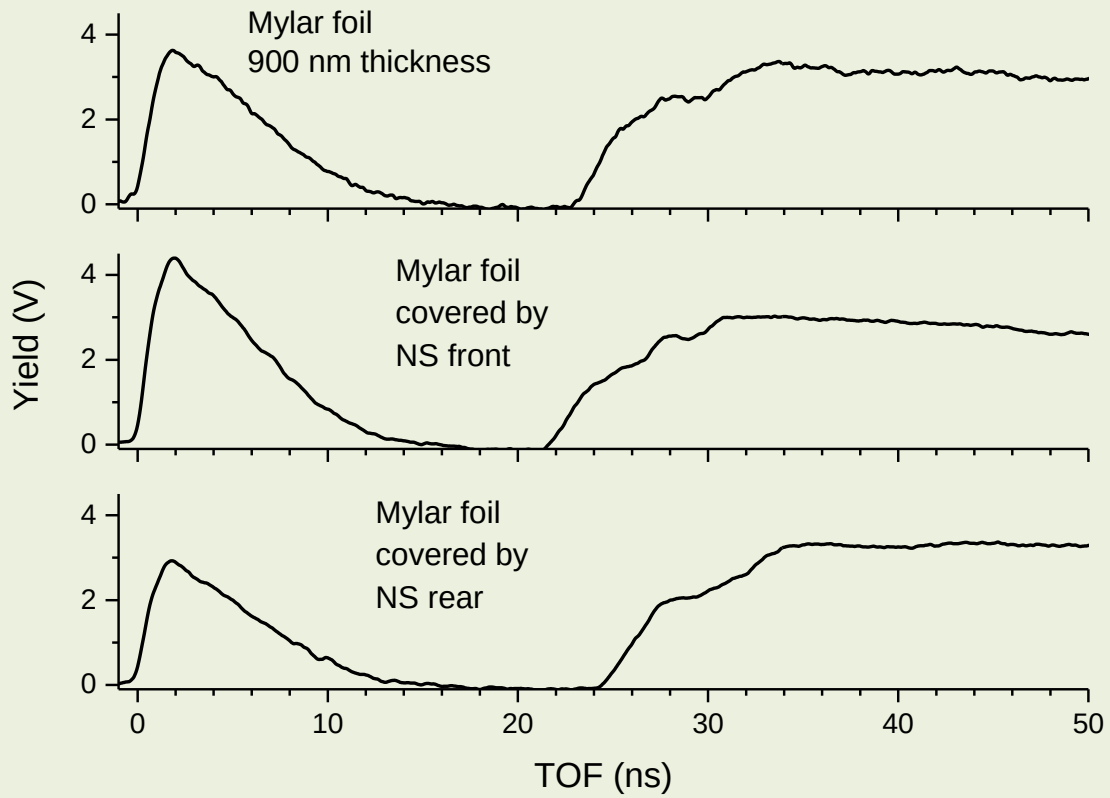
Experiment @ LLC
Nanospheres targets





NS on the rear surface of the target

Experiment @ LLC
TOF measurements



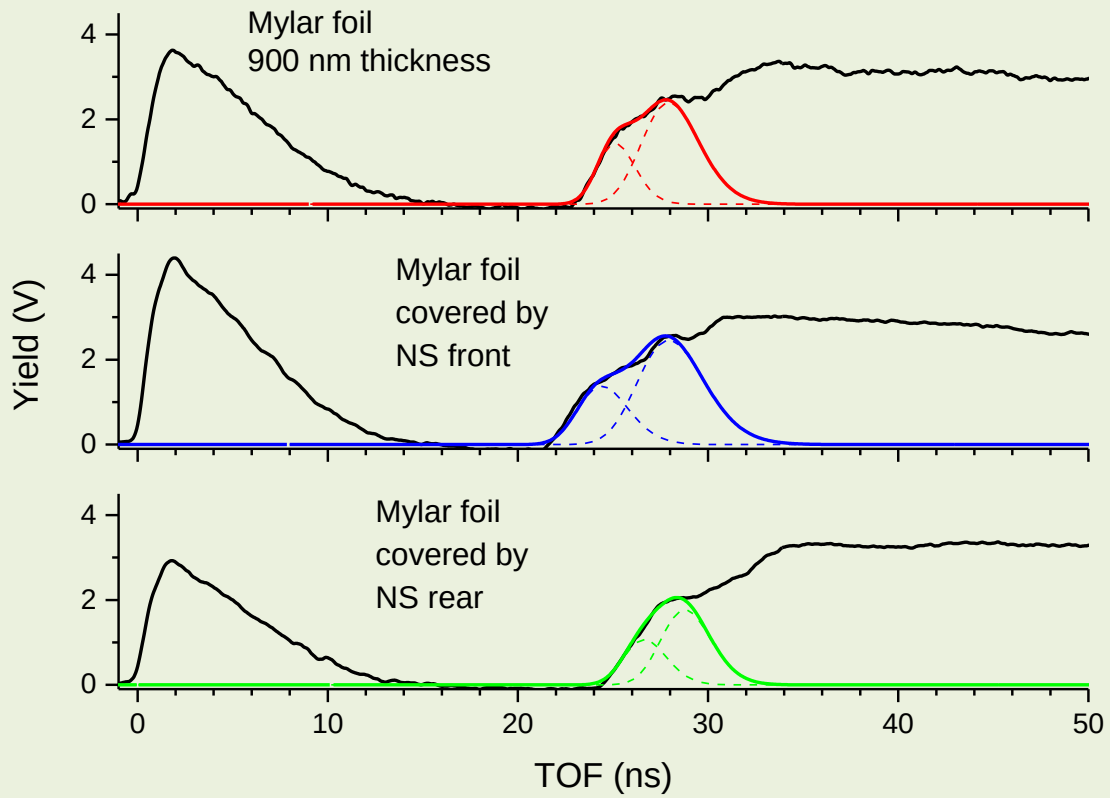
CVD detector @ 9°, 56 cm

Proton and ion signal is partially overlapped

What about protons???

Deconvolution by Maxwell-Boltzmann shifted functions

Experiment @ LLC
TOF measurements

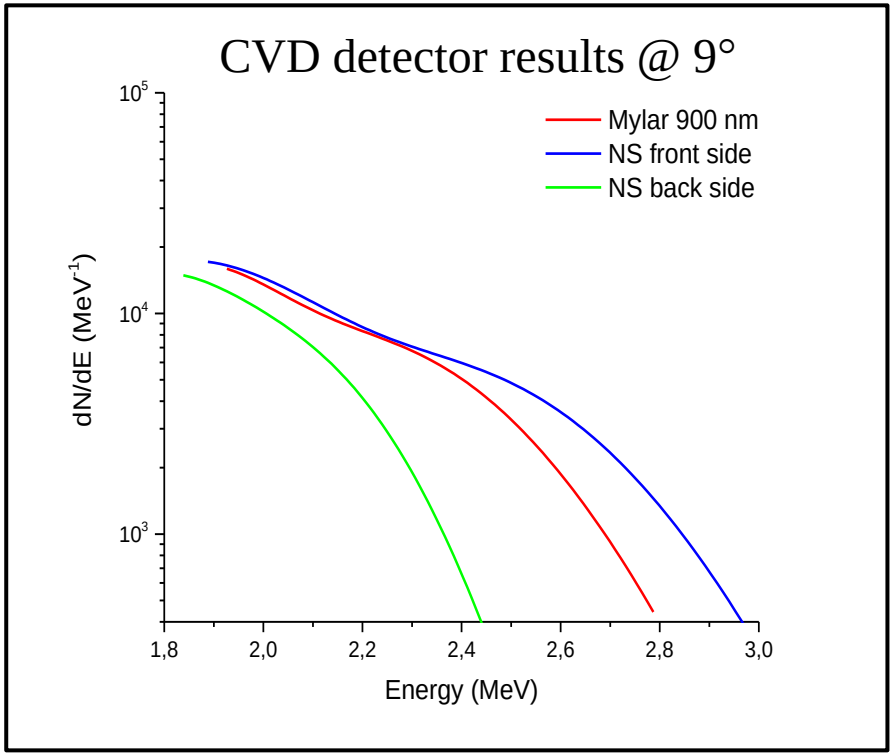


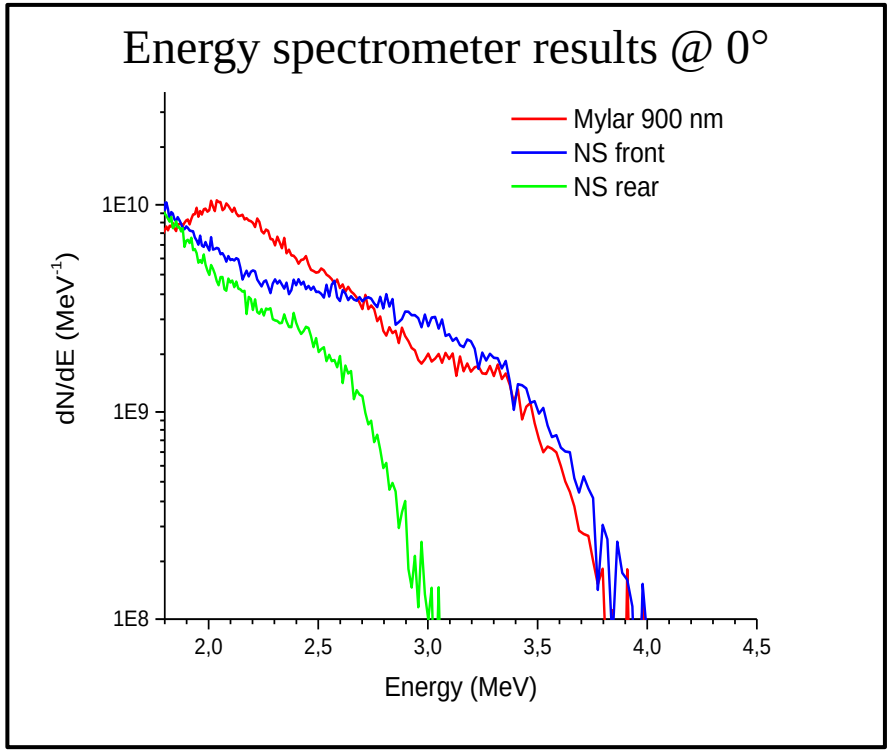
Colored curves are estimation of the proton signal

for the energy distribution dN/dε

$$\frac{dN}{d\varepsilon[eV]} = \frac{\varepsilon_G[eV]U(t)[V]}{e[C]R[\Omega]\varepsilon^2[eV]}\left(-\frac{1}{2}t[s] - \delta t[s]\right)\frac{\Omega_{BEAM}[sr]}{\Omega_{DETECTOR}[sr]}$$

Experiment @ LLC
Energy distribution





	Spectrometer	CDV
	E_{max}(MeV)	E_{Max}(MeV)
Mylar foil	3,8	2,8
NS front	4	3
NS rear	3	2,4

Remarks

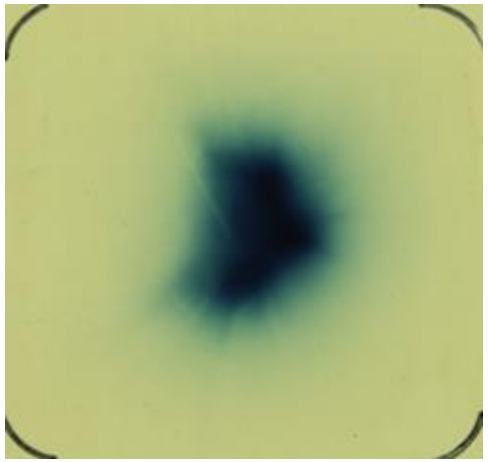
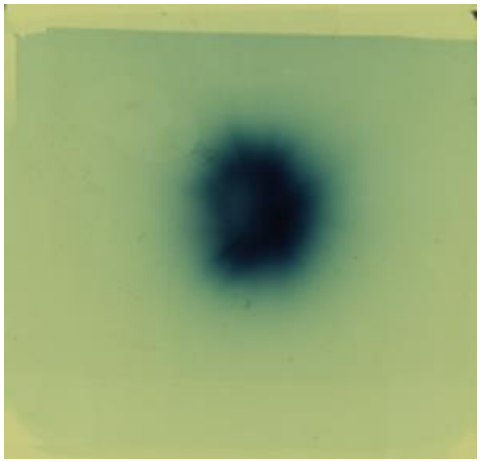
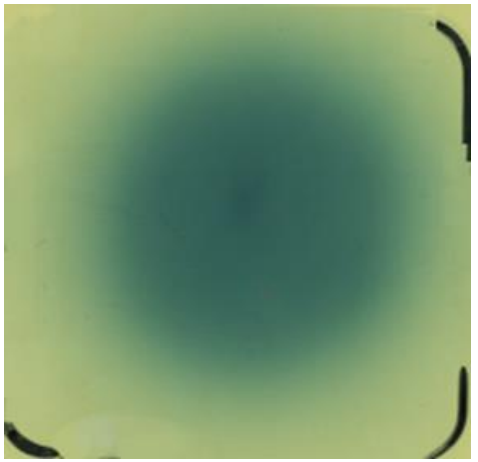
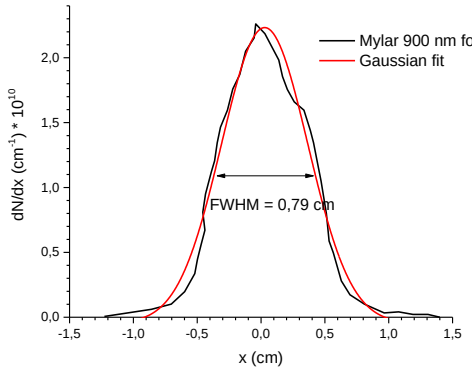
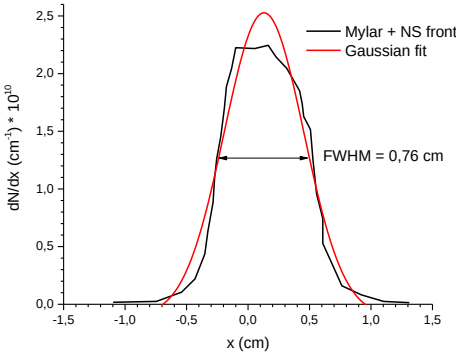
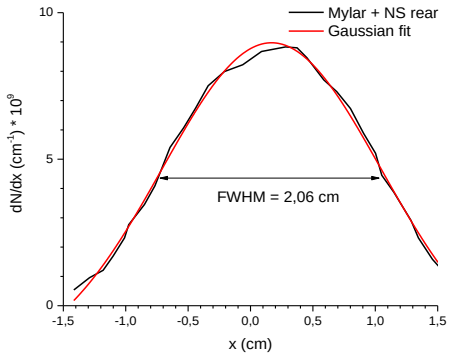
- ✓ No enhancement in NS front targets;
- ✓ E_{max} in NS rear target is lower.

Because 45° laser-target *(in agreement with J. Appl. Phys. 114, 083305 (2013).)*

smaller homogeneity in the electric field

smaller efficiency on the acceleration mechanism

Experiment @ LLC
Spatial distribution

Mylar 900 nm	NS front side	NS rear side
		
		

Divergence	5°	4,3°	10,3°
Inhomogeneity	16%	11%	8%
Protons	1,9e10	2,4e10	1,7e10

EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research,
Development and Education
MINISTRY OF EDUCATION
YOUTH AND SPORTS

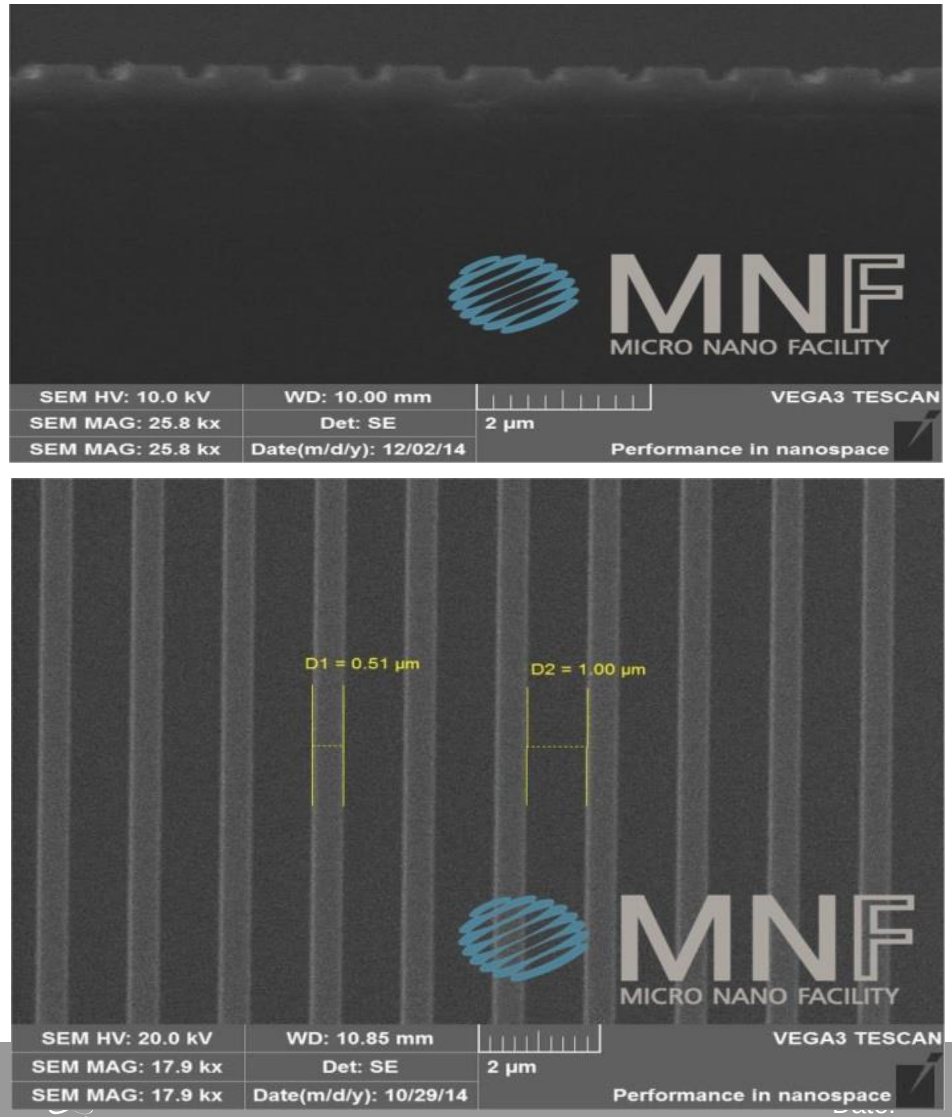
- **Nanosphere targets**:
  - Previous achievements;
  - Our experiment @ LLC

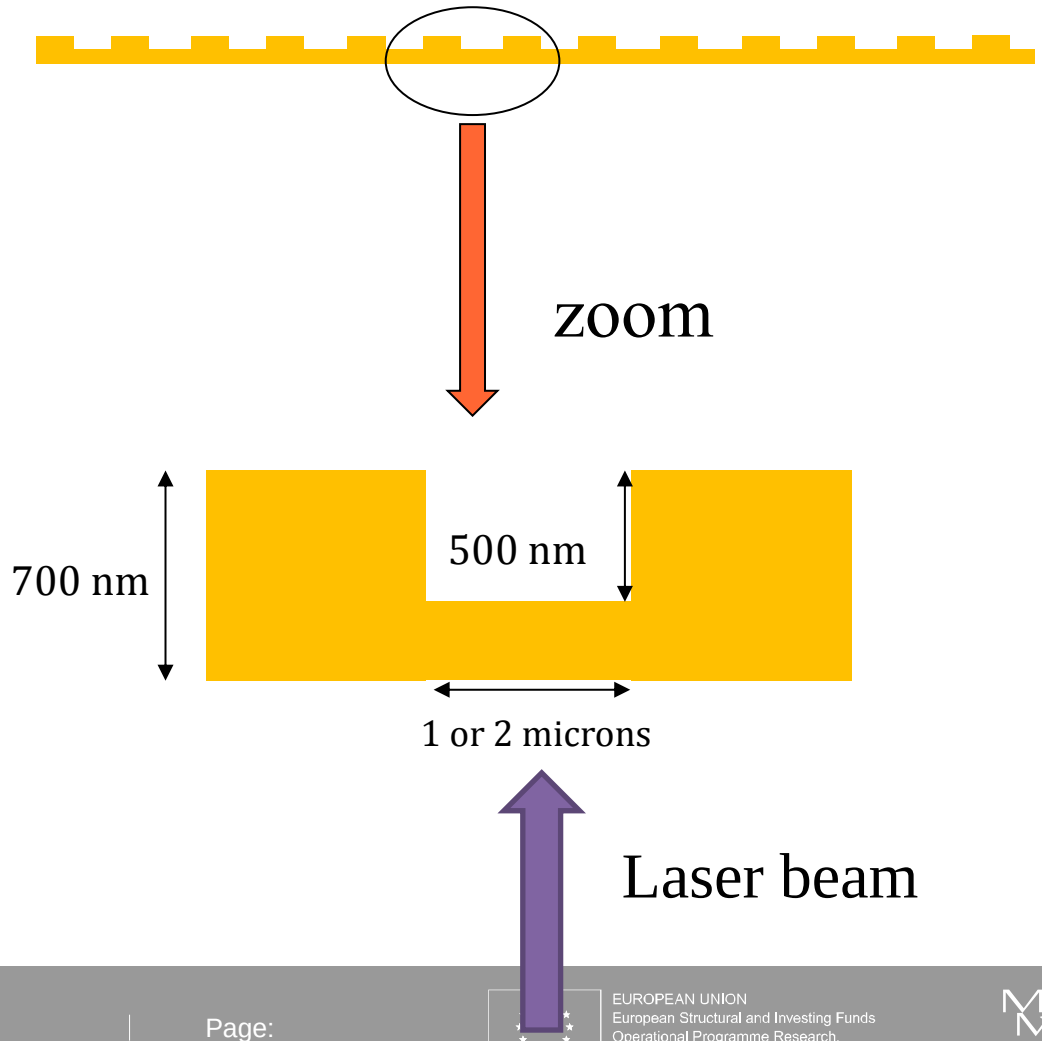
- **Grating targets**:
  - Experimental results vs PIC simulations

- Conclusions

EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research,
Development and Education
MINISTRY OF EDUCATION
YOUTH AND SPORTS

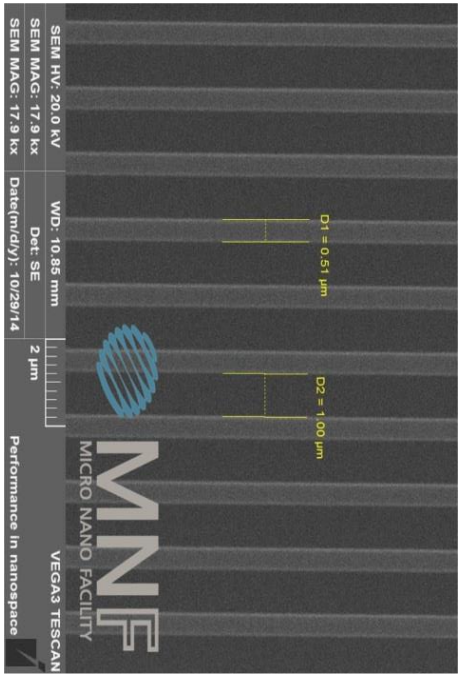
Experiment @ LLC
Grating targets



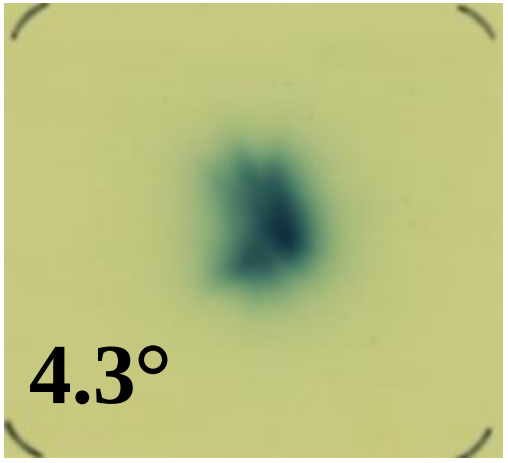


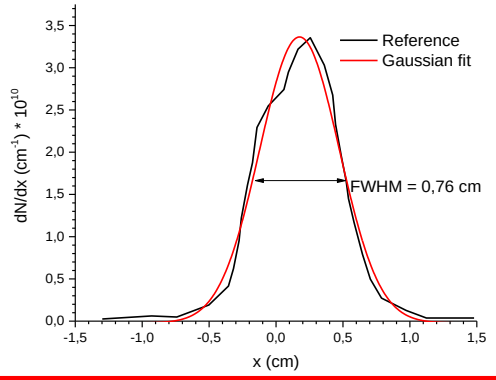
EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research,
Development and Education
MINISTRY OF EDUCATION
YOUTH AND SPORTS

Experiment @ LLC
Spatial distribution

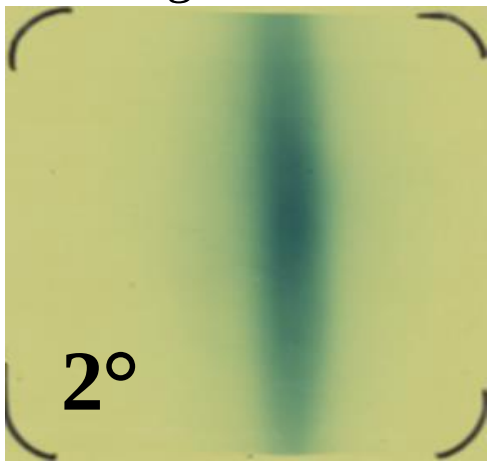


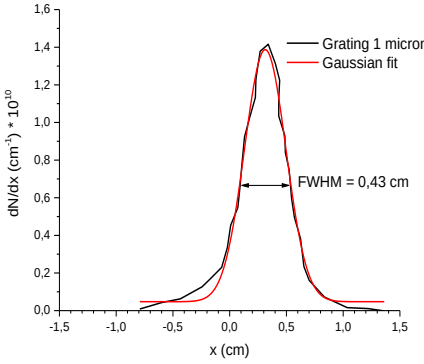
Reference



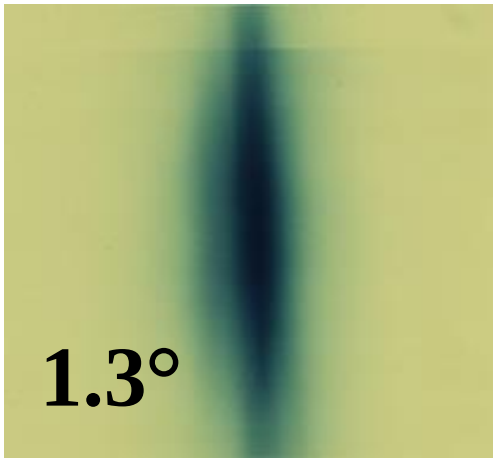


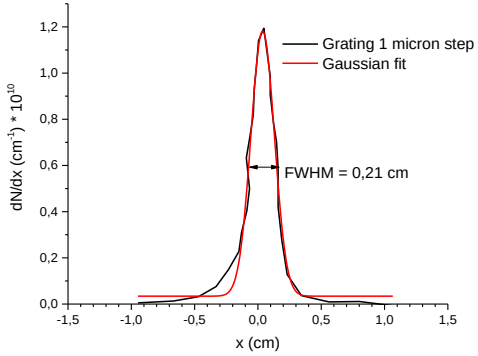
Grating 1 micron





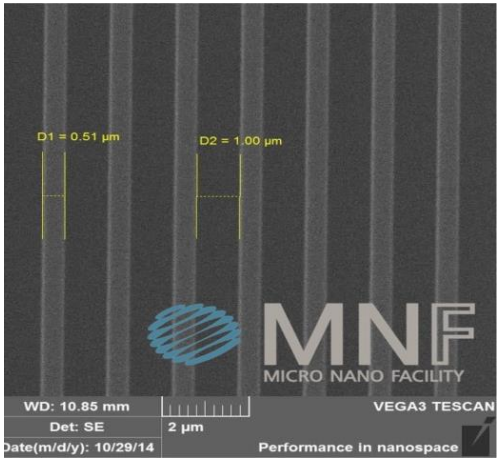
Grating 2 micron



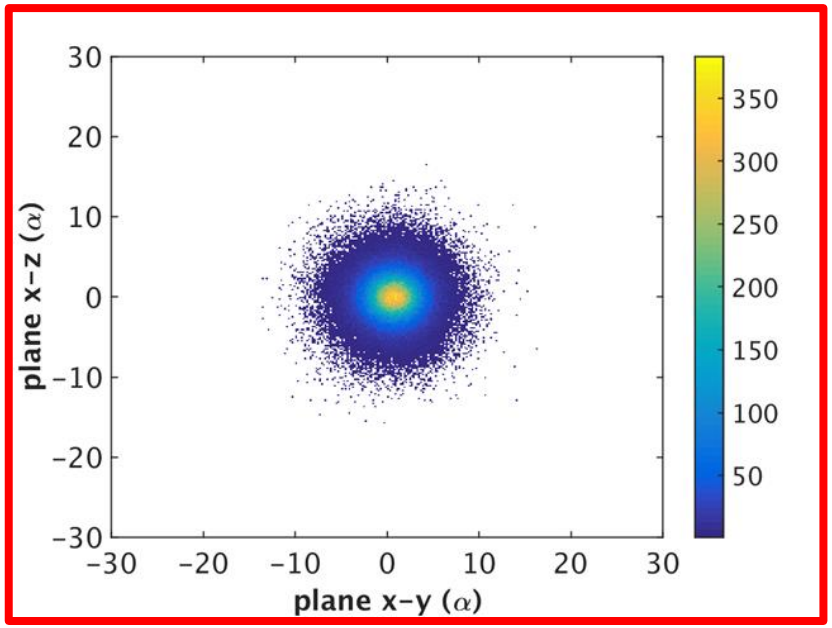


- Divergence **reduced parallel** to the grating orientation
- **Stretched** beam **perpendicular** to the grating orientation

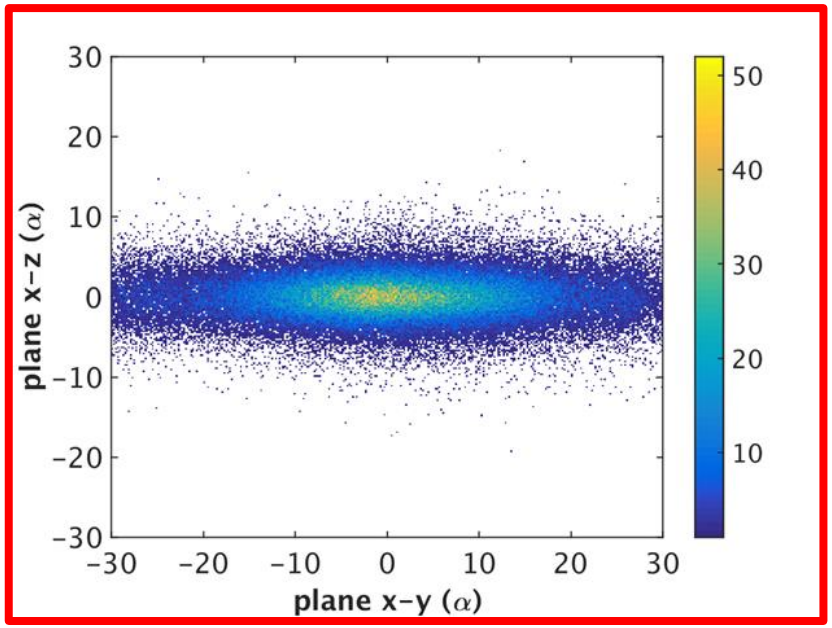
Experiment vs 3D PIC simulations



Reference target



2 μm grating target



In flat foil proton beam ~3 times denser

larger Coulomb repulsion and thermal expansion by hot electrons

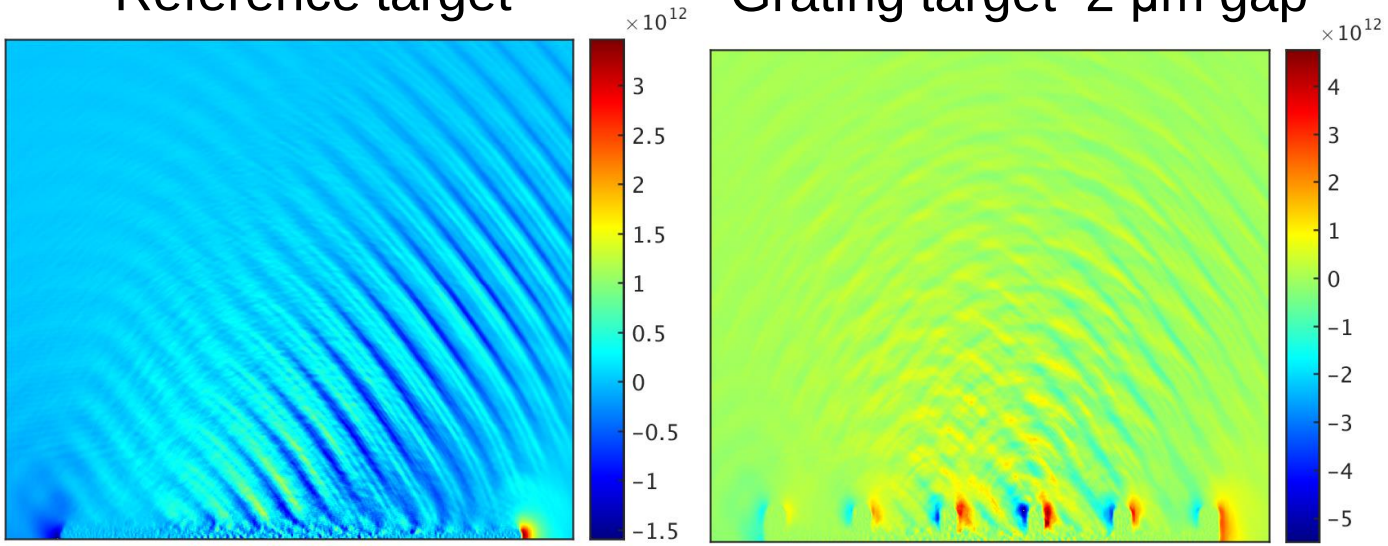
increasing the beam divergence

3D PIC simulations: Electric field E

Reference target

Grating target 2 μm gap

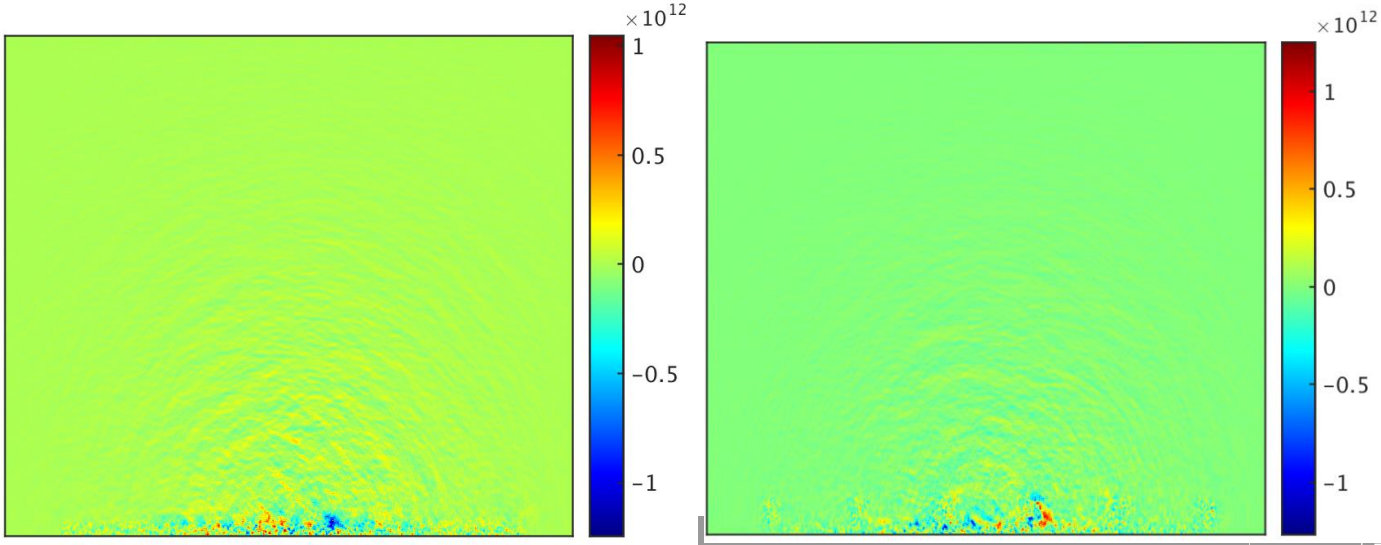
E ⊥ grating



Transverse component of E

broader angular distribution of protons (stretching effect)

E ∥ grating



E field similar

No difference in term of divergence

EUROPEAN UNION
European Structural and Investing Funds
Operational Programme Research, Development and Education
MINISTRY OF EDUCATION YOUTH AND SPORTS

Conclusions

Mylar covered by NS targets

1. ***NS front targets***
   - ✓ **Enhancement of the homogeneity**; ☺
   - ✓ **Enhancement of the proton dose**; ☺
   - ✓ **No enhancement in the maximum proton energy** ☹
2. ***NS rear targets***
   - ✓ **Enhancement of the homogeneity**; ☺

Grating targets

1. **Reduced proton beam divergence parallel to the grating orientation**; ☺
2. **Stretched proton beam perpendicular to the grating orientation**. ☺

Spatial profile modulation and control with target engineering

Applications???

Thank you!


DANKSCHEEN
SPASSIBO
SNACHALHUYA
NUHUN
CHALTU
TASHAKKUR ATU
YAQHANYELAY
YUSPAGARÀTAM
TINGKI
BİYAN
SHUKRIA
GRACIAS
WABEEJA
MAITEKA
HUI
SUKSAMA
EKHMET
DHANYABAAD
ANIHA
ATTO
MERSI
SPASIBO
DENKAUJA
NENACHALHIYA
UNALCHÉÉSH
GUI
HATUR
EKOJU
SIKOMO
THAN
ARIGATO
SHUKURIA
SANCO
MERASTAWHY
GAEJTHO
TAVTAPUCH
MEDAWAGSE
GOZAIMASHITA
EFCHARISTO
AGUYJE
FAKAAUE
KOMAPSUMNIDA
MAAKE
LAH
GRAZIE
MEHRBANI
PALDIES
YOU
MAKETAI
MINMONCHAR
BAIKA
JUSPAXAR
BOLZÏN
MERCI