High Repetition Target Systems and Novel Techniques for Proton Acceleration

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Key Laboratory for Laser Plasmas , SJTU

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Max-Born Institute

Laboratory for Laser Plasmas

Minhang Campus of SJTU

Established in 2010 as a key laboratory of the Ministry of Education **(Director: Prof. Liejia Qian)**

Currently with 28 research staffs and about 50 graduate students

Research Groups:

- **High energy density physics (group leader: J. Zhang)** → **Laser plasma based particle acceleration and radiation, laboratory astrophysics**
- Ultrafast electron beam and applications (group leader: X. Wang)
- Solid sta
- Nonline F. Chen)
- Laser Er r: J.Q. Xu)
- Theory and simulation group (group leader: Z.M. Sheng)

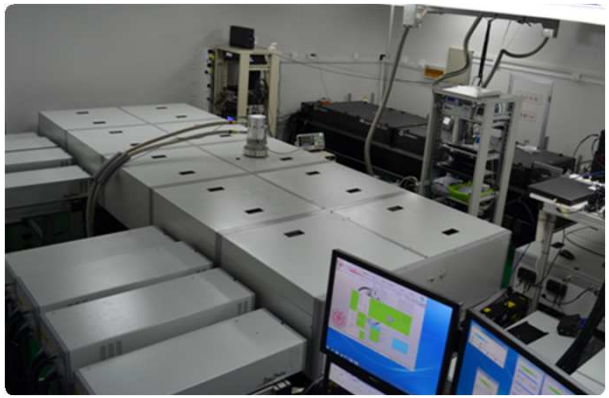
Looking for talented Postdocs and PhD. Students

Sokollik@sjtu.edu.cn

T. Sokollik	**exp. group leader**
N. Hafz	**e-acceleration**
X.H. Yuan, F. Liu	**ion-acceleration**

Laboratory (200TW)

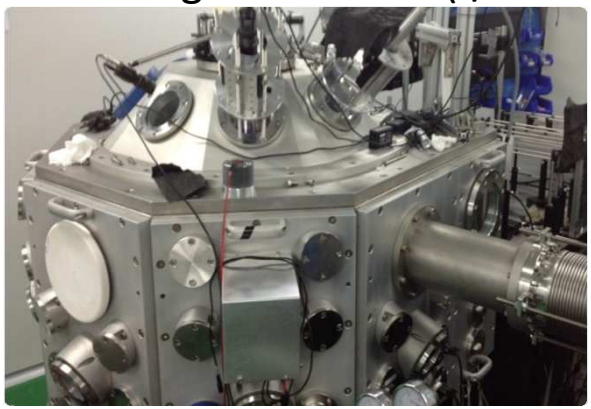
200TW laser System



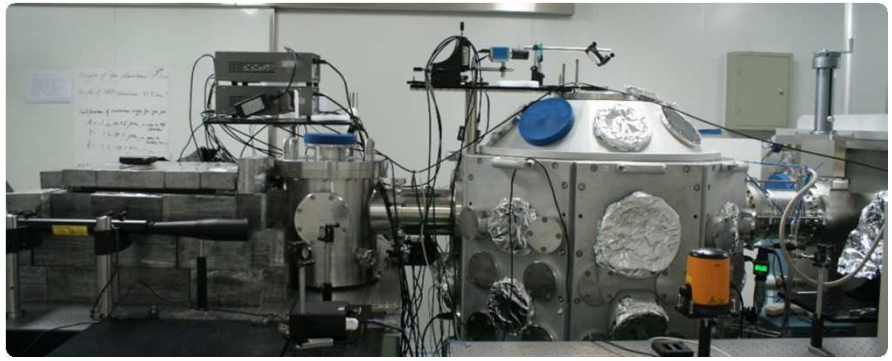
5J, 25fs, contrast 10^{10}-10^{9}

Experimental Areas

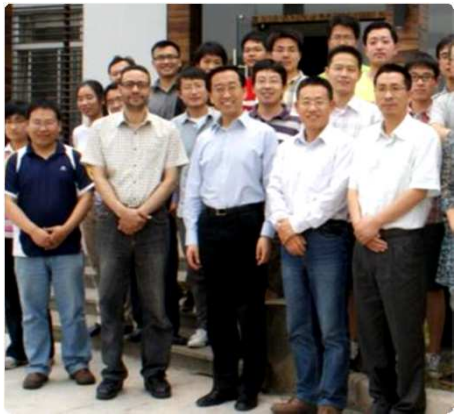
Solid Target Chamber (f/4 OAP)



Gas Target Chamber (f/20 OAP)



Our Team



High Repetition Target Systems and Novel Techniques for Proton Acceleration

Can laser driven Ion sources be used for real world applications?

Technical Requirements of the source:

- Stability
- Energy
- Flux
- Availability of source (ON-hours)
- (Tailored energy spectra)

For real world applications of laser driven proton beam High repetition target system are required.

- High repetition rate (rep. rate of laser system)
- Large number of shots
- Debris management or debris free

With laser repetition rates increasing in the future (e.g. ICAN) a sufficient target system has to be found.

Advantages:

- Statistics, correlation between laser fluctuations and proton spectra
- Novel Techniques: e.g. Online optimization using evolutionary algorithms

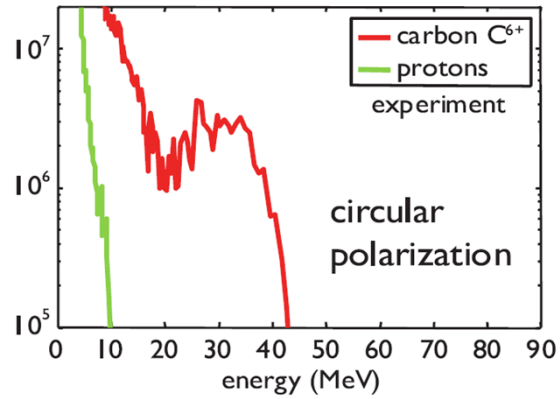
What target systems can we use for high repetition operation?

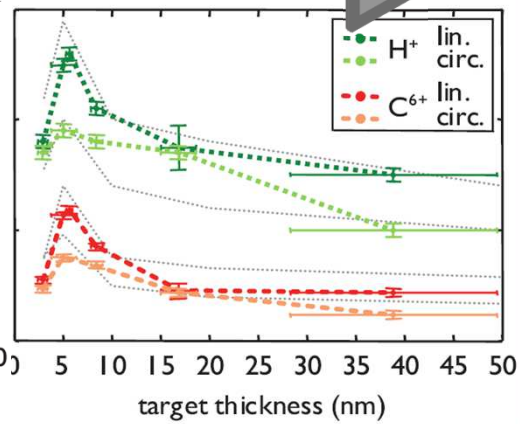
Target Systems

- Ultra thin foils ⇒ RPA
- Low density ⇒ NCD
  (Foam, expanded Foils, gas)
- Small Targets ⇒ MLT
  (spherical, planar)

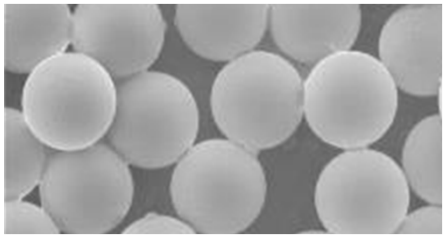
Ultra thin foils Berlin (MBI+MPQ) exp: 5nm

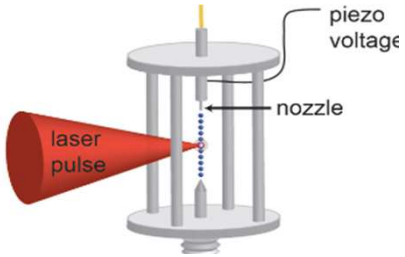
A. Henig *et al.*, PRL 103, 245003 (2009)

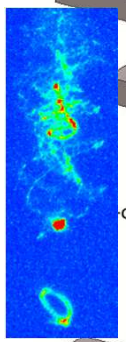




Mass limited targets





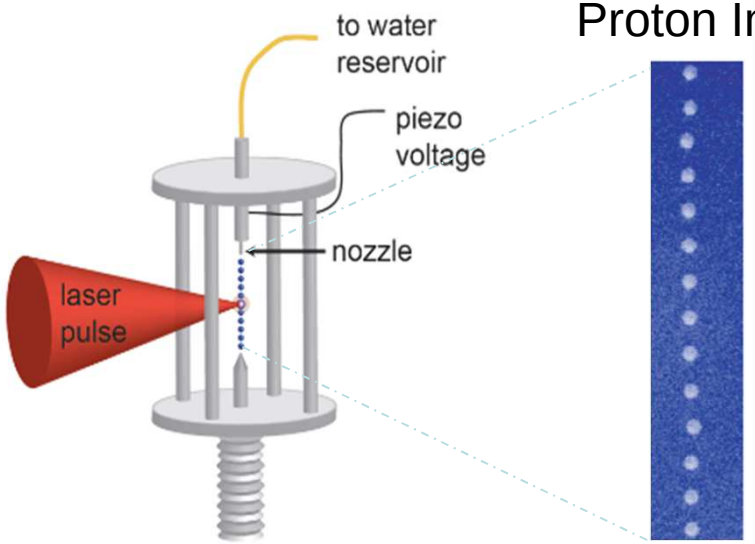


T. Sokollik *et al.* PRL 103, 135003 (2009)

T. Sokollik *et al.*, New Journal of Physics, 12, 113013 (2010)

High repetition Target Systems

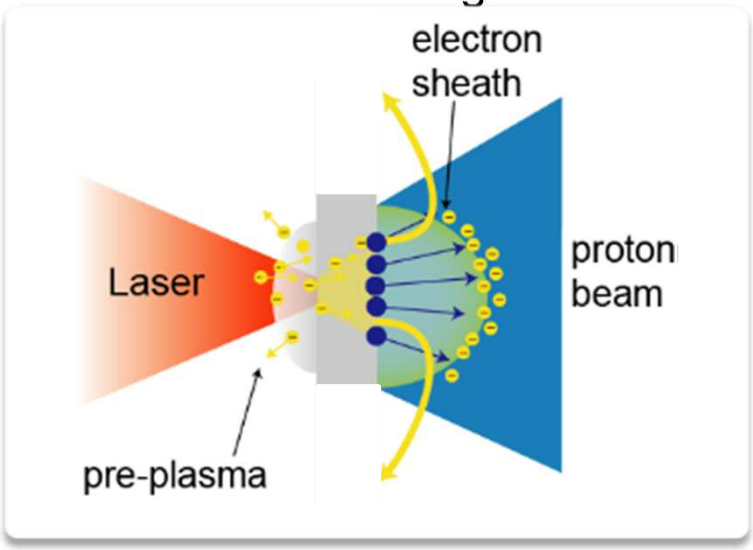
Water Droplets



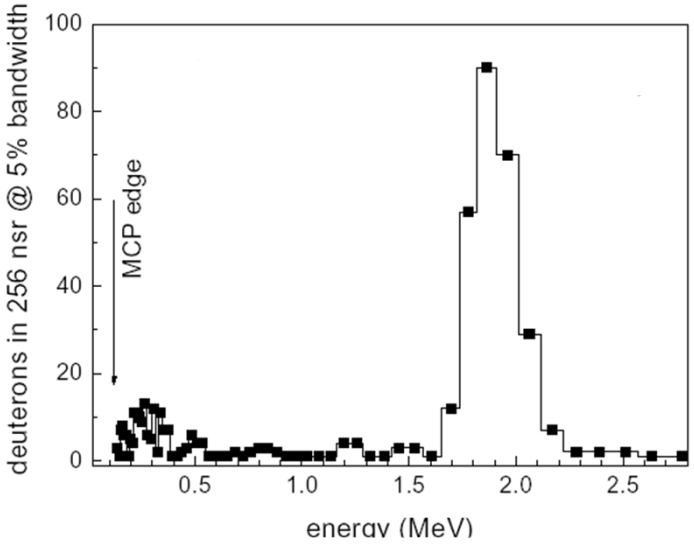
Proton Image

Repetition rate ~MHz

Mass-limited Targets



Mono-energetic features can be observed:



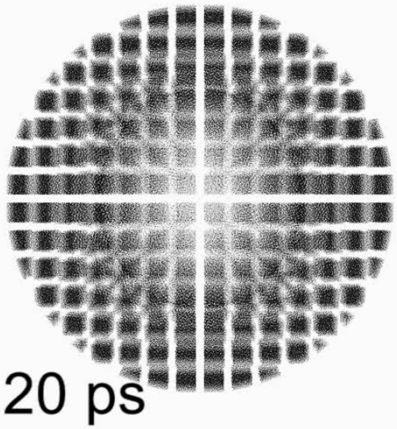
T. Sokollik *et al.* **PRL** 103, 135003 (2009)
S. Ter-Avetisyan e.al., **PRL** 96 145006(2006)

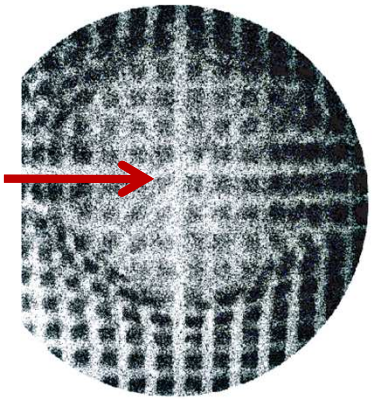
Proton Imaging of Mass limited Targets

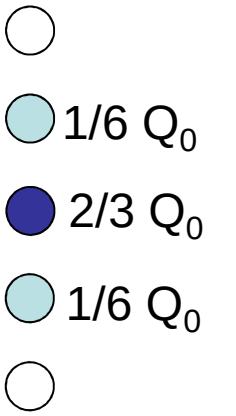
3D particle tracing

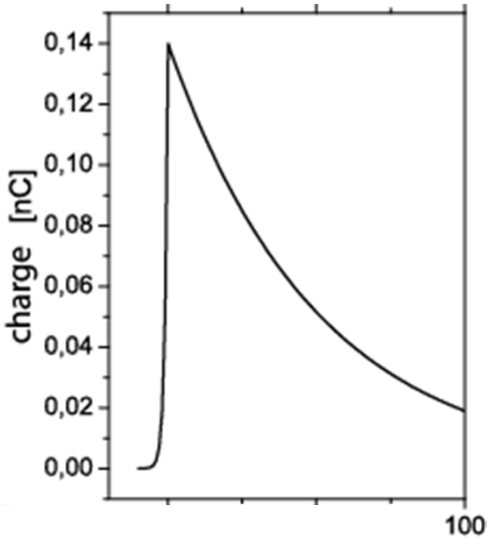
experiment

Q~0.14 nC
decay
time ~50 ps



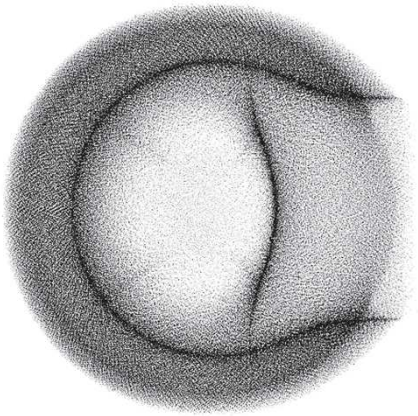


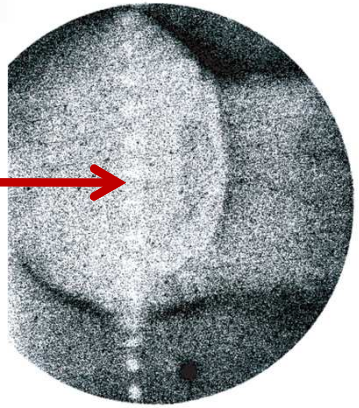


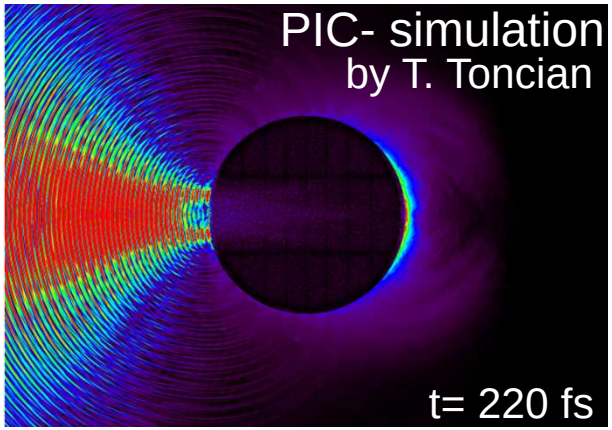


+

moving
ion front





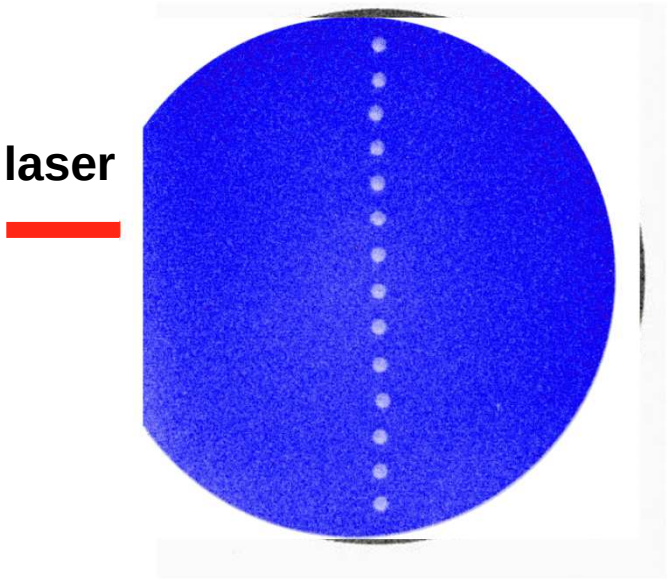


electric field distribution

T. Sokollik *et al.* PRL 103, 135003 (2009)

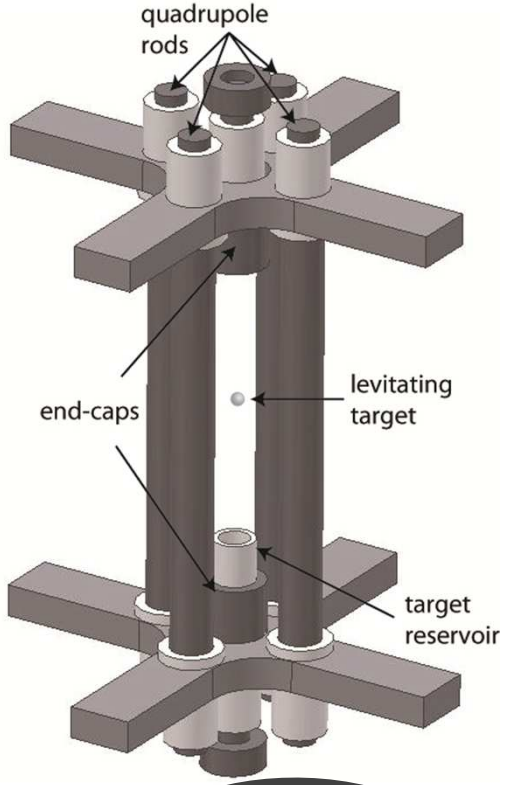
Limitations of Water Droplet Target Systems

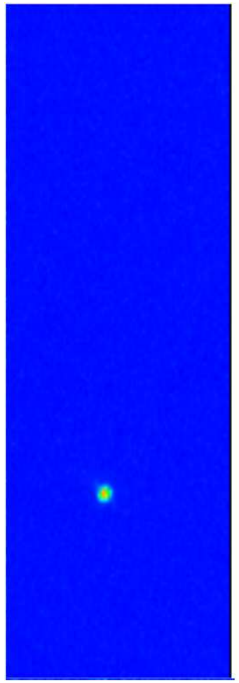
- Size limitation: minimum ‘thickness’ ~ focus spot size
- Low proton energies: no increase due to MLT effect observed
  possible reason:
  - Ambient gas due to evaporation of water
  - Influence of neighbor droplets

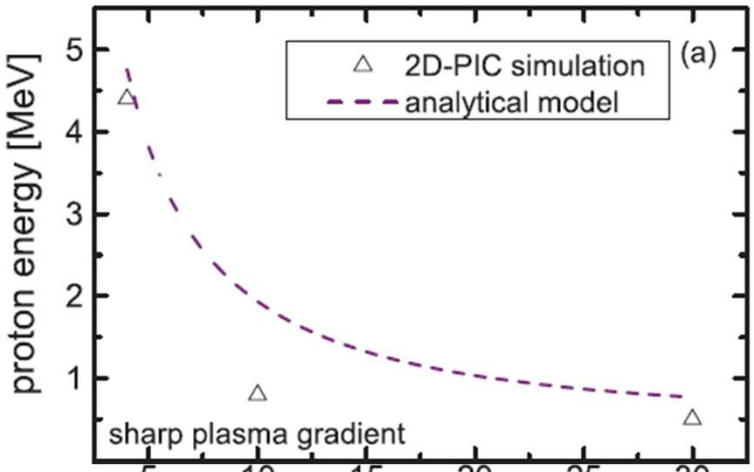


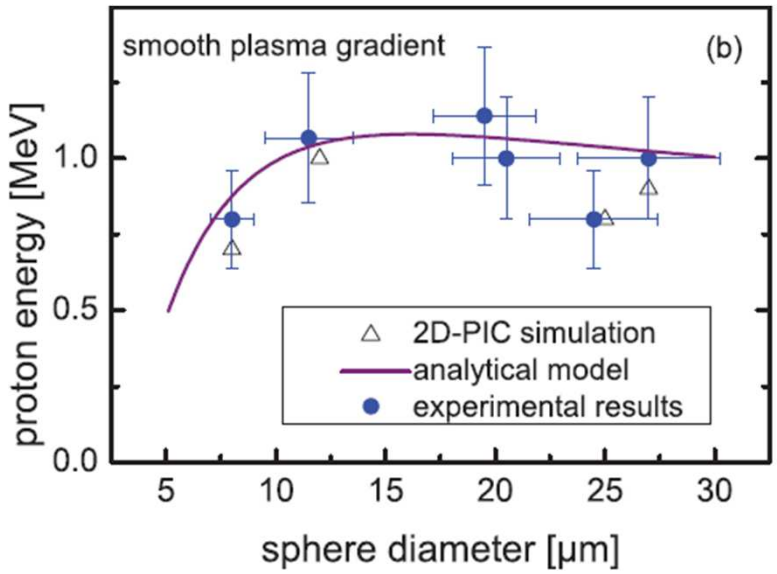
Need isolated spheres!

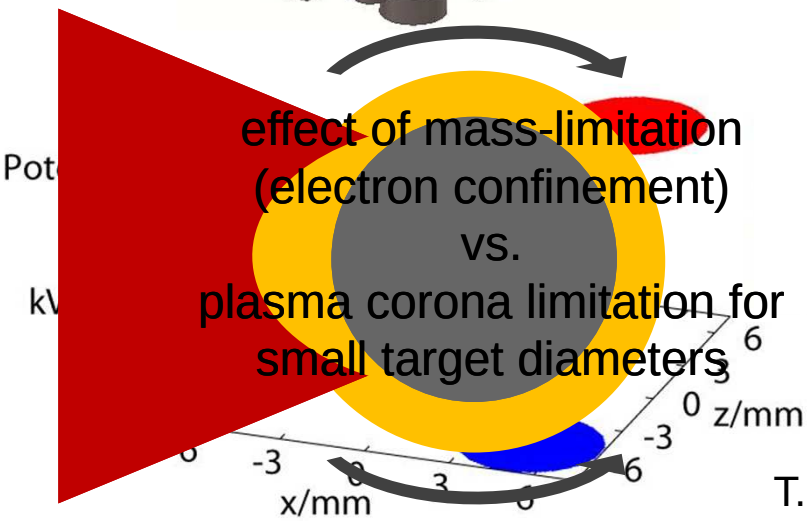
Isolated Mass-limited Target











effect of mass-limitation
(electron confinement)
vs.
plasma corona limitation for
small target diameters

T. Sokollik *et al.*, New Journal of Physics, 12, 113013 (2010)

Tape Drive a test bench

Tape Drive

Tape material:
15 µm VHS (Mylar)

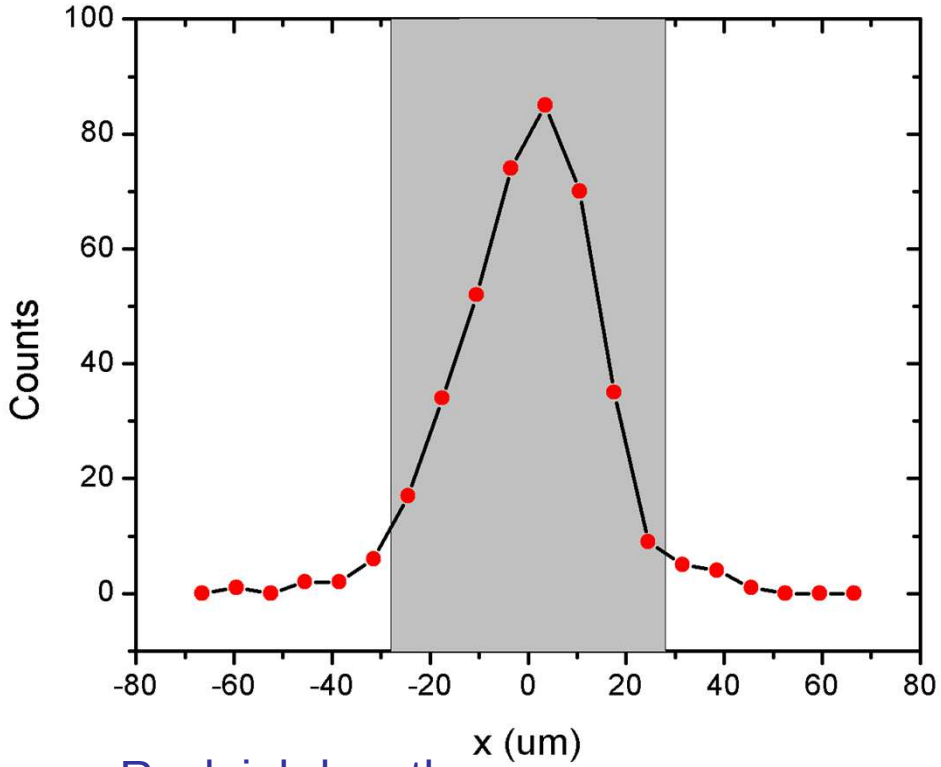
Tape Drives can be test bench to test high repetition techniques and diagnostics.

Tape Drive stability

Tape Drive

Tape material:
15 µm VHS (Mylar)

Surface position stability 2□ 28 µm



Rayleigh length:
Focus spot size 5 µm □100 µm
3 µm □35 µm

Surface fluctuation well within Rayleigh length

Same Target System - different Laser systems

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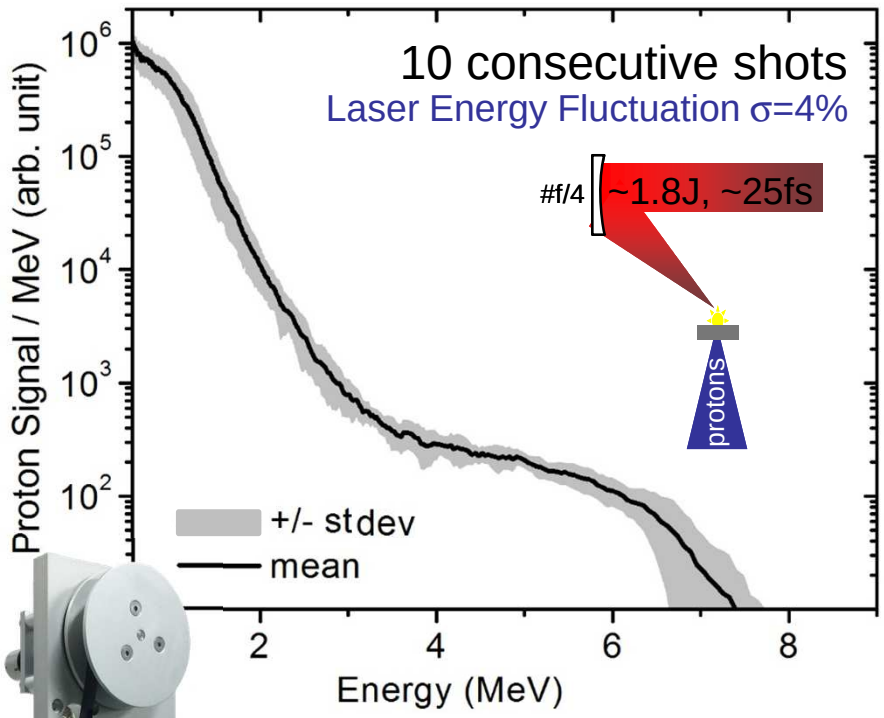
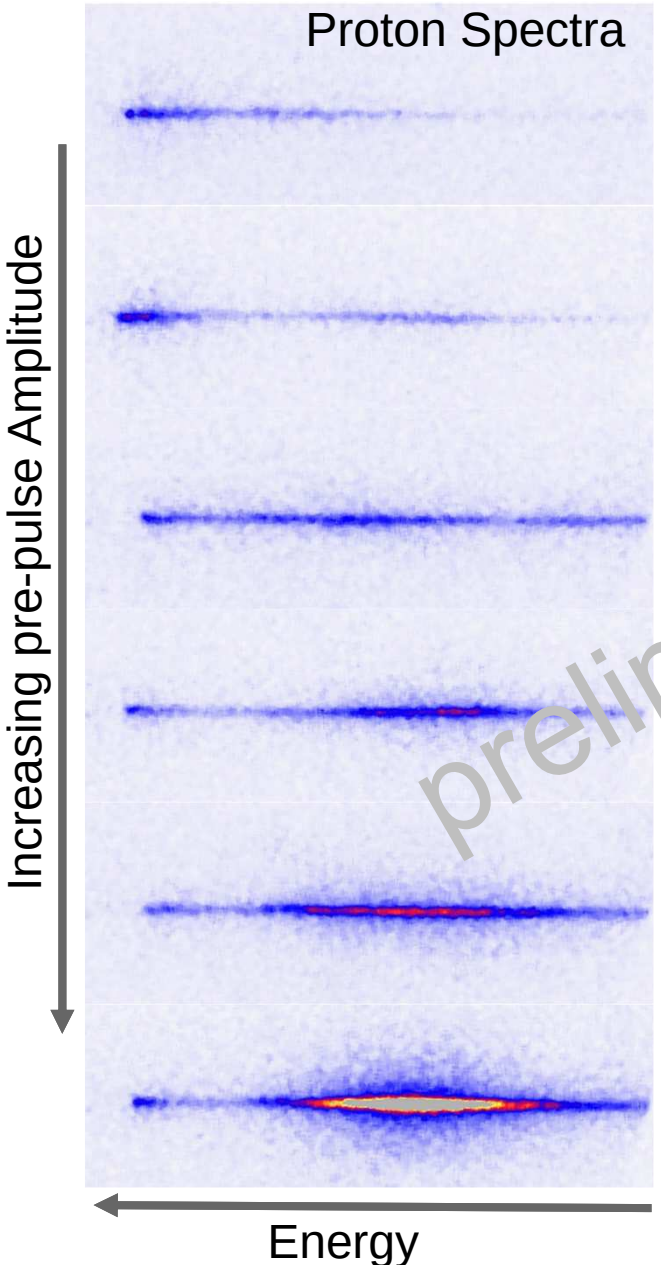


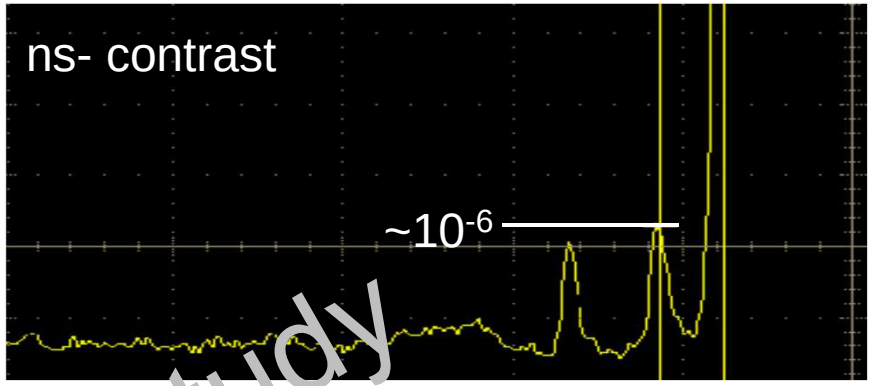
Different contrast conditions cause different spectral shapes

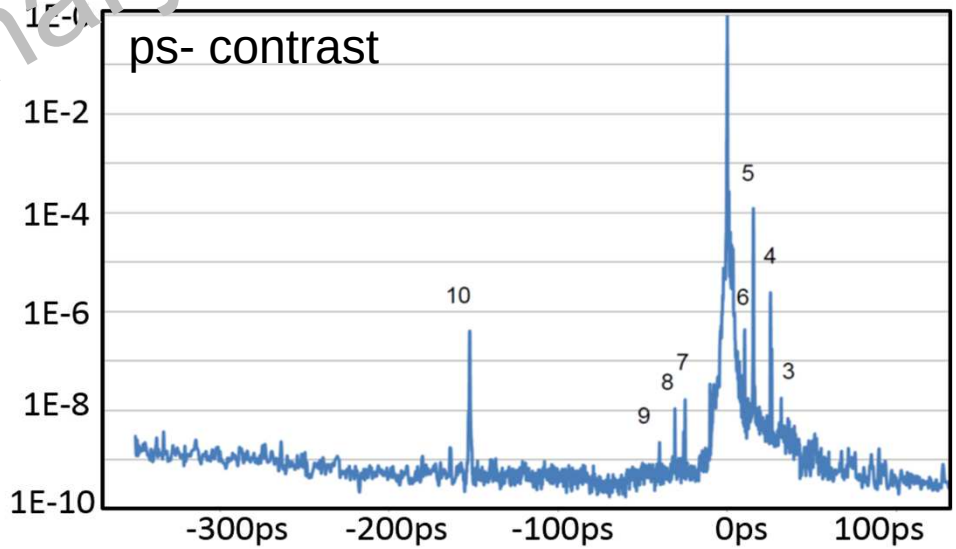
What are the parameters causing fluctuations in proton spectra?

- Investigations ongoing
- High repetition target system allows studies on stability and laser parameter correlation

Proton Spectra Influenced by Laser Contrast

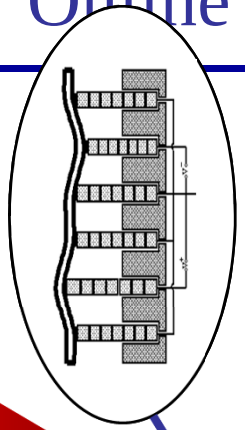






Online Optimization using Evolutionary Algorithm

MBI

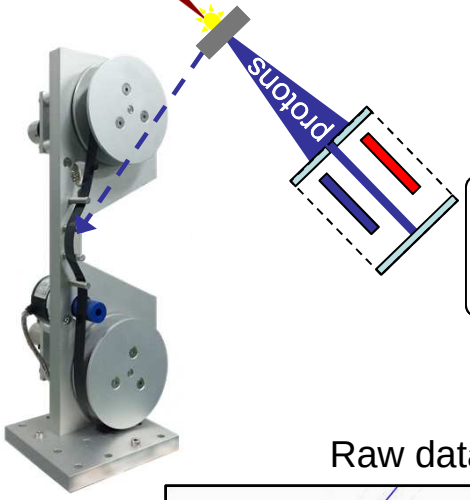


one Mirror setting
is one 'Individual'

#f/2.5 OAP

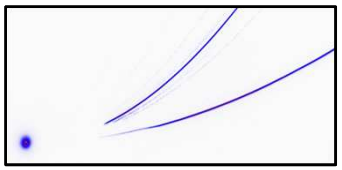
~2J, ~30fs

Deformable
Mirror

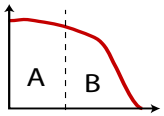


Online Spec.
+ Analysis

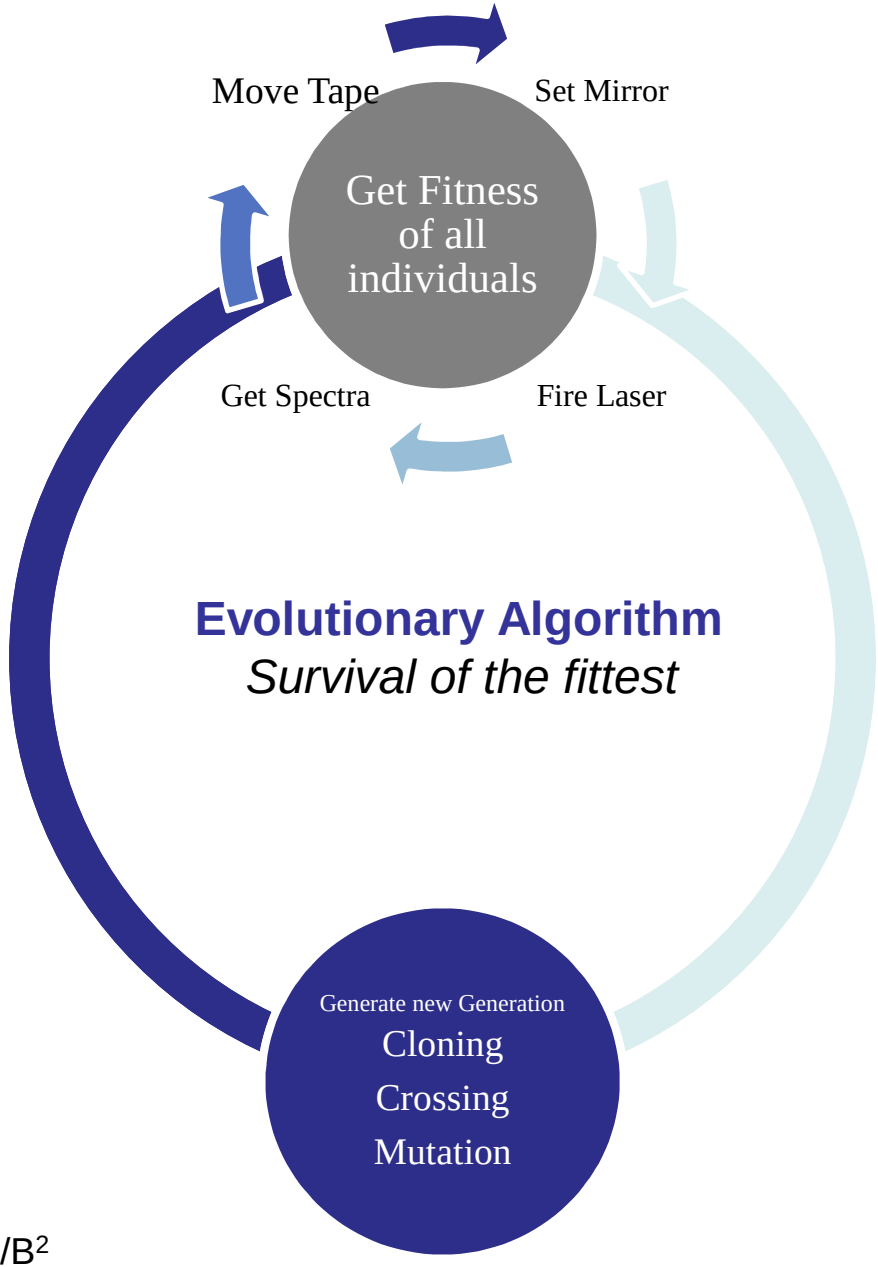
Raw data



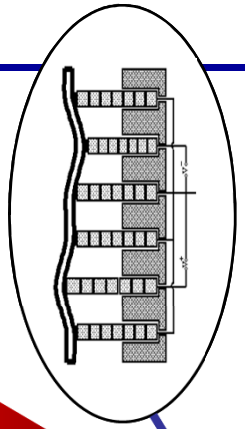
Fitness function



e.g. Fitness=A/B^2



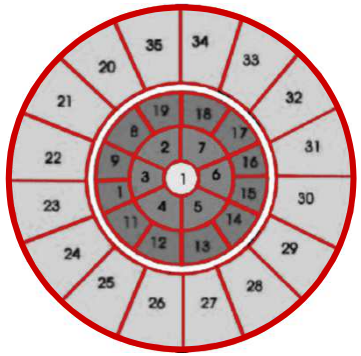
Focus spot optimization



#f/2.5 OAP

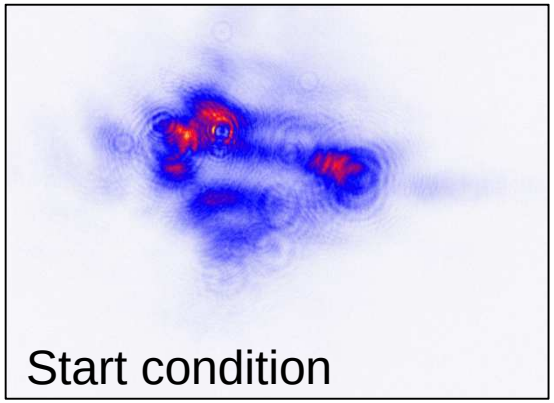
Deformable Mirror

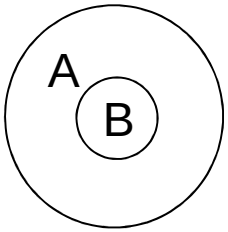
All actuators (31) changed



Starting with misaligned OAP

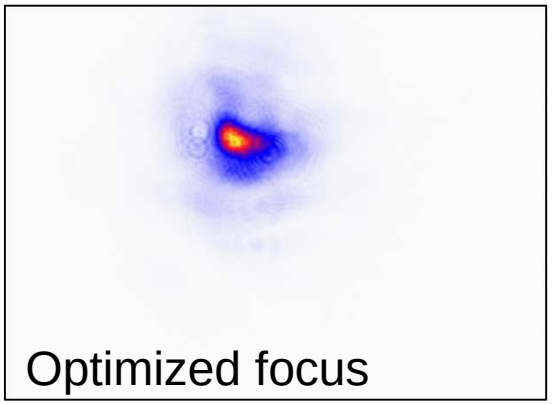
Focus Spot



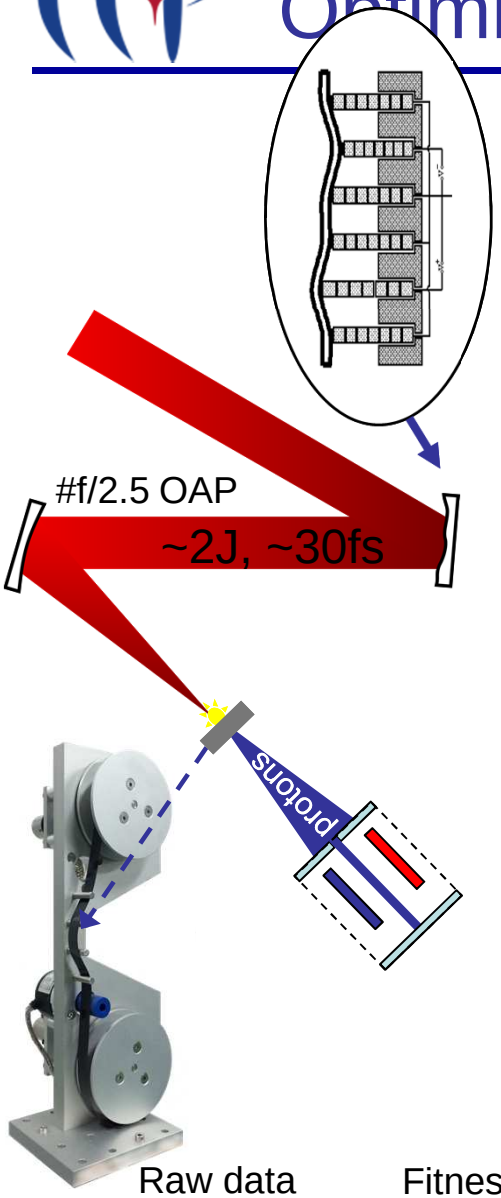


Fitness=A/B^2

Focus Spot

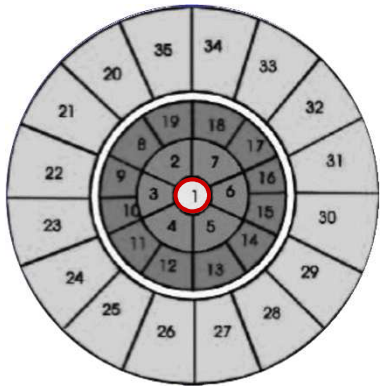


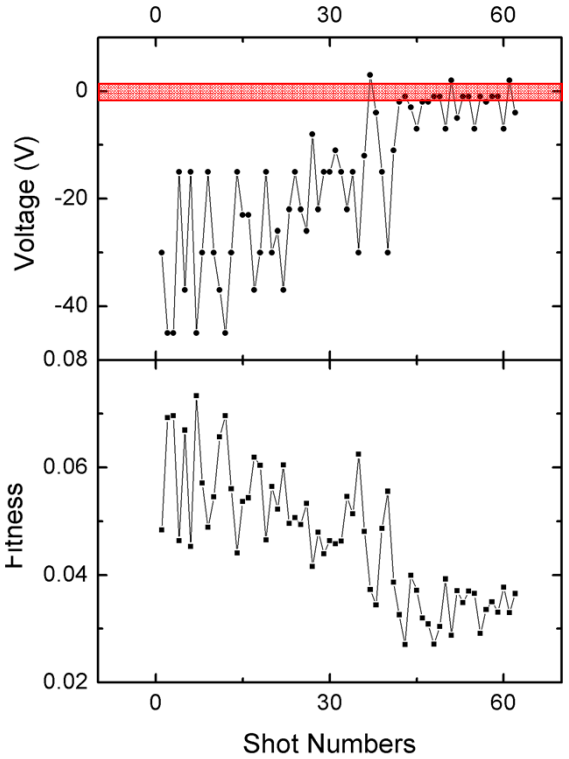
Optimization of Proton Spectra using DM



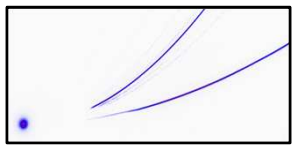
Only one parameter changed, responsible for focus/defocus

V_{start}=-30
V_{opti}=-1

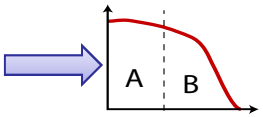




Raw data

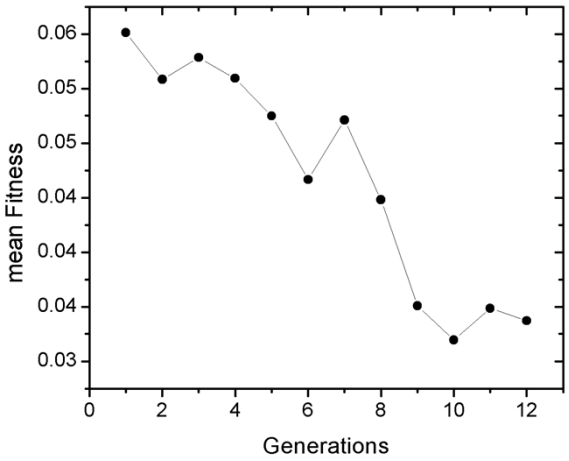


Fitness function

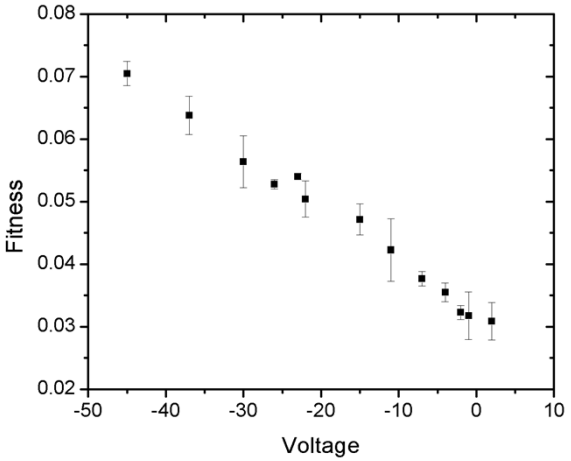


e.g. Fitness=A/B^2

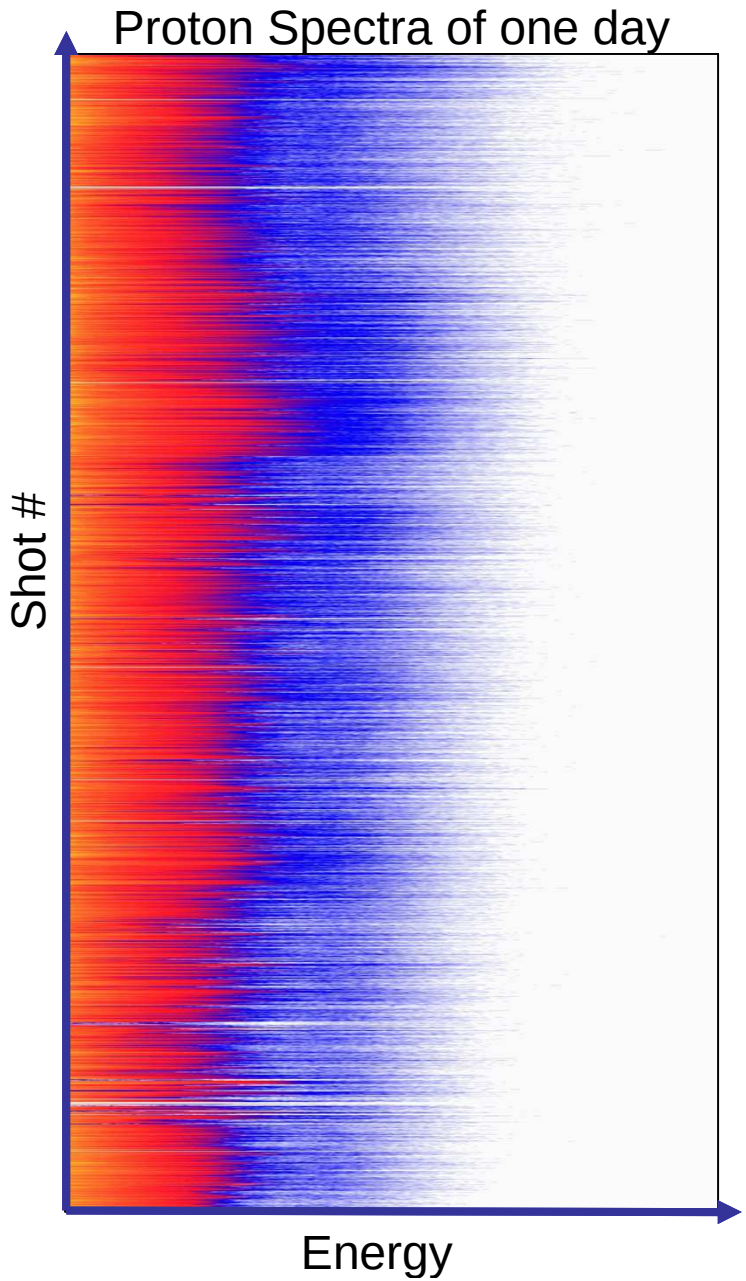
Fitness evolution



Voltage – Fitness Correlation

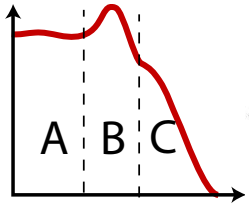


Does Non-trivial Optimization work?



Multiple parameter optimization:

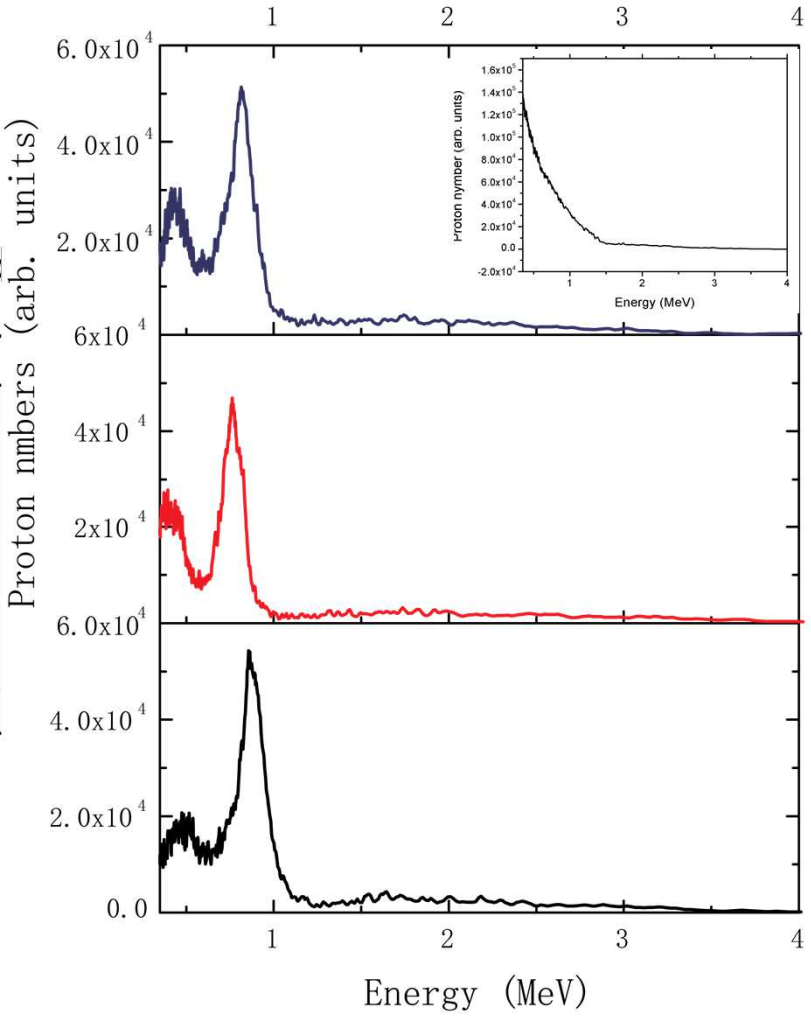
Can the shape of the proton spectra be influenced?



Is there a cond
enhanced/redu

No obvious infl

Analysis is still



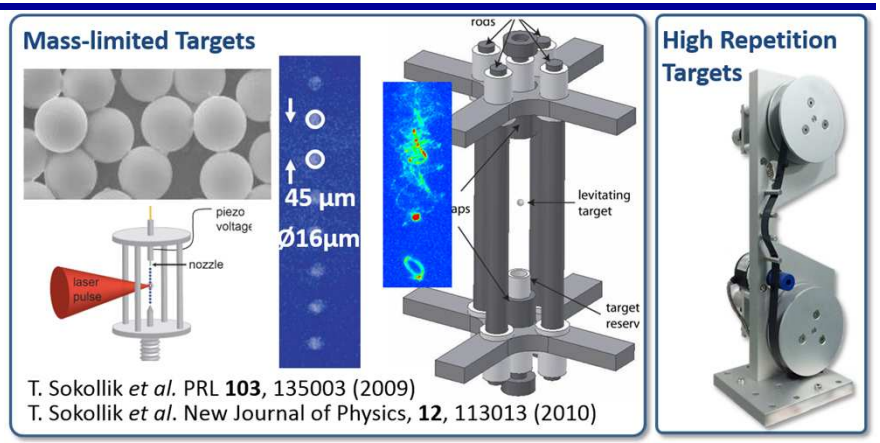
Summary and Outlook

Summary

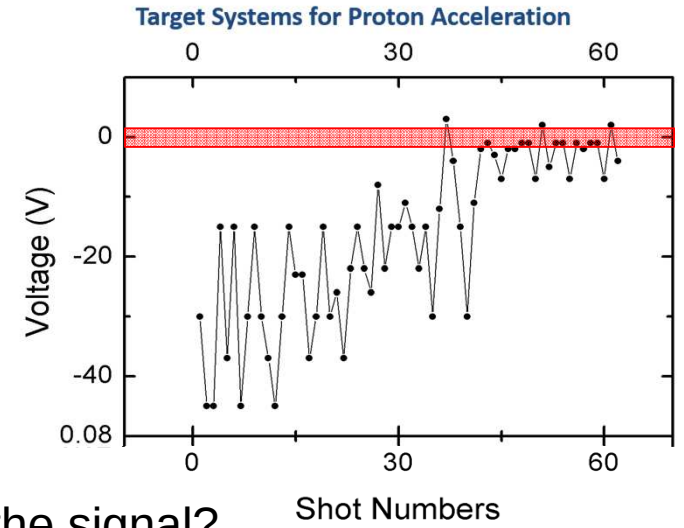
Review off different target systems

Developed stable Tape Drive surface fluctuation (2.28µm) within Rayleigh length

Proof-of-principle Experiment of online optimization using evolutionary algorithm



- Source is stable enough for this method
- Optimization of focus/defocus successful
- Controlled tailoring of spectra not observed (data analysis ongoing, improvement of algorithm ongoing)
- Debris management required



Outlook

What parameters we can change in order to optimize the signal?

e.g. Optimization using temporal pulse shaping (optimization of pre-plasma)

Tape Drive can most likely only be a temporary solution due to the limitation on the proton energy and due to debris. But can be a good test bench to test high repetition techniques and diagnostics.

Thank You