A Laser Proton Accelerator for 70^{th} birthday

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Outline

1. Introduction
2. Compact laser plasma accelerator at Peking University
3. Experiments of generation and focusing of laser accelerated proton beams at PKU
4. Laser accelerator of 3-9 MeV proton beams with 1% energy spread
5. Summary

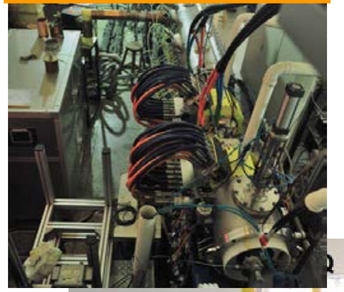
SKL of Nuclear Physics and Technology @ PKU

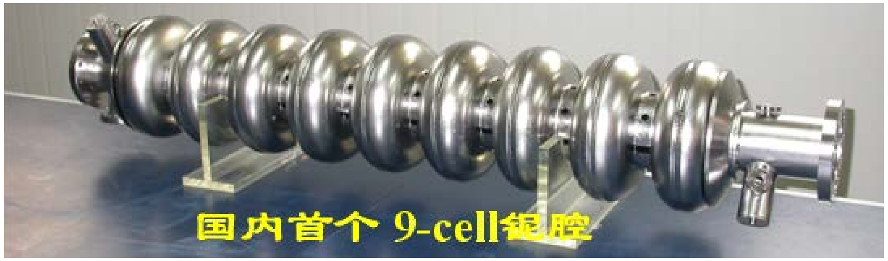
4.5 MV electrostatic

2*6 MV tandem, AMS/material

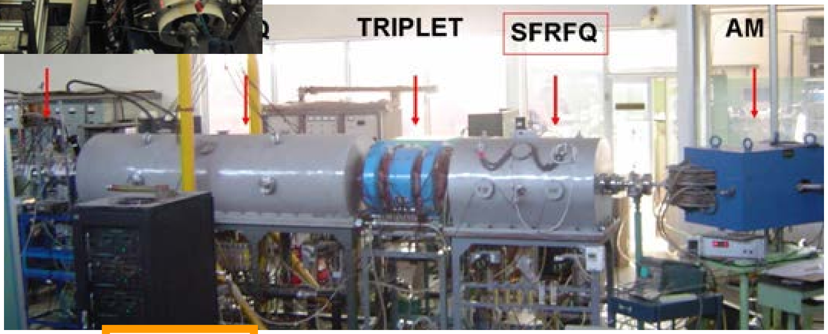
AMS facility

RFQ neutron radiography

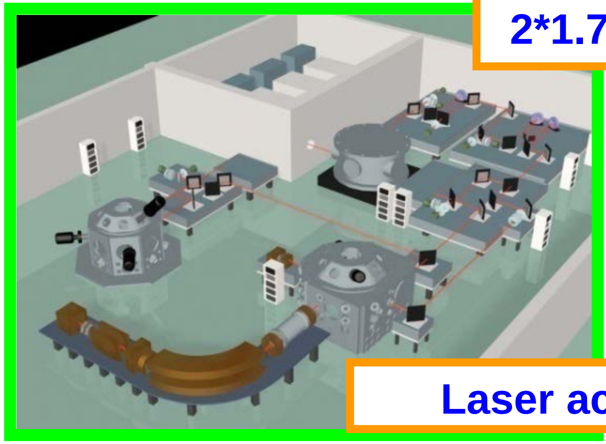




2*1.7MV tandem

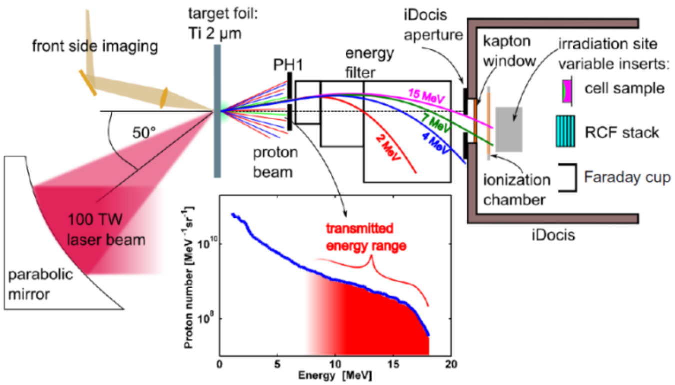


Linac

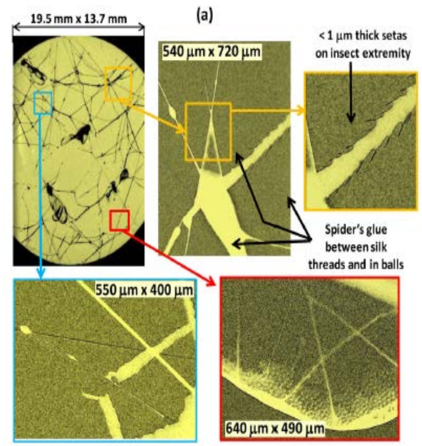


Laser accelerator

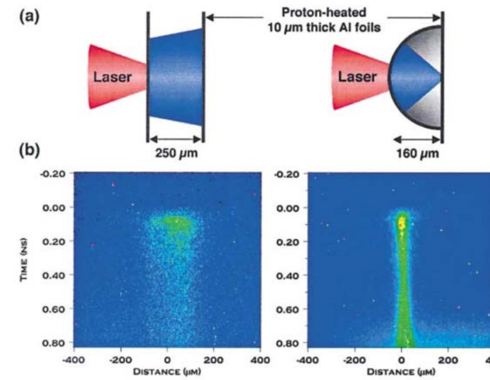
Application of Laser Driven Ions



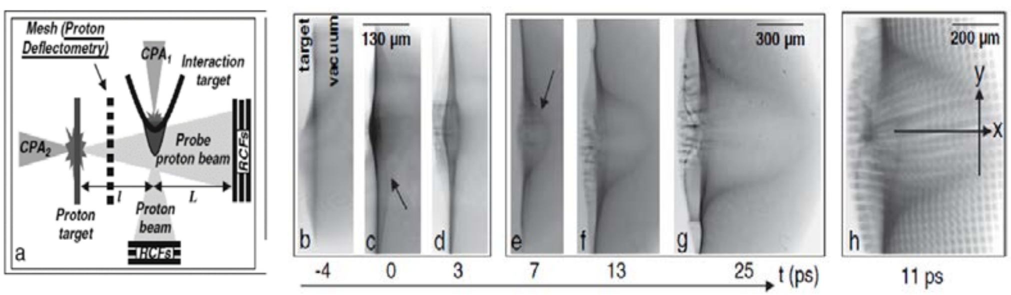
Biological irradiation



Ion radiograph

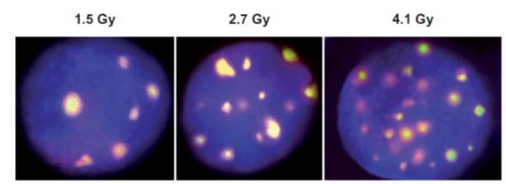


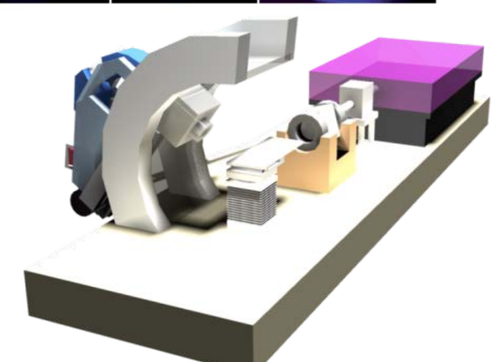
WHM



Ion probe

Radiotherapy





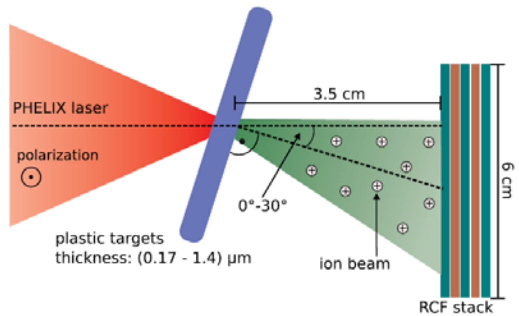
In China in 2016:

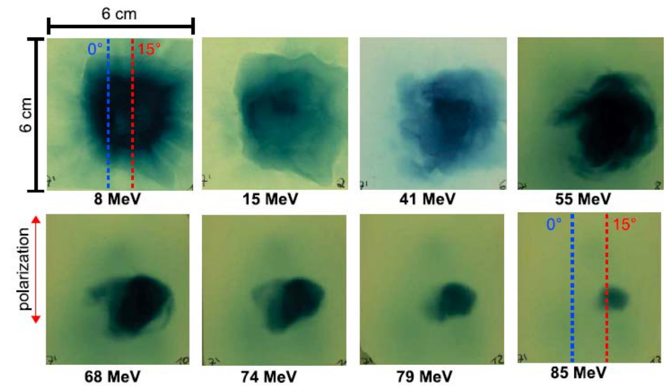
- ✓ Cancer patients --4.29M and death by cancer ---2.81M.
- ✓ The best way to do Cancer therapy is radiation therapy.

NJP 12 085003 (2010) PRL 95,195001 (2005) PRE 95, 023208 (2017)
POP 14,055502 (2007) APL 95,101107 (2009) PRL 114, 215002 (2015)

Highest energy ~100 MeV/u

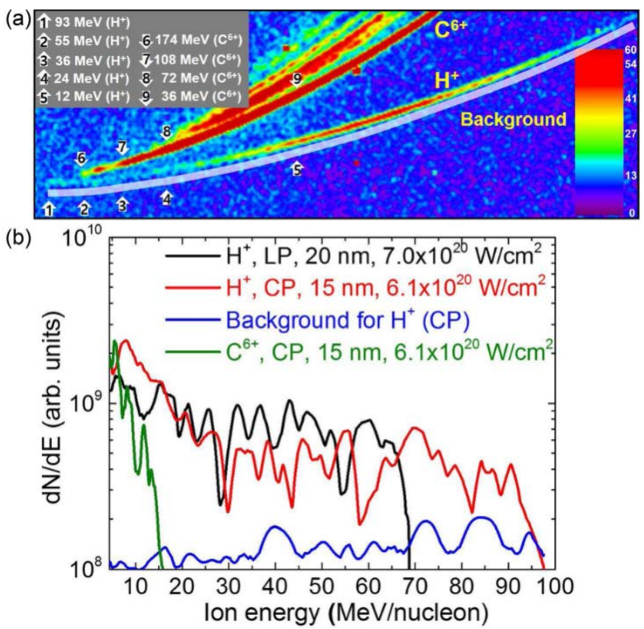
TNSA 85 MeV Proton





PRL 116, 205002 (2016)

RPA 93 MeV Proton



POP 23, 070701 (2016)

Characteristics of Laser Driven Ion Beam

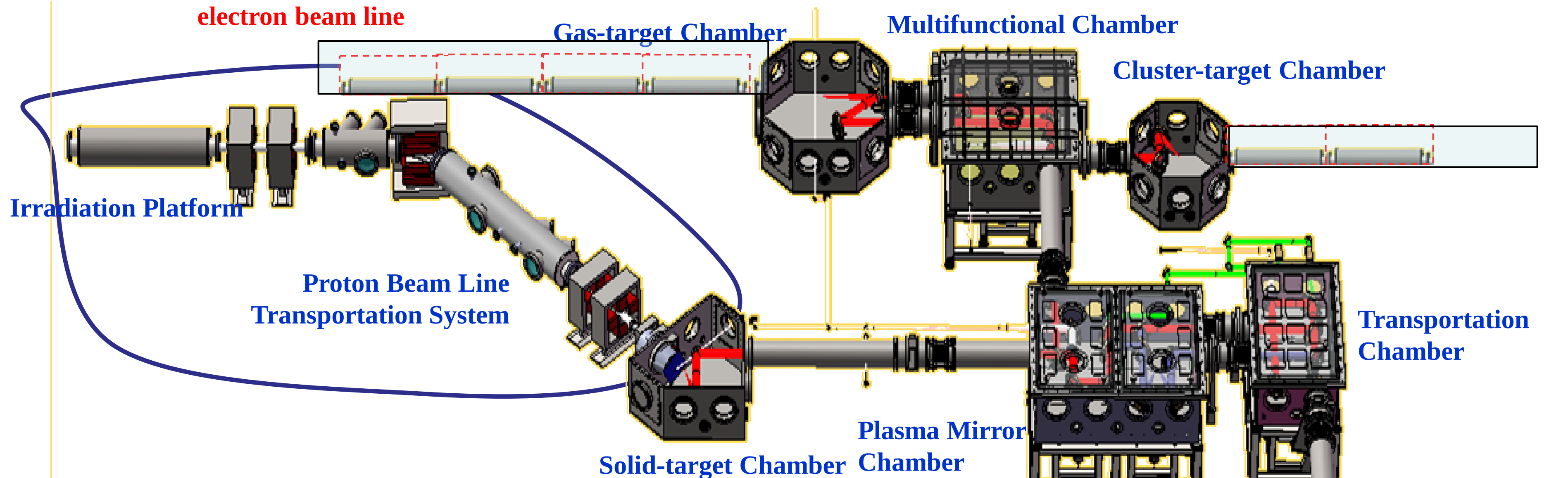
- Large energy spread~100%
- Large diverge angle~10°
- Small emittance ~0.1 π mm.mrad
- Small initial size, spot source ~5μm
- Short pulse duration ~a few ps
- High peak current ~ 10^{10}-10^{13}ppp, KA

new features for beam optics

Except maximum energy, RAMI (Repeatability, Availability, Maintainability and Inspectability) is important for applications in the near future.

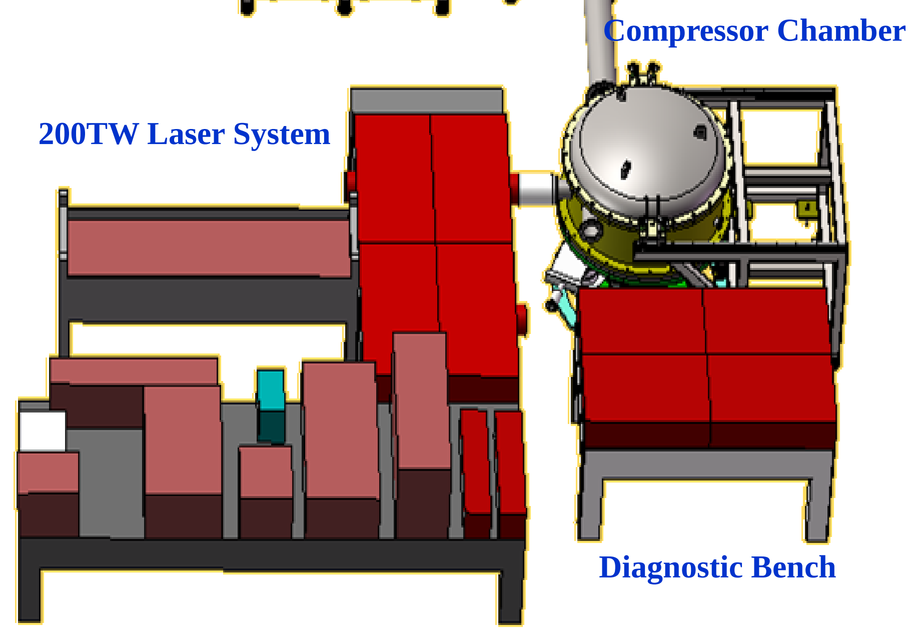
CLAPA at Peking University

(Compact LAser Plasma Accelerator)

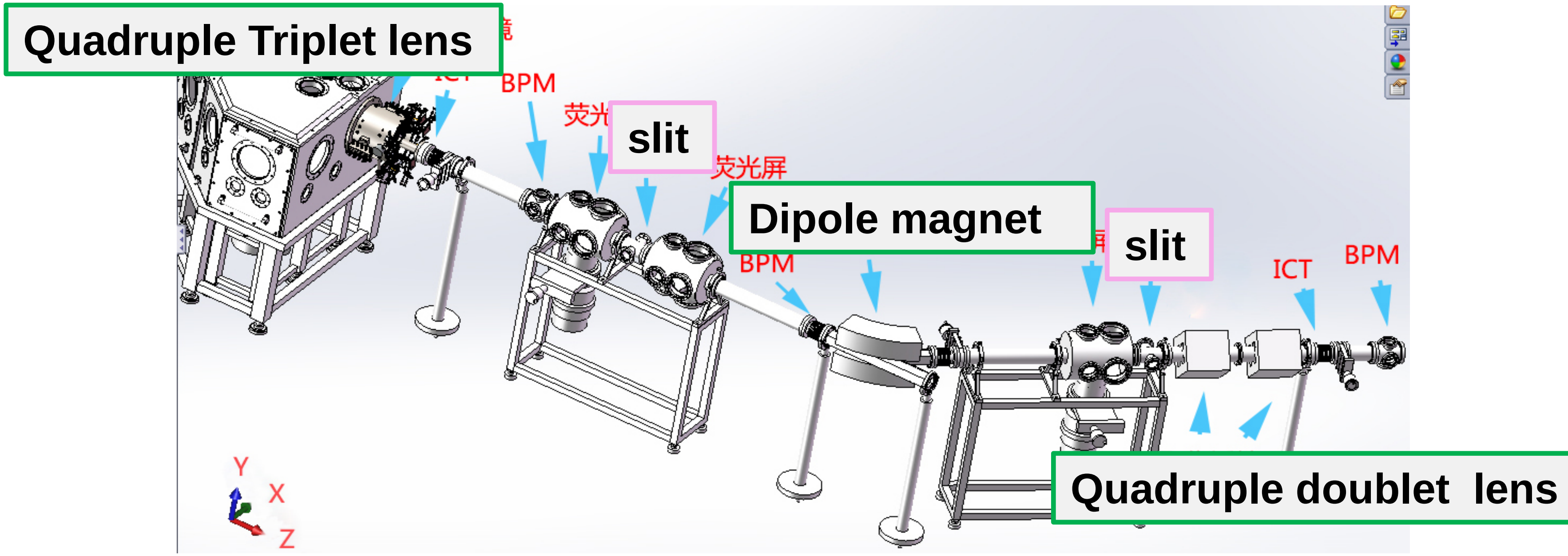


High Contrast 5Hz 200TW Laser System

Pulse Energy	5 J
Duration:	25 fs
Repetition :	5 Hz
Wavelength:	800 nm+/-10 nm
Contrast Ratio:	> 10^{10}:1 @ ~ns
	10^{10}:1 @ 100 ps
	10^{9}:1 @ 20 ps
	10^{6}:1 @ 5 ps
	10^{3}:1 @ 1 ps



Laser Proton Accelerator with a beam line



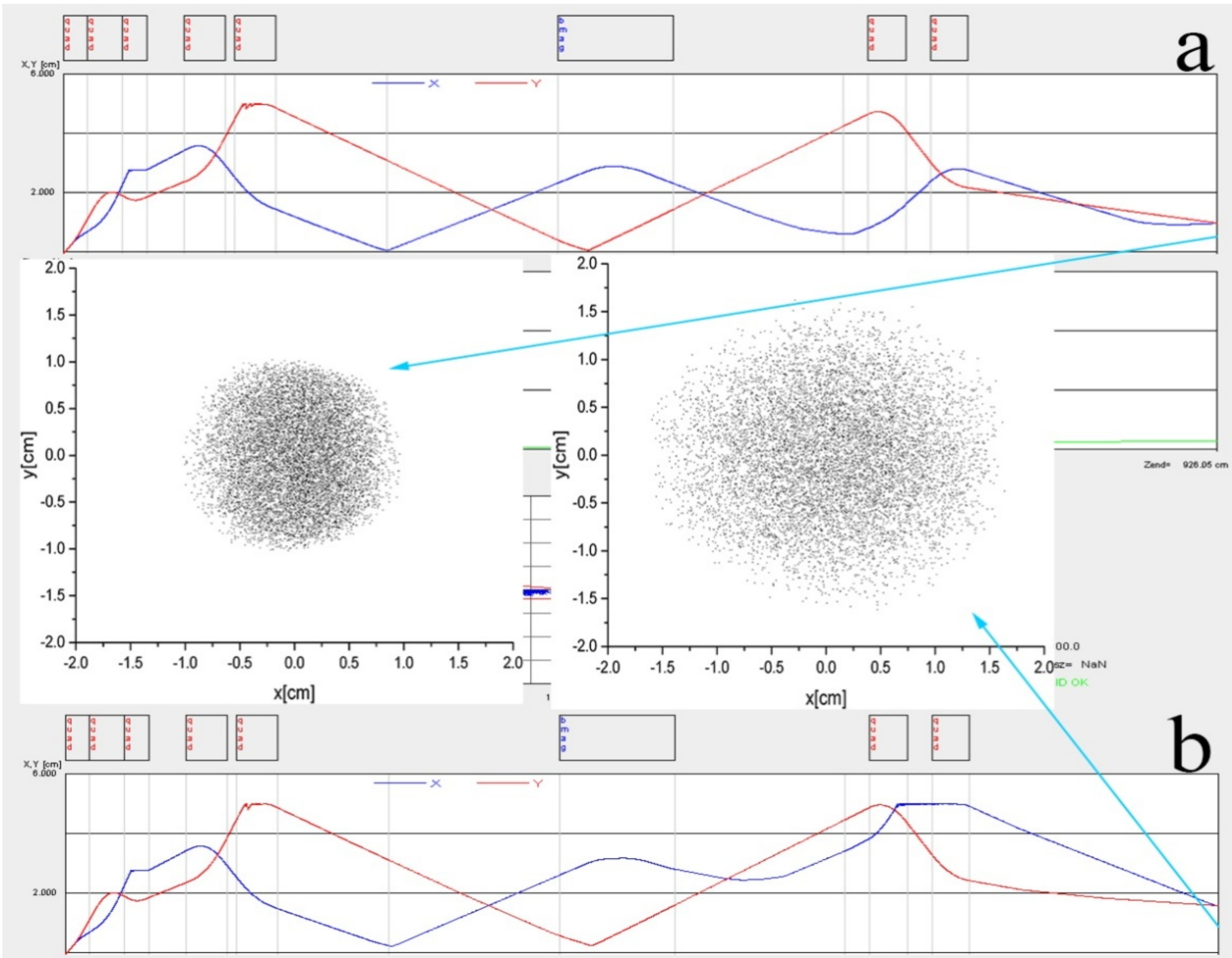
Energy :1-44 MeV

Energy spread: 0.5~±5%

Transfer efficiency >90%

Number: 10^8-10^10

Beam Spot on The Irradiation Platform

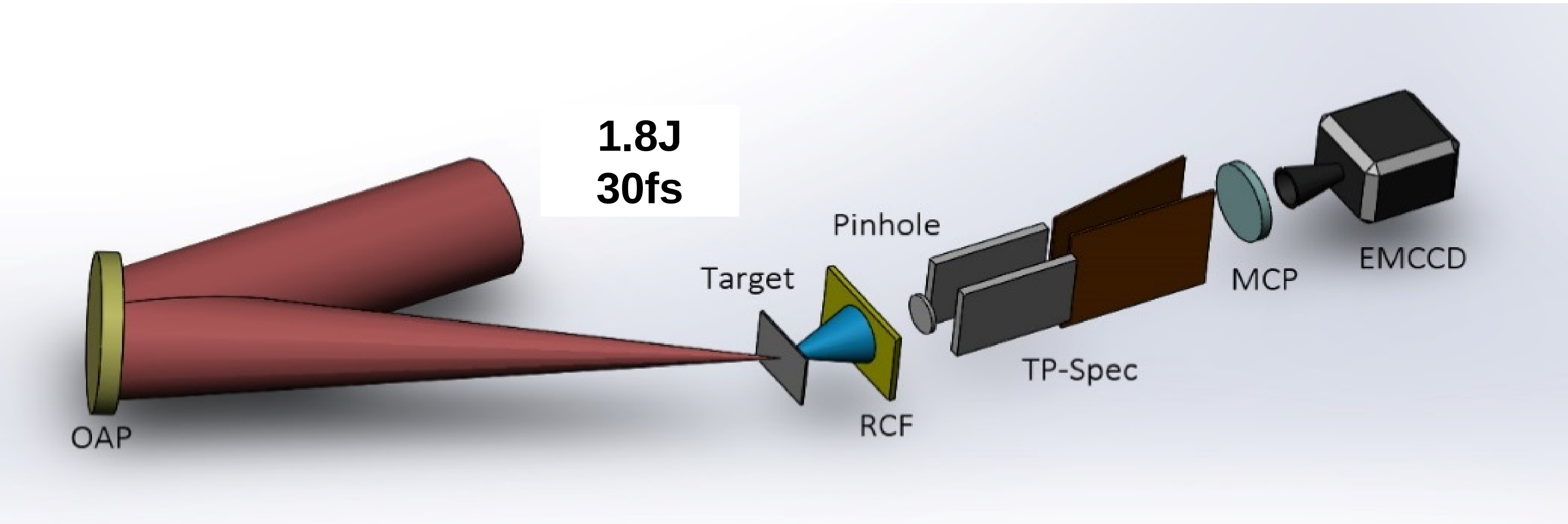


44 MeV with ±1% energy spread

44 MeV with ±4%energy spread

Jun-Gao Zhu *et al.*, Chin. Phys. Lett. 5, 34 (2017)
Jun-Gao Zhu *et al.*, Chinese Physics C. (2017).

Experiments of Laser proton acceleration



Laser parameters

Energy: 1.8 J

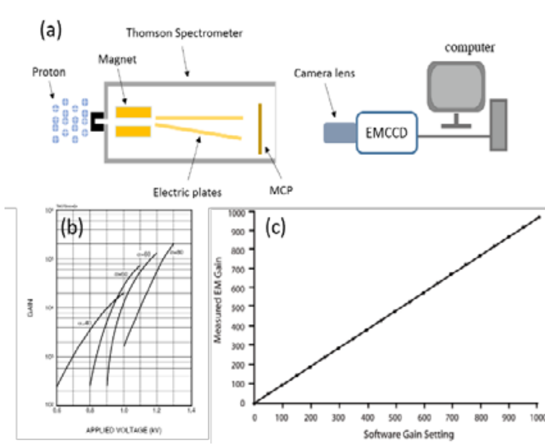
Duration: 30 fs

Spot: 4.5 μm×5.3 μm

intensity: 8.3×10^{19} W/cm^2

Incident angle: 30 degree

0.8 μm-6 μm Al
0.2-6 μm plastic

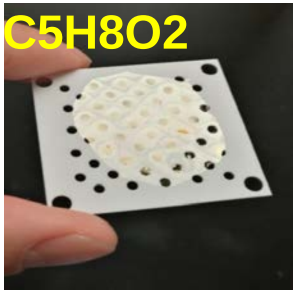


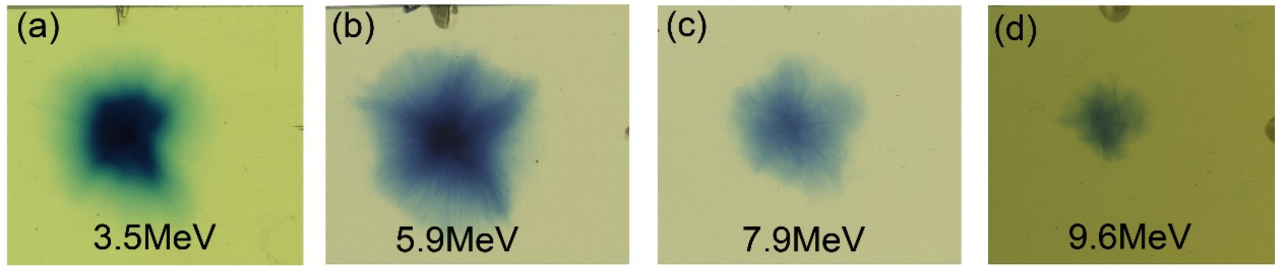
TP

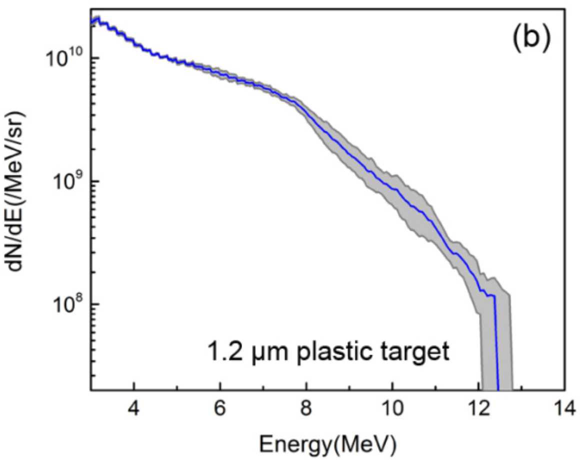
100μm Al foil
RCF HD-V2
RCF MD-V3
RCF MD-V3
RCF EBT-3
RCF EBT-3

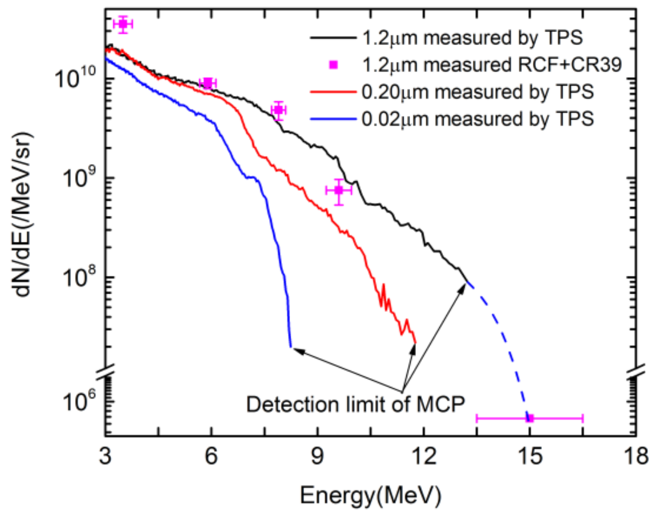
RCF stack

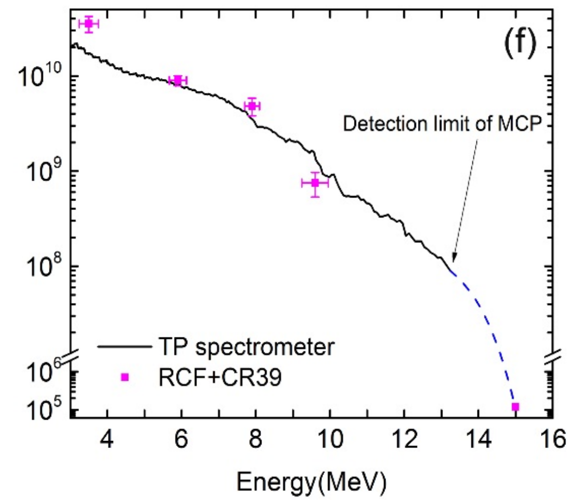
Experiment with plastic target









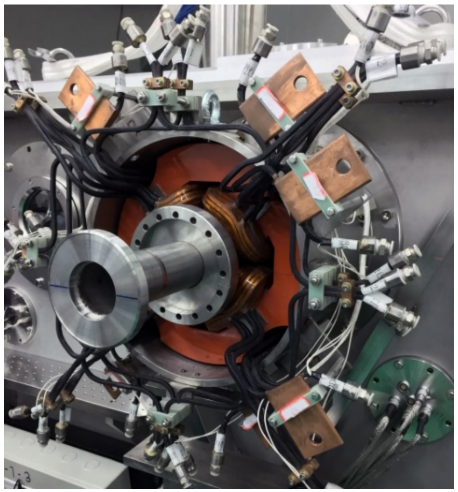


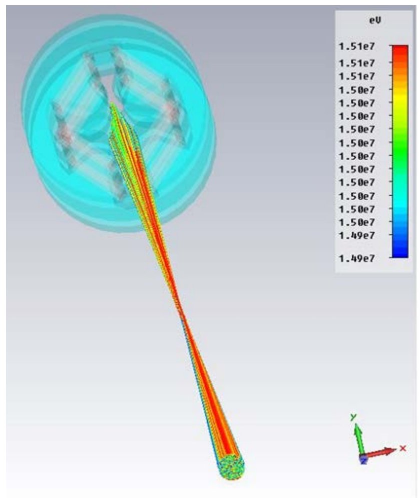
Plastic targets produced proton beams with good stability and the beam cutoff energy stability better than 3%

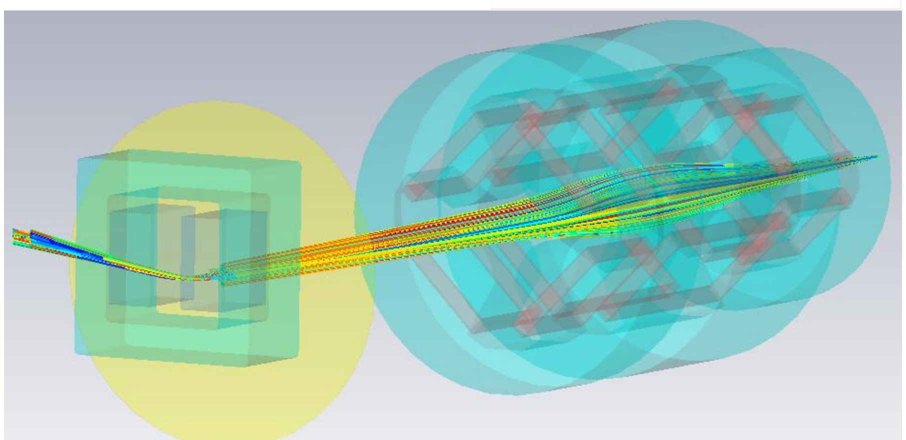
Stable protons were generated based on 20nm plastic target without PM.

Focusing with quadruple triplet lens (1)

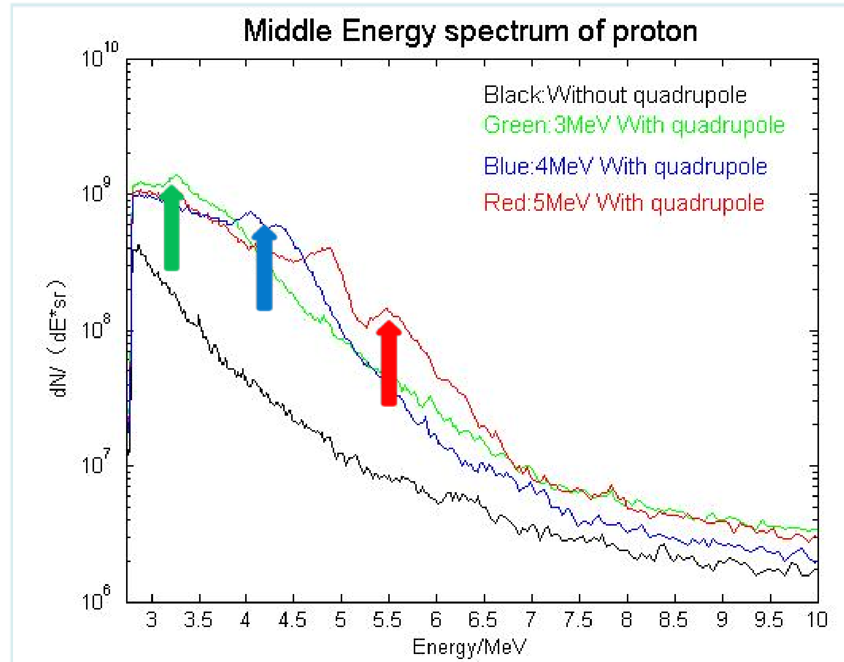
The distance between target and quadruple triplet was 19 cm with a collection angle ±50 mrad.







Quadruple triplet lens + angular energy spectrum



The proton charge on MCPwas Significantly enhanced:

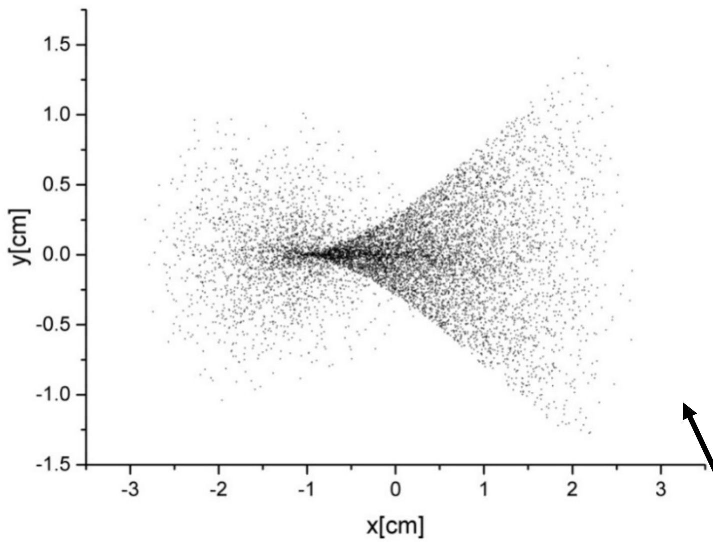
3.5 MeV ×7

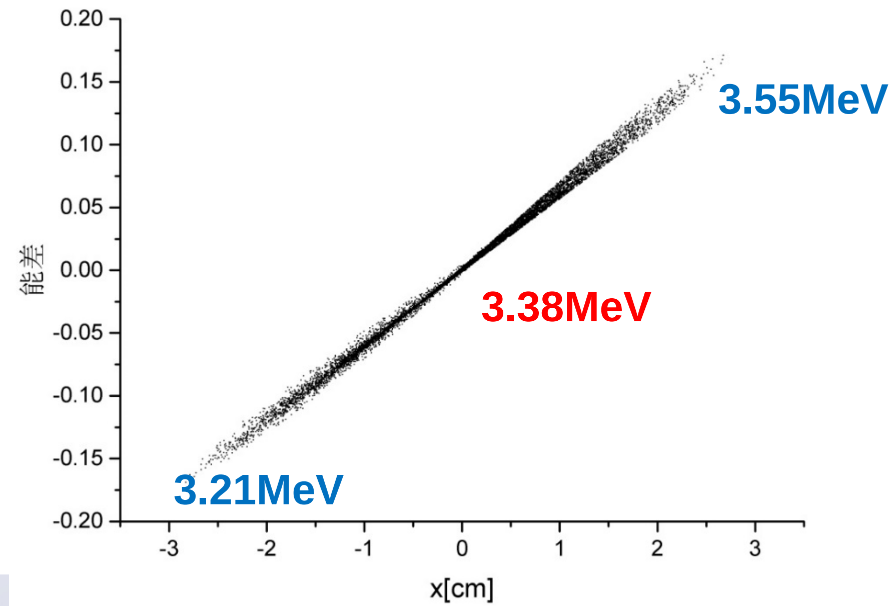
4.5 MeV ×20

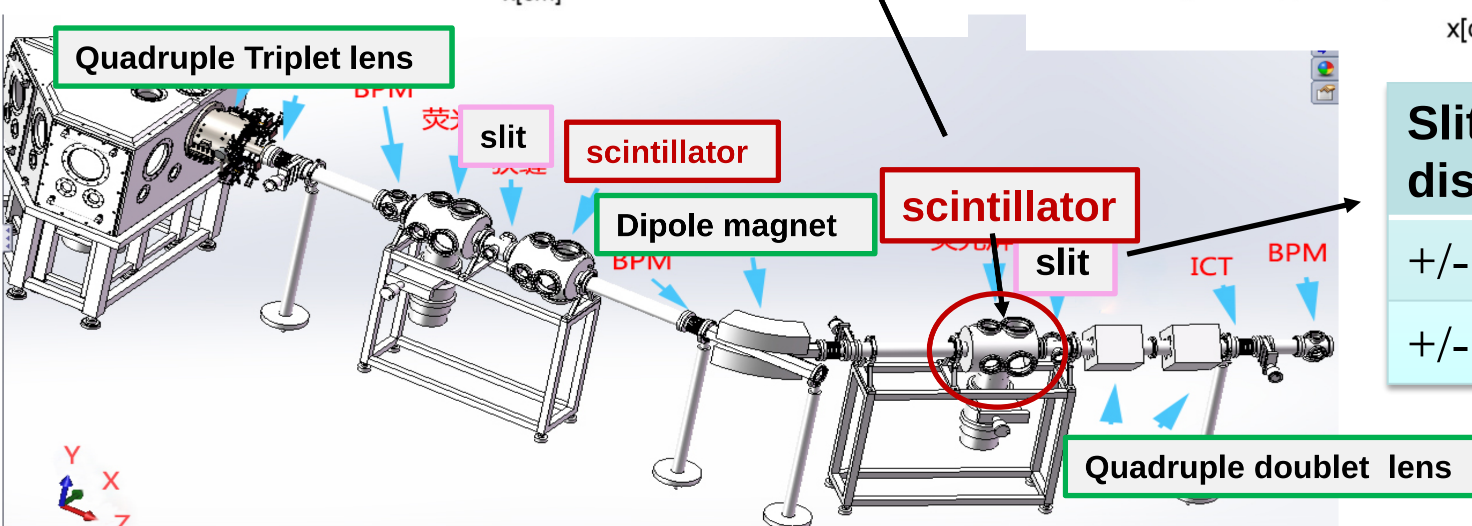
5.5 MeV ×20

Dipole magnet for energy selection (1)

Simulated distribution of proton with 3.3788 MeV central energy and ±5%energy spread on the third scintillator .

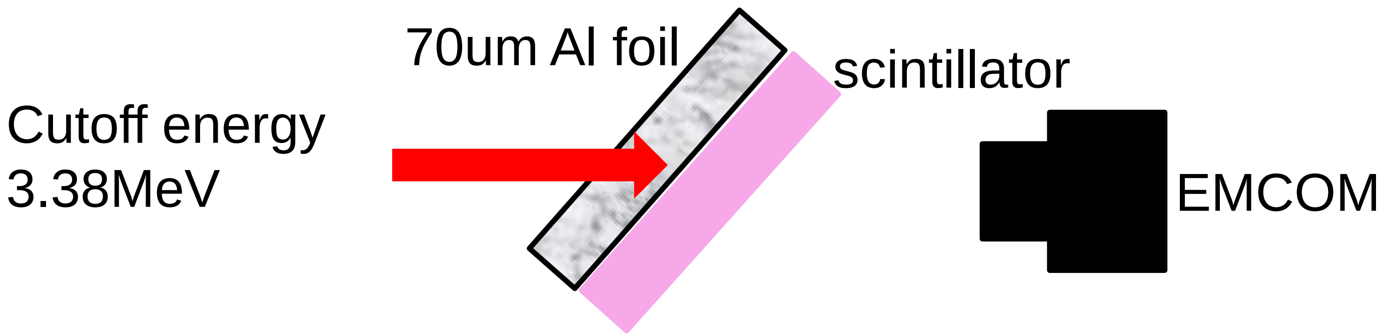


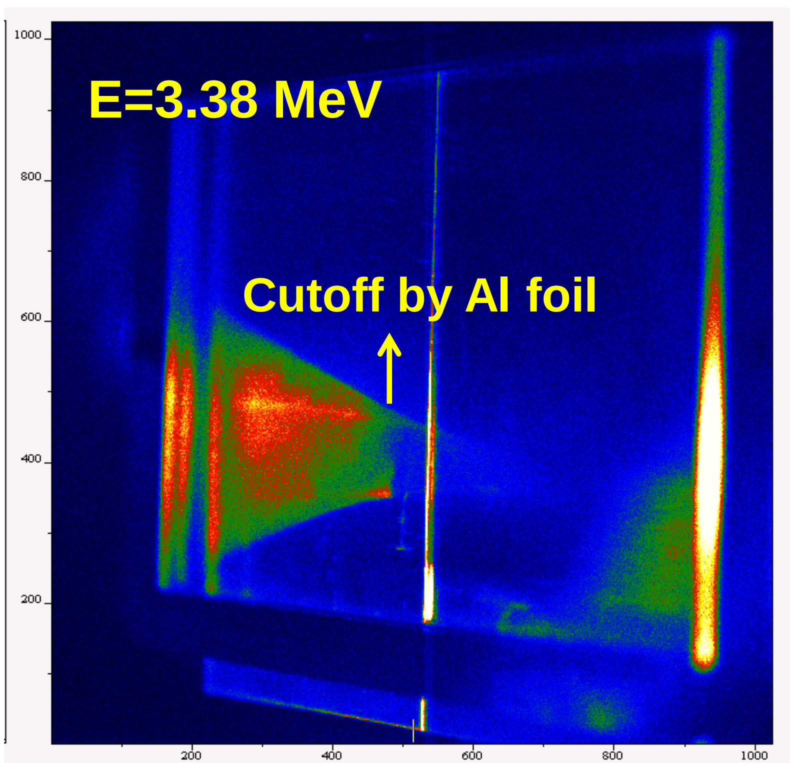


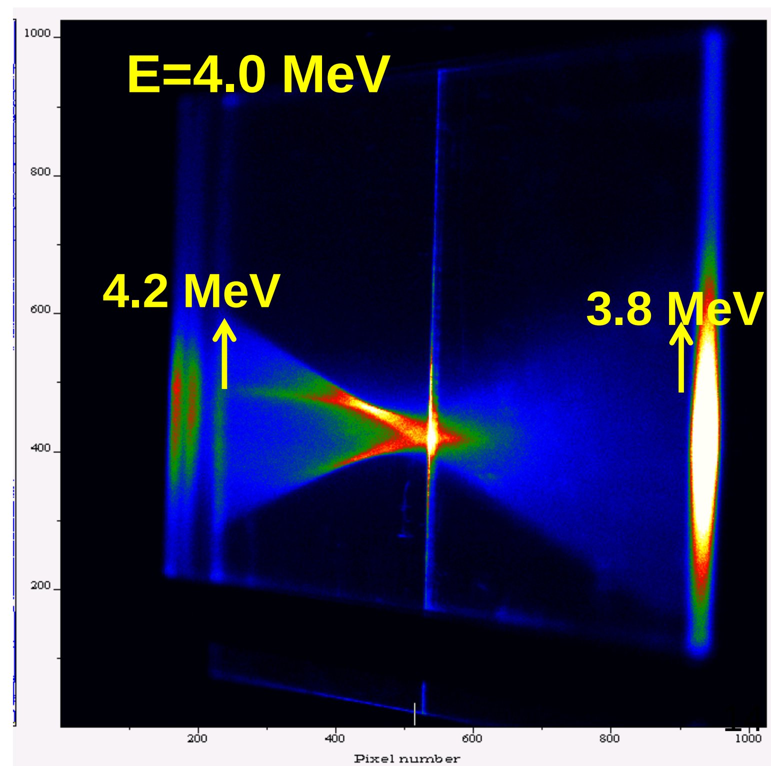


Slit distance	Energy spread
+/-7mm	1%
+/-30mm	5%

Dipole magnet for energy selection (2)

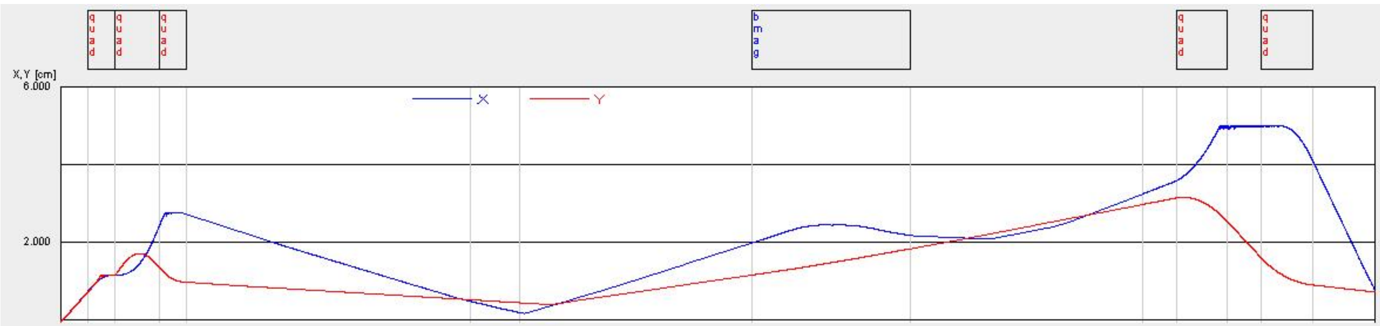




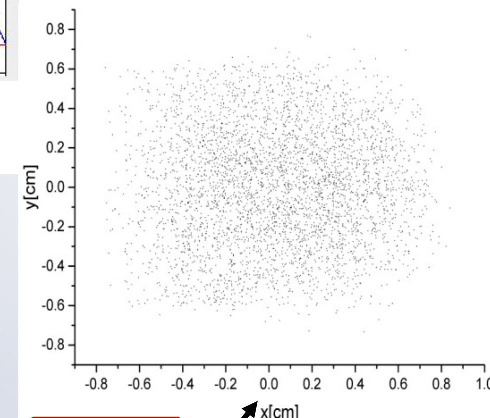


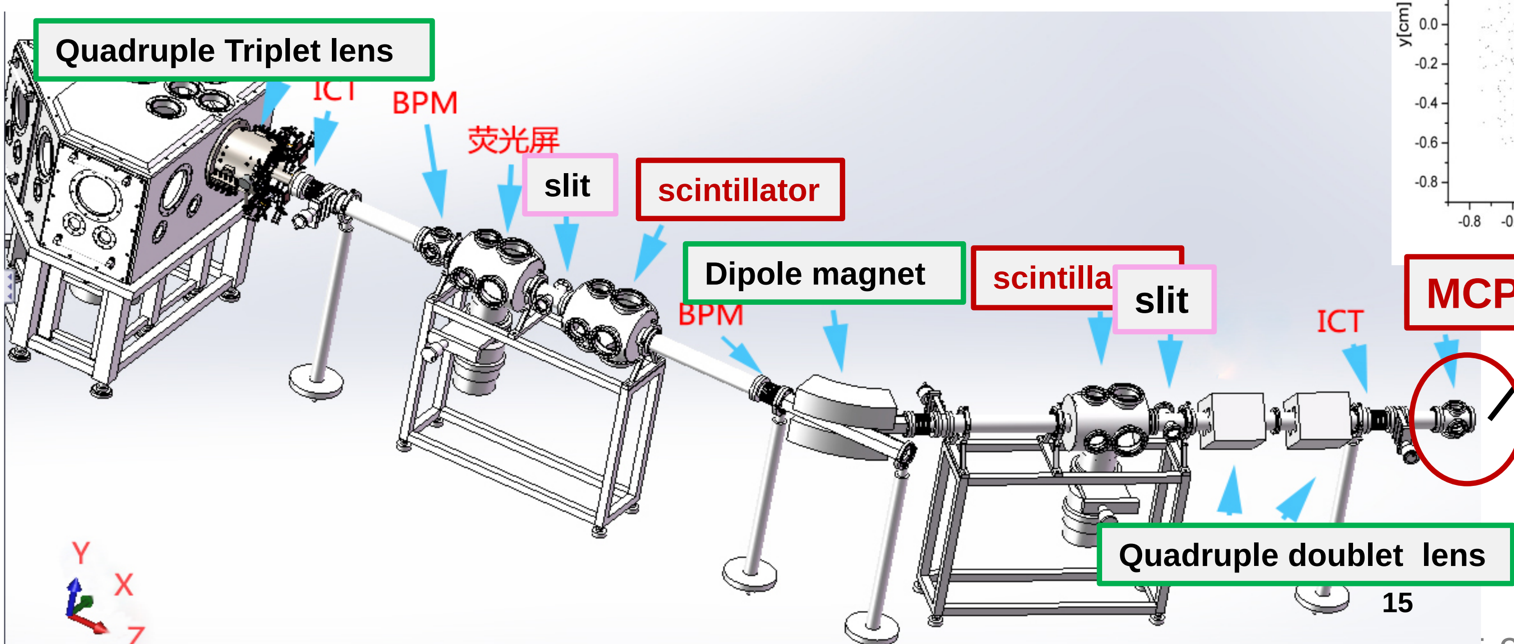
Quadruple doublet lens to refocus the beam

Proton propagation envelope with 5 MeV central energy and 5% energy spread.



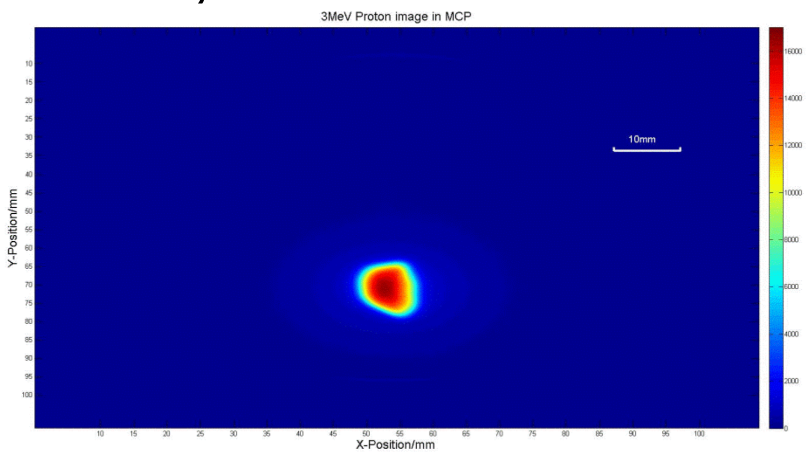
Simulated proton distribution on MCP



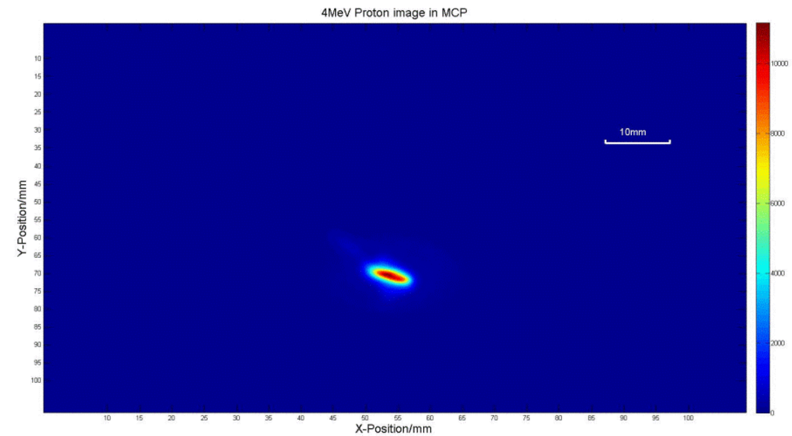


Focused proton beams with different energies

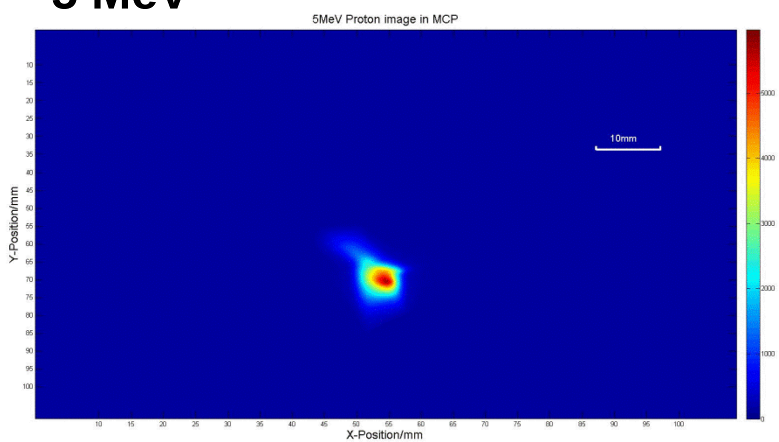
3 MeV, 1%



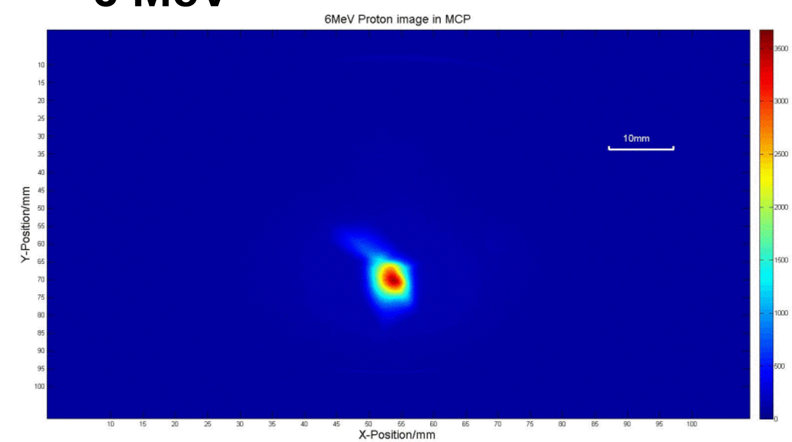
4 MeV



5 MeV

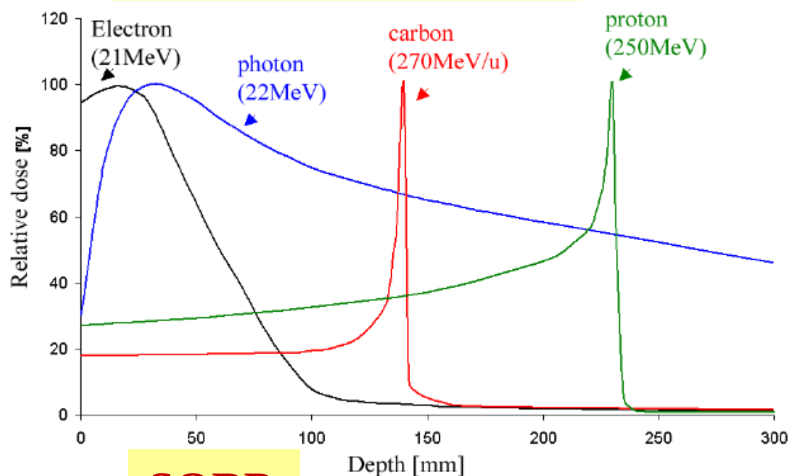


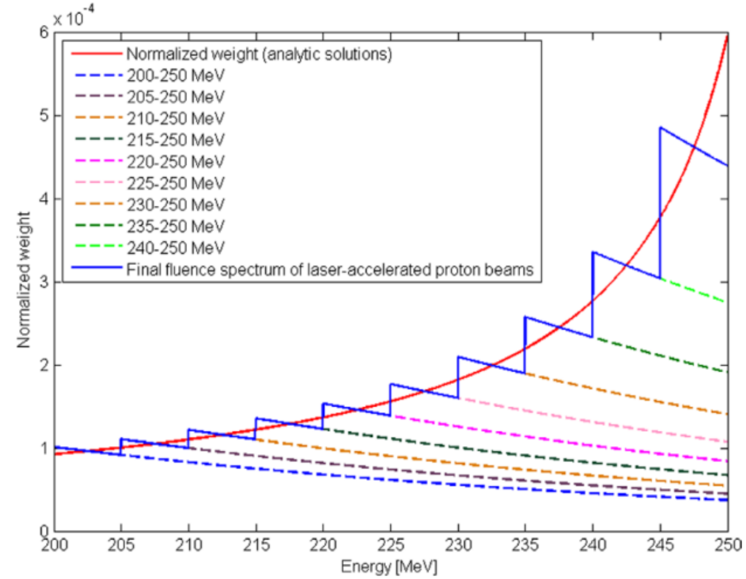
6 MeV



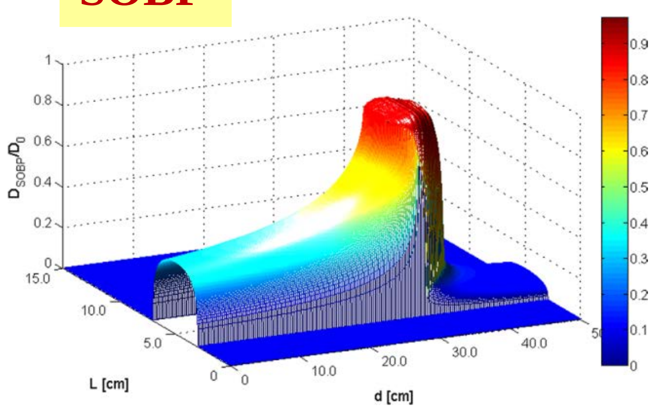
Spread-out Bragg Peak using CLAPA Beamline

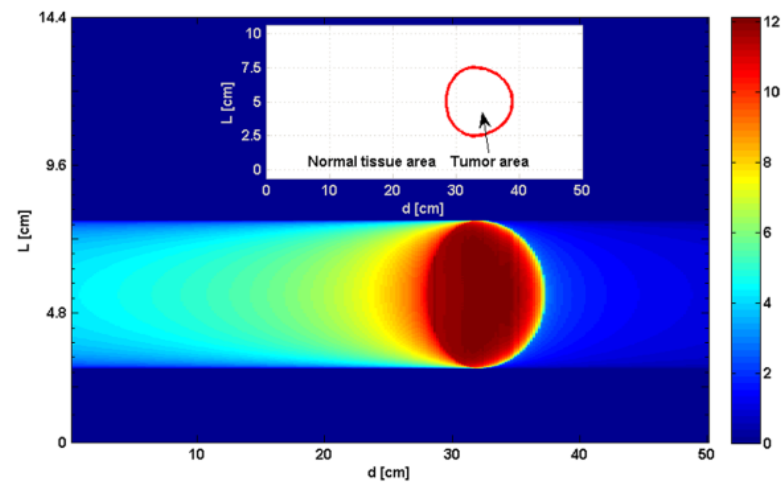
Single Bragg Peak





SOBP



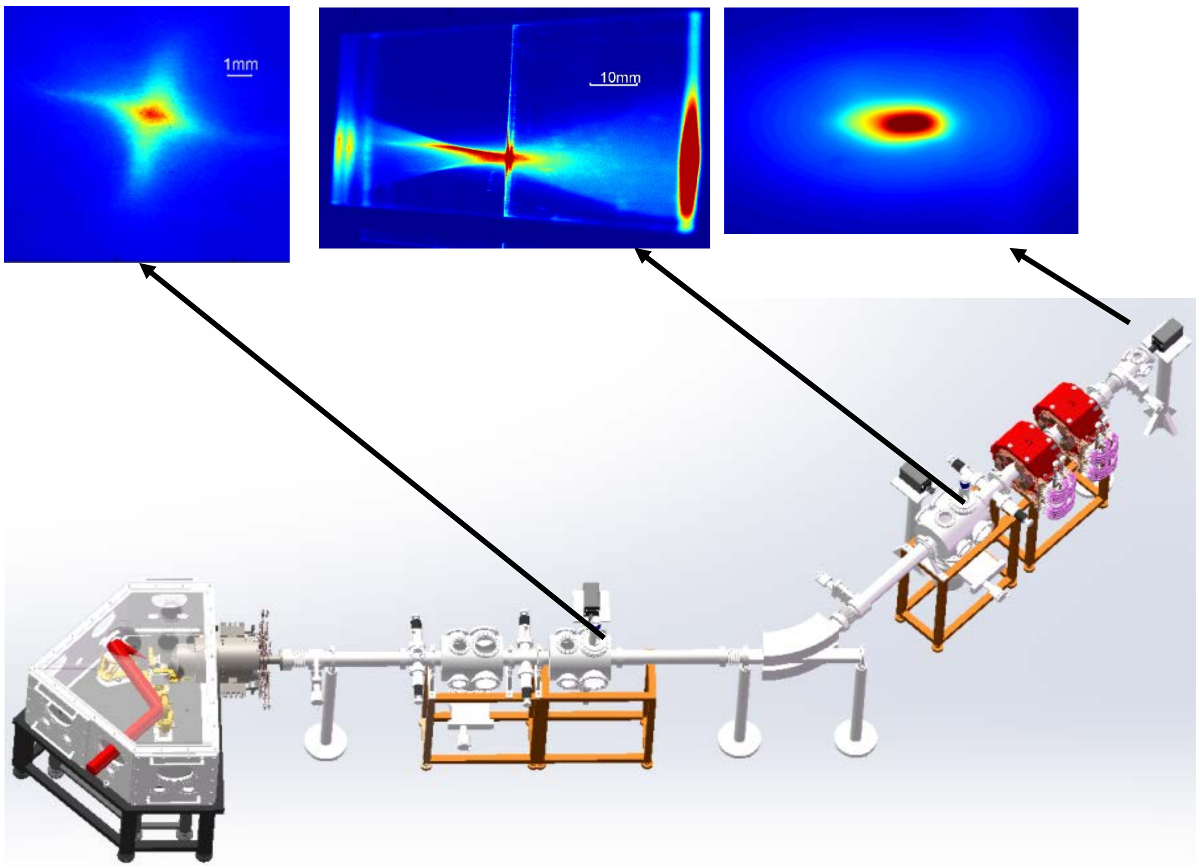


L Tao *et al.* Phys. Med. Biol. 62 (2017) 5200

Figure 6. The 2D reconstruction result of the SOBP for an ideal situation with a specific tumor region.

Proton beam with 1%energy spread/10pC/10MeV

With the development of high-rep rate PW laser technology ,now we can envision a table-top proton cancer therapy machine very soon.



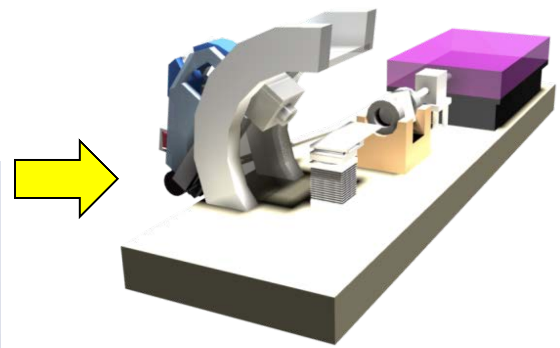


Table-top proton cancer therapy machine with RAMI

RAMI：
Reliability Availability
Maintainability Inspectability

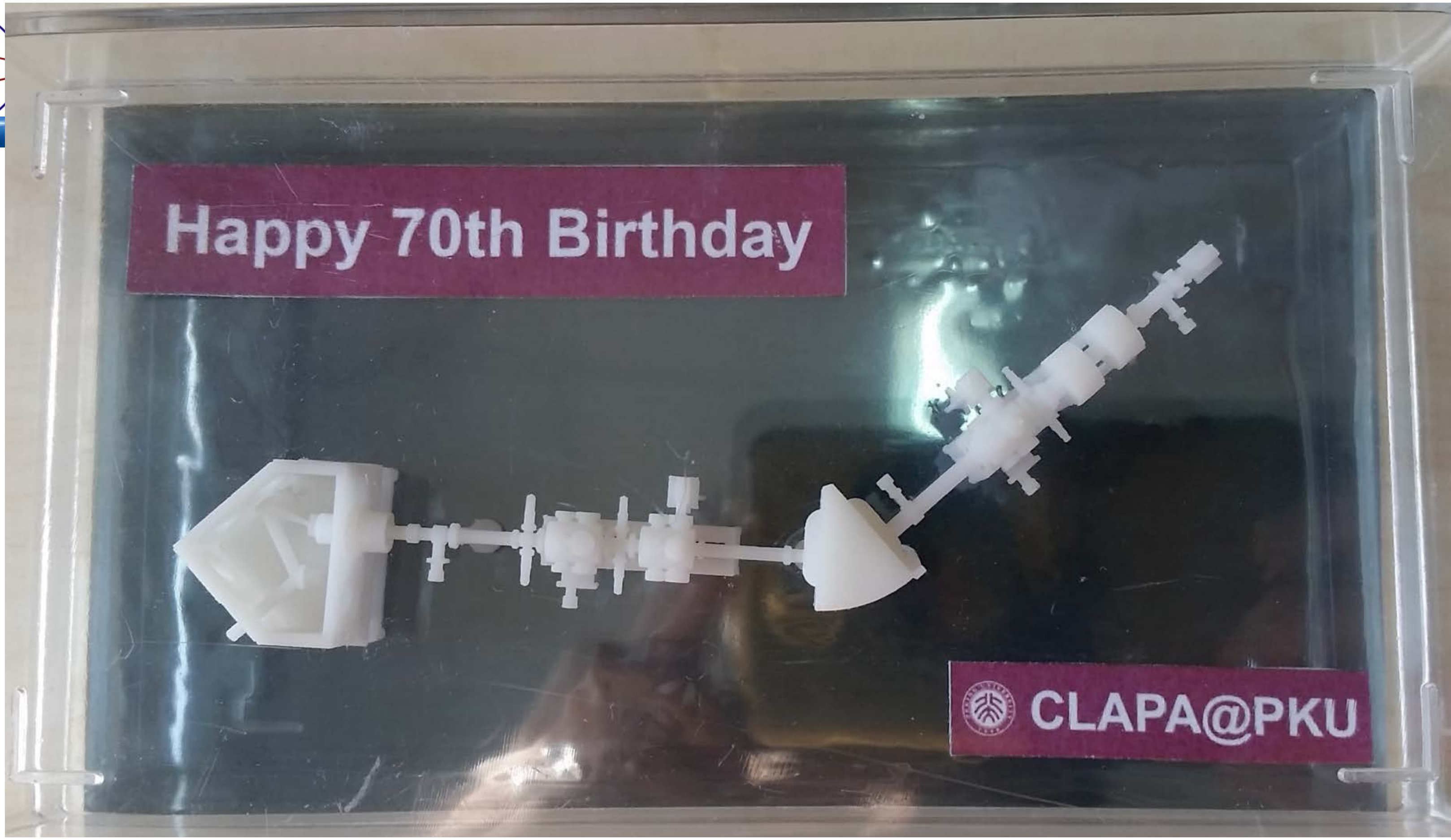
Summary

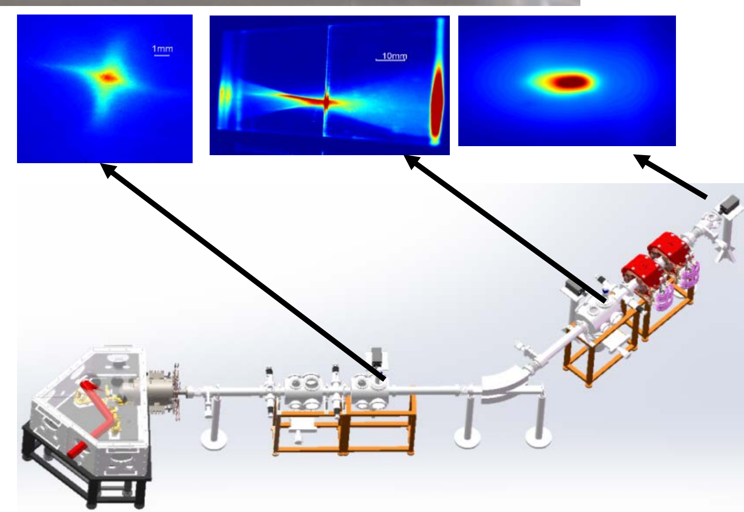
- ✓ A compact laser plasma accelerator (CLAPA) at Peking University has been built.
- ✓ 3-15 MeV proton beams have been generated with stability better than 3% by using plastic targets.
- ✓ With the beam line, laser accelerator of 3-9 MeV proton beams with 1% energy spread and 1-20 pC has been achieved.

Happy 70th birthday !

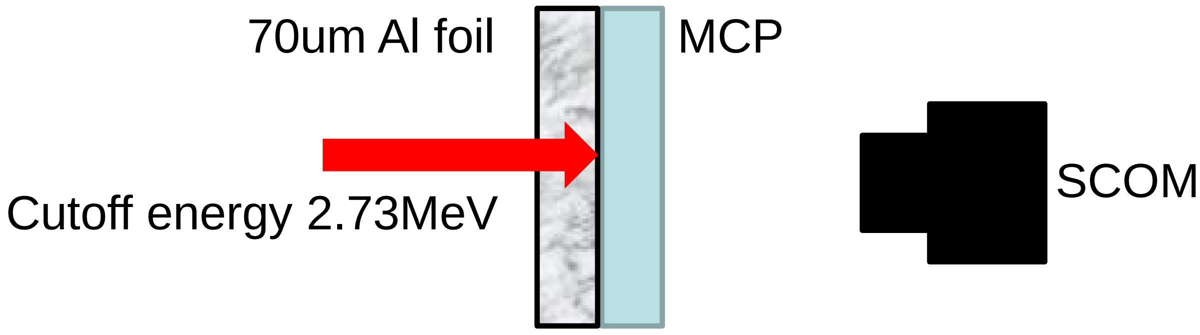
SKL
CAPT

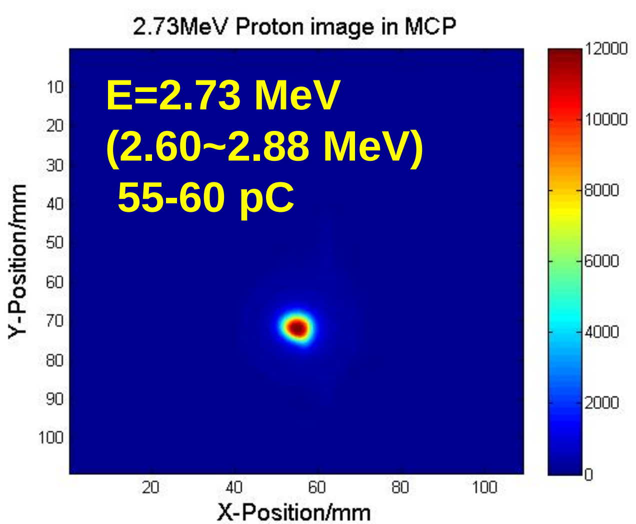
PEKING UNIVERSITY 1898

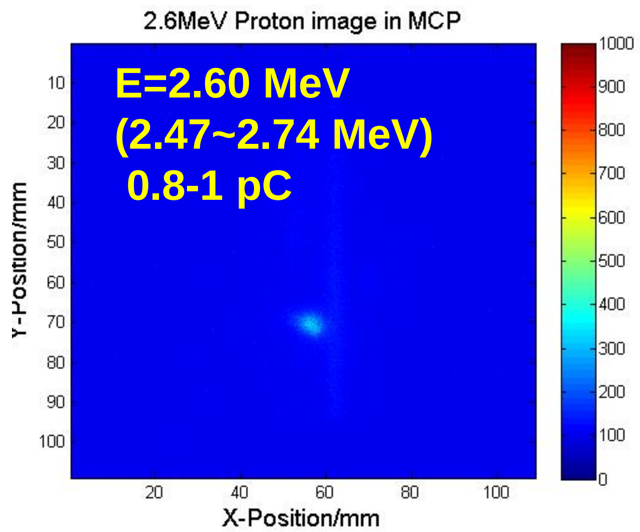


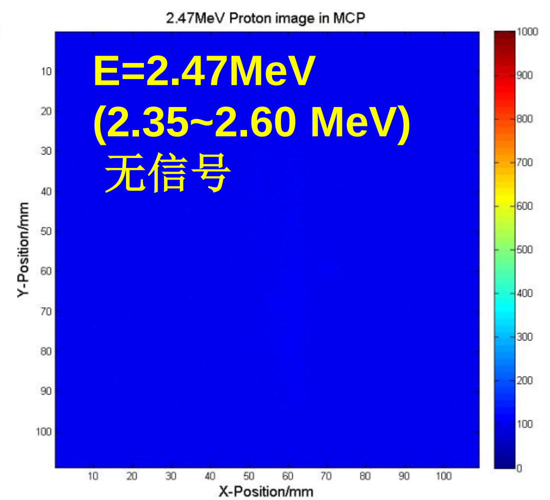


Verification of the energy accuracy



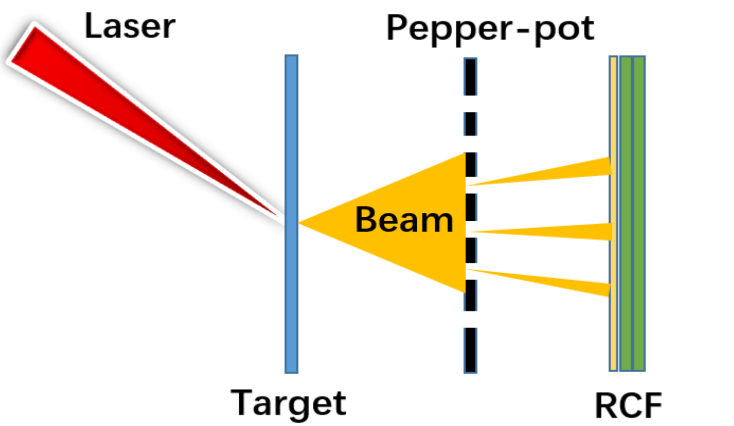




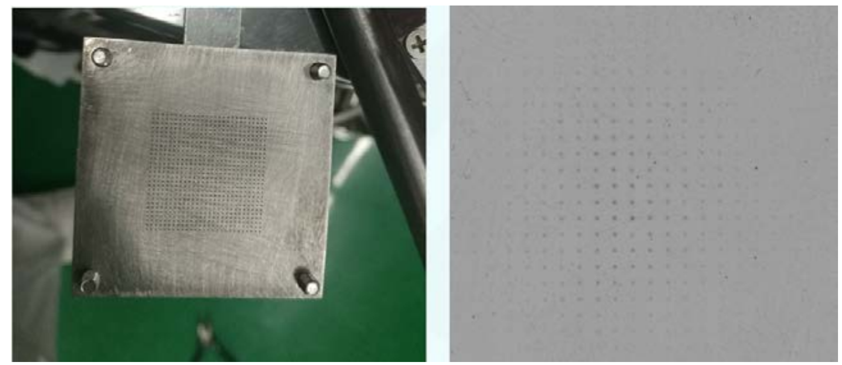


By using the aluminum foil cut-off energy, the accuracy of the beam line has been verified,

Emittance Measurement (1)



$$\varepsilon^2=\gamma^2 \left(\langle x^2 \rangle\langle x'^2 \rangle-\langle xx' \rangle^2 \right)$$



Molybdenum，20 × 20 array of 0.1 mm holes

The emittance of 2.8 MeV proton from CLAPA