Fast and compact proton radiography imaging system for proton radiotherapy

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Why do we need proton radiography?

- ✧ Proton radiography/CT imaging has a big potential to minimize the uncertainties of proton stopping powers (PSP) from 3-5% or bigger (currently used in clinics) down to 1%. This is necessary to make an accurate proton treatment plan for the patient and spare surrounding healthy tissues
- ✧ Proton radiography/CT delivers PSP directly, thus model independent

The Idea/Concept → Ideal tracking detection system

- Both tracking & residual energy (or range) detectors equally fast to process high amount of protons (~10^6/cm^2/s)
- Good energy resolution detector (<1%) required for accurate PSP determination
- Good angular resolution required for proton selection to minimize image blurring due to multiple Coulomb scattering (MCS)
- Tracking detector built from low Z and small Water Equivalent Thickness (WET) materials (<0.5 mm) to minimize MCS
- A complete proton radiography image acquired in the time scale of seconds

Systems used so far in experiments

With tracking and residual energy-range detectors

Group	Year	Tracking detector (# of units)	Residual Energy-Range Detector	Rate (Hz)	Imaging device
PSI	2005	x-y Sci-Fi (4)	Plastic scintillator telescope	1 M	pRad
LLU/UCSC/NIU	2013	x-y SiSDs (4)	CsI (Tl)	15 k	pCT
LLU/UCSC/ CSUSB	2014	x-y SiSDs (4)	Plastic scintillator hybrid telescope	2 M	pCT
AQUA	2013	x-y GEMs (2)	Plastic scintillator telescope	1 M	pRad
PRIMA I	2014	x-y SiSDs (4)	YAG:Ce calorimeter	10 k	pCT
PRIMA II	2014	x-y SiSDs (4)	YAG:Ce calorimeter	1 M	pCT
INFN	2014	x-y Sci-Fi (4)	x-y Sci-Fi	1 M	pCT
NIU/FNAL	2014	x-y Sci-Fi (4)	Plastic scintillator telescope	2 M	pCT
Niigata University	2014	x-y SiDs (4)	NaI (Tl) calorimeter	5 k	pCT
PRaVDA	2015	X-u-v SiSDs	CMOS APS telescope	1 M	pCT

Other system types

Group	Year	Detection system	Measured	Imaging device
HU/ NCC	2008	Scintillation screen + CCD camera	Depth-dose distribution	pCT
MGH/ EU/SNC	2013	2D diode-array	Residual proton range	pCT
TU/HU/ ToU	2016	Plastic scintillator + CCD camera	Residual proton range	pCT
HT/IBA	2016	Multilayer ionization chamber	Residual proton range	pRad

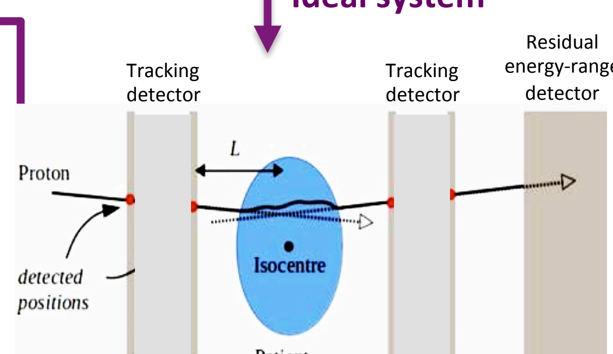
PSI: Paul Scherrer Institut (CH); **LLU**: Loma Linda University (USA); **UCSC**: University of California Santa Cruz (USA); **NIU**: Northern Illinois University (USA); **CSUSB**: California State University, San Bernardino (USA); **AQUA**: Avanced Quality Assurance; **PRIMA**: PRoton IMAging; **INFN**: Instituto Nazionale di Fisica Nucleare (IT); **FNAL**: Fermilab National Accelerator Laboratory (USA); **PRaVDA**: Proton Radiotherapy Verification and Dosimetry Application; **HU**: Hanyang University (KR); **NCC**: National Cancer Center (KR); **MGH**: Massachusetts General Hospital (USA); **TU**: Tokyo University (JP); **HU**: Hiroshima University (JP); **ToU**: Tokai University (JP); **HT**: Hospital of Trento (IT)

[1] *G. Poludniowski et al., Br J Radiol (2015)* ***88****:20150134*
[2] *M. Testa et al., PMB* ***58*** *(2013) 8215-8233*
[3] *S. Tanaka et al., PMB* ***61*** *(2016) 4156-4167*
[4] *P. Farace et al., PMB* ***61*** *(2016) 4078-4087*

✓ Tracking detectors

- Low Z and WET → minimum proton scattering angle in a detector
- Fast → high count rate, based on Timepix3/Timepix4, time resolution ~ns
- Good spatial resolution → 50 µm
- Full proton track determination
- Modular → ultimate size 30x30 cm^2

Ideal system



✓ Residual energy-range detector

- Fast scintillator (YAG:Ce, LaBr$_3$) with a good energy resolution of up to 1%

✓ Easy to mount on a gantry in proton therapy centers

✓ Scan time in a clinic of up to 10 s

Potential Impact

A fast and compact detection system, which provides a proton track with good spatial, angular and energy resolutions (compatible with reconstruction algorithms), will deliver an accurate proton stopping power map of the patient to fully benefit from proton therapy