Fast and compact proton radiography imaging system for proton radiotherapy

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ATTRACT NL Kick-off event,
9th February 2017, Amsterdam, The Netherlands

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PARTREC
Particle Therapy Research Center

Proton therapy work flow

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CT scan

$$HU = 1000\,\frac{\mu - \mu_{water}}{\mu_{water}}$$

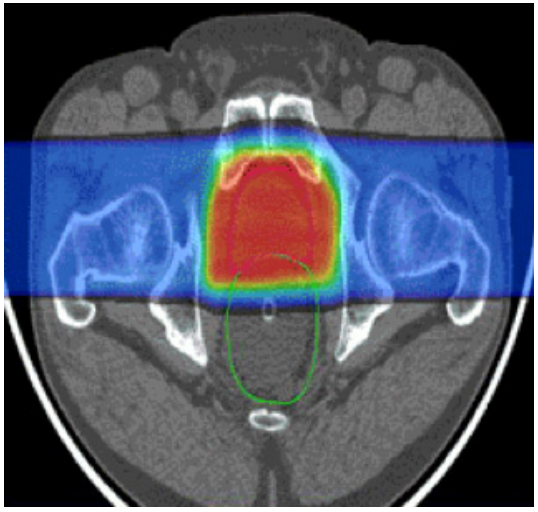
Knowledge of patient

Translation

3D map of proton stopping powers (PSP)

$$\left(-\frac{dE}{dx}\right)$$

Treatment planning



Treatment

Treatment verification

Knowledge of the patient and its consequence

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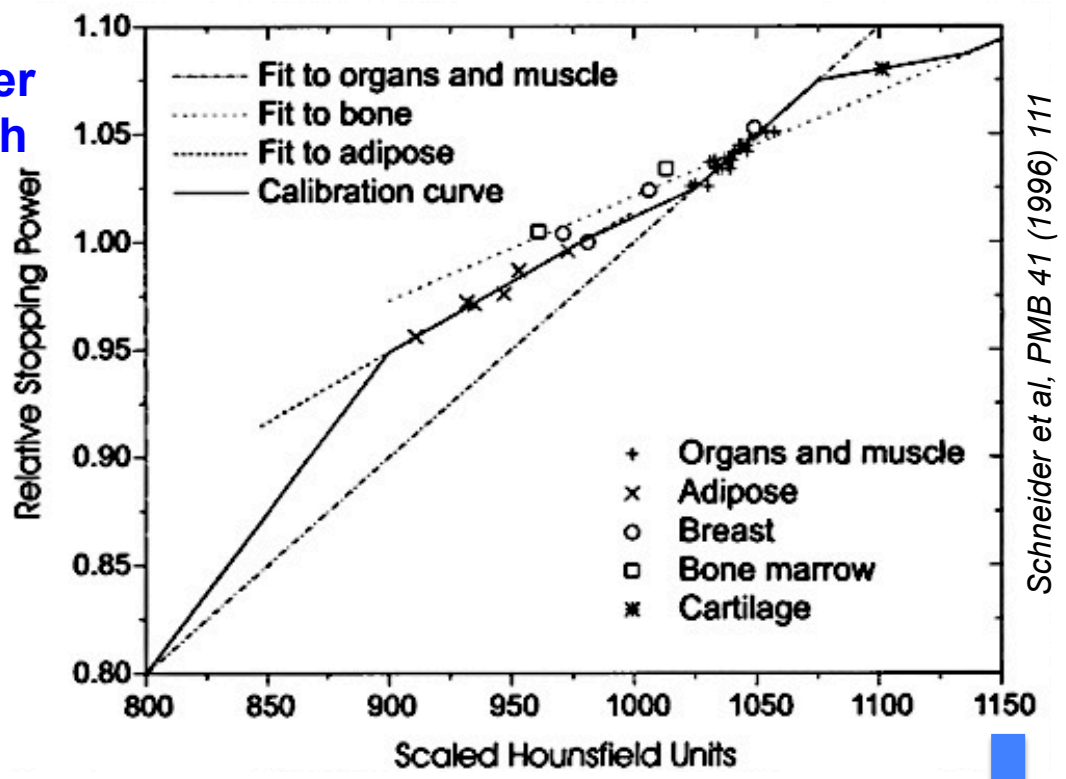
CT scan

$$HU = 1000\,\frac{\mu - \mu_{water}}{\mu_{water}}$$

Schneider approach



- Conversion HU to proton stopping power is NOT unique
- Systematic uncertainties of 3-4% or more require larger than neccessary irradiation safety margins around the tumor

3D map of proton stopping powers $\left(-\frac{dE}{dx}\right)$

Increased dose to healthy tissues

Why proton radiography?

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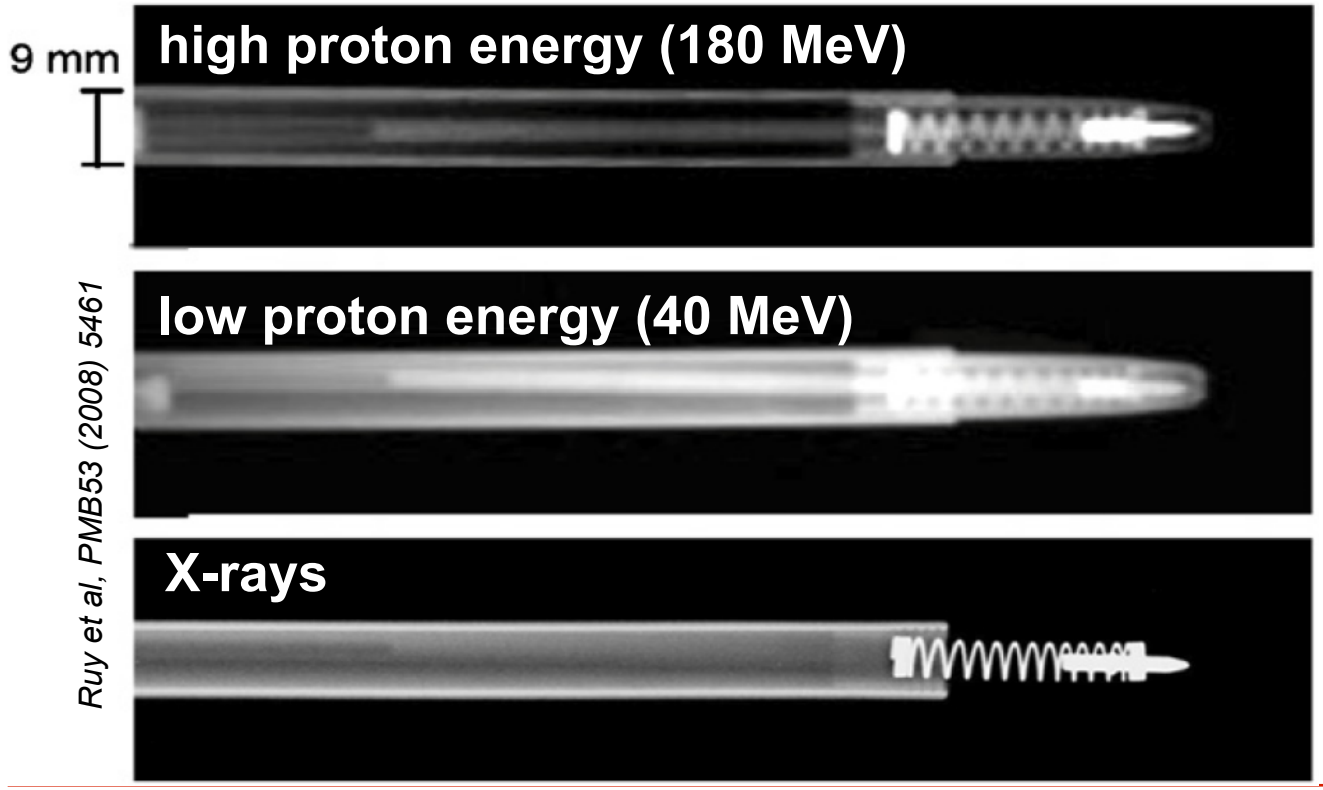
- Direct measurement of proton stopping powers (model free)
- High resolving power for proton beam (centerpiece of the pen visible)
- X-ray produces a clearer image of the spring,
  but density resolution for the centerpiece is not high



Protons help determining energy losses in "soft materials"

Current systems with tracking detectors

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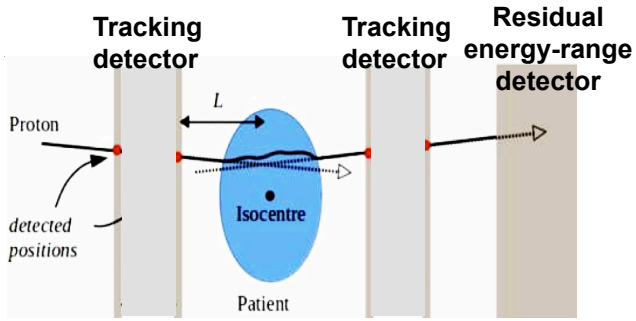

- Trend towards Si tracking detectors (individual proton)

Fast, BUT with high Z, high ρ more Multiple Coulomb Scattering → more blurred image

- Different approaches for energy/range detectors

Too slow / too thin

- Count rate close to required

Size / configuration not yet optimal

*G. Poludniowski et al., Br J Radiol (2015) **88**:20150134*

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

Ideal system with tracking detectors

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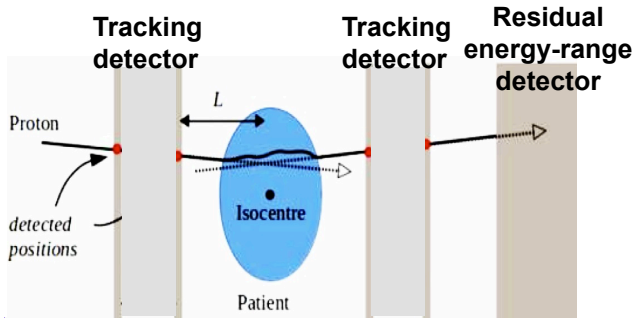

✓Tracking detectors

- **Low Z and WET** → minimum MCS in detector
- **Fast** → high count rate (> MHz), time resolution ~ns
- **Spatial resolution** → 50 μm
- **Full proton track** determination
- **Modular and compact** → 30x30 cm^2

✓Residual energy detector

- **Good energy resolution** of up to 1% (YAG:Ce, $LaBr_3$)
- **Fast** → high count rate (> MHz)

Ideal system with tracking detectors

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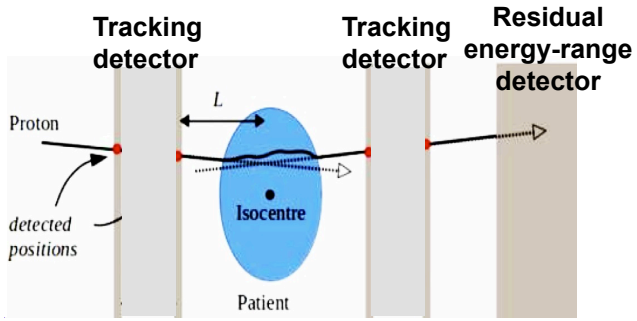

✓ **Easy to mount on a gantry in proton therapy centers**

✓ **Scan time + reconstruction of up to few sec**

All to be clinically acceptable!

✓Tracking detectors

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Energy loss radiographs: $\Delta E = E_{beam} - E_{residual}$ (Geant4)

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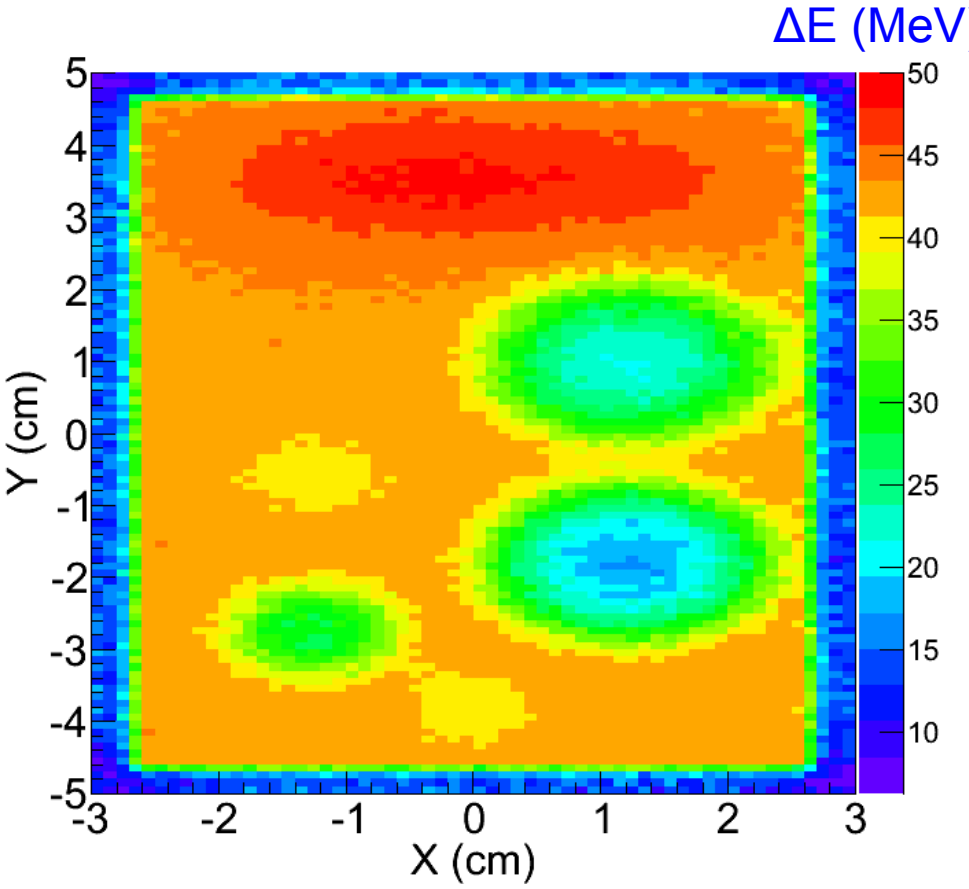
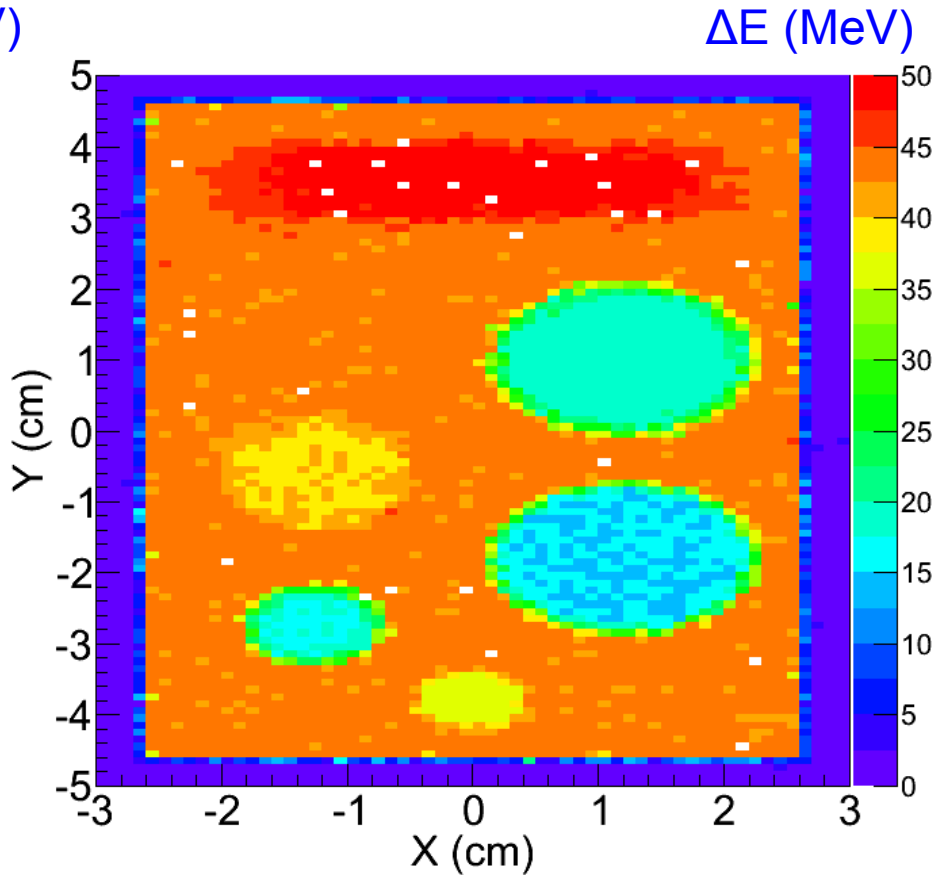
- All protons that passed through phantom and three detectors



- Protons with maximum scattering angle $\theta < 5.2$ mrad



Selecting protons traveling along straight lines improves the image quality

A.K. Biegun et al., JINST **11** C12015 (2016)

Proton radiography @KVI–CART (Exp'2015)

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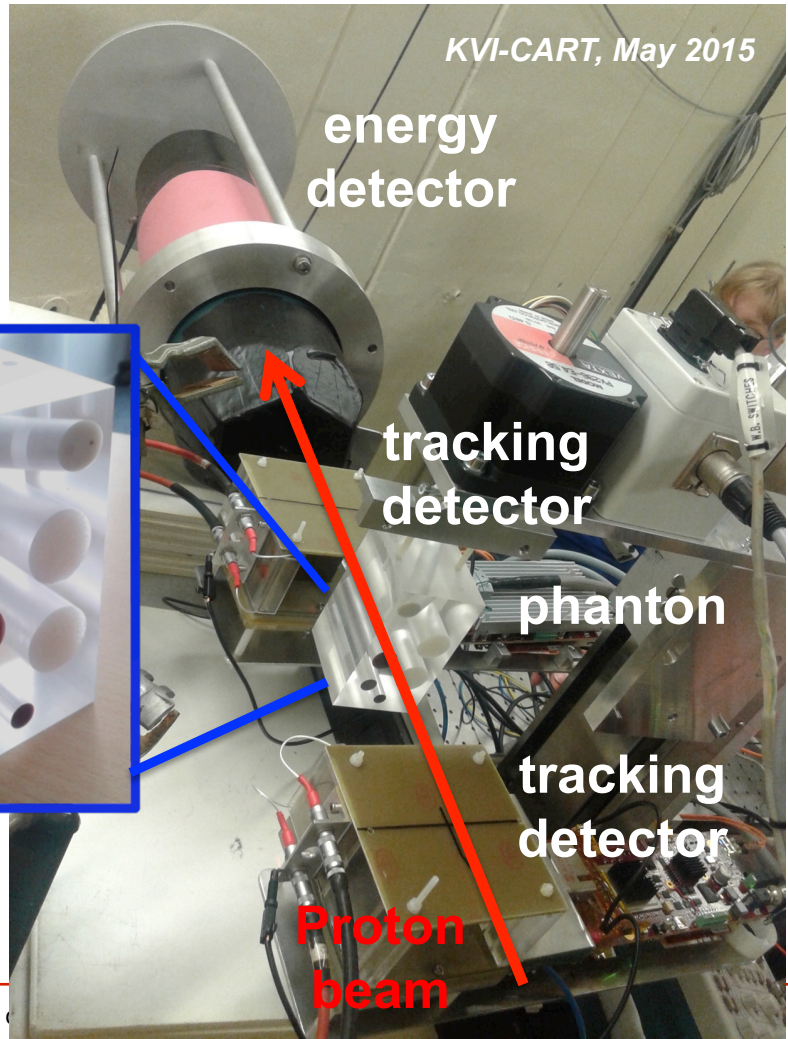
Collaboration with J. Visser, M. van Beuzekom, E. Koffeman

Nikhef

Improved part of detection system:

Position: TPC based on **Timepix3 - factor 100 faster** data acquisition compared to GridPix used in experiment (May'14)
→ 100x more data
Energy: BaF_2 scintillator



Count rate ~20 kHz increased by factor 100!!

… but still not high enough for clinical requirement…

Energy loss reconstruction: Sims vs. Exp'2015

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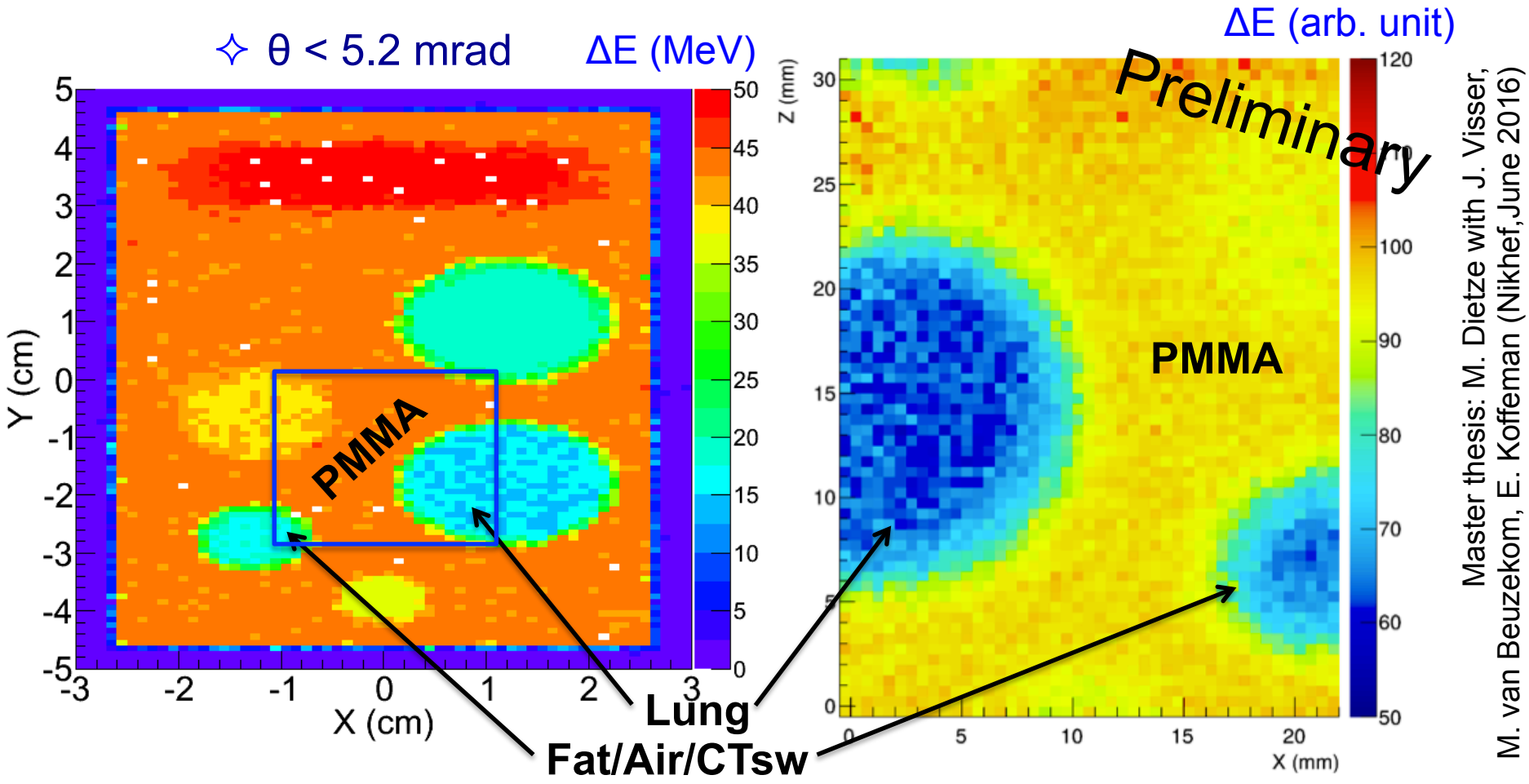
✧ Phantom partially covered by Timepix3-based TPCs (3.0 x 3.0 cm^2)



Simulations and experimental results are comparable

Summary

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- Fast and compact detection system
- Good spatial, angular and energy resolutions
- Compatible with reconstruction algorithms

An accurate proton stopping power map of the patient

→ Accurate treatment plan

→ Full benefit from proton radiotherapy