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An experimental imaging dose estimation method for the Phase II proton CT scanner

2024 Ion Imaging Workshop

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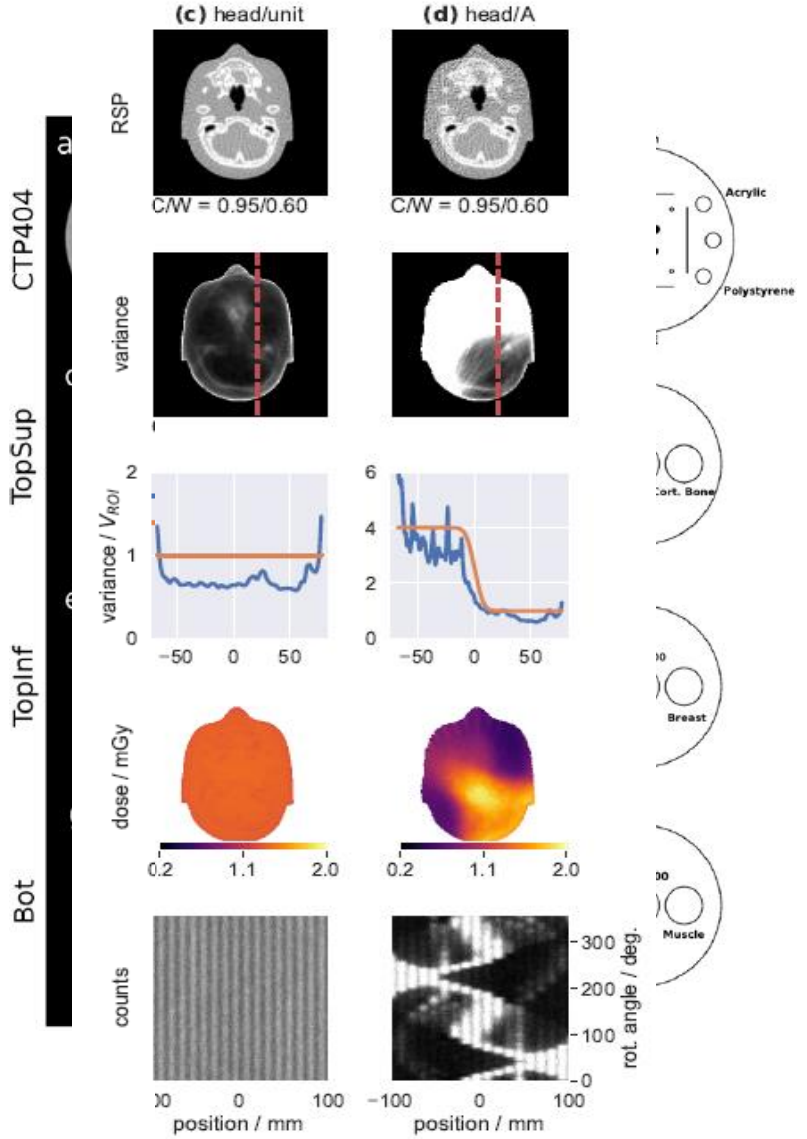
Background
Imaging in Proton Therapy

- Imaging in proton treatment planning
  - A volumetric map of the patient's RSP is needed
  - Single energy X-ray CT (≈ 1-3%)
  - Dual energy X-ray CT (0.67%)
  - Proton CT (0.55%)
- Imaging for setup and plan adaptation in treatment delivery
  - Leading to imaging dose increase
  - Less radiological dose to the patient compared to getting the equivalent information using X–ray CT
  - Previous work on dose reduction: fluence-modulated pCT(FMpCT)

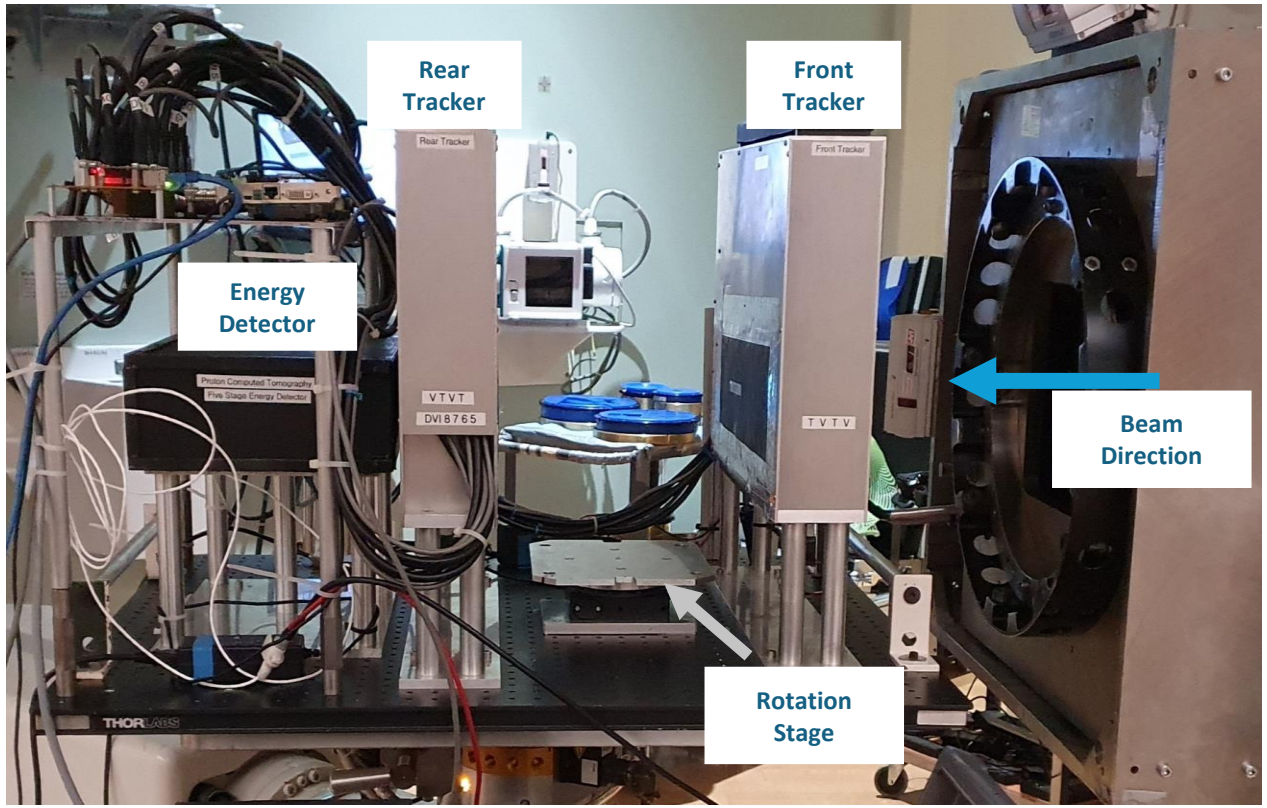


G. Dedes et al. (2019), PMB, 64, 16

Dickmann et al. (2020), Med. Phys., 47, 4

Background
Prototype II Proton CT scanner

- Tracking detectors
  - Two stacked silicon strip planes
  - Record the horizontal t– and the vertical v– coordinate
- Energy detector
  - Five scintillating detectors
  - Determine the water-equivalent path length(WEPL)

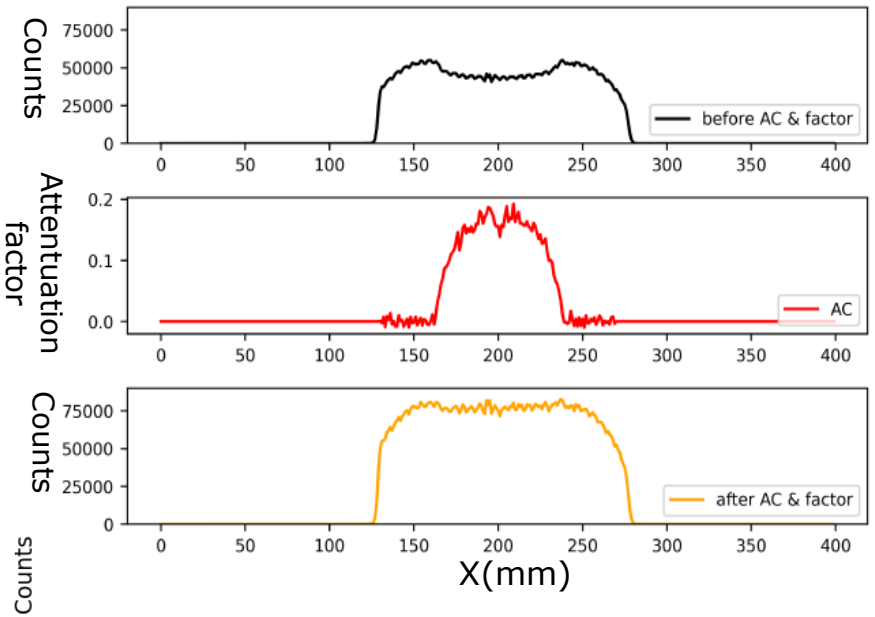


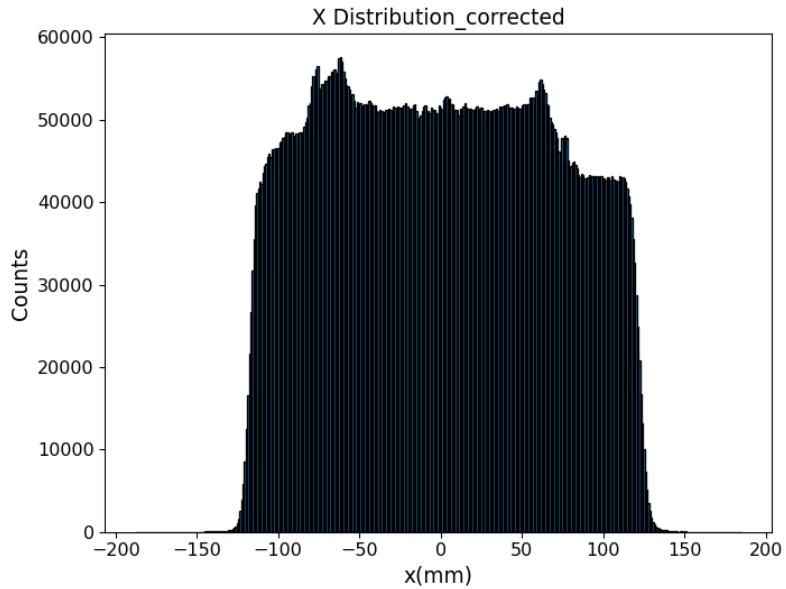
The Phase II prototype pCT scanner at the Northwestern Medicine Chicago Proton Center

Background

Dose evaluation method of pCT

- "True" imaging dose?
- Measurement dose
  - Ionization chambers (IC)
  - Absolute dose measurements
- Estimation by simulation
  - Monte Carlo simulation motivation: full physics modelling in complicated geometry and materials.
  - Source data from scanner: the same irradiation field
  - Energy-detector-triggered method
    - requiring an attenuation correction of the proton fluence
    - highly dependent on the phantom used
- **Aim**
  - **To develop a new dose estimation method to bypass attenuation correction**
  - **Based on front-tracker-triggered data**

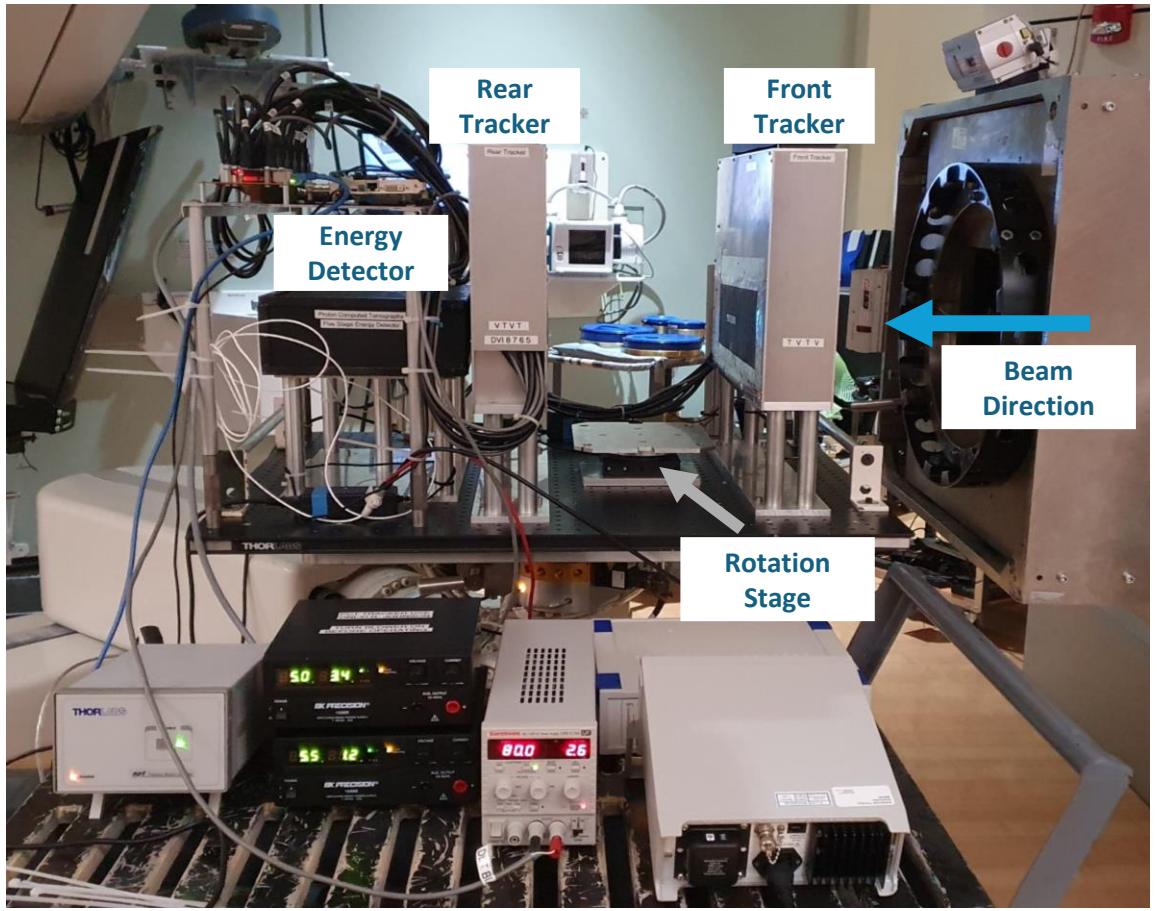




Materials & Method

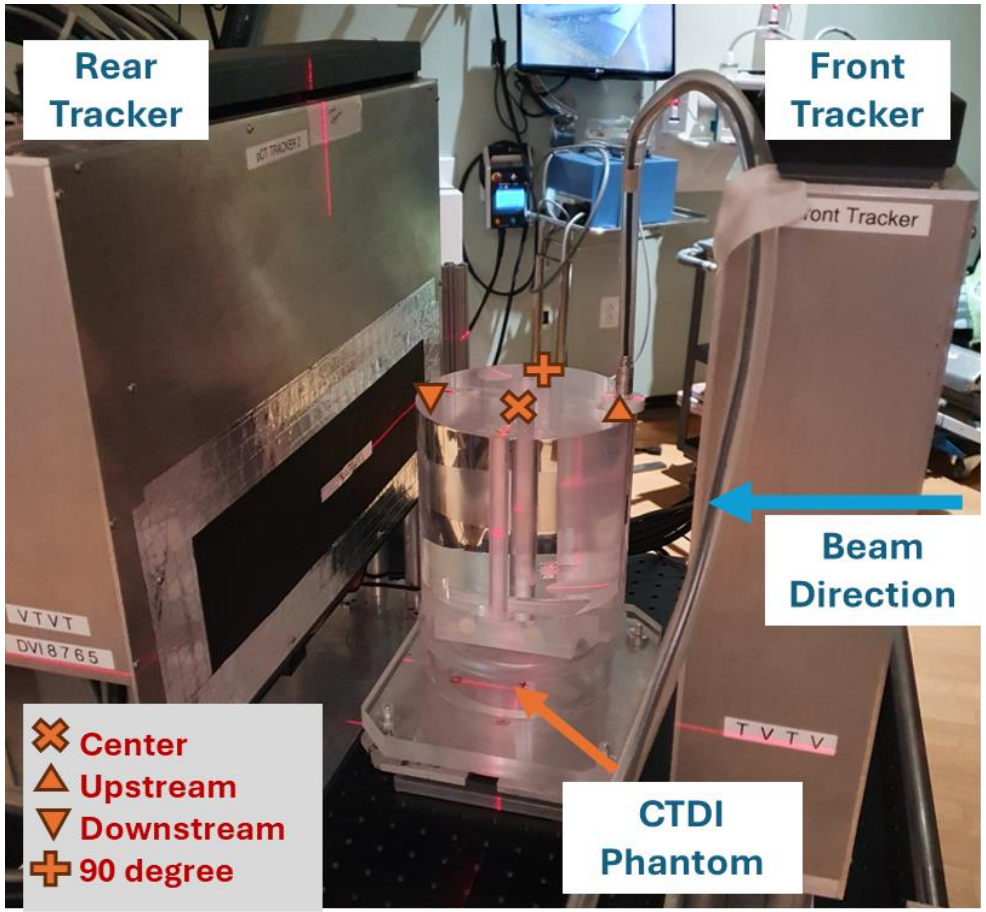
Measurement – Scanner and Ionization Chamber

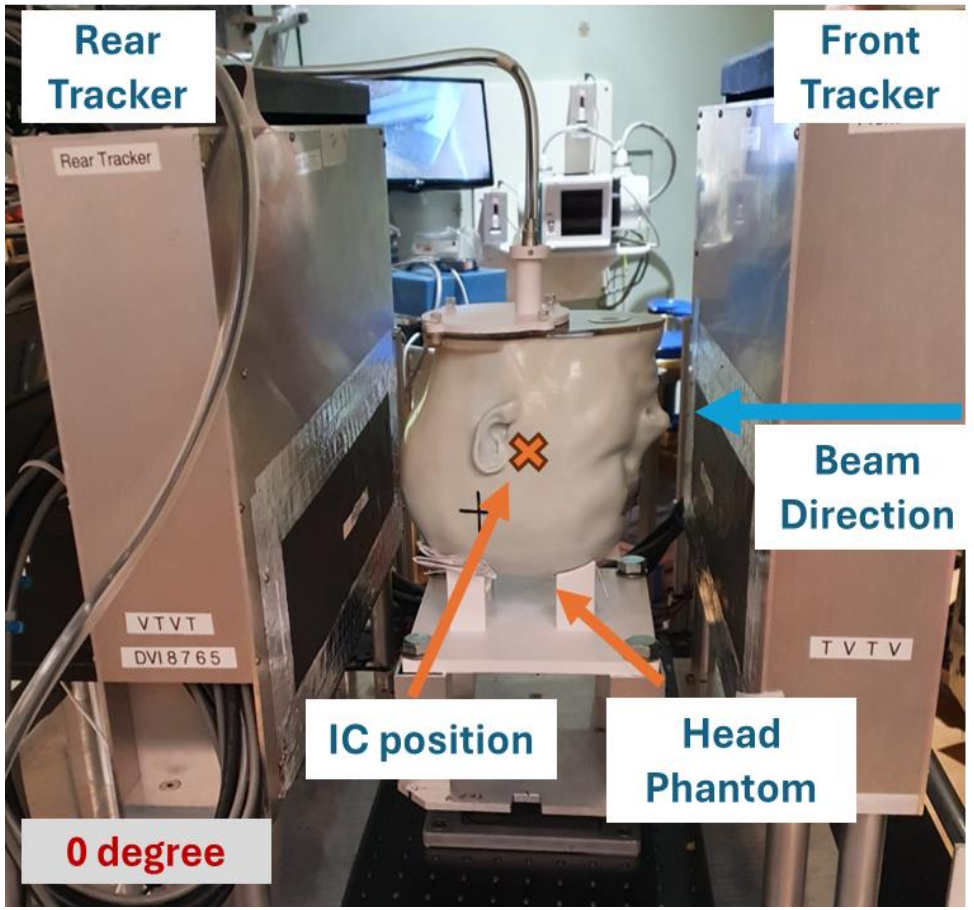
- The Phase II prototype pCT scanner at the Northwestern Medicine Chicago Proton Center
- Farmer ionization chamber (IC) (FC65-P, IBA Dosimetry, Schwarzenbruck, DE) connected to an electrometer (SUPERMAX, Standard Imaging, Middleton, WI).



Materials & Method

Measurement - Phantoms





Materials & Method

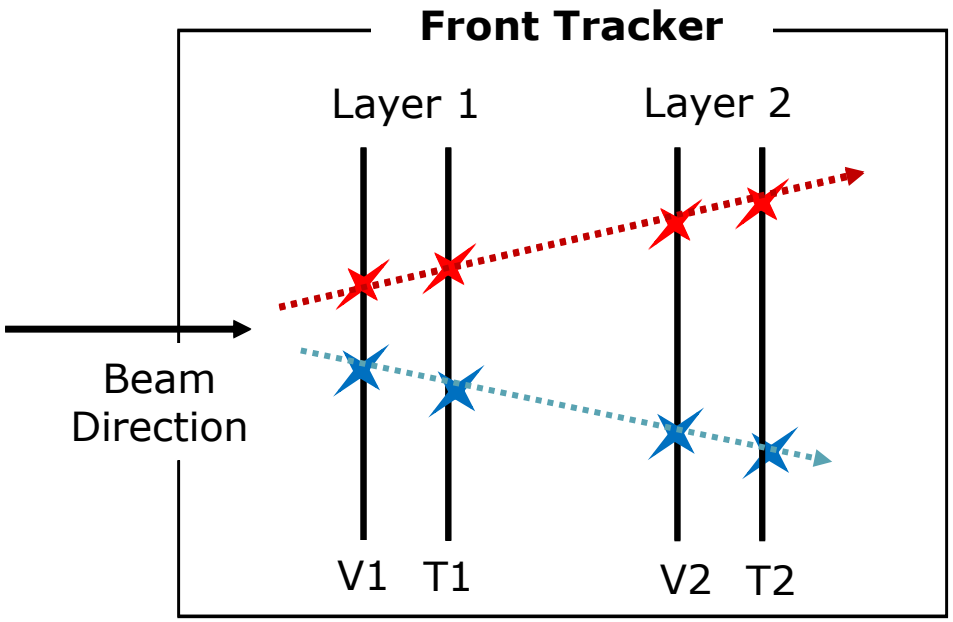
Measurement – Scan Parameters

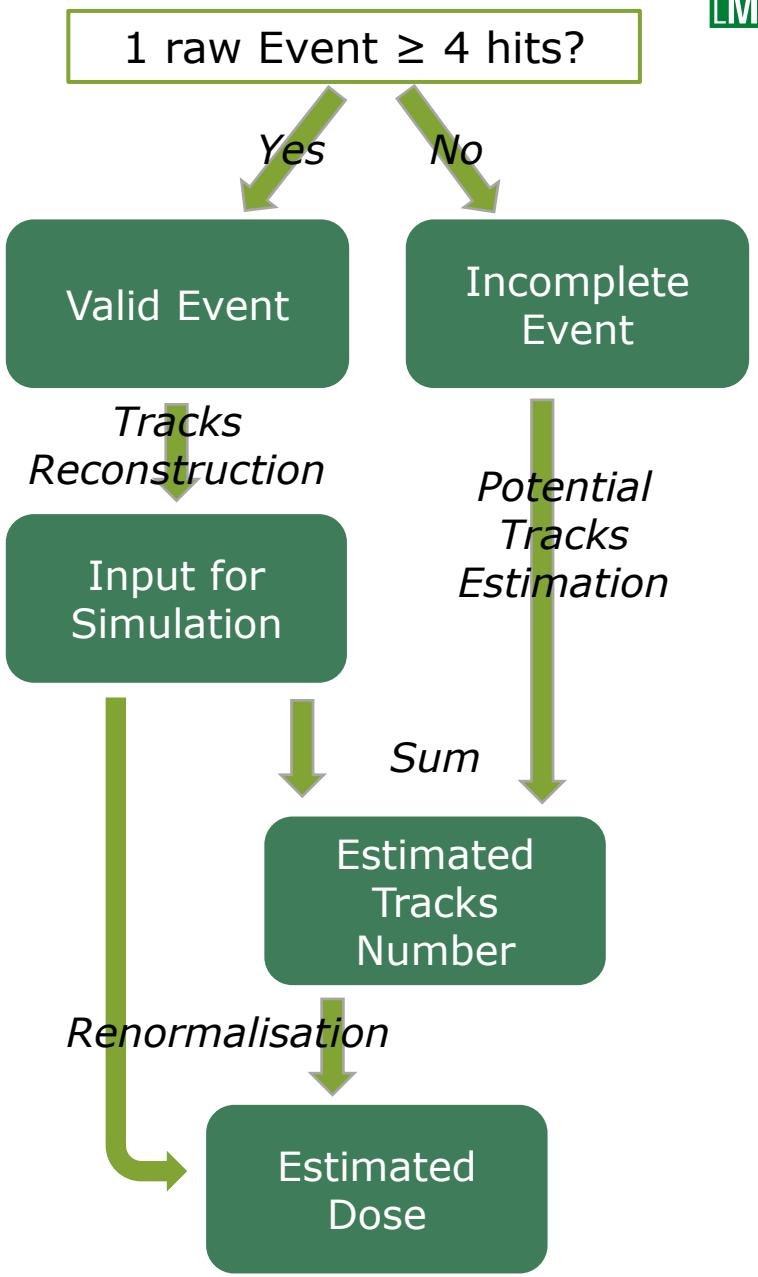
Phantom type	Rotation	IC position	Time	Trigger type
CTDI Phantom	no	center	30s	energy detector
	no	upstream	30s	front tracker
	no	downstream	30s	front tracker
	no	90 degree	30s	front tracker
	360 degree	center	360s	energy detector
Head Phantom	0 degree	center	30s	energy detector
	45 degree	center	30s	energy detector
	90 degree	center	30s	energy detector
	360 degree	center	360s	energy detector

Materials & Method

Dose Estimation by Simulation

- Source data from scanner
  - Raw data processing
  - Measured proton fluence/number

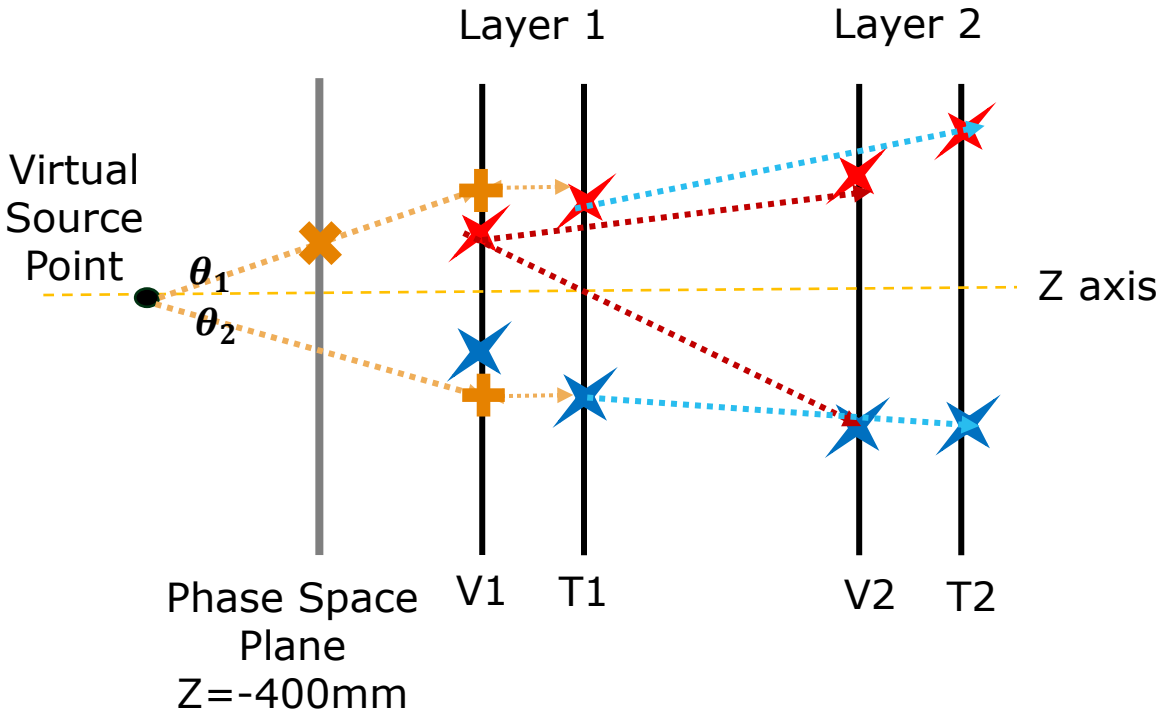


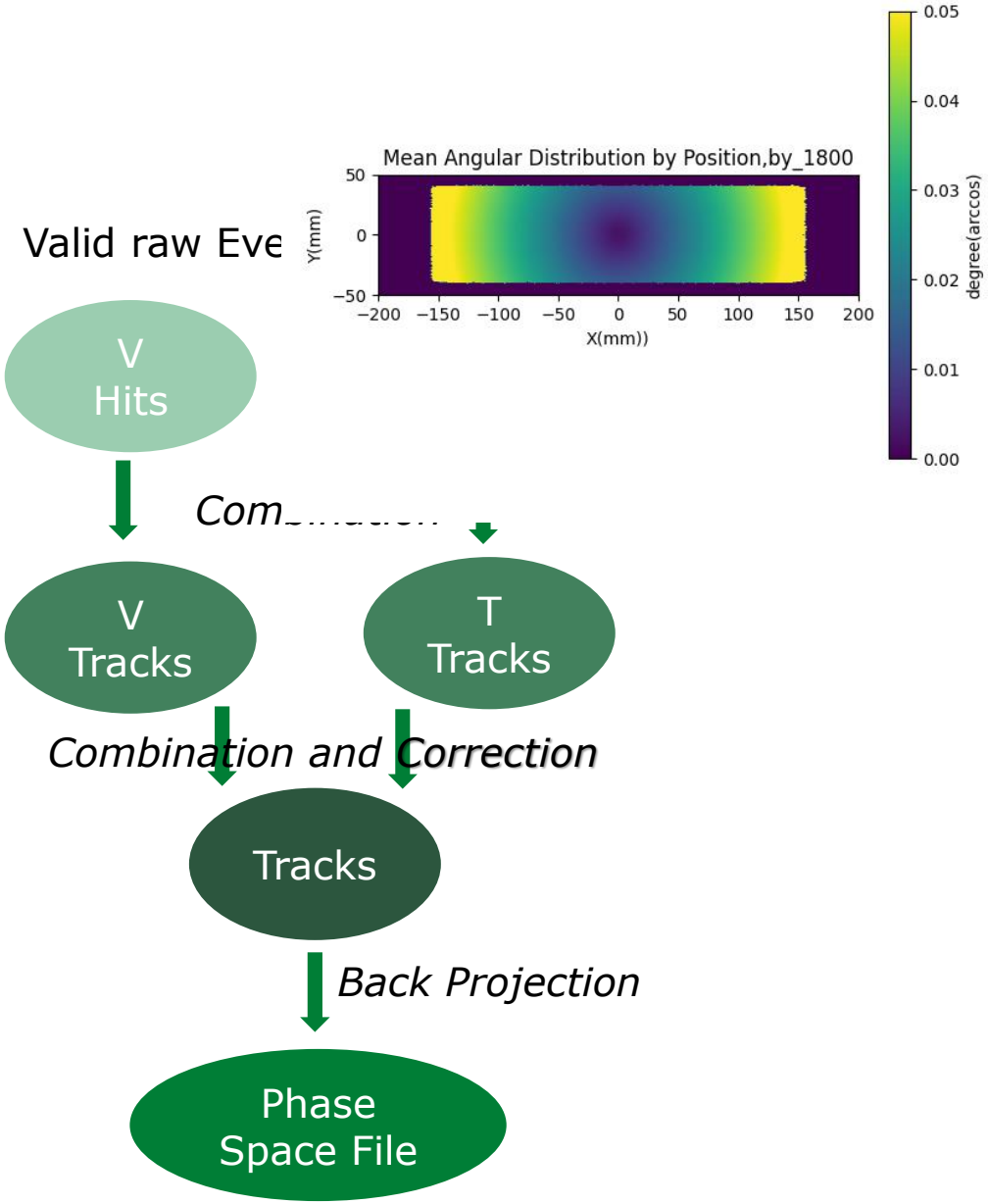


Materials & Method

Valid Event – Tracks Combination

- Without track quality selection
- Single/Multiple proton tracks?

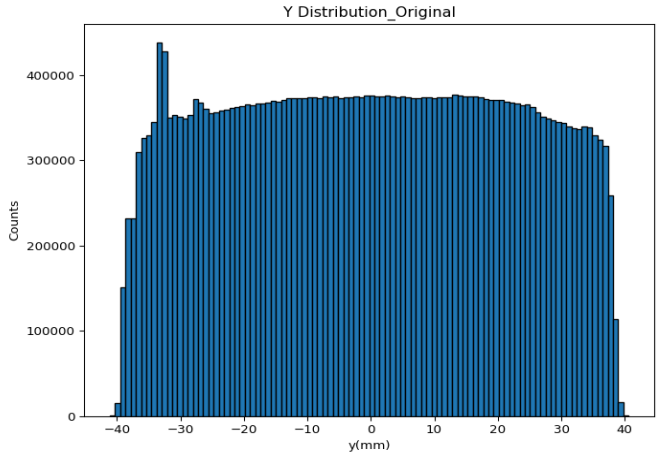


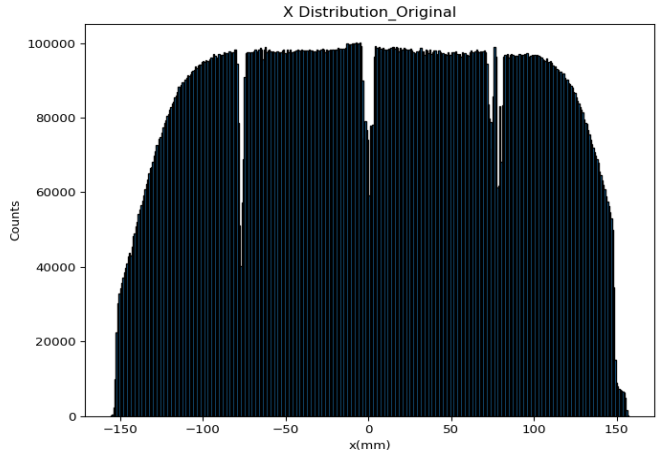


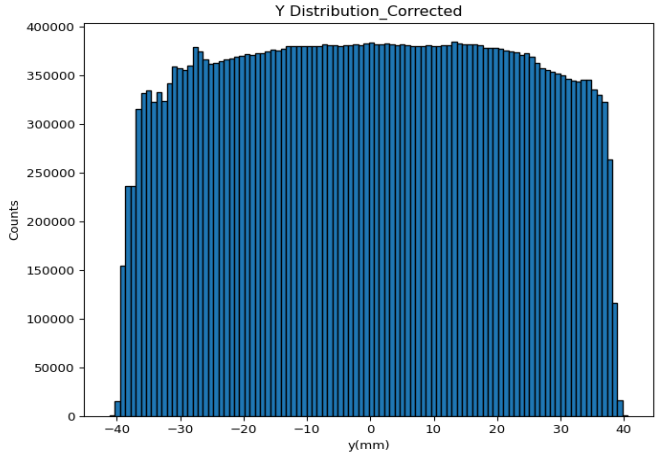
Materials & Method

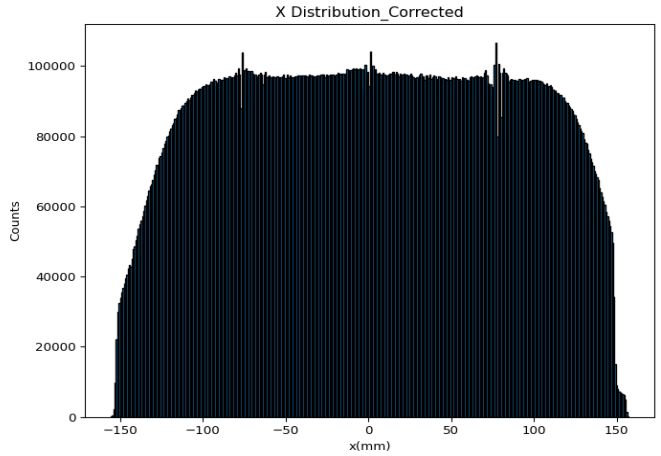
Valid Event – Correction

- Direction distribution correction
  - A virtual source point used
  - Done during combination
- Position distribution correction
  - Noisy strips
  - Weight adjustments









Materials & Method

Incomplete Event

- About 20% of incomplete events, but still contribute to overall dose estimation
- Valid event and Incomplete event have the same probability of creating single/multiple proton tracks
  - $Ratio = \frac{Reconstructed\ Tracks}{Event\ Number}$
- $Estimated\ Proton\ Tracks = \frac{Reconstrcuted\ proton\ tracks}{Valid\ event\ ratio}$

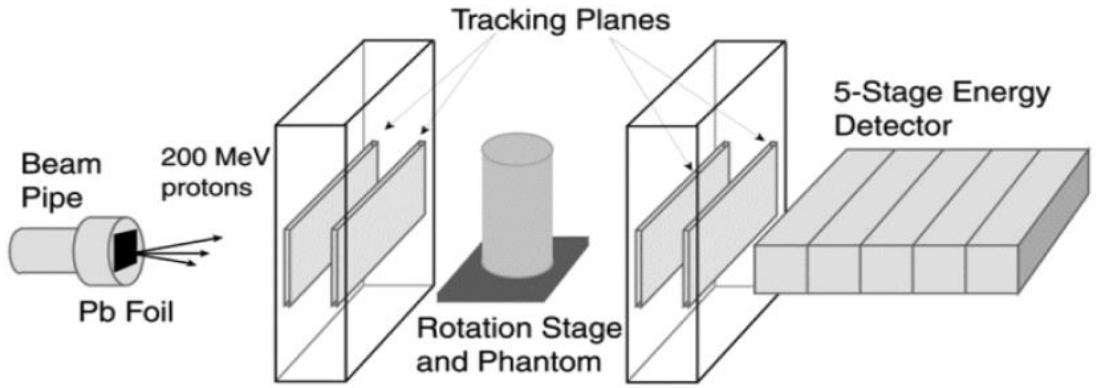
Tracks Data from measured CTDI phantom with front tracker trigger

Source	Event number	Incomplete event number	Valid event ratio	Reconstructed proton tracks	Estimated proton tracks
Upstream	3.57E+07	6.84E+06	80.8%	3.42E+07	4.23E+07
Downstream	3.50E+07	6.77E+06	80.6%	3.32E+07	4.12E+07
90 degree	3.48E+07	6.74E+06	80.6%	3.30E+07	4.09E+07
Averaged	3.52E+07	6.78E+06	80.7%	3.35E+07	4.15E+07

Materials & Method

Simulation and Renormalisation

- Simulation, Geant4
  - Input source: phase space file from front tracker triggered measured data or averaged.
  - Phantom: CTDI/Head phantom and IC were filled with water.
  - Dose scoring: voxel size 1mm*1mm*1mm



A schematic depiction of the phase-II head scanner

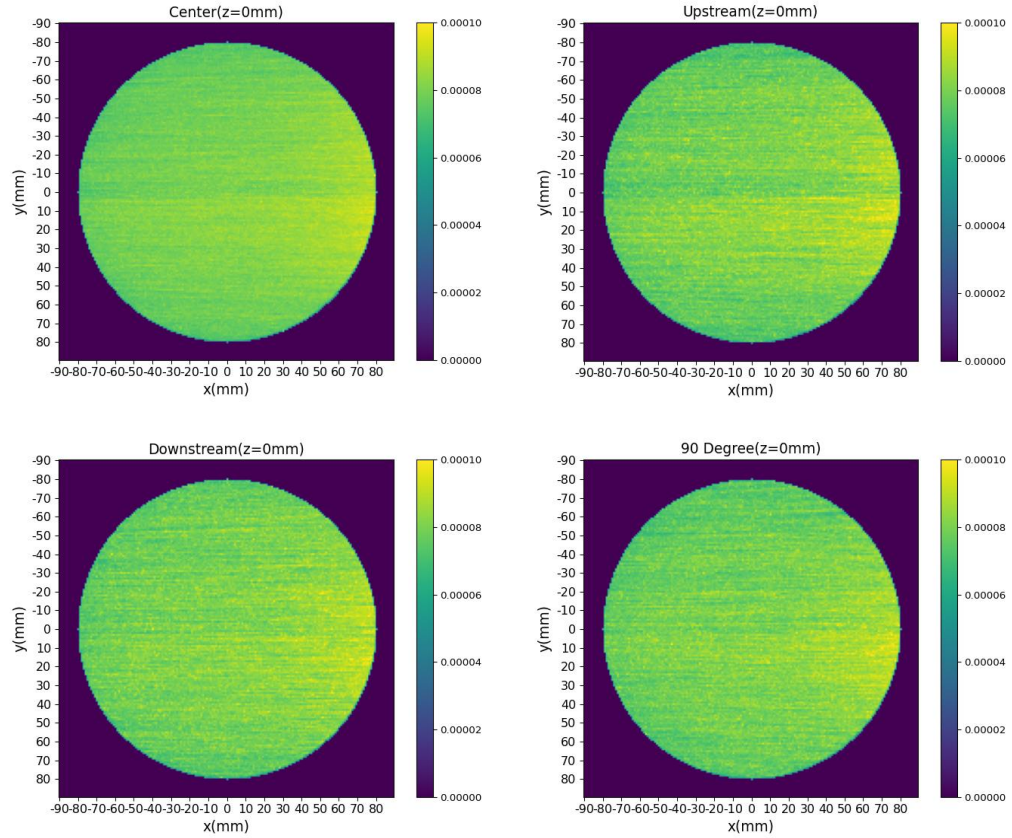
- Renormalisation
  - Simulated dose(arbitrary number) renormalised to estimated proton tracks(measured proton fluence).

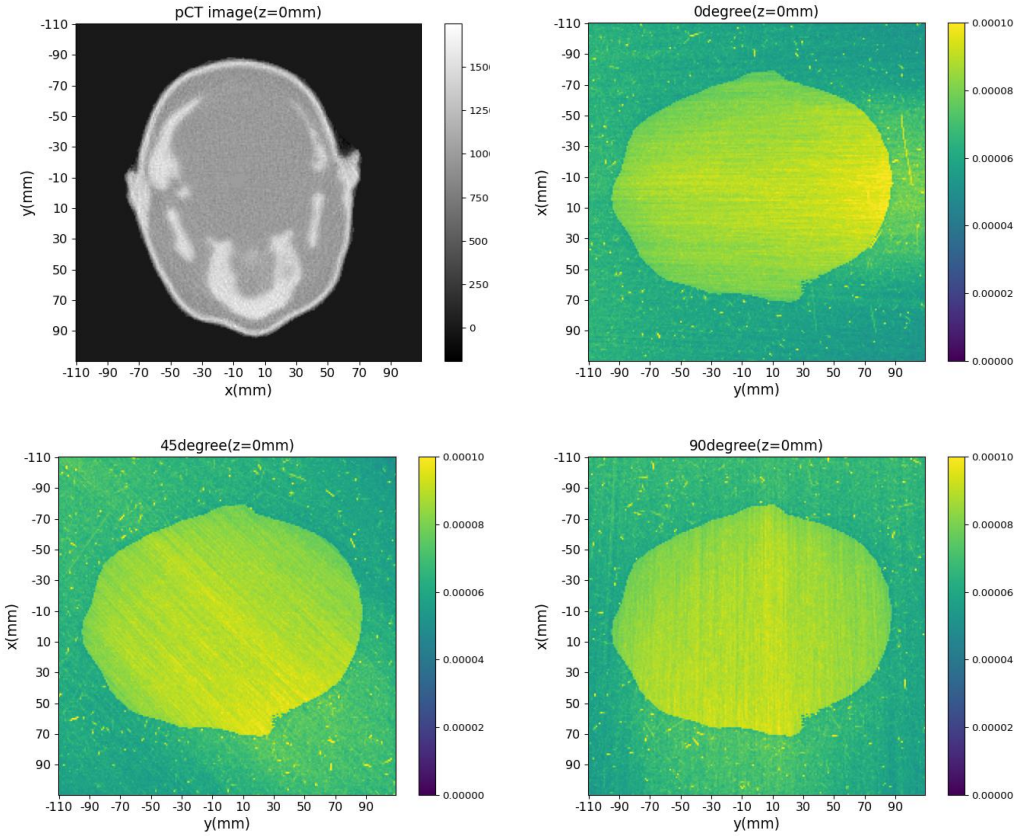
Johnson RP, et al. (2016), IEEE Trans Nucl Sci.

Results

Simulated dose distribution

- Dose distribution in central slice(z=0mm).





Results

Dose Comparison

- IC Measured dose corrected with temperature and pressure.

Phantom Type	Rotation	IC position	Mean IC Measured dose(mGy)	Renormalised simulated dose(mGy)	Mean Diffs to meas(%)	Standard deviation(%)
CTDI Phantom	no	center	0.116	0.112	-3.3%	1.8%
	no	upstream	0.109	0.106	-2.9%	1.6%
	no	downstream	0.125	0.121	-2.9%	0.7%
	no	90 degree	0.106	0.103	-2.9%	1.2%
	360 degree	center	1.429	1.349	-5.6%	0.5%
Head Phantom	0 degree	center	0.120	0.115	-4.2%	/
	45 degree	center	0.119	0.112	-6.6%	/
	90 degree	center	0.117	0.111	-4.5%	/
	360 degree	center	1.343	1.451	-7.7%	/

Conclusion & Outlook

- Successfully developed and implemented Front-Tracker-Triggered method
- Validated with IC-measured data
- Optimised for use with both CTDI and head phantom and successfully estimated dose

- Investigate how the beamline elements affect the beam energy
  - Assumption now is 200MeV
- Refine algorithms to increase accuracy
- Extend to more complex phantoms

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Thank you for your attention

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