# The Northern Illinois University, Loma Linda University Medical Center, and Santa Cruz Institute for Particle Physics Collaboration on

# *Proton Computed Tomography*

Loma Linda University Medical Center


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Energetic proton beams have distinct features that set them apart from photons and make them desirable for cancer therapy as well as medical imaging. Proton computed tomography (pCT) solves one important problem related to X-ray CT-based proton treatment planning: the relatively large uncertainty in the exact position of the Bragg peak. Our project aims at making pCT a reality in a proton treatment environment. We present an overview of the pCT project, including some brief historical remarks, the physical and mathematical basis of proton CT, and a description of the collaboration among the three participating institutions: Northern Illinois University (NIU), Loma Linda University Medical Center (LLUMC) and the Santa Cruz Institute for Particle Physics (SCIPP). The research plan, theoretical advancements and hardware developments for proton tracking information collection and processing are addressed. Highlights of recent improvements in modeling proton paths in materials and subsequent image reconstruction methods are presented.


## Background

### *Uncertainties in Proton Therapy*

- **Target definition**
- **Target motion:** Intrafraction motion, Interfraction motion
- **Dose localization relative to target & critical structures:** Lateral boundaries; distal boundaries; electron density distribution; biological effectiveness

### *Image-Guided Proton Beam RT: Ingredients for Success*

- **Clear delineation of gross tumor volume(s) (GTV) within clinical target volume (CTV)**
- **Precise target localization in the treatment room**
- **Control of target motion (intra- and inter-fraction)**
- **Exact calculation of proton beam range**

### *Why Proton CT and not Cone Beam CT with X-rays?*

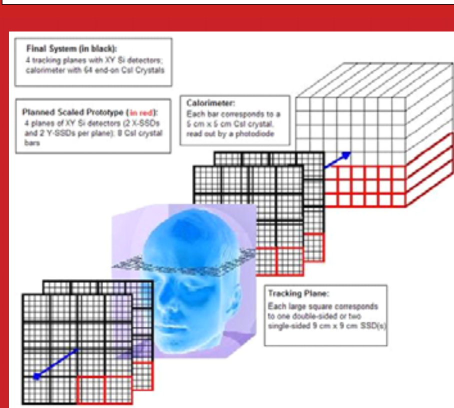
- **The accuracy of X-ray CT generated electron density maps is inherently limited**
- **Precise calculation of beam depth requires accurate density maps**
- **Cone Beam CT with X-rays for daily verification is dose-intensive and limited by sampling artifacts**
- **Proton cone beam CT is more dose efficient**
- **Proton cone beam CT has no artifacts**

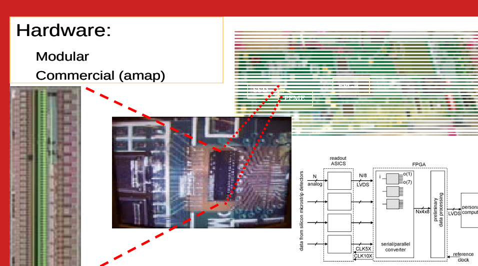
### Brief History

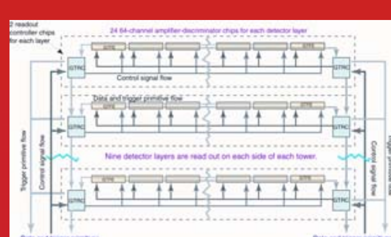

### The Future: The NIPTRC

## Hardware

### Hardware Development Overview

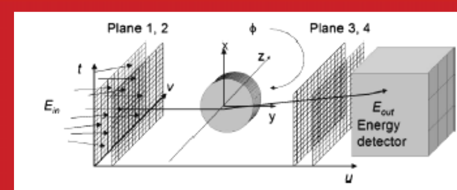


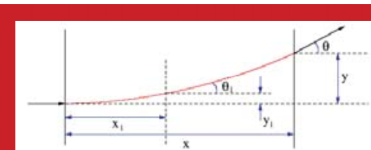



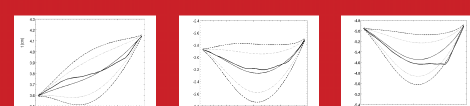



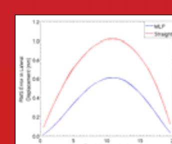

## Software

### The Most Likely Path







### Image Reconstruction Algorithms in pCT

ART

$$x^{(k+1)} = x^k + \lambda \frac{\left(h_i - \langle a_i, x^k \rangle\right)}{\|a_i\|^2} a_i$$

SART

$$x_j^{k+1} = x_j^k + \frac{\lambda}{\sum_{i\in B} a_{ij}} \sum_{i\in B} \frac{\left(h_i - \langle a^i, x^k \rangle\right)}{\sum_{j=1}^{J} a_{ij}} a_{ij}$$

BICAV

$$x_j^{k+1} = x_j^k + \lambda \sum_{i\in B} \frac{\left(h_i - \langle a^i, x^k \rangle\right)}{\sum_{j=1}^{J} s_j a_{ij}^2} a_{ij}$$

DROP

$$x_j^{k+1} = x_j^k + \lambda U \sum_{i\in B} \frac{\left(h_i - \langle a^i, x^k \rangle\right)}{\|a^i\|^2} a_{ij}$$

### Image Reconstruction