

# Application of Monte Carlo to four-dimensional radiotherapy

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### Acknowledgements

Virginia Commonwealth University National Cancer Institute American Cancer Society Varian Medical Systems Philips Medical Systems Standard Imaging

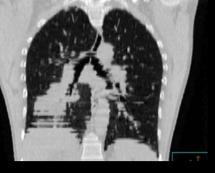


Application of Monte Carlo to 4D radiotherapy Outline

#### Why

- > Lung tumours
- Monte Carlo
- > 4D radiation therapy
- How
  - ► 4D and MC
- Results





# Why Lung Tumours?

 15% 5-year survival
 Lung complications correlated with mean lung dose
 Reduce lung mean dose

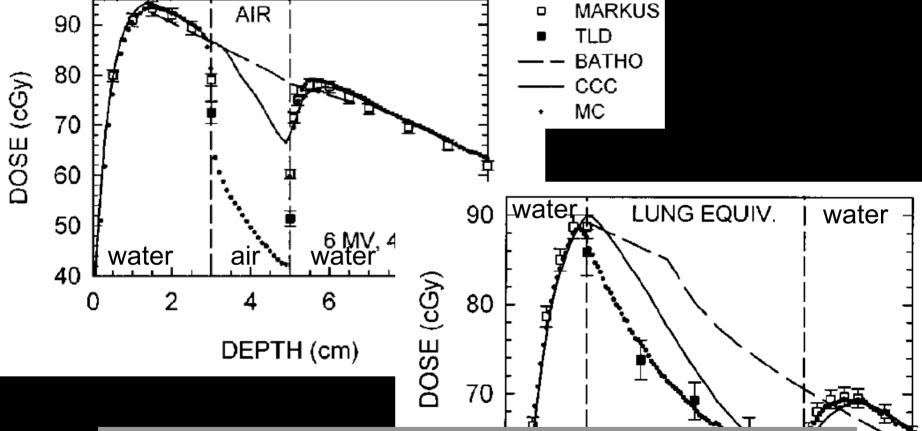
Reduce lung mean dose, reduce complications

Dose escalation predicted to benefit (>85 Gy)

Increase dose, expect increase cures



# **Effect of Heterogeneities on Dose**

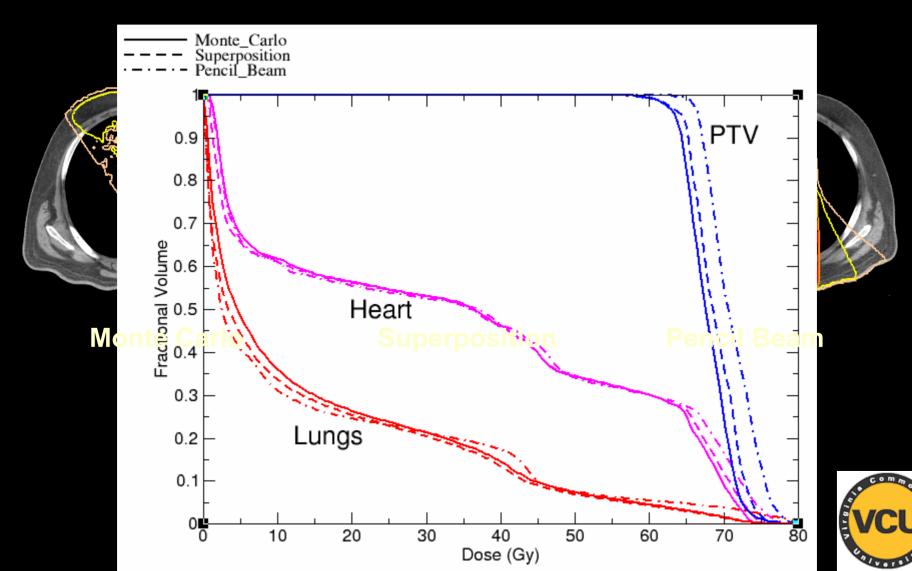


Arnfield Monte Carlo is recognized as the most accurate dose calculation algorithm, it is limited only by accuracy of inputs.

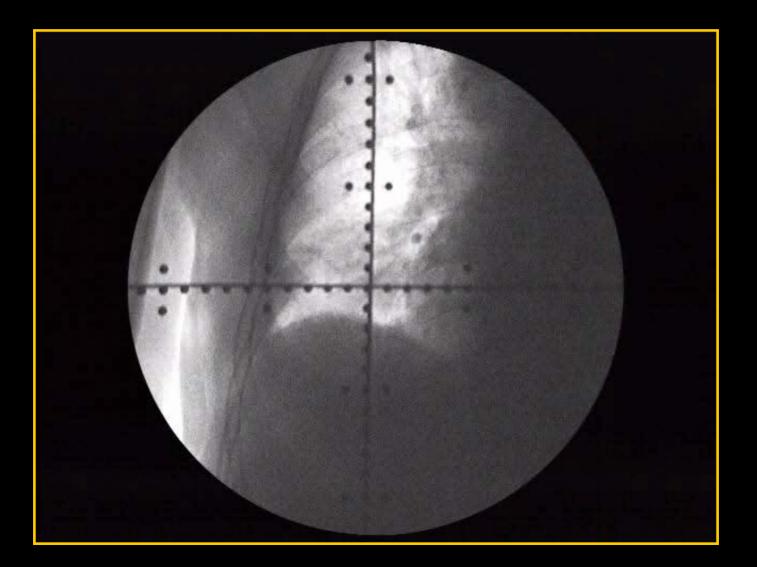
DEPTH (cm)

14

#### Lung Patient Algorithm Comparison

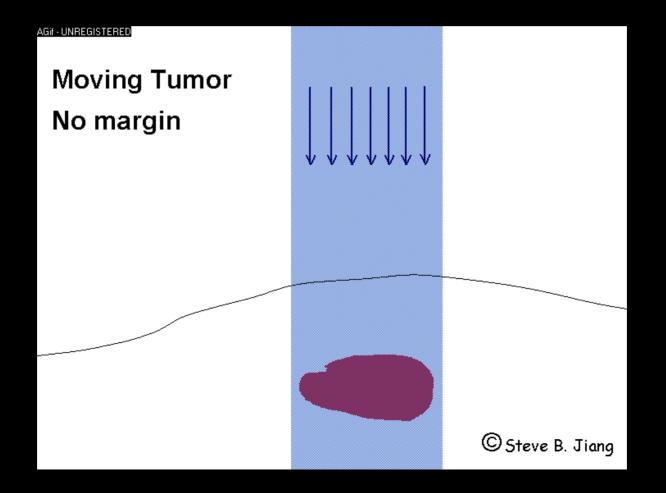


## **Problem II** The tumour moves with time



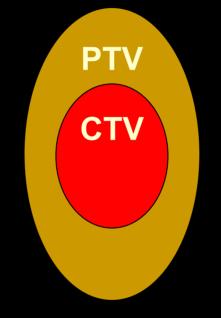


#### Problem II Respiratory Motion





#### **Conventional Solution** Use large margins to ensure coverage

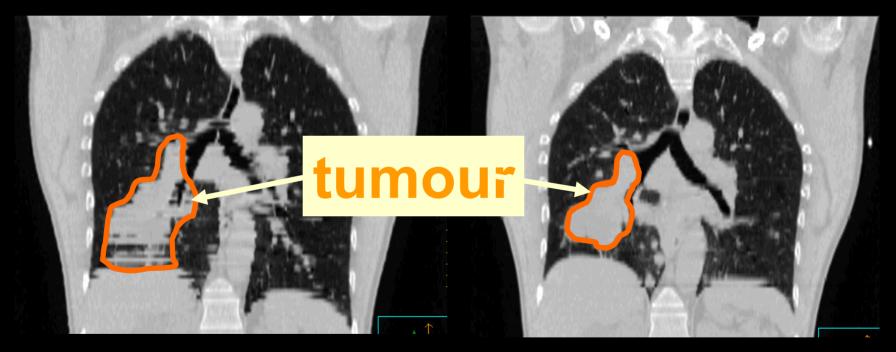


#### Conventional

Results in large normal tissue dose
Limits target dose (complications)



### Problem III Distorted images, incorrect anatomical positions, volumes or shapes

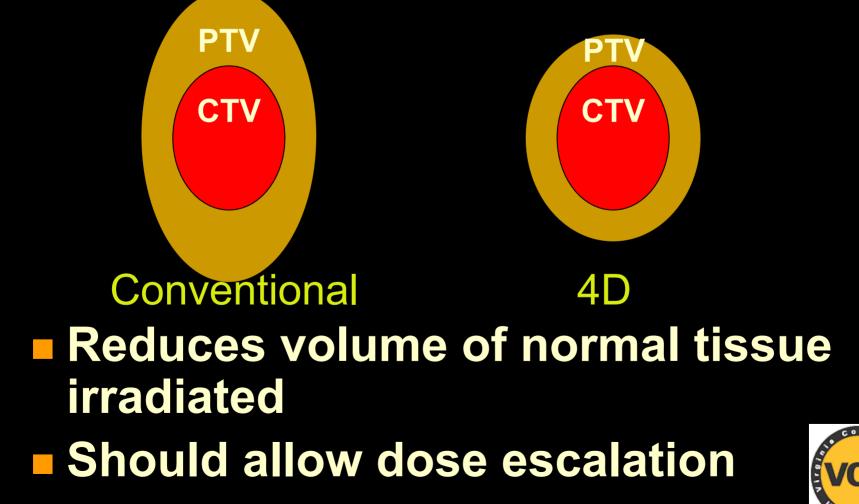


#### Conventional

#### With 4D imaging



#### Alternative Solution Track tumour motion with 4D imaging and therapy



# The 4D radiotherapy process

#### 4D Radiotherapy

The explicit inclusion of the temporal changes in anatomy during the imaging, planning and delivery of radiotherapy

#### 4D CT Imaging

Acquisition of a sequence of CT image sets over consecutive phases of a breathing cycle

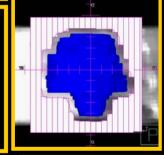
#### **4D Treatment Planning**

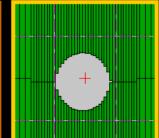
Designing treatment plans on CT image sets obtained for each phase of the breathing cycle

#### **4D Treatment Delivery**

Continuous delivery of the 4D treatment plans throughout the breathing cycle









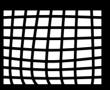


- 1. Develop 4D Monte Carlo methodology
- 2. Apply this technique to a 4D treatment plan
- 3. Evaluate implications of 4D Monte Carlo

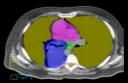


### **Method and Materials**

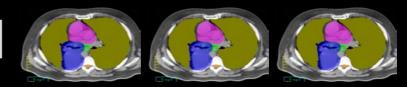
Create deformation fields



Define anatomy on reference CT

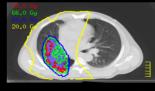


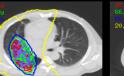
Map anatomy to all CT sets

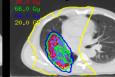


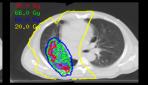
4 Create Monte Carlo treatment plan on reference CT

<sup>5</sup>Create treatment plan on all CT sets









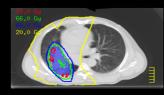


(1)

 $\mathbf{2}$ 

3

Combine dose distributions and display on reference CT



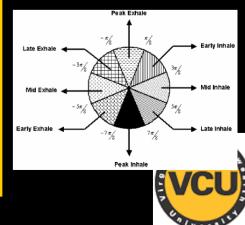


#### CT Image Acquisition 4D CT images



Vedam *et al* PMB 2003 48:45-62

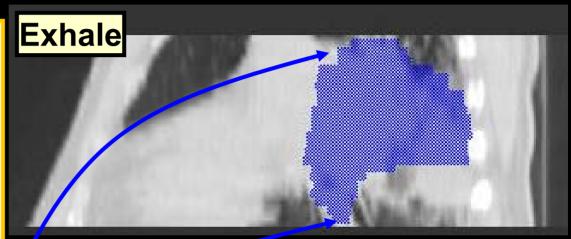
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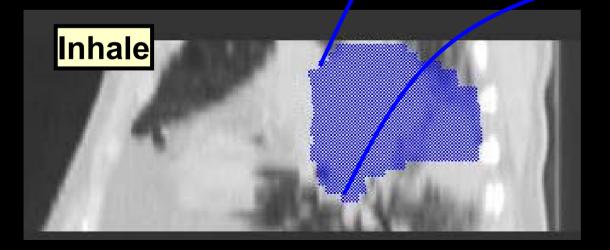


#### **Contouring and deformations Determine anatomical deformations**

Large deformation diffeomorphic image warping

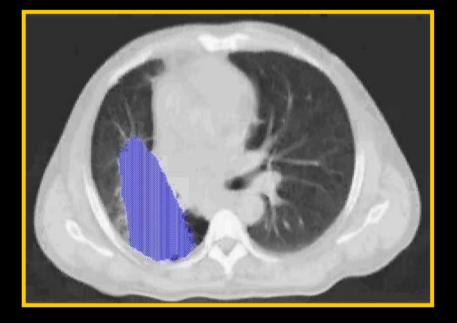
- Christensen *et al* PMB 1994 39: 209-618
- Christensen *et al* IEEE Trans Med Imag 1997 16:864-877
- Miller *et al* in Toga (Ed.) Brain Warping, Academic Press



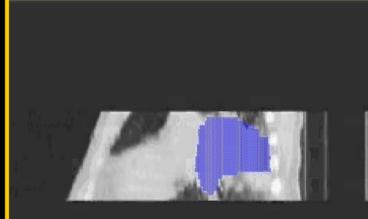




### **4D PTVs**



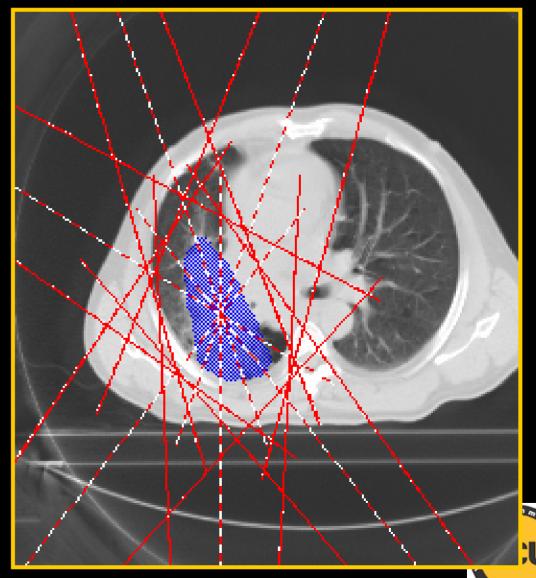




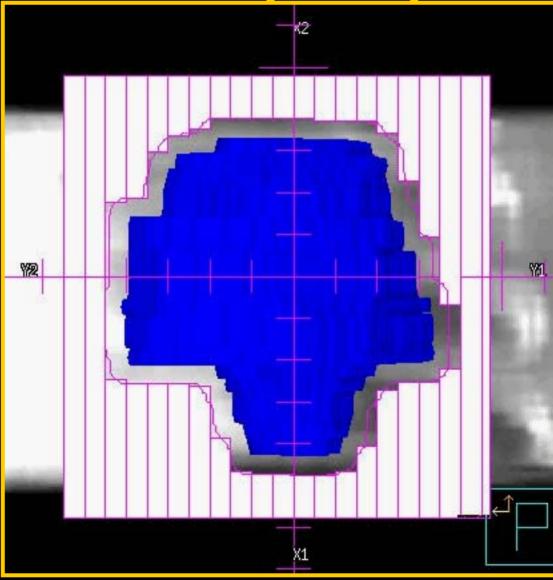


## **Define Field Arrangement**

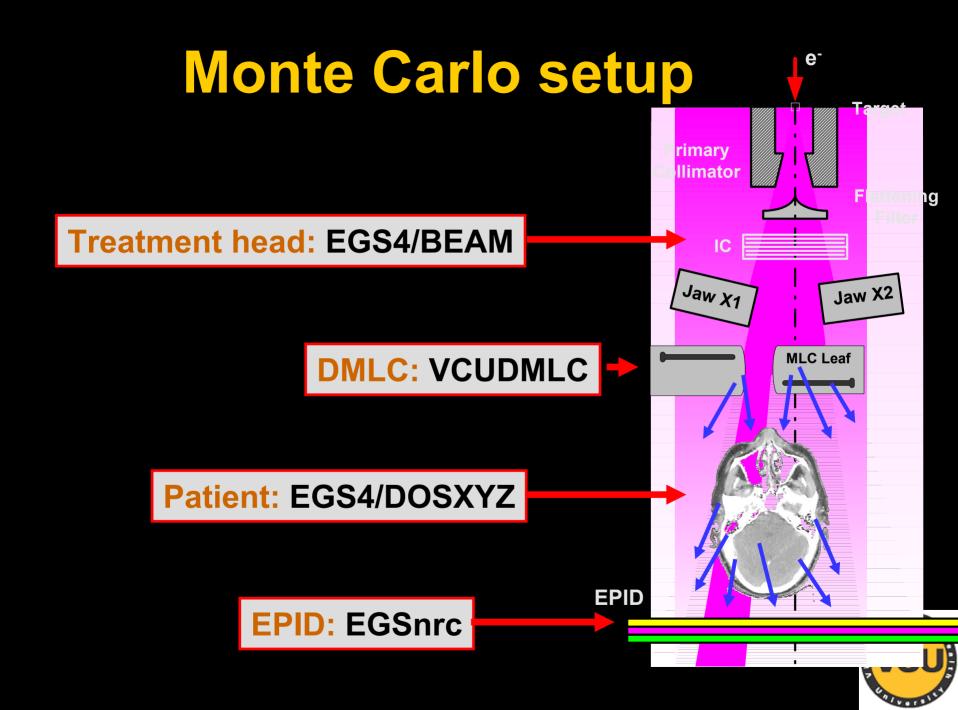
6 fields Non-opposed Coplanar **6 MV** Autoblock **PTV + 0.5 cm** 



#### **Develop 4D plan**







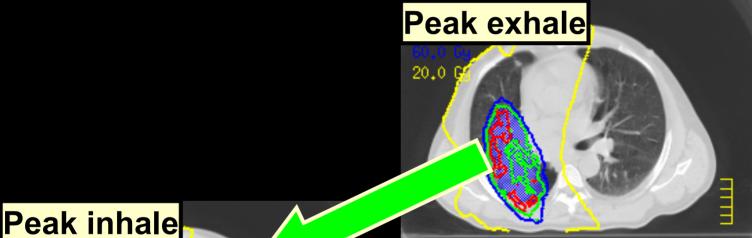
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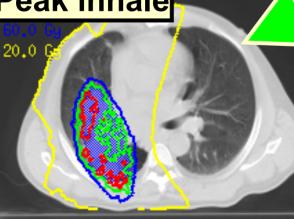
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Pind Sirest     HotScr Click on button to Pencil Beam Calc Monte Carlo Dose to Water	ri pts	File Options I FourDCRTMC Current Name	Localize Windows	Exte Dose Grid Dose Disp Prescrip Blocks Machine Ori Dose Status Computed	entation Collim	ent Planning	20 Alim 30	Visualiz	ation Relative V	Dose	Weight Locked
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View Find Spread HotScr Click on button to Pencil Beam Calc Monte Carlo Dose to Water Zero Dose Outside Make Plots	ripts to run HotScript	File Options I FourDCRTMC Current Name (m180 (m140 (m020 (m220 (m300)	Localize Windows Dose Engine Adaptive Convolve Adaptive Convolve Adaptive Convolve Adaptive Convolve Adaptive Convolve	Exte Dose Grid Dose Disp Prescrip Blocks Machine Orri Dose Status Computed Computed Computed Computed Computed	rnal Beam Treatm	ent Planning	20     1       21     1       22     1       33     -	Visualiz	ation Relative V 16.07 % F 23.21 % F 23.21 % F 8.93 % F 12.50 % F	Dose	Weight Locked

Data Merging Map dose distributions from each of n 3D CT set onto a 'reference' CT set for visualization and analysis



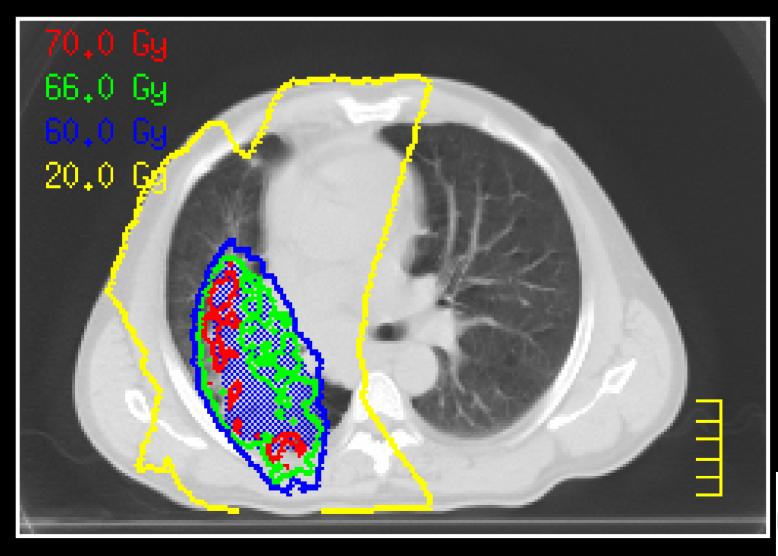






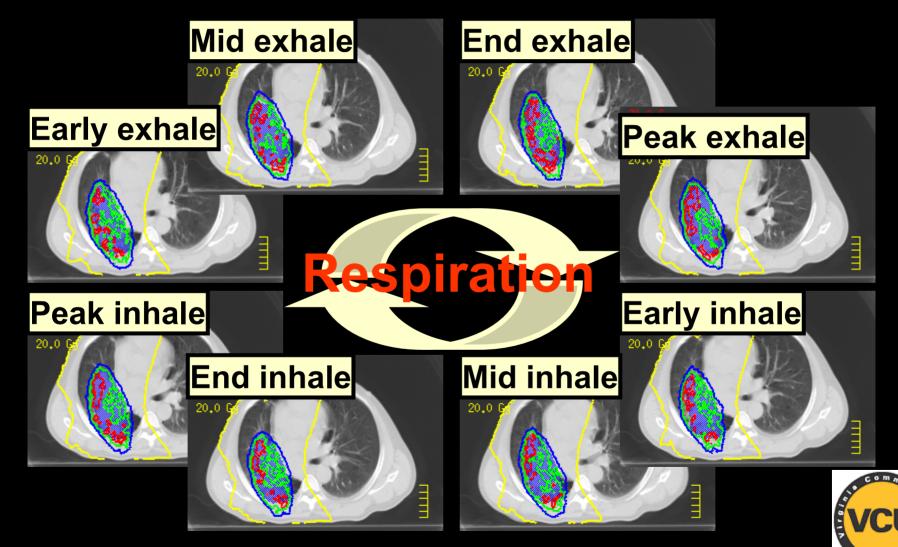


# Isodoses from 6% uncertainty calculation per beam at peak inhale





# Isodoses from 6% uncertainty calculation per beam for all phases



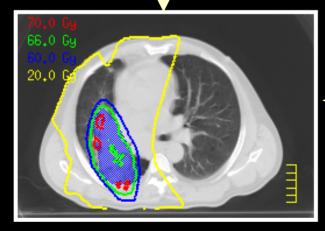
## Map dose distributions to reference (equi-time)

End inhale

Mid inhale

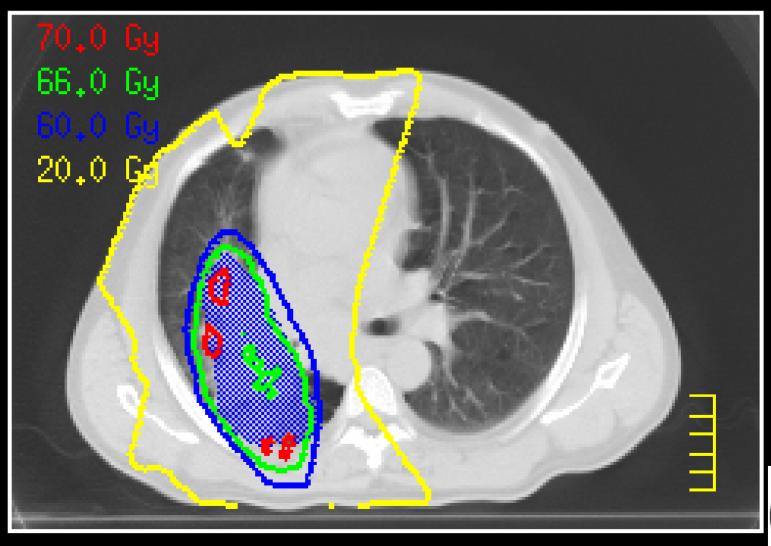
Ξ

20,0





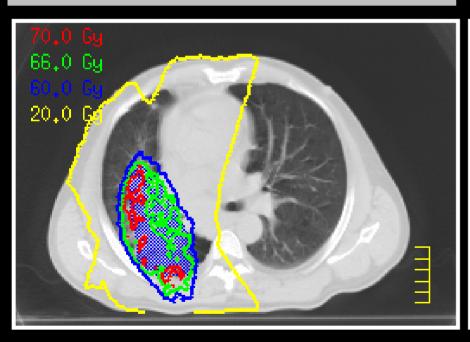
#### Isodoses from all phases deformed to peak inhale

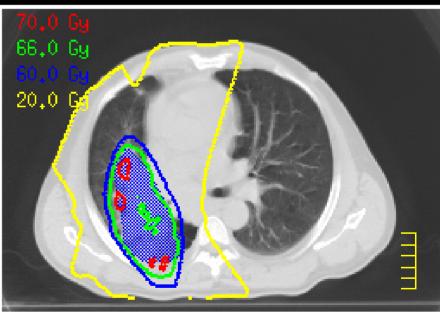




# 6% uncertainty per beam

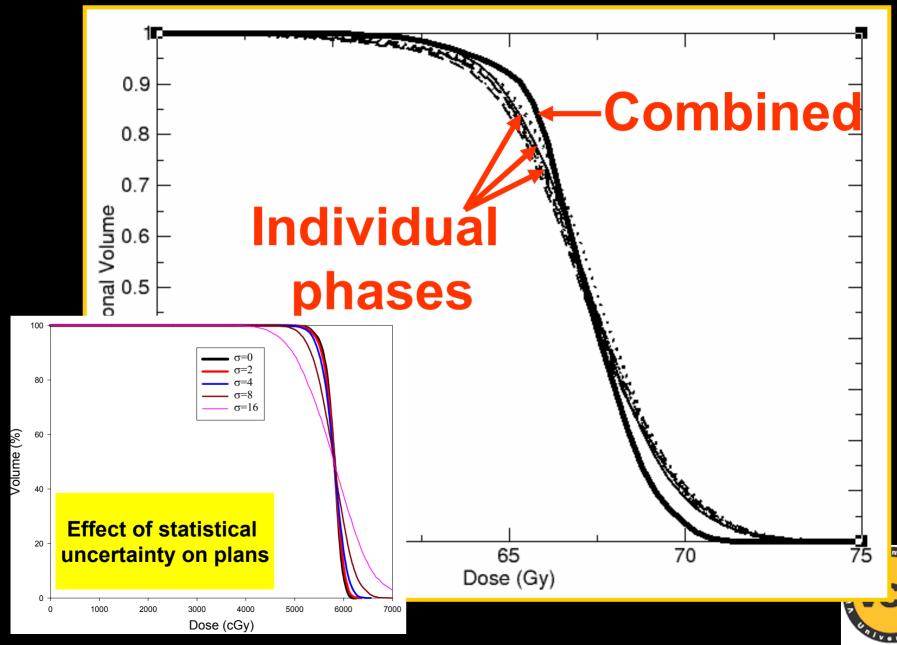
## Combined 8 phases



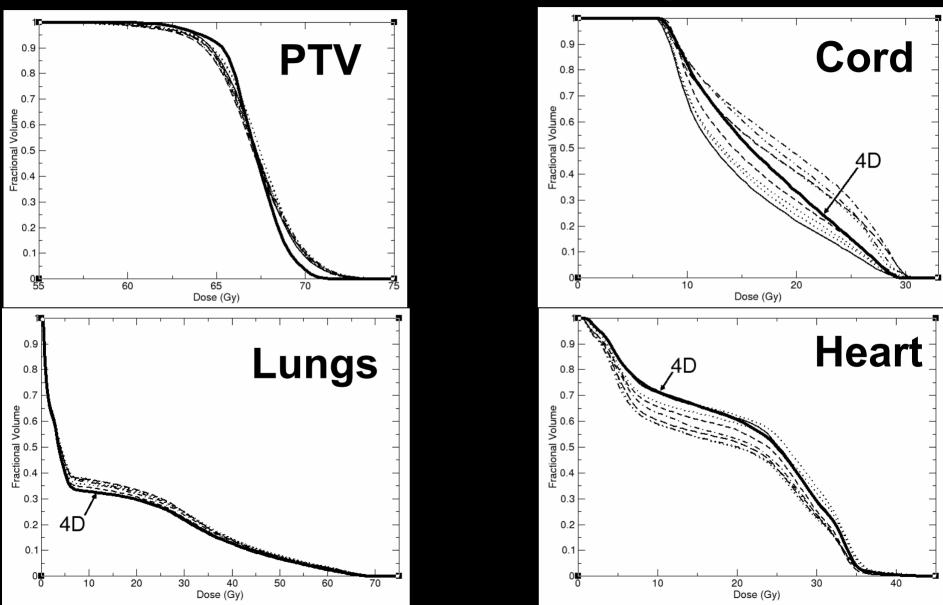




#### **PTV DVHs**



#### **Dose Volume Histograms**



## **Future Work**

#### Imaging

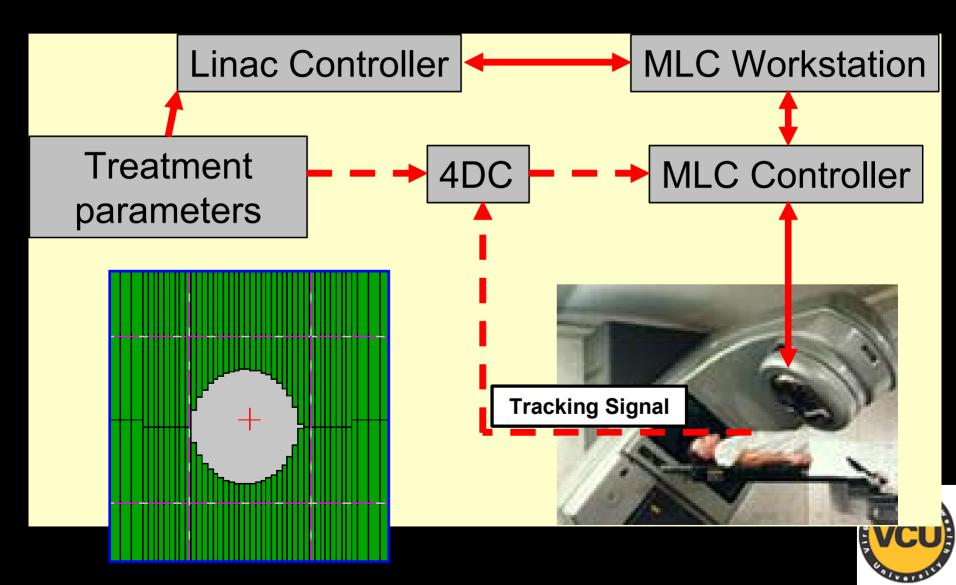
- Acquire complete 4D image sets
- > Quantify deformation maps

#### Planning

- Margin reduction allowed by 4D
- Potential toxicity reduction for 4D
- Potential dose escalation for 4D
- Potential benefits of MC for 4D
  - Dose accuracy
  - Dose calculation speed



#### Future 4D Radiotherapy Delivery





#### Conclusion

- Methodology for 4D Monte Carlo radiotherapy calculations has been developed
- 4D radiotherapy planning with Monte Carlo has two advantages
  - (1) higher accuracy for calculation in electronic disequilibrium conditions such as those encountered during lung radiotherapy
  - > (2) if deformable image registration is used, the calculation time for Monte Carlo is
     ≈independent of the number of 3D CT image sets constituting a 4D CT (same time for 4D and 3D calculation)



