



4D simulation of secondary emissions for in vivo verification

Katia Parodi, Ph.D.

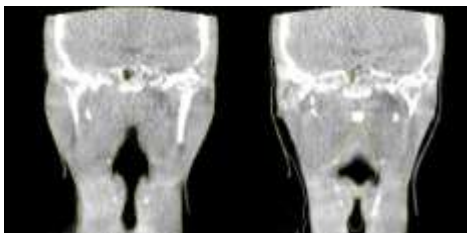
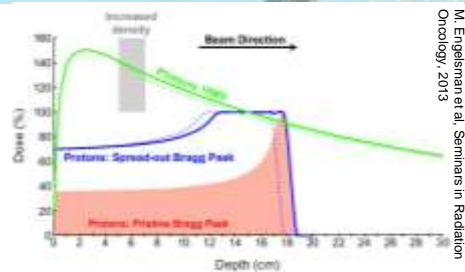
Ludwig-Maximilians University (LMU) Munich, Germany
Heidelberg Ion Beam Therapy Center, Germany

Dresden, November 27th, 2015

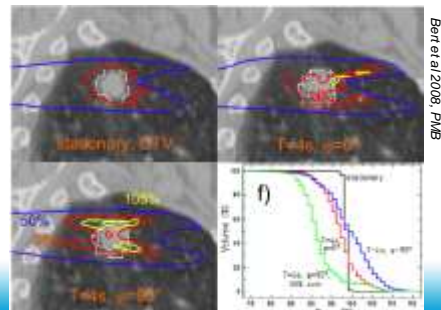
4D Treatment Planning Workshop 2015



- Protons and heavy ions RT
 - Highly conformal dose delivery
- Delivery uncertainties:
 - Patient positioning
 - **Changes in patient anatomy**
 - **Target motion**



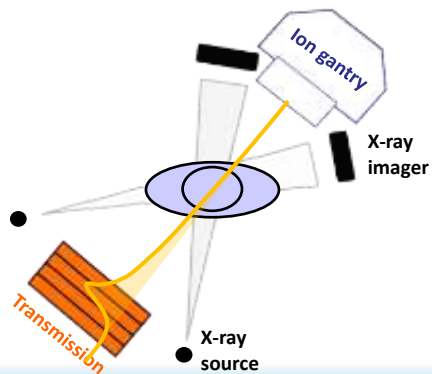
Landry et al, MP 2015





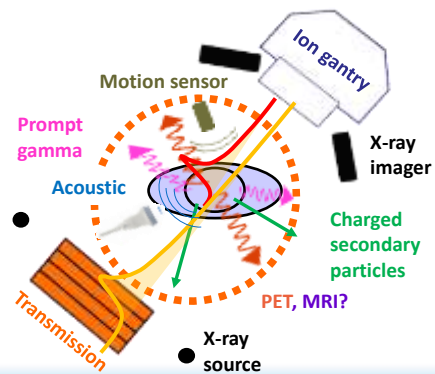
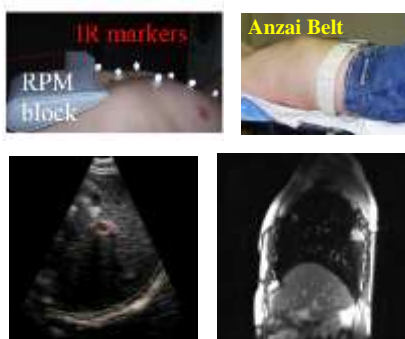
Current efforts for in-room imaging in ion beam therapy

- Anatomical confirmation via X-rays or transmitted ions



Current efforts for in-room imaging in ion beam therapy

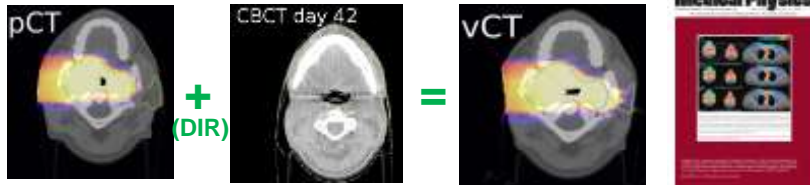
- Anatomical confirmation via X-rays or transmitted ions
- Range monitoring via emerging secondary radiation or transmitted ions



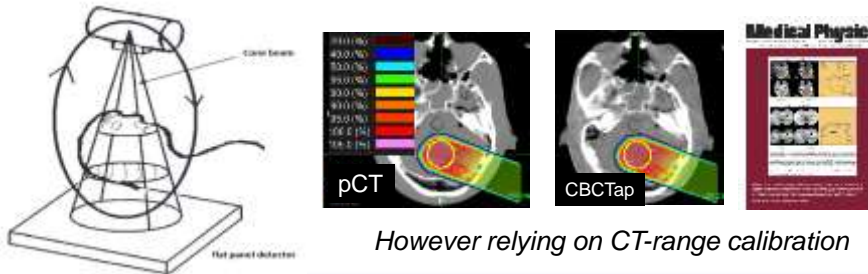
Courtesy G. Baroni, J. Jenne

LMU UNIVERSITÄT MÜNCHEN *Research Center for Advanced Therapies LMU* **Inter-fractional anatomical motion**

SECT, CBCT, DECT and ion CT:



Landry, ..., Parodi MP 2015

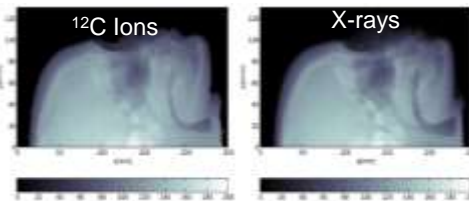
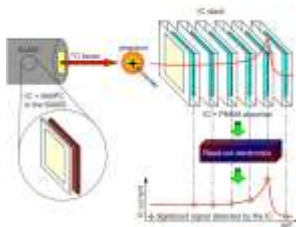


Park et al MP 2015

LMU UNIVERSITÄT MÜNCHEN *Research Center for Advanced Therapies LMU* **Inter-fractional anatomical motion**

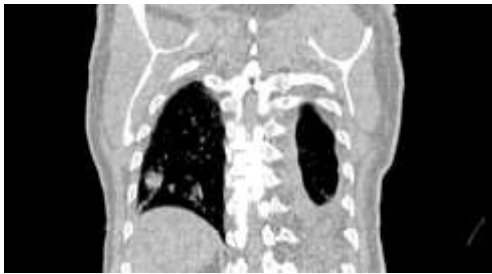
SECT, CBCT, DECT and ion CT:

Improved stopping power ratio and tissue composition



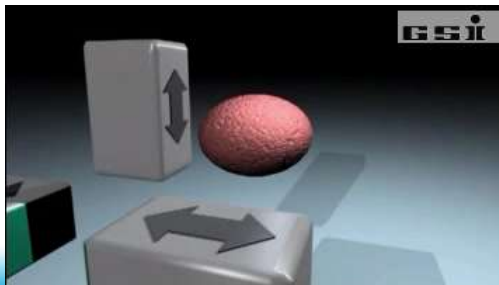
Rinaldi...Parodi, PMB 2014a,b,

LMU UNIVERSITÄT MÜNCHEN **Intra-fractional anatomical motion**



Challenges

- Synchronization effects & Motion monitoring
- Anatomy reproducibility
- Counting statistics & Imaging performances



What we have learnt

- PMMA phantom experiments and patient studies with offline PET/CT at HIT Heidelberg

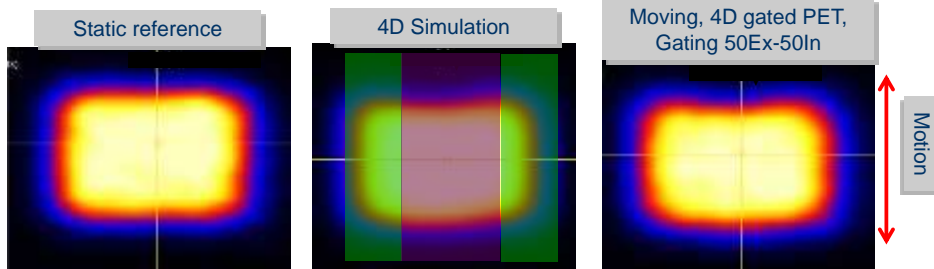
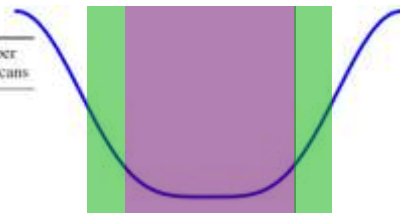


Source: GSI

LMU UNIVERSITÄT MÜNCHEN **Intra-fractional motion: phantom experiments**

Study	Lateral field size (cm)	Beam energy (MeV u ⁻¹)	Total number of particles	GWs (%)	Number of rescans
Square	4.8 x 4.8	200.28	7,4562 · 10 ⁹	20 and 50	60

'Interplay' of breathing motion and accelerator cycle



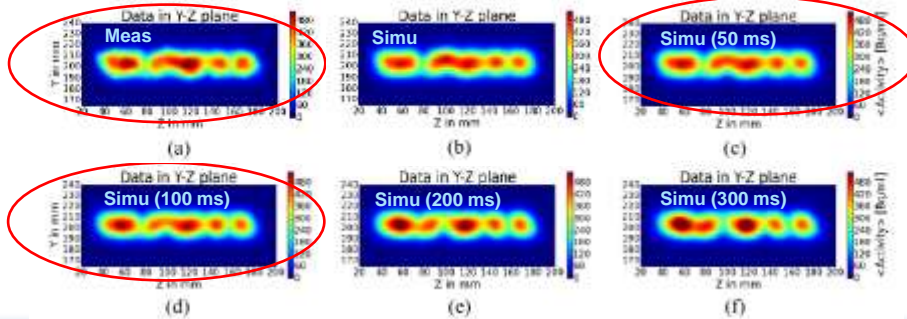
Kurz, ... Parodi PMB 2015

LMU UNIVERSITÄT MÜNCHEN **Intra-fractional motion: phantom experiments**



Study	Lateral field size (cm)	Beam energy (MeV u ⁻¹)	Total number of particles	GWs (%)	Number of rescans
Line Mult	14.1 x 1.5	200.28, 212.12 219.79, 227.20	2.0045 · 10 ⁸	20 and 50	16

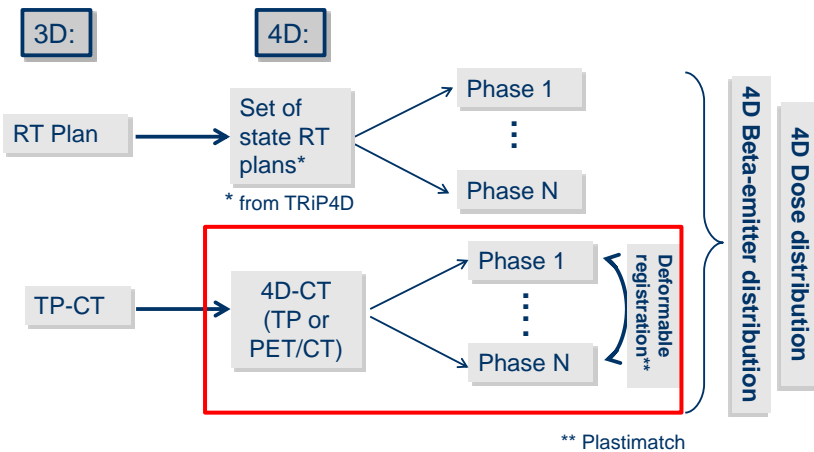
Sensitivity to phase shifts between Anzai motion monitor and beam delivery



Kurz, ... Parodi PMB 2015

LMU UNIVERSITÄT MÜNCHEN **Intra-fractional motion: clinical investigations**

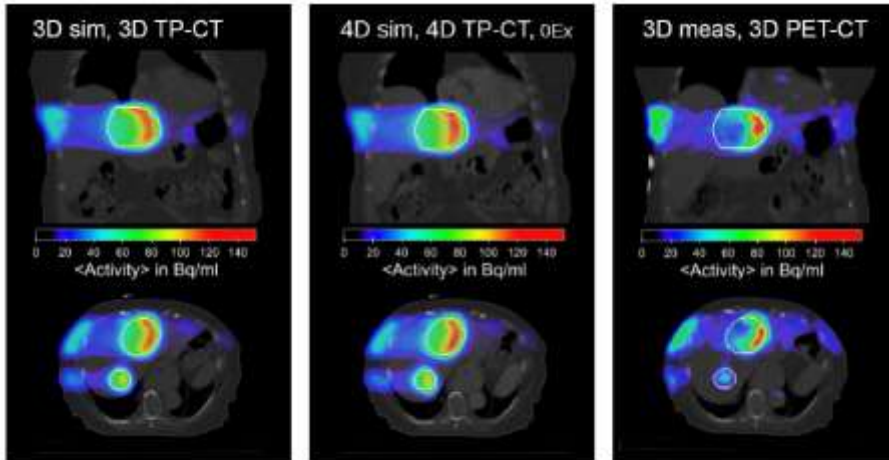
4D simulation based on unknown anatomy derived from 4D CT data



Courtesy C. Kurz



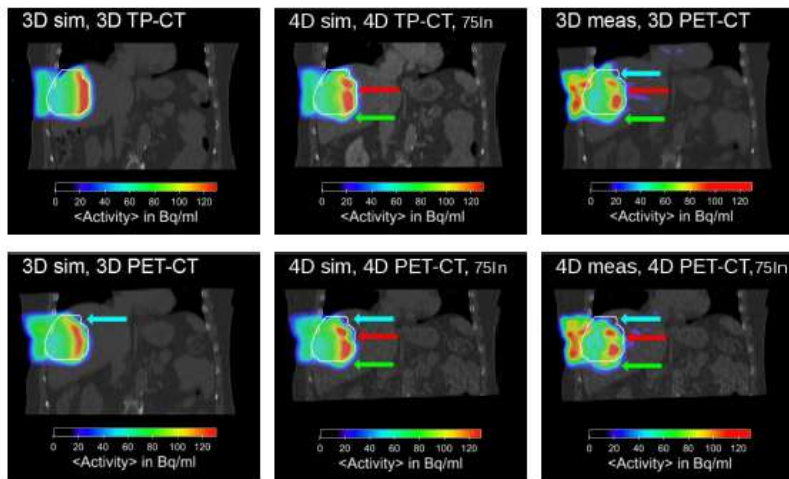
Case 1: almost no influence of motion on 3D vs 4D simulation



Kurz, ... Parodi tentatively accepted MP; PhD Thesis C. Kurz, LMU Munich 2014



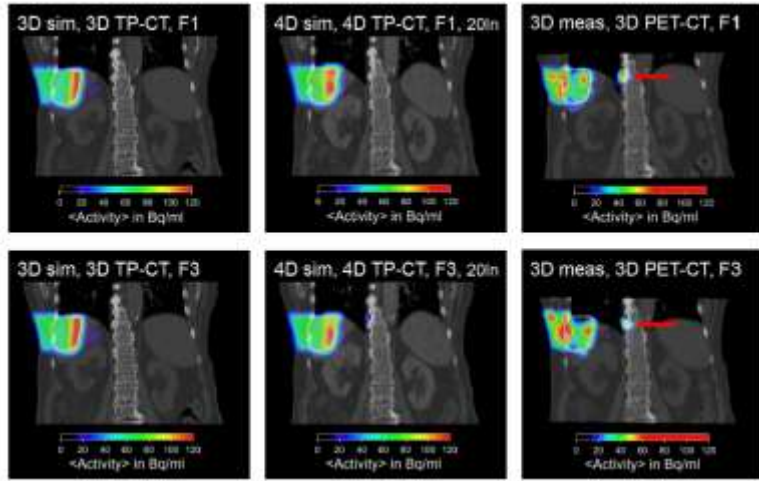
Case 2: Interplay effects in 4D simulation, better match of 4D CT from PET/CT



Kurz, ... Parodi tentatively accepted MP; PhD Thesis C. Kurz, LMU Munich 2014

LMU UNIVERSITÄT MÜNCHEN *Maximilian University for Advanced Therapies LMU* **Intra-fractional motion: clinical investigations**

Case 3: Interplay effects in 4D simulation, insufficient motion model of 4D TP-CT

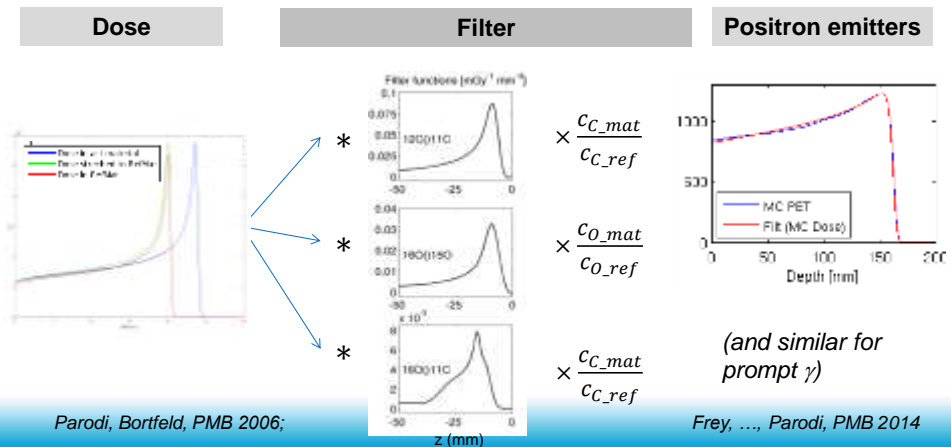


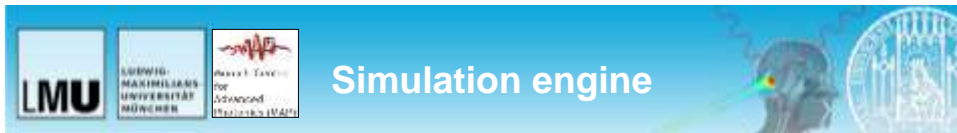
Kurz, ... Parodi tentatively accepted MP; PhD Thesis C. Kurz, LMU Munich 2014



LMU UNIVERSITÄT MÜNCHEN *Maximilian University for Advanced Therapies LMU* **Simulation engine**

- MC calculations are typically used, however time consuming for routine usage
- Fast and simple analytical tool for prompt γ and positron emitters prediction in proton therapy

$$d(z) * f(z) = p(z)$$





Simulation engine

- Being implemented in a research version of RayStation



K. Kröniger, M. Pinto, E. Traneus, K. Parodi







Summary

Conclusion

- 4D secondary emission calculations are powerful tools for pre-treatment sensitivity studies and implementation of in-vivo dosimetry methods
- Integration in TPS enables fast calculation, full 4D capabilities and inherits pencil-beam algorithm limitations for **consistent TPS validation**

Remaining inherent challenges are

- Synchronization effects & Motion monitoring
- Anatomy reproducibility
- Counting statistics & Imaging performances



*(Former) colleagues / team at HIT and
Universitätsklinikum Heidelberg*

New team at LMU Munich

*Collaborators (GSI, Polimi, HZDR,
Raysearch)*

*DFG (MAP, IonCT), BMBF (SPARTA)
EU-FP7 (ENVISION)*



Thank you