Cyclotron Centre Bronowice

THE HENRYK NIEWODNICZAŃSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

# Proton radiotherapy of moving targets at the Cyclotron Centre Bronowice

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Research and Development Laboratory

Thursdays for the young at IFJ PAN
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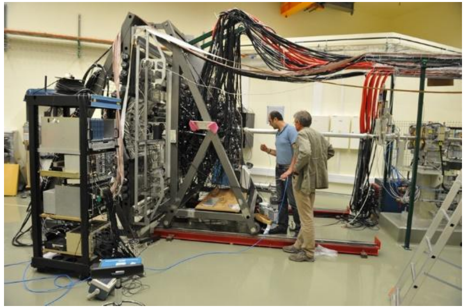
# Outline

1. CCB - current status
2. Radiotherapy of moving targets
3. Clinical implementation
4. Robust 4D dose evaluation
5. Summary and conclusions

# Cyclotron Centre Bronowice – current status

- First and still the only proton radiotherapy center in Poland
- Collaboration with the **National Institute of Oncology - National Research Institute** (NIO-PIB), Krakow Branch (Gliwice branch for pediatric patients)
- Fully utilized its **potential** - technical possibilities and staff workload
- Developed **scientific activities** and international colaborations

NIO-PIB, Krakow branch



Experimental Hall, CCB

# Cyclotron Centre Bronowice – current status

**2011** — **2010-15** — **since 2016** — **2024**

**First eye treatment (AIC-144 cyclotron)**

**Construction of the new facility (CCB)**

**Patients treated at gantries**

**UP TO NOW:**

- more than **750 patients** treated since 2016
- even **50** patients per day
- **28 completed therapies for patients with moving targets**
- radiotherapy conducted until late in the evening
- implementation of scientific projects

# Cyclotron Centre Bronowice – indications

**06.2016**
head and neck area
perimedullary area
cerebrospinal axis

**11.2016**
First patient in CCB!

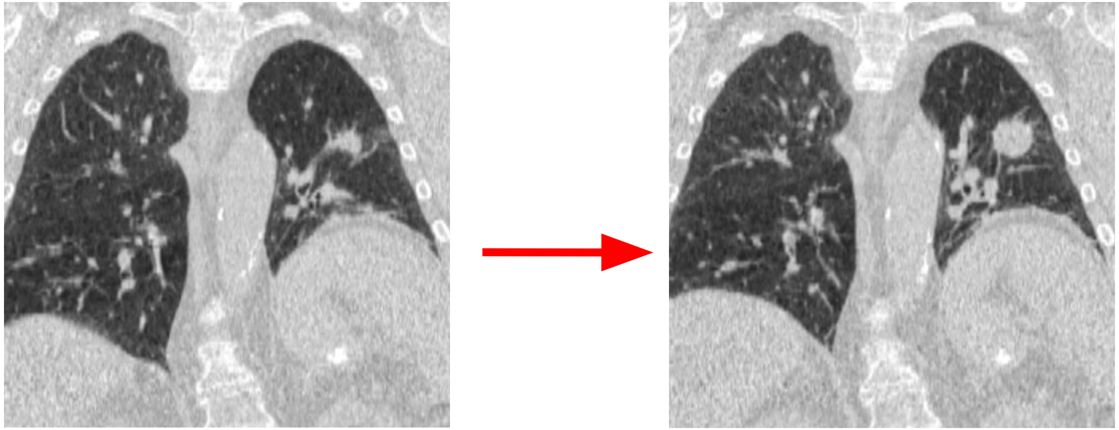
**01.2019**
head and neck area
paraspinal area
“re-treatment”

**01.2023**
head and neck area
Hodgkin’s lymphoma or non-Hodgkin's lymphoma (...) in mediastinum

**05.2023**
First patient with moving target!

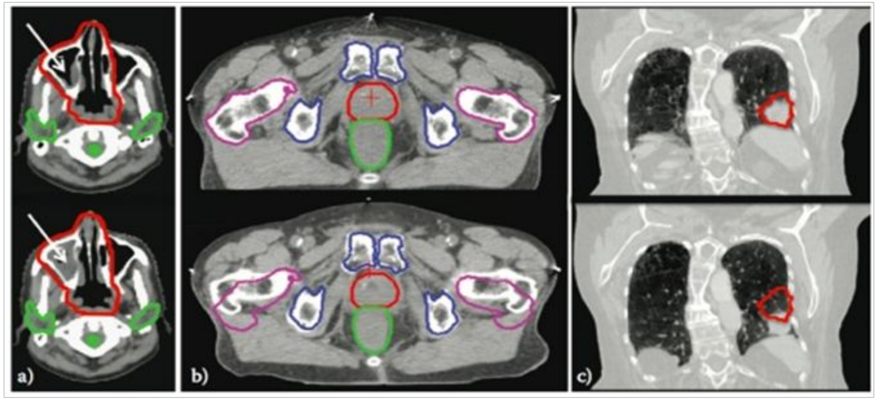
# What are moving targets?

- their position varies during treatment - due to both internal organ motion and/or respiratory motion
- chest and abdominal areas
- motion affects not only dose to a target, but also to organs-at-risks (OARs)



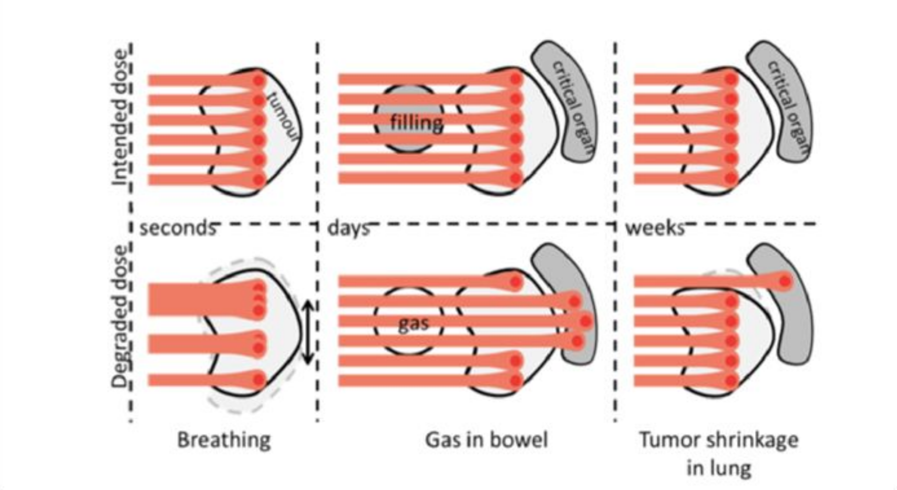
Werner R et al, Radiat Oncol. 2017, 19;12(1):100. doi: 10.1186/s13014-017-0835-7.

# What are moving targets?




(Paganetti, Proton Therapy Physics , 2012)

a) Changes in head density over the entire treatment period.
b) Interfractional changes in the position of the femoral heads.
c) Intrafractional changes in the position of a lung tumor




The impact of changes in medium density on the path of a proton beam:

- Breathing – lung expansion
- Gas bubbles – increased proton range
- Tumor reduction – irradiation of healthy tissues

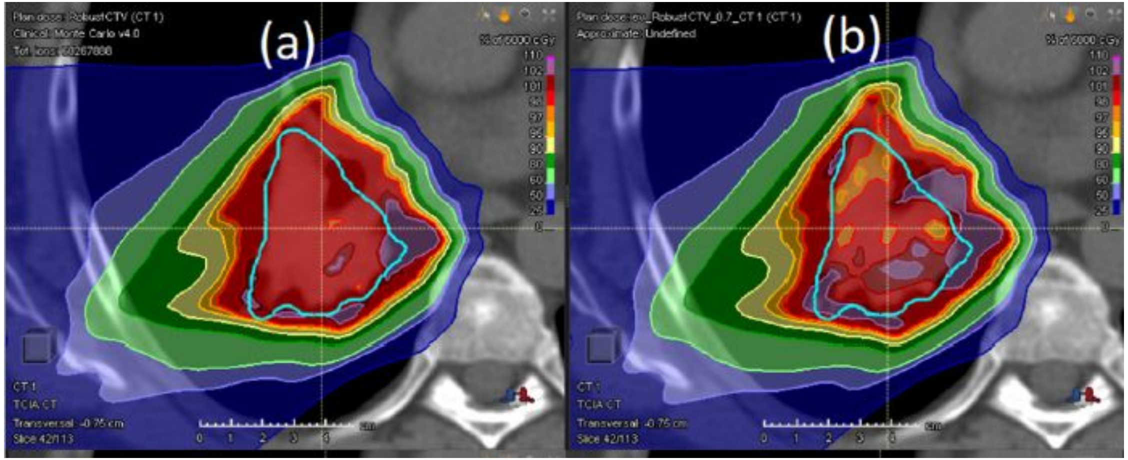


Cyclotron Centre Bronowice

# Dose delivery to a moving target

## 4D radiation therapy (X, Y, Z, Time)

- **imaging: 4DCT - motion assessment**
- Free-Breathing (FB)
- Respiratory gating
- **Deep-inspiration breath-hold (DIBH)**
- **Robust 4D dose evaluation**



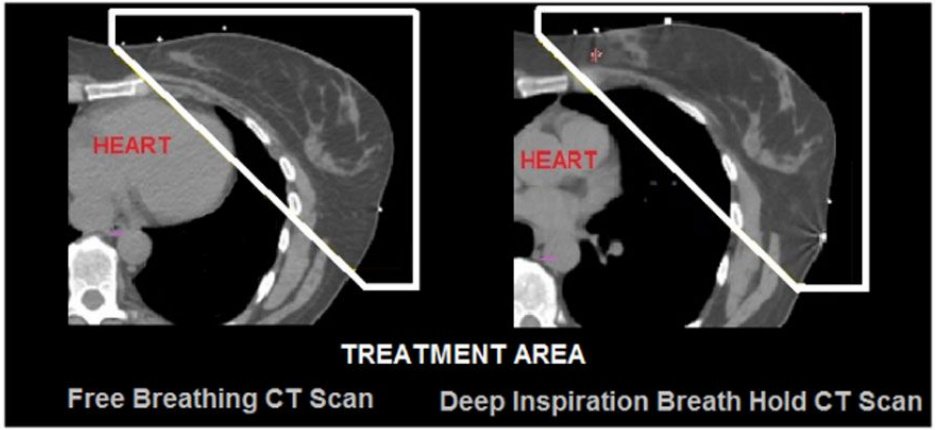

Presentation of an interplay effect for a lung cancer case:
a) reference (nominal) plan and b) perturbed dose distribution
(K.Czerska, doctoral dissertation, 2022)

## Influenced by uncertantites:

- Interplay effect
- Dose blurring
- Dose degradation

# Proton radiotherapy of moving targets at CCB

**Deep-Inspiration Breath Hold** - limiting radiation exposure mainly to the **heart**!



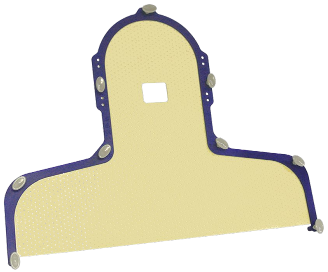

https://www.fvhospital.com/learn-more/deep-inspiration-breath-hold-and-active-breathing-coordinator/

- Hodgkin's lymphoma or non-Hodgkin's lymphoma in children and adults up to 40 years requiring mediastinal irradiation
- Proton radiotherapy preceded by 3-6 cycles of combined chemotherapy
- Area treated: mediastinum + lymph nodes in the neck and/or axillary area

# Tools available for 4D treatment in CCB

**Tools available:**

- Patient immobilization accessories



Qfix thermoplastics masks

Qfix supine breast & lung

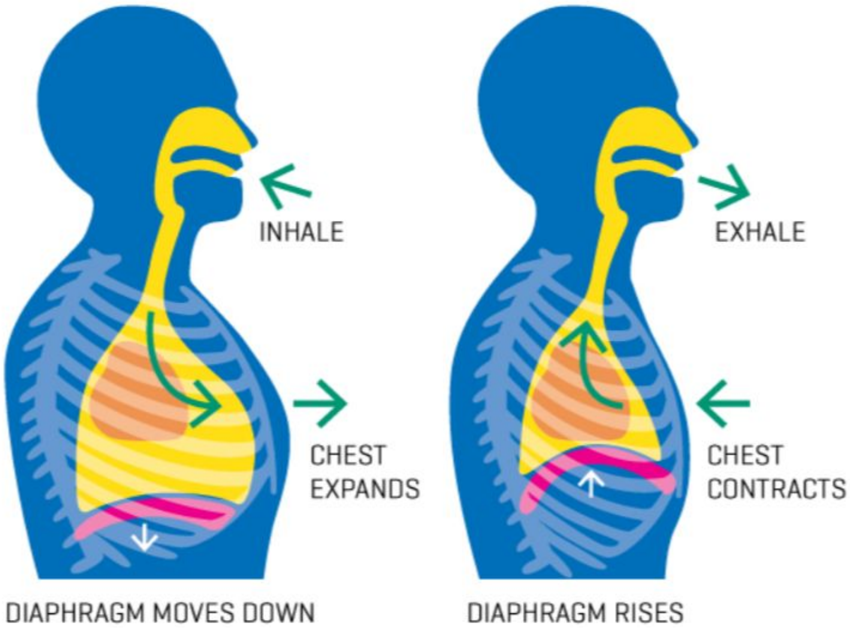
- Orthogonal X-ray Imaging for verifying patient position
- **AlignRT** Optical patient positioning system - SGRT (Surface Guided Radiation Therapy)

# Clinical implementation (1)

1. **Preparing for immobilization**
2. **Learning to breathe (approx. 30-60 s. of breath-hold)**

- At least 3 visits to the CCB
- an informational brochure for home exercises


https://www.visionrt.com/applications/dibh/




https://iconcancercentre.sg/en/technique/deep-inspiration-breath-hold/

# Clinical implementation (2)

3. **Computed tomography**

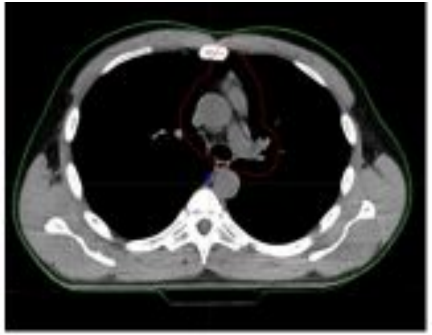
- FD „FullDose” (120kV, 2mm slice)
- LD „LowDose” (70kV, 2mm slice)

4. **Treatment planning**

- Prescribed dose: 2Gy x 15 = 30 Gy
- Required margins
- Directions of therapeutic beams (330-30 st)

5. **Dosimetric verification**

6. **Irradiation**



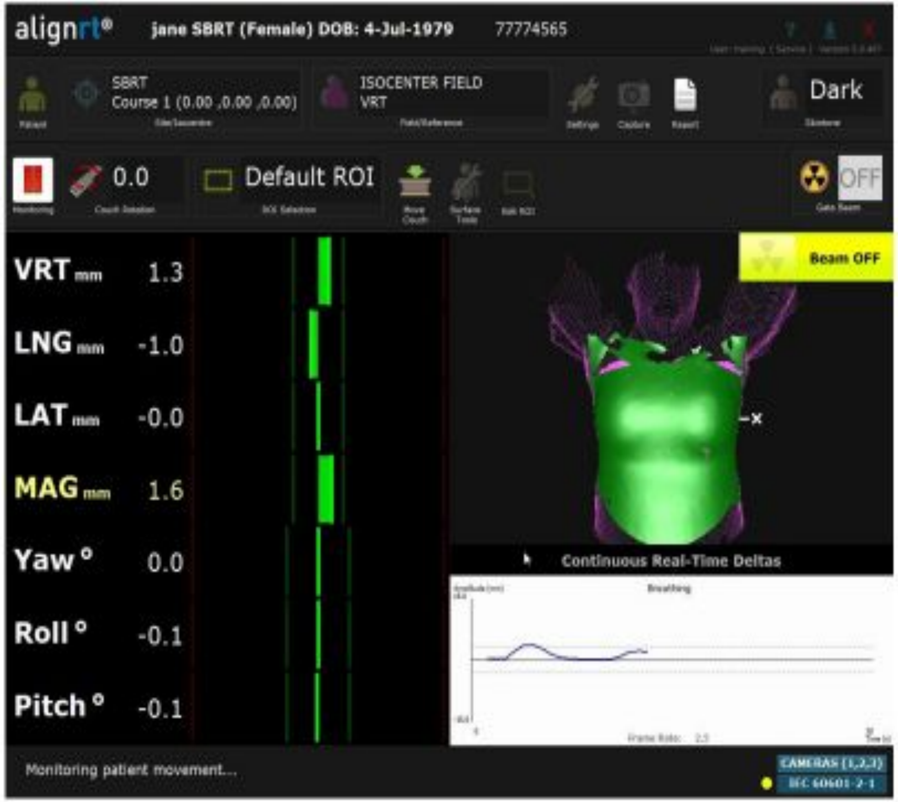
FD: CT scan for planning treatment

LD: CT scan for mobility assessment

# Clinical implementation (3)

**AlignRT system**

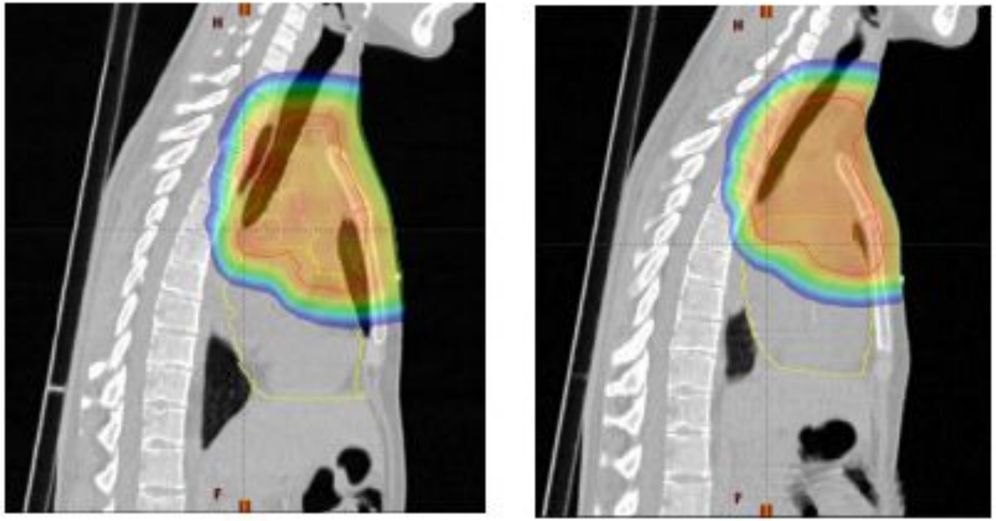
- Patient Positioning
- 3D Surface Matching Algorithm
- Graphical Visualization of Surface Mismatch



# DIBH vs FB treatment plans

Free breathing plans were made for 6 patients treated at CCB using the DIBH technique:

- heart dose reduction - approx. **30-40%**
- lung dose reduction - approx. **10-15%**

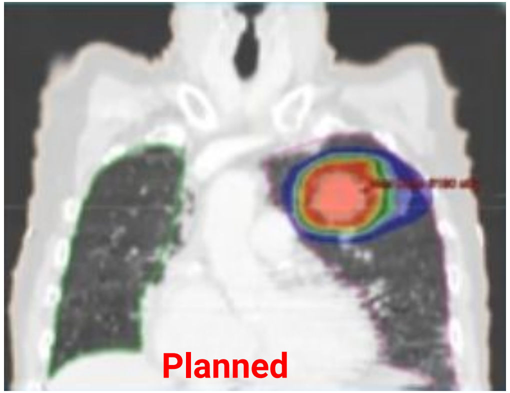
DIBH  FB

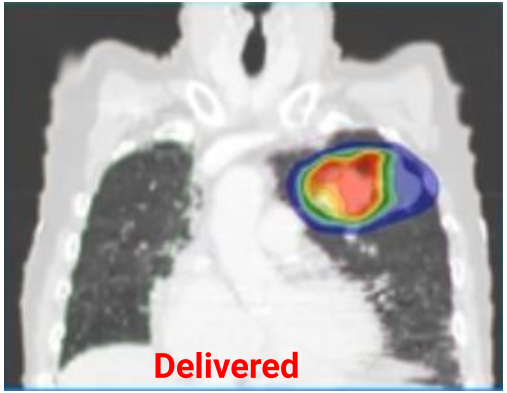
# Robust dose evaluation in radiotherapy

**Robust analysis = dose stability assessment**

**Consideration of uncertainties** - patient movement, anatomical changes, dose delivery uncertainties, setup and density errors

- ➔ Minimizing the risk of inaccurate irradiation
- ➔ "What-if" scenario simulations
- ➔ Better tumor control
- ➔ Reduced side effects



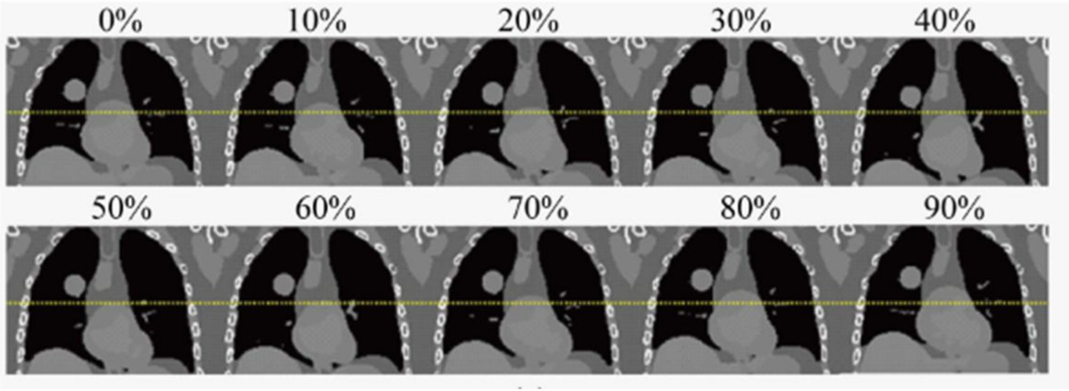

https://www.raysearchlabs.com/media/webinars/

# 4DCT patient scan

**Multiple CT scans of the same anatomical region over time**

➔ Visualization of organ motion

➔ Spatial and temporal information




➔ 10 independent CT scans corresponding to 10 respiratory phases

➔ Average-Value-CT (AVE-CT)

➔ Maximum Intensity Projection-CT (MIP-CT)

# Source uncertainties in 4D proton therapy

**Source uncertainties:**

- setup errors
- range errors

} **3D** → 

**How to deal with it?**

- isocenter shift
- CT calibration curve

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- breathing motion/anatomy changes
- machine errors
- interplay effect/dose blurring

} **4D** →

- 4DCT
- machine log files interpretation
- Monte Carlo simulations

# Treatment scenarios in 4D proton therapy

**Treatment scenarios:**

- setup errors: +/- 2mm in X, Y and Z direction
- range errors: density (HU) scalling by -3.5%, +3.5%

} **3D**

- breathing cycle start point: 0, 1, 2, 3 and 4 s

} **4D**

# Robust 4D dose evaluation in proton therapy

## 4D robust plan recalculation for single fraction

| | | | | |
|---|---|---|---|---|
| considered error | breathing motion/anatomy changes, machine errors, interplay effect | | | setup and range error |
| | 4DCT → Average CT ← reference image for DIR, planning image | 10 respiratory phases (0-90%)<br>10 separate sub-plans | 5 different starting phase (in breathing cycle):<br>0s, 1s, 2s, 3s, 4s | robust 3D on each phase separately<br>+/- 2mm (in X, Y, Z), +/-3.5% HU |
| number of recalculations | | 1 full recalculation<br>10 sub-plans recalculations | 5 full recalculations<br>50 sub-plans recalculations | 5 x 13 full robust recalculations (65)<br>50 x 13 sub-plans recalculations (650) |

# Tools available for robust 4D dose evaluation in CCB

1. **Machine log-files interpreter**
   - ➔ **for extracting essential information related to irradiation, including temporal data, from the machine log files**
   - ➔ **in-house software**

**AS A RESULT:**
**table with important information (time, layer, energy, range, position, intensity, gantry angle, couch angle etc) for each spot**

# Tools available for robust 4D dose evaluation in CCB

2. **GPU-accelerated FRED Monte Carlo code**
   - ➔ for fast and precise alternative dose calculations
   - ➔ on a desktop computer
   - ➔ quick calculations - approx. 650 scenarios in max. several hours

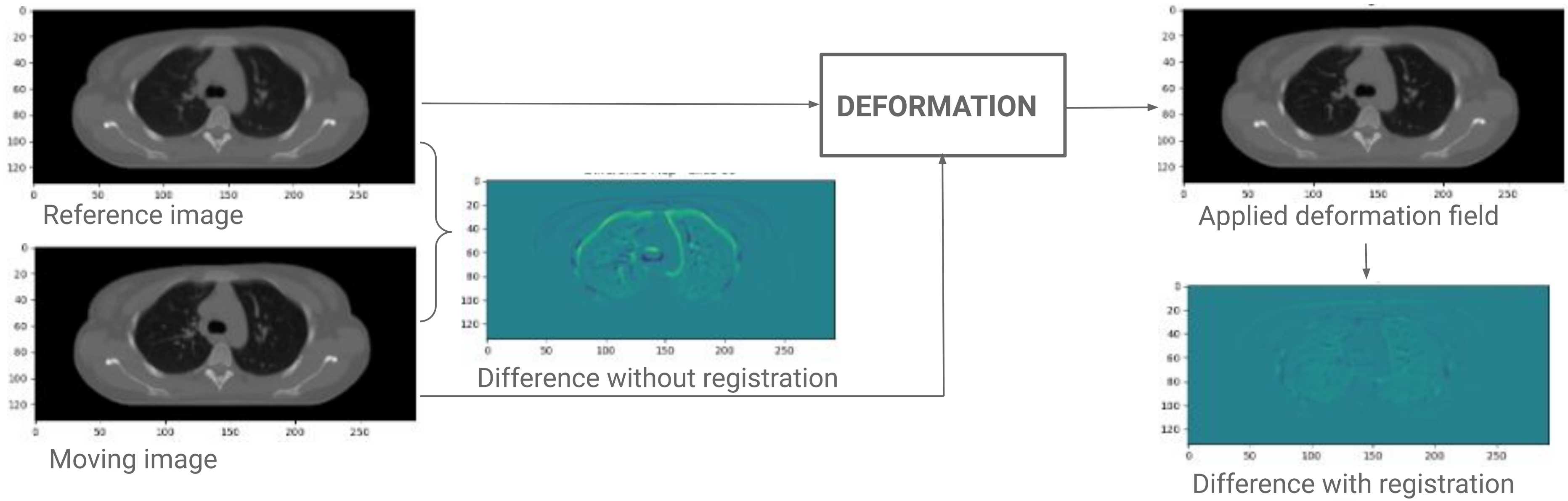
3. **FREDTools**
   - ➔ for data analysis

www.fredtools.ifj.edu.pl

# Tools available for robust 4D dose evaluation in CCB

4. **Deformable image registration**

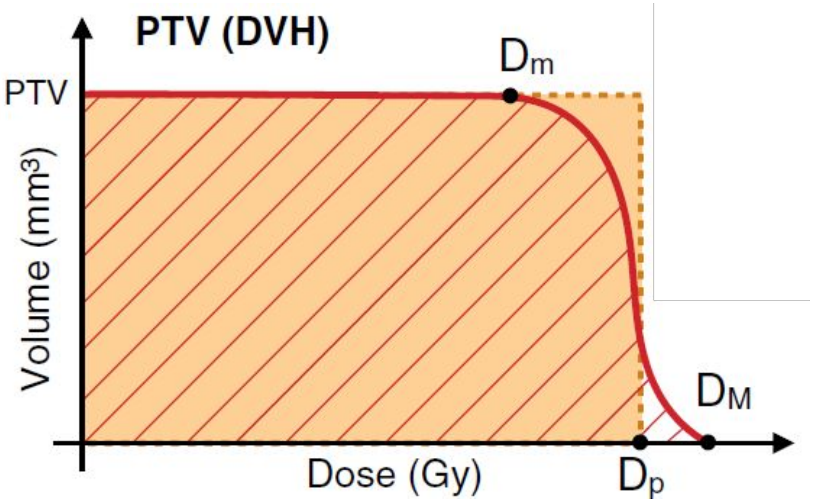
- **for tracking changes in the position of a patient's internal organs over time (open-source Plastimatch software)**

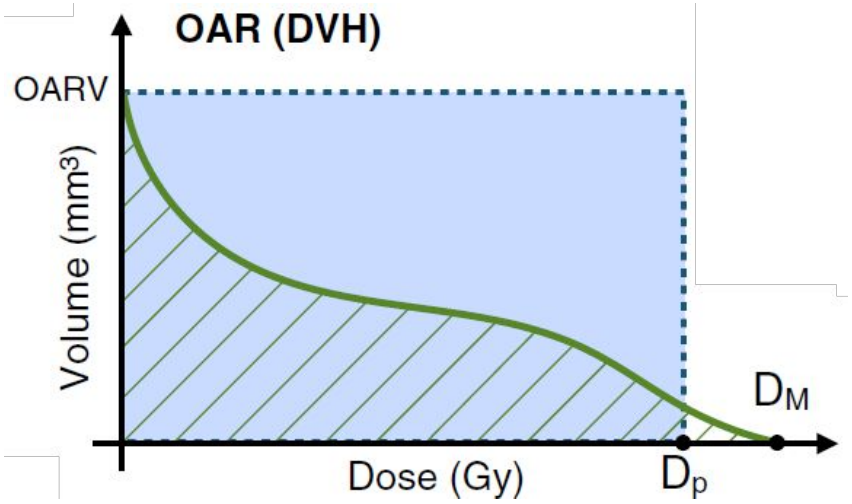


# Evaluation of scenario doses (1)

**Dose-Volume Histograms**

Graphical representations plotting the percentage of a target volume receiving at least a specific dose of radiation




Alfonso et al., Radiation Oncology, 2015

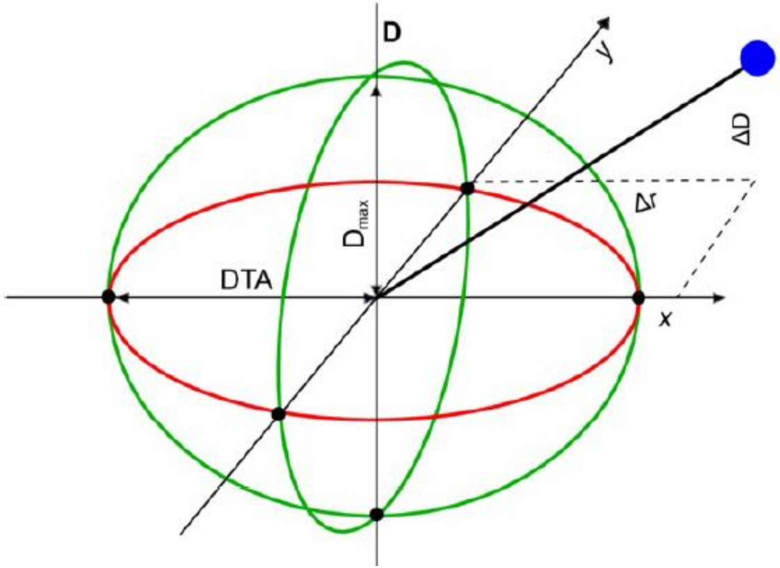
# Evaluation of scenario doses (2)

**Gamma-index map**

- A quantitative tool used to compare the dose distributions

**Calculation Parameters**:

- Distance-to-Agreement (DTA)
- Dose Difference (DD)

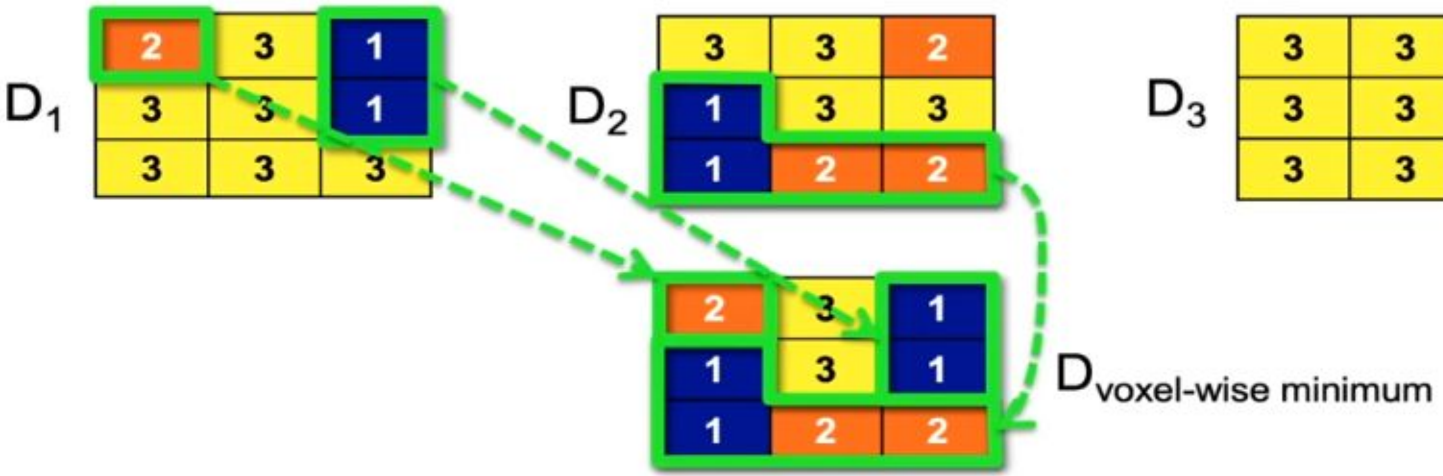



M.Garbacz, doctoral dissertation, 2022

# Evaluation of scenario doses (3)

**Multiple dose distributions can't be reviewed individually**

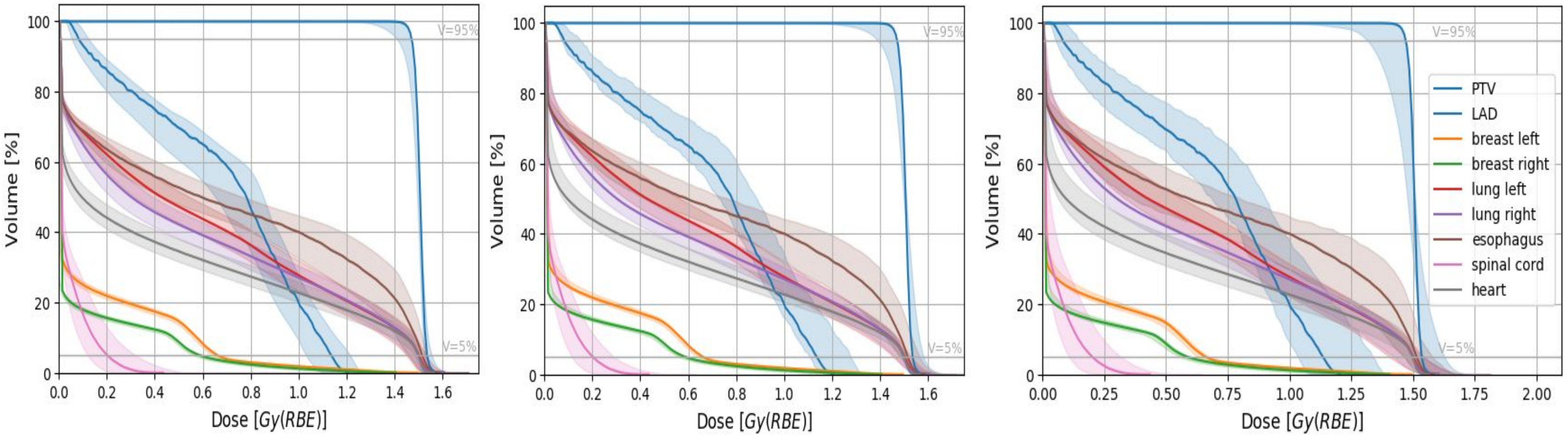
**Solution: Voxel wise worst case dose distribution**




(Korevaar et al. Radiat and Oncol. 2019)

# Example results (1)

**Robust analysis - DVH for a sample patient with Hodgkins lymphoma. Solid line presents reference (TPS).**




TPS 3D robust analysis | FRED 3D robust analysis (TPS rec.) | FRED 4D robust analysis

# Example results (2)

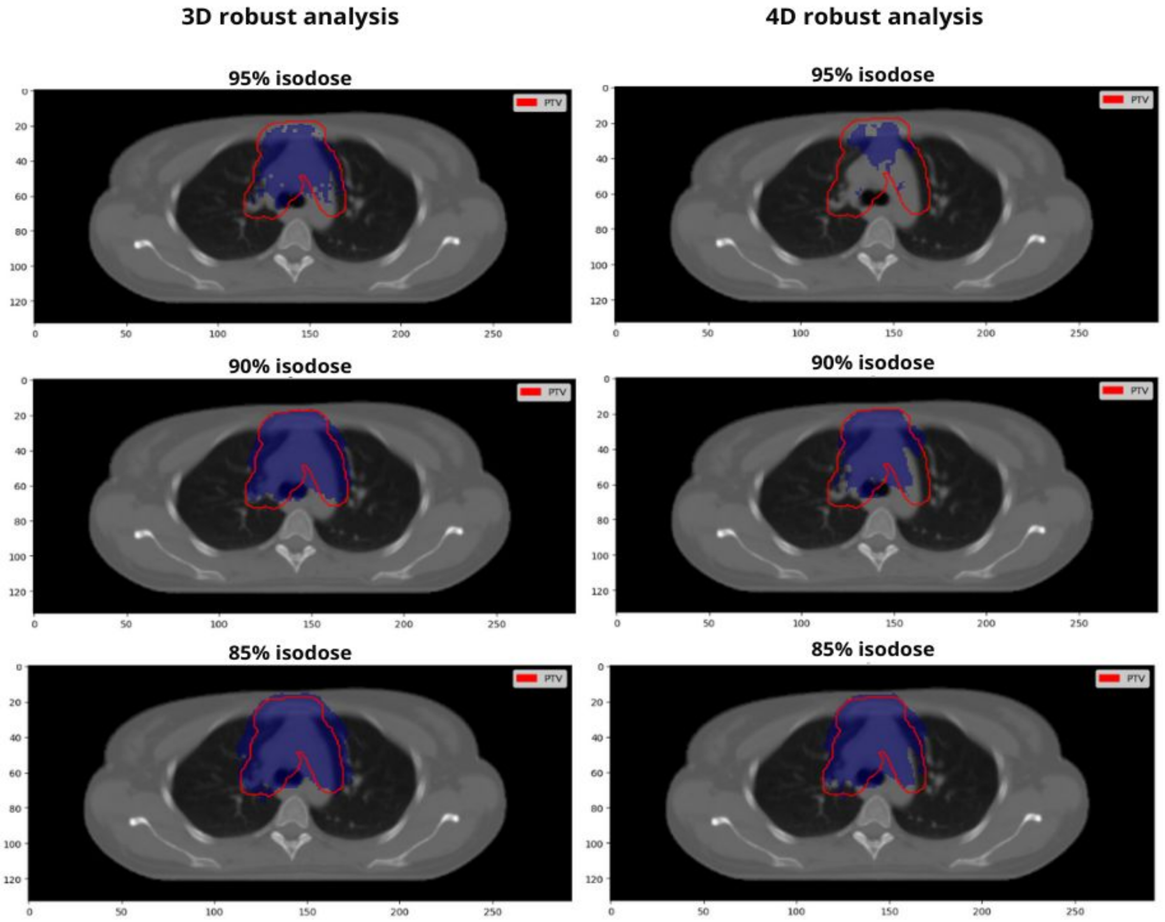
**Robust 4D dose evaluation - gamma index 3D (3%/3mm)**

- ➔ TPS plan simple rec. with FRED - **98.62%**
- ➔ 3D robust analysis - 12 scenarios (FRED) **89.08% - 97.12%**
- ➔ 4D robust analysis - 65 scenarios (FRED) **73.50% - 91.36%**

# Example results (3)

**Robust 4D dose evaluation -**

**voxel-wise minimum dose**



# Summary and conclusions

➔ CCB is fully utilizing its technical potential

➔ Treating moving targets requires motion mitigation methods and patient monitoring during all treatment phases

➔ CCB treats lymphoma patients using the DIBH technique

➔ Using DIBH reduces the dose to critical organs, especially the heart

➔ The proposed tool for robust 4D dose evaluations allows analysis of worst-case scenarios, accounts for uncertainties due to respiratory motion

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# Thank you for your attention

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**for substantive support and providing materials**

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Head of the project:
Renata Kopeć, DSc, Eng, Associate Professor

SCIENCE FOR THE SOCIETY