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## **Image-guidance in particle therapy (@ CNAO)**

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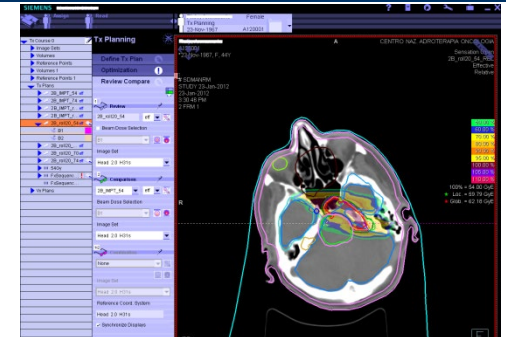


# High-precision radiotherapy

## A “computer assisted – robotic surgery” paradigm

### ✓ Planning stage:

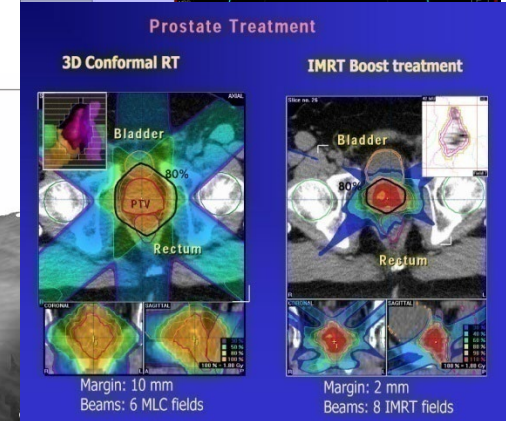
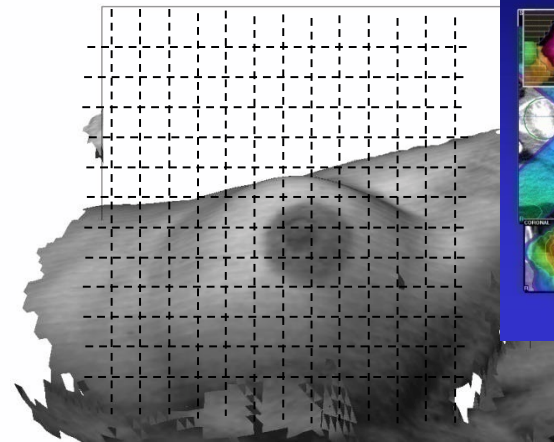
- X-ray volumetric imaging (3D/4D-CT)
- Functional imaging (PET , fMRI)
- Contouring (semi-automatic)
- Definition of treatment physical and geometry parameters
- Dose distribution simulation / optimization / evaluation



Uncertainties

### ✓ Delivery/treatment stage:

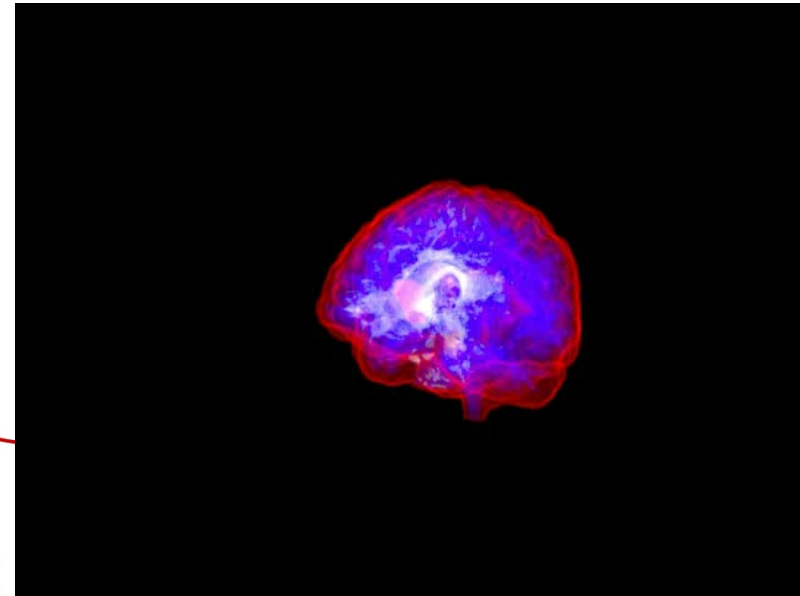
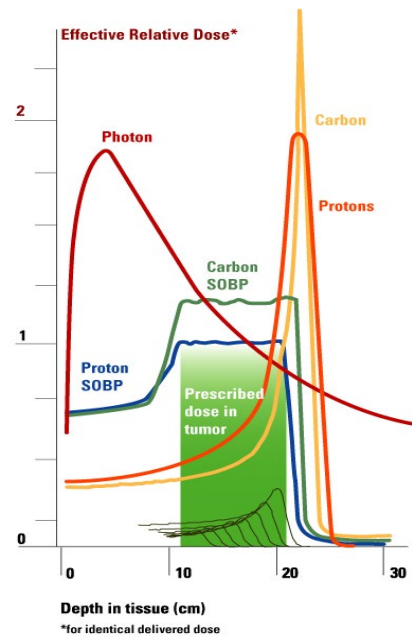
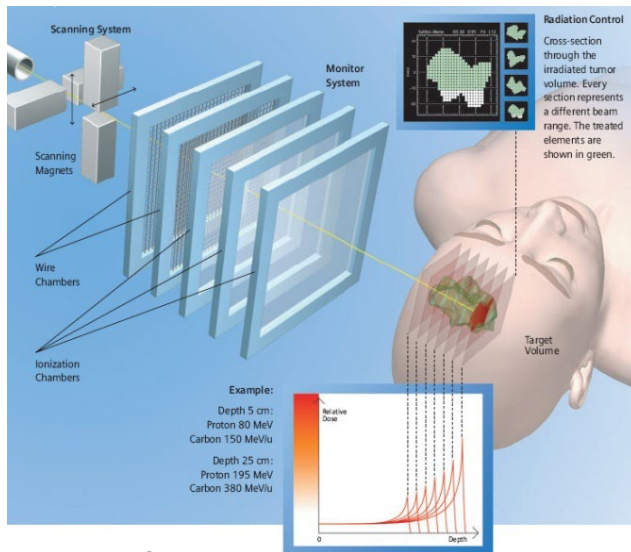
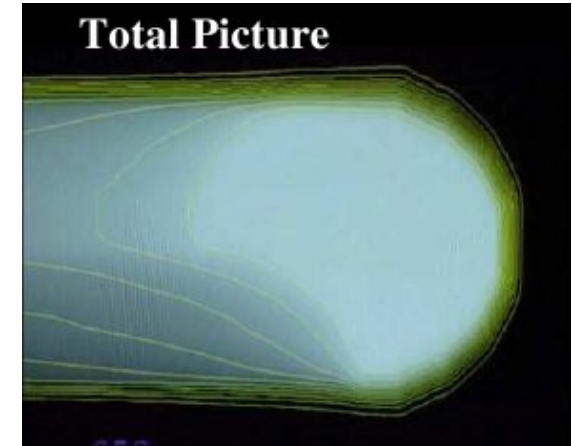
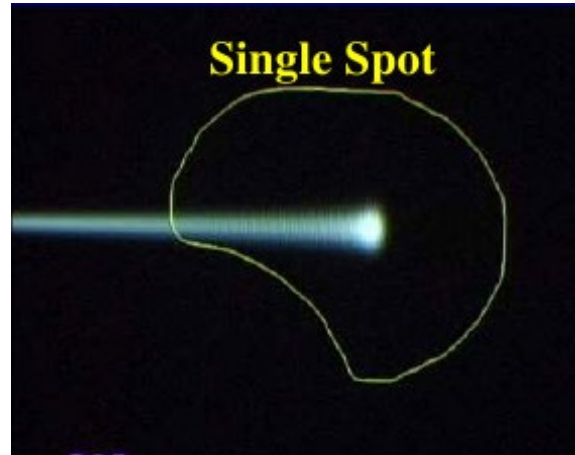
- Patient set-up errors compensation
- Geometry verification (Image Guidance)
- Compensation of inter-fractional patient deviations
- Dose delivery with compensation of intra-fractional patient deviations





# “The curios case of...” particle therapy

- ✓ Higher biological effectiveness
- ✓ Higher geometrical selectivity
- ✓ Much higher effects of geometrical uncertainties on dose distribution
- ✓ Technological “gap” still existing in image-guidance between photon and particle radiotherapy



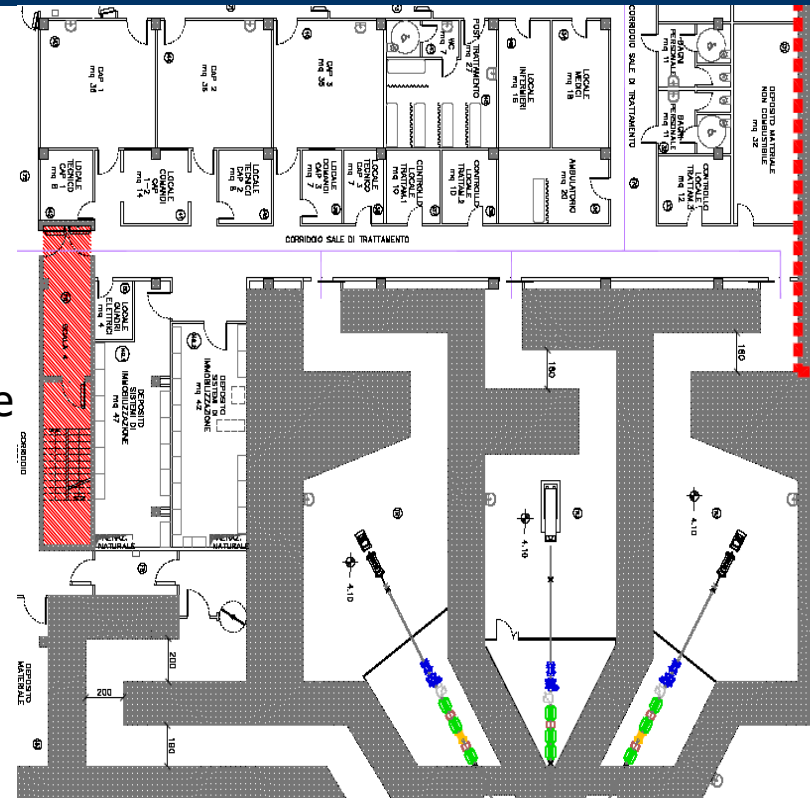
Courtesy of Siemens AG

# High-precision radiotherapy: IGRT in particle therapy in the CNAO facility

- ✓ Centro Nazionale di Adroterapia Oncologica ([www.cnao.it](http://www.cnao.it))
  - ✓ first center in Italy (2<sup>nd</sup> in Europe; 5<sup>th</sup> worldwide) for active scanning proton and carbon-ion therapy
  - ✓ 3 treatment rooms with fixed beamline
    - ✓ 2 lateral room with single H beamline
    - ✓ 1 central room with 1 H and 1 V beamline

## State of the art technologies for in-room image guidance

- ✓ 6 dof patient positioning system
- ✓ IR optical tracking for set-up and immobility verification
- ✓ X-ray projection systems for 2D-3D registration
- ✓ X-ray robotic system for CBCT reconstruction and 3D-3D registration
- ✓ Under clinical activity since 2011





# Patient Positioning and Verification strategy at CNAO Integrated robotic, X-ray and IR localization system



**3D Real-time IR Optical Tracking (OTS)**

- Real time reconstruction of spherical markers
- Sub-millimeter accuracy : peak 3D errors  $<0.5$  mm
  - 3D data flow @70 Hz

**X-ray Patient Verification System (PVS)**

- 2 X-ray tubes (deployable),
- 2 flat panels (deployable)
- Supporting structure rotation:  $\pm 180^\circ$
- Rotation and deployment accuracy:  $\pm 0.15$ mm,  $\pm 0.1^\circ$

**Patient Positioning System (PPS)**

- Automatic couch or chair docking
- Absolute accuracy:  $\approx 0.3$  mm

(Pella et al., *TCRT*, 2014)

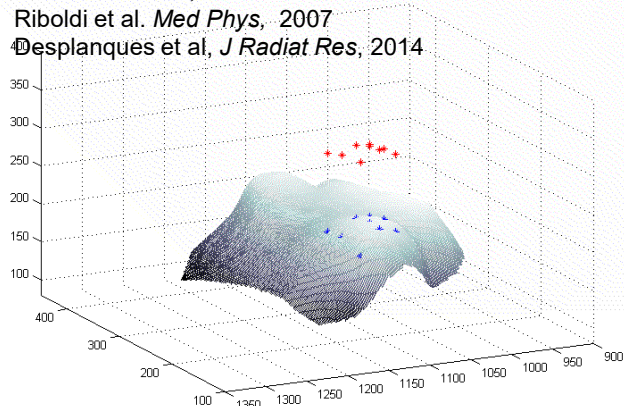


# High-precision radiotherapy: IGRT Optical tracking localization technologies

- ✓ Powerful techniques to capture motion in 3D and “real-time” (50-100 Hz sampling rate)
- ✓ State of the art of computer assisted surgery for “navigation” (intrinsically accurate, FLE<1mm)
- ✓ Applied in radiotherapy for set-up error detection and compensation
- ✓ References defined at treatment planning
- ✓ Real-time calculation of corrective 6dof parameters
- ✓ Position estimation of target (and OARs) through frameless stereotactic approach
- ✓ Continuous monitoring during irradiation



Baroni et al *Med Biol Eng Comput* , 1998; Ribodi et al. *Med Phys.*,2006;  
Baroni et al. *Radiother Oncol*, 2000; Baroni et al. *J Radiat Res*, 2007  
Baroni et al *CAS*, 2000;  
Baroni et al *IJROBP*, 004;  
Baroni et al *IJROBP*, 2006;





✓ At CNAO, OTS is daily used for patient position correction and monitoring

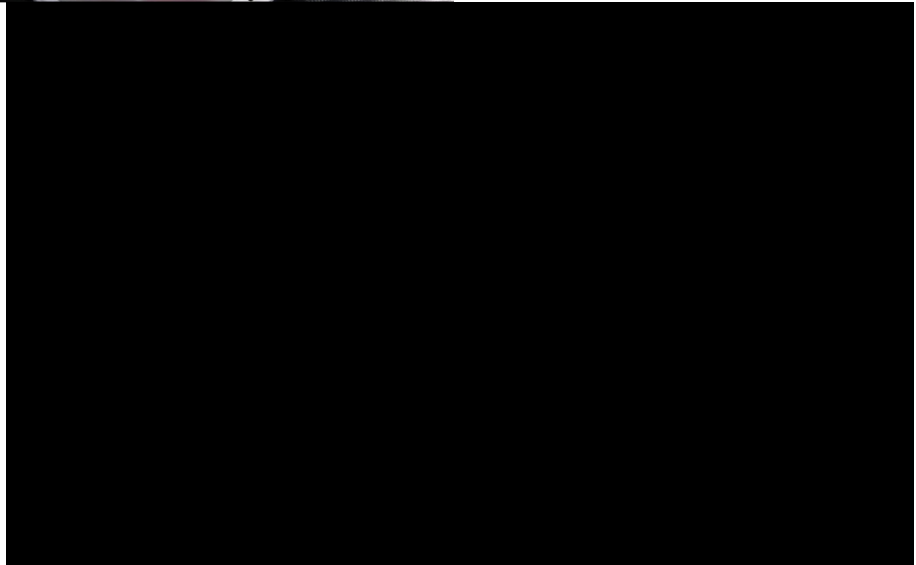
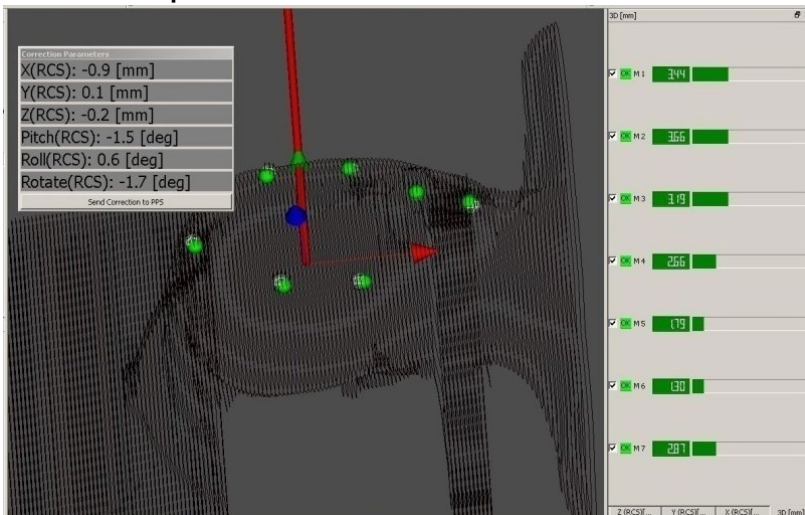
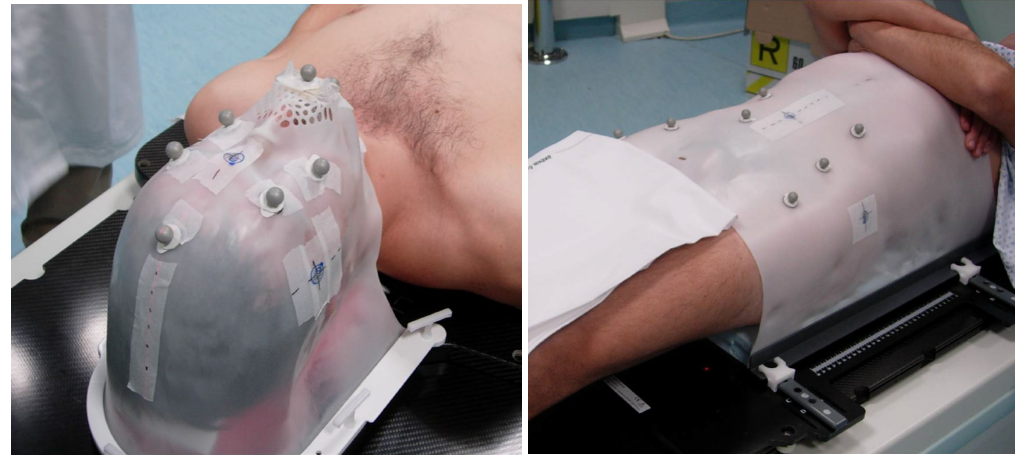
(Fattori et al., *IEEE Trans Biomed Eng.* 2012 )

✓ 3 TVC configuration

✓ Commercial HW – basic acquisition SW and calibration (BTS-Bioengineering, Italy)

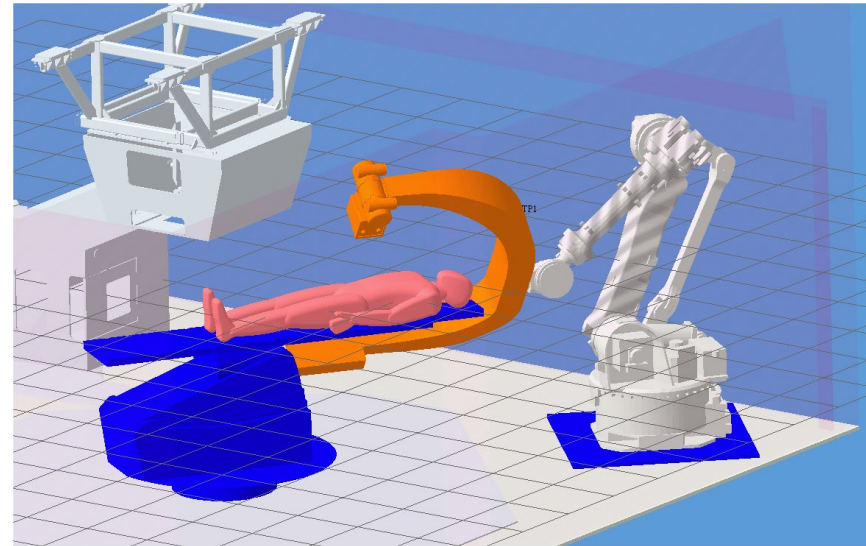
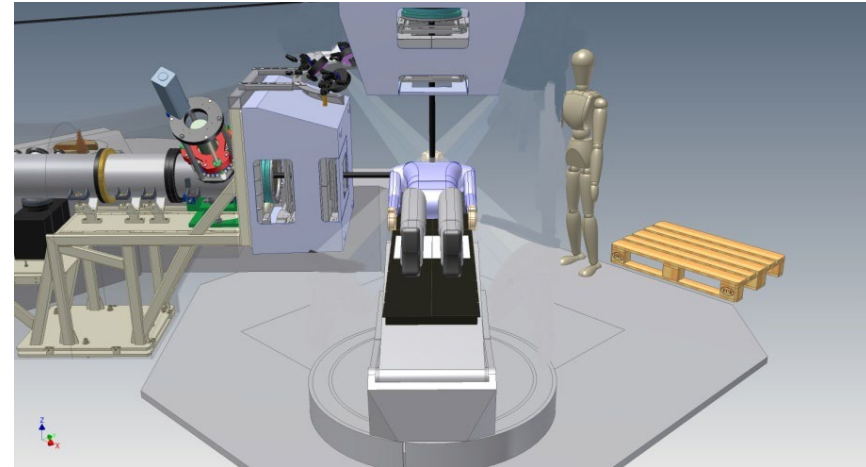
✓ In-house dedicated SW featuring:

- mapping reference system to isocenter
- real-time markers monitoring
- estimation of a 6 dof correction vector (point-based registration w.r.t. reference position extracted from planning CT)
- send position correction to PPS



# High-precision radiotherapy: Robotics imaging in CNAO central room

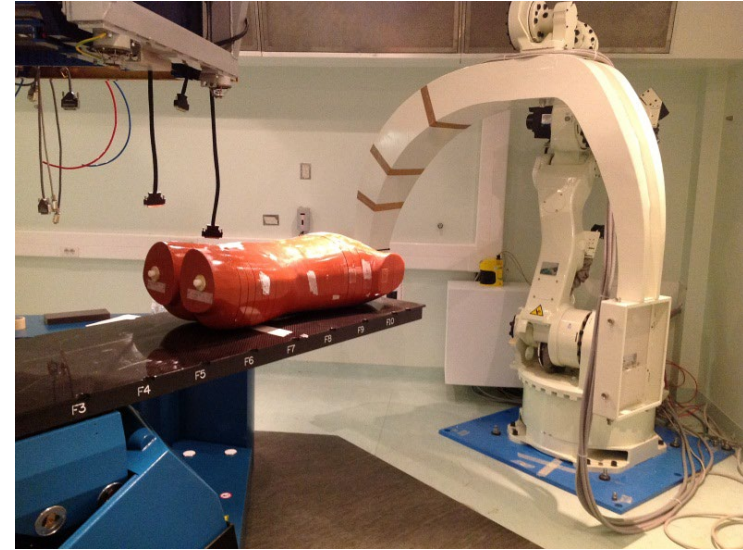
- ✓ Off-isocenter solution
- ✓ Industry-derived serial kinematic manipulator for static and dynamic patient imaging
- ✓ C-arm with kV X-ray tube and flat panel mounted on a 6-dofs robotic serial manipulator
- ✓ Dedicated in-house developed SW for:
  - ✓ multiple imaging and 2D-3D image registration
  - ✓ cone-beam CT and 3D-3D registration
- ✓ Selected robot: Kawasaki ZX300-S:
  - ✓ 300 kg load capability
  - ✓ 0.3 mm repeatability
- ✓ Selected imaging componens:
  - ✓ Varian A277 X-ray tube with fluoroscopy capabilities
  - ✓ Varial 4030D flat panel (2048x1536 pixels)
  - ✓ Sample rate up to 30 Hz





# High-precision radiotherapy: IGRT Robotic imaging in CNAO central room

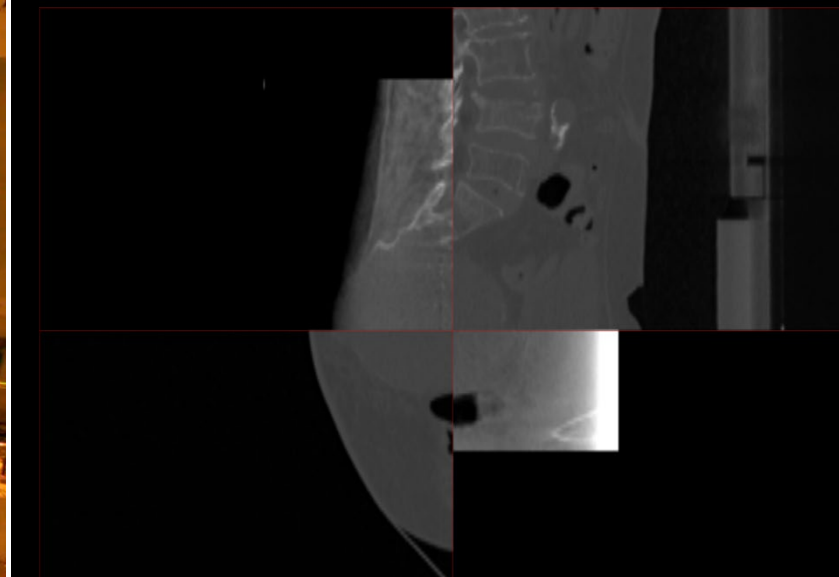
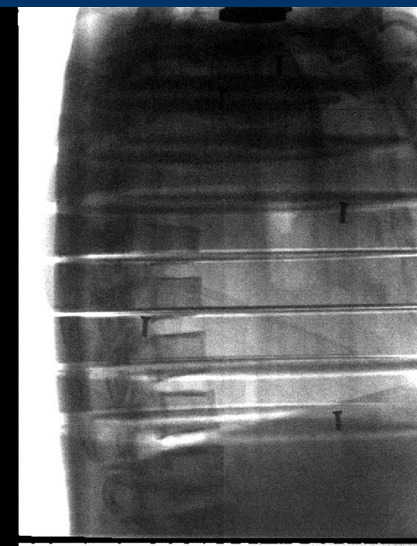
- ✓ 2D-3D image registration between DRR from TPS and acquired multiple projections
- ✓ 3D-3D registration between in-room CBCT and planning CT
- ✓ Under clinical application since March 2013



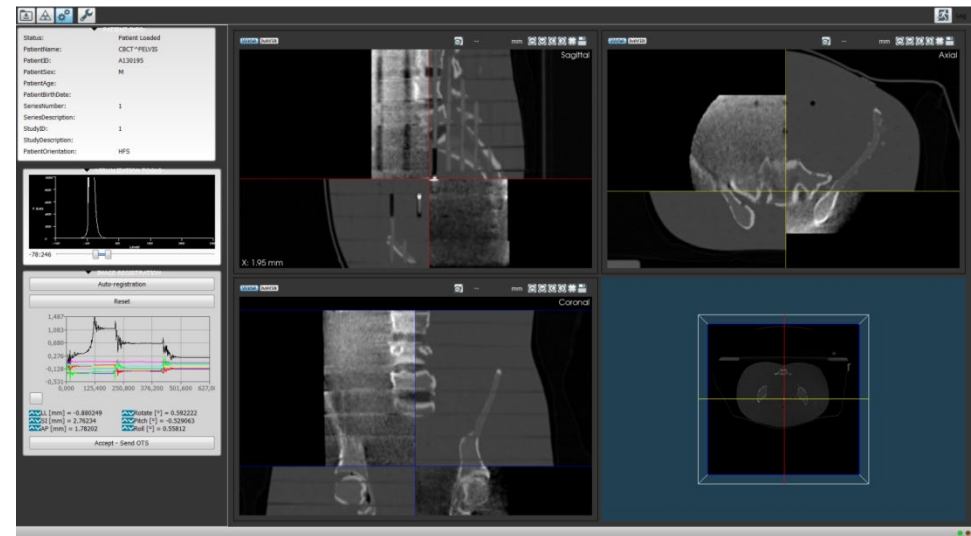
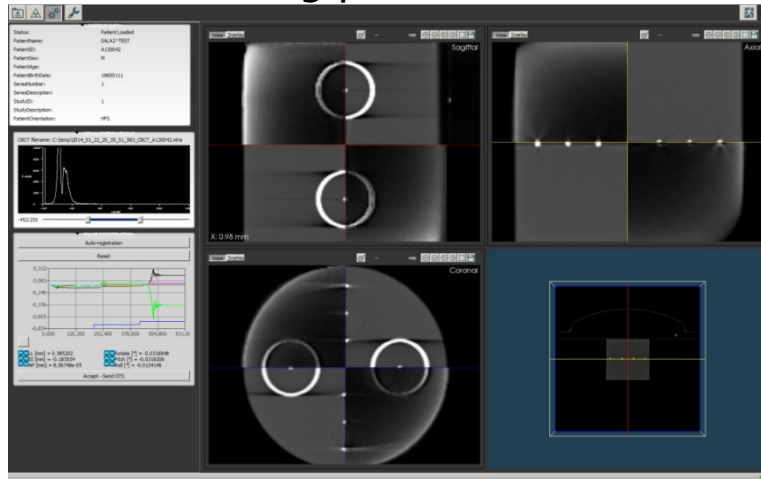


# High-precision radiotherapy: IGRT Localization technologies: Image-based

- ✓ 3D-3D registration between CBCT and planning CT
  - ✓ 615 projections over 220° ROM acquisition time <40 sec
  - ✓ Reconstruction time (GPU parallelized FDK) < 20 sec (depends on desired resolution)
  - ✓ 220x220x220 mm resolution
  - ✓ 3D-3D registration time <60 sec
  - ✓ Clinical application ongoing since summer 2014



✓ Commissioning phase



*Imposed error*

	RL rotation [°]	SI rotation [°]	AP rotation [°]	RL [m m]	SI [m m]	AP [m m]
1	0	0	0	-1	-2	3
2	-2	-2,5	1,5	0	0	0
3	-1	-1,5	0,5	3	2	5
4	0,5	1,5	2	-2	-5	-4

*Correction parameters*

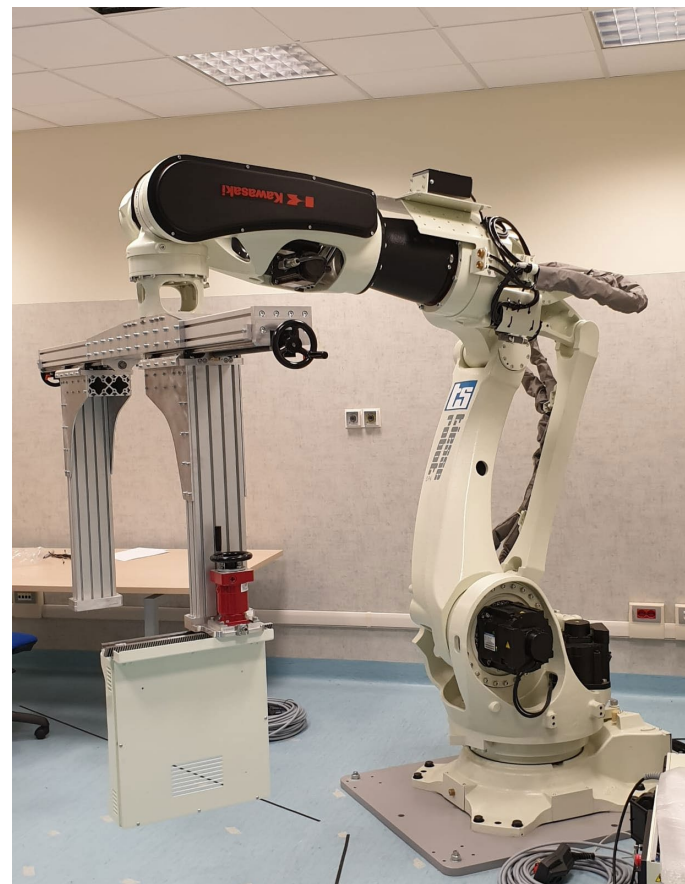
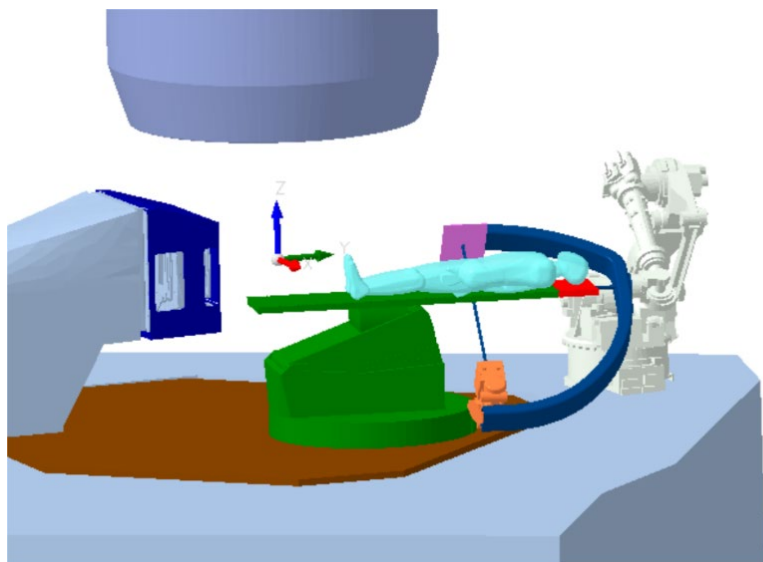
	RL rotation [°]	SI rotation [°]	AP rotation [°]	RL [m m]	SI [m m]	AP [m m]
1	-0,50	-0,26	-0,39	-1,25	-1,80	2,37
2	-1,86	-2,54	1,02	-0,06	0,54	-0,26
3	-1,41	-1,29	0,35	3,00	2,24	4,45
4	-0,17	1,59	1,56	-2,80	-4,64	-4,87

(Fattori et al., *Phys Med*, 2015)



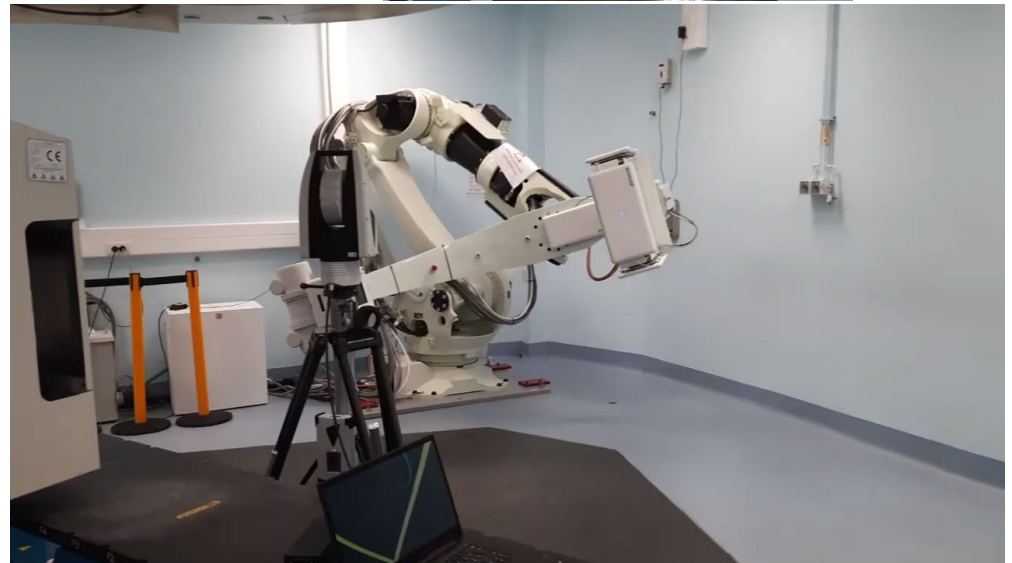
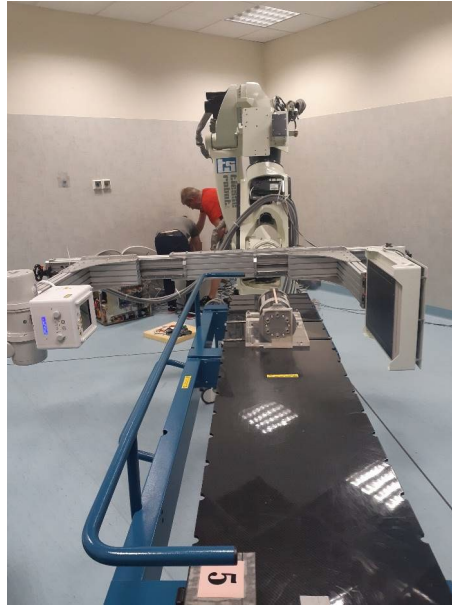
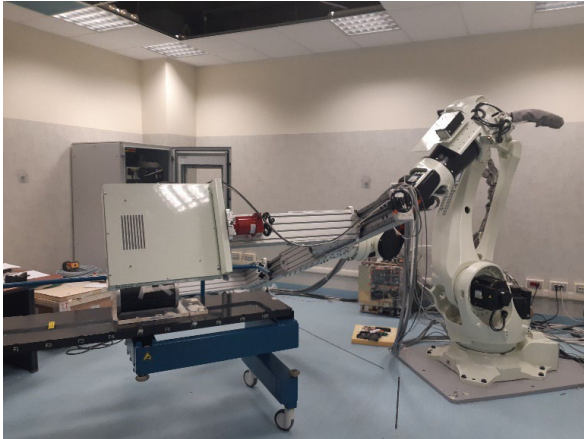
# High-precision radiotherapy: IGHT Localization technologies: Image-based in lateral room

- ✓ New project in lateral room #1 for CBCT with improved FOV dimensions
  - ✓ New project in Room #1 (CNAO-Politecnico di Milano)
  - ✓ Major upgrade: implementation of half-fan reconstruction modality for improved FOV dimensions
- ✓ Selected robot: Kawasaki BX300-S:
  - ✓ 300 kg load capability
  - ✓ 0.3 mm repeatability
- ✓ Selected imaging components:
  - ✓ Varian A277 X-ray tube with fluoroscopy capabilities
  - ✓ Varial 4030D flat panel (2048x1536 pixels)
  - ✓ Sample rate up to 30 Hz



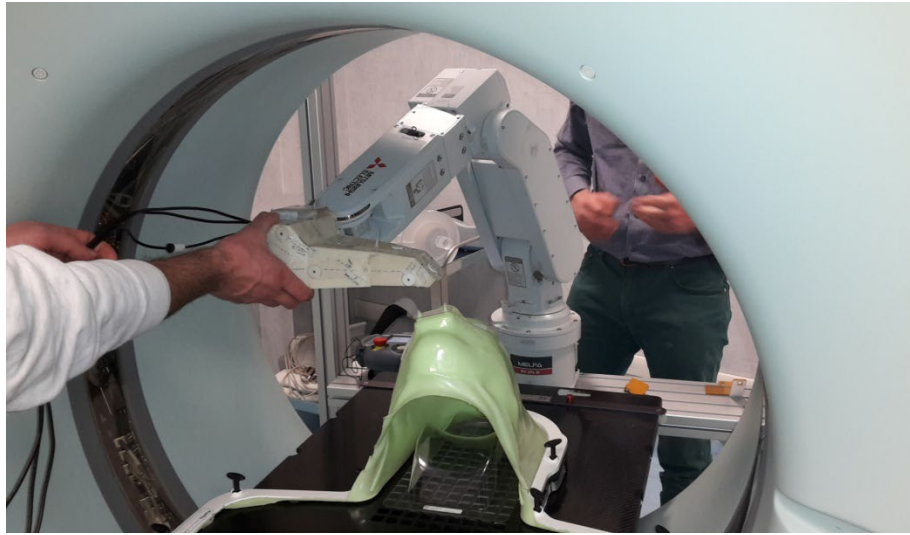


# High-precision radiotherapy: IGHT Localization technologies: Image-based in lateral room





# Eye Tracking system (ETS) in CNAO



## Irradiation

### X-ray imaging

Point-based registration on clips

Residuals  $\leq 1\text{mm}$

Name	Error
LDRR 1	4.36
LDRR 2	3.69
LDRR 3	4.43
LDRR 4	4.31
XR 1	3.69
XR 2	3.78
XR 3	4.43
XR 4	?

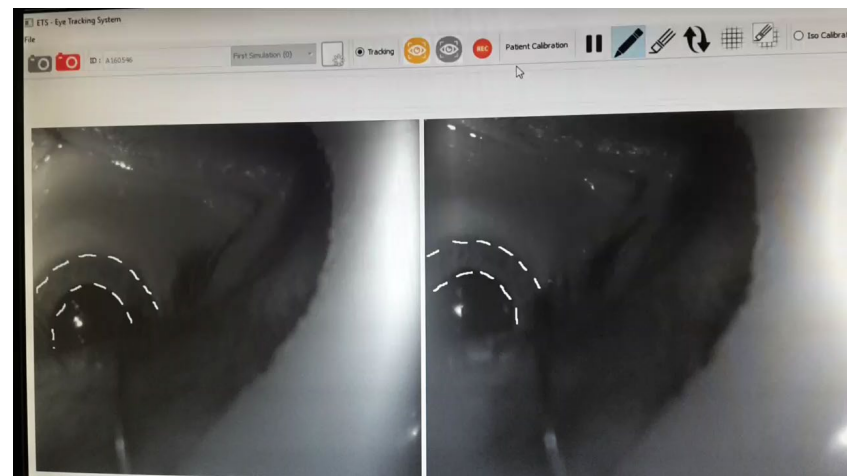
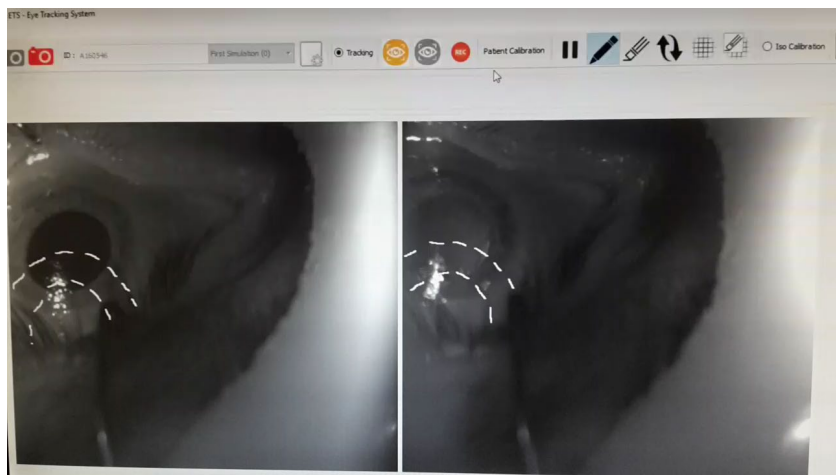
Error: D = 4.10mm, Max = 4.43mm

Translation [cm]		Rotation [°]	
+0.315	0.00	0.00	0.00
-0.145	0.00	0.00	0.00
+0.214	0.00	0.00	0.00

Name	Error
LDRR 1	0.56
LDRR 2	0.63
LDRR 3	0.42
LDRR 4	0.37
XR 1	0.56
XR 2	0.63
XR 3	0.42
XR 4	0.37

Error: D = 0.49mm, Max = 0.63mm

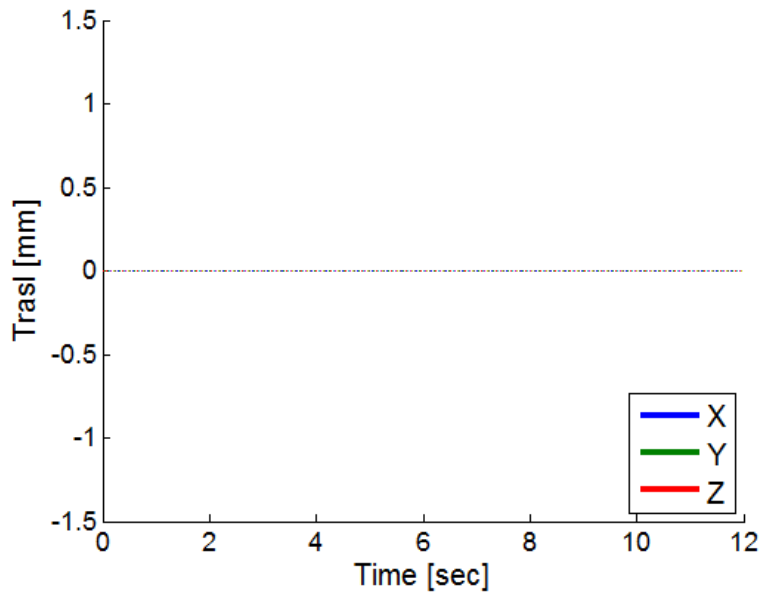
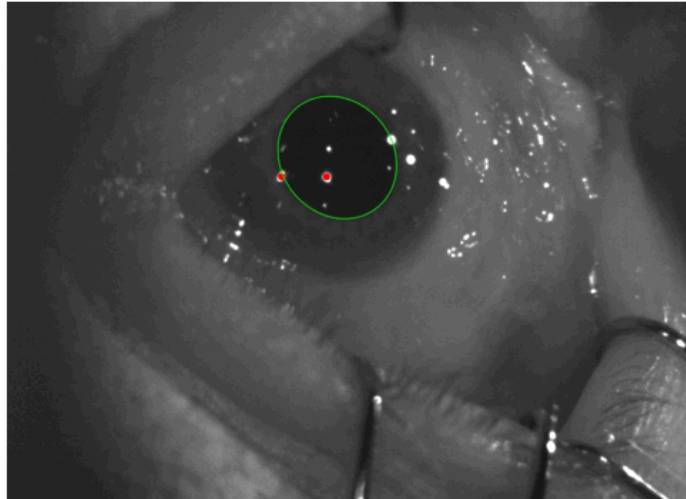
### Dose delivery



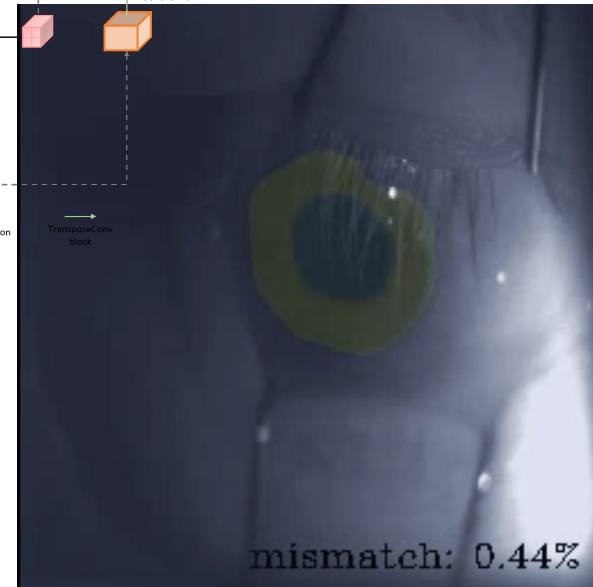
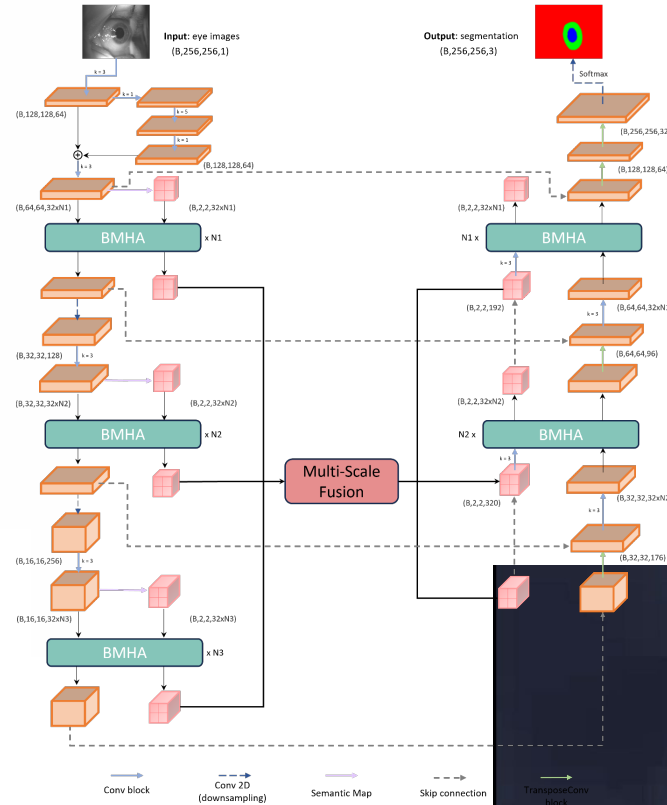


# 3D video oculography for gaze direction control

## Glints 3D localization vs Deep learning for automatic segmentation (work in progress)



MedFormer Model







Thank you for the attention



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