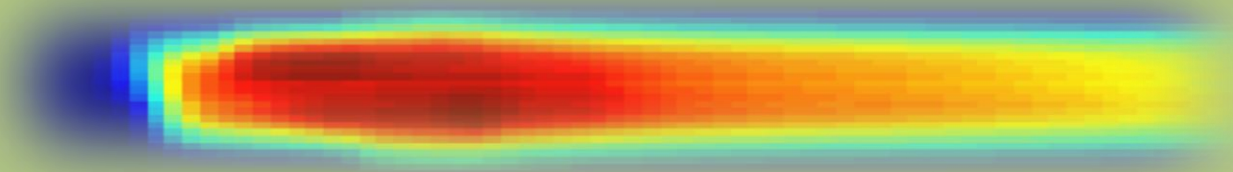


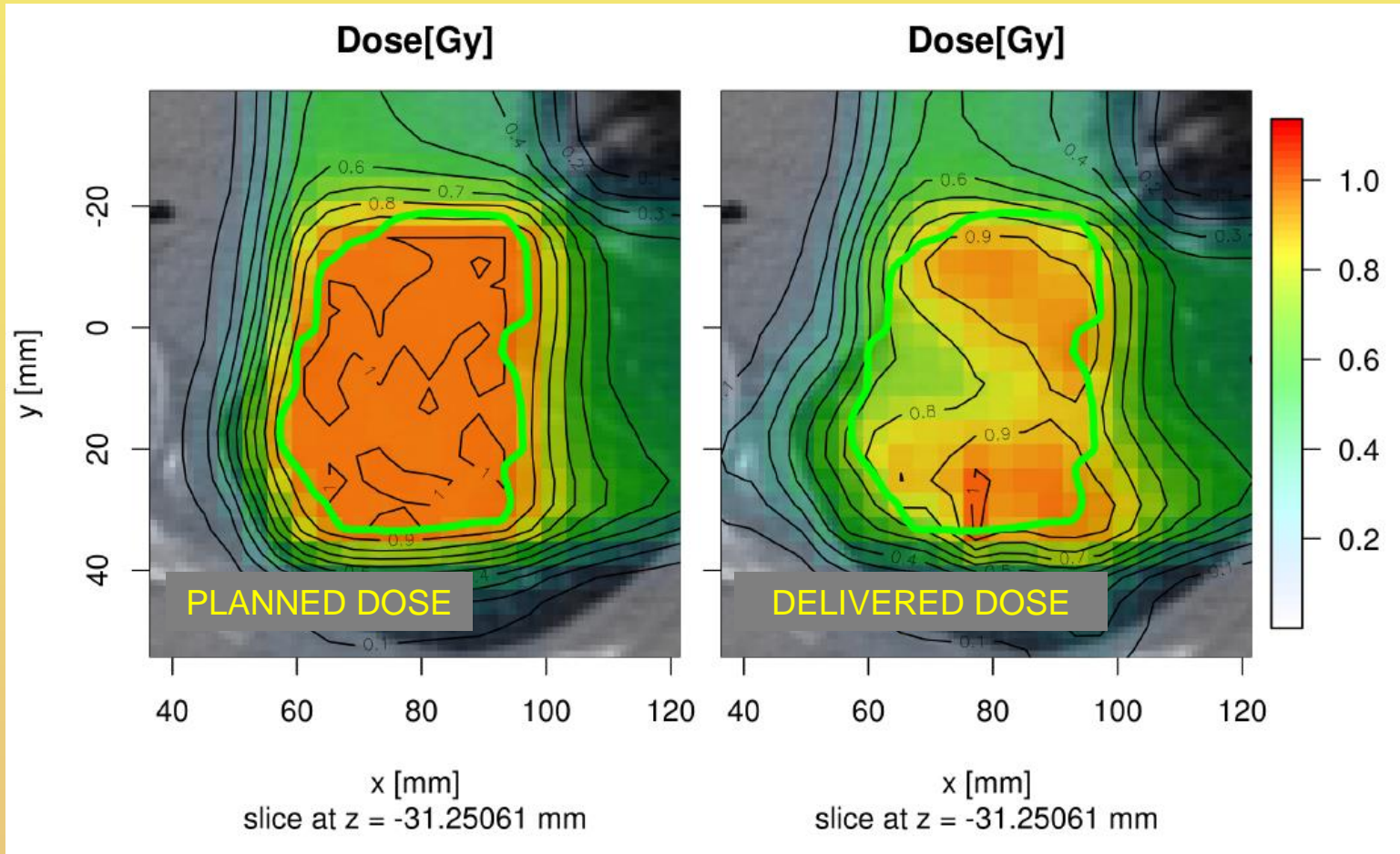


The RIDOS-INFN project:
an on-line GPU forward planning
integrated into a dose delivery
system for hadrontherapy with
scanning ion beams.





Goal

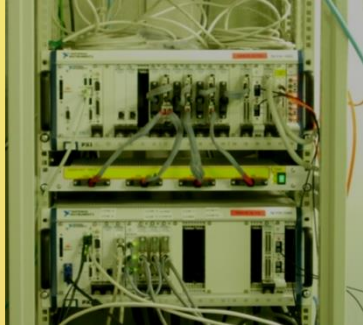


Calculate online the dose distribution, using measured data of the beams and of the patient's movement.



Strategy

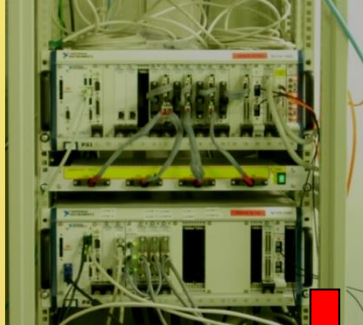
CNAO DDS





Strategy

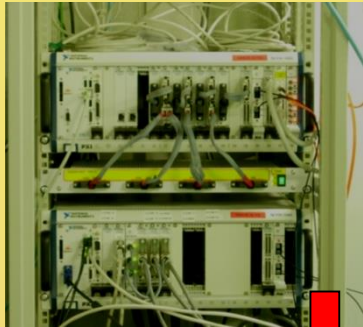
CNAO DDS



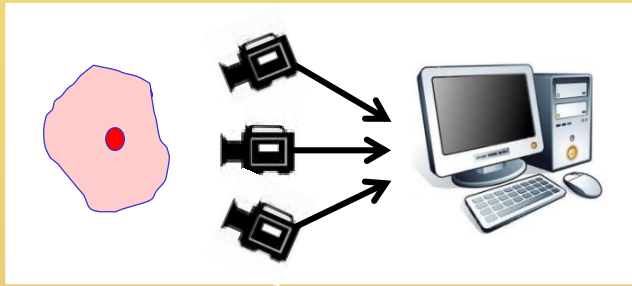


Strategy

CNAO DDS



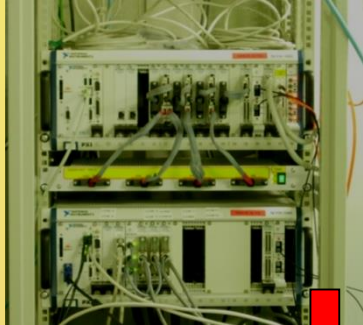
Target tracking system



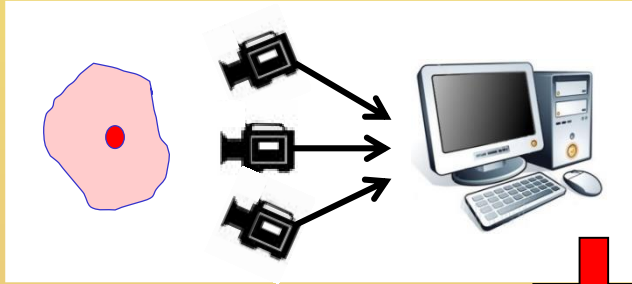


Strategy

CNAO DDS



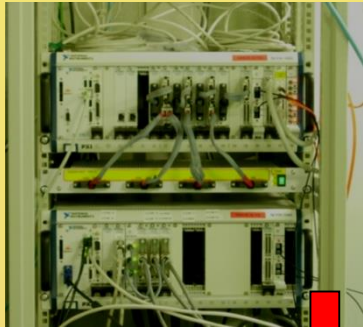
Target tracking system



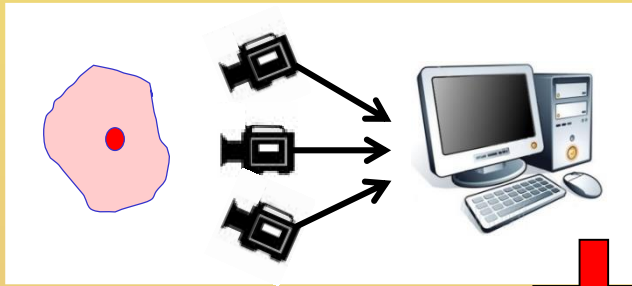


Strategy

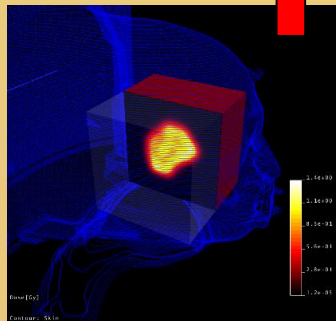
CNAO DDS



Target tracking system



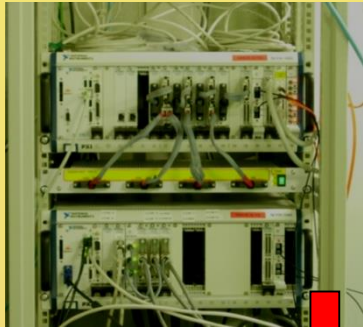
Fast Dose
Computation
based on GPU



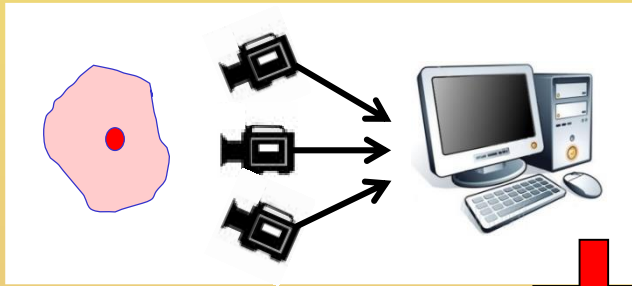


Strategy

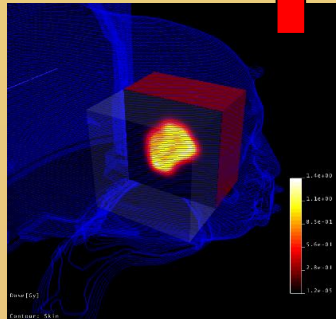
CNAO DDS



Target tracking system



Fast Dose
Computation
based on GPU

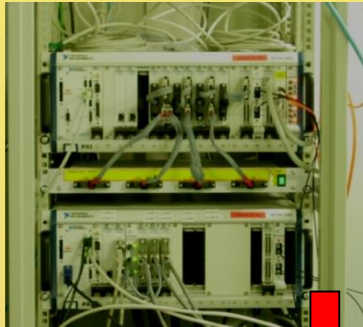


TO OBTAIN THE DELIVERED
DOSE DISTRIBUTION *ONLINE*

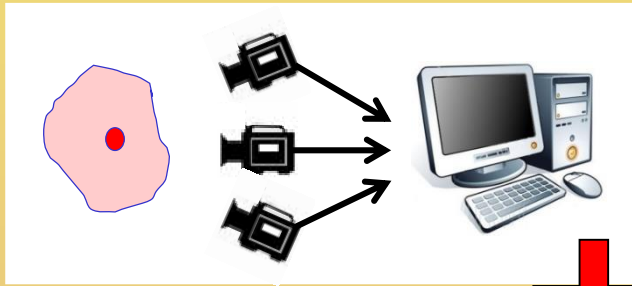


Strategy

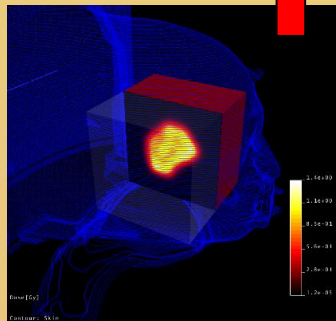
CNAO DDS



Target tracking system

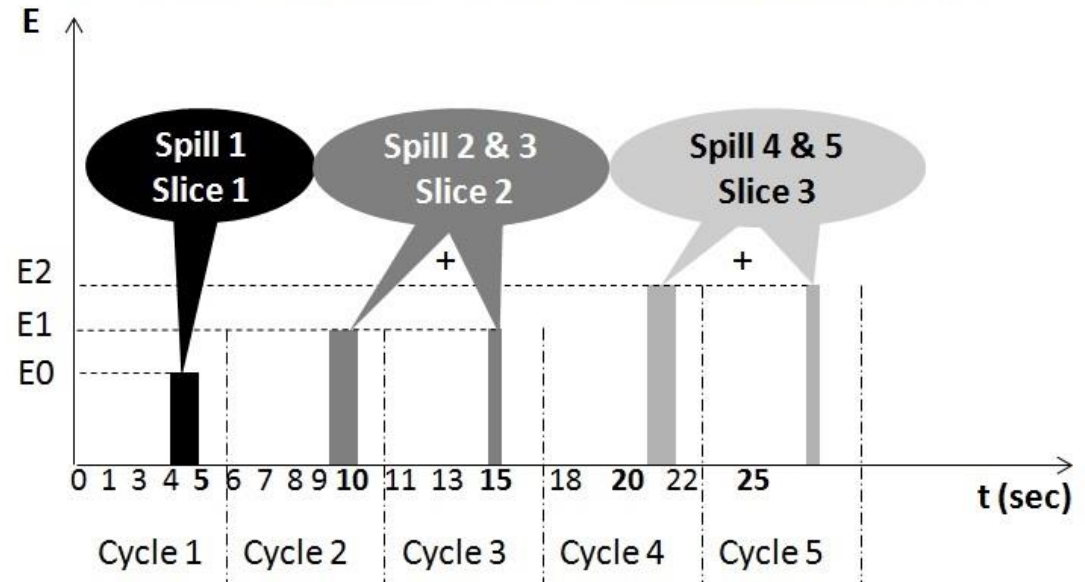


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

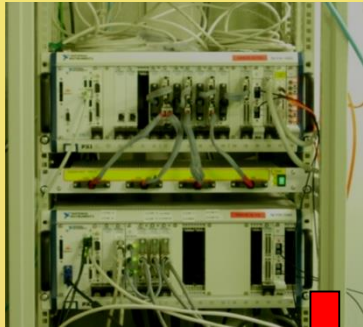


«ON LINE» = Inter spill time.

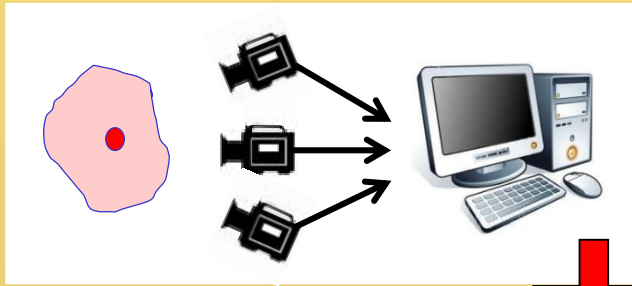


Strategy

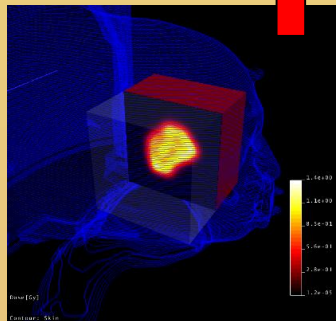
CNAO DDS



Target tracking system

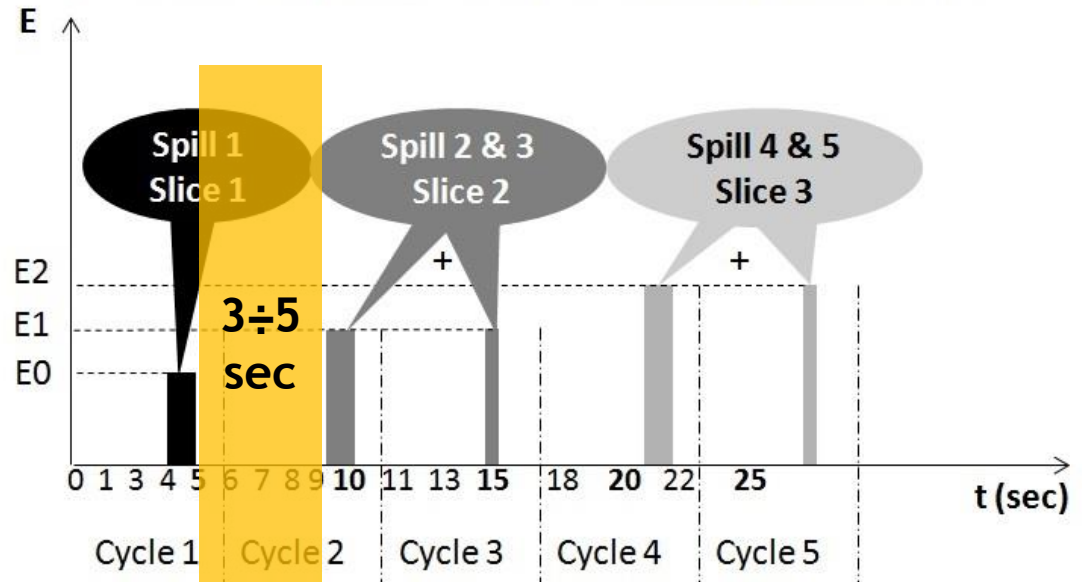


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

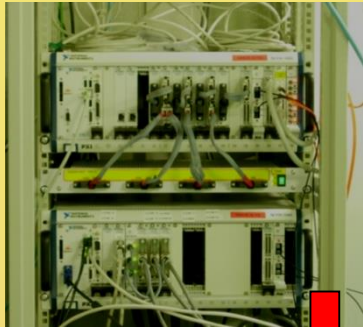


«ON LINE» = Inter spill time.

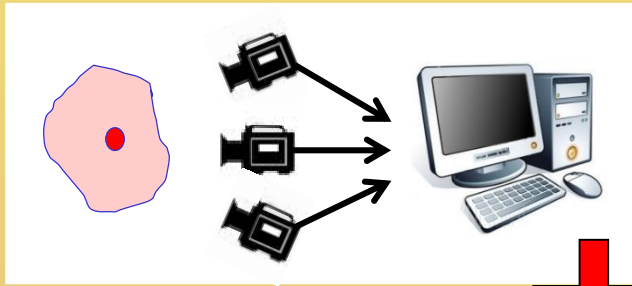


Strategy

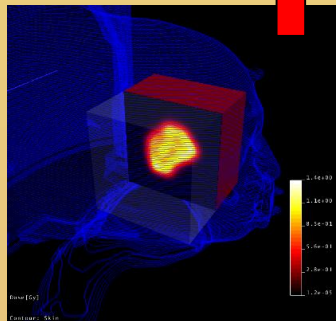
CNAO DDS



Target tracking system

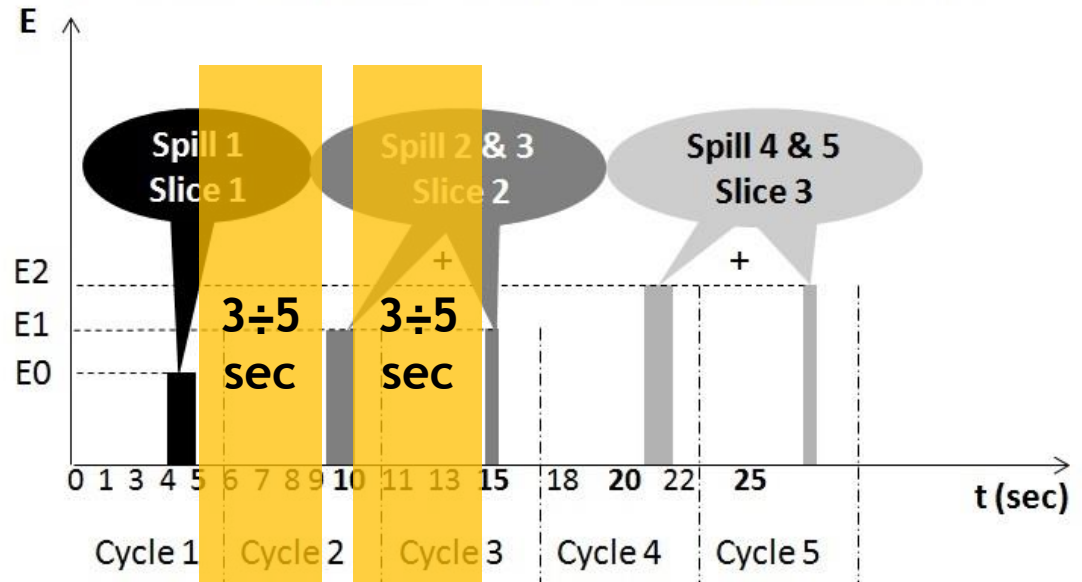


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

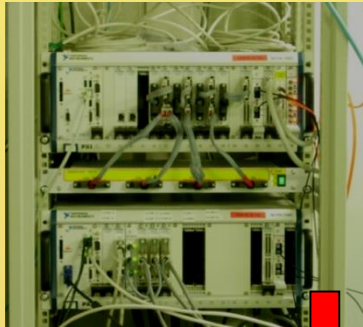


«ON LINE» = Inter spill time.

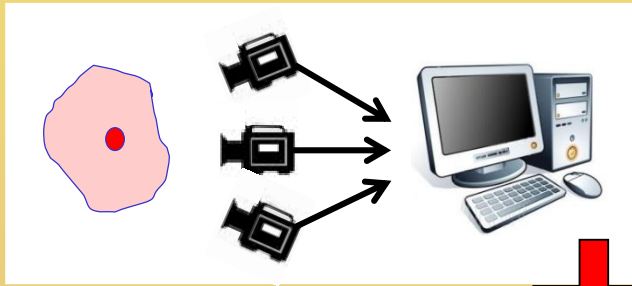


Strategy

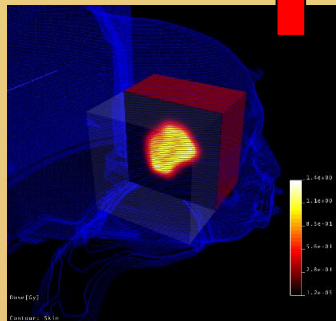
CNAO DDS



Target tracking system

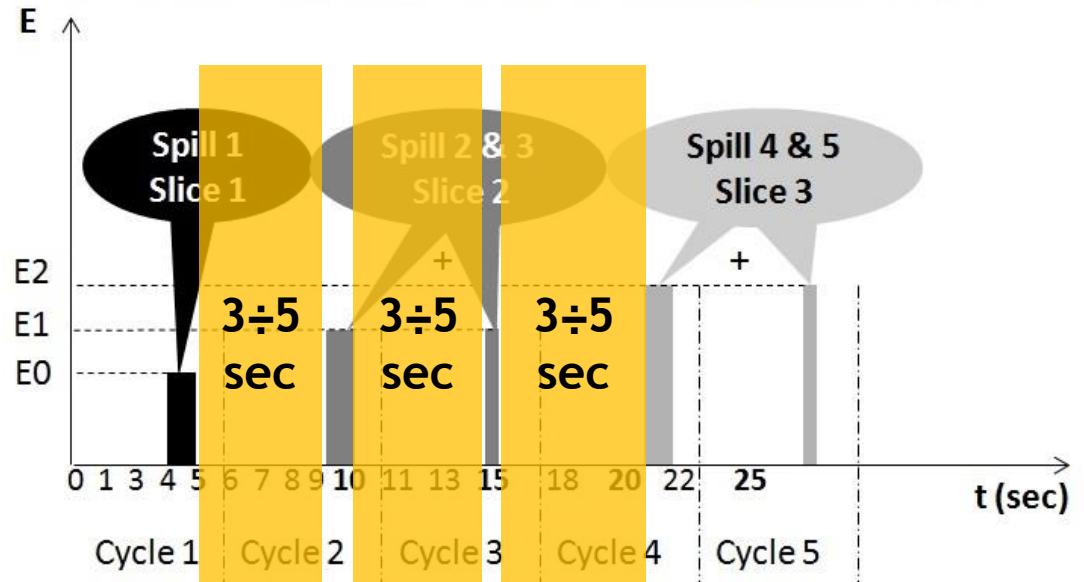


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

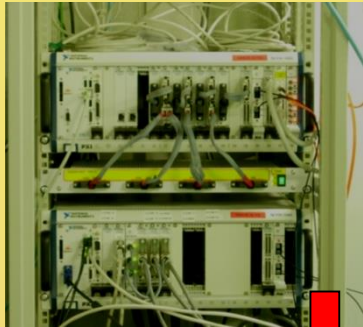


«ON LINE» = Inter spill time.

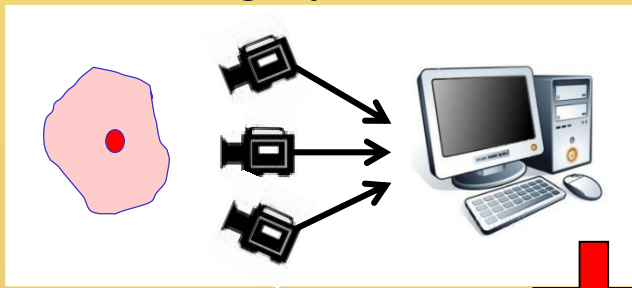


Strategy

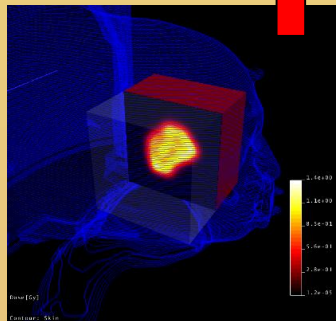
CNAO DDS



Target tracking system

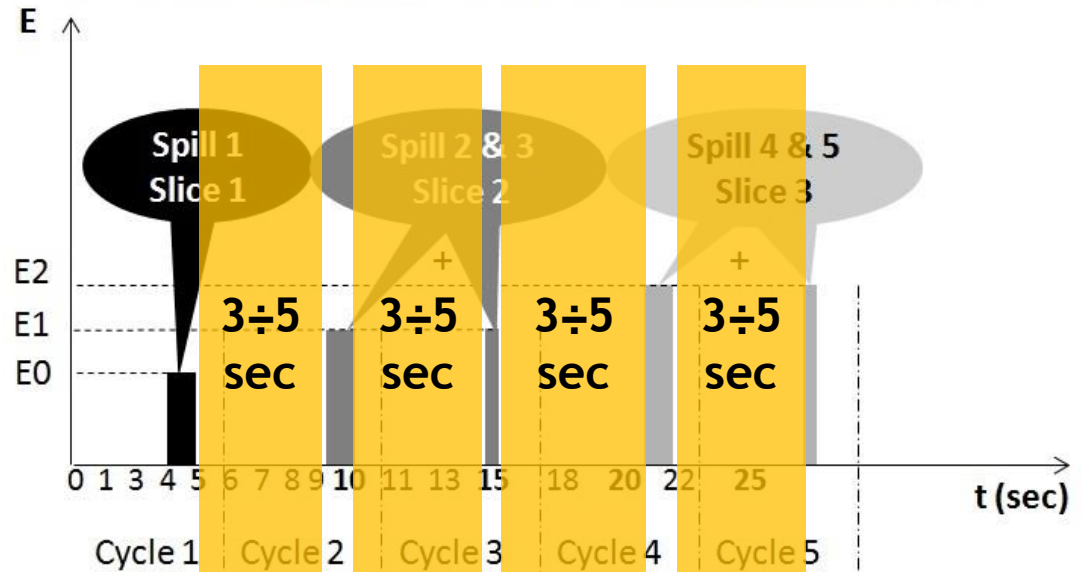


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

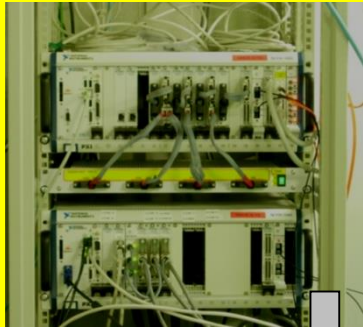


«ON LINE» = Inter spill time.

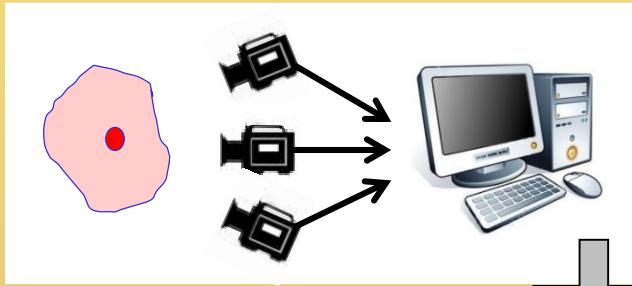


Strategy

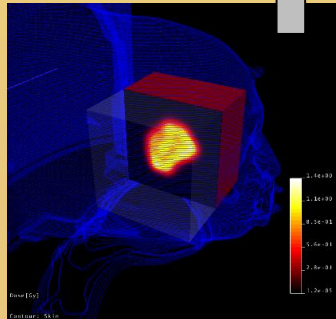
CNAO DDS



Target tracking system

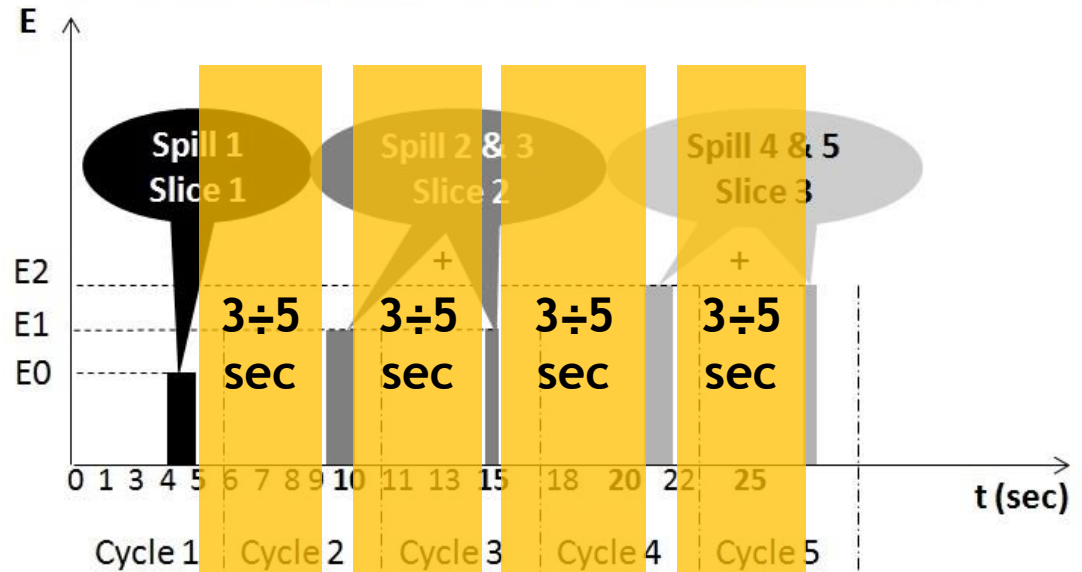


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

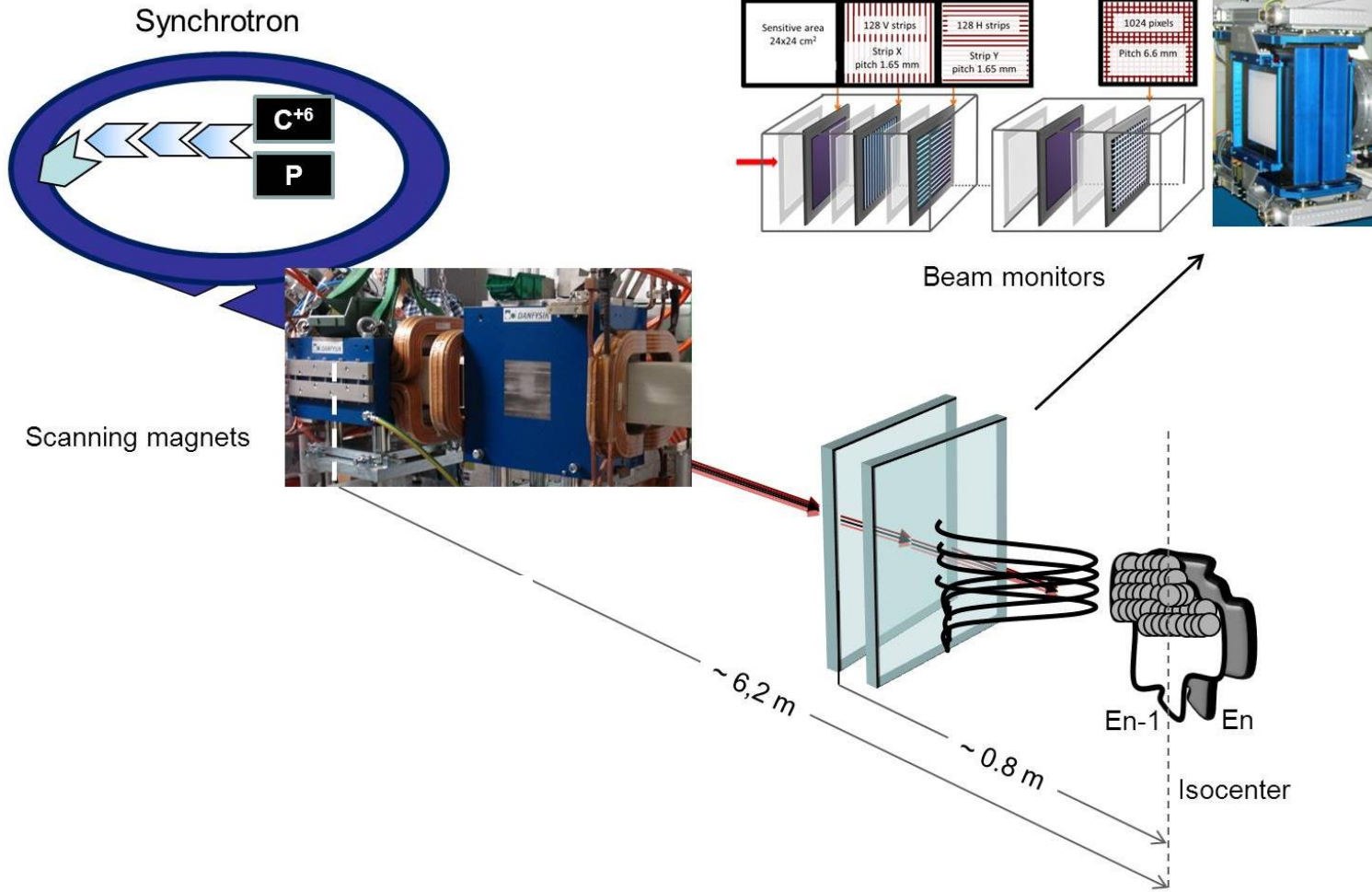
Dose delivery time structure with Synchrotron



«ON LINE» = Inter spill time.



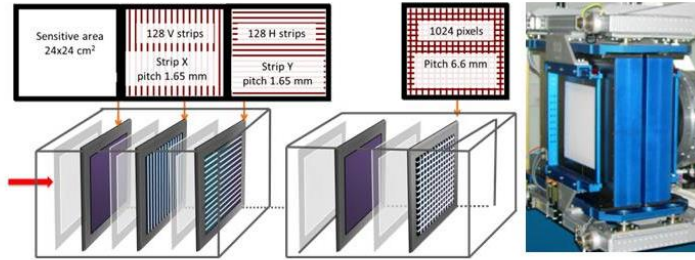
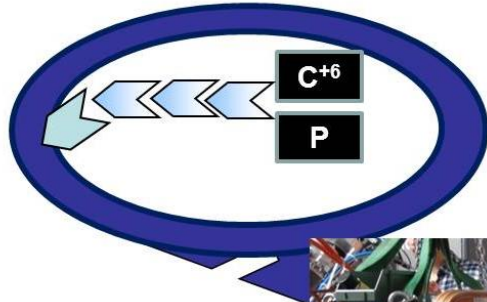
DDS – Dose Delivery System





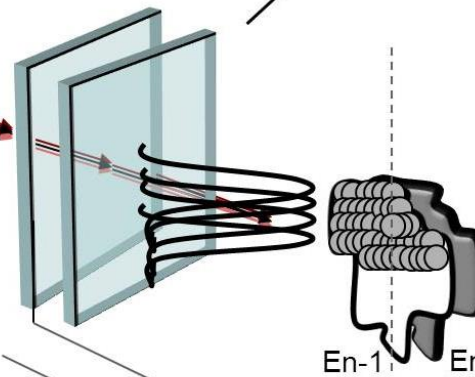
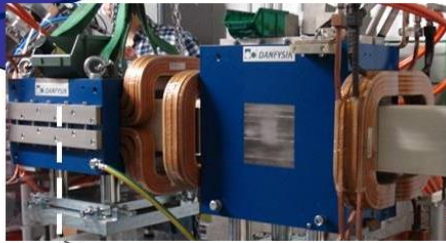
DDS – Dose Delivery System

Synchrotron



Beam monitors

Scanning magnets



En-1 En

Isocenter

~ 6,2 m

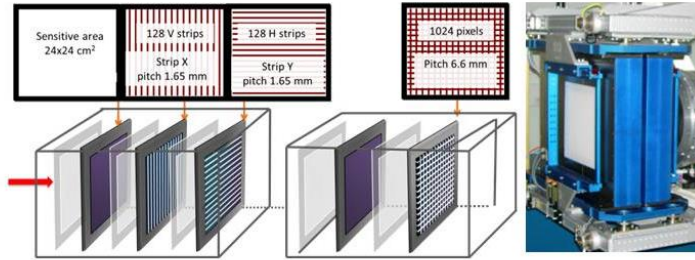
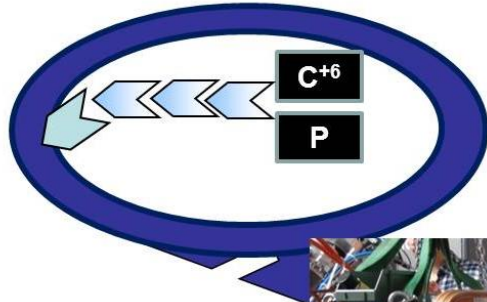
~ 0.8 m





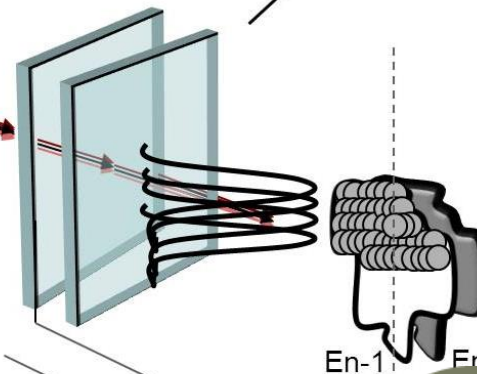
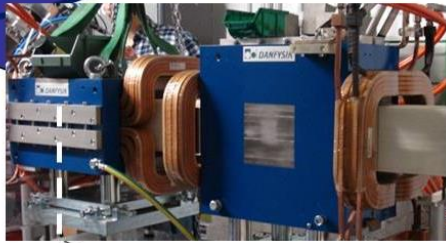
DDS – Dose Delivery System

Synchrotron



Beam monitors

Scanning magnets



~ 6,2 m

~ 0.8 m

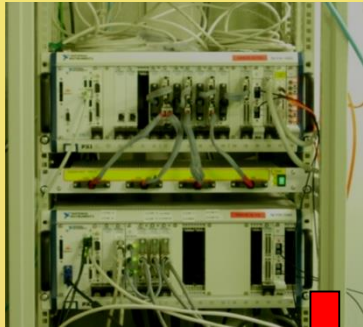


INFN sezione di TORINO (2005-2011):
Design, construction and commissioning of CNAO DDS.

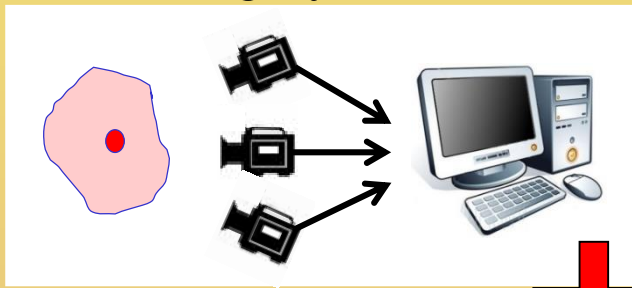


Strategy

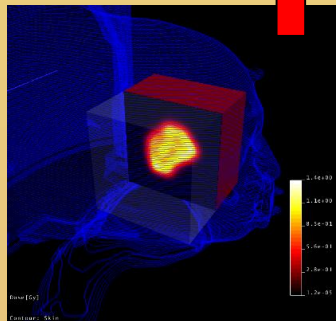
CNAO DDS



Target tracking system

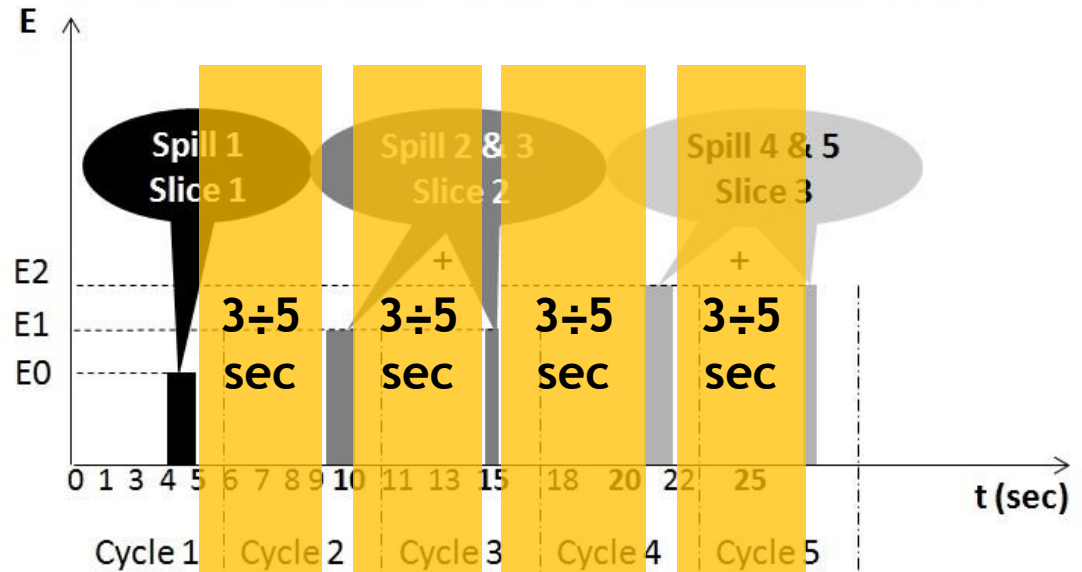


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

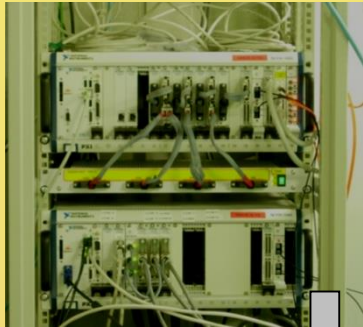


«ON LINE» = Inter spill time.

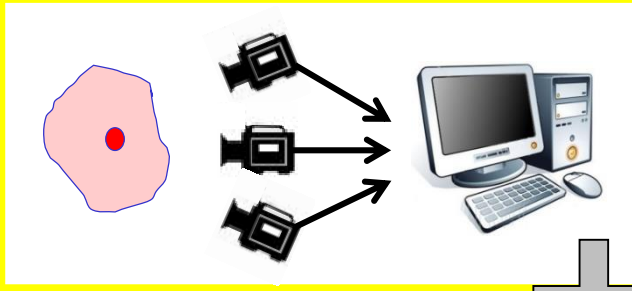


Strategy

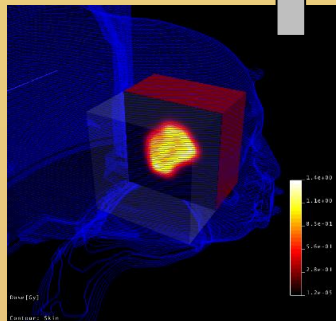
CNAO DDS



Target tracking system

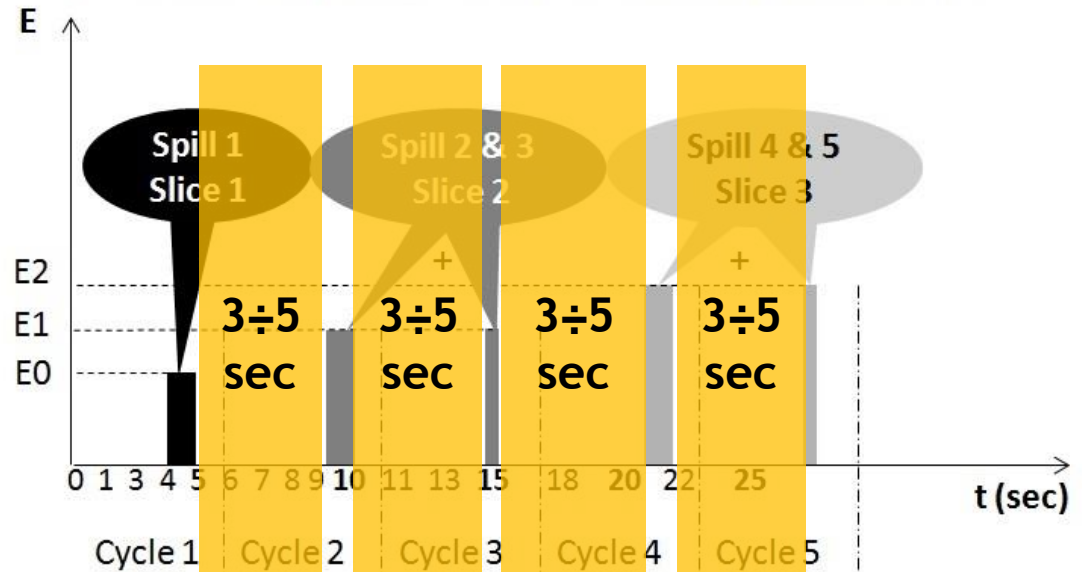


Fast Dose
Computation
based on GPU

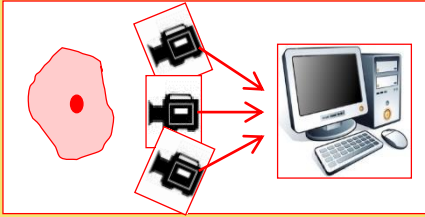


TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

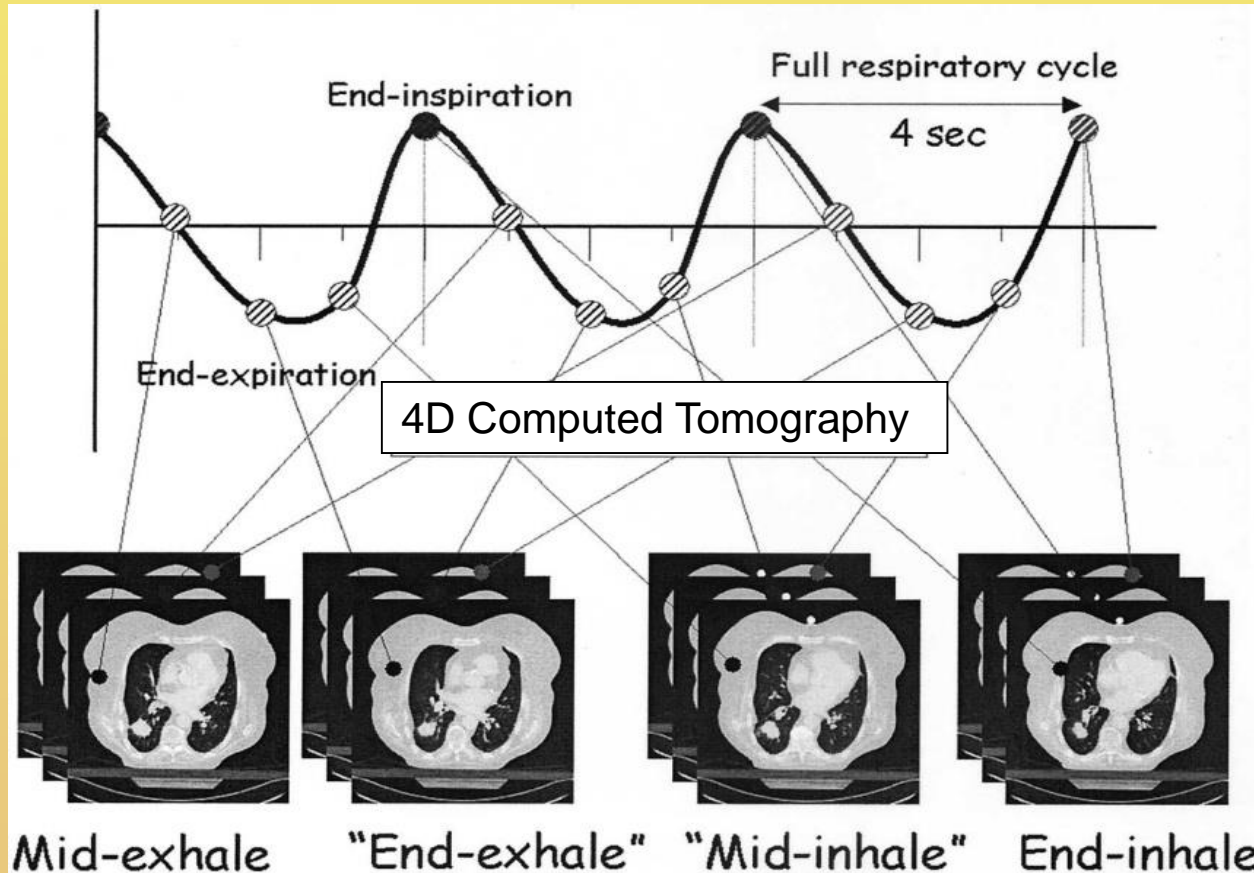
Dose delivery time structure with Synchrotron



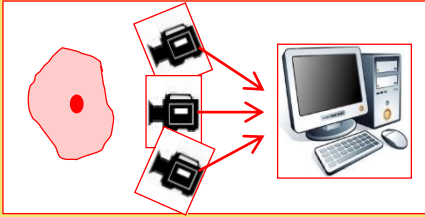
«ON LINE» = Inter spill time.



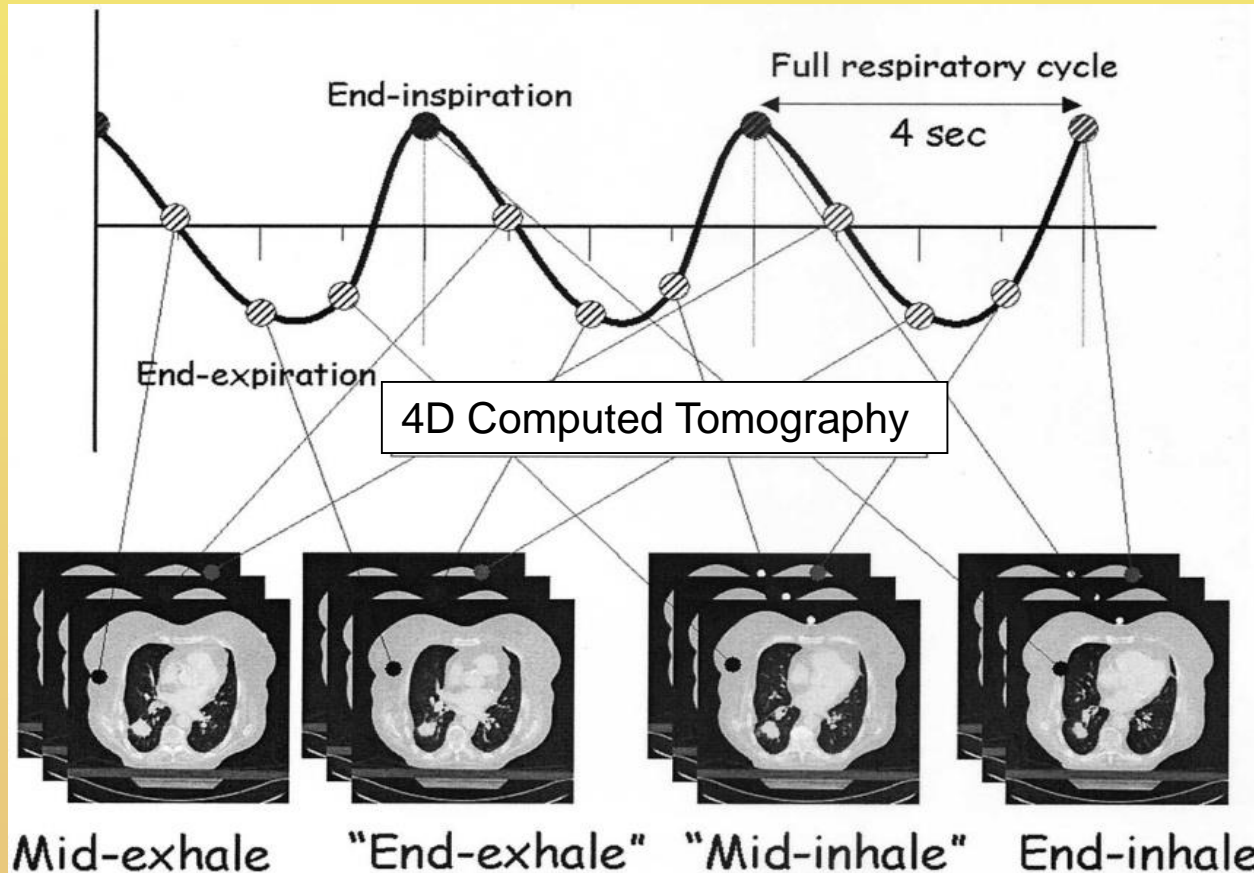
Tracking System



- ✓ Patient positions (ΔX , ΔY , ΔZ);
- ✓ Respiratory phase.



Tracking System



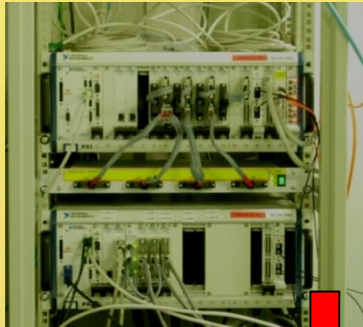
- ✓ Patient positions ($\Delta X, \Delta Y, \Delta Z$);
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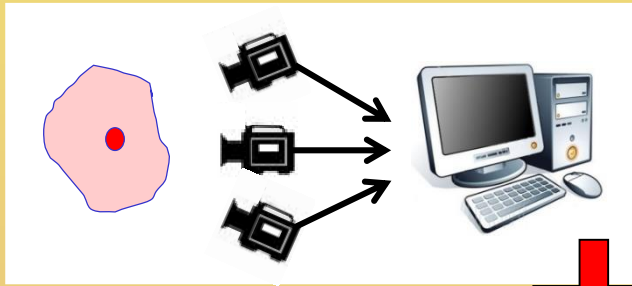


Strategy

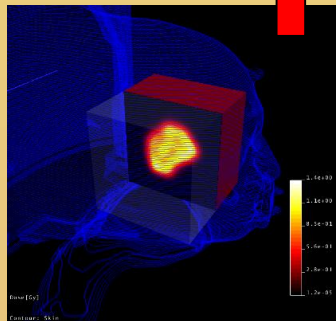
CNAO DDS



Target tracking system

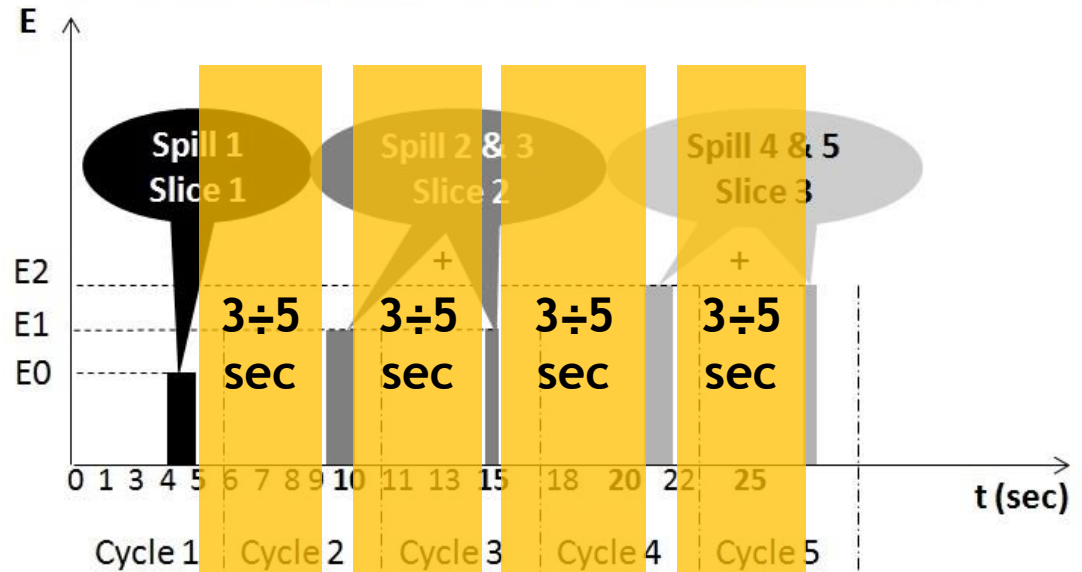


Fast Dose Computation based on GPU



TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

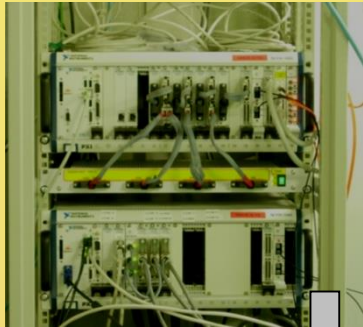


«ON LINE» = Inter spill time.

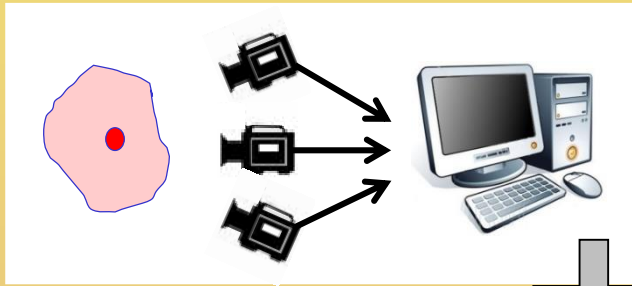


Strategy

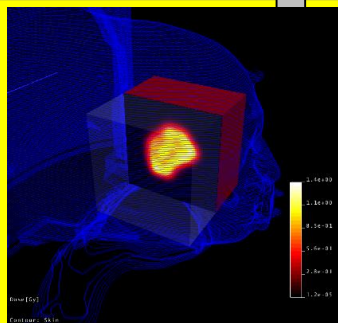
CNAO DDS



Target tracking system

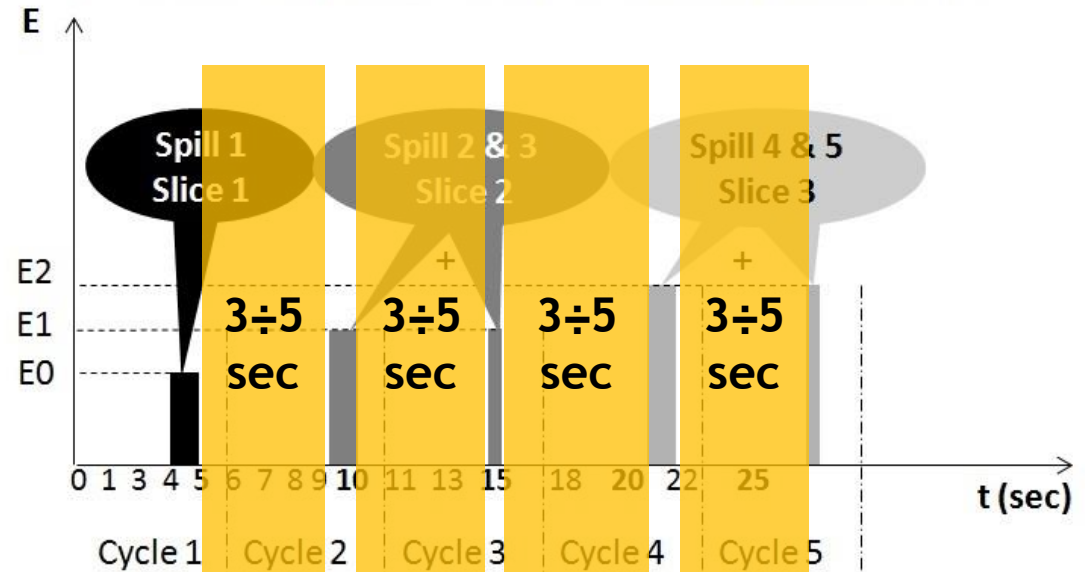


Fast Dose Computation based on GPU

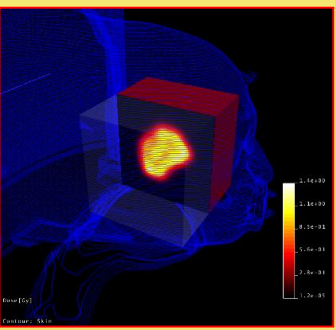


TO OBTAIN THE DELIVERED DOSE DISTRIBUTION *ONLINE*

Dose delivery time structure with Synchrotron

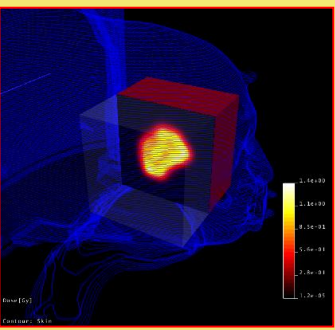


«ON LINE» = Inter spill time.



GPU Dose Computation

Porting on GPU of the Forward Planning algorithm (TPS PlanKIT).



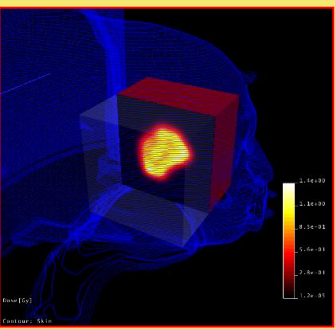
GPU Dose Computation

Porting on GPU of the Forward Planning algorithm (TPS PlanKIT).

Graphics Processing Unit, programmable through API (CUDA)



Nvidia
Tesla K40



GPU Dose Computation

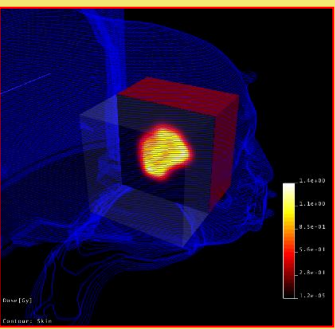
Porting on GPU of the Forward Planning algorithm (TPS PlanKIT).

Graphics Processing Unit, programmable through API (CUDA)

TPS (Treatment Planning System) is an algorithm to simulate and optimize the dose distribution.



Nvidia
Tesla K40



GPU Dose Computation

Porting on GPU of the Forward Planning algorithm (TPS PlanKIT).

Graphics Processing Unit, programmable through API (CUDA)

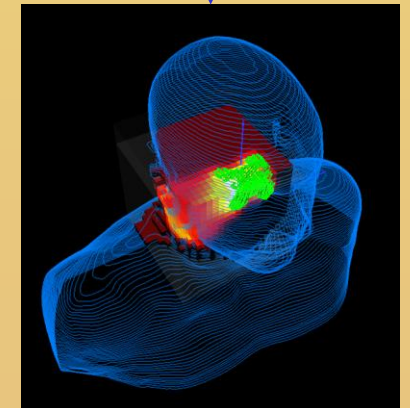
TPS (Treatment Planning System) is an algorithm to simulate and optimize the dose distribution.

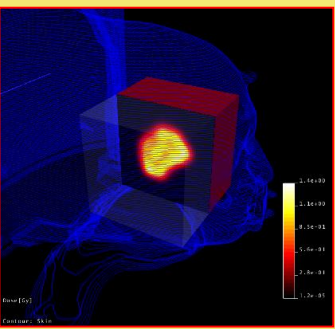
Anatomical information;
Irradiation set-up;
Prescription.

FORWARD
PLANNING



Nvidia
Tesla K40





GPU Dose Computation

Porting on GPU of the Forward Planning algorithm (TPS **PlanKIT**).

Graphics Processing Unit, programmable through API (CUDA)

TPS (Treatment Planning System) is an algorithm to simulate and optimize the dose distribution.

Anatomical information;
Irradiation set-up;
Prescription.

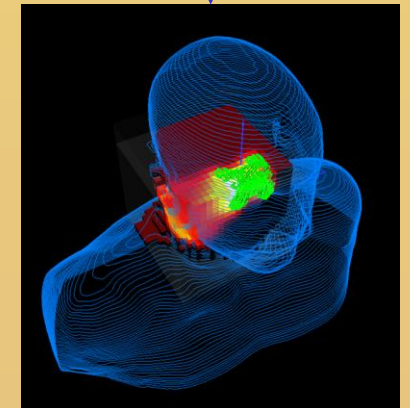
FORWARD
PLANNING

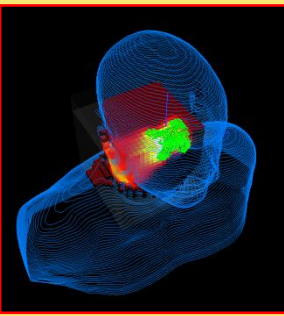


Nvidia
Tesla K40

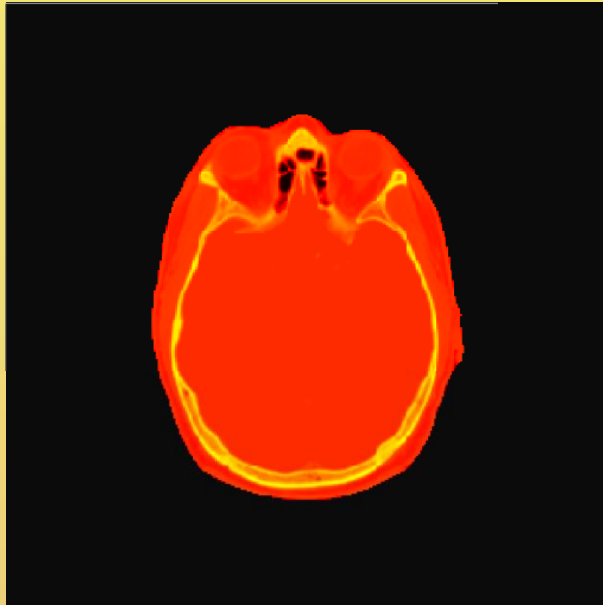


INFN sezione di
TORINO:
contributed to the
PlanKIT development

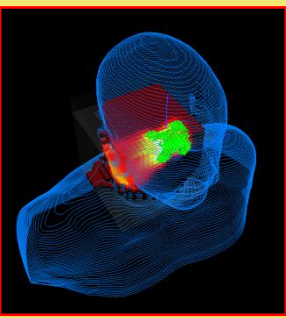




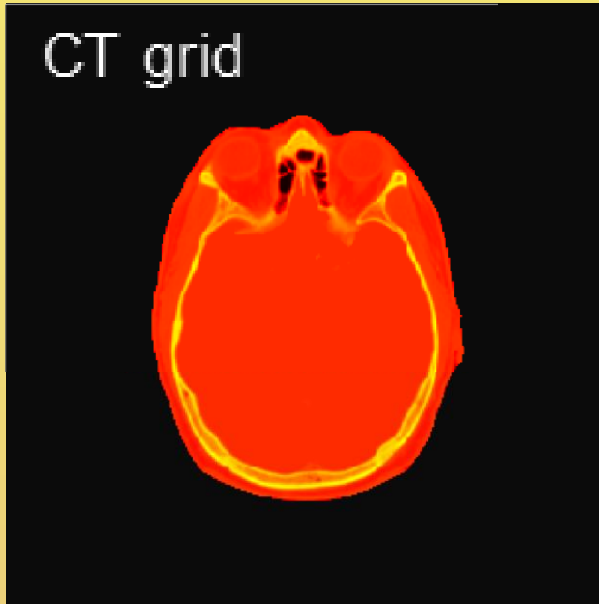
GPU Dose Computation - Scheme



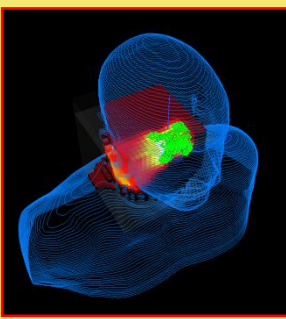
CT.



GPU Dose Computation - Scheme

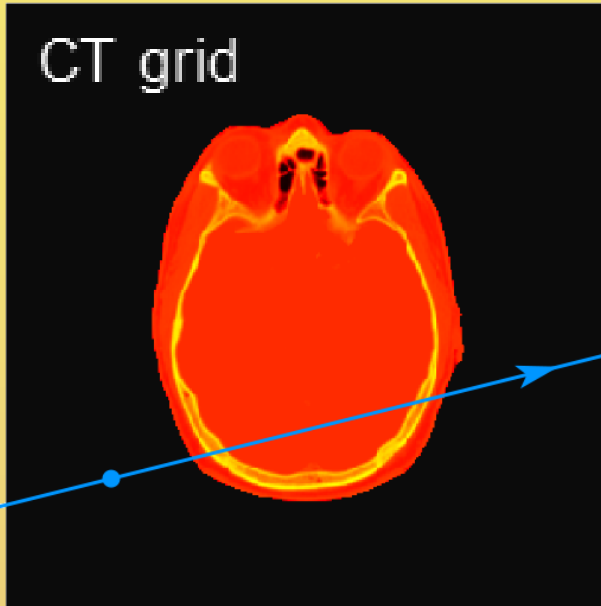


CT grid.

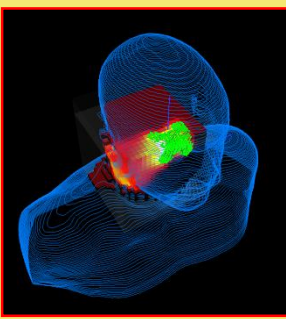


GPU Dose Computation - Scheme

CT grid



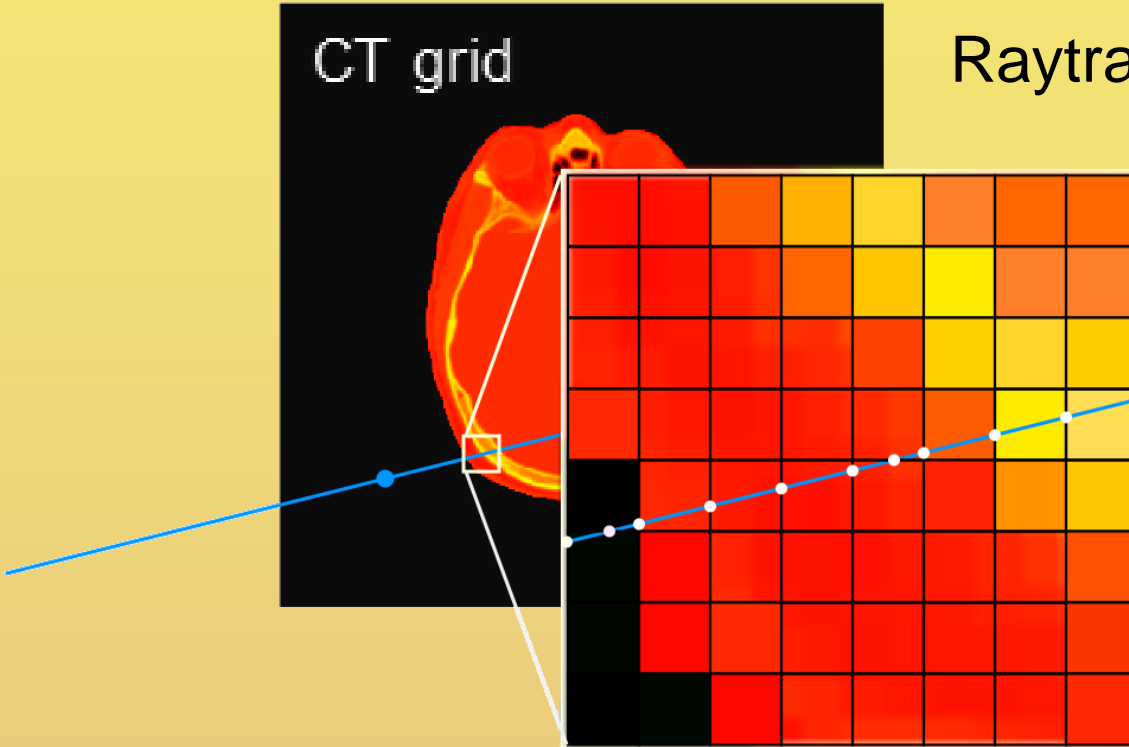
Raytracing – find intercepts.

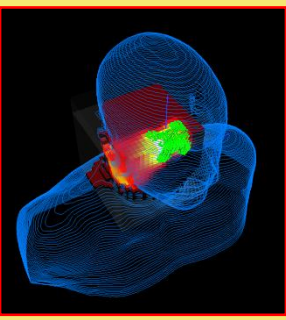


GPU Dose Computation - Scheme

CT grid

Raytracing – find intercepts.

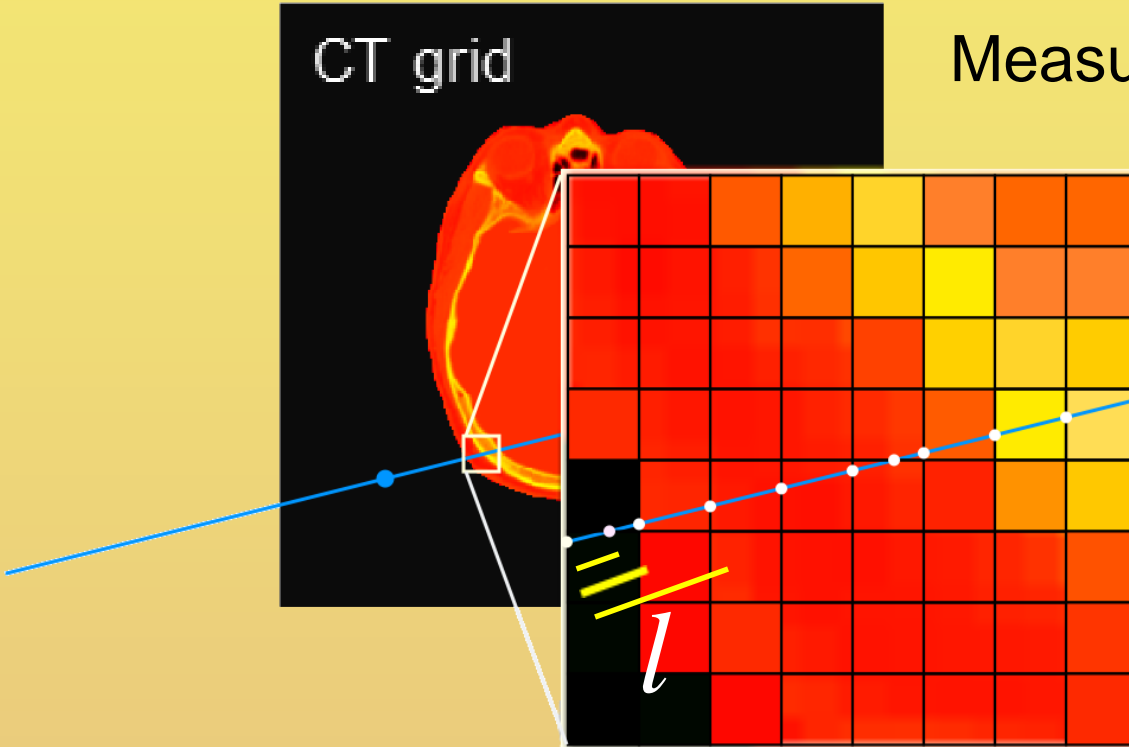


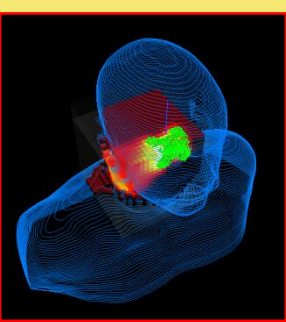


GPU Dose Computation - Scheme

CT grid

Measure the path-length (l).

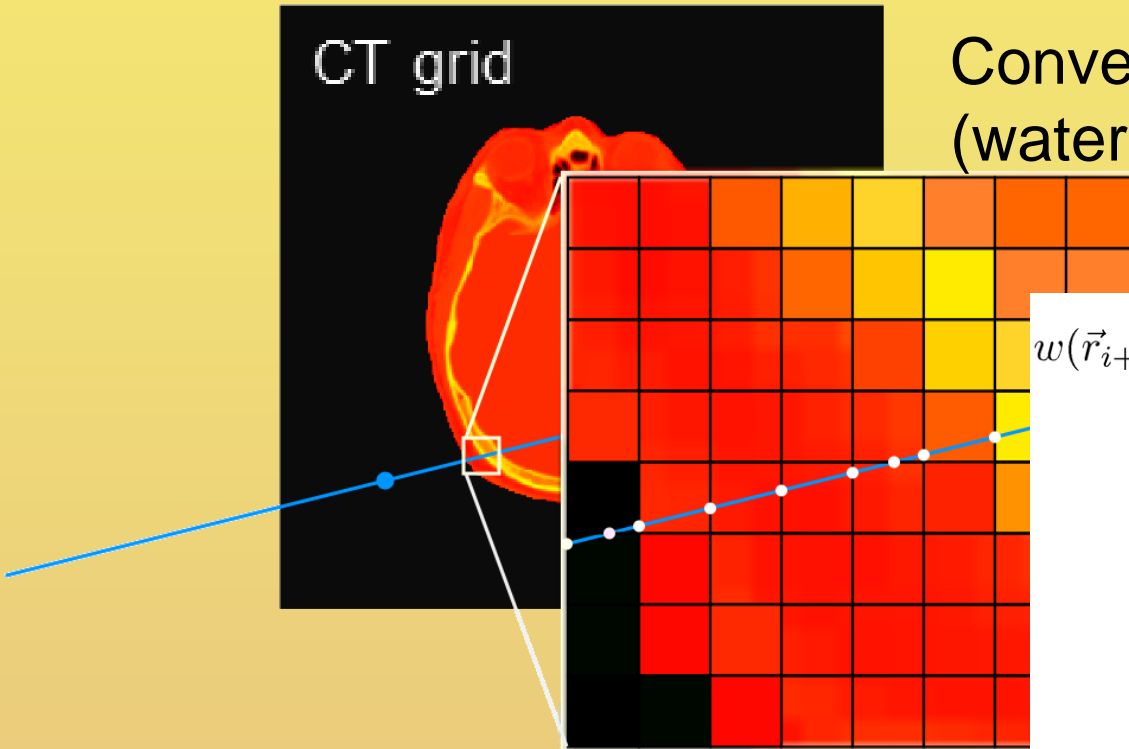




GPU Dose Computation - Scheme

CT grid

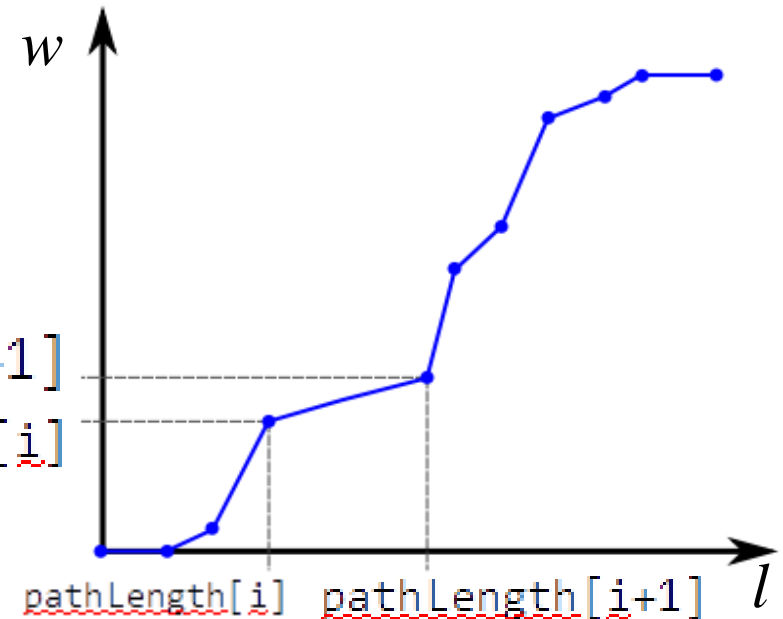
Convert the path-length into WEPL
(water equivalent path-length).

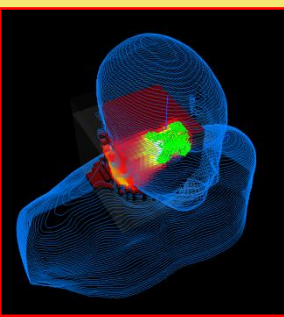


$$w(\vec{r}_{i+1}) = w(\vec{r}_i) + \rho \left(\frac{\vec{r}_{i+1} + \vec{r}_i}{2} \right) \left[l(\vec{r}_{i+1}) - l(\vec{r}_i) \right]$$

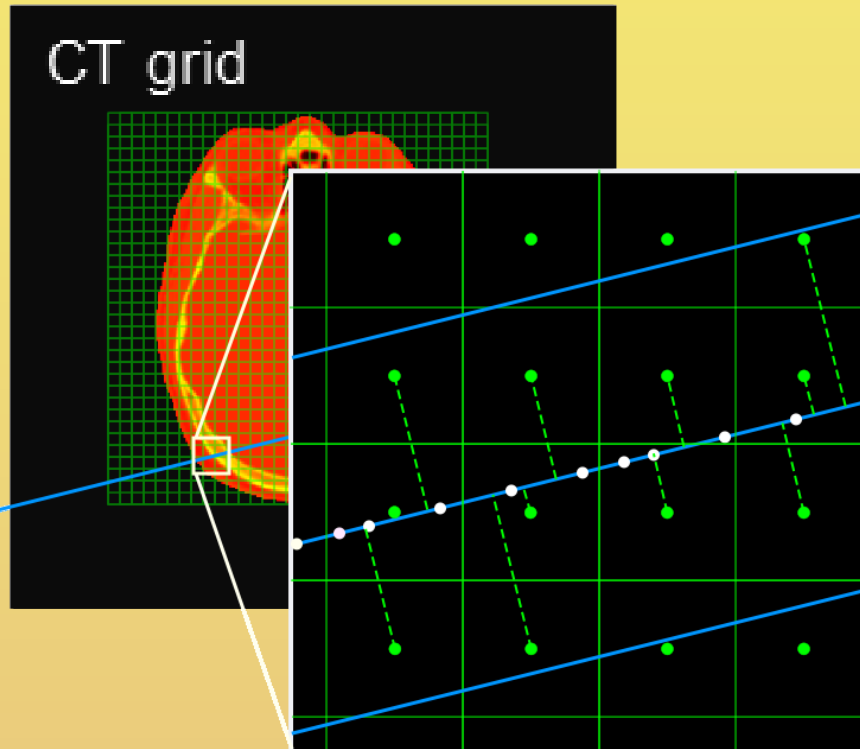
wepl[i+1]

wepl[i]

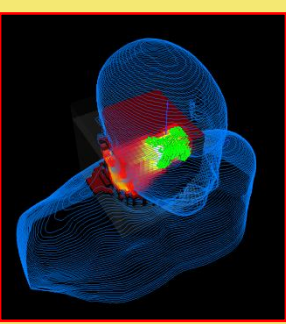




GPU Dose Computation - Scheme

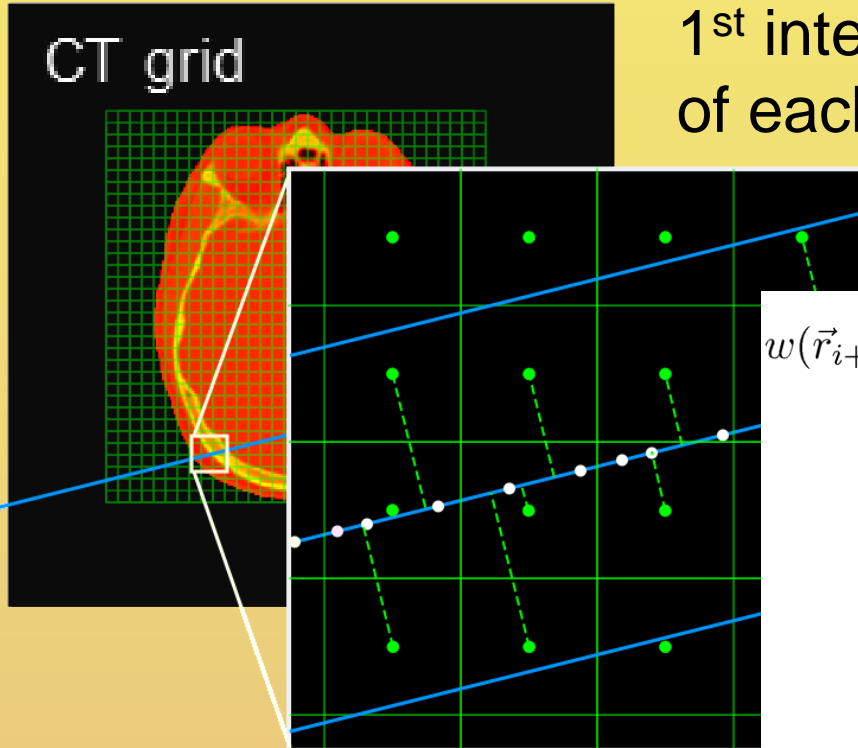


Identify the voxels within the chosen cut-off (on the CT grid or different computational grid)



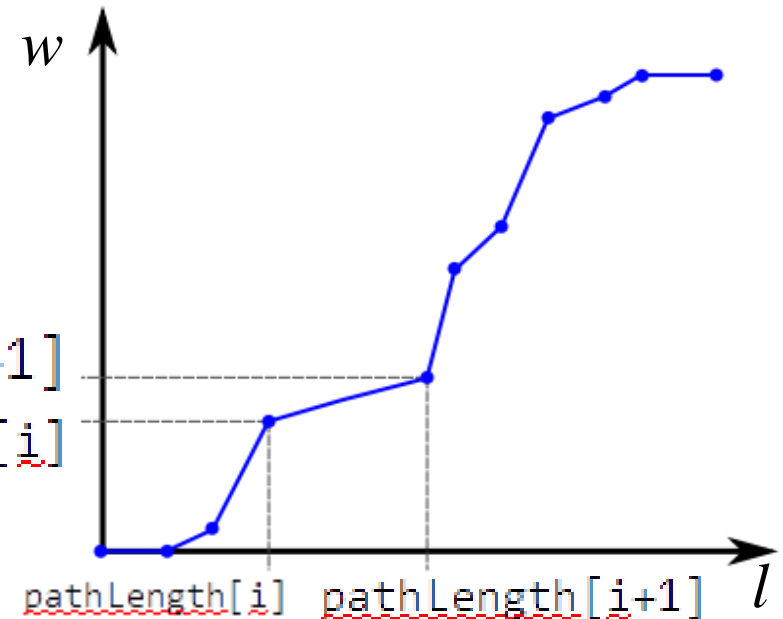
GPU Dose Computation - Scheme

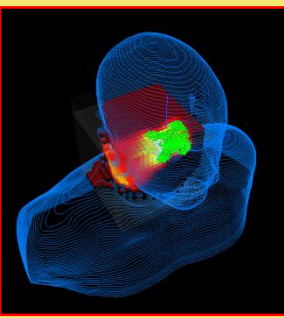
CT grid



1st interpolation: find the WEPL value of each voxel within the cut-off.

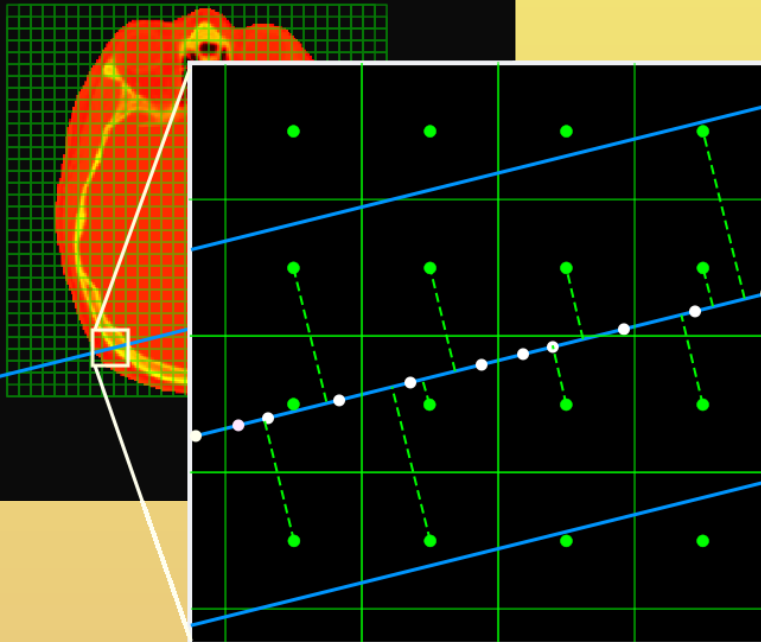
$$w(\vec{r}_{i+1}) = w(\vec{r}_i) + \rho \left(\frac{\vec{r}_{i+1} + \vec{r}_i}{2} \right) [l(\vec{r}_{i+1}) - l(\vec{r}_i)]$$





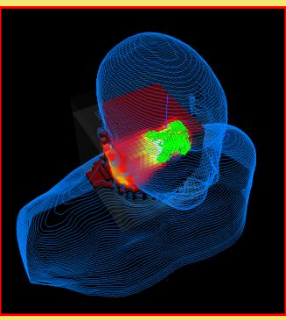
GPU Dose Computation - Scheme

CT grid

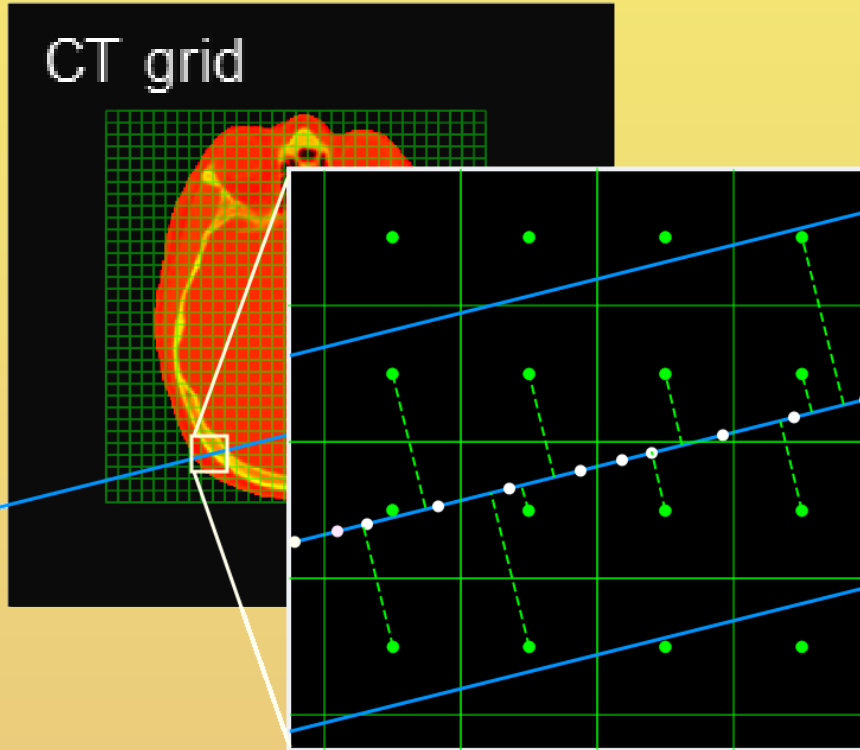


2nd interpolation: obtain from the LUT the dose value corresponding to the WEPL of each voxel.

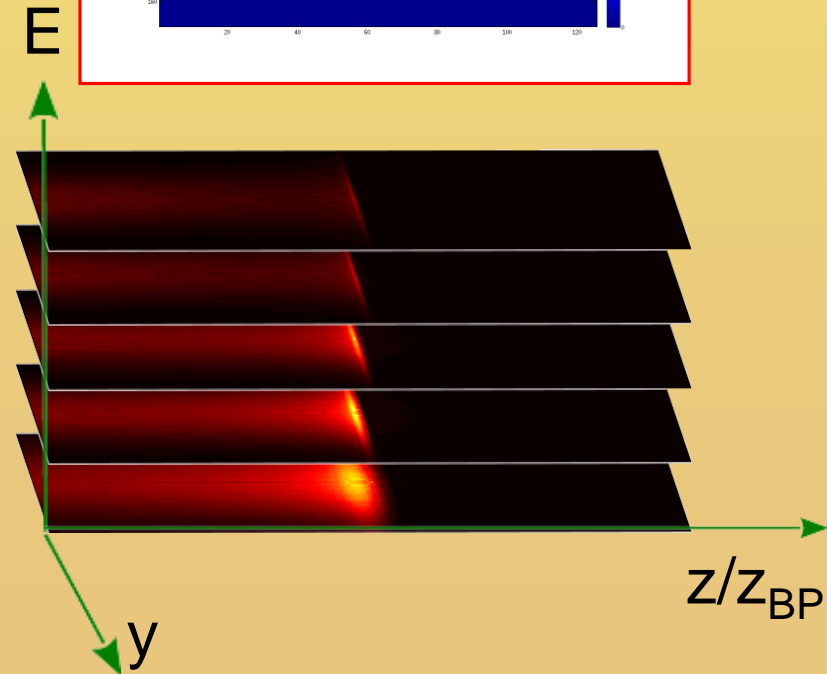
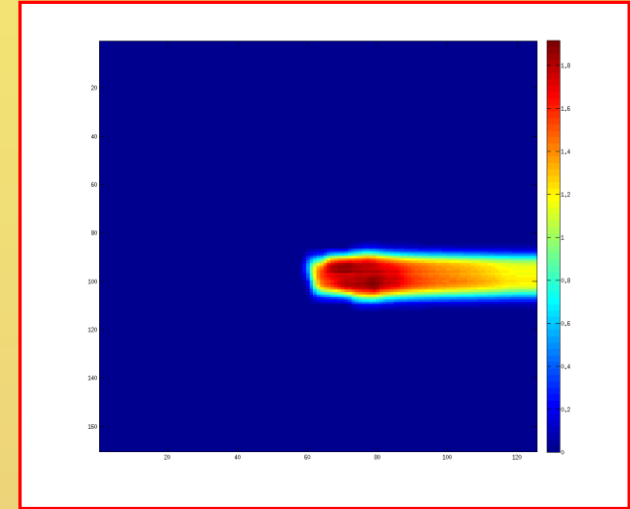


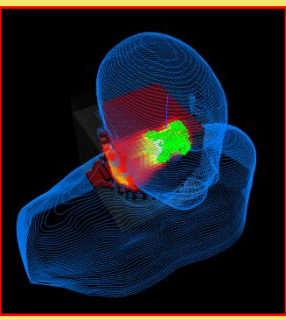


GPU Dose Computation - Scheme



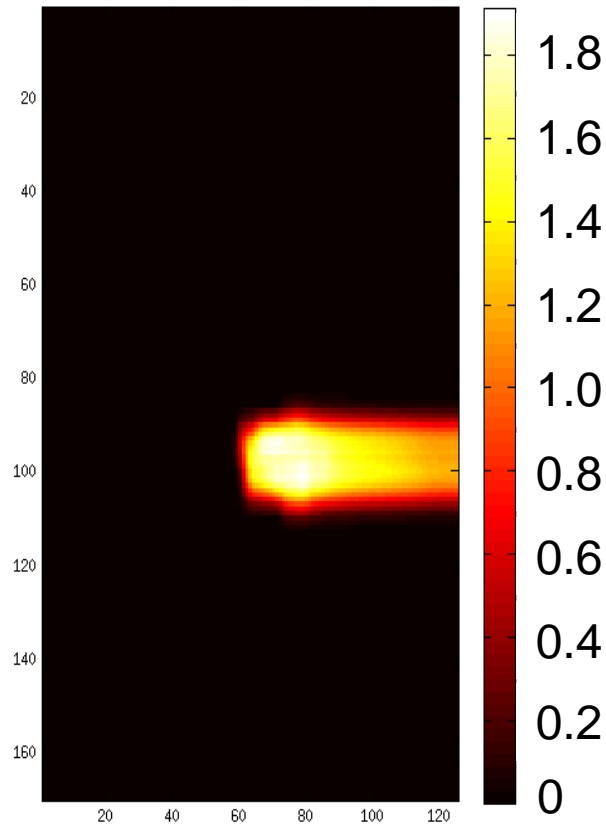
Physical Dose distribution



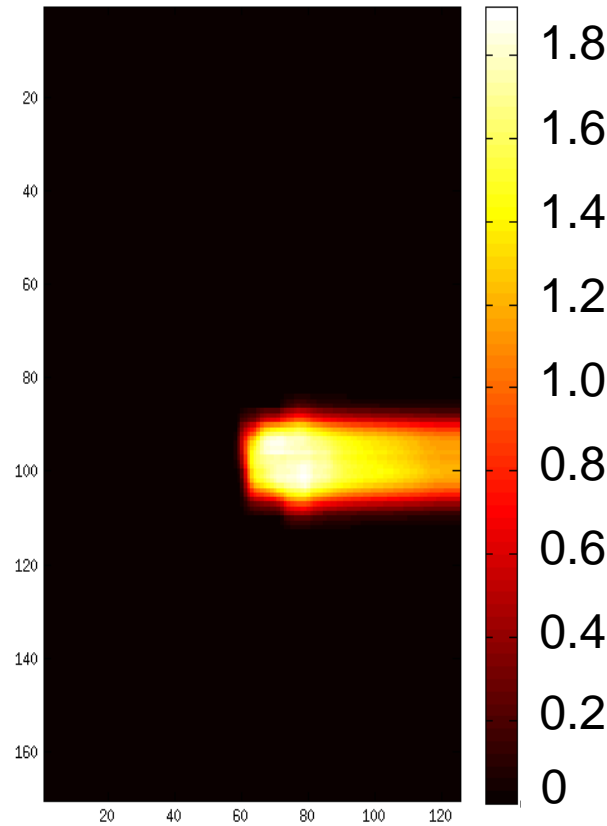


GPU Dose Computation - Protons

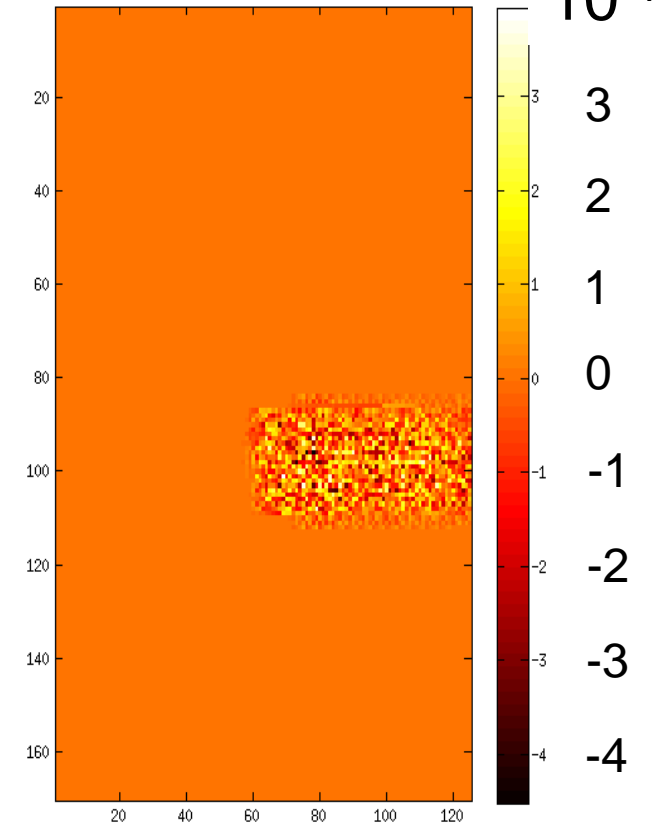
Dose (PlanKIT) [Gy]

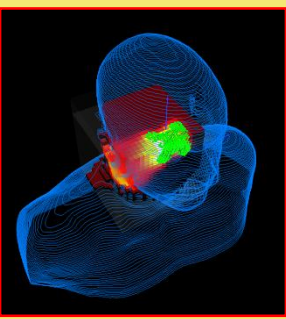


Dose (GPU) [Gy]



Differences [Gy]

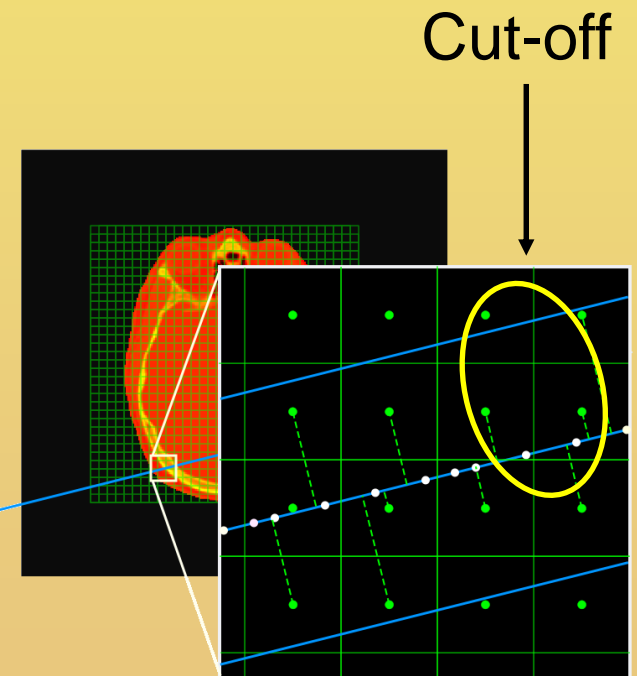


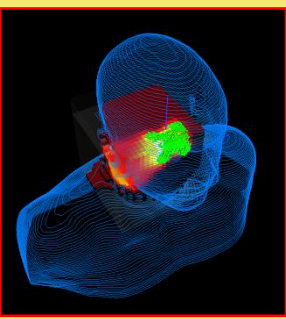


GPU Dose Computation - Protons

Computing Grid = 170x170x125; CPU: XeonE5-1620v2-3.7-4C-16GB
 N of Rays = 1248; N of slice = 39; GPU: Nvidia TESLA-K20c.

Cut_off (mm)	N_Voxels	time gpu (sec)	time PlanKIT (sec)	Gain
10	11167	1.7	40	24
20	44678	1.8	157	87
40	178702	2.6	636	245
50	279243	2.9	997	344
80	714861	4.5	2534	563

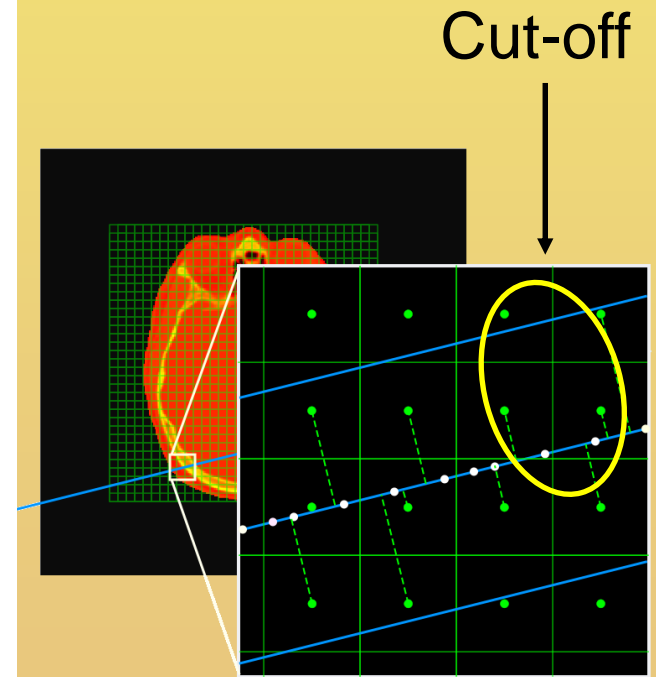
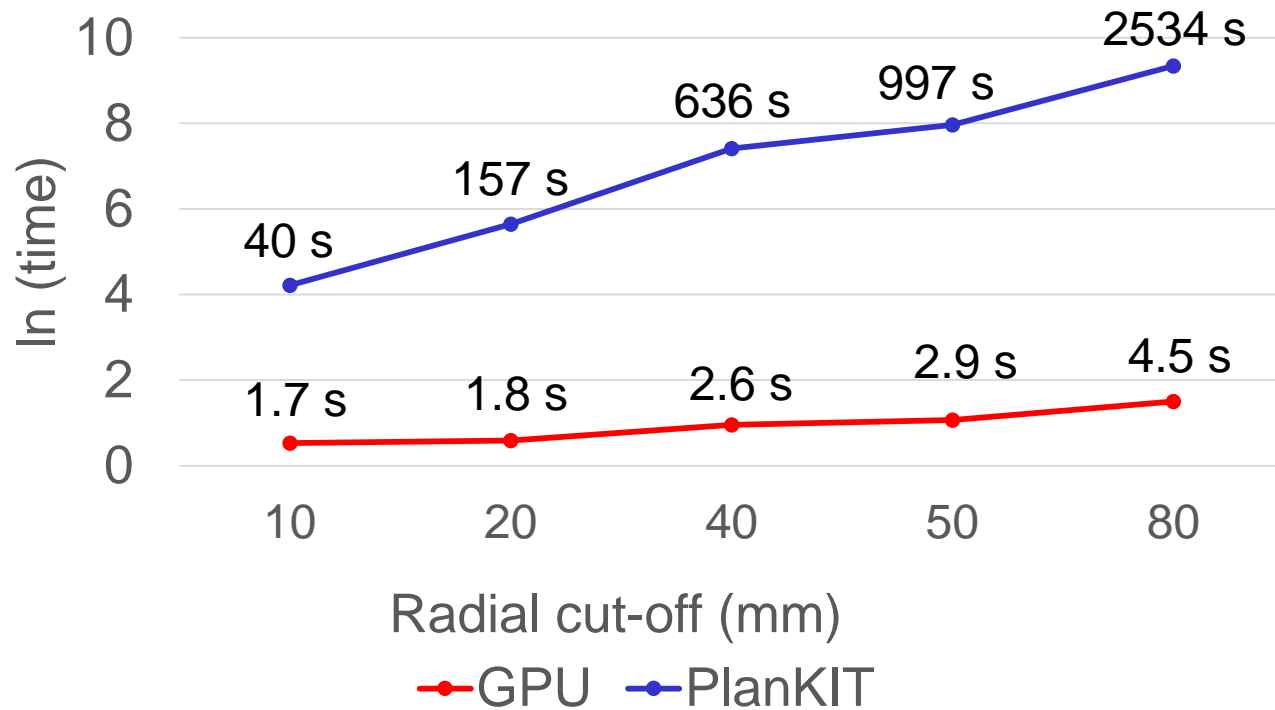


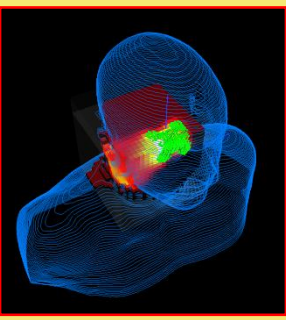


GPU Dose Computation - Protons

Computing Grid = 170x170x125; CPU: XeonE5-1620v2-3.7-4C-16GB
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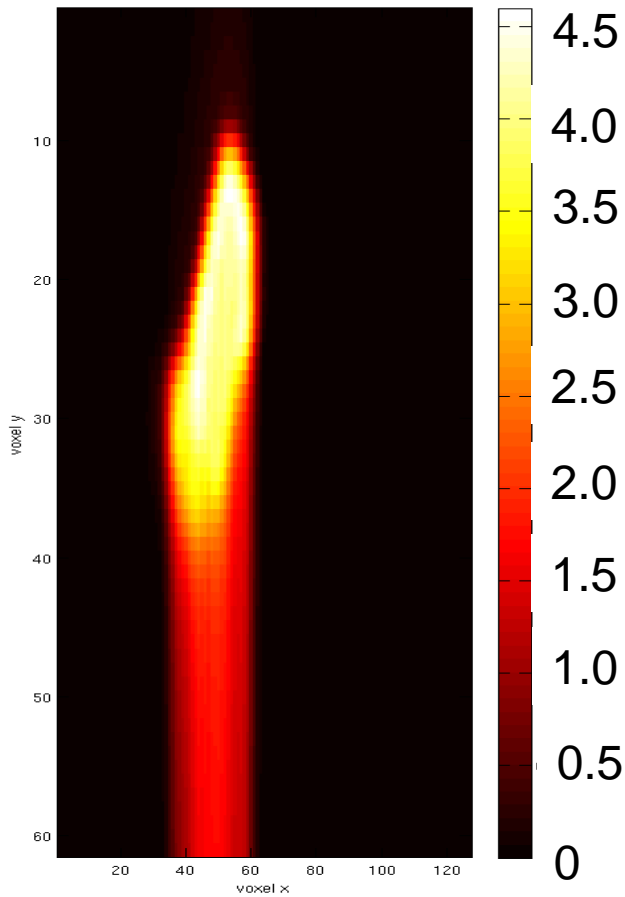
PlanKIT - GPU time comparison



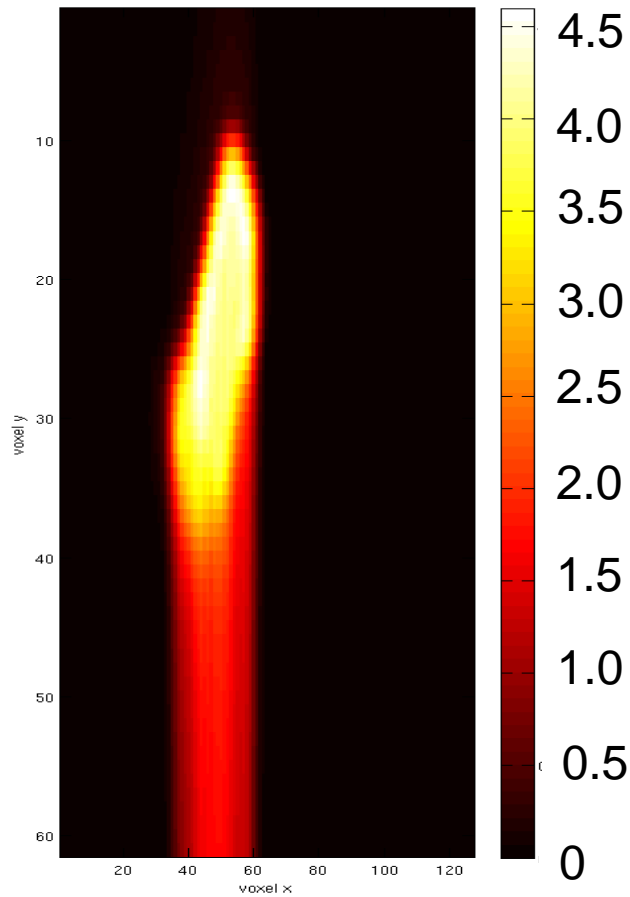


GPU Dose Computation - Carbon

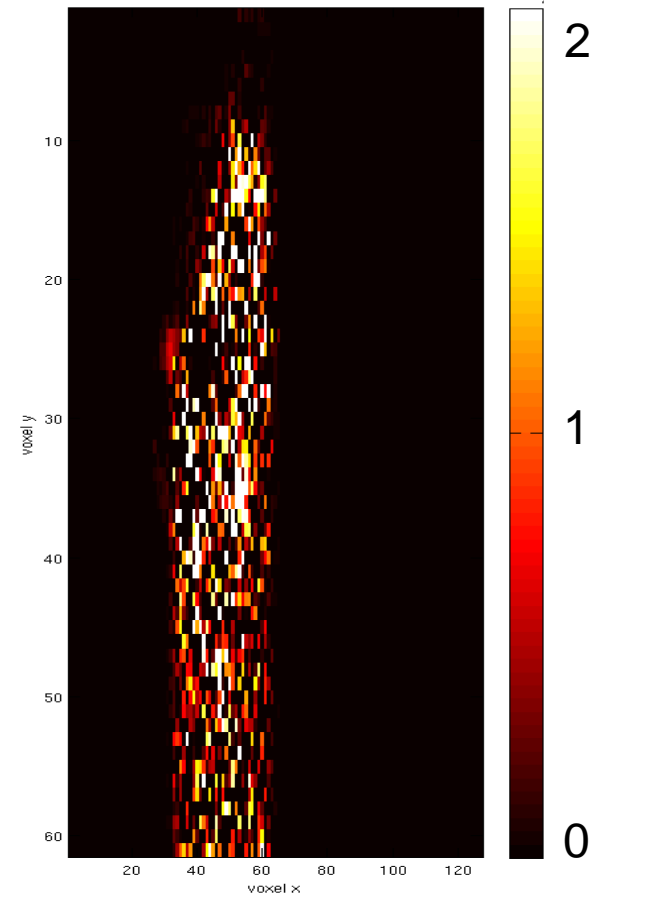
Dose (PlanKIT) [Gy]

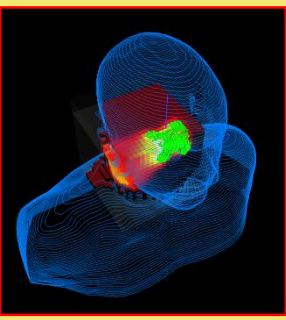


Dose (GPU) [Gy]



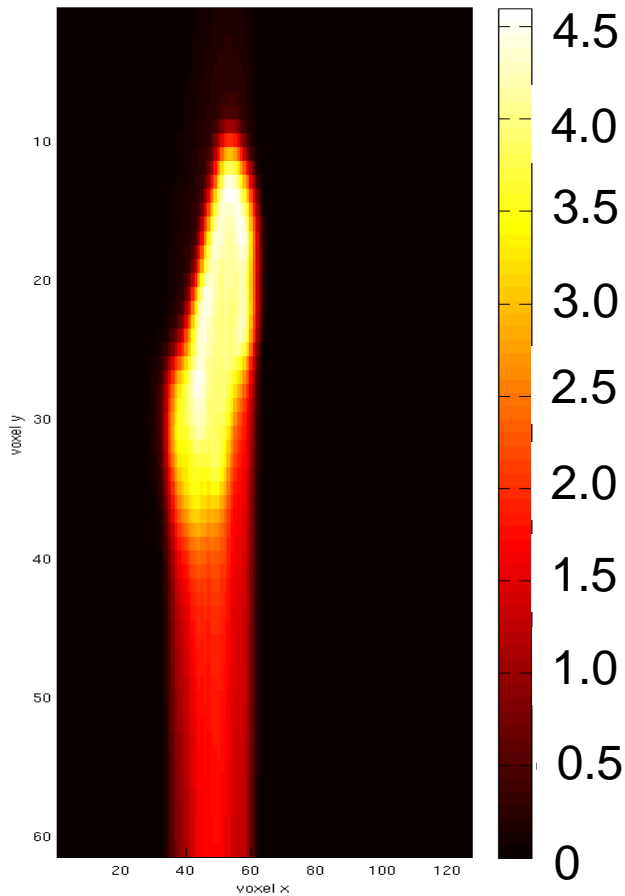
Differences [Gy]



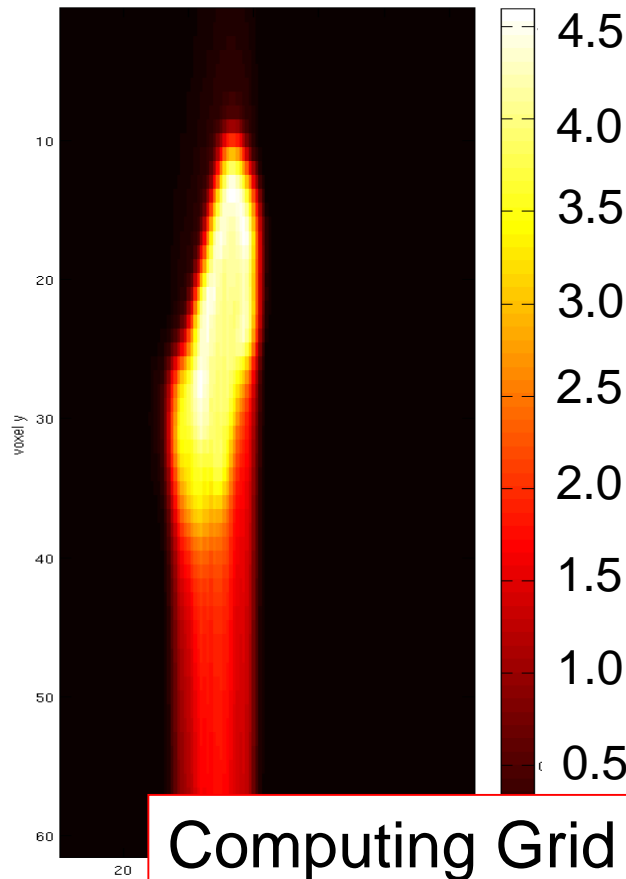


GPU Dose Computation - Carbon

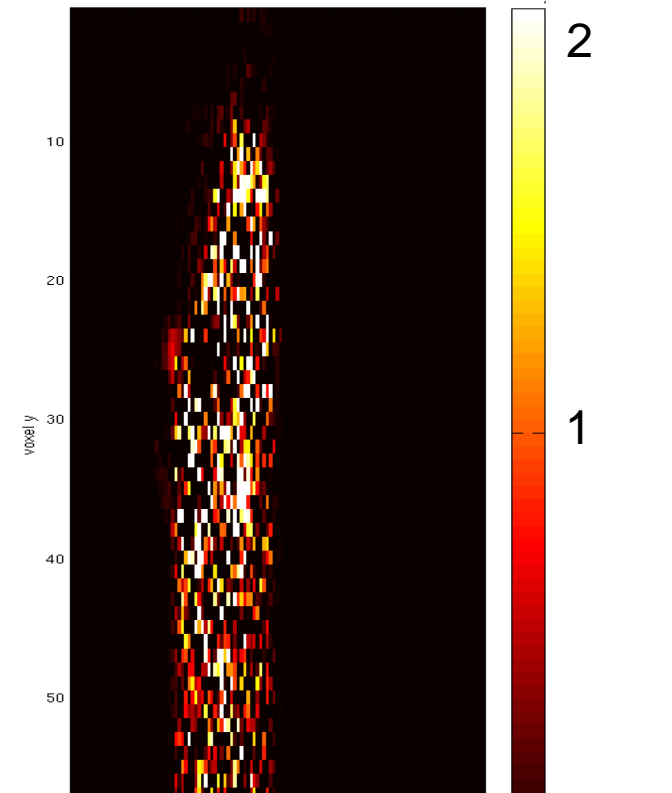
Dose (PlanKIT) [Gy]



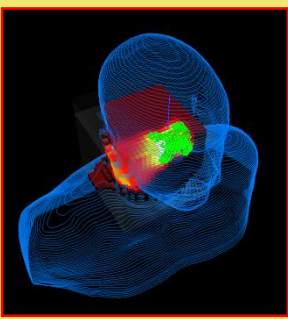
Dose (GPU) [Gy]



Differences [Gy]



Computing Grid = 170x170x127;
N of Rays = 10761; N of slice = 51;
N voxels= 7292; radial cut-off=10 mm.

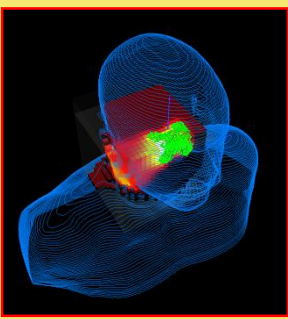


RIDOS

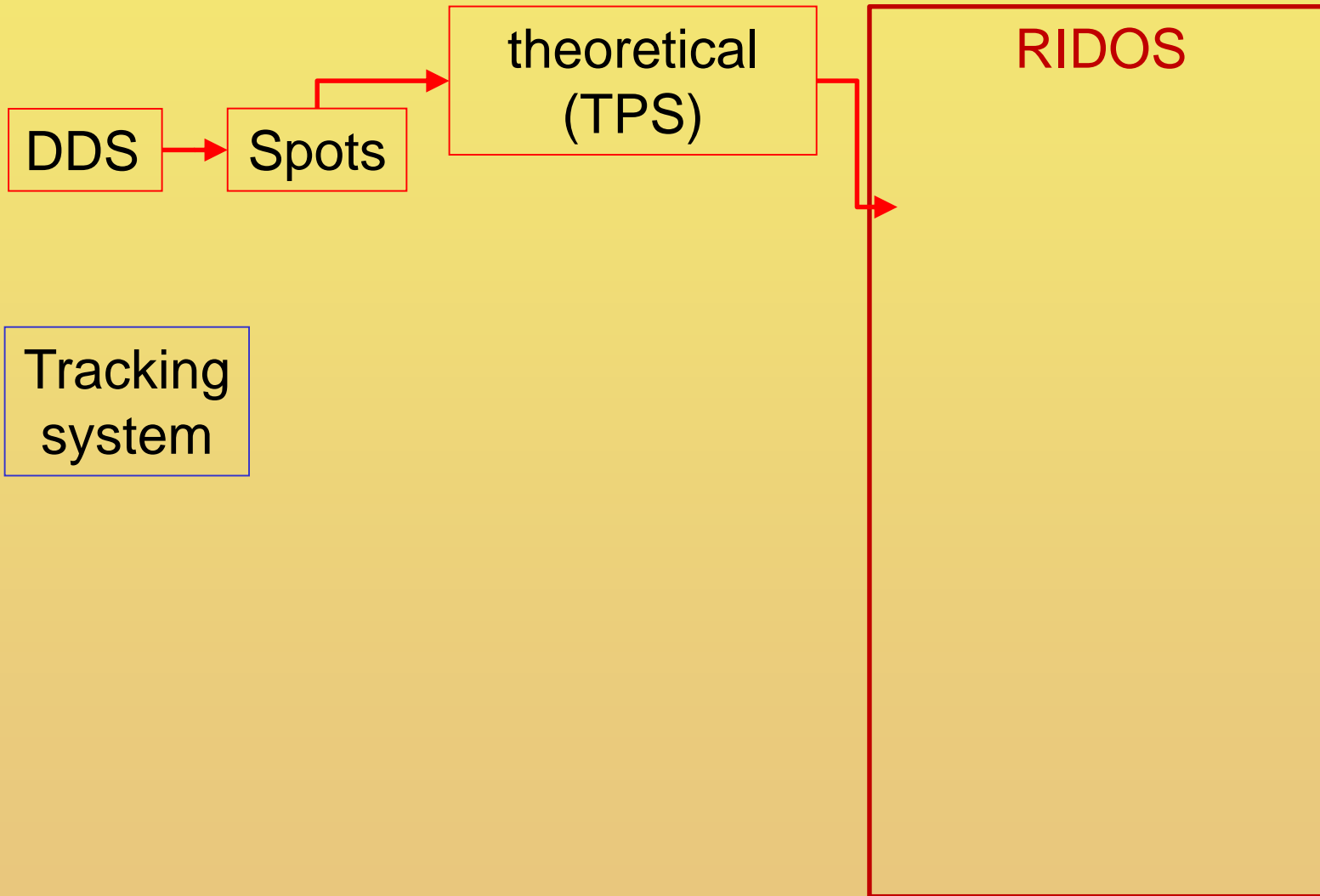
DDS

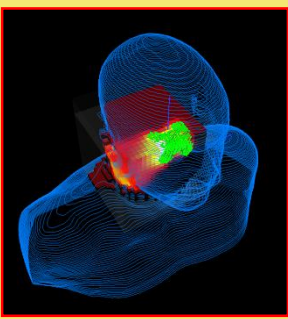
Tracking
system

RIDOS

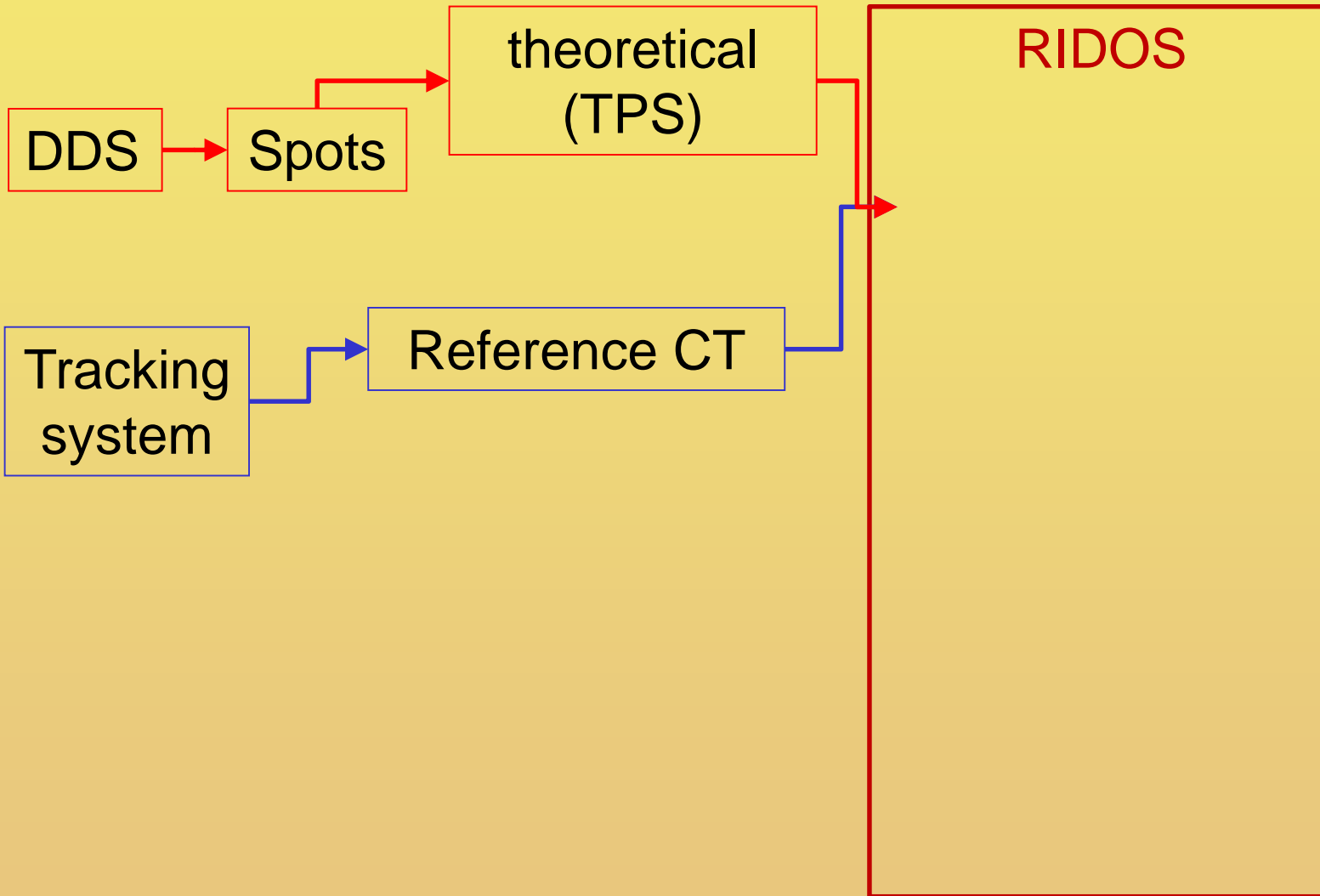


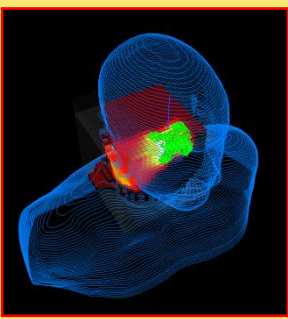
RIDOS



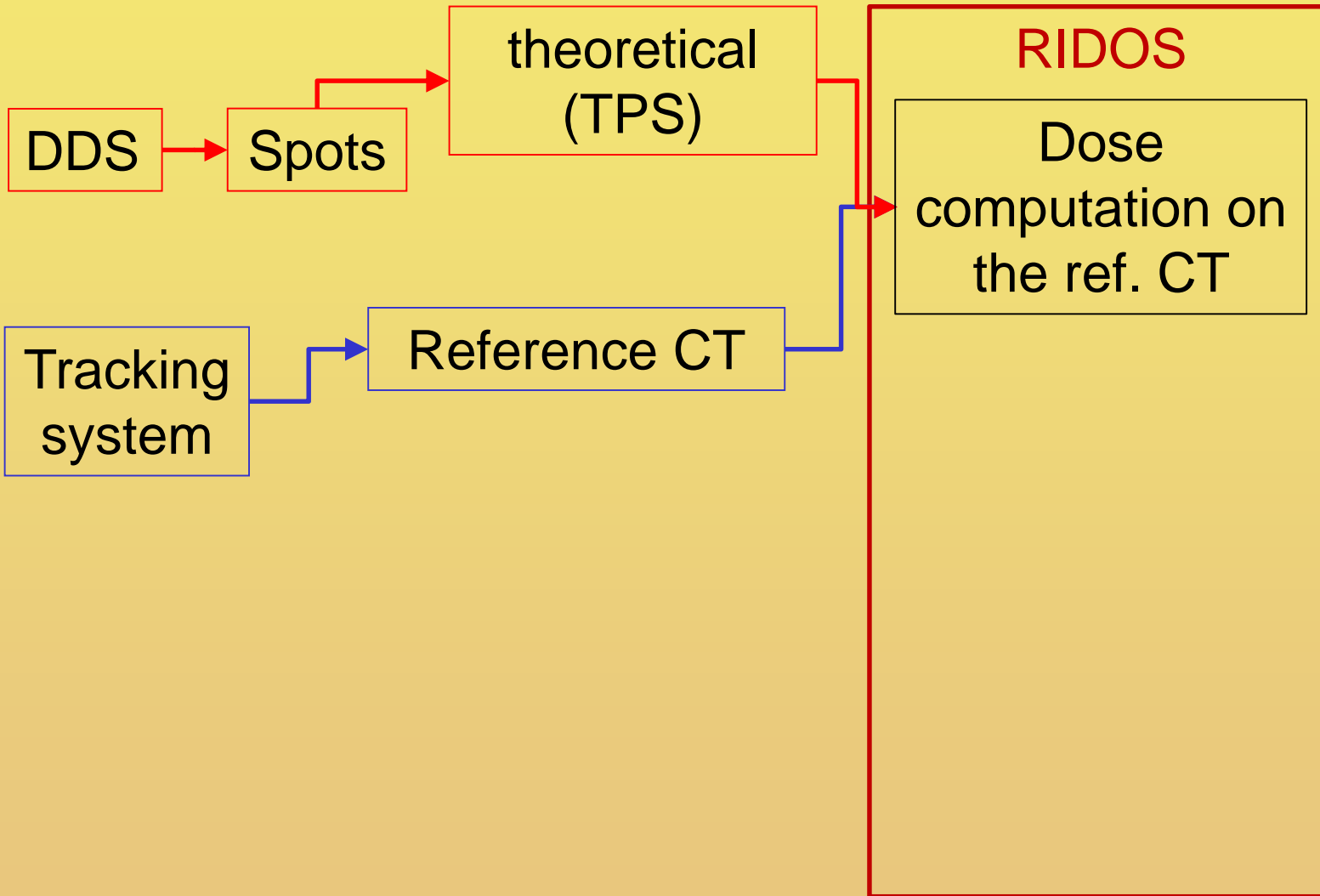


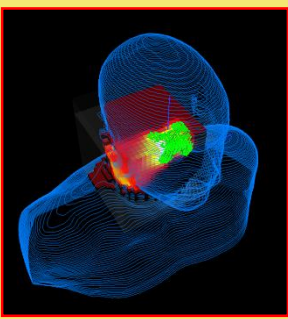
RIDOS



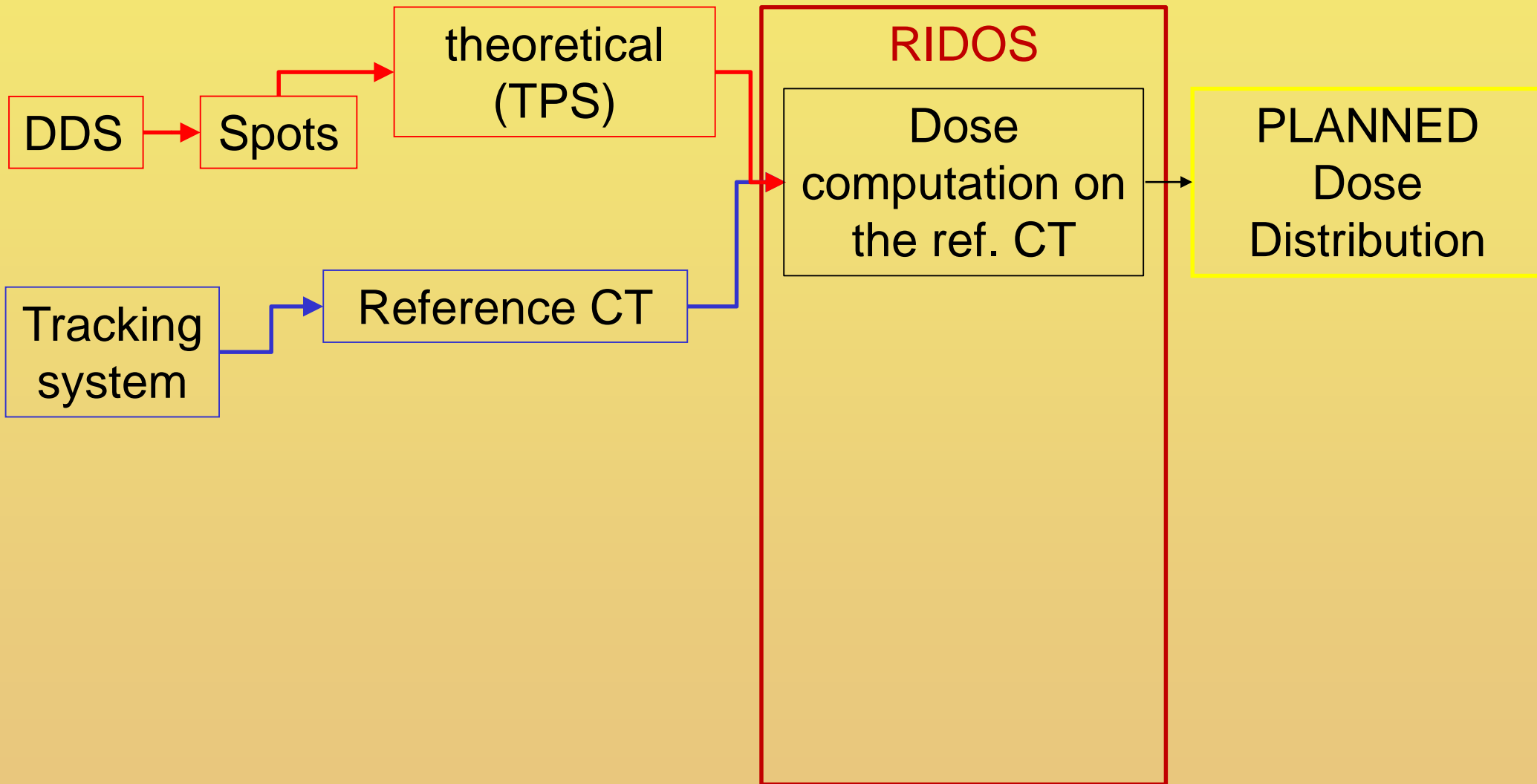


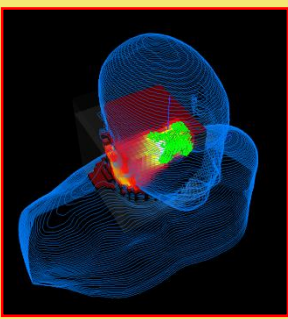
RIDOS



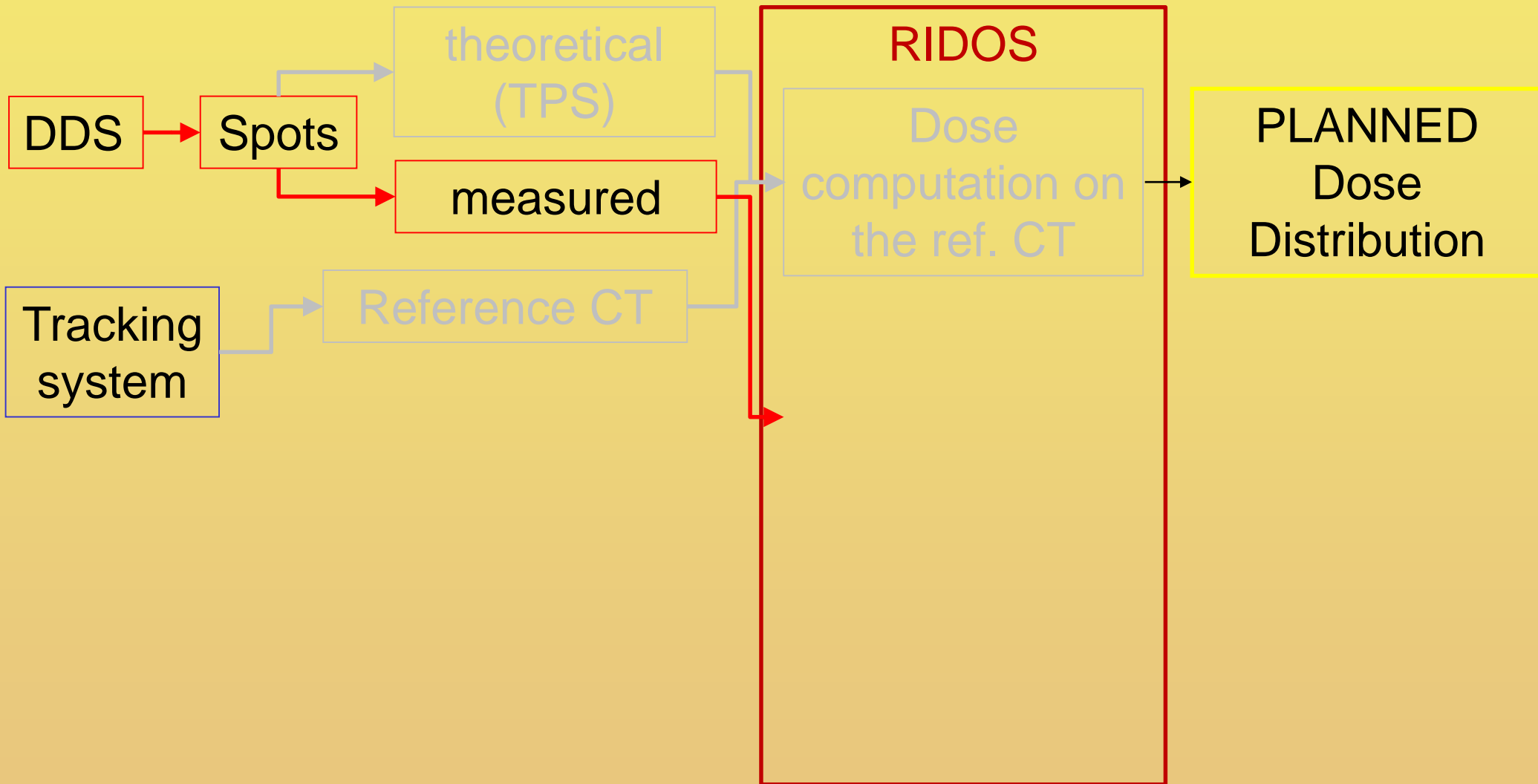


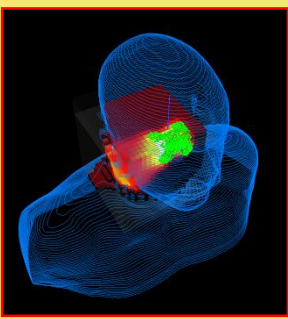
RIDOS



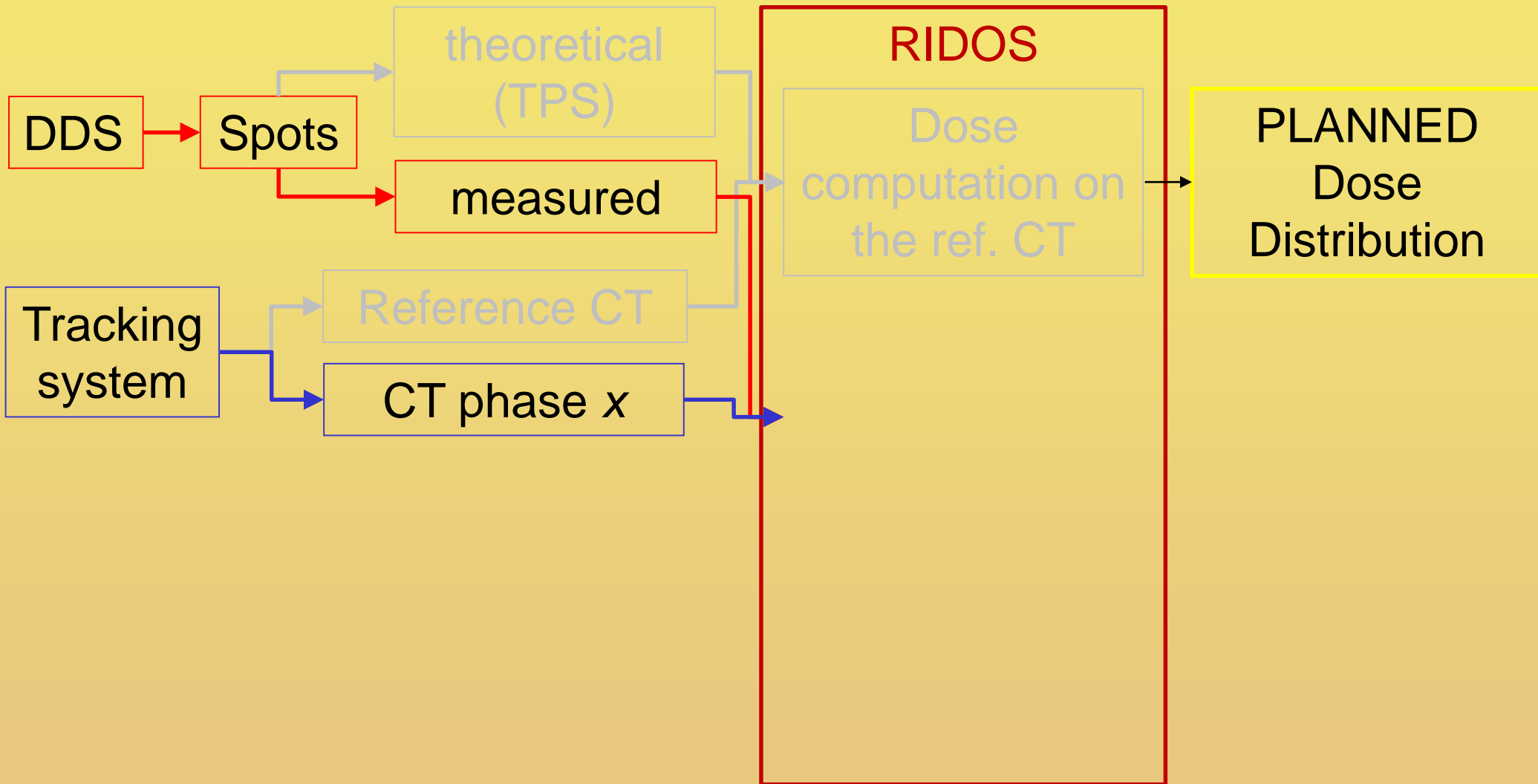


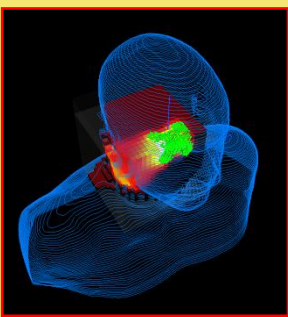
RIDOS



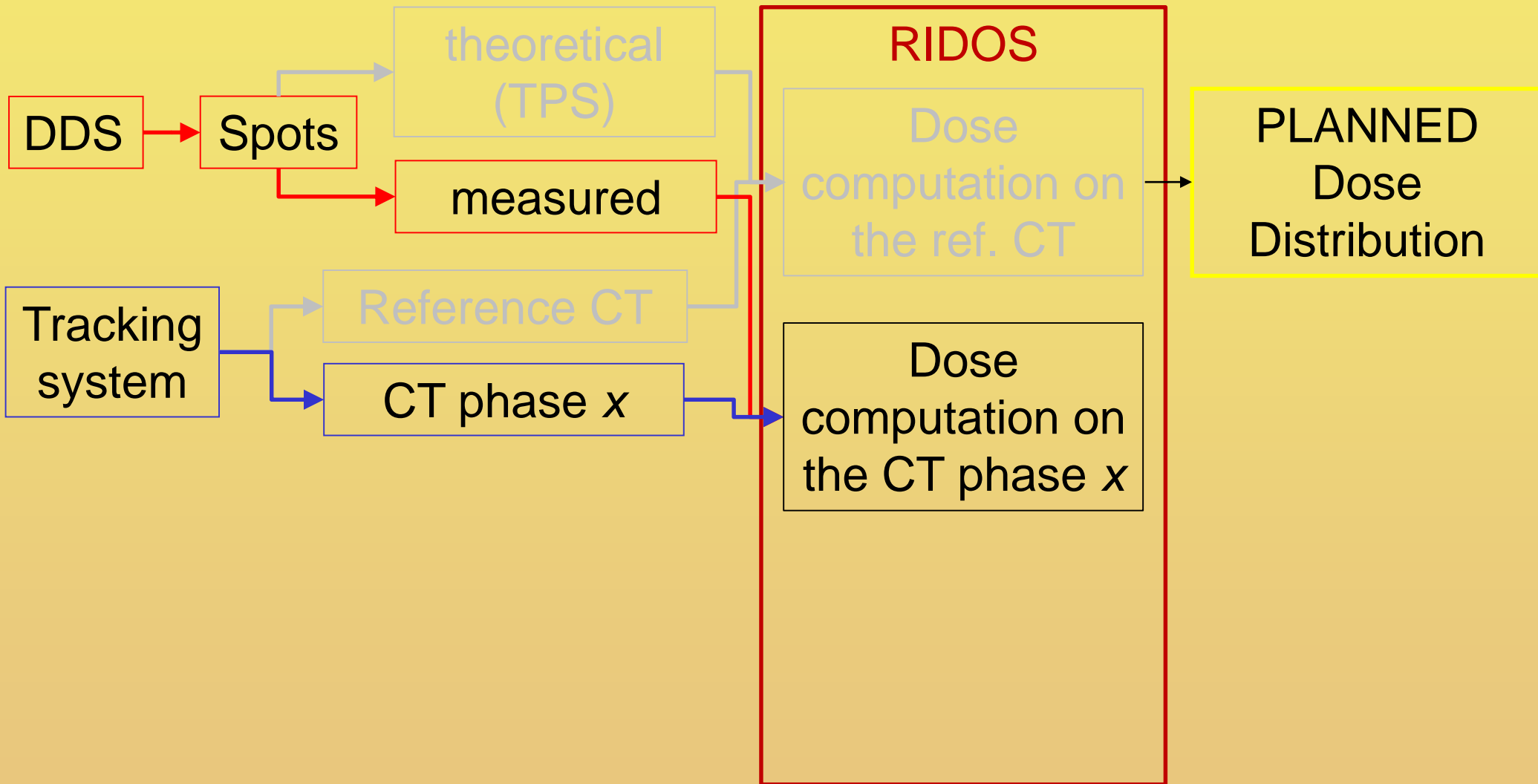


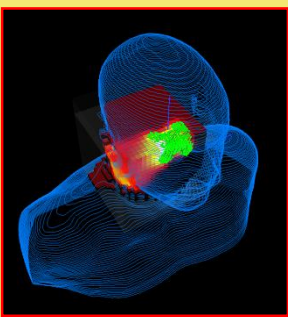
RIDOS



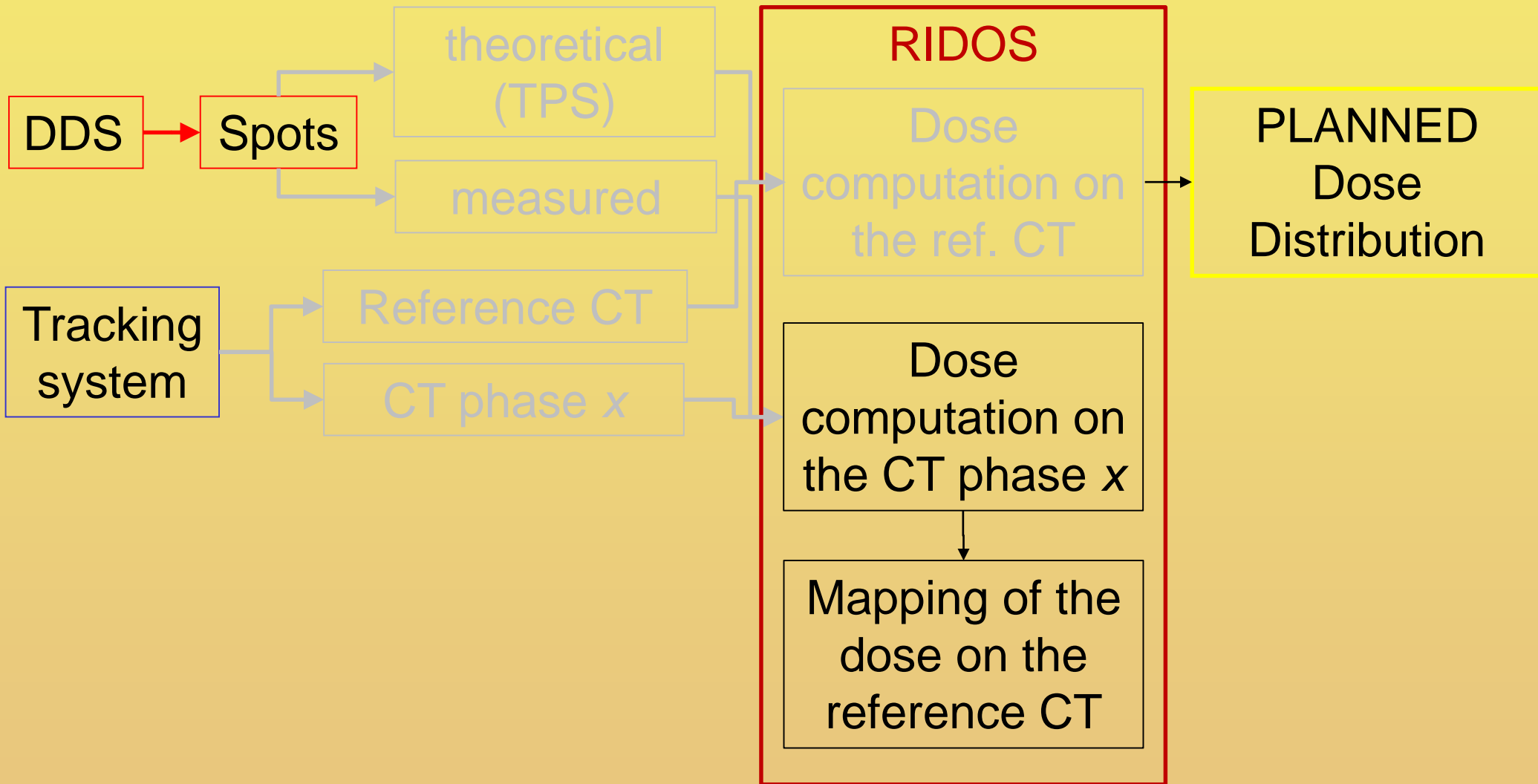


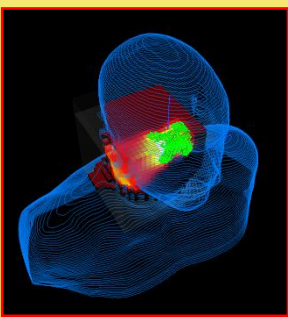
RIDOS



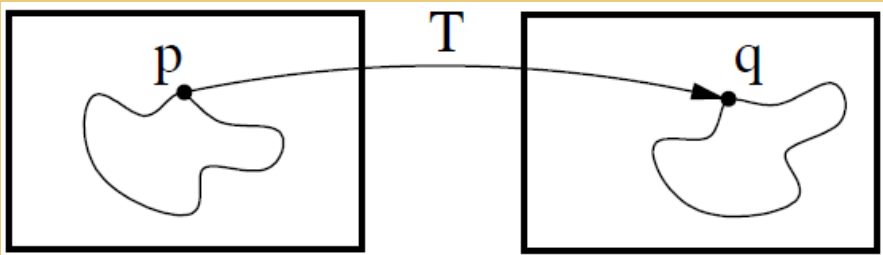
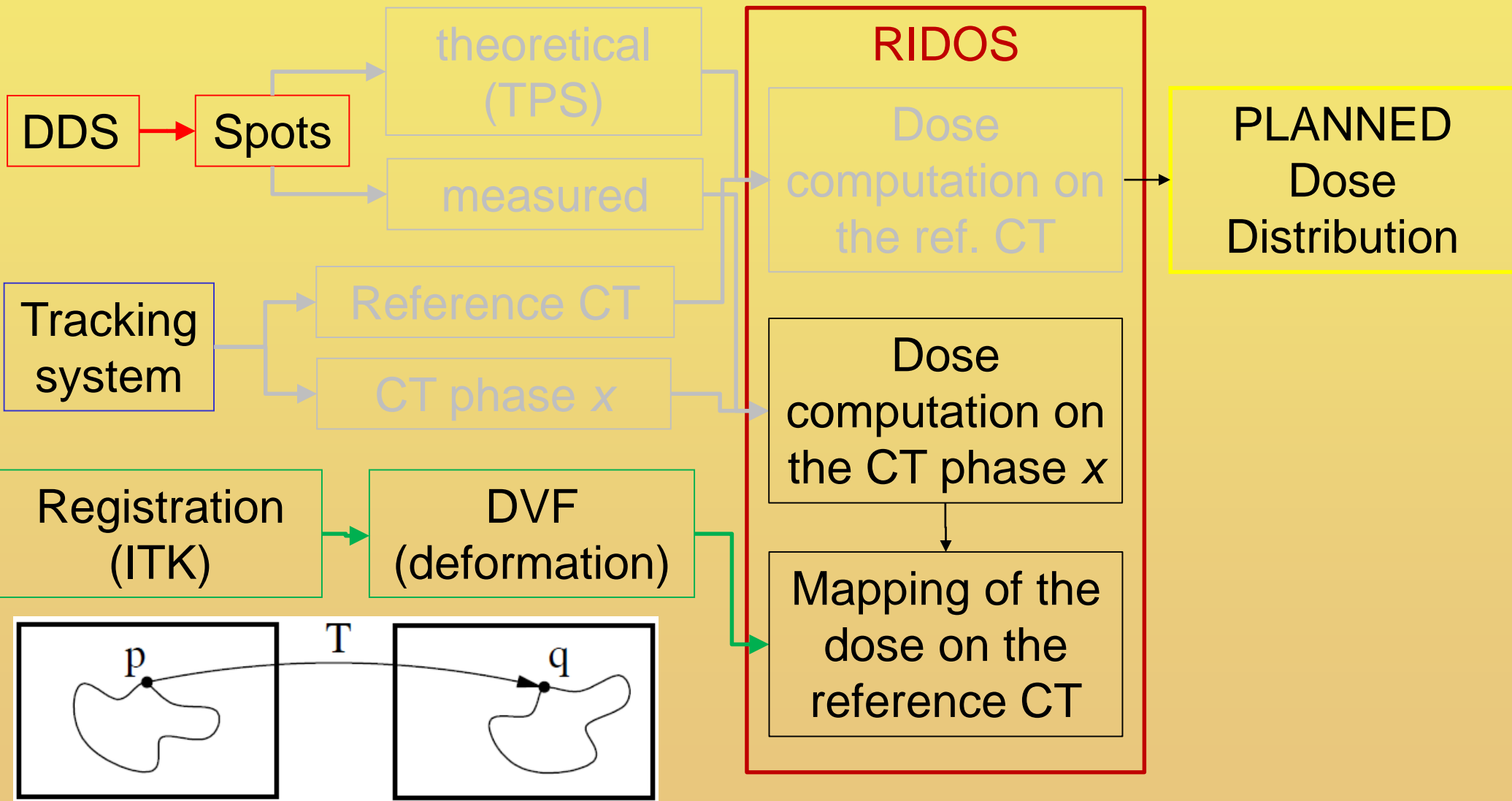


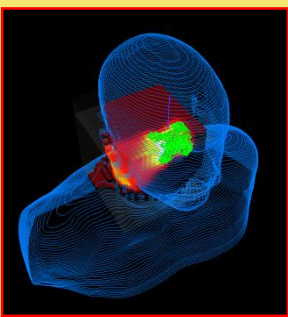
RIDOS



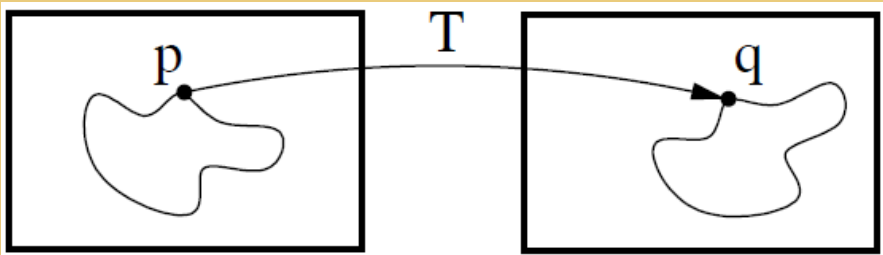
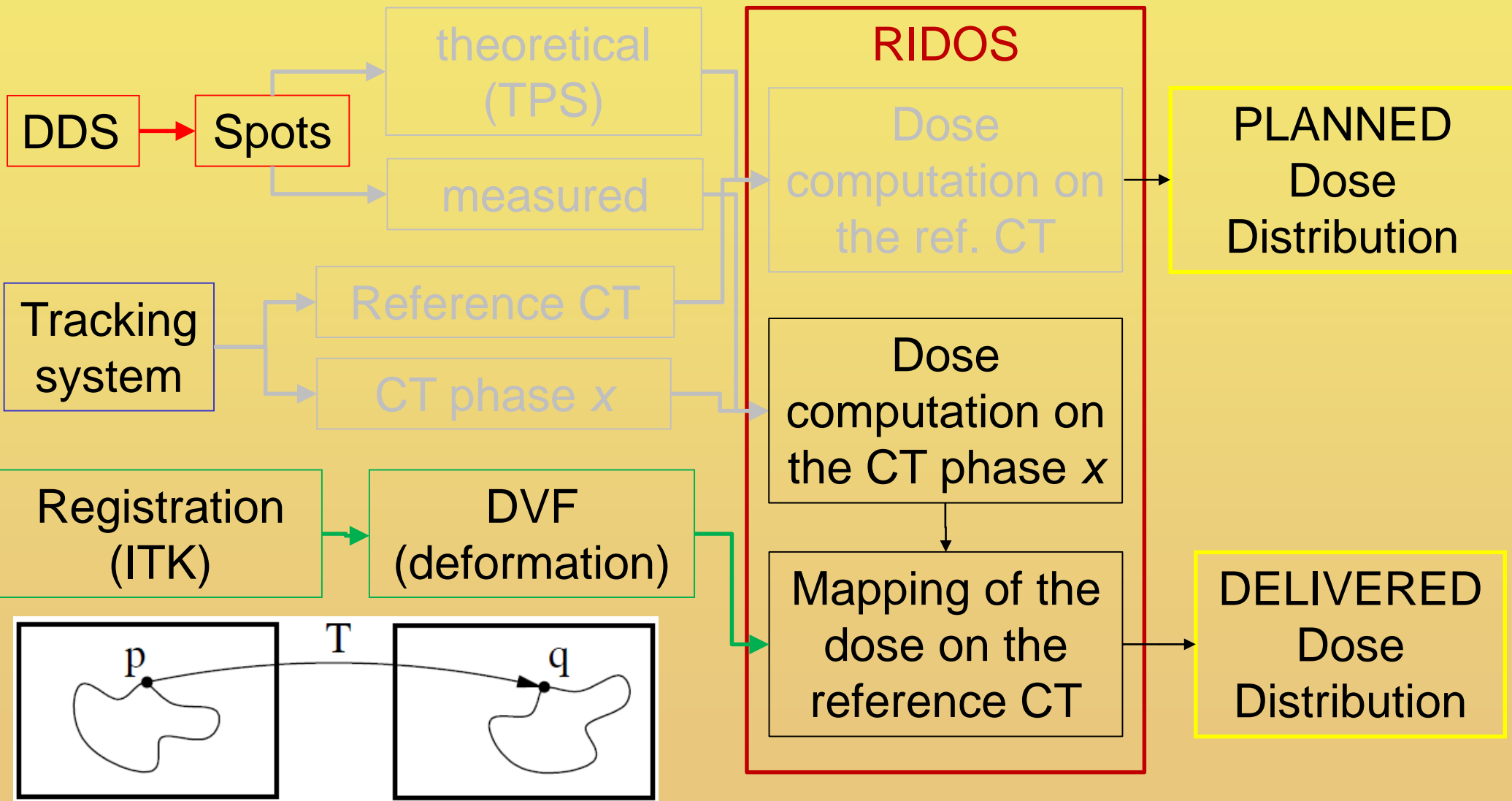


RIDOS





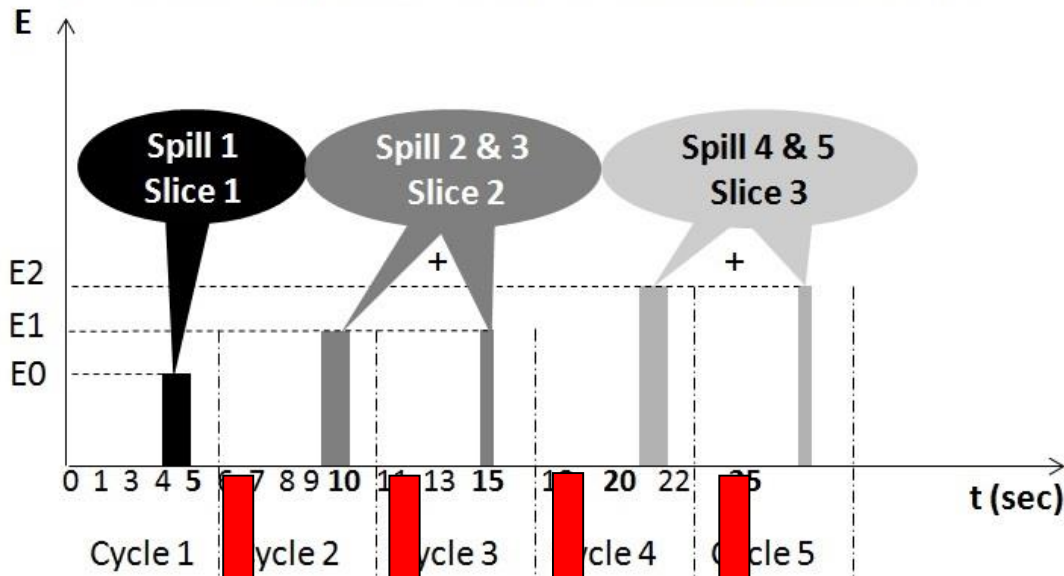
RIDOS





Comparison partial – total doses

Dose delivery time structure with Synchrotron



PLANNED dose (PARTIAL)

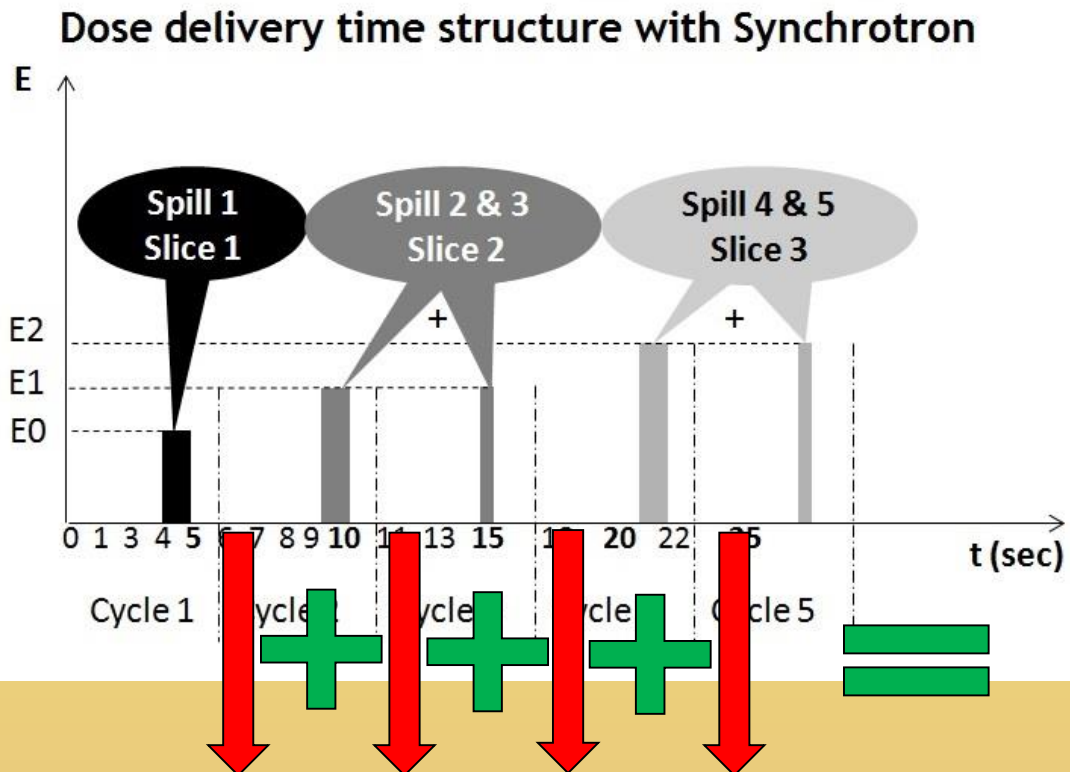
VS

DELIVERED dose (PARTIAL)





Comparison partial – total doses

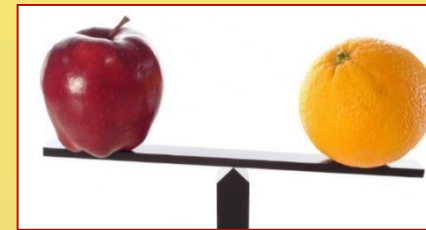
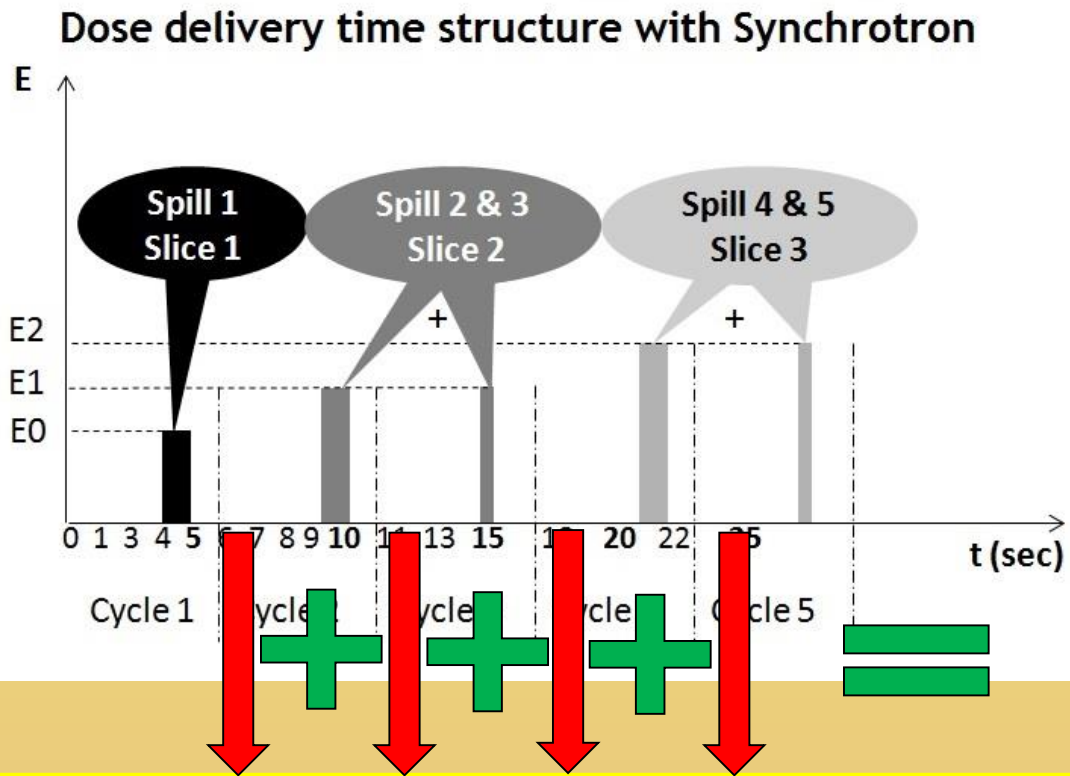


PLANNED dose (total)
VS
DELIVERED dose (total)

PLANNED dose (PARTIAL)
VS
DELIVERED dose (PARTIAL)



Comparison partial – total doses



comparison:

GAMMA INDEX
(gpu)

PLANNED dose (total)
VS
DELIVERED dose (total)

PLANNED dose (PARTIAL)
VS
DELIVERED dose (PARTIAL)



Conclusion

2016 → commissioning and clinical validation at CNAO.



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RIDOS will be a tool for the quality control of the effects related to the possible patient's movements during the delivery.





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RIDOS will be a tool for the quality control of the effects related to the possible patient's movements during the delivery.



RIDOS is a step towards the control of the progressive motion-corrected dose distribution during treatment.



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