INFN RESEARCH PROJECT (Grant for Young Researcher CSN5) call 2013

A GPU-based Planning and Delivery System to treat moving targets with therapeutic scanned ion beams

PI: Simona Giordanengo - INFN - Torino

INFN

RDH/IRPT Meeting 17 Dicembre 2014

UNIVERSITÀ DEGLI STUDI DI TORINO
ALMA UNIVERSITAS TAURINENSIS

Progetto INFN di Gruppo V

RIDOS: **R**eal-Time **I**on **Do**se Planning and Delivery **S**ystem

2 years: January 2014 – December 2015

Annual budget : 75 kE

RIDOS keywords…

…used to design and write the project

Dose delivery

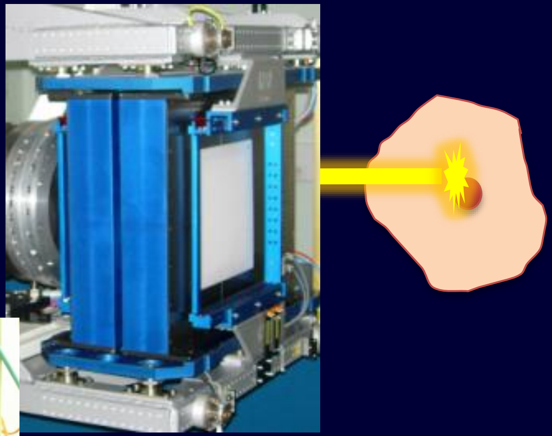
Moving target

GPU

Introduction

2005 -2011

Dose Delivery System of CNAO
Design, construction and commissioning



A

Real-Time system to control the delivery of clinical ion beams

Università degli Studi di Torino
Scuola di Dottorato in Scienza e Alta Tecnologia
Indirizzo: Fisica e Astrofisica

Tesi di Dottorato di Ricerca in Scienza e Alta Tecnologia
XXII Ciclo

Design, implementation and test of the hardware and software for the Fast Control of the Dose Delivery System of Centro Nazionale di Adroterapia Oncologica (CNAO)

Simona Giordanengo

PhD thesis

Giordanengo S, et al. «The CNAO Dose Delivery System for ion pencil beam scanning radiotherapy" Medical Physics 42(1) January 2015

Introduction

EU Project Ulice 2011 - 2012

DDS upgrade to interface the DDS with the CNAO organ motion compansation system
- Preliminary interface with the CNAO Optical Tracking System OTS to implement the «tracking compensation technique» in order to treat moving target.

B

Introduction

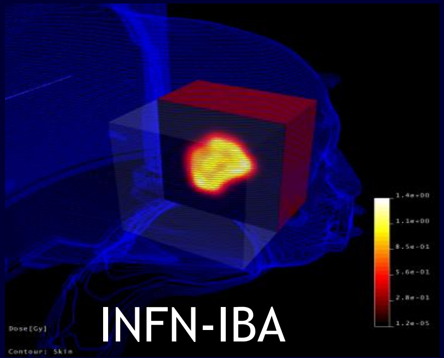
2012 - 2013

C

DDS clinical data analysis

DDS performances evaluation using the Planning Kernel for Ion Therapy (PlanKIT) TPS

(Dose distributions analysis throgh 3D Gamma index, isodose curves, DVHs)



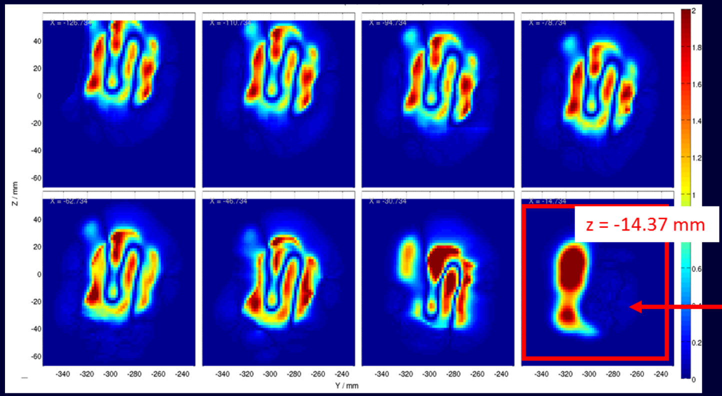


Fig 6. Gamma index Reference vs Delivered (2%, 2mm, 0.1 mm grid)

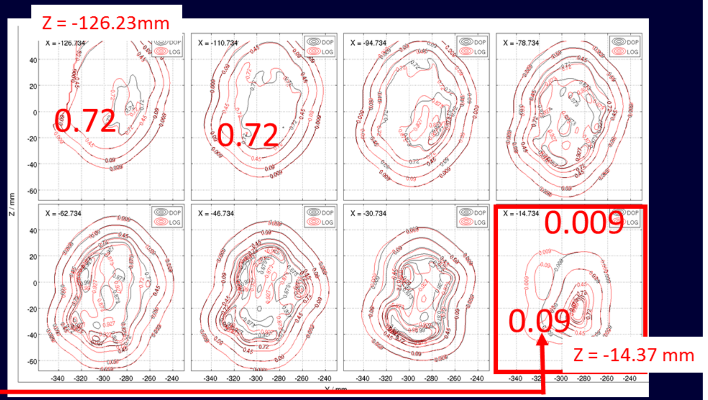


Fig 7. Isodose curves for the same dose distributions of Figure 6

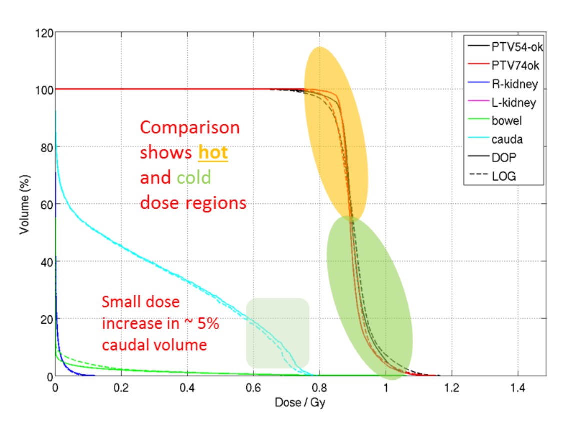
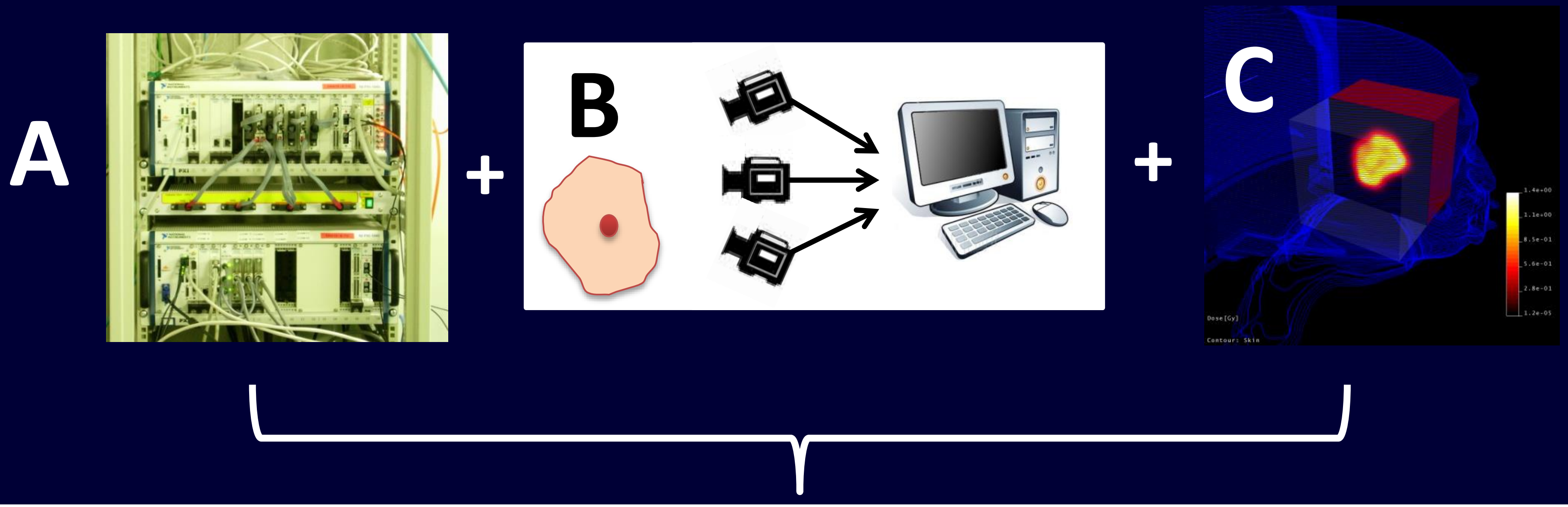


Fig 8. DVH for the same dose distributions of Figure 6 and 7

Project aim

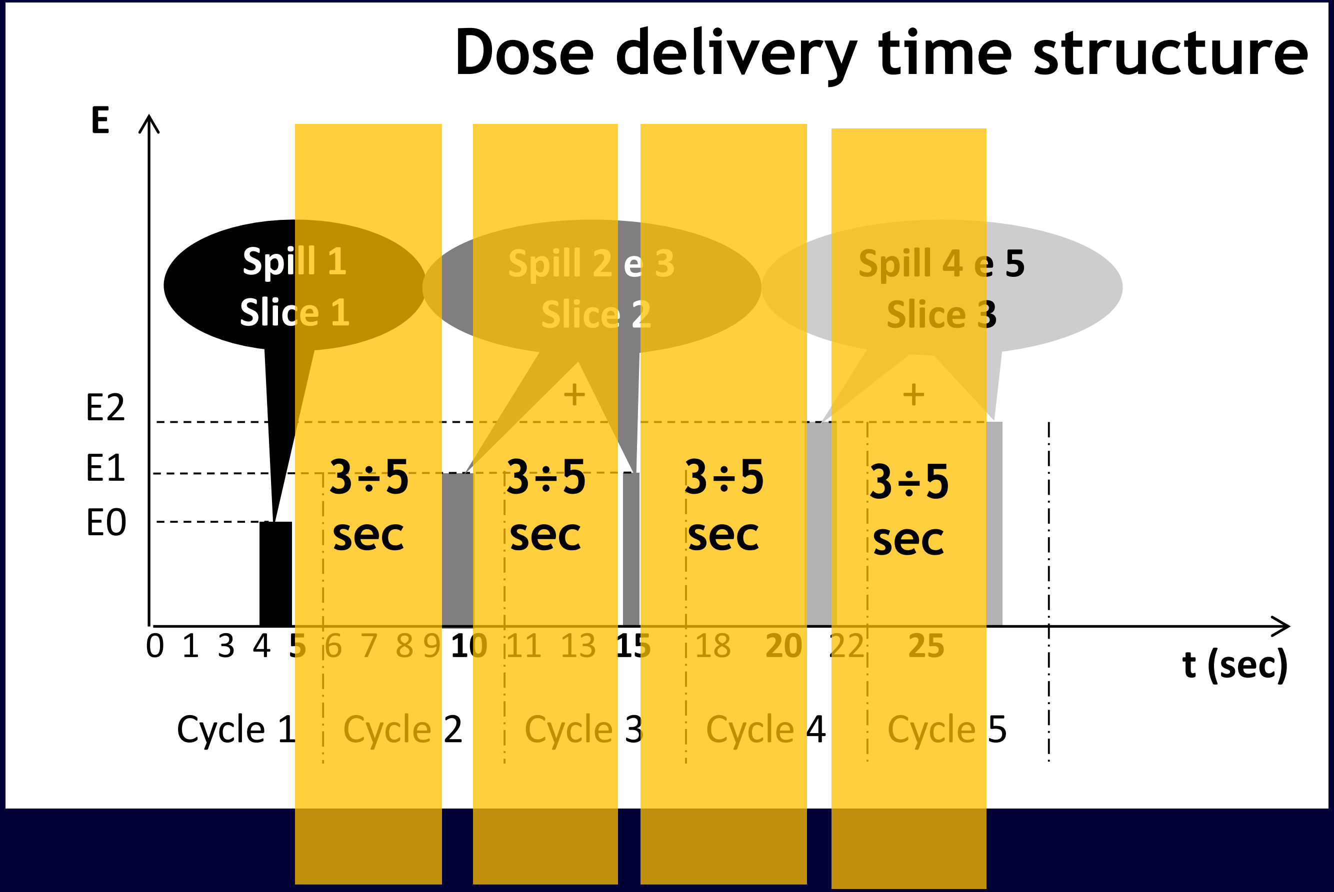


New dose Planning and Delivery System

able to modify and adapt in real-time the pencil beams distribution in order to compensate for the uncertainties due to measured organ motions

(towards Adaptive Particle Therapy)

Why not using the inter-spill time?

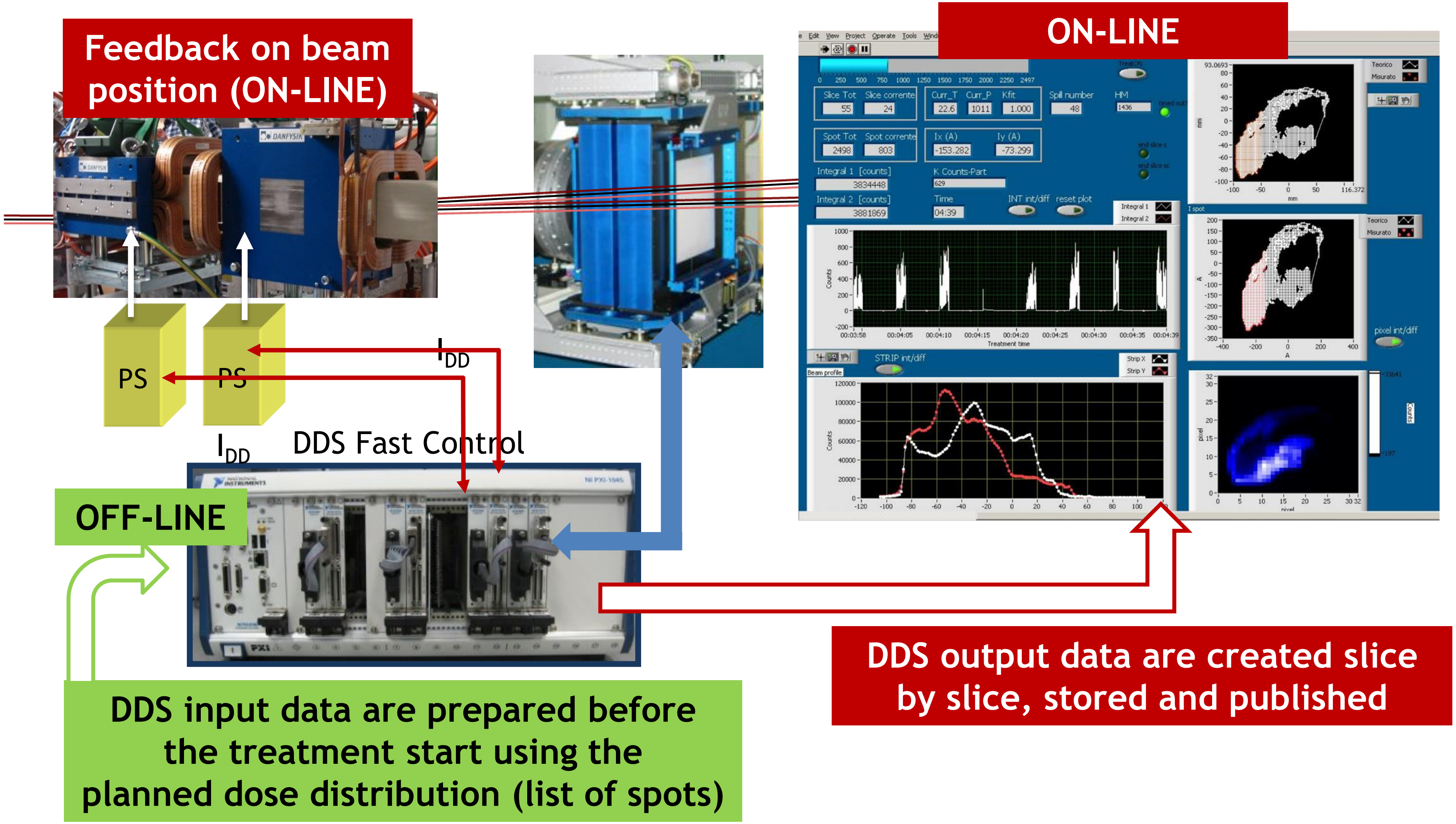


3÷5 sec (ideal)

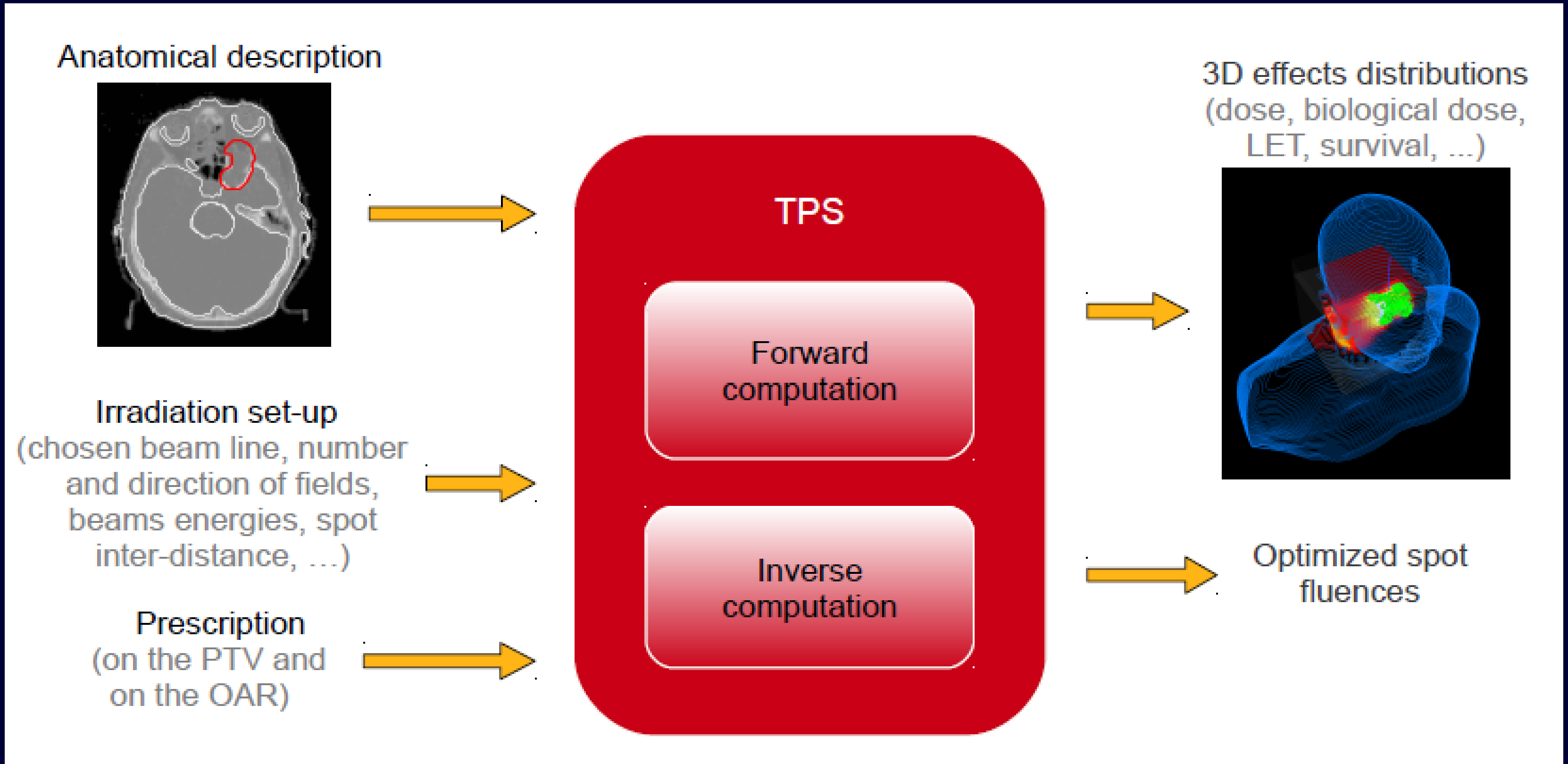
5÷15 sec acceptable

Inter-spill time available to reconstruct the partial dose delivered up to the last spill

State of the art (I)
The CNAO Dose Delivery System



State of the art (II)
Treatment planning PlanKIT for ion beams



Pre-treatment computation → no big time constraints

- **15 minutes/optimization→ list of optimized spot parameters (number of particles and positions)**

State of the art (II)
Off-line Forward planning using measured spot parameters

LogFile by DDS

List of spots with measured beam positions and particles

Reference CT

FP with PlanKIT TPS
$[D_n (t_n)]$

Dose Distribution by Forward Planning (FP)

Dose distributions analysis

(3D Gamma index, isodose curves, DVH)

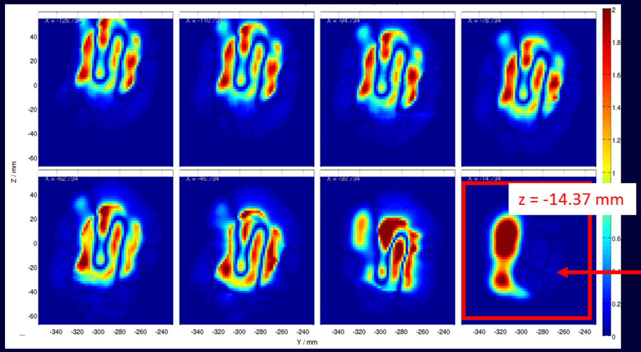


Fig 6. Gamma index Reference vs Delivered (2%, 2mm, 0.1 mm grid)

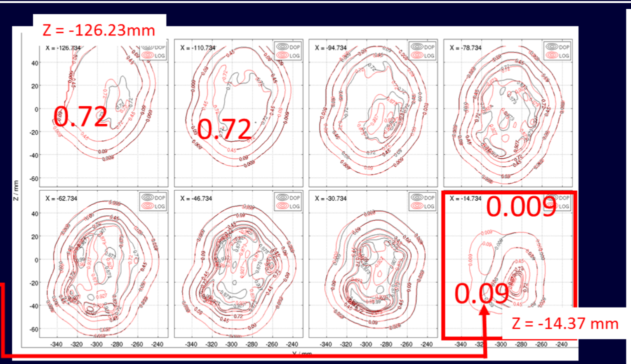


Fig 7. Isodose curves for the same dose distributions of Figure 6

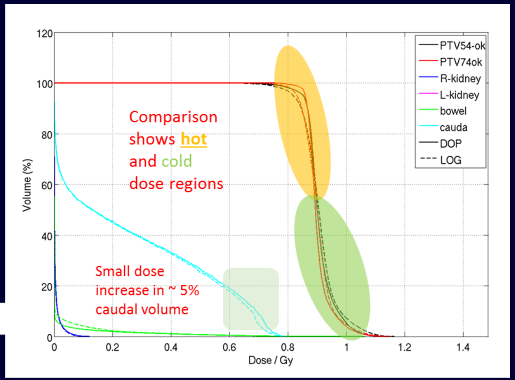
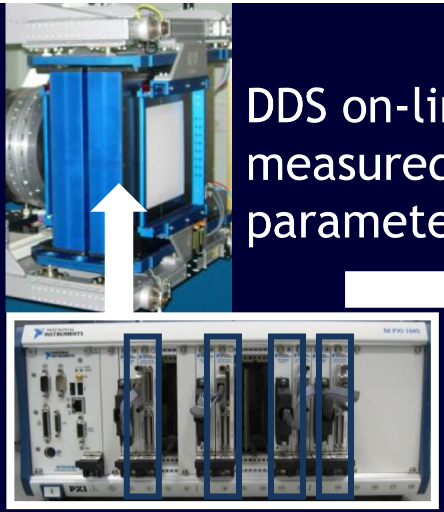


Fig 8. DVH for the same dose distributions of Figure 6 and 7

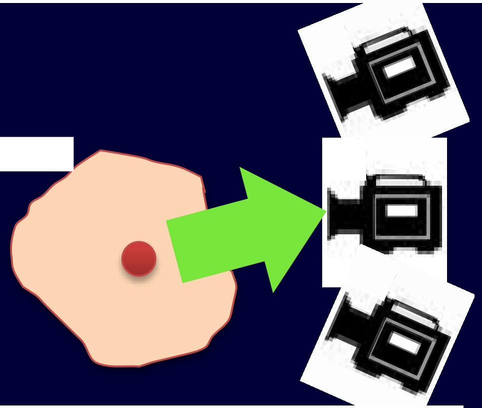
Operations to perform in the inter-spill time



DDS on-line measured spot parameters

DDS real-time control

Fast forward planning computes the <u>partial delivered dose</u>



Measured «target» positions (ΔX, ΔY, ΔZ)
+
Respiratory phase

By comparison with the prescription, **corrections** to spot parameters can be implemented

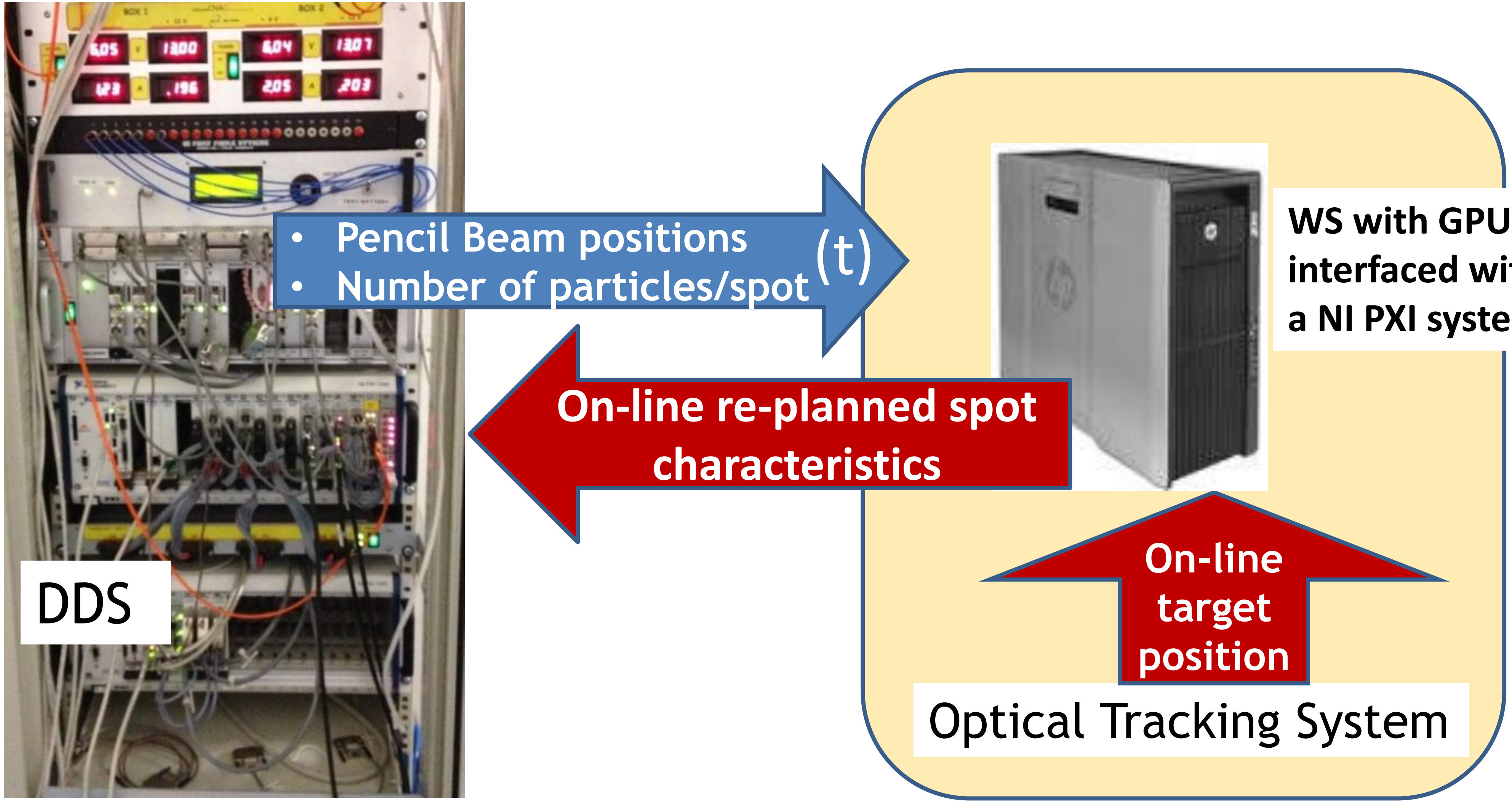
New DDS input for next spill

DDS parameters translation for each spill

- Nparticles
- Spot Positions (X,Y)iso

- Monitor counts
- (Xstrip, Ystrip)
- Currents Ix, Iy

Main deliverable (end 2015):
fast on-line Forward Planning integrated in the DDS and interfaced with the OTS and/or respiratory phase signal



Main activities and issues

Three main activities:

- A1: Fast Forward Planning implementation with CUDA and PlanKIT libraries (SW)
- A2: Development of a simulator for preliminary out-of-beam tests (HW+SW)
- A3: HW design and development (HW)

A1: Fast Forward Planning on GPU

- First prototype ready and under test
  - Main CUDA algorithms raytracing, interpolations to compute water equivalent path length, LUT interpolation to compute the dose for each ray

- Benchmark with dedicated C/C++ algorithms and with PlanKIT/DEK

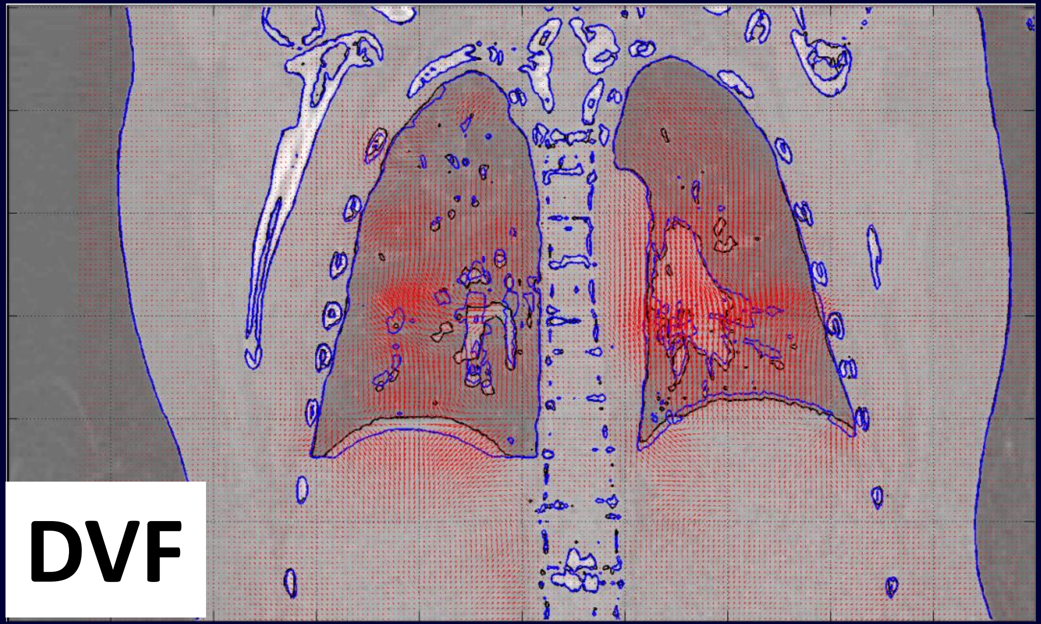
- preliminary results will be presented in CSN5

A2: SIMULATOR (SW tools - I)

- ✓ Off-line studies with PlanKIT TPS on 4D treatments to manage 4DCT and treatments of moving targets (introduced by A. Attili)

Registration of CT images corresponding to different breathing phases.

The registration is performed using the RayStation platform (RaySearch company) (courtesy of Mauriziano Hospital in Turin and Tecnologie Avanzate). An assessment of the registration capabilities provided by the OS Insight Toolkit (ITK), is also ongoing.

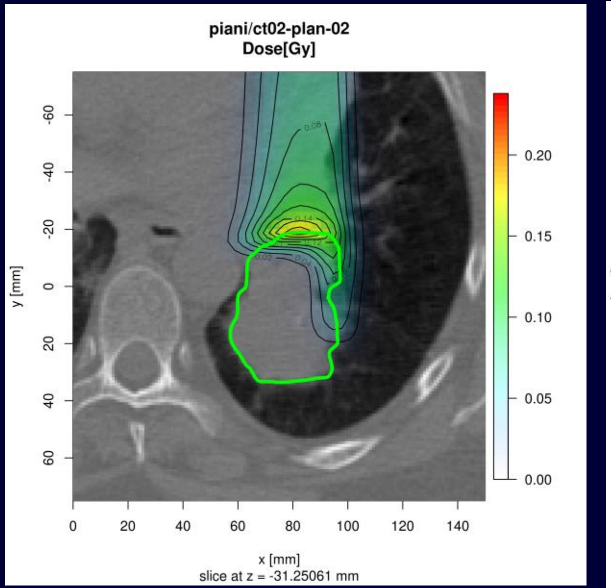


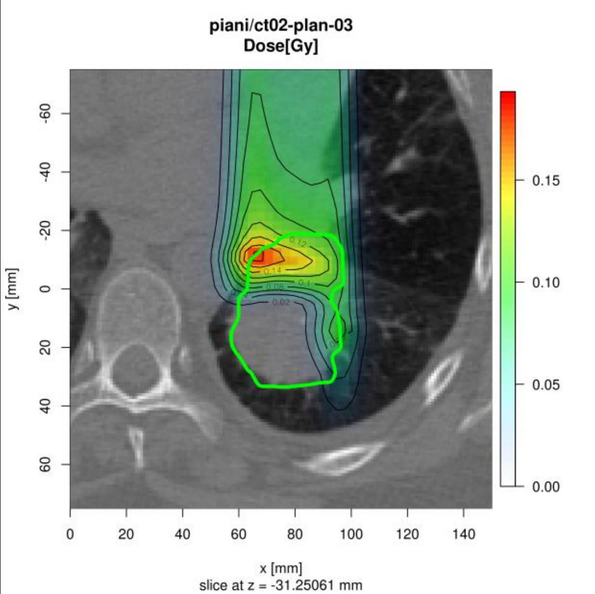
The registration is necessary to extract deformation vector fields (DVFs) that describe the evolution of the treated volume along time.
The DVF map points of a reference breathing phase to the corresponding points in the other phases.

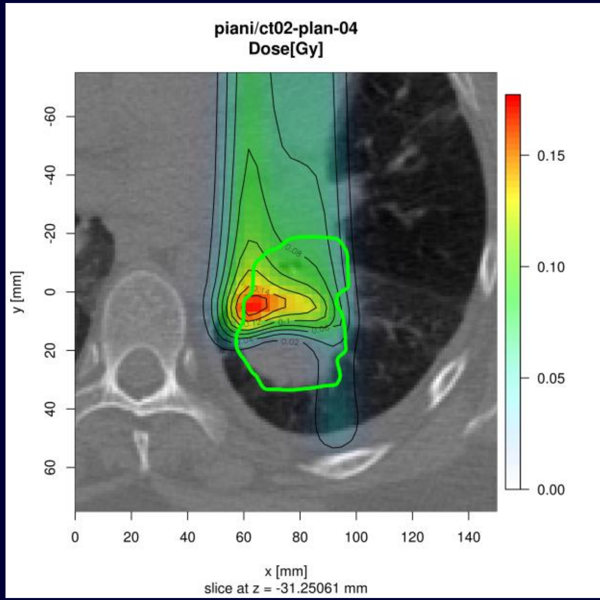
This mapping is necessary to superimpose the dose contributions corresponding to the irradiation in the different phases.

A2: SIMULATOR (SW developments)

EXPECTED INPUT-OUTPUT DATA SIMULATION
Studies on 4DCT for lung tumor (partial doses computation selecting the spots delivered in the expected respiratory phase).







A2: SIMULATOR (SW developments - II)

- **Simulations to define** the most suitable **delivery technique** for on-line re-planning (tracking, gating, scanning path optimization, beam characteristics etc…)

A2: SIMULATOR (SW developments - III)

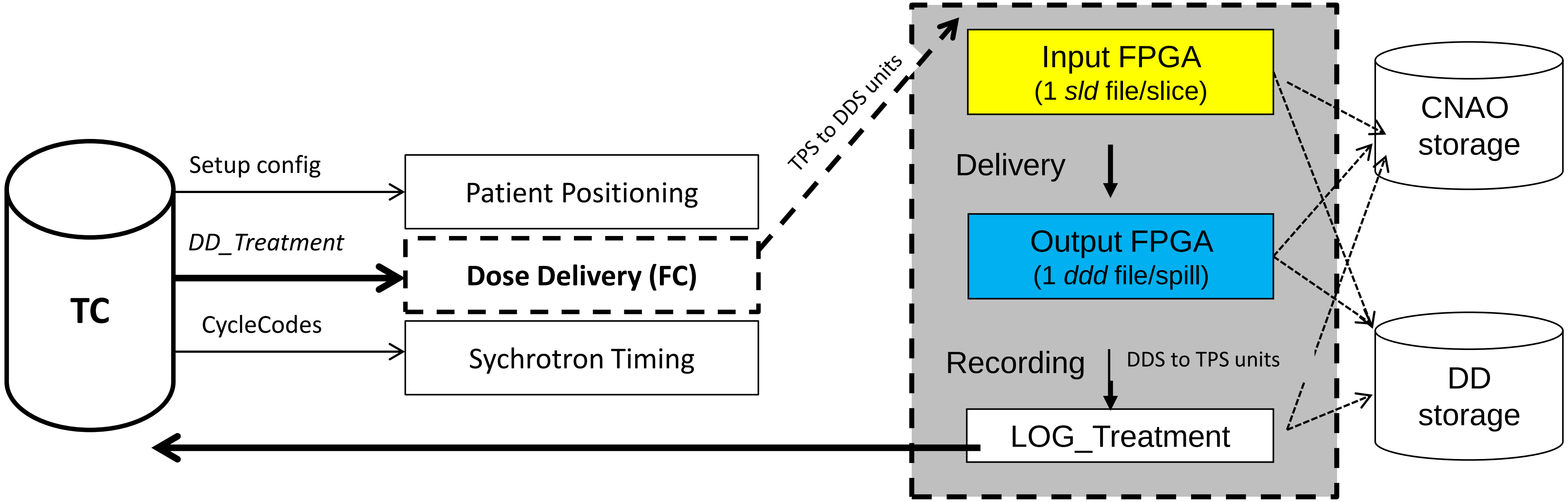
- **The compensation strategy** is a crucial and challenging issue but is not a RIDOS goal: we will start with simple re-painting of under-dose regions slice by slice, adding for example dummy empty spots in the original treatment at the end of the slice to fill if necessary.

A2-A3: HW developments (I)

- Interface with DDS (designed as a “plug & play system” for the existing system)
- Interface with OTS and CNAO Timing System

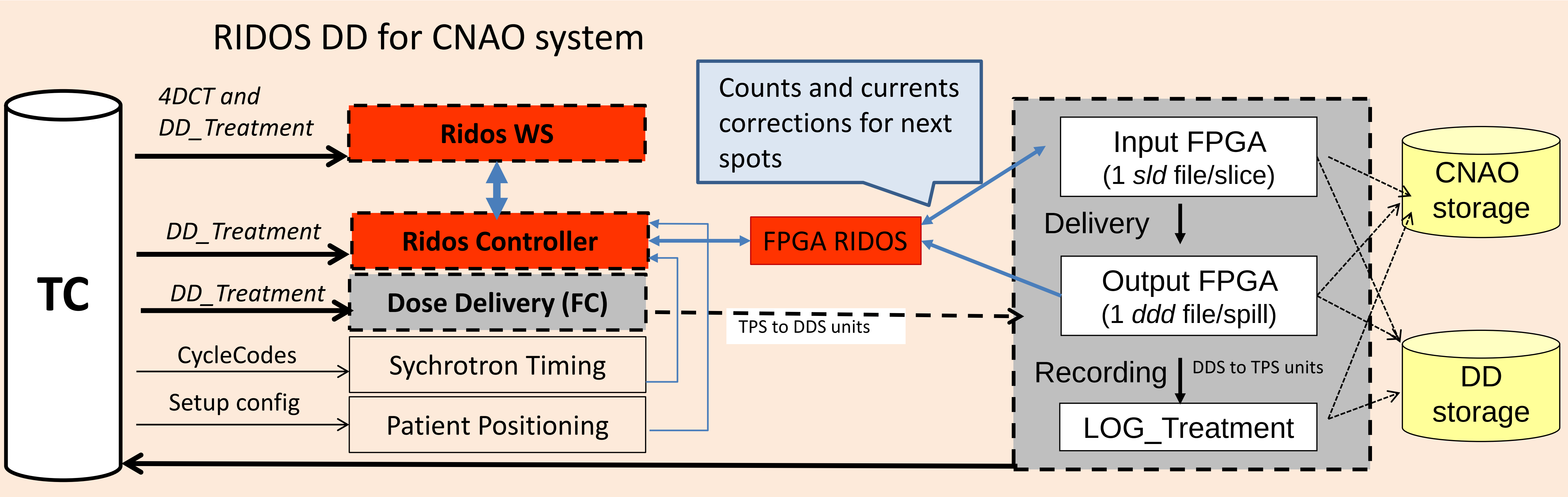
CLINICAL DDS processed data

Pre-delivery processed data

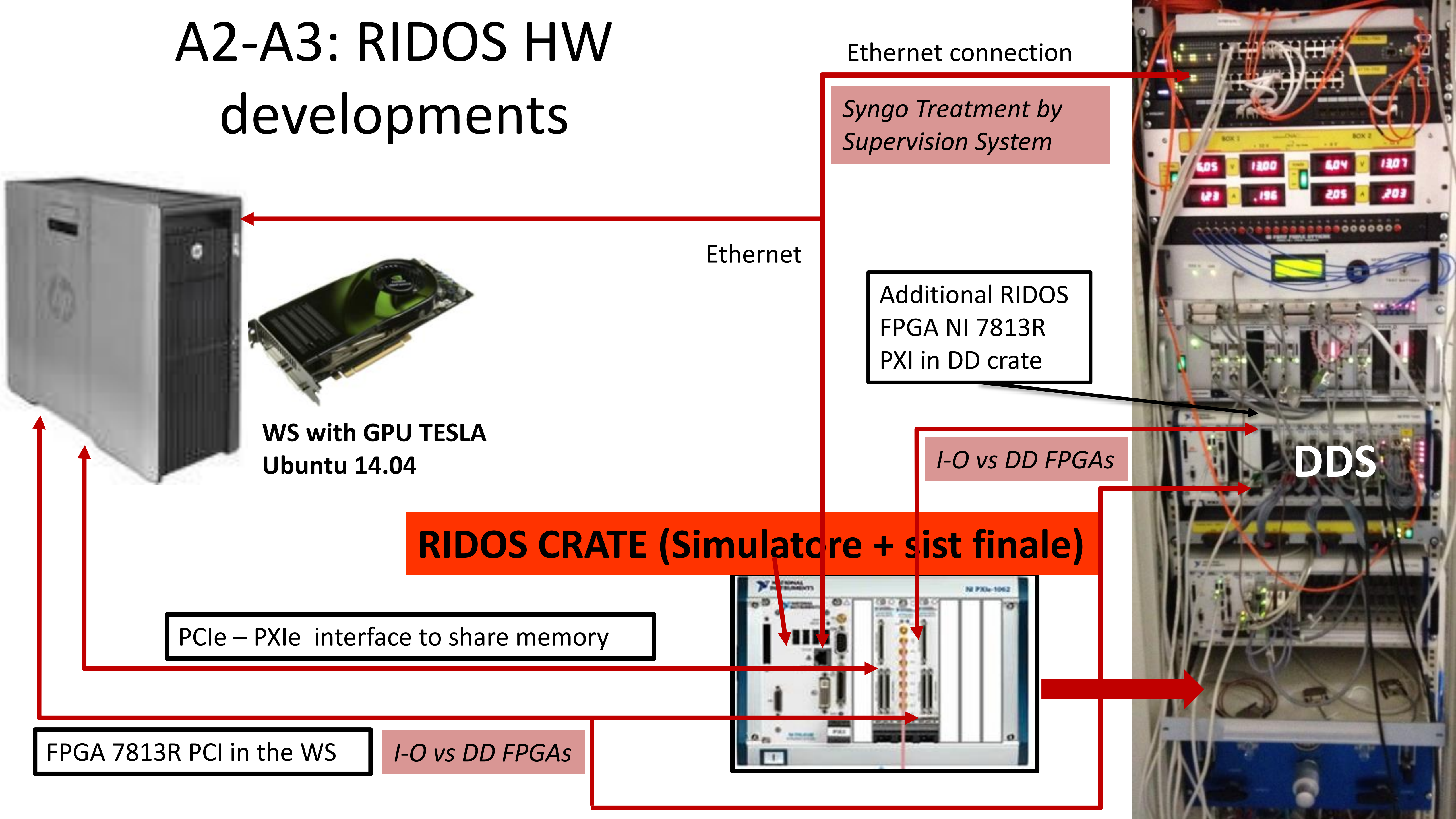


Post-delivery processed data

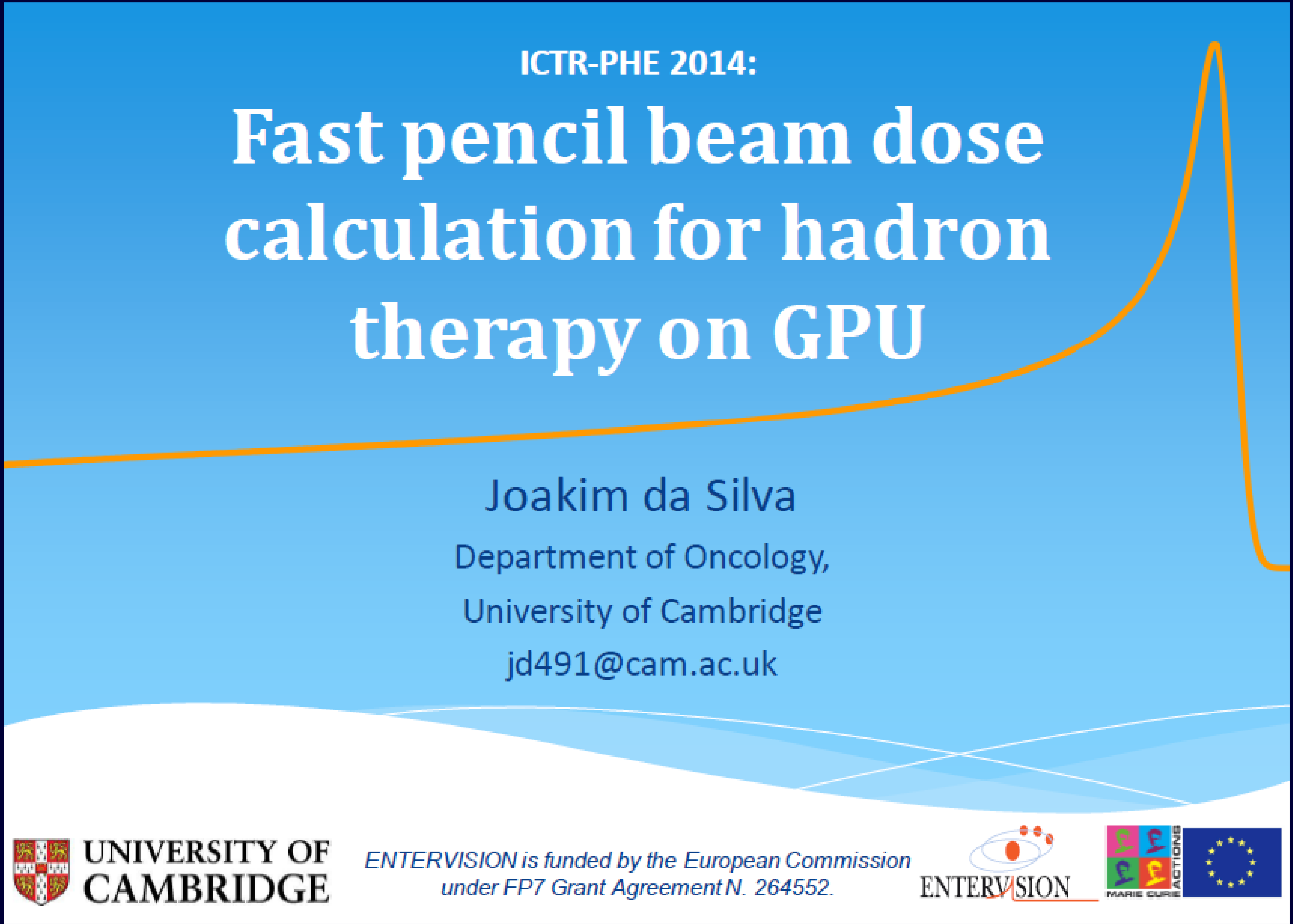
DYNAMIC RIDOS DDS data flow



A2-A3: RIDOS HW developments

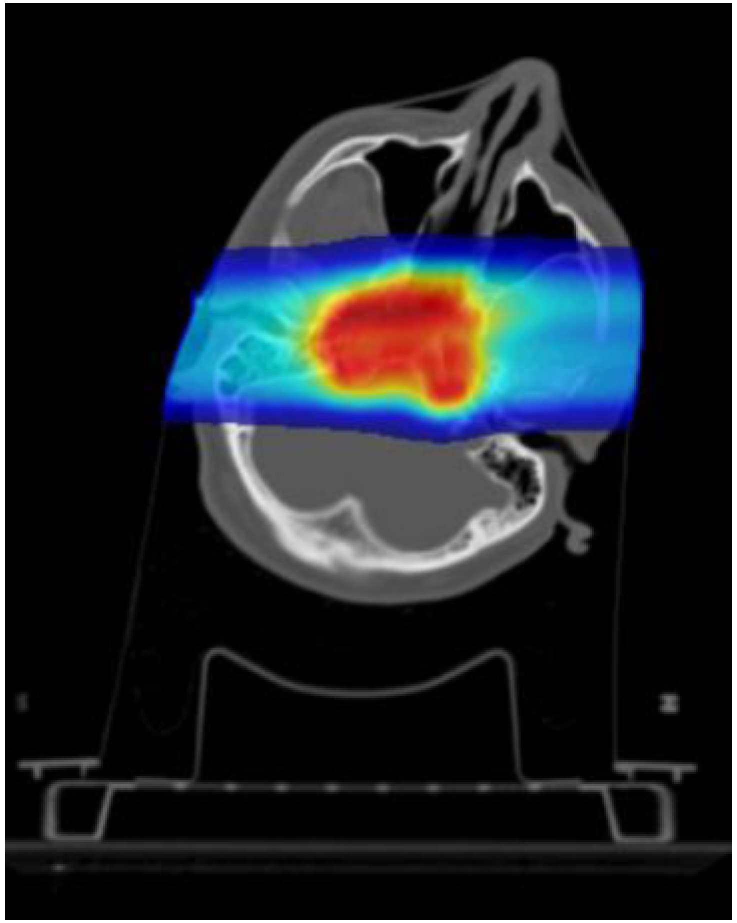


Collaborations (I)



Joakim da Silva results

Preliminary results skull base case



- 2 fields, 99 energy layers, 8872 spots
- Resolution: 1x1x1 mm^3
- Laptop (Quadro1000M): 3.7 s
- Desktop (GeForce GTX 680, non-optimised): <1 s

Contacts with new INFN projects

COSA
(COmputing on Soc Architectures)

- Tommaso Boccali – INFN Pisa
- Andrea Ferraro e Daniele Cesini del CNAF di Bologna

Innovative Multi-chip system for multi-purpose PAttern Recognition Tasks (IMPART)

Principal investigator: Alberto Stabile

INFN - Milano

Progetto vincitore Grant Giovani ricercatori 2014

Conclusions

The treatment of moving targets with charged particles is a major and very complex issue which still requires progress in diagnostic, planning, delivery and verification methods

RIDOS can be seen as a step towards adaptive adrontherapy and should complement developments of in-vivo dose measurements and verification modalities (prompt gamma, on-line PET, ultrasounds, on-line CT, on-line MRI, ...)

The project stands on the expertise gathered by the medical physics group of INFN of Torino in many years of activity in this field

Grazie

medicalphysicsweb | newswire

15 Dicembre 2014

Ultrasound and MRI line up for 4D radiotherapy

Planning and delivering radiotherapy to moving targets is an enduring challenge. …..

For proton therapy, in which motion can introduce density changes in the beam path, the implications of such uncertainties can be particularly severe.

…recent years have seen many interesting technology developments, clinical transfer of these techniques is not easy

http://medicalphysicsweb.org/cws/article/opinion/59650

TALKING POINT

Dec 15, 2014

Ultrasound and MRI line up for 4D radiotherapy

Planning and delivering radiotherapy to moving targets is an enduring challenge. Tumours can change shape, location and functionality between treatment fractions, while patients may undergo anatomical changes during a radiotherapy course. Tumours and organs-at-risk can also move during treatment delivery - and not necessarily in synch with each other. For proton therapy, in which motion can introduce density changes in the beam path, the implications of such uncertainties can be particularly severe.

This "4D radiotherapy problem" is not a recent realization; attempts at 4D treatment planning to account for motion and deformation have been ongoing for at least two decades. But while recent years have seen many interesting technology developments, clinical transfer of these techniques is not easy. "We are making incremental progress," said Uwe Oelfke, head of the Joint Department of Physics at the UK's Institute of Cancer Research and the Royal Marsden. "But a big breakthrough pushing into the clinic has not been achieved."

Acoustic waves characterize proton beams

Range-verification methods such as PET and prompt gamma imaging are under ongoing investigation, **and a third approach is now emerging: beam verification using acoustic signals.**

http://medicalphysicsweb.org/cws/article/research/59217

RESEARCH

Nov 6, 2014

Acoustic waves characterize proton beams

Proton therapy's main advantage for cancer treatment lies in the protons' steep dose gradient at the Bragg peak. However, uncertainties in the exact Bragg peak location necessitate the use of larger-than-desirable target margins, resulting in deliberate over- and undershoot of the proton beam into healthy tissue. To fully exploit the advantages of the proton Bragg peak, it is critical to reduce the range uncertainties.

Range-verification methods such as PET and prompt gamma imaging are under ongoing investigation, and a third approach is now emerging: beam verification using acoustic signals. This "protoacoustic" technique works by measuring the pressure wave that arises when a pulsed proton beam travels through tissue, depositing energy and causing localized heating. Researchers at the University of Pennsylvania have performed numerical simulations to characterize this emission, with the ultimate goal of locating the Bragg peak from proton-induced acoustic measurements (*Phys. Med. Biol.* 59 6549).

"We wanted to know how much we could learn about the proton beam by listening to the sound it produces," explained Kevin

A 4D dose computation method to investigate motion interplay effects in scanned ion beam prostate therapy
F. Ammazzalorso - University of Marburg
Physics in Medicine and Biology
Volume 59, Issue 11, 7 June 2014, Pages N91-N99

Dosimetric consequences of intrafraction prostate motion in scanned ion beam radiotherapy
F. Ammazzalorso (DKFZ)Heidelberg
Radiotherapy and Oncology
Volume 112, Issue 1, 1 July 2014, Pages 100-105

GPU-accelerated automatic identification of robust beam setups for proton and carbon-ion radiotherapy
F. Ammzzalorso
Journal of Physics: Conference Series
Volume 489, Issue 1, 2014, Article number 012043

A GPU-accelerated and Monte Carlo-based intensity modulated proton therapy optimization system

Jiasen Ma,[a)] Chris Beltran, Hok Seum Wan Chan Tseung, and Michael G. Herman
Department of Radiation Oncology, Division of Medical Physics, Mayo Clinic, 200 First Street Southwest, Rochester, Minnesota 55905

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