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NPL, Teddington, UK

Monte Carlo Validation of the EYEPLAN Treatment Planning System for ocular proton therapy

G.A.P. Cirrone, PhD
on behalf of
G. Cuttone, F. Di Rosa and G. Russo

the Geant4 Medical Group of

Laboratori Nazionali del Sud – INFN, Catania (I)

Outline

1. Radiotherapy with protons and Ions

CATANA: The only italian protontherapy center

MC and Potontherapy

EYEPLAN Validation procedure

Step1: MC vs Exp

Step2: TPS vs MC

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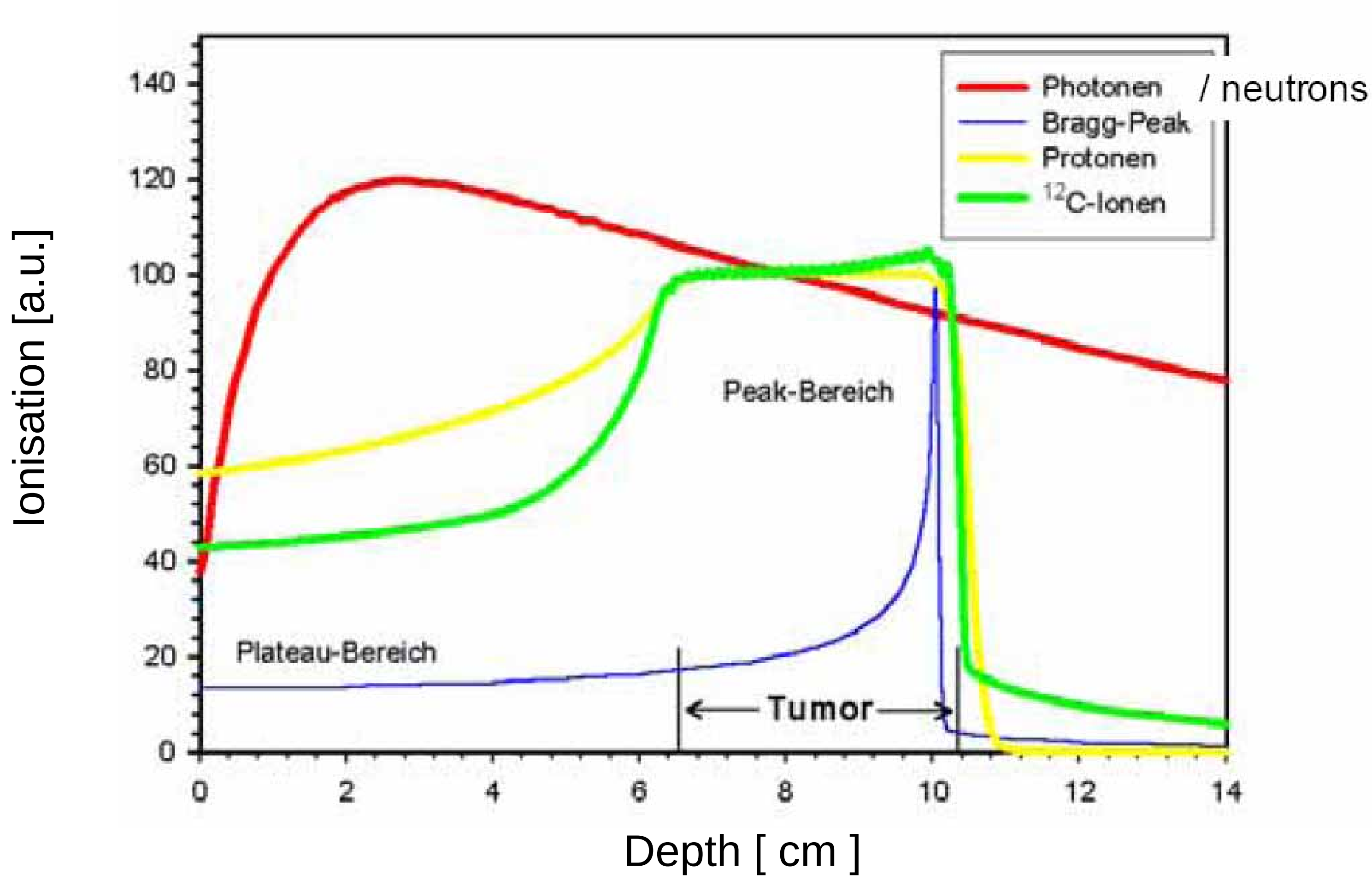
    2. Step2: TPS vs MC

Why PROTON and ADRON BEAMS in RADIOTHERAPY?



By Dr. Oliver Jakel (dkfz) Germany

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5. And about Ion beams?

The Monte Carlo methods in radiotherapy with protons and carbon ions

- Beam line Design and Optimization
- Dose distributions benchmarking in clinical cases
- Analytic TPS Commissioning
- Monte Carlo planning

- Verify of the transport model beam for inelastic process
- Verify of radiobiological models

(especially for carbon ions)

Is the Monte Carlo method quite accurate for:

The TPS proton-therapy validation?

A design dedicated TPS based on Monte Carlo method?

A Monte Carlo (MC) code can be used to commission and validate a proton therapy treatment planning system:

1. MC validation versus experimental data is a fundamental step

2. The computation time for the entire virtual commissioning process is enough long for clinical routine

MONTE CARLO CODES IN PROTON-THERAPY

MCNP	FLUKA
MCNPX	PETRA
GEANT4	LAHET

MC systems actually adopted in the clinical case

VMCPro M. Fippel et al – A Monte Carlo dose calculation algorithm for proton therpy – Med. Phys. 31 (8), August 2004

PEREGRINE L.J. Cox et al. – Proc. Int'l. Conf. NDST-94, p730,

ISTAR R. D Ilic et al. – Phys. Med. Biol. 50 (2005) 1011 – 1117

XiO by CMS Next future

TPS COMMISSIONING FOR OCULAR

PROTON-TRERAPY USING A MONTE

CARLO METHOD

OUR EXPERIENCE

We replace the Newhauser's* work using a SOBP for TPS commissioning in a real clinical case

The output TPS informations are compared to Monte Carlo Geant4 simulation code of a 60 MeV proton beam

We also design and perform a particular new eye-phantoms to compare the TPS output dose distribution to experimental measurement and Monte Carlo results

The composite analysis proposed by Low** is applied for the 3D dose distribution comparison. In this study, the possible accepted criteria for proton therapy are analyzed and discussed

*** Monte Carlo simulations of a nozzle for the treatment of ocular tumours with high-energy proton beams**
[Phys. Med. Biol. **50** (2005) 5229–5249]

**** Evaluation of the gamma dose distribution comparison method [**Med. Phys. 30 .9., September 2003**]**

OUR EXPERIENCE

1. Eyeplan analytical ocular proton treatment planning

- Feature
- Algorithm
- Output

2. MC code to verify dose distribution

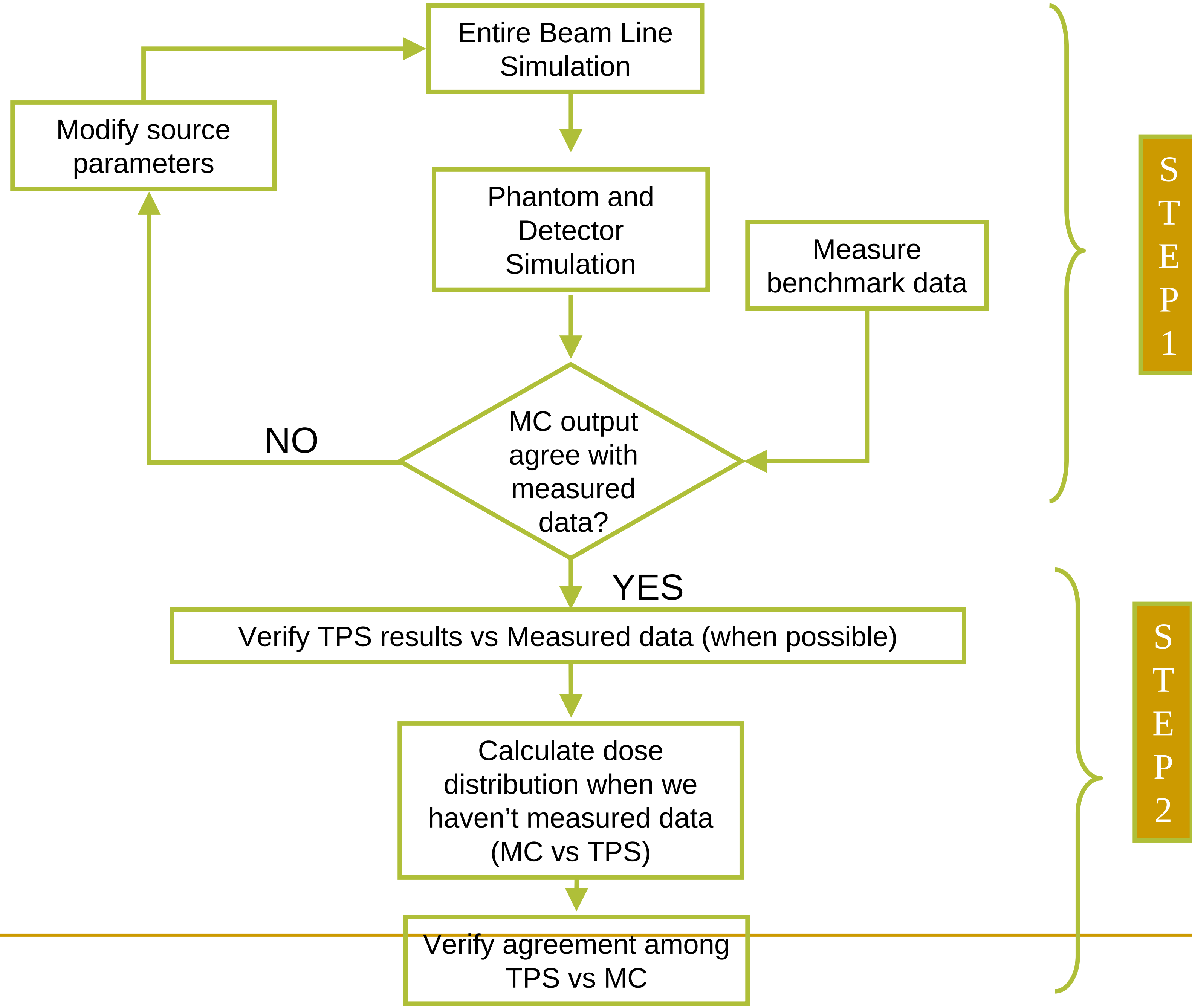
- Validation Procedure
- Beam Line
- Analysis
- GEANT4
- Guideline

3. Dosimetric TPS validation: Measured and Monte Carlo data

- Experimental Setup
- Measured Data
- Dose distribution Comparison

4. Results

- Discussion
- Computation Time
- Outlook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STEP 1
STEP 2

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STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

Application developed using GEANT4 libraries: *Hadrontherapy*

Hadrontherapy is an advanced example inside the GEANT4 toolkit distribution:

`geant4_installDir/examples/advanced/hadrontherapy`

- General geometric proton beam line configuration
- 3D dose distribution calculation using a sensitive detector with cubic voxel in different materials
- More physics model implementations

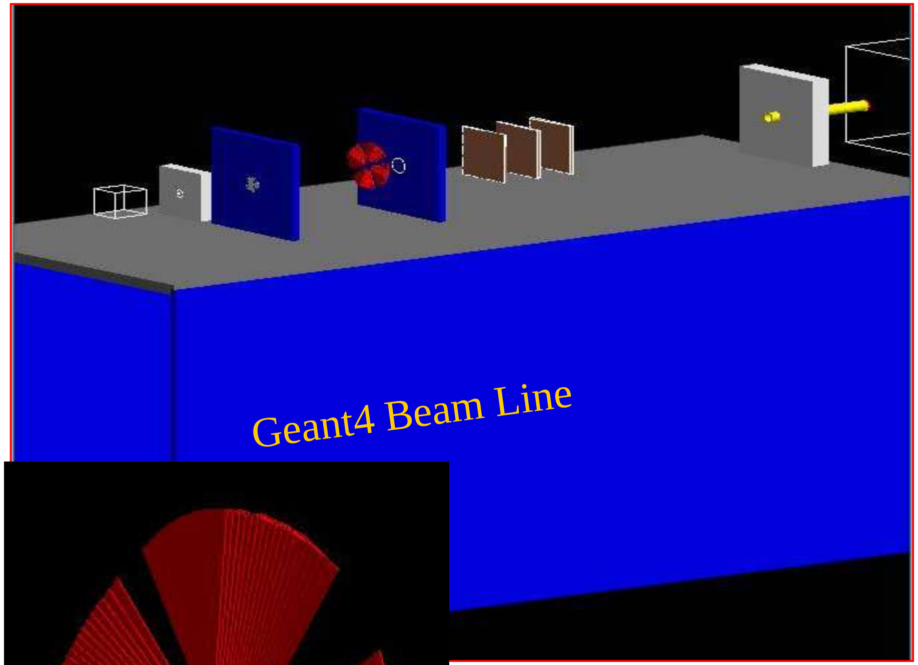
G. Cirrone, G. Cuttone et al. " ***The GEANT4 toolkit capability in the hadrontherapy field: simulation of a transport beam line***", Nucl. Phys. B

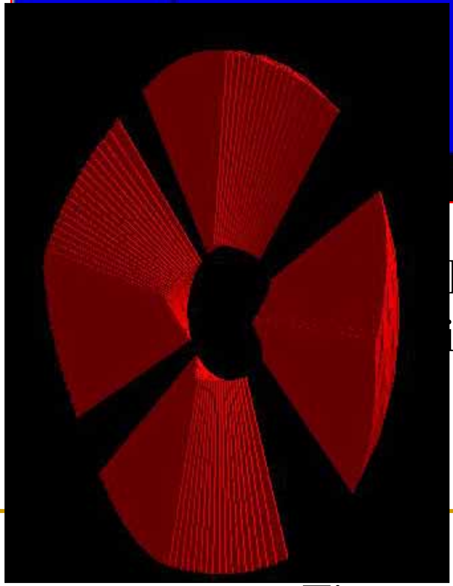
G.A.P. Cirrone, G. Cuttone et al., ***Implementation of a New Monte Carlo - GEANT4 Simulation Tool for the Development of a Proton Therapy Beam Line***, *IEEE Trans. Nucl. Sci*., vol. 52, no. 1, pp. 262-265, Feb. 2005.

MONTE CARLO – GEANT4

CATANA beam line simulation

Final Nozzle in treatment room
CATANA





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ine

Time – dependent geometry

MONTE CARLO – GEANT4 PHYSIC MODELS

EM MODELS

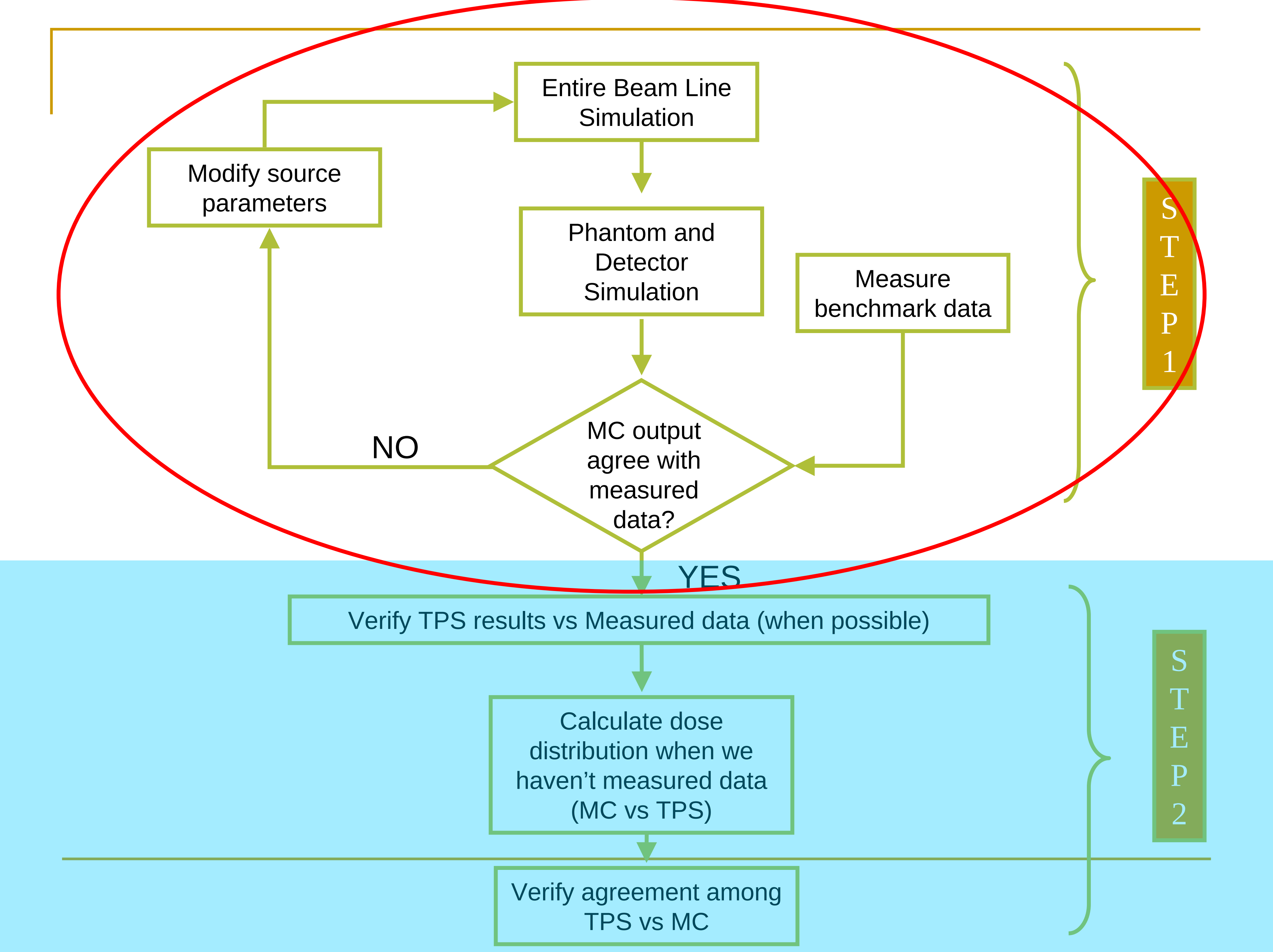
- EM process Model:
  - LowEnergy
  - Standard
- EM model for proton:
  - Low Energy - ICRU 49,
  - Low Energy - Ziegler77,
  - Low Energy - Ziegler85,
  - Low Energy Ziegler 2000,
  - Standard

HADRONIC MODEL

- “Precompound” Model
- “Binary” + Precompound Model
- “Bertini” Model
- LEP

“The differences between nuclear interaction models are not observable as long as we consider dose distributions”*.

* **Paganetti et Al. “***Accurate Monte Carlo simulations for nozzle design, commissioning and quality assurance for a proton radiation therapy facility***” [**Med. Phys. 31 .7., July 2004**]**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STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

DOSIMETRIC PARAMETERS USED TO COMPARE THE AGREEMENT BETWEEN SIMULATED AND EXPERIMENTAL DATA

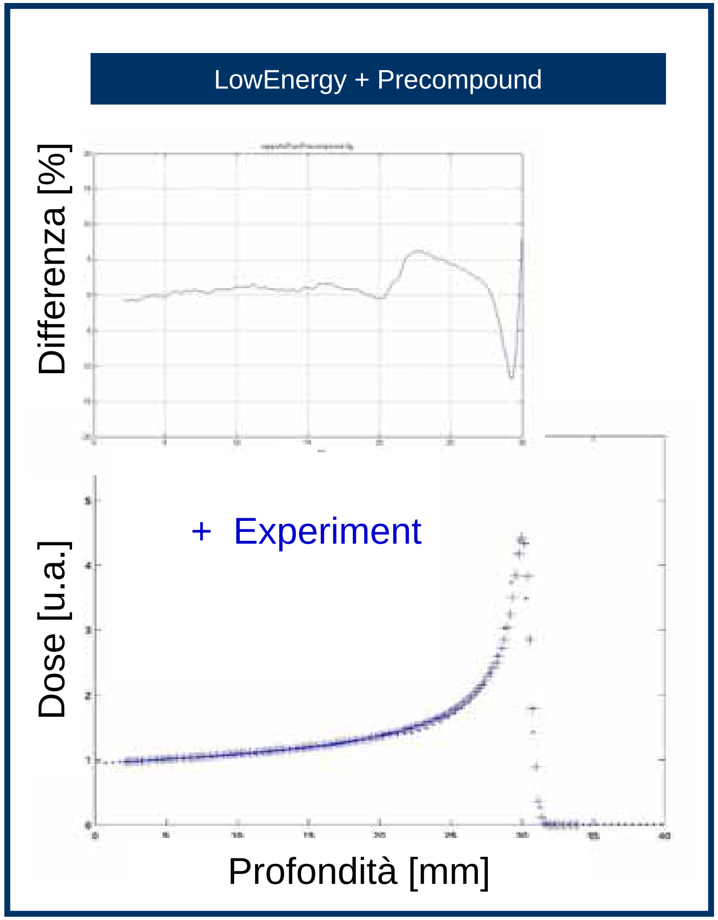
Full Energy Bragg peak and SOBP →

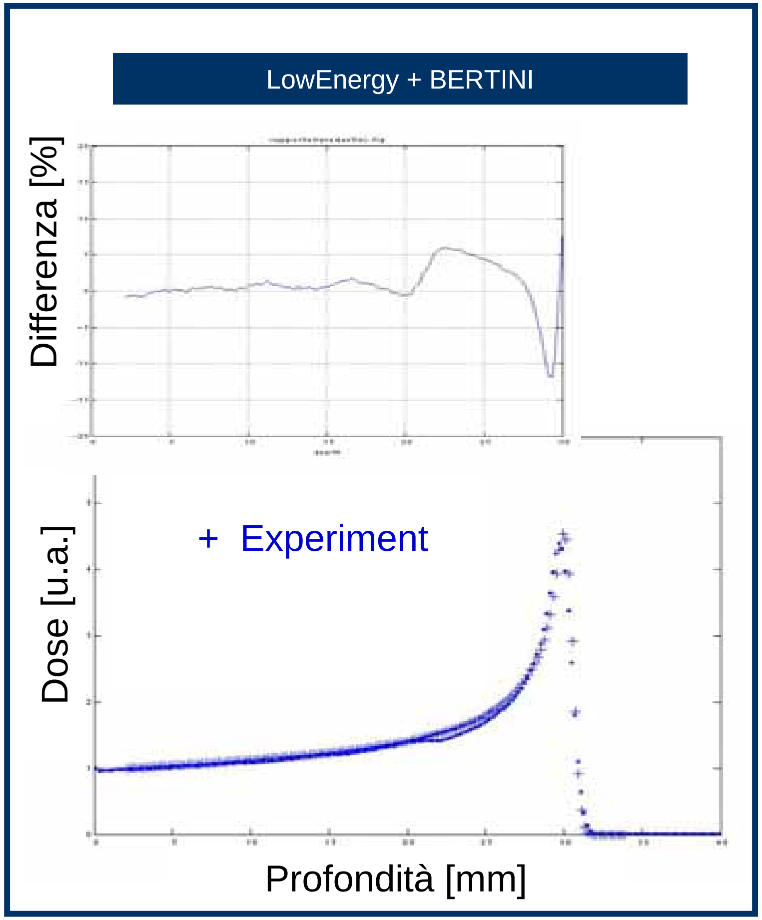
- Peak – plateau Ratio
- Pratical Range
- Distal dose fall-off (90%-10 %)
- FWHM
- Modulation Range

Profile →

- Beam Width 50%
- Penumbra (80% – 20%)
- Homogeneity
- Symmetry

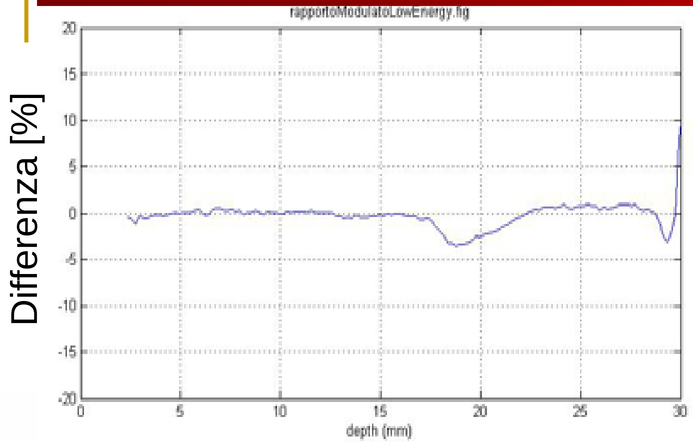
STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS



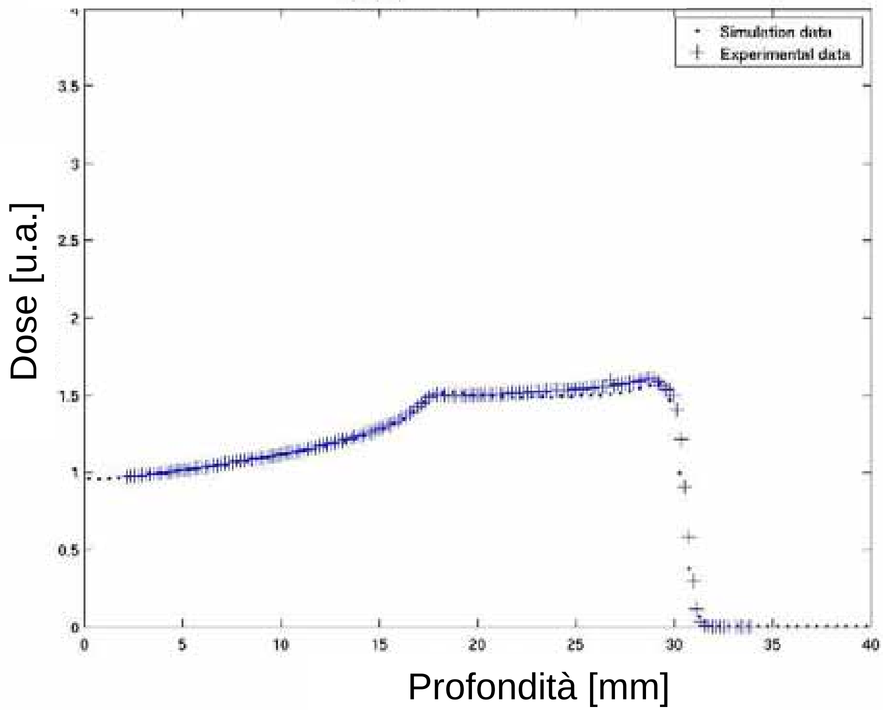


Parametri	Rapporto Picco-Plateau	FWHM [mm]	Range Pratico [mm]	Penombra90/10 [mm]
LowEn+Bertini	4.39	3.34	31.21	1.10
LowEn+Precompound	4.54	3.35	31.12	1.05
Sperimentale	4.54	3.59	31.09	0.8

STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS



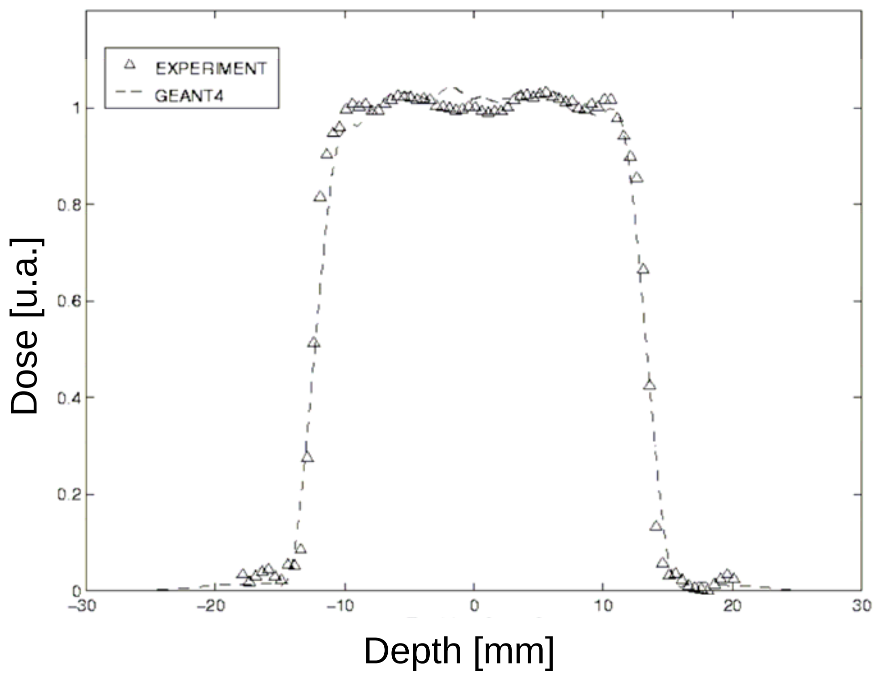
LowEnergy + Precompound



SOBP			
Dosimetric Parameters	Modulation Region $d_{90\%} - p_{100\%}$ (mm)	Penumbra $d_{90\%} - d_{10\%}$ (mm)	Pratical Range (mm)
Geant4 Simulation	11.85	1.15	31.25
Experimental data	12.35	0.95	31.30

STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

Experimental and Simulated Lateral dose distribution comparison

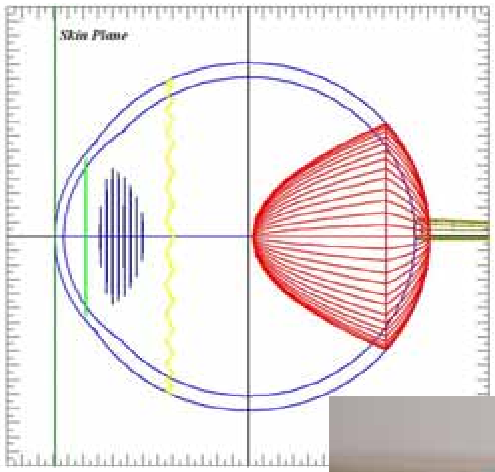


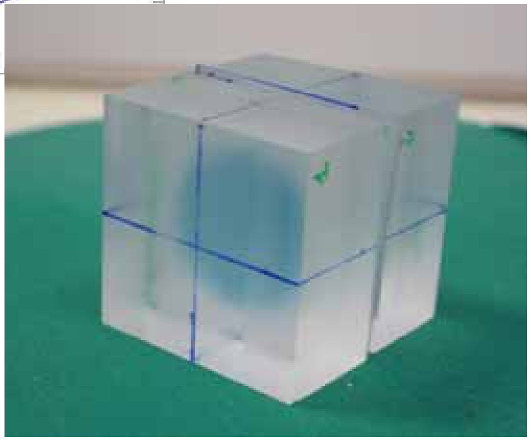
Parametri	W95% (mm)	Penombra Laterale DX	Penombra Laterale SX	Simmetria (%)	Omogeneità
Simulato	21.6	1.2	1.2	103	0.95
Sperimentale	22	1.1	1.2	102.5	0.91

LATED AND MEASURED RESULTS

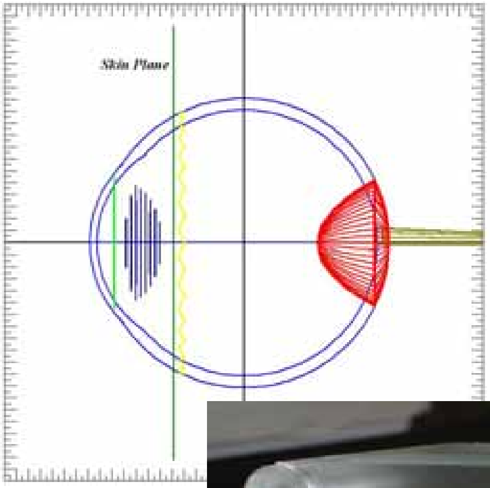
Two different configurations planned

NON Clinic Case



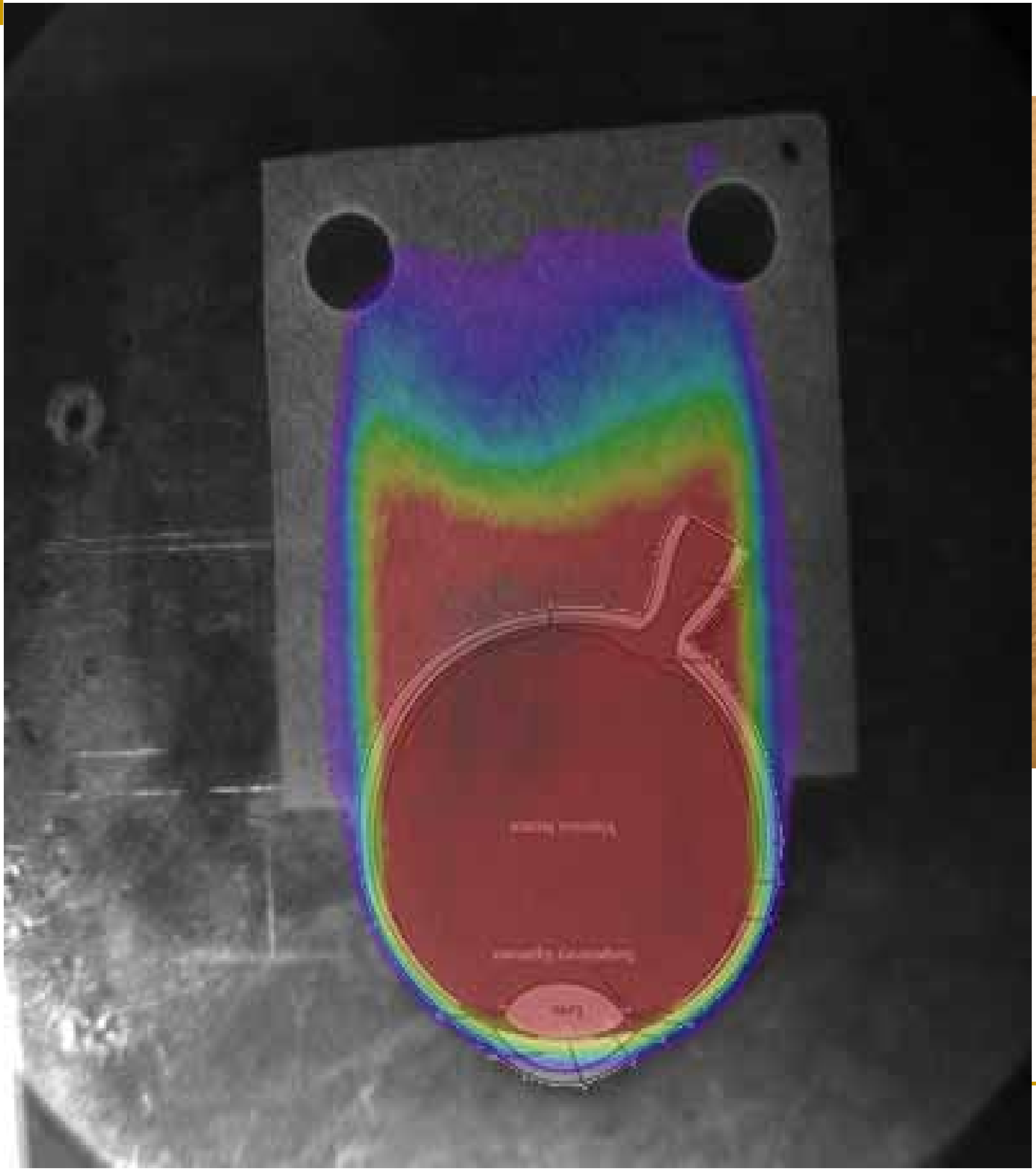


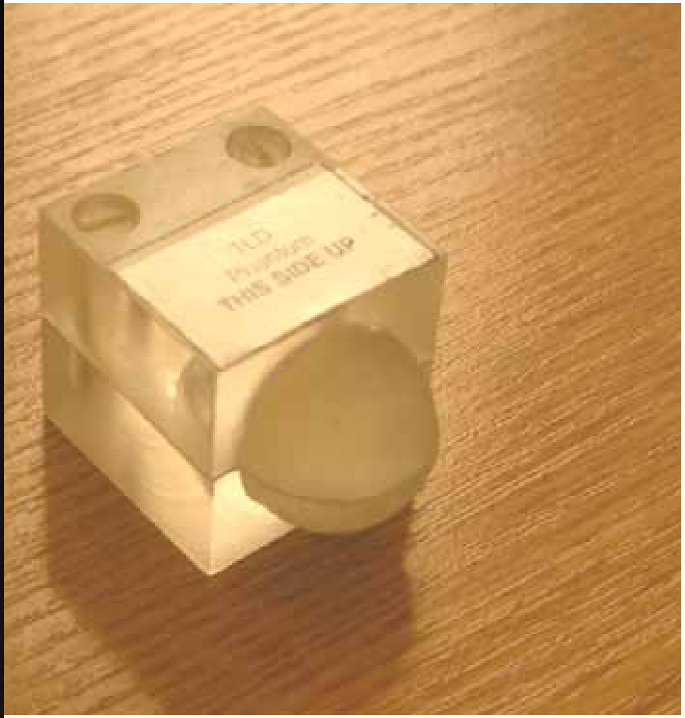
Clinical Configuration



The Comparisons between dose distribution are along and perpendicular to beam direction at different PMMA depth

STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS





GUIDELINE

J. Van Dyk et al.
Commissioning and quality assurance of treatment planning computers
Int. J. Radiat. Oncol. Biol. Phys. 26: 261-273, 1993

B. Fraass et al.
American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: Quality assurance for clinical radiotherapy treatment planning
Med. Phys. 25: 1773-1836, 1998

Any report, currently in literature related to the quality assurance of a TPS, NO introduces sections dedicated to proton beam radiotherapy

The guidelines traced by various authors are however of general nature, so we can extend the procedures to any treatment planning system in general

How compare Two dose distributions?

Analysis System used

Composite Analysis: Dose Difference, DTA e Gamma function

D. A. Low et al.

A technique for the quantitative evaluation of dose distributions

Med. Phys. 25: 656-661, 1998

NAT Distribution

N. L. Childress et al.

The design and testing of novel clinical parameters for dose comparison

Int. Radiation Oncology Biol. Phys. Vol. 56, N° 5, pp 1464-1479, 2003

NDD e MADD

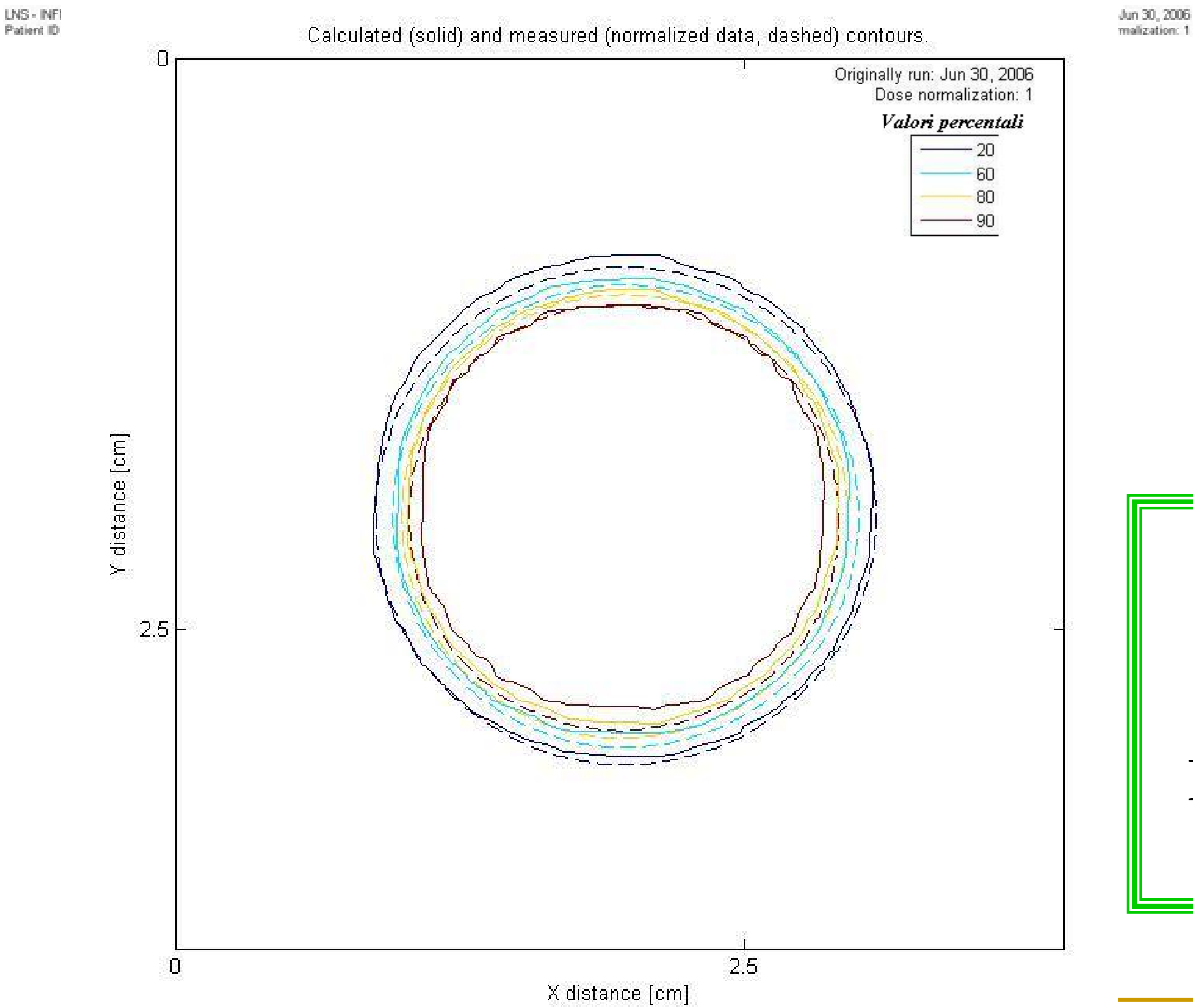
S. B. Jiang et al.

On dose distribution comparison

Phys. Med. Biol. 51: 759-776, 2006

STEP1: AGREEMENT BETWEEN SIMULATED AND MEASURED RESULTS

NON Clinical case (Perpendicular to beam direction)



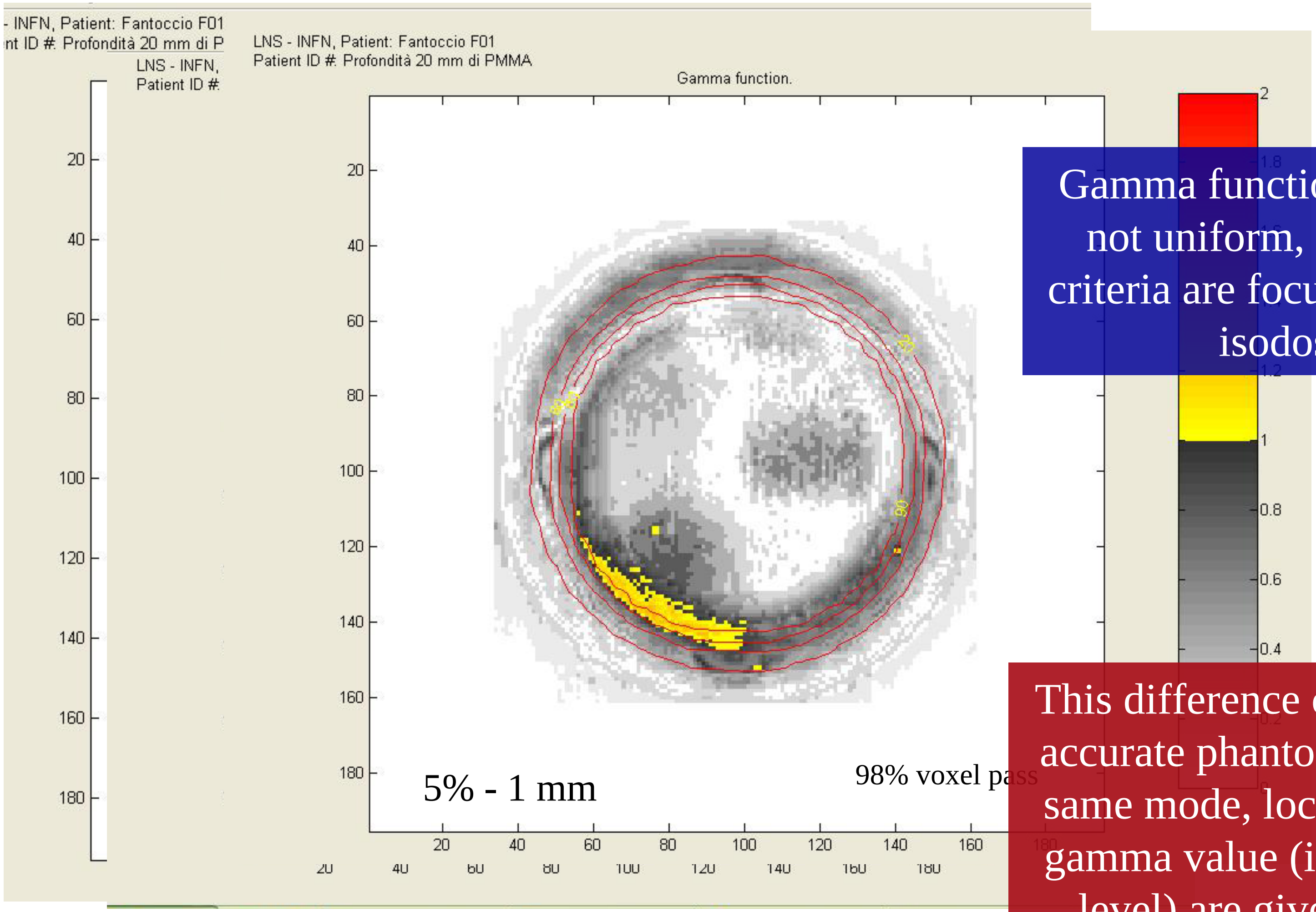
Direct Comparison between Isodoses levels

GOOD Agreement among TPS and Measured Data. Isodose level Maximum difference = 1 mm

STEP1: VALIDAZIONE DEL MC RISPETTO A DATI SPERIMENALI

NON Clinical case (Perpendicular to beam direction)

2D gamma function distribution



Gamma function distribution is not uniform, the values fails criteria are focused around 90 % isodose level

This difference can be due to a non accurate phantom centering. In the same mode, local spot near to unit gamma value (inside 90% isodose level) are given by a non ideal detector homogeneity

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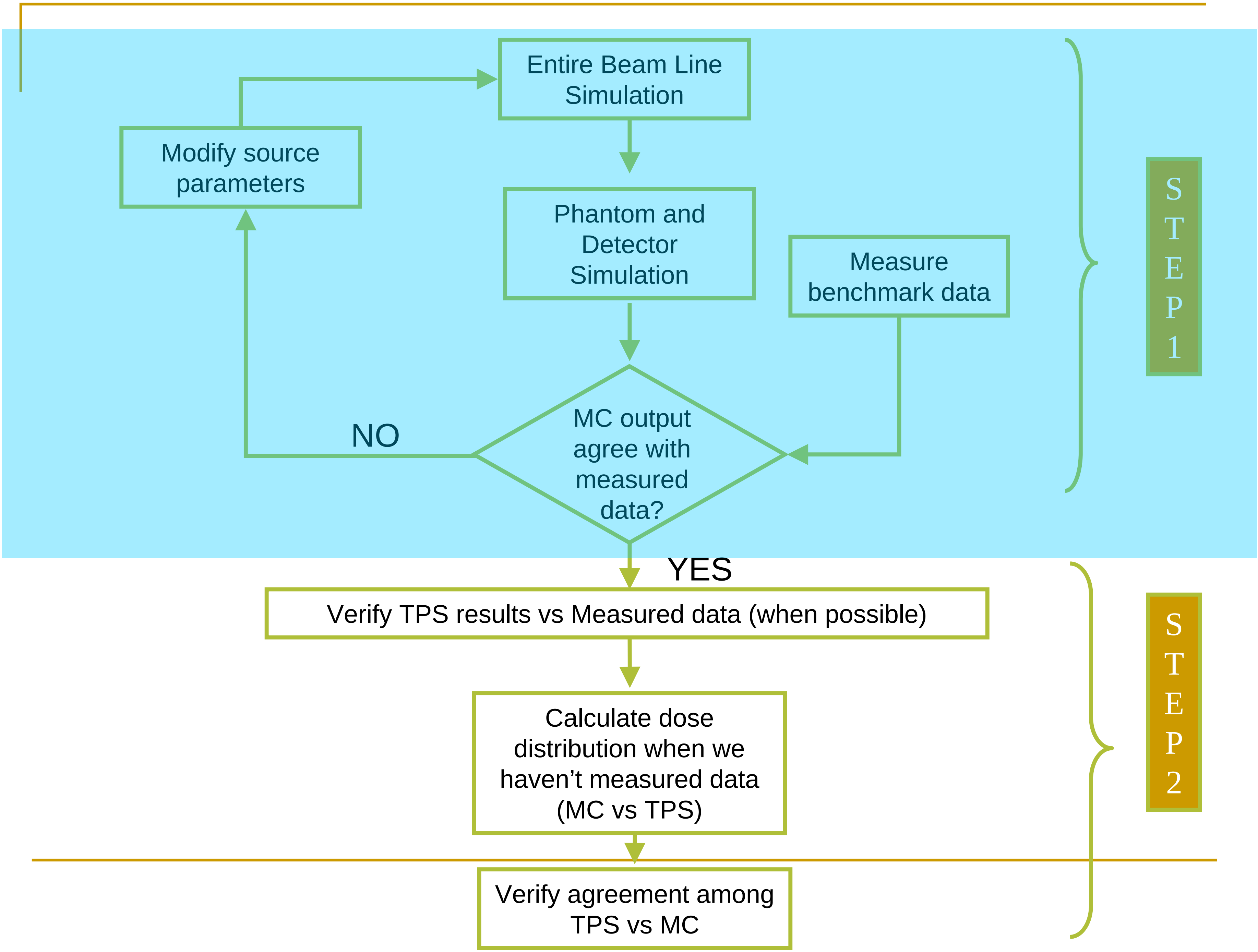
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MC output agree with measured data?
S T E P 1
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S T E P 2

STEP2: EYEPLAN COMMISSIONING

EYEPLAN

T. Miller, M. Goitien (1983)

M. Sheen (2000)

Many of its features apply to treatment planning program in general:

- Three – dimensional definition of the tumor volume and normal structures
- Possibility of delivering the treatment beam from any direction in space
- Provision of arbitrary viewpoints including a beam's eye point of view

INPUT NEED (configuration of Enviroment file)

2 geometric parameters

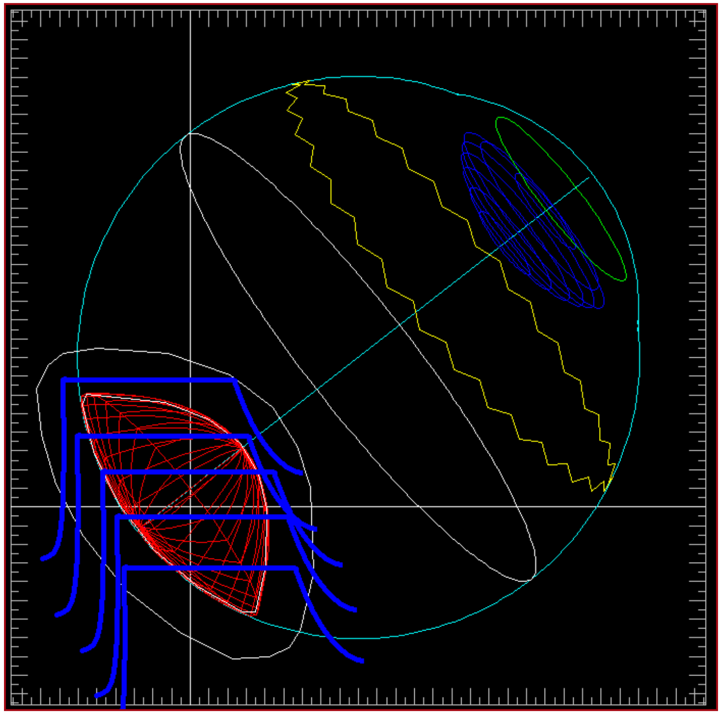
(Virtual source – isocenter, Final collimator – isocenter)

3 dosimetric parameters

(Later penumbra, dose distal fall-off (Range) and Proximal Bragg Peak Points

STEP2: EYEPLAN COMMISSIONING

Ultra Simplified Broad beam method using the dosimetric parameters (Enviroment file) to get out a non-divergent beam, large enough beam so that the relative depth-dose curve on the central axis does not depend on the field amplitude



Eyeplan reconstructs eye dose distribution so that isodose 90% enclose totally PTV, with a security Margin of 2,5 mm

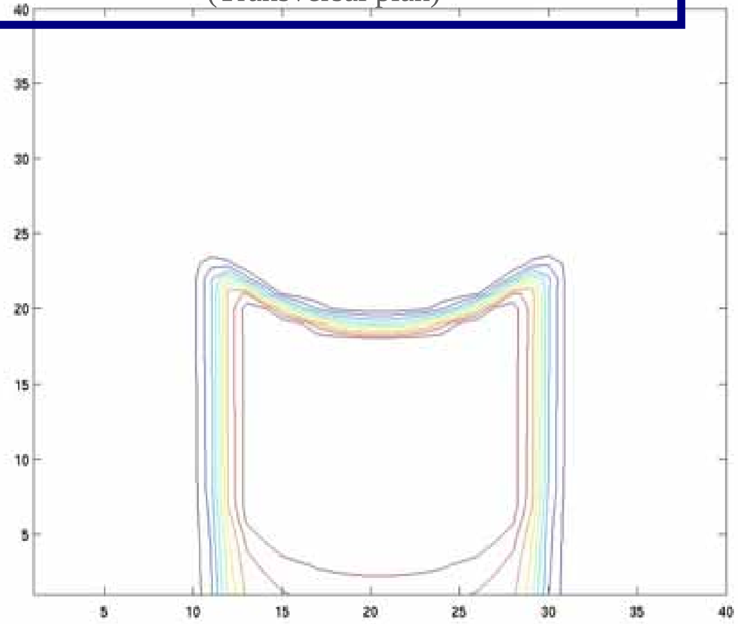
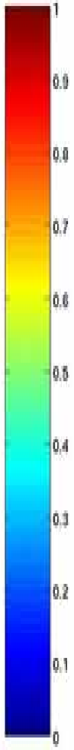
Eyeplan uses a dose plane divided in voxels (Variable dimension) to perform all 3D dose distribution in entire eye

There is no density measurement in Eyeplan, as it gives range and modulation in millimeters of whatever the eye material is. The density only makes a difference when you convert the measured range from the material you use to measure it. Eyeplan only uses one model of the beam penumbra and depth dose for all combinations of range and modulation

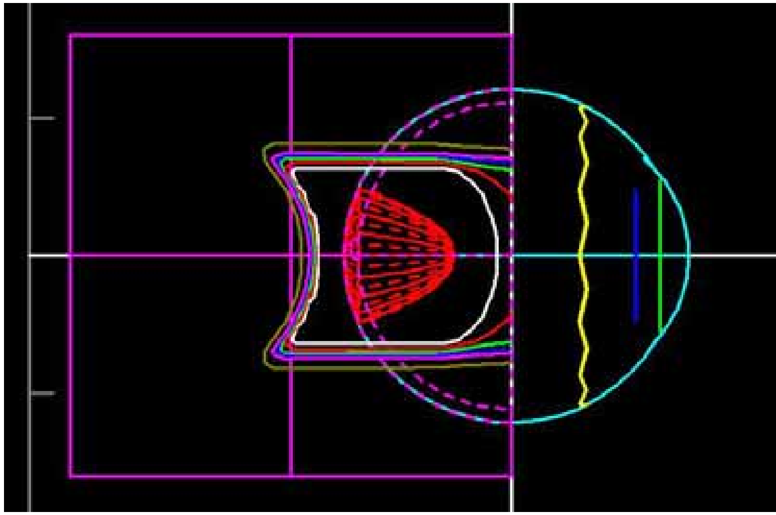
STEP2: EYEPLAN COMMISSIONING

3D EYEPLAN dose distribution

(Transversal plan)

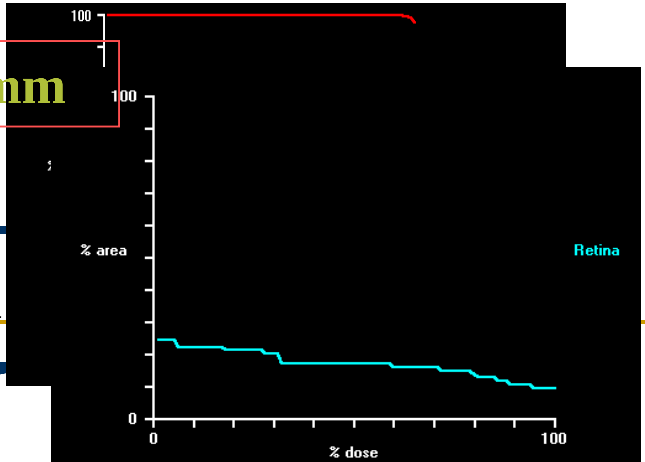



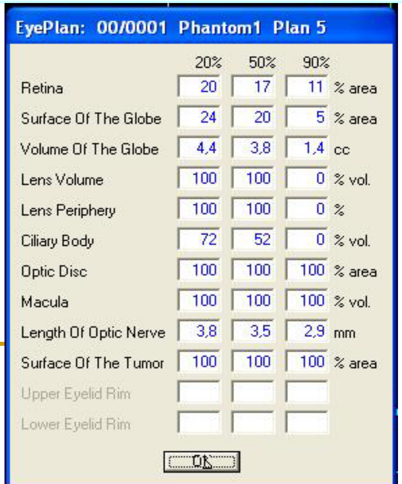
Calculation and Visualization of isodose curve in more eye section plane



Mean Spatial Resolution = 0.8 mm

Dose-Volume histogram (HDV) for more important eye structure and PTV

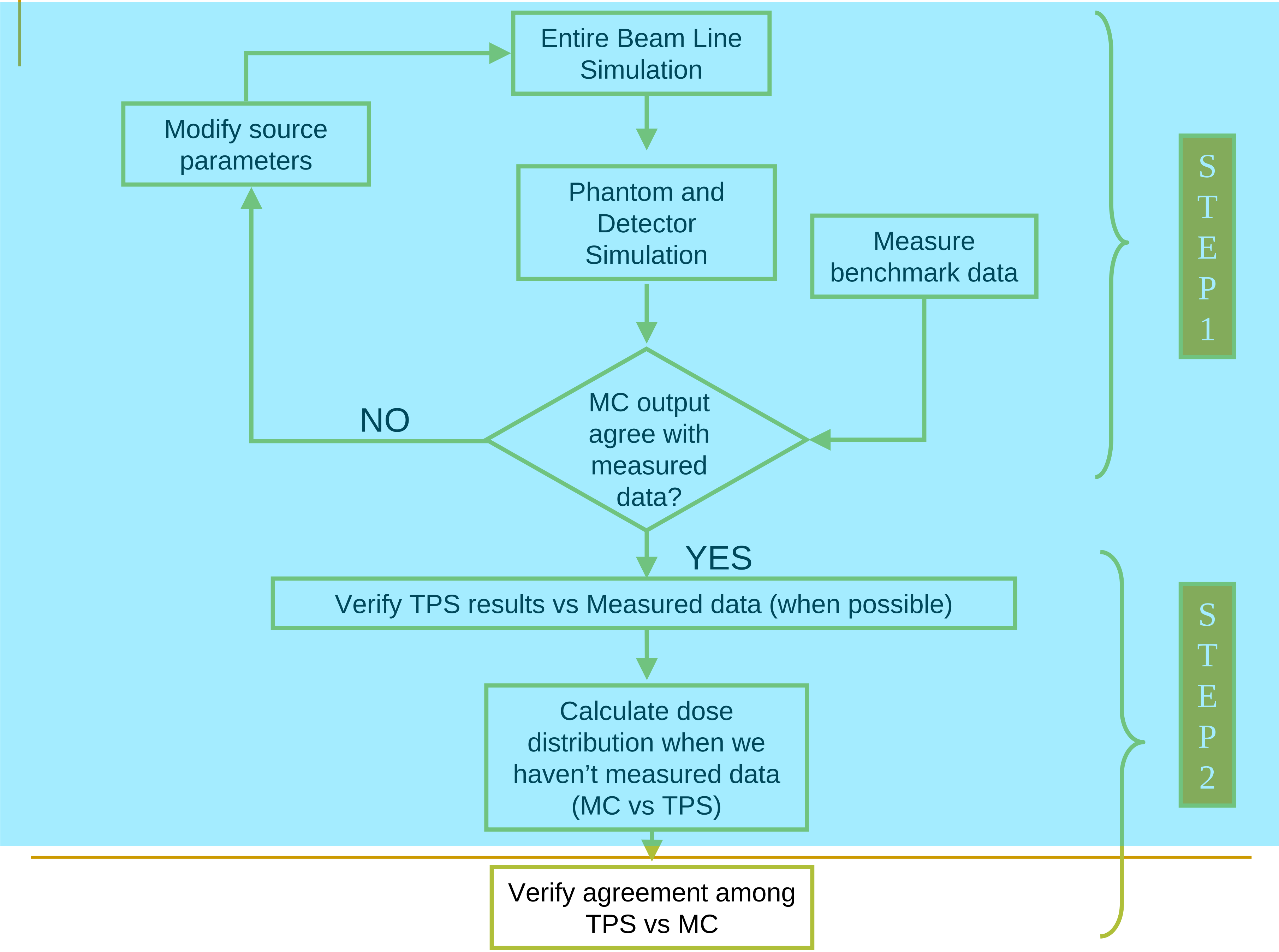




EyePlan: 00/0001 Phantom1 Plan 5

	20%	50%	90%	
Retina	20	17	11	% area
Surface Of The Globe	24	20	5	% area
Volume Of The Globe	4,4	3,8	1,4	cc
Lens Volume	100	100	0	% vol.
Lens Periphery	100	100	0	%
Ciliary Body	72	52	0	% vol.
Optic Disc	100	100	100	% area
Macula	100	100	100	% vol.
Length Of Optic Nerve	3,8	3,5	2,9	mm
Surface Of The Tumor	100	100	100	% area
Upper Eyelid Rim				
Lower Eyelid Rim				

OK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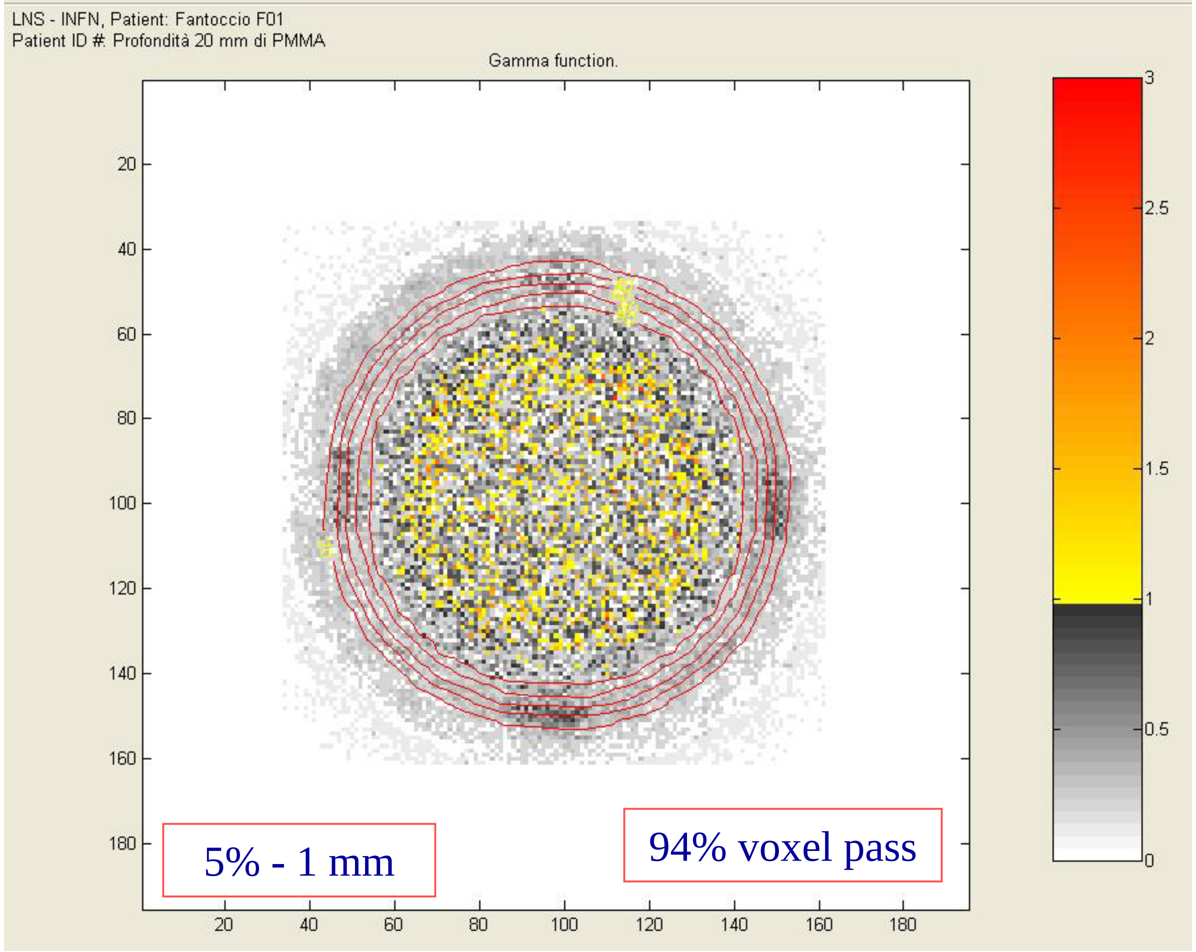
STEP 2: TPS vs Monte Carlo

NON Clinical case (Perpendicular to beam direction)



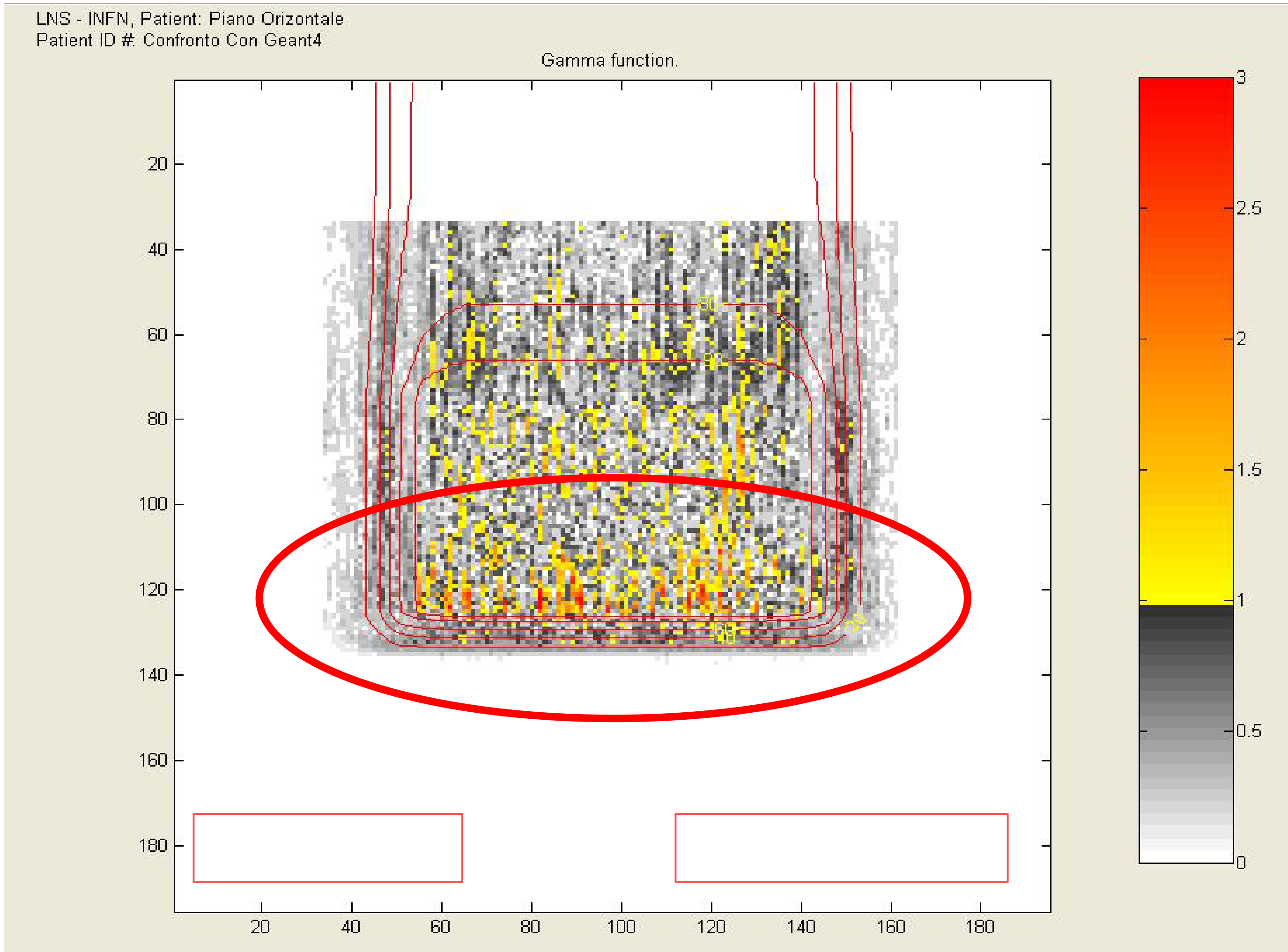
Geant confirms the initial perception about positioning error and film inhomogeneity.

The gamma voxel distribution, when the test fails, is uniform on the whole gamma function distribution inside the 90% dose level (Statistic fluctuations in the MC simulation)

STEP 2: TPS vs Monte Carlo

NON Clinical case (Along beam direction)

Direct Comparison between Isodoses levels



...ement TPS versus MC
... difference = 0.6 mm

...nge Difference
...dodose) < 0.2 mm

...es between 20% Isodose
...along beam direction
= 0.6 mm

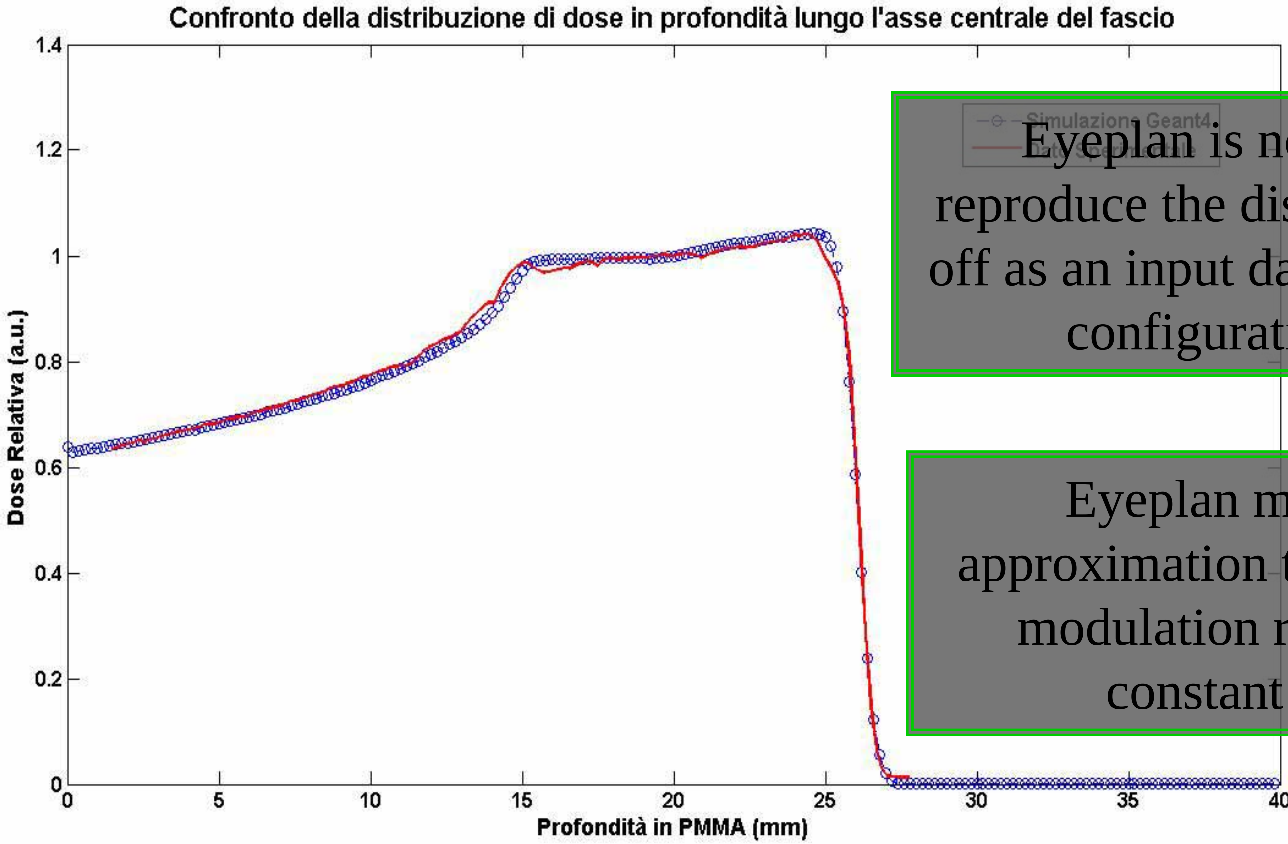
...hese differences????

STEP 2: TPS vs Monte Carlo

NON Clinical case (Along beam direction)

Only along beam direction there is experimental data (SOBP as input in Enviroment file configuration)

The accuracy of Monte Carlo simulations is superior to that of EYEPLAN

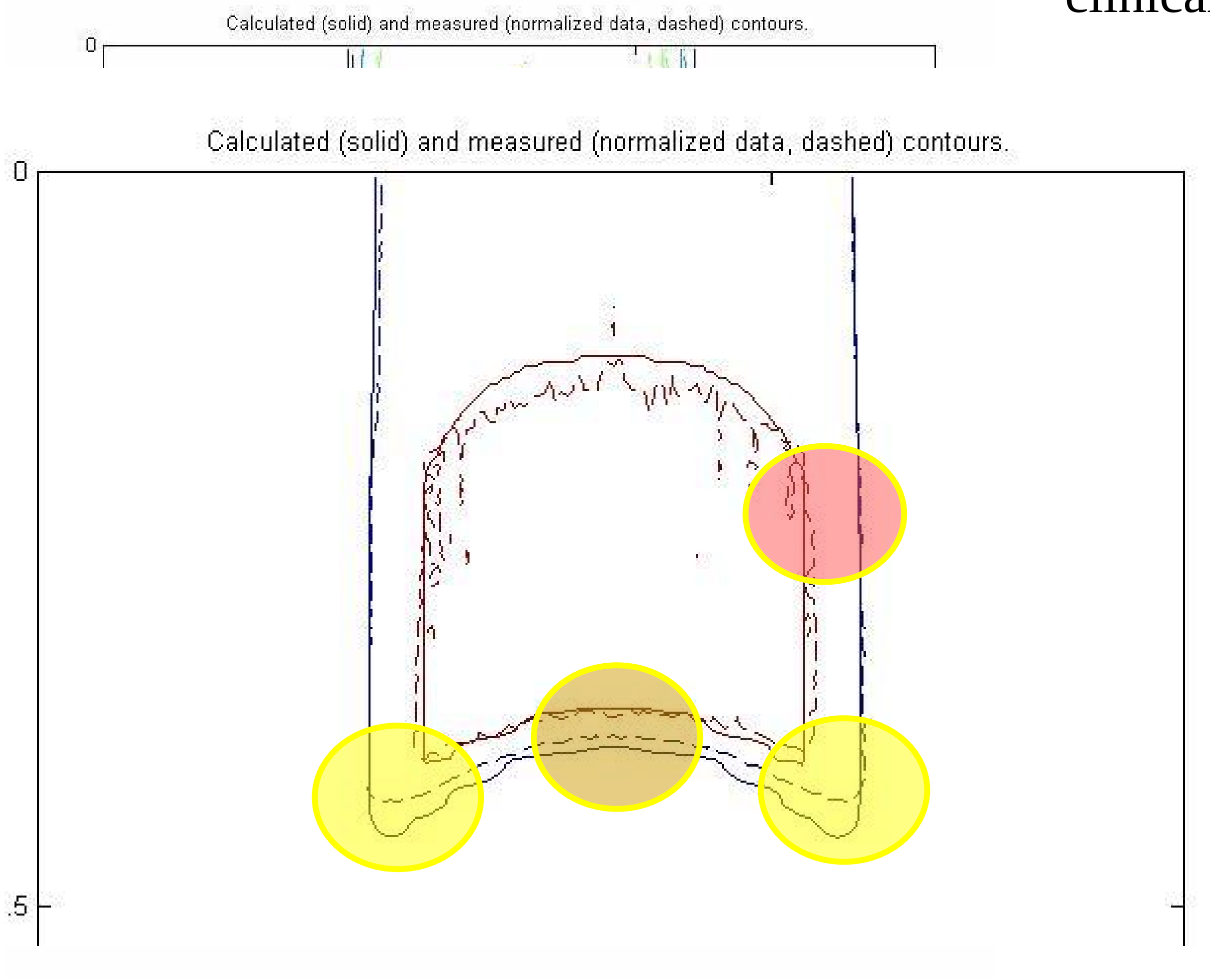


Eyeplan is not able to reproduce the distal dose fall-off as an input data in the TPS configuration file

Eyeplan makes an approximation the treatment modulation region to a constant value

STEP 2: TPS vs Monte Carlo

Clinical Configuration (Along beam direction)

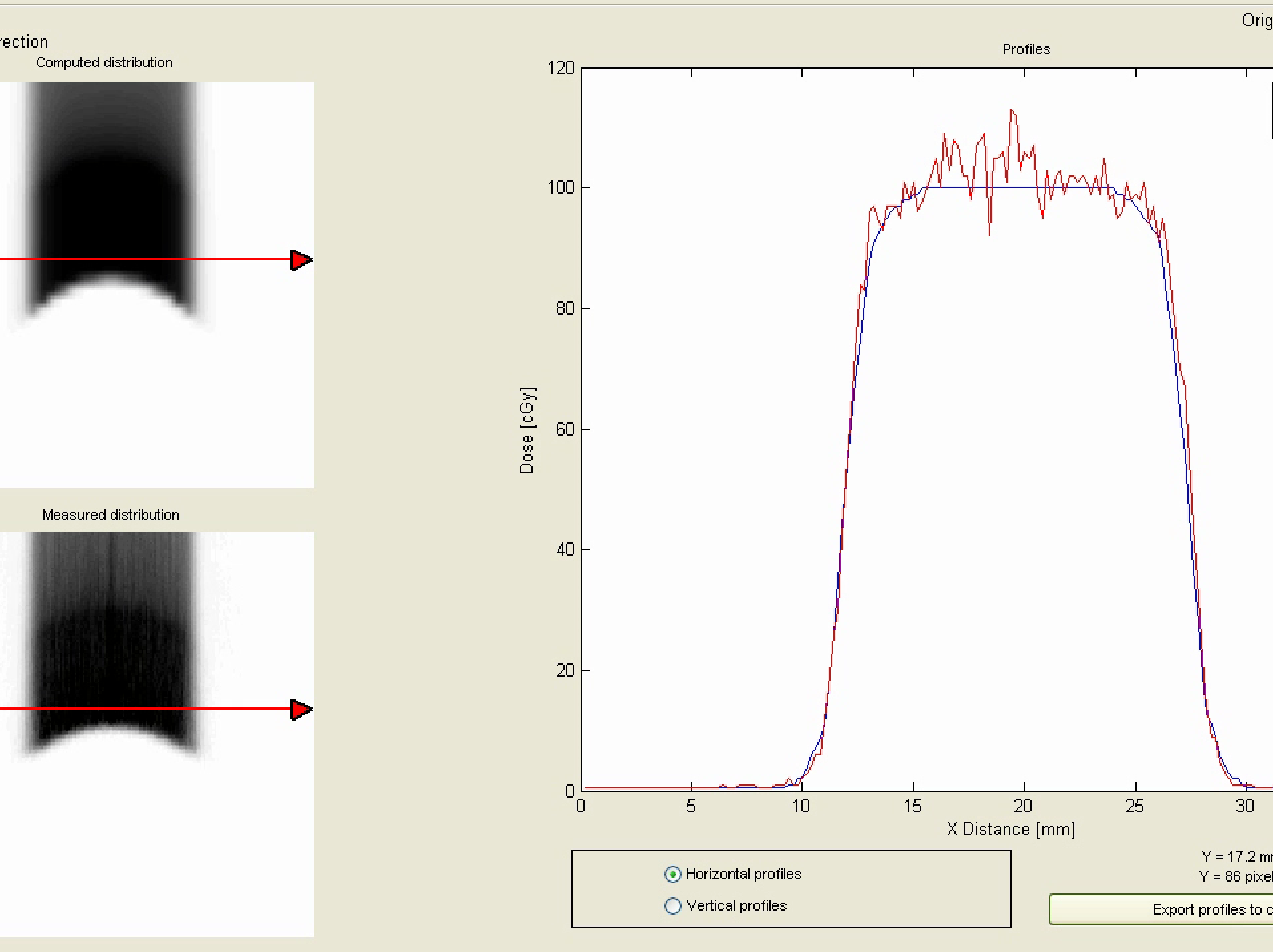


Eye structure complexity, in a real clinical case, can modify the results found?!

Range Difference (90% Isodose level) < 0.2 mm

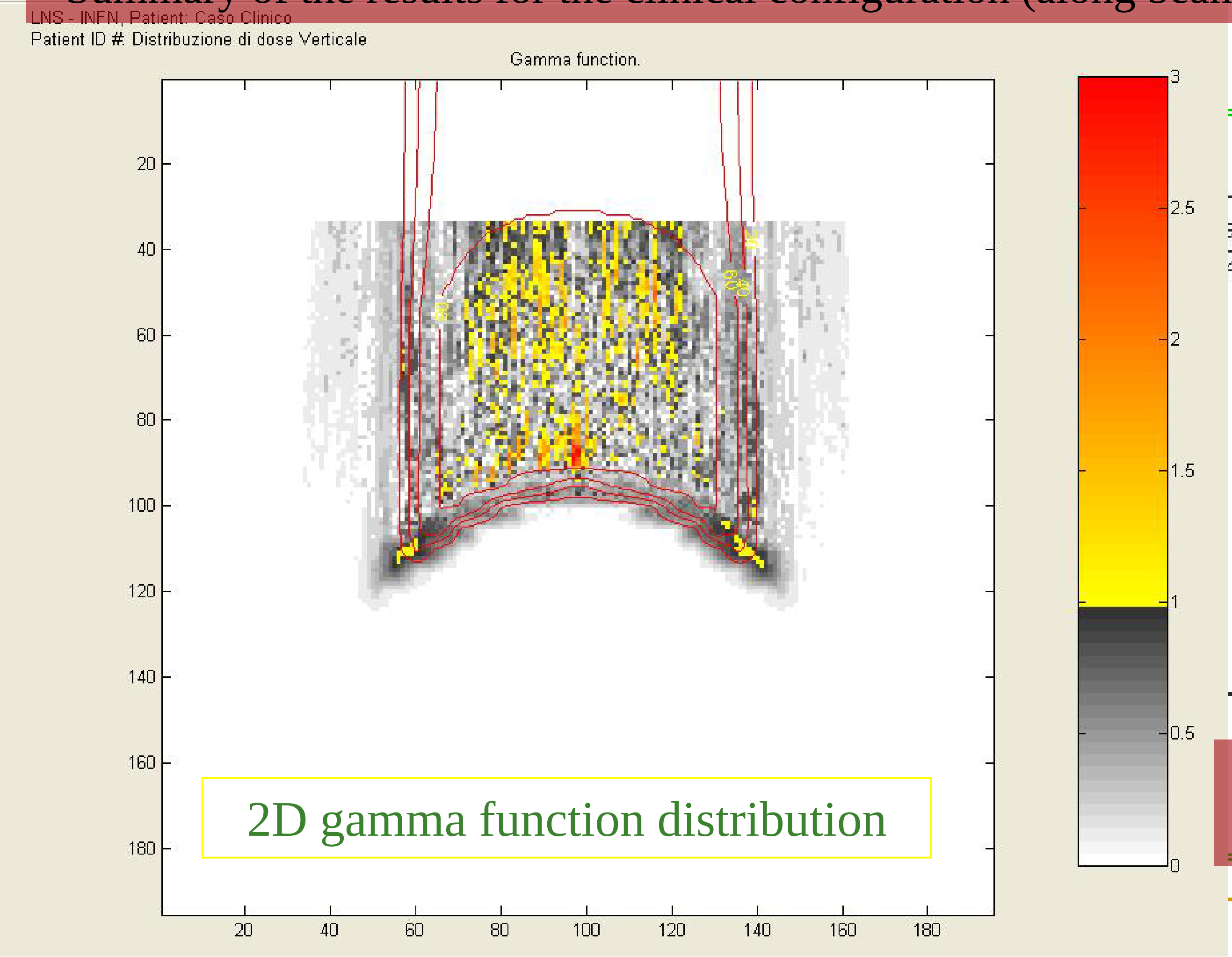
Difference in lateral penumbras < 0.2 mm

Eye structure emphasizes the maximum differences in dose distal fall-off calculation


Orig
rection
Computed distribution
Measured distribution
Profiles
Dose [cGy]
X Distance [mm]
0
20
40
60
80
100
120
0
5
10
15
20
25
30
Horizontal profiles
Vertical profiles
Y = 17.2 mr
Y = 86 pixel
Export profiles to c

Clinical Configuration (Along beam direction)

Summary of the results for the clinical configuration (along beam)



2D gamma function distribution

The discordances appear also in gamma distribution

DISCUSSION

Our results suggest that the GEANT4 Monte Carlo code is suitable to validation procedure

THE COMPARISON DEMONSTRATE SOME DIFFERENCES AMONG MC RESULTS AND TPS OUTPUT. THESE DIFFERENCES ARE DUE TO TPS LIMITS:

LOW SPATIAL RESOLUTION

ESTIMATE MAXIMUM DOSE TO CONSTANT VALUE

NO MULTIPLE SCATTERING

THESE MAXIMUM DISCREPANCIES ARE EQUAL TO THOSE REPORTED IN LITERATURE BY NEWHAUSER’S WORK (NON CLINICAL CONFIGURATION)

THE EYE STRUCTURE IN EYEPLAN INVOLVES A MORE INACCURACY. HOWEVER THE DIFFERENCES REVEALED ARE VERY CONTAINED AND CLINICALLY ACCEPTABLE

OUTLOOK

WE EXPECT THAT THESE TECHNIQUES WILL BE USED FOR NOZZLE DESIGN WORK, DOSE-PER-MONITOR-UNIT PREDICTIONS AND, EVENTUALLY, ROUTINE TREATMENT PLANNING

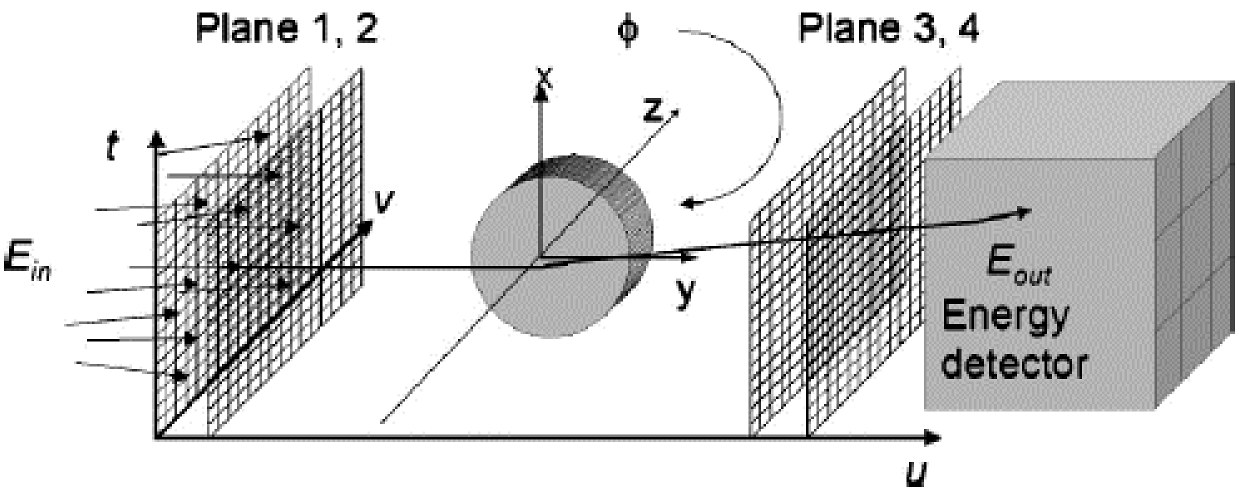
TO RAISE TPS ACCURACY (Analytic and Monte Carlo):

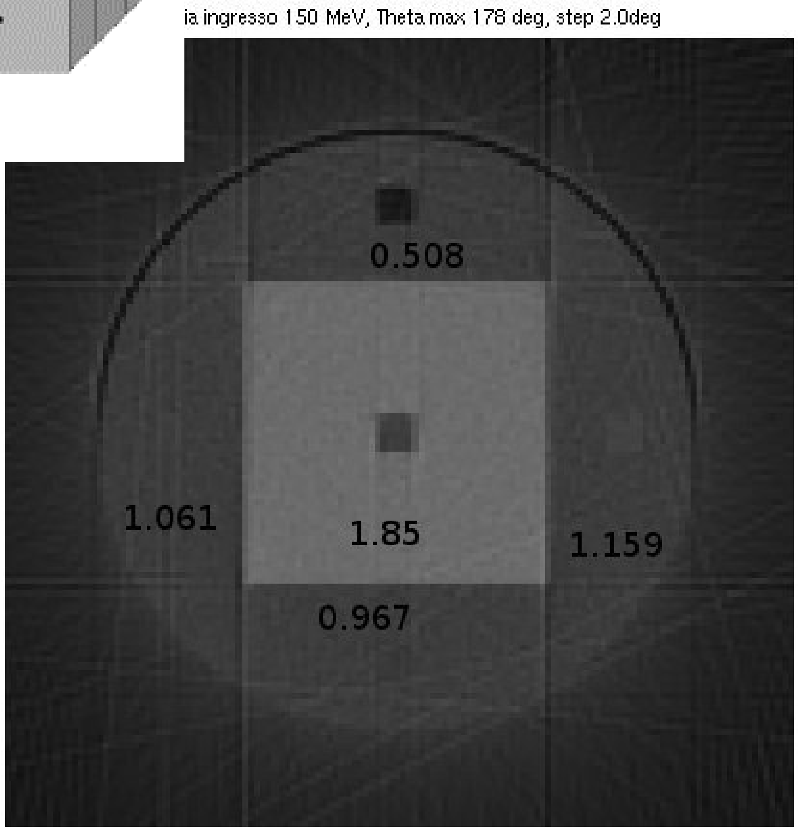
- Study of Multiple scattering effect (especially in more high energy beams)
- Imagines DICOM (anatomical more accurate than mathematical reconstruction)
- pCT e no xCT for DICOM imagines

TO REDUCE COMPUTATION TIME

- Optimization of the simulation processes
- To use a “more and more-node” cluster system

OUTLOOK


Plane 1, 2
ϕ
Plane 3, 4
x
z
t
v
E_{in}
y
E_{out}
Energy detector
u


ia ingresso 150 MeV, Theta max 178 deg, step 2.0deg
0.508
1.061
1.85
1.159
0.967

Supported by


Thank you
for your attention