Radiation and Particle Therapy

Alessio Bocci
DITANET Experienced Researcher

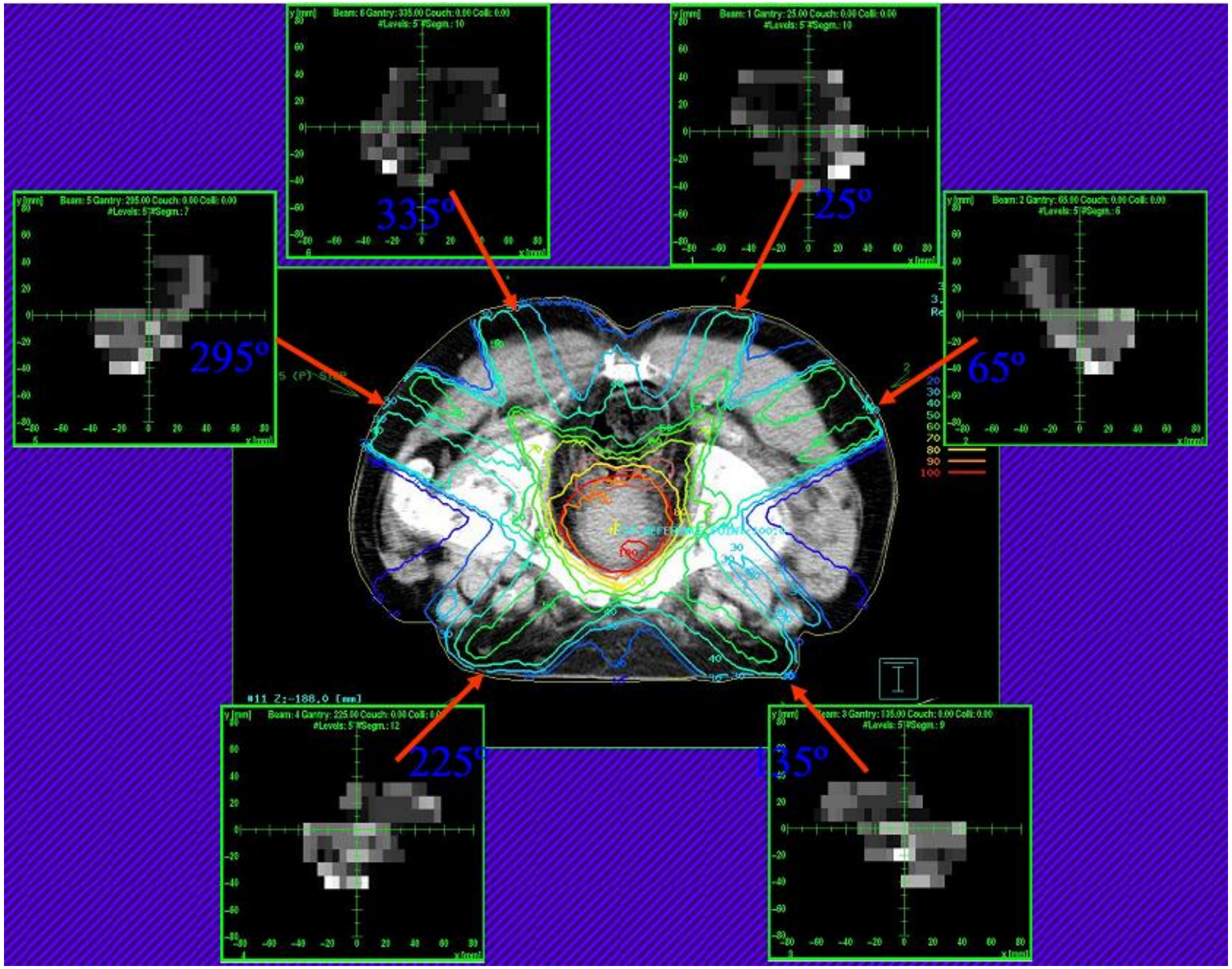
Outline

- FIRST YEAR PROJECT:
- Complex radiation therapy treatments - IMRT
- RADIA2 project - experimental set-up
- Measurements and results
- Conclusions I

- SECOND YEAR PROJECT:
- Particle Therapy: FIRST experiment at GSI
- Experimental set-up
- Conclusions II

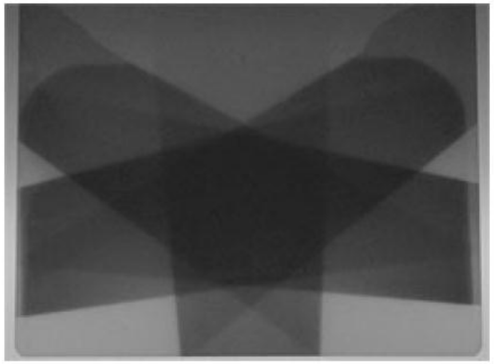
Intensity Modulated Radiation Therapy

Many beam directions and entrance points
for conformal doses distributions
modulating in space the fluence of each radiation field



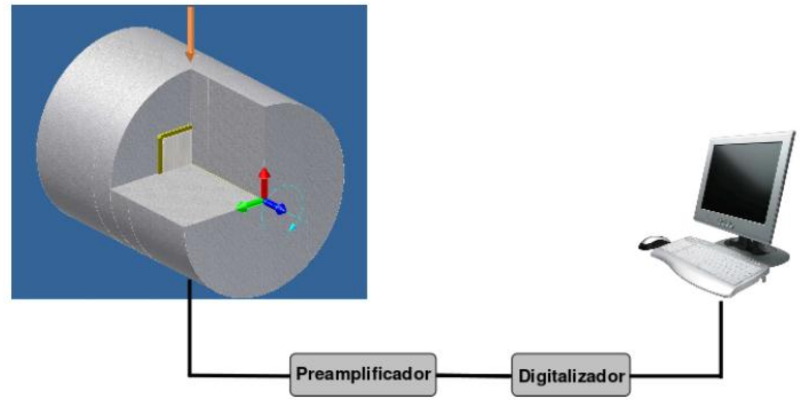
New detection systems

Traditional detectors



Radiographic films

New detection systems



	Film dosimeters	2D commercial digital detectors	New detection systems
On-line	no	✓	✓
Spatial resolution	✓	poor	✓
2D detectors	✓	✓ Not monolithic!	✓
Axial plane	✓	no	✓

Our project is dedicated to develop a **new detection system** that **enhance the traditional ones**, and that is able to verify in a simple and accurate way complex treatment planning

inexpensive
radiation hard
easy to use

RADIA2 Project Si-DETECTOR

• Commercial silicon detector

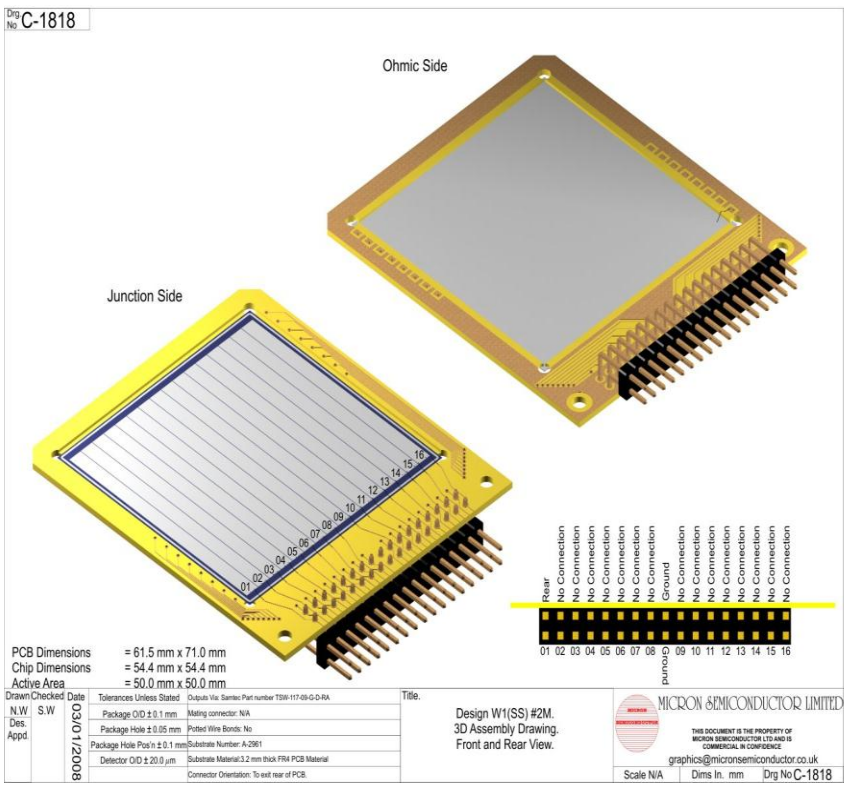
•Low cost

Normally used on particle detection **(see tomorrow Ziad Abou-Haidar talk)**

(W1 type from Micron Semiconductor Ltd)

• Single sided 16 strips (3.1 mm pitch)

• Active area 50 x 50 mm² & 500 µm thick



RADIA2 Project – Collaboration

Z. Abou-Haidar[1], M. A. G. Alvarez[1], R. Arrans[3], A. Bocci[1],
M. A. Cortes-Giraldo[2], J. M. Espino[2], M. I. Gallardo[2], A. Perez Vega-Leal[4]
F. J. Perez Nieto[5], J. M. Quesada[2]

1. DITANET group @ National Accelerator Centre (CNA)
2. Department of Atomic, Molecular and Nuclear Physics (FAMN), University of Seville
3. Virgen Macarena University Hospital, Seville
4. School of Engineering, University of Seville
5. Instalaciones Inabensa S.A.

A. Bocci et. al., Empirical characterization of a silicon strip detector for a novel 2d mapped method for dosimetric verification of radiotherapy treatments, *Radiotherapy and Oncology*, Volume 99, Supplement 1, May 2011, Page S172

A. Bocci et. al., A silicon strip detector for a novel 2D dosimetric method for radiotherapy treatment verification submitted to NIM-a (October 2011)

M. A. Cortes-Giraldo et al. , "Geant4 Simulation to Study the Sensitivity of a MICRON Silicon Strip Detector Irradiated by a SIEMENS PRIMUS Linac", Progress in Nuclear Science and Technology, in press (2011)

LINAC accelerator

University Hospital Virgen Macarena
(Seville, Spain)

Siemens PRIMUS linac dual energy machine operating at **6 MV photon mode**

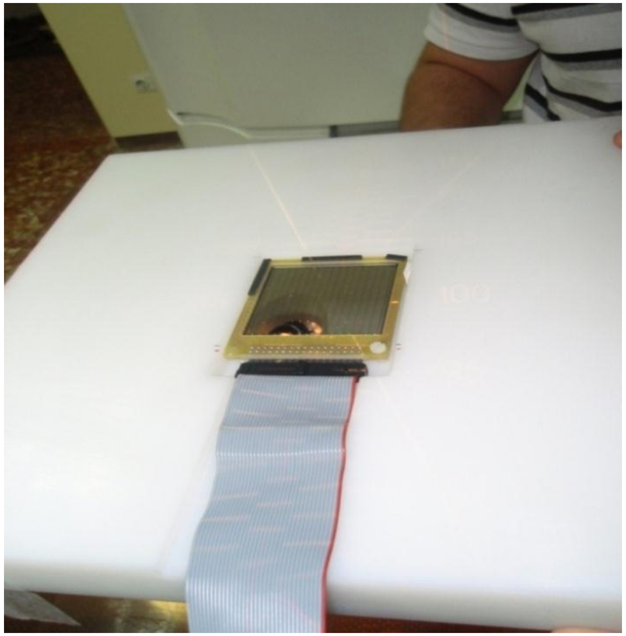
A treatment planning system TPS (Philips Pinnacle) was used to calculate dose distributions. Calculations were compared to experimental data.

Experimental Set-up

Two phantoms prototypes were designed and built

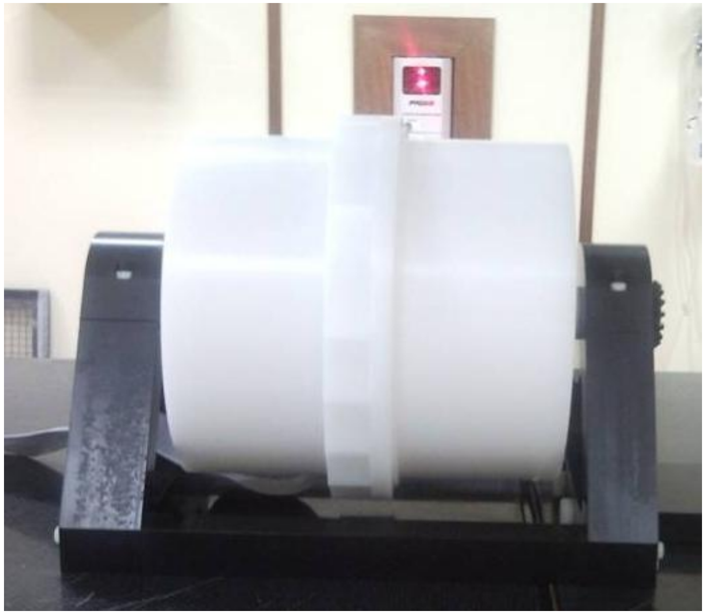
Polyethylene slab material

1. A slab phantom for:
detector characterization
(sensitive area perpendicular to the beam direction)



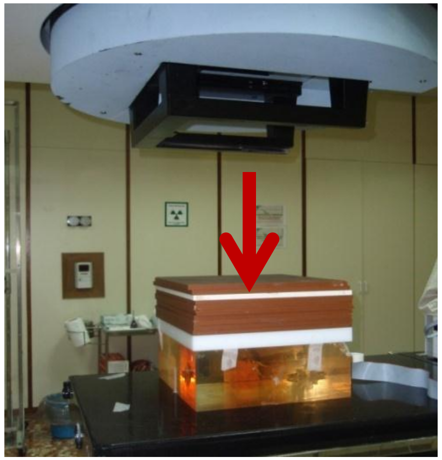
Cylindrical phantom

2. A cylindrical phantom for:
angular response measurements &
2D treatment plans verification in the axial plane



Measurements with the slab phantom

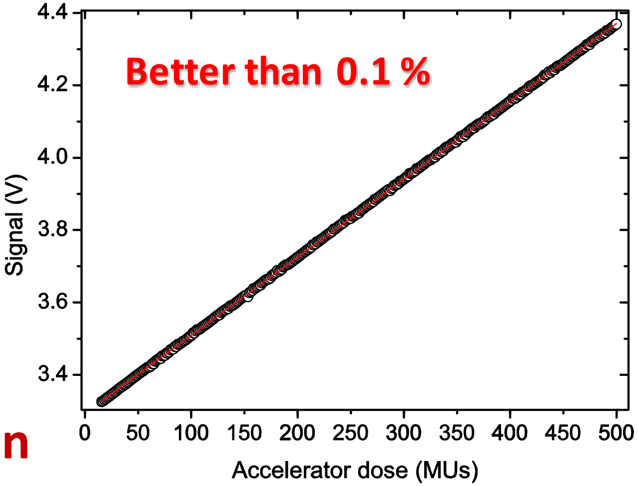
Set-up 1:
SSSSD perpendicular to the beam direction



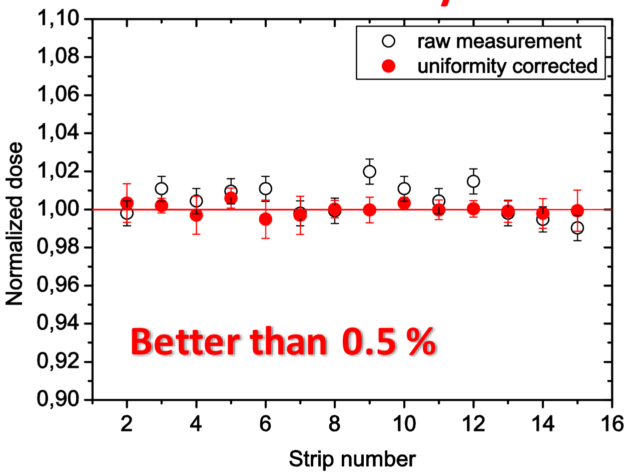
- **Linearity**
- **Uniformity**
- **Percent Depth Dose**
- **Penumbra**

Suitable for IMRT verification plans

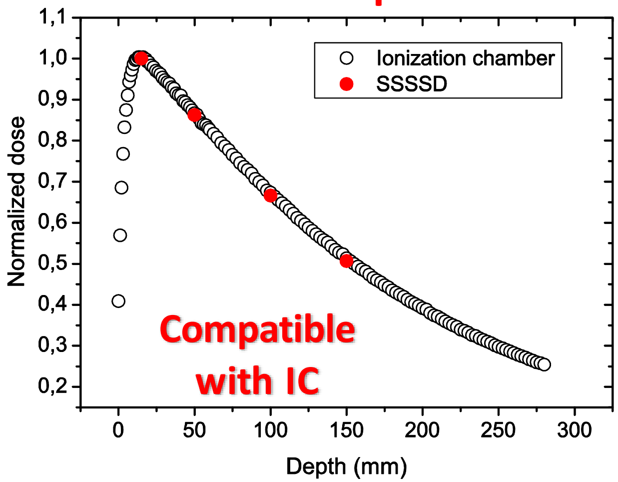
Linearity



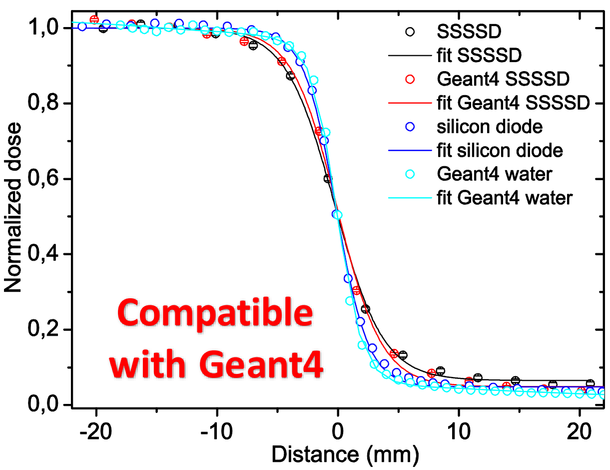
Uniformity



Percent Depth Dose



Penumbra



Cylindrical phantom: angular response

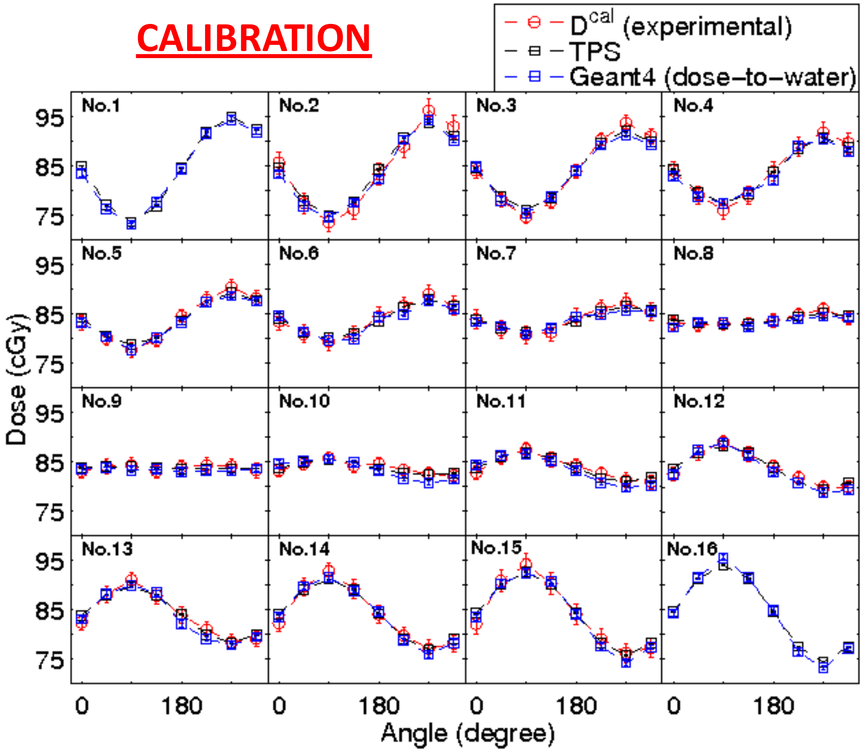
Cylindrical phantom:

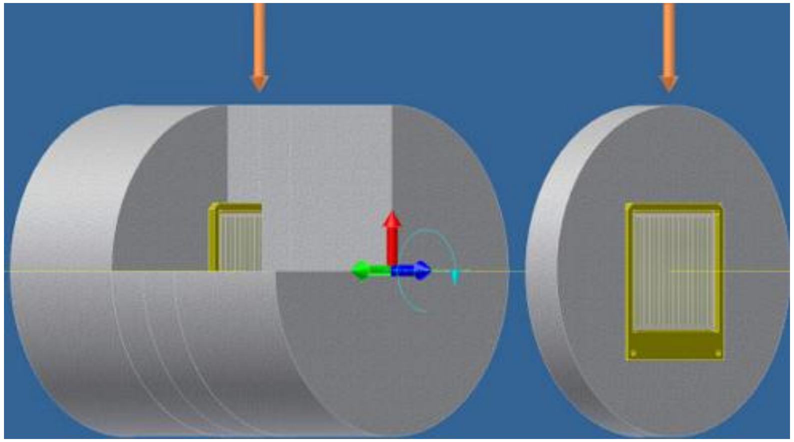
- The detector was housed in the axial plane

This condition is close to the one used in clinical applications

- Measurements of the angular response was obtained

CALIBRATION





Results:

- **Experimental data: response is independent of angular irradiation and of strip number**
  Constant calibration factors
- **CALIBRATION: relative difference between the calibrated dose and TPS calculations are better than 2 %**
- **Geant4 simulations: compatible results with respect to TPS and to experimental data**

Conclusions I

- Radiation Therapy : main objective was to characterize and benchmark a new detection system based on a Si-strip detector dedicated to 2D dose measurements in the axial plane of a cylindrical phantom
- SSSSD characterization: the prototype is suitable for IMRT verification plans (remarkable linearity, uniformity, PDD)
- The angular response in the axial plane compared to TPS calculations was independent of the irradiation angle and of strip number. Final calibration with respect to TPS gives differences smaller than 2 % for all the strips
- The system is patent pending

  OEMP PATENT number P201101009
- Future: work is in progress in order to obtain a 2D dose maps from experimental data using an in-house developed reconstruction algorithm based on Radon Transform

PARTICLE THERAPY: the “FIRST” EXPERIMENT @ GSI

Fragmentation processes relevant on hadron-therapy

FIRST stands for:

Fragmentation of Ions Relevants for Space and Therapy

The collaboration

INFN: LNF,LNS,Milano,Roma2,Roma3,Torino (ITALY): G.Cuttone, C.Agodi, G.Battistoni, G.A.P.Cirrone, M.De Napoli, E.Iarocci, A.Mairani, V.Monaco, M.C.Morone, A.Paoloni, V.Patera, G.Raciti, E.Rapisarda, F.Romano, R.Sacchi, P.Sala, A.Sarti, A.Sciubba, E.Spiriti, C.Sfienti

DSM/IRFU/SPhN CEA Saclay, IN2P3 Caen, Strasbourg, Lyon (FRANCE): S.Leray, M.D.Salsac, A.Boudard, J.E. Ducret, M. Labalme, F. Haas, C.Ray

GSI (GERMANY): M.Durante, D.Schardt, R.Pleskac, T.Aumann, C.Scheidenberger, A.Kelic,M.V.Ricciardi, K.Boretzky,M.Heil,H.Simon, M.Winkler

ESA: P.Nieminem, G.Santin

CERN: T.Bohlen

CNA/USE (SPAIN): A.Bocci, M.Alvarez , Z. Abou-Haidar (DITANET group) J.M.Quesada, M.A.G.Cortes, J.P.Fernandez (USE)
(software)

Politecnico Torino: F.Iazzi, K. Szymanska-Mertens, + PhD student (TOFWALL)

Sassari/Cagliari INFN: M.Carpinelli, B.Golosio, P.Oliva (PCAL)

Strasbourg: C. Finck, F.Haas, L. Stuttge, M. Rousseau (VERTEX)

Motivation and Objective

➢ Motivation:

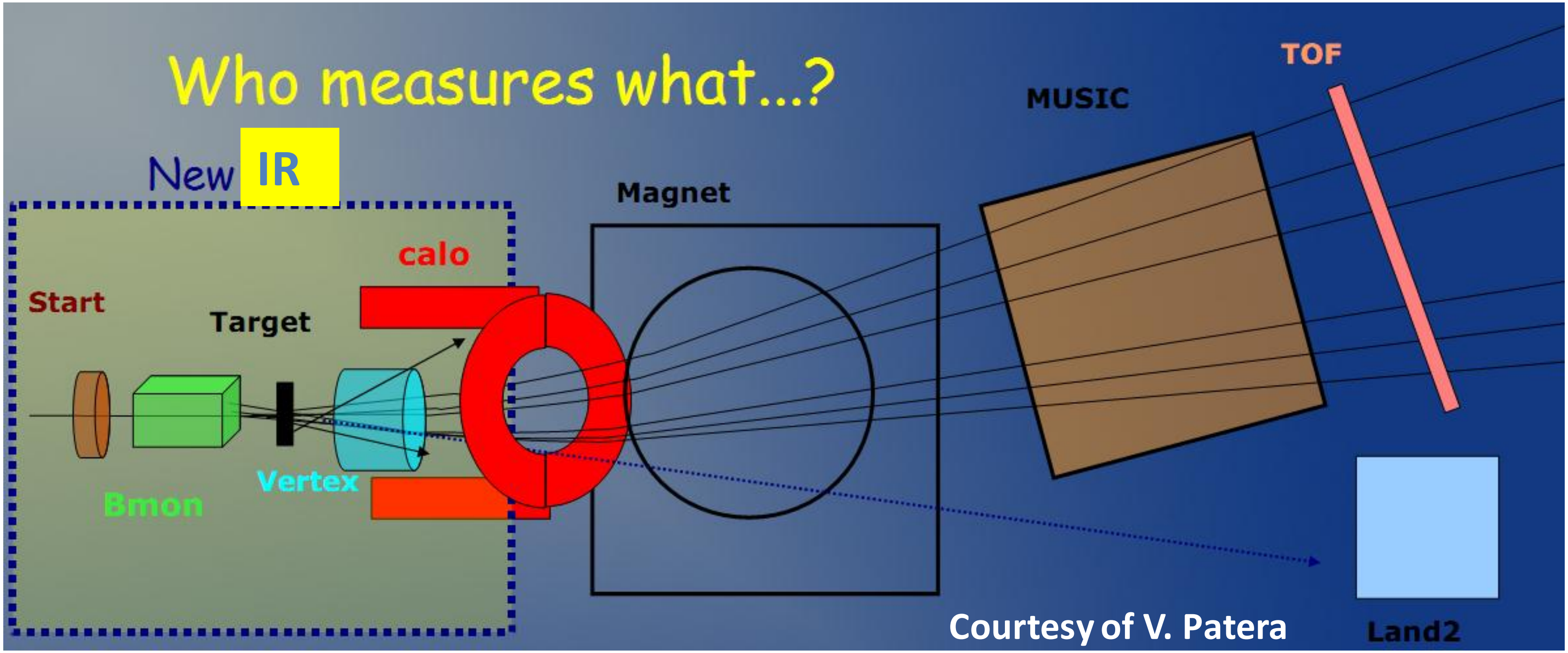
- Carbon ions combine significant advantages with respect to radiation therapy with photons, both in the dose-depth deposition pattern physics and in the biological effectiveness

➢ Objective

- Nuclear fragmentation cross-sections are necessary for accurate treatment planning calculations for heavy-ion radiotherapy

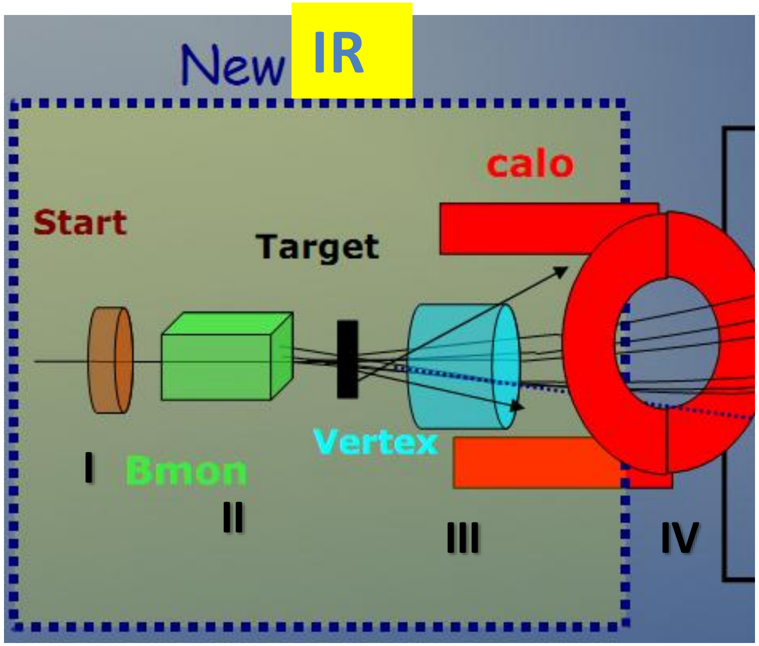
The FIRST experiment measured double-differential cross sections of carbon ions in the energy range 100-500 MeV/nucleon for improving transport codes used in cancer therapy

Experimental set-up



The **FIRST** experiment consists of different sub-detectors divided in **two main blocks**: the **interaction region** and the **large detection region**

Experimental set-up



Interaction Region

Name	Type	Function
Interaction Region		
Start Counter	Scintillator	Start of TOF
Beam Monitor	Multi-wire drift chamber	Beam direction and impact point on target
Vertex Detector	Silicon Pixel	Fragment emission angle from target
KENTROS	Scintillator	TOF, ΔE and coarse spatial resolution

I. **Start Counter Scintillator :** ToF measurements

II. **A Drift chamber Beam Monitor:** beam trajectory and impact point on the target

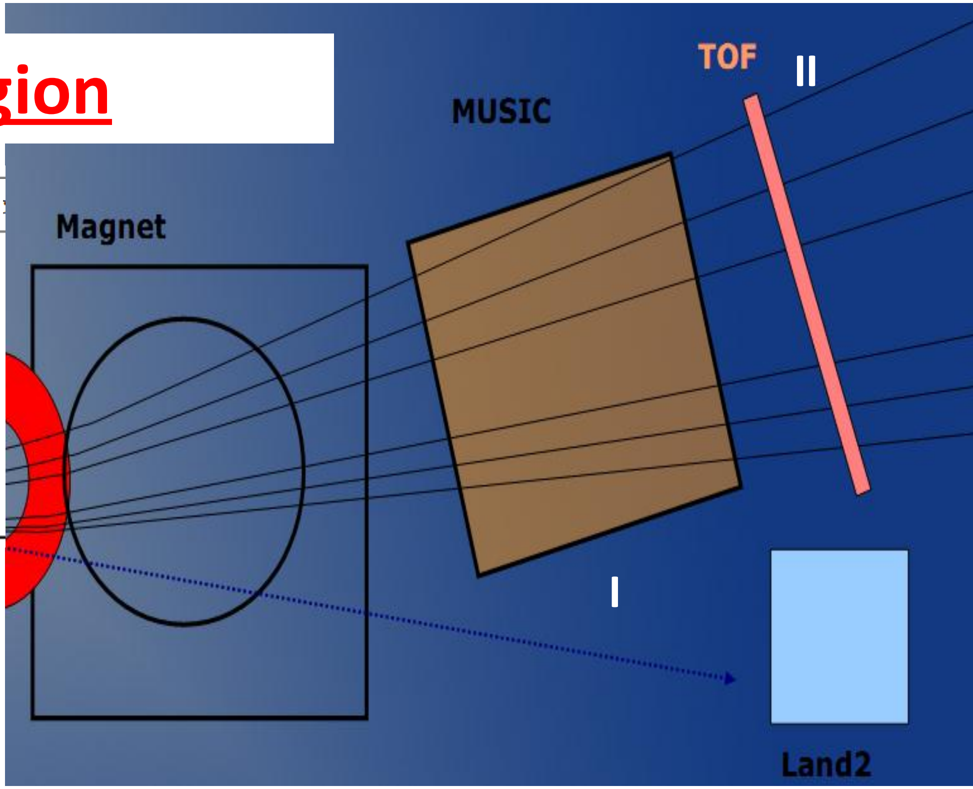
III. **A pixel silicon Vertex Detector:** tracks the charged fragments emerging from the target

IV. **A thick scintillator Proton Tagger:** detects the large angle light fragments

Experimental set-up

Large detection region

Large Detector Region		
TPC-MUSIC IV	Time projection chamber	ΔE, Fragment fragment tracking after bending
TOFWALL	Scintillator	Stop of TOF, ΔE and coarse spatial resolution
Veto Counter	Scintillator	Trigger veto, TOF, ΔE
LAND2	scintillator	Neutron detector, TOF, ΔE and coarse spatial resolution



Fragments enter in the large detector region

I. **A Large volume Time Projection Chamber (MUSIC IV): measures tracks direction and energy release**
II. **A large area system of scintillator (ToF-WALL): provides the measurement of the impinging point and the arrival time of the particles**

Software Reconstruction

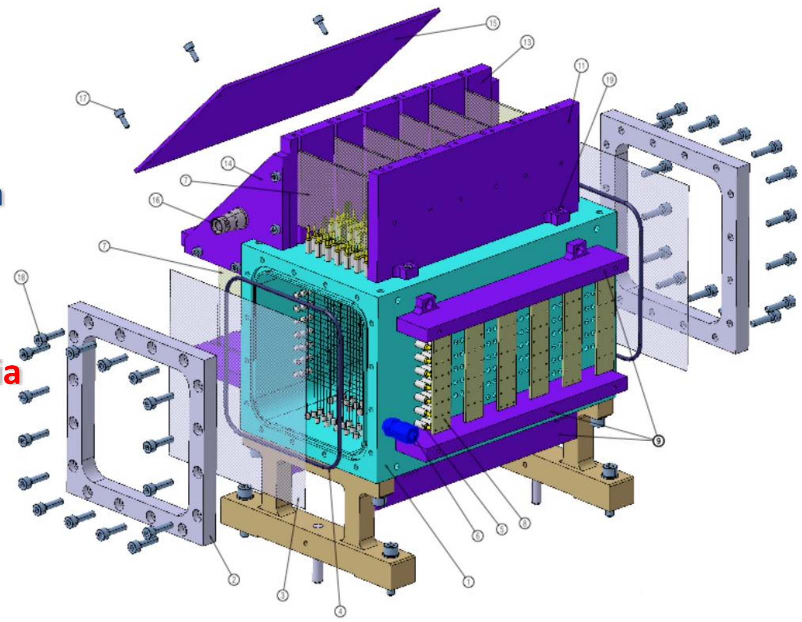
The reconstruction software:

1. Reconstruct the **sub-detector informations**
2. Perform a full **event track fit** of the **fragmented particles**

Drift Monitor Beam Chamber

Drift Chamber
Data Analysis Team

M. Alvarez
A. Bocci
J. P. Fernandez Garcia
M. C. Morone
V. Patera
A. Sarti



Chamber active volume: $2.4x2.4x14cm^3$
Argon/CO2 gas mixture

The **multi-wire chamber** is made of two perpendicular views (**Side and Top**)
Each one is constituted by **6 planes** with **36 sensitive wires**

The main task is **to track the arrival carbon**, with a precision on the impact point on the target of the order of **100 µm**

A. Sarti et al, The Upstream Detectors of the FIRST Experiment at GSI, TIPP 2011

Conclusions II

- **Particle Therapy** is an expanding field in cancer treatments and generally is based on protons or carbon ions
- **Nuclear fragmentation cross-sections** are essential for accurate treatment planning for heavy-ion radiotherapy
- The **FIRST** experiment is dedicated to measure **double-differential cross sections of carbon ions** at **400 MeV/nucleon** for improving transport codes used in **cancer therapy**
- **FIRST** data taking, **Summer 2011**. Work is in progress on **beam tracking reconstruction** of the **beam monitor drift chamber**
- **Data analysis of the experiment is in progress**

DITANET Seville group – Selected publications

Radiation therapy project – RADIA2

A. Bocci et. al., Empirical characterization of a silicon strip detector for a novel 2d mapped method for dosimetric verification of radiotherapy treatments, *Radiotherapy and Oncology*, Volume 99, Supplement 1, May 2011, Page S172.

A. Bocci et. al., A silicon strip detector for a novel 2D dosimetric method for radiotherapy treatment verification **submitted to NIM-a (October 2011)**

M. A. Cortes-Giraldo et al., "Geant4 Simulation to Study the Sensitivity of a MICRON Silicon Strip Detector Irradiated by a SIEMENS PRIMUS Linac", **Progress in Nuclear Science and Technology, in press (2011)**

Abstract accepted to ICTR-PHE 2012 Conference, **A Novel On-Line Treatment Verification System Based on Silicon Strip Detectors for Measuring 2D Axial Dose Maps in Radiotherapy**

Particle Therapy project – FIRST experiment

FIRST experiment at GSI, **submitted to NIM-a (October 2011)**

Experiments @ CNA

'First Measurements of Non-Interceptive Beam Profile Monitor Prototypes for Medium to High Current Hadron Accelerators', J. M. Carmona, A. Ibarra, I. Podadera Aliseda, **Z. Abou-Haidar**, **A. Bocci**, **B. Fernández**, J. García López, M. C. Jiménez-Ramos, and **M. Álvarez**. *Proceedings: HB2010 Conference*, Morschach, Switzerland: 27th September-1st October 2010.

Non-interceptive fluorescence profile monitor prototypes for IFMIF-EVEDA accelerator. First measurements with 9 MeV deuterons, J. M. Carmona, I. Podadera, and A. Ibarra, **A. Bocci**, **M. Álvarez**, J. García López, M. C. Jiménez-Ramos, **Z. Abou-Haidar**, **B. Fernández** , accepted to PRST-AB (2011).

Thank you for your attention!!!

Motivation and Objective

- **Motivation:**

  Nowadays, particle therapy is an expanding field in cancer treatments, and generally exploits protons or carbon ions. Carbon ions combine significant advantages both in the physics dose-depth deposition pattern and in the biological effectiveness and may represent a significant breakthrough in hadron-therapy

- **Objective**

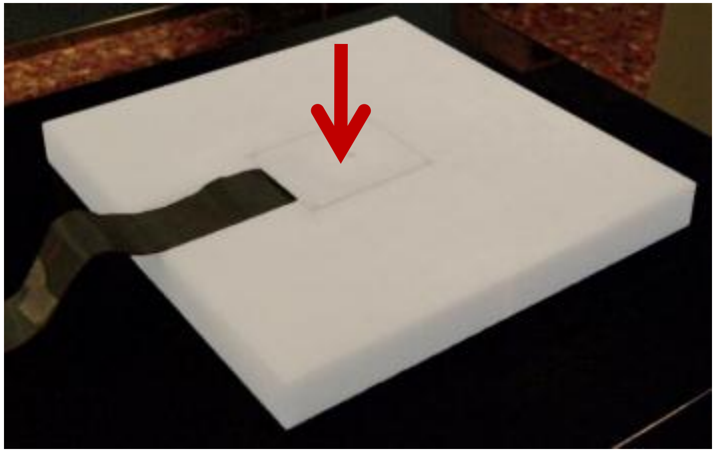
Nuclear fragmentation cross-sections are essential for accurate treatment planning. Treatment plans are generally based on deterministic codes, but the great accuracy (3%) required for medical treatment planning makes necessary several inter-comparison of the codes with Monte Carlo calculations. All these calculations are based on measured nuclear fragmentation cross-sections of carbon ions in water or tissue-equivalent materials

The FIRST experiment measures double-differential cross sections of carbon ions in the energy range 100-500 MeV/nucleon for improving transport codes used in cancer therapy

Measurements

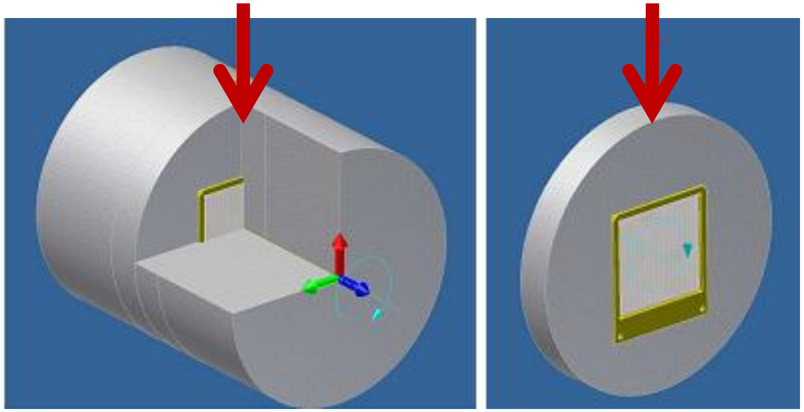
Set-up 1:

- Linearity
- Uniformity
- Calibration
- Percent Depth Dose (PDD)
- Penumbra



Set-up 2:

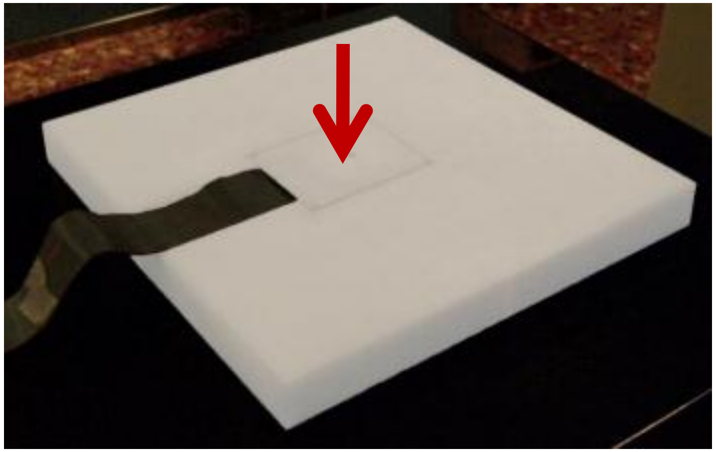
- TPS and Geant4 Simulations
- Angular response
- Final calibration



Measurements

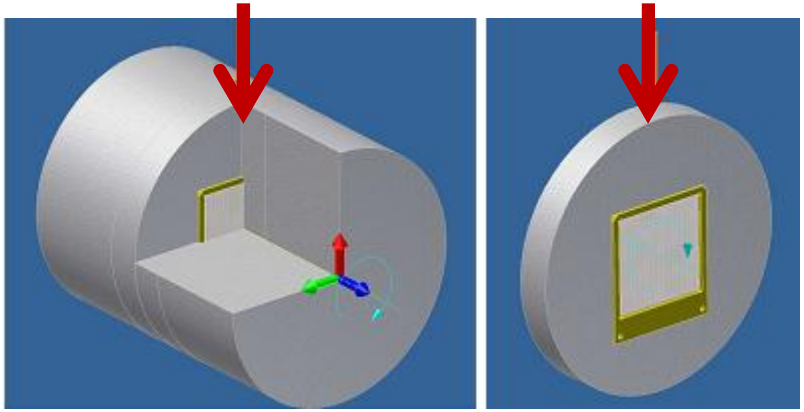
Set-up 1:

- ✓ **Linearity**
- Uniformity
- Calibration
- Percent Depth Dose (PDD)
- Penumbra

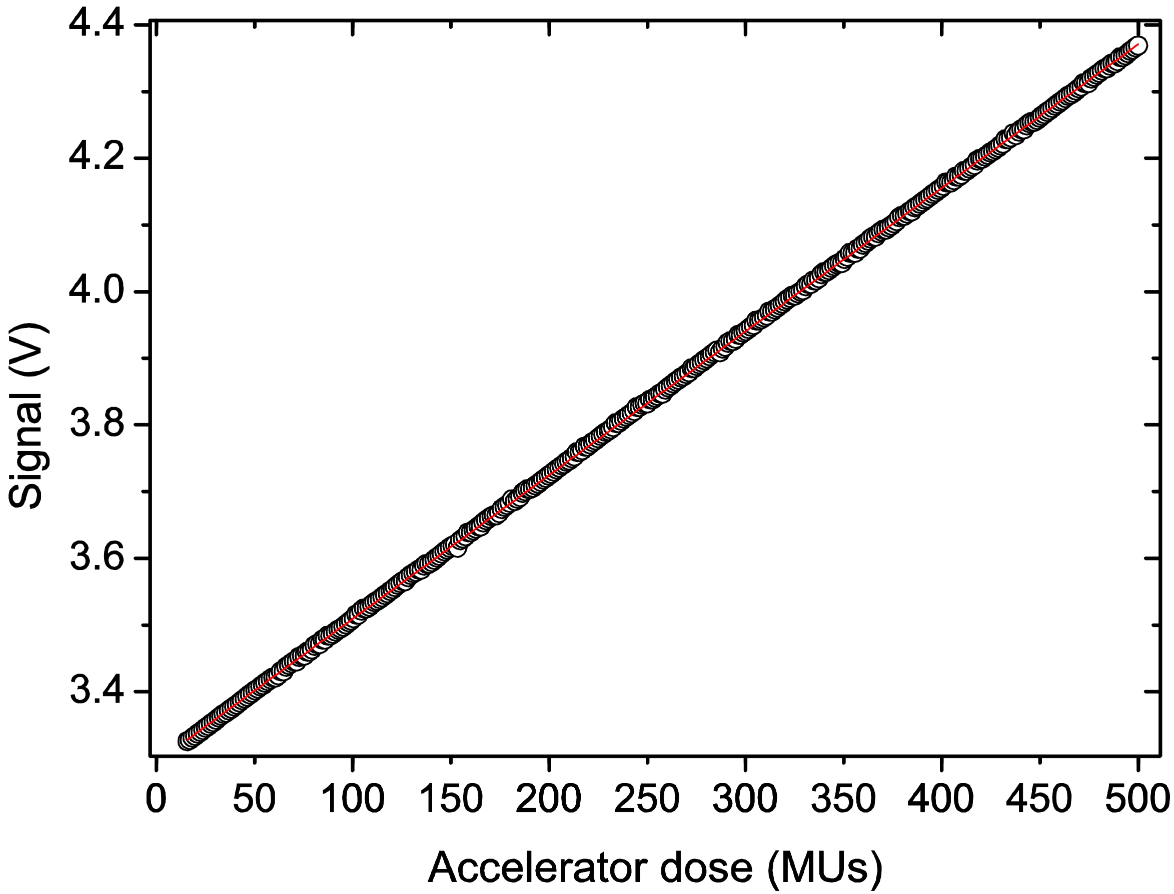


Set-up 2:

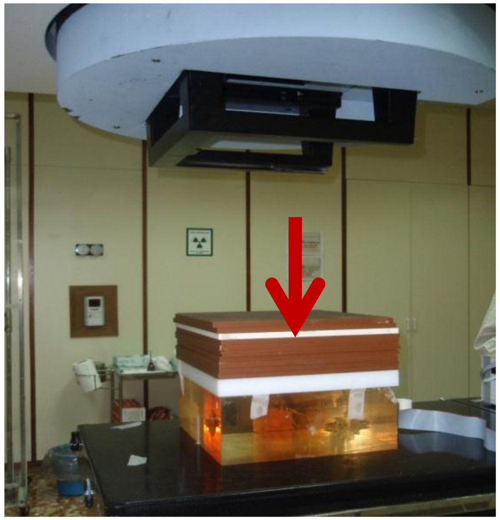
- TPS and Geant4 simulations
- Angular response
- Final calibration



Linearity



Set-up 1:
SSSSD perpendicular to the beam direction

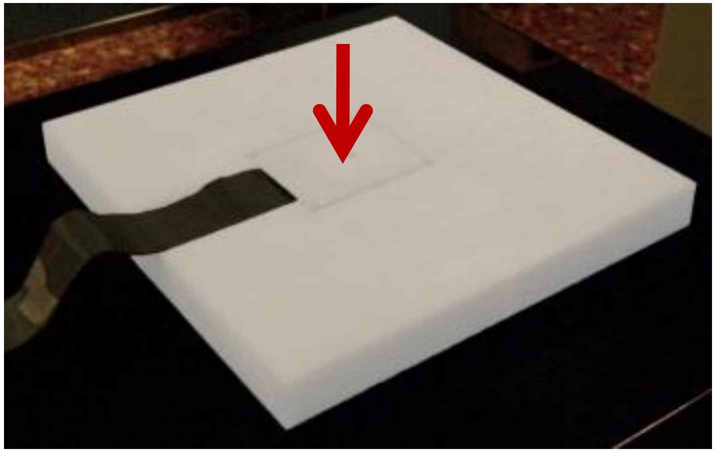


Linearity with dose better than 0.1 % for all channels

Measurements

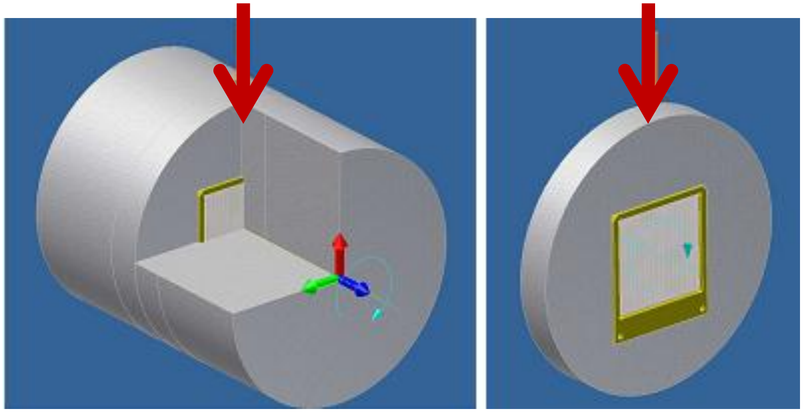
Set-up 1:

- Linearity
- ✓ **Uniformity**
- Calibration
- Percent Depth Dose (PDD)
- Penumbra

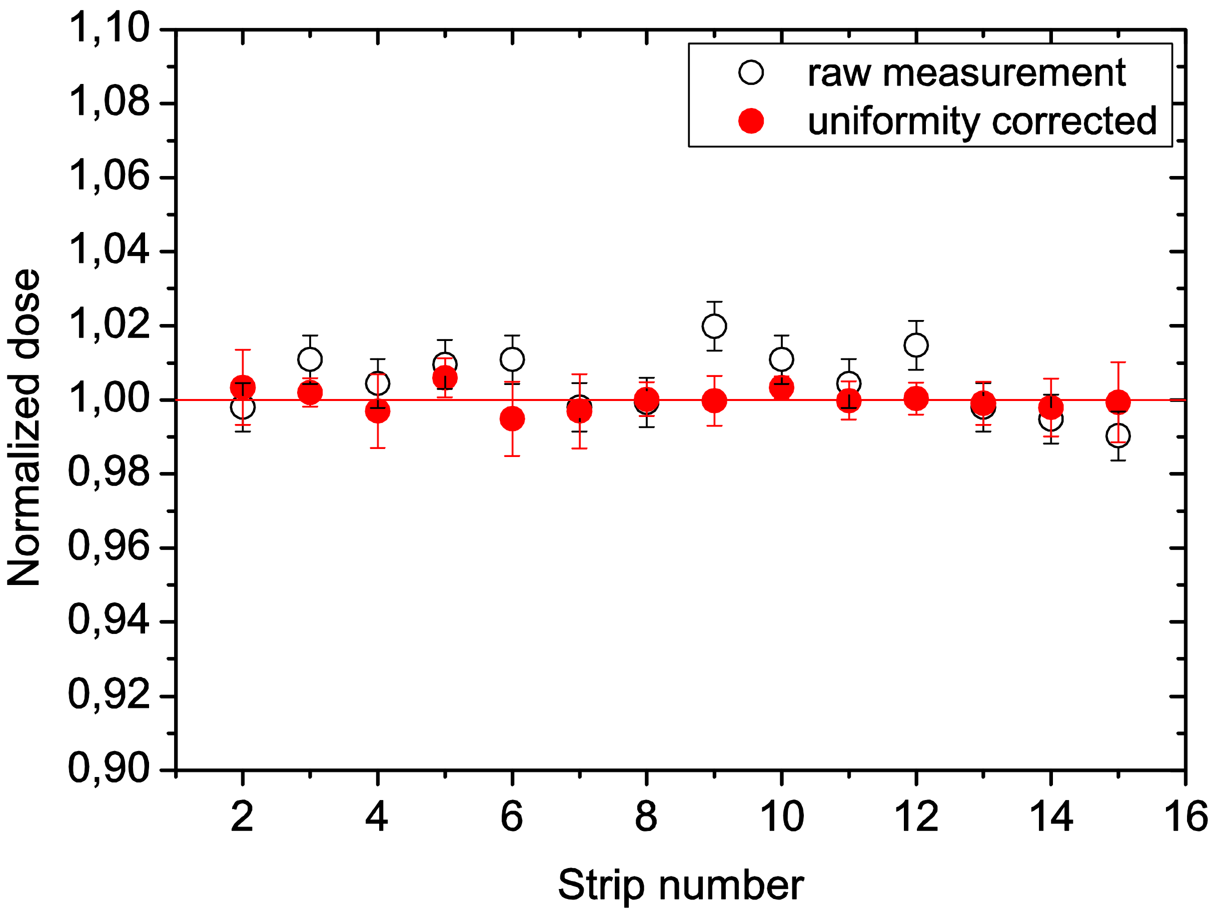


Set-up 2:

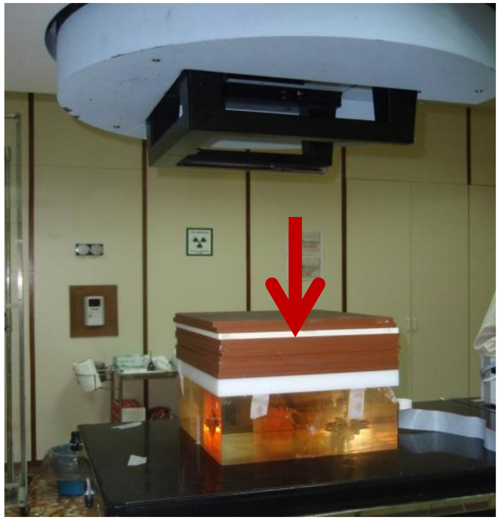
- TPS and Geant4 simulations
- Angular response
- Final calibration



Uniformity



Set-up 1: SSSSD perpendicular to the beam direction



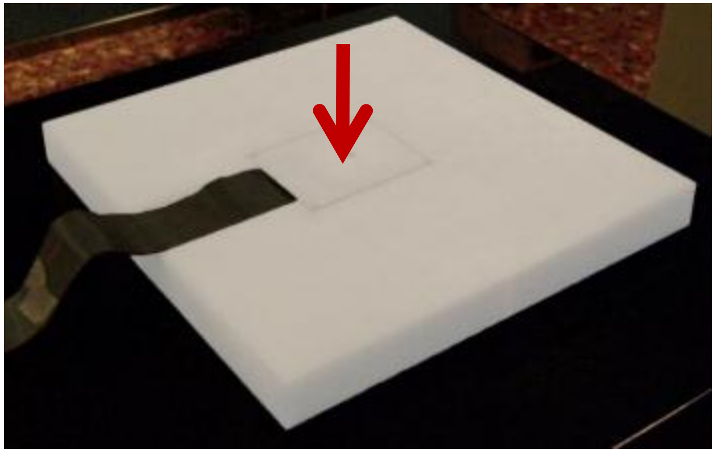
Non-uniformities depend by the different strip efficiency and gain of the electronics

Uniformity better than 0.5 % for all channels

Measurements

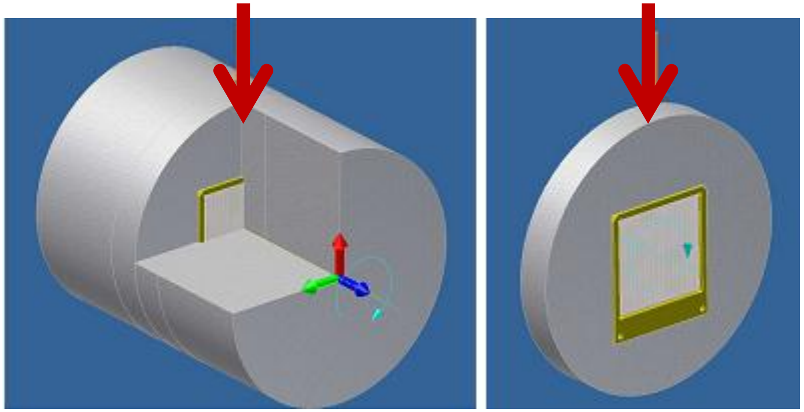
Set-up 1:

- Linearity
- Uniformity
- ✓ **Calibration**
- Percent Depth Dose (PDD)
- Penumbra

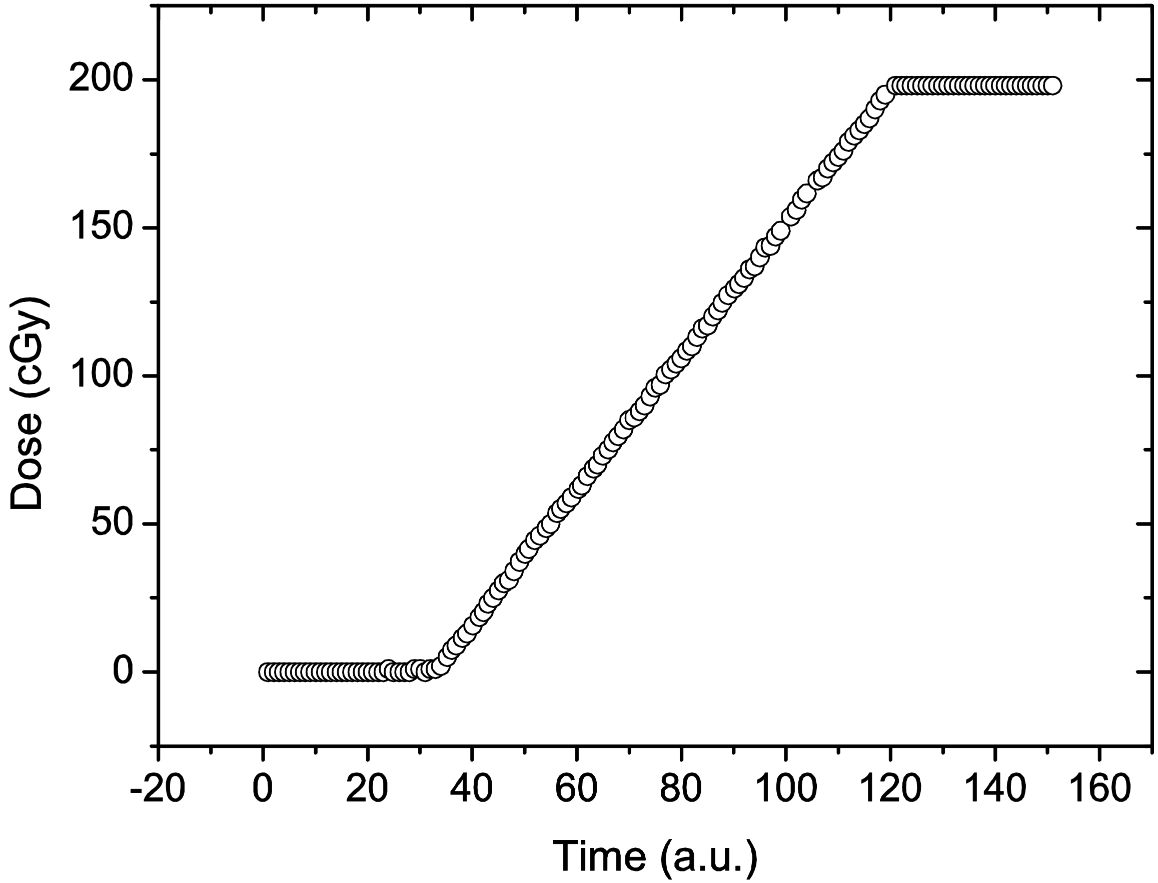


Set-up 2:

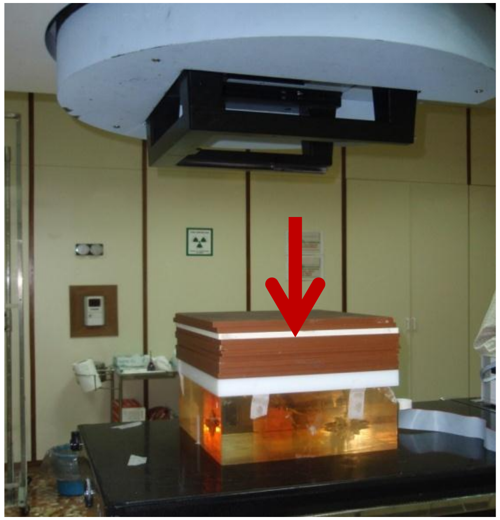
- TPS and Geant4 simulations
- Angular response
- Final calibration



Calibration



Set-up 1:
SSSSD perpendicular to the beam direction



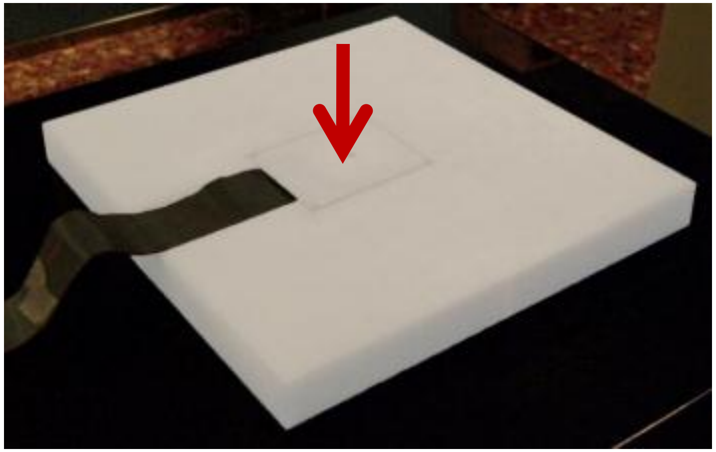
Monitor Units –> cGy

Calibration in standard condition
radiation field 10 × 10 cm^2
source-to-surface distance (SSD) = 100 cm
1.5 cm of water slabs

Measurements

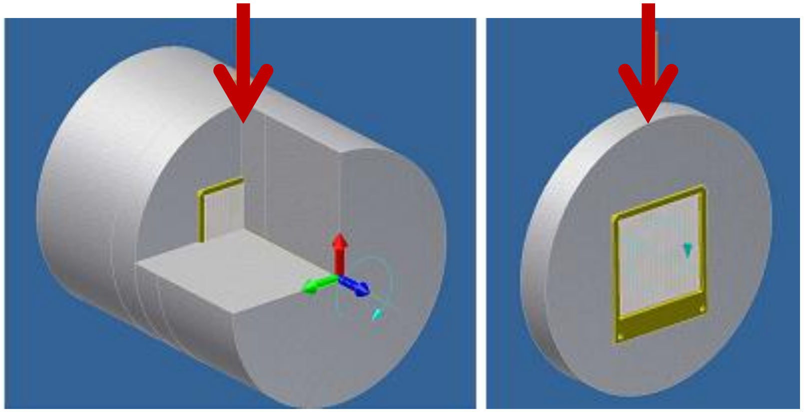
Set-up 1:

- Linearity
- Uniformity
- Calibration
- ✓ **Percent Depth Dose (PDD)**
- Penumbra

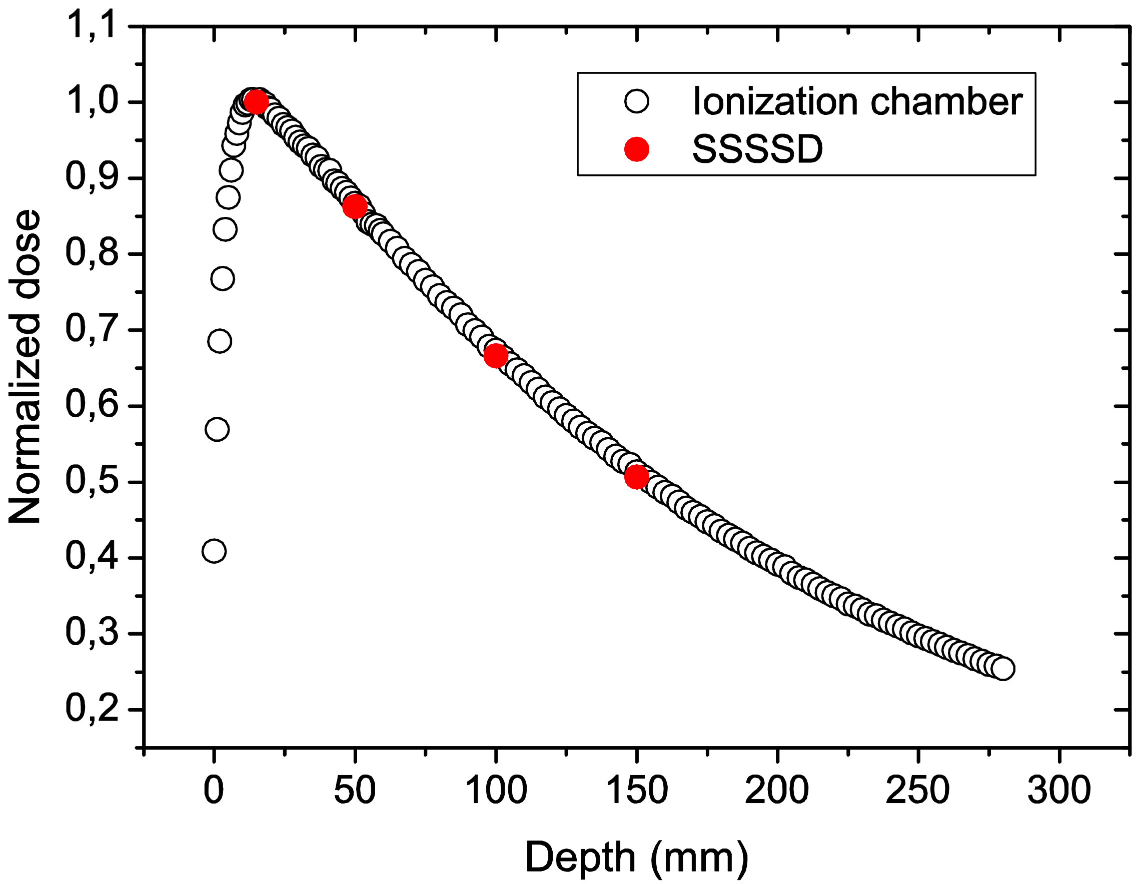


Set-up 2:

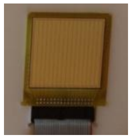
- TPS and Geant4 simulations
- Angular response
- Final calibration



Percent Depth Dose



Set-up 1:
SSSSD perpendicular to the beam direction



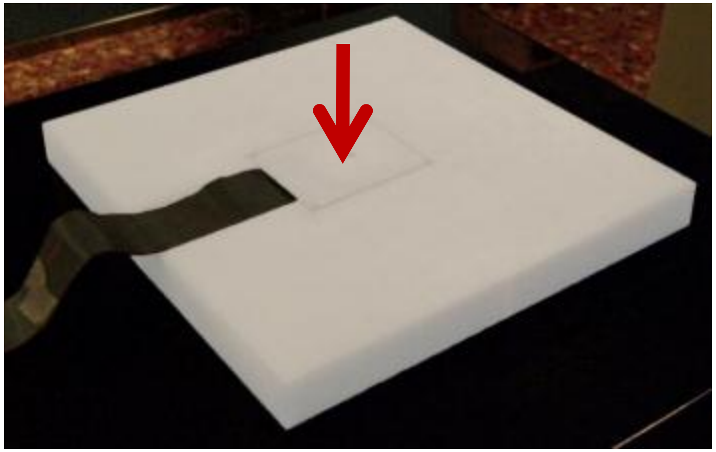
Dose at different depth using different water-equivalent solid slabs

The difference between SSSSD and ionization chamber is:
0.68 % at 10 cm and 0.73 % at 15 cm

Measurements

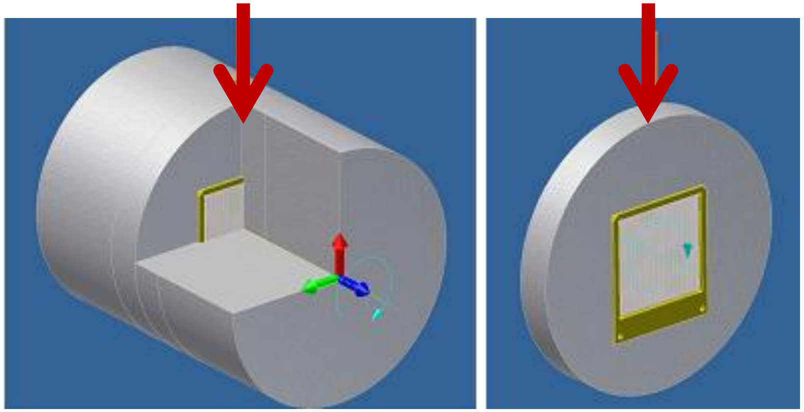
Set-up 1:

- Linearity
- Uniformity
- Calibration
- Percent Depth Dose (PDD)
- ✓ **Penumbra**



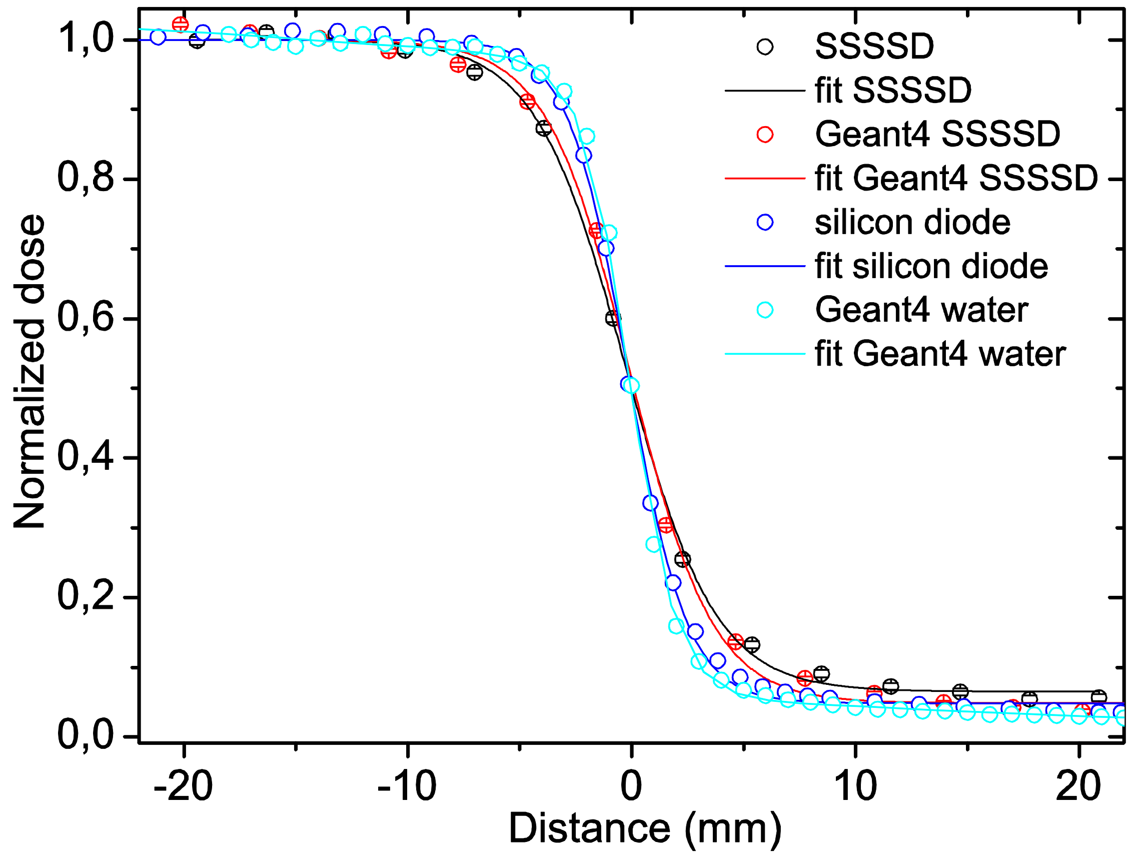
Set-up 2:

- TPS and Geant4 simulations
- Angular response
- Final calibration

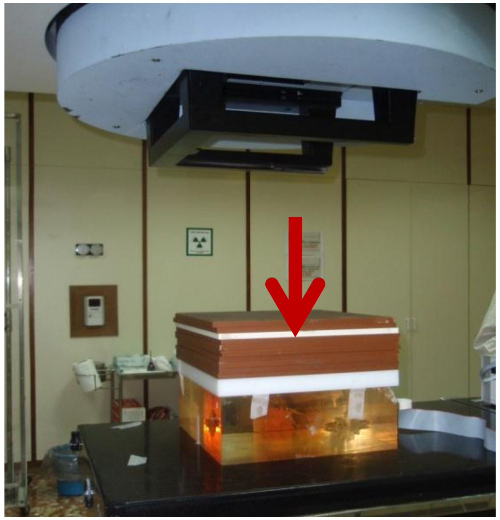


Penumbra

The penumbra size of the treatment field is the region between 20% and 80% of the maximum dose levels at 1.5 cm water depth.



Set-up 1: SSSSD perpendicular to the beam direction



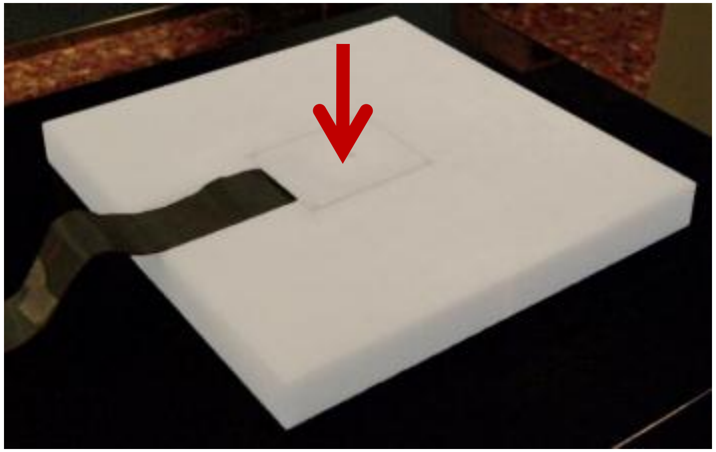
SSSSD 6.17 ± 0.56 mm - single silicon diode 3.92 ± 0.20 mm

SSSSD penumbra value larger than the one obtained when using a single silicon detector
This was mainly due to the SSSSD strips pitch of 3.1 mm
Geant4 simulations gave compatible results

Measurements

Set-up 1:

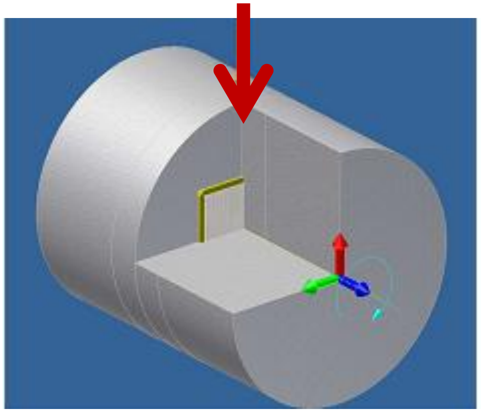
- Linearity
- Uniformity
- Calibration
- Percent Depth Dose (PDD)
- Penumbra

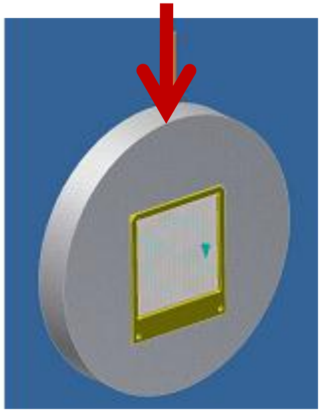


Set-up 2:

✓ **Geant4 simulations and TPS calculations**

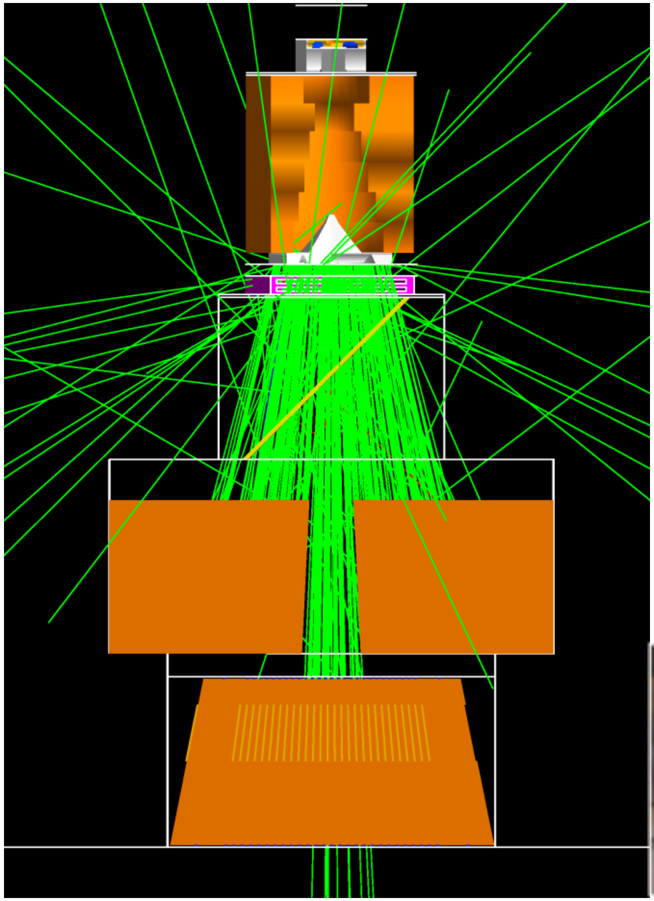
- Angular response
- Final calibration



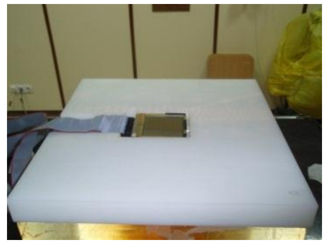


Geant4 simulations and TPS calculations

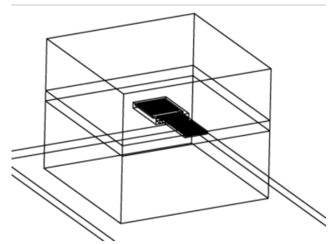
Geometry Model



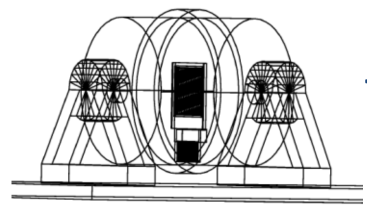
Phantom



SSSSD Detector

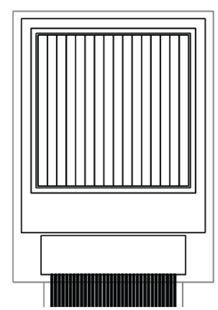


The geometry of the Siemens treatment head at 6 MV nominal energy photons, was reproduced in detail



The geometric model of the phantoms was built according to the design layouts

The SSSSD was also reproduced following the specifications of the manufacturer



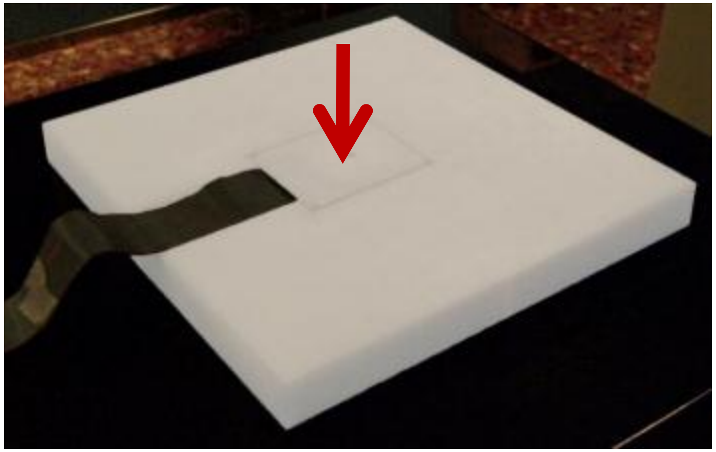
Geant4 Simulations were performed also for the dose-to-water case for the comparison with TPS calculations

M. A. Cortés Giraldo, Ph. D. Thesis, 2011

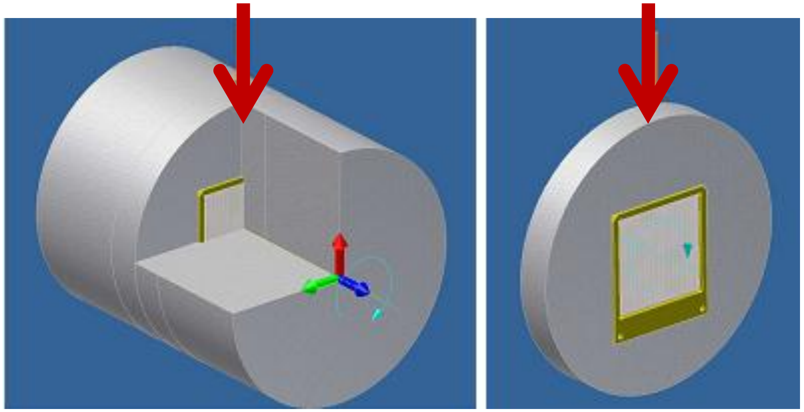
M. A. Cortes-Giraldo et al. , Progress in Nuclear Science and Technology, in press (2011)

Measurements

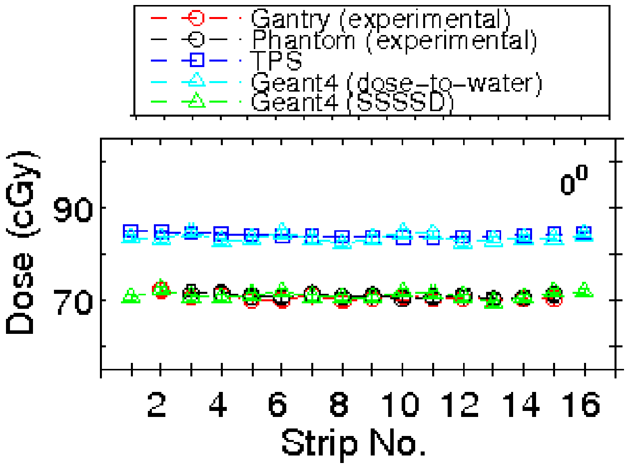
Set-up 1:
- Linearity
- Uniformity
- Calibration
- Percent Depth Dose (PDD)
- Penumbra

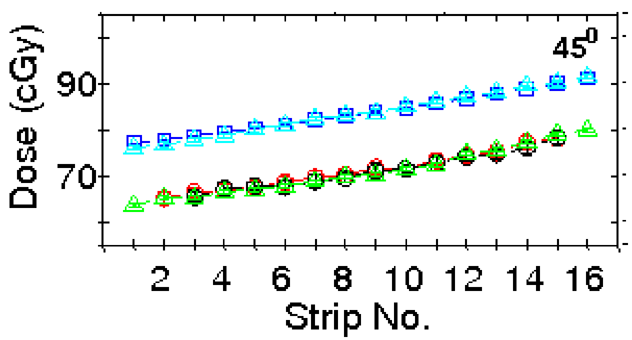


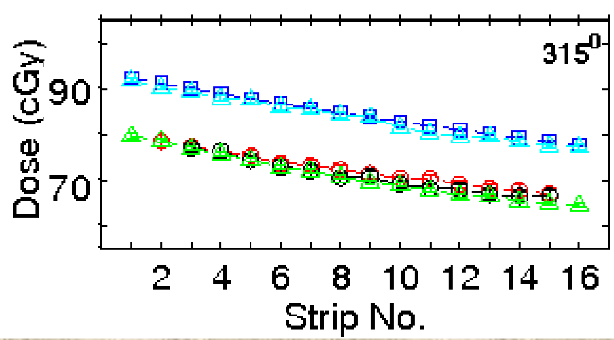
Set-up 2:
- ✓ Geant4 simulations and TPS calculations
- ✓ **Angular response**
- Final calibration



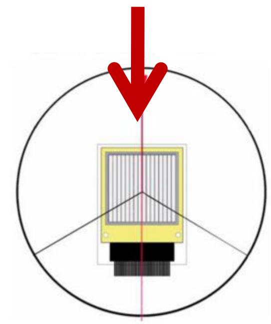
Angular Response



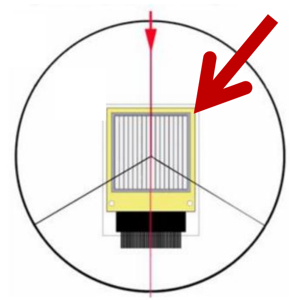




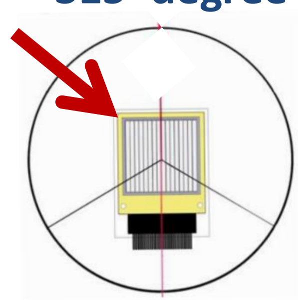
0^0 degree



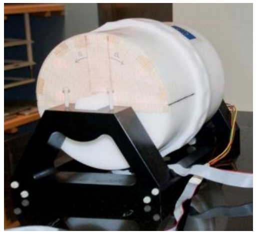
45^0 degree

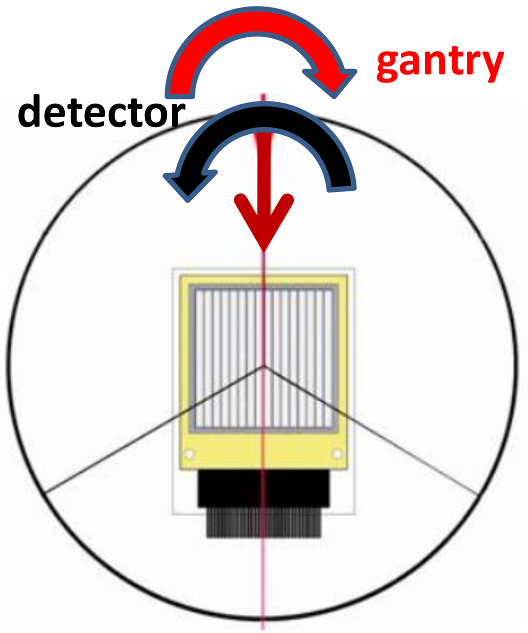


315^0 degree



Set-up 2:
SSSSD parallel
to the beam direction

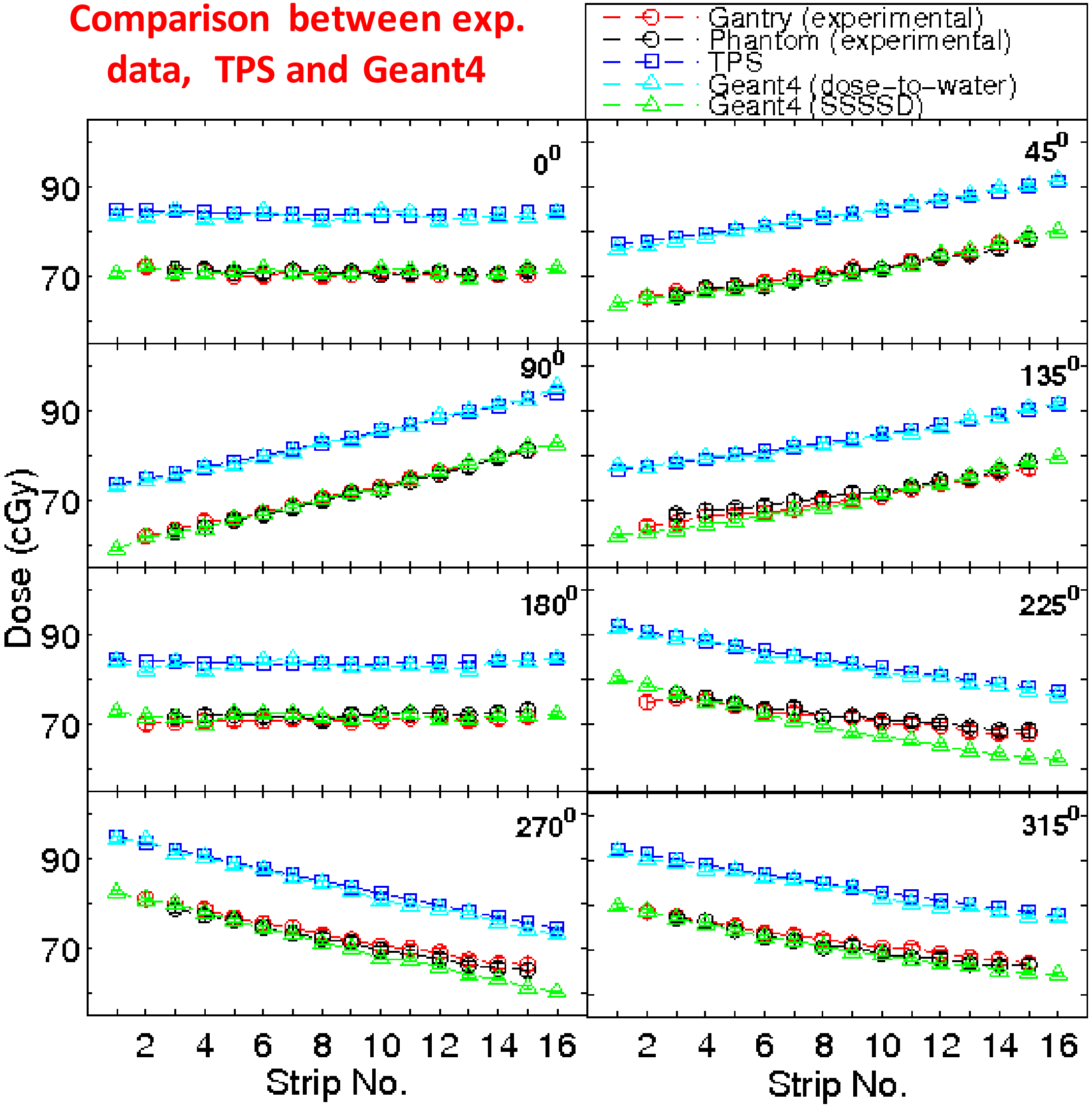




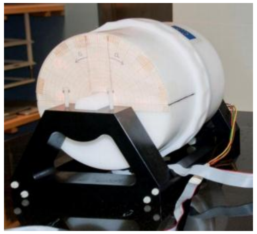
Angular Response

Comparison between exp. data, TPS and Geant4

Steps of 45⁰



Set-up 2: SSSSD parallel to the beam direction

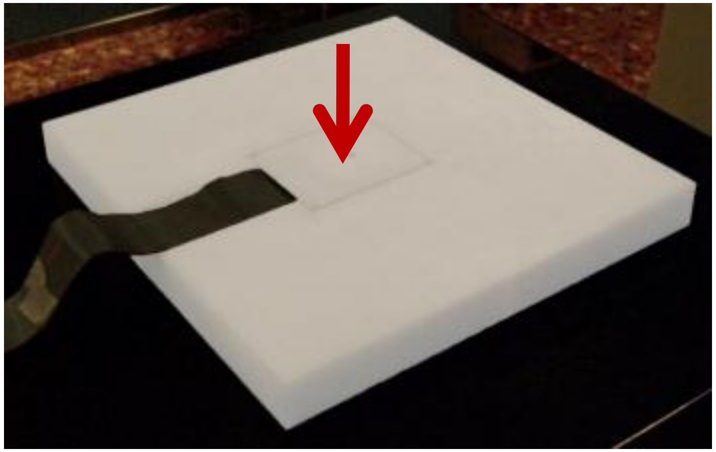


The agreement between the tendency of experimental data with Geant4 (SSSSD case) calculations at different angles and the TPS is notable. This implies that a new calibration will be independent of the irradiation angle.

Measurements

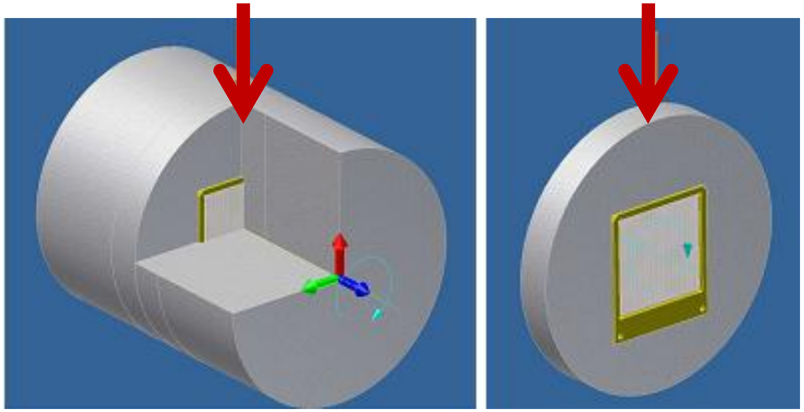
Set-up 1:

- Linearity
- Uniformity
- Calibration
- Percent Depth Dose (PDD)
- Penumbra



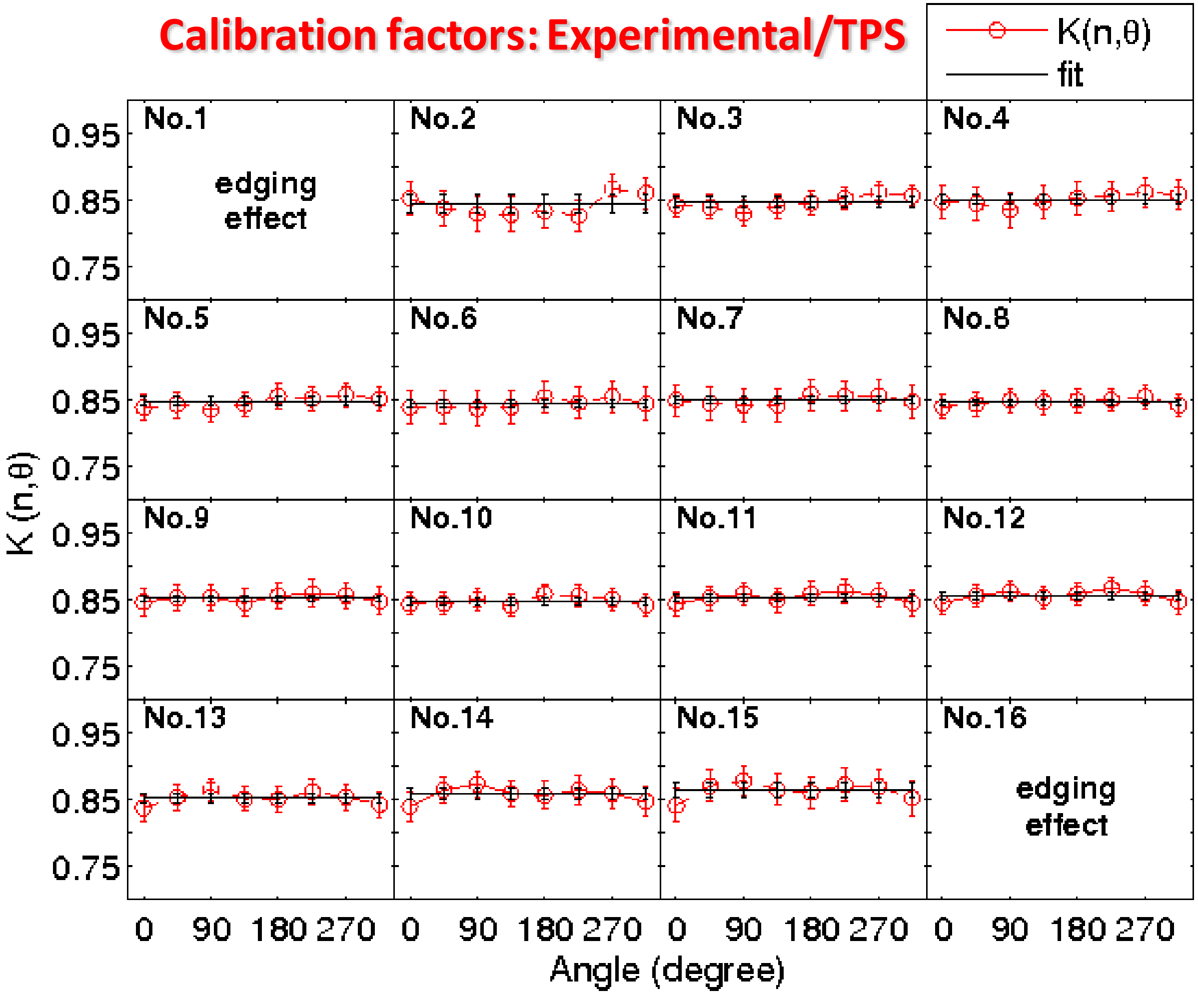
Set-up 2:

- ✓ Geant4 simulations and TPS calculations
- Angular response
- ✓ **Final calibration**



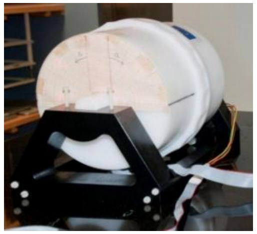
Final Calibration

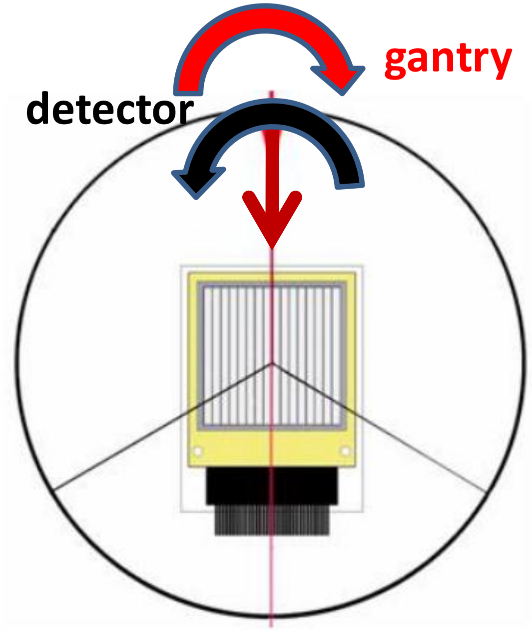
Calibration factors: Experimental/TPS



Calibration factors independent of angular irradiation and of strip number

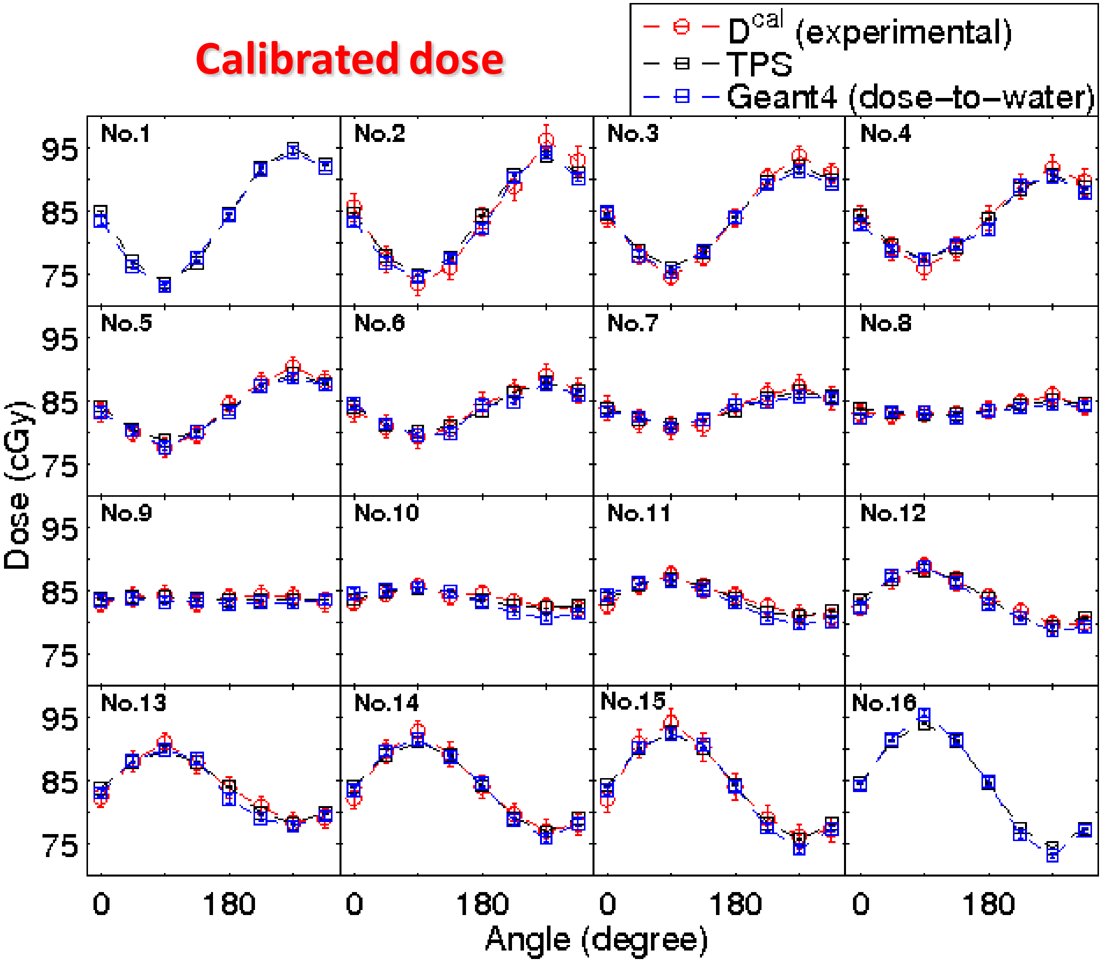
Set-up 2: SSSD parallel to the beam direction



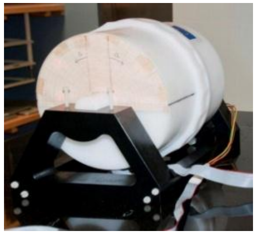


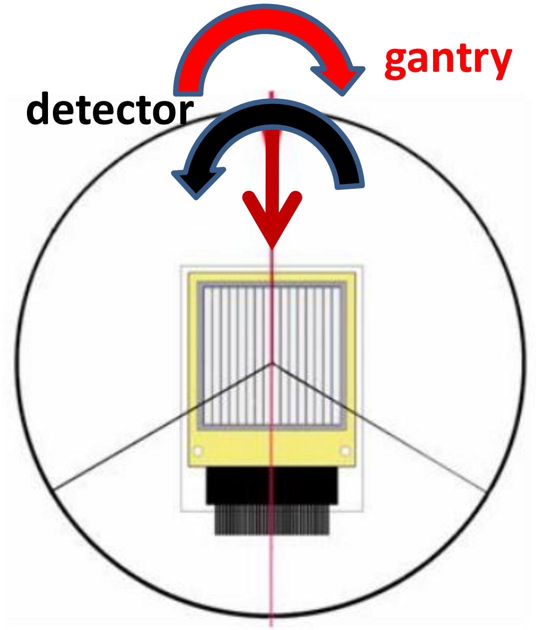
Final Calibration

Calibrated dose



Set-up 2:
SSSSD parallel
to the beam direction





Relative difference between the calibrated dose and TPS calculations are better than 2 %

Conclusions

- Main Objective: Characterize and benchmark a new detection system based on a Si-strip detector and dedicated to 2D dose measurements in the axial plane of a cylindrical phantom
- SSSSD characterization: the prototype showed the necessary characteristics to be used in IMRT verification plans (good linearity, uniformity, PDD…)
- The angular dependence in the parallel configuration compared to TPS calculations was independent from the irradiation angle and strip number
- Geant4 simulations gave compatible results both when compared to TPS and to experimental data
- Final calibration with respect to TPS gives differences smaller than 2 % for all the strips
- The system is in the process of being patented

Future developments

- Future: work is in progress in order to obtain a **2D map from experimental data** using the reconstruction algorithm

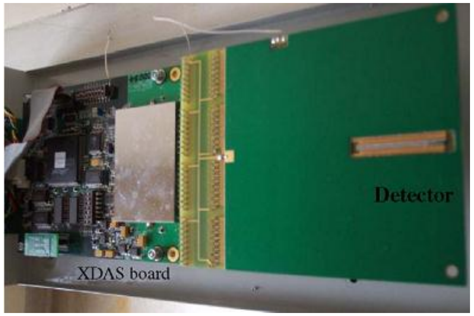
- **A new SSSSD** prototype and a new experimental set-up has been designed to improve the spatial resolution of the actual system

Thank you for your attention!!!

Single Strip and 2D monolithic silicon detectors

Research is directed towards silicon microstrip technology to improve spatial resolution

1. DOSI

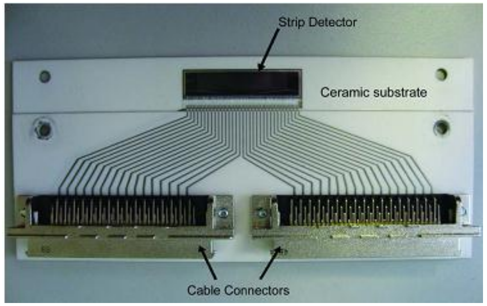


Single crystal n-Si
128 channels
32 mm x 0.2 mm

I. Redondo-Fernandez et al, NIM-a, (2007) 141–144

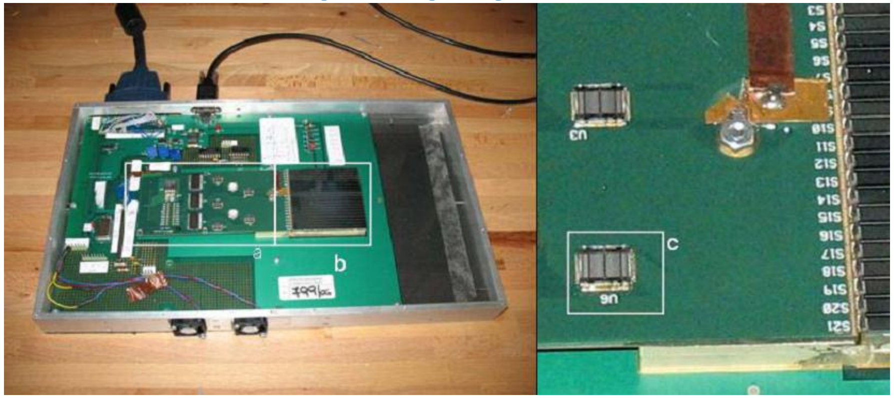
2. CMRP DMG

128 phosphor implanted n+ strips on a p-type silicon wafer



J. H. D. Wong et al., Medical Physics 37 (2010) 427–439

3. European project MAESTRO



Pixellated monolithic silicon detectors such as the 2D array

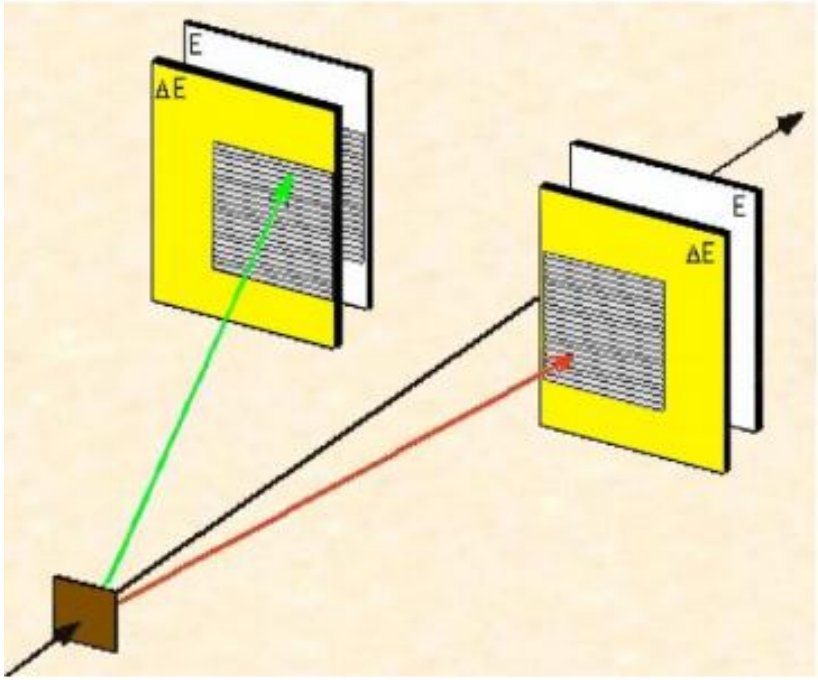
441 Si n+p diodes
50 µm epi layer growth on MCz p.
Active area: 6.29 x 6.29 cm^2.

D. Menichelli et al., Nucl. Instr. and Meth. A, 583, 109 (2007)

From Nuclear Physics to Medical Applications

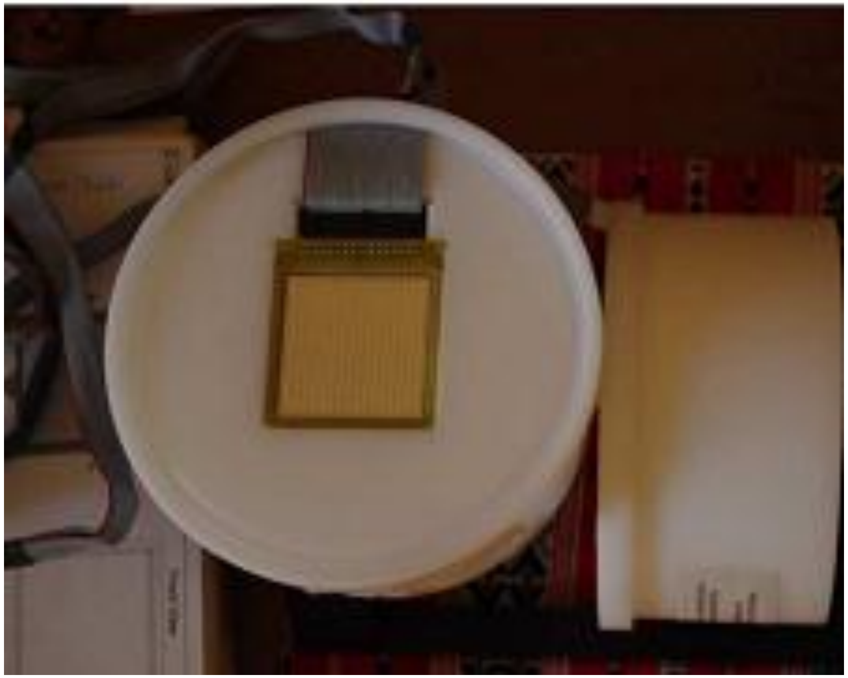
Detectors dedicated to medical applications can benefit the developments and the knowledge obtained on nuclear and high energy physics technology

Silicon strip detectors mounted @ CNA in a telescope configuration



silicon tracking detectors

Silicon strip detectors mounted @ Virgen Macarena Hospital in Seville



silicon detectors for medical applications

Motivation and Objective

- **Motivation:**

  Cancer is the second most frequent cause of death in developed countries. At present, although surgery is the most effective way to remove the malignant tissue, when it is combined with radiation therapy improves the cure rate by 40% approximately.

- **Objective**

  Characterization of a silicon strip detector dedicated to 2D dose measurements in the **axial plane of a phantom** for the verification of **Intensity Modulated Radiation Therapy (IMRT)** treatment plans.