Development of silicon monolithic arrays for dosimetry in external beam radiotherapy

RESMDD14 Florence
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Motivation

Modern radiotherapy:

IMRT, VMAT, Stereotactic treatments, Proton therapy

Characterized by:

Radiation fields with high dose gradients

Strong modulation of dose rate

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IMRT, VMAT, Stereotactic treatments, Proton therapy

Characterized by:

Radiation fields with high dose gradients
Strong modulation of dose rate

Most critical detector requirements:

- ***High spatial resolution***
- ***Sensitivity independent on dose rate and energy***

Outline

Collaboration Results

2006-2007: Single Epitaxial diodes

Characterization at University hospital of Florence

2007-2011: 2D Monolithic epitaxial silicon detector

MV photons: Florence University hospital (radiotherapy unit)
62 MeV protons:LNS Catania
^{60}Co: Lucca Hospital, Radiotherapy division.

2013-2014: 1D monolithic array prototype

^{60}Co and MV: IBA Doslab (focus on basic performances)
MV photons: Florence University hospital (radiotherapy unit) (focus on LINAC QA)
226 MV protons: Proton Therapy Center Prague

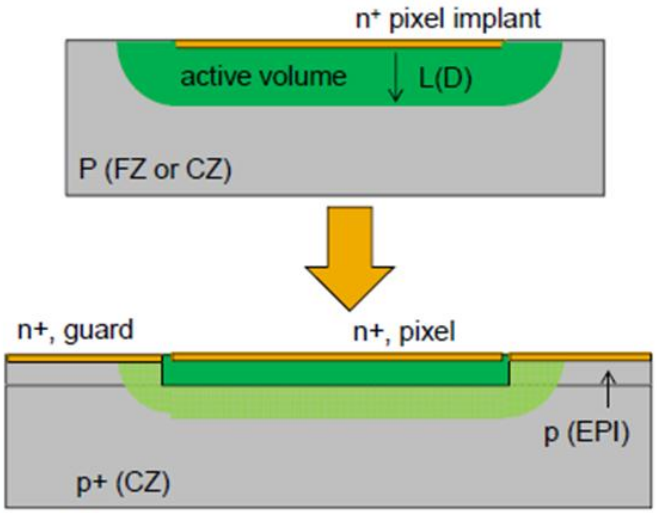
Single diodes (epitaxial, guarded)

Part I

Single epitaxial diodes
Concept and design I

Drawback of silicon diodes*: Sensitivity decreases with dose*

$$V_{bias} = 0 \text{ , } S \propto \text{Active Volume}$$

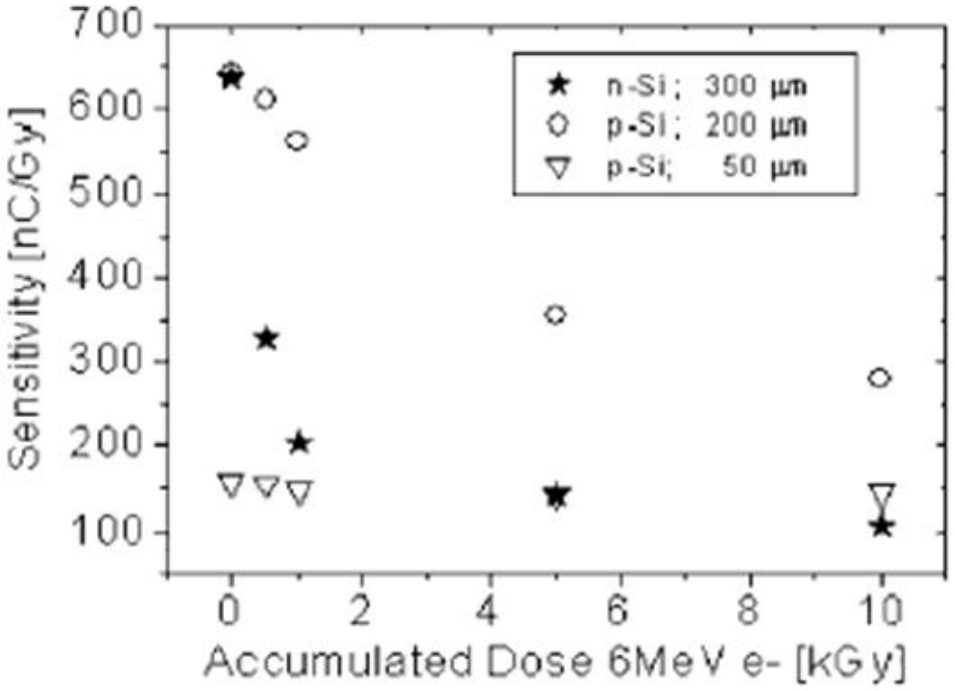


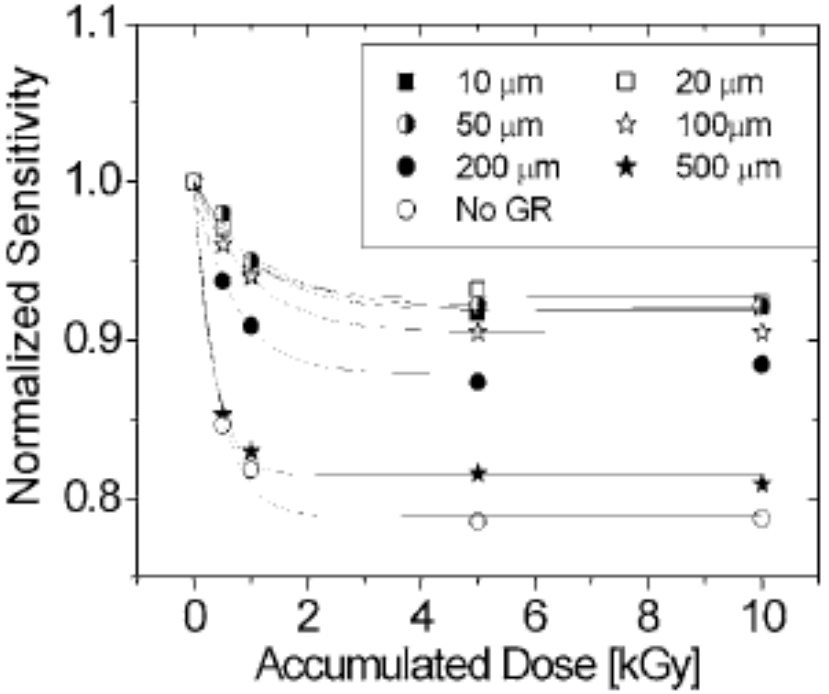
L: minority carrier diffusion length
$L = (D \cdot \tau)^{1/2}$ → τ decreases with dose

Limit the active volume with an epitaxial layer and a guard ring

M.Bruzzi et al. Appl. Phys. Lett 90 (2007) 172109 1-3

Single epitaxial diodes
Concept and design II





M.Bruzzi et al. Appl. Phys. Lett 90 (2007) 172109 1-3

Single epitaxial diodes
Conclusions

High stability of **sensitivity** vs **accumulated dose** with:

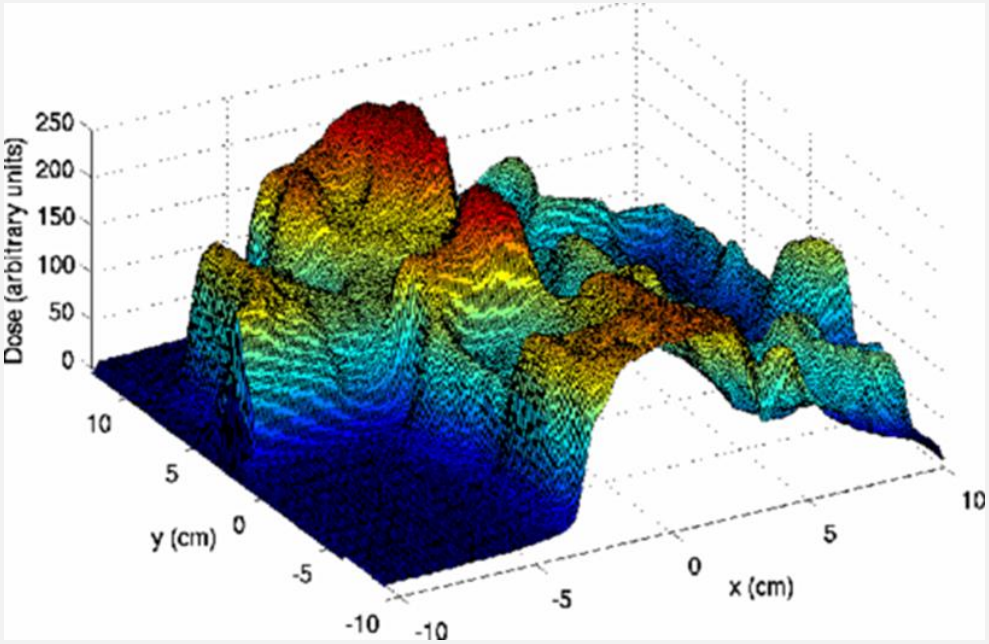
- Thickness of p-type epitaxial Si: 50 µm
- Distance electrode - guard ring: 20 µm

2D Monolithic epitaxial silicon detector

Part II

2D Monolithic Array
Motivation

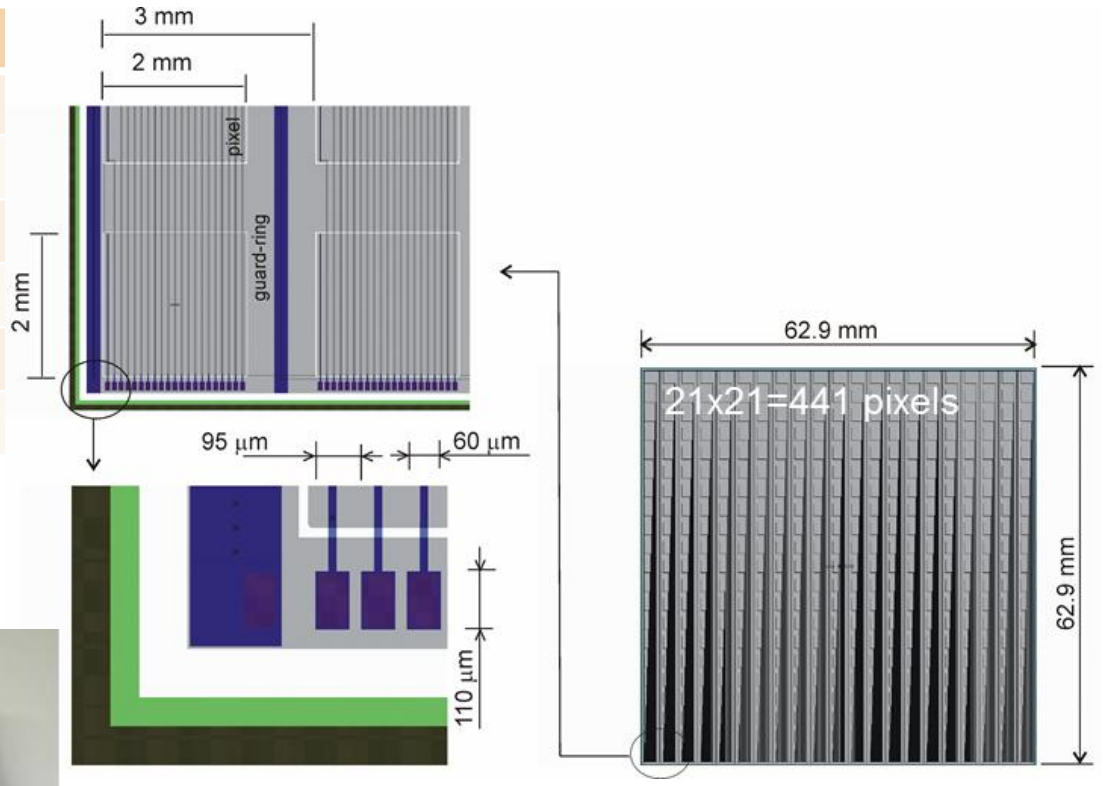
- 2D pre-treatment dose verification
- High gradient: critical deviation between calculated and delivered dose

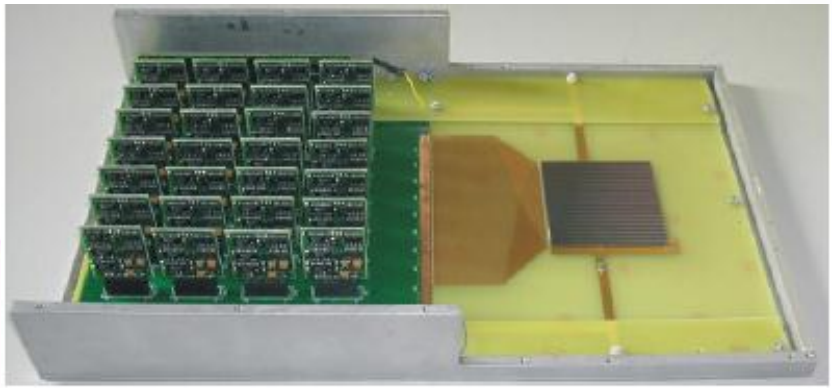


A Gago-Arias *et al* 2012 *Phys. Med. Biol.* **57** 2005.
doi:10.1088/0031-9155/57/7/2005

2D Monolithic Array
Detector description

Sensor description
21 x 21=441 diodes
2x2 mm^2 active area
3mm pitch
Thickness of epitaxial silicon layer: 50 µm
Distance electrode to guard ring : 20 µm

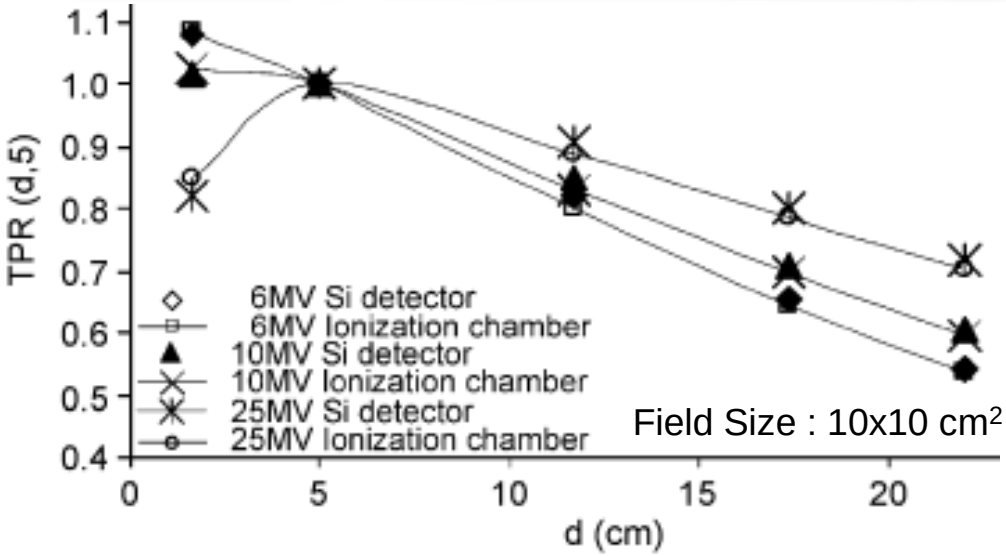




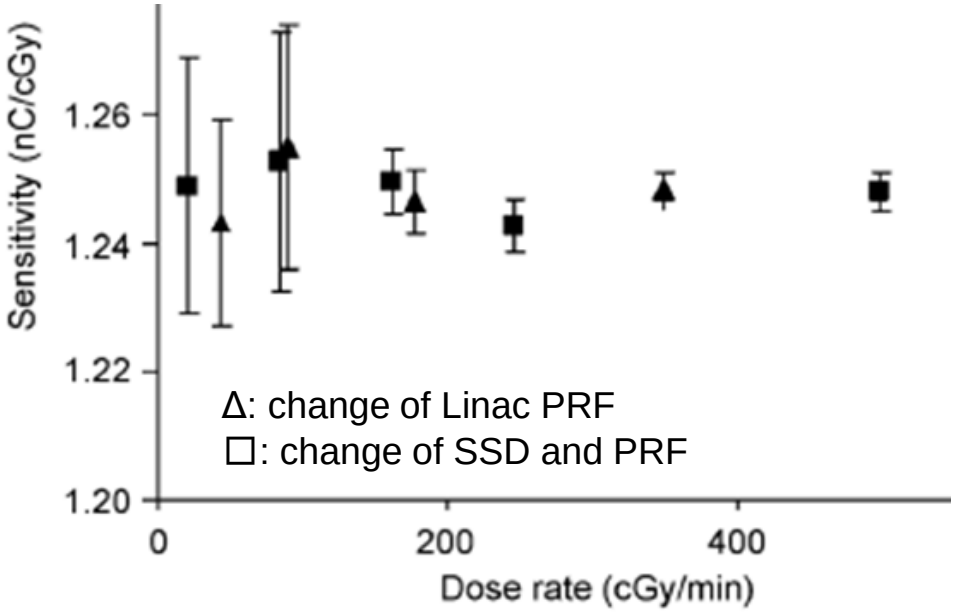
Readout: LMC6084 Op. Amp.

D. Menichelli et al., Nucl. Instr. and Meth. A, 583, 109 (2007)
C. Talamonti et al., Nucl. Instr and Meth. A., 583 (2007) 114

2D Monolithic Array
Results (6MV photons)

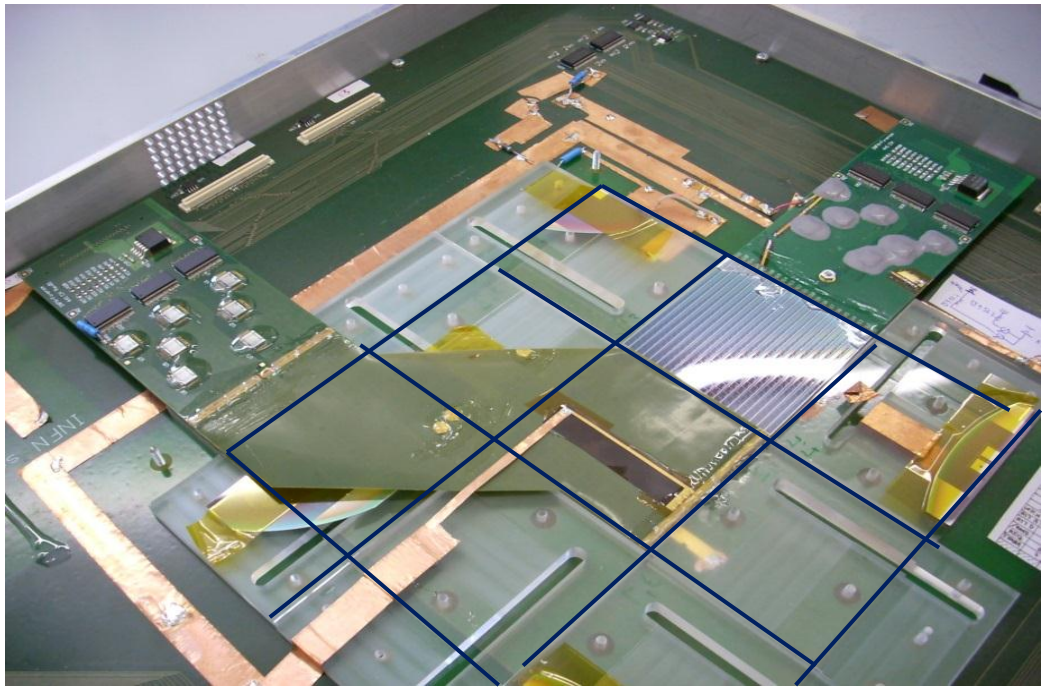


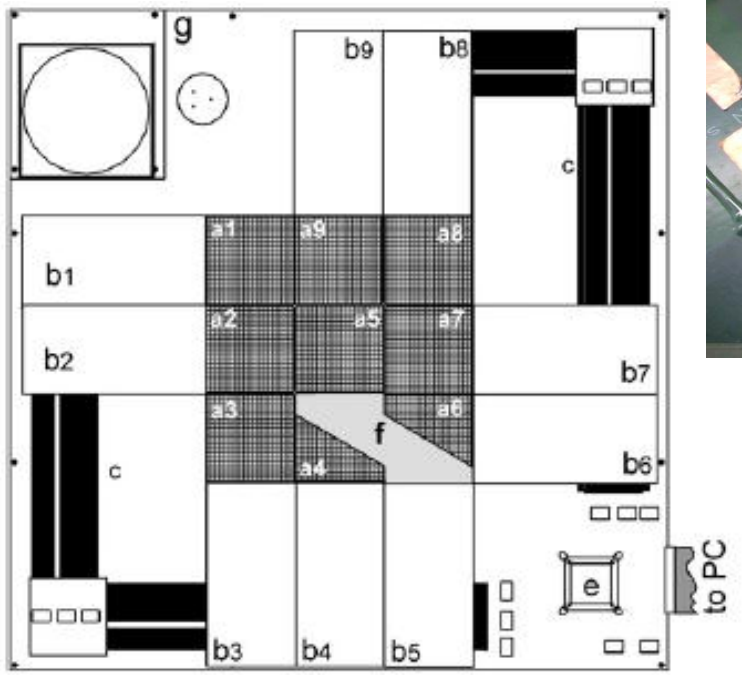
C.Talamonti et al.
Nucl. Inst. and Meth. A 583(2007) 114-118



2D Monolithic Array Detector description

Readout: TERA06 (INFN Turin)
64ch, digital output
100fC typical resolution





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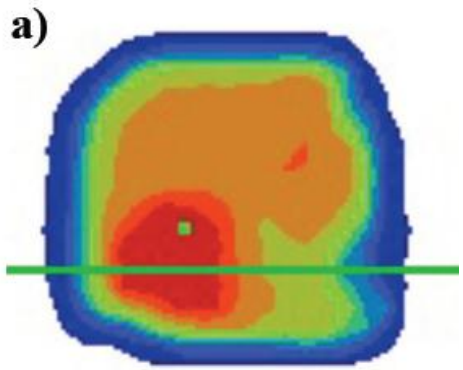
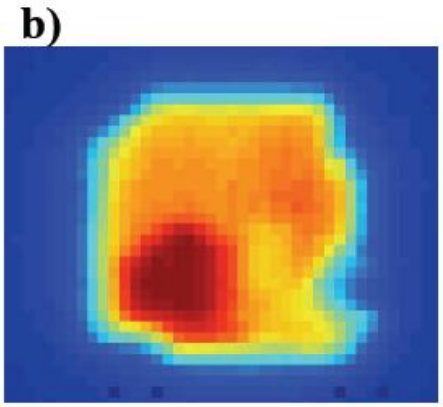
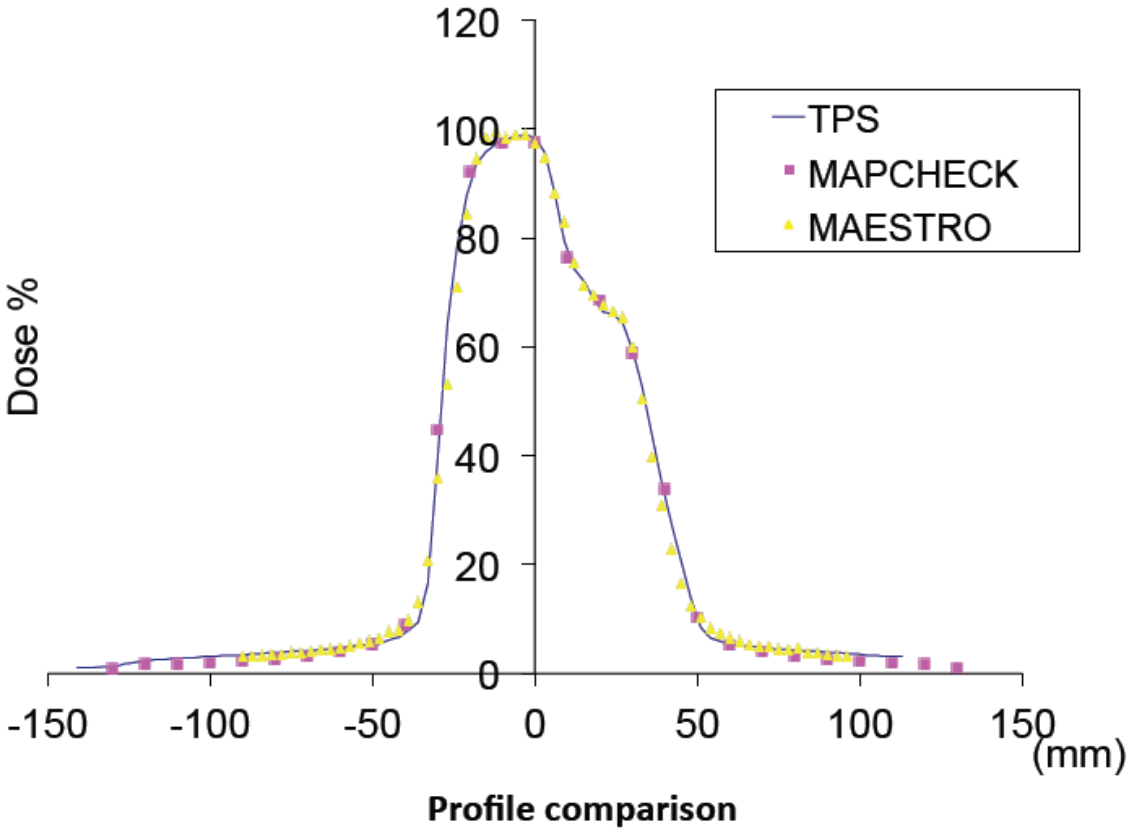
C. Talamonti et al., Nucl. Instr and Meth. A., 583 (2007) 114
C. Talamonti et al., Nucl. Instr. And Meth. A 658, 84 (2011)

2D Monolithic Array
Results II (IMRT verification)







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2D Monolithic Array
Conclusions

- Suitability of monolithic silicon technology to build 2D dosimeters for clinical radiotherapy

1D Monolithic Array Prototype

Part III

1D Monolithic Array prototype

Detector description

Detector description
64 pixel/Sensor module
1mm pixel pitch
0.6x1 mm^2 pixel active area
4 x 64 mm assembling

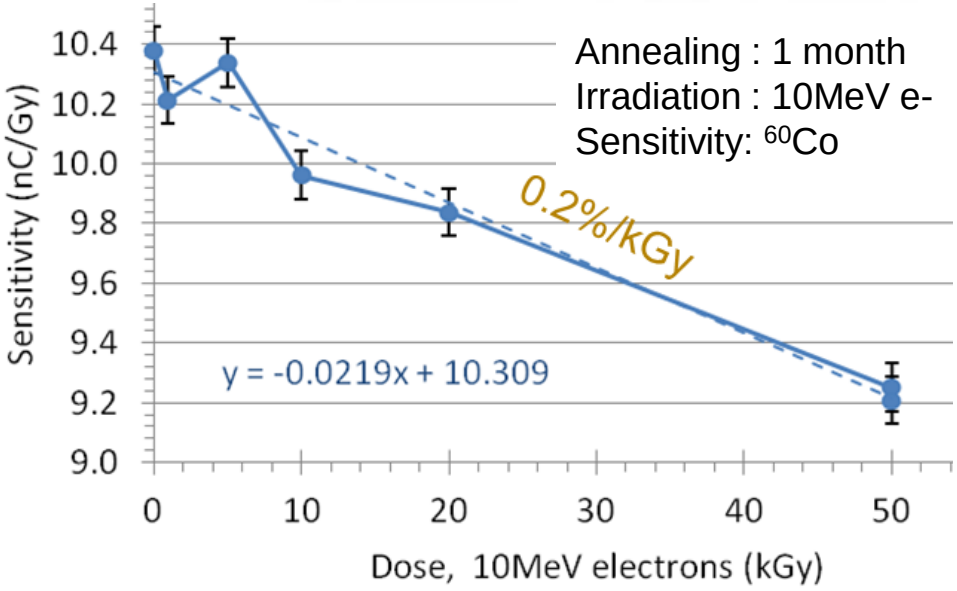
Readout: ZEBRA Electrometer

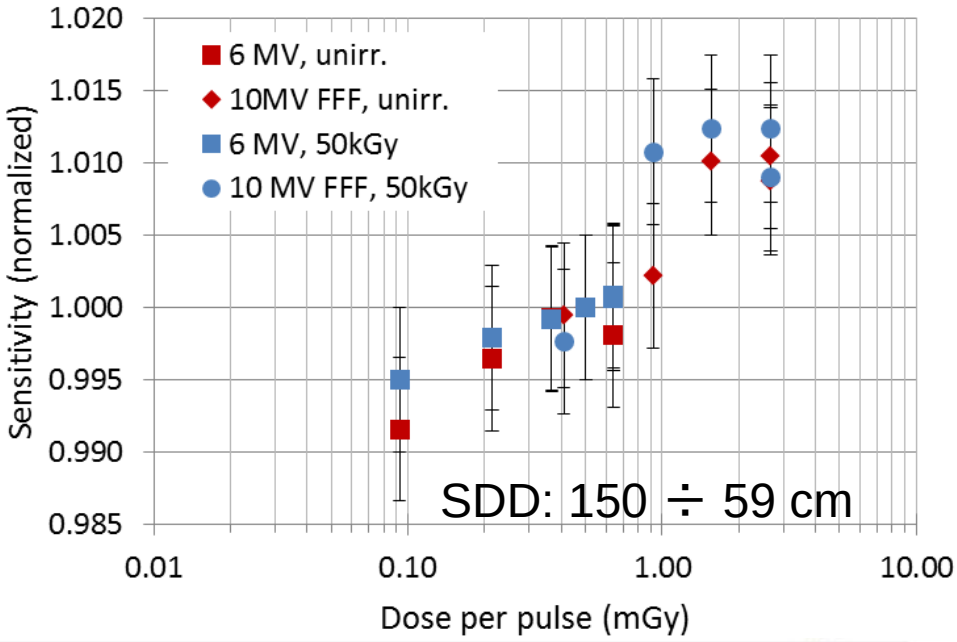
Motivation:

- Check pitch actually needed for small fields
- New chip design to improve further dosimetric performances
- Increase yield of production process
- 1D design to simplify and accelerate prototyping

1D Monolithic Array prototype

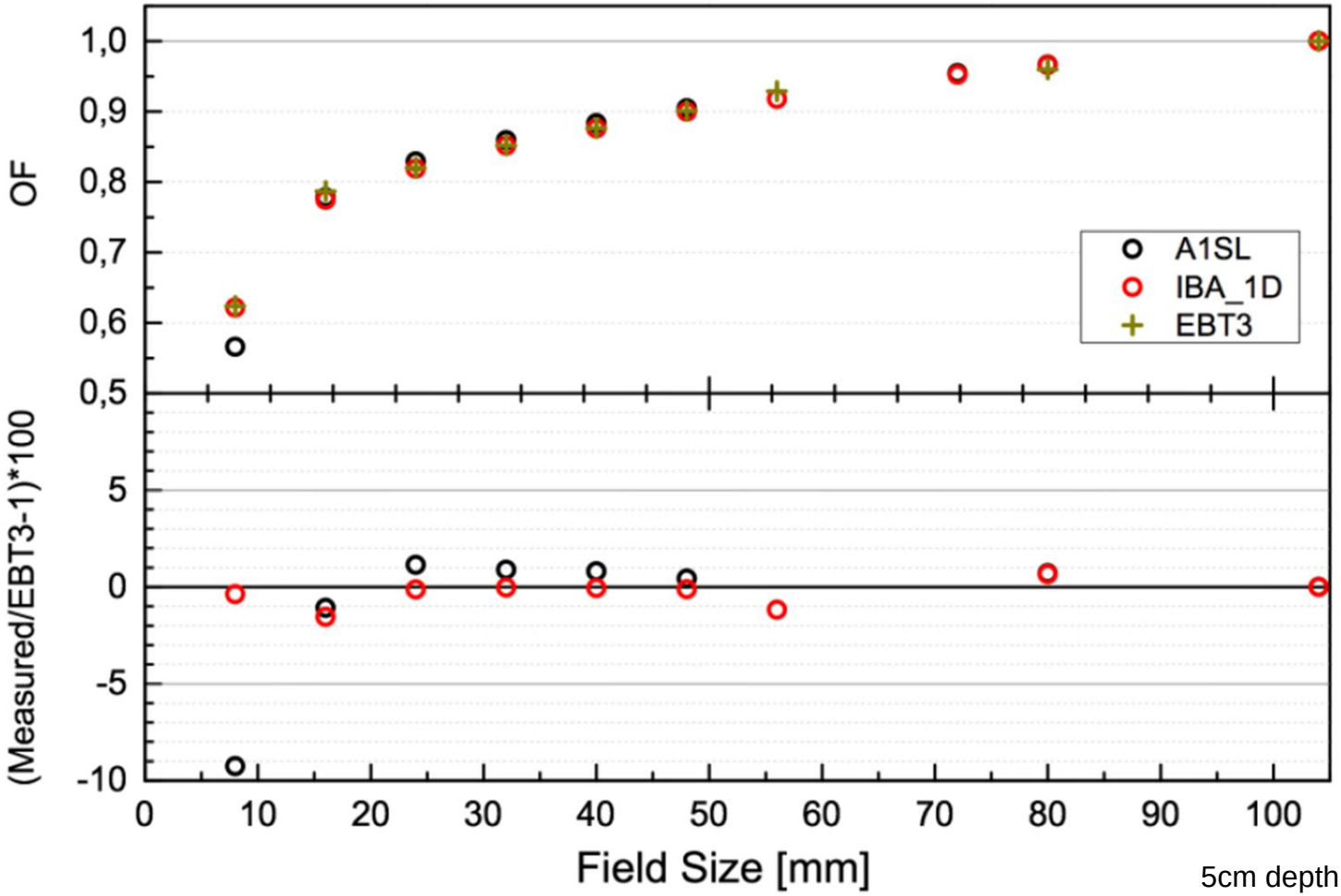
Basic Performance





1D Monolithic Array prototype

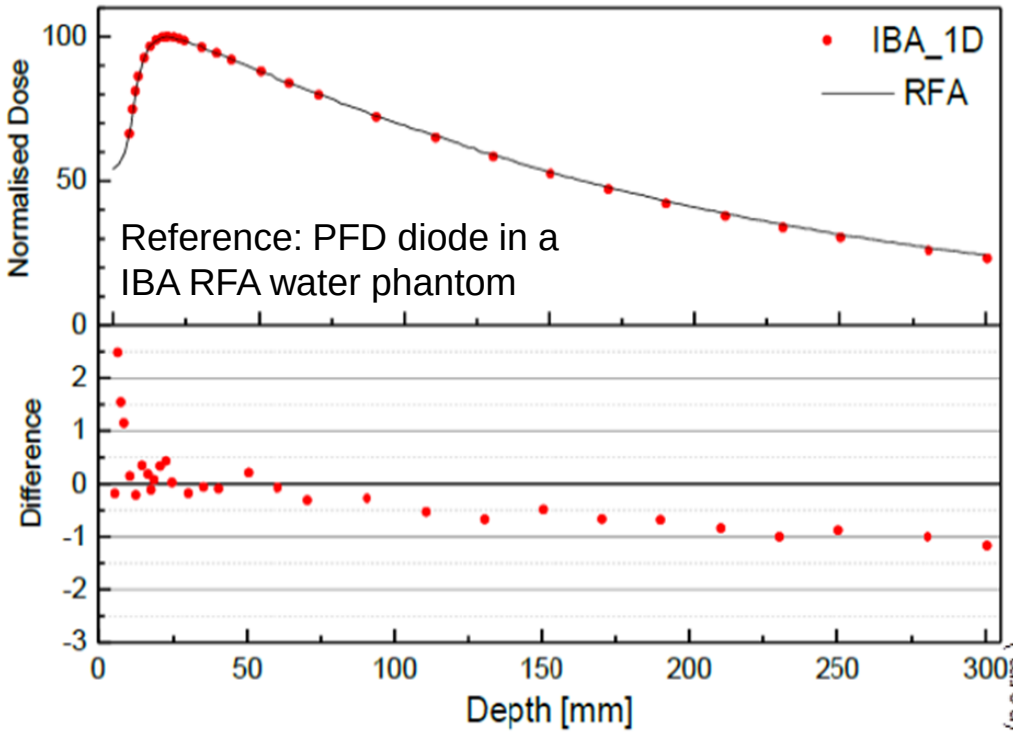
Basic Performance

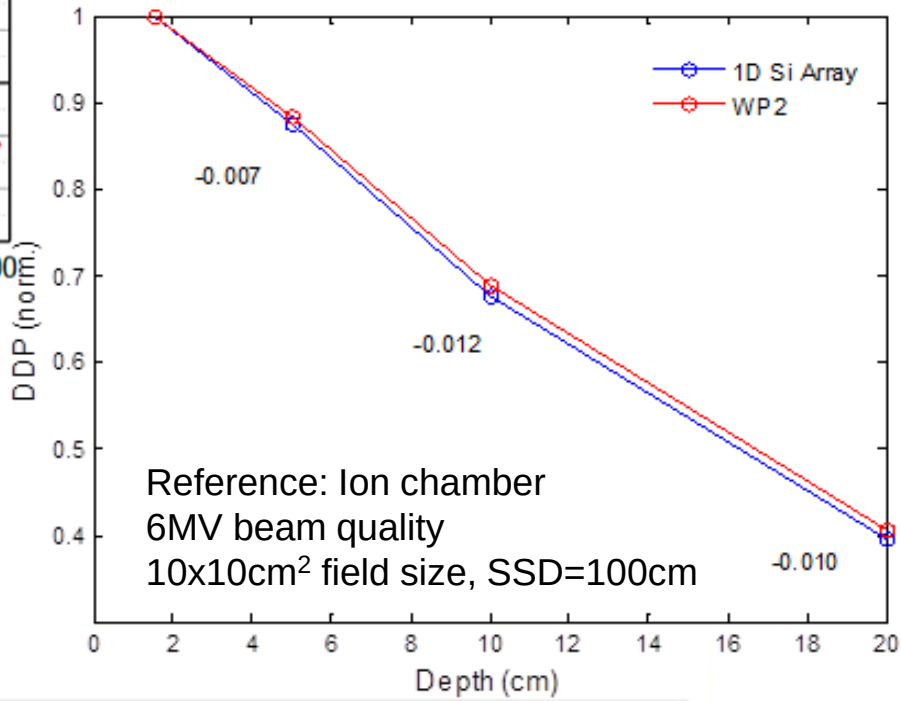


5cm depth
A1SL: ionization chamber

1D Monolithic Array prototype

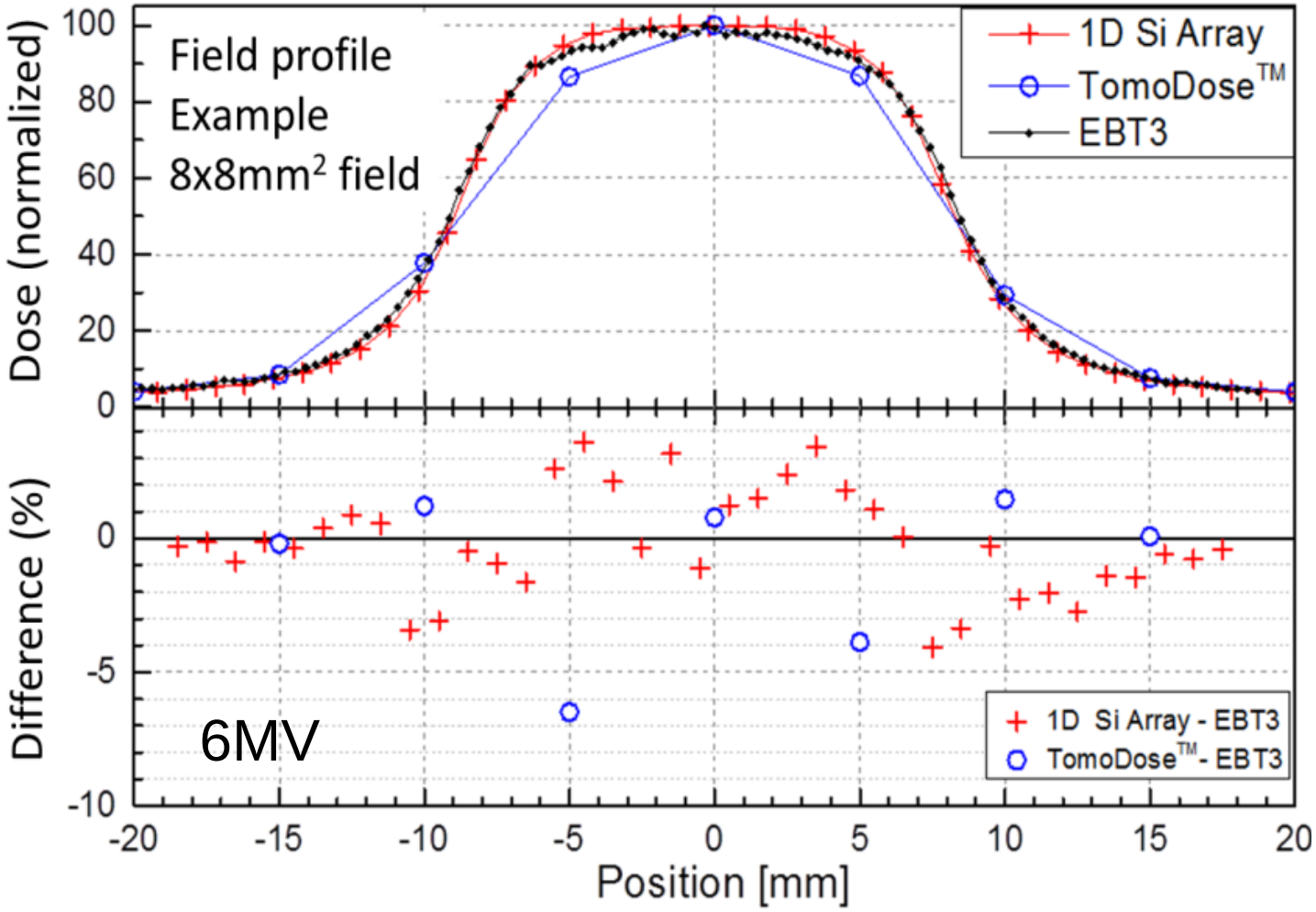
Basic Performance





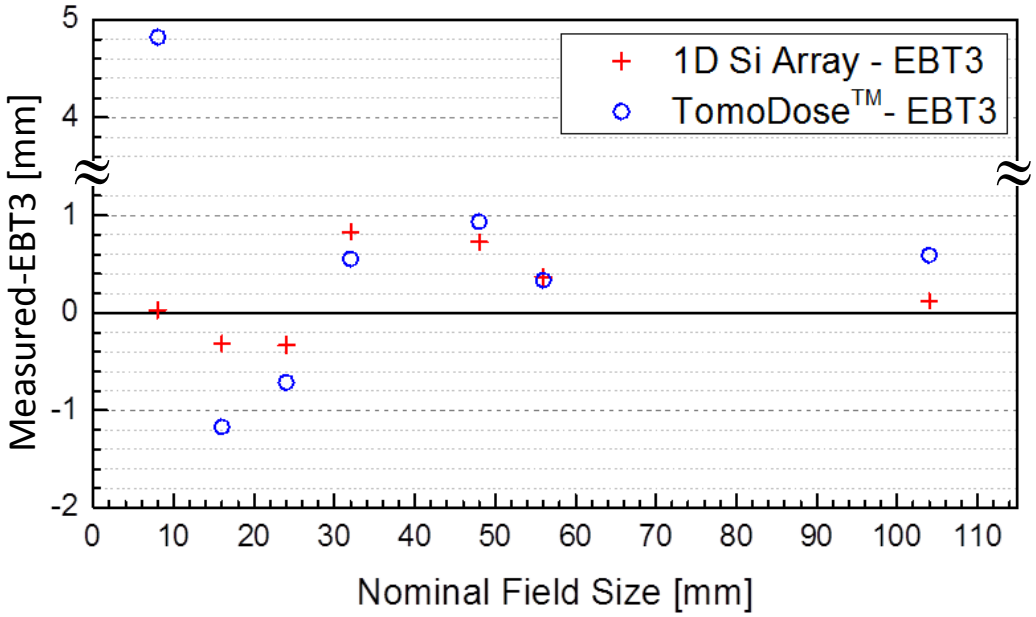
1D Monolithic Array prototype

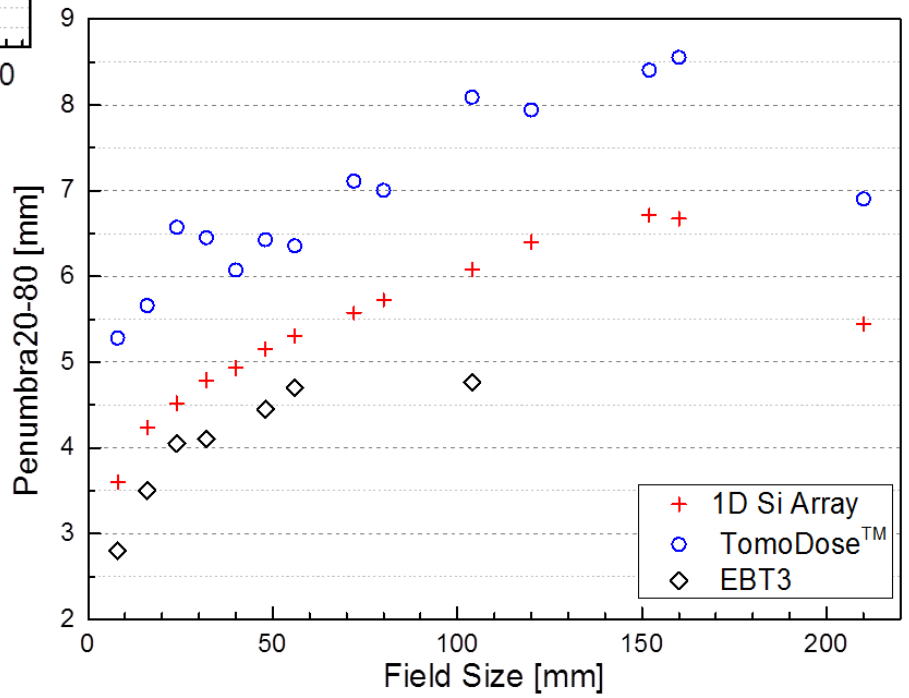
Small Photons Field



1D Monolithic Array prototype

Small Photons Field

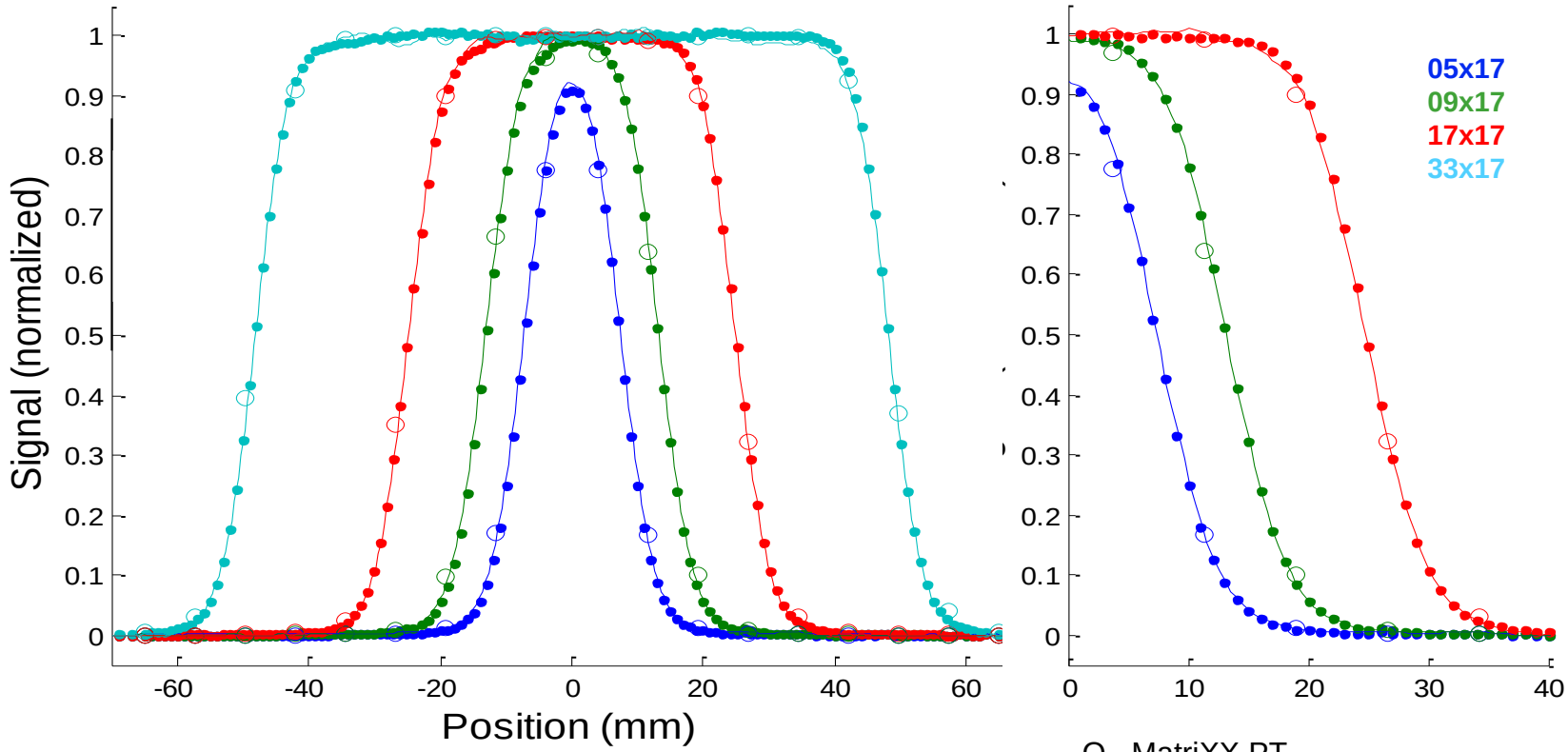




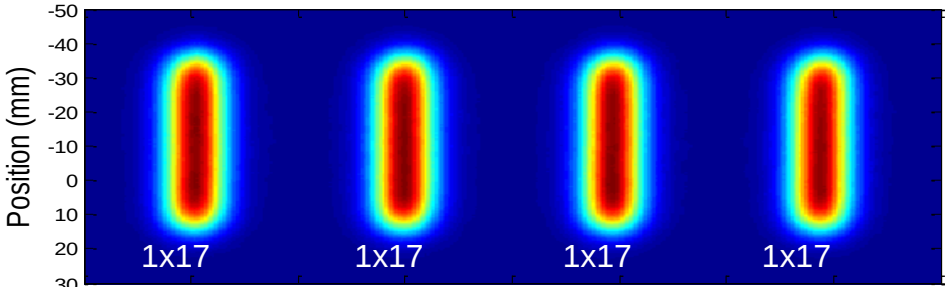
1D Monolithic Array prototype

Proton beam

3mm spot σ at 226MeV

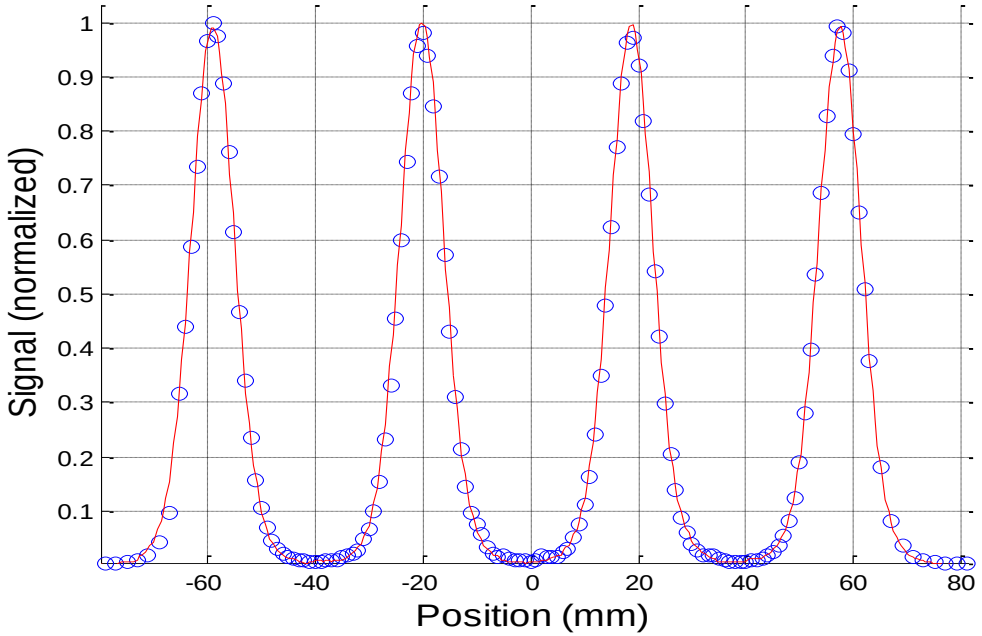


1D Monolithic Array prototype
Proton beam



PBS mode

1MU/spot
226MeV
4x17 spot map
(40x2.5mm pitch)



O 1D Si Array
-- Lynx

1D Monolithic Array prototype
Conclusions

- Radiation hardness: very low dS/dD and dose per pulse dependence (even with FFF beams)
- 1mm pitch: very good profiling of small photon fields and proton PBS
- Small pixel size: accurate evaluation of output factors
- Overall performances: good agreement with reference detectors

Conclusions

Results achieved:

- High spatial resolution
- High dosimetric performances can be achieved
- No energy dependence problems with medium and small field sizes
- Silicon monolithic technology suitable for dosimetry with high dose gradients

Thank you very much for your attention.

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2D Monolithic Array
Results (62 MV protons)

62 MV CATANA