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- The Monte Carlo (MC) method has been shown to be able to model realistic beams from medical accelerators, including those used in Intra Operative Electron Radiotherapy (IOERT). However, it needs a realistic and reliable description of the electron beam that delivers the dose, and this is not usually available.
- The purpose of this work is to derive complete phase spaces (PHSP) for IOERT without the need of a detailed description of the accelerator head or applicator. An iterative algorithm (EM-ML) has been employed to obtain the details of the PHSP of the particles coming from the accelerator, such as energy spectra, fluencies, and angle of emission of particles. The procedure has been tested against MC simulation of a generic conventional LINAC with a typical IOERT applicator, taken as reference and then applied to data from a real accelerator.

METHOD

I) Phase Space Representation

- The PHSP is defined as a set of elementary-sources which include all the relevant degrees of freedom for IOERT and does not make *ad-hoc* assumptions on the PHSP.
- PHSP is a function of Energy (E), radial position (r), and two angular variables (γ , ϕ). It is discretized into bins of each variable.
- Each bin represents an elementary source. Thousands to millions of bins can be employed in the procedure.

II) Dose Calculation

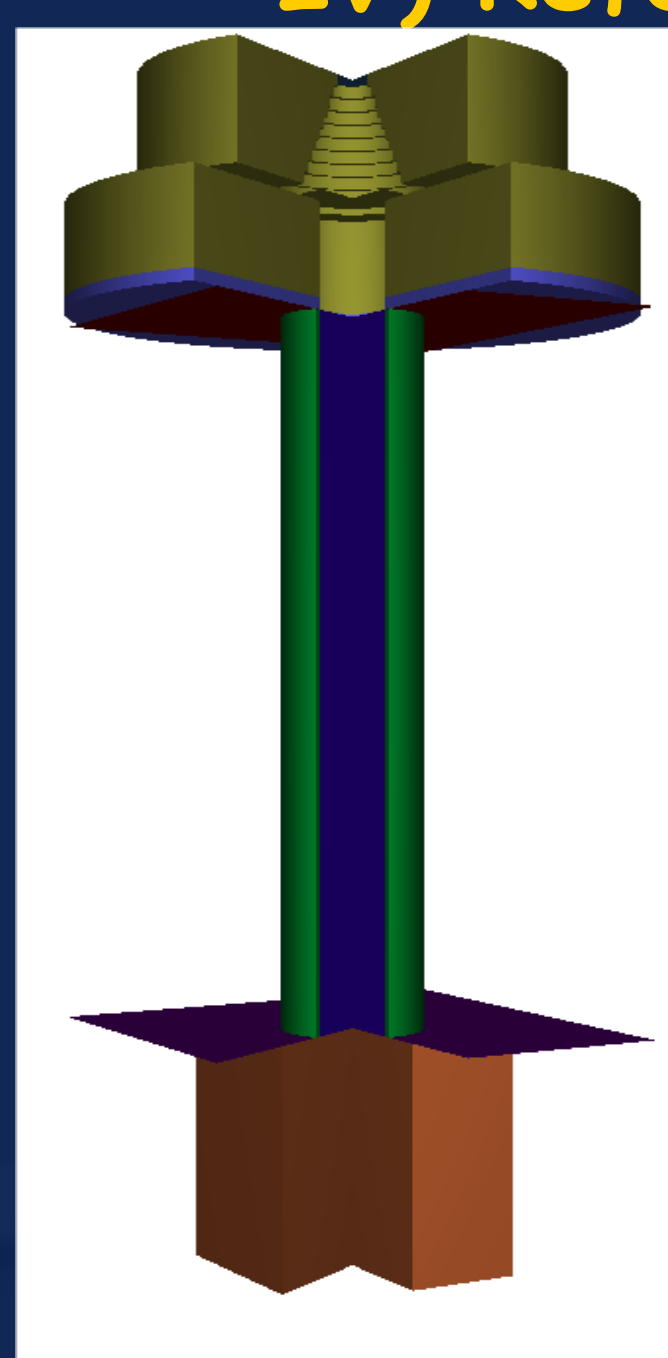
- The dose of each elementary source at the applicator exit is computed in r-z ring-elements for either water or air. DPM [2] is used for this calculation.
- Typically 4000 ring-elements (2x2 mm) in r-z are used.
- We look for an arbitrary linear combination of elementary sources which reproduces measured dose profiles in water or in air and water:

$$\text{Dose}(r, z) = \sum(E, r0, \gamma, \phi) a(E, r0, \gamma, \phi) \times \text{Dose}(f(E, r0, \gamma, \phi), r, z)$$

III) Phase Space Determination

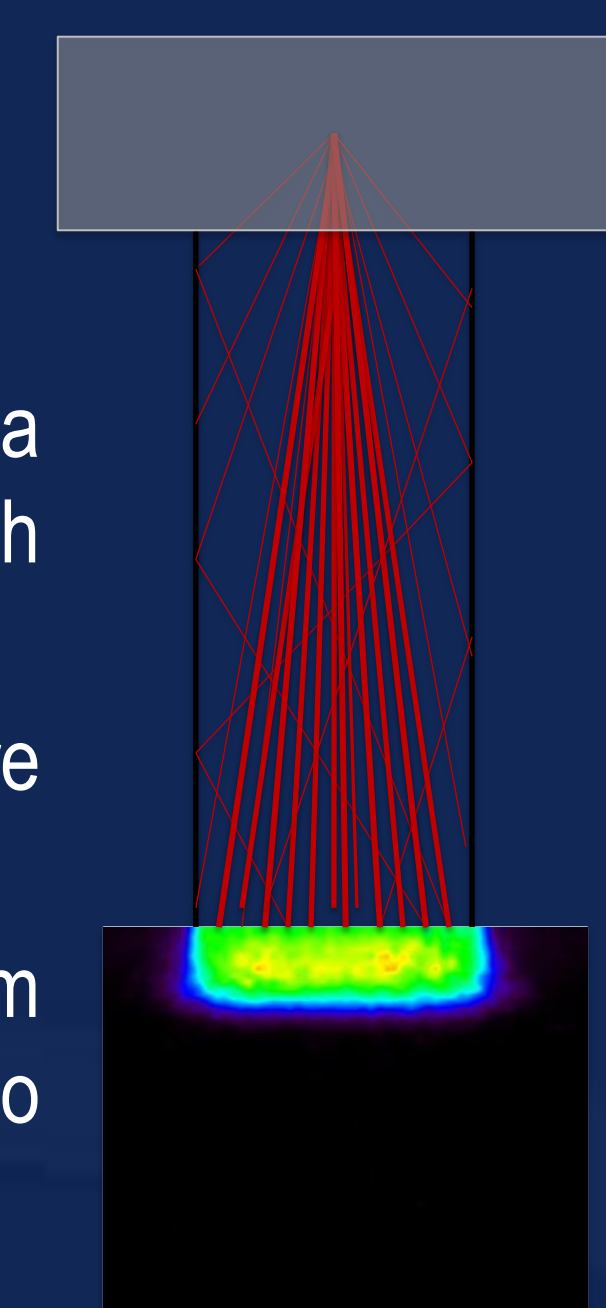
- We use an iterative Maximum Expectation Maximization algorithm (MLEM) [1].
- From the expected dose at each r-z value, $D'(r,z)$ and the measured data $D(r,z)$, correction ratios $c(r,z)=D(r,z)/D'(r,z)$, needed to update the coefficients $a(E, r0, \gamma, \phi)$, are obtained.
- All corrections $c(r,z)$ "connected" with a given elementary source are weighted-averaged to yield an updating factor to the coefficient $a(E, r0, \gamma, \phi)$. The weights are the 'elementary-doses' at ring-element $s(r,z)$.

IV) Reference Cases



A. Simulated Data

- A test problem is built simulating a LINAC +IOERT applicator with PenEasy [3] (PHSP DATA)
- Dose volumes in water and air are computed from PHSP-DATA
- Dose Profiles (PDD and cross beam profiles) are obtained and compared to the reference ones



B. Experimental Data

- Dose profiles are measured in water
- Reference dose volumes are generated by interpolating the experimental dose profiles
- The dose generated by the solution PHSP is compared with the experimental water profiles

RESULTS

A. Dose comparison with simulated data

We show in table 1 the result of the comparison of the reference against dose obtained from a PHSP reconstructed from simulated data in air and water, in terms of gamma function results (3%-3 mm criteria) for the case of homogeneous objects of air and of water, and for the four setups shown in Fig1.

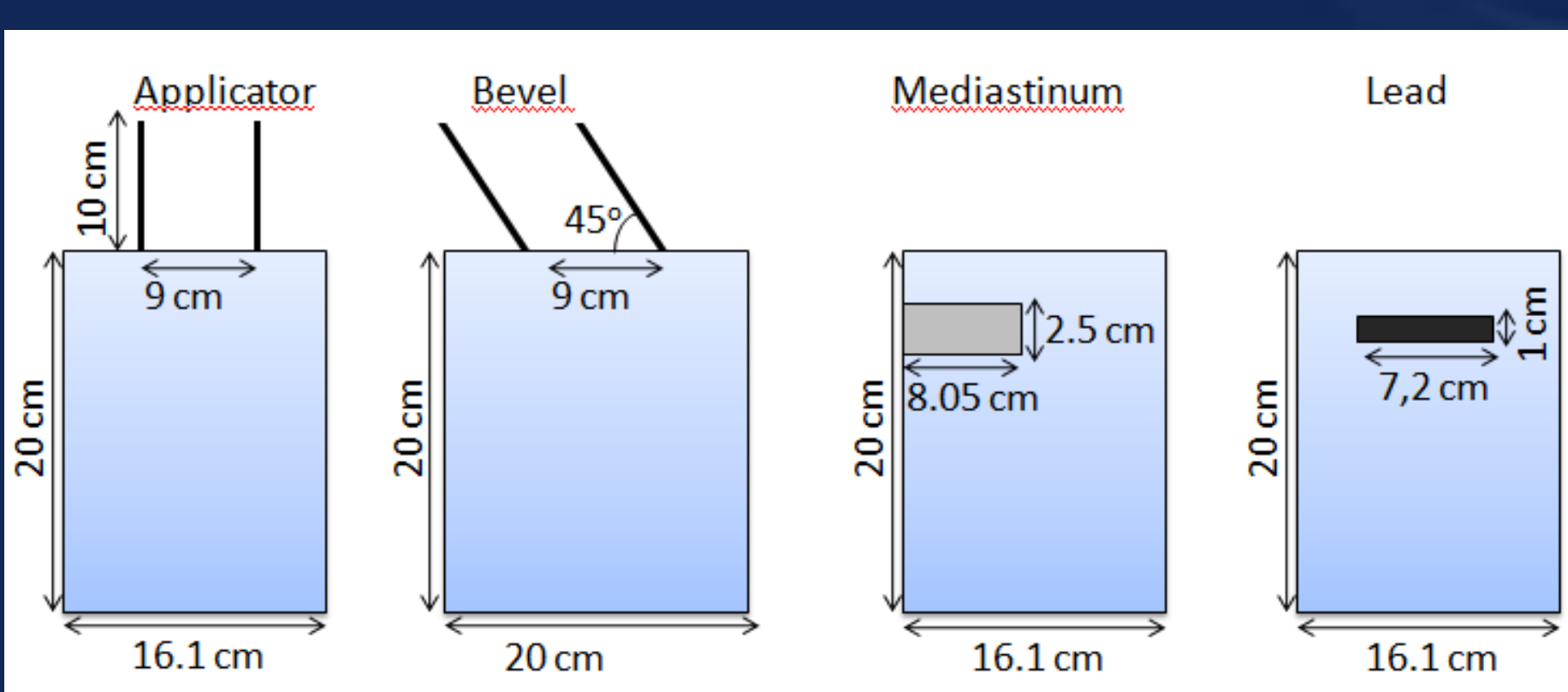


Figure 1. Additional setups where the dose produced by the solution and reference PHSP are compared.

Water	Air	Applicator	Bevel	Mediast.	Lead
100.0	100.0	99.8	100.0	100.0	100.0

Table 1. Percentage of voxels with Gamma < 1 (3%-3 mm criteria) within the region which dose larger than 5% of the maximum dose, for different solution PHSP and validation setups

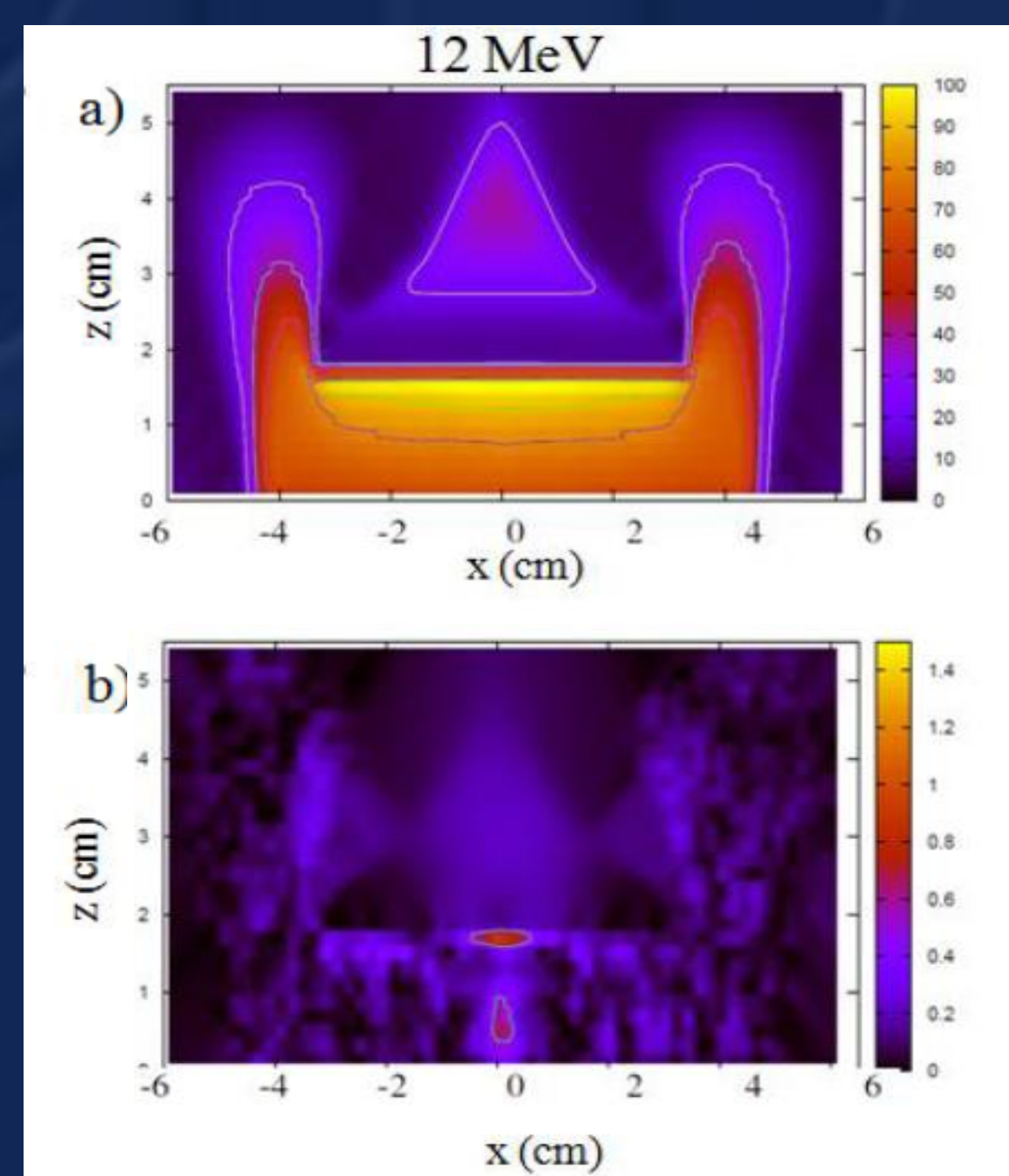


Figure 2. a) 2D dose map distribution for the water + lead setup. Figure b) shows the map of the gamma distribution (3%-3 mm)

B. Dose comparison with experimental data

We show in figure 3 the comparison of the dose obtained from a PHSP reconstructed from experimental water profiles against data measured with radiochromic films for the mediastinum setup. In terms of gamma function, MC simulation is in good agreement with the data at the 3%-3 mm level.

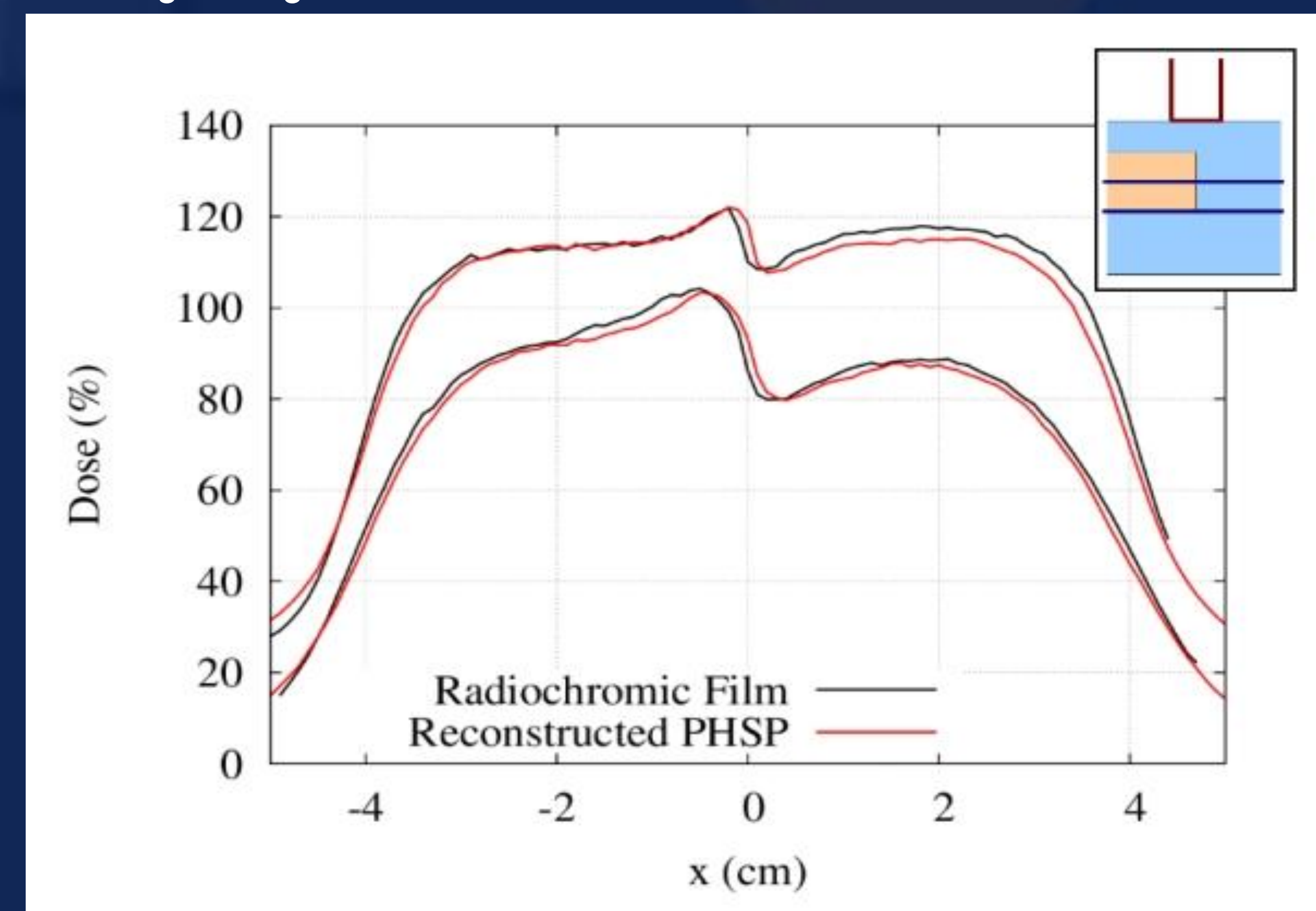


Figure 3. Transverse dose profiles at 2.5 (shifted up by 20%) and 3.5 cm depth, obtained with the mediastinum phantom.

CONCLUSIONS

- ✓ The method proposed for PHSP determination of electron beams can be employed to obtain PHSP files from a few reference measurements
- ✓ Solution PHSP are obtained in a short computing time
- ✓ Dose distributions obtained with the solution PHSP in phantoms different from the ones employed in the fit are in good agreement with the ones obtained from the reference PHSP.
- ✓ Comparisons against experimental data have been performed and confirmed the predictive power of the solution PHSP.

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