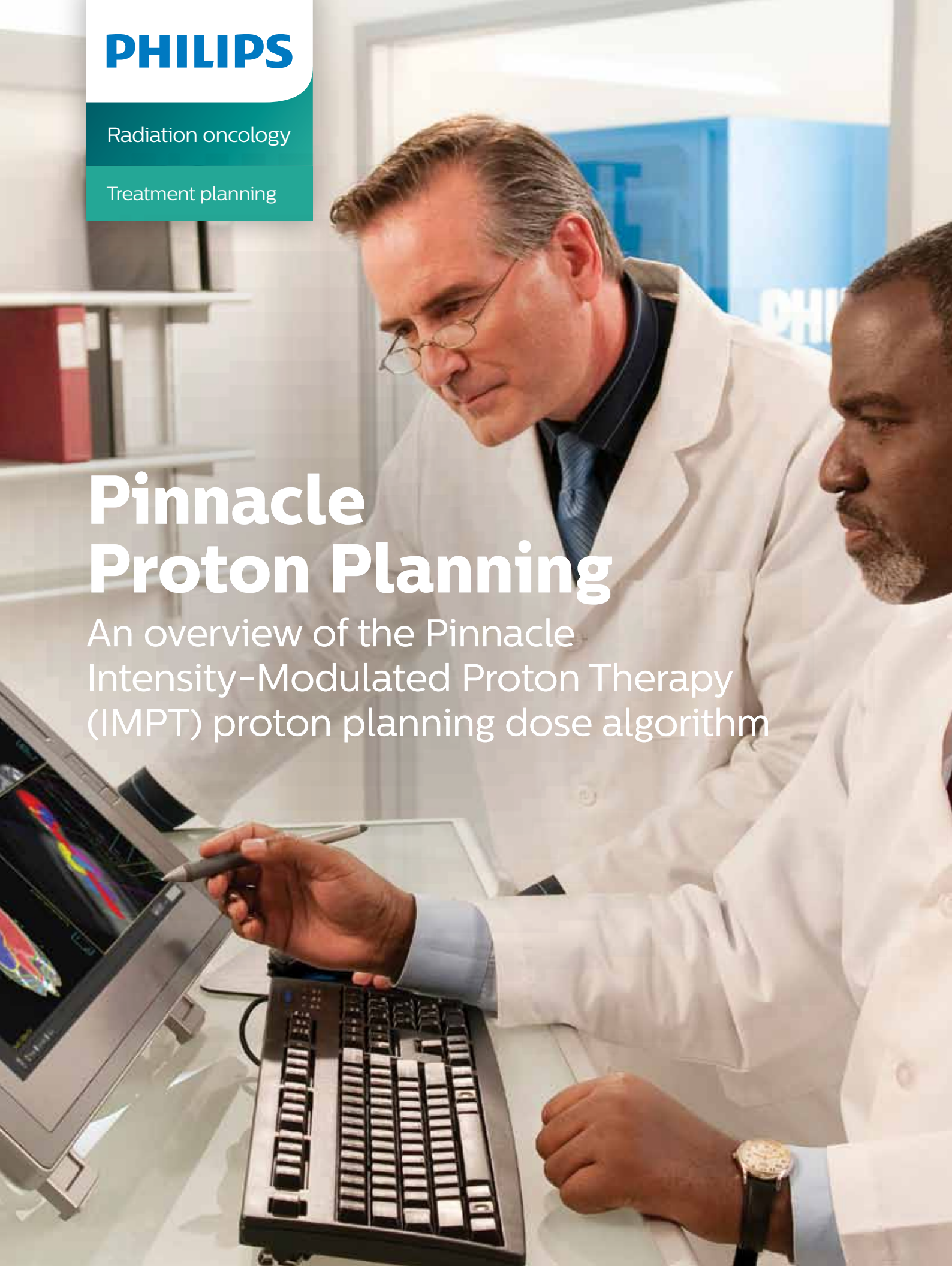
PHILIPS

Radiation oncology

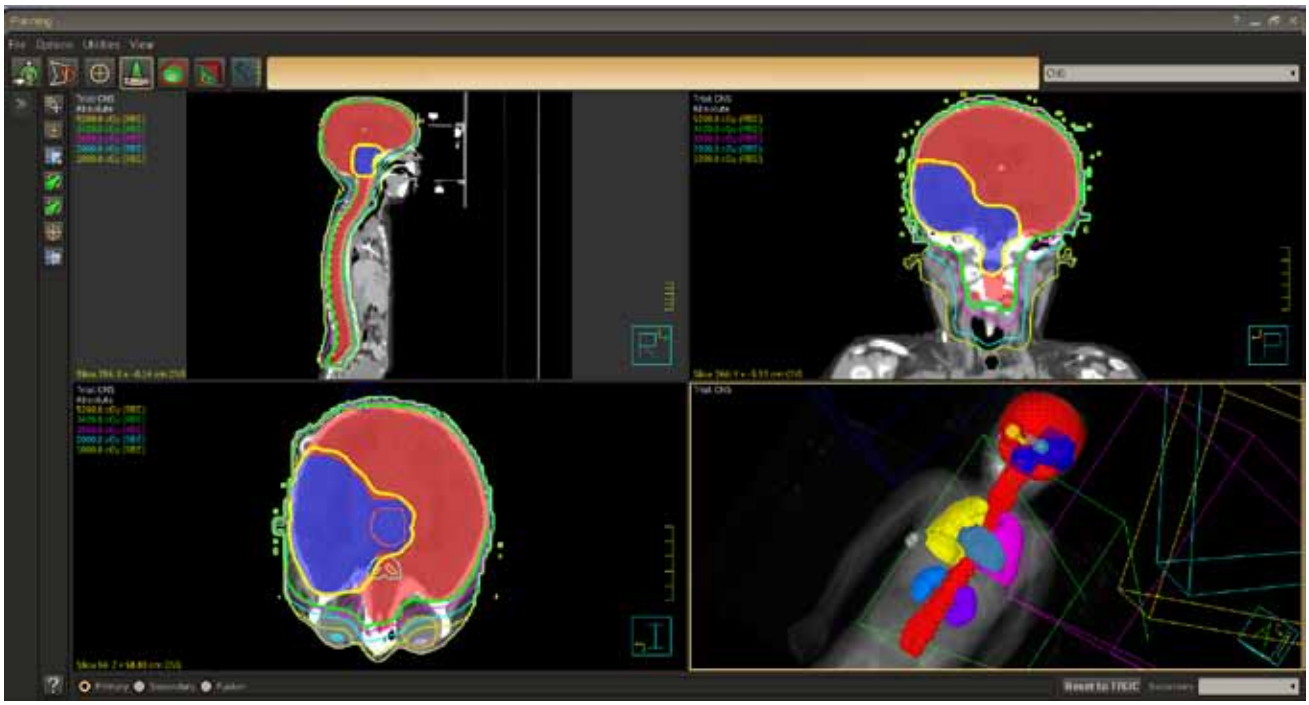
Treatment planning



# Pinnacle Proton Planning

## An overview of the Pinnacle Intensity-Modulated Proton Therapy (IMPT) proton planning dose algorithm

# The Pinnacle Proton Planning with IMPT



## Spot scanning dose computation

Pinnacle utilizes the data collected during physics modeling such as the Integral Depth Dose curve (IDD) and In-air Fluence (IAF) to compute dose for each desired spot individually. The total dose for each beam is the summation of dose from all non-zero weighted spots in the spot list generated or imported prior to dose calculation. The fundamental equation for dose calculation of each spot is:

$$D(x,y,z,E_0) = MU \times (w_{nuc}\dot{D}_{nuc}(x,y,z,E_0) + w_{DG}\dot{D}_{DG}(x,y,z,E_0) + w_{SG}\dot{D}_{SG}(x,y,z,E_0))$$

The spot's dose is a combination of 3 components:

1. the dose contribution from the single Gaussian portion of the fluence,
2. the dose contribution from the double Gaussian portion of the fluence and
3. the nuclear contribution within the patient. The user has the choice during commissioning to model the IAF as either single or double Gaussian-shaped. The ratio and shape of the single and double Gaussian fluence is fitted during commissioning. If the machine is modelled as single Gaussian only, then the wDG will be zero. The nuclear component's weight is a function of energy and water equivalent depth.

Pinnacle subdivides the contribution of the single Gaussian component into many sub spots, each of which is individually computed. This allows for accurate corrections for heterogeneities lateral to the spot's central axis.

The dose rate for the Single Gaussian component can be represented as:

$$\dot{D}_{SG}(x,y,z,E_0) = \sum_{k=1}^{N_{Sub}} w_k \dot{d}_k(x,y,z,E_0)$$

$w_k$ is the weight of the sub spot and is calculated as the partial surface integral of the single Gaussian fluence component in air. The value of $N_{Sub}$ is dependent upon several factors including the size of the in-air fluence ($\sigma_{SG_x}$ and $\sigma_{SG_y}$) of the spot and desired spot spacing for

# spot scanning dose engine algorithm

the beam, both of which affect the sub spot resolution. Pinnacle ensures that no fewer than 4 sub pencils are used per 3 sigma lateral distance of the in-air fluence. Additionally, Pinnacle computes laterally 4 sigma for the primary fluence, yielding at least 134 sub spots per spot dose computation. Generally, the number of sub spots can be substantially larger than this during dose computation, exceeding 300 or more. This is because the sub spot resolution is determined for the smallest desired spot in air and used for all spots for the current beam. In addition, Pinnacle ensures that the central axis of the spot lies at the center of the desired spot spacing. This prevents partial voxel effects at the expense of generally making the sub spot resolution finer and increasing the number of sub spots used per spot.

$\dot{d}_k$ represents the dose rate contribution of the sub spot at the desired location according to the following equation:

$$\dot{d}_k(x,y,z,E_0) = \frac{0.25}{d_x d_y} IDD_{E_0}(z_{eq}) \left( erf \frac{0.5d_x - x}{\sqrt{2}\,\sigma_{tot}} + erf \frac{0.5d_x + x}{\sqrt{2}\,\sigma_{tot}} \right) \times \left( erf \frac{0.5d_y - y}{\sqrt{2}\,\sigma_{tot}} + erf \frac{0.5d_y + y}{\sqrt{2}\,\sigma_{tot}} \right)$$

x and y are the distances from the center of the spot to the dose calculation point in the x and y directions respectively. $d_x$ and $d_y$ are the dimensions of the sub spot in the x and y directions. Pinnacle computes dose using a dual divergent source model in order to account for the difference in divergence from the two sweeping magnets at different SADs (SADx and SADy) as defined in physics. Thus, each sub spot is computed on a dual divergent dose grid with rectangular pixels (dx, dy). The integral dose rate at each depth is determined from $IDD_{E_0}(z_{eq})$ which was modeled during commissioning for the desired initial spot energy. $z_{eq}$ is the water equivalent depth at this physical dose calculation depth.

$\sigma_{tot}$ represents the total scatter at each depth for each sub spot. $\sigma_{tot}$ is calculated as:

$$\sigma_{tot} = \sqrt{\sigma_{MCS}^2 + \sigma_{MCS}^2}$$

$\sigma_{MCS}$ is computed individually for each sub spot and represents the Multiple Coulomb Scattering due to the patient. Starting at the surface of the patient, the scattering power of each step along each sub spot is calculated and propagated to get the total MCS at the dose calculation point. This method does not utilize any approximations based on water equivalent thickness (WET). In other words, the MCS is computed in a stepwise fashion incorporating all materials that intercept the sub spot's path. In this manor, the MCS can be more accurately computed compared to methods that utilize the WET and an MCS lookup table.

$\sigma_{RS}$ is the Gaussian contribution of scatter to the sub spot due to the range shifter, if one is utilized for the current beam. The range shifter is modelled as having a finite thickness as entered during commissioning. In addition, the range shifter has an explicit distance from isocenter. The range shifter position is assumed adjacent to the downstream face of the snout (snout position). $\sigma_{RS}$ is propagated from an effective source position within the range shifter which was commissioned during beam modeling. The effective source position is a function of energy and specific range shifter. Thus, the size of the scatter contribution due to the range shifter can be controlled/adjusted during modeling. $\sigma_{RS}$ is calculated based on its WET, Air Gap, and effective source position.

The nuclear and double Gaussian components are computed similarly as the equation for $\dot{d}_k$ above, with the exception that only a single sub spot is used and the $\sigma_{tot}$ is combined in quadrature with the $\sigma_{nuc}$ and $\sigma_{DG}$, respectively.

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