Physical and biological investigations using Geant4 Monte Carlo simulations of the beam delivery line components in particle therapy

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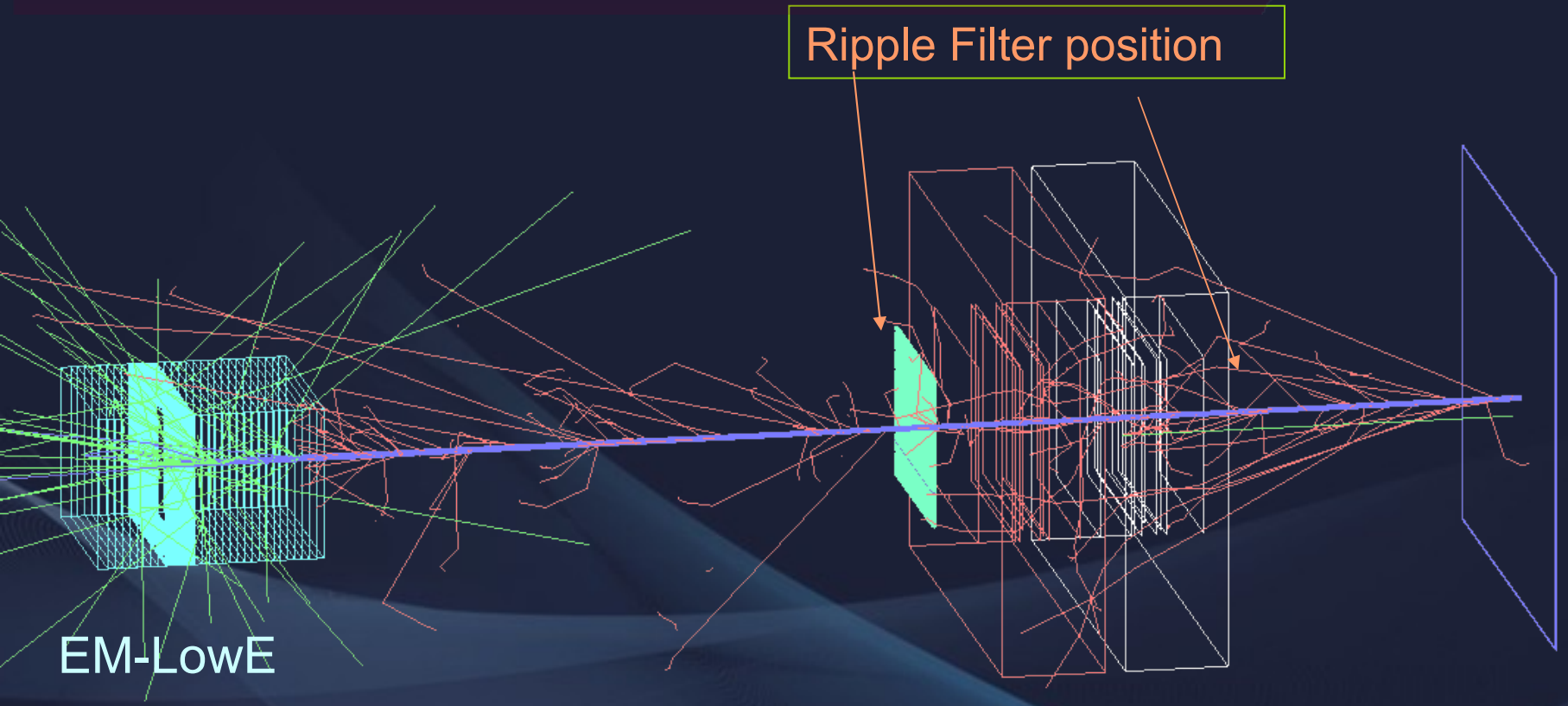
Outline

- Beam delivery line simulation
- Ripple filter design and simulation
  - Ripple filter study for both proton and carbon ion beam
    - Double filtering
    - Proton beam
    - Carbon ion beam
- Biological equivalent dose with ripple filter

Monte Carlo Beam Delivery Simulation BDS



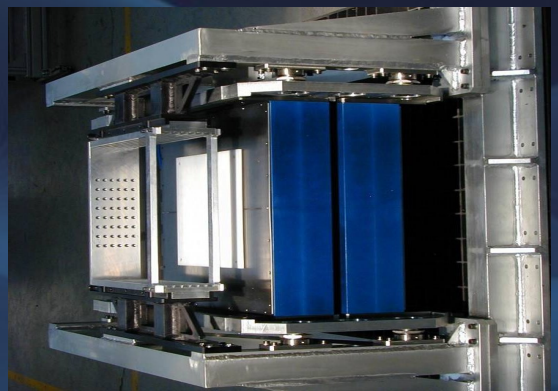
EM-LowE

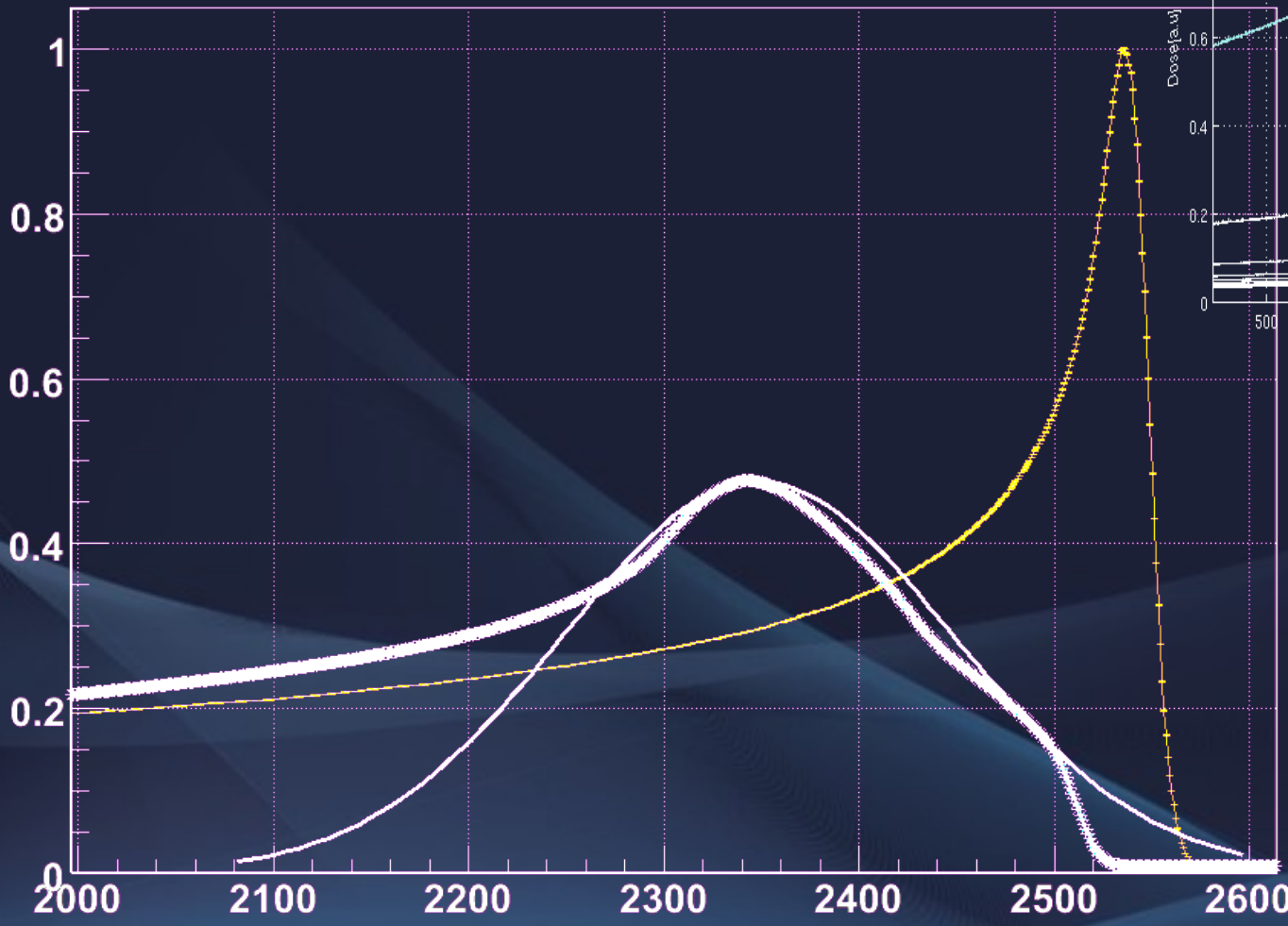
hadron-handro-Elastic

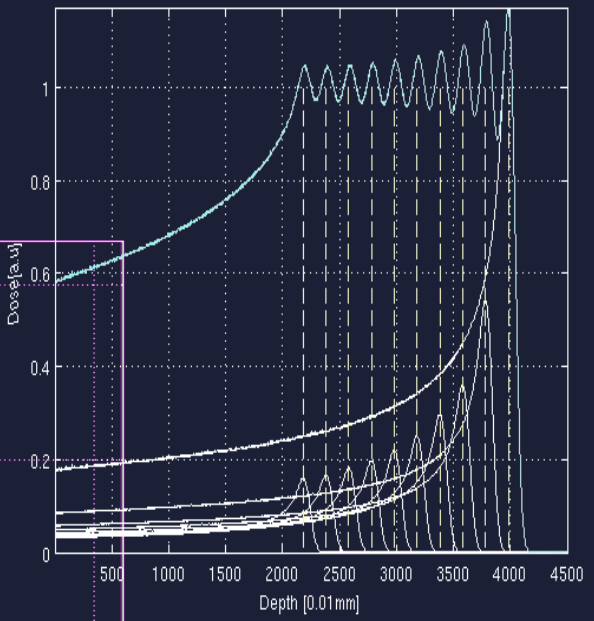
Inelastic

Proton Precompound Binary

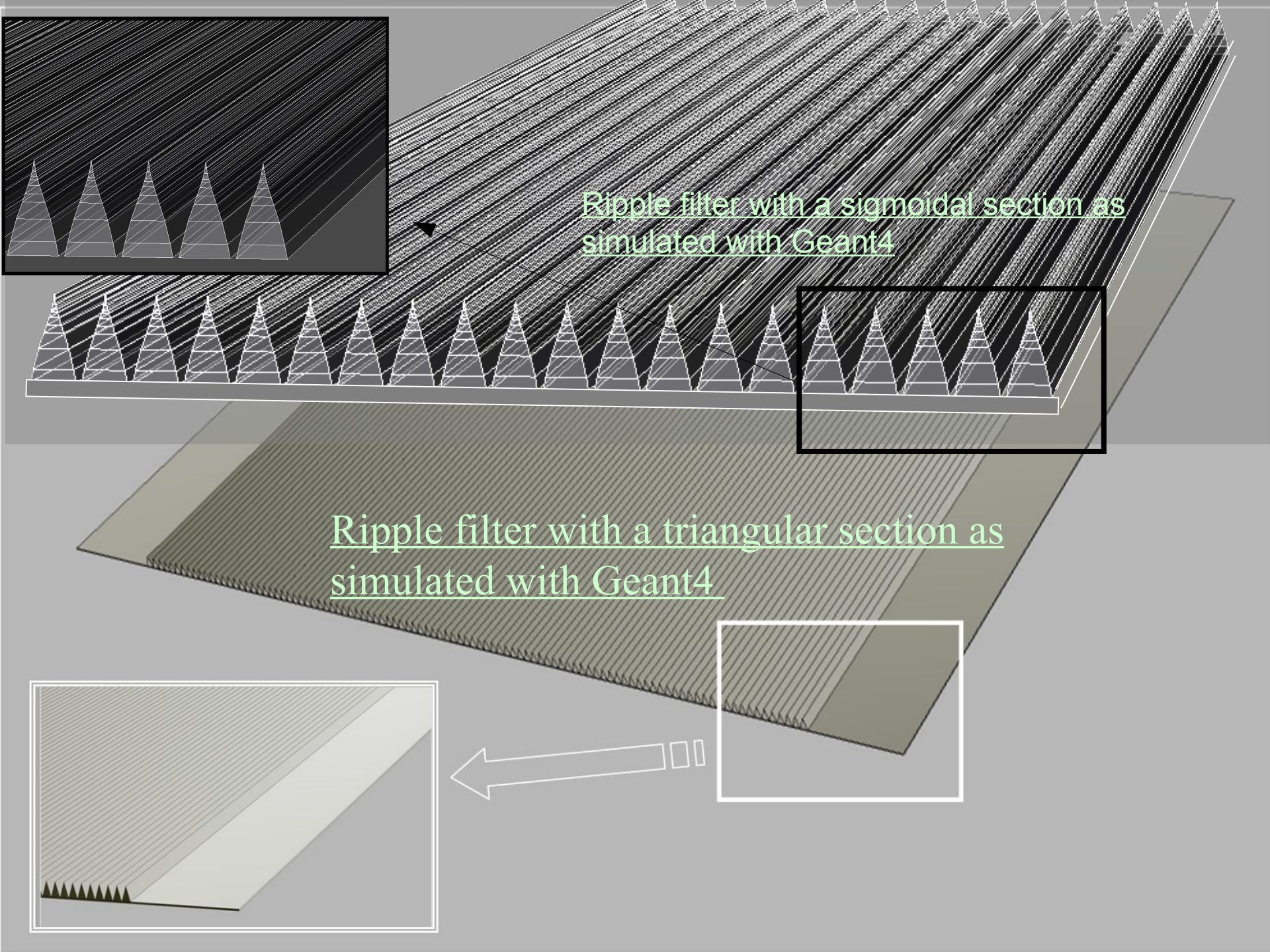
Carbon Ion Physics







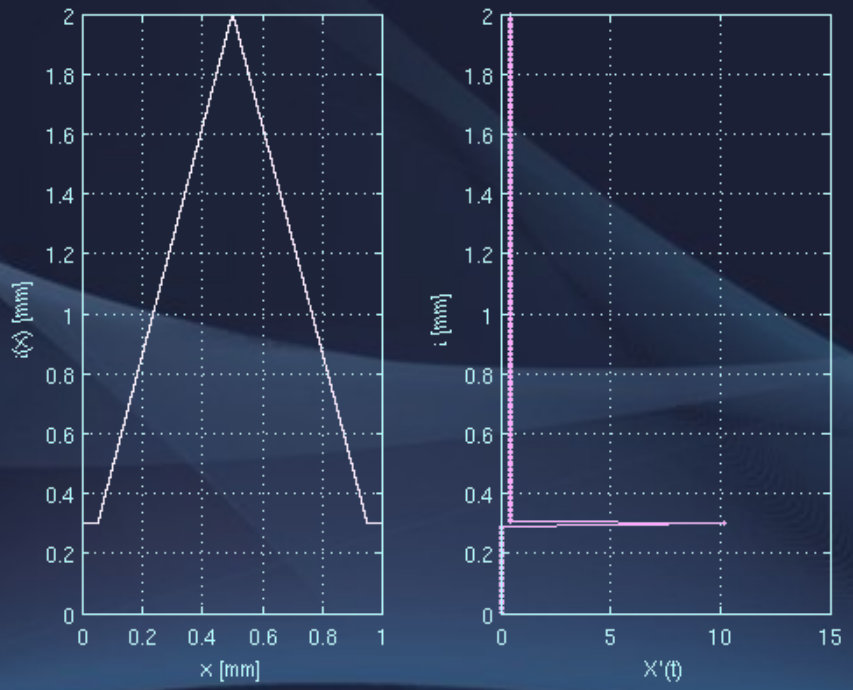
Robust algorithm for dose homogeneity optimization on the SOBP.


Ripple filter with a sigmoidal section as simulated with Geant4
Ripple filter with a triangular section as simulated with Geant4

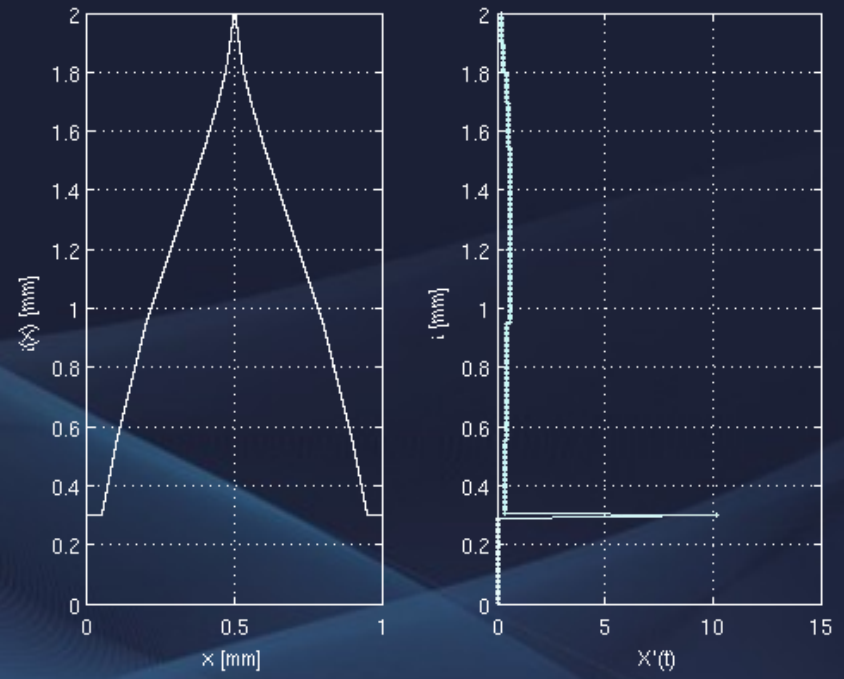
Analytical Study

Transfer functions

Triangle



Sigmoid

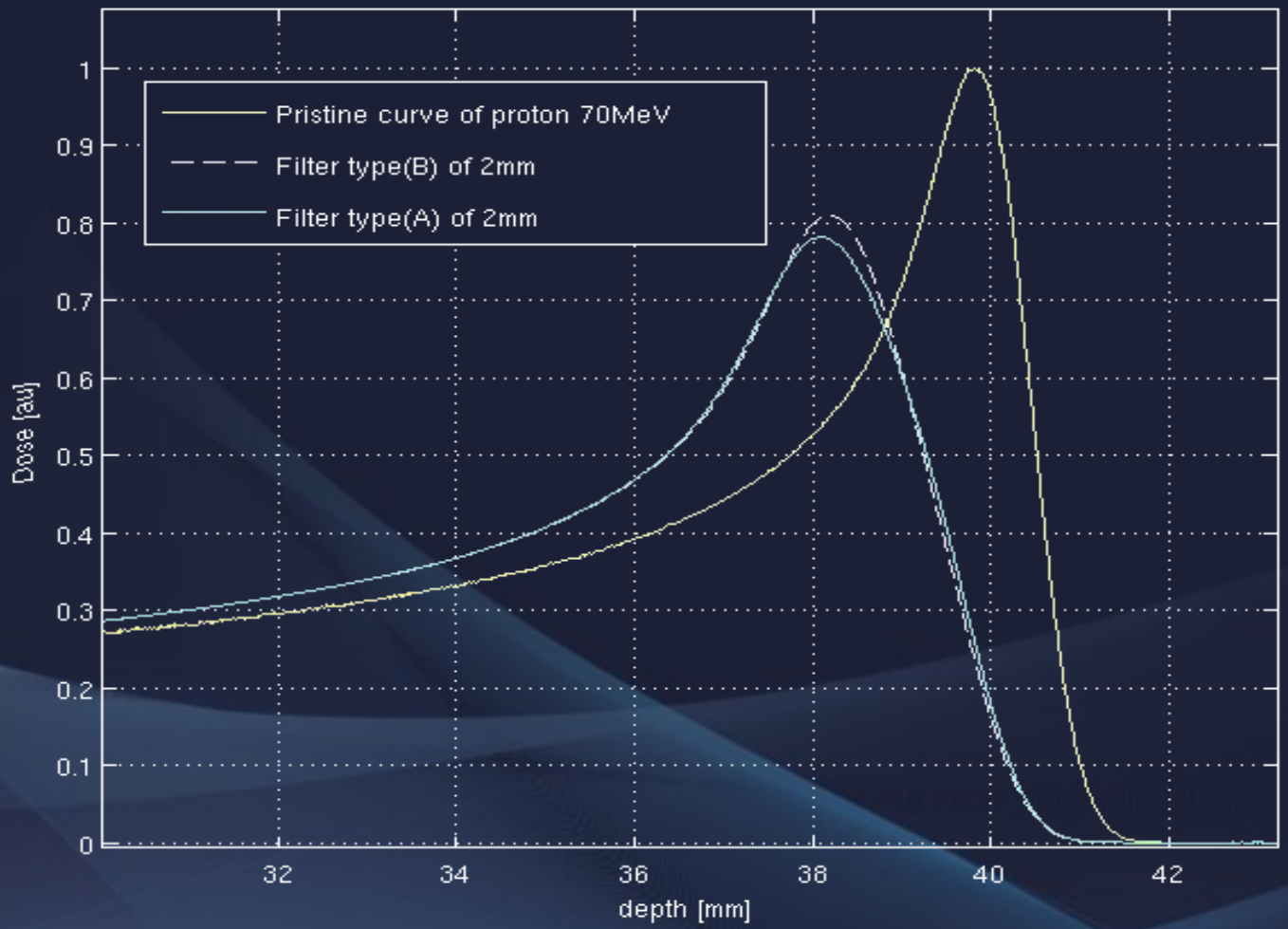


Results

- Proton beams

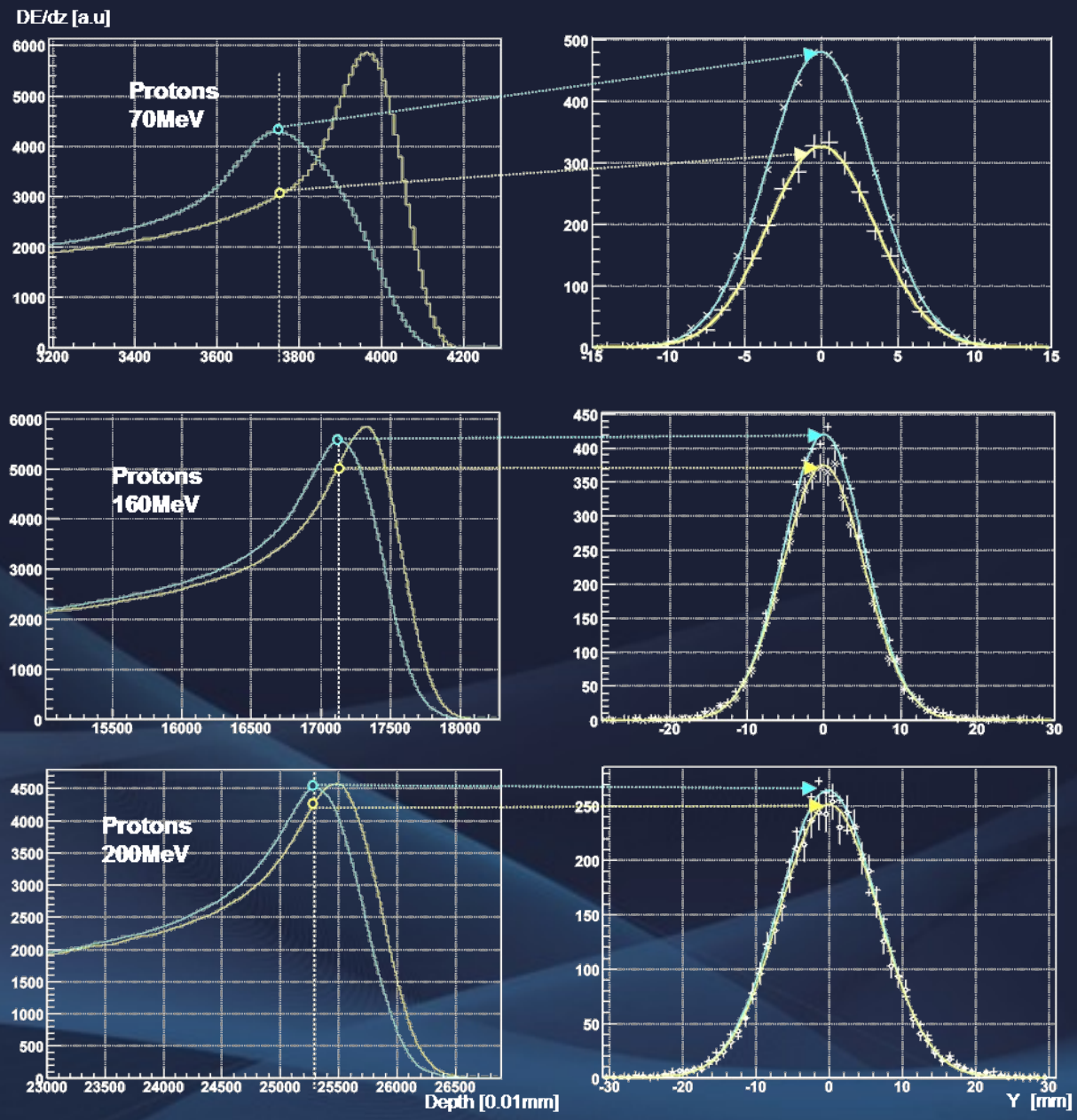
- Carbon ion beams

Proton beams

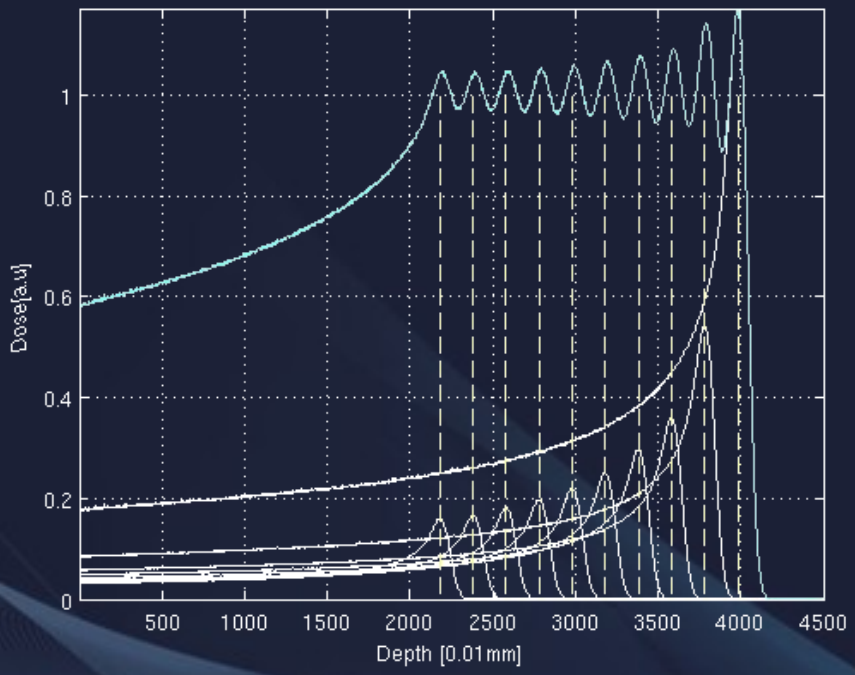


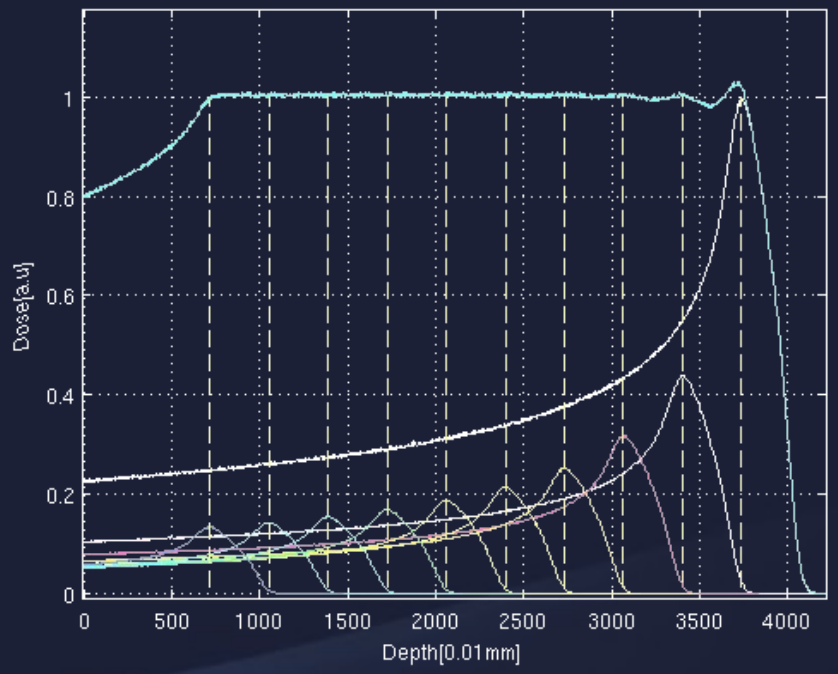
Comparison of the effect of the original ripple filter type (B) as described by Weber et al and the approximated ripple filter type (A)

Total energy loss in depth for proton beams of 70 MeV, without and with a ripple filter type (A) of 2 mm, and the corresponding lateral distribution at the peak position with ripple filter.



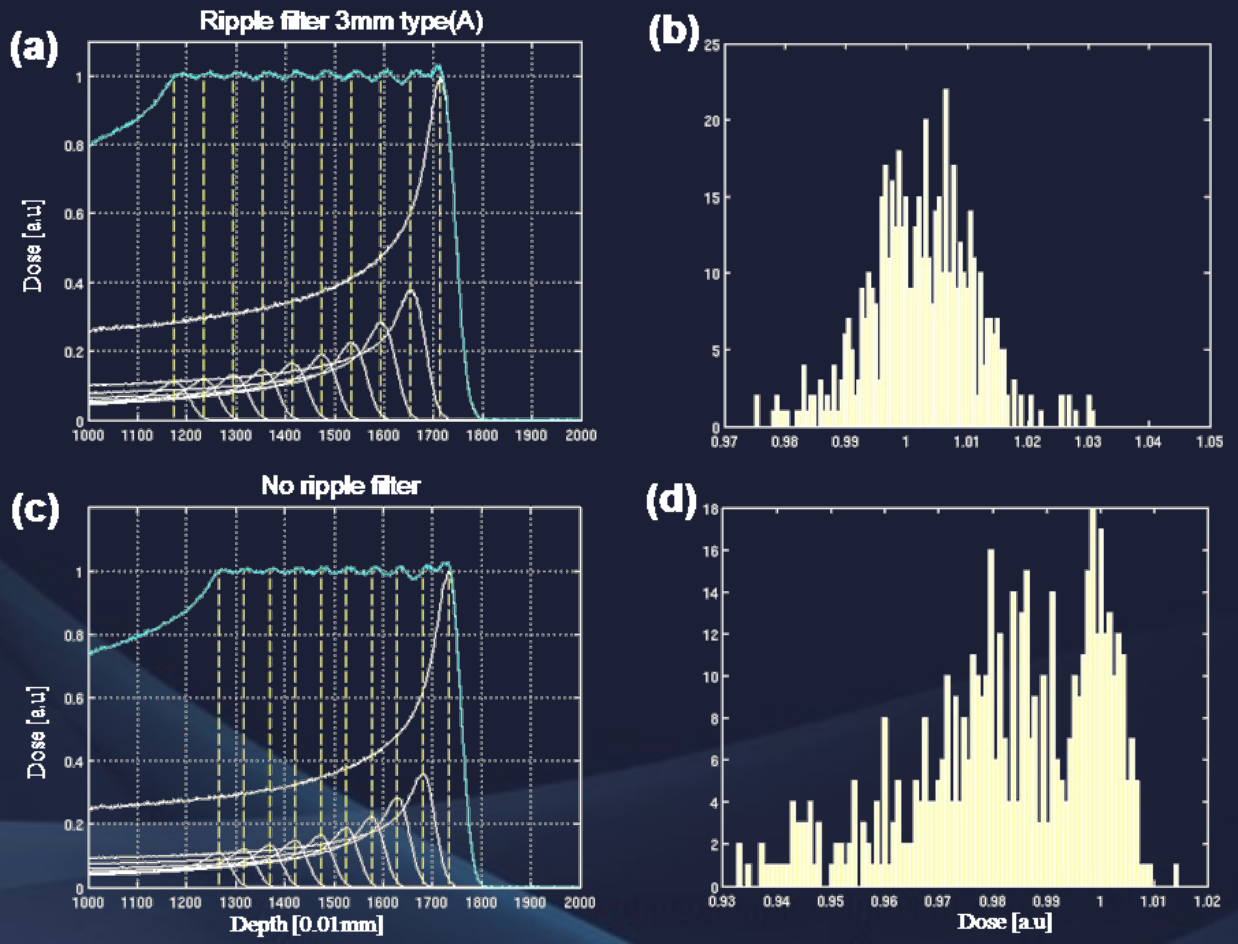
Proton beams





Spread out of the Bragg peak for proton beam of 70 MeV respectively without ripple filter and with ripple filter type(A) of 3 mm.

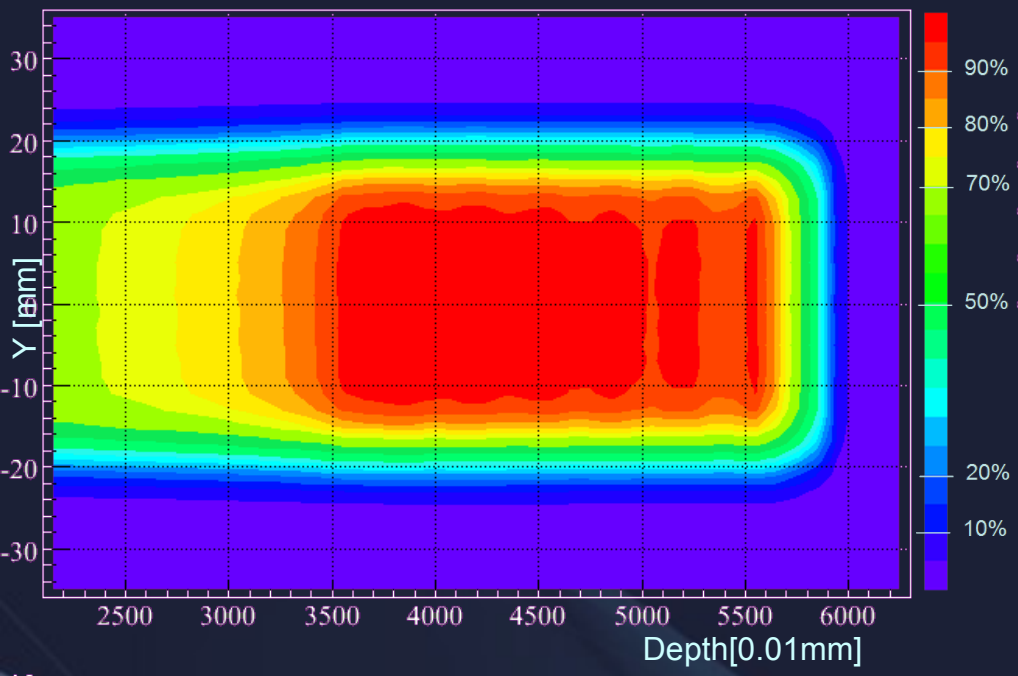
Proton beam of 160 MeV

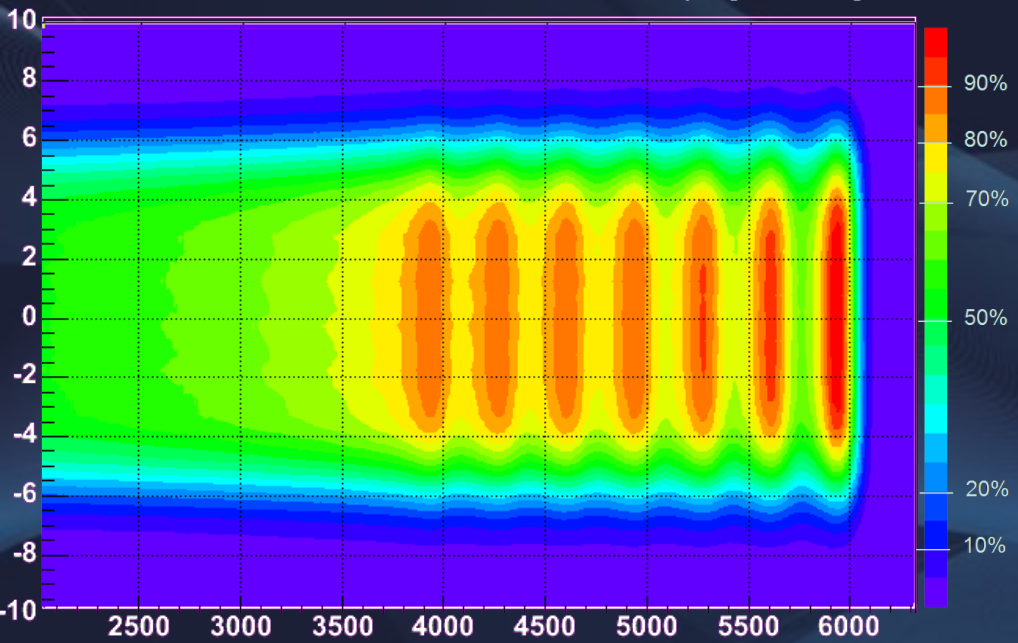


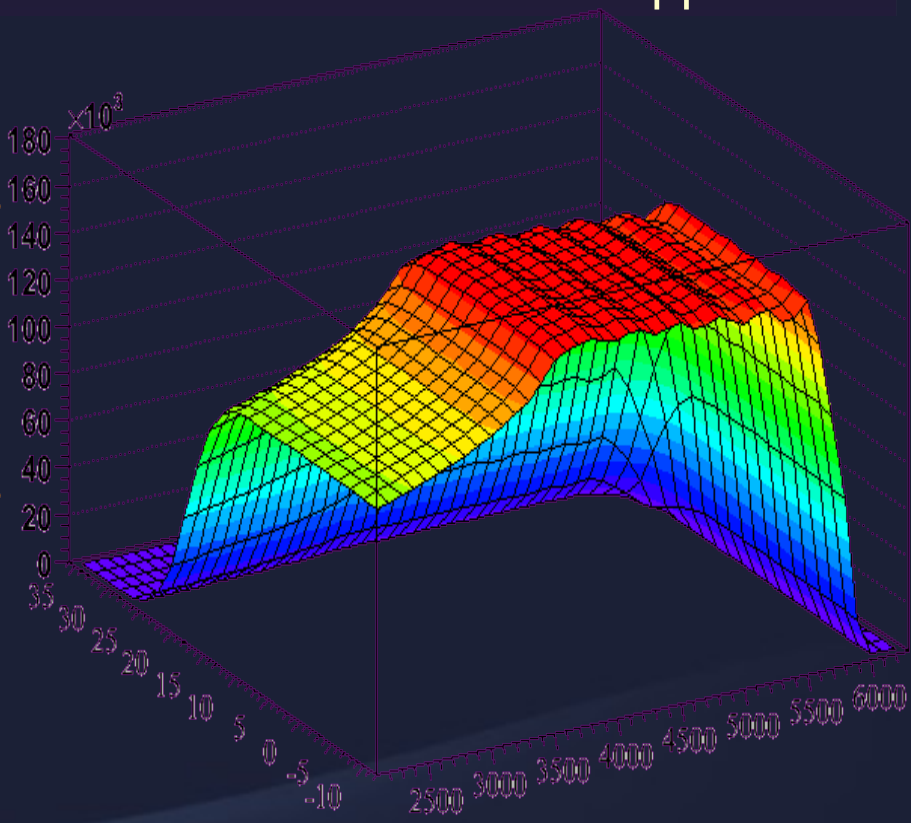
Spread out of the Bragg peak for proton beam of 160 MeV respectively with ripple filter type(A) of 3 mm and without ripple filter (a-c) and the corresponding histograms of dose distribution on the SOBP (b-d)

Proton beams

3D distributions –with and without ripple filter

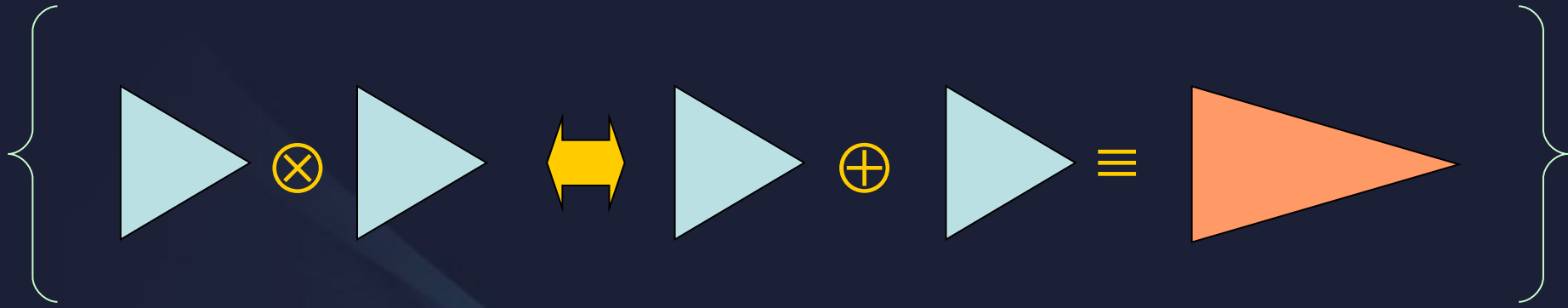




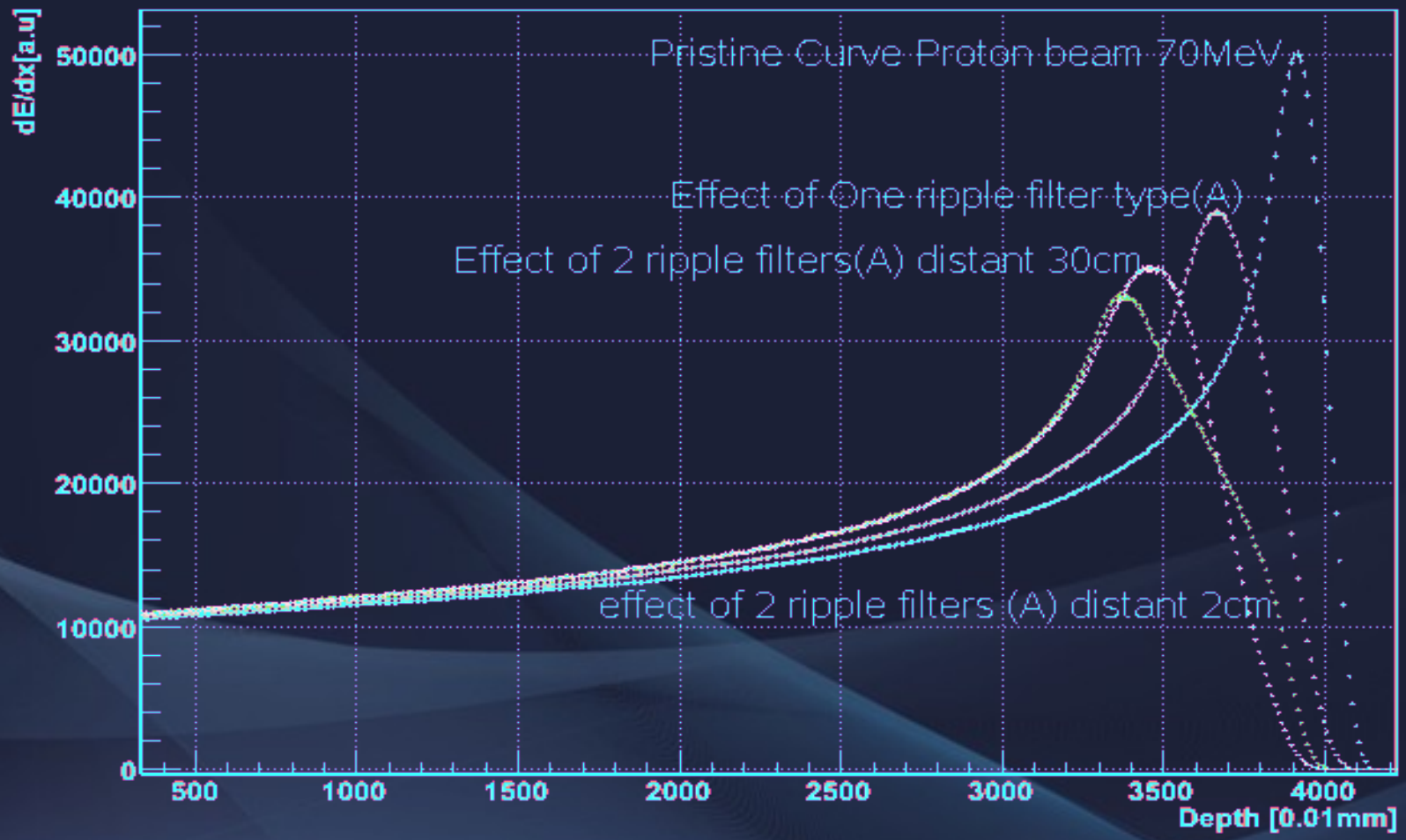


Step of 3.5mm between spots in depth

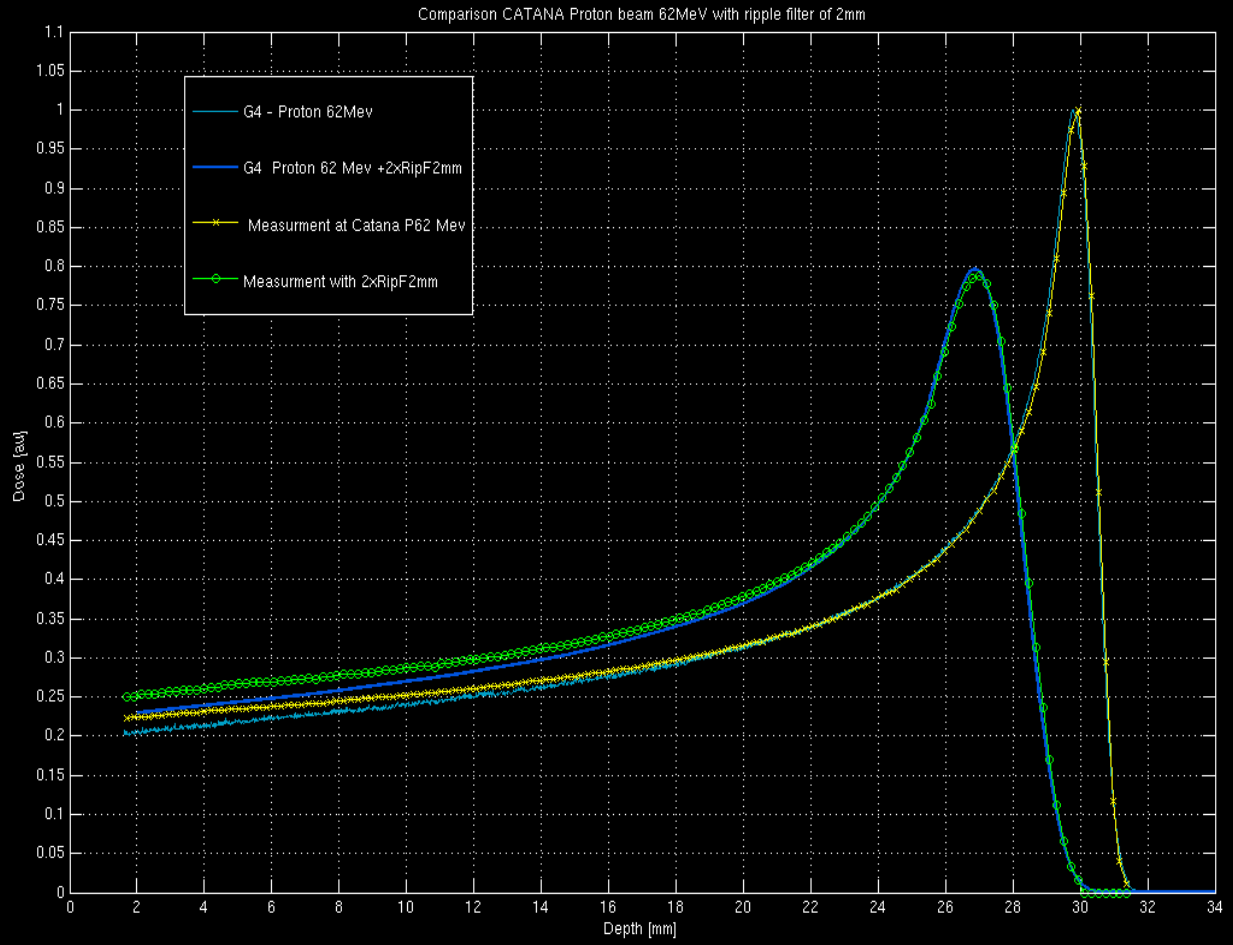
If (distance between filters is not enough)

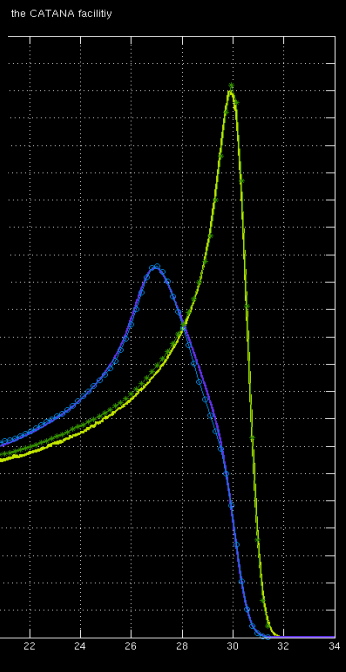


Else



Geant4 simulations of energy losses as functions of depth for different setting of ripple filters in the proton beam path before the water tank


Comparison CATANA Proton beam 62MeV with ripple filter of 2mm
G4 - Proton 62Mev
G4 Proton 62 Mev +2xRipF2mm
Measurment at Catana P62 Mev
Measurment with 2xRipF2mm
Dose [au]
Depth [mm]

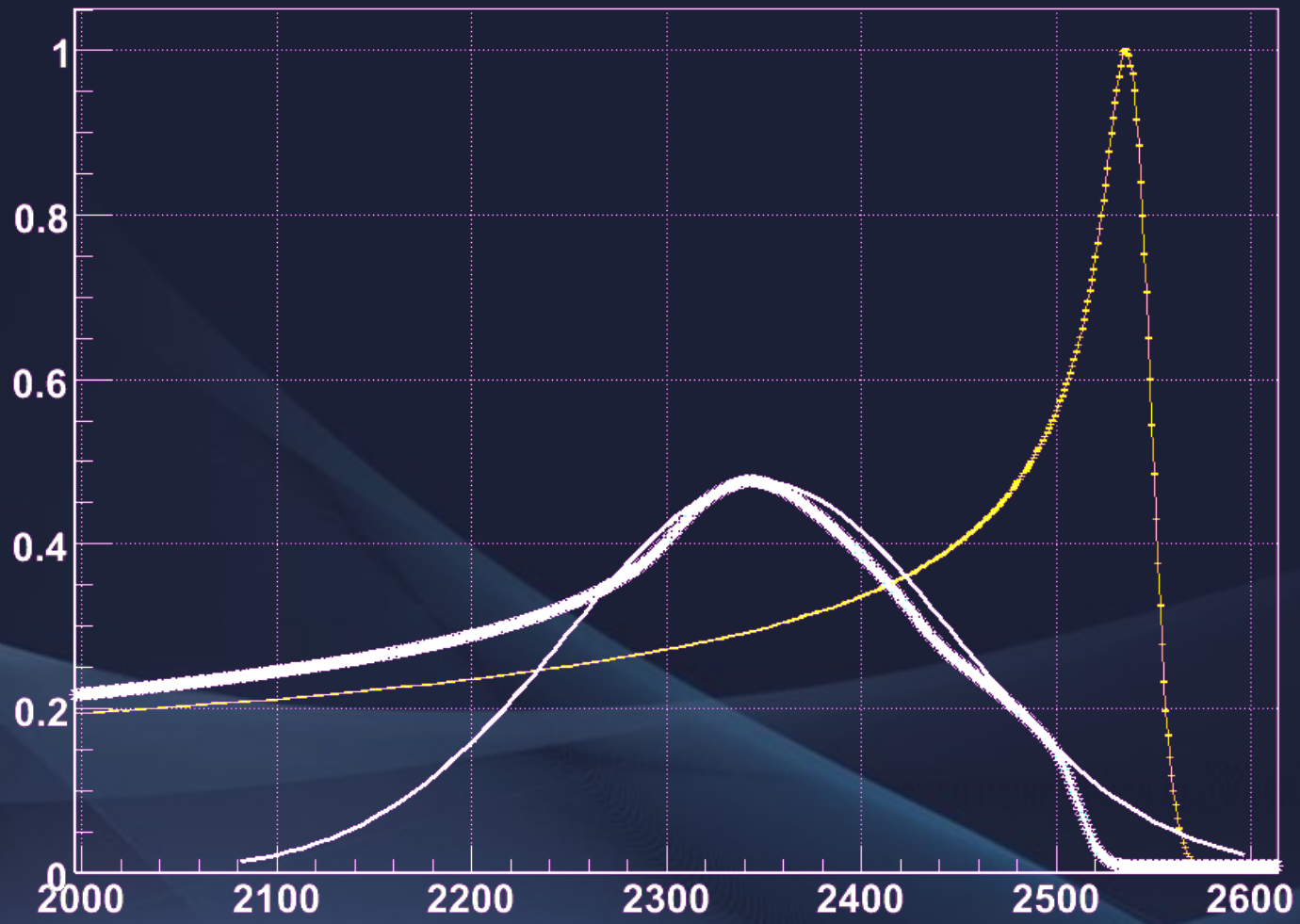

the CATANA facilitiy

Dose
depth [mm]

Results

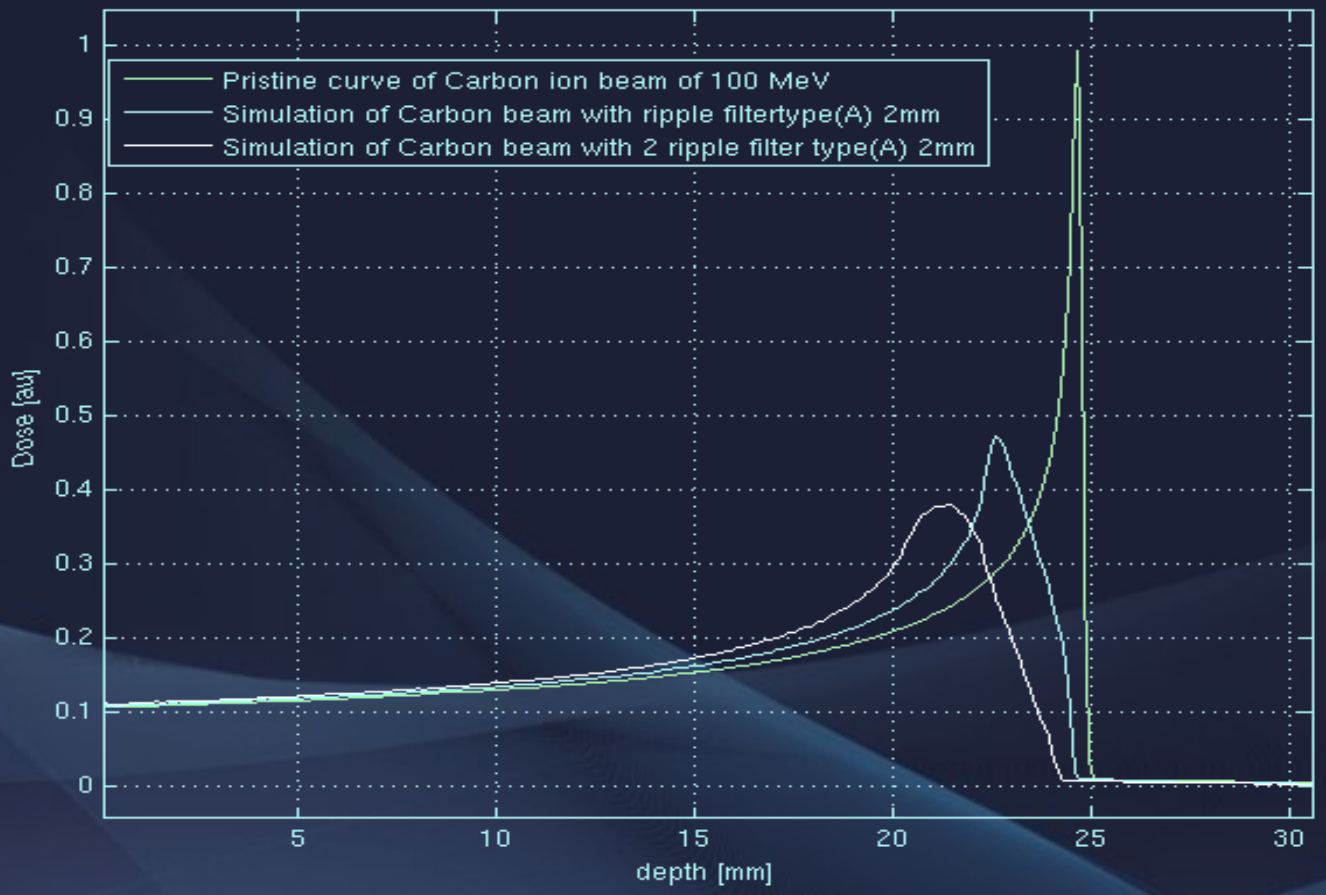
- Proton beams

- Carbon ion beams



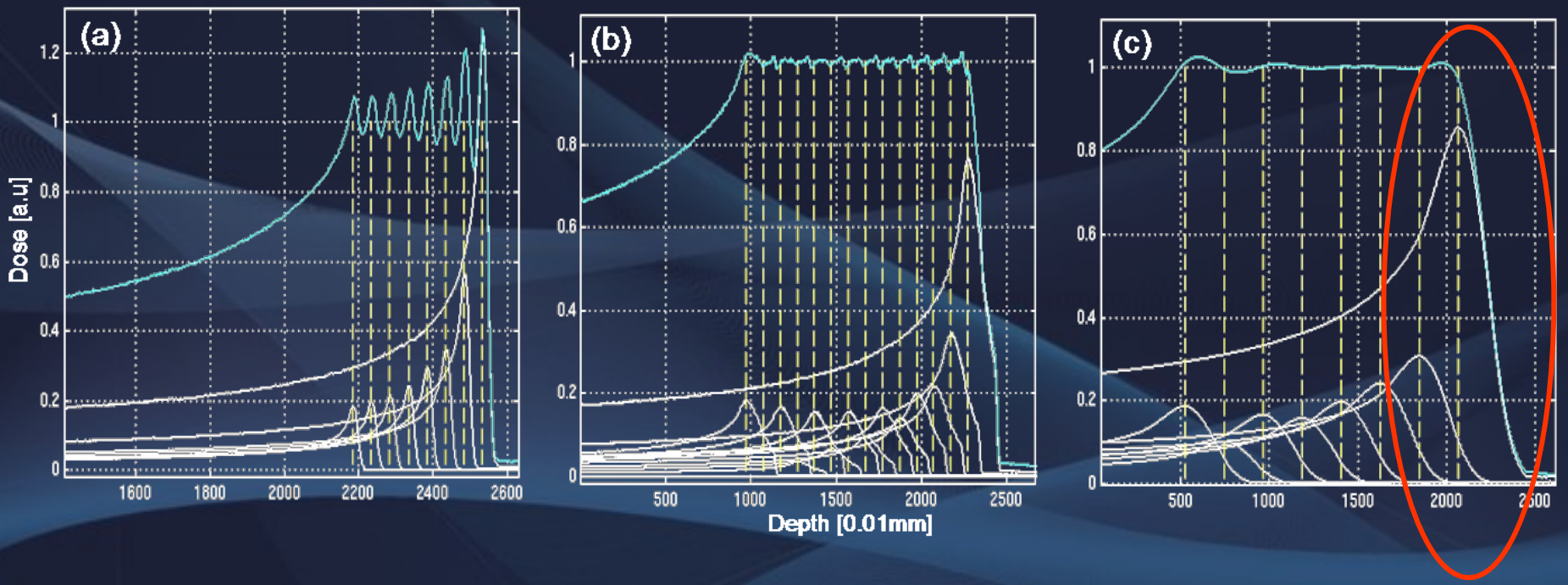
Carbon ion beams of 100 MeV with and without a ripple filter .

Effect of double filtering

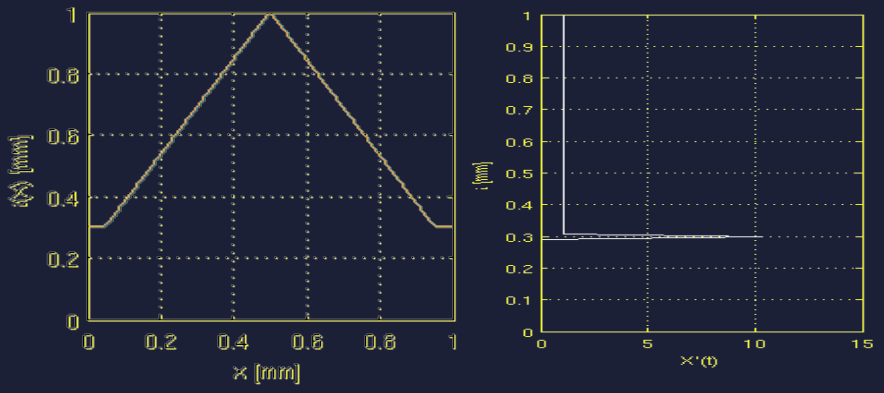


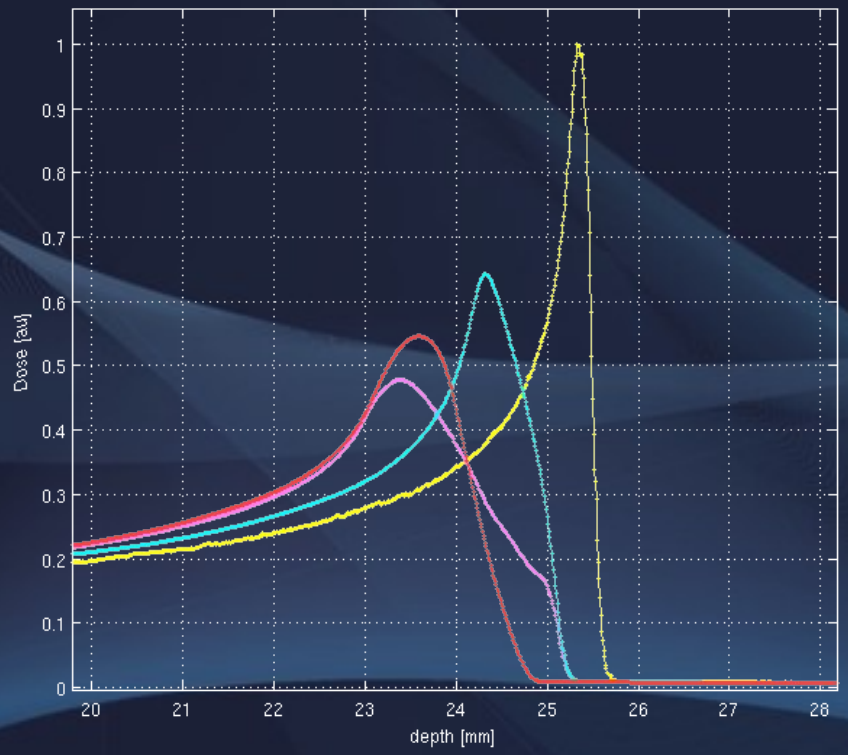
Comparisons between dose-depth curve simulated with respectively one and two ripple filters for carbon ion beam of 100 MeV/u

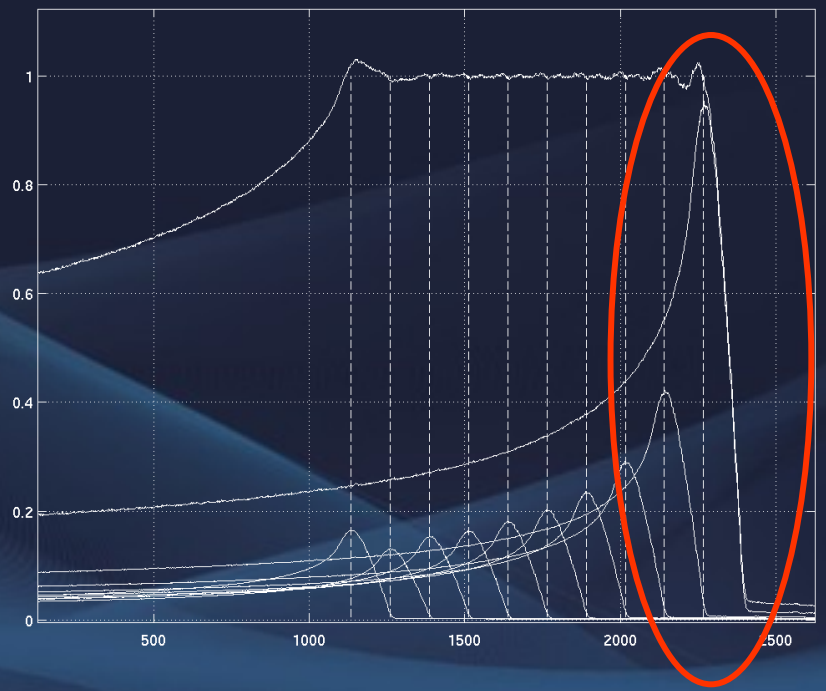
Spread out Bragg peak of carbon ion beam of 100 MeV/u with:
(a) pristine Bragg curve using 8 spots at 0.5 mm step,
(b) Bragg curve after passing through one ripple filter type (A) of 2 mm, using 14 single spots at 1 mm step,
(c) Bragg curve after passing through two ripple filters type(A) distant 30 cm, using 8 single spots with step of 2.2 mm



- Falloff problem !??

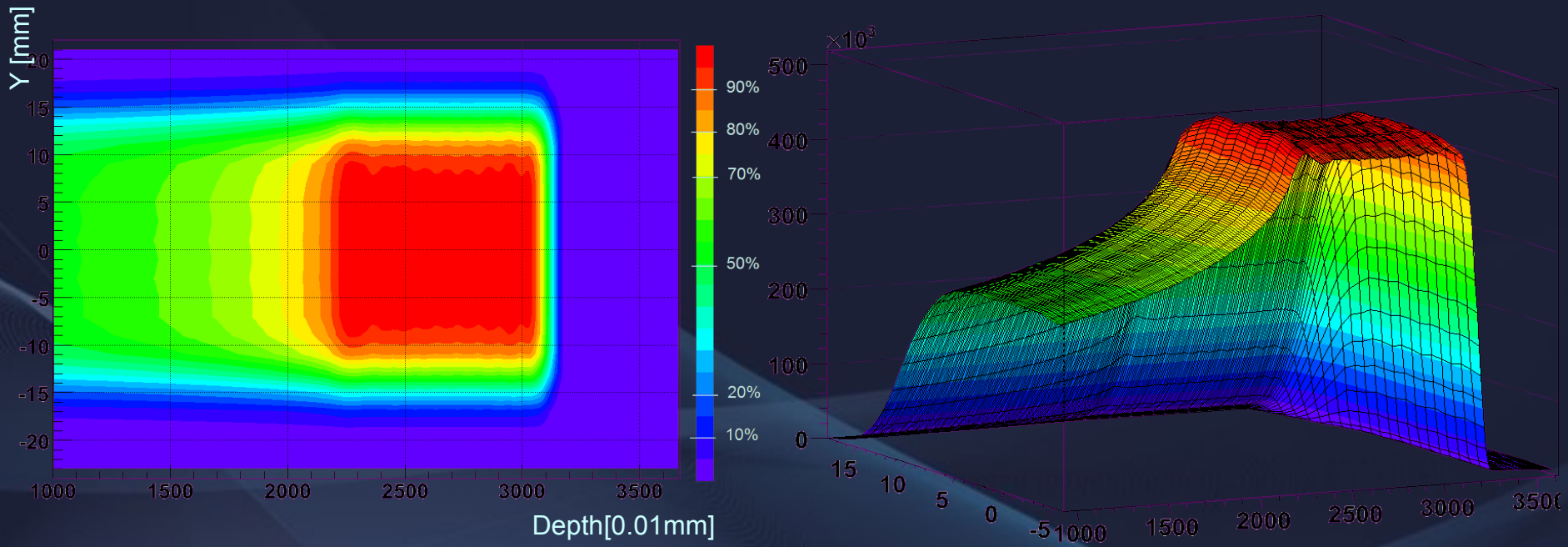






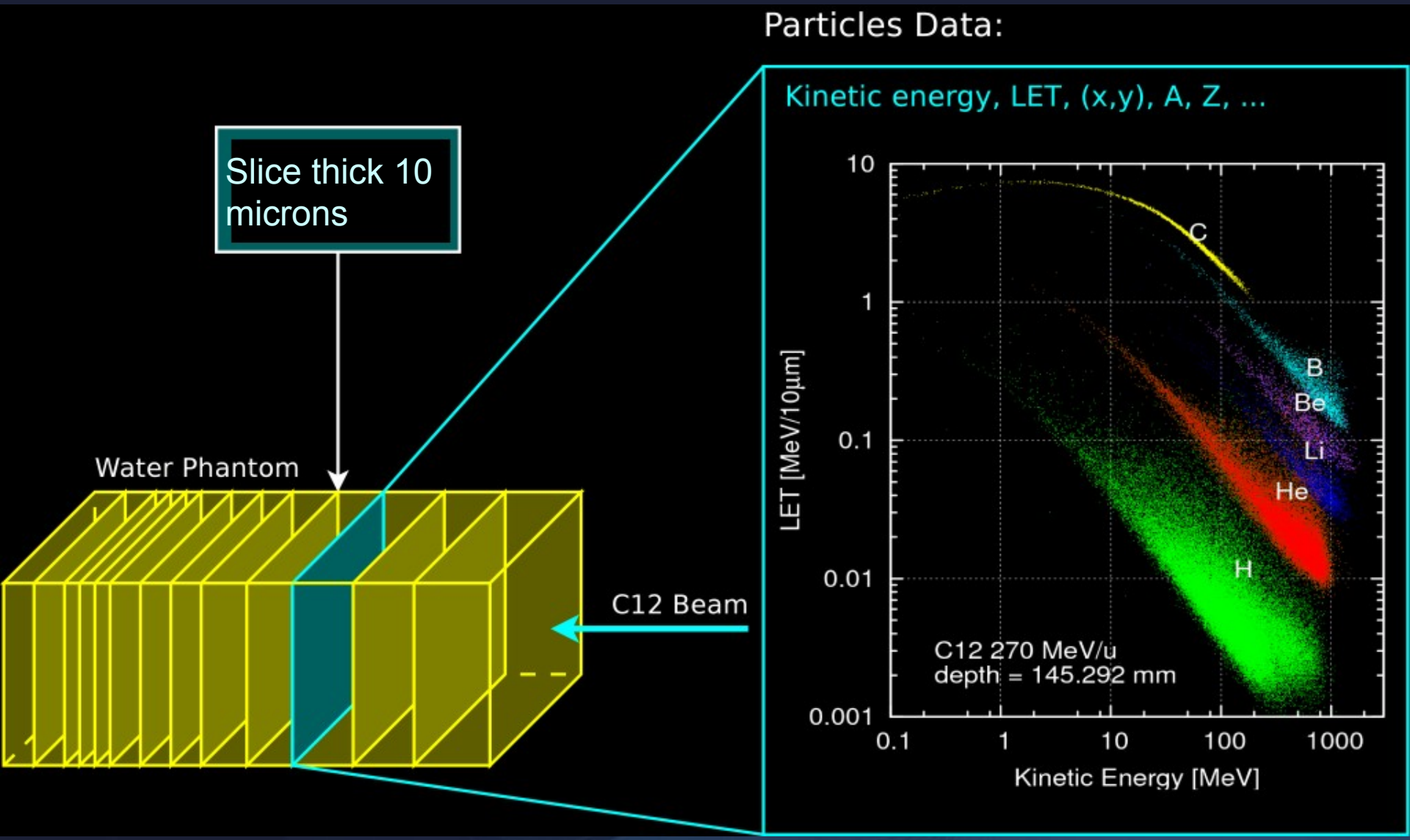
Carbon ion beams

3D distributions –one ripple filter



10 X 7 spots

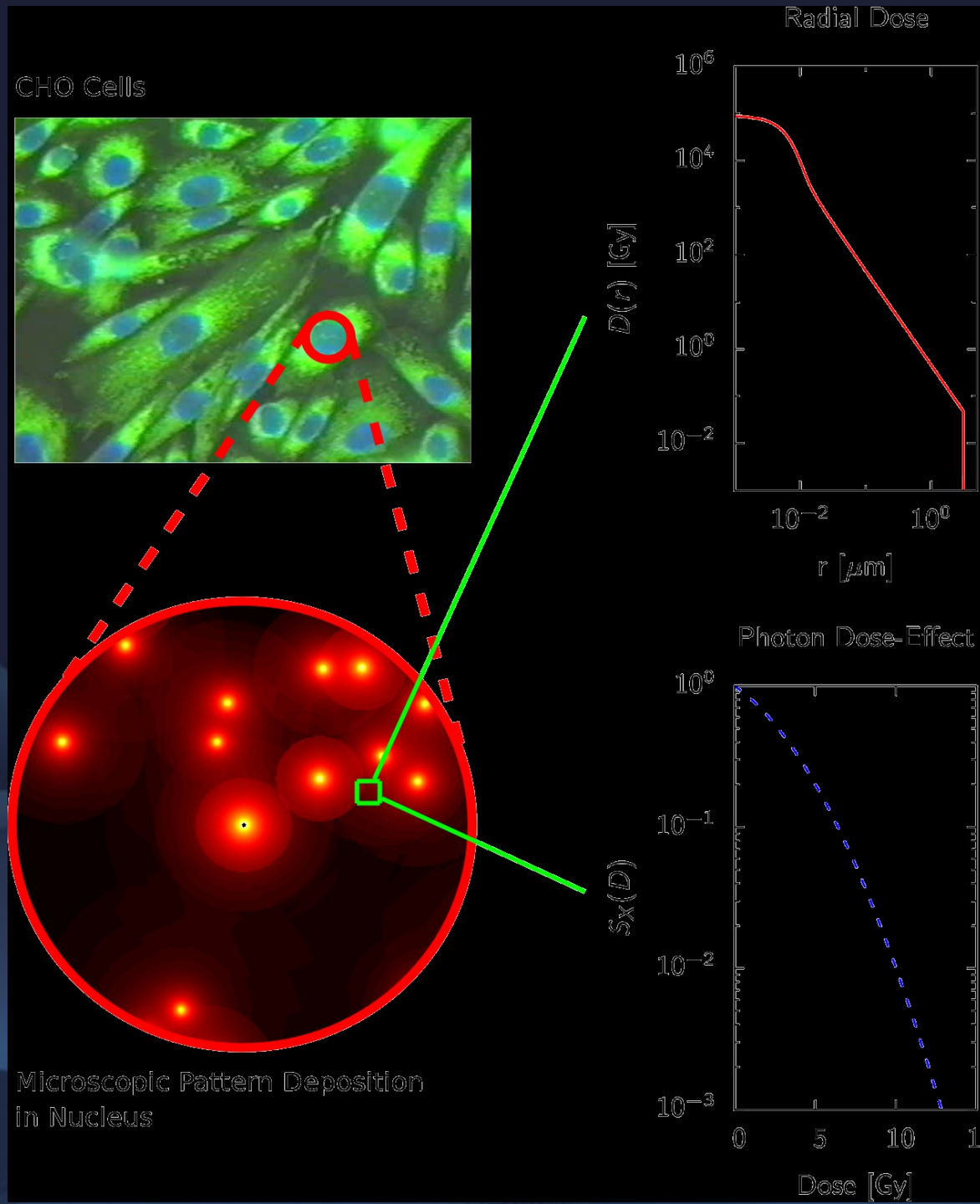
Data Sampling for Radiobiological calculations with Local Effect Model (LEM)



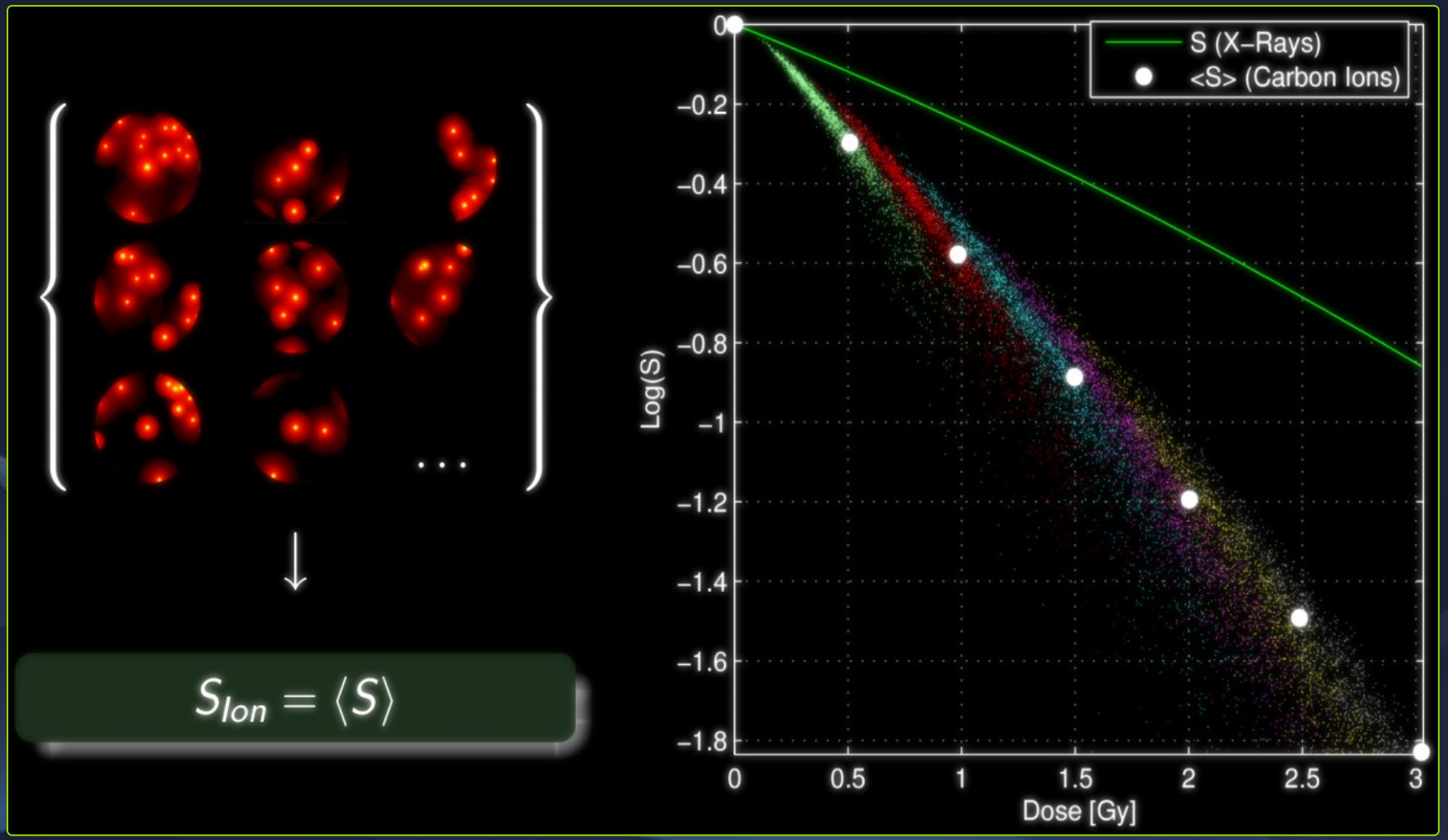
Local Effect Model

Evaluation of cells survival

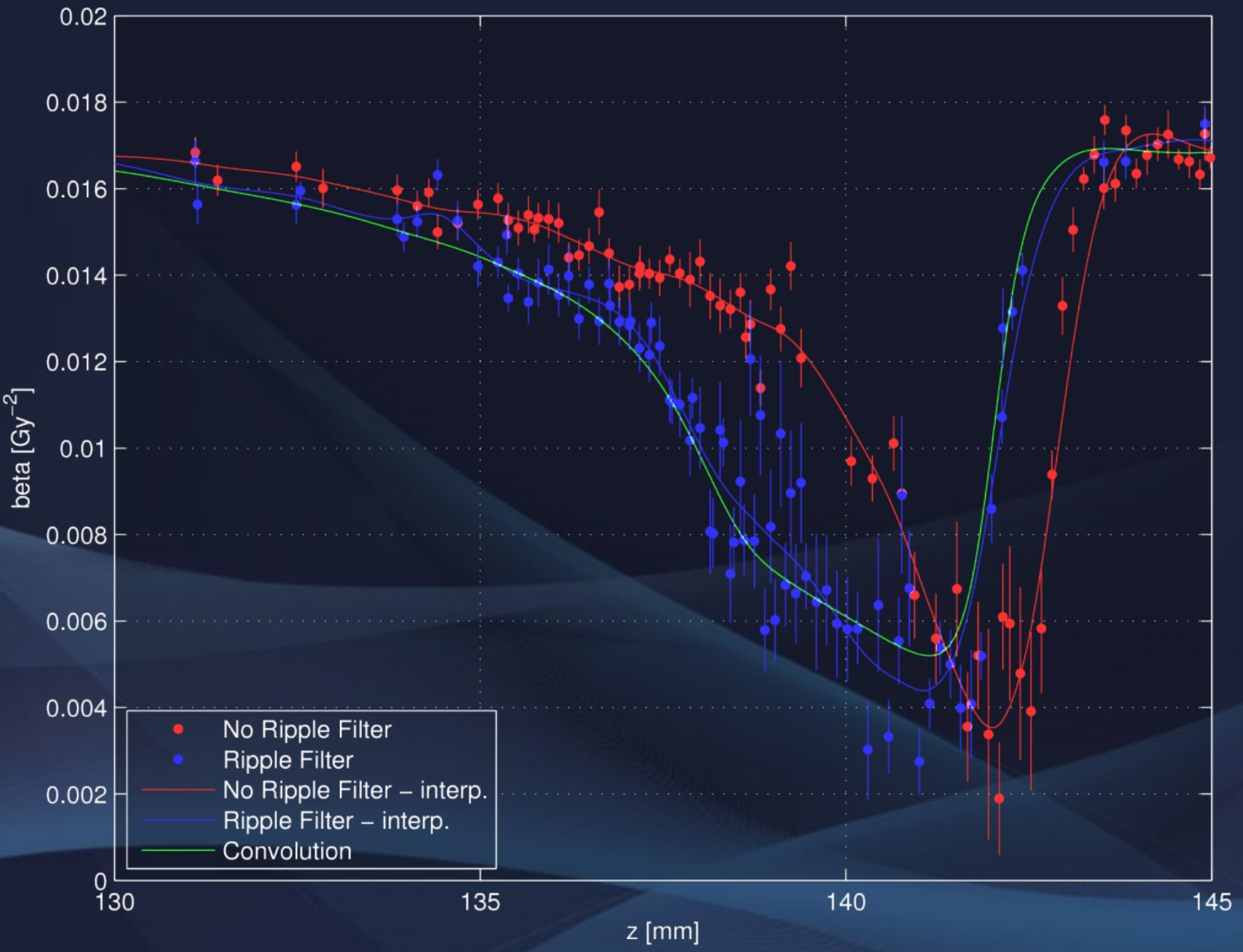
$$S(D) = \exp(-\alpha D - \beta D^2)$$



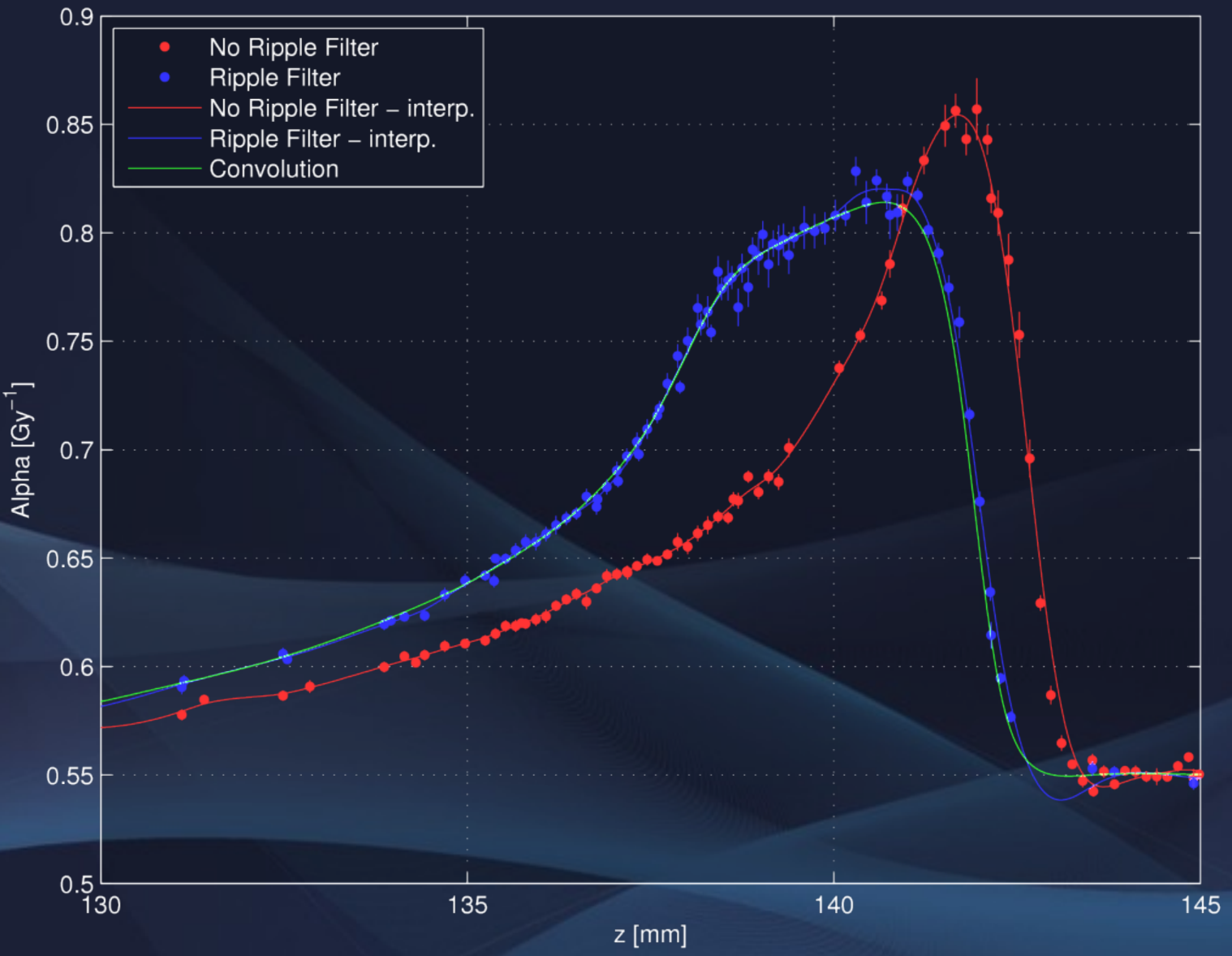
Cells survival calculation



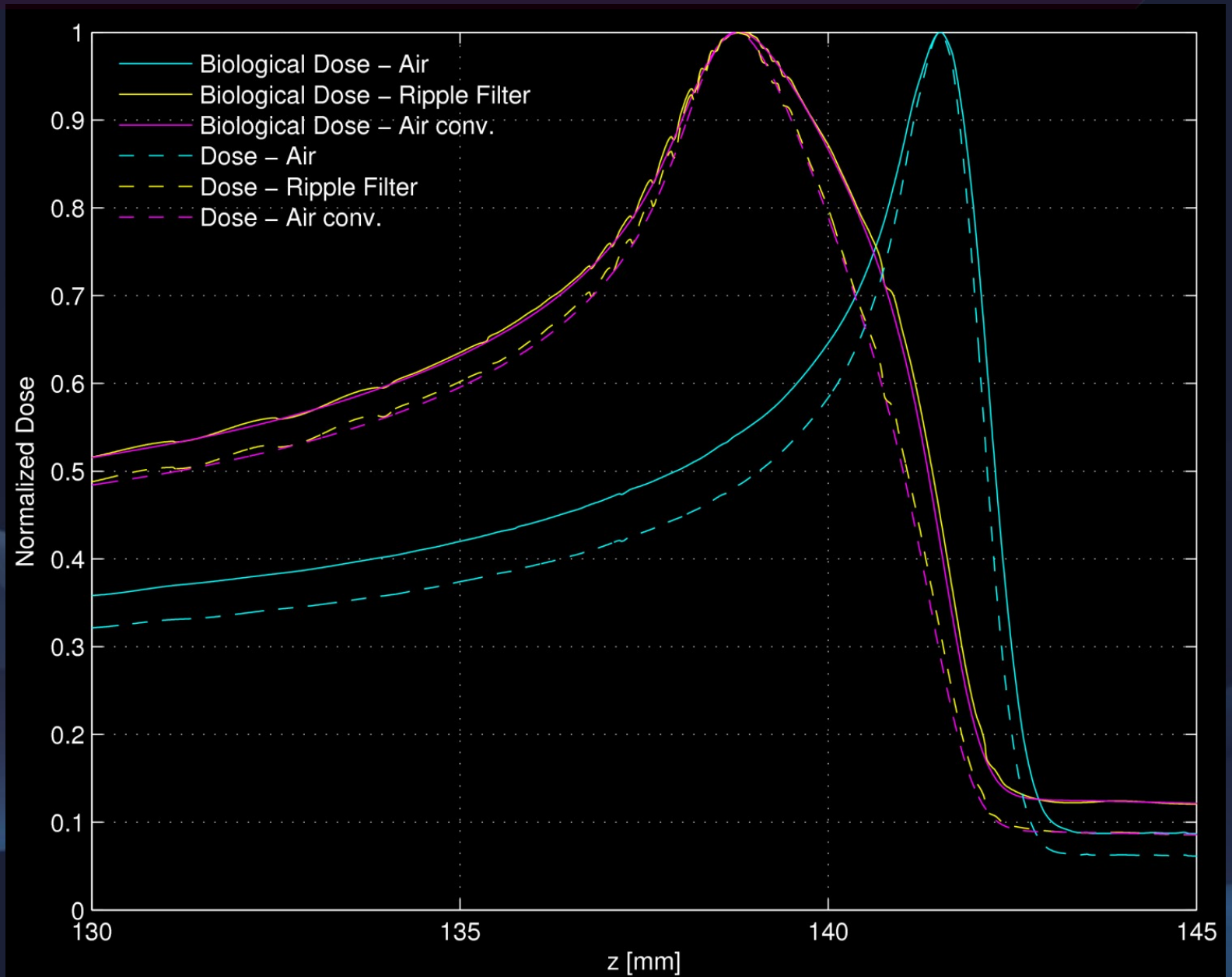
Ripple-Filter simulations – beta



Ripple-Filter simulations – RBE-alpha



Physical and Biological Bragg peak comparison



Conclusion and Perspectives

- Design and test of new ripple filters
  - Characterizations of ripple filters for proton and carbon ion beams.
  - Advantages in the use of ripple filter with simplified sections
  - Use of a double-filter, coupling two ripple filters.
- Good agreement with experimental measurments
- Definition of the transfer function relative to each ripple filters.

- => Investigations on the biological equivalent dose.

Linear-Filter Approach

- The beamline is considered as a "black box";
- the net effects are described by a *transfer function* f;
- the dose look-up tables are obtained by linear filter convolution:

$$D = f * D^0$$

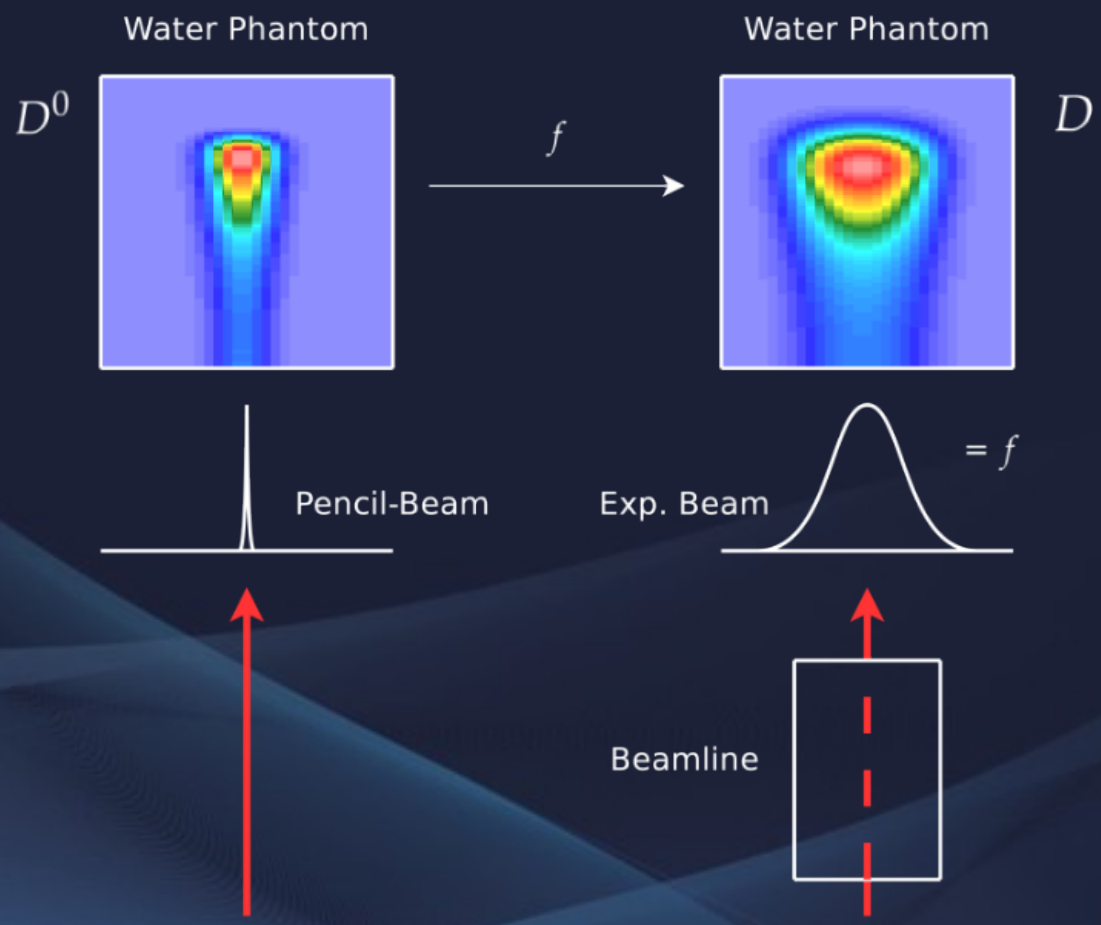
- the f is obtained from experiment, via a deconvolution procedure:

$$f = \mathcal{F}^{-1}(\mathcal{F}(D)/\mathcal{F}(D^0))$$

- the (α, β) look-up tables are obtained by "LQ" convolution:

$$\alpha = f * [\alpha^0 D^0]/D,$$

$$\beta = (f * [\sqrt{\beta^0} D^0]/D)^2$$



- $D^0, \alpha^0, \beta^0 \rightarrow$ *pencil beam* (simulated);
- $D, \alpha, \beta \rightarrow$ *experimental beam*.