Updates on TOPAS/Geant4 simulations of focused electron beams dose distribution in water

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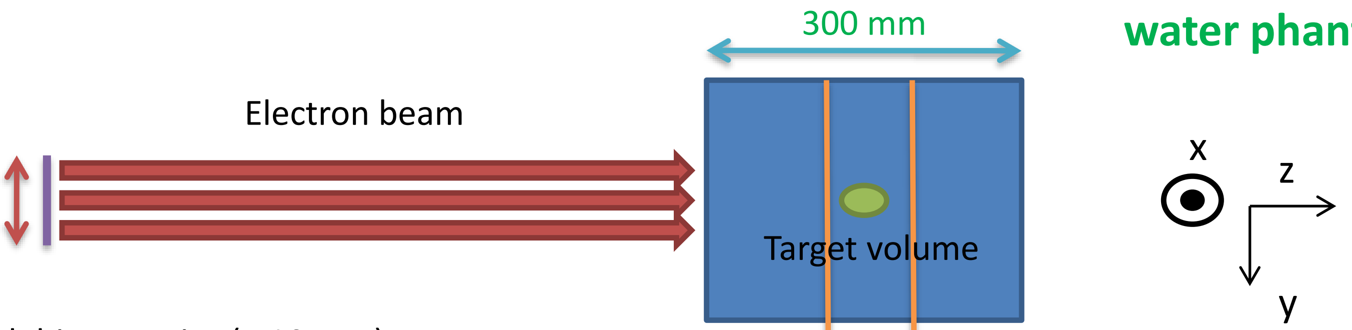
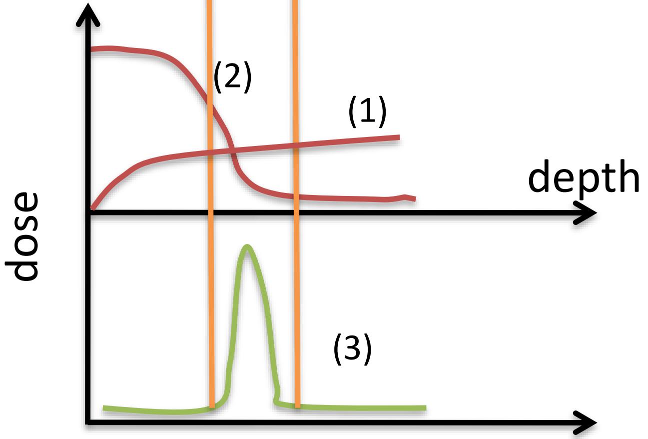
PITZ Physics Seminar

Introduction and problematic



(1) : parallel beam with big spot size (> 10 mm)
(2) : parallel beam with small spot size (< 5 mm)
(3) : ideal beam



- What are the parameters to obtain depth dose pulse shape ?
→ **Focused beam**
- How can we shift the position of the peak ?
→ **Beam energy and beam size**

Motivation and goals

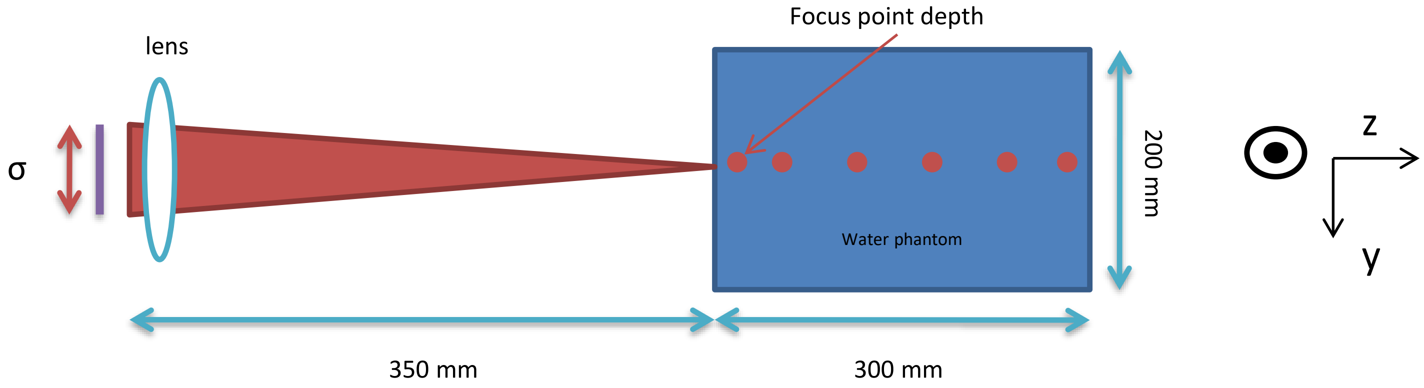
- **Focused electron beams** demonstrates **dose focusing** capabilities.
- The depth of maximal energy deposit is controlled by
  - Beam size before focusing
  - Beam energy
- Other aspects should be addressed :
  - What are the capabilities of the focused electron beams in the case of a thick water phantom 20x20x30 cm^3
  - Depth dose Vs Focusing plane depth in the water phantom.
  - Evolution of depth of maximum dose (Zmax) Vs Focusing plane depth in the water phantom. (is it linear ??)
  - Evolution of beam size Vs focusing plane depth in the water phantom.
  - Evolution of depth dose FWHM Vs focusing plane depth.
  - Impact of beam energy spread on Zmax and maximum energy deposit (Dmax) for a 1 mm^3 dose grid resolution.

For :

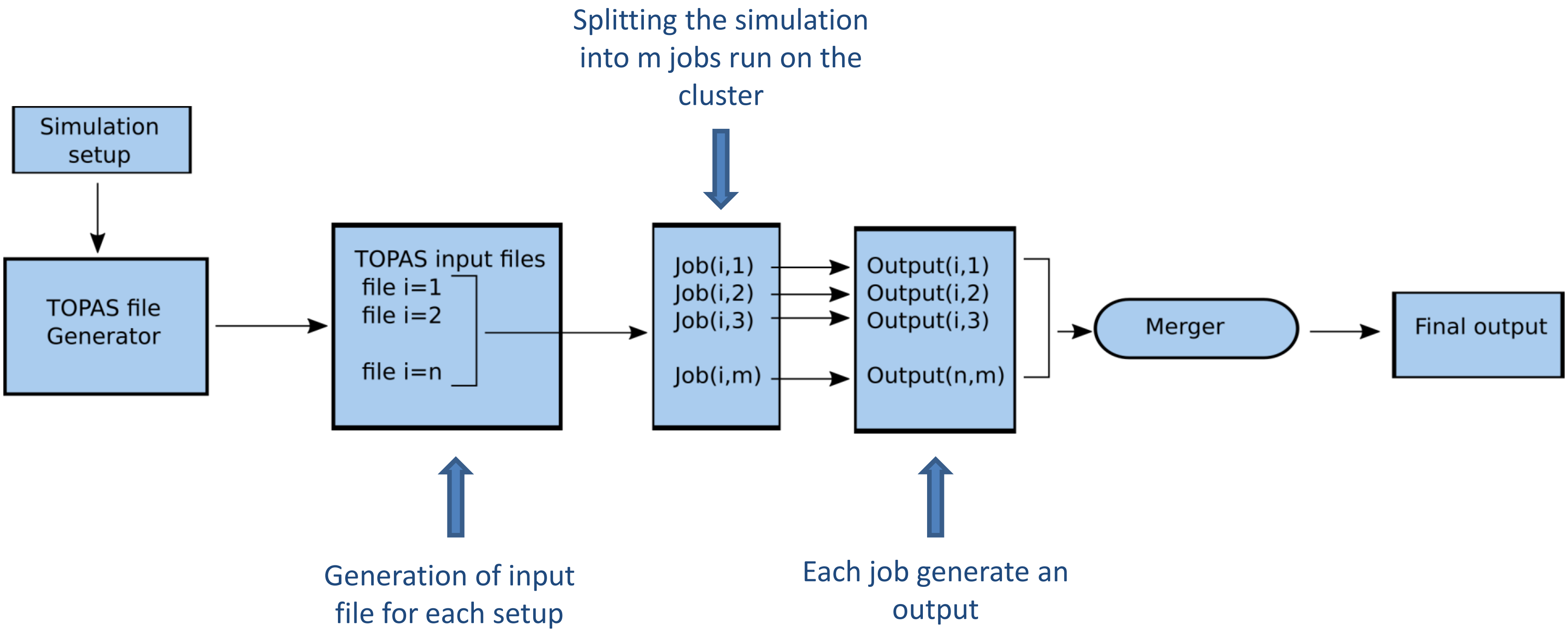
- Different beam energies
- Different beam spot size

Simulation setup

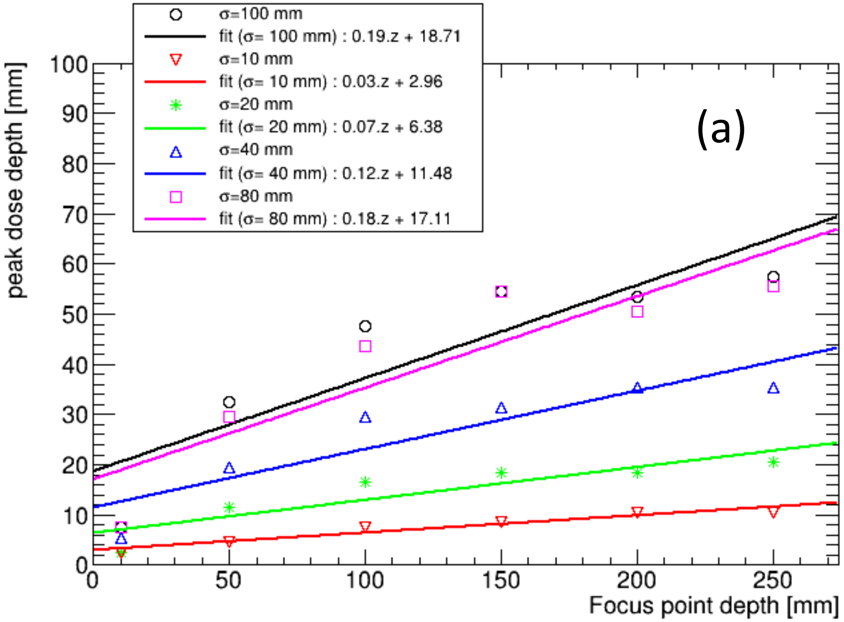
- TOPAS/Geant4 simulations were carried out.
- Water phantom 20x20x30 cm^3;
- Voxel resolution 1x1x1 mm^3;
- Beam energies E={22, 100, 150, 200, 250, 500} MeV
- Beam size before focusing σ={10, 20, 40, 80, 100} mm
- For beam energy spread σ_E={0, 1, 2, 4, 5}% (percentage of the mean beam energy)
- A beam size of 1 mm is considered at the focus point in air (without phantom) for all simulations.



Simulation methodology



Focused electron beam energy 22 MeV



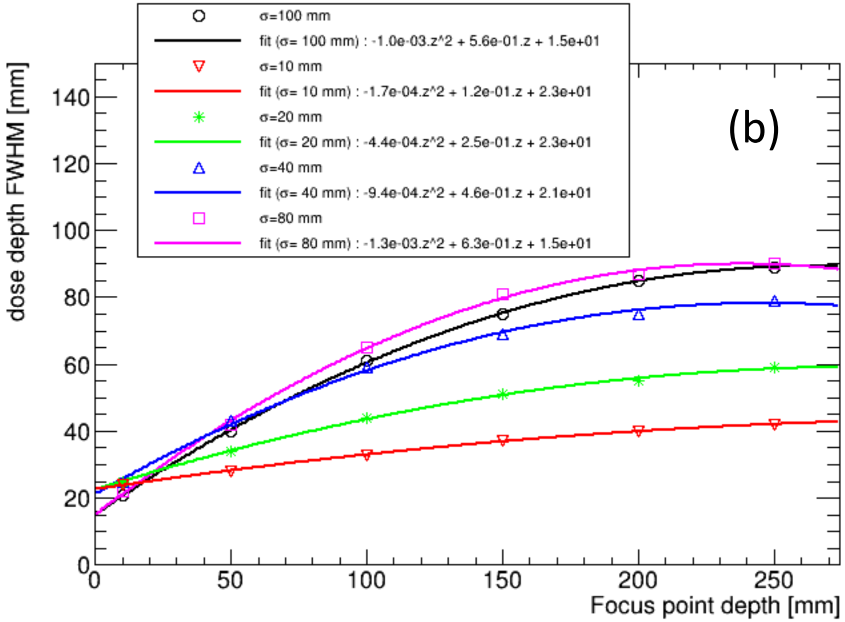


Fig.1 : 22 MeV Dose distribution analysis in terms of focus plane depth in water for different beam sizes. (a) : Focus plane depth in the water Vs peak dose depth (zmax). (b) : Focus plane depth in the water Vs depth dose FWHM

Focused electron beam energy 22 MeV

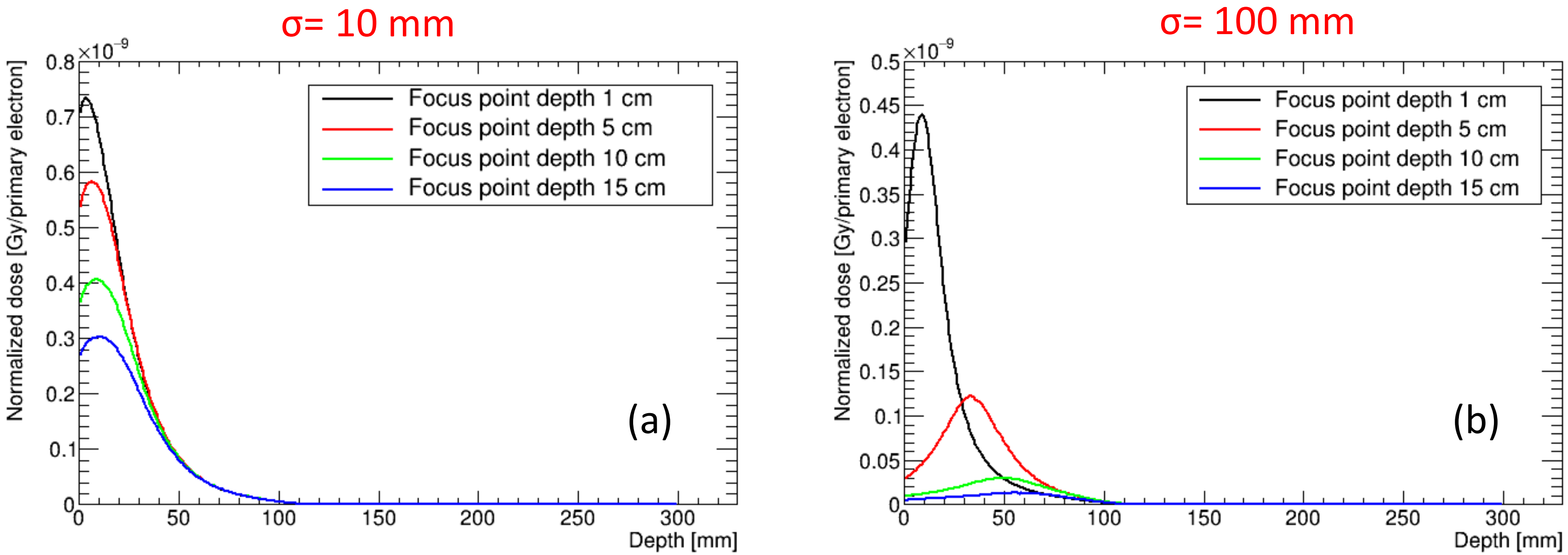


Fig.2 : 22 MeV percent depth dose for different focus point in the water phantom. (a) :Beam size 10 mm. (b) : beam size 100 mm

Focused electron beam energy 22 MeV

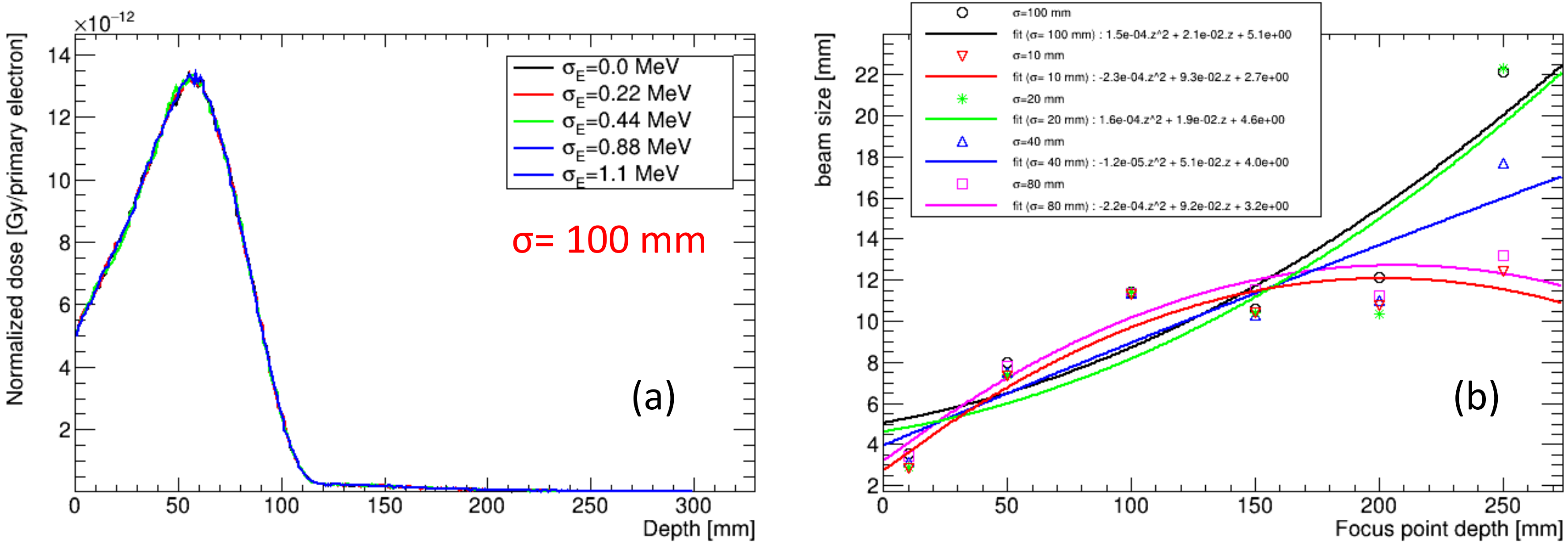


Fig.3 (a) : Energy spread effect (22 MeV electron beam) on depth dose curves for 100 mm beam size. (b) : Beam size evolution in terms of focusing plane depth in the water phantom.

Focused electron beam energy 100 MeV

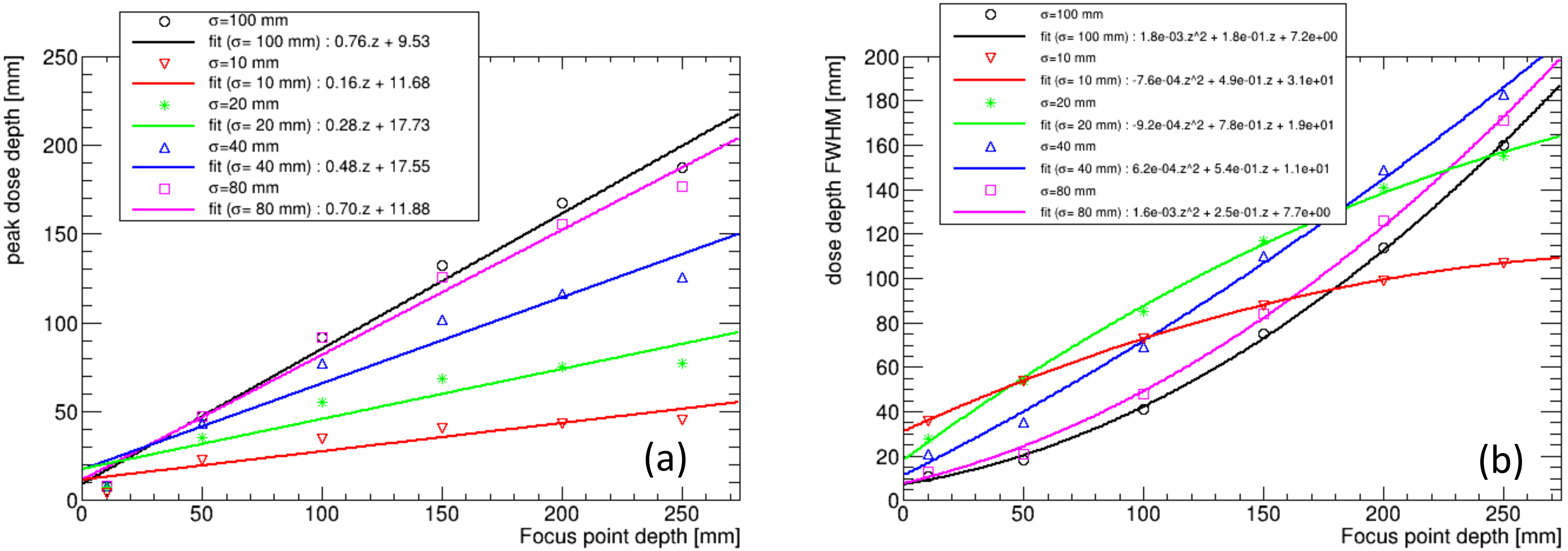


Fig.4 : 100 MeV Dose distribution analysis in terms of focus plane depth in water for different beam sizes. (a) : Focus plane depth in the water Vs peak dose depth (zmax). (b) : Focus plane depth in the water Vs depth dose FWHM

Focused electron beam energy 100 MeV

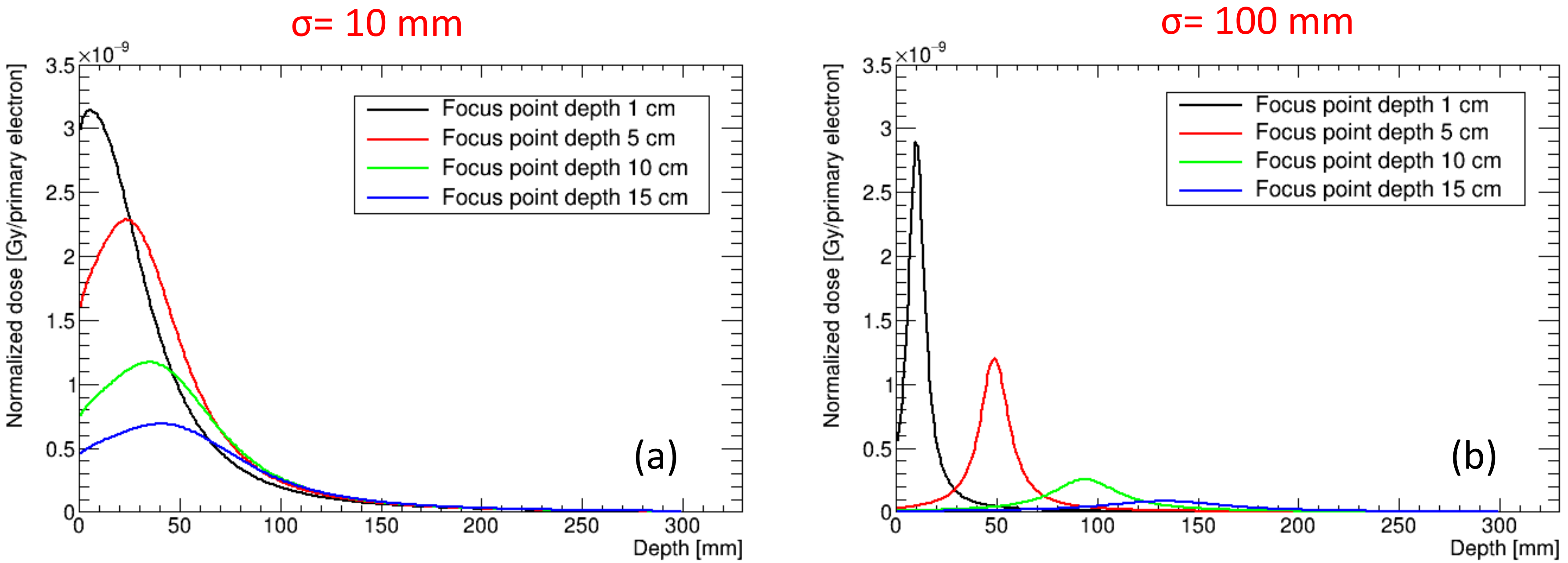
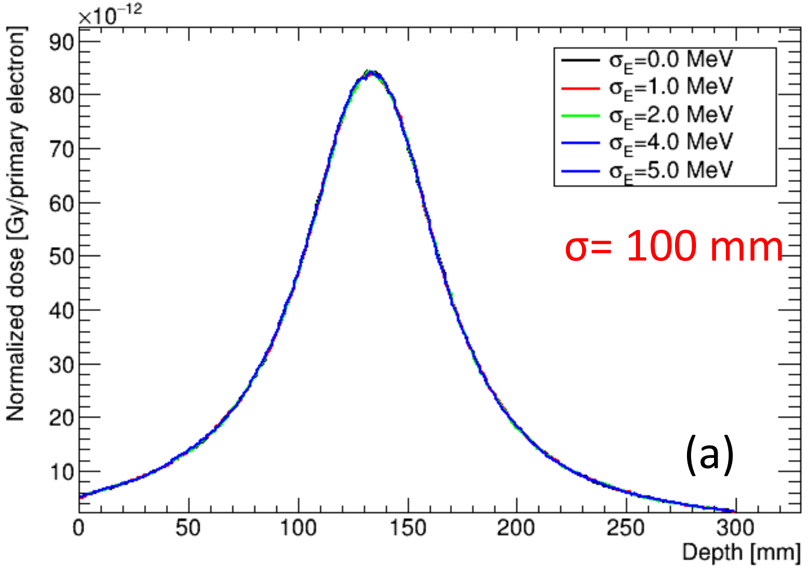


Fig.5 : 100 MeV percent depth dose for different focus point in the water phantom. (a) :Beam size 10 mm. (b) : beam size 100 mm

Focused electron beam energy 100 MeV



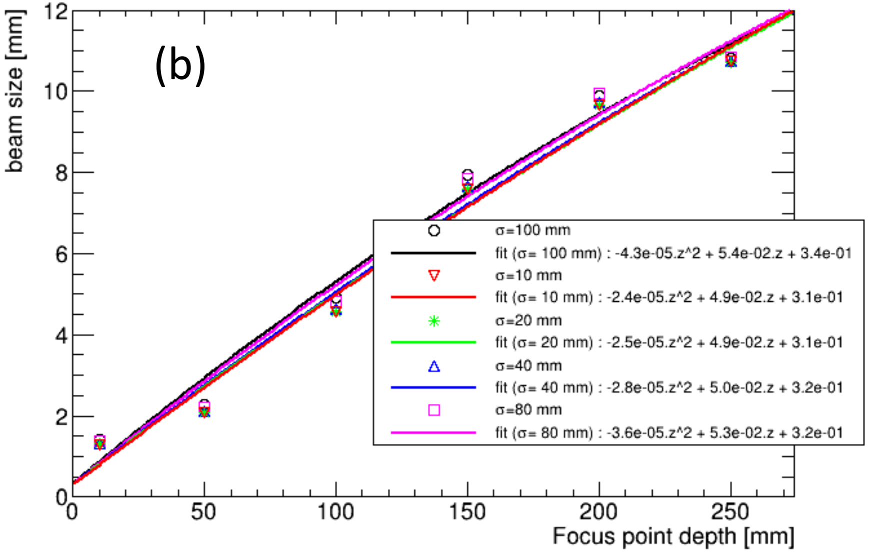


Fig.6 : (a) : Energy spread effect (100 MeV electron beam) on depth dose curves for 100 mm beam size. (b) : Beam size evolution in terms of focusing plane depth in the water phantom.

Focused electron beam energy 250 MeV

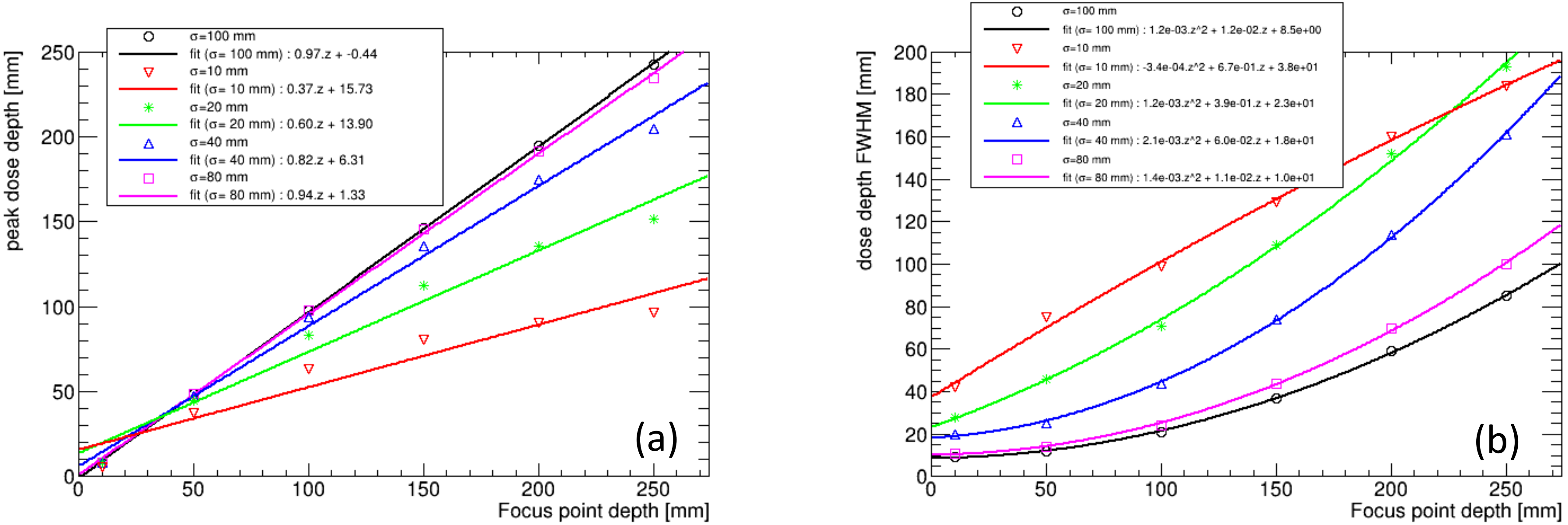


Fig.7 : 250 MeV Dose distribution analysis in terms of focus plane depth in water for different beam sizes. (a) : Focus plane depth in the water Vs peak dose depth (zmax). (b) : Focus plane depth in the water Vs depth dose FWHM

Focused electron beam energy 250 MeV

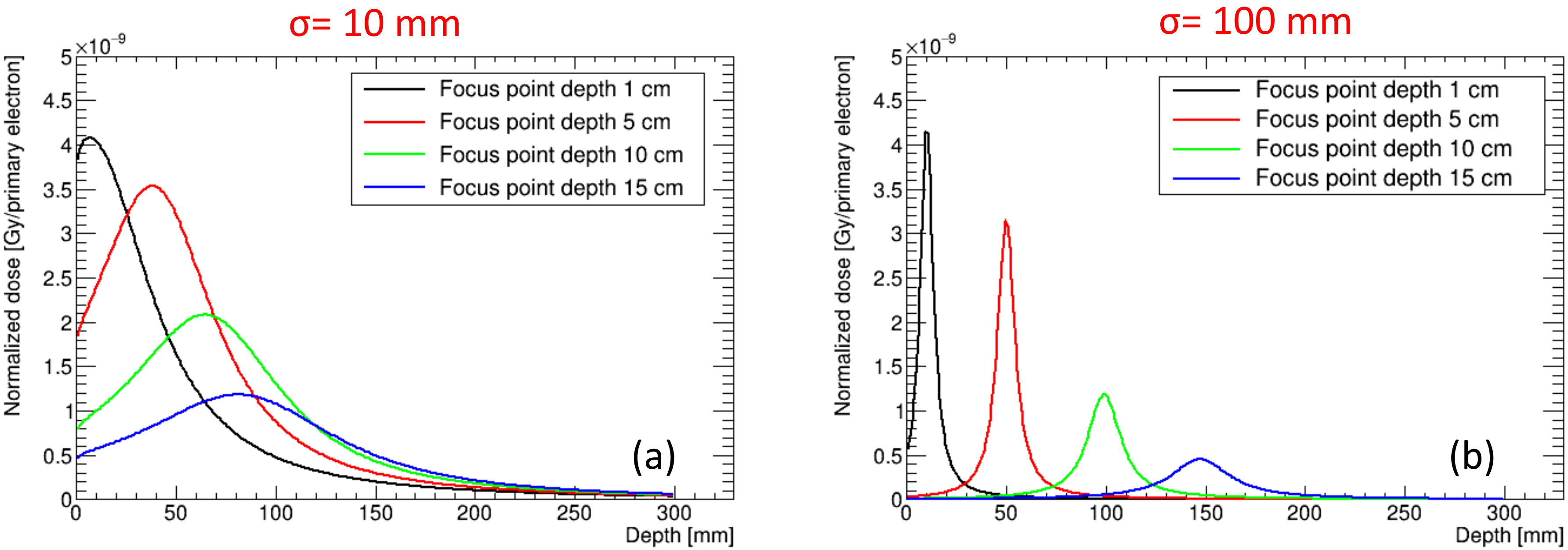
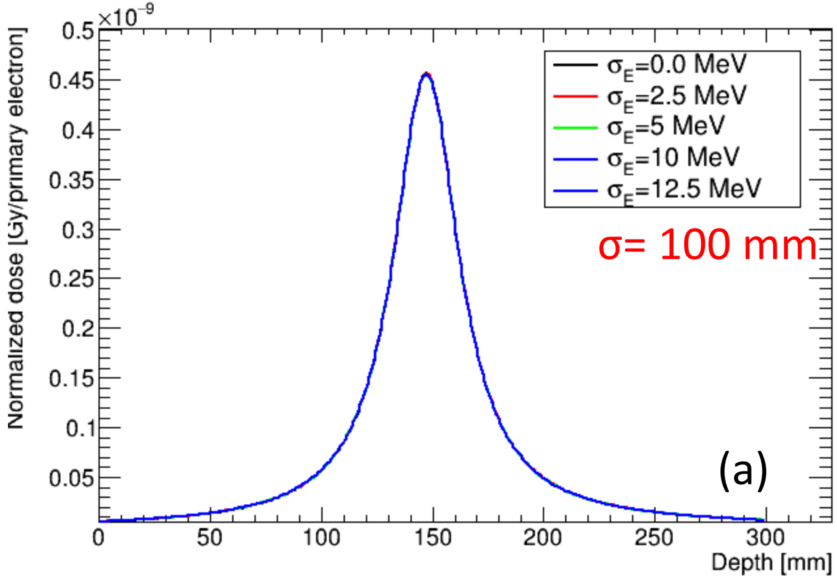


Fig.8 : 250 MeV percent depth dose for different focus point in the water phantom. (a) :Beam size 10 mm. (b) : beam size 100 mm

Focused electron beam energy 250 MeV



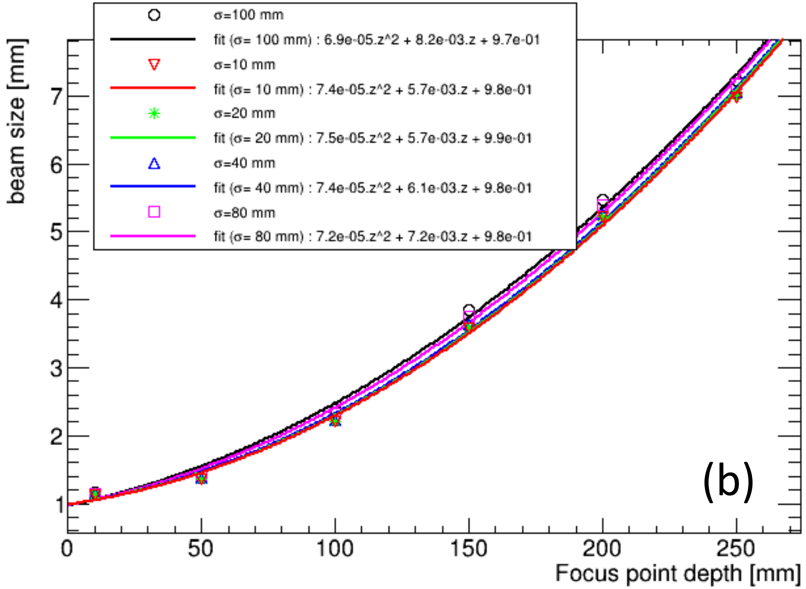


Fig.9 : (a) : Energy spread effect (250 MeV electron beam) on depth dose curves for 100 mm beam size. (b) : Beam size evolution in terms of focusing plane depth in the water phantom.

Focused electron beam energy 500 MeV

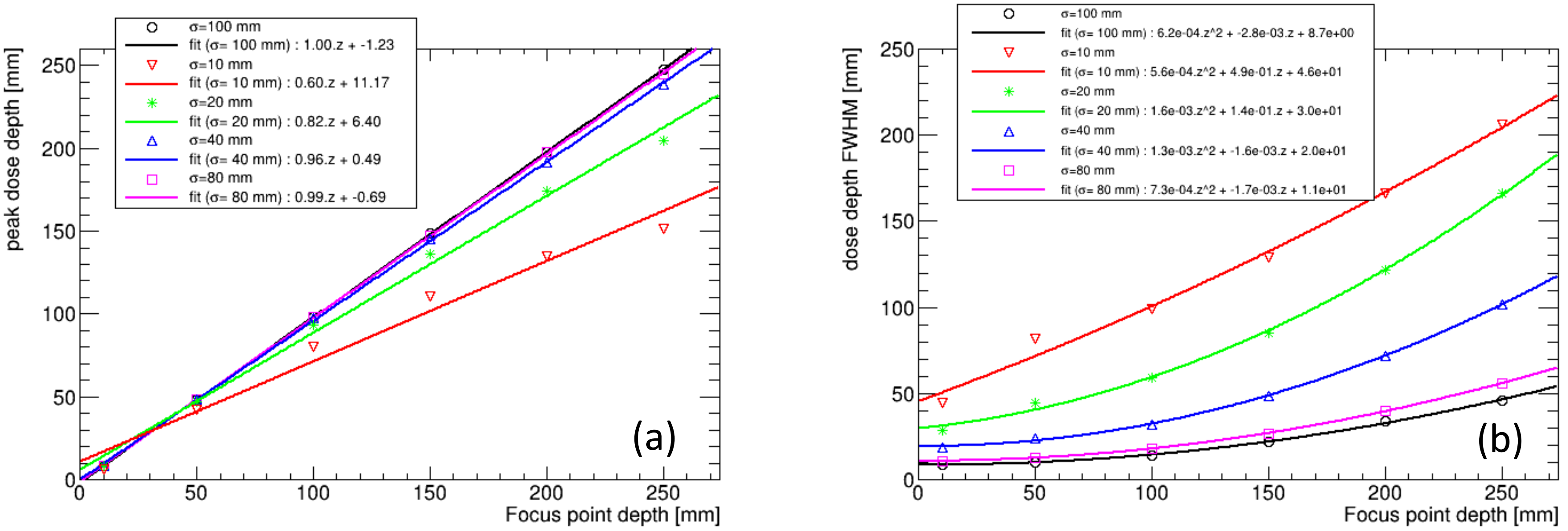
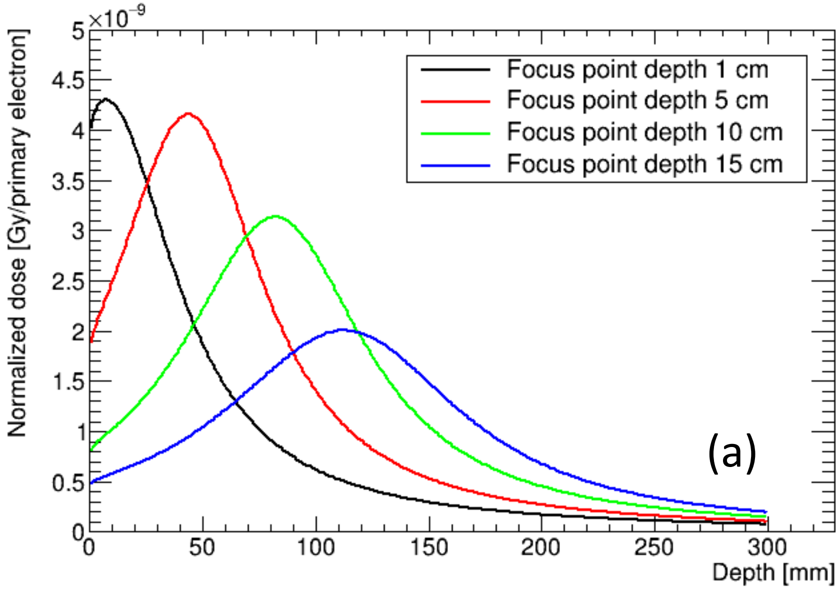


Fig.10 : 500 MeV Dose distribution analysis in terms of focus plane depth in water for different beam sizes. (a) : Focus plane depth in the water Vs peak dose depth (zmax). (b) : Focus plane depth in the water Vs depth dose FWHM

Focused electron beam energy 500 MeV

σ= 10 mm



σ= 100 mm

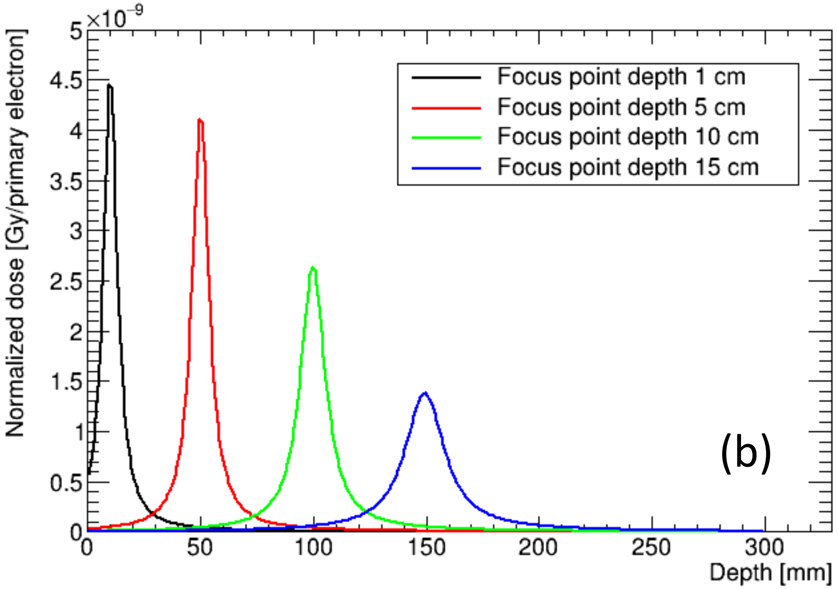


Fig.11 : 500 MeV percent depth dose for different focus point in the water phantom. (a) :Beam size 10 mm. (b) : beam size 100 mm

Focused electron beam energy 500 MeV

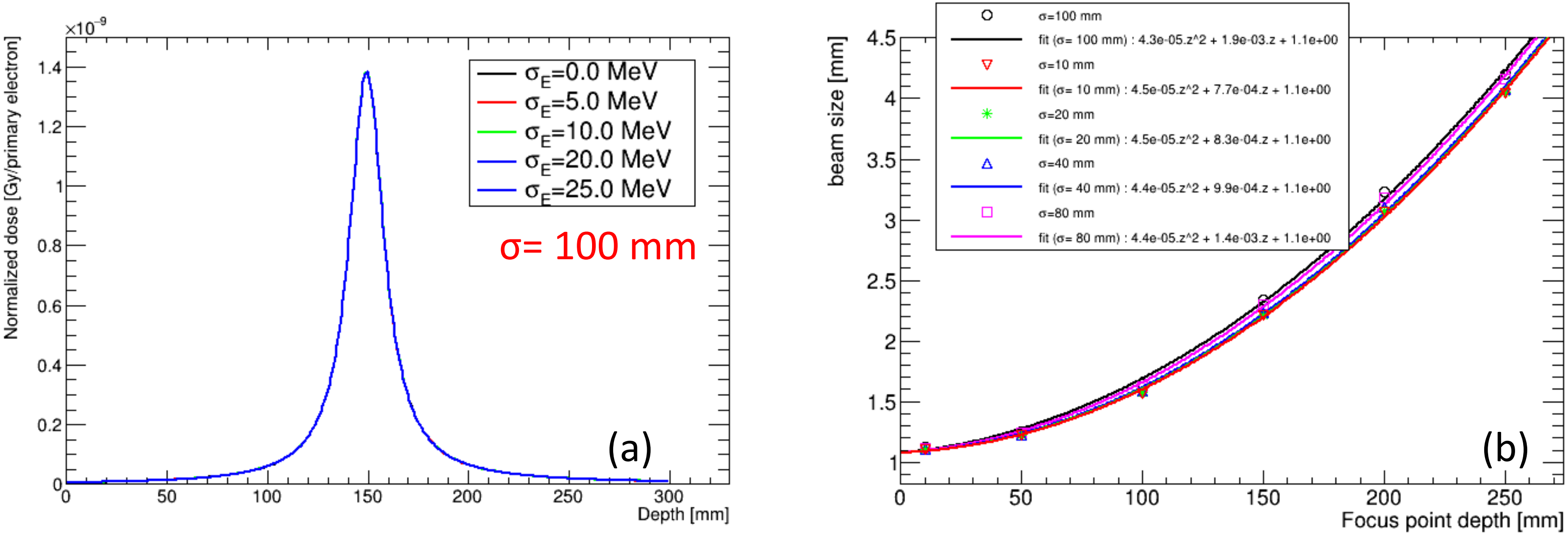


Fig.12 : (a) : Energy spread effect (500 MeV electron beam) on depth dose curves for 100 mm beam size. (b) : Beam size evolution in terms of focusing plane depth in the water phantom.

Conclusion

- Simulations of focused electron beams in a thick volume (human body size) have demonstrated the possibility to control dose distribution for an **efficient therapy** and **tissue sparing** effect.
- For low energies (<100 MeV) :
  - the variation of dose peak position (Zmax) in terms of the focus point depth is **not linear**.
  - The position of the peak do not coincide with the desired focus point.
  - The penetration of the beam is very limited even for strong focusing of a large beam size (Ex: 22 MeV, σ=100 mm, focus point depth in water=150 mm → Zmax=56 mm)
  - The increase of depth dose curve FWHM is quadratic for all beam sizes.
  - For 22 MeV, beam size reaches 22 mm for focus point depth=250 mm (focused beam size in vacuum 1 mm).
  - Not suitable for thick volume irradiation.
- For high energies (≥100 MeV) :
  - the variation of peak depth in terms of the focus point depth is **linear**.
  - A slope of 0.97 is obtained for the energy 250 MeV and beam size σ=100 mm (→ The focus point coincides with the peak energy deposit).
  - Beam size increases quadratically with the focus point position, it achieves 7.2 mm at 250 mm depth in water, 250 MeV beam (focused beam size in vacuum is 1 mm).
- Energy spread variation up to 5% of the mean beam energy have no significant effect on Dmax, Zmax and FWHM of the percent depth dose curves (beam energy distribution is considered as Gaussian).