Monte Carlo commissioning of photon beams in medical LINACS using wide-field profiles in a water phantom

F.Gómez[1], L. Franco[1], A. Iglesias[1], J. Pardo[1], J. Pena[1], A. Rodríguez[1], R.Lobato[2], J. Mosquera[2], M. Pombar[2], J. R. Sendón[2]

[1] Universidade de Santiago de Compostela, Depto. de Física de Partículas, Facultade de Física. Santiago de Compostela, Spain
[2] Hospital Clínico Universitario de Santiago. Santiago de Compostela, Spain

GIR GRUPO DE INVESTIGACION EN RADIOFISICA

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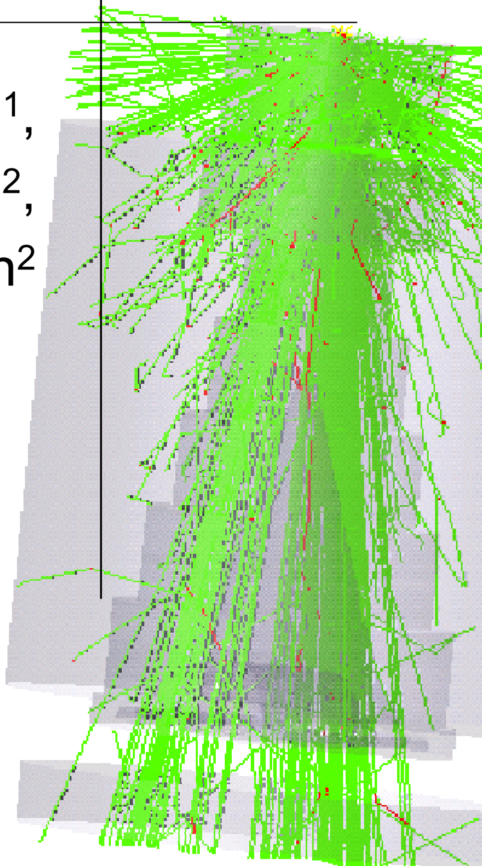
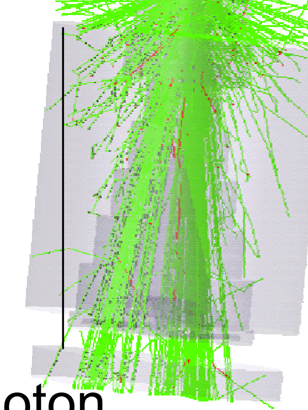


Discussion and motivation



The less known parameters in a Monte Carlo simulation of photon beams from a medical LINAC are the **incident electron beam energy spectrum and spatial distribution.**

General procedure for tuning this parameters:

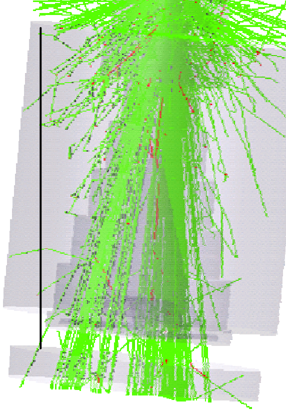
PDD simulation varying nominal energy → Nominal energy determined → Profiles simulation varying radius → **All Parameters calculated !!**

Measured PDD

Measured profiles

Problems of this method:

- Depth dose profiles are rather insensitive to the nominal energy
- Profiles are very sensitive to the nominal energy
- Small-field profiles suffer from phantom scatter and JAWS+MLC contributions making the radial dependence blurry

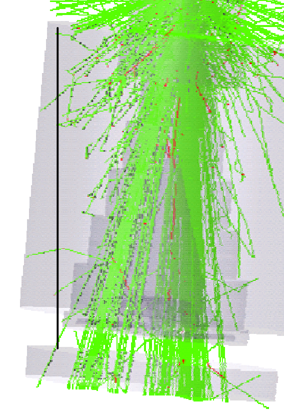


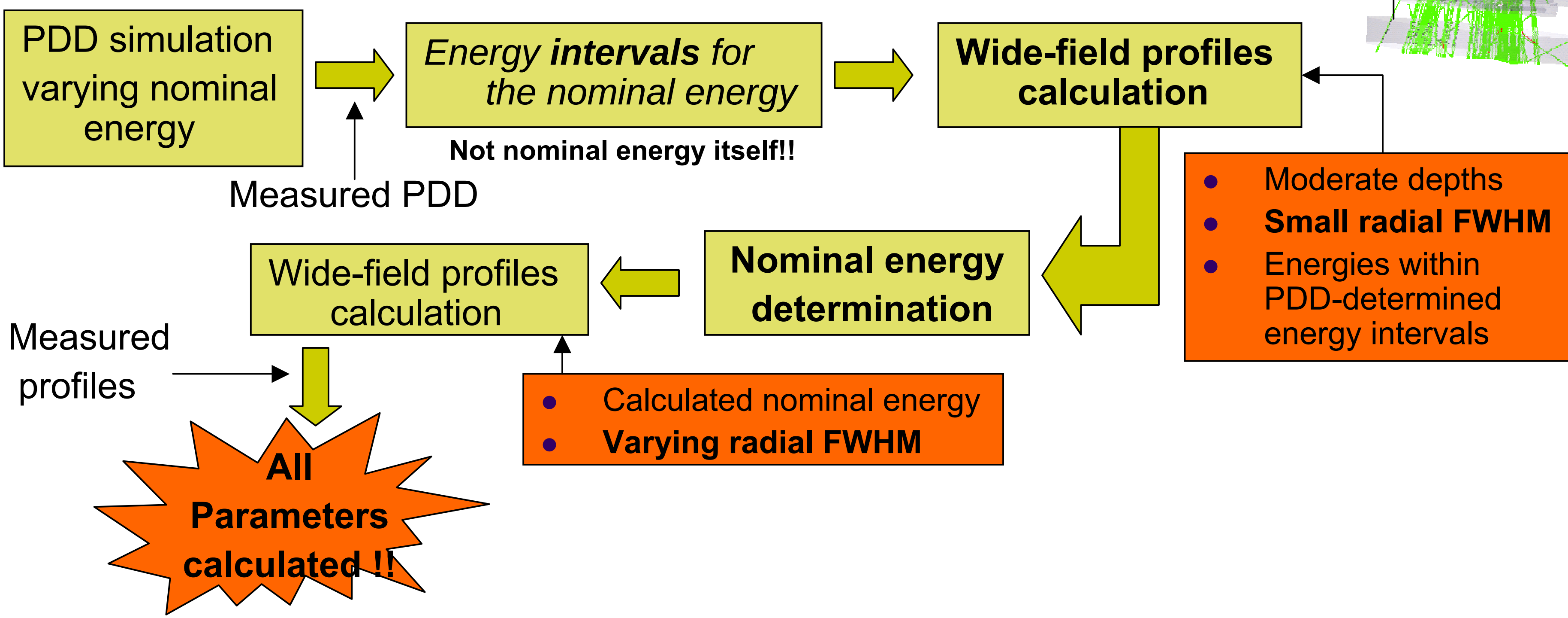
Discussion and motivation

Other ways of making the commissioning:

- Sheikh-Bagheri and Rogers: **in-air off-axis factors**
  - Very sensitive to most of the simulation parameters and the geometry details of the accelerator
  - **Require dedicated measurements!!**
- This work: *wide-field* lateral profiles in a water phantom at *moderate depth*
  - Advantages:
    - <u>Very sensitive to both nominal energy and radial distribution</u>
    - Little contribution from phantom scatter and beam-defining elements → JAWS+MLC and TARGET+PC+FF simulations clearly separated
    - **No dedicated measurements!!**

How to do the commissioning using wide-field profiles??

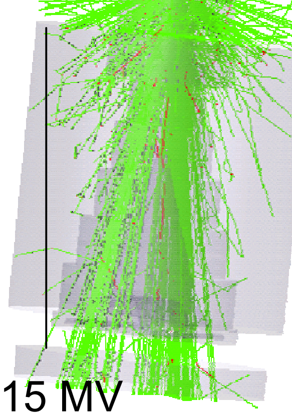


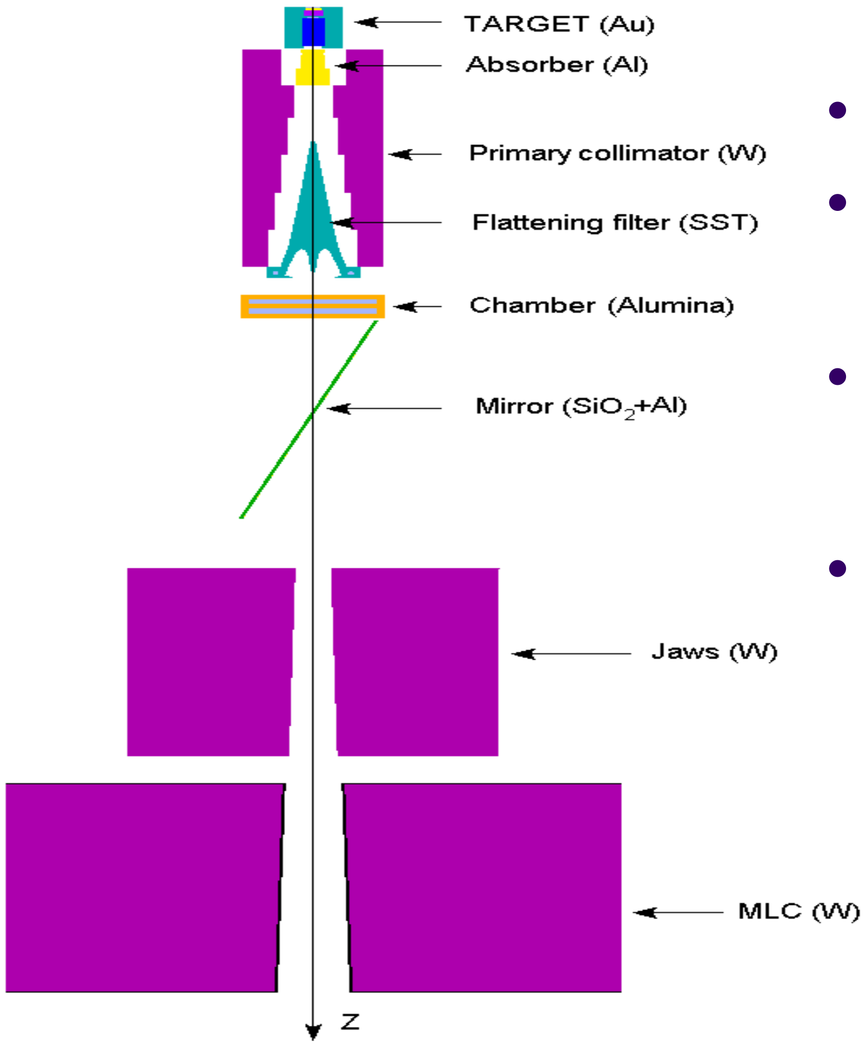


Problems in using this method:

- Profiles are sensible to the nominal energy and spatial distribution at the same time → necessary the help of the PDDs in the nominal energy determination

The Siemens Primus LINAC



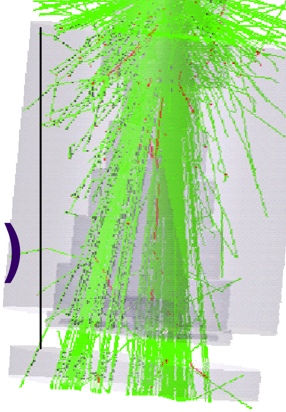


- We have simulated both 6 MV and 15 MV configurations in a "generic accelerator".
- V.R. techniques: **Selective Bremmstrahlung Splitting** with SSD=100cm, NMIN=40, NBRSPL=400 and FS = 10+field width
- Energy cutoffs:
  - photons: 10 KeV
  - electrons: 700 KeV (rest+kinetic)

- Available information from the manufacturer:

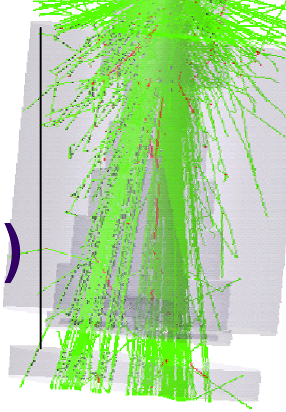
	6MV	**15MV**
Nominal energy	5.47 MeV	12.0 MeV
Energy spectrum	Gaussian 14% FWHM	Gaussian 14% FWHM
Radial distribution	??	??

Influence of the incident electron beam parameters on the percentage depth doses (PDDs)



We have made three simulations with **a nominal energy of 12 MeV** (15 MV configuration) but varying both energy spectrum and the FWHM of a gaussian radial distribution:

- Monoenergetic beam with radial FWHM = 0.001 cm (**monoenergetic pencil beam**)
- Gaussian energy spectrum (FWHM=14%) with radial FWHM=0.001 cm (**gaussian pencil beam**)
- Idem as before but FWHM=0.35 cm (**gaussian broad beam**)



Influence of the incident electron beam parameters on the percentage depth doses (PDDs)

Accelerator simulation

- **$1.5\cdot10^6$ electrons** (2.1 hours in a P4, 2.4 Ghz)
- Russian Roulette = OFF
- Same random number seeds for the 3 different beams
- Field size: **10cm x 10cm at SSD = 100cm**

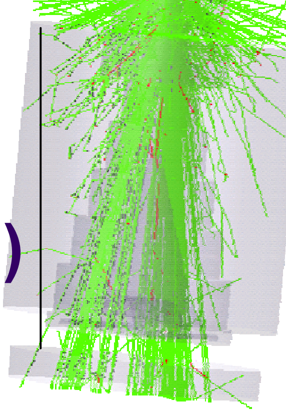
PDD calculation

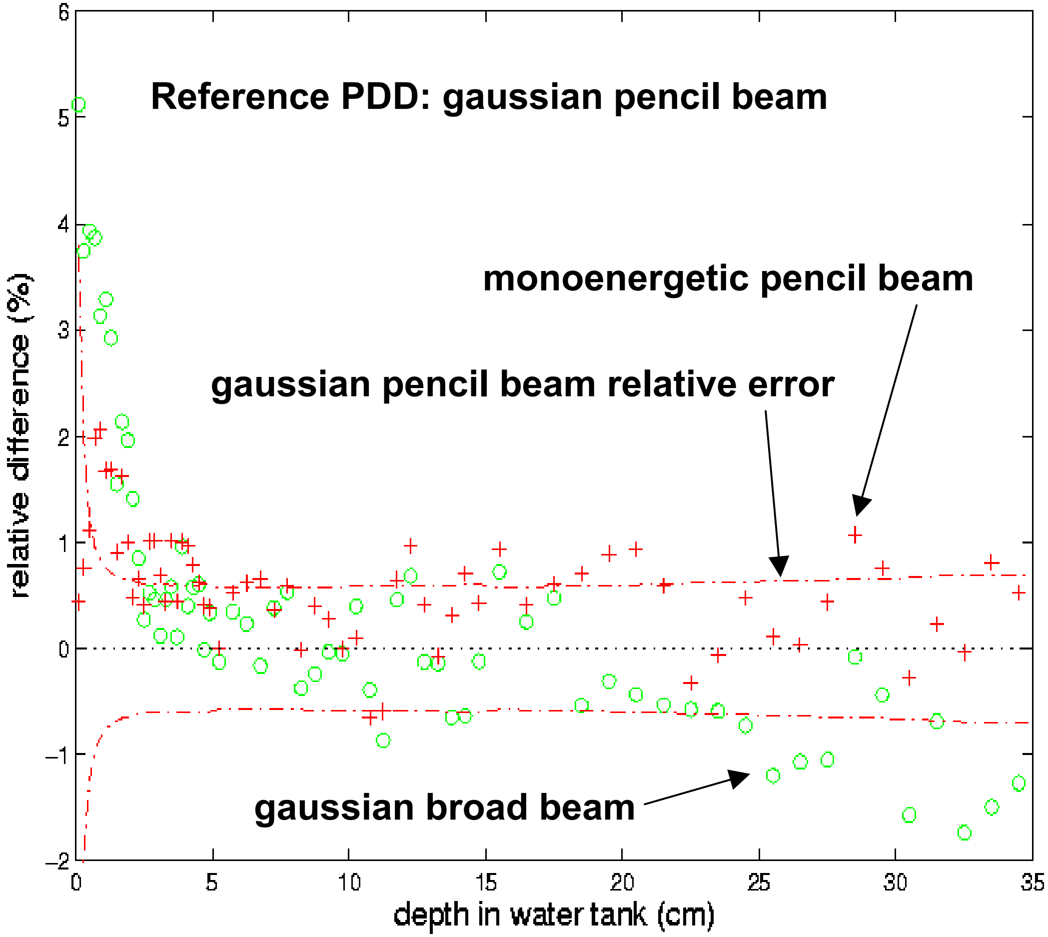
- **$2.5\cdot10^8$** histories (8 hours in a P4, 2.4 Ghz CPU) from a phase space file situated at a SSD=100 cm with ~ $2\cdot10^6$ histories
- We used the CHAMBER CM to simulate a water phantom with a voxel size of:
  - **0.2 cm** until 5cm depth
  - **0.5 cm** from 5cm to 15 cm depth
  - **1 cm** from 15 cm to 40 cm depth
- ECUT = *521KeV* and PCUT = *10 KeV*

PDD comparison

- Presented PDDs where **normalized at 10 cm depth** using a 4th degree polynomial fitting from 5cm to 15 cm depth

Influence of the incident electron beam parameters on the percentage depth doses (PDDs)



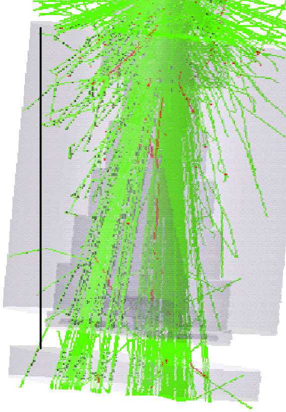


- PDD of the monoenergetic distribution simulates a higher nominal energy
- PDD with the highest radial FWHM shows a lower energy behaviour
- Both of them <u>are within the relative uncertainty of the gaussian pencil beam</u>

Relative difference calculated as:

$$\frac{PDD_{BEAM\_x}(i) - PDD_{gaussian\_pencil\_beam}(i)}{PDD_{gaussian\_pencil\_beam}(i)} * 100$$

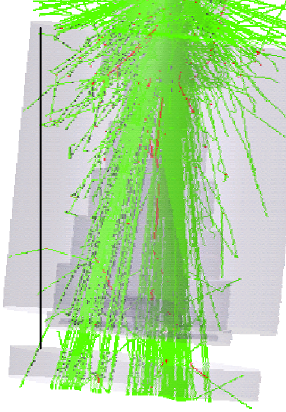
Influence of the nominal energy on the PDDs

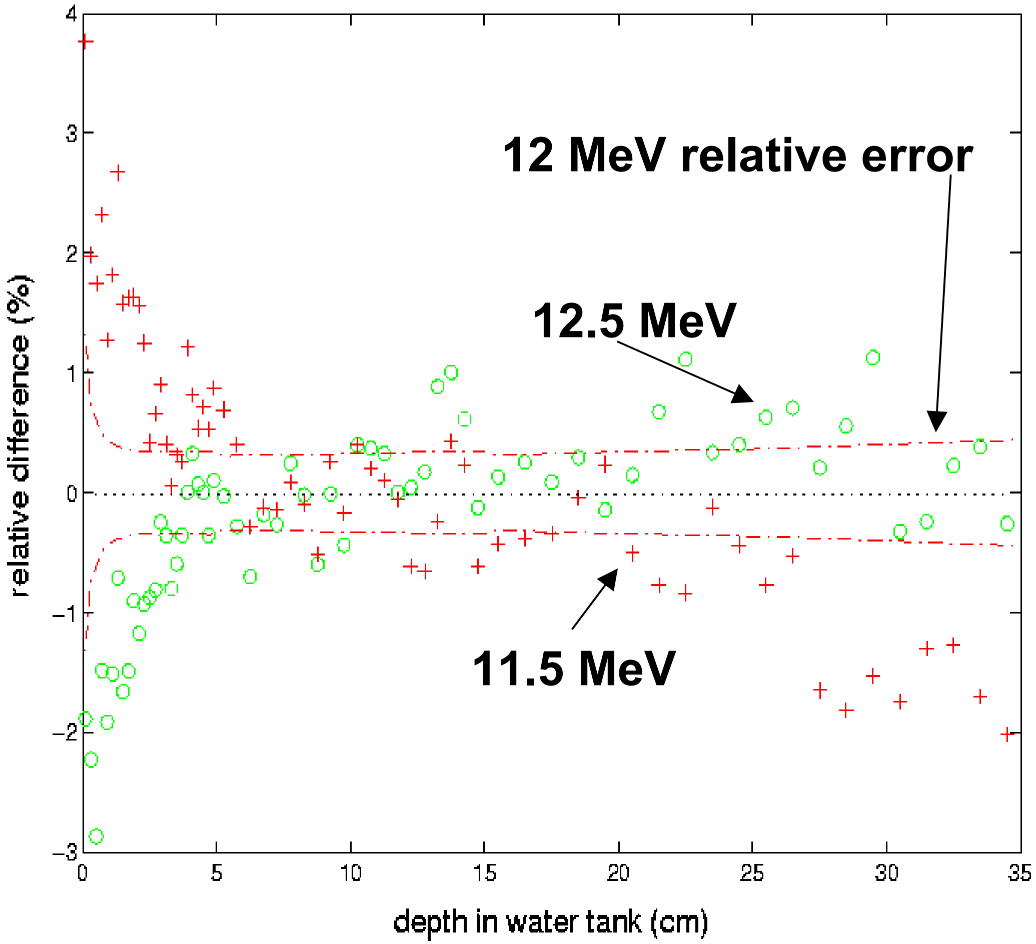


Assuming a gaussian energy spectrum with FWHM = 14% and a gaussian radial distribution with FWHM = 0.2 cm we have simulated PDDs for 11.5, 12.0 and 12.5 MeV of nominal energy

- Accelerator simulation ran **$9\cdot10^6$ electrons**, generating a ph.sp. file at SSD=100cm with ~$12\cdot10^6$ histories
- Field size: **10cm x 10cm at SSD=100cm**
- Cutoff energy: electrons: 700 Kev, photons: 10 KeV

Influence of the nominal energy on the PDDs

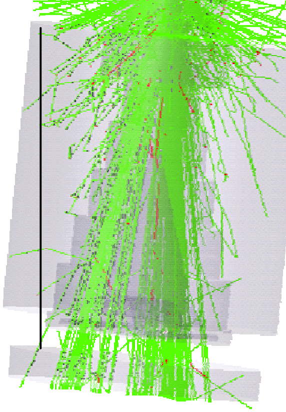




- Some of the points of both 11.5 MeV and 12.5 MeV fall within the 12 MeV error !!

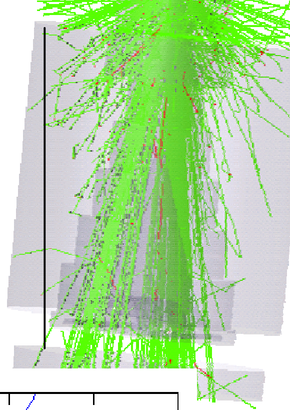
PDDs with a nominal energy difference of 0.5 MeV are NOT so different !!!

Nominal energy calculation



We have simulated several PDDs varying the nominal energy:

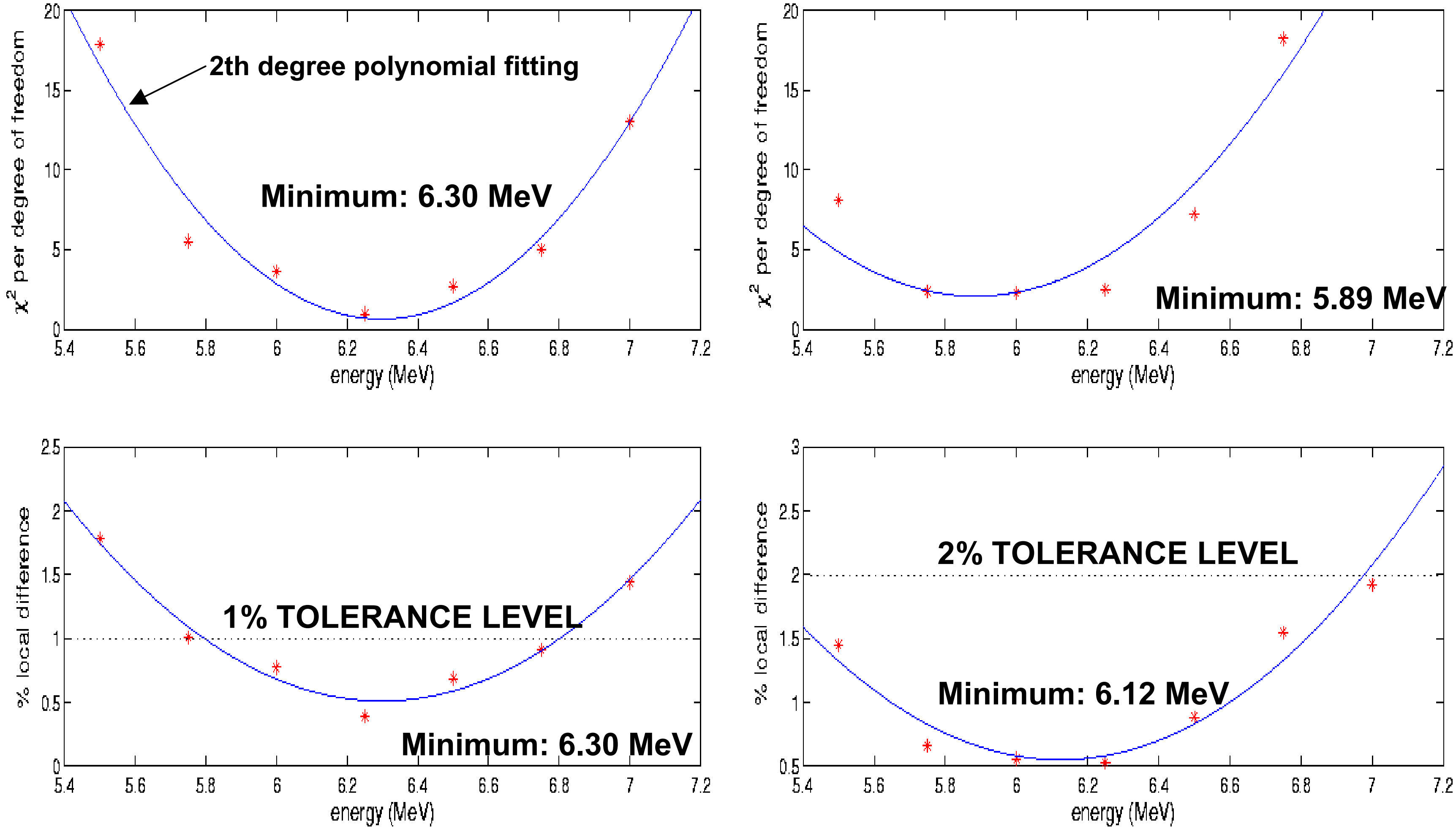
- Energy ranges were:
  - between 5.5MeV and 7MeV for the 6MV configuration
  - between 11MeV and 14MeV for the 15MV configuration.
- Measured depth dose profiles:
  - Chamber: PTW semiflex tube chamber, type 31002 (0.125 cm^3)
  - Water phantom: PTW MP3 water tank (60x50x40 cm^3)
  - Corrections: effective point of measurement: 0.6*0.275 (chamber radius).
- χ^2/NDF and % mean local relative difference calculation:
  - Tails region: between 5 cm and 35 cm depth
  - Buildup region: between 0.7cm and 5 cm depth



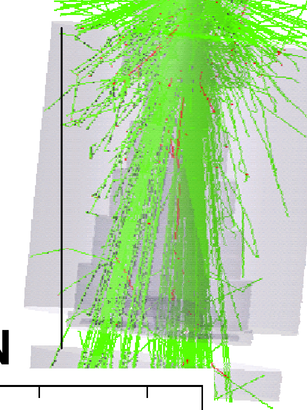
Nominal energy calculation (6 MV)

TAILS REGION

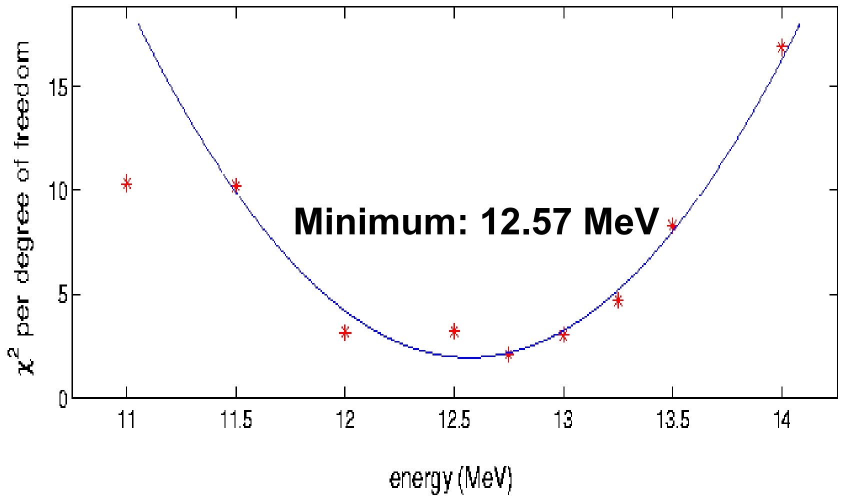
BUILD-UP REGION



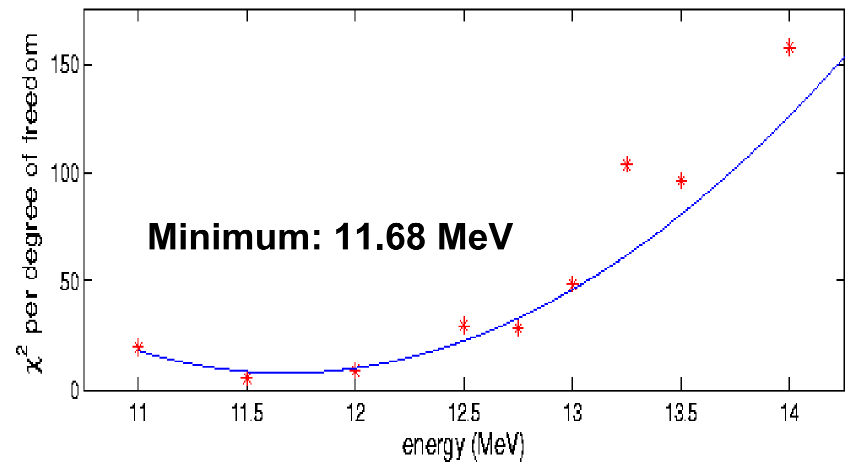
Nominal energy calculation (15 MV)

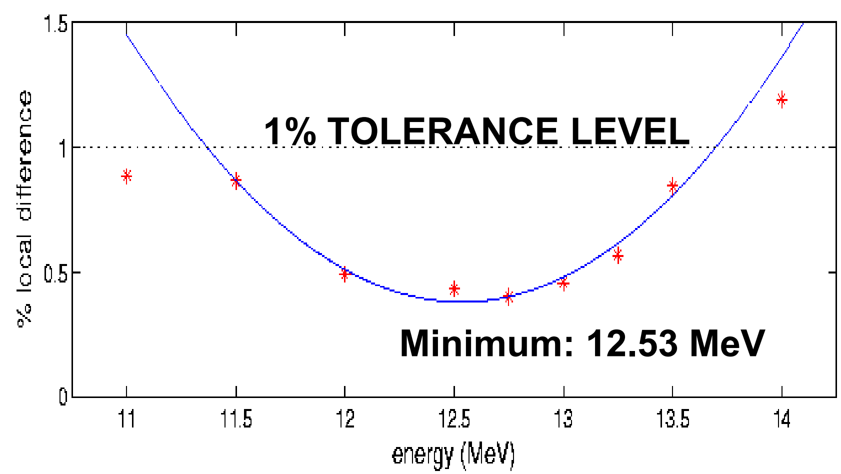


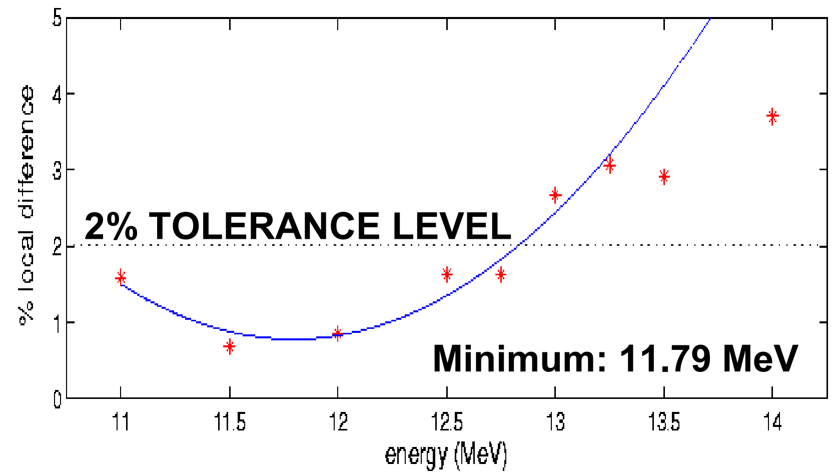
TAILS REGION



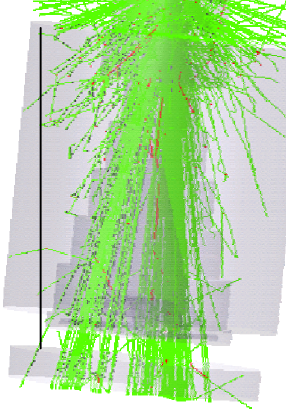
BUILD-UP REGION







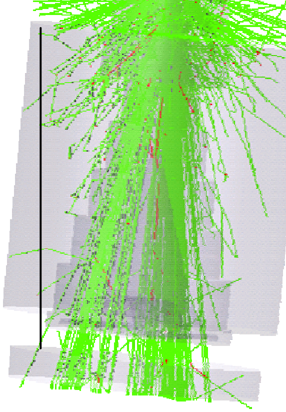
PDD study conclusions



- **PDD dependence on initial electron beam parameters establish a minimum uncertainty in the nominal energy determination** from PDD calculations and measurement comparison.
- Setting “maximum tolerance levels” in χ^2/NDF and % mean local relative difference **we open an energy window of 1-1.5 MeV width** for the nominal energy value.

Water profiles could help us in fine-tuning the nominal energy !!!

Wide-field profiles calculation



- We have simulated 40cm x 40cm fields at a SSD=100cm with a **5cm thick water slab** (~10 MeV electron CSDA range), scoring a phase space file at **Z=105 cm**.

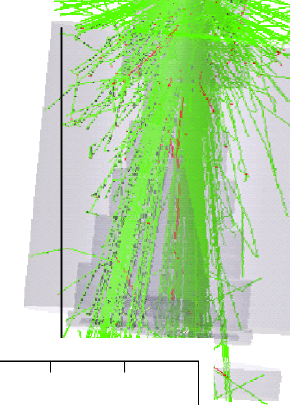
  $5 \cdot 10^5$ electron histories (~1 hour in a P4, 2.4 Ghz)→ ~$14 \cdot 10^6$ histories in the ph.sp. files

- **Assuming CPE we calculated the dose multiplying the initial photon fluence by the water mass energy absorption coefficient** (using ring bins of 1 cm width).

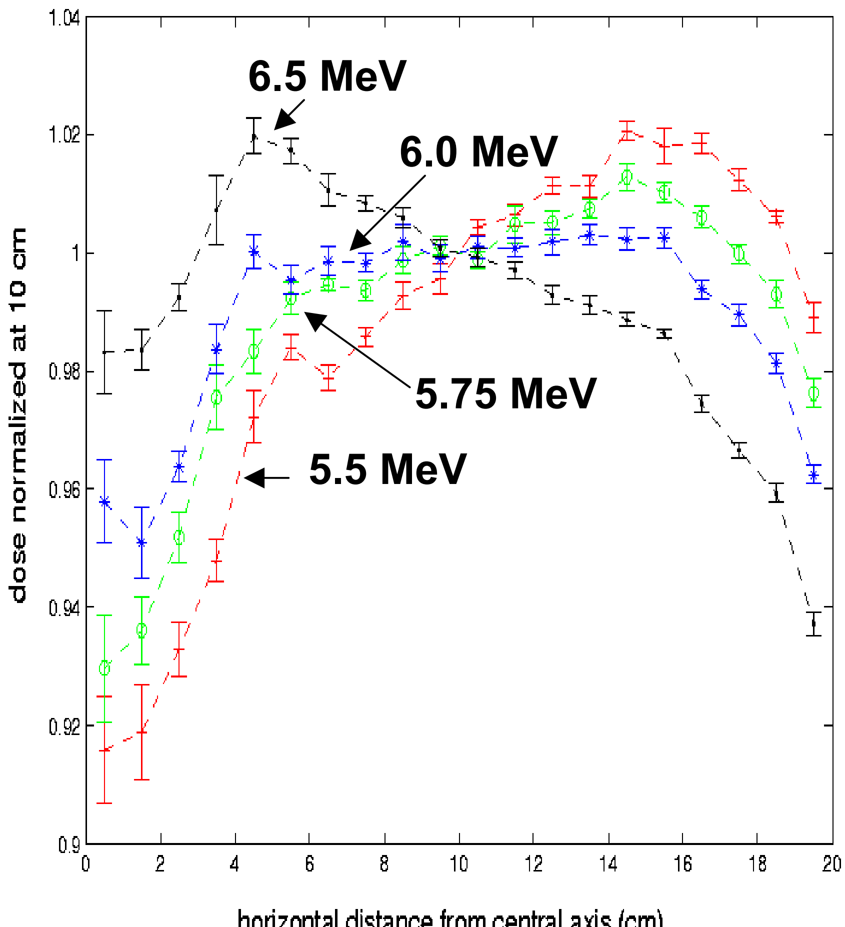
  Incident fluence photon separated from phantom-generated photons using different LATCH bits

  Uncertainty calculation using 10 BATCHES

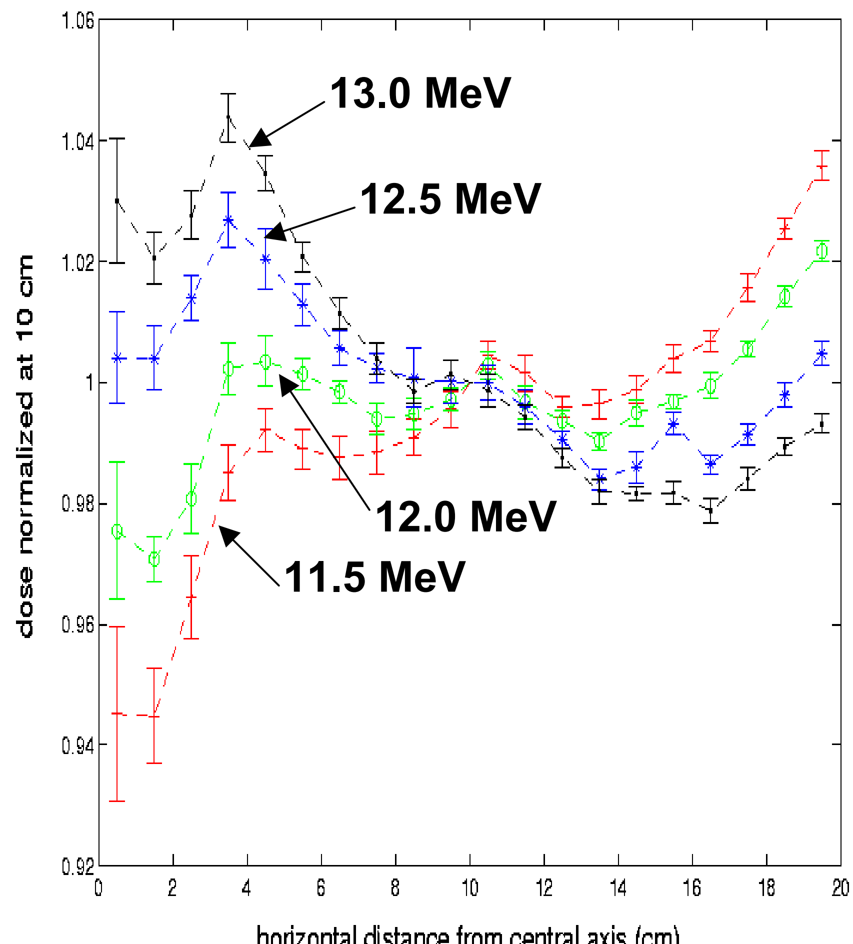
Sensitivity of the profiles to the nominal energy



6 MV

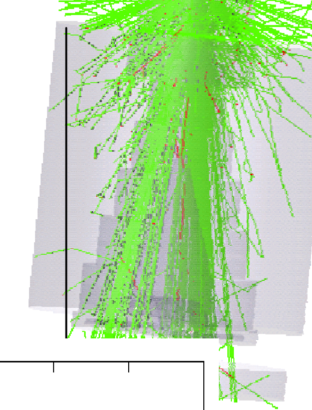


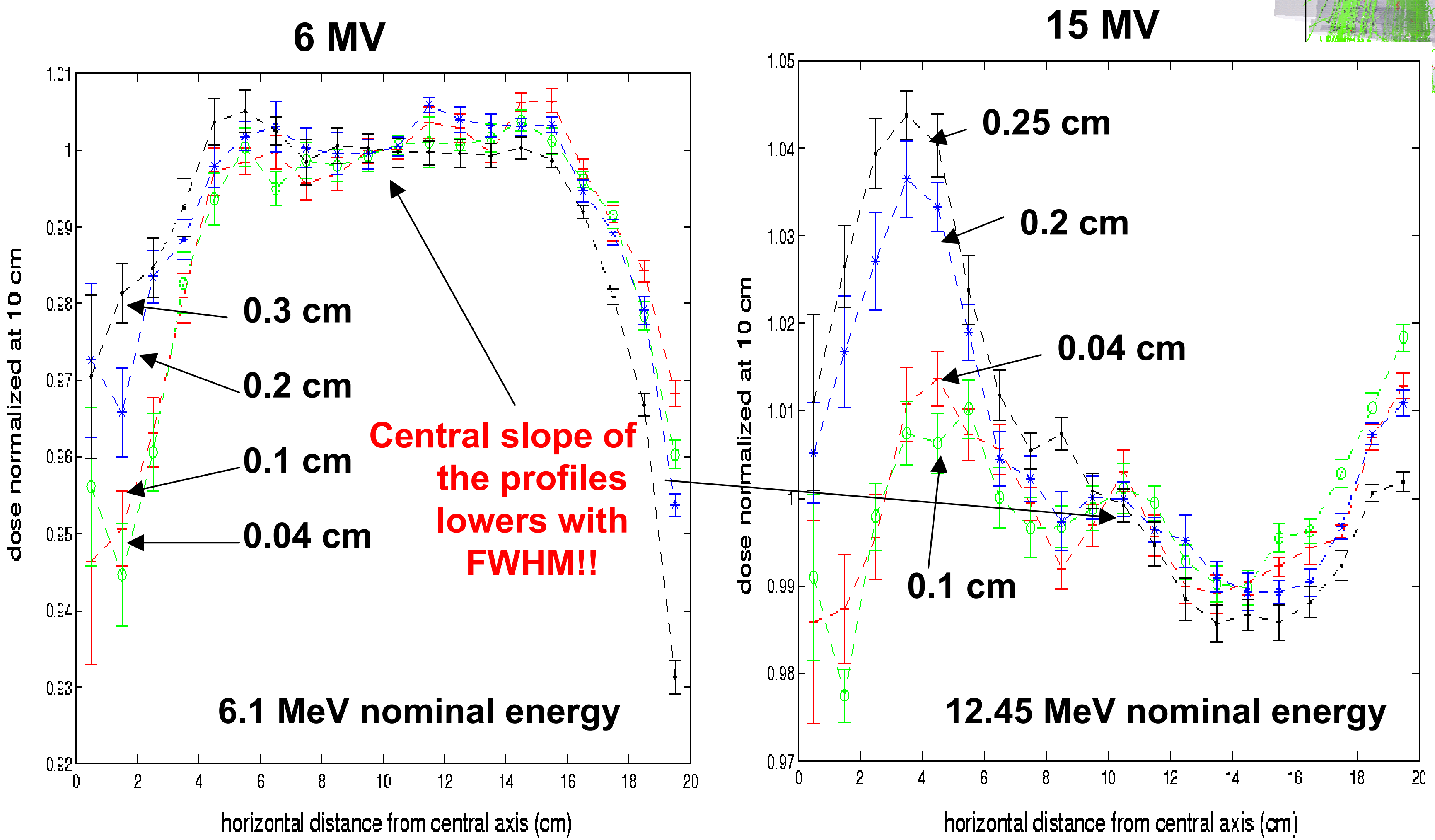
15 MV



The highest the nominal energy, the lowest the "slope" of the profiles !!

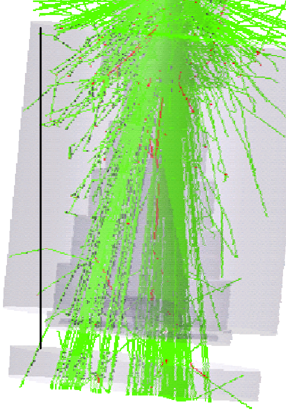
Sensitivity of the profiles to the radial FWHM





The highest the radius, the highest the ratio dose at central axis/dose at 10 cm !!

Calculating the nominal energy using the profiles



Lateral dose profiles simulation **varying nominal energy** → ***Nominal energy determined!!***

Measured profiles ↑

- **Nominal energies within "energy windows"**
- **FWHM=0.1 cm** → **"maximum slope"**
- **5 cm water depth** → **Low phantom scatter**

Energy windows

- 6 MV: 5.5 MeV – 6.5 MeV
- 15 MV: 11.5 MeV – 13 MeV

Profiles measurements were made in the same conditions as PDDs

X profiles showed but Y profiles yielded to the same results

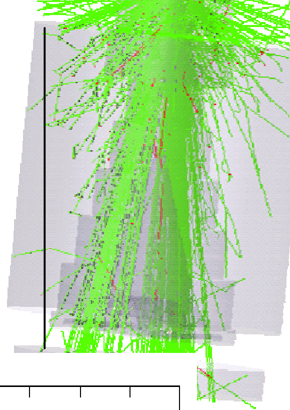
CPE condition

- Depth past buildup maximum.
- Lateral off-axis maximum distance:
  - 6MV: 17.45cm (20cm – 5MeV electron CSDA range[1])
  - 15MV:15 cm (20cm – 10 MeV electron CSDA range[2])

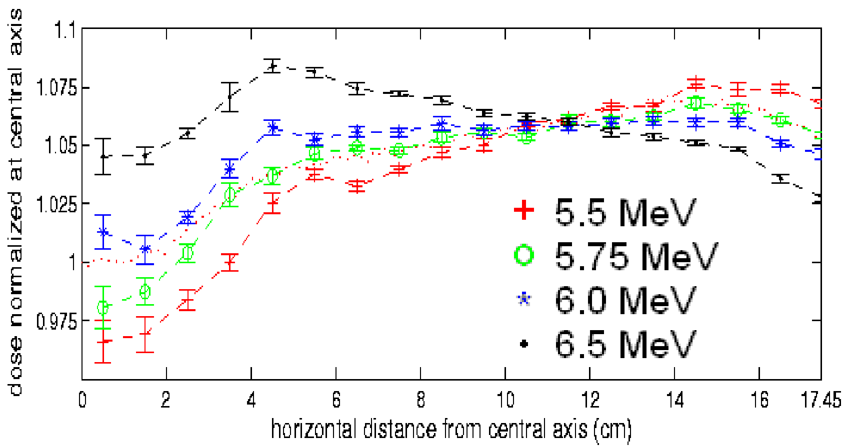
[1] only 0.94% of the photons in the incident fluence > 5 MeV

[2] only 1.06% of the photons in the incident fluence > 10 MeV

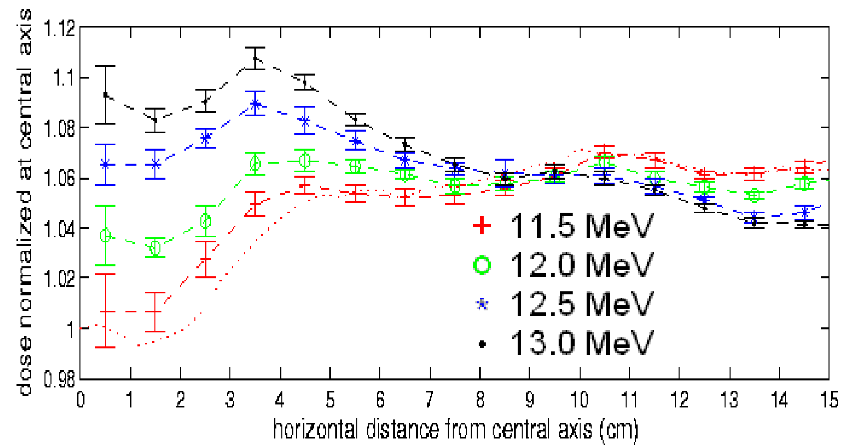
Derived nominal energy

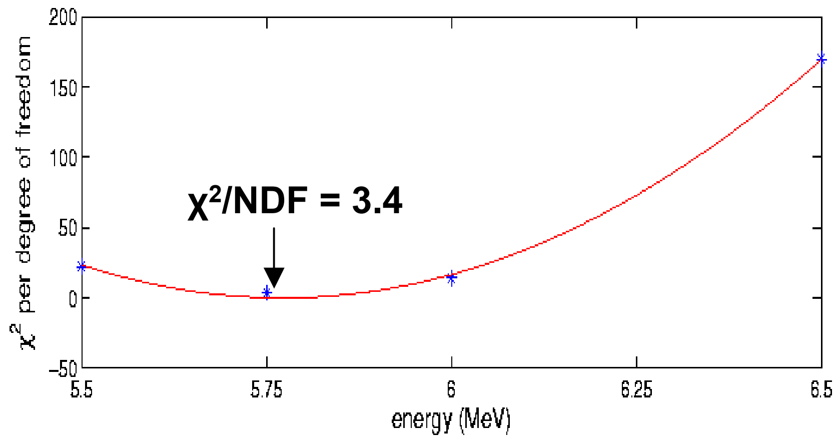


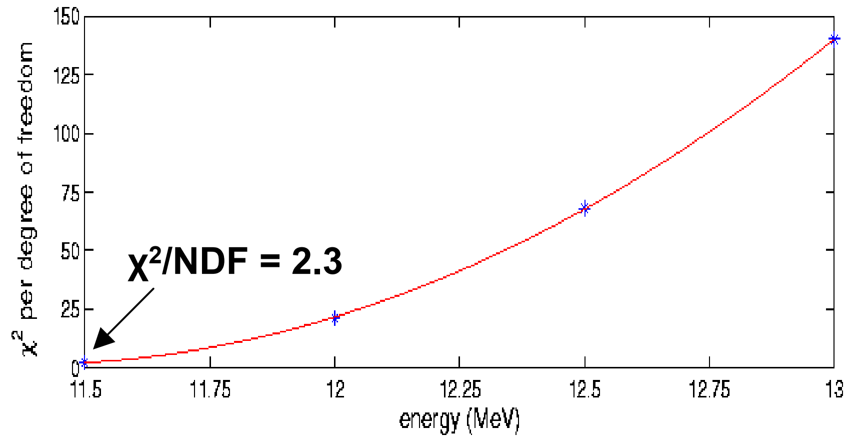
6 MV



15 MV



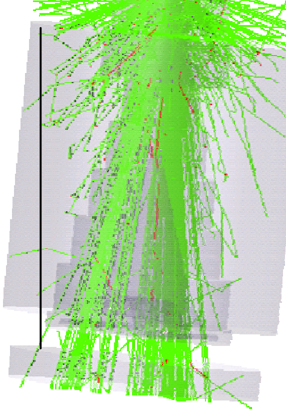




Derived energy: 5.75 MeV

Derived energy: 11.5 MeV

Calculating the radial FWHM using the profiles



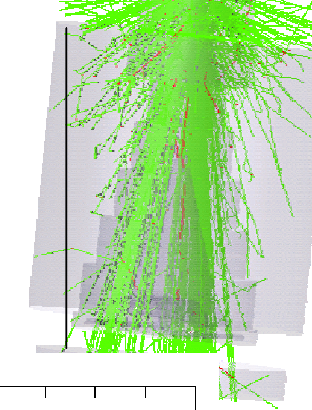
Lateral dose profiles simulation **varying radial FWHM**

→ ***Radial FWHM determined!!***

Measured profiles

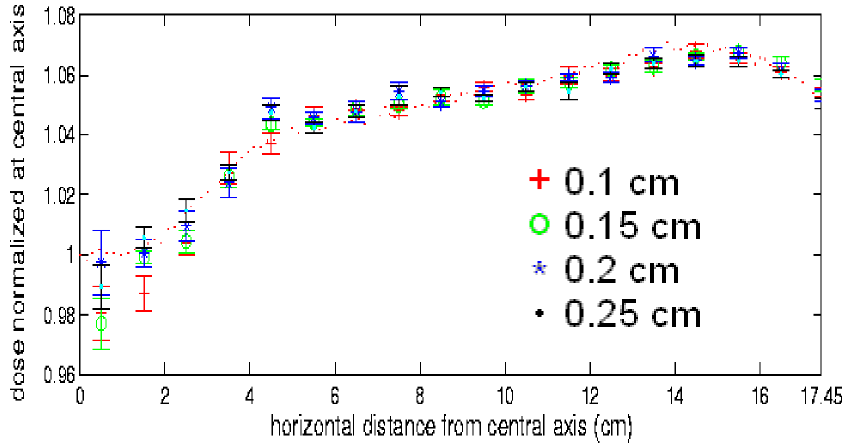
- **Nominal energy found in the previous section**

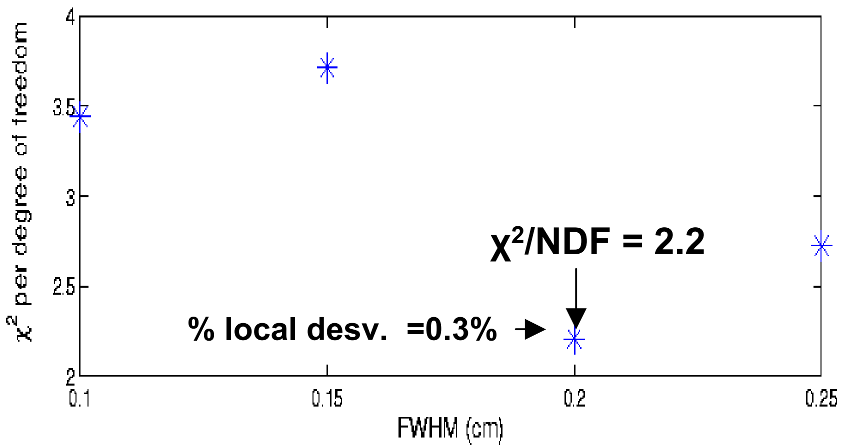
→ **6MV: 5.75 MeV**
15MV: 11.5 MeV



Derived radial FWHM

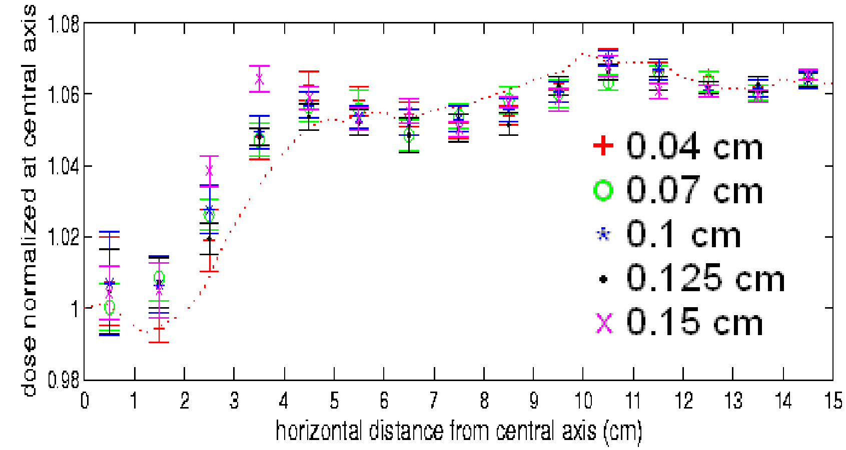
6 MV

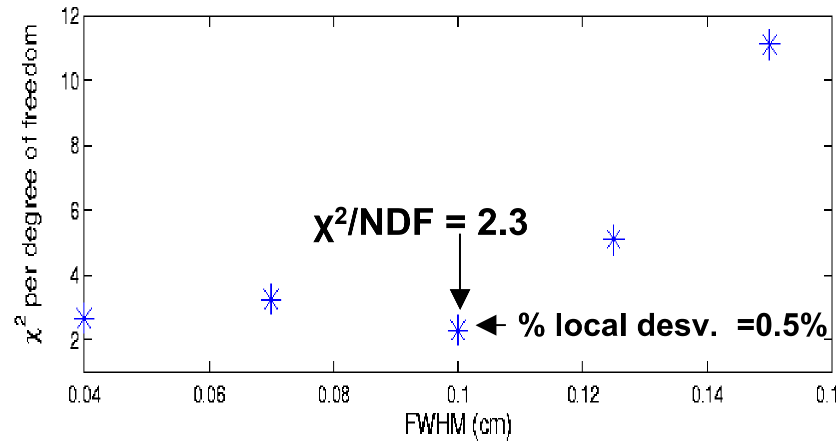




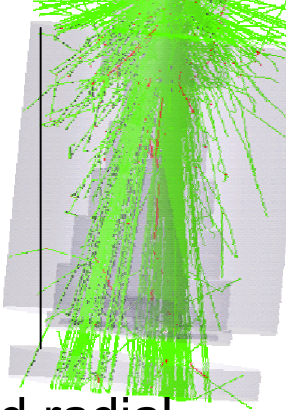
Derived FWHM: 0.2 cm

15 MV





Derived FWHM: 0.1 cm



Conclusions

- PDDs show some dependence on both energy spectrum and radial distribution of the initial electron beam
- A nominal energy determination using only PDDs can lead to wrong results and has a significant minimum uncertainty
- Wide-field profiles are very sensitive to both nominal energy and radial distribution of the initial electron beam thus serving as a way of determining this parameters
- This kind of commissioning is also very sensible to geometrical and composition features of the accelerator
- No dedicated measurements needed

	Original		**Derived**	
	6 MV	**15 MV**	**6 MV**	**15 MV**
Nominal energy	5.47 MeV	12.0 MeV	5.75 MeV	11.5 MeV
Radial FWHM	--	--	0.2 cm	0.1 cm

Thank you for your attention !!