Comparison of Geant4 electromagnetic physics for a gamma radiotherapy linac

Pedro Arce
CIEMAT, Madrid

Outline:
- Method of adjusting MC to data
- CPU optimization
  - Geometry
  - Physics cuts
  - Bremsstrahlung splitting
  - Reusing particles that traverse linac
- Comparison of EM models
  - Comparison of brems. angular dist.
  - Comparsion of Livermore, Penelope and Standard

RT linac simulation:

Details of the machine are not completely known:

☺ Geometry from manufacturer

☹ Beam parameters unknown

- Energy: ~ 6 MeV
- Beam intensity profile (assume 2D XY Gaussian): few mm FWHM
- Beam dispersion: < few degrees

➢ We need a method to find beam parameters: follow AAPM TG 53

✓ Match data and Monte Carlo dose profiles in water, for different jaws apertures fields: 5X5 cm, 10x10 cm, 15x15 cm, 20x20 cm

- Percentage Depth Dose: dose along beam central axis
- Cross profiles: beam transverse profiles at different depths: 1.4 cm (maximum), 10 cm, 20 cm, 30 cm

RT linac simulation: Optimizing beam parameters

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

METHOD:

0. CPU optimization
1. Check beam is centered and measurements are horizontal
2. Match **beam E** to PDD
3. Match **beam width** to X-profiles
4. Match **beam E** again if PDD has worsen

- Consider E fix: Dose is almost independent of E dispersion
- Beam angle dispersion: Dose is almost independent of it

Precise determination of beam parameters:

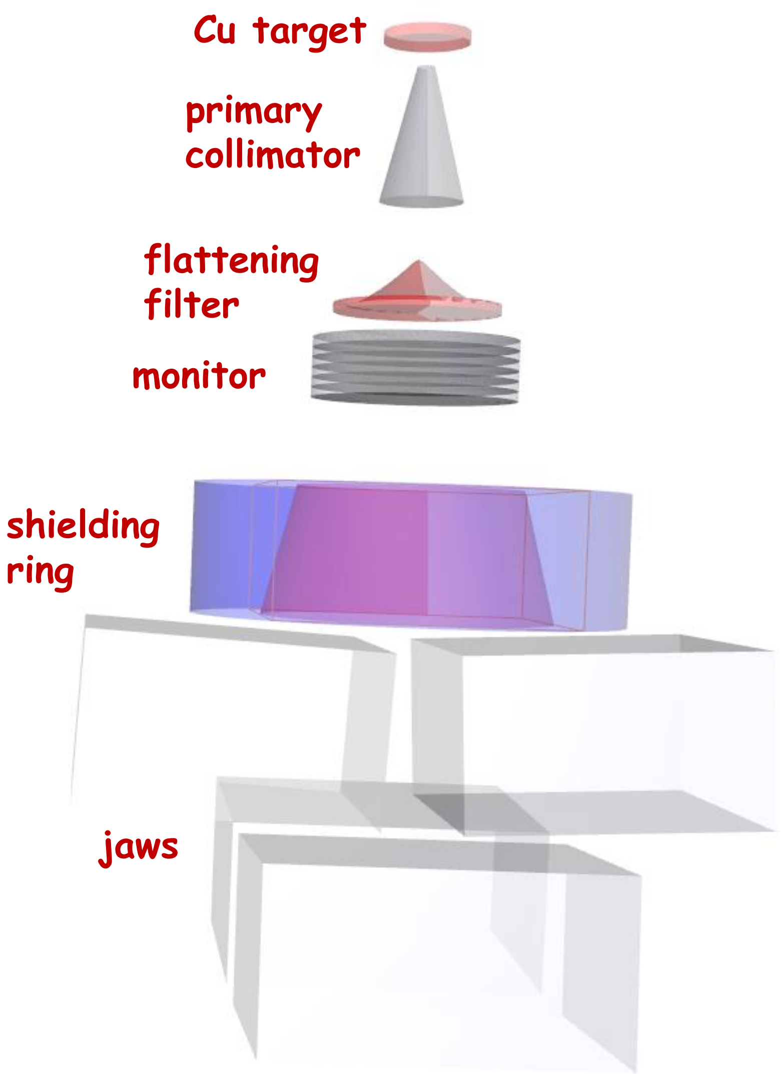
- Wide set of dose distributions (**20**)
- High number of measuring points (**each 2 mm**)
- High MC statistics **(<1 % statistical error**)

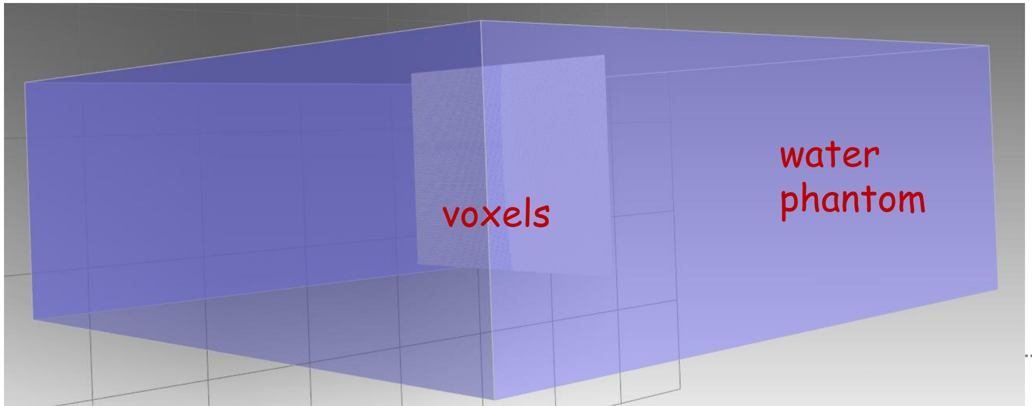
(~20,000 days of CPU)

CPU optimization: Geometry

Do not simulate linac shield
(surrounding upper linac parts)
- ✓ Check it has no effect
- ☺ **Save 4.5 %**

Phantom voxelization:
- ➢ Only 2D, not 3D, as data is taken only along two directions
  - ☺ **Save a factor 3**
  - ➢ No factor 2 gain if 3D, because X – Y symmetry is not perfect





CPU optimization: Physics cuts at linac

GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Production thresholds:

- ❖ Make a region for each linac component
- ✓ Use GAMOS tool for automatic optimization

PRODUCTION THRESHOLD (mm)		
GEOMETRY REGION	e- from ionization	Gamma from bremsstrahlung
Target	1.	10.
Primary Collimator	0.1	10.
Flattening filter	1.	10.
Monitor	1.	10.
Shielding	1.	10.
Jaws	0.3	1.
Outside linac components	10.	10.

☺ CPU time w.r.t. default 0.1 mm: **Save 31 %**

☺ Applying to processes **41 %**

Minimal kinetic energy user limits:

- ✓ Use GAMOS tool for automatic optimization

😐 Gain is negligible

	CUT 0.1 mm	OPTIMIZED CUT	OPT. CUT APPLIED TO ALL PROCES.
Particle / region	% Time	% Time cut 0.1 mm	% Time cut 0.1 mm
e- / target	59.9 %	47.0 %	42.3 %
e- / primary collimator	3.7 %	3.5%	0.1 %
e- / flattening filter	0.3 %	0.2 %	0.01 %
e- / monitor	0.2 %	0.1 %	0.01 %
e- / shielding ring	0.1 %	0.05 %	0.01 %
e- / jaws	0.3 %	0.3 %	0.05 %
e- / outside linac	16.6 %	3.4 %	3.1 %
gamma / target	10.8 %	6.0 %	5.6 %
gamma / primary collimator	5.1 %	5.1 %	4.2 %
gamma / flattening filter	0.5 %	0.5 %	0.5 %
gamma / monitor	2.0 %	2.0 %	1.9 %
gamma / shielding ring	0.2 %	0.2 %	0.2 %
gamma / jaws	0.5 %	0.2 %	0.2 %
gamma / outside linac	0.02 %	0.02 %	0.02 %

CPU optimisation: Physics cuts in phantom

Production thresholds:

✓ Use GAMOS tool for automatic optimization

Phantom Cut (mm)	DOSE / DOSE 0.001 mm CUT (%)	CPU Time gain (%)
0.01	0.0	0
0.1	**0.46**	**23**
0.25	1.35	27
0.5	6.4	29
1	14	33
2.5	32	38
5	53	43

Minimal kinetic energy user limits:

✓ Use GAMOS tool for automatic optimization

😐 Gain is negligible

CPU optimisation: Bremsstrahlung splitting

- 3 bremsstrahlung splitting techniques available in GAMOS
  - Based on Geant4 general biasing
    - Added: fully managed by user commands
    - Added: biasing operator only affects selected particle / processes

1. **Uniform Bremsstrahlung Splitting**

2. **Directional Bremsstrahlung Splitting**
   - UBS + User selects XY plane at a given Z position: bremss. gammas not directed towards this plane killed by Russian roulette

3. **Equal Weight Bremsstrahlung Splitting**
   - DBS + Reweight all particles created by any process, so that all particles reaching the phantom have the same weight (based on EGSnrc DBS)

CPU optimisation: Bremsstrahlung splitting

Optimize splitting number (for the 3 techniques):

- ➢ Bigger N
  - ☺ bigger fraction of time in gammas, less in e-'s
  - ☹ bigger particle weight differences → bigger error
  - ☹ may create artifacts (inadequate sampling of phase space)

Efficiency = 1 / (T σ^2)

T = CPU time

σ = dose error = average error in voxels with dose > 50 % maximum dose (AAPM TG 53)

Check artifacts are not too big:

- ✓ Chi2 comparison dose in half-right vs. half-left and check p-value is not too small

OPTIMAL: **EWBS with N = 100 : save a factor 2.5**

CPU optimisation: Reuse particles that traverse linac

Only very few particles traverse the full linac:

- ☹ ~1.6/1000 for a 10x10 field (without splitting)
- ☹ With EWBS and N_SPLIT=100, time in linac is 100X time in phantom
- ⇨ **Reuse particles that reach phantom**

❑ Usually this is done storing in a phase space file the particles that reach a XY plane close to the phantom, and reading them back in a second job

✓ GAMOS allows particle reusing in a single job, without wasting time writing/reading a file

- ✓ Option to mirror in XY to diminish artifacts

With 1E9 initial particles, 1.6E8 reach the phantom = 64,000 per voxel

⇨ **Reusing 100 times** seems to be OK for not producing artifacts

EM physics models comparison: Method

Compare EM physics packages

- ❖ Standard
- ❖ Livermore
- ❖ Penelope
- ❖ Option3 and Option4 for Standard (supposed to be more precise)
- ❑ Change bremsstrahlung angular distributions for Standard and Livermore
  - ❖ DipBust
  - ❖ Tsai
  - ❖ Koch-Motz 2BS
  - ❖ Koch-Motz 2GN

➢ For each case: optimize beam energy in **steps of 0.25 E** with beam width 0 and beam angle 0 (bigger beam widths and angles always worsen the fit)

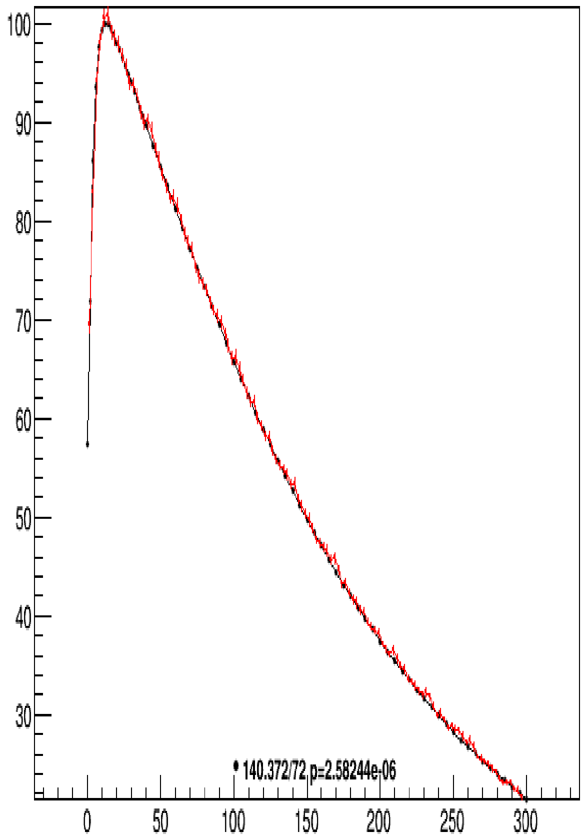
- ✓ Optimize matching of the 20 distributions

geant4.10.02.p02

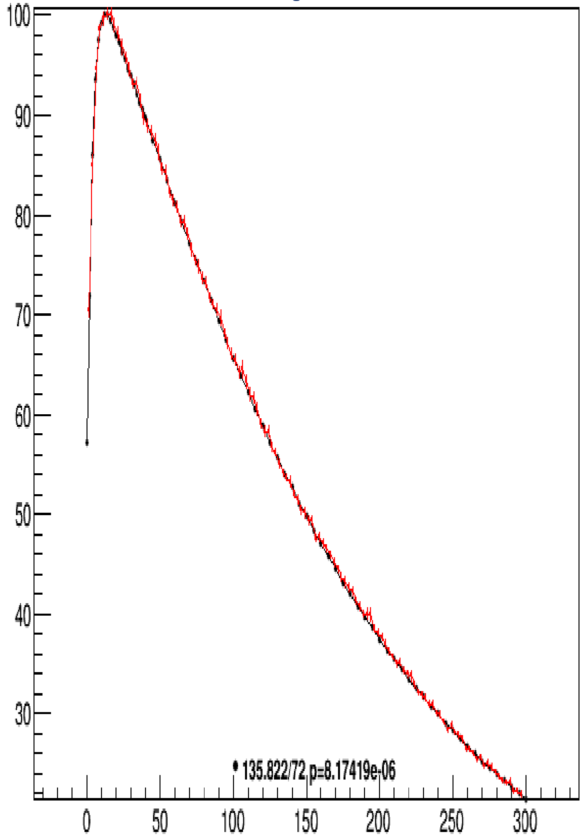
EM physics:
3 EM models: PDD

10x10 cm field

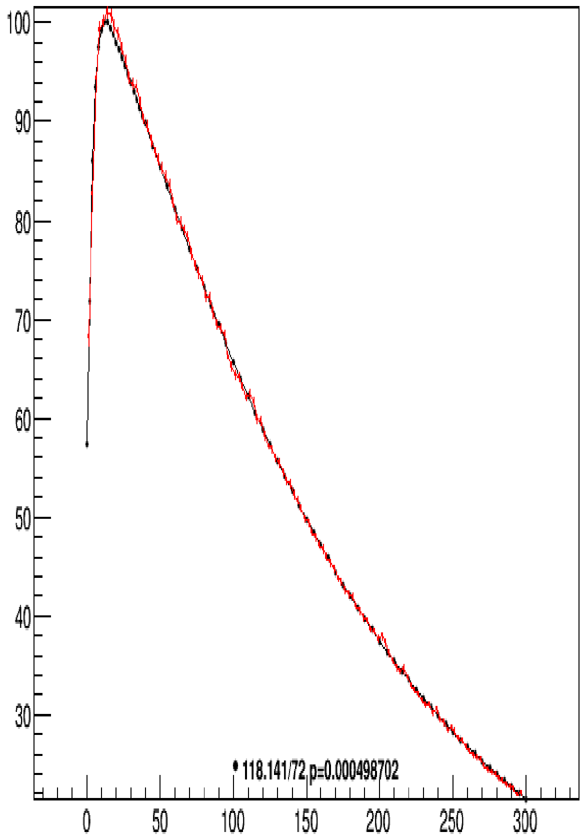
Livermore 5.75 MeV



Penelope 5 Mev



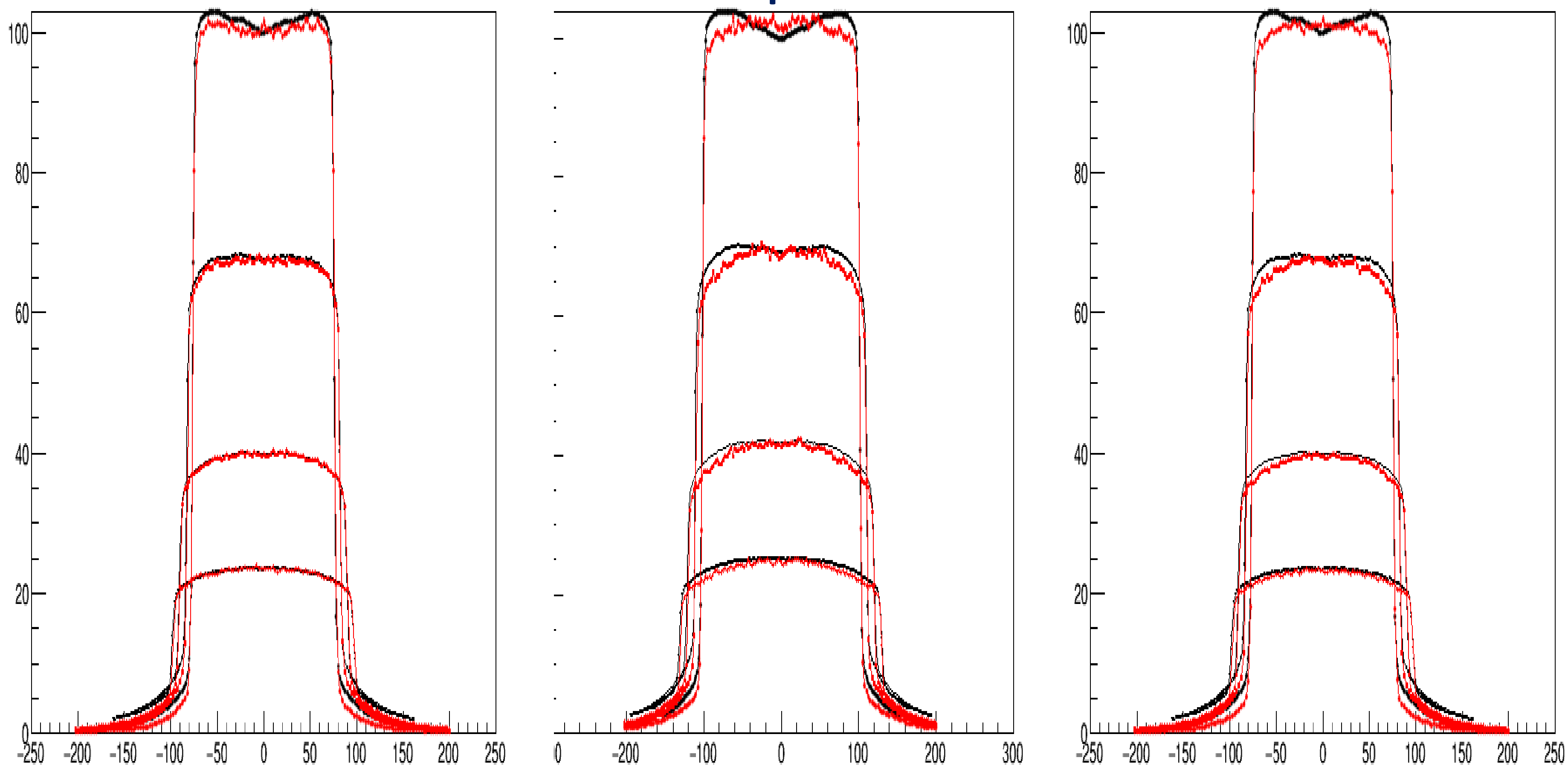
Standard 5 Mev



EM physics:
3 EM models: X-profiles

20x20 cm field

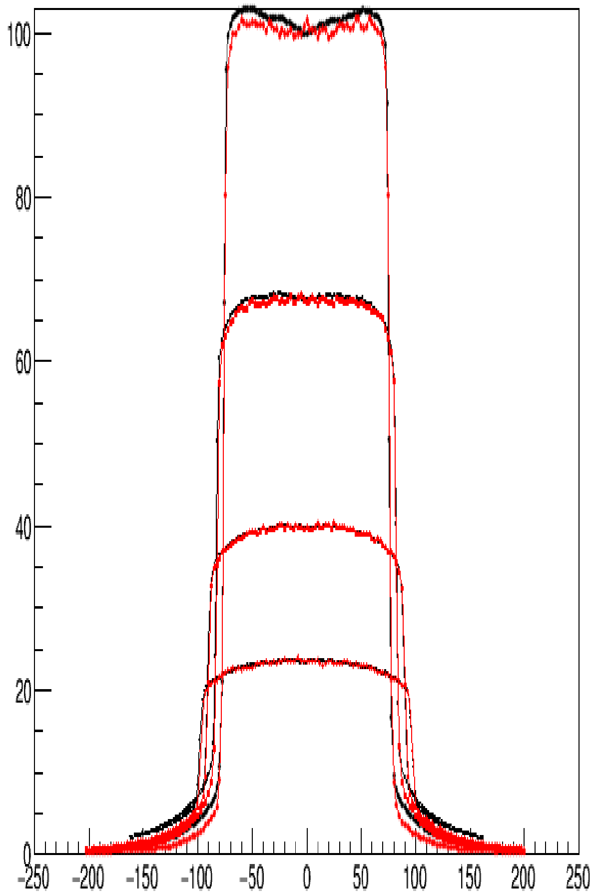
Livermore 5.75 MeV | Penelope 5 Mev | Standard 5 Mev



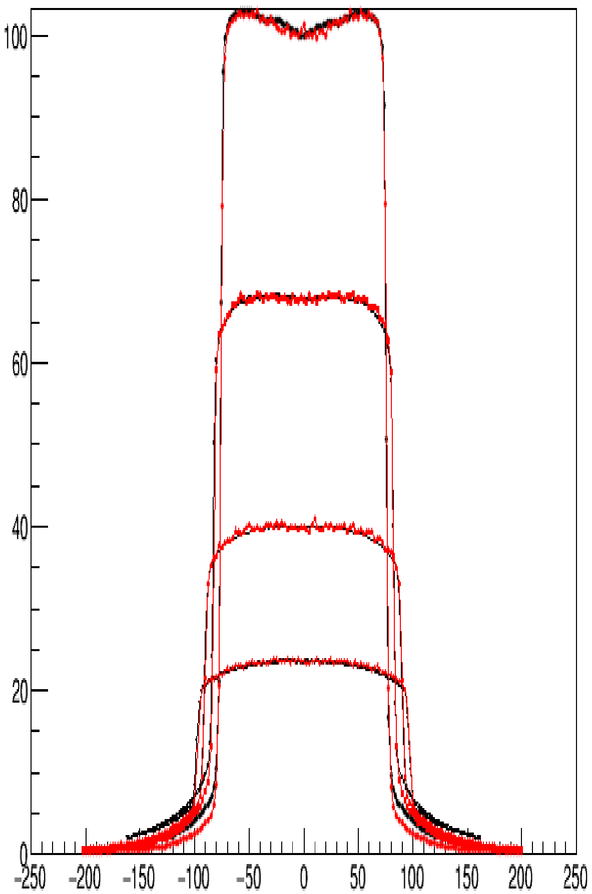
EM physics:
Livermore: brems. angular dist.

20x20 cm field

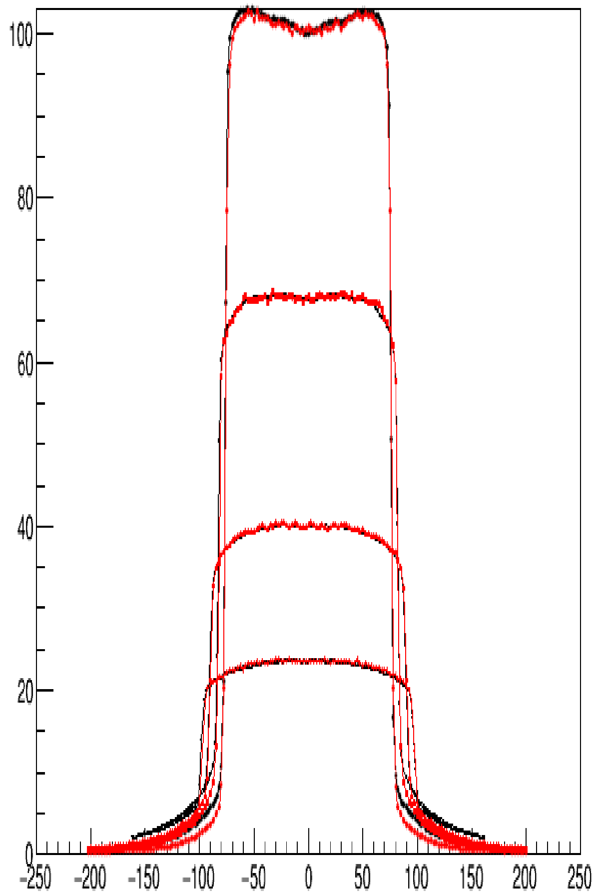
Tsai (default)



Koch-Motz 2BS



Koch-Motz 2BN

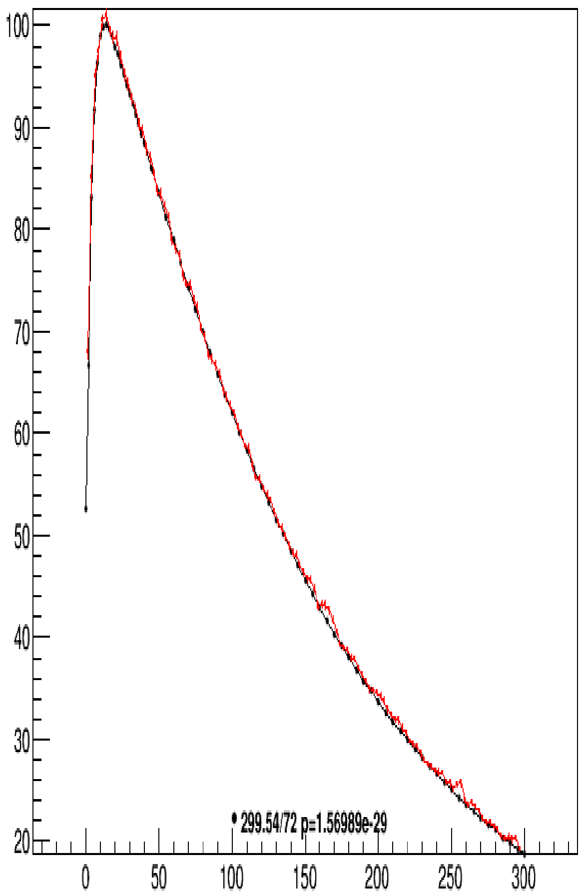


Best: Koch-Motz 2BS (Livermore & Standard)

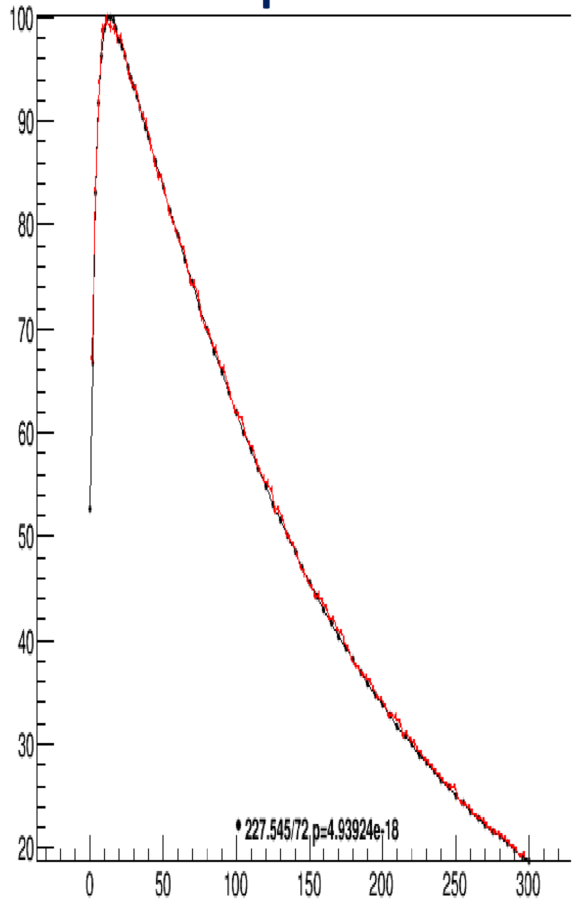
EM physics:
3 EM models: PDD 5x5 field

5x5 cm field

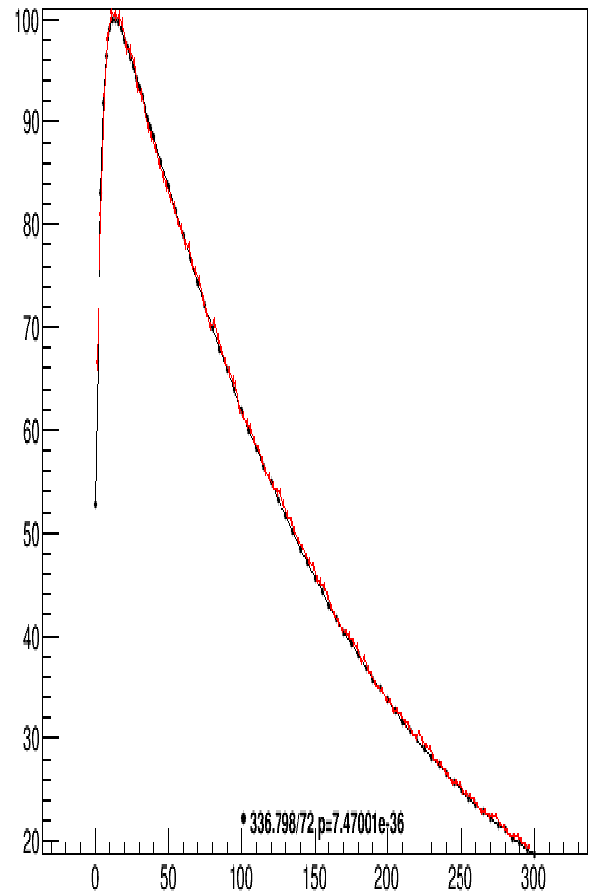
Livermore 5.75 MeV



Penelope 5.5 Mev



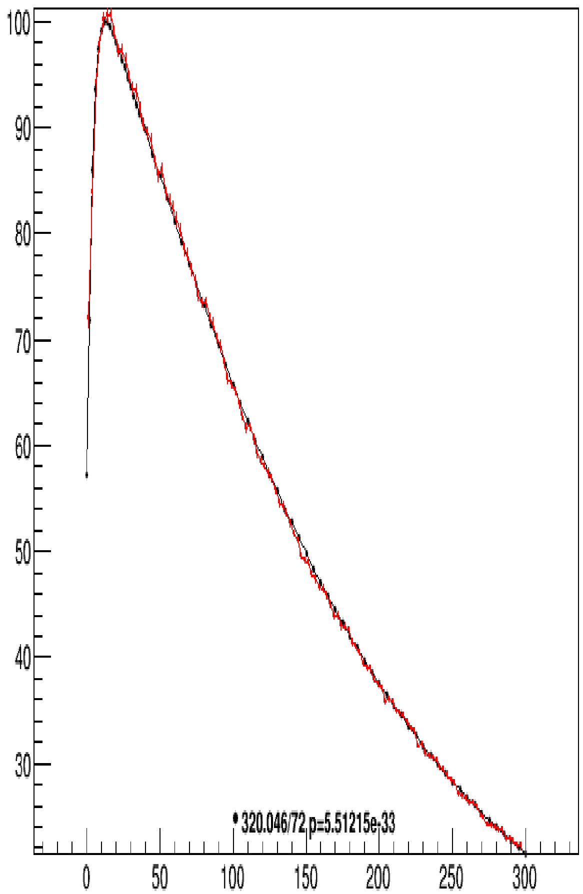
Standard 5.5 Mev



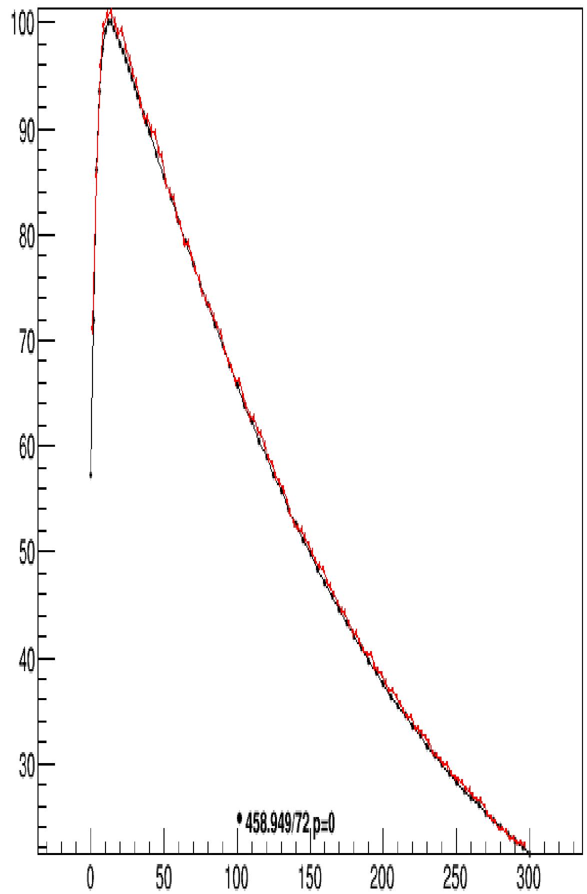
EM physics:
3 EM models: PDD 10x10 field

10x10 cm field

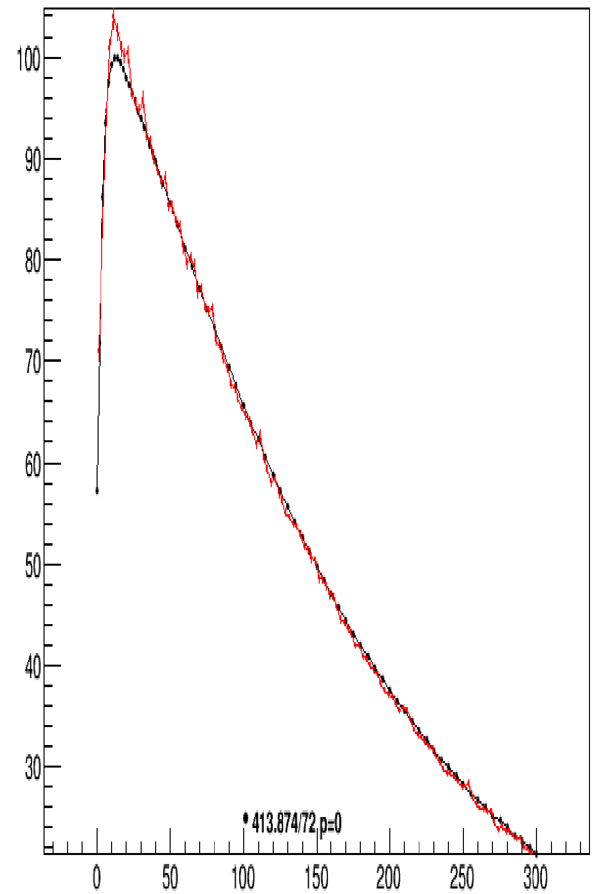
Livermore 5.75 MeV



Penelope 5.5 Mev



Standard 5.5 Mev

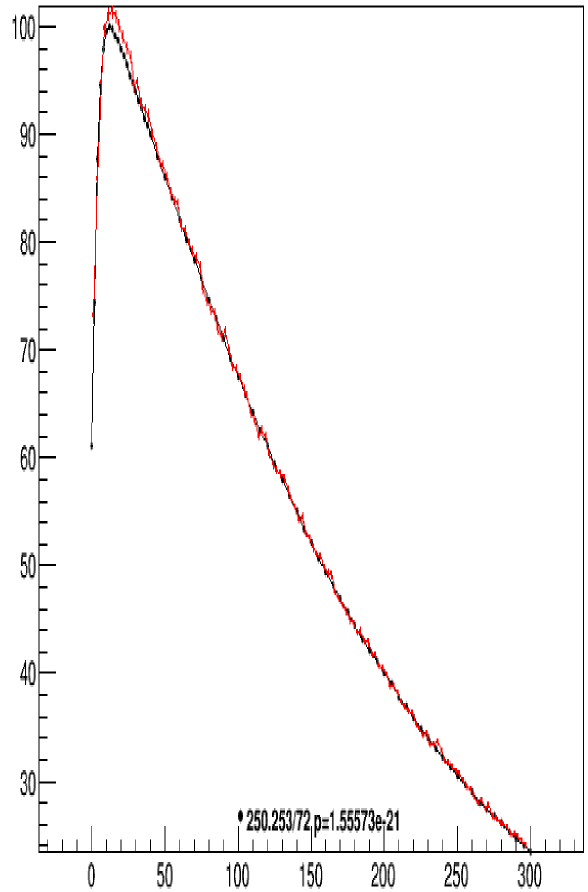


GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

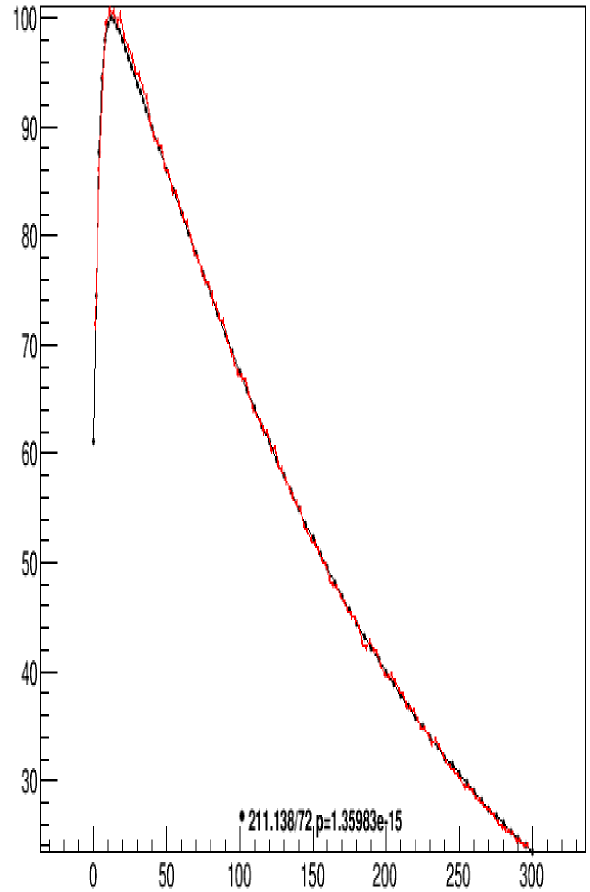
EM physics:
3 EM models: PDD 15x15 field

15x15 cm field

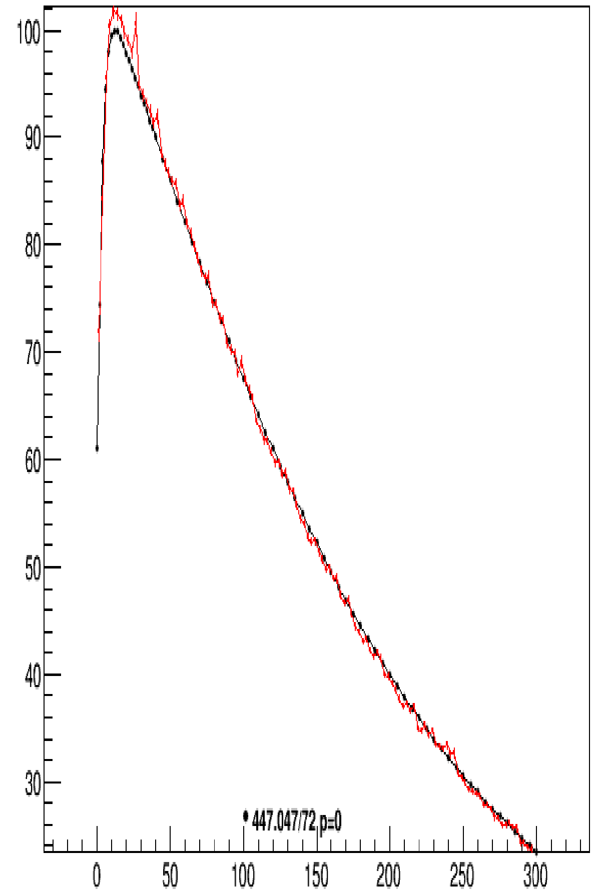
Livermore 5.75 MeV



Penelope 5.5 Mev



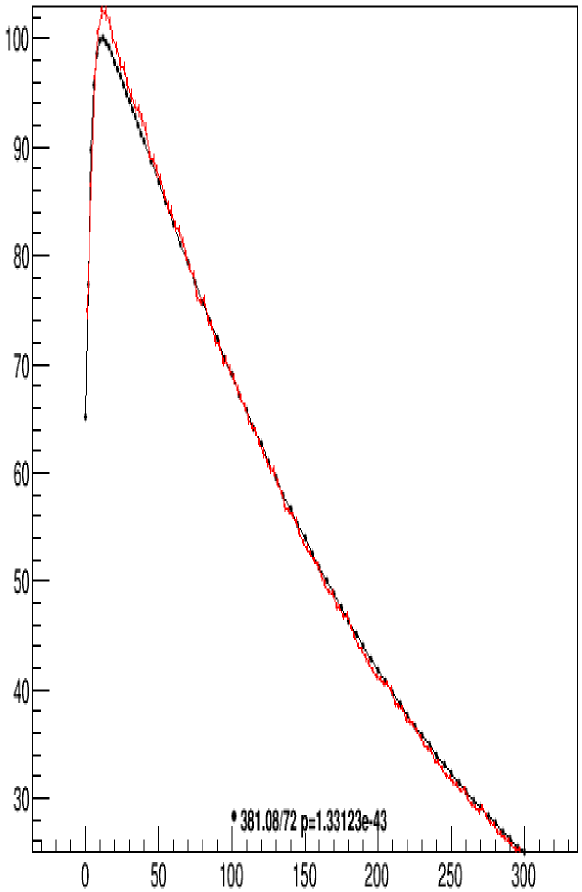
Standard 5.5 Mev



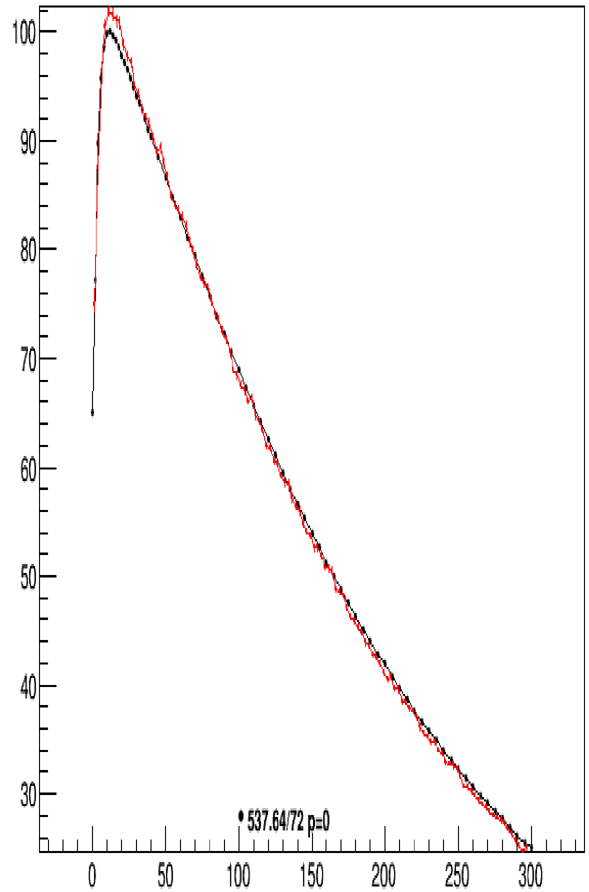
EM physics:
3 EM models: PDD 20x20 field

20x20 cm field

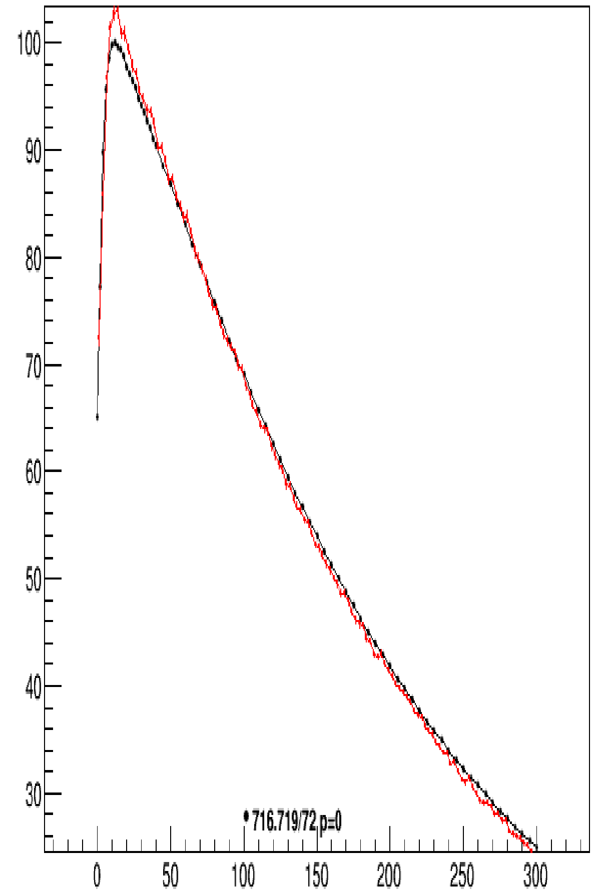
Livermore 5.75 MeV



Penelope 5.5 Mev



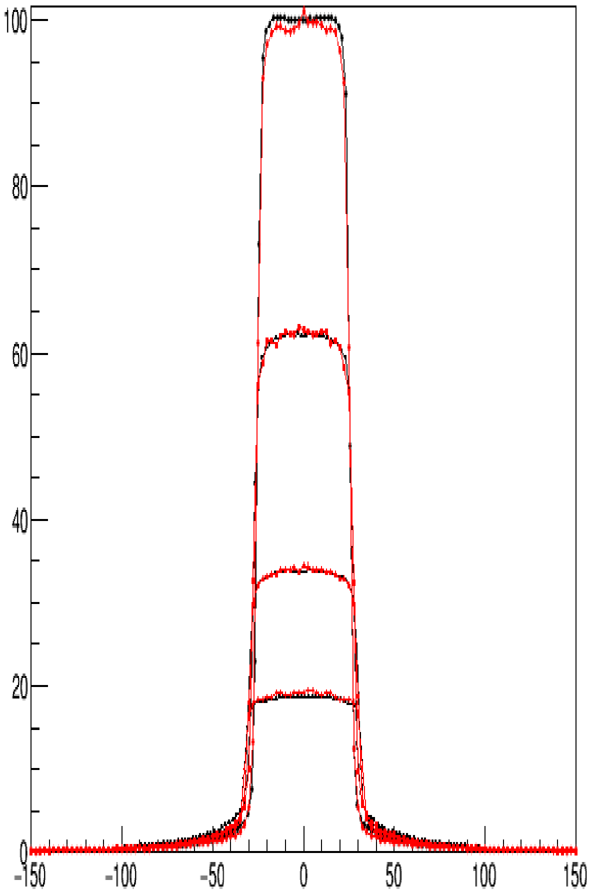
Standard 5.5 Mev



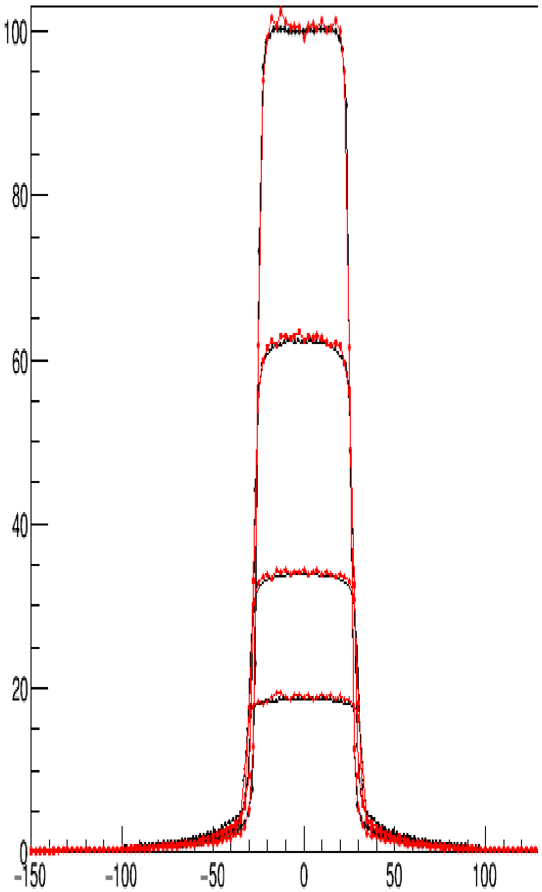
EM physics:
3 EM models: X-prof 5x5 field

5x5 cm field

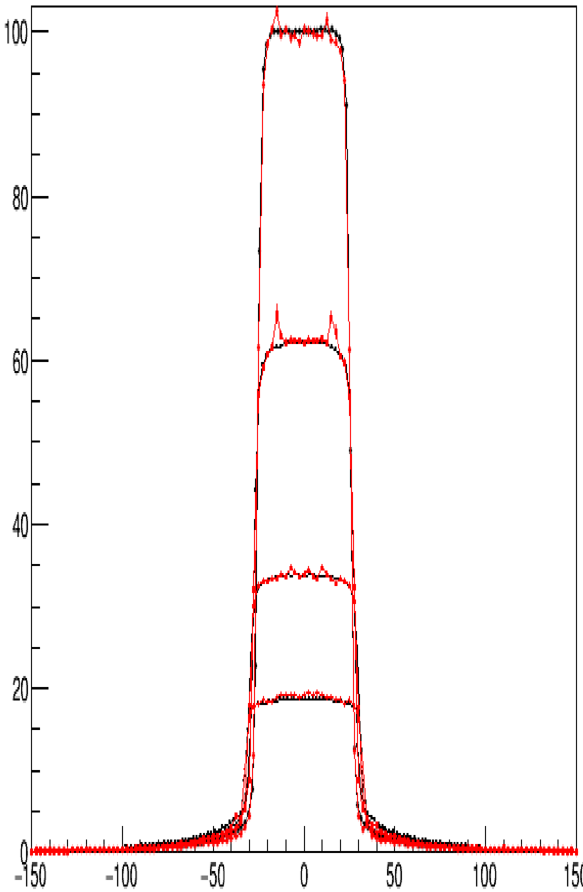
Livermore 5.75 MeV



Penelope 55. Mev



Standard 5.5 Mev

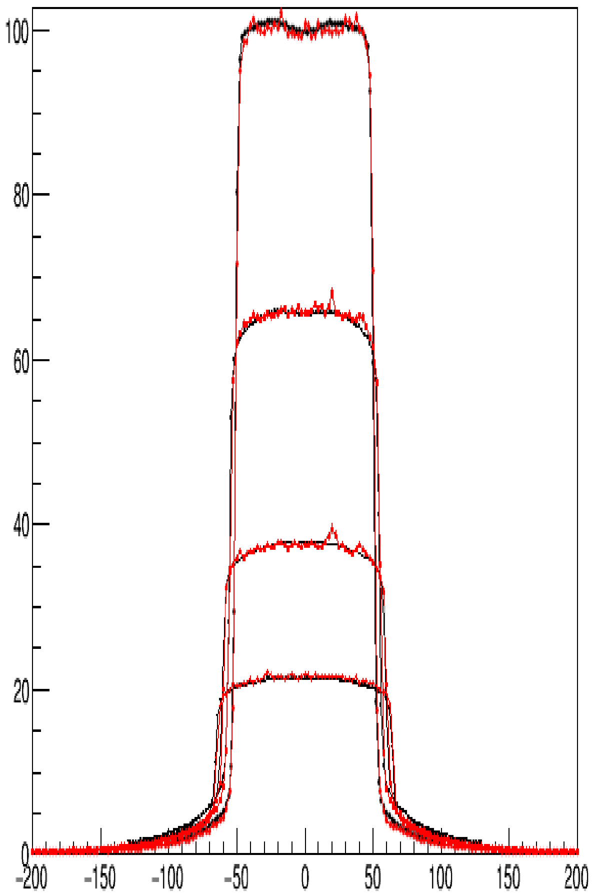


EM physics:
3 EM models: X-prof 10x10 field

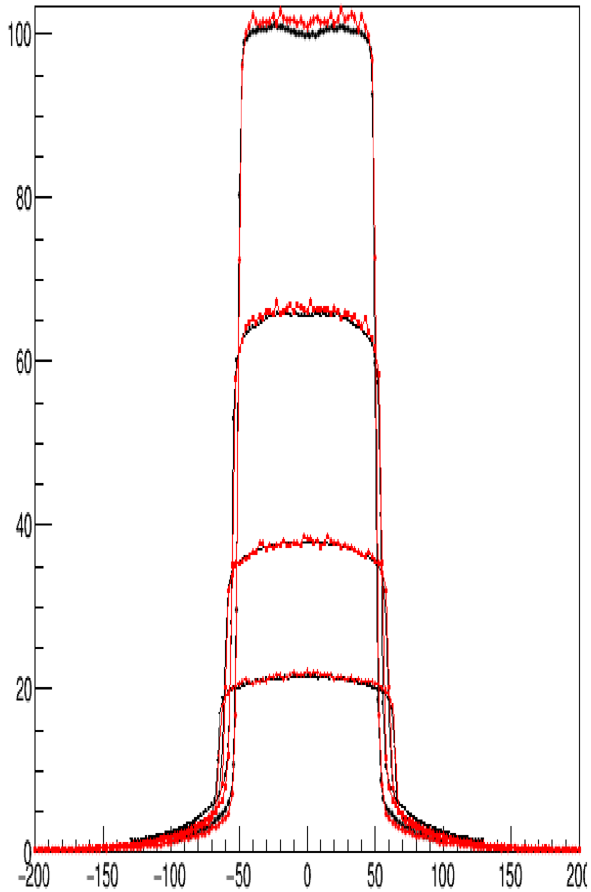
GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN | Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

10x10 cm field

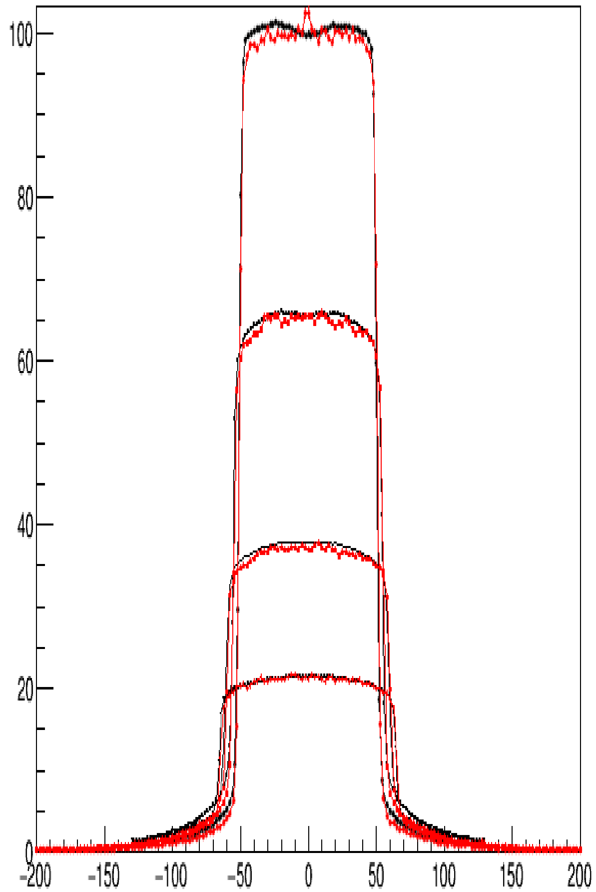
Livermore 5.75 MeV



Penelope 5.5 Mev

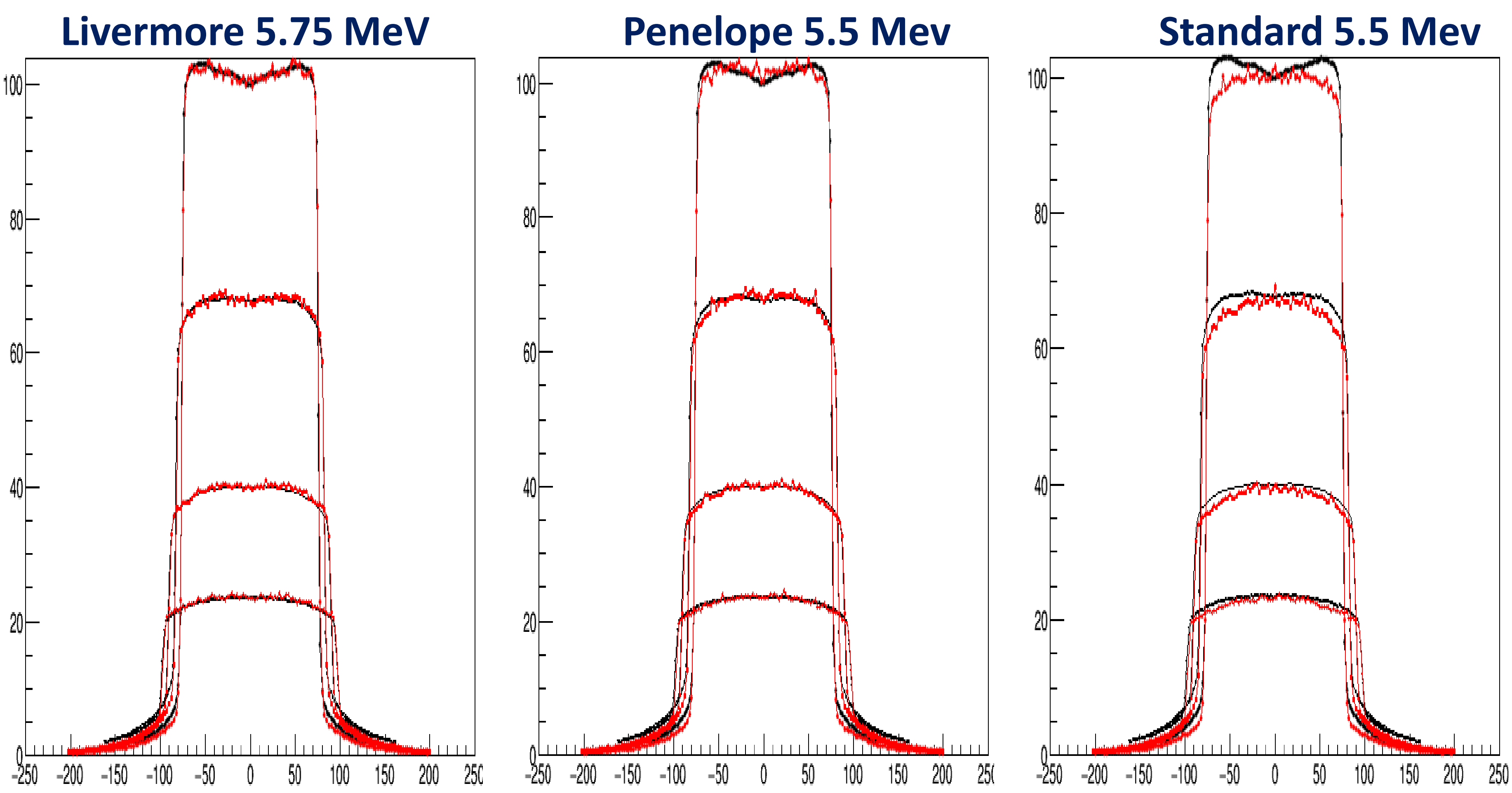


Standard 5.5 Mev



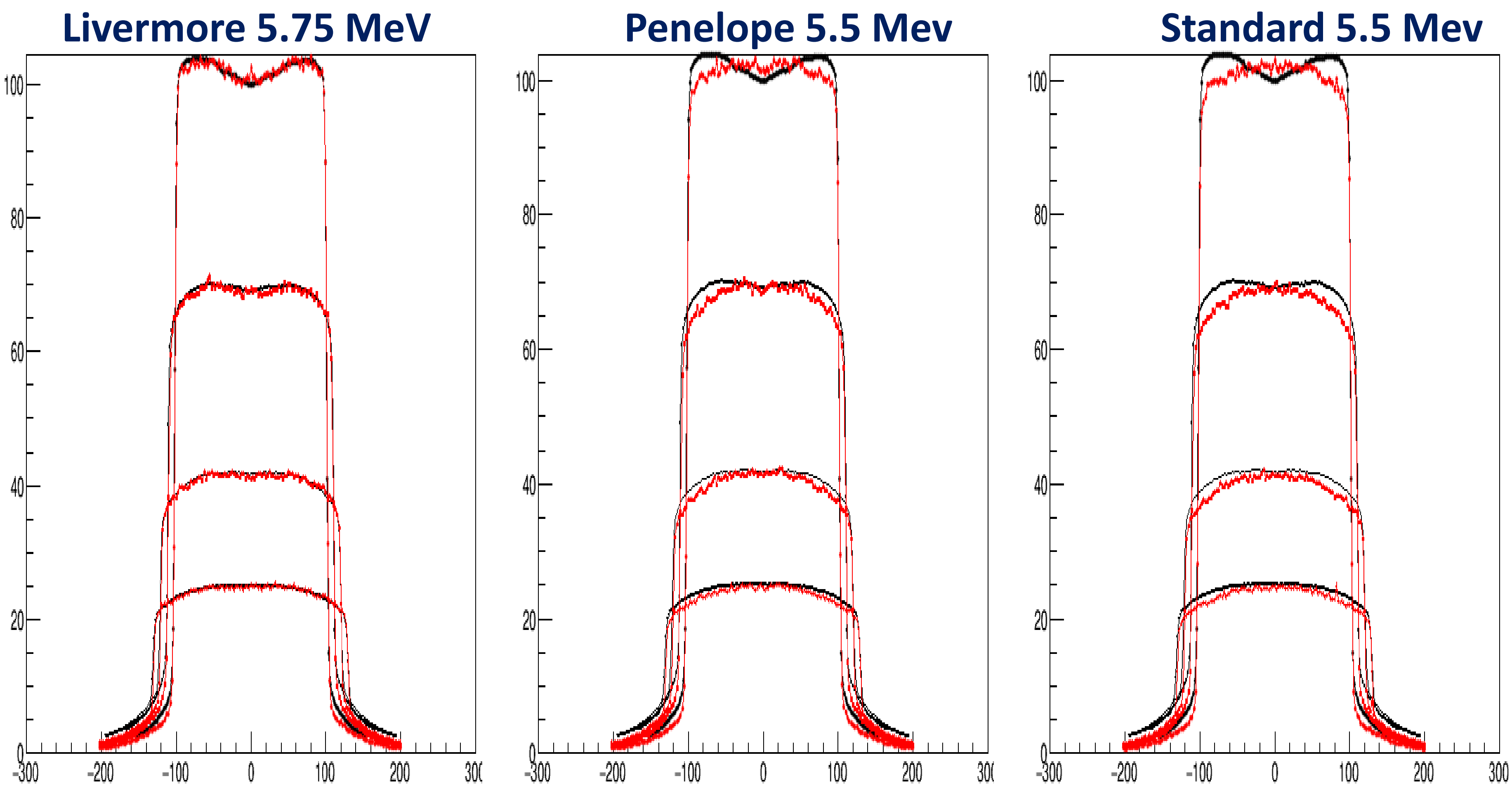
EM physics:
3 EM models: X-prof 15x15 field

15x15 cm field



EM physics:
3 EM models: X-prof 20x20 field

20x20 cm field



Conclusions

- A VARIAN 6 MeV gamma radiotherapy linac has been simulated with precision
  - PPD and X-profile experimental data at 4 fields and 4 depths have been compared with MC

- First, CPU optimization has been done
  - ✓ Geometry
  - ✓ Production cuts and user limits
  - ✓ Bremsstrahlung splitting
  - ✓ Reusing of particles that reach phantom

- **Agreement with data is reasonable**

- **Koch-Motz (specially 2BS) give much better results**

- **Livermore gives best results, Standard Slightly worse than Penelope**