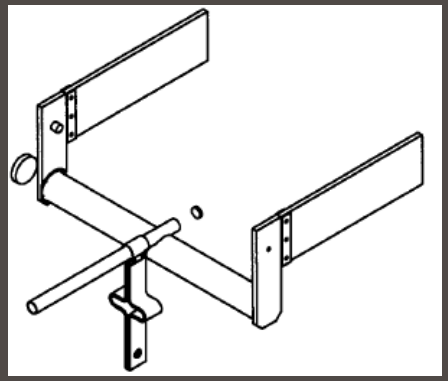
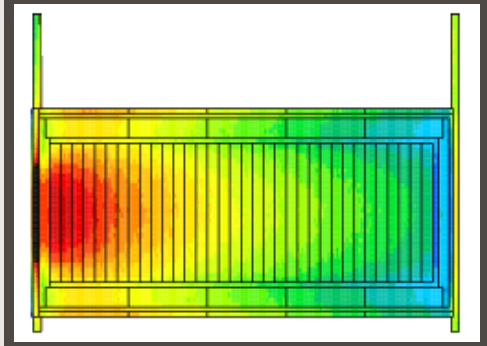




Study of Photo-Production of Radioactive Ion Beams

Nikita Bernier

2nd FLUKA advanced course and Workshop

September 15-20, 2012.

Overview

- Radioactive Ion Beams
- Photo-production of ^{8}Li
- Preliminary Tests
- FLUKA input
  - Geometry and Media
  - Primary Beam
  - Physics and Transport
  - Biasing
  - Scoring
- FLUKA results
- Further Study

Radioactive Ion Beams

Primary beam → Target → Ion source

Protons, Electrons

NiO, Nb, TaC

Surface, FEBIAD

→ Mass separator

→ Nuclear physics experiments

TRIUMF ARIEL

ADVANCED RARE ISOTOPE LABORATORY

50 MeV, 10 mA electron beam →

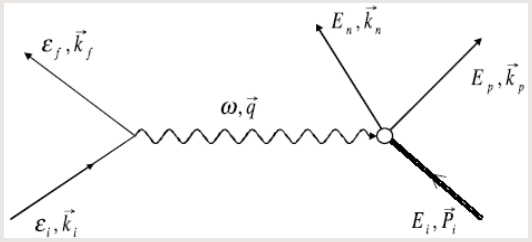
BeO pellets

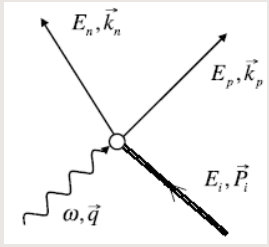
Photo-production of ^{8}Li

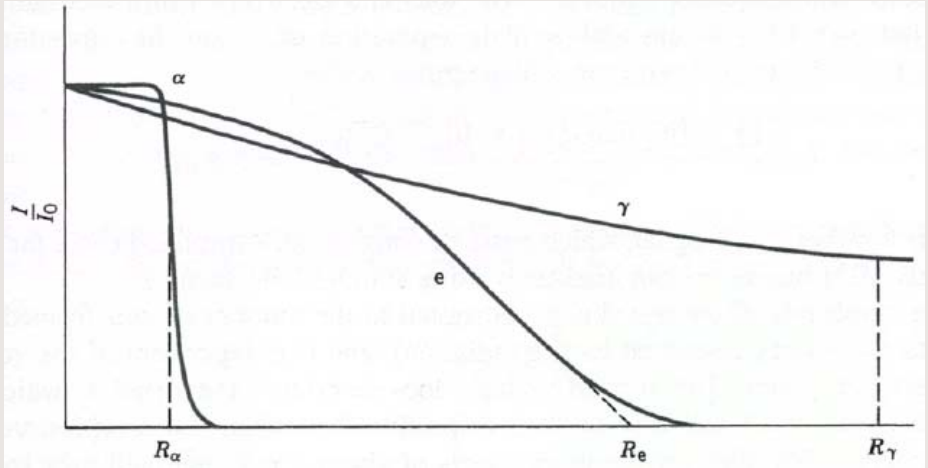
Converter [Radiator]

Primary beam → Target → Ion source

- Electrodisintegration : **^{9}Be(e,p)e'^{8}Li**
  - Without a converter
- Photodisintegration : **^{9}Be(γ,p)^{8}Li**
  - With a converter







Yuly and Mittelstaedt PhysRevC.68.014601 (2003) + Krane.

Preliminary Tests

TRIUMF ARIEL
ADVANCED RARE ISOTOPE LABORATORY

50 MeV, 10 mA, 500 kW electron beam

BeO pellets

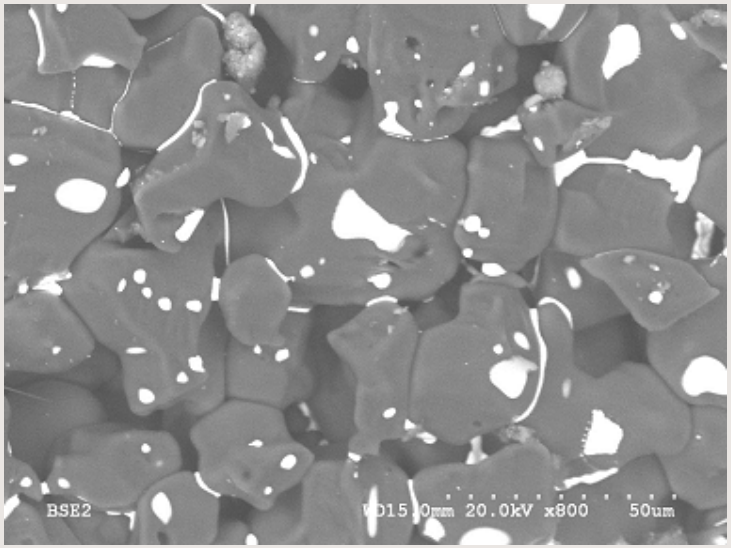
IPN ORSAY ALTO
Accélérateur Linéaire et Tandem à Orsay

50 MeV, 10 µA, 500 W electron beam

- Target Adaptation
  - Rugged enough to survive the Atlantic
  - Fits their target oven.

Target Fabrication

Porous enough to favour diffusion of light isotopes.



SEM on sintered BeO pellets (x800)

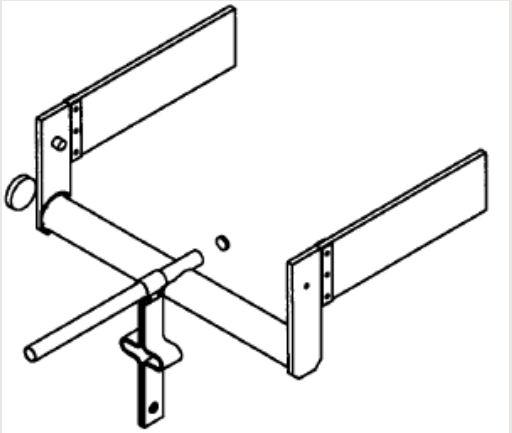
- High speed treatment of BeO powder + Binder
- Oily additive
- Pressing
- Sintering at 1600°C.

Target Components

- Target material

- BeO pellets

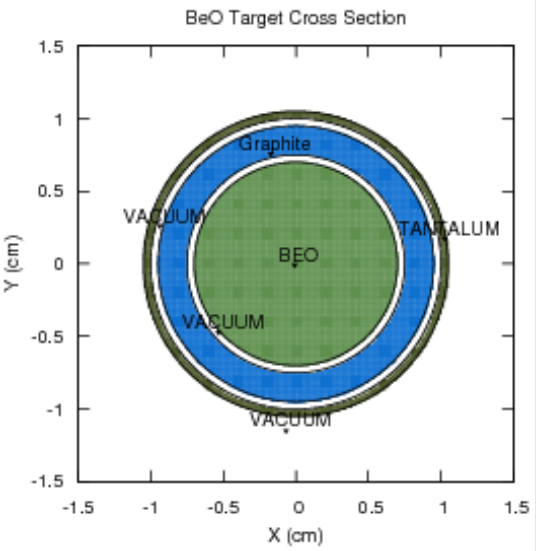
- Target oven

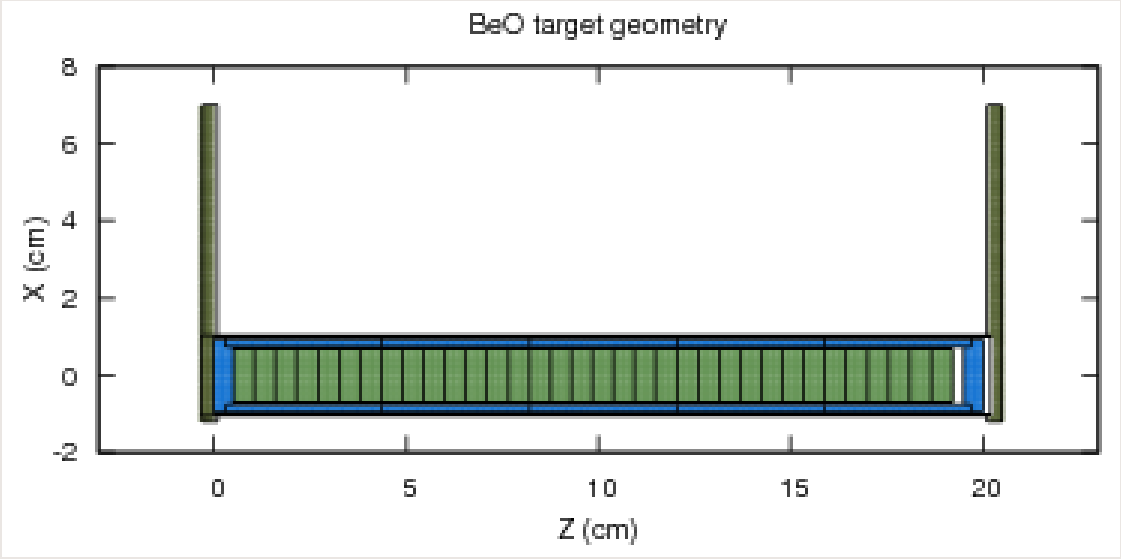


- Ta oven
- Graphite container
- Ta converter/radiator

Geometry and Media

- Using only infinite bodies : planes and cylinders. Using no parentheses.
  - Just to be on the safe side.

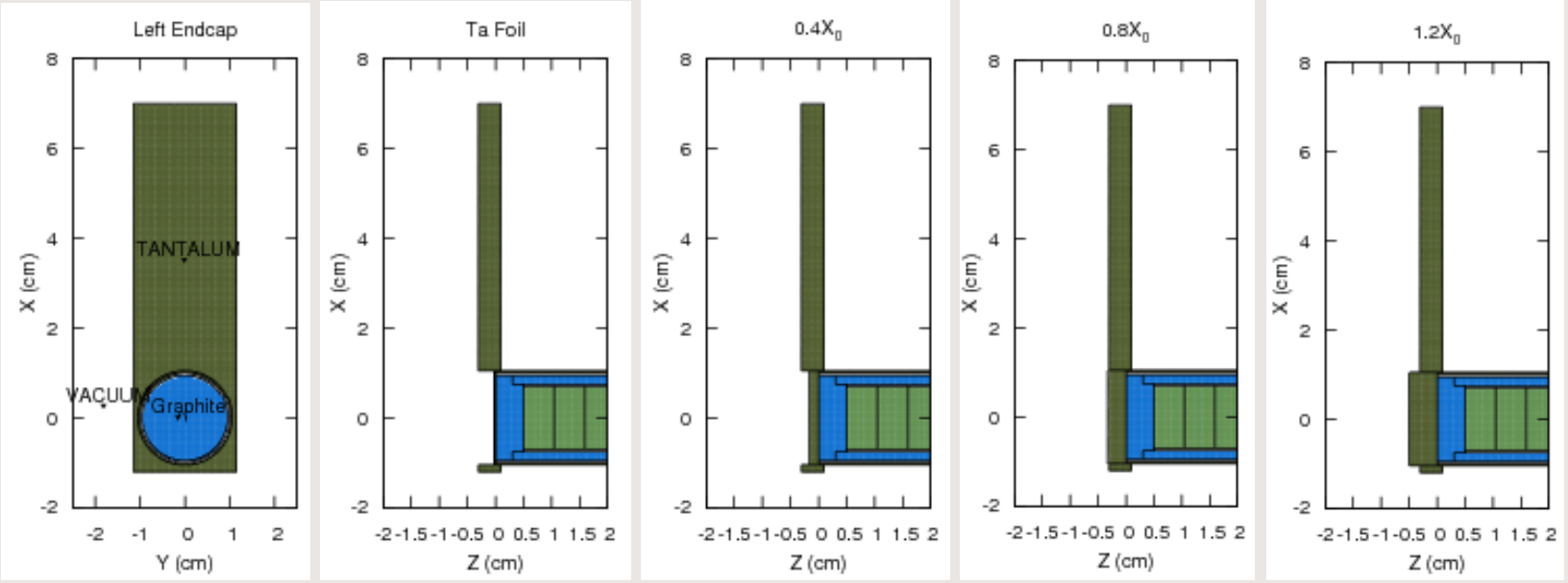




- **LOW-MAT** Mat: Graphite ▼ LowMat: C. Graphite bound nat. Carbon, 296K ▼
  - Sets the correspondence between the material and the low-energy neutron cross sections library.

Tantalum Converter

Optimization of the Ta converter thickness, in factors of the radiation length X_0 = 0.409 cm.



Multiple setups using preprocessor definitions

```
#if          Conv0.8X ▼
   CONVERTER thickness = 0.8*X0 = 0.328 cm
   XYP       encaplef                z: -0.328
#elif        Conv1.1X ▼
```

....

Primary Beam

- DEFAULTS PRECISIO ▼
  - Detailed transport of electrons, positrons and photons and more.
- Multiple runs using preprocessor cards
  - Average beam kinetic energy E : 20, 30, 40, 50 MeV

```
#define   20MeV                :
#define   30MeV                :
#define   40MeV                :
#define   50MeV                :
#if       20MeV ▼
  Define the beam characteristics :
  20 MeV e- beam (10 mA).
  BEAM                  Beam: Energy ▼   E: 0.02     Part: ELECTRON ▼
        Δp: Flat ▼              Δp: 0.01   Δϕ: Flat ▼      Δϕ: 0.01
  Shape(X): Annular ▼           Rmin:      Rmax: 0.5
#elif     30MeV ▼
  BEAM                  Beam: Energy ▼   E: 0.03     Part: ELECTRON ▼
        Δp: Flat ▼              Δp: 0.01   Δϕ: Flat ▼      Δϕ: 0.01
  Shape(X): Annular ▼           Rmin:      Rmax: 0.5
#elif     40MeV ▼
  BEAM                  Beam: Energy ▼   E: 0.04     Part: ELECTRON ▼
        Δp: Flat ▼              Δp: 0.01   Δϕ: Flat ▼      Δϕ: 0.01
  Shape(X): Annular ▼           Rmin:      Rmax: 0.5
#elif     50MeV ▼
  BEAM                  Beam: Energy ▼   E: 0.05     Part: ELECTRON ▼
        Δp: Flat ▼              Δp: 0.01   Δϕ: Flat ▼      Δϕ: 0.01
  Shape(X): Annular ▼           Rmin:      Rmax: 0.5
#endif
```

Physics and Transport

- Activates gamma interactions with nuclei
  PHOTONUC Type: ▼ All E: On ▼
  E>0.7GeV off ▼ Δ resonance off ▼ Quasi D off ▼ Giant Dipole off ▼
  Mat: VACUUM ▼ to Mat: @LASTMAT ▼ Step:

- **PHYSICS** Type: COALESCE ▼ Activate On ▼
  PHYSICS Type: EVAPORAT ▼ Model: New Evap with heavy frag ▼
  - Emission of fast complex particles
  - Residual nuclei production.

- Set production threshold for e+, e- to 50 keV and photon to 10 keV in all materials.
  EMFCUT Type: PROD-CUT ▼
  e-e+ Threshold: Kinetic ▼ e-e+ Ekin: 5e-05 γ: 0.00001
  Fudgem: Mat: VACUUM ▼ to Mat: @LASTMAT ▼ Step:
  Set transport threshold for e+, e- to 50 keV and photon to 10 keV in all regions.
  EMFCUT Type: ▼
  e-e+ Threshold: Kinetic ▼ e-e+ Ekin: 5e-05 γ: 0.00001
  Old bremss.: off ▼ Bremsstrahlung: off ▼ Pair Prod.: off ▼ e+ ann @rest: off ▼
  Compton: off ▼ Bhabha&Moller: off ▼ Photo-electric: off ▼ e+ ann @flight: off ▼
  Reg: VOID ▼ to Reg: @LASTREG ▼ Step:
  - Recommended to be equal.

Biasing

- Bias the decay length of unstable particles.
  LAM-BIAS Type: ▼ × mean life: × λ inelastic: 0.02
  Mat: ▼ Part: PHOTON ▼ to Part: ▼ Step:
  - Increases the probability of gamma interactions.

- Leading particle biasing.
  EMF-BIAS Type: LPBEMF ▼ Ethr e-e+: Ethr γ:
  Old bremss.: off ▼ Bremsstrahlung: On ▼ Pair Prod.: On ▼ e+ ann @rest: On ▼
  Compton: On ▼ Bhabha&Moller: On ▼ Photo-electric: On ▼ e+ ann @flight: On ▼
  Reg: VOID ▼ to Reg: @LASTREG ▼ Step:

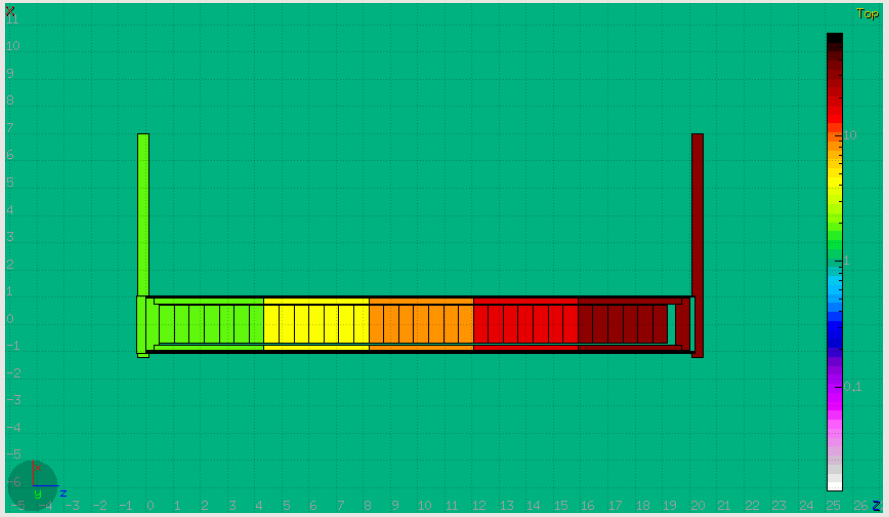
- Region importance biasing

#define Flag_BIAS :
#if Flag_BIAS ▼
Increasing region importances through target by factors of two.
Importance 2 : 2 regions + 7 pellets + 2 endcaps + 1 converter
BIASING Type: All particles ▼ RR: 1.0 Imp: 2.0
Opt: ▼ Reg: ENDCAPL ▼ to Reg: ▼ Step:

. . . .

Importance 4 : 2 regions + 7 pellets
BIASING Type: All particles ▼ RR: 1.0 Imp: 4.0
Opt: ▼ Reg: OUTCYL2 ▼ to Reg: ▼ Step:

. . . .



Activation and Residual Nuclei

- Activation
  RADDECAY
  Decay: Active ▼ | Patch Isom: On ▼ | Replicas: 3.0
  h/μ Int: ignore ▼ | h/μ LPB: ignore ▼ | h/μ WW: ignore ▼ | e-e+ Int: ignore ▼
  e-e+ LPB: ignore ▼ | e-e+ WW: ignore ▼ | Low-n Bias: ignore ▼ | Low-n WW: ignore ▼
  decay cut: 10.0 | prompt cut: 10.0 | Coulomb corr: ▼
  - Request decay of produced radioactive nuclides.
- Definition of irradiation profile : 10 days 10 mA = 6.24146E16 part/s
  IRRPROFI
  Δt: =10*day p/s: 6.2415E16
  Δt: p/s:
  Δt: p/s:
- Definition of decay times
  DCYTIMES
  t1: =-5*day | t2: 0.0 | t3: =5*day
  t4: =10*day | t5: =20*day | t6: =1*month
  - Requested with DCYSCORE.
- Production rate in nuclei/primary
  RESNUCLE
  Type: All ▼ | Unit: 54 BIN ▼ | Name: ResNuc_0
  Max Z: | Max M: | Reg: @ALLREGS ▼ | Vol: 1.0

  Residual Nuclei after 5 days of cooling
  DCYSCORE
  Cooling t: =5*day ▼ | Kind: RESNUCLE ▼
  Det: ResNuc_5 ▼ | to Det: ▼ | Step:

  RESNUCLE
  Type: All ▼ | Unit: 55 BIN ▼ | Name: ResNuc_5
  Max Z: | Max M: | Reg: @ALLREGS ▼ | Vol: 1.0
  - Given in [Bq/cm³] when linked to DCYSCORE.

Scoring with USRBIN

- Beam particules in beam particle/cm²/primary
  USRBIN
  Type: X-Y-Z ▼ Part: BEAMPART ▼
  Xmin: -2.0 Ymin: -2.0 Zmin: -2.0
  Xmax: 2.0 Ymax: 2.0 Zmax: 22.0
  Unit: 51 BIN ▼
  Name: BeamPart NX: 80. NY: 80. NZ: 240.
  - Confirms the beam is hitting the target.

- Cooling time for all detectors
  DCYSCORE
  Cooling t: 0.0 ▼ Det: EneDep ▼
  Kind: USRBIN ▼ to Det: AllDose_0 ▼ Step:

  Dose conversion coefficients for all detectors
  AUXSCORE
  Type: USRBIN ▼ Det: EneDep ▼
  Part: ALL-PART ▼ to Det: AllDose_5 ▼
  Se: EWT74 ▼ Step:

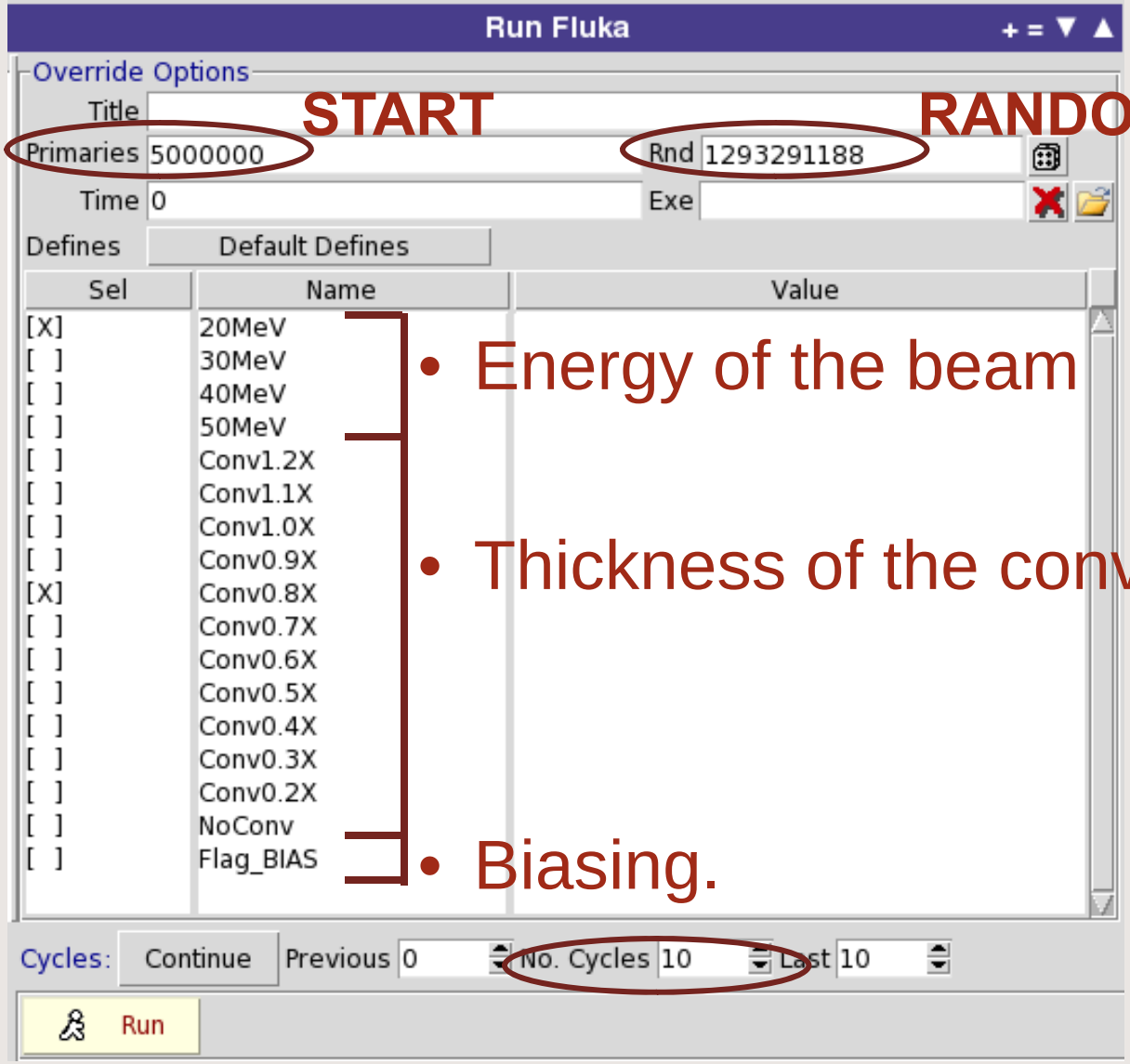
  Energy deposition in GeV/cm³/primary
  USRBIN
  Type: X-Y-Z ▼ Part: ENERGY ▼
  Xmin: -2.0 Ymin: -2.0 Zmin: -2.0
  Xmax: 2.0 Ymax: 2.0 Zmax: 22.0
  Unit: 52 BIN ▼
  Name: EneDep NX: 80. NY: 80. NZ: 240.

- Equivalent dose at 1 meter from all particules in pSv/s
  USRBIN
  Type: X-Y-Z ▼ Part: DOSE-EQ ▼
  Xmin: -50.0 Ymin: -50.0 Zmin: -50.0
  Xmax: 50.0 Ymax: 50.0 Zmax: 50.0
  Unit: 53 BIN ▼
  Name: AllDose_0 NX: 50.0 NY: 50.0 NZ: 50.0

  DCYSCORE
  Cooling t: =5*day ▼ Det: AllDose_5 ▼
  Kind: USRBIN ▼ to Det: ▼ Step:

  Equivalent dose at 1 meter after 5 days of cooling in pSv/s
  USRBIN
  Type: X-Y-Z ▼ Part: DOSE-EQ ▼
  Xmin: -50.0 Ymin: -50.0 Zmin: -50.0
  Xmax: 50.0 Ymax: 50.0 Zmax: 50.0
  Unit: 58 BIN ▼
  Name: AllDose_5 NX: 50.0 NY: 50.0 NZ: 50.0
  - Given in [pSv/primary] when not linked to IRRPROFI.

Run Fluka



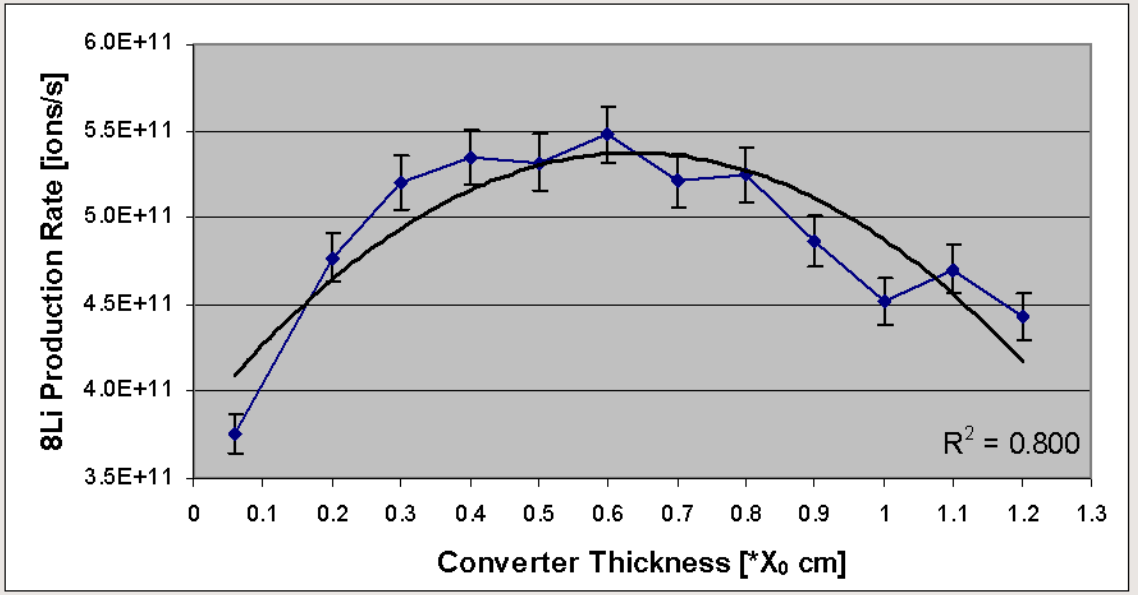
- Energy of the beam
- Thickness of the converter
- Biasing.

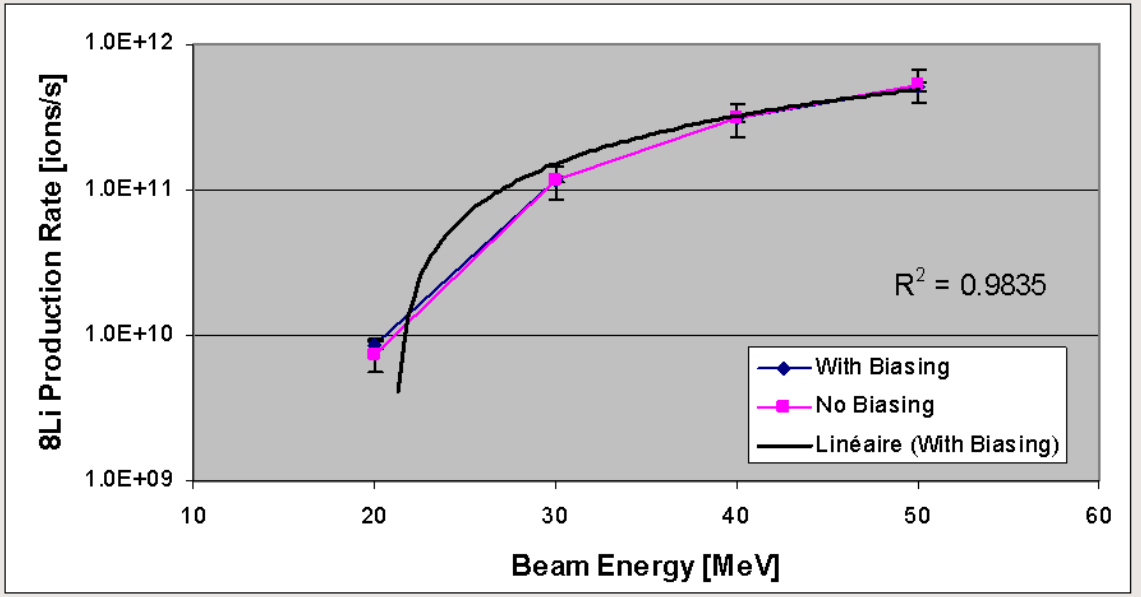
- Different random number seed for each run.

^{8}Li Production Rate

- For a 50 MeV e- beam.

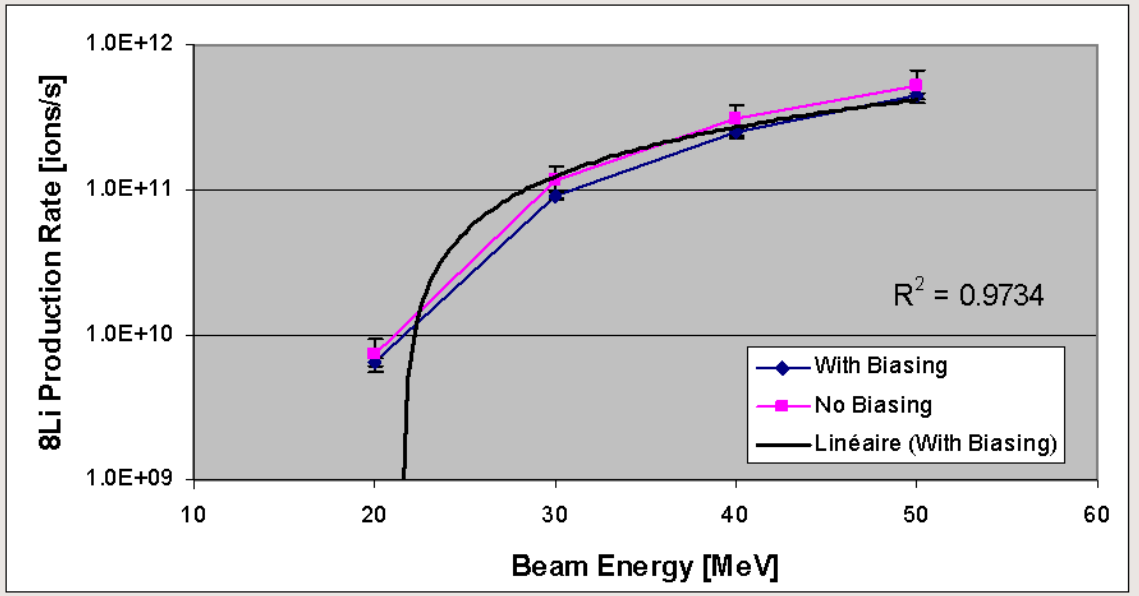
- For a 0.8X_0 (0.328 cm) converter.

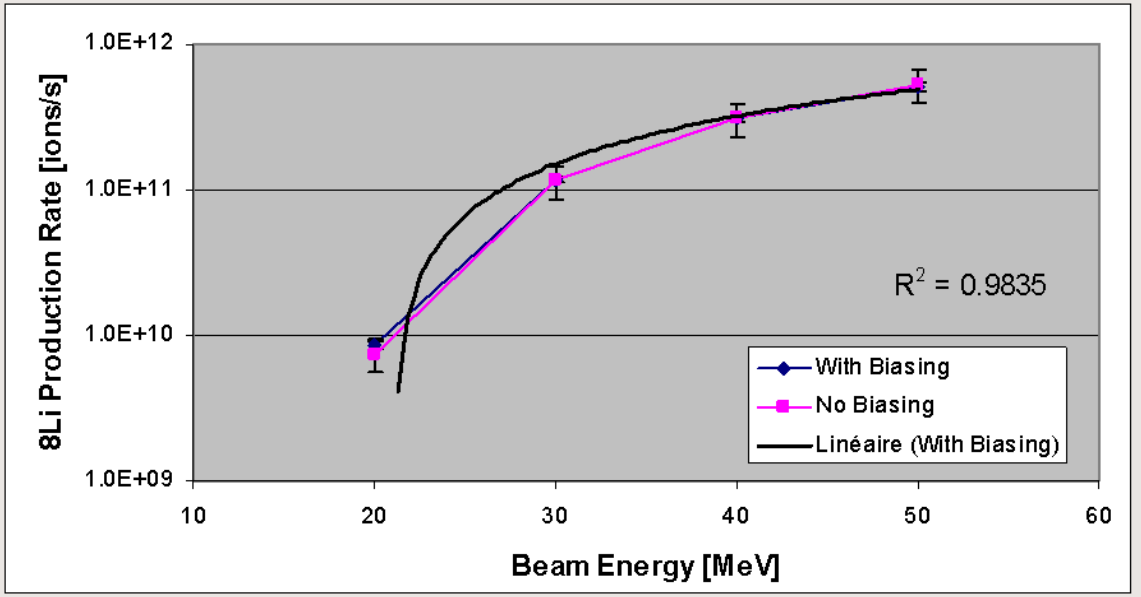




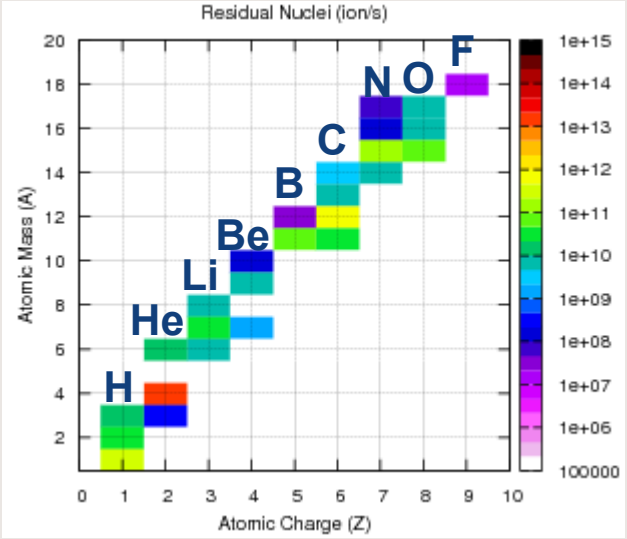
^{8}Li Production Rate

- For 2^{E}06 primaries.
- For 50^{E}06 primaries.

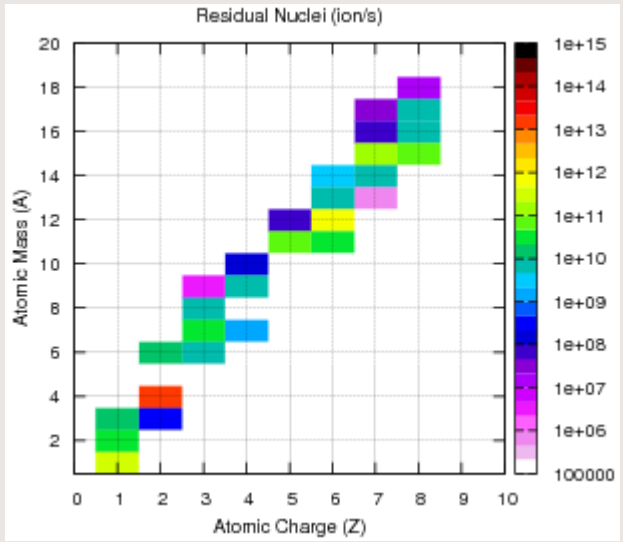




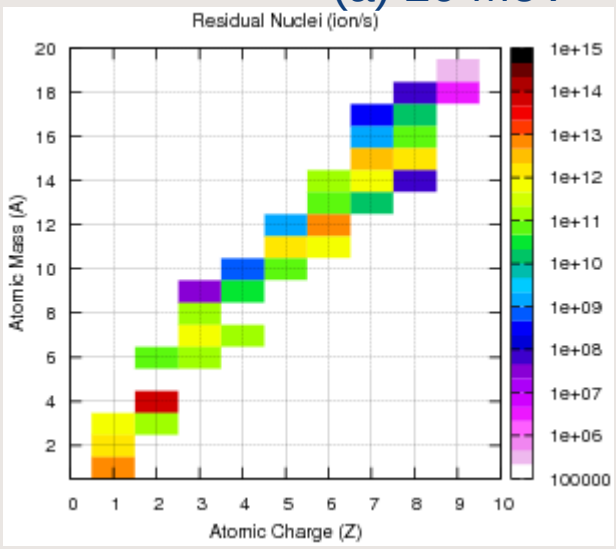
Production Rates Summary



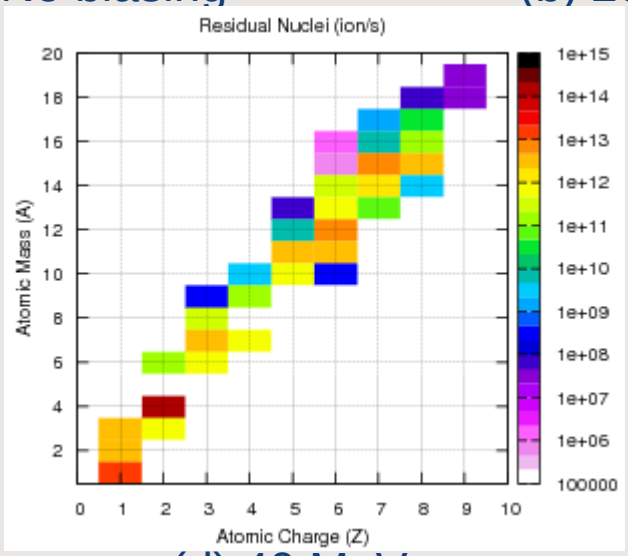
(a) 20 MeV – No biasing



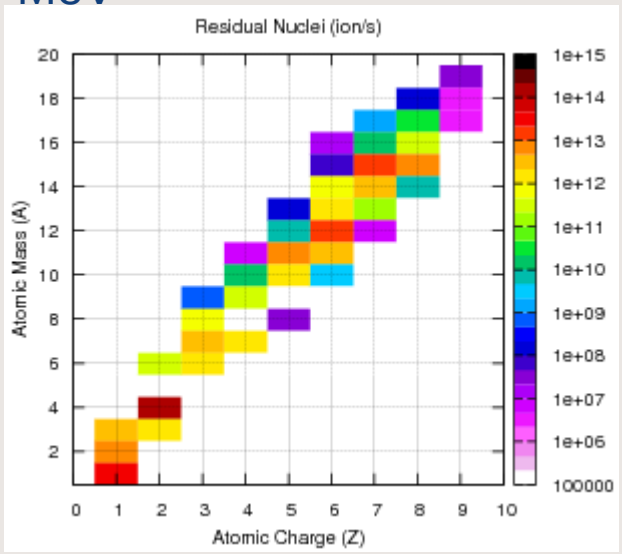
(b) 20 MeV



(c) 30 MeV

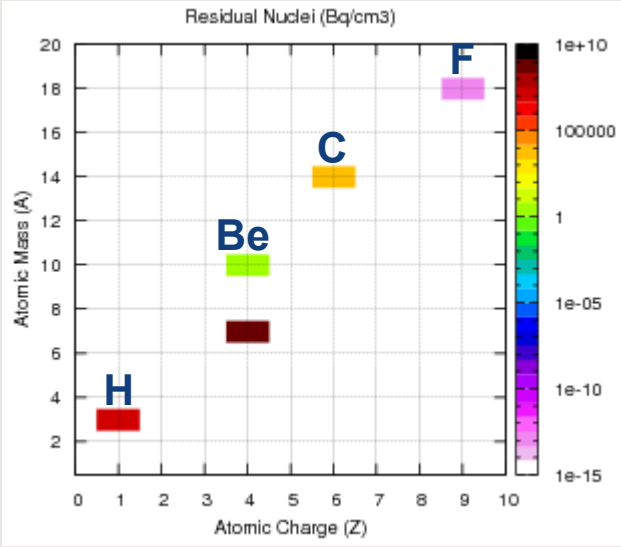


(d) 40 MeV

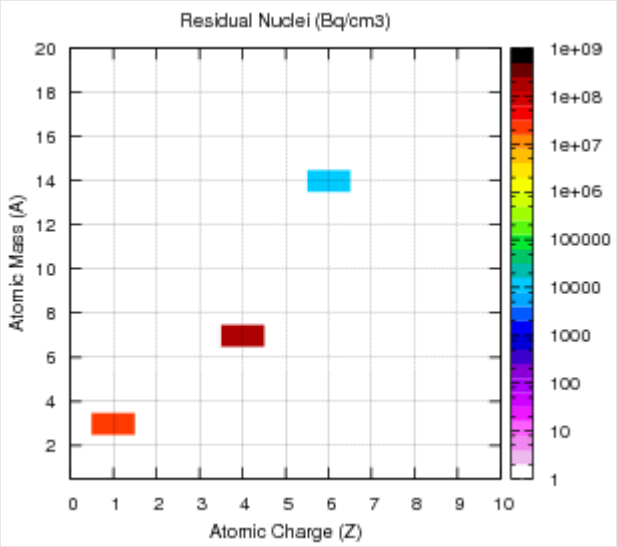


(e) 50 MeV

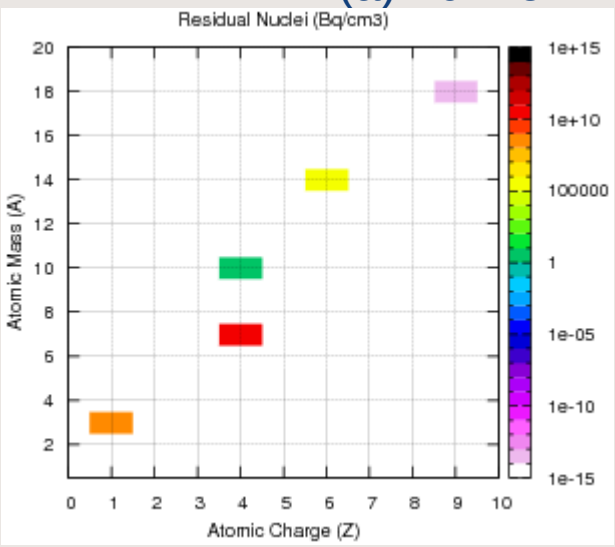
Residual Nuclei after 5 days



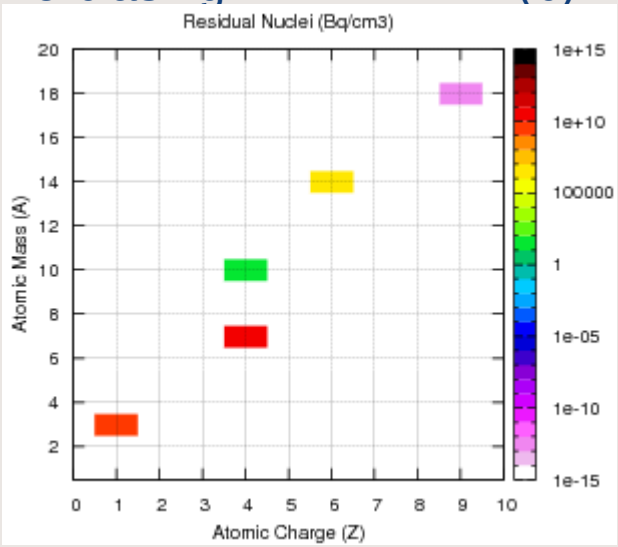
(a) 20 MeV – No biasing



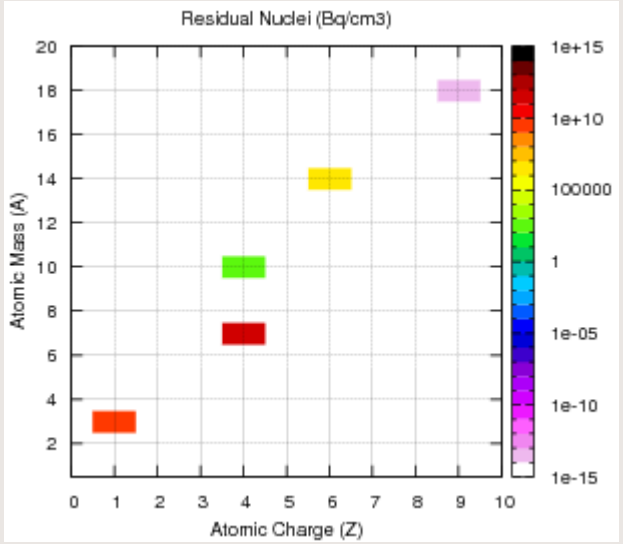
(b) 20 MeV



(c) 30 MeV

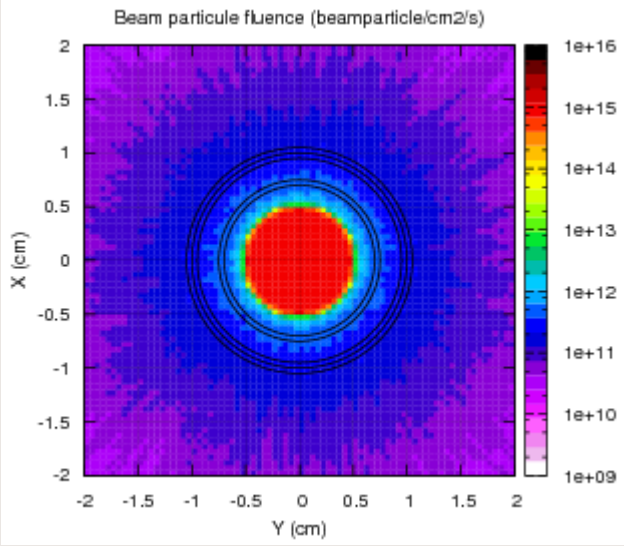


(d) 40 MeV

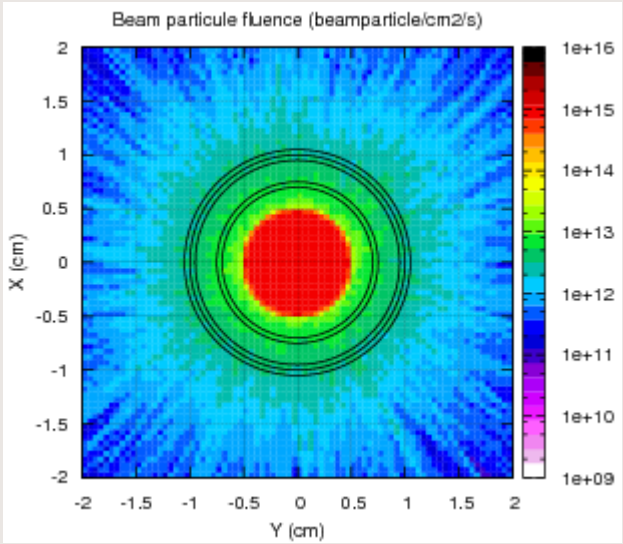


(e) 50 MeV

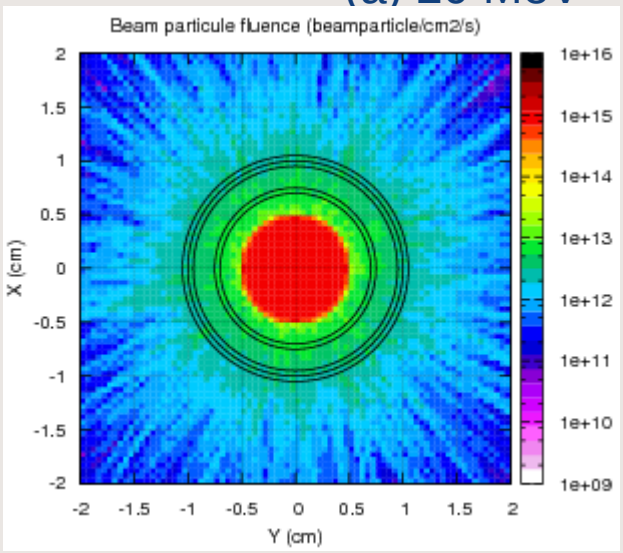
Beam Particle Fluence



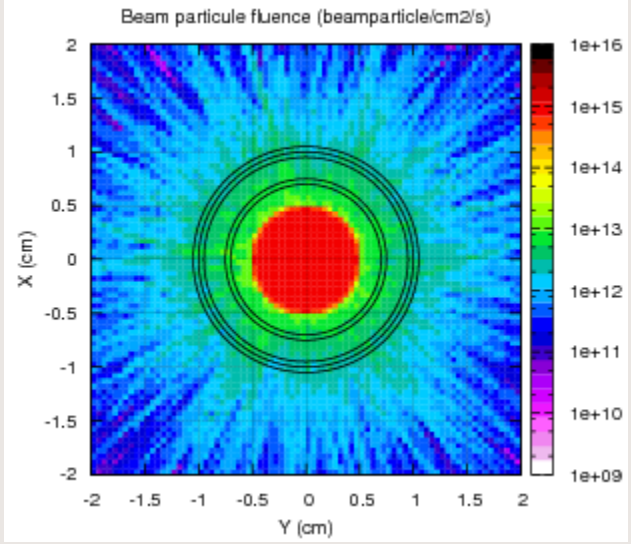
(a) 20 MeV – No biasing



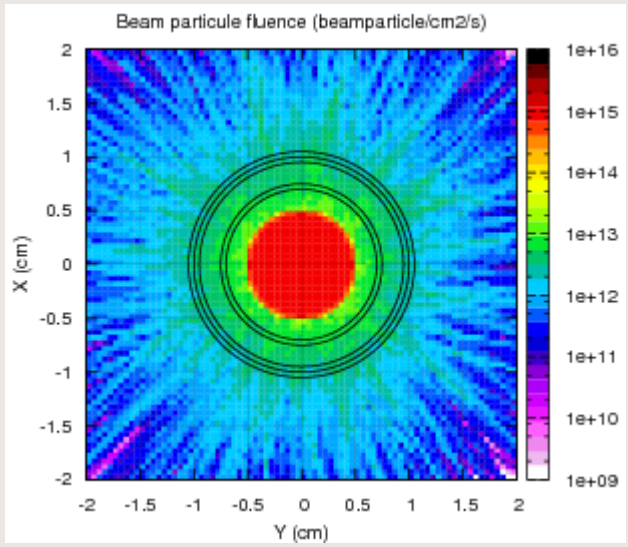
(b) 20 MeV



(c) 30 MeV

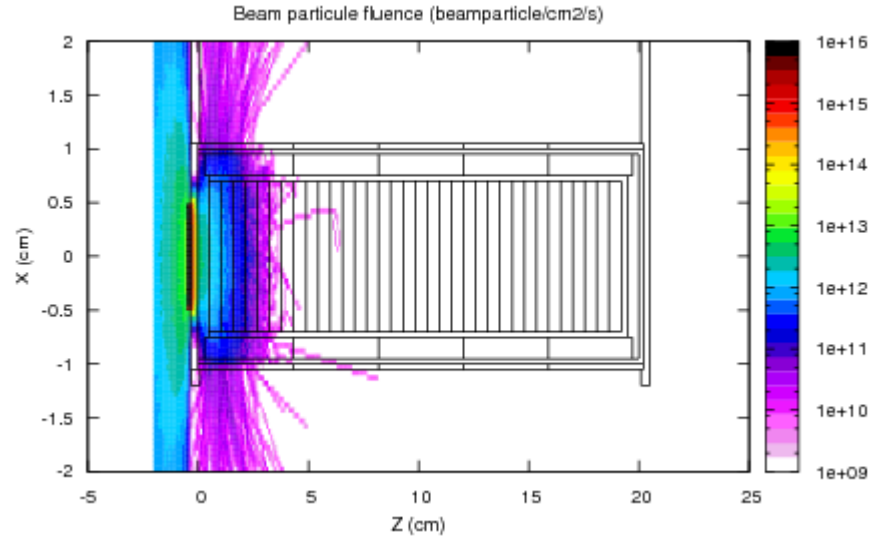


(d) 40 MeV

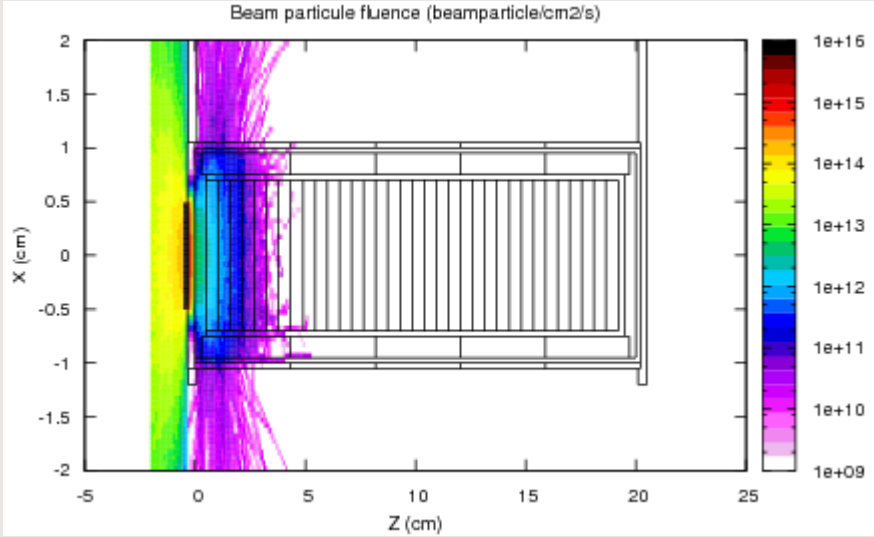


(e) 50 MeV

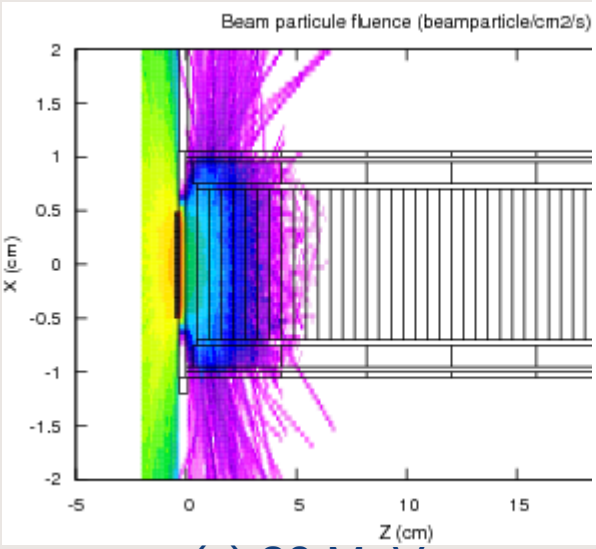
Beam Particle Fluence



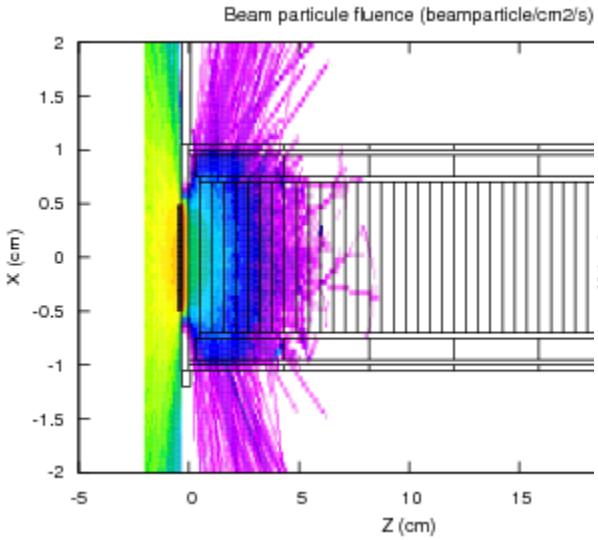
(a) 20 MeV – No biasing



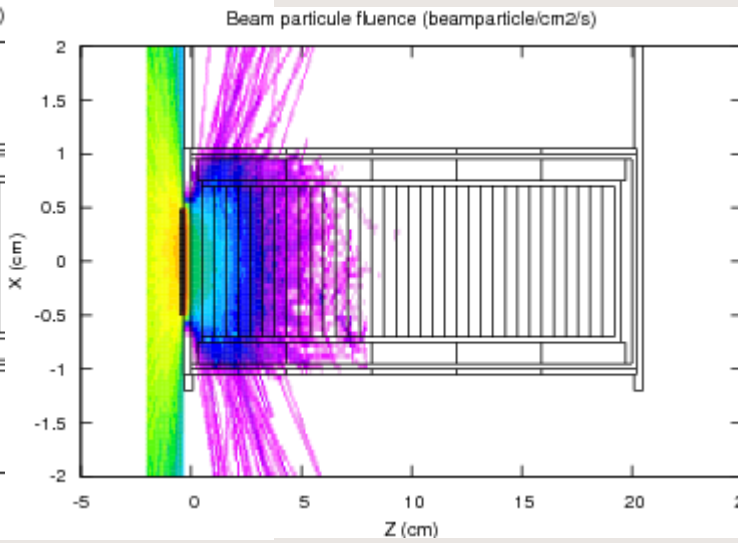
(b) 20 MeV



(c) 30 MeV

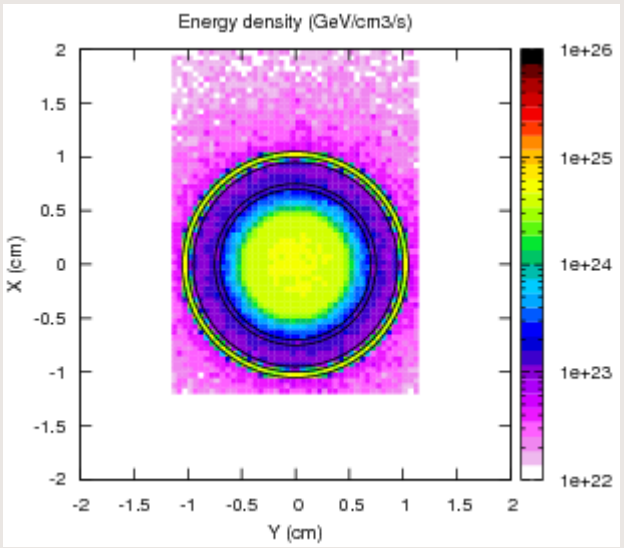


(d) 40 MeV

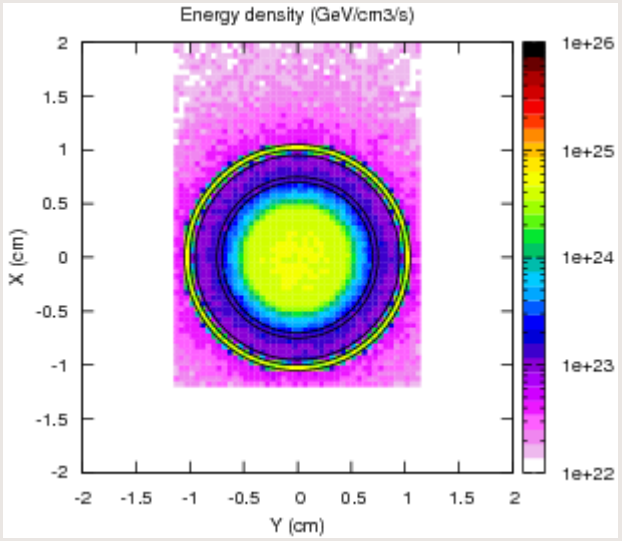


(e) 50 MeV

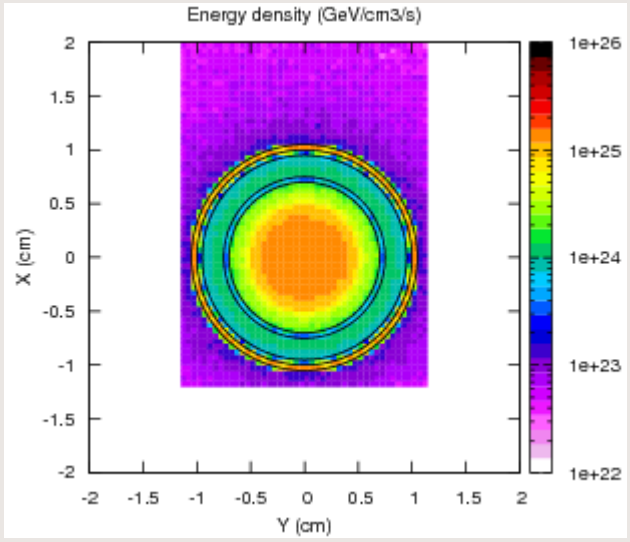
Energy Density



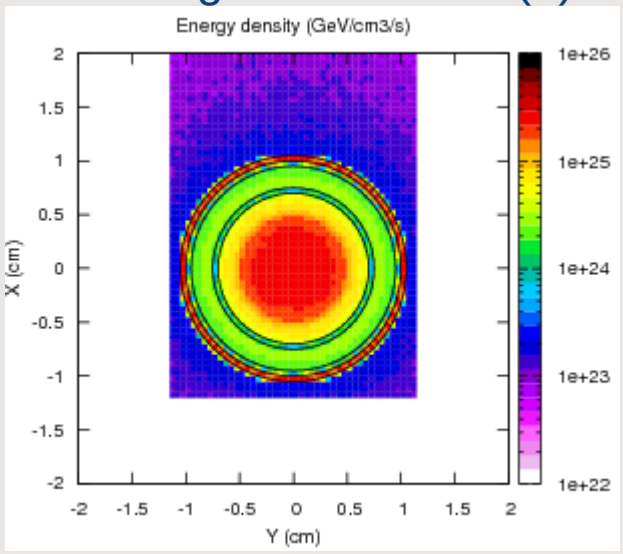
(a) 20 MeV – No biasing



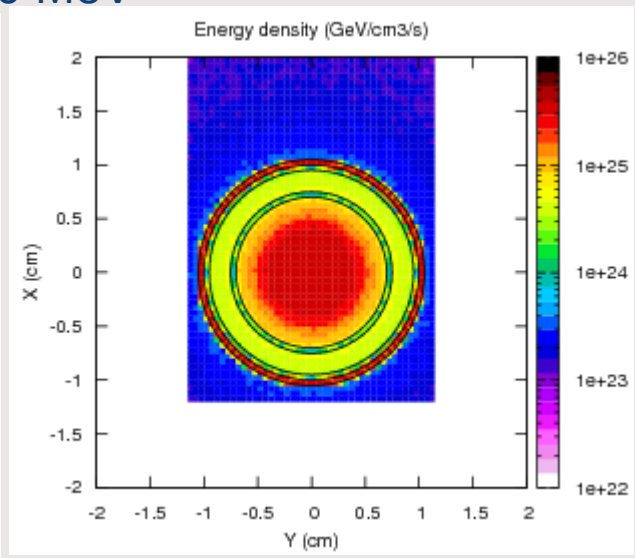
(b) 20 MeV



(c) 30 MeV

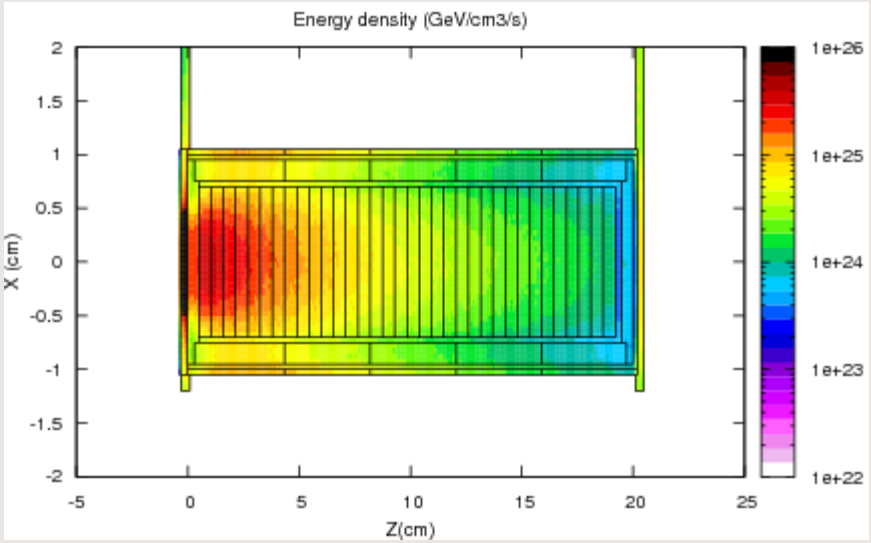


(d) 40 MeV

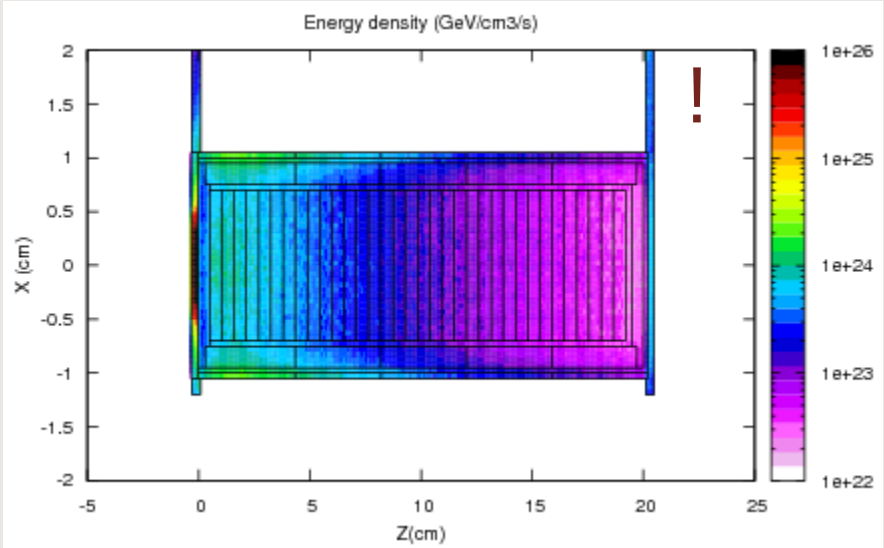


(e) 50 MeV

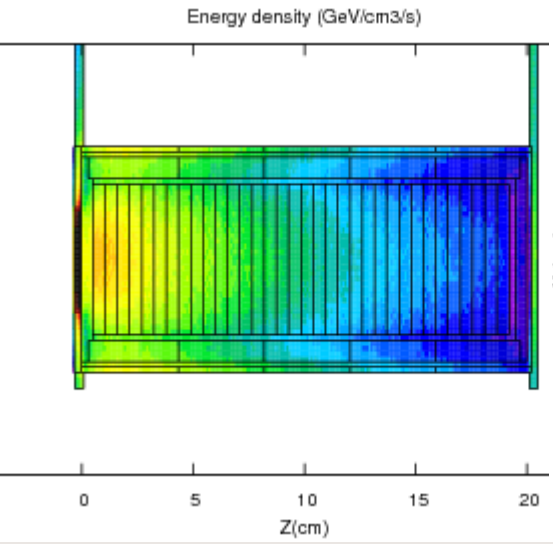
Energy Density



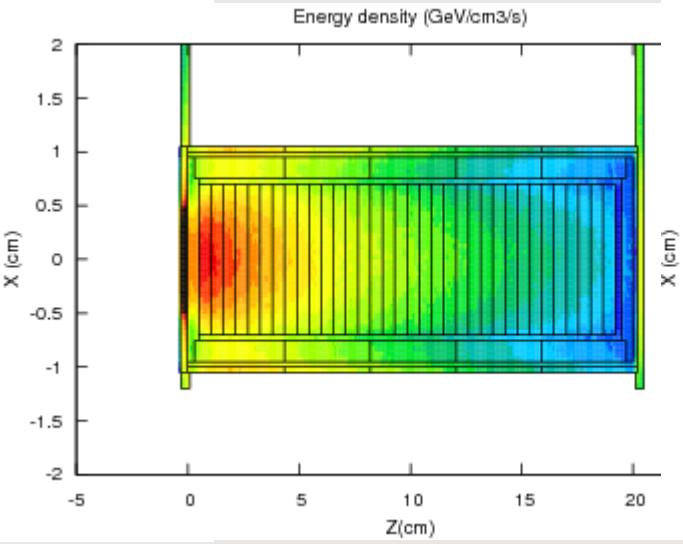
(a) 20 MeV – No biasing



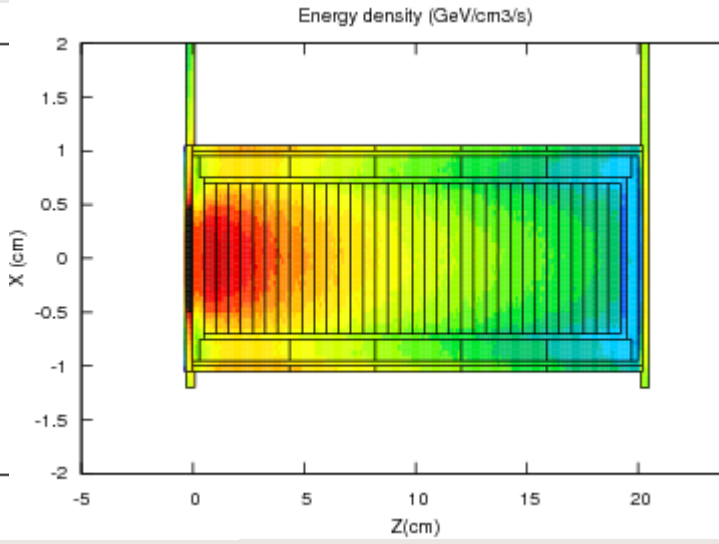
(b) 20 MeV



(c) 30 MeV

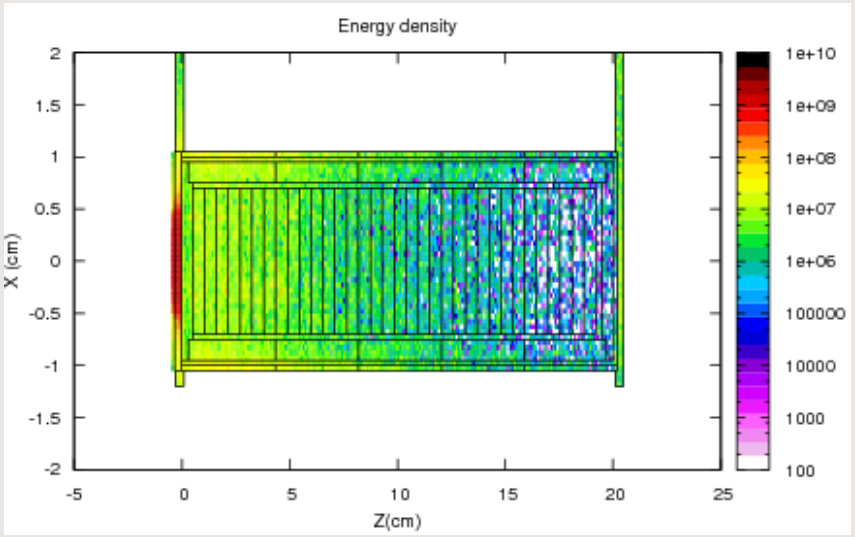


(d) 40 MeV

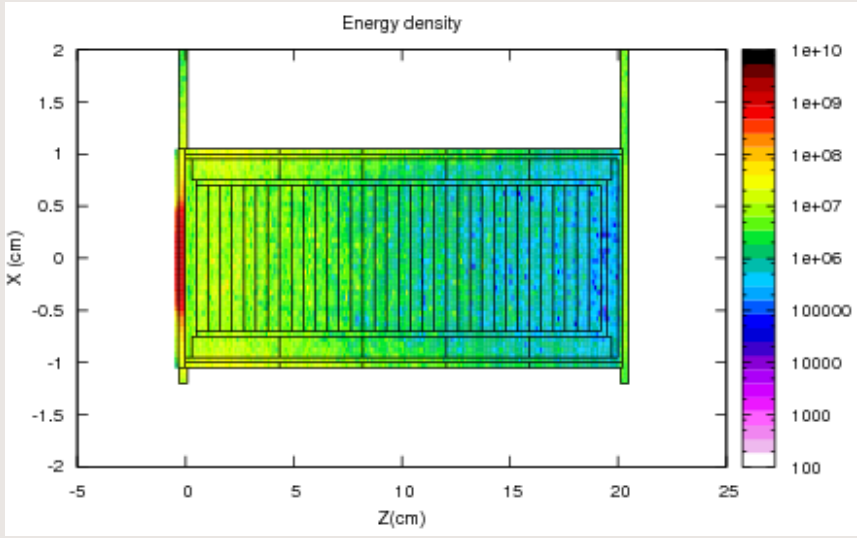


(e) 50 MeV

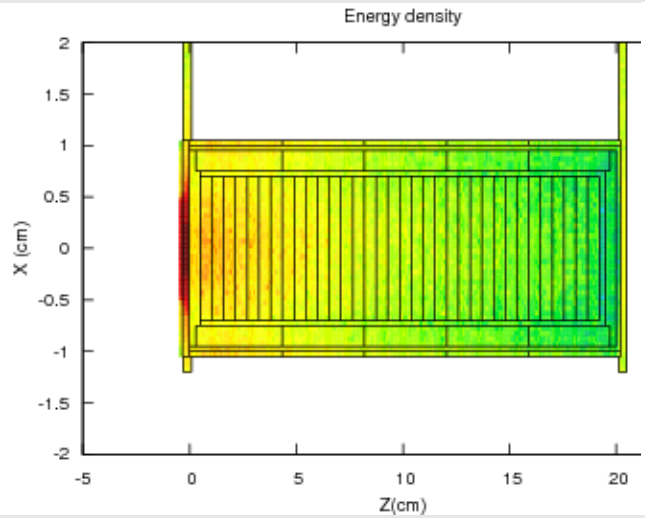
Energy Density: 2^E06 primaries



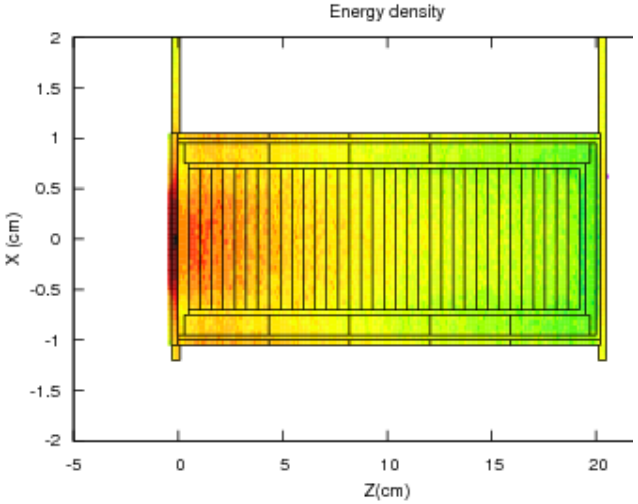
(a) 20 MeV – No biasing



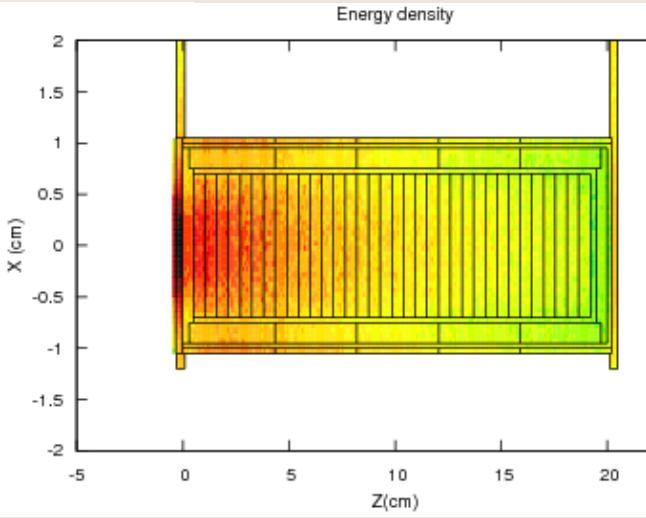
(b) 20 MeV



(c) 30 MeV



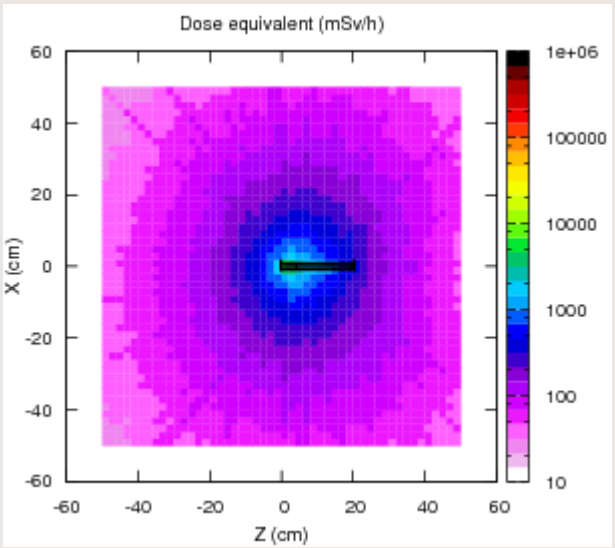
(d) 40 MeV



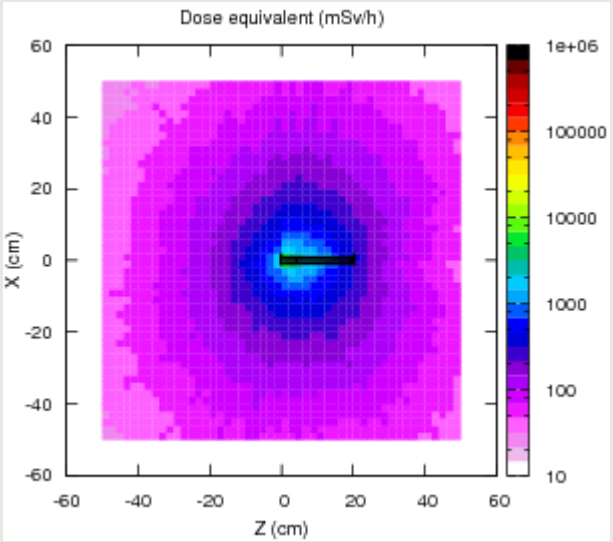
(e) 50 MeV

Dose Equivalent

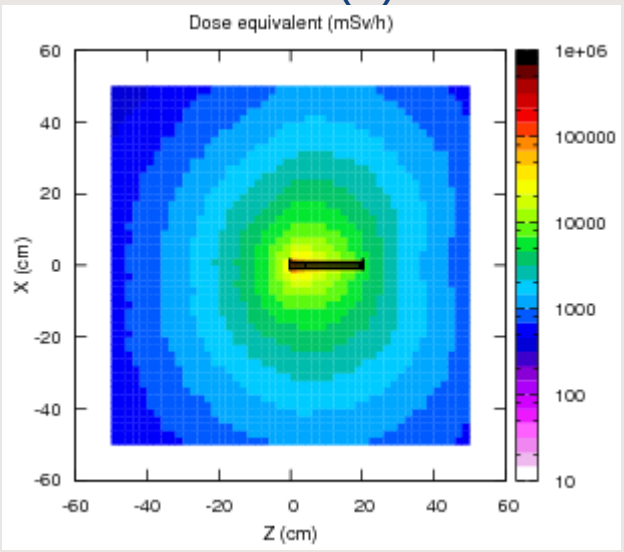
after 10 days of irradiation



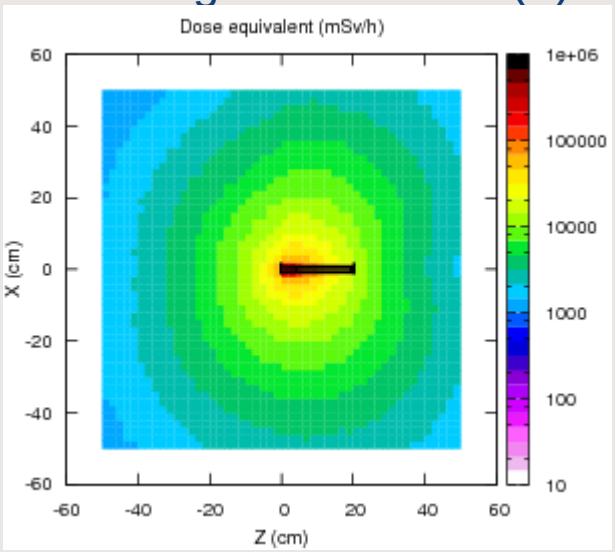
(a) 20 MeV – No biasing



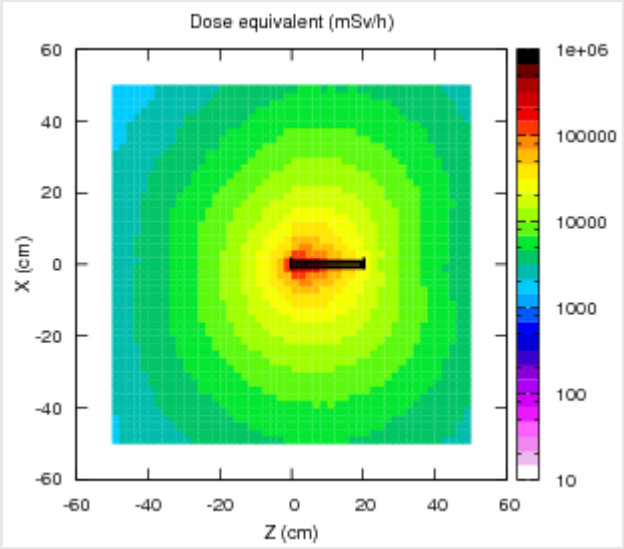
(b) 20 MeV



(c) 30 MeV



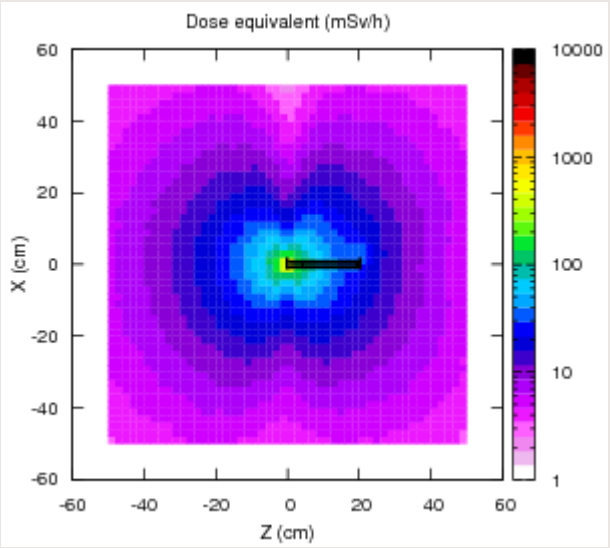
(d) 40 MeV



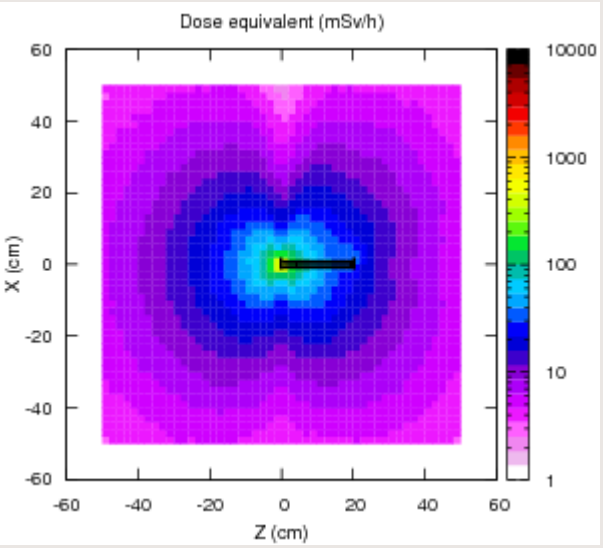
(e) 50 MeV

Dose Equivalent

after 5 days of cooling

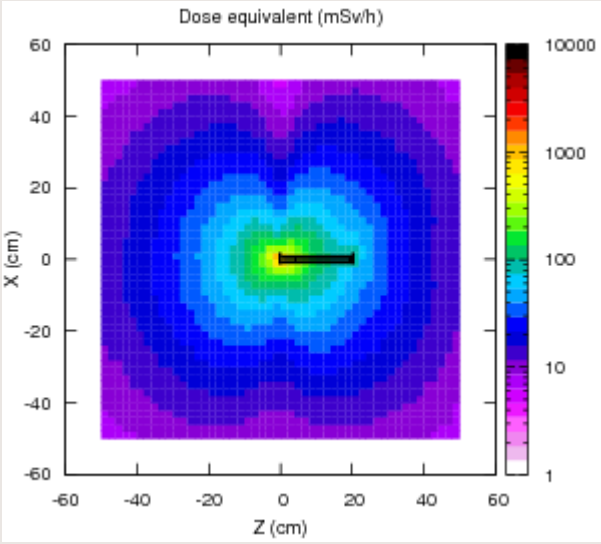


(a) 20 MeV – No biasing

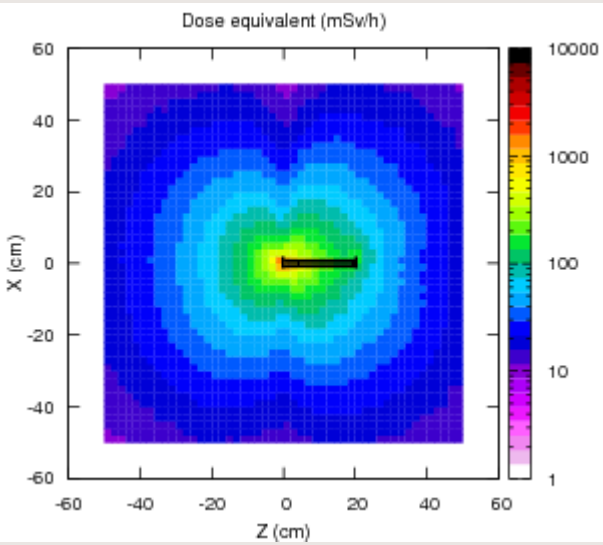


(b) 20 MeV

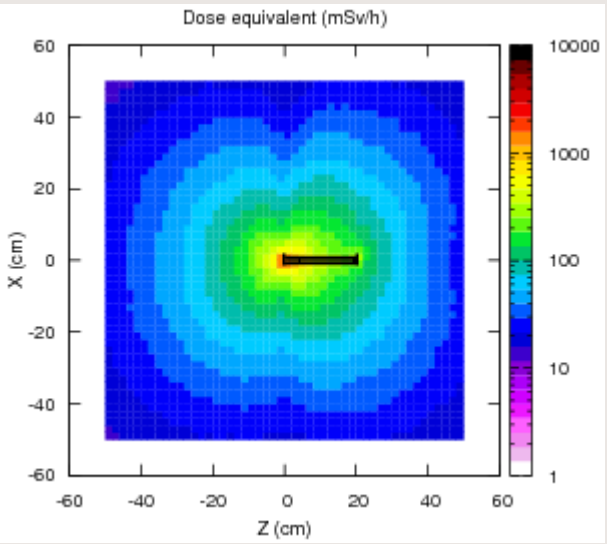
!



(c) 30 MeV



(d) 40 MeV



(e) 50 MeV

Further Study

- Results
  - Production rates before diffusion
  - Penetration depth and Target Length
  - Estimation of the minimum shielding required.

- Still in progress
  - Optimization of Biasing
  - Final target pellets composition
  - Target chamber configuration
  - Real data at Orsay.

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Merci!
Thank you!

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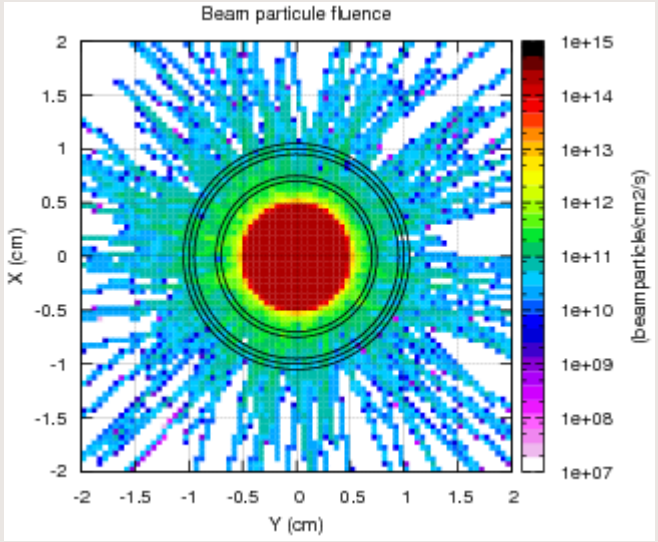
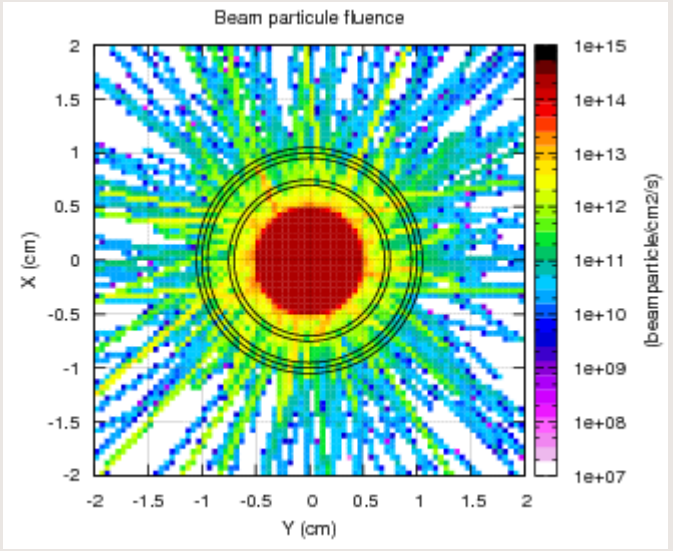
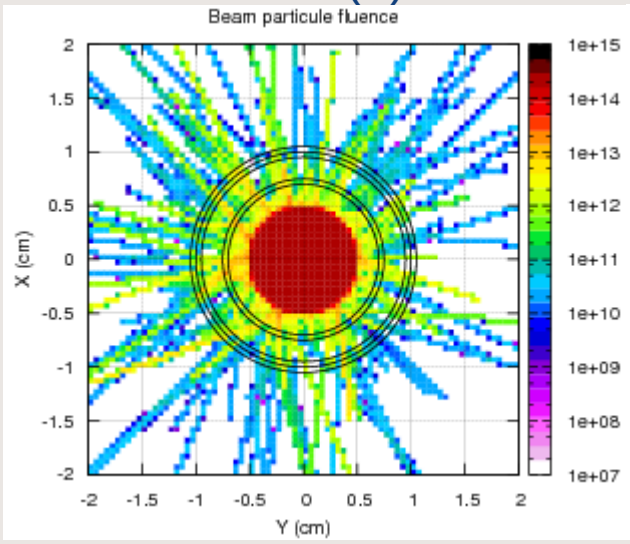
$2^{E}06$ primaries : Beam particle fluence



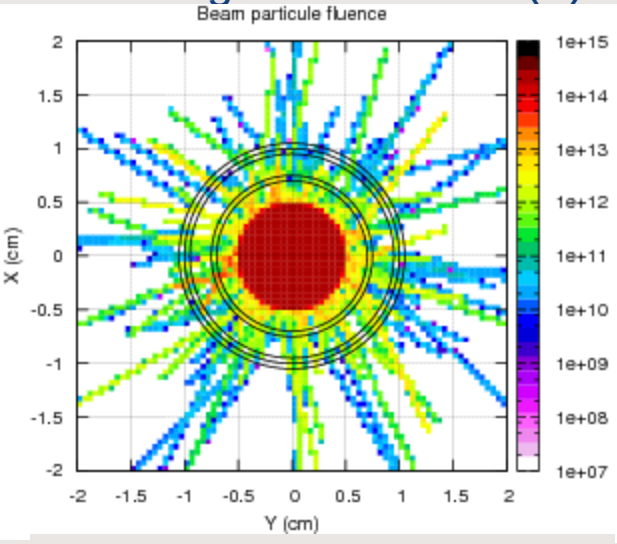
(a) 20 MeV – No biasing



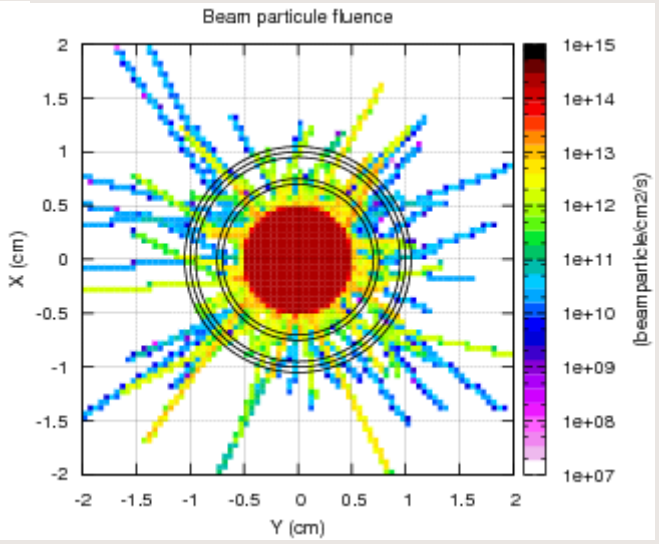
(b) 20 MeV



(c) 30 MeV

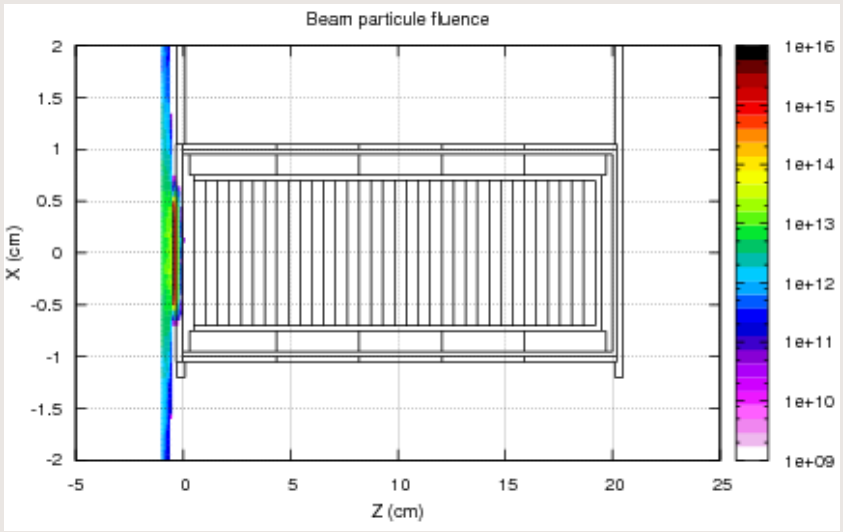


(d) 40 MeV

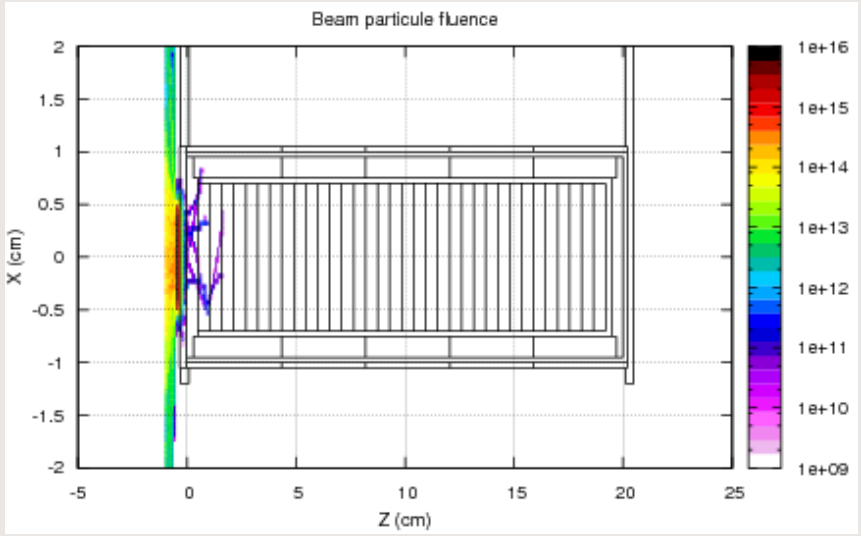


(e) 50 MeV

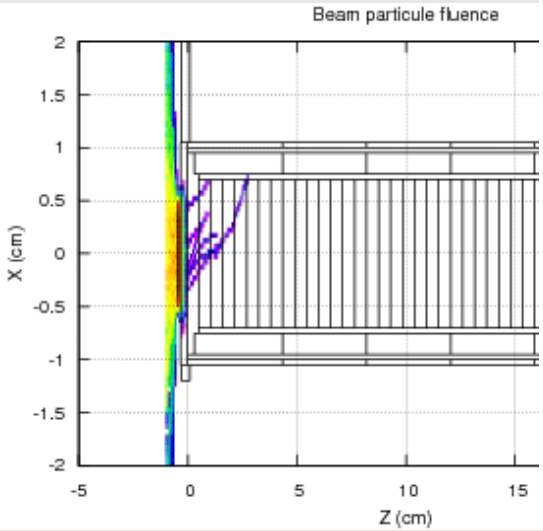
2^E06 primaries : Beam particle fluence



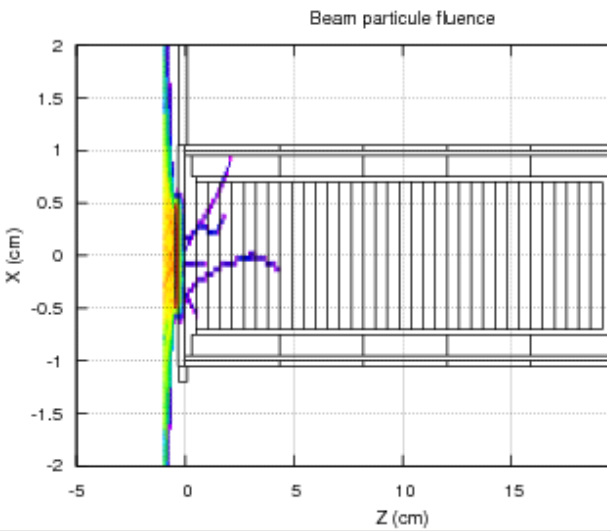
(a) 20 MeV – No biasing



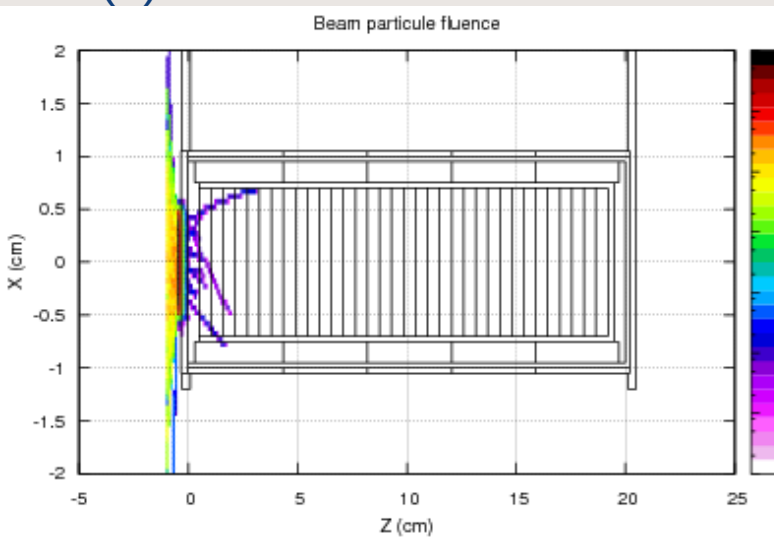
(b) 20 MeV



(c) 30 MeV

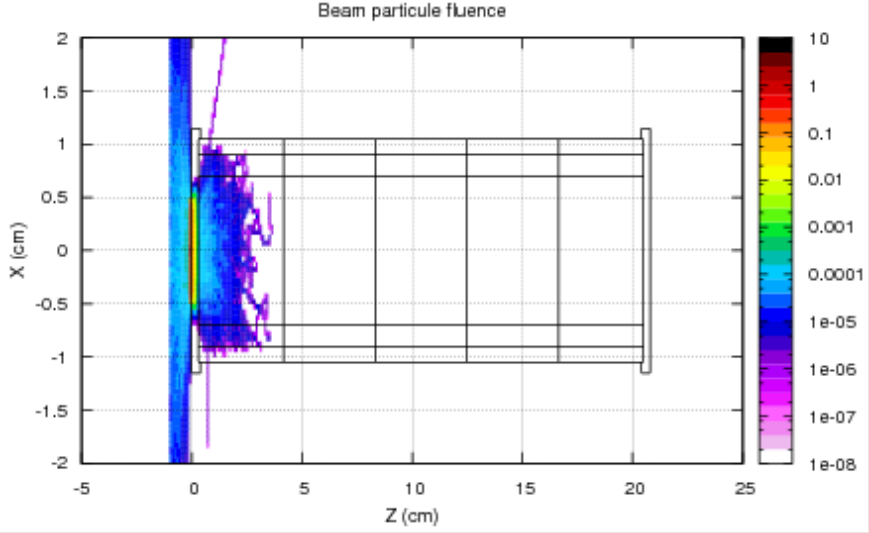


(d) 40 MeV

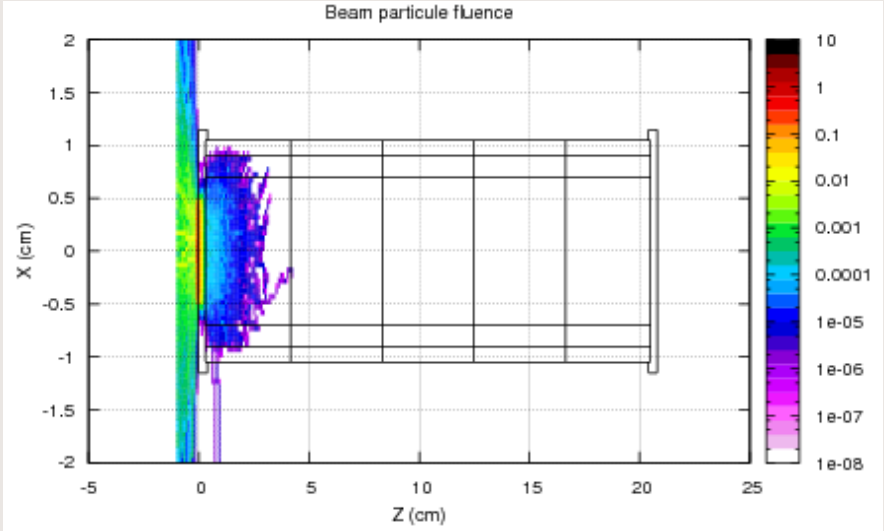


(e) 50 MeV

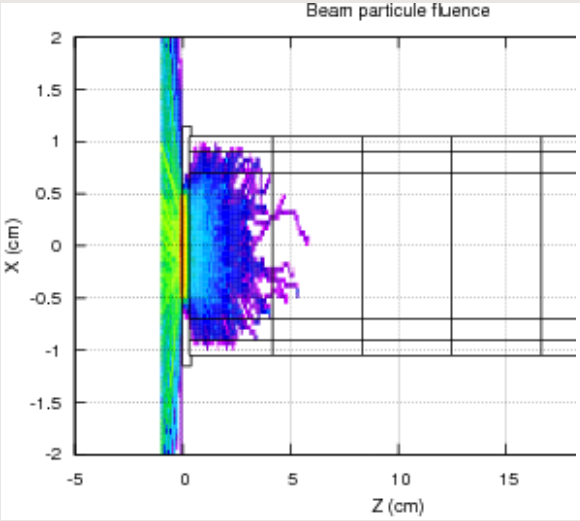
2^E06 primaries, No Graphite Cap : Beam particle fluence



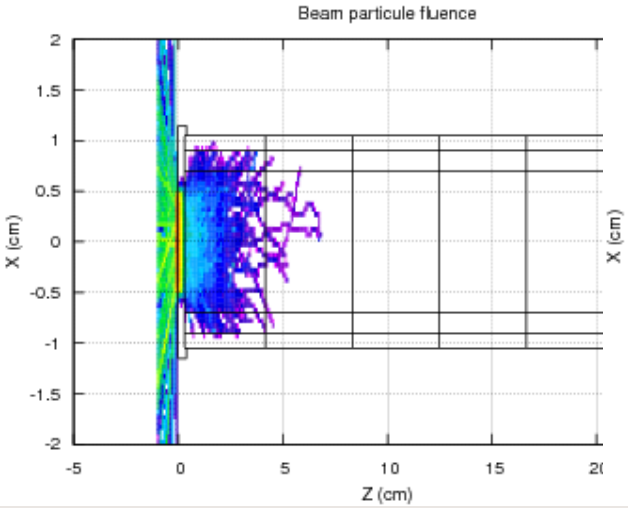
(a) 20 MeV – No biasing



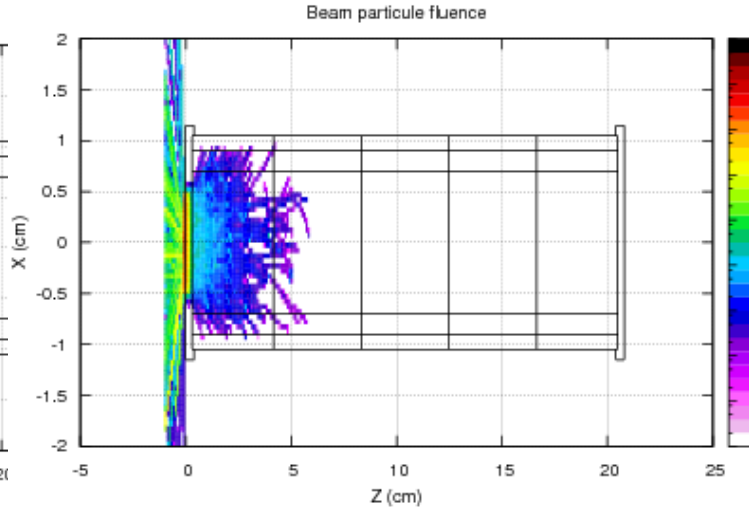
(b) 20 MeV



(c) 30 MeV

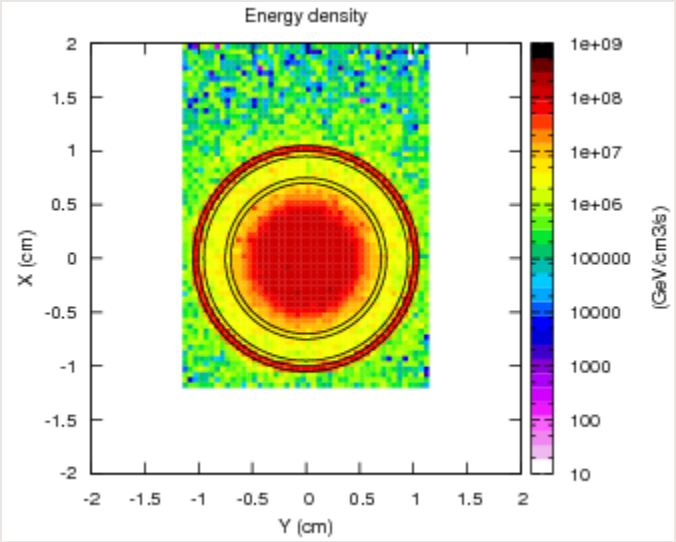


(d) 40 MeV

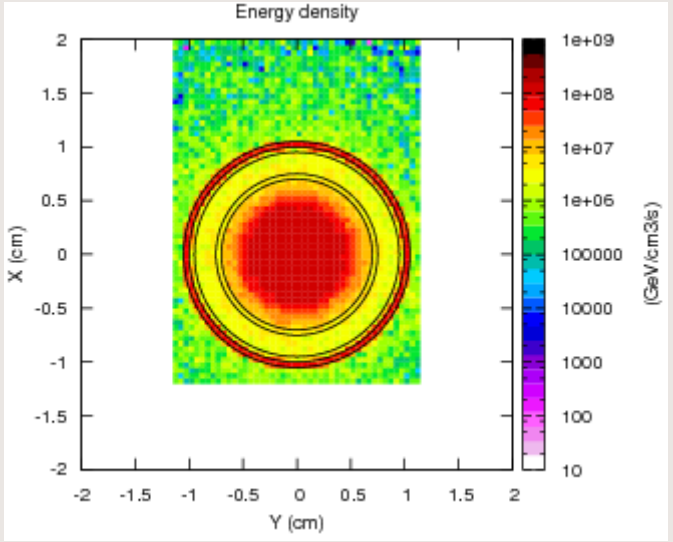


(e) 50 MeV

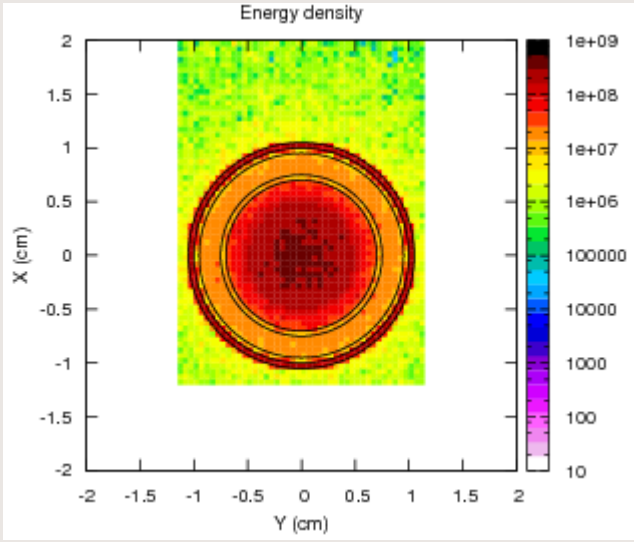
Energy density



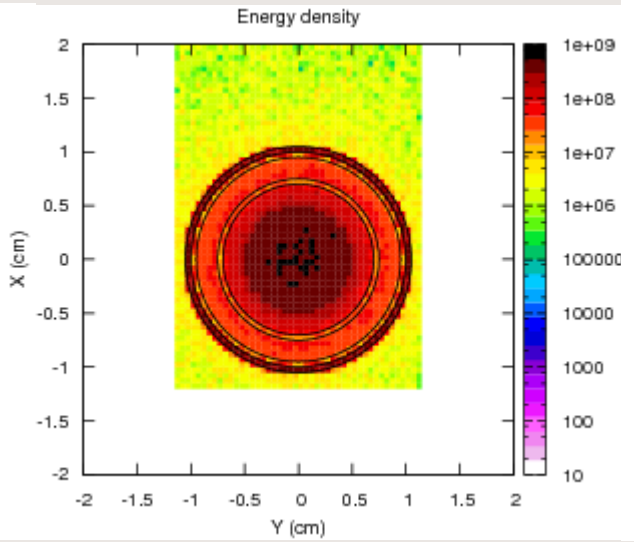
(a) 20 MeV – No biasing



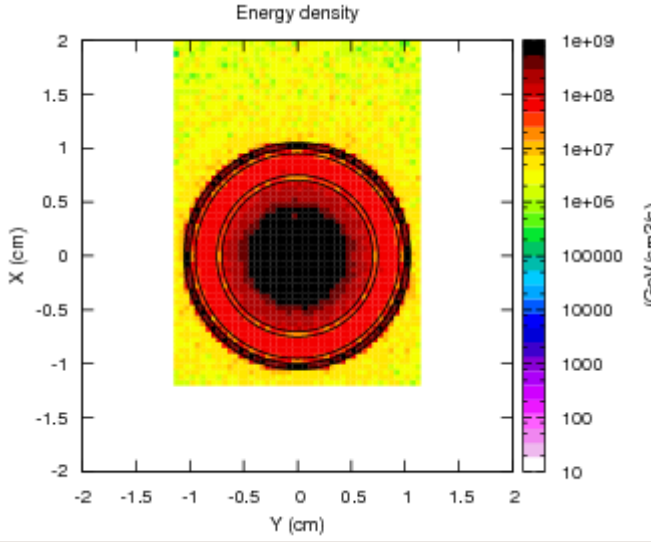
(b) 20 MeV



(c) 30 MeV



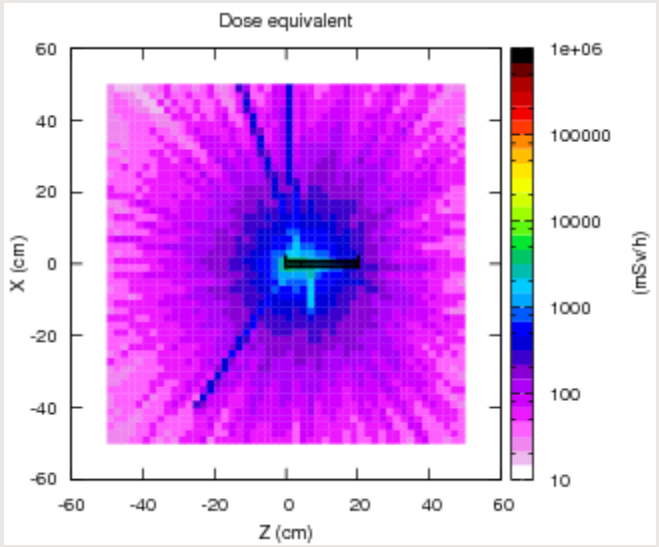
(d) 40 MeV



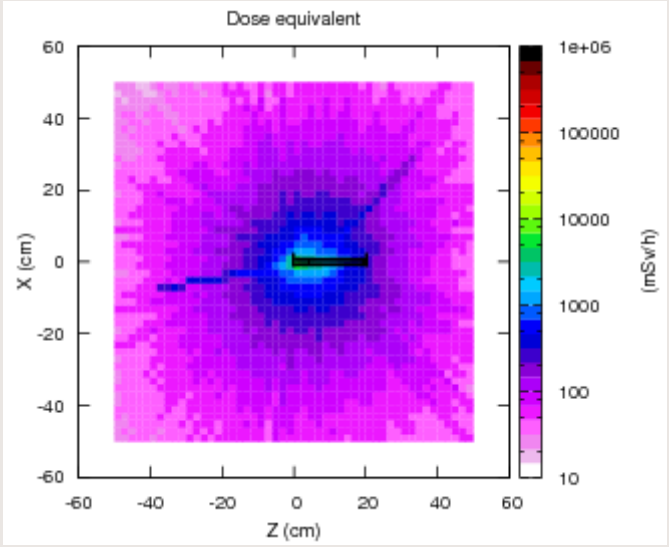
(e) 50 MeV

Dose equivalent

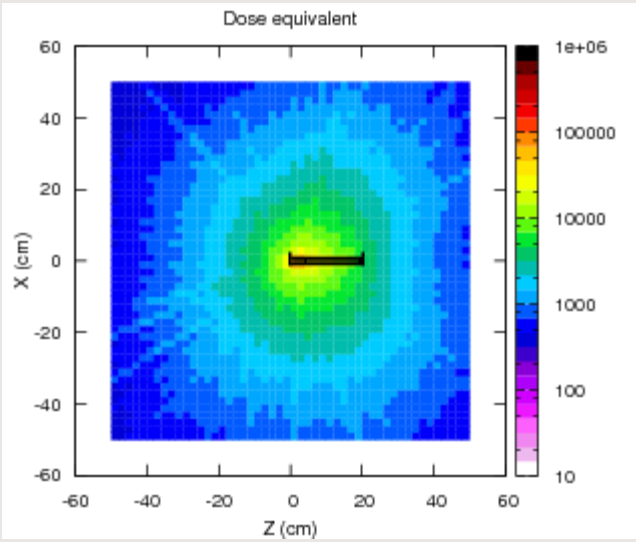
after 10 days of irradiation



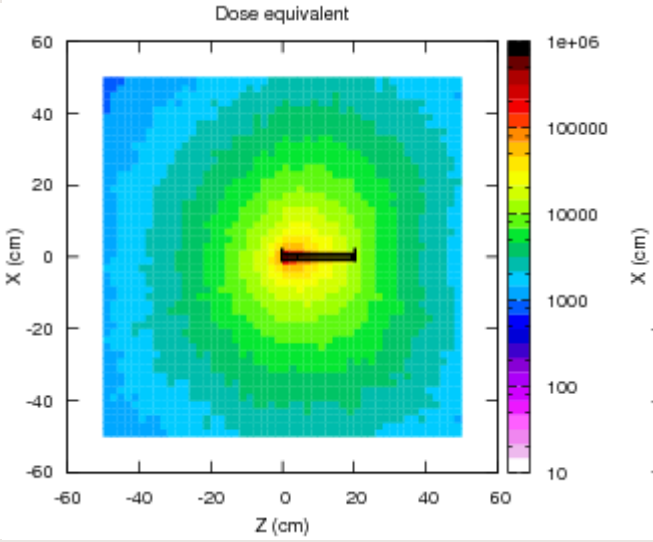
(a) 20 MeV – No biasing



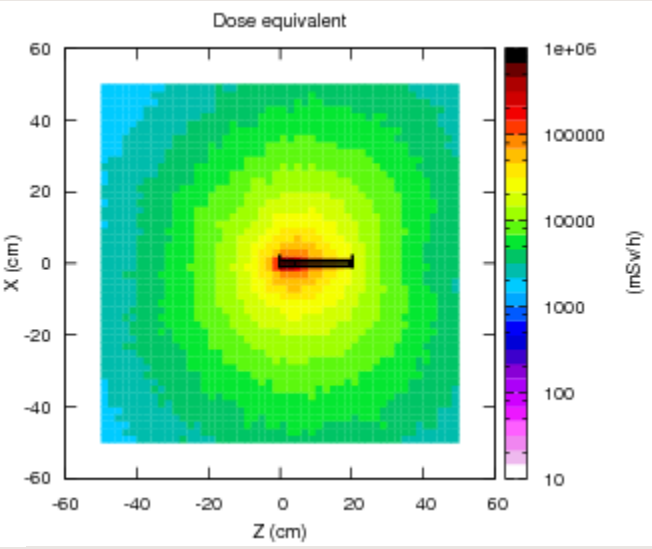
(b) 20 MeV



(c) 30 MeV



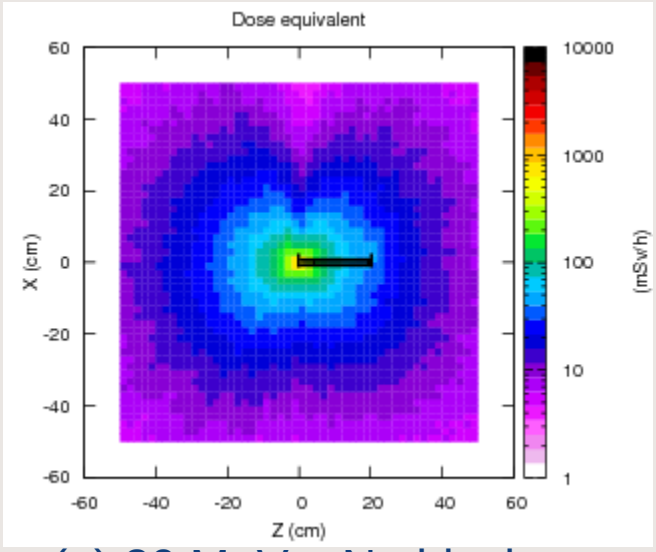
(d) 40 MeV



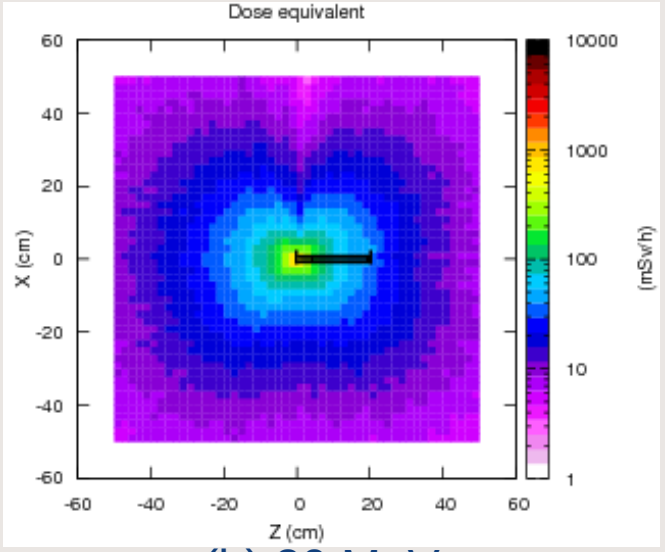
(e) 50 MeV

Dose equivalent

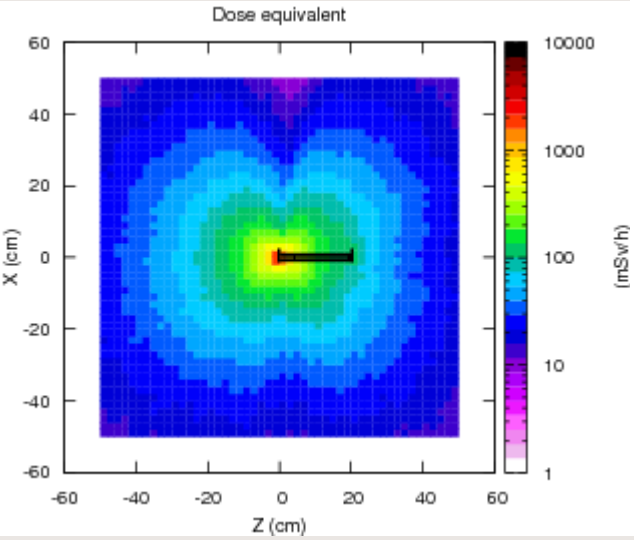
after 5 days of cooling



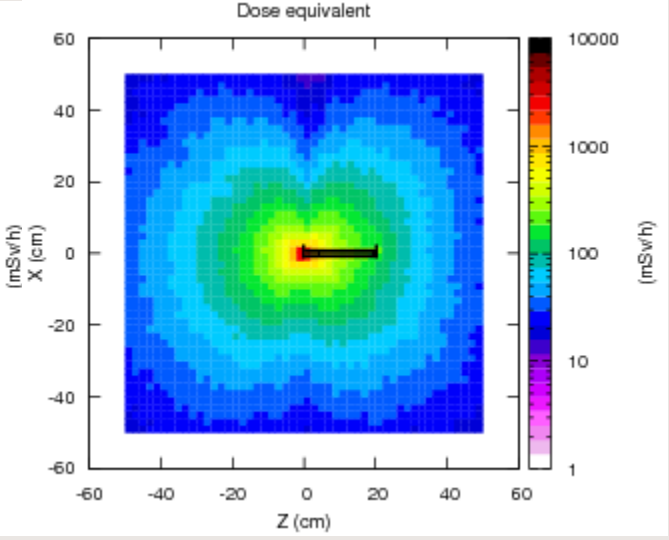
(a) 20 MeV – No biasing



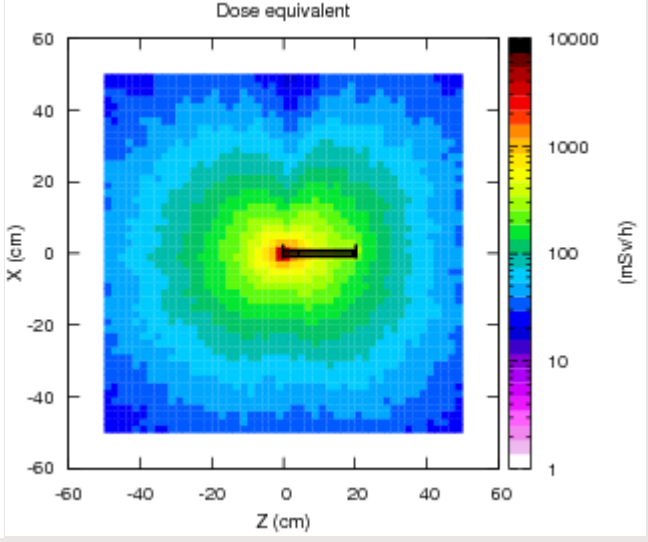
(b) 20 MeV



(c) 30 MeV



(d) 40 MeV



(e) 50 MeV