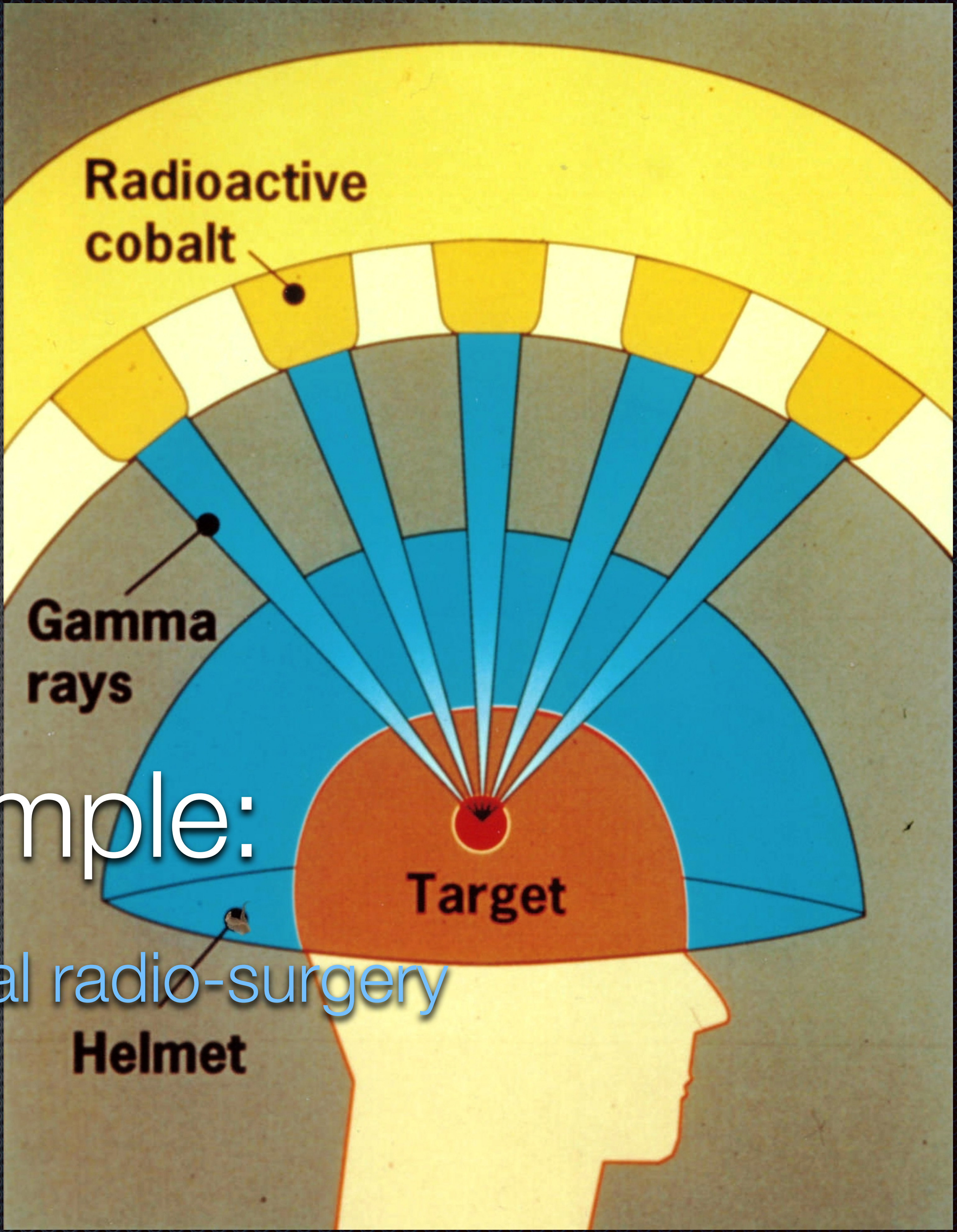
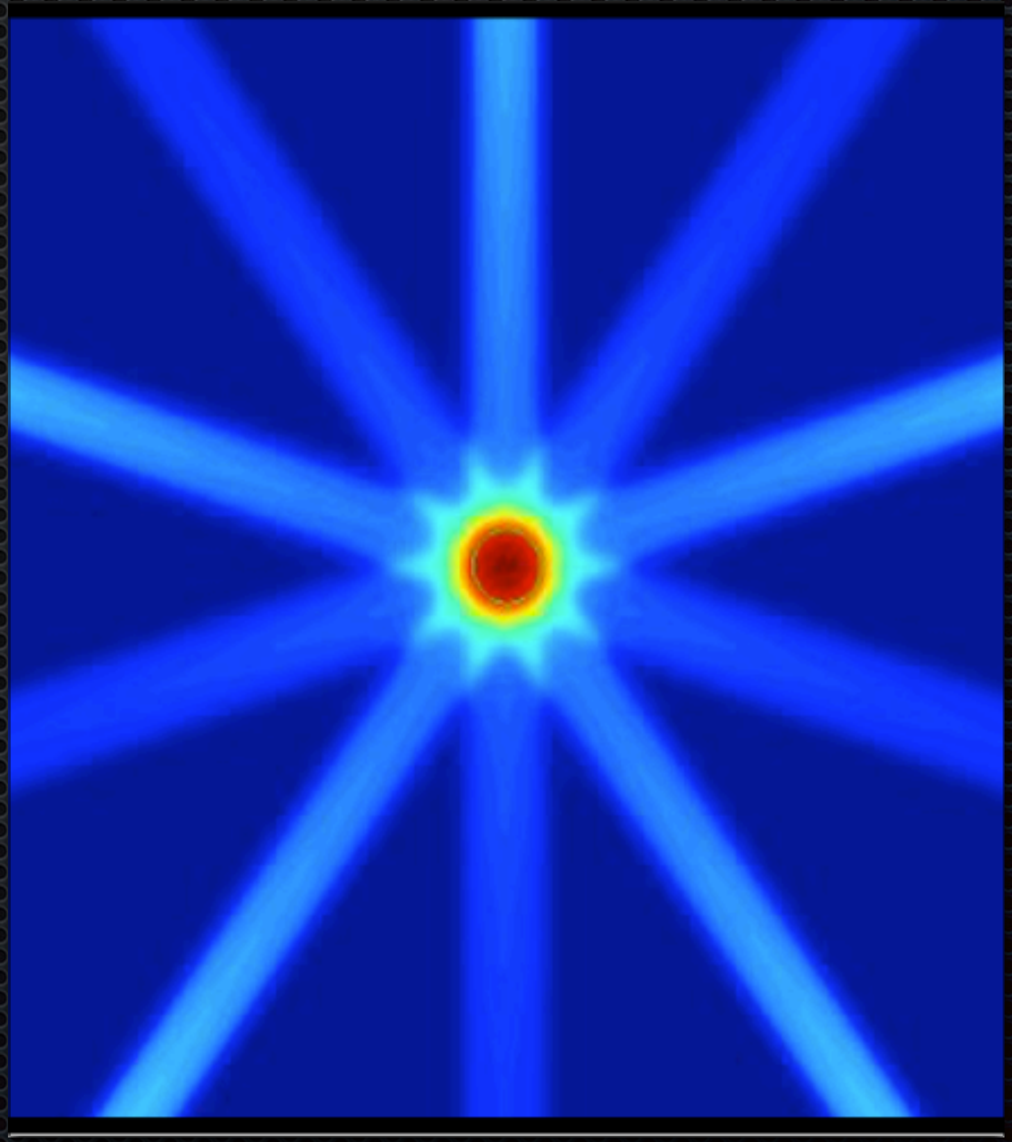
GEANT4 example:

Gamma Knife for cranial radio-surgery



Concept of Radio-surgery

- Use multiple narrow beams of radiant energy directed at the target in the brain from different directions
- This produces a local destruction of the tissue in the desired region, minimising damages to adjacent tissues
- Concept developed by Lars Leksell in the 1950’s
- With **stereotactic radio-surgery** the patient's diagnostic images are correlated with the actual target position in the patient (inc. in real time)

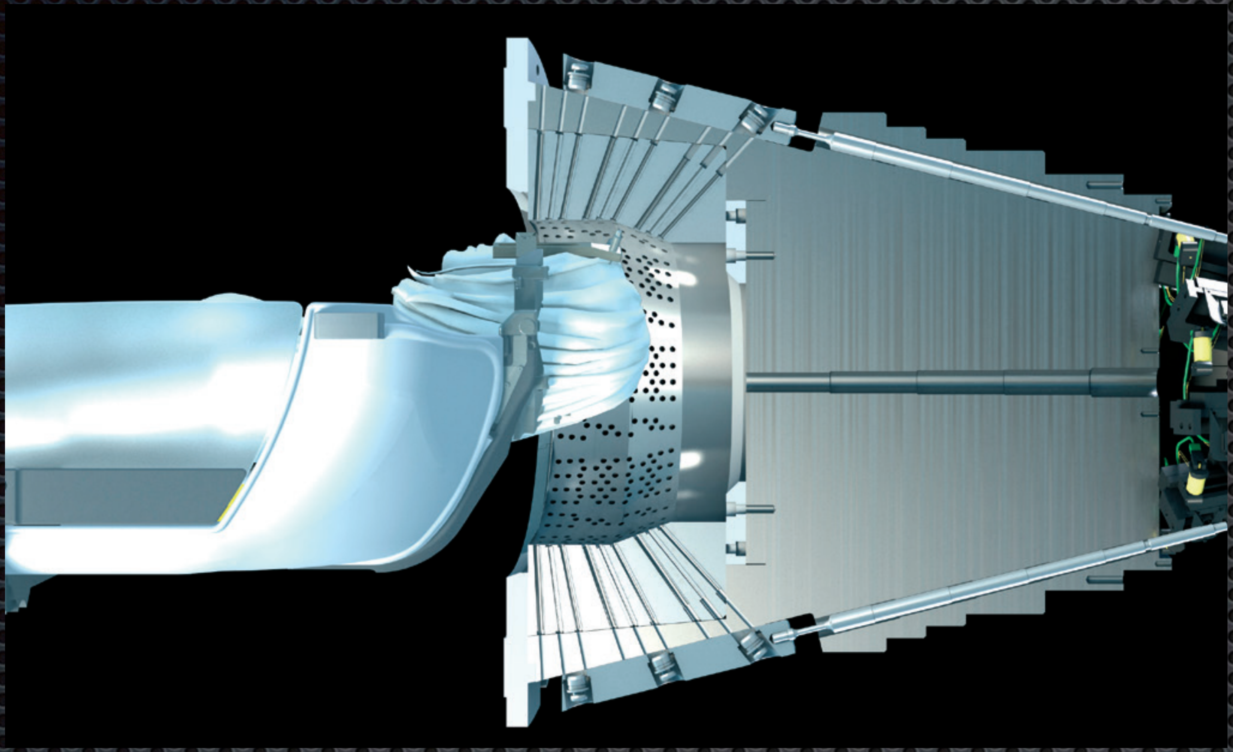


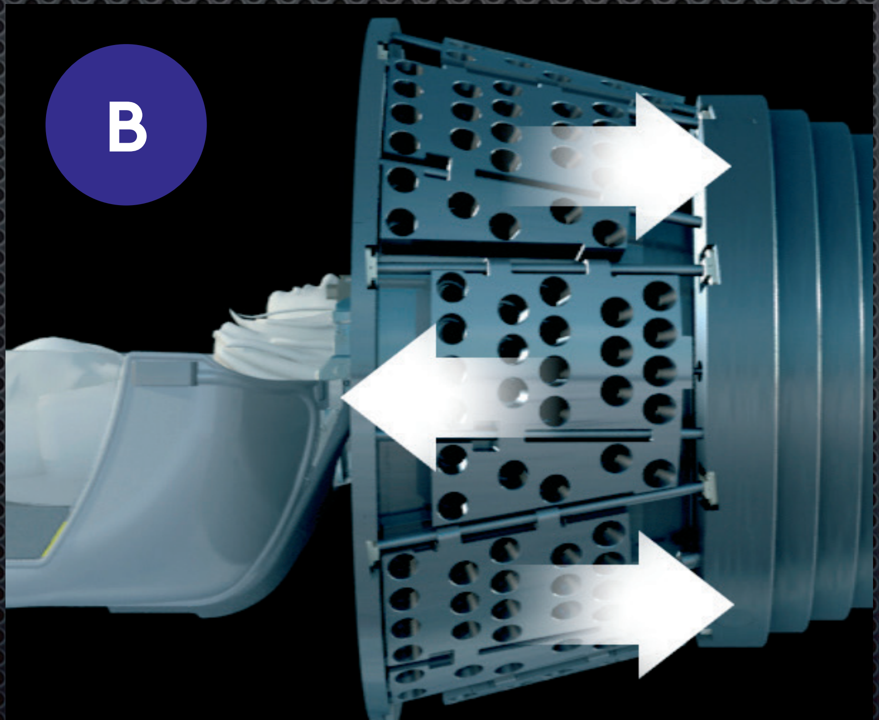
A working example:
The Elekta Leksell Gamma Knife

- 200 ^{60}Co sources (6000 Ci total initial activity $= 2.22 \times 10^{14}$ decays /s!!!)
- Sources are positioned and collimated to focus radiation precisely at isocenter
- Sub-mm accuracy (0.5 mm guaranteed, 0.15 mm typical value)

Perfexion (2006)

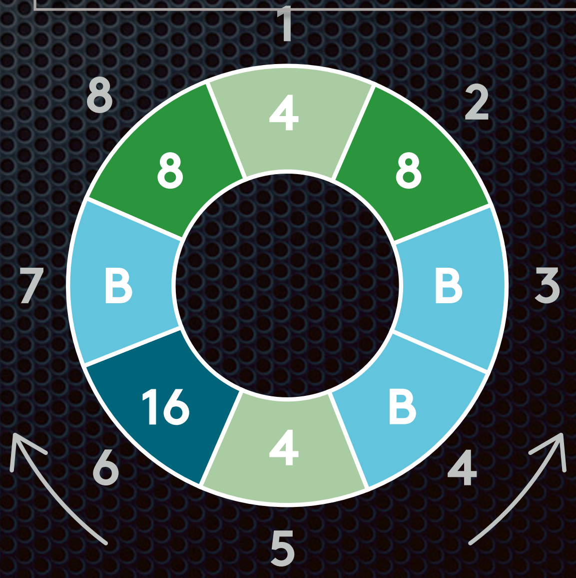
A working example:
Elekta Leksell





- Prescription volume shaped to match the target volume by:
  - translating the patient in 3 orthogonal directions between “shot” settings
  - using appropriately sized W collimators for each shot

$\rho_W = 19.3\ g/cm^3$



A working example:

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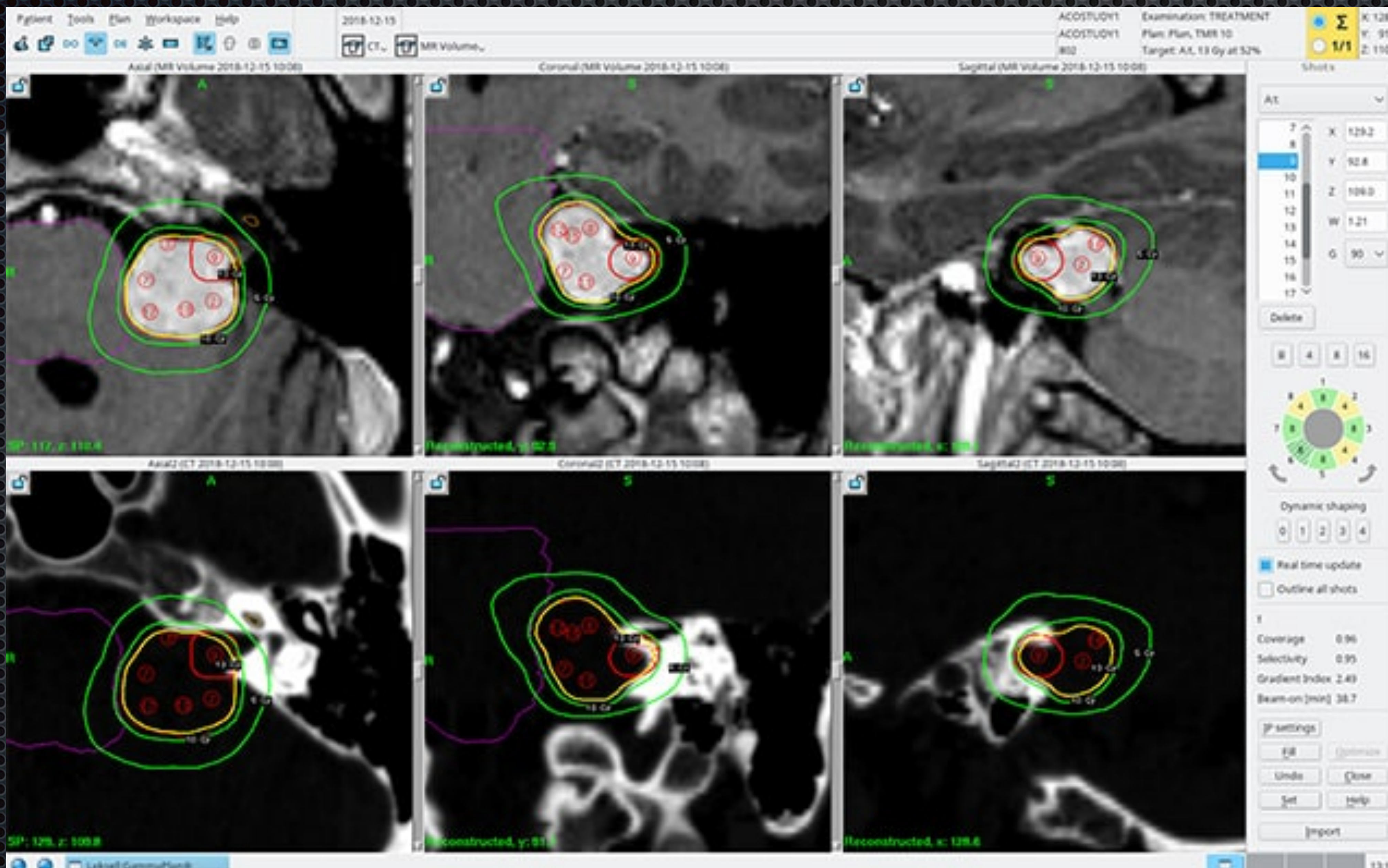


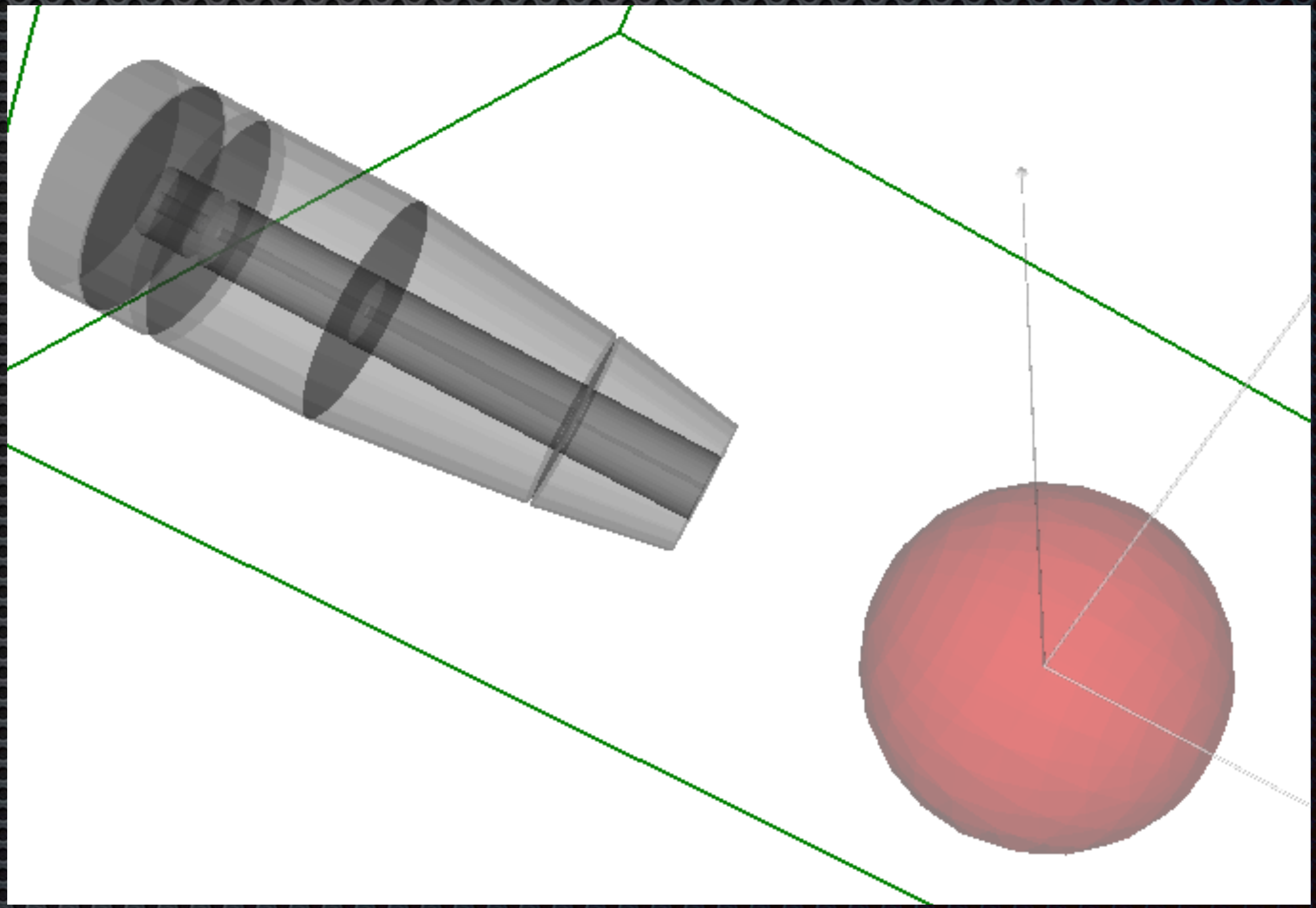
Treatment plan, with isodose lines

Some more resources

- Elekta website
- Overview video of an Elekta Perfexion
- Treatment plan example video
- A much more in-depth presentation about the Gamma Knife technique

GEANT4 Simulation

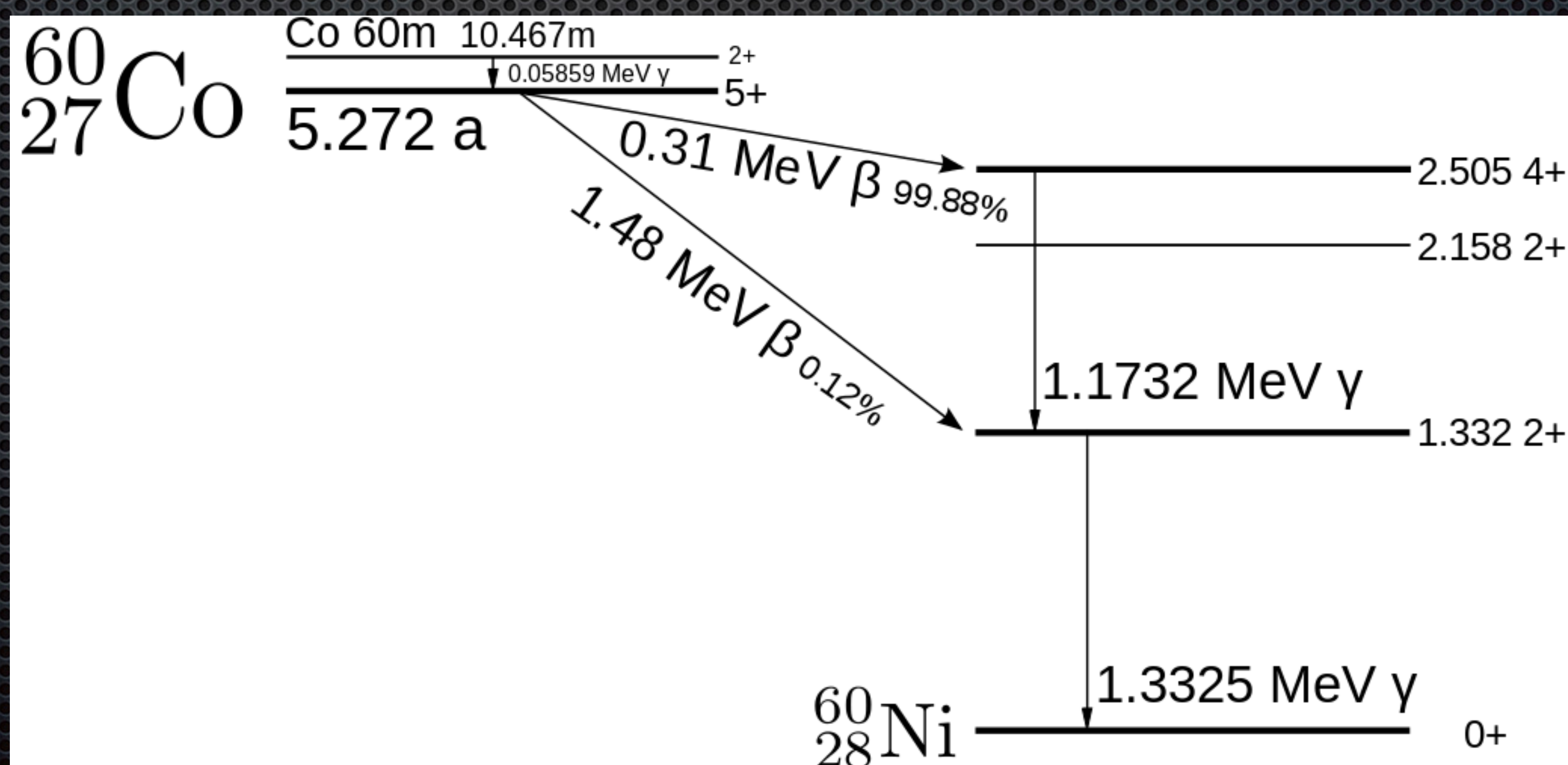
- Simplified geometry
- A spherical water phantom
- The phantom is divided in voxels, and we can get the deposited energy in each voxel
- Only one collimator setup
- We can rotate the ‘head’ to simulate the ~200 collimators



^{60}Co Decay Scheme

- Produced by neutron activation of ^{59}Co
- Half-life: 5.3 years
- ^{60}Co decays by beta decay to the stable ^{60}Ni
- The final excited Ni nucleus emits two gamma rays with energies of 1.17 and 1.33 MeV

$$^{59}_{27}\mathrm{Co} + n \rightarrow {}^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + e^{-} + \bar{\nu}_e + \text{gamma}$$



GEANT4 Simulation

- ^{60}Co source is not simulated isotropically, but rather in a 3 degree angle (to reduce computation time)
- Initial positions uniformly sampled inside a 20 mm length and 1 mm radius cylinder
- The collimator has 3 stages, with 4 final apertures (to get a 4, 8, 14 or 18 mm beam in the centre of the sphere)
- The phantom has 45 x 45 x 45 1 mm cubic voxels, energy deposition in each in stored in `eDep_scorer.out`

Steps to run the simulation

- Download the zipped file from here, unzip and move the folder to your work area
- Navigate to the simulation folder using the File Explorer and open a terminal
- Compile and run the simulation as usual
  - `make`
  - `gammaknife`

Steps to run the simulation

- Let's quickly go through the materials and geometry definition:
  - open the file src/GammaKnifeDetectorConstruction.cc
- The primary particles (1.17 and 1.31 MeV gammas) are defined in the macro GPS.in
- We are not going to change the code, only use macro files to configure and run the simulation
- When you start the simulation without arguments, it will run the macro file defaultMacro.mac
  - runs the macro setting the primary gammas
  - defines the cubic mesh that will be used to store energy deposits
  - sets visualisation properties
  - defines beam width at the center of the phantom
  - runs a few events

Run the simulation in batch mode

- Using visualisation is good for checking the geometry, primary generation, etc.
- But it makes the simulation extremely slower… after the initial checks, we should use batch mode
- Let’s start by using a single angle: singleAngleSimulation.mac
  - this macro will simulate 1M Co-60 decays
  - collimator aperture is 14 mm
  - run the simulation with this macro and let’s analyse the output:
  - `gammaknife singleAngleSimulation.mac`

Output analysis

- Open the file `eDep_scorer.out` and check the structure
- Feel free to use whatever analysis software you're more familiar with. The following steps apply to ROOT
  - To make file loading easier, delete the header and replace the commas by tabs
  - Open root and load the data file:
    - `root -l`
    - `.x LoadFile.C`
  - The data is now in a memory structure called `gKnife`, and contains the variables `x, y, z, E, E2 and I`
  - To plot these quantities, type (e.g.) gKnife->`Draw("E")`
  - To apply a cut when plotting, pass it as a 2nd argument: `gKnife->Draw("E","E>0")`
  - Some interesting things to plot:
    - z:y:x
    - z:y:x for E>0
    - y:x for E>0
    - sqrt(x**2 + y**2) for E>0
    - E:sqrt(x**2 + y**2) for E>0
    - E:z

Exercise 1

- Change the aperture of the collimator to 4 mm and compare the distributions, in particular the radius of the beam inside the phantom

Exercise 2

- Run the full simulation, cycling through all the angles to simulate a full gamma knife device
(use the `full_simulation.mac` macro for this)
- As in the case of the mono-directional beam, study the energy distribution with the position inside the sphere (in particular with the radius from the centre)
- Estimate the size of the irradiated region
- Modify the macro to have a smaller opening in the collimator and compare the distributions

More GEANT4 examples

Look for the examples folder in the Geant4 directory structure
`/usr/local/geant4/geant4.10.04.p03-install/share/Geant4-10.4.3/examples/advanced/`

- human_phantom
- brachytherapy
- hadrontherapy — basic version
  (full version available in
  https://twiki.cern.ch/twiki/bin/view/Geant4/AdvancedExamplesHadrontherapy)
- iort_therapy
- medical_linac
- radioprotection