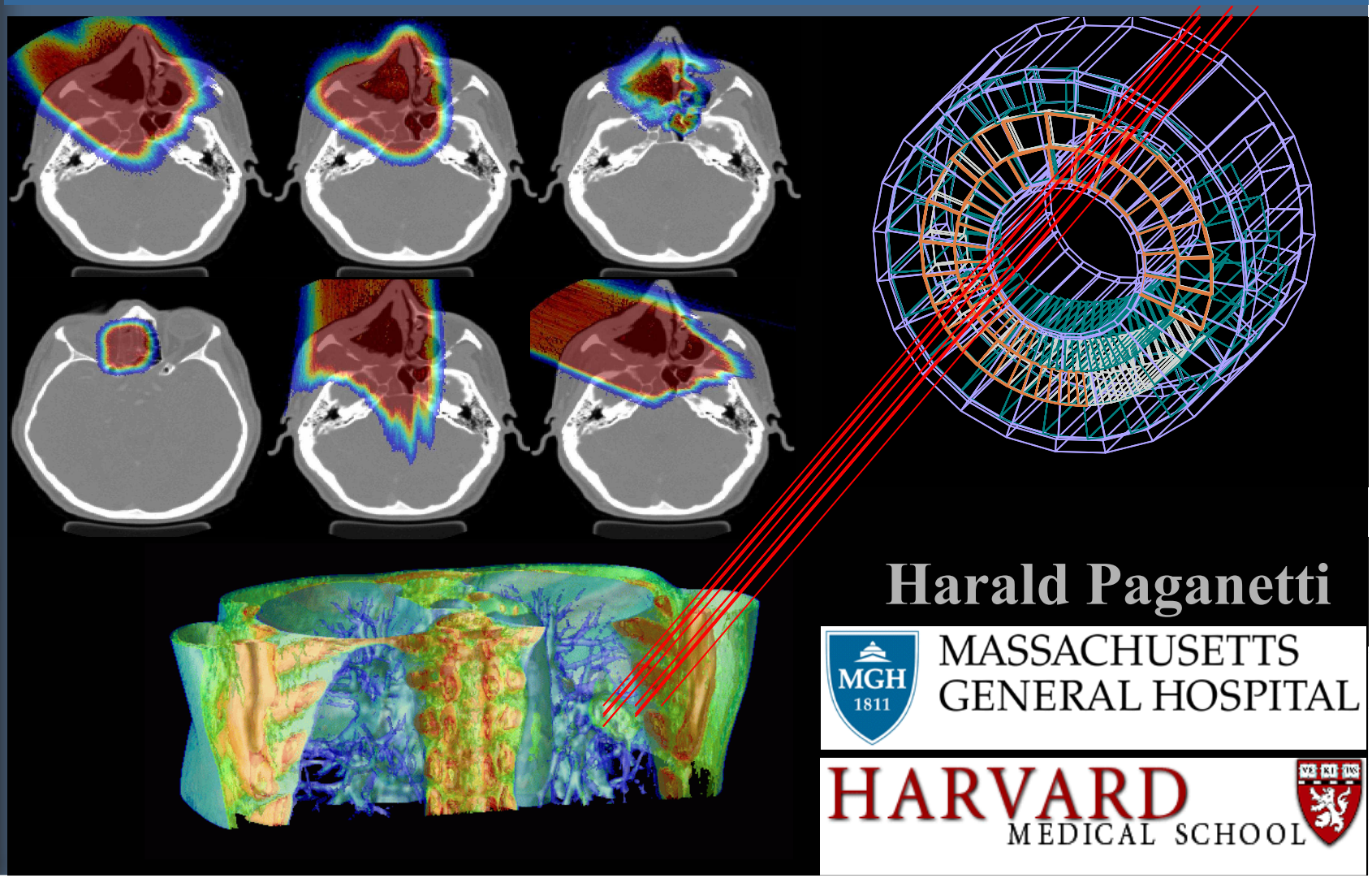
GEANT4 based proton dose calculation in a clinical environment: technical aspects, strategies and challenges



Harald Paganetti

MASSACHUSETTS GENERAL HOSPITAL

HARVARD MEDICAL SCHOOL

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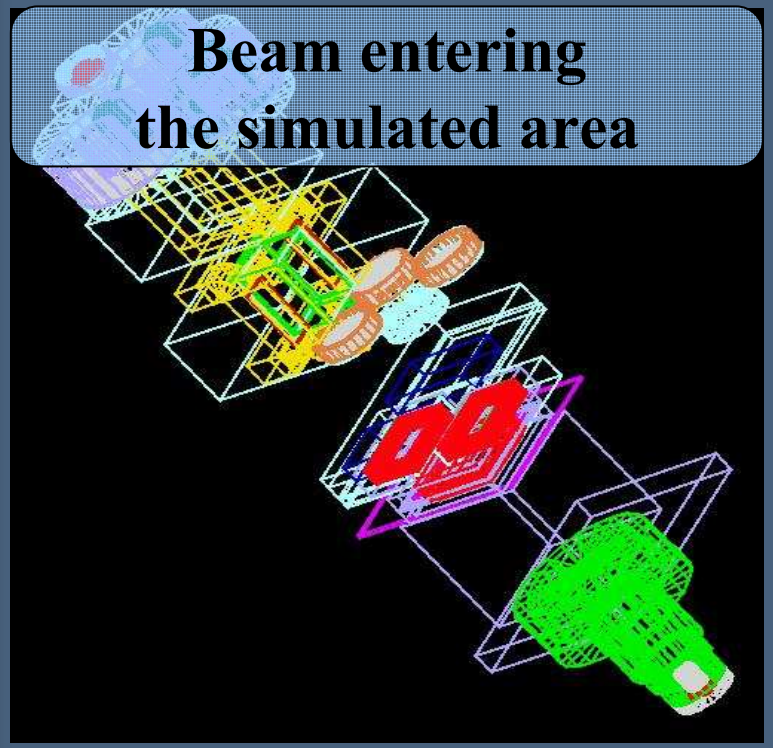
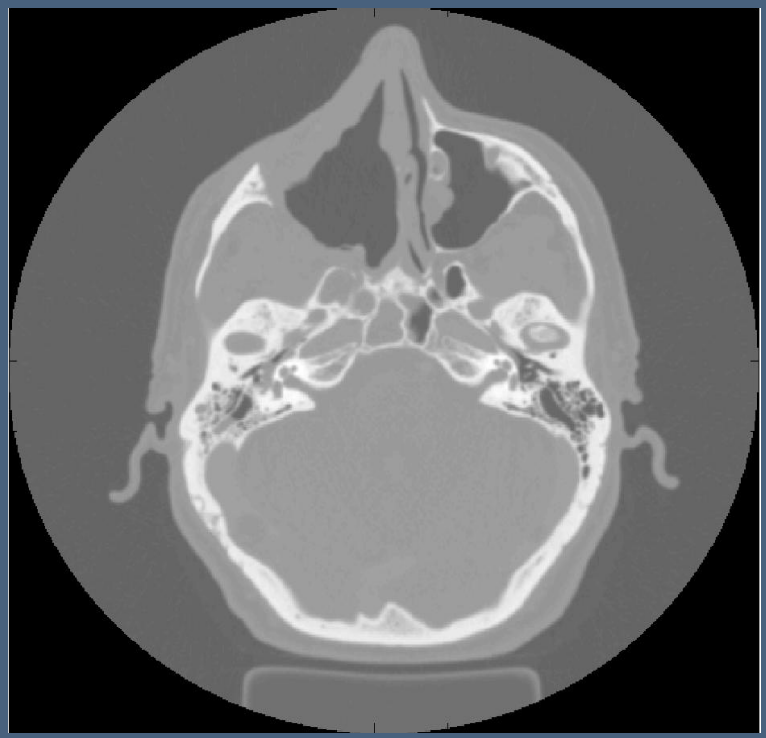
Clinical implementation of Monte Carlo dose calculation: strategies and challenges

Physics Setup





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Beam input parameters

Beam at nozzle entrance:

Beam angular spread	(manufacturer info)
Beam size and spread	(IC measurement)
Beam energy	(control system)
Beam energy spread	(manufacturer info, slightly adjusted)

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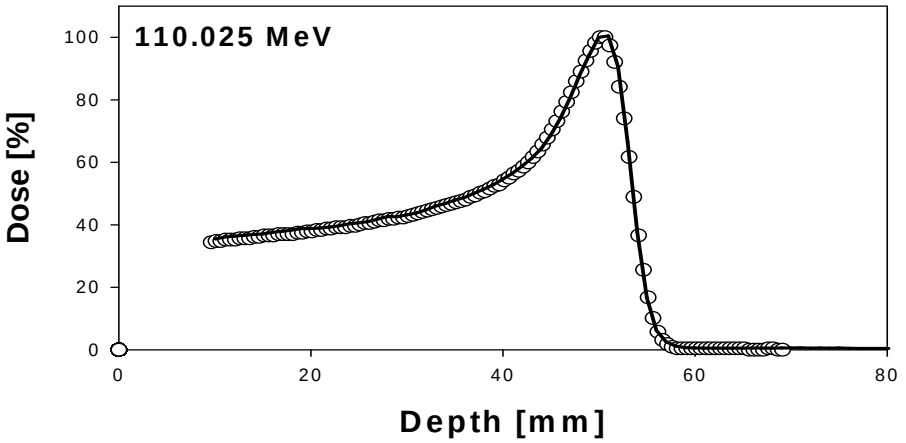
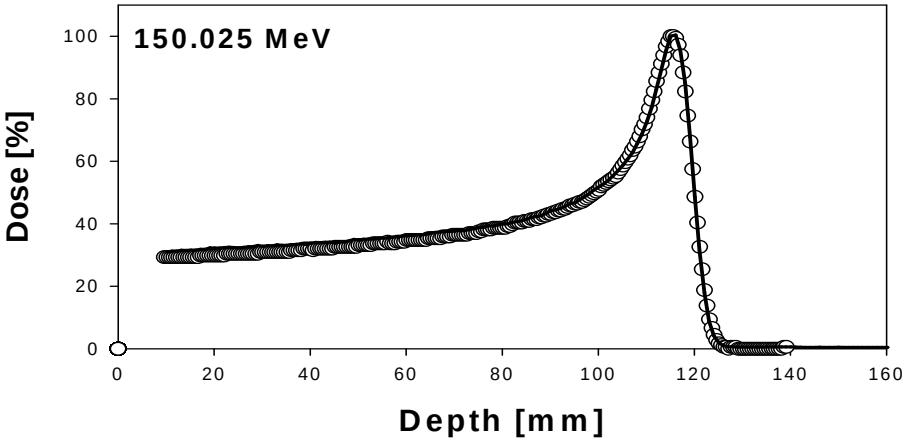
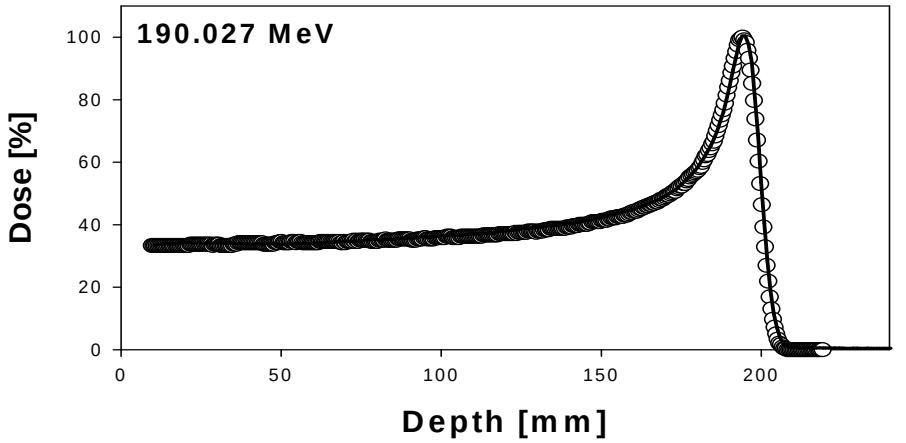
Accuracy of the nozzle model

Pristine Curves







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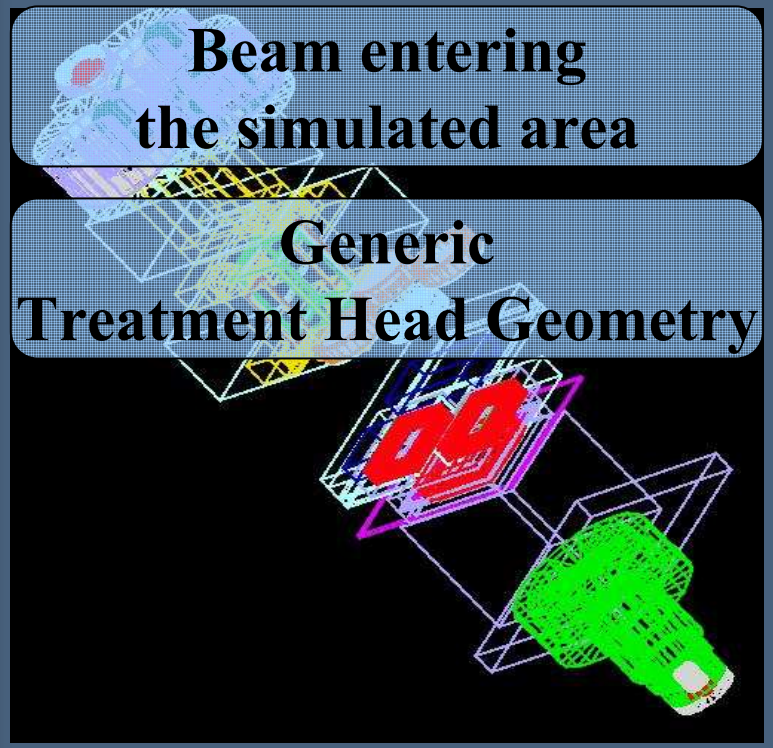
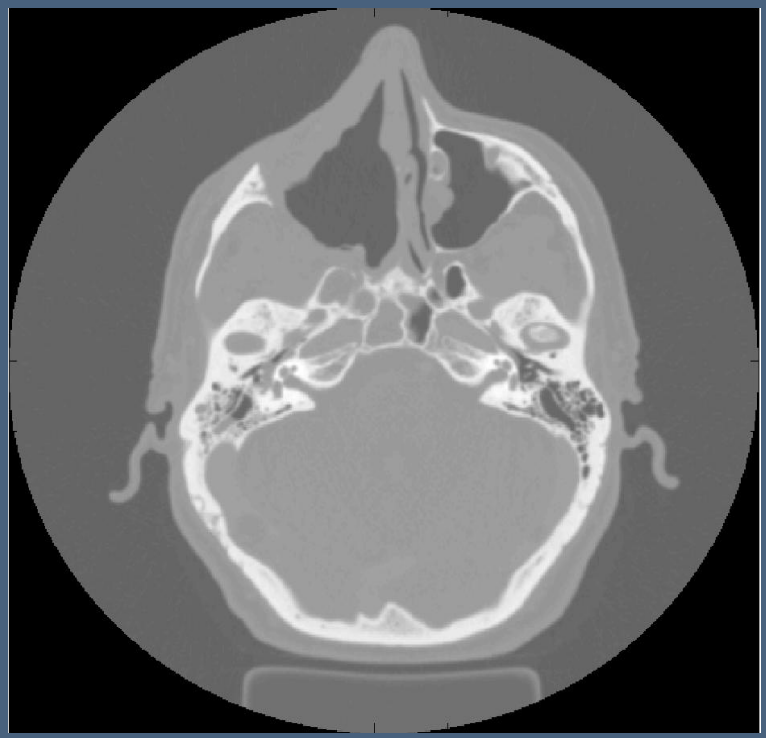
Clinical implementation of Monte Carlo dose calculation: strategies and challenges

Physics Setup





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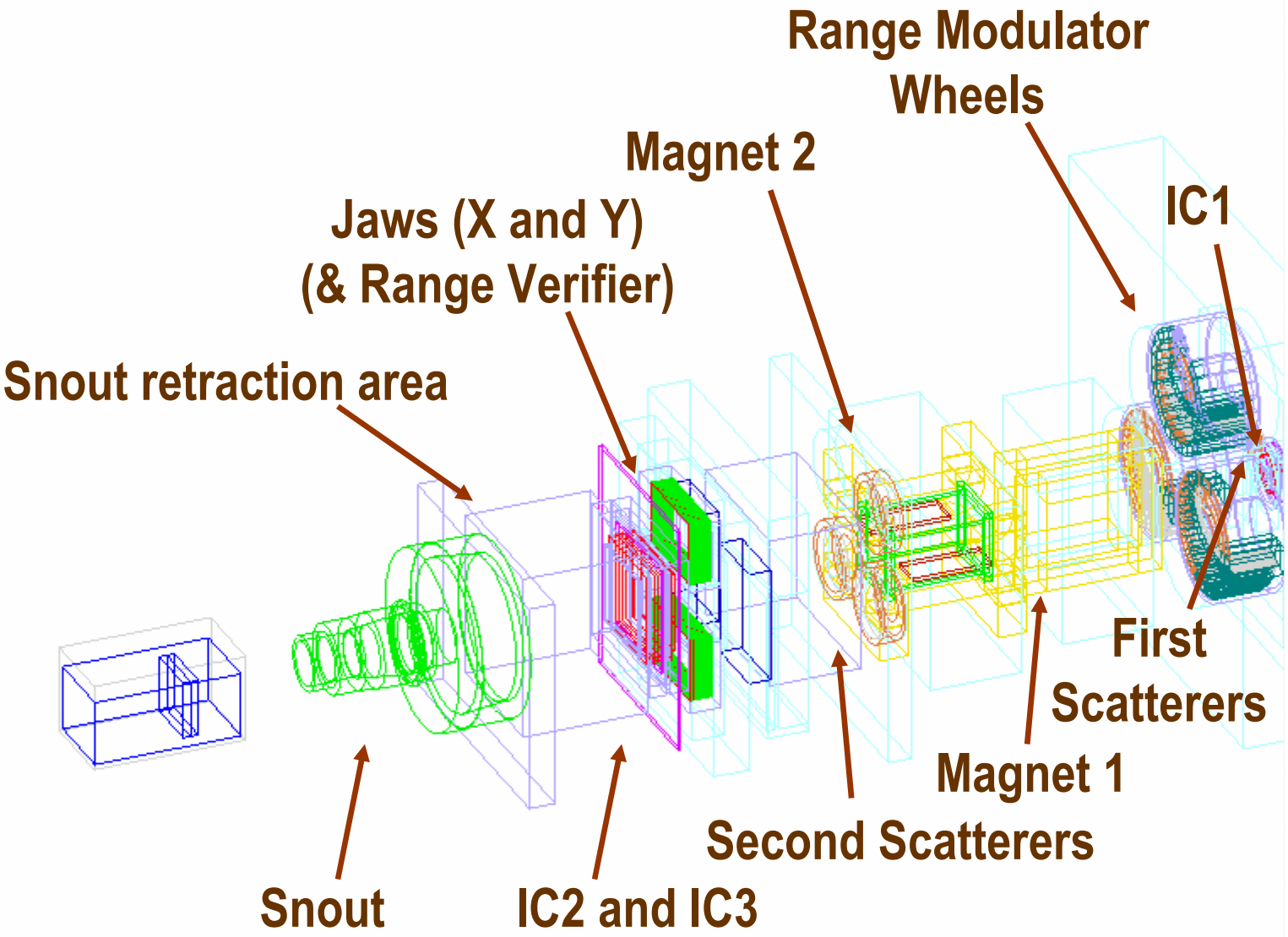

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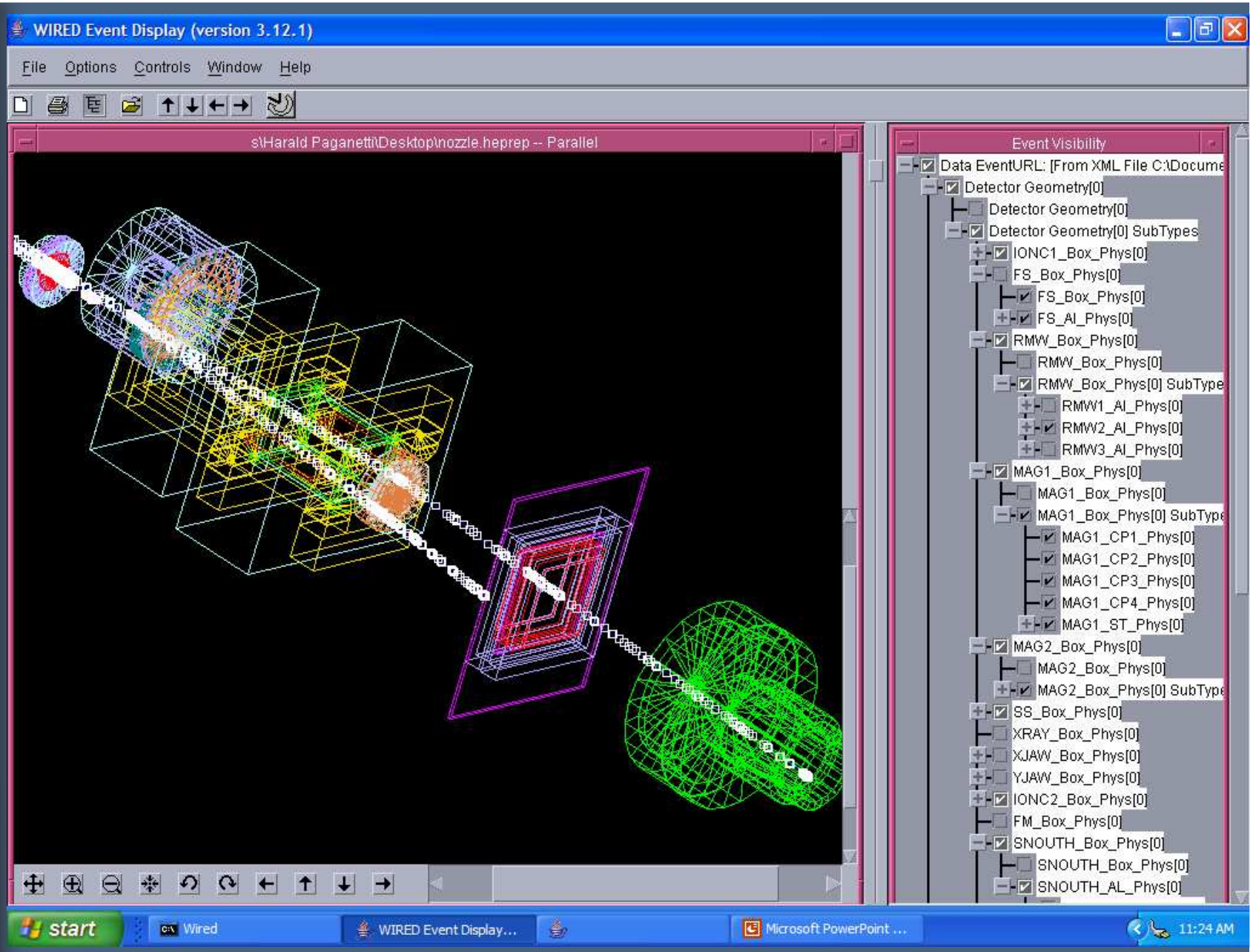

Monte Carlo model of the nozzle (~1000 objects)

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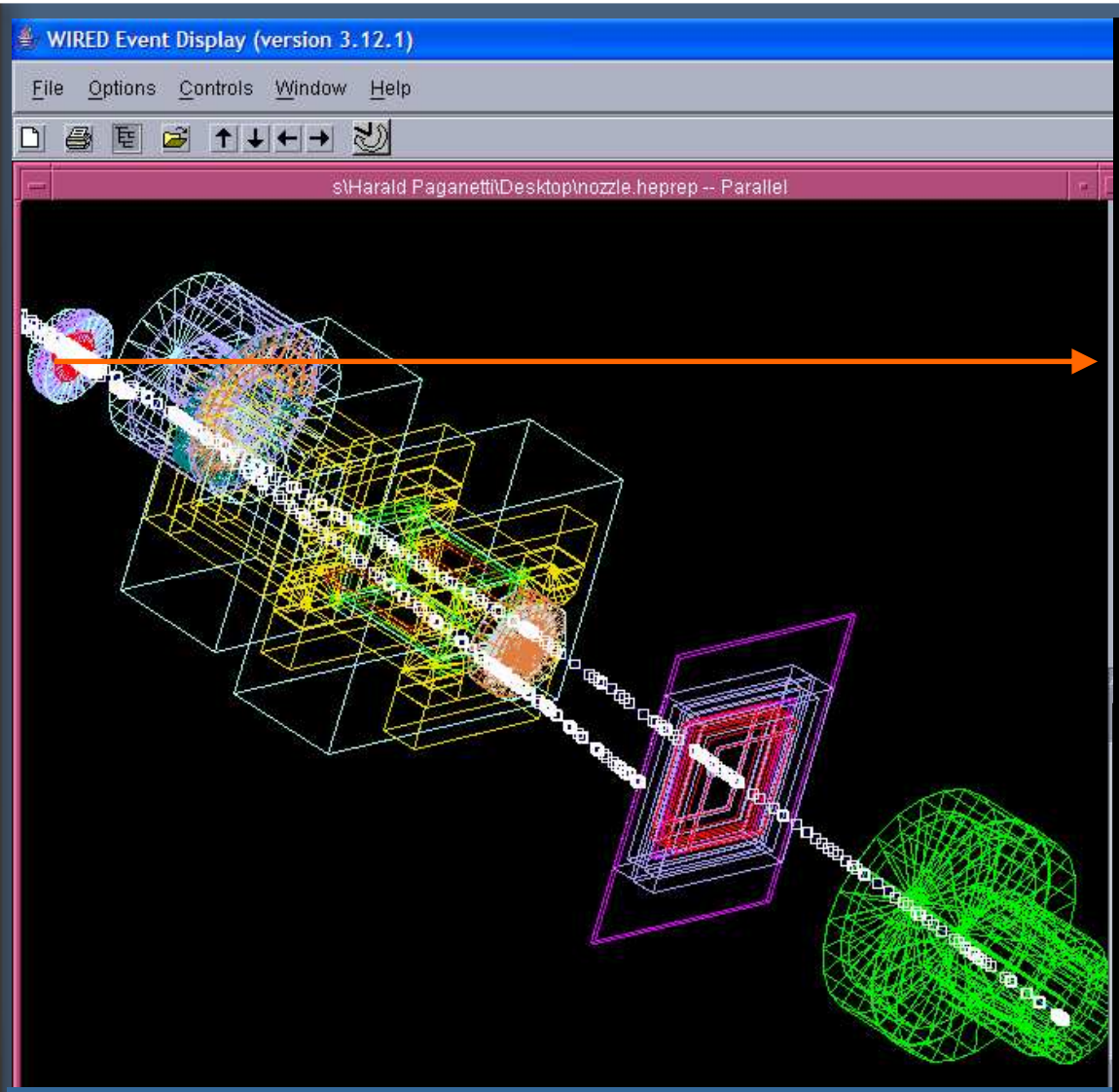

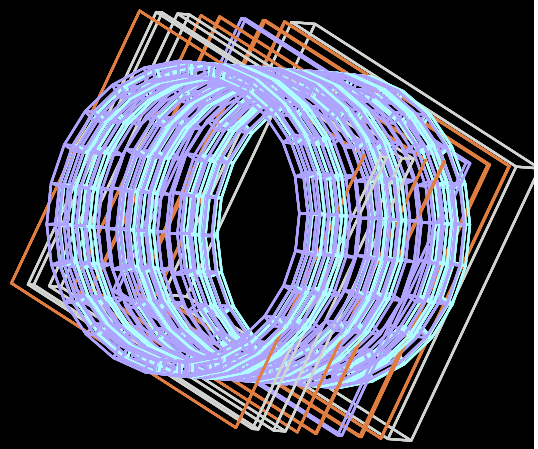

```
G4Box *FS = new G4Box(…);
G4LogicalVolume *FS_Log =
        new G4LogicalVolume(…);
new G4PVPlacement(…);
```

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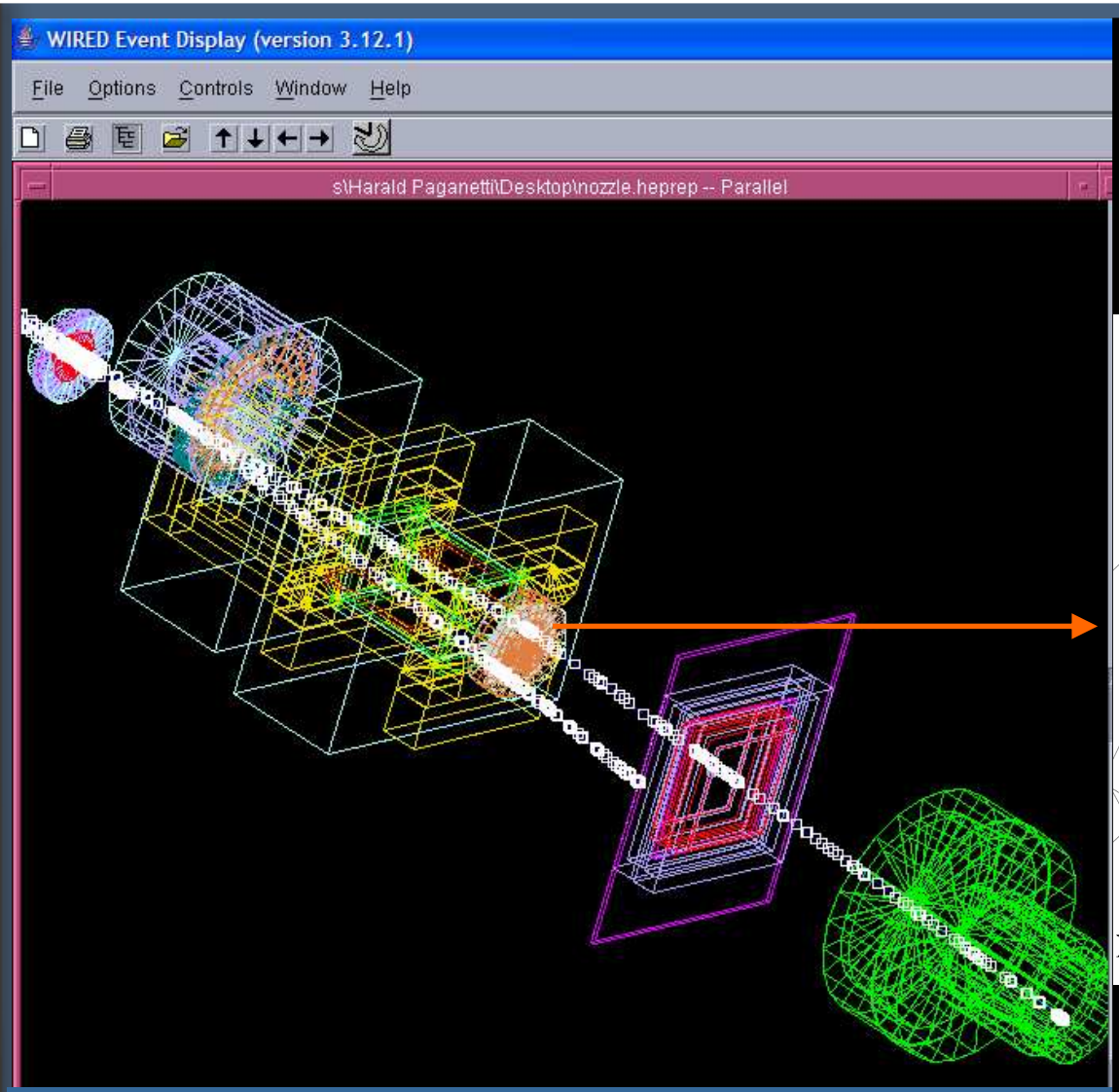

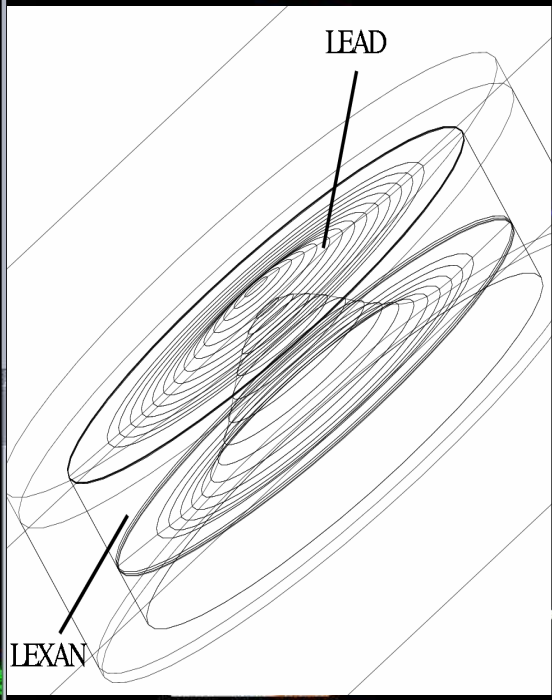

G4Polycone *SS2_BR1

= new G4Polycone(…)

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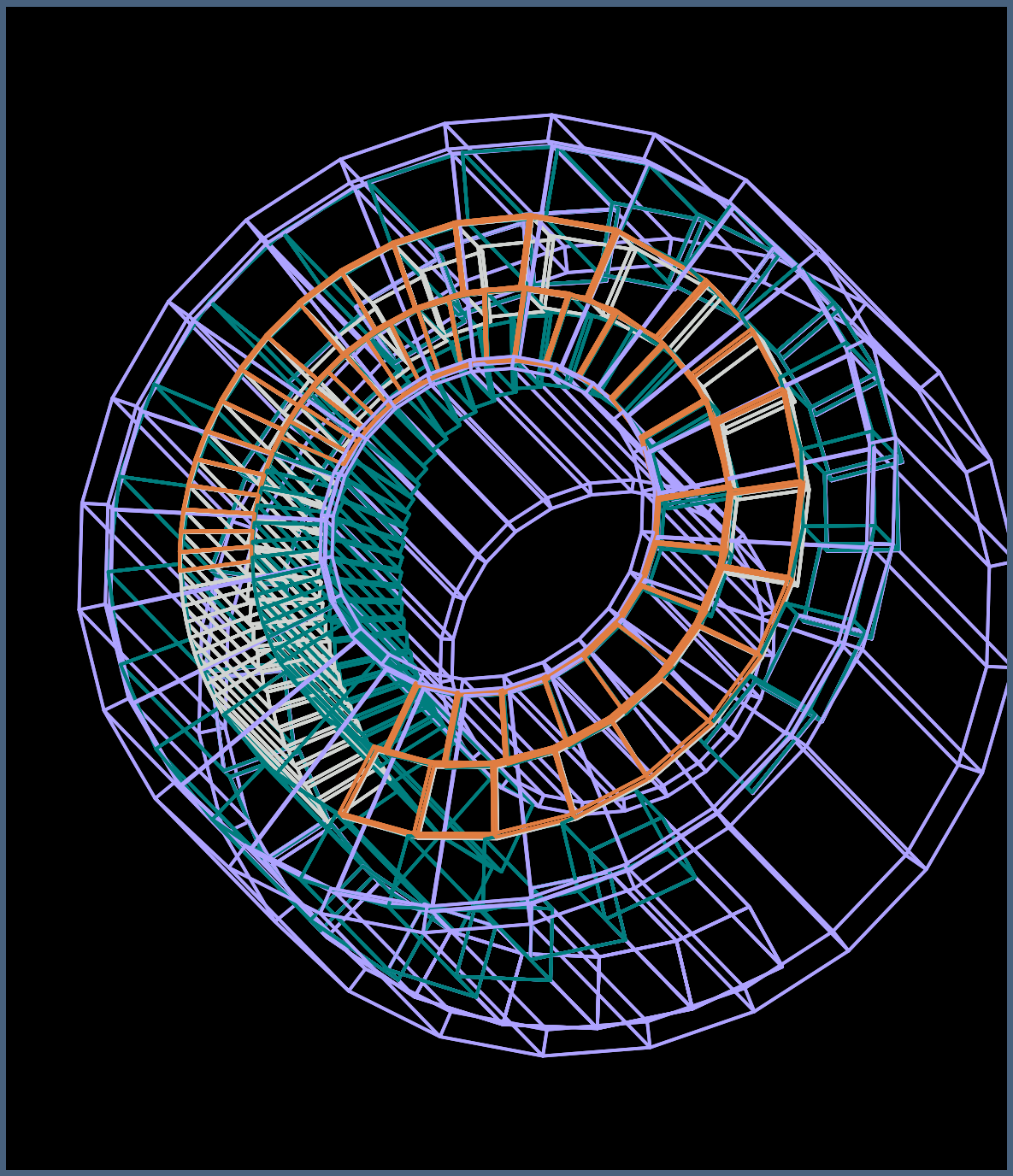
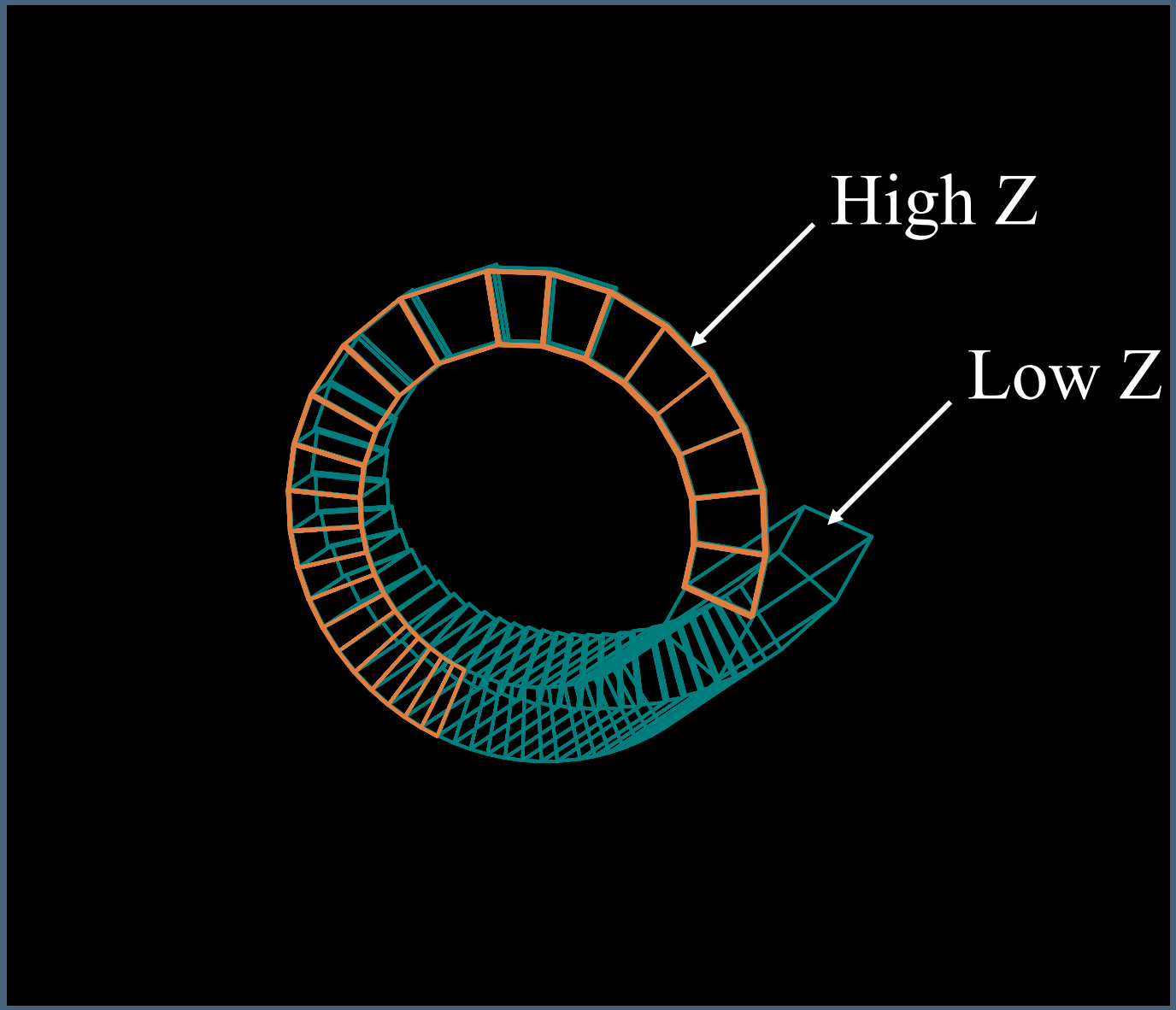


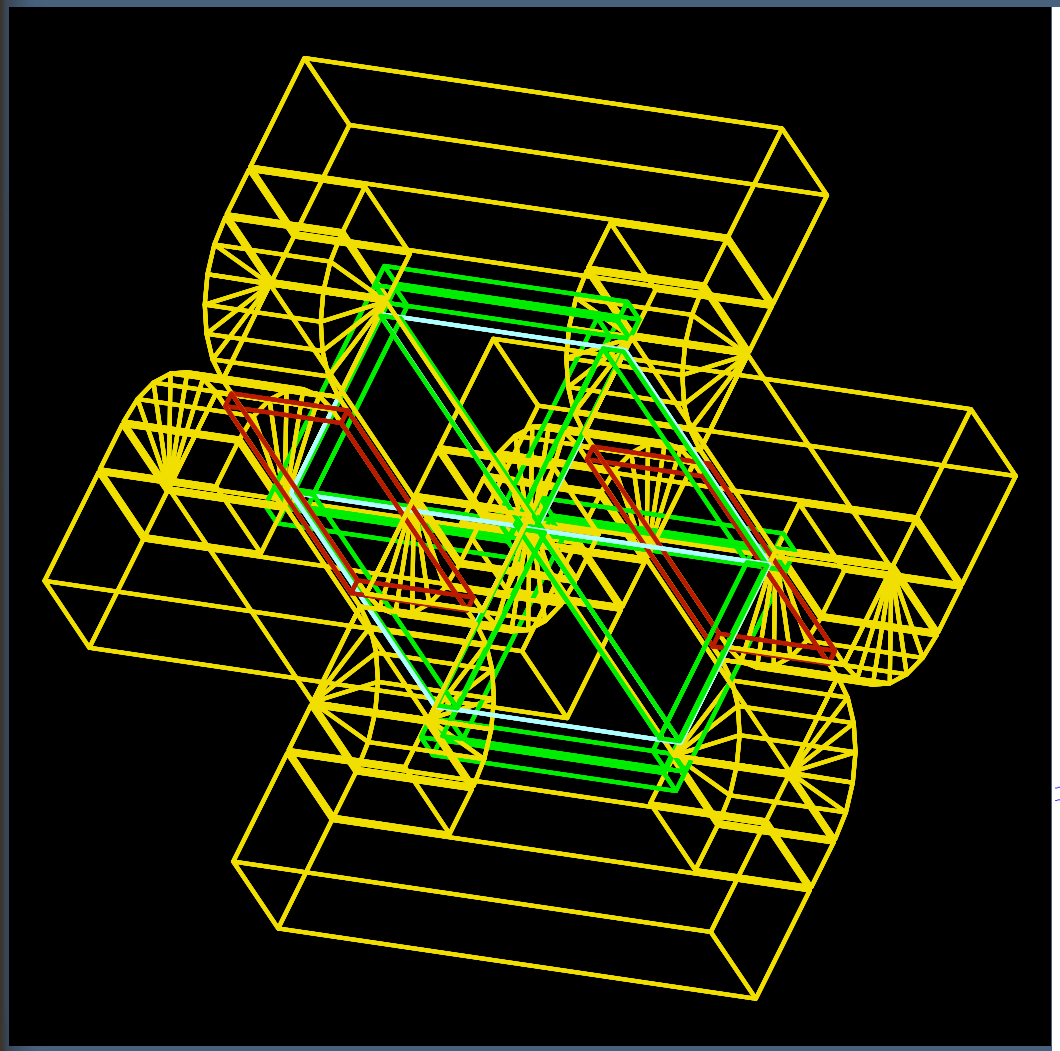
Geant 4

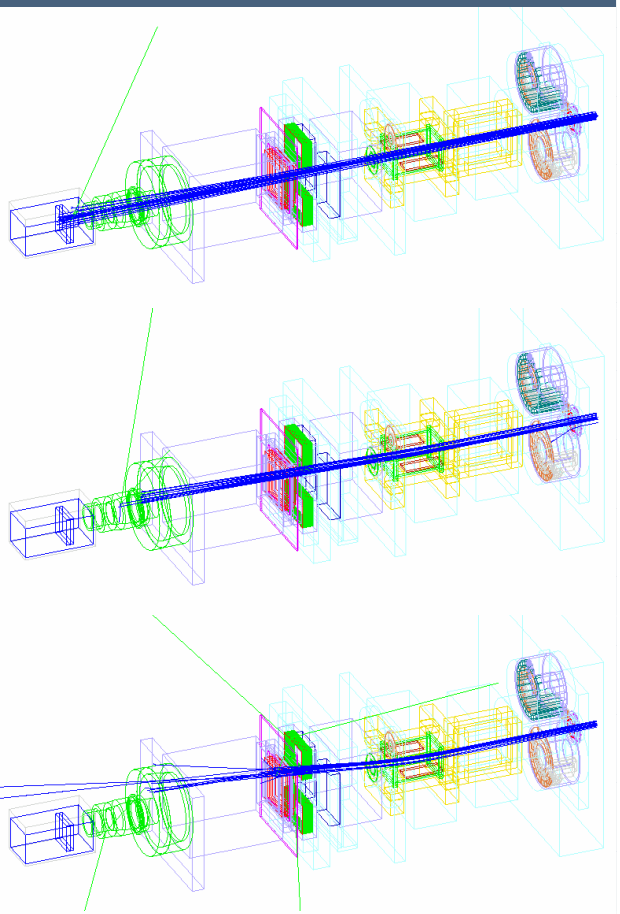
BORDEAUX 2005

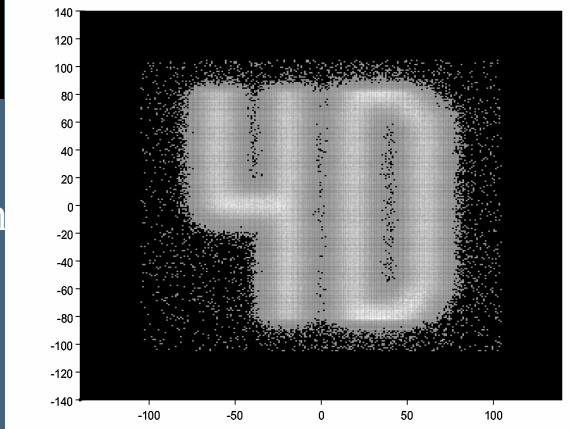


Geant 4

BORDEAUX 2005








```
G4FieldManager* fieldMgr
      = G4TransportationManager::GetTransportation
fieldMgr->SetDetectorField(MagneticFields);
fieldMgr->CreateChordFinder(MagneticFields);
fieldIsInitialized = true;
```

Geant 4

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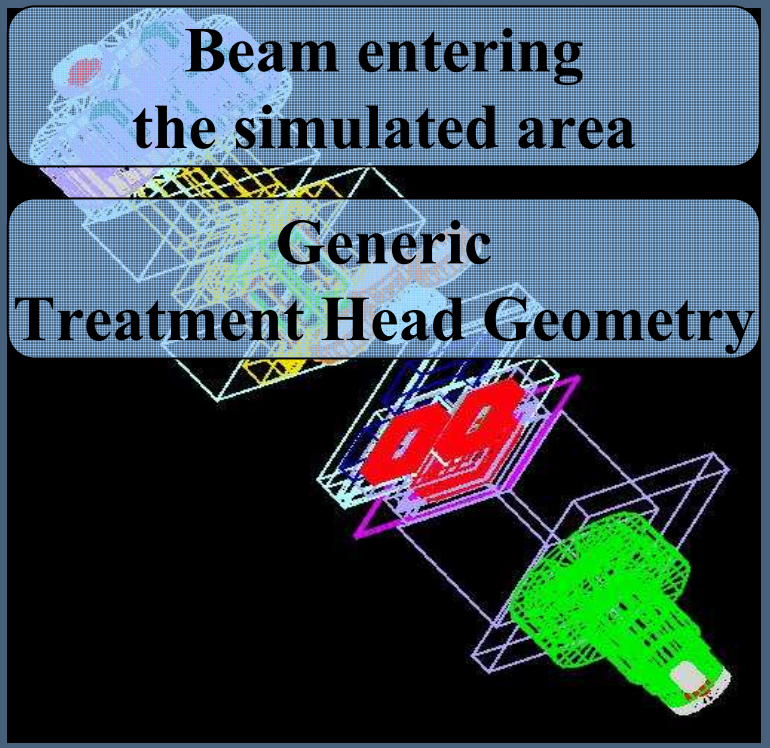
Clinical implementation of Monte Carlo dose calculation: strategies and challenges

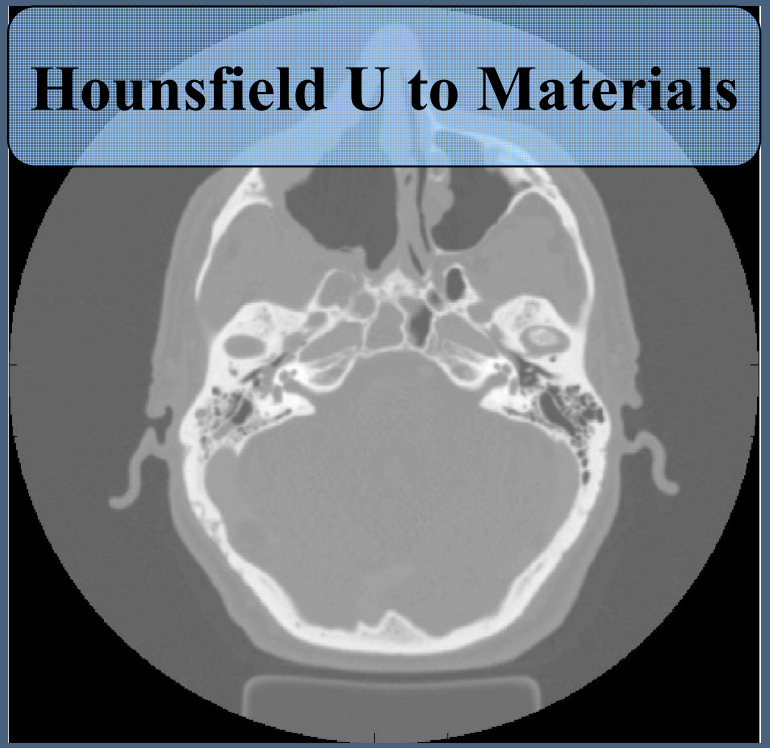
Physics Setup

Beam entering the simulated area

Generic Treatment Head Geometry



Hounsfield U to Materials



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Issues related to dose calculations on CT data:

– HU conversion –

Solution within the GEANT4 framework

- **Solution:**
  HU space is divided into 24 groups (Schneider et al.) with members of each group sharing the same element composition but differ in mass density

Modification of the GEANT4 source code

- **Dynamic assignment of mass density**
  Only one material is defined for each CT HU group.
  The composition of the material is preserved, but the mass density varies

~ 3000 materials (cross section sets)

– HU conversion –

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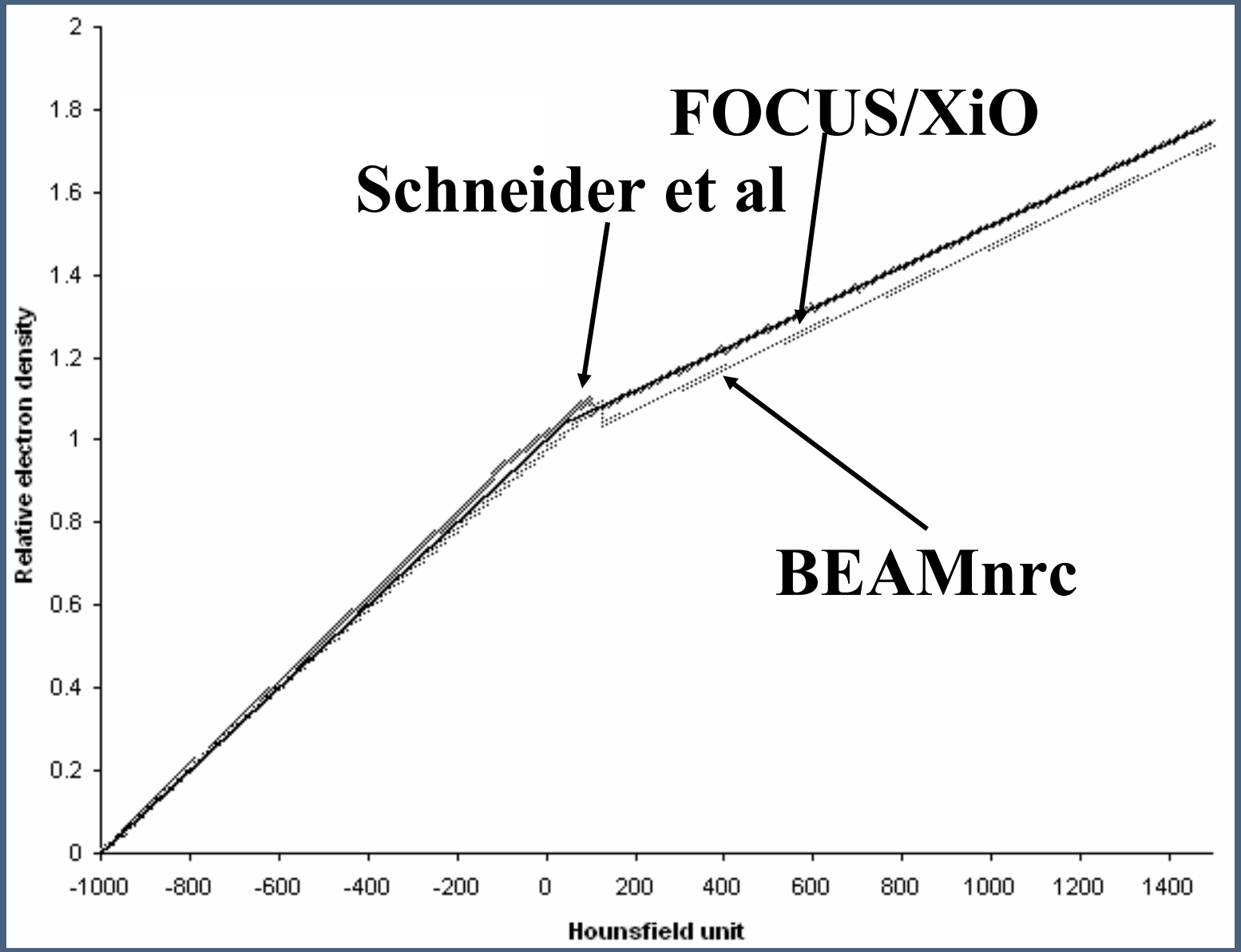

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Clinical implementation of Monte Carlo dose calculation: strategies and challenges

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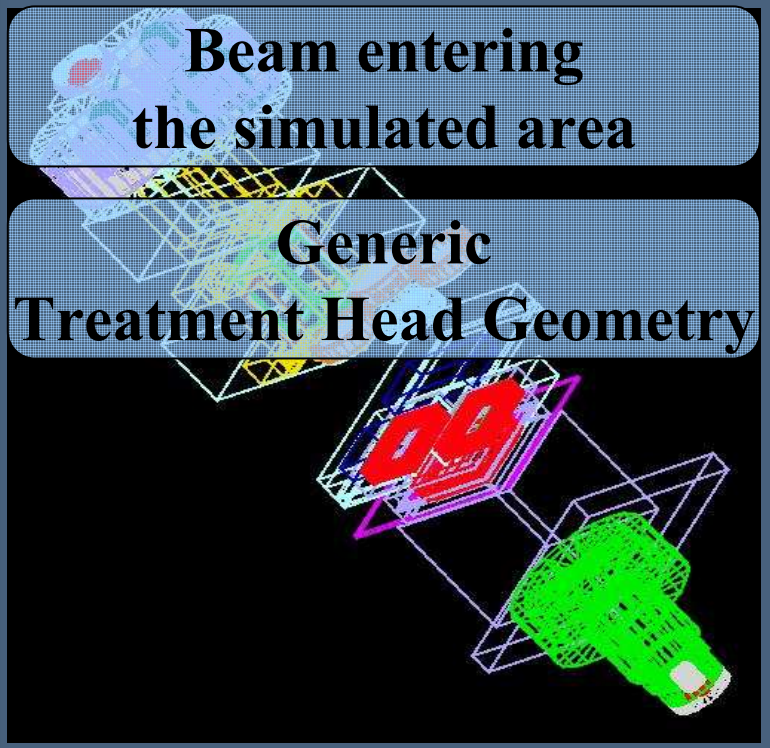
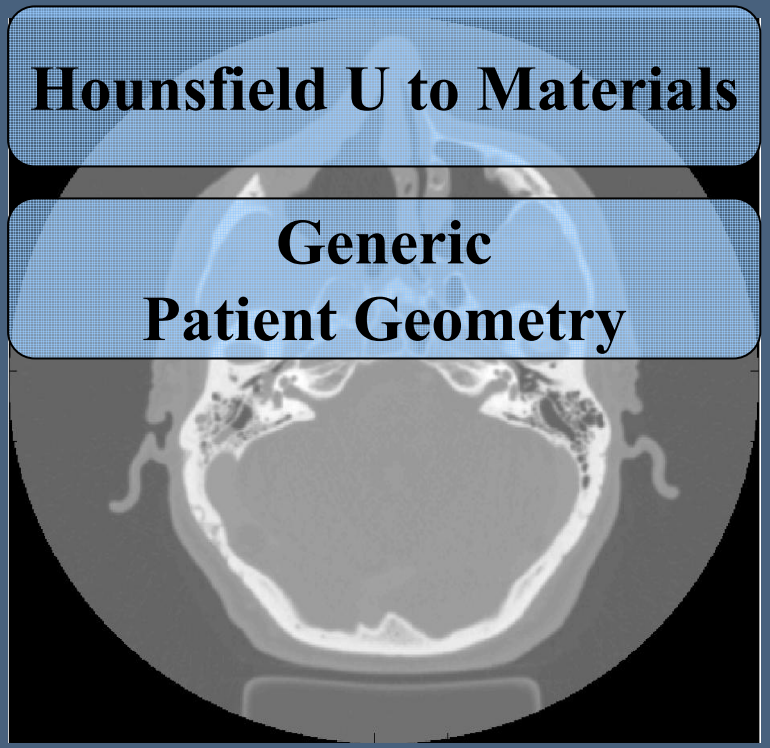


Hounsfield U to Materials

Generic Patient Geometry



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Issues related to dose calculations on CT data:

– Memory Consumption -

Solution within the GEANT4 framework

- **Parameterized volume:**
  allows the least computer memory usage for CT voxels (two bytes per voxel)

Modification of the GEANT4 source code

- **Much faster way to transport particles in CT voxels**
  Abandoned the general, but low-efficient algorithm in GEANT4.

Slow tracking through parameterized volumes

+ Cross section data are no longer loaded at material change but loaded once at initialization

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Clinical implementation of Monte Carlo dose calculation: strategies and challenges

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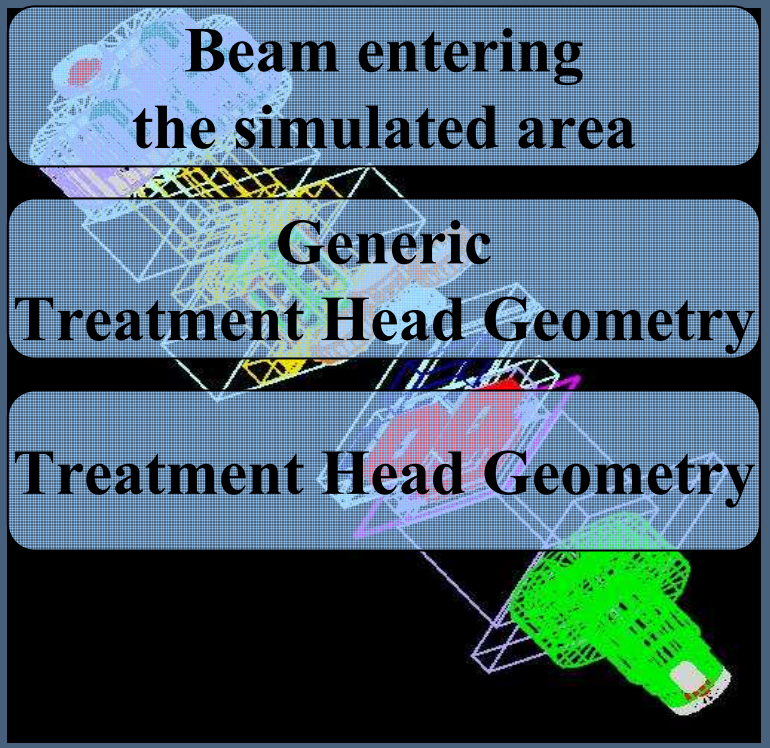
Treatment Head Geometry



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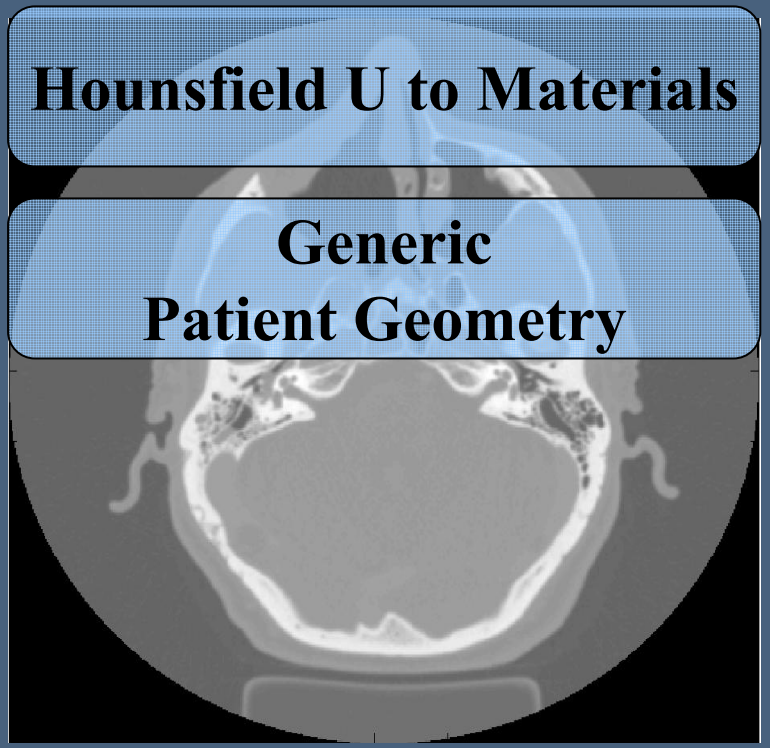

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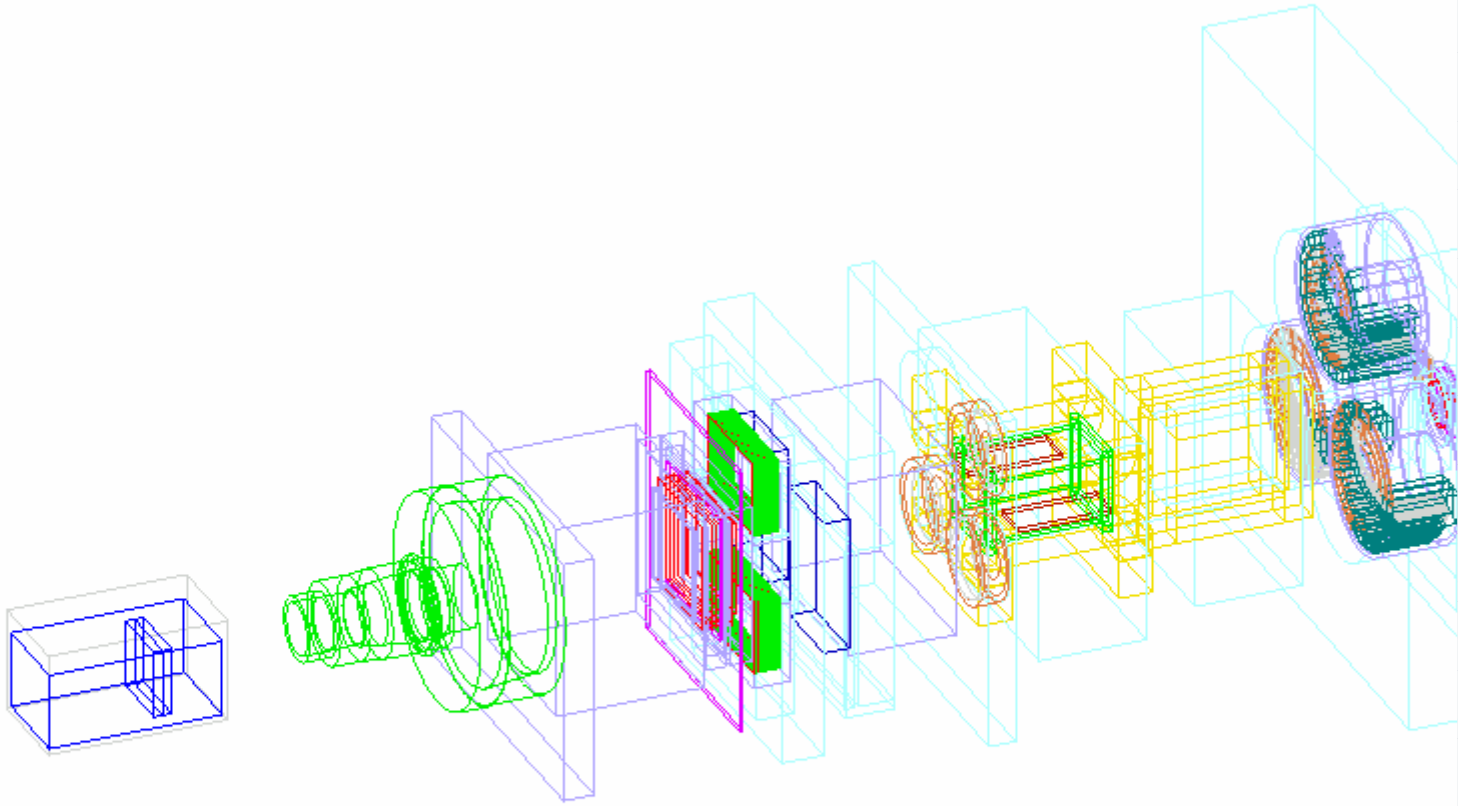

myDetector->Set_Snout(SnoutCmd->GetNewDoubleValue(newValues));

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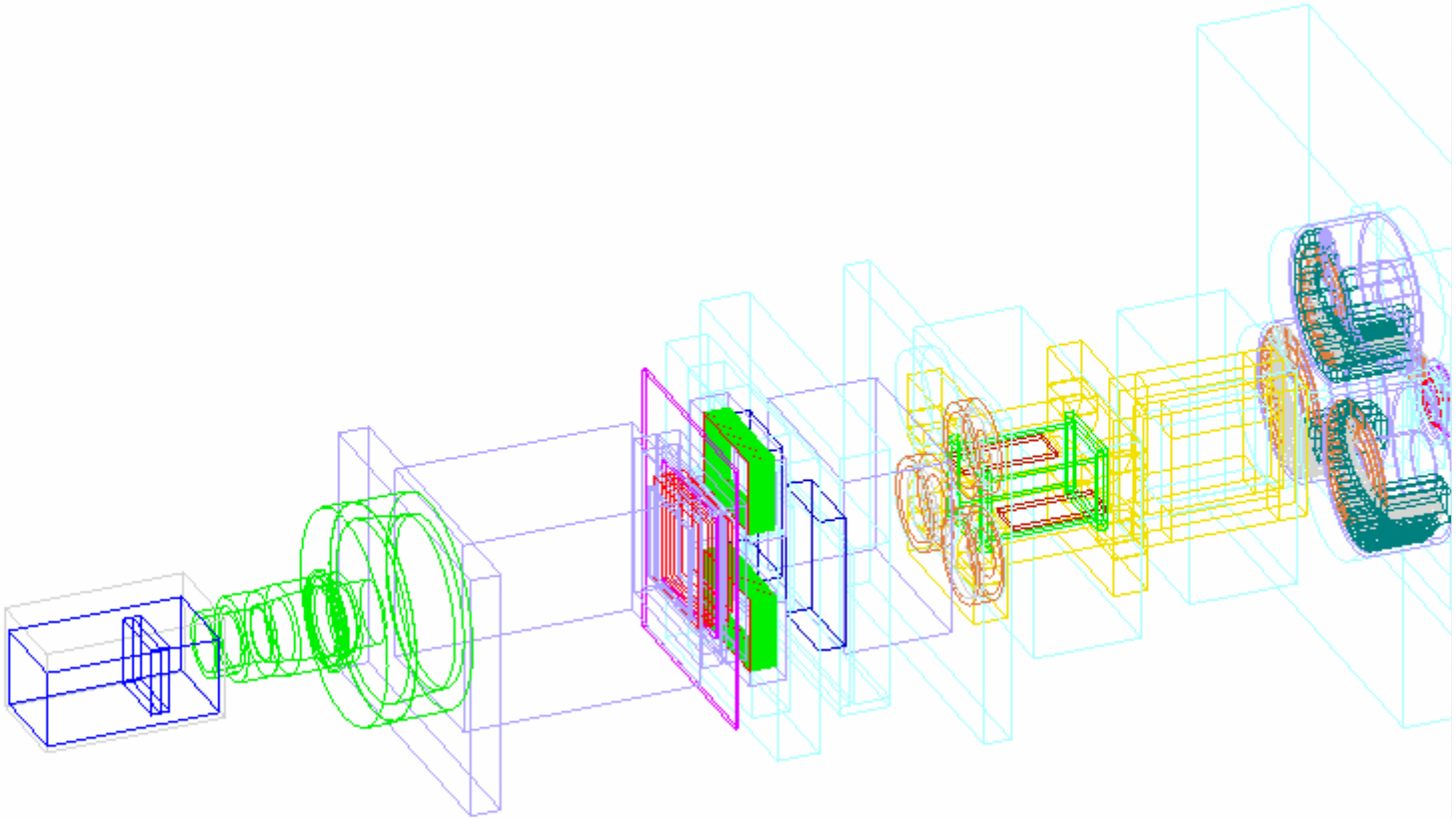

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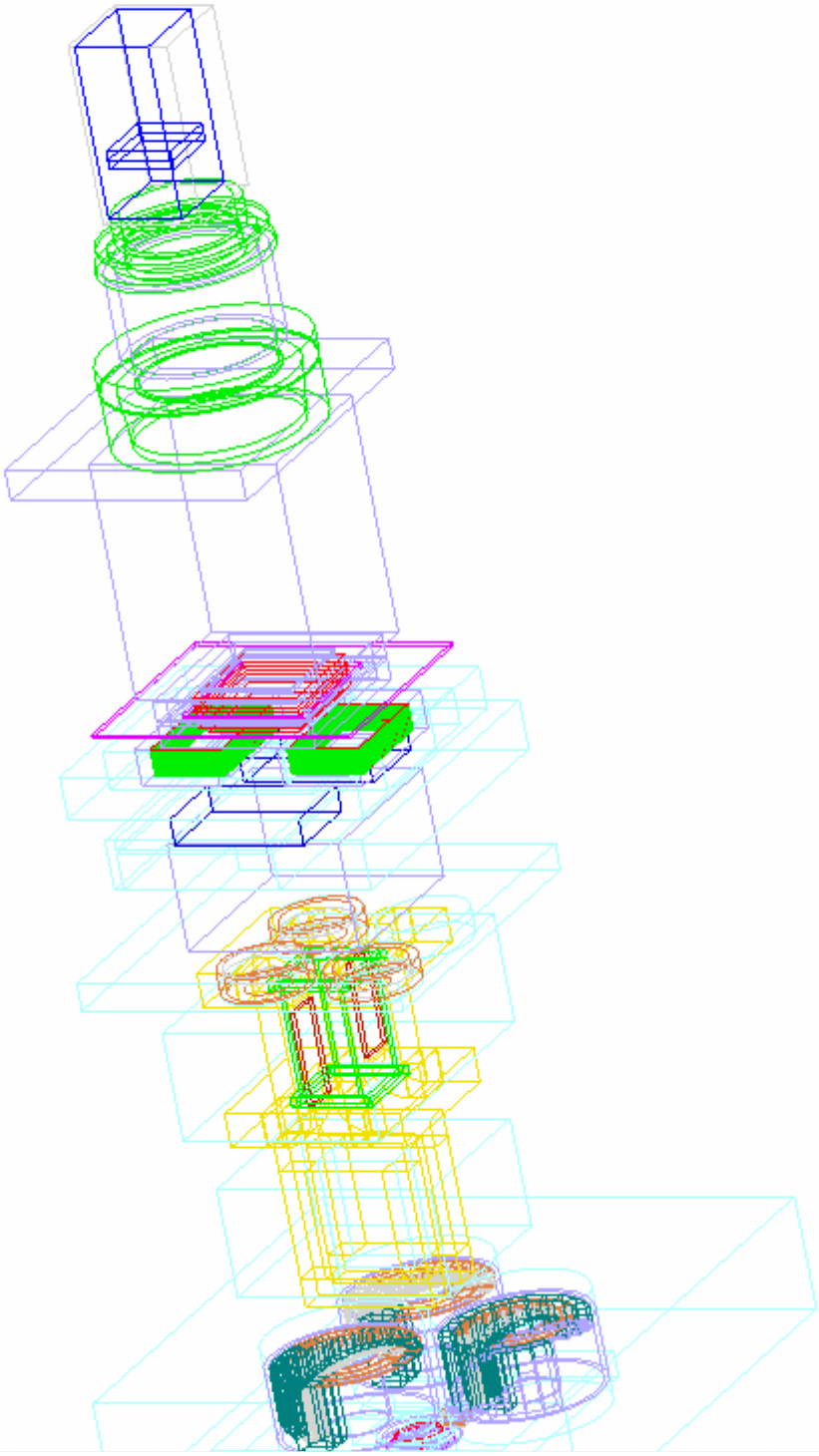
Geant4



Snout with Aperture and Compensator

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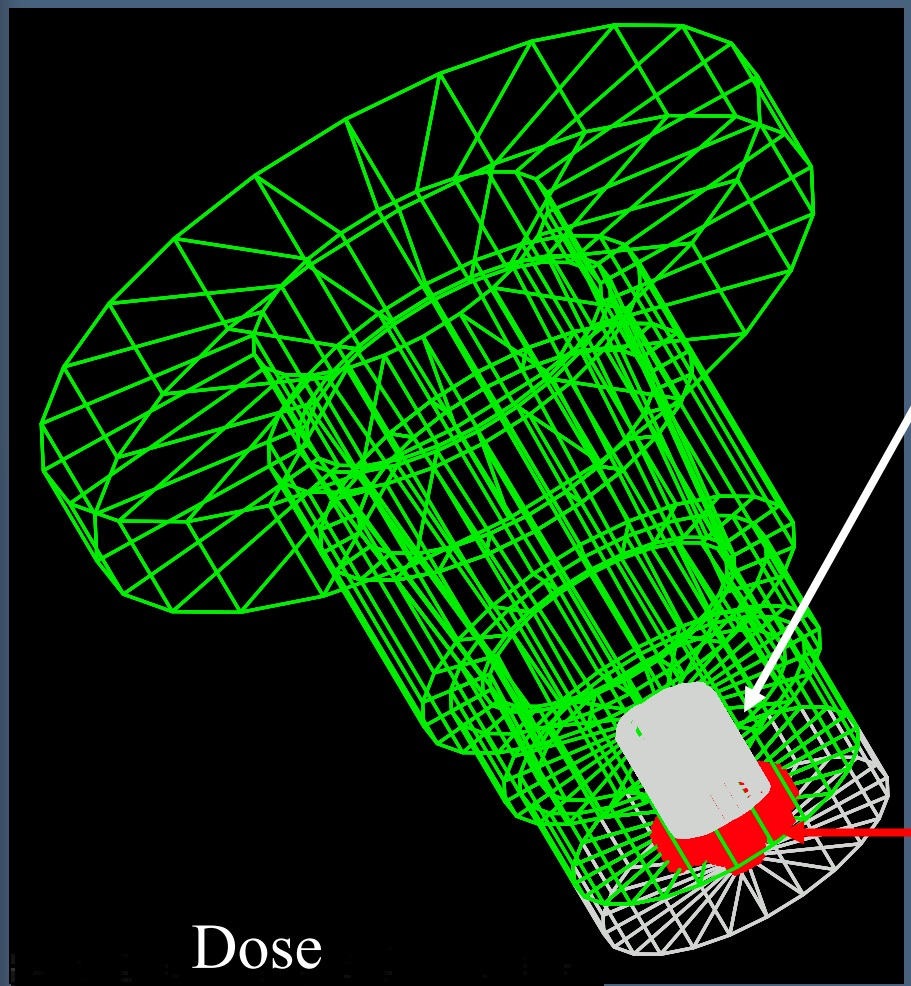

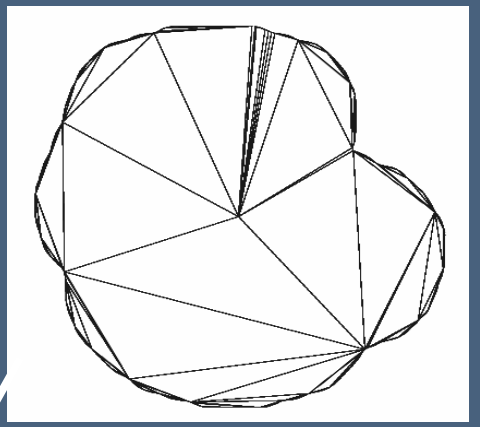

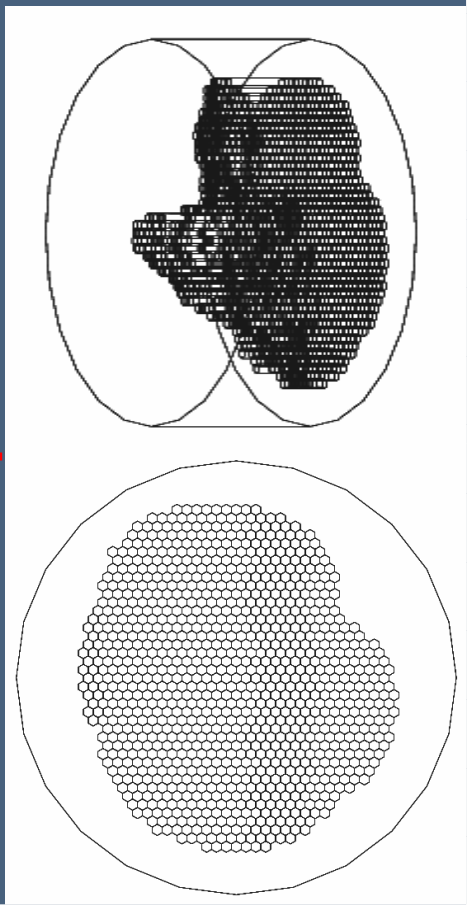

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Clinical implementation of Monte Carlo dose calculation: strategies and challenges

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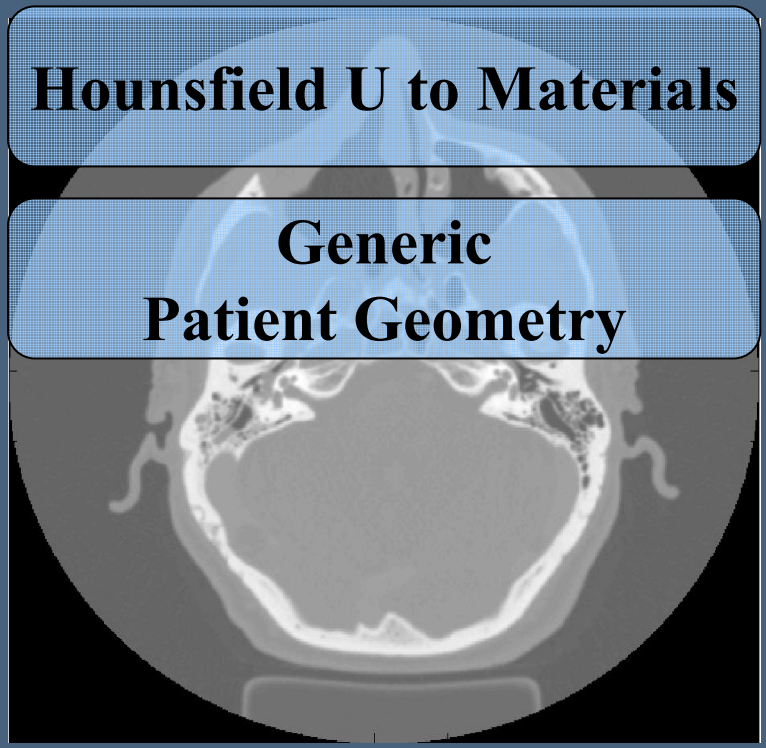
Generic Patient Geometry



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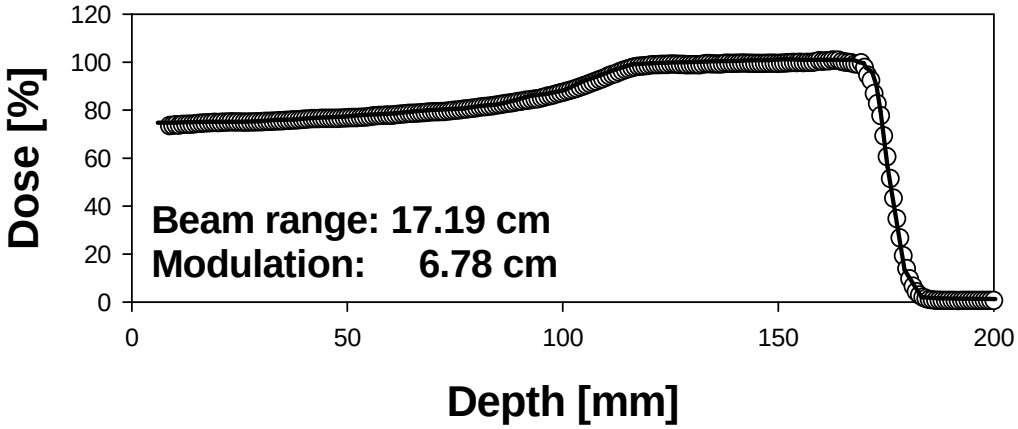
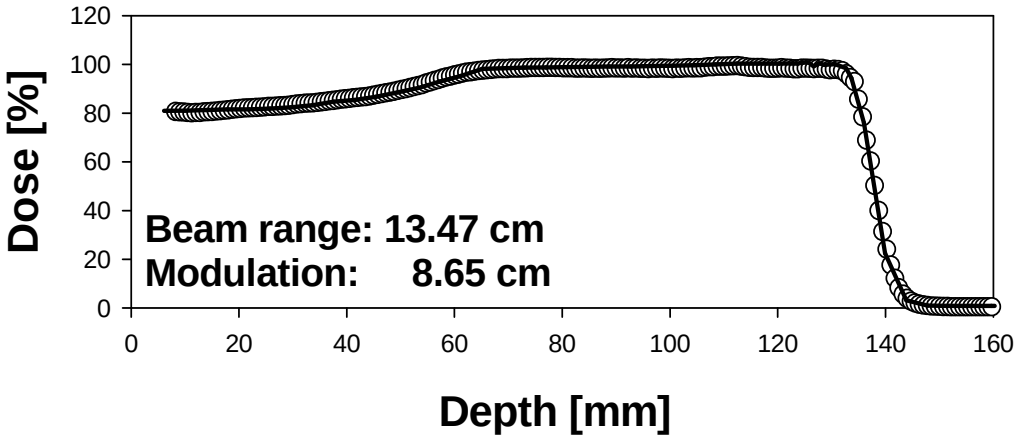
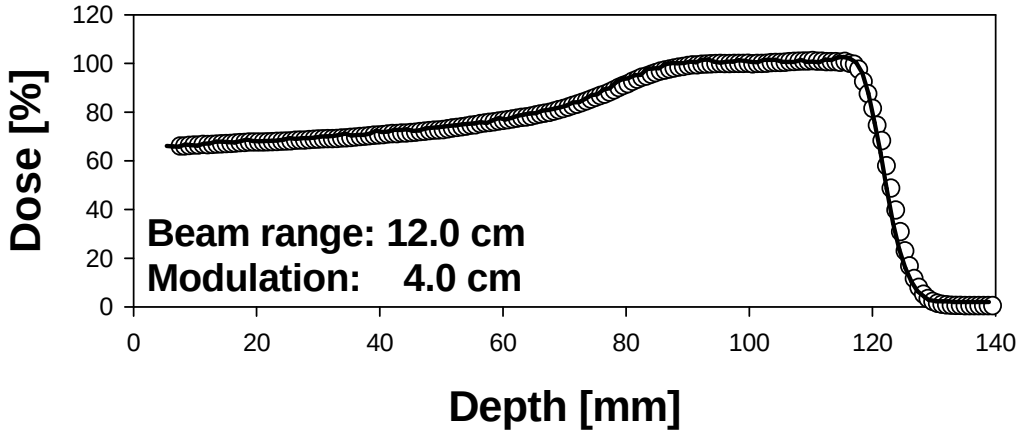
- scatterers
- wheel / track
- beam current
  modulation
- etc







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Clinical implementation of Monte Carlo dose calculation: strategies and challenges

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Patient Geometry

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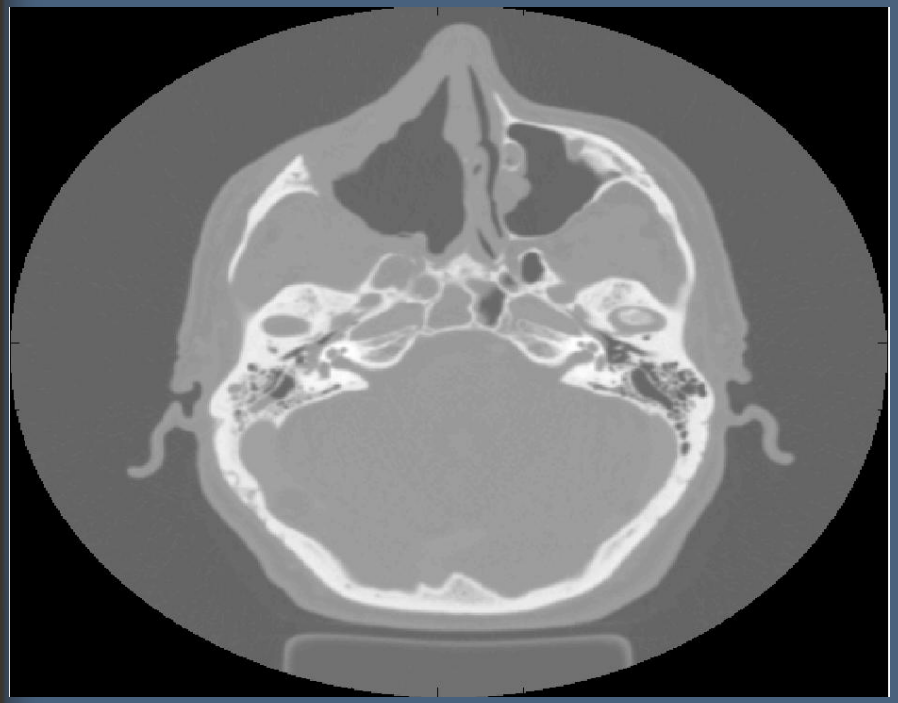
Example: Head and Neck CT scan

134 CT slices, 512 × 512 voxels/slice,
0.488 mm × 0.488 mm × 1.25/2.5 mm



Six fields:

	Gantry	Couch	ISO
AP1A	0º	0º	1
AS1A	65º	270º	1
RS1A	305º	50º	1
RA1A	295º	0º	2
RS2A	300º	60º	2
AS2B	90º	270º	3

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Format: DICOM or planning program internal

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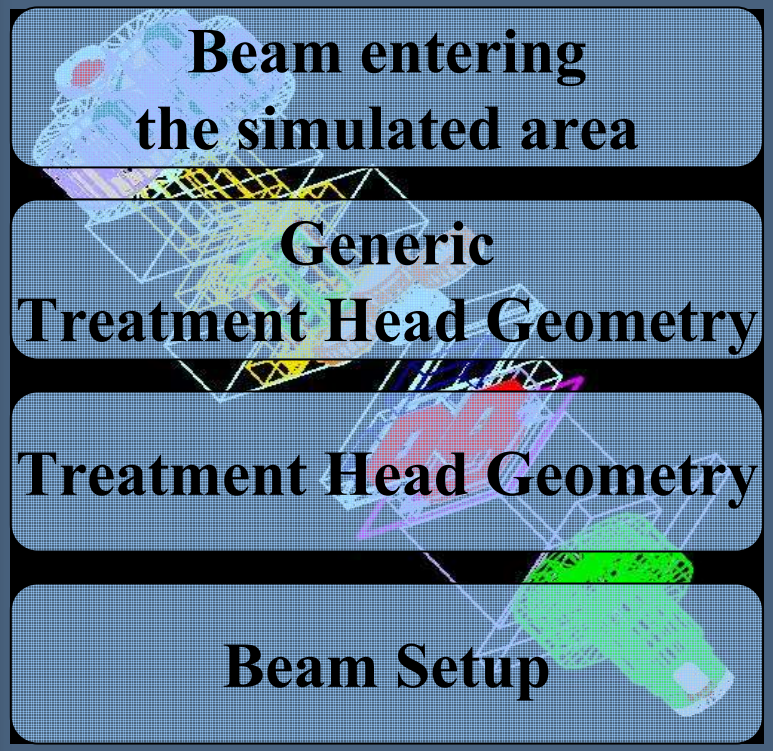
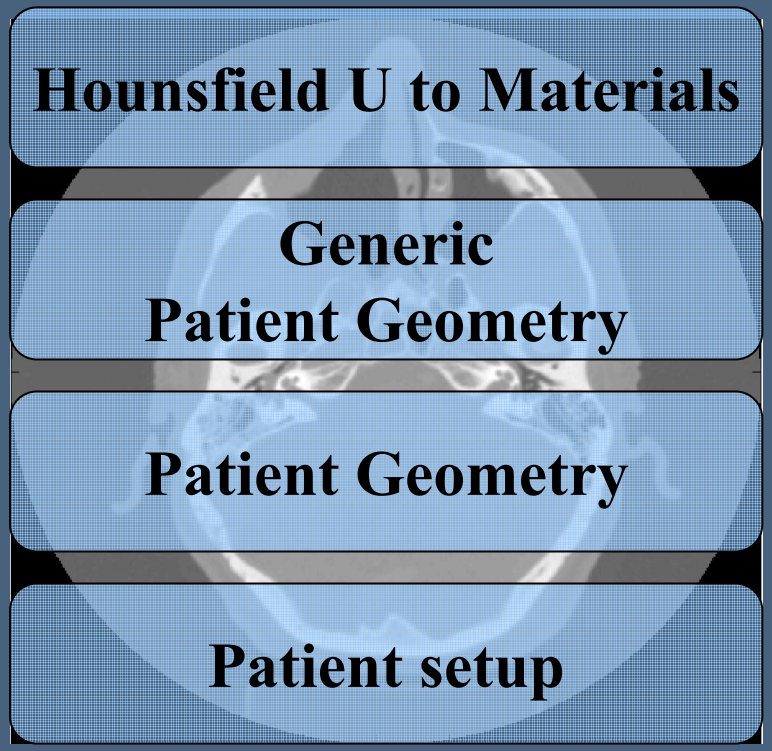
Clinical implementation of Monte Carlo dose calculation: strategies and challenges

Physics Setup





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Gantry Angle

Patient Couch:
Position XYZ
Rotation
Pitch
Roll

Air Gap

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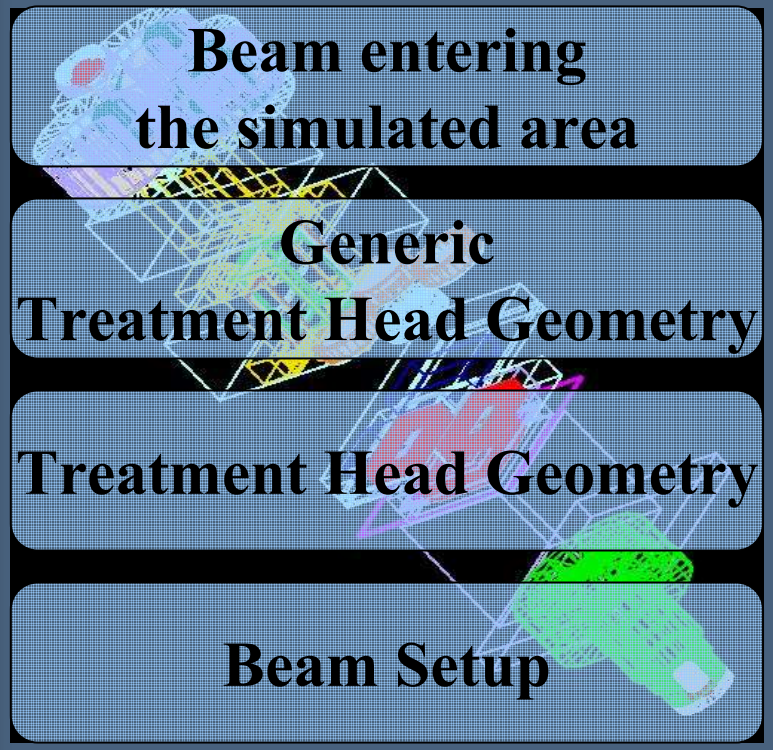
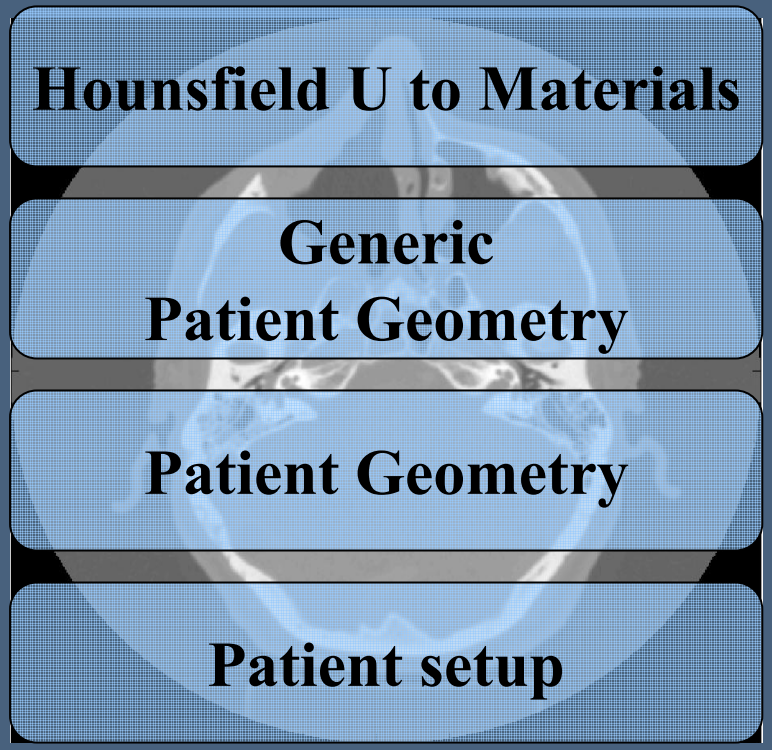
Clinical implementation of Monte Carlo dose calculation: strategies and challenges

Physics Setup





Absolute dosimetry

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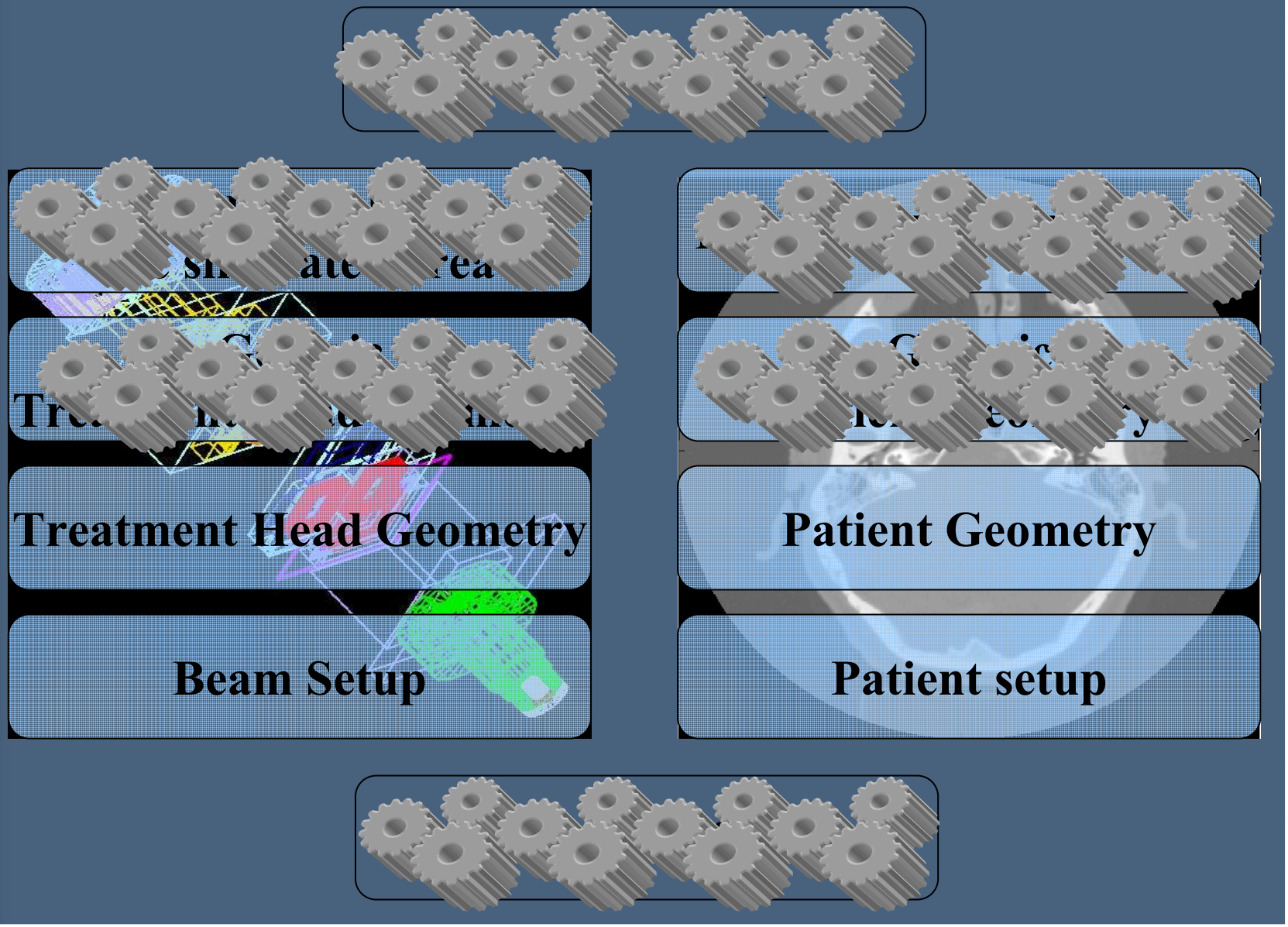
Clinical implementation of Monte Carlo dose calculation: strategies and challenges



Geant 4

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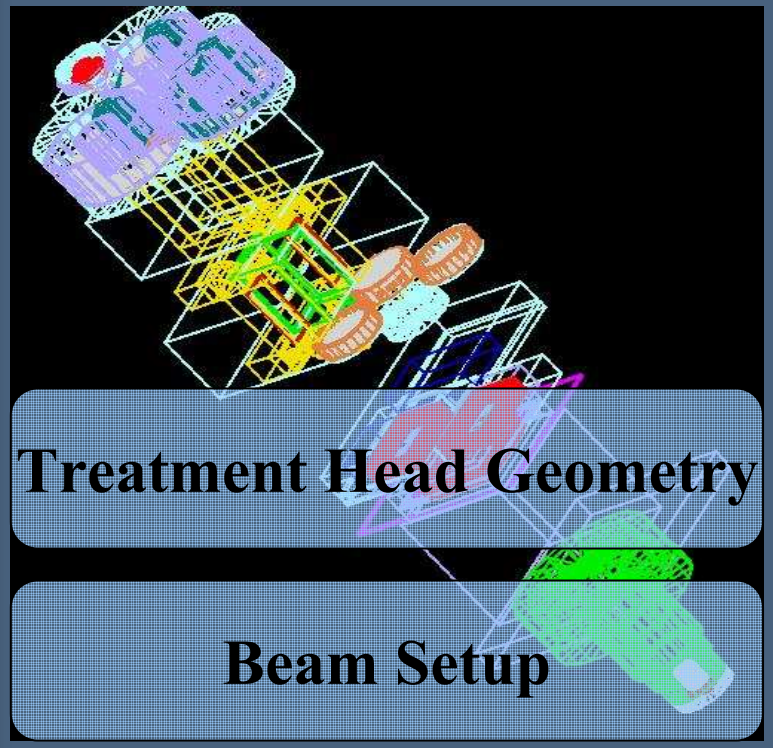
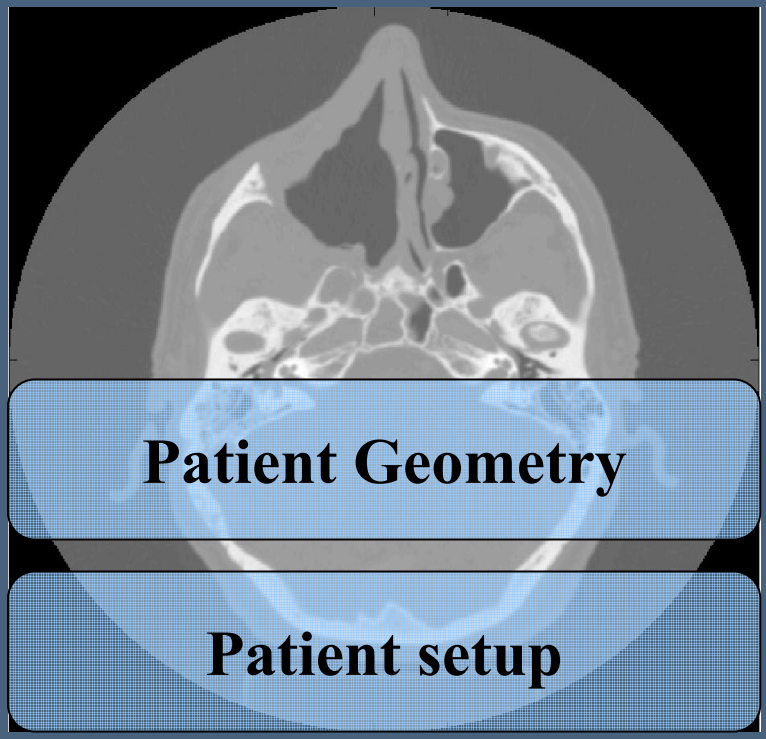
Clinical implementation of Monte Carlo dose calculation: strategies and challenges



Treatment Head Geometry

Beam Setup



Patient Geometry

Patient setup

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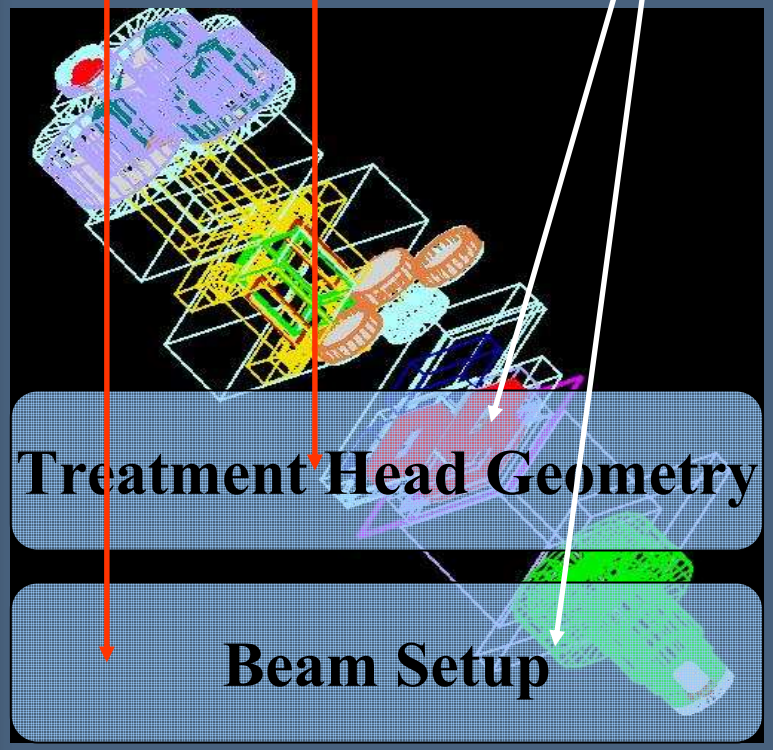
Treatment Control System

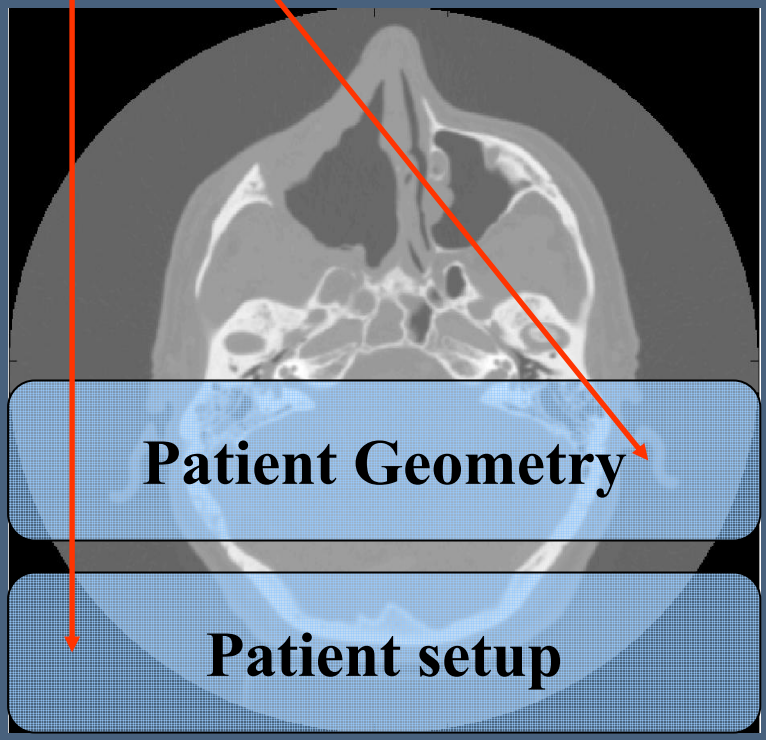
Treatment Planning FOCUS/XiO

Patient Database



Treatment Head Geometry

Beam Setup



Patient Geometry

Patient setup

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GUI program

```
Dir | space:/diskarray/stripe7/proton_data/patient
Number of slices| 134
[Xmin, Xmax]| -101.6,  104.3
[Ymin, Ymax]|  -90.6,  161.9
[Zmin, Zmax]| -113.3,  125.6
Patient Treatment Orient | Head In
ACTIVE |  ON
AIR GAP |  2.0
APERTURE ID |  ASV2CTV
APERTURE Iso Dist |  21.87
APERTURE STATE |  FROZEN
BEAM TYPE |  PROTON
BEAM WEIGHT |  1638.00
COLLIMATOR ANGLE |  -0
COMP BLK ID |  NONE
COUCH ANGLE |  270
FROZEN DATE |  2003-09-30 19:52:27
GANTRY ANGLE |  65
ISOCENTER |  -16.400, 25.000, 48.600
MACHINE ID |  NPTCclinical
MLC EXISTS |  No
MODULATION |  12.340
RANGE |  19.200
RANGE COMP ID |  ASV2CTV
SAD |  227.00
SNOUT ID |  124
SOURCE SURFACE DIST |  218.1
STATE |  FROZEN
TRACK OPTION |  A6
```

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Input file preparation: patient settings

```
# Parameters for patient positioning
/nozzle/GantryAngle 305
/nozzle/CouchAngle 50
/nozzle/XIsoCMS -1.64
/nozzle/YIsoCMS 2.5
/nozzle/ZIsoCMS 4.86
/nozzle/CTFirstSliceCenter_CMS 16.187
/nozzle/CTLastSliceCenter_CMS -9.063
/nozzle/VoxelX 512
/nozzle/VoxelY 512
/nozzle/VoxelZ 134
/nozzle/VoxelDimX 0.0488
/nozzle/VoxelDimY 0.0488
/nozzle/VoxelDimZ 0.25
/nozzle/SliceNo 8
/nozzle/SliceThickness 0.125
/nozzle/SliceNo 9
/nozzle/SliceThickness 0.1875
/nozzle/SliceNo 38
/nozzle/SliceThickness 0.25
/nozzle/SliceNo 39
/nozzle/SliceThickness 0.1875
/nozzle/SliceNo 94
/nozzle/SliceThickness 0.125
/nozzle/SliceNo 95
/nozzle/SliceThickness 0.1875
/nozzle/SliceNo 134
/nozzle/SliceThickness 0.25
/nozzle/FilePath  /exports/jiang/monte_carlo/geant4.5.0_executables/Linux-g++/
/nozzle/CTFileName William_HeadIn
/nozzle/update
# modify CT position
/nozzle/CTPositionX  0
/nozzle/CTPositionY  0
/nozzle/CTPositionZ  9.5
/nozzle/ModifyCTPosition
```

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Input file preparation: nozzle settings

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- Range
- Modulation
- Field radius
- Dose rate

```
# Particle Generator Settings
# initial proton energy in MeV
/gun/ENER 180.406 MeV
/gun/ESPR 0.8
/gun/ANGU 0.0032
# beam spot size
/gun/SPOT_CX 0 cm
/gun/SPOT_CY 0 cm
/gun/SPOT_X 0.65 cm
/gun/SPOT_Y 0.65 cm
# Treatment Room
/nozzle/Gantry 1
# First Scatterer
/nozzle/Lollipop_1 0
/nozzle/Lollipop_2 1
/nozzle/Lollipop_3 1
/nozzle/Lollipop_4 0
/nozzle/Lollipop_5 0
/nozzle/Lollipop_6 1
/nozzle/Lollipop_7 0
/nozzle/Lollipop_8 0
/nozzle/Lollipop_9 1
# Modulator Wheel
/nozzle/RM_number 5
/nozzle/RM_track 5
# Second Scatterer
/nozzle/SS_number 2
# Magnetic Fields
/nozzle/magnets/Mag1 0
/nozzle/magnets/Mag2 0
/nozzle/MagnetSteps 20.0 mm
# Jaw Openings
/nozzle/Xjaw 14.5
/nozzle/Yjaw 11.9
# Snout
/nozzle/Snout_Size 12
/nozzle/Snout_Extension 20
```

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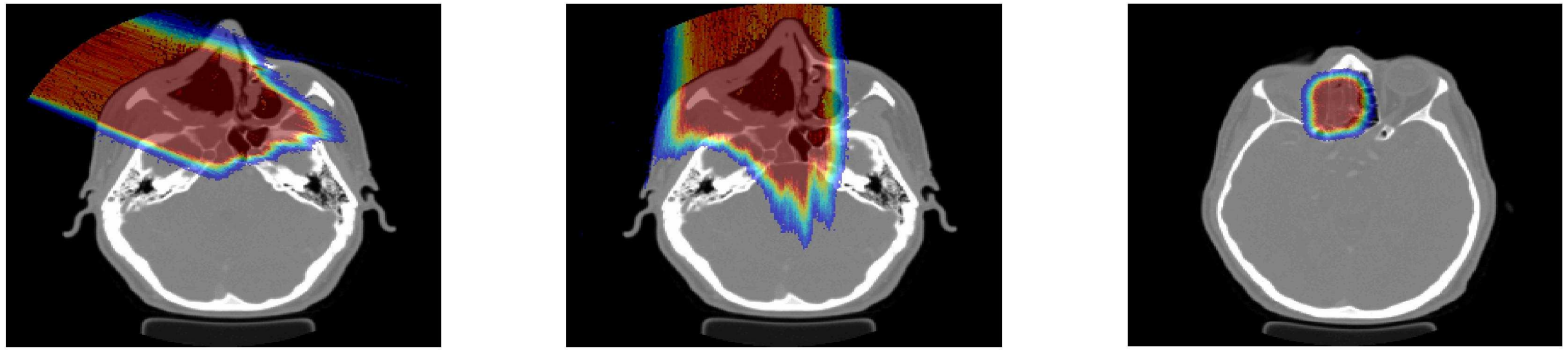
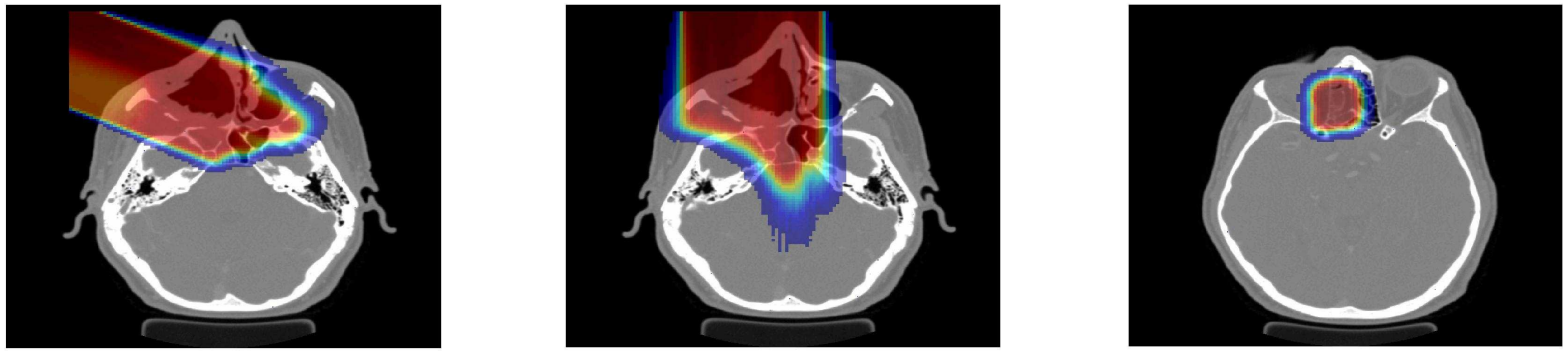
Monte Carlo dose calculation, Example 1: Paranasal sinus



Monte Carlo



FOCUS

>95% prescription dose (dark red), >80% (red), >70% (orange), >60% (yellow), >50% (green), >30% (blue), ≤30% (dark blue)

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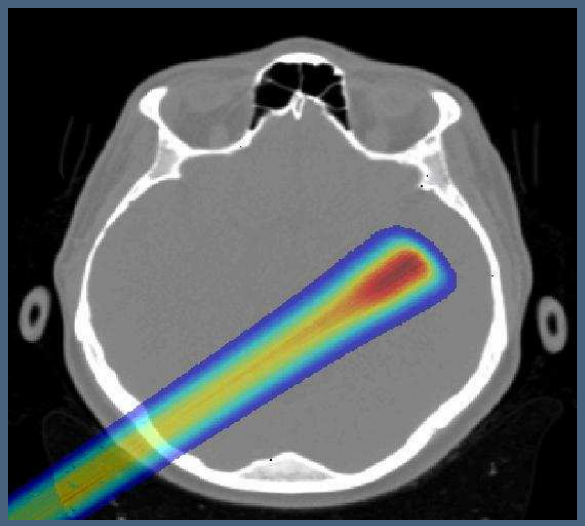
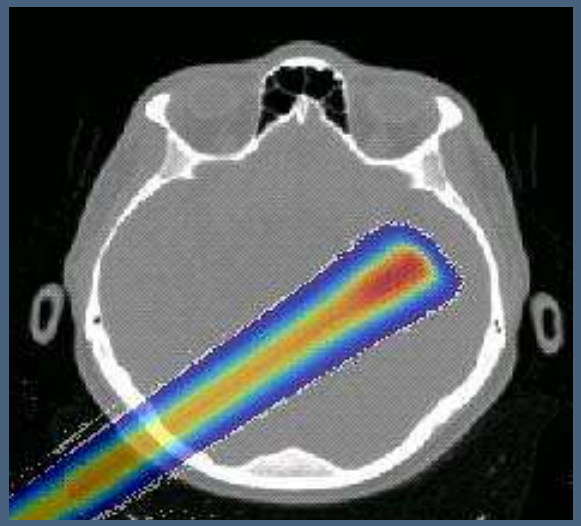
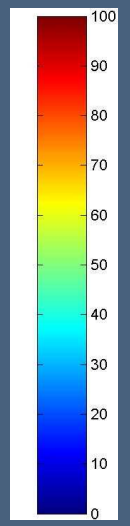
Monte Carlo dose calculation, Example 2: Radiosurgery (4 fields)

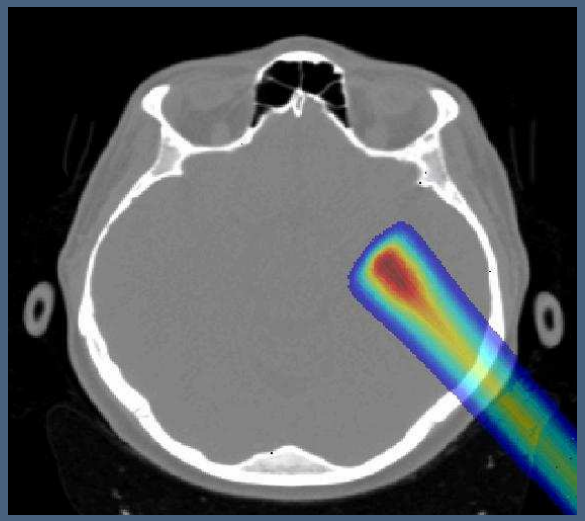


FOCUS

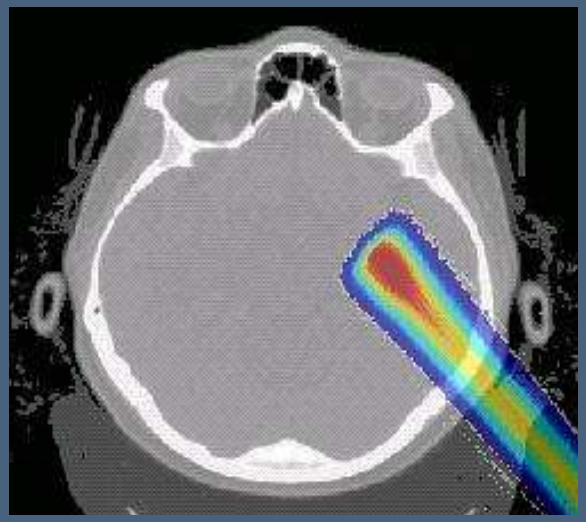


Monte Carlo

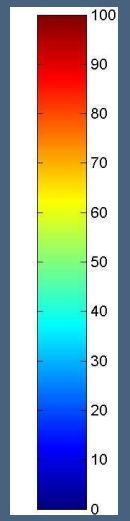




FOCUS



Monte Carlo



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Conclusion

Routine use of (proton) Monte Carlo dose calculation (using GEANT4)

- **requires work in many different areas of treatment head and patient modeling**
- **requires establishing a link between treatment planning and Monte Carlo**
- **is being done at MGH**

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