

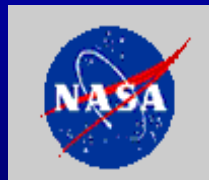


The Use of Voxel-Based Phantoms in FLUKA

Embedding Voxel Geometries within FLUKA from
Raw CT-Scans

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⁸University of Leipzig, Germany

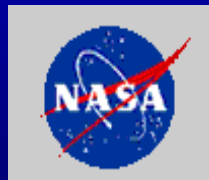




The NASA Project

FLEUR-S [Fluka Executing Under Root – Space]

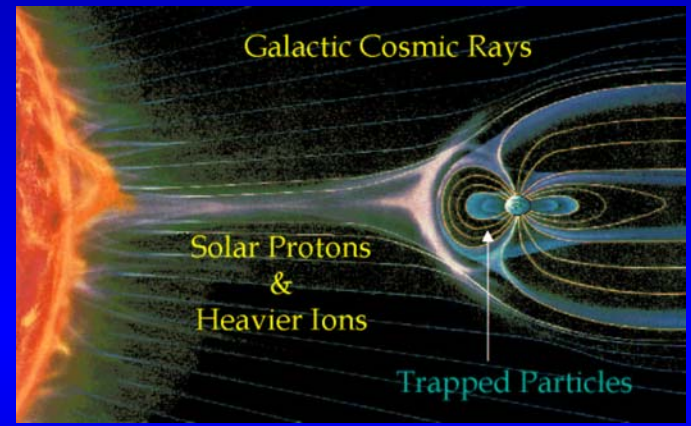
- This project was initiated by, and has been primarily funded by **NASA** in order to develop an integrated Monte-Carlo based transport code to be used in the simulation of the Space Radiation environment.
- **FLUKA** was chosen for the basic transport framework, with **DPMJET** (2.5 & 3 for energies > 5 GeV/A) and **RQMD** (for energies from 100 MeV/A up to 5 GeV/A) have been integrated into the code to provide an internal event generator for nucleus-nucleus interactions.





NASA's Interests

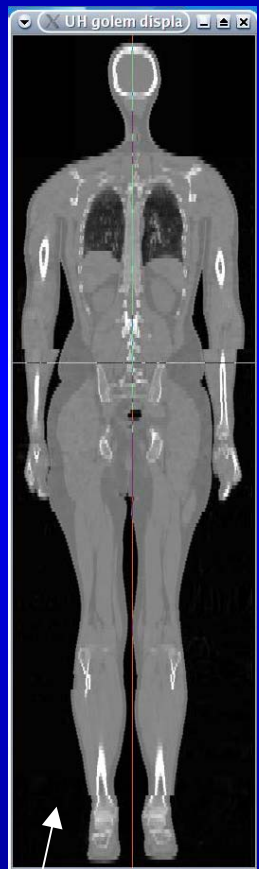
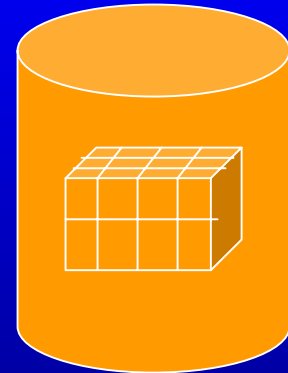
- The **Space Radiation** environment consists of virtually every form of radiation including relativistic heavy ions. This environment is, of course, **hazardous to living organisms** as well as to micro-electronic circuitry. In order to facilitate the simulation of the expected environments within spacecraft and on or near planetary surfaces, transport codes are needed that include all of the relevant interactions...
- In order to evaluate the detailed dose within astronauts bodies, a high resolution **human phantom geometry** is needed within the spacecraft geometry being simulated...





Voxel Geometries in FLUKA

- FLUKA can embed voxel volumes within its normal combinatorial geometry.
- The “Embedded” voxel volume is currently limited to a Regular Parallelepiped region.
- Transport through the voxels is optimized and efficient...
- **Raw CT-Scan outputs can be imported directly!**



“Golem” Whole-Body CT-Scan-GSF Munich





Space v. Therapy Applications

- **NASA** is interested in “**Generic**” RISK ASSESSMENT for Crew Members.
 - Generic Phantoms, such as GOLEM are generally sufficient, although a variety are needed to span the size, age and gender ranges.
- **Therapy Applications** Require Currently Accurate **Patient-Specific** Phantoms.
 - Typically, CT-Scans done immediately prior to the treatment are used for detailed planning.





CT-Scan Voxels in FLUKA

- CT-Scans only give voxel density values that are proportional to electron density...
- For use in FLUKA (and all Monte Carlo transport codes), each individual voxel must have a material composition assigned as well as a density...
- In addition, voxels containing micro-porous material (like **bone** or **lung** tissue) are problematic due to the variation of effective pathlengths for slightly different trajectories of traversing tracks.



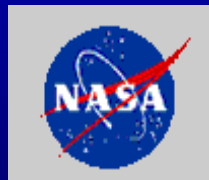
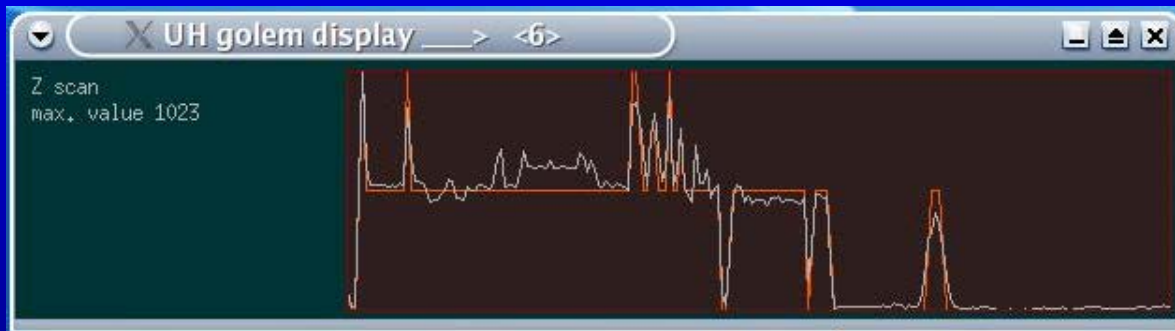


Automated Algorithms to assign Material Compositions to CT-Scans

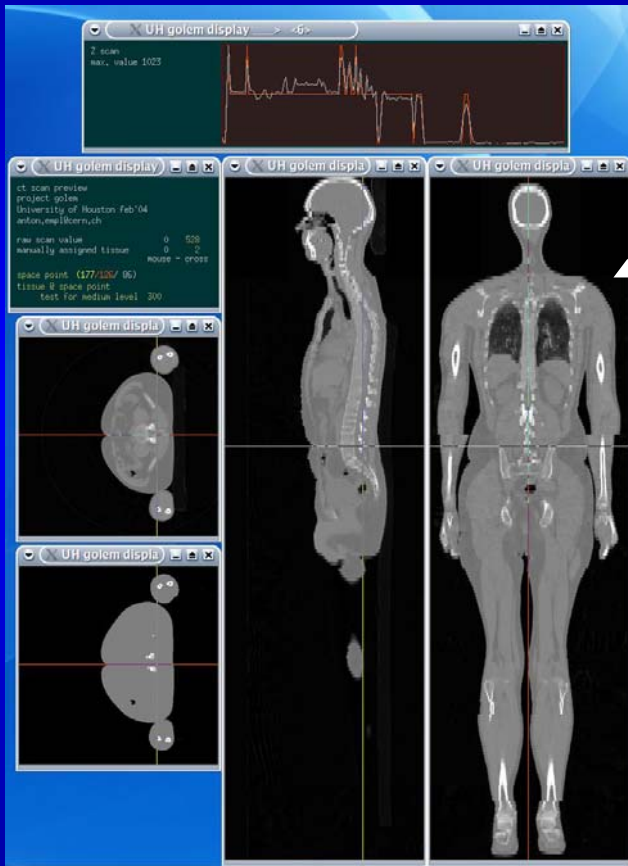


(...A Well-Known Pattern Recognition Problem In Conventional Diagnostic CT-Scan Interpretation)

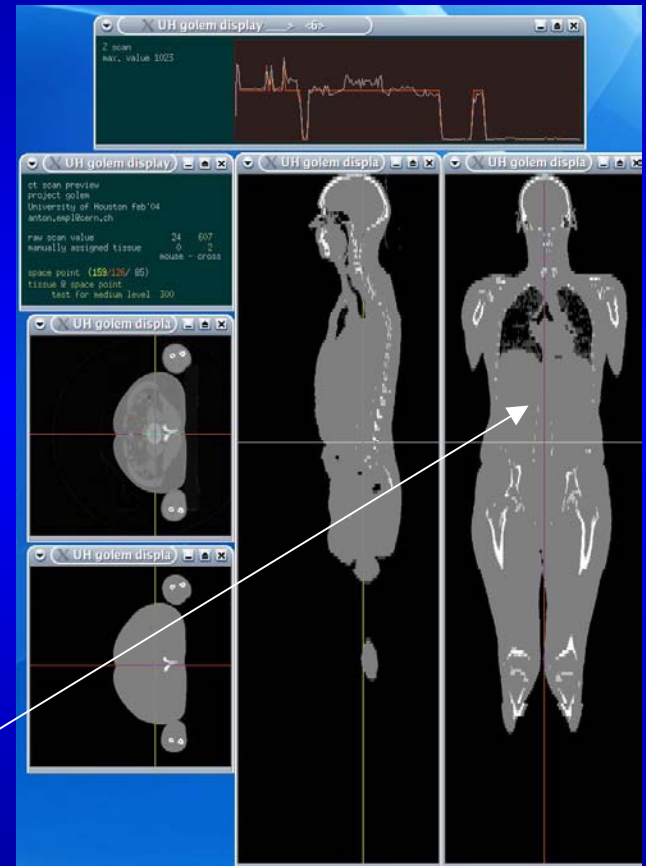
- The algorithm employed here will identify 4 material types of voxels in human CT-Scans: Generic Soft Tissue, Hard Bone, Trabecular Bone, and Lung Tissue. (The individual voxel densities are still preserved).
- The identification is based simply on density and “geographic” situation.
- Voxels are forced into one of the 4 material types, even when it is a “boundary” voxel that is likely to be a combination of types (e.g. Soft Tissue-Hard Bone).



Assigning Voxel Types with "Golem"



Original



Material Types Assigned





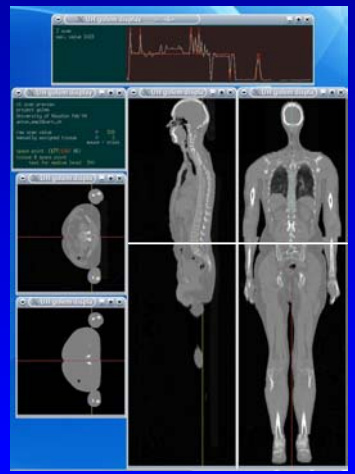
Some Algorithm Details

- One cannot simply use density because, for example, the trabecular bone tissue has a similar density to normal soft tissue.
- As such, geometric properties can be used to distinguish regions internal to the hard-bone shell, for example.
- Similarly, the general region of the Lungs can be tagged to allow identification of porous lung tissue as distinguished from bowel gas, for example.

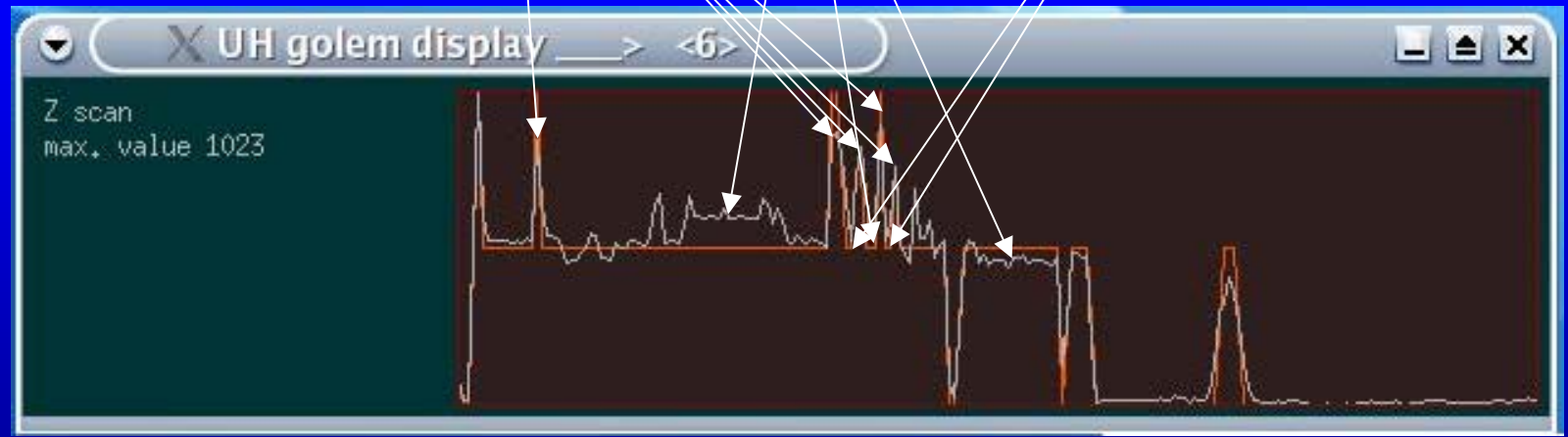




Use of Geometry to ID Tissue



Hard Bone Soft Tissue Trabecular Tissue





Dealing with Porous Tissue Trabecular Bone



- Traversal of **porous** tissue by radiation is subject to a **considerable variation in pathlength** (in gm/cm^2).
- Approximation as a **homogeneous average** gives rise to a **considerable error** in such predictions as the spread in the subsequent Bragg peak.
- To deal with the problem of the variation in pathlengths within porous media where the porosity is too small as a practical matter, to be measured and included in detail within transport codes, **FLUKA is implementing a special new type of material type with a *MULTIPLE DENSITY*.**





Multiple Density Materials in FLUKA



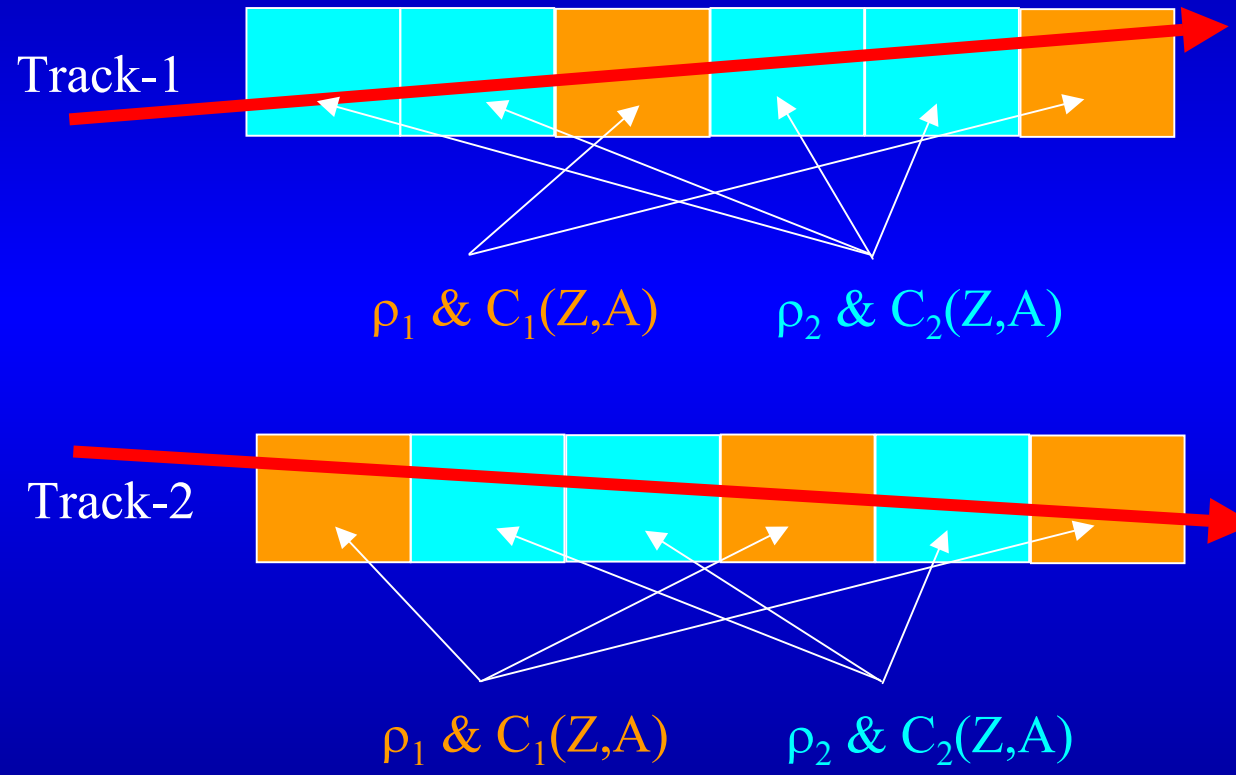
- In *multiple density* materials, FLUKA will randomly select a material and density from a predetermined set of specific choices.
- One then needs the relative probability of encountering each one of the possibilities.
- **In practice, the choice is limited to two.** (e.g. hard bone v. soft tissue for trabecular bone and air v. soft tissue for lung tissue)
- Thus, **we need** to develop **models of the pathlength distributions** in these media to provide the needed probabilities...





Multiple Density Materials

An example of density & material assignments for the same voxels for successive tracks.

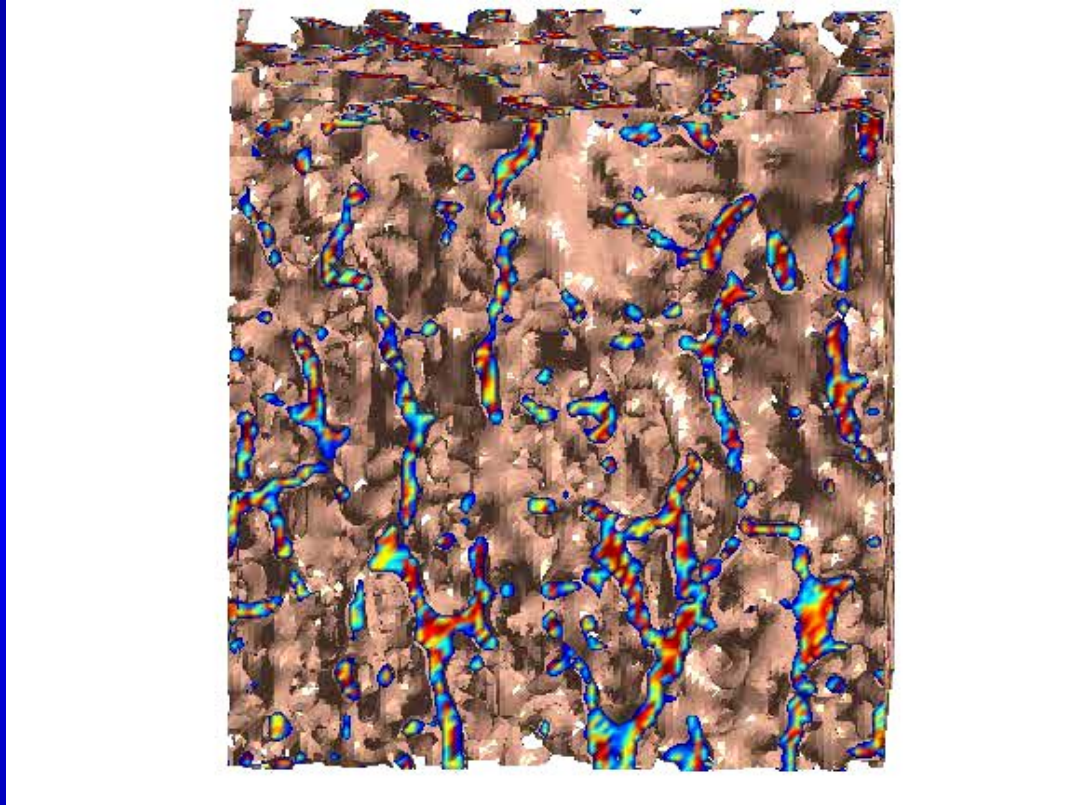


The Material choice for each voxel is independently chosen each time a track traverses it according to the relative probability of that material's presence.





Trabecular Bone



~10% Voxels are
Hard Bone ($\rho \sim 1.9$)
~90% is marrow...

There is an
asymmetry along
the longitudinal axis
of the bone...

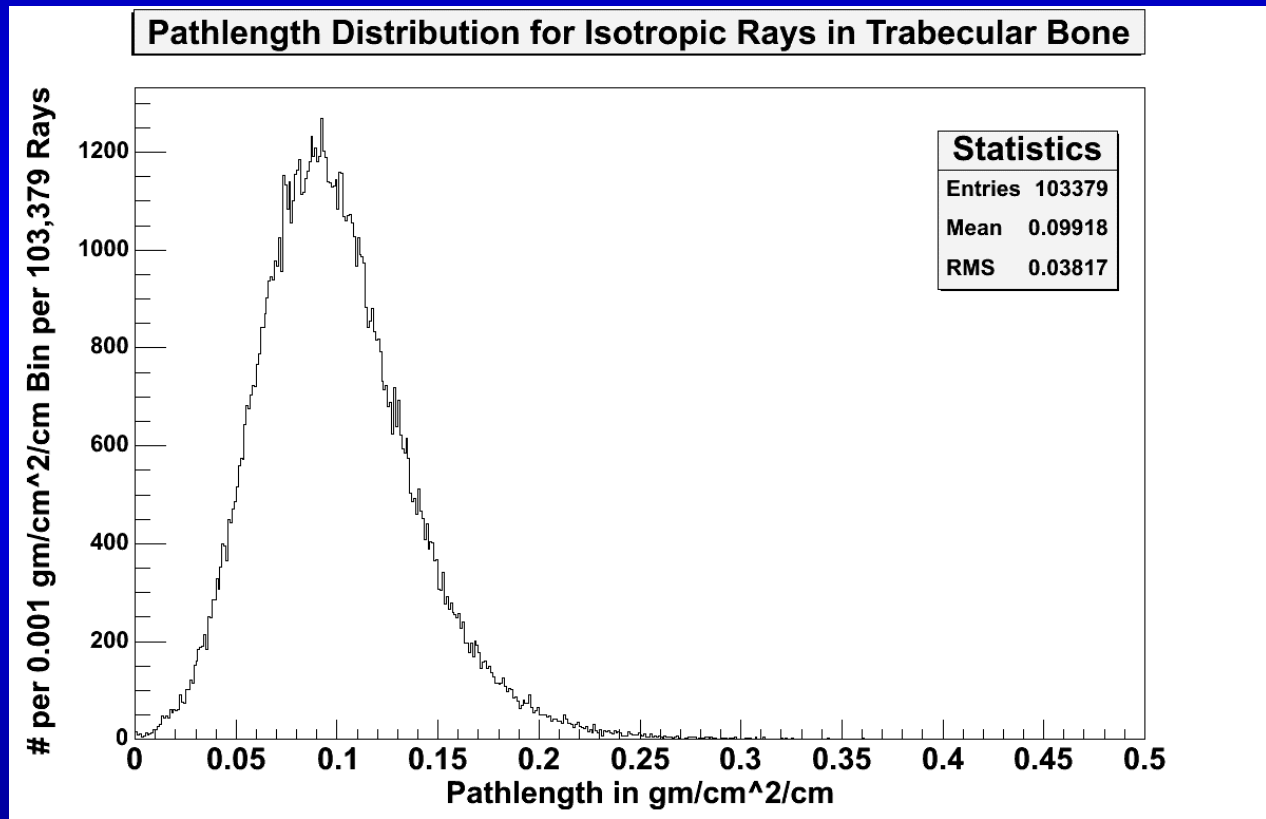
Human bone is
mostly Trabecular
Bone with ~1-2 mm
of Hard Bone shell.

Data from 40 μm Voxel CT-Scans from M. Leibschner





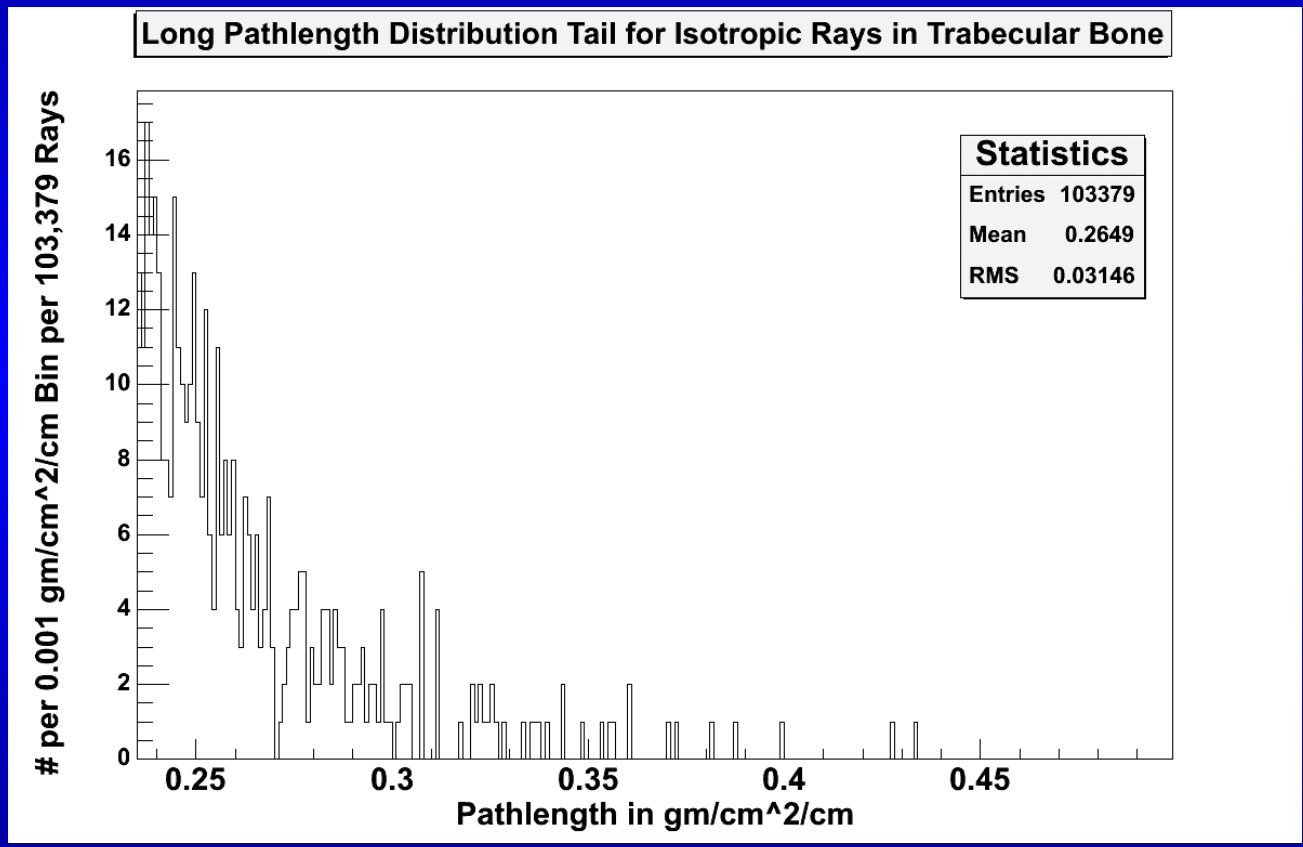
Using FLUKA “Rays” to Determine the Isotropic Pathlength Distributions in Trabecular Bone





Trabecular Bone

Isotropic Long Pathlength Tail

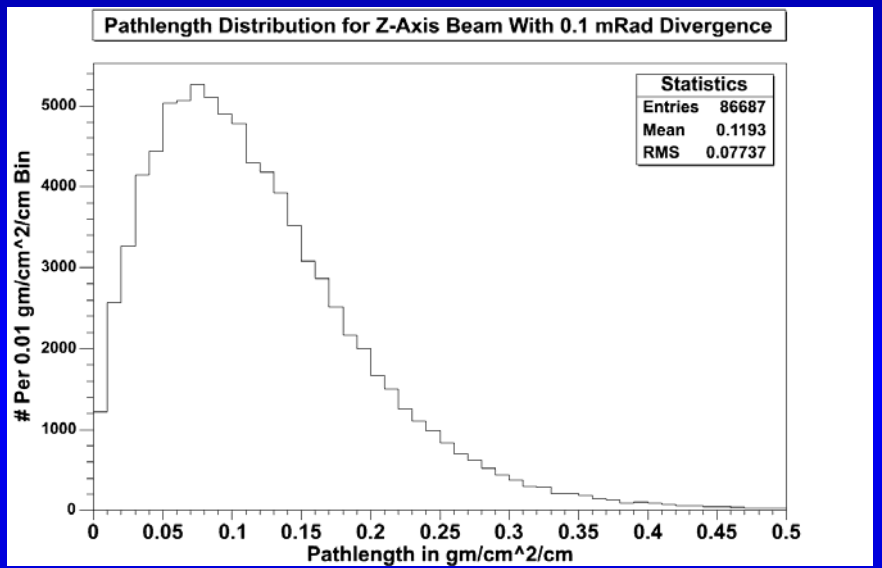
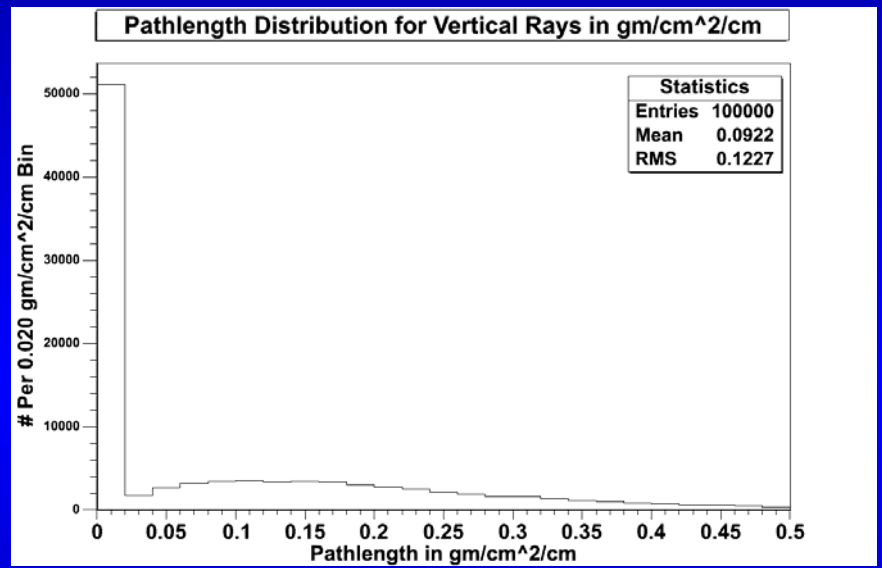


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Pathlength Asymmetries along the Longitudinal Axis of Trabecular Bone



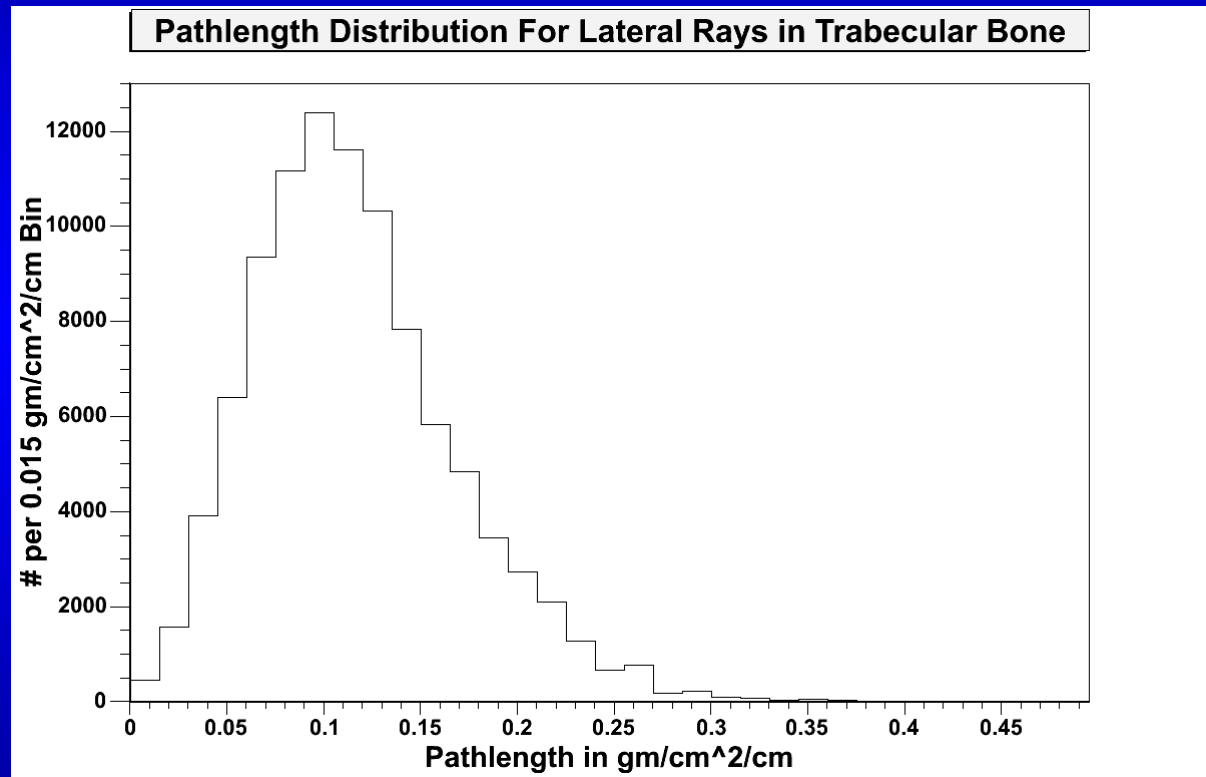
Pathlength distribution for “Rays” Parallel to longitudinal axis...

Pathlength distribution for “Rays” with a divergence of 100 mRadians Around the longitudinal axis...





Pathlength Distribution for “Rays” Parallel to an Axis Perpendicular to the Longitudinal Axis of Trabecular Bone



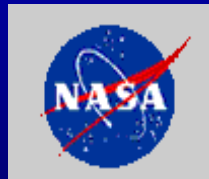
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Web Sites...

- FLEUR-S <<http://www.cern.ch/~fleur>>
 - NASA Project status and publications!
- FLUKA <<http://www.fluka.org>>
 - Download manuals and software (Linux)
- ROOT <<http://root.cern.ch>>
 - Download tutorials and software (Linux, Unix, Windows, Mac)





The End
&
Thank You For Your Attention...

