Hammersmith Imanet

Implementation and Evaluation of the Single Scatter Simulation Algorithm in the *STIR* Library

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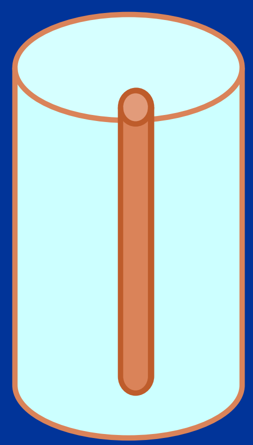
Overview

- Scatter in 3D PET
- Single Scatter Simulation (*SSS*)
- *SSS* Implementation in *STIR*
- Simulation Characteristics
  - Scanner Sampling
  - Simulation Parameters
- Scatter Sinogram Profiles
- Evaluation using SimSET
- Comparison to Measured Scatter
- Discussion
- Future Work

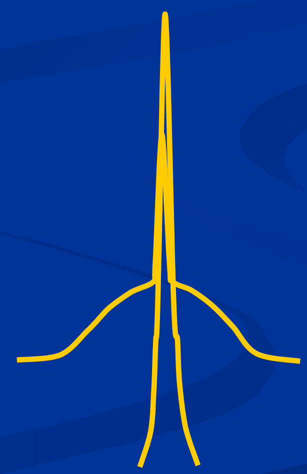
Scatter in 3D PET

NO SCATTER CASE
SCATTER CASE

Phantom



Sinogram Radial Profile



Scatter in 3D PET

~~Scatter outside of FoV~~ Scatter inside of FoV

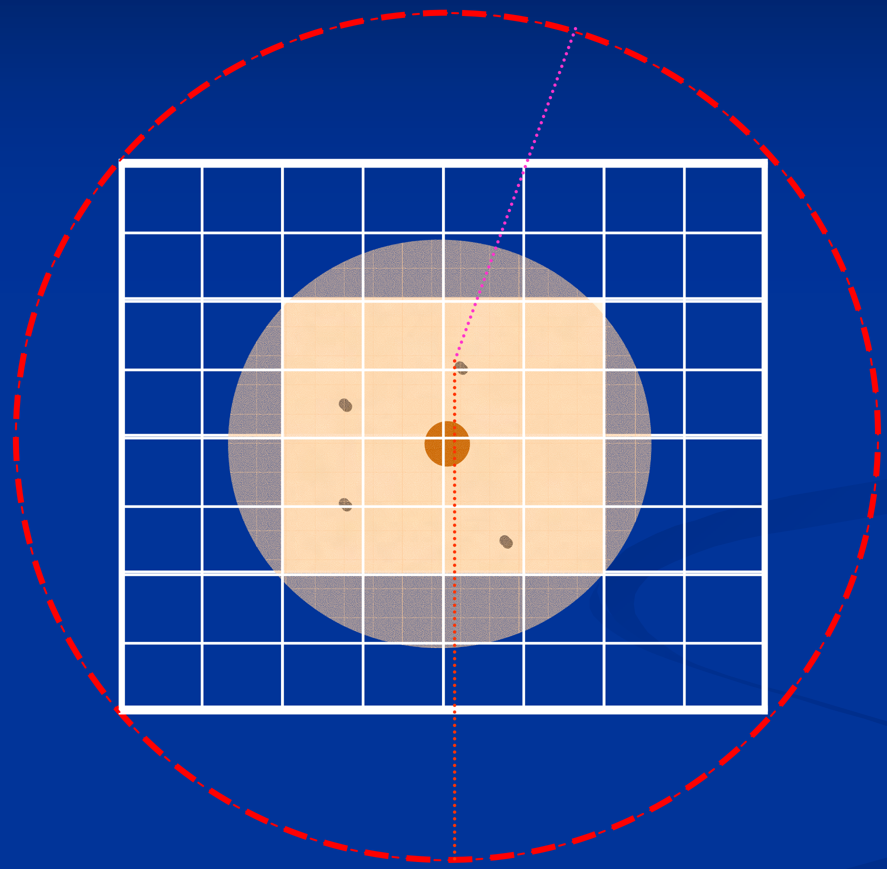
Scatter Fraction (SF) for a point source at the centre of the FoV, surrounded by a water filled cylinder (30cm diameter, 20cm length) [Adam et al.][1]:

- SF = (Scattered/Total) Events
- 2D PET SF ≈ 29%
- 3D PET SF ≈ 41%
- 3D PET Single SF (S_1F) ≈ 25%

Single Scatter Simulation (SSS)

- Interpolate Attenuation and Emission Images.
- Select Scatter Points Randomly in the Attenuation Image, above a Threshold.
- Sample the Detectors using a Sinogram Template.
- Find the Single Scatter Distribution (Sinogram) using the algorithm proposed by Watson[2].

Single Scatter Simulation (SSS)



SSS Implementation in *STIR* (II)

- Scatter Buildblock
- Scatter Inline
  - Scatter (EXECUTABLE)

Reconstructed Image
Attenuation Map
Sinogram Template
Scatter Sinogram Name
Attenuation Threshold
Lower & Upper Energy
Use of Random Points (?)
Use of cache (?)

Write statistics

Create Scatter Viewgram

Random Points

Sample Scatter Point

Estimate Scatter from all Scatter Points

Estimate Scatter from one Scatter Point

Cache Factors

No Cache

Cache

Differential and Total Cross Section
Detection Efficiency

Scatter Point to Detector Integrals
Emission and Attenuation

Scanner Characteristics

Scanner Sampling (I, …, IV)

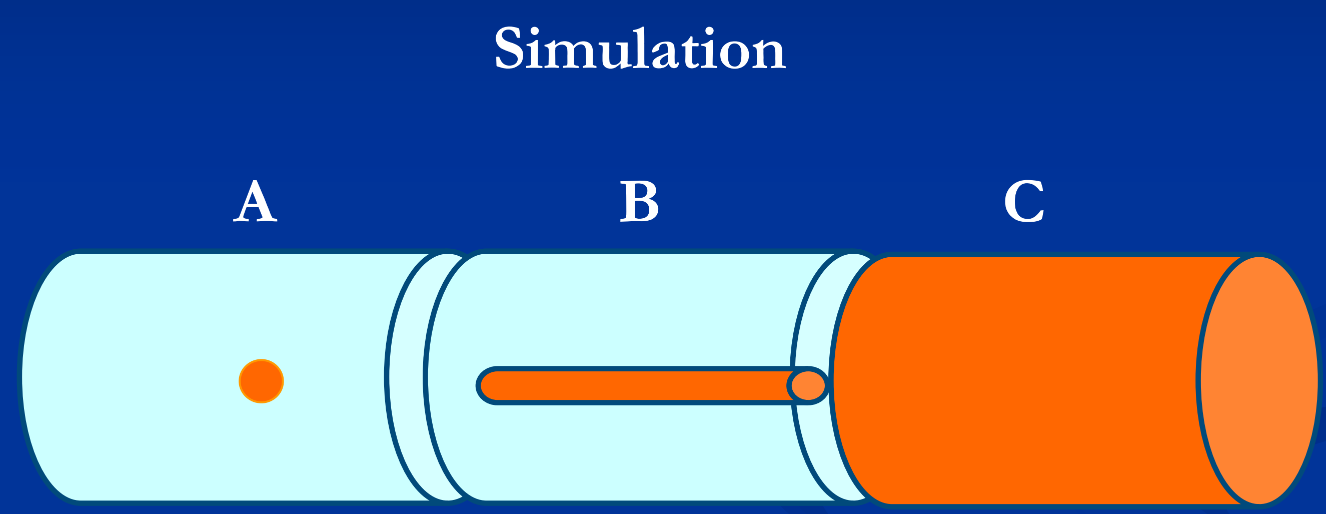
Characteristics	EXACT HR+	I	II	III	IV
Detectors per ring	576	72	144	72	144
Number of Rings	32	8	8	16	16
Ring Distance (mm)	4.85	19.4	19.4	9.2	9.2
Scanner length (mm)	155.2				
Ring diameter (mm)	825				

BGO crystals resolution: 25% at 511keV

Energy window: 350-650 keV

Wider Energy window (*W-SSS*): 320-650 keV

Phantoms for Evaluation



<u>A) Point source:</u> Sphere of Emission Voxel Size diameter.

<u>B) Line Source:</u> Emission Voxel Size diameter, Scanner length.

<u>C) Cylinder Source:</u> 20cm diameter, Scanner length.

<u>Attenuation Cylinder:</u> 20cm diameter, Scanner length.

Simulation Parameters

Attenuation / Emission Image Interpolation and Relative Standard Deviation

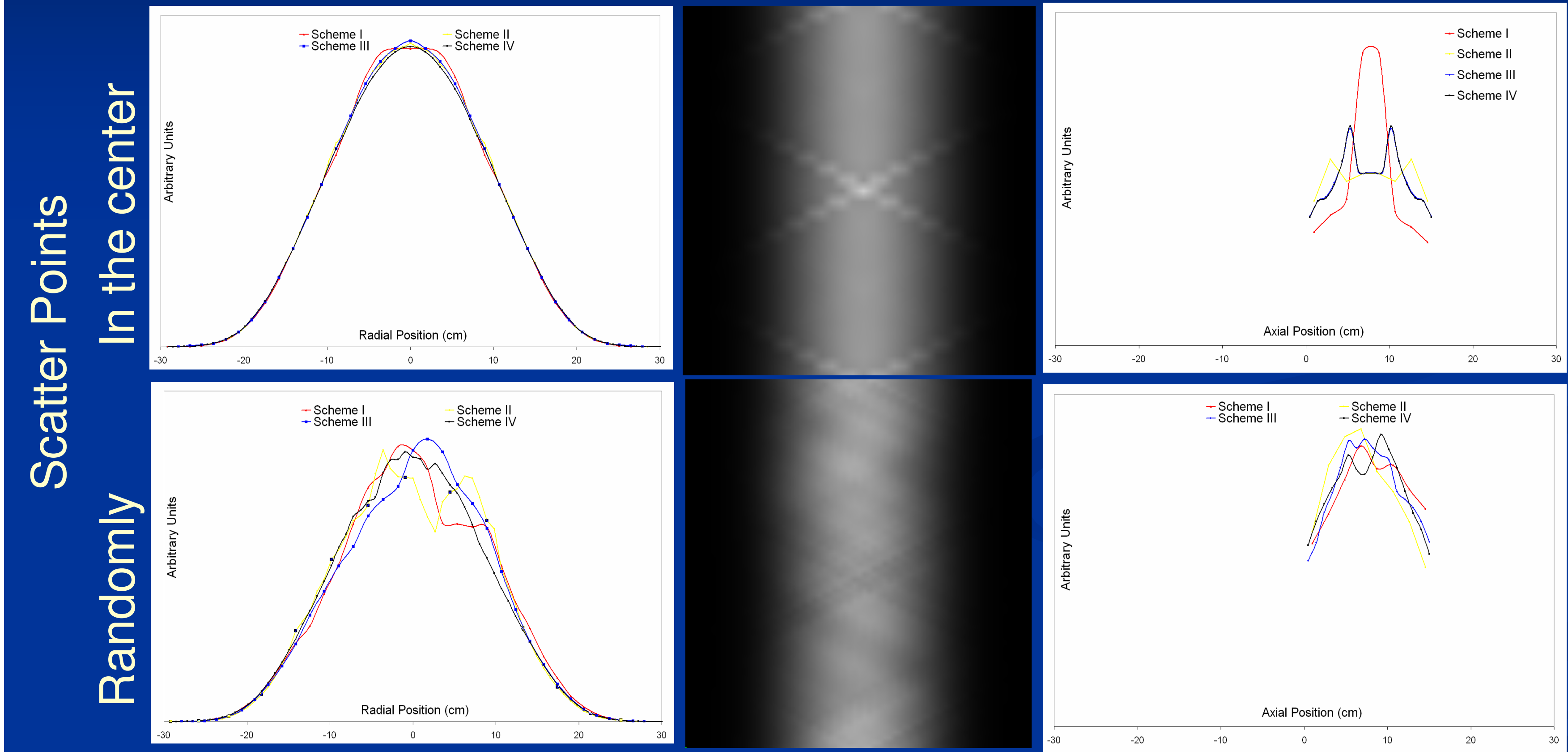
Sampling	Sinogram size	Attenuation/Emission Voxel (mm^3)	CPU Time/Scatter Points* for C, ~min	Relative Standard Deviation** (%) for B
I – direct	$36 \times 36 \times 8$	$20 \times 20 \times 20$	0.30/712	3.20
II – direct	$72 \times 72 \times 8$	$20 \times 10 \times 10$	4.64/2331	2.77
III – direct	$36 \times 36 \times 16$	$10 \times 20 \times 20$	1.15/1157	3.32
IV – direct	$72 \times 72 \times 16$	$10 \times 10 \times 10$	17.54/4329	2.83
IV – (in)direct	$72 \times 72 \times (16+2)$	$10 \times 10 \times 10$	19.57/4329	2.76

*CPU time approximately needed for *W-SSS* by a processor AMD Athlon MP 1900+, for the simulation **C**.

Relative Standard Deviation over all views through the centre of a sinogram, for simulation **B.

Single Scatter Sinogram Profiles[11]

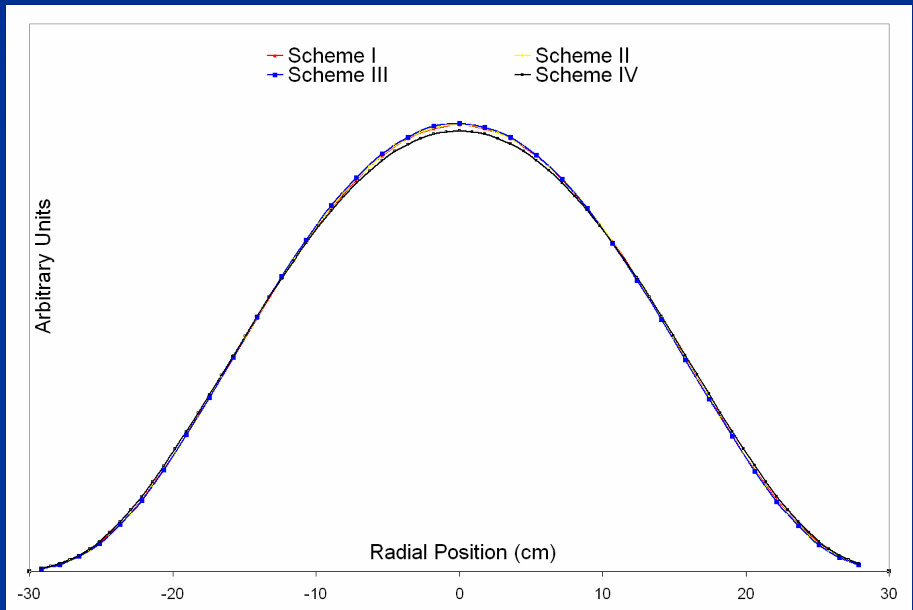
Comparing Profiles for different schemes of the *SSS* for simulation **A**, along radial direction, through a single view of a direct sinogram, and along axial direction through the center of a viewgram.

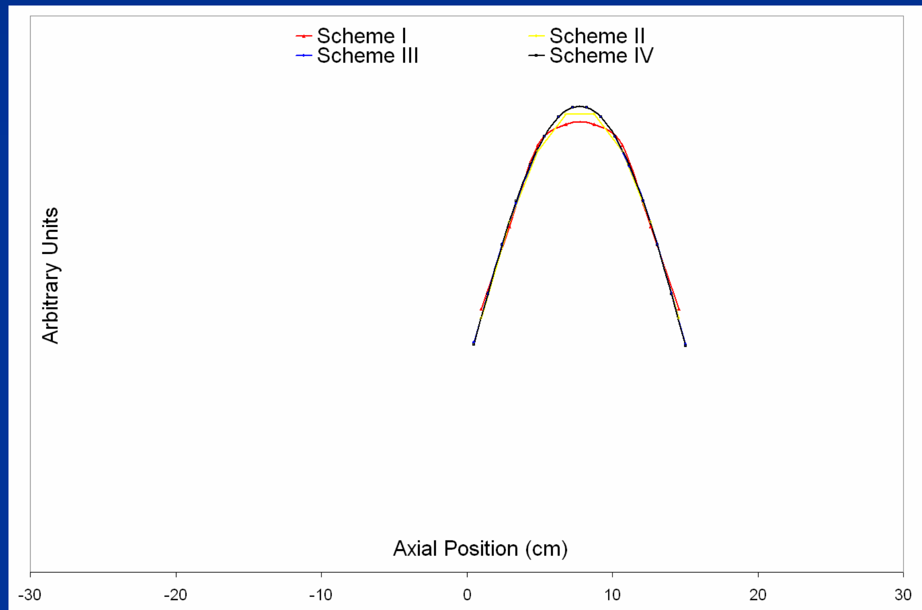


- ➢ Shape of the distribution has significant importance.
- ➢ Random scatter points reduce discretisation artefacts.
- ➢ Essentially, all radial profiles have the same shape.

Single Scatter Sinogram Profiles

Comparing Profiles for different schemes of the *SSS* for simulation **C**, along radial and axial directions.





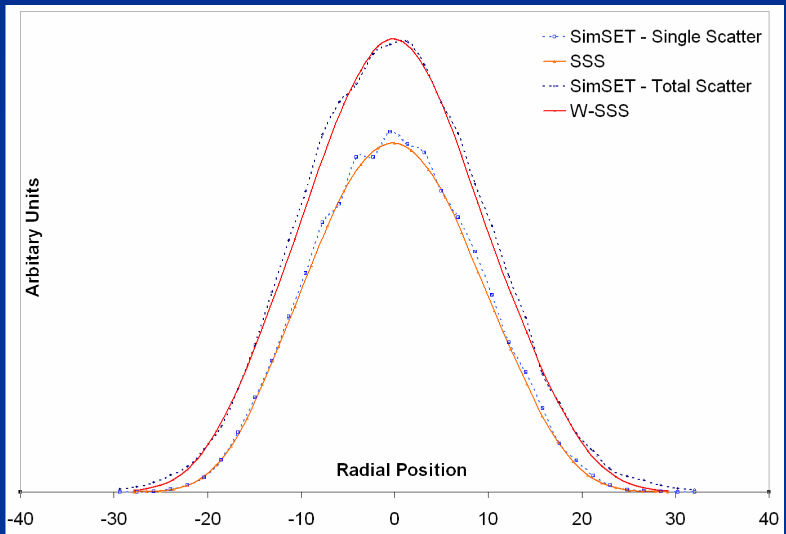
Essentially, all profiles **axial** and **radial** have the same shape.

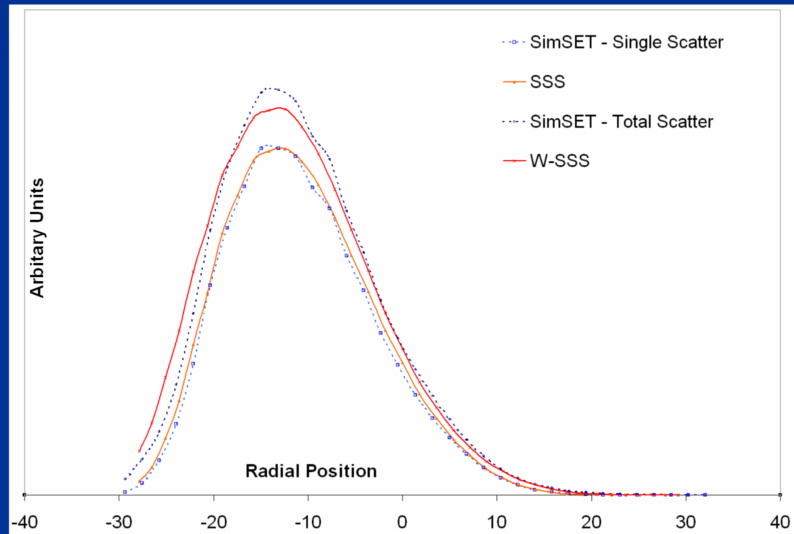
Comparison to Measured Data

- Data acquired on an ECAT EXACT HR$^+$ scanner:
  - NEMA ’94 – Scatter Acceptance Tests.
  - Uniform cylinder, 20cm diameter, filled with water.
  - Ge line source, 2mm diameter.
  - Line Source, radial, at ~0mm and ~80mm.
- Perform *SSS* using:
  - Energy Window (350 – 650) keV.
  - Wider Energy Window (320 – 650) keV (*W – SSS*).
  - Scheme I.
- Perform SimSET simulation using:
  - Energy Window (350 – 650) keV
  - Detector sampling characteristics based on Scheme I.

Scatter Sinogram Profiles

Comparing Profiles along radial direction for vertical view of the simulation **B** and SimSET (Scheme I) using Experimental Data.

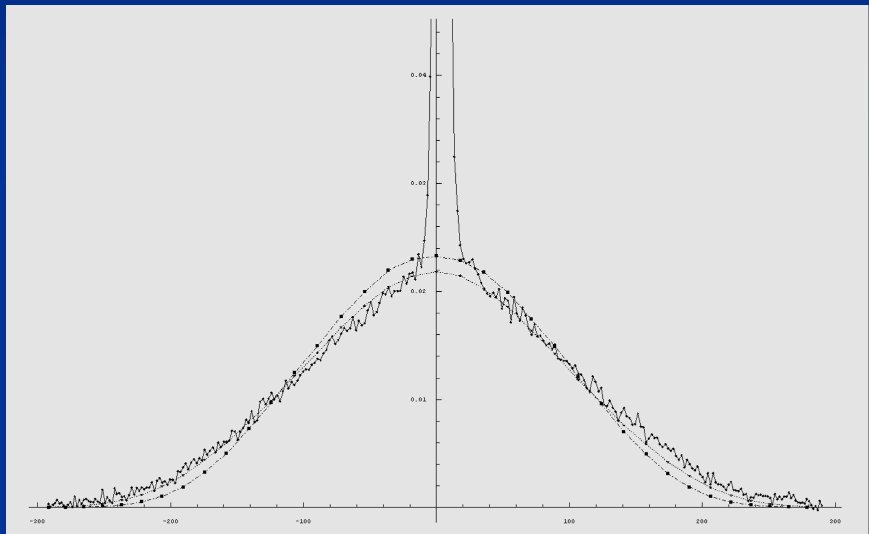


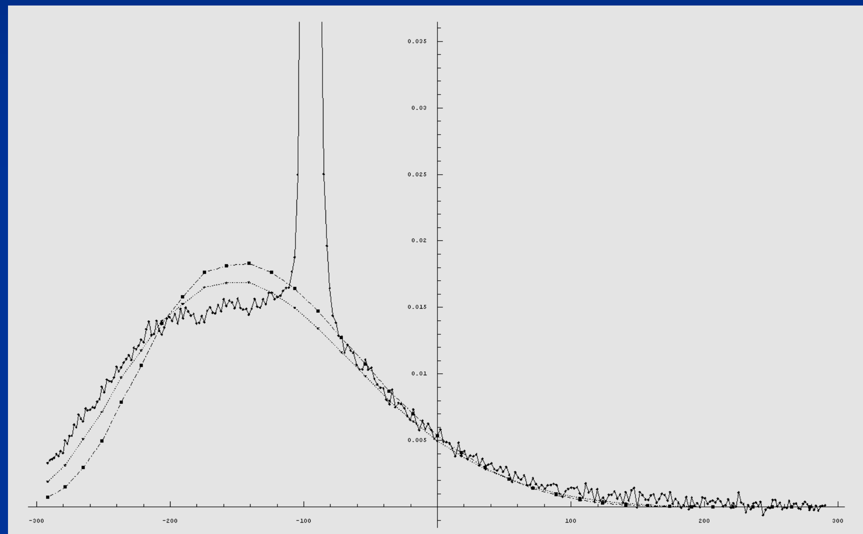


- Mean values of the profiles are the same after global scaling.
- The total scatter distribution is wider than the SSS, as expected.
- *SSS* has excellent agreement in both positions.
- *W-SSS* has quite good agreement with SimSET, but not excellent.

Scatter Sinogram Profiles

Comparing *SSS* and *W-SSS* Profiles along radial direction for vertical view of the simulation **B** - Scheme I and normalised measured sinogram, at ~0mm and ~80 mm.





➢Mean values of the profiles are the same, ignoring the peak.

➢ The y-axis is scaled such that the maximum in the measured data corresponds to 1.

➢Estimated single scatter distribution too narrow, as expected.

➢The *W-SSS* overcomes, somehow, this problem.

➢Reasonable agreement with the measured data.

How scatter is corrected with *STIR* ? (1st release)

1) Sample the detectors of the scanner using a *Sinogram Template*, constructed by *STIR*.
2) Reconstruct Emission and Attenuation image (*Em*, *Att*) doing the appropriate pre-corrections to the projection data.
3) Rescale the reconstructed images and perform the *SSS* or *W-SSS*.
4) Interpolate the Scatter Sinogram (*SS*) to have the same dimensions with the Emission Sinogram (*ES*).
5) Find the sum of the tails, at the *SS* and *ES* and define a global scaling factor (*s*).
6) Remove the scatter by subtraction and multiply with the Attenuation Sinogram (*AS*) to obtain a scatter Corrected Sinogram (*CS*):

$$CS = AS \cdot (ES - s \cdot SS)$$

7) Reconstruct the Corrected Sinogram (*CS*).

Why to use *STIR* Scatter Correction ?

- Easy to use. Package will include Visual C++ scatter project.
- All needed functions/utilities will be included into the first release.
- Flexible choice of the voxel sizes for the Emission and Attenuation images and of the detector sampling characteristics.
- Easy to change between *W-SSS* to *SSS*.
- Open Source under Lesser GNU License.

Future Work – MIC 2005 (?)

- Find a robust scale factor of the scatter distribution to the emission distribution.
- Evaluate using Brain and whole Body phantoms.
- Test if the indirect scatter sinogram has significant information.
- Integrate the Scatter Estimation into Analytic and Iterative Reconstruction Algorithms.
- Include it into *STIR*[5] and make it available to PET community.

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References

[1] Adam L E, Karp J S and Brix G, "Investigation of scattered radiation in 3D whole-body positron emission tomography using Monte Carlo simulations." *Phys. Med. Biol.* 44 2879–95, 1999.

[2] C. C. Watson, New, faster, image-based scatter correction for 3D PET, *IEEE Trans. Nuclear Sci.* 47 (4) 1587-1594, 2000.

[3] NEMA Standards Publication NU 2, Performance Measurements of Positron Emission Tomography: National Electrical Manufacturers Association, 1994.

[4] SimSET web site: http://depts.washington.edu/simset/html/simset_home.html, June 2004.

[5] *STIR* 1.3 software library and documentation http://stir.HammersmithImanet.com, September 2004.