The Halo-Artifact in ^{68}Ga-PSMA-PET/MR: Studies Using Phantom and Clinical Data

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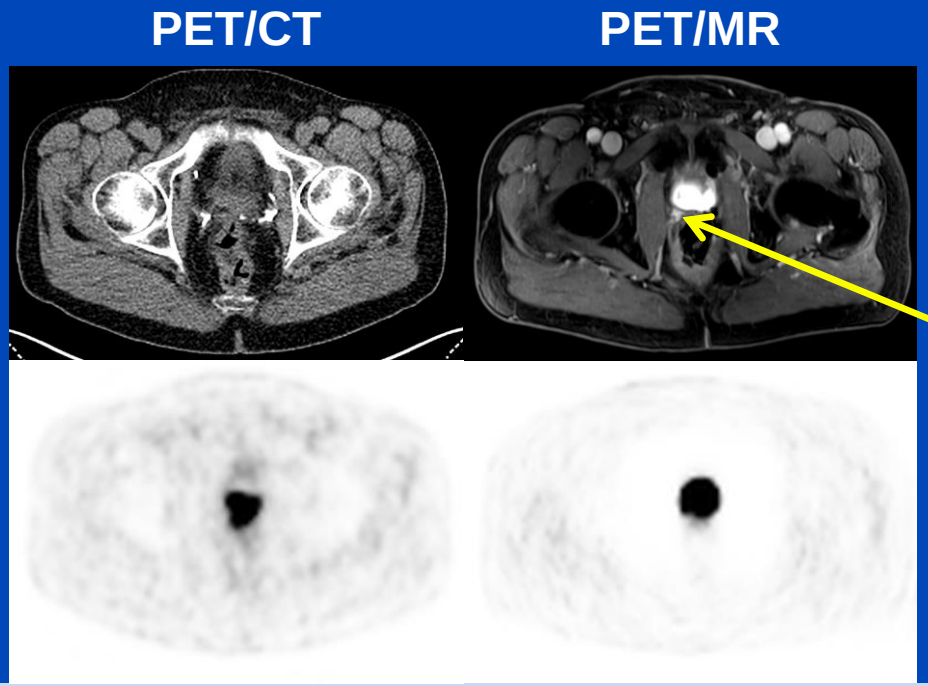
dkfz. DEUTSCHES KREBSFORSCHUNGSZENTRUM IN DER HELMHOLTZ-GEMEINSCHAFT

Motivation

- Prostate-specific membrane antigen (PSMA)
  - PET targeting PSMA is used to detect recurrent prostate cancer
- ^{68}Ga-PSMA imaging
  - Key application for hybrid PET/MR imaging?
- Photopenic artifacts ('halo')
  - May impair PET image quality



Aim

- Investigate the halo-artifact in ^{68}Ga-PSMA PET/MR
  - performing phantom measurements.
  - evaluating clinical data.
- Deduce guidelines which help to avoid the occurrence of halo-artifacts.
- Provide workaround techniques effectively reducing the size of the halo-artifact.

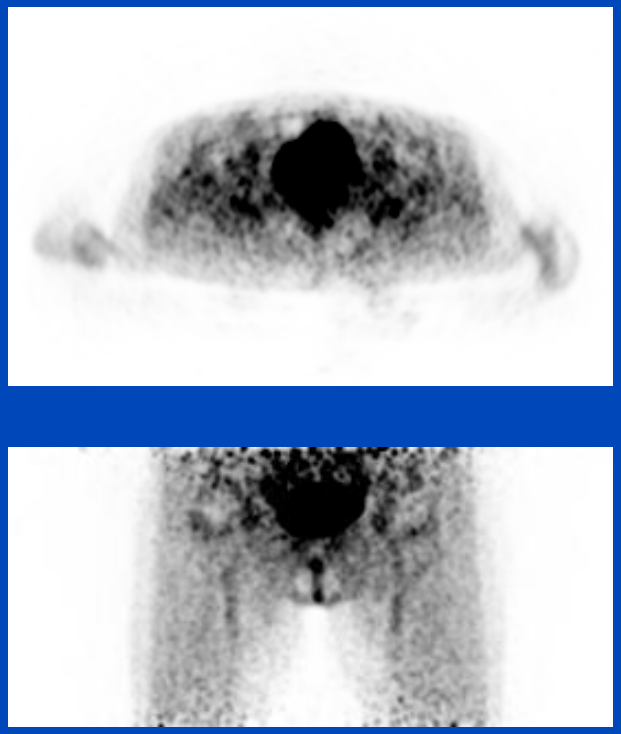
Devices and Software

- **Devices**
  - Siemens Biograph mMR (model number 2008)
  - Siemens Biograph mCT (model number 1104)
- **Software**
  - Siemens e7tools offline software package
    - mMR: version VA20
    - mCT: version VG40
- **Reconstruction**
  - Ordinary-Poisson OSEM
    - Accounting for normalization, randoms, scatter, and attenuation
    - $N_{iter} = 3$
    - $N_{sub} = 21$

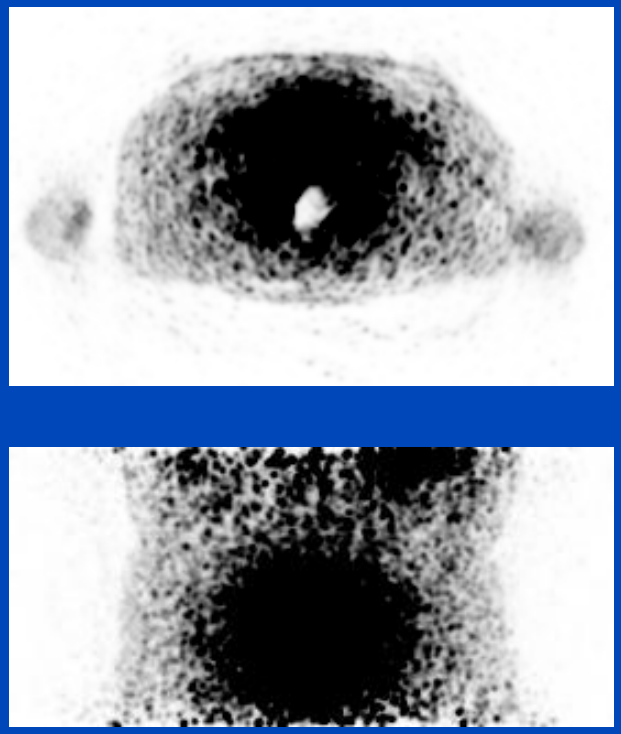
^{18}F-FDG vs. ^{68}Ga-PSMA

Without Scatter Correction

^{18}F-FDG



^{68}Ga-PSMA



4.0

0.0

[kBq/mL]

0.6

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248 MBq
85 min p.i.

144 MBq
104 min p.i.

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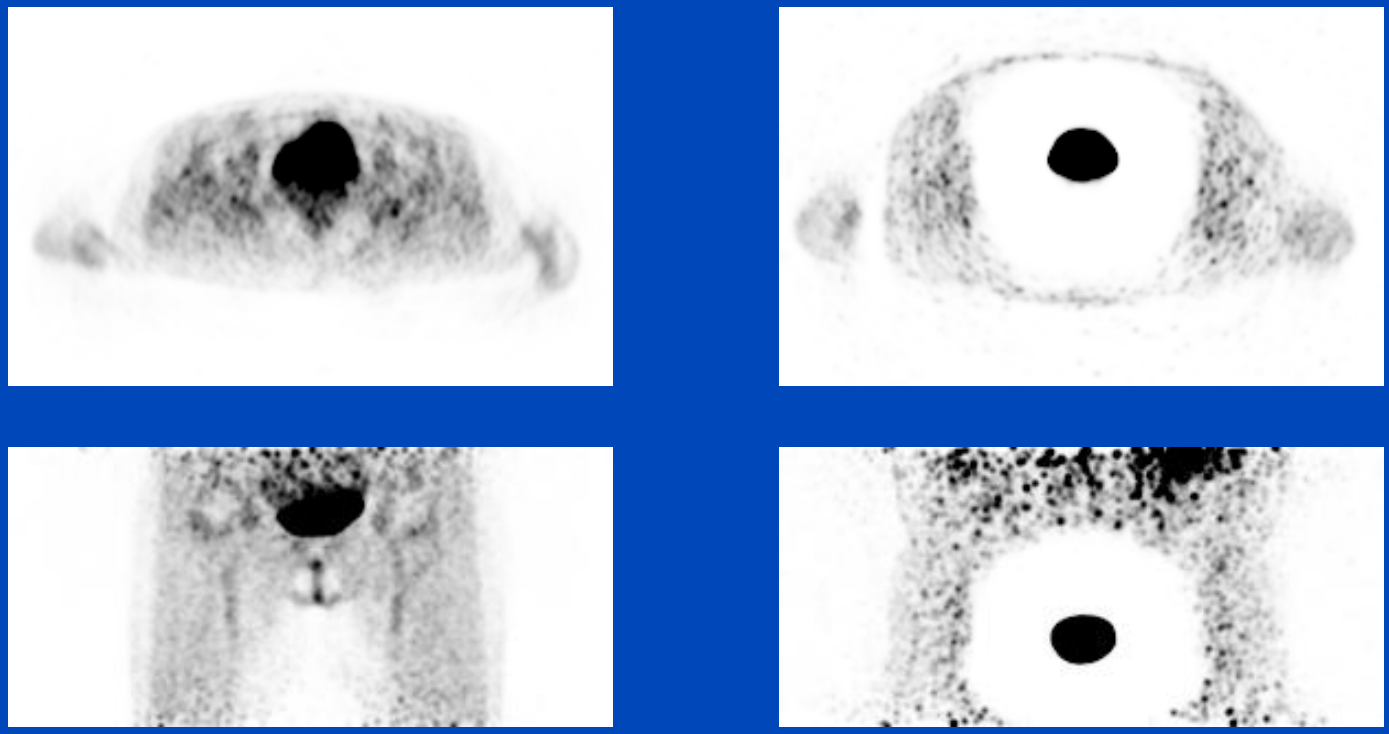
^{18}F-FDG vs. ^{68}Ga-PSMA

With Scatter Correction

^{18}F-FDG

^{68}Ga-PSMA



248 MBq
85 min p.i.

144 MBq
104 min p.i.

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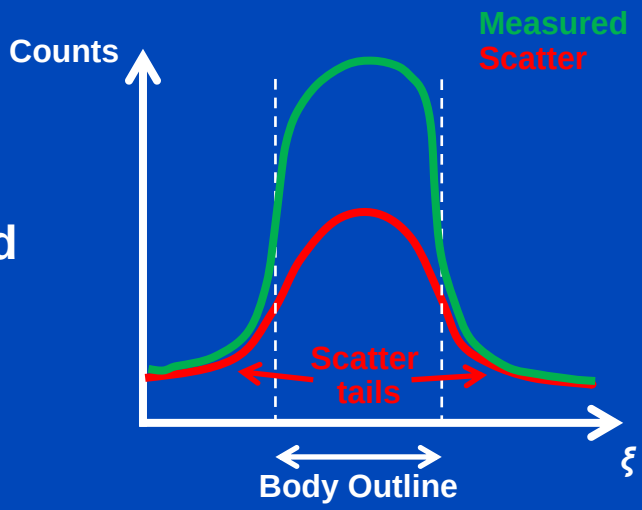
Single Scatter Simulation (SSS)[1]

- Scatter estimation is based on SSS
- **Relative** version
  - Estimated scatter is scaled to fit the ‘scatter tails’
- **Absolute** version
  - Estimated scatter is intrinsically scaled
- Default parameters
  - No prompt gamma correction (PGC) applied
  - Maximum scatter fraction MaxSF = 75 %
  - …



[1] C. C. Watson, “New, faster, image-based scatter correction for 3D PET,” *IEEE Trans. Nucl. Sci.* 47(4), 1587-94 (2000).

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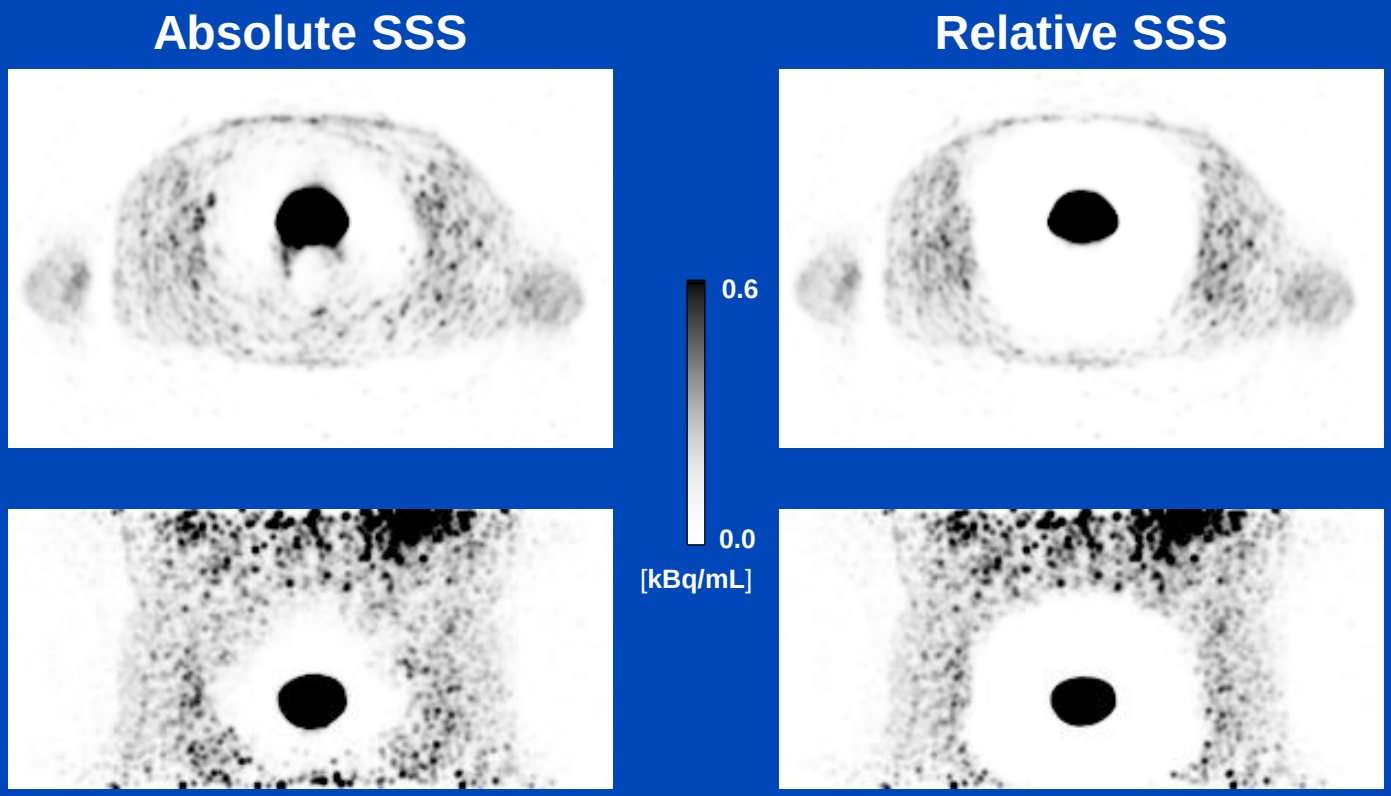
Single Scatter Simulation (SSS)

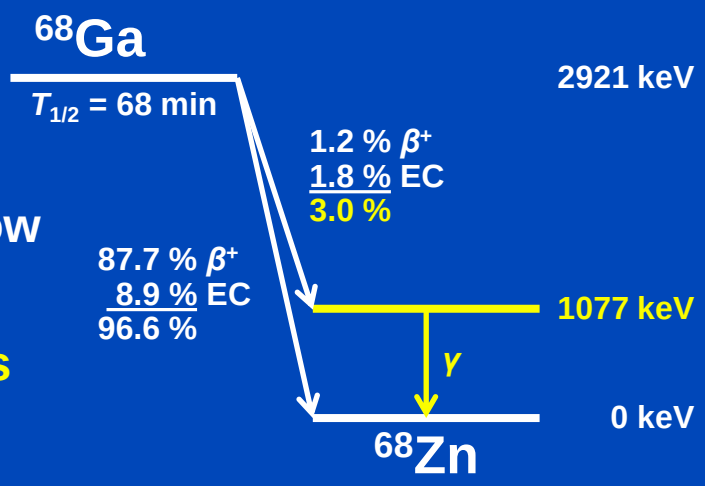
Absolute vs. Relative SSS

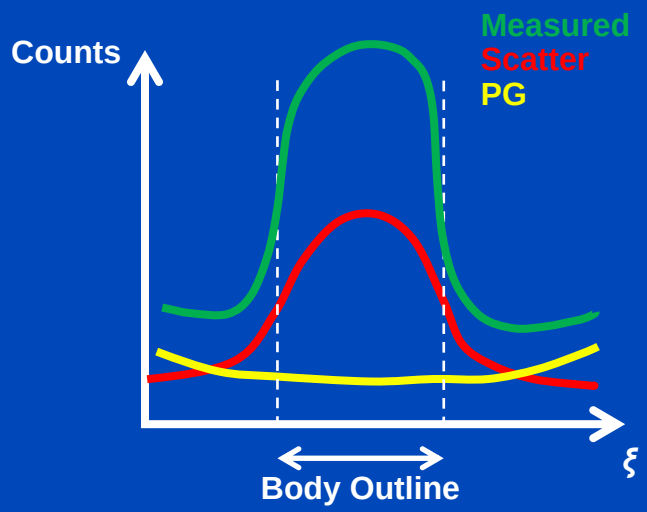


Single Scatter Simulation (SSS)

Prompt Gamma Correction (PGC)

- **Prompt gammas**
  - within coincidence timing window
  - may fall within energy acceptance window
  - may produce valid coincidence events
  - result in an approximately homogeneous background activity distribution
- **Prompt gamma correction[1,2]**
  - Include estimation of prompt gamma distribution into scatter correction
  - Reduces scatter overestimation
  - Has been shown to reduce the halo around the kidneys in ^{68}Ga-PSMA-PET/CT[2]





[1] B. J. Beattie, R. D. Finn, D. J. Rowland, and K. S. Pentlow, "Quantitative imaging of bromine-76 and yttrium-86 with PET: a method for the removal of spurious activity introduced by cascade gamma rays," *Med. Phys.* 30(9), 2410-23 (2003).
[2] I. Hong, H. Rothfuss, C. Michel, and M. Casey, "Prompt Gamma Correction on Ga-68 PSMA PET Studies," *IEEE Med. Img. Conf. Rec.* (2015).

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Single Scatter Simulation (SSS)

Maximum Scatter Fraction (MaxSF)

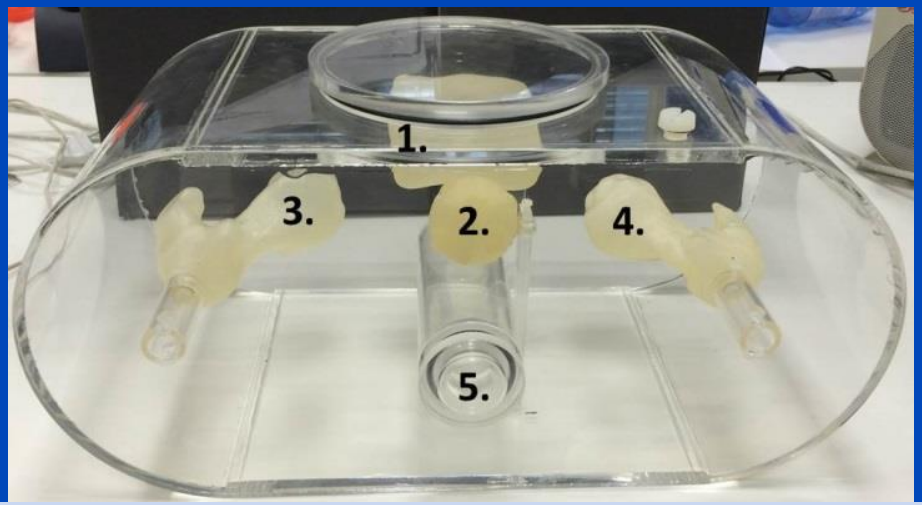
- MaxSF gives the maximum allowed scatter-to-primary ratio
- Default value: **MaxSF = 75 %**
- Typical scatter fraction in whole-body PET/MR scan: **SF ≈ 30-50 %**[1]

- **Does decreasing MaxSF from 75 % to 40 % reduce the halo without introducing new artifacts?**

[1] G. Delso, S. Fürst, B. Jakoby, R. Ladebeck, C. Ganter, S. G. Nekolla, M. Schwaiger, and S. Ziegler, "Performance measurements of the Siemens mMR integrated whole-body PET/MR scanner," *J. Nucl. Med.* 52(12), 1914-22 (2011).

Phantom Experiments

- **Dedicated pelvis phantom[1]**
  - **Background: Plastic box filled with water (≈ 11 L)**
  - **Bladder: Bladder insert filled with water (≈ 80 mL)**
- **Data acquisition**
  - **10^7 events acquired during each measurement**
  - **Attenuation and scatter correction based on CT-derived attenuation map (plastic box not visible in MR-based attenuation map)**



[1] P. Mann, T. Heußer, H. de las Heras Gala, R. Weigel, M. Kachelrieß, and P. Bachert, "A hybrid imaging phantom for quality assurance and research," *RSNA Scientific Assembly and Annual Meeting* (2015).

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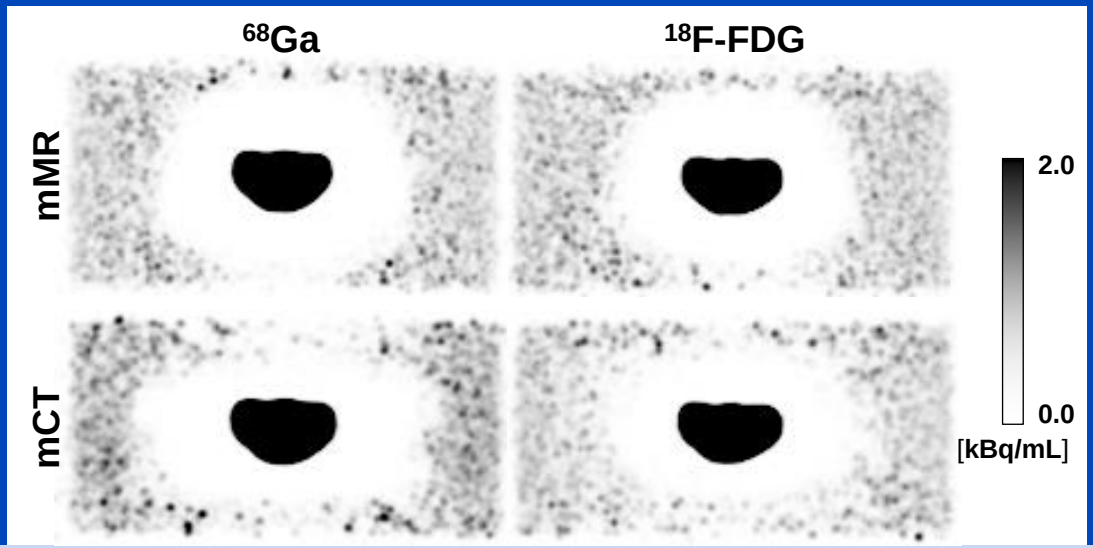
Phantom Experiments

^{68}Ga vs. ^{18}F-FDG

- ^{68}Ga or ^{18}F-FDG
- Administered activity
  - Bladder: 30.0 MBq
  - Background: 5.3 MBq
- Resulting organ-to-background ratio:
  OBR ≈ 800

- Scan with mMR and mCT
- Use absolute SSS
- No PGC
- MaxSF = 75 %

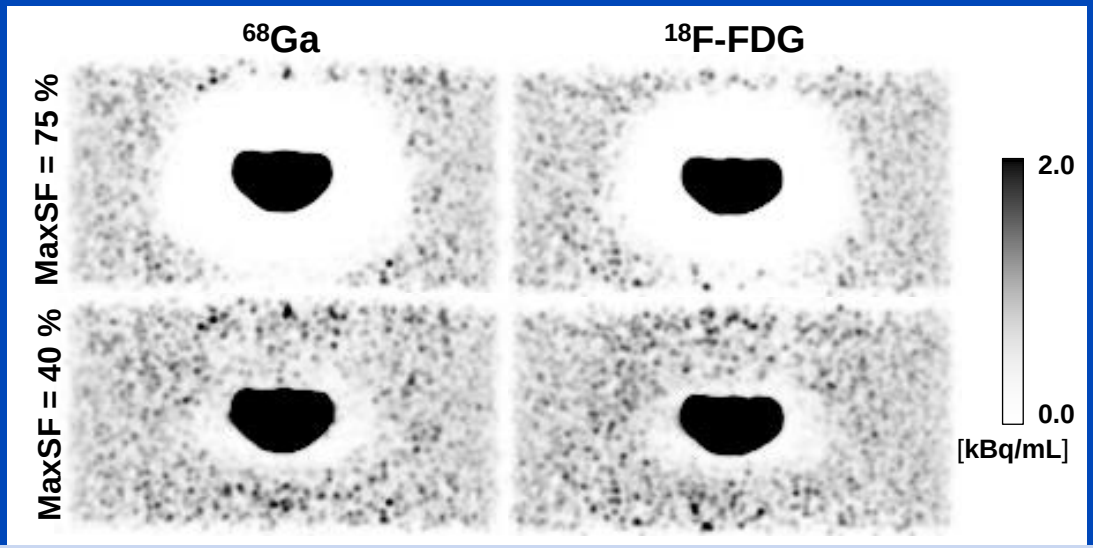


Phantom Experiments

Reducing MaxSF

- ^{68}Ga or ^{18}F-FDG
- Administered activity
  - Bladder: 30.0 MBq
  - Background: 5.3 MBq
- Resulting organ-to-background ratio:
  OBR ≈ 800

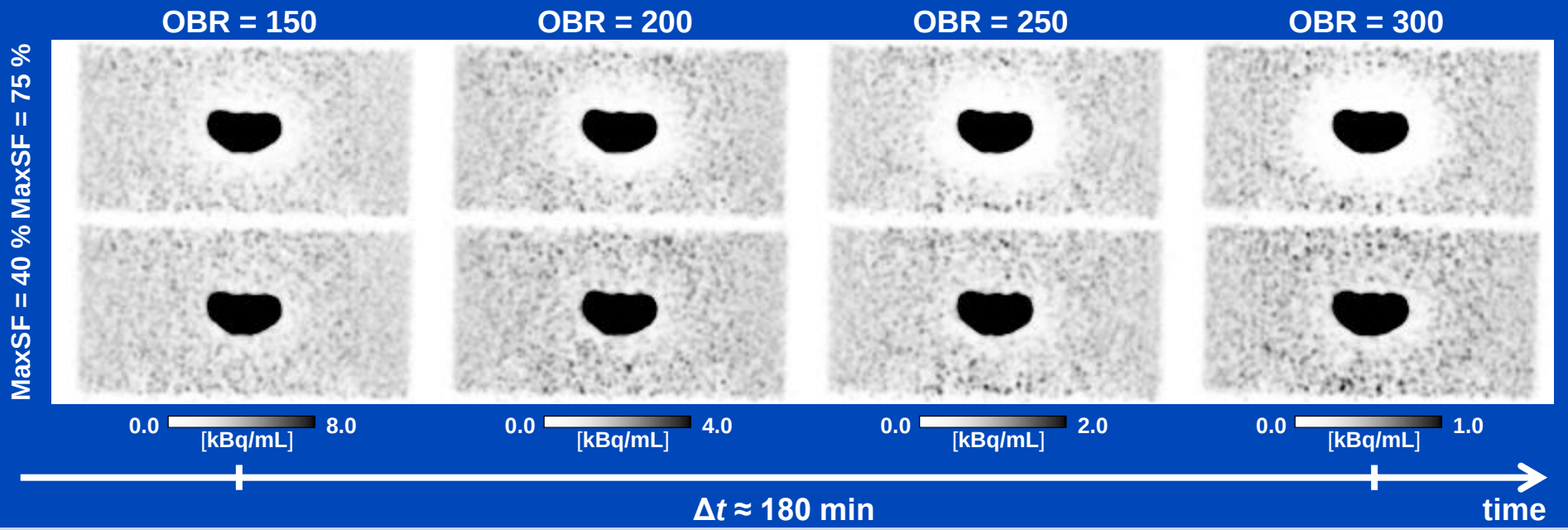
- Scan with mMR
- Use absolute SSS
- No PGC



Phantom Experiments

Dual Tracer Approach

- Background: ^{68}Ga (33 MBq, $T_{1/2}$ = 68 min)
- Bladder: ^{18}F-FDG (23 MBq, $T_{1/2}$ = 110 min)
- Allows for a time-dependent OBR
- OBR doubles every $\Delta t \approx 180$ min



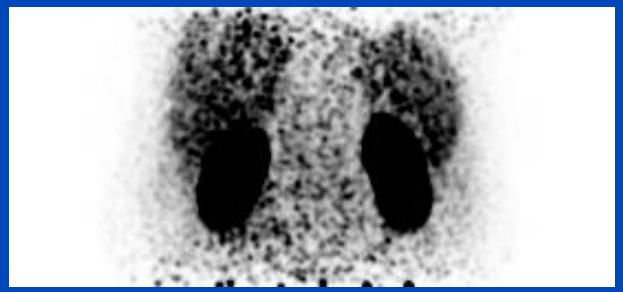
Patient Data

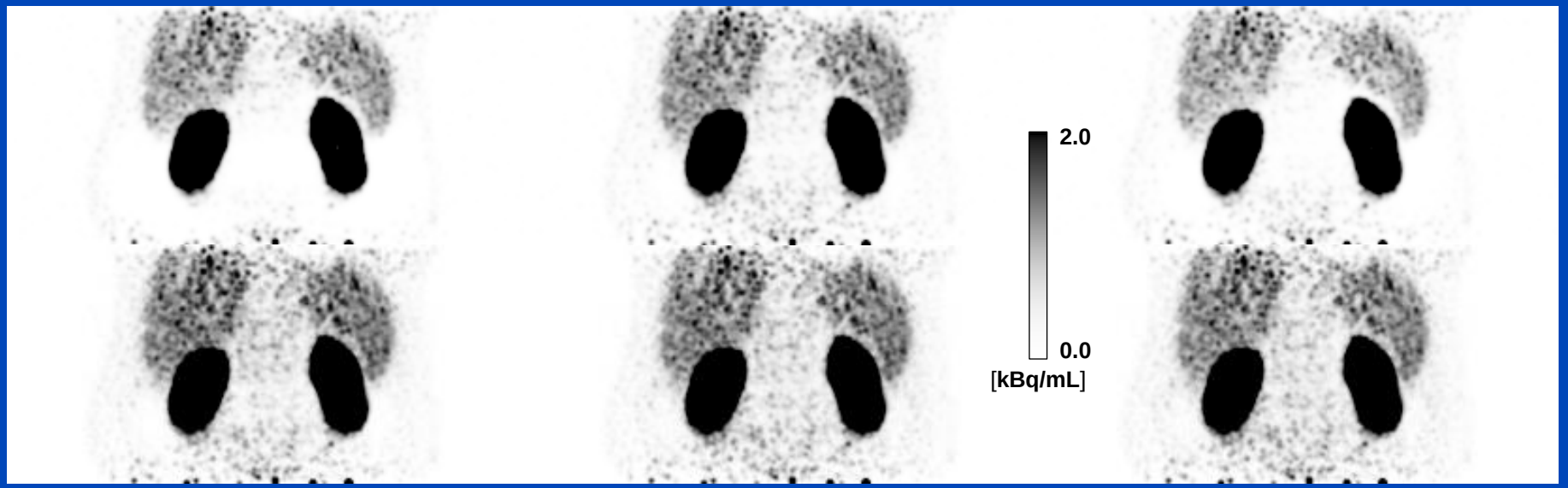
- 25 ^{68}Ga-PSMA PET/MR patients
  - Administered activity: 213 ± 66 MBq
  - Acquisition time: 119 ± 44 min p.i.
  - Arms down
- Scatter Correction (SC)
  - Relative or absolute single scatter simulation (SSS)
  - Maximum scatter fraction MaxSF = 75 % or 40 %
  - ^{68}Ga Prompt Gamma Correction (PGC) off/on (for relative SSS only)

Patient Data

Results Patient 1

160 MBq
128 min p.i.
OBR ≈ 70

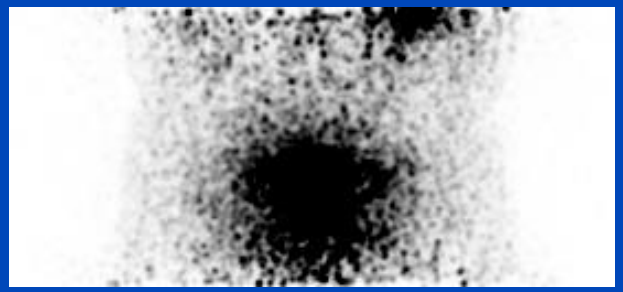


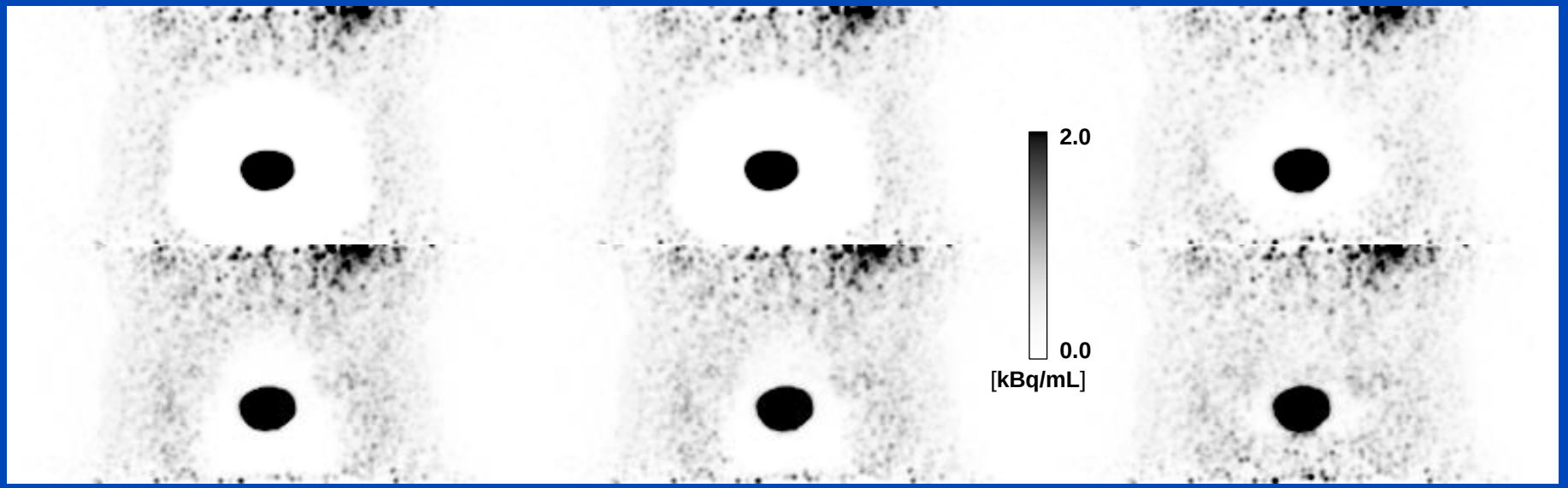


Patient Data

Results Patient 2

144 MBq
104 min p.i.
OBR ≈ 700



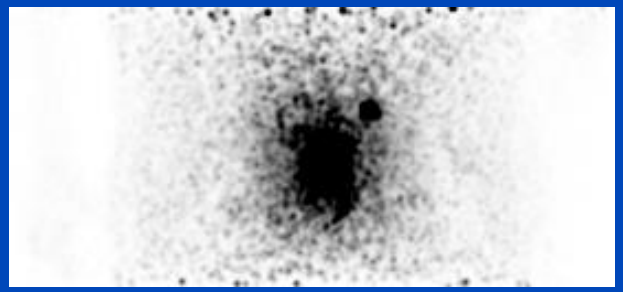


Patient Data

Results Patient 3

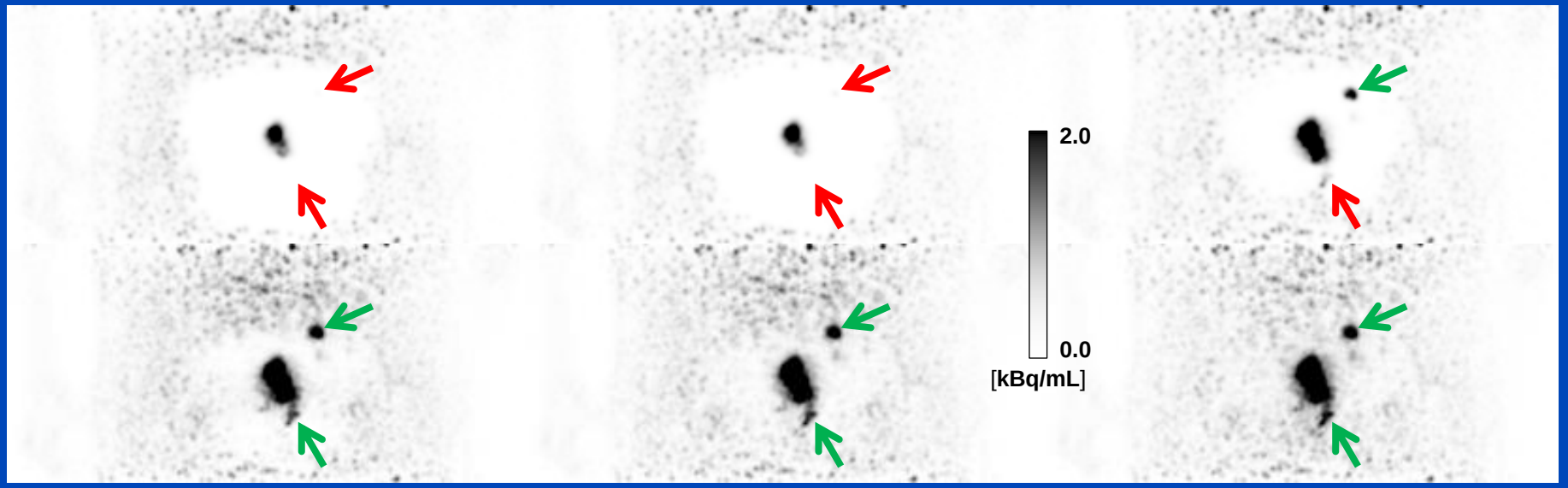
189 MBq
179 min p.i.
OBR ≈ 350

No SC



Rel SC | Rel SC and PGC | Abs SC

MaxSF = 40 % MaxSF = 75 %



Patient Data
Results

- 25 ^{68}Ga-PSMA PET/MR patients
- Investigate halo around bladder
  - Halo present or not?

	no Halo	Halo
Relative SSS (MaxSF = 75 %)	5	20
Absolute SSS (MaxSF = 75 %)	17	8
Relative SSS (MaxSF = 40 %)	21	4
Absolute SSS (MaxSF = 40 %)	24	1

Summary

- **Phantom experiments**
  - Size of halo increases with increasing OBR.
  - No significant differences between PET/MR and PET/CT.
  - Prompt gammas do not seem to be the (main) reason for halo artifact.
  - Decreasing the maximum scatter fraction to MaxSF = 40 % reduces halo size and thus improves image quality.
- **Patient Data**
  - Halo-artifact may occur around bladder and/or kidneys.
  - Absolute SSS results in better image quality than relative SSS.
  - PGC does not reduce halo size in case of severe halo-artifacts.
  - Decreasing MaxSF from 75 % to 40 % improves image quality.

Conclusions

- To avoid the occurrence of halo-artifacts in ^{68}Ga-PSMA-PET/MR, the patient
  - should be scanned as fast as possible after tracer injection.
  - should be asked to void the bladder prior to data acquisition.
- Reducing the maximum scatter fraction to MaxSF = 40 % significantly reduces the halo size.

- Accurate quantitative ^{68}Ga-PSMA PET/MR independent of the workflow mandates new scatter estimation techniques.

Thank You!

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Parts of the reconstruction software RayConStruct-IR were provided by RayConStruct® GmbH, Nürnberg, Germany.

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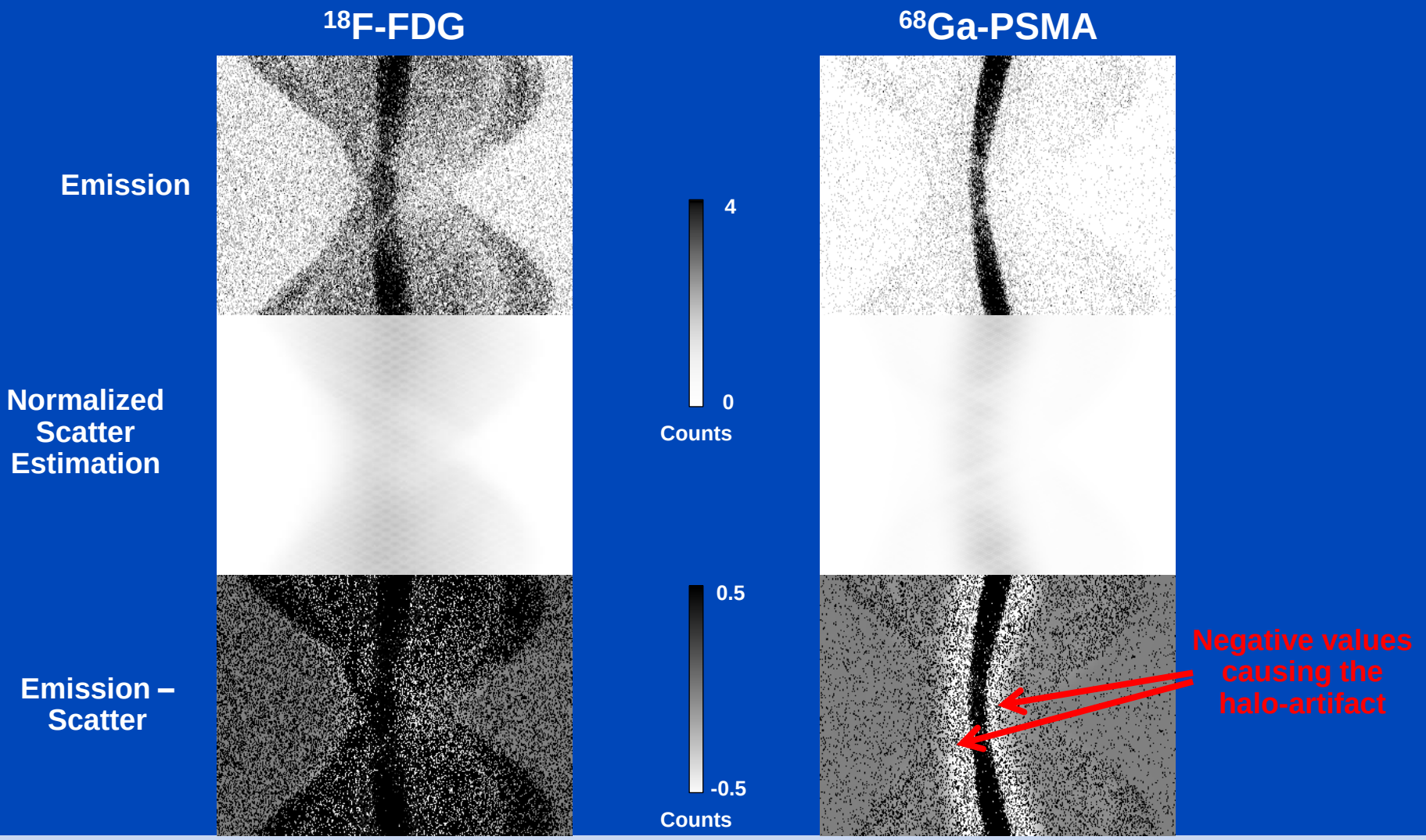
BONUS SLIDES

^{18}F-FDG vs. ^{68}Ga-PSMA
Sinograms



PET Image Reconstruction

- **Ordinary-Poisson Ordered Subset Expectation Maximization (OP-OSEM)**
- **Update equation:**

$$\lambda_i^{(n+1)} = \lambda_i^{(n)} \frac{1}{\sum_{j \in J} M_{ij}\, a_j / N_j} \sum_{j \in J} M_{ij} \frac{p_j}{\sum_k M_{kj} \lambda_k^{(n)} + (N_j r_j + s_j)/a_j}$$

i	Voxel index	λ	Image	a	Attenuation
j	LOR index	p	Emission data	N	Normalization
n	Iteration number	J	Subset	r	Randoms
M	System matrix			s	Scatter

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Patient Data

Results Patient 4

283 MBq
180 min p.i.
OBR ≈ 600