Just-in-time Dosimetry using Positron Emission Tomography

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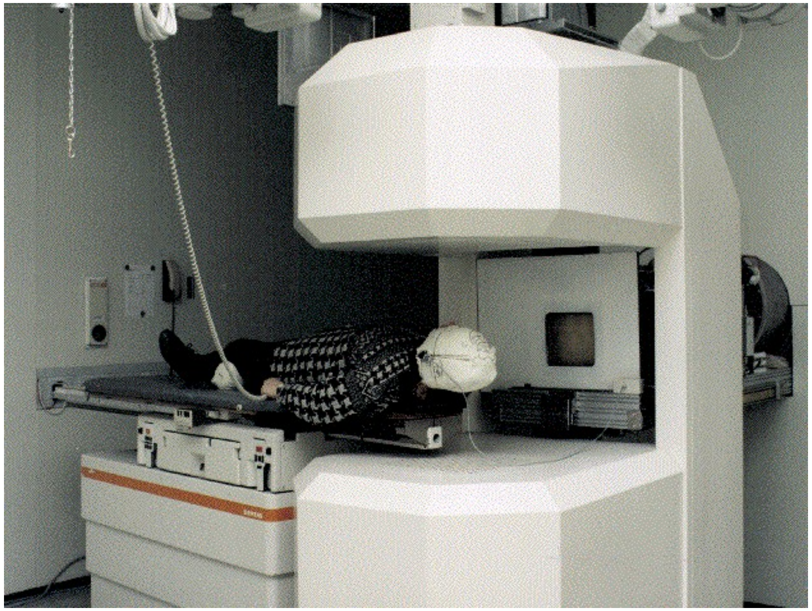
Medical in-beam Positron Emission Tomography (PET)

Radiation treatment for head tumor

- Protons / heavy ions
- Multiple irradiation sessions [weeks]
- Sessions possibly fractionized [1 hour]



- **Goal: Dosimetry imaging at the time of irradiation**

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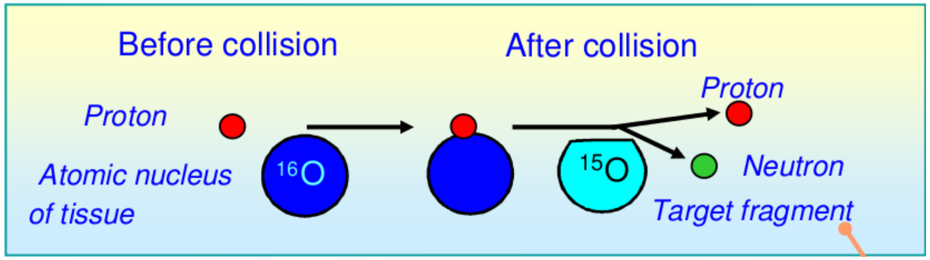
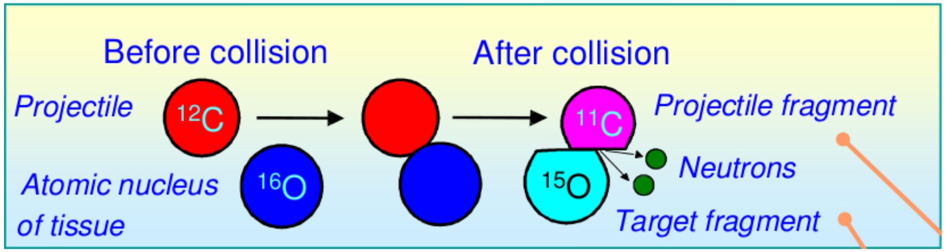
Signal originates from positron-electron-annihilations





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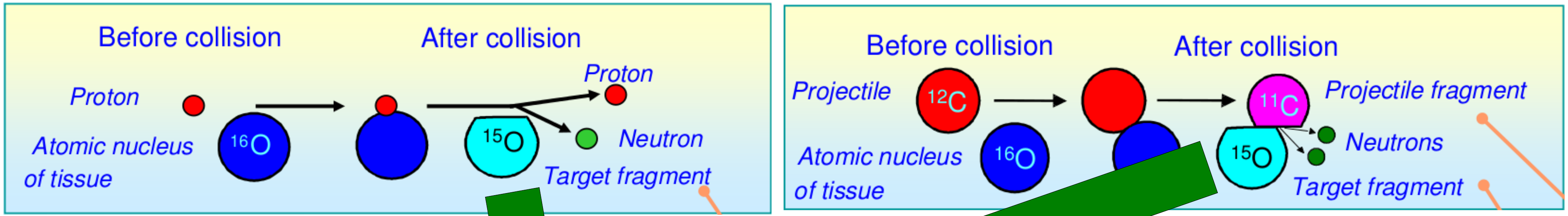
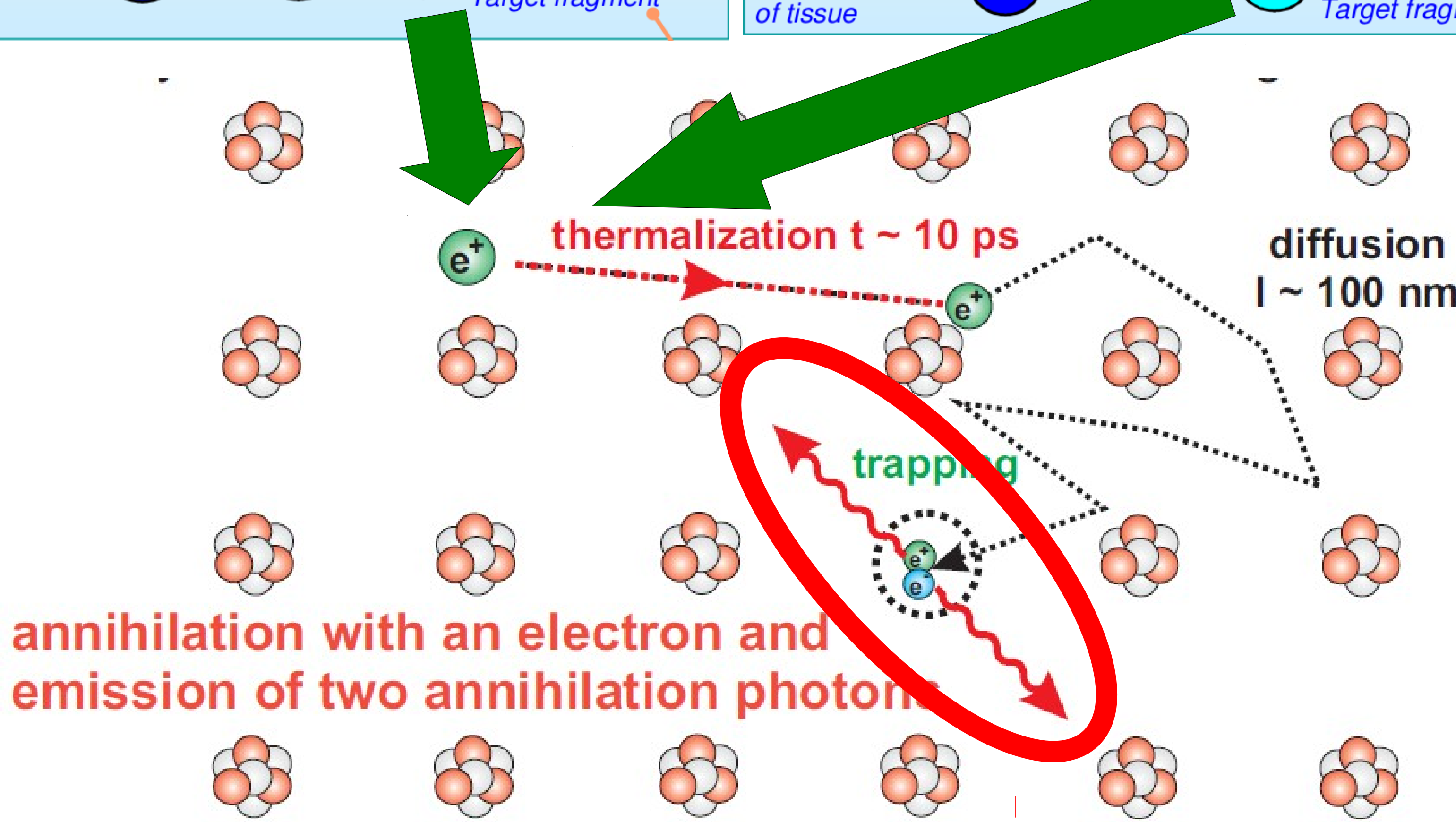
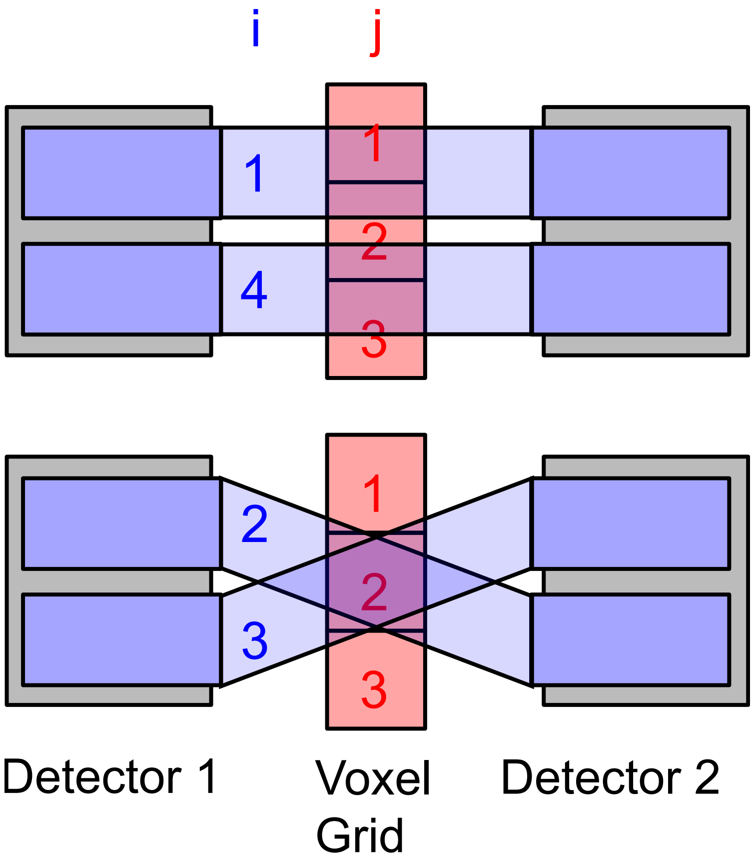




Coincidence detection



- Annihilation photons detected in pixel detectors
- „Event“: Coincident detection in two different detectors
- Pixel pairs = lines of response (LOR) → here: blue stripes with indices *i*

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Detector systems

Numbers:

- Typically ~100 pixels per detector
- Up to ~10.000 pixels in total
- Up to ~10e5 .. 10e6 LORs
- Maybe additional LORs through translation, rotation

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Remember: Dosimetry wanted

- Number of measured coincidences from a volume ~ number of beta(+) decays
- That's **activity**
- Dose applied along the way with dependence on tissue properties
- **Dose** is not activity
- **Wanted quantity is not easily correlated to the signal!**

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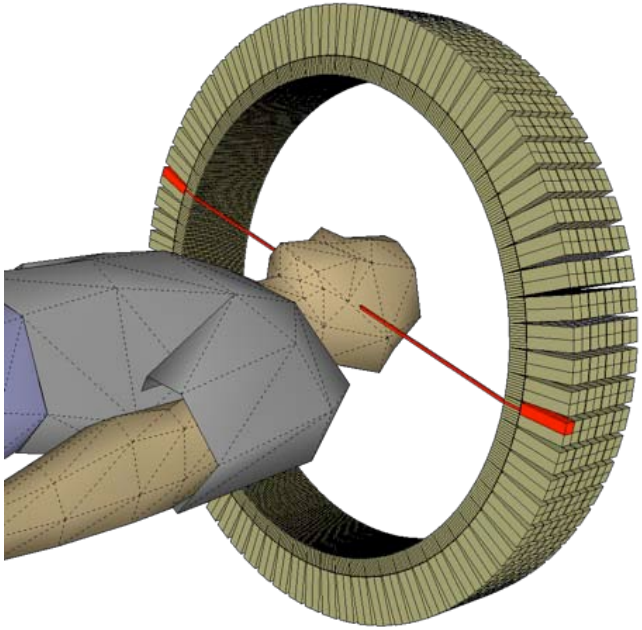
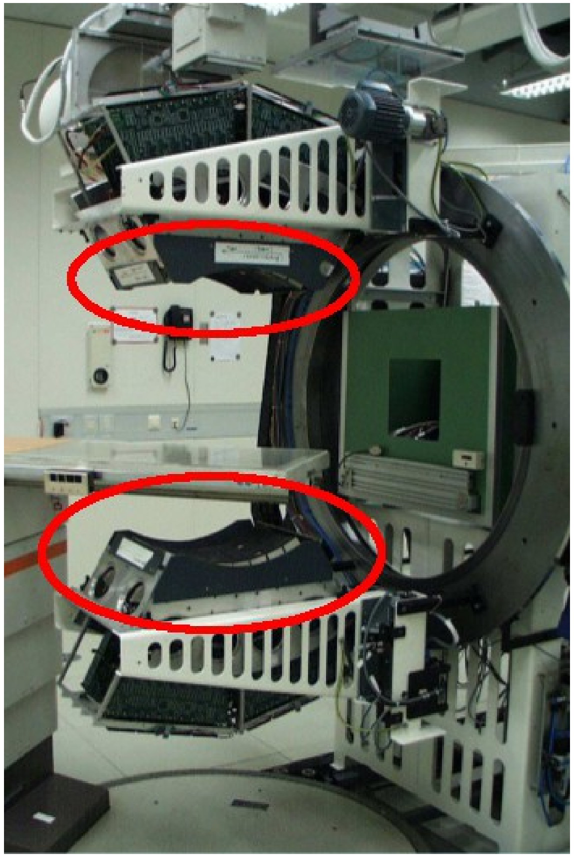
Detector systems

Scanner-Ring





In-beam PET-Scanner @GSI

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Data

- Roughly some 10 MB / min
- Total: 100 MB .. 1 GB
- That's relatively few → poor counting statistics
- Tunable - to a degree - by choice of detector
- Depends on total irradiation!

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Implications for the reconstruction

Challenging!

- Direct methods hard / impossible to employ
- Dose non-trivially correlated to measured „activity“ signal
- Use as in-situ imaging for feedback: Reconstruction should take no longer than **a few minutes**

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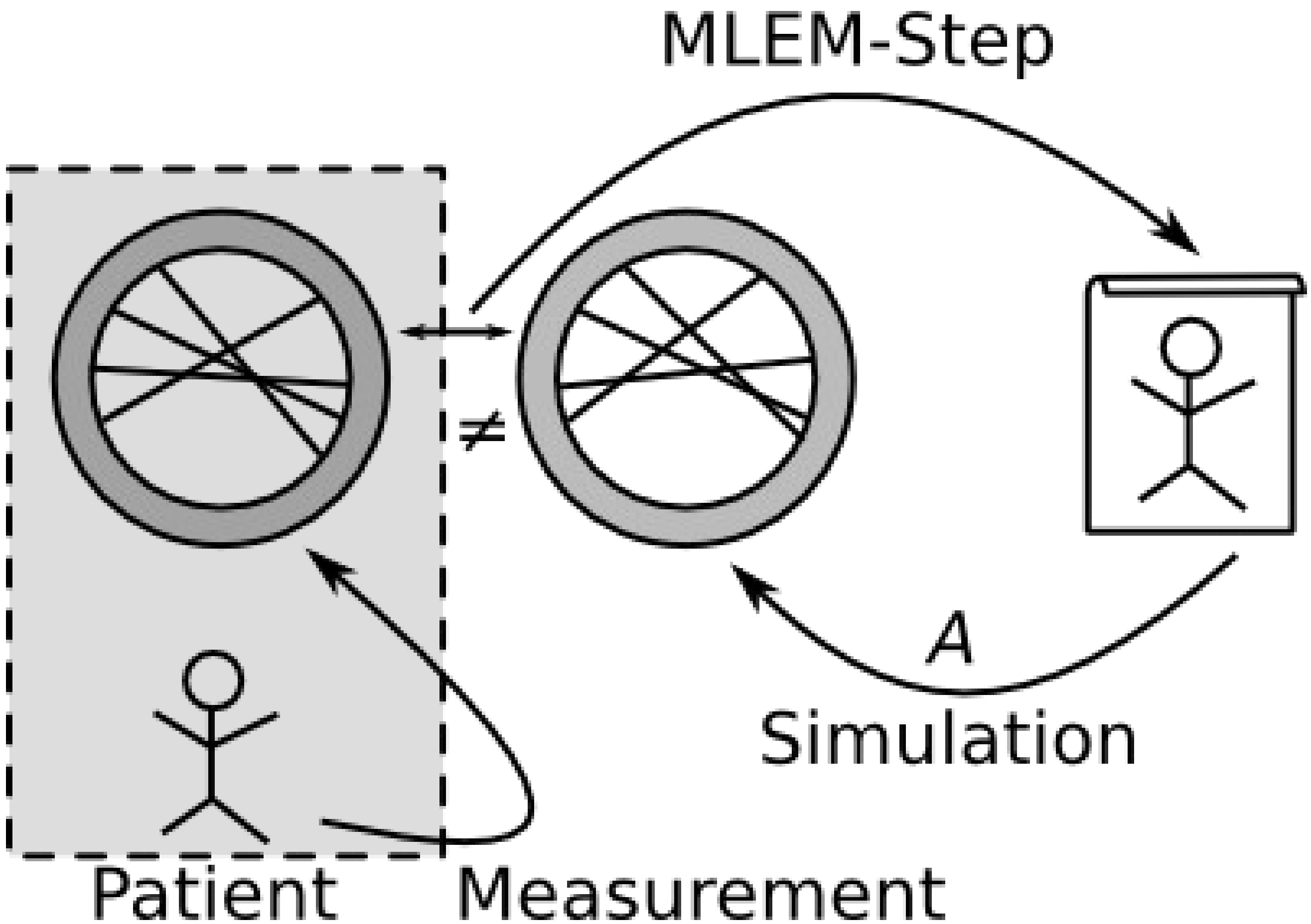
Iterative reconstruction is method of choice



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Iterative reconstruction is method of choice

Maximum Likelihood Expectation Maximization (MLEM):

- Statistical approach
- Uses forward projection, can linearly be described as **System Matrix (SM)** ***A***
- Pro: Put any knowledge into SM → dosimetry
- Roughly 50 iterations necessary

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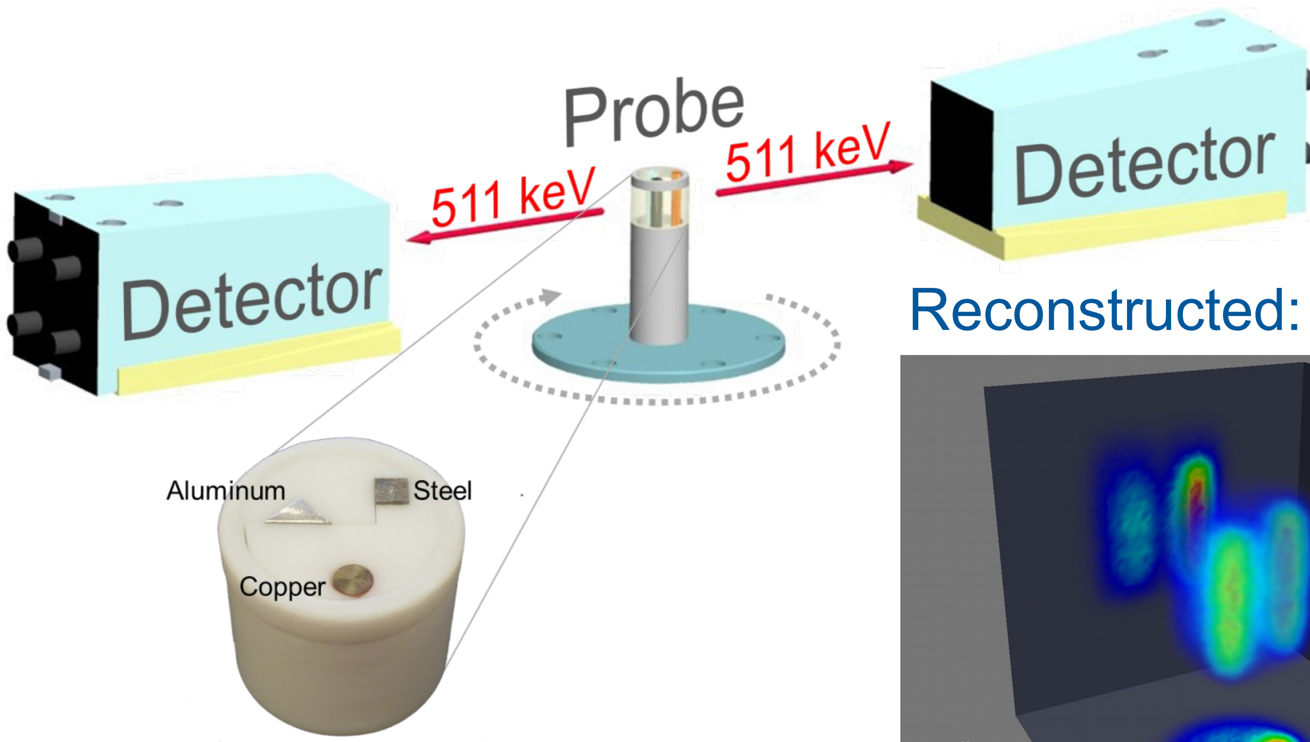
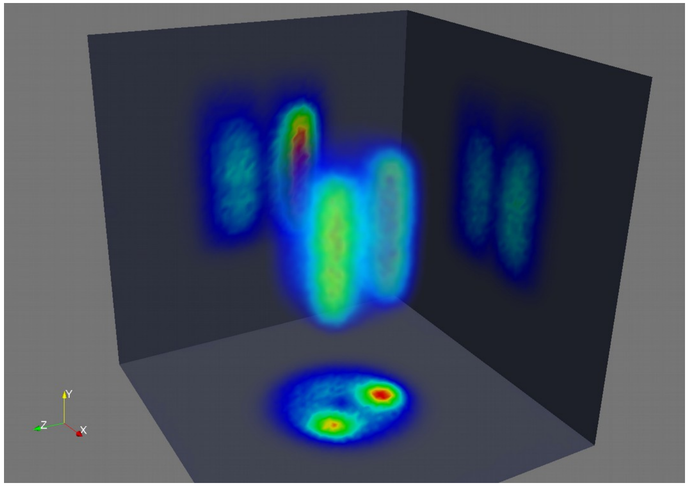
Plastic and metal phantom as an exemplary model system



Reconstructed:



- 180 * (13 * 13) * (13 * 13) LORs ≃ 5,000,000 LORs
≃ **50 MB input data**

- 64 * 64 * 64 voxel ≃ 250,000 voxel

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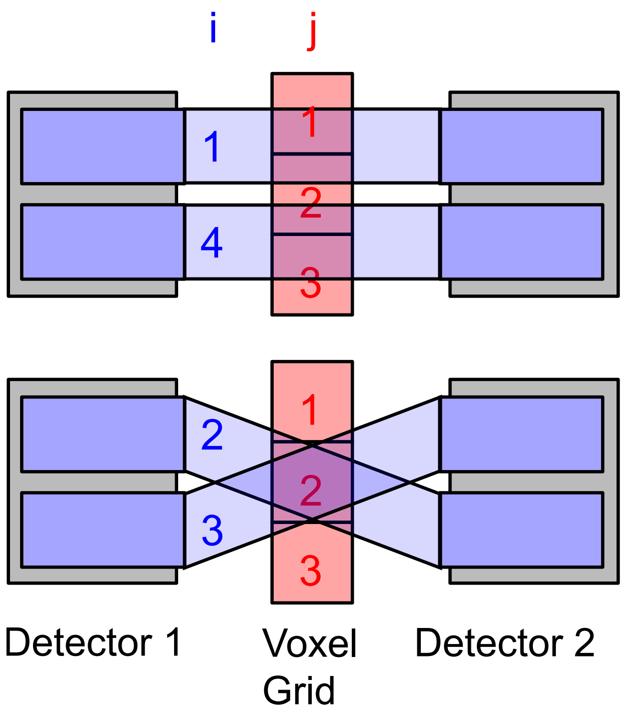
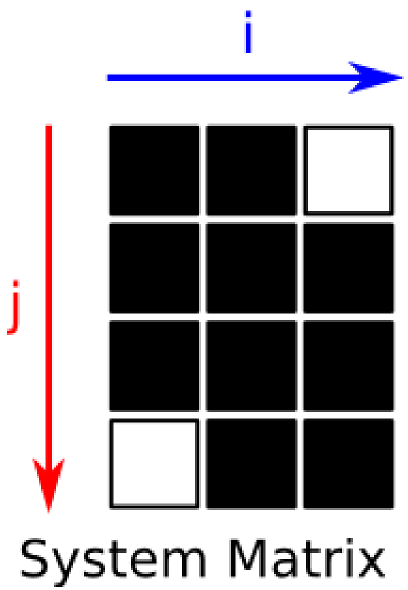
Estimation of SM size





- SM is thinly occopied, ca 5 %
- 6.7e10 non-zero SM elements = **500 GB**

Reconstruction becomes an HPC problem

Time for model reconstruction:

- 1 GPU: 10 h / 1 reconstruction step
- Note: **500 GB SM - Big Data even though input was just 50 MB!**
- Let's look into parallelization ...

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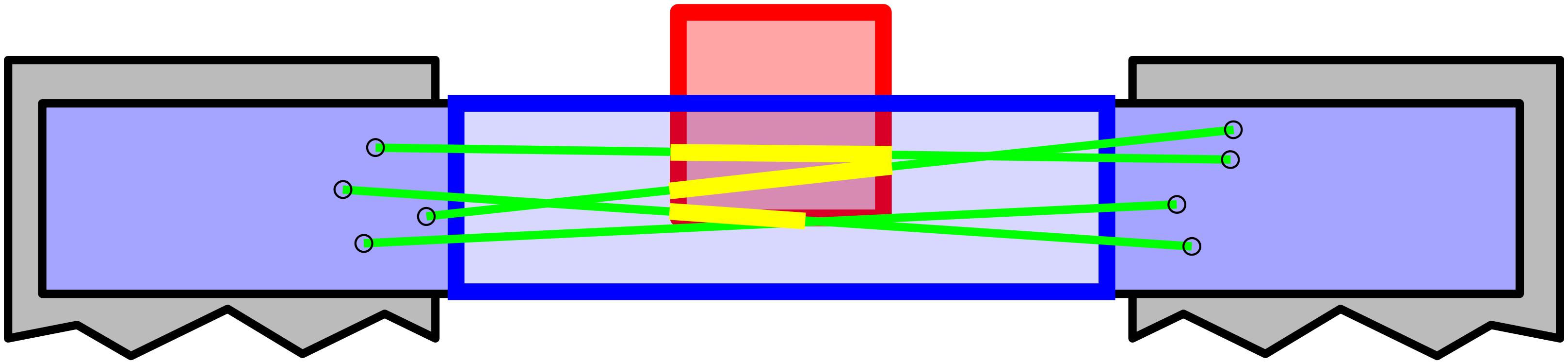
Calculating the system matrix is simulating the measurement process



Put knowledge about measurement process here!

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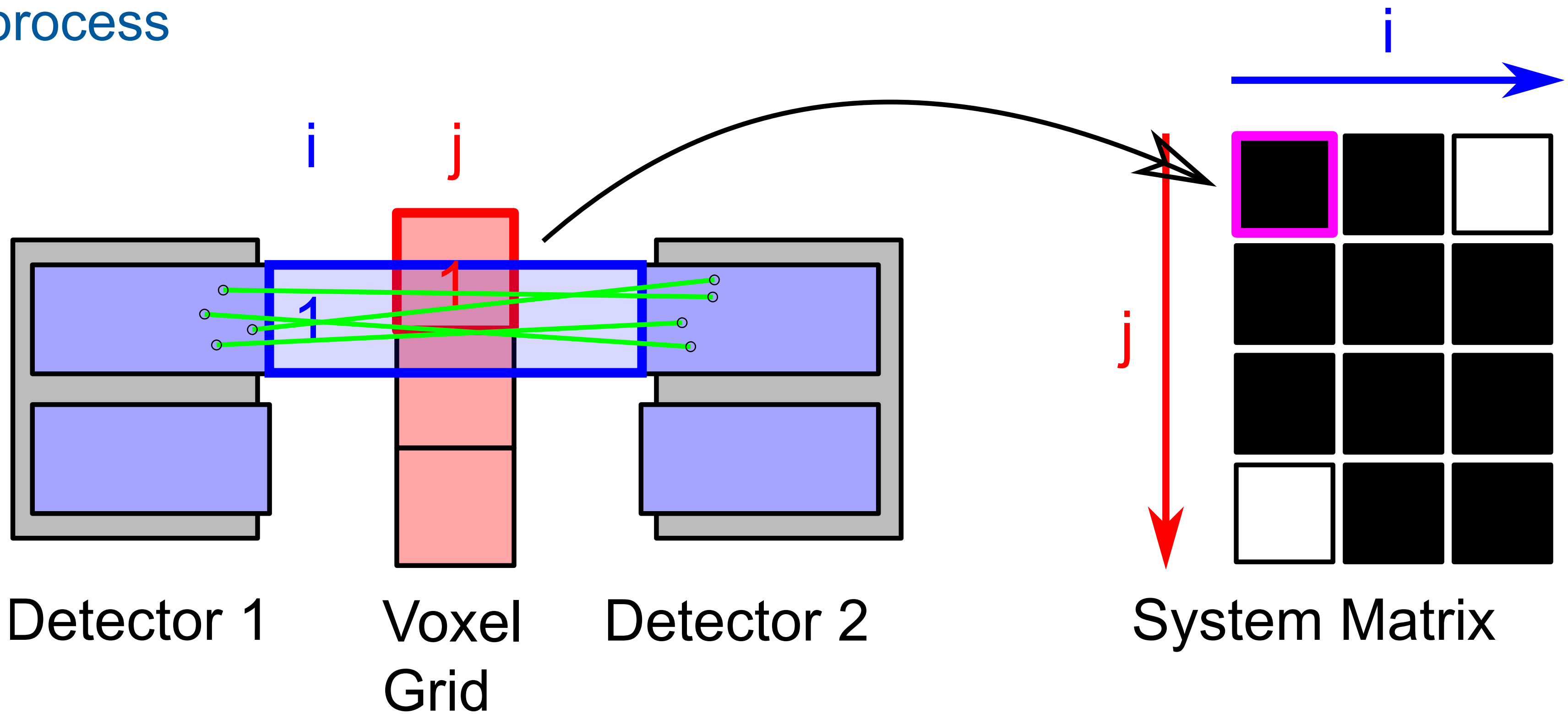

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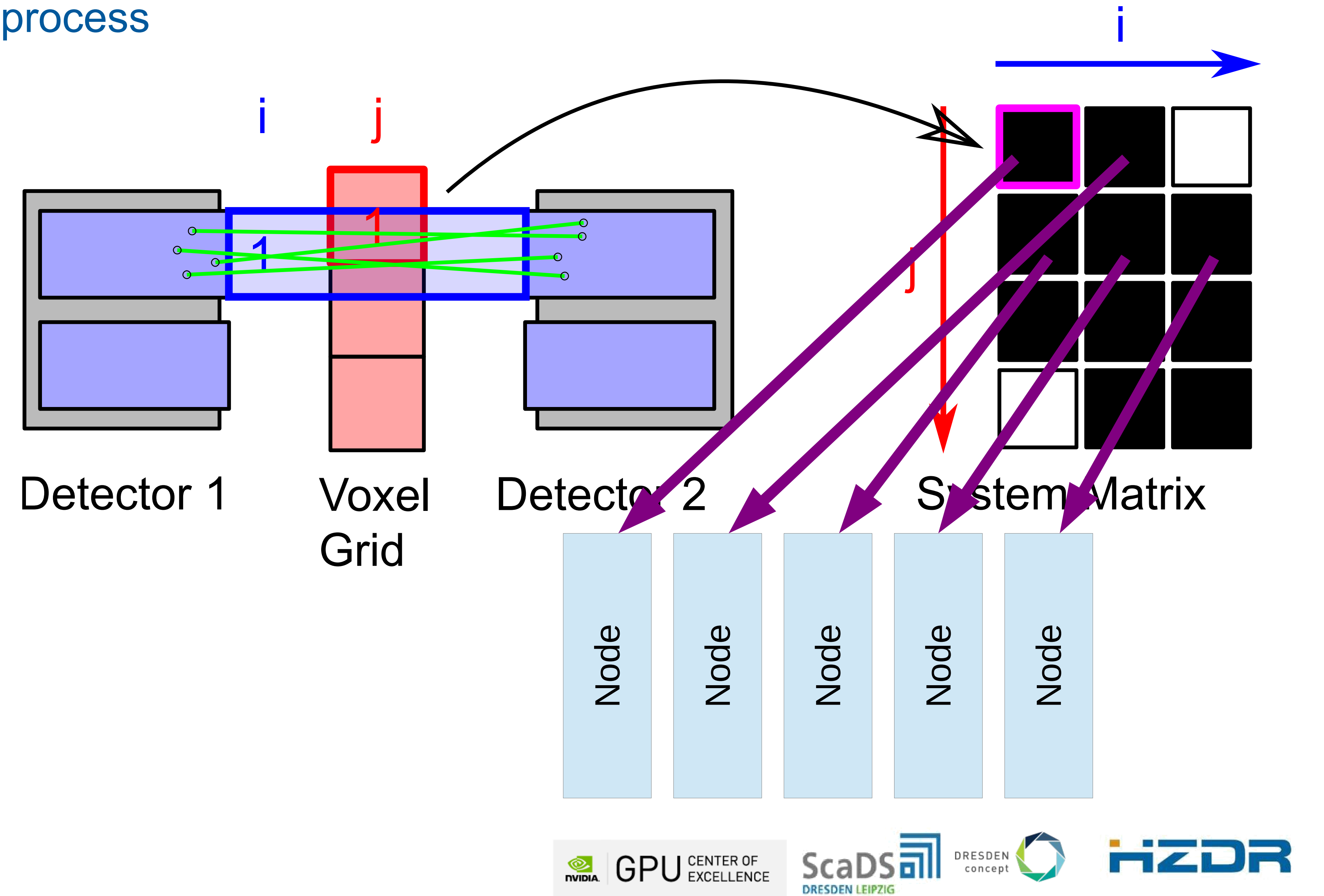
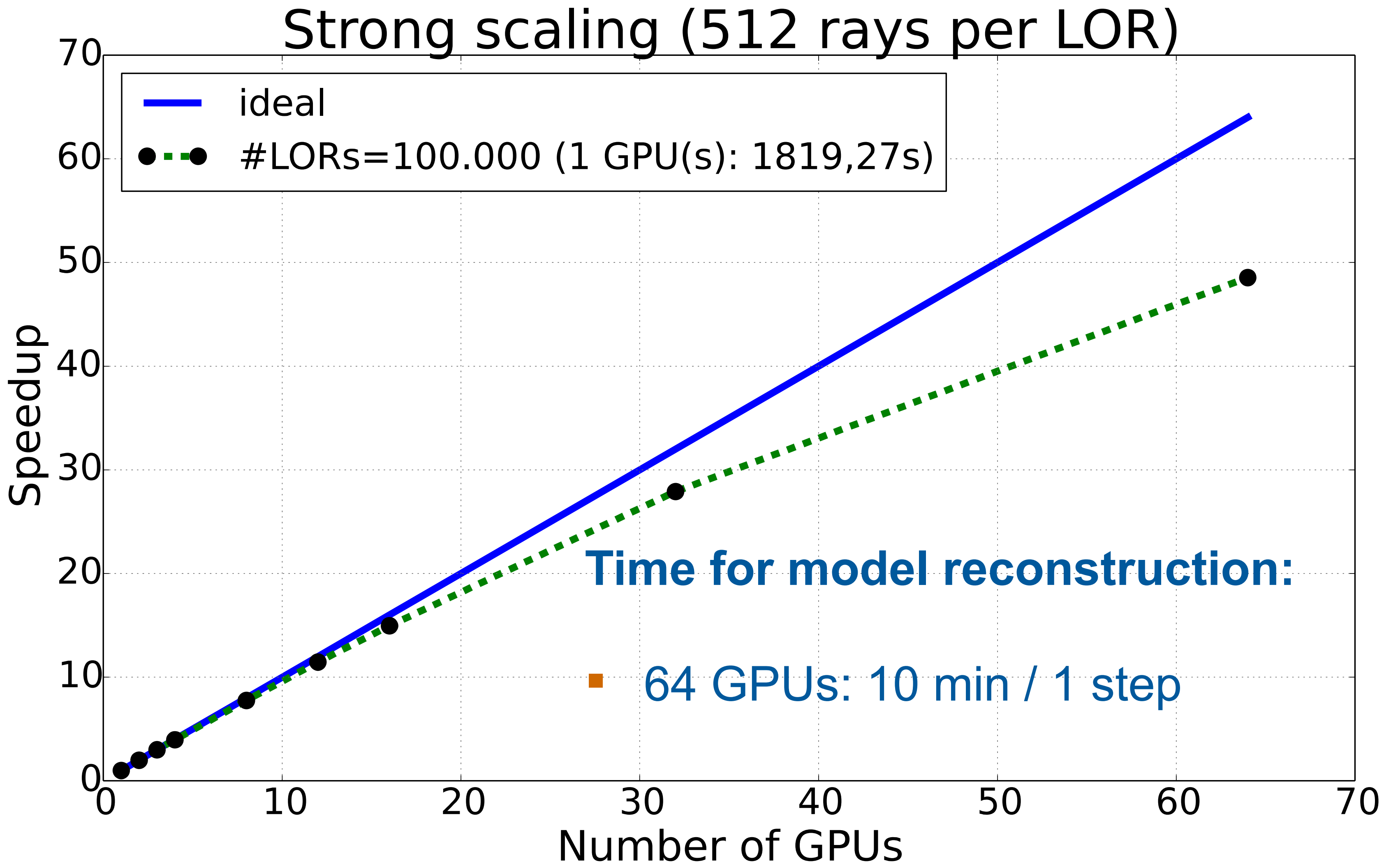


First step done: Whole reconstruction runs parallely



Time for model reconstruction:

- 64 GPUs: 10 min / 1 step

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Keep the system matrix!

Good assumption:

- Rigid, unchanging target → **constant SM**
- Adoptable to patient
- Use CPU mem for saving the SM between steps

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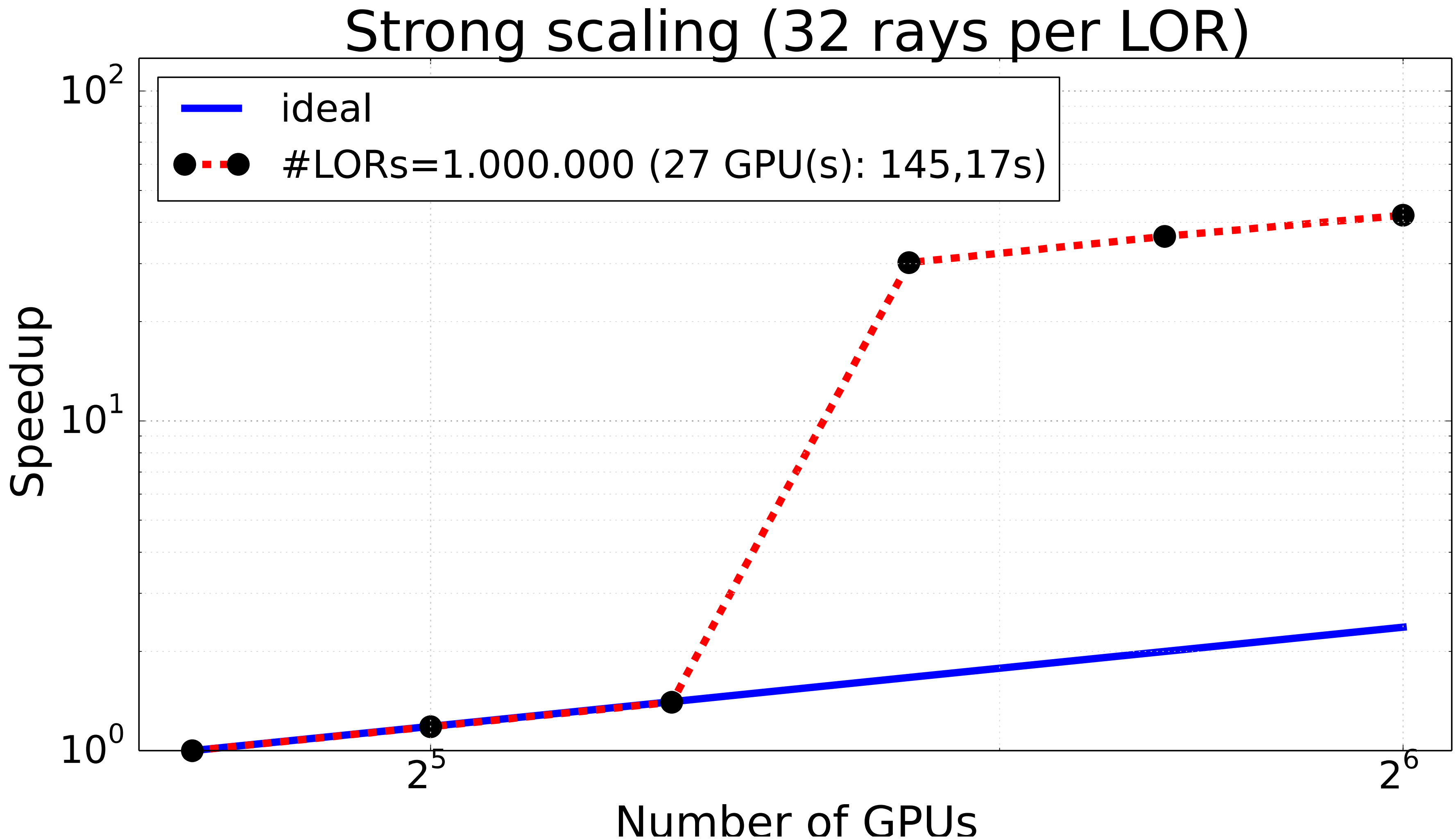
With system matrix in CPU mem



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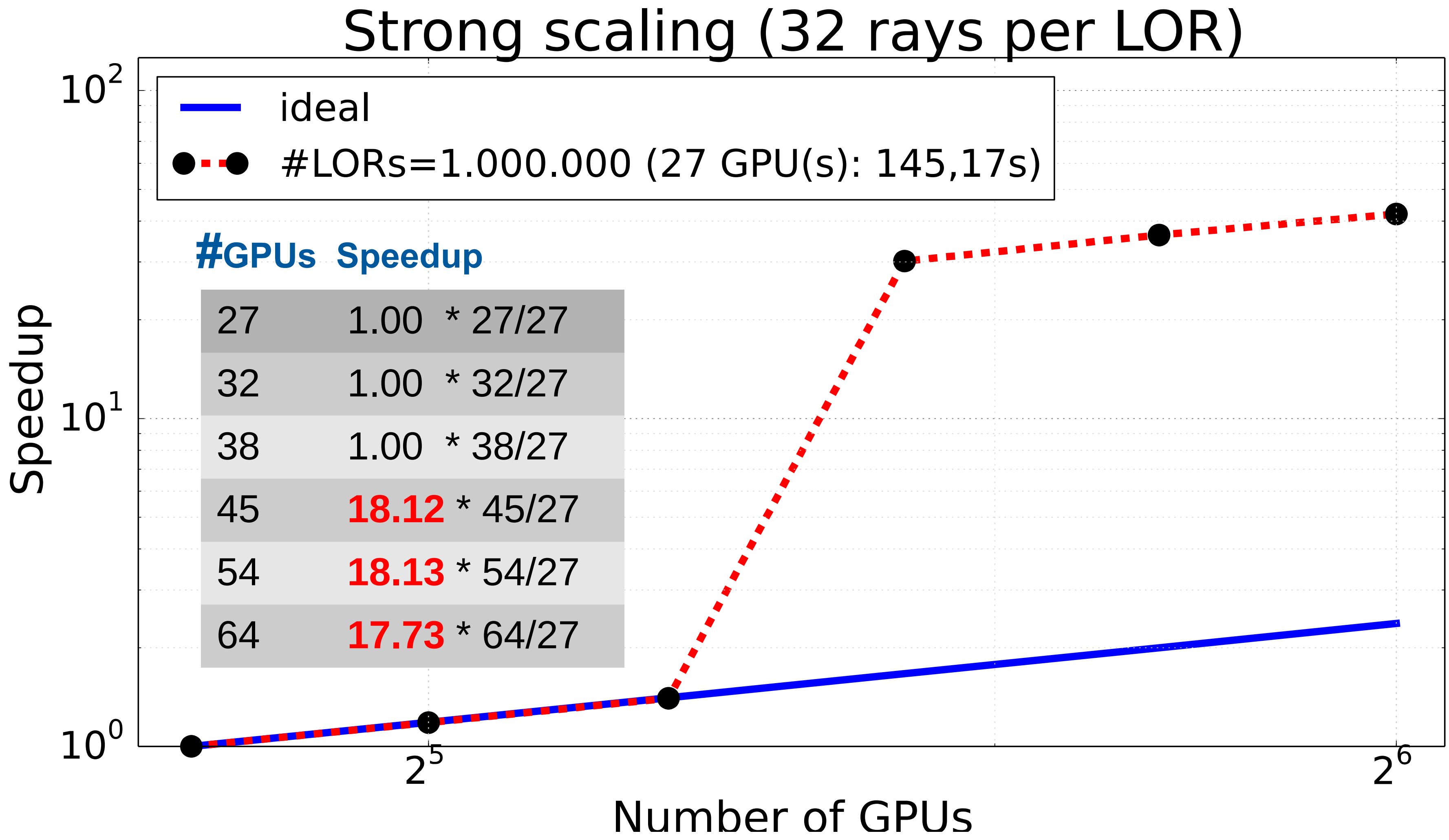

#GPUs	Speedup
27	1.00 * 27/27
32	1.00 * 32/27
38	1.00 * 38/27
45	18.12 * 45/27
54	18.13 * 54/27
64	17.73 * 64/27

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Outlook

- Keep SM *on GPU*
- Implement caching techniques (CPU, GPU)
- Porting to Alpaka, Graybat :-)

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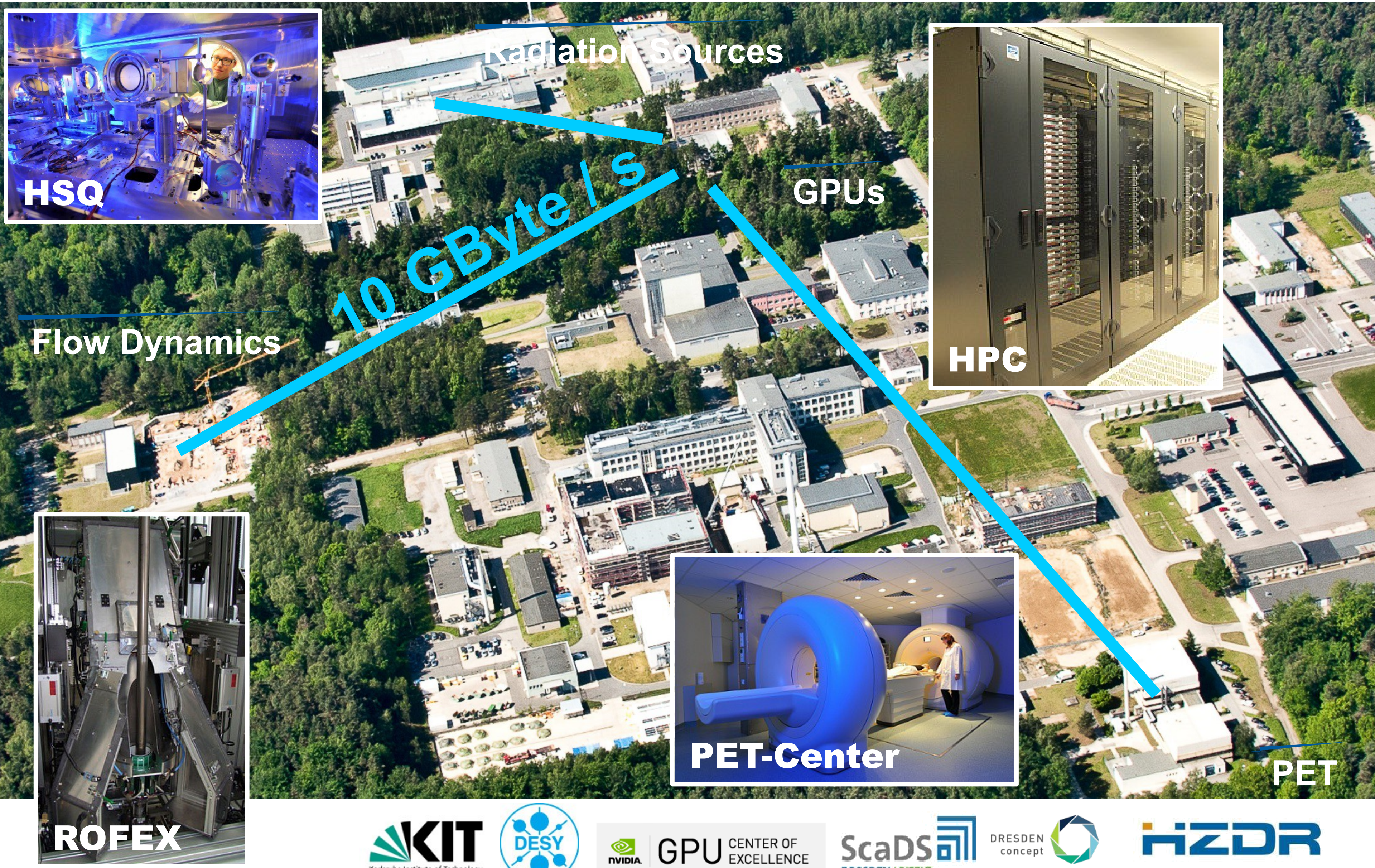
Central GPU-accelerated realtime Data Analysis @ HZDR



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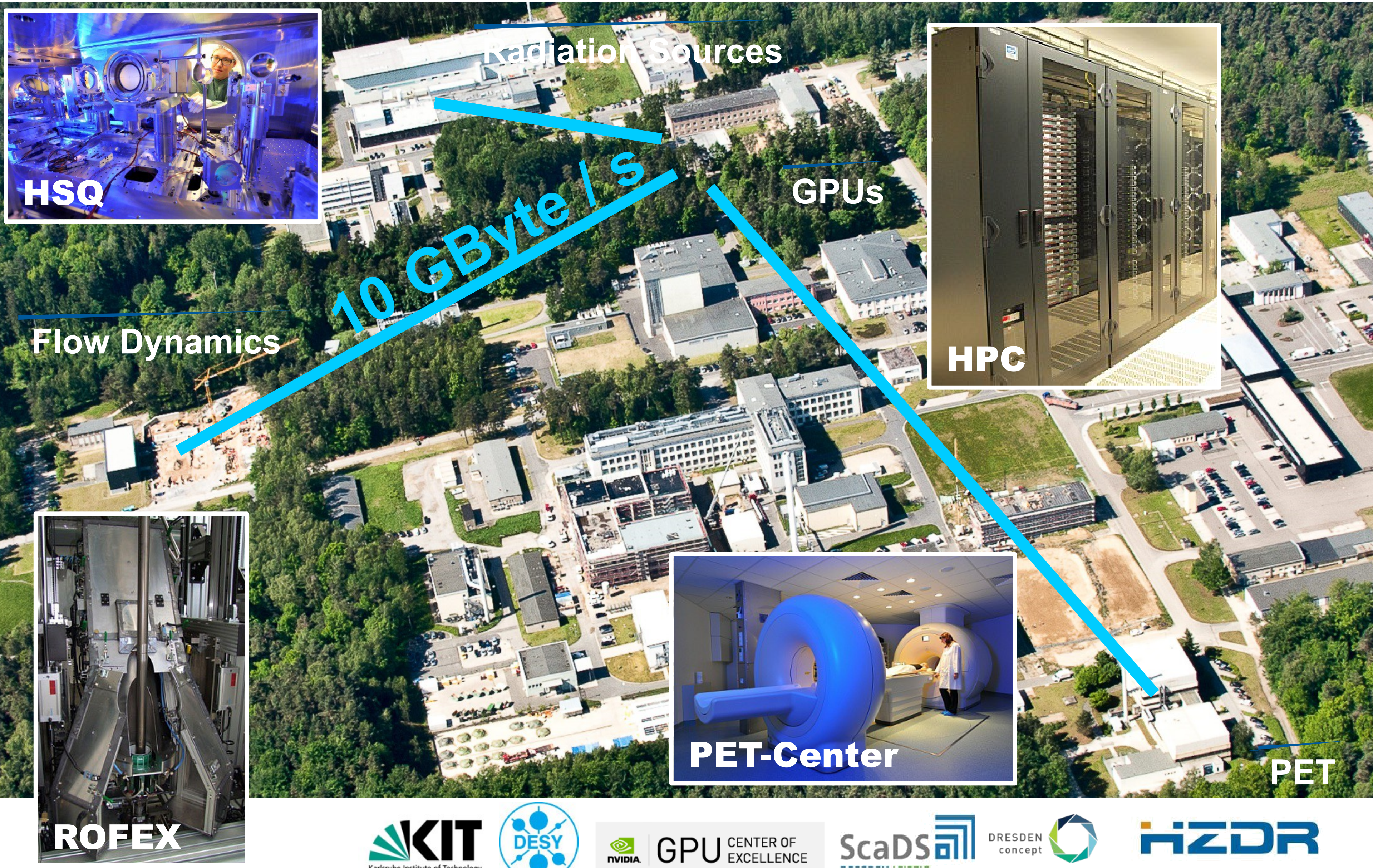

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HZDR GPU-accelerated Plattform for Data-intensive Computing

9 compute nodes in total, 1 node equipped with

- 4 × NVIDIA K80 (24 GB) @ full PCIe 3.0 Bandwidth
- 2 × INTEL XEON 8-core
- 256 GB memory (~ 2.7 × GPU memory, 16 GB / core)
- Mellanox 56 GB/s FDR

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