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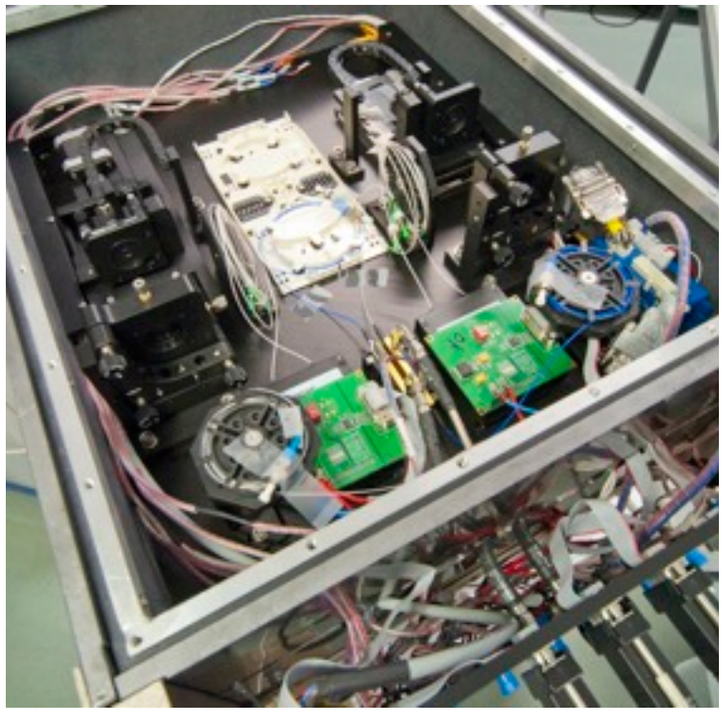
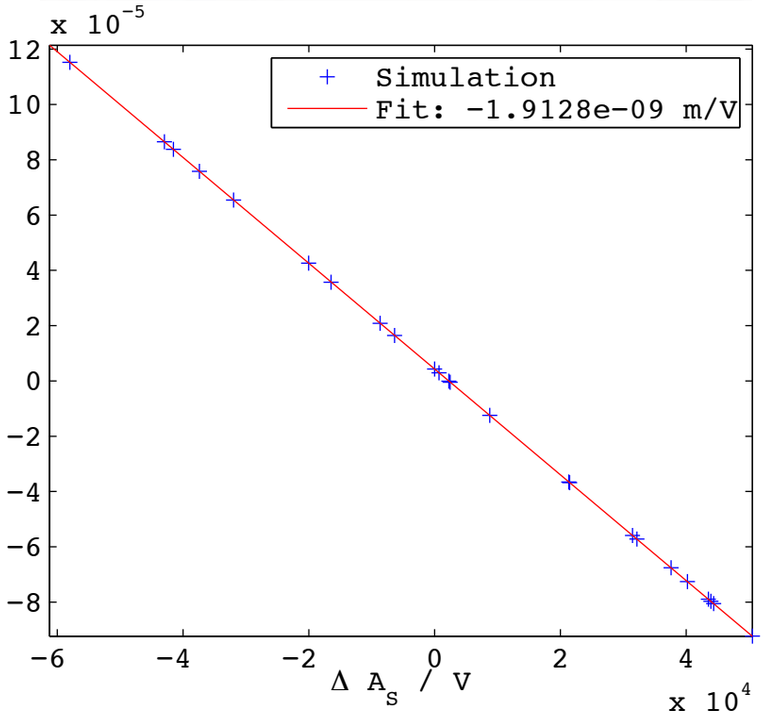
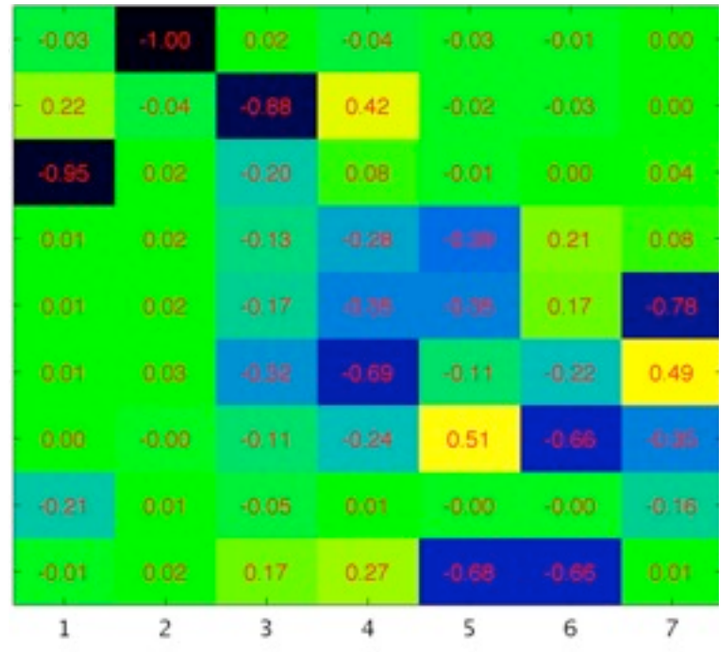






SwissFEL Longitudinal Diagnostics Response Matrix

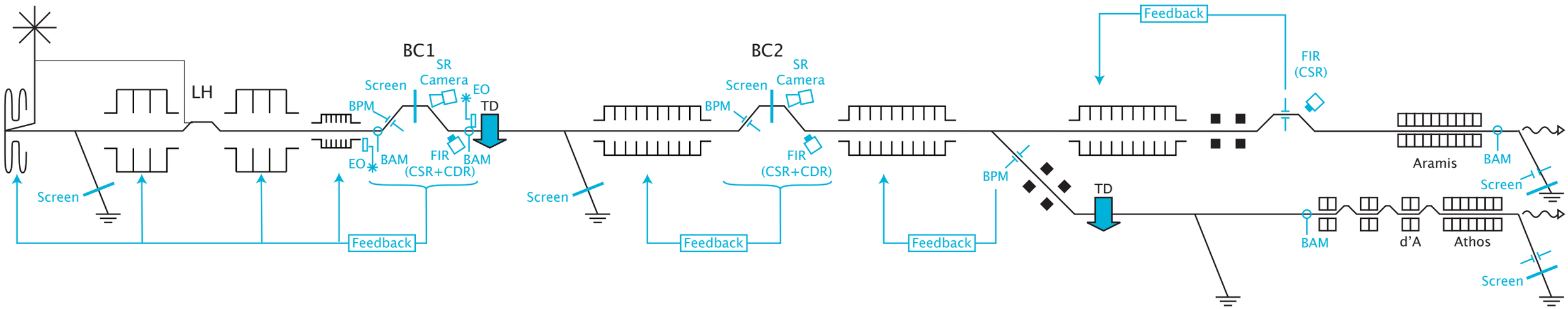
Rasmus Ischebeck, Bolko Beutner, Roger Kalt, Peter Peier, Sven Reiche, Thomas Schilcher, Volker Schlott

Longitudinal Diagnostics for SwissFEL

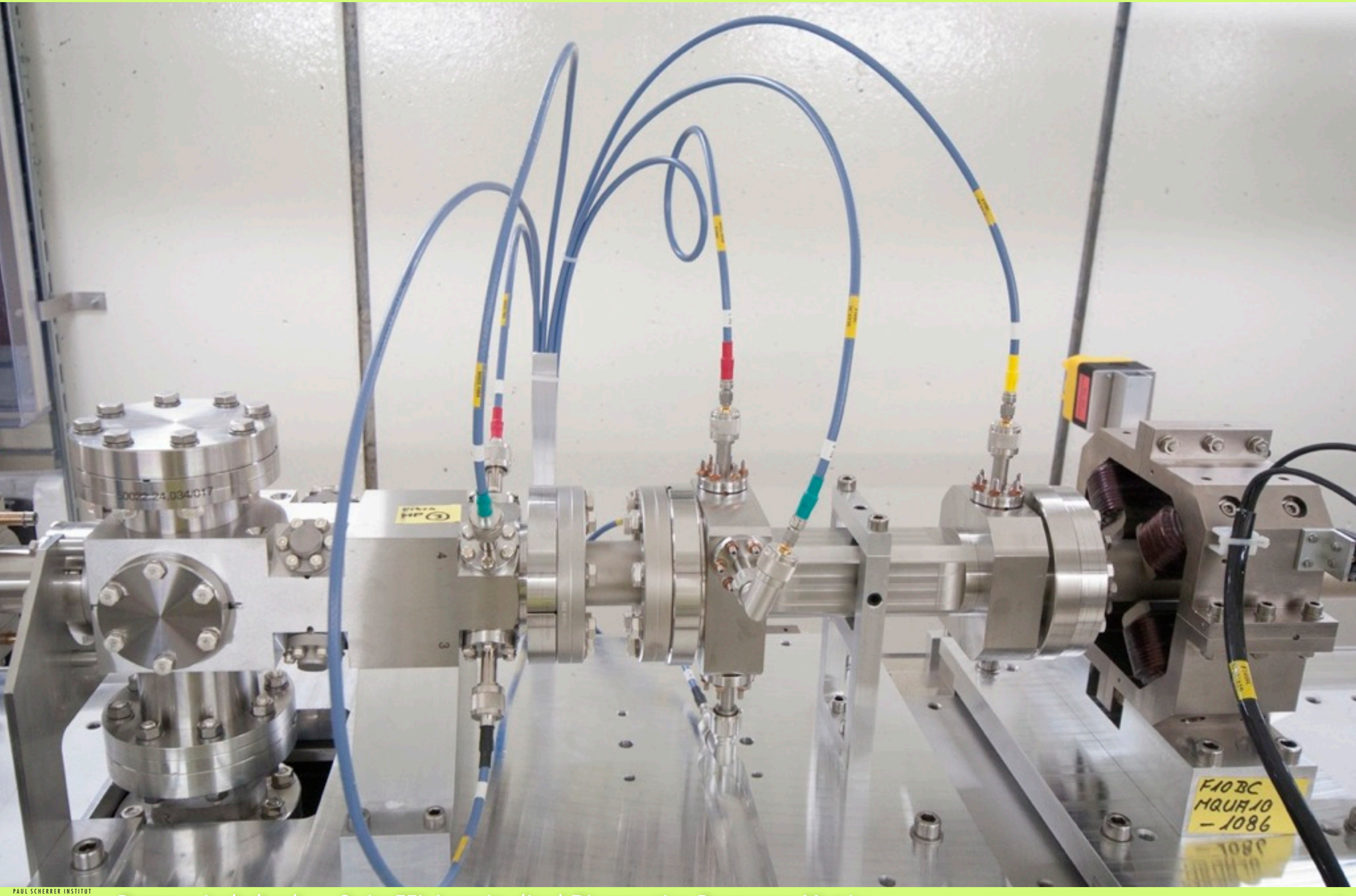
- > Hard X-ray SASE FEL
- > The accelerator physicists' view:
  - > Low beam energy (5.8 GeV)
  - > Low bunch charge (200 pC, 10 pC)
- > The users' view
  - > Short pulses (20 fs, 1.5 fs)
  - > Good stability (20 fs, 5 fs)
  - > Synchronization to external laser source
- > Transverse stability
  - > Cavity BPMs
  - > Feedback system
- > Longitudinal stability
  - > Instrumentation
  - > Possible feedbacks

} This Talk

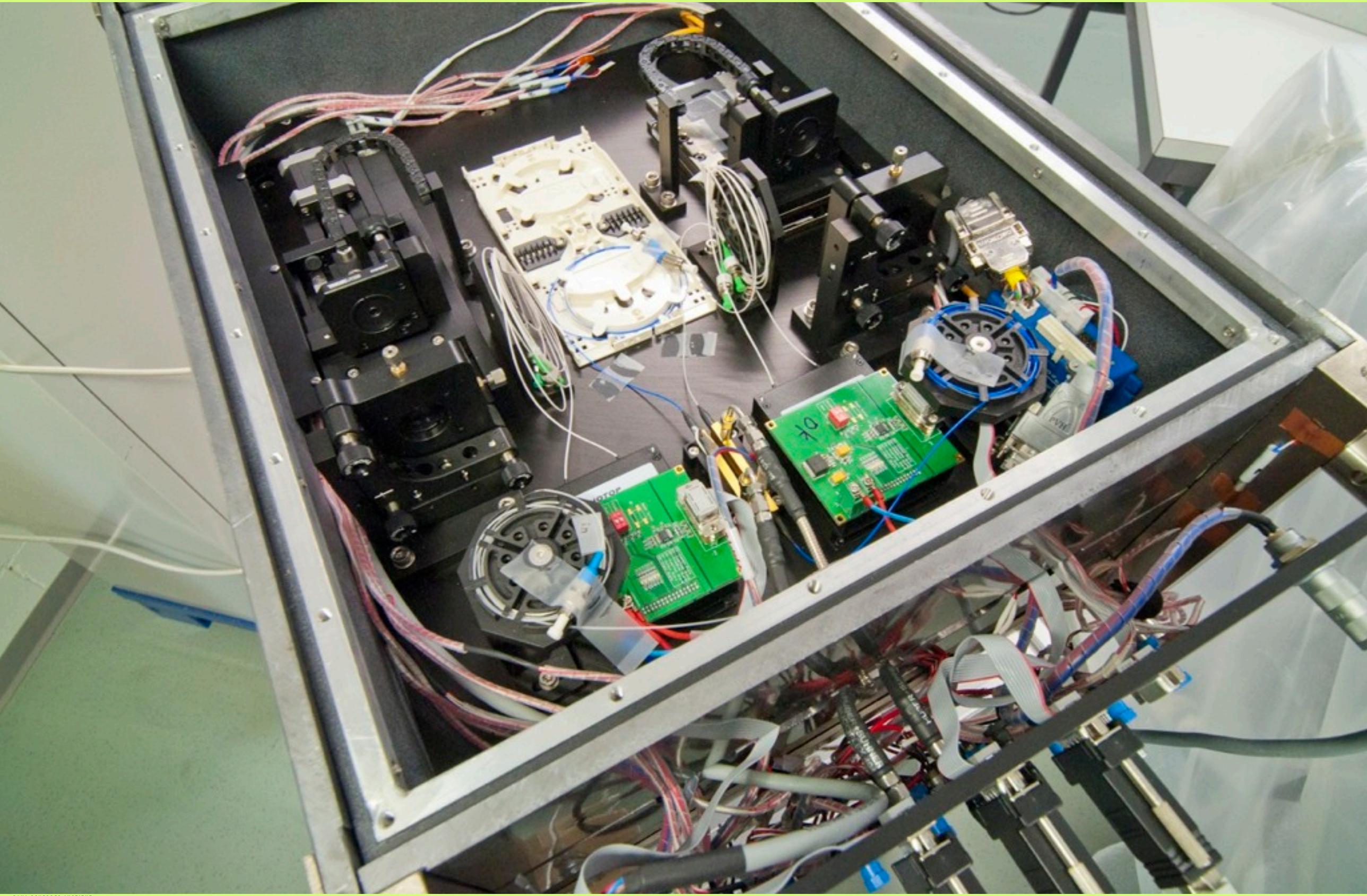
Longitudinal Diagnostics



Beam Position Monitors in Dispersive Sections

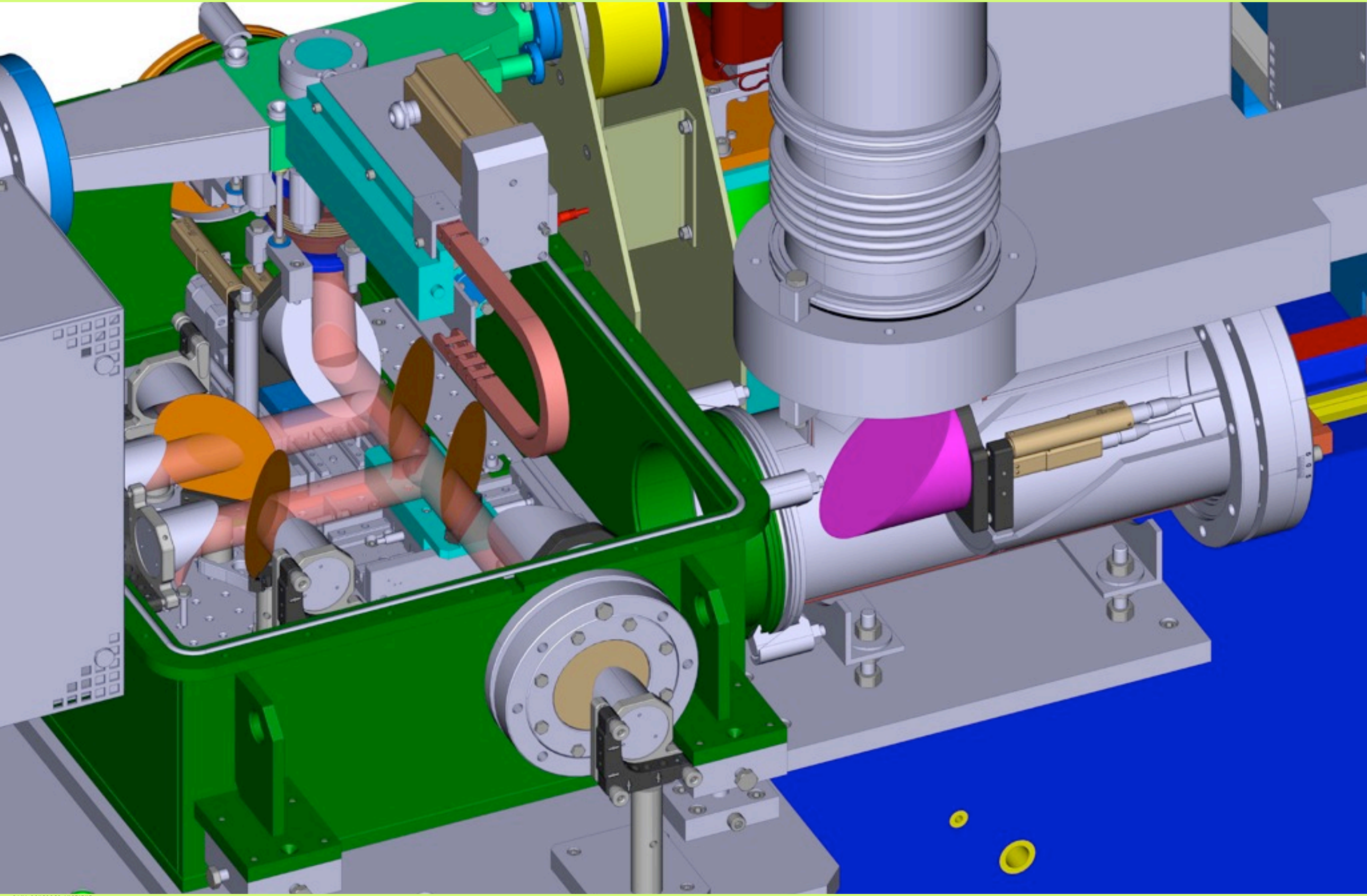


Bunch Arrival Monitor

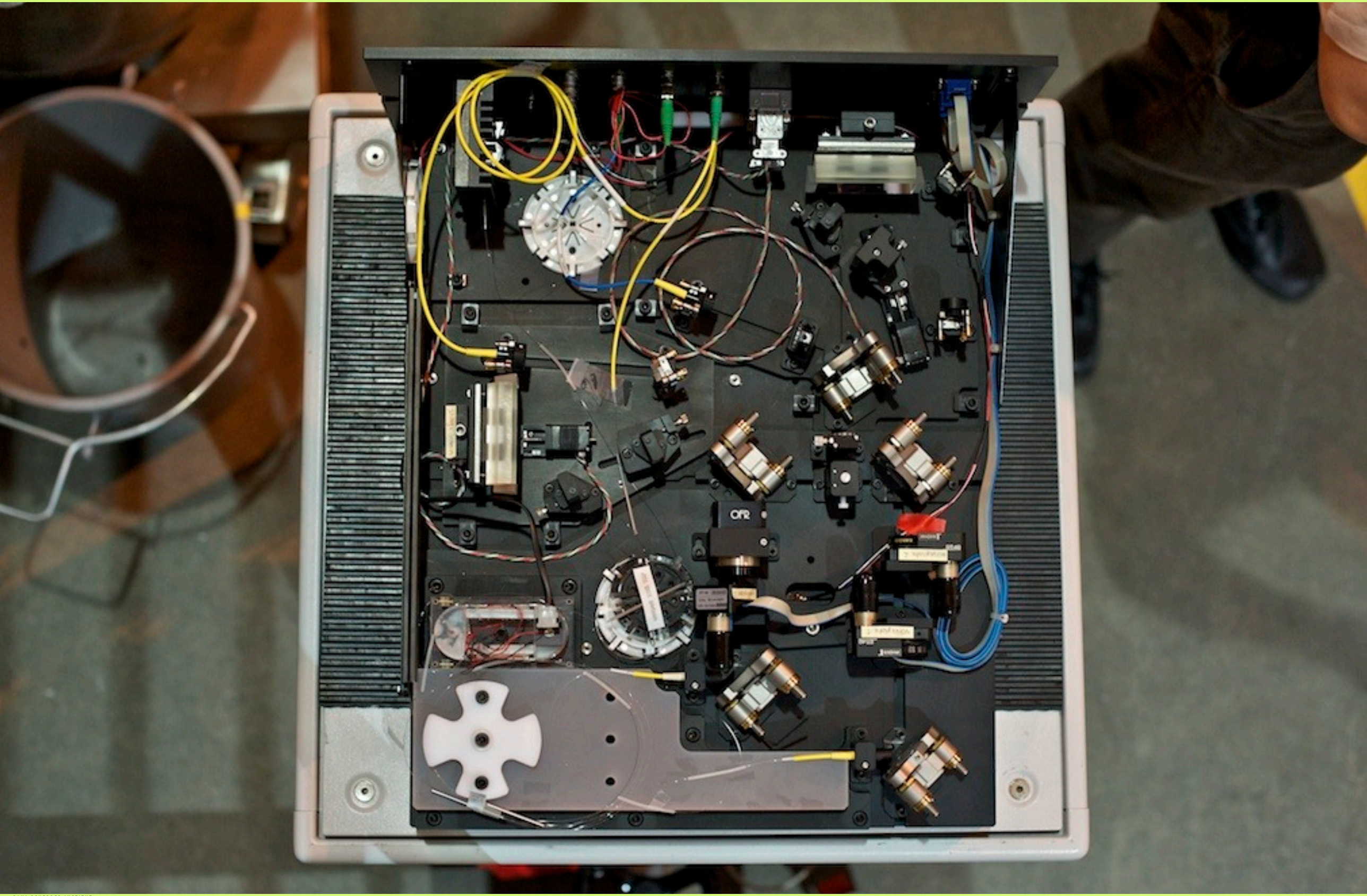


Synchrotron Radiation Imaging

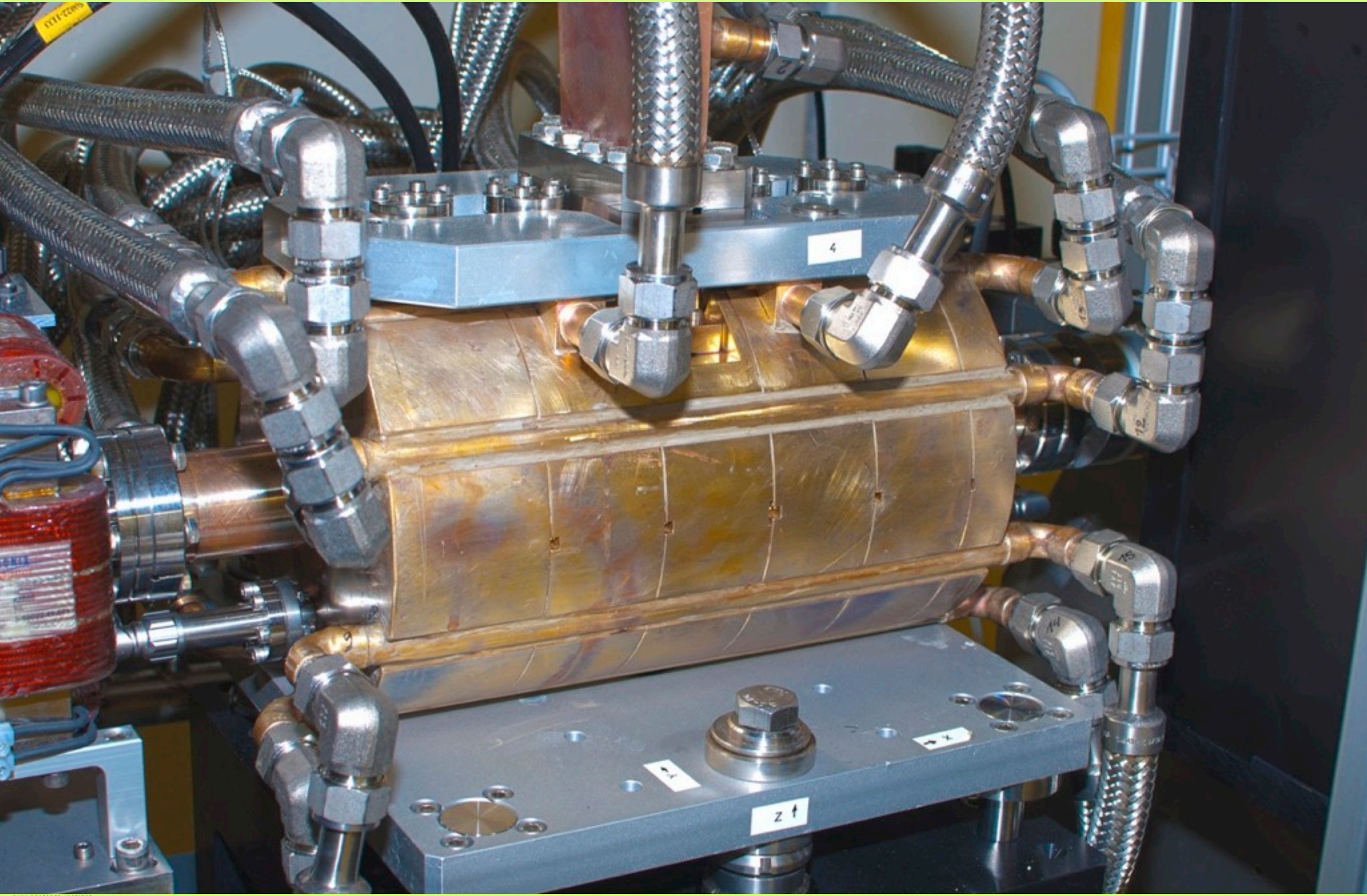
Coherent Terahertz Radiation Monitors



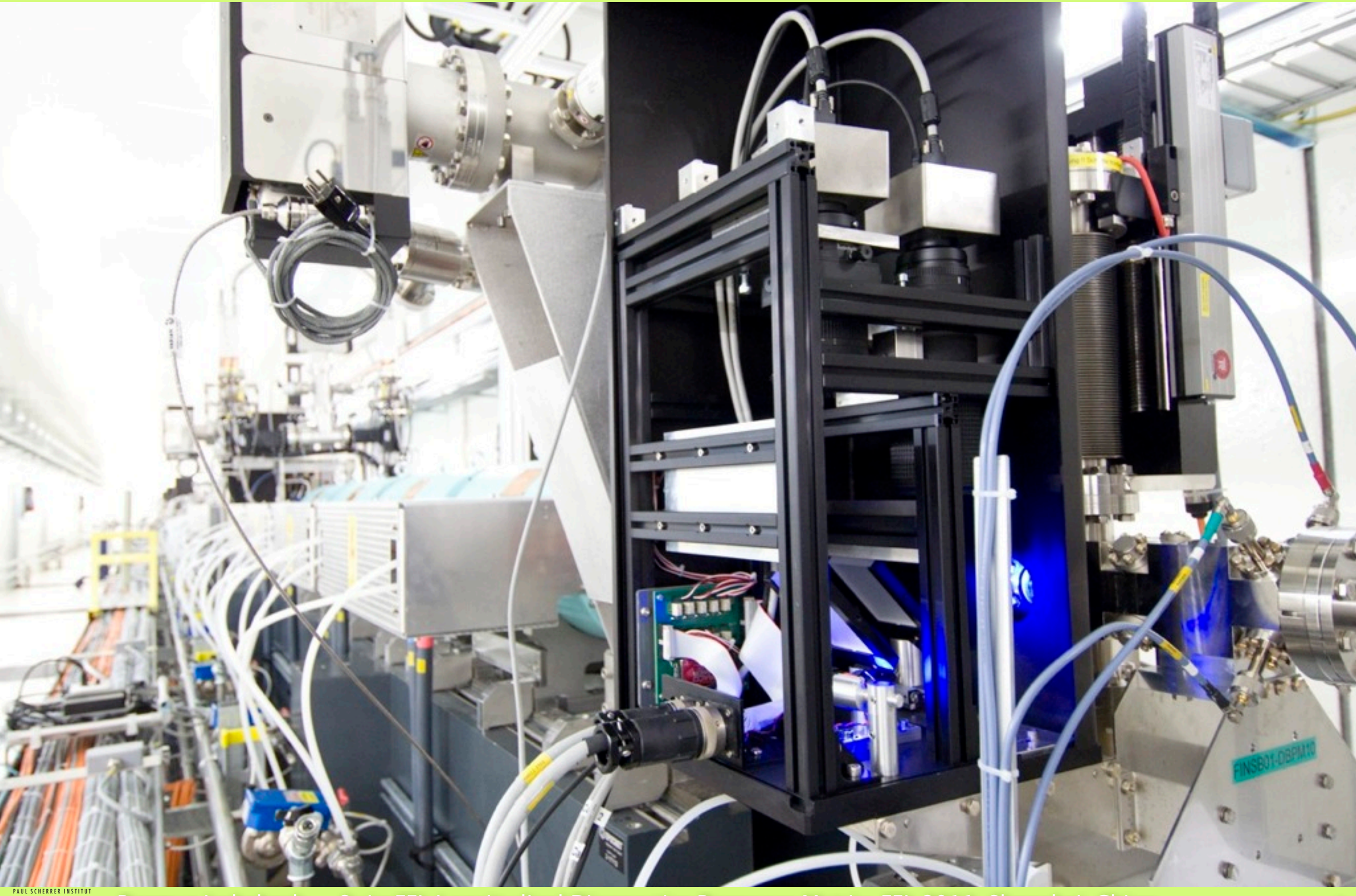
Electro-Optical Monitors



RF Transverse Deflecting Cavity

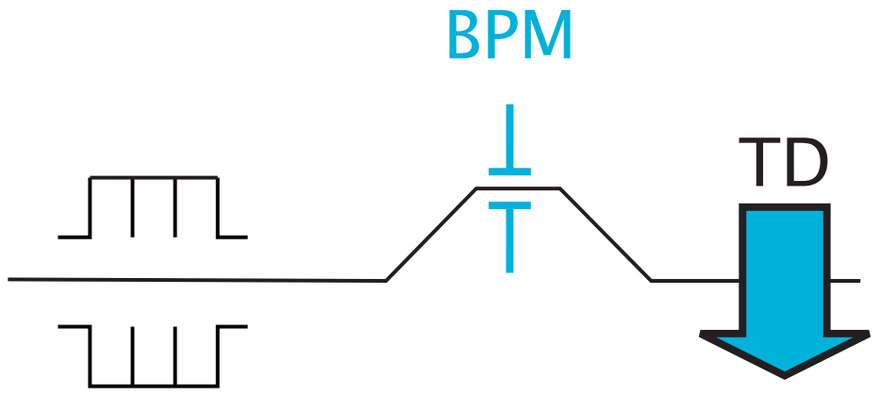


Screen Monitor



A Simple Case

> Imagine an accelerator made from one RF module and one bunch compressor



> Two diagnostics, energy and bunch length

> The response matrix can be calculated analytically

$$\begin{bmatrix} E \\ \sigma_t \end{bmatrix} = \mathbf{R} \cdot \begin{bmatrix} A \\ \Phi \end{bmatrix} \qquad \vec{d} = \mathbf{R} \cdot \vec{a}$$

> The matrix can be inverted

$$\begin{bmatrix} A \\ \Phi \end{bmatrix} = \mathbf{R}^{-1} \cdot \begin{bmatrix} E \\ \sigma_t \end{bmatrix}$$

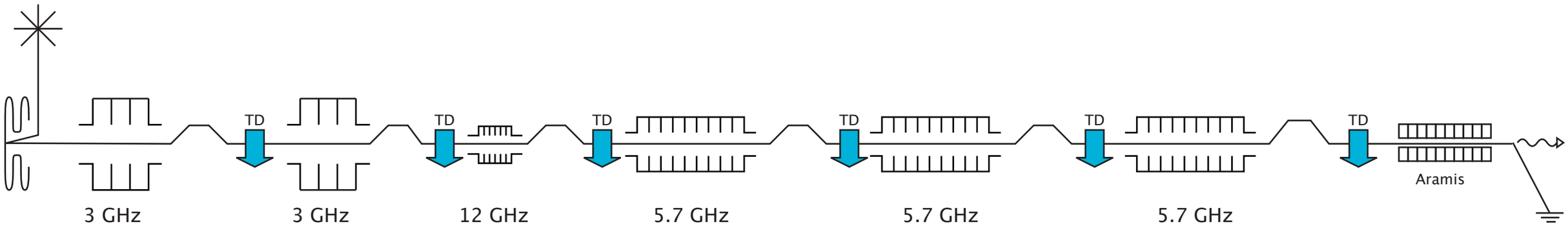
and this is our feedback

$$\begin{bmatrix} \Delta A \\ \Delta \Phi \end{bmatrix} = -\mathbf{R}^{-1} \cdot \begin{bmatrix} \Delta E \\ \Delta \sigma_t \end{bmatrix}$$

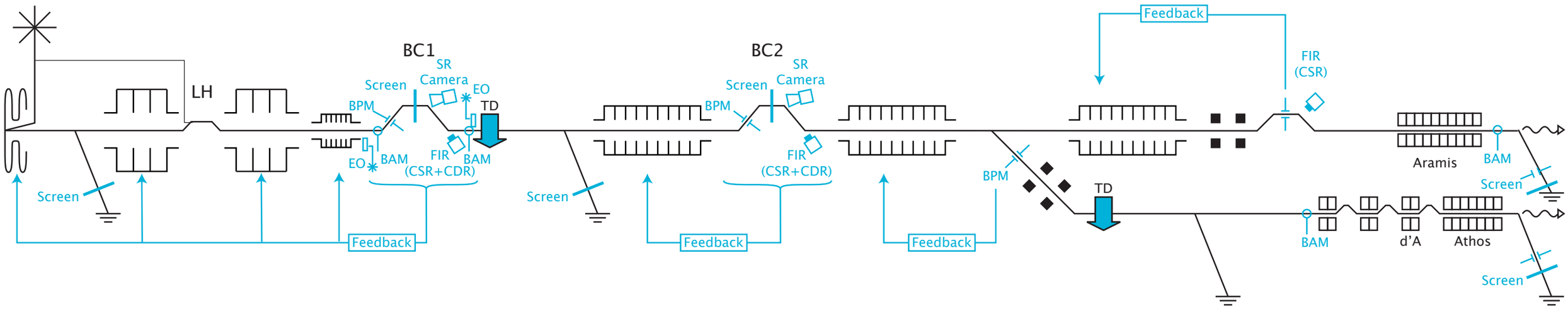
$$\Delta\vec{d} = \mathbf{R}^{-1} \cdot \Delta\vec{a}$$

“Ideal” Diagnostics for SwissFEL

> Full phase space characterization after every RF structure



Longitudinal Diagnostics for SwissFEL



> Response is not easy to calculate analytically

> Response matrix cannot be inverted easily

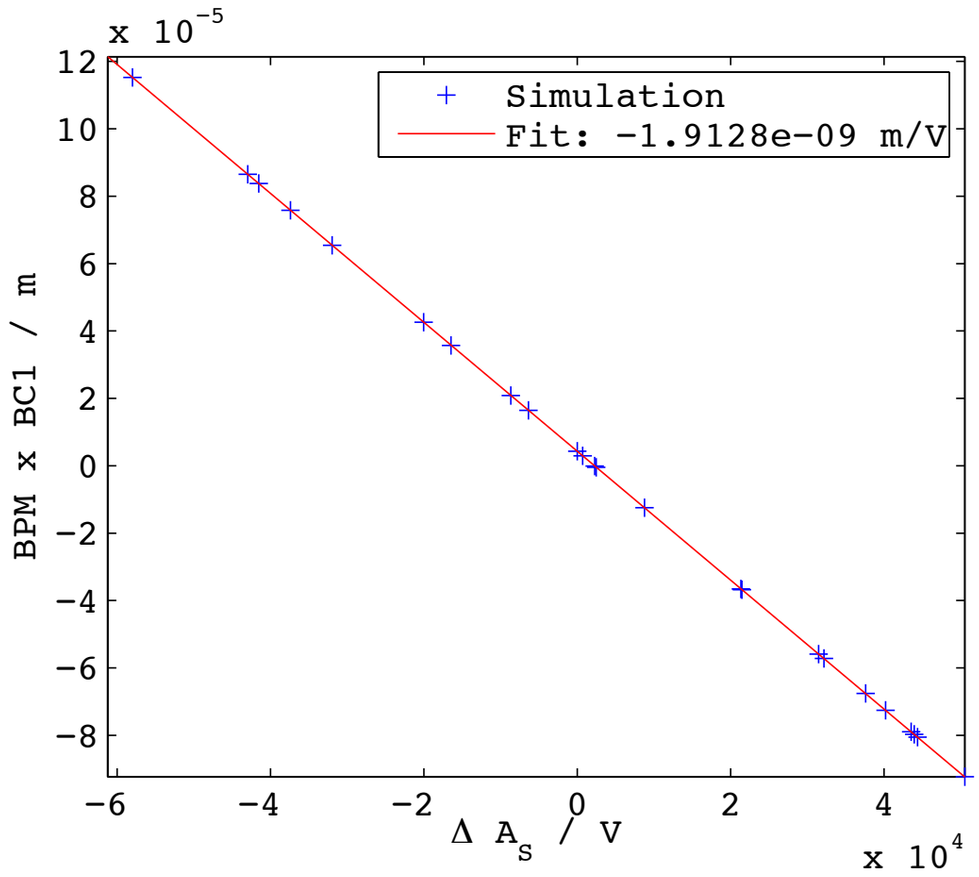
Response Matrix of SwissFEL Instrumentation

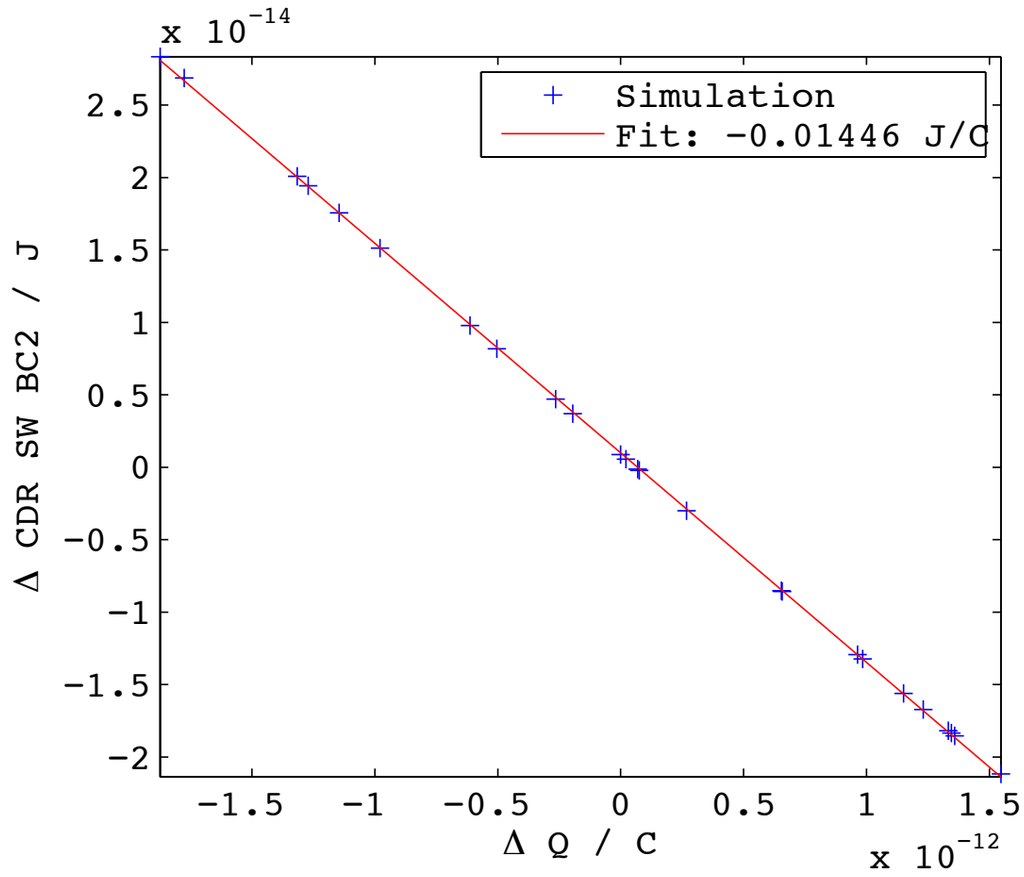
> Simulation of small variations in accelerator parameters (ELEGANT)

  > vary 1 parameter at a time, ± a few times the expected stability

> Dump full phase space at each diagnostics

> Simulation of diagnostics response for each parameter (MATLAB, LabVIEW)





> All response functions are linear (within the range)

> Normalize to expected stability and expected resolution

> Linear Algebra can be applied

Calculated Response Matrix

	Q	t_0	E_0	Φ_S	A_S	Φ_X	A_X	Φ_{C1}	A_{C1}
BPM Q	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BAM t_0	0.00	3.00	–0.12	–0.00	–0.00	–0.00	0.00	–0.00	–0.00
BPM x BC1	0.64	–8.45	–1.84	–3.16	–5.01	–0.75	0.54	–0.00	–0.00
SRC σ_x BC1	–0.09	0.20	–0.02	–0.19	–0.01	0.29	0.01	0.00	0.00
CDR LW BC1	–0.10	0.21	–0.04	–0.26	–0.04	0.35	0.01	0.00	0.00
CDR MW BC1	–0.16	0.36	–0.08	–0.52	–0.09	0.67	0.03	0.00	0.00
CDR SW BC1	0.01	0.08	–0.03	–0.20	–0.04	0.21	0.01	0.00	0.00
BAM Δ t BC1	0.14	–1.86	–0.41	–0.70	–1.11	–0.16	0.12	0.00	0.00
EO FW ABC1	–0.08	–0.22	0.04	0.25	0.05	–0.26	–0.03	–0.00	–0.00
BPM x BC2	–0.11	–2.81	3.19	4.53	7.10	0.98	–0.76	–6.83	–4.16
SRC σ_x BC2	–0.02	–0.25	0.10	0.36	0.18	–0.36	–0.03	–0.11	–0.01
CDR LW BC2	–0.05	0.01	0.01	0.00	0.04	0.04	–0.00	–0.04	–0.00
CDR MW BC2	–0.42	0.09	0.13	0.03	0.32	0.32	–0.03	–0.30	–0.04
CDR SW BC2	–3.64	0.77	1.09	0.29	2.70	2.72	–0.23	–2.46	–0.32
BAM Δ t BC2	–0.00	–0.33	0.37	0.53	0.83	0.12	–0.09	–0.80	–0.49

Singular Value Decomposition of the Response Matrix

> Diagnostics response to accelerator parameters

$$\vec{d} = \mathbf{R} \cdot \vec{a}$$

> Task: invert **R**

> Singular Value Decomposition

> For this: there exists a factorization of **R**

$$\mathbf{R} = \mathbf{U} \cdot \mathbf{\Sigma} \cdot \mathbf{V}^T$$

> such that

> **U** has orthonormal columns $\mathbf{U}^{-1} = \mathbf{U}^T$

> **Σ** is a diagonal matrix

> $\mathbf{V}^T$ has orthonormal rows

$$\vec{d} = \mathbf{U} \cdot \mathbf{\Sigma} \cdot \mathbf{V}^T \cdot \vec{a}$$

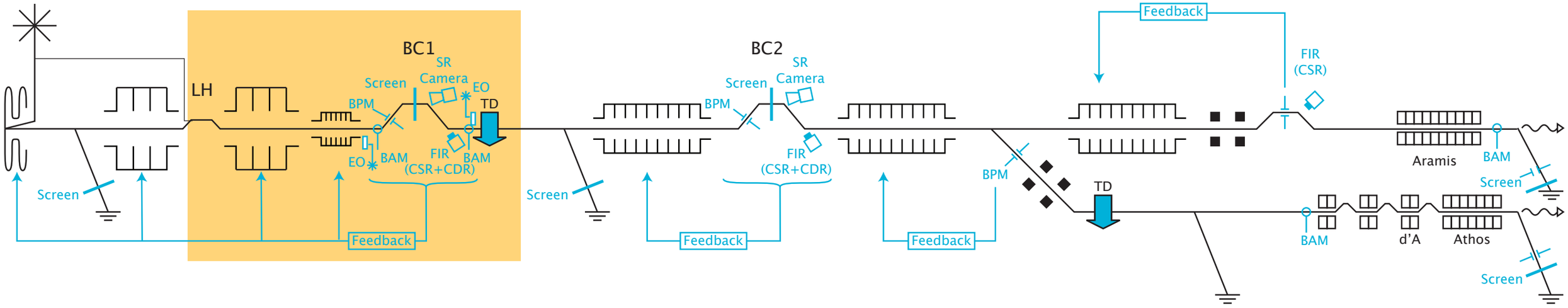
$$\vec{d} = \mathbf{U} \cdot \mathbf{\Sigma} \cdot (\mathbf{V}^T \cdot \vec{a})$$

$$\mathbf{U}^T \cdot \vec{d} = \mathbf{\Sigma} \cdot (\mathbf{V}^T \cdot \vec{a})$$

New coordinate systems!

Singular Value Decomposition

Longitudinal Diagnostics



	Q	t_0	E_0	Φ_S	A_S	Φ_X	A_X
BPM Q	5.00	0.00	0.00	0.00	0.00	0.00	0.00
BAM t_0	0.00	3.00	–0.12	–0.00	–0.00	–0.00	0.00
BPM x BC1	0.64	–8.45	–1.84	–3.16	–5.01	–0.75	0.54
SRC σ_x BC1	–0.09	0.20	–0.02	–0.19	–0.01	0.29	0.01
CDR LW BC1	–0.10	0.21	–0.04	–0.26	–0.04	0.35	0.01
CDR MW BC1	–0.16	0.36	–0.08	–0.52	–0.09	0.67	0.03
CDR SW BC1	0.01	0.08	–0.03	–0.20	–0.04	0.21	0.01
BAM Δ t BC1	0.14	–1.86	–0.41	–0.70	–1.11	–0.16	0.12
EO FW ABC1	–0.08	–0.22	0.04	0.25	0.05	–0.26	–0.03

SVD Decomposition of the Response Matrix

Σ

	1	2	3	4	5	6	7
1	11.07	0	0	0	0	0	0
2	0	5.00	0	0	0	0	0
3	0	0	1.91	0	0	0	0
4	0	0	0	0.99	0	0	0
5	0	0	0	0	0.04	0	0
6	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0

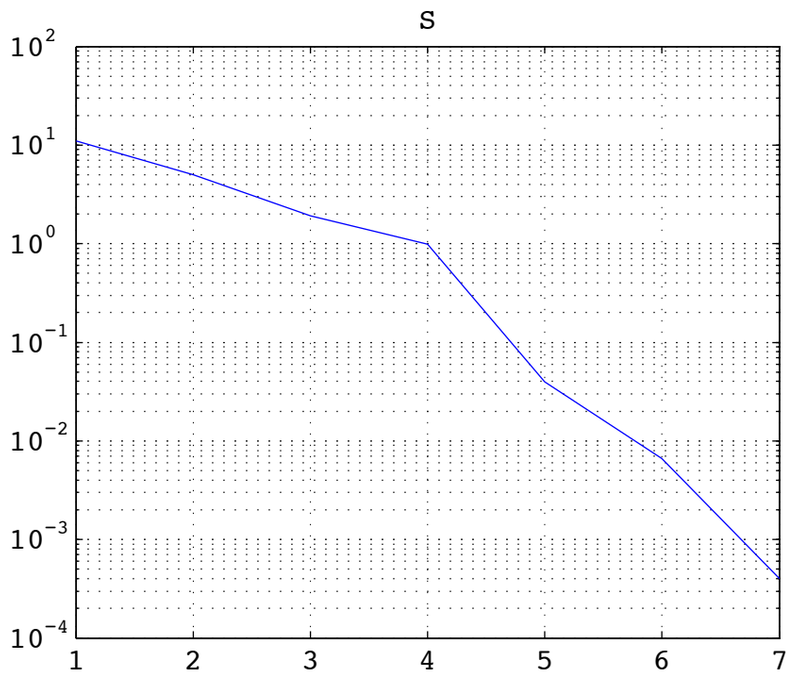
U

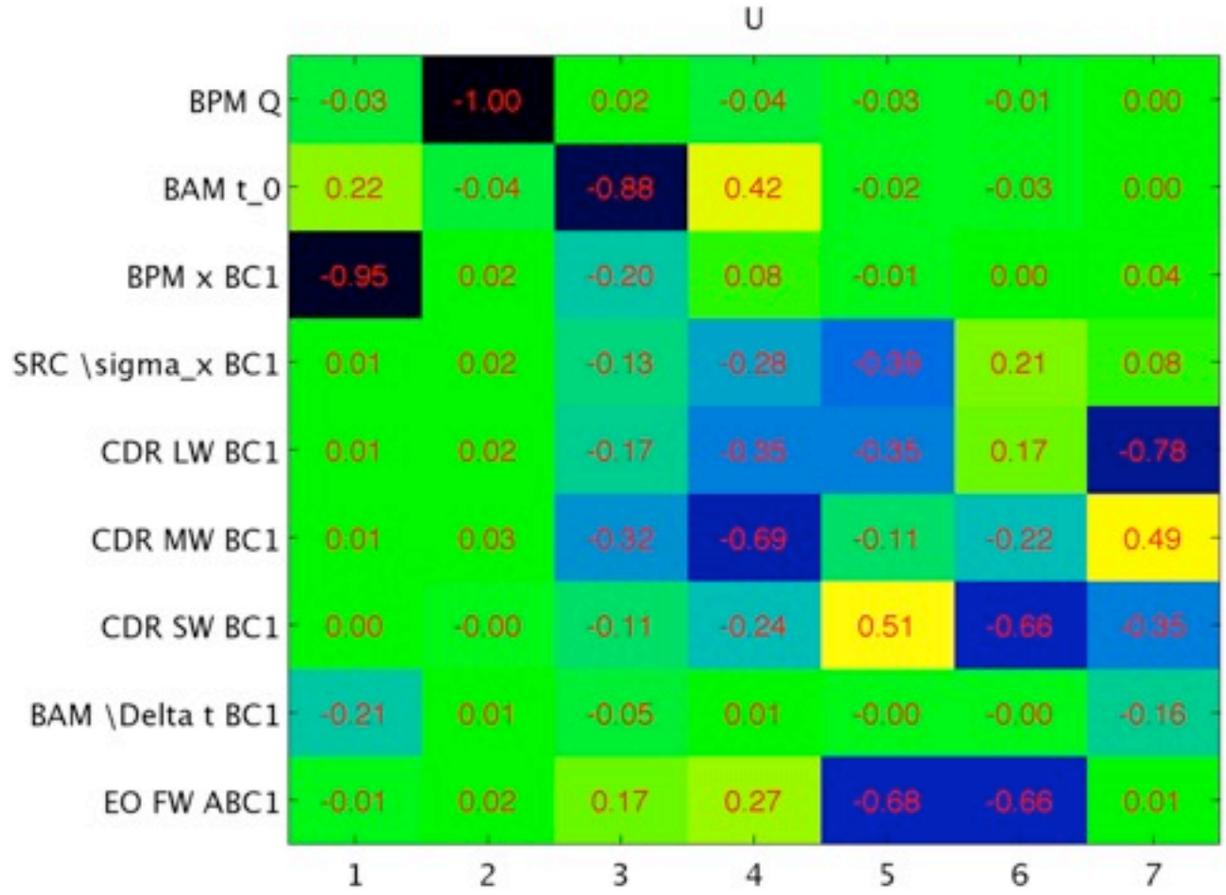
	1	2	3	4	5	6	7
BPM Q	–0.03	–1.00	0.02	–0.04	–0.03	0	0
BAM t_0	0.22	–0.04	–0.88	0.42	–0.02	–0.03	0
BPM x BC1	–0.95	0.02	–0.20	0.08	0	0	0.04
SRC σ_x BC1	0.01	0.02	–0.13	–0.28	–0.39	0.21	0.08
CDR LW BC1	0	0.02	–0.17	–0.35	–0.35	0.17	–0.78
CDR MW BC1	0.01	0.03	–0.32	–0.69	–0.11	–0.22	0.49
CDR SW BC1	0	0	–0.11	–0.24	0.51	–0.66	–0.35
BAM Δ t BC1	–0.21	0	–0.05	0.01	0	0	–0.16
EO FW ABC1	0	0.02	0.17	0.27	–0.68	–0.66	0.01

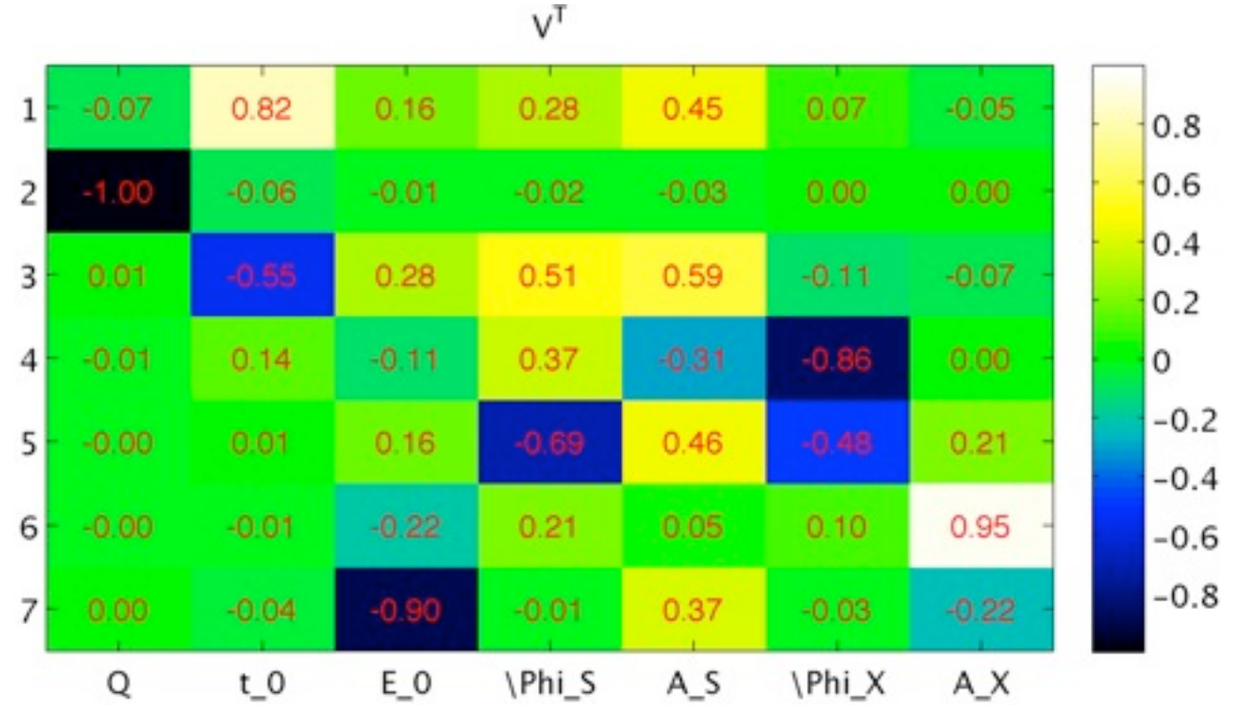
V^T

	Q	t_0	E_0	Φ_S	A_S	Φ_X	A_X
1	–0.07	0.82	0.16	0.28	0.45	0.07	–0.05
2	–1.00	–0.06	0	–0.02	–0.03	0	0
3	0	–0.55	0.28	0.51	0.59	–0.11	–0.07
4	0	0.14	–0.11	0.37	–0.31	–0.86	0
5	0	0	0.16	–0.69	0.46	–0.48	0.21
6	0	0	–0.22	0.21	0.05	0.10	0.95
7	0	–0.04	–0.90	0	0.37	–0.03	–0.22

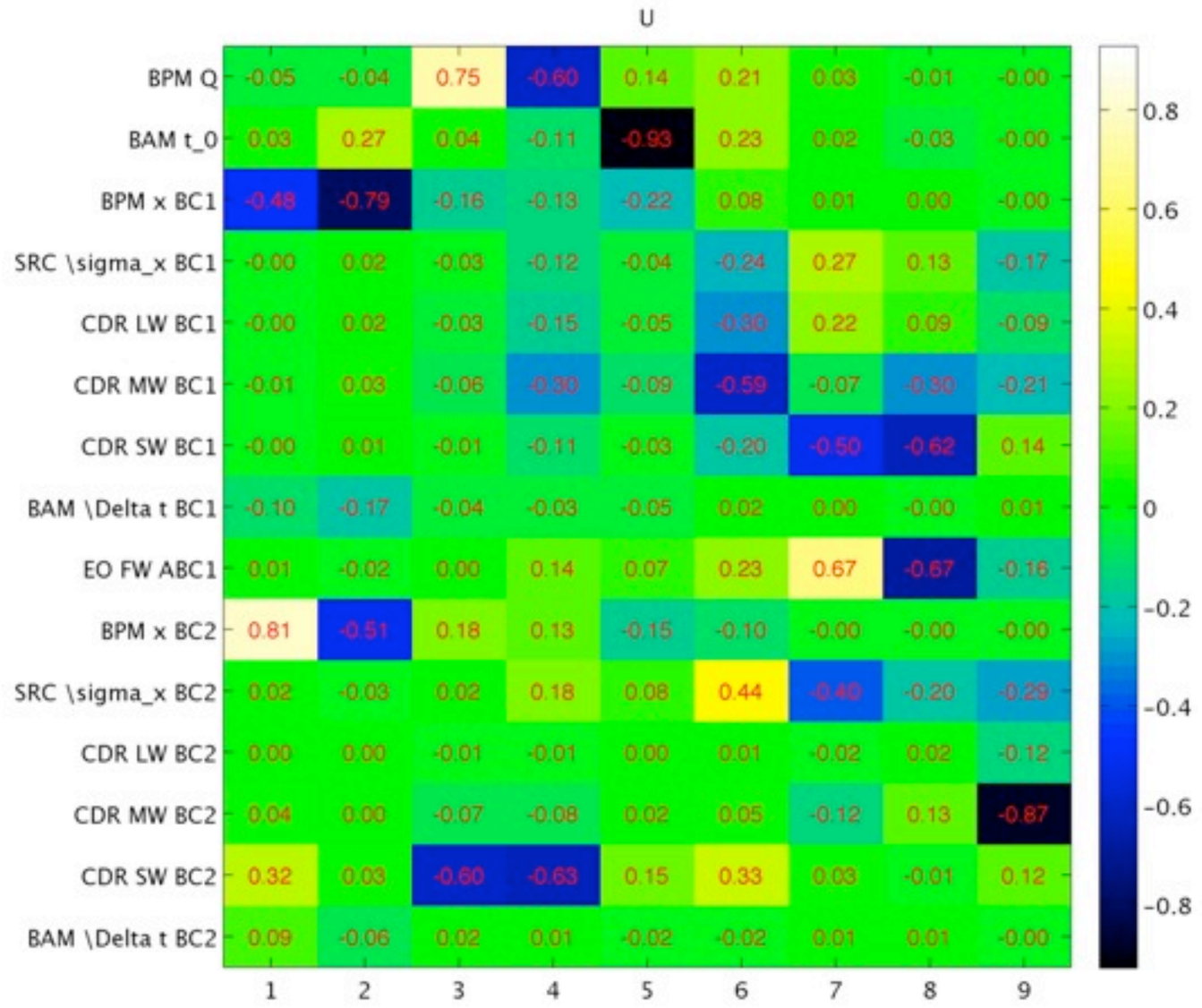
SVD Decomposition of the Response Matrix

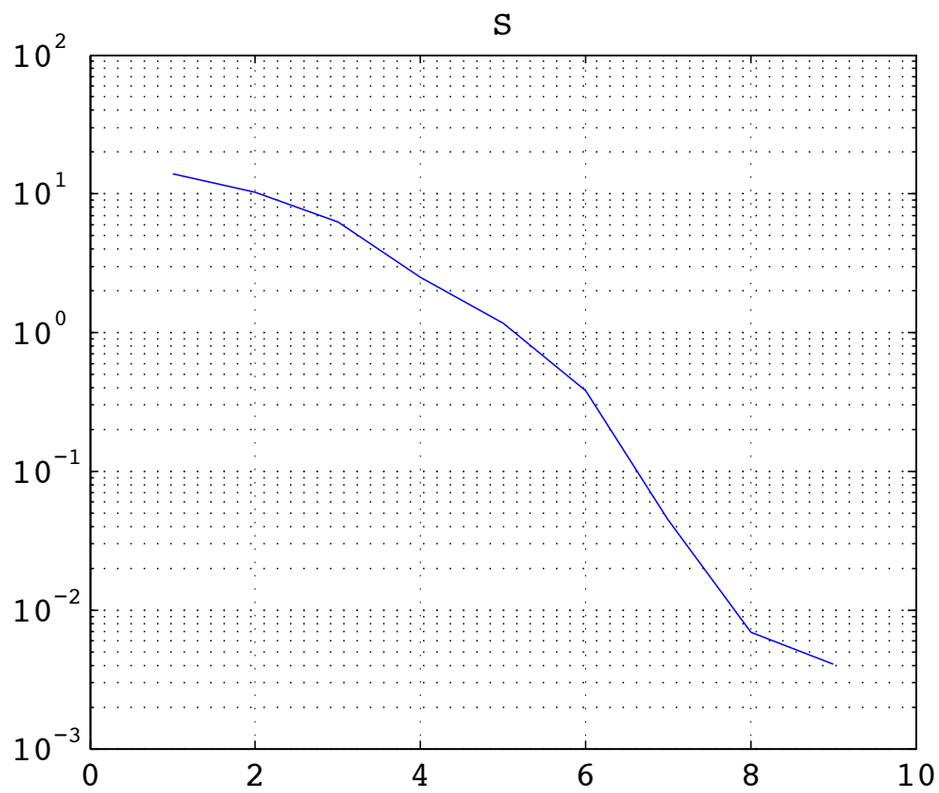


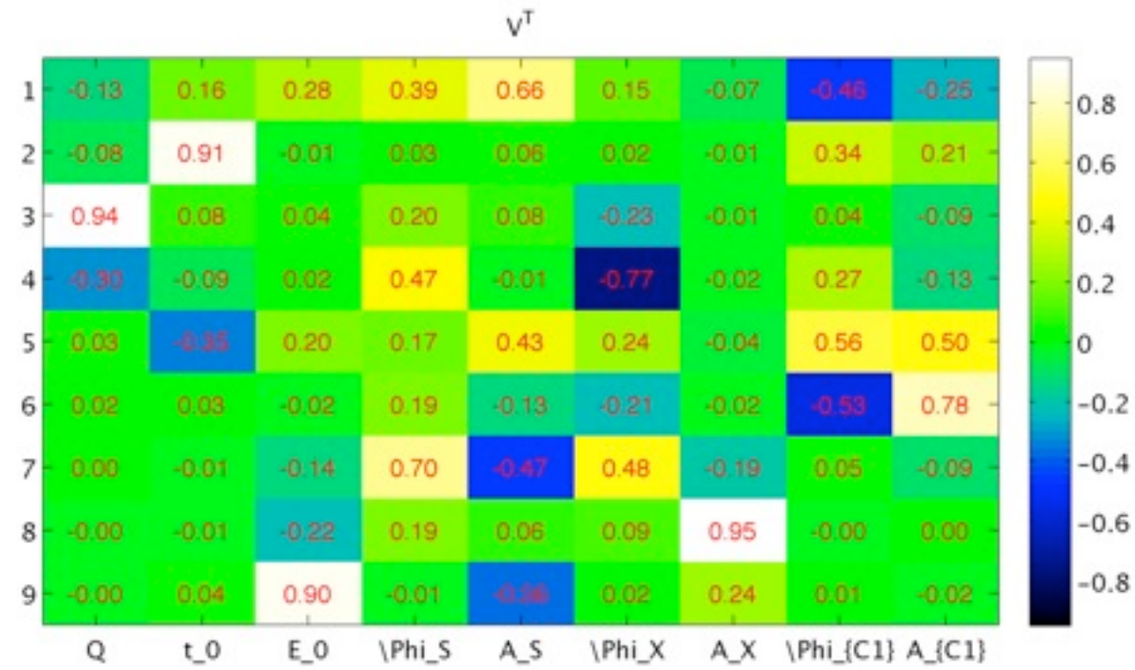




SVD of Response Matrix up to BC2







SwissFEL Longitudinal Diagnostics Response Matrix

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- SwissFEL stability goals: 20 fs / 5 fs
- Longitudinal Instrumentation
- Modeling of accelerator and instrumentation
  - Response matrix
- SVD decomposition
  - Principal vectors of the diagnostics response
  - Feedbacks

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