

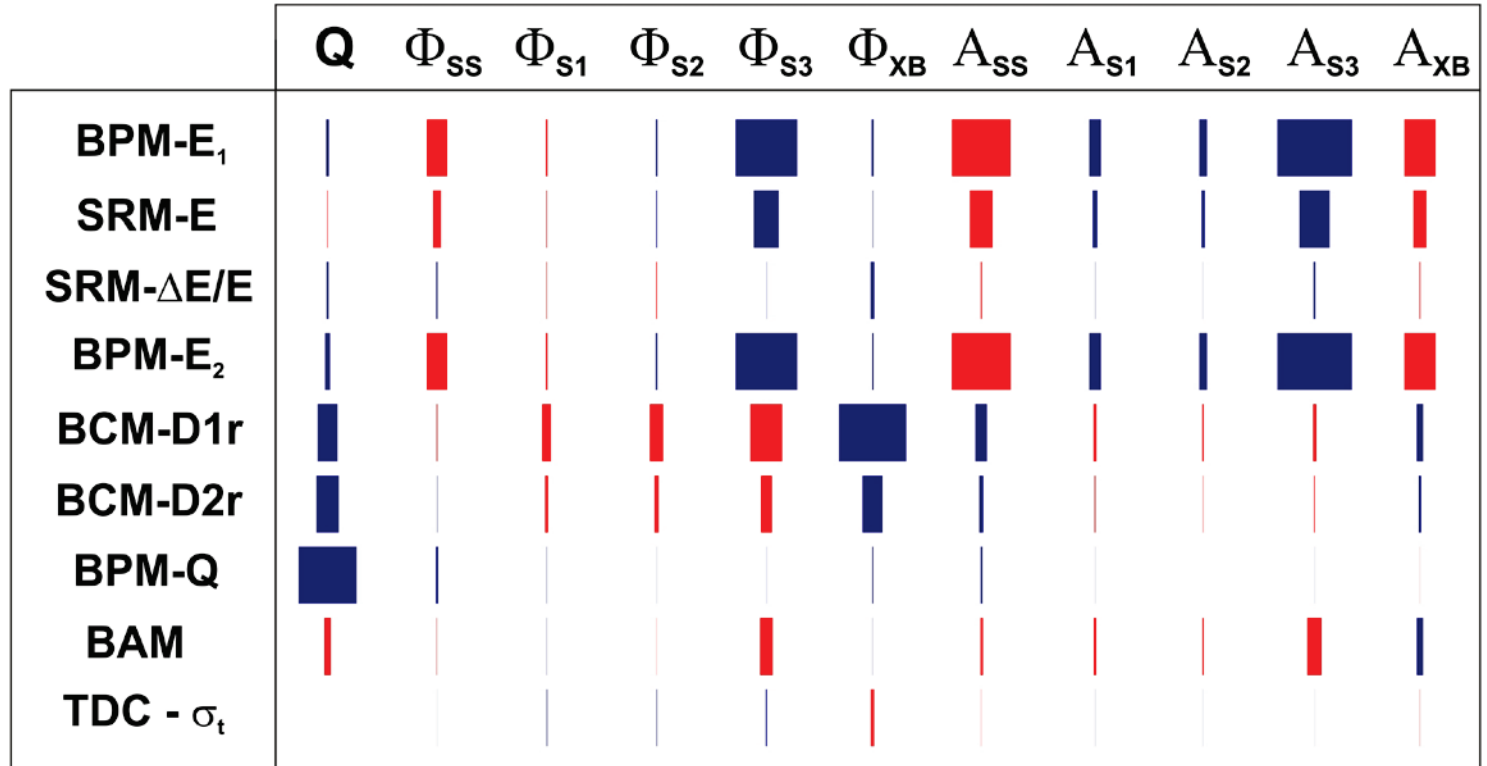


Wir schaffen Wissen – heute für morgen

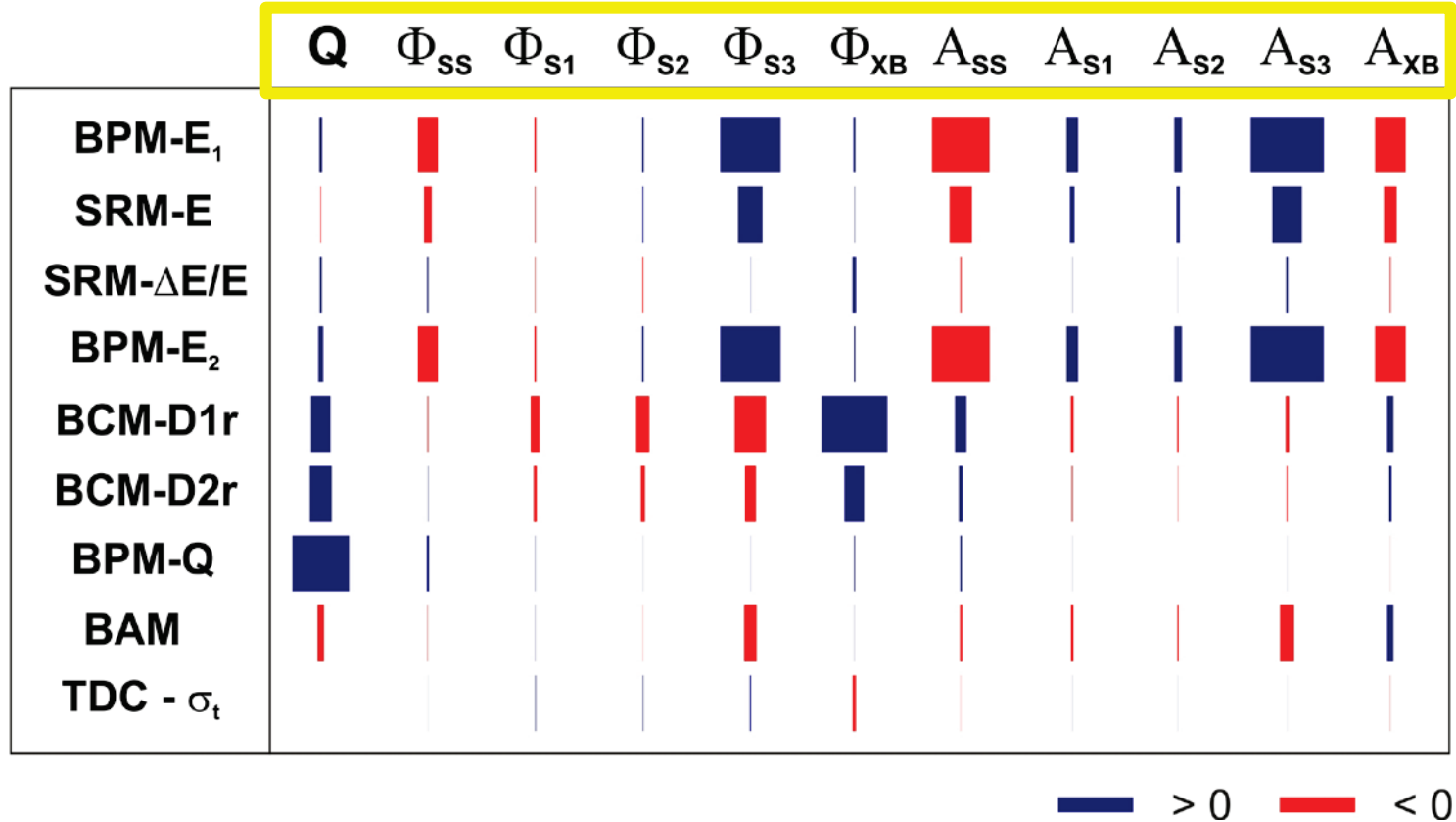
Paul Scherrer Institut

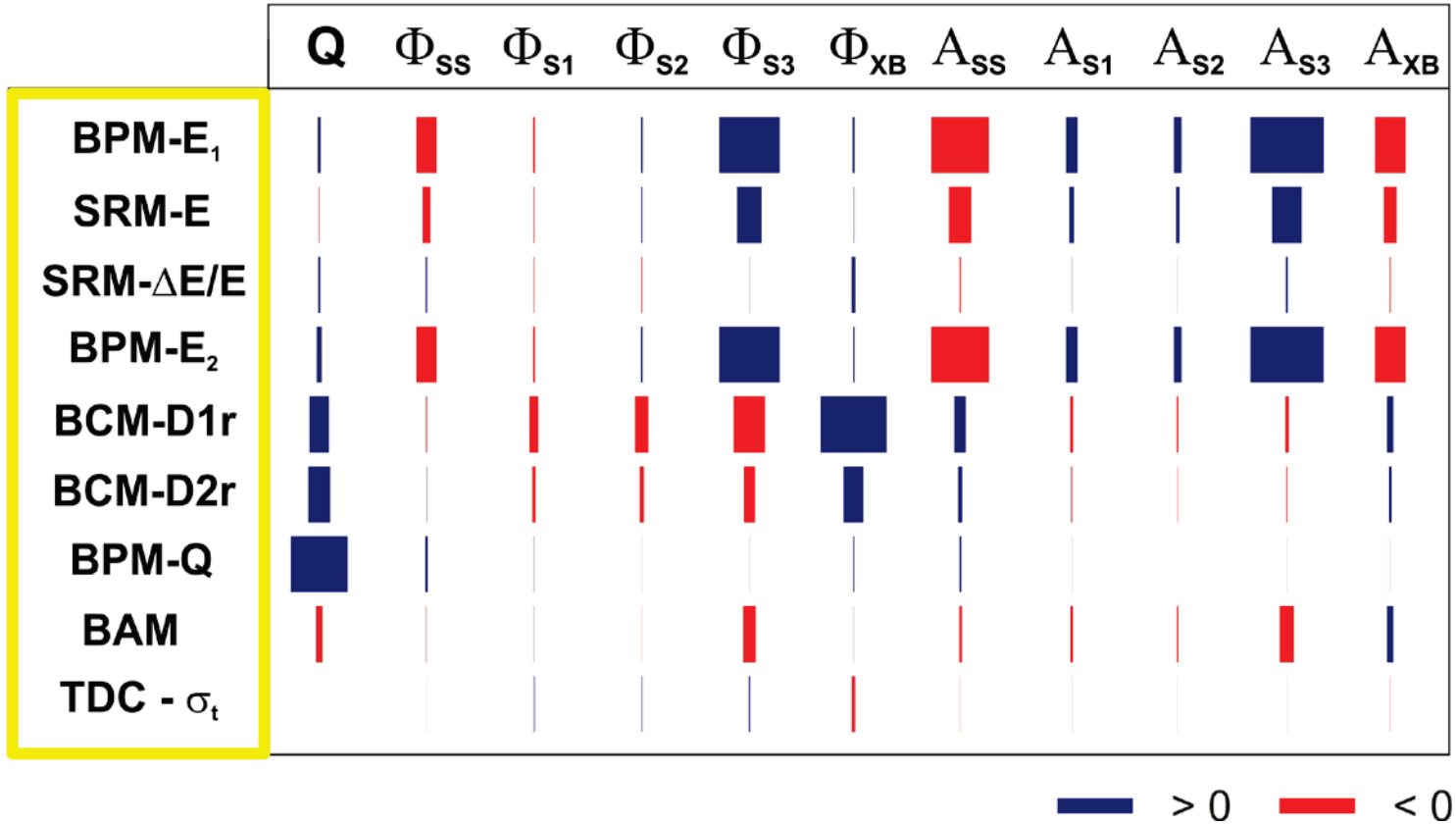
F. Frei, V. Arsov, H. Brands, A. Saa Hernandez, R. Ischebeck, F. Löhl, B. Kalantari, R. Kalt, B. Keil, W. Koprek, G.L. Orlandi, T. Schilcher, V. Schlott

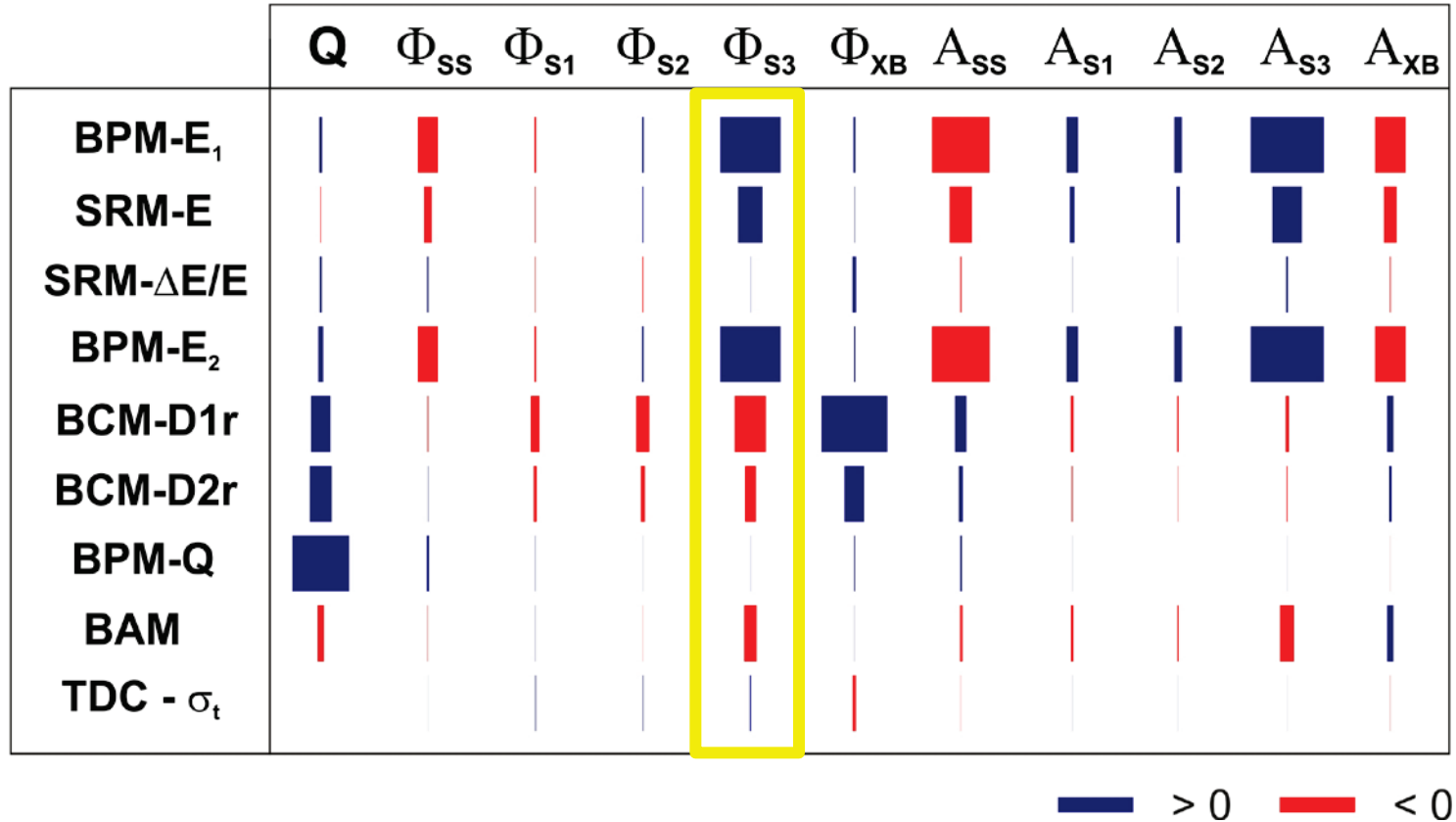
Experimental Results of Diagnostics Response for Longitudinal Phase Space

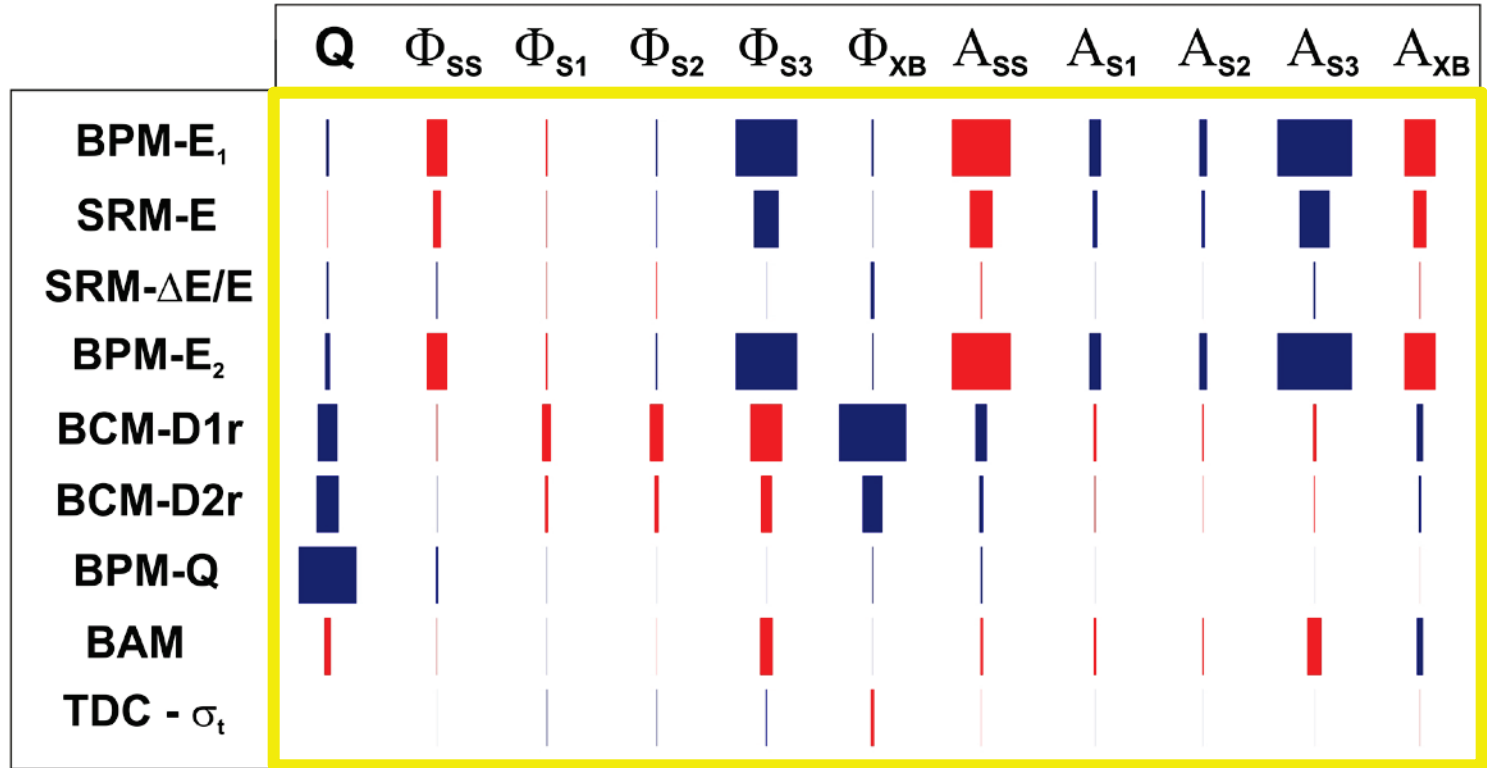


■ > 0 ■ < 0

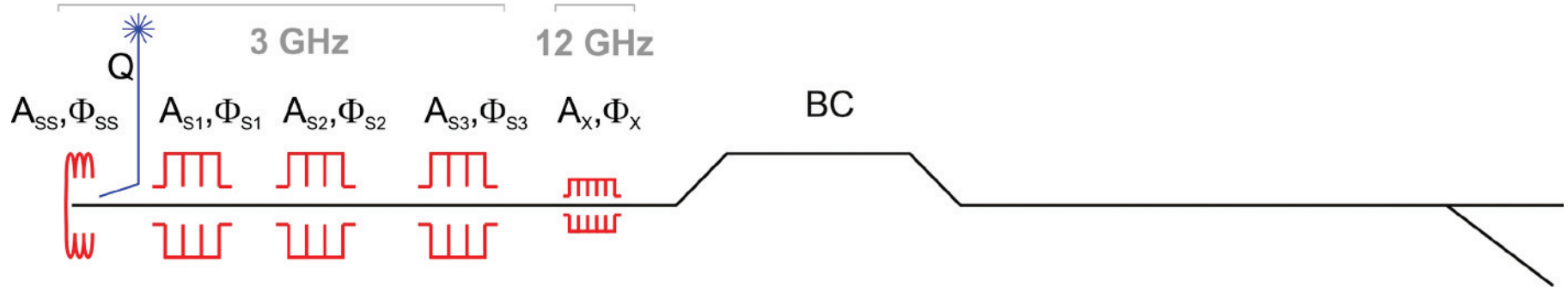








■ > 0 ■ < 0



estimated on crest energy gain of a particle:

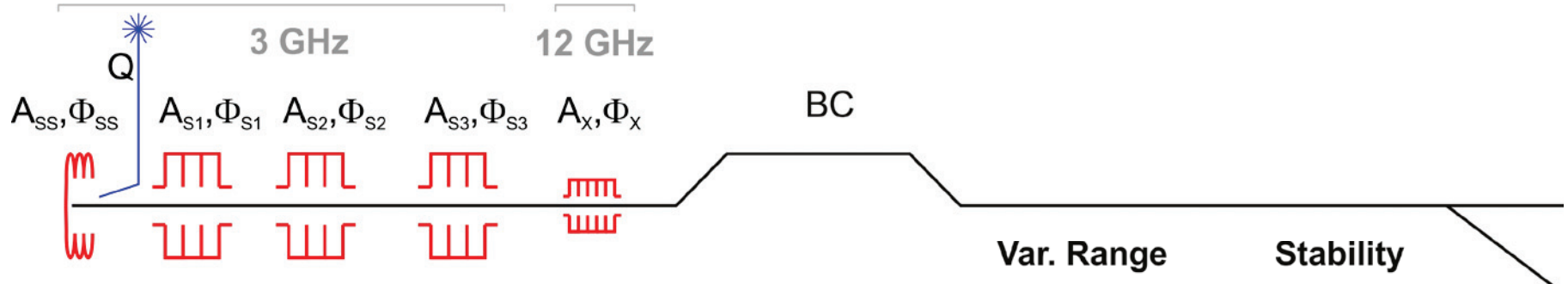
7 53.7 70.8 102.7 14.2 [MeV]

Initial Settings:

Charge: 20.5 pC @ 10 Hz

Energy: 200 MeV

Bunch length: ~260 fs rms



estimated on crest energy gain of a particle:

7 53.7 70.8 102.7 14.2 [MeV]

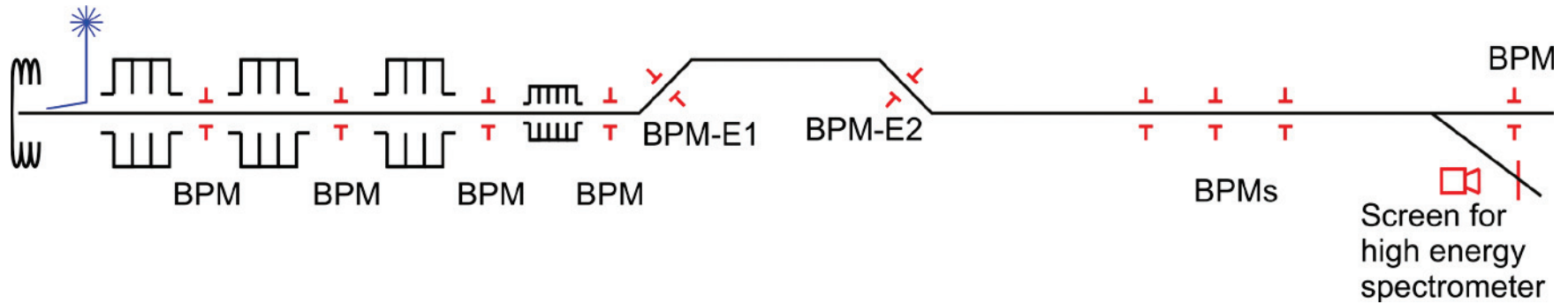
Initial Settings:

Charge: 20.5 pC @ 10 Hz

Energy: 200 MeV

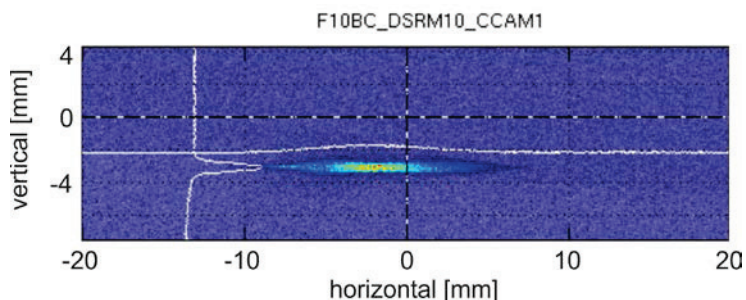
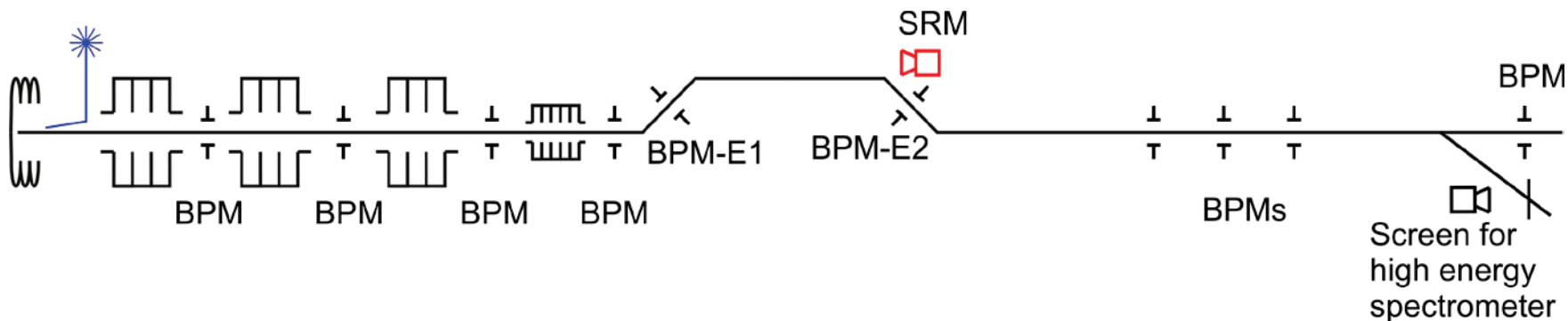
Bunch length: ~260 fs rms

	Var. Range	Stability
Q	18.6-21.9 pC	0.18 pC
Φ_{SS}	$\pm 1.5^\circ$	0.039° (36 fs)
A_{SS}	-2.64 - 2.04 %	0.04 %
Φ_{S1}	$\pm 1.5^\circ$	0.022° (21 fs)
A_{S1}	± 1.67 %	0.011 %
Φ_{S2}	$\pm 1.5^\circ$	0.026° (24 fs)
A_{S2}	± 0.51 %	0.007 %
Φ_{S3}	$\pm 1.5^\circ$	0.035° (32 fs)
A_{S3}	± 6.0 %	0.056 %
Φ_{XB}	$\pm 1.5^\circ$	0.18° (42 fs)
A_{XB}	± 8.6 %	0.13 %

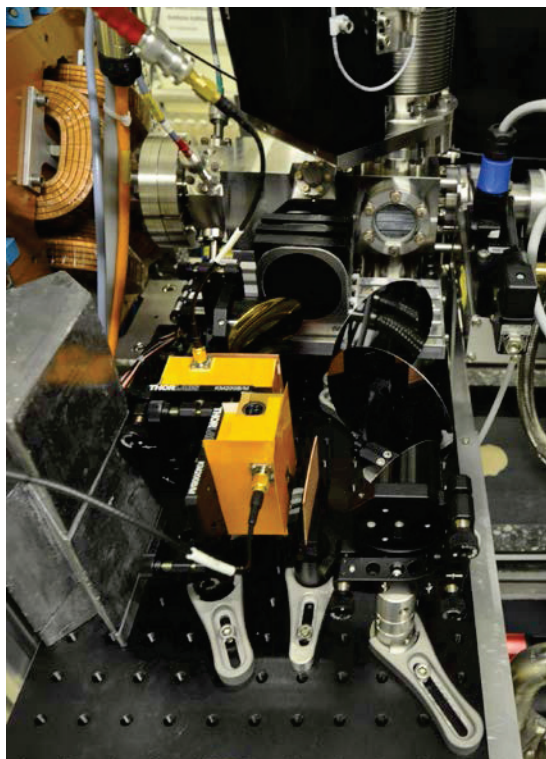
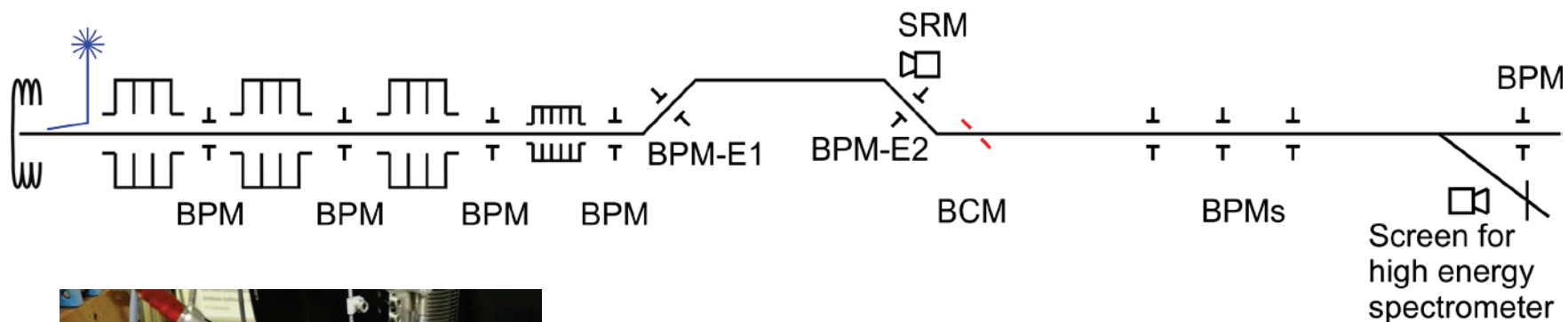


B. Keil

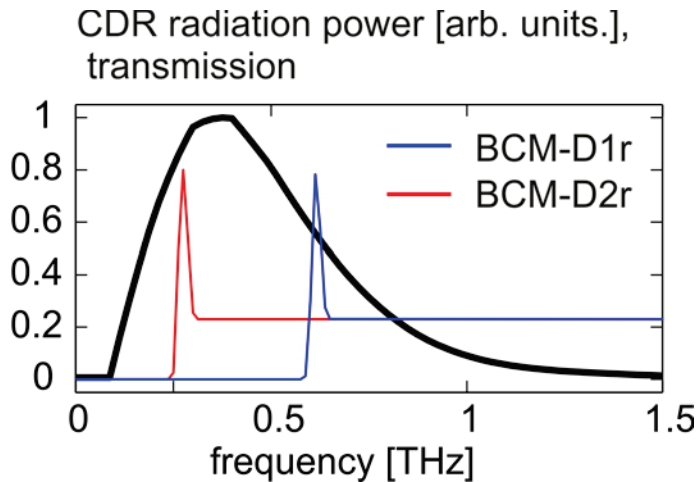
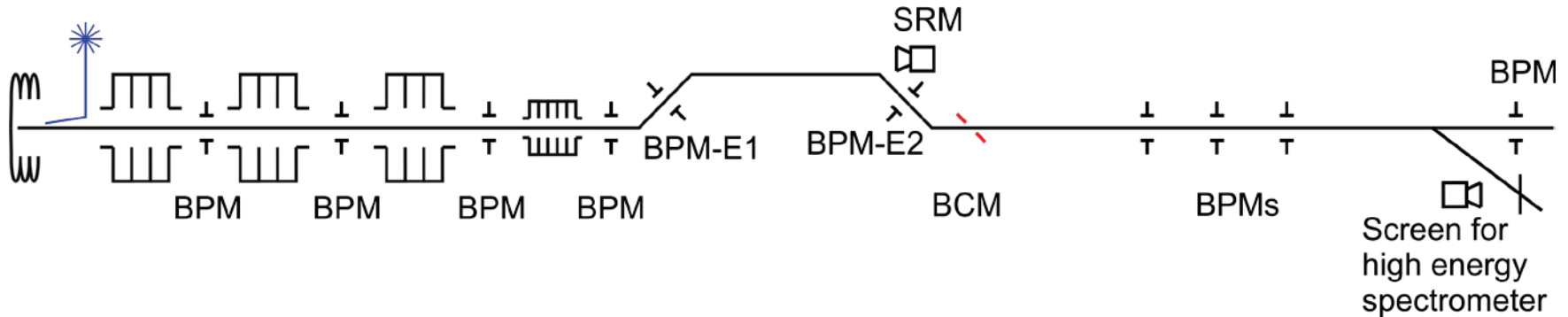
	Quantity measured	Resolution
BPM-E1	energy	9.3 keV
BPM-E2	energy	9.3 keV
BPM-Q	charge	62 fC (0.3 %)



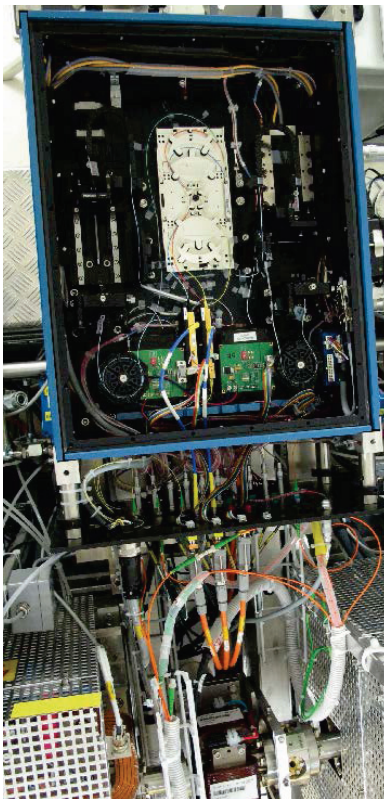
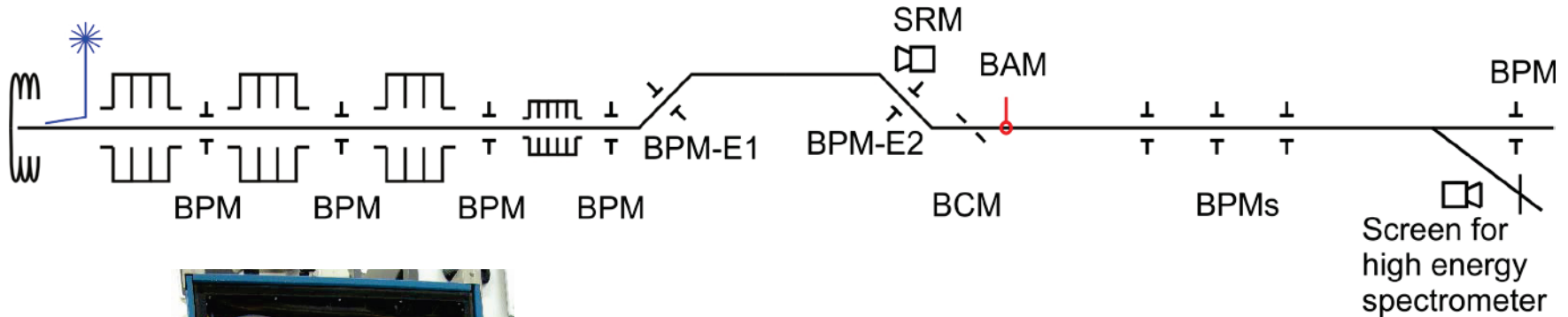
	Quantity measured	Resolution
BPM-E1	energy	9.3 keV
SRM-E	energy	24 keV
SRM-$\Delta E/E$	rel. energy spread	$1.2 \cdot 10^{-4}$
BPM-E2	energy	9.3 keV
BPM-Q	charge	62 fC (0.3 %)



	Quantity measured	Resolution
BPM-E1	energy	9.3 keV
SRM-E	energy	24 keV
SRM- $\Delta E/E$	rel. energy spread	$1.2 \cdot 10^{-4}$
BPM-E2	energy	9.3 keV
BCM-D1r	CDR, int 0.6-2 THz	1.6 mV (0.8 %)
BPM-D2r	CDR, int 0.26-2 THz	2.4 mV (0.6 %)
BPM-Q	charge	62 fC (0.3 %)

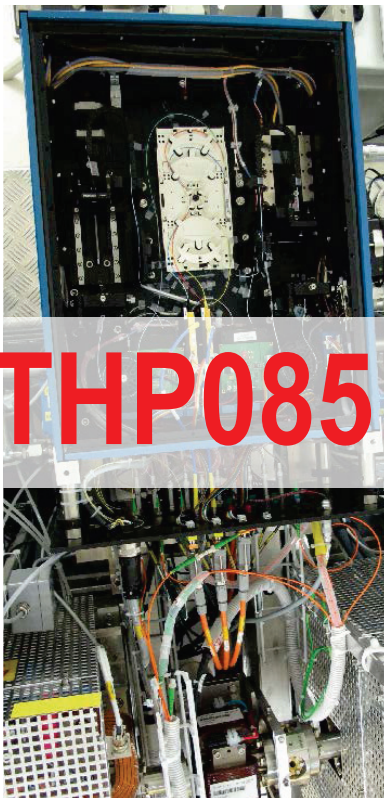
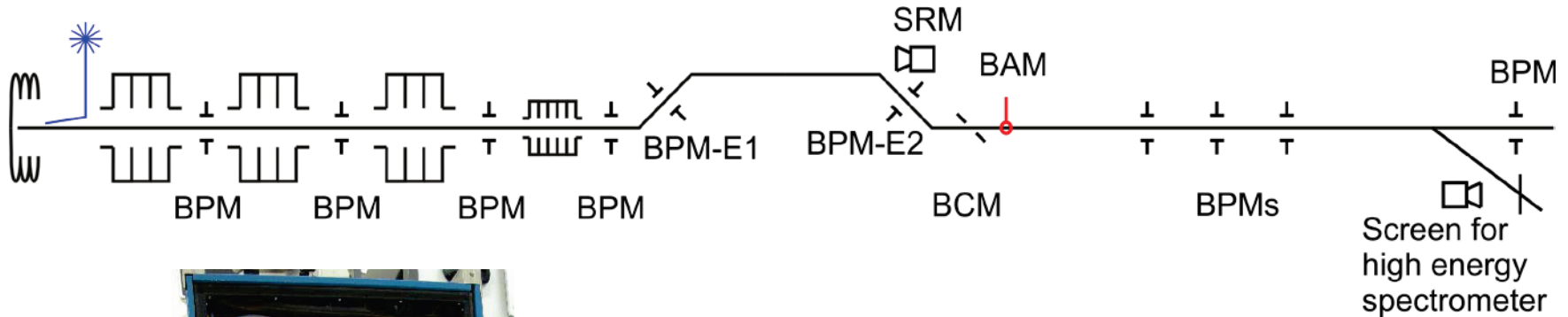


	Quantity measured	Resolution
BPM-E1	energy	9.3 keV
SRM-E	energy	24 keV
SRM-$\Delta E/E$	rel. energy spread	$1.2 \cdot 10^{-4}$
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BCM-D1r	CDR, int 0.6-2 THz	1.6 mV (0.8 %)
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BPM-Q	charge	62 fC (0.3 %)



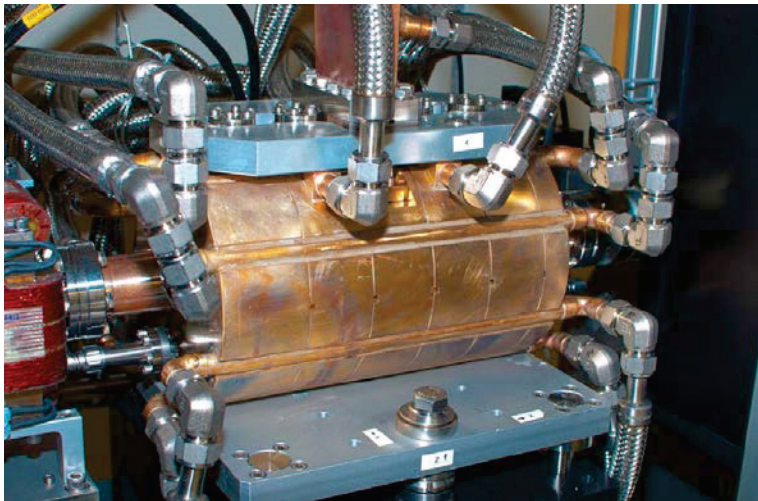
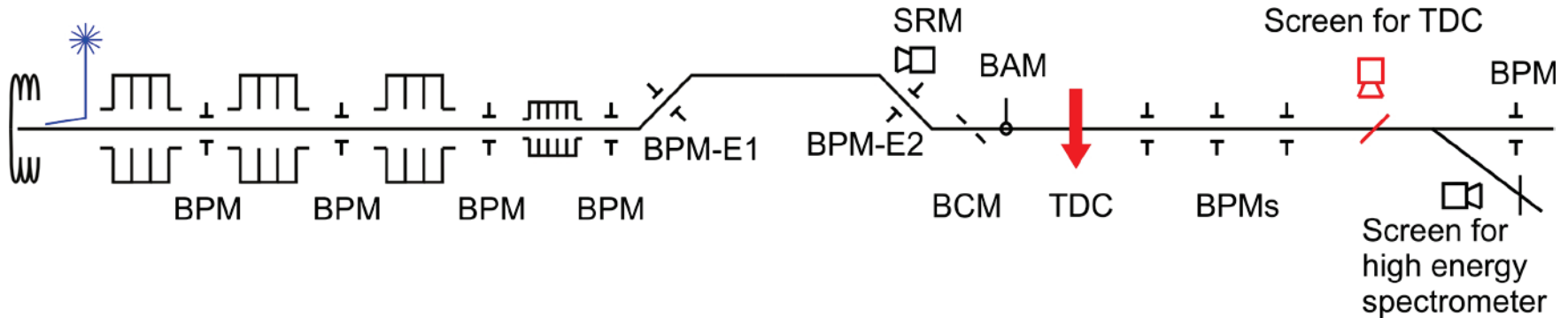
V. Arsov

	Quantity measured	Resolution
BPM-E1	energy	9.3 keV
SRM-E	energy	24 keV
SRM- $\Delta E/E$	rel. energy spread	$1.2 \cdot 10^{-4}$
BPM-E2	energy	9.3 keV
BCM-D1r	CDR, int 0.6-2 THz	1.6 mV (0.8 %)
BPM-D2r	CDR, int 0.26-2 THz	2.4 mV (0.6 %)
BPM-Q	charge	62 fC (0.3 %)
BAM-t	bunch arrival time after BC	52 fs



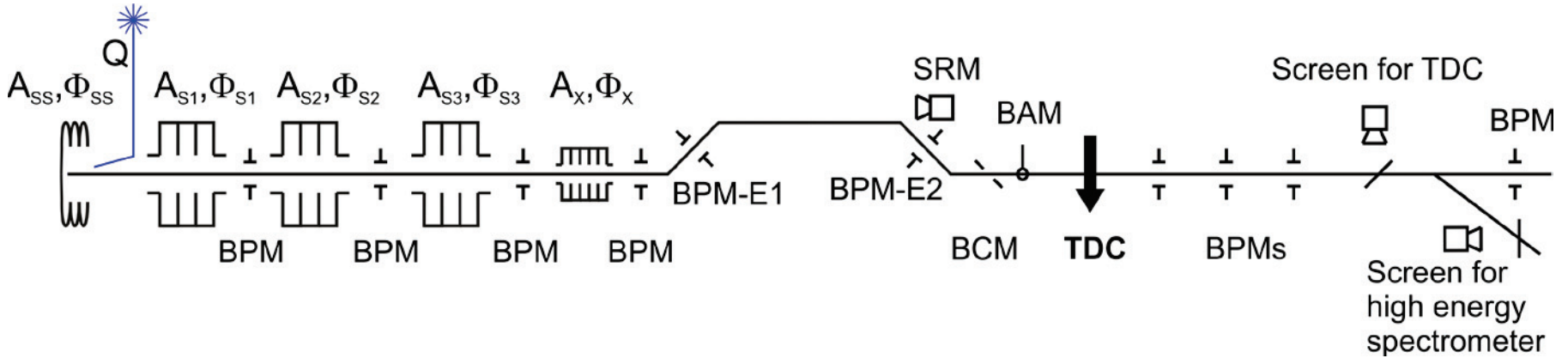
V. Arsov

	Quantity measured	Resolution
BPM-E1	energy	9.3 keV
SRM-E	energy	24 keV
SRM- $\Delta E/E$	rel. energy spread	$1.2 \cdot 10^{-4}$
BPM-E2	energy	9.3 keV
BCM-D1r	CDR, int 0.6-2 THz	1.6 mV (0.8 %)
BPM-D2r	CDR, int 0.26-2 THz	2.4 mV (0.6 %)
BPM-Q	charge	62 fC (0.3 %)
BAM-t	bunch arrival time after BC	52 fs



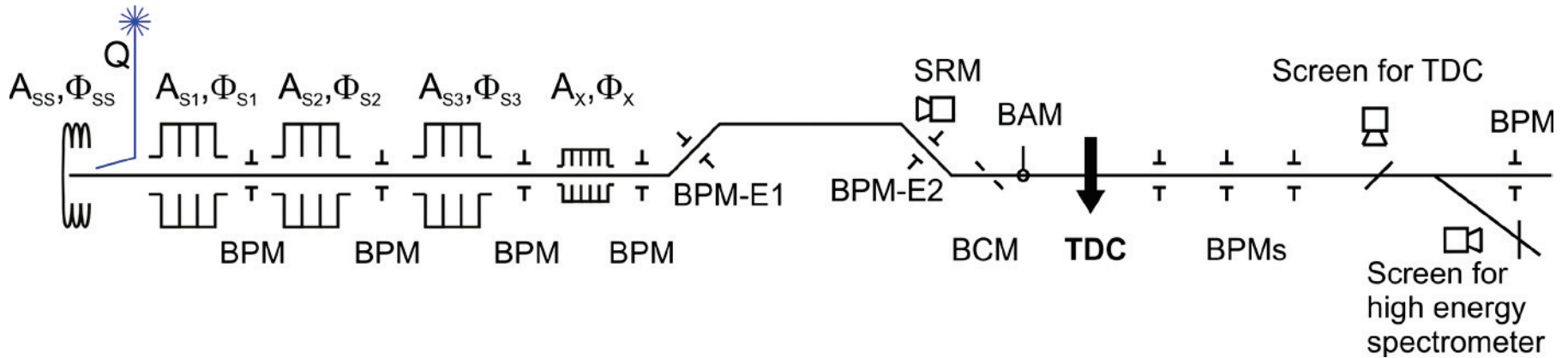
A. Falone

	Quantity measured	Resolution
BPM-E1	energy	9.3 keV
SRM-E	energy	24 keV
SRM- $\Delta E/E$	rel. energy spread	$1.2 \cdot 10^{-4}$
BPM-E2	energy	9.3 keV
BCM-D1r	CDR, int 0.6-2 THz	1.6 mV (0.8 %)
BPM-D2r	CDR, int 0.26-2 THz	2.4 mV (0.6 %)
BPM-Q	charge	62 fC (0.3 %)
BAM-t	bunch arrival time after BC	52 fs
TDC- σ_t	bunch length	40 fs



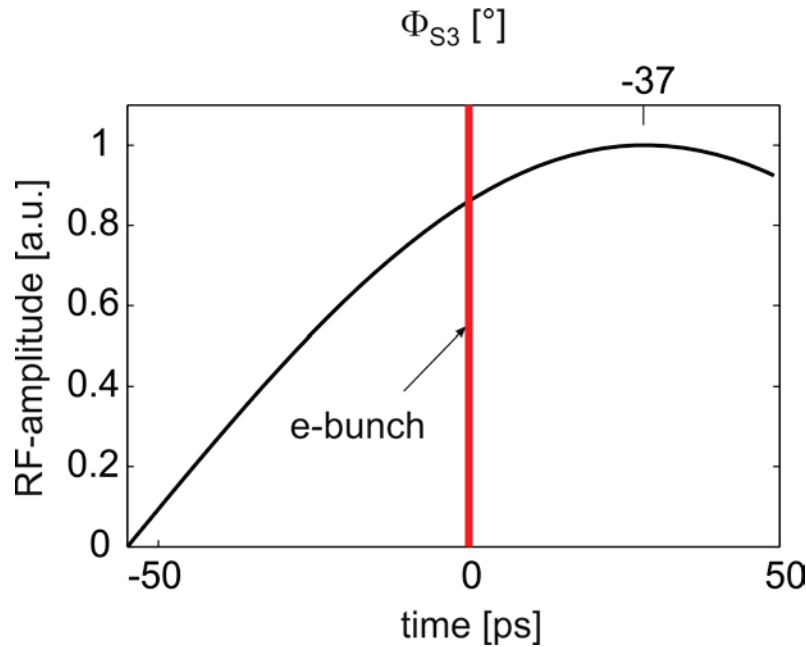
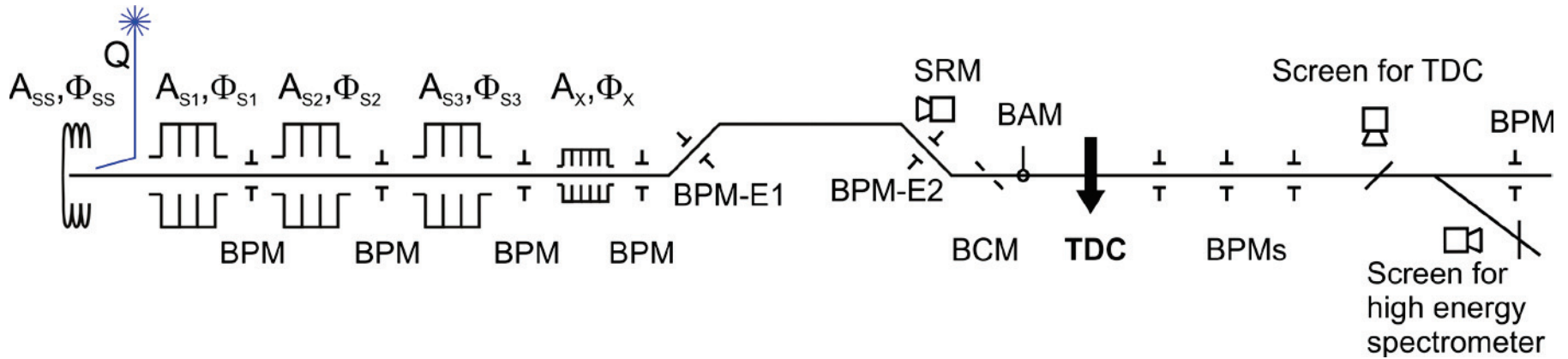
	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A_{SS}	A_{S1}	A_{S2}	A_{S3}	A_{XB}
BPM-E ₁	—	■	—	—	■	—	■	—	—	■	■
SRM-E	—	—	—	—	■	—	■	—	—	■	■
SRM- $\Delta E/E$	—	—	—	—	—	—	—	—	—	—	—
BPM-E ₂	—	■	—	—	■	—	■	—	—	■	■
BCM-D1r	■	—	■	■	■	■	■	—	—	—	■
BCM-D2r	■	—	—	—	—	■	—	—	—	—	—
BPM-Q	■	—	—	—	—	—	—	—	—	—	—
BAM	—	—	—	—	—	—	—	—	—	■	—
TDC - σ_t	—	—	—	—	—	—	—	—	—	—	—

■ > 0 ■ < 0



	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A_{SS}	A_{S1}	A_{S2}	A_{S3}	A_{XB}
BPM-E ₁	—	■	—	—	■	—	■	—	—	■	■
SRM-E	—	■	—	—	■	—	■	—	—	■	■
SRM- $\Delta E/E$	—	—	—	—	—	—	—	—	—	—	—
BPM-E ₂	—	■	—	—	■	—	■	—	—	■	■
BCM-D1r	■	—	■	■	■	■	■	—	—	—	—
BCM-D2r	■	—	—	—	—	■	—	—	—	—	—
BPM-Q	■	—	—	—	—	—	—	—	—	—	—
BAM	—	—	—	—	—	—	—	—	—	■	—
TDC - σ_t	—	—	—	—	—	—	—	—	—	—	—

■ > 0 ■ < 0



if Φ_{S3} ↑

energy

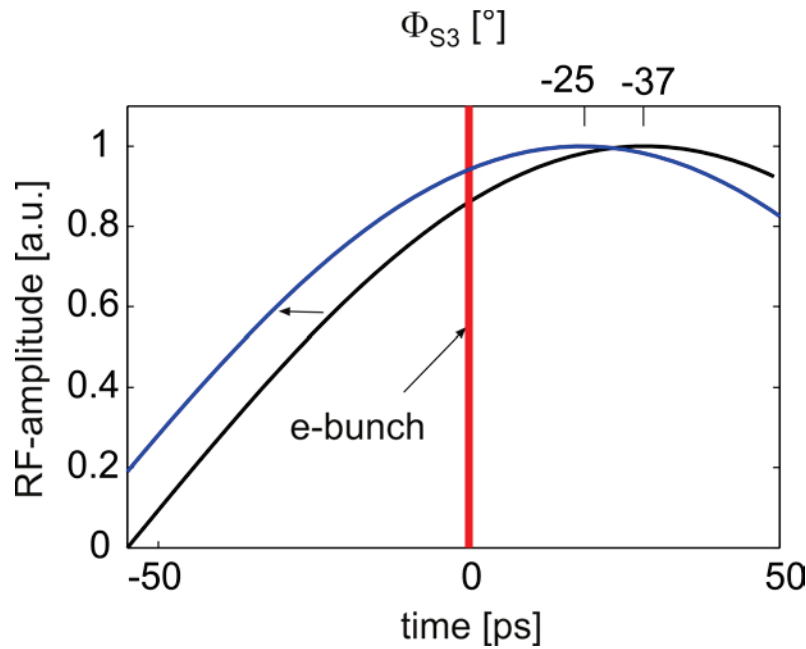
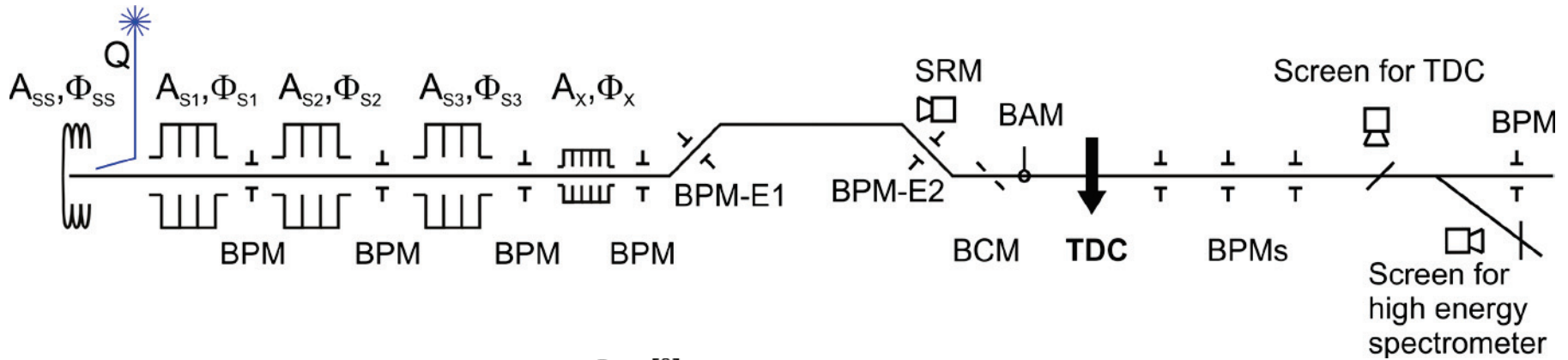
$\Delta E/E$

BCM

Q

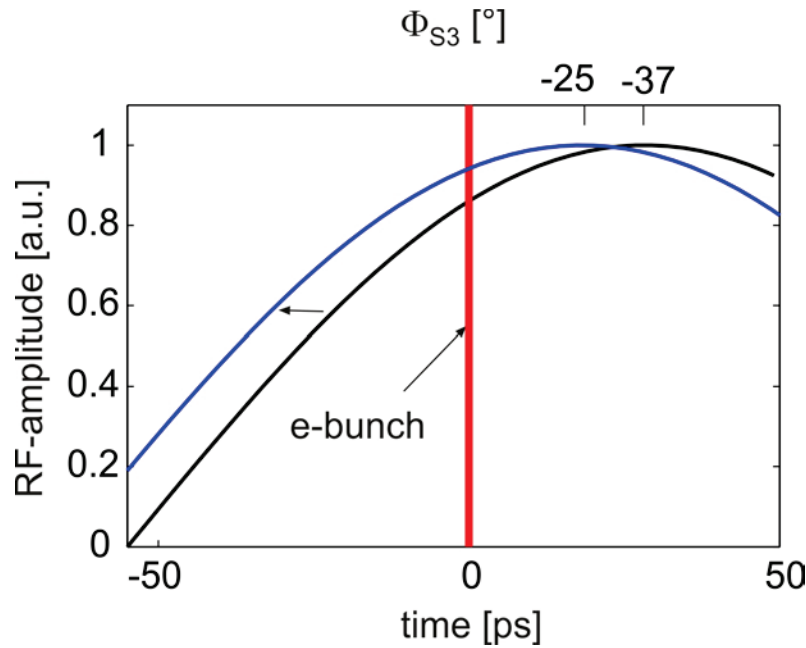
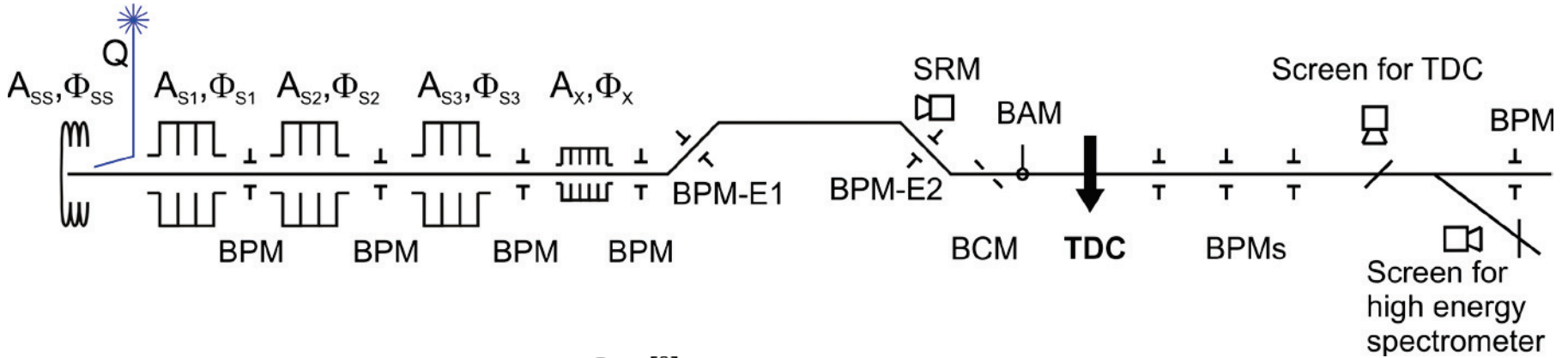
BAM

TDC

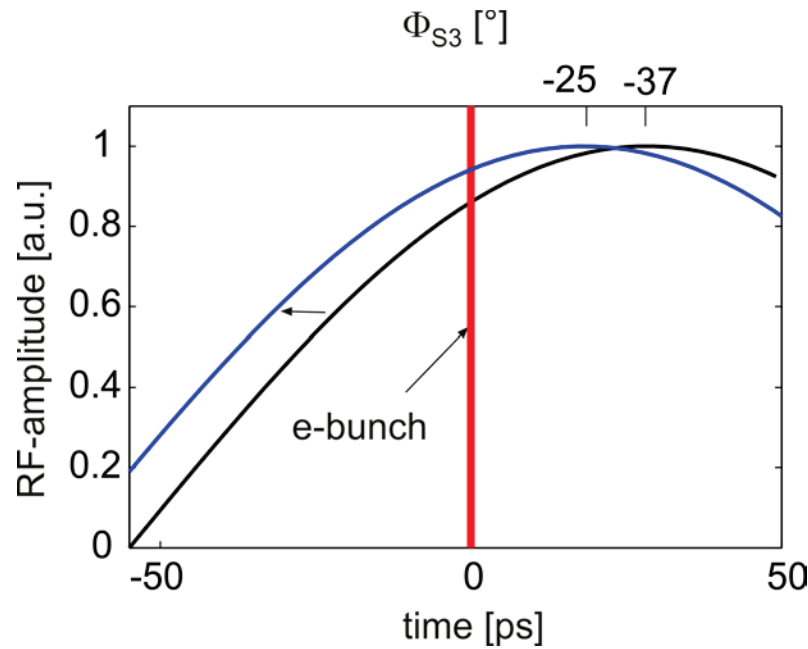
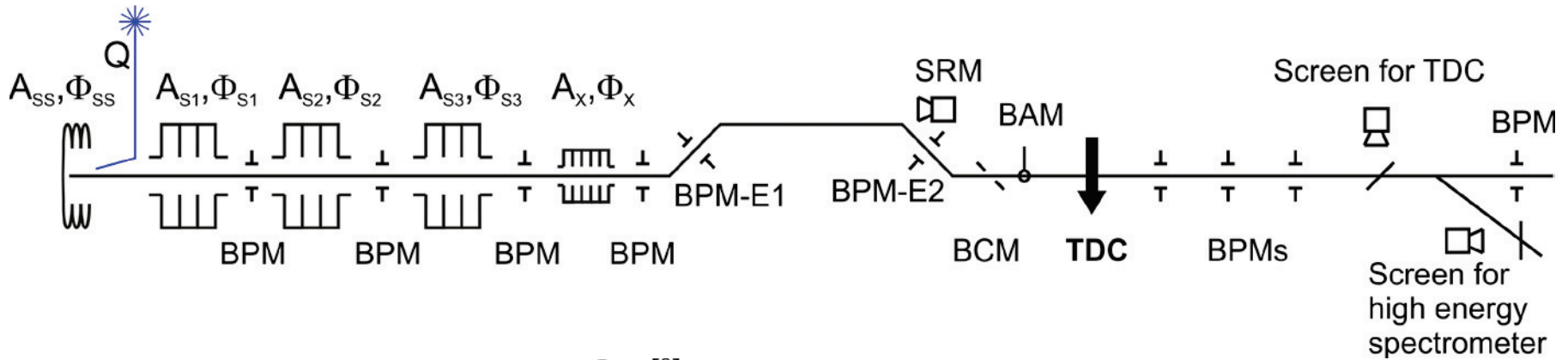


if $\phi_{S3} \uparrow$

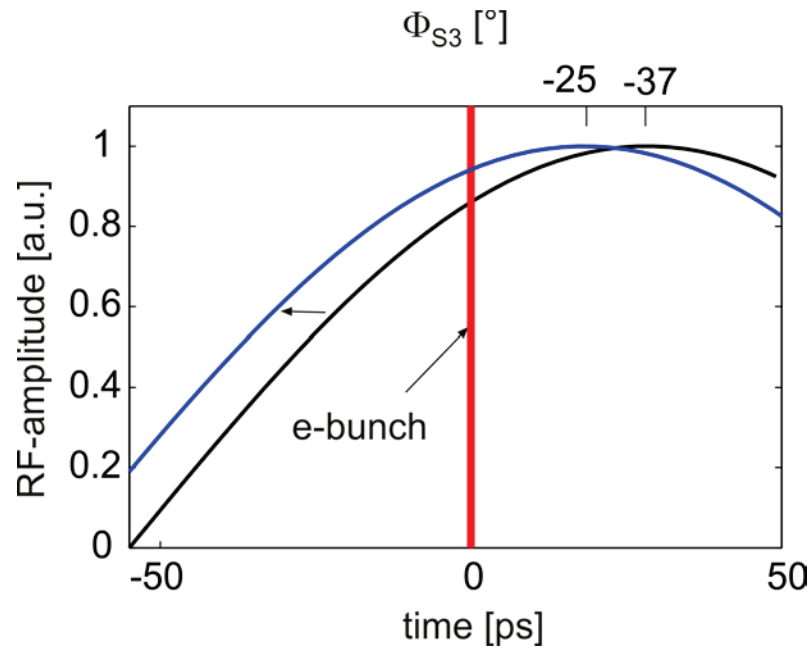
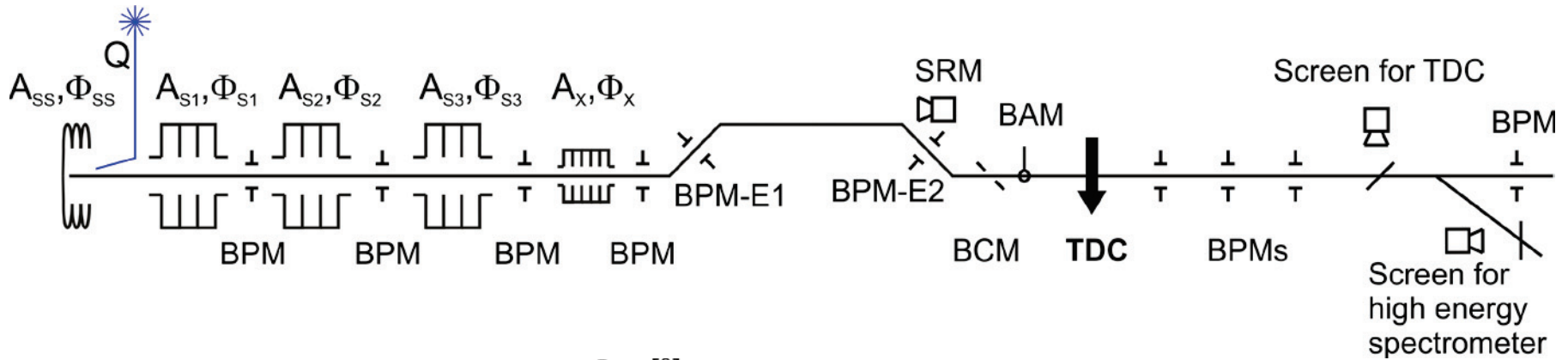
energy
 $\Delta E/E$
 BCM
 Q
 BAM
 TDC



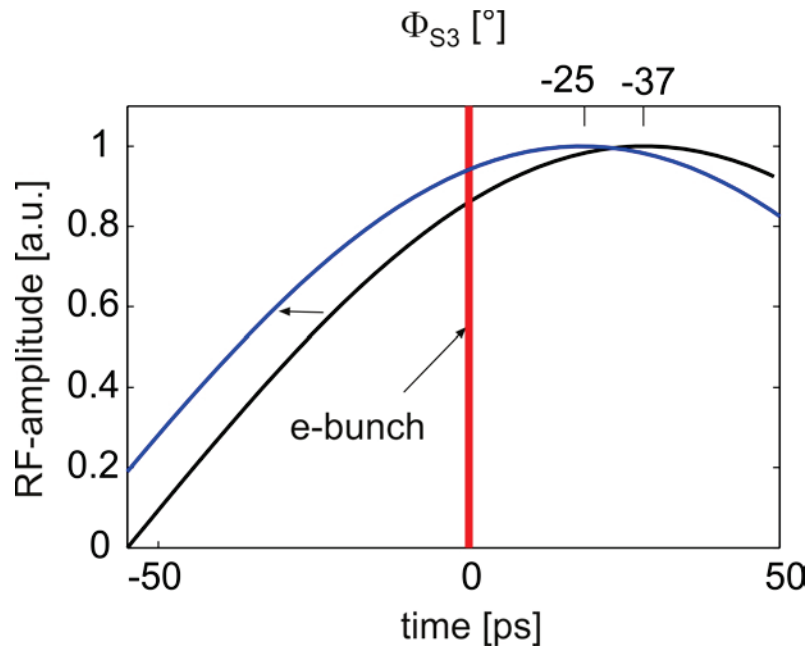
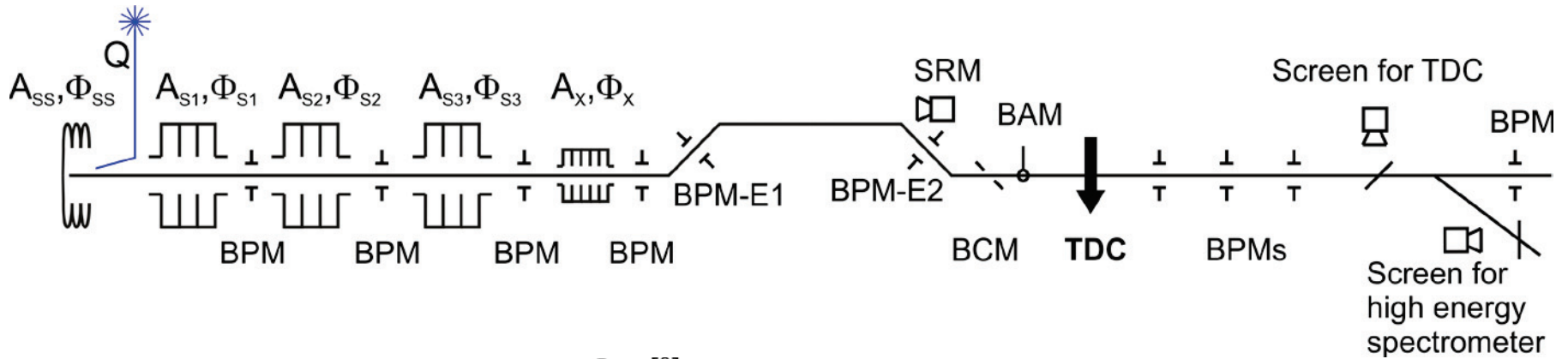
if $\Phi_{S3} \uparrow$
 energy
 $\Delta E/E$
 BCM
 Q
 BAM
 TDC



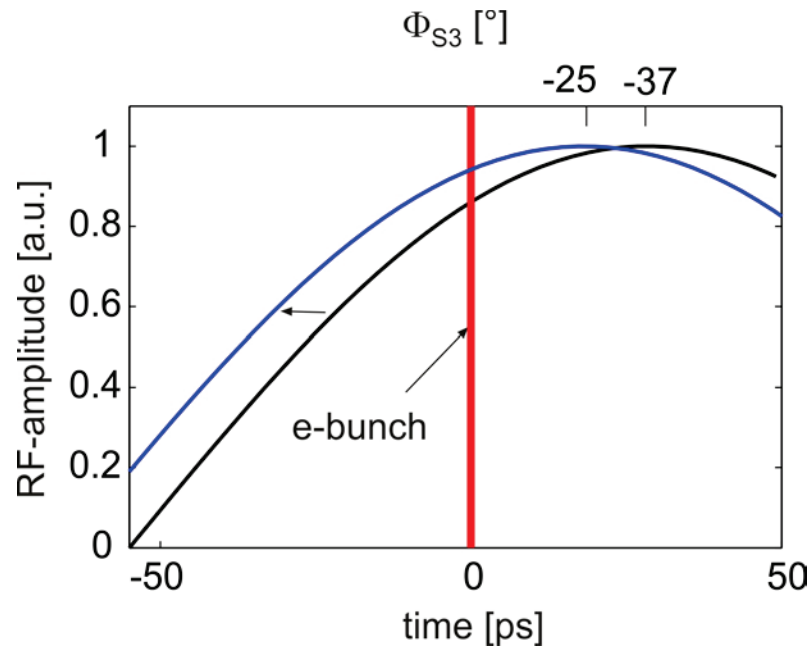
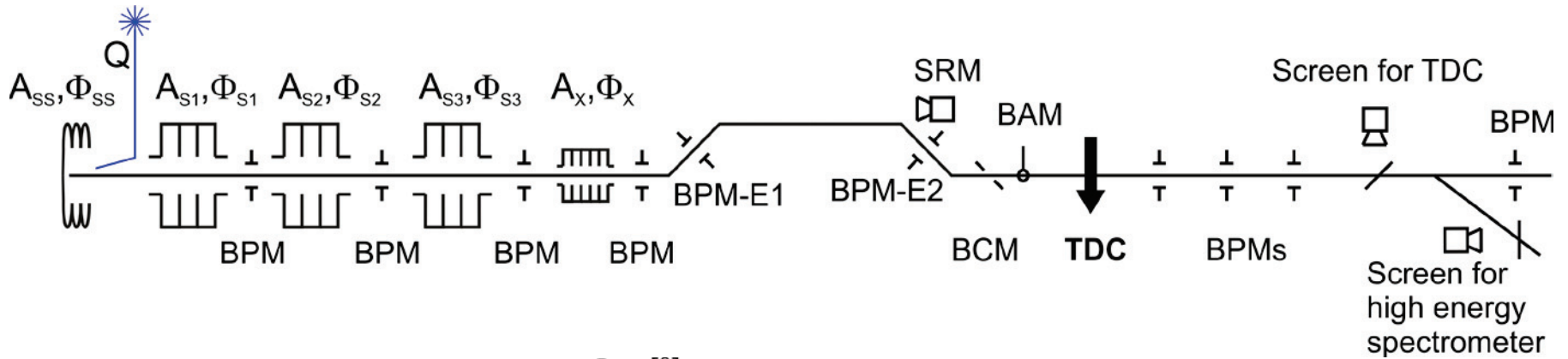
if Φ_{S3} ↑
 energy ↑
 $\Delta E/E$ ↑
 BCM →
 Q →
 BAM →
 TDC →



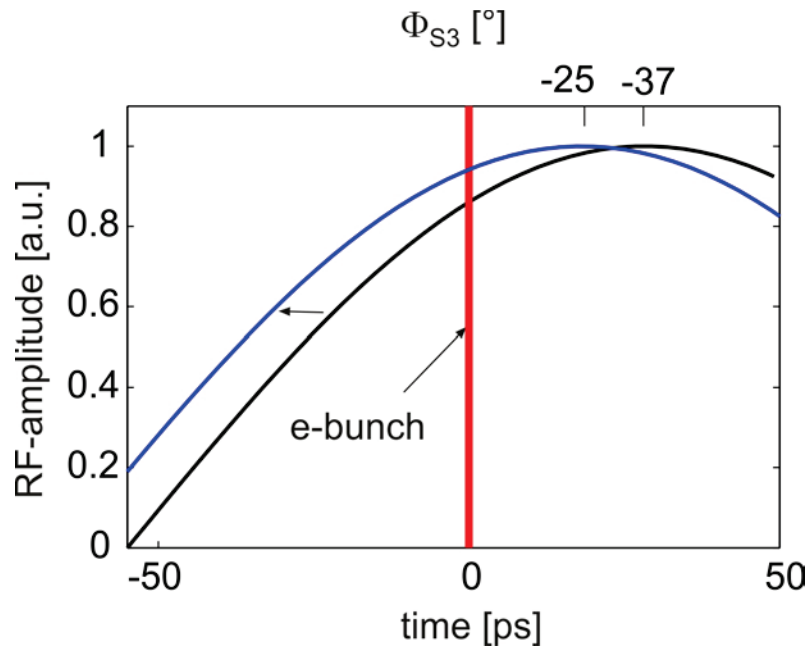
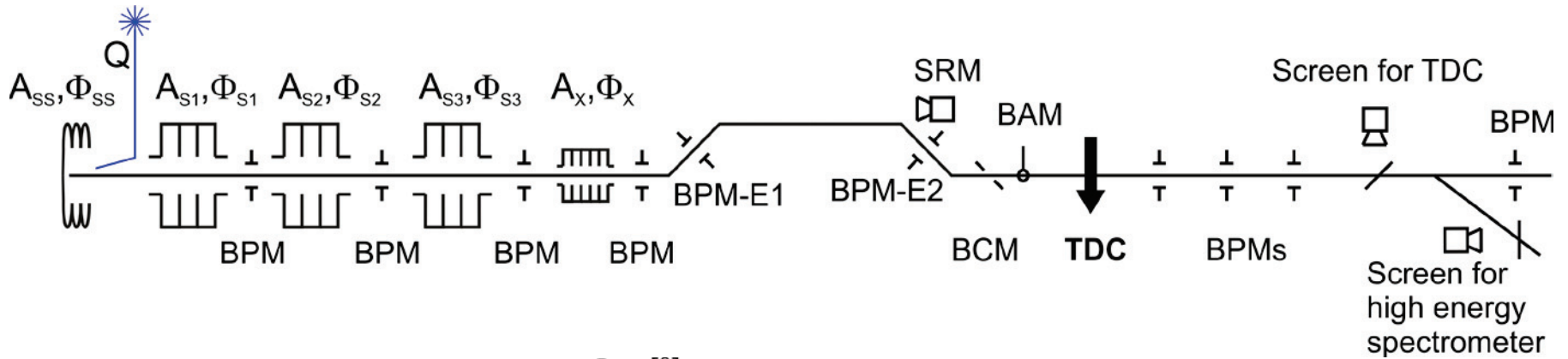
if Φ_{S3} \nearrow
 energy \nearrow
 $\Delta E/E$ \rightarrow
 BCM \rightarrow
 Q \rightarrow
 BAM \rightarrow
 TDC \rightarrow



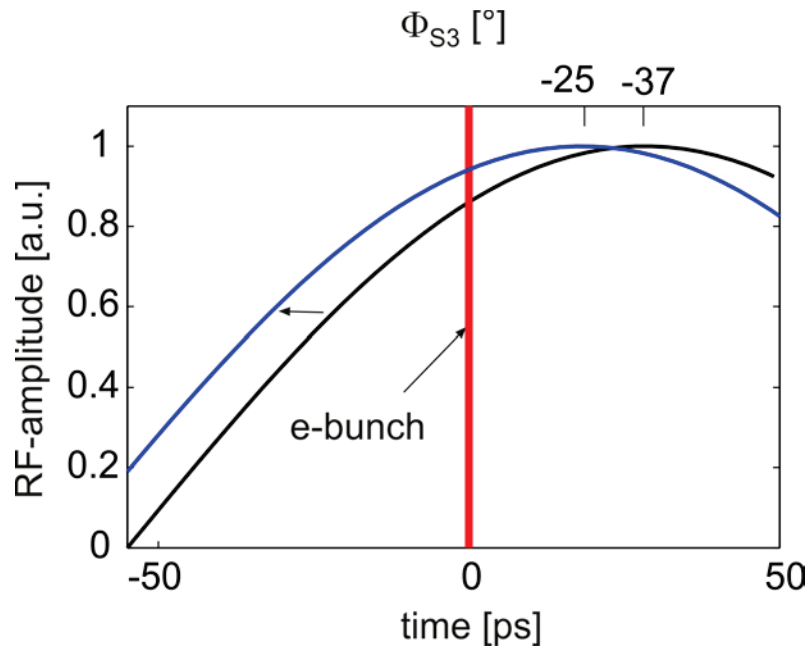
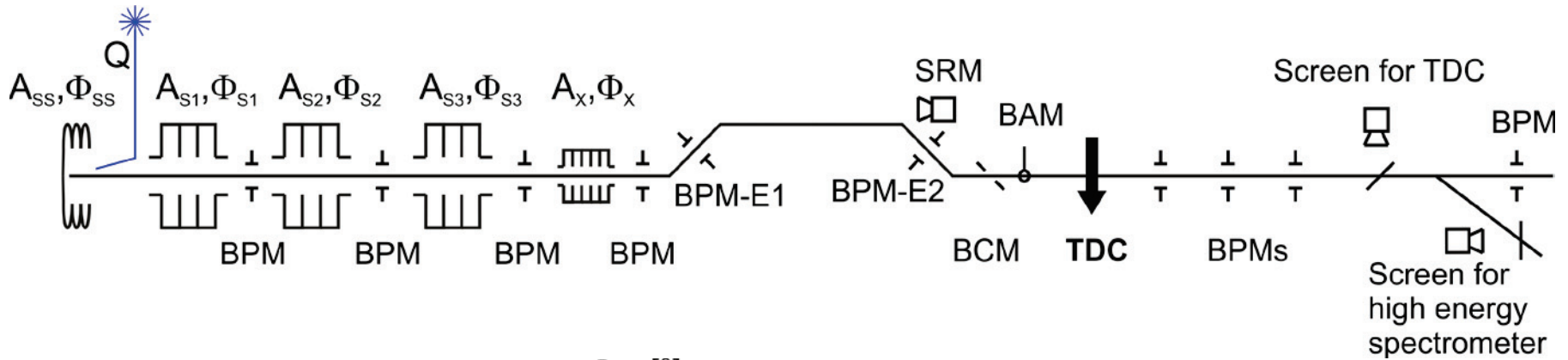
if $\Phi_{S3} \uparrow$
 energy \uparrow
 $\Delta E/E \rightarrow$
 BCM \rightarrow
 $Q \rightarrow$
 BAM \rightarrow
 TDC \rightarrow



if $\Phi_{S3} \uparrow$
 energy \uparrow
 $\Delta E/E \rightarrow$
 BCM \rightarrow
 $Q \rightarrow$
 BAM \rightarrow
 TDC \rightarrow



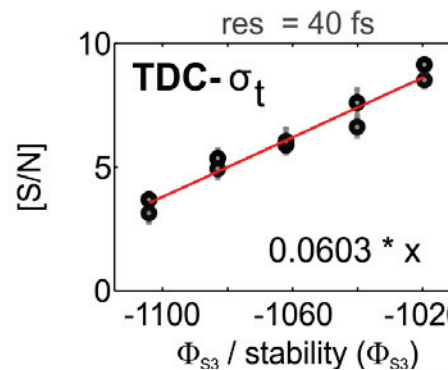
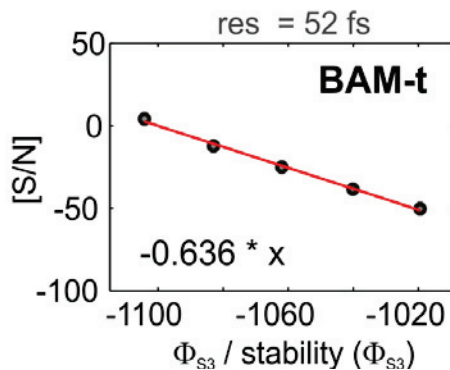
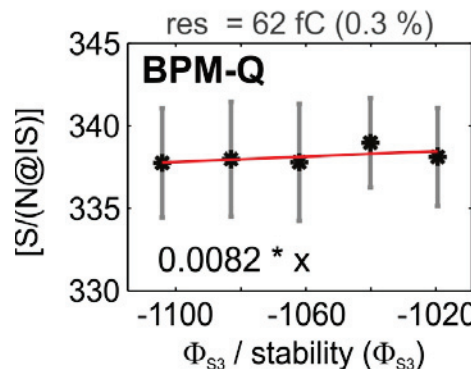
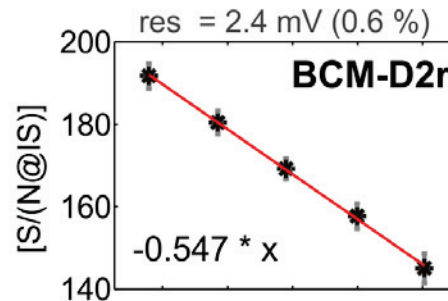
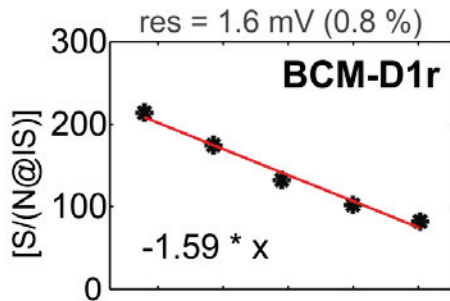
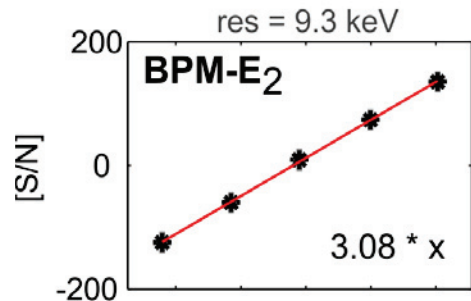
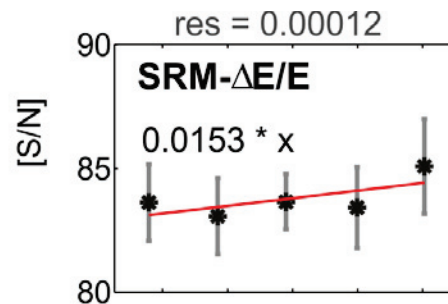
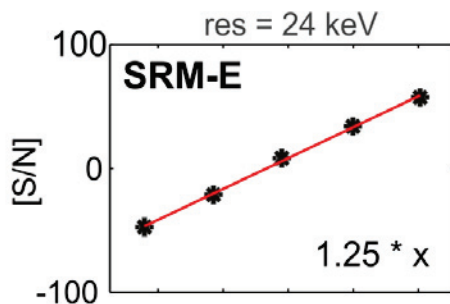
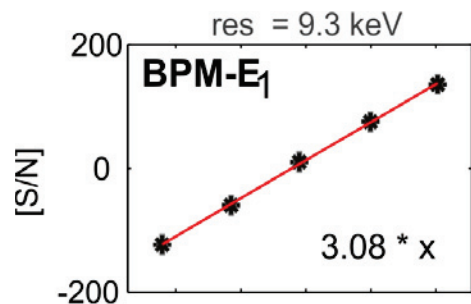
if Φ_{S3} ↑
 energy ↑
 $\Delta E/E$ ↑
 BCM ↑
 Q ↑
 BAM ↑
 TDC ↑



Simulations:
THP097



Varying the compression phase Φ_{S3}



if Φ_{S3} \nearrow

energy \nearrow

$\Delta E/E$ \rightarrow

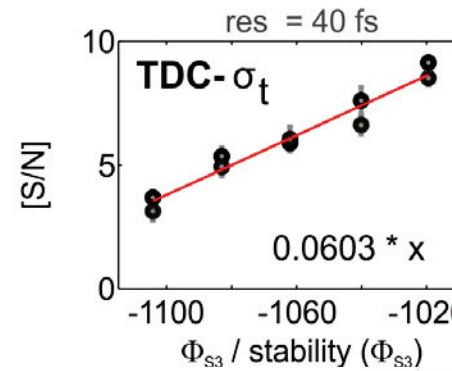
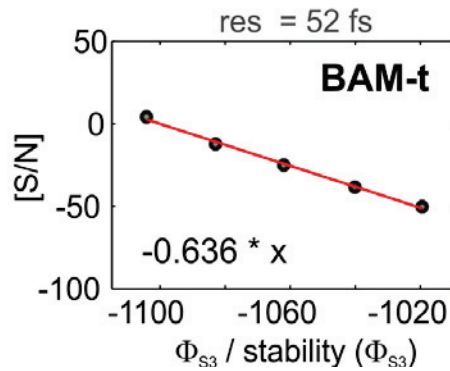
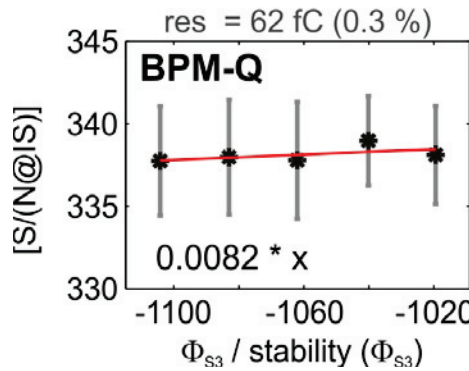
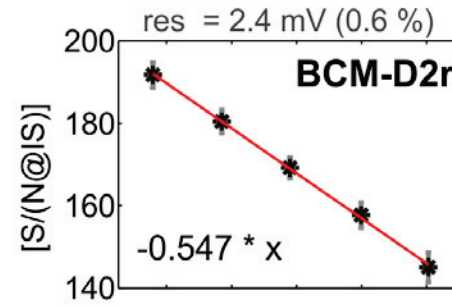
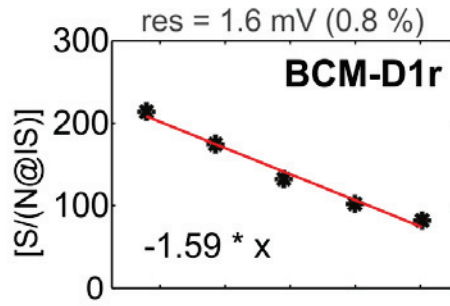
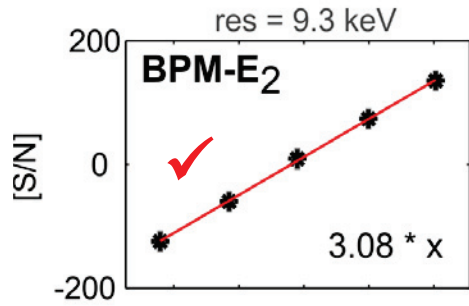
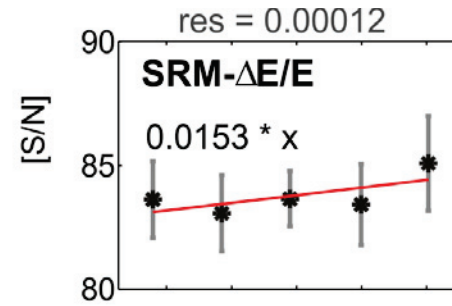
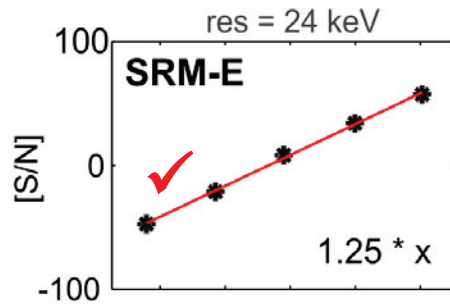
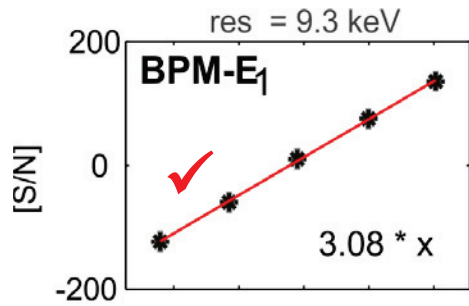
BCM \nearrow

Q \nearrow

BAM \nearrow

TDC \nearrow

Varying the compression phase Φ_{S3}



if Φ_{S3} \nearrow

energy \nearrow

$\Delta E/E$ \rightarrow

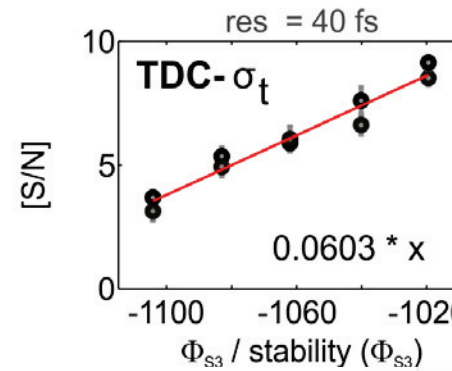
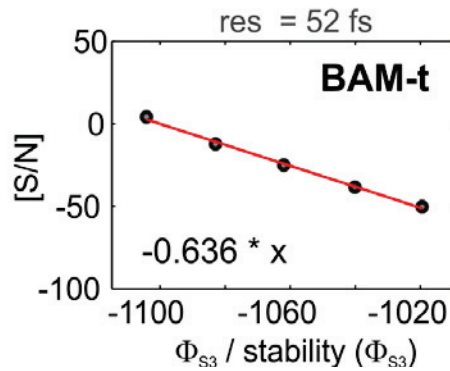
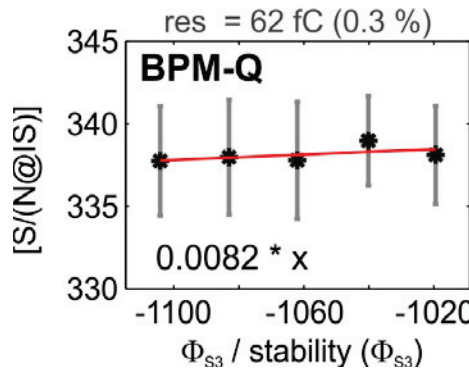
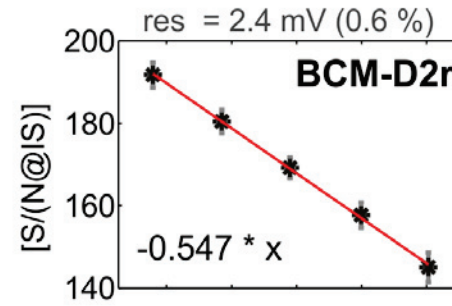
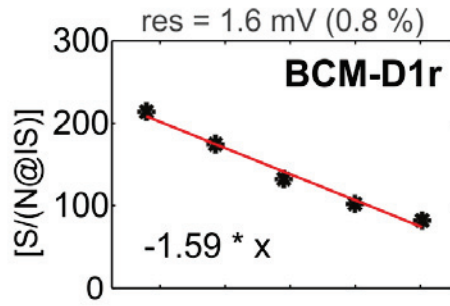
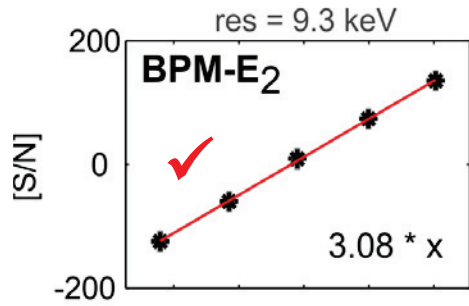
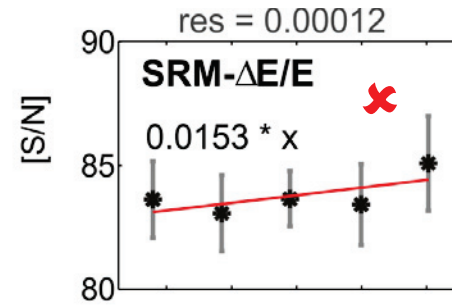
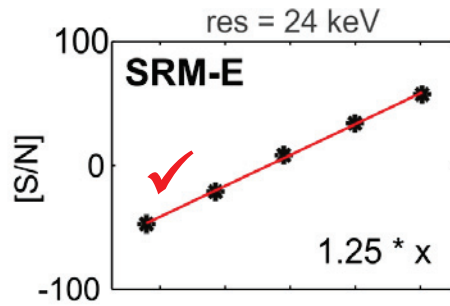
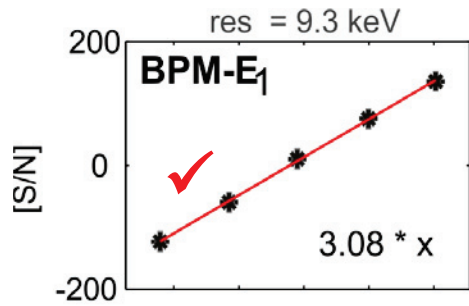
BCM \nearrow

Q \nearrow

BAM \nearrow

TDC \nearrow

Varying the compression phase Φ_{S3}



if Φ_{S3} \nearrow

energy \nearrow

$\Delta E/E$ \rightarrow

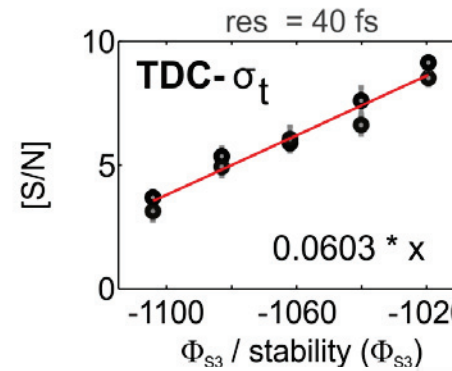
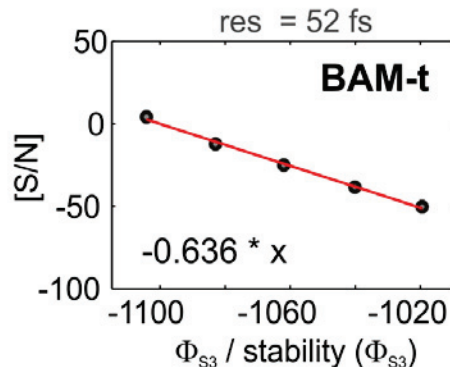
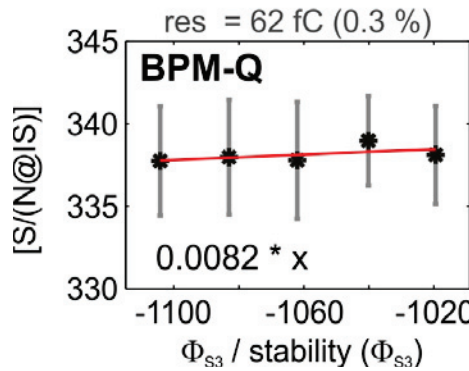
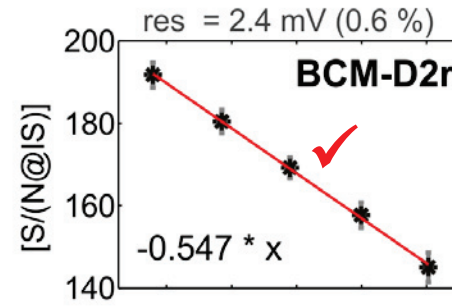
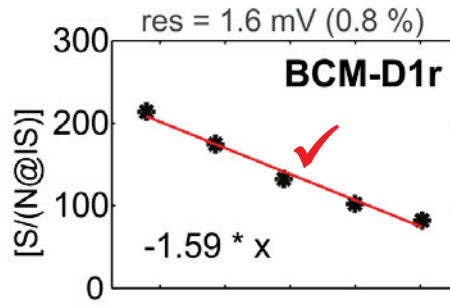
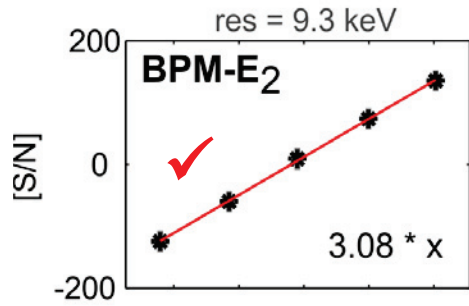
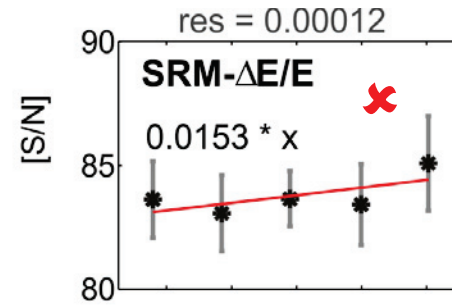
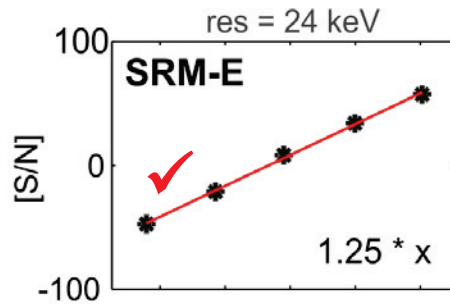
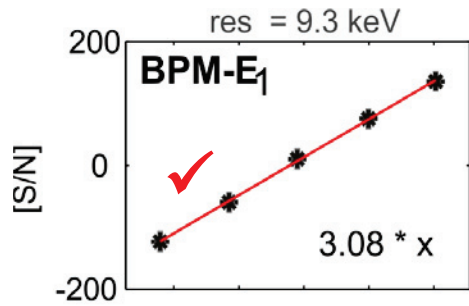
BCM \nearrow

Q \nearrow

BAM \nearrow

TDC \nearrow

Varying the compression phase Φ_{S3}



if Φ_{S3} \nearrow

energy \nearrow

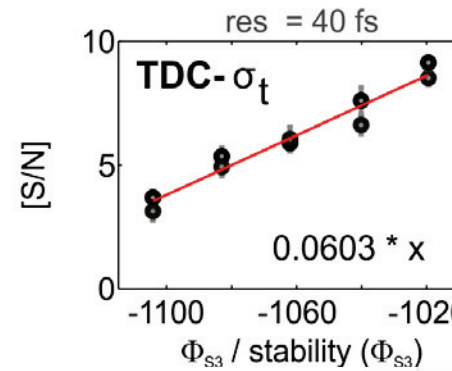
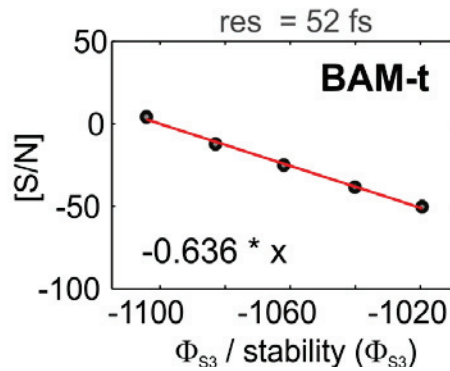
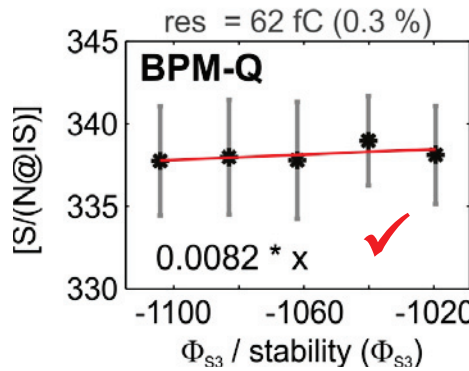
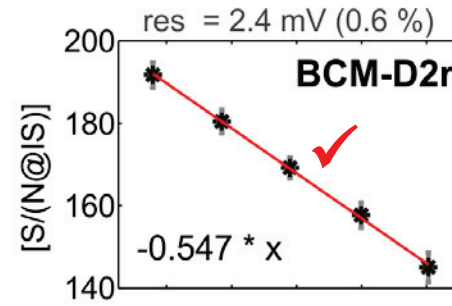
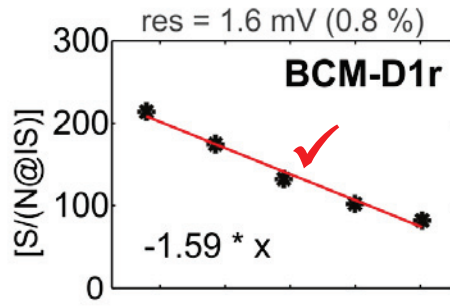
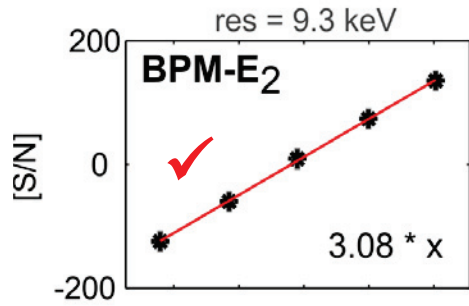
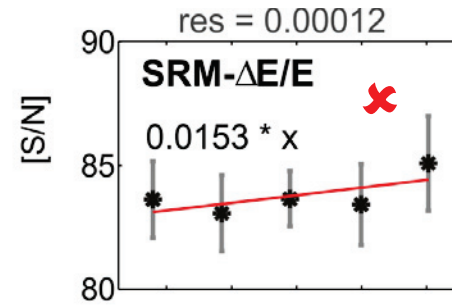
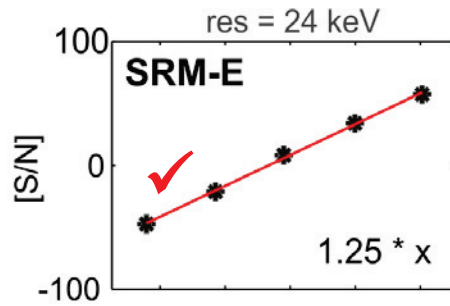
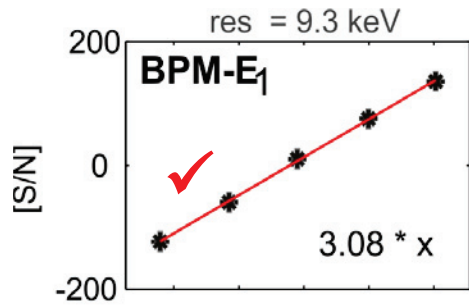
$\Delta E/E$ \rightarrow

BCM \nearrow

Q \nearrow

BAM \nearrow

TDC \nearrow



if Φ_{S3} \nearrow

energy \nearrow

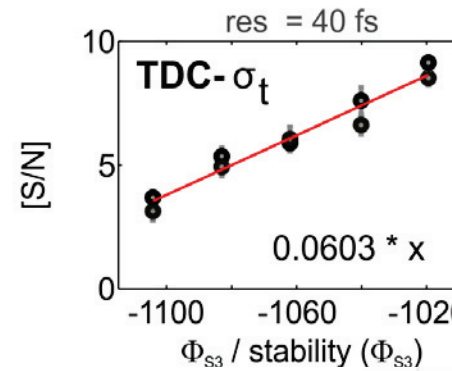
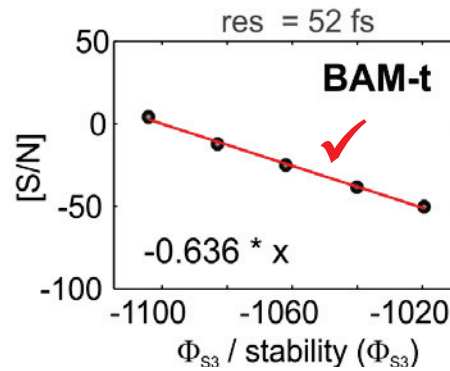
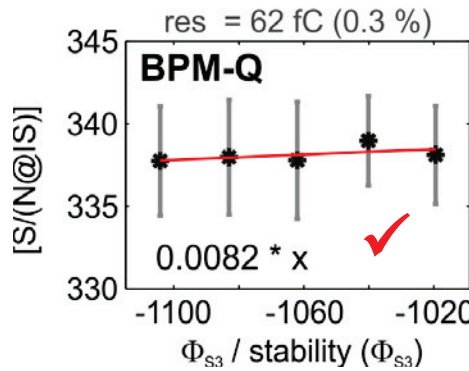
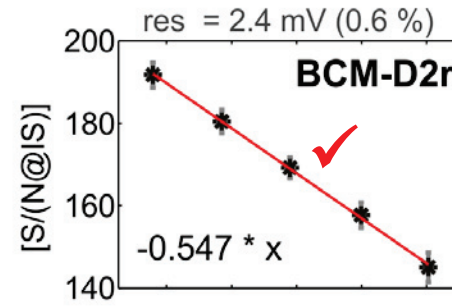
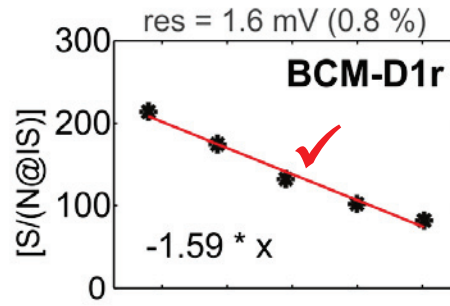
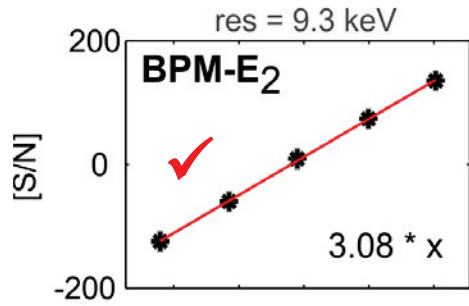
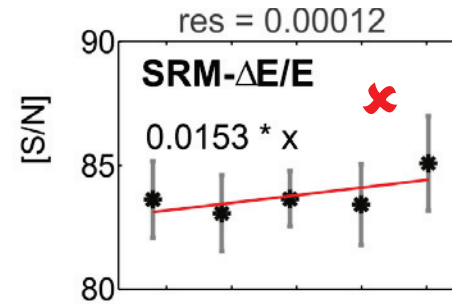
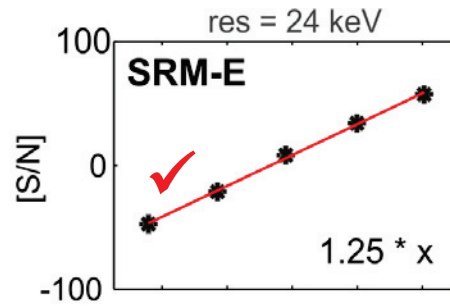
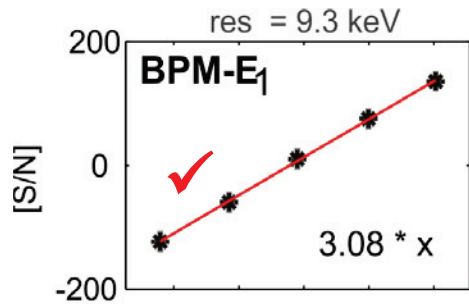
$\Delta E/E$ \rightarrow

BCM \nearrow

Q \nearrow

BAM \nearrow

TDC \nearrow



if Φ_{S3} \nearrow

energy \nearrow

$\Delta E/E$ \rightarrow

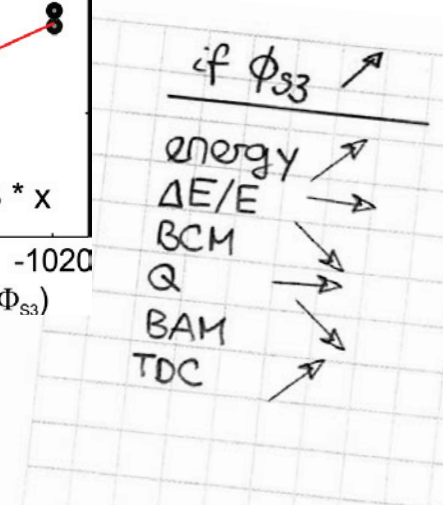
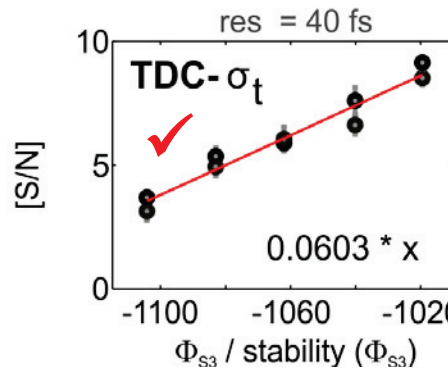
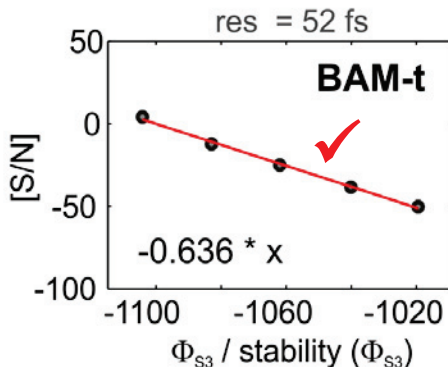
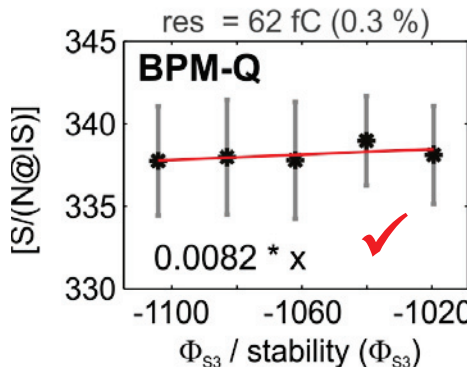
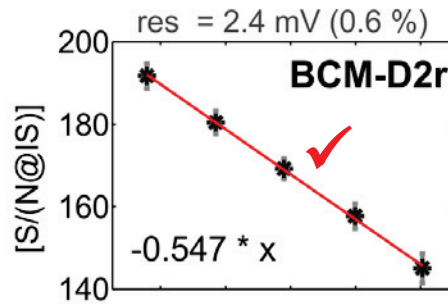
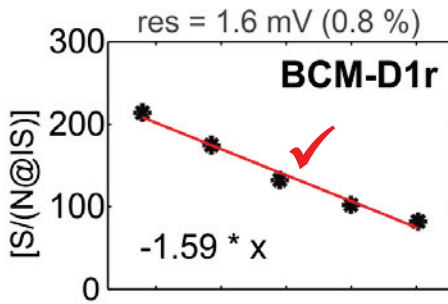
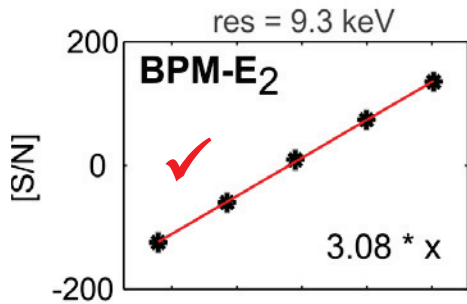
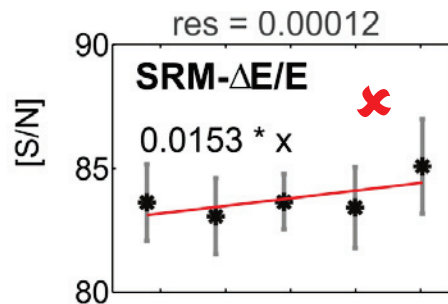
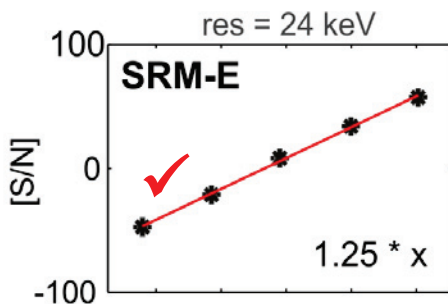
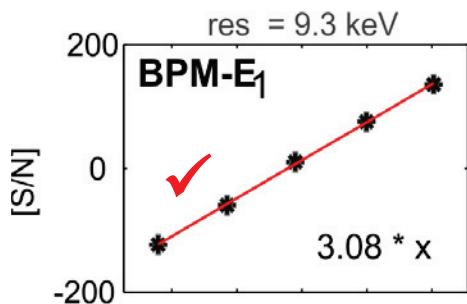
BCM \nearrow

Q \nearrow

BAM \nearrow

TDC \nearrow

Varying the compression phase Φ_{S3}



	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A_{SS}	A_{S1}	A_{S2}	A_{S3}	A_{XB}
BPM-E₁	0.11	-1.03	-0.07	0.07	3.08	0.08	-2.93	0.57	0.38	3.73	-1.55
SRM-E	-0.02	-0.38	-0.03	0.03	1.25	0.02	-1.13	0.23	0.16	1.50	-0.63
SRM-$\Delta E/E$	0.08	0.05	-0.02	-0.03	0.02	0.18	-0.05	0.01	0.01	0.10	-0.03
BPM-E₂	0.25	-1.03	-0.07	0.07	3.08	0.05	-2.94	0.57	0.39	3.72	-1.56
BCM-D1r	0.98	-0.04	-0.45	-0.66	-1.59	3.37	0.57	-0.14	-0.08	-0.16	0.31
BCM-D2r	1.12	0.01	-0.14	-0.22	-0.55	1.01	0.20	-0.04	-0.02	-0.04	0.10
BPM-Q	2.89	0.09	0.01	0.00	0.01	0.04	0.08	0.00	-0.00	0.01	-0.01
BAM	-0.32	-0.02	0.01	-0.01	-0.63	0.01	-0.13	-0.12	-0.07	-0.72	0.31
TDC - σ_t	-	0.00	0.02	0.02	0.06	-0.17	-0.01	0.00	0.01	0.00	-0.01

Singular Value Decomposition (SVD) : $R = U \cdot \Sigma \cdot V^T$

$$R = U \cdot \Sigma \cdot V^T$$

Σ

	1	2	3	4	5	6
1	8.96					
2						
3						
4						
5						
6						

U

	1	2	3	4	5	6
BPM-E ₁	-0.67					
SRM-E	-0.27					
SRM- $\Delta E/E$	-0.01					
BPM-E ₂	-0.67					
BCM-D1r	0.17					
BCM-D2r	0.06					
BPM-Q	0.00					
BAM	0.09					
TDC - σ_t	-0.01					

V^T

	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A _{SS}	A _{S1}	A _{S2}	A _{S3}	A _{XB}
1	-0.00	0.16	0.00	-0.03	-0.53	0.06	0.48	-0.10	-0.06	-0.61	0.26
2											
3											
4											
5											
6											

Energy

$$R = U \cdot \Sigma \cdot V^T$$

Σ

	1	2	3	4	5	6
1	8.96	0				
2	0	4.22				
3						
4						
5						
6						

U

	1	2	3	4	5	6
BPM-E ₁	-0.67	0.11				
SRM-E	-0.27	0.03				
SRM- $\Delta E/E$	-0.01	0.05				
BPM-E ₂	-0.67	0.12				
BCM-D1r	0.17	0.82				
BCM-D2r	0.06	0.36				
BPM-Q	0.00	0.40				
BAM	0.09	-0.05				
TDC - σ_t	-0.01	-0.03				

V^T

	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A _{SS}	A _{S1}	A _{S2}	A _{S3}	A _{XB}
1	-0.00	0.16	0.00	-0.03	-0.53	0.06	0.48	-0.10	-0.06	-0.61	0.26
2	0.57	-0.05	-0.10	-0.14	-0.18	0.75	-0.03	0.00	0.00	0.19	-0.02
3											
4											
5											
6											

Energy
Bunch compression - Charge

$$R = U \cdot \Sigma \cdot V^T$$

Σ

	1	2	3	4	5	6
1	8.96	0	0			
2	0	4.22	0			
3	0	0	2.70			
4						
5						
6						

U

	1	2	3	4	5	6
BPM-E ₁	-0.67	0.11	-0.07			
SRM-E	-0.27	0.03	-0.04			
SRM- $\Delta E/E$	-0.01	0.05	-0.02			
BPM-E ₂	-0.67	0.12	-0.02			
BCM-D1r	0.17	0.82	-0.46			
BCM-D2r	0.06	0.36	0.11			
BPM-Q	0.00	0.40	0.87			
BAM	0.09	-0.05	-0.11			
TDC - σ_t	-0.01	-0.03	0.04			

V^T

	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A _{SS}	A _{S1}	A _{S2}	A _{S3}	A _{XB}
1	-0.00	0.16	0.00	-0.03	-0.53	0.06	0.48	-0.10	-0.06	-0.61	0.26
2	0.57	-0.05	-0.10	-0.14	-0.18	0.75	-0.03	0.00	0.00	0.19	-0.02
3	0.82	0.08	0.08	0.10	0.14	-0.52	0.07	0.00	-0.00	-0.11	0.00
4											
5											
6											

Energy
Bunch compression - Charge
Charge - Bunch compression

$$R = U \cdot \Sigma \cdot V^T$$

Σ

	1	2	3	4	5	6
1	8.96	0	0	0		
2	0	4.22	0	0		
3	0	0	2.70	0		
4	0	0	0	0.62		
5						
6						

U

	1	2	3	4	5	6
BPM-E ₁	-0.67	0.11	-0.07	-0.06		
SRM-E	-0.27	0.03	-0.04	0.06		
SRM- $\Delta E/E$	-0.01	0.05	-0.02	0.03		
BPM-E ₂	-0.67	0.12	-0.02	-0.10		
BCM-D1r	0.17	0.82	-0.46	0.03		
BCM-D2r	0.06	0.36	0.11	-0.05		
BPM-Q	0.00	0.40	0.87	-0.10		
BAM	0.09	-0.05	-0.11	-0.98		
TDC - σ_t	-0.01	-0.03	0.04	0.00		

V^T

	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A _{SS}	A _{S1}	A _{S2}	A _{S3}	A _{XB}
1	-0.00	0.16	0.00	-0.03	-0.53	0.06	0.48	-0.10	-0.06	-0.61	0.26
2	0.57	-0.05	-0.10	-0.14	-0.18	0.75	-0.03	0.00	0.00	0.19	-0.02
3	0.82	0.08	0.08	0.10	0.14	-0.52	0.07	0.00	-0.00	-0.11	0.00
4	-0.06	0.23	-0.01	-0.02	0.33	0.07	0.82	0.06	0.04	0.35	-0.16
5											
6											

Energy
 Bunch compression - Charge
 Charge - Bunch compression
 Bunch arrival time

$$R = U \cdot \Sigma \cdot V^T$$

Σ

	1	2	3	4	5	6
1	8.96	0	0	0	0	
2	0	4.22	0	0	0	
3	0	0	2.70	0	0	
4	0	0	0	0.62	0	
5	0	0	0	0	0.08	
6						

U

	1	2	3	4	5	6
BPM-E ₁	-0.67	0.11	-0.07	-0.06	-0.03	
SRM-E	-0.27	0.03	-0.04	0.06	0.17	
SRM- $\Delta E/E$	-0.01	0.05	-0.02	0.03	0.89	
BPM-E ₂	-0.67	0.12	-0.02	-0.10	-0.05	
BCM-D1r	0.17	0.82	-0.46	0.03	0.06	
BCM-D2r	0.06	0.36	0.11	-0.05	-0.36	
BPM-Q	0.00	0.40	0.87	-0.10	0.11	
BAM	0.09	-0.05	-0.11	-0.98	0.06	
TDC - σ_t	-0.01	-0.03	0.04	0.00	-0.14	

V^T

	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A _{SS}	A _{S1}	A _{S2}	A _{S3}	A _{XB}
1	-0.00	0.16	0.00	-0.03	-0.53	0.06	0.48	-0.10	-0.06	-0.61	0.26
2	0.57	-0.05	-0.10	-0.14	-0.18	0.75	-0.03	0.00	0.00	0.19	-0.02
3	0.82	0.08	0.08	0.10	0.14	-0.52	0.07	0.00	-0.00	-0.11	0.00
4	-0.06	0.23	-0.01	-0.02	0.33	0.07	0.82	0.06	0.04	0.35	-0.16
5	-0.02	0.86	0.08	0.13	0.28	0.21	-0.27	-0.07	-0.00	-0.19	0.02
6											

Energy
 Bunch compression - Charge
 Charge - Bunch compression
 Bunch arrival time
 Rel. Energy spread

$$R = U \cdot \Sigma \cdot V^T$$

$$\Sigma$$

	1	2	3	4	5	6
1	8.96	0	0	0	0	0
2	0	4.22	0	0	0	0
3	0	0	2.70	0	0	0
4	0	0	0	0.62	0	0
5	0	0	0	0	0.08	0
6	0	0	0	0	0	0.06

$$U$$

	1	2	3	4	5	6
BPM-E ₁	-0.67	0.11	-0.07	-0.06	-0.03	-0.10
SRM-E	-0.27	0.03	-0.04	0.06	0.17	0.06
SRM- $\Delta E/E$	-0.01	0.05	-0.02	0.03	0.89	0.39
BPM-E ₂	-0.67	0.12	-0.02	-0.10	-0.05	0.07
BCM-D1r	0.17	0.82	-0.46	0.03	0.06	-0.26
BCM-D2r	0.06	0.36	0.11	-0.05	-0.36	0.81
BPM-Q	0.00	0.40	0.87	-0.10	0.11	-0.24
BAM	0.09	-0.05	-0.11	-0.98	0.06	-0.01
TDC - σ_t	-0.01	-0.03	0.04	0.00	-0.14	0.20

$$V^T$$

	Q	Φ_{SS}	Φ_{S1}	Φ_{S2}	Φ_{S3}	Φ_{XB}	A _{SS}	A _{S1}	A _{S2}	A _{S3}	A _{XB}
1	-0.00	0.16	0.00	-0.03	-0.53	0.06	0.48	-0.10	-0.06	-0.61	0.26
2	0.57	-0.05	-0.10	-0.14	-0.18	0.75	-0.03	0.00	0.00	0.19	-0.02
3	0.82	0.08	0.08	0.10	0.14	-0.52	0.07	0.00	-0.00	-0.11	0.00
4	-0.06	0.23	-0.01	-0.02	0.33	0.07	0.82	0.06	0.04	0.35	-0.16
5	-0.02	0.86	0.08	0.13	0.28	0.21	-0.27	-0.07	-0.00	-0.19	0.02
6	-0.01	0.41	-0.08	-0.35	-0.60	-0.30	-0.10	0.10	0.09	0.46	-0.13

Energy

Bunch compression - Charge

Charge - Bunch compression

Bunch arrival time

Rel. Energy spread

- a diagnostics response matrix measured at **one working point** at SITF
- numbers in the matrix depend on **stabilities and resolutions**
- the **charge and compression modes might be disentangled** by compensating the influence of the charge on the BCM in the data processing
- **redundant energy measurements** from the SRM and the BPMs in the BC
- SRM also measures **relative energy spread**
- no clear distinction between the influence of the **S- and X-band phase**

- a diagnostics response matrix measured at **one working point** at SITF
- numbers in the matrix depend on **stabilities and resolutions**
- the **charge and compression modes might be disentangled** by compensating the influence of the charge on the BCM in the data processing
- **redundant energy measurements** from the SRM and the BPMs in the BC
- SRM also measures **relative energy spread**
- no clear distinction between the influence of the **S- and X-band phase**
 - considering the shape or some measure for the asymmetry of the energy distribution in the SRM?

**... all the people contributing to a successful installation
commissioning and operation of SITF**

