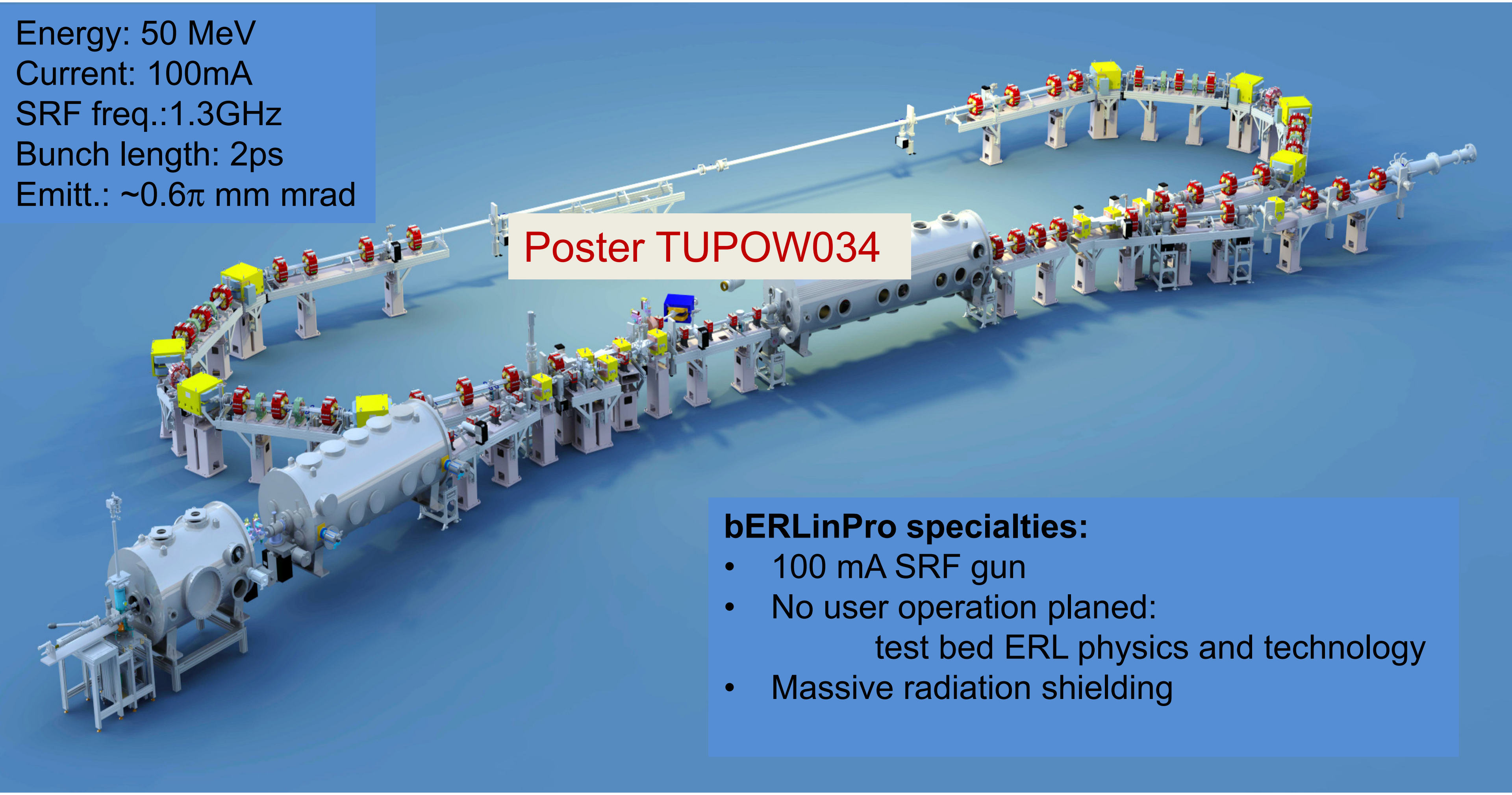
START-TO-END SIMULATIONS AND TRAJECTORY CORRECTION FOR bERLinPro

B. Kuske, C. Metzger-Kraus

bERLinPro: A high current, low emittance Energy Recovery Linac

Energy: 50 MeV
Current: 100mA
SRF freq.:1.3GHz
Bunch length: 2ps
Emitt.: ~0.6π mm mrad



Poster TUPOW034

bERLinPro specialties:

- 100 mA SRF gun
- No user operation planed:
  test bed ERL physics and technology
- Massive radiation shielding

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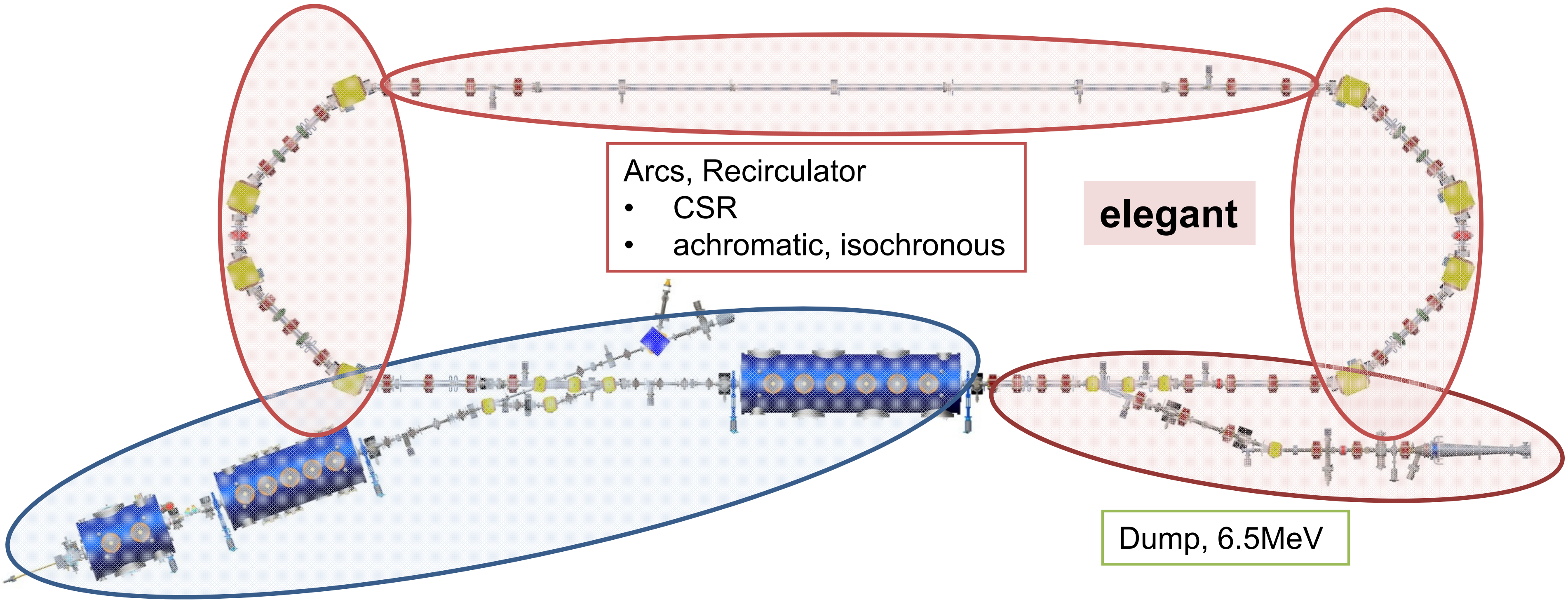
ERL simulation:



Injector:
- Space charge
- Emittance compensation

ASTRA,
anal. emittance compensation code

Interfacing between codes cumbersome – esp. for statistical studies, trajectory correction => OPAL

AMAS: Accelerator Modelling and Advanced Simulations

PAUL SCHERRER INSTITUT PSI

AMAS GROUP

OPAL: Object Oriented Particle Accelerator Library

- **open source**, **C++** framework for general particle accelerator simulations
- including **3D space charge** and short range wake fields (**CSR**)
- ‘ab initio’ **massively parallel**, to tackle large problems
- **http://amas.web.psi.ch/**

OPAL: *…has been around for some time, problems have been reported ….*

Initiate update of OPAL-T to meet bERLinPro simulation demands:
C. Metzger-Kraus: **OPAL-3D**

- fields now placed arbitrarily in 3D space
- dipole routine completely rewritten
- statistical errors incorporated
- ….
- Not all OPAL features ported yet, work in progress

Poster WEPOY034

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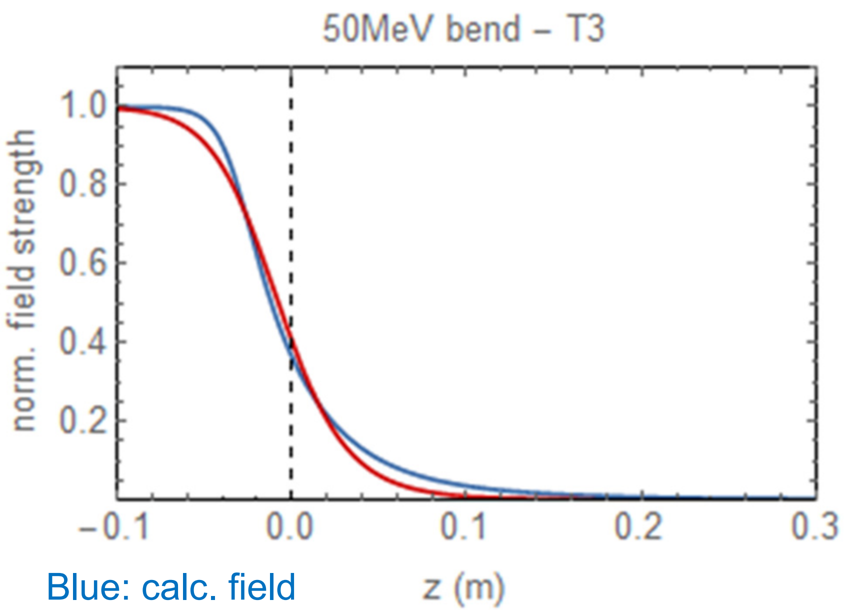

Blue: calc. field

Red: analytic, using 3 Enge coefficients

Bottelneck: dipole representation

bERLinPro:
8x 45° rectangular dipoles, length 0.6m
gap: 52mm

Producer: BINP, Novosibirsk,
field maps provided

Benchmarking elegant / OPAL-3D:

- OPAL: analytic representation of fringe field (8 Enge coefficients)
- Good agreement elegant NIBEND-element (provides tracking through dipoles) and OPAL both using 3 Enge coefficients
- elegant matrix element SBEND + adapted fringe field parameter, FINT (-10%) => acceptable agreement

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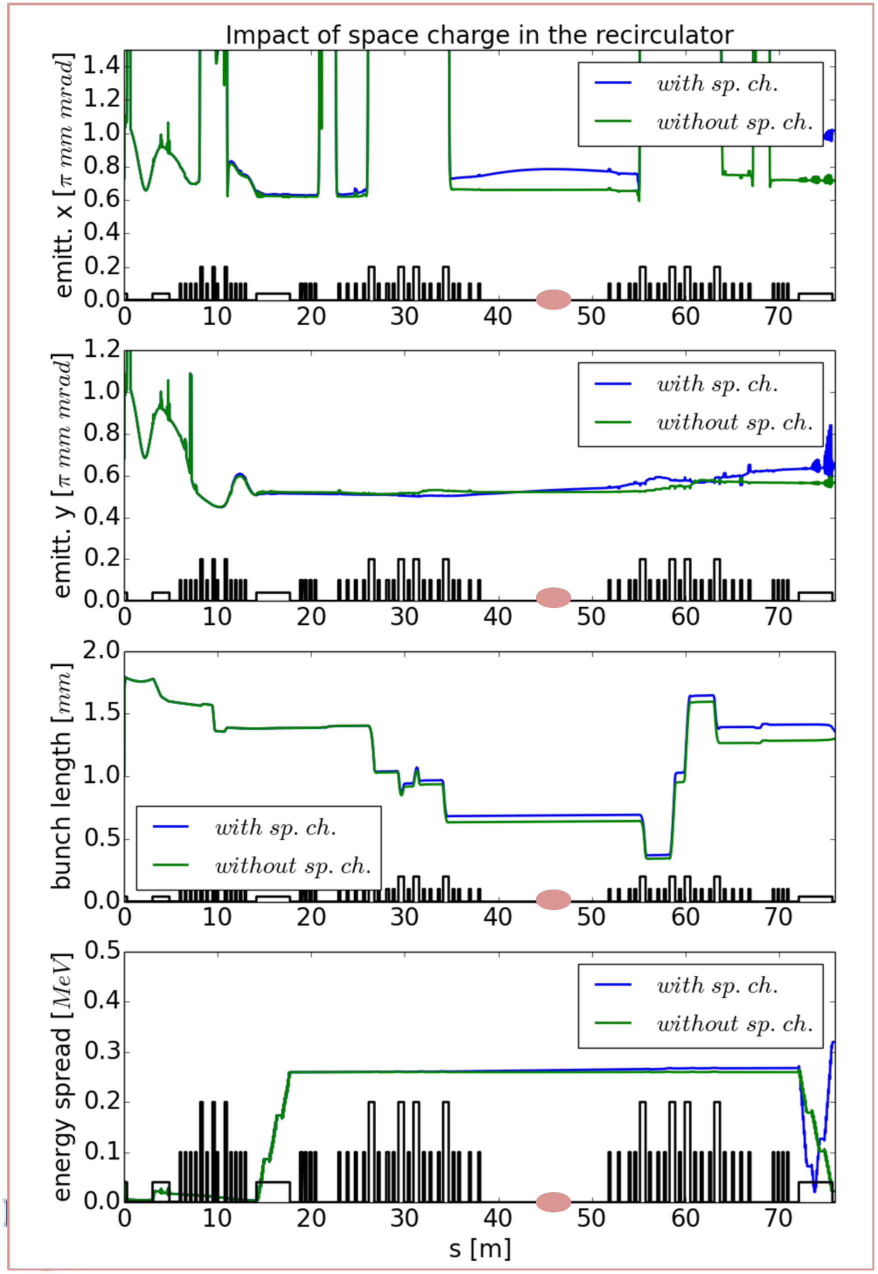

+16% in horiz. emittance
Now: 0.78 π mm mrad
: potential location of experiment

+1% vertical emittance
Now: 0.53 π mm mrad

Space charge again relevant in recirculator after bunch compression to 2 ps

+8% in bunch length
Now: 0.69 mm / 2.3ps

+3% in energy spread
at linac re-entry

Results from injector tolerance studies (IPAC 2014, TUPRO038):

5 dominant error sources:

Error source	rms-error	Counter measures
1 - trans. offsets solenoid, cavities, quadrupoles	250 μm, <400μm	trajectory correction

Error source	rms-error / (ref. value)	Counter measures
2 - laser timing	0.3 ps*	limitation of tolerances feedback systems
3 - laser pulse length	0.5 ps / (7 ps)	
4 - gun field rel.	5e-4 / (30 MV/m)	
5 - synchronization	0.25°, 0.5ps	

*: value reduced compared to injector studies (0.5 ps)

- arrival time and energy jitter before re-entry to linac
- variation bunch properties at experiment, before dump line

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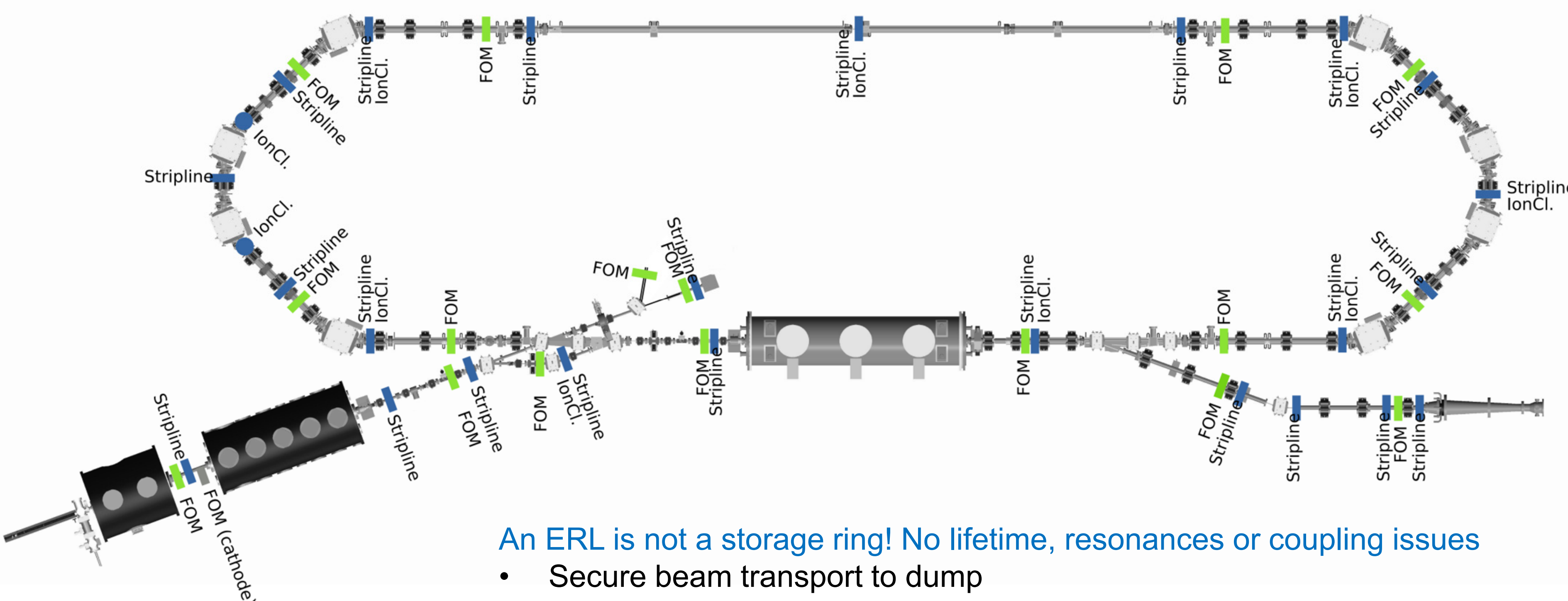
bERLinPro hardware for trajectory correction:

- 25 BPMs (86m)
- In each quadrupole: either H- or V-corrector
- In dipoles: H-correctors (not yet incl. in correction scheme)
- Two H-/V-steering coils in gun module and between gun and booster



An ERL is not a storage ring! No lifetime, resonances or coupling issues

- Secure beam transport to dump
- Alignment of beam in SRF modules (excitation of HOMS, 1-2mm)
- Preservation of goal parameters (emittance, bunch dimensions)

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CORRECTION METHOD

- **S**ingular **V**alue **D**ecomposition (SVD) of the steerer response matrix* (RM)
  benefit: directly applicable in machine, model independent
- Single pass machine: RM is upper triangular matrix
  - Less response towards the end of the machine
  - All BPMS contribute to initial correctors settings
    ERL: large trajectory excursions (after deceleration)

Cutout of typical RM

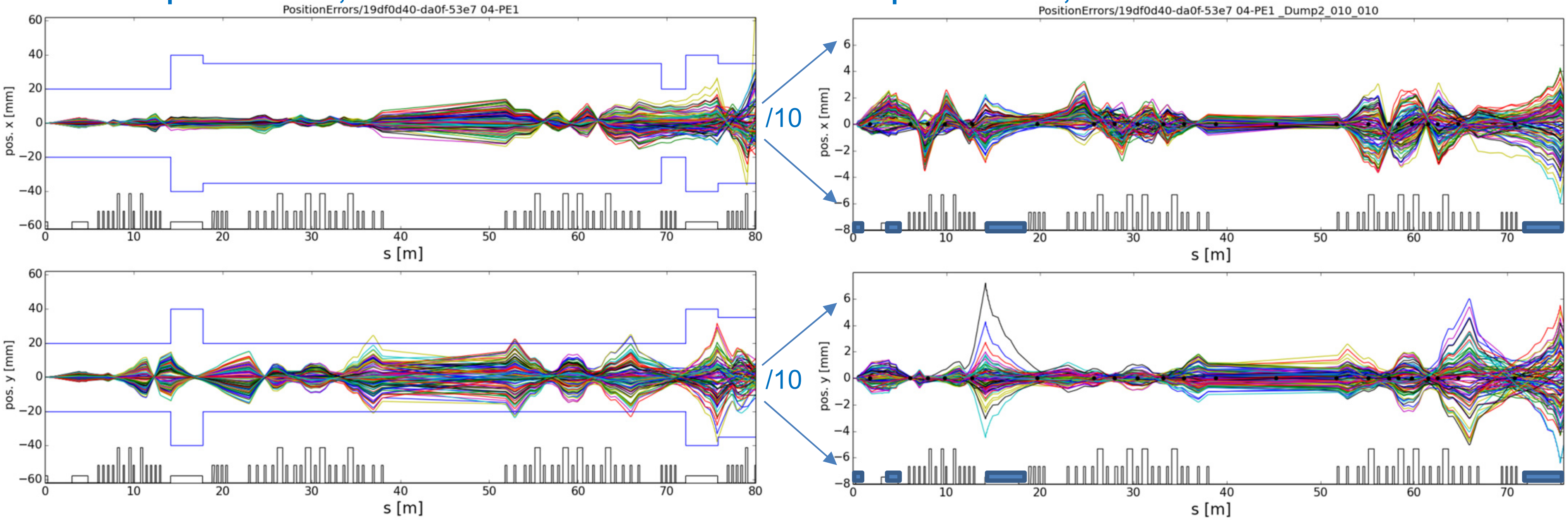
	BPM1	BPM2	BPM3	….					
Corrector1	0.8629	1.5651	0.4537	-1.7476	2.2012	-2.1345	2.1071	0.8860	1.4092
Corrector2	0.0000	1.4452	0.7301	-0.8262	1.0124	-0.9354	0.8893	0.4817	1.0546
Corrector3	0.0000	-0.0000	0.9761	3.2779	-4.2313	4.2614	-4.2243	-1.6063	-2.1754
…	0.0000	0.0000	0.3778	2.3972	-3.0749	3.0701	-3.0506	-1.1681	-1.5871
	0.0000	0.0000	0.0000	0.0000	0.2953	-0.4803	0.5535	-0.0882	-0.9523
	0.0000	-0.0000	-0.0000	-0.0000	1.1063	-1.2399	1.2813	0.2848	-0.1785
	-0.0000	-0.0000	-0.0000	-0.0000	0.0000	0.5033	-0.6310	0.2704	1.7895
	0.0000	-0.0000	-0.0000	-0.0000	0.0000	-0.0000	2.3320	-1.4417	-8.4465
	0.0000	0.0000	-0.0000	-0.0000	0.0000	-0.0000	0.1439	2.5060	10.2227
Corrector n-1	-0.0000	-0.0000	-0.0000	-0.0000	0.0000	-0.0000	0.0000	0.0000	2.5180
Corrector n	-0.0000	0.0000	0.0000	0.0000	-0.0000	0.0000	-0.0000	-0.0000	0.0379

Sij: trajectory change at BPM[j] due to kick of corrector [i]

*Y. Chung, G. Decker, K. Evans, Jr., "Closed Orbit Correction Using Singular Value Decomposition of the Response Matrix", in Proc. PAC'93, p. 2263

100 randomized error simulations: top – horizontal, bottom - vertical

SVD correction: 10 H-, V- singular values top – horizontal, bottom - vertical



After a single correction:

- Secure beam transport ✓
- rms x,y < 1.7 mm in all SRF modules
  - Booster, acc. linac passage ✓
  - decelerating linac passage to be improved
  - amplification due to RF focusing
- Preservation of beam parameters: few percent
  - will improve with better correction ✓

rms of beam parameters 100 corr. trajectories

Parameter	Unit	rms value 100 runs @ 45m
Trajectory-x, y	mm	0.2, 0.5
Beam size	%	1.7, 4.4
Bunch length	%	4.6
Emittance x, y	%	6.2, 5.7

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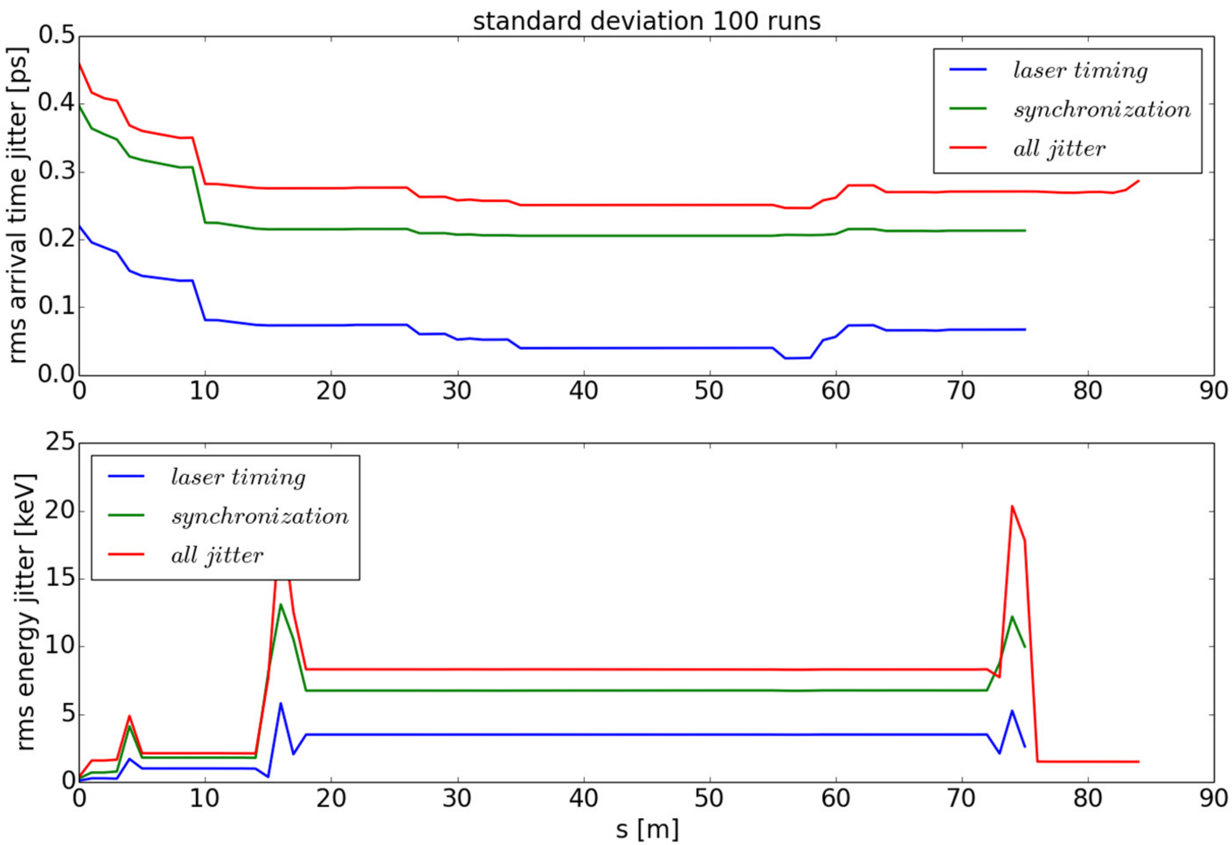
100 RANDOMIZED JITTER SIMULATIONS, 3 SCENARIOS

- (red) Laser timing, synchronization, laser pulse length 0.5 ps rms and gun field amplitude 5e-4 rel.
- (green) Synchronization: uncorrelated jitter of all RF phases and laser timing 0.25° rms
- (blue) Laser timing jitter: 0.3 ps rms



Arrival time jitter:

- Compression of jitter in parallel with bunch compression
- Dominant contribution of synchronization errors (64%)
- 270 fs rms jitter before re-entry of linac well within LLRF-system acceptance ✓

Energy jitter:

- 2e-4 @ linac ✓
- 2.2e-4 @ dump - much smaller than energy spread ✓

rms beam parameters for 100 random jitter simulations

Parameter	Unit	rms value of 100 runs	
		@ dump	@ pot. experiment
Trajectory-x, y	mm	0.01, 0.0	0.01, 0.0
Bunch length	%	2.2	2.2
Beam size-x,y	%	3.4, 2.7	2.1, 1.9
Energy	%	0.022	0.017
Energy spread	%	6.2	3.7
Emittance x, y	%	6.0, 4.6	5.5, 5.7

Bunch properties:

- All bunch parameter variations in the few percent region, within measurement accuracy
- No indication of increased losses in dump line

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bERLinPro start-to-end simulation:

- Use of second, independent code extremely valuable

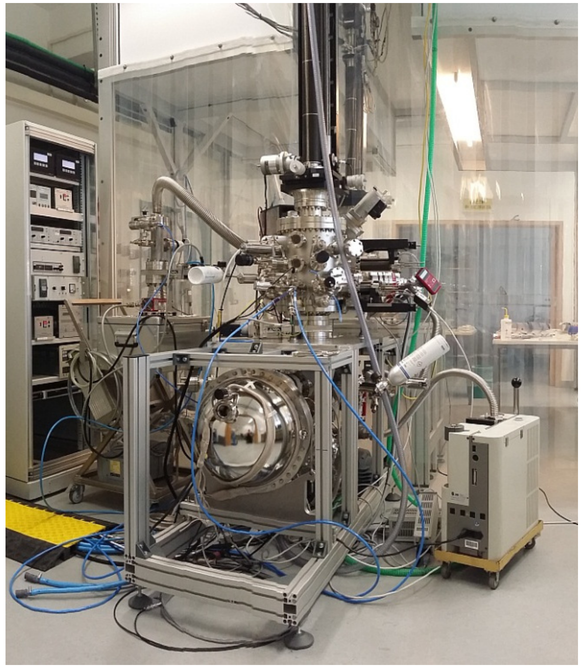
- OPAL-3D - overcomes many obstacles that limited OPAL-T performance
  - not yet released, results shown still preliminary
  - extremely promising tool for start-to-end simulations
  - parallel capabilities for statistical investigations

- Trajectory compensation using standard SVD works
  - Almost satisfying results with single correction
  - Adaptation to ERLs: SVD on sequential subsets of correctors/BPMs

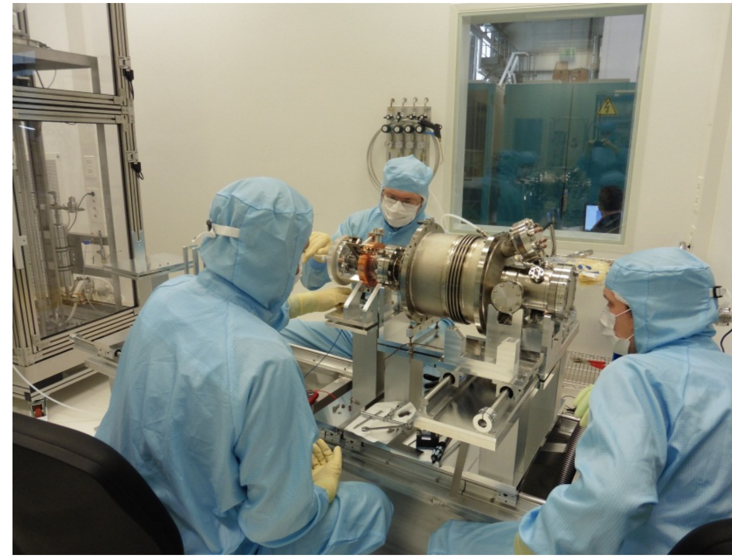
- Jitter simulations did not reveal limiting impact of fixed tolerances

STEPS TOWARDS 'FIRST ELECTRONS' IN bERLinPro

Set up of SRF infra structure vertical test stand, HPR, clean room



First 'home-grown' Cs-K-Sb cathodes QE ~5 %



First and successful clean room assembly at HZB: cold string for Gun1

Time table:

- First electrons in GunLab 2016-09
- Building ready for installation 2016-12
- Machine installation of low energy part 2017
- First electrons in bERLinPro 2018

bERLinPro CONSTRUCTION SITE MAY, 2ND, 2016

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Thank you for your attention