4th ARD ST3 Workshop – Matter and Technology

Status and Applications of Superconducting Radio-Frequency (SRF) Photoinjectors

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15.7.2016

OUTLINE

1) SRF Photoinjector

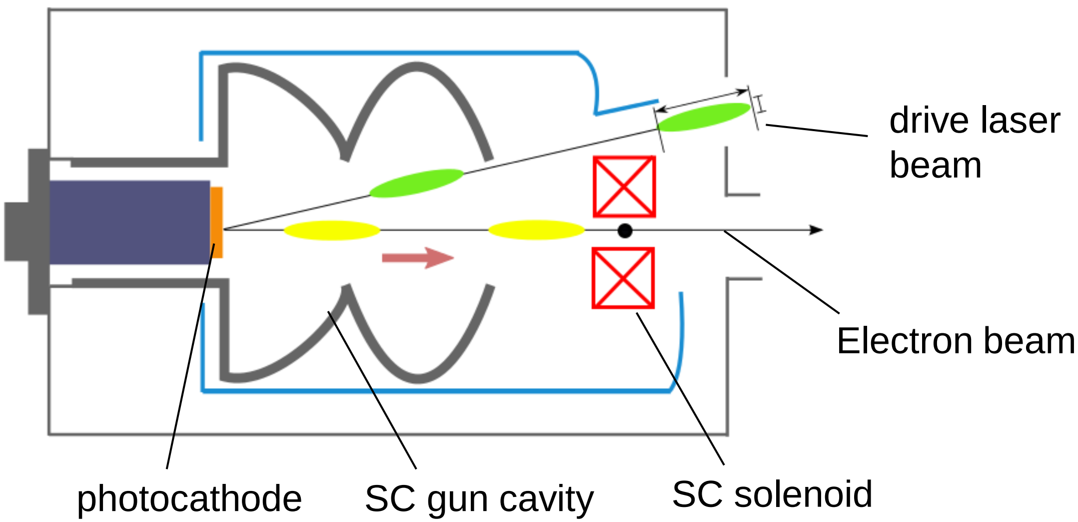
2) Energy Recovery Linac (ERL) application - bERLinPro

3) Summary and outlook of ERL application

4) Ultrafast Electron Diffraction (UED) application

5) Summary and outlook of UED application

SRF Photoinjectors



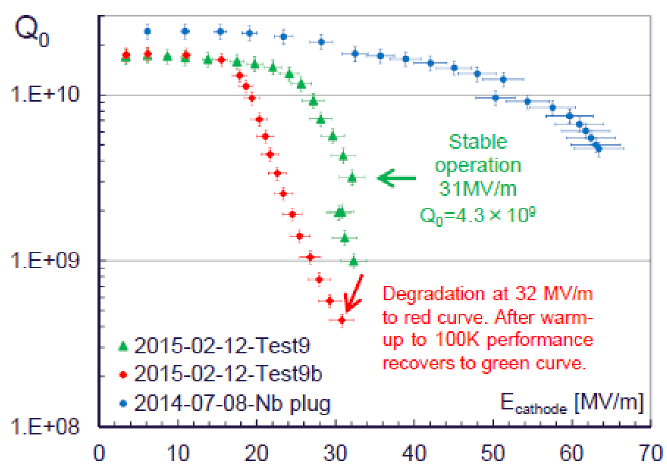
Features of SC cavities

- Potential for high cathode gradient (several tens of MV/m)
- cw operation at 100% duty cycle possible
- relatively young technology
  → more experimental setups

- control of multipacting and dark current from field emission
- implications due to high QE cathode/ SRF cavity interface
  → impact on cavity performance

Courtesy D. Kostin

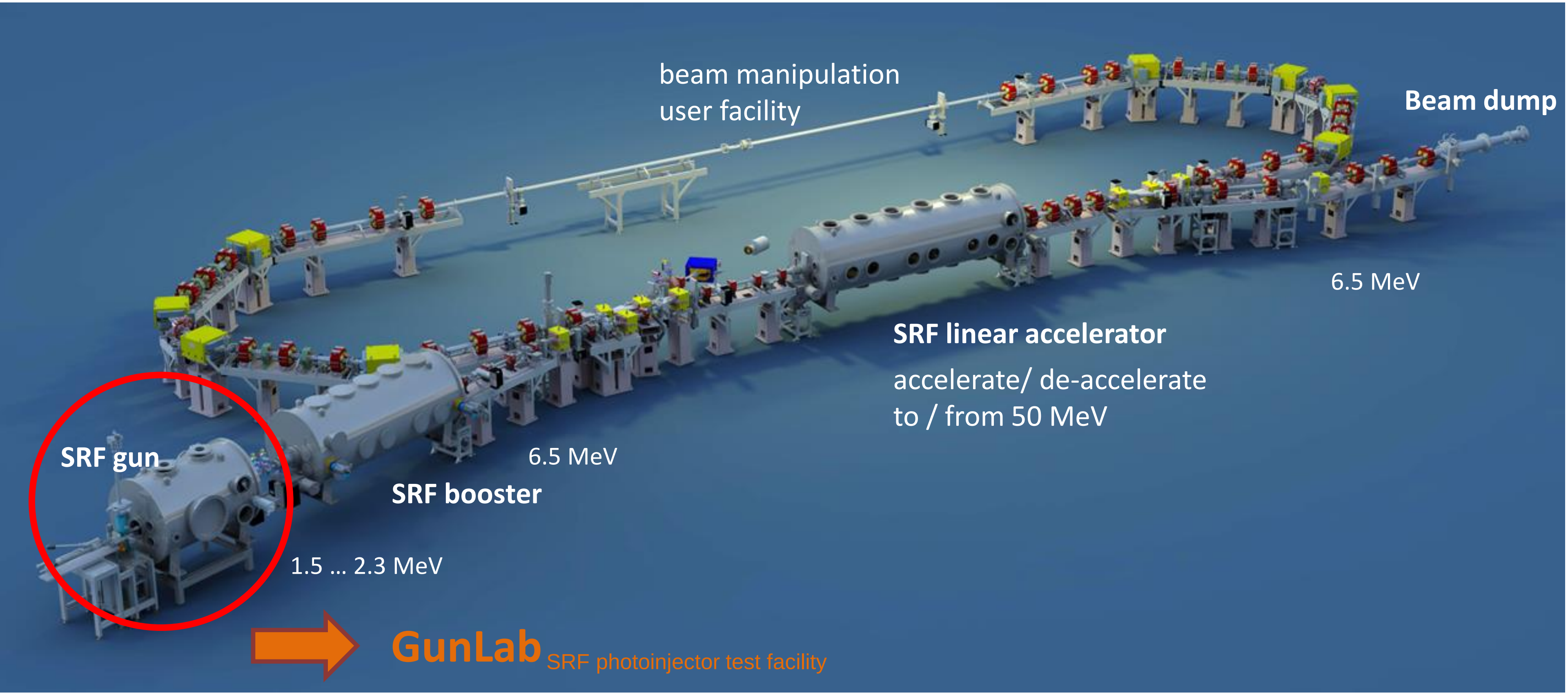
D. Kostin, et al., presented at SRF 2015



Application of SRF photoinjectors

ERL	UED
ps regime	fs regime

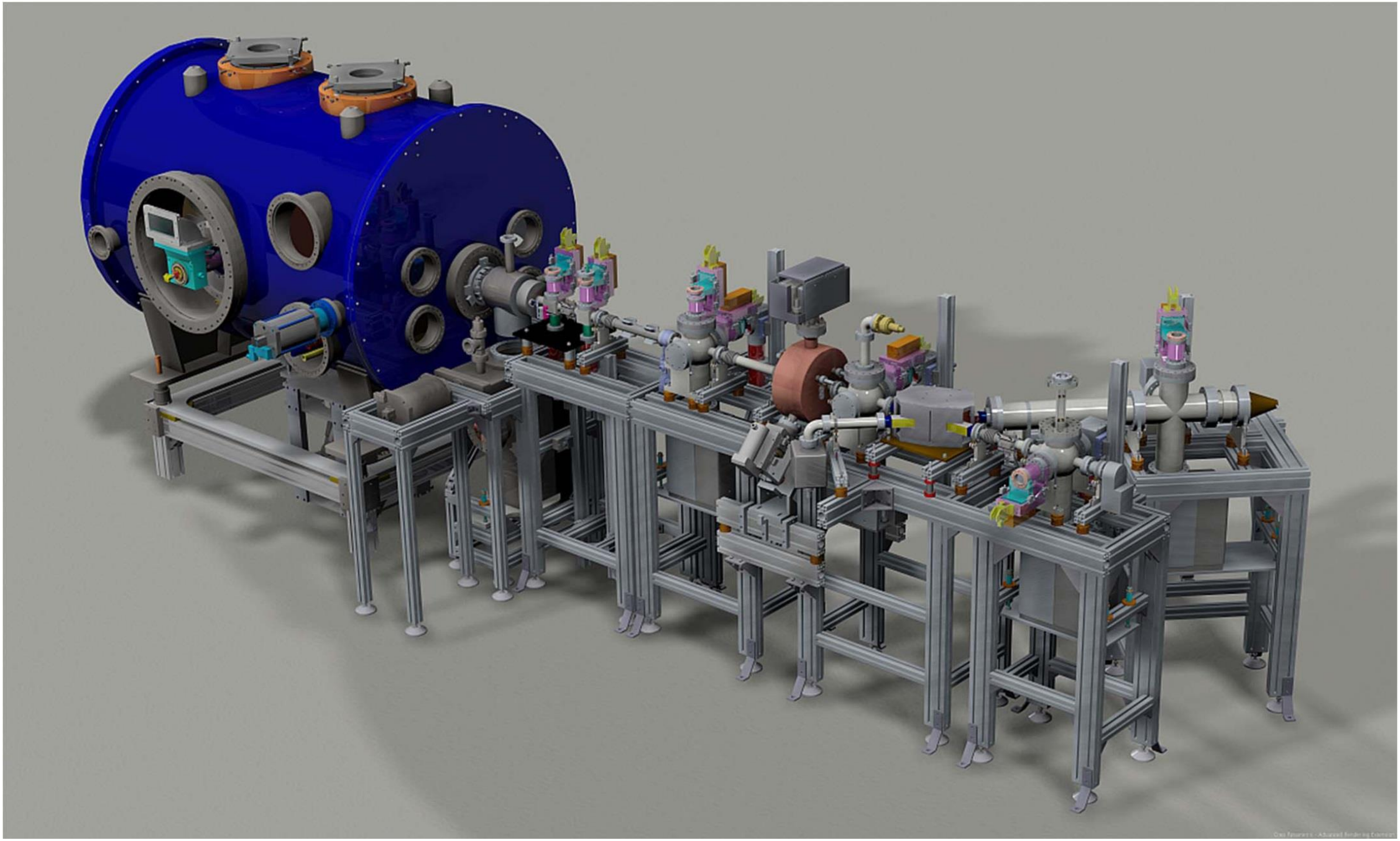
bERLinPro = Berlin Energy Recovery Linac Project



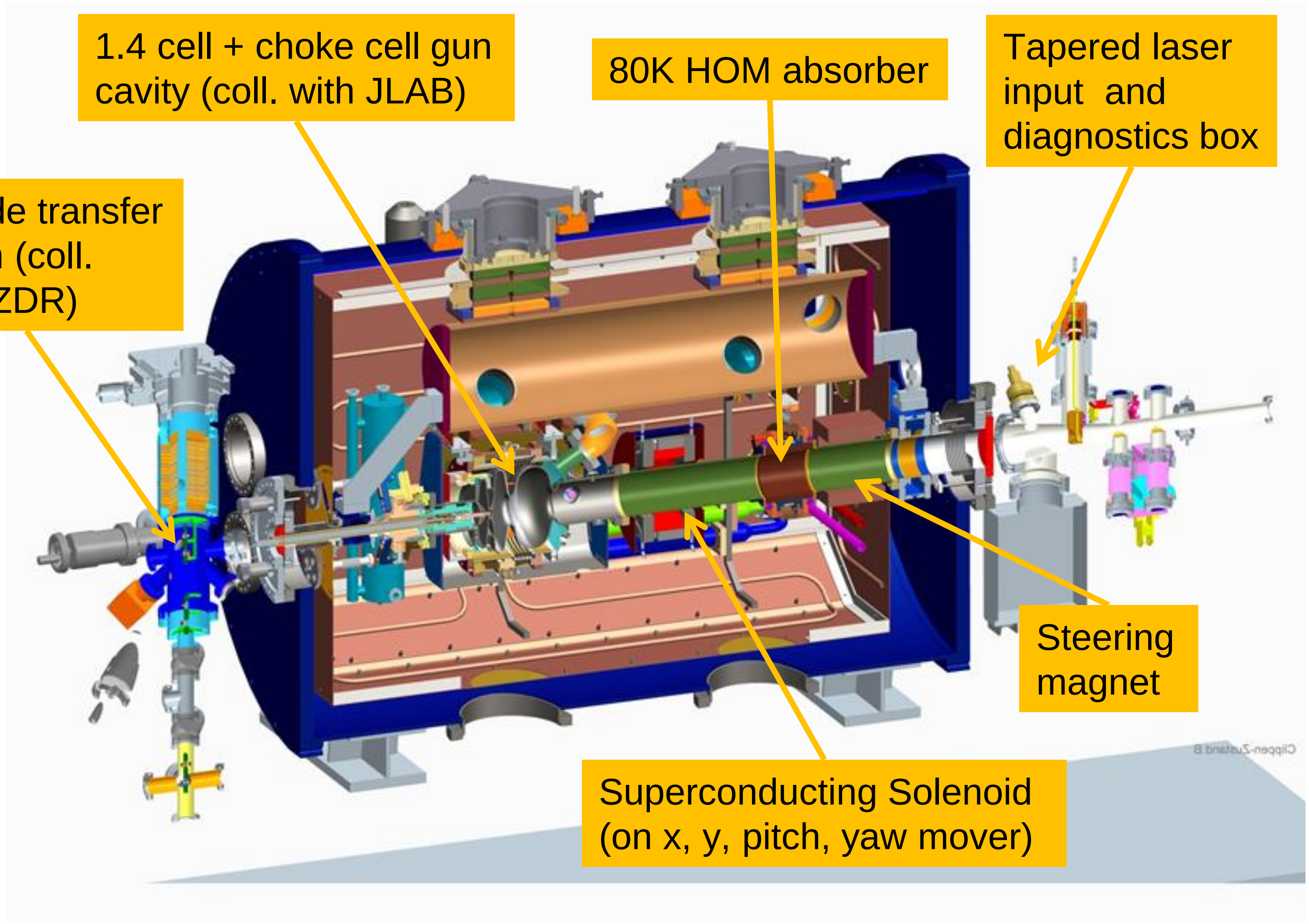
- Goal: Build and operate a 100 mA, low emittance technology demonstrater
- Target parameters flexible but geared towards light source application

Max. beam energy	**50 MeV**
Max. average current	**100 mA (77pC at 1.3 GHz)**
Normalized emittance	**< 1mm mrad**
Bunch length	**< 2 ps**

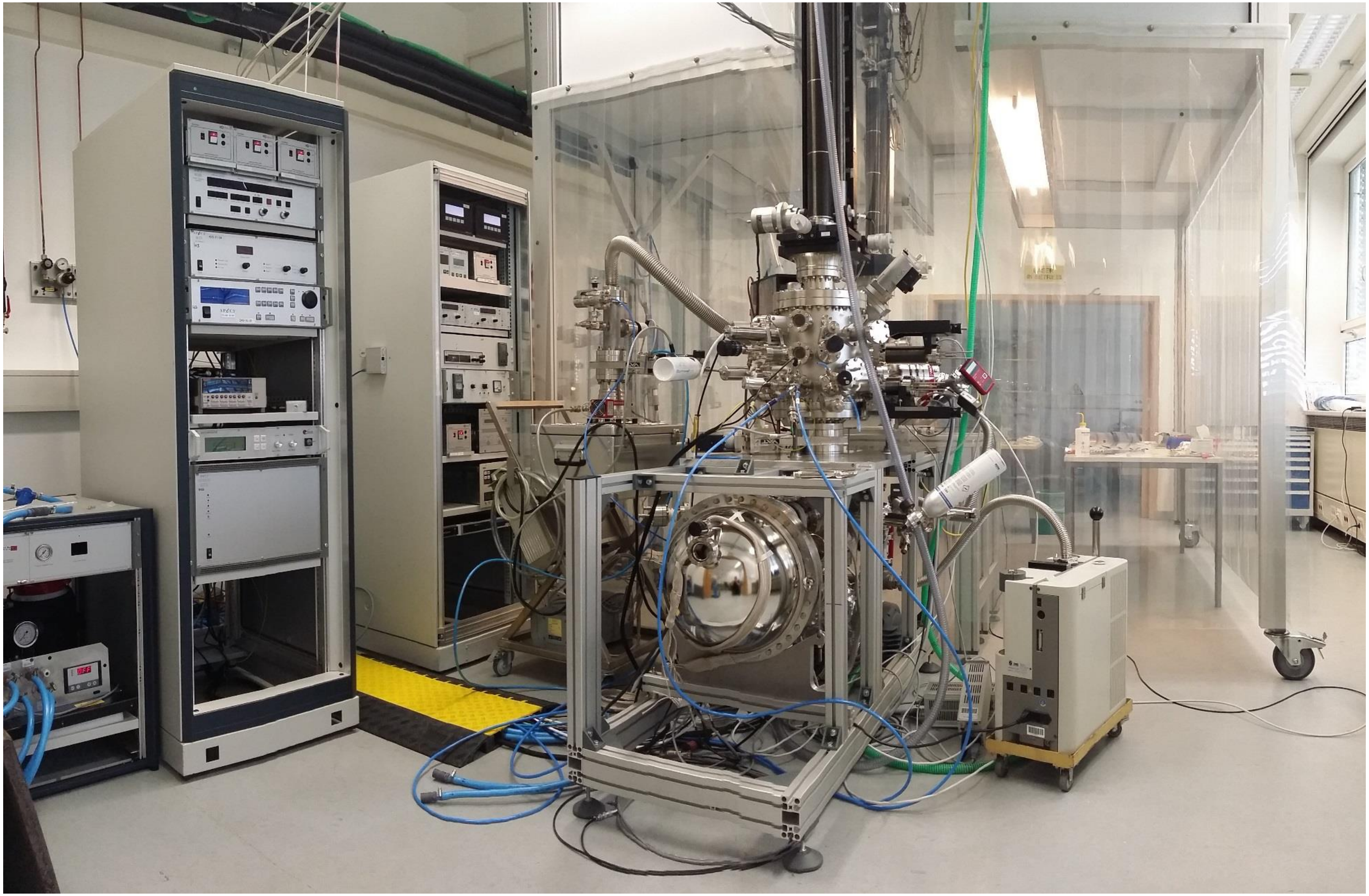
GUNLAB – SRF PHOTOINJECTOR TEST FACILITY FOR BERLINPRO



GUNLAB – SRF PHOTOINJECTOR TEST FACILITY FOR BERLINPRO

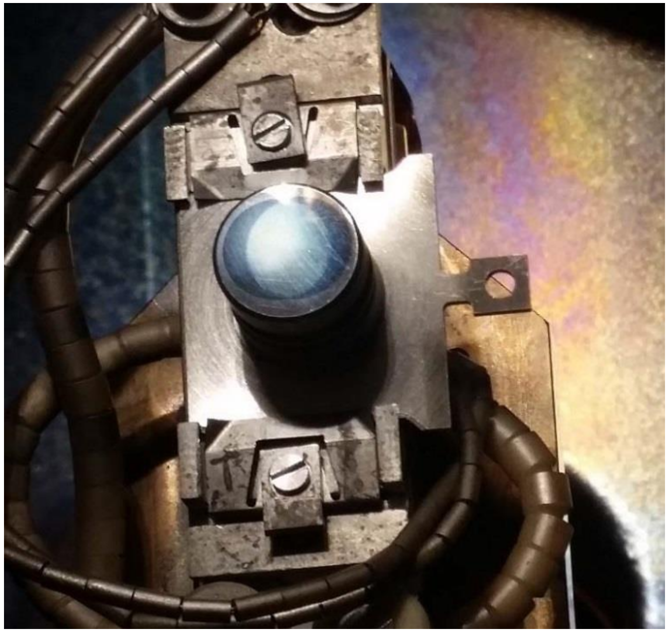


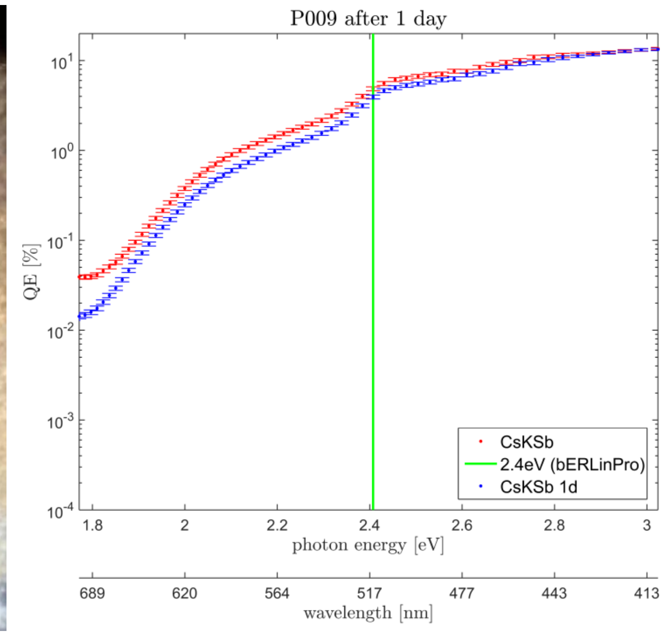
PHOTOCATHODE R&D FOR BERLINPRO



Courtesy J. Kühn, M. A. H. Schmeißer, H. Kirschner, T. Kamps

PHOTOCATHODE R&D FOR BERLINPRO

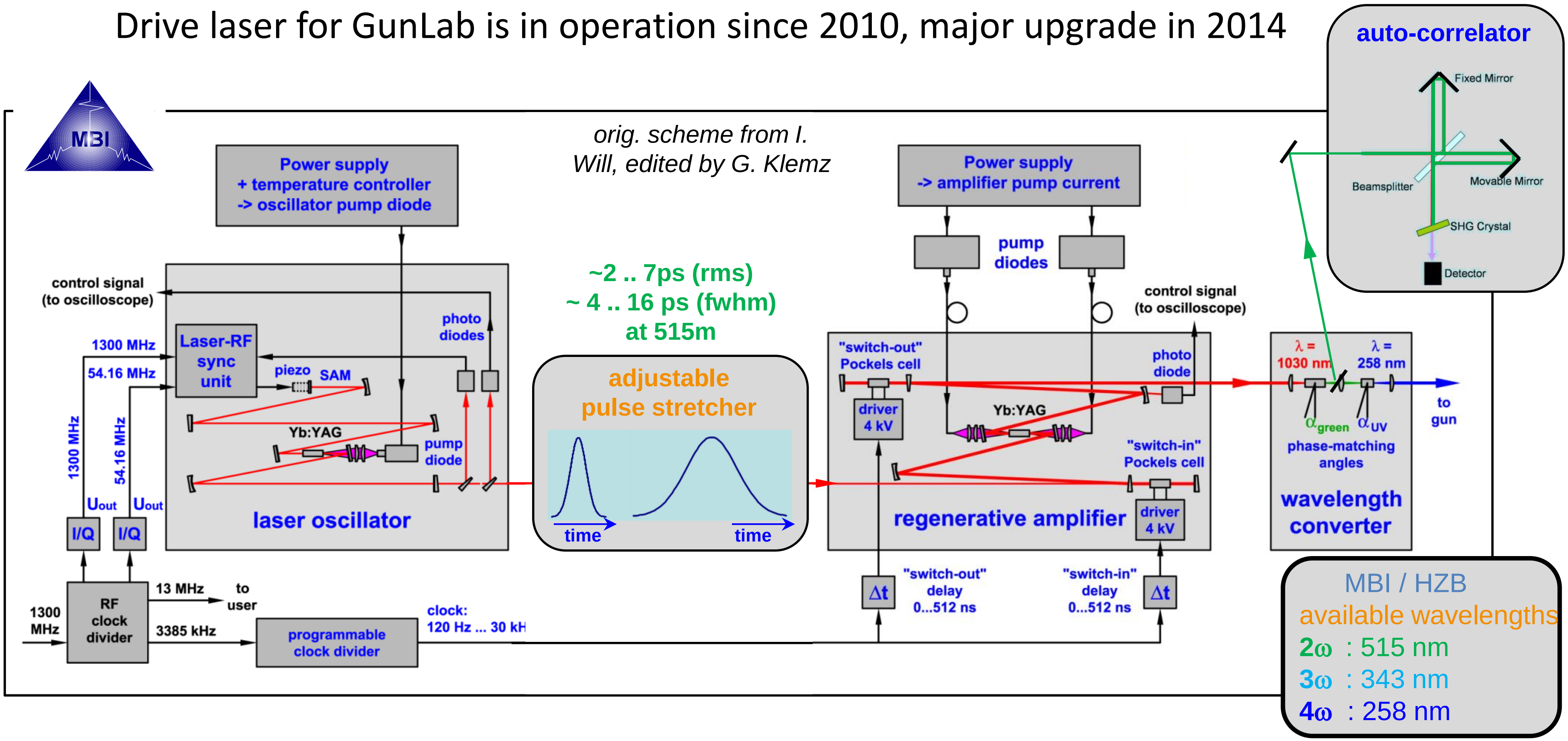




- Started cathode R&D in 2010
- Initial work on SC Pb photocathode for Gun 0
  (QE treatment (laser cleaning), surface roughness, material science methods)
- In parallel design, construction and setup of a preparation and analysis chamber (XPS, momentatron, mass spectrometer, spectral response)
- System now in operation
  → Producing CsK_2Sb photocathodes with QE > 5% at 532 nm
  (within bERLinPro specs)

DRIVE LASER

Drive laser for GunLab is in operation since 2010, major upgrade in 2014



- Development of drive laser for bERLinPro on-going
- Goals: Output power: 50 W at 515 nm (→ 100W at IR), Pulse length: 3…12 ps rms,
  Rep rate 1.3 GHz
- Various operation modes for commissioning and reaching 100 mA

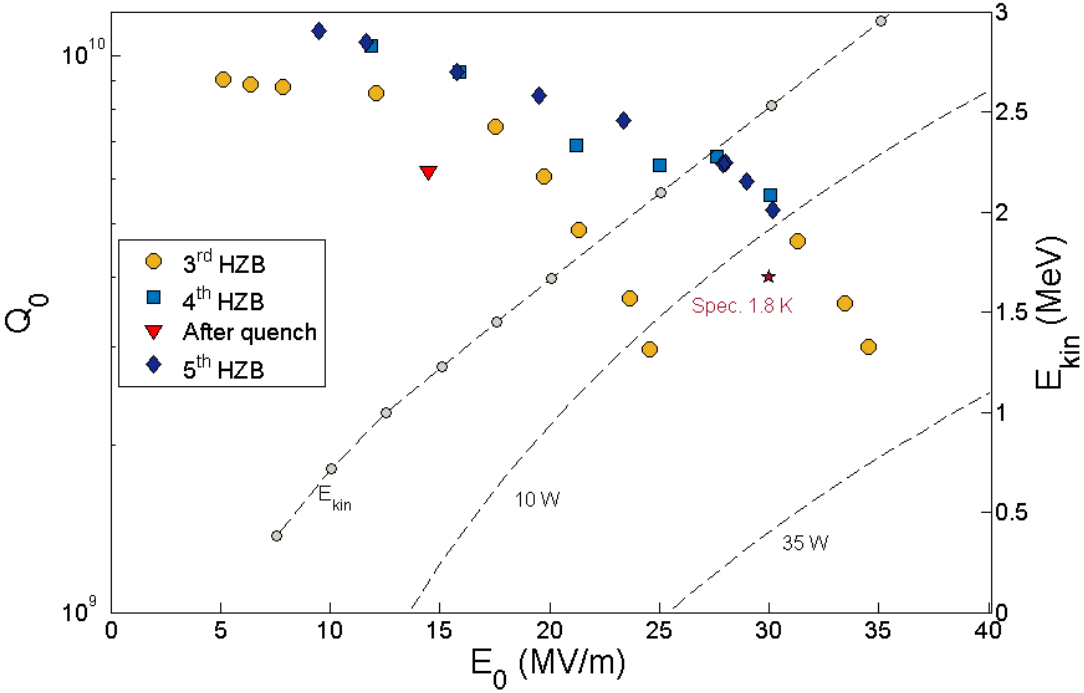
SC CAVITY APPROACH

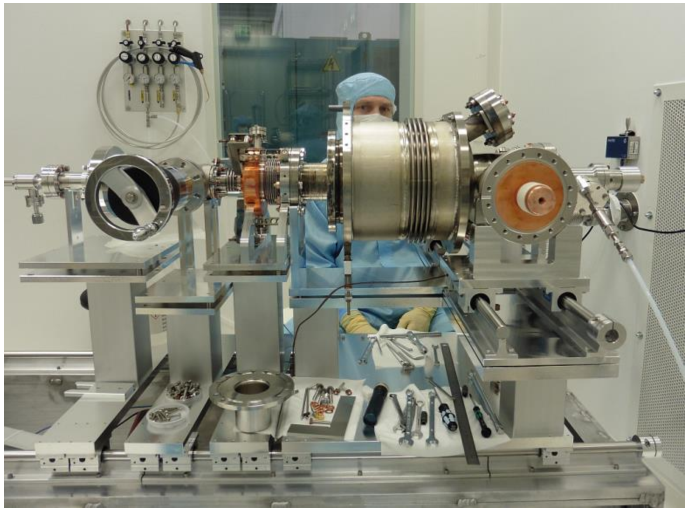
Gun System No.	Cavity	Cathode	Interface	Achievements / Goals
Gun0 2010 - 2013	0.1: 1.6cell with standard TESLA geometry	Pb 10^{-4} at UV	Pb film coated on backwall by plasmonic arc deposition	First beam, Emittance studies, Cathode QE studies and manipulation with laser cleaning
	0.2: 1.6cell with standard TESLA geometry	Pb	Plug with Pb film fitted into hole of cavity backwall	Emittance studies, Beam energy of 2.5 MeV (27 MV/m)
Gun1	1.1: 1.4cell optimized for ERL class gun with CW coupler	CsK2Sb 10^{-2} at Green	Electrically and thermially insulated cathode insert	High brightness beam from high QE cathode up to 5 mA
	1.2: 1.4cell as 1.1	CsK2Sb	Cathode insert	
Gun2	2.1: 1.4cell optimized for ERL class gun with high power coupler	CsK2Sb or other multi-alkali	Cathode insert	High average current up to 100 mA
	2.n:	…	…	

Courtesy T. Kamps

SC CAVITY APPROACH

First results for gun cavity 1.1





complete cold string

E_o = 30 MV/m — 2.5 MeV,

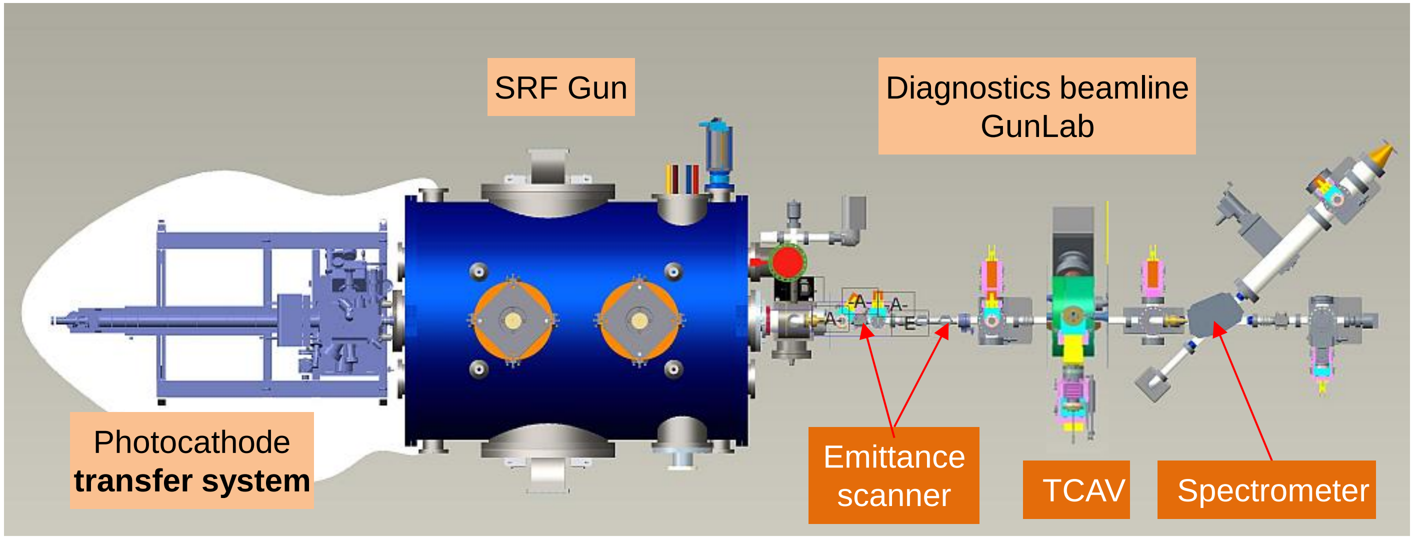
E_{peak} = 57.3 MV/m — Q_0=5.3·10^9@ 1.8k

B_{peak} = 110.4 mT — Satisfactory

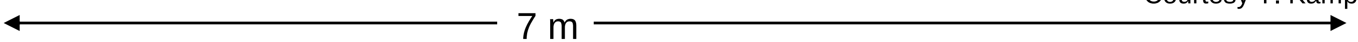
Courtesy A. Neumann

BEAM DIAGNOSTICS

In operation since 2010, with major upgrades ≤ 2016



Courtesy T. Kamps



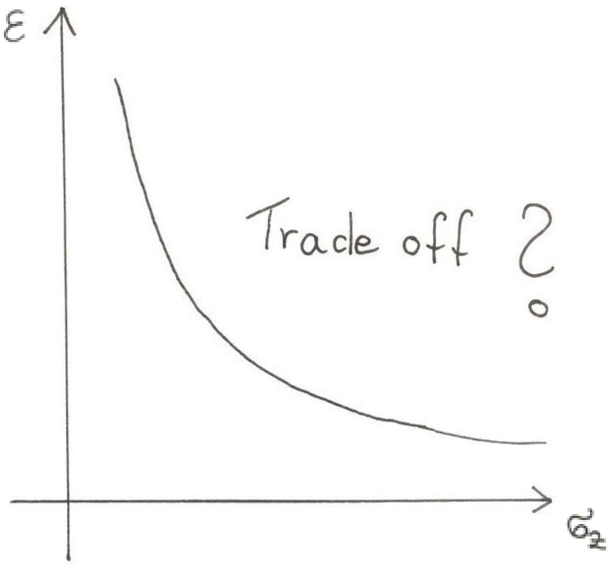
- Fast emittance scanner with cos(θ) coils and slit mask
- Spectrometer dipole for longitudinal phase mapping
- Transverse deflecting cavity (TCAV) to measure longitudinal phase space (σ_t , σ_E) and slice emittance (will be installed in 2107)
- Screens/Faraday Cup

can run with: → beam energy up to 3.5 MeV
→ pulse length ≤ 6 ps rms
→ bunch charge ≤ 200 pC at ≤ 10 kHz repetition rate

OPTIMIZATION OF SRF PHOTOINJECTOR

bERLinPro

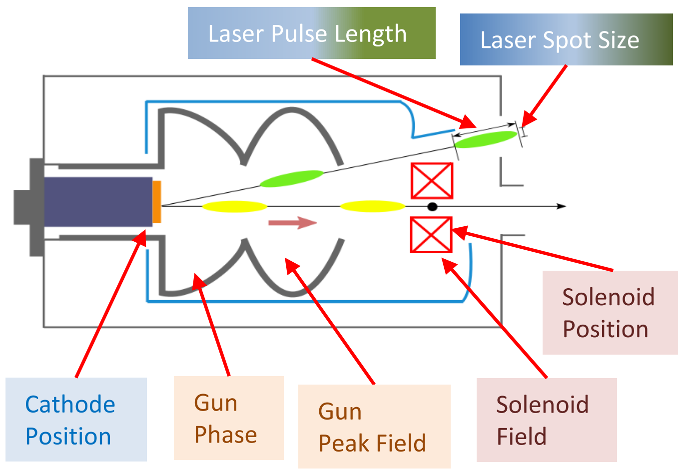
Parameter	Value
Beam energy	50 MeV
Beam current	**100 mA**
Bunch charge	77 pC
Bunch length	**< 2 ps**
Emittance	**< 1 mm mrad**

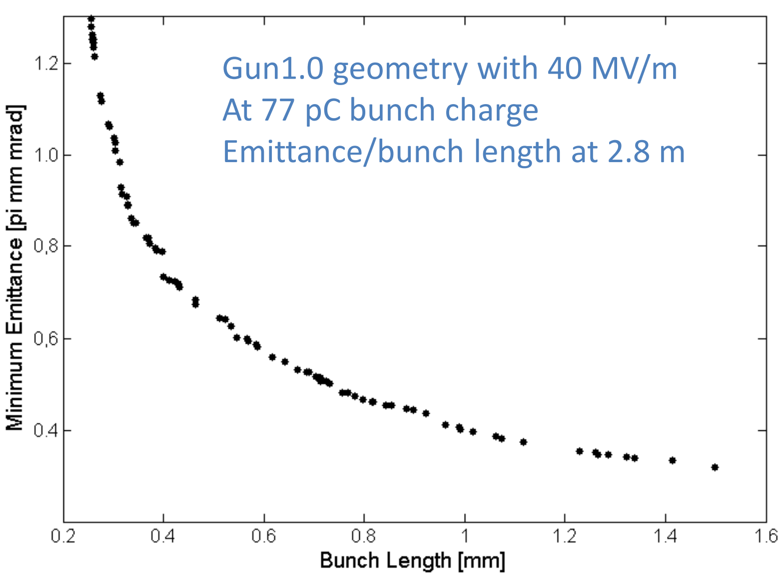


OPTIMIZATION OF SRF PHOTOINJECTOR

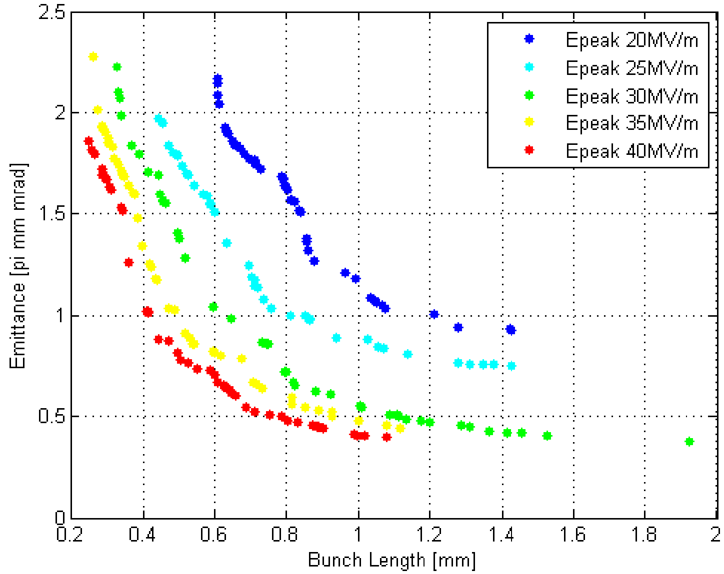
- Multi-objective optimization of SRF gun design and set parameters
- Minimize transv. emittance and bunch length at 77 pC bunch charge
- six free parameters at fixed gun gradient
- MATLAB programme with SPEA2 algorithm and interface to ASTRA for particle tracking

Next Step: Replace ASTRA with actual gun measurement

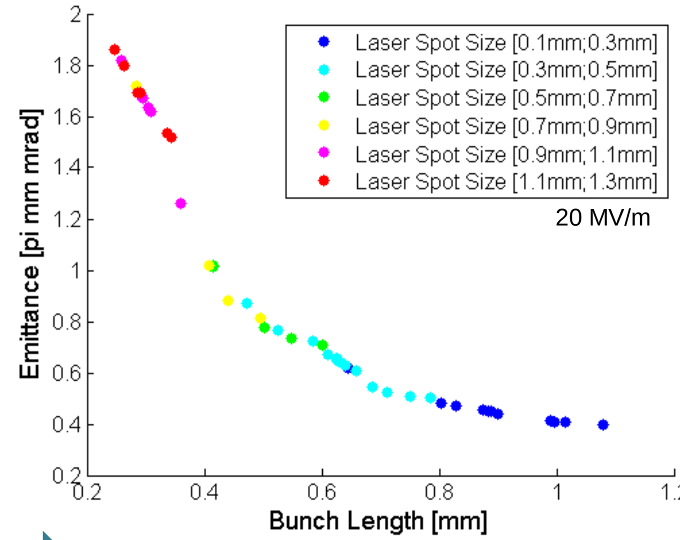




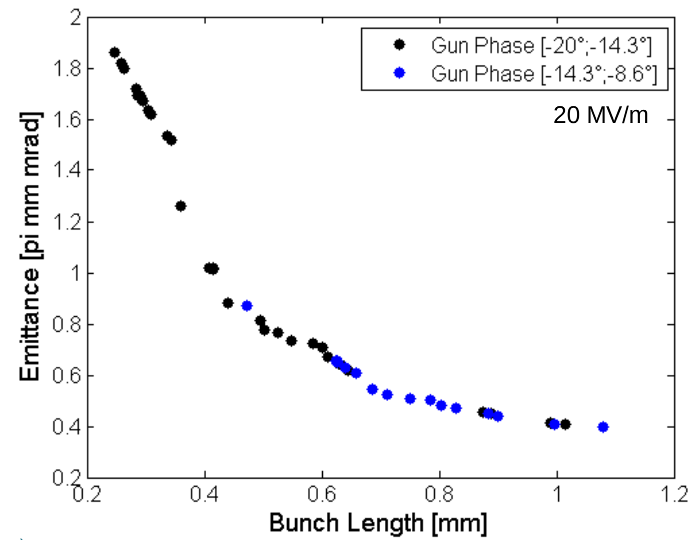
FIRST RESULTS WITH MULTI-OBJECTIVE OPTIMIZATION



The lower limit of the Pareto optimum is given by the maximum gradient reached in the gun cavity (→ gun design)



Laser spot size impacts intrinsic emittance



RF focusing at negative gun phases (relative to on crest phase)

SUMMARY – SRF GUN FOR ERL APPLICATION

- GunLab is a compact test facility for SRF Photoinjectors
- Gun 0 provided emittance studies and demonstrated an acceleration up to 2.5 MeV
- Gun 1 design fulfils the bERLinPro parameters
- Goal Gun 1: High brightness beam from high QE photocathode
- Goal Gun 2: High average current up to 100 mA

Next steps:

- Complete setup of Gun 1 will be finished November 2016
- First electron beam winter 2016
- Transverse deflecting cavity will be added to the diagnostic beamline in 2017
- Further multi-objective optimization, phase space studies for Gun 1
- First measurements to varify optimization results and adjust the optimization model

SRF GUN FOR ULTRAFAST ELECTRON DIFFRACTION (UED)

THE
PHYSICAL REVIEW

Second Series *December, 1927* *Vol. 30, No. 6*

DIFFRACTION OF ELECTRONS BY A CRYSTAL OF NICKEL

BY C. DAVISSON AND L. H. GERMER

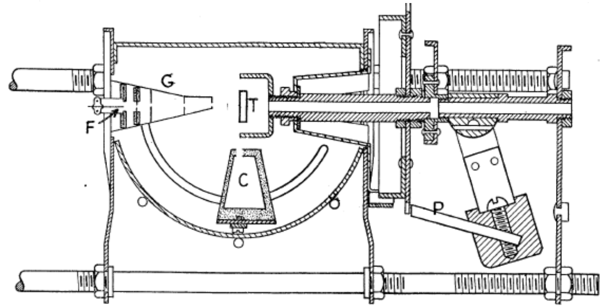
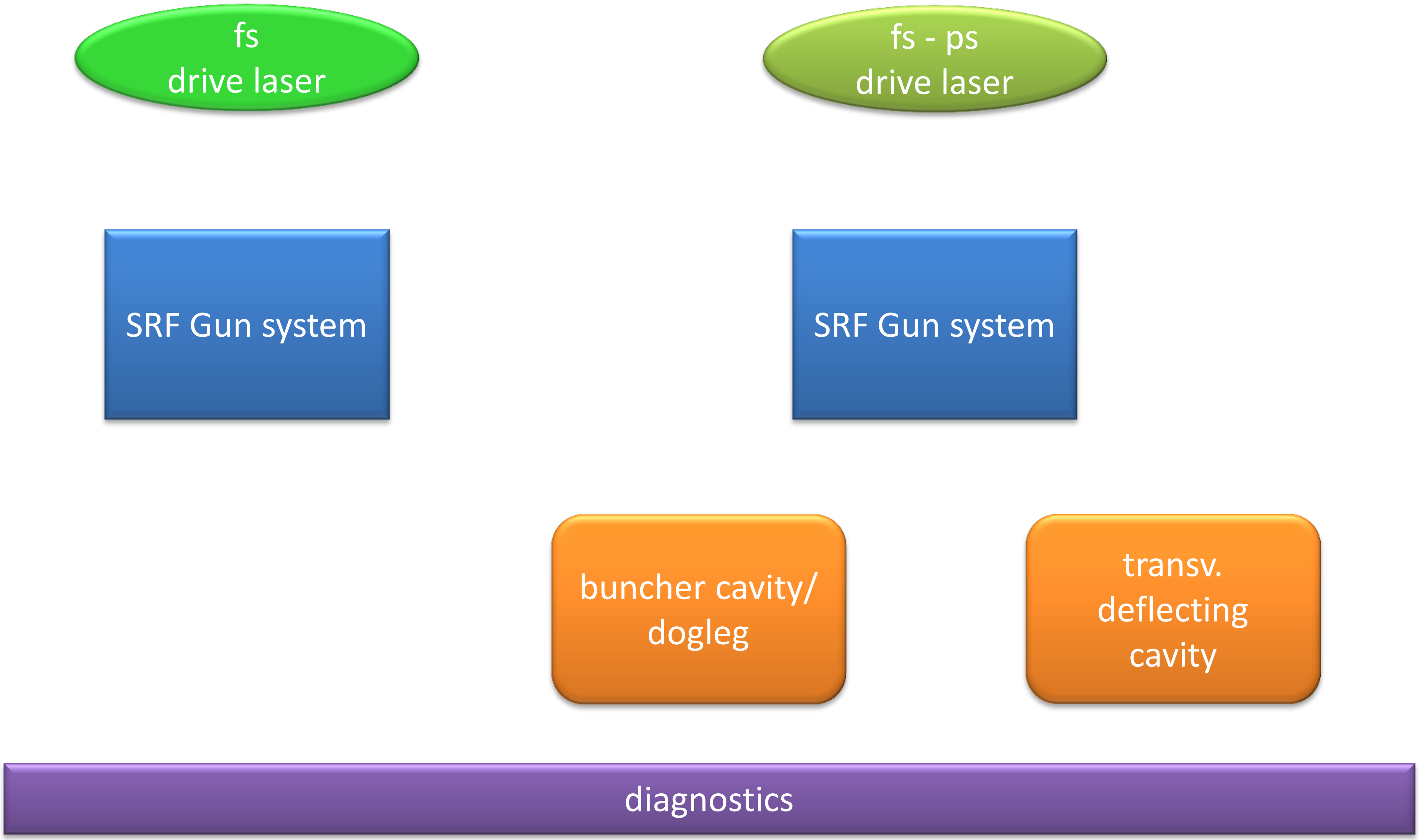


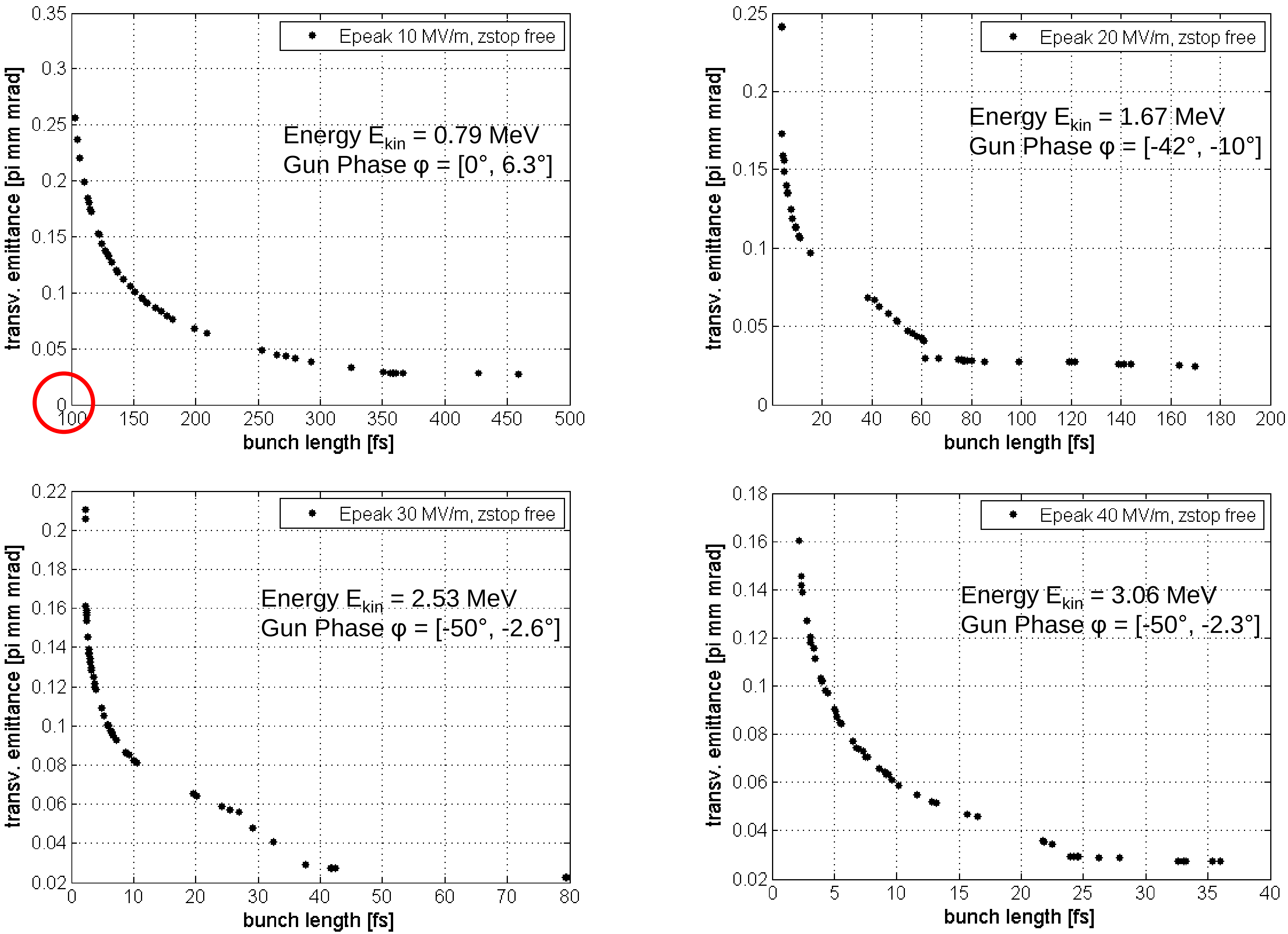
Fig. 2. Cross-sectional view of the experimental apparatus—glass bulb not shown.

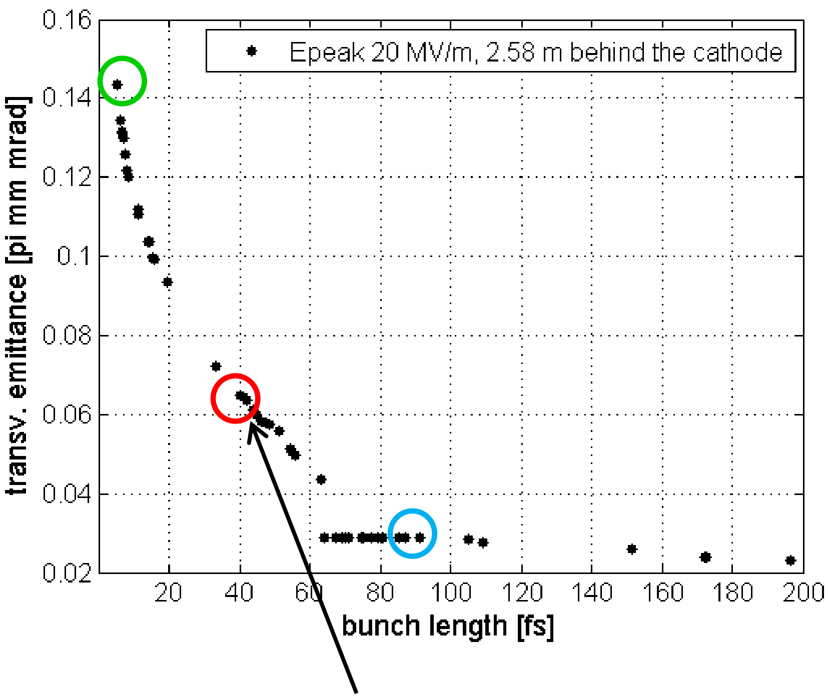
✓ Enable ultrafast science → time resolved structural dynamics ✓ Higher cross section for electrons compared to photons ($\sigma_T/\sigma_R \sim 10^5$) ✓ Electrons preferred choice for surfaces, thin films, gas phase ✓ Less damage in biological samples ✓ Polarized probe electrons possible	Challenging accelerator physics - Beam dynamics at low charge and short pulse length - Synchronization - Beam instrumentation - Close interaction between accelerator scientists and user, single user experiment

HOW TO GENERATE AN ELECTRON BEAM FOR UED



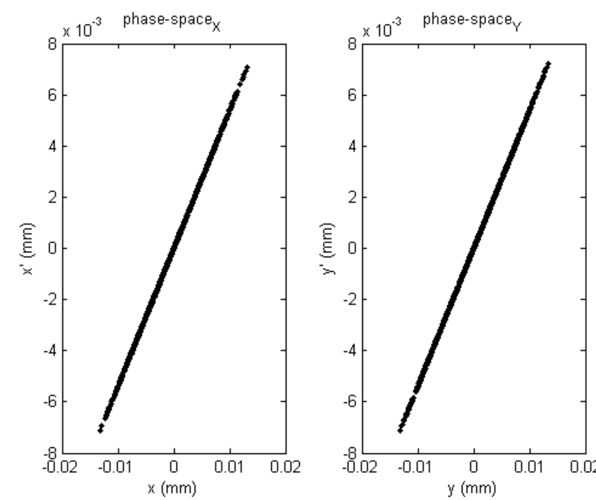
MULTI-OBJECTIVE OPTIMIZATION FOR ULTRAFAST ELECTRON DIFFRACTION





position behind cathode	2.58 m
peak field	20 MV/m
beam energy	1.66 MeV
transv. emittance	< 0.2 µm
beam energy	1.66 MeV
shortest bunch length (transv. emittance)	**5.38 fs** (0.143 mm mrad)
smallest transv. emittance (bunch length)	**0.03 mm mrad** (91.45 fs)
shortest bunch length transv. emittance	42 fs 0.06 mm mrad

laser spot size	0,12 mm
laser pulse length	75,59 fs
cathode position	0 mm
gun phase (rel. to crest)	-41,35 °
gun peak field	20 MV/m
solenoid position	0,55 m
solenoid field	0,01 T



Bunch compression by a factor of 2

SUMMARY – SRF GUN FOR UED APPLICATION

- Different setup possibilities for UED with SRF photoinjector

  fs drive laser + SRF gun system + manipulator should be a good choice

- Promising results for fs laser and current SRF gun design

  [bunch length < 50 fs]

- Cooperation with Max Born Institute (Berlin) on user experiment is planned

  ⇒ **RED project** (relativistic electron diffraction)

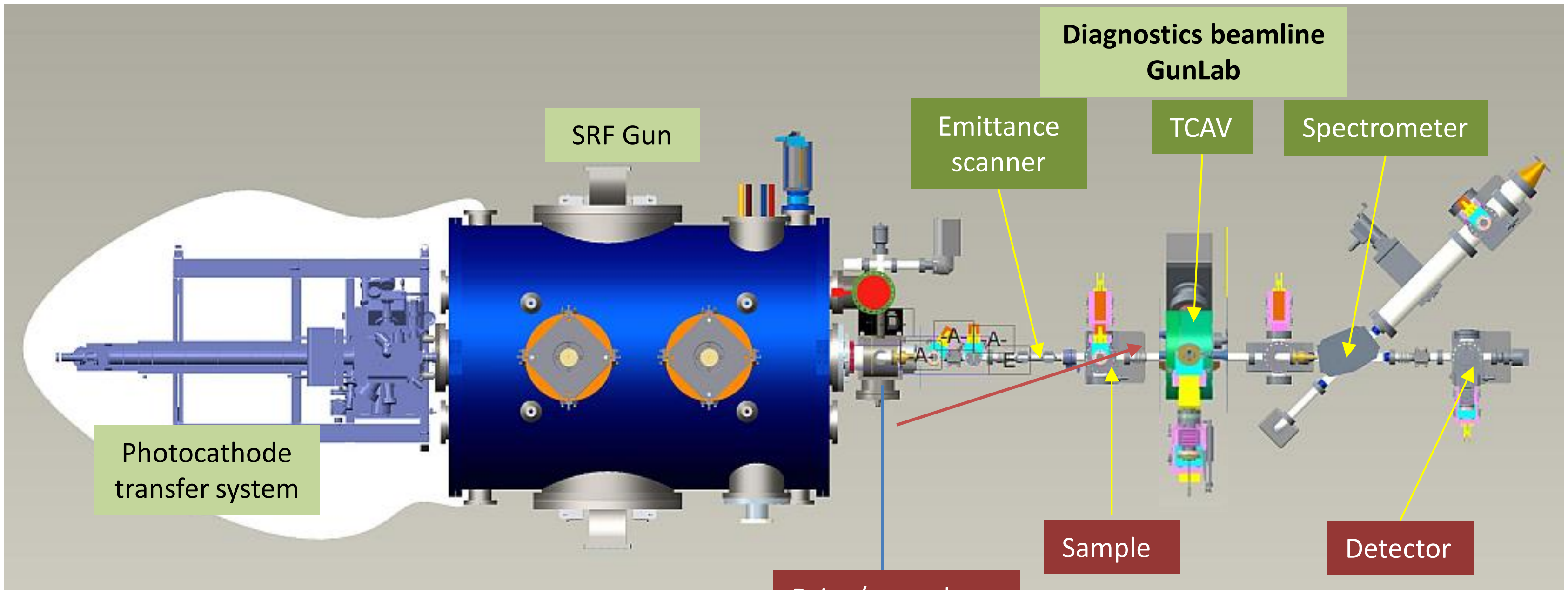
OUTLOOK – SRF GUN FOR UED APPLICATION

Next steps:

- Bunch compression studies for fs electron pulses:
  - ⇨ Multi-objective optimization for UED application using a manipulator (buncher cavity, dogleg)
  - ⇨ Beam dynamics studies for continuous time-resolved UED using the transverse deflecting cavity in the diagnostics beamline
- Find suitable diagnostic tools for (slice) emittance, beam size and bunch length measurements
- First test measurements with the transverse deflecting cavity
  → Add sample chamber and detector to the GunLab beamline

OUTLOOK – SRF GUN FOR UED APPLICATION

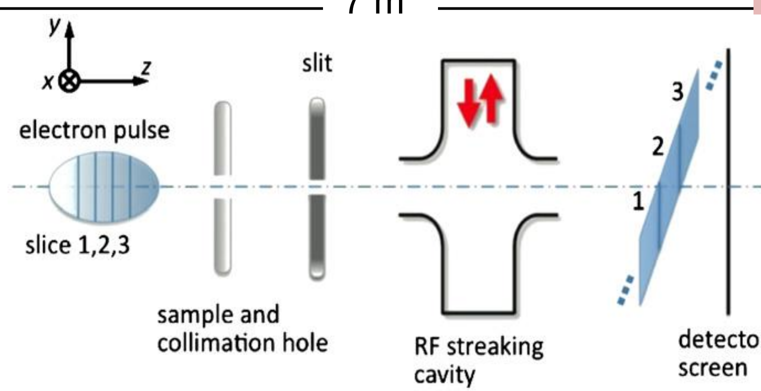
First test measurements with the transverse deflecting cavity
→ Add sample chamber and detector to the GunLab beamline



Courtesy T. Kamps

RED test project

7 m



http://www.sciencedirect.com/science/article/pii/S016890021000210X

MANY THANKS to

The bERLinPro project team:

M. Abo-Bakr, W. Anders, A. Büchel, K. Bürkmann-Gehrlein, V. Dürr, A. Frahm, S. Heling, A. Jankowiak, H. W. Glock, T. Kamps, G. Klemz, J. Knobloch, J. Kolbe, G. Kourkafas, J. Kühn, O. Kugeler, B. Kuske, P. Kuske, A. Matveenko, A. Meseck, G. Meyer, R. Müller, A. Neumann, N. Ohm, S. Rotterdam, J. Rudolph, F. Pfloksch, M. Schmeisser, K. Ott, J. Rahn, J. Völker

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T. Kamps, G. Klemz , G. Kourkafas, J. Kühn, M.A.H. Schmeißer, J. Völker

Thank you for your attention!