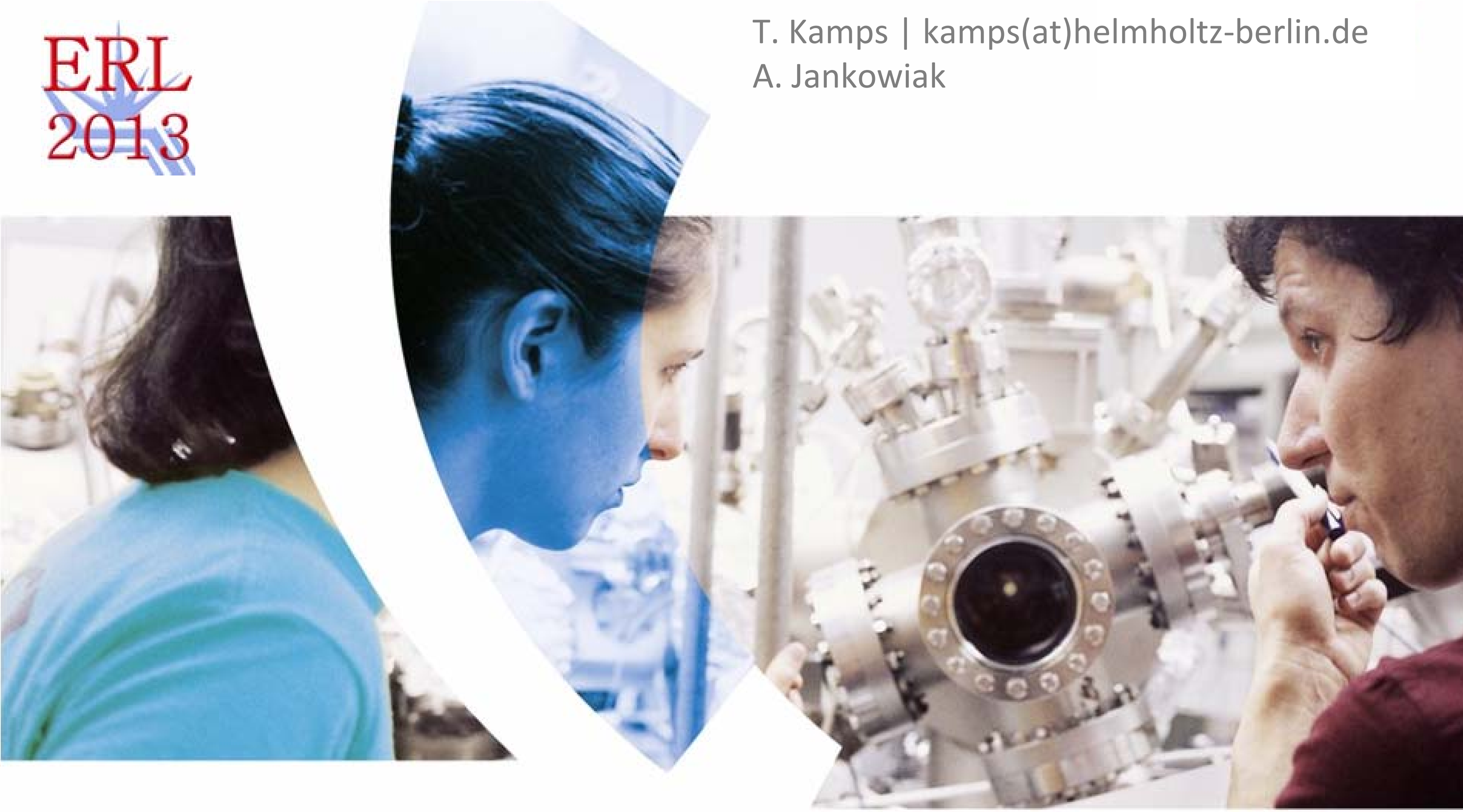
Status and Perspectives of SRF Gun Development for B*ERL*inPro

T. Kamps | kamps(at)helmholtz-berlin.de
A. Jankowiak

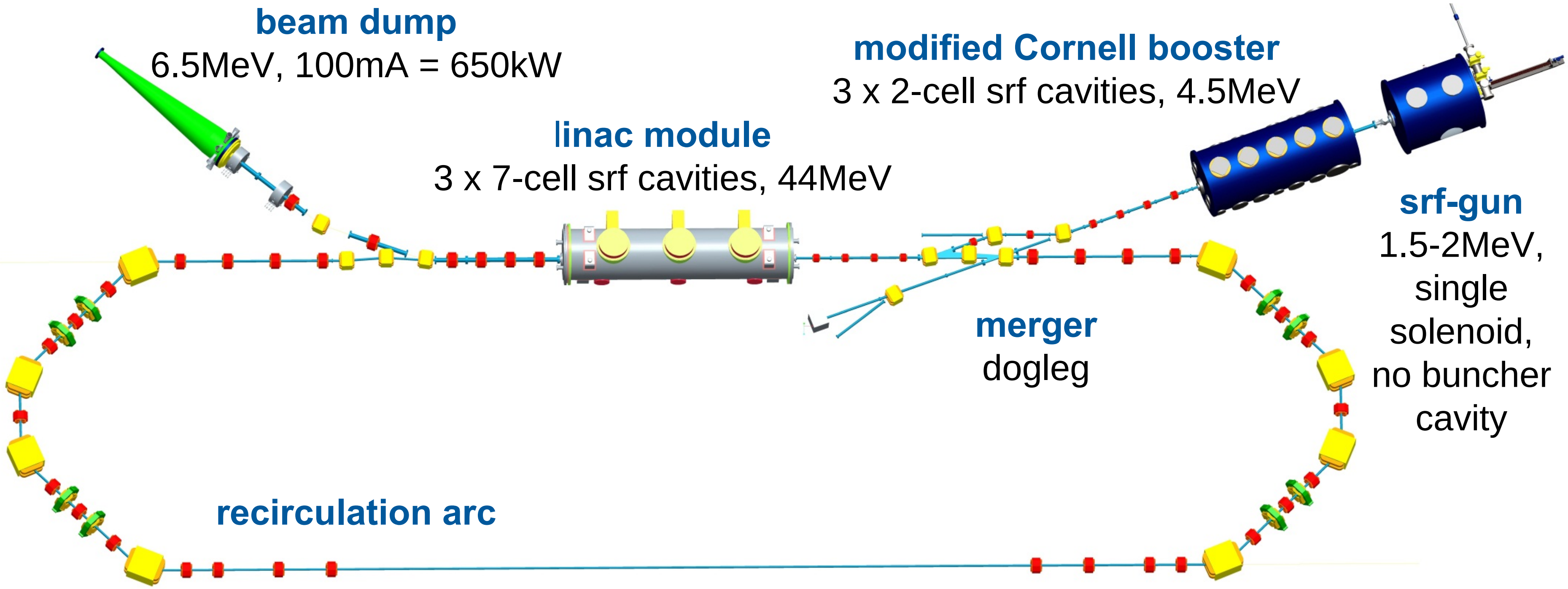


ERL 2013 Workshop | 09. – 13.09.2013 | BINP| Novosibirsk | Russia

B*ERL*inPro @ Helmholtz-Zentrum Berlin

B*ERL*inPro = Berlin Energy Recovery Linac Project

100mA / low emittance technology demonstrator (covering key aspects of large scale ERL)

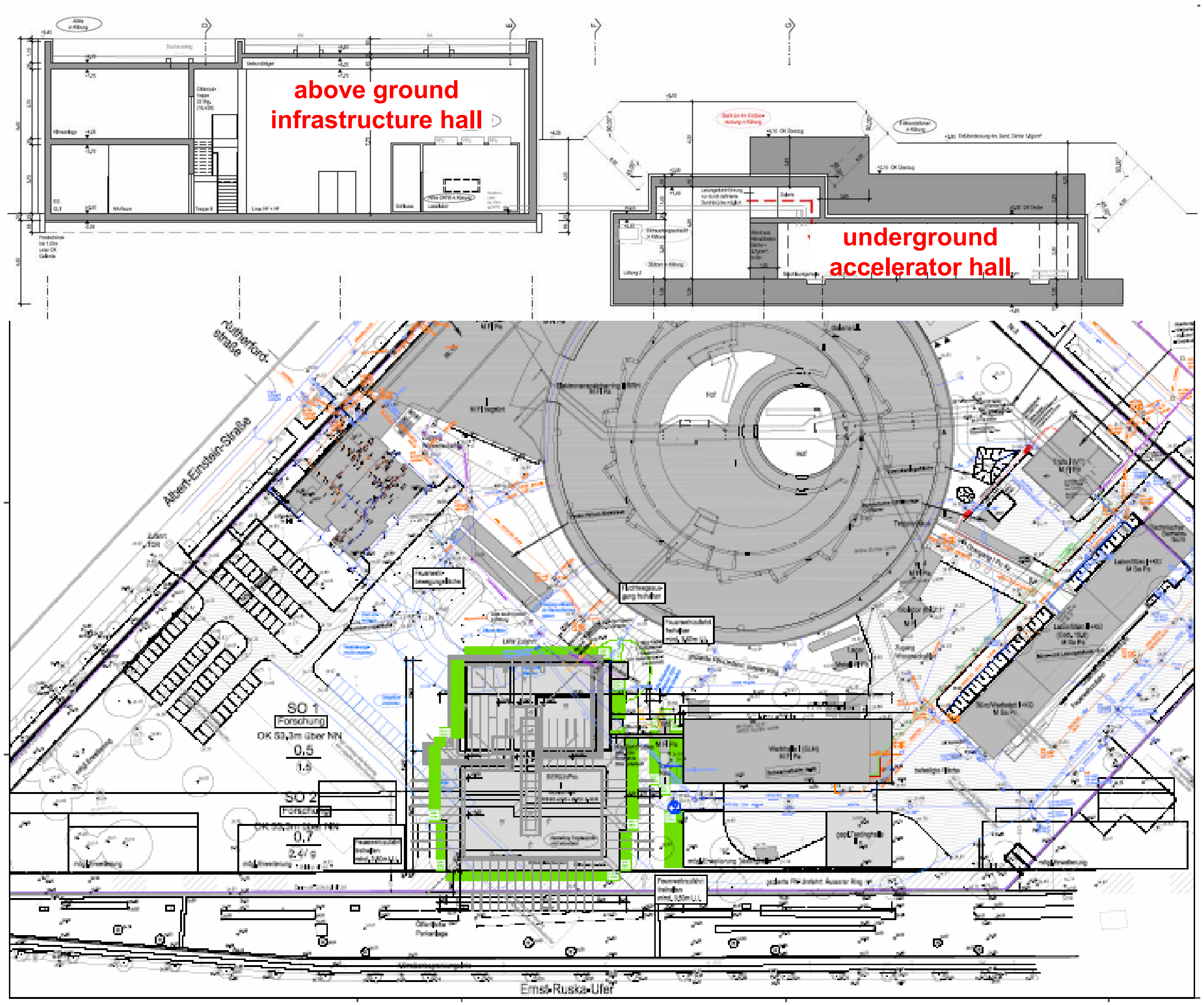


Project start 2011,
fully funded (36.5 Mio€)

already 11,8 Mio€ spent (power transmitters, srf-gun development)

	Basic Parameter
max. beam energy	50MeV
max. current	100mA (77pC/bunch)
normalized emittance	1 π mm mrad
bunch length (straight)	2 ps or smaller
rep. rate	1.3GHz
losses	< 10^{-5}

B*ERL*inPro building construction



03/2013
start of building planning team (architect, facility and energy planning)
09/2013
pre planning phase finished
12/2014
ground breaking
12/2015
building ready for installation

First high current (~mA) electrons through booster and merger not before 2017!

but srf-gun development in full swing thanks to gun-lab / HoBiCaT

Scope of this talk

At the last ERL workshop we reported on first results obtained with Gun0 at HZB

Gun0 is a SRF photoinjector with Pb cathode embedded in 1.6cell 1.3 GHz cavity

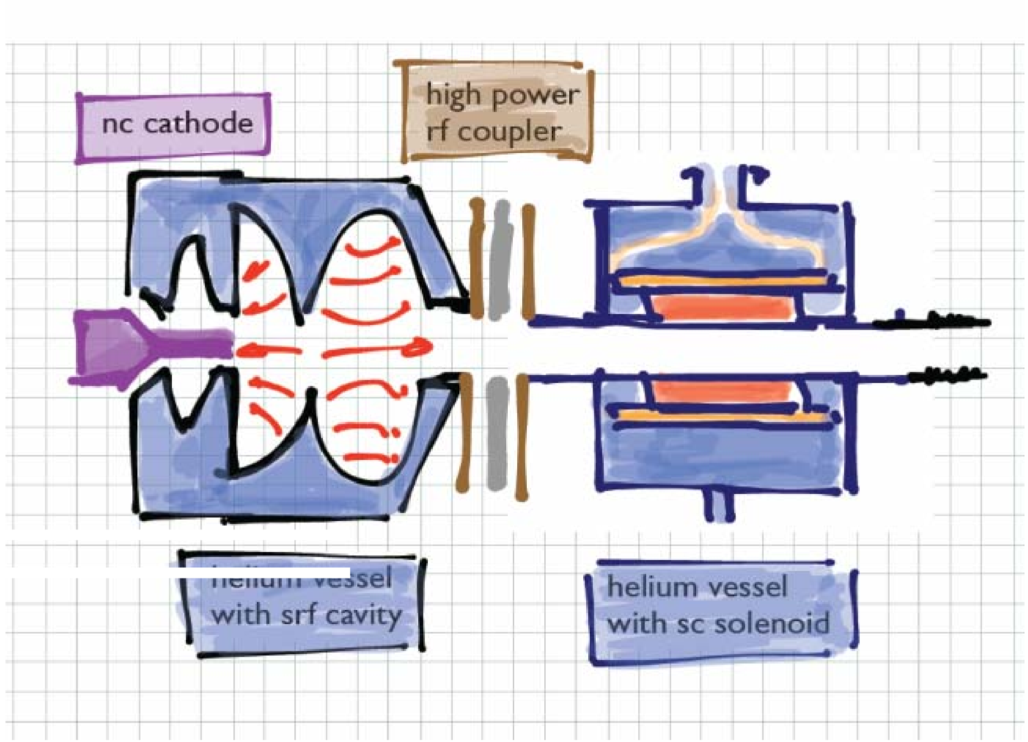
Since ERL 2011 we operated two cavities with beam and characterized RF and beam performance → many lessons learnt.

The next step is the development of an ERL class SRF photoinjector with high QE photocathode, the focus now is on

- development of the cold mass, especially the gun cavity
- R&D towards high QE photocathodes
- studies of dark current from field emission
- high average power drive laser development
- setup of GunLab, the gun testbed for BERLinPro

The goal is to develop a SRF photoinjector within the parameter envelope for an ERL as a lightsource driver

Basic idea for SRF photoinjector
High QE (> 1% at VIS) NC photocathode inserted in SRF gun cavity (E_l> 10 MV/m). High RF power feeds (> 250 kW). SC solenoid



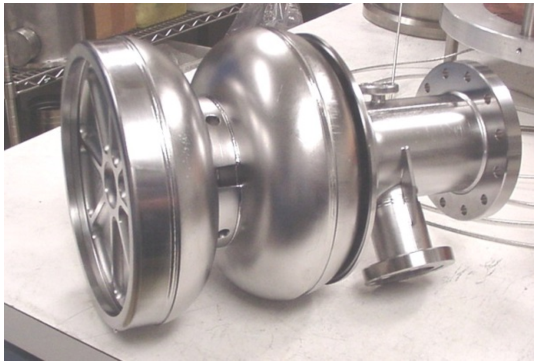
Approach the goals for BERLinPro in stages, tackling issues concerning generation, brightness and acceleration

	Gun0 (HoBiCaT) "lead gun"	BERLinPro Gun
Goal	Beam Demonstration (First beam 04/2011)	Brightness (2014) and average current (2017)
Cathode material	Pb (SC)	CsK_2Sb (NC)
Cathode QE_{max}	1*10^-4@258 nm*	1*10^-2@515 nm
Drive laser wavelength	258 nm	515 nm
Drive laser pulse length and shape	2.5 ps fwhm Gauss	≤ 20 ps fwhm Gauss
Repetition rate	8 kHz	1.3 GHz
Electric peak field in cavity	27 MV/m*	≤ 20…30 MV/m
Operation launch field on cathode	7 MV/m*	≥ 10 MV/m
Electron exit energy	2.5 MeV*	≥ 2.3 MeV
Bunch charge	6 pC*	77 pC
Electron pulse length	2…4 ps rms*°	≤ 6 ps rms
Average current	50 nA*	100 mA
Normalized emittance	2 mm mrad* (proj.)	1 mm mrad (proj.) and 0.5 mm mrad (sliced)

For Gun0 results, see:
T. Kamps *et al*, Proc. of IPAC 2011, A. Neumann *et al.*, Proc. of IPAC 2011,
R. Barday *et al.,* Proc. of PSTP 2011, J. Völker, *et al.*, Proc of IPAC 2012
S. Schubert, *et al.*, Proc of IPAC 2012, M. Schmeißer, et al., Proc. of IPAC 2013

*Preliminary data / results,
° value represents bunch emission time

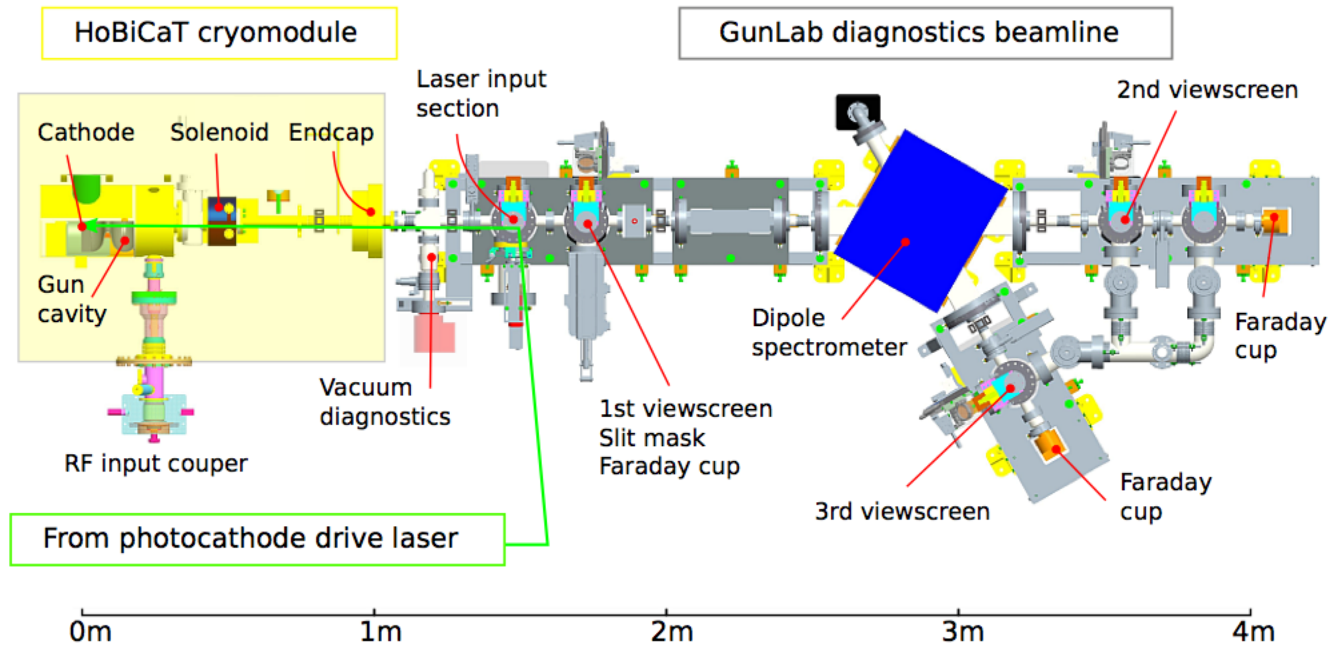
Gun0: First beam demonstration and operation of two gun cavities in all SC/SRF gun in 2011-2012. Operation in modified HoBiCaT cryomodule. Reached up to 2.5 MeV beam energy.

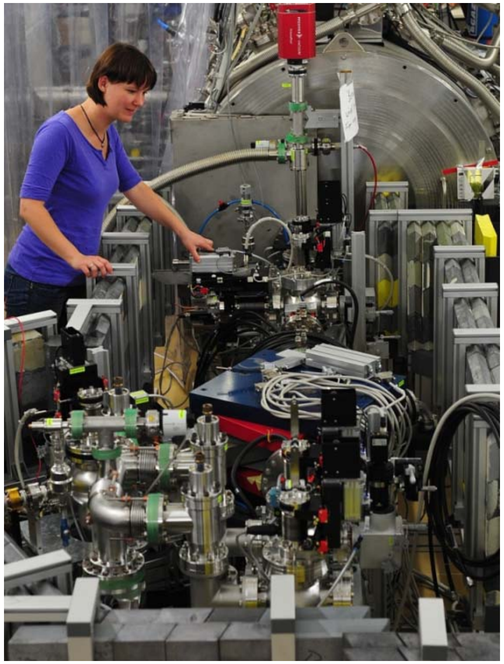


Next step include high QE cathode into SRF cavity and generate high brightness beam in 2014.

Then add high power RF coupler and operate gun at 230 kW average power in 2016.

Gun0: Install SRF gun cavity in HoBiCaT cryomodule, add drive laser and electron beam diagnostics





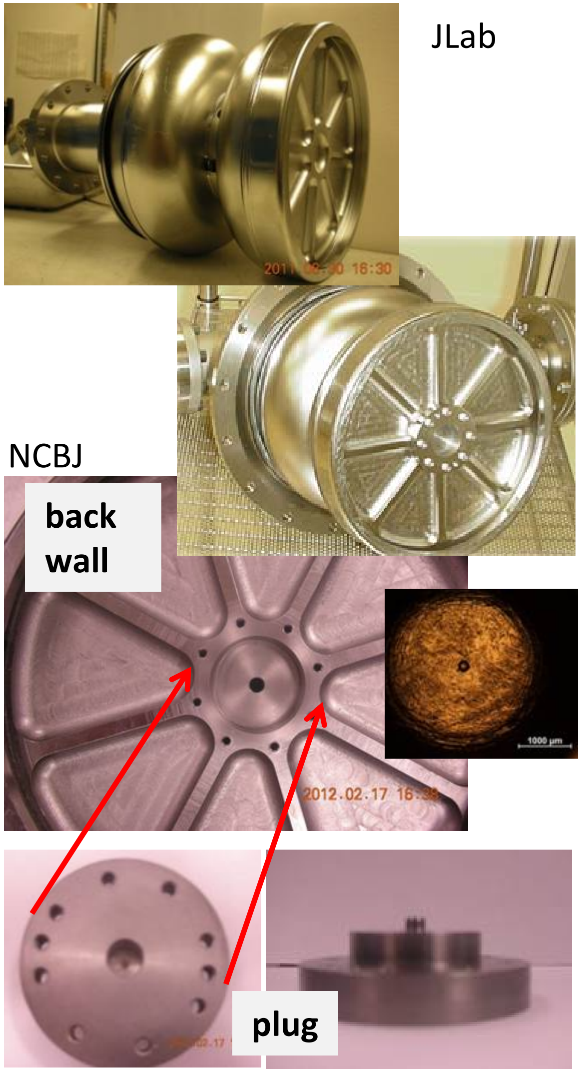
Study RF properties → Q_o vs E_{acc}, LLRF microphonics, operation with TTF-III coupler, interaction with SC solenoid, steering magnet

Beam dynamics studies → Viewscreens, slit mask, Faraday cups, dipole spectrometer

Cathode performance → measure QE maps, thermal emittance and dark currenet, do laser cleaning

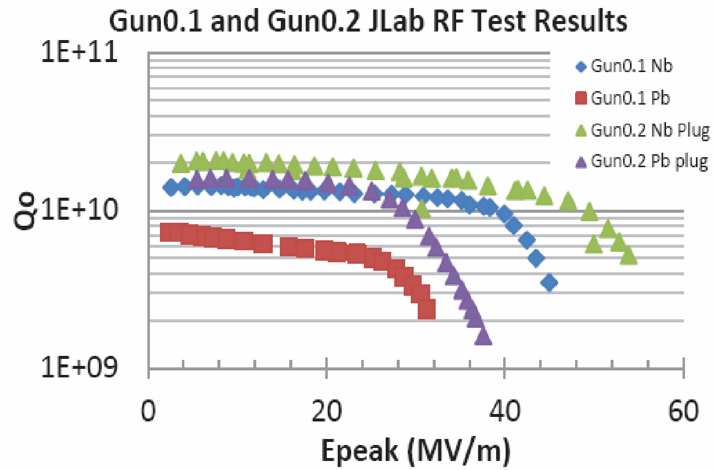
→ Learn for next generation SRF gun

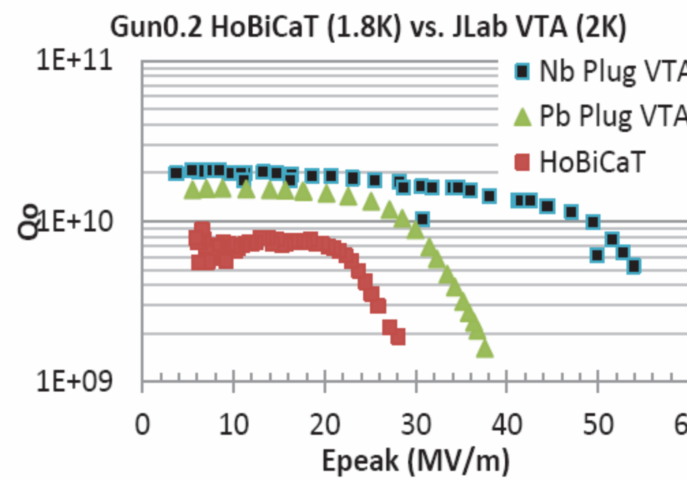
Gun0 results from RF measurements with two SRF gun cavities



Modifications cavity 0.1 → 0.2
Introduce Stiff back plate (30 mm thick) with opening for Nb cathode plug.
LHe vessel demountable.
Saclay-style tuner push/pull rear wall.
Found leak in connection between plug and cavity, RF processed cavity to remove Helium gas.

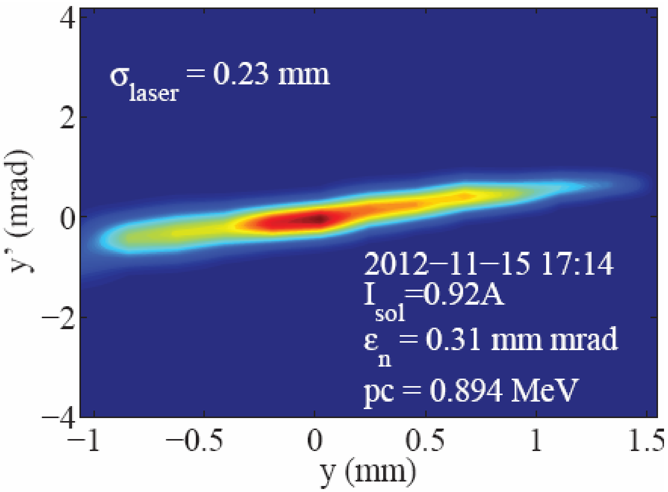
Removable cathode plug helps decoupling cavity treatment (HPR, BCP) and cathode preparation.
Field processing increased achievable peak field from 20 to 28 MV/m, limited by field emission and quench.
Qo performance decrease at HoBiCaT due to lack of magnetic shielding and residual fields.

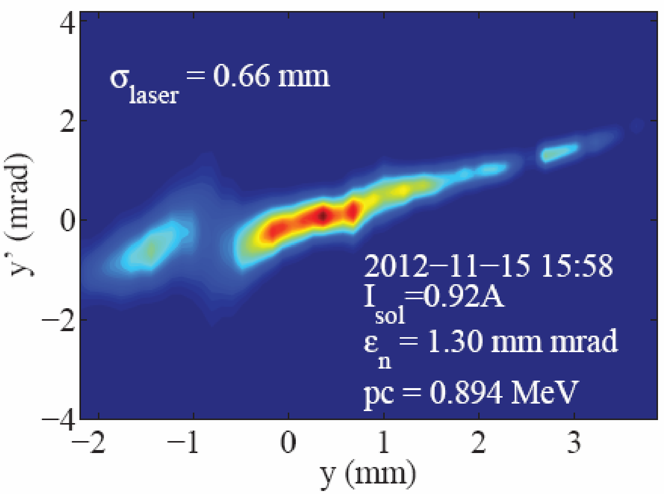




A. Burrill, et al., Proc. of IPAC 2013, WEPWO002

Gun0 results from emittance and phase space measurements: emittance dominated by rough and structured emission surface





M. Schmeißer, et al.,
Proc. of IPAC 2013, MOPFI002

Findings with cavity 0.1, Pb film directly on Nb wall:

Measured emittance at low bunch charge with solenoid scan technique

Found strong scaling of emittance with laser spot size.

Largest contributions from solenoid astigmatism and bifurcated emission from cathode.

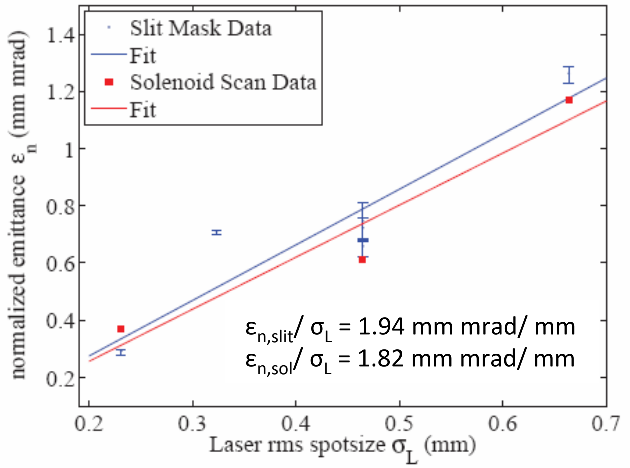
Cathode film covered with protrusions from Pb droplets.

Findings with cavity 0.2, Plug coated with Pb:

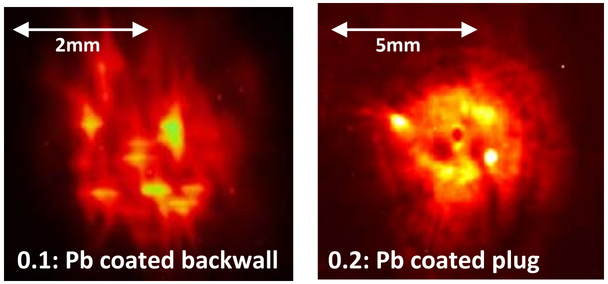
Measured phase space with slit mask.

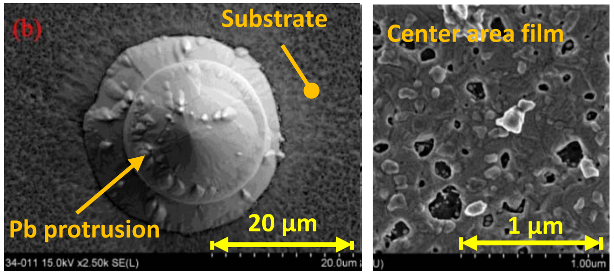
Emittanceof 0.2 three times lower than 0.1, improved cathode surface with less protrusions.

Shorter arc and slit aperture avoid formation and reach of micro-droplets



Emission spot imaged with solenoid on first view screen





Summarizing the experience after two successful and insightful runs with the hybrid Pb/Nb SRF gun

Cavity RF performance suffers compared to results from JLab VTA. → Need to improve magnetic shielding, measures against cold leaks and contamination during cavity handling.

Cavity tuner works well, LLRF control of cavity functioned as expected.

Photocathode drive laser delivered laser pulses according to specs. → Need to improve on intensity and pointing stability.

Electron beamline diagnostics worked very well. → Missed bunch length monitor at 2.5 MeV beam energy.

Solenoid mover helps with beam based alignment. → Care needs to be taken in solenoid design and heat intercepts

Steering magnet also critical to getting beam out of gun

Pb cathode demonstrated and achieved results closely match those from the cathode test system

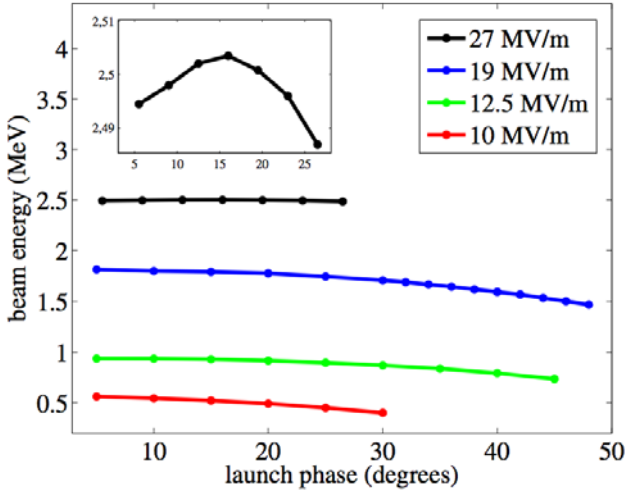
→ Laser cleaning works as expected, QE slightly lower than the bench measurements

→ Cathode surface critical to emittance and dark current minimization

→ Cathode plug greatly improves cleaning and sputtering processes.

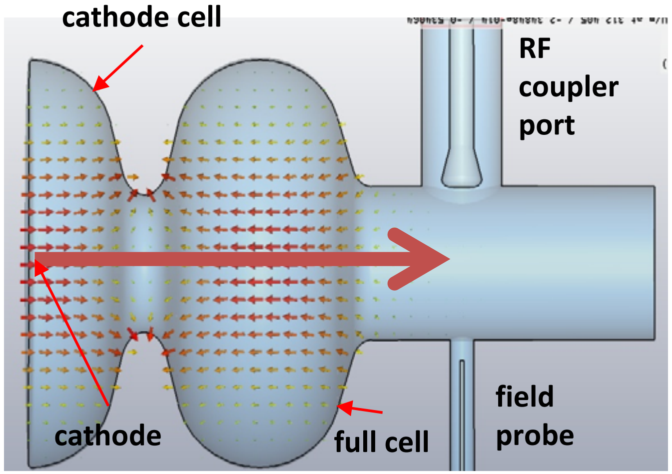
→ By addressing these items "lead" Gun could be used as a long term electron source for a low average current application like cw FEL or THz radiation sources.

From Gun0 to Gun1:
boundary conditions for gun cavity design



Gun0 result: For 2.5 MeV exit energy need 27 MV/m peak field and 15 deg launch phase → only 7 MV/m effective launch field.

For better longitudinal beam dynamics performance need higher launch phase → higher effective launch field.



Boundary conditions for next generation gun cavity design

Allow integration of normal conducting high QE photccathode on thermally and electrically insulated cathode insert → high average current from NC cathode

Low emittance → high launch field during electron beam emission, high peak field and high launch phase. Retractable cathode plug to obtain RF focusing during electron emission.

High average current → achieve good propagation of HOM to absorber, damping capabilities

Avoid losses of unwanted beam, dark current generation from field emission → keep peak field in cathode surface within limits.

Beam dynamics driven design of 1.4cell cavity for 2.5 MeV ERL class, average power limited, SRF photoinjector

Beam dynamics requires…

high launch field for low intrinsic emittance, and rapid acceleration to mitigate space charge effects,

radial field in cathode region → initial focusing to minimize emittance growth due to aberrations.

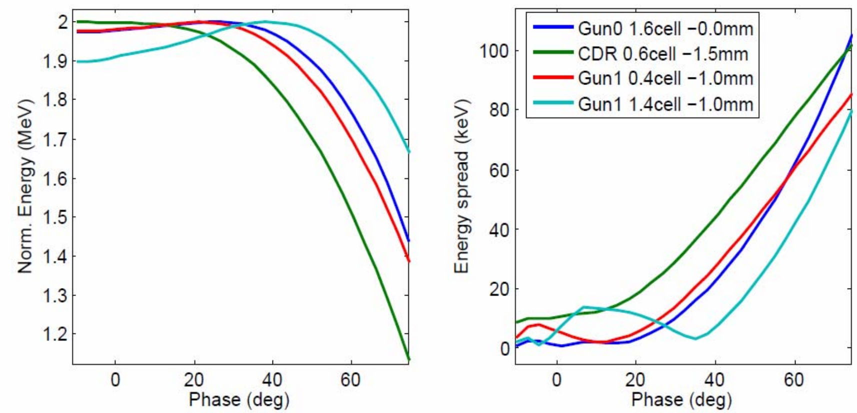
SRF operations wants…

min. ratio E_{pk}/E_{cath} to reduce probability of field emission,

min. H_{pk}/E_{pk} to minimize losses,

max. R/Q for TM_{010} π Mode,

propagation of HOMs out of cavity.



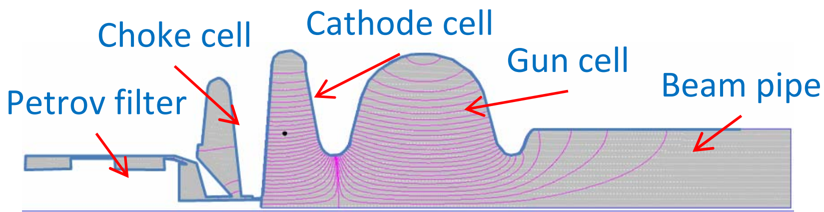
T. Kamps, LINAC 2012

Loop through cavity design and optimize SRF criteria, field flatness, target frequency

Check longitudinal beam dynamics with single particle energy vs. phase scans.

Take settled design to multi particle ASTRA parameter studies

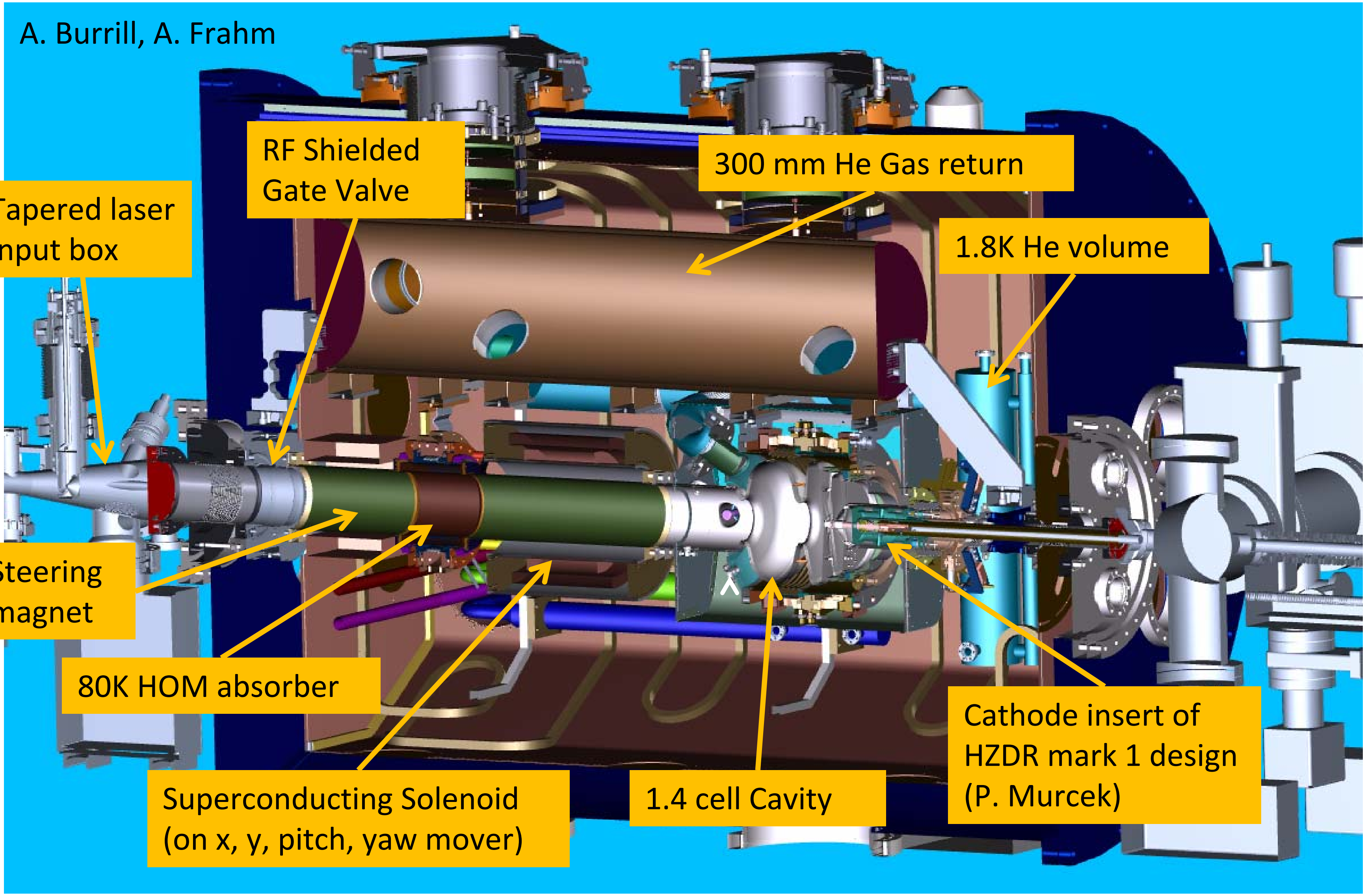
Elliptical 1.4 cell 1.3 GHz with Choke filter



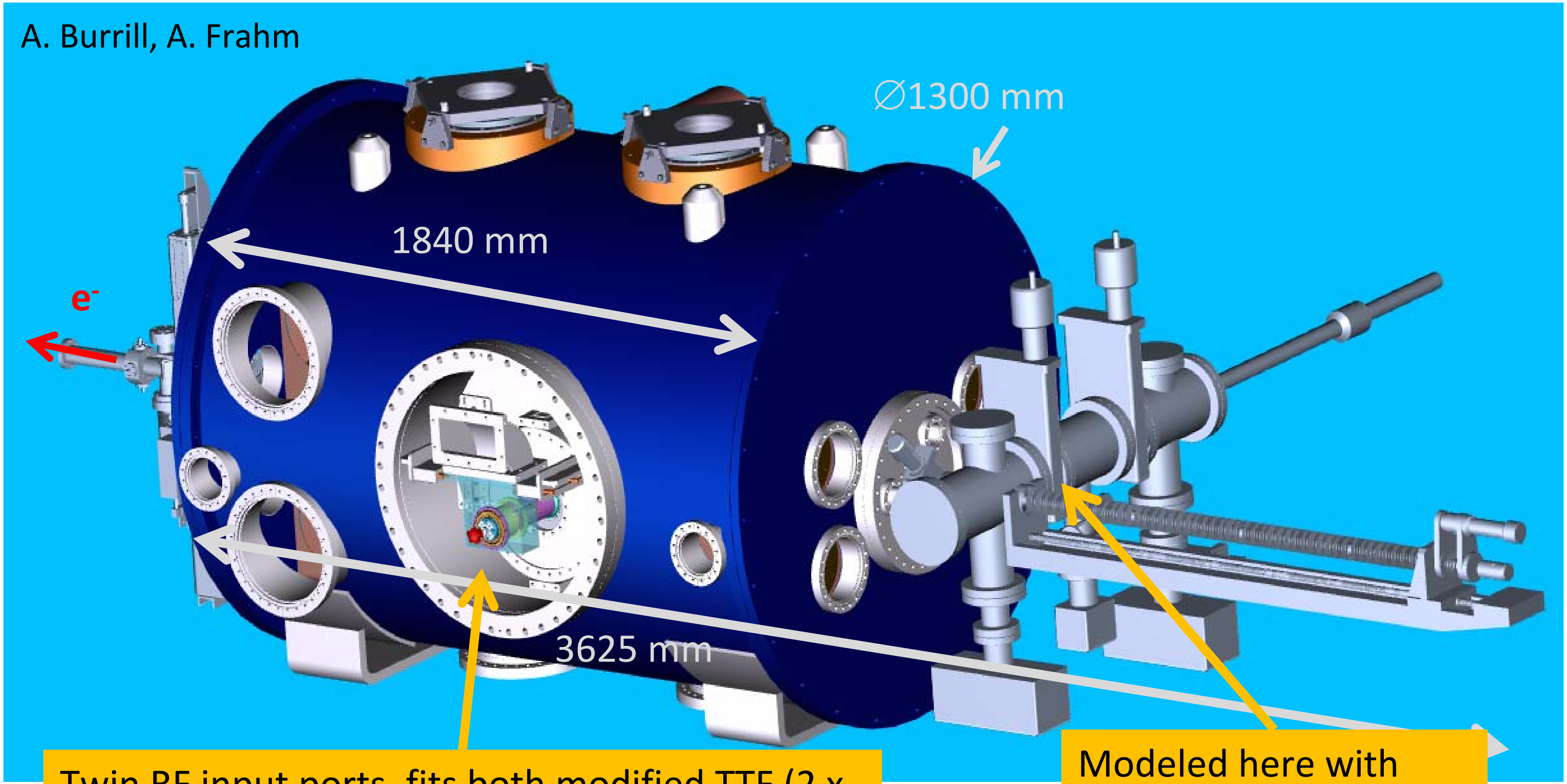
A. Neumann, LINAC 2012

R/Q	= 150 (190) Ω	At E_0	= 30 MV/m
H_{pk}/E_{pk}	= 2.3 (4.4) mT/(MV/m)	E_{pk}	= 45 MV/m
E_{pk}/E_0	= 1.5 (1.86)	E_{kin}	= 2.4 MeV
E_{cath}/E_0	≈ 0.8 (1.0)	Φ_{Emax}	= 50 deg
		E_{cath}	= 24 MV/m
Values for 1.4cell (1.6cell)		E_{launch}	= 18.4 MV/m

The cold mass includes cathode insert shaft, gun cavity, solenoid and steering magnets, HOM absorber and RF/cryo infrastructure



The cryomodule design is in line with the booster module, can be fitted with high and low power coupler, and connects to cathode system



Twin RF input ports, fits both modified TTF (2 x 10kW) and high power coupler (2 x 130kW)

Modeled here with HZDR mark 1 cathode exchange system (Courtesy P. Murcek)

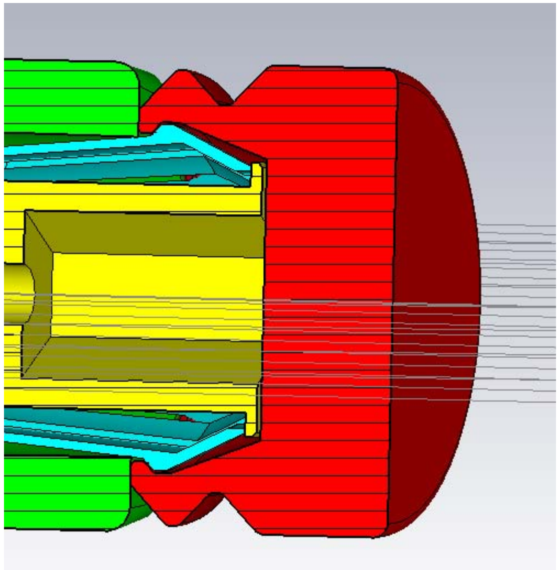
Photocathode plug and insert

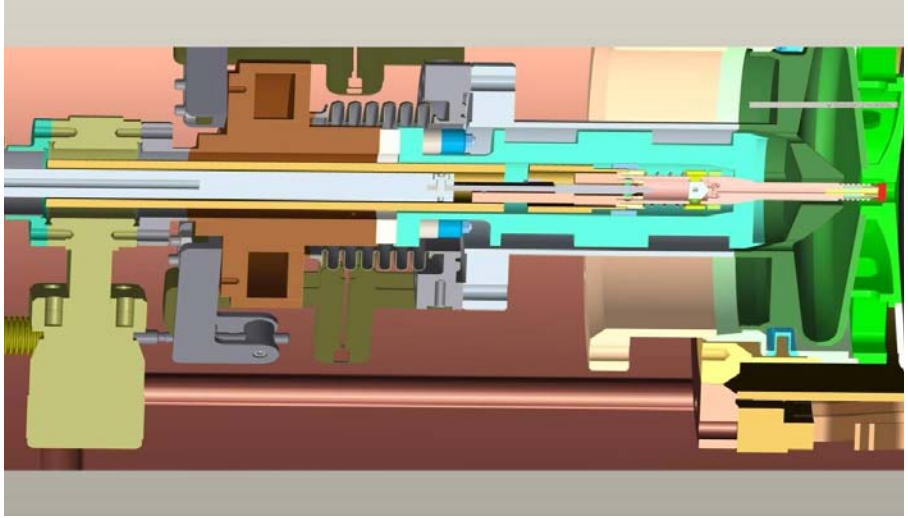
Requirements

- evolution of HZDR system, compatibility
- compact size, plug < 10 mm to fit inside beamline experiments
- good thermal and electrical contact between plug and cathode body
- easy set on/off procedure without turning movement
- avoid particle generation from surface contact movements

Spring solution

- first tests inside HZDR SRF gun
- thermo contact experiment
- compatibility to JGU Mainz system

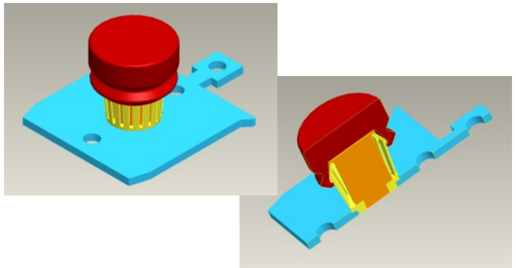




Preparation and analysis system to grow CsK2Sb cathodes and study characteristics before/after use in gun and under gases

Preparation chamber:
Four evaporation sources (two simultaneous), mass spectrometer, two quarz crystal microbalances, photocurrent measurement, and sputter gun for substrate preparation

Manipulator
allows sample heating and cooling, application of bias voltage

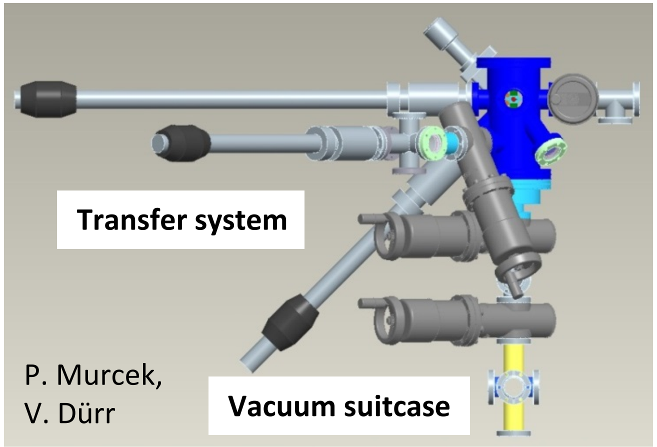


Cathode plug on sample holder

S. Schubert,
D. Böhlick

Analysis chamber:
XPS, LEIS, energy analyzer and momentatron for chemical composition, depth profiling, surface composition, deposition rate, spectral response and intrinisc emittance measurement.

Transfer chamber/ suitcase:
under development

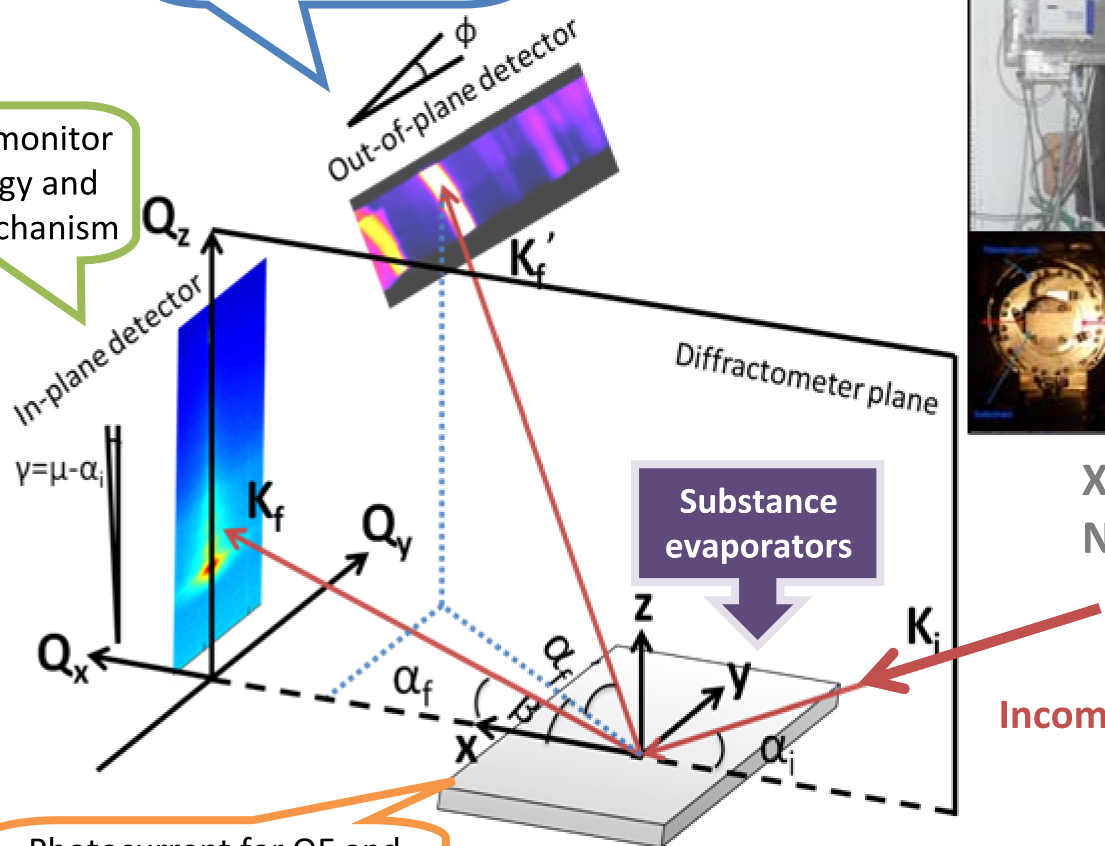


P. Murcek,
V. Dürr

With BNL system combined growth and analysis experiment to discover correlations between growth, structure and QE

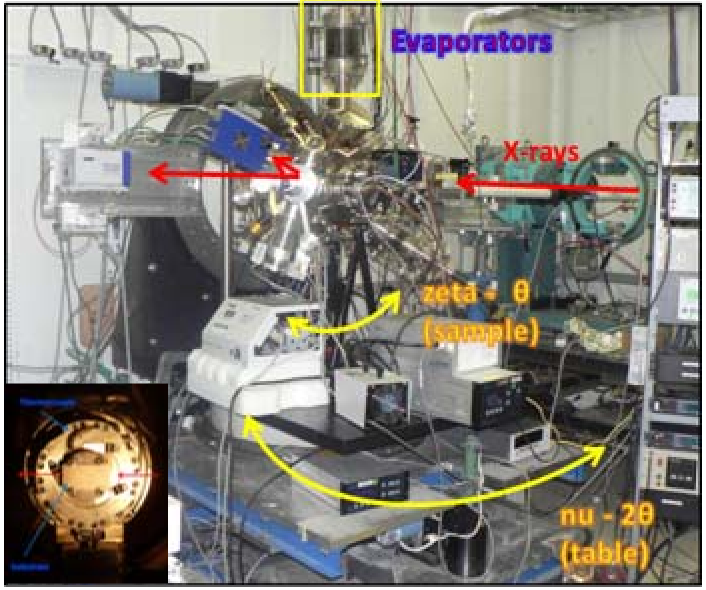
XRD to monitor lattice information and preferred orientation

GiSAXS to monitor morphology and growth mechanism



Photocurrent for QE and XRR for cathode thickness

Si substrate

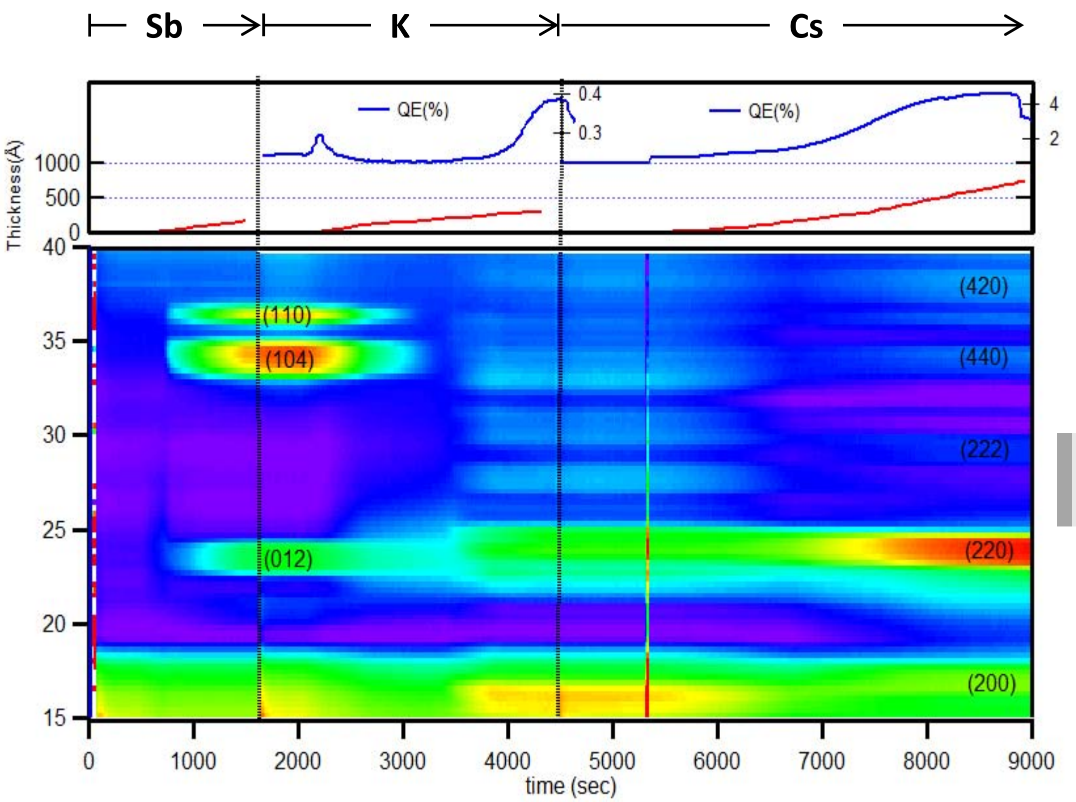


X21 experiment setup at NSLS/BNL and CHESS/Cornell

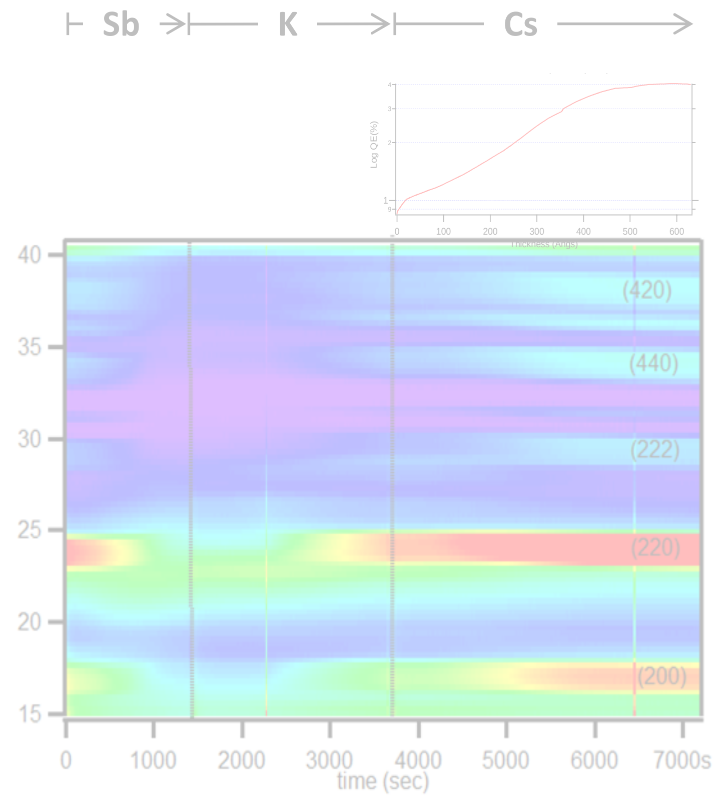
S. Schubert, M. Ruiz Oses, E. Muller, J. Xie, J. Wong, J. Smedley, A. Woll

Prepare CsK2Sb according to the traditional recipe (Sommer) and observe evolution of diffraction pattern, thickness and QE

Growing of 1st cathode

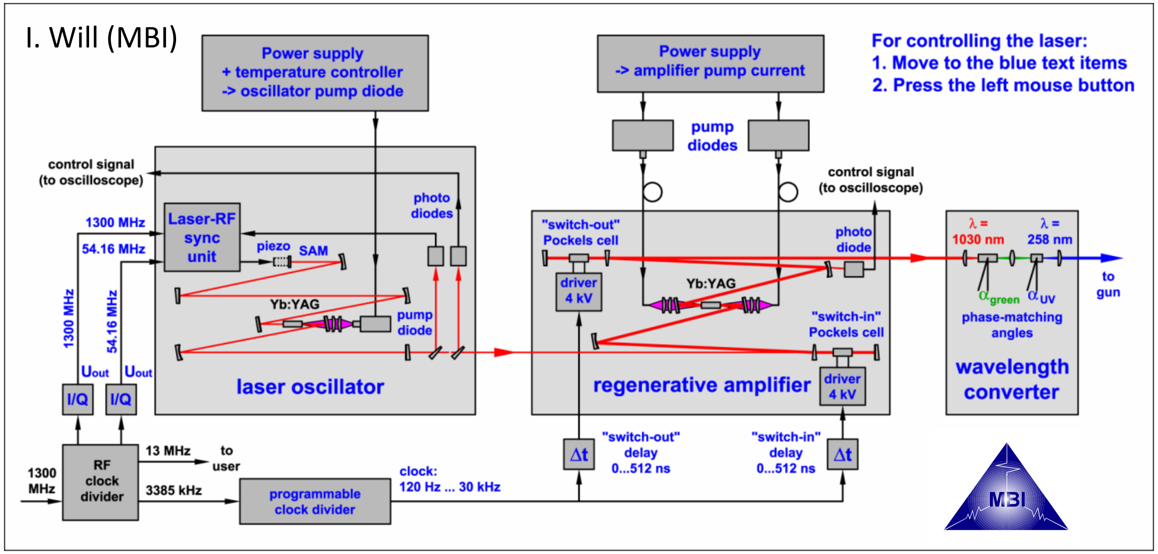


Growing of 2nd on top of 1st



S. Schubert, M. Ruiz Oses, E. Muller, J. Xie, J. Wong, J. Smedley, A. Woll

Two laser systems: 1.) Upgrade of exisiting kHz laser to serve GunLab and to test longitudinal pulse shaping



Drive laser developed by MBI:

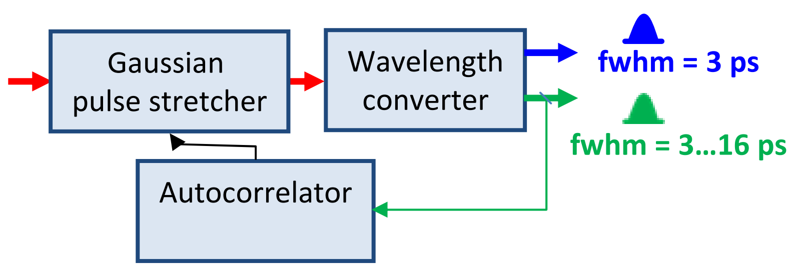
initially to run at 258 nm for Pb cathode in Gun0, now upgrade for GunLab (515 and 258 nm).

P_{avg} = 0.5 W at IR

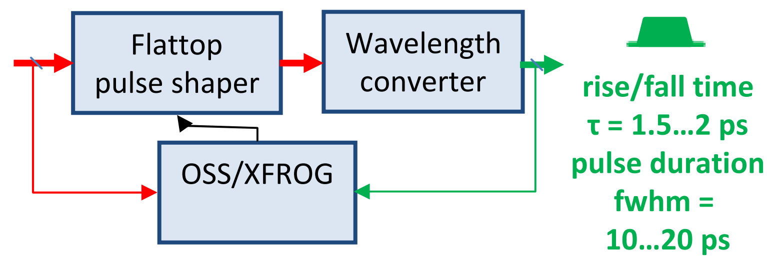
fwhm = 2…3 ps at UV

Max E_p = 0.5 µJ at UV

Synchronized to RF master with accuracy ≤ 2 ps

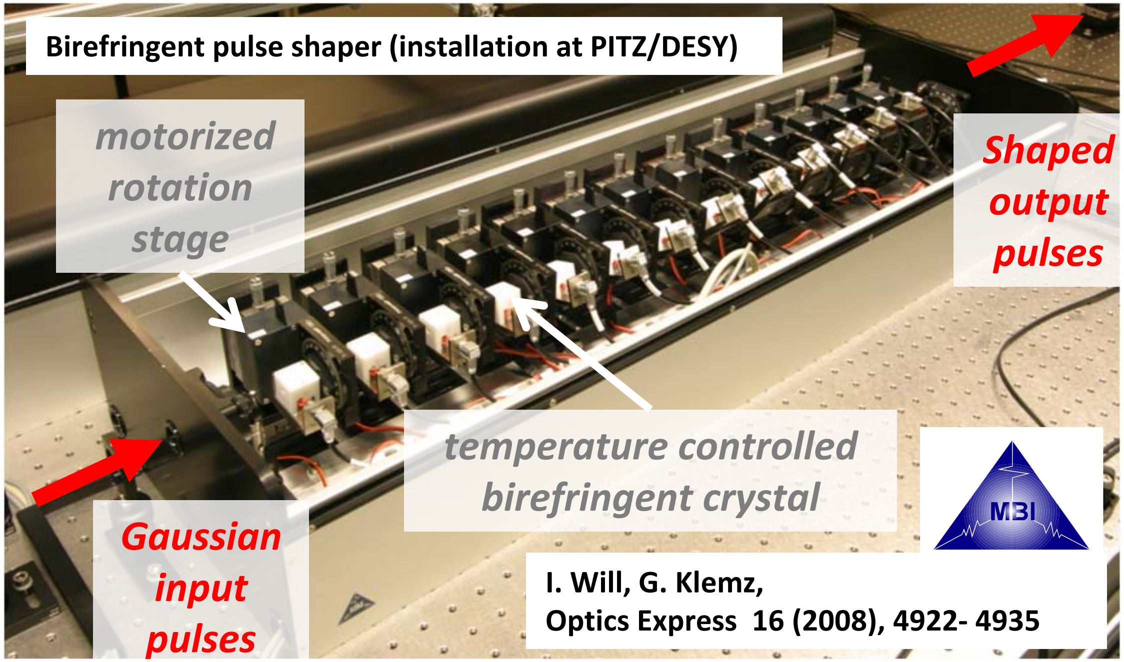


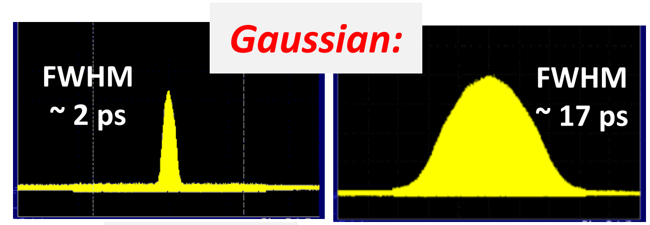
Step 1: setup two output channels for Green and UV light, Gaussian pulse shaper for commissioning of Gun1 and beam dynamics studies.

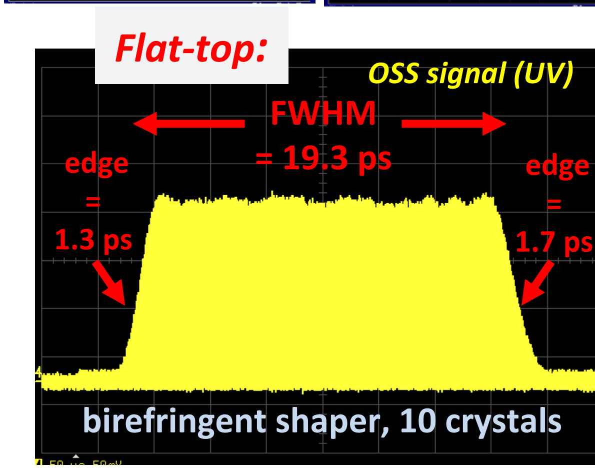


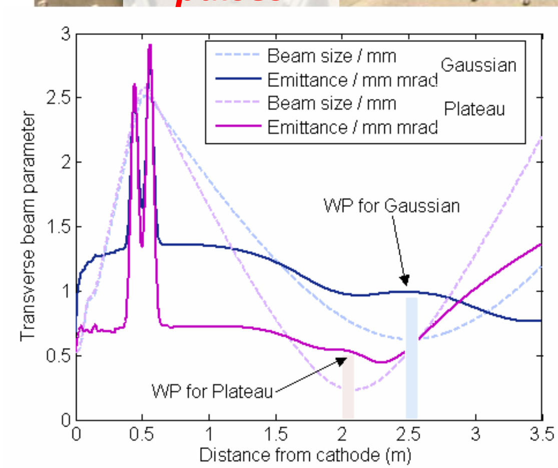
Step 2: setup and commissioning of Flattop pulse shaper. Beam dynamics studies for low emittance and population of long. and trans. tails to minimize losses.

Longitudinal pulse shaping benefical to achieve low transverse emittance and and less population of longitudinal tails







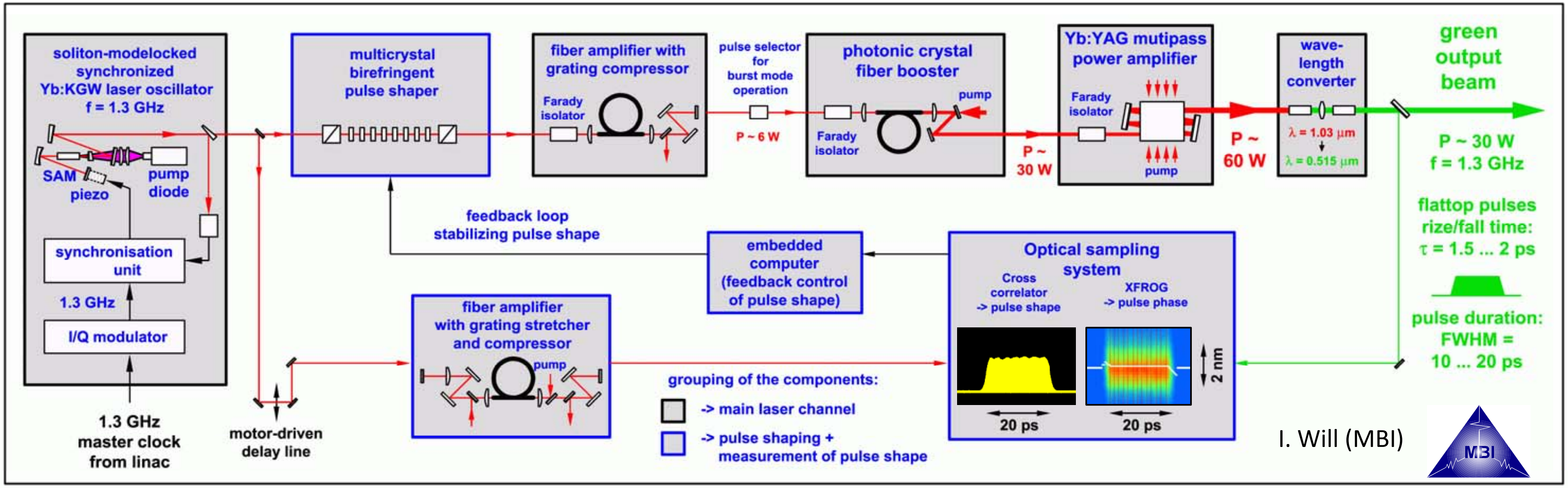


Pulse shaping implemented by using multicrystal birefringent filter. Extremly stable with feedback system (developed for XFEL).

Results in linear self fields inside shaped bunch → can be compensated with linear lens.

Shorter longitudinal tails → allows lower losses for beam transport
Experiment at Gunlab with few stage shaper and dedicated diagnostics (TCAV), and 10^9 particle simulations required.

2.) High average power 1.3 GHz repetition rate with fiber and Yb:YAG booster amplifier for 60 W at IR serving BERLinPro



(pulse shape + XFROG: measurement at another system at MBI)

Challenges on the path: Development of …

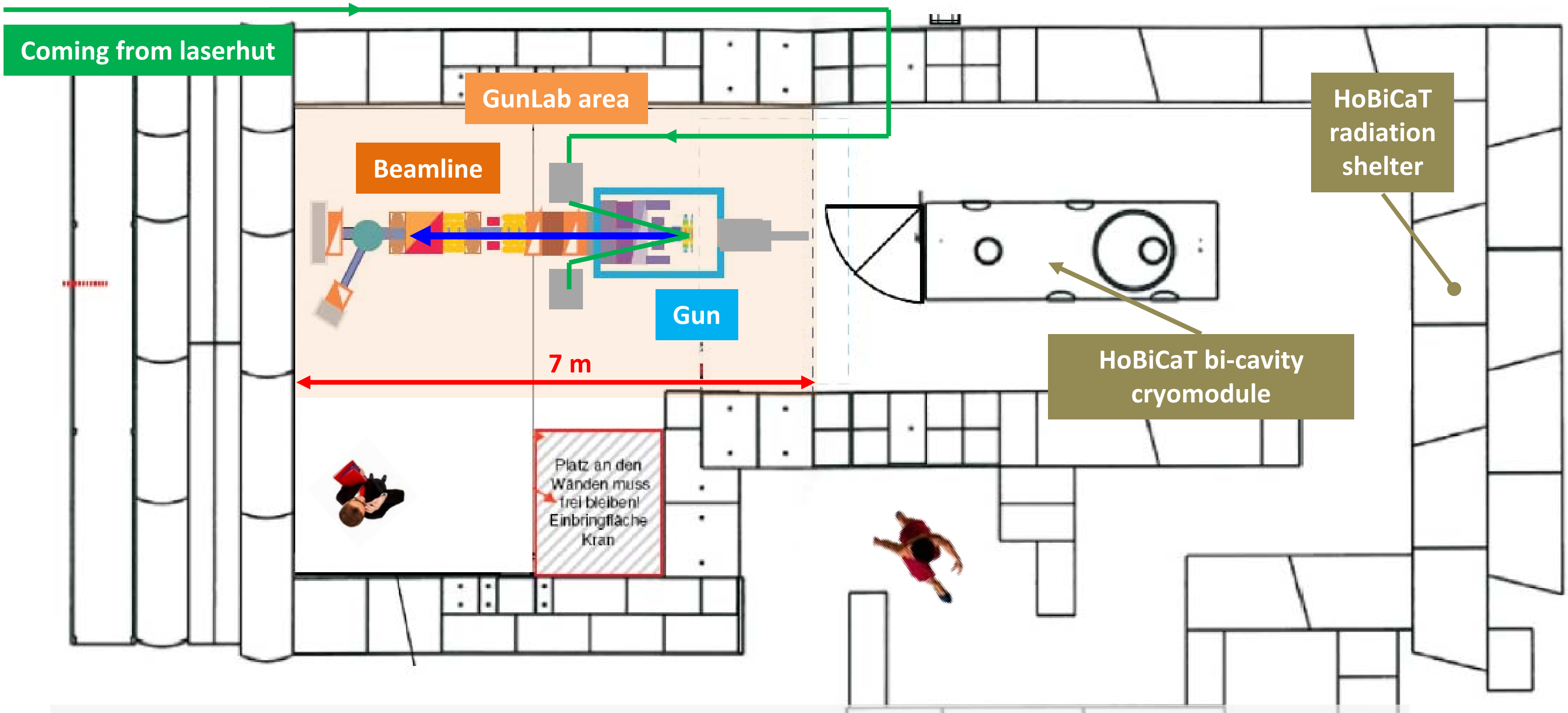
1.3 GHz oscillator with synchronisation ≤ 1ps to external master.

Booster amplifier to bring average power at IR > 60 W → thin-disk geometry.

Diagnostics mode with reduced duty cycle and repetition rate, from 24 W at 1.3 GHz down to 0.2 µW single pulses at 10 Hz (10^8).

Pulse selector and picker with rise/fall time faster than bunch spacing of 770 ps.

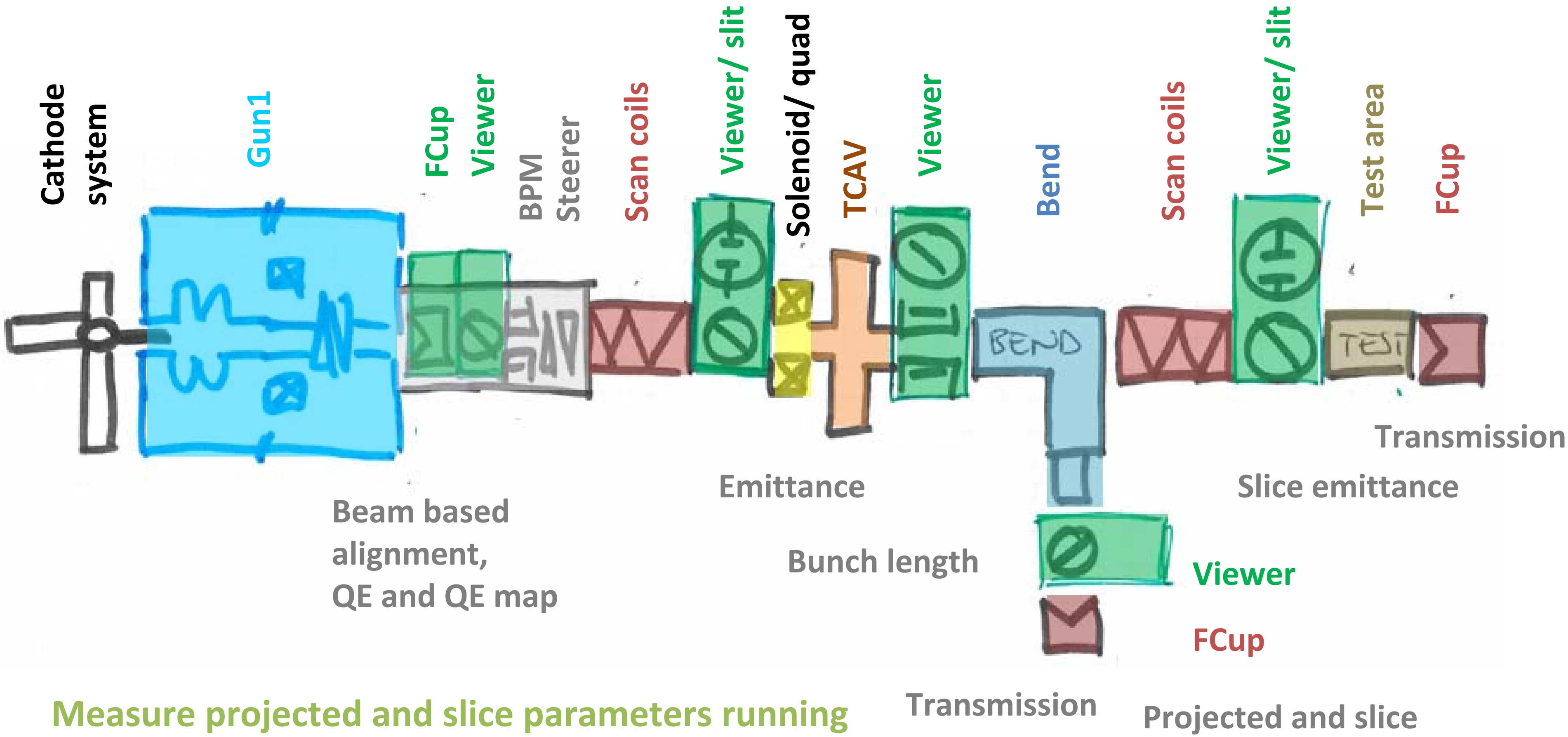
Gunlab: The next SRF guns will be installed, setup and comissioned in the HoBiCaT bunker, next to the bi-caviy cryomodule



GunLab is the R&D platform for SRF photoinjector development for BERLinPro.
Equipped with diagnostics beamline and drive laser with UV and Green output.
All guns for BERLinPro will be commissioned and characterized at GunLab.
Generation of I_{avg} = 5 µA and acceleration up to E_b = 3.5 MeV possible.
Collaboration on TCAV with TU Dortmund and longitudinal phase space measurements with Moscow State University.

Gunlab: beamline draft physics design

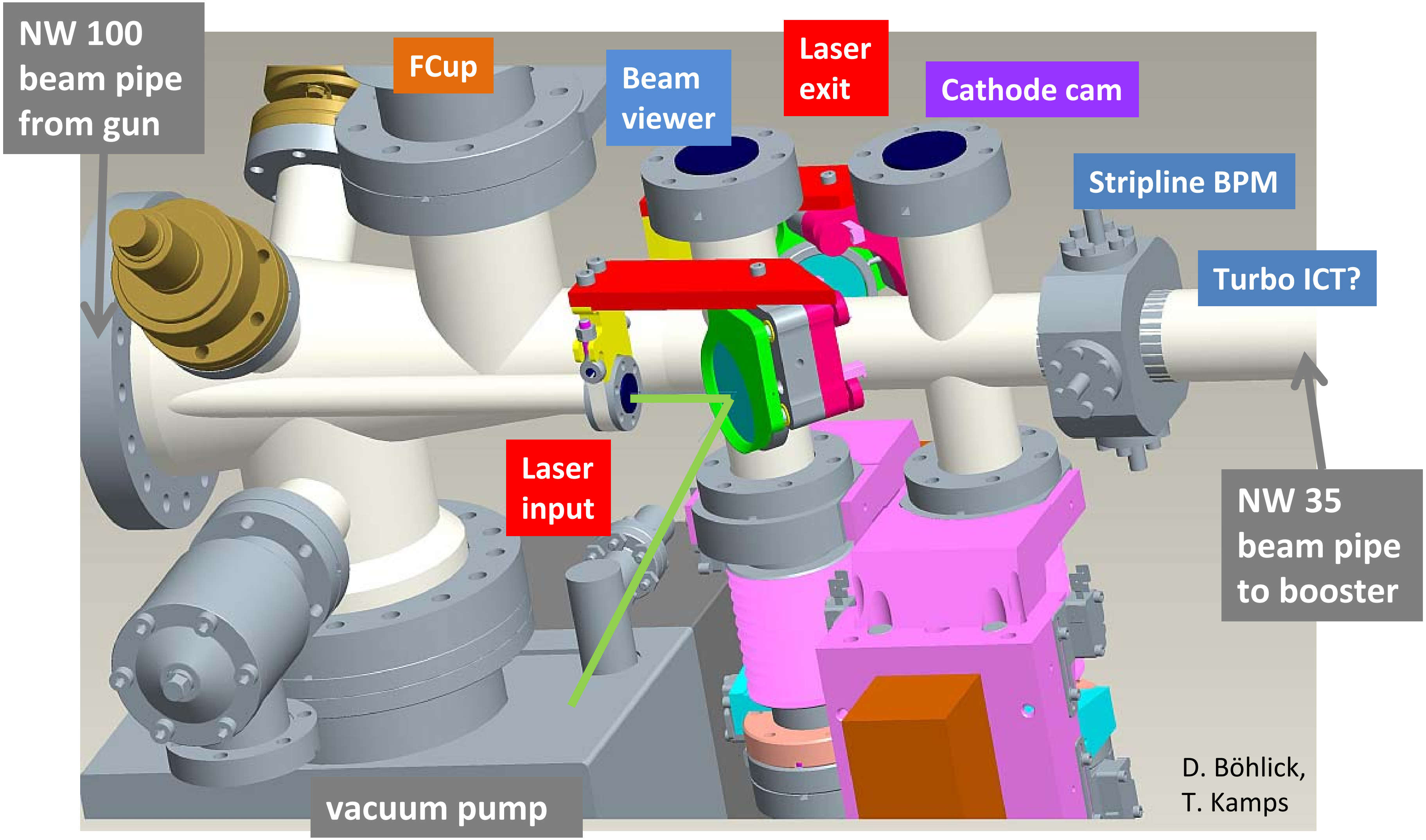
Measurements and tools, PhD thesis topic J. Völker



Measure projected and slice parameters running single bunches at 77 pC with 0.5…3.5 MeV energy.
Recycle viewers from Gun0 beamline and add TCAV for bunch length and slice measurements.

Gunlab: Mimic the first meter between gun and booster

Laser input, comissioning, BBA and charge/position feedbacks



Conclusions

Getting a head start with Gun0 proved very valuable → many lessons learnt

- **Cavity design and operation.**
- **Beam diagnostics and phase space characterization.**
- **Cold mass solenoid.**
- **Laser beam transport and diagnostics.**

Now the focus is on

- **Realization of ERL class gun cavity.**
- **Cathode/ cavity interface.**
- **Photocathode growth and characterization.**
- **Field emission studies.**
- **Improvement of beam diagnostics of GunLab for slice measurements.**
- **Drive laser upgrade.**

Plan to start Gun1 with beam September 2014.

People involved

Thorsten Kamps, Wolfgang Anders, Roman Barday, Andrew Burrill, Andreas Jankowiak, Jens Knobloch, Oliver Kugeler, Alexander N. Matveenko, Axel Neumann, Eva Panofski, Martin Anton Helmut Schmeißer, Jens Voelker (HZB, Berlin), Susanne Gundula Schubert (BNL, Upton, Long Island, New York), Alessandro Ferrarotto, Thomas Weis (DELTA, Dortmund), Evgeny Zaplatin (FZJ, Jülich), Jochen Teichert (HZDR, Dresden), Ingo Will (MBI, Berlin), Vasiliy Ivanovich Shvedunov (MSU, Moscow)

And many more at HZB, BNL, DELTA, FZJ, HZDR, MBI, MSU, JGU, ….