SRF Photoinjector development for BERLinPro

J. Knobloch, Helmholtz-Zentrum Berlin

Project goals

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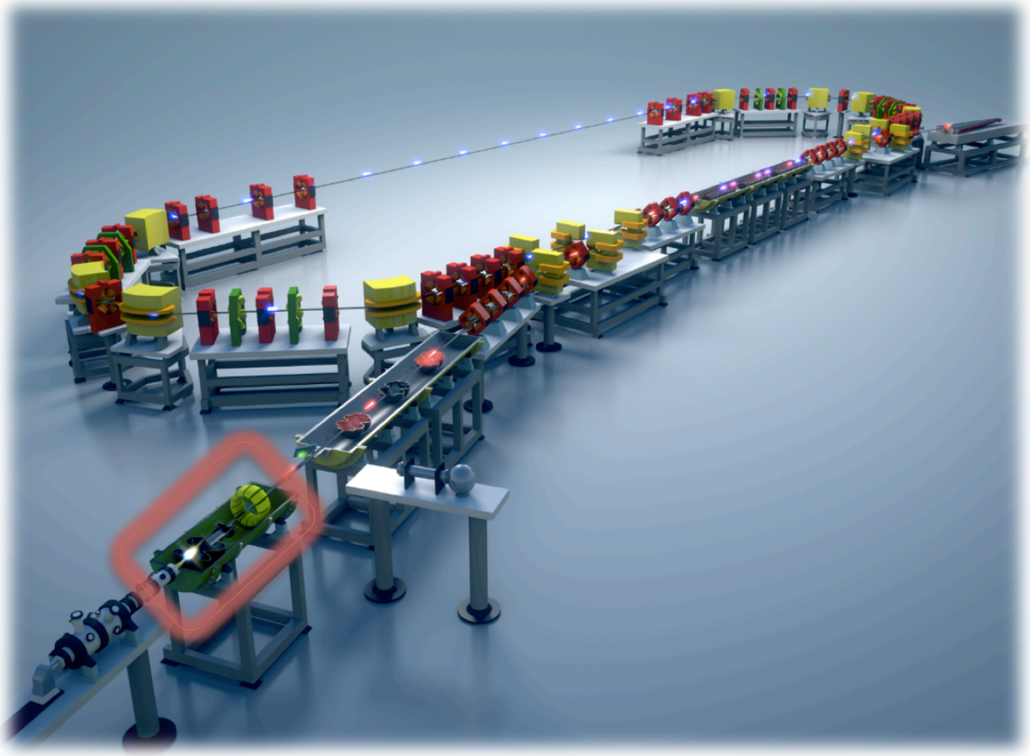
J. Knobloch, TTC Meeting 11-2012

(Some of) the B*ERL*inPro Project Goals

- Demonstration facility for ERL Technology and Accelerator Physics.
- 50 MeV
- High current: 100 mA @ 77 pC per bunch
- Low normalized emittance: 1 mm mrad
- Short pulses < 2 ps
- Project period: 2011 – 2018



One of the main challenges

- 2.3 MeV SRF Photoinjector
- Development in three stages

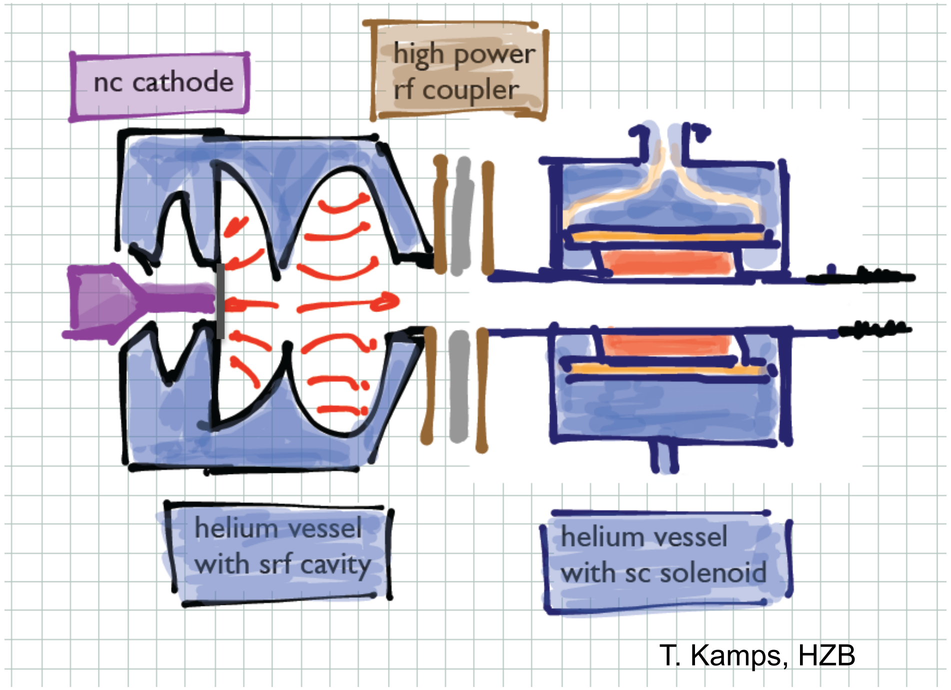
3 stages towards a B*ERL*inPro injector

Try to separate out the big challenges of an SRF injector

Injector 0: Get the "feet wet" with an all SRF system (SC cavity, SC Pb cathode, SC solenoid) → low charge, low-average current (2011-12)

Injector 1: Next worry about the NC cathode (CsK_2Sb) and its integration in the SRF cavity → nominal charge, mA average current (2014)

Injector 2: Finally add high power (input/HOM) capabilities for 100 mA current (2016)



3 stages towards a B*ERL*inPro injector

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	Stage 1 Gun0 (HoBiCaT)	Stage 2 Gun1	Stage 3 Gun2
Goal	Beam Demonstration (First beam April 2011)	High brightness R&D gun with NC cathode	High average current & brightness with NC cathode
Cathode material	**Pb (SC)**	**CsK_2Sb (NC)**	**CsK_2Sb (NC)**
Cathode QE_{max}	10^{-4} @258 nm*	10^{-2} @532 nm	10^{-2} @532 nm
Drive laser wavelength	**258 nm**	**532 nm**	**532 nm**
Drive laser pulse length and shape	2.5 ps fwhm Gauss	≤ 20 ps fwhm Gauss	≤ 20 ps fwhm Gauss
Repetition rate	8 kHz	54 MHz/25 Hz	1.3 GHz
Electric peak field in cavity (on cathode)	**20 MV/m***	**≤ 20…30 MV/m**	**≤ 20…30 MV/m**
Operation launch field on cathode	5 MV/m*	≥ 10 MV/m	≥ 10 MV/m
Electron exit energy	1.8 MeV*	≥ 1.8 MeV	≥ 1.8 MeV
Bunch charge	**6 pC***	**77 pC**	**77 pC**
Electron pulse length	2…4 ps rms*°	≤ 6 ps rms	≤ 6 ps rms
Average current	**50 nA***	**4 mA/40 µA**	**100 mA**
Normalized emittance	2 mm mrad* (proj.)	1 mm mrad (proj.) and 0.5 mm mrad (sliced)	

*Preliminary data / results,
° value represents emission time

T. Kamps *et al*, Proc. IPAC 2011, PRST-AB (in preparation)
A. Neumann *et al.*, Proc. IPAC 2011, PRST-AB (in preparation)
R. Barday *et al.,* Proc. of PSTP 2011
J. Völker, *et al.*, Proc of IPAC 2012
S. Schubert, *et al.*, Proc of IPAC 2012

Stage 1: All SC Photoinjector System

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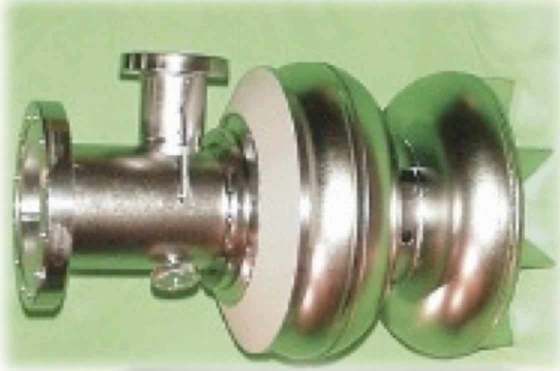
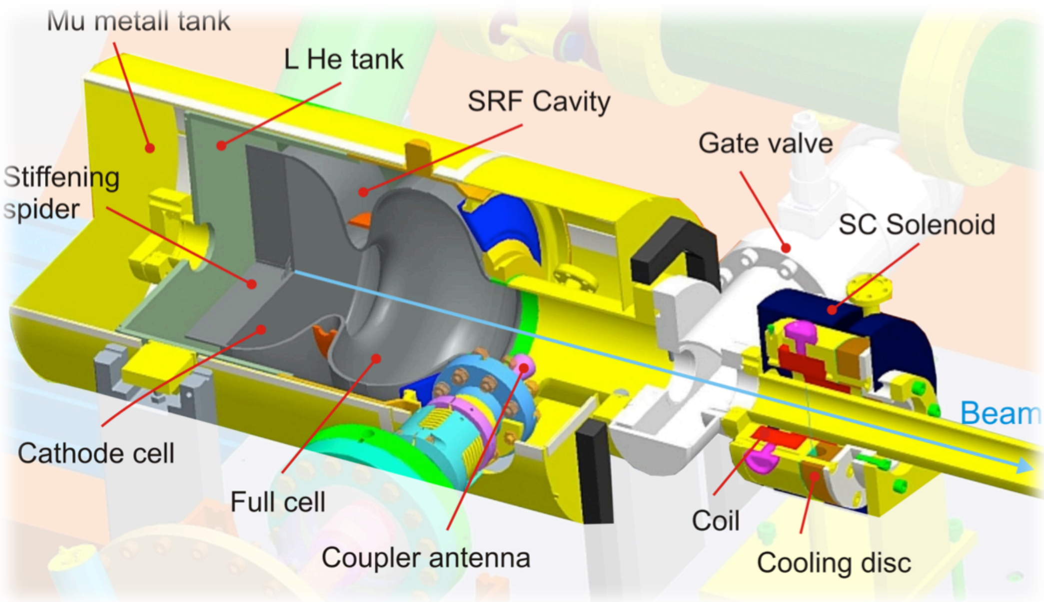
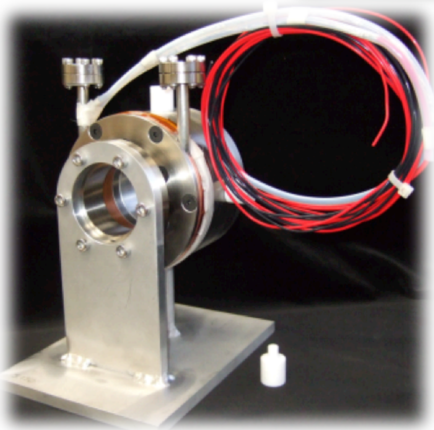


Photoinjector 0

- Don't worry about NC cathode: use SC Pb cathode
- Idea first developed by J. Sekutowicz (DESY)
- Produced at JLAB (P. Kneisel) and cathode coa-ted at Nat. Centre for Nucl. Research (R. Nietubyc)
- Add SC NbTi solenoid (Niowave)
- Of interest for low-ave-current CW LINACs (e.g., FEL)





Stage 1: All SC Photoinjector System

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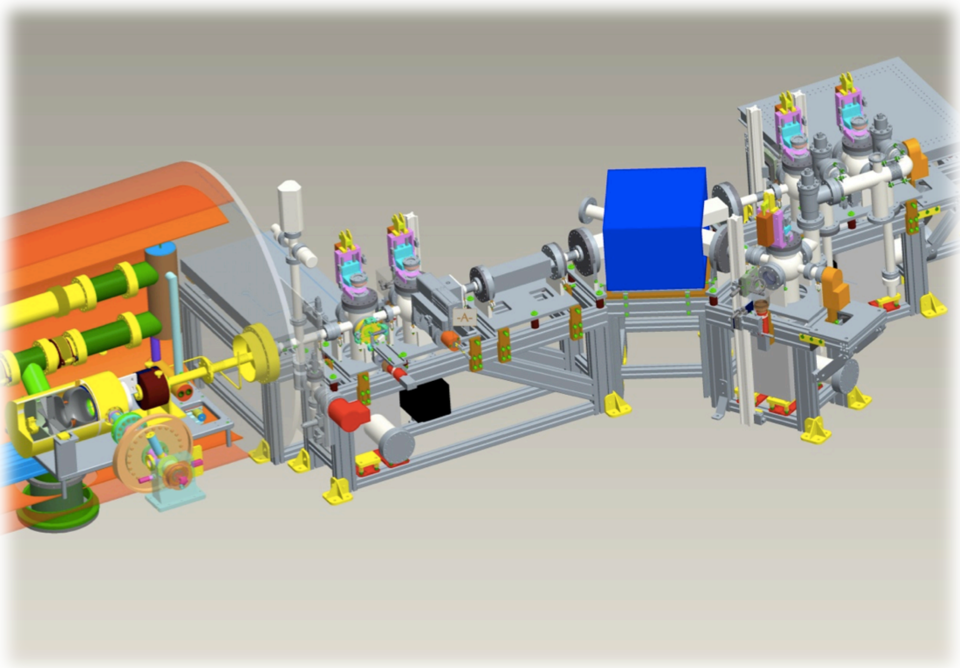
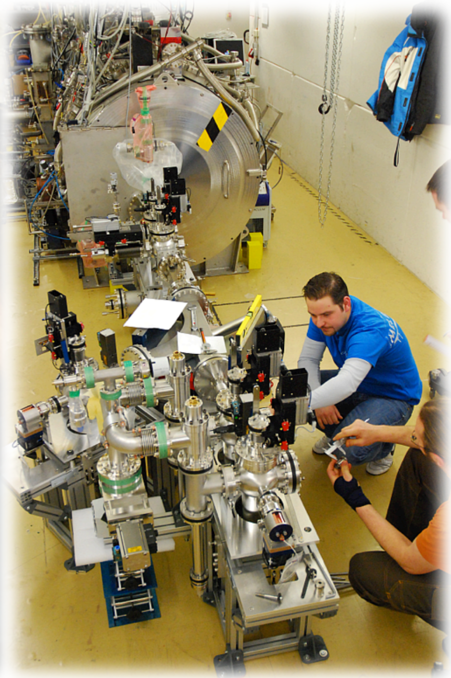
Beam tests in HoBiCaT

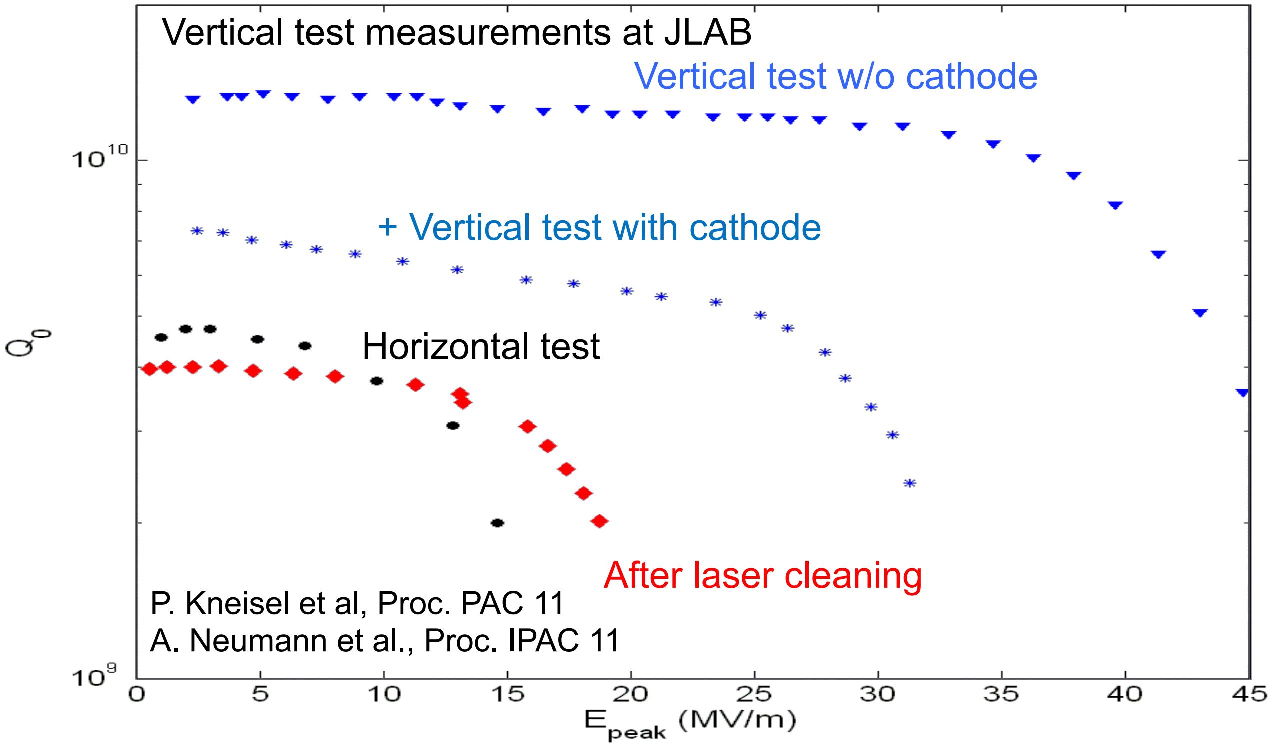
- SRF system was integrated in HoBiCaT cryostat
- Simple beamline for diagnostics, UV Drive laser (MBI, I. Will)
- First tests in March 2011

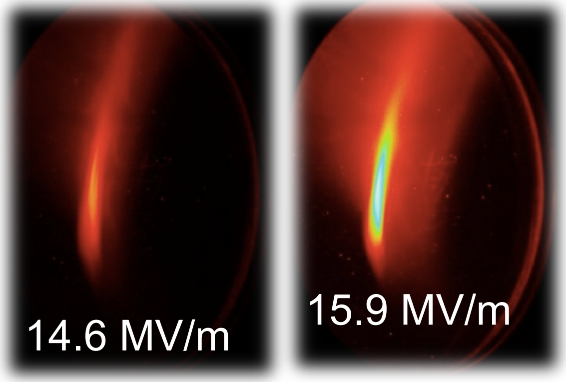




Q-measurement history

- Cavity Q suffered due to application of Pb cathode
- Installation in HoBiCaT → significant degradation
- 10's nA of dark current from cathode. Improved by laser cleaning (excimer laser) but Q dropped slightly further
- Solenoid close to cavity but no performance Q degradation due to solenoid observed





Dark current focussed by SC solenoid (before laser cleaning)

Stage 1: All SC Photoinjector System

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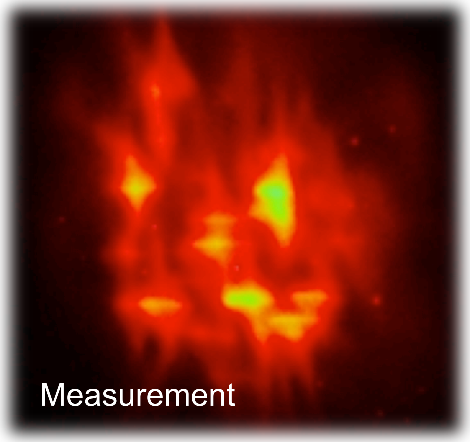
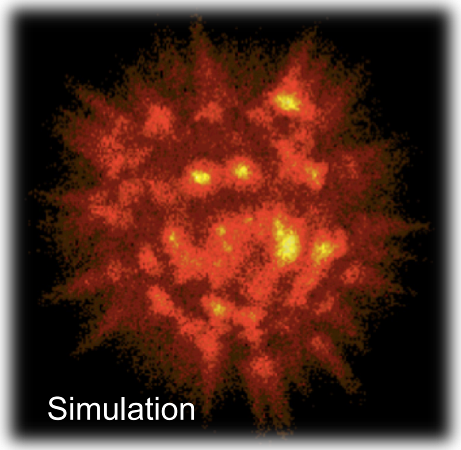
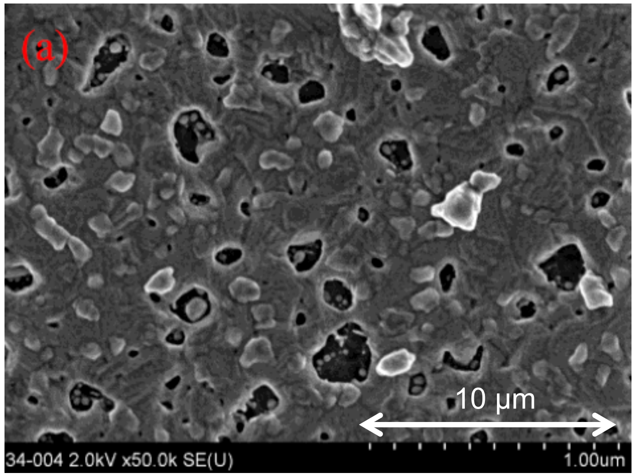
First beam

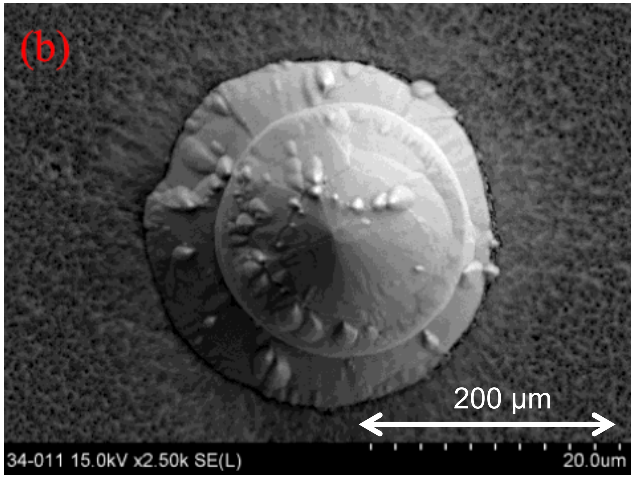
- Pb cathode not evenly coated
  → may explain observed FE and QE variation.
- Emittance about seven times the therm. emittance.
- Irregularities on the cathode modeled and likely source of degradation.
- Misalignment (solenoid, cavity) caused astigmatism and emittance degradation → cold mover essential





J. Völker
(MSc thesis, 2012,
Humboldt U., & IPAC
2012)





G. Lorenz, FHI Berlin

V. Volkov et al., Proc. IPAC 2012

Stage 1.2: All SC Photoinjector System

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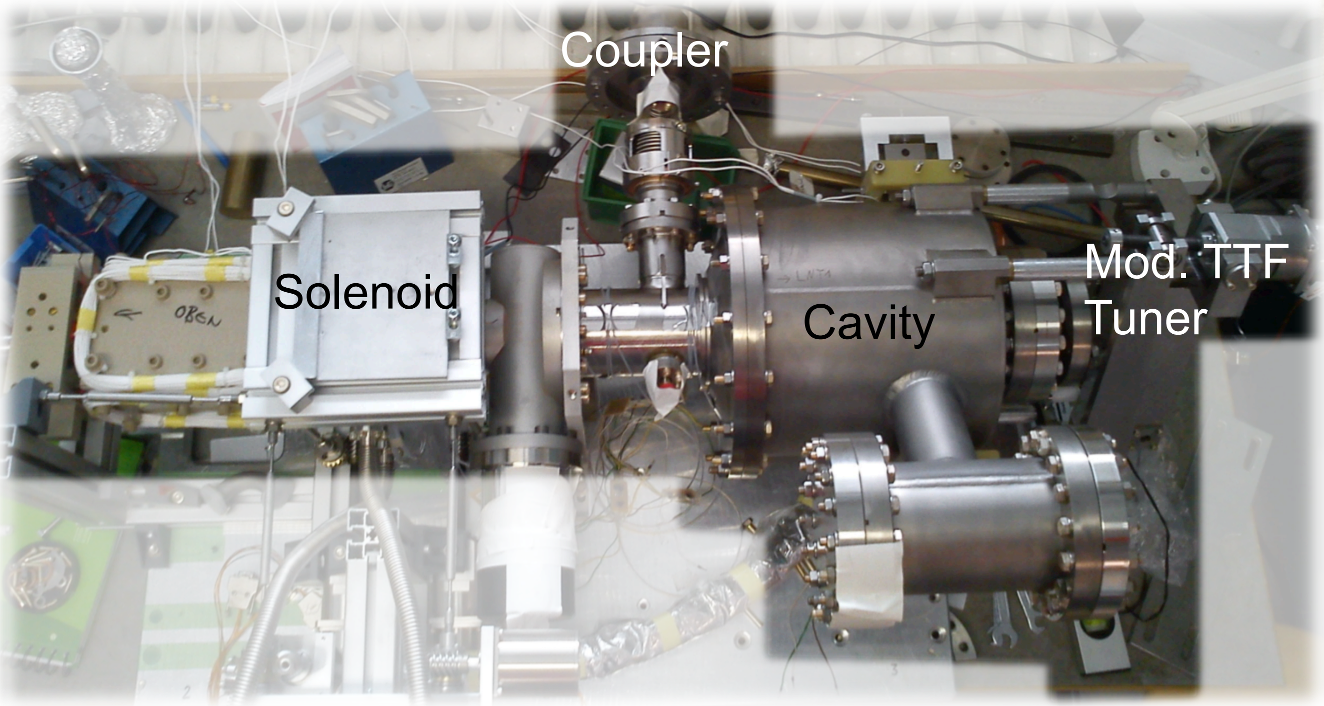
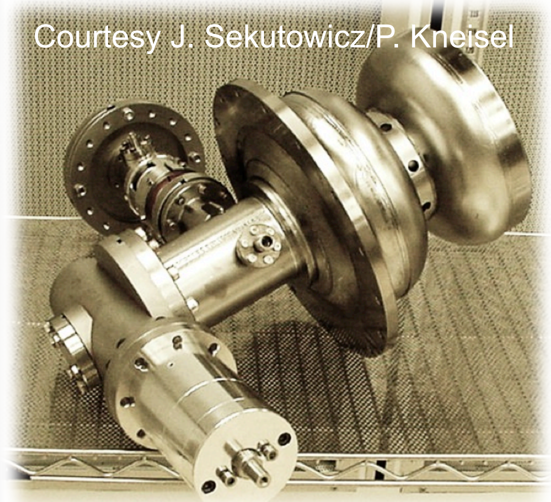
J. Knobloch, TTC Meeting 11-2012

Now include "lessons learned" in a second version of Injector 0

- Includes tuner system
- Demountable cathode plug & helium tank
- Solenoid mover
- Cavity design & production DESY/JLAB



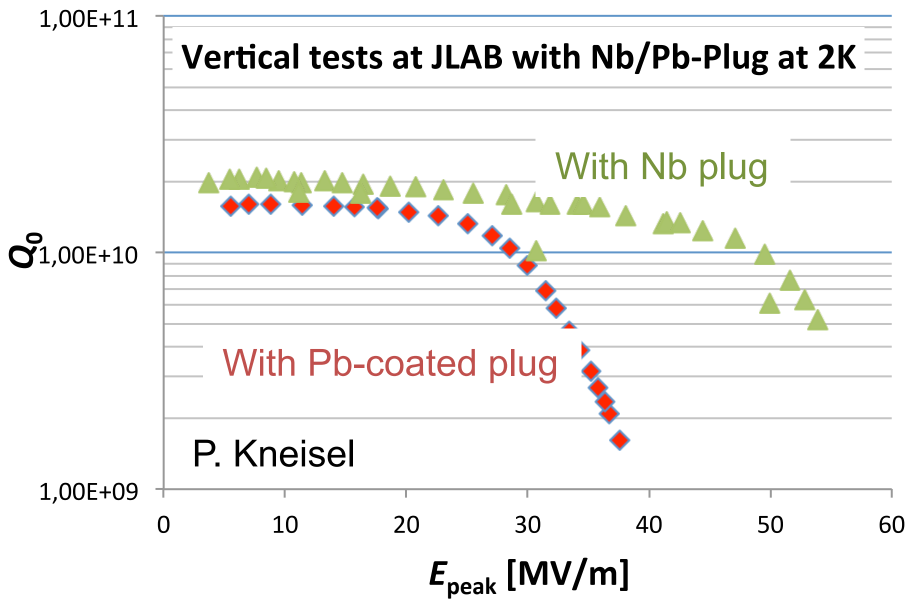


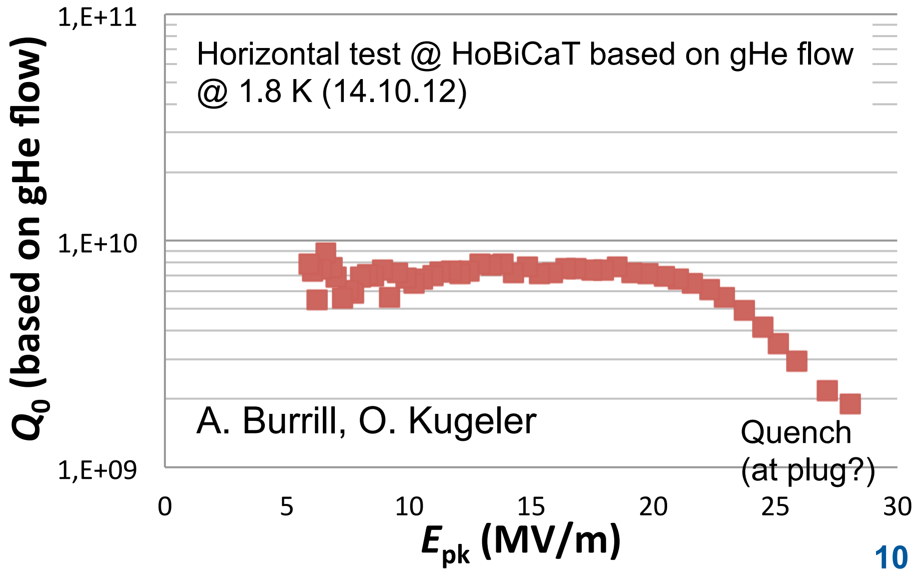
Injector 2.1 as installed at HoBiCaT

Stage 1.2: All SC Photoinjector System

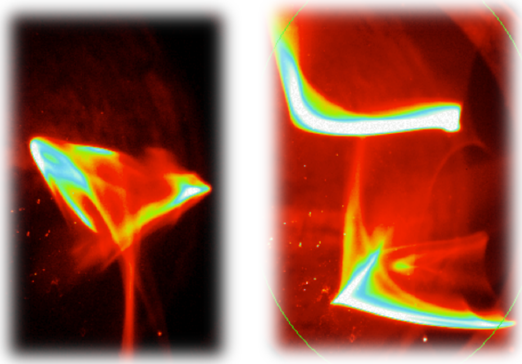
Photoinjector 0.2

- Commiss. @ HoBiCaT under way
- Much less field emission (< 1 nA at 20 MV/m) after much processing
- *Q* lower than in VT but still OK. (Problem =no cold mag. shield=?)
- Measurements ongoing
  - Beam dynamics
  - Solenoid mover
  - LLRF
  - Microphonics and impact on beam

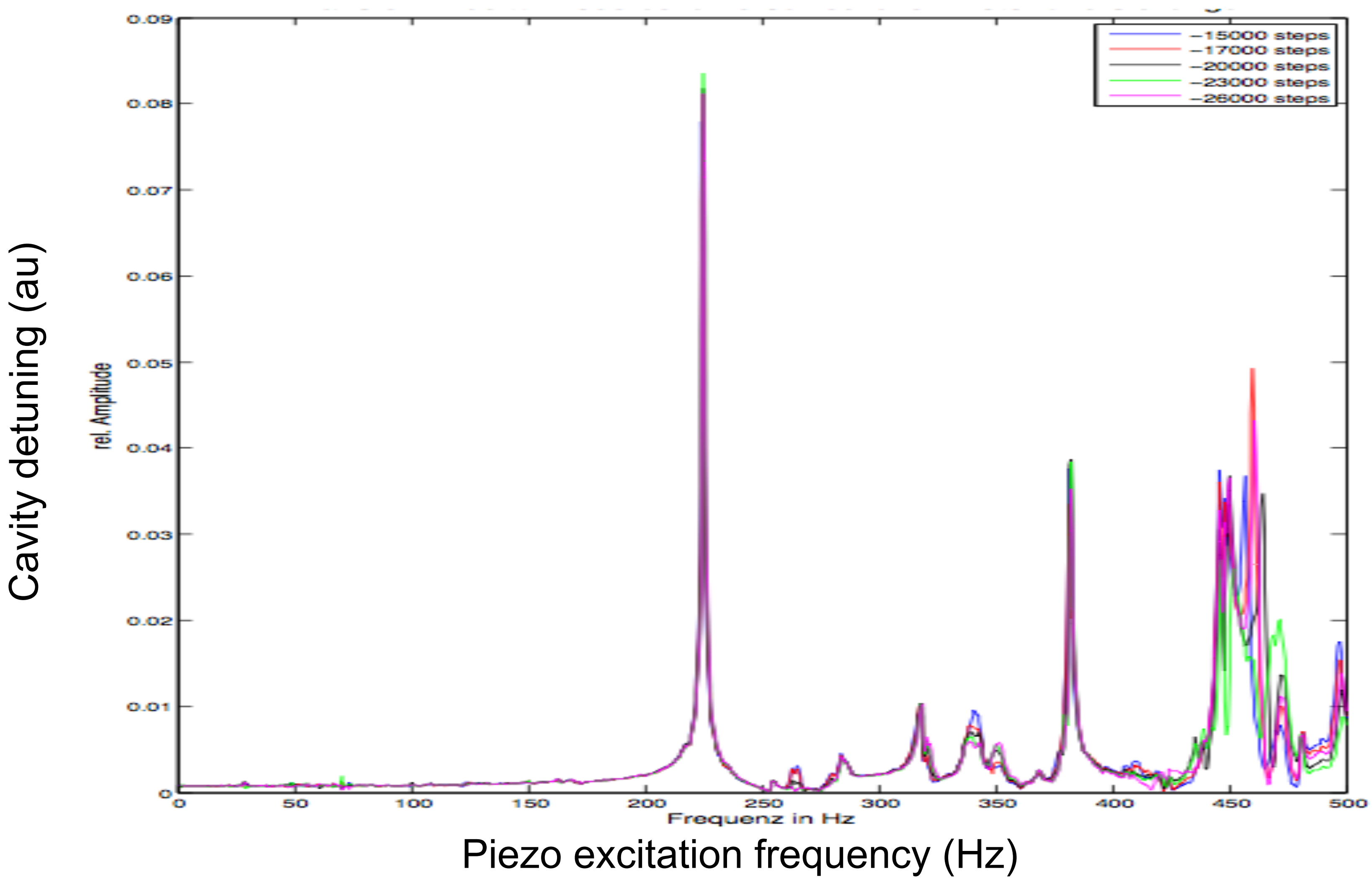




Images of FE current



Transfer-function measurement at different tuner settings



P. Lauinger, A. Neumann, O. Kugeler, HZB

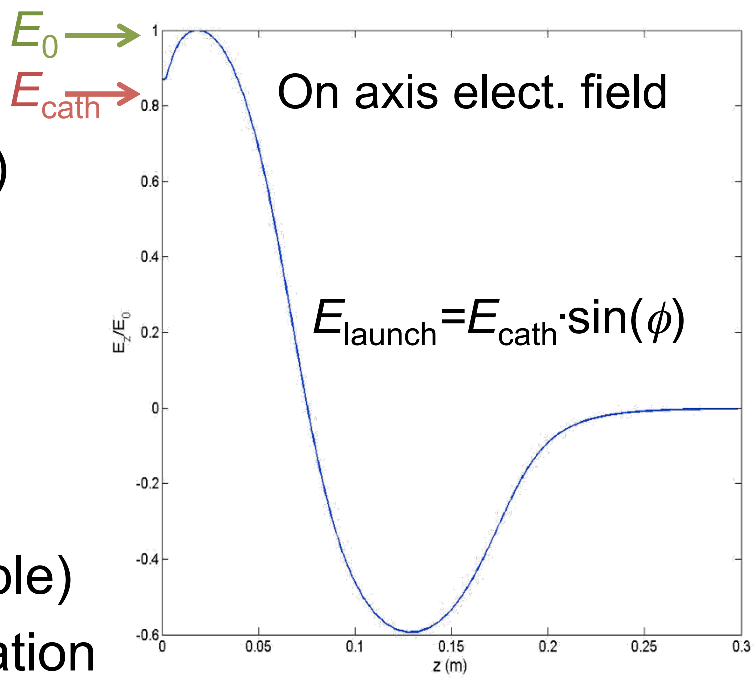
Stage 2: SRF Injector + NC cathode

Intermediate step towards high current gun:

- Optimize cavity shape for beam dynamics
- Include a NC cathode (CsK_2Sb) via choke filter
- Moderate beam loading (< 10 mA): "BESSY-style" TTF-III couplers
- Solenoid mover

What do we care about?

- V_{acc} limited by coupler power (< 2.3 MeV)
- Maximum E-field limited by FE
  → keep E_{pk}/E_0 small.
  → keep $0.6 < E_{cath}/E_0 < 1$.
- Avoid space-charge issues at launch
  → design cavity for max energy gain at ϕ near 90° (high E_{launch} while E_{cath} reasonable)
- RF focusing for beam emittance preservation
- Design cavity for heavy HOM damping.



A. Neumann et al., Proc. LINAC 12
T. Kamps at al., Proc. LINAC 12

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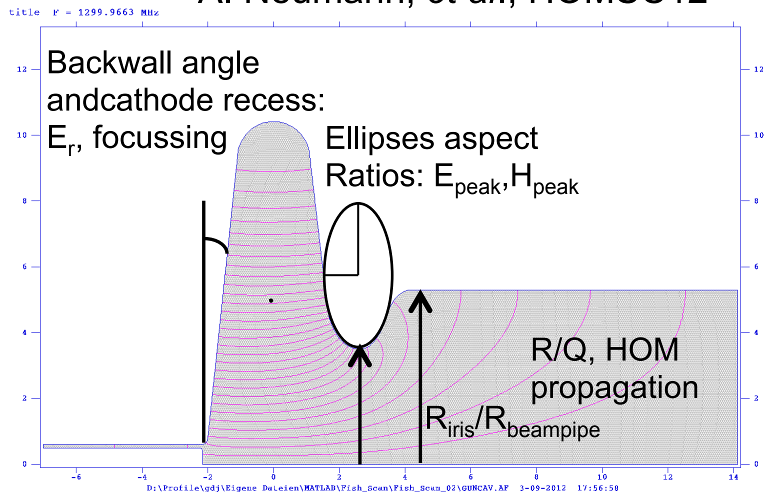
Study two different layouts: 0.x-cell and 1.x-cell

A. Neumann, *et al.*, HOMSC12

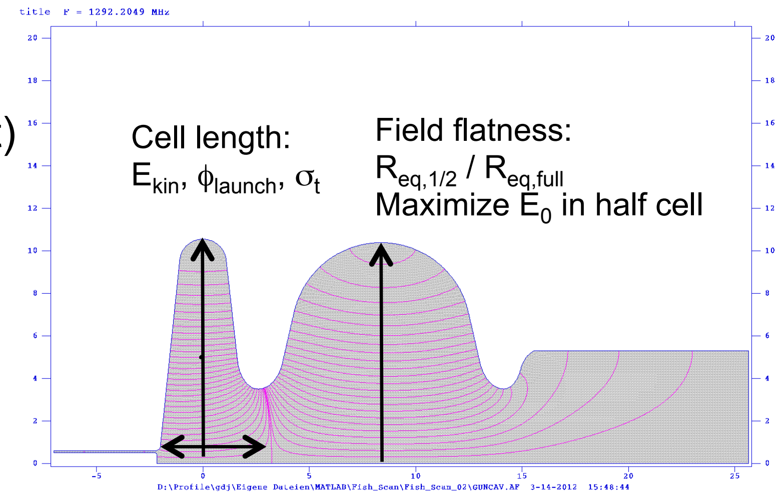
R/Q = 90 Ω
H_{pk}/E_{pk} = 2.3 mT/(MV/m)
E_{pk}/E_0 = 1.5
E_{cath}/E_0 ≈ 0.8

At E_0 = 30 MV/m
E_{pk} = 45 MV/m
E_{kin} = 1.2 MeV
Φ_{launch} = 18 deg
E_{cath} = 24 MV/m
E_{launch} = 7.4 MV/m



R/Q = 150 Ω
H_{pk}/E_{pk} = 2.3 mT/(MV/m)
E_{pk}/E_0 = 1.5
E_{cath}/E_0 ≈ 0.8

At E_0 = 30 MV/m
E_{pk} = 45 MV/m
E_{kin} = 2.4 MeV (coupl. limit)
Φ_{launch} = 50 deg
E_{cath} = 24 MV/m
E_{launch} = 18.4 MV/m

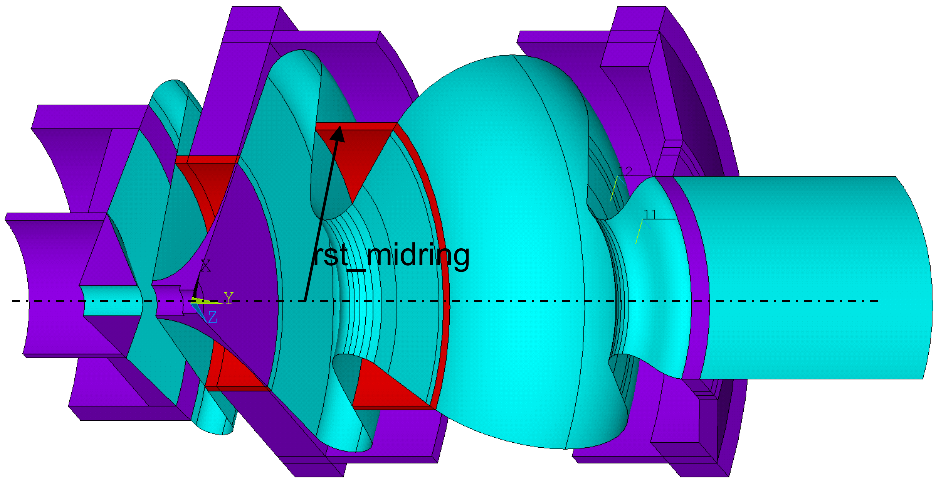


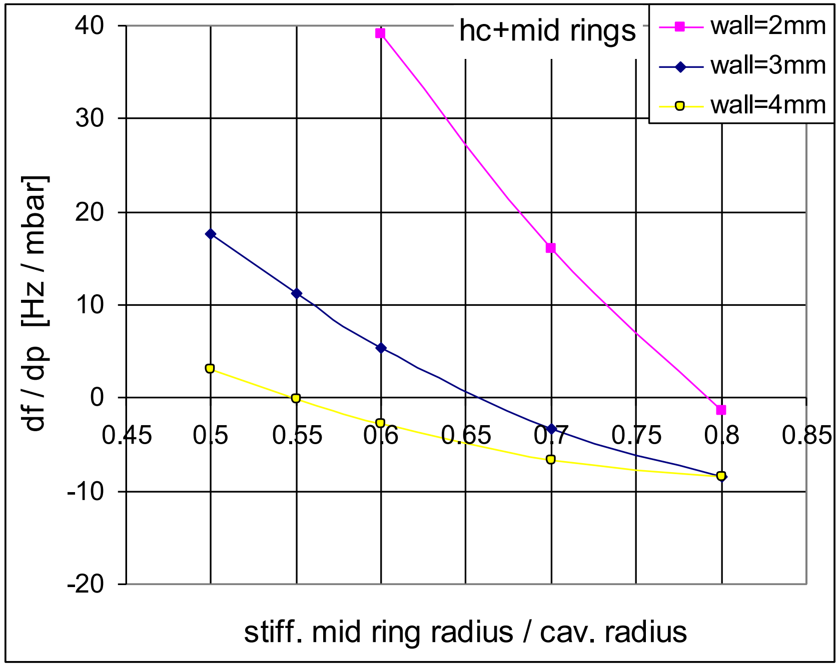
To achieve same kinetic energy, 0.4 cell would have to operate near E_{pk} = 90 MV/m, E_{cath} = 48 MV/m! →
Concentrate on 1.4 cell

Photoinjector 1 design

Mechanical optimization

- EM design is complete. Now mechanical modeling ongoing (E. Zaplatin, FZ-Jülich) to reduce pressure sensitivity.
- Typical: df/dP ≈ 100 Hz/mbar without stiffening (due to back plate)
- Can be reduced to zero with proper placement of stiffening rings and choice of material thickness.

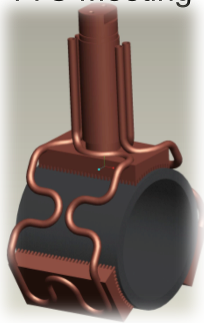




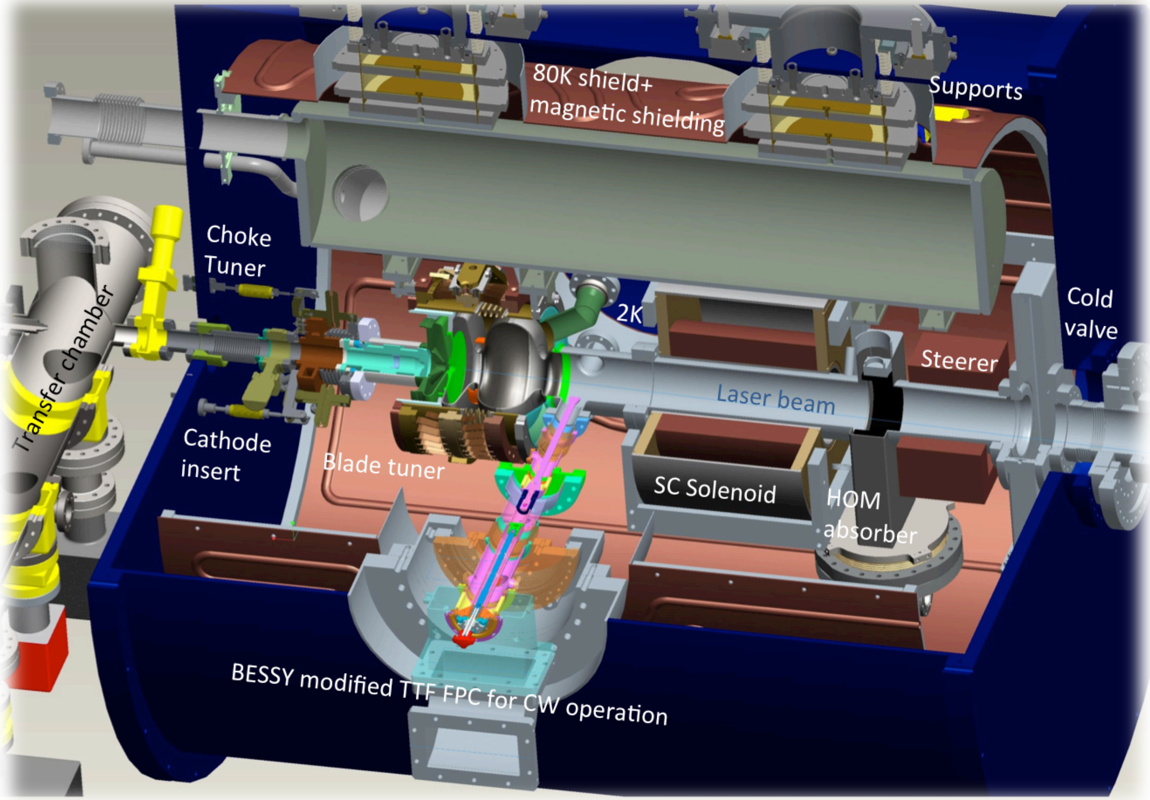
E. Zaplatin, FZJ

Stage 2: Photoinjector 1 design

J. Knobloch, TTC Meeting 11-2012



- Cryomodule concept based on Cornell booster module system
- Cathode insert/choke filter based on HZDR design
- HOM absorber: based on SiC design (DESY)



First tests

- Mid 2014 @ HoBiCaT/gunlab (low average current)
- Early 2016 @ B*ERL*inPro (> 1 mA)

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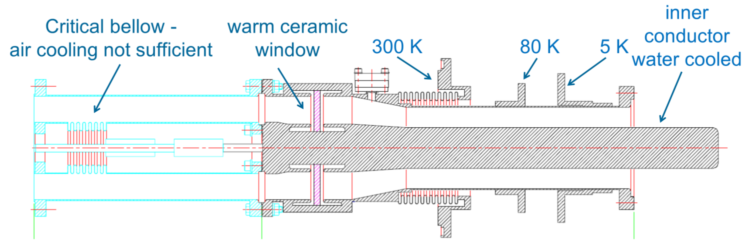
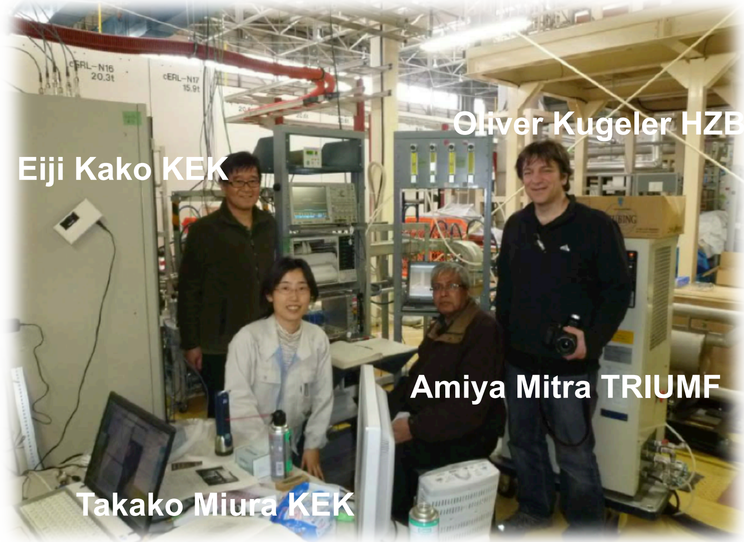
Final step: 100-mA capable photoinjector

- Lessons learned regarding photocathode
- Lessons learned regarding beam dynamics
- Lessons learned regarding HOMs
- …



- High power couplers (120 kW each) based on KEK design.
  - Must be modified to increase power capability (warm part). Current limit 40 kW.
  - Must be modified to permit horizontal installation in cryomodule.
- First beam with Injector 2: 2016, > 10 mA ops by 2017



ACKNOWLEDGEMENTS

Many labs are key to the development of the injector

Apologies if this list is incomplete!

- **DESY** (J. Sekutowicz)
  - Design and tests of Injector 0.1 and 0.2, HOM absorber
- **HZDR** (P. Michel, J. Teichert, A. Arnold, P. Mulczek)
  - Production of Injectors 0.1 via CRADA with JLAB
  - Cathode insert mechanism for Injector 1
  - Photocathode studies + more …
- **JLAB** (P. Kneisel)
  - Production/preparation/vertical tests of Injector 0 and Injector 1
- **Cornell University**
  - Booster cryomodule design
- **National Centre for Nuclear Research** (R. Nietubyc)
  - Coating of Pb cathodes
- **Max-Born Institut** (I. Will)
  - Development and commissioning of UV photocathode laser
- **Brookhaven National Lab** (J. Smedley)
  - Commissioning Injector 0.1 and laser cleaning
  - Production of photocathodes
- **KEK** (E. Kako)
  - High-power coupler systems
- **Budker Institut** (V. Volkov)
  - Gun simulations, incl. dark current simulations
- **FZ-Jülich** (E. Zaplatin)
  - Photoinjector RF and mechanical simulations
- **UCLA** (P. Musumeci)
  - Beam diagnostics
- **TU Dortmund** (T. Weis, A. Ferrarotto)
  - Beam instrumentation
- **JGU Mainz, Moscow State U, St. Petersberg State Polytechnik**
  - Photocathode development

The HZB team

W. Anders, M. Abo-Bakr, R. Barday, D. Böhlick, A. Frahm, M. Dirsat, F. Hoffmann, A. Jankowiak, T. Kamps, J. Knobloch S. Klauke, O. Kugeler, J. Rudolph, A. Matveenko, A. Neumann, T. Noll, T. Quast, M. Schenk, M. Schuster, S. Schubert, J. Völker