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EuCARD WP SRF Meeting, Paris, France
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Slice emittance measurements at HZDR and Pb cathode SRF gun at HZB

Part 1:
Slice emittance measurements at HZDR

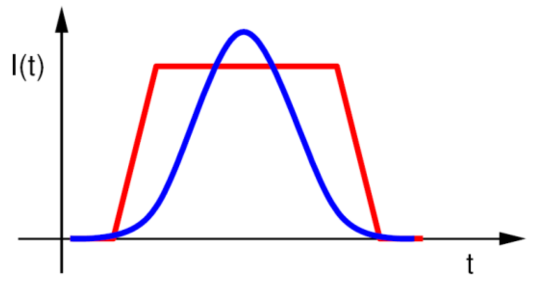
an appetizer, see presentation by J. Rudolph (PhD student at HZB) at EuCARD Annual Meeting in Paris on 13.05.2011

work done by J. Rudolph, A. Arnold, M. Abo-Bakr, M. Justus, T. Kamps, U. Lehnert, J. Teichert and R. Xiang

supported by the ELBE crew and the Accelerator Physics group at HZB.

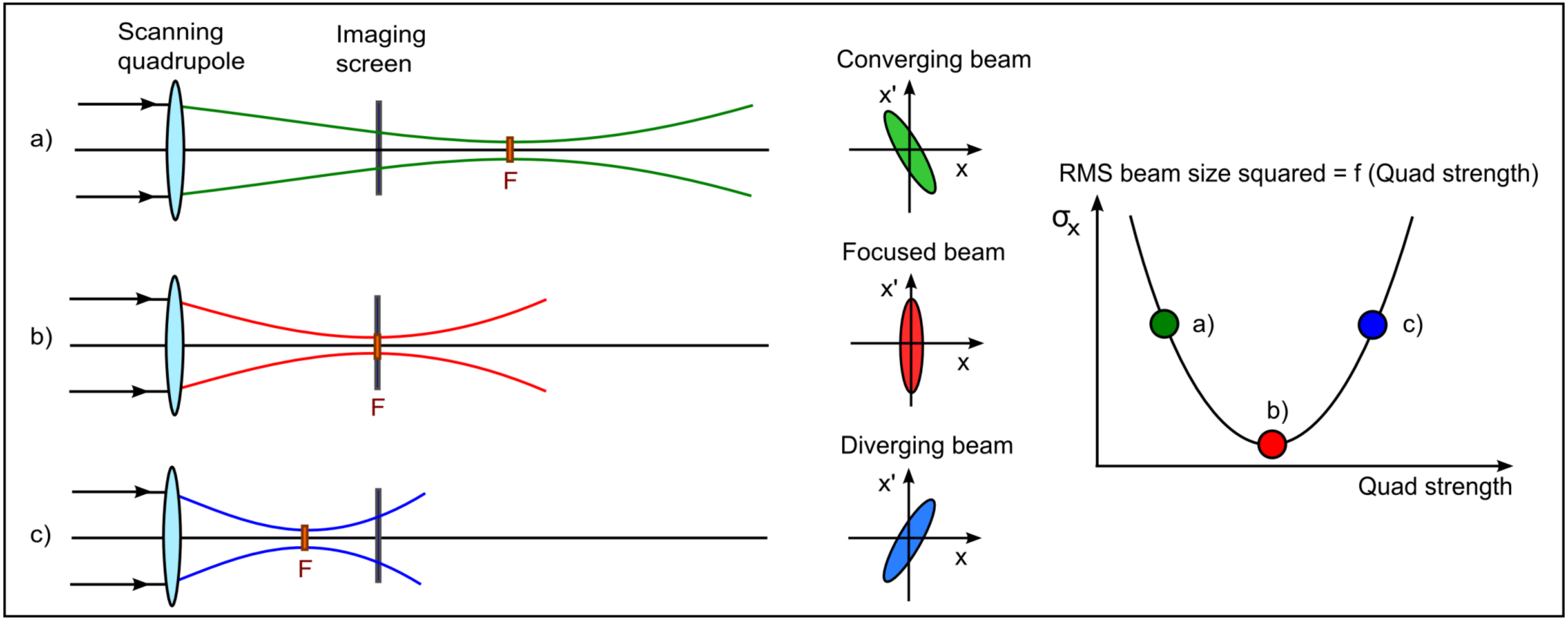
WP 10.7.1 Slice measurements of beam parameters at ELBE

- Transverse beam emittance in linear accelerator is determined by beam dynamics processes involving (among others) space-charge and RF focusing
- These processes depend on local current distribution (space-charge) and are also time-dependent (RF focusing)
- Resolve time-dependent beam dynamics with slice diagnostics - → need to measure slice emittance, energy spread
- Combine quad scan with time-sensitive measurement like zero-phasing
- Do this at the ELBE linac



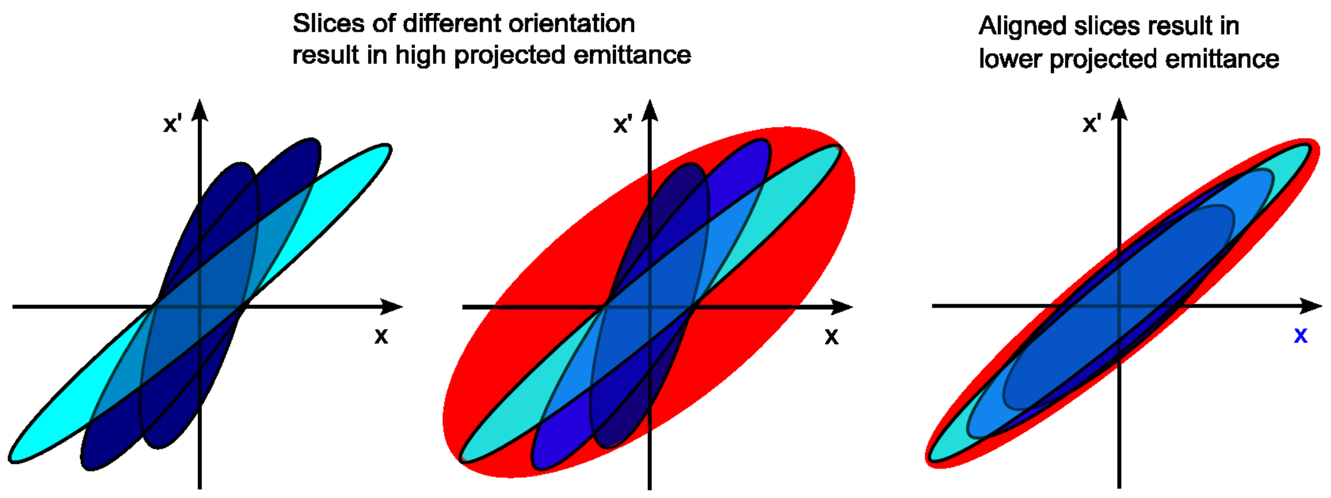
Emittance Measurement: Quadrupole Scan Technique

- Quadrupole scan technique: vary quadrupole strength and measure beam size on screen
- RMS beam size on screen is a function of quadrupole strength
- Determine sigma matrix elements from fitting procedure → calculate emittance



From Projected Emittance to Slice Emittance

- Normally: image beam on screen, measure projection of whole bunch
  - → 'Projected emittance'
- 'Slice Emittance': emittance as function of longitudinal position in bunch
  - Slices experience different focusing effects
  - Relevant for: emittance compensation schemes, FEL operation

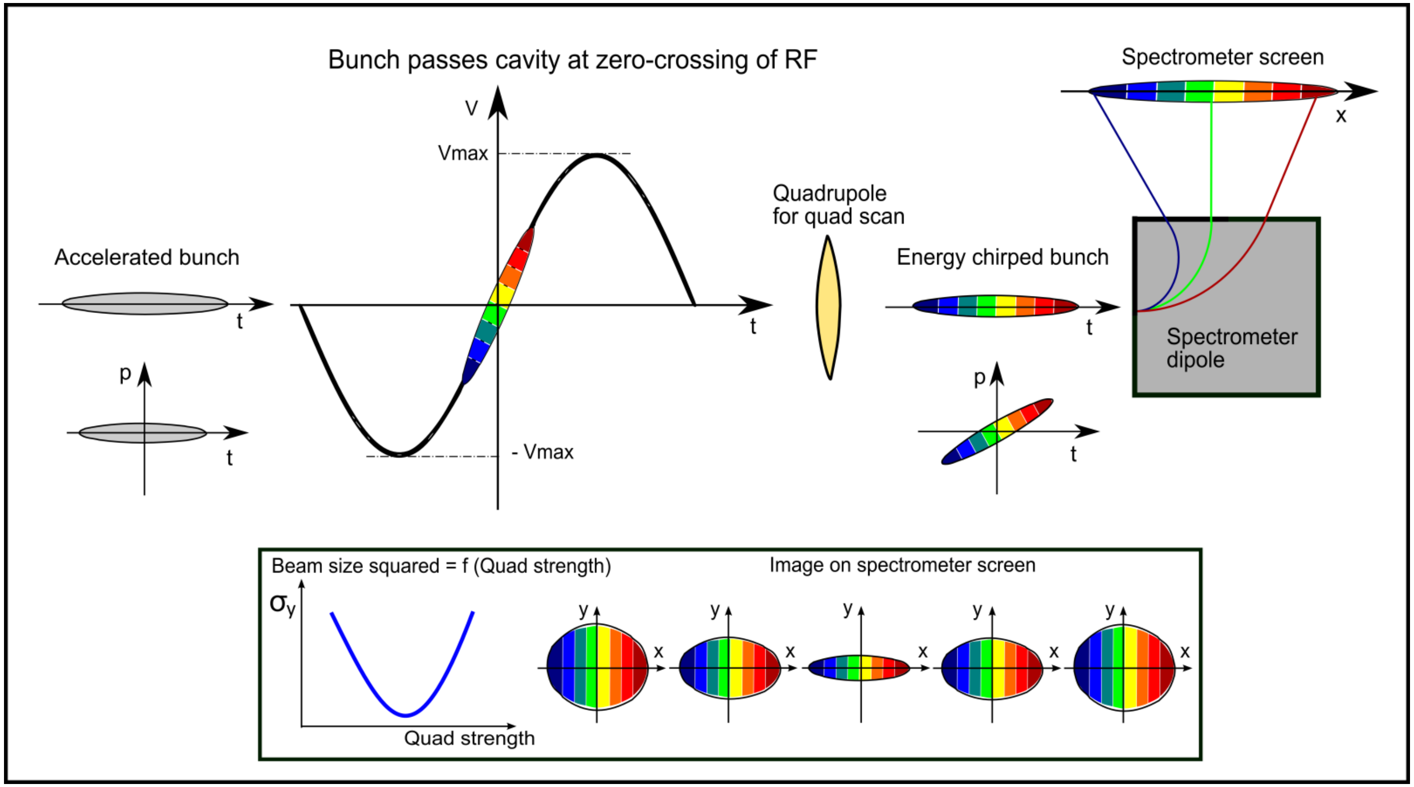


Blue: Slices of different emittance and orientation
Red: Resulting projected emittance

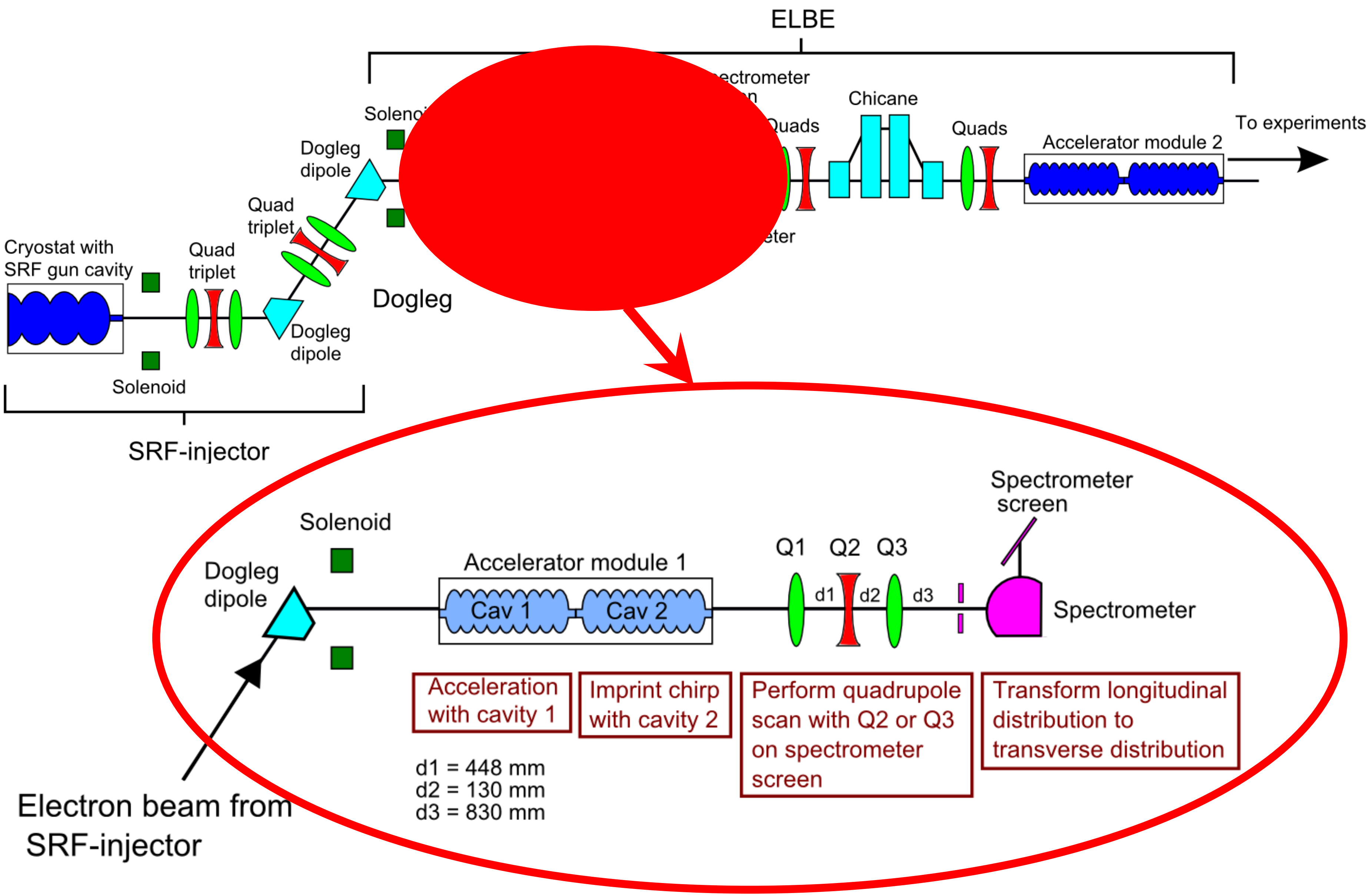
- Find a way to access slices and measure emittance
  → convert longitudinal distribution to transverse distribution
- How do we do that? → Zero-Phasing: Chirped energy beam + spectrometer dipole

Principle of Zero-Phasing Technique for Slice Diagnostics

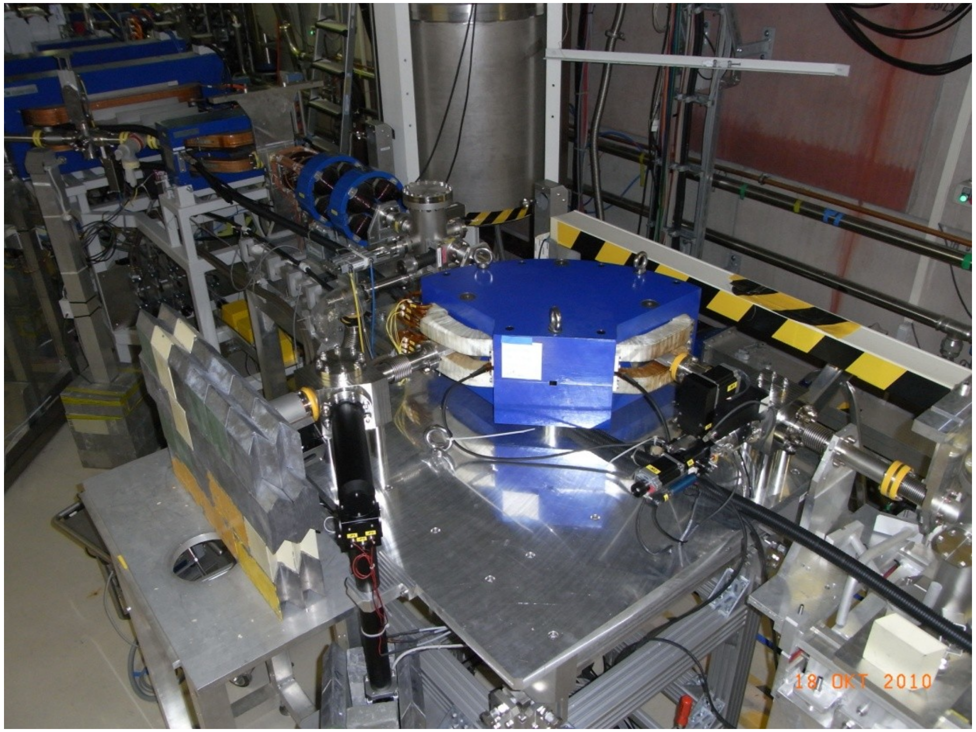
- Bunch passes cavity at zero-crossing of RF phase → correlation between energy and longitudinal bunch position
- Chirped beam send through spectrometer → longitudinal distribution transferred to transverse distribution → longitudinal slices accessible
- Beam size in **vertical** direction for each longitudinal slice measured
- Combination with quadrupole scan technique allows to reconstruct the vertical emittance for different slices

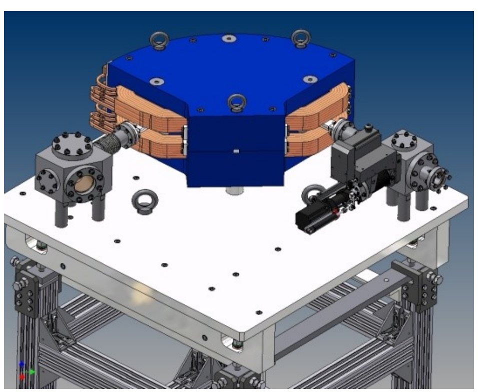


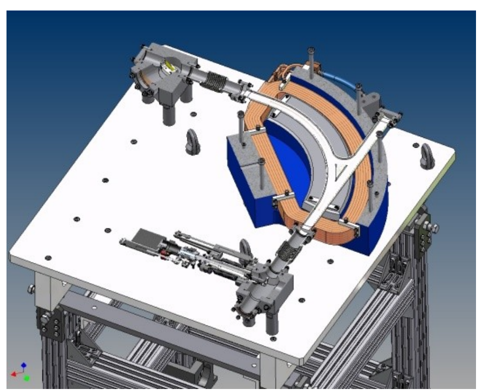
Optics Setup for Zero-Phasing at ELBE

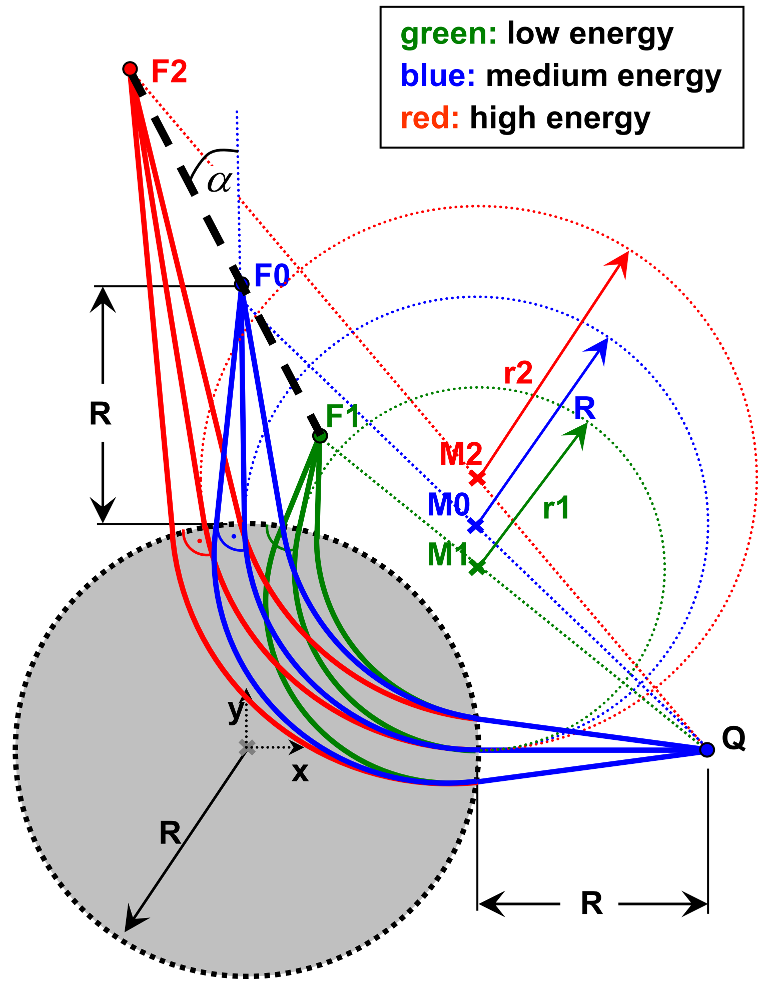


Browne-Buechner Spectrometer





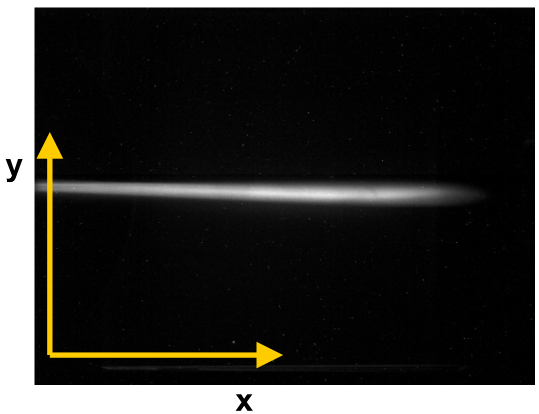


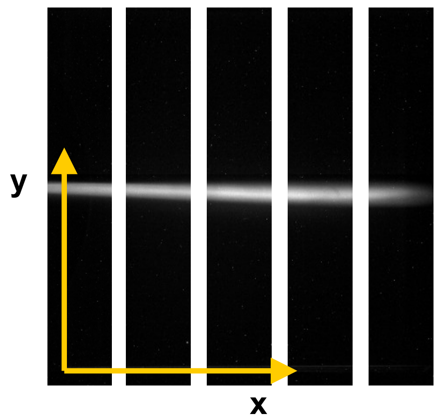


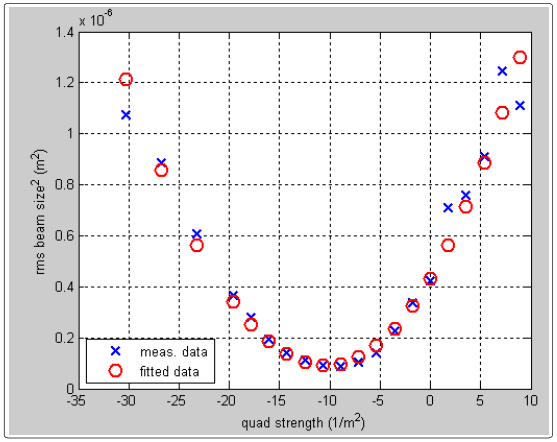
Overview: First Measurement and Analysis Procedure

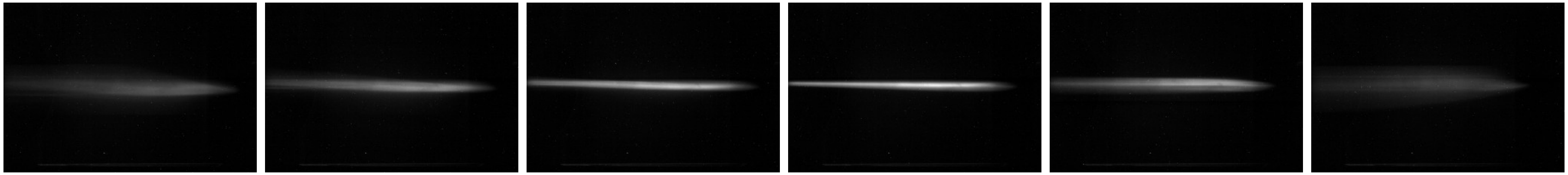
- Measurements performed at ~18 MeV and 10 pC for different phase settings of gun cavity and 2. linac cavity, spectrometer slit width 20 mm

- Projection over y for each slice, calculate vertical rms beam size
- Energy information used to start ‘elegant’ simulation to determine energy dependent transfer matrices (m33 and m34 needed)
- Calculate emittance from beam size and matrix elements using least-squares fit
- Position on screen → energy deviation → cav. phase → position in bunch
- Slice definition: numbering of slices: left to right in bunch position profile plot





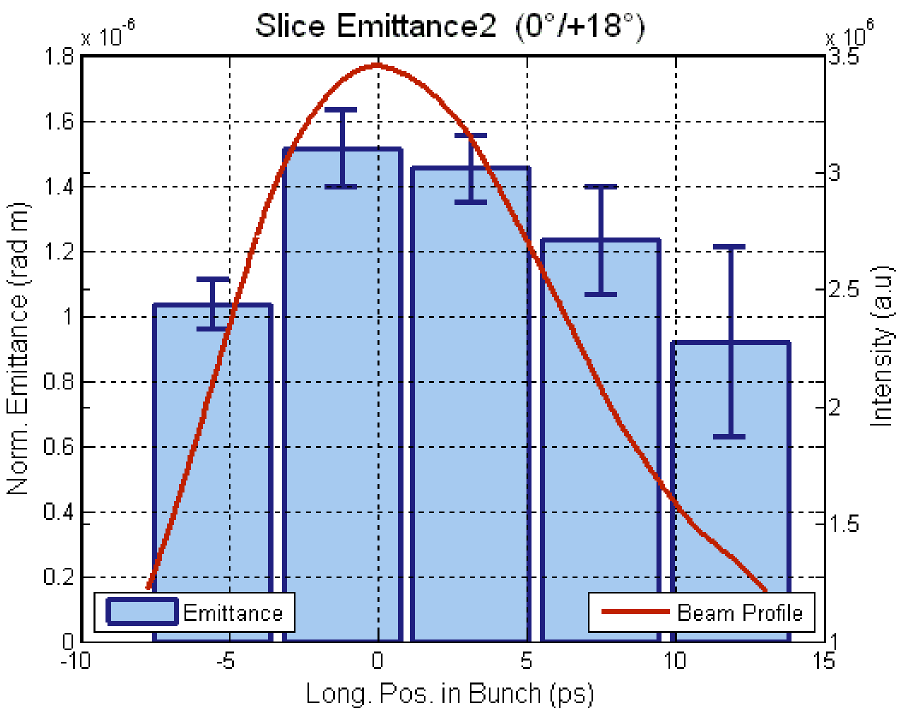


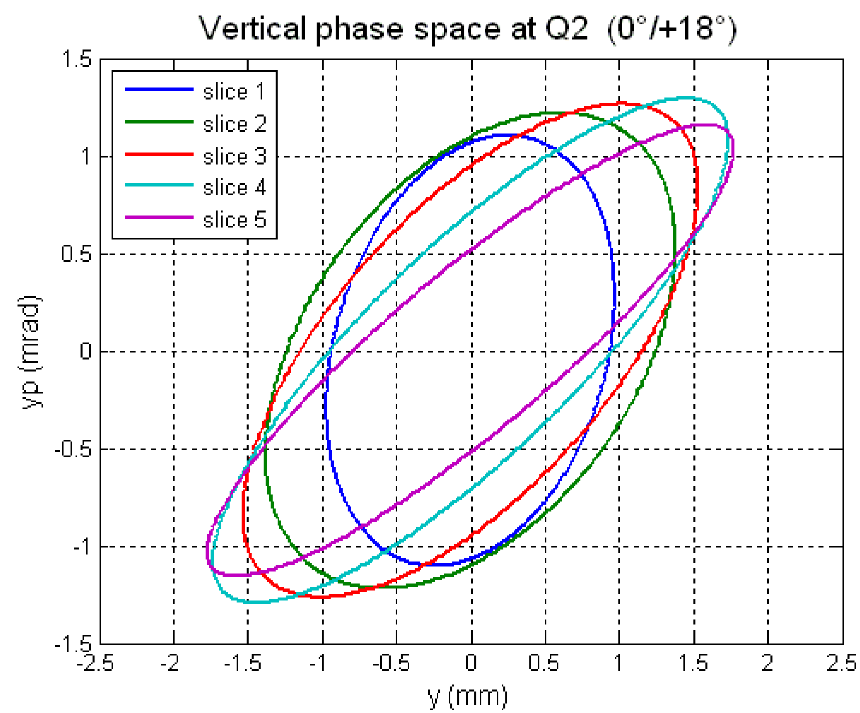


Slice Emittance Results – Series 2

slice	emitt +/- emittErr	beta + /- betaErr	alpha + /- alphaErr	gamma +/- gammaErr
1	1.035e-006 +/- 7.715e-008	9.09e-001 +/- 6.32e-002	-2.63e-001 +/- 5.05e-002	1.18e+000 +/- 6.00e-002
2	1.514e-006 +/- 1.186e-007	1.25e+000 +/- 8.74e-002	-4.81e-001 +/- 6.85e-002	9.82e-001 +/- 6.36e-002
3	1.453e-006 +/- 1.017e-007	1.61e+000 +/- 6.65e-002	-8.81e-001 +/- 5.03e-002	1.10e+000 +/- 4.47e-002
4	1.232e-006 +/- 1.668e-007	2.44e+000 +/- 9.50e-002	-1.52e+000 +/- 6.98e-002	1.36e+000 +/- 5.79e-002
5	9.209e-007 +/- 2.911e-007	3.41e+000 +/- 1.93e-001	-1.99e+000 +/- 1.34e-001	1.45e+000 +/- 9.89e-002

- rms bunch length: 5.4 ps



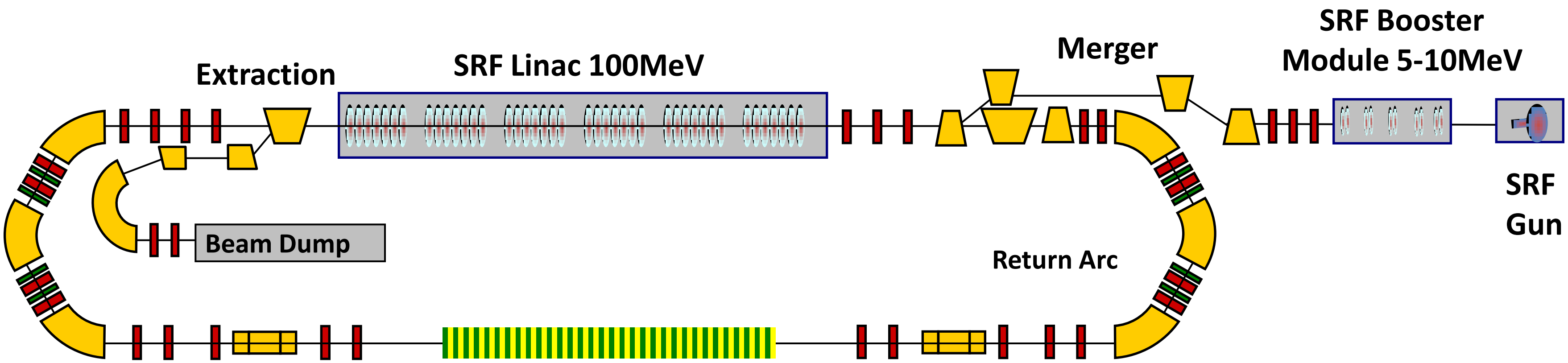


Part 2:
The Pb cathode SRF gun at HZB

work done by T. Kamps, W. Anders, R. Barday, D. Böhlick, A. Frahm, M. Dirsat, F. Hoffmann A. Jankowiak, S. Klauke, J. Knobloch, O. Kugeler, J. Rudolph, A. Matveenko, A. Neumann, T. Quast, M. Schenk, M. Schuster, S. Schubert , P. Kneisel (JLAB), R. Nietubyc (Soltan), J. Sekutowicz (DESY), J. Smedley (BNL), J. Teichert (FZD), V. Volkov (BINP), I. Will (MBI)

supported by the Accelerator Physics, SRF and Experimental Support groups at HZB.

At HZB we are working on BERLinPro, a physics and technology study for an Energy Recovery Linac



Max. beam energy	100 MeV
Max. average current	100 mA
Nominal bunch charge	77 pC
Max. rep. rate	1.3GHz
Normalized emittance	< 1mm mrad
Cryo load @ 1.8K	240 W

The SRF Gun needs to fulfill these challenging target parameters

What are the challenges and current limits for SRF guns with respect to our target beam parameters?

- HZDR/ELBE gun shows feasiblity of the SRF gun concept
  → SRF cavity with normal-conducting cathode works!
- For our application, we need different performance:
  - Beam dynamics: How can we have more control on the transverse and longitudinal beam parameters? Mainly determined by field on cathode and setup of any focusing elements.
  - Average current: How can we generate 100 mA? Need cathode with high QE at VIS, which can operate in SRF environment.
  - Average power: How can we couple P_{avg} = 100 mA x E_b power into the SRF cavity?

Put these three questions into three stages

Stage 1 is a beam demonstrator experiment with SC Pb cathode (2011), study beam dynamics, cavity performance

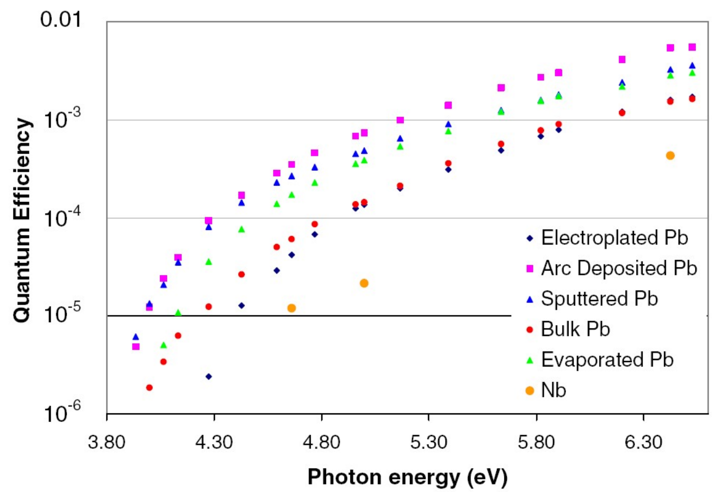
During Stage 2 add NC cathode with high QE at VIS, study cathode lifetime, slice/projected emittance performance (2013)

In Stage 3 add RF input power coupler for 200 kW (2014), study high power operation

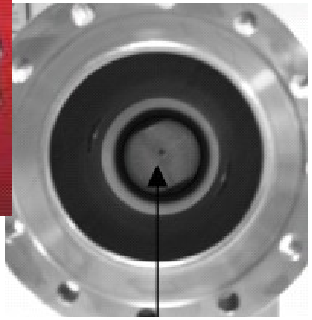
Parameter	HoBiCaT Stage 1	Source lab Stage 2	BERLinPro Stage 3
Goal	Beam Demonstrator	Brightness R&D gun	Current Production gun
Electron energy	≥ 1.5 MeV		
RF frequency	1.3 GHz		
Design peak field	≤ 50 MV/m		
Operation launch field	≥ 10 MV/m		
Bunch charge	≤ 77 pC		
Repetition rate	30 kHz	54 MHz / 25 Hz	1.3 GHz
Cathode material	Pb	CsK_2Sb	CsK_2Sb
Cathode QE	5*10^-4 at 258 nm	10^-1 at 532 nm	10^-1 at 532 nm
Laser wavelength	258 nm	532 nm	532 nm
Laser pulse energy	0.15 µJ	1.8 nJ	1.8 nJ
Laser pulse shape	Gaussian	Flat-top	Flat-top
Laser pulse length	2.5 ps FWHM	≤ 20 ps	20 ps
Average current	0.5 µA	≤ 10 mA / 0.1 mA	100 mA

Stage 1 takes advantage of the work done by Jacek Sekutowicz & Co for the hybrid Nb/Pb gun cavity

- Utilitzes a thin Pb film on the backwall of cavity as photo-electron emitter
- Pb is also a superconductor of type I with H_{crit} = 8 mT at 1.3 GHz and 2K, and has QE at least one order of magnitude higher than bare Nb backwall
- Started with this idea and added few things to get beam as quickly as possible

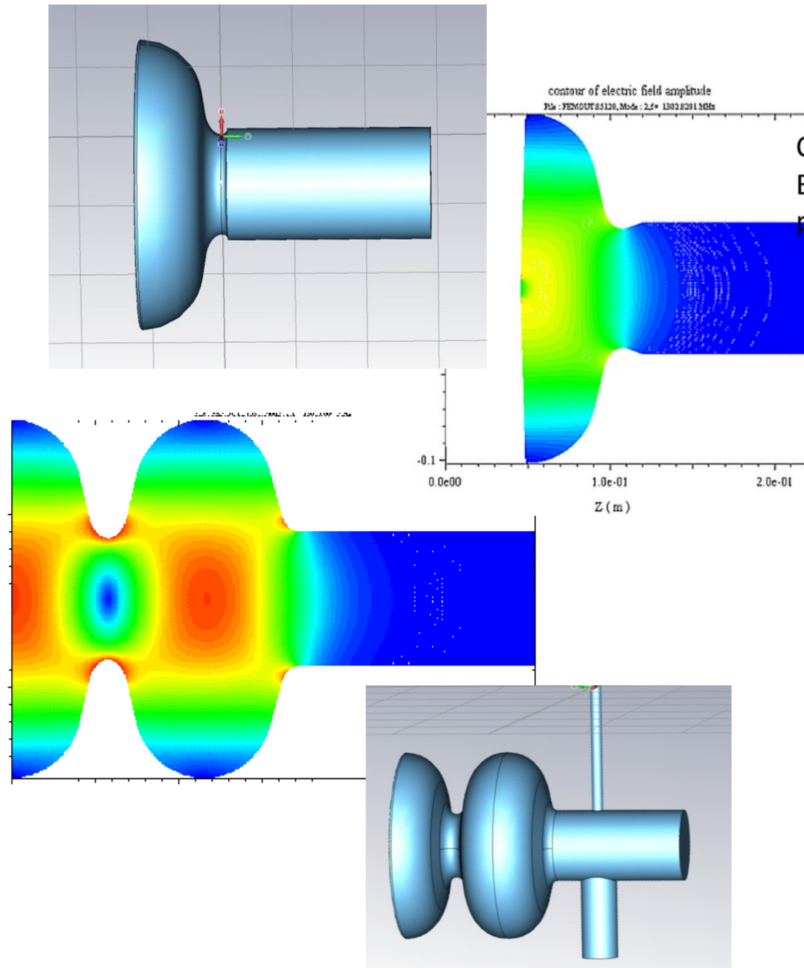


J. Smedley et al., PRST-AB 11, 013502 (2008)

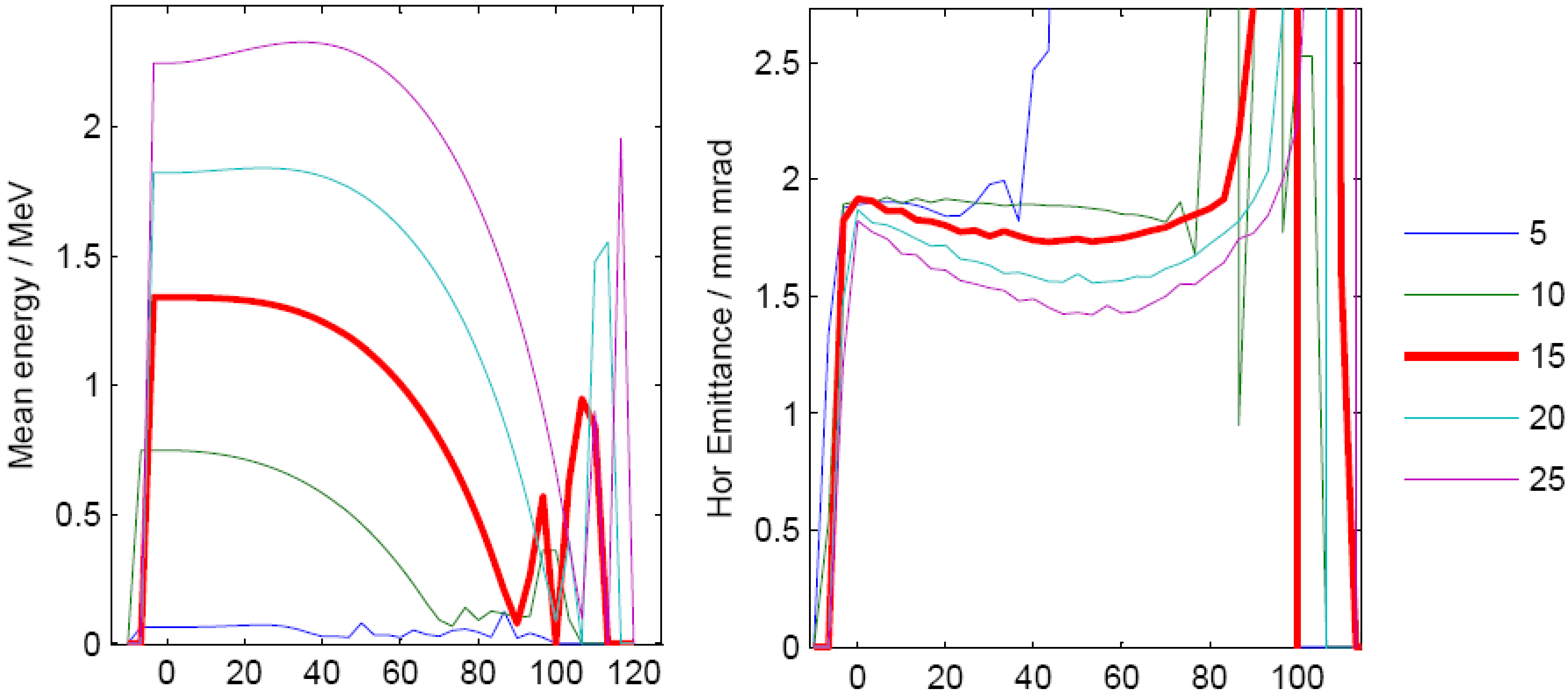


Optimize cavity design to get good control on transverse and longitudinal beam parameters

- Have > 10 MV/m on cathode during extraction and > 1 MeV after gun exit
- Frequency of accelerating mode set to 1.3 GHz like for the booster and man linac modules.
- Start with ½ cell
- Transverse emittance ok, but longitudinal performance not satisfactory.
- Add one or more cells to ½ cell structure to improve longitudinal pulse compression →1 ½ cell design.



Beam dynamics simulation of gun performance

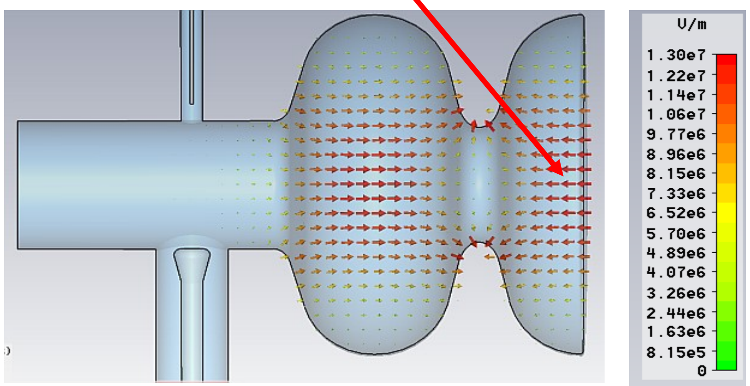


ASTRA simulation of energy and emittance versus injection phase.
Electron bunch has 10 pC charge in 1 ps RMS pulse length

Turning the physics design of the SRF cavity into engineering design compatible with operation in HoBiCaT

Target for em design was to optimze electric field on cathode

Need to add stiffening to back-plane as Helium pressure fluct-uations cause frequency shift of fundamental mode



Type	JS	SuperFish	CST MWS	measured
without	662	527	615	-
short bar	199	200	-	474
long bar	131	130	-	-
spider	-	-	-	146

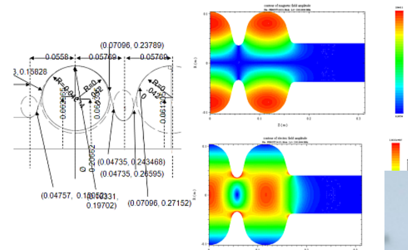
(All values are given in Hz/mbar)

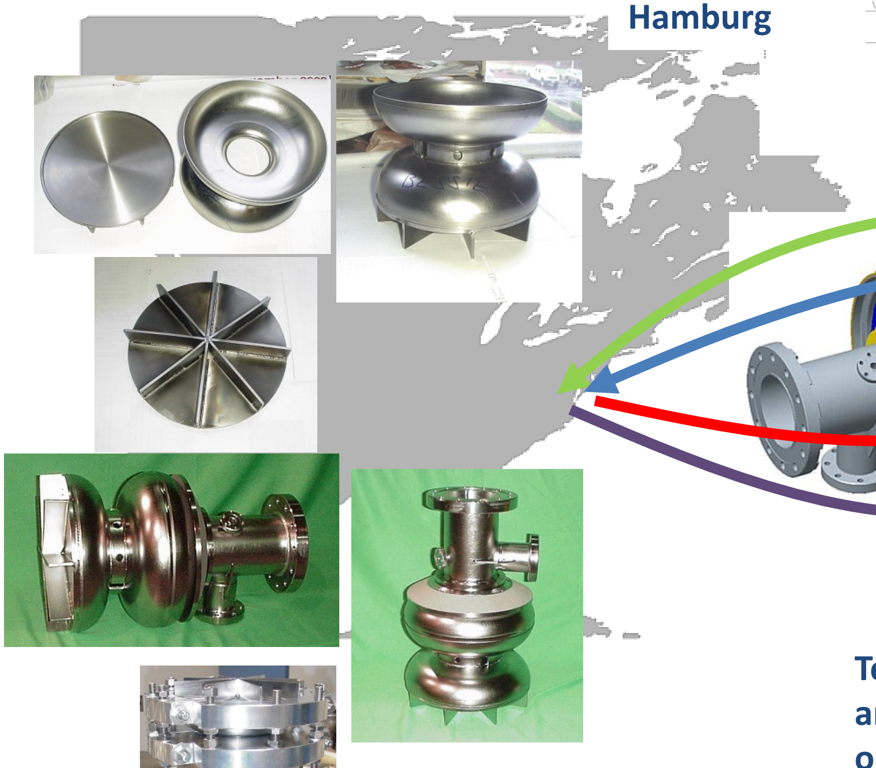
Frequency π-mode	1300 MHz
E_{peak}/E_{acc} (β=1)	1.86
H_{peak}/E_{acc}	4.4 mT/(MV/m)
Geometric factor	212 Ω
R/Q (linac, β=1)	190 Ω

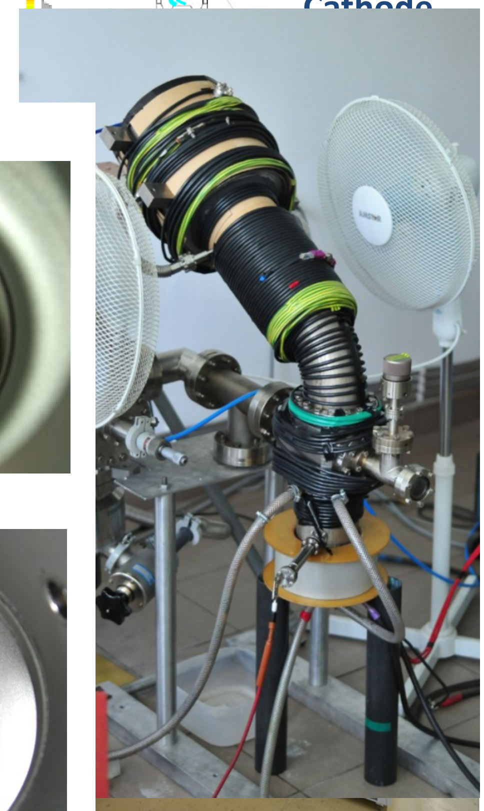
With I_b < 2 µA and E_b < 3.8 MeV can run with 700 W forward power from solid state amp.

The cavity collected some 20.000 air miles… keeping its Q vs E_{pk} performance…

EM Design at DESY in Hamburg





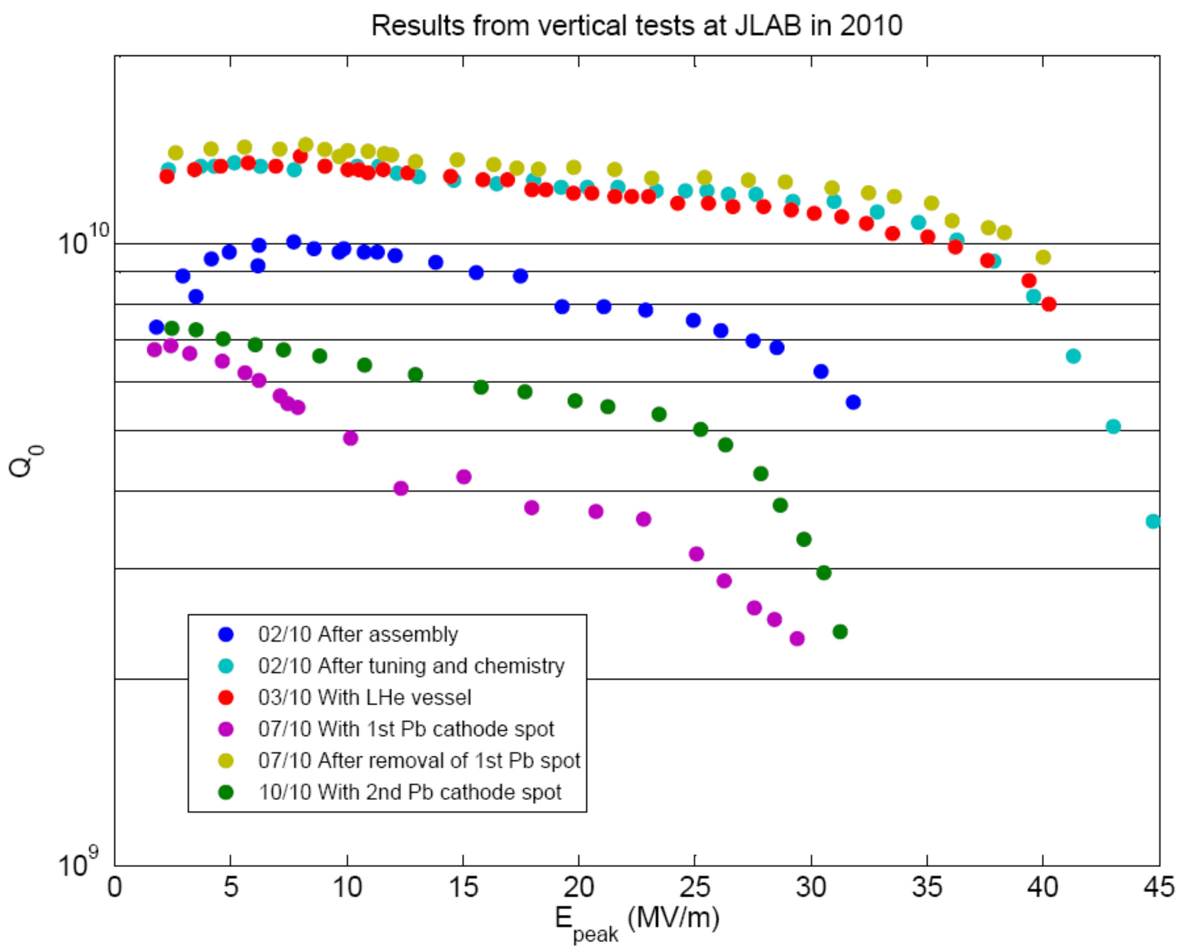


before

after

Production, RF-tests, Cleaning at JLAB in Newport News

Results from vertical tests at JLAB, from assembly of cavity to delivery for Berlin



02/10 Initial test after assembly, tuning, BCP etching and rinsing of the cavity. The field flatness was only 66%.

02/10 Further tuning improved field flatness to 94%, the following BCP treatment improved the RF performance.

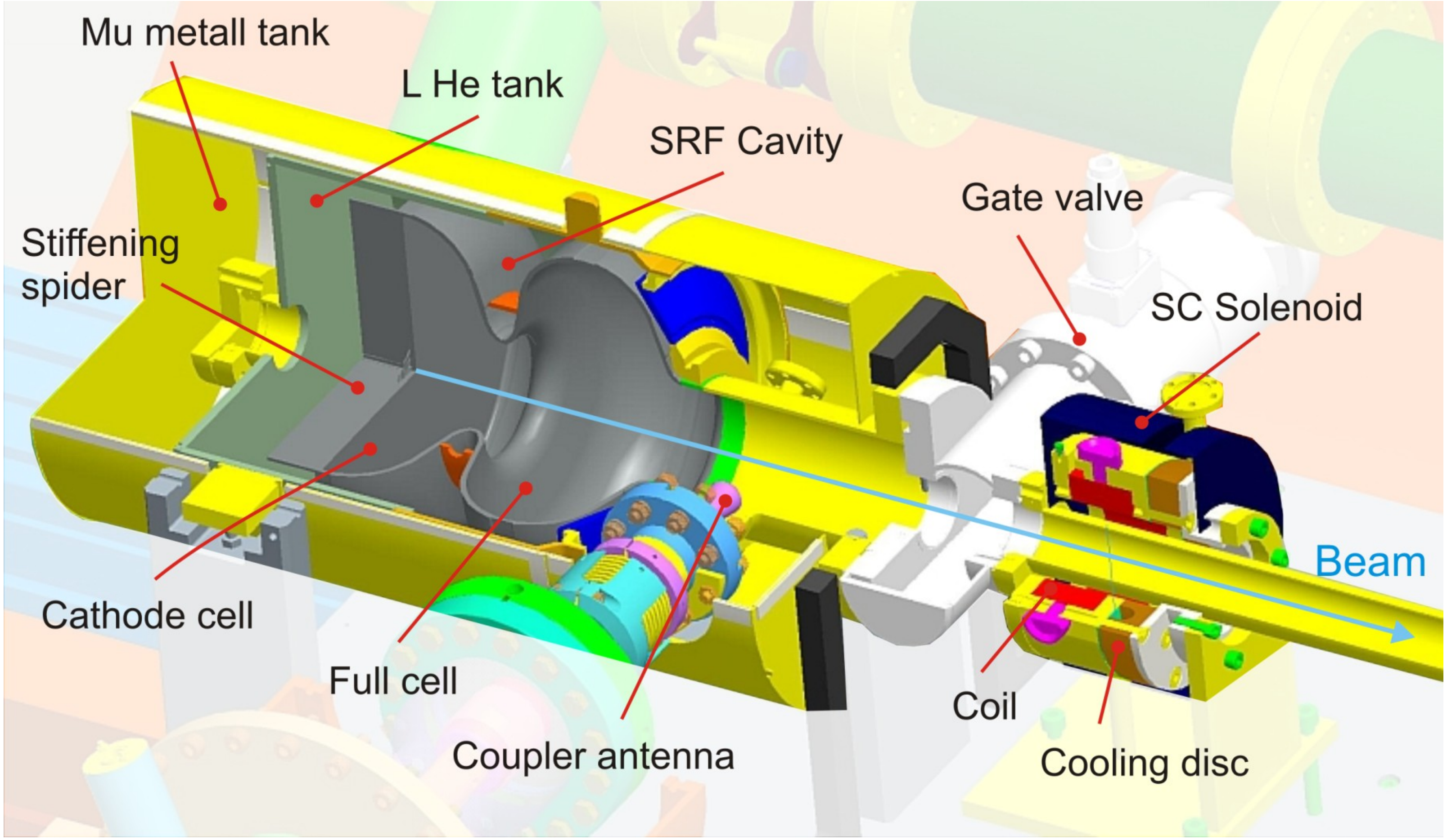
03/10 After installation of the helium vessel, limitation by moderate field emission.

07/10 With first cathode coating

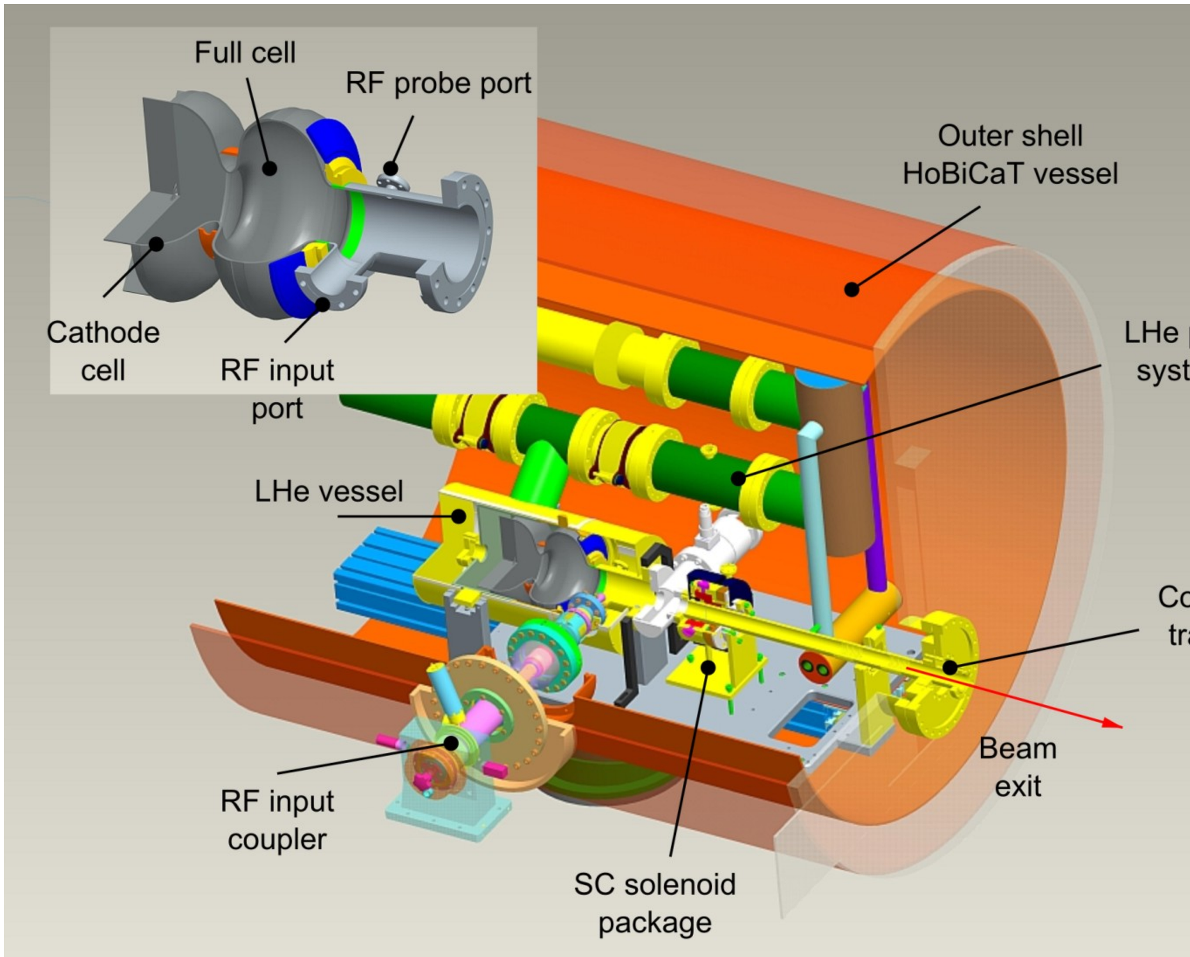
07/10 Test after accidential loss of lead cathode and removal of remnants by grinding and BCP.

10/10 With second cathode coating

Complete cold mass: cavity, coupler, gate valve, solenoid and beam pipe



Completed cold mass now inside cryomodule of HoBiCaT.



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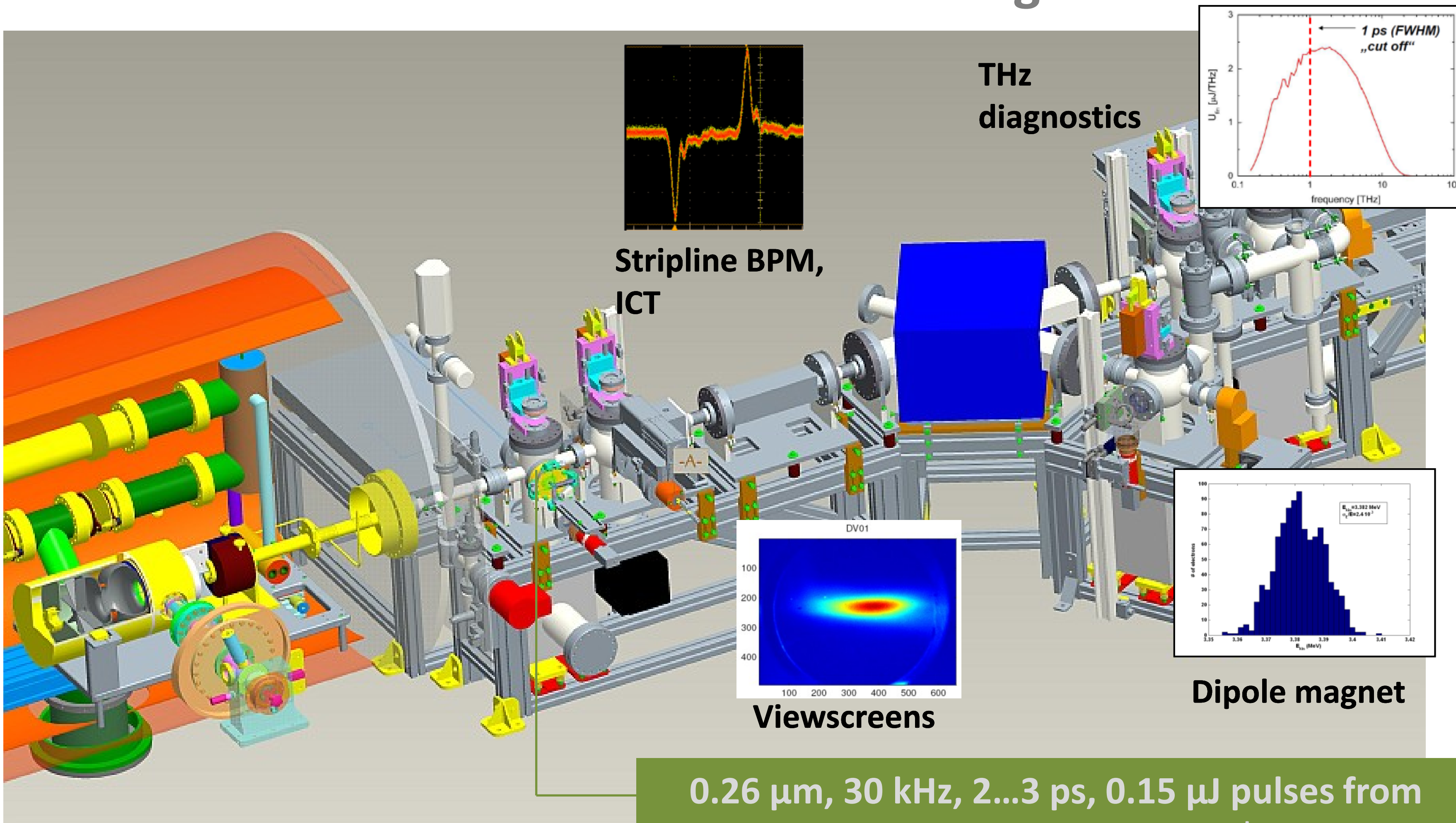
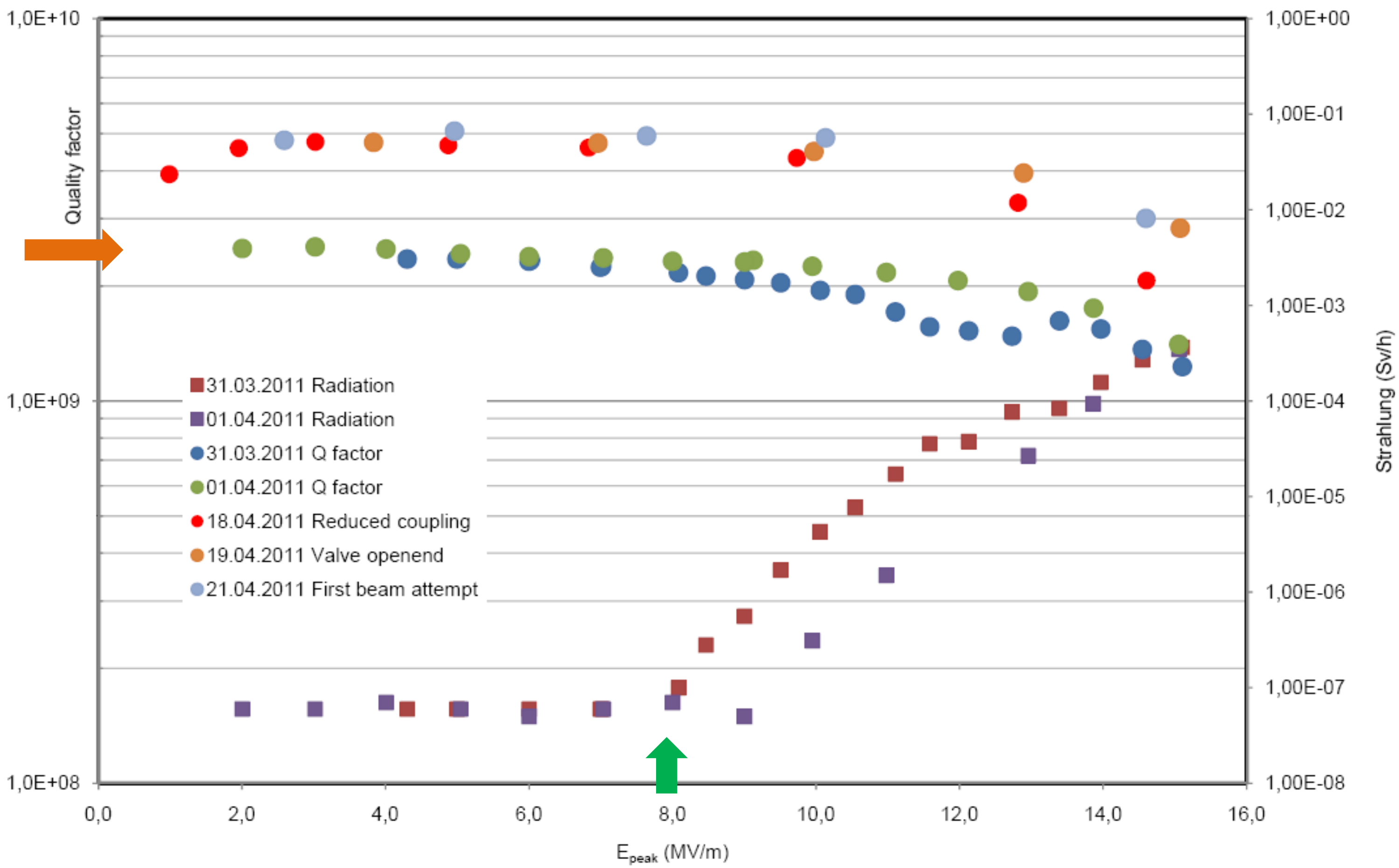
Two more systems required for beam test: drive laser and electron beam diagnostics



0.26 µm, 30 kHz, 2…3 ps, 0.15 µJ pulses from Yb:YAG oscillator + regen. amp. + 4th harm conv.

First measurements of Q vs E with HoBiCaT



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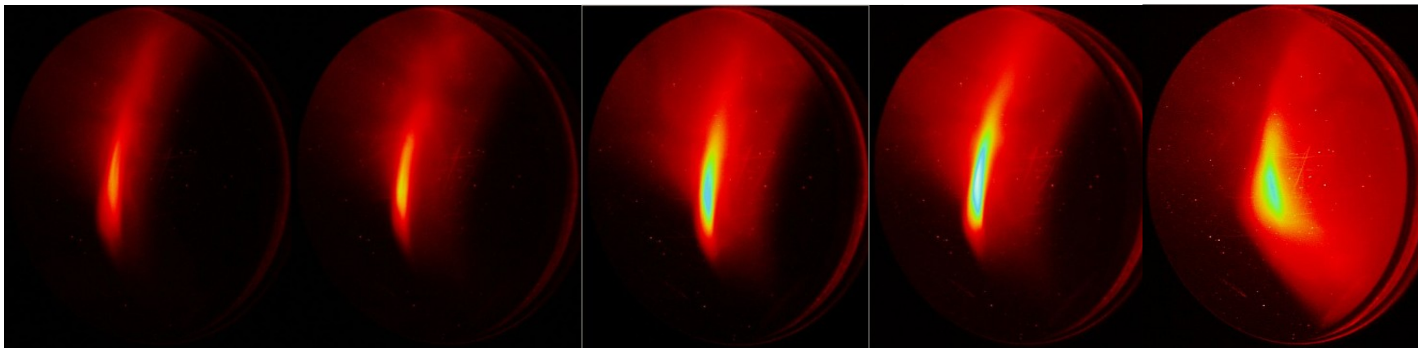
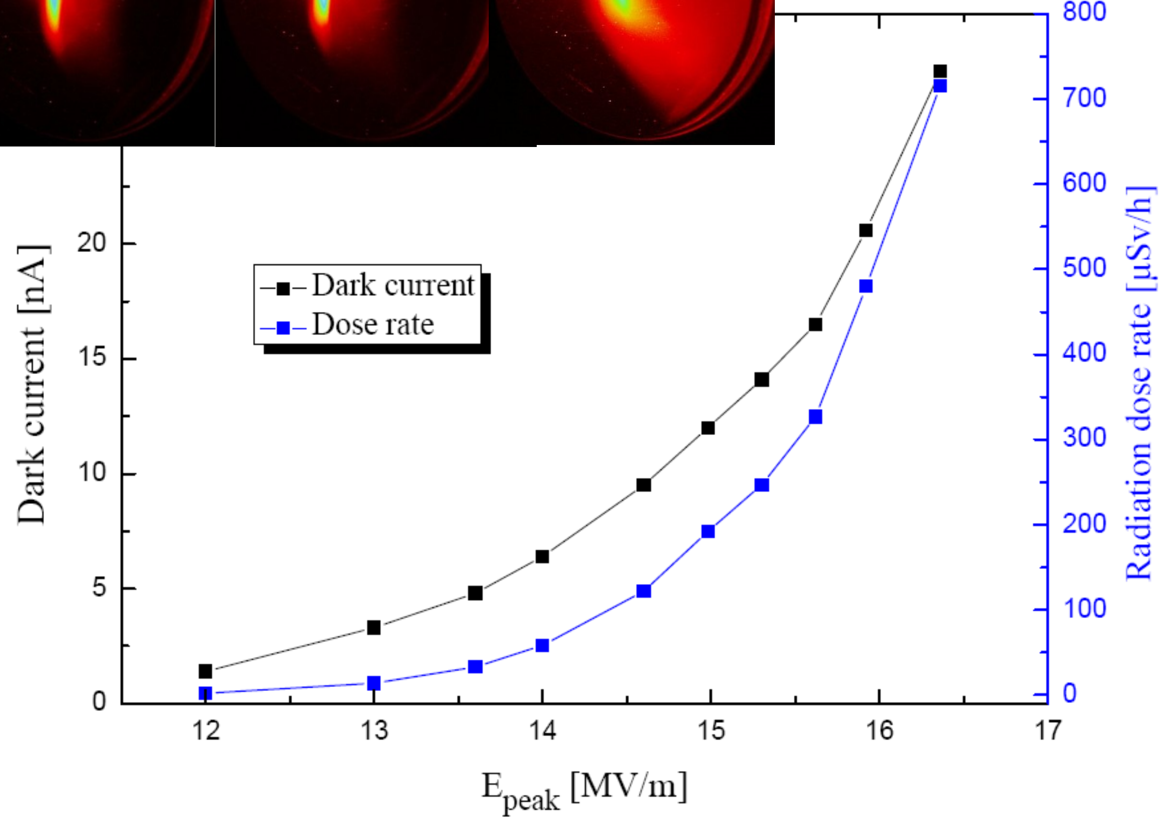
Dark current measurements for different field gradients

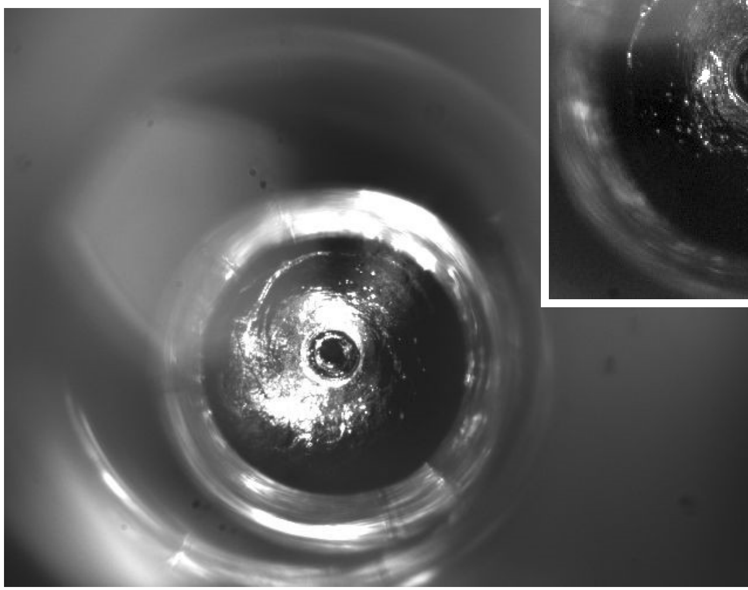
screen shots taken at last five data points

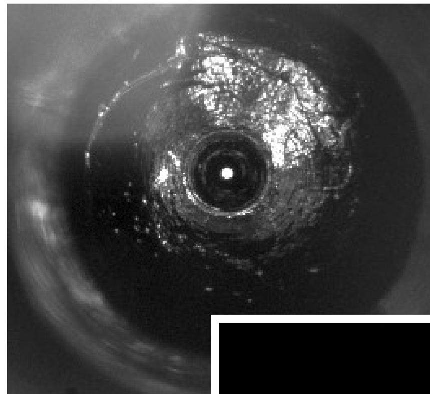


Focus the beam with solenoid on first creen.
Replace screen with Faraday cup and measure dark current.
Measure dose rate with proportional counter close to Faraday cup



First beam of photoelectrons from Pb cathode generated and accelerated at 21st Aptil 2011, < 2 years after project approval





Switch on RF, adjust phase (still very cumbersome), steer and focus with solenoid

Start with steering of laser beam spot on backwall of cavity