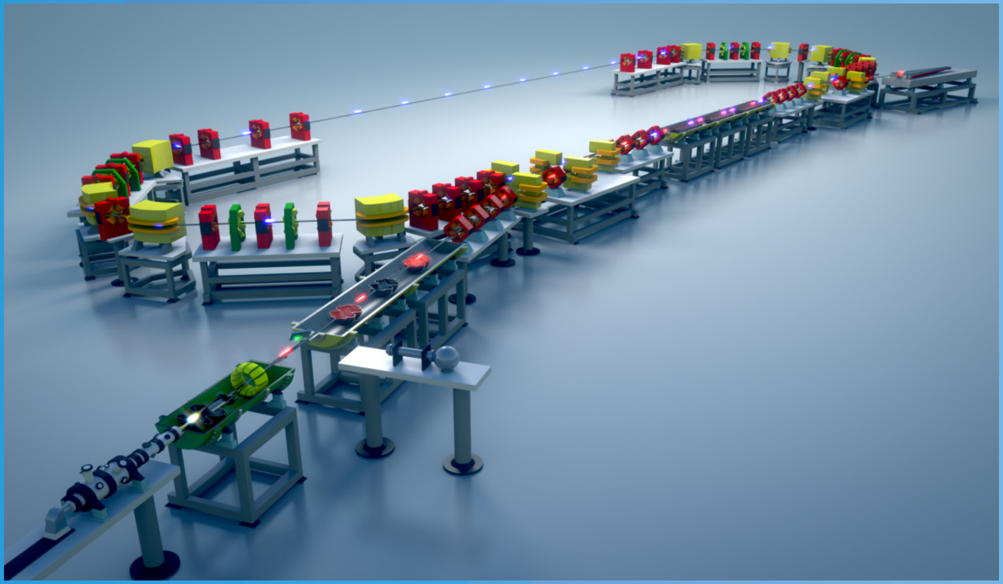
B*ERL*inPro

CW-RF Meeting ELBE March 14-15, 2013

Wolfgang Anders

general BERLinPro talk courtesy Andreas Jankowiak



Content

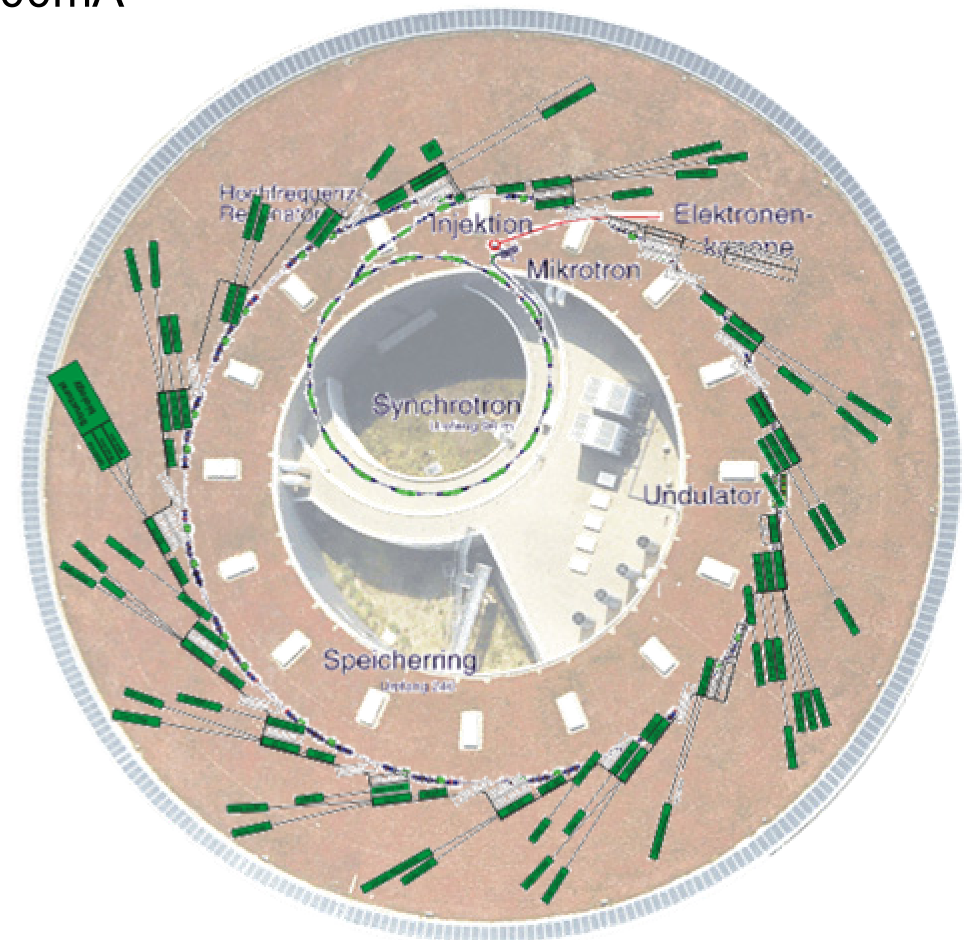
- Energy Recovery Linacs
  principle and promises
  d promises
   promises
  promises
  Recovery Linac Project
  why?, how?, and status
  hy?, how?, and status
  y?, how?, and status
  ?, how?, and status
  ro sc RF installations
  ansmitters, cryogenics

3rd generation light sources: e.g. BESSY II

BERLinPro

Energy/current	1.7GeV / 300mA
Emittance	6 nm rad
Straight sections	16
Undulators / MPW+WLS	10 / 1+3
ID / dipole beam lines	32 / 20
end stations (fixed+var)	52

~ 5500 h/a user service
~ 2400 users / a



>> from THz to keV <<
- spectroscopy & scattering
- imaging & lithography
- dynamic studies

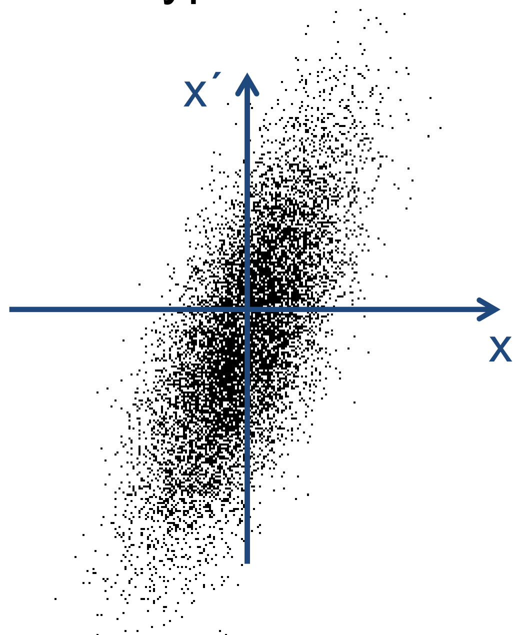
low α
ps beams, CSR, THz

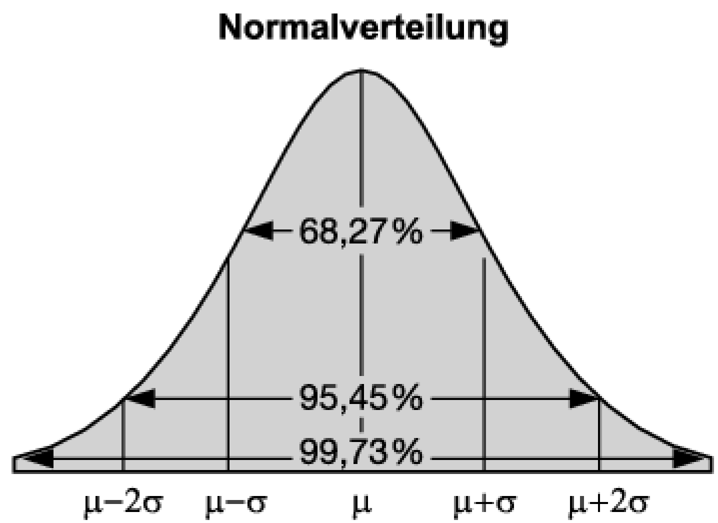
femto slicing
100fs, polarised x-rays
6kHz and variable
pump probe laser

flexible fill patterns
single bunch, camshaft, ...

transversal typical: ~ nm rad

longitudinal typical: ~6mm = 20ps





equilibrium between (synchrotron) radiation damping and heating
(defined by lattice e.g. DBA, TBA, MBA and insertion devices)

$$\varepsilon_x = C_\gamma \frac{\gamma^2}{J_x} \cdot \frac{\left\langle \frac{1}{R^3} H(s) \right\rangle}{\left\langle \frac{1}{R^2} \right\rangle} \sim \gamma^2$$

USR = ultimate storage ring
("diffraction limited storage ring")
some 100 pm rad down to 10pm !?

$\varepsilon_y \sim 1/100 \cdot \varepsilon_x$ (coupling)

low-alpha mode
~ ps
(very limited intensity)

$$\sigma_s \sim \sqrt{\frac{\alpha}{V'}} \cdot \sigma_E$$

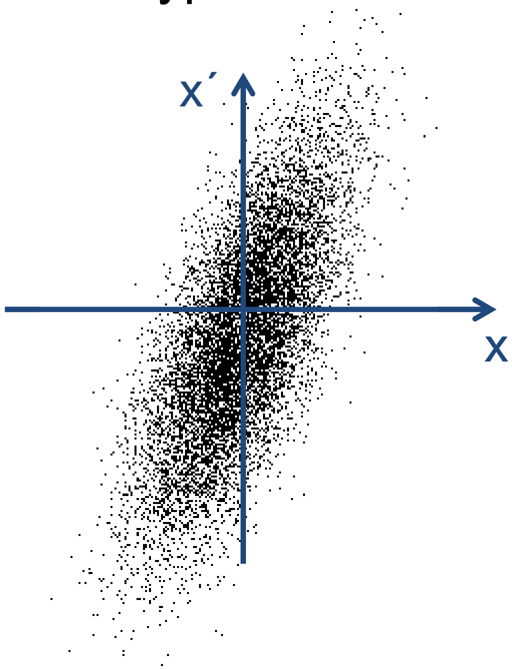
$\alpha = \frac{\delta L / L_0}{\delta p / p}$: momentum compaction factor

$V' = \frac{dV}{ds}$: gradient of accelerating voltage

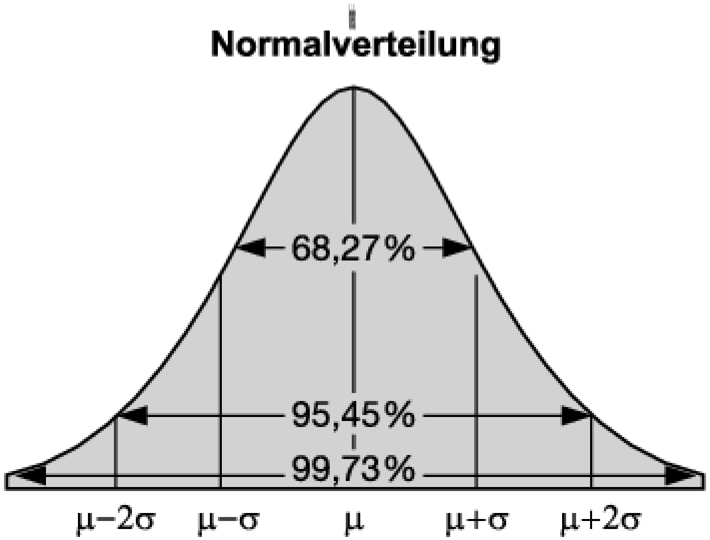
σ_E : rms energy spread of beam

Beam emittance and pulse length (if a fairy asks for a wish)

transversal typical: ~ nm rad



longitudinal typical: ~6mm = 20ps



transversal: ~ point like

longitudinal: ~ needle

If no fairy is available:
take a low emittance electron source and just accelerate,
manipulate longitudinal phase space (compressor)

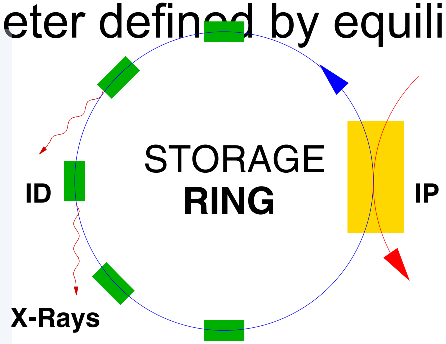
$$\varepsilon \sim \frac{1}{\gamma} \cdot \varepsilon_{source}$$

$\varepsilon < 100$pm, pulse length < ps down to fs

Energy Recovery Linacs: The idea

- high average („virtual“) beam power (up to A, many GeV)
- mature technology – many user stations
- resonant system interaction experiment ↔ ring
- beam parameter defined by equilibriu

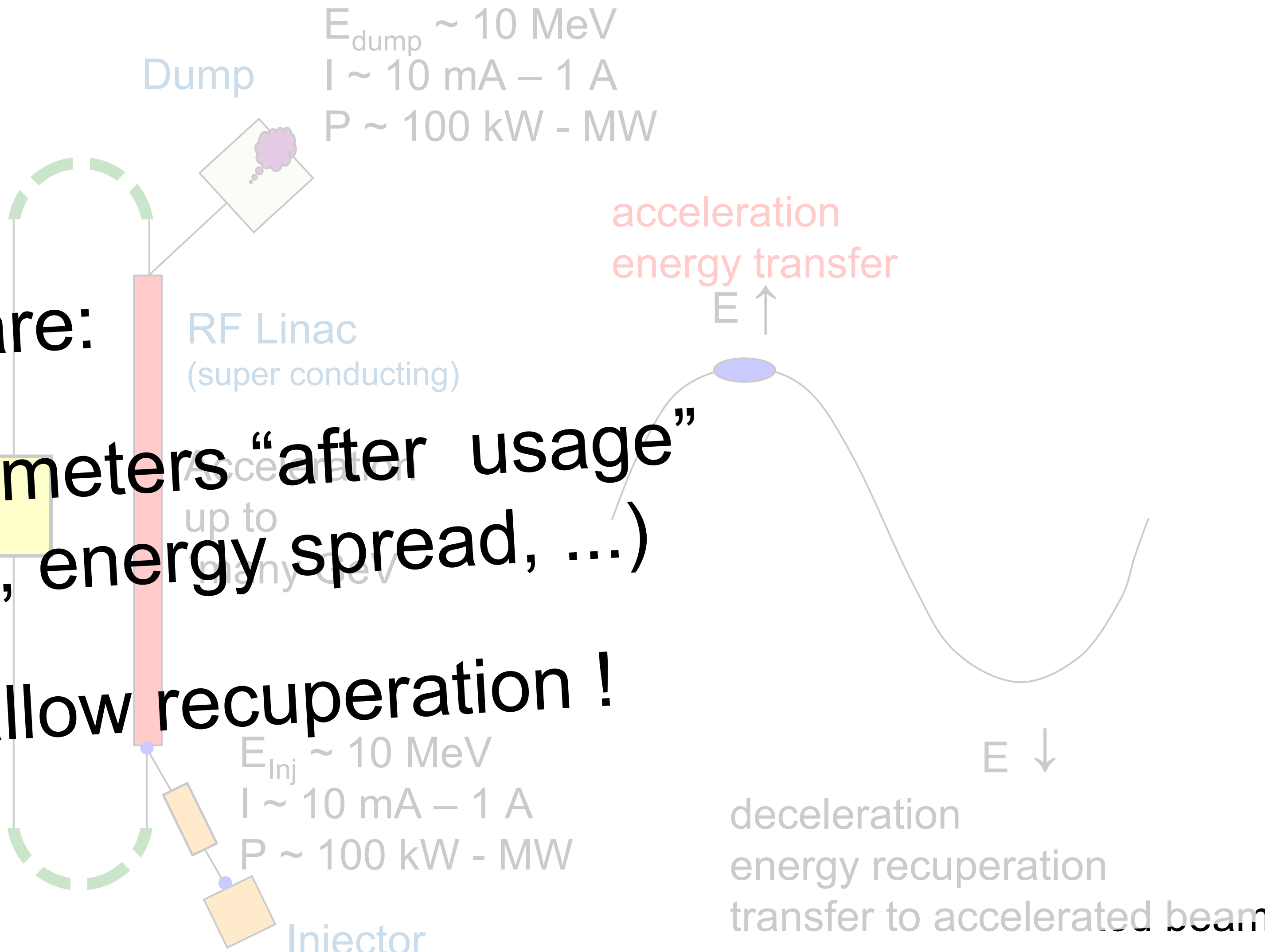
e.g. ESRF:
6 GeV, 200 mA
1.2 GW
virtual power,
stored energy
only 3380 J



- outstanding beam parameter
- single pass experiments
- high flexibility
- low number of user stations
- limited average beam power (<<mA)

e.g. XFEL:
17.5GeV, 33 μA
"only" ~600kW,
but real power

The Energy Recovery Linac Principle



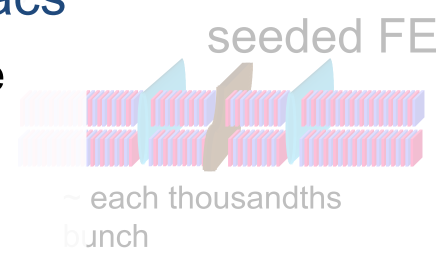
„experiment“ needs „virtual“ power MW to GW and an always „fresh“ beam

But take care:

beam parameters “after usage” (emittance, energy spread, ...)

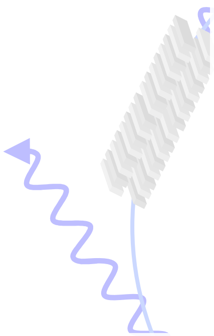
needs to allow recuperation !

ERL as next Generation Multi-GeV, Multi-User SR-Source



Combines the two worlds of storage rings and linacs

- with energy recovery: ~100mA @ many GeV possible
- always “fresh” electrons (no equilibrium)
  - → ultra low emittanz, round beams
  - → high brilliance, high transversal coherence
  - → short pulses (ps and shorter)
- individually tailored optics of each straight possible
- real multi-user operation at many beam lines
- sngle pass short pulse FEL facility as “add on” possible



+

Flexible operation modes (brilliance, short pulse, variable pulse patterns) adaptable to user requirements!

ERLs opens up the complementary dimensions of energy, space and time (spectroscopy, structure und dynamics)

OtherApplication of ERL Technology

High energy electron cooling of bunched proton/ion beams
(low Energy ~ 100MeV, high current rules out VdG or SR)

Ultra high luminosity electron – ion collider (ELIC, LHeC)
(beam beam effect electron ring limits luminosity)

Compact radiation sources:
FEL, compton sources,
13.5nm for next generation lithography

and ...

Still many challenges to be solved

BERLinPro

Electron source:
high current , low emittance (100mA – A) cw / ε_{norm} < μm rad) not yet demonstrated
(big step forward: Cornells 50mA)

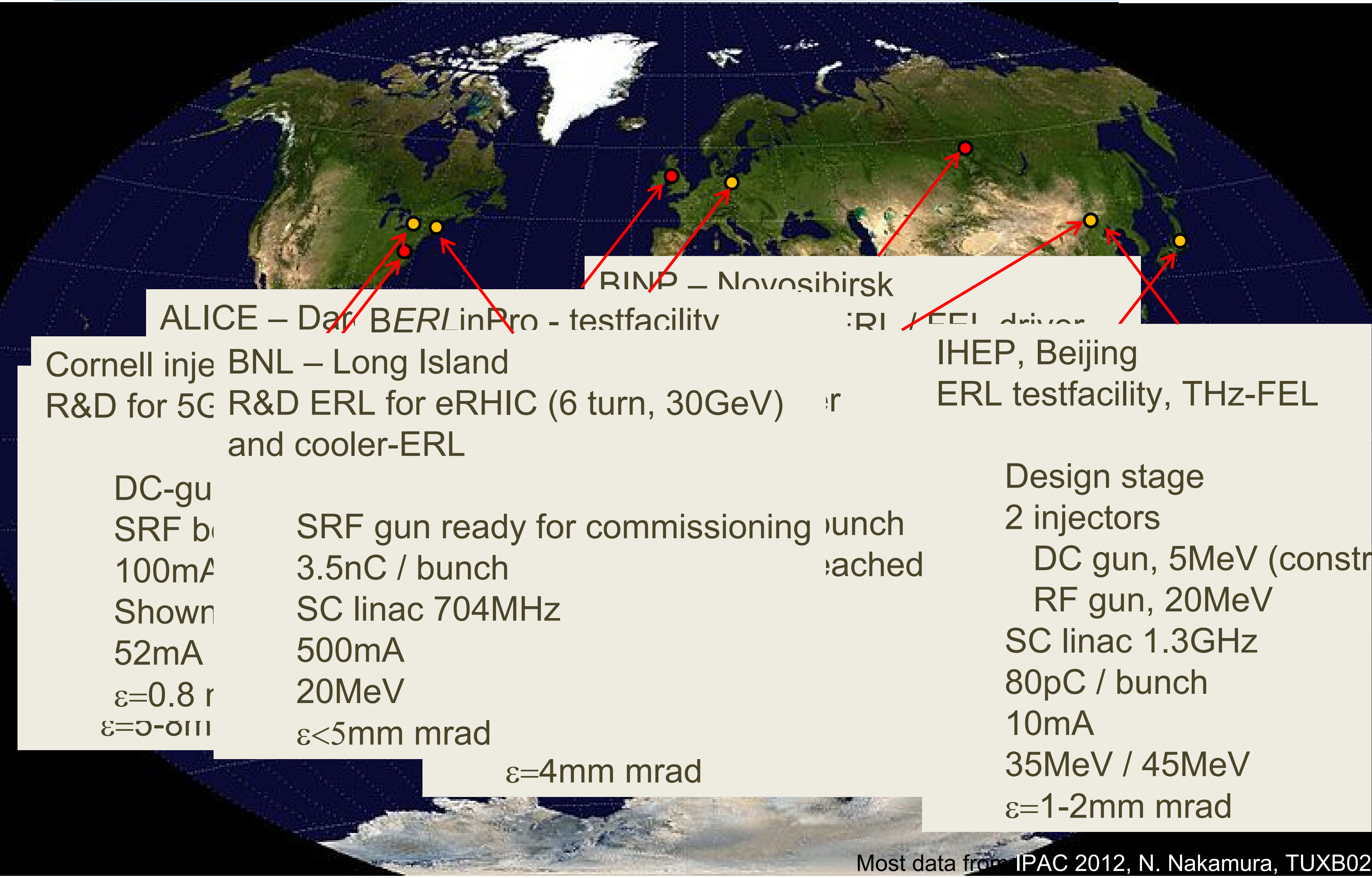
Injector/Booster:
100mA @ 5 – 15MeV = 500 – 1500kW beam loading (coupler, HOM damper, beam dump)

Main-Linac:
100mA recirculating beam → beam break up (BBU), higher order modes (HOM), highest cw-gradients (>15MV/m) with quality factor > 10^{10} → reduce cryo costs

Beam dynamics / optics:
recirculation, flexible optics, bunch compression schemes = flexibility

Control of beam loss
unwanted beam = dark current fromcathode, gun, cavities due to field emission, stray light laser beam halo, collimation schemes !?

Current ERLs in operation and Test Facilities



BINP – Novosibirsk

ALICE – Dar

BERLinPro - testfacility

ERL / FEL driver

Cornell inje

R&D for 5G

DC-gu

SRF b

100mA

Shown

52mA

ε=0.8 r

ε=5-8m

BNL – Long Island

R&D ERL for eRHIC (6 turn, 30GeV) and cooler-ERL

SRF gun ready for commissioning

3.5nC / bunch

SC linac 704MHz

500mA

20MeV

ε<5mm mrad

r

unch

eached

ε=4mm mrad

IHEP, Beijing

ERL testfacility, THz-FEL

Design stage

2 injectors

DC gun, 5MeV (constr

RF gun, 20MeV

SC linac 1.3GHz

80pC / bunch

10mA

35MeV / 45MeV

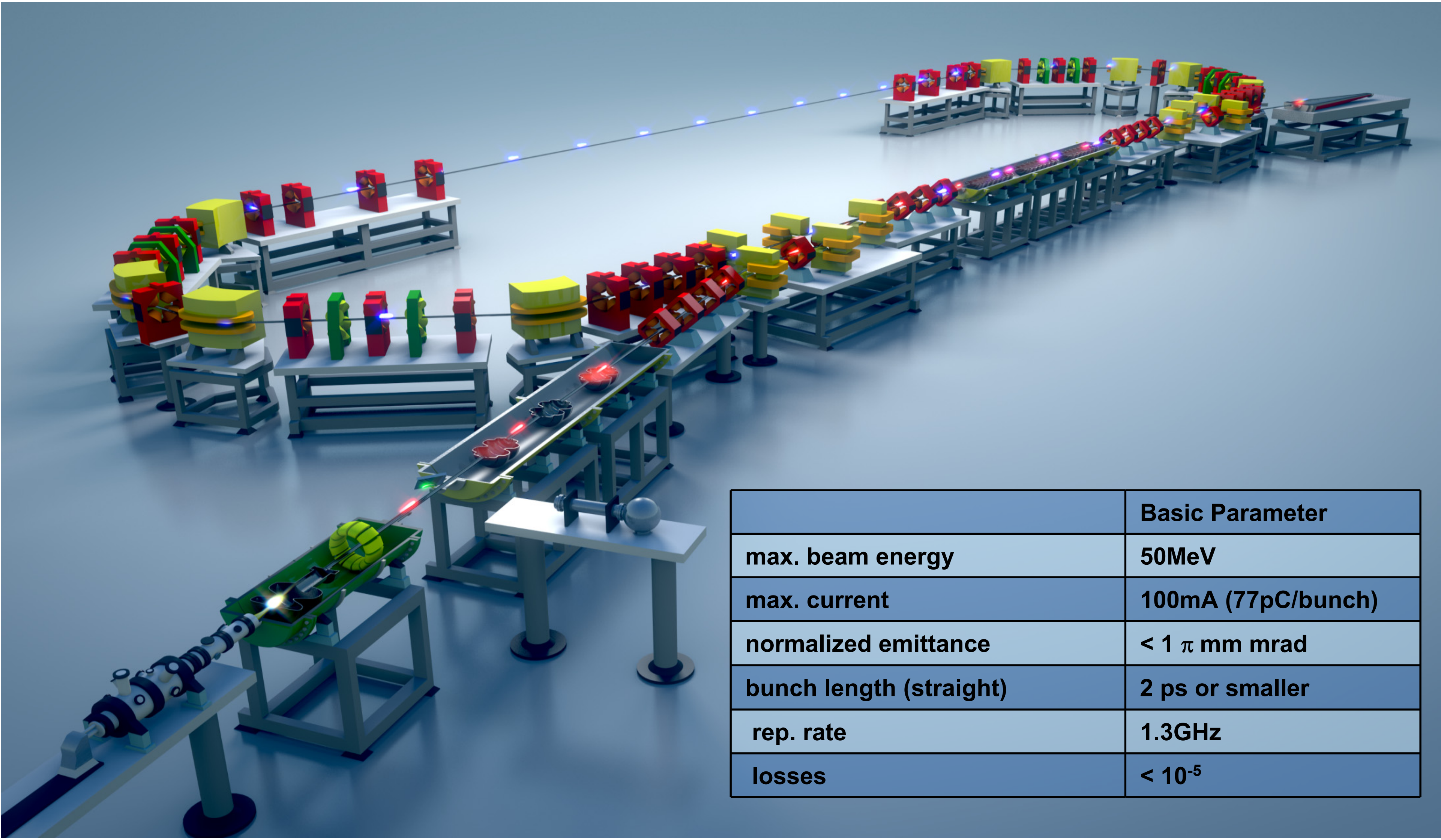
ε=1-2mm mrad

Most data from IPAC 2012, N. Nakamura, TUXB02

BERLinPro – Machine layout / parameters

BERLinPro = Berlin Energy Recovery Linac Project

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



	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 – Project goals

Produce and accelerate an electron beam with

emittance: 1 π mm mrad (normalized)
current: 100mA cw
(1.3GHz, 77pC bunch charge)

pulse length: 2 ps

at reasonable energy (50MeV) in „user quality“ (low losses in recirculation) with stable and reliable operation

→ Facility for ERL beam tests and developments

- develop the required srf technology (gun/booster/linac)
- explore the parameter space of emittance, charge and pulse length
- understand to control “unwanted” beam(loss)
- educate accelerator physicists, engineers and technicians
- acquire expertise to be prepared for future large scale projects
- foster international collaboration on ERL technology

Challenges (i)

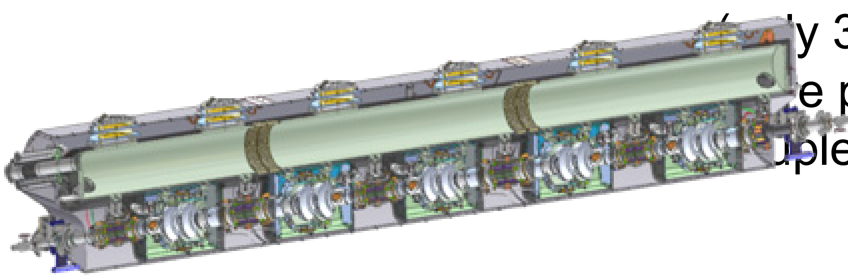
- **electron source** with cathode and laser system
  staged approach for development of srf photo electron source

Gun_0 → Gun_1 → Gun_2

ady started, fully sc (Pb cathode film), first beam 21.04.11
demonstrator, beam dynamic

athode, CsK_2Sb cathode
beam dynamic, emittance, cathode performance

- generate **high power beam** in booster
  modified Cornell booster design , adapt to our needs
  y 3 cavities,
  e power per
  pler – KEK design)

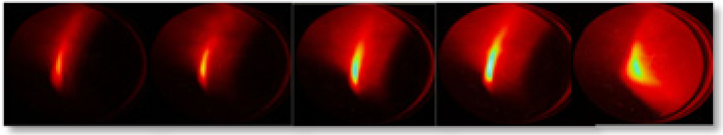


Challenges (ii)

- **emittance compensation and preservation**
  - merger design and operation
  - 2d-emittance compensation scheme gun to end of linac
  - control of CSR effects (2ps@100mA = 4kW average power !)

- **linac cavities** for high current (HOMs, BBU)
  starting point JLAB 5 cell with waveguide damper + Cornell 7 cell
  → Cornell like 7 cell cavities with waveguide damper

- **control of beam losses**



Pat O'Shea, Univ. Maryland
cited by D. Douglas, JLAB

- dark current from gun and cavities due to field emission
  - Halo from laser spot, non linear fields, bunch compression, CSR, ...
- collimation schemes (but where and how ????)

Challenges (iii)

- high "virtual" beam power, **very high loss rates possible**

BESSY II:	200µC / a @ 1.7GeV	typical
B*ERL*inPro:	some 100µC / 1s @ 50 MeV	possible
		(30kW linac RF-power)

new regime of operation (compared to storage ring)

→ **radiation protection issues** favor an underground bunker

SRF gun development – The strategy

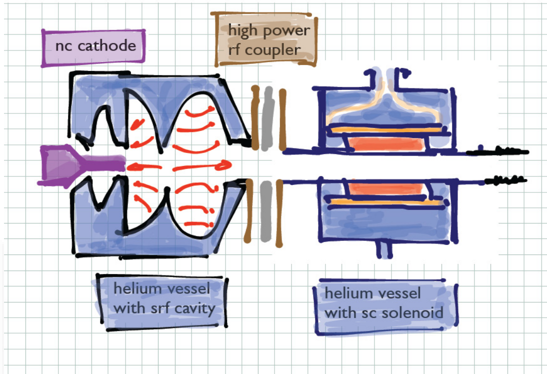
The photoelectron injector concept is the enabling technology for high performance linac driven lightsources and FELs

Follow staged approach:

First beam demonstration and operation of two gun cavities in all SC/SRF gun in 2011-2012.

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.

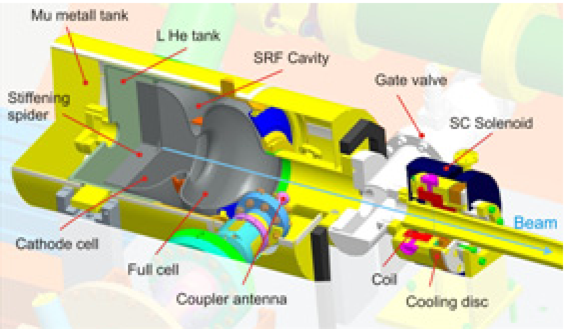


T. Kamps *et al*, Proc. of IPAC 2011, PRST-AB in preparation,
A. Neumann *et al*., Proc. of IPAC 2011 , PRST-AB in preparation
R. Barday *et al.*, Proc. of PSTP 2011
J. Völker, *et al*., Proc of IPAC 2012
S. Schubert, *et al*., Proc of IPAC 2012

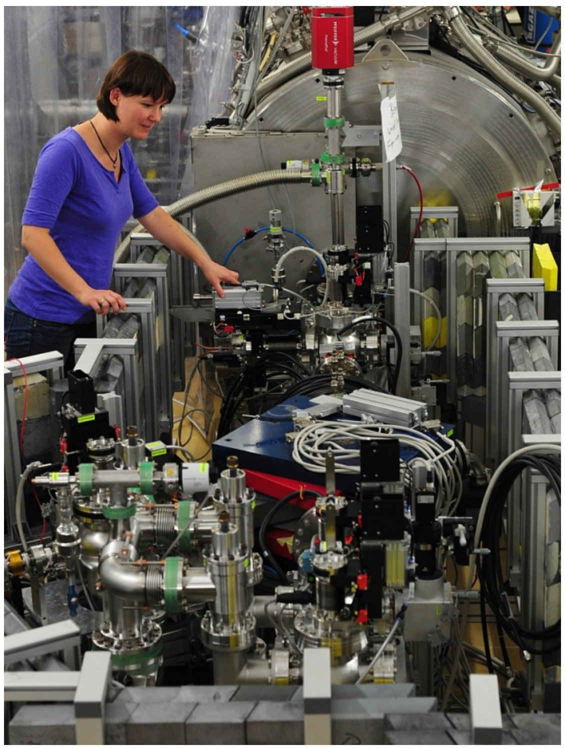
	Gun0 (HoBiCaT)	BERLinPro Gun
Goal	Beam Demonstration (First beam 04/2011)	Brightness (2014) and average current (2016)
Cathode material	Pb (SC)	CsK_2Sb (NC)
Cathode QE_{max}	1*10^-4@258 nm*	1*10^-2@532 nm
Drive laser wavelength	258 nm	532 nm
Drive laser pulse length and shape	2.5 ps fwhm Gauss	≤ 20 ps fwhm Gauss
Repetition rate	8 kHz	1.3 GHz
Electric peak field in cavity	20 MV/m*	≤ 20...30 MV/m
Operation launch field on cathode	5 MV/m*	≥ 10 MV/m
Electron exit energy	1.8 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)

*Preliminary data / results,
° value represents emission time

SRF gun development – Gun0=fully sc gun with lead spot cathode



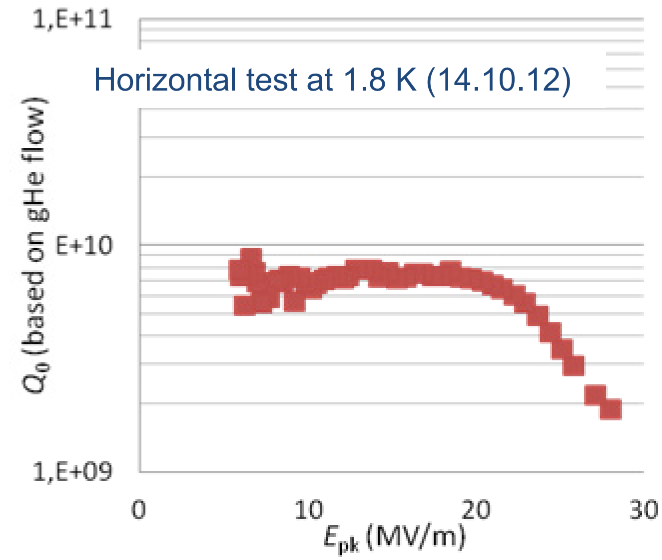
Two gun cavities (developed by DESY/JLAB) with Pb cathode film (NCBJ) tested with beam.

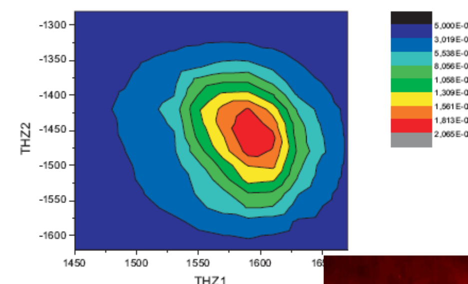


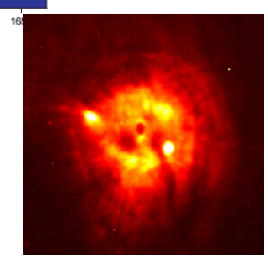
At HZB cavity was setup inside HoBiCaT cryovessel.

Current version is equipped with BERLinPro gun-type tuner system. Tuner and LLRF control succesfull commissioned. After RF processing very little dark current and gradient up to 28 MV/m.

Collaboration between HZB, DESY, JLAB, BNL, NCBJ, MBI, supported by EuCARD





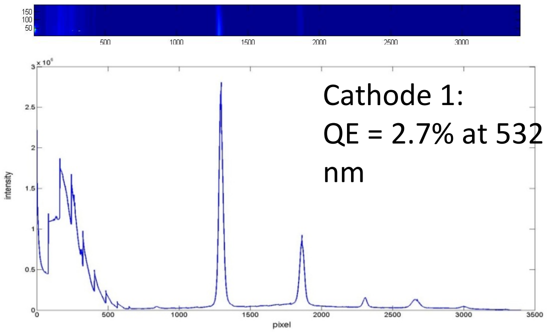


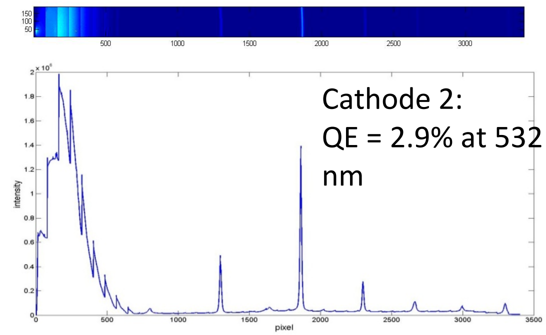
QE Map and image of emission area for metallic Pb cathode

T. Kamps, R. Barday, J. Völker, A. Burrill, O. Kugeler, A. Neumann, et al.

SRF gun development – High QE photo cathodes

XRD: x-ray diffraction pattern of final cathode film

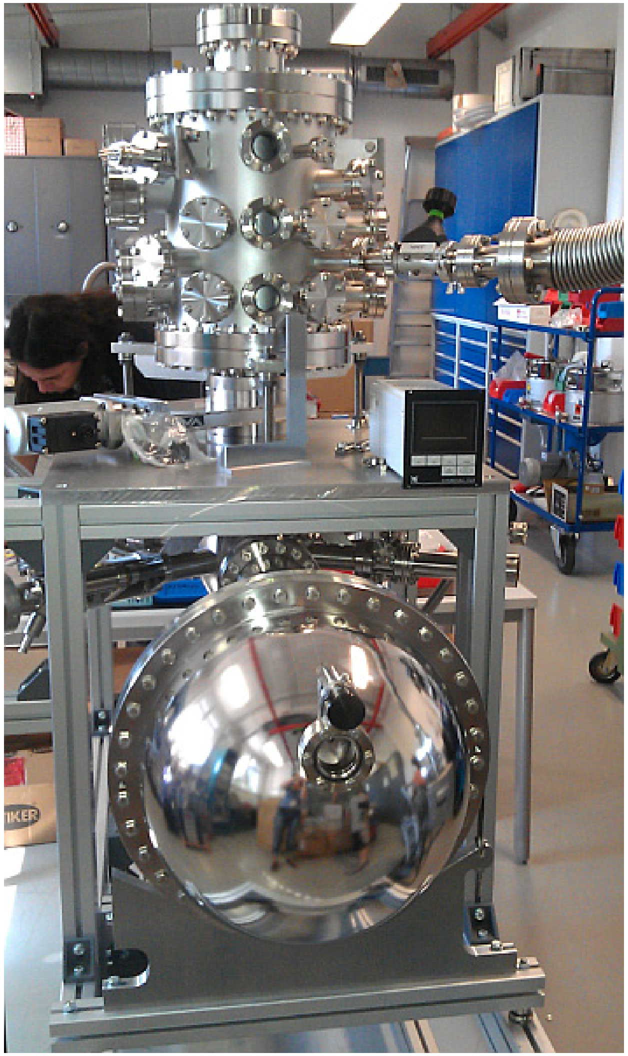




S. Schubert, M. Ruiz-Oses, et al.

Preparation and Surface Analysis of Multialkali CsK_2Sb Photocathodes. Photocathode preparation and analysis chamber built and shipped to BNL on collaborative agreement. Expect first photocathodes autumn 2013.

Preperation and analysis chamber setup exercise at HZB



S. Schubert, D. Böhlick, et al.

Field Emission (FE) and Thermocontact (TC) experiments.

•Study potential limit by field emission Dedicated FE setup under development.

•Investigate alternative, common plug design with respect to thermal performance in TC experiment.

Supported by German-Russian collaboration on high average current photocathodes (BMBF)

B*ERL*inPro – Project timeline + mile stones

fully funded
36.5 Mio€ (BMBF, Land Berlin, HA)
(including building)

2011

- **Project Start**
- **First MAC**
- **Project re-design**
- **First electrons from injector 0**

2012

- **Conceptual Design Report**
- **Building design complete**
- **Setup cathode preparation**
- **Design of Injector 1**

2013

- **Detailed Design Report**
- Application for building permits
- **Injector beamline @ HoBiCaT ("Gunlab")**
- **First photocathodes produced**
- **Design booster module**
- Building permit (inkl. rad. prot allowance **recieved**

2014

- Start building construction
- **First electrons in Gunlab**
- Building ready for occupancy
- **Start Injector Installation**

2015

- 4-K Cryogenics relocated
- **Installation Injector 1**
- **Installation booster**
- **Production Injector 2**

2016

- First electrons through booster (up to 4mA CW)
- Production LINAC module
- Purchase recirculator comps.
- **Start Injector 2 operation with** merger **("path to 100 mA")**

2017

- **Installation main LINAC**
- **Install recirculation**
- **Injector 2 operation (high current, 100 mA)**

2018

- **50-MeV electrons**
- **Recirculation**

SRF related issues of *BERL*inPro

RF TRANSMITTERS OVERVIEW

Two types of transmitters:

- Three (1x gun, 2x booster) injector transmitters 270 kW_{cw} to cover beam loading
- One injector transmitter 15 kW_{cw} (cost driven), upgrade to high power possible

270 kW transmitters staged approach (cost driven):

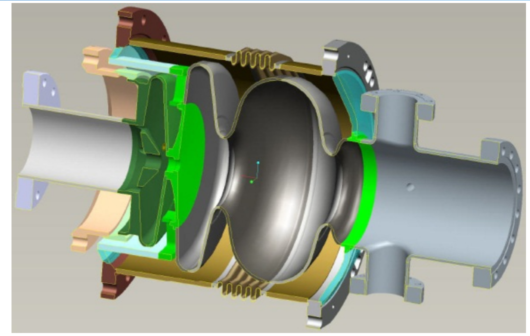
- Stage 1: 160 kW (RF limit at ~40 mA beam current)
- Stage 2: 270 kW full power for 100 mA beam loading

- Three Linac transmitters 15 kW to generate cavity voltage and to compensate microphonics

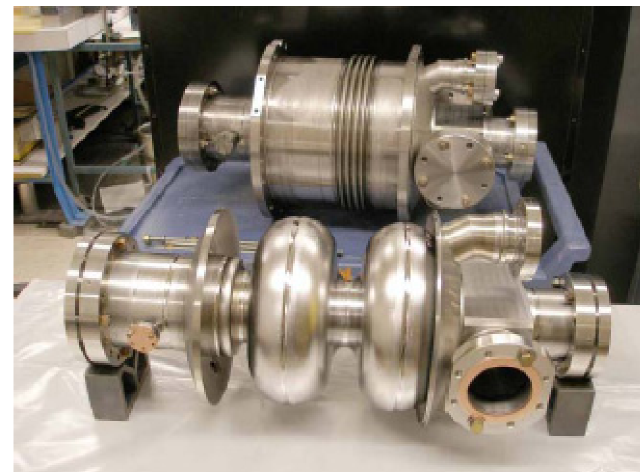
	base design		upgrade option
	stage 1	stage 2	
	transmitter power		
Gun cavity	160 kW	→ 270 kW	270 kW
Booster Cavity 1	15 kW	15 kW	→ 80 kW
Booster Cavity 2	160 kW	→ 270 kW	270 kW
Booster Cavity 3	160 kW	→ 270 kW	270 kW
Linac Cavity 1-3	15 kW	15 kW	15 kW

CAVITY STRUCTURES

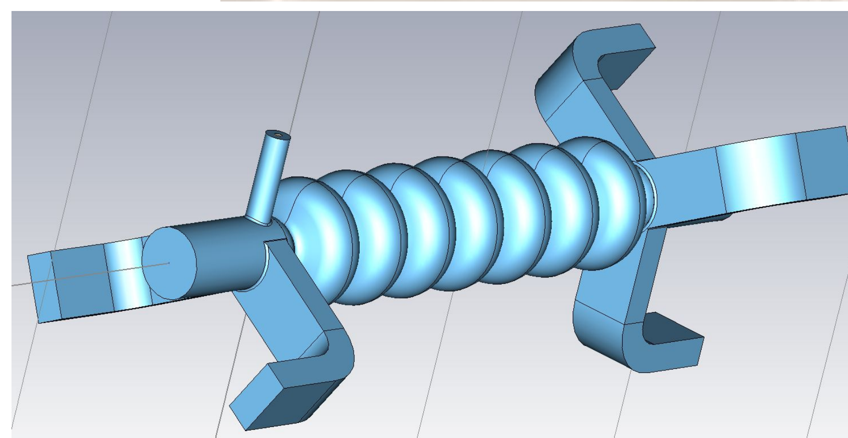
- Gun cavity
  - → 1.4 cell



- Booster cavity
  - → 2-cell Cornell design

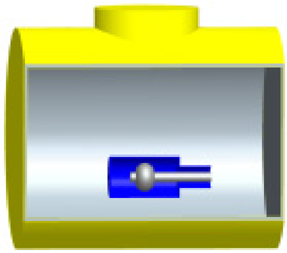


- Linac cavity
  - → 7-cell



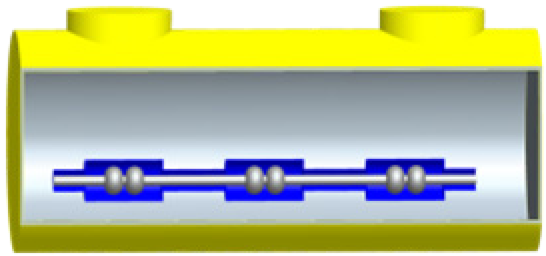
SRF MODULES

Gun



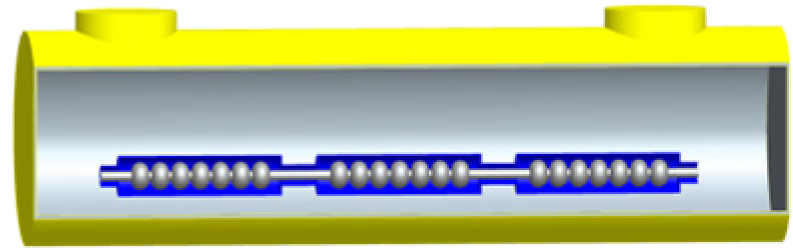
- 1 cavity
- 0.6 (0.4)/1.4-cell
- beam pipe HOM damper
- 2 KEK coupler
- 160 / 270 kW transmitter

Booster



- 3 cavities
- 2-cell (Cornell)
- beam pipe HOM damper
- 3x 2 KEK coupler
- 2x 160 / 270 kW + 1x 15 kW transmitter

Linac



- 3 cavities
- 7-cell
- waveguide HOM damper
- 3x 1 BESSY coupler
- 3x 15 kW transmitter

INJECTOR MODULES -- BERLINPRO

"Best of All – Module"

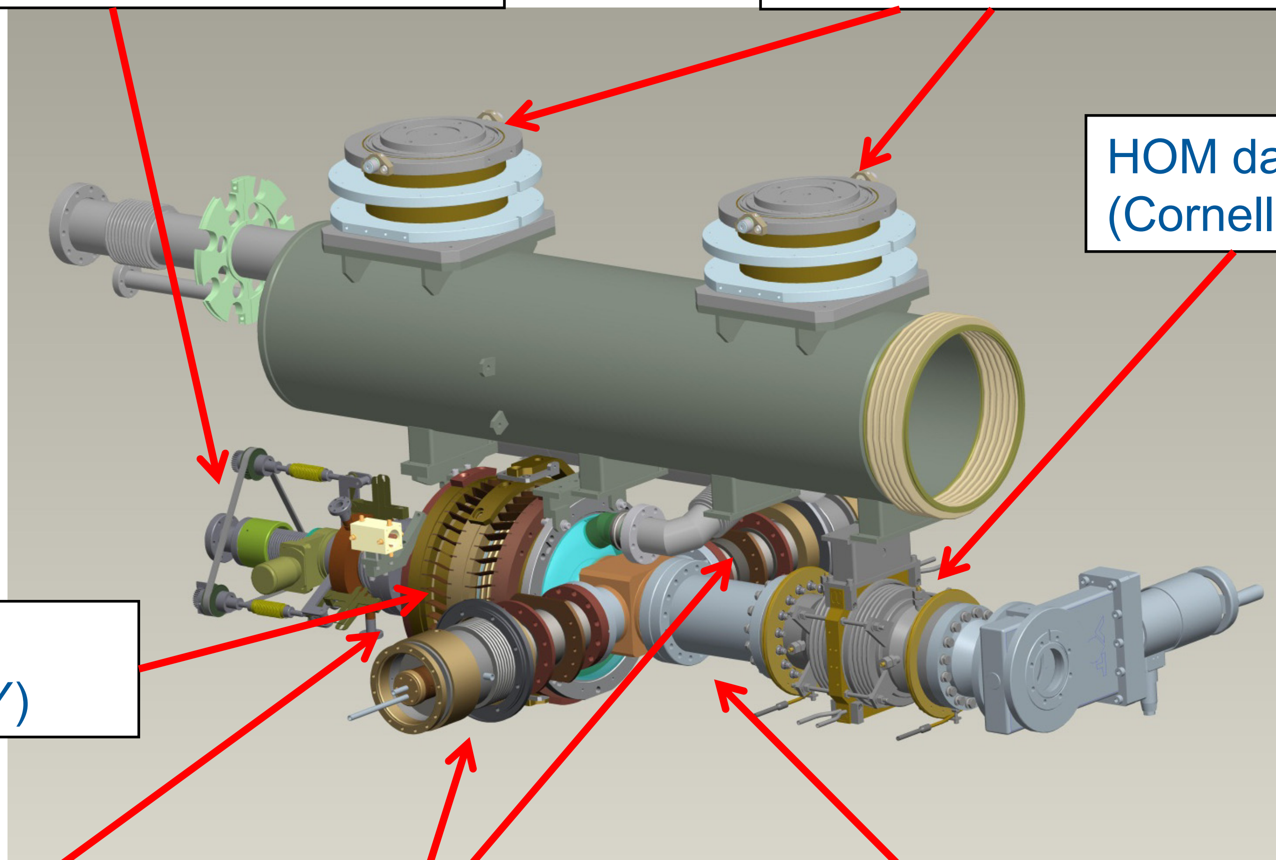
Example Gun1 module

Module design will be used for Gun1, same components for booster, linac ???

Cathode insert (HZDR)

Cavity support structure (Cornell)

HOM damper (Cornell)



Blade tuner (INFN/DESY)

Cavity structure (HZB)

Coupler (KEK)

Moveable Solenoid (HZB)

Cryogenic load table

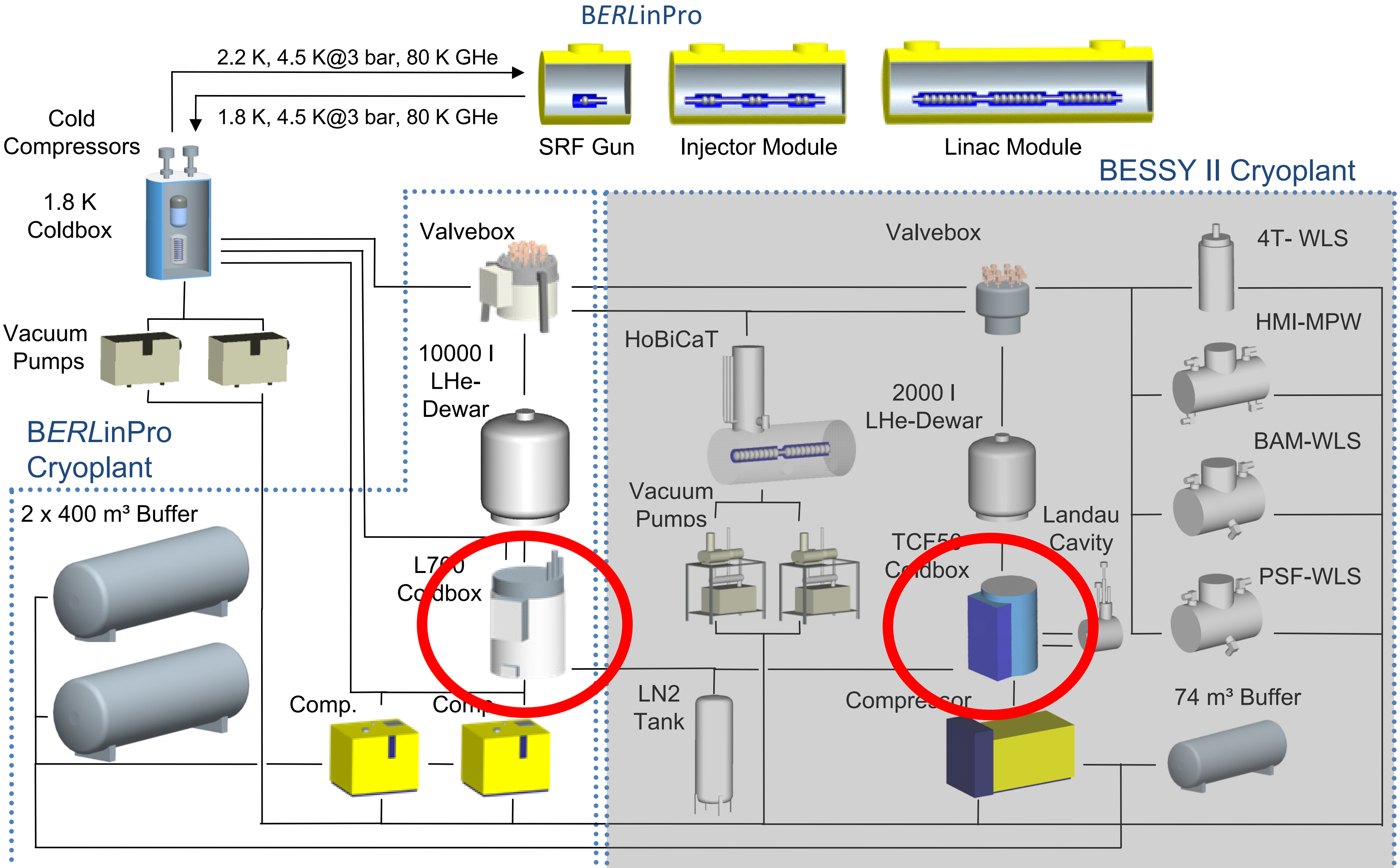
Cryogenic loads

	1.8 K		4.5 K		80 K (LN2 generated)	
Heat in Leaks [W]	Static load	Dynamic load	Static load	Dynamic load	Static load	Dynamic load
Photoinjector module	7	16	34	8	130	75
Booster Module	11	39	62	24	180	270
Linac module	21	79	59	6	203	30
Cryodistribution	3	-	45	-	550	-
TOTAL	42	134	200	38	1063	375

Massflow 9 g/s + Massflow 12 g/s = Required Liquefaction 21 g/s

LAYOUT OF THE CRYOSYSTEM

Cryoplant scheme



Thank you for your attention

BERLinPro