Report from the ERL17 Workshop

LHeC and FCC-eh Workshop

11-13 September 2017
CERN

Erk JENSEN/CERN

Committees

- Scientific Program Committee (chair O. Brüning), working groups:
  1. ERL Injectors
  2. ERL Optics, beam dynamics & instrumentation
  3. Test Facilities around the world
  4. Superconducting RF
  5. Applications
- International Organizing Committee (chair: E. Jensen)
- Local Organizing Committee (chair: L. Hemery)
- …. Plus the Editors team - publications via Jacow

Big thanks! The committees were very efficient and did a great job!

Particular choices:

- No parallel sessions
- Posters on display during the entire workshop

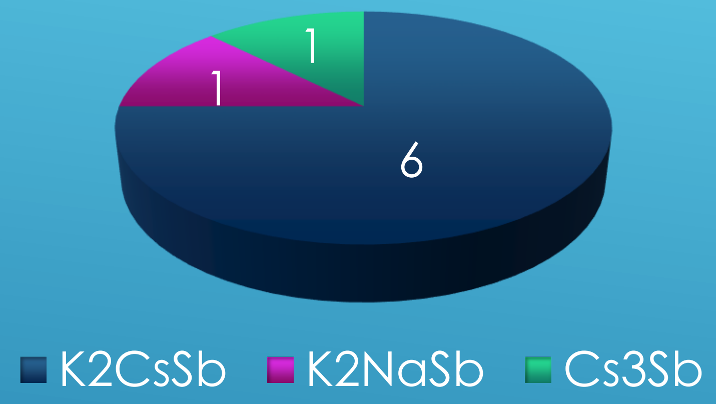
Some statistics

- 90 participants
- 60 plenary talks
- 20 posters

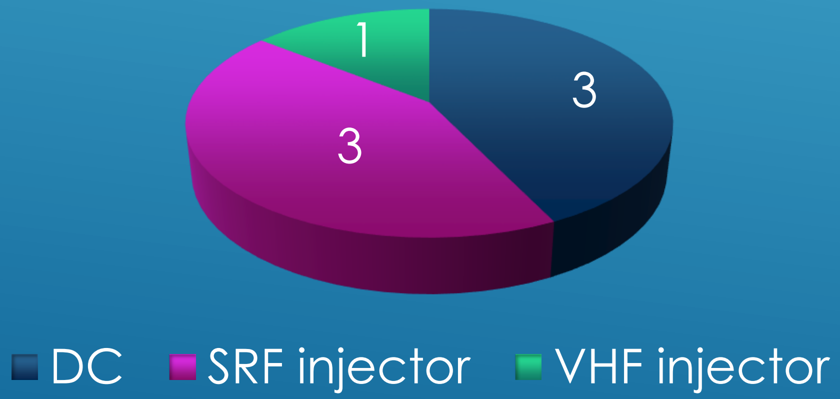
WG1: Injectors

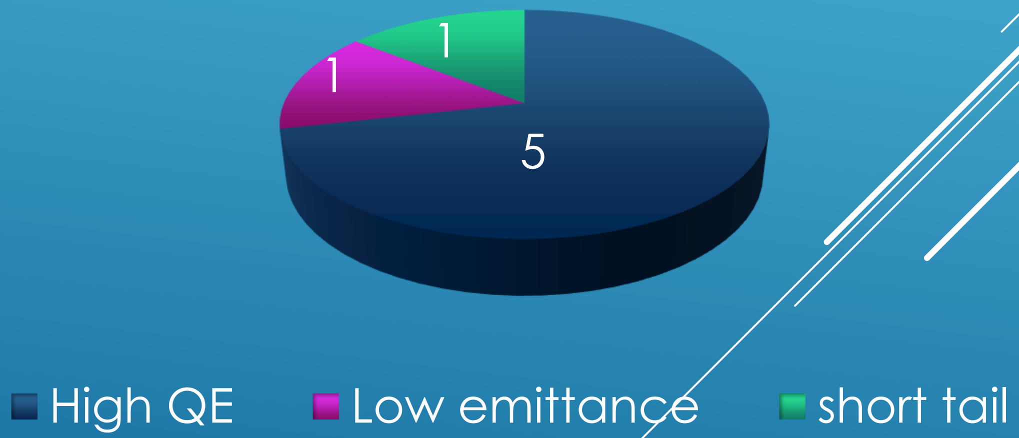
K. Aulenbacher, E. Wang

Photocathodes:



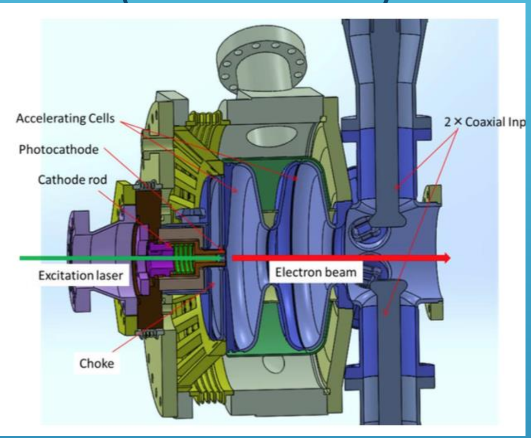
7 presentations



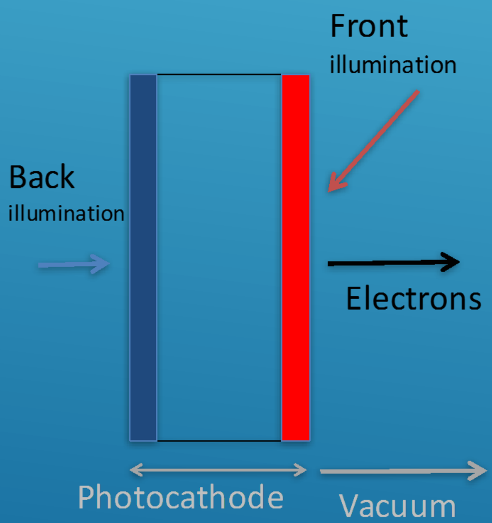


Highlight: back-illuminated cathodes

- KEK (T. Konomi): Development of cathodes with laser back-illumination, using a transparent superconducting layer.

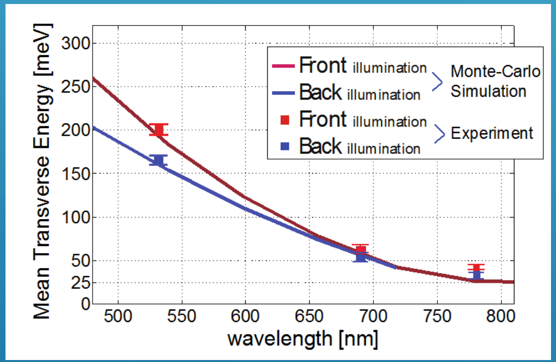


- Cornell (I. Bazarov):



When you shine the laser from back, electrons travel longer through the cathode

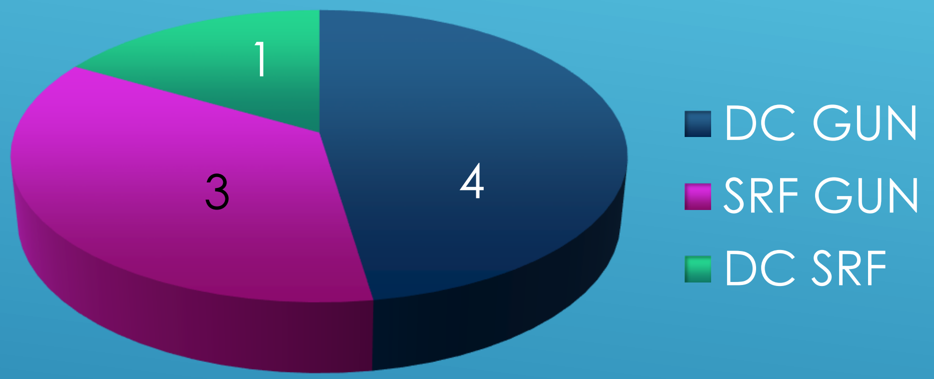
Monte-Carlo simulation & experiments showed
The kinetic E reduction

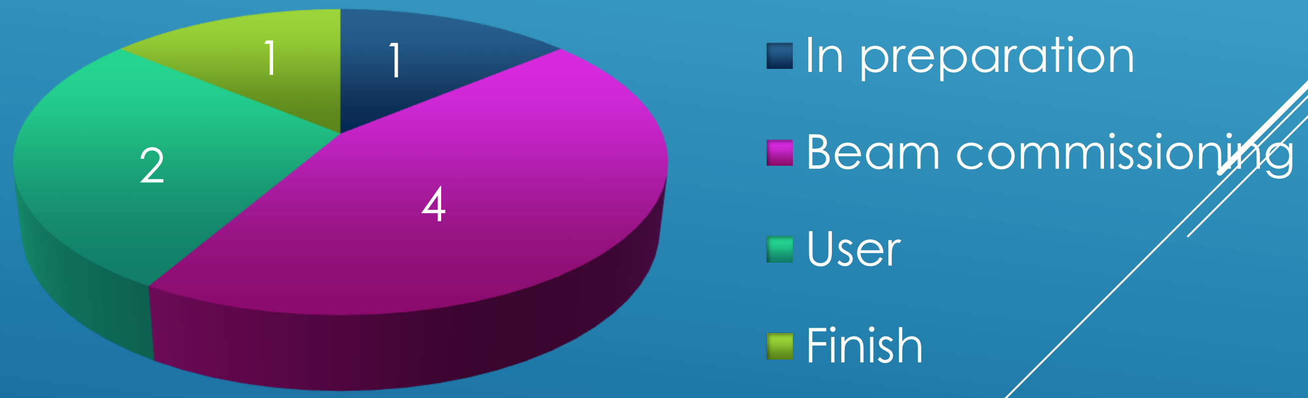


Back illumination makes brighter electron beams!

Electron Guns:

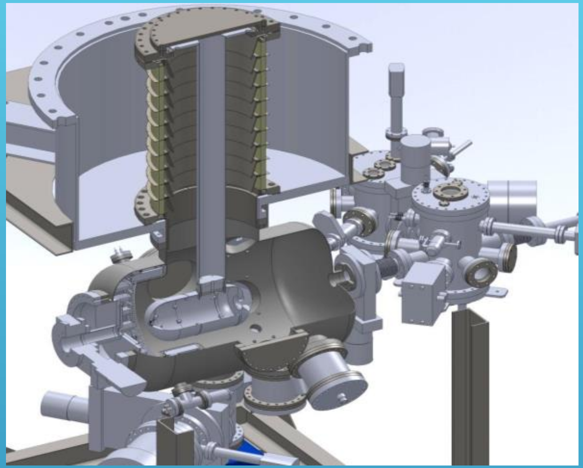
8 presentations



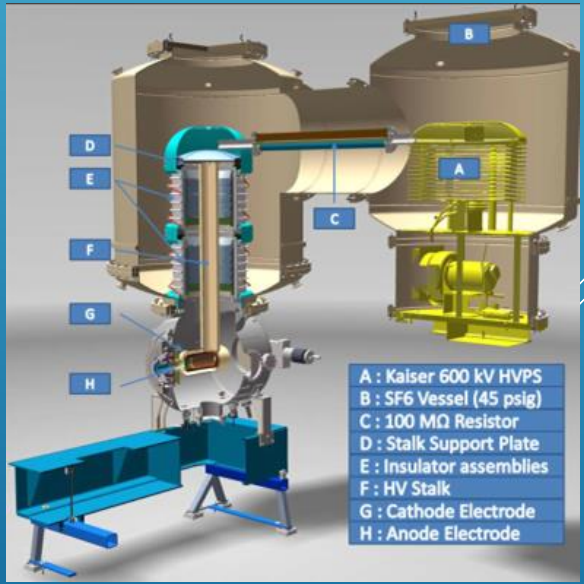


Highlights: some DC guns

- DC gun at KEK (N. Nishimori) – operated at 550 kV, 1 mA stable at 390 kV, > 30 C from GaAs cathode:



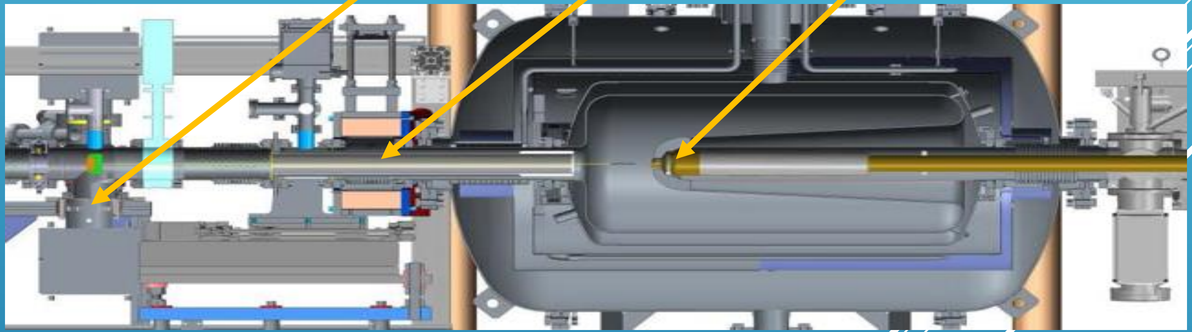
- DC gun for CBETA (K. Smolenski) – delivered 75 mA (!)
  2.6 days e^{-1} lifetime @ 65 mA
  Satisfies needs for CBETA!



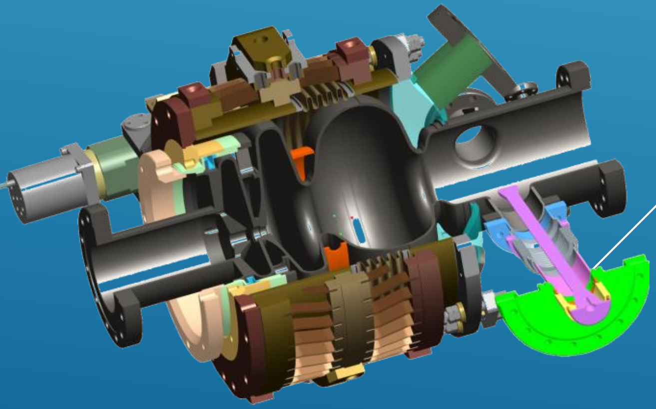
Highlight: SRF guns

	FZDR	HZB	NPS	Wisconsin	CeC
Charge [pC]	300	6	78	100	3900
E [MV/m]	5	5-7	6.5	12	21
Frequency [MHz]	1300	1300	500	200	113
Cathode	Cs_2Te	Pb	Nb	Cu	CsK_2Sb

- "Low frequency SRF gun at BNL" (I. Pinarev) QWR operated at 119 MHz, for Coherent e-Cooling (CeC)



- SRF gun for bERLinPro (A Neumann) design to deliver 100 mA/1.3 GHz
- Achieved $E_{acc} = 26\,\mathrm{MV/m},\ Q_0 = 5 \cdot 10^9$ @ 1.8 K



WG1 Summary

- DC Photo-injectors mature
- High QE photocathodes – alkali-antimonide: lifetime!!
- SRF guns have made significant progress (HZDR, BNL)
- Semiconductor cathodes show encouraging lifetimes (months!)

WG2:
Beam Dynamics, Optics and Instrumentation

D. Schulte, A. Bogacz

Learn from past experience

- Projects discussed (present and past, construction, planned):
  cERL, ALICE, CBETA, MESA, bERLinPro, PERLE, LHeC, eRHIC
  Lessons learnt from past ERLs (e.g. ALICE):
  - Provide diagnostics to verify your lattice and your beam in all planes!
  - Model step-by-step procedures how you will commission and operate!
  - Don't compromise on feedback systems – they're key to stability!
- Issues to be solved for multi-turn ERLs (e.g. CBETA):

1. High current effects
   a) space charge
   b) halo dynamics
   c) HOM heating
   d) Intra-Beam Scattering
   e) Touschek scattering
   f) Rest Gas scattering
   g) Ion accumulation
      i) optics changes
      ii) nonlinear dynamics
      iii) scattering
2. Beam Quality
   a) Emittance matching
   b) Time of flight control of energy spread
   c) Wakefield interactions
   d) Micro bunching instability
   e) Coherent Synchrotron Radiation
3. Transport of damaged beam
   a) Phase space rotation for energy spread
   b) Large 6-D phase-space-aperture optics
4. Recovery topics
   a) Energy spread growth during deceleration.
   b) Halo transverse growth during deceleration.
   c) Recirculative Beam Breakup instabilities.
      i) Transverse Dipole BBU
      ii) Longitudinal BBU
      iii) Quadrupole BBU
   d) Ion instabilities
   e) Simultaneous control of multiple beams

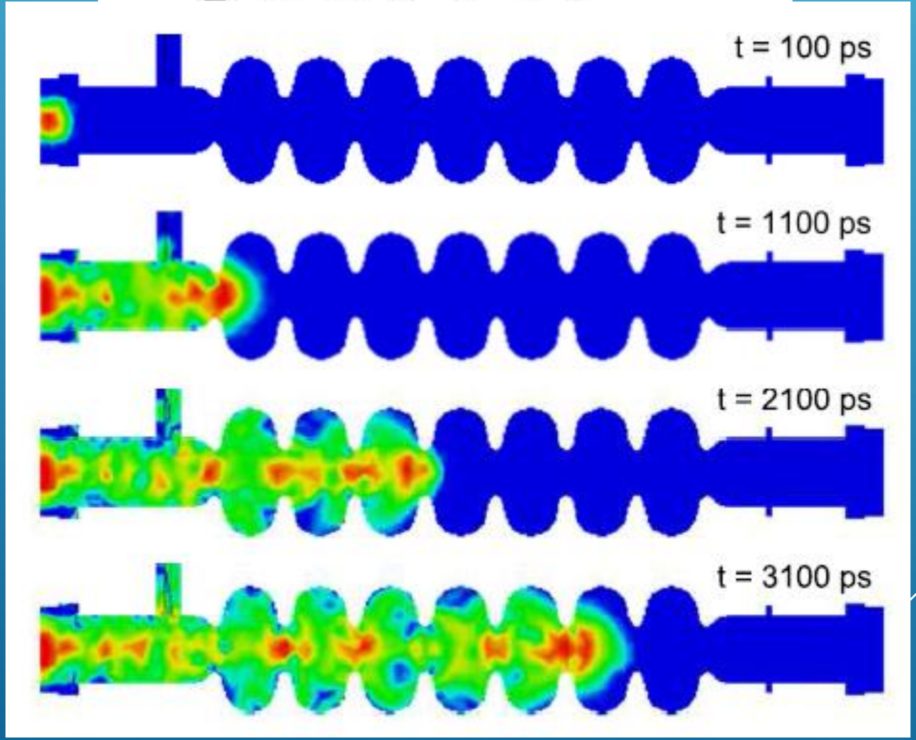
Beam break-up – the current current limit

G. Hoffstaetter:

$$V(t) = T_{12}\frac{e}{c}\int_{-\infty}^{t} W(t-\tau)\,V(\tau-T)\,I(\tau)\,d\tau$$

… and

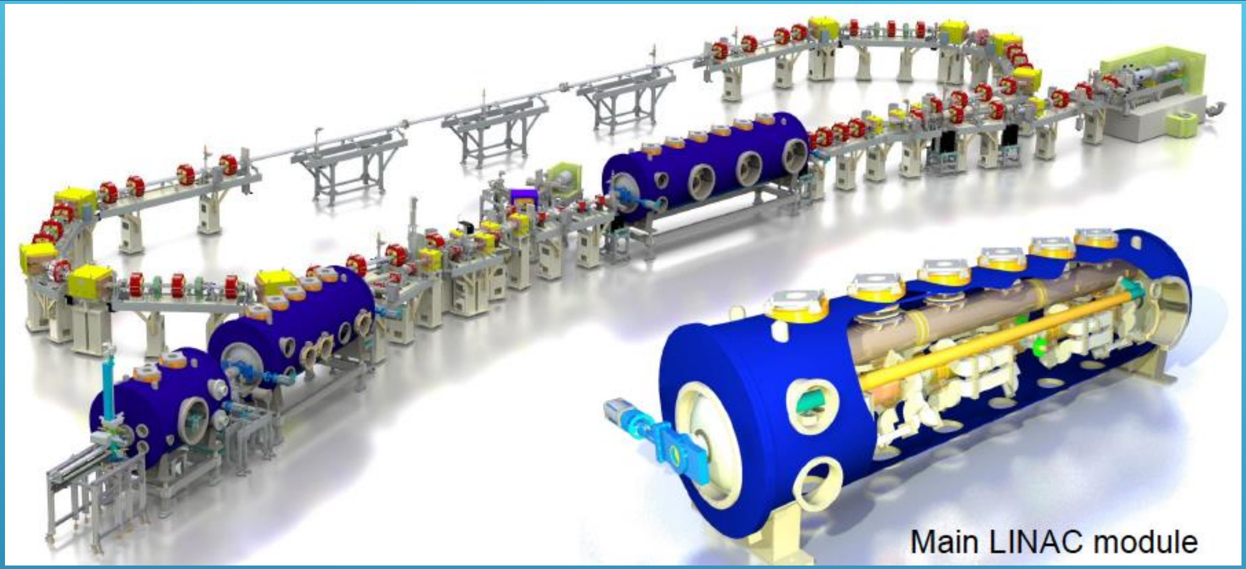
$$I_{\text{threshold}} \propto \frac{1}{Q_{\text{HOM}}}$$



Virtual power

bERLinPro

A. Jankowiak,
M. Abo-Bakr

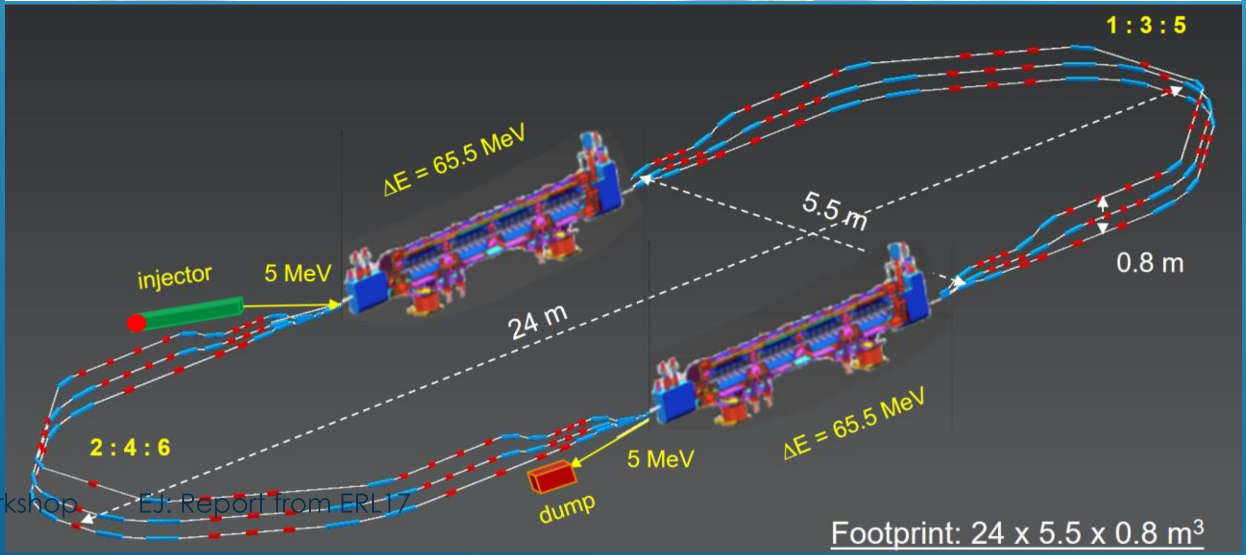


100 mA
50 MeV

Virtual power: 5 MW.

PERLE

W. Kaabi,
A. Bogacz



15 mA
400 MeV

Virtual power: 6 MW.

WG2 Summary

- There is valuable experience out there with existing/past ERL's – use it:
  - Think of plenty diagnostics for lattice and beam!
  - Think of how you will set up your machine!
  - Invest in sufficient feedback!
- There are a number of multi-turn ERL's planned, conceived or under construction! Especially for those, BBU limits the current – an substantial effort is underway to overcome this limit.

WG3:
Facilities around the world

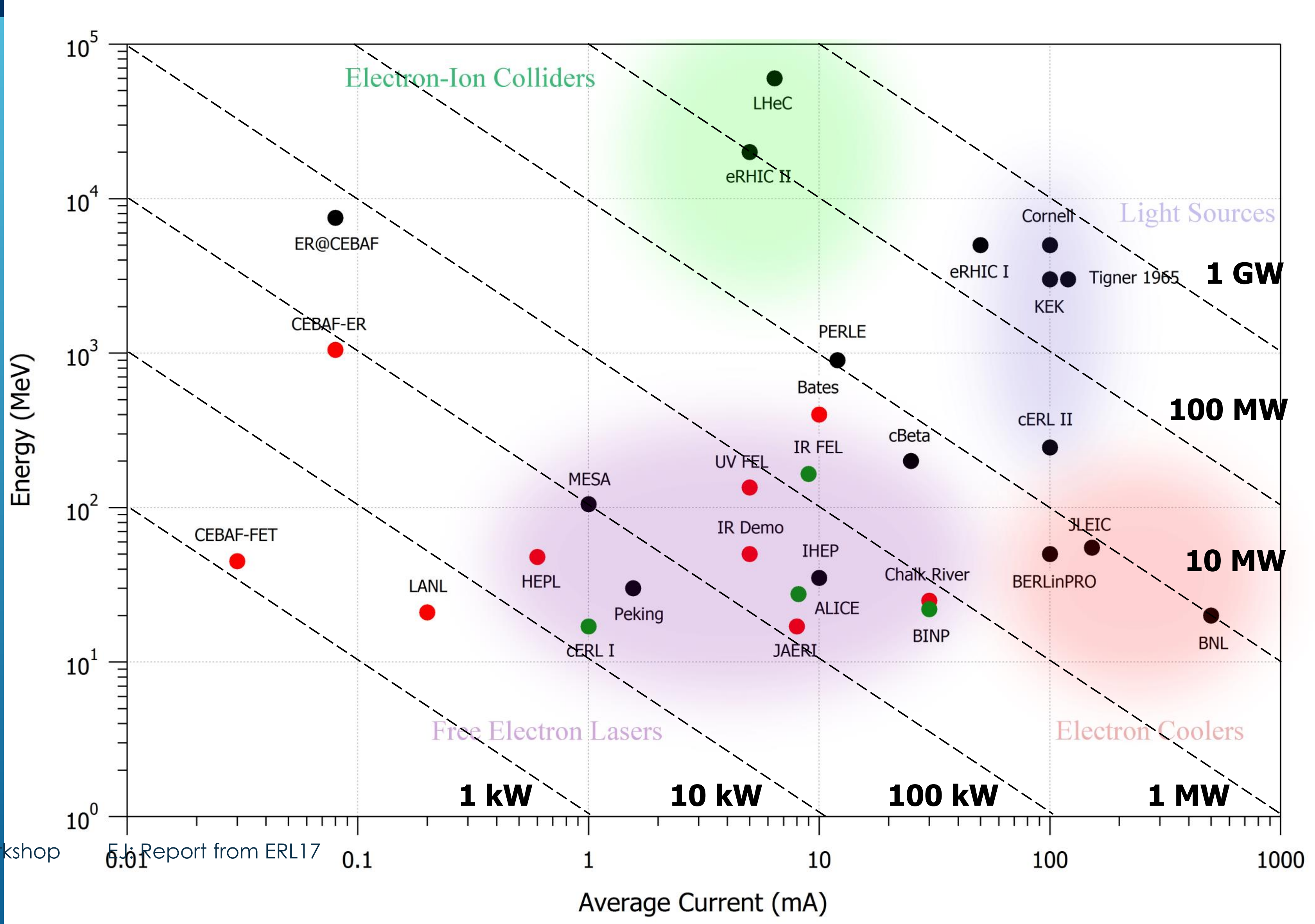
G. Hoffstaetter, A. Stocchi

Highlight Outcome: table of ERLs

Name	CEBAF-ER	ERL DEMO	IR ERL Upgra	ER@CEBAF	cERL start	cERL end	EUV Source	ALICE Start	ALICE End	bERLinPro	CBETA	S-DALINAC
Institute	JLab	JLab	JLab	JLab	KEK	KEK	KEK	STFC	STFC	HZB	Cornell	U Darmstadt
Main application: Test Facility [TF],	TF	TF	LS	TF	TF	TF	LS	TF, UF	TF, UF	TF	TF	TF
Commissioning Start	2003	1997	2001	2018	2013	2016	2018	2005	2016	2018-2020	2017	2017 (ERL)
Operation End	2003	2001		2018	2016	2016		2016	2016	tbd	tbd	tbd
# Re-Circulations	1	1	1	5	1	1	1	1	1	1	4	2
RF type	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC	SC
RF Frequency [GHz]	1.5	1.5	1.5	1.50	1.3	1.3	1.3	1.3	1.3	1.3	1.3	3
Bunch Frequency [MHz]								81.25	81.25	1300	325	3000
Accelerating Voltage ML [MeV/m]	5, 12			5, 12, 20	8.2	8.2	12.5 to 15	10 (14)	10 (14)	18	7	5
Accelerating structure ML	2 linacs in racetrack, 20 CM / linac, 5-			2 linacs, racetrack, 25 CM per linac,	one cryomodule with 2 9-	one cryomodul e with 2 9-	one cryomojule with 4 9-cell	1 cryomodule with 2 cavities 2	1 cryomodule with 2	one cryomodule with 3 7-cell	1 cryomodu le with 6	4 CM with 2 20-cell cavities each
Energy gain / linac [MeV]	500	48		700.00	17	17	50	24	24	44	36	30.4
Accelerating Voltage Injector [MeV/m]										9		5
Accelerating structure Injector										SRF Photo		CM1: 1 2-
Bunch charge @ inj [pC]	0.07	60	135	0.20	0.77	40	60	10	80	77	123	0.007
Bunch length [ps]	0.7		0.15	0.70	0.2 to 3	0.2 to 3	0.05 to 2	1	1	2	3	5
Energy spread (extraction)	0.0001 (%)		0.5	0.0001 (2-3%)	1.2×10^{-4}	1.2×10^{-4}	1×10^{-3}	5 keV	5 keV	0.005	4.00E-04	no data
Transverse emittance [gamma mm mrad]	0.5		15	0.50	1-1.6 (7.7pC/bunch)	1-1.6 (7.7pC/bunch)	0.8 (60pC/bunch)	5 to 10	5 to 10	0.4 - 0.6	0.5	no data
Av. Current @ inj [mA]	0.035	5	9	0.10	0.01	1	10	0.001	0.013	100	40	0.02
Av. Current @ inj [mA] macro pulse									6.5			
Duty factor for pulsed operation	1	1	1					0.001	0.001			
Pulse length	CW	CW	CW									
Injector Energy [MeV]	56	9	9	79.00	2.9	2.9	10.5	8.35	8.35	6.5	6	7.6

Live document – at present 30 entries! See under www.cern.ch/ERL17 "ERL Facility Summary"

Global ERL Landscape (C. Tennant)



Common achievements & challenges

International achievements:

1. About 0.75 MW injector power
2. Stable DC-gun operation
3. Low emittance tuning
4. About 1 MW virtual beam power
5. About 75 mA current through SRF cavity
6. Applications for FEL, THz, and Compton Scattering
7. Operation stability for many days

Main common challenges:

1. Multi-pass operation
2. Higher current (100 mA)
3. Higher power (8 MW in near term, 900 MW for LHeC)
4. Polarized beams
5. Stable SRF microphonics
6. Permanent magnets and FFAG transport
7. Networking, sharing of information, micro-workshops, commissioning sharing

Common research interests

1. Cathodes with higher QE, better lifetime, low thermal emittance
2. Polarized cathodes
3. Design of cryomodules for low microphonics
4. LLRF control for high Q_{ext} operation with microphonics
5. Multi-turn beam control
6. Halo control and machine protection
7. Benchmarking of simulations

WG3 Summary

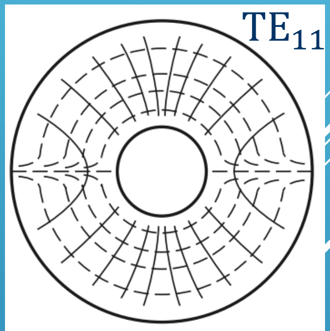
- For the first time, facilities (in construction or planned) reach the multi-MW-range for the virtual beam power (MESA: 1 MW, bERLinPro: 5 MW, C-BETA: 6 MW, PERLE: 8 MW)
- The trend clearly goes towards multi-pass operation
- Both these features mean new challenges that are now addressed.
- The community is coherent and working together well. Common interests are clearly identified.

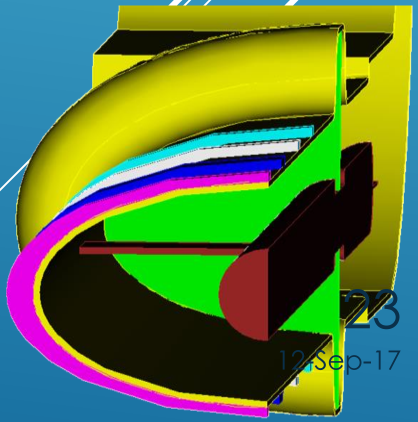
WG4: Superconducting RF

I. Ben-Zvi, F. Gerigk

WG4 Summary

- Due to the ERL principle, CW fundamental power is relatively low (tens of kW), while the stored energy is large. Cryogenic losses are very important!
- Recent progress in SRF (nitrogen treatments – significantly improved Q_0) are very relevant for ERLs!
- To allow the CW power to be low, microphonics are of paramount importance!
- Main remaining issues:
  - Keep microphonics at bay (stiffer cavities, CM design, LHe feed, …)
  - Large current ⟺ strong HOM damping! HOM couplers same power level as FPCs!
- Coaxial couplers seem very interesting, in particular TE11 type coaxial, which would allow easier cooling (thermal anchor).





WG5: Applications

I. Konoplev, P. MacIntosh

WG5 Summary

- An increasing interest in a variety of ***photon applications*** can be observed.
- THz, IR-FEL, EUV-FEL and Laser Compton Scattering (LCS) X-Ray applications, all require
  - Good stability, low emittance, good availability!
- Applications presented:
  - LERF: "Dark Light" experiments (e- p interaction internal target)
  - NovoFEL (BINP), user facility: THz, IR and EUV. E.g.: Spectrometry, photo-chemistry, surface plasmon polaritons (SPP)
  - Asymmetric ERL (JAI proposal): THz: security, EUV: lithography
  - CBETA: Specific test facility for e-RHIC, many of the above plus:
    - Beam for time-resolved electron diffraction from 1-6 MeV,
    - Beam for Plasma Wakefield Acceleration with High Transformer Ratio
  - PERLE: Many of the above plus:
    - Testing of SRF components with beam,
    - Testing of detector components for LHC & FCC
  - With LCS: Vortex beams (beams with helical wave front, could solve "proton spin puzzle")
  - MESA: nuclear physics applications, proposed eperiments
    - "MAGIX" (MAinz Gas Internal eXperiment, to solve "proton radius puzzle", dark photon searches, …)
    - "P2" (external target experiment, no energy recovery)

Thank you very much!