ERL Operation of the Superconducting Darmstadt Electron Linear Accelerator S-DALINAC – a Facility Report

M. Arnold, J. Birkhan, A. Brauch, M. Dutine, J. Enders, M. Fischer, R. Grewe, M. Herbert, L. Jürgensen, M. Meier, N. Pietralla, F. Schliessmann, D. Schneider, V. Werner

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Picture: Jan-Christoph Hartung

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EL EM EN TS

ACCELENCE

Nuclear Photonics

Bundesministerium für Bildung und Forschung

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Prepared for submission to JINST

The Development of Energy-Recovery Linacs

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[n] *KEK, Tsukuba, Japan*
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[p] *INFN, Milano, Italy, and LASA*
[q] *Lancaster University, Lancaster, UK*
[r] *Novosibirsk State University, 630090, Novosibirsk, Russia*
[s] *University of Siegen, Siegen, Germany*
[t] *SLAC, Menlo Park, CA, USA*
[v] *Fermilab, Batavia, IL, USA*

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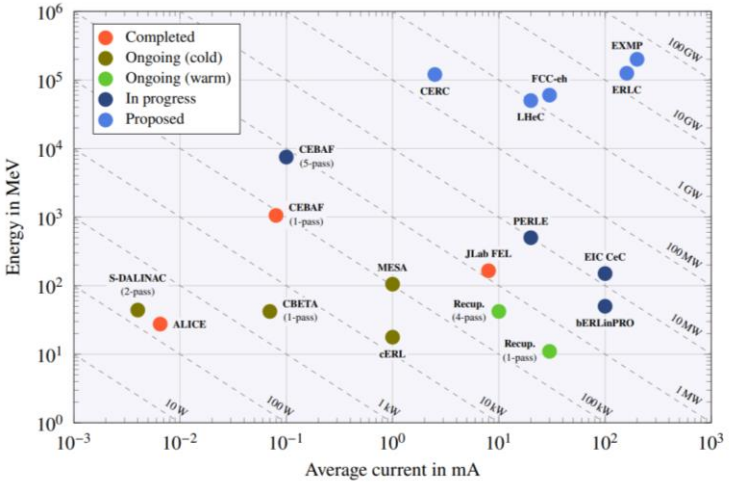
[1] Corresponding author.

arXiv:2207.02095 [physics.acc-ph]



See also talk by Andrew Hutton (Mon, 9:50)

Outline

- Overview
- ERL operation
- ERL diagnostics
- Future

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S-DALINAC

Superconducting **DA**rmstadt **LIN**ear **AC**celerator

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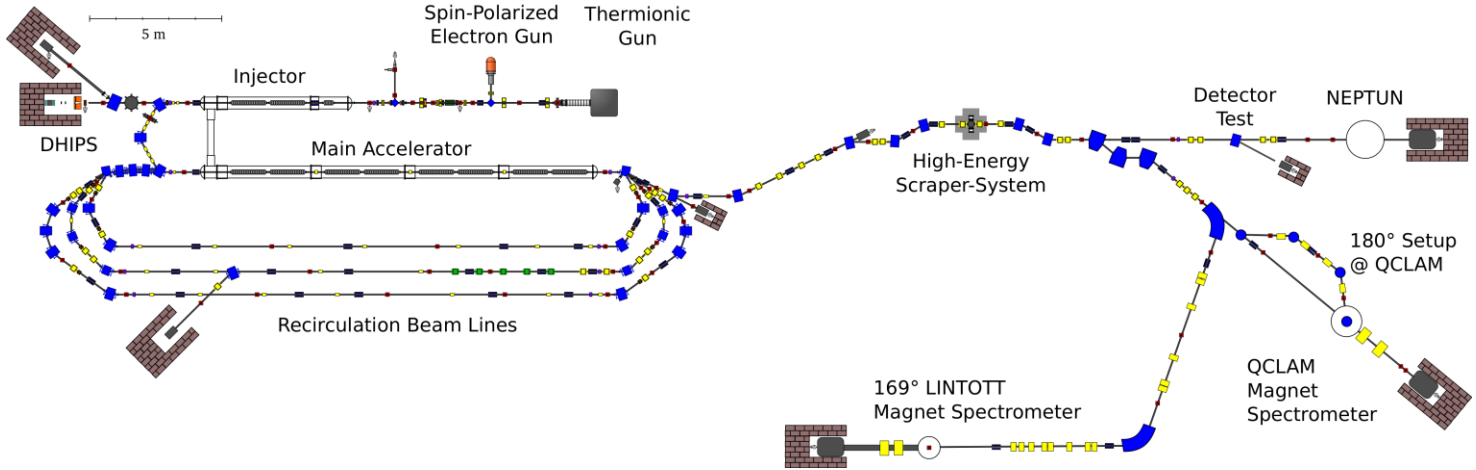


<u>Thrice recirculating operation</u>

Energy gain injector: 7.6 MeV

Energy gain LINAC: 30.4 MeV

Beam current: 20 µA

Design (extracted beam): 130 MeV, 20 µA

Design (NRF): 10 MeV, 60 µA

Particles: electrons

Rep. rate: 2.9973 GHz, cw

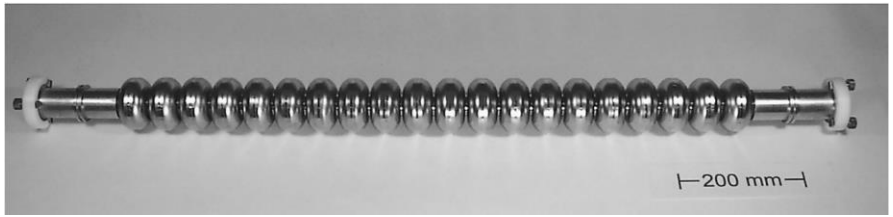
Parameters SRF and ERL

SRF injector

- 1x 6-cell (β=0.86) as capture
- 2x 20-cell (β=1)

SRF main linac

- 8x 20-cell (β=1)



f = 2.9973 GHz

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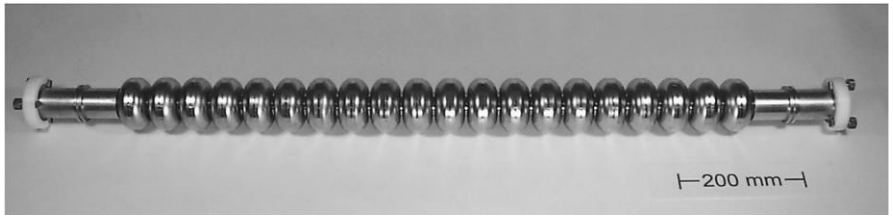
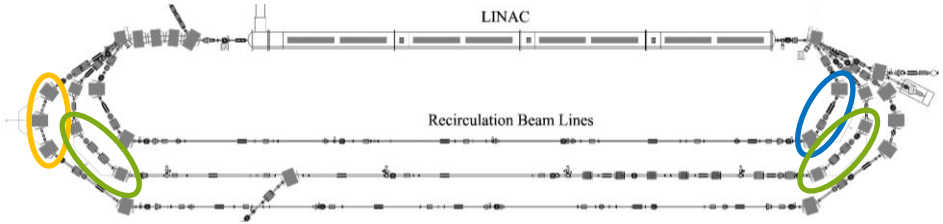


f = 2.9973 GHz

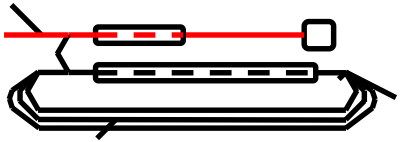
- ERL mode possible since upgrade in 2015/2016
- 360° path length adjustment system in second recirculation → ERL mode
- 265° for first recirculation
- 205° for third recirculation



Overview Operation Modes/Commissioning

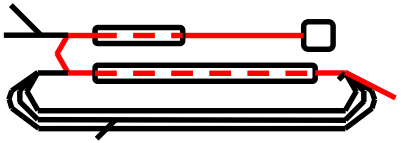
- Modification lattice 2015/2016
- Commissioning of modes followed beam time schedule

Injector



December 2016

Single pass



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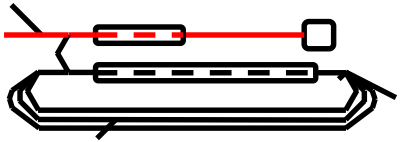
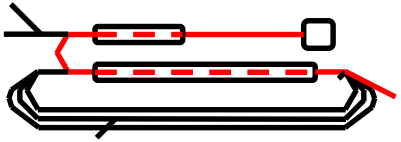
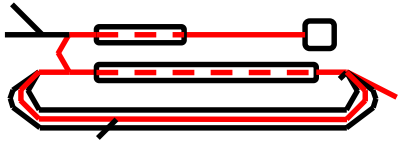
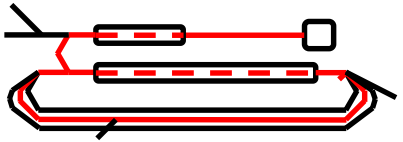
Injector  December 2016

Single pass  December 2016

1x rec.  May 2017

1x ERL  August 2017

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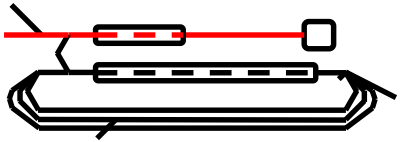
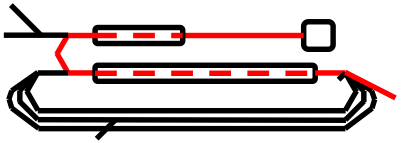
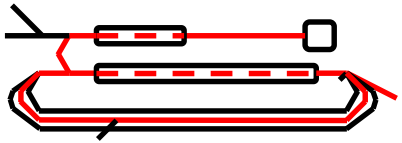
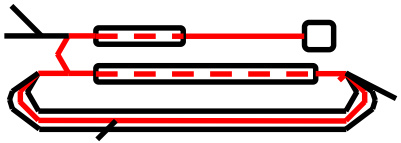
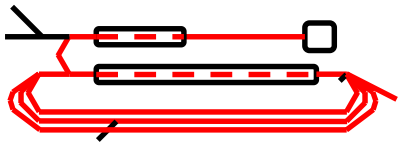
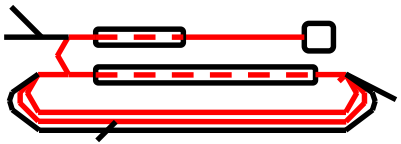
Injector		December 2016	Single pass		December 2016
1x rec.		May 2017	1x ERL		August 2017
3x rec.		November 2018	2x ERL		August 2021

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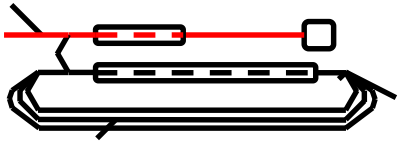
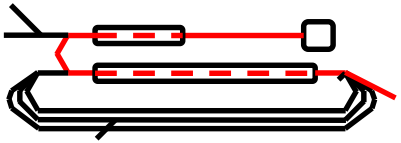
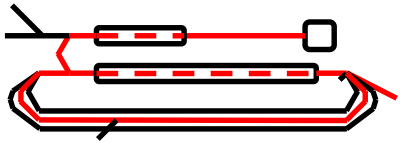
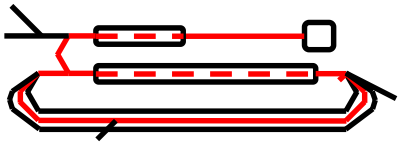
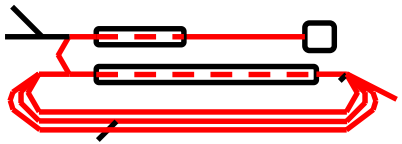
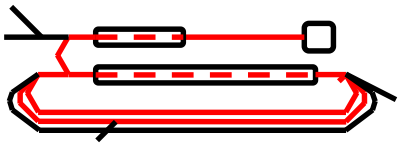
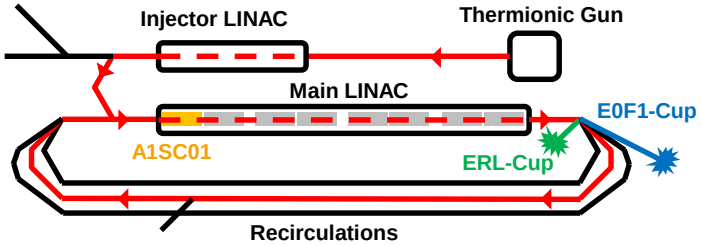
Injector		December 2016	Single pass		December 2016
1x rec.		May 2017	1x ERL		August 2017
3x rec.		November 2018	2x ERL		August 2021

Once-Recirculating ERL Operation

- Energy gain injector: 2.5 MeV
- Energy gain LINAC: 20.0 MeV
- Current (I_{in}): 1.2 µA



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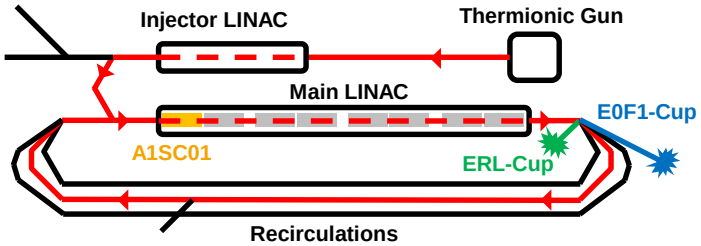
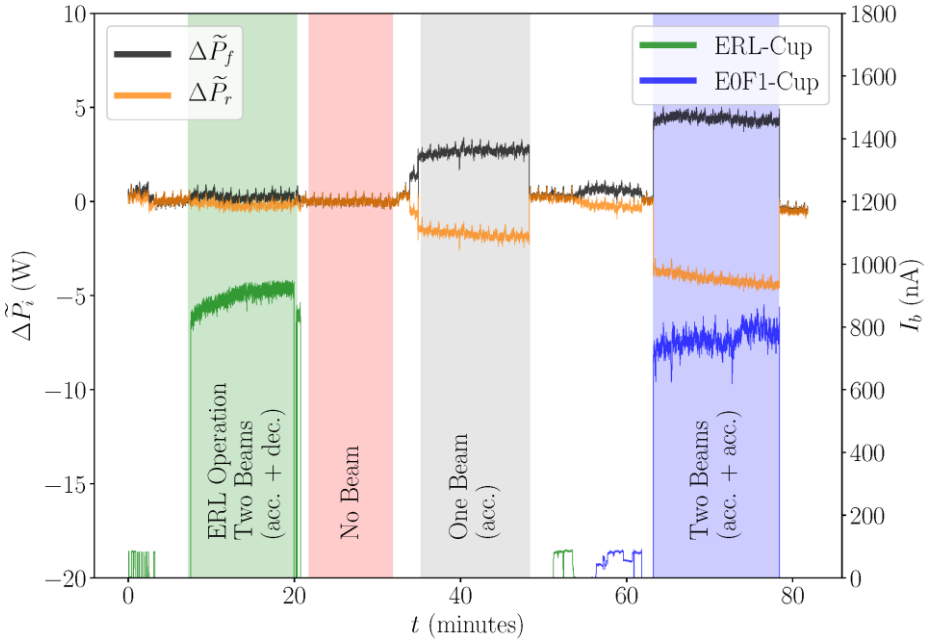
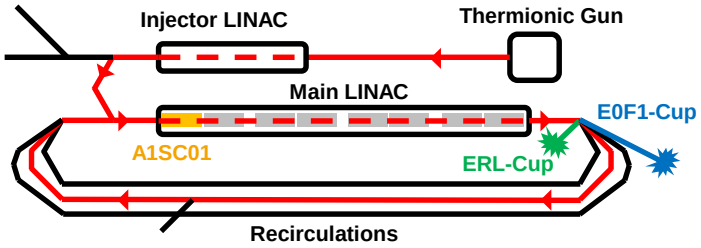


Four phases:

- Phase 1 (ERL Operation): one accelerated and one decelerated beam
- Phase 2 (no beam): RF operation of cavity without beam
- Phase 3 (1x acc.): one accelerated beam
- Phase 4 (2x acc.): two accelerated beams

Once-Recirculating ERL Operation





RF-recovery effect:

$$\varepsilon_{\mathrm{RF}} = \frac{P_{RF,acc.} - P_{RF,ERL}}{P_{RF,acc.}}$$

$$\varepsilon_{\mathrm{RF}} = (90.1 \pm 0.3)\%$$

*M. Arnold et al., Phys. Rev. Accel. Beams **23**, 020101 (2020).*

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- Modification lattice 2015/2016
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Injector December 2016

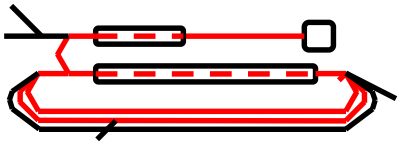
Single pass December 2016

1x rec. 

See talk by Felix Schliessmann (Tue, 8:50)

 August 2017

3x rec. November 2018

2x ERL  August 2021

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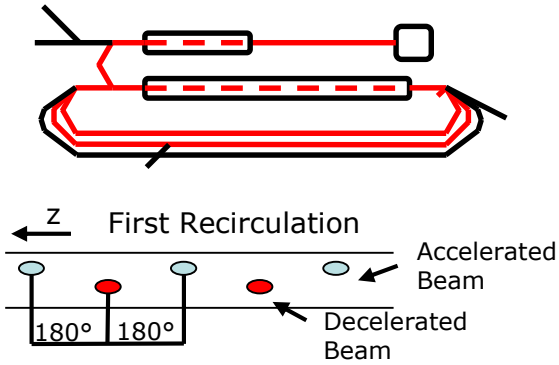
2x ERL: Beam Diagnostics System



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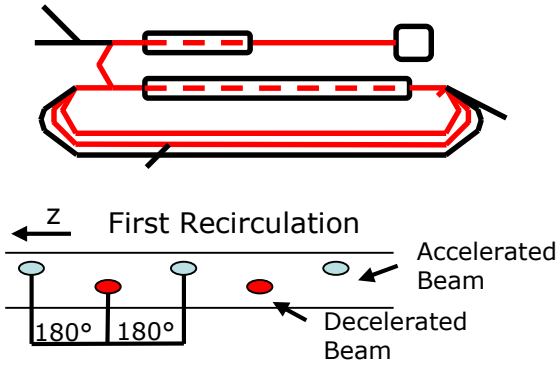

- (Non-)destructive position measurement for both beams simultaneously
- Suitable for low bunch charges (S-DALINAC: ~30 aC to ~7 fC in recirculating mode)
- Two options under investigation: Wire scanner and 6 GHz cavity BPM (double of fundamental frequency)

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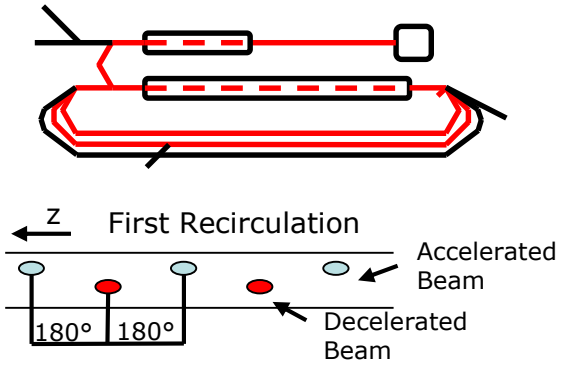

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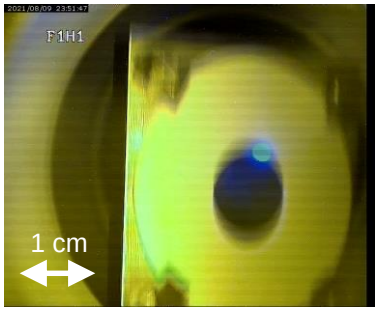
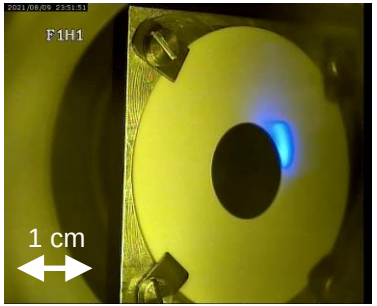
Further diagnostics:

- RF beam loading
- BLMs
- 3 GHz RF monitors
- BeO target with hole



1x acc. beam

1x dec. beam



Wire Scanner

Measurement routine:

1) Measure one-accelerated beam alone
2) Measure both beams simultaneously
3) Substract result of 1) from result of 2)

→ Gain position of once-decelerated beam

- Tuning of the first beam results in a re-calibration of system

Wire Scanner

Measurement routine:

1) Measure one-accelerated beam alone (see a))
2) Measure both beams simultaneously (see b))
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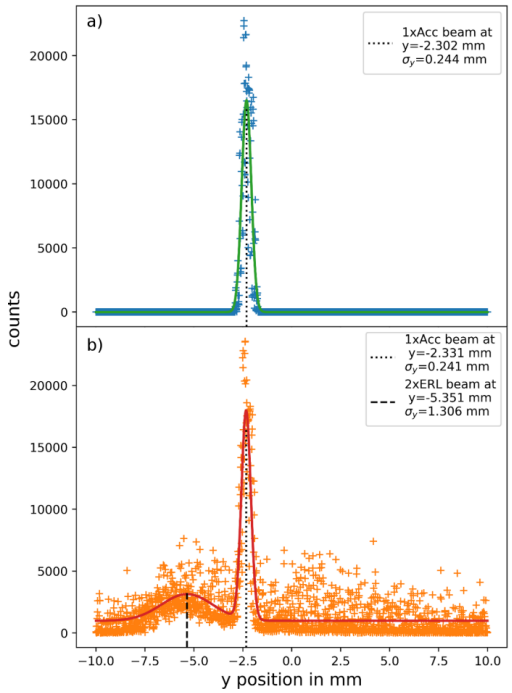
→ Gain position of once-decelerated beam

- Tuning of the first beam results in a re-calibration of system

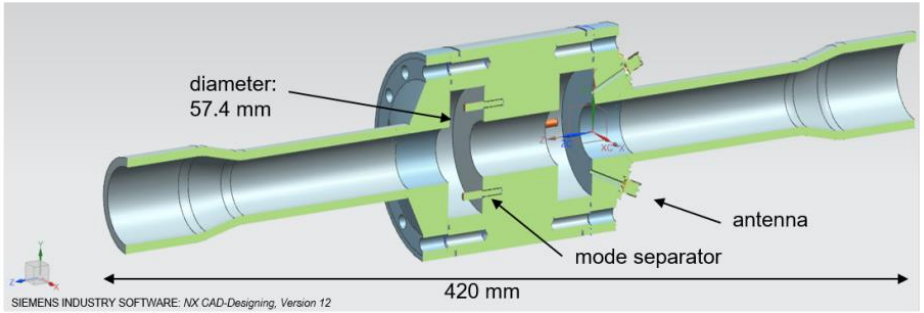


M. Dutine et al., Proc. of IPAC 2022, p. 254 (2022).

6 GHz Cavity BPM

Measurement routine:

- Identical to wire scanner
- Advantage: online measurement instead of defined measurement points
- Tested at test stand
- Read out electronics under development
- Test with beam planned for end of 2022
- Comparison to wire scanner



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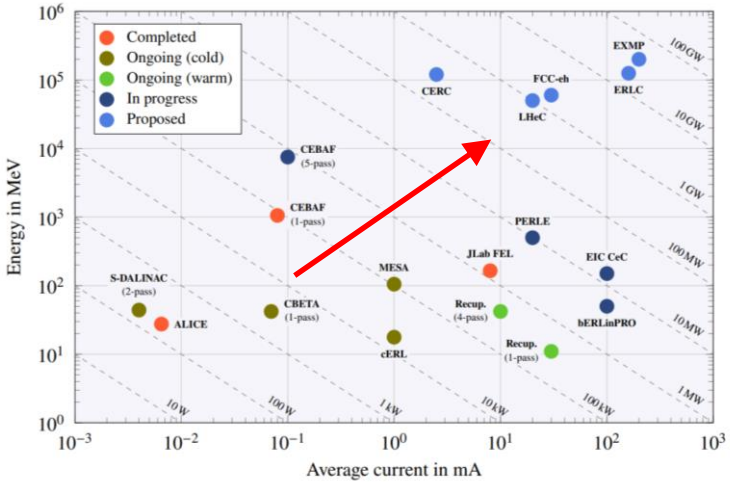
What will the Future bring?



- Clear goal for future ERLs: multi-turn SRF needed
- S-DALINAC in operation since 1991 → no future as high-power ERL
- Successor needed at TU Darmstadt

arXiv:2207.02095 [physics.acc-ph]

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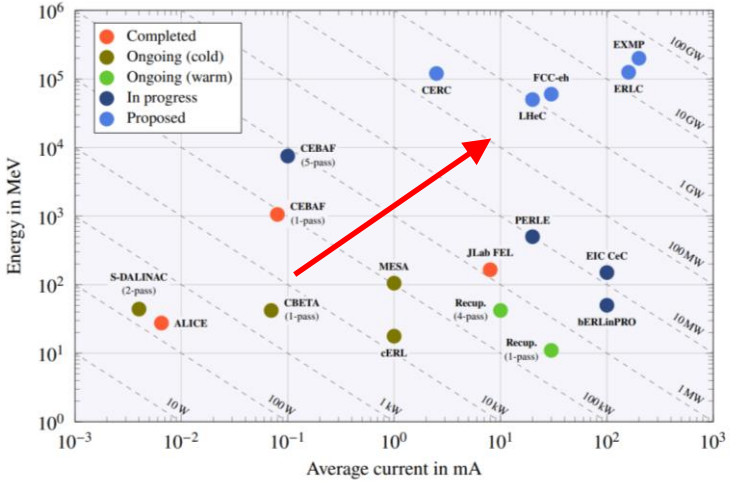

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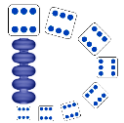
DICE

(Darmstadt **I**ndividually-recirculating **C**ompact **E**RL)

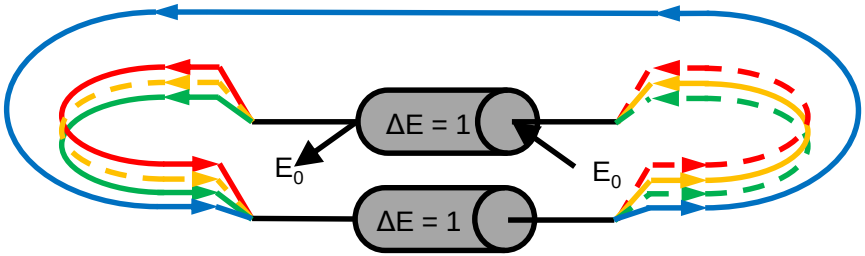


DICE

- Decision on technologies – straight foreward:
  - SRF
  - Multi-turn ERL

- Further decision - frequency:
  - A state-of-the-art frequency regime
  - Compatible to CERN as future large scale ERL

  → 802 MHz



Idea of separate transport: Peter Williams

P. Williams, ERL Design Concepts DIANA and DICE, Electrons for the LHC: Workshop on the LHeC, FCC-eh and PERLE (2019). https://indico.cern.ch/event/835947/contributions/3553736/

- Further decision - Topology:
  - Our experience: limitation of common transport, lack of degrees of freedom for perfect longitudinal match (→ talk F. Schliessmann)

  → Separate transport for more flexibility, robustness and reliability

DICE

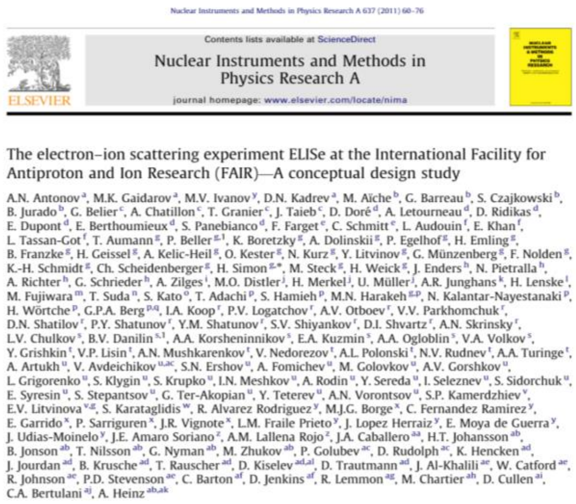
Parameters (as of today)

- Max. energy: 520 MeV
- Max. current: 20 mA
- Duty cycle: cw and pulsed (~ 40 MHz)

- Site consideration: DICE@FAIR → ELISe programme (ELISe not part of FAIR MSV)

- Main experimental programme (as of today)
  - (e,A)-collider
  - Electron scattering: (e,e'), (e,e'γ), (e,e'f)
  - Nuclear resonance fluorescence
    - Bremsstrahlung
    - Tagging of photons
    - Laser Compton backscattering

- Supported by the FAIR - NUSTAR community
  - White paper in preparation



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The electron–ion scattering experiment ELISe at the International Facility for Antiproton and Ion Research (FAIR)—A conceptual design study

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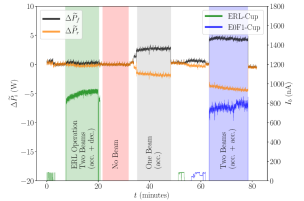
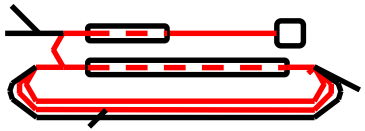
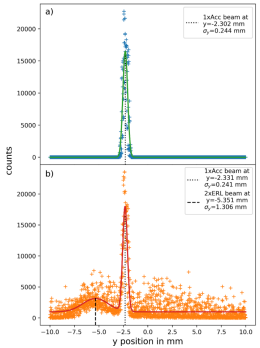
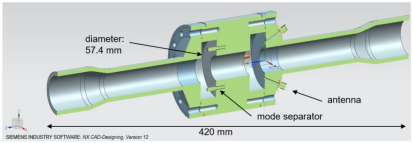
Thank you for your Attention!









Picture: Jan-Christoph Hartung