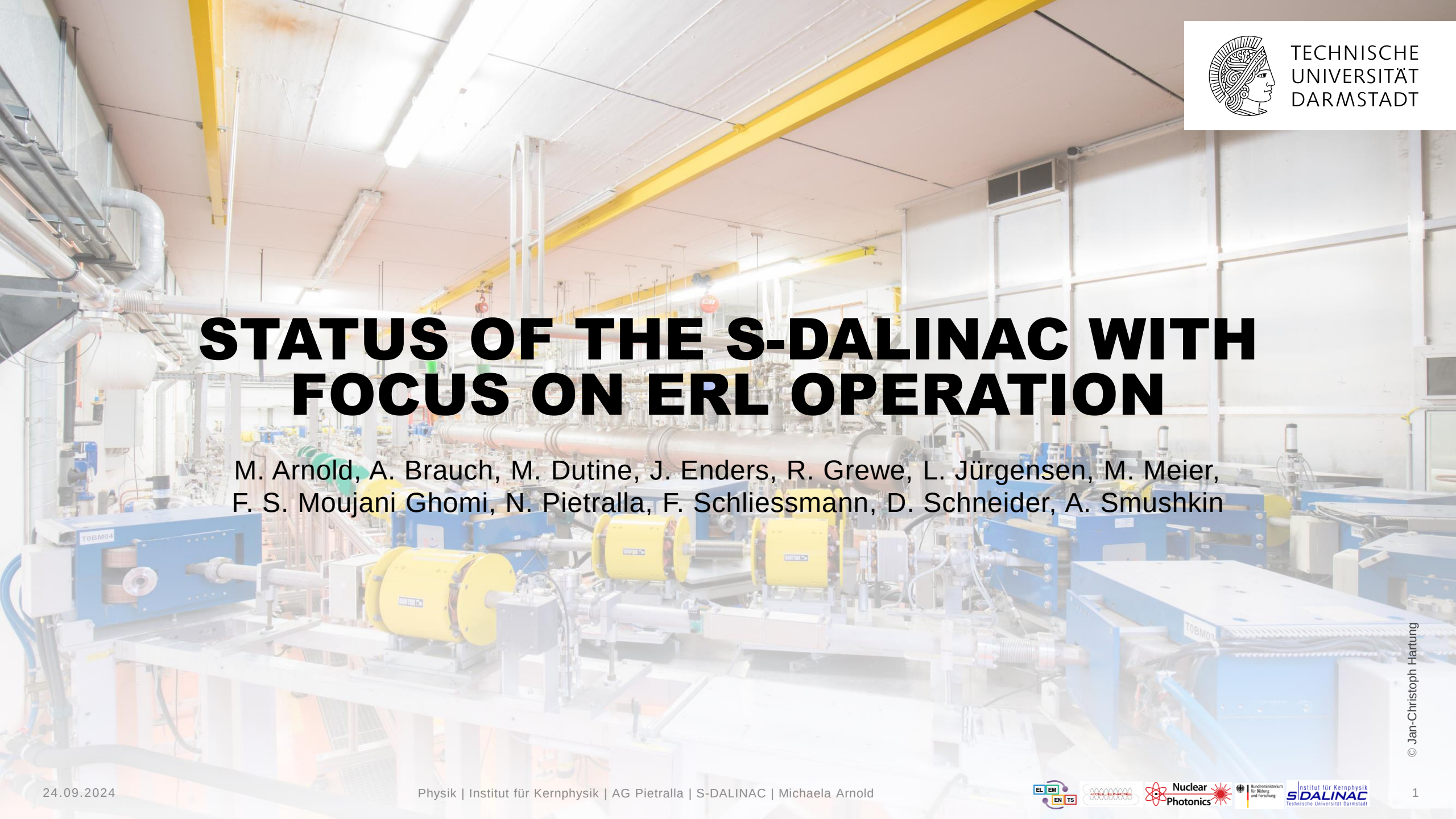

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# STATUS OF THE S-DALINAC WITH FOCUS ON ERL OPERATION

M. Arnold, A. Brauch, M. Dutine, J. Enders, R. Grewe, L. Jürgensen, M. Meier,
F. S. Moujani Ghomi, N. Pietralla, F. Schliessmann, D. Schneider, A. Smushkin

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# OUTLINE

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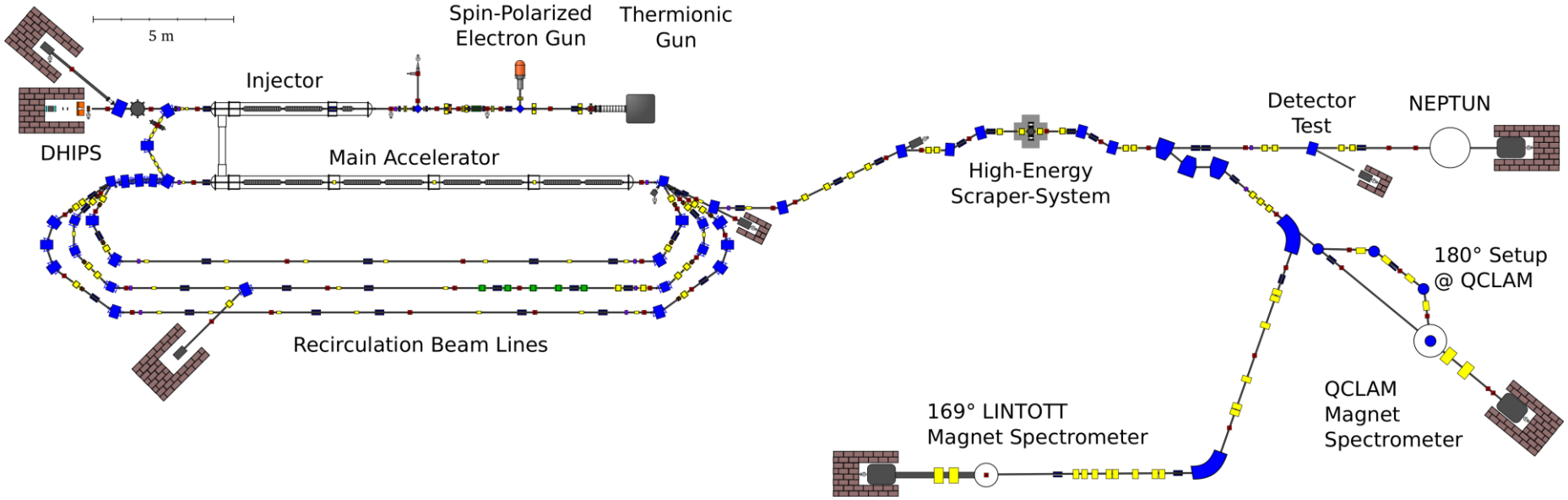
# S-DALINAC

## SUPERCONDUCTING DARMSTADT LINEAR ACCELERATOR




- **Design (extracted beam):** 130 MeV, 20 µA
- **Design (NRF):** 10 MeV, 60 µA
- **Particles:** electrons
- **Rep. rate:** 2.9973 GHz, cw

- In operation since 1991, modified, improved and operated mainly by students

Virtual tour (click here, bottom of page)

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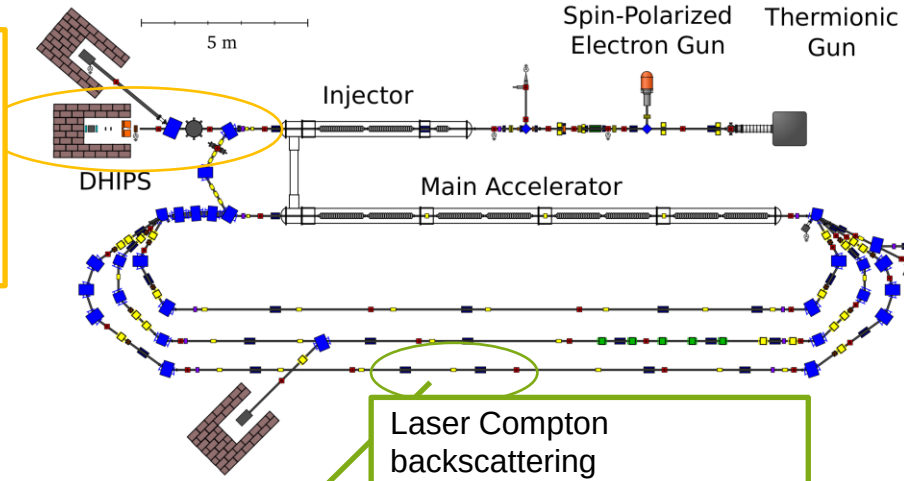
# EXPERIMENTAL SITES

Nuclear resonance fluorescence (~ 2 MeV to 10 MeV; up to 60 µA)

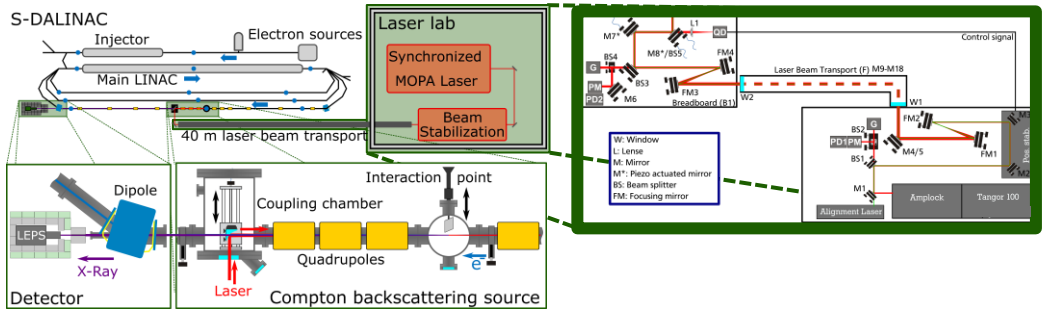



Detector Test (~ 10 MeV to 130 MeV; up to 20 µA)

High resolution photon tagger (~ 10 MeV to 65 MeV; up to 20 µA)

(e,e'), large acceptance spectrometer, 180° scattering, coincidence experiments (~ 10 MeV to 130 MeV; up to 20 µA)

Laser Compton backscattering (~ 40 MeV to 100 MeV; up to 20 µA)




(e,e'), high-resolution spectrometer (~ 10 MeV to 130 MeV; up to 20 µA)

## QCLAM special setups

- 180°
- (e,e'γ)
- sLHe-target
- Electrofission (in prep.)

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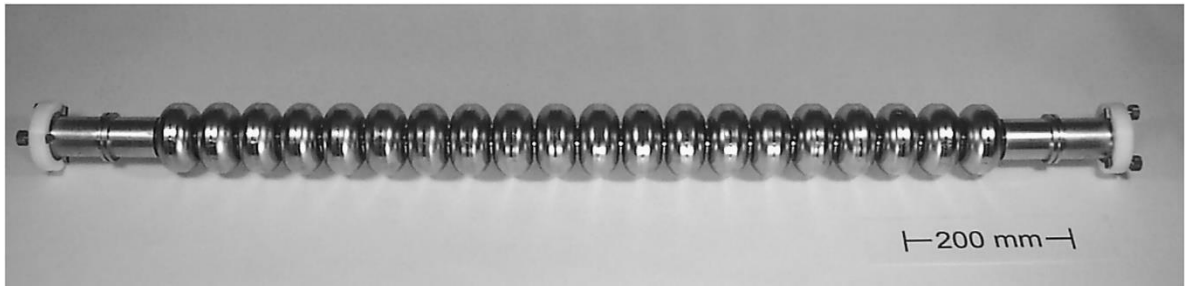
# PARAMETERS SRF AND ERL

SRF injector

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

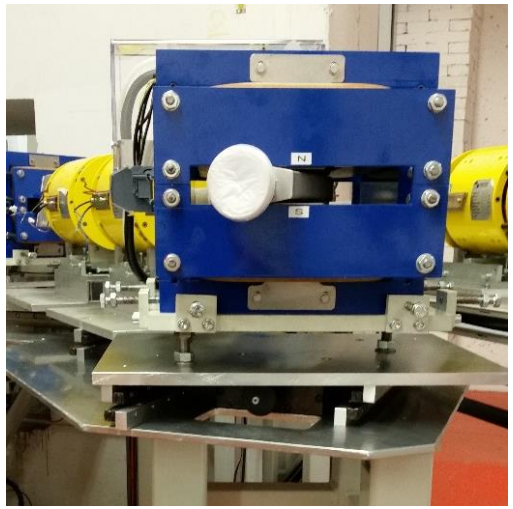
SRF main linac

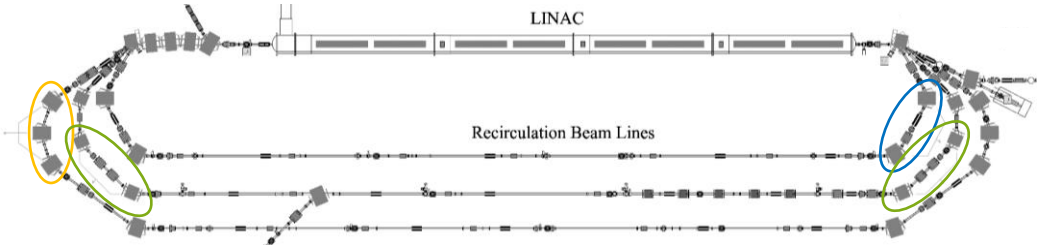
- 8x 20-cell (β=1)




f = 2.9973 GHz

- 360° path length adjustment system in second recirculation → ERL mode
- 265° for first recirculation
- ~ 360° for third recirculation
- Bunch length important for every setting





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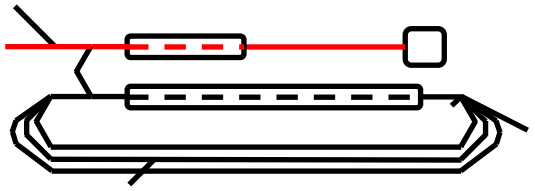
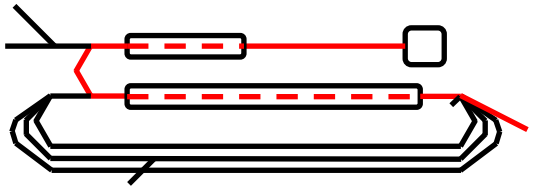
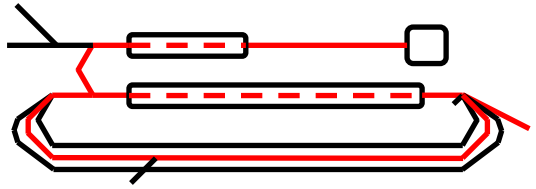
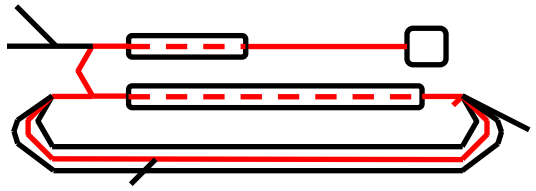
# OVERVIEW OPERATION MODES/COMMISSIONING

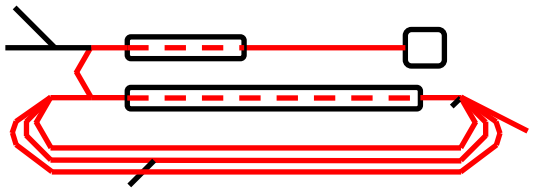
- Modification lattice 2015/2016
- Commissioning of modes followed beam time schedule

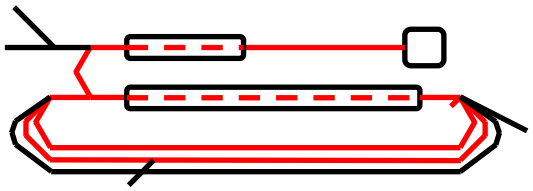
Injector  December 2016

Single pass  December 2016

1x rec.  May 2017

1x ERL  August 2017

3x rec.  November 2018

2x ERL  August 2021

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# OUTLINE

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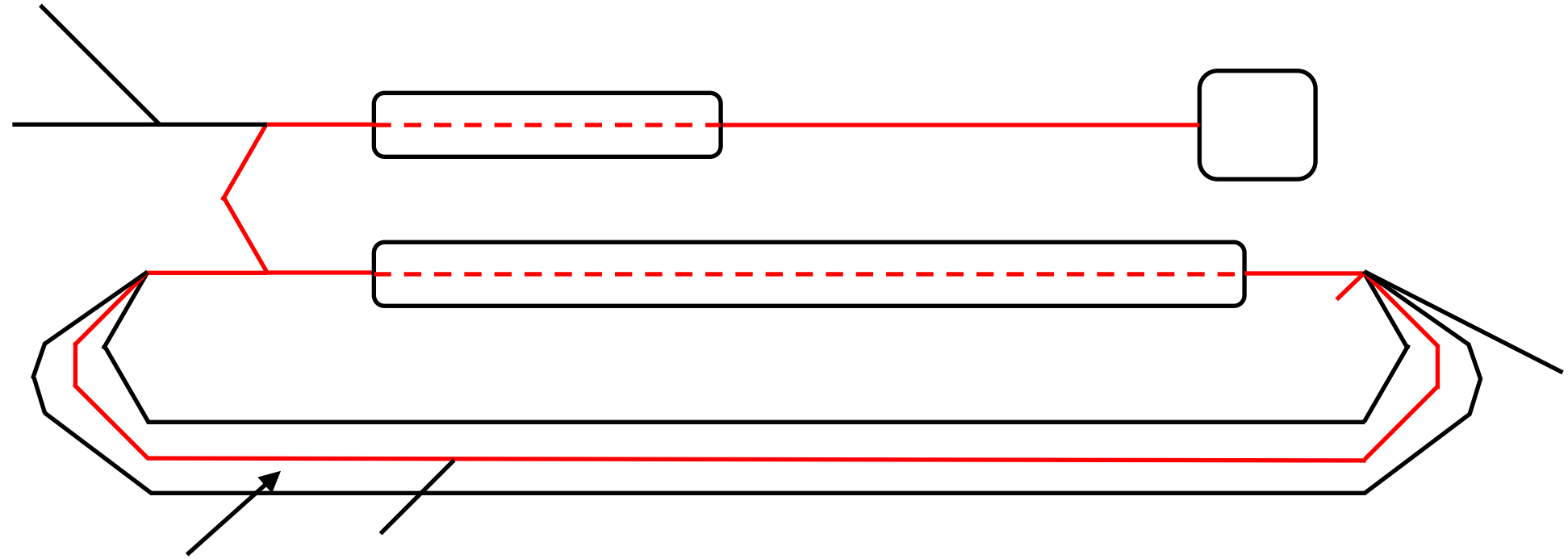
# ONE-TURN ERL



180° phase shift

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# ONE-TURN ERL

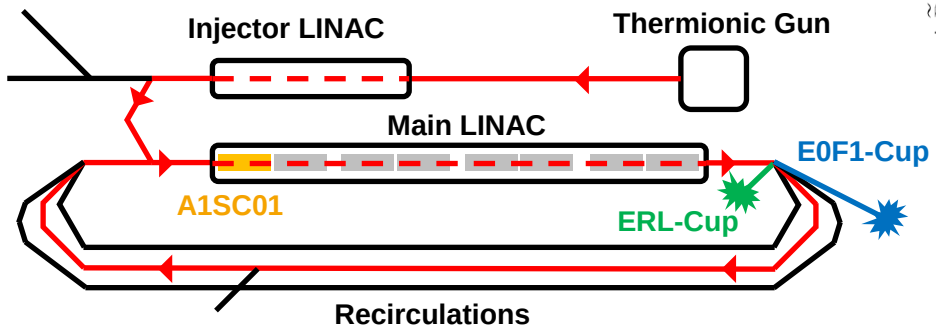
| Operation mode | Load at A1SC01 (W) |
|---|---|
| No Beam | $0.00 \pm 0.01$ |
| One Beam (acc.) | $4.51 \pm 0.16$ |
| ERL (acc. + dec.) | $0.45 \pm 0.03$ |
| Two Beams (acc. + acc.) | $8.59 \pm 0.01$ |

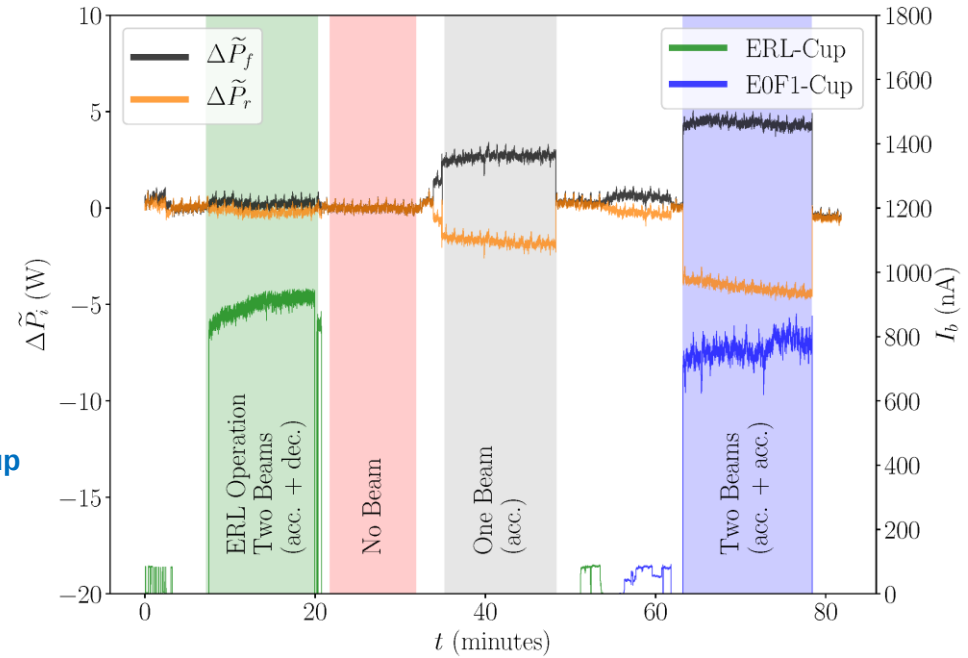
$$\eta_{\mathrm{A1SC01}} = \frac{P_{\mathrm{b,A1SC01,1x\,acc.}} - P_{\mathrm{b,A1SC01,1x\,ERL}}}{P_{\mathrm{b,A1SC01,1x\,acc.}}} = (90.1 \pm 0.3)\ \%$$

$E_{\mathrm{kin\ injection}}$ = 2.5 MeV

$\Delta E_{\mathrm{Main\ LINAC}}$ = 20 MeV

$I_{\mathrm{initial}}$ = 1.2 µA




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

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# OUTLINE

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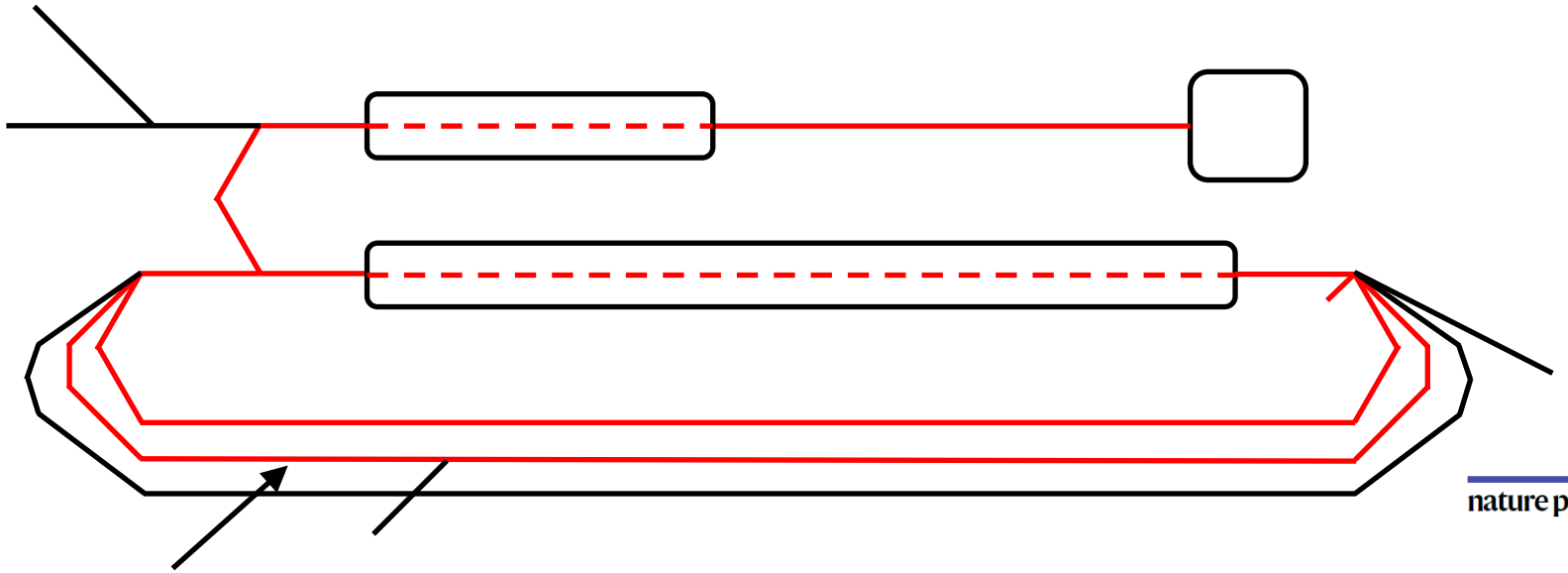
# TWO-TURN ERL



180° phase shift

nature physics

Article

https://doi.org/10.1038/s41567-022-01856-w

## Realization of a multi-turn energy recovery accelerator

Received: 28 March 2022

Accepted: 26 October 2022

Published online: 26 January 2023

Felix Schliessmann, Michaela Arnold, Lars Juergensen, Norbert Pietralla, Manuel Dutine, Marco Fischer, Ruben Grewe, Manuel Steinhorst, Lennart Stobbe & Simon Weih

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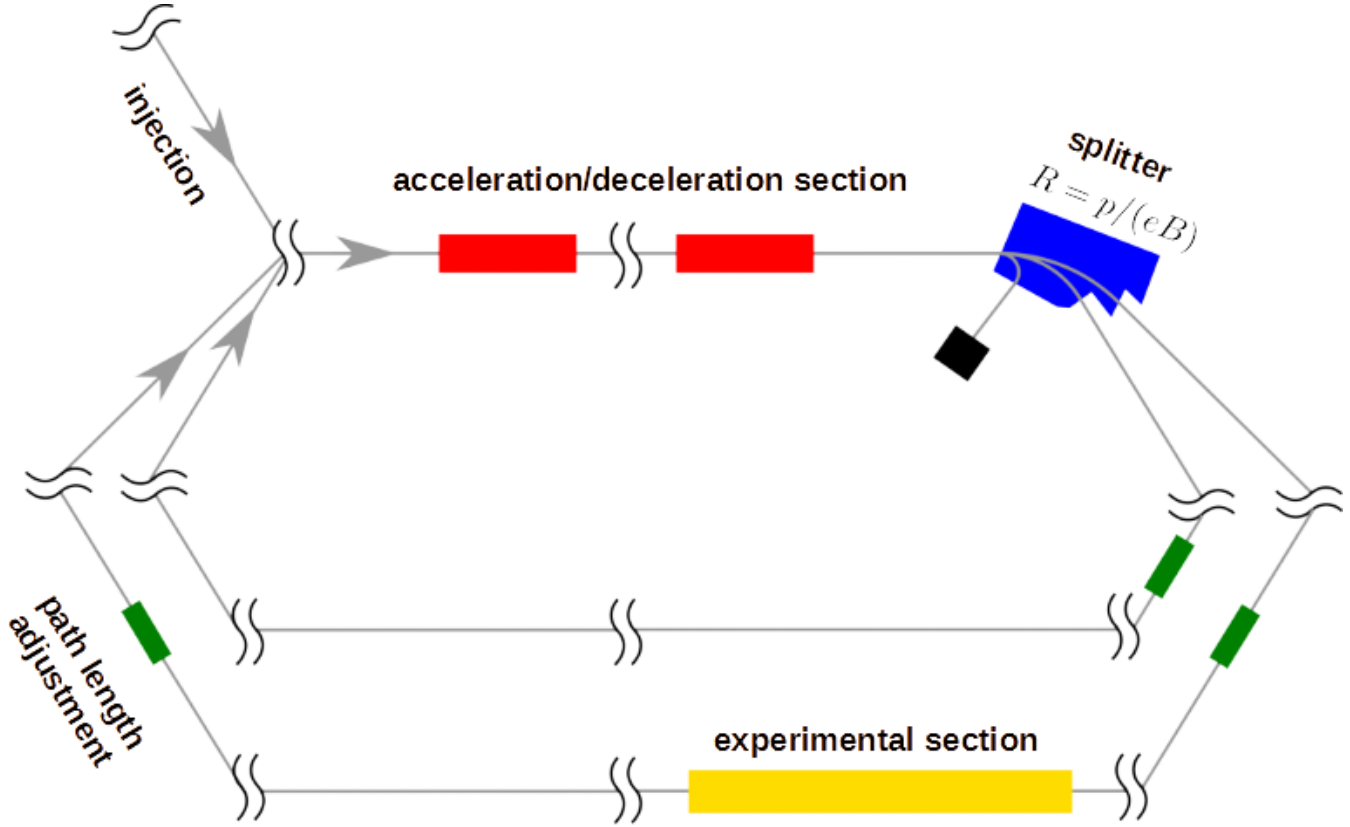
# CHALLENGES

Concept based on: R. Koscica et al., Phys. Rev. Accel. Beams **22**, 091602 (2019)




- Objective functions result from
- Splitter magnet ratio:
- $p_I : p_F : p_S = 1 : 4.73 : 8.32$

Degrees of freedom:

$\vec{A}, \vec{\phi}, \vec{L}, \vec{R}_{56}$

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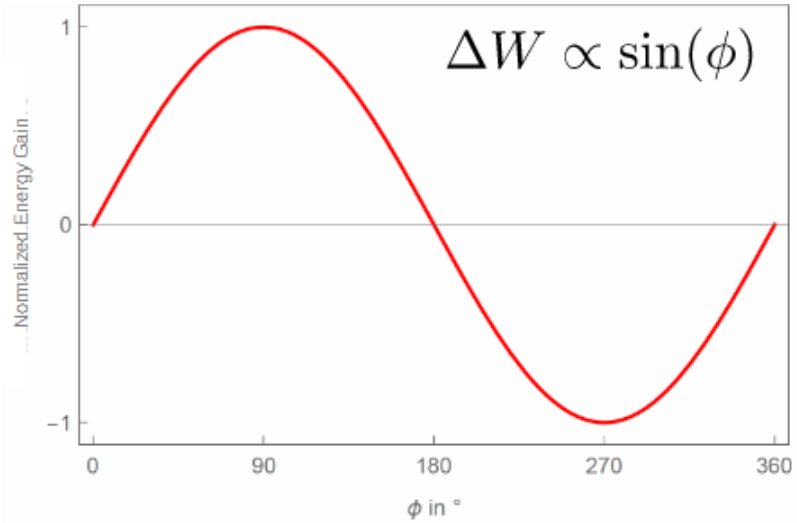
# REMINDER: PHASE SLIPPAGE

## Simplified model of energy gain



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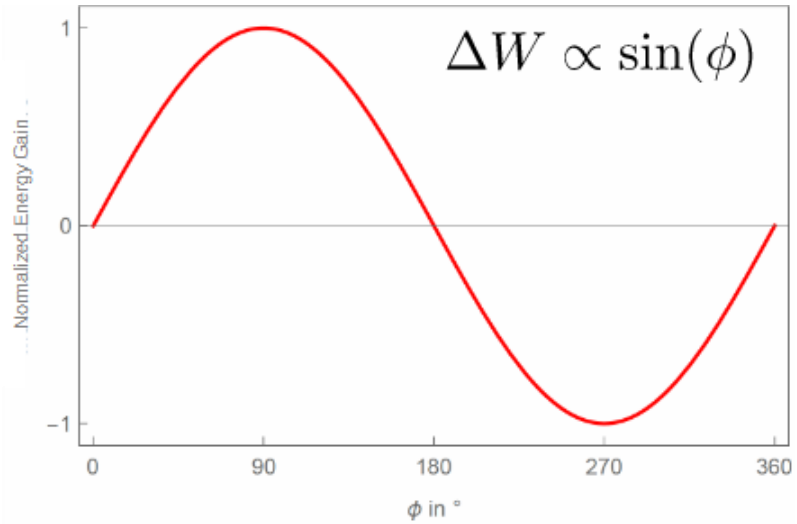
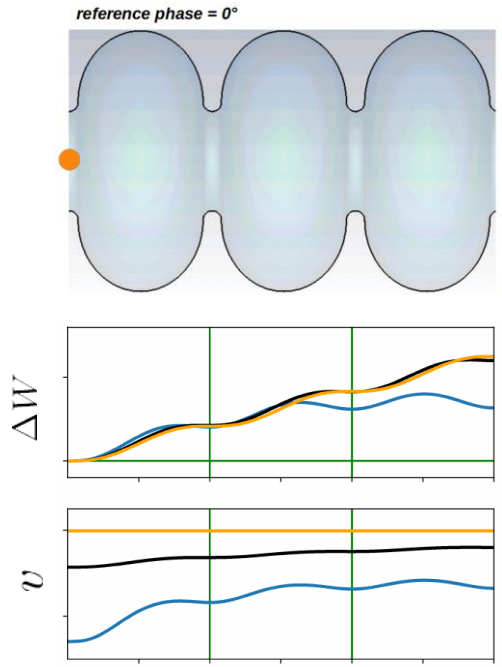
# REMINDER: PHASE SLIPPAGE

## Simplified model of energy gain



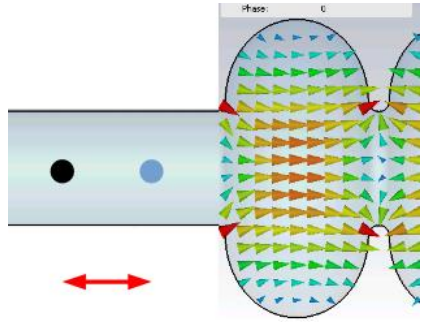

## More complex model of energy gain




Speed changes along the cavity

→ Influences interaction with alternating electric field

→ Numerical simulations required



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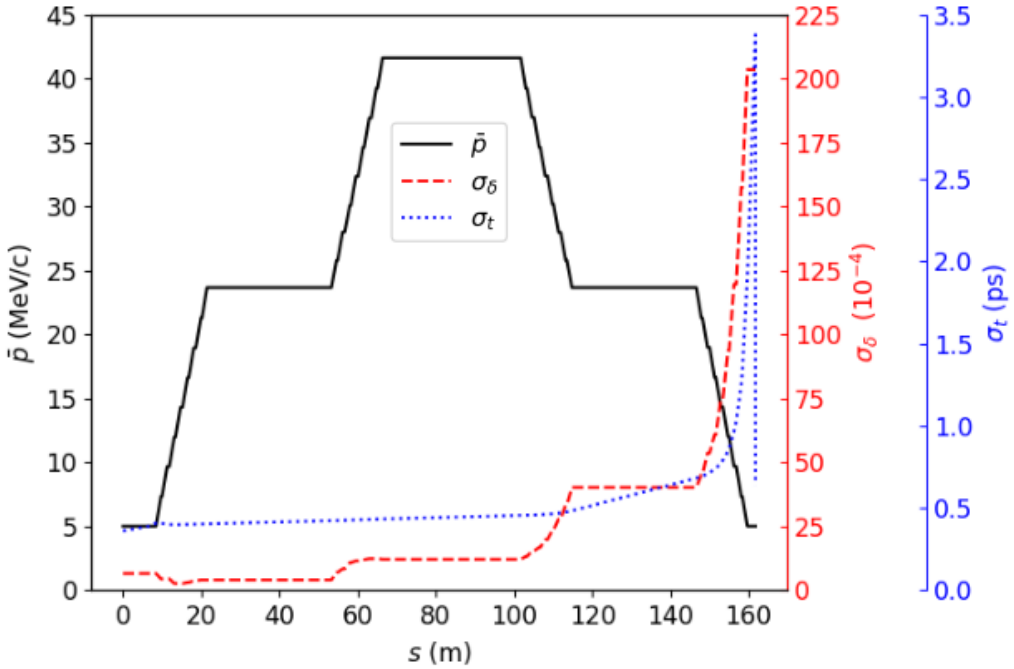
# SOLUTION FOR LONGITUDINAL QUANTITIES

For min. deviation
from target momenta



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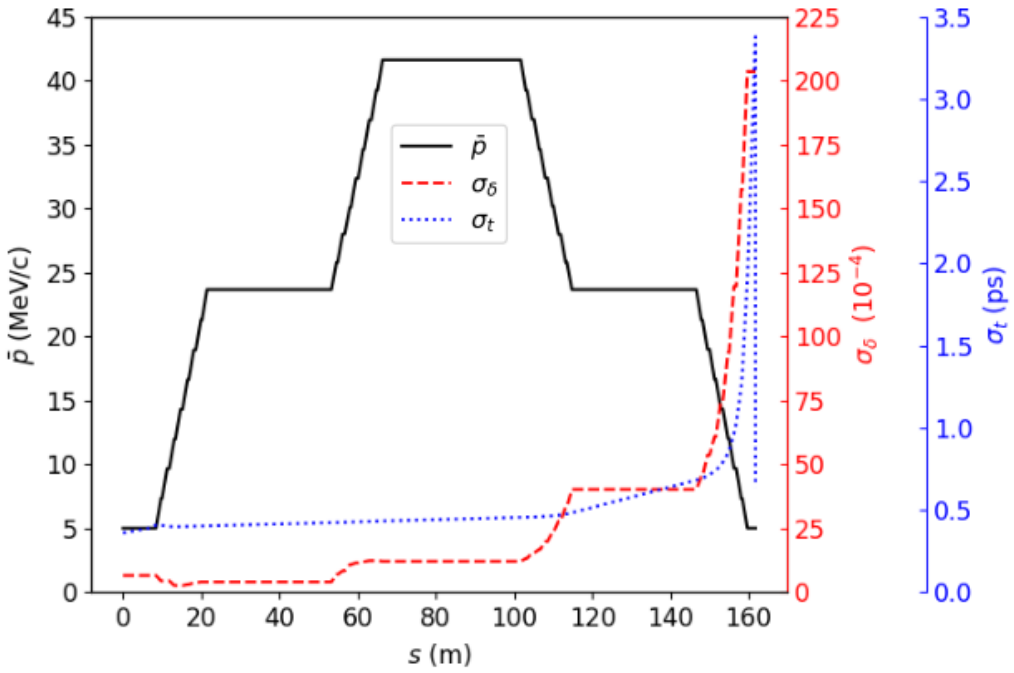
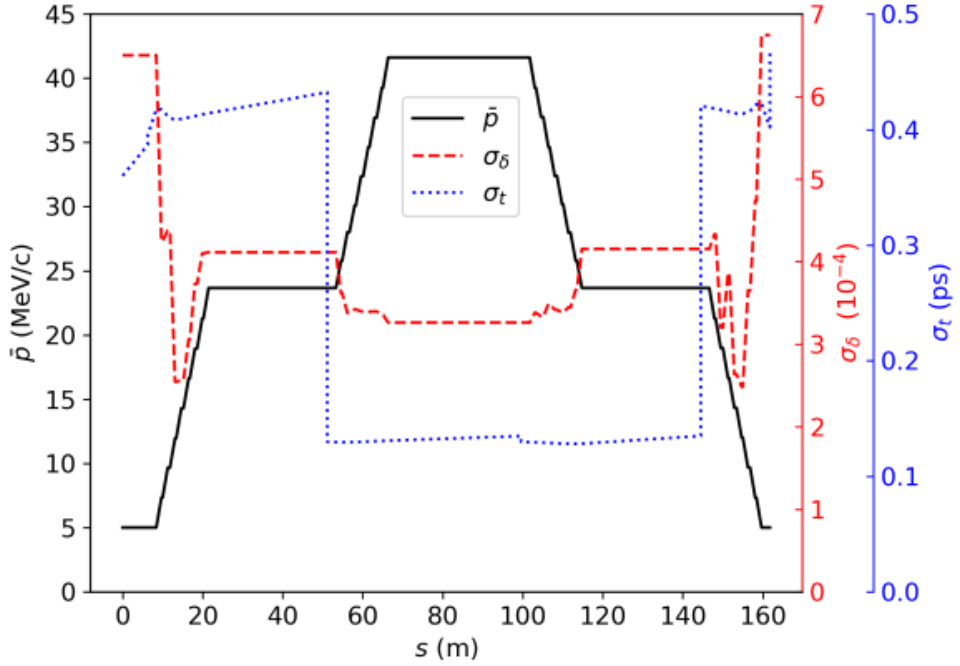
# SOLUTION FOR LONGITUDINAL QUANTITIES

For min. deviation from target momenta




For min. deviation from target momenta **and** min. momentum spread



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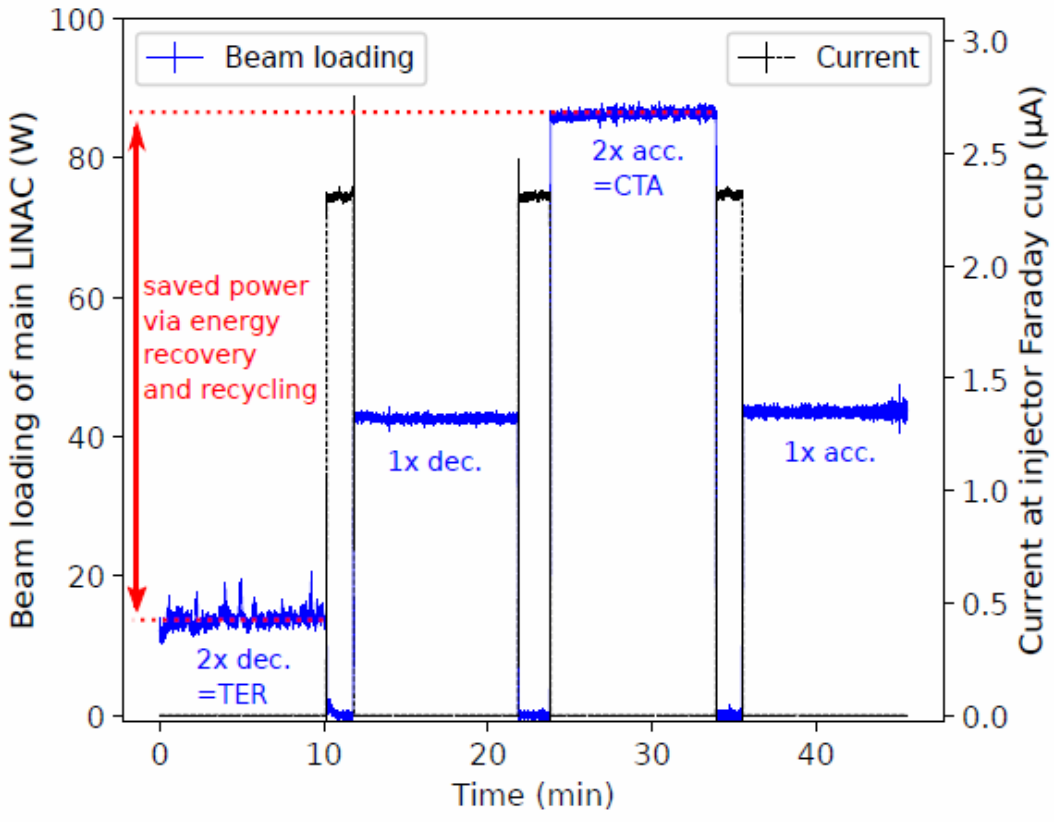
# TWO-TURN ERL MODE




F. Schliessmann et al., Nat. Phys. **19**, 597-602 (2023).

- Momentum injector: 5 MeV/c
- Max. Momentum ERL: 41.61 MeV/c

| Operation mode | Load at main LINAC (W) |
|---|---|
| 1x acc. | $43.5 \pm 0.2$ |
| 2x acc. | $86.3 \pm 0.3$ |
| 1x dec. | $42.6 \pm 0.2$ |
| 2x dec. | $13.8 \pm 1.1$ |

Energy-recycling efficiency:

$$\eta_{\text{main LINAC}} = \frac{P_{\text{b,main LINAC,2x acc.}} - P_{\text{b,main LINAC,2x ERL}}}{P_{\text{b,main LINAC,2x acc.}}} = (84.0 \pm 1.2)\ \%$$

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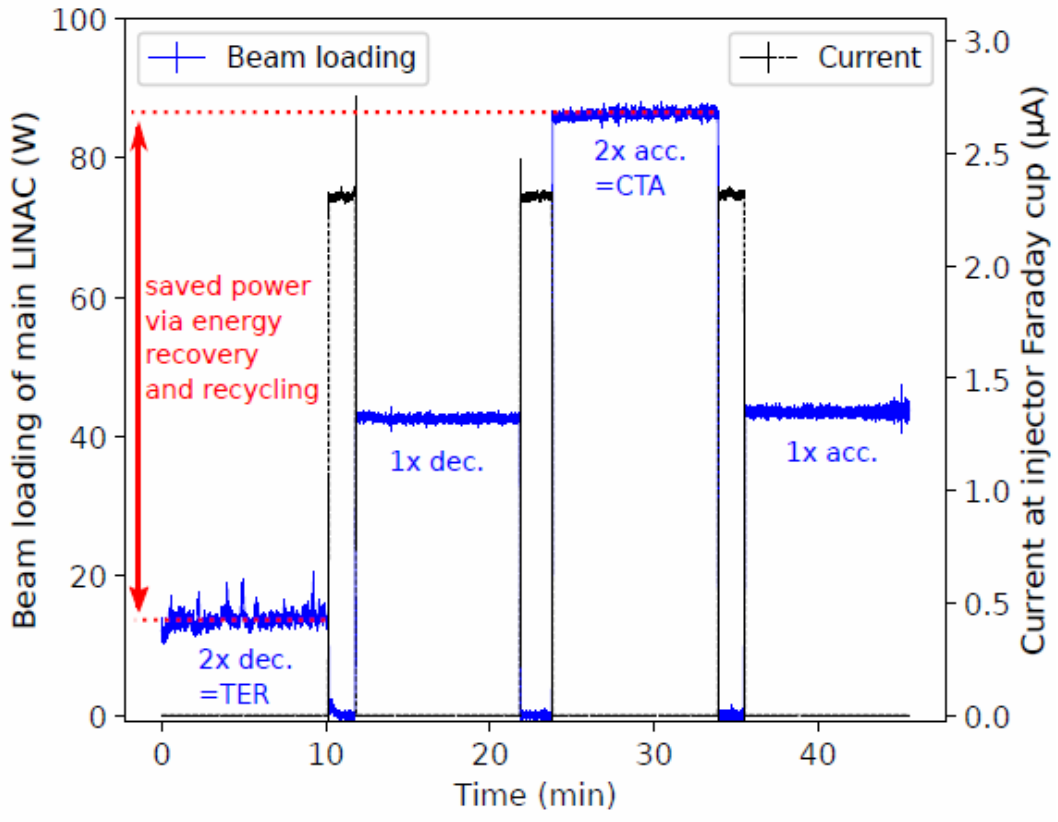
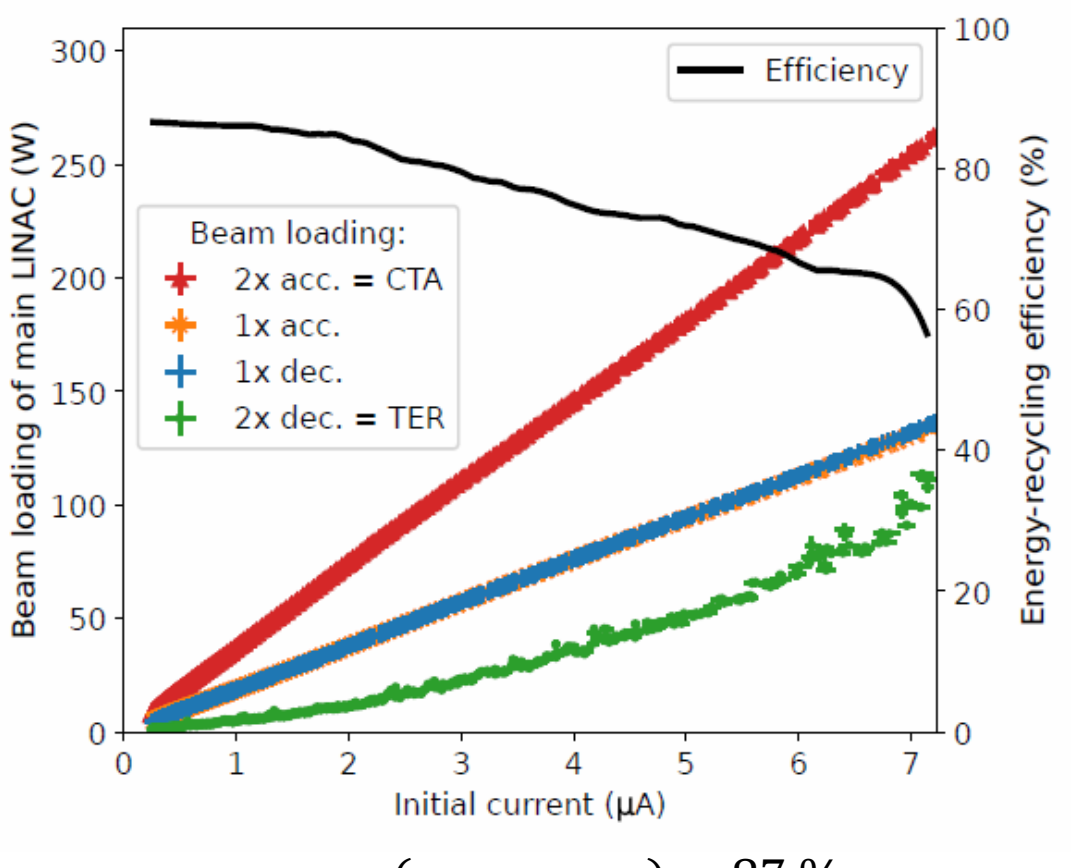
# TWO-TURN ERL MODE




$\max(\eta_{\text{main LINAC}}) \approx 87\ \%$

F. Schliessmann et al., Nat. Phys. **19**, 597-602 (2023).

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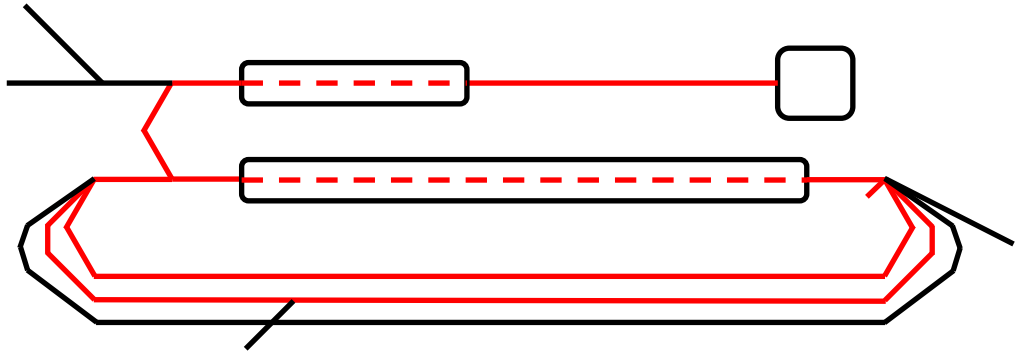
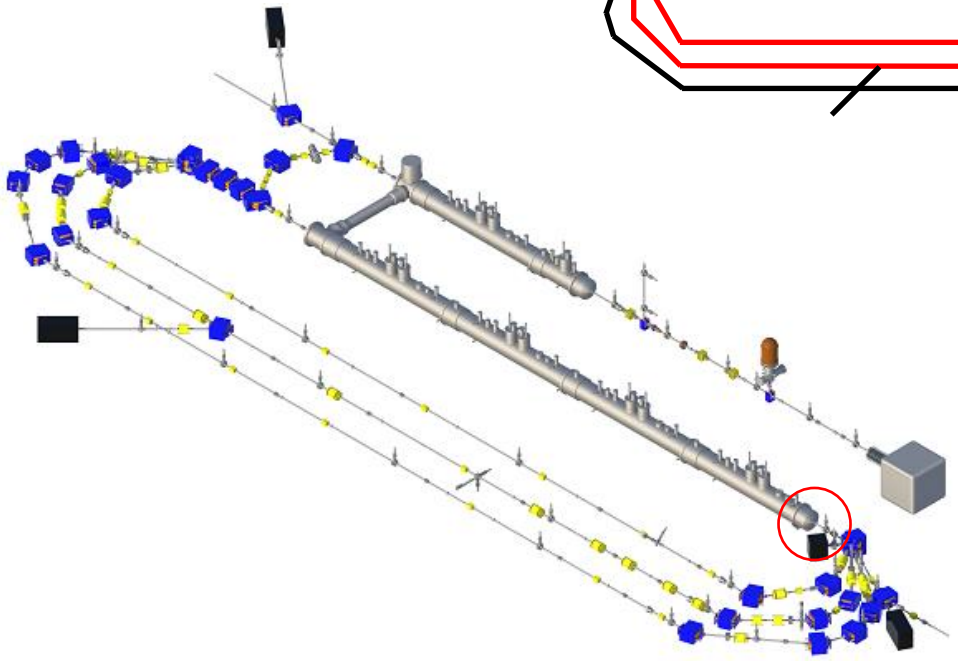
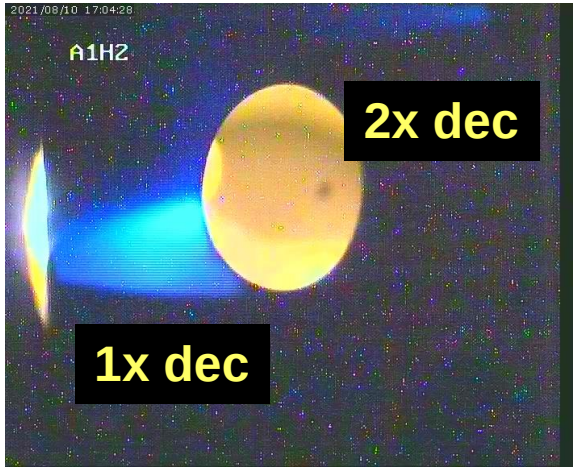
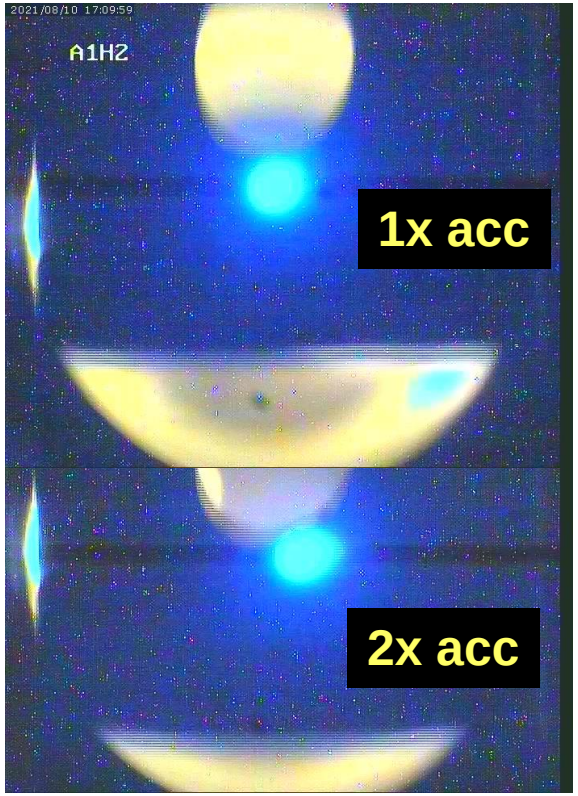
# LIMITS OF TRANSVERSE TUNING





3 cm



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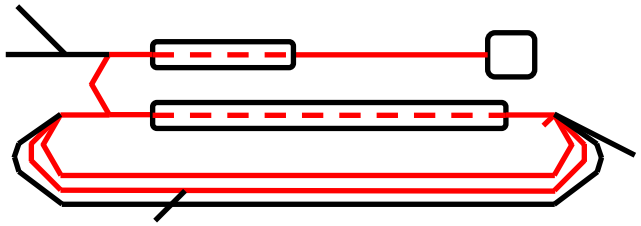
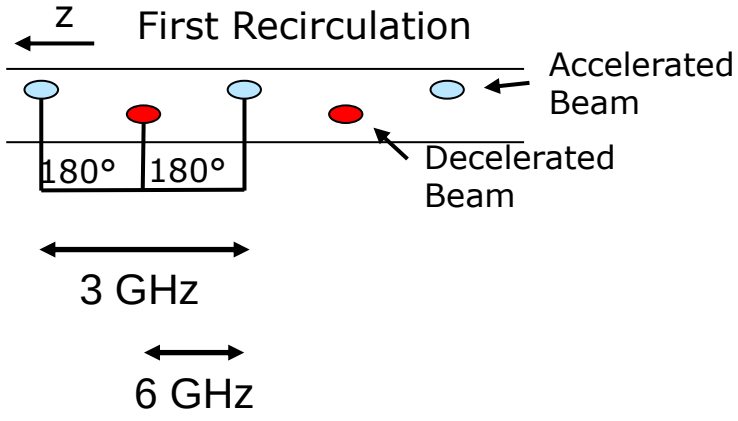
# INSTRUMENTATION OF SUPERIMPOSING BEAMS

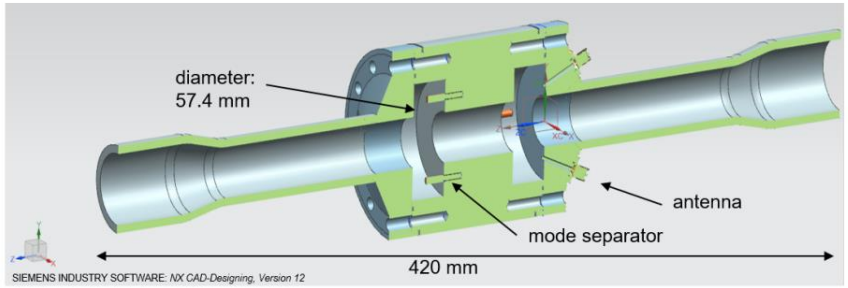
See talk by Manuel Dutine (Tue, 17:20)






- (Non-)destructive position measurement for both beams simultaneously

M. Dutine et al., Proc. of IPAC 2022, p. 254-256 (2022).




- Options
  - RF beam loading
  - Screen with hole
  - Beam loss monitors
  - Wire scanner
  - 6 GHz cavity BPM (double of fundamental frequency)
  - 3 GHz cavity BPM in combination with bunch trains

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# OUTLINE

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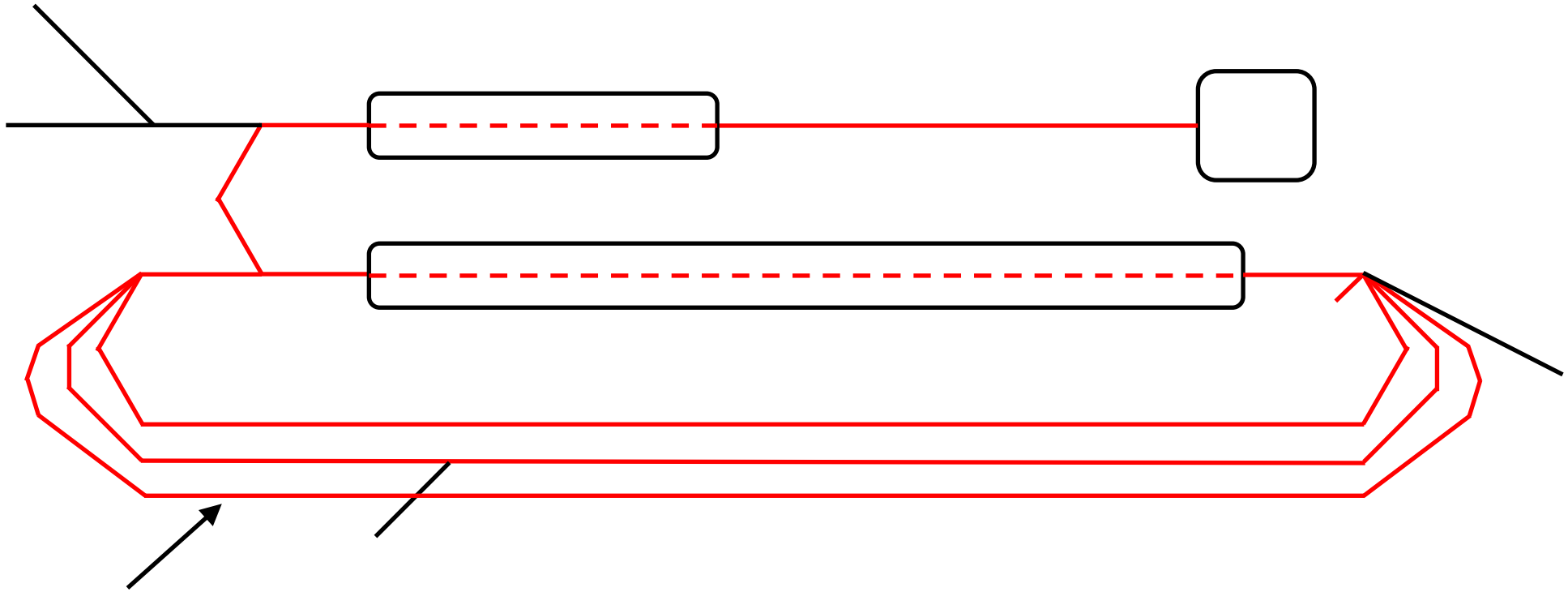
# THREE-TURN ERL



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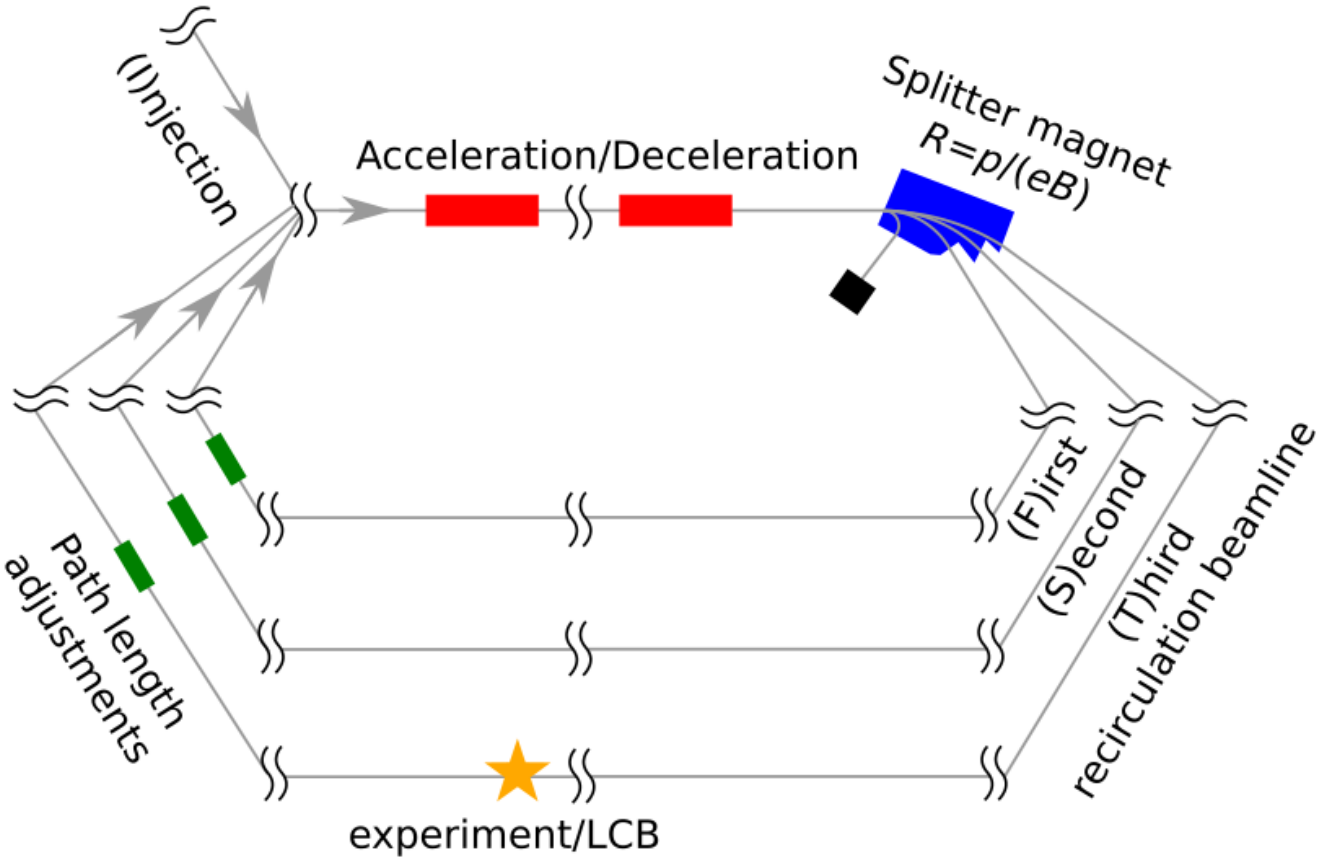
# CHALLENGE

- The higher the turn number, the less degrees of freedom
  →Objective functions result from splitter-magnet ratios

- Presence of phase slippage due to small injection momentum of 5 MeV/c

=> Setup must be precisely determined in advance via simulations



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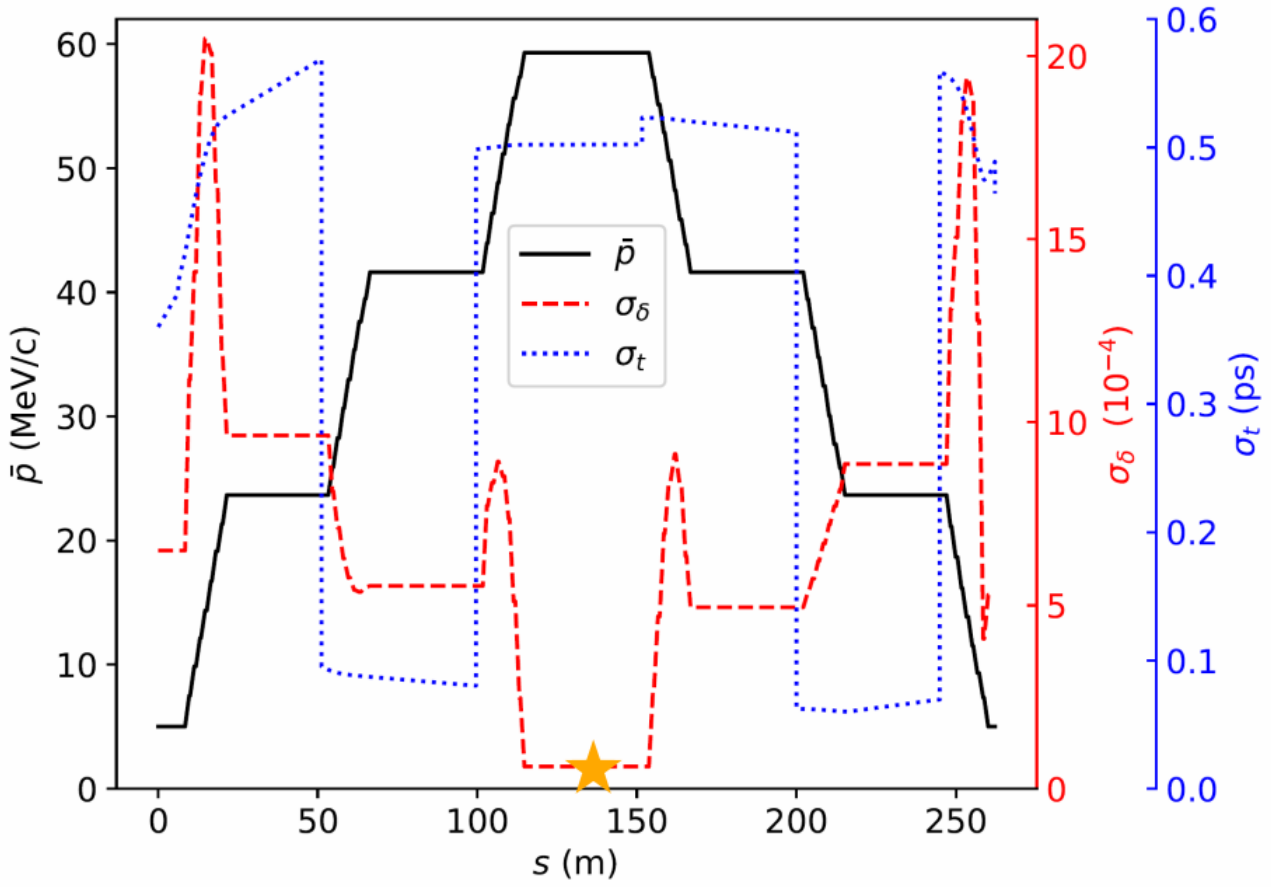
# SIMULATION RESULTS

- Target centroid momenta reached with accuracy of ±1 eV/c
- Reduced momentum spread compared to injection

- First longitudinal study successful
- Futher improvements and transversal simulations will follow




F. Schliessmann et al., Proc. IPAC 2023 (2023) 2143-2146.

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# OUTLINE

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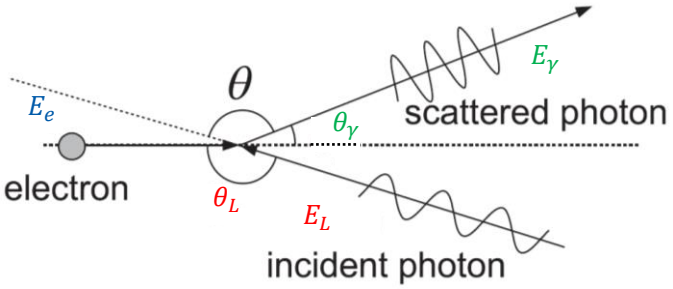
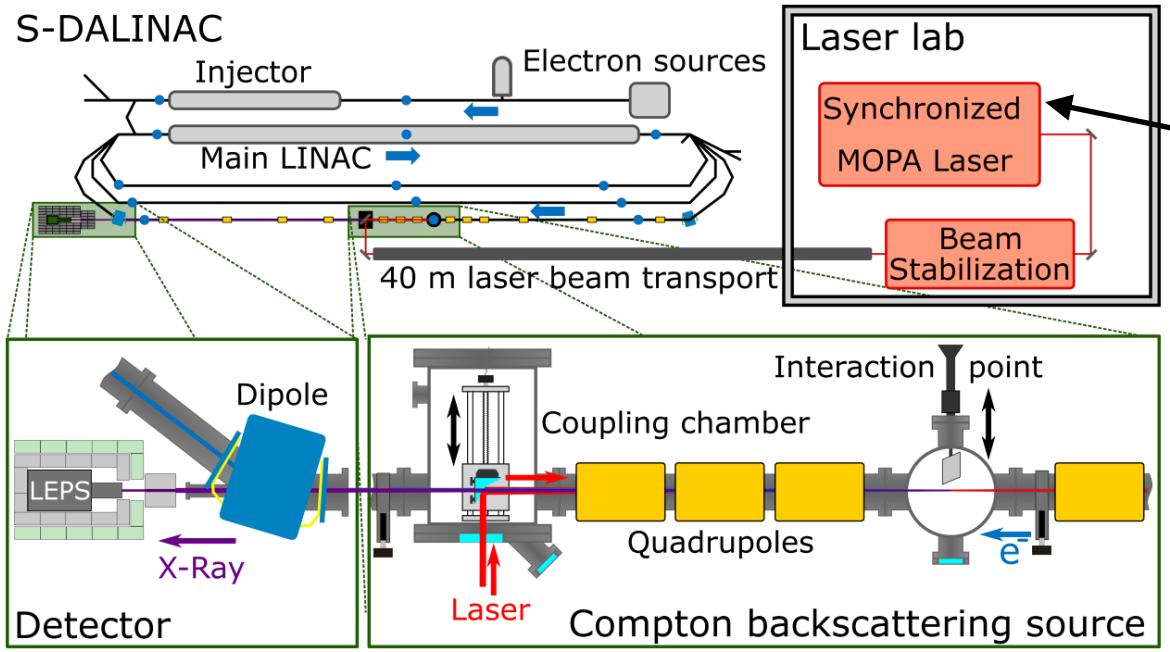
# LAYOUT

Implementation of a Laser Compton Backscattering Source at the S-DALINAC: COBRA




$$E_{ph}^{max} = 4\gamma^2 E_L$$

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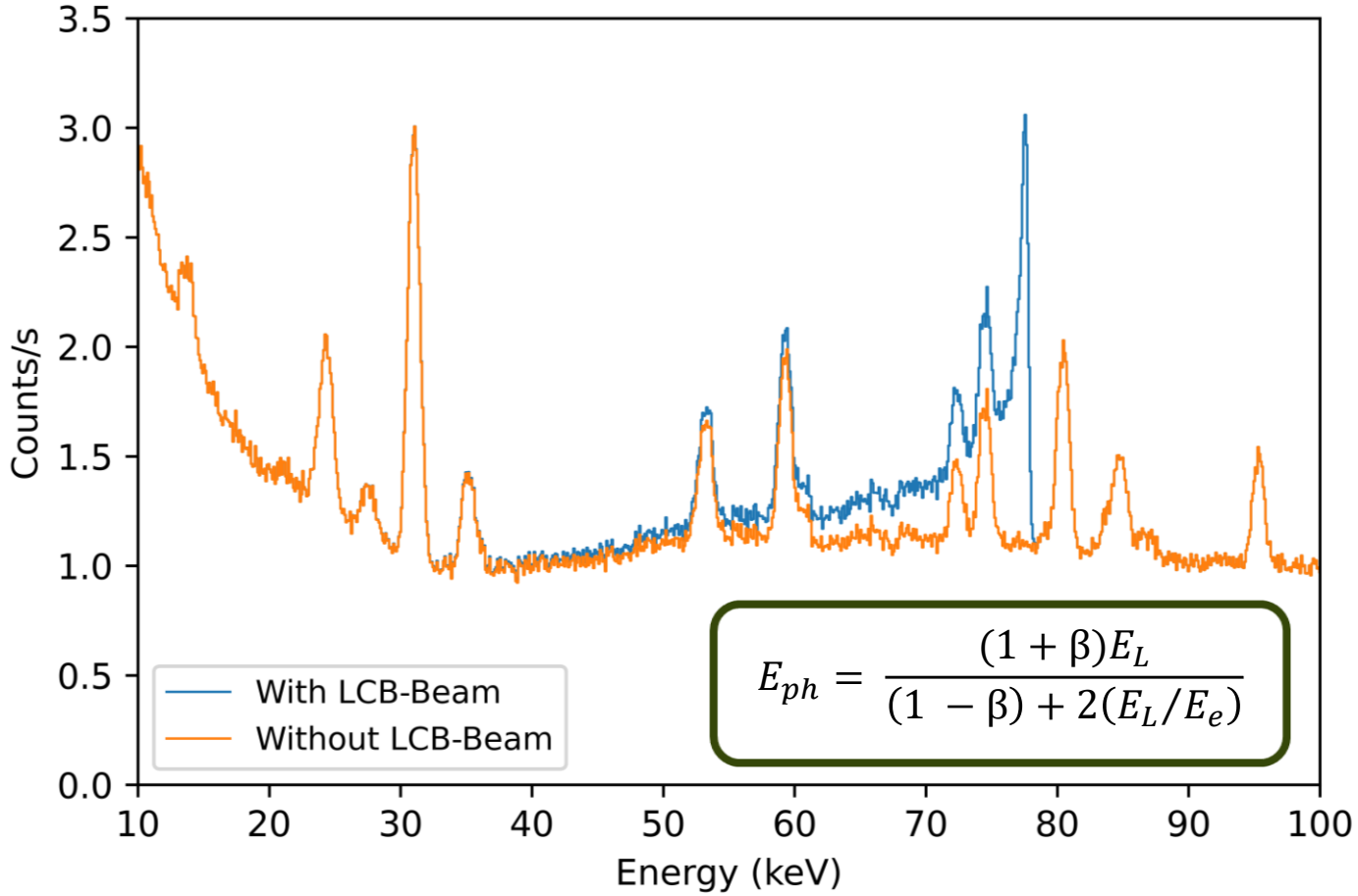
# DIAGNOSTICS TOOL AND BACKGROUND MEASUREMENT

- Determination of electron energy and energy spread
- Future live use in the ERL mode of the S-DALINAC

- Measurement with electron beam: 65 MeV @ IP (85 MeV max.), 5 µA
- Simulation with laser: 100W@1030 nm

→ LCB: 77.8 keV



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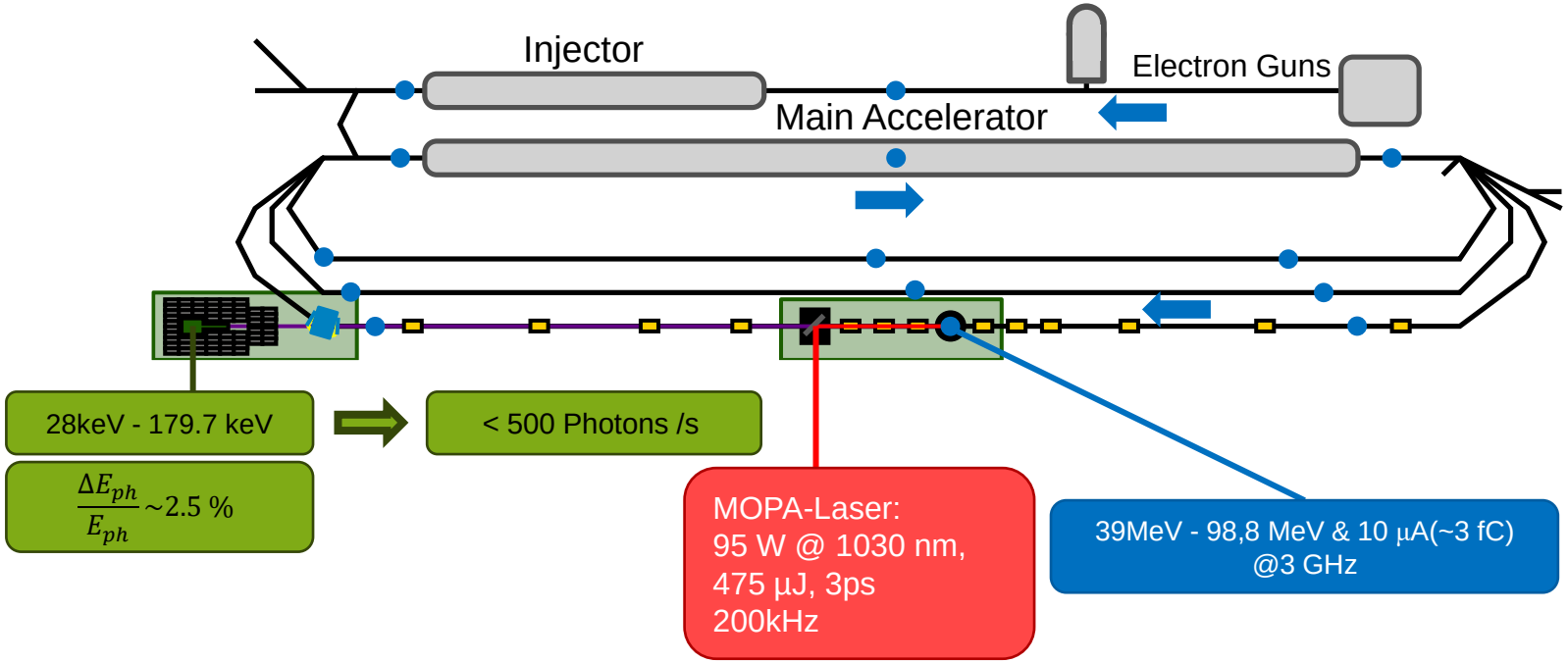
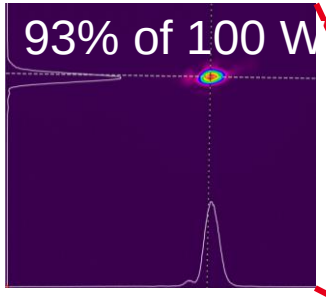
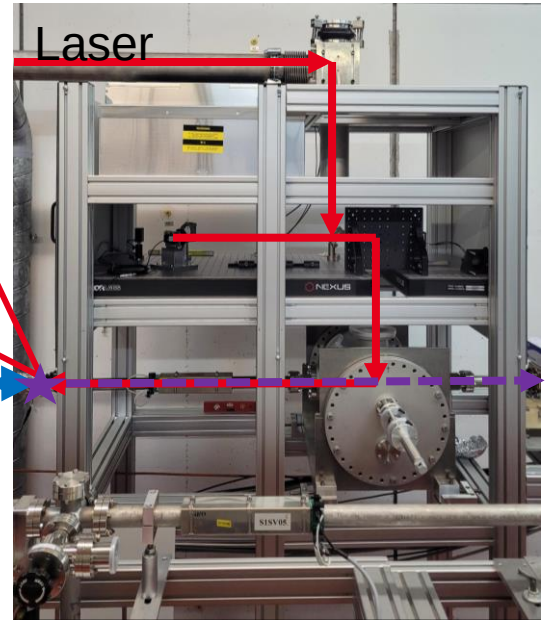
# STATUS

- Example parameters for collission




Electron Beam

- Commissioning of collission planned for 2025

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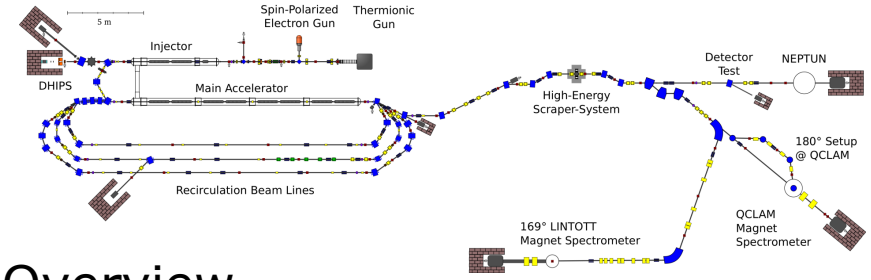
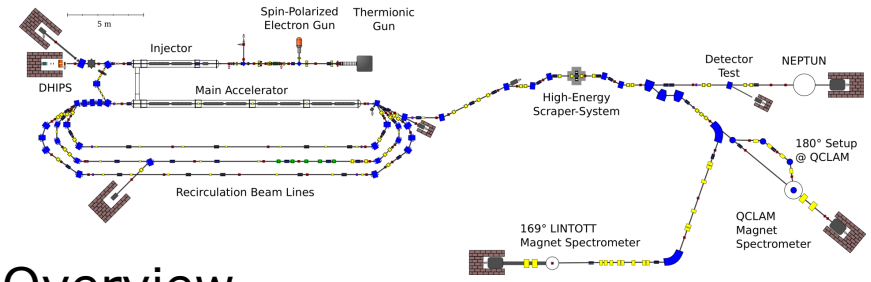
# OUTLINE

# TAKE HOME MESSAGE




Overview

# TAKE HOME MESSAGE

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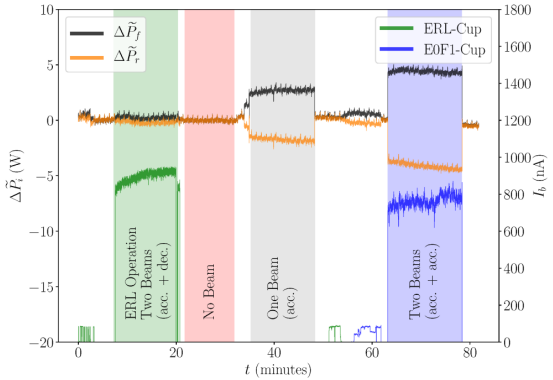
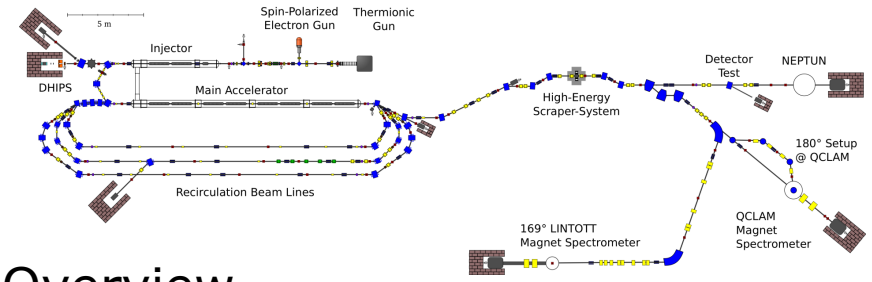



One-turn ERL operation

# TAKE HOME MESSAGE

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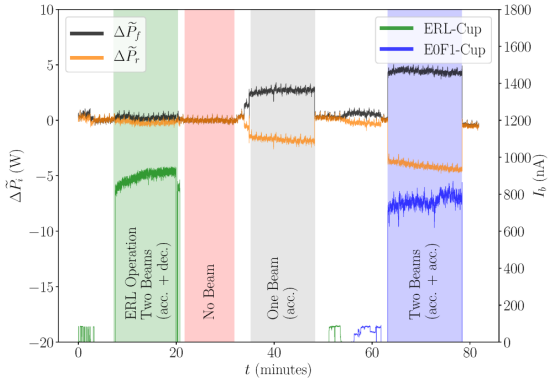
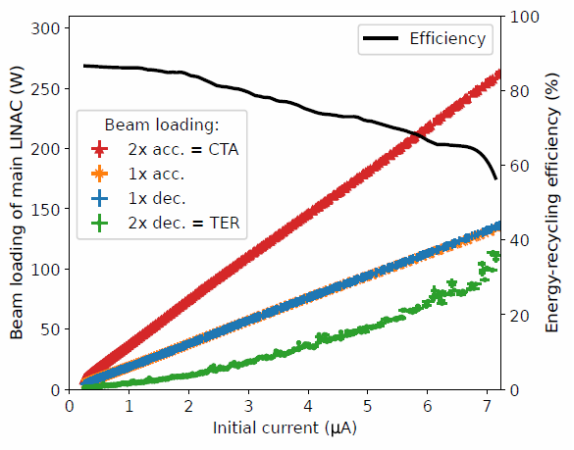
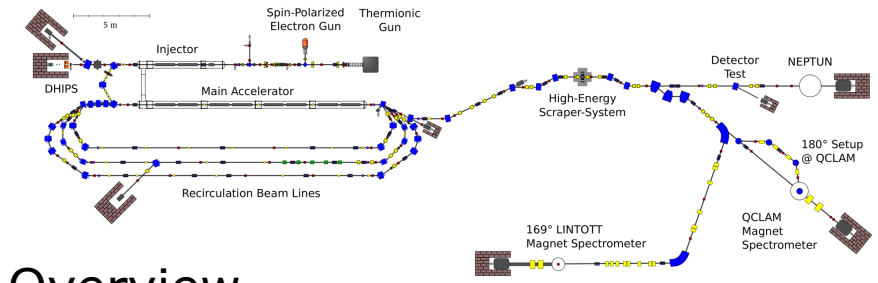



One-turn ERL operation

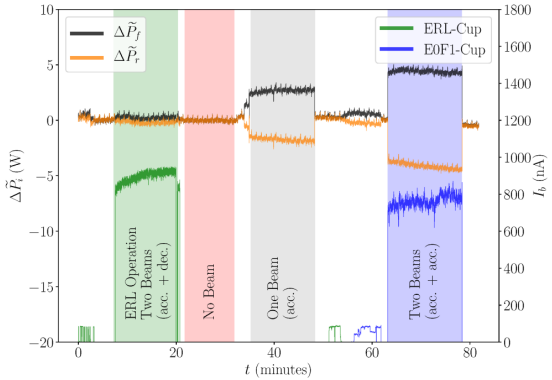



Two-turn ERL operation

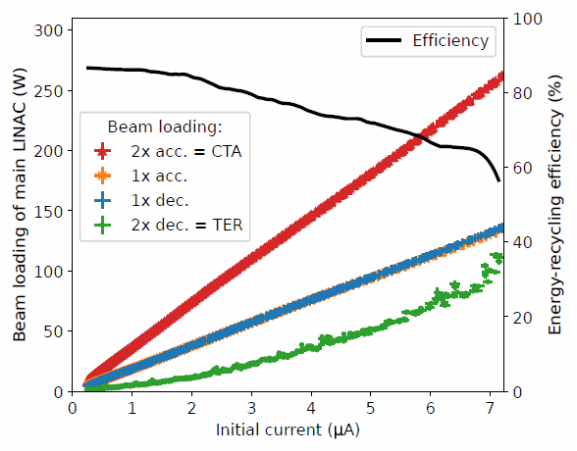
# TAKE HOME MESSAGE




Overview

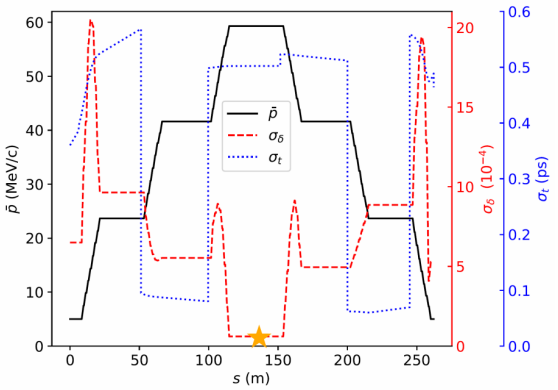



One-turn ERL operation

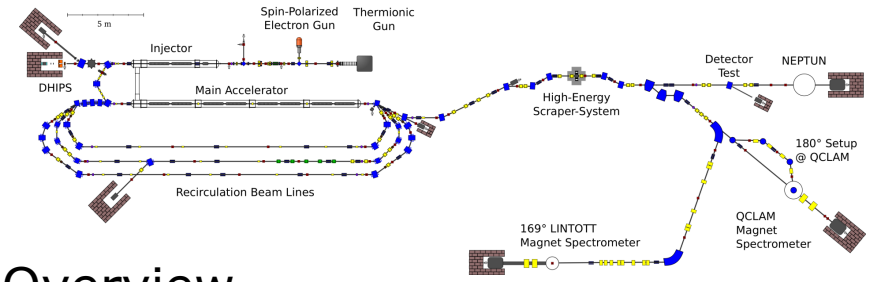



Two-turn ERL operation

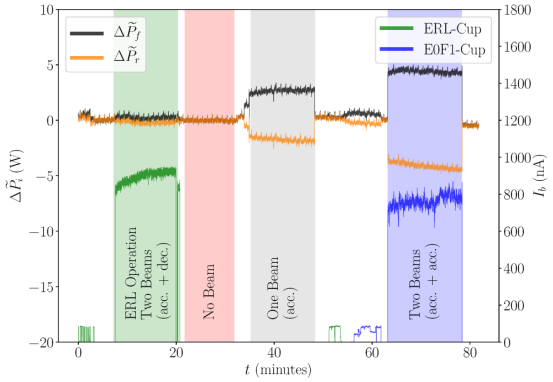
Three-turn ERL study



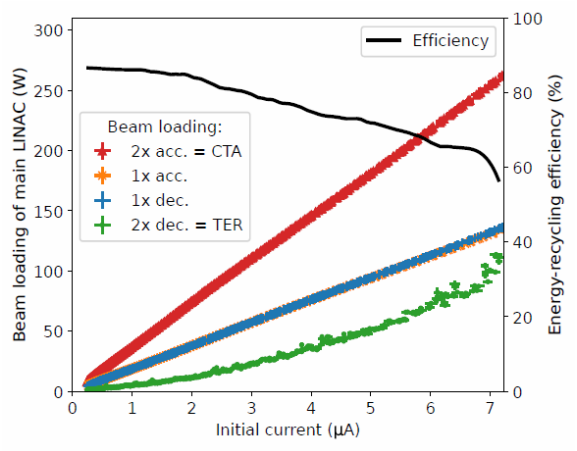
# TAKE HOME MESSAGE



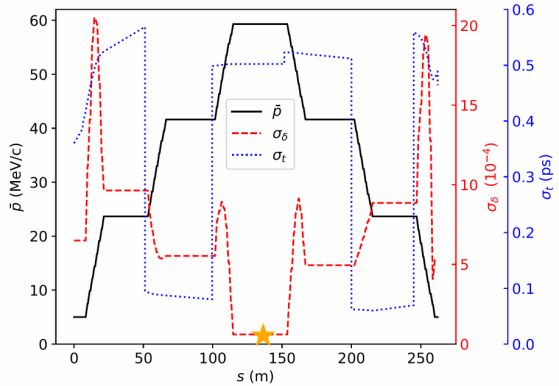

Overview



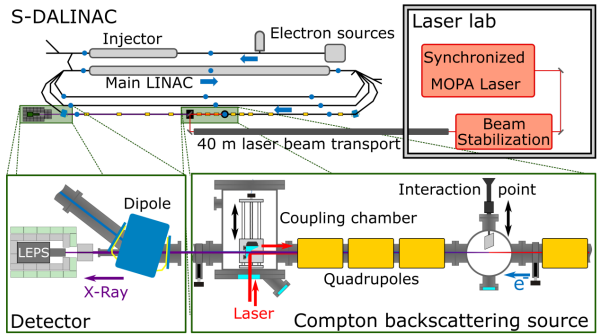

One-turn ERL operation




Two-turn ERL operation




Three-turn ERL study




Experiment: Laser Compton Backscattering

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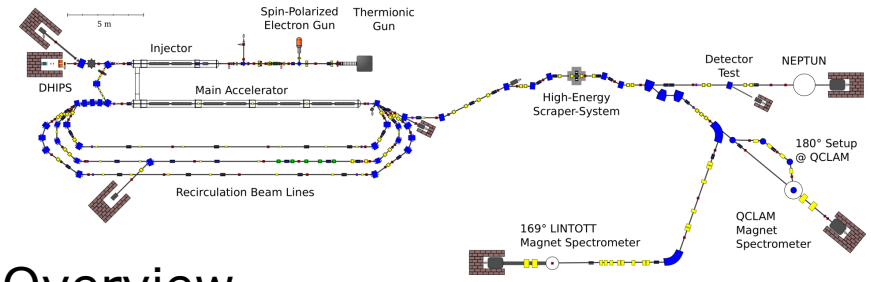
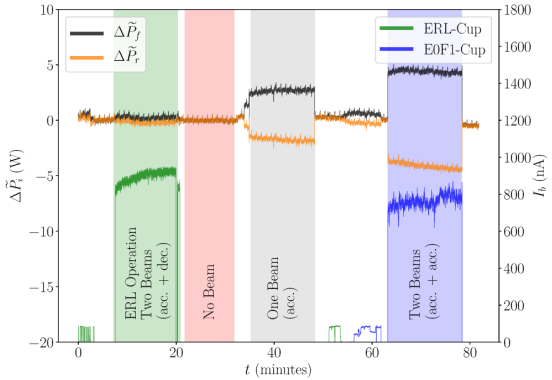
# TAKE HOME MESSAGE

Thank you for your attention!




Overview

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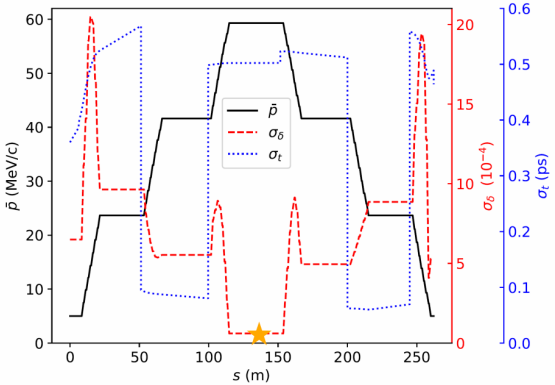


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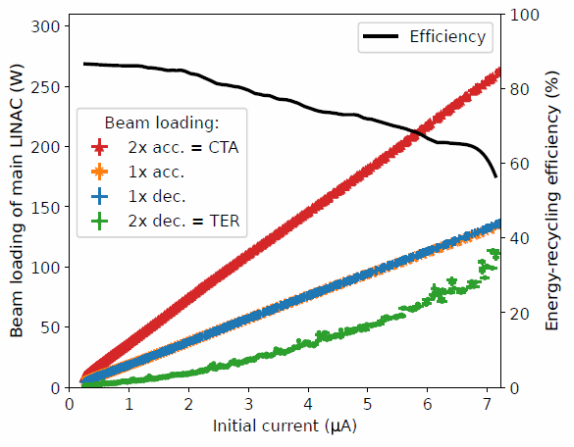


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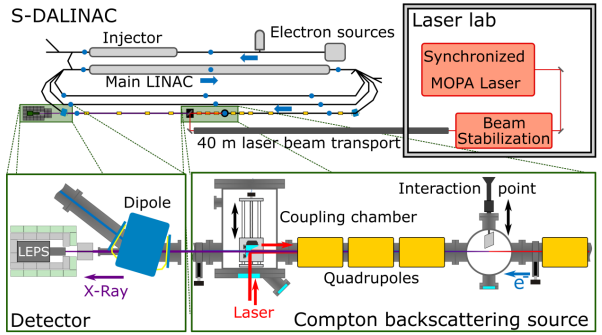


Experiment: Laser Compton Backscattering