An accumulator ring for the 5 MW beam for the

ESS
NEUTRINO
SUPER BEAM

Maja Olvegård, Uppsala University

on behalf of the ESSnuSB WP3 team

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European Union

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Outline

UPPSALA
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- ESS and ESSnuSB
- The accumulator ring
  - Injection
  - Collimation
  - RF
  - Extraction
- The beam switchyard
- Outlook

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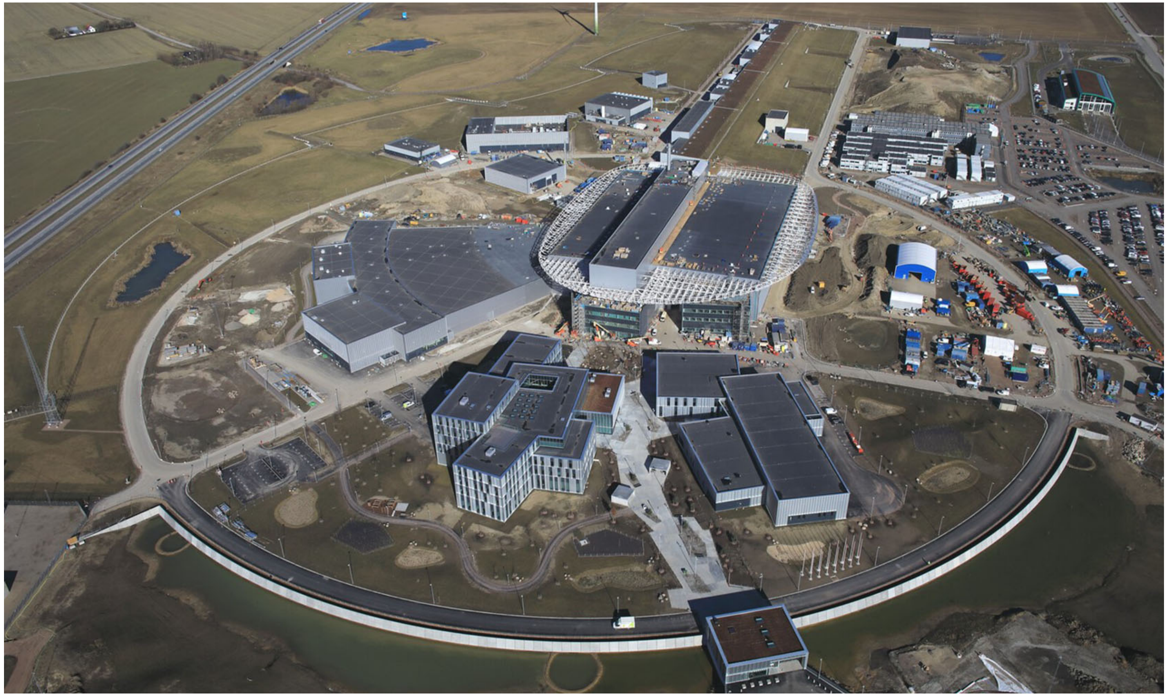
ESS – a unique linac

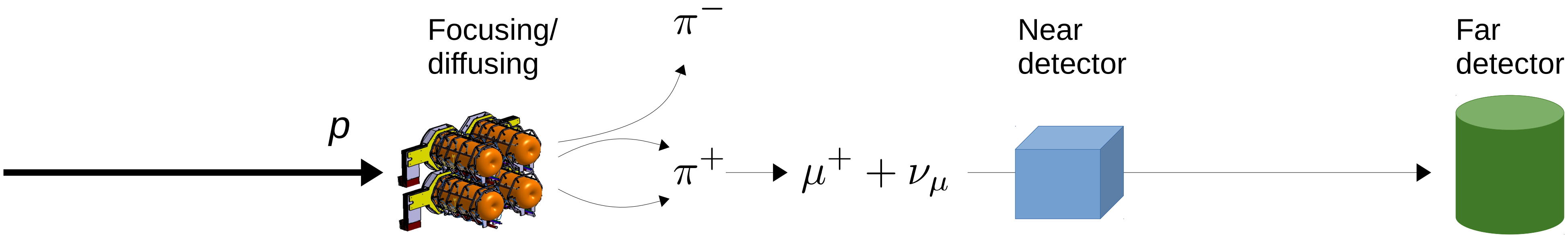


- World unique beam power
  - 5 MW average
  - 125 MW peak
- Moderate energy 2 GeV
- Long pulses
- Moderate rep. Rate: 14 Hz
- Low duty cycle: 4%

We want to increase the duty cycle by doubling the pulse repetition rate.

ESS Neutrino Super Beam

A long-baseline neutrino oscillation experiment



5 MW average beam power from the ESS linac

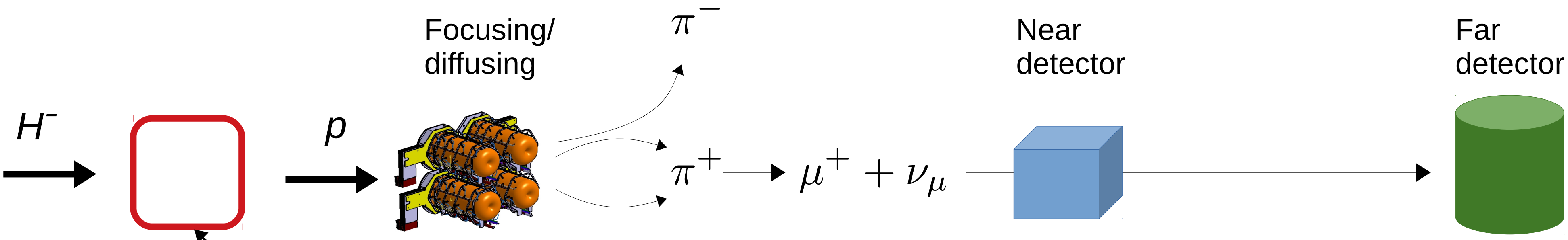
EUROnu study: 1.25 MW average beam power on each of four targets

We need microsecond to…

- reduce experiment background
- save the focusing horn from melting

ESS Neutrino Super Beam

A long-baseline neutrino oscillation experiment



5 MW average beam power from the ESS linac

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Pulse compression through multi-turn injection single-turn extraction in an accumulator ring

We need microsecond to…

- reduce experiment background
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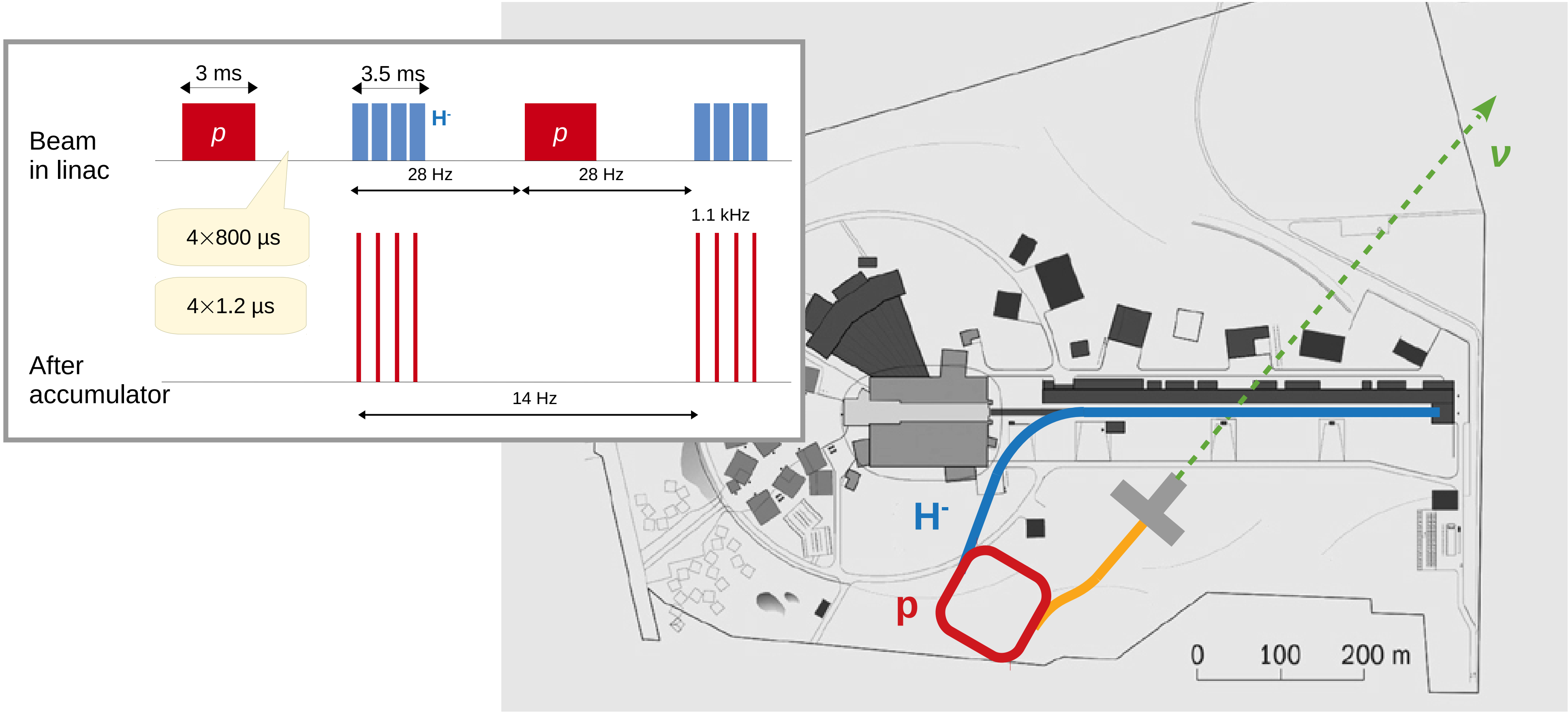
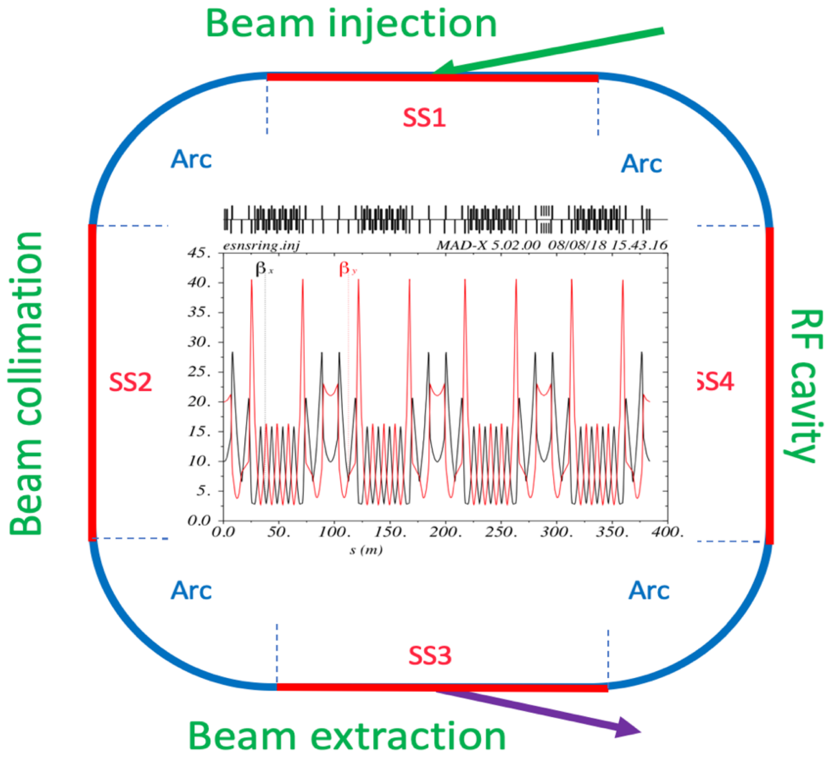
ESS Neutrino Super Beam



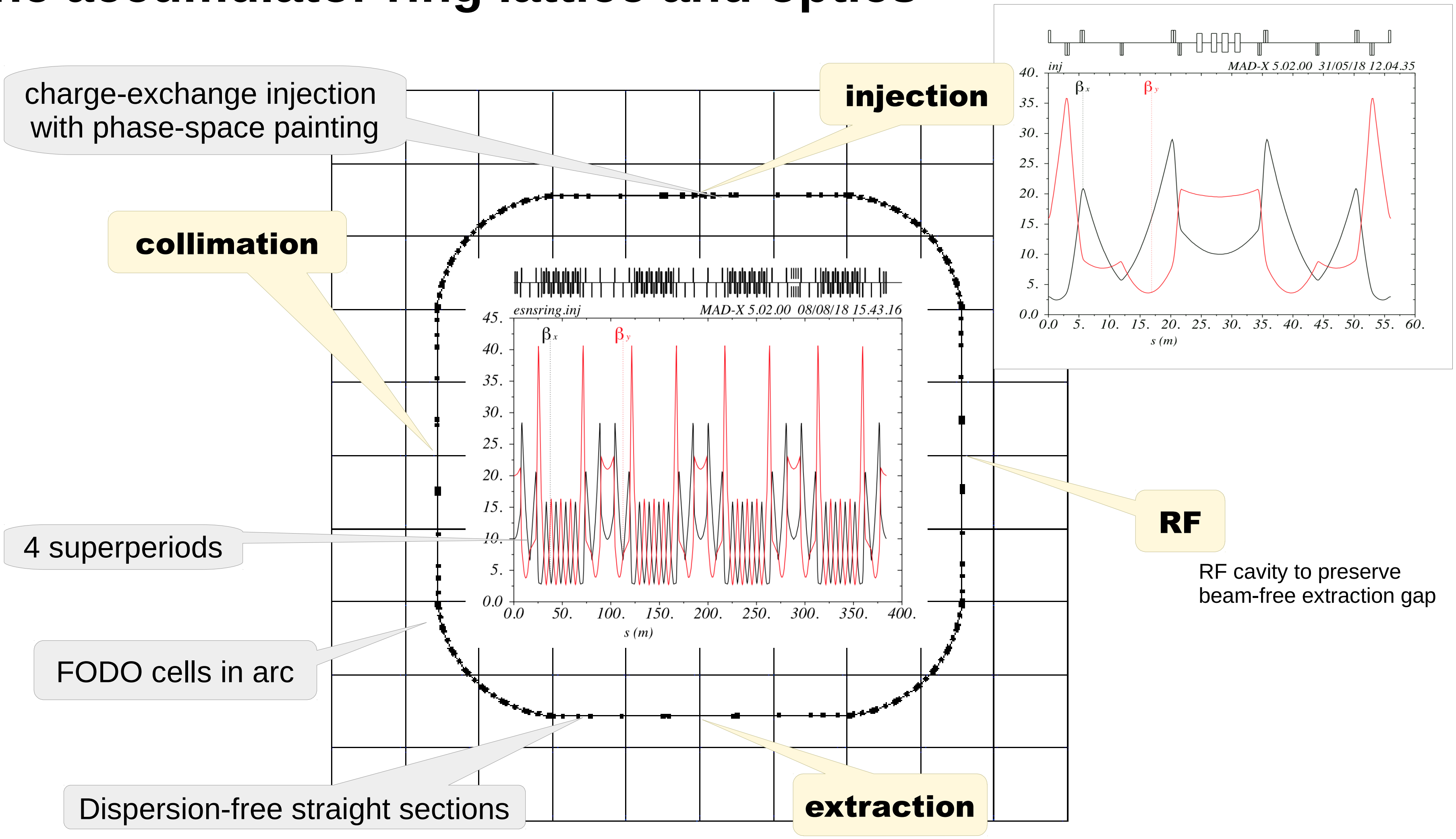
Accumulator ring

- Ring design inspired by the accumulator ring * at the Spallation Neutron Source, SNS, Oakridge
  - Adapted for higher energy and intensity
- Original lattice by H. Schönauer, CERN
- Accumulation and storage, no acceleration.
- Multi-turn injection of H^-
- Single-turn extraction
- Challenges:
  - Uncontrolled beam loss <1 W/m
  - Injection and stripping
  - Extraction gap
- 384 m circumference, 1.33 μs revolution period



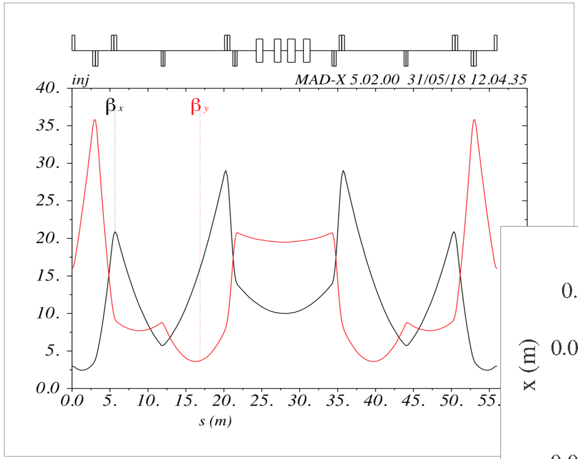
* J. Wei et al., https://journals.aps.org/prab/abstract/10.1103/PhysRevSTAB.3.080101

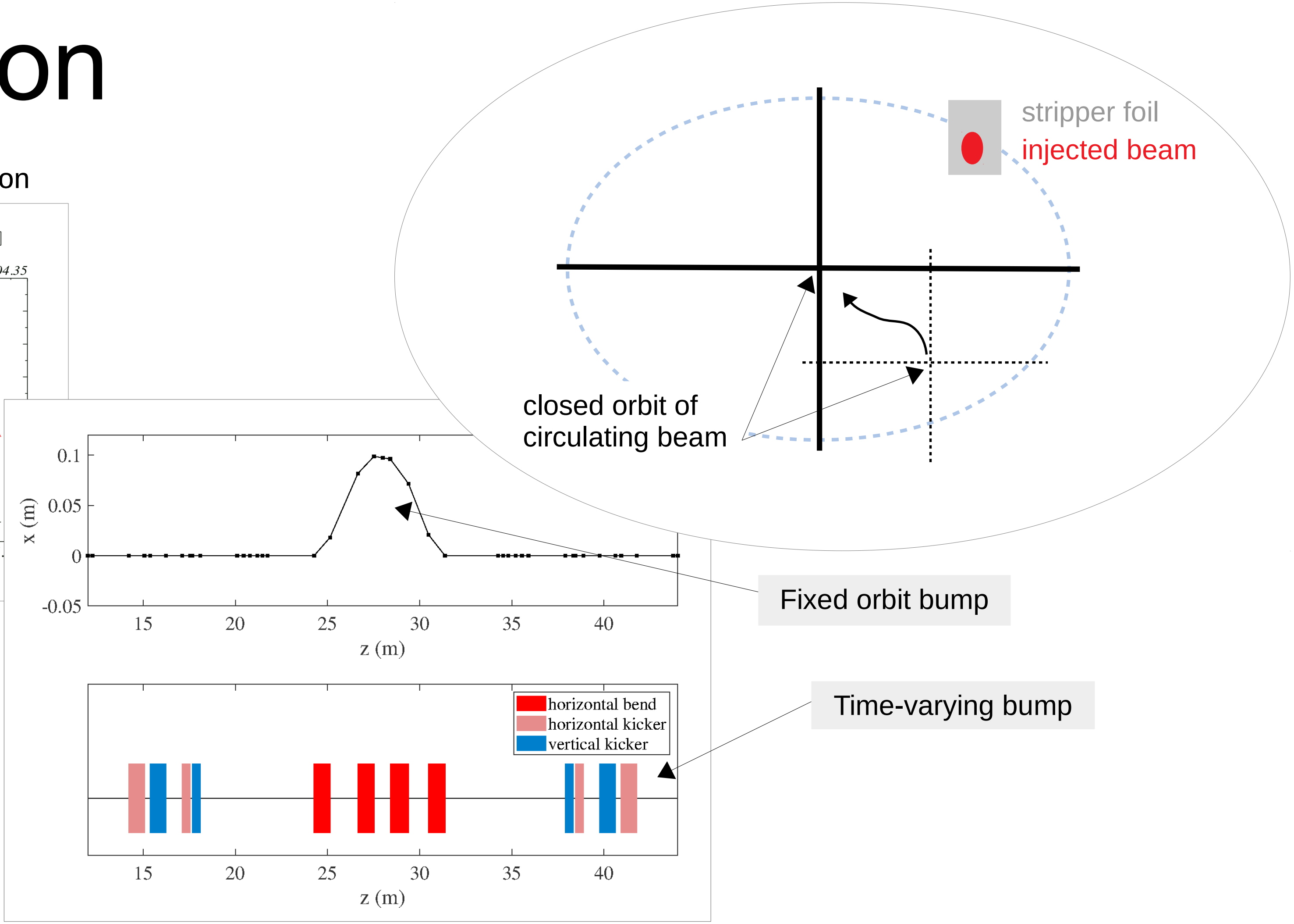
The accumulator ring lattice and optics



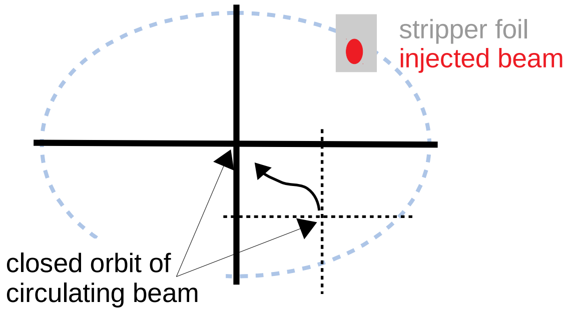
H^- injection

Beta functions in the injection section



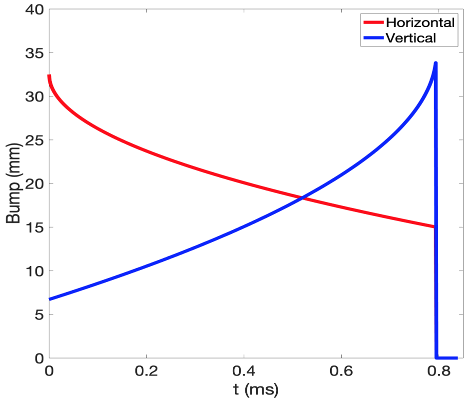


Phase-space painting

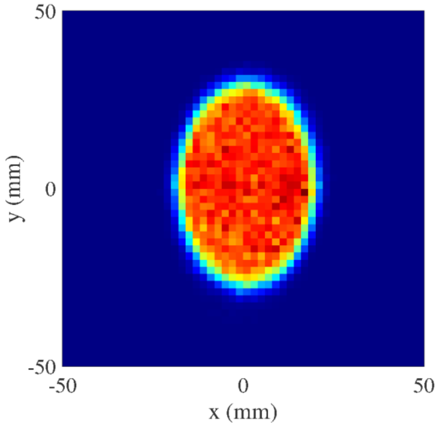


- Phase space painting optimized through multi-particle tracking simulations with PTC-ORBIT and pyORBIT.
- Flat distribution to minimize space charge
- Reduce stray foil hits of circulating particles
- Final emittance ~70 mm mrad
  - Possible to go down to 30-40 mm mrad without too much space charge issues (halo formation, tune shift).
- Tune spread <0.05

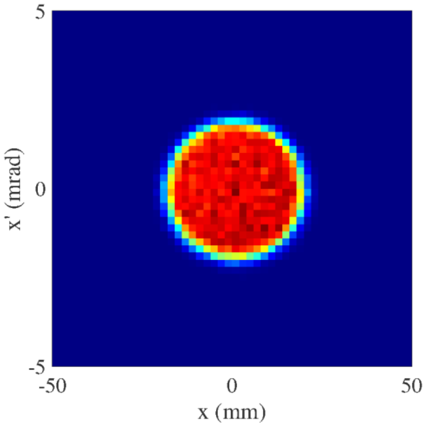
Orbit bump amplitude



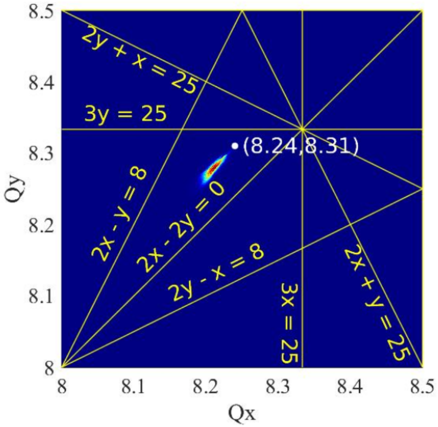
Real space



Phase space

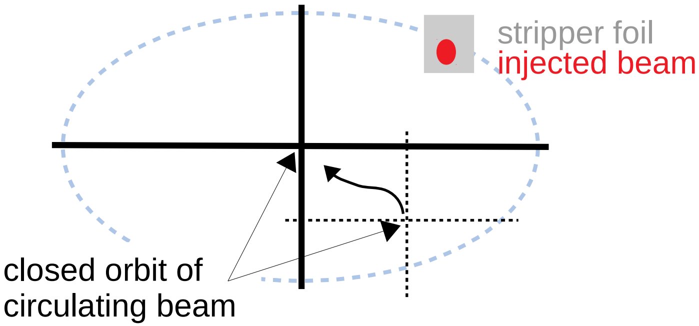


Tune map



Y. Zou, Uppsala University

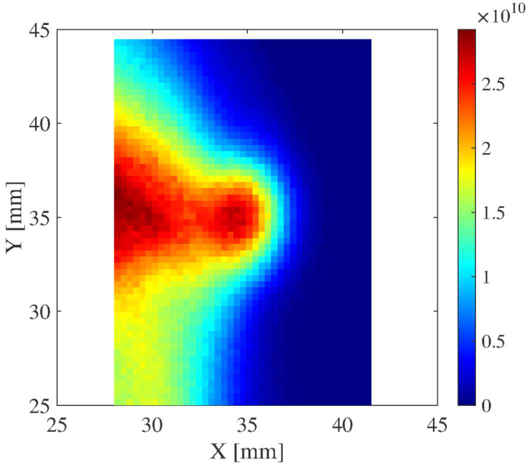
Injection stripper foil

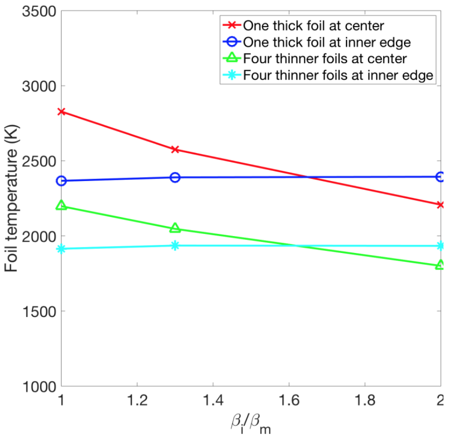


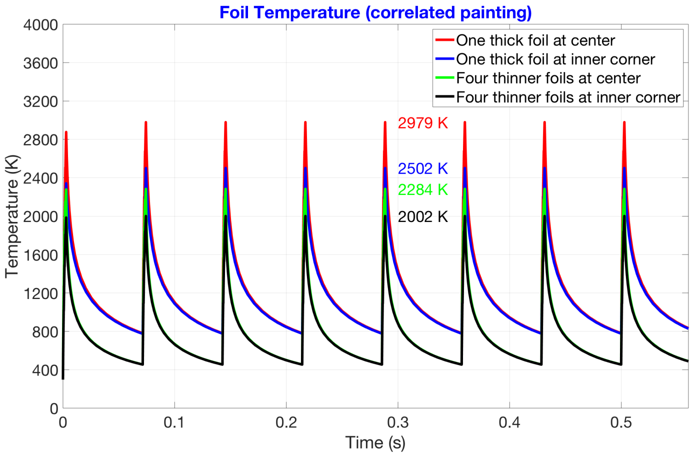
M. Plum, HB2016, 2016

Experience from SNS:

- Stripper foil lifetime an issue.
- Laser-stripping experiments ongoing.
- Convoy electrons must be carefully taken care of.

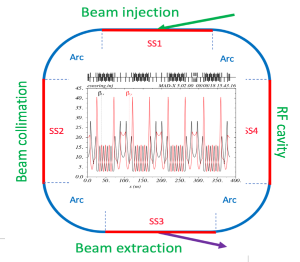




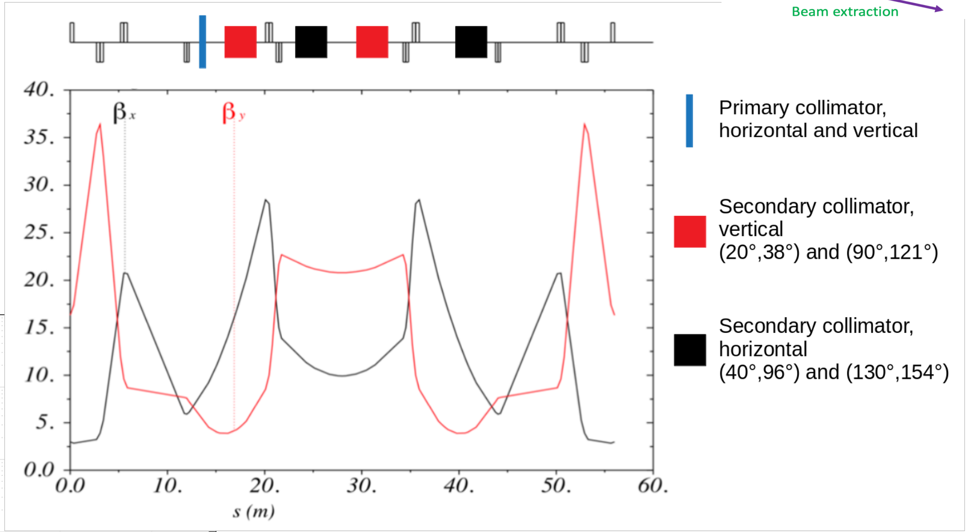


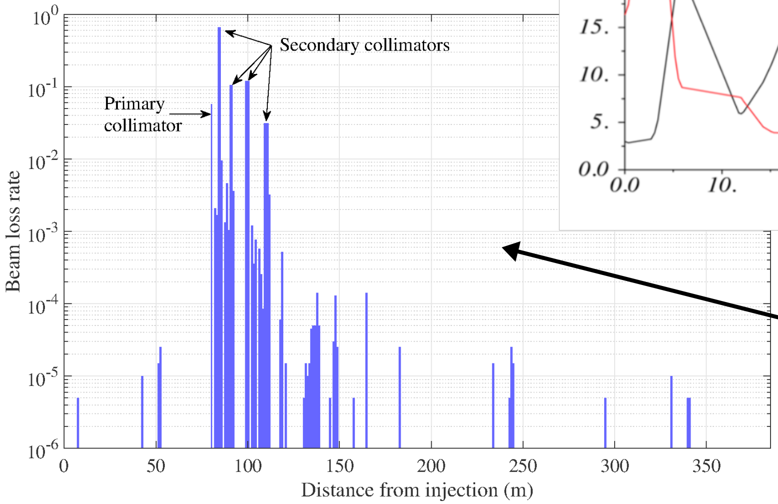
Y. Zou, Uppsala University

Collimation



- 1 W/m means fractional loss <10^{-4}
- Collimation for controlled beam cleaning
- Two-stage system:
  1. Scraper
  2. Absorbers



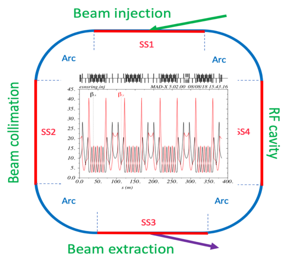


97% collimation efficiency

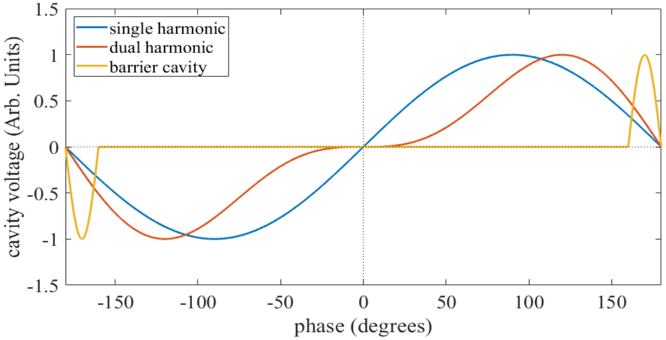
200π mm mrad machine acceptance

Y. Zou, Uppsala University

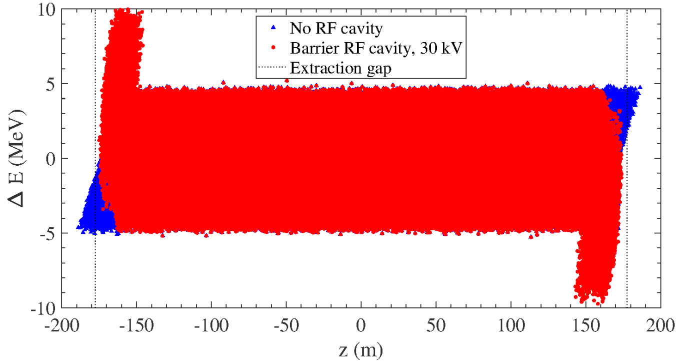
RF cavities



RF waveforms

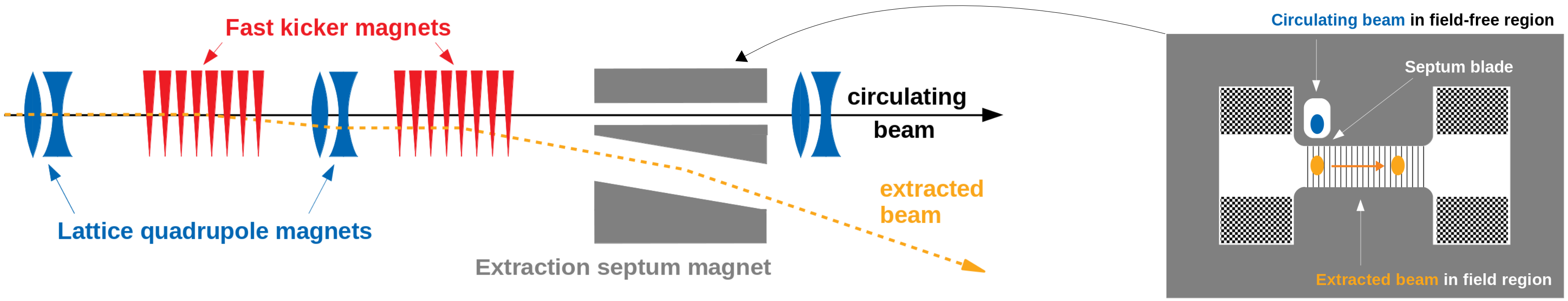


Beam distribution

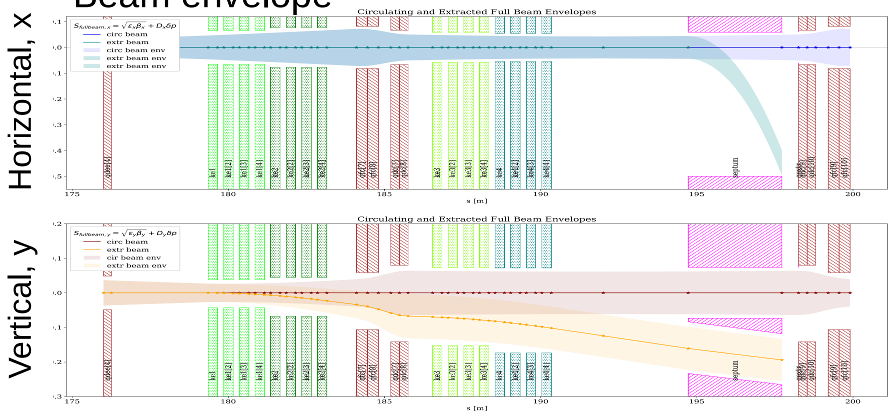


- 10% extraction gap for every turn
  - Beam free gap for ramping extraction kicker magnets
- Created in the linac by chopping
- Maintained >100 ns in the ring with barrier RF cavities
  - Kicks eloping particles back into the core
  - Preserves energy distribution
- Dual-harmonic increases energy spread too much.
- Barrier RF is better.

Single-turn Extraction



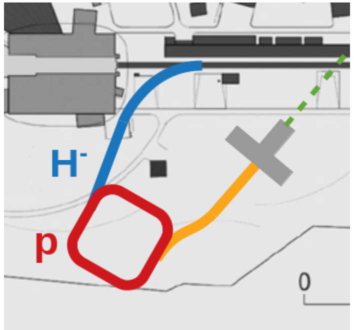
Beam envelope



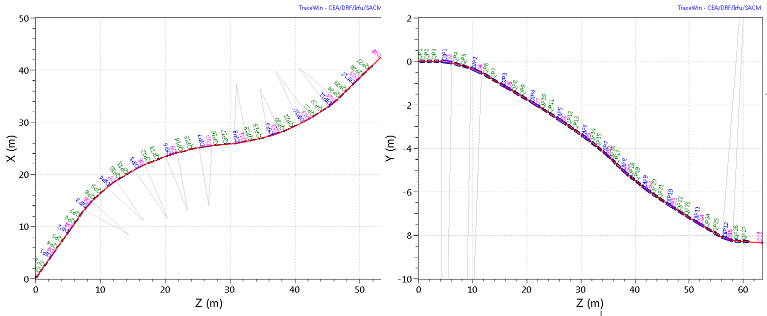
- Goal: loss-free single-turn extraction
- 4x4 extraction kicker magnets
  - Ramped in 100 ns
  - Vertical kick
- Horizontal dipole septum magnet deflects beam
- Tolerance for kicker failure

A. Alekou and I. Efthymiopoulos, CERN

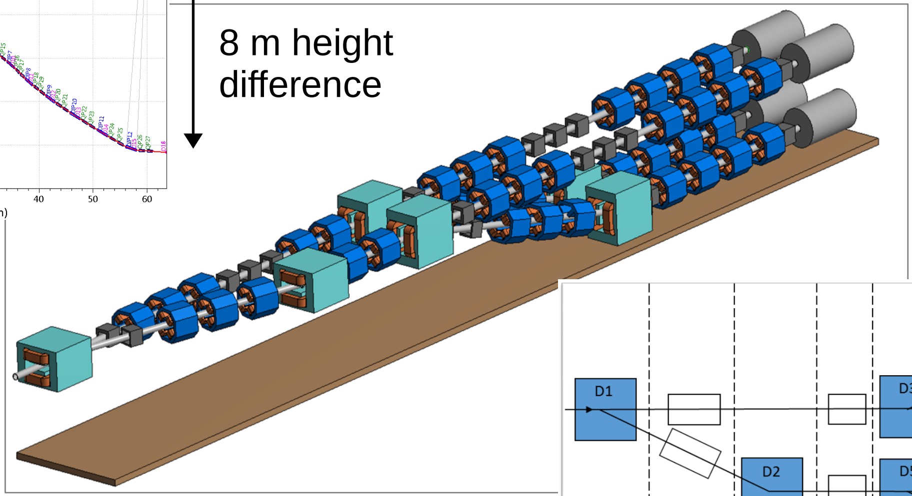
Transfer line and switchyard



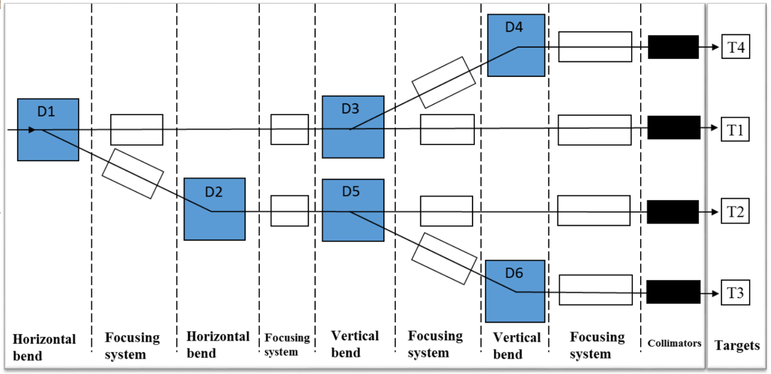
Ring-to-switchyard transfer line



Beam switchyard



Switching scheme



E. Bouquerel, IPHC Strasbourg

ESSnuSB accelerator complex

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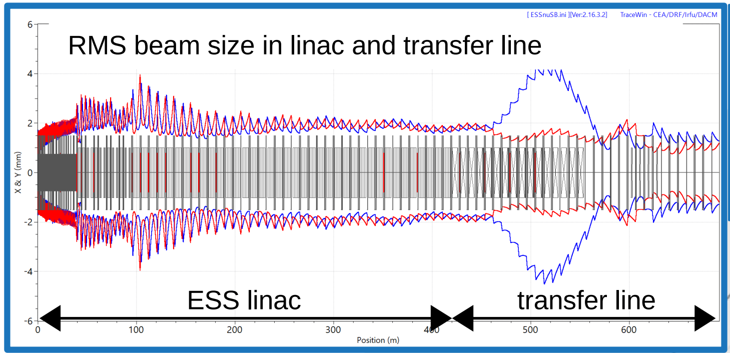
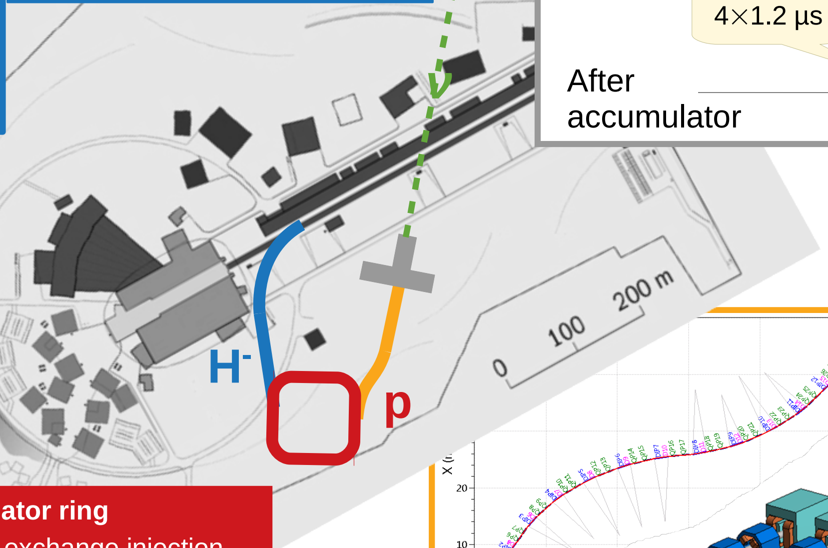
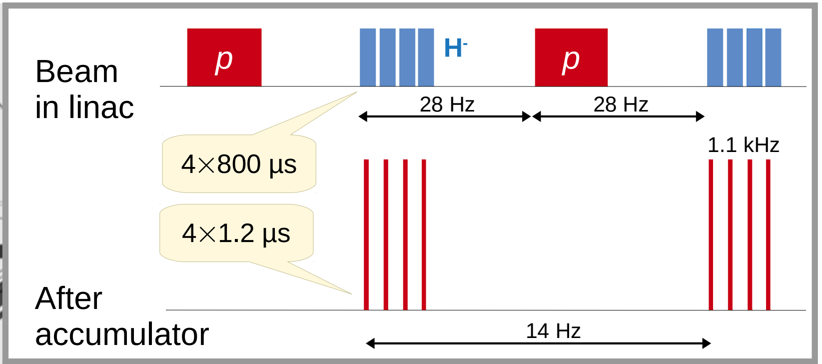
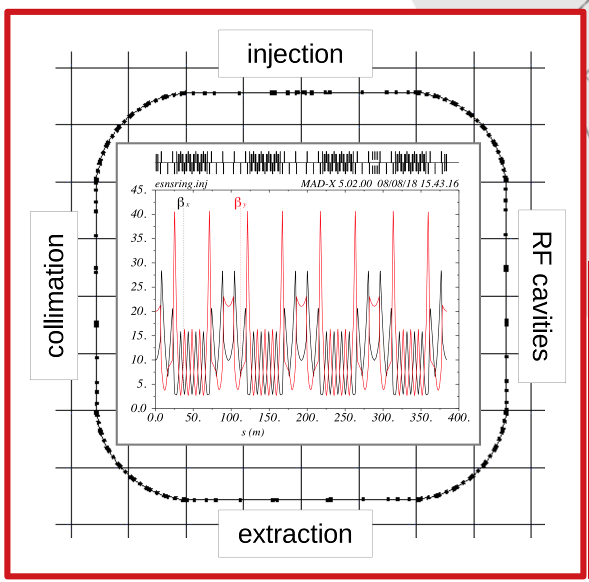


Linac-to-ring transfer line

- Limit magnetic field to 0.15 T to limit Lorentz stripping of H^-
- Balance beam size and dispersion to limit aperture and intra-beam stripping losses.

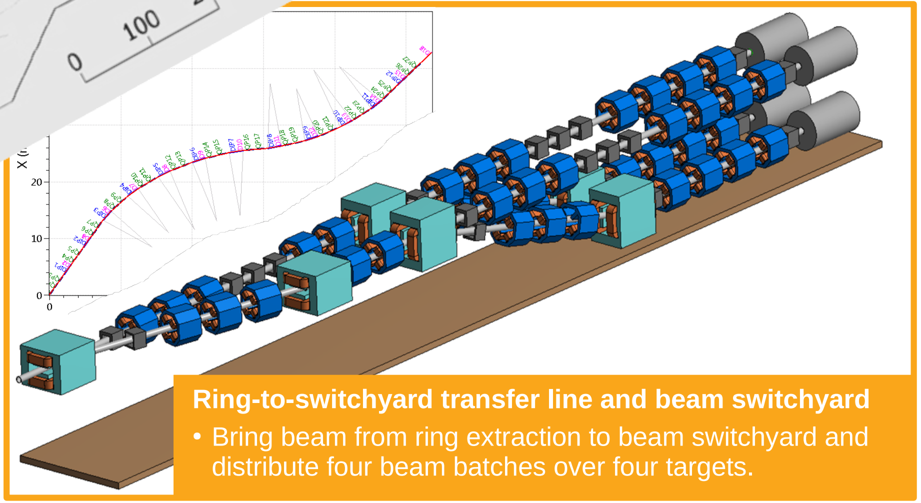






Accumulator ring

- Charge-exchange injection with phase-space painting
- Two-stage collimation system for beam loss control
- RF cavities for maintaining beam free extraction gap
- Single-turn extraction with kicker magnets and septum



Ring-to-switchyard transfer line and beam switchyard

- Bring beam from ring extraction to beam switchyard and distribute four beam batches over four targets.

Outlook

- ESSnuSB design study coming to an end
  - Conceptual Design Report taking shape
  - Cost estimate
- Next step: prepare for the next phase
  - Refined design and sensitivity studies
  - Muon program

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Extra slides

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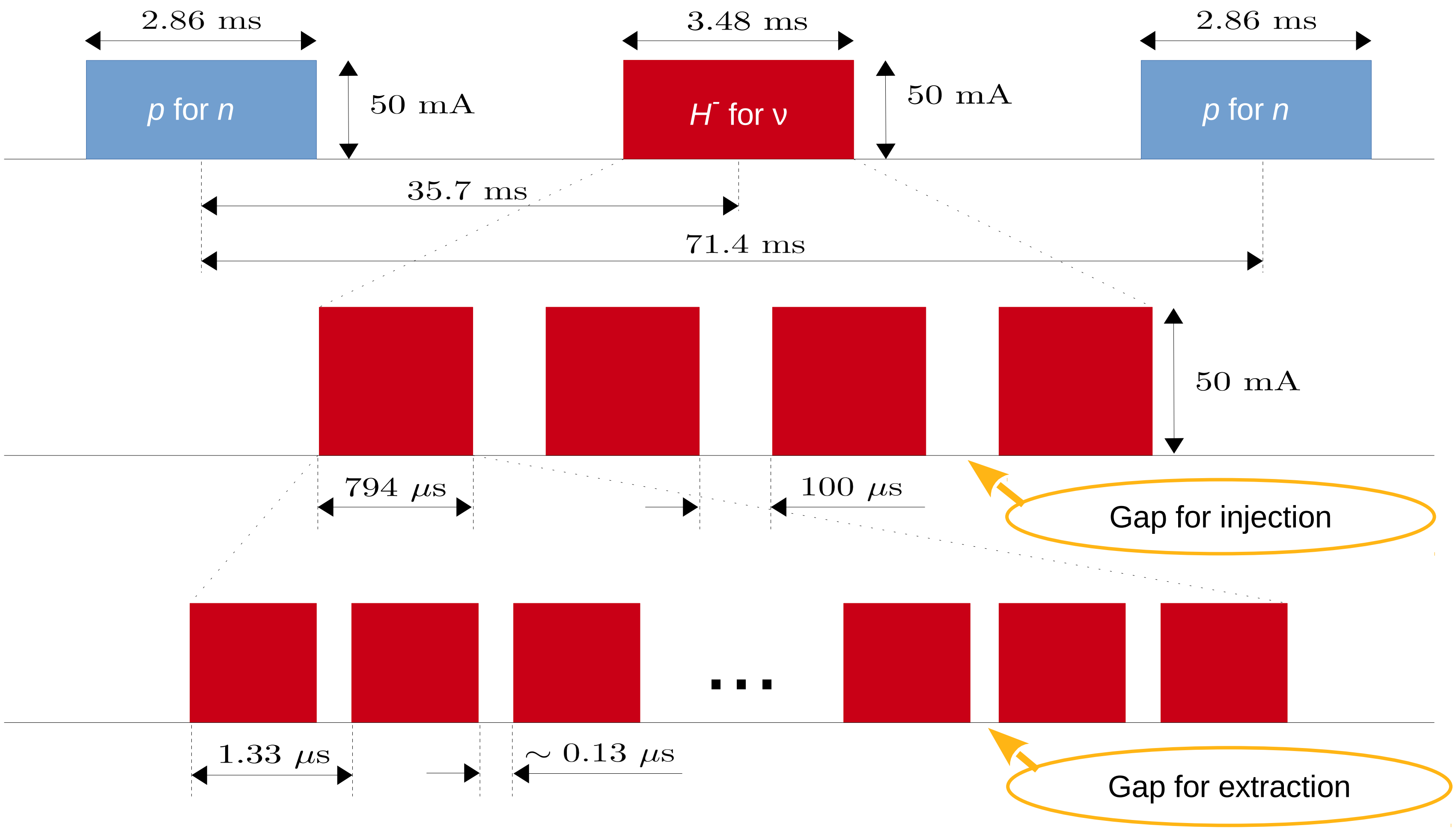
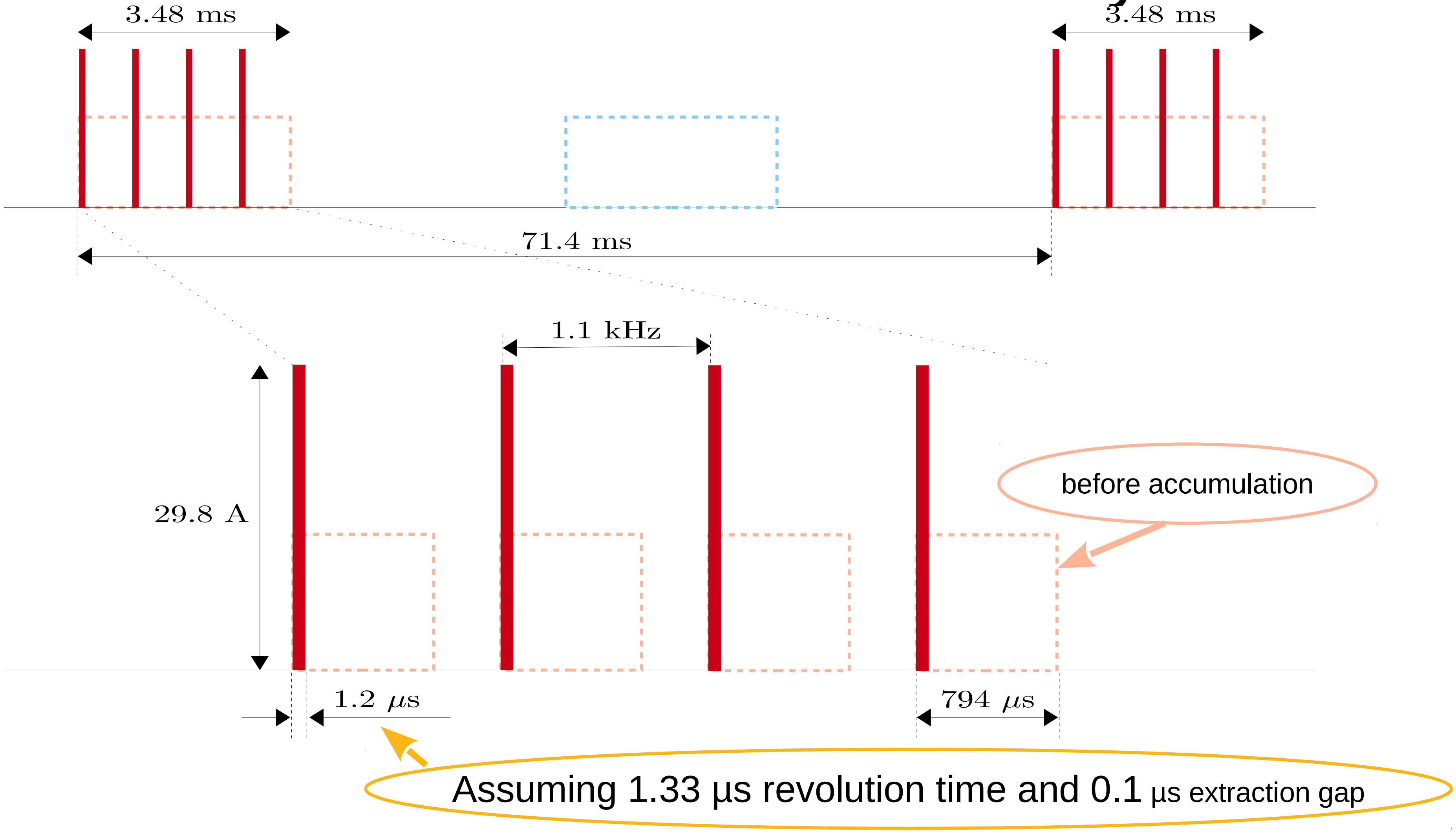
Pulse structure: End of linac/transfer line



Number of injected turns: 597

Pulse structure: In the switchyard



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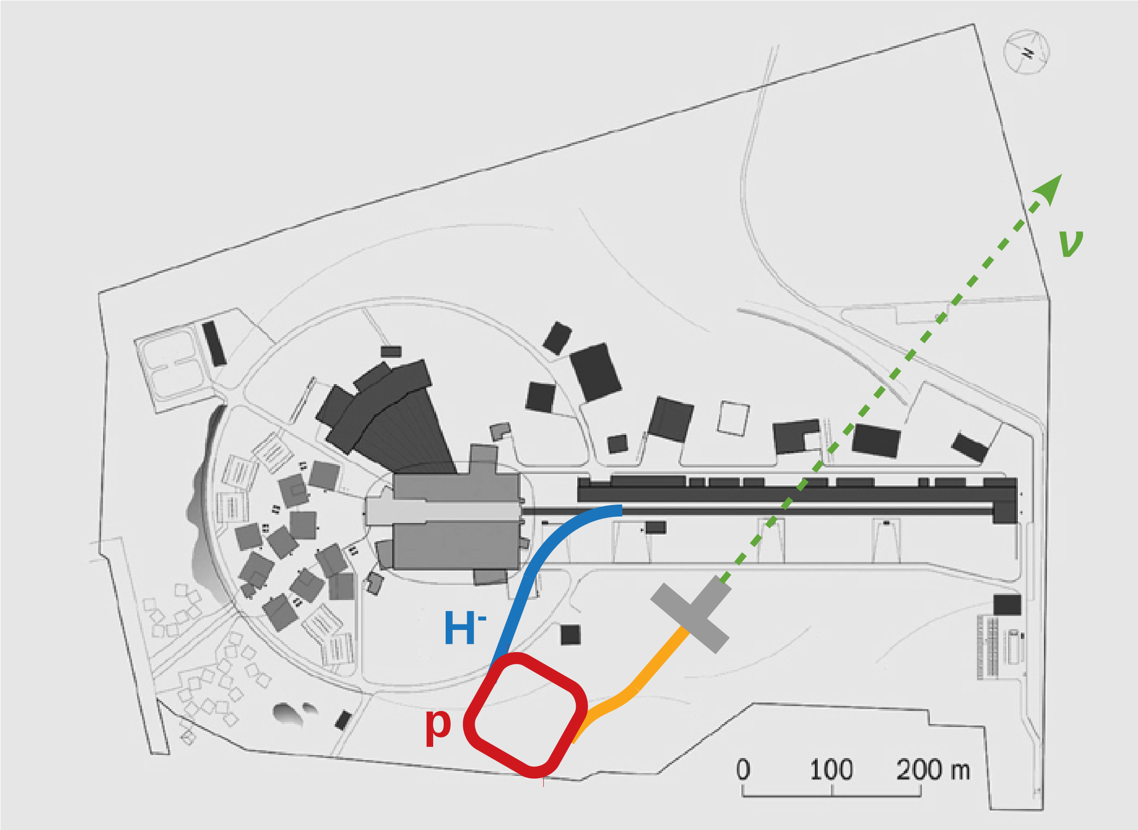

Beam energy	2.5 GeV
Filling time	800 μs
Ring circumference	384 m
Revolution time	1.33 μs
Injected turns	600
Extraction gap (at inj./extr.)	0.13/0.10 μs
Pulse duration at extraction	1.2 μs
# protons per fill	2.23E14
Emittance at extraction (unnormalized, 100%)	70 mm mrad
Pulse frequency at extraction	1.1 kHz

Max. magn. field in transfer line	0.15 T

Energy distribution