EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

The ESSnuSB Accumulator Ring

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Upgrading Existing High Power Linacs
Lund, November 8, 2016

With great support from:

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Hannes Bartosik, Elena Benedetto,
Vincenzo Forte, Frank Schmidt,
Horst Schonauer and Tord Ekelöf

Outline

- The ESSnuSB project
- The ring and the beam
- Space charge simulations
- Outlook

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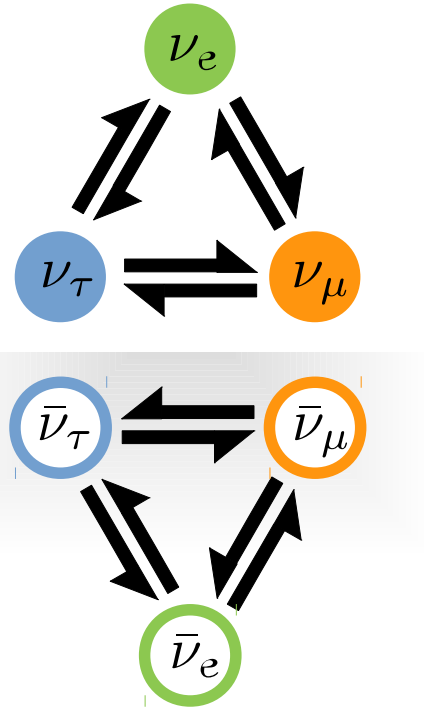
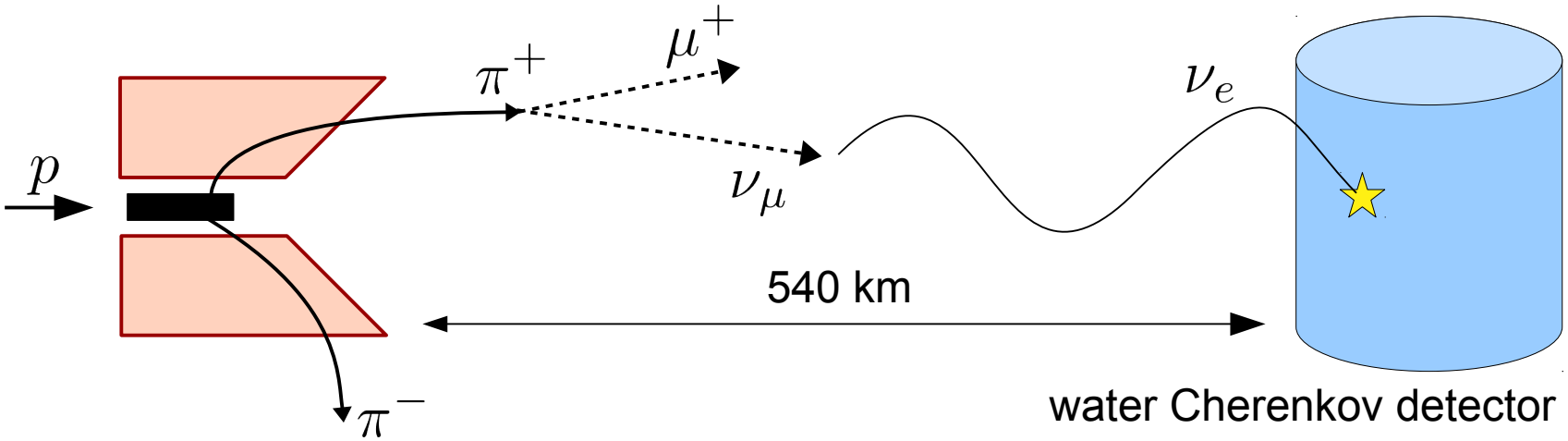
Leptonic CP violation

- Leptonic CP violation could explain the matter – antimatter asymmetry
- Measure the CP violating phase by comparing neutrino and antineutrino oscillation levels.
- Such an experiment requires
  1. an intense, clean neutrino beam
     - a powerful proton driver
  2. a large neutrino detector at a suitable location





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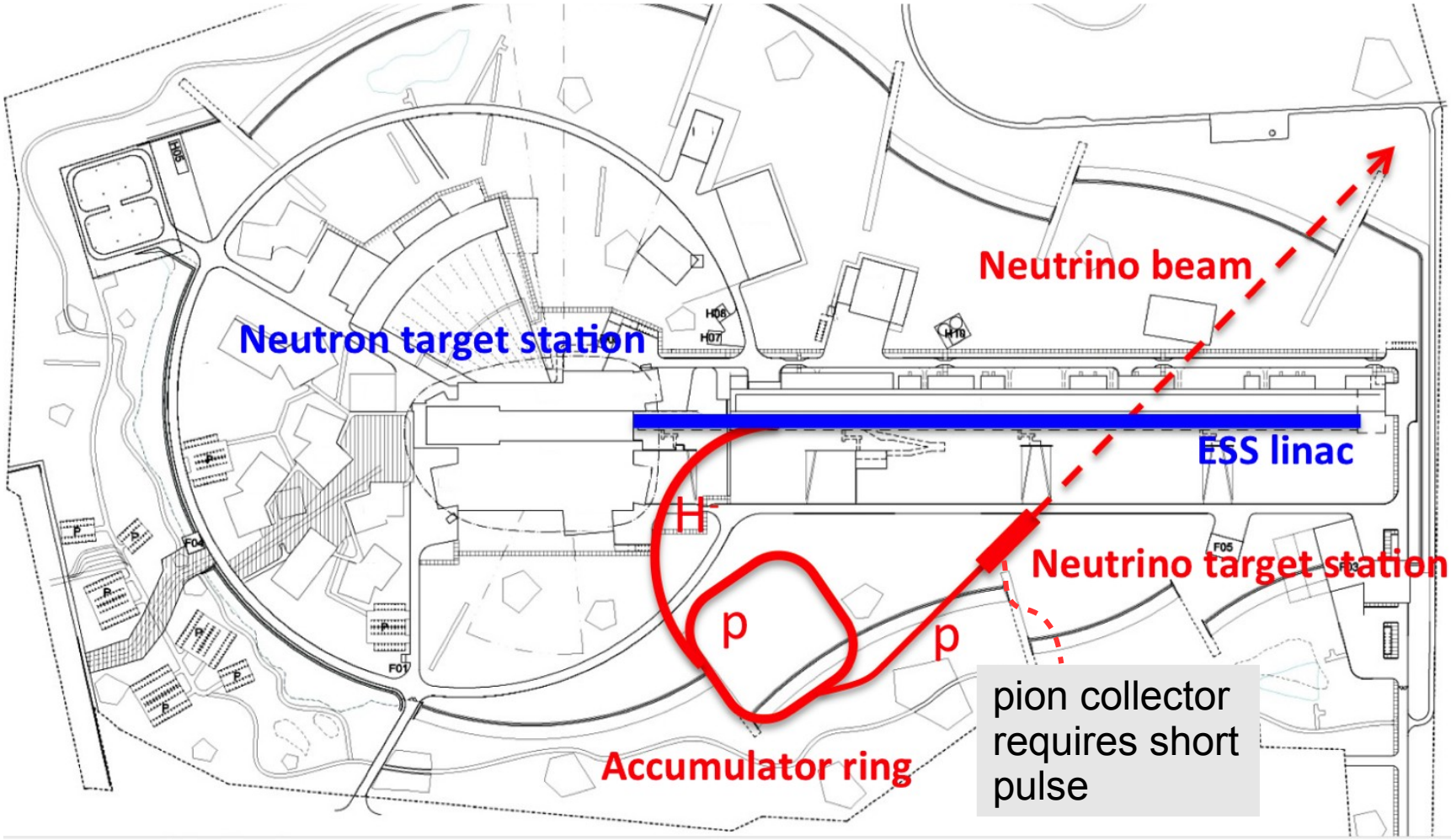
ESSnuSB

European Spallation Source, Lund



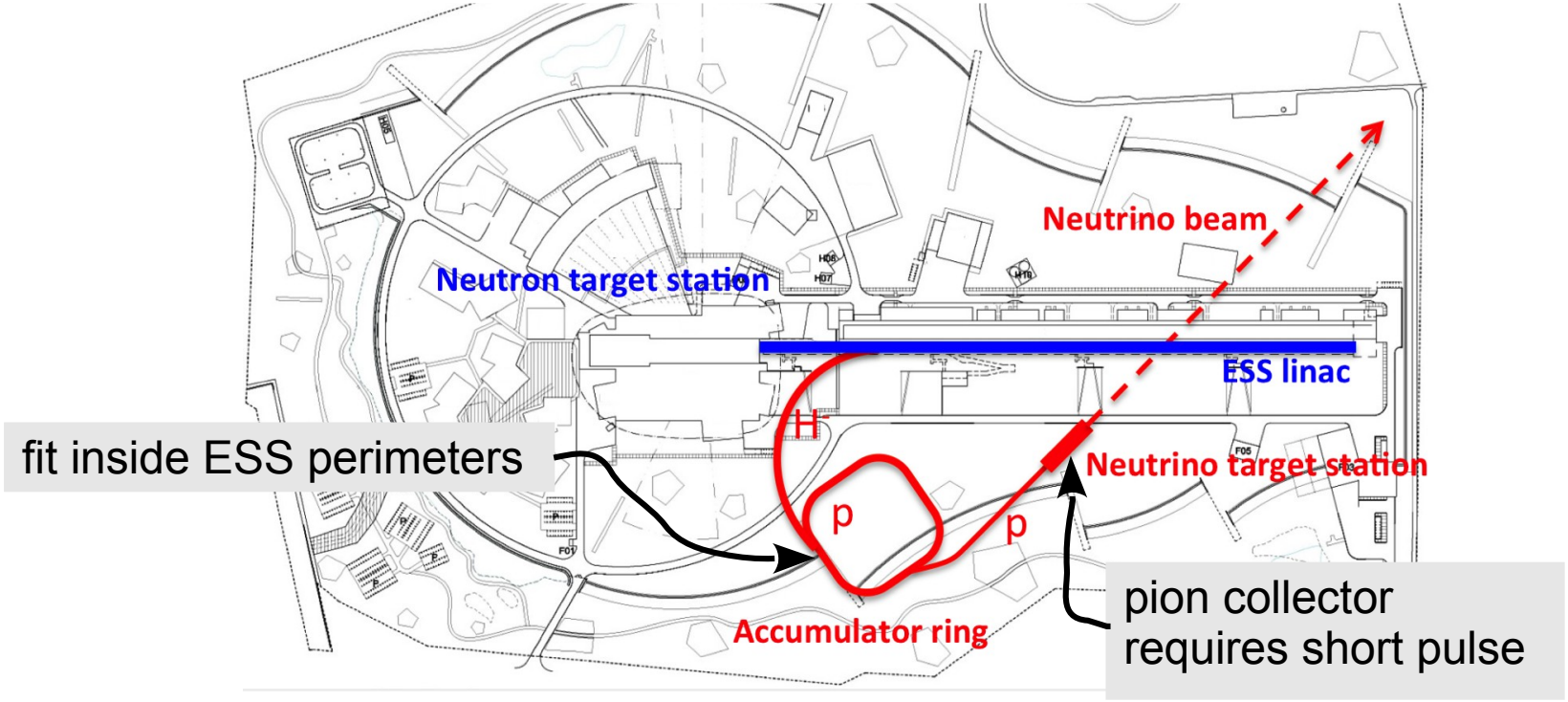
5 MW proton beam
3 ms pulses
1e15 protons/pulse

5 MW H-/proton beam
<2 μs pulses

ESS → ESSnuSB

Ring requirements

- Accumulate/compress 1.1E15 protons to pulses <2 μs
- Loss free injection and extraction
  - charge exchange injection with phase space painting
  - H- acceleration in the linac



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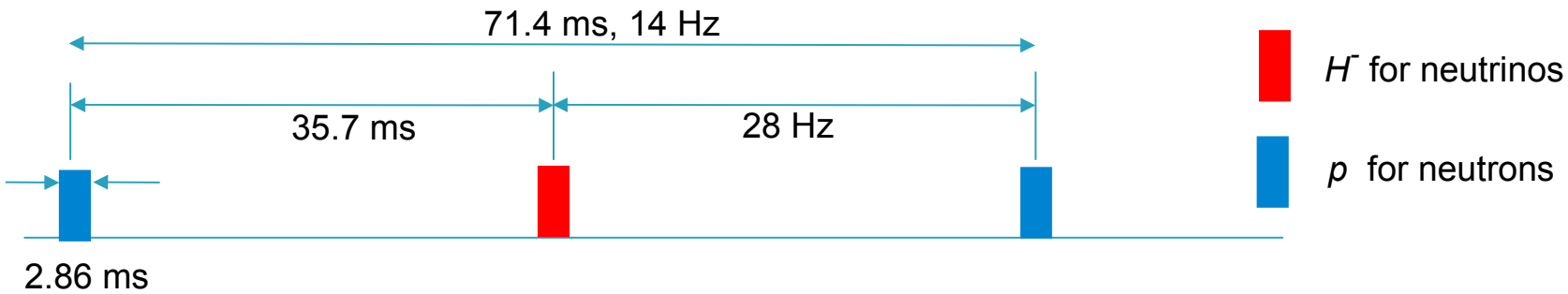
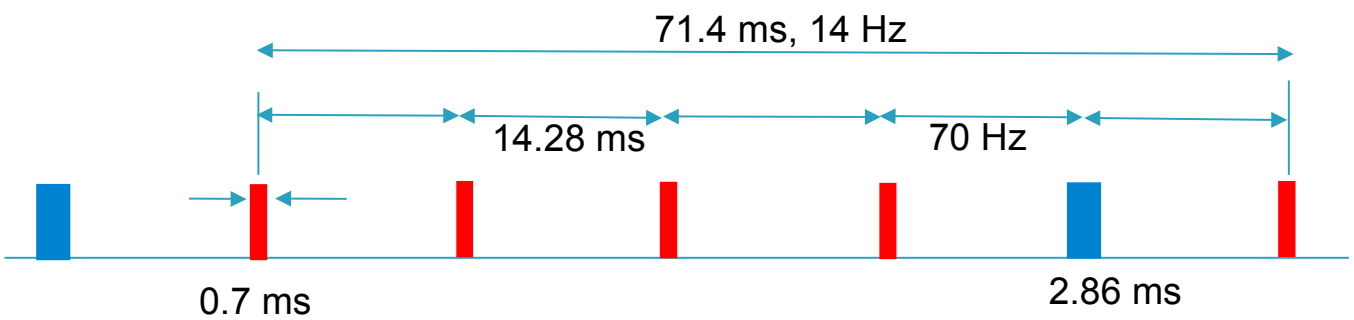
Linac Operation Mode

Scheme A: ⇨ 2 - 4 stacked rings, similar to PSB



Scheme B: ⇨ 1 ring, 70 Hz pulsing of the linac



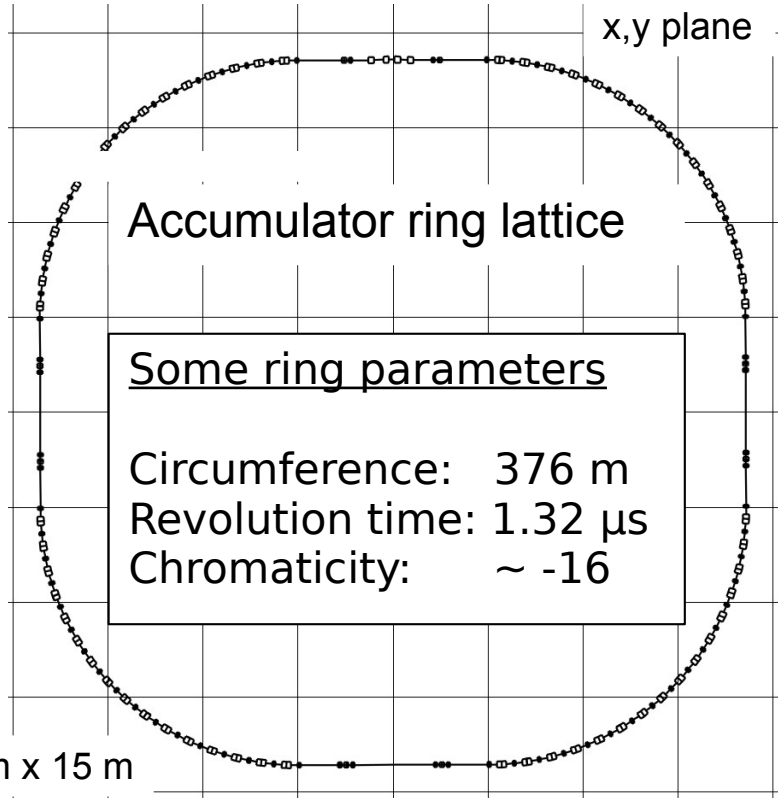
The ring

- An up-scaled and modified version of the SNS accumulator.
  - Four straight sections for injection, RF, etc.
  - FODO lattice in the arcs.
- Ring design made by J. Jonnerby and H. Schönauer.
- Double harmonic RF for capture.
- Three working points tested:

a) $Q_x = 10.395 \quad Q_y = 11.321$

b) $Q_x = 10.395 \quad Q_y = 11.254$

c) $Q_x = 10.395 \quad Q_y = 11.202$



Grid size 15 m x 15 m

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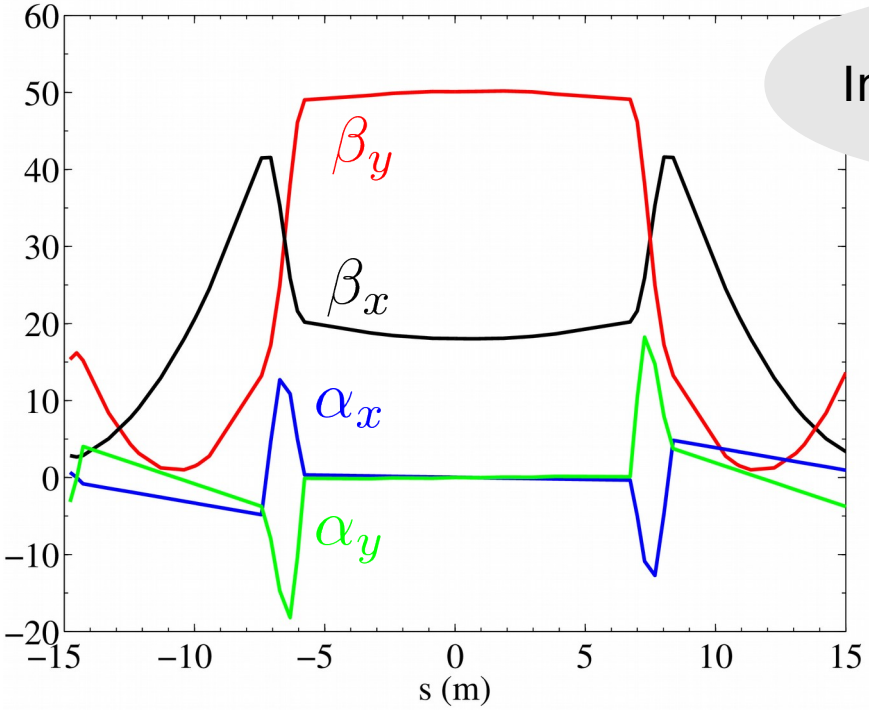
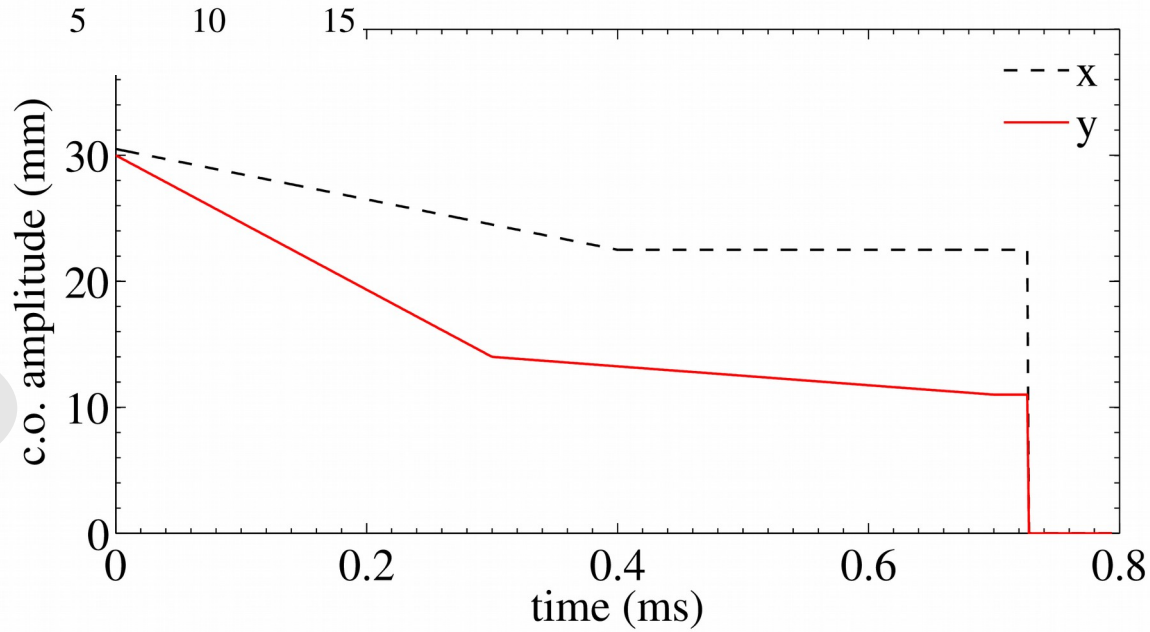
Injection



Injection region

- 4 slow magnets
  - quasi-static orbit bump
- 4 fast kickers
  - transverse painting

Amplitude of fast orbit bump



Space Charge Simulations

- Beam tracking with space charge in pyORBIT and PTC-ORBIT to test the ring design. Start with 1/4 of a linac pulse per fill, corresponding to 540 injected turns.

1. First simulation series to chose working point.
   - Assuming painting complete, full intensity from start
2. Simulate full injection with painting
   - Try with space charge turned *on* and turned *off*.

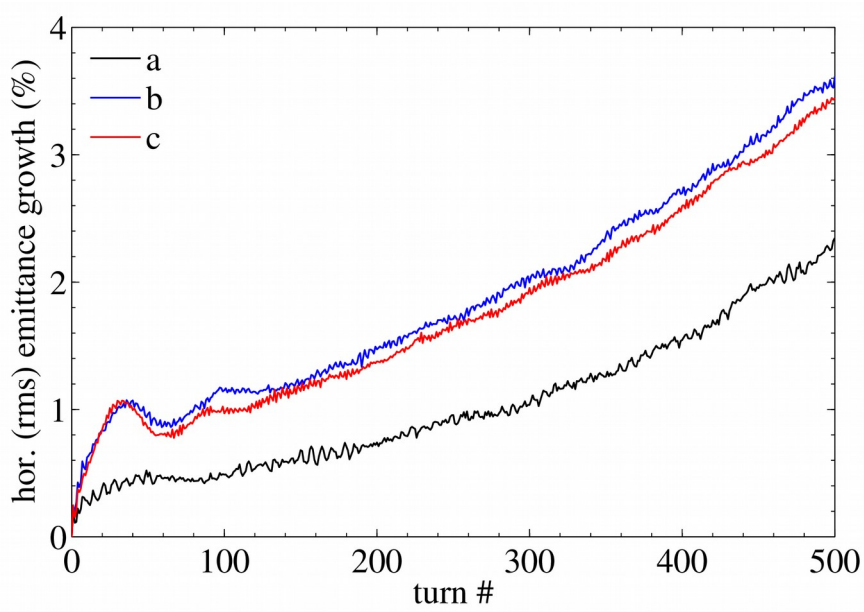
- 2.5D transverse space charge model, “sliced“ 2D
- 1D longitudinal space charge model
- Large aperture (~100 mm radius), losses not yet studied.

1. Full intensity from start

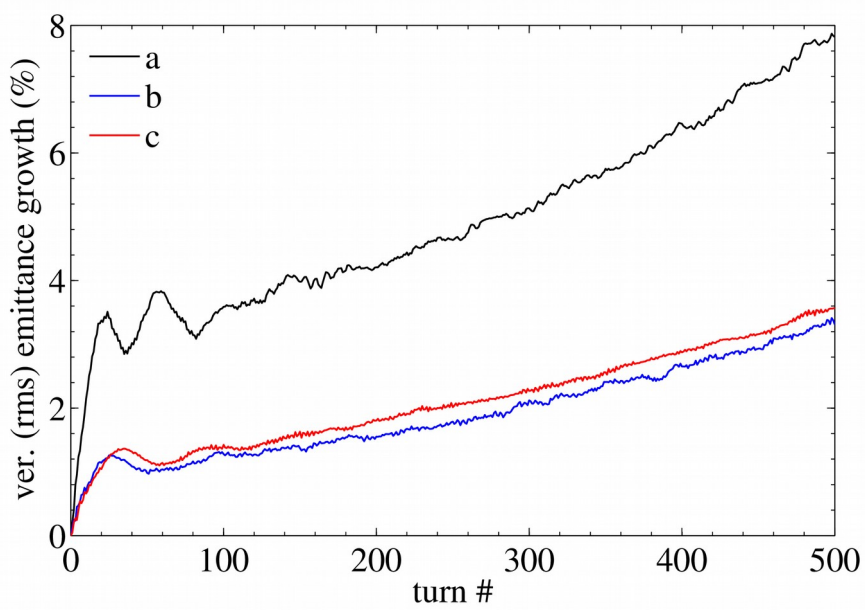
- 2.75E14 protons in the ring.
- Track for 500 turns.
- Uniformly distributed longitudinal distribution with 15% extraction gap.
- Gaussian energy distribution with rms 0.02%.
- Gaussian transverse distributions, matched at injection.
- Normalized 86.5% emittance of 100 mm mrad, corresponding to geometrical rms emittance of 8.5 mm mrad.

1. Emittance evolution

Horizontal emittance increase



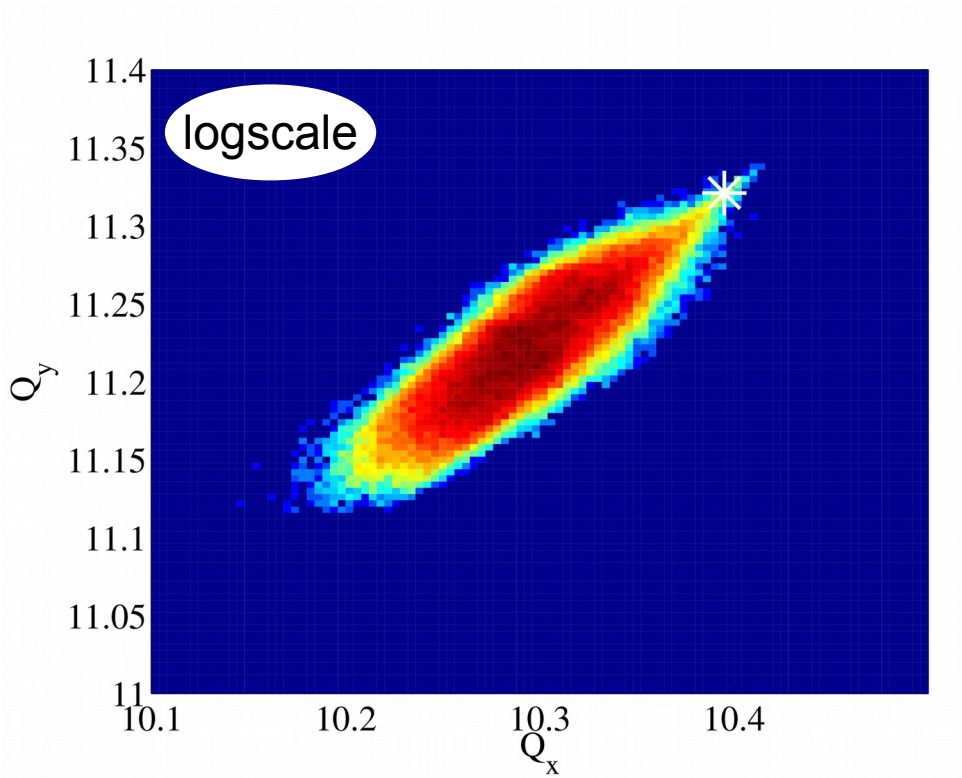
Vertical emittance increase



Reminder:

- I track 1/4 of the linac intensity, corresponding to 2.75E14 protons, for 500 turns.
- Initial emittance: 8.5 mm mrad, rms. (100 mm mrad normalized, 86.5%)

1. Tune spread



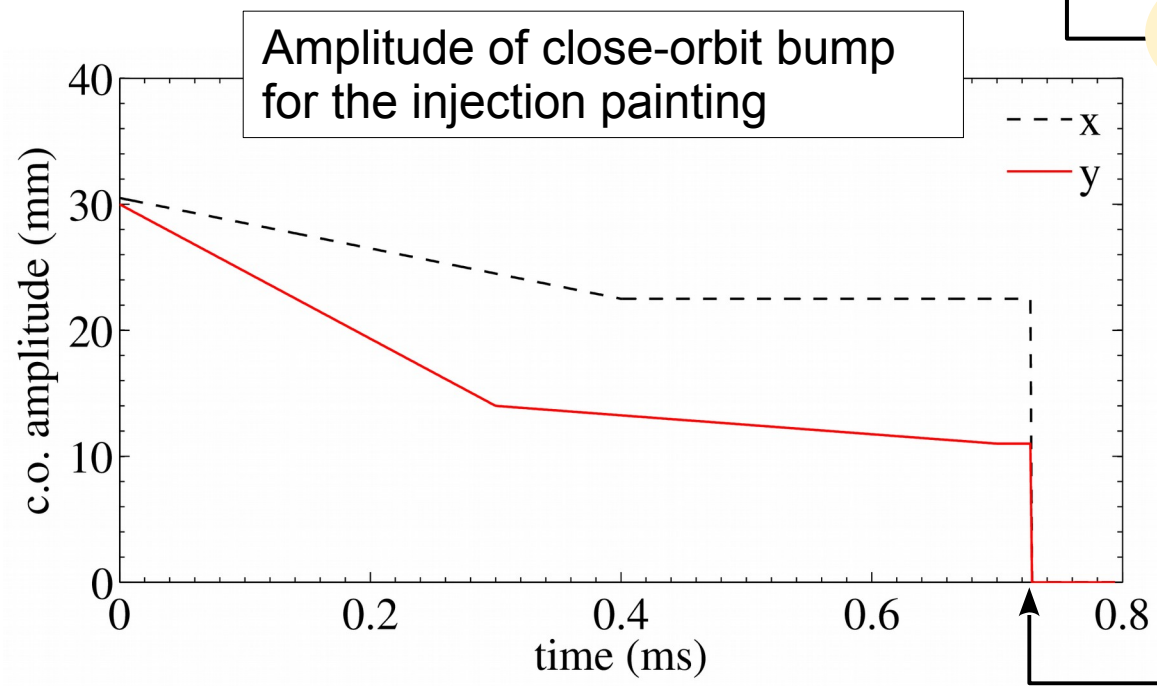
$$\Delta Q \approx 0.2$$

- Tune spread about 0.2 in both planes. Similar result for working points a), b) and c).
- Matches the analytically calculated Laslett tune shift for a Gaussian beam, uniform in the longitudinal plane.

2. Transverse Painting

- Inject during 550 turns → fill time 0.7 ms.
- Final intensity 1/4 of a linac pulse, i.e. 2.75e14 protons.
- Injected rms emittance 0.084 mm mrad.
- Uniformly distributed “bunch” that fills 85% of the ring.

micro-bunching ignored



fill complete

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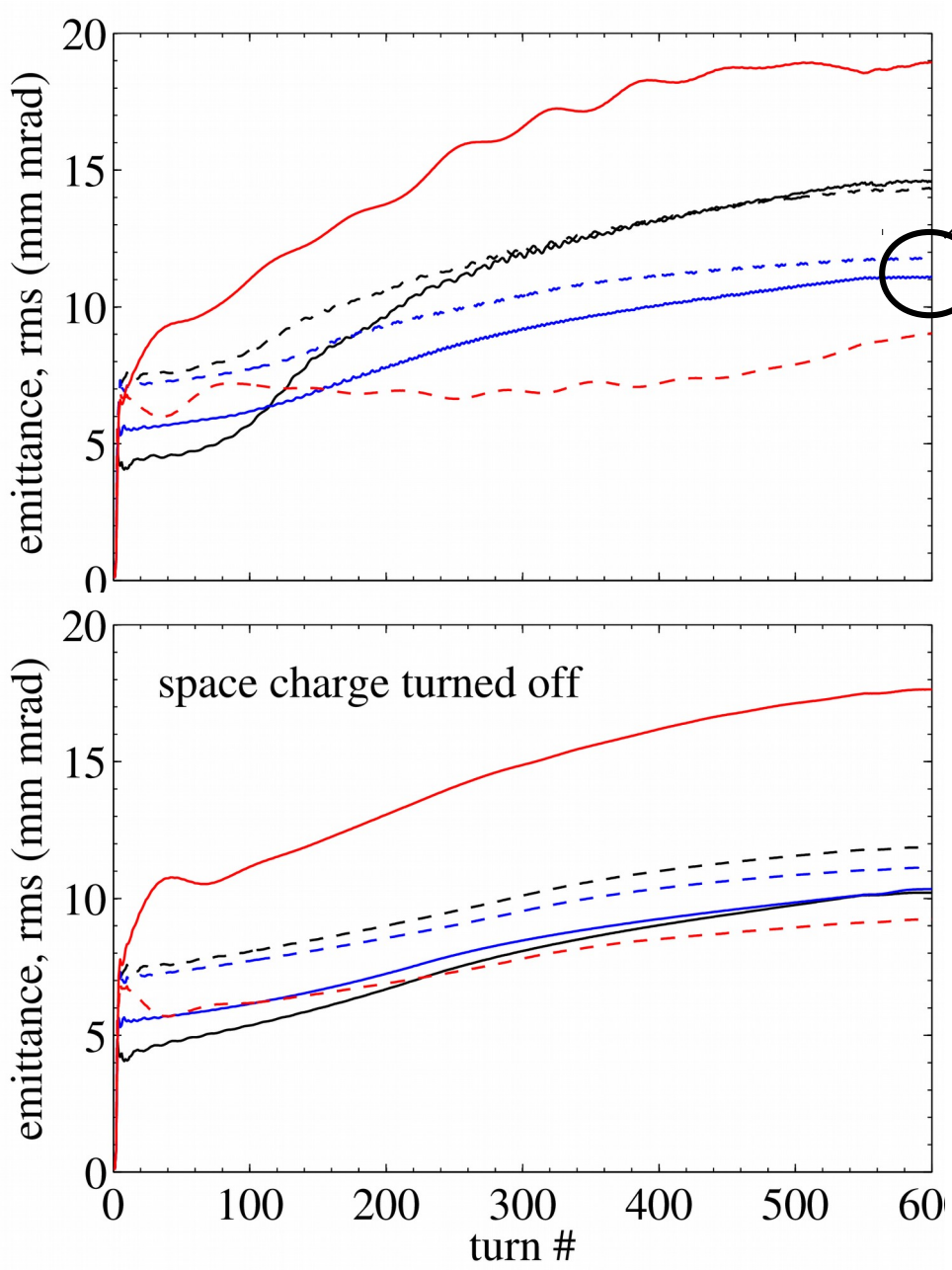
2. Emittance with painting



The target rms emittance depends on the final distribution shape.

11-12 mm mrad

horizontal

vertical

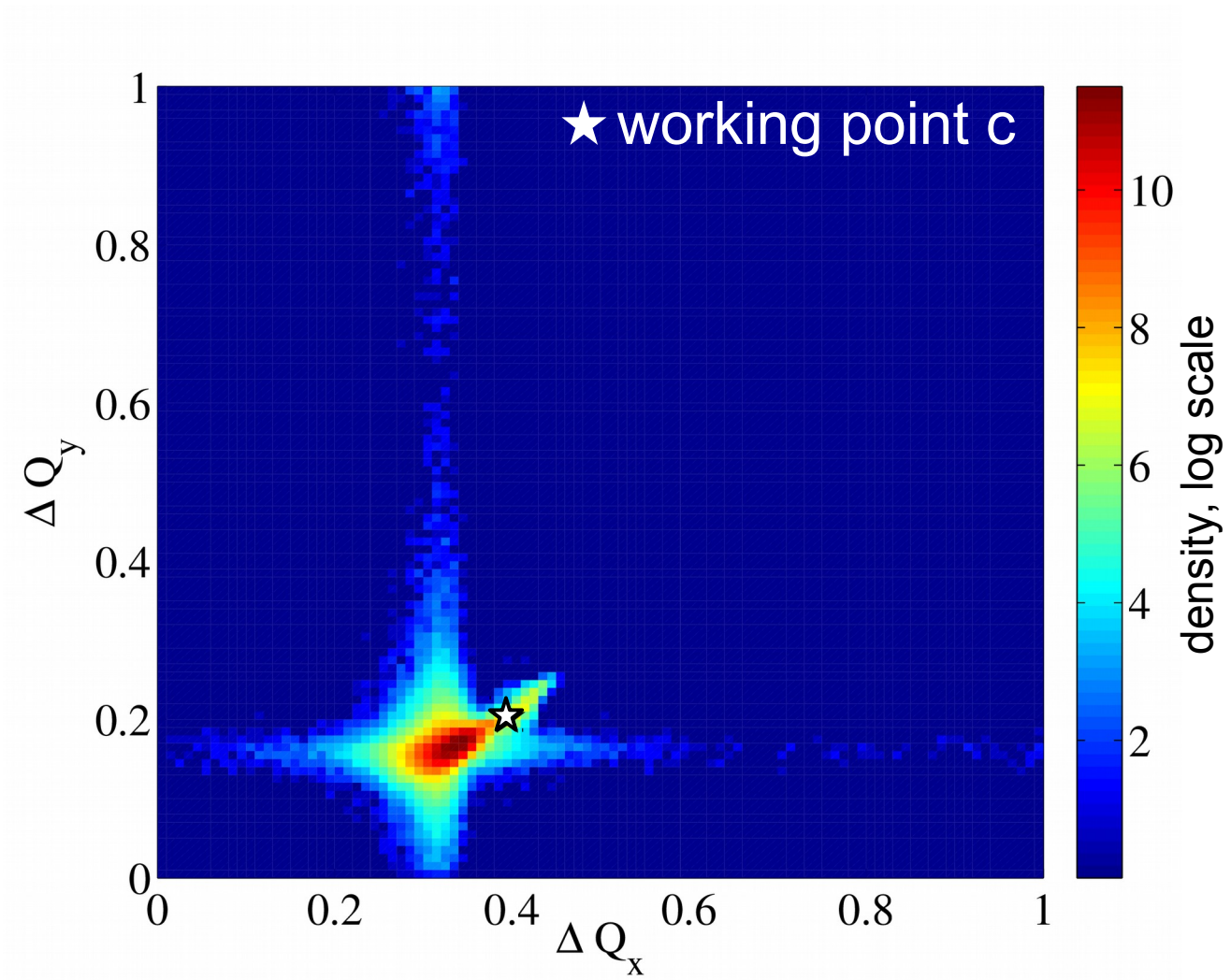
$Q_x = 10.395$

a) $Q_y = 11.321$

b) $Q_y = 11.254$

c) $Q_y = 11.202$

2. Tune Spread



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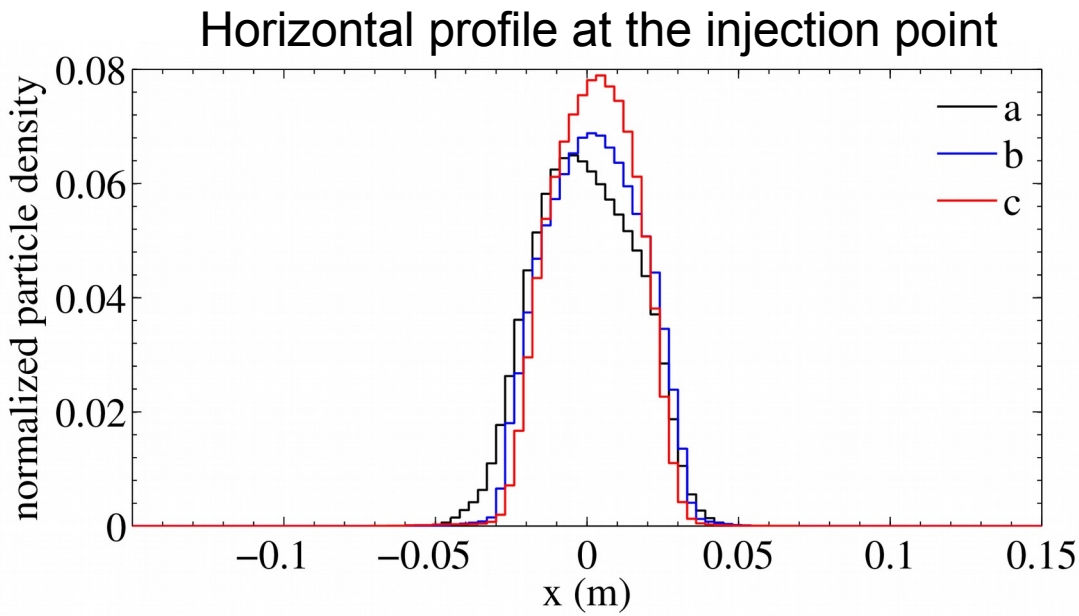
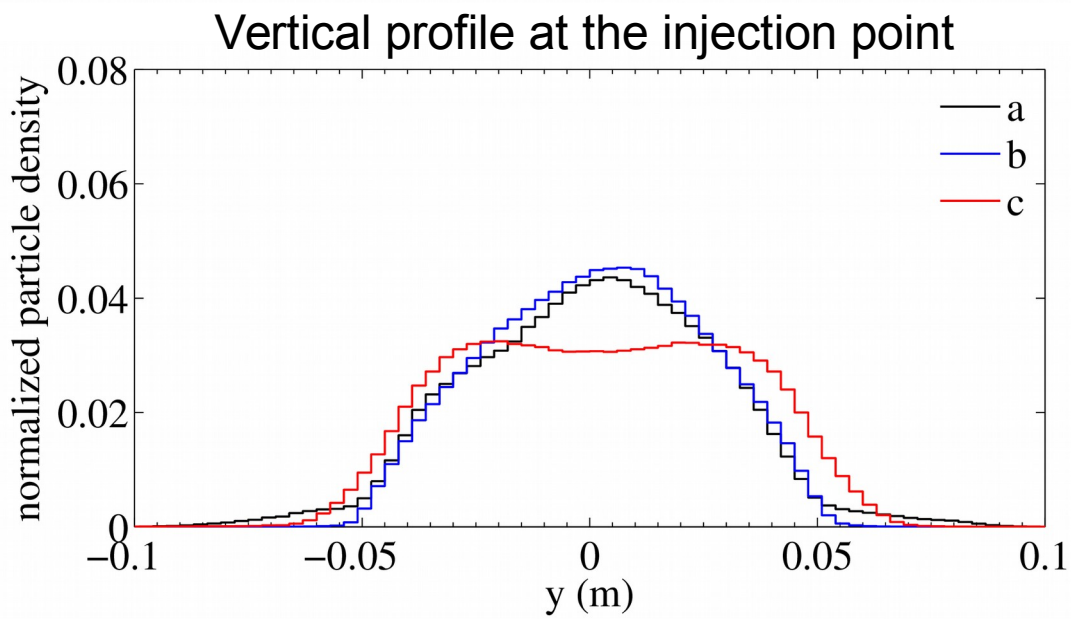
2. Beam profile with painting





Painting can probably be improved for more uniform profiles

Outlook

- Revisit lattice design
  - help from experts?
- Remodel injection painting
  - more uniform transverse distribution
  - diagnostic for the foil in pyORBIT?
  - look at 95% emittances
  - look at apertures and losses
- Looking at effect of micro-bunching?
  - requires 3D space charge model: heavy simulations.
- Test the intensity limit of the ring
  - 1/3 or even 1/2 of the linac pulse?

Extra slides

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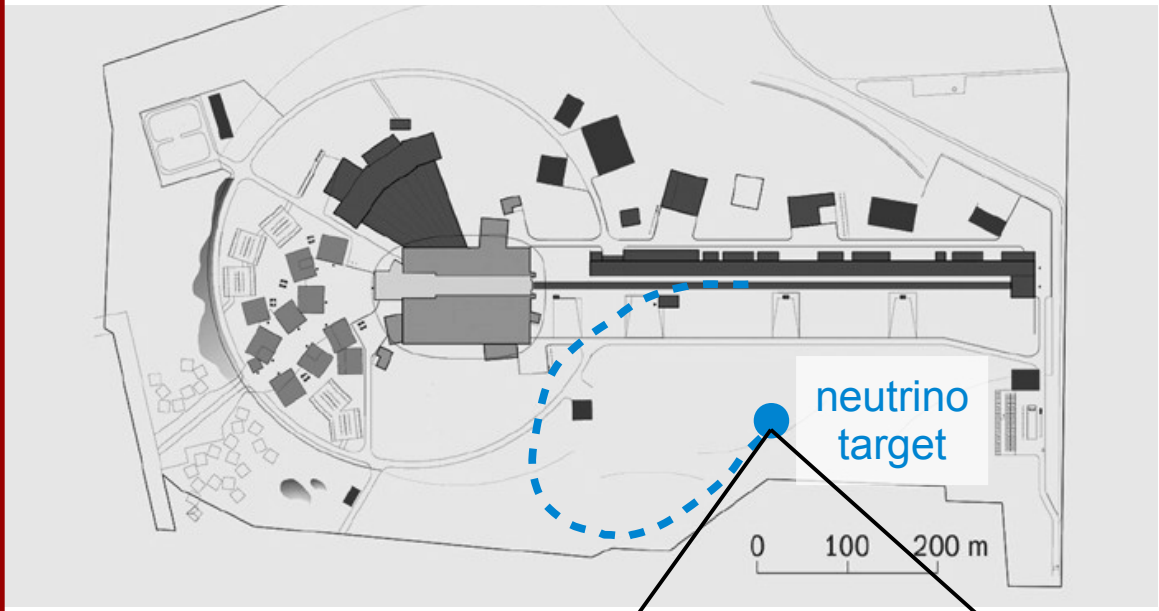
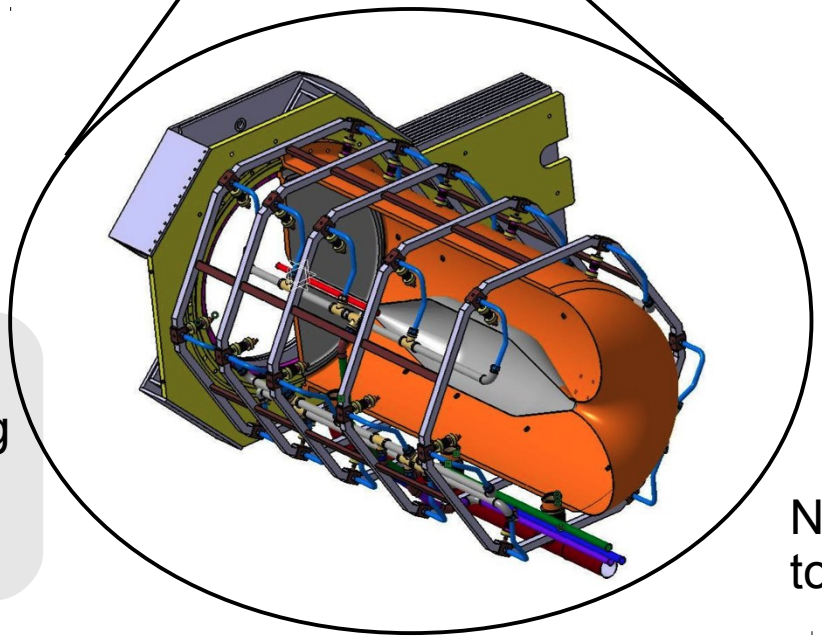
ESS → ESSnuSB



ESS linac beam

pulse length:	3 ms
current:	62.5 mA
energy:	2 GeV (2.5 GeV)
rep. rate:	14 Hz
bunch frequency:	352 MHz



"Horn" for pion focusing around the target

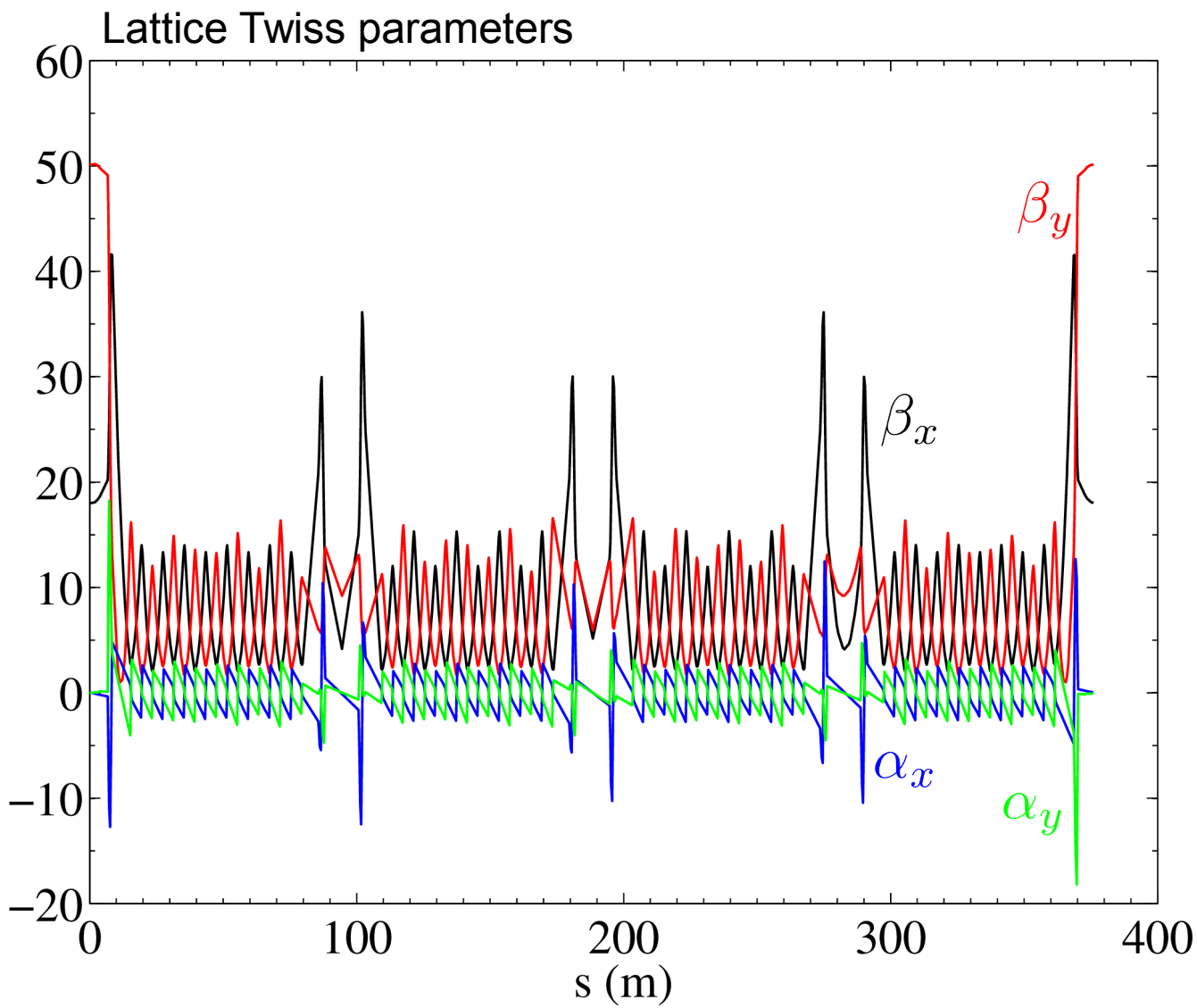
The magnetic horn is normal-conducting powered with 350 kA => can only be powered for < 2 μs.

Need an accumulator ring to reduce the pulse length.

The ESS Linac Beam

Bunch train duration	3 ms
Bunch duration	3 ps
# protons/train	1.1E15
Norm. emittance, rms	0.25 mm mrad
Energy spread, rms	0.02 %
Train rep. rate	14 Hz
Bunch frequency	352 MHz

Lattice


Lattice Twiss parameters
60
50
40
30
20
10
0
−10
−20
0
100
200
300
400
s (m)
β_y
β_x
α_x
α_y

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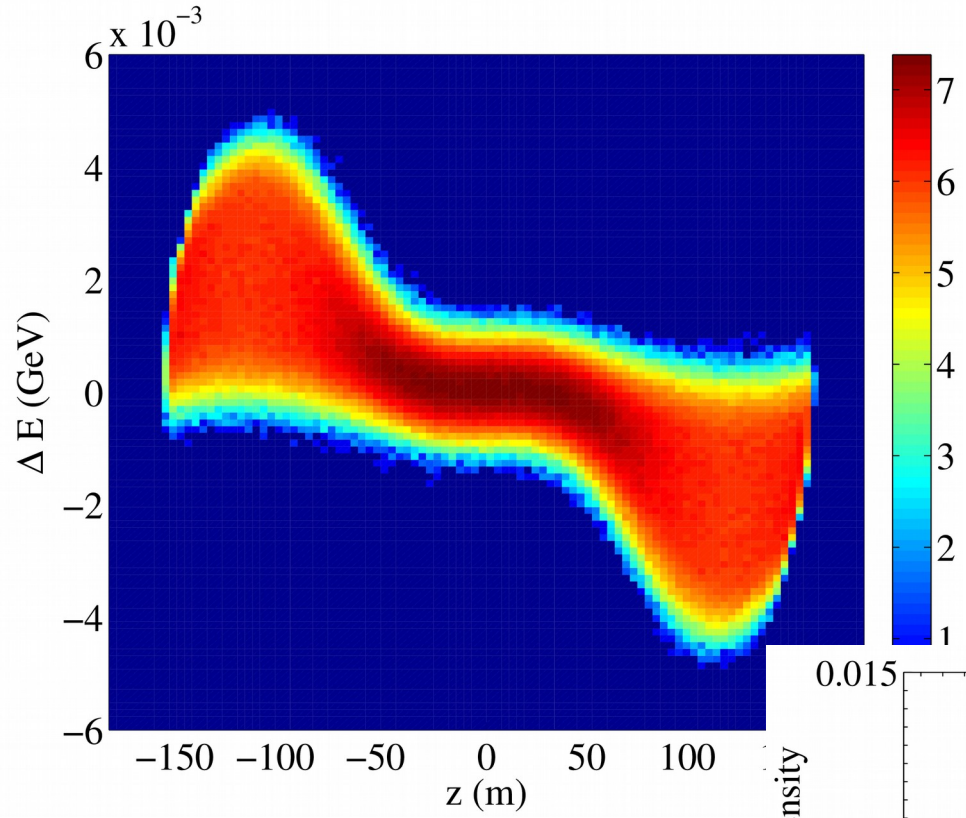
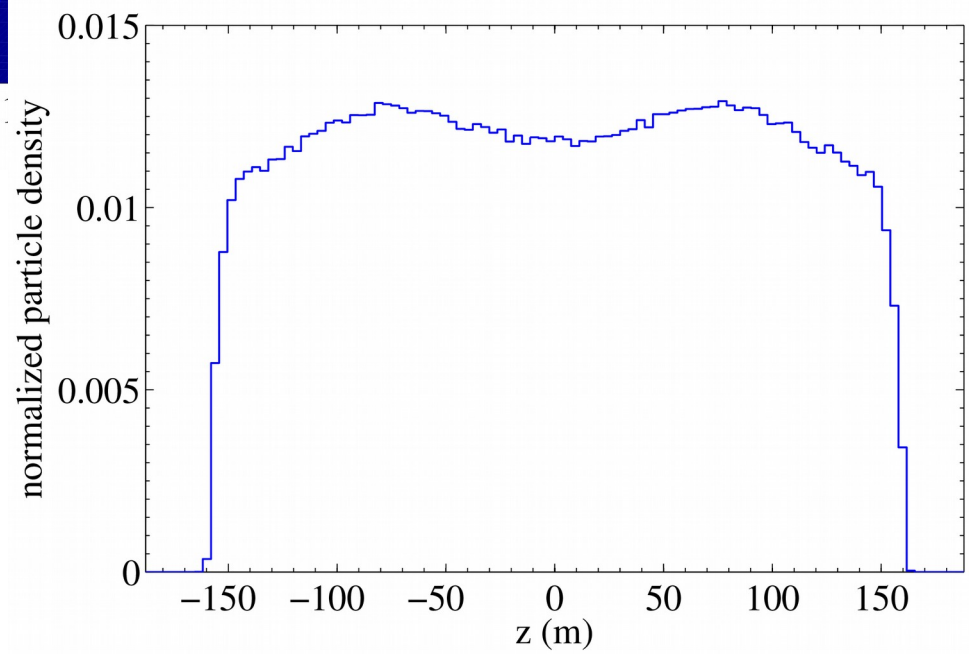
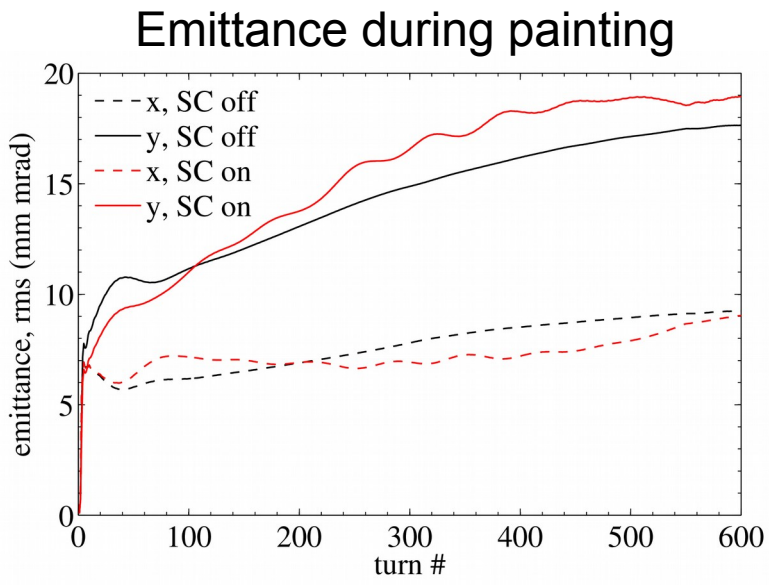
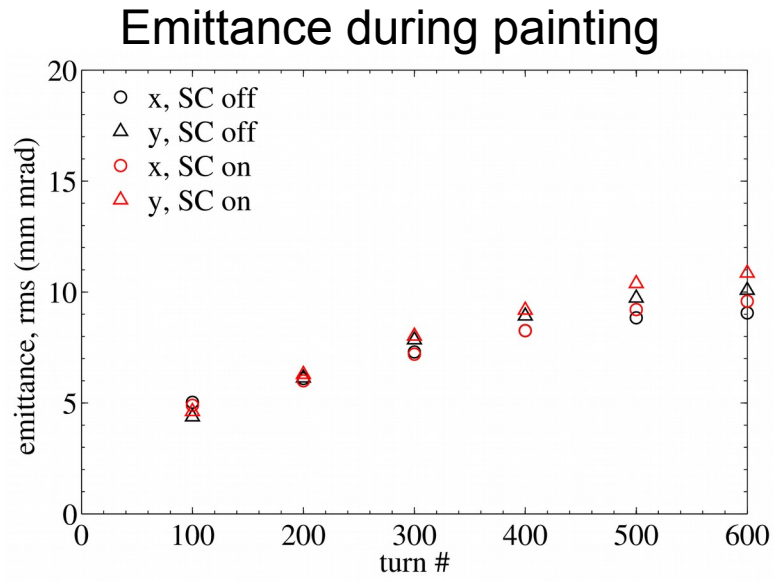
Longitudinal distribution

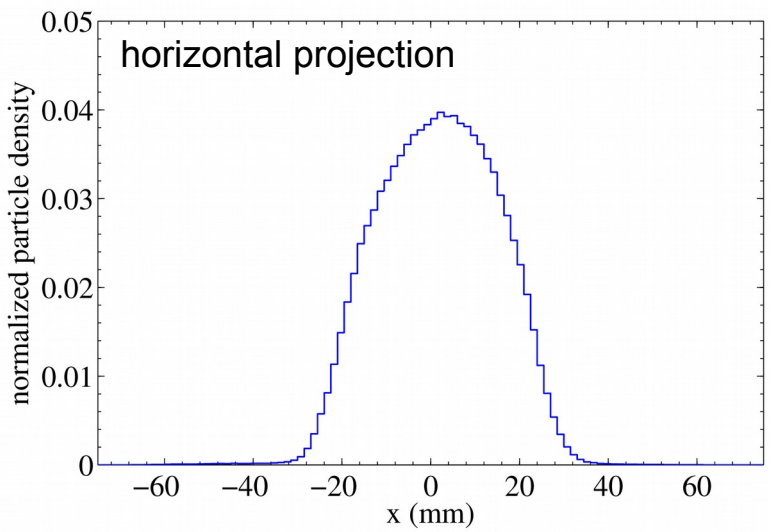


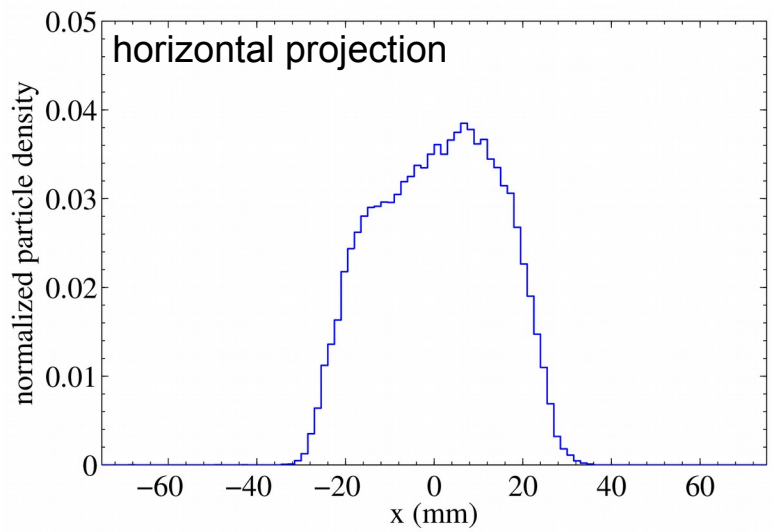


pyORBIT Vs ACCSIM









pyORBIT Vs ACCSIM

colors in logscale