UPPSALA
UNIVERSITET

The nuSTORM project

in ESSnuSB+

Maja Olvegård

Uppsala University

On behalf of the ESSnuSB collaboration

ESS neutrino Super Beam plus

Co-funded by the European Union

UPPSALA UNIVERSITET

Outline

- ESS – European Spallation Source
- ESSnuSB – European Spallation Source Neutrino Super-Beam
- ESSnuSB+ – European Spallation Source Neutrino Super-Beam plus
- nuSTORM – Neutrinos from Stored Muons
- Objectives and challenges

UPPSALA UNIVERSITET

The European Spallation Source

- The most powerful proton driver in the world!
  - 5 MW average beam power
  - 125 MW peak power
- 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.

April 2022.

The ESS neutrino Super-Beam

- A long-baseline neutrino oscillation experiment
- Measure with precision the CP violating phase at the second oscillation maximum
- Excellent performance
- ESSnuSB Design study (Horizon 2020)
  - Complete conceptual design of the facility
  - Conceptual Design Report published in November 2022: Eur. Phys. J. Spec. Top. **231**, 3779–3955 (2022)
  - Including almost 1 km of new beamline to transport and transform the 5 MW ion beam

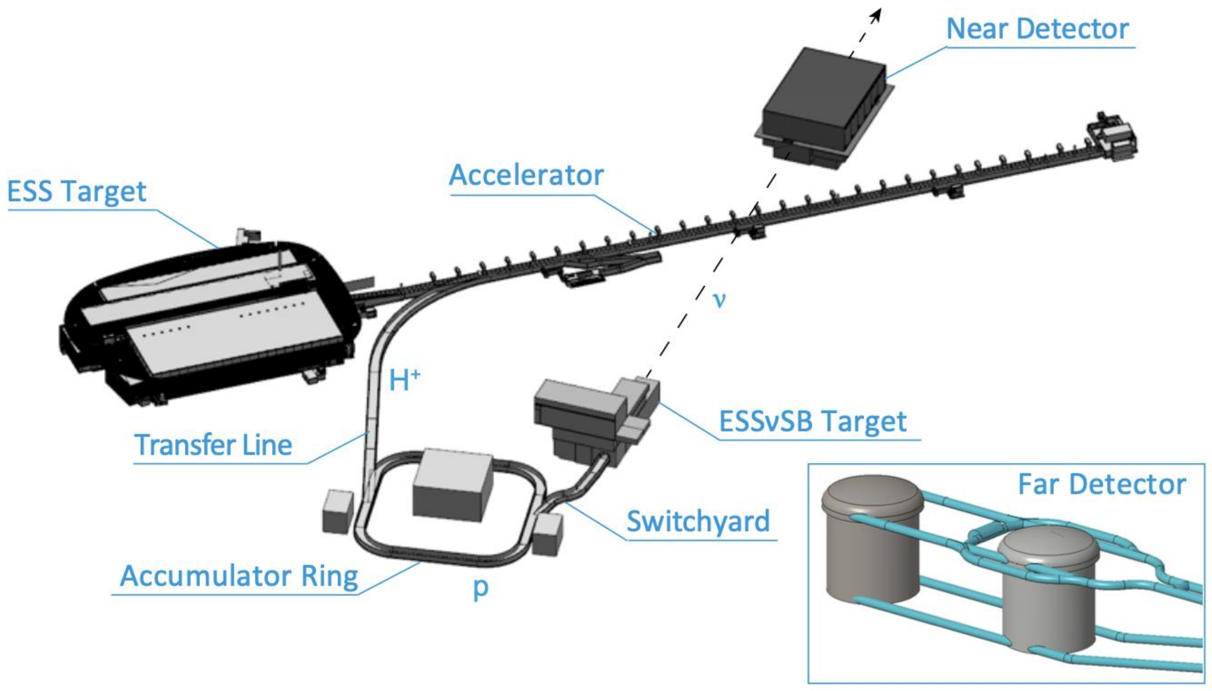


Figure 2.1: The layout of the ESSνSB components on the ESS and the far detector sites.

Alekou, A., *et al.* The European Spallation Source neutrino super-beam conceptual design report. *Eur. Phys. J. Spec. Top.* **231**, 3779–3955 (2022). https://doi.org/10.1140/epjs/s11734-022-00664-w

ESS neutrino Super Beam plus

20 institutes in
11 countries

Runs in 2023-2026

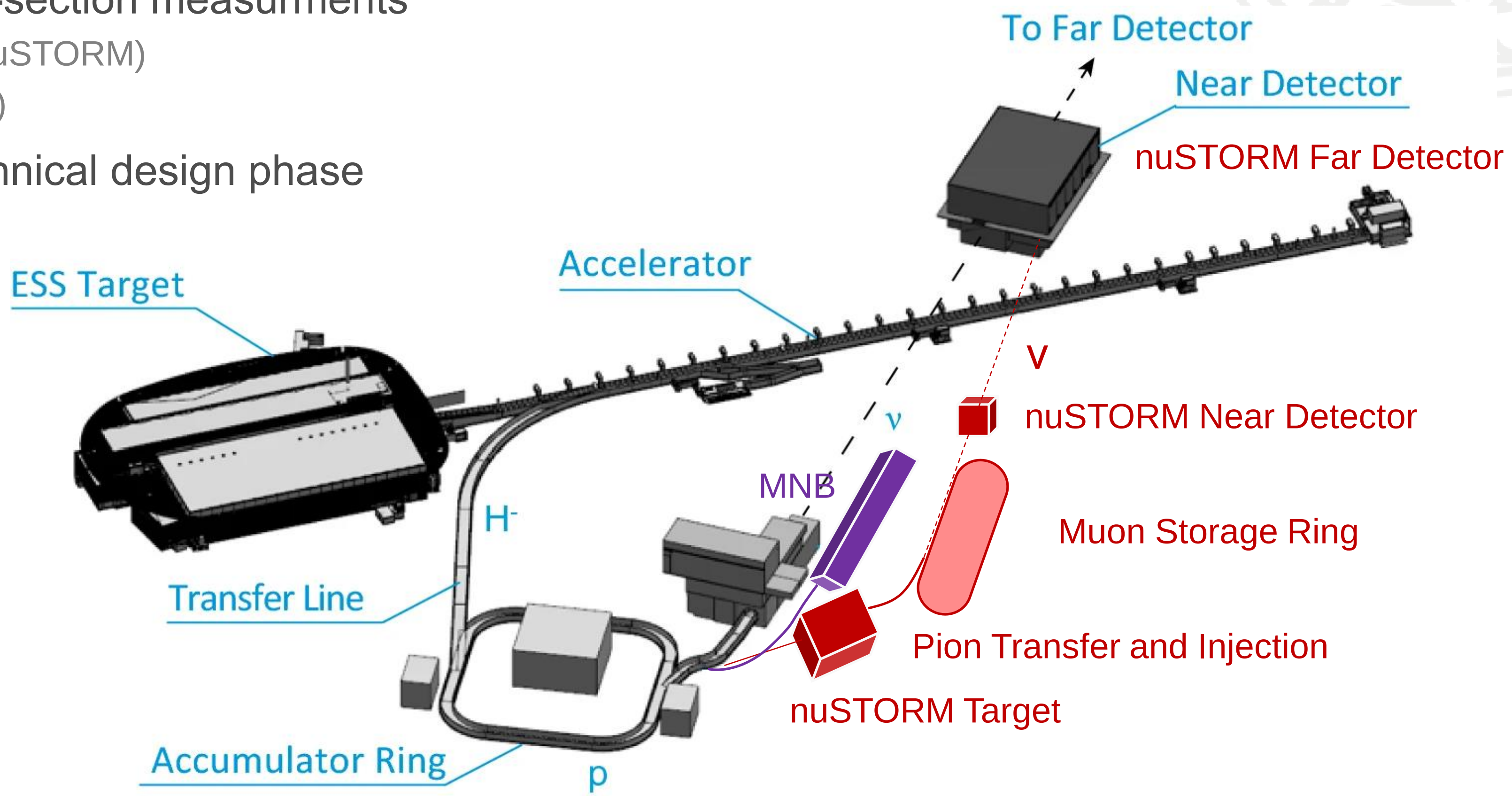
5 MEUR tot. budget
3 MEUR from
Horizon Europe

Co-funded by
the European Union

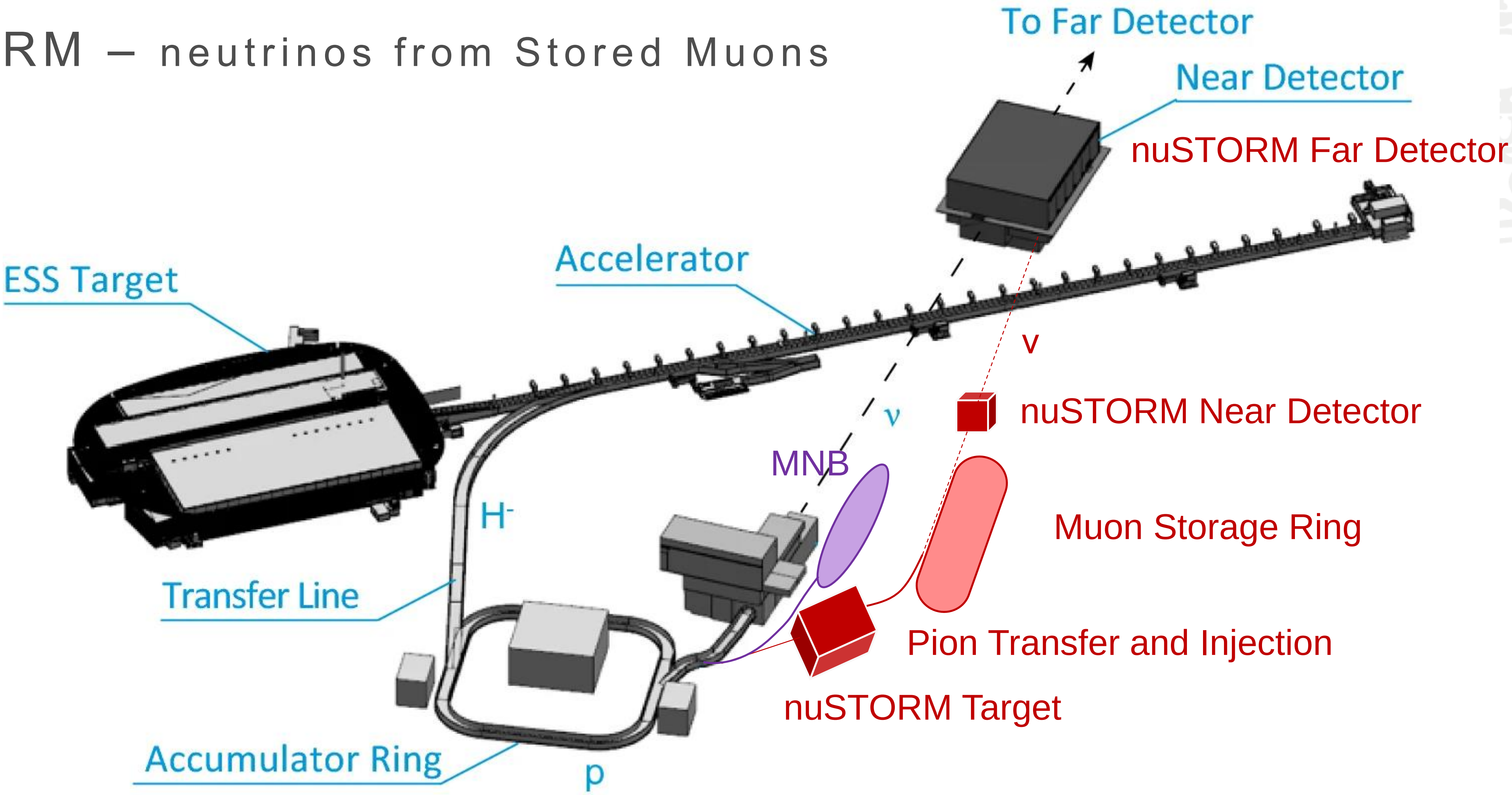
Université de Strasbourg
cnrs
Lunds Universitet
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG
European Commission
Uppsala Universitet
RB
名古屋大学 Nagoya University
Roma Tre Università degli Studi
Aristotle University of Thessaloniki
ess
INFN Istituto Nazionale di Fisica Nucleare
CERN
ESS Bilbao
Università degli Studi di Milano Bicocca
Universidad Autonoma de Madrid
Cukurova University 1973
Università degli Studi di Padova
Luleå University of Technology

ESSnuSB+

- Added features: neutrino cross-section measurments
  - neutrinos from Stored Muons (nuSTORM)
  - Monitored Neutrino Beam (MNB)
- Beyond conceptual but pre-technical design phase
  - Consolidated design
  - Plan for infrastructure
- Six work packages

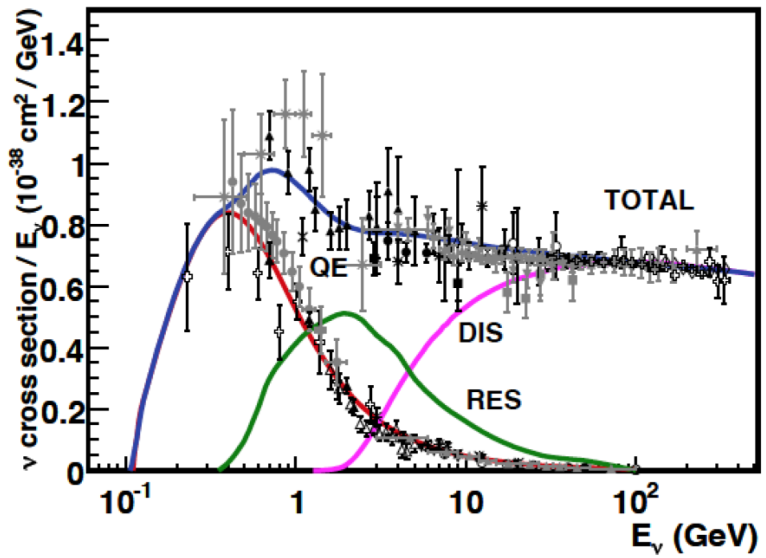


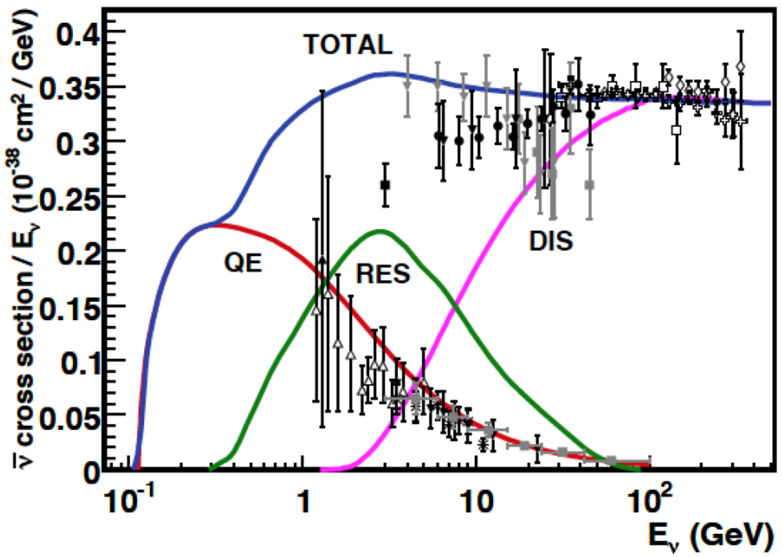
nuSTORM – neutrinos from Stored Muons



Neutrino cross-section measurements

- The stored muon flux and spectrum accurately known
- Produces equal amounts of electron and muon neutrinos
- Switch polarity of magnetic elements to go from neutrino to anti-neutrino mode.



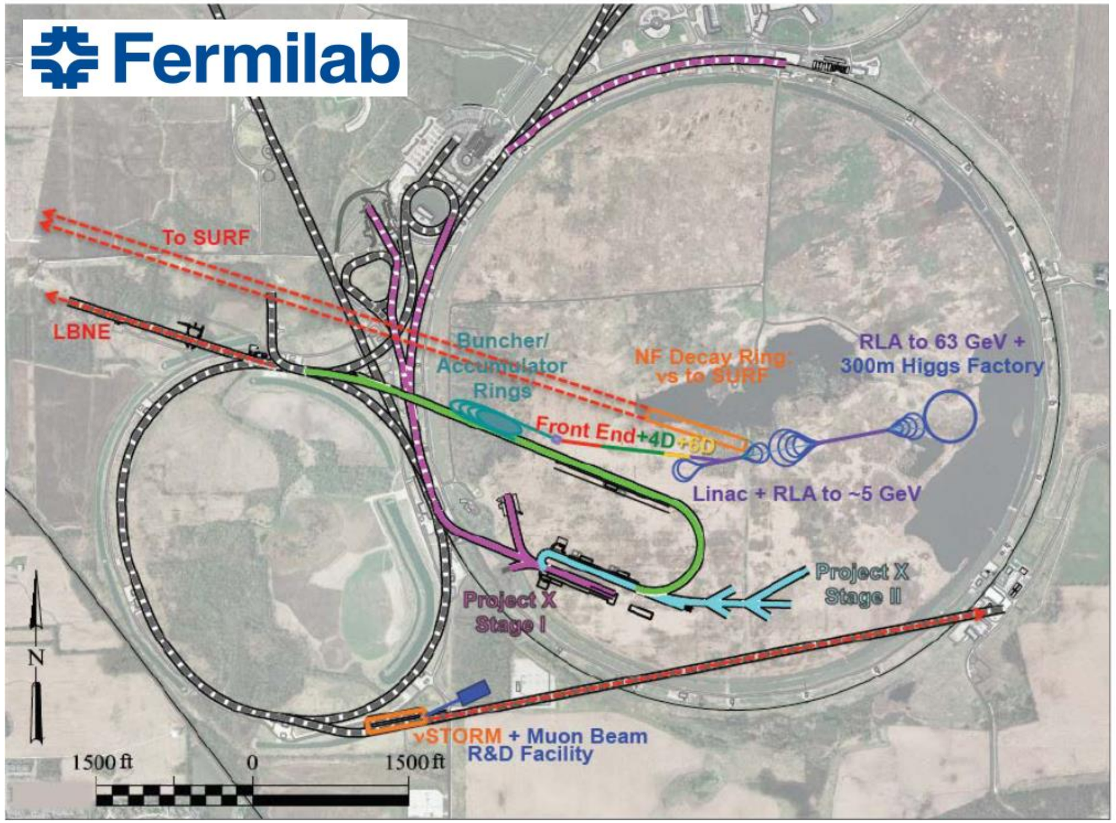


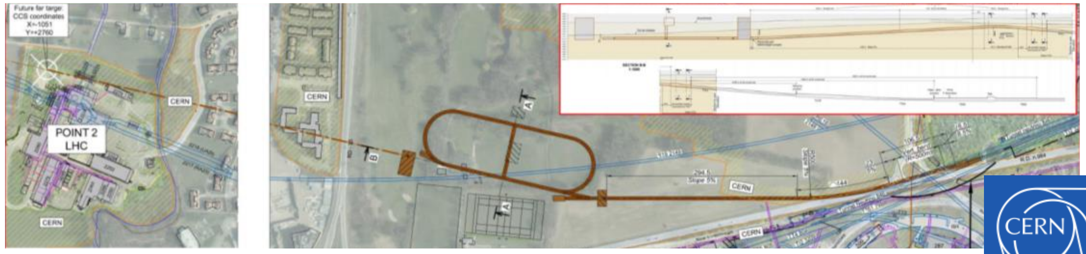
J. A. Formaggio and G. P. Zeller, https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.84.1307

essνsb+

UPPSALA UNIVERSITET

Other nuSTORM initiatives





K. Long, https://indico.cern.ch/event/768000/contributions/3275092/

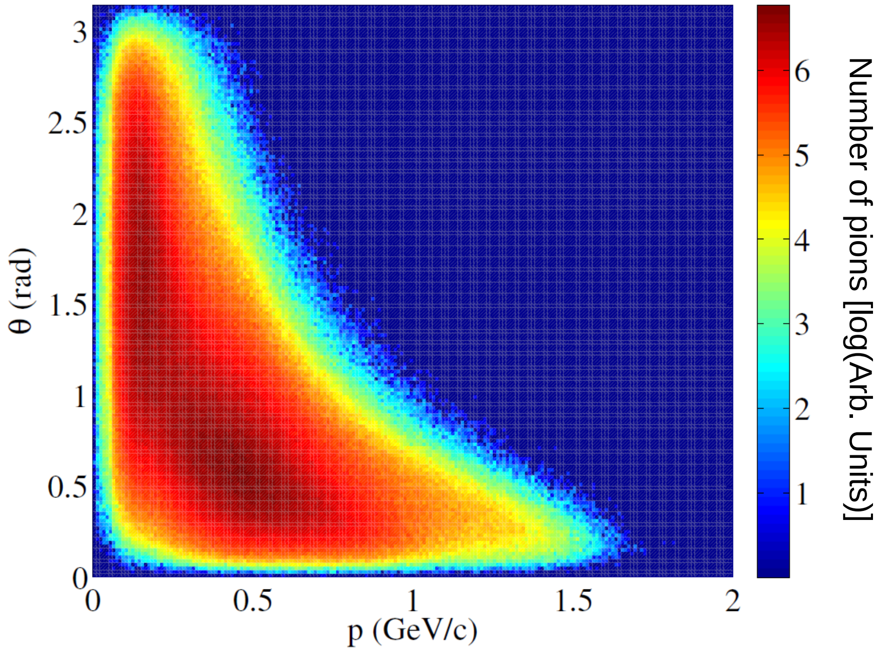
100 GeV protons from SPS

120 GeV protons from Main Injector

J.-P. Delahaye, https://arxiv.org/abs/1308.0494

Challenges associated with the low-energy nuSTORM

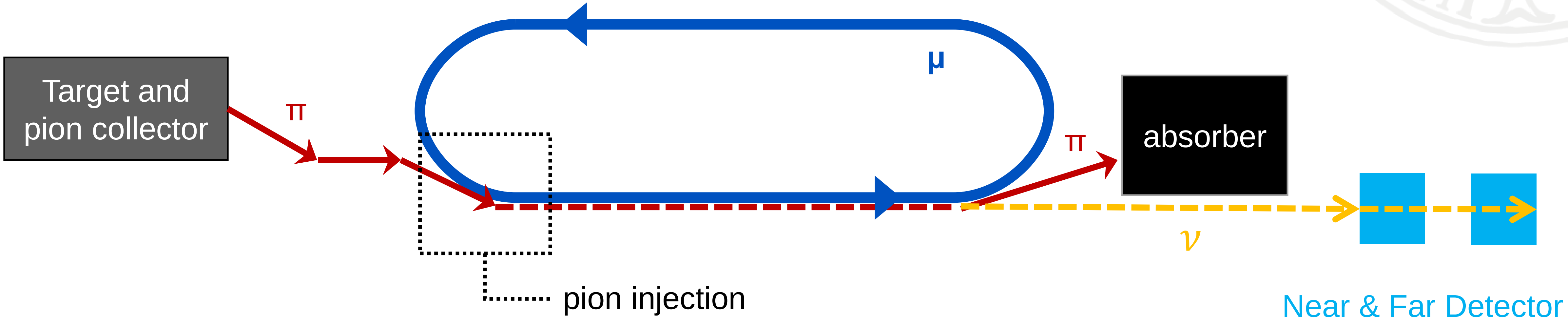
Example of pion distribution coming out of the target



- Low energy protons
  - ➢ low energy pions and muons
  - ➢ Large spread in momentum and direction
    - ➢ Huge "beams"
  - ➢ Decay fast ~ 0.1 μs
  - ➢ Short pion transfer < 20 m

UPPSALA UNIVERSITET

nuSTORM layout



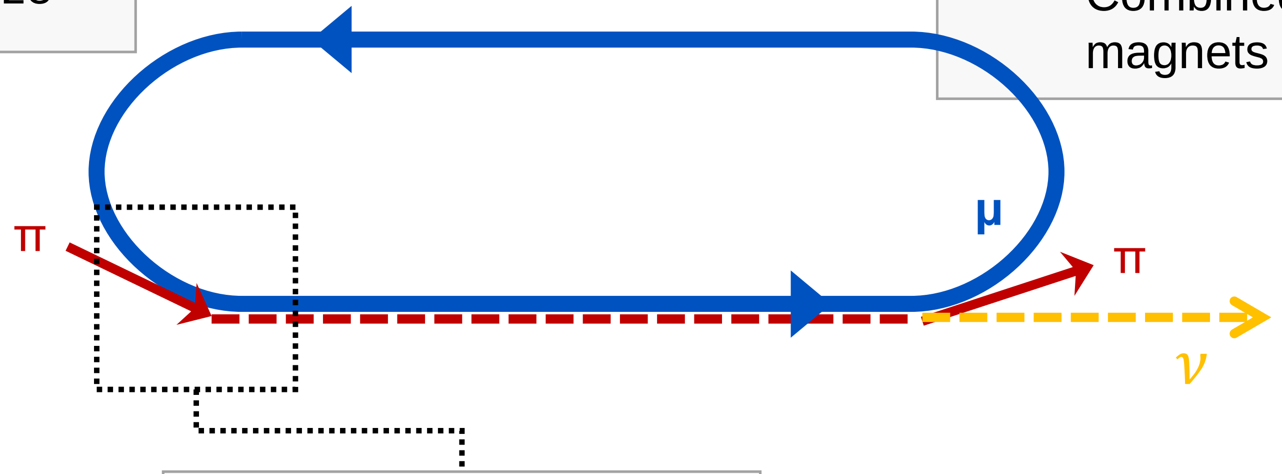
Muon storage ring

Large transverse acceptance

- Large magnet bores
- Smoothly varying beam size

Short arcs

- Strong magnets
- Compact arc lattice
  — Combined-function magnets



Large energy acceptance

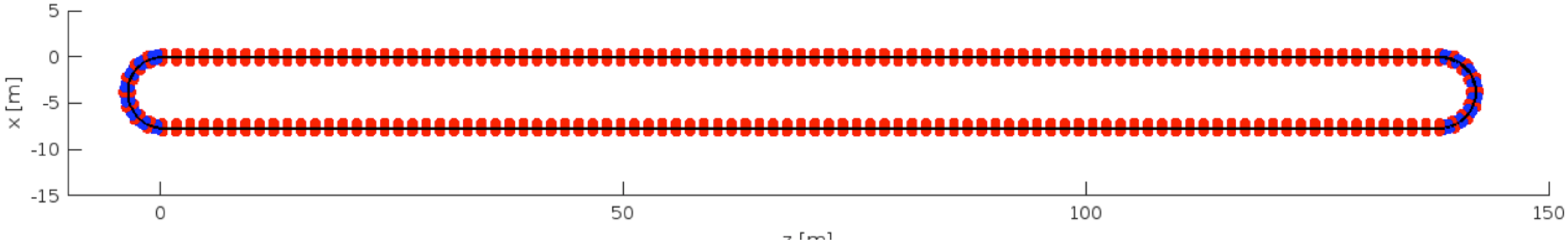
- Chromatic compensation
- Large magnet bores
- Exotic lattice type

Injection

- Dispersive ”stochastic”
- Kickers

UPPSALA UNIVERSITET

First attempt: 300 m storage ring



Ting Wing Choi, Uppsala University

Summary and Outlook

- Conceptual design work for a low-energy nuSTORM has been launched
  - Proton transfer line design: IPHC Strasbourg
  - Target and pion capture: IPHC Strasbourg and U. Hamburg
  - Pion transfer and injection: CERN
  - nuSTORM racetrack ring: Uppsala
- Reoptimize the ESSnuSB design: ESS, Uppsala, ESS Bilbao, CERN
- Physics and detectors: RBI Zagreb, Lund U, KTH, and others
- Infrastructure: ESS, Luleå TU, Uppsala U

- Strong synergies between the ESSnuSB R&D program and the Muon Collider study
  - High-power proton driver
  - Proton accumulation
  - Multi-MW target
  - Pion and muon capture and storage

UPPSALA UNIVERSITET

Thanks for your attention!

Maja Olvegård
Uppsala University
On behalf of the ESSnuSB collaboration

ESS neutrino Super Beam plus

Co-funded by the European Union

UPPSALA UNIVERSITET

nuSTORM ring comparison

	FNAL FODO*	CERN FFA#	ESS
Proton energy	120 GeV/c	100 GeV	2.5 GeV
Pion energy	5 GeV/c	5 GeV/c	~ 0.7 GeV/c
Muon momentum	3.8 GeV/c	3.8 GeV/c	~ 0.6 GeV/c
Momentum acceptance	±10%	±16%	?
Transverse acceptance	2π mm rad	1π mm rad	?
Length of decay straight	181 m	180 m	20-80 m
Circumference	490 m	510 m	80-200 m
Mean distance traveled (μ)	24 km	24 km	~4 km
	~ 50 turns	~ 50 turns	20-50 turns

* FODO = Focusing – Defocusing
# FFA = Fixed Field alternating gradient Accelerator

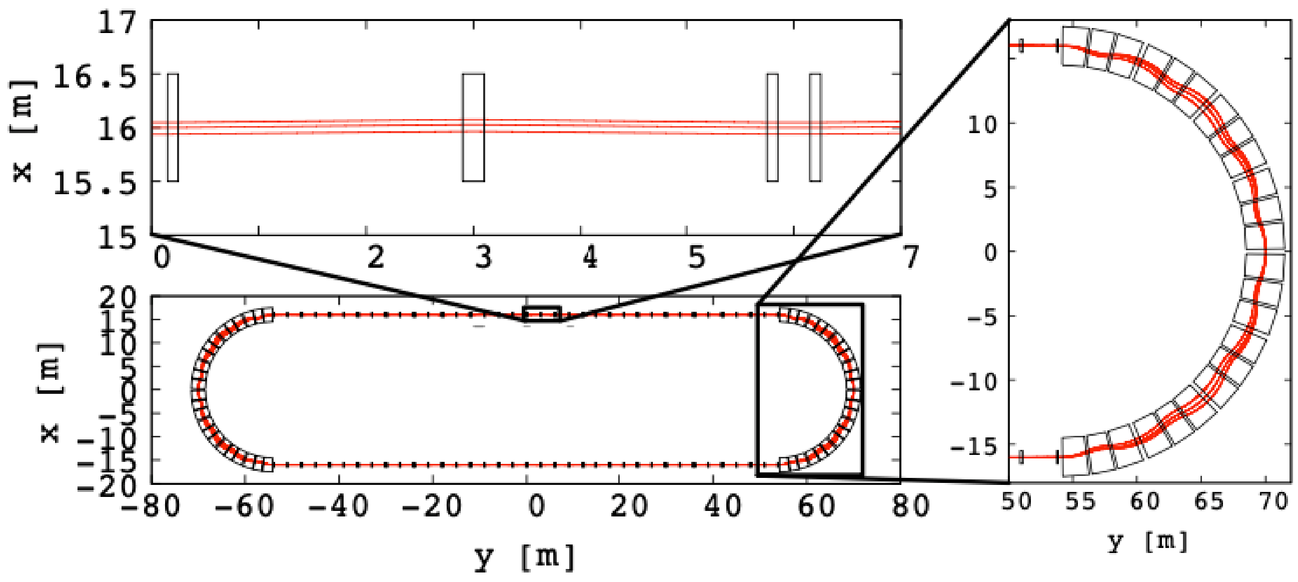
UPPSALA UNIVERSITET

Decay ring lattice: FODO

Regular Focusing–Defocusing magnet structure (FODO)

- Superconducting combined-function magnets in the arcs
  - Compact
  - Strong field
- Very large bores
  - 60 cm diameter
- Dispersion-free straight sections
- Large losses even within acceptance

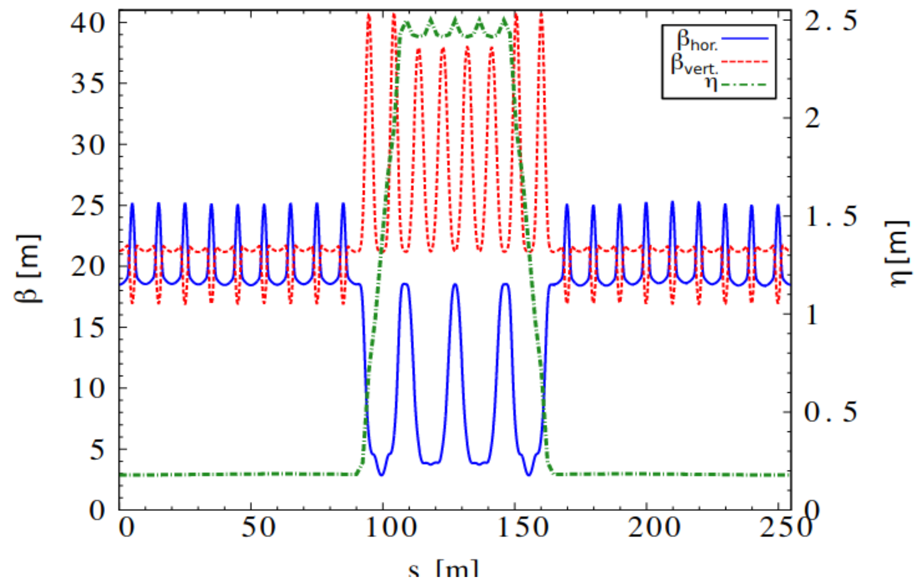
Fermilab (FNAL) design



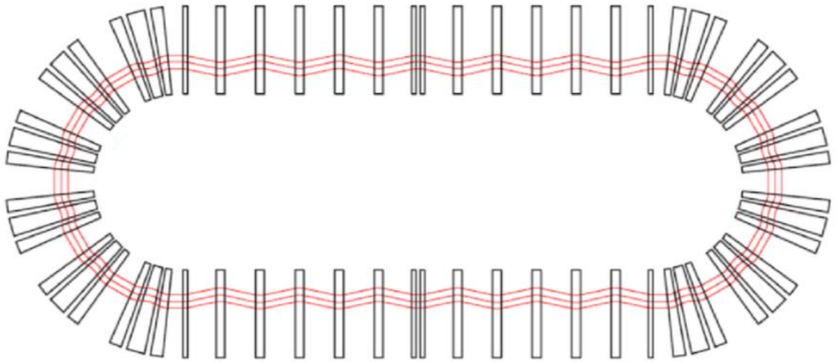
https://lss.fnal.gov/archive/thesis/2000/fermilab-thesis-2015-04.pdf

Decay ring lattice: FFA

- FFA = Fixed Field alternating gradient Accelerator
- Inherently large momentum acceptance
- "Wriggle" in straight sections lowers neutrino flux by 20%
- Slightly lower losses than FODO lattice
- Reduced pion capture efficiency due to dispersion in the straight section



J.-B. Lagrange et al., https://arxiv.org/pdf/1806.02172.pdf

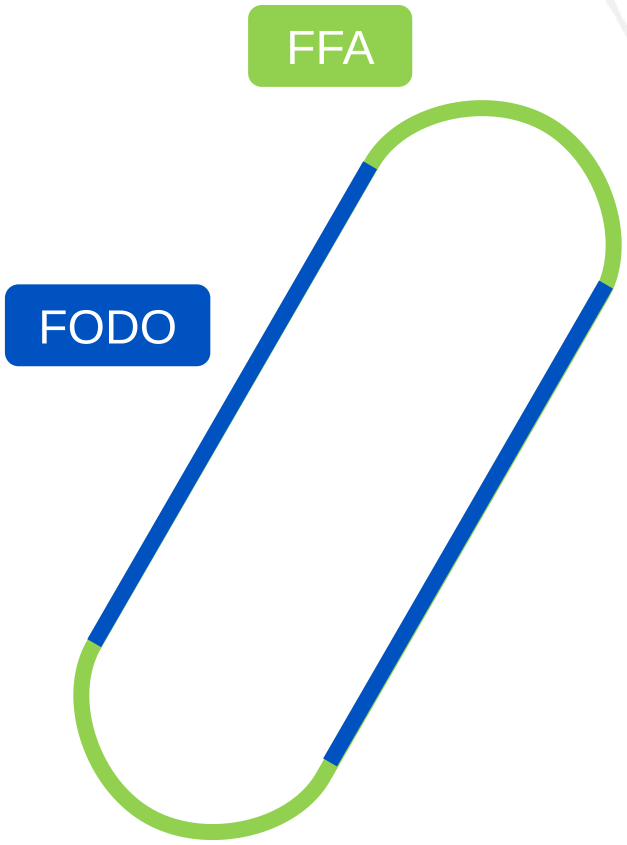


https://ffa20.triumf.ca/wp-content/uploads/2020/11/lagrange_nustorm.pdf

UPPSALA UNIVERSITET

Decay ring lattice: Hybrid

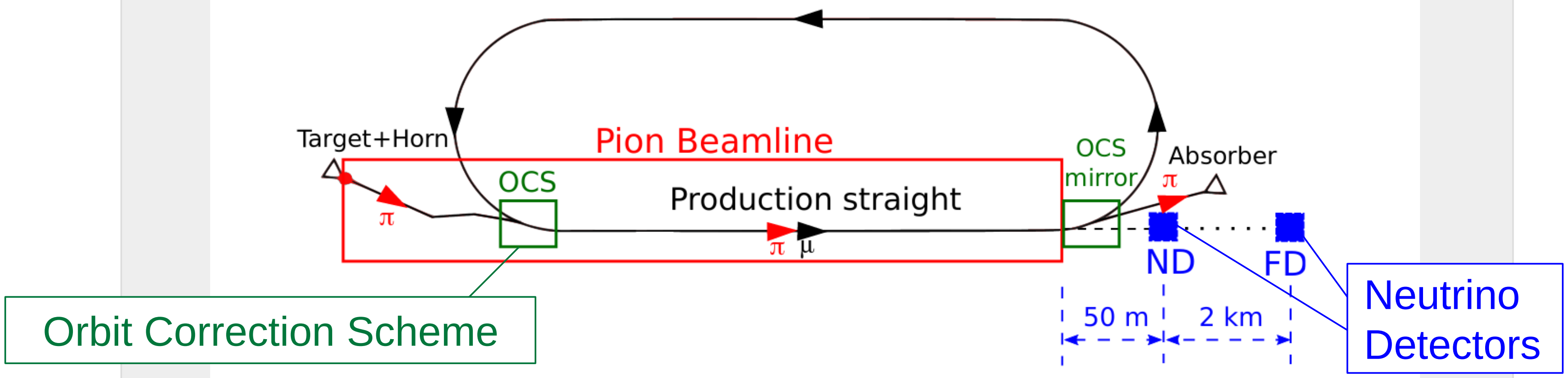
- FFA arcs
  - Large acceptance
- FODO or similar in straight sections
  - No dispersion or wriggle
  - Higher capture efficiency
- Higher neutrino flux
- Slightly reduced 6D acceptance compared to full FFAG solution
- Magnet R&D still needed



UPPSALA UNIVERSITET

nuSTORM characteristics

nuSTORM racetrack at FNAL:



A. Liu et al., https://iopscience.iop.org/article/10.1088/1748-0221/12/07/P07018

UPPSALA UNIVERSITET