Beam Delivery to the Target

Final focus system, instrumentation and dilution

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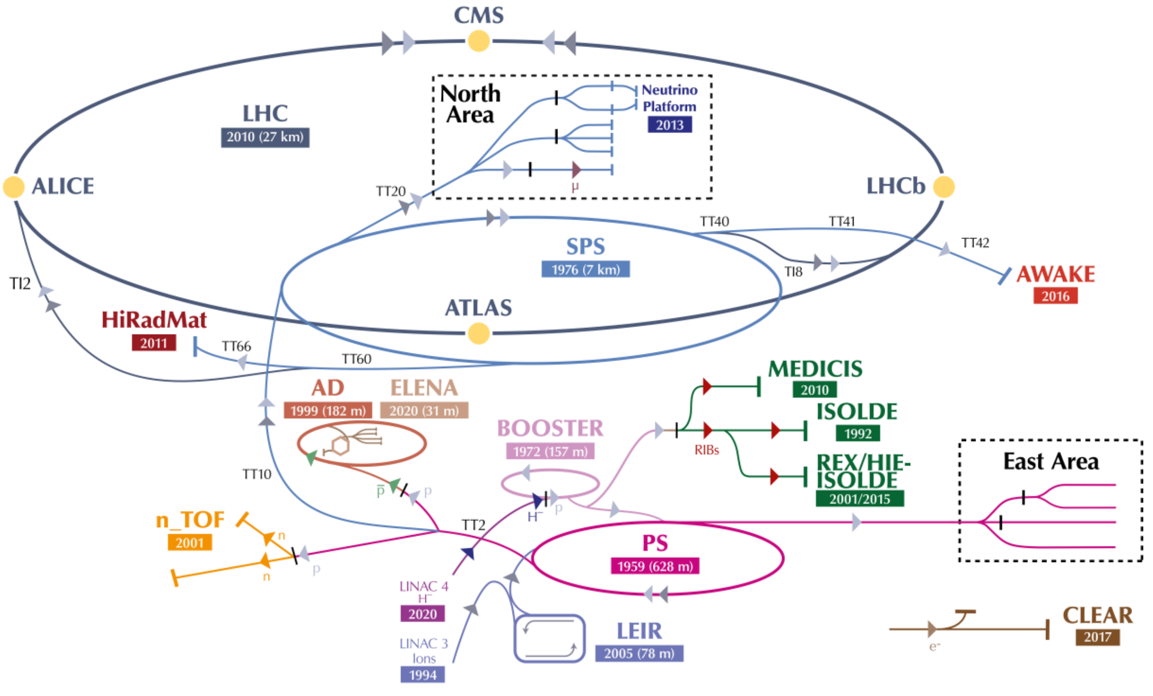
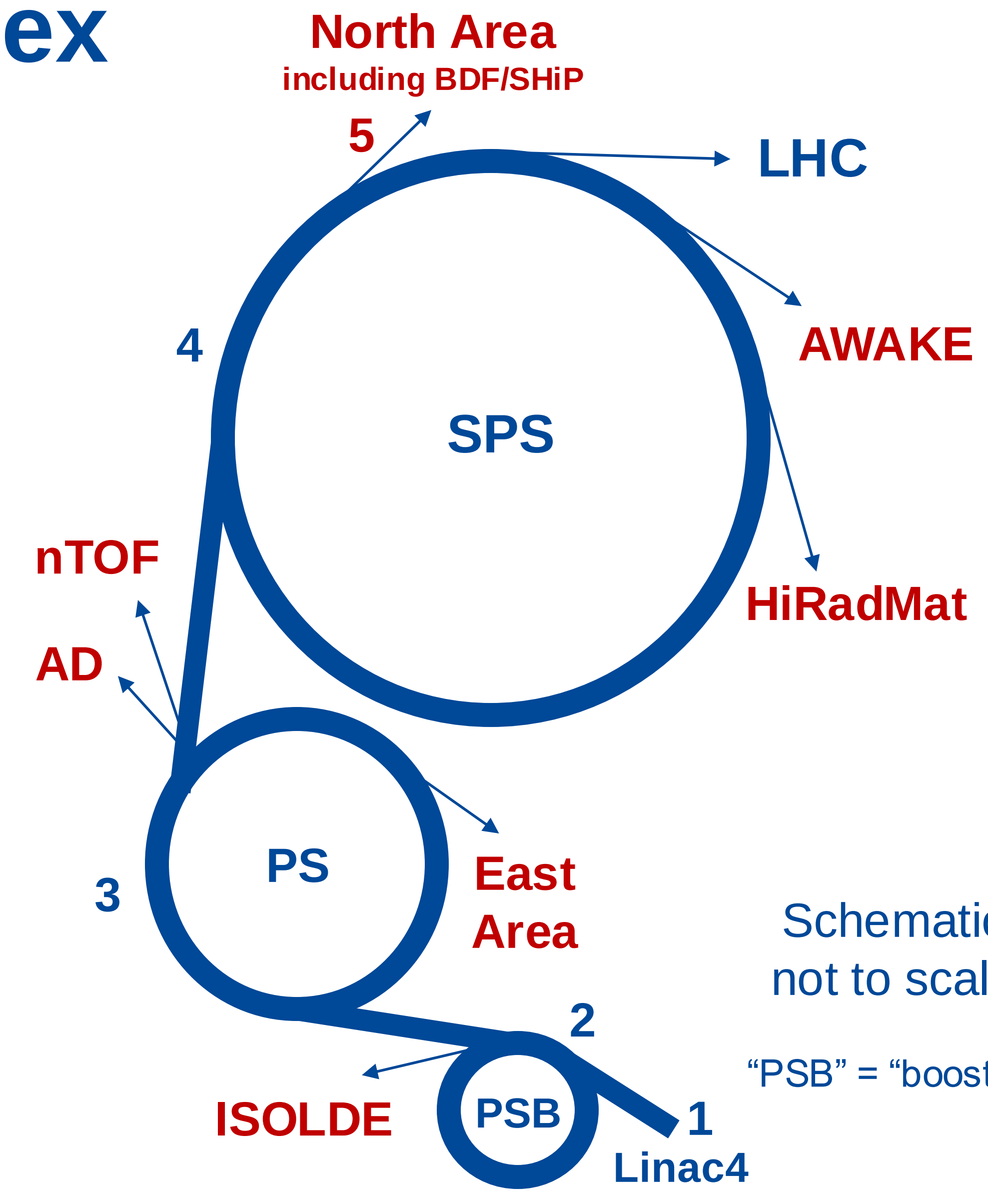
21st February 2025

BDF / SHiP in the CERN Complex



H⁻ (hydrogen anions) · p (protons) · ions · RIBs (Radioactive Ion Beams) · n (neutrons) · p̄ (antiprotons) · e⁻ (electrons) · μ (muons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive EXperiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform



Schematic not to scale

"PSB" = "booster"

Supercycles

- The injector complex delivers protons to multiple facilities in parallel, typically over ~31 weeks per year
  - PSB → PS, ISOLDE
  - PS → SPS, nTOF, EAST, AD
  - SPS → LHC, North Area, AWAKE, HiRadMat
- A supercycle is a sequence of cycles directed to the different facilities

- The supecycles are defined based on the accelerator capabilities & facility requests
- The proton sharing between facilities is achieved using supercycles
- Below is a typical supercycle

See T. Prebibaj's talk for details: https://indico.cern.ch/event/1469359/contributions/6233099/

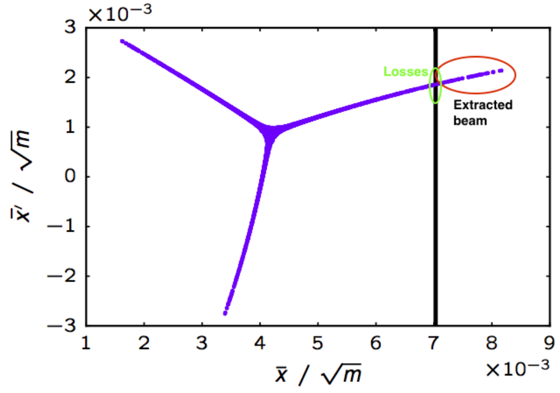
Time [s]			1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8	12.0	13.2	14.4	15.6	16.8	18.0	19.2	20.4	21.6	22.8	24.0	25.2	26.4	27.6	28.8	30.0	31.2	32.4	33.6	34.8	36.0	37.2	38.4
SPS			North Area (SFTPRO)									LHC filling																				Hysteresis / RMS current limits		
PS		SPS	SPS	East Area		nTOF	East Area		Zero	SPS			SPS			SPS			SPS			MD			Zero	AD		nTOF	nTOF	East Area		East Area		
PSB	PS	PS	PS	ISO	PS	PS	ISO	MD	PS	PS	ISO	PS	PS	ISO	PS	PS	ISO	PS	PS	ISO	PS	PS	Zero	ISO	PS	ISO	PS	PS	PS	Zero	PS	ISO		

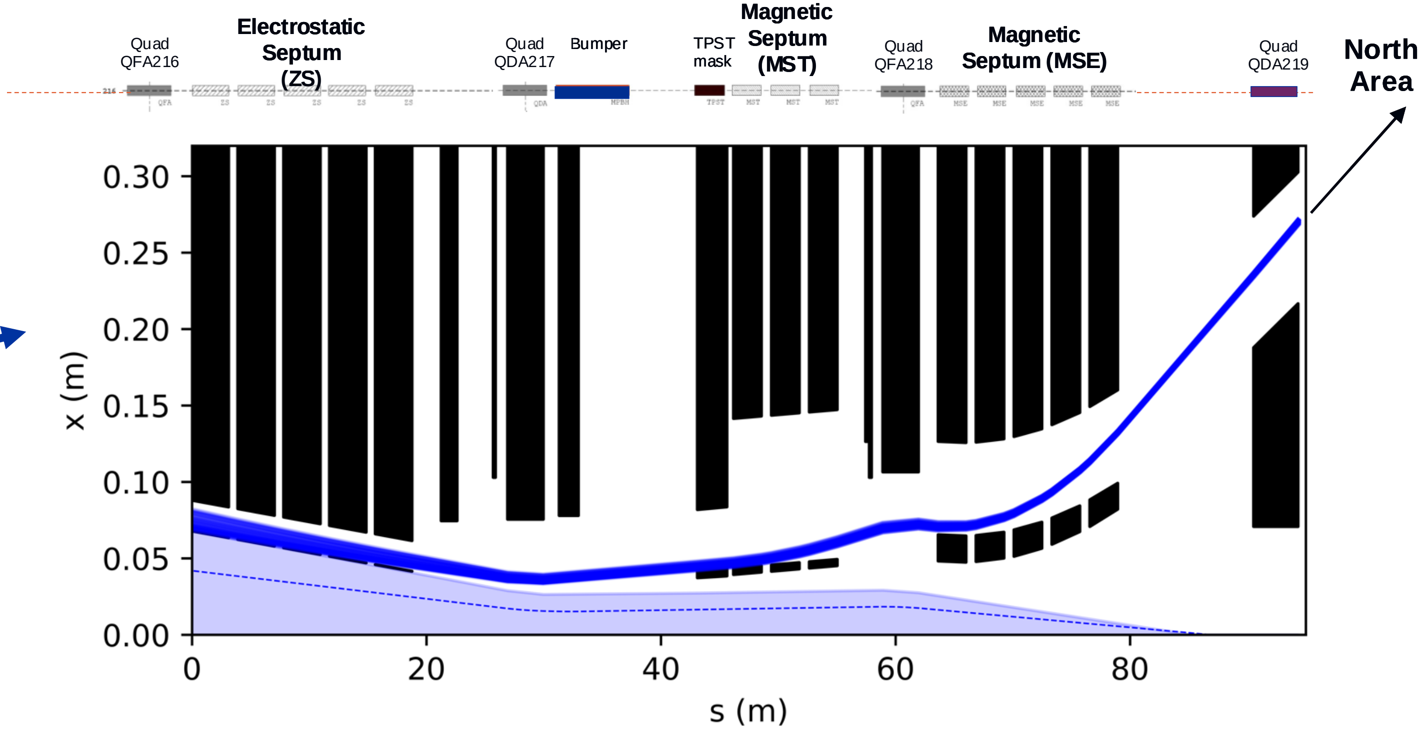
T. Prebibaj

SPS Slow Extraction

- The beam in the SPS is excited with a 3rd order resonance in the horizontal plane
- RF gymnastics are performed first to reduce momentum spread and give the most uniform distribution in time
- High amplitude particles are extracted with a thin electro-static septum
- The beam extracted is nominally **uniform in time** with no bunch structure

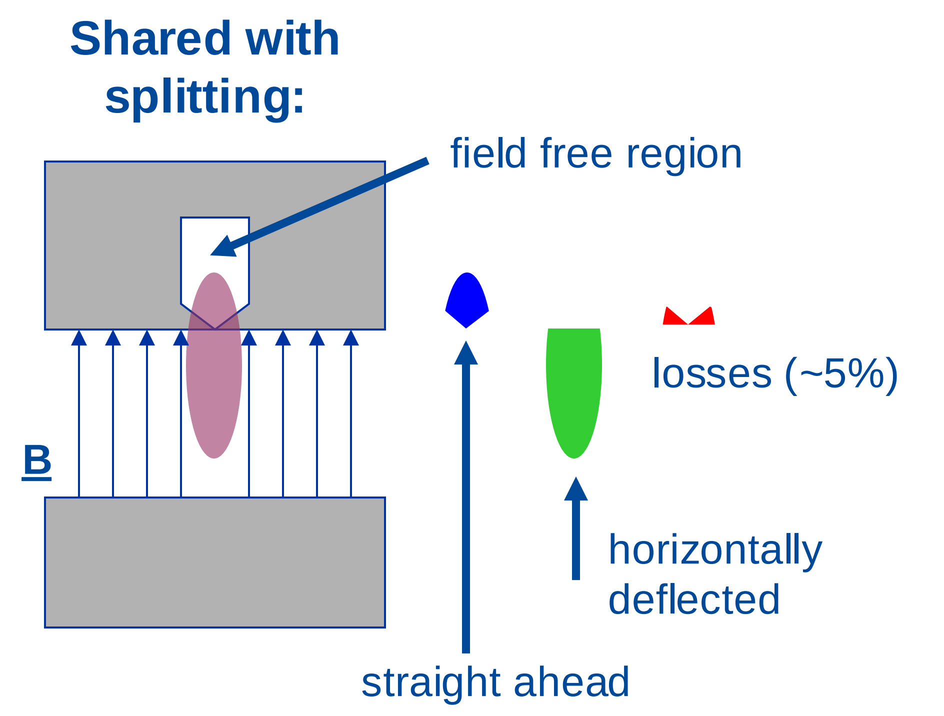
horizontal phase space

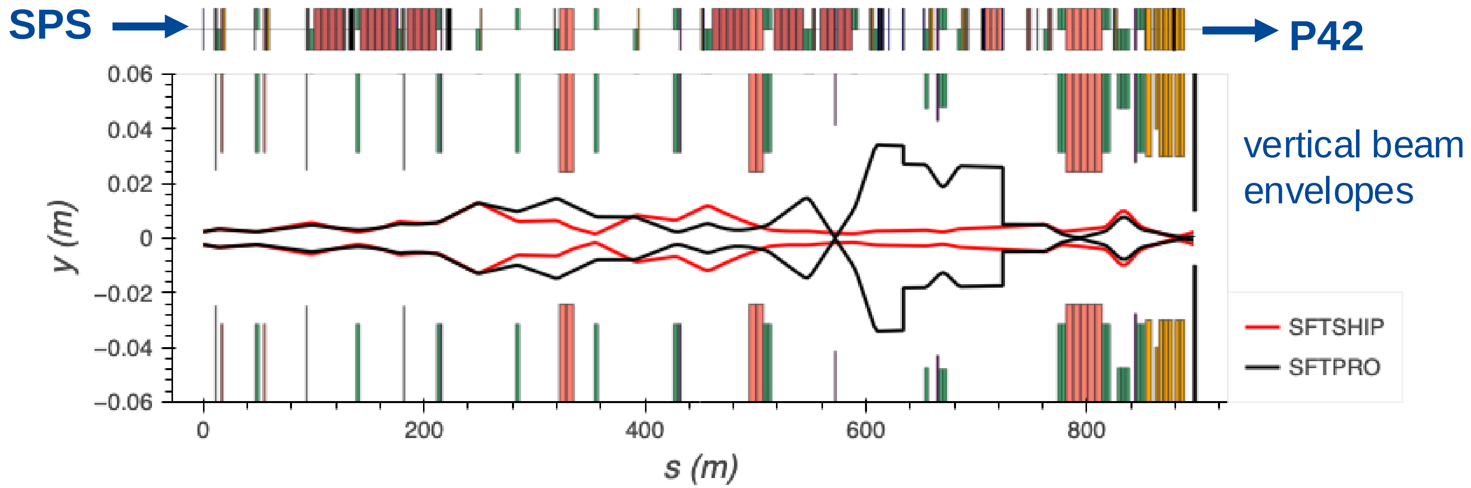


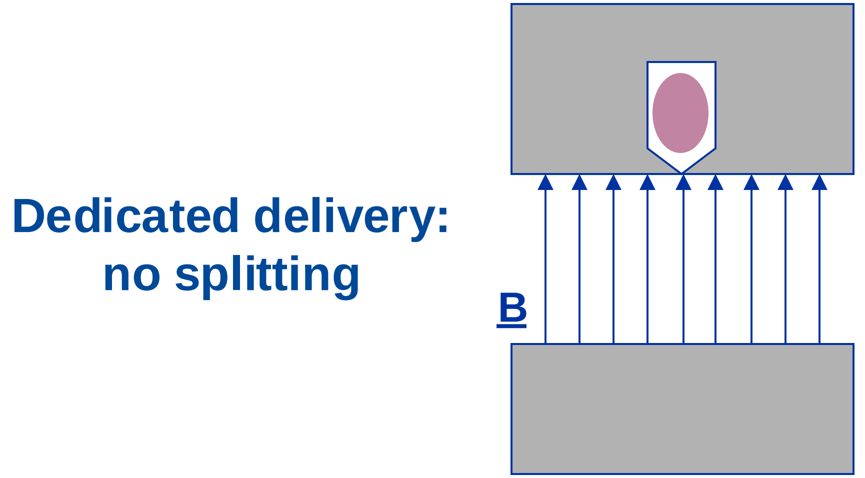


Shared and Dedicated Beam

- The beam from the SPS is normally split with magnetic splitters twice
  - the vertical position on the splitter determines the sharing ratio
  - the 3 beams are directed onto 3 targets producing 5 secondary beams and 1 left-over primary beam
- For BDF / SHiP, a new set of optics will be used that **bypass** the splitters **without splitting** (low losses)



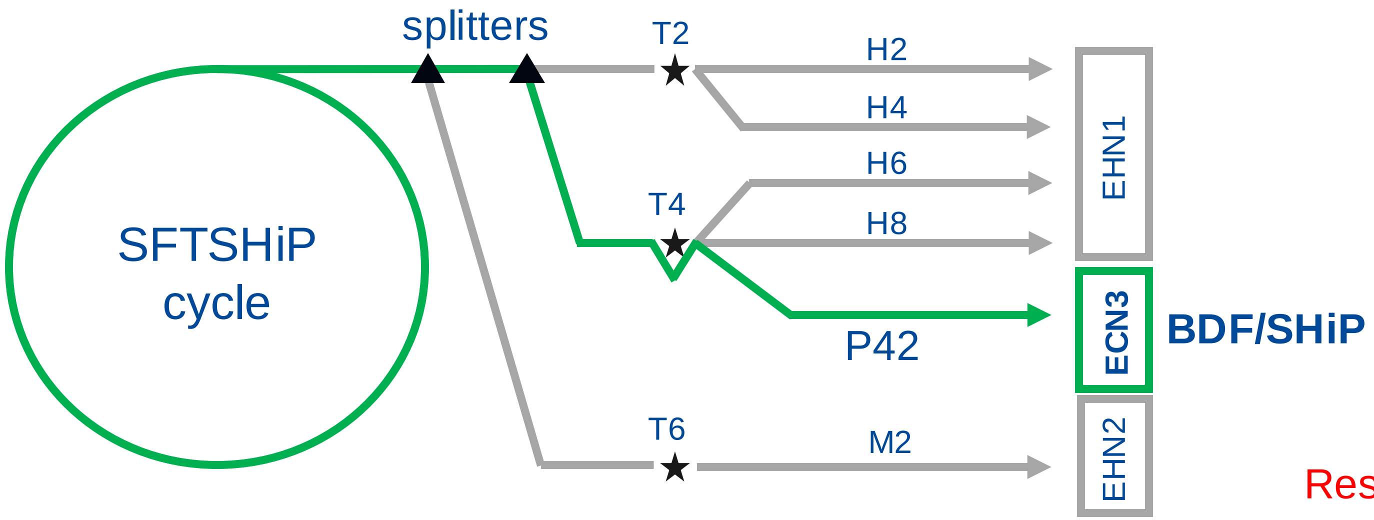


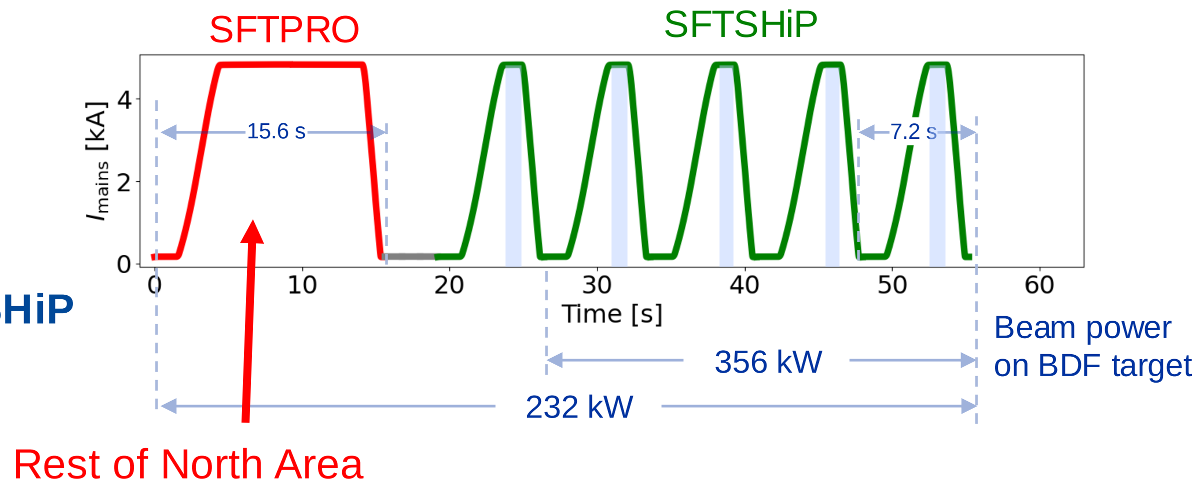


BDF Beam and SPS Supercycle Composition

- Nominal **4 x 10^{13} protons in a 1s spill** to BDF/SHiP
  - the 1 s of continuous beam is inside a 7.2 s overall cycle
- A study has shown 5 x 10^{13} protons / spill would mean ~40% more spills to other North Area users
  - MDs this year will investigated SPS intensity limits
  - previously operated at 4.8 x 10^{13} for CNGS (fast extraction)
  - greater North Area availability from a proton-sharing point of view

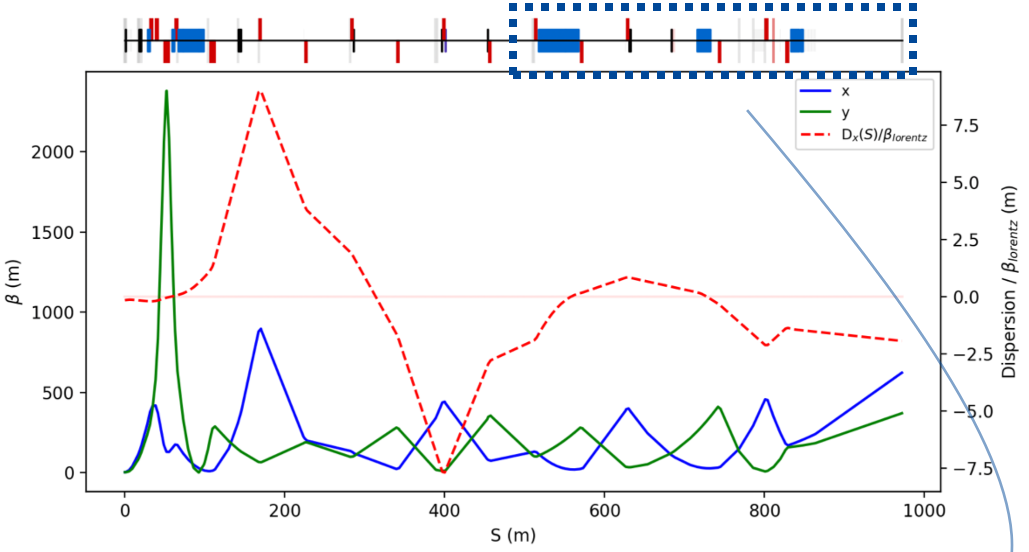
Nominal Design Parameter	Value
Beam type	proton
Beam momentum [GeV/c]	400
Beam pulse intensity [$\times10^{13}$ p]	4.0
Spill length [s]	1
Beam pulse power [kW]	2560
Average beam power [kW] (7.2 s)	356
POT [$\times10^{20}$ p over 15 years]	6.0



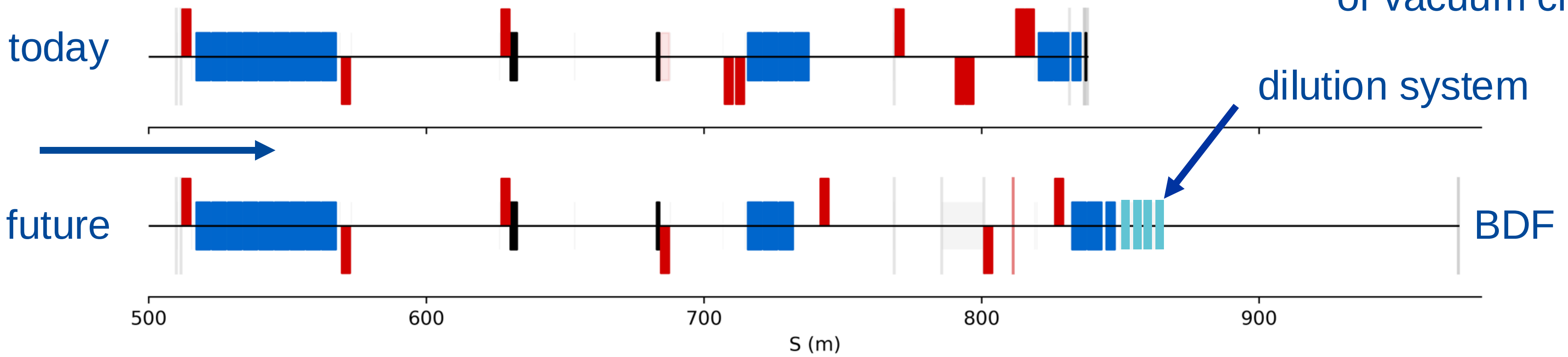


P42 Final Focus & Dilution System

- The beamline "P42" that delivers protons to ECN3 will be modified in the final 200 m
  - quadrupoles will be removed and shifted to create a much larger beam
  - beam size and ratio will be adjustable independently
  - 100 m from last magnet to front of BDF target
- A dilution system of N dipoles will sweep the beam in a circle
  - number of magnets / plane depends on possible failures and being studied
- No sweeping and a large beam size is possible, but we must stay clear of the aperture



Beam size can easily be produced from σ = 1 - 20 mm, but choice affects design of vacuum chamber



There will be beam halo and the aperture must be clear of this

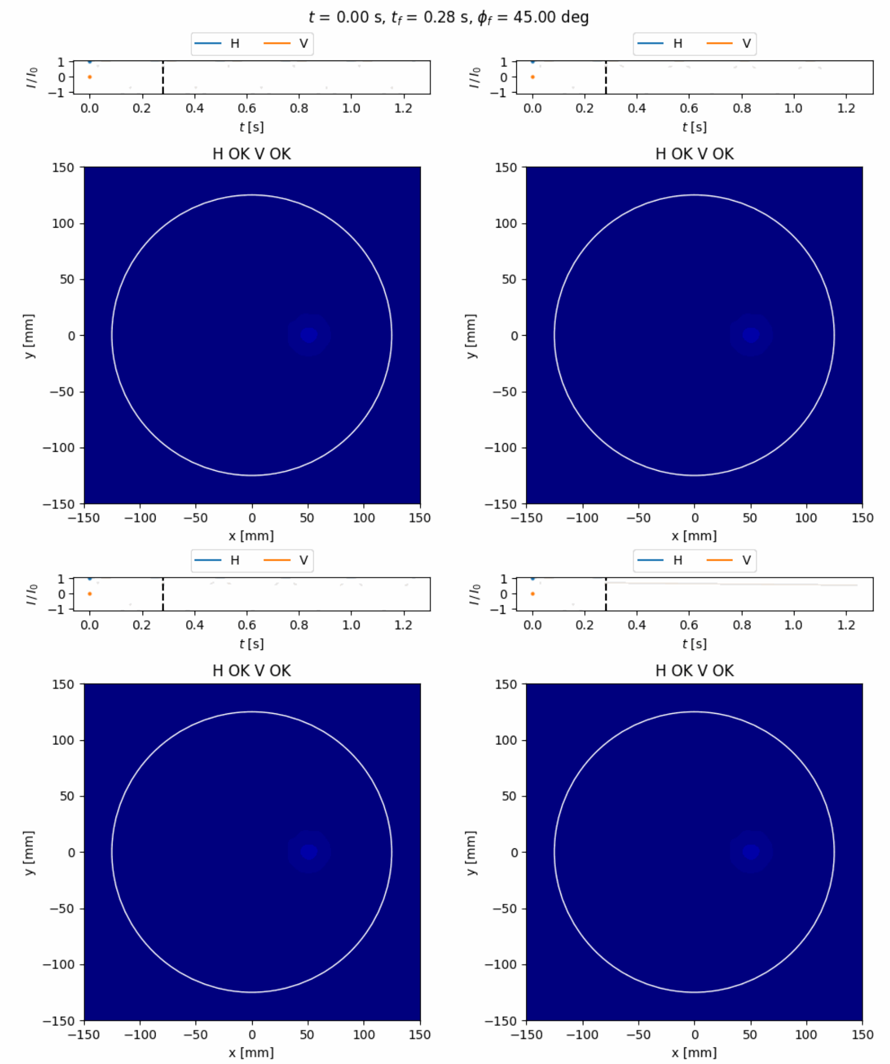
Nominal and Accident Scenarios

- Magnets along the beamline can fail
  - change in beam position and size as the field drops
- Beam loss monitors will be placed on each quadrupole to cut the beam quickly if losses high
- A crucial failure mode will be that of the dilution system magnets and power supplies

1 magnet per plane   2 magnets per plane

N failures	C1		C2			
	H	V	H1	H2	V1	V2
1						
2						
3	-					
4						

Patterns on target vary depending on the magnet and exact time of failure



Beam Instrumentation Requirements

Beam Delivery & Experiment

- Beam position during spill
  - can be given after each spill to the experiment
  - ensure sweeping radius
- Beam intensity (< 3% absolute error)

Target

- Beam position to ensure sweeping
- Beam spot size each spill
- Avoid front-mounted diagnostics as complicated to access / maintain

- The strategy for beam instrumentation immediately before BDF is **being studied**
- Background for the experiment created by matter interaction with the beam being studied
  - muons far from the axis could possibly be captured into the experiment (to be studied)
- We must align the beam axis well w.r.t. the target and know the beam size and sweep radius
- Foresee an instrumentation package 10 - 20 m upstream of the front of the target
- Diagnostics must give feedback during the spill on a short time-scale
  - avoid slow, high-level software interlocks

Interlocking

- The baseline maximum intensity allowed without sweeping is 2 x 10^{12} protons
  - this corresponds to a maximum of a 50 ms spill at the nominal extraction intensity
- Fast interlocks can act on the time-scale of O(100 μs) and cut the SPS extraction
- The current of most transfer line power converters will be monitored
  - this includes the ramp across the spill to compensate for the shift in momentum
- Beam loss monitors (BLMs) will be placed beside each quadrupole and in key locations
- We will consider an independent method of verifying the beam sweeping pattern on the target
  - e.g. an independent current measurement
  - or, 4 beam loss monitors for position via asymmetry of back-splash

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Tunnel Names