Collimation for beta-beams

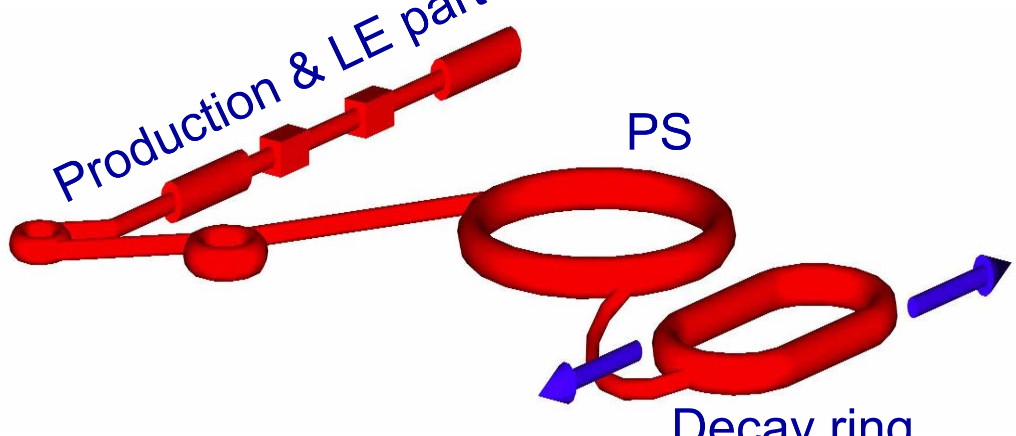
A. Fabich, CERN AB-ATB

for the Beta-beam task

EURISOL town meeting, CERN, Nov. 2006

Outline

- The Beta-beam complex
- The PS machine
  - Operation cycle
  - Beam losses
- The decay ring
  - Layout and injection
  - Particle turn-over
  - Absorption & Collimation
- Summary & outlook



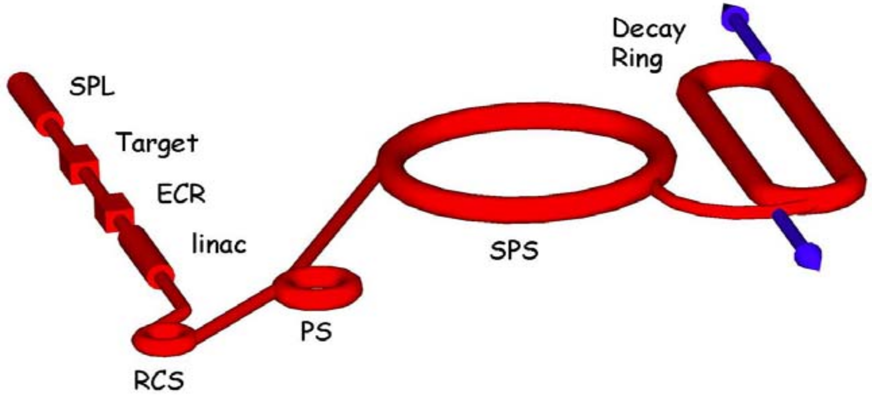
EURISOL Beta-beam

located at CERN

- integrate existing PS and SPS

- Ions: ^{6}He, ^{18}Ne
  - Representative ions for (anti-)neutrino production

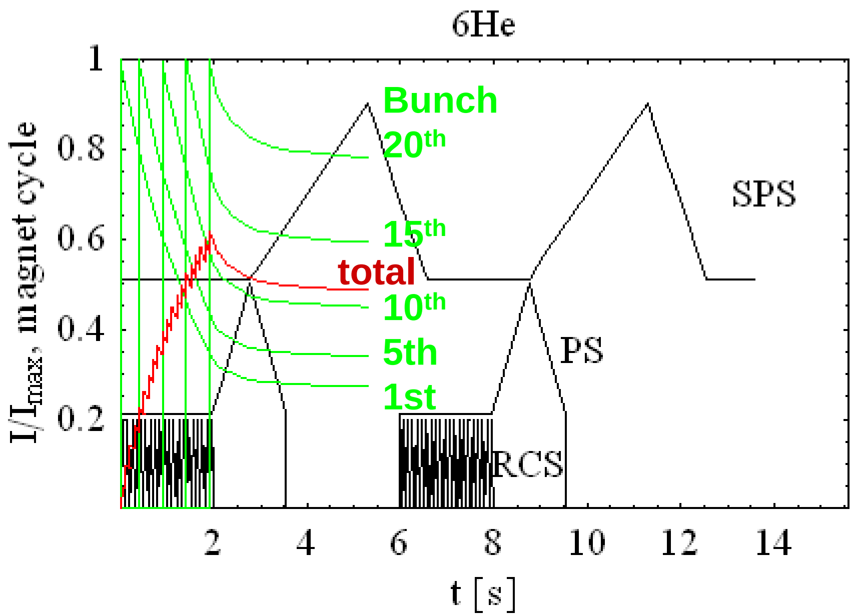
- Acceleration to γ=100/100
  - SPS limitation: $\gamma \in [150,250]$

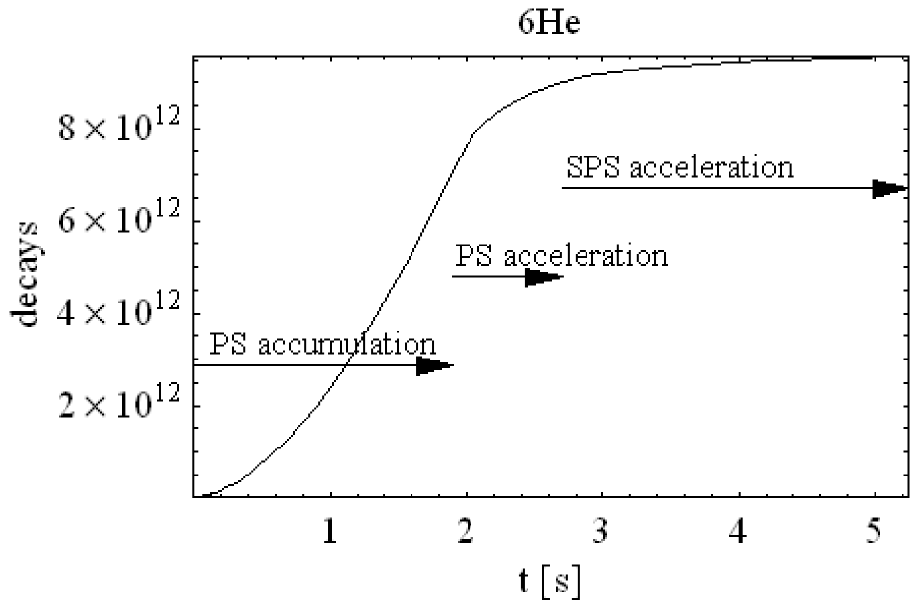


- Cycle rate of the accelerator chain
  - ^{6}He: 6 seconds
  - ^{18}Ne: 3.6 seconds

  leads to a repeated injection of ion bunches into the decay ring.

Intensity evolution during acceleration





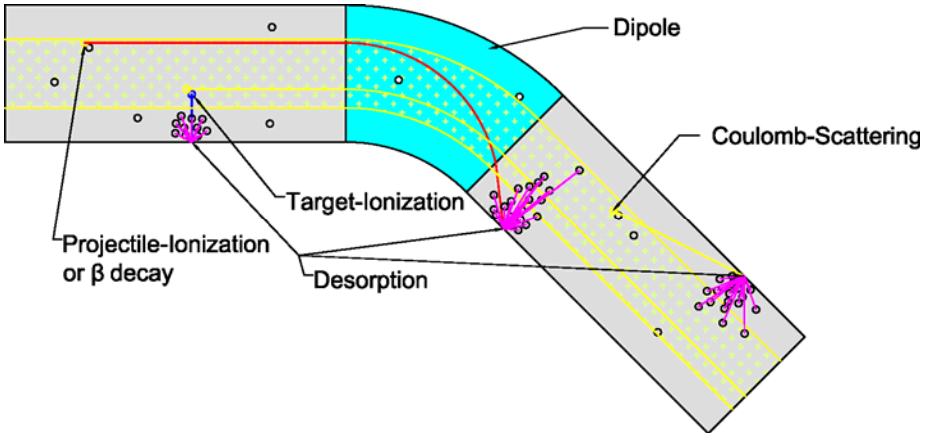
- Overall 50% of ^{6}He or 80% ^{18}Ne produced reach the decay ring.
- 90% of all decays during acceleration occur in the PS machine.
- Beam losses during acceleration are dominated by the decay process.

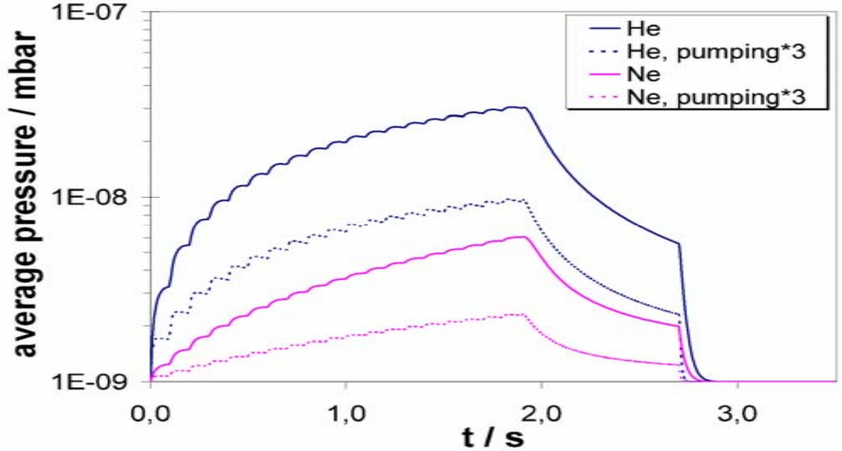
Dynamic vacuum

C. Omet, GSI

Vacuum degradation is caused by desorption through

- Decay products
- Rest-gas ionisation (target ionisation)
- Coulomb-scattering



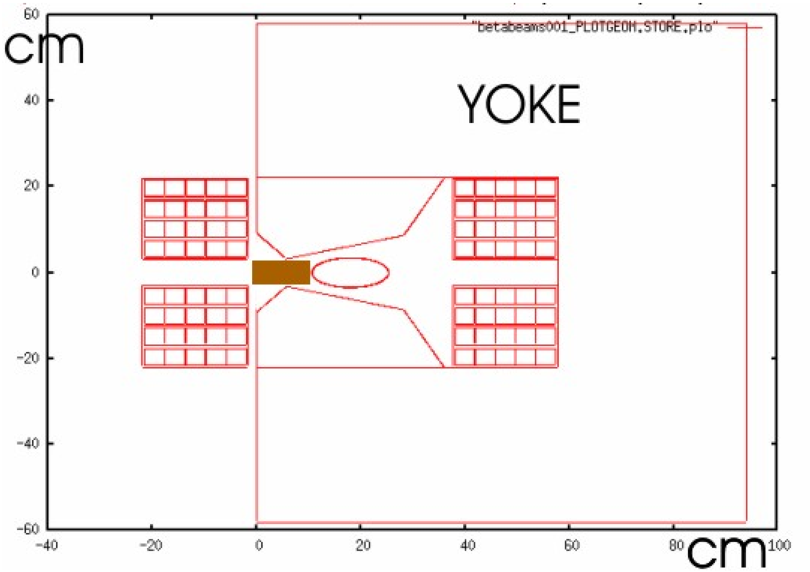


- Dynamic vacuum degrades to a few times 10-8 mbar.
  - Increasing pumping power
  - Installing a collimation system

Collimation upgrade in the PS

- PS is not designed for operation with high losses.
- The free space along the beam line for the installation of a collimation system is very limited.

- Installation of collimators considered in the open gap of the C-shaped magnet yoke.

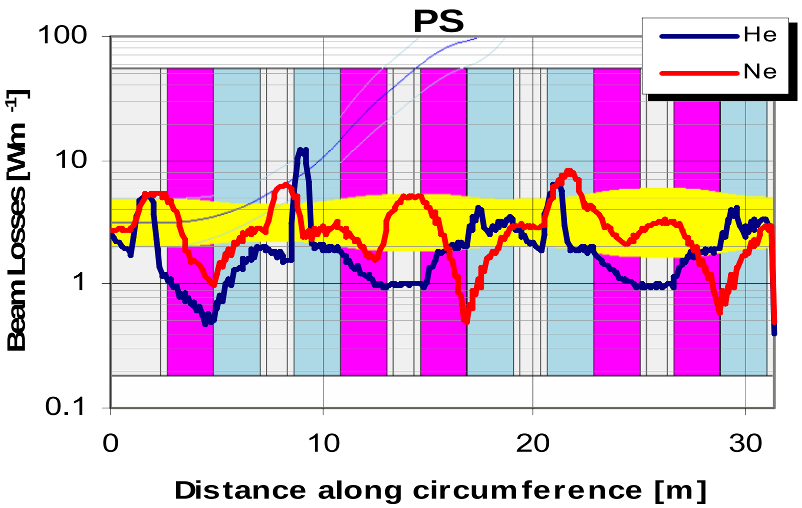


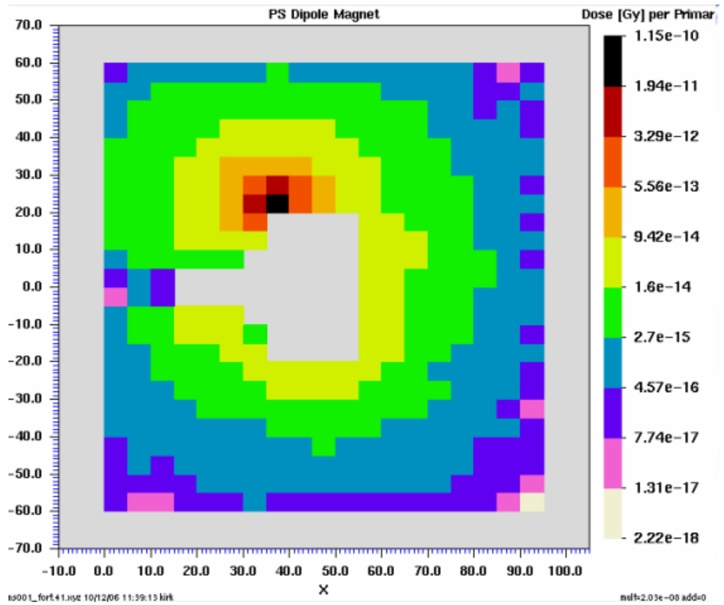
M. Kirk, GSI

PS Operation

M. Kirk, GSI

- Activation
  - 3 W/m average power deposition averaged over machine and cycle.





Fluka-simulation:

- Nominal Beta-beam operation
- Impact of pencil-like beam on single location of yoke
- An activation (peak) of 10 MGy is reached within 3.5 years.

Passing through the SPS ...

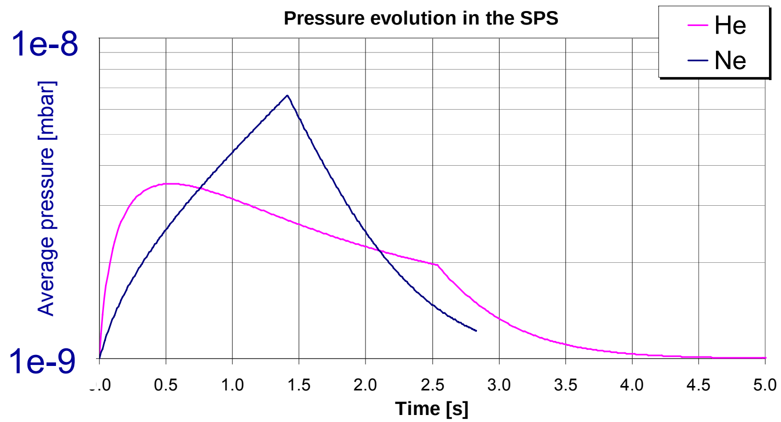
- Ion lifetime (γ_{inj}*$t_{1/2}$~10 s) is much larger than the acceleration delay (~1 s).

- Averaged power loss:

  $P_{loss} < 0.5$ W/m

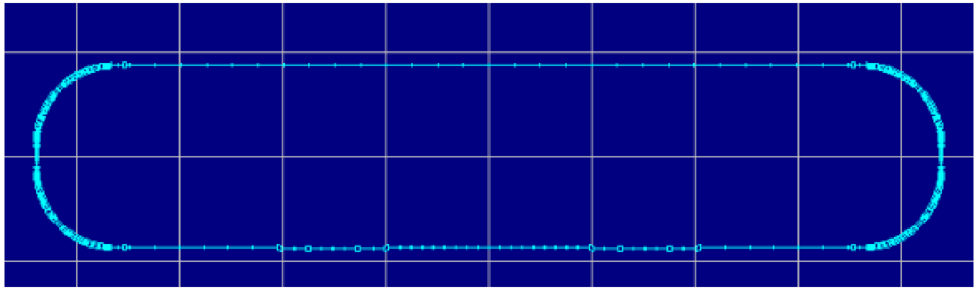
The ion losses in the SPS machine are not a critical item.

- Dynamic vacuum:

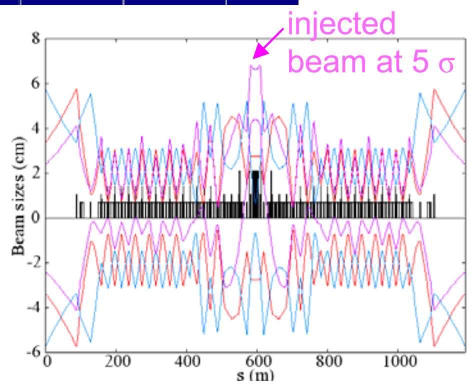


The decay ring

- Produce a directed neutrino beam (γ_{ion}=100)
  - Maximize the straight decay section heading towards the detector
  - Recirculate primary ions $\frac{\gamma t_{1/2}}{t_{revolution}} \approx 10^6$



- Layout
  - Circumference similar to SPS: ~7 km
  - Straight section: 2x 2500 m
  - Arcs with SC dipoles: 2x 1.5 km
  - Ion injection in the arcs

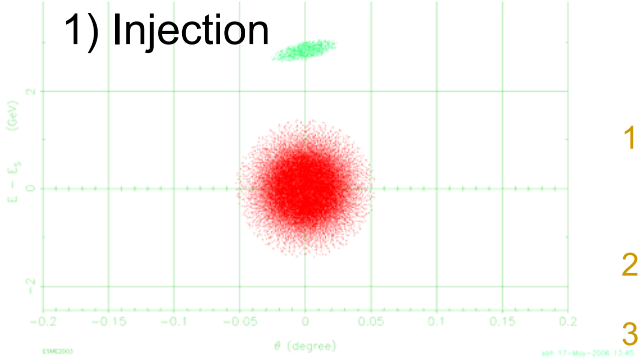


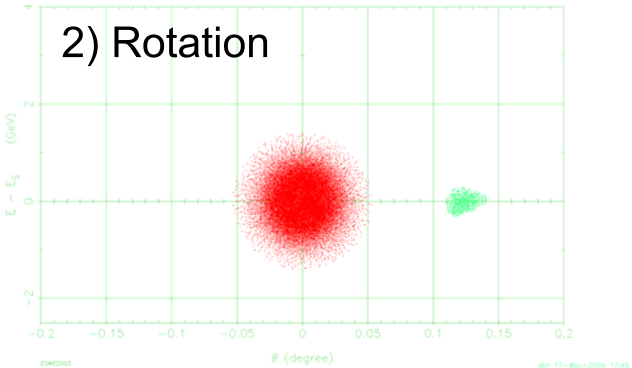
Injection: Stacking process

S. Hancock, CERN

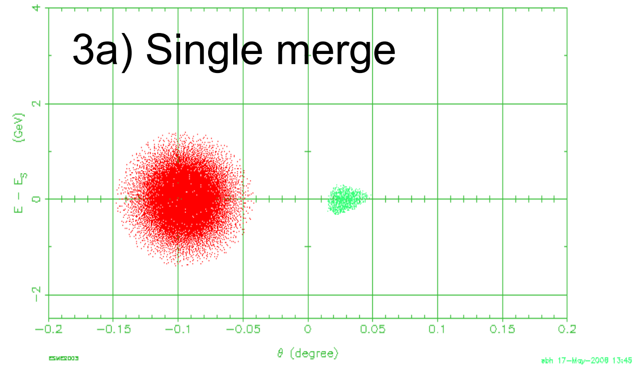
Longitudinal merging for accumulation

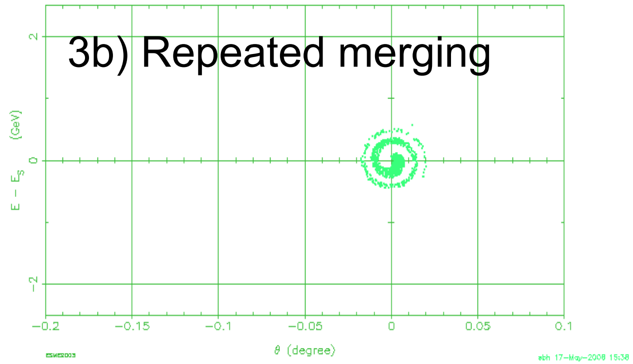
- Mandatory for success of the Beta-beam concept
- Lifetime of ions (minutes) is much longer than cycle time (seconds) of a beta-beam complex
- Stacking improves the neutrino rate by on order of magnitude.



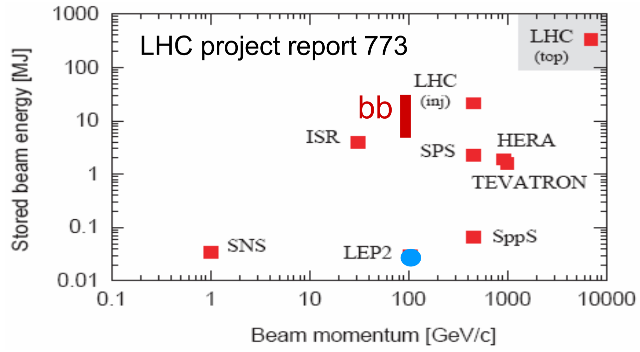


1. Injection: off-momentum
2. Rotation
3. Merging: “oldest” particles pushed outside longitudinal acceptance → momentum collimation



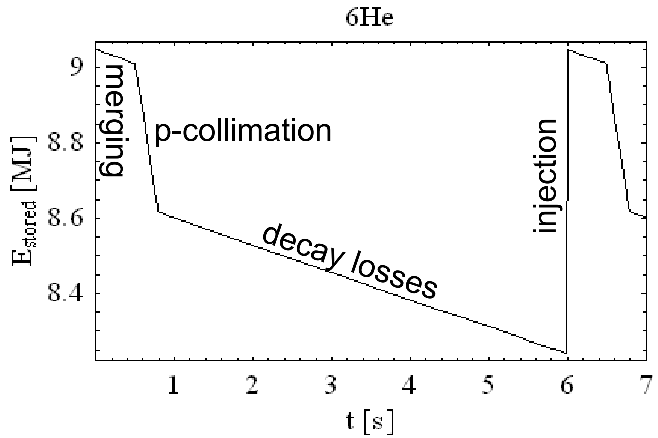


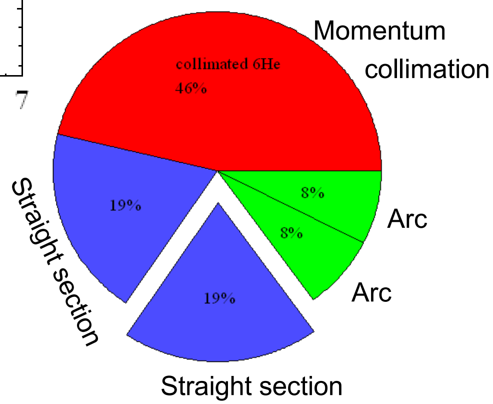
Particle turnover

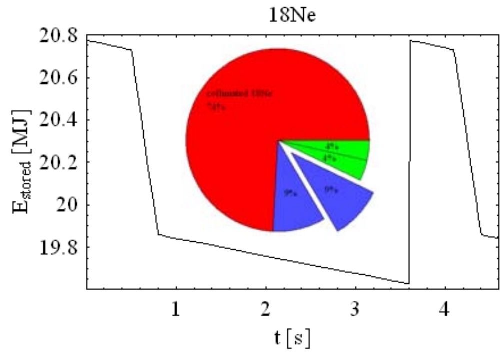


- 810 kJ respect. 1150 kJ beam energy/cycle injected
  - → "ejection"
  - All ions have to be removed again
  - either as parent or daughter ion
  - P~25 W/m average

	Beta-beam		LHC	
	He^6	Ne^{18}	proton	Lead ion
τ_{cycle} (s)	6	3.6	hours	hours
$N_{stored\ ions}$	**$9.71\ 10^{13}$**	**$7.4\ 10^{13}$**	**$3.2\ 10^{14}$**	**$4\ 10^{10}$**







- Momentum collimation: ~5*10^{12} ^{6}He ions to be collimated per cycle
- Decay: ~5*10^{12} ^{6}Li ions to be removed per cycle per meter

Power loss in the decay ring

- Decay deposition in **arcs**: protect SC dipoles from quench caused by deposition accumulated after drift (quench limit 10W/m)

- Decays accumulated along straight section: 300 (400) kJ dumped per cycle (60 or 120 kW average) via extraction system at end of straight section

- Momentum collimation at/after merging process:
  - Cycle average: 62 or 230 kW (6 resp. 3.6 s)
  - Process average: 1.2 or 2.8 MW (0.3 s, continuous collimation during bunch compression)

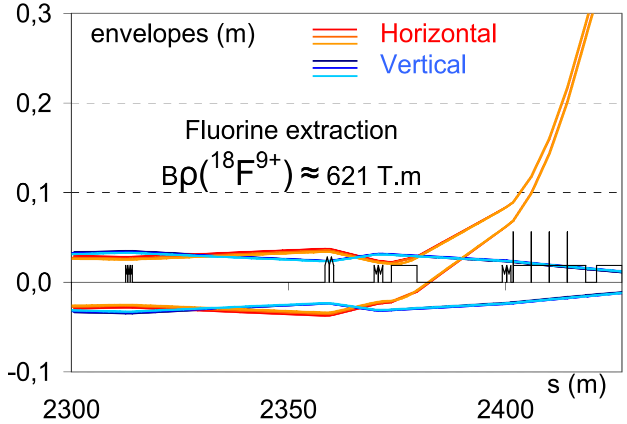
- Power deposition on LHC collimators
  - Typical (τ_{beam} = 10 hours): 10 kW average
  - Peak specifications: 100 kW over seconds or 500 kW peak

Decay losses

Decay products originating

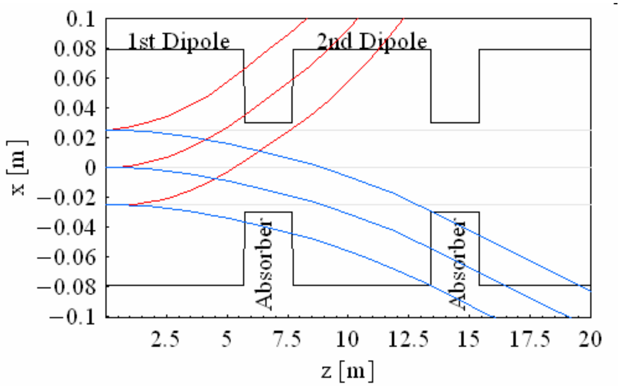
1) from straight section
2) in arcs

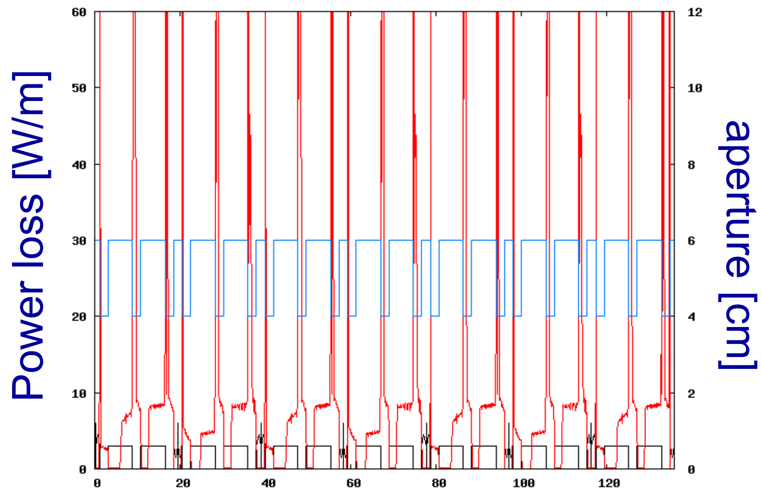
1) are extracted after the first dipole in the arc, sent to dump



2) Arc lattice optimized for absorption of decay products

- To accommodate either ion species, the half-aperture has to be very large (~ 8cm for the SC dipoles).





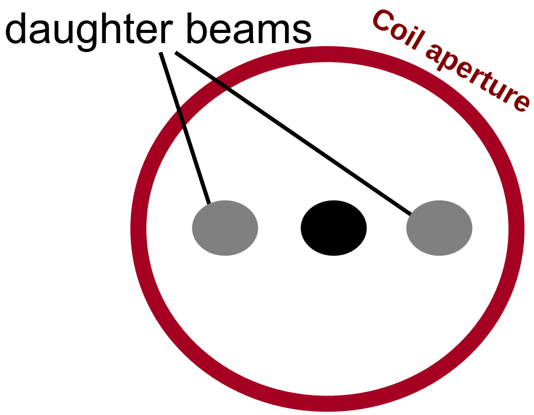
- Absorbers take major part of decay losses ion arcs.
  - About 60 W each
  - SC dipoles still have to stand <10 W/m.

A. Chance et al., Saclay

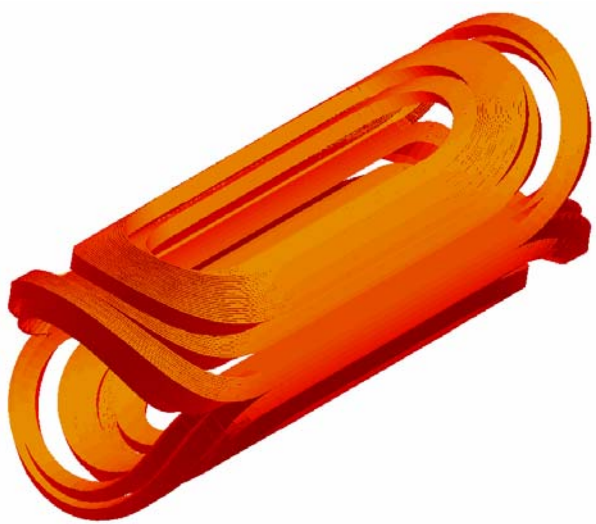
SC dipoles

E. Wildner et al., CERN

- Super-conducting dipoles
  - B_{max} = 6 Tesla
  - large aperture: ~ 8cm



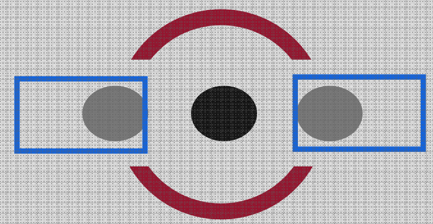
Circular coil cross section is a "safe" solution for first estimate



Alternative:

SC dipoles

with open mid-plane



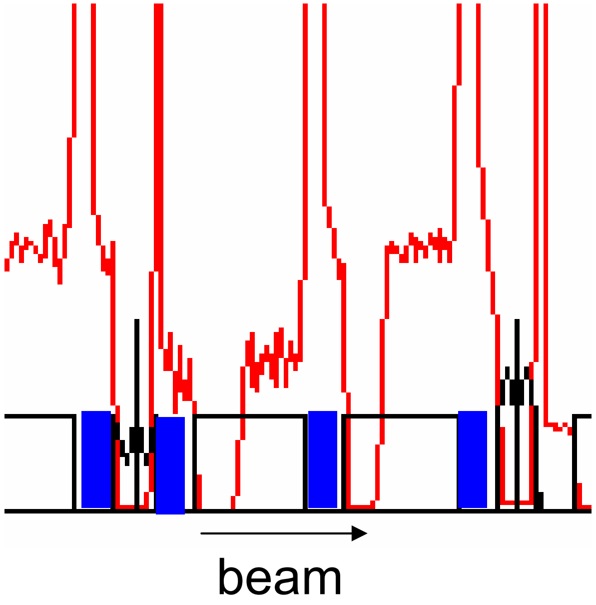
absorbers on the midplane

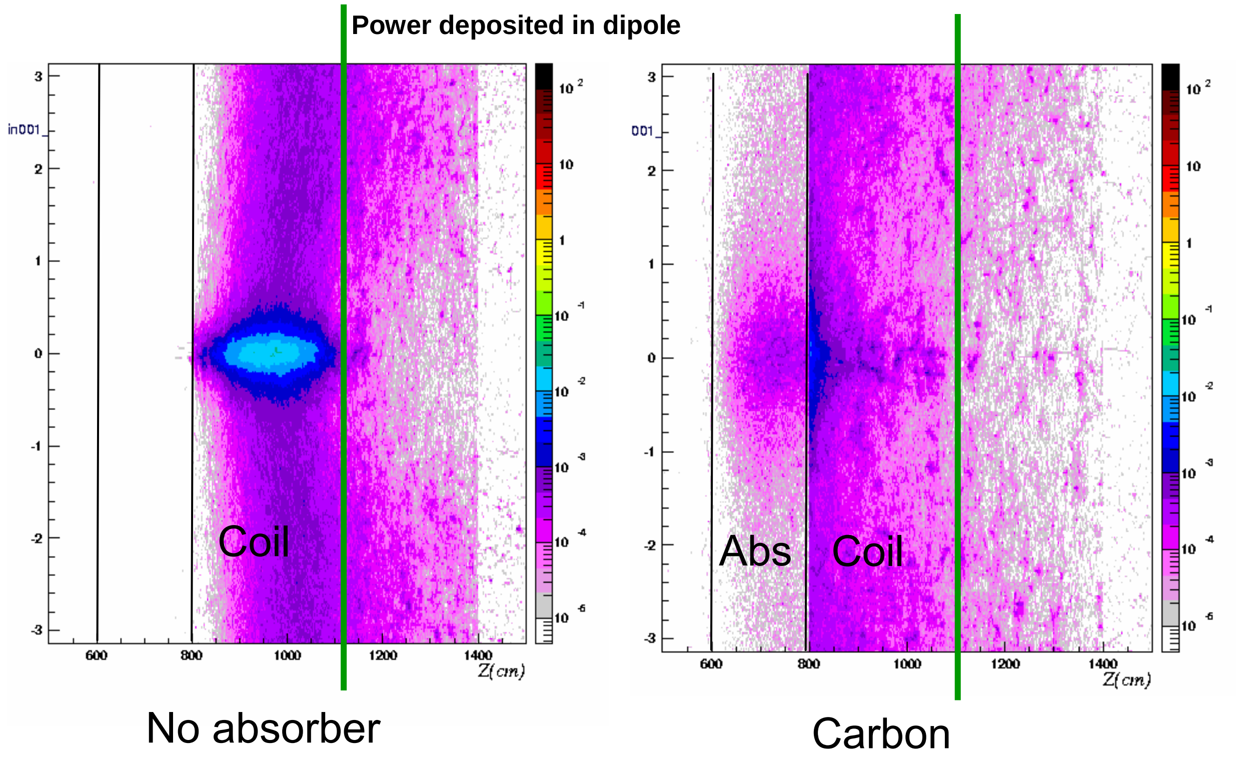
"Open Mid Plane" if the coil cannot stand the heat deposition from the decay products in the mid plane

Absorbers

E. Wildner et al., CERN

- Space for 1m long absorbers in between dipoles/quadrupoles
- Reduce energy deposition in SC coils





Decay ring - Momentum collimation

After 15 (20) merges 50% (70%) of the injected 6He (18Ne) ions of the “oldest” bunch are pushed outside the acceptance limits.

Momentum collimation

- ⇒ High normalized dispersion needed
- ⇒ Dispersion bump in the collimation section with dedicated dipoles

High intensities to collimate

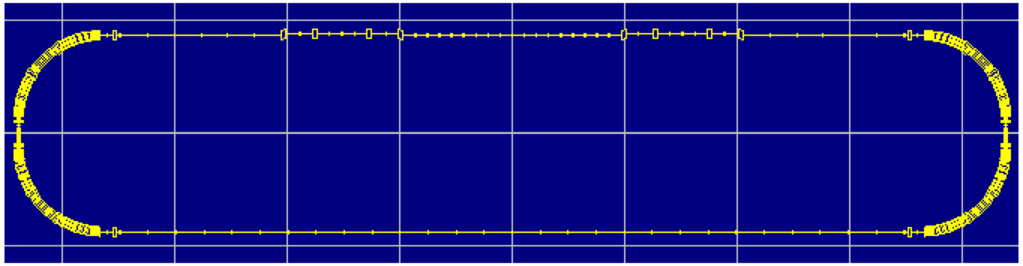
- ⇒ Not possible to use superconducting magnets
- ⇒ Multistage collimation: insertion of secondary collimators after the primary collimator
- ⇒ Long drift after the primary collimator to collect the secondary particles

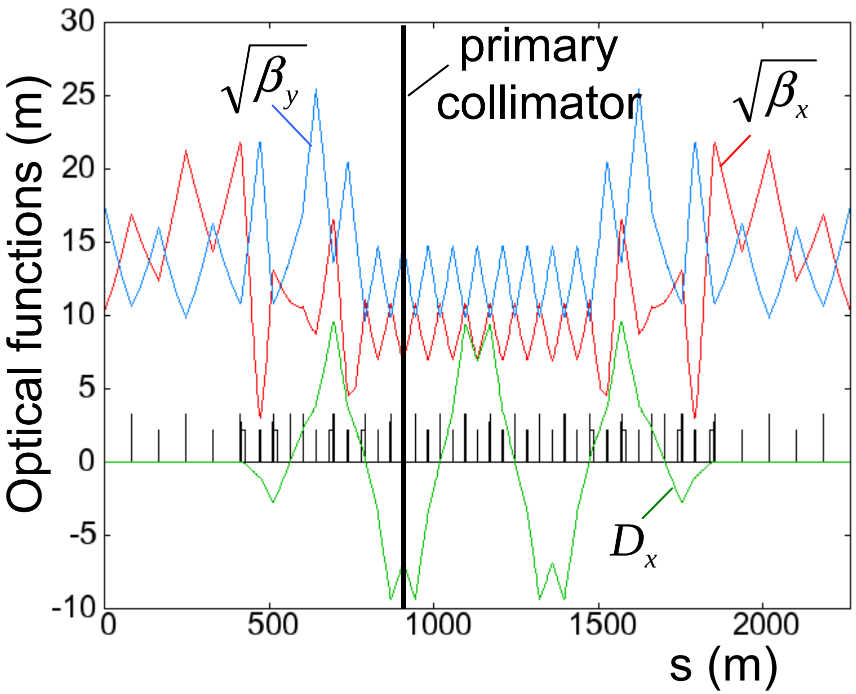
The best place for a multistage momentum collimation is in one of the two straight sections:

_ No superconducting magnet

_ We have an ENORMOUS space to realize a chicane and the momentum collimation

Layout of the collimation section





Warm dispersion bump in the straight section.

- Quadrupoles (warm) every 38 m
- Additional equipment
  - Vacuum system: pumps, ...
  - Scrapers and Collimators
  - ...
  - RF system

Systematic study

- Multi-stage collimation
  - Primary Collimator: “thin” scraper
    - Considerations on nucl. interaction length and fragmentation length
  - Secondary collimators
    - Absorb the total beam energy
    - Up to 10 kW/m, needs several ten to hundred meter of collimator
  - Avoid absorption of total energy at a single collimator.

- Simulation studies on-going using FLUKA and ACCSIM.

Summary & outlook

- Identification of critical items:
  - Decay losses in the arcs of the decay ring
  - High power in momentum collimation
- Conceptual layout for
  - SC dipoles and absorber in the arcs
  - Momentum collimation section
- Next steps:
  - Technical aspects of absorber/collimators
  - Combining studies on particle interaction and particle tracking in absorber and collimation sections.