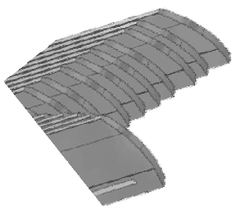
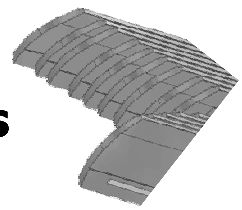


Collimators



High Power Hadron Machines, CAS Bilbao, 31.05.2011

Sławomir Wronka

Outline

- Introduction & definitions
- Types of collimators
- Typical chalanges & problems
- Examples

Definition

A **collimator** is a device that narrows a beam of particles or waves. To "*narrow*" can mean either to cause the directions of motion to become more aligned in a specific direction (i.e. collimated or parallel) or to cause the spatial cross section of the beam to become smaller.

http://en.wikipedia.org/wiki/Collimator

Collimators

- Different goals – different construction of collimators
- Linac vs Sinchrotron
- Jaws / scrapers
- Often work toogether with cleaning magnets and dumps

What for ?

Historically collimators in hadron machines were used to reduce the radiation background at the experiments.

However, high energy and beam intensity in new powerful machines and the use of superconducting technologies require a sophisticated collimation system for beam cleaning and machine protection.

What for ?

New high intensity machines:

High intensity in core and halo!

What is potentially “dangerous” for the machine:

Quenches – **Activation** – **Heating** – **Damage**

What for ?

- To obtain low uncontrolled beam loss
- To minimize proton/ion beam halo
- To minimise the activation of downstream beam line components
- To allow faster access
- To protect the machine itself

Example: Tasks of LHC protection systems

First priority

- Protect (sensitive) LHC equipment from damage. Downtime after damage of superconducting magnet about 1 months

Second priority

- Protect superconducting magnets from quenching. Downtime after a quench is in the range of 1 hour – 8 hours

Not to be forgotten

- **Protect the beam:** The protection systems should only dump the beam when necessary. False beam dumps to be avoided…
- **Provide the evidence:** In case of failure, complete and correct diagnostic messages should get to the operator (post mortem recording)

Rüdiger Schmidt, Review on Collimators for the LHC
30 June 2004

How ?

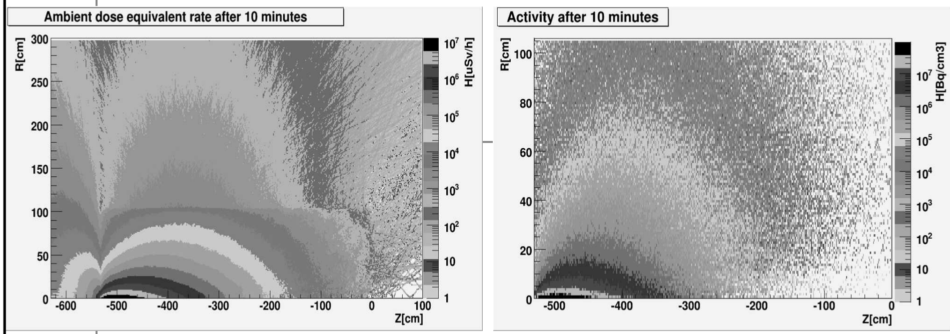
By optimization of:

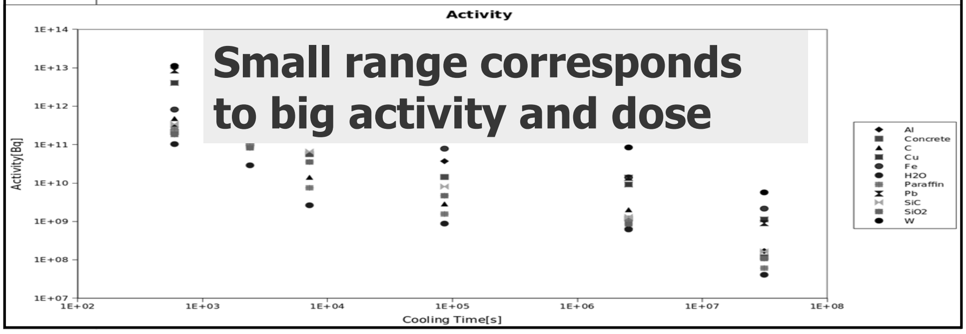
- collimating tube length,
- shape,
- location,
- number of collimators (along the lattice and in each set),
- aperture size of primary collimators and secondary collimators
- collimator material
- stationary/movable ? (if movable – define the algorithm)

Example: Fluka calculations, comparison of ranges

Material	Density[g/cm^3]	Range[cm]
Al	2,70	440
Concrete	2,30	490
C	2,26	530
Cu	8,96	160
Fe	7,87	170
H_2O	1,00	1020
Paraffin	0,89	1080
Pb	11,35	155
SiC	3,16	385
SiO_2	2,32	525
W	19,30	95

Carbon





Small range corresponds to big activity and dose

LHC example: High Z materials would be damaged (copper, but even aluminium)

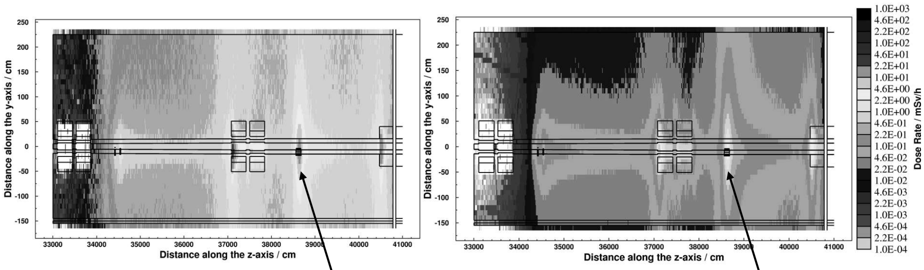
↓

Graphite has been chosen as jaw material.

Remanent Dose Rates: LHC EXAMPLE

Remanent dose rates after 180 days of operation

1 day of cooling | 4 months of cooling



~5 mSv/h ~1 mSv/h

Dose rate maps allow a detailed calculation of intervention doses

Intervention Doses: *Intervention on Vacuum System*

<u>*Collimator exchange*</u> due to a leak (Conflat flanges with chain clamps)

Total accumulated dose per person (*vacuum group*) in mSv

Collimator exchange between two quadrupole in IR7 due to a leak: CF flanges with chain clamps

Actions		Time required (min)	1h	8h	1d	1w	1m	4m
Transportation of the material (tooling box, leak detector, pumping stations,		= 4 x 5 min	0.120	0.084	0.039	0.009	0.003	0.000
Connection of two pumping stations		= 2 x 3 min	0.273	0.192	0.138	0.070	0.041	0.017
Connection of the leak detector		5 min	0.230	0.162	0.116	0.059	0.035	0.015
Leak detection (including checking of the pumping station)		10 min	0.565	0.402	0.299	0.165	0.097	0.040
Fine leak leak detection / confirmation		10 min	0.963	0.701	0.555	0.345	0.200	0.082
Installation of the venting line + venting follow up		5 min	0.230	0.162	0.116	0.059	0.035	0.015
Exchange of the collimator								
	Disconnection	2 min	0.282	0.149	0.096	0.037	0.012	0.002
	Cleaning of the flanges	2 min	0.334	0.252	0.218	0.143	0.081	0.033
	Installation of the new collimator	5 min	0.678	0.358	0.230	0.088	0.029	0.005
	Connection	= 2 x 3 min	0.807	0.427	0.274	0.104	0.035	0.006
Starting the pumping		5 min	0.180	0.124	0.084	0.036	0.021	0.009
Pumping follow up		5 min	0.180	0.124	0.084	0.036	0.021	0.009
Leak detection		10 min	0.565	0.402	0.299	0.165	0.097	0.040
Bake out follow up		10 min	0.565	0.402	0.299	0.165	0.097	0.040
Disconnection of the pumping stations and leak detectors		15 min	0.683	0.481	0.345	0.175	0.103	0.043
Transportation of the material (tooling box, leak detector, pumping stations,		= 4 x 5 min	0.120	0.084	0.039	0.015	0.009	0.003
		Sum	**6.8**	**4.5**	**3.2**	**1.7**	**0.9**	**0.4**

How ?

- Local shielding! Intervention doses significantly smaller when removed remotely before the intervention.
- *Quick coupling/ uncoupling systems* for short intervention time

What is imporant in high power machines ?

Even small beam losses become significant and cause damage and/or high activation levels !

- LHC
- SNS
- ESS
- SPL
- FAIR
- ILC, VLHC ….

Collimator jaws / scrapers / absorbers

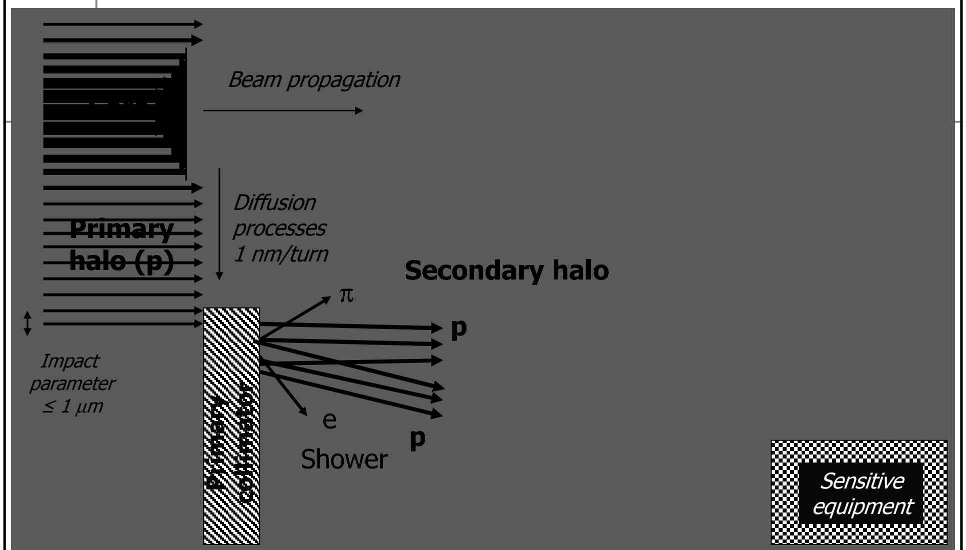
Components of the collimation system can be distinguished by their function:

- **Jaws:** Elastic and inelastic interactions of the beam. Precise devices with two blocks, used for efficient beam cleaning. Small gaps and stringent tolerances.
- **Scrapers:** Used typicaly for **beam shaping and diagnostics**. Thin one-sided objects.
- **Absorbers:** Absorb **mis-kicked beam** or products of proton-induced **showers**. Movable absorbers can be quite similar in design to jaws, but mostly with high-Z jaws. Larger gaps and relaxed tolerances.

- **Precise set-up & alignment required!**

R. Assmann

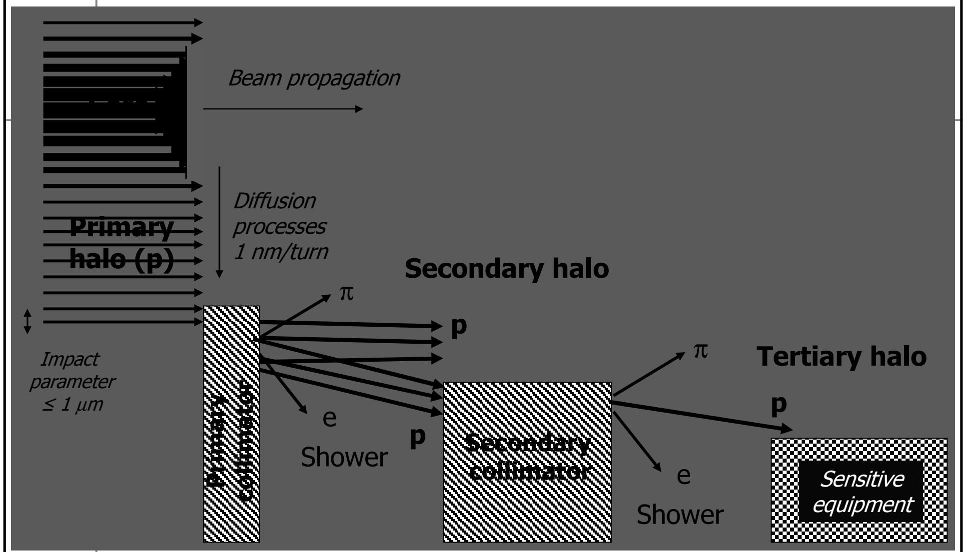
Example LHC: Principle of Beam Collimation



R. Assmann

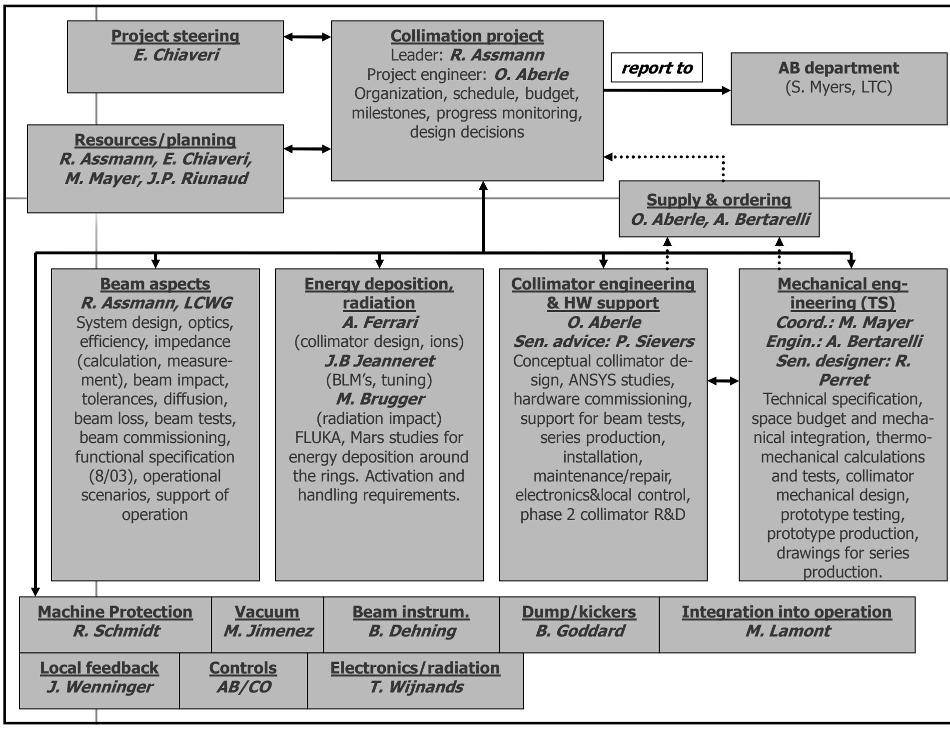
... one stage cleaning ...

Example LHC: Principle of Beam Collimation



R. Assmann

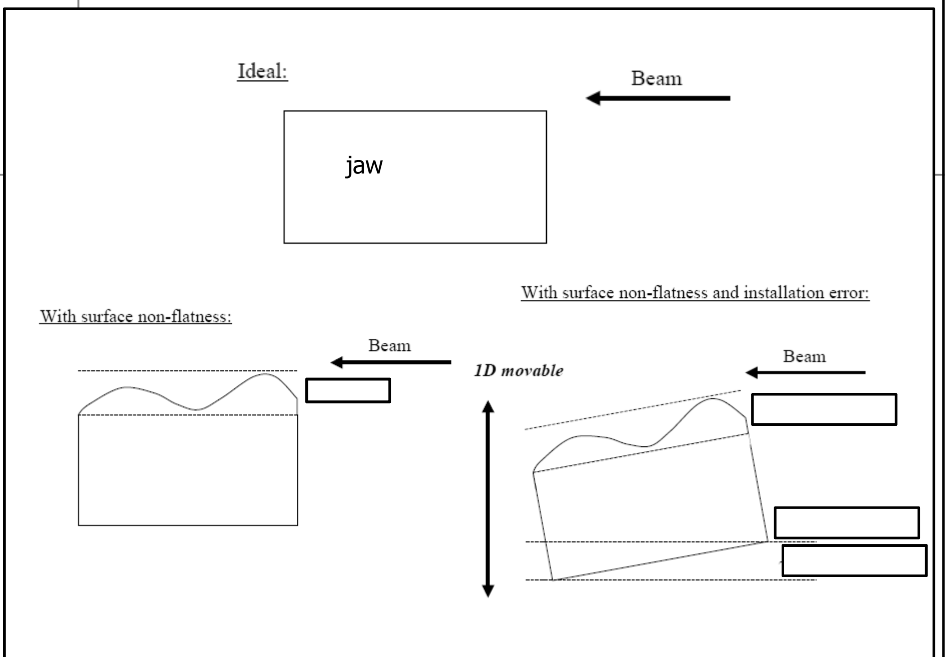
... two stage cleaning ...



Design new high power machine ?

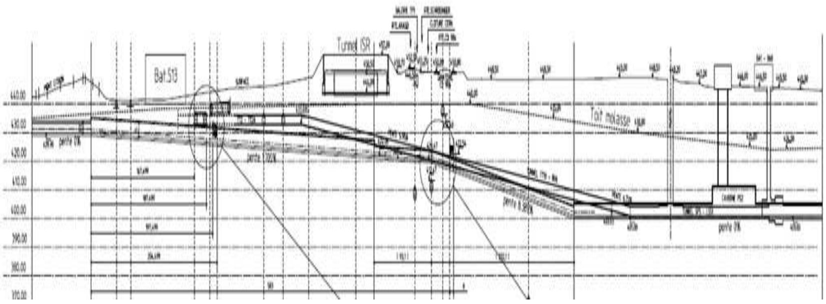
Take into account:

- All potential losses and beam halo.
- Showers in collimators and other equipment. Electron clouds.
- Materials behavior and beam-induced damage. Elastic and inelastic deformations. Coatings ?
- Precise mechanical movement and highly efficient cooling.
- Radioactivity level in collimator regions (material, personnel).
- Tolerance requirements.

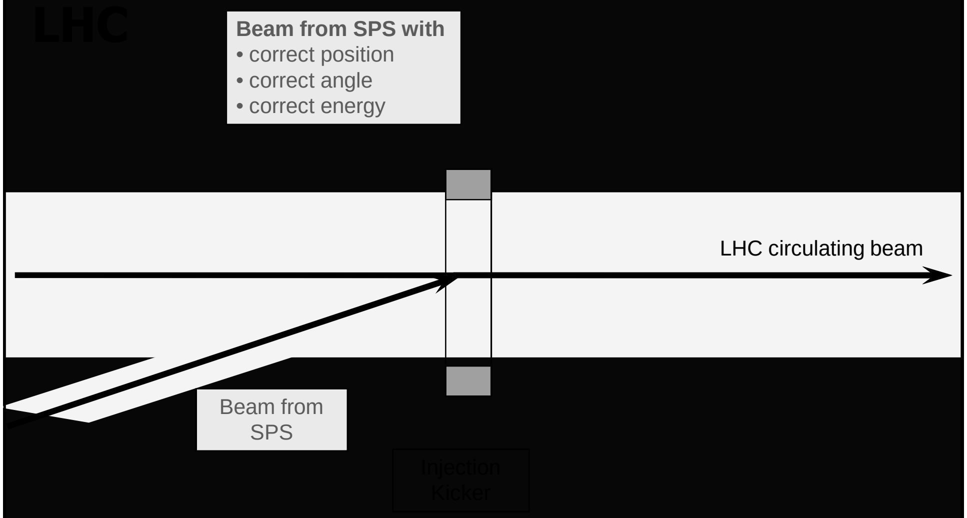


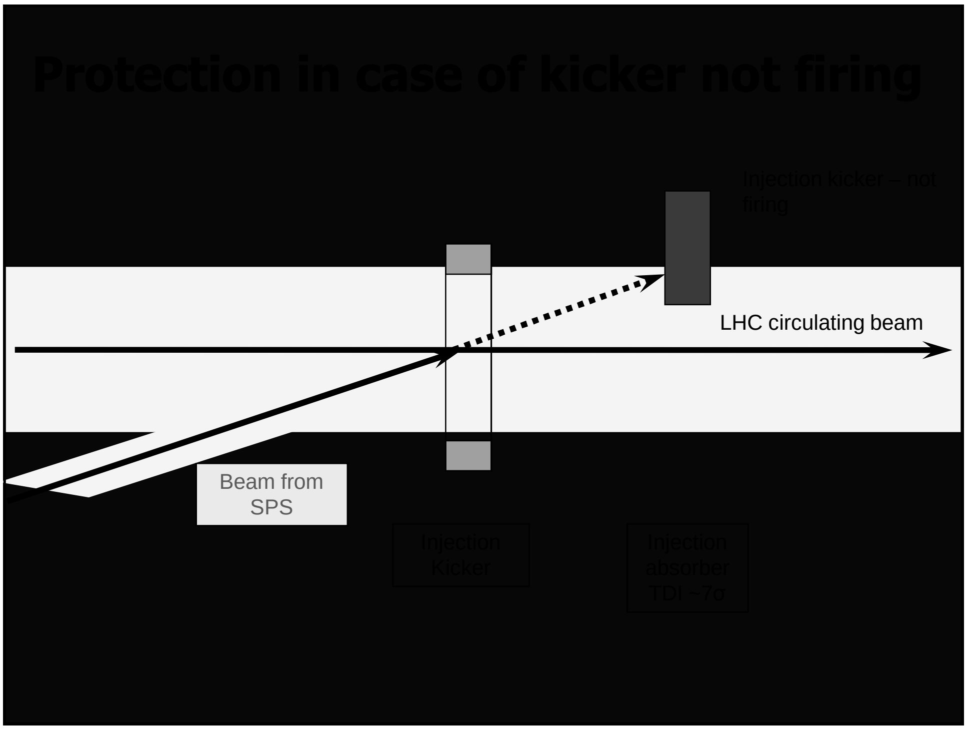
http://lhc-collimation.web.cern.ch/lhc-collimation/files/coll-22-10.pdf

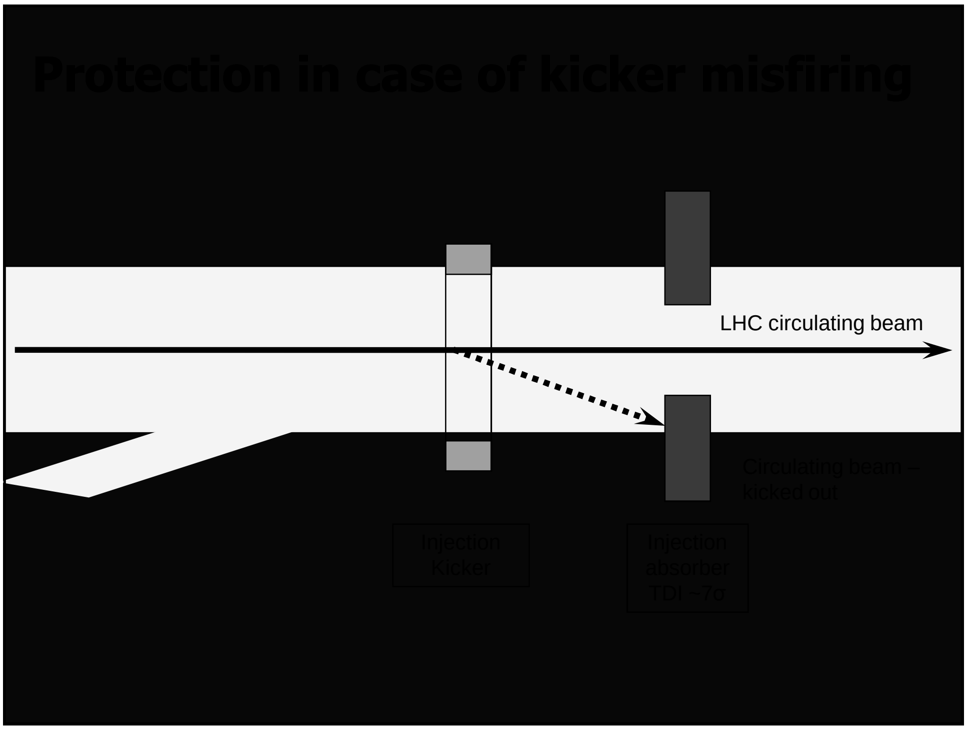
Collimators in transfer lines - example

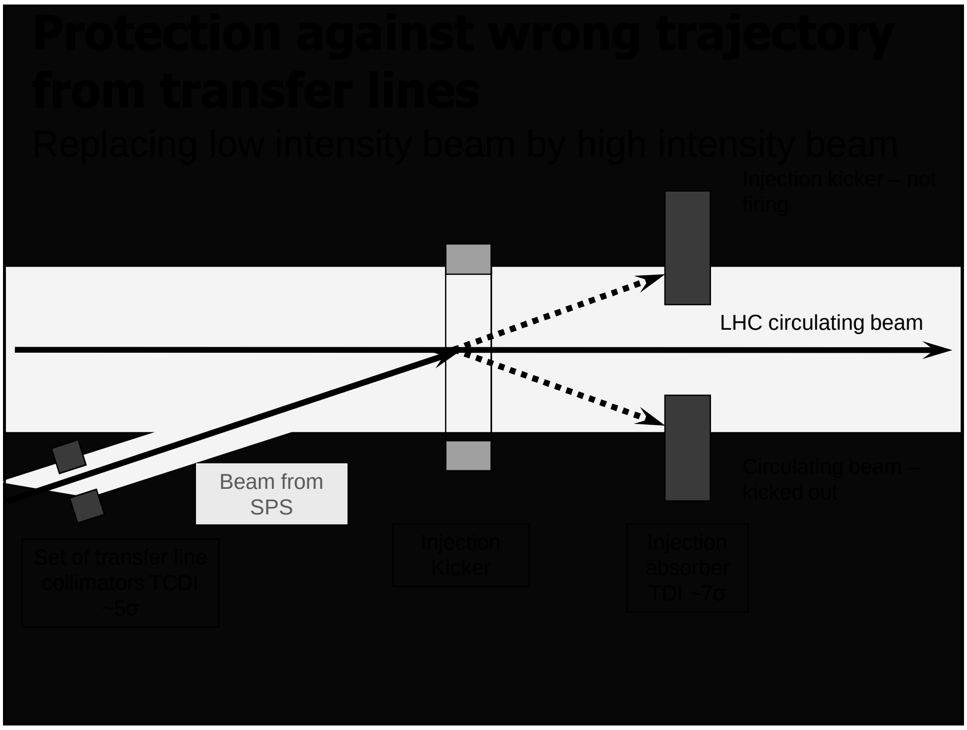


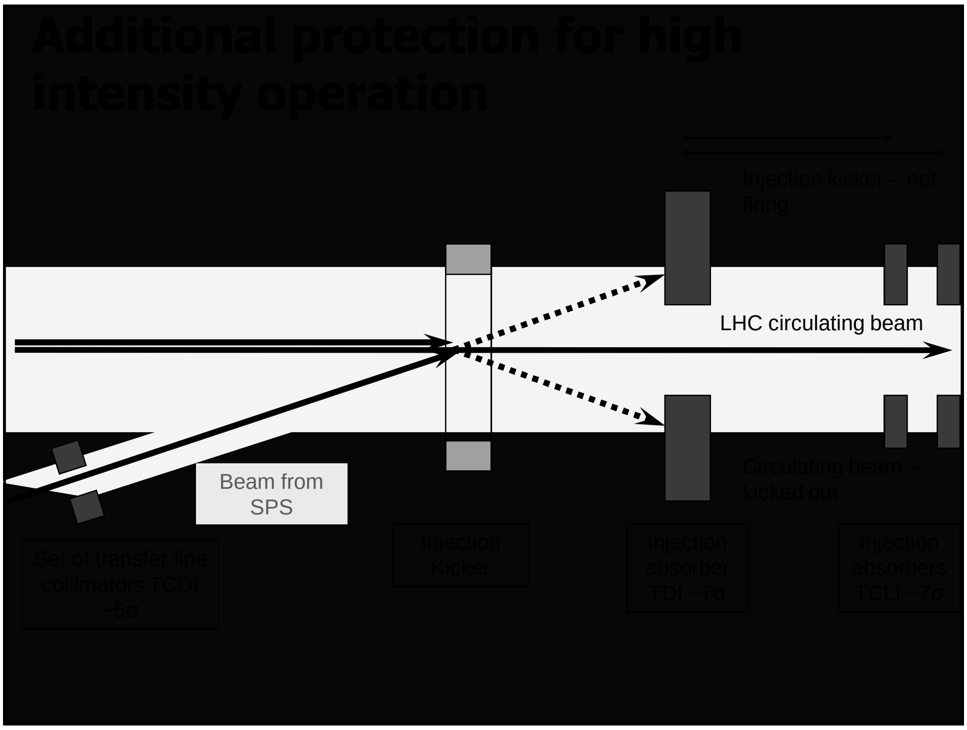
Example: Correct injection into the LHC




Protection in case of kicker not firing
Injection kicker – not firing
LHC circulating beam
Beam from SPS
Injection Kicker
Injection absorber TDI ~7σ


Protection in case of kicker misfiring
LHC circulating beam
Circulating beam – kicked out
Injection Kicker
Injection absorber TDI ~7σ


Protection against wrong trajectory from transfer lines
Replacing low intensity beam by high intensity beam
Injection kicker – not firing
LHC circulating beam
Beam from SPS
Circulating beam – kicked out
Set of transfer line collimators TCDI ~5σ
Injection Kicker
Injection absorber TDI ~7σ


Additional protection for high intensity operation
Injection kicker – not firing
LHC circulating beam
Beam from SPS
Circulating beam – kicked out
Set of transfer line collimators TCDI ~5σ
Injection Kicker
Injection absorber TDI ~7σ
Injection absorbers TCLI ~7σ

Design new high power linac ?

- Your design must intercept beam power of .... at energies ….
- Think about low activation of the collimators themselves and of downstream elements together with the shielding requirements for each collimation section.
- A „distributed collimation approach", where small collimators are placed in many places sandwiched between other elements or „bulk collimation", where beam collimation is only done at 2 or 3 locations ?

For linac as an first level accelerator:

- Do you need a beam cleaning in the transfer line to synchrotron ? For example to reduce the activation of the injection septum ?

Design new high power linac ?

The output of this study should be the definition of the collimator geometry, collimation material and the cooling requirements for the various levels of intercepted power.

i) which scheme is more suitable in order to minimize machine activation,
ii) geometry of the collimators and suitable collimation materials,
iii) activation and heat-load for downstream elements,
iv) optimum position for the (distributed) collimators: before, after, or in between quadrupoles.

Example: SNS

In the SNS case collimation is done using a foil scraper to convert the H^- into protons and a quadrupole downstream defocuses this proton halo towards a local beam dump.

Advantage : scraped halo is not transported along the H-beam.

Disadvantage : activation generated in the local dumps.

How to compare different scenarios ?

Collimator inefficiency

$$\text{Cleaning inefficiency} = \frac{\text{Number of escaping p}}{\text{Number of impacting p}}$$

Collimators control system and machine interlocks

- Position during the operational phases must be well defined and controlled (for example can change with beam optics during ramping).
  - It cannot be tolerated to open the jaws when operating with high beam intensity
  - Interlocks on wrong collimator position, depending on the operational phase
  - „Negative” logic
- Collimators and beam absorber must always be considered together

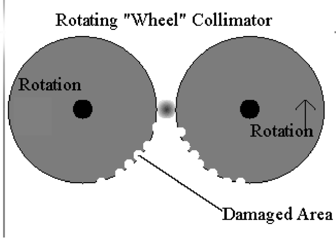
Future ideas ?

Collimator types

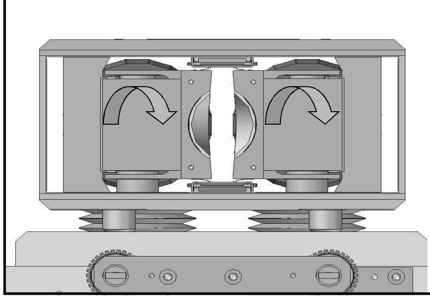
- Single use: Collimators are replaced if damaged: Standard Jaws / Apertures
- Multi use: Collimators designed to be damaged multiple times: Rotating wheels.
- Indestructible: Collimators which can be repaired after each shot: Liquid, Exotic

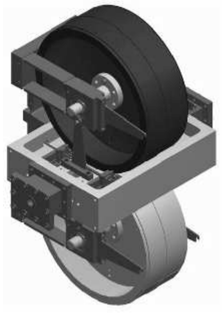
Josef Frisch

Rotating collimator



R. Assmann, N.Mokhov, M. Pivi, A.Seryi



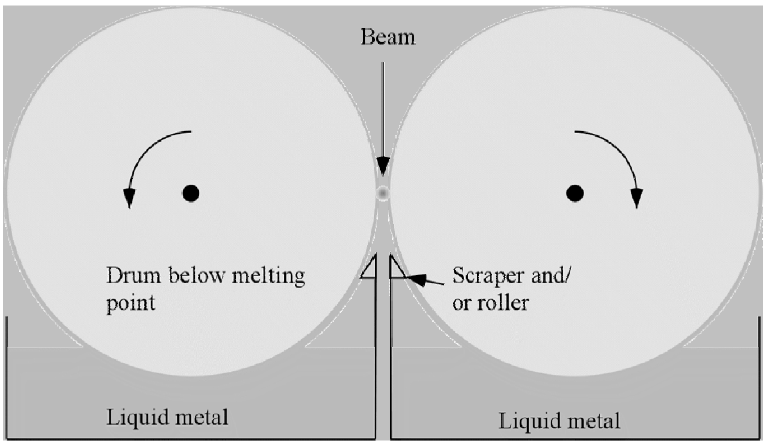


Types of Indestructible Collimators

- Flowing liquid: Jets, waves: Indestructible, but tolerances are difficult. (Should study jet stability)
- Liquid film / Solidifying: Might have good tolerances, but limited film thickness.
- Exotic: Lasers, etc: No practical designs

Josef Frisch

Solidifying collimator concept



Josef Frisch