Machine Protection

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Acknowledge: JAS, CINVESTAV, CERN, KEK, J-PARC, J-PARC Monitor Group.

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G) Collimator

- My experience in Machine Protection

A) Machine Protections Studies for CCs in the HL-LHC

B) Beam Loss Monitors in the MR at J-PARC

The material of this talk is based on:

- Lectures of Joint Accelerator School on Beam Loss and Accelerator Protections. (http://uspas.fnal.gov/programs/JAS/JAS14.shtml)

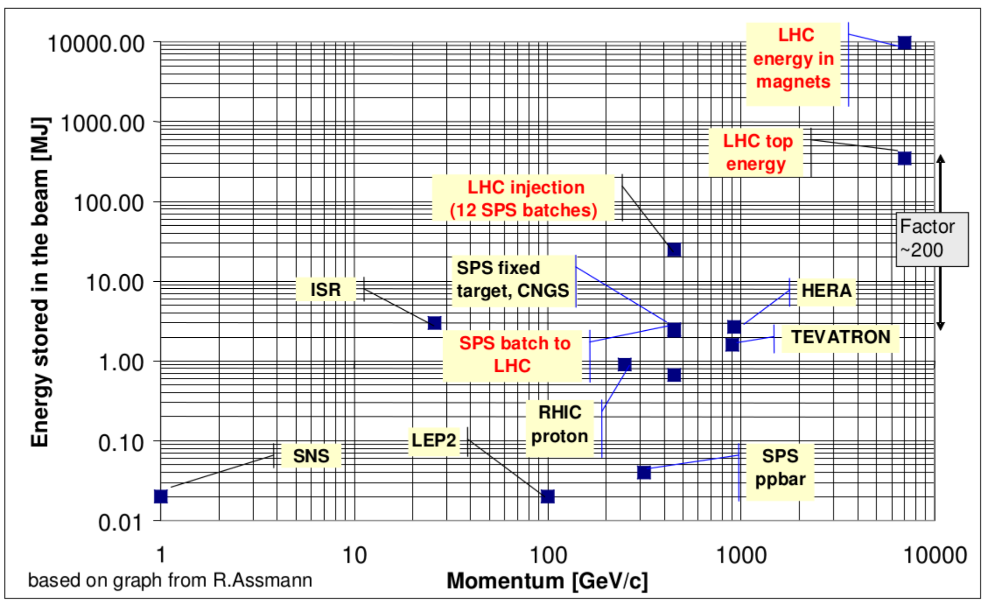
  Specially in the Lectures of R. Schmidt and F. Willeke

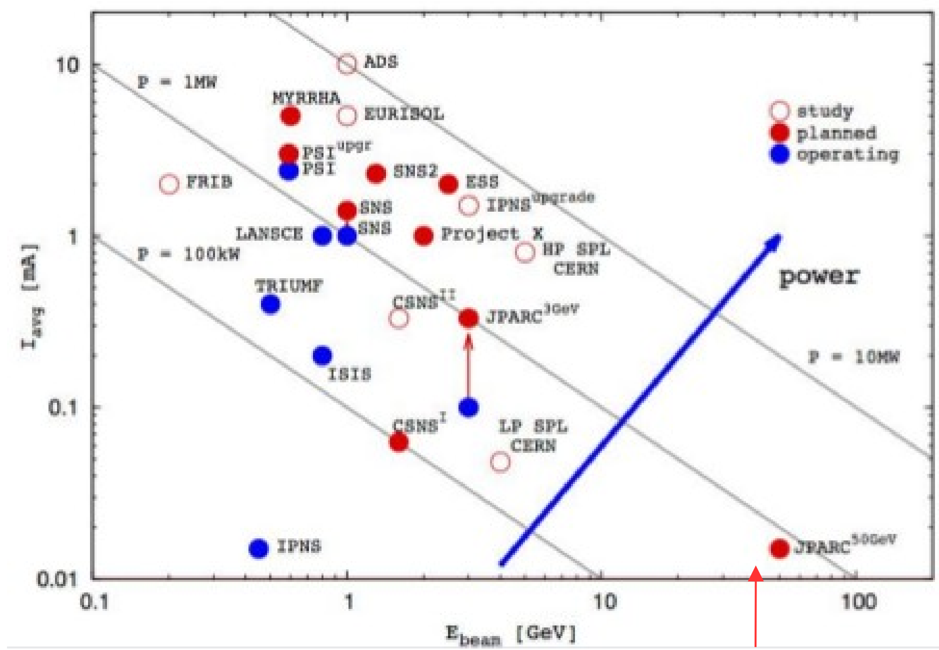
- Beam Loss Monitor by K. Wittenburg (http://cas.web.cern.ch/cas/France-2008/Lectures/Wittenburg-BLM.pdf)

Introduction to Machine Protection

Motivation

- Nowadays, many machines operate with high power intensity and/or high particle energy (J-PARC, LHC, SNS and ESS) and the future projects (HL-LHC, FCC). Therefore, the Machine Protection System (MPS) becomes more important for the good performance of the accelerator.





Right Now J-PARC runs at 30 GeV

Courtesy of R. Schmidt

Energy and Power

Every generation of accelerators increase in beam intensity and/or particle Energy

- For storage rings and synchrotrons, the **energy stored** in the beam increases.
- For linear accelerator and fast cycling machines, the **beam power** increased.

For example:

360 MJ: the energy stored in one LHC beam corresponds approximately to…

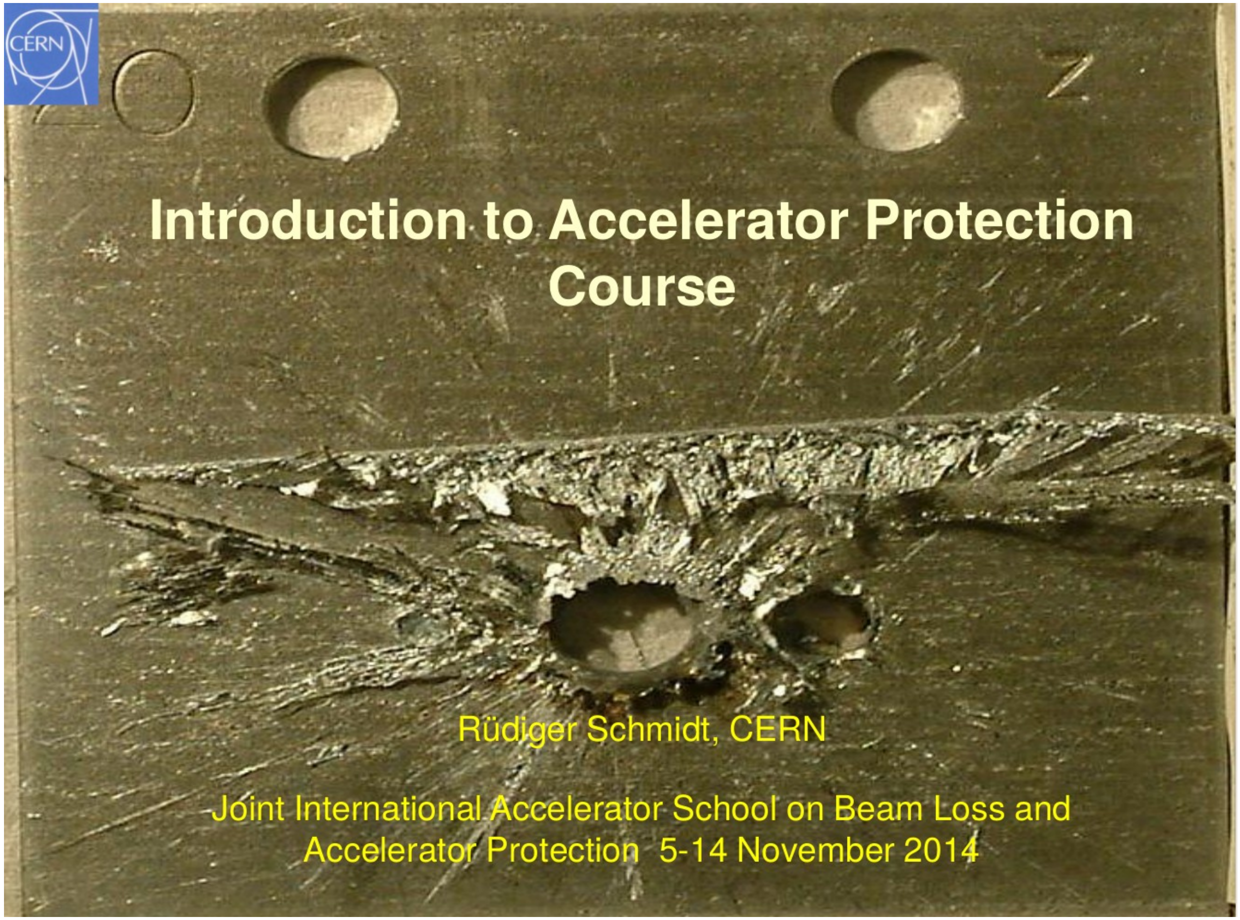
- 90 kg of TNT
- 8 litres of gasoline
- 15 kg of chocolate

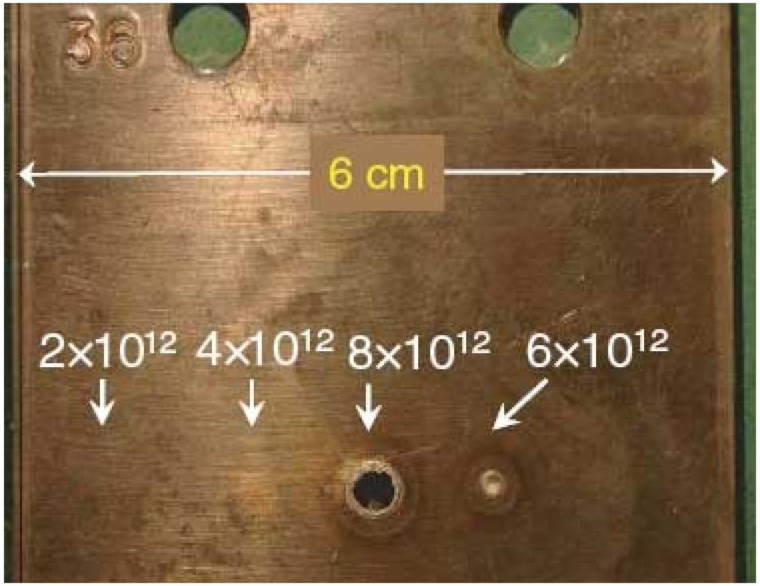
It matters most how easy and fast the energy is released !!

"If something goes wrong, the beam energy or power must to be safely deposited"
R. Schmidt

Courtesy of R. Schmidt

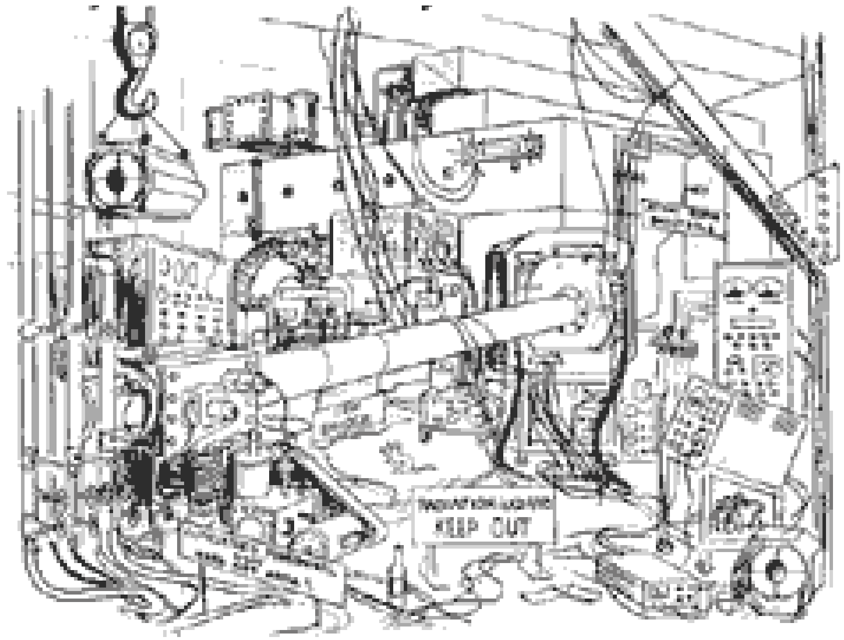
Damage produce by the Beam





Courtesy of R. Schmidt.

Why it is necessary a BLM system?



Courtesy of LBL Image Library.

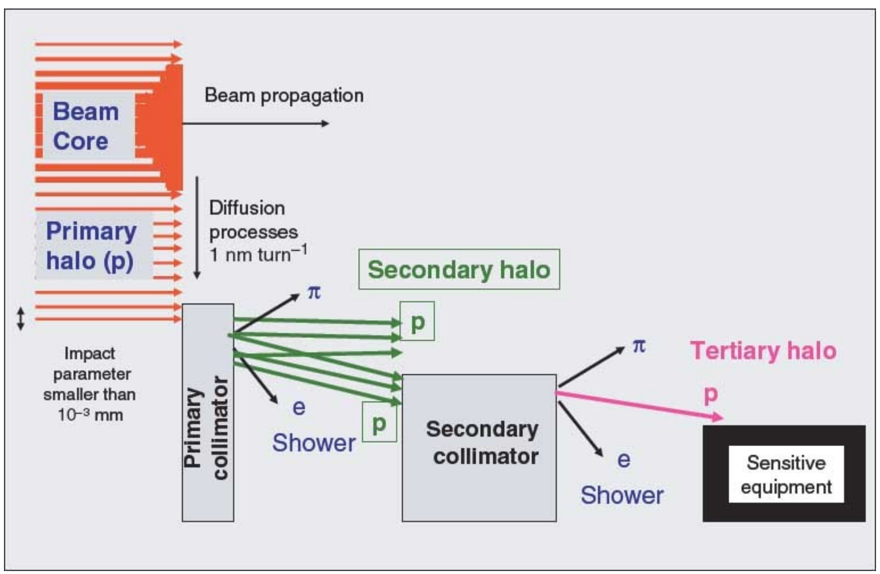
“You do not need a BLM System as long as you have a perfect machine without any problems. However, you probably do not have such a nice machine, therefore you better install one”.

K. Wittenburg

What is beam lost?

Beam loss particles can be defined as the particles accidentally interact with the elements of the accelerator producing radiation.

We want 



Courtesy of R. Schmidt.

We don't want 

Courtesy of shutterstockt.

Types of beam losses

- The beam losses can be classified as: Controlled and Uncontrolled.

- Controlled losses (regular or slow) are commonly concentrated on the collimator system (injection, Touschek effect, tune scans, etc).

- These progressively losses occur during operation and correspond to the lifetime/ transport efficiency.

- The lowest possible loss rate is defined by the theoretical beam lifetime limitation due to various effects, e.g., Touschek effect, beam-beam interactions, collisions, etc.

- Uncontrolled losses (irregular or fast) are often the result of malfunctioning or erroneous of the accelerators devices and a misaligned beam (superconducting quench, trip of the RF, vacuum).

- These losses can occur spontaneously during the operation and can produce an irreversible damaged or shut down in the accelerator.

Failures classification in the LHC

Class	Examples
Slow > 1s manual intervention possible	• Cryogenics problem • Transverse beam instability • Failure of orbit/tune feedback • …
Fast > 15ms protection by multiple systems	• Trip of accelerating RF • Trip of power converter for superconducting circuit • Superconducting magnet quench • …
Very fast > 3 turns (270μs) protection by fastest systems	• UFOs (particle falling into beam) • Normal conducting magnet failure (e.g. D1) • Failure of transverse damper • Very fast crab cavity failure (HL-LHC)
Ultra fast < 3 turns too fast for protection dump	• Injection and extraction failure • Ultra fast crab cavity failure (HL-LHC) • Missing long-range beam-beam deflection

This classification is different for another machines.
For instance, at J-PARC this is a faster failure

Courtesy of T. Baer.

Goal of the Machine Protection

- Safety of the people (workers and civilians). ← For J-PARC the Personnel Protection System is in charge of that.
- Protection of the environment (avoid the leaking outside of the secure areas). ← For J-PARC the Radiation Safety System is in charge of that.
- Protection of the equipment/machine (from the beam-induced damage and elements activation)
- Protect the beam (reducing the numbers of false beam trips).
- Provide Evidence (post-mortem analysis).
- Etc.

Reliability

“Reliability is the probability of fulfilling the Major Design Function (MDF) of the system, continuously and without interruption, for a predefined period of time”

R. Andersson

“Reliability is the machine's ability to run safely and without interruptions for a specified period of time”

Machine protection at ESS

$$R(t)=e^{-\lambda t}$$

where λ is the failure rate and t the predefined time period.

Availability

"Availability is the probability to find the machine fulfilling its MDF, when it is claimed to be in operation"

R. Andersson

"Availability refers to the percentage of the planned operation time that the machine is actually operation as it is supposed to"

Machine protection at ESS

$$A(t) = 1 - \frac{MTBF}{MTBF + MDT}$$

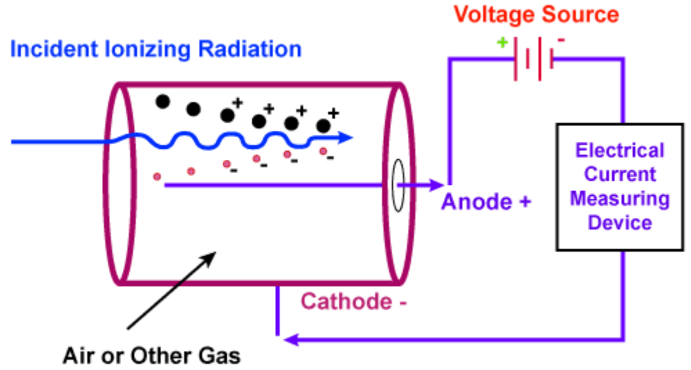
where MTBF is the Mean Time Between Failures and MDT is the Mean DownTime.

BLM system

- A BLM system consists of an equipment which detect the radiation produced due to the particle loss.
- An efficient BLM is able to distinguish the radiation produced by the beam loss particles (unintentional, LINAC -Xray RF at J-PARC) from the one generated by the interaction between the beam and the beam diagnostic instrument (Collimators, scrapers, intentional).
- The BLM works using the principle of energy deposition (Bethe-Bloch equation), this consists in the interaction of the particles with the material, the beam energy ionizes the medium. The way that the losses can be detected is by ionization or by fluorescence.

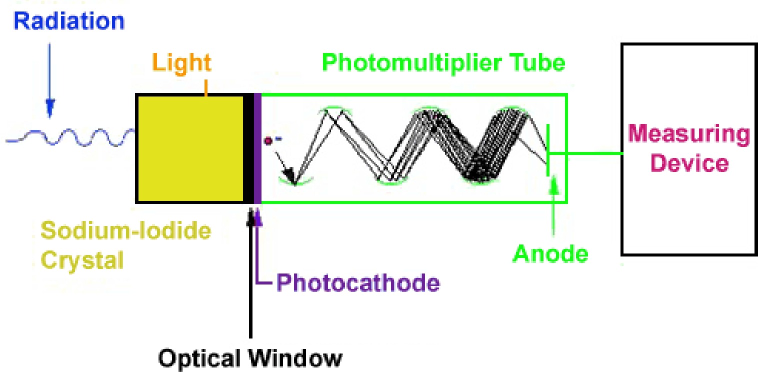
BLM examples

Ionization chamber



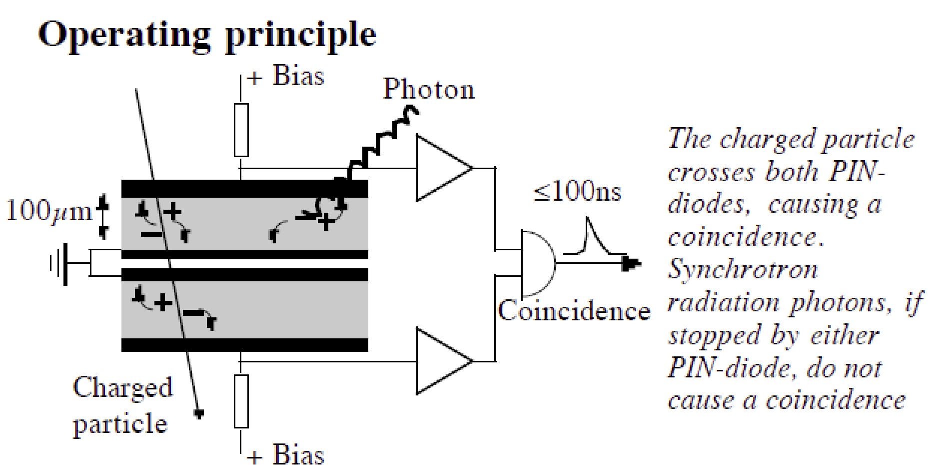
Courtesy of Equippo

Scintillation detectors



Courtesy of Equippo

Pin Diode



Courtesy of GEEBEE INTERNATIONAL

Active Protection

Example for Active Protection - Traffic

- A monitor detects a dangerous situation

- An action is triggered

- The energy stored in the system is safely dissipated

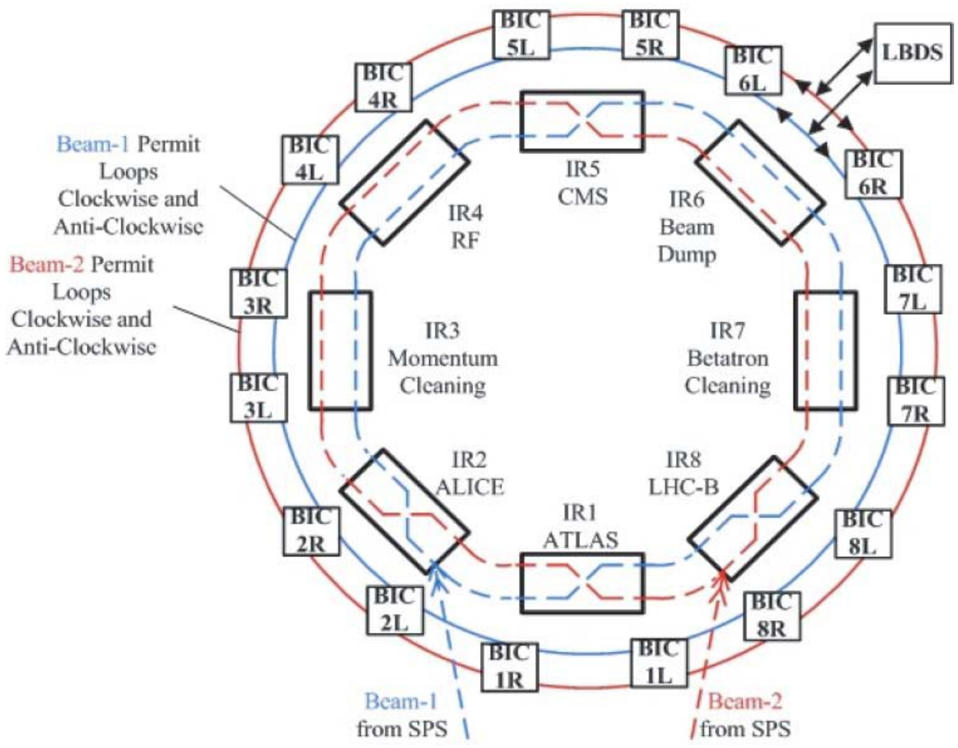
Courtesy of R. Schmidt

Rüdiger Schmidt JAS 2014 page 79

BIS

The Beam Interlock System (BIS) is in charge to allow the injection and the circulation of the particles in the accelerator and in the case of abnormal beam behavior, its extraction.

LHC BIS

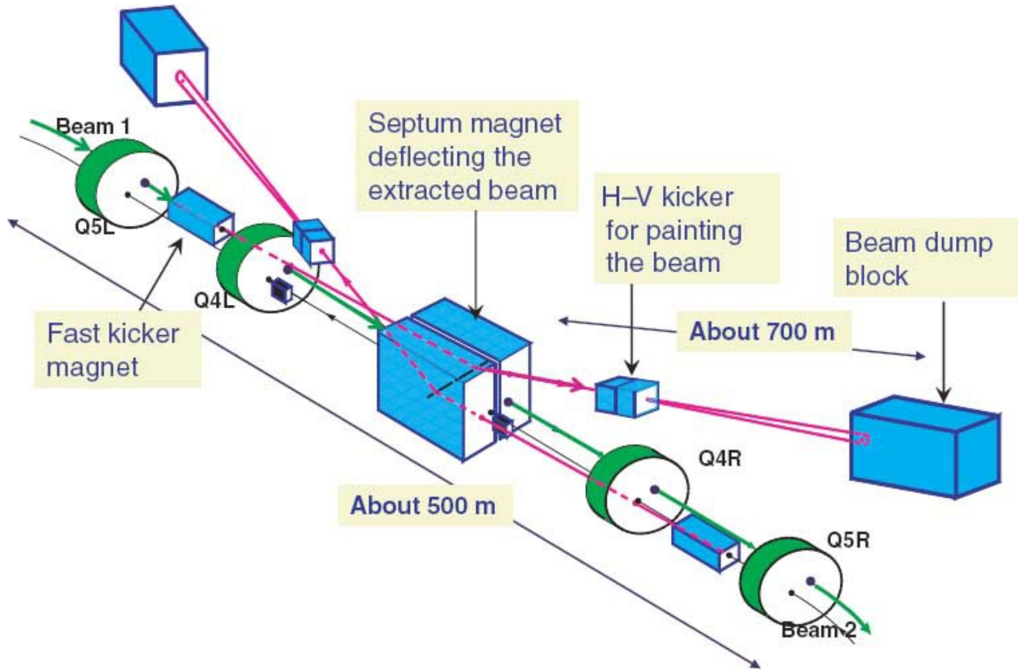


Courtesy of B. Todd

BDS

The Beam Dump System (BDS) is in charge of the safe extraction of all the beam bunches in case of a failure.

LHC BDS



Courtesy of M. Gyr

Passive Protection

Example for Passive Protection

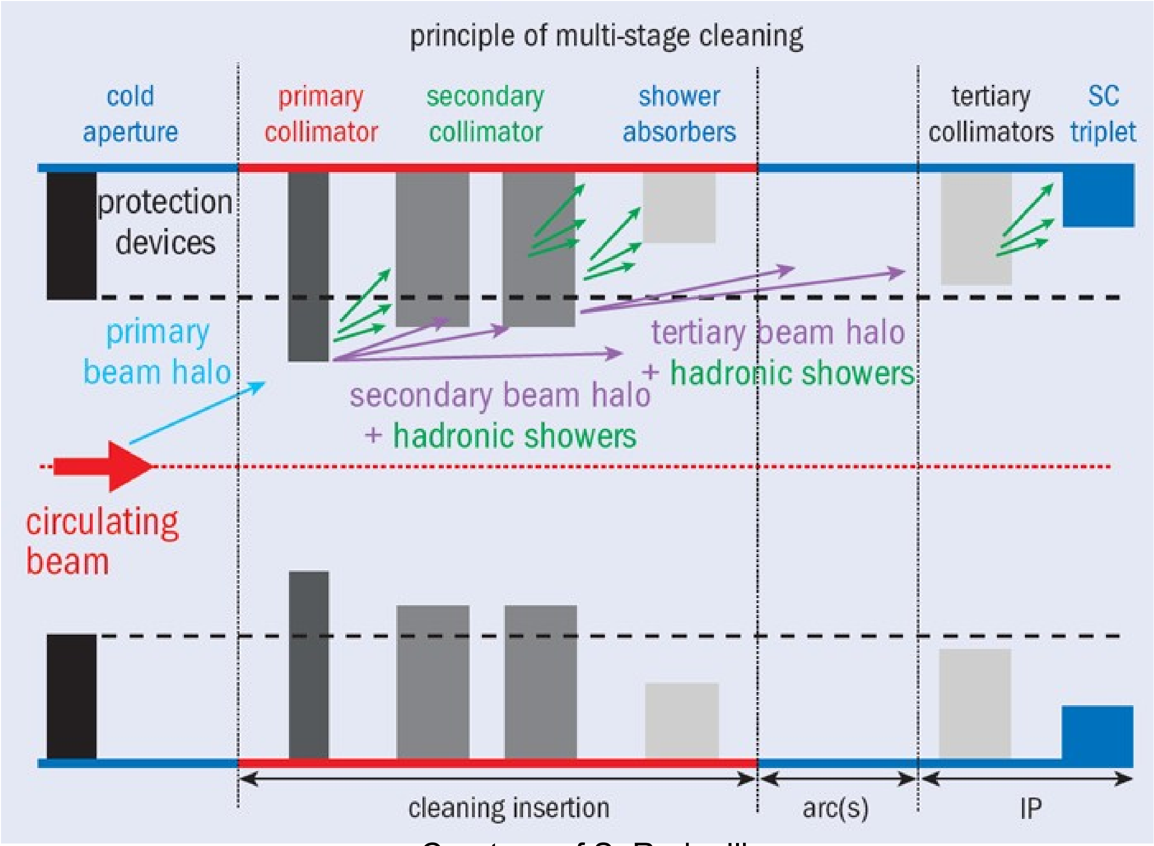
- The monitor fails to detect a dangerous situation
- The reaction time is too short
- Active protection not possible – passive protection by bumper, air bag, safety belts

Courtesy of R. Schmidt

Collimator

The collimation system is designed to protect the accelerator components (the cold superconducting magnets) against unwanted beam loss. The collimators remove the particles beyond a certain transverse amplitude, which could eventually impact on the beam pipes or magnets.

LHC Collimation system



Courtesy of S. Radealli

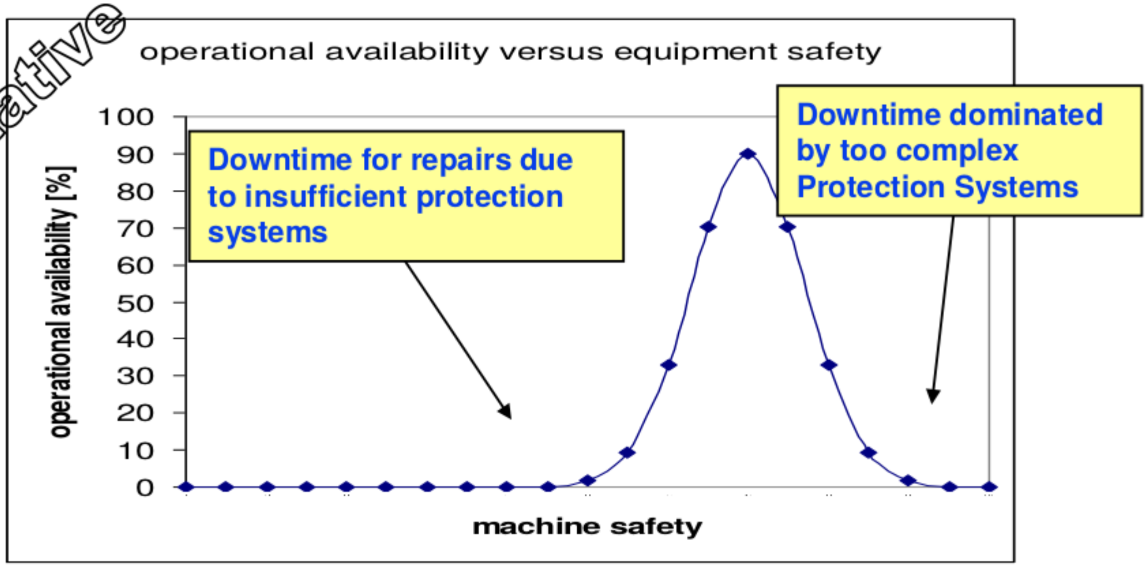
Remember

Machine Protection is not an objective in itself, it is to

- maximise operational availability by minimising down-time (quench, repairs)
- avoid expensive repair of equipment and irreparable damage

Operations workshop
R.Schmidt - Villars
30/01/2001

Qualitative



Side effects from LHC Machine Protection System compromising operational efficiency must be minimised

Example: For J-PARC Main Ring, during machine study time beam losses are allowed. MPS by BLMs are masked.

My experience to Machine Protection

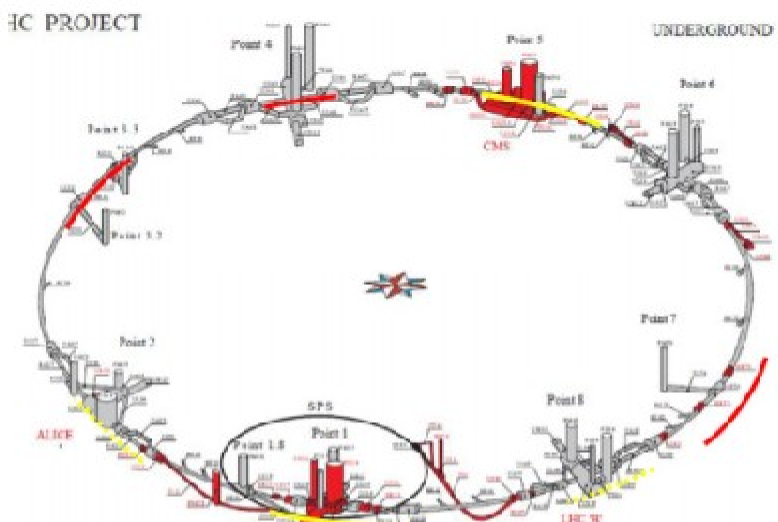
Studies of Machine Protections for Fast Crab Cavity Failures in the High Luminosity Large Hadron Collider

HL-LHC

The HL-LHC Project

High Luminosity LHC

- Physics driven requirements:
  - Increase luminosity limiting Pile-Up (PU) to ~140 events/crossing
    - L = 5 x 10^{34} cm^{-2} s^{-1}
  - Limit PU linear density to ~1 event/mm



- New IR-quads Nb_3Sn (inner triplets)
- New 11 T Nb_3Sn (short) dipoles
- Crab Cavities
- Collimation upgrade
- Cryogenics upgrade
- Machine protection
- …

Bunch size reduction

Topics relates with this thesis

Major intervention on more than 1.2 km of the LHC

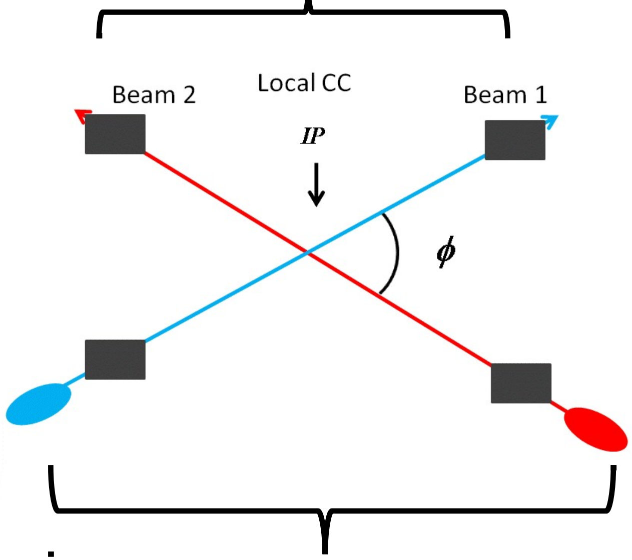
Fermilab

7 G. Apollinari – High Field Magnet Development Toward the High Luminosity LHC 6/17/2014

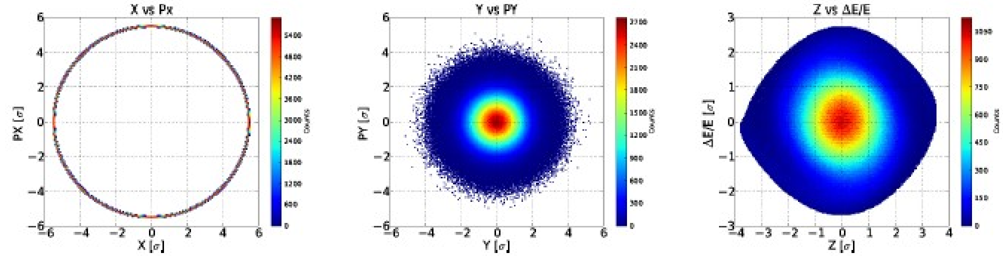
Courtesy of G. Apollinari , IPAC´14 , TUOCB02.

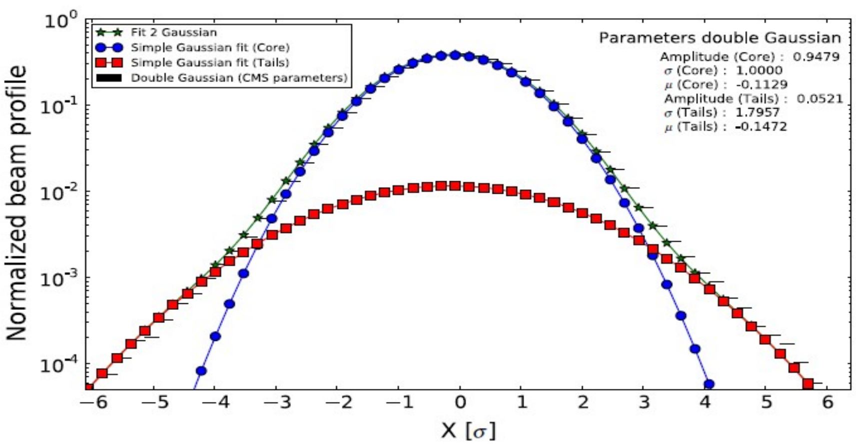
Summary

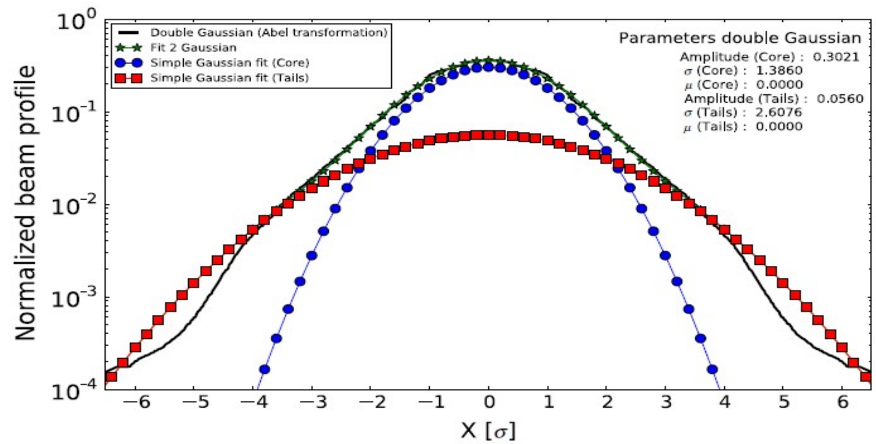
CCs that closed the crab bump



CCs that open the crab bump







Conclusions & future work

- This beam tracking study shows the first results of **crab cavity** failures scenarios considering a **realistic steady-state beam distribution** in the LHC.

- The effect of the CCs in the **global inefficiency** is negligible.

- The **CC failures** produces large losses for the distribution with **long tails** on the plane that the CCs apply the kick.

- To estimate an upper limit for the energy deposited in our simulations, we can assume that all the particle energy is deposited on the element.

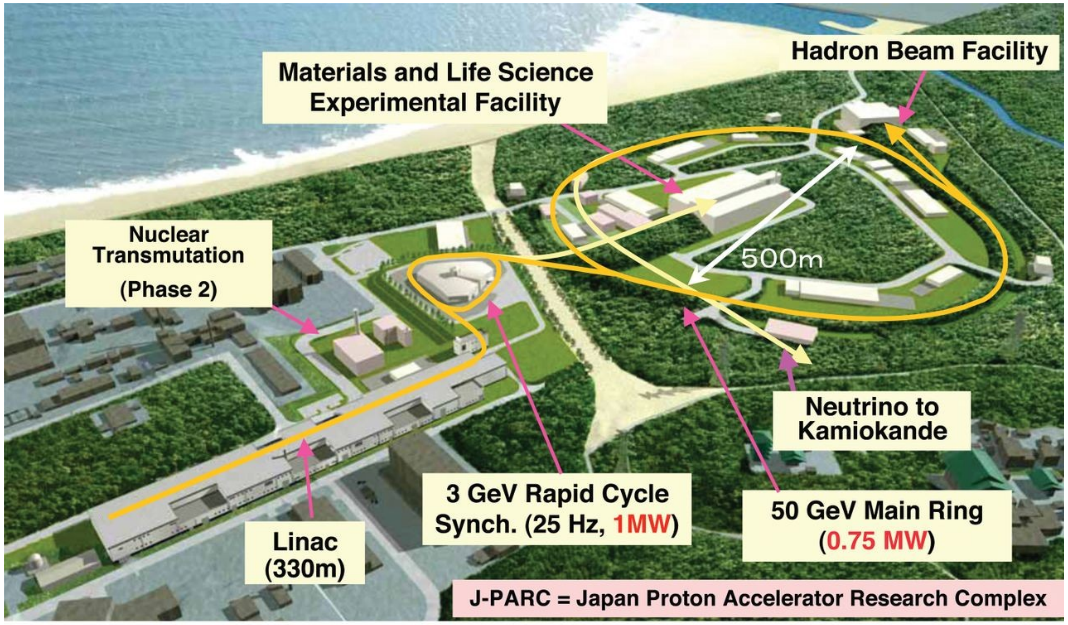
- The test of the CCs prototypes in the **SPS** in **2017** will allow to develop more realistic CC failure models which will help to obtain more accurate results of CC failures in the HL-LHC.

- More special runs for **beam scraping** or another **beam measurements** are necessary to have a better description of the particle distributions which emphasis in the tails.

- Finally, **halo monitoring** and **control** during LHC operation become essential **operational tools** for **guaranteeing** the machine safety with crab cavities operation.

Beam lost monitor study in MR at J-PARC

J-PARC



Courtesy of J-PARC

Joint Project between KEK and JAEA

Parameters	LINAC	RCS	MR
Particle	H^-	p	p
E [GeV]	0.4	3	30
Length [m]	340	348.333	1567.5
Frq [Hz]	50	25	0.3
Intensity [x 10^{13}]	----	8.3	3.3
Beam power [MW]	---	1.0	0.75
Avg Beam Current [μA]	700	333	15

Topic works

- “LARGE RESIDUAL RADIATION BUT SMALL BEAM LOSS SIGNAL AT J-PARC MR”
- “ELECTRON CLOUD OBSERVED DURING DEBUNCHING FOR SLOW BEAM EXTRACTION AT J-PARC MAIN RING”
- “RESIDUAL RADIATION MEASUREMENT WITH THE BLMS IN J-PARC MR”

LARGE RESIDUAL RADIATION BUT SMALL BEAM LOSS SIGNAL AT J-PARC MR

- For FX (fast extraction), we measured a large residual radiation at address 45 and 52 (ARC A), however, the signal for the BLM is small.

- The figure 1 presents the residual radiation in 11/Mar/2015 (blue) and 17/Mar/2015 (red). It seen a different results from beam loss signal and residual radiation.

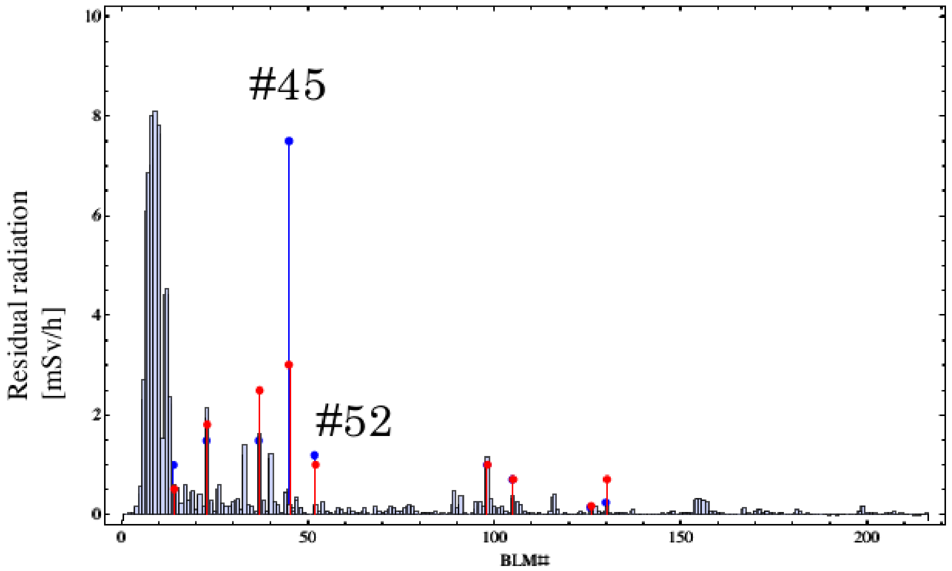
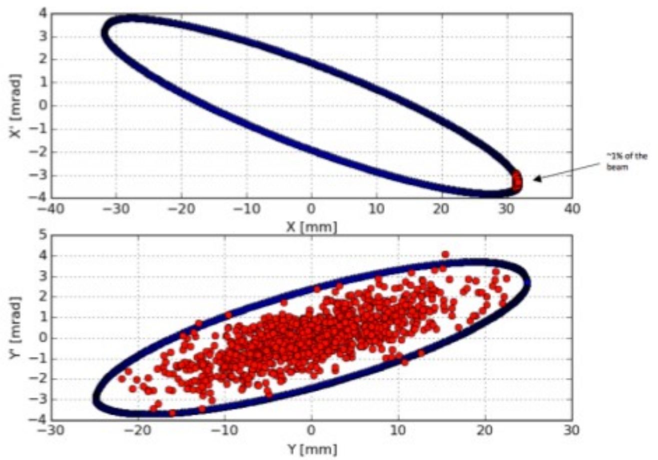
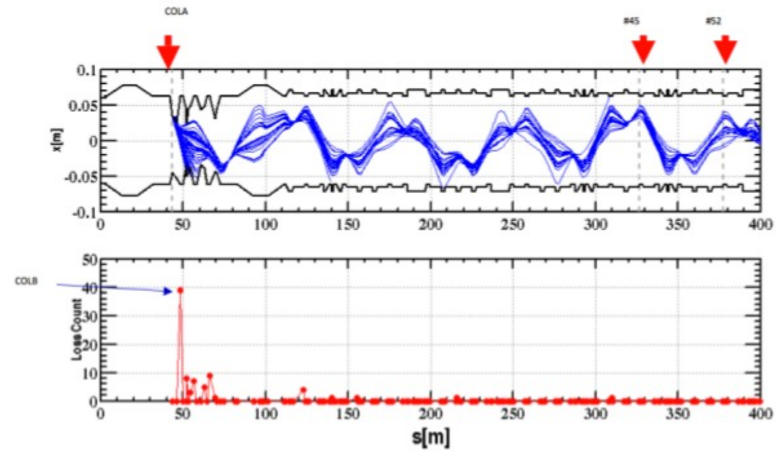


Figure 1: Beam loss signals during operation vs. residual radiation measured with the BLMs.

My contribution (Simulations with SAD)



(a) Vertical: Gaussian, horizontal: hollow distribution.



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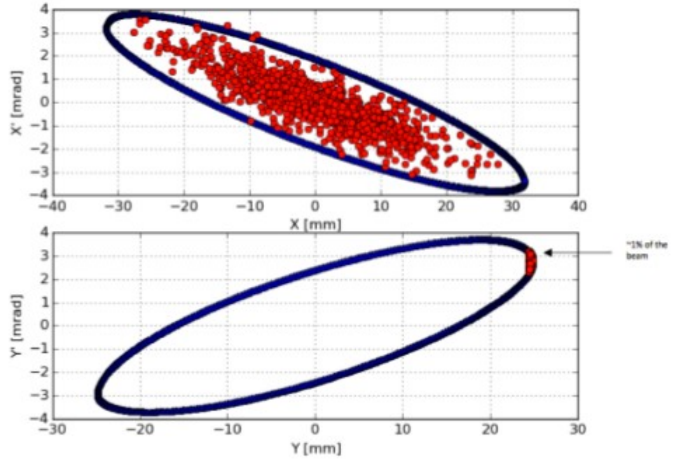
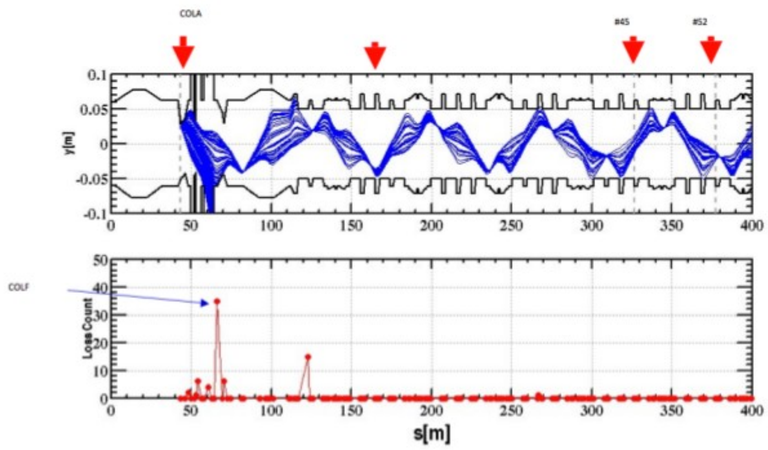


(b) Horizontal: Gaussian, vertical: hollow distribution.



(b) Horizontal: Gaussian, vertical: hollow distribution.

どうもありがとうございます
(Thank so much)

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