Academic Training: 18-22 April 2005

The LHC machine/experiment interface

D. Macina TS/LEA

Lecture 5

Hardware interface issues for near-beam detectors

Machine-induced backgrounds

Signal exchange between experiments and machine

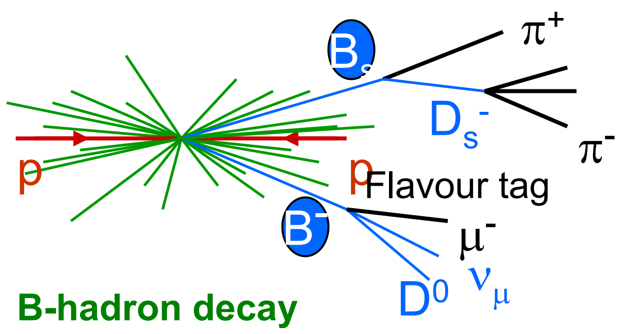
Previous lectures

- Physics topics and potential of LHC (S. Tapprogge)
- LHC experiments and requirements (S. Tapprogge)
- LHC machine (R. Assmann)
- Experimental zones (E. Tsesmelis)

PLAN OF TALK

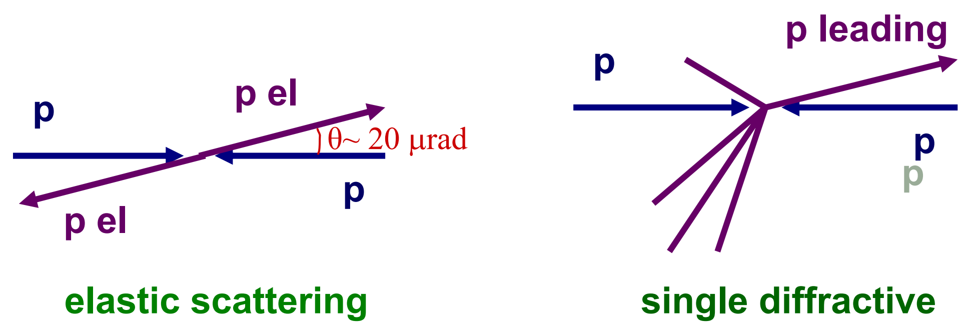
- Hardware interface issues for near-beam detectors
  - Physics motivation
  - Integration issues into the machine primary vacuum
  - Example: LHCb Vertex Locator
  - Integration issues for the detectors located in the machine tunnel: ALICE ZDCs
- Machine-induced backgrounds
  - Introduction
  - Example: shielding in IR8 (LHCb)
- Signal exchange between experiments and machine
  - Introduction
  - Example: experiments interlocks

Near beam detectors: physics motivation



B-physics requires detectors at ~ 8 mm from the beam

➡ LHCb VELO



The study of the pp elastic scattering (and diffractive physics) requires detectors at ~ 2 mm from the beam axis

➡ TOTEM Roman Pots

Integration into the machine primary vacuum

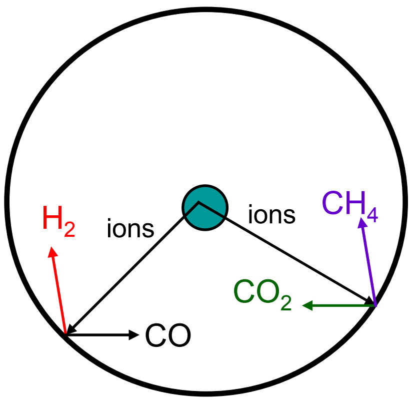
Integration issues into the LHC primary vacuum

- Fulfil the very demanding LHC vacuum requirements in order to reach a pressure P ~ 10^{-13} bar

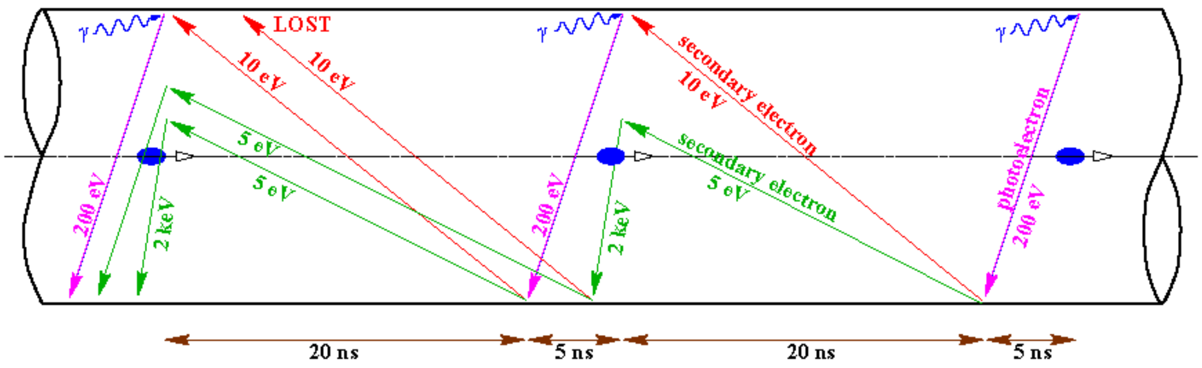
Compatibility with UHV

- Some materials have an excessive outgassing rate not compatible with the Ultra High Vacuum requirements of the LHC
- Examples are Si, Kapton, some ceramics etc..
- Therefore silicon detectors, commonly used as vertex detectors, and their front end electronics cannot be placed into the machine vacuum
- Solution: place the detectors in a secondary vacuum box leak-tight and made of UHV compatible material
  - Drawback: this adds material between the interaction point and the detectors. Therefore the shape and the thickness of the box has to minimize the material traversed by the particles preserving leak tightness

Beam induced dynamic effects



Ion stimulated desorption



Schematic of electron-cloud build up in the LHC beam pipe.

- Ion stimulated desorption (it can lead to vacuum instability)
- Synchrotron Radiation stimulated desorption
- Electron stimulated desorption
  (it can lead to a fast build-up of the e cloud)

Choice of the materials is fundamental !

Vacuum specifications for the warm sections of the LHC

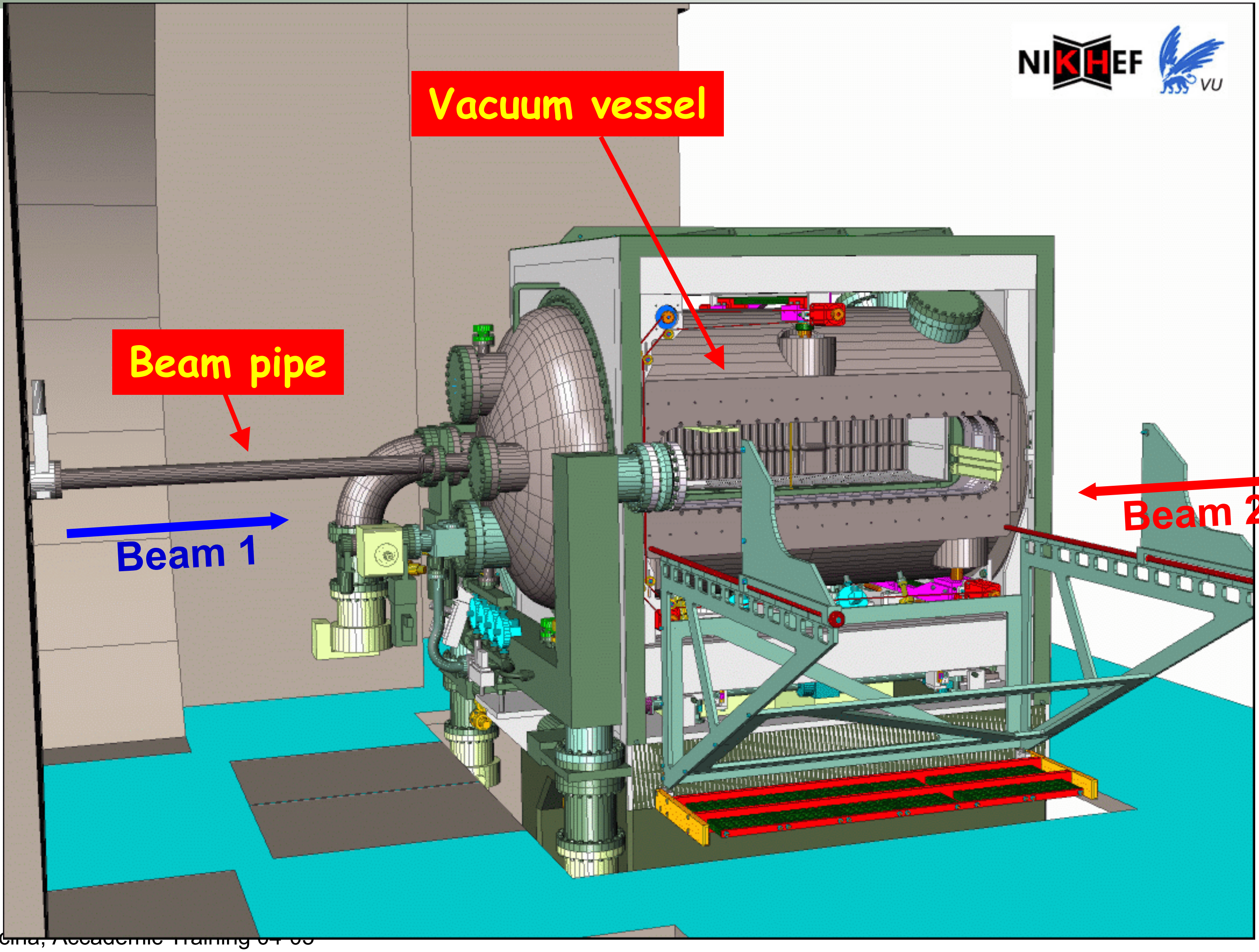
- UHV compatibility (no excessive outgassing)
- Compatibility with an in-situ bakeout to at least ~ 250°C for 24 hours to reduce gas desorption to assure vacuum stability
- Coated with Non-Evaporable Getters* (NEG) to pump and reduce Secondary Electron Yield. Heating to 200°C for ~ 24 hours is requested for the NEG activation

  * (getters are materials able to fix gas molecules on their surface. To do so, their surface must be clean. A way of producing a clean gettering surface is by heating the getter to the so called activation temperature)

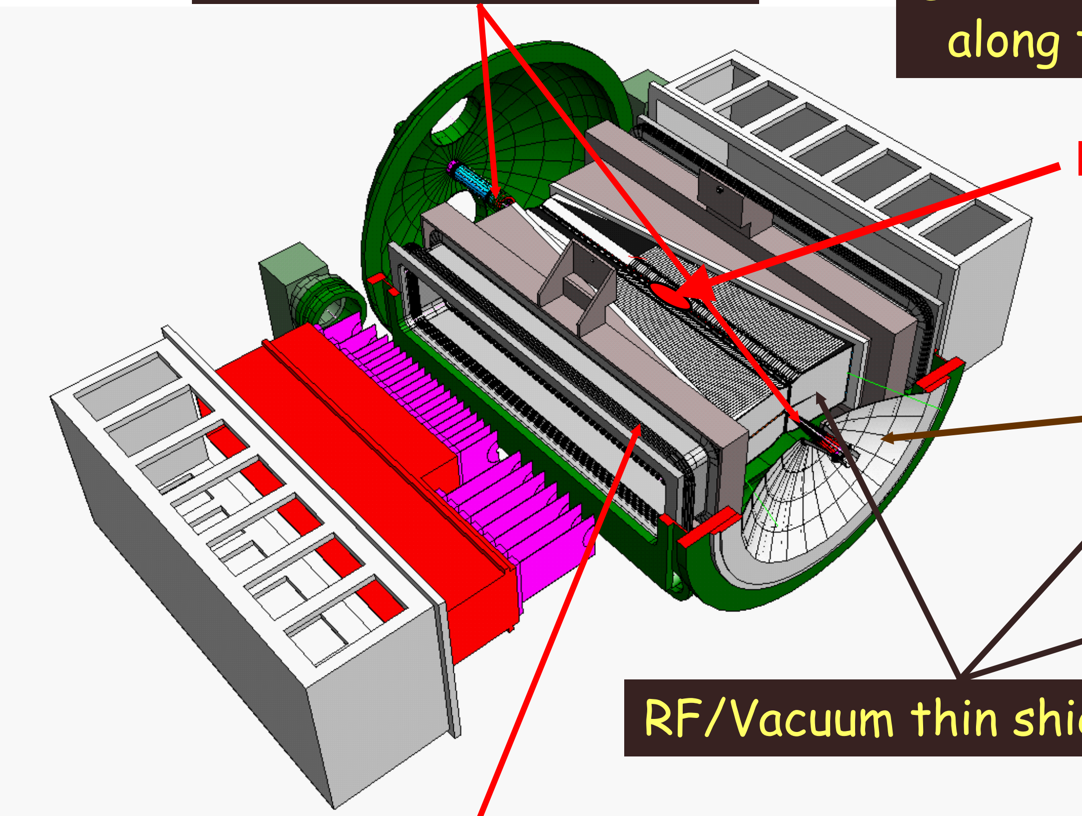
Integration issues into the LHC primary vacuum

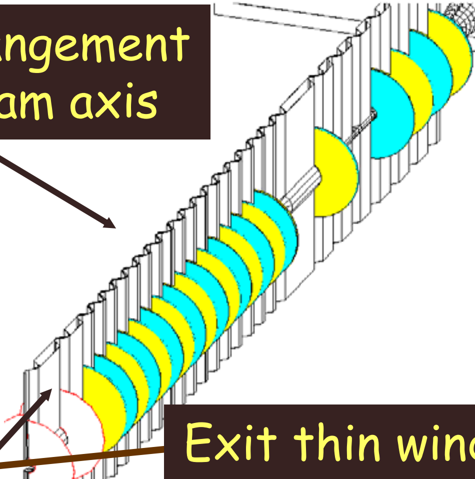
- Fulfil the very demanding LHC vacuum requirements in order to reach a pressure P ~ 10^{-13} bar
- Beam bunches passing through the near beam detectors structures can generate wake fields as a consequences of the geometrical changes and/or of the finite resistivity of the wall materials. This needs to be suppressed to avoid beam instabilities. It can be achieved by using low resistivity material and smooth vacuum chamber geometry
- The near beam detector has to leave enough aperture for the circulating beam during the whole cycle (from injection to dump)
- To avoid a major downtime of the machine, the reliability of the whole system has to be very high and the damage risk be minimized

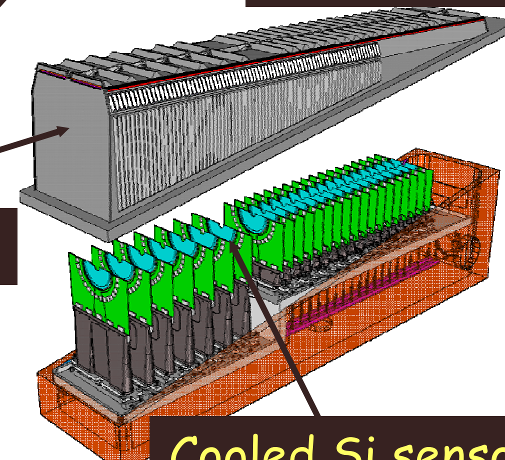
LHCb Vertex LOcator



VELO Mechanical design

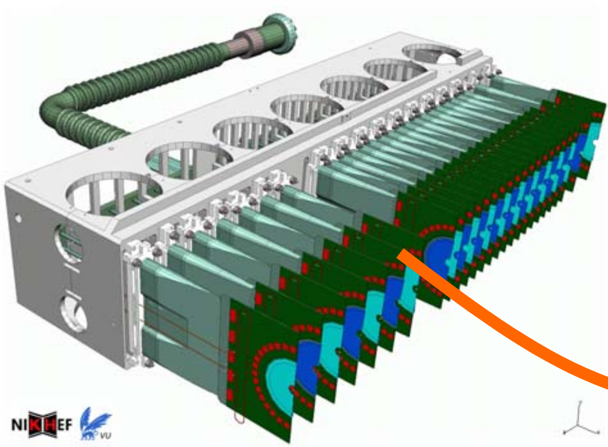


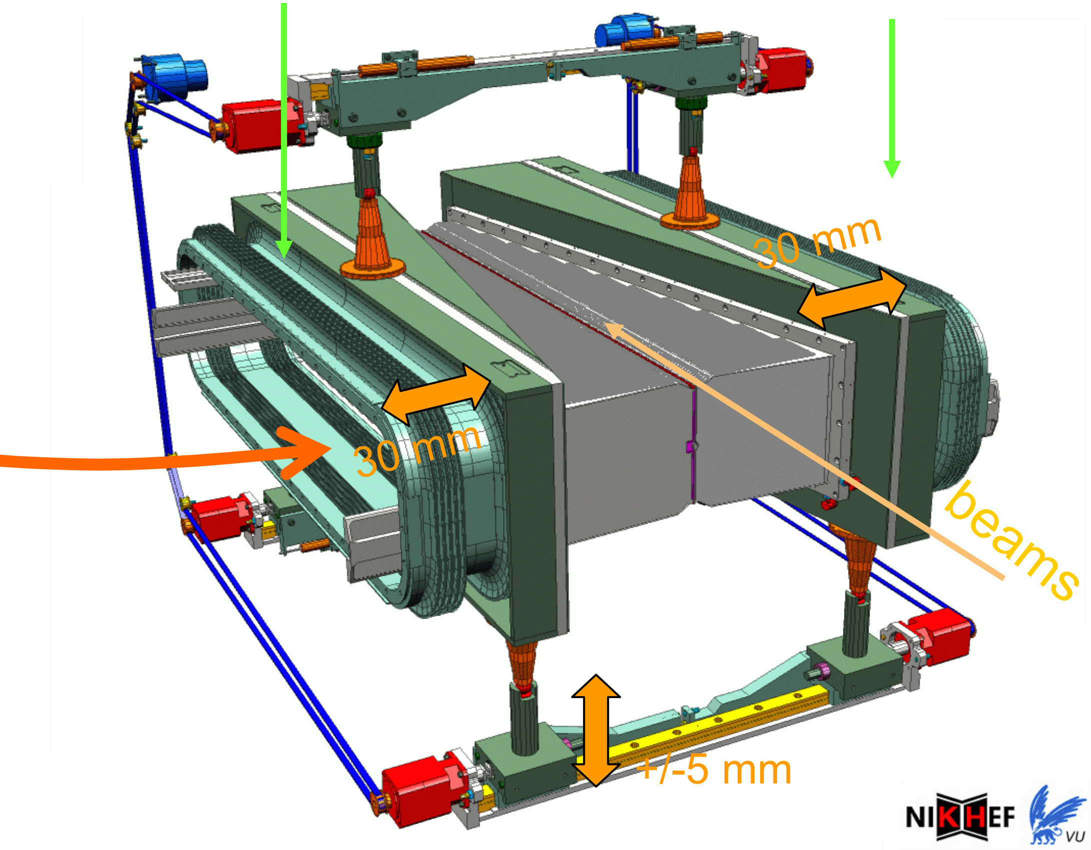




Movable Detector

Flanges fixed to vacuum vessel





Detector mounted to movable support to leave enough aperture at injection when the beams are bigger

Detector vacuum box

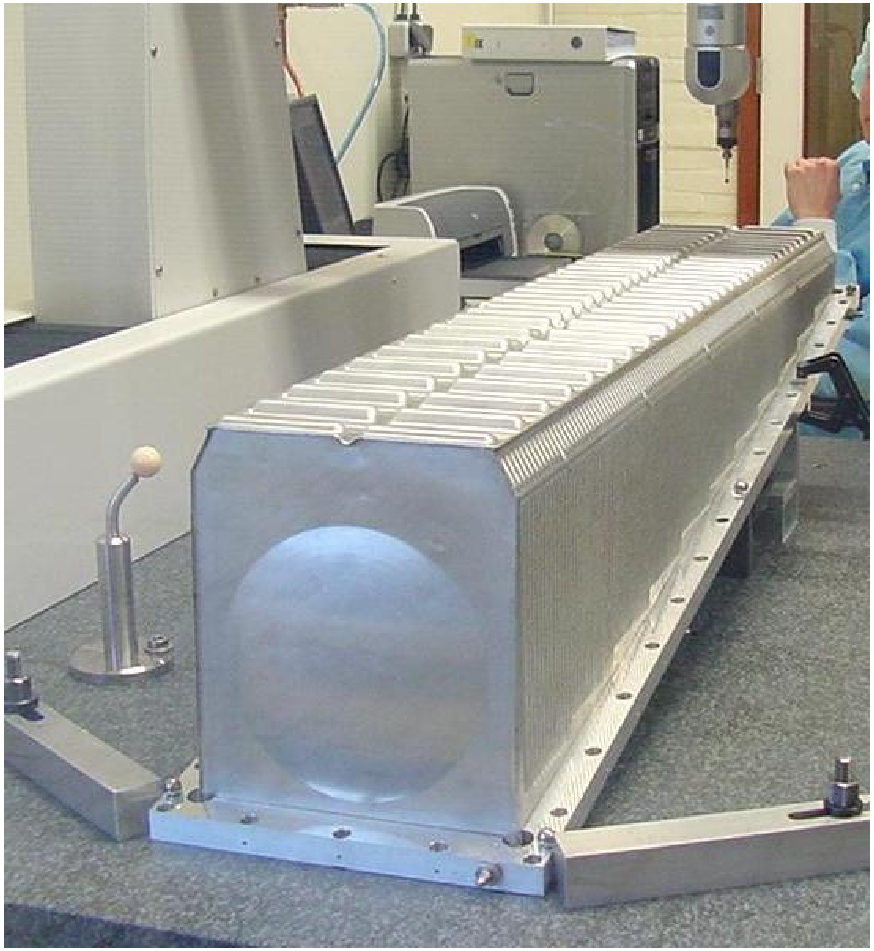
More than just a vacuum box…

LHCb physics requirements:

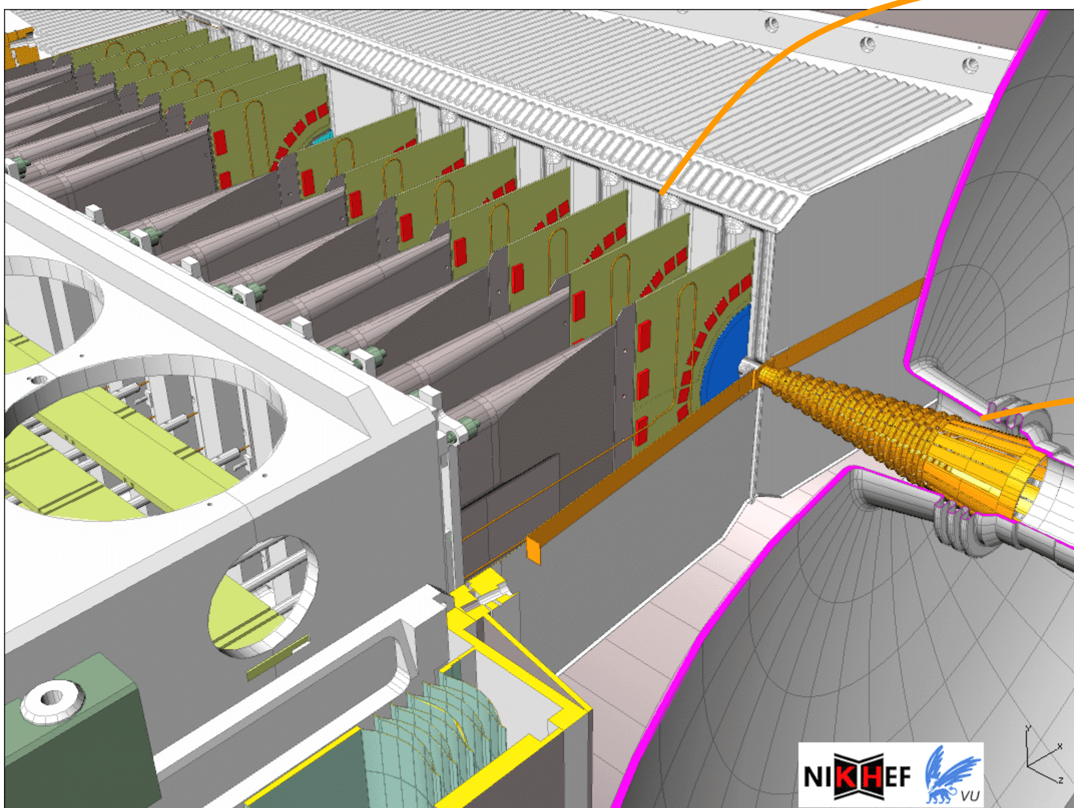
- be transparent… massless … non-existing… (~ 0.3 mm thickness)
- allow overlap of left sensors with right sensors
- shield sensors+electronics against RF

LHC machine requirements:

- leak tight
- be LHC-UHV compatible (AlMg3)
- suppress dynamic vacuum phenomena and e- cloud (NEG coating)

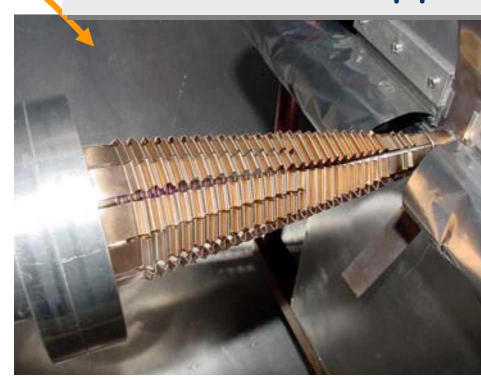


Smooth conducting structures…

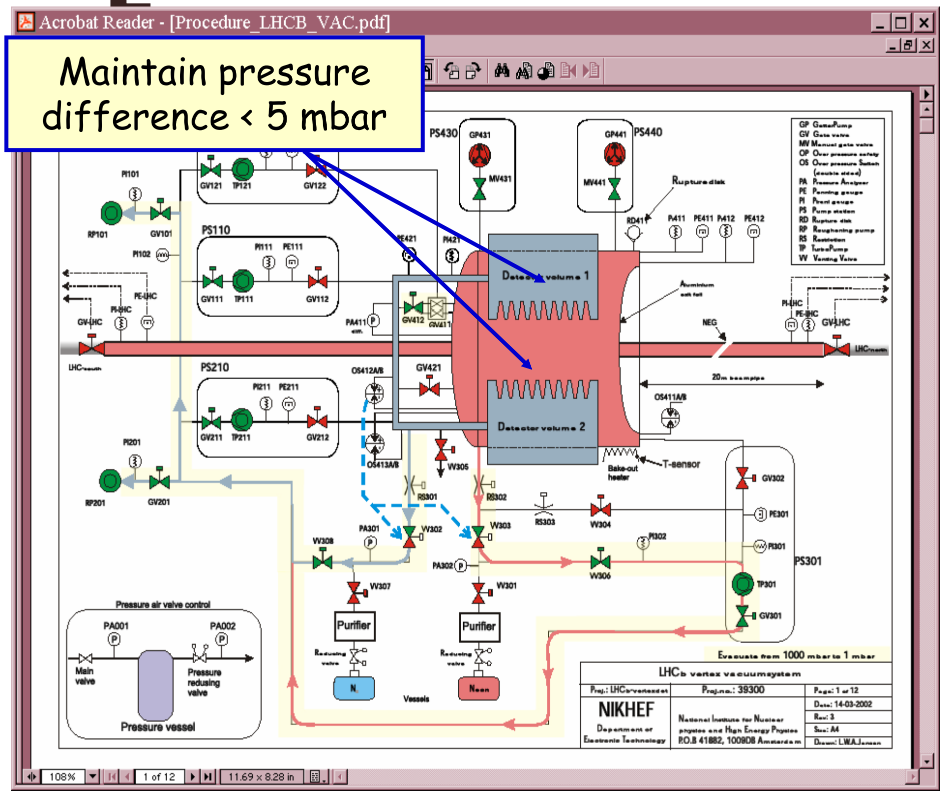


RF box corrugation

Wake field suppressor



Risk analysis



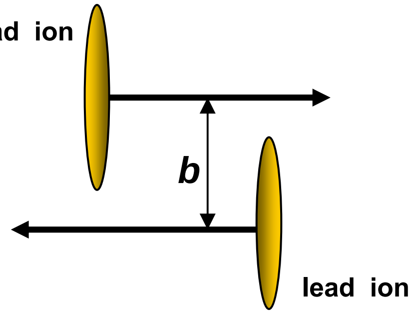
Some examples:

- Rupture or irreversible deformation of the thin foil: two kinds of safety valves to avoid Δp> 5 mbar
- Rupture of the exit window/beam pipe: fast valves to avoid contamination of the neighbouring sections
- Beam displacement: fast radiation detectors
- Power failure: UPS and high-power diesel generator

Even in the improbable case of the most catastrophic scenarios (which would require replacing VELO with an emergency beam pipe) the downtime for LHC would not exceed 2 weeks, provided the damage does not extend to the low-β triplets

Integration of ALICE ZDCs at IR2

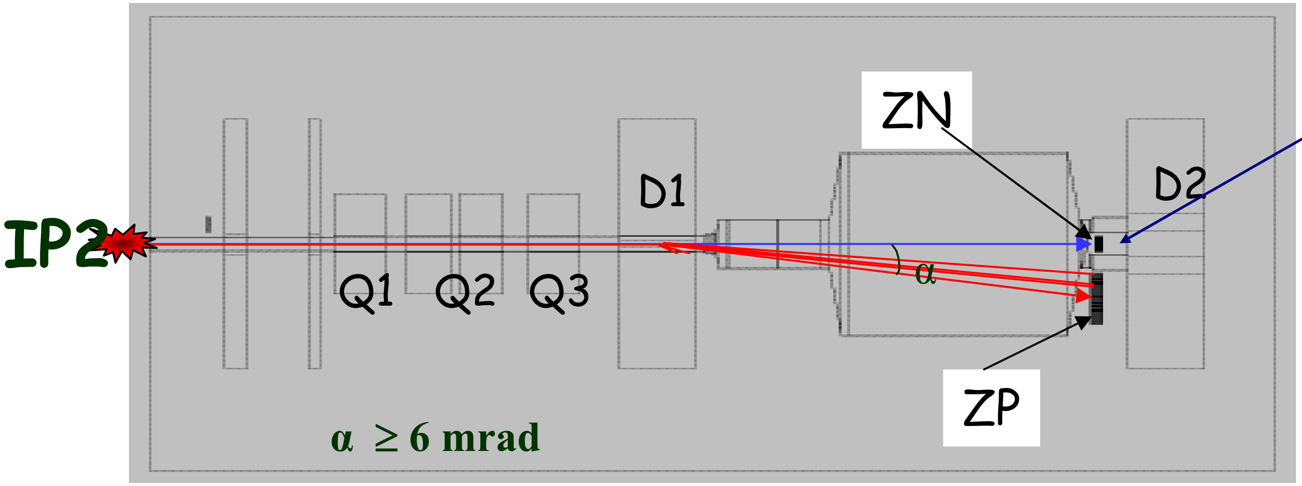
Impact parameter *b*

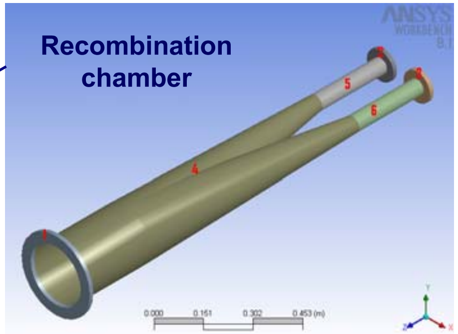


***b* is related to the number of non-interacting nucleons flying at ~ 0 degrees**

Integration in the tunnel

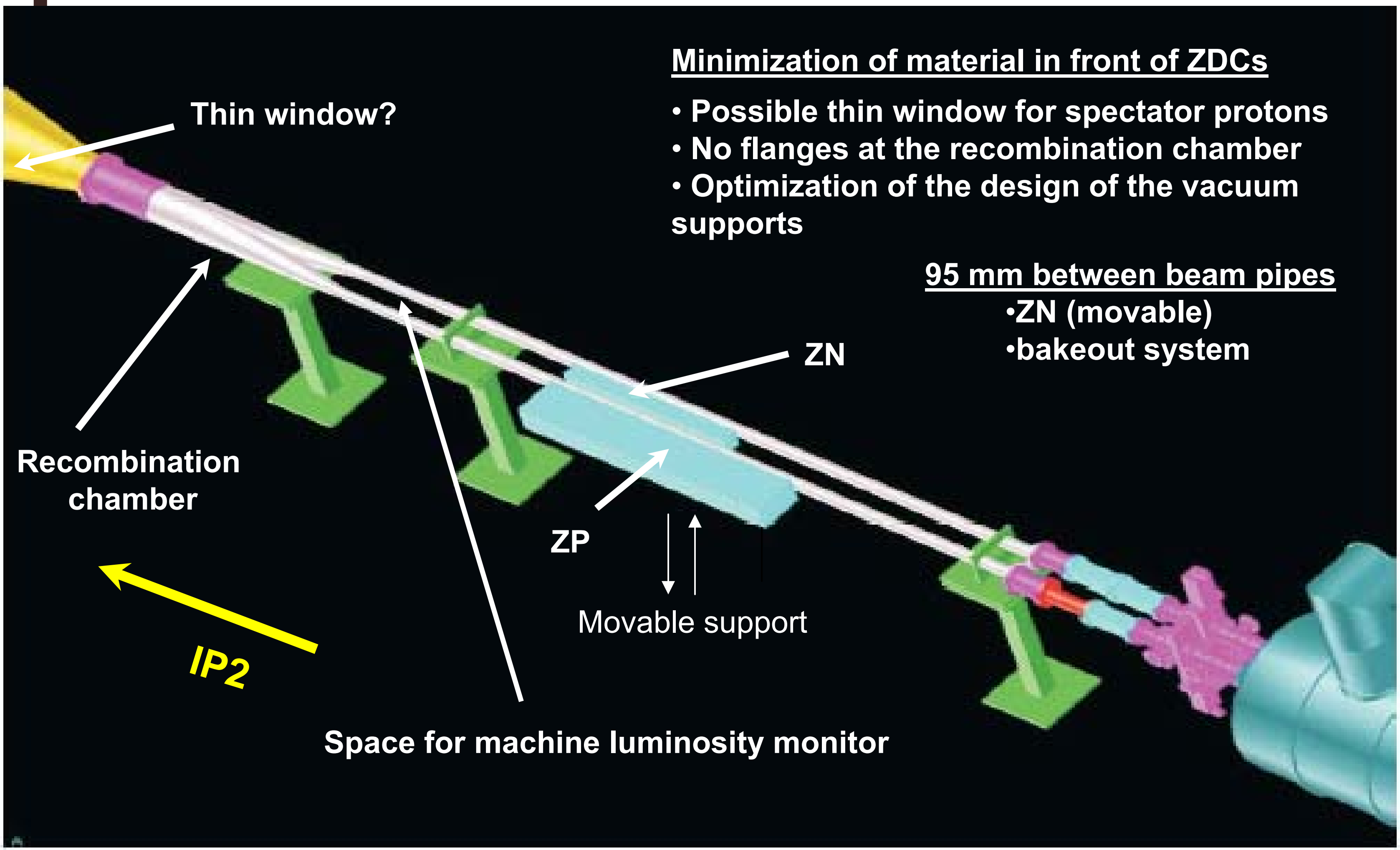
- Aperture from D1 to ZP: maximize the spectator protons acceptance in the ZP
- Minimize the amount of material in front of the ZDCs
- Enough space between the two beam pipes for the ZN



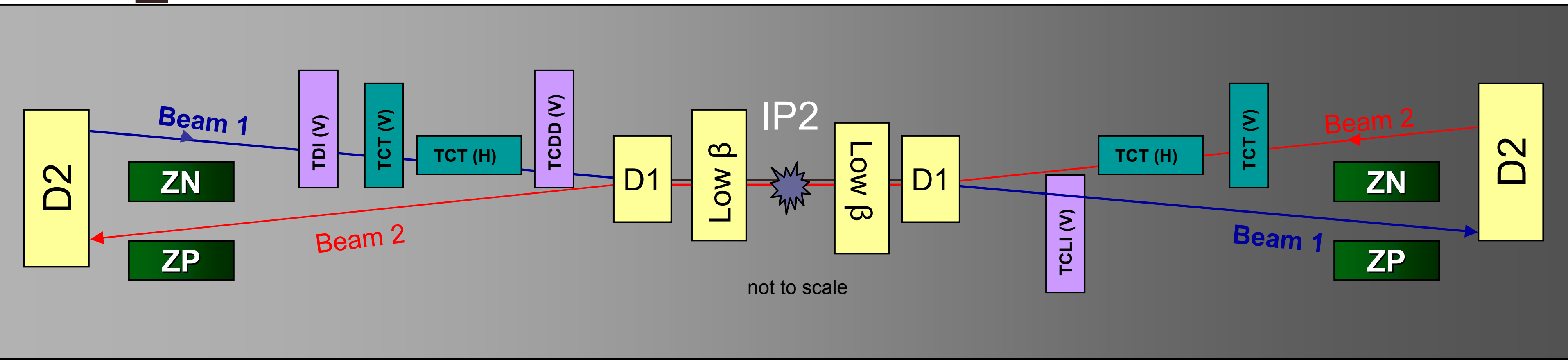


Courtesy C. Rathjen

Beam pipe layout close to ZDCs



IR2: injection and interaction region



Movable absorbers to protect from injection errors

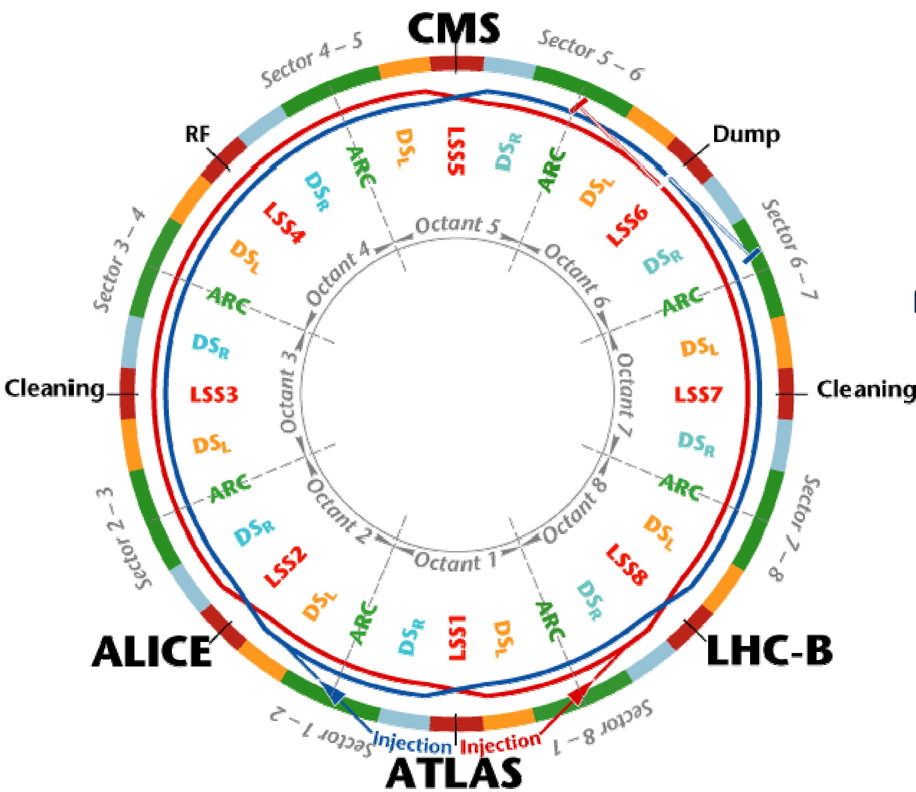
Movable absorbers to protect the low β triplet from peaks in the secondary beam halo

Their design takes into account the ZDCs aperture requirements (one common beam pipe)

Machine-induced background

- It consists of fluxes of secondary particles induced by proton losses upstream and downstream the IP
- The fluxes are proportional to the machine beam current, contrary to background from pp collision which scales with the luminosity at the IP
- In general it is due to the interactions of the beam protons with the residual gas nuclei resulting in multiple production of secondary particles
- Secondary particles from inelastic interactions cannot be transported through the magnetic structure of the machine
- Secondary particles from elastic interactions can successfully travel with the beam long distances and interact far from the point of the primary collision

Origin of the machine induced background



Inelastic scattering

Beam protons collisions with nuclei of residual gas in arcs, DS and LSS

Elastic/diffractive scattering

Beam protons collisions with nuclei of the residual gas with a leading p in the final state

Cleaning inefficiency

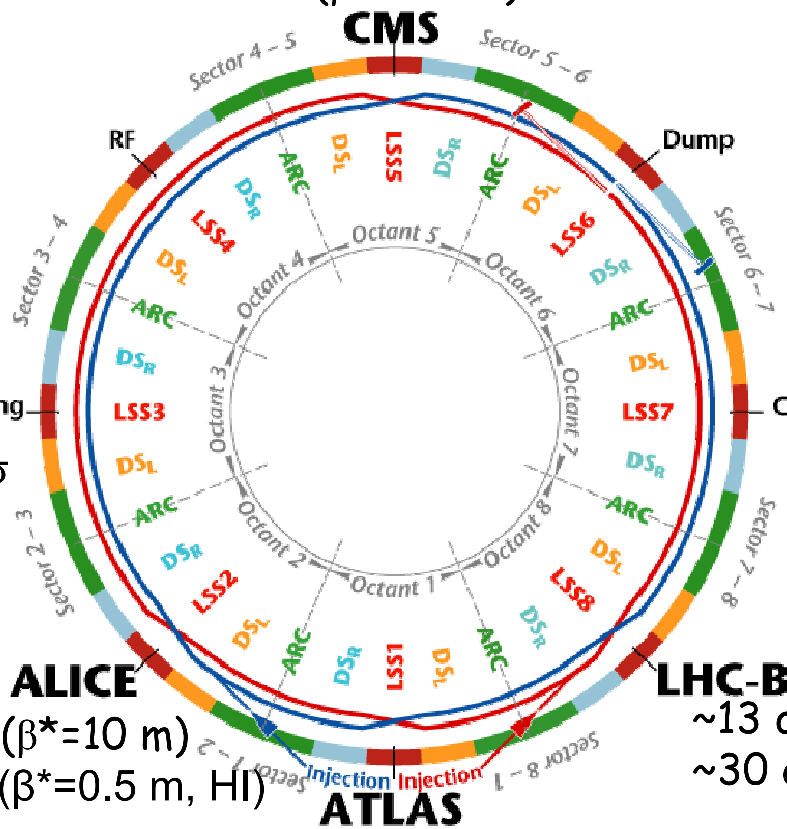
Beam p out-scattering from the collimators not followed by the absorption in the other elements of the cleaning system

Collisions at the IPs

Energetic p produced at the IP which may be transported to and lost in the next IR

Where do we lose particles?

~10 σ (β*=0.5 m)



~ 15 σ

~6-7 σ

~30 σ (β*=10 m)
~10 σ (β*=0.5 m, HI)

~13 σ (β*=1 m)
~30 σ (β*=10 m)

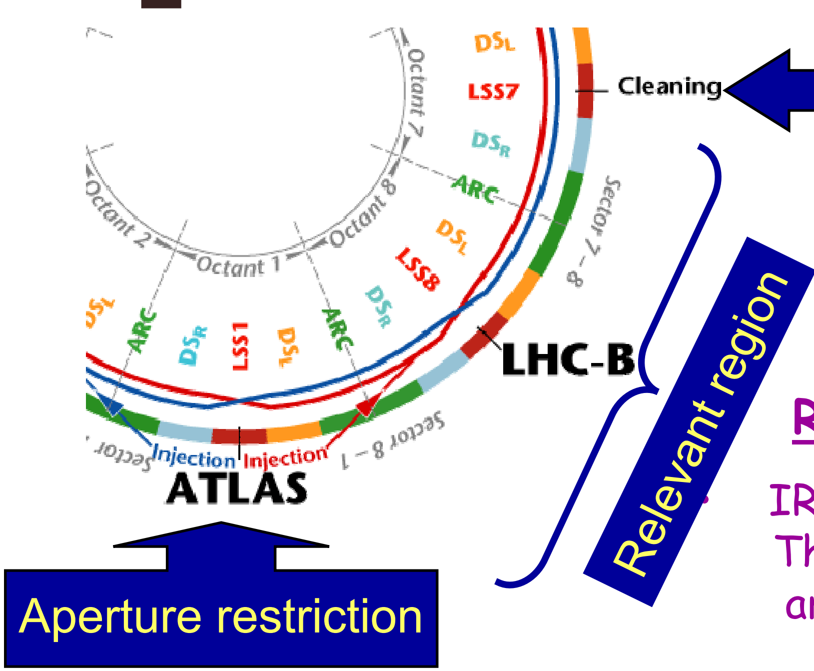
~10 σ (β*=0.5 m)

$$L \propto \frac{N_1 N_2}{\beta^*}$$

Particles are likely to be lost in the machine aperture restrictions. At collision, the aperture restrictions are:

- low-β triplets in exp. LSS
- collimators in exp. LSS
- collimators in IR3 and IR7

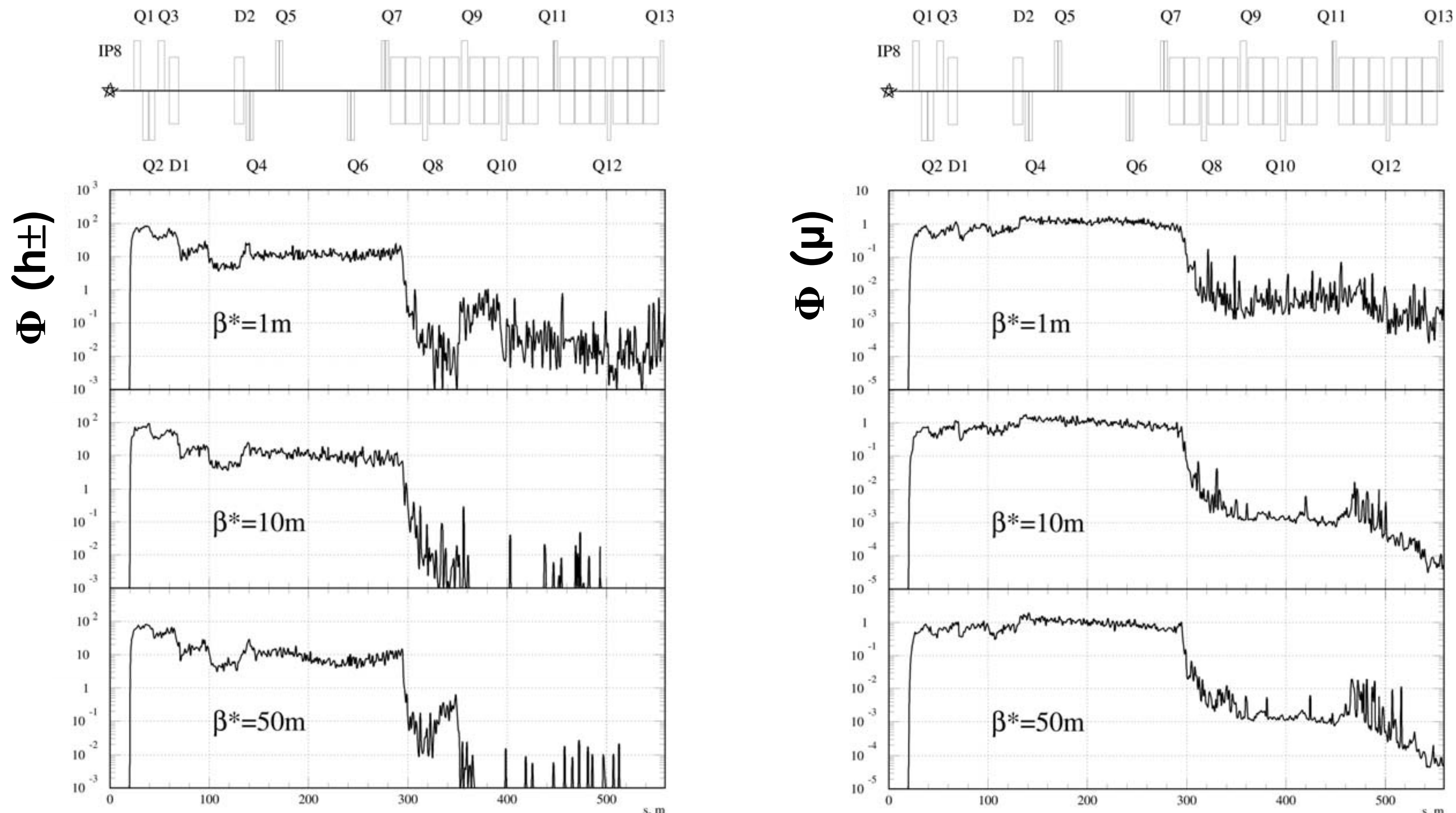
Example: induced background simulation at IR8



Reduction of the problem and assumptions

- IR8 is situated between two aperture restrictions. Therefore, only particles produced in the octant 8 are relevant to the simulation
- Previous simulations have demonstrated that:
  - Beam gas scattering is the main distant source of losses in IR8
  - Contributions from collimation inefficiency (IR7) is negligible
  - Contribution from IP1 negligible

Results from simulation



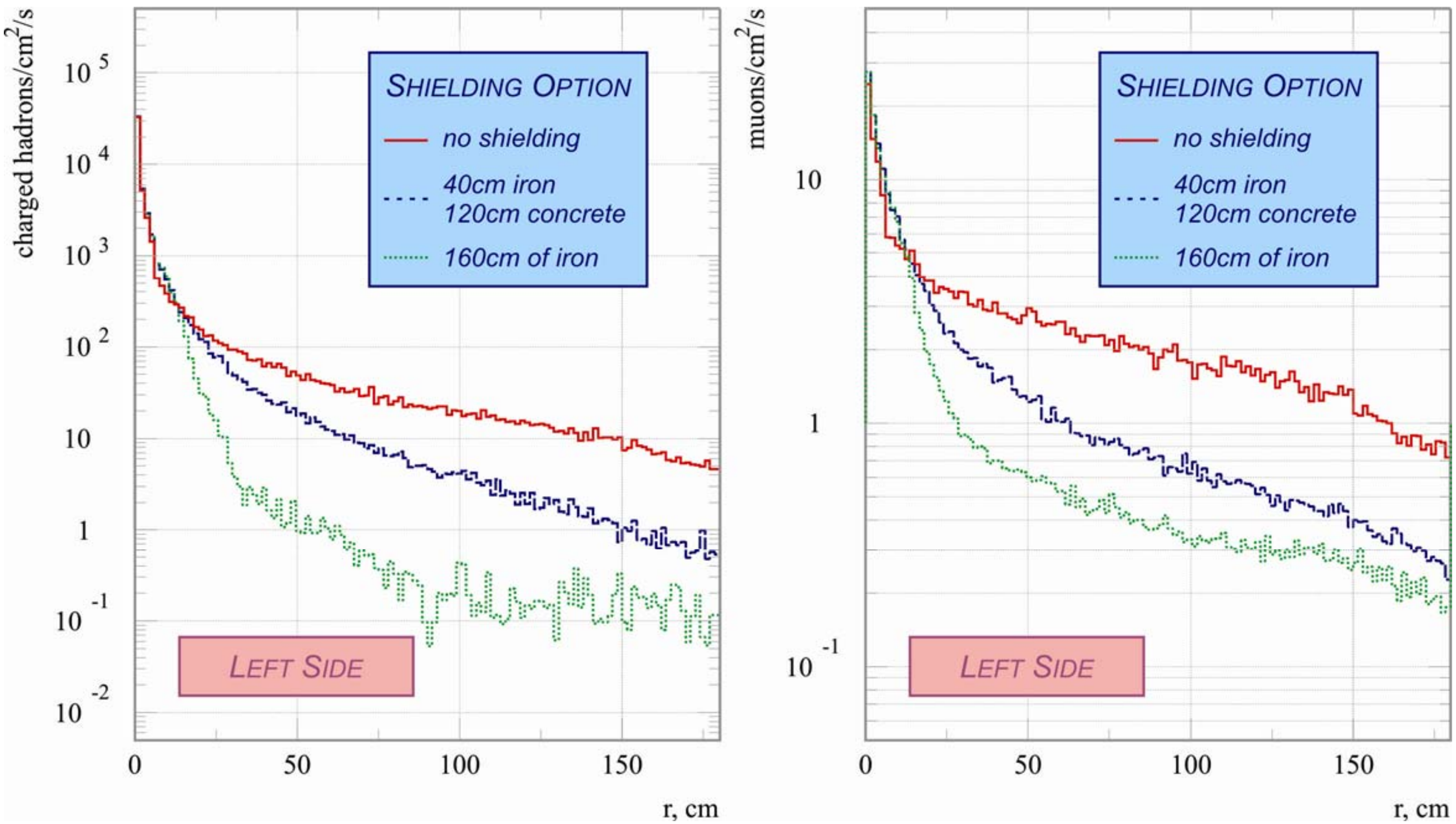
Courtesy V. Talanov

Particle fluxes entering the LHCb cavern as function of the distance of the primary interaction from IP8

Consequences for the LHCb experiment

- The machine induced background degrades the efficiency of the LHCb trigger (in particular the muon trigger). The relative signal efficiency loss depends on the assumed gas densities in the LSS,DS and arcs around IP8 during the various phases of the LHC commissioning and operation
- Simulations have been performed to study the efficiency of a shielding at both entrances of the LHCb cavern
- The simulation results show a relevant decrease of the machine induced particle fluxes
- Therefore, a shielding has been implemented at both entrances of the LHCb cavern taking into account, of course, the space constraints in the machine tunnel

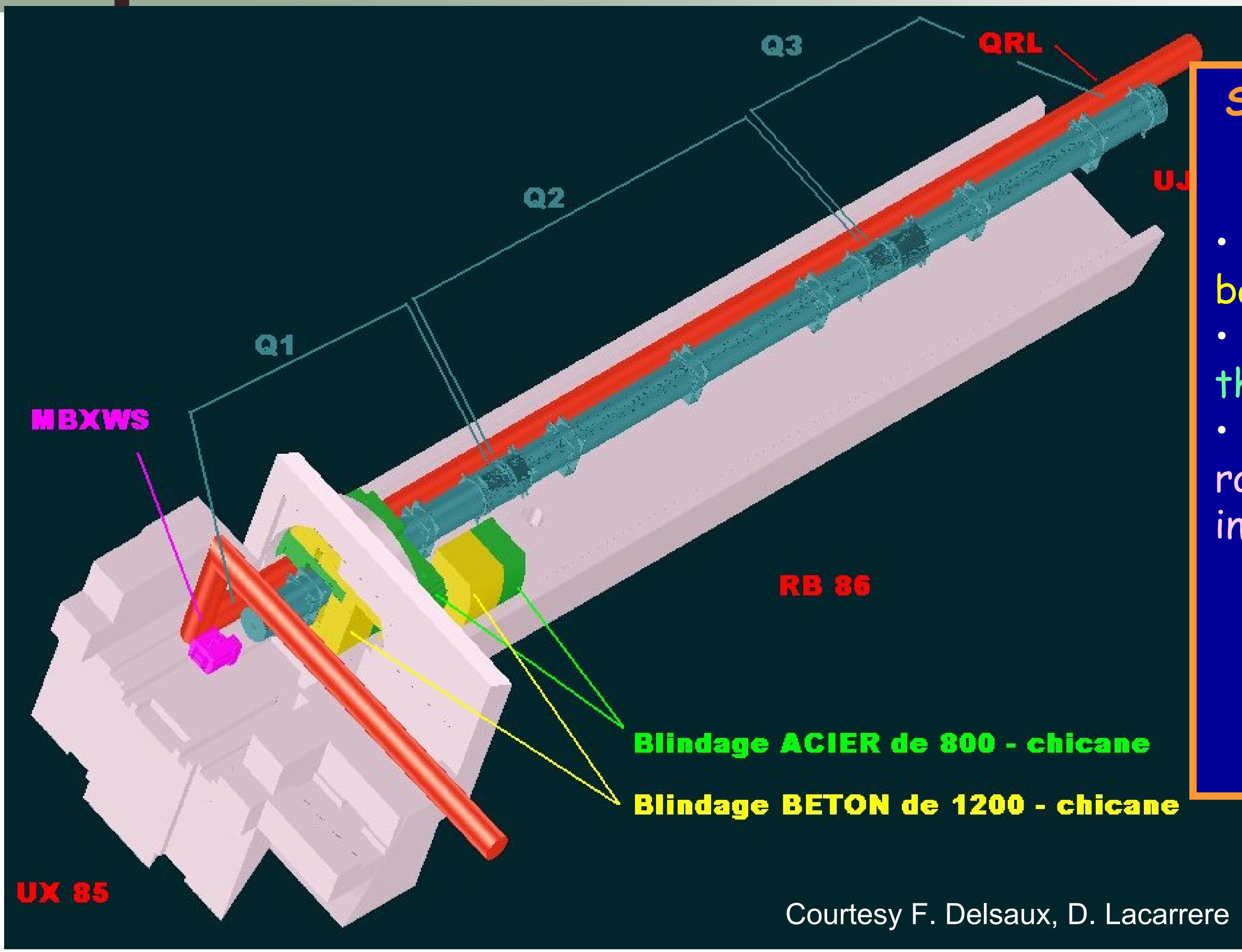
Machine induced background simulation results



Radial distribution of particle flux density at the entrance of the LHCb cavern

Courtesy V. Talanov

Shielding implementation (right side)



Courtesy F. Delsaux, D. Lacarrere

Shielding implementation criteria

- minimization of LHCb background
- the space available in the tunnel
- minimization of the radiation levels both in the tunnel and in UX85

Signal exchange between experiments and the machine

- It concerns the interaction between the machine and the experiments during the LHC operation
- Two working groups are dedicated to this subject:
  - LHC Experiment Accelerator Data Exchange (LEADE) where the user requirements are discussed

    http://lhc-data-exchange.web.cern.ch/lhc-data-exchange

  - LHC Data Interchange Working Group (LDIWG) where the user requirements are discussed at the technical level (both hardware and software)

http://ab-div-co.web.cern.ch/ab-div-co-is/Controls/WG/LDIWG/Welcome.html

Data flow from Experiments to Machine

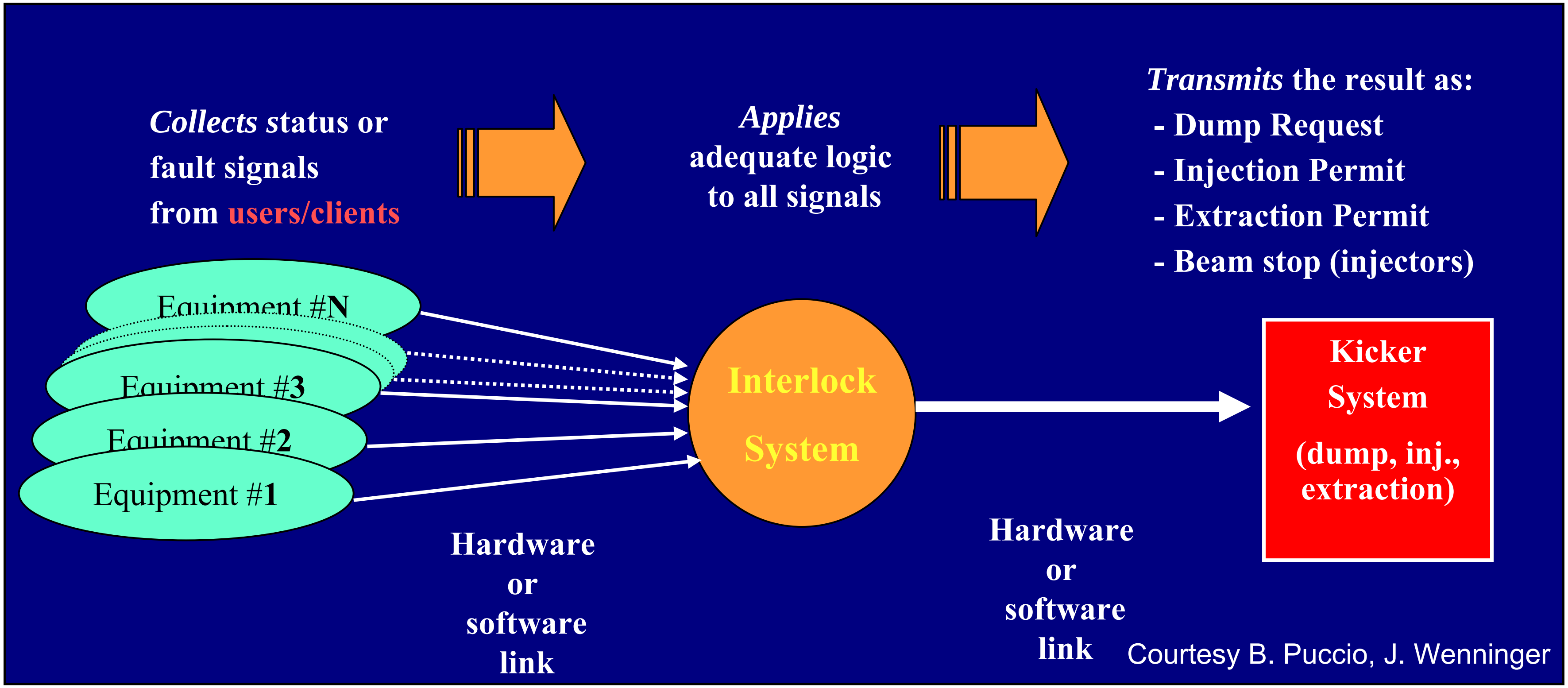
Entity	Detail	Remarks
Spectrometer Magnets	Currents and polarity	
Position of Movable Detectors	LHCb VELO (TOTEM and potentially ATLAS Roman Pots)	The Roman Pots will be operated by the machine . It is an input signal for interlocks
Background Measurements in detectors	Spatial and temporal distributions	
Beam condition monitors	Standardized background monitors used as reference for machine tuning	Used also as input signal for the interlocks
Beam Characteristics	Vertex position (x,y,z) Luminous region	ATLAS&CMS: Vertex Precision ± (0.01, 0.01, 2) mm. Lum. Region: 95% in ± 9 cm (< 5% outside ± 11 cm to preserve detector performance)
Absolute and Instantaneous Luminosity	Various sources for instantaneous (calorimeter currents, dedicated counters);TOTEM for absolute	
Interlocks	See later…	See later..
…………….		…………………

Data flow from the machine to the experiments

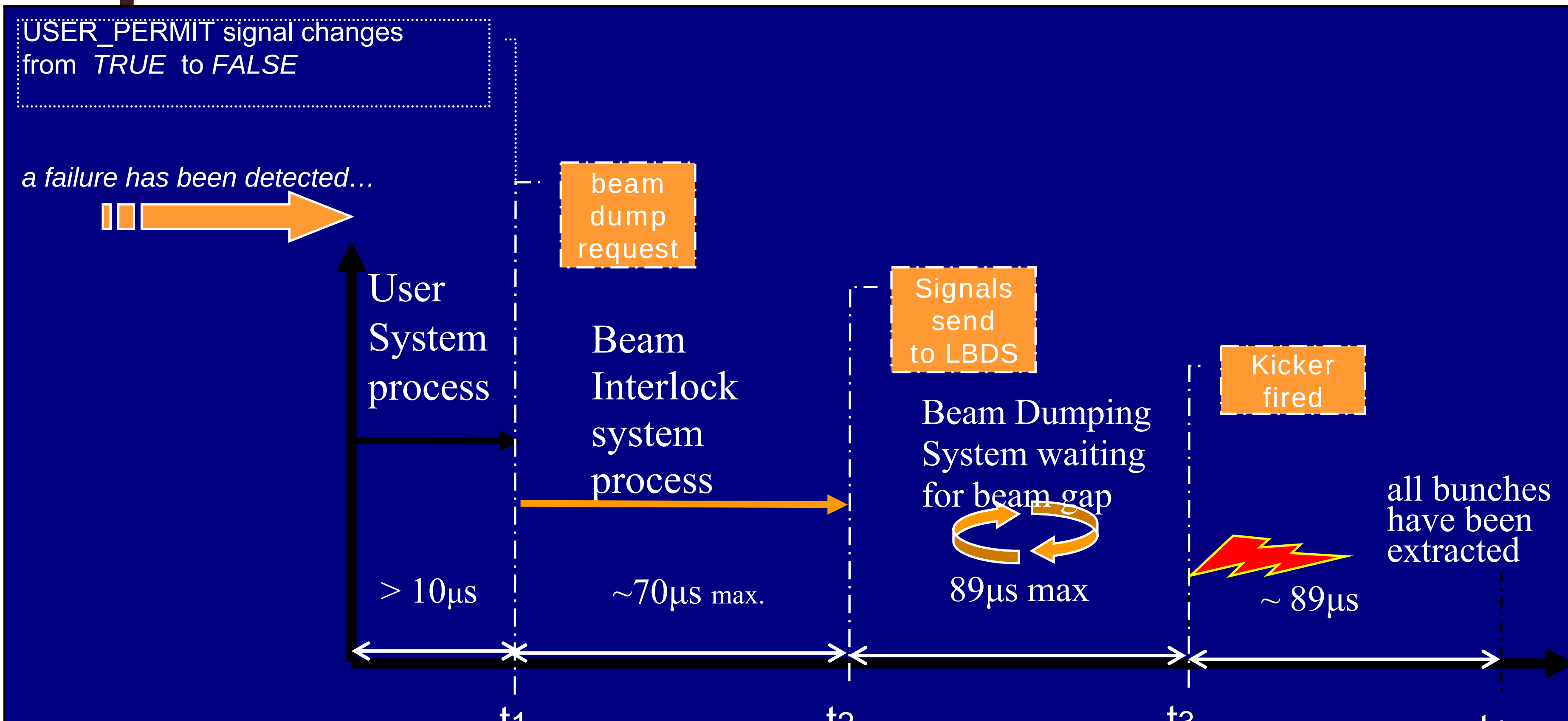
Entity	Remarks
Total beam intensity	
Individual bunch intensity	
Average transverse beam size	
Average bunch length	
Total longitudinal distribution	To detect ghost bunches at 0.1% of the nominal
Average beam transverse position	From the BPMs located at the Quadrupoles either side of each IP
Luminosity	Relative measurements between bunches
Average beam loss	Average of up to 50 selectable BLMs
Clocks and timing signals	Detector synchronization
Machine status	See later
……………………..	…………………………

Machine-Experiments Safety: Beam Interlock System

- collect interlock signals from users/clients
- apply an adequate logic to the signals
- transmit result to the relevant system for 'action'



Interlock Response time



The achievable TOTAL response time is in the range of 100 µs to 270 µs

(between the detection of a beam dump request and the completion of a beam dump)

Courtesy B. Puccio, J. Wenninger

Interlock for the experiments

Machine Cycle Modes* (transmitted to the experiments over hardware link)
Injection
Ramp
Squeeze
Unstable beams
Stable beams (data taking for exp.)
Beam Dump
Recover

Experiments Interlocks

(transmitted by the experiments to the IS via hardware link)

Injection inhibit

It prevents extraction from SPS. It indicates that experiments voltages are not set for injection or movable devices not in position for injection

Beam Dump

It indicates that backgrounds are over acceptable level

Position Interlocks for movable devices

Movable devices are allowed to leave their garage/out position only during stable beams. If not true, it would lead to an injection inhibit or dump

*This is just an example. LHC modes are not officially defined yet

Additional considerations on interlocks

- Roman Pots are special devices since they can 'compete' with the collimators in terms of beam scraping (distance from the beam is ~ 10 σ). They have to be in the shadow of the collimators for beam/device protection reasons. Therefore, they will be operated by the global collimator control system.
- When the machine is in "stable beam" operation mode and, in particular, the Roman Pots and VELO in the IN position, risky operations like squeezing and major retuning of the machine should not be allowed without informing the experiments that may take appropriate steps to minimize the possible damage to the detectors. The definition of "risky operations" is not unique and experiment dependent………discussion needed
- etc…..

CONCLUSIONS

- I hope that the 5 lectures have convinced you that the machine-experiments interface is fundamental in order to fulfil the challenging LHC Physics Goals
- I would like to underline that the machine-experiments issues imply a strict collaboration among the experiments, the AB, AT, PH and TS Departments
- Please, do not hesitate to contact us for future questions and information on this subject

Thank you for your attention