A preliminary Specification for the Collimation system of LHC

BI review, 20th Nov 2001

J.B. Jeanneret

/Text/LHC/2001/coll/bi_rev_nov/rev.tex

Outline

- Collimation of the beam halo (the primary goal of the system)
- Number and kinds of collimators
- Specification data (not exhaustive)
- Single pass losses and machine integrity
  - injection oscillations
  - injection kicker errors
  - dump kicker errors
- Strategical considerations

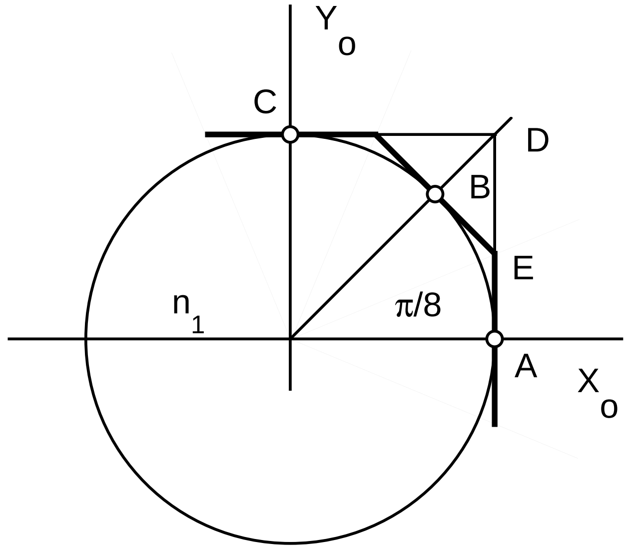
Needs and basic parameters

To protect the machine aginst beam losses, we need :

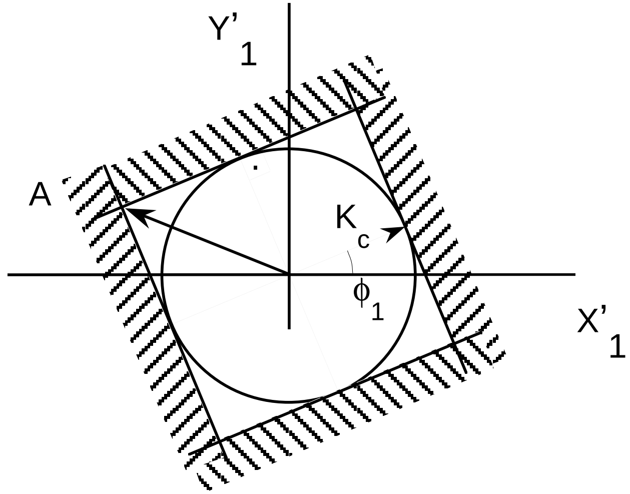
- β-collimation - never questioned
- δ_p-collimation
  recurrently questionned, but mandatory (RF capture at injection, Longitudinal lifetime at top energy)
- primary and secondary collimators
  (machine aperture : $10\sigma_\beta$ both arc@inj and low-beta@collision)
- transverse collimation location $n_1 < 7$, $n_2 < 8.5$ (normalised)
  (see Ralph's talk)

Optics and scattering

injection



top energy



$$n_1 = 7, n_2 = 8.2 \rightarrow K_c = \sqrt{n_2^2 - n_1^2} = 4.2$$
$$\Rightarrow A_{sec} = \sqrt{n_1^2 + 2K_c^2} = 9.2$$

Real case : 9.8 (optics not optimum, true scattering)

Table 1: Correlated phase advances μ_x and μ_y and $X - Y$ jaw orientations α_{Jaw} for three primary jaw orientations α and four scattering angles ϕ with $\mu_o = \cos^{-1}(n_1/n_2)$.

α	ϕ	μ_x	μ_y	α_{Jaw}	
0	0	μ_o	-	0	mom. coll.
0	π	$\pi - \mu_o$	-	0	mom. coll.
0	$\pi/2$	π	$3\pi/2$	μ_o	mom. coll.
0	$-\pi/2$	π	$3\pi/2$	-μ_o	mom. coll.
$\pi/4$	$\pi/4$	μ_o	μ_o	$\pi/4$	
$\pi/4$	$5\pi/4$	$\pi - \mu_o$	$\pi - \mu_o$	$\pi/4$	
$\pi/4$	$3\pi/4$	$\pi - \mu_o$	$\pi + \mu_o$	$\pi/4$	
$\pi/4$	$-\pi/4$	$\pi + \mu_o$	$\pi - \mu_o$	$\pi/4$	
$\pi/2$	$\pi/2$	-	μ_o	$\pi/2$	
$\pi/2$	$-\pi/2$	-	$\pi - \mu_o$	$\pi/2$	
$\pi/2$	π	$\pi/2$	π	$\pi/2 - \mu_o$	
$\pi/2$	0	$\pi/2$	π	$\pi/2 + \mu_o$	

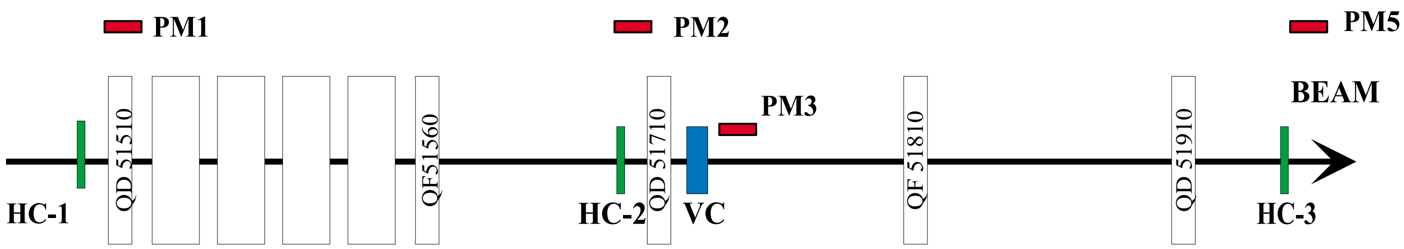
Real LHC optics: only an approximation of this perfect case

$$\text{Efficiency as product of :} \quad \text{tertiary flux/input flux}$$
$$\text{(here old simulation, see Ralph's talk)}$$
$$\text{and dilution of the tertiaries in the arc}$$

Using: Primary collimator $n_1 = 6\,\sigma_\beta$ and secondary $n_2 = 7\,\sigma_\beta$

Energy	Ring aperture in σ_β			
	20	10	8	
	Inefficiency [1/m]			
.45 TeV	6×10^{-6}	3×10^{-5}	2×10^{-4}	
7 TeV	5×10^{-6}	2.5×10^{-5}	1×10^{-4}	
	Margin factor			*Loss case*
.45 TeV	120	25	3.5	3% off bucket at ramping
7 TeV	300	60	15	$\tau_{\mathrm{beam}} = 40$ hrs

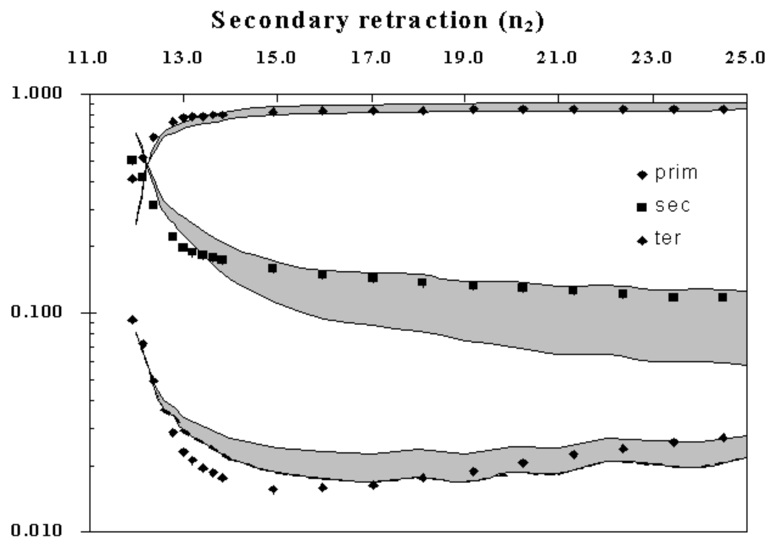
A collimation experiment at 120 GeV in the SPS



- Three horizontal collimators (HC-i) (PRIM-SEC-TER) + One vertical
- 120 GeV coasting beam made to diffuse with noise in a damper
- Measurement of the inelastic rates in all collimator with scintillators
- Fix $n_1 = 12$ (PRIM) , $n_3 = 18$ (TER - Simulates a ring aperture limitation)
- Vary $n_2 = [12, 25]$ (SEC)
- Compare to K2 (+GEANT) simulations

Experiment at 120 GeV - Thesis of Nuria Catalan

- Dots : data , Grey areas : K2 simulation, $\mathbf{n_1 = 12}$, $\mathbf{n_3 = 18}$, $\epsilon_n = 3.75\ \mu$m
- Multiturn effect clearly visible
- Worst relative difference data/simulation : 40%



Here: Efficiency without tertiary dilution is 1.5%

Mechanical tolerances

Based on old simulations (TT+JBJ)
but more systematic ones are going-on (Ralph Assmann)

Basic reference number: Relative normalised retraction PRIM/SEC

$$\Delta n = n_2 - n_1 \simeq 1 \text{ with } \sigma_\beta \simeq 250\ \mu\text{m} \ (7\text{TeV}) \tag{1}$$

- mechanical+survey $\sim 150\ \mu$m r.m.s (Present offer)
  $\rightarrow$ *a priori, no need of angular control, see Ralph's talk*
- deformation under heat $\sim 30\ \mu$m max (spec.)
  requires heat input, steady and transient,see below
- CO stability $\sim 20\ \mu$m rms (7 TeV) (spec.)

Kinds of collimators

- Low Z better (efficiency,energy density vs. impacting flux)
  $\rightarrow$ *OK for primary collimators: Al*
- Secondary ones must absorb $\rightarrow$ Be, Al : 160 cm ,Cu : 60 cm (4 abs. length)
  compromise with mech.precision/simplicity $\rightarrow$ $\mathbf{Cu}$
  but stategy against destructive events need more work, see below
- Present choice :

PRIM :	Aluminium	20 cm
SEC :	Copper	50 cm
SINGLE PASS, inj+exp :	Copper (Al?)	100 cm
SINGLE PASS, dump :	Low Z	to be studied

Number of collimators per beam and total

Function	Prim	Sec	Single Pass	beams
β-coll.	4	16	-	2
δ_p-coll.	1	6	-	2
IP2,8-inj	-	-	2	2
IP1,5-exp	-	-	4	2
DUMP	-	-	2?	2
Total:	10	44	12 + 4?	-
Total tanks:	66 + 4?	(all kinds)		
Total motors:	132 + 8?	(all kinds)		

? : low-Z against dump failure, to be studied /decided

Steady power deposition - Momentum cleaning

Normalised to 3×10^9 protons/s captured in the insertion
or : beam lifetime of $\tau_{\mathrm{beam}} = 40$ hours ($\rightarrow \tau_{\mathcal{L}} < 20$ hours)
(Target value of yellow book)

Collimator	Injection P [W]	Collision P [W]	
TCP1	0.45	3.2	
TCS1	19	**606**	($\tau_{\mathrm{beam}} = 4$ hr $\rightarrow 6$ kW)
TCS2	14	158	
TCS3	13	160	
TCS4	3.8	69	
TCS5	3.0	51	
TCS6	1.2	24	

Open issue: What shall be the target value for τ_{beam} in collision?

At injection : $\tau_{\mathrm{beam}} = 4$ hr OK

Power and energy deposition

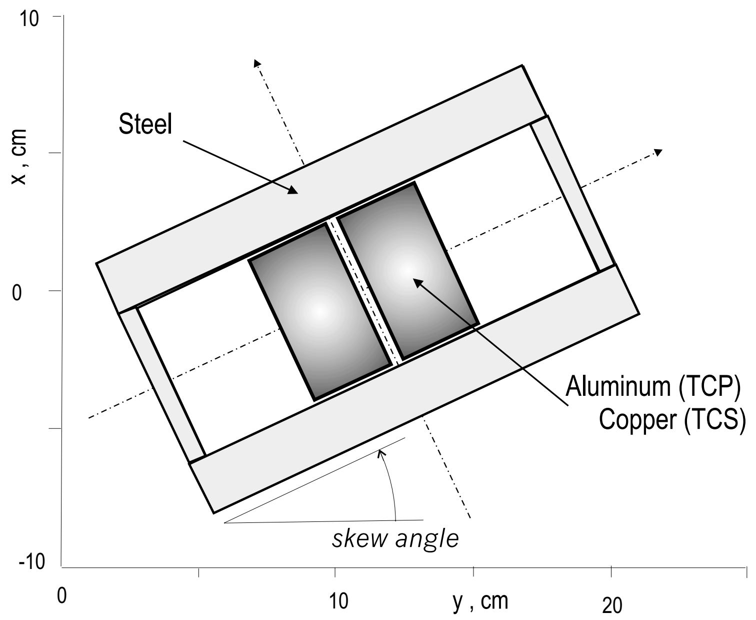
- Energy and power maps studied by SL/AP and IHEP/Protvino (partly done, future is subject to approval of a new contract)

- Heat diffusion and extraction by EST, including thermal deformations *(deadline worries, to be clarified)*

Collective effects

- Need tapering - Need longer tanks ($\simeq$ 20 cm), no major difficulty
- Request for longitudinal RF contact - More annoying
  (unless distance to wall small enough - not yet quantified)

(cut view, beam orthogonal to drawing, drive/motor not shown)



Expected radiation doses per year

Input : $1/3$ *of all injected beam lost at 7TeV in IR3 and IR7*

$\Rightarrow 10^{16}$ protons/yr

	Dose[MGy/yr]
Jaws(max)	~ 110
Tanks(max)	~ 2
Motors	~ 0.1
BPMs	~ 1

Destruction limits - Based on simul. by Igor Baishev

Margin on destruction case : $\sim 30\%$

Number of bunches computed with 1 bunch $n_p = 1.05 \times 10^{11}$

Impact angle : $\pi/2$, straight on

	Copper	Aluminium	Berylium
Nb of bunches	N_b^d	N_b^d	N_b^d
Injection	5	44	
Top	0.05	0.5	5
(Top, grazing/arc	0.4)	-	-

Single pass losses

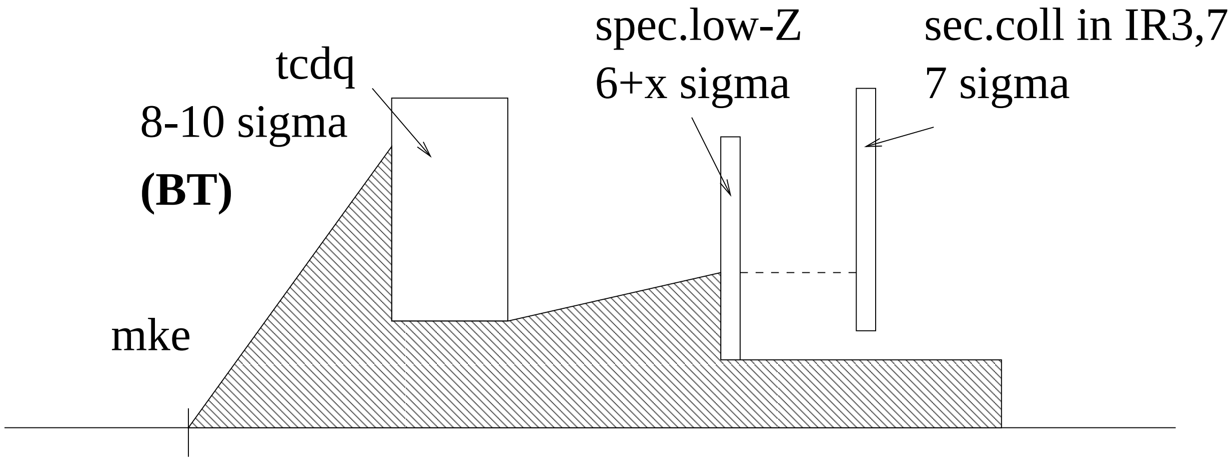
- Injection oscillations
- mis-fire of injection kicker, TDI does the big job, supplemented by two 1m-long collimators (Cu,Al) in IR2,8 *kicker sweep error: 220 bunches on TDI,* ≤ 4 *on collimator.*
- mis-fire of dump kicker: *More difficult*

Injection oscillations

- Collimation in IR3 and IR7 cannot protect the ring from bad injections in IR2 and IR8 during the first turn
- 5 bunches out of 240 are destructive
- The TDI protects only from MKI errors (Vertical, one phase)
- *Need a deep collimation near the end of the transfer lines*
- Discussed at Chamonix 2001: *still under study*
  - Cut at 5+x σ_β H and V
  - At least two phases (0, $\pi/2$)

Recently opened issue: MKE module erratic trigger

More frequent than earlier expectations ($\sim$ once per year)
Need to protect the secondary collimators (in addition to the arc)



- Density of the sprayed beam: 3-4 bunches/σ_β $\rightarrow$ kills everything except low-Z material
- Special low-Z absorbers (Be, ceramic) to be studied (IR6 and/or PRIM-V)
- Who shall study this new device (BI,BT?)
- How many do we need (1,2 per beam?), where to locate them

Strategical considerations - I

Considering dump erratic triggers

- *Either* : Replace some collimators (Al,Cu) by lower Z material *then compromise with*
  - Performance, precision
  - Mechanical simplicity, reliability
- *Or* : Add a few low-Z absorbers, to protect the SEC-collimators

Requires

- BT, BI, AP coordination
- Fix a boundary between BT- and BI-like absorbers/collimators

Strategical considerations - II

Destructive effects are possible with small fractional losses

Collimation is not a marginal system (unlike in former machines)

- Uncontrolled operation can be destructive
- Collimators alone cannot grant good and safe operation
- Defining adequate Protocols of operation is an outstanding task
  Many (all?) groups must be involved

Status of the functional specification

- **What is done :**
  - Collimation theory, Optics, Insertion layout
  - Quench limits, Efficiency calculation
- **What is partly done :**
  - Robustness studies of optics
  - Damage limits
  - Damage scenarios
  - Heat and power maps
- **External data :**
  - Update of beam parameters, fix upper limits for lifetime (LCC?)