Beam loss and Collimation at LHC

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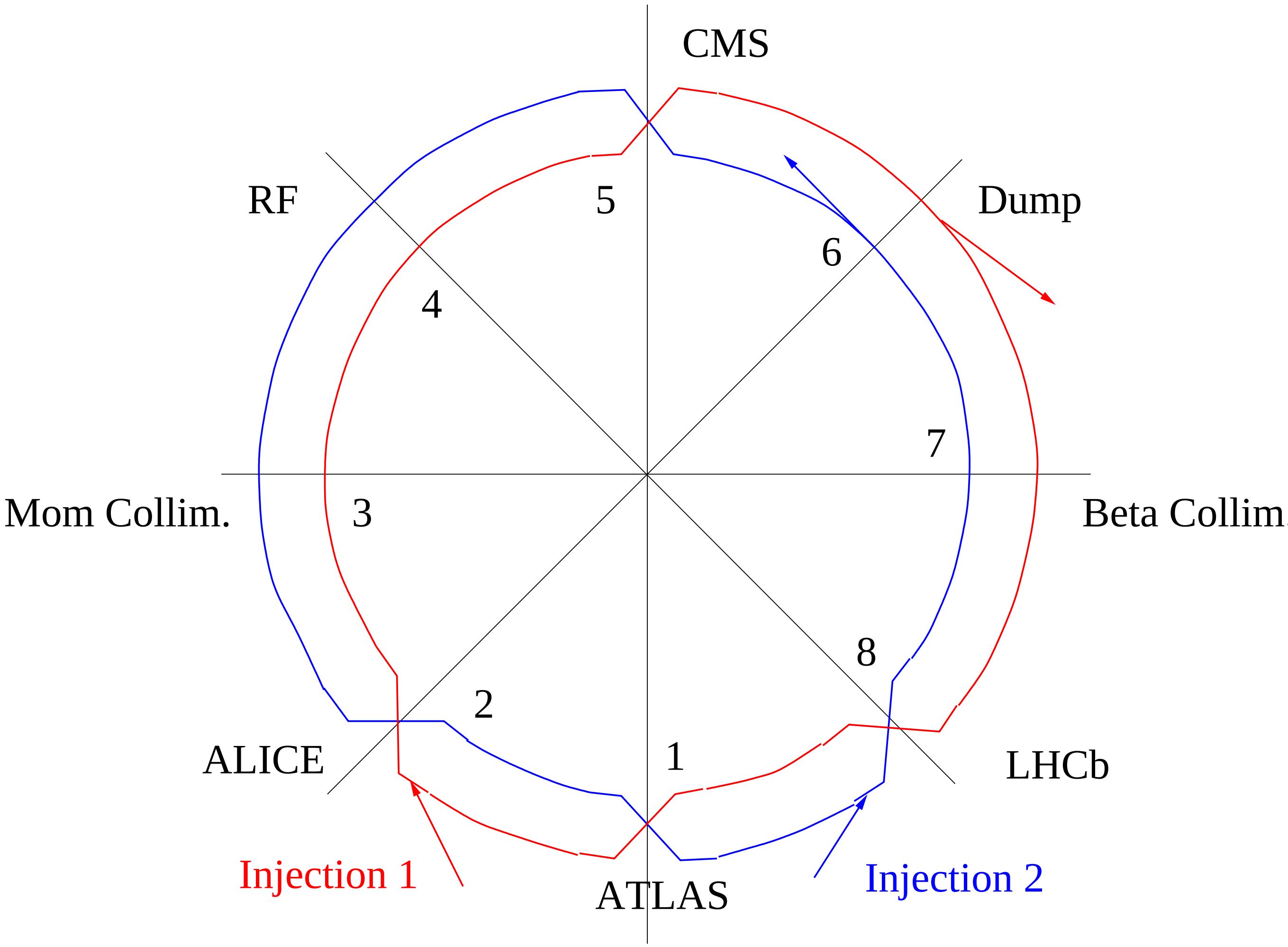
Outline

- Why collimation is needed in LHC
- Two-stage collimation and efficiency
- Geometrical aperture consideration
- Robustness of optics
- Dump kicker failure
- Materials

Schematic LHC rings



LHC beam parameters

Luminosity	10^{34}	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	
σ^* at crossing	10	μm	$\beta^* = 0.5$ m
Stored beam	3×10^{14}	protons	$2800 \times 1.05 \times 10^{11}$
Beam energy	7000	Gev	(injection 450 GeV)
Injected energy	2×10^6	J	$\equiv 24 \times 4$ kg melted Copper
Stored energy	340×10^6	J	$\equiv 2 \times 800$ kg melted Copper

Expected losses versus quench limit - 1

- 5% of a batch lost after injection

$$\Delta N_{loss} = 5\% \times 2.5 \times 10^{13} = 1.25 \times 10^{12} \text{ p}$$

- 10% $\overline{RF}$ at ramping

$$\Delta N_{loss} = 0.1 \times 3 \times 10^{14} = 3 \times 10^{13} \text{ p}$$

- Beam lifetime $\tau_{beam} = 1$ hour with 3×10^{34} p stored

$$\dot{N}_{loss} = 10^{11} \text{ p/s}$$

Expected losses versus quench limit - 2

Case	Losses [p(s^{-1})]	Quench [p $m^{-1}(s^{-1})$]
Injection	$\Delta N_{injection} = 1.25\ 10^{12}$	$\Delta N_q = 2.5\ 10^{10}$
Ramping	$\Delta N_{\overline{RF}} = 3\ 10^{13}$	$\Delta N_q = 2.5\ 10^{10}$
Collision	$\dot{N} = 8\ 10^{10}$	$\dot{N}_q = 6\ 10^{6}$

Clear need for collimation – betatronic and momentum with collimation efficiency $> 10^4$ m

Injection must be made with collimators in working position

In addition: survive to dump kicker failure

Collimation, halo and efficiency

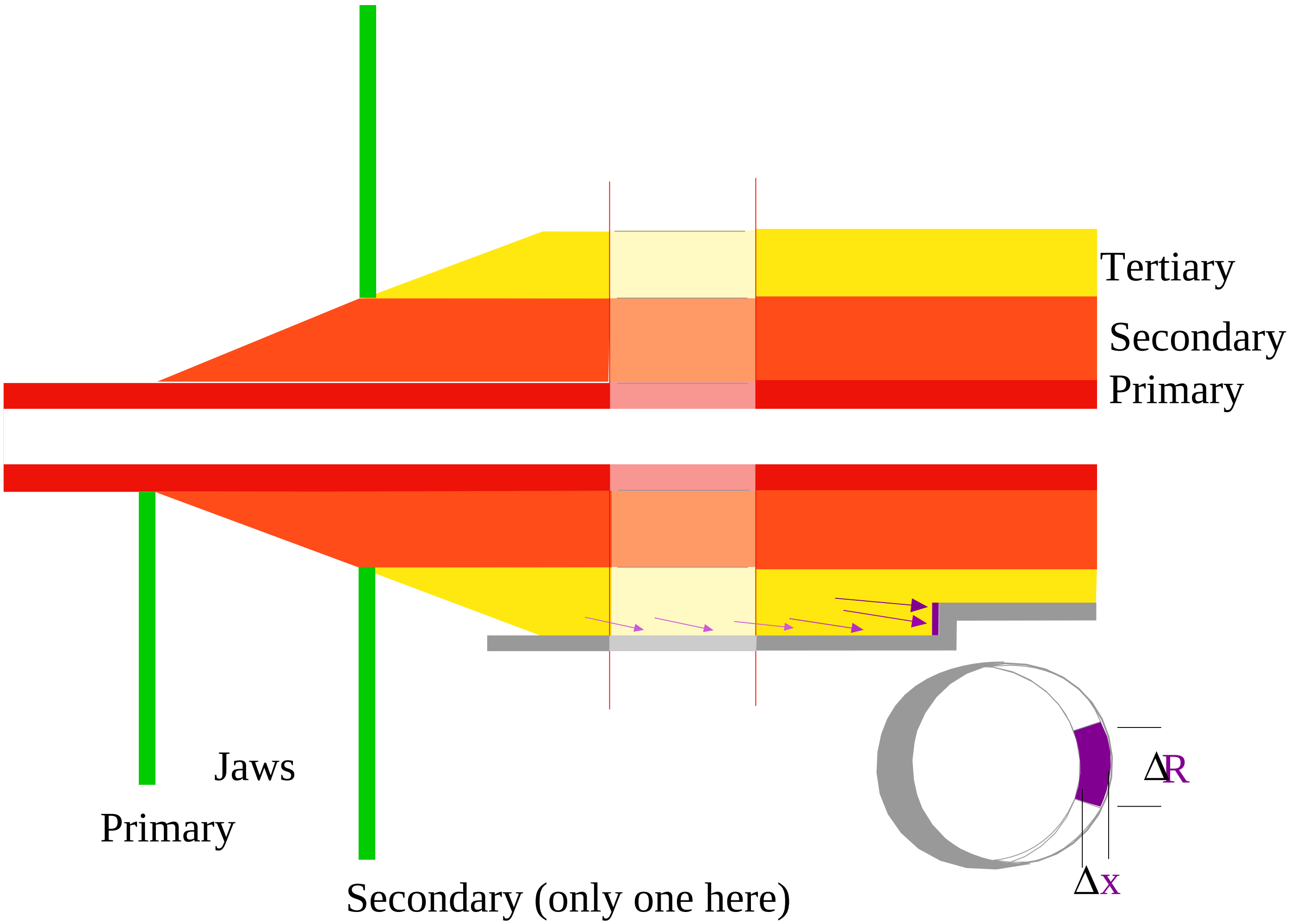
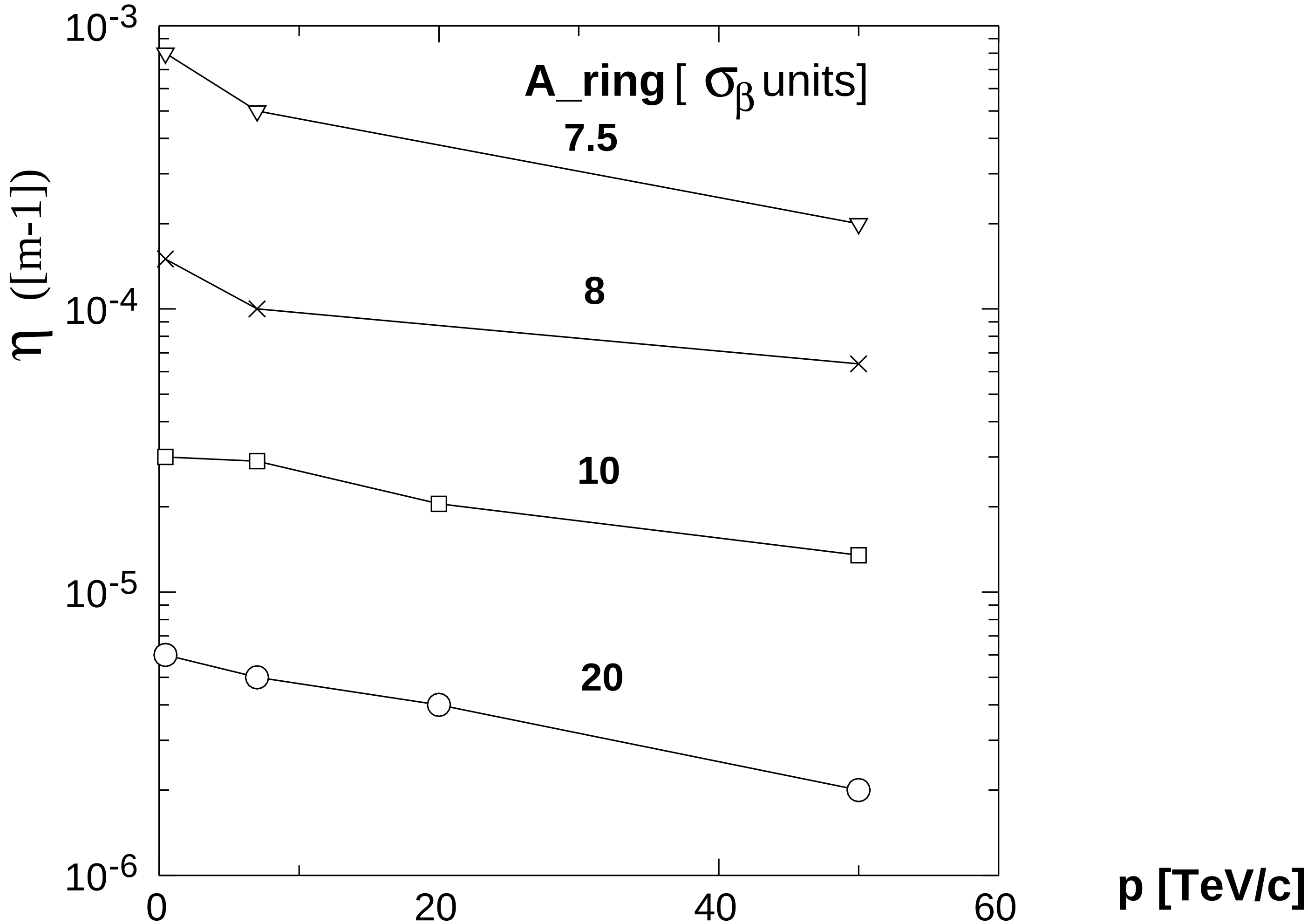


Table 1: Correlated phase advances μ_x and μ_y and $X-Y$ jaw orientations $\alpha_{\rm Jaw}$ for three primary jaw orientations α and four scattering angles ϕ with $\mu_o = \cos^{-1}(n_1/n_2)$.

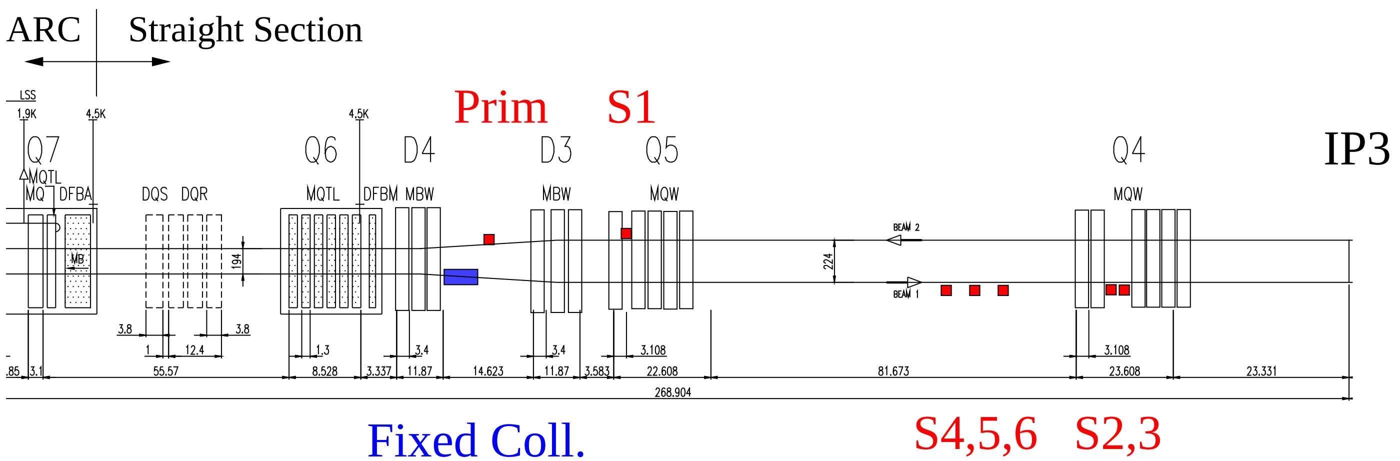
α	ϕ	μ_x	μ_y	$\alpha_{\rm Jaw}$	
0	0	μ_o	-	0	mom. coll.
0	π	$\pi-\mu_o$	-	0	mom. coll.
0	$\pi/2$	π	$3\pi/2$	μ_o	mom. coll.
0	$-\pi/2$	π	$3\pi/2$	-μ_o	mom. coll.
$\pi/4$	$\pi/4$	μ_o	μ_o	$\pi/4$	
$\pi/4$	$5\pi/4$	$\pi-\mu_o$	$\pi-\mu_o$	$\pi/4$	
$\pi/4$	$3\pi/4$	$\pi-\mu_o$	$\pi+\mu_o$	$\pi/4$	
$\pi/4$	$-\pi/4$	$\pi+\mu_o$	$\pi-\mu_o$	$\pi/4$	
$\pi/2$	$\pi/2$	-	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: an adequate approximation of this perfect case

Collimation inefficiency - K2 code

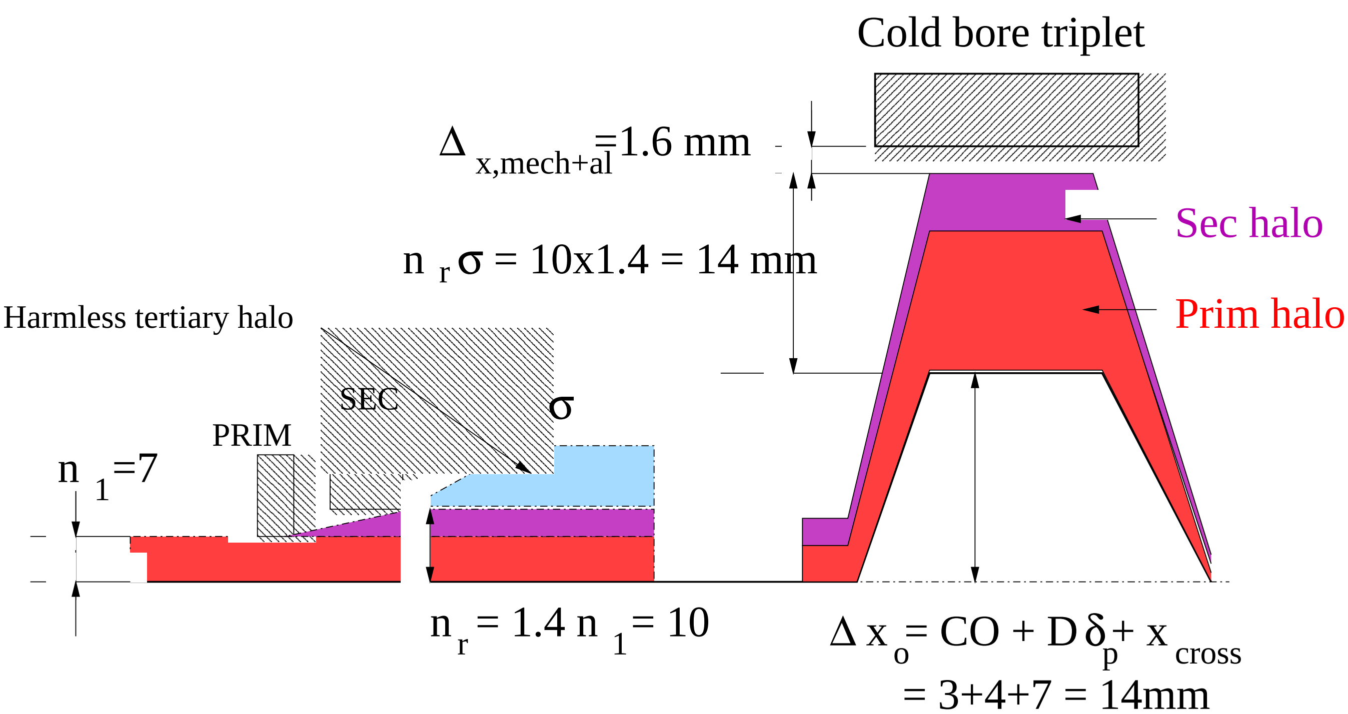


Schematic layout of the momentum collimation section



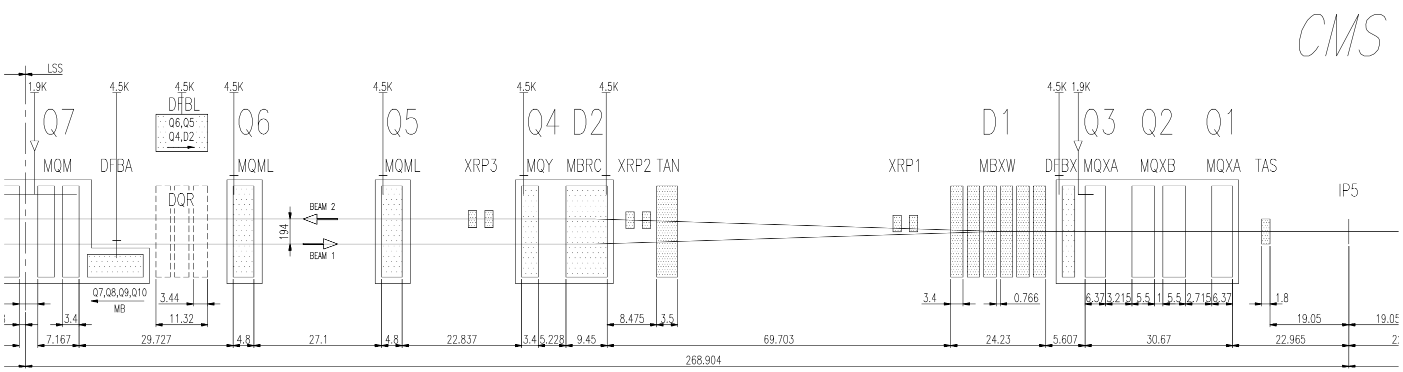
D3-D4 dog-leg structure to grow sweep-out neutrals

Halo and aperture in Experimental triplet



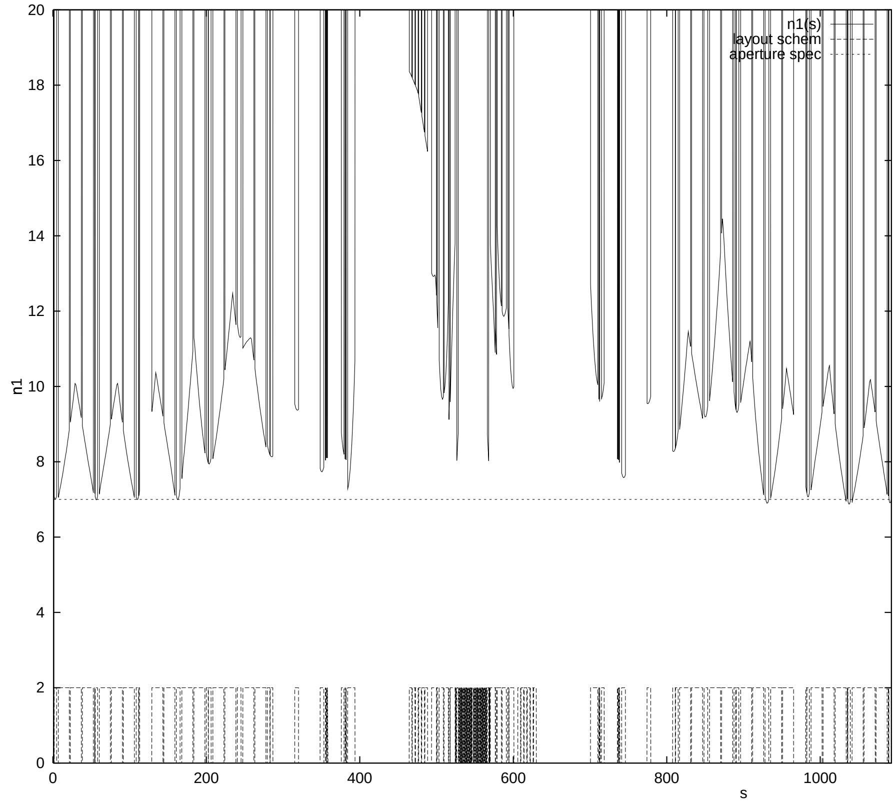
$\Delta x_o + n_r\sigma + \Delta_{x,mech+al}$ = 29.6 mm =~ $r_{cold.bore}$ = 30 mm

Schematic layout - IP5-CMS



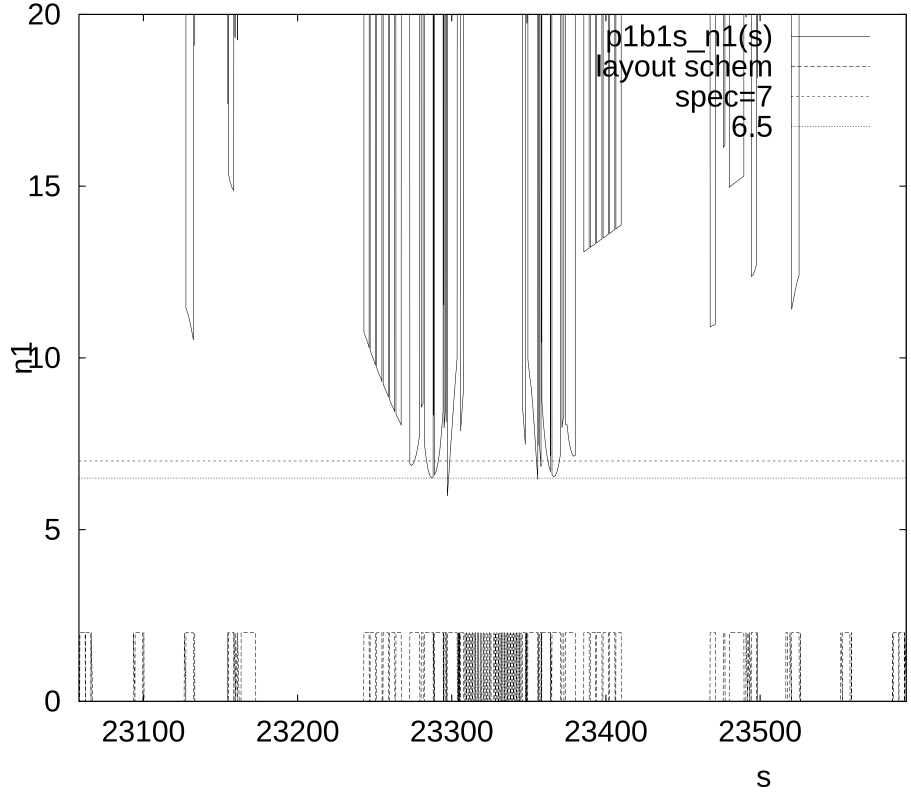
Equivalent primary aperture - Injection, IP1-ATLAS

Effective normalised aperture is $1.4 \times n_1(s)$



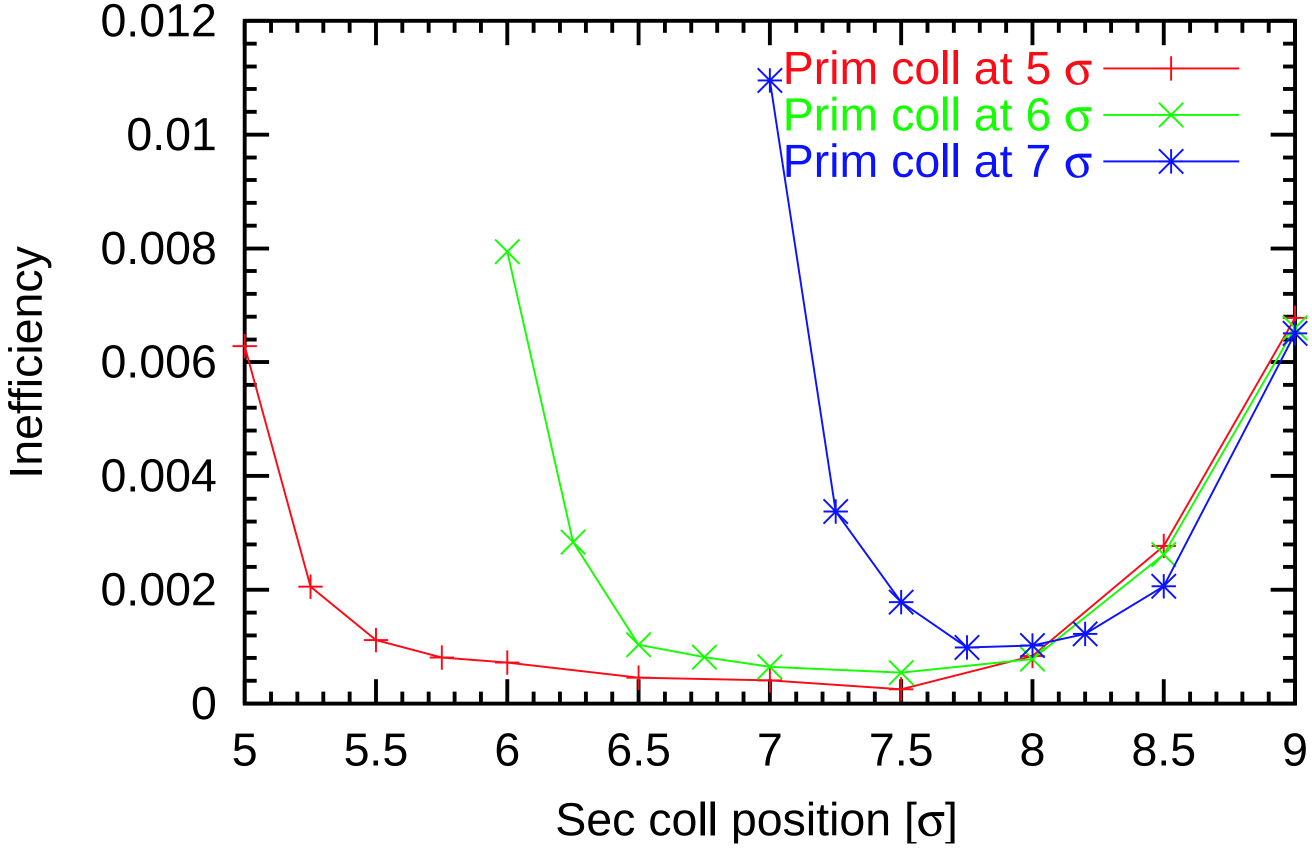
Equivalent primary aperture - Collision, IP5-ATLAS

Effective normalised aperture is $1.4 \times n_1(s)$



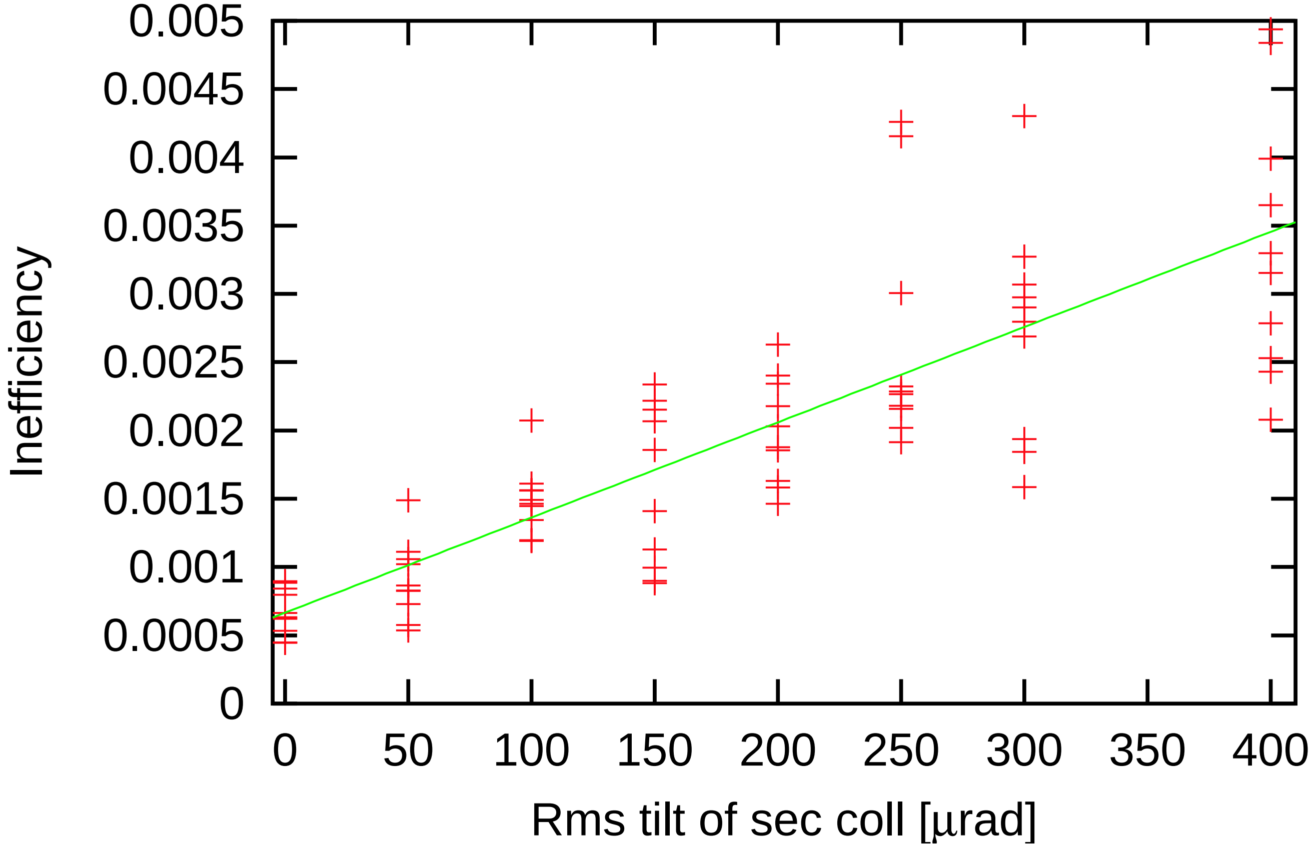
Inefficiency and collimation depth

No longitudinal dilution



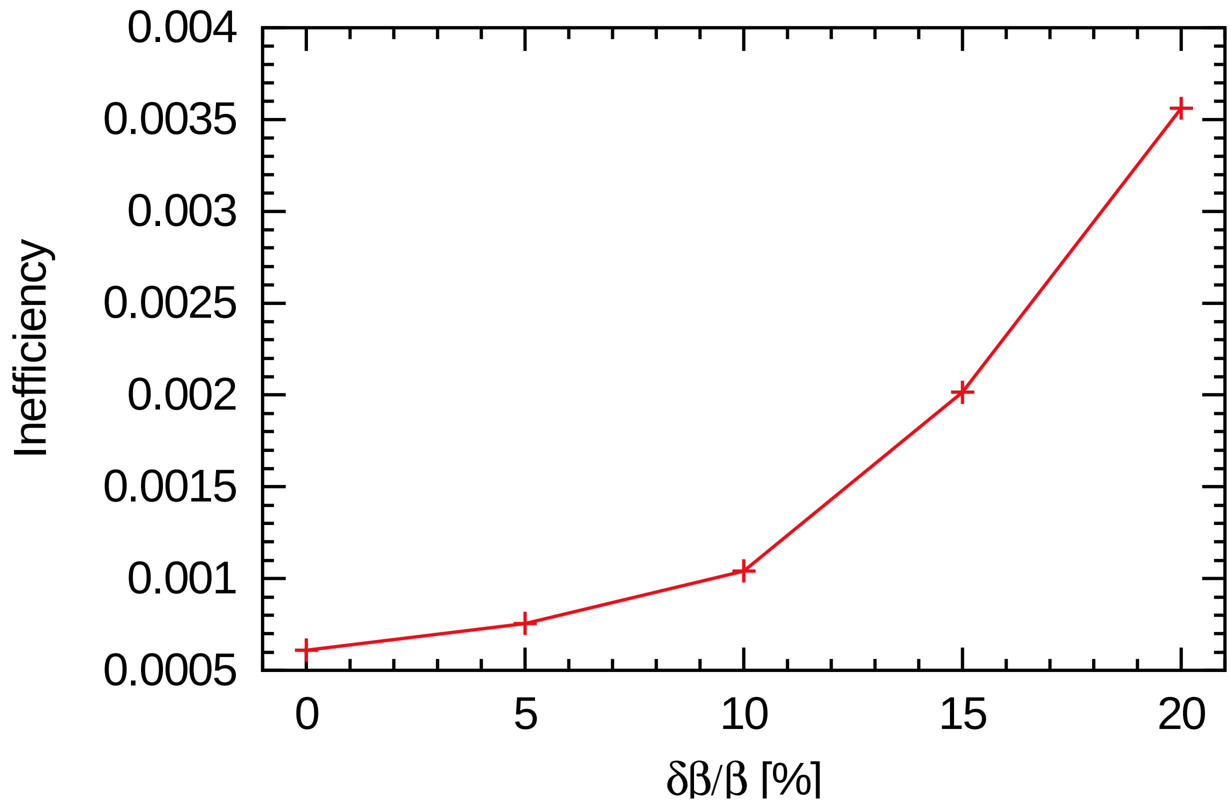
Inefficiency and jaw longitudinal tilt error

No longitudinal dilution

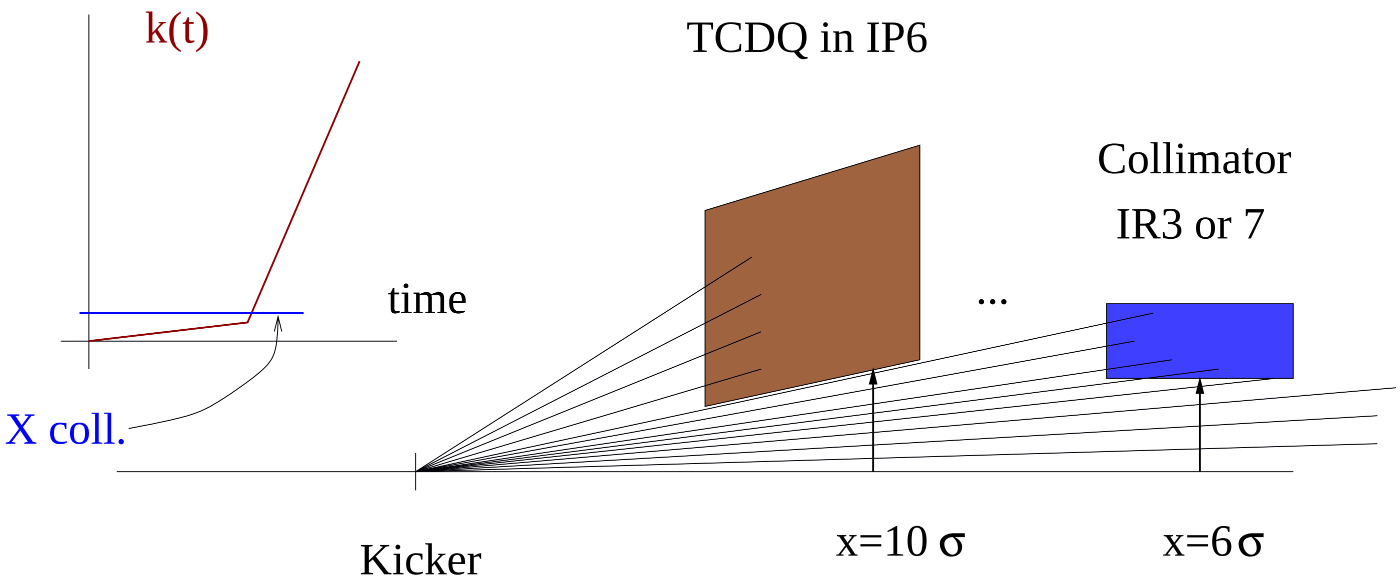


Inefficiency and beta beating

No longitudinal dilution



Erratic dump kicker error



Exact $k(t)$ not yet known

Nb of bunches on collimator varies between 6 and 16

Dump error and materials for the jaw

Erratic dump error is the worst case for jaw integrity

Shower studies clearly display advantage for low-Z materials

Case: possible reduction of mech. properties (allowed once/year)

Need more professional expertise

		N [bunches]	Margin Factor
Expected		$6 - 16$	
Allowed for:	Beryllium	$16 - 20$	1-2
	Graphite	$10 - 20$	1-2
	Copper/Aluminium	$0.1/0.5$	0.01-0.03

With low-Z, power deposition is low , $\overline{RF}\ :\ \Delta T < 20$ K

$\longrightarrow$ no harmful longitudinal deformation

Materials for the jaws

- NEED low-Z materials
- Serious candidates:
  - Be, but toxicity
  - Pyrolythic Graphite, but brittle+dust, but poor conductor
  - Boron Nitride, but $\sim$ clay, but dielectric
- Challengers:
  - Graphite with diamond coating, Fiber reinforced ceramics
  - Composite jaws: graphite core with Be plate near beam,...
- In-depth study starting now

Dynamic stress analysis for 10 bunches impact on Be

3D Ansys analysis, with MARS energy density map, Preliminary data

Dynamic peak stress $\sigma = 1.5 \times 10^9$ Pa

Static peak stress $\sigma = 1.9 \times 10^9$ Pa

$\sigma_{uts} = 0.8 \times 10^9$ Pa