Ongoing work with Collimation at LHC

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(IHEP,TRIUMF and CERN)

/Text/LHC/2003/halo03/halo03.tex

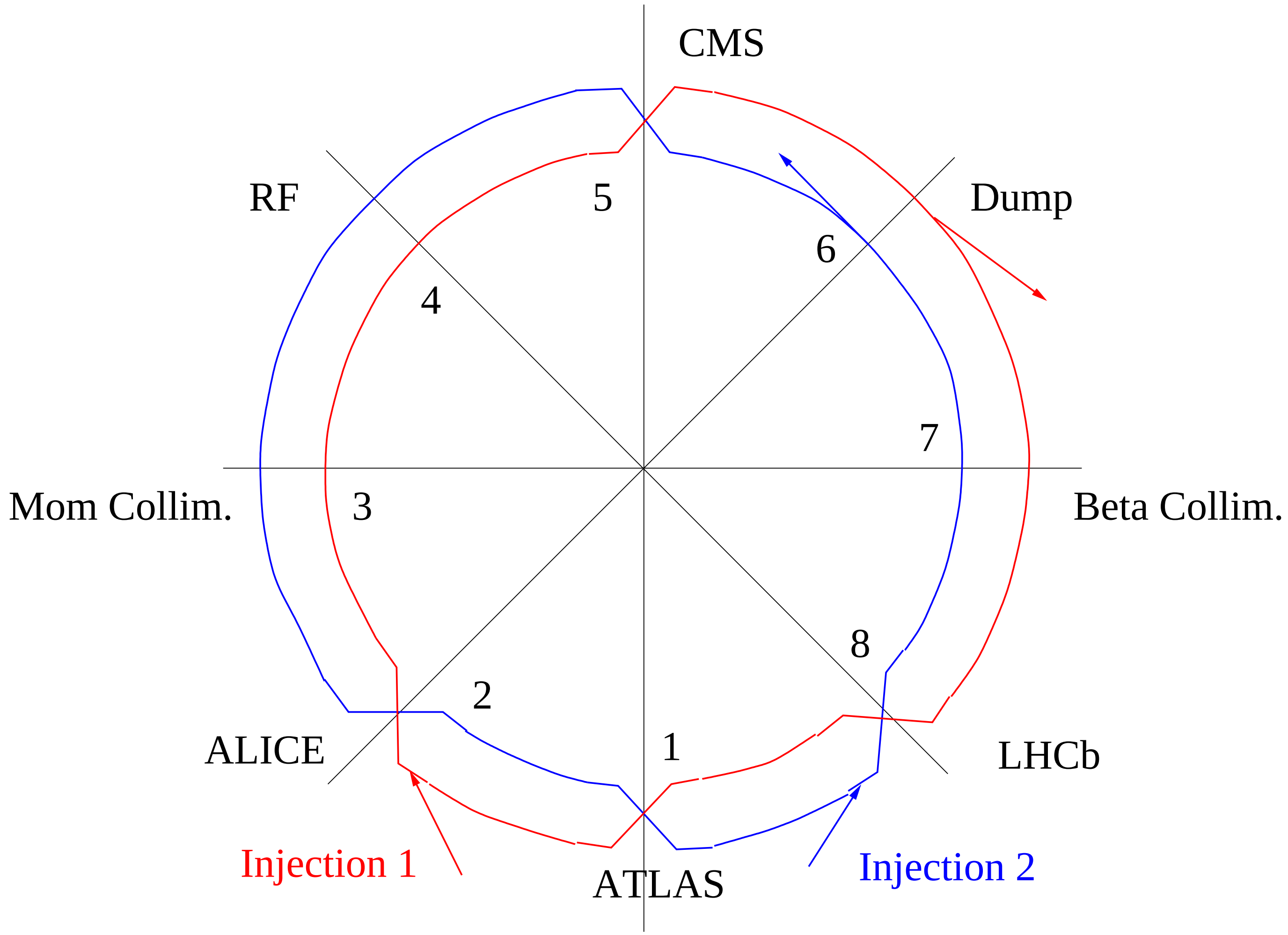
OUTLINE

- Baseline of the Collimation System (rapidly)
- Collimator materials and dump failure
- Transverse impedance of collimators
- Abort gap filling with off-bucket protons
- Beam Loss Monitoring near collimators

LHC beam parameters

Luminosity	10^{34}	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	
σ^* at crossing	16	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 Cu
Stored energy	340×10^6	J	$\equiv 2 \times 800$ kg melted Cu
Steady Loss rate	3×10^9 p	$\equiv 1$ kW	$\tau_{\mathrm{beam}} = 30$ hour
Peak loss rate	10^{11} p	$\equiv 30$ kW	$\tau_{\mathrm{beam}} \sim 1$ hour

Schematic LHC rings

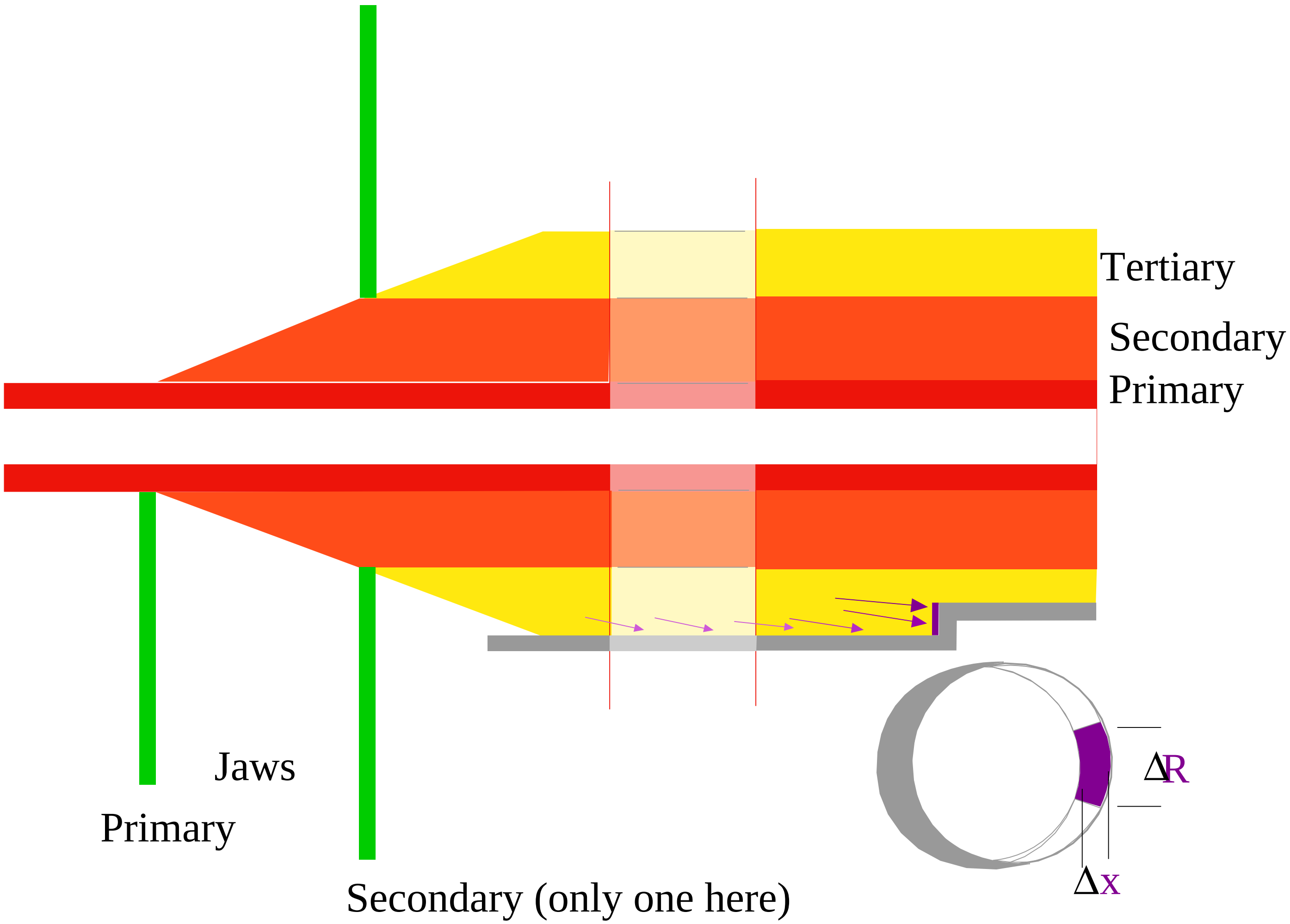


Issues solved, or believed to be under control

- Momentum collimation down to
  $\delta_p = 3$ o/oo (injection) , $\delta_p = 1$ o/oo (collision)
  with one primary and 6 secondary collimators
- Betatron collimation at $n_1 = 6$ radially
  with 3 primaries and 12 secondary (or 4/16, still debated)
- Two separate insertions (IR3-mom,IR7-betatron)
- Optics , phase advance, ... granted, no further debate
- Needed efficiency $10^{-4} - 10^{-5}\ \mathrm{m}^{-1}$ believed to be at hand

(With D. Kaltchev)

Collimation, halo and efficiency



Collimation inefficiency - K2 code

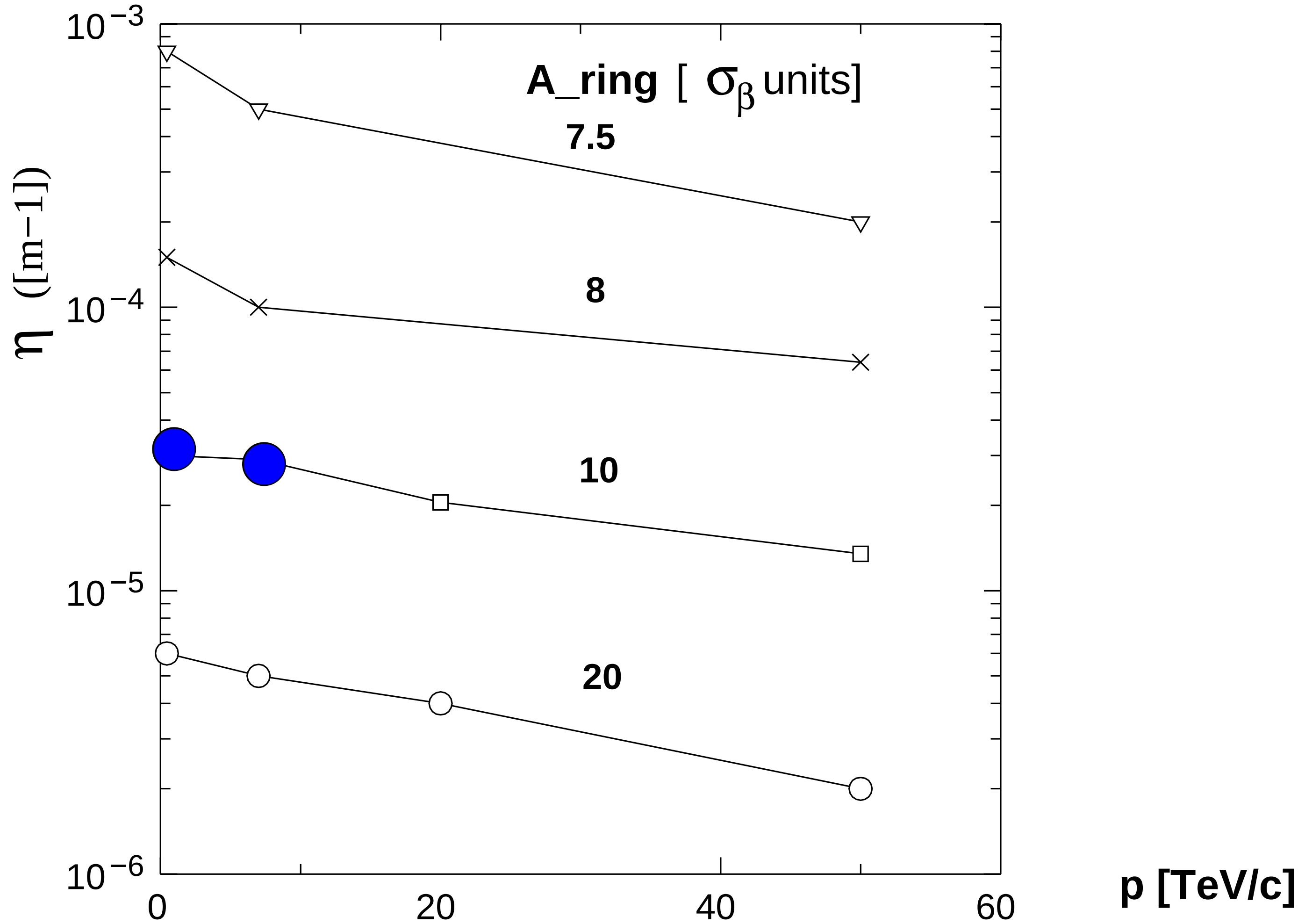
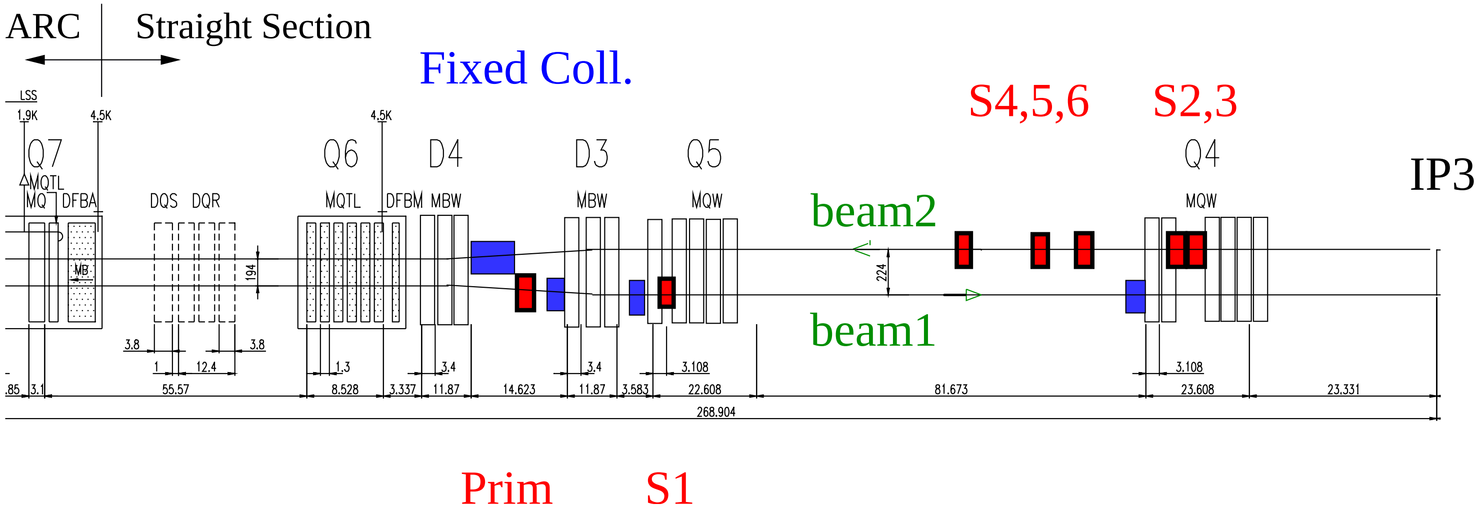


Table 1: Correlated phase advances μ_x and μ_y and $X - Y$ jaw orientations $\alpha_{\rm Jaw}$ for three primary jaw orientations α and four scattering angles ϕ with $\mu_o = \cos^{-1}(n_1/n_2)$.

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

Schematic layout of the momentum collimation section



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

and low energy charged particles

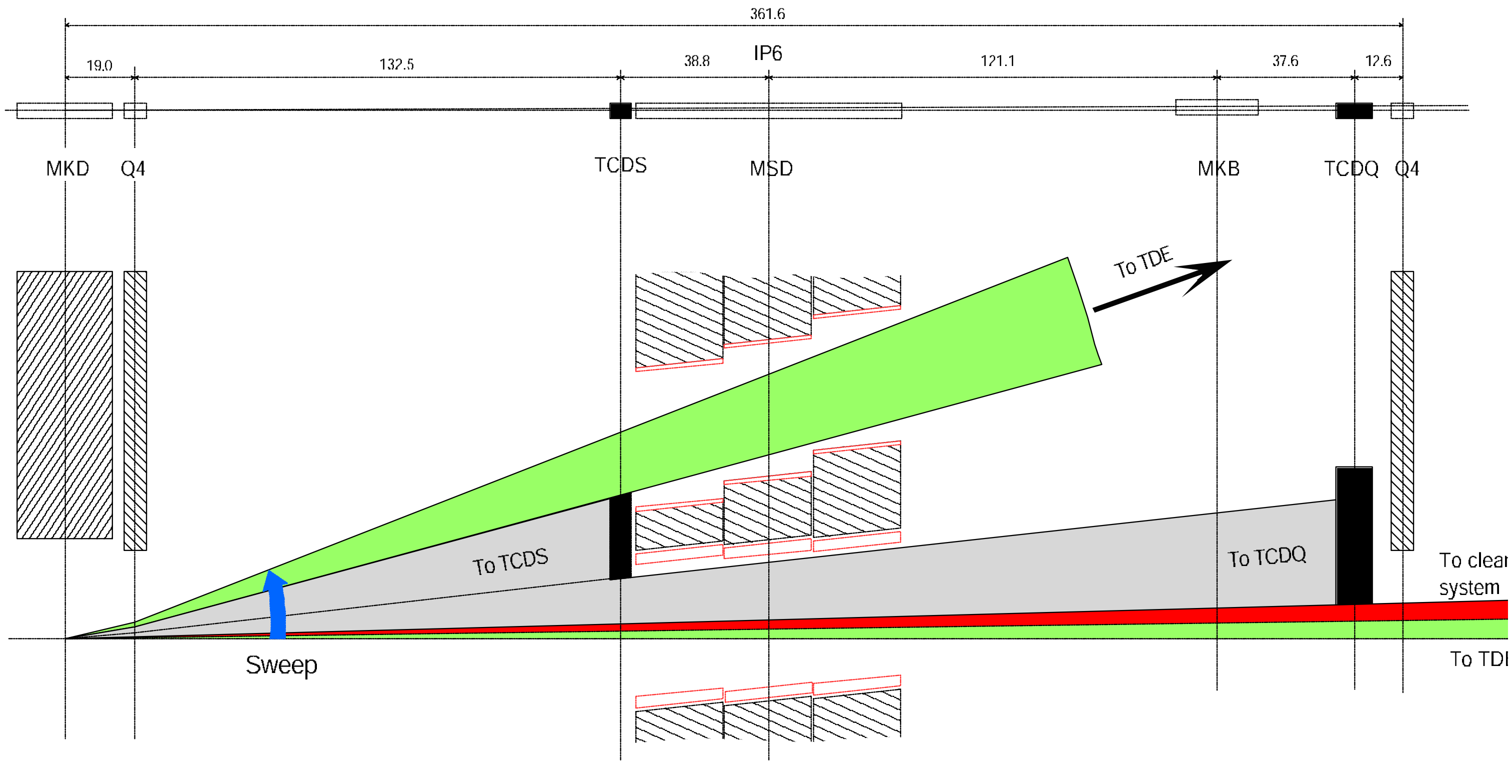
Fixed absorbers : radiation lifetime of warm coils

\+ quench limit of cold Q6 ($\tau_{\rm beam} \sim 1$ hour)

(with I. Ajguirei and I. Baishev, I. Kourotchkin and D. Kaltchev)

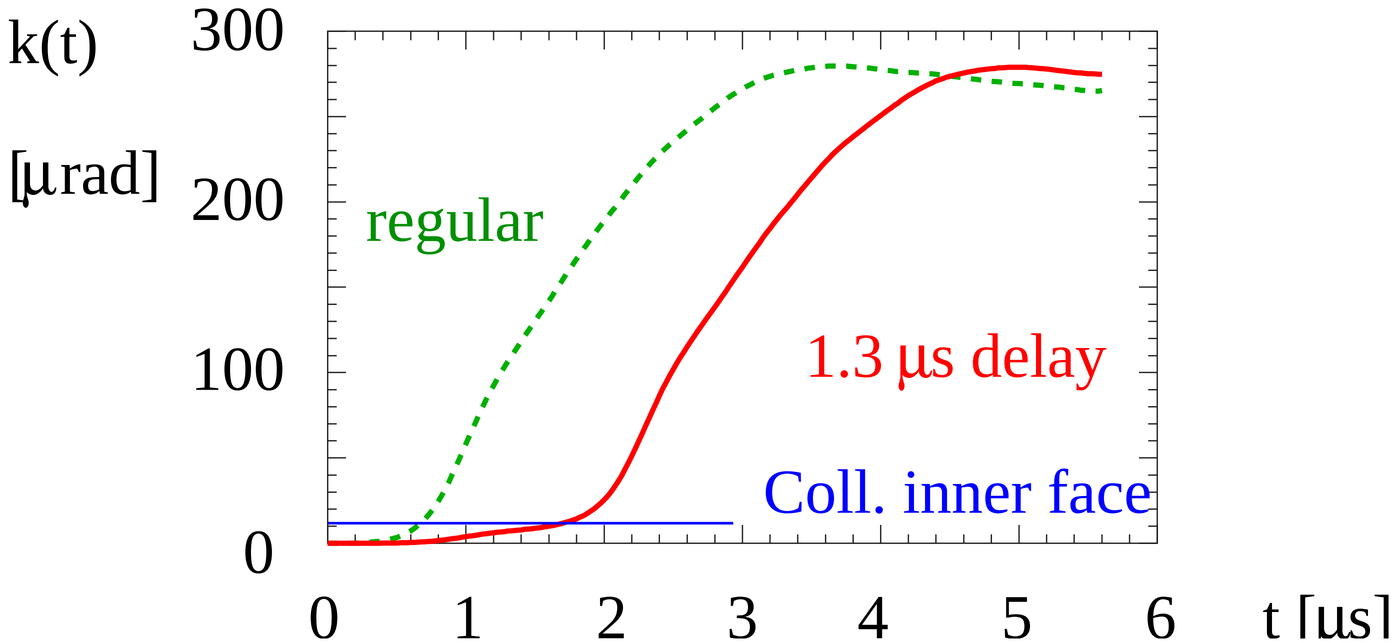
Collimator materials and dump failure

Erratic dump kicker error - I



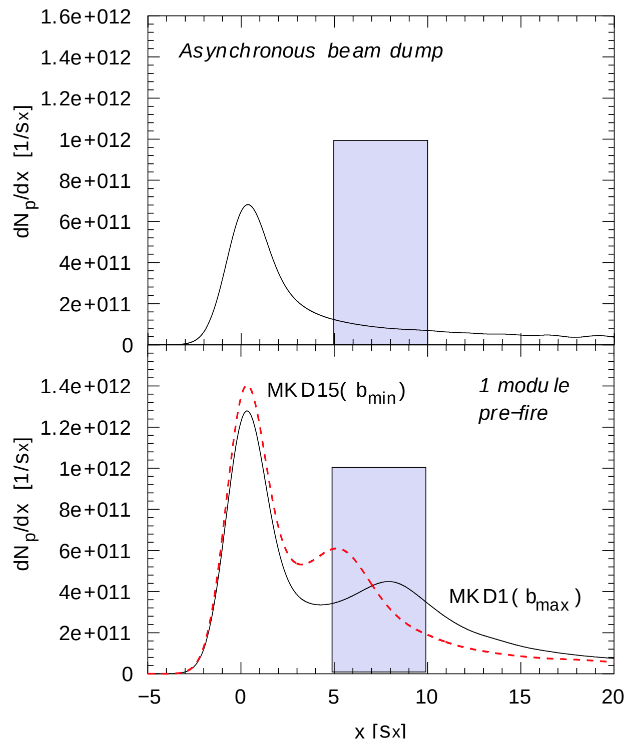
TCDQ and Q4 coil quench limit: N. Mokhov, I. Rakhno, LHC Rep. 478

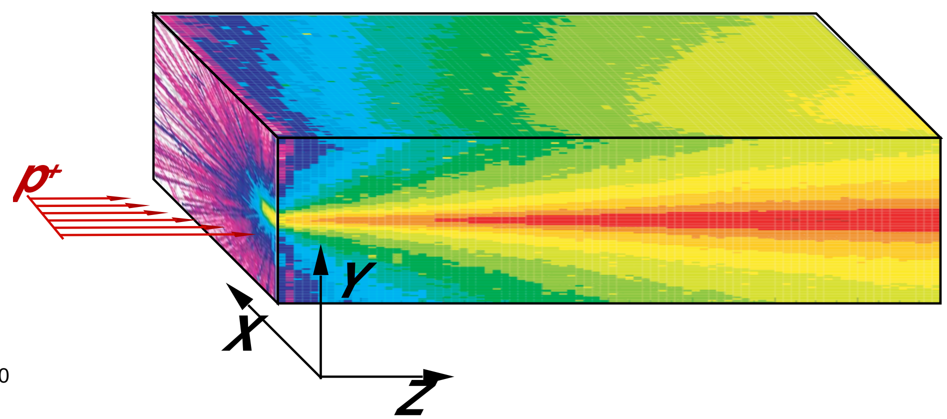
Erratic dump kicker error - II



- External asynchronous trigger
- Auto-trigger of one module, old baseline delay
- Thanks to kicker designers: new delay $\Delta T < 0.7\ \mu$s
  (E. Carlier, B. Goddard, J. Uythoven, E. Vossenberg)

Erratic dump kicker error - III

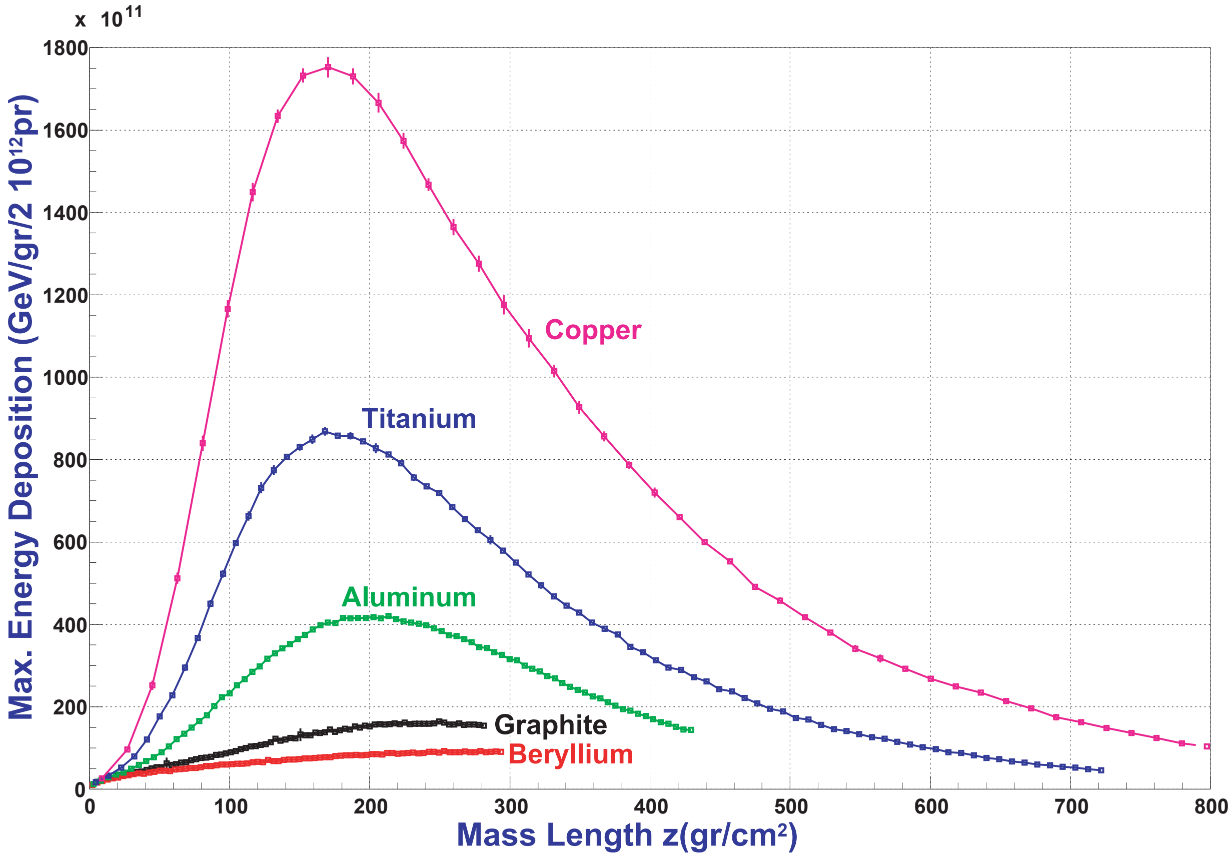




FLUKA → 3D-ANSYS → Peak stress

(O. Aberle, L. Bruno, A. Ferrari, P. Sievers, V. Vlachoudis)

Materials for the jaws - I



⇒ Low-Z materials mandatory

Materials for the jaws - II

Case	Nb. bunches on jaw	Survival deficit factor Graphite	Survival deficit factor Berylium
1.3 μs	20	3	9
0.7 μs	8	1.2	3.6
Regular	5	0.75	2.2

- Survival for a very large number of events
- if probabilities are small, $\sim$ 30% more margin
  $\longrightarrow$ Graphite OK with 0.7 μs delay
- But transverse impedance is too large for graphite
  and $\sim$ 25 collimators

Materials for the jaws - III

- Berylium
  - Good electrical conductivity
  - Factor ~ 3 above thermal stress limit vs. dump failure
  - Toxicity issues
- 'Ordinary' graphite
  - $\sim$ OK with thermal stress
  - OK with vacuum (tested)
  - bad electrical conductivity $\longrightarrow$ impedance

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

$\longrightarrow$ no harmful deformation for steady state operation

Transverse impedance of collimators

Transverse impedance - I

- Dominated by resistive part
- Allowed budget $100 - 200\ \mathrm{M\Omega/m}$, OK with Copper
- Graphite : $1000\ \mathrm{M\Omega/m}$ at nominal depth (6/7 σ)
- $Z_\perp \propto b^{-3}$, with b the jaw opening
  - problem at top energy only
  - may use n_1 as impedance knob, but affects $\mathcal{L}$) :

$$n_1 = 6 \rightarrow 7.5 \Rightarrow Z_\perp/2 \Rightarrow 0.7\mathcal{L}$$

Transverse impedance - II

- Scenario 1:
  - Graphite for betatronic H-collimators
    (on the way of mis-kicked bunches, $\sim 1/3$ of them)
  - All the others (included momentum coll.) : berylium
- Scenario 2:
  - All graphite at injection
  - Collision : Graphite primaries / Copper sec. at 10 σ
    $\rightarrow$ requires tertiaries at high-β sections

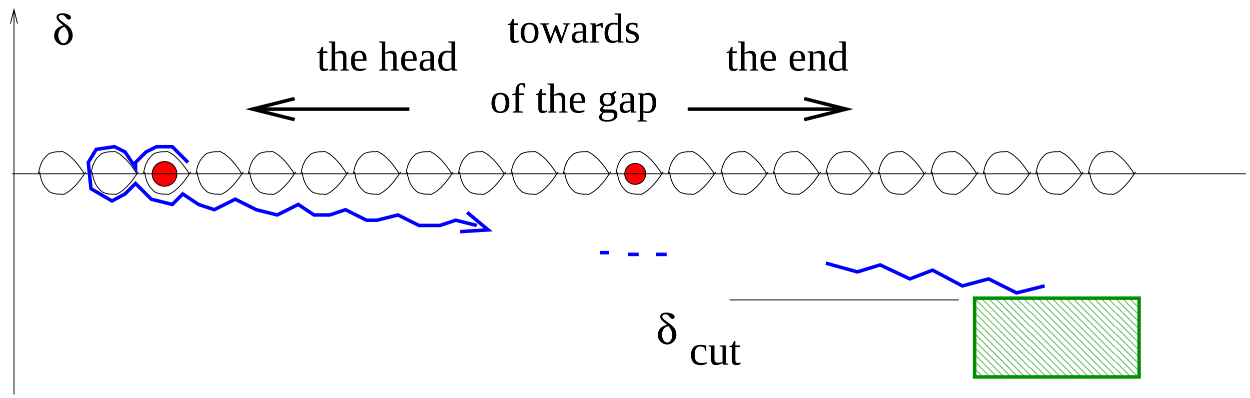
To be further worked-out, decision : summer 2003

Abort gap filling with off-bucket protons

Abort gap population - I

- Protons leaving a bucket loose energy by emitting synchrotron radiation
- They drift longitudinally and invade the abort gap
- Regular dump action may then provoke a quench
- Momentum collimation limits their density
- Compare expected to allowed steady state densities

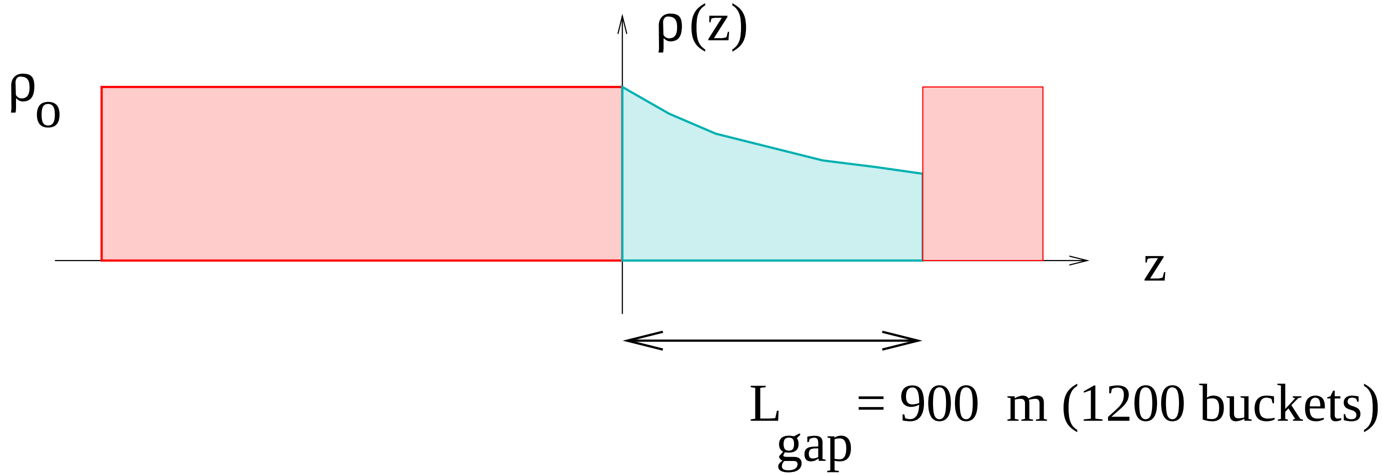
Abort gap population - II



- Compute the flux for $(z_{\rm gap} - z_{\rm bunch})$, then $\dot{z}_{\rm gap}$ and $\rho_{\rm gap}$
- Sum over all bunches
- Numeric integration needed (longitudinal motion with RF)

Paper in preparation (E. Chapochnikova, S. Fartoukh and B.J.)

Abort gap population - III



$$\rho_0 \simeq 0.7 \, \frac{N_0}{\tau_{\rm long} L_{\rm ring}} \frac{\delta_{\rm cut}}{\dot{\delta}} = 2.2\, 10^7 \;\; \mathrm{p/m} \quad \mathrm{for} \quad \tau_{\rm long} = 10 \; \mathrm{hr}$$

$$\mathrm{with} \quad \dot{\delta} = \frac{\mathrm{U_0}}{\mathrm{E_{beam}}} \mathrm{f_r} = 10^{-5} \;\; (7\mathrm{keV}/7\mathrm{TeV}, /1.1\; 10^4)$$

$$\mathrm{and} \quad \dot{\delta}_{\rm cut} \simeq \; 10^{-3}$$

Abort gap population - IV

- Critical location : MQY cold magnet behind TCDQ
- Steady density at the head of the gap (no damper):

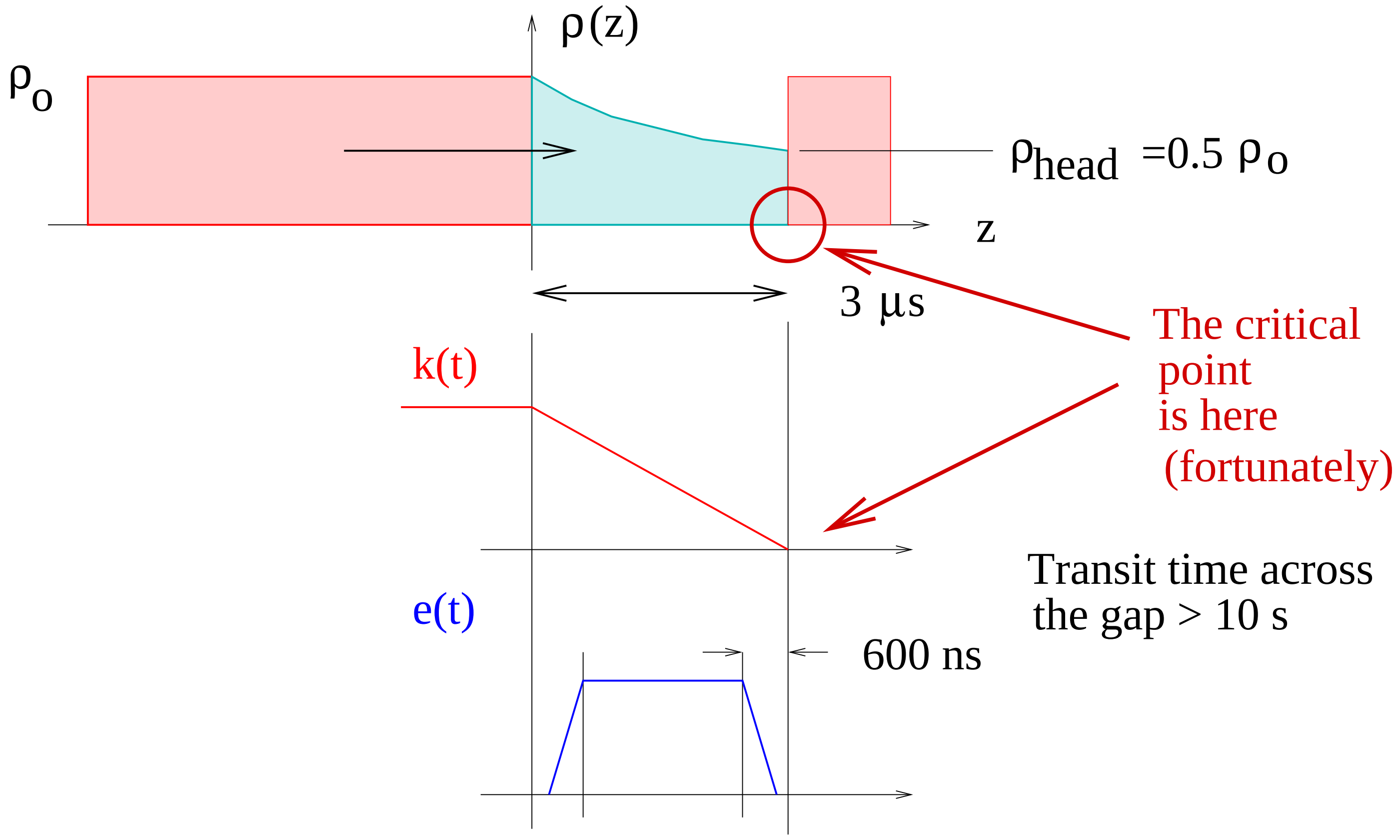
$$\rho_{\mathrm{head}} = 1.2 \times 10^7 \text{ p/m} \quad (\tau_{\mathrm{long}} = 10 \text{ hours})$$

- Tolerable density for MQY:

$$\rho_{\mathrm{tol}} = 0.3 \times 10^7 \text{ p/m}$$

$\longrightarrow$ Excitation with transverse damper needed

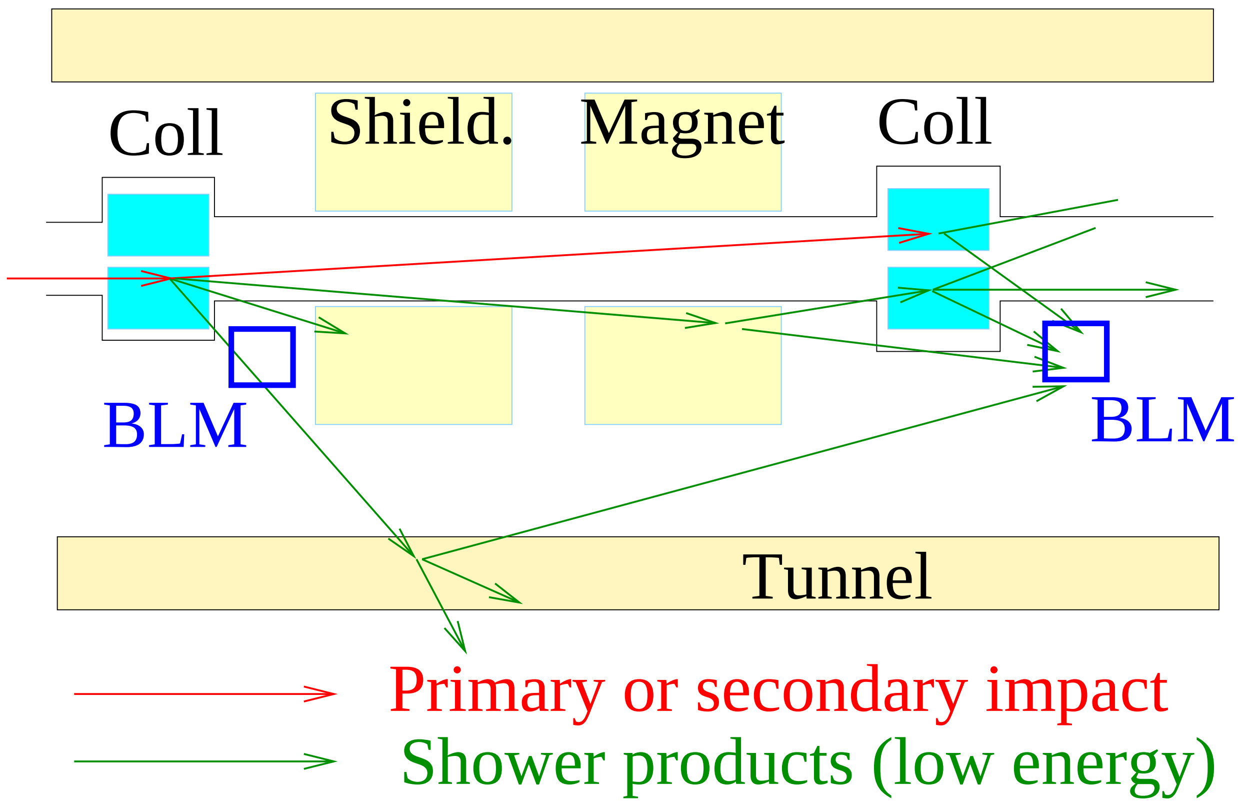
Abort gap population - V



Available damper power believed to be sufficient (W. Hofle), but more work needed

Beam Loss Monitoring near collimators

Beam Loss Monitoring near collimators - I



Beam Loss Monitoring near collimators - II

- Multiturn tracking with edge-scattering (K2) to get a precise primary + secondary impact map ($\delta_p <$ few %)
- prim+sec map $\longrightarrow$ MARS with everything
- Run for the map on each jaw separately
  $\longrightarrow$ partial signal m_{ij} for every BLM i counter
  from every collimator j
- Explored simpler case: momentum cleaning (7 collimators)

On-going work with IHEP (B. Dehning, I. Kourotchkine, I. Ajguirei and I. Baishev)

Beam Loss Monitoring near collimators - III

$$\vec{s} = \mathbf{M}\,\vec{r}$$

$$\mathbf{M} = \left|\begin{array}{ccccccc}
0.0178 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.4662 & 1.19 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.02684 & 0.02911 & 1.081 & 0.00039 & 0.0 & 0.0 & 0.0 \\
0.04321 & 0.03889 & 1.085 & 1.044 & 0.0 & 0.0 & 0.0 \\
0.0079 & 0.00361 & 0.138 & 0.3245 & 0.9891 & 0.0 & 0.0 \\
0.00361 & 0.00177 & 0.03858 & 0.1187 & 0.513 & 0.9848 & 0.0 \\
0.00123 & 0.00069 & 0.00992 & 0.03493 & 0.16417 & 0.5093 & 0.9445
\end{array}\right|$$

Beam Loss Monitoring near collimators - IV

- **M** built for nominal $n_1 = 6$, $n_2 = 7$
- Vary n for every jaw, and build **M** again, on-going
- Analysis will say how precisely we can get

  n_1 and $n_{2,\mathrm{i}}$ from $\vec{s}$ (with **M** not constant)
- If necessary, add more counters
- Real case: invest time to built **M** with beam

Betatron collimators: same problem but 20 jaws $\longrightarrow$, a bit later