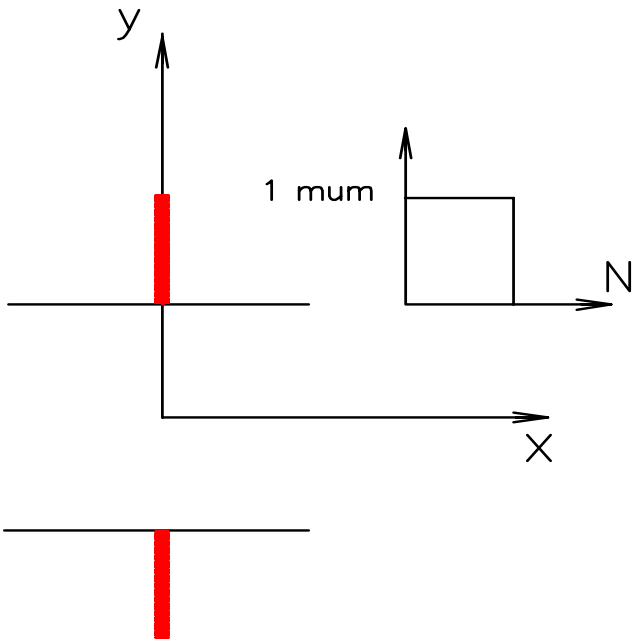
Collimation efficiency in presence of collimator misalignment and sample closed orbit errors

procedure

- the study is done with Dimad
  LHC Beam1 thick-element lattice (injection)
  no field errors; sextupoles only ⇒ chrom. = 2;
- TDRIVE basic block (author Igor Baichev) now implemented in dimad (tracks within the coll-rs)
- The initial point for tracking is set just before the first primary collimator of IR7 [a] and two on-momentum beams are generated entering at micrometer impact distances the upper and lower jaw.
- and track until all lost in the coll-s and on the 2-cm aperture

[a] similar procedure and lattice has been set to model the halo created by IR3, not reported here



a fixed seed = two on–momentum ($\delta = 0$) beams ($\sim 10^5$ particles) entering the first primary of IR7, and corresponds to a new initial seed for the impact distribution and simultaneously new initial seed in the `STRUCT` module. We record average and maximum values over 10 seeds.

we use elimination procedure – only particles impacting within 1 mum from the jaw edge are tracked.

BEAM and GENERATE commands, see next

Losses on aperture R=2 cm set at all drift entrances

1. "2cm inefficiency": radial aperture set R=2 cm at all drift entrances $\Rightarrow$

$$N_{part\ lost\ at\ 2cm\ apert.}/N_{total\ lost\ part.}$$

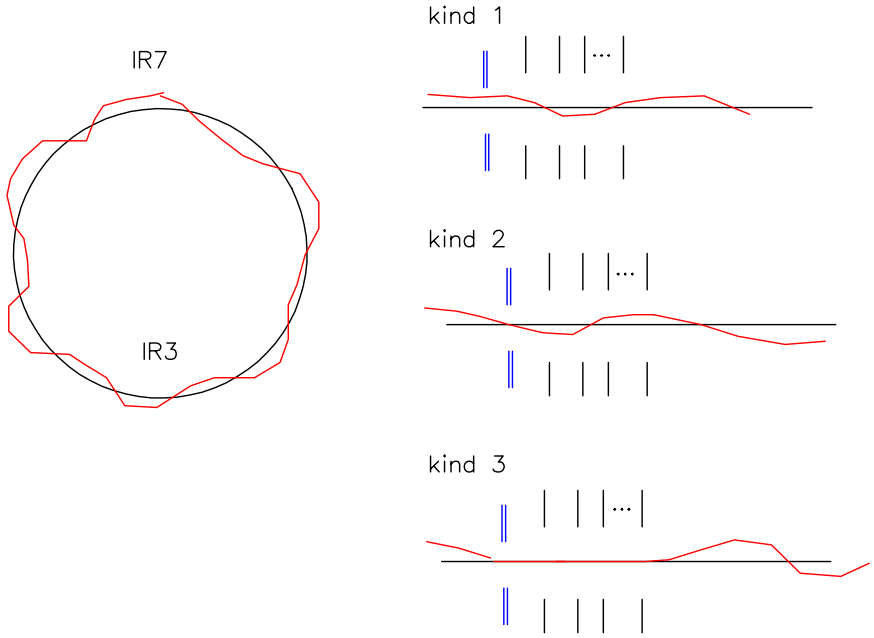
Sample Dimad input:

```
! Snapshot date: 03/12/01 Time: 131444
...                                          <--  LHC B1 lattice here in line format
                                                  STARTS AT IR7 PRIMARY called TCPA
k2d=-0.106404818276                          <--  must have correct chromaticity 2
k2f=0.065210125333

TCPA: COLLIMATOR,L=.05,p1=1,p2=0.006,p3=1.57
...                                                p1 = material
...                                                p2 = half dist between jaws
                                                   p3 = angle in rad
USE, LHCB1
MATRIX                                        <-- show the 2 ord matr. and chrom.
...
MACHINE                                       <-- the Twiss
...
SET COL
DUMMY
SET COL
TCPA   5  0  10   10  0,     <-- name, iprint, iblack, Apx, Apy, m/turn
...
SET SYMPLECTIC OPTION ON
BEAM                              <-- beam sigmas in TRANSPORT not.
1.e-40  0 0 0 0 0
1.e-40 0 0 0 0
1.e-6 0 0 0                       <-- mum impact distr (uniform)
1.e-40 0 0
1.e-40 0
1.e-40
-1,

MISALIGNMENT DEFINITION                       <--  shift in transv. dir. 2 arc quads
RQFA78Bx   .75e-3 0.  0       0. 0. 0. 0. 1
RQDA78Bx   0      0.  .75e-3  0. 0. 0. 0. 1              CO2  = 4 mm peak to peak
99,
SET MISALIGNMENT
REFERENCE ORBIT                                <-- find closed orbit
...
GENERATE PARTICLES
45000                                               <-- per jaw
0.0  0.0  0.66224207E-02  0.69429323E-04  0.0  0.0 <--   beam centroids
0.0  0.0 -0.66224207E-02 -0.69429323E-04  0.0  0.0,

TRACKING
```

Sample Dimad output

```
 OPERATION LIST ,
 TRACKING
 tot part   90000
 total latt elts 11517
 tot arc quads    392
     turn   ncpart
       1   90000
 discarded (impact) =  15279
       2    9437
...
      65       6
 LAST  6  ARE NOT TRACKED

Loss statistics after passage   65

        coll. name  lost    10    20    30    40    50
     1    DUM          0     0     0     0     0     0
     2    TCPA     29044 28640   214   171    14     5       <-- first primary
     3    TCPB         8     8     0     0     0     0           of IR7
     4    TCPC       718   679    31     6     1     1
     5    TCPD       831   789    22    17     2     1
     6    CS71      4974  4909    37    26     1     1
     7    CS72      3086  3033    30    18     4     1
     8    CS73      3569  3519    24    23     3     0
     9    CS74      6083  5994    47    34     6     2
    10    CS75      6336  6253    48    31     2     2
    11    CS76      4822  4750    36    29     5     2
    12    CS77      1382  1363    12     7     0     0
    13    CS78      1710  1680    17    11     2     0       <--  all IR7 secondary
    14    CS79        52    52     0     0     0     0            coll-s are loaded
    15    CS710     3251  3204    27    17     3     0
    16    CS711      319   315     1     3     0     0
    17    CS712       43    43     0     0     0     0
    18    CS713      295   273    18     4     0     0
    19    CS714      180   170     7     3     0     0
    20    CS715     3585  3522    38    22     2     1
    21    CS716      329   324     2     2     0     1
    22    TCP3         0     0     0     0     0     0
    23    CS31         0     0     0     0     0     0       <-- the IR3 coll-s. are retracted
    24    CS32         0     0     0     0     0     0
    25    CS33         0     0     0     0     0     0
    26    CS34         0     0     0     0     0     0
```

```
    27    CS35          0     0     0     0     0     0
    28    CS36          0     0     0     0     0     0
    29    TJ            0     0     0     0     0     0

Discarded at impact      15283
Total entered            74717

Collimator losses
IABS=1                   25593
Win                      44778
DppLim                     246
total lost in coll-s     70617              0.94513

total lost coll apert     1756

Aperture losses
 apert  COS7               3995     0.05347
 apert  COS3                  4     0.00005
 apert  outside COS          99     0.00132
 total lost on apert.      4098              0.05485

total lost               74715              0.99997
total survived               6              0.00008
turn-in turn-out      1    65
```



One would like to consider all these and put some jaw misalignment and optics errors on top.

In what follows **we only take kind 3 plus transverse collimator misalignment**.

perfect and imperfect systems

- **Ideal**

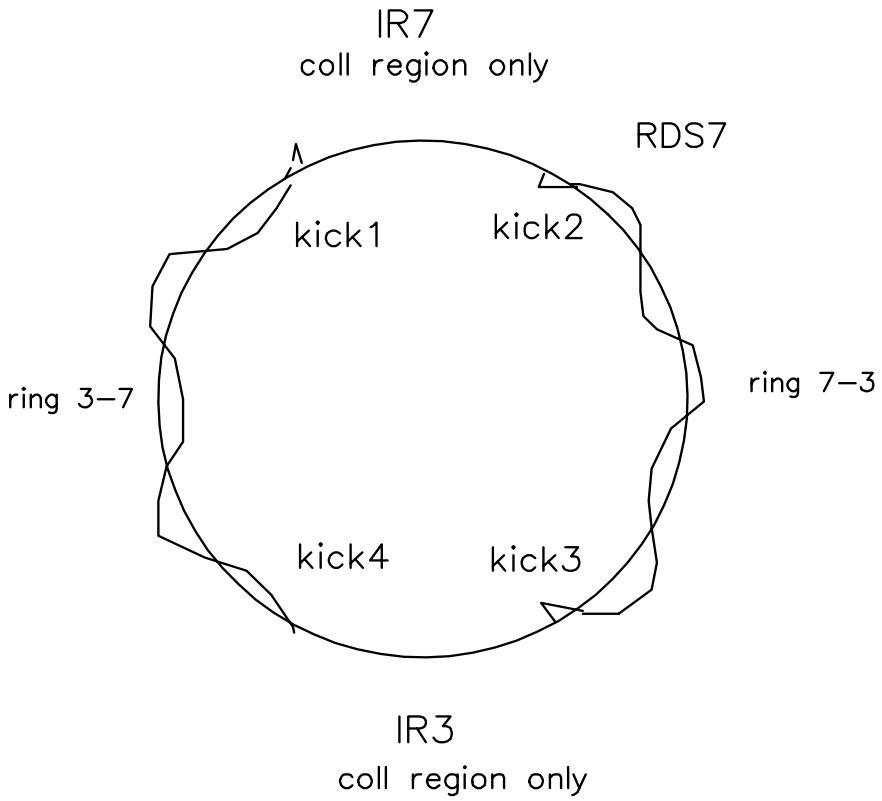
  27 coll-s set w.r.t. the vac. chamb. axis at:
  $n_1 = 6, n_2 = 7$ (IR7), $n_1 = 8.5, n_2 = 9.5$ (IR3)
  (σ units; n_1 for prim, n_2 for sec.) with rot. angles as database
  $L_{primary} = 0.2\ m$ (Al) $\qquad$ $L_{sec} = 0.5\ m$ (Cu)

- shift a QF,QD pair $\Rightarrow$ CO with nearly equal rms and max in both planes

- **Corrected closed orbit CO2 (4mm p2p in the arc)** *from the entrance of the first to the exit of the last* coll-r in each IR7 and IR3. Note: an ideal every-turn correction !

- **corrected + jaw.mis (random transverse with amplit 0.5 mm and 1 mm)**

  random transverse shifts of the midpoints (centres) of the coll-s w.r.t. to the vacuum chamber axis (all coll-s except for the first primary where tracking starts)



collimator-occupied sections COS7 and COS3 and four orbit-correcting kicks applied at entrances and exits of the two COS. The region outside both COS is left uncorrected – it consists of RDS7, ring 7-3 and ring 3-7. We count number of part.:

1) **absorbed in coll-s** and
2) **lost on the 2cm aperture over:**

COS7

COS3

outside both COS

" ring 7337" = ring 7-3 + ring 3-7

Halo losses, injection, no IR3 coll-s 10 seeds $\times 810^4$ part					
	absorbed in collimators	on the 2 cm radial apert			
		COS7	COS3	outside COS	ring 7337
	Ideal				
ave	0.94514	0.05344	0.00002	0.00140	1.710^{-4}
max	0.94606	0.05424	0.00005	0.00156	2.510^{-4}
	Ideal + corrected CO2				
ave	0.94493	0.05355	0.00002	0.00149	2.310^{-4}
max	0.94604	0.05407	0.00003	0.00160	2.810^{-4}

Table 1: Average and maximum values of 10 seeds (`STRUCT` random generator).

Initially, the IR3 collimators were retracted.

Ten patches (seeds) generated (810^4 part per patch) are applied to each Ideal and Corrected CO2 systems.

The fraction lost in RDS7 is given by the difference of the numbers in the last two columns.

Halo losses, injection, no IR3 coll-s worst seed w.r.t. CO2 effect					
	abs.in coll-s	on the 2 cm radial apert			
		COS7	COS3	out. COS	ring 7337
Ideal	0.94474	0.05383	0.	0.00135	1.610^{-4}
corr. CO2	0.94494	0.05355	0.	0.00155	2.810^{-4}
c. CO2 + worst seed j.mis. 0.5mm	0.94389	0.05412	0.00005	0.00205	7.610^{-4}
c. CO2 + worst seed j. mis. 1mm	0.94385	0.05158	0.0001	0.00455	1.910^{-3}

The worst seed w.r.t. CO2 effect on ring 7337 losses.

Halo losses, injection, with IR3 coll-s worst seed w.r.t. CO2 effect		
	on the 2 cm radial apert	
	outside COS	ring 7337
Ideal	0.00137	1.410^{-4}
corr. CO2	0.00150	1.710^{-4}
corr. CO2 + worst seed 0.5 mm jaw mis.	0.00205	7.410^{-4}
corr. CO2 + worst seed 1 mm jaw mis.	0.00443	1.810^{-3}

IR3 collimators included.

The 10 seeds for **CO2 + jaw mis.**
random uniform $|dx|_{max} = |dy|_{max} = 0.5\ mm$

	outside COS
Ideal	0.00135
seed 1	0.00391
2	0.00336
3	0.00431
4	0.00532
5	0.00525
6	0.00548
7	0.00455
8	0.00522
9	0.00543
10	0.00450

#	elm.name	drift name	s[m]	N lost
325	RBA78B1	D000039	837.017	4
329	BPM	D000056	838.538	1
831	ROFA78B1	D000057	1908.191	1
1099	RCSA78B1	D000040	2494.945	1
1497	D000014	MCBX3L8	3456.911	1
1578	RQ5R8B1	D000071	3680.509	1
5932	BPMW	RCBWH5R3	13647.172	1
10099	BPMYC	D000024	23306.371	7
10101	RQ5L6B1	D000023	23310.043	1
10131	MKD	D000180	23341.918	1
10133	BPMYC	D000024	23342.771	15
10135	RQ4L6B1	D000023	23346.443	17
10179	BPMYC	D000024	23722.771	4
10181	RQ5R6B1	D000023	23726.443	2

Summary and conclusions

Inefficiency of an imperfect collimation system at injection (only the halo produced at the IR7 primary collimator). We have approximately replaced the LHC vacuum chamber with a 2-cm radial aperture limitation at all drift entrances.

For the Ideal system, studied with $\sim 10^6$ particles divided in 10 patches, the 2-cm inefficiency with respect to ring 7337 was found to be average 1.710^{-4} and maximum 2.510^{-4} (this includes the losses on a ~ 10 sigma absorber) and w.r.t. to the RDS7 – $\sim 1.310^{-3}$

A sample error closed orbit, corrected at every turn to zero within the jaw sections of both IR7 and IR3 has been found to increase the average occupancy of ring 7337 by around 40 %), nearly preserving the maximum one. Introducing IR3 has in this case an improving effect on the worst error seeds (around 60 %).

The worst seed of random uniform transverse misalignment of all collimators in both planes

and both directions with amplitude 0.5 mm, added on top of the corrected orbit, increased the losses nearly 5 times with respect to Ideal.

In future one should consider a more realistic chamber geometry. Correct treatment of the off-momentum particles requires acceleration to be included in the model.