LHeC machine-detector interface, detector shielding & protection

Synergy workshop between ep/pA and pp/pA/AA physics experiments

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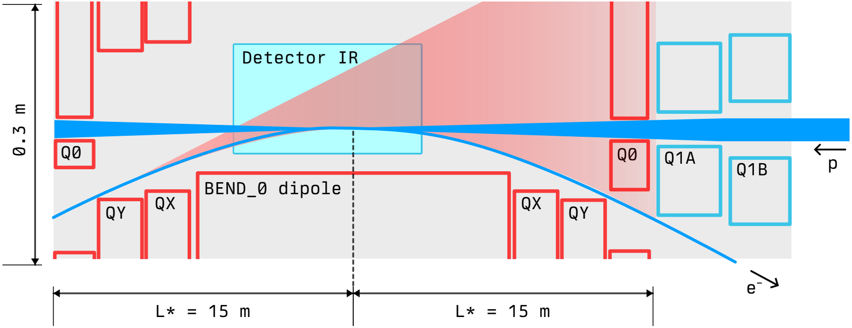
Introduction

Large fluxes of synchrotron light expected from steering of electron beam in the interaction region

- can potentially lead to premature aging of all optical elements downstream the e^{-} beam path



$e - p$ lattice for $L^{*} = 15$ m. Adapted from: K. J. André

Scope of this study:

- evaluate the radiated power in all elements of the e/p beamlines
- provide hints for mitigation of synchrotron radiation on critical elements

Critical energy – a reminder

Given an electron beam circulating in an electromagnetic field,

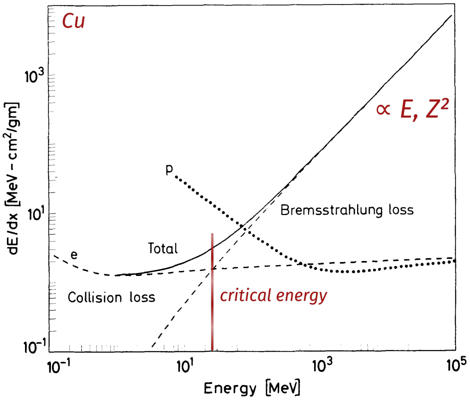
$$\left(\frac{dE}{dx}\right)_{tot} = \underbrace{\left(\frac{dE}{dx}\right)_{rad}}_{\text{Bremsstrahlung}} + \underbrace{\left(\frac{dE}{dx}\right)_{coll}}_{\sim\text{Bethe-Bloch}}$$

and, at $E = E_c$, $\left(dE/dx\right)_{rad} = \left(dE/dx\right)_{coll}$
From kinematic arguments,

$$E_c = h\underbrace{\left[\frac{3}{2}\frac{\gamma^3 c}{\rho}\right]}_{\omega_c},\ P_{synchr} = h\left[\frac{2\alpha_{em}}{3}\frac{\gamma^4 c^2}{\rho^2}\right]$$

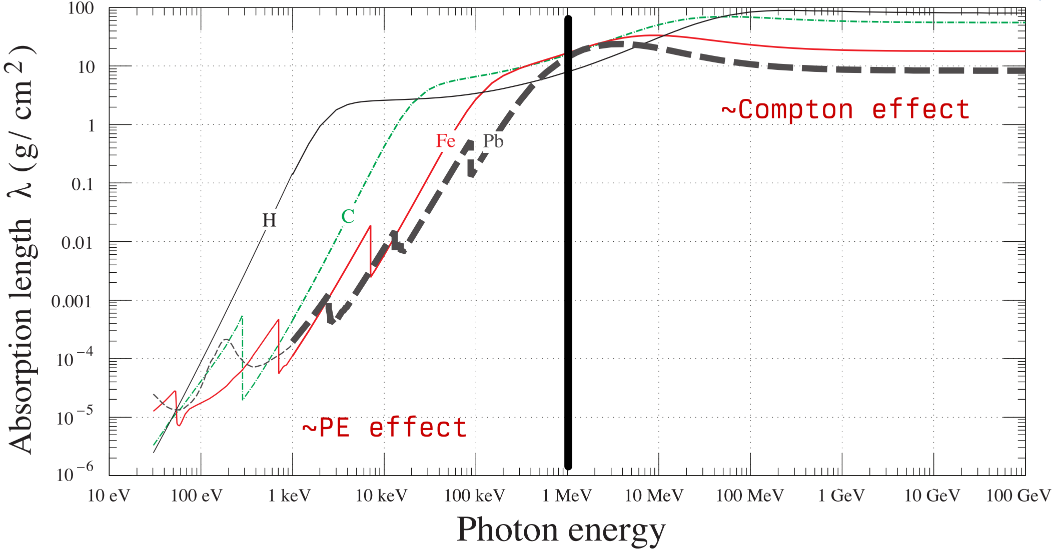
- e.g. in a dipole, with a constant B field

$$E_c = h\left[\frac{3}{2}\frac{\gamma^3 c^2}{p_e}|B|\right]$$



Source: W.R. Leo, Techniques for Nuclear and Particle Physics Experiments

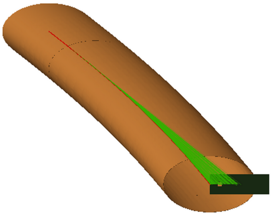
Critical energy – the lower the better

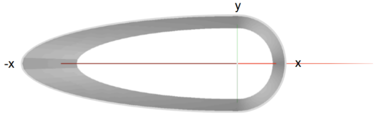


Source: R.L. Workman et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022)

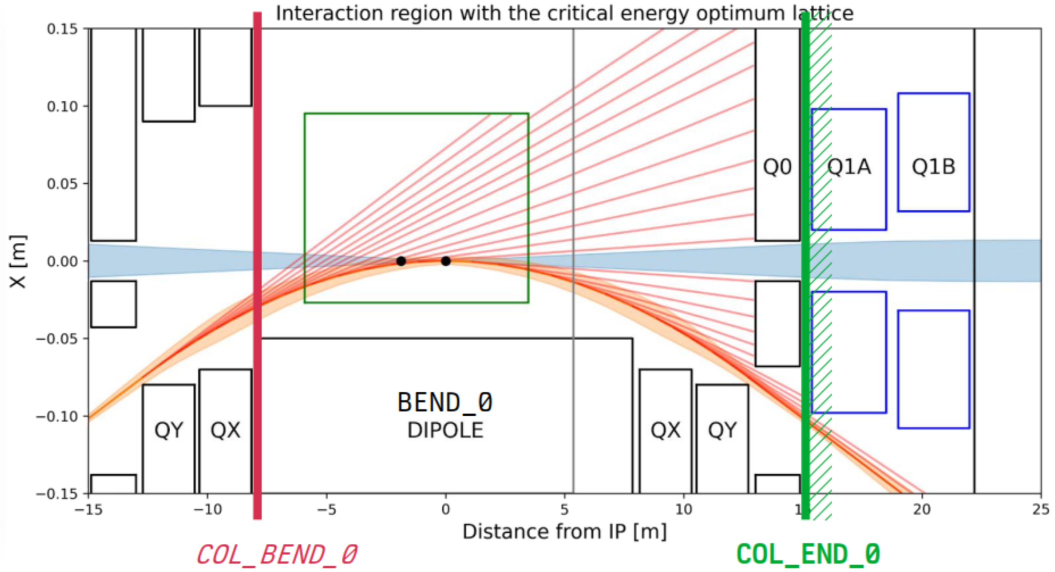
A bit of technicalities

- Simulation tool: BDSIM, wrapper around **Geant4** with standardised definition of **common beamline elements**
- In this stage of the study, only considering electron beamline components (simulating a 50 GeV e^- beam)
  - proton side: QX/QY treated as upstream/downstream sector-bends ; full description and optimisation work: see talk by T. Von Witzleben
  - sampling at all optical elements, conventional **EM** physics list (ionisation, bremsstrahlung, mult.scattering), with addition of **synch_rad** EM processes (E_γ^{min} = 100 keV)
- Lattice assumption: critical energy optimum, as optimised upstream
  - see talk by K. J. André for details about optimisation
  - "realistic", circular-elliptical beamline optimised for three-beam circulation (previously using an elliptical beamline), 0.5×0.3 cm^2 apertures

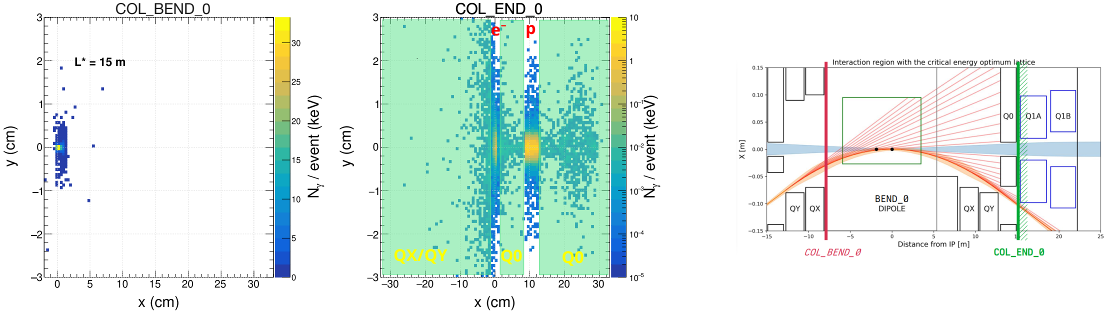




Simulated electron beamline



Synchrotron radiation along e^- beamline



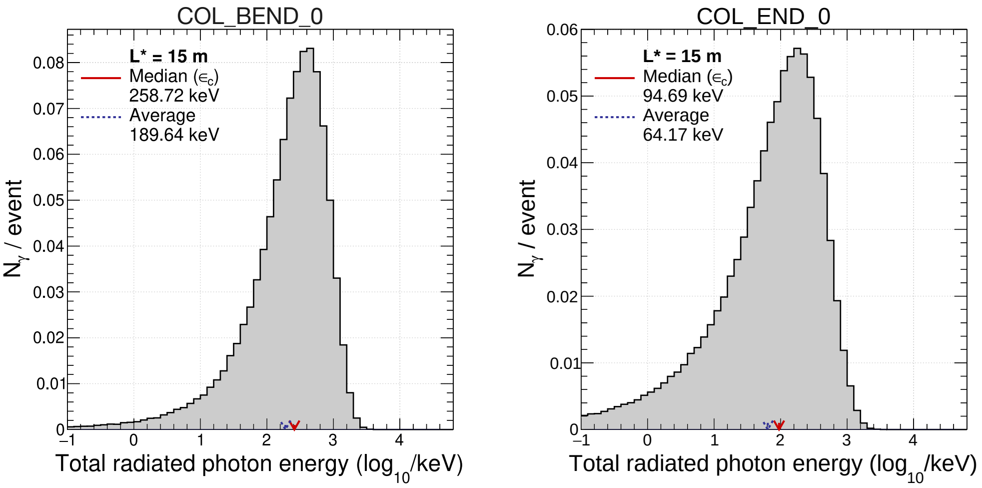
Flux of photons scored right before Q1A, and without collimator ; the $x = 0$ axis refers to the electron beamline coordinate system (i.e. red curve on rhs. figure)

First observations

Q0s already act as a strong passive shielding for all downstream e/p beamline elements, **even without collimator upstream the IR**

Critical energy

E_c, as computed as the median of the dN_γ/dE_γ flux distribution:

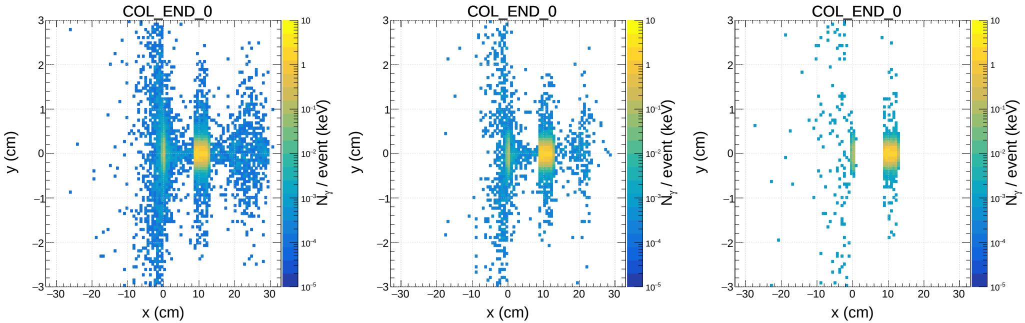


Photon energy distribution at the entrance of the detector dipole (left), and at the end of the $e - p$ lattice, upstream the proton Q1A (right)

Introducing some shielding – at Q1A

Simulation of the **addition of a shielding** upstream the detector dipole, right after QY/QX pair

- collimator with a ~1 cm aperture
- tested a few collimator **thicknesses** and **materials**

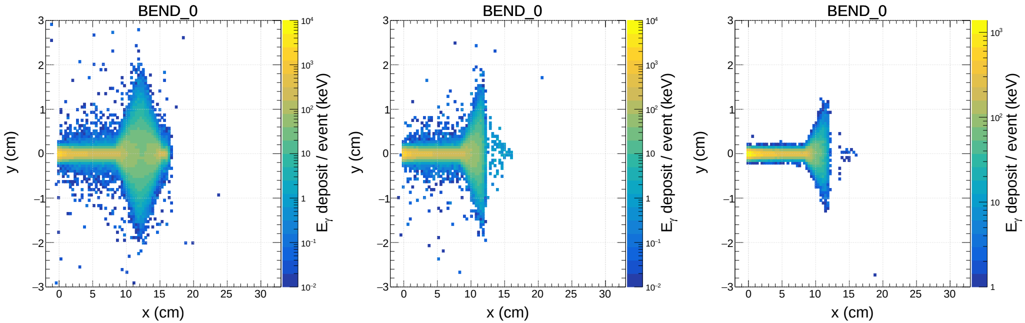


Left to right: without collimator, with a 4 cm upstream collimator after QX, with a 10 cm collimator at the same location.

Introducing some shielding – end of detector volume

Simulation of the **addition of a shielding** upstream the detector dipole, right after QY/QX pair

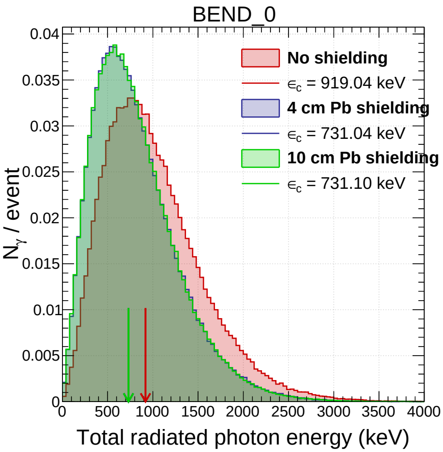
- collimator with a ~1 cm aperture
- tested a few collimator **thicknesses** and **materials**



Left to right: without collimator, with a 4 cm upstream collimator after QX, with a 10 cm collimator at the same location.

Geometrical observation: shielding → partial scraping of intermediate-energy flux of photons entering the proton beam region

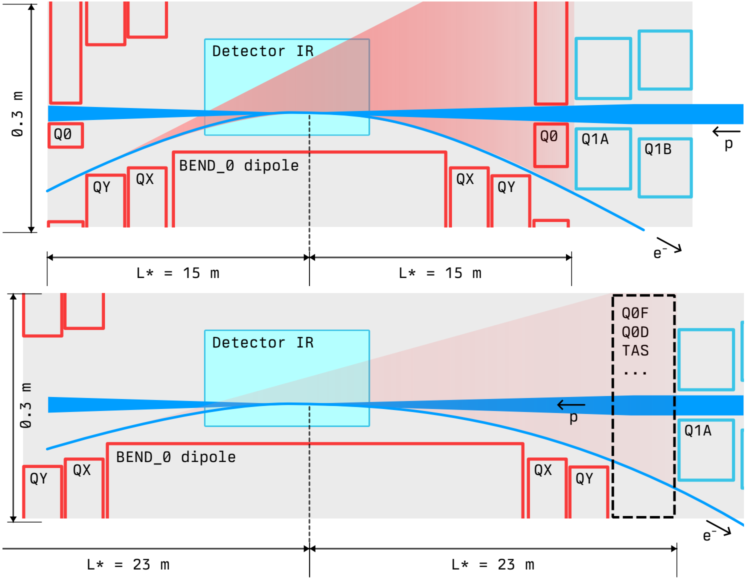
Photon critical energy at the exit of beamline elements



No difference to be expected in critical energy along beamline elements

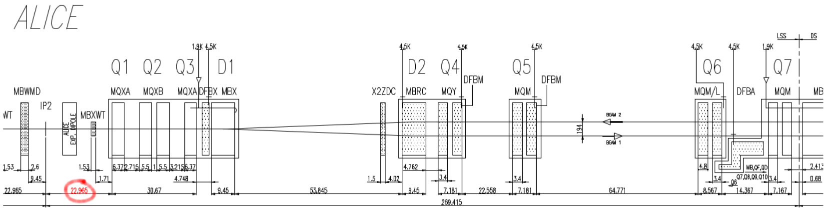
- different assumptions on a shielding introduced upstream the interaction region
- ~flat 20% reduction of critical energy downstream the shielding

From L* = 15 m to 23 m



More space between QX/QY and Q1s to fit additional TAS/collimators/...

From L* = 15 m to 23 m



Source: LHC Design Report, matching section in IR2 – 10.5170/CERN-2004-003-V-1

Larger free drift (half-)length L^* $\rightarrow$ increased space for experimental apparatuses + TAS/TCL/Qx

Requires a re-optimisation of the full beamline optics & Twiss parameters (K. André):

- **proton side**: no need for extra half-quadrupole
  - addition of two off-centered quadrupoles: Q0F and Q0D
  - increased space for dipole, same “crossing” angle at interaction point
- **electron side**: extra drift between detector dipole & Q1A, amended bending angle to maintain separation parameters

Operational parameters for 15 and 23 m

- Re-optimisation (K. André) of the beam & lattice parameters given the released geometrical constraints
  - $P_{\text{syn}}/\varepsilon_c$-based minimisation, further optimised for horizontal beam size

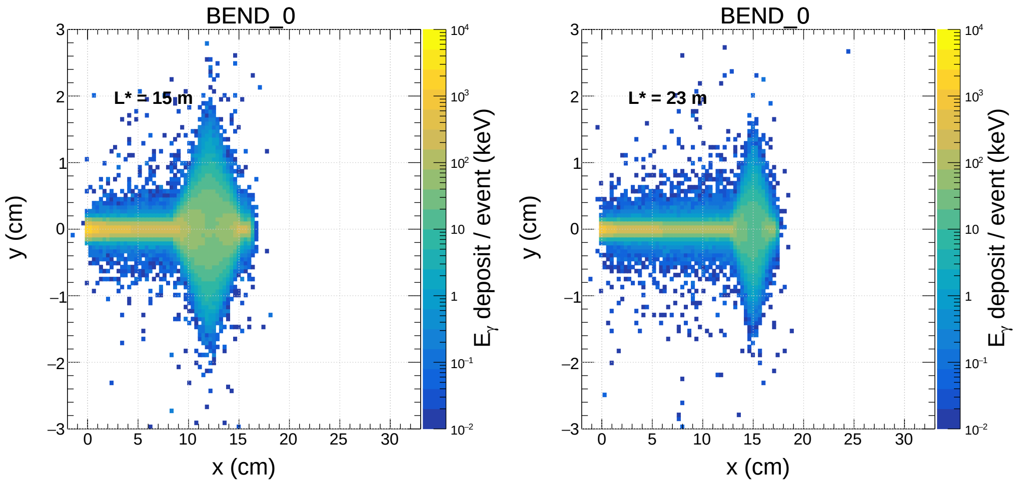
- Critical energy minimisation for two L^* scenarios:

Parameter	L^* = 15 m	L^* = 23 m
initial drift	2.67 m	6.74 m
Q0F gradient	30.1 T/m	29.0 T/m
Q0D gradient	-18.4 T/m	-21.9 T/m
Q0F/D angles	2.07 mrad	0.83 mrad
Q0F/D lengths	2.18 m	1.85 m
half IR length	7.85 m	11.95 m
half IR angle	5.38 mrad	=

Twiss parameter	L^* = 15 m	L^* = 23 m
α_x, α_y	-0.036/99.949	-0.079/6.279
β_x, β_y @ Q1A	9.1/48.81 cm	43.5/16.99 cm
D_x, D'_x	13.4/1.2 cm	5.2/0.3 cm
D_y, D'_y	0	=
$\varepsilon_{x,y}$	5×10^{-10}	=
σ_E	0.28 MeV	=

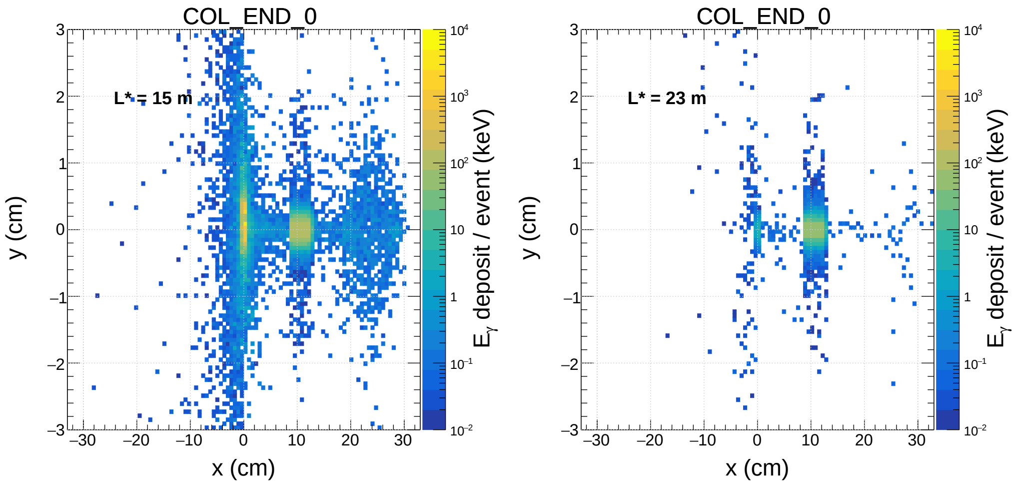
Lattice (left) and beam (right) operational parameters for the two free drift lengths scenarii

L^* and photon hits energy distributions outside IR



Number of photon hits scored as a function of the free-drift length at the exit of the detector dipole, for $L^* = 15$ m (left) and 23 m (right).

L* and photon energy distributions at the end of e^- beamline (final collimator before Q1A)

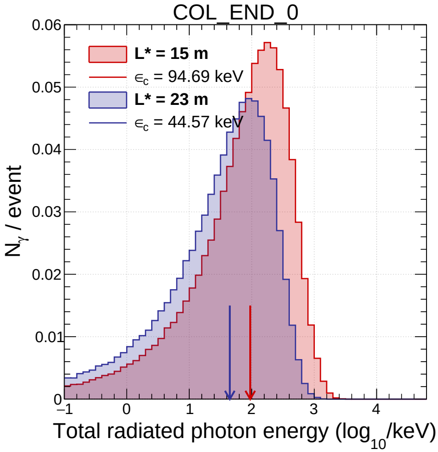


Number of photon hits scored as a function of the free-drift length at the Q1A entrance, for L^* = 15 m (left) and 23 m (right).

Photon critical energy at the exit of beamline elements

- Roughly a **factor 2 reduction** expected in critical energy for **all major beamline elements**
- Moreover, integrated **along the full electron beamline/arc**:

Parameter	L^* = 15 m	L^* = 23 m
Mean free path	1.00 m	2.13 m
E_c	267.8 keV	123.3 keV



Summary and outlook

Study of the machine-detector interface (again) on rails

Full simulation of the (electron, for now) beamline components in BDSIM

- first studies of synchrotron photon energy spectra and **critical energy** under several assumptions
- **already performed**: effect of shielding upstream the detector volume (material, opening, thickness), increase of L^*

Already providing some **promising insights** on beamline constraints

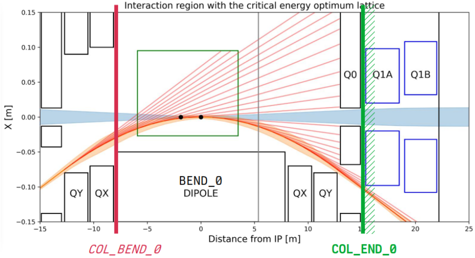
- worse case scenario ($L^* = 15$ m, no shielding of detector area): $E_c \sim$ 270 keV integrated over full beamline
- synchrotron radiation already under control for $L^* = 21$ m

A look forward

Synergies to be developed with **ep/eA@CERN Study WG4**: integration of detectors constraints in this framework

Spares

Simulated electron beamline



Name	Type	L (m)	Angle (mrad)	S Start(m)	S End (m)
uDRIFT50	Drift	0.5	0.0	0.0	0.5
uDRIFT_Q0	Drift	1.87198	0.0	0.5	2.37198
uDRIFT30_0	Drift	0.3	0.0	2.37198	2.67198
uBEND_QY	SBend	2.17713	2.072436	2.67198	4.8491
uDRIFT20	Drift	0.2	0.0	4.8491	5.0491
uBEND_QX	SBend	2.17713	2.072436	5.0491	7.22623
uDRIFT30_1	Drift	0.3	0.0	7.22623	7.52623/*7.50623*
COL_BEND_0	*R-Collimator*	*0.02*	*0.0*	*7.50623*	*7.52623*
BEND_0	SBend	15.70306	14.947956	7.52623	23.22929
dDRIFT30_0	Drift	0.3	0.0	23.22929	23.52929
dBEND_QX	SBend	2.17713	2.072436	23.52929	25.70642
dDRIFT20	Drift	0.2	0.0	25.70642	25.90642
dBEND_QY	SBend	2.17713	2.072436	25.90642	28.08354
dDRIFT30_1	Drift	0.3	0.0	28.08354	28.38354
dDRIFT_Q0	Drift	1.87198	0.0	28.38354	30.25552
dDRIFT50	Drift	0.495	0.0	30.25552	30.75052
COL_END_0	**R-Collimator**	**0.005**	**0.0**	**30.75052**	**30.75552**

$L^* = 15$ m beamline description