Tungsten shielding in the MDI and muon background

Do we need tungsten shielding to protect the final focus quads from quenching ?

would need space and add weight to the tight MDI design

- SuperKEKB
- Strategy, experience from other machine
- Scattering processes, beam-gas, thermal, muon-production

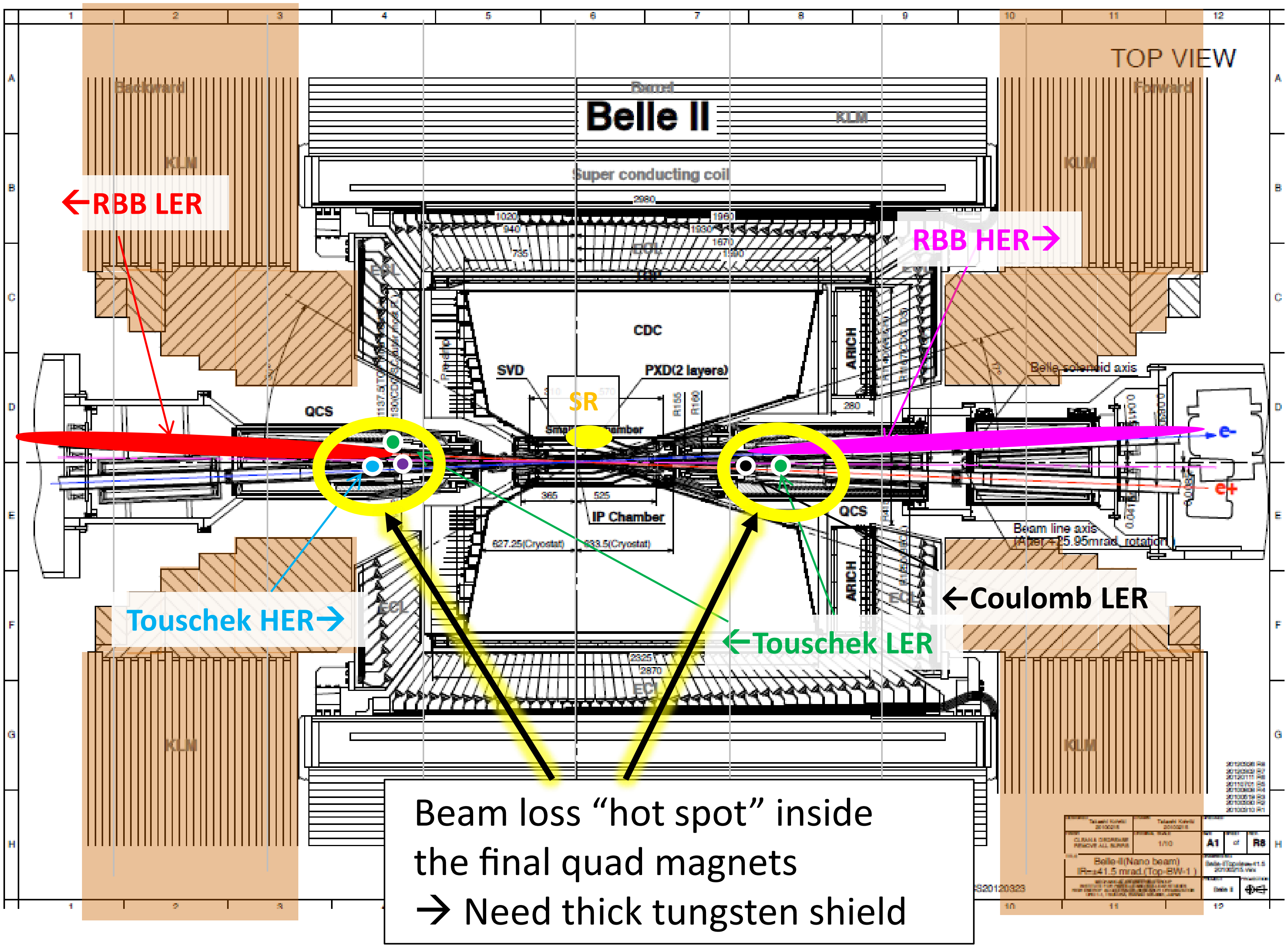
  scaling of energy + angular dependence, rough estimates

Acknowledgement :

many thanks to Hiroyuki Nakayama / KEK on SuperKEKB

FCC-ee MDI team ; former LEP colleagues with in particular Georg von Holtey

SuperKEKB, Belle II

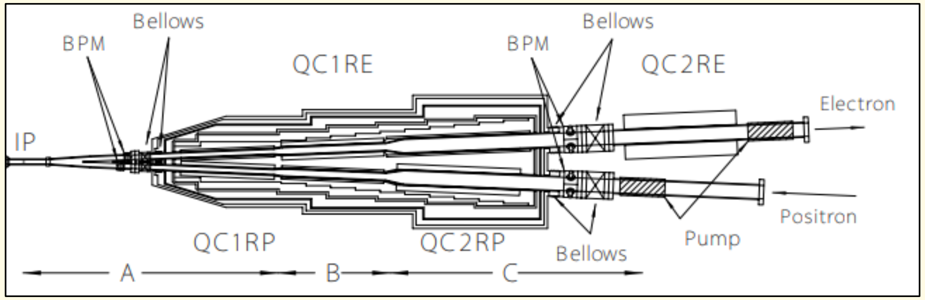


Hiroyuki Nakayama @ Oct. 2023 International Circular Collider “CEPC” workshop

SuperKEKB

Hiroyuki Nakayama [Oct. 2023 Int. Circ. Collider "CEPC" workshop]

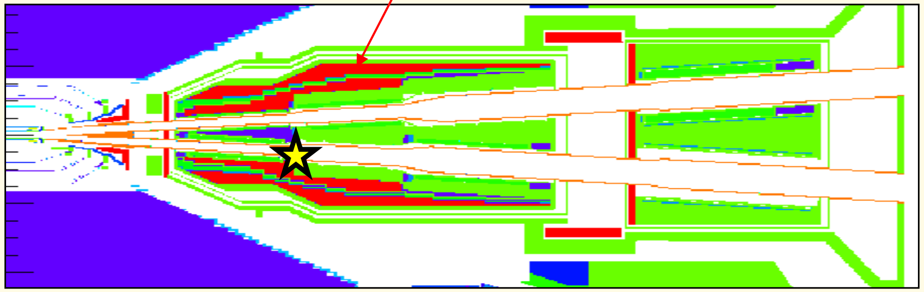
TDR(2010)



- TDR is prepared just after the change of SuperKEKB design concept ("High current " → "Nano-beam")
- Therefore, at that time, no beam background estimation was available for the "Nano-beam" optics
- No shield considered inside the cryostat

Final design

thick tungsten layers



- As background simulation developed, we found a significant beam loss inside the final focus magnet
- I made a strong request to put as much heavy-metal shield as possible inside the cryostat
- It required major modification on the already-started cryostat fabrication process

Takeaway message: Reserve enough space for the BG shields between detectors and beam pipes!

SuperKEKB : HER 7 GeV e- LER 4 GeV e+

To which extend do we need that for the FCC-ee IR ?

Caution : shielding also source of background

DESY - PETRA 2.3 km e+e- ring, early operation ~ 1980 at 18 GeV / beam

backgrounds increased when Sn shields were added around experimental beam pipe

IR should be transparent for beam + halo

realistic halo + scattering of secondaries

non-trivial to simulate

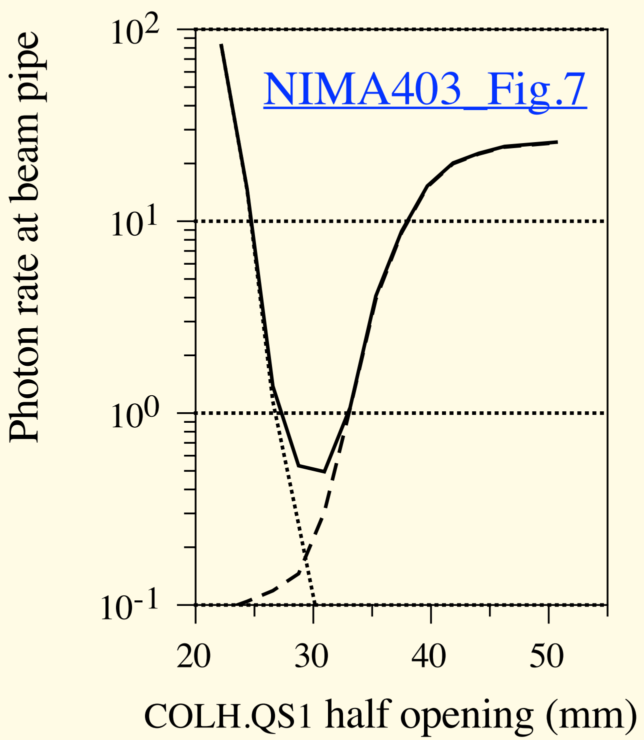
Fluorescence, Rayleigh, specular reflection

misalignment, fringe fields, muon production

frequently underestimated or even missing

Typical collimator gap

vs background picture

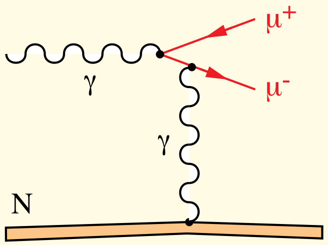


Good strategy confirmed by LEP measurements

1) minimize background at the source
2) collimate halo far from IP ; do not reduce lifetime
3) off-momentum collimation end of arc each IP

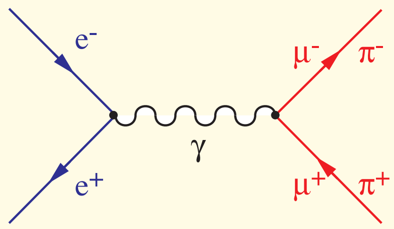
Muon backgrounds

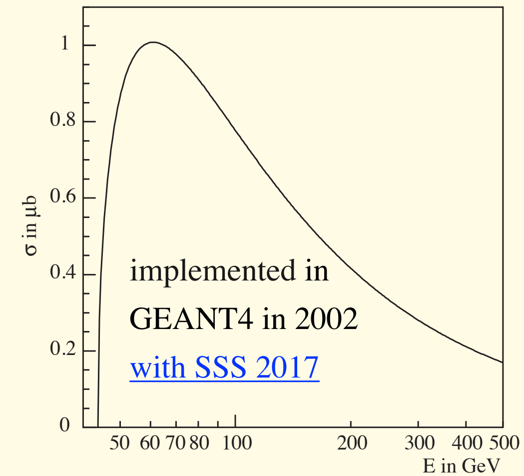
Collimating high energy e+, e– will generate muons, roughly at the 10^{-4} – 10^{-5} level



beam e+

on atomic e-





G4AnnihiToMuPair G4GammaConversionToMuons

examples/extended/electromagnetic/TestEm6

came as a bad surprise for SLC, hard to avoid in linear colliders

carefully studied for CLIC, hard to reduce ≳ 40 m long magnetized shielding

Muon Sweeper Design, Aloev et al. , Belgin Pilicer thesis

not an issue for LEP-MDI ; losses were collimated far from the experiments

In FCC-Z we expect to lose several 10^{11} e+, e– per second generating millions of muons / second

→ **minimize collimation of e+, e- in line of sight to experiments**

LHC

LHC rather different the major source of radiation in the IR are the pp-collisions produced at the IP + contribution from halo collimation + local beam gas

major ingredients of going from LHC to High Lumi LHC :

lighter beam-pipe + Al2219 support structures at IR

new much larger aperture final focus quadrupoles

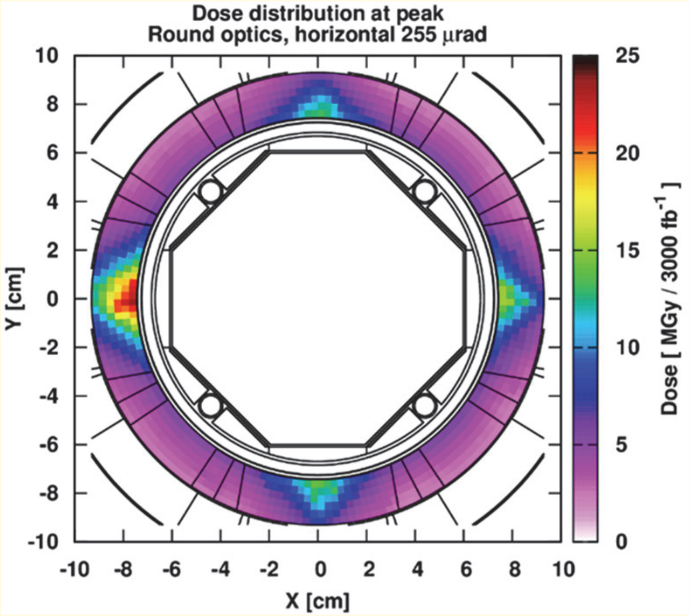
inner diameter 70 mm → 150 mm

final focus quadrupoles starting 23 m from the IP

behind a 1.8 m thick Cu - absorber

with reinforced tungsten alloy shielding in beam screens

16 mm thick in first quad, then 6 mm



Energy Deposition and Radiation
F. Cerutti et al. High Lumi LHC book, 2nd Ed.

Recent ALICE background issue in LHC PbPb operation

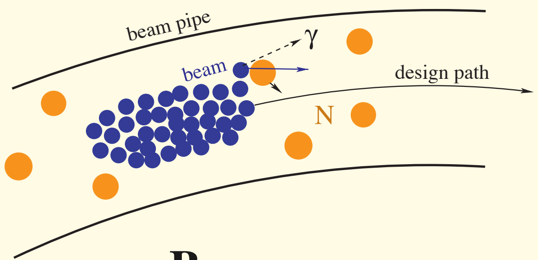
Main source halo hitting the vertical collimator TCTPV.4L2.B1 at 117 m in front of ALICE

identified by background decrease when opening collimator gap

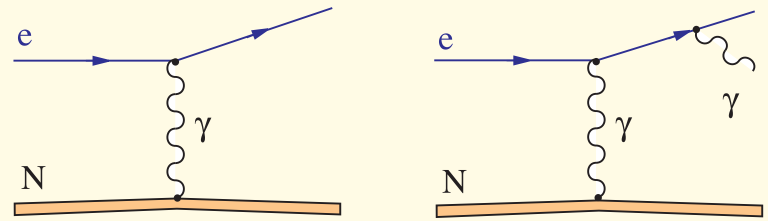
later mitigated with dispersion dump, origin and consequences currently under study

Pb208 ions losing one neutron Pb207 appearing as 0.5 % off-momentum particle

Beam-gas, thermal photons, off momentum

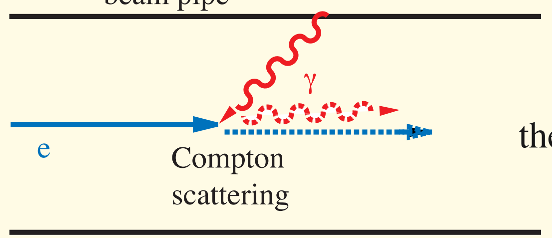


Beam-gas



e-N elastic, Coulomb   e-N inelastic, Bremsstrahlung

Figs. from my contribution to [Landolt-Börnstein New Series I/21C]



thermal photon scattering

At high energy elastic scattering small

mainly inelastic off-momentum tail

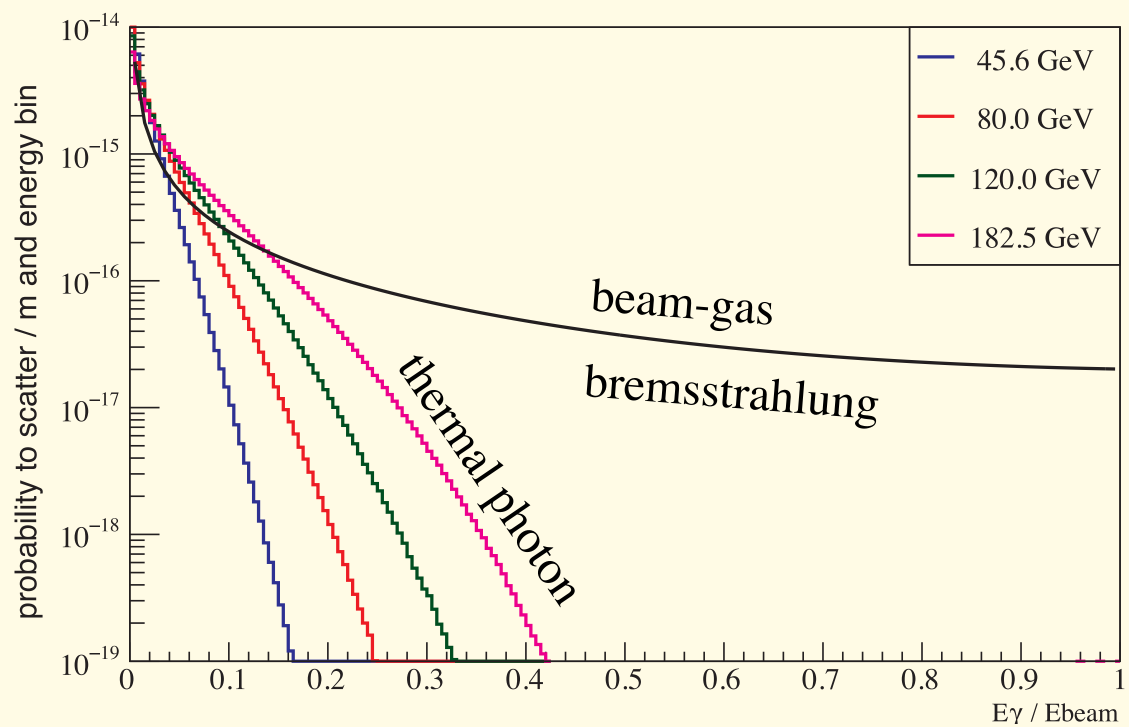
well visible in LEP, possible to protect

that not a major issue

< 1 electron lost at IR / crossing

thanks to

- **excellent vacuum**
- **powerful momentum collimation**



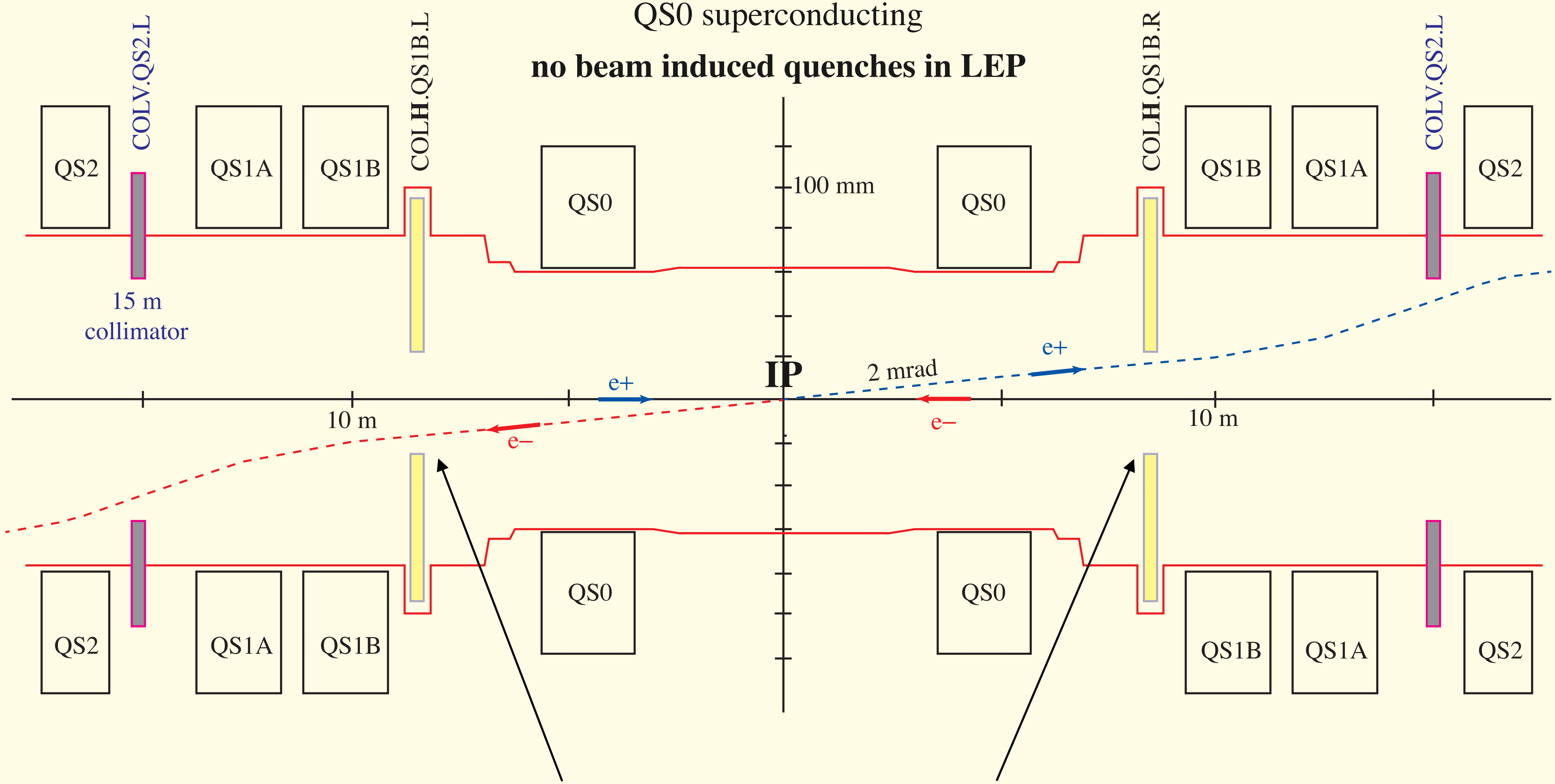
both in dedicated collimation section + local each IR

LEP IP region

Schematic layout based on '91 Nucl.Phys paper redrawn/updated

QS0 superconducting

no beam induced quenches in LEP



SiW instrumented horizontal 8.5 m collimator

used as machine interaction rate and mostly off-momentum **background monitor**

used to benchmark simulations and optimize local collimation, details in MD-notes 107, 111 …

Quench limit estimate final focus quadrupole

Mike Koratzinos estimate for QC1

FCCee MDI meeting 14/3/2022

NbTi standard Kapton insulated

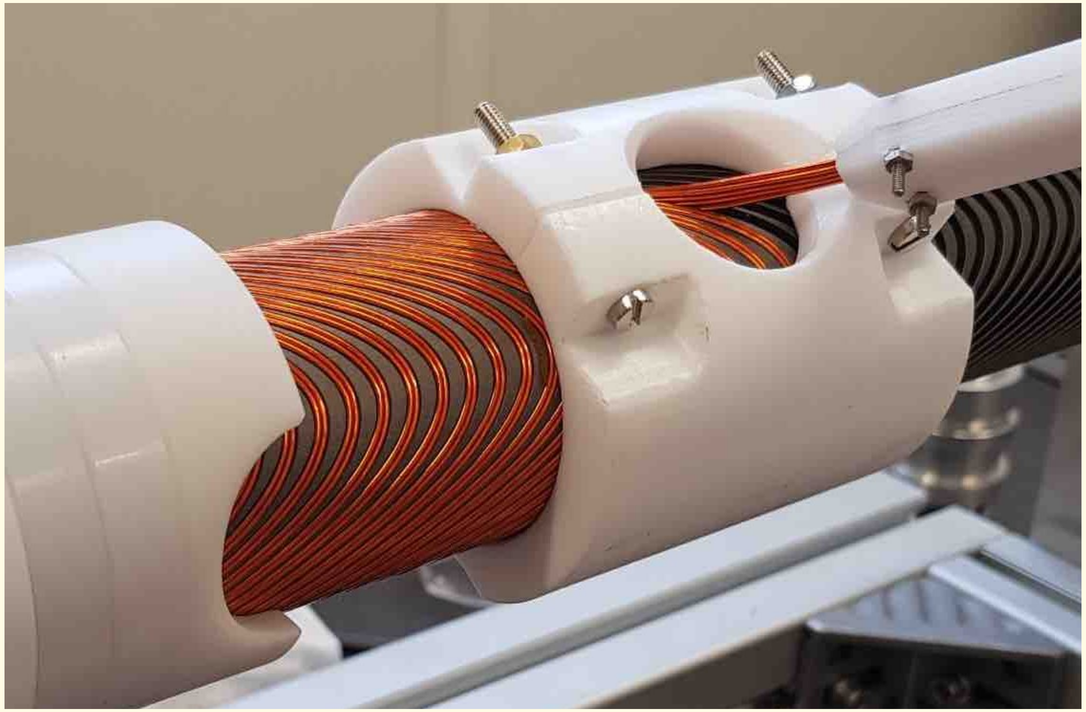
LHC cable 0.825mm × 0.970mm

1.9 K Icrit = 1100 A / mm^2

100 T / m max gradient

quench limit 3 mW / cm^3

= 1.9×10^7 GeV / cm^3 s



continuous energy loss should be < 2×10^7 GeV / cm^3 s

1 eV = 1.602176634e-19 Ws exact with 2019 unit revision

Rough estimates FCCeeZ compared to SuperKEKB

- **Elastic** **Coulomb scales with E^2** **numbers for $\theta > 100\ \mu$rad**

σ_{COU} = 163 Barn @ 4 GeV SuperKEKB LER $P_{col} = 5.3 \times 10^{-13}$/m

σ_{COU} = 1.25 Barn @ 45.6 GeV FCCee Z Collision Probability $P_{col} = 4.1 \times 10^{-15}$/m

- **Inelastic ~ independent of beam energy**

σ_{BREM} = 6.56 Barn for 1% energy acceptance, $P_{col} = 2.1 \times 10^{-14}$/m

Residual Gas, FCC-ee vacuum system presented yesterday by Roberto Kersevan

here 23°C and simple const 1 nTorr = 1.33×10^{-7} Pa CO LEP typically 2× less

Beam currents or #particles / second FCCeeZ and SuperKEKB very similar

Ibeam = 1.27 A 7.9×10^{18} particles / second multiplied with P_{col}

rates per meter and second

1.7×10^5 / m s inelastic off-momentum, σ_{BREM}, FCCee in addition thermal photon

little dispersion around IP, make sure to screen from off-momentum and halo

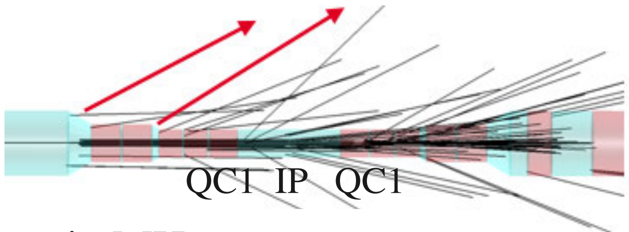
produced at larger distances

4.2×10^6 / m s elastic LER

3.2×10^4 / m s elastic FCCeeZ ~ managable

Beam-gas and thermal photon simulation

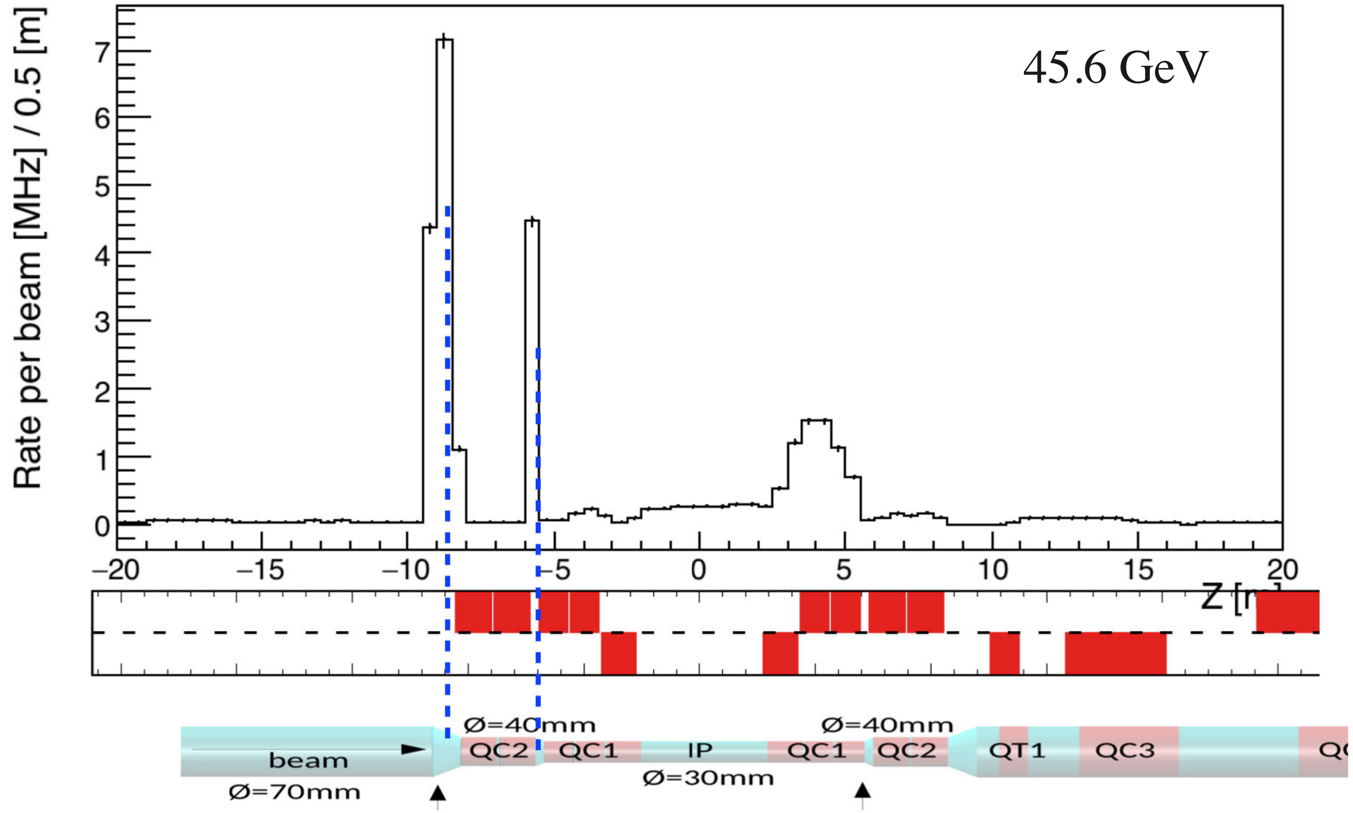
Beam-gas background characterization in the FCC-ee IR, Boscolo et al. J. Phys.: Conf. Ser. 1067 022012 2018



rates in MHz

	1 km	± 20m
Z	147	29.2
W	15.8	3.43
H	2.96	0.536
T	0.526	0.969

without local
off-momentum collimation



Beam losses at IR, FCC week 2019 with thermal photon scattering around the ring

possible to suppress off-momentum losses from arc towards IR

with horizontal collimators 640 m and 480 m from IP

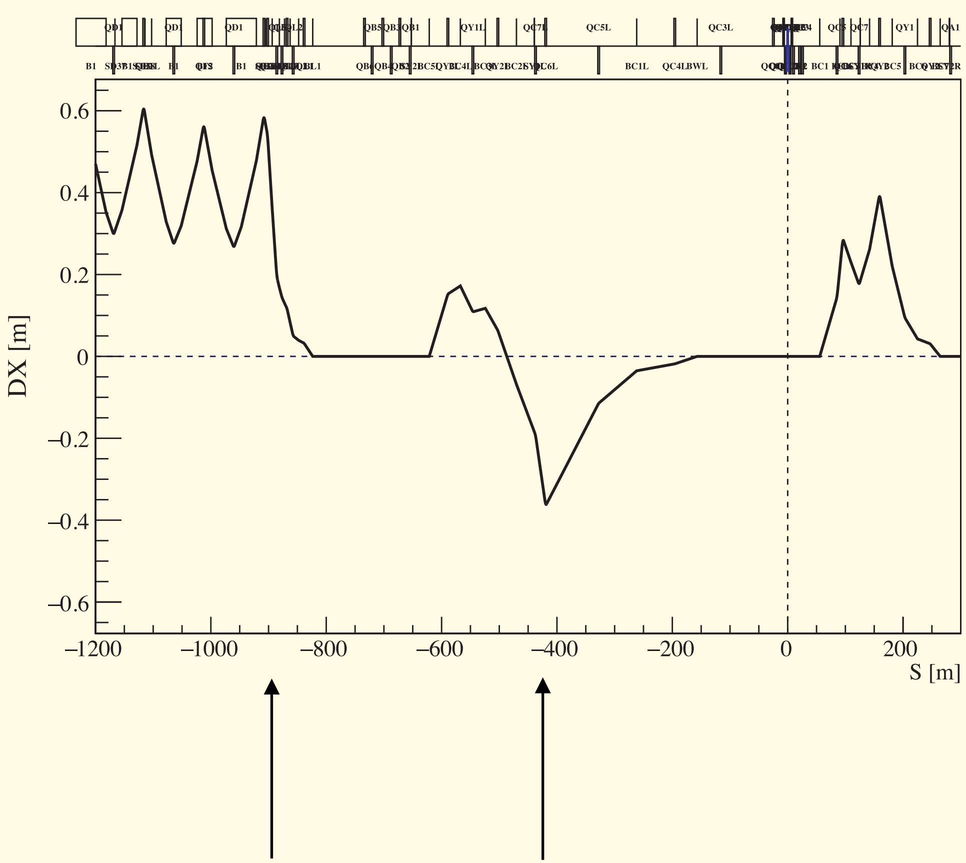
Meanwhile optics and aperture changes and more work on halo collimation by Andrey Abramov et al.

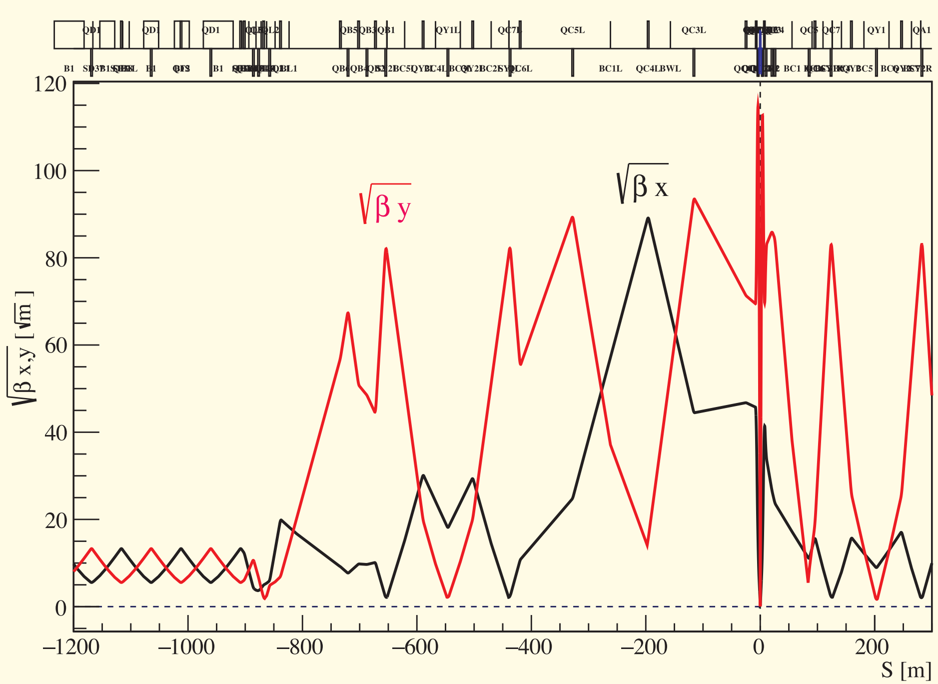
and SR collimation as shown earlier today by Kevin André

+ radiative Bhabha generated at IP - not possible to shield from outside

IR region optics, potential places for local cleaning

FCCee_z_572_nosol K.Oide [170th FCC-ee Optics Design Meeting 20/7/2023]() + [install_IP_solenoid]()





local momentum collimation

local halo collimation

Summary

- **Thick tungsten shielding of the final focus quads was found to be essential for SuperKEKB**
  their takeaway message to reserve space should better be considered seriously

- **The IR region is tight and packed**
  absorbing the much higher energy FCC-ee halo particles
  generates more heating, radiation and some very penetrating muons

- **The importance of Coulomb + Touschek scattering decreases with energy**
  and the FCC-ee ring is much larger offering more space to clean halo away from the IR
  making thick shielding in the IR more optional
  to be confirmed & optimized by further
  beam-gas / thermal photon / radiative Bhabha / collimation & IR modeling studies

Backup

LEP, example of background particle tracking

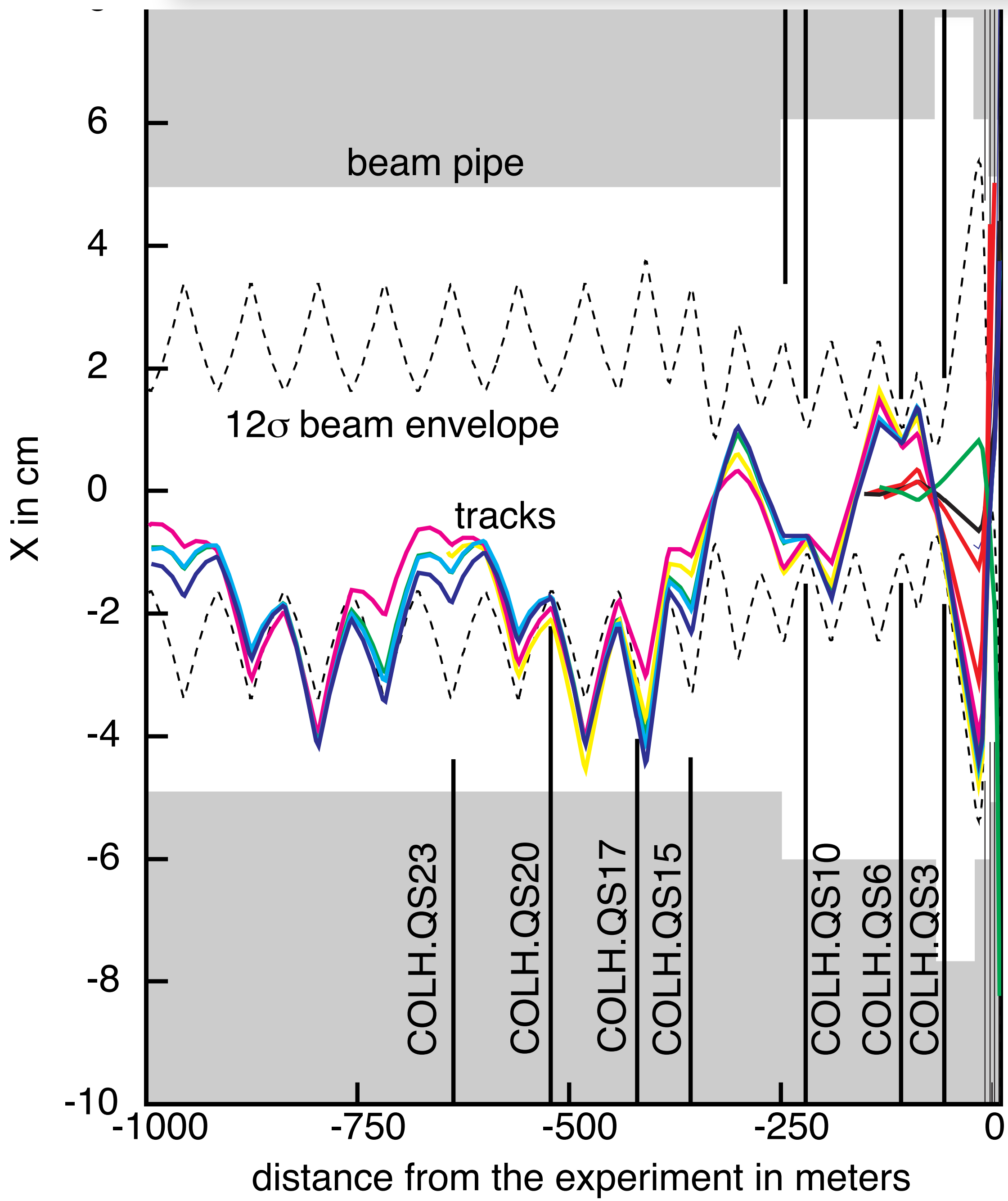


Illustration of beam particle tracking through the LEP lattice over 1000 meters up to an experimental region (cs coordinates).
The distance X from the nominal orbit is given in cm units.
The tracks are for particles that are lost within ±9 m from the interaction point.
The 12σ beam envelope is shown as broken line.
The physical aperture limitation given by the beam pipes is shaded.
The position of collimators (called COLH.QS15, COLH.QS17..) as used in LEP physics runs is shown as vertical straight lines.

Codes : MAD8, Turtle, DIMAD, EGS
+ "own generators" beam gas, thermal, SR, radiative Bbhabha

plot from my simulation for the 1998 LEP background paper Ref [1]