APERTURE MODEL AND COLLIMATION SECTION IN THE FCC-ee

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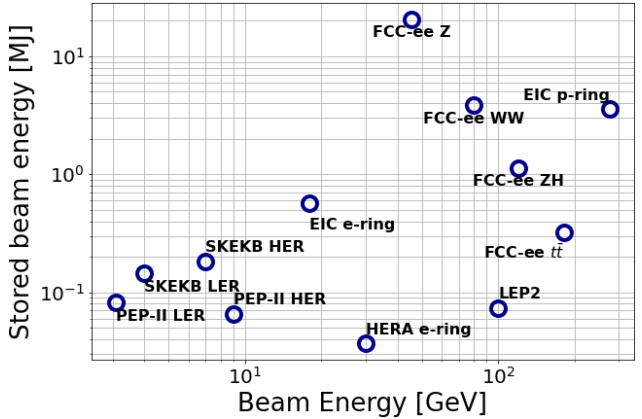
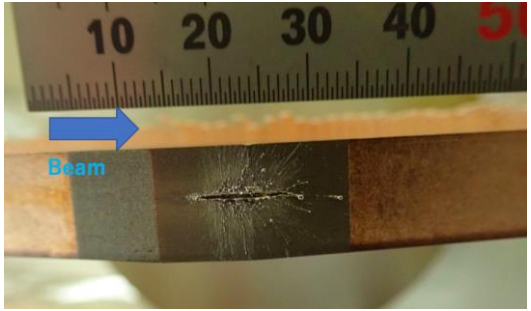
Introduction

- Ongoing studies on collimation system in the FCC-ee
  - Main roles are:
    - Protect equipment from highly destructive beams
    - Reduce backgrounds in Experiments

- For studying cleaning efficiency, first steps are:
  - Establish aperture model of the ring to determine bottlenecks
  - Integrate betatron/momentum collimation system for use in tracking studies



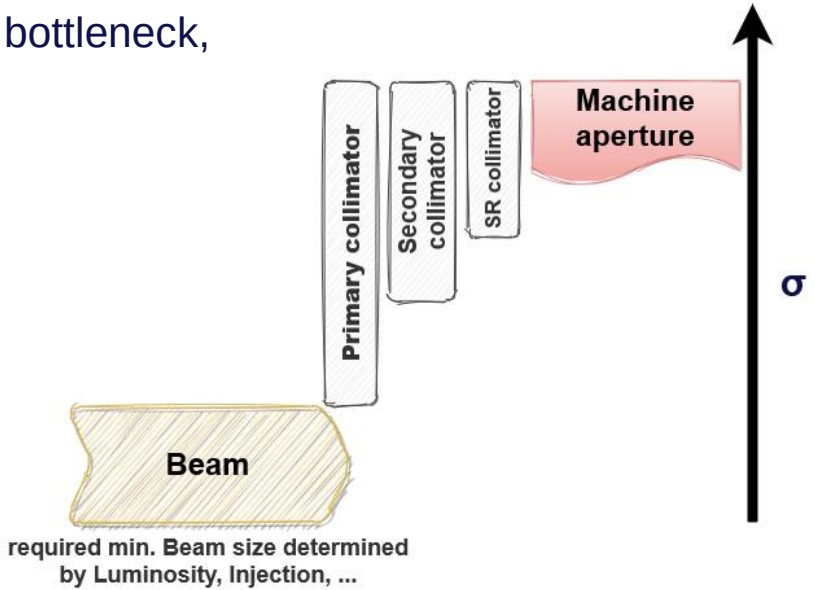
Damaged jaw of D02V1 in LER due to the sudden beam loss



T. Ishibashi, FCC collimation meeting #32

Constraints

- Follow LHC approach of a two-stage system with one primary collimator per plane as aperture bottleneck, followed by secondary collimators
- Collimator openings limited by two constraints
  - Min. collimator opening/required aperture determined by collider performance
  - To protect machine aperture, max. collimator opening smaller than aperture bottleneck

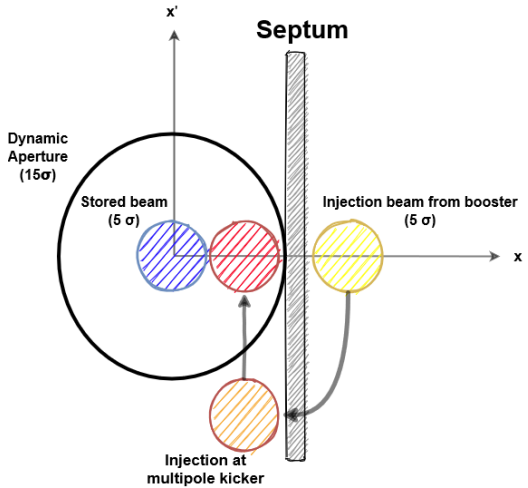


Minimum aperture requirement

- For top-up injection, the minimum required aperture was initially defined as 15 $\sigma_x^{collider}$ (ref)
  - Assume $5\sigma_x^{collider} + 10\ \sigma_x^{injected}$
  - Using emittance estimates from booster design (ref), the requirement can be refined in terms of $\sigma_x^{collider}$

Operation mode	Z	W	H	tt
Aperture requirement [$\sigma_x^{collider}$]	10.8	10.8	14.2	13.9

  - To be further refined including septum width in case of orbit bump injection and optics mismatch
- Momentum acceptance to keep reasonable beam lifetime in the presence of beamstrahlung (ref)
  - For Z, W, H: $\delta_{acceptance} > 1.5\%$
  - For $t\bar{t}$: $\delta_{acceptance} > 2.8\%$



Adapted from M.Aiba et. al.,*Top-up injection schemes for future circular lepton collider,* NIM A 880 (2018)

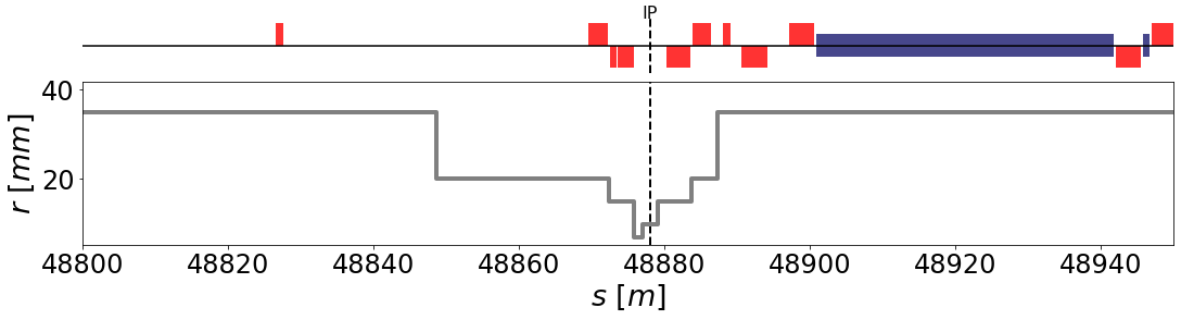
Aperture model

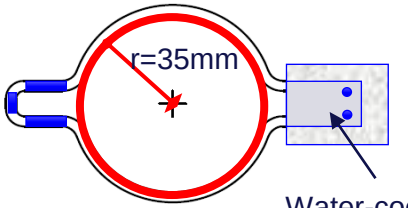
- Define aperture and alignment tolerances for each element in the machine to identify aperture bottleneck, thereby determining collimator opening

Element type	Transverse misalignment [μm]	Tilt [μrad]
Arc quadrupole and arc sextupole	50	100
Dipoles	1000	0
IR quadrupole and sextupoles	100	100

M. Moudgalya, CERN-THESIS-2021-326

  - For most of the ring, circular beam pipe with $35\ mm$ radius
  - Smaller beampipe in the final focus quadrupole and central chamber
    - Transitions between elements to be defined





Water-cooled SR absorber

Plot adapted from R. Kersevan, "Vacuum system", at FCC November Week 2020

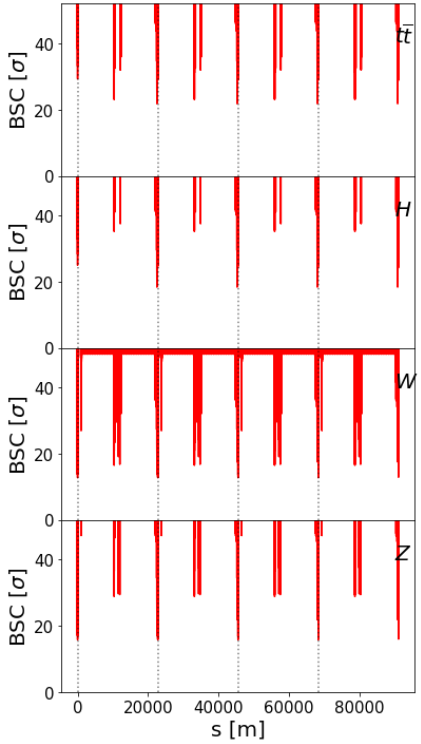
Aperture bottlenecks

- Beamstayclear evaluated using MAD-X APERTURE module including optics errors derived from tuning studies

Aperture parameter	
Radial closed orbit uncertainty	250 μm
β-beating	20%
Parasitic dispersion	0

- In all operation modes, bottlenecks close to the IP
  - For Z & W, bottleneck in hor. plane bottleneck is final focus quadrupole
  - For H & tt, bottleneck in hor. Plane is dipole upstream of IP
  - Final focus quadrupole is bottleneck in the vertical plane in all modes

Operation mode	Minimum hor. beamstayclear [$\sigma_x^{collider}$]	Minimum ver. beamstayclear [$\sigma_y^{collider}$]
Z	15.8	111
W	12.8	71.5
H	18.4	109
tt	21.8	91



Whole ring

Aperture bottlenecks

- Beamstayclear evaluated using MAD-X APERTURE module including optics errors derived from tuning studies

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Radial closed orbit uncertainty	250 μm
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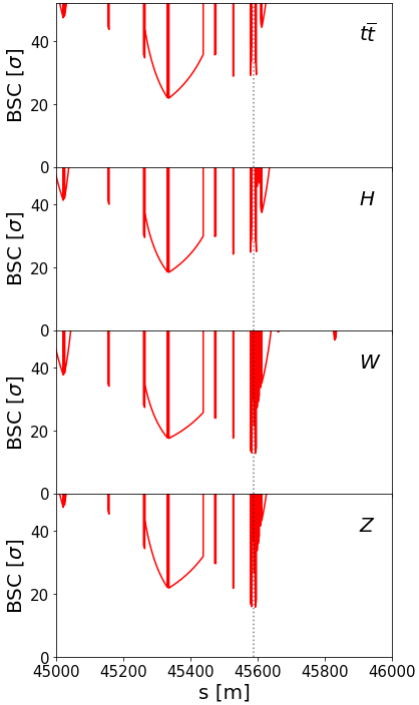
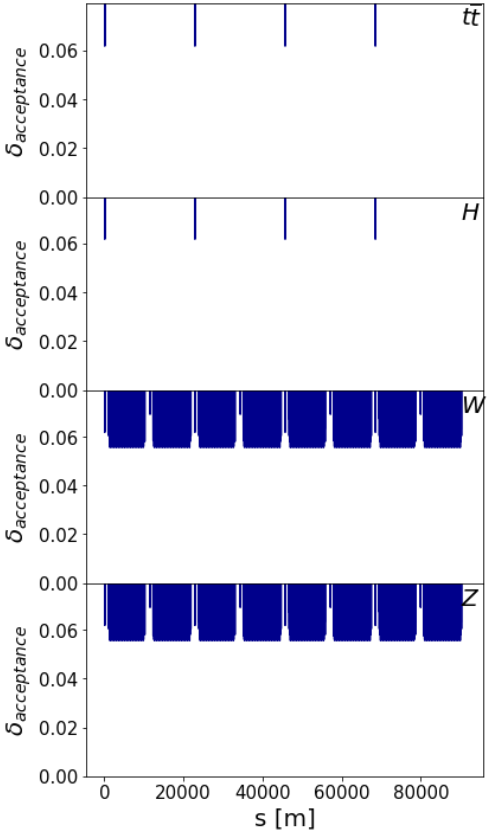


Zoom IP

Momentum acceptance

- Momentum acceptance to keep reasonable beam lifetime in the presence of beamstrahlung (ref)
  - For Z, W, H: $\delta_{acceptance} > 1.5\%$
  - For $t\bar{t}$: $\delta_{acceptance} > 2.8\%$
- Momentum acceptance of the bare machine in all modes $\delta_{acceptance} = {}^{D_x}/_{Aperture} \geq 5\%$
  - Including an $8\,\sigma_x$ offset has only minor effect $\delta_{acceptance} = {}^{(D_x + 8\sigma_x)}/_{Aperture} \geq 4.3\%$
- Automated workflows to check aperture model for changes (repo)



Collimator settings

- Based on the requirements and constraints, first potential settings for primary and secondary collimators found
  - Horizontal primary collimator setting following the requirement from top-up injection
    - Secondary collimator retraction by $1 - 2\ \sigma_x$
  - In the vertical plane, lower limit determined by minimum half-gap of $1\ mm$ and tolerable impedance
  - Primary momentum collimator to cut just above required momentum acceptance
- Settings to be refined following results of tracking studies and input from other groups

Operation mode	Minimum collimator opening from top-up inj. $[\sigma_x^{collider}]$	Minimum hor. beamstayclear $[\sigma_x^{collider}]$
Z	10.8	15.8
W	10.8	12.8
H	14.2	18.4
tt	13.9	21.8

Operation mode	Minimum ver. beamstayclear $[\sigma_y^{collider}]$
Z	111
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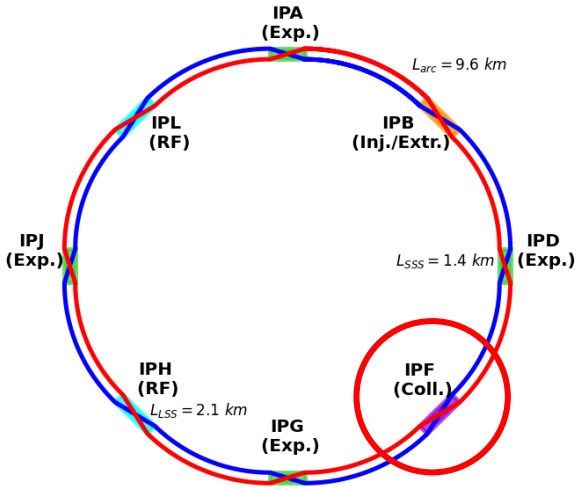
H	109
tt	91

Collimation section

- For FCC-ee, dedicate straight section F to for betatron & momentum collimation
  - In current 4-IP layout, beam crossing in every straight section
  - Separate primary and momentum primary collimator to allow for better control of the different cuts

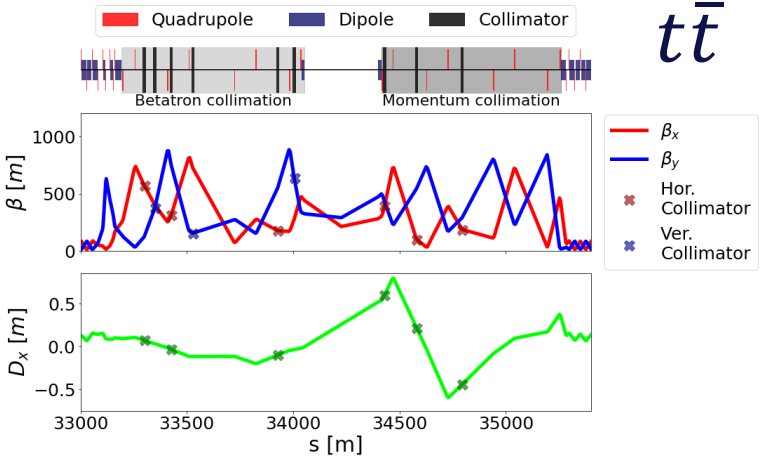


Collimation layout

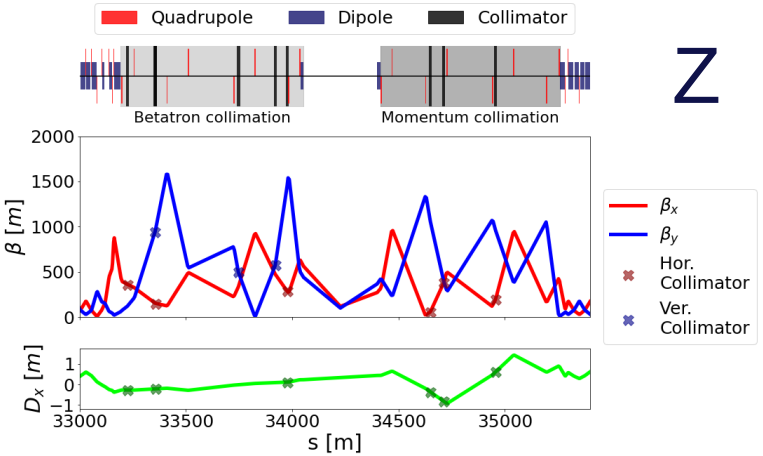
- Layout integrated and optics matched to arcs
  - Betatron collimation upstream of beam crossing and with low dispersion
  - Momentum collimation downstream and with large dispersion

- Determine location for primary collimator and find location for secondary collimator following (PRSTAB1, 081001)
  - Phase advance between primary and secondary collimators $\tan\mu = \sqrt{n_2^2 - n_1^2}/n_1$ with $n_{1,2}$ opening in σ of primary/secondary collimator

$t\bar{t}$



Z



Conclusions

- Ongoing studies on a betatron/momentum collimation system in the FCC-ee
  - Protect equipment for high stored beam energy and reduce backgrounds in Exp.

- Aperture model of the collider ring established to identify bottlenecks
  - Together with requirements from top-up injection and lifetime, first set of collimator settings established
  - Reevaluate constraints and requirements on a running basis as machine design progresses

- Layout for a collimation section in FCC-ee integrated and optics for different operation modes matched
  - In the future, adjust and simplify layout based on the input from different studies

Thanks for your attention!