STATUS AND PLANS FOR FCC-HH COLLIMATION

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CDR studies:
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Outline

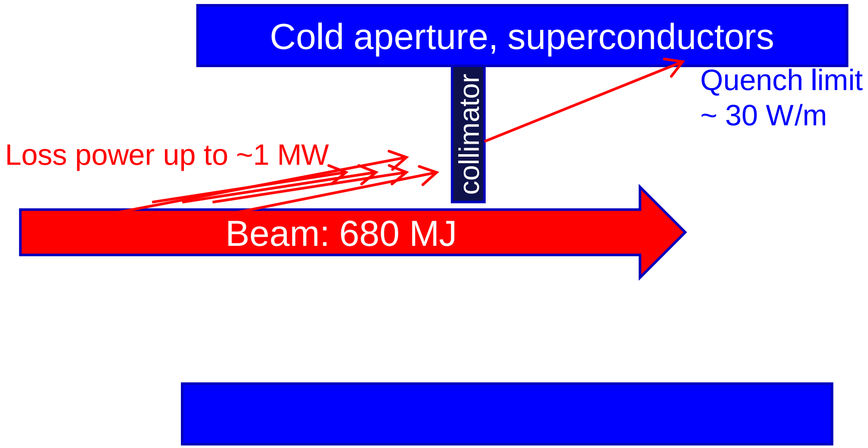
- Introduction and motivation
    - Challenges with collimation in high-energy hadron colliders
    - FCC-hh vs LHC
- Recap of collimation design for CDR
- Updates since CDR
- Outlook and needed future work
- Conclusions

Collimation in high-energy colliders

- High energy and intensity => Typically, very high stored beam energy
- Need superconducting magnets to reach sufficiently high magnetic fields
  - Cooled to cryogenic temperatures
  - Sensitive to heating => Small temperature rise causes a quench (loss of superconductivity)
- Beam losses are unavoidable during regular operation
  - Even a tiny loss could cause a quench, or even material damage
- Need collimation system to safely intercept and attenuate these losses

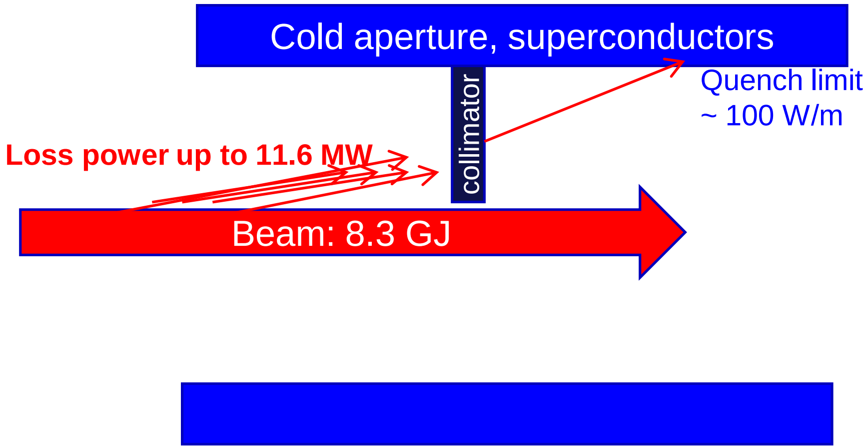
Collimation challenge: LHC vs FCC

HL-LHC



Needed loss attenuation: factor $\sim 3\times10^4$

FCC-hh



Needed loss attenuation: factor $\sim 10^5$

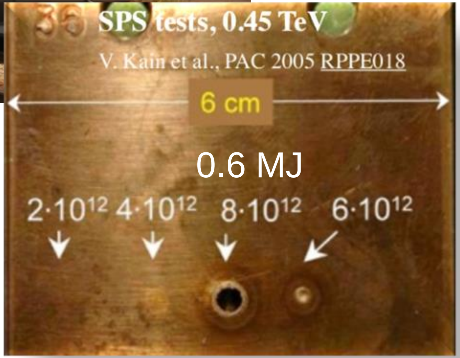
How much is 8.3 GJ?

LHC: 362 MJ - kinetic energy of

TGV train cruising at 155 km/h

FCC-hh: 8.3 GJ – kinetic energy of

Airbus A380 (empty) cruising at 880 km/h



FCC-hh beams are highly destructive!!

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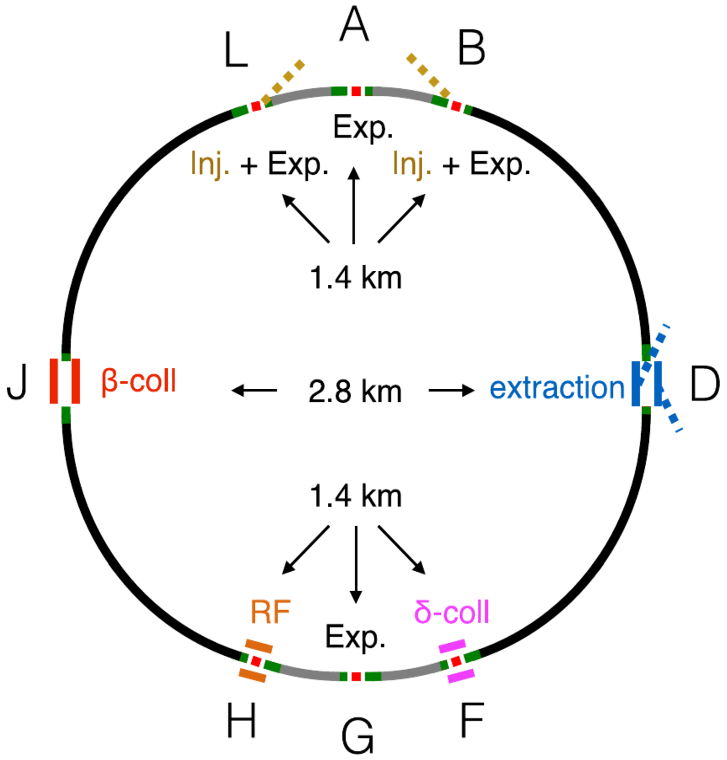
FCC-hh collimation layout: CDR version

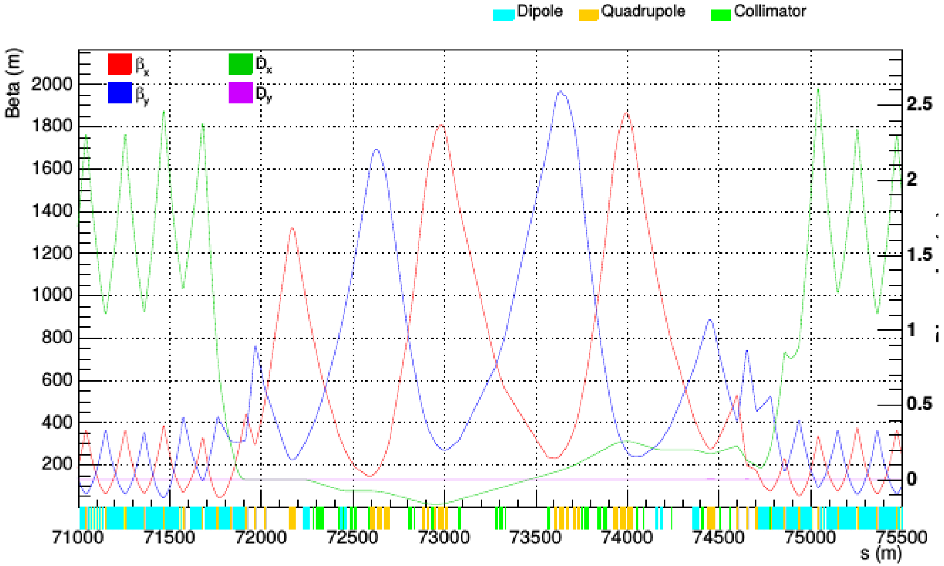
- The following few slides are a summary of previous studies for CDR, references:
  - R Bruce *et al* 2019 *J. Phys.: Conf. Ser.* **1350** 012009
  - Previous FCC week talks, FCC collimation meetings
  - Long CDR (not yet published)
- Separate betatron (PJ) and momentum cleaning (PF)
- The FCC-hh collimation system is a scaled up version of the HL-LHC/LHC system *(NIM, A 894 (2018) 96-106)*



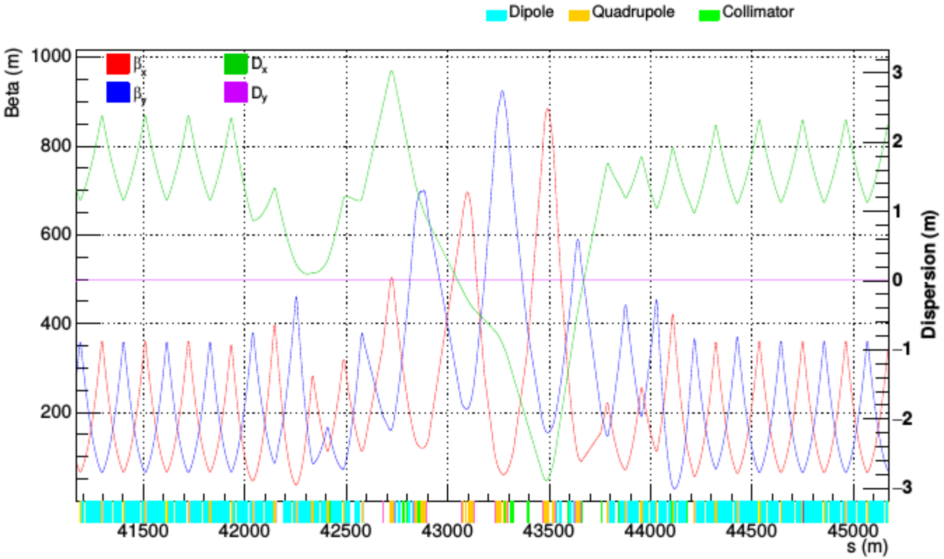
Optics of collimation insertions: CDR version

- Scaled β-functions and insertion length by factor 5 from the LHC → 2.8 km insertion length
- Increased dispersion in momentum cleaning insertion

IRJ (Betatron cleaning)

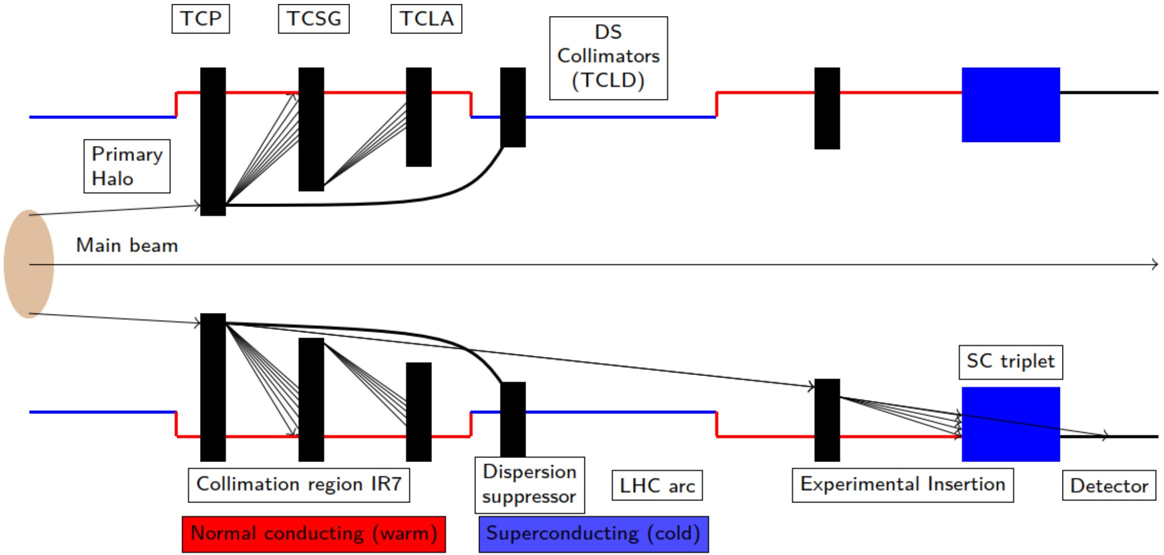


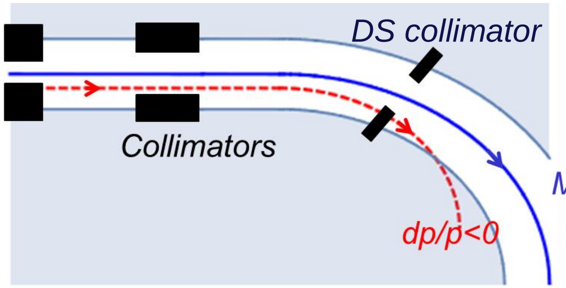
IRF (Momentum cleaning)



FCC-hh multi-stage collimation system

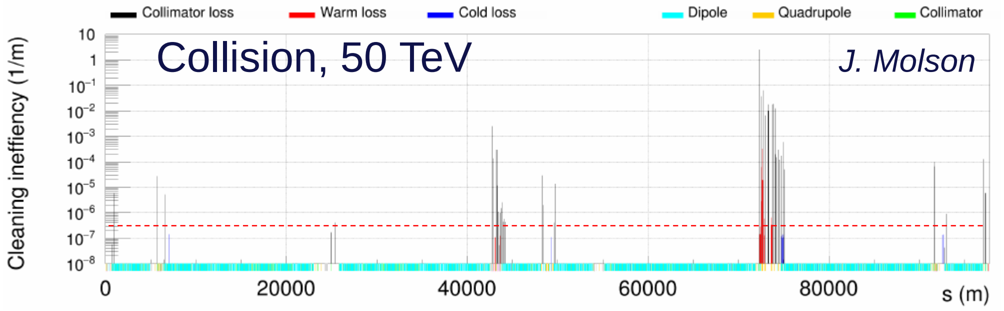
- As in the LHC, using a multi-stage system with primary and secondary collimators, shower absorbers, dispersion suppressor (DS) collimators
  - DS collimators are placed in the cold region, in between dipoles where dispersion has risen
- Similar layout as the LHC, but some modifications: DS collimators in many insertions, extra shower absorbers in extraction insertion, removal of skew primary





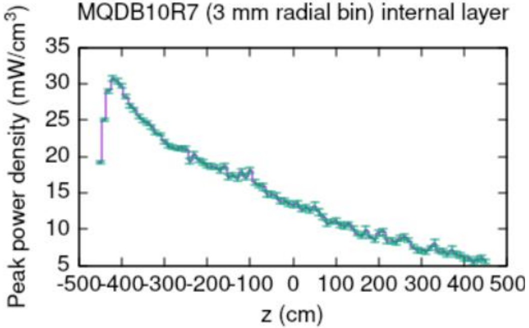
Collimation performance – FCC-hh protons

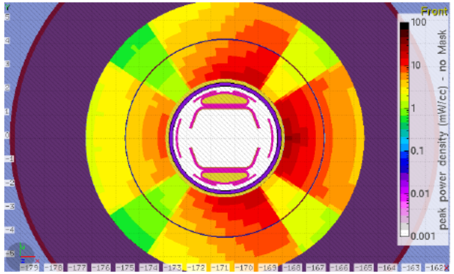
- Collimation performance checked with tracking studies using the SixTrack-FLUKA coupling and dedicated FLUKA simulations of exposed magnets
- Collimation system is extremely efficient at absorbing horizontal and vertical losses – almost no losses on cold machine aperture, thanks to dispersion suppressor collimators



Most loaded cold magnet

M. Varasteh





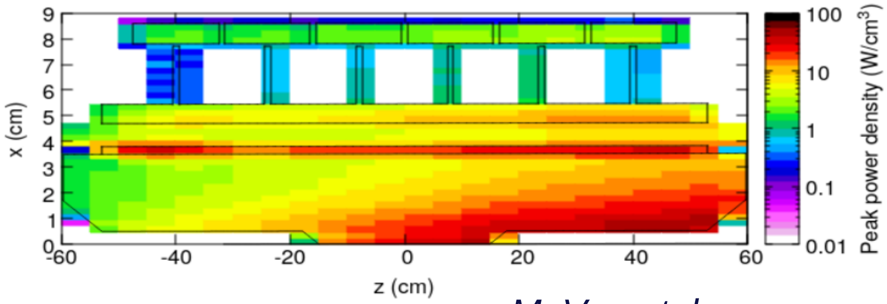
FCC collimator design

- Assuming LHC-type collimators, with some design modifications, following iterative simulations of tracking, energy deposition and thermo-mechanical response

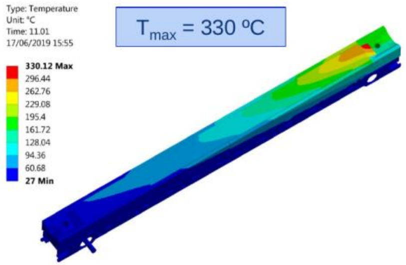
- Materials
  - Primary collimators, and most loaded secondary collimator made of carbon-fiber-composite (CFC) for maximum robustness
  - Remaining secondary collimators in MoGr with 5 μm Mo coating for a good compromise between impedance and robustness

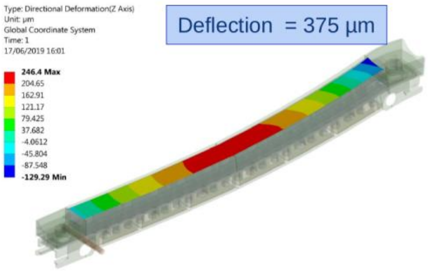
- Collimators would survive design losses in simulations, but some challenges remain: high temperature leading to potential outgassing, high deflection, load on cooling pipes

Horizontal primary



M. Varasteh





G. Gobbi, M. Pasquali

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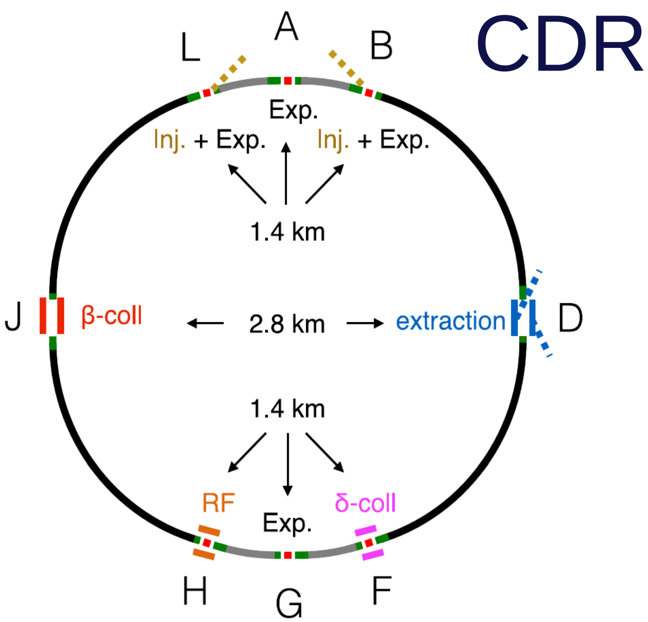
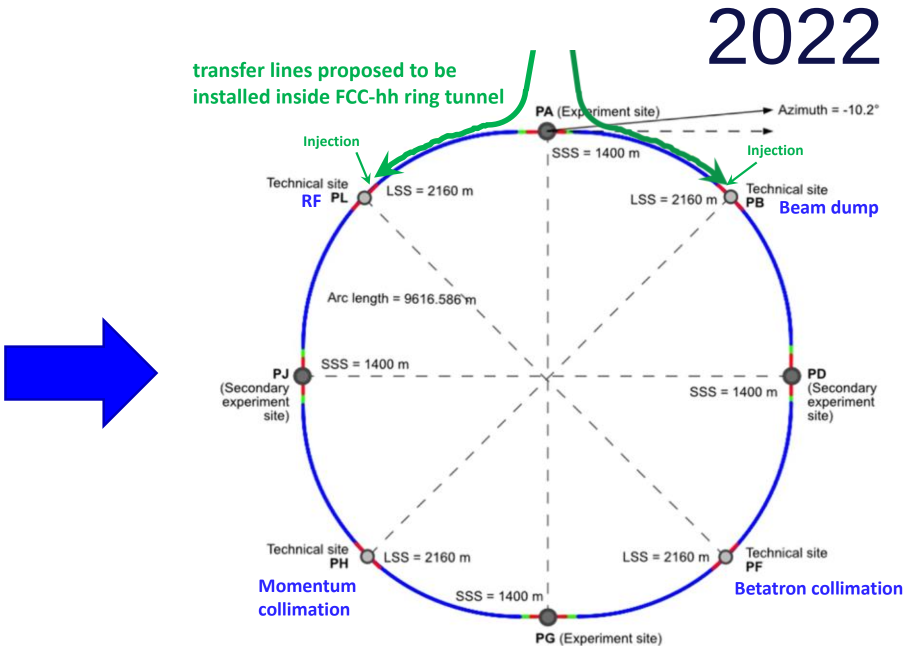
Updates since CDR

- Tunnel layout updated – see talk M. Giovannozzi
  - Need to revisit optics and layout of the whole ring
- Symmetric 8-point layout, ring circumference decreased from 97.7 km to 91.1 km
- Betatron collimation moved to shorter insertion: 2.1 km instead of 2.8 km
- Momentum collimation in longer insertion: 2.1 km instead of 1.4 km

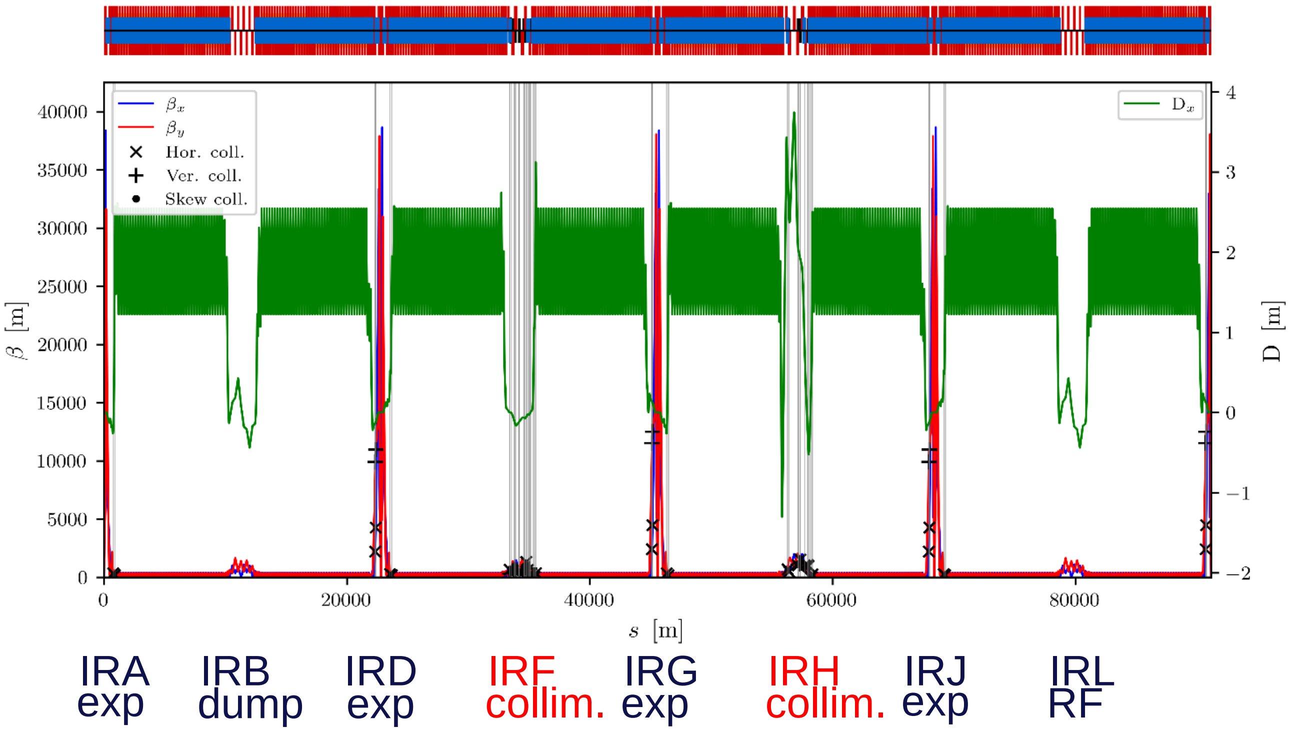




Updates to FCC-hh ring

- New layout and optics under development – work in progress, but first results available (T. Risselada)
  - Details shown in talk by M. Giovannozzi

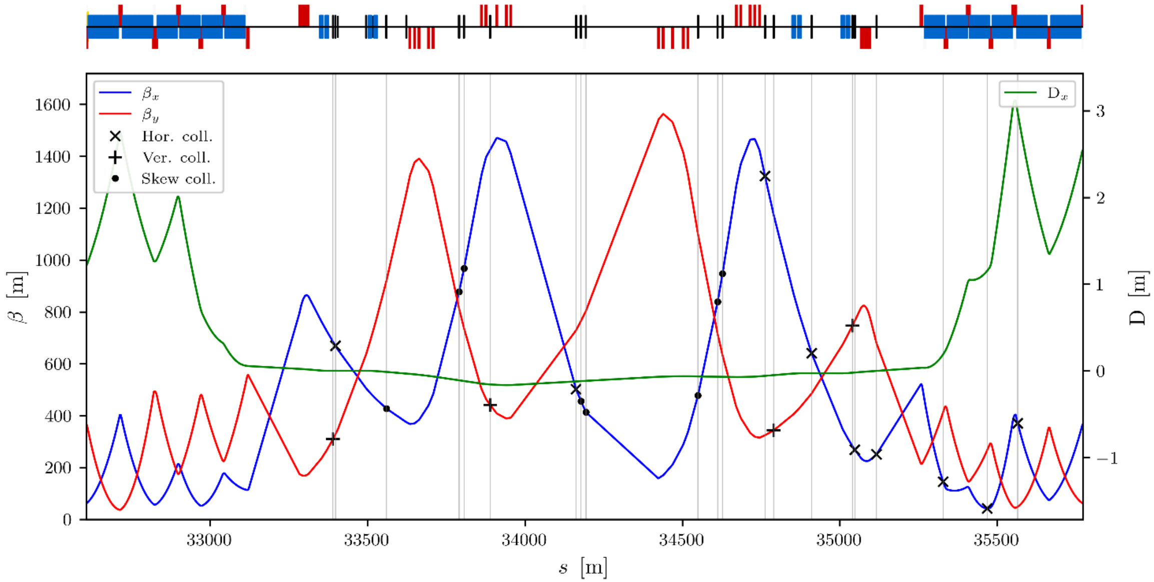
- Inserted collimators similar to LHC layout, including betatron and momentum collimation, tertiary collimators at experiments
  - Some collimators still to be implemented (at beam dump, physics debris…)



Updates to betatron collimation layout

- Scaling the original LHC collimation optics to new insertion lengths (T. Risselada)
- Similar collimator layout as LHC, but including 3 dispersion suppressor collimators as CDR-version of FCC-hh
- Insertion length and beta functions scaled by a factor ~4 compared to the LHC
- Smallest collimator half gap (vertical primary) around 0.8 mm
    - Compare: ~1mm in LHC

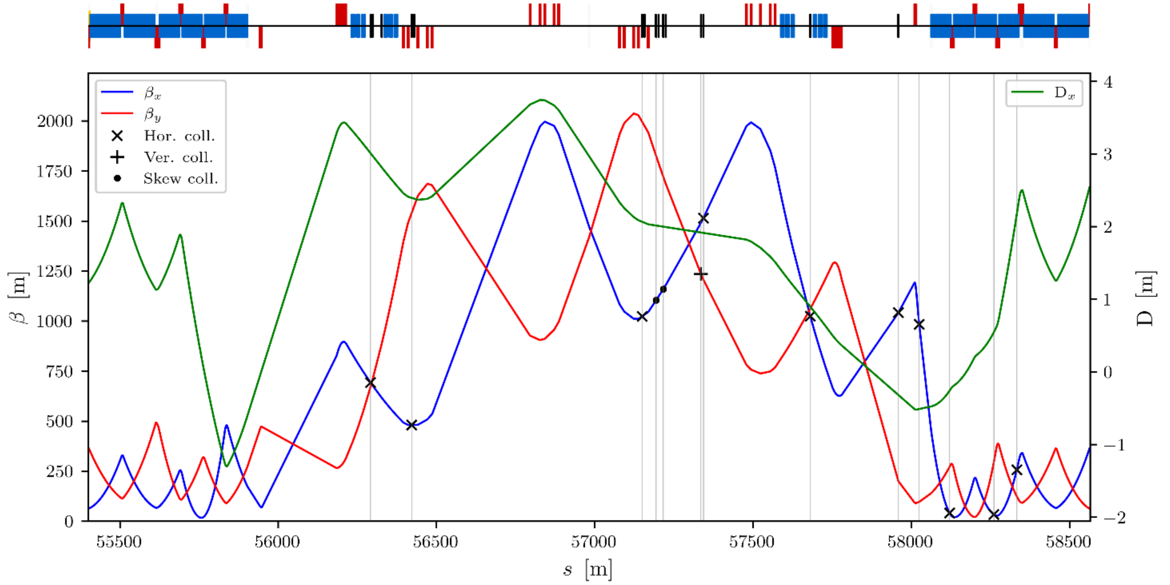
IRF



Momentum collimation

- For momentum collimation, LHC scaling used as starting point
- First implementation of optics and layout available
- Features high dispersion at primary collimator to give flexibility and independence between betatron and momentum cuts
- DS collimators added

IRH



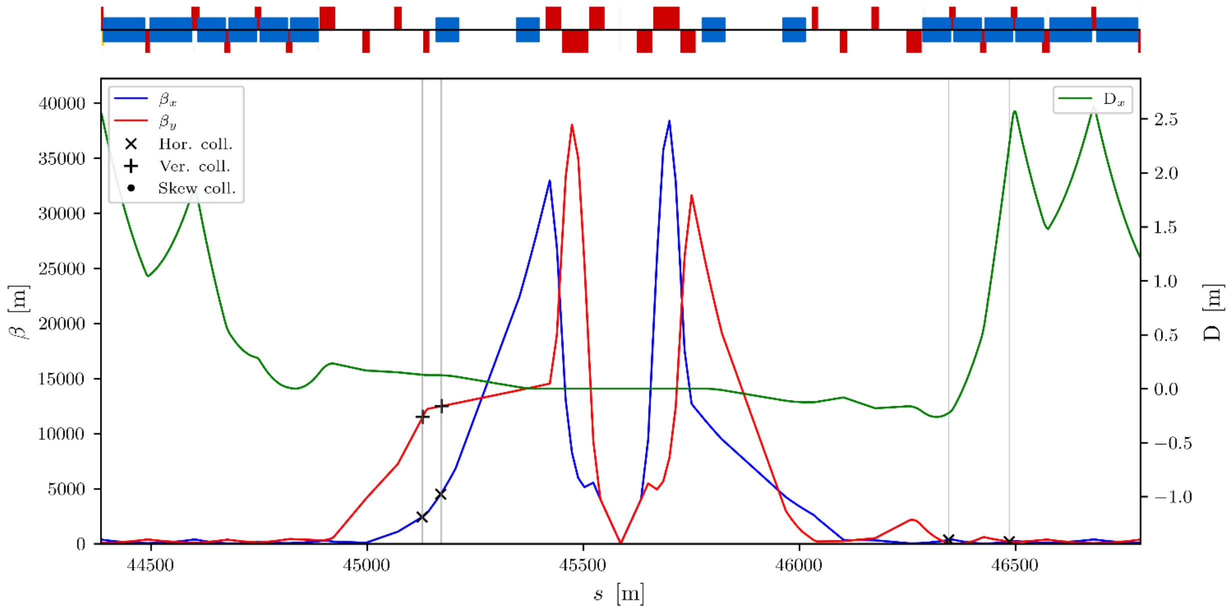
Optimization of doglegs

- Dogleg changes the distance between the beams in collimation insertion
  - Separate primary beam from neutrals.
  - Minimise flux of neutrals on the first superconducting magnet on right side of IP
  - Needed separation depends on geometry of insertion
- CDR layout: dogleg scaled from the LHC
- New version: dogleg geometry worked out based on actual geometry in IRH
  - 290 mm separation proposed (compare 250 mm in the arc)
  - To be confirmed with energy deposition studies

Collimation in experimental insertions

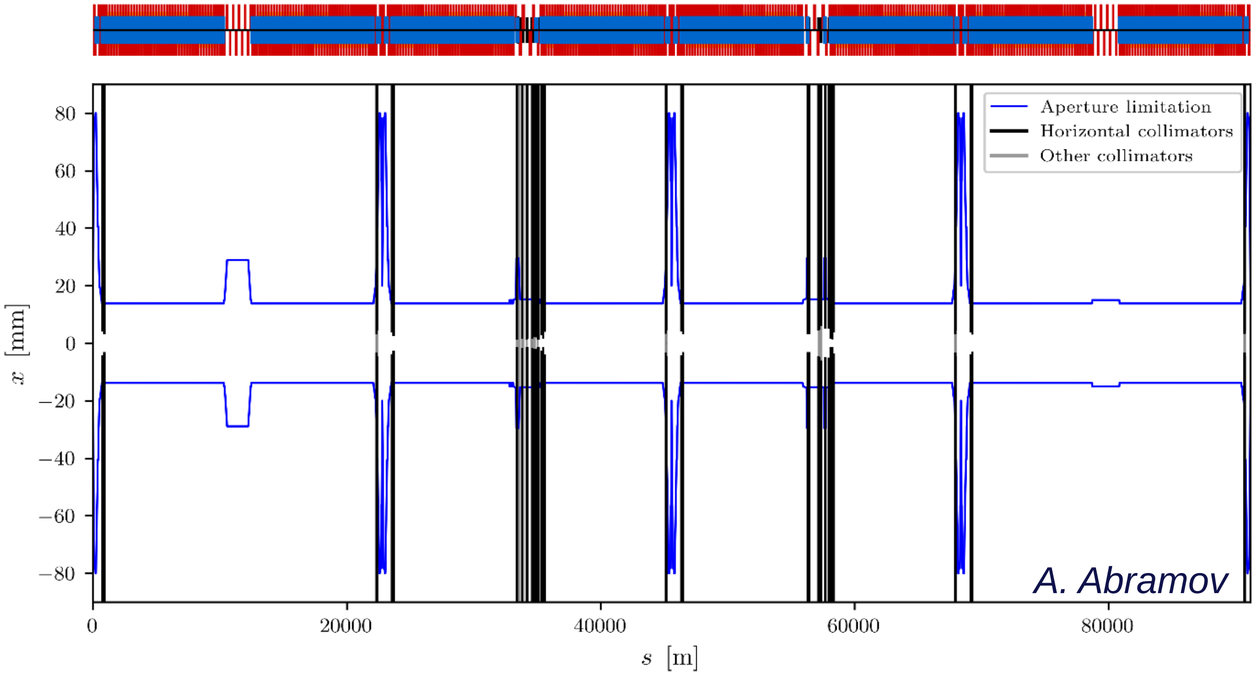
- Two pairs (horizontal-vertical) tertiary collimators on incoming beam
- Two dispersion suppressor collimators on outgoing beam
- Physics debris collimators still to be implemented

IRG



Updates to aperture model

- A detailed aperture model around the ring is crucial for collimation studies
- First implementation of new aperture model, based on mapping from CDR lattice (A. Abramov)
  - Including main magnets and collimators in insertion regions and arcs
- To be refined in future iterations

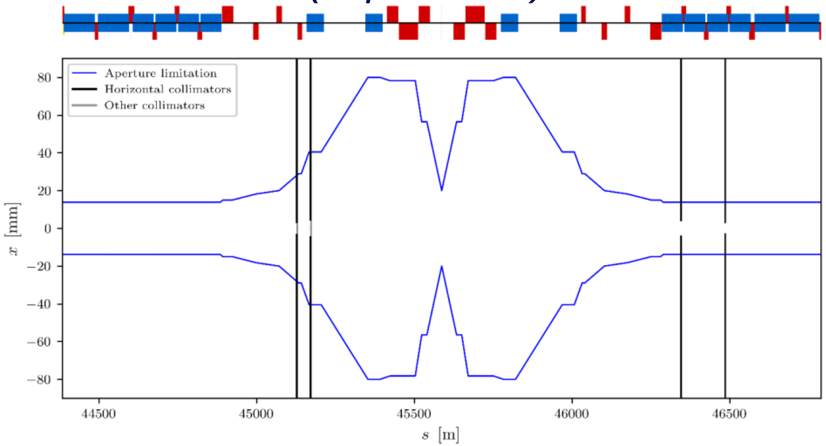


Aperture model in insertions

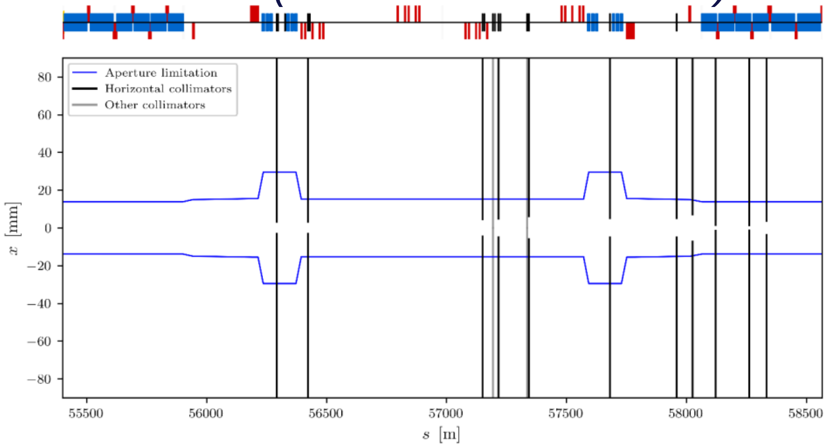
- Apertures mapped from similar elements in CDR lattice – to be refined in future iterations

Preliminary result

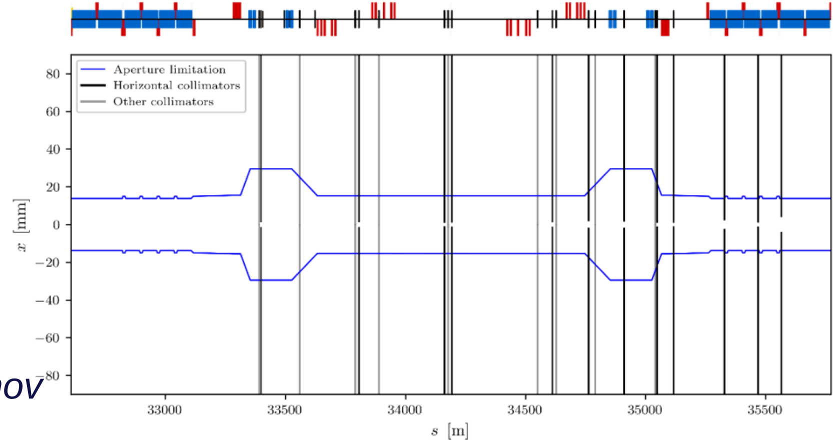
IRG (experiment)



IRH (momentum collimation)



IRF (betatron collimation)

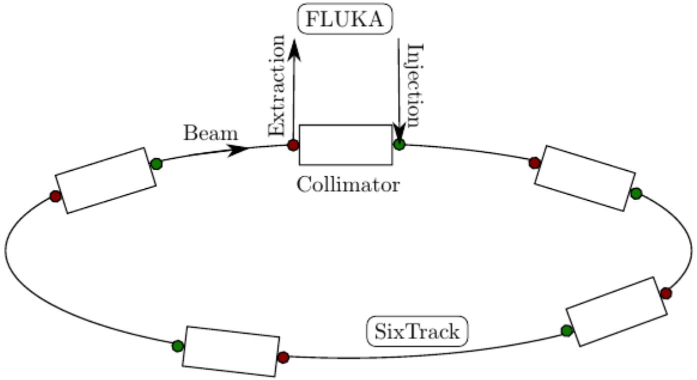


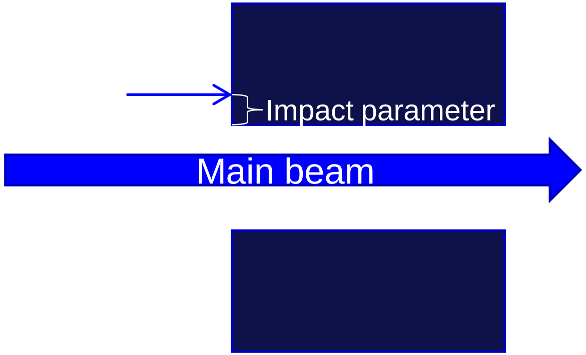
A. Abramov

Simulations of collimation performance

- Collimation performance simulated for latest version of FCC-hh using the SixTrack-FLUKA coupling
    - Magnetic tracking using SixTrack, particle-matter interactions in FLUKA

- Simulation assumptions
    - 1 µm impact parameter of generic halo on primary collimator – not simulating diffusion bringing halo onto collimators
    - Same collimator settings in σ and materials as in CDR

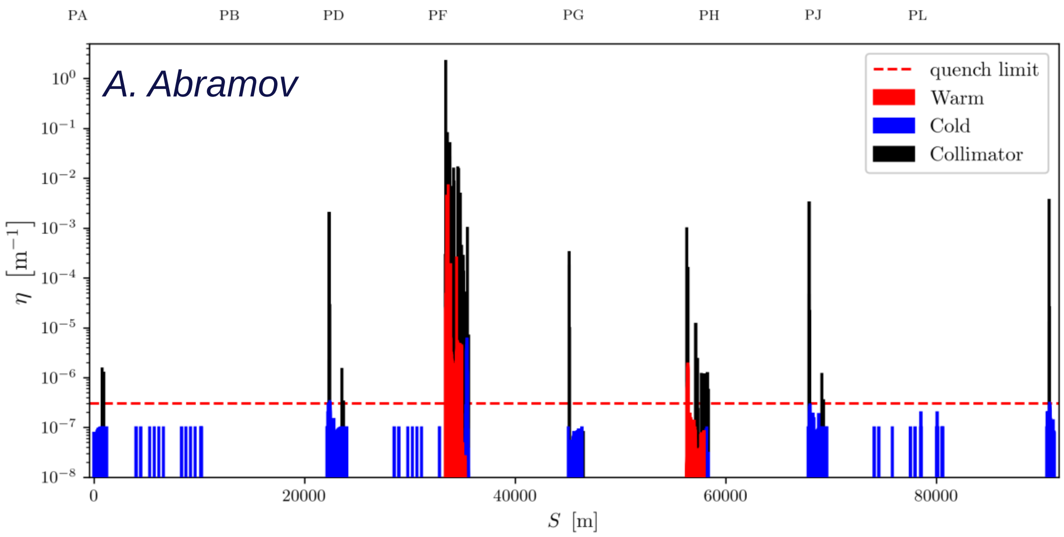




Simulated performance

- Generally very good protection of the ring, losses localized on betatron collimation system
- Rather high losses on tertiary collimators, with downstream leakage to cold magnets
  - Potentially problematic, to be followed up in future iterations

Horizontal halo, beam 1, 50 TeV

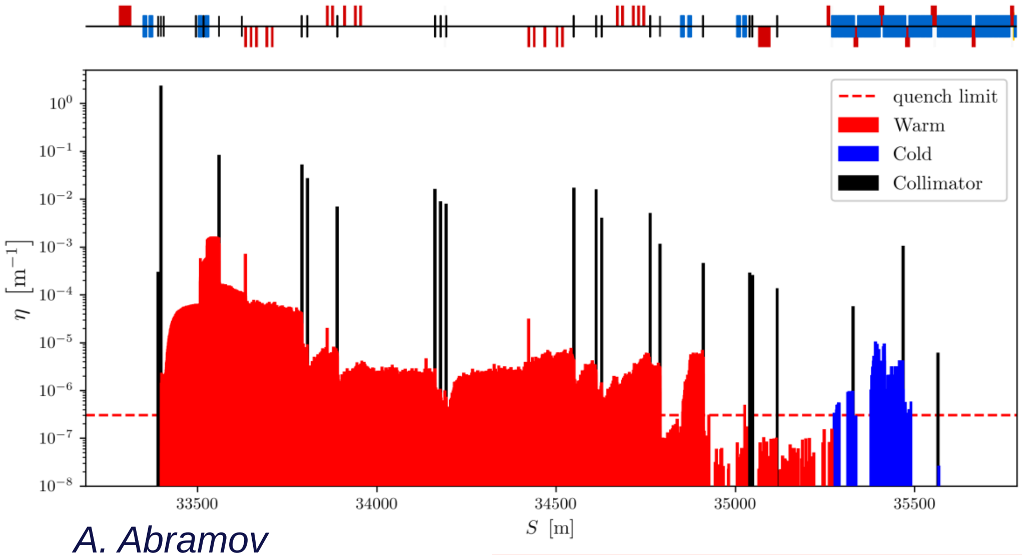


Preliminary result

Simulated performance - IRF

- Dispersion suppressor collimators essential for protecting the ring and the DS
- Nevertheless losses in between them are well above the assumed quench limit
  - Further iterations are needed to optimize collimation performance
- Energy deposition should be evaluated with dedicated studies at critical locations – future work
  - Compare power load in magnet coils with quench limit
  - Note: Particle showers not seen in the loss map plots, which show only proton losses

Horizontal halo, beam 1, 50 TeV, Zoom in IRF



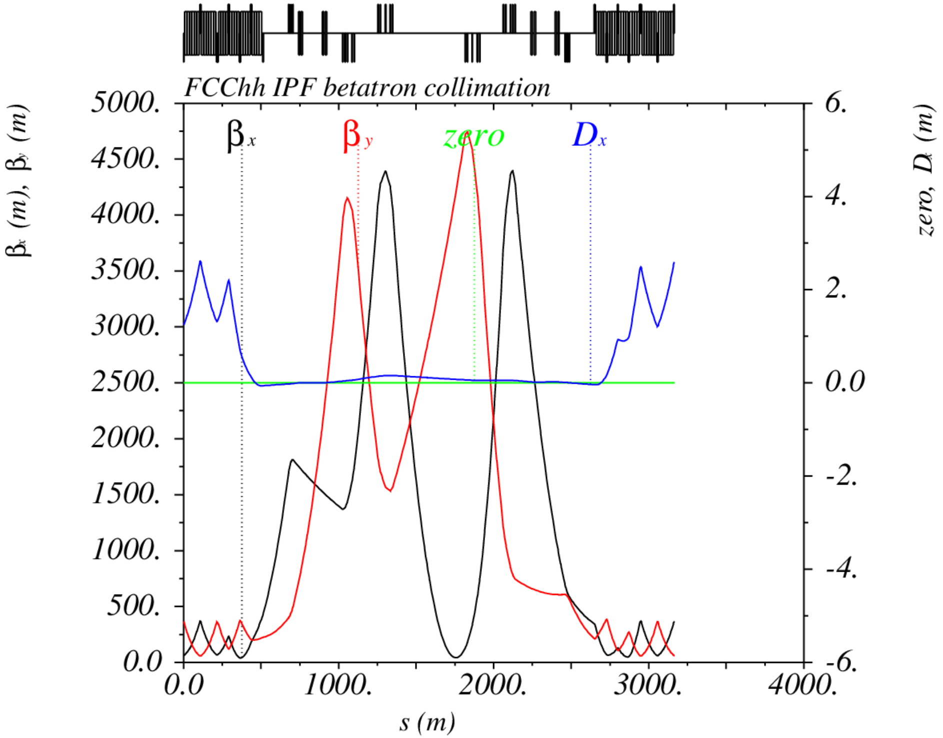
A. Abramov

Preliminary result

High-β optics for collimation

T. Risselada

- Small collimator gaps might lead to problematic impedance (to be evaluated)
- Could be mitigated through an optics with larger β-functions
- Such an optics could also give significant gains in cleaning efficiency
  - As for LHC studies in IPAC'21 paper
- First exploratory studies carried out for new FCC-hh layout (T. Risselada)
  - To be followed up with impedance and cleaning performance studies



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Next steps

Need to repeat work from CDR for new layout

- Explore optimizations of optics and collimator settings
- Study performance of momentum cleaning
- Study impedance
- Energy deposition studies to quantify risk of quench for design losses
- Maybe new thermo-mechanical studies of most loaded collimators
- Study outgassing and cooling of the most impacted elements in collimation insertion
- Study failure scenarios
- Collimation for Pb ion operation
  - Energy deposition studies of collimation insertion and dispersion suppressor, possibly including imperfections
  - Further studies of secondary beams from collision points
- Imperfection studies?
- Think of possible HiRadMat tests?
  - Potential alternative: Laser-induced mechanical shock – possible synergies with tests carried out at GSI facility?

Conclusions

- An excellent collimation performance is crucial to keep the FCC-hh safe, and to operate smoothly without quenches
  - 8.3 GJ stored beam energy, 11.6 MW beam loss power

- Fairly mature design presented in CDR, new iterations needed with latest layout
  - Shorter insertion length for betatron collimation
  - First new optics and collimation layout developed for betatron and momentum cleaning insertions
    - Work in progress

- First studies of cleaning performance with new lattice performed
  - Generally good performance, but some bottlenecks need further study and performance improvements
    - Tertiary collimators
    - IRF dispersion suppressor

Thank you for your attention.