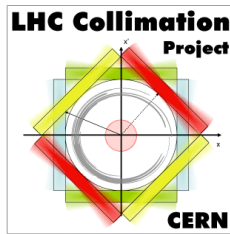


Status of FCC-hh collimation studies

R. Bruce

On behalf of many colleagues...



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- Talk based on material from many colleagues
- Author list for collimation chapter in long CDR:
 - CERN BE/ABP: S. Arsenyev, R. Bruce, M. Fiascaris, A. Krainer, A. Langner, R. Martin, A. Mereghetti, D. Mirarchi, J. Molson, S. Redaelli, D. Schulte
 - CERN EN/STI: M.I. Besana, F. Cerutti, S. Gilardoni, A. Lechner, E. Skordis, M. Varasteh
 - CERN EN/MME: A. Bertarelli, F. Carra, G. Gobbi, M. Pasquali
 - CERN TE/ABT: W. Bartmann, E. Renner
 - RHUL: A. Abramov, L. Nevay
 - LAL/IN2P3: A. Faus-Golfe, J.L. Perrot
 - CEA: B. Dalena, A. Chance
 - LAPP/IN2P3: M. Serluca, G. Lamanna
 - FNAL: Y. Alexahin, E. Gianfelice-Wendt, N. Mokhov, I. Tropin
 - NIU: A. Narayanan, M.J. Syphers

Further talks on collimation

- FCC-hh proton collimation in this session

11:00	Status of FCC-hh collimation studies	<i>Roderik Bruce</i>
	Ground floor	11:00 - 11:15
	Collimation inefficiency	<i>James Molson</i>
	Ground floor	11:15 - 11:30
	Updated energy deposition	<i>Mohammad VARASTEH</i>
	Ground floor	11:30 - 11:40
	Thermo-mechanical studies of collimator robustness	<i>Giorgia Gobbi</i>
	Ground floor	11:40 - 11:55
12:00	Lunch	

- FCC-hh ion collimation this afternoon

FCC-hh heavy-ion collimation	<i>Andrey Abramov</i>
Ground floor	17:45 - 17:55

- HE-LHC collimation on Thursday afternoon

HE-LHC collimation system	<i>Matthew Paul Crouch</i>
Ground floor	14:30 - 14:50

Why do we need collimation?

- Roles of collimation system: **clean unavoidable regular losses, passive machine protection, optimize background and radiation dose**
 - At the same time, keep the impedance within limits
- Main design loss scenarios
 - Unavoidable off-momentum losses of unbunched beam at start of ramp:
1% loss over 10 s
 - Extraction and injection kicker pre-fire, other possible failures
 - Betatron cleaning 0.2 h beam lifetime during 10 s or “steady-state” 1 h beam lifetime
 - 0.2 h lifetime and 8.3 GJ stored energy => **11.6 MW beam loss power**

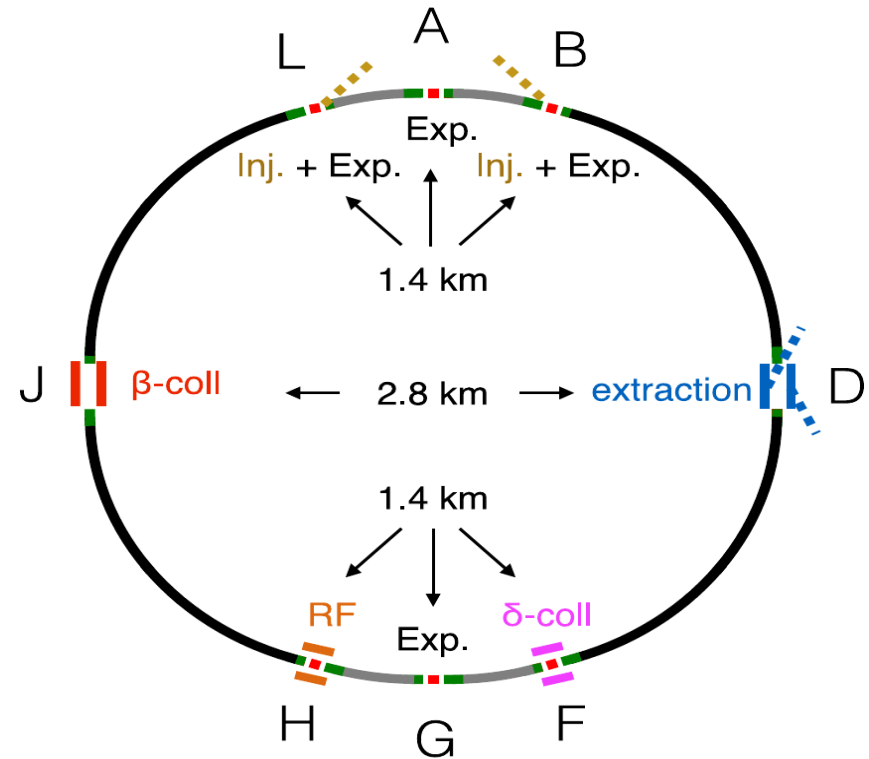
How much is 8.3 GJ?

- 8.3 GJ = kinetic energy of an empty Airbus A380 cruising at 880 km/h



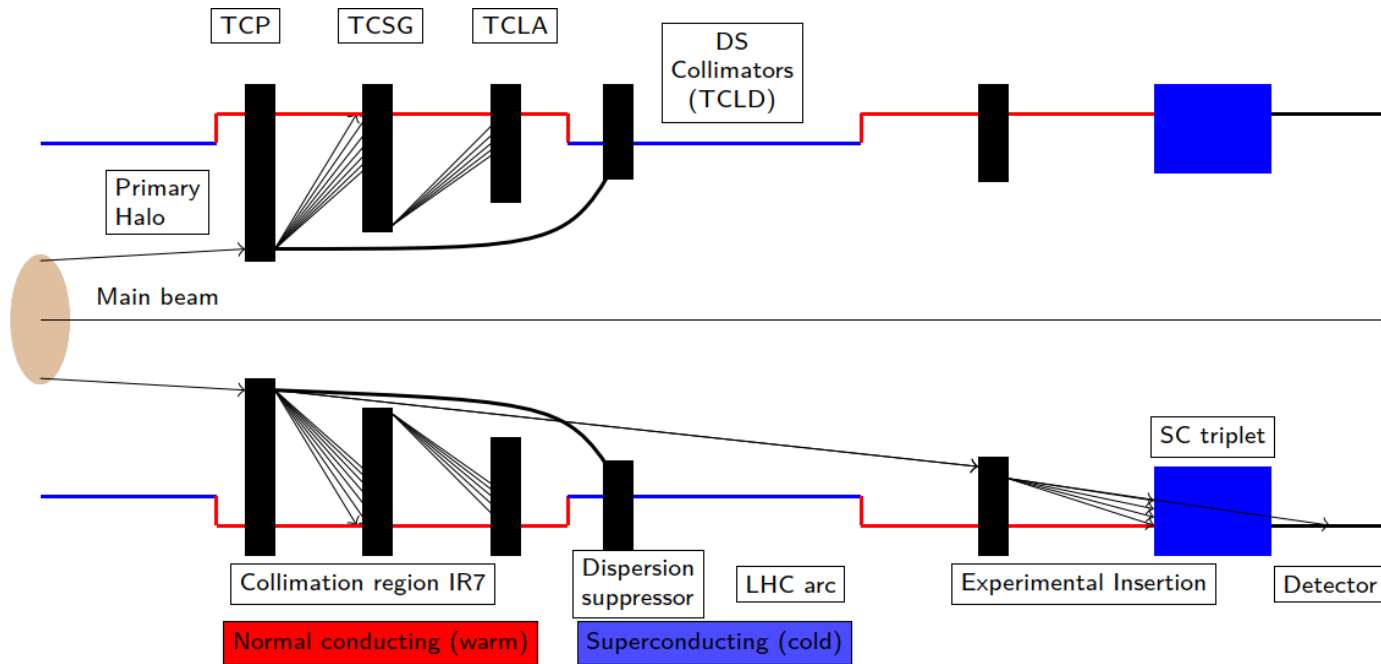
FCC collimation insertions

- The FCC-hh collimation system is a **scaled up version of the HL-LHC/LHC system** (*NIM, A 894 (2018) 96-106*)
 - Betatron collimation in IPJ
 - Momentum collimation in IPF



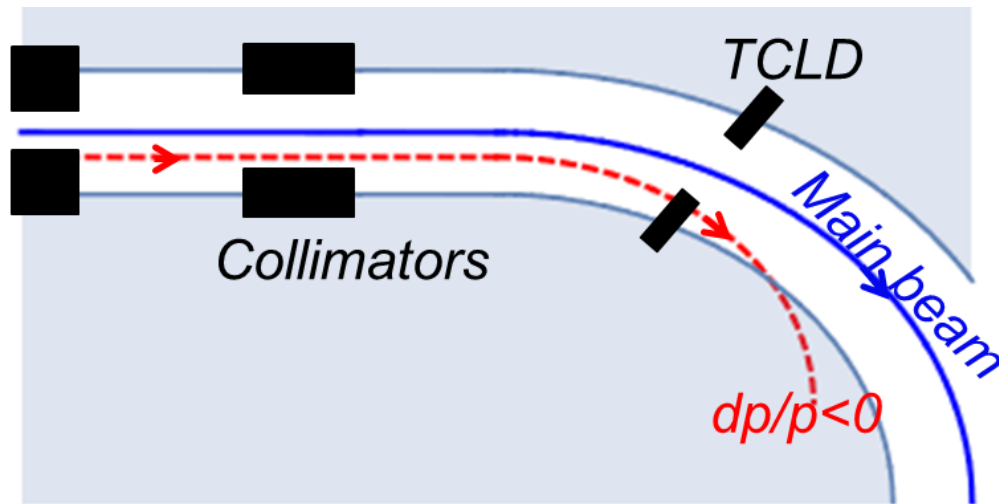
Collimation hierarchy

- Multi-stage system to intercept and absorb the losses
- Dispersion suppressor collimators to intercept off-energy particles



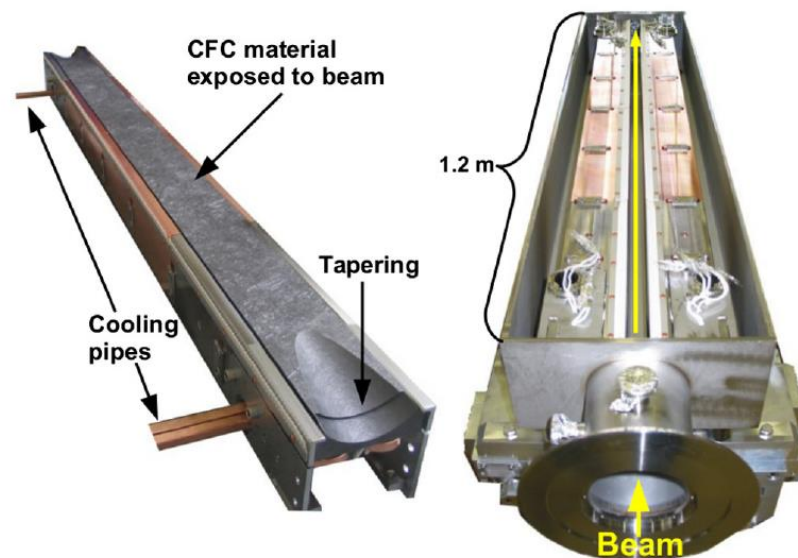
Dispersion suppressor collimators

- Dispersion suppressor collimators (TCLD) intercept off-energy particles
 - scattered out of primary (mainly) in collimation insertion
 - created in collisions at IPs
 - LHC installation of TCLDs on each side of IR2 and IR7 planned for LS2 (for HL-LHC)



FCC-hh collimators

- Assuming HL-LHC type collimators
 - Two movable jaws per collimator
- Some modifications
 - Shortened primaries
 - Thicker jaws of primary and some secondary



News since last year

- Studies and **optimization of system performance with new lattice** (v 10)
- **Optics optimizations** (A. Chance, J. Molson)
 - New optics in momentum cleaning insertion for significantly improved momentum cut and off-momentum cleaning performance
 - Removed dispersion peaks around the ring that caused local losses
- **Added new collimators at critical locations** (J. Molson)
 - More dispersion suppressor collimators (TCLDs) and active absorbers (TCLAs)
- Extended **studies of energy deposition , quench limits and collimator robustness** (see talks M. Varasteh, G. Gobbi)
- Studied **Pb ion collimation** in detail (see talk A. Abramov)
- Revised **collimator materials** to stay within impedance budget

Present baseline collimation system

- Most loaded collimators (primaries and first secondary) in CFC (carbon-fibre composite) for robustness, other secondaries in molybdenum-graphite with Mo coating for better impedance (taking over the HL-LHC design)

	Collimator	Material	Number	Injection ($n\sigma$)	Collision ($n\sigma$)	
primary	β TCP	CFC	2	7.6	7.6	Betatron cleaning
secondary	β TCSG	CFC/MoGr	11	8.8	8.8	
absorber	β TCLA	W	5	12.6	12.6	
dispersion suppressor	β TCLD	W	3	21.0	35.1	
primary	δ TCP	CFC	1	10.8	18.7	Momentum cleaning
secondary	δ TCSG	MoGr	4	13.0	21.7	
absorber	δ TCLA	W	5	14.4	24.1	
dispersion suppressor	δ TCLD	W	4	21.0	35.1	
tertiary	TCT	W	12	14.0	10.5	Experiments
dispersion suppressor	experimental TCLD	W	8	21.0	35.1	
dump protection (ABT)	TCDQ	CFC	1	9.8	9.8	Extraction
absorber	extraction TCLA	W	2	11.8	11.8	
dispersion suppressor	extraction TCLD	W	1	21.0	35.1	

Still to be added in lattice: active physics debris absorbers

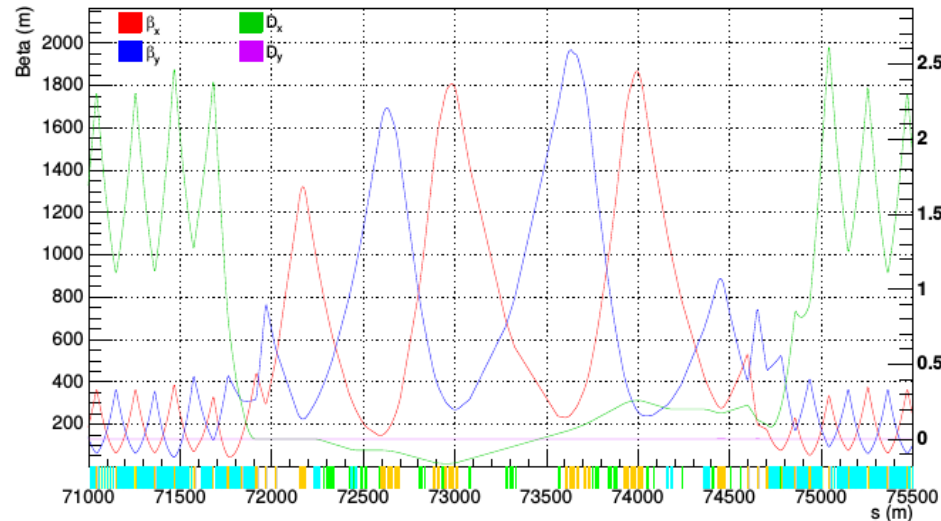
For 2.2 μm emittance

Optics of collimation insertions

- Starting point: Scaled β -functions and insertion length by factor 5 from the LHC
- News since last FCC week: Increased dispersion in IRF, added TLCDs

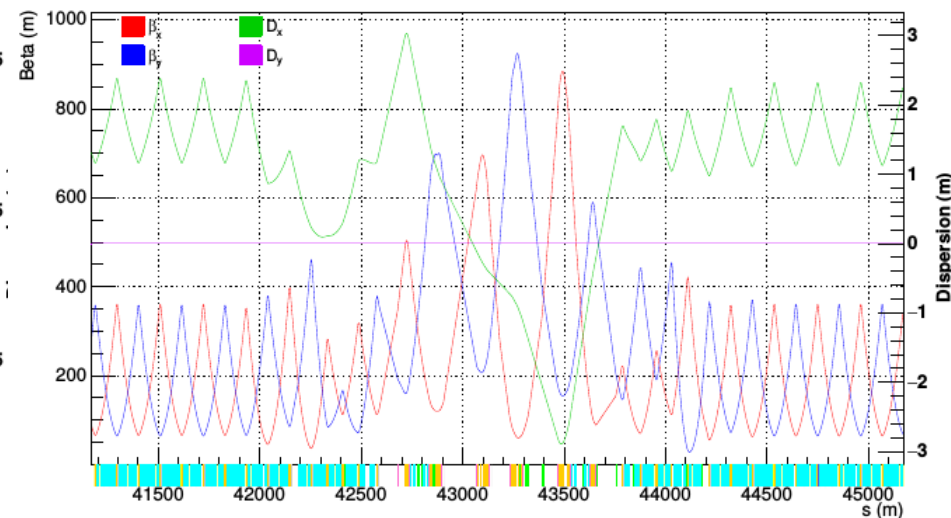
IRJ (Betatron cleaning)

■ Dipole ■ Quadrupole ■ Collimator



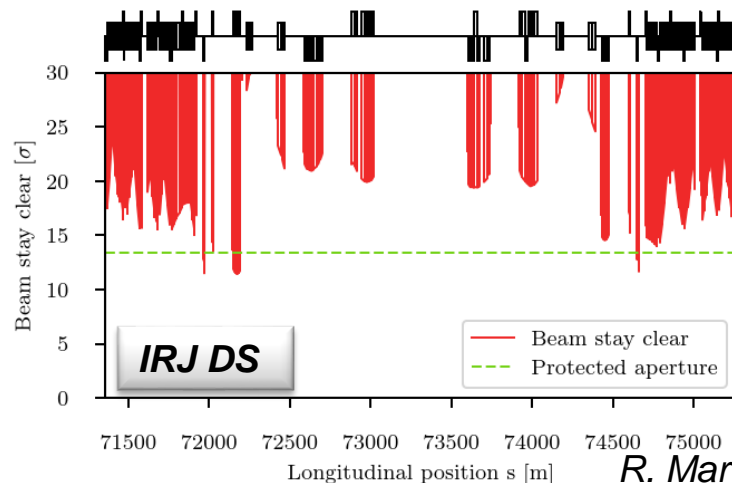
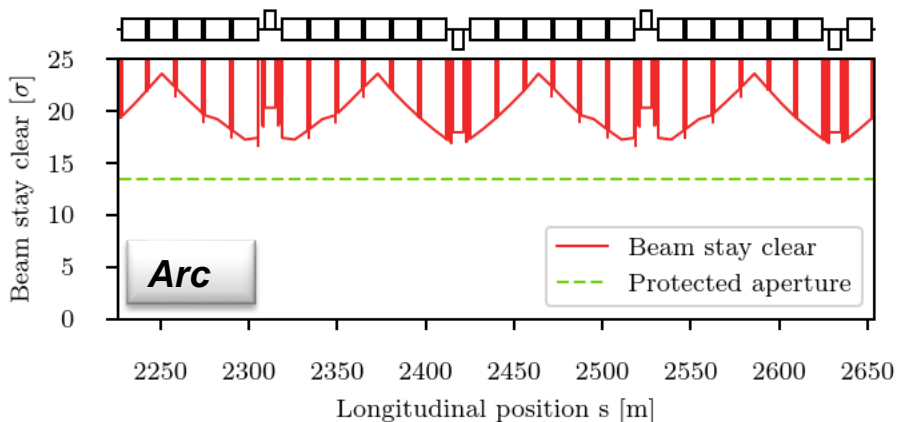
IRF (Momentum cleaning)

■ Dipole ■ Quadrupole ■ Collimator



Geometric aperture

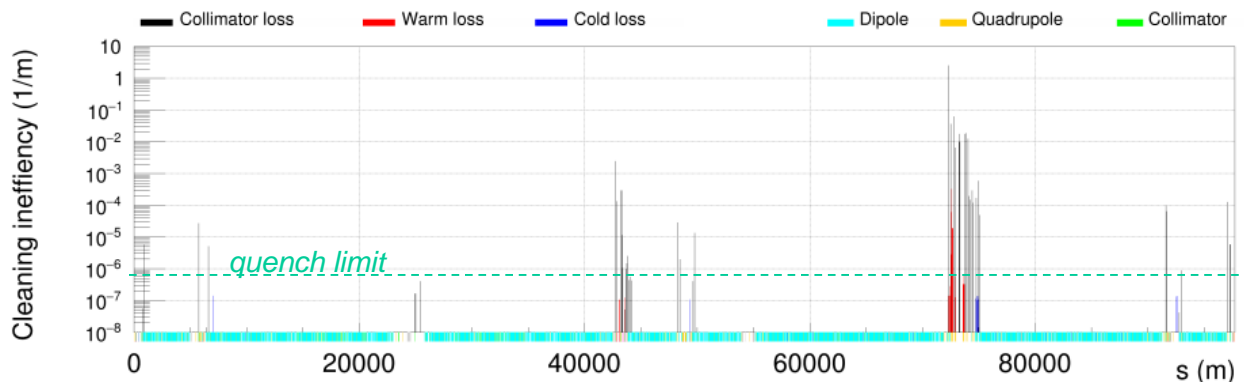
- At injection, larger quench margin than at 50 TeV, but **geometrical aperture more critical due to larger emittance**
 - Using 13.4 sigma criterion for allowed aperture scaled from HL-LHC, **vast majority of ring elements are within spec**
 - Very few (< 10) outliers**: dispersion suppressors, a couple of quadrupoles β -collimation
 - Good hope for solution: switch of magnet type and minor design changes from LHC elements
 - Still some work to do, in particular on refining aperture tolerances and calculation models



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Status of betatron cleaning studies

- Betatron cleaning has been the priority so far. Most critical case for quenches: **top energy (50 TeV)**
- After some iterations, cleaning inefficiency in the new lattice is OK (see talk J. Molson)
 - Protection of cold magnets around the ring for design losses (talk M. Varasteh)



- 3-step simulation with tracking, energy deposition and thermo-mechanical studies
- Significant power loads on collimators is challenging for the collimator robustness (talk G. Gobbi)
 - No serious showstopper found, but a few issues that require further iteration

Status of other studies

- Momentum cleaning
 - With new lattice, momentum cleaning is within specification for losses at the start of the ramp
 - Still to check: Quantify tolerable ramp rate at the start
- Extraction failure
 - With new extraction design from CERN/ABT team, extraction kickers segmented (150 modules)
 - With present lattice and optics, up to three kickers could pre-fire before collimators are damaged
 - Relies on a “good” phase advance between kickers and primary collimator
- More details: talk J. Molson

Conclusions (1)

- The collimation system, as described in the CDR, protects the machine aperture very well and survives without damage to active absorbers in spite of 11.6 MW loss power
 - Most challenging part: the collimators and warm section must sustain very high power loads during betatron losses at 50 TeV
- A few points require further iteration
 - Outgassing from collimators due to high temperatures
 - Power loads on warm magnets passive absorbers – study local shielding
 - Material of cooling pipes – risk of damage

- Possible topics for future studies
 - Placement of skew primary
 - Crystal collimation
 - Active halo control (hollow electron lens?)
 - Novel collimator materials
 - New improved system design, possibly shorter, not starting from the LHC