FCC-HH COLLIMATION – BRIEF STATUS

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Outline

- Introduction: collimation in the FCC-hh
- Layout of collimation system
- Simulated performance
- Conclusions and future work

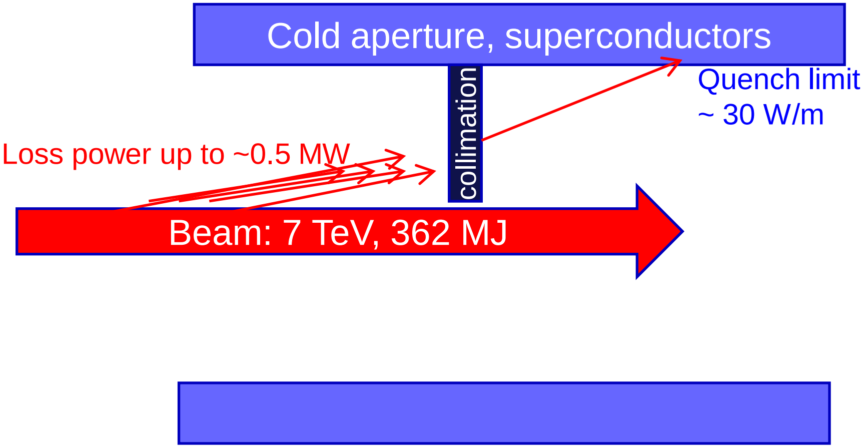
Collimation challenge: LHC vs FCC-hh

Loss of even a very small fraction of the beam could cause

- Damage to impacted elements
- Heating of superconducting magnets, leading to a quench

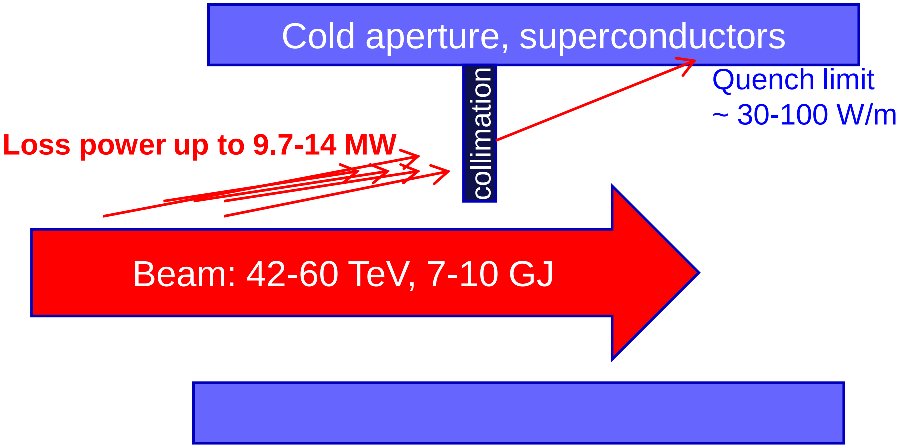
Need collimation!

LHC



Needed loss attenuation: factor ~2×10^4

FCC-hh



Needed loss attenuation: factor >10^5

Higher energy ➔ smaller collimator gaps

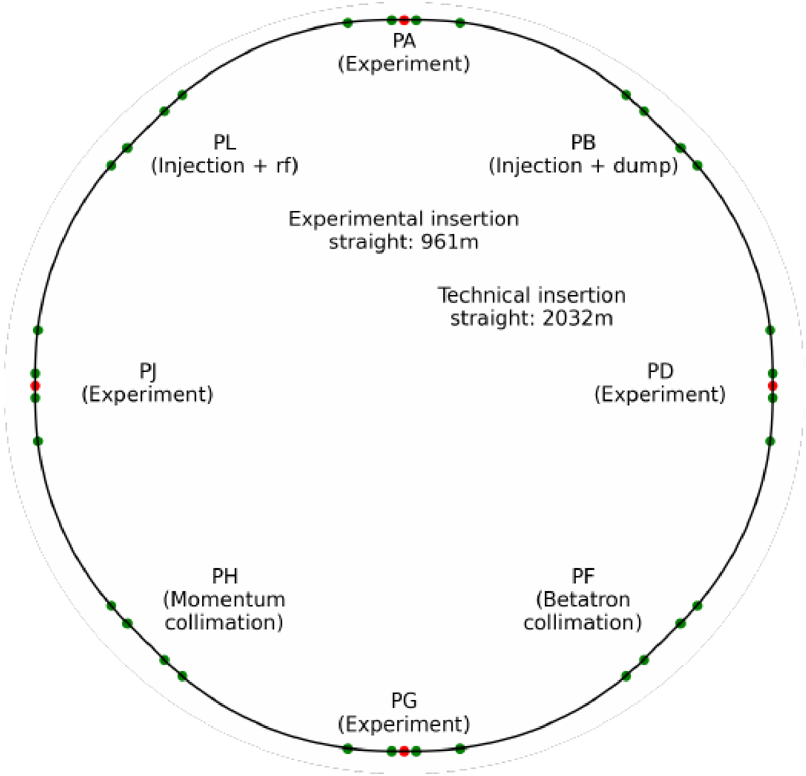
Roles of FCC-hh collimation system

- **Need collimation system to**
  - clean unavoidable regular losses and protect superconducting magnets from quenches
  - passive machine protection
  - optimize background and radiation dose
  - At the same time, keep the impedance within limits

- **Main design beam loss scenarios**
  - Betatron cleaning 0.2 h beam lifetime during 10 s or “steady-state” 1 h beam lifetime
    - 0.2 h, 50 TeV, 8.3 GJ stored energy => 11.6 MW beam loss power
  - Off-momentum losses of unbunched beam at start of ramp: 1% over 10 s
  - Extraction and injection kicker pre-fire, other possible failures

FCC-hh collimation layout

- Initial system design implemented for the CDR, with betatron collimation in PJ (2.8km)
- Following layout changes:
  - **Betatron collimation system in PF**
  - **Momentum collimation system in PH**
  - Note: New layout under study with momentum collimation in PB (combined with injection) and betatron collimation in PH (see talk G. Perez)
- Both collimation insertions have a length of 2.032 km
  - **Needed to redo the design of the collimation layout and optics**
- More info on studies for latest design in paper by A. Abramov et al. at HB'23
  - Basis for results shown in this talk

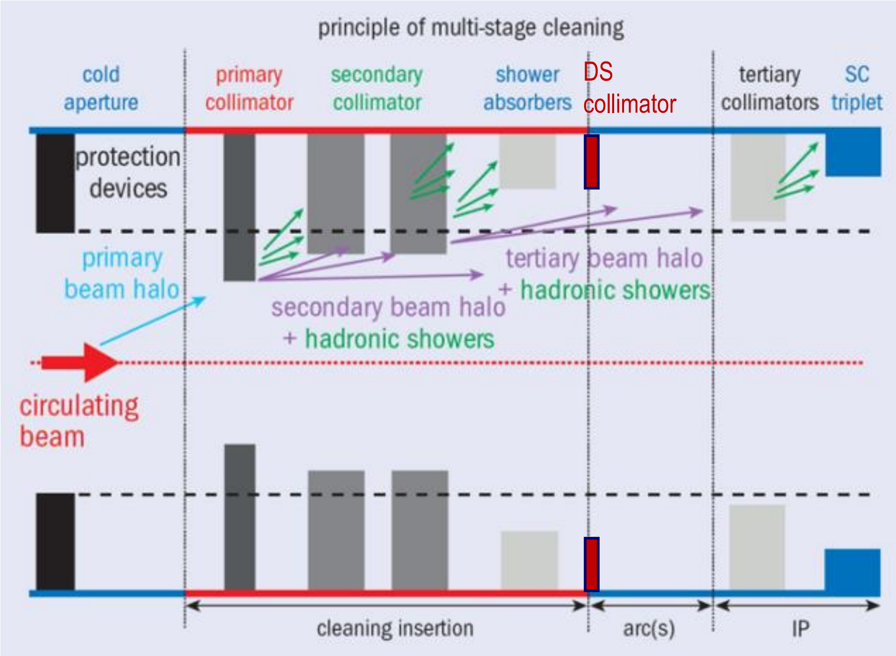


Ring length: 90.66 km,
16-dipole arc cell

Design of FCC-hh collimation system

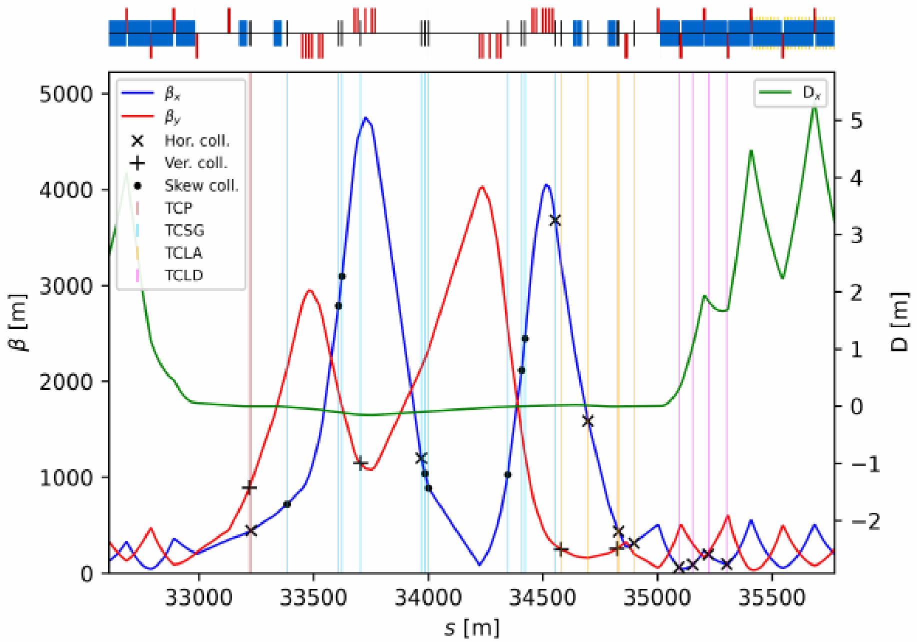
- **Multi-stage system in each collimation insertion, as in the LHC**
  - primary and secondary collimators, shower absorbers, tertiary collimators in experimental insertions

- **Some modifications / additions implemented for the CDR**
  - Dispersion suppressor collimators in cold region in many insertions, in between dipoles
  - extra shower absorbers in extraction insertion
  - removal of skew primary



Betatron collimation insertion

- New optics matched with **larger β-functions**, as in MD optics for the LHC. Potential benefits:
  - **Lower impedance** due to larger collimator gaps
  - **Better cleaning** due to larger normalized kicks due to larger β

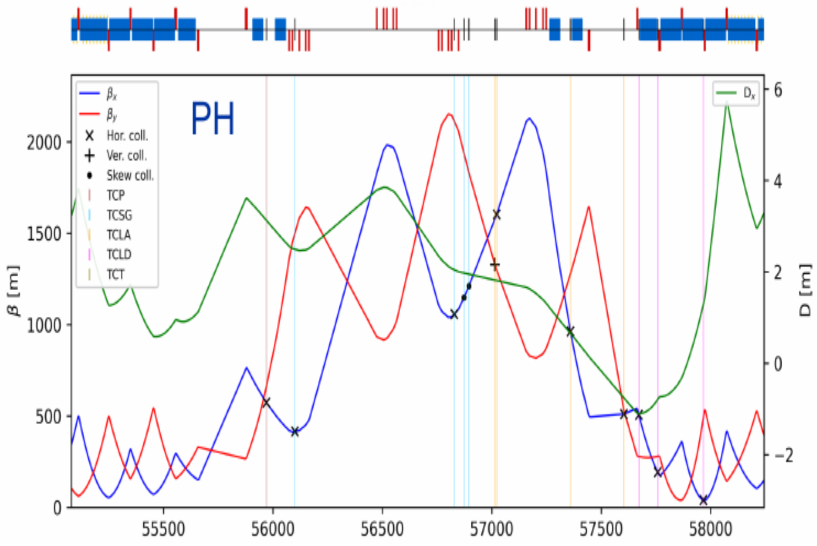


Optics: PA31 V3.1

Momentum collimation insertion

- **LHC-like layout and optics**
- **3 TCLD collimators in the dispersion suppressor**

PH

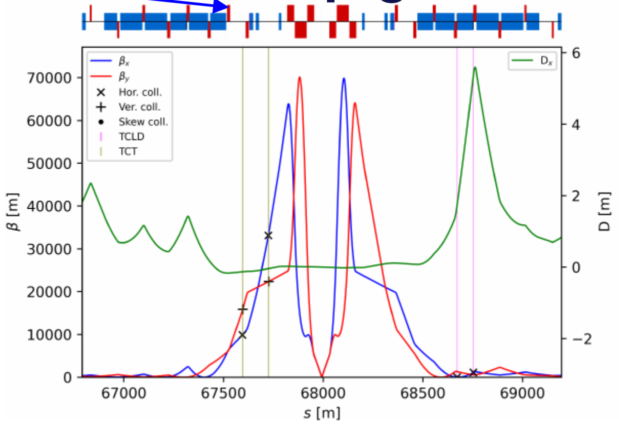


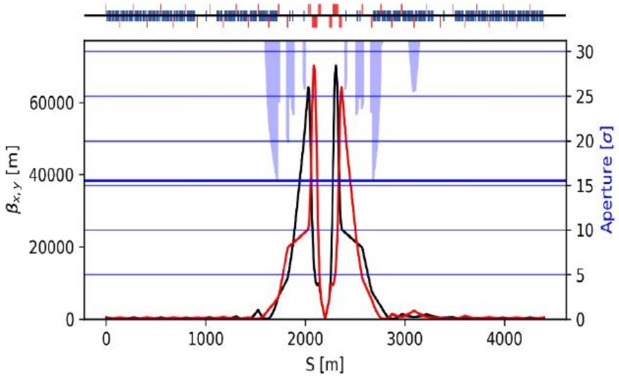
Optics: PA31 V3.1

Collimation in experimental insertions

PJ

Aperture bottleneck





- **Two pairs of tertiary collimators** on the incoming beam, as in LHC
- **Aperture bottleneck** is no longer in the triplet, but **in first cell of the DS**
  - TCT placement downstream of bottleneck not optimal
  - Alternative upstream TCT placement studied – see later

Assumed collimator settings

- Collimator gaps calculated for a reference normalized emittance of 2.2 µm

- Assuming also LHC-type collimators in CFC, MoGr, Inermet180

Type	Material	Length [m]	Gap [σ]
TCP PF	CFC	0.3	7.6
TCSG PF	MoGr, CFC	1.0	8.6
TCLA PF	Inermet180	1.0	10.6
TCLD PF	Inermet180	1.0	35.1
TCP PH	CFC	0.3	18.1
TCSG PH	MoGr	1.0	21.7
TCLA PH	Inermet180	1.0	24.1
TCLD PH	Inermet180	1.0	35.1
TCT PA,D,G,J	Inermet180	1.0	22.1
TCLD1 PA,D,G,J	Inermet180	1.0	125.4
TCLD2 PA,D,G,J	Inermet180	1.0	35.1
TCDQ PB	CFC	10.0	10.8
TCLA PB	Inermet180	1.0	14.8
TCLD PB, PL	Inermet180	1.0	35.1

Simulation setup of collimation performance

- **FCC-hh betatron cleaning simulated for latest layout**
  - Generic halo losses at 50 TeV
  - Impact parameter of 1 μm, 10^8 primary protons, 700 turns

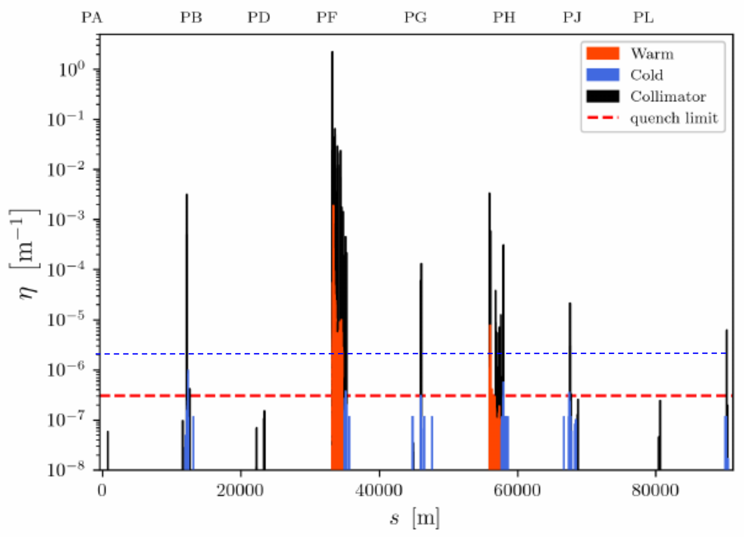
- **Simulation tools: SixTrack-FLUKA coupling, XSuite-BDSIM coupling** (used here)
  - XSuite-FLUKA coupling is being set up, also to be used in future studies
  - Energy cut: not tracking particles below 1 TeV

- Compare with **rough estimate of quench limit**
  - depends on magnet and design – has significant uncertainties
  - Assuming 12 min beam lifetime, and that 4.3 10^5 p/m/s cause 10 mW/cm^3 power load
    - From FLUKA simulations by M. Varasteh et al.
  - If quench limit is 10 mW/cm^3 => Max local cleaning inefficiency is 3×10^{-7} m^{-1}
  - If quench limit is 70 mW/cm^3 => Max local cleaning inefficiency is 2×10^{-6} m^{-1}

Simulated cleaning performance

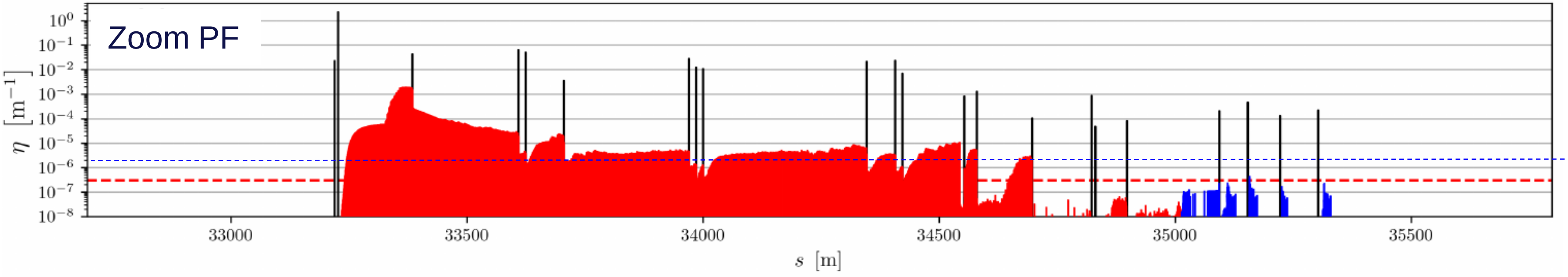
B1H

- Losses focused in betatron cleaning insertion in PF
- Overall, very good loss suppression
- Almost all losses below estimated quench limits
- High losses on TCLA collimators in PB (injection+dump) with downstream cold losses need optimization



Optics: PA31 V3.1

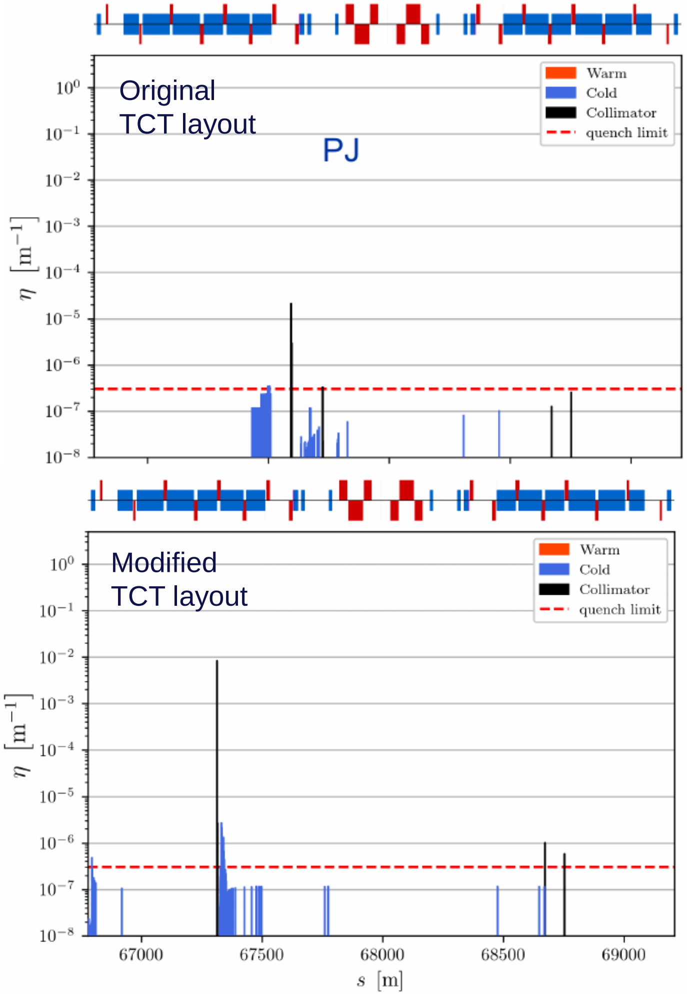
Simulated cleaning performance



- Cold DS losses in PF and showers would need dedicated FLUKA study to determine risk of quenching
- As for CDR, loads on collimators and nearby warm elements need further study

Losses in experimental IRs

- With initial TCT position, **cold losses observed upstream TCTs** at global aperture bottleneck
- **Alternative TCT layout investigated,** but very high losses on TCTs observed
  - Possibly problematic for beam background and for the TCT in case of high losses
- **Future work:** study and optimize TCT positions as well as leakage from PF to the experimental insertions



Conclusions

- **FCC-hh beams are highly destructive – a good collimation system is crucial**
- **Adapted collimation system to latest FCC-hh baseline**
  - Using new high-β optics
- First iteration of cleaning performance studies performed
  - **Overall good performance**
  - Some areas with concerning losses need further optimization (PB, TCTs)
  - Might need to revisit optics and layout in PF to further optimize leakage
- Future work to
  - **study other beam loss scenarios and imperfections:** Off-momentum losses, failures, …
  - further studies of off-momentum system in new layout, combined with injection
  - repeat key studies done for CDR: **energy deposition** studies, **thermo-mechanical studies, impedance studies,** possibly also **beam background studies**

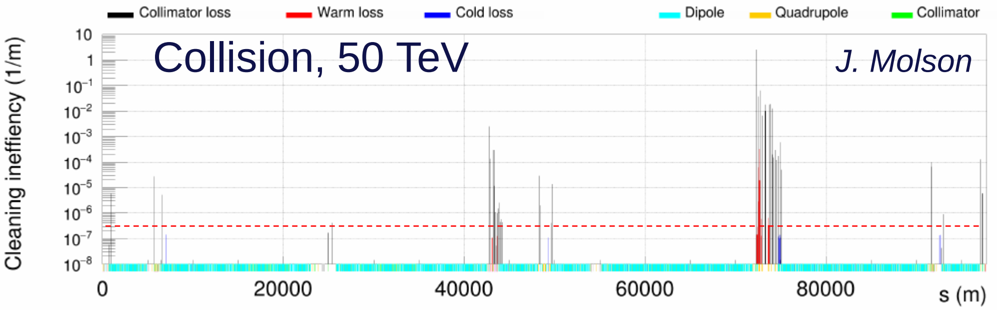
FCC

Thank you
for your attention.

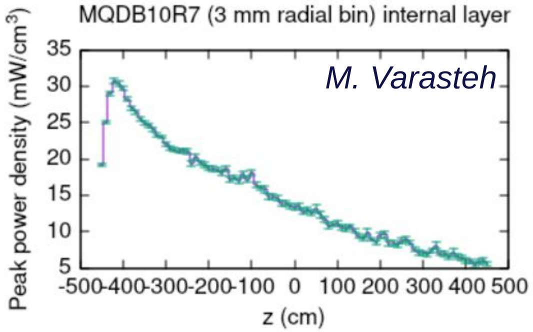
Backup

Design studies for the CDR (1)

- **Tracking studies**
  - Cleaning performance for betatron and off-momentum losses
  - Accidental scenarios (asynchronous beam dump)
  - Conclusion: collimation system provides excellent protection of cold aperture; dispersion suppressor collimators are critical



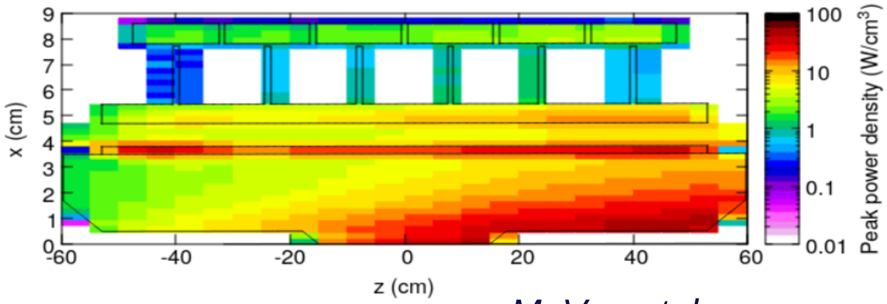
- **Tracking + energy deposition studies** on most exposed cold magnets
  - Peak power density of up to about 30 mW/cm3 – factor ~2 below estimated quench limit



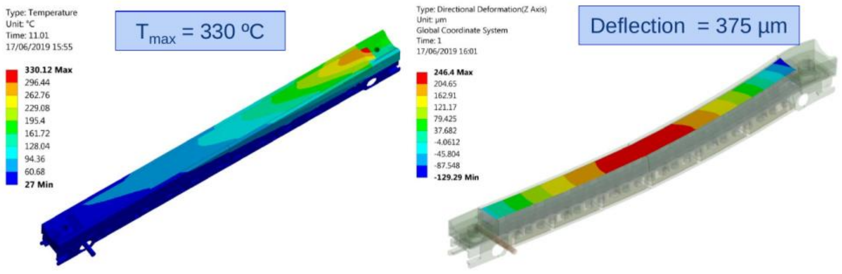
Design studies for the CDR (2)

- **Tracking + Energy deposition + thermomechanical studies of most exposed collimators**

- Conclusions:
    - 92 kW on most loaded secondary collimator – should be OK, no permanent damage
    - 50 kW/cm³ peak power density at surface of primary collimator; 660º peak temperature – similar conditions achieved at HiRadMat without damage
    - Challenges: high temperature leading to potential outgassing, high deflection, load on cooling pipes



M. Varasteh



G. Gobbi, M. Pasquali

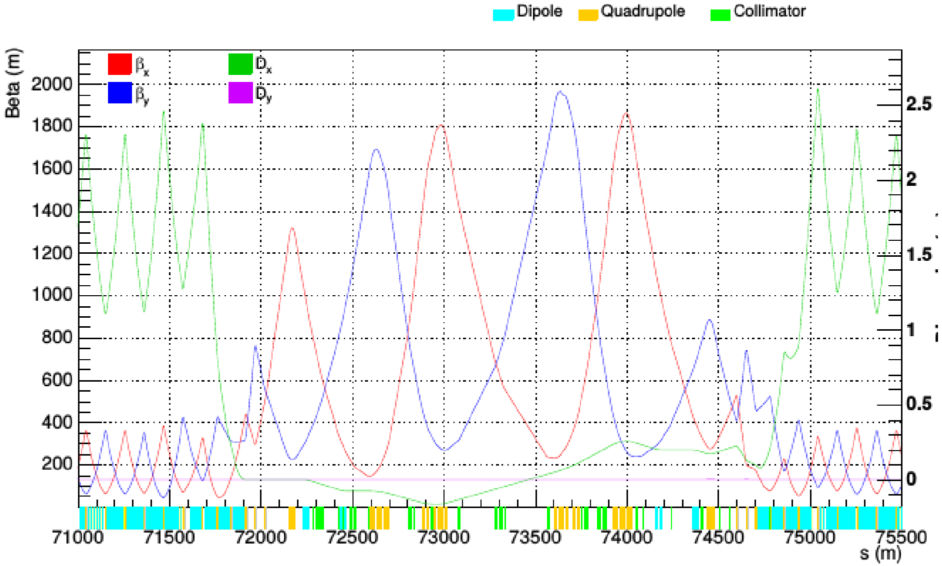
Next steps

- Need to move to new 16-dipole lattice and repeat basic performance studies
- 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?

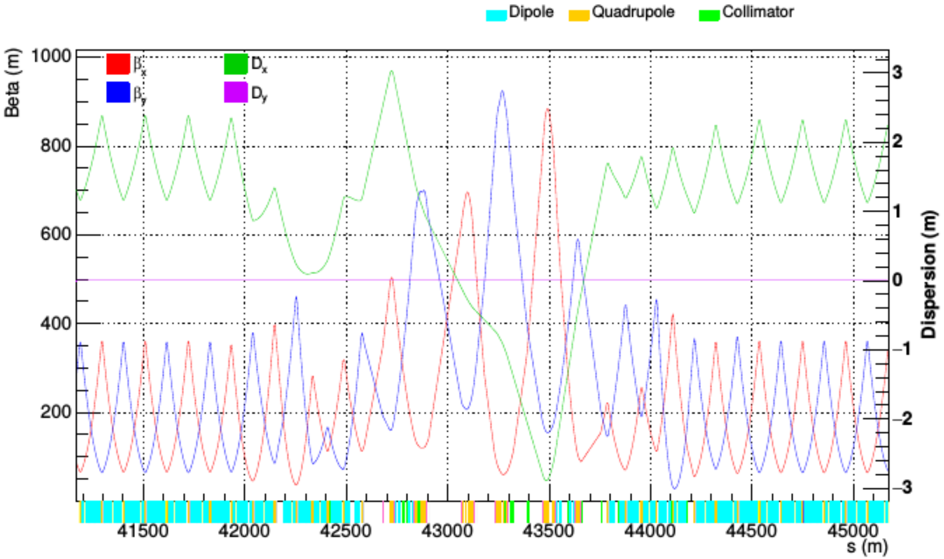
Optics of collimation insertions: CDR version

- 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)



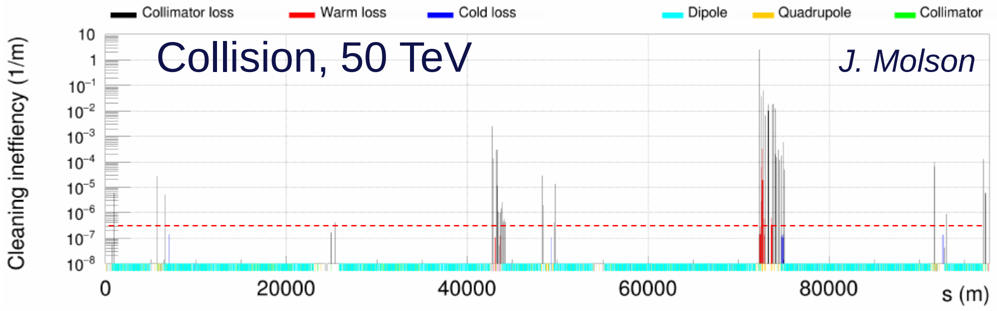
IRF (Momentum cleaning)



Collimation performance – FCC-hh protons

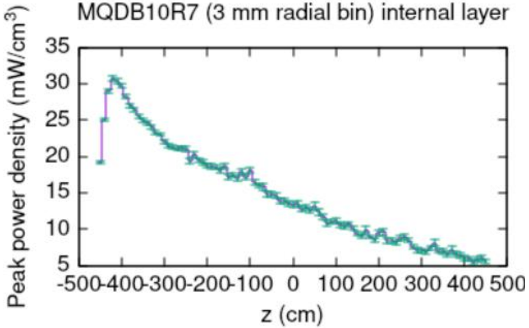
- Collimation performance checked with tracking studies using the SixTrack-FLUKA coupling and dedicated FLUKA simulations of exposed magnets

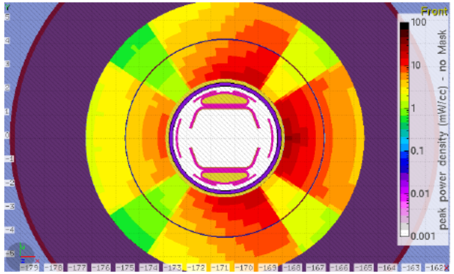
- Collimation system is extremely efficient at absorbing horizontal and vertical losses – almost no losses on cold machine aperture, thanks to dispersion suppressor collimators



Most loaded cold magnet

M. Varasteh





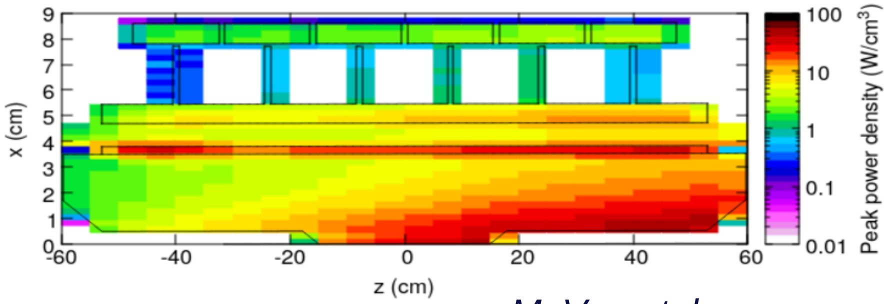
FCC collimator design

- 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



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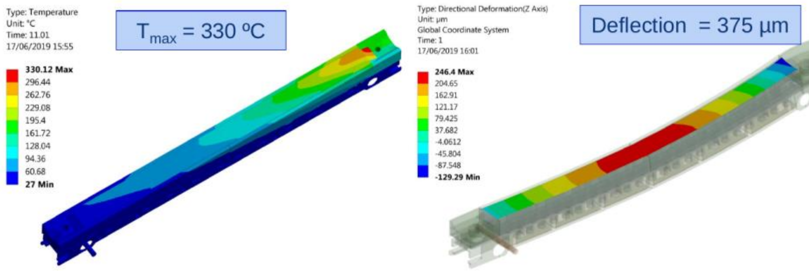

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