Status of FCC-hh collimation studies

R. Bruce

On behalf of many colleagues…

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Collaboration

- Talk based on material from, and discussions with:
- CERN
  - S. Arsenyev, W. Bartmann, A. Bertarelli, I. Besana, F. Burkart, F. Carra, F. Cerutti, E. Logothetis-Agaliotis, M. Fiascaris, S. Gilardoni, G. Gobbi, B. Goddard, A. Krainer, A. Langner, A. Lechner, R. Martin, A. Mereghetti, D. Mirarchi, J. Molson, S. Redaelli, E. Renner, M. Schaumann, D. Schulte, E. Skordis, M. Varasteh, Y. Zou
- IN2P3: LAL-IPNO and LAPP
  - LAL-IPNO: A. Faus Golfe, J. Molson (until 30/09/2017), S. Chance, L. Perrot
  - LAPP: M. Serluca, G. Lamanna
- FNAL
  - Y. Alexahin, E. Gianfelice-Wendt, N. Mokhov, A. Narayanan, M. Syphers, I. Tropin
- Apologies if I forgot anyone – please let me know!

Further talks on collimation

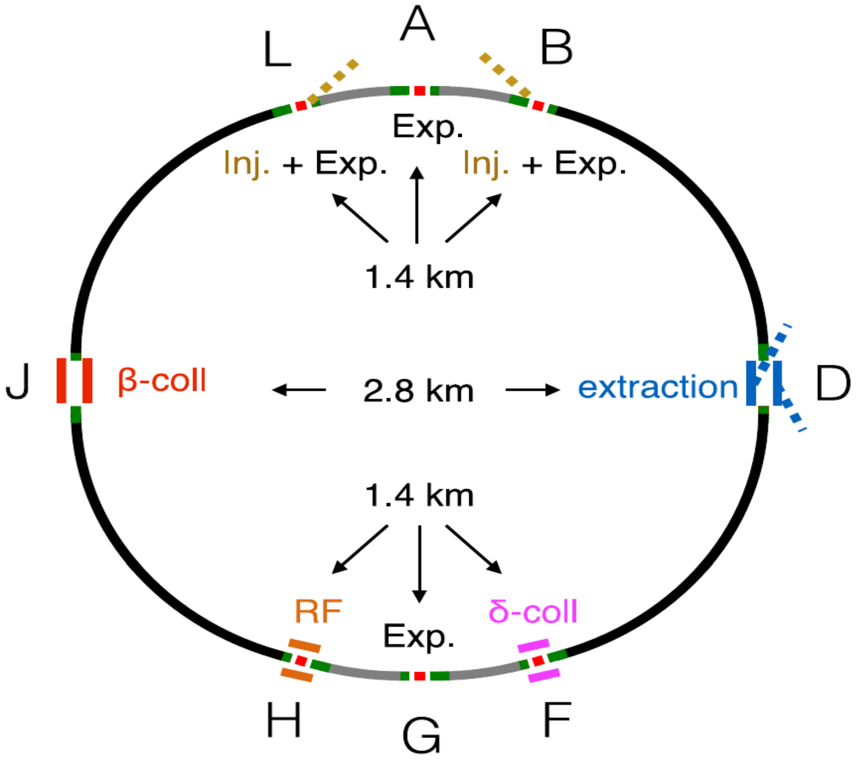
	Status of collimation system studies *P1 Effectenbeurszaal, 0.4*	*Roderik Bruce* 13:30 - 13:55
14:00	**Betatron collimation system insertions** *P1 Effectenbeurszaal, 0.4*	*James Molson* 13:55 - 14:20
	Collimation efficiency with imperfections *P1 Effectenbeurszaal, 0.4*	*Maurizio Serluca* 14:20 - 14:40
	Beam loss in collimators *P1 Effectenbeurszaal, 0.4*	*Mohammad VARASTEH* 14:40 - 15:00
15:00		

Roles of collimation system

- Provide sufficient betatron cleaning to avoid spurious dumps and quenches, and without risk of collimator damage
  - Machine aperture needs to be sufficiently far behind collimator
- Provide sufficient momentum cleaning
- Provide passive protection in case of failures
  - Asynchronous beam dump, injection failures ....
- Help in optimizing the background from the machine to the experiments
- Protect machine elements from damaging radiation dose: concentration of dose in controlled areas
- All while keeping impedance under control

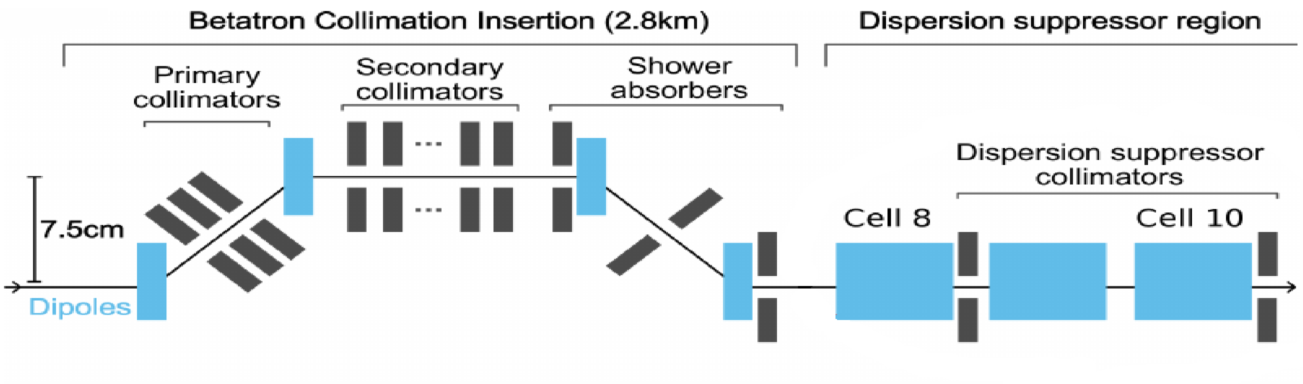
FCC collimation insertions

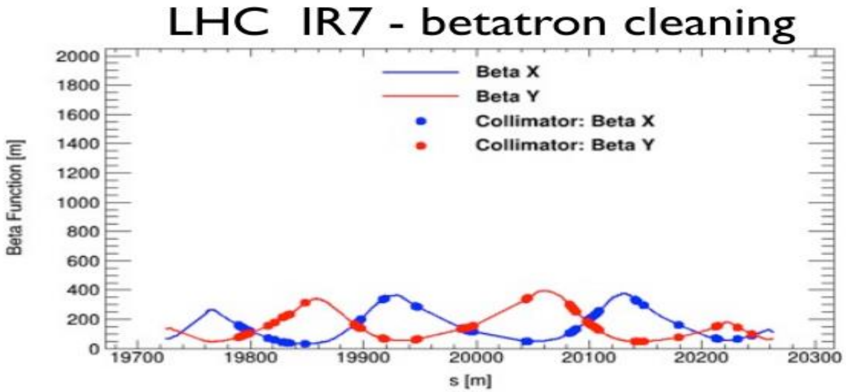
- First design of FCC-hh collimation system is a scaled up version of the HL-LHC/LHC system (M. Fiascaris, S. Redaelli et al.)
  - Betatron collimation in IPJ
  - Momentum collimation in IPF

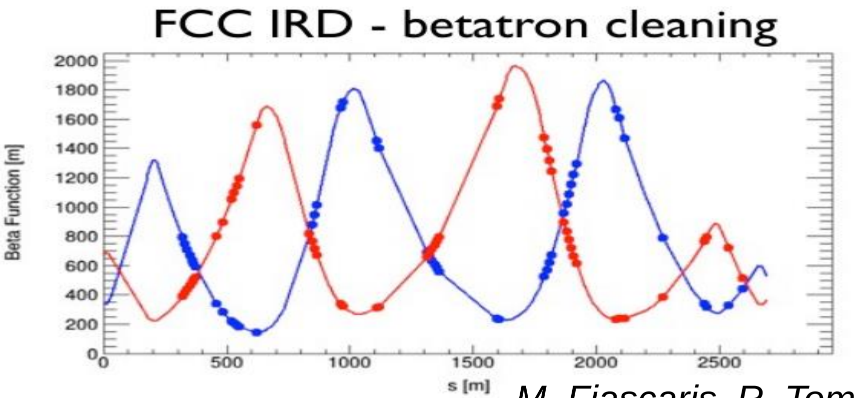


Betatron collimation design

- Keep layout, design and material of HL-LHC collimators
  - But collimators with highest loads made of CFC
- Scale β-functions and insertion length by factor 5 from the LHC







M. Fiascaris, R. Tomas

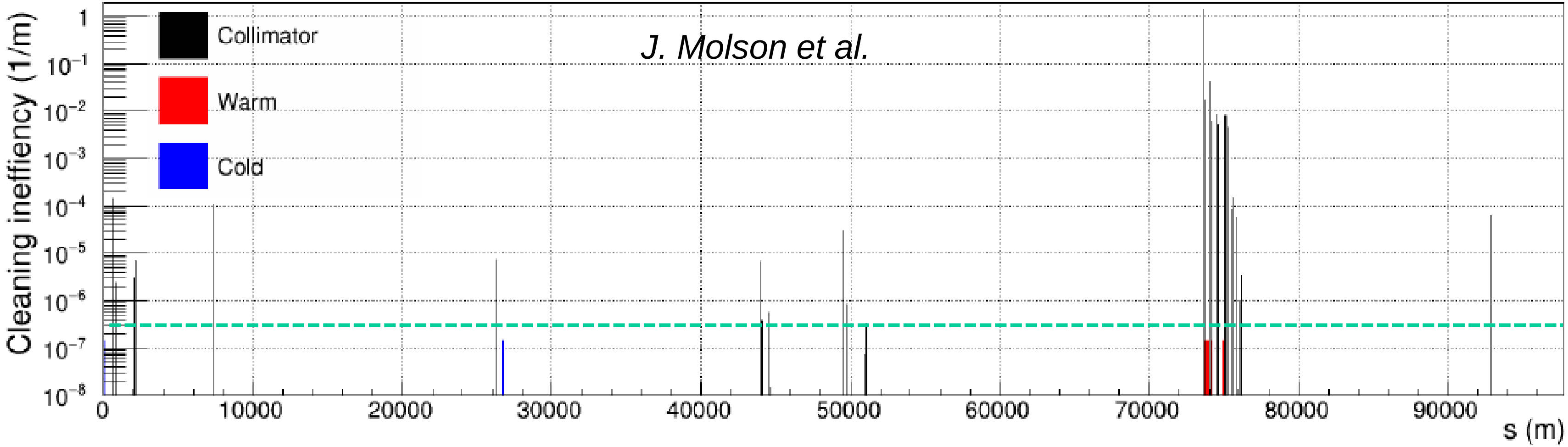
Betatron cleaning

- Has been the priority so far
- Most critical case for quenches: top energy (50 TeV)
  - Studied on following slides
- Worst case assumed: beam losses during a lifetime drop to 12 minutes, during up to 10 s, corresponding to a beam power of 11.8 MW at 50 TeV
  - Very challenging for the collimation system.
  - Not only protection of magnets is critical, but also the survival of the collimators themselves
- First step: tracking studies for loss maps. Output: losses on aperture and collimators around the ring
  - Recent iterations on layouts, new collimators introduced in extraction and IRs

Tracking simulations for loss maps

- Leakage of losses expected to be most critical in IPJ dispersion suppressor
- With dispersion suppressor collimators, as for HL-LHC, very few primary beam protons lost in the ring (statistics: 100 M particles) -> significant improvement!

See talk J. Molson



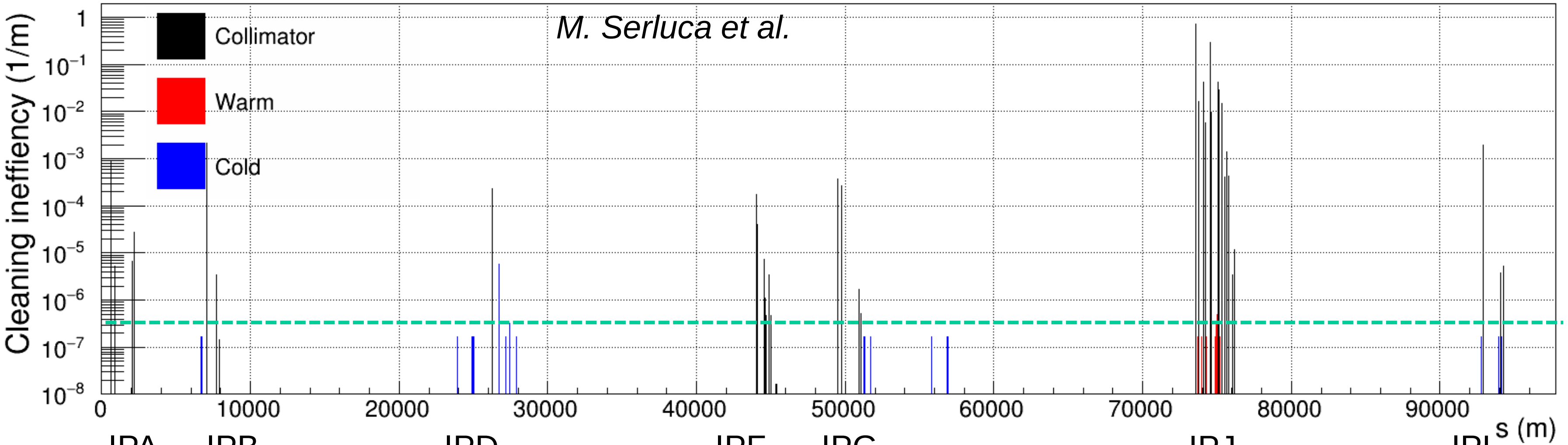
IPA IPB experiments
IPD extraction
IPF δ-coll.
IPG experiment
IPJ β-coll.
IPL experiment

Example: betatron cleaning, 50 TeV collision, on-momentum, horizontal plane, latest lattice

Tracking simulations with imperfections

- First simulations including imperfections: in general, still robust protection of ring
- Some spurious losses appear around the ring, but no dramatic effect
  - Highest peak above estimated required cleaning at top energy with 10 cm binning (D. Schulte, 3E-7 /m, based on avoiding quench for 12 minute minimum beam lifetime).

See talk M. Serluca



IPA IPB experiments

IPD extraction

IPF δ-coll.

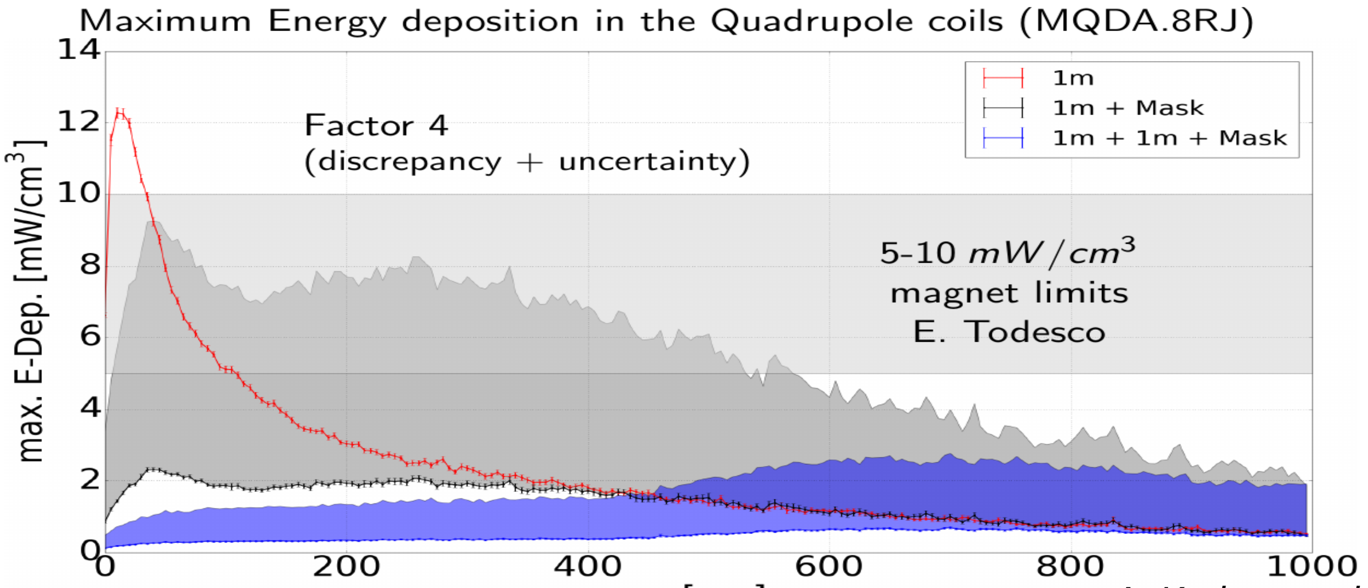
IPG experiment

IPJ β-coll.

IPL experiment

Energy deposition in the DS (cold magnets)

- In spite of no primary losses, showers from collimators could be critical
- FLUKA studies of energy deposition needed to assess quenches –A. Krainer
- IPJ DS (and all other cold elements) **sufficiently protected by present collimation system**



Betatron cleaning

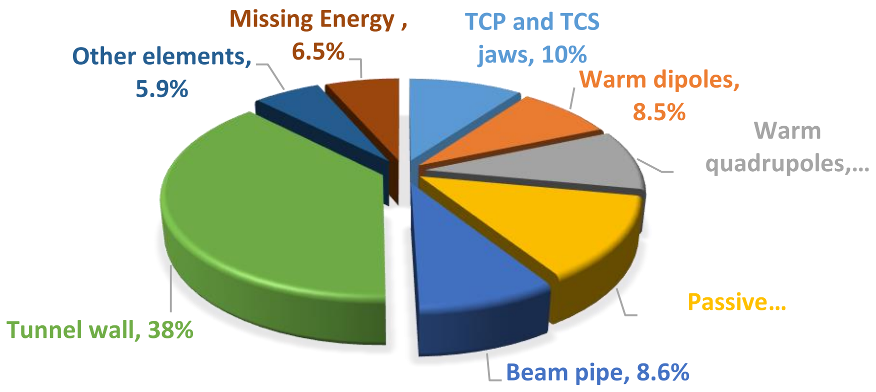
A. Krainer et al.

Summary of energy deposition in IRJ

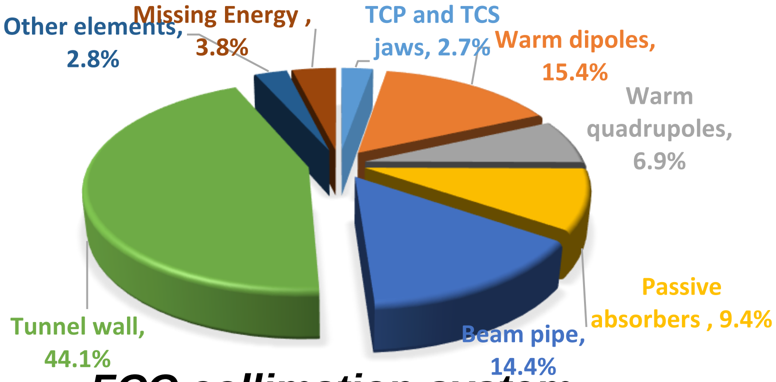
See talk M. Varasteh

- Can the collimation system and warm elements absorb the large power load?
- FLUKA studies performed of energy deposition in the warm insertion using tracking as starting conditions
- Collimators are not the main absorbers of energy neither in FCC nor LHC – they rather start the showers
- Still, collimators absorb very high power loads per volume

LHC collimation system



M. Varasteh et al.

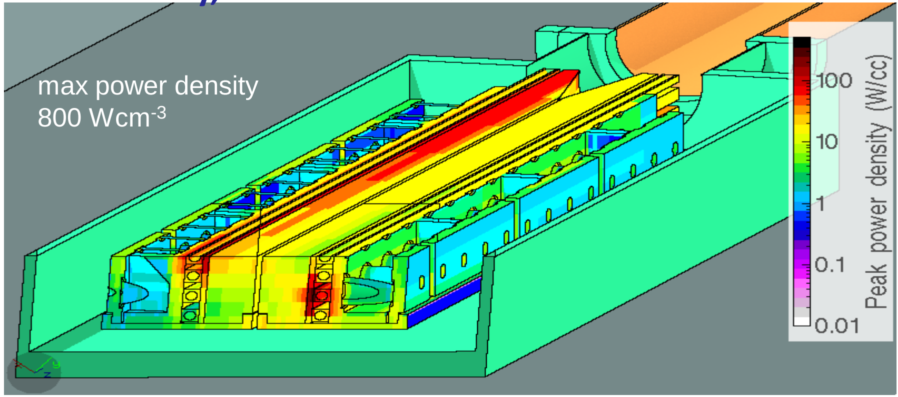


FCC collimation system

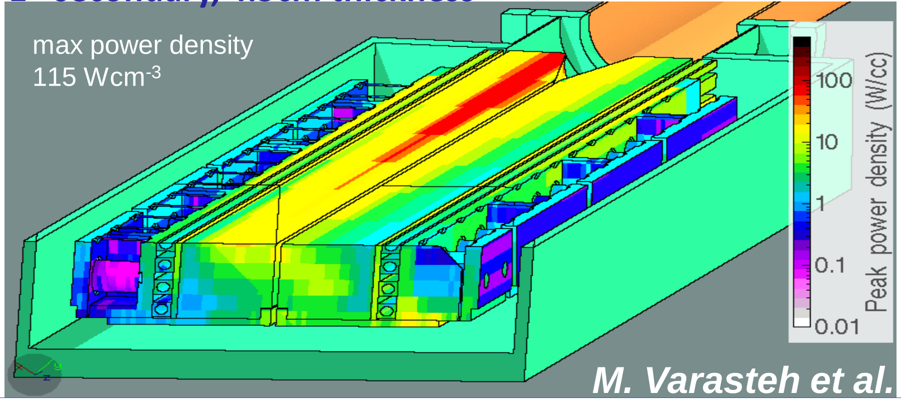
Modified collimators

- A few adjustments to design since first iterations
  - Shorter primaries (30 cm)
  - Removal of skew primary
    - LHC losses predominantly in hor. or ver. plane
    - Ongoing study to quantify impact
  - Thicker jaws of first secondary and primaries (4.5 cm instead of 2.5 cm)
- With modifications
  - Power on most loaded primary goes down from 260 kW to 80 kW
  - Power on most loaded secondary goes down from 225 kW to 92 kW

1st secondary, 2.5cm thickness



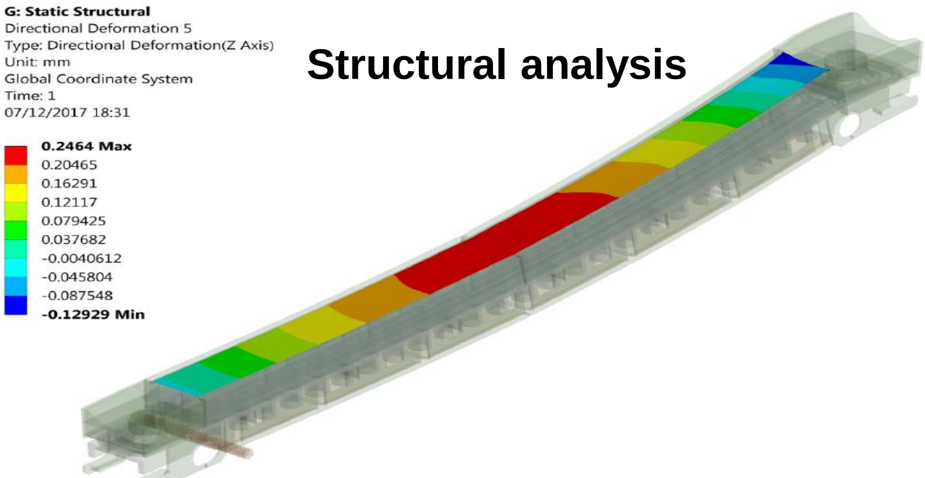
1st secondary, 4.5cm thickness

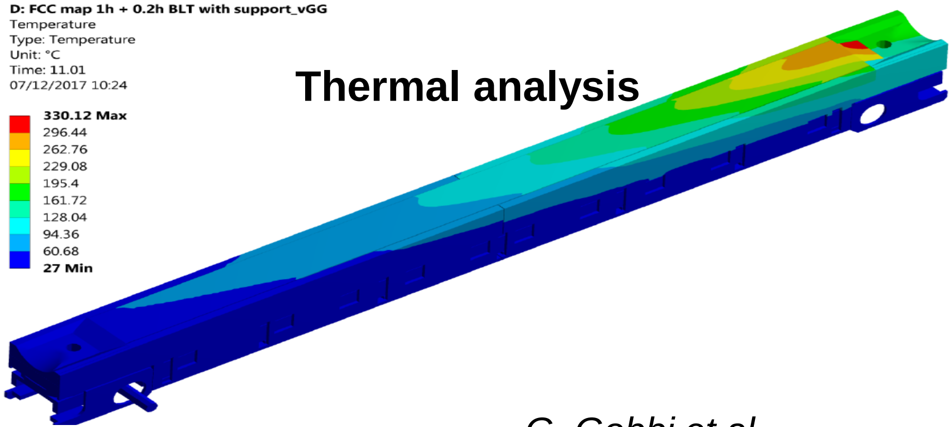


M. Varasteh et al.

Thermo-mechanical studies

- Thermo-mechanical studies with updated collimation system
  - Ansys study of most loaded secondary collimator, taking energy deposition profile from FLUKA as input
  - Assuming 12 minute beam lifetime over 10 s – total beam loss power of 11.8 MW
  - Using TCSP design but with thicker jaws – stiffer structure than LHC TCSGs





G. Gobbi et al.

Thermo-mechanical studies

Scenario	old design	new design
Total power on collimator (kW)	227	92
Max. temperature (C)	393	330
Max. deflection (µm)	1174	375

For 12 min. beam lifetime, 50 TeV

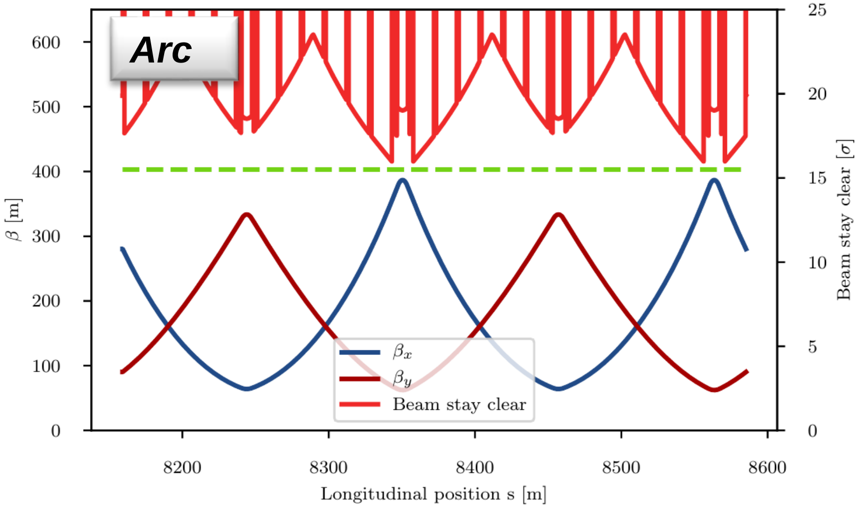
- Significant improvement with new design
- Secondary collimator **jaw survives without permanent damage**
- Remaining issues
  - Temperature of collimator jaws challenging – need to study outgassing and vacuum pumping
  - Still significant deflection of jaw – need to study influence on cleaning performance
    - Not likely a showstopper, since only the first secondary is deformed that much
  - With new design, still have plastic deformation of cooling pipes
    - Can probably be cured with a different pipe material – not likely a showstopper

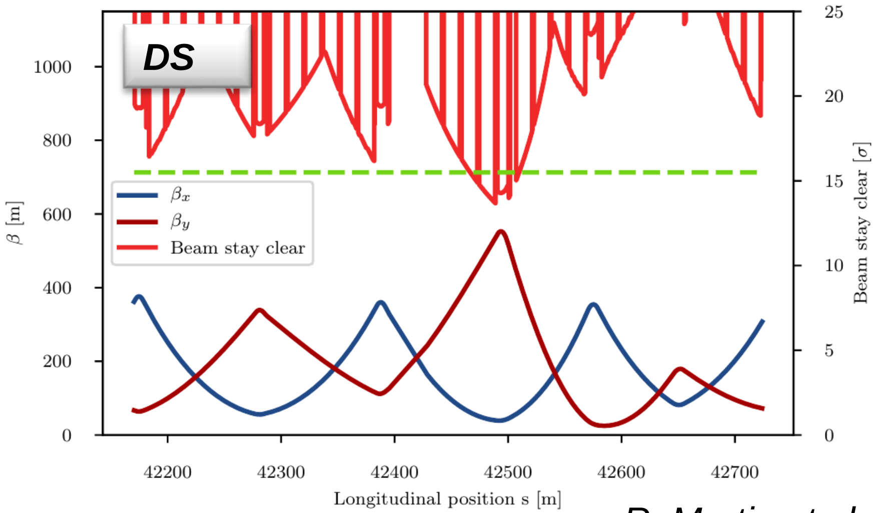
Power load on other elements

- Primary collimators
  - significant improvement with shorter length and removed skew
  - Still very high peak power density at thin layer close to surface. Studies of thermo-mechanical response ongoing
- Beam pipe: Peak power density under study
- Warm magnets
  - Can add shielding exchange at front face. Cooling / radiation damage to be studied
  - Possibility of shorter / weaker dipoles to be studied (smaller dogleg excursion)
- Passive absorbers: Need more detailed studies on design / cooling
- Tunnel wall absorbs almost half of deposited energy
  - Spread out over a very large volume – not an issue

Geometric aperture

- At injection, larger quench margin than at 50 TeV, but geometrical aperture more critical due to larger emittance
  - Using conservative 15.5 sigma criterion for allowed aperture from HL-LHC, most elements are within spec
  - A few outliers : dispersion suppressors, a couple of quadrupoles β-collimation
  - Good hope for solution: work on refining aperture criterion, tolerances, “golden” magnet or beam screen at critical locations

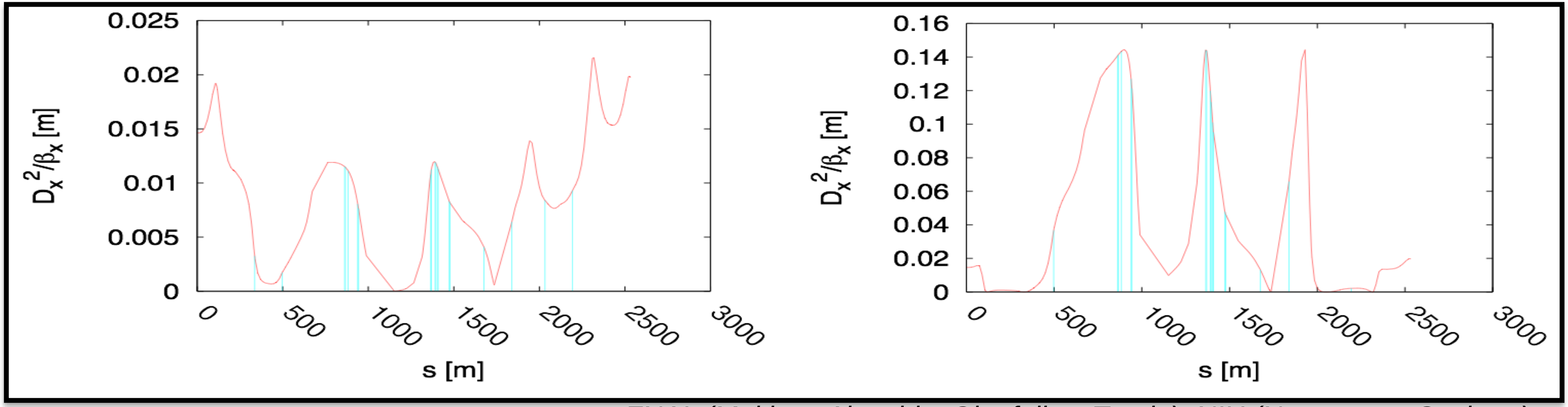




R. Martin et al.

Momentum cleaning

- Most critical case: losses at start of ramp.
  - Conservative loss specification, based on LHC: Tolerate 1% beam loss over 10 s => average beam loss power of 560 kW. Requirements less stringent for momentum cleaning at top energy
- Studies on momentum collimation lattice design: optimize ratio $\frac{D}{\sqrt{\beta}}$

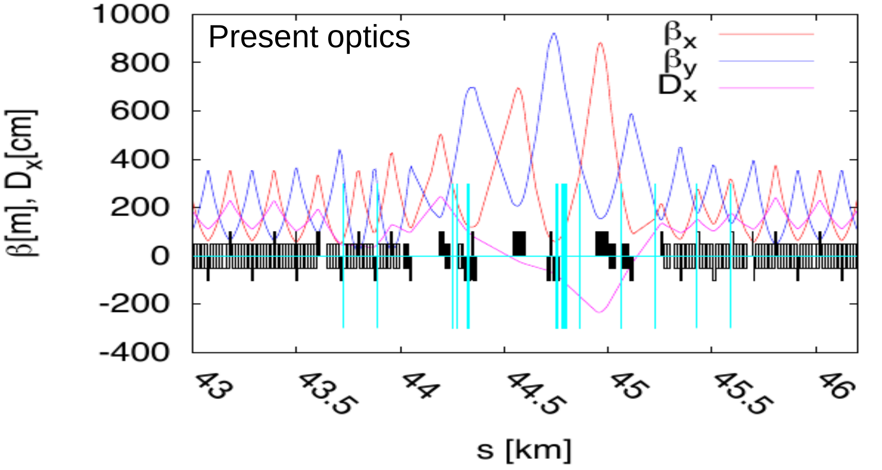


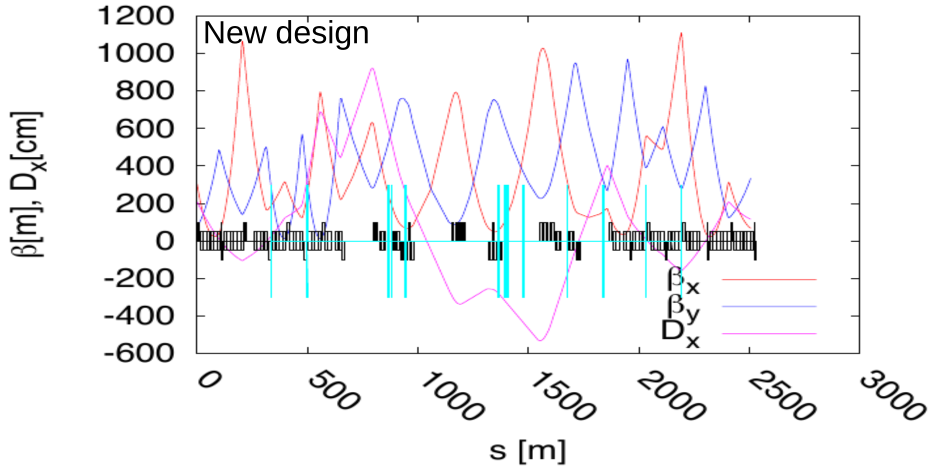
FNAL (Mokhov, Alexahin, Gianfelice, Tropin), NIU (Narayanan, Syphers)

Optics studies for momentum collimation

- New momentum collimation optics developed

FNAL (Mokhov, Alexahin, Gianfelice, Tropin), NIU (Narayanan, Syphers)



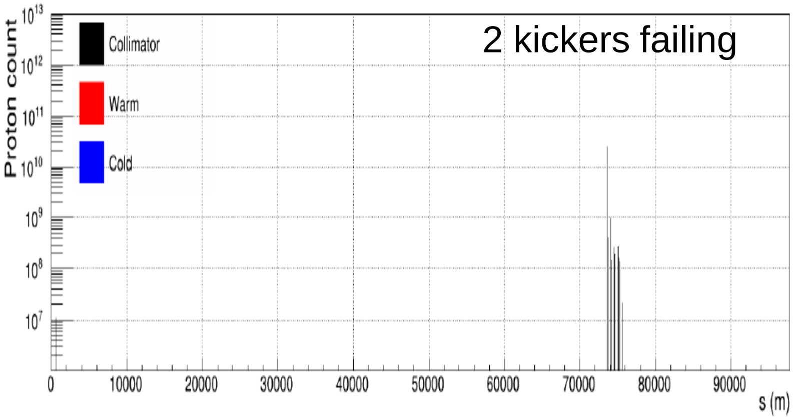


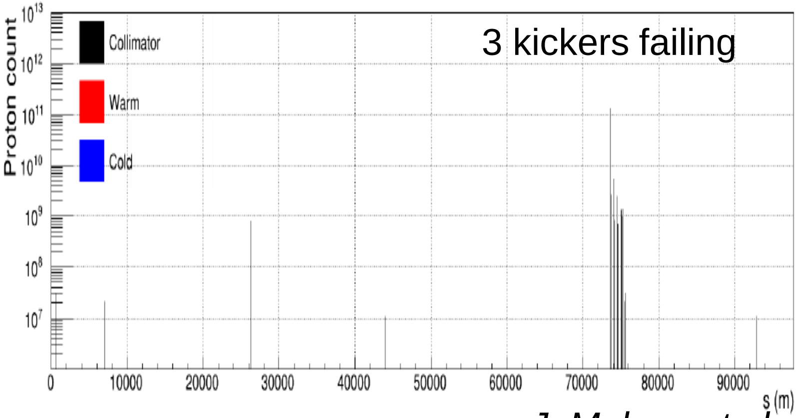
- Next steps: Optimize placement of secondary collimators. Study aperture, cleaning performance, power deposition
  – New MARS - MAD-X/PTC interface recently completed

Failure cases

See talk J. Molson

- Asynchronous beam dump at top energy could potentially be very critical
  - Miskicked protons escaping the dump protection collimators risk to damage machine elements
  - Has been a main limitation for the LHC performance reach
- First studies of system with 300 horizontal extraction kickers => Up to three kickers (about 3 σ kick) can trigger erratically without damaging collimators or other elements. Robust protection!
  - New vertical extraction design under study
  - Further imperfection studies planned
- Other failures to be studied: injection failure, warm magnets, crab cavities …. (J. Molson, E. Renner, Y. Nie)





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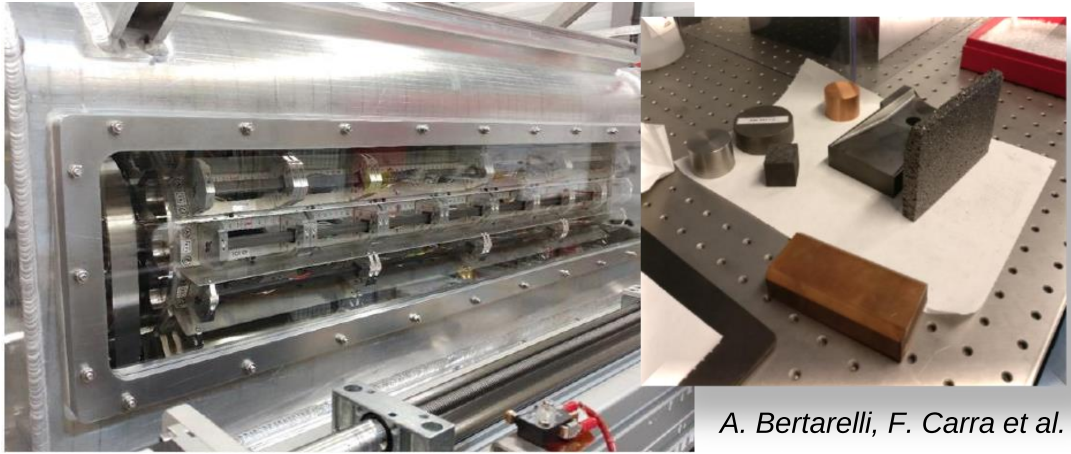
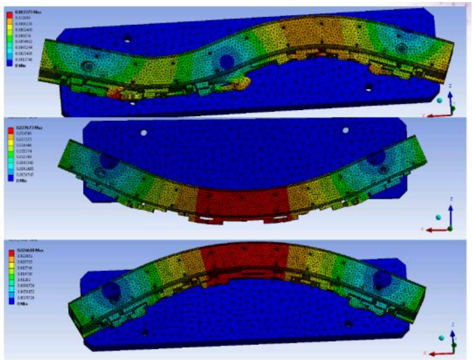
Future development and areas for study

- Challenge for FCC-hh collimation: very high power loads
  - Investigate new materials in jaws – e.g. Multimat test in 2017, driven by HL-LHC.
  - Work package including material development for beam intercepting devices in Special Technology R&D
  - Study active correction of jaw deflection
    - Ongoing study in Huddersfield for HL-LHC
- Controlled halo depletion using hollow electron lens
- Crystal collimation?



A. Bertarelli, F. Carra et al.



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Summary (1)

- Collimation for FCC-hh is very challenging: 8.5 GJ stored energy, up to 11.8 MW beam loss power
- **Betatron cleaning**: 3-stage simulation completed: tracking, energy deposition, thermo-mechanical analysis, with iterations on system design =>
  - Cleaning efficiency, energy deposition in cold magnets and loads on collimators in general under control
  - To be fixed: loads on cooling pipes (likely fixed by different material)
  - To be studied: surface of primary collimator, warm magnets and passive absorbers, vacuum, deflection, quantify impact of removed skew primary
    - Ideas on the table - hope to solve these points in next iterations
  - Probably acceptable also to increase minimum allowed beam lifetime

Summary (2)

- **Aperture at injection:** OK except a few outliers. good hope to find a solution
- **Beam failures** - preliminary: Collimators survive a failure of 1-3 extraction kickers.
- Other ongoing studies: momentum cleaning, IR collimation, heavy-ion collimation
- Future studies: advanced collimation concepts (electron lens, crystals…), optimization / re-design of collimation lattice
- Please see following talks for more details on the recent studies!