Status of FCC-hh collimation studies

R. Bruce

On behalf of many colleagues…

Collaboration

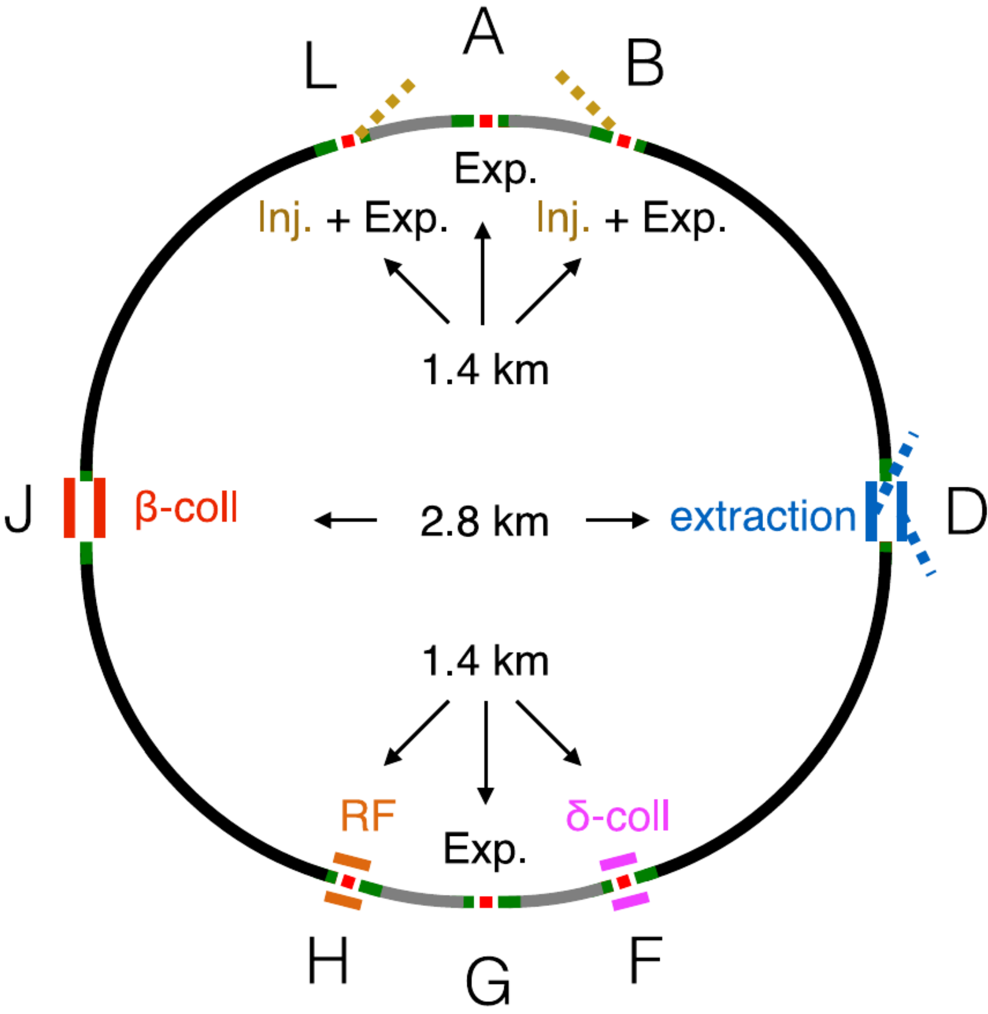
- Talk based on material from, and discussions with:
- CERN
  - W. Bartmann, S. Arsenyev, I. Besana, F. Burkart, F. Cerutti, M. Fiascaris, B. Goddard, A. Krainer, A. Langner, A. Lechner, A. Mereghetti, D. Mirarchi, J. Molson, S. Redaelli, D. Schulte, E. Skordis, M. Varasteh, Y. Zou
- IN2P3: LAL and IPNO
  - LAL: A. Faus Golfe, J. Molson (until 30/09/2017)
  - IPNO: L. Perrot
  - possible participation of LAPP-Annecy is under negotiation and a new PhD will join the LAL team
- FNAL
  - Y. Alexahin, E. Gianfelice, N. Mokhov, A. Narayanan, M. Syphers
- Apologies if I forgot anyone – please let me know!

Roles of collimation system

- Provide sufficient betatron cleaning to avoid spurious dumps and quenches, and without risk of collimator damage
  - Injection and top energy
  - 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

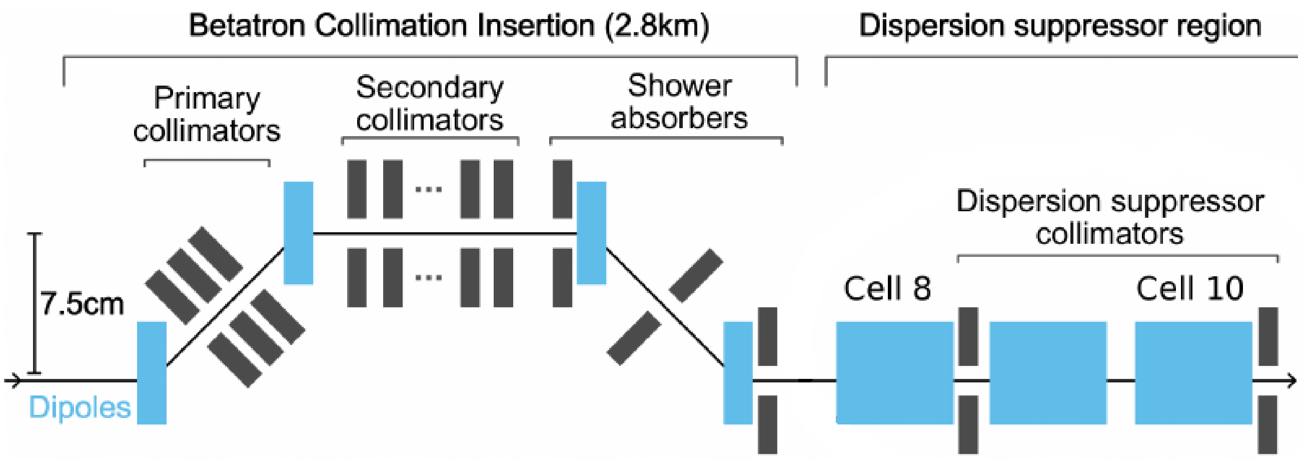
FCC collimation insertions

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

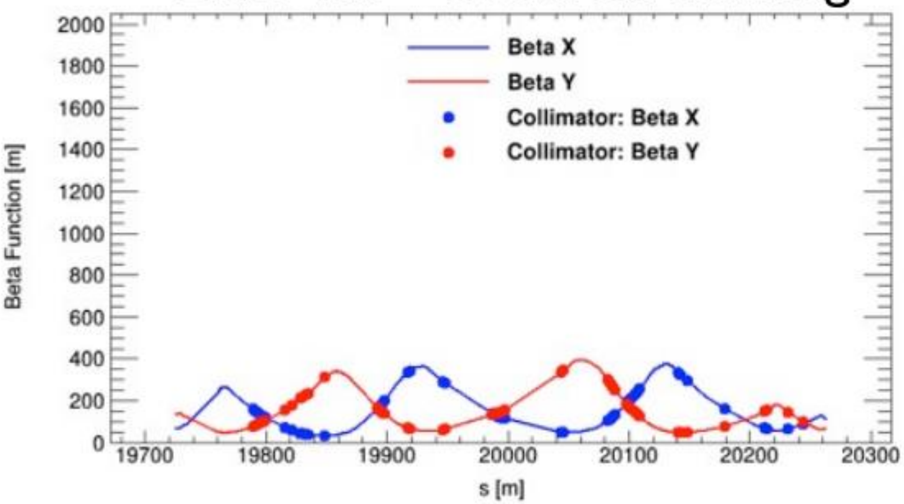


Betatron collimation design

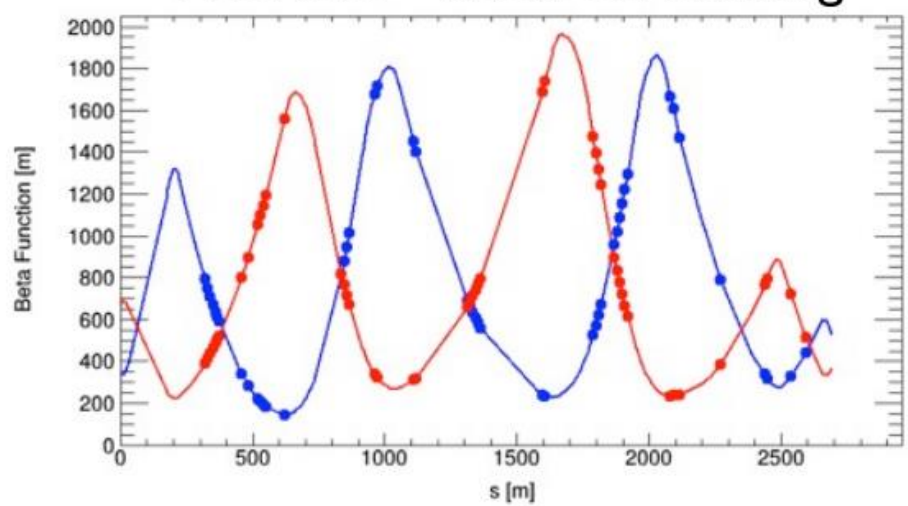
- Keep layout, design and material of LHC collimators
- Scale β-functions and insertion length by factor 5 from the LHC



LHC IR7 - betatron cleaning



FCC IRD - betatron cleaning



M. Fiascaris, R. Tomas

Baseline collimator settings

- Present baseline for betatron collimation - scaled from HL-LHC

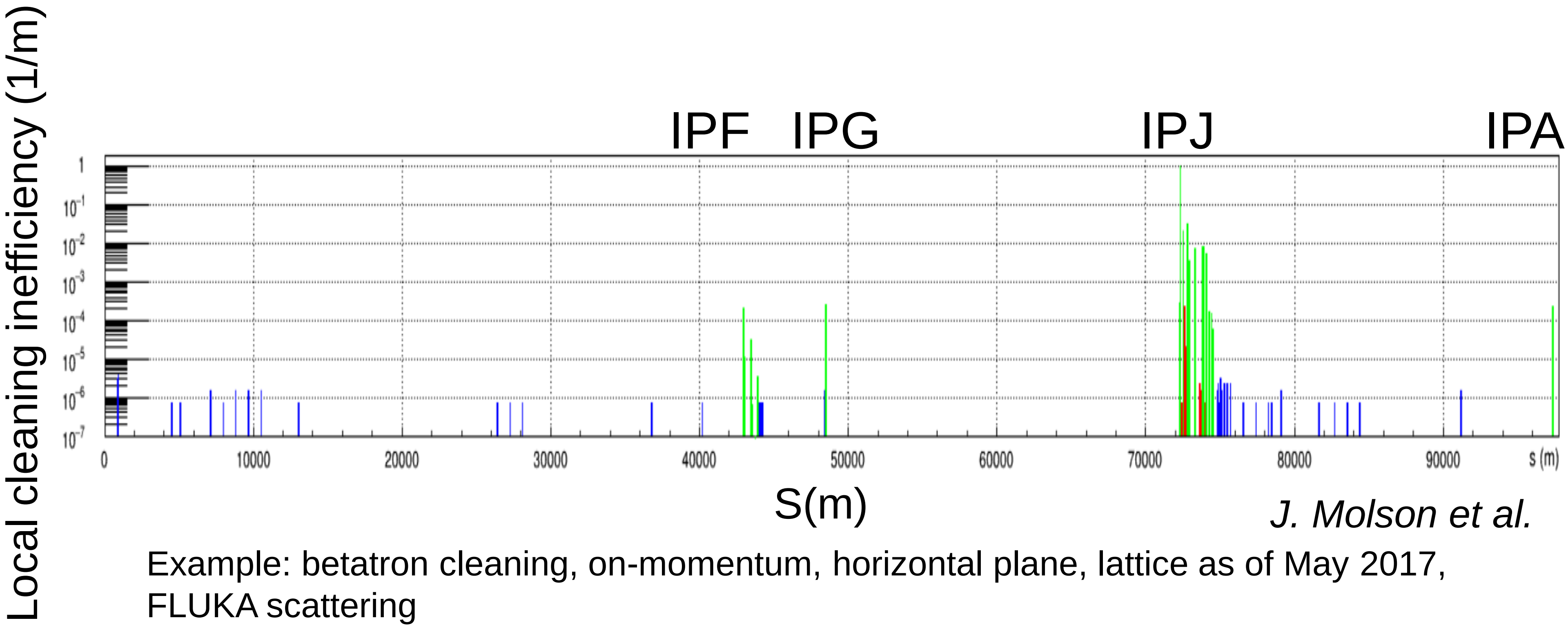
	HL-LHC ε = 2.5 μm	FCC-hh ε = 2.2 μm
Primaries	6.7	7.2
Secondaries	9.1	9.7
TCDQ	10.6	11.4
Tertiaries	12.9	13.7
min. aperture	14.5	15.5

Betatron cleaning

- Has been the priority so far
- Most critical case for quenches: top energy
- Worst case assumed: beam losses during a lifetime drop to 12 minutes, corresponding to a beam power of 11.8 MW at 50 TeV
  - Very challenging for the collimation system
- First step: tracking studies for loss maps
- Output: losses on aperture and collimators around the ring

Tracking simulations for loss maps

- Comparison of different scattering models - see talk J. Molson
- Leakage of losses from betatron collimators in IPJ most critical in downstream dispersion suppressor

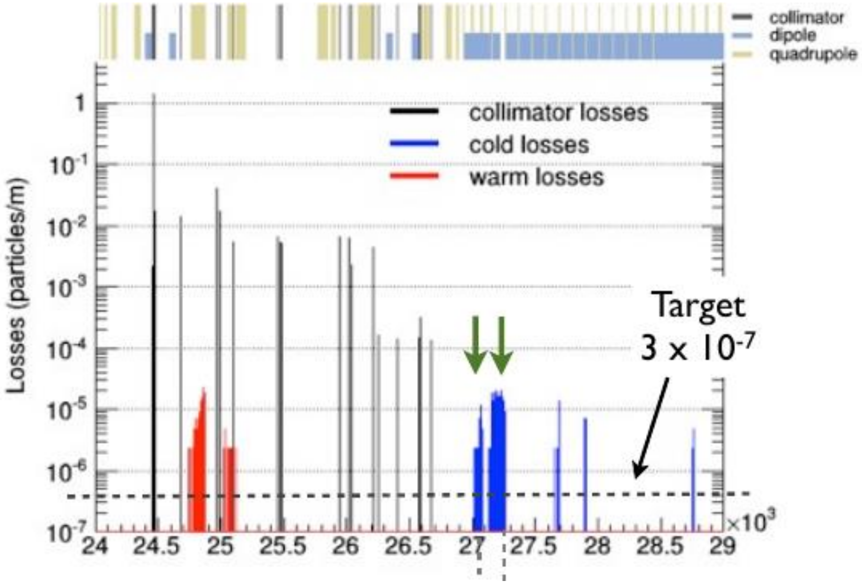


Example: betatron cleaning, on-momentum, horizontal plane, lattice as of May 2017, FLUKA scattering

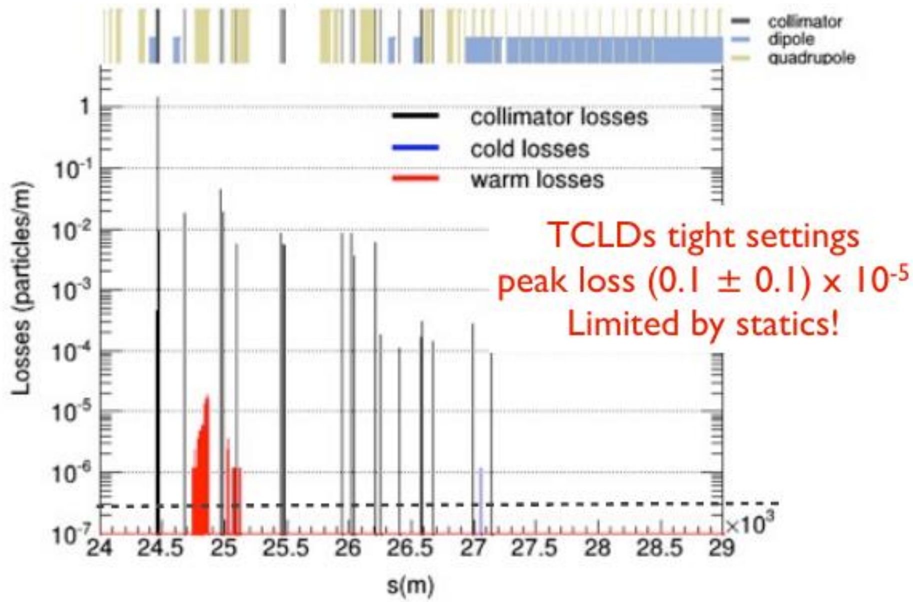
Protection of the DS

- Most critical location for losses: DS of IPJ
- As for HL-LHC, introduce additional collimators (TCLDs) in the DS to catch these losses

No TCLDs



With TCLDs

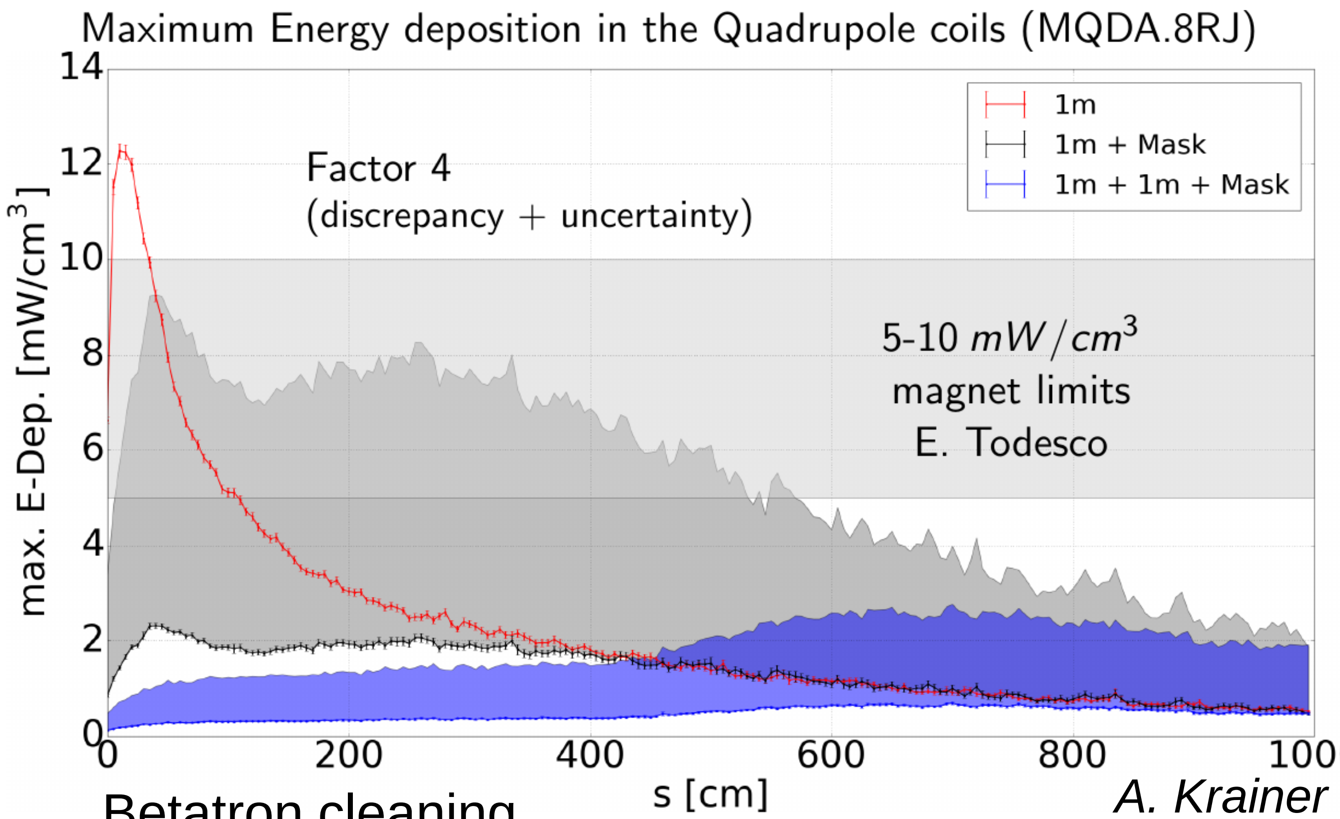


Example: horizontal betatron cleaning

M. Fiascaris et al., Rome 2016

Energy deposition in the DS (cold magnets)

- FLUKA studies of energy deposition needed to assess quenches – more details in talk A. Krainer
- IPJ DS (and all other cold elements) sufficiently protected by present collimation system

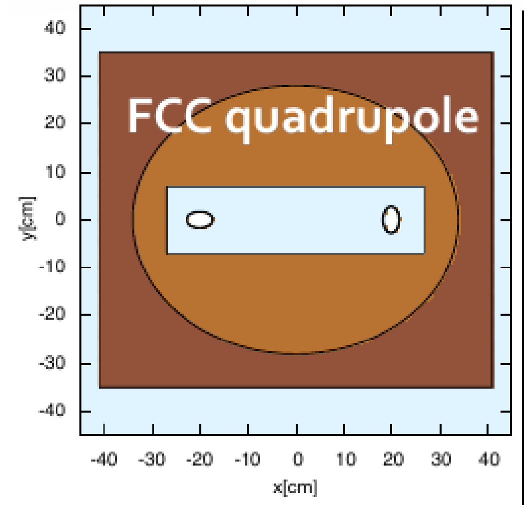


Betatron cleaning

A. Krainer et al.

FLUKA studies of warm insertion

- Can the collimation system and warm elements absorb the large power load?
- FLUKA geometry of warm insertion region implemented
- FLUKA studies performed of energy deposition in the warm insertion (I. Besana et al.) using tracking as starting conditions



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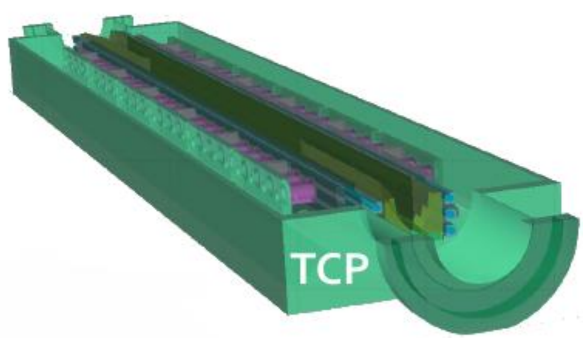
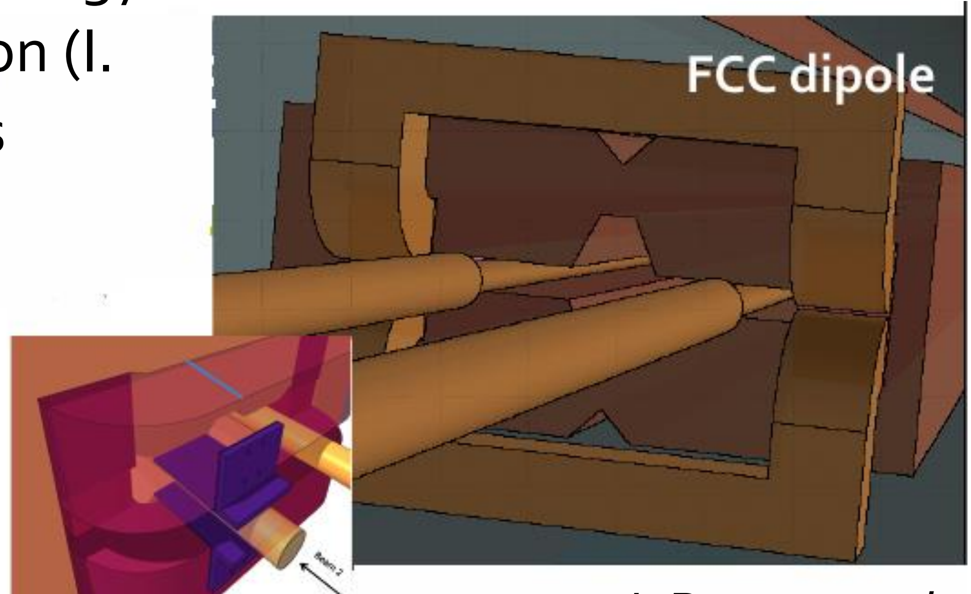




I. Besana et al

Energy deposition in collimation insertion

- Sharing of power: betatron losses

I. Besana et al.

Power Fraction	Horizontal	Vertical
TCP and TCS jaws	5.1%	6.7%
Warm dipoles	16%	13.7%
Warm quadrupoles	4.6%	5.4%
Passive absorbers (TCAP)	8.6%	7.9%
Beam pipe	14.2%	14.2%
Tunnel wall	44.4%	44.9%
Other Elements	3.1%	3.3%
Neutrinos/E → m	4%	4%

- As in LHC, only a small amount of total power is deposited in the collimators

Power on collimators

- Only primary collimators and the first secondary seem very critical

Collimator Jaws	Horizontal [kW]	Vertical [kW]
Primaries		
TPC_D6L	0.02	14.7
TPC_C6L	23.1	158.7
TPC_B6L	209.0	260.8
Secondaries		
TCSG_A6L	233.6	220.9
TCSG_B5L	8.2	10.6
TCSG_A5L	35.7	40.8
TCSG_D4L	27.6	33
TCSG_B4L	7.1	8.2
TCSG_A4L	13.1	10.8
TCSG_A4R	15.9	13.7
TCSG_B5R	4.9	3.9
TCSG_D5R	9.0	6.7
TCSG_E5R	15.7	10.9
TCSG_6R	3.5	1.8

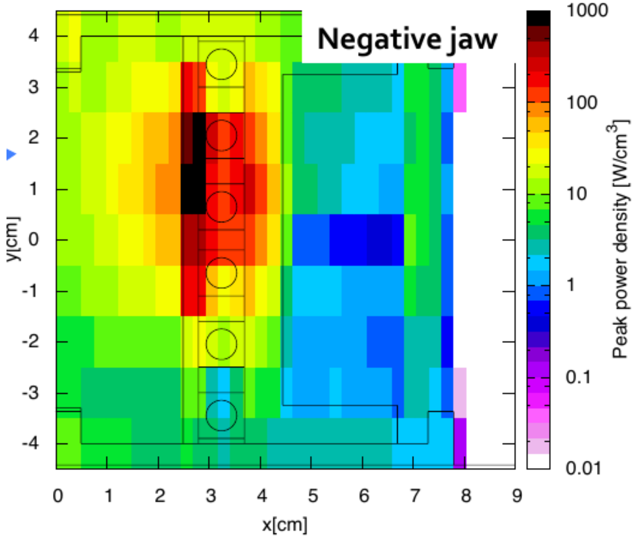
I. Besana et al.

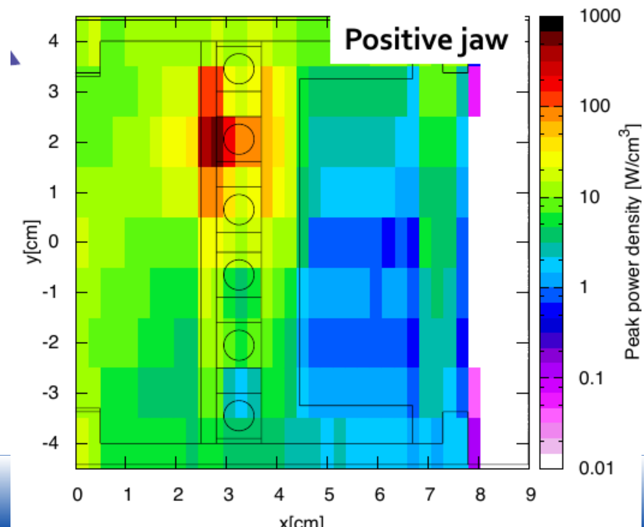
Potentially critical elements under study

- Primary collimators: shortening the length could improve the load
- Warm dipoles: Can add shielding exchange at front face. Cooling / radiation damage to be studied
- Passive absorbers: Needs more detailed studies on design / cooling
- Tunnel wall absorbs almost half of energy deposited
  - Should study activation and dose
- First secondary collimator: thicker jaws decrease power load

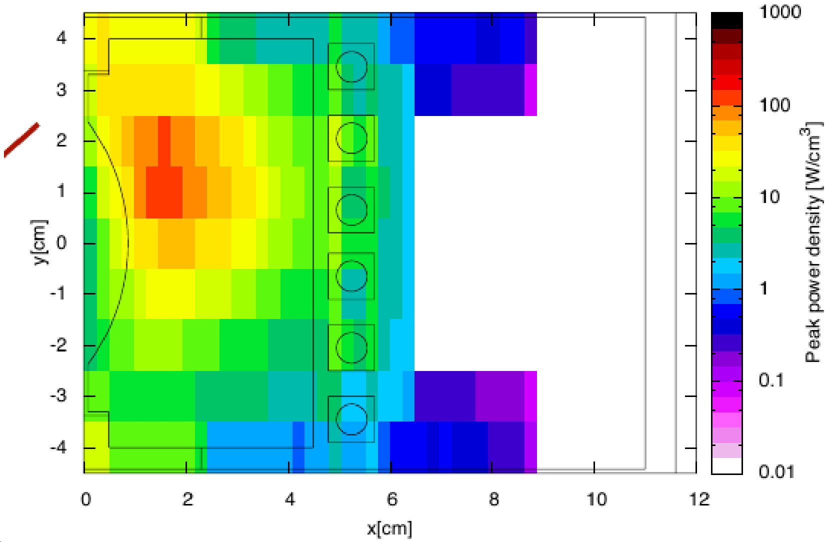
Secondary collimator: try thicker jaws

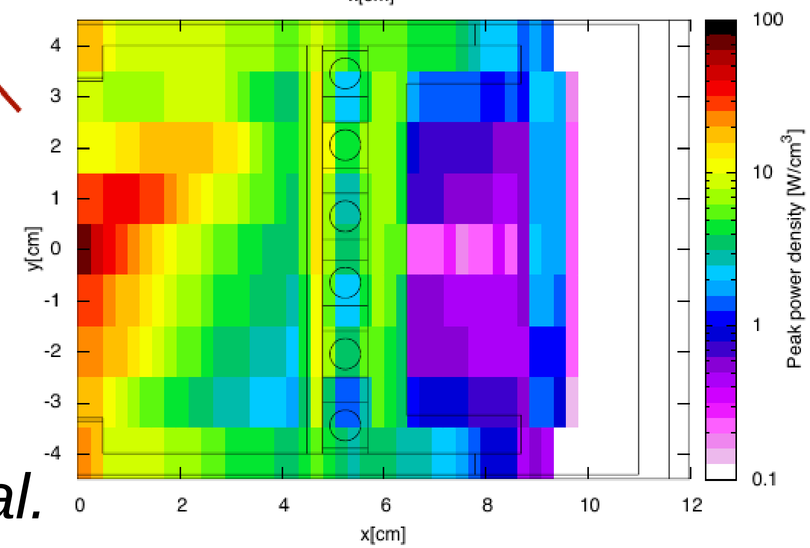
- Energy deposition peak is not in active part of the jaw but in metallic plate
  - Try to make the jaw thicker to distribute energy more in low-Z active part





Thicker jaws

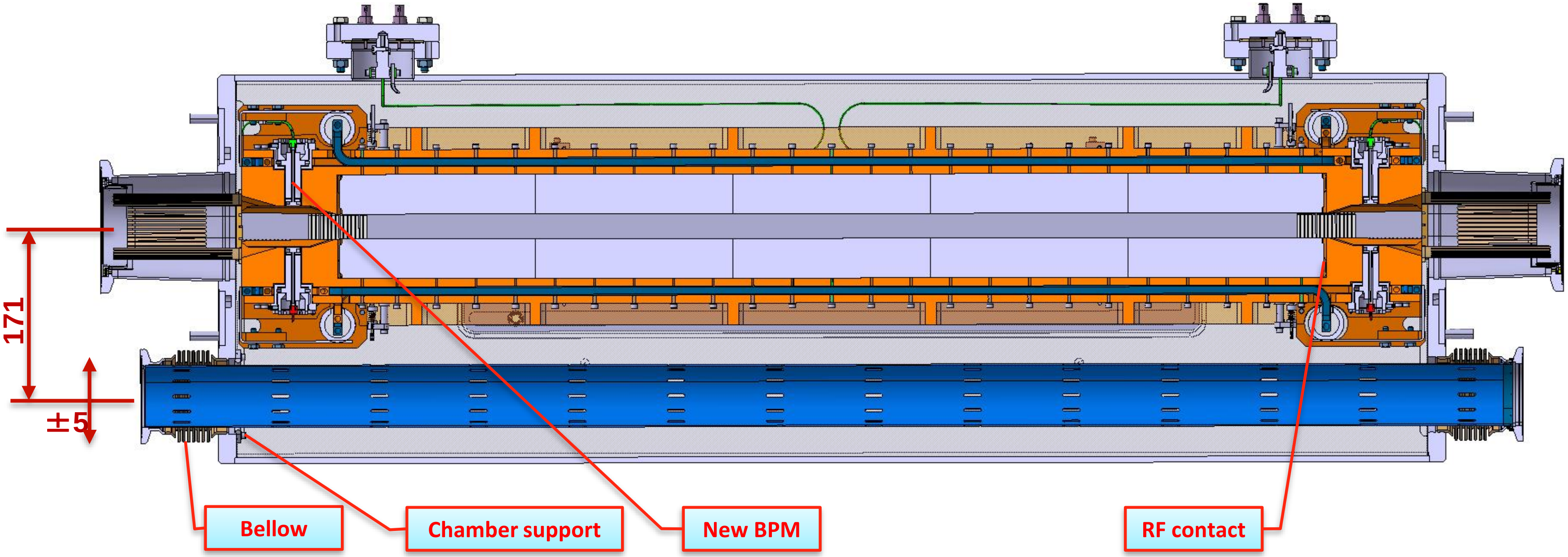




I. Besana et al.

Design of thicker jaws for HL-LHC

- Collimator design with thicker jaws feasible - anyway developed for HL-LHC (TCLX)



L. Gentini et al.

Power on collimators, thicker TCSG

- Total load on worst TCSG reduce by more than factor 2

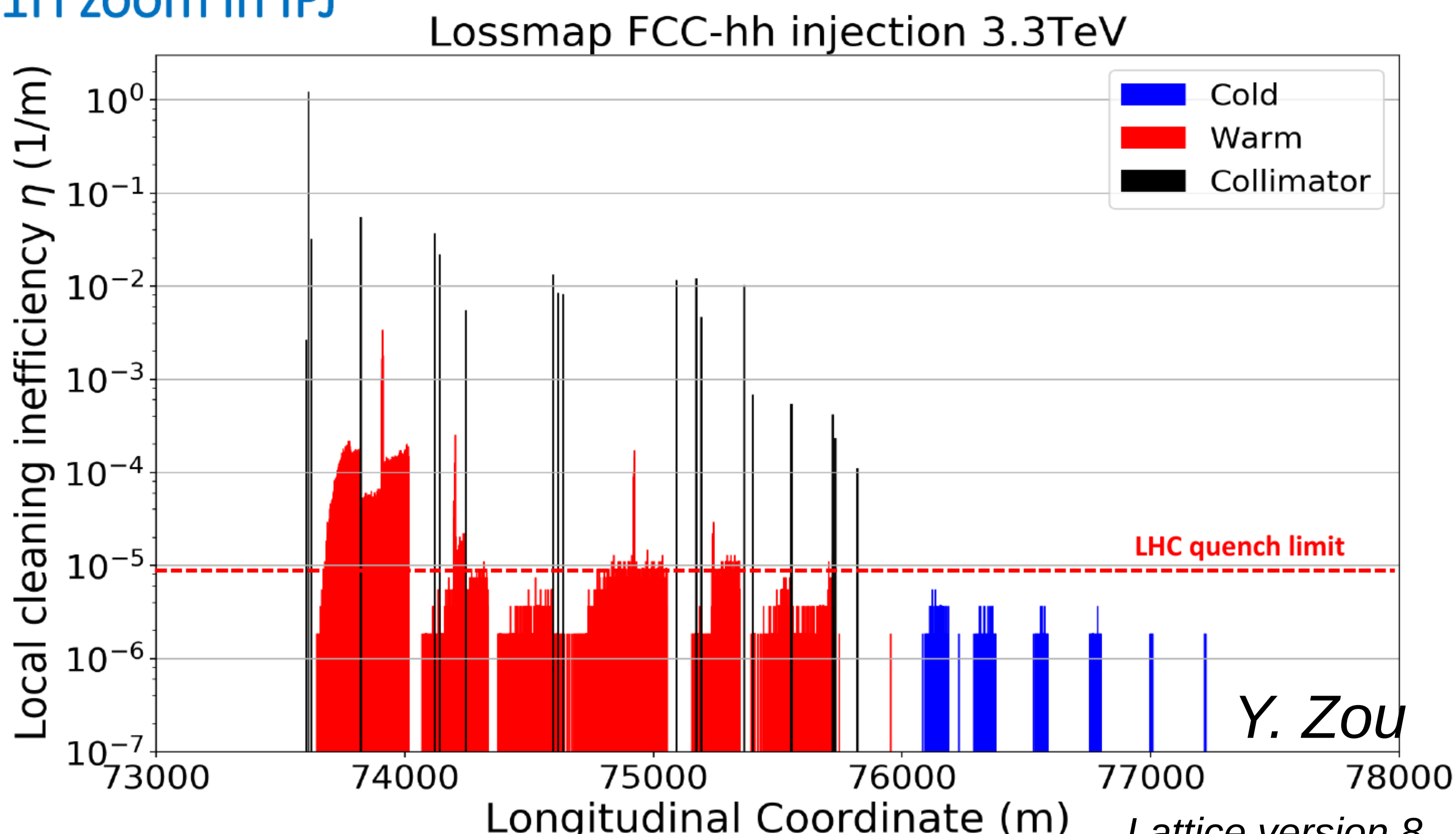
Collimator Jaws	LHC jaws Vertical [kW]	Thicker jaws Vertical [kW]
Primaries		
TPC_D6L	14.7	14.4
TPC_C6L	158.7	156.7
TPC_B6L	260.8	257.3
Secondaries		
TCSG_A6L	220.9	91.6
TCSG_B5L	10.6	8.0
TCSG_A5L	40.8	32.8
TCSG_D4L	33	26.4
TCSG_B4L	8.2	4.4
TCSG_A4L	10.8	9.0
TCSG_A4R	13.7	11.7
TCSG_B5R	3.9	2.5
TCSG_D5R	6.7	5.4
TCSG_E5R	10.9	9.5
TCSG_6R	1.8	1.6

I. Besana et al.

Betatron cleaning at injection

- Obviously less critical than at top energy
- Does not seem too problematic even without DS collimators

B1H zoom in IPJ



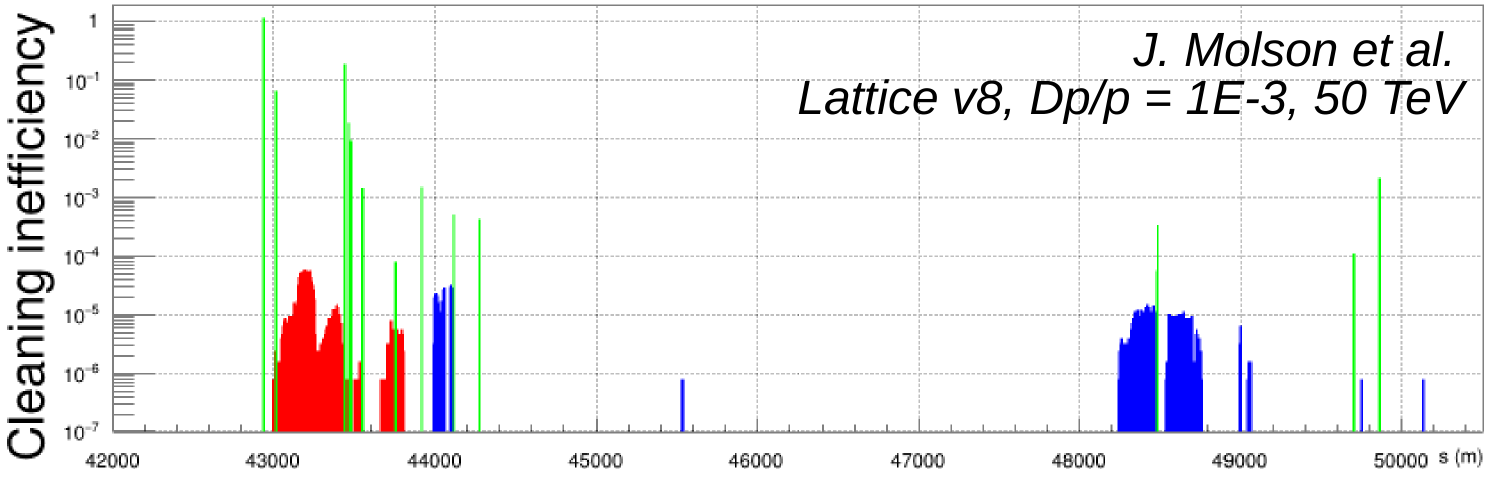
Lattice version 8
On-momentum

Aperture at injection

- Geometrical aperture more critical than at top energy due to larger emittance
  – Studies A. Langner: using 15.5 sigma criterion for allowed aperture from HL-LHC, we are not within spec (13.2 sigma for the arc, and 11.4 sigma for the DS)
- Needs to be fixed! Possibilities:
  – Study stricter tolerances on optics, orbit, alignment than for HL-LHC.
  – Calculations of realistic losses for FCC, comparing with FCC quench limit, to refine criterion of allowed aperture - ongoing
  – Tighten cleaning hierarchy to allow smaller aperture.
  – Work on the beam screen design of the elements

Momentum cleaning

- Tracking studies at top energy show significant losses upstream of experiments – possible need for re-optimization of system
  - Requirements less stringent for momentum cleaning at top energy



- Possibly most critical case: losses at start of ramp.
  - Proposed specification: Tolerate 1% beam loss over 10 s
  - Studies at injection ongoing
- Ongoing effort at Fermilab to improve energy collimation. See talk Y. Alexahin

Failure cases

- Studies starting in collaboration with the injection and dump team (F. Burkart, B. Goddard, E. Renner, W. Bartmann et al.)
- 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
- Planned to soon start detailed tracking studies
- Injection failure: to be discussed with injection team
- Other failure modes?

Summary

- Betatron cleaning at top energy
  - Cleaning efficiency and energy deposition in cold magnets under control
  - Energy deposition on collimators and warm magnets: some open points but good hope to solve them in next iterations
  - Aperture at injection is not sufficient– several ideas being investigated, good hope to find a solution
- Momentum collimation:
  - Studies ongoing. Optimization of layout/optics might be needed, but less critical than betatron cleaning
- Beam failures:
  - Studies now starting in collaboration with dump team
- Points for future study: activation, radiation damage, design of shielding / absorbers, further optimization of optics, advanced collimation concepts (electron lens, crystals…)