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NM4SixTrack

Implementation of new composite materials for HL-LHC collimator upgrades in SixTrack

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Outline

- Motivation and goals
- Update of collimation material implementation in SixTrack
- Cleaning simulations with advanced secondary collimators
- Conclusions
- Outlook

Motivation and goal of the work

- During Run I, **material-related concerns** limited the LHC performance, such as contribution from present non-metallic collimators (like TCSGs) to whole machine impedance and beam instability
- HL-LHC beam cannot be stable unless impedance is reduced
  → Collimation system must be upgraded
- **MATERIAL R&D** for advanced collimator: **novel composite materials** newly developed, characterized, tested and irradiated
- Work supported by *EUCARD2 WP11*: *Collimator MATerials – High Density Energy Deposition*:
  - Task 11.2: Material testing for fast energy density deposition and high irradiation doses
  - Task 11.3: Material mechanical modelling
  - **Task 11.4: Material specification**

Simulations with new materials used to iterate on specifications and collimator design

Set requirements that material R&D program have to satisfy

Motivation and goal of the work

- **Collimator material implementation in SixTrack UP TO DATE**, which now includes new composites, with the aim of:
  - Understanding the role of materials in the halo cleaning efficiency of the overall system
  - Predicting relevant loss scenarios for nominal LHC

Nominal 7 TeV case already studied and recently published:
"Collimation cleaning at the LHC with advances secondary collimator materials", E. Quaranta et al., IPAC15, Richmond, Virginia

- Predicting relevant **loss scenarios for HL-LHC**

Focus of today

- Providing inputs for energy deposition studies in the IR7 with new loss profiles → feedback to the new collimator mechanical design

Coming soon

Collimator material implementation in SixTrack (I)

- So far, the routine treats mono-element materials only.
- **4 novel composite materials added** to existing implementation:
  - ✓ MoGr → *Promising materials for low-impedance secondary collimators in HL-LHC upgrade*
  - ✓ CuCD →
  - ✓ Glidcop → *Copper-based composite used in collimator back-stiffner support*
  - ✓ Inermet180 → *Tungsten heavy alloy for jaws of tertiary collimators and absorbers*

- Main changes in the code done in the `scdata` block
- Composite materials are dealt with by calculating off-line "effective" input parameters starting from material composition

- First checks of various distributions after single pass interactions using a "toy collimator" of 1 cm thickness made by new composites are in line with what expected

Collimator material implementation in SixTrack (II)

Atomic number Z and **atomic weight A**
as average weighted on the atomic fraction of the components:

$$p = \sum_i at_i \, p_i, \qquad (1)$$

- p = [Z,A] of compound to compute
- p_i = values of the property for i-th element in material (from [1])
- $at_i[\%]$ = atomic content of i-th element in compound

[1] K.A. Olive et al. Particle Data Group. Chin. Phys. C, 38, 090001, 2014

	Z	A [g/mol]	ρ [g/cm^3]	σ_{el} [MS/m]	**at. content** [%]	χ_0 [cm]	λ_{tot} [cm]	λ_{inel} [cm]
CFC	6	12.01	1.67	0.14	100 C	25.57	35.45	51.38
MoGR	6.653	13.532	2.5	1	2.7 Mo_2C, 97.3 C	11.931	24.84	36.42
CuCD	11.898	25.238	5.4	12.6	25.7 Cu, 73.3 CD, 1 B	3.162	13.56	20.97
Glidcop	28.823	63.149	8.93	53.8	99.1 Cu, 0.9 Al_2O_3	1.442	9.42	15.36
Inermet180	67.657	166.68	18	8.6	86.1 W, 9.9 Ni, 4 Cu	0.385	6.03	10.44

Note: CFC, already coded in SixTrack as pure carbon, is listed only for comparison

Collimator material implementation in SixTrack (III)

Density ρ and **electrical conductivity σ_{el}** are measured from available specimens received from material suppliers

	Z	A [g/mol]	ρ [g/cm^3]	σ_{el} [MS/m]	**at. content** [%]	χ_0 [cm]	λ_{tot} [cm]	λ_{inel} [cm]
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Atomic content calculated after production process of composite materials

Collimator material implementation in SixTrack (IV)

Mean excitation energy I and radiation length χ_0
as average weighted on the mass fraction of the components:

$$\frac{1}{p} = \sum_i \frac{wt_i}{p_i}, \qquad (2)$$

- p = mean ionization energy I and radiation length χ_0 of compound to compute
- wt_i = mass fraction of i-th element in compound

	Z	A [g/mol]	ρ [g/cm^3]	σ_{el} [MS/m]	**at. content** [%]	χ_0 [cm]	λ_{tot} [cm]	λ_{inel} [cm]
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Deflection angle due to elastic collisions:

$$\theta_0 = \frac{13.6\ MeV}{\beta c p} z \sqrt{\frac{x}{\chi_0}} \left(1 + 0.038\ ln \frac{x}{\chi_0}\right)$$

Collimator material implementation in SixTrack (V)

Collision length λ_{tot} and **inelastic length λ_{inel}**
as average weighted on the mass fraction of the components:

$$\frac{1}{p} = \sum_i \frac{wt_i}{p_i}, \qquad (2)$$

- p = mean ionization energy I and radiation length χ_0 of compound to compute
- wt_i = mass fraction of i-th element in compound

	Z	A [g/mol]	ρ [g/cm^3]	σ_{el} [MS/m]	**at. content** [%]	χ_0 [cm]	λ_{tot} [cm]	λ_{inel} [cm]
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Total cross section and inelastic cross section:

$$\sigma_{tot,inel} = \frac{A}{N_{Av}\,\varrho\,\lambda_{tot,inel}}$$

Cleaning with advanced collimators for HL-LHC scenario: SIMULATION SETUP

To study the effects of new collimator materials on the collimation cleaning efficiency for HL, SixTrack simulations were performed with the following setup:

- > 6×10^{6} protons at **7 TeV**
- **HL-LHC v1.0** optics (β*=15cm)
- 3.5μm rad normalized emittance
- **Beam 1**, H halo
- Full LHC collimation system in place
- **W** used so far for TCTs and Absorbers **replaced by Inermet180**
- **2σ retraction** between IR7 TCPs and TCSGs
  Collimator settings are listed in table:

Collimator families	Settings [σ]
IR7 TCP/TCSG/TCLA	5.7/7.7/10
IR3 TCP/TCSG/TCLA	15/18/20
IR6 TCSG/TCDQ	8.5/9
IR1/5 TCTs	10.5
IR2/8 TCTs	30

In the simulated cases, all **present CFC secondary collimators** in the betatron cleaning insertion (IR7) **replaced** either **by MoGr**, **CuCD** or **Inermet180**.

Note: Inermet180 not foreseen in the upgrade plan for secondary collimators due to limited robustness, here used in simulation for comparison only.

Cleaning with advanced collimators for HL-LHC scenario: <u>FIRST RESULTS</u>

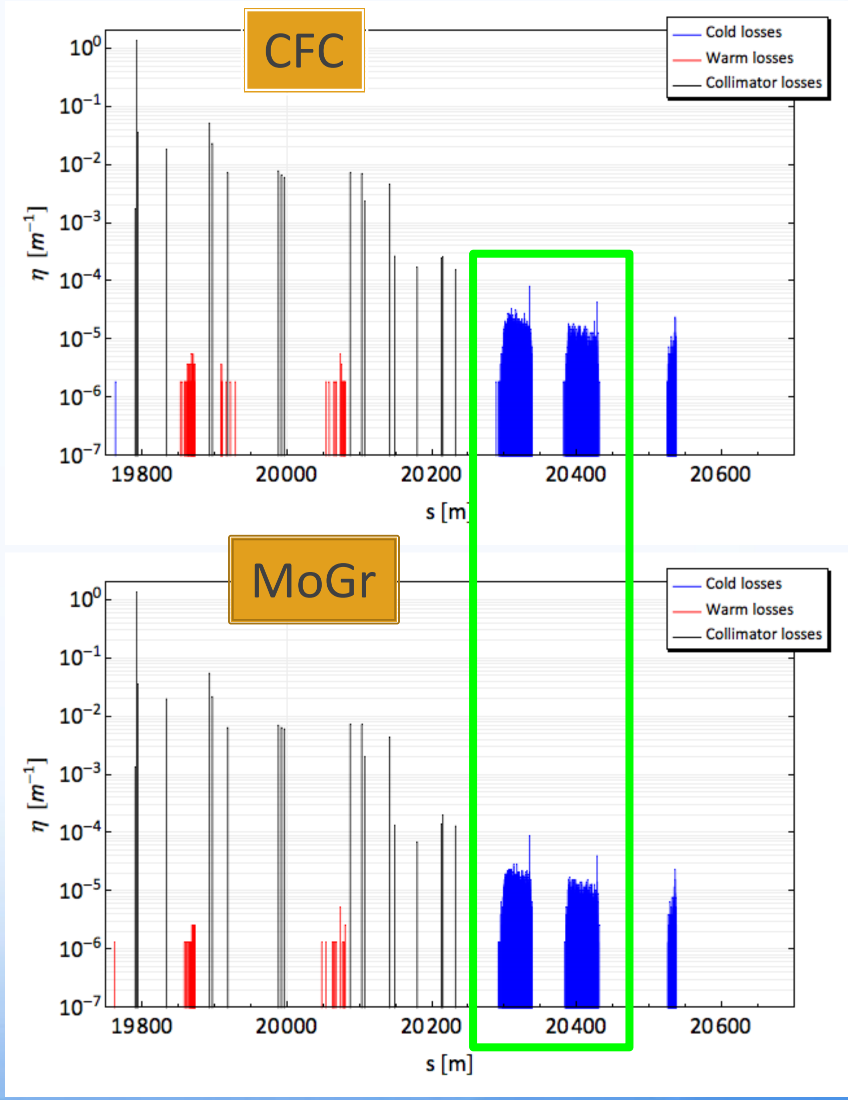
Distribution of particles lost in IR7 for two simulated cases:

- IR7 TCSGs made of CFC
- IR7 TCSGs made of MoGr

IR7 DS → highest loss location

<u>Not largely affected</u> by TCSG materials, losses dominated by single diffractive events in primary collimators.

<u>Note</u>: TCT and absorbers in Inermet180 in both simulated cases

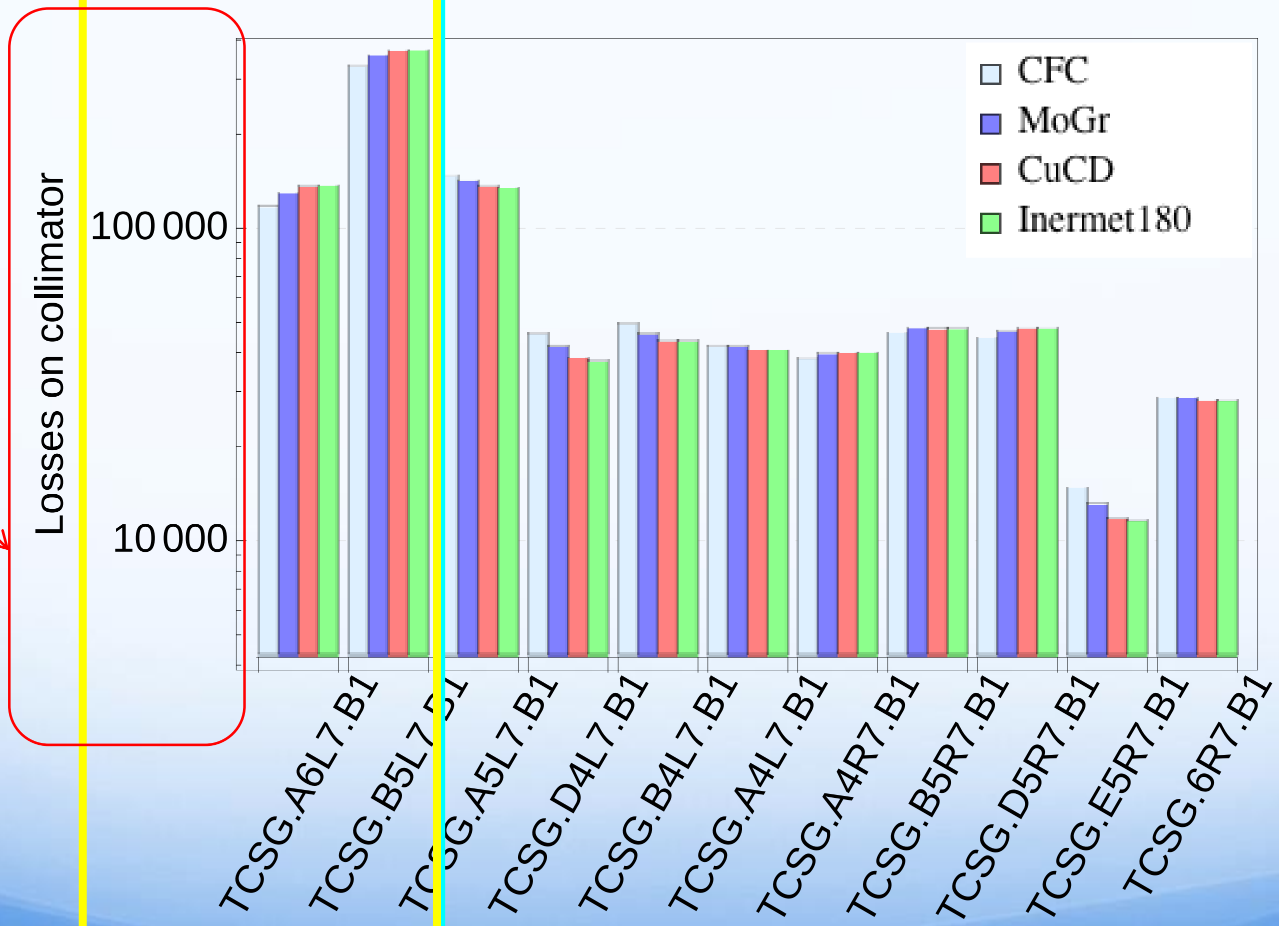


Simulated losses in IR7 secondary collimators for HL-LHC (I)

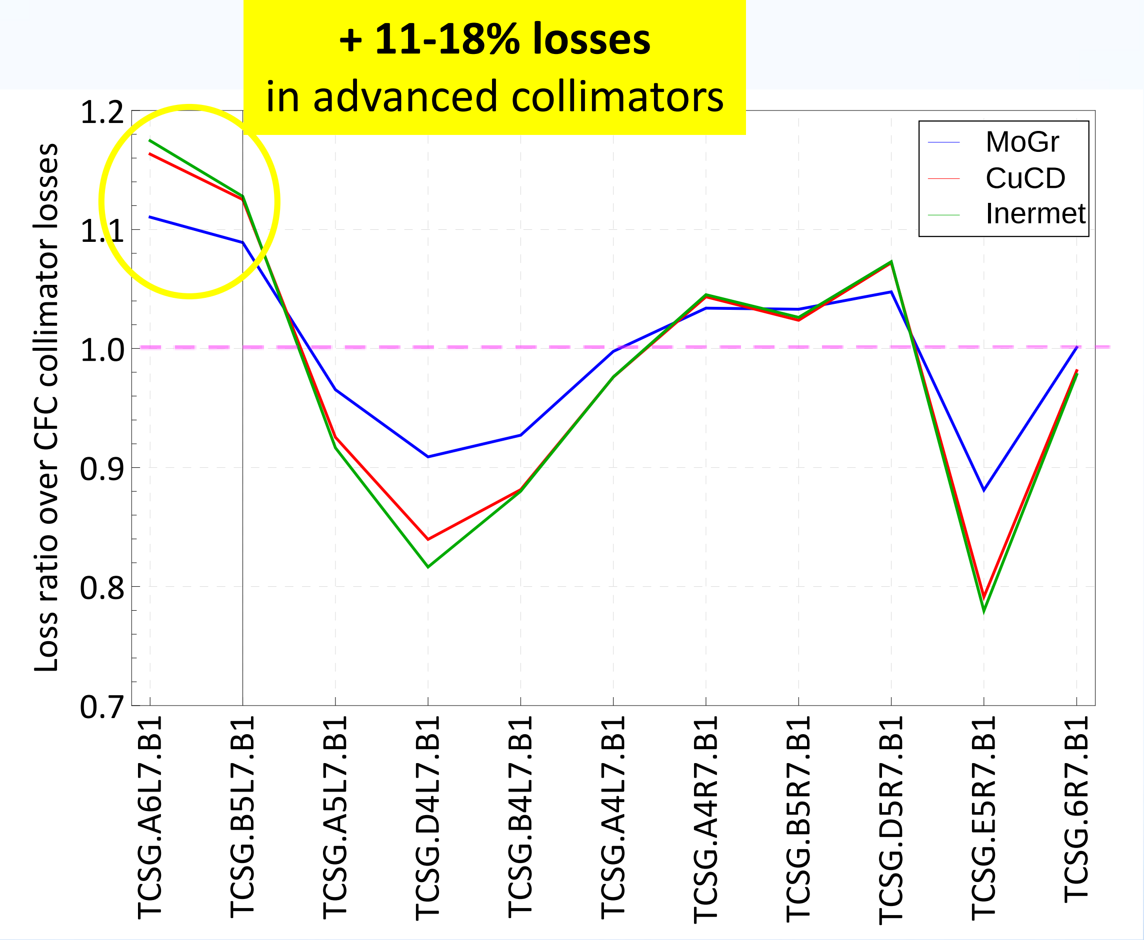
First two TCSG more loaded than CFC case (load ↑ as effective Z ↑)

Less differences in losses for downstream TCSGs, larger fraction of secondary halo absorbed by first two TCSGs

Log scale!



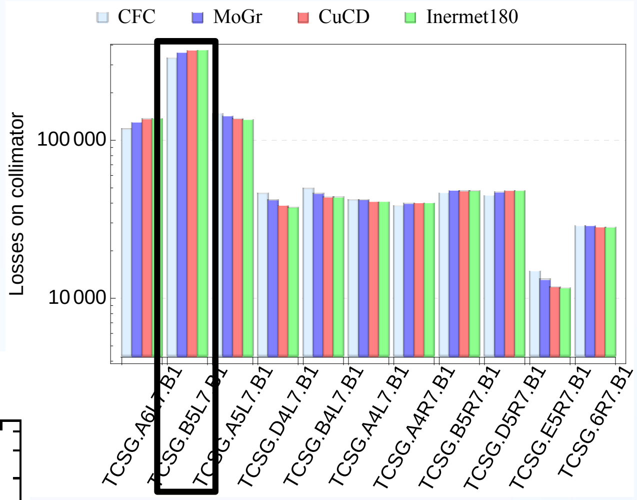
Simulated losses in IR7 secondary collimators for HL-LHC (II)

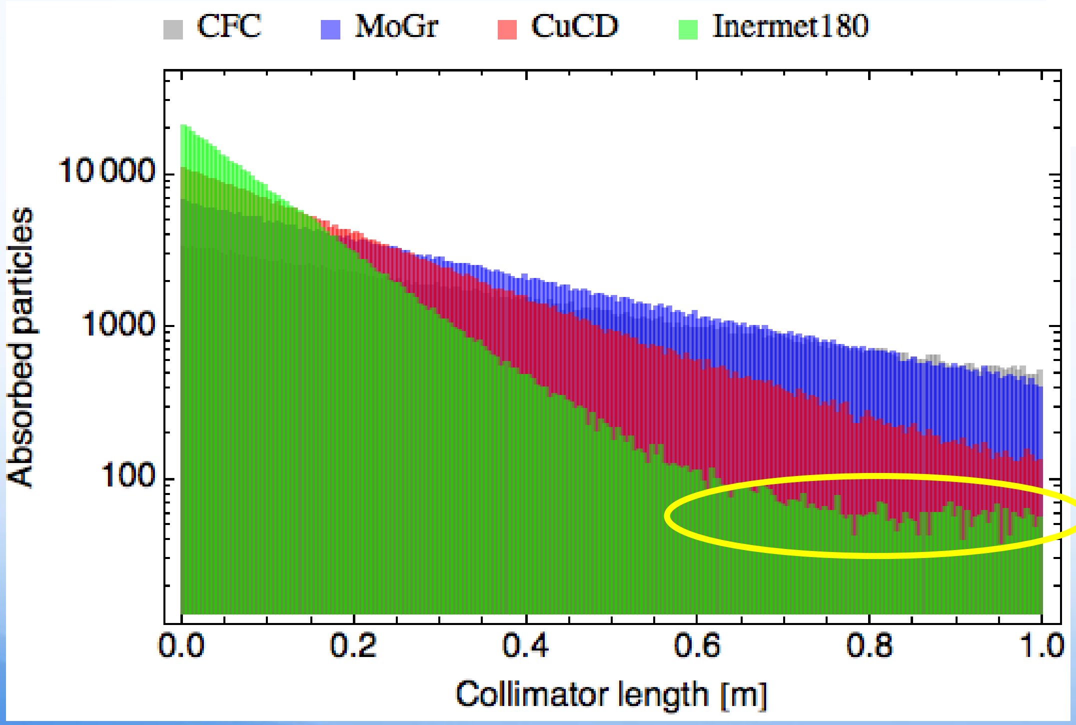


Input for complete simulation chain (Sixtrack → FLUKA → ANSYS) to see if load compatible with present dynamic deformation limits. If confirmed, actual collimator design (with only material inserts replacement) will be still adequate for HL-LHC parameter set.

Simulated losses in IR7 secondary collimators for HL-LHC (III)

Distribution of absorbed particles along the length of the **most loaded** secondary collimator in IR7: **TCSG.B5L7.B1**



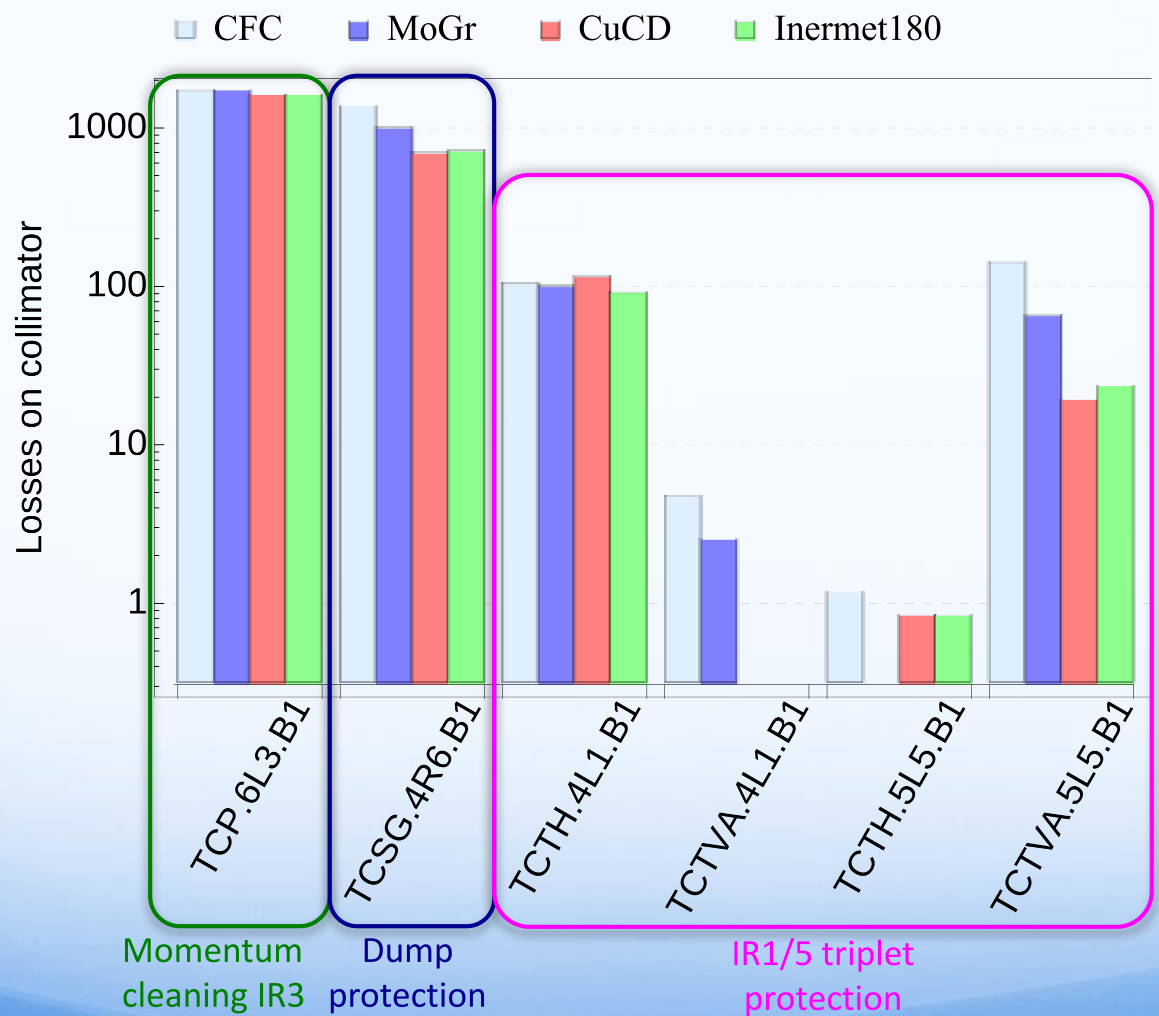


Exponential decrease due to inelastic scattering events, steeper for materials with higher Z, as expected

Due to particles hitting the jaws not on front face but on the side. Not visible for other materials, dominated by EXP trend.

Losses in other LHC collimator locations

Load significantly reduced in other collimators when advanced materials are used.



Summary & Conclusion

- Composite materials successfully implemented in SixTrack and available for simulations of collimation cleaning at the LHC
- Updated collimation material implementation relies on calculation of “effective” material properties of composite materials
- 4 composites added to the existing database: MoGr, CuCD, Glidcop, Inermet180.
- First halo cleaning simulations performed with novel collimator materials:
  - HL-LHC v1.0 optics
  - Present IR7 TCSGs made of CFC replaced by either MoGr, CuCD (or Inermet180, for comparison)
- Preliminary results:
  - Global cleaning inefficiency not affected by replacement
  - Local change of load distribution in TCSGs in IR7
  - TCSG.A6L7.B1, TCSG.B5L7.B1: +11-18% load → still safe? → to follow up with FLUKA
  - Load on other IPs decreases when advanced materials in IR7

Outlook

- Benchmark SixTrack simulation results obtained using advanced collimators with other codes (FLUKA, GEANT4..)

- Simulation of other possible scenarios of interest:
  - HL-LHC v1.2 optics: repeat same case done for HL-LHC v1.0
  - Nominal 7 TeV optics:
    1. Replace all IR7 TCPs with advanced materials, keeping present CFC TCSGs + TCP length scan (60, 40, 20, 5 cm)
    2. Replace selected IR7 TCSGs, the ones contributing more to machine impedance (see "*Collimator impedance measurements in the LHC*", N. Mounet et al., Shanghai, China, 2013), keeping present CFC TCPs and 60 cm length
    3. Include a collimator prototype made of advanced materials to the present LHC layout in SixTrack

Thank you for your attention!

Questions or comments?