Collimation in pp colliders: The FCC case

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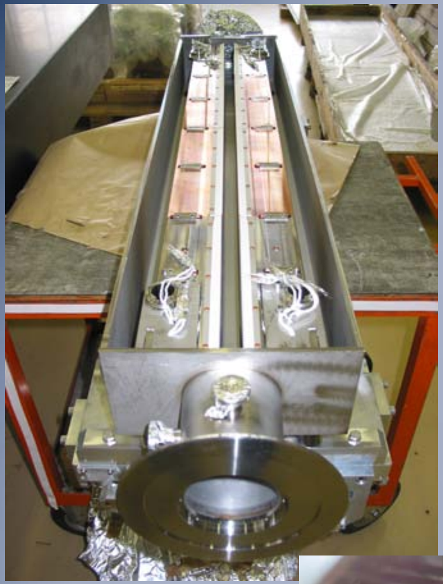
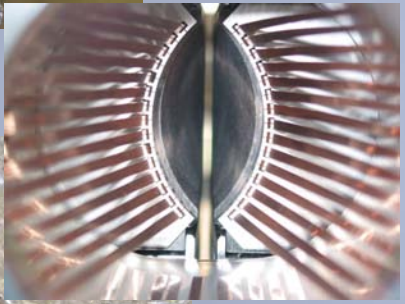
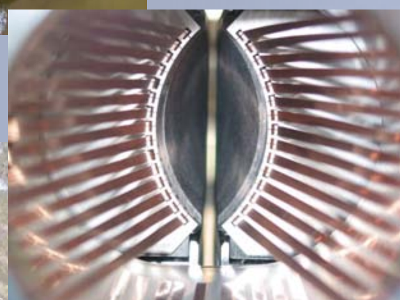
LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE


OUTLINE

- ***Collimation in pp colliders***
  - ***Role of collimation***
  - ***Multistage collimation***
  - ***Parameters and Challenges***
- ***Current Simulation Tools***
  - ***Codes for collimation simulation***
  - ***Benchmarking and Comparison: the FCC case***
- ***New ideas***
  - ***Standard systems***
  - ***Advance collimator concepts***
- ***Summary***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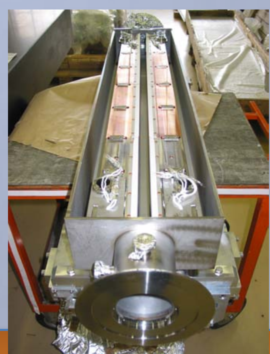
COLLIMATORS IN pp COLLIDERS

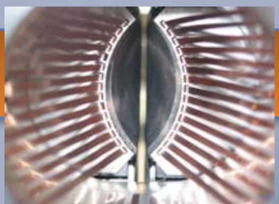
Role of collimation

- ***Protect against***
  - **SLOW continuous unavoidable beam halo loss**
  - **FAST accident scenarios (magnet failures, cavity failures, injection errors, etc)**
- ***Prevent magnets*** ***to quench in SC machines***
- ***Reduce***
  - **RADIATION DAMAGE to the tunnel environment and electronic systems**
  - **EXPERIMENTAL BACKGROUNDS**



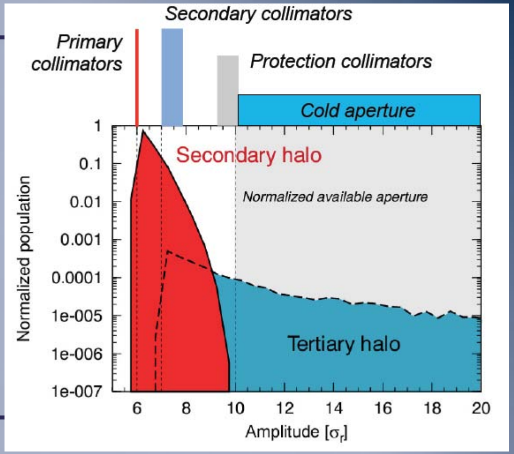




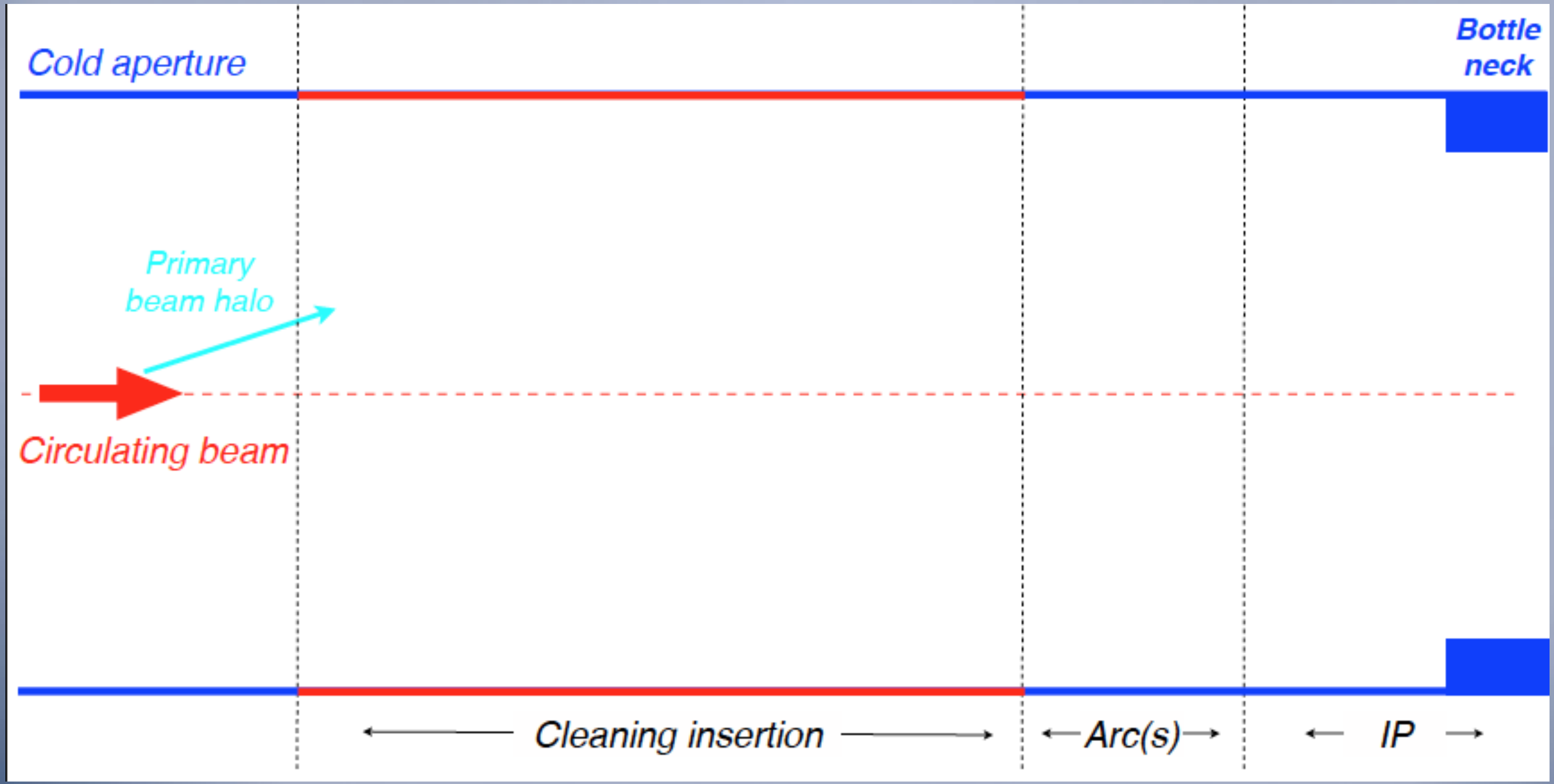


COLLIMATORS IN pp COLLIDERS

Multistage collimation

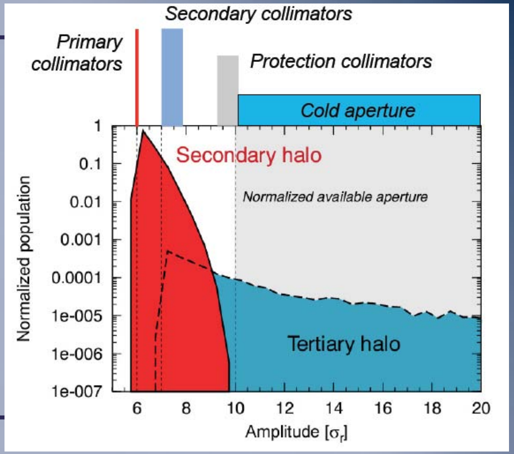


- ***Reminder hierarchy***
  - **PRYMARY, SECONDARY, TERTIARY**



COLLIMATORS IN pp COLLIDERS

Multistage collimation



- ➢ *Reminder hierarchy*
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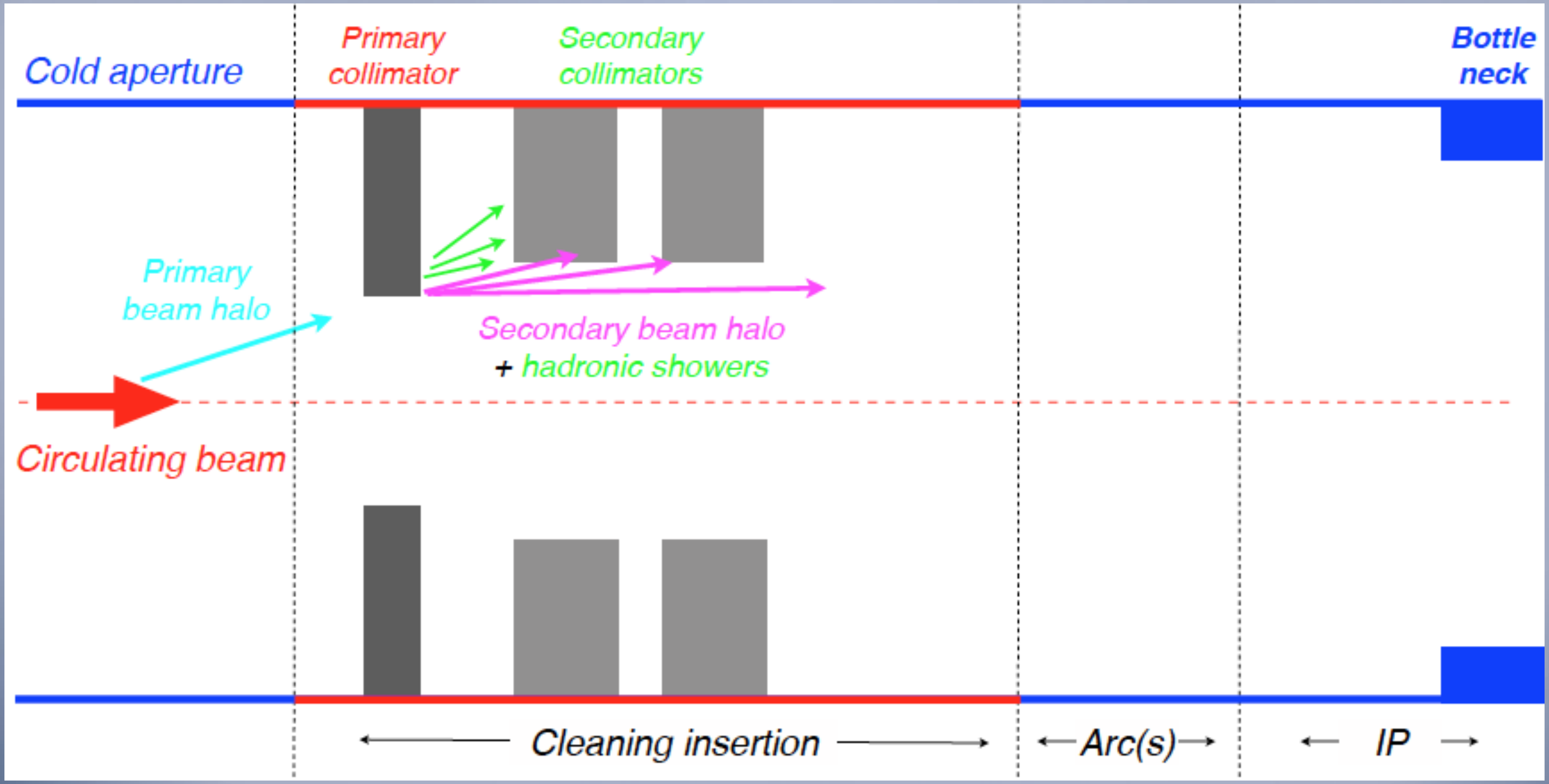
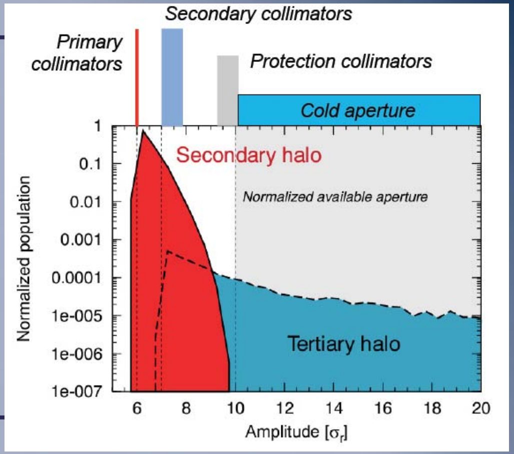


COLLIMATORS IN pp COLLIDERS

Multistage collimation



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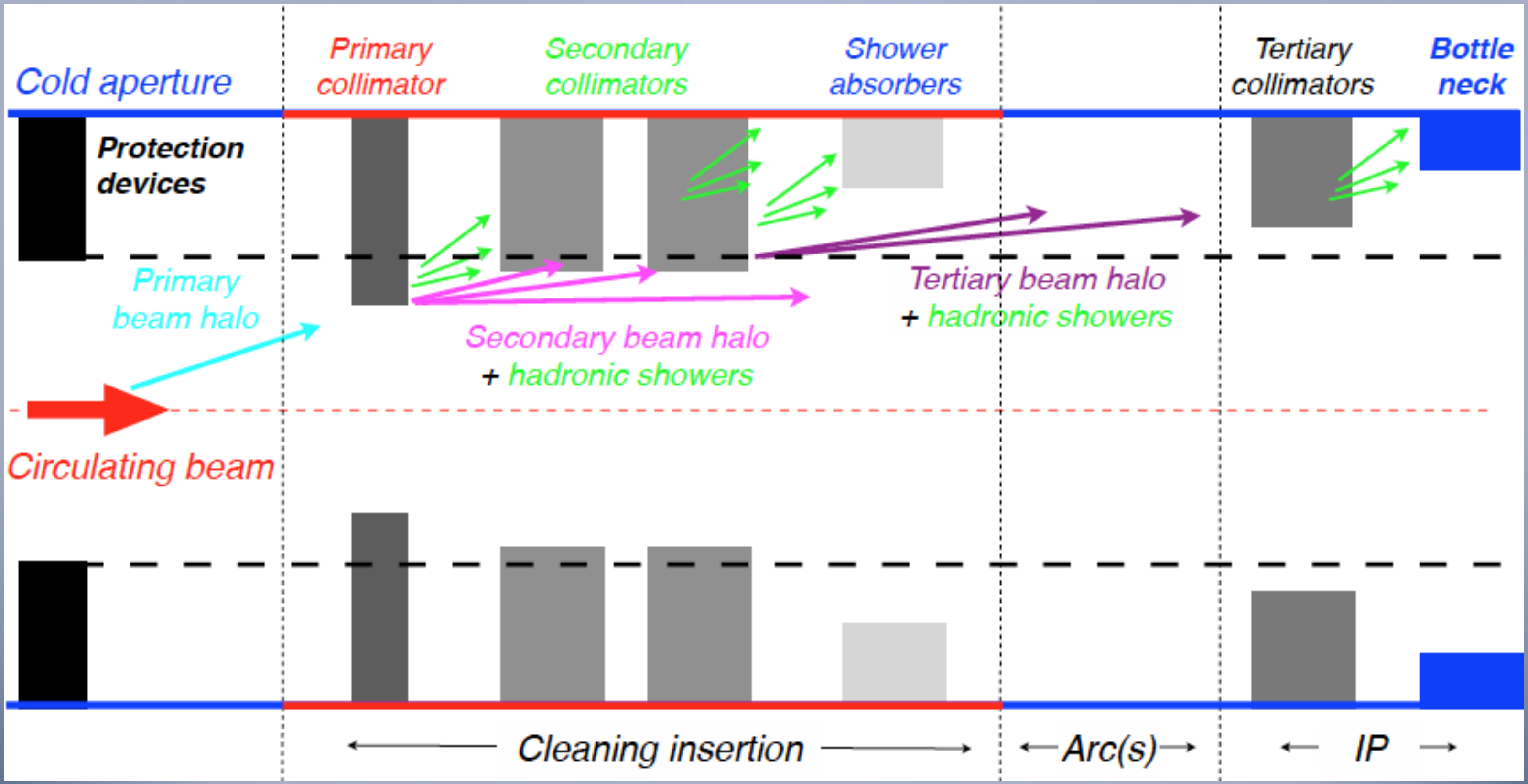
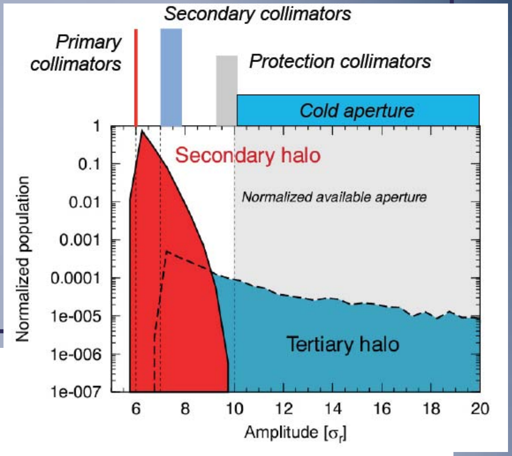


COLLIMATORS IN pp COLLIDERS
Multistage collimation



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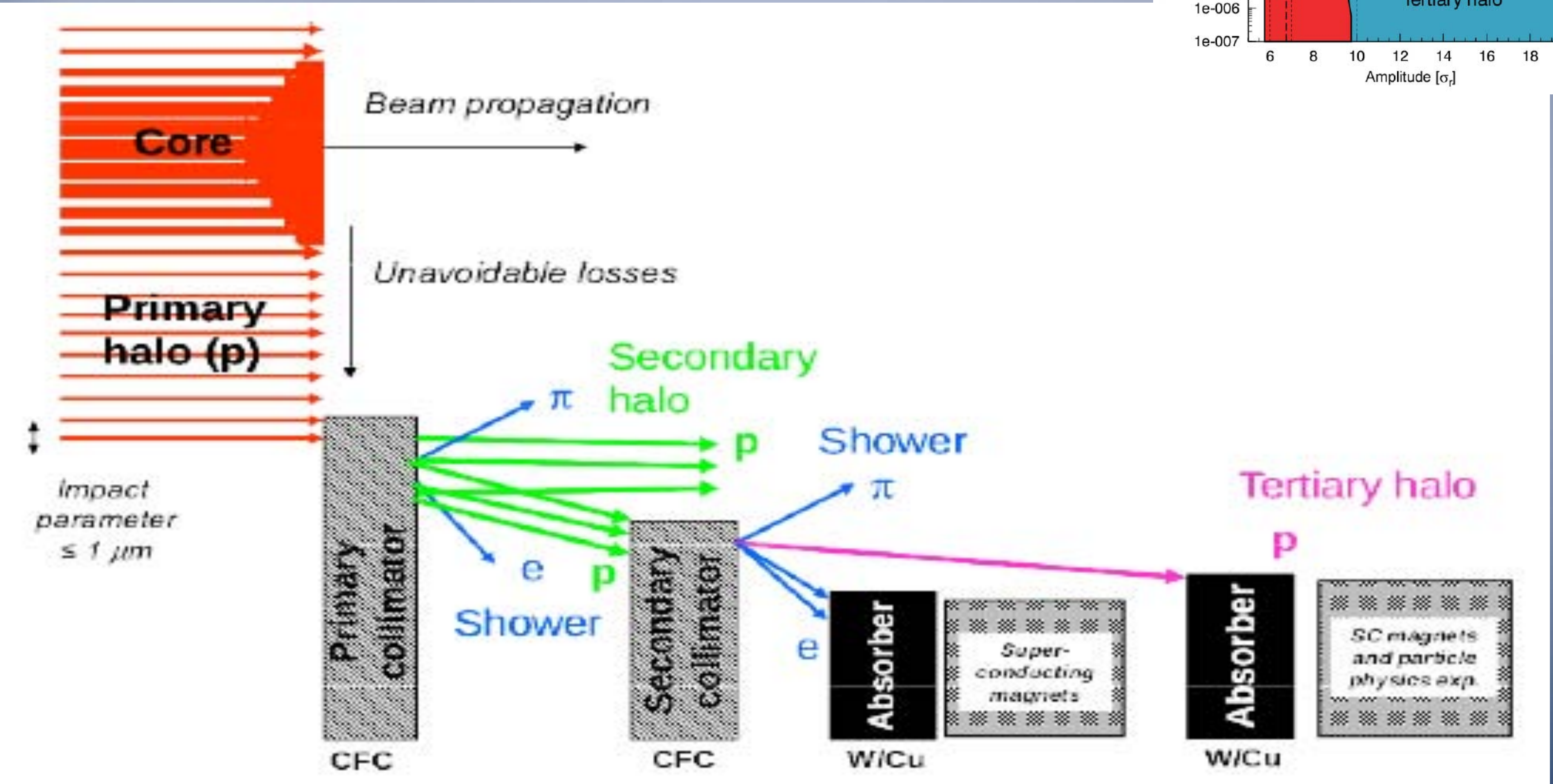


COLLIMATORS IN pp COLLIDERS

Parameters and Challenges

Parameter	LHC	HL-LHC	HE-LHC	SPPC	FCC-hh
Proton energy (TeV)	7	7	12.5-13.5	37.5	50
Number of bunches	2808	2808	2808	10080	10600
Protons per bunch ($\times 10^{11}$)	1.15	2.2	2.5	1.5	1
Stored energy (GJ)	0.36	0.69	**1.4**	**9.1**	**8.4**
Interaction energy (GeV)	115	115	153-159	265	306

$\approx$ Factor 20

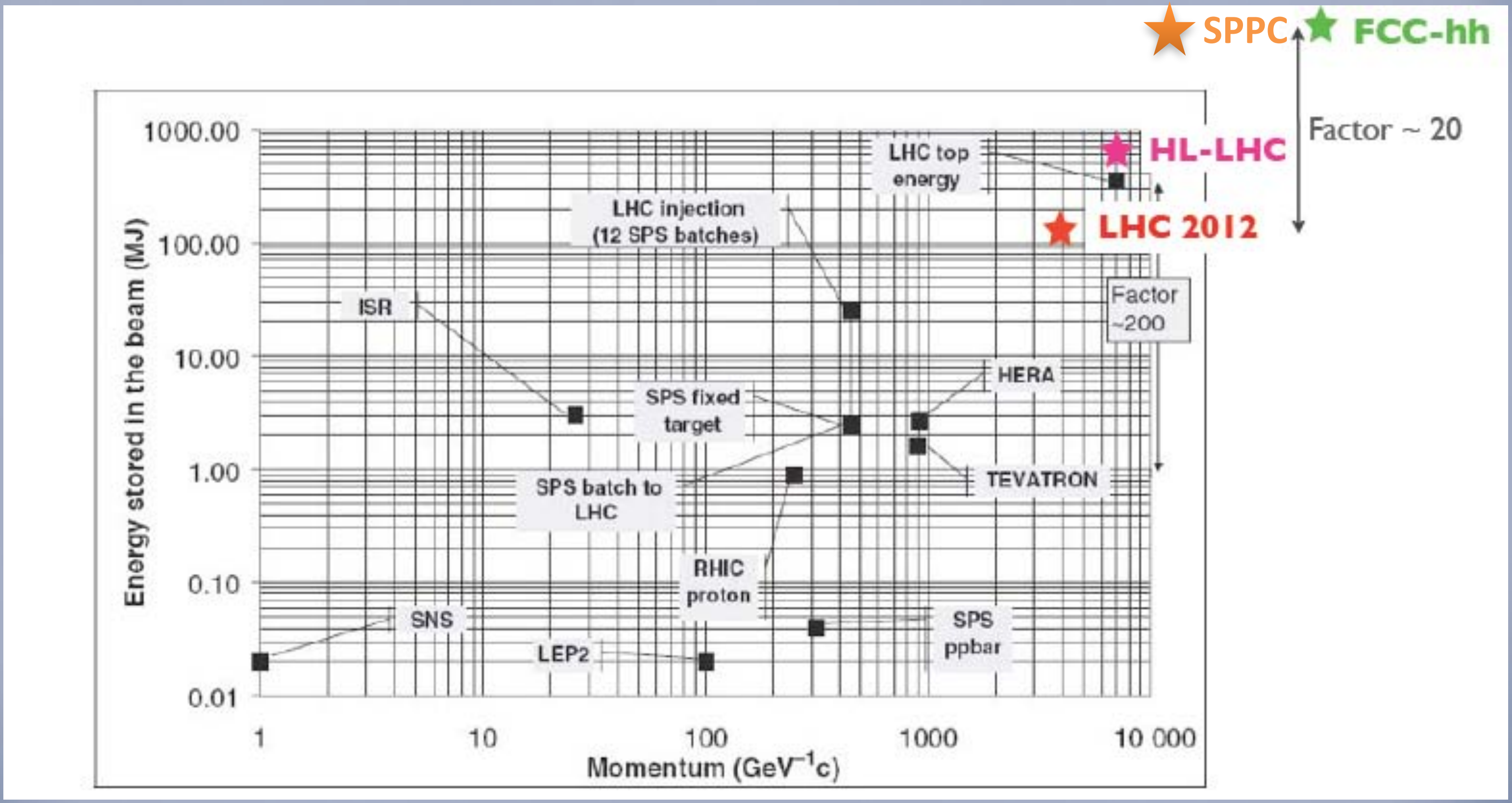
stringent cleaning requirements

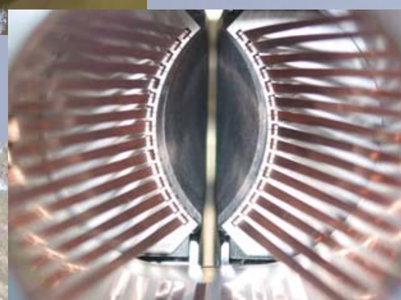
$\approx$factor 2

challenging for collimator material

Interaction energy **is the available energy when a proton collides with a fixed target nucleon in a collimator**

COLLIMATORS IN pp COLLIDERS
Parameters and Challenges





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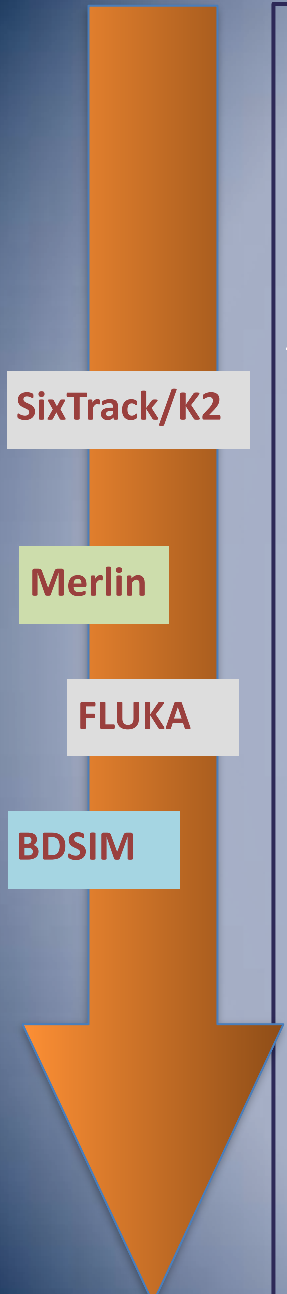
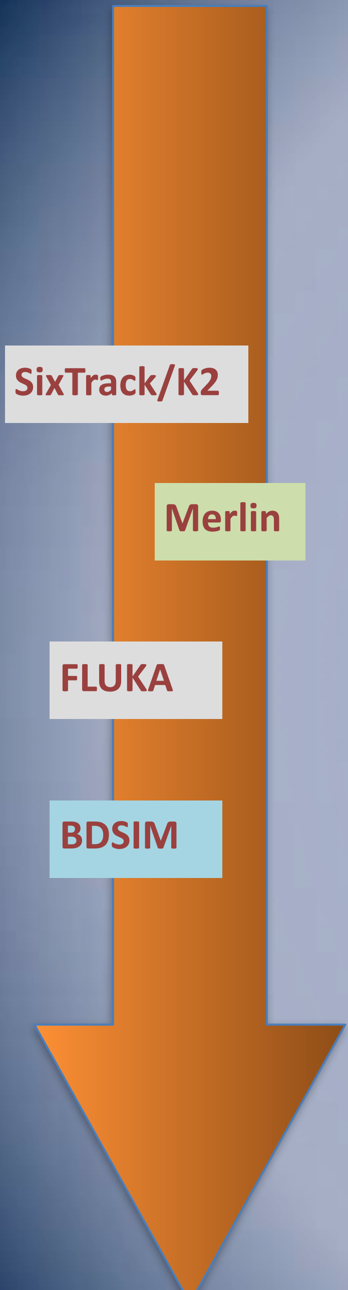


CURRENT SIMULATION TOOLS

Codes for collimation simulations

A number of codes is currently used for collimation simulations:

- **SixTrack/K2** one of the first codes used to design LHC collimation. Simplified models, especially for nucleus modelling. Designed to be fast - only simulates protons. Fortran, open source.
- **Merlin** initially used for ILC, adapted after for LHC. Interaction physics is based off K2, but with a number of enhancements for calculation of the outgoing energy distribution -enhanced ionisation models, single diffraction, and elastic scattering. C++, open source.
- **FLUKA** multipurpose code for radiation transport modelling. Has already been run coupled with a special version of SixTrack for (DPMJET-III). Simulate all relevant interaction physics for collimation, will kill all non-proton secondary particles, and perform a cut on protons at 30% energy loss. C. Full collimator tank and jaw geometry is included. Fortran, closed source.
- **BDISM (Geant4)** radiation transport code similar to FLUKA. Multiple different internal physics models (FTFP_BERT/QGSP_BERT). Similar cuts to FLUKA are used.Simple “block" geometry used for the collimators. C++, open source.



CURRENT SIMULATION TOOLS

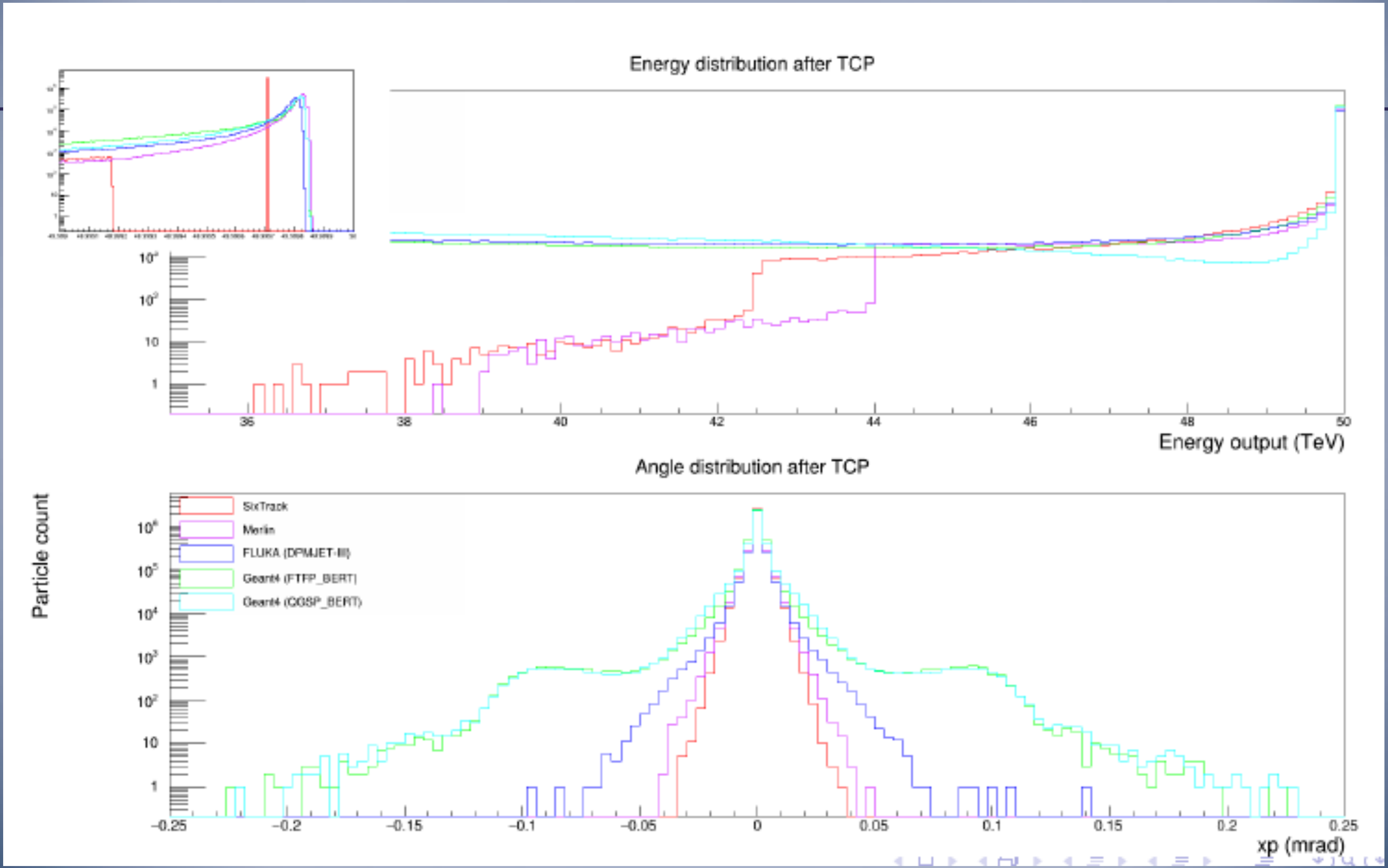
Benchmarking and Comparison

The differences in codes could be for tracking or for physics. In order to solve the problem all the physics models have been implemented in Sixtrack, so that the tracking, post-processing will be the same.

- ***Single jaw test***
  - **Beam impacting the FCC-hh primary collimator**
  - **60cm graphite collimator jaw**
  - **Pencil beam - i.e. a point like distribution**
  - **12.8 million protons at 50 TeV**
  - **Output phase space is dumped by SixTrack after the collimator.**

CURRENT SIMULATION TOOLS

Benchmarking and Comparison



CURRENT SIMULATION TOOLS

Benchmarking and Comparison

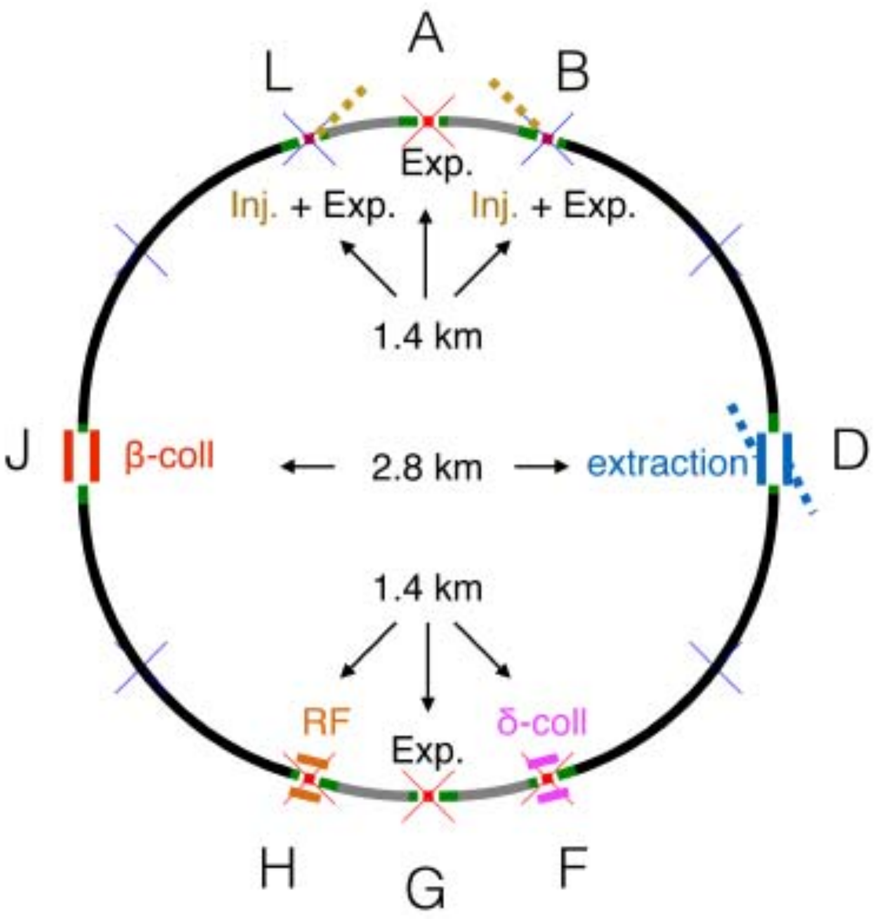
- ***Loss maps***
  - **Each code produces different output distributions after interactions with a collimator.**
  - **How important it this to the operation and effectiveness of the collimation system?**
  - **Test with the current FCC-hh lattice**
  - **200 turns, 12.8 million protons at 50 TeV, with a horizontal betatron halo distribution - a ring in (x, $x_{p)}$ that just touches the horizontal primary collimator jaw, normal distribution cut at 3 sigma in (y, y_p).**

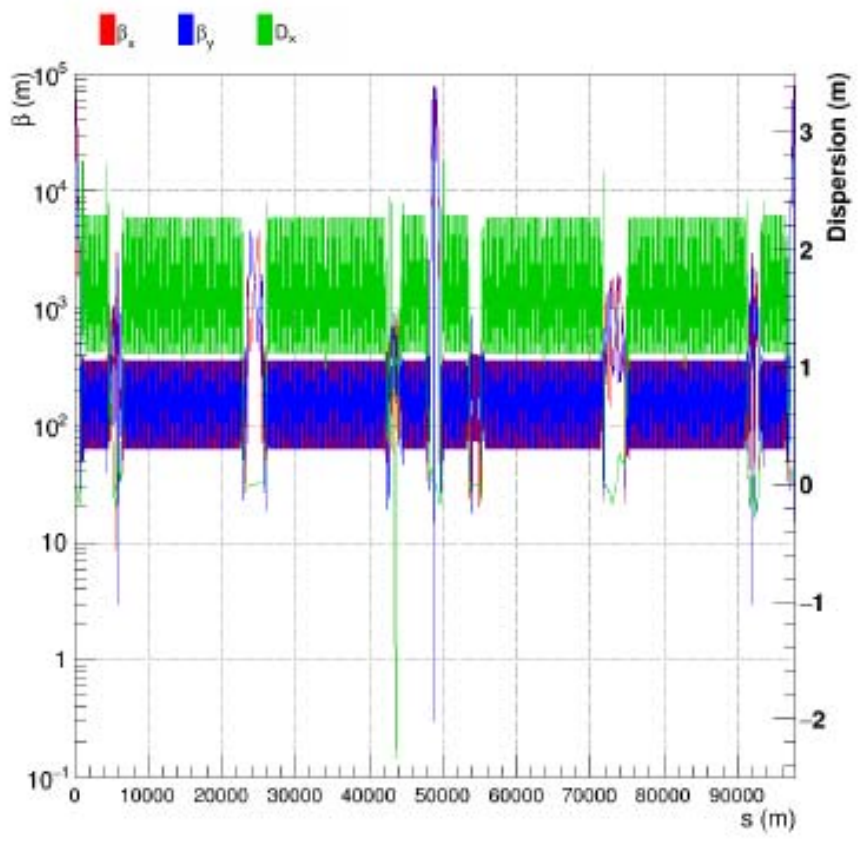
Loss maps show the distribution of losses around an accelerator ring. In an ideal world all losses will be confined to the collimators, and any normal conducting magnets. Losses into superconducting magnets are to be avoided (Quench limits of superconducting magnets are 15 mW cm^{-3}).

CURRENT SIMULATION TOOLS

Benchmarking and Comparison

➢ ***Loss maps:*** **FCC lattice**





CURRENT SIMULATION TOOLS

Benchmarking and Comparison

➢ ***Loss maps:*** **FCC lattice full ring**

CURRENT SIMULATION TOOLS

Benchmarking and Comparison

➢ ***Loss maps:***

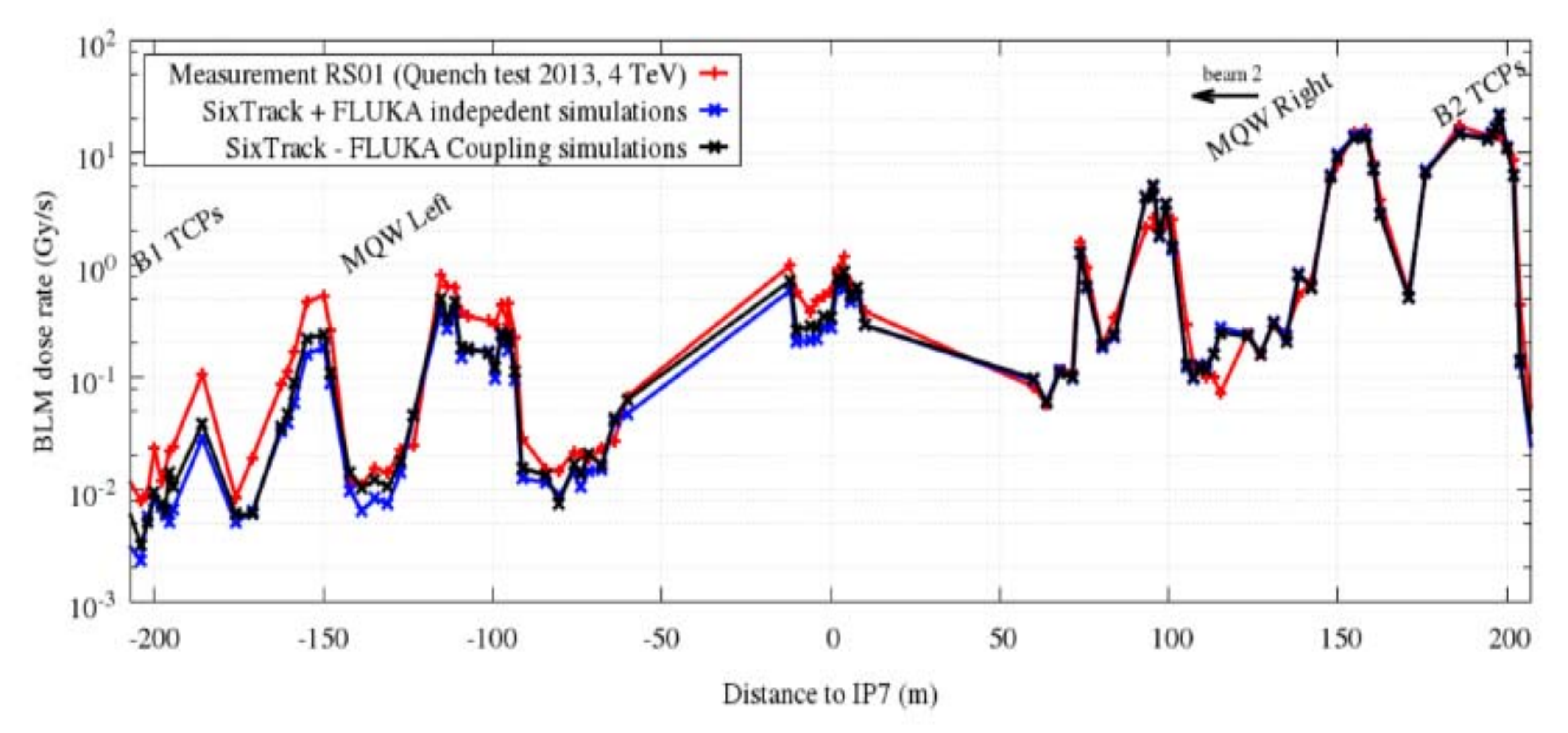
- ➢ **Qualitatively there is an excellent agreement between each code's loss map**
- ➢ **This gives good confidence in our simulation tools**
- ➢ **When performing a more detailed quantitive comparison this changes**

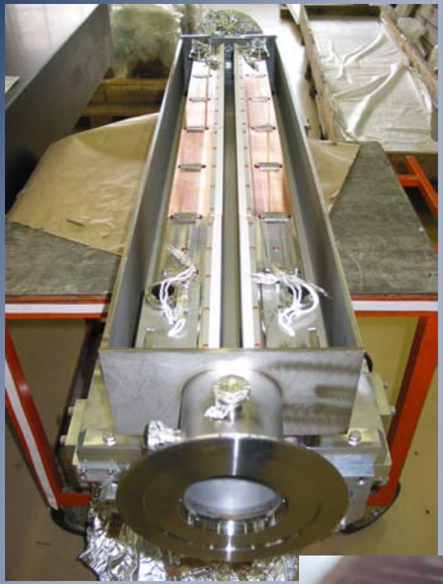
Region	Merlin	FLUKA	G4 FTFP	G4 QGSP
β TCP	1.00	1.01	0.92	0.94
β TCSG	1.00	1.27	1.45	1.32
β TCLA	0.92	1.50	2.37	1.91
β DS1	0.51	0.57	0.68	0.066
β DS2	0.44	0.45	0.52	0.032
β DS3	0.41	0.43	0.51	0.027
β DS4	0.41	0.45	0.47	0.086
δ TCP	0.45	1.39	1.12	0.69
δ TCSG	0.49	1.36	1.24	0.79
δ TCLA	0.51	1.3	1.22	0.92
Total	1	1.05	0.99	0.99

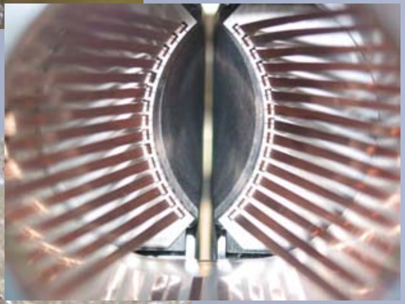
CURRENT SIMULATION TOOLS

Benchmarking and Comparison

➢ ***Experimental data*** **FLUKA shows a good match with the losses measured at the LHC**







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NEW IDEAS

Standard concepts

- ***Strong Dogleg chicane***

  Make the doglegs strong enough to separate and locally catch the Singe-Diffractive events (lower energy particles) or ion debris. Radiation-resistant and heating-tolerant magnets will be needed (off-energy dump)

- ***Combined betatron-energy collimation system***

  See the ideas already implemented in the CPPC lattice

- ***No more hierarchy***

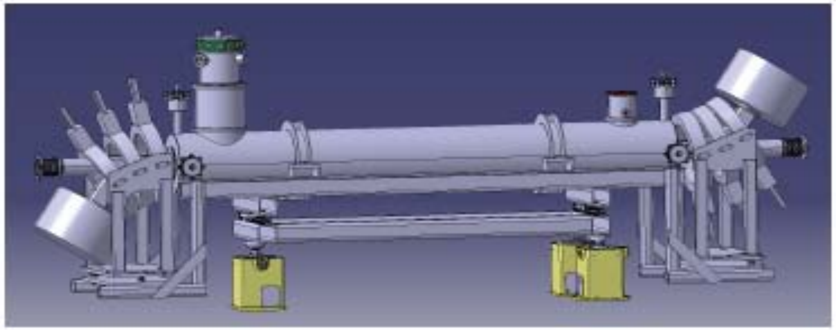
  “Triple Primary Collimator” for tighter phase space coverage separated 45^{o} in order to protect against transient beta beat and orbit perturbation

NEWS IDEAS

Advance Collimator Concepts

Hollow e-lens

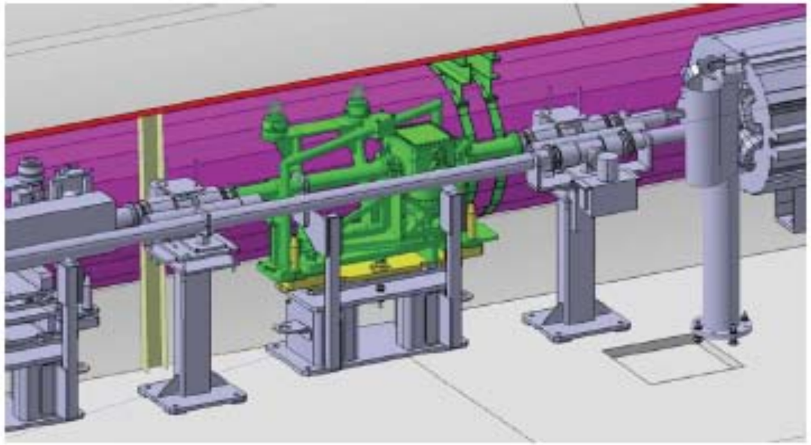
- Hollow electron beam parallel to the p-beam:
  - halo particles see field dependent on (Ax, Ay) plane, while core is unaffected
  - adjusting e-beam parameters can be used as halo scraper



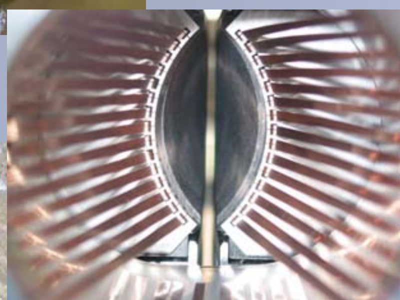
- Expect to be a key asset to control loss rates on collimators
- Working on a design for implementation in LHC in LS2. Decided to build test bench at CERN → also crucial for FCC

Crystal collimation

- Bent crystal can be used for channeling and extracting the beam halo in a controlled way
  - can improve cleaning efficiency
  - reduce impedance: less secondary collimators, larger gaps



- Low intensity beam tests at the LHC in 2015
- Promising for the FCC, but large uncertainties on extrapolations to high energies and several operational challenges.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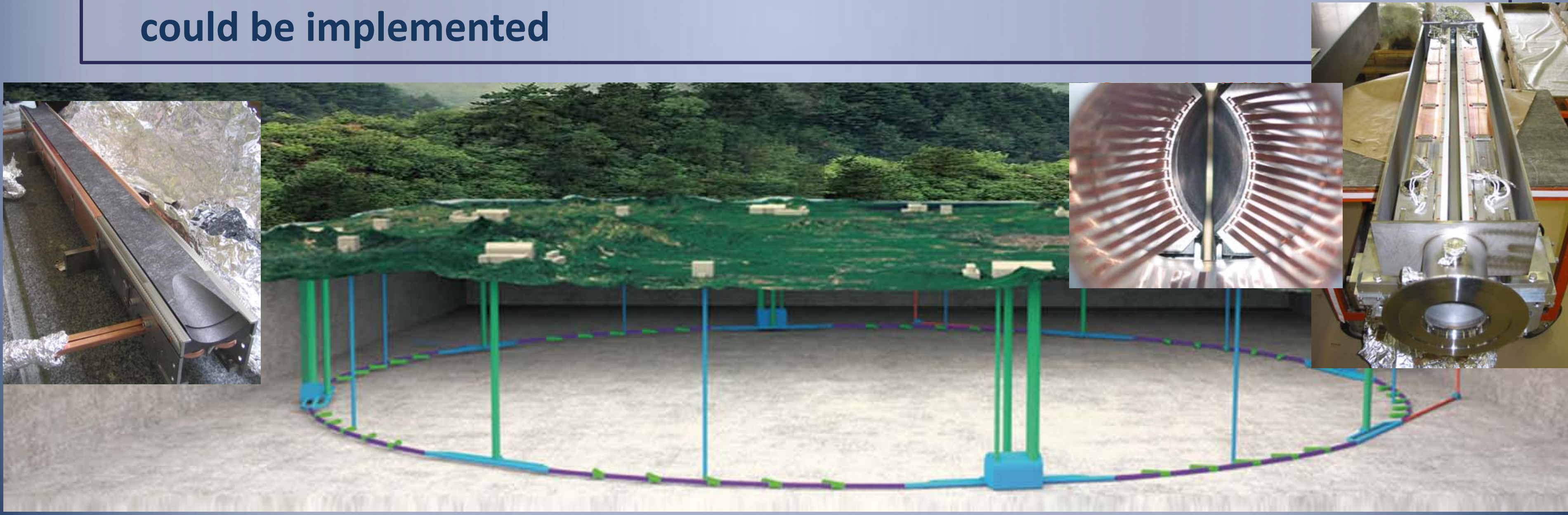
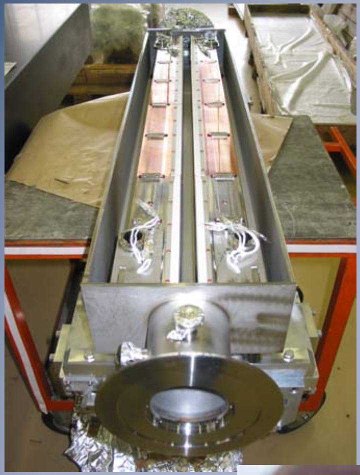
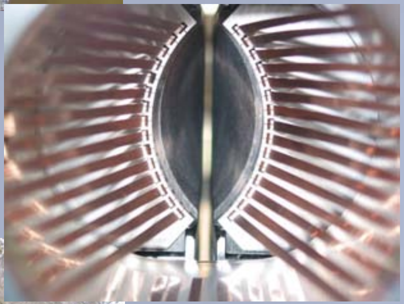
SUMMARY

- In high-beam energy and high-stored beam current collimation is challenging - requires accurate simulations in order to make predictions

- We can now run our simulations with more confidence of the loss locations - all codes generally agree in loss locations, differences are mostly in the magnitude of the losses.

- Future pp colliders are the ground where further ideas and developments could be implemented

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- **Ideas from: R*. Assmann, Y. Zhou…***