FLUKA for the LHC (models and applications) & prospects of integrated FLUKA/Sixtrack simulations

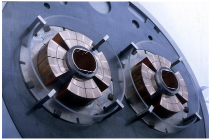
A. Lechner on behalf of the CERN FLUKA team

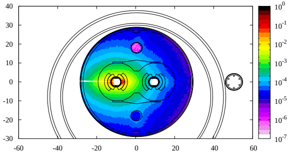
Thanks to everybody who provided some input

3rd Joint HiLumi LHC-LARP Annual Meeting

Nov 15th, 2013

LHC beam-machine interaction studies: from beam losses to secondary shower description



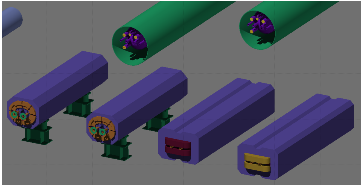


FLUKA is the tool regularly used at CERN to perform LHC beam-machine interaction simulations in the context of

- machine protection
- collimation
- high-luminosity upgrade
- design studies
- radiation to electronics (R2E project)
- activation
- ...

Types of beam losses in the LHC simulated with FLUKA – both, normal and accidental ...

- luminosity production in experiments
- halo collimation
- injection failures
- asynchronous beam dump
- residual gas in vacuum chamber
- dust particles falling into beam
- ...



modular: FLUKA element database (magnets, colls, etc.)

This talk:

- a brief overview of LHC FLUKA geometry models and application examples
- prospects of integrated FLUKA/Sixtrack simulations

Contents

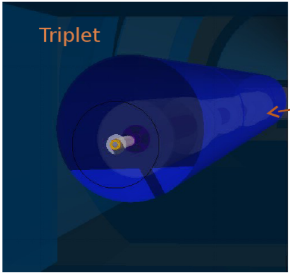
1 Examples of LHC FLUKA geometry models and applications

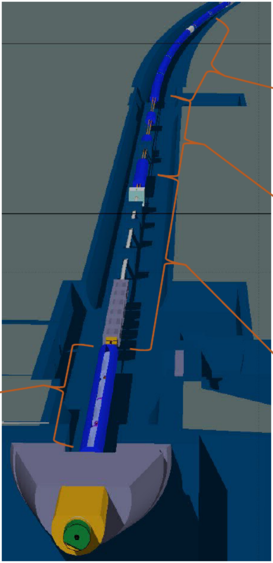
2 Prospects of integrated FLUKA/SixTrack simulations

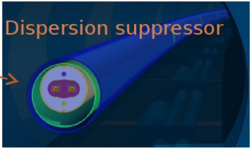
3 Summary and conclusions

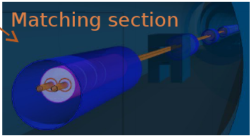
Geometry model of experimental insertions: IR1/5 (high-lumi experiments)

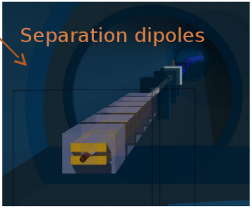
- LineBuilder
  - Python tool for creating FLUKA geometries of accelerator lines based on lattice described in TWISS files
  - Regularly used for LHC applications





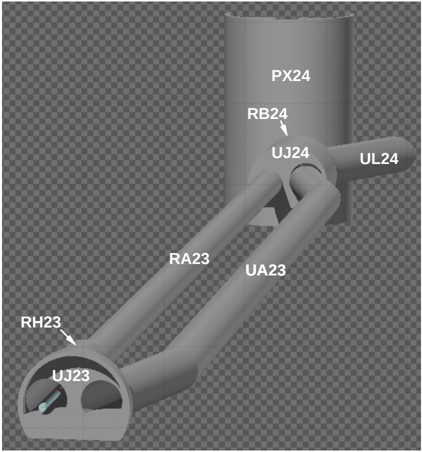


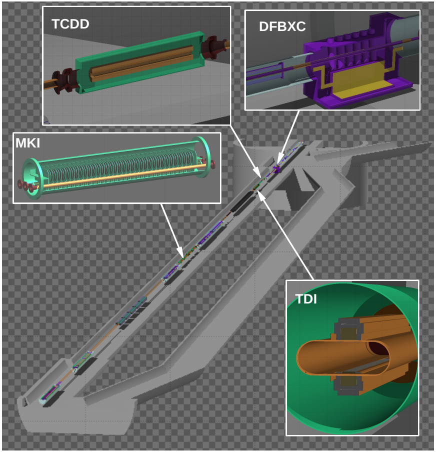




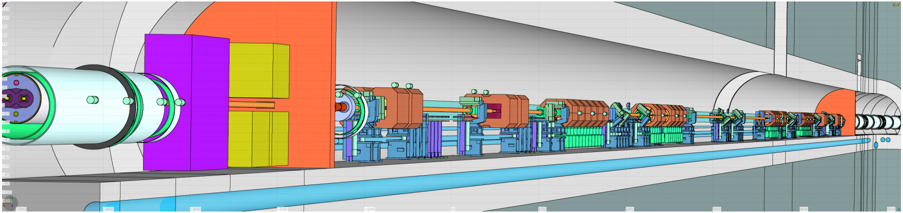
LineBuilder implemented by A. Mereghetti

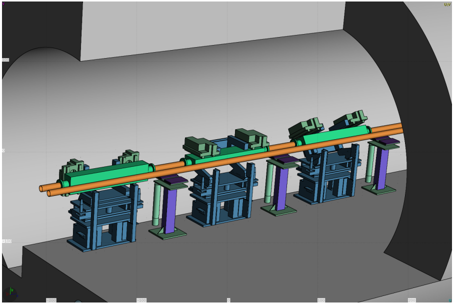
Geometry model of experimental insertions: IR2/8 (lower lumi, but injection regions)

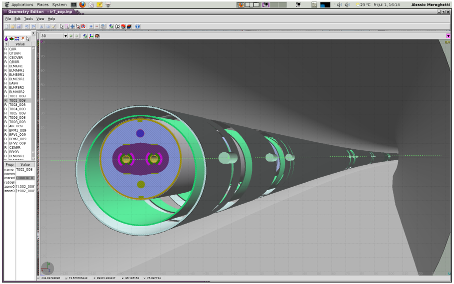




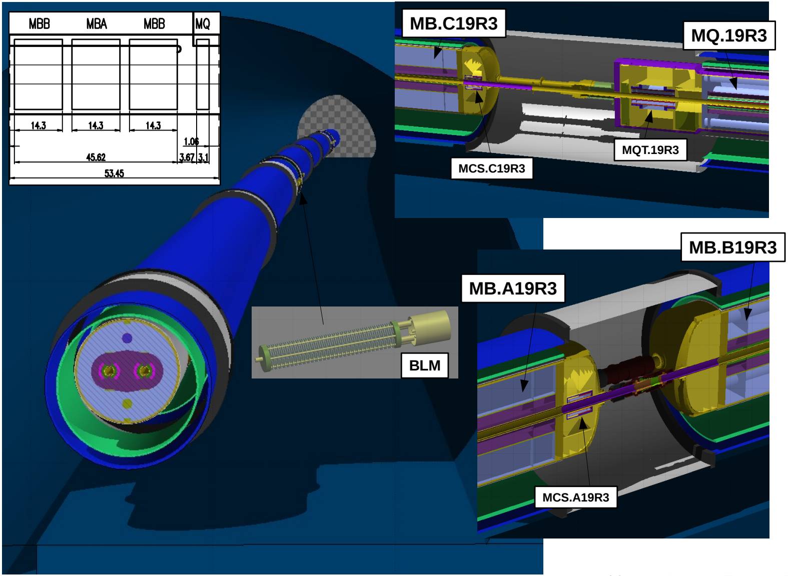
Geometry model of collimation insertions: IR7 and adjacent DS







Geometry model of LHC arc



Optics implementation in FLUKA geometries: orbit accuracy

Generally we achieve an agreement with MAD-X better than few μm over several hundred meters of beamline.

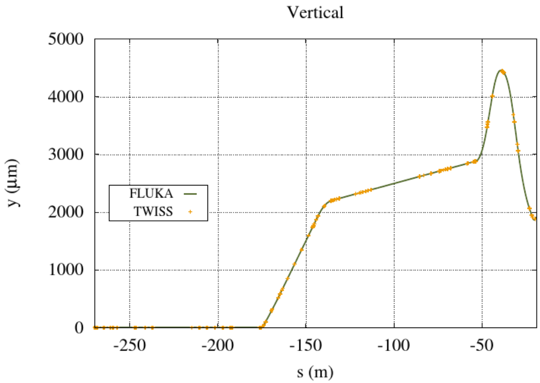


Figure: Orbit verification FLUKA vs MAD-X, vertical plane along IR2 up to the scoring plane. Vertical kicks are applied by MCBYV.5L2 and MCBYV.A4L2.

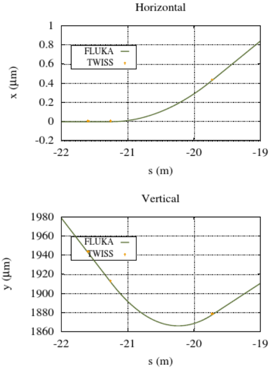


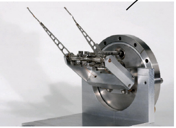
Figure: Orbit verification FLUKA vs MAD-X, horizontal (top) and vertical (bottom) plane in vicinity of MBXWT.1L2. MBXWT.1L2 applies a kick in both planes since the magnet is tilted.

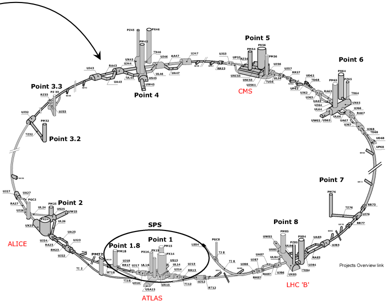
Validation I: BLM response due to losses induced by wire scanner (p@3.5 TeV)

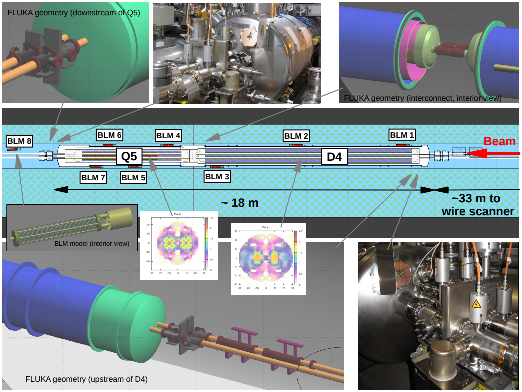
- First years of LHC operation yielded opportunity to perform validation against dose measurements
- Wire scanner test (by CERN BLM team): controlled benchmarking conditions, allowing for an absolute comparison
  $\longrightarrow$ # of impacting protons well known:

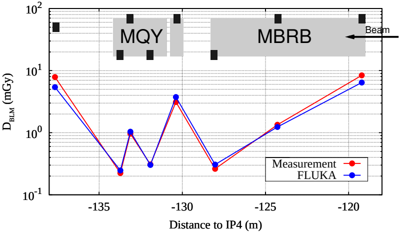
$$N_{prot\ impact} = N_{beam} f_{LHC} d_{wire} / v_{wire}$$

- Figure bottom right: comparison of calculated and measured BLM pattern, **agreement within 30%!**



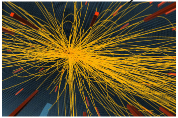


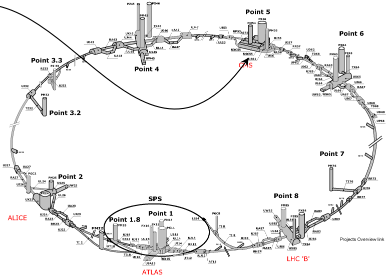


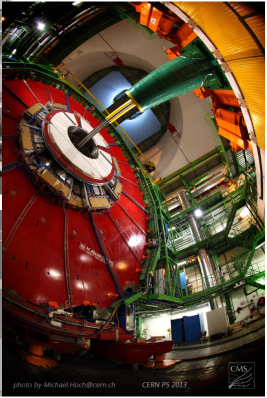


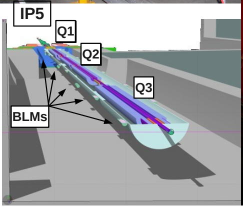
Validation II: BLM response due to collision debris from IP5 (p@3.5 TeV)

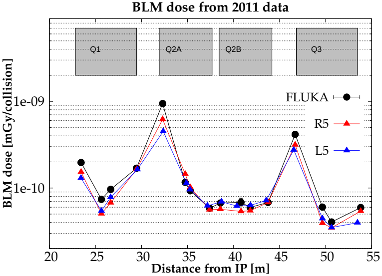
- Another validation study, this time concerning the collision debris from CMS
- Simulation of p-p collisions with DPMJET
- Figure bottom right: Comparison of calculated and measured BLM pattern along the inner triplet in IR5, **generally good agreement!**
- Note: comparison incorporates CMS luminosity measurement and 73.5 mb p-p cross-section (from TOTEM)







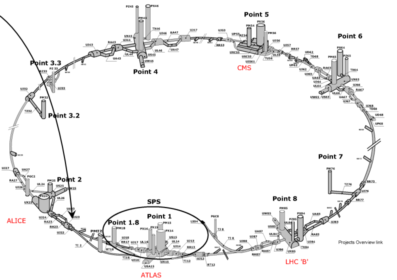


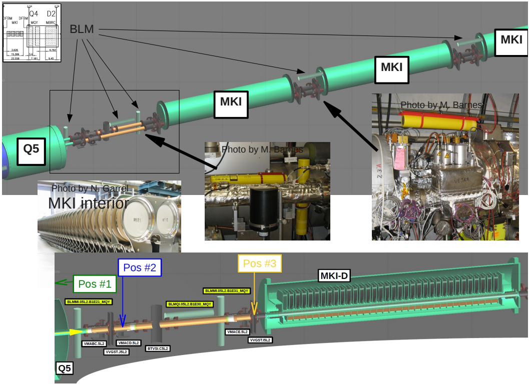


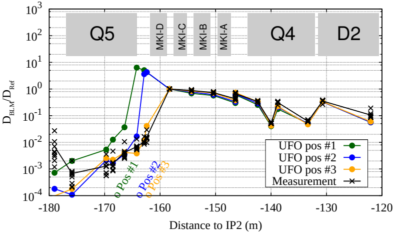
FLUKA study: L.S.Esposito et. al.

Unexpected beam losses: hunting UFOs

- Beam losses due to proton interactions with micrometer dust particles in the vacuum chamber,
  UFOs = Unidentified Falling Objects
- During past years of operation, UFOs have caused several beam dumps
- Figure bottom right: by analysing BLM pattern, FLUKA studies allowed to determine UFO locations around IR2 injection kickers (MKIs)

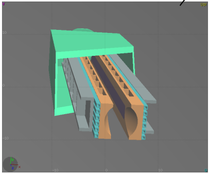


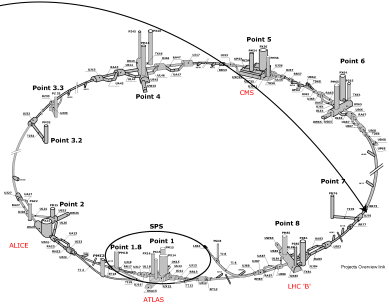




BLM signals due to coll. leakage (DS): SixTrack(©collimation team)+FLUKA (p@4 TeV)

- Machine study: collimation quench test@4 TeV was performed by collimation team in IR7 (see ATS note below)
- **SixTrack loss distribution (input to FLUKA) calculated by collimation team**
- Corresponding FLUKA shower calculations were performed, spanning over several hundred meters (from TCPs until dispersion suppressor)
- BLM signal pattern nicely reproduced (good absolute agreement in warm section!), see Roderik's talk in the same workshop





CERN-ATS-Note-2013-XXX MD

4 June 2013

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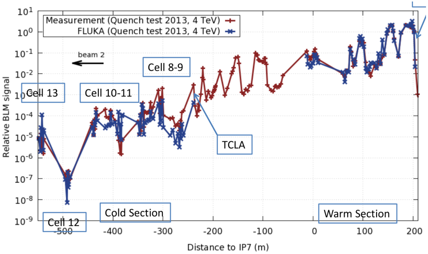
Results proton collimation quench tests MD at 4 TeV

B.Salvachua, R.Bruce, M.Cauchi, D.Deboy, W.Hofle, E.B.Holzer, D.Jacket, L.Lari, E.Nebot, D.Mirarchi, E.Quaranta, S.Redaelli, M.Sapinski, R.Schmidt, G.Valentino, D.Valuch, J.Wenniger, D.Wollmann, M.Zerlauth, CERN, Geneva, Switzerland

Keywords: LHC, collimation, quench, protons, 4TeV

Summary



Contents

1. Examples of LHC FLUKA geometry models and applications
2. Prospects of integrated FLUKA/SixTrack simulations
3. Summary and conclusions

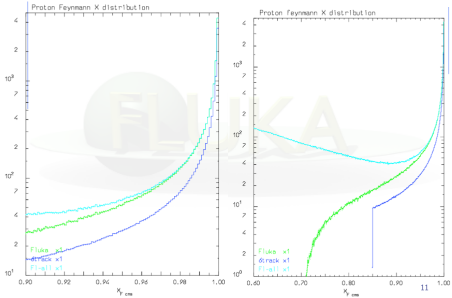
Online coupling of FLUKA with optics tracking codes like SixTrack

What can the coupling provide?

- efficient simulation of beam-machine interactions in a realistic multi-turn approach with a state-of-art account of physics processes

Some motivation behind coupling FLUKA with tracking codes:

- letting each code do what it is designed for (tracking *vs* interactions)
- avoiding simplifications in the modelling of physics processes, in particular for complex interactions like single diffractive scattering or ion interactions
- limiting human intervention (e.g. no need of manually checking files, units, etc) and hence making the overall process less error-prone



Proton Feynman X distribution: comparison of FLUKA (single diffr., single diffr. + inelastic,) and SixTrack (A. Ferrari and V. Vlachoudis, 2009)

Status

- First implementation in 2009 to couple FLUKA with ICOSIM (SPS scraper simulations)
- Meanwhile, coupling with SixTrack was completed (in close contact with SixTrack authors and librarian), recently first feasibility test of integrated LHC simul.

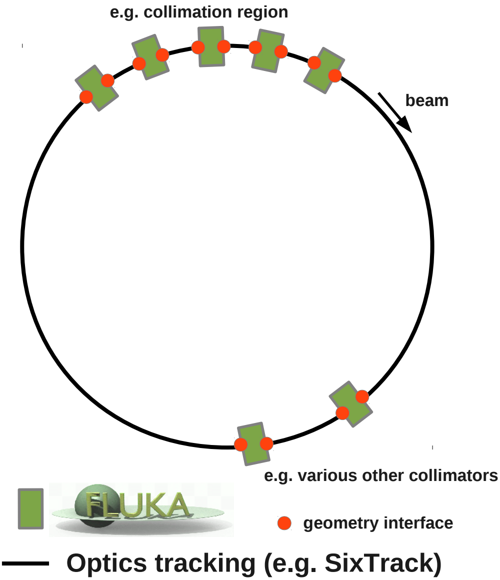
$\rightarrow$ anticipate further development and application together with collimation team

Some more physics prospects for ions

- cross sections are energy dependent and ionization plays for ions a not negligible role in changing their energy along their path in matter
- energy loss evaluation needs a treatment significantly more sophisticated than the Bethe formula adopted in ICOSIM (e.g. including Mott corrections as well as pair production)
- moreover, Landau fluctuations have to be taken into account
- it's not enough to know the probability for generating a given fragment, since its momentum is altered in the interaction; this makes fragments nominally far from the beam rigidity to fall in reality inside the machine acceptance (e.g. tritium)
- all fragments can reinteract in the collimator material

$\longrightarrow$ the coupling would intrinsically overcome all these issues

How does it work?



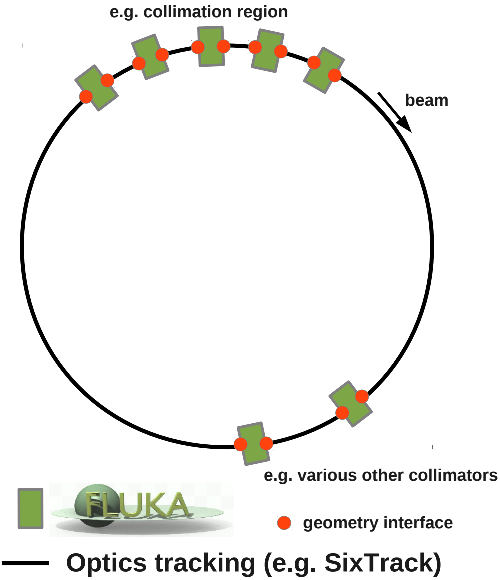
Implementation:

- one process of tracking program
- one FLUKA process
- online communication through a network port (dedicated library and message passing protocol implemented on top of TCP/IP sockets)
- take over from each other at geometry interfaces

Passing particles from one program to the other (and back):

- a portion of the TWISS sequence is labelled for transport in FLUKA
- primary particles are transported turn by turn by the tracking code throughout the lattice
- whenever they reach a labelled section, they are transferred to FLUKA for transport in its 3D geometry and for simulating the interaction with accelerator components
- at the end of a FLUKA insert, they are sent back to the tracking program

How does it work?



Some features of the FLUKA inserts:

- multiple inserts can be used per setup
- may contain geometries of (nearly) any complexity
  - through powerful FLUKA combinatorial geometry
- in particular, one may employ any material
  - e.g. for collimators there is virtually no effort needed to move to new materials
- time-dependent geometries are supported, i.e. geometries may change turn by turn (e.g. interesting for scrapers)

Application to the LHC: limited by CPU time?

FLUKA transport in inserts:

- FLUKA simulations are sometimes perceived to be very CPU-intensive
  - Can certainly be true e.g. for detailed energy deposition studies for large LHC geometries and TeV beam energies where one applies
    - × low secondary production and transport cuts down to MeV energies or less (for a detailed description of shower development, particularly $e^-/e^+,\gamma$),
    - × and many fine-grained scoring meshes (to calculate point-like quantities necessary to estimate e.g. quench levels),
  - *However, it is not true if one applies high cuts and/or if one switches off unnecessary physics processes ($e^-/e^+,\gamma$ prod. and transport, generation of all inelastic collision products and their transport)*
- When applied to the LHC, the coupling is meant to work in the latter mode
  - One focusses on particles which can still propagate in machine (in order to create a lossmap) and not in the local shower development

FLUKA/SixTrack communication:

- Online communication through a network port means no useless I/O via files and hence saves considerable CPU time

First CPU benchmarks on FLUKA cluster with 10^6 particles

Test: Get a loss map *à la* Sixtrack

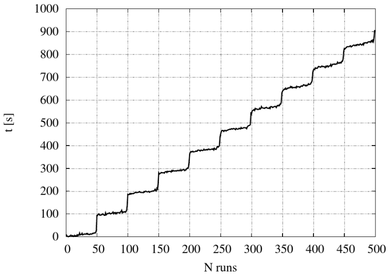
Test setup:

- LHC beam 1, nominal machine
- 39 collimators simulated via FLUKA inserts
- p@7 TeV
- halo of 0.0015σ width, above 6.3σ

settings → not meant as test of physics results but as a feasibility study wrt CPU time

FLUKA physics settings:

- 1 TeV cut
- no simulations of e^-, e^+ and γ
- single scattering
- if deep inelastic nuclear interaction occurs, particle is dumped (no secondaries transported)
- if single diffr. interaction occurs, information about interaction is stored in file and particle is kept for further tracking



Cumulated CPU time for 10^6 particles tracked over max. 100 turns (steps are due to the time delay on the queue system)

CPU times:

- Simulation of 500 jobs, each of which tracks 2000 particles over (max.) 100 turns
- Average CPU time per job was ∼10 sec
- With some time overhead due to queue system, the test took roughly a quarter of an hour for 10^6 particles on one CPU
  → 6 million partices would take roughly 1.5h

Contents

1 Examples of LHC FLUKA geometry models and applications

2 Prospects of integrated FLUKA/SixTrack simulations

3 Summary and conclusions

Summary and conclusions

FLUKA is commonly used at CERN for beam-machine interaction simulations

- a comprehensive set of FLUKA geometry models of various LHC regions have been implemented over years (continously improving)
- first years of operation allowed to validate FLUKA simulations in the TeV energy regime against beam loss monitor measurements
- for controlled loss scenarios (e.g. wire scanner test 2010, ADT quench test 2013 (not shown)), we were able to achieve an absolute agreement better than 30% in BLMs downstream of loss location (Note: accurate positioning of BLM in simulations can be crucial)

Prospects of integrated FLUKA/SixTrack calculations

- Offers realistic multi-turn simulations including sophisticated physics models (particularly for single diffractive scattering and ion interactions)
- CPU time appears not to be an issue for application to LHC (as shown in first feasibility test)
- → anticipate further development and application together with collimation team