SixTrack project
status, runtime environment and new developments

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Features Highlights

- SixTrack is fast single particle tracking code used to simulate charged particle trajectories in synchrotrons for many turns or many particles or both.
- It contains symplectic models for drift, thick dipole and quadrupoles, thin multipoles and solenoids, accelerating cavities, (frozen) beam-beam interactions, linear and non-linear deflecting cavities, wire, hollow e-lens, scattering models for collimators, beam gas interaction.
- It can be interfaced with Fluka, Geant4, ROOT.
- It also computes:
  - Phase space observables from tracking data: Linear and non linear invariants, Lyapunov analysis, tunes;
  - Optics functions using 4D, 5D, 6D Mais-Ripken formalisms;
  - High order transfer maps, normal forms;
- It supports Linux, Windows, MacOs, FreeBSD, NetBSD, OpenBSD, GNU hurd, on x86, amd64, ARM, ARM, PPC using gfortran, intel, nagfor compilers in a numerically portable way for all combinations.
- It originates from RaceTrack and it has been developed at CERN in the last few decades mainly by F. Schmidt and E. Mcintosh.
- It is open source and developed also outside CERN.

What is used for at CERN

SixTrack is <u>used to</u>:

- Evaluate impact of magnetic field imperfection in the LHC, HL-LHC, HE-LHC, FCC and specify target for field quality.
- Evaluate the impact of weak-strong beam-beam effect in the LHC, HL-LHC, FCC with or without machine imperfections.
- Simulate losses and collimation efficiencies and background in the SPS, LHC, HL-LHC. FCC
- Simulate failure scenarios (e.g. crab cavities in the SPS and HL-LHC).

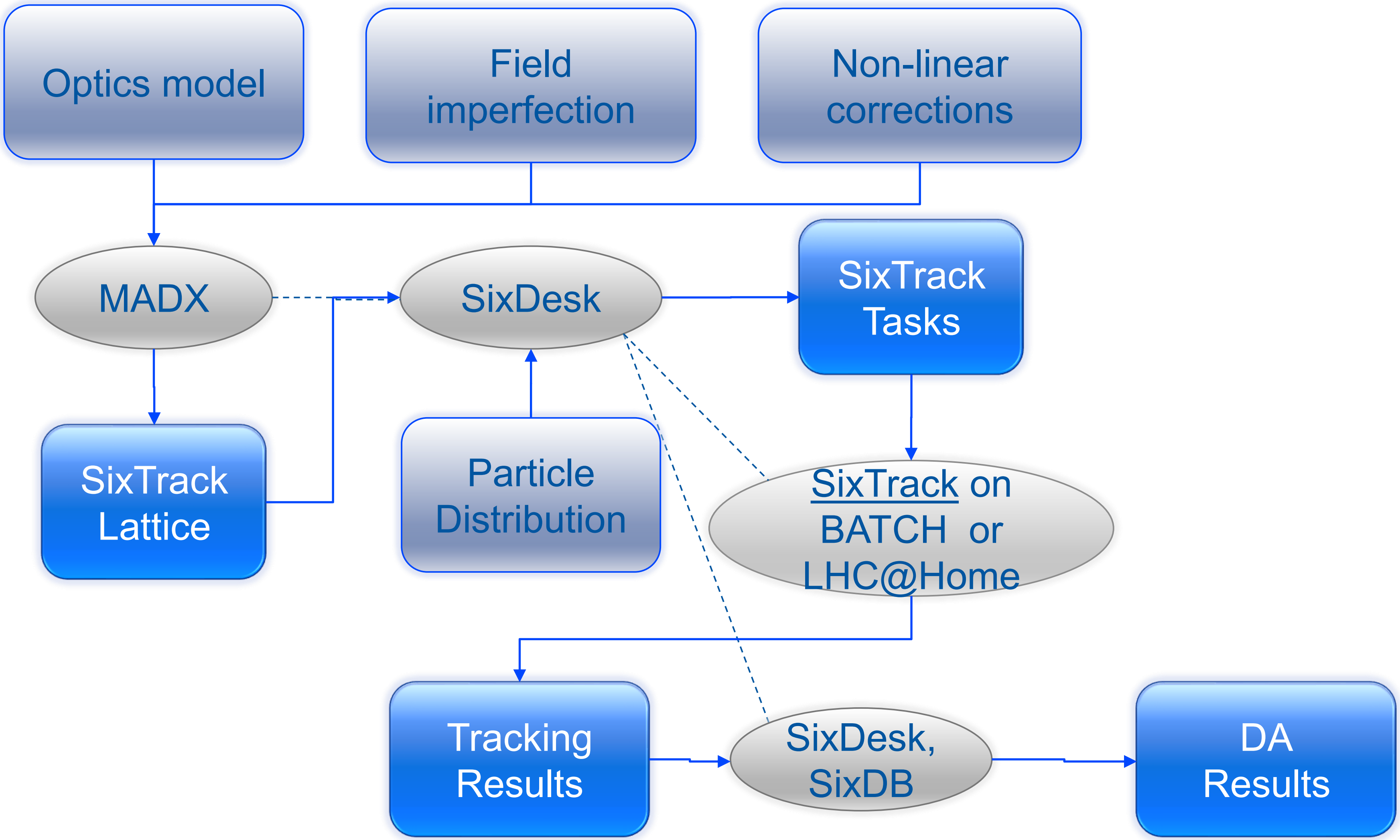
SixTrack is <u>used whenever</u>:

- the speed of MadX is not sufficient
- the flexibility and accuracy of MadX/PTC is not needed

SixTrack <u>main value</u> is:

- in the integration in the CERN BATCH and LHC@Home environment (using the SixDesk runtime environment) and in the toolchains of many different LHC studies.

LHC Dynamic Aperture Studies (DA) pipeline



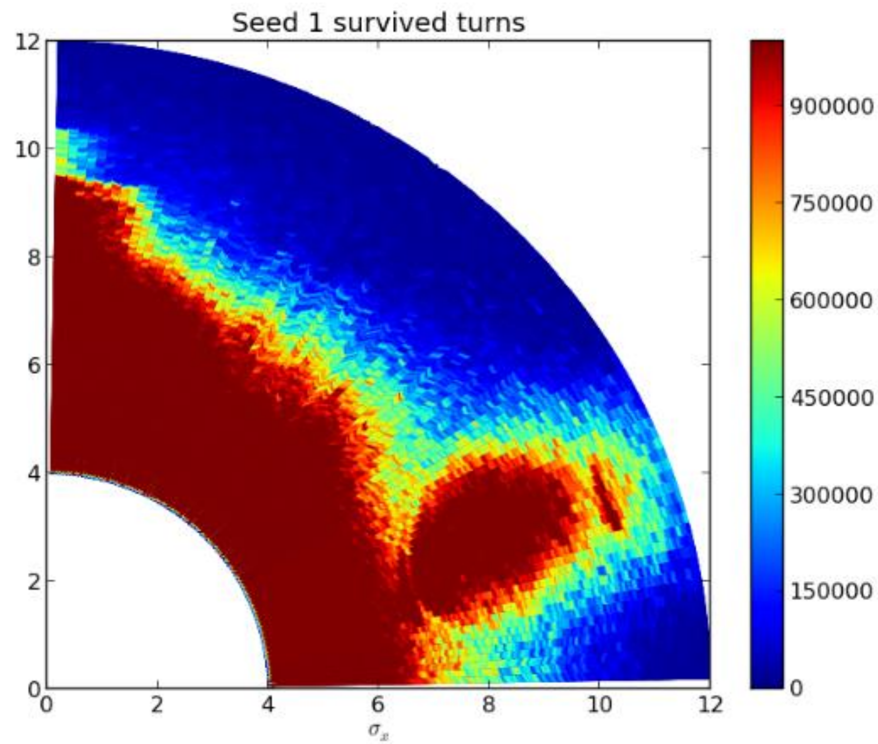
Example of usage

Example of an LHC simulation:

- 30k initial conditions;
- 10^7 turns;
- 20k beam line elements
- 4k high order multipoles
- 200 beam-beam interactions

Code speed:

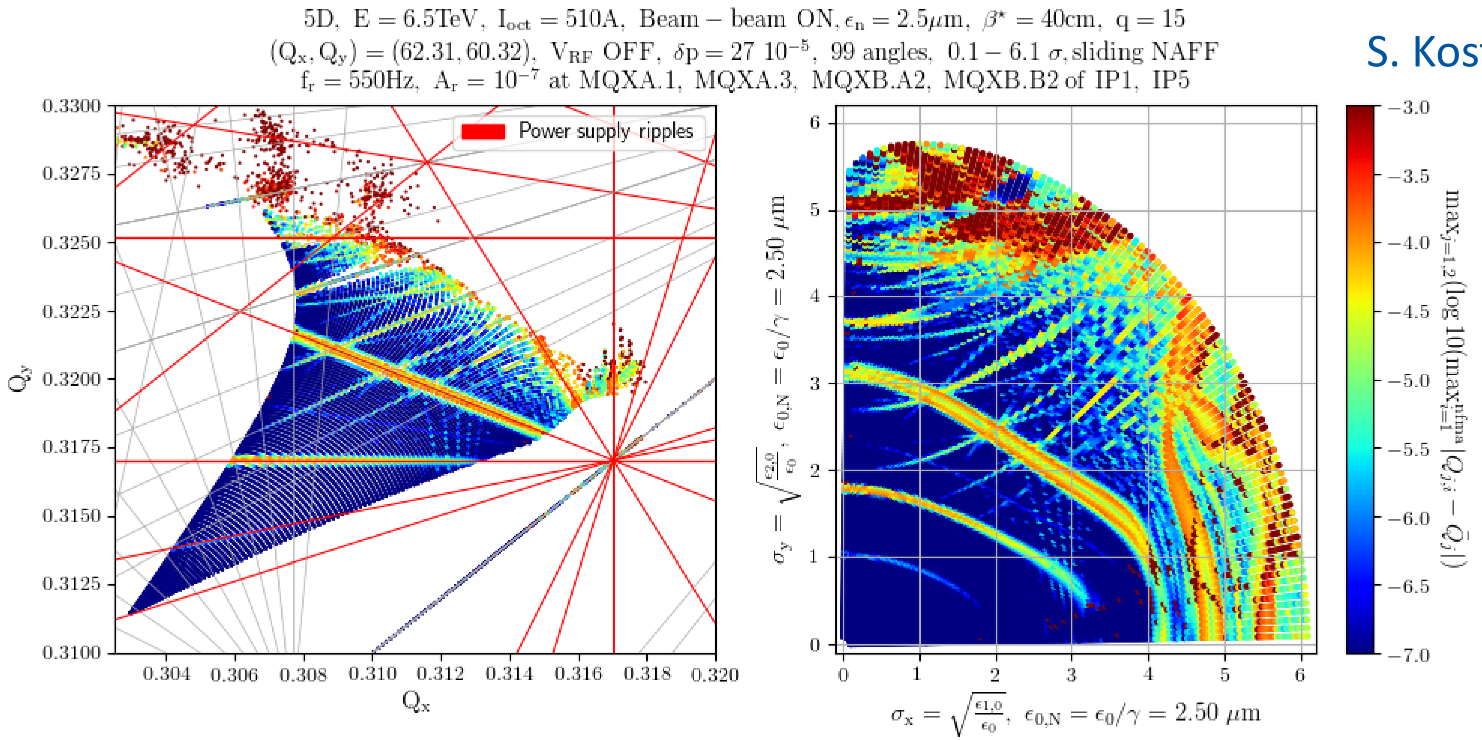
- average 100 ns per particle per beam element
- 250-400 µs turn-particle on single core (depending on the hardware
- Memory footprint 100 MB



Survival time in number of turns as a function of decoupled actions.

Example of usage

S. Kostoglou



HL-LHC simulation with the combination of beam-beam effects, Landau octupoles and power converter ripple in triplets.

Analysis using Laskar's tune analysis post processing method from LifeTrack.

Programming languages, style

SixTrack is made of:

- 70K lines ported to Fortran 2008 from Fortran 77/90 code blocks.
- It use an external (but embedded) C library to generate portable special functions (crlibm) and perform frequency analysis (naff-cpp)
- It supports several compilers and operating systems
- Can be linked with BOINC libraries for the LHC@Home project.

The style is monolithic, procedural with very few functions/procedures, dynamically allocated shared state.

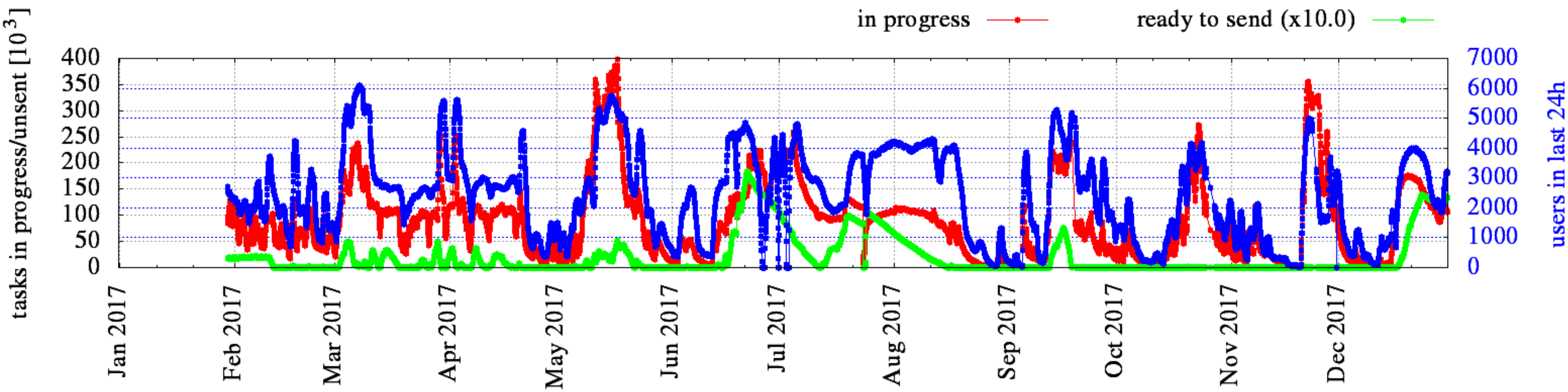
Very steep learning curve, but the resulting executable is very fast.

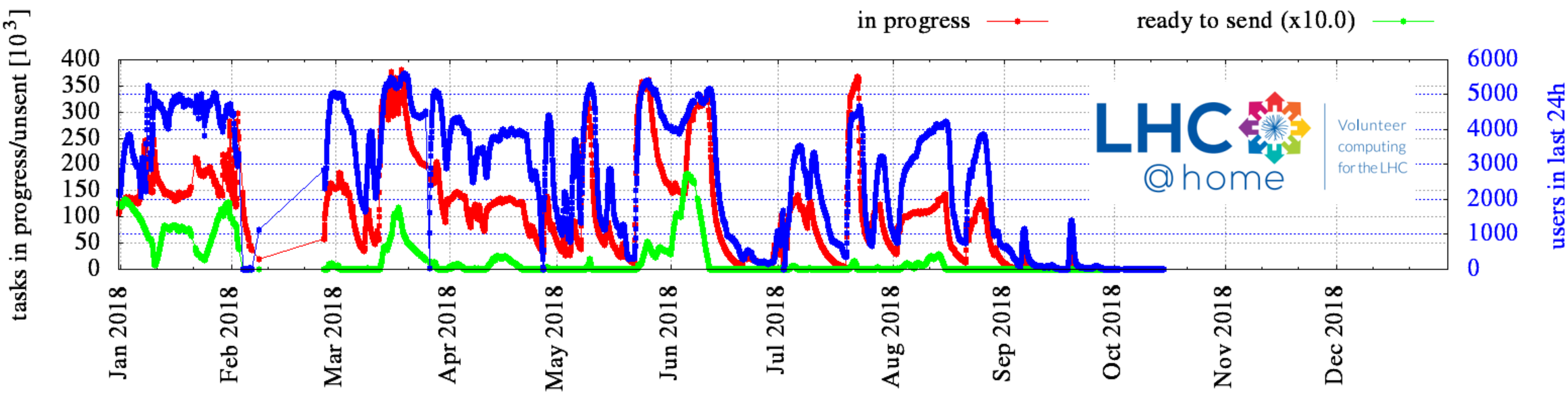
The code use vectorization as a form of parallelization.

SixDesk and SixDB are used to prepare, submit, manage, collect and process jobs for LHC and FCC studies starting from MadX input and a parameter definition file.

- About 70k lines shell scripting, Python.
- Jobs management and physics intermixed.

SixTrack Deployment on LHC@Home





Each task is 60 particles for 10^5 turns in the LHC (~1/2 hours), <u>25M task per year.</u>
LHC@Home more resources than what are we able to use.

SixTrack GPU effort

Main strategy:

- rewrite CPU intensive loop in subset of C such that it can be compiled for CPU and GPU using both OpenCL (1.2) to use the largest set of available hardware.
- Be compatible with CUDA for specific application if needed

Status:

- first proofs of principles and benchmark with realistic simulations done;
- still furthers tests, exploration of optimization strategies and feature coverage needed to go in production.

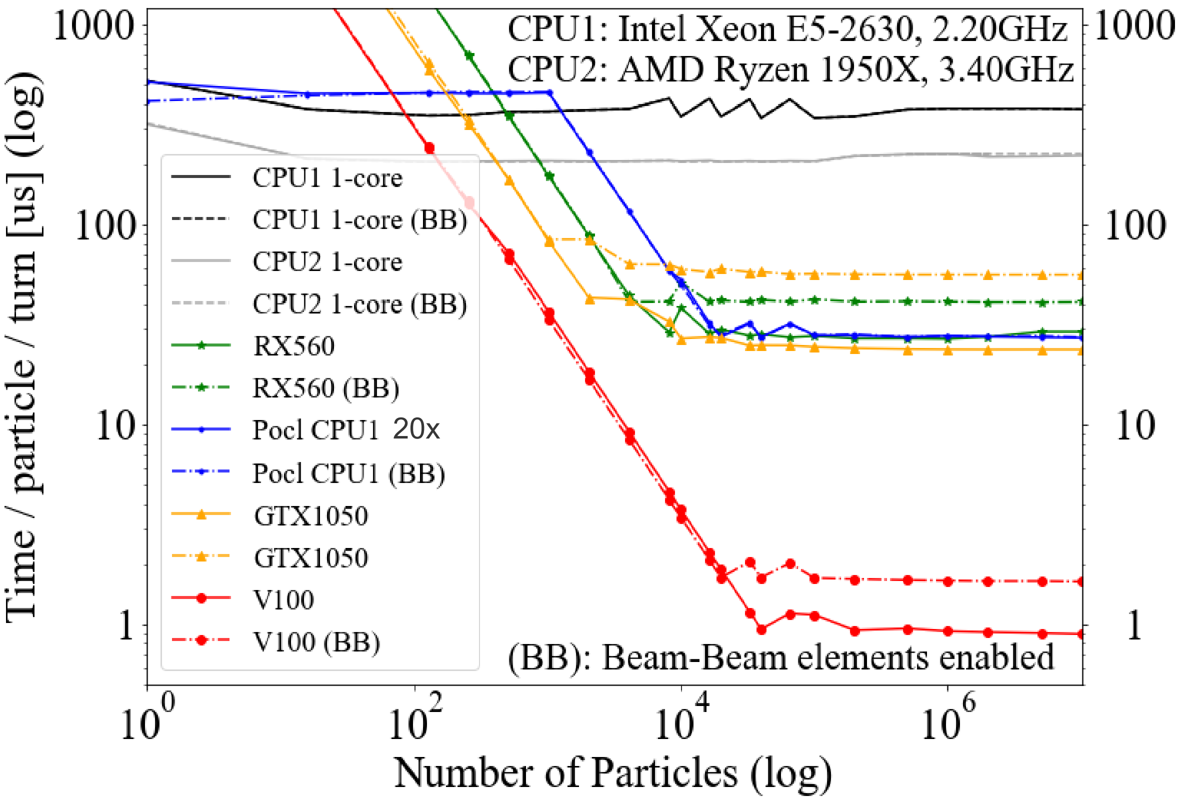
LHC: 8k drifts, 4.6k >11th order multipoles, 20k particles

	Year	Cores	Clock [MHz]	GFlops FP64	Speed [us/(part*turn)]
Intel i7 920	2009	1	2670	5.2	545
Intel Xeon E5-2630	2016	1	2200	17	364
Intel 2x Xeon E5-2630	2016	2x10	2200	2x340	16
Nvidia GTX 1080	2016	2560/32	1700	288	12.8
Nvidia K20x	2015	2688/2	732	1312	10.8
AMD R9 280x	2013	2048/4	1000	1024	4.3
AMD W8100	2014	2560/2	824	2110	4.0
Nvidia P100	2016	3584/2	1480	5300	1.8
Nvidia V100	2017	5120/2	1370	7014	0.9

Main bottleneck for GPU: # of register and FP64 Gflops rate

The aim is to produce an independent and portable C library to incorporate it SixTrack and in any other code that needs a fast tracking engine.

SixTrackLib: scaling



Scaling using monolithic kernel:

- Whole simulation without leaving GPU
- Big switch-case statement to choose the element.

Two examples:

- minimal kernel: just the elements needed
- BB: additional beam-beam lens in the code, but not used!

Optimal scaling: 20k particles

Optimization work: kernel complexity, number of kernels

Resources and future plans

Website (cern.ch/sixtrack) is the single point of information:

- Access to code: GitHub repository for SixTrack
- Documentation:
  - User manual: stable but under review
  - Physics manual: draft in progress but almost complete
  - Developer Wiki: informal live wiki document
- Contacts: Support email, Mailing List.
- SixTrack is licensed with LGPLv2.0

Future plans:

- Continue the development and support of the main code:
  - Adding new physics for LHC/HLLHC/FCC studies
  - Continuous effort in refactoring and documentation
- Develop SixTrackLib:
  - C Library implementing SixTrack Physics that can be embedded in other applications
  - Support GPU