

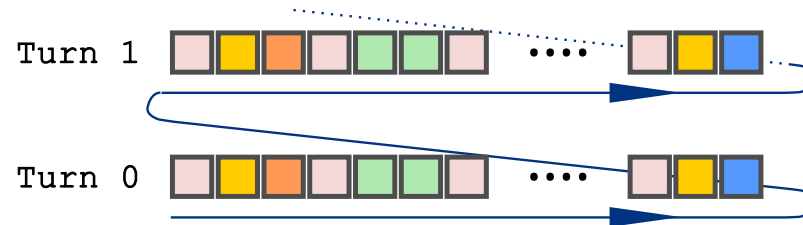
SixTrackLib: A Library for GPU Accelerated Single-Particle Tracking

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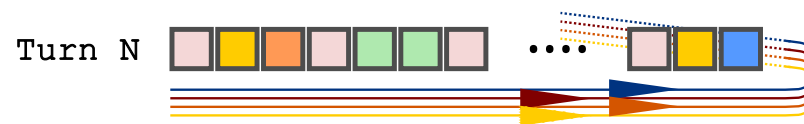
ABP Group Information Meeting February 2020 :: 2020/02/27

Motivation

- Tracking one particle over lattice → sequential operation



- Tracking over $N_T \geq 10^4 \dots 10^8$ turns → numerically expensive
- Tracking $N_P \gg 1$ non-interacting particles over lattice



→ "embarrassingly parallel problem"

- Idea:** Reimplement Core of SixTrack as a stand-alone library, suitable for (massively) parallel systems → **SixTrackLib**

SixTrackLib: Features

- SixTrackLib: <https://github.com/SixTrack/sixtracklib>
- OpenCL 1.2, CUDA, SIMD Auto-Vectorisation / C, C++, Python3

- Particles: 6D Phase-Space

$$\{x, y, p_x, p_y, \zeta, \delta\}$$

Common Implementation
(C99, header-only) for
physics models accross all
architectures, languages, ...

- Beam-Elements

- Drift, DriftExact,
- Multipole, DipoleEdge
- Cavity, RFMultipole,
- Limit (Rect, Ellipse, Rect+Ellipse)
- XYShift, SRotation,
- Beam-Fields: Coasting & Bunched
- Frozen Space-Charge, 6D/4D BeamBeam,...

- Related Python-Centric Projects

- cobjects: <https://github.com/SixTrack/cobjects>
- pysixtrack: <https://github.com/SixTrack/pysixtrack>
- sixtracktools: <https://github.com/SixTrack/sixtracktools>

Example: Create Lattice, Tracking Using The CPU

```
In [3]: import sixtracklib as st

# Build a Fodo Lattice
lattice = st.Elements()
quad_f  = lattice.Multipole(knl=[0.0, 0.165])
drift01 = lattice.Drift(length=10.0)
quad_d  = lattice.Multipole(knl=[0.0, -0.165])
drift02 = lattice.Drift(length=10.0)

# Create a beam with a set of particles for tracking
beam = st.ParticlesSet()
particles = beam.Particles(num_particles=10, p0c=4.5e11)

# Save lattice and particle states to files for later re-use
lattice.to_file('./example_lattice.bin')
beam.to_file('./example_particles.bin')

# Create a CPU SixTrackLib TrackJob
job = st.TrackJob(lattice, beam)

status = job.track_until( 1 )

job.collect_particles()
print( f"particles at_turn: {particles.at_turn}")
```

```
particles at_turn: [1 1 1 1 1 1 1 1 1 1]
```

Example: Import Lattice From MAD-X

```

In [4]: # Using cpymad and pysixtrack
from cpymad.madx import Madx
import numpy as np
import pysixtrack as pyst

m_p = 938e6 # [m_p] = 1 eV
c0 = 299792458.0 # [c0] = 1 m/s

beam = st.ParticlesSet()
p0c = 450e9 # [p0c] = 1 eV
Etot = np.sqrt( p0c * p0c + m_p * m_p * c0 ** 4 ) * 1e-9 # [Etot] = 1 GeV !!!
particles = beam.Particles(num_particles=10, p0c=4.5e11)

mad = Madx()
mad.call(file="fodo.madx")
mad.command.beam(particle="proton", energy=str(Etot))
mad.use(sequence="FOD0")

fodo = mad.sequence.FOD0

pyst_line = pyst.Line.from_madx_sequence(fodo, exact_drift=True)
pyst_line.remove_zero_length_drifts(inplace=True)

lattice = st.Elements()
lattice.append_line( pyst_line )

# .... Continue like above ...

```

```

+++++
+      MAD-X 5.05.01  (64 bit, Linux)      +
+ Support: mad@cern.ch, http://cern.ch/mad +
+ Release   date: 2019.06.07              +
+ Execution date: 2020.02.27 09:50:28      +
+ .....

```

Example: OpenCL Tracking (GPU or CPU)

```
In [5]: # Same lattice and beam definition, but now track on an OpenCL device
# First: find out which devices are available
!clinfo -l
```

```
Platform #0: Portable Computing Language
  -- Device #0: pthread-Intel(R) Core(TM) i5-5300U CPU @ 2.30GHz
Platform #1: Intel(R) OpenCL
  +-- Device #0: Intel(R) HD Graphics
  -- Device #1: Intel(R) Core(TM) i5-5300U CPU @ 2.30GHz
Platform #2: Experimental OpenCL 2.1 CPU Only Platform
  -- Device #0: Intel(R) Core(TM) i5-5300U CPU @ 2.30GHz
```

```
In [6]: # Then create an OpenCL track-job using one of the devices
lattice = st.Elements.fromfile('./example_lattice.bin')
beam = st.ParticlesSet.fromfile( './example_particles.bin')
cl_job = st.TrackJob(lattice, beam, device="opencl:2.0")

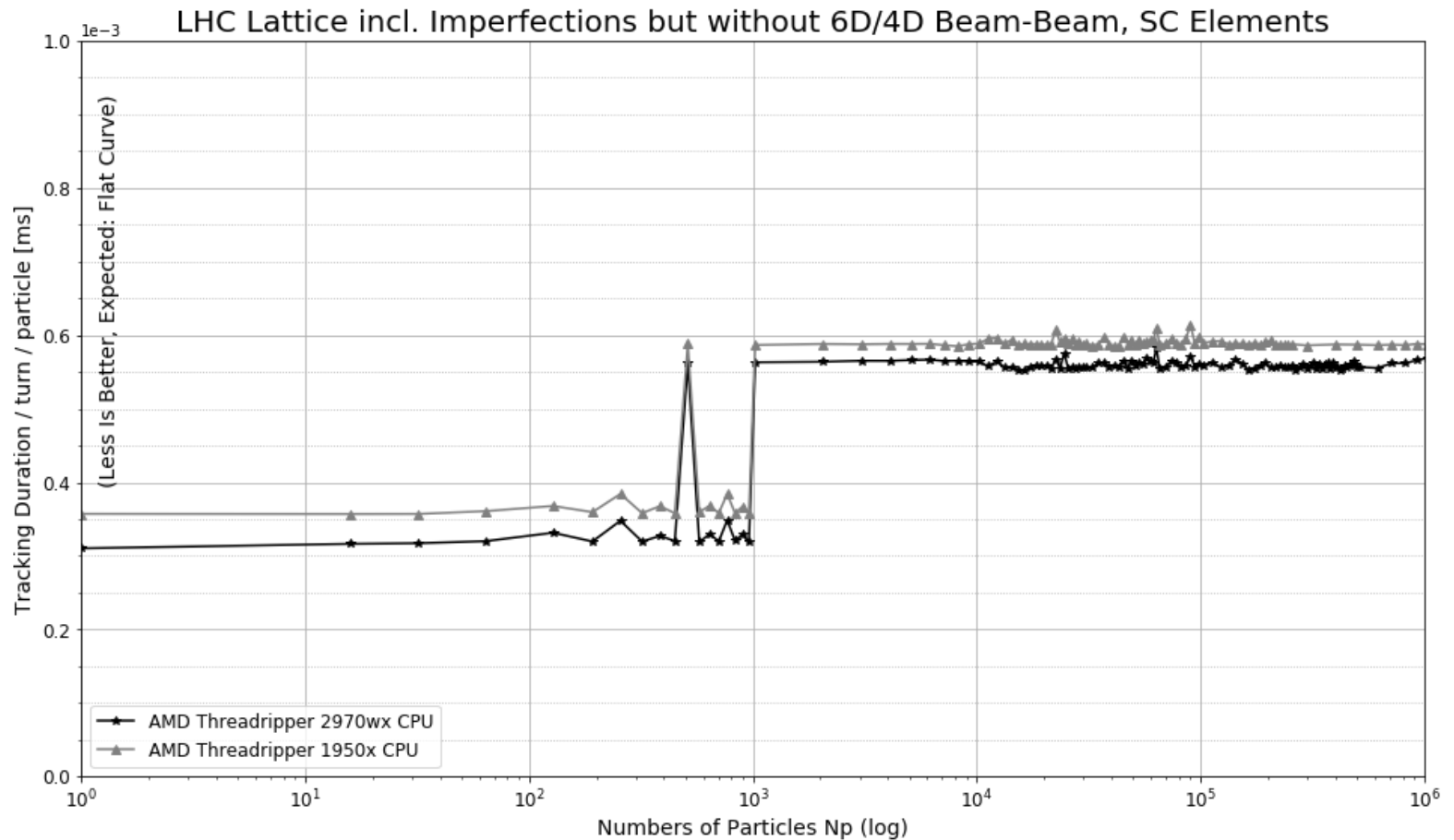
# The rest is like before
status = cl_job.track_until( 2 )
cl_job.collect_particles()

particles = beam.cbuffer.get_object(0)
print( f"particles at_turn: {particles.at_turn}")
```

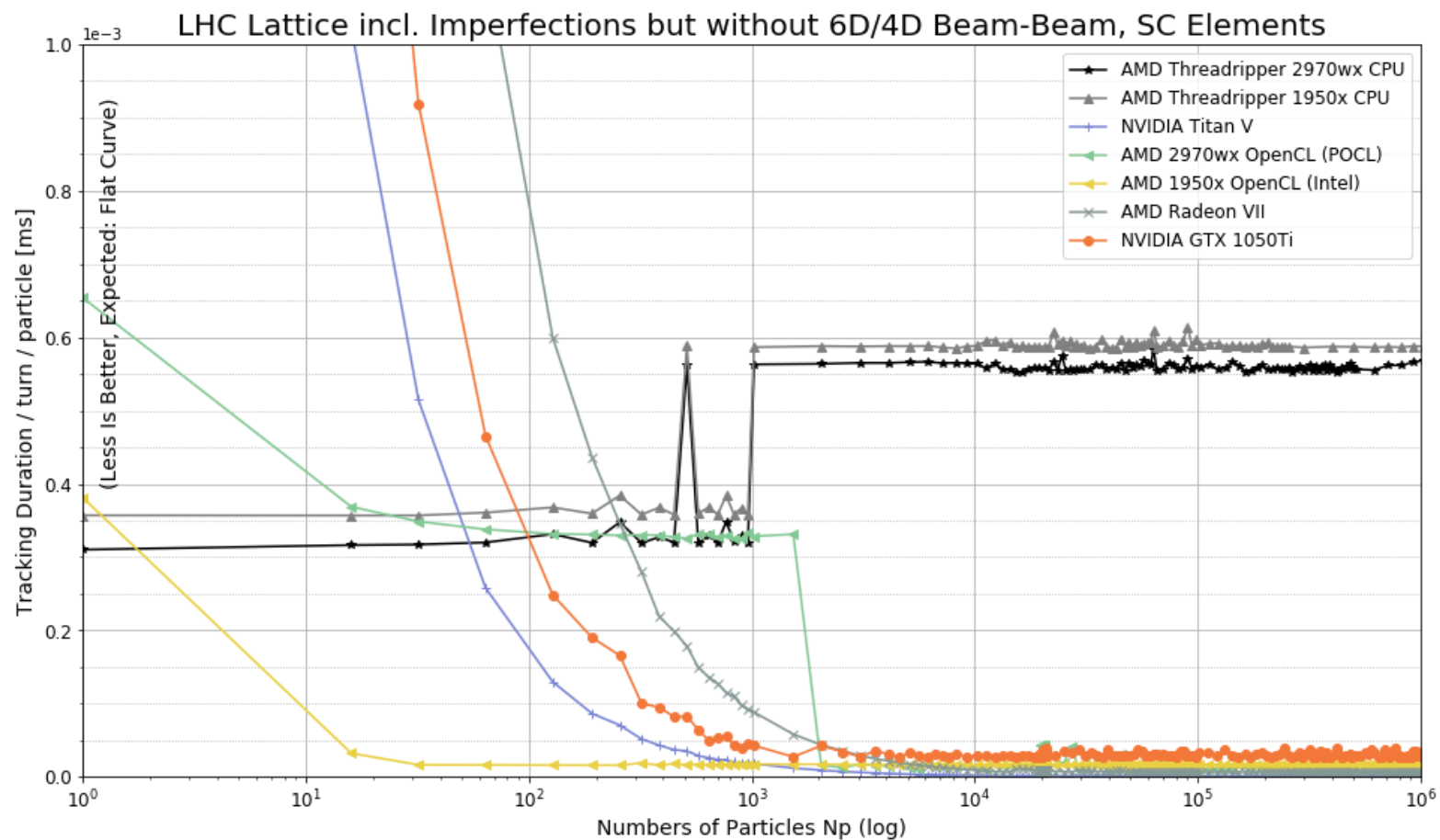
```
particles at_turn: [2 2 2 2 2 2 2 2 2 2]
```

Scaling: LHC Lattice (Field Imperfections, no BB, no SC)

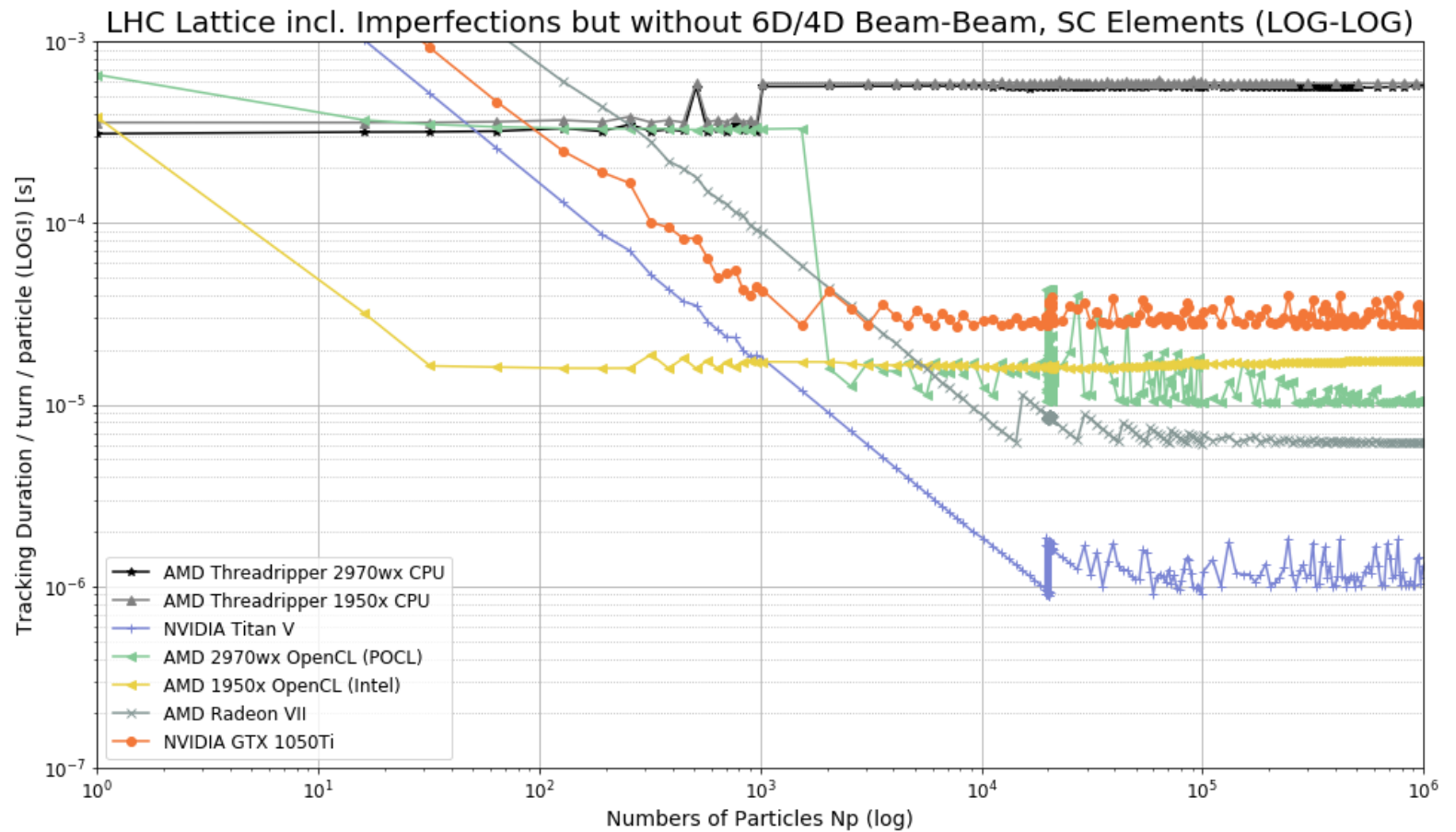
```
In [13]: plt = plot_cpu_comparison(plt, files)
plt.rcParams["figure.figsize"]=(16,9)
```



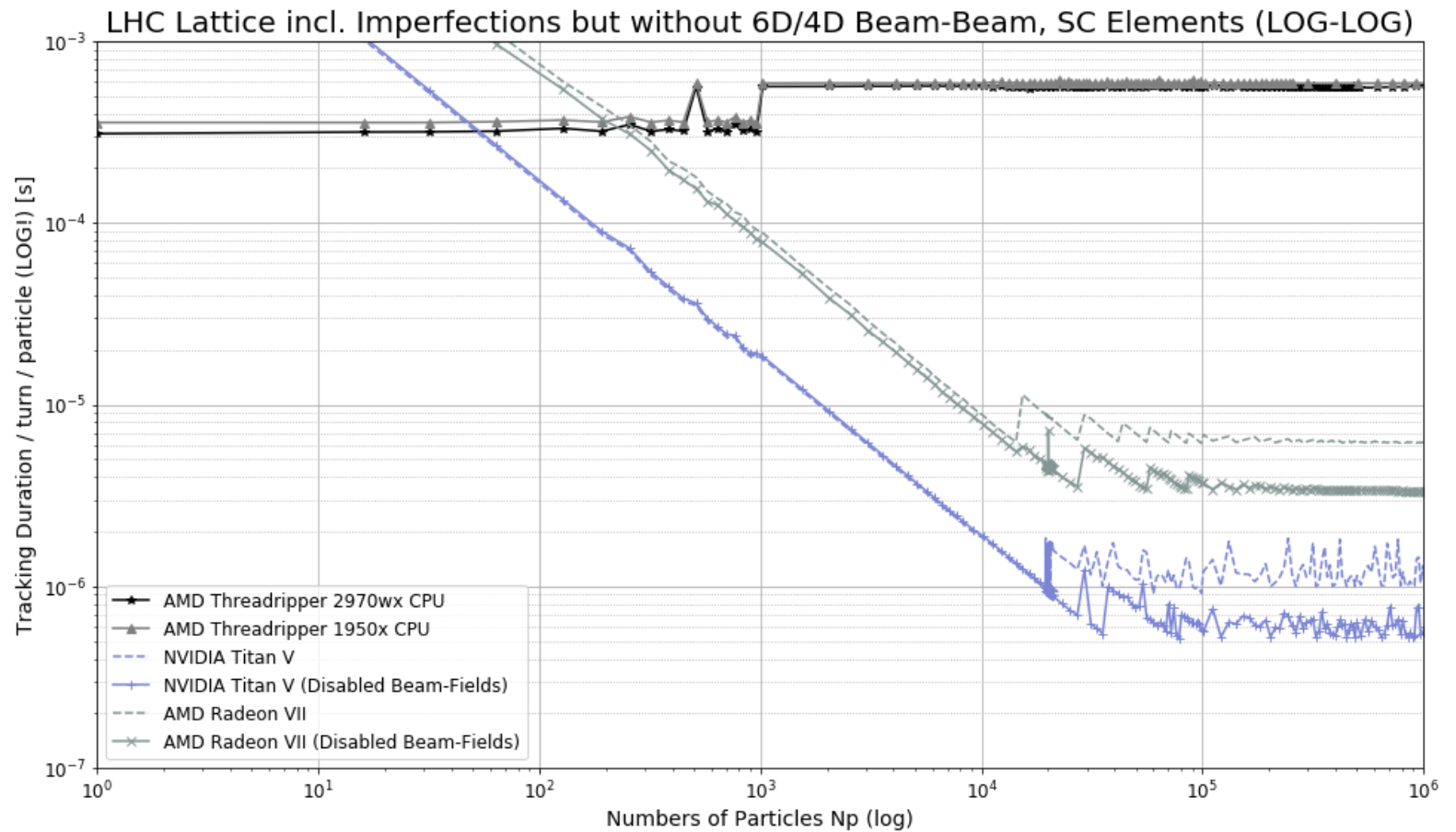

```
In [15]: plt = plot_cpu_vs_ocl_all_enabled(plt, files)
plt.rcParams["figure.figsize"]=(16,9)
```



```
In [17]: plt = plot_cpu_vs_ocl_all_enabled_log_log(plt, files)
plt.rcParams["figure.figsize"]=(16,9)
```



```
In [19]: plt = plot_cpu_vs_ocl_all_none_enabled_log_log(plt, files)
plt.rcParams["figure.figsize"]=(16,9)
```



Status, Conclusion & Outlook

- SixTrackLib: 2-3 Ord. of Mag. Speedup (Depending on HW, Np, Lattice,...)
- Currently used as a "building-block" in dedicated studies
- Focus on testing, physics benchmarking, optimization
- Further Integration with Frameworks like PyHEADTAIL
- API and ABI might still change / break → "Selected Experienced Users"
- Goals:
 - Use as an (optional) tracking backend for SixTrack
 - Prepare & Test use within the Framework of BOINC (LHC@Home)
 - C++ Bindings are fully templated → MultiPrec, SIMD, evt. TPSA

Thank You For Your Attention!

<https://www.github.com/SixTrack/sixtracklib>

- Related Studies, Publications, and Präsentations (Selection):
 - ▶ A. Oeftiger "GPU accelerated space charge simulations using SixTrackLib and PyHEADTAIL"
(4th ICFA Mini-Workshop on Space Charge 2019, CERN)
<https://indico.cern.ch/event/828559/contributions/3528454/>
 - ▶ H. Bartosik "Studies on tune ripple"
(4th ICFA Mini-Workshop on Space Charge 2019, CERN)
<https://indico.cern.ch/event/828559/contributions/3528378/>
 - ▶ K. Paraschou "Symplectic kicks from an electron cloud pinch"
(ABP Group Info Meeting, January 2020, CERN) <https://indico.cern.ch/event/880340/>