# EPFL-CERN Software Collaboration

# Introduction

- Large **number of tools** used in FCC study
  - Often **specialised** to one purpose/aspect of beam physics
  - Sometimes tools with **overlapping purpose** used, depending on the **user's expertise**
- Vast and very active community in the **CERN ABP Computing Working Group**
  - Maintenance, improvement, complement **existing codes**
  - **Development** of modern, robust and broad tools for the **entire accelerator community**
- **Large community** outside of FCC and CERN with overlapping interests
  - **Potential for synergies** and **cooperation**

# FCC Software Framework Project

- **Understand requirements** for the development and simulation of FCC
  - **Which effects** need to simulated and which **tools exist** or **need to be developed/optimised** for these purposes
  - Identify which simulations need to **interplay/overlap** and understand how they fit together in the **"bigger picture"**
- Ensure that the needs of the FCC study are met by
  1. **Maintaining, benchmarking** and **improving current simulation tools**
  2. Actively contributing to the **development** of **new simulations tools**
  3. Create tools to allow for **interfacing** between different simulation tools
- Work closely with the **ABP Computing WG** and identify synergies and come up with a **common strategy**
- Offer a **first point of contact** for external collaborators that see synergies

# Available and Used Codes

- Behold the Jungle

# Codes used for FCC-ee (Courtesy to Michael Hofer)

**EPFL**

| Domain | Organisation | Codes |
|---|---|---|
| Optics and Tracking | **CERN** | **MAD-X, MAD-X PTC, SixTrack, SixTrackLib, Xsuite, MAD-NG, Placet, CPyMAD** |
| | KEK | SAD |
| | ESRF | PyAT |
| | Cornell | BMAD |
| | Manchester/Huddersfield | MERLIN++ |
| | ANL | Elegant |
| Beam-Beam | **CERN** | **GUINEA PIG, COMBI** |
| | LBNL | BeamBeam3D |
| | KEK | BBSS |
| | IHEP | IBB |
| | BINP | LifeTrac |
| Collective Effects | **CERN** | **pyHEADTAIL, TRAIN, DELPHI** |
| Impedance Modeling | **CERN** | **IW2D** |
| | Dassault systems | CST Studio |
| Ecloud Simulations | **CERN** | **PyECLOUD** |
| Vaccum | **CERN** | Synrad+ |
| Energy Deposition | **CERN** | **FLUKA, MDISIM** |
| | Royal Holloway | BDSIM |

# Dedicated Codes

- Development and Optimisation within FCC-ee Software Framework

# Optics Codes

- Efforts by **CERN** colleagues to ensure **MAD-X** has adequate **functionality to simulate FCC-ee**
  - **Benchmark** with other simulation tools such as SAD (L. van Riesen-Haupt)
  - **Implement new features** that are essential to simulate FCC-ee (R. de Maria, T. Persson and many others)
    - Tapering
    - Permanent misalignments
    - Exact Solenoid
  - Create and share useful **MADX scripts** (G. Simon, M. Hofer and others)
    - https://gitlab.cern.ch/acc-models/fcc/fcc-ee-lattice
- Increased use of **CPyMAD**
  - Used in and together with python tools
  - Lower barrier of entry for new collaborators





L. van Riesen-Haupt, *Code comparison and lattice models,* FCC IS WS 2021
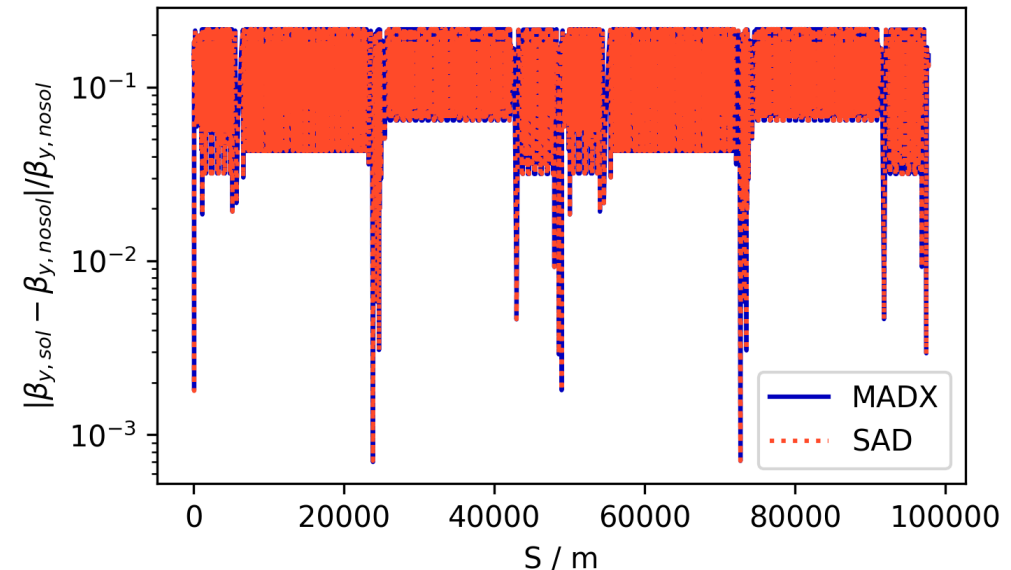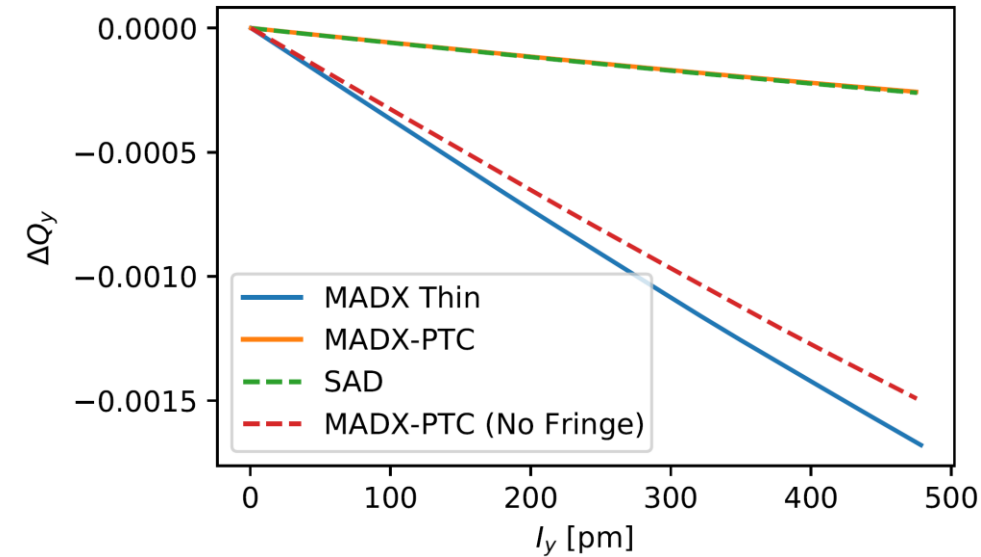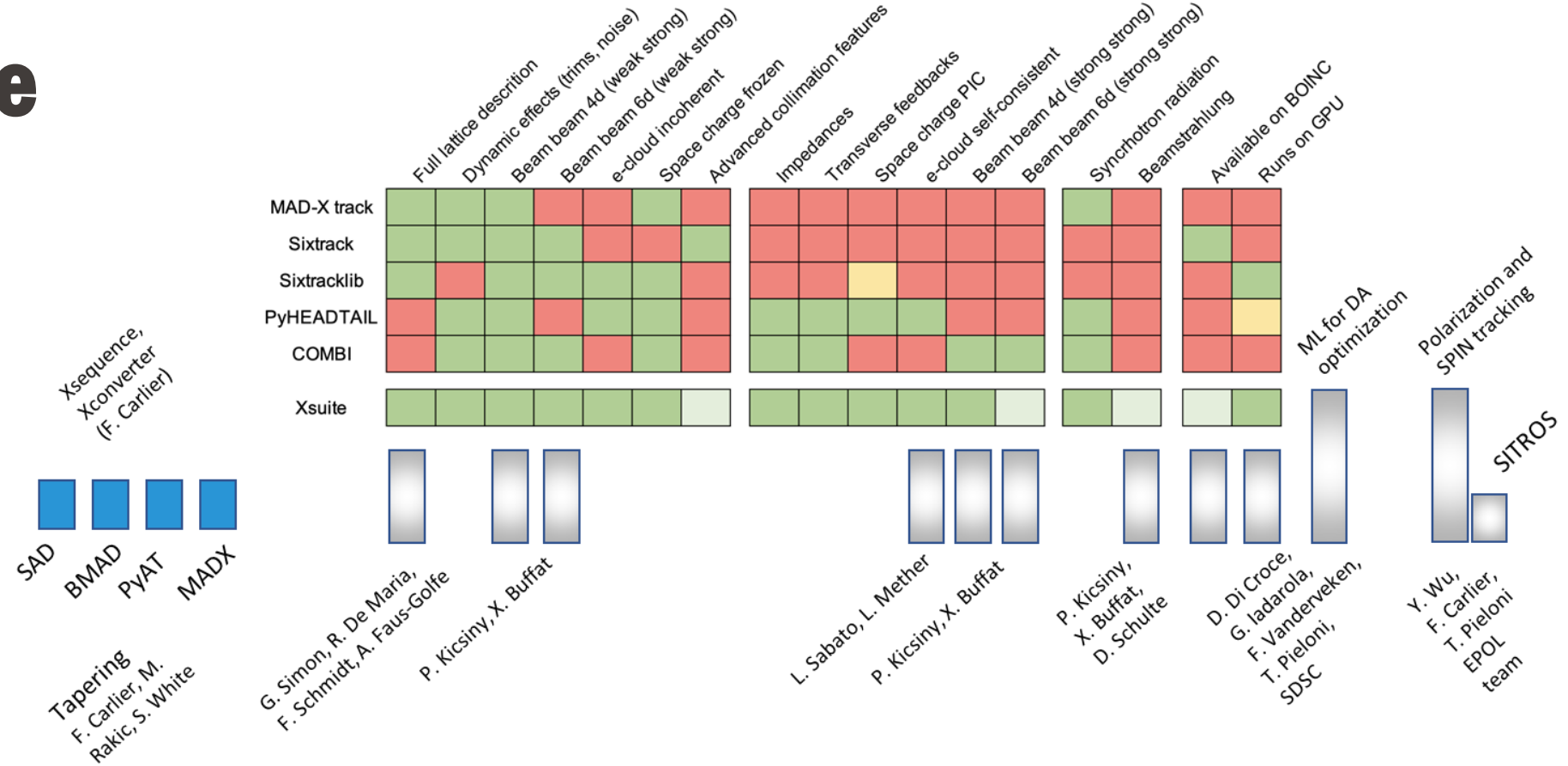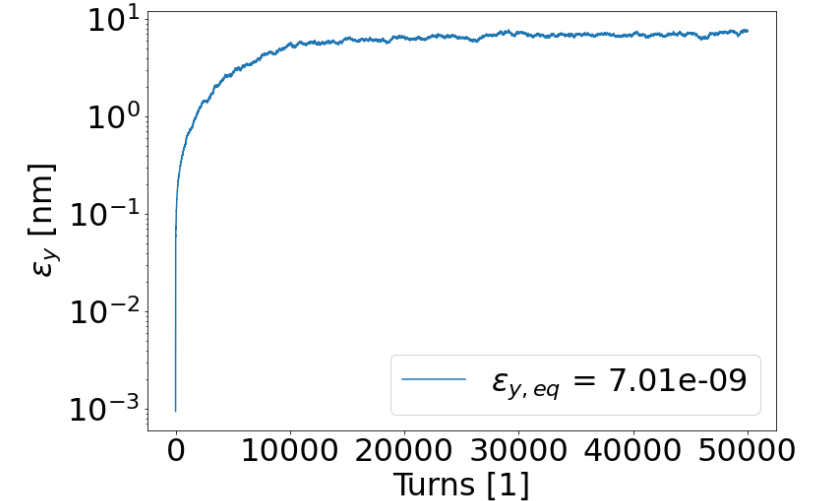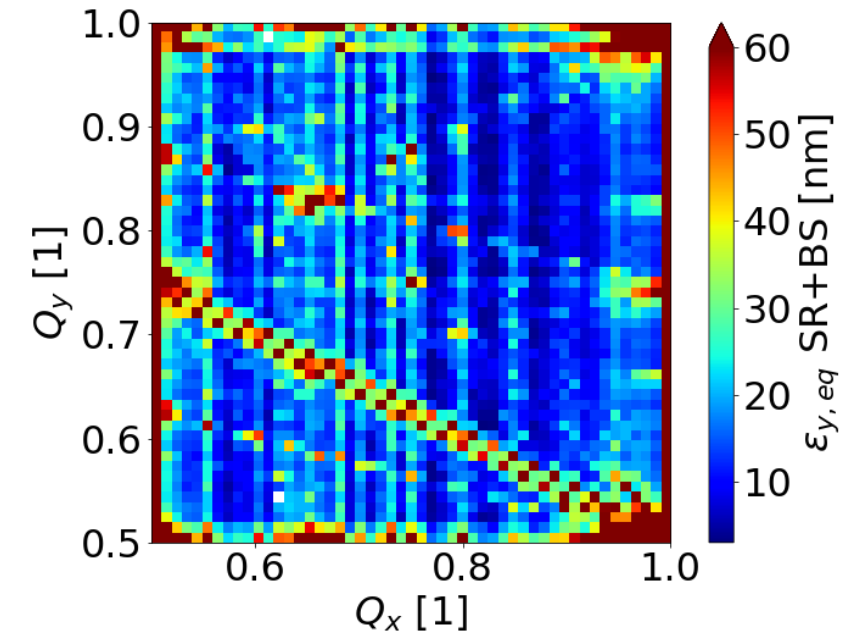
# Xsuite



- Xsuite is a **modern multiparticle simulation** software developed by **R. de Maria, G. Iadarola** and the **ABP Computing WG** that aims to:
  - Provide a **broad functionality** currently only partially provided by an array of CERN codes
    - Thereby also **simplify** the **development and maintenance** of codes
  - Make use of **modern computing platforms** such as GPUs
  - Can be used for a **wide range of machines**, including injectors, LHC, HL-LHC and future design studies such as FCC-ee

- The same **ethos** can/should be applied to FCC-ee code development

# Beam-Beam, Beamstrahlung and Synchrotron Radiaiton

- EPFL PhD project of **P. Kicsiny** and **X. Buffat**

- Integration of **various beam-beam models** in **Xsuite**
  - **Benchmarking** against existing codes (COMBI, GUINEA-PIG)
  - Possibilities to exploit **modern technologies** such as OpenMP and GPU
  - Simulate other effects such as **Beamstrahlung** and **interplay** with other types of simulations

- Work complimented by **analytical work** by **K. Le Nguyen Nguyen**

- Essential for finding the **ideal working point** using most realistic simulations



P. Kicsiny, *Simulation of FCC-ee Beam-beam Effects with Xsuite*, FCC Week 2022

# Electron Cloud

- Efforts by **L. Sabato** and **L. Mether**
- Improve **electron cloud models** based on LHC experience
- Identify design **parameter range** where electron cloud effects are most significant
  - **Speed up studies**
- Integrate models into **Xsuite**
  - **Benchmark** and test
  - Enable **comprehensive studies** with multiple effects
- Provide input to **vacuum chamber design**
  - Which will also take into account other effects



L. Sabato, *Electron Cloud Studies for FCC*, EPFL-LPAP Activity Meeting
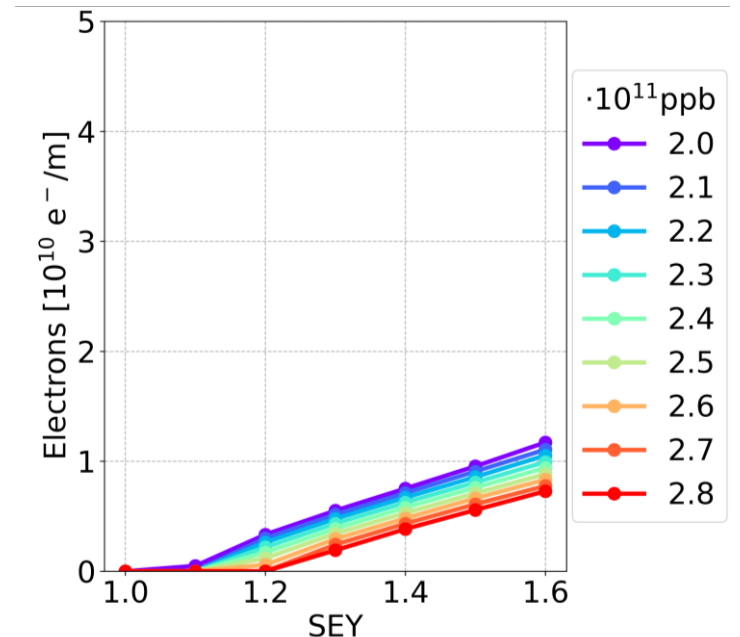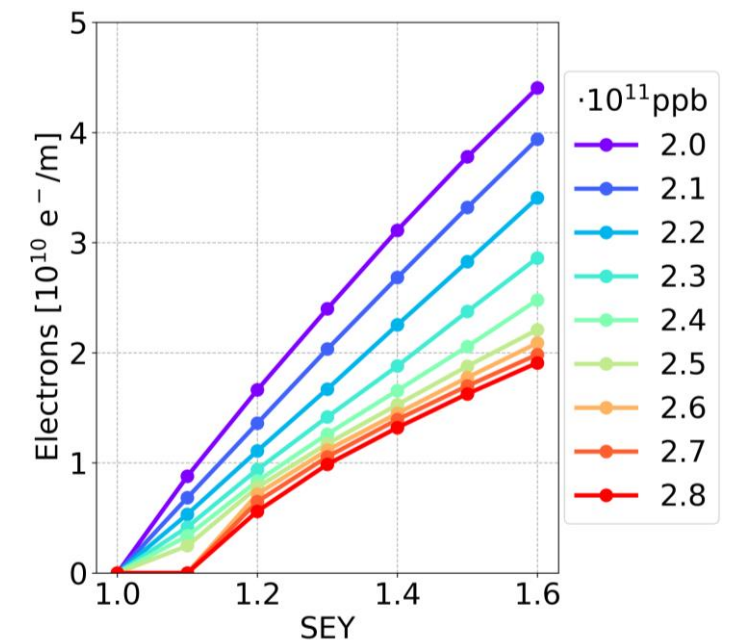
# Spin Polarisation

- EPFL PhD project of **Y. Wu** with various **CERN** and **international collaborators**
- Ensuring reliable **polarisation studies** by
  - Understanding **spin dynamics theory**
  - **Benchmarking** simulation tools (BMAD and SITROS)
  - Eventually implement in **XSuite**
- Ensure **interplay** between polarisation studies and other FCC efforts
  - **Orbit** corrections and bumps
  - **Optics** corrections
- Ensure **sufficient polarization** levels for **energy calibration** using resonant depolarization
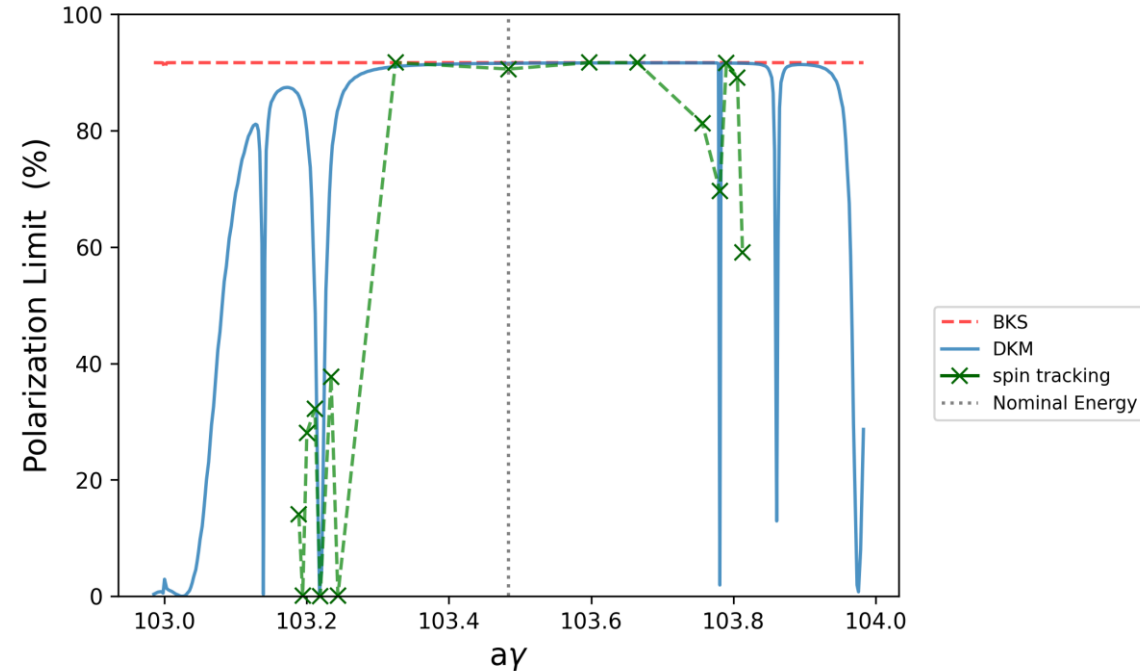


Y. Wu, *Spin Polarization Simulations for the Future Circular Collider e+e- using BMAD*, 2d FCC Polarization Workshop

# Speeding up Tracking Studies and Applying Machine Learning

EPFL

- Efforts led by **D. di Croce, Frederik van der Veken, G. Iadarola**
- Expect an **increased computing time** for tracking studies for FCC compared to LHC
  - **Larger machine** with **more** particle statistics
  - Require 6D tracking with **radiation effects**
- **Xboinc** aims to increase computation speed of tracking studies
  - Enable **xtrack simulation** to run on **BOINC**
  - Possibly develop **GPU support**
- **Active Learning for Accelerators** (ALA)
  - **Machine learning software** to predict DA without costly simulations
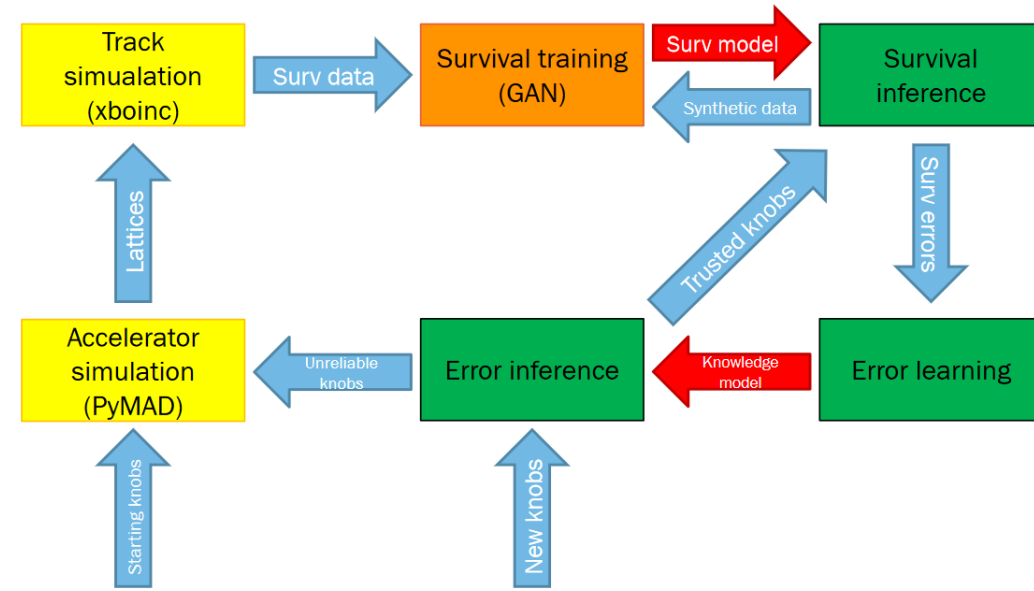


D. Di Croce, *Machine learning for FCC*, EPFL-LPAP Activity Meeting

# Bringing it Together

- Lattice Management and Conversion

# Sequence Converter - Xconverter

- **Sequence conversion** tool in development by EPFL
  - All previous contributions driven by **Felix Carlier**
- Enable conversion between **different simulation** codes
  - Facilitate **interplay** between simulations
  - Ensure **up-to-date lattices** can **quickly** be **propagated** to users
  - Increased **consistency** between different simulations
- Written in **python** and available on **github**
  - https://github.com/fscarlier/xconverters

| Codes | Import | Export |
|---|---|---|
| MAD-X (cpymad) | 🟩 | 🟩 |
| SAD | 🟩 | 🟥 |
| pyAT | 🟩 | 🟩 |
| Xsuite | 🟧 | 🟩 |
| Bmad | 🟥 | 🟥 |
| Elegant | 🟥 | 🟧 |

T. Pieloni, *Overview of the FCC Software framework developments,* FCC Week 2022

# Sequence Manager - Xsequence

- **Sequence manager** developed by **EPFL**
  - Also previously driven by **Felix Carlier**
- Systematic and **universal sequence description** in python
  - **Independent** of the software the sequence was first written in
  - **Conserve circuits** and dependencies using the xdeps package (Riccardo de Maria)
- Provides an intermediate step for conversion
  - Allows **modular additions** to Xconverter
- https://github.com/fscarlier/xsequence
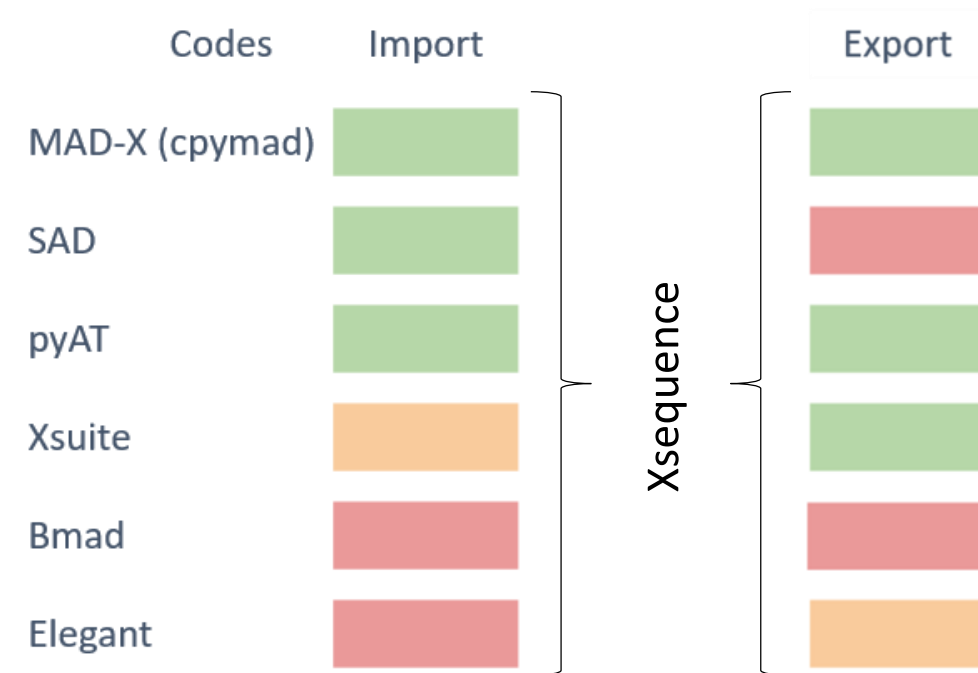
# Optics Matching After Conversion

- **Conversions** can **cause mismatch in optics** due to
  - Differences in **element definitions** after translation
  - **Slicing** and thin lens approximation (e.g. for tracking)
- **First order** correction would be a **global matching**
  - (Tune, chromaticity etc.)
- Preferable to **recover key optics properties** in various locations
  - ($\beta^*$, phase advance between critical correction schemes etc.)
- Currently **implemented in MAD-X**
  - Successfully used for **sliced lattices**
- In the future define strategy in **Xsequence**
  - **Match** in every code **after translation**

# Next Steps

- Define and implement **post-conversion matching** for Xconverter

- Add **more component** definitions to Xsequence
  - **Tilted solenoid**
  - **Overlapping magnets**

- Increase **number of codes** importing to and exported from Xconverter
  - First target: **export to SAD**

| Codes | Import | Export |
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| MAD-X (cpymad) | 🟩 | 🟩 |
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| Bmad | 🟥 | 🟥 |
| Elegant | 🟥 | 🟧 |

T. Pieloni, *Overview of the FCC Software framework developments,* FCC Week 2022

# Conclusion

- Established a strong the foundation for **a community of accelerator code developers** with common interests to
  - Develop **modern codes** for broad purposes
  - Develop and maintain codes that will **be essential to FCC-ee**
- FCC-ee code and simulation developments at **CERN and EPFL** to
  - Provide accurate **dynamic aperture** studies with improved **tracking** tools and **machine learning**
  - Accurately simulate effects like **beam-beam** and **electron cloud** for **lepton colliders**
  - Simulate lepton collider specific effects such as **polarisation**
- Develop and improve an extensive **lattice management and conversion** tool to facilitate **interplay** of and ensure **consistency** between simulation