Simulation Tools for Future Colliders

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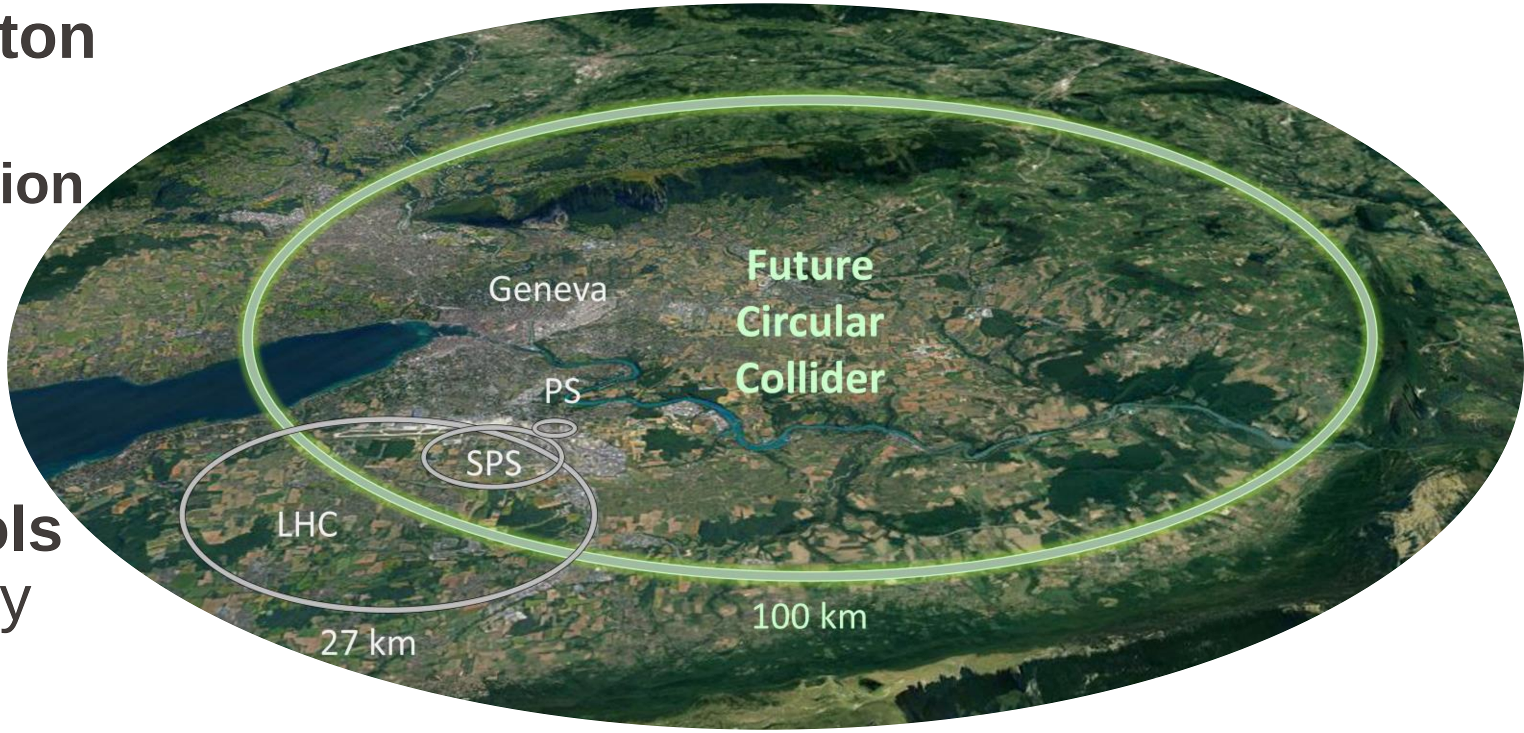
Motivation

- Challenges set out by Future Circular electron-positron Collider (**FCC-ee**)
  - **Large** and **complex** machine with many components
  - Challenging **collision parameters** and insertion region design
  - Tight **alignment**, **manufacturing** and **correction** tolerances

- Challenges unique to **lepton colliders**
  - E.g. **synchrotron radiation** effects
  - Recent focus in CERN on **hadron machines**
- Work with **experts** in the **community** to create **tools** for the broader community



Jungle of Simulations

- Many different types of simulations including **different effects** and **specialised** codes
- Types of simulations largely differ in
  - **Number** of particles simulated
  - **Time/distance** over which particles are simulated
  - Inclusion of **interactions** with other **particles, beams, components** of the machine
- Often **interplay** of different effects and simulations is **essential**
  - Get a **full and accurate picture** of machine behaviour
  - Requires **interfacing** between simulations
  - Efficient **propagation** of design changes to all codes

Examples of Simulations

Simulation type	Description	Purpose
Optics	Fast linear approximation of the motion of beam centroid	Lattice design and optimisaiton
Dynamic Aperture	Tracking large number of particles over many turns	Establishing the dynamically stable regime
Beam-Beam	Interaction of particles in opposite colliding beams	Study of the perturbation due collisions
Collimation	Interaction of particles with matter and energy deposition	Machine protection and experimental background
Electron Cloud	Interaction of beam and electrons emitted from beam pipe	Determining beam stability
Collective effects	Interaction between particles in beams and bunches	Understand collective instabilities and behaviour

Examples of Simulations

Simulation type	Number of Particles	Turns/Distance	Interaction with
Optics	Single particle	Single or few turns	Magnets, (RF cavities)
Dynamic Aperture	Thousands	Thousands of turns	Magnets, (RF cavities)
Beam-Beam	Thousands	Interaction point (short)	Particles in the colliding beam
Collimation	Thousands	Large number of turns	Magnets, solid matter, secondary particles
Electron Cloud	Large number of macroparticles	Along bunch, thousands of turns	Beam pipe, emitted electrons
Collective effects	Large number of particles	Within bunch/beam, over entire machine/many turns	Particles in the same beam

EPFL

Jungle of Codes used for FCC-ee

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	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

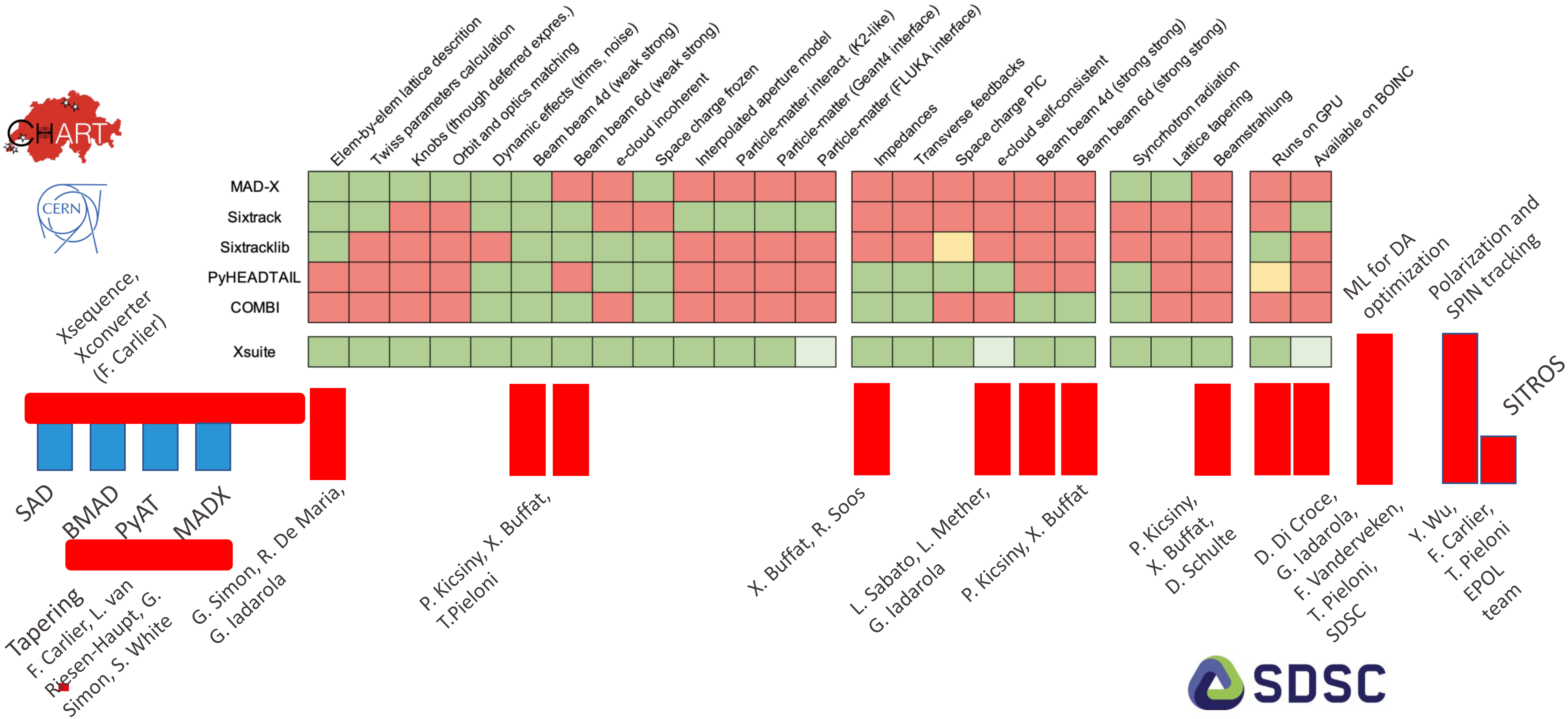
Sequence Converter and Manager

- **Sequence manager** and **converter** developed by **EPFL**
  - Efficient **interfacing** and **conversion** between codes
- **XConverter**
  - **Convert** to and from different codes
  - **Modular** approach via XSequence
- **XSequence**
  - **Python** based sequence manager
  - **Backbone** of XConverter
  - Allows for **code independent** lattice management and modification

Swiss Army Knife - XSuite

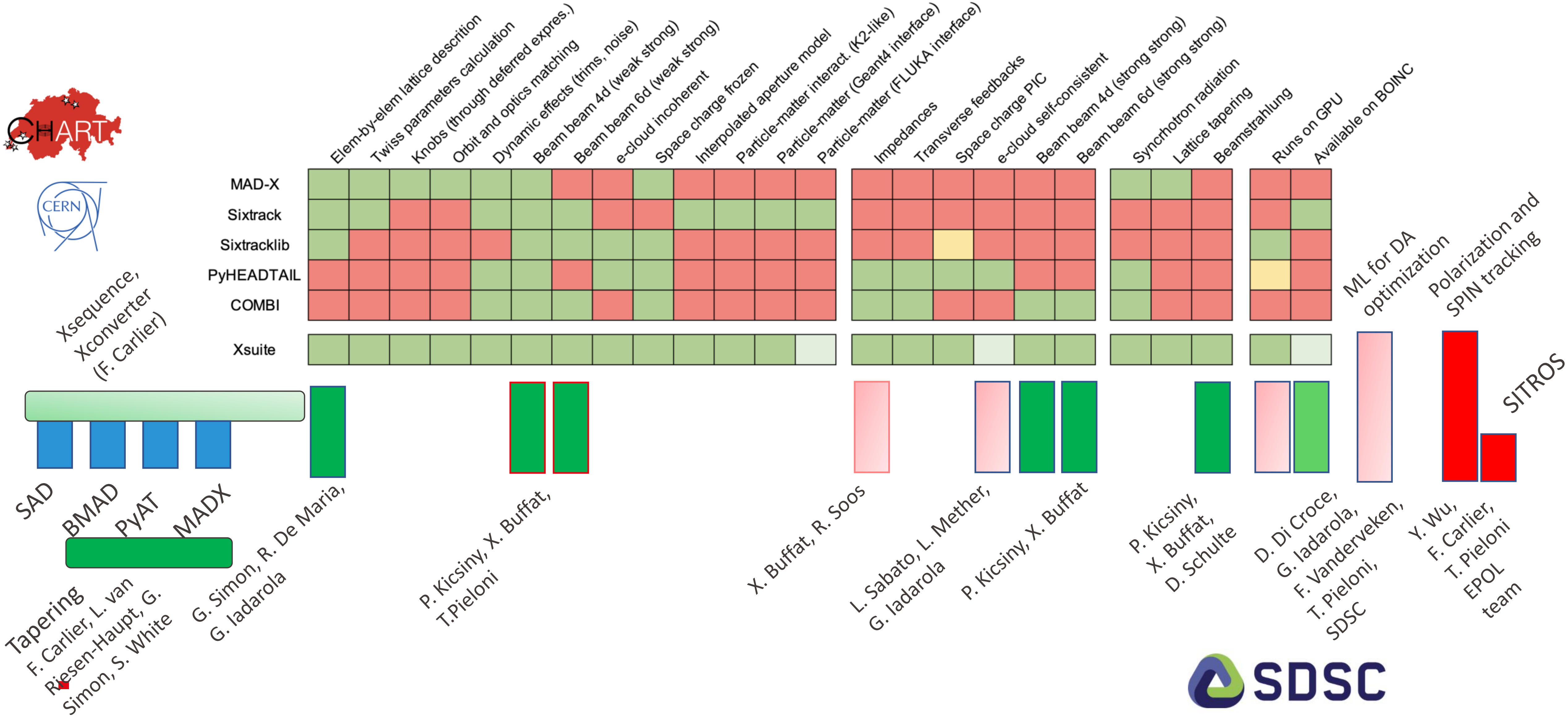
- Identified **XSuite** a software as cornerstone for software framework
  - Aims to cover a large **range of functionality**
  - Written in **python** for easier interfacing
  - Large and growing **CERN community**
- Aim to provide direct **input** relevant for FCC-ee study by
  - **Implementing** features
  - **Benchmarking** new features
  - Being **first time users** and inputting needs
- **Conversions** still relevant to convert **to and from XSuite** and all legacy codes
  - Also for benchmark studies
- Use software for meaningful **contributions to FCC** study

XSuite



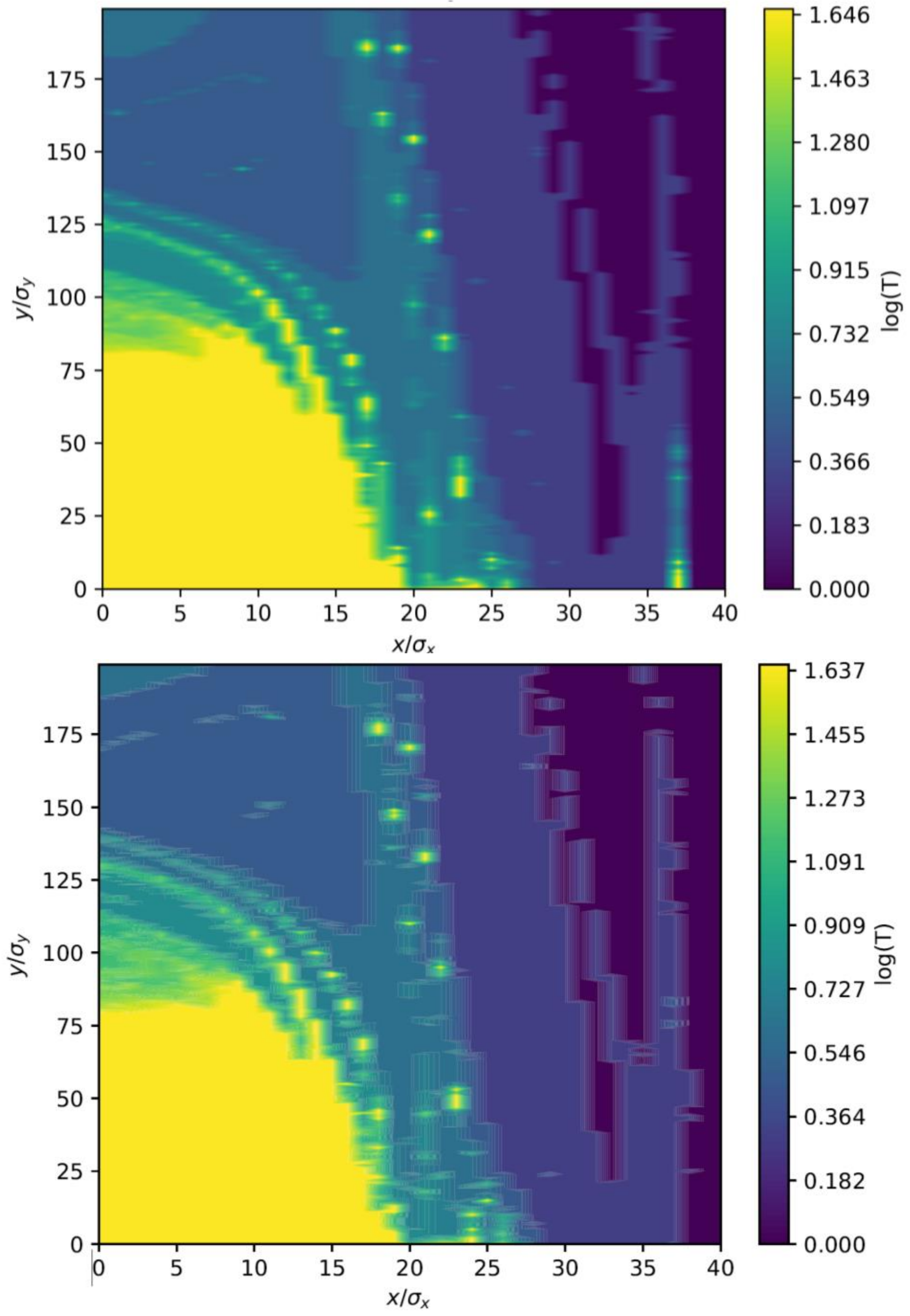
Elem-by-elem lattice descrition
Twiss parameters calculation
Knobs (through deferred expres.)
Orbit and optics matching
Dynamic effects (trims, noise)
Beam beam 4d (weak strong)
Beam beam 6d (weak strong)
e-cloud incoherent
Space charge frozen
Interpolated aperture model
Particle-matter interact. (K2-like)
Particle-matter (Geant4 interface)
Particle-matter (FLUKA interface)
Impedances
Transverse feedbacks
Space charge PIC
e-cloud self-consistent
Beam beam 4d (strong strong)
Beam beam 6d (strong strong)
Synchrotron radiation
Lattice tapering
Beamstrahlung
Runs on GPU
Available on BOINC
MAD-X
Sixtrack
Sixtracklib
PyHEADTAIL
COMBI
Xsuite
Xsequence, Xconverter (F. Carlier)
SAD
BMAD
PyAT
MADX
Tapering
F. Carlier, L. van Riesen-Haupt, G. Simon, S. White
G. Simon, R. De Maria, G. Iadarola
P. Kicsiny, X. Buffat, T.Pieloni
X. Buffat, R. Soos
L. Sabato, L. Mether, G. Iadarola
P. Kicsiny, X. Buffat
P. Kicsiny, X. Buffat, D. Schulte
D. Di Croce, G. Iadarola, F. Vanderveken, T. Pieloni, SDSC
ML for DA optimization
Polarization and SPIN tracking
SITROS
Y. Wu, F. Carlier, T. Pieloni EPOL team

Great Progress



Consistency - Benchmarking

- Important to **benchmark** new tools with existing codes
  - Simple examples before **multiple effects**
  - **Understand** possible inconsistencies
- Extensive study benchmarking **XSuite** since this is a primary tool
  - **Optics** with radiation and tapering compared to optics codes (MADX,SAD)
  - **Dynamic** aperture with and without radiation (MADX, SAD, MADX-PTC)
  - **Emittance** from tracking
    - Compared to other **tracking** codes
    - Compared to matrix **methods**
  - Radiated **photon spectrum**



FCC-ee survival plot with radiation using SAD (top) and Xtrack (bottom)

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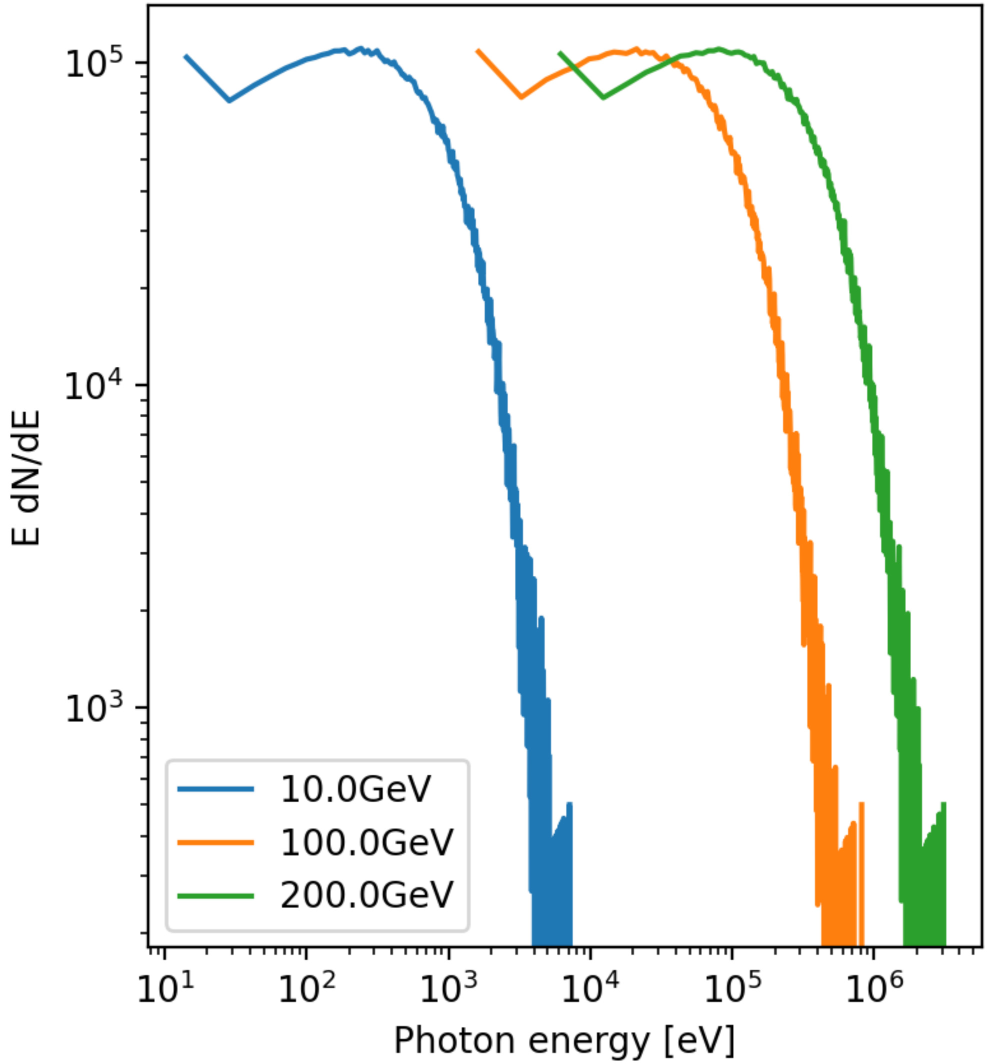
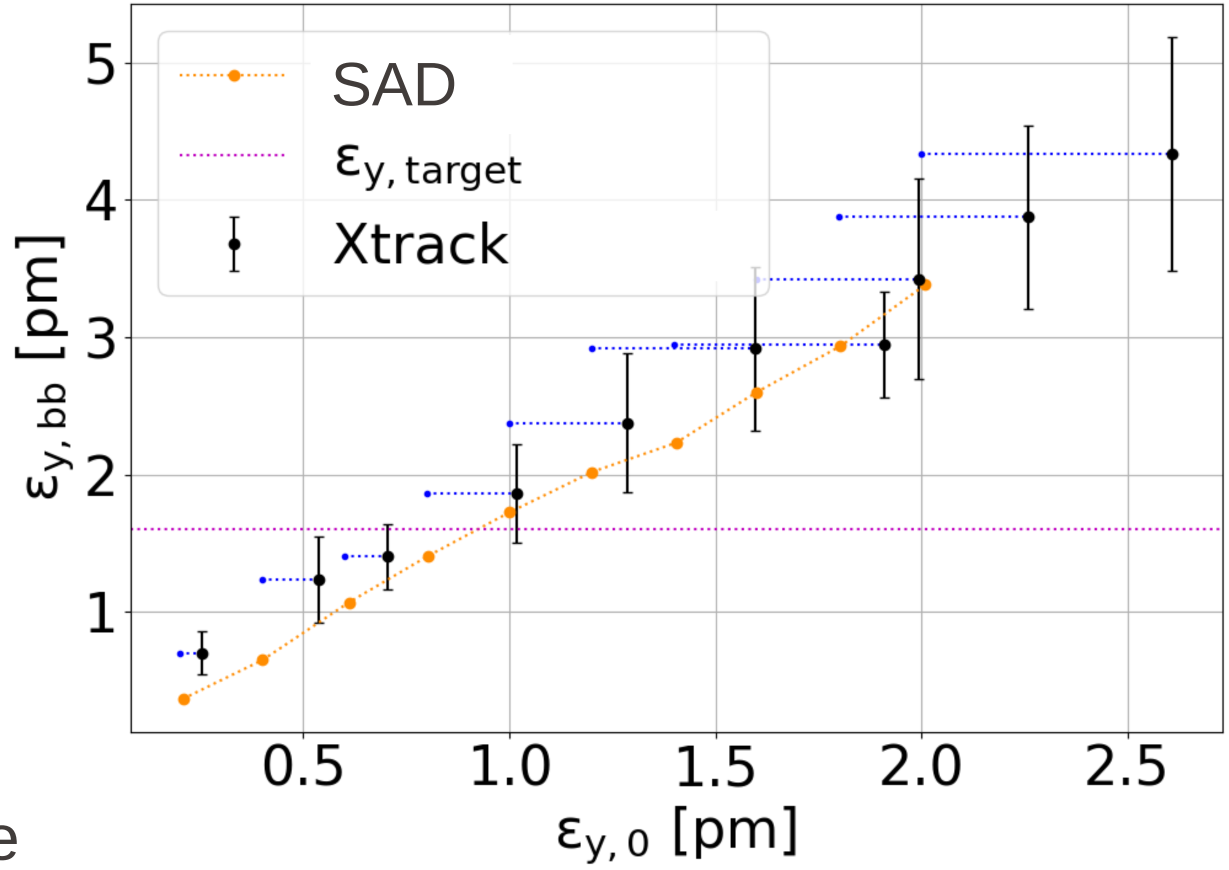


Power spectrum of photons emitted in 2T dipole at different energies in XSuite

First Results: Optics, Beam-Beam and Emittance

- First example of “**bringing it together**”
  - Optimising optics of the machine
  - Including beam-beam effects
  - Tracking in lattice for emittance and beam-beam
- Full **benchmarking** with previous studies
- Many upcoming studies for FCC-ee
  - **Tune spread** of particles in beam
  - **Dynamic aperture**
  - **Emittance** evolution



Emittance increase due to beam-beam from tracking in XSuite for various lattice emittances compared to SAD results. (Preliminary)

Conclusion

- Large amount of different software used for FCC-ee and accelerators in general
  - Many different unique purposes
  - Dependent on specialised development and knowledge of few experts/labs
- Improved interoperability by
  - Facilitating conversion and model management
  - Contribute to the development of modern broader tools
    - Steer towards and use for FCC-ee purposes
    - Benchmark against established codes
    - Many meaningful contributions by CHART colleagues
- First studies using new tools underway contributing to the FCC-ee study