Positron source:

Modelling and benchmarking studies.

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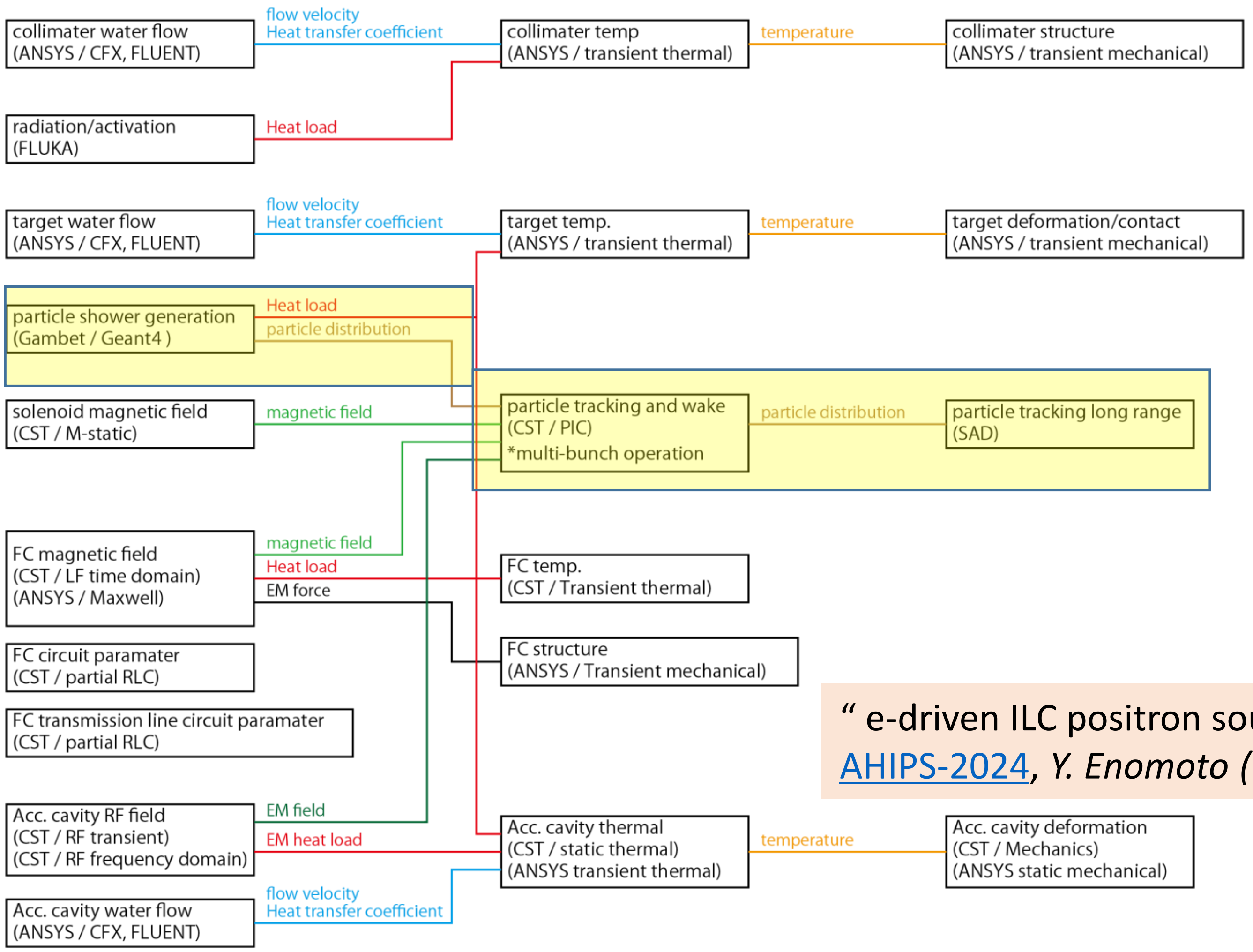
Outline

- Positron production and tracking: modelling and simulation tools.
- Example of benchmarking study performed at SuperKEKB positron source.
- Machine learning in application to the FCC-ee positron source optimization.
- Summary and conclusion.

Simulation flow of positron source

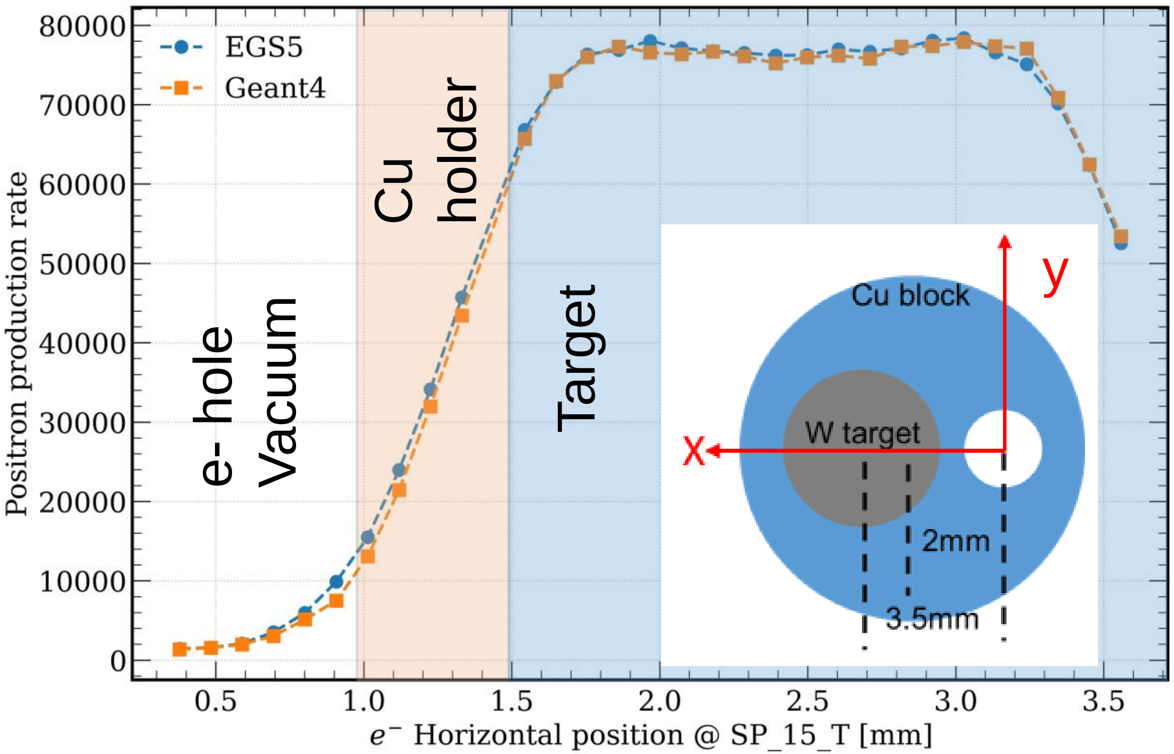


" e-driven ILC positron source and prototyping at KEK", AHIPS-2024, *Y. Enomoto (KEK)*

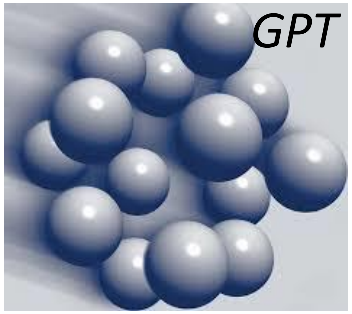
- Simulation of the passage of particles through matter (**target & positron production**)

[1] [2] [3] [4] [5]

- An example of simulation to simulation comparison , for the **SuperKEKB target**.



Positron production modelling and simulation tools.



Positron capture & tracking :

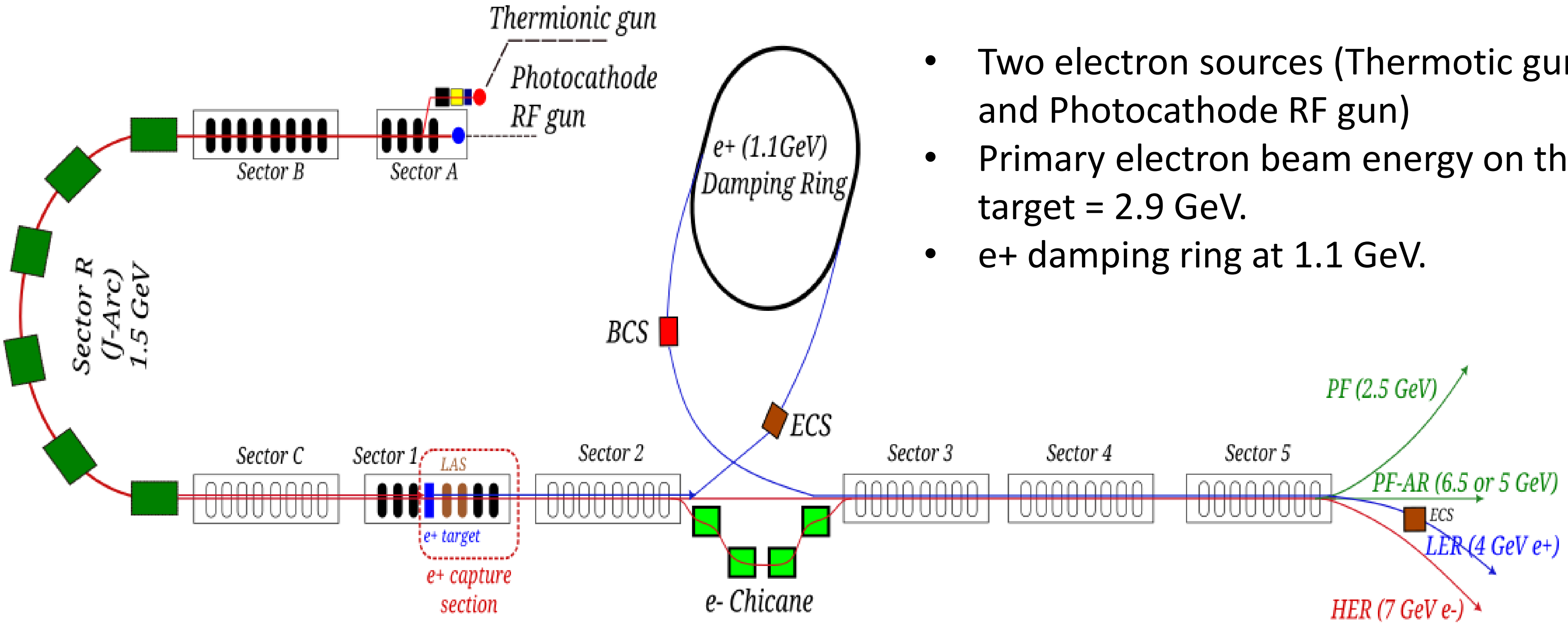
- RF-Track. [6]
- A Space Charge Tracking Algorithm (ASTRA). [7]
- General Particle Tracer (GPT). [8]

- Simulation tools used for the FCC-ee positron source, starting for the production until the damping ring are based on : ***Geant4 and RF-Track*.**
- Validation and benchmarking of the simulation model is indispensable.
- To do so , multiple measurements are performed at the SuperKEKB positron source.

Example of benchmarking study performed at SuperKEKB positron source.

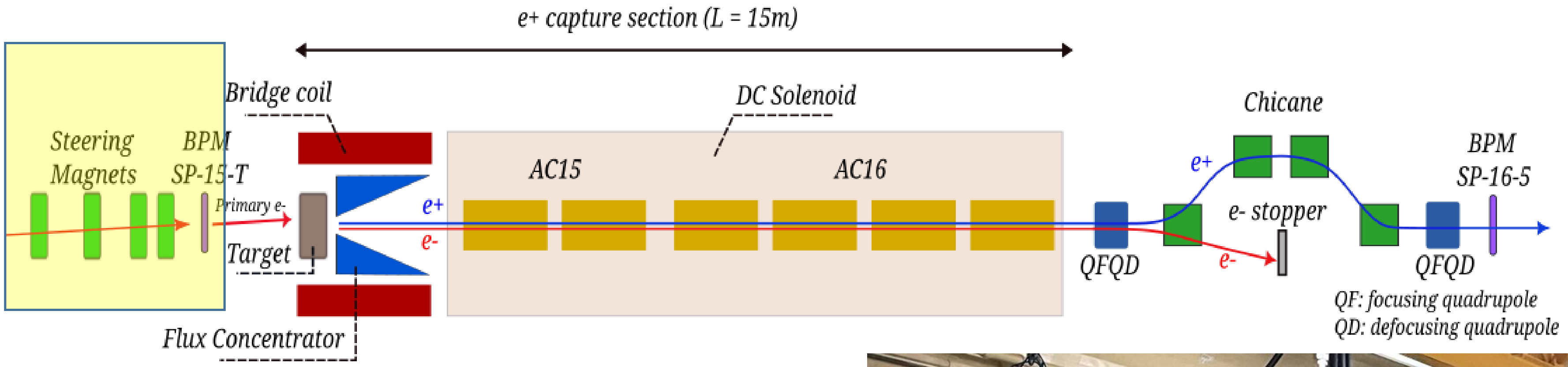
SuperKEKB injector

- SuperKEKB is an electron positron collider with highest record of luminosity.
- Positron source at SuperKEKB is the current stat-of-the-art with the highest intensity.



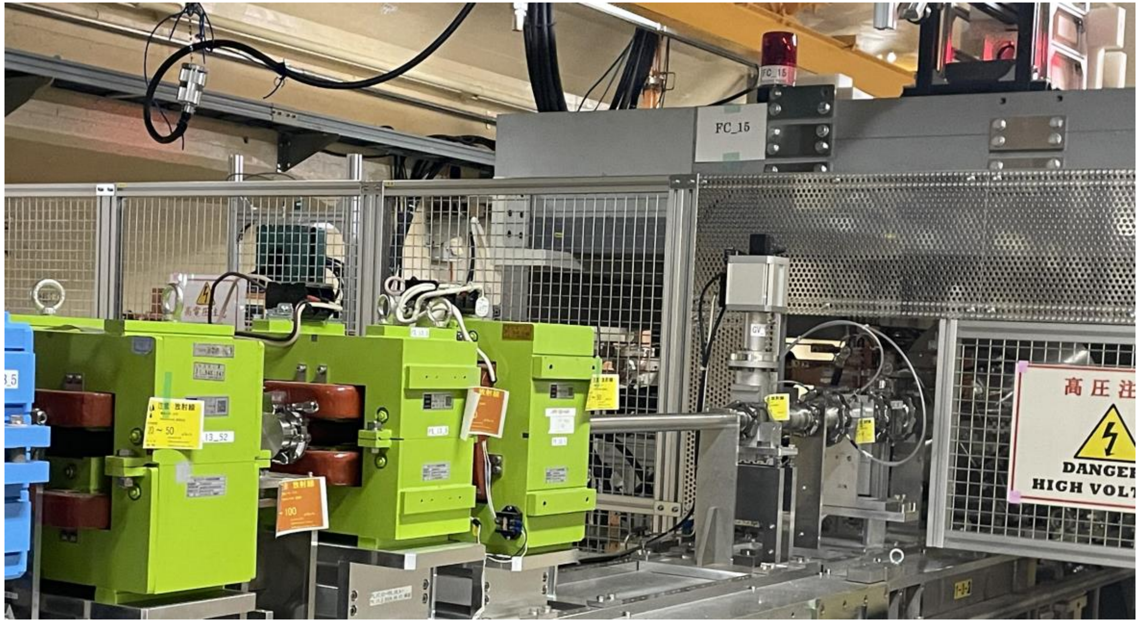
- Two electron sources (Thermotic gun and Photocathode RF gun)
- Primary electron beam energy on the target = 2.9 GeV.
- e+ damping ring at 1.1 GeV.

SuperKEKB positron source

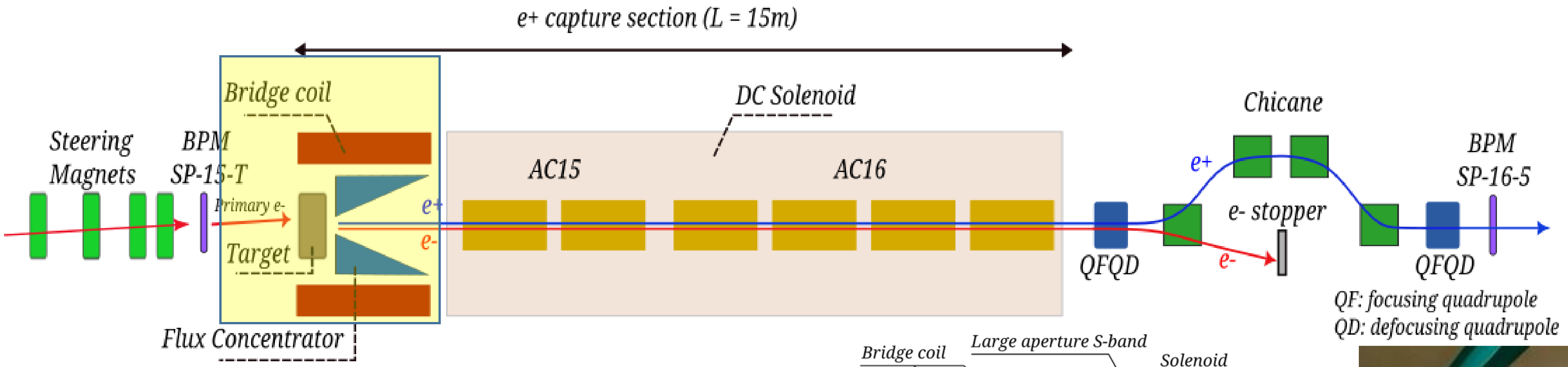


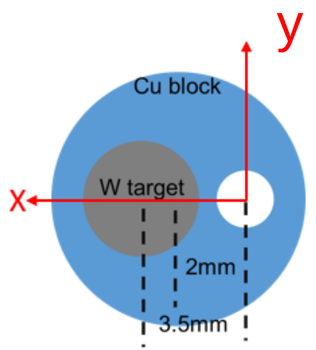
- **Four steering magnets** (horizontal and vertical) placed upstream of the target to guide the beam off-axis.

- **BPM: SP_15_T** used to measure the charge and the position of the primary electron beam.

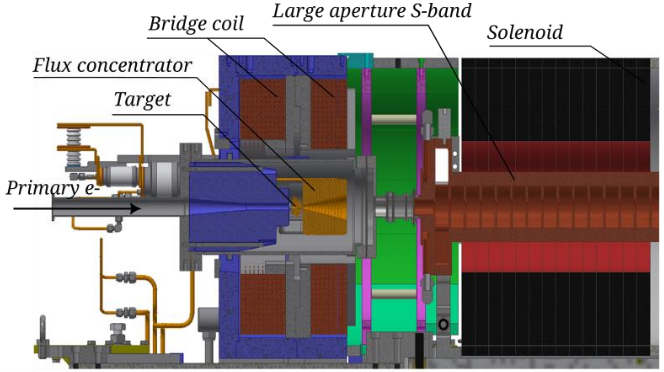


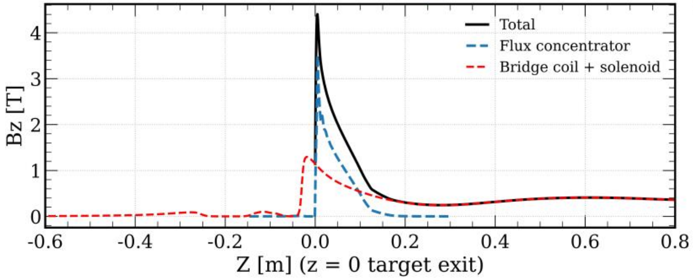
SuperKEKB positron source



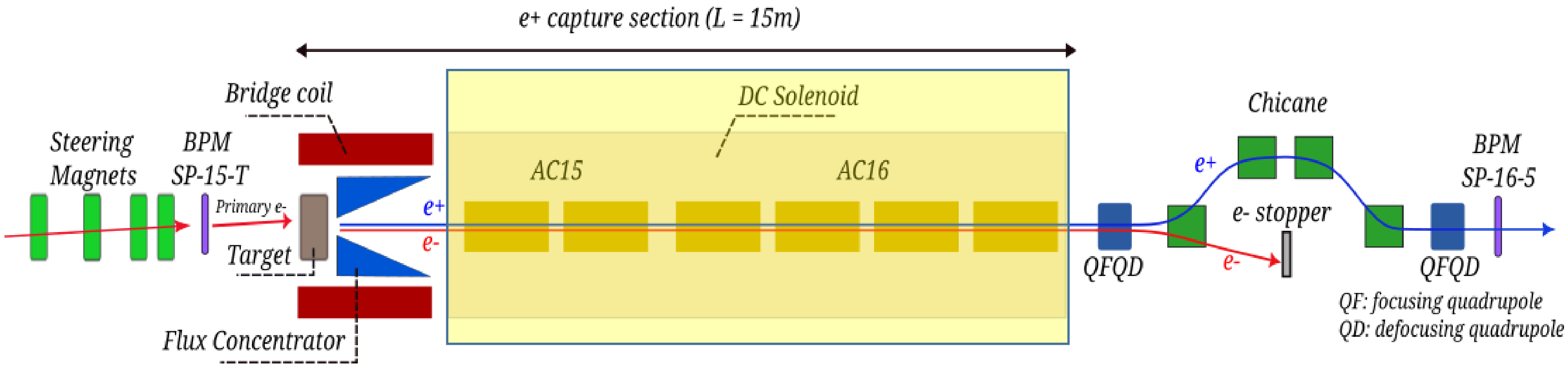


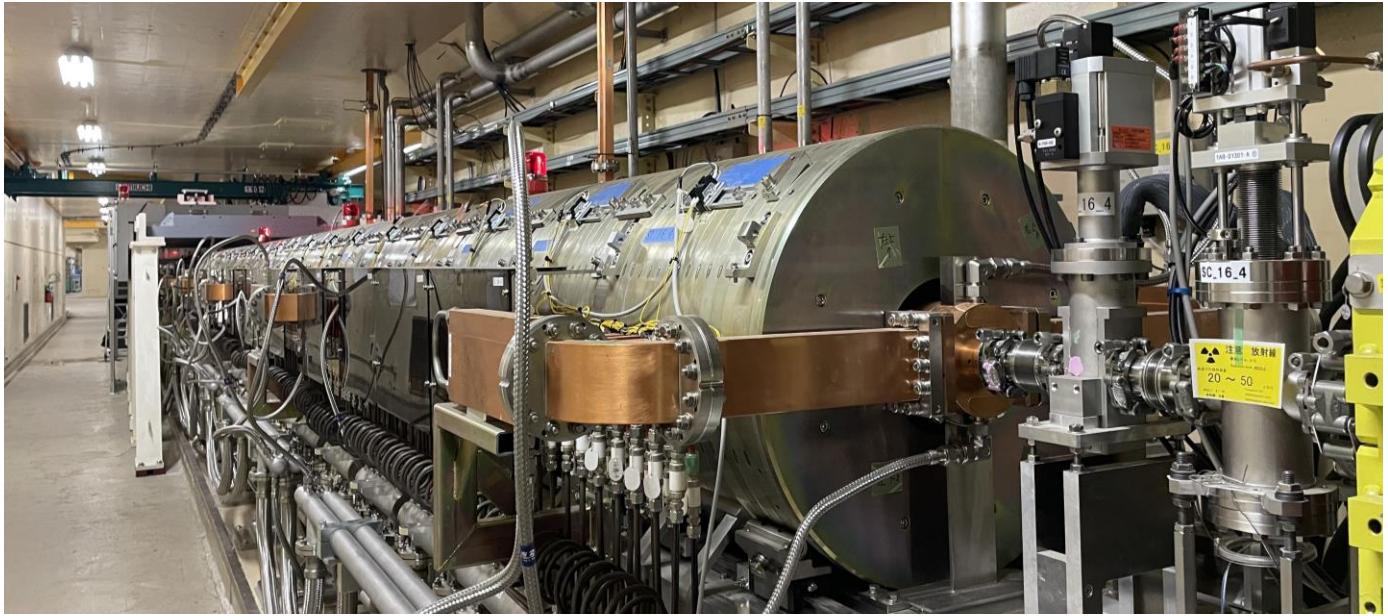
- **Tungsten target** with 14mm thickness and 4mm diameter.
- **Target placed** off-axis to allow HER e- beam to pass.
- **Flux concentrator** used as a matching device with a **bridge coil** to increase the field.





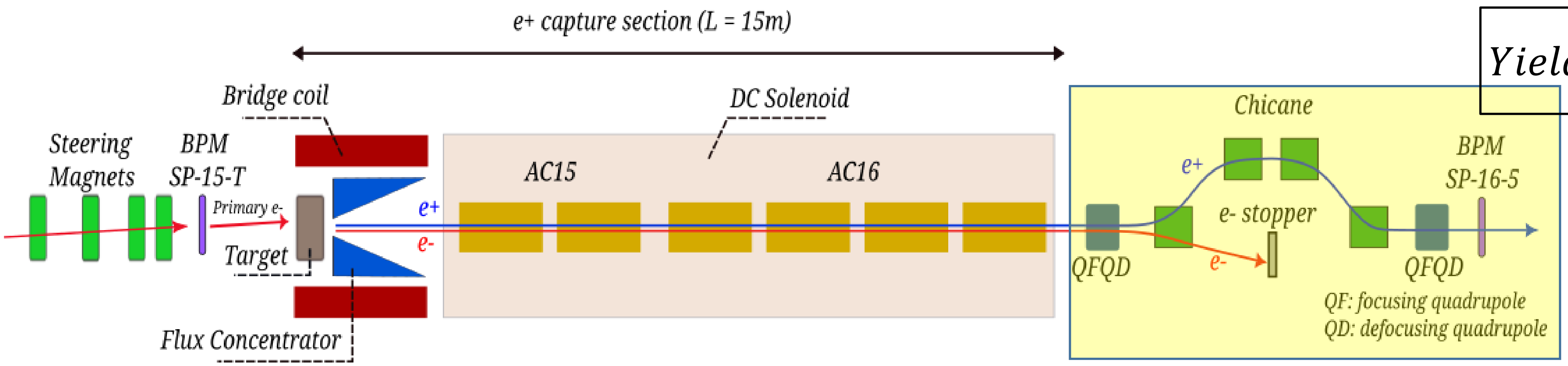
SuperKEKB positron source





- **Two Klystron units** (KL15, KL16) are powering 6 RF Large aperture S-band structures.
- **Gradient**: KL15 = 8.13MV/m KL16 = 9.47 MV/m
- **Normal conducting solenoid** surrounding the RF structures with peak field = 0.5T.

SuperKEKB positron source

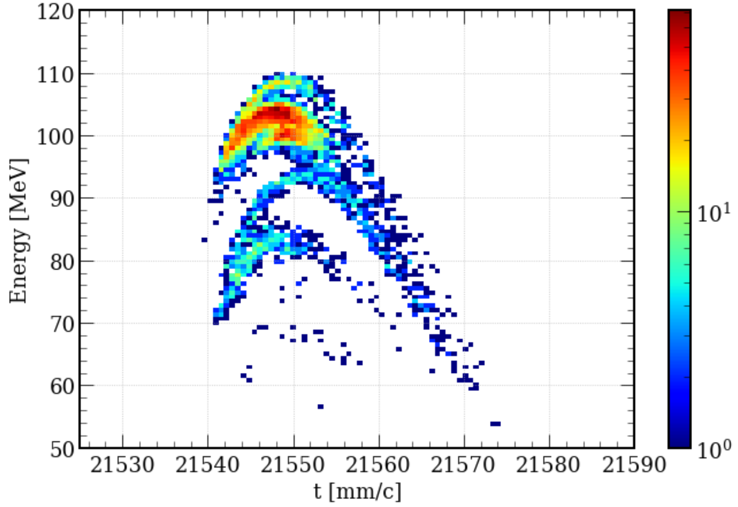


$$Yield = \frac{Q\ @(SP\_16\_5)}{Q\ @(SP\_15\_T)}$$

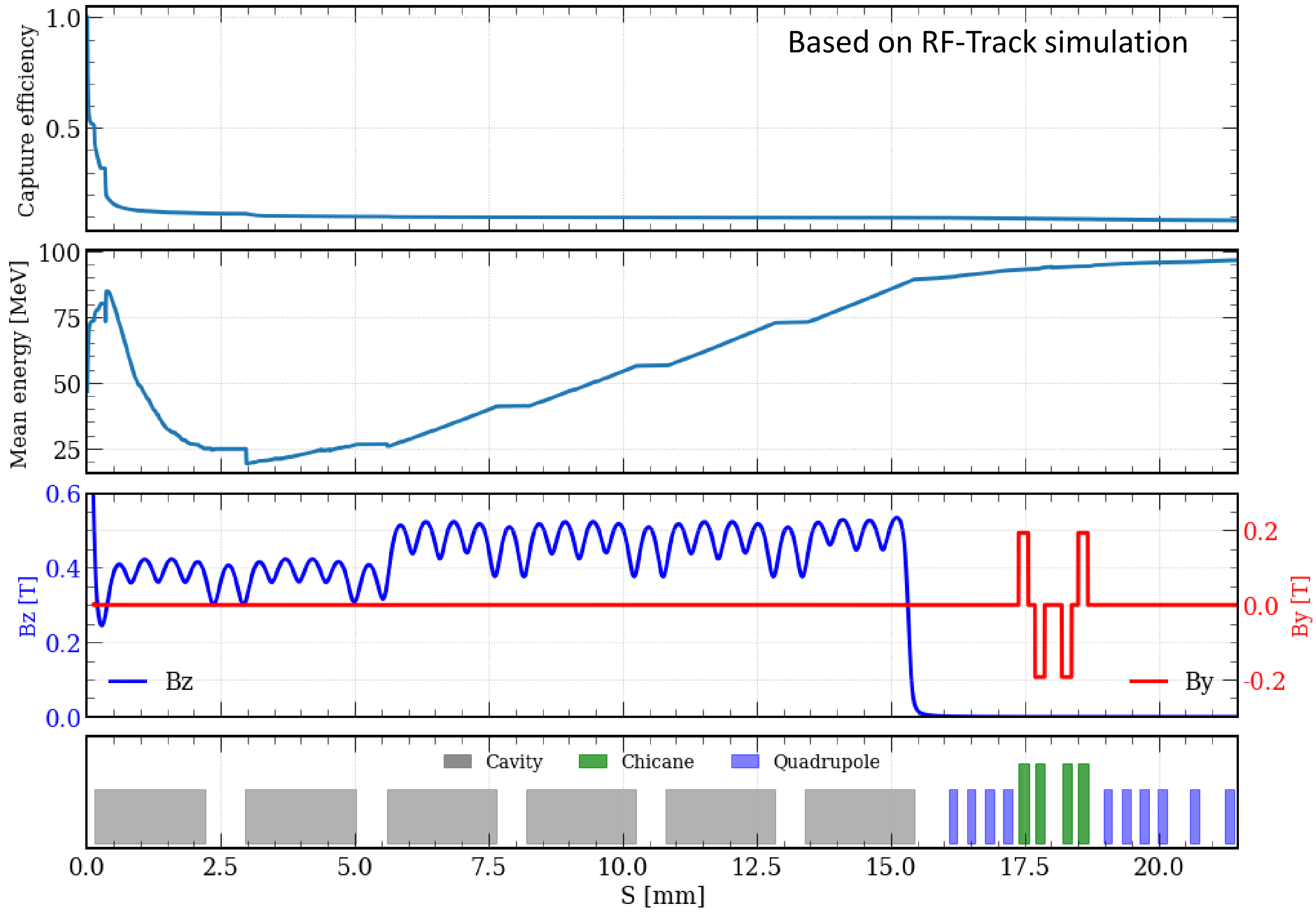
- **Series of focusing / defocusing quads** placed at the exit of the solenoid channel.
- **Chicane**: 4 dipole magnets with peak field = 0.2T.
- **e- stopper** is placed at the center of the chicane to stop the secondary e-.
- **BPM SP_16_5** : used to measure the position and the charge of the e+ beam

Tracking in the capture section – nominal parameters

- Most of the positron losses observed at the entrance of the first RF-structure.
- Positron yield: after the target = 7.6, and at the location of SP_16_5 = 0.61

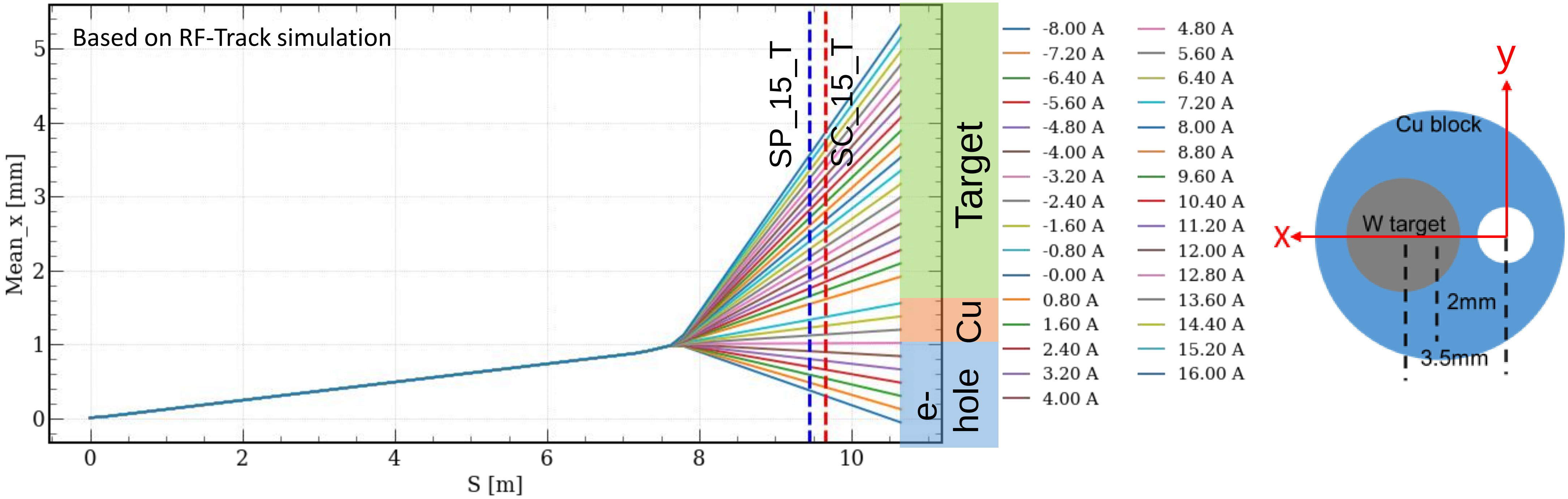


Longitudinal phase space at SP_16_5



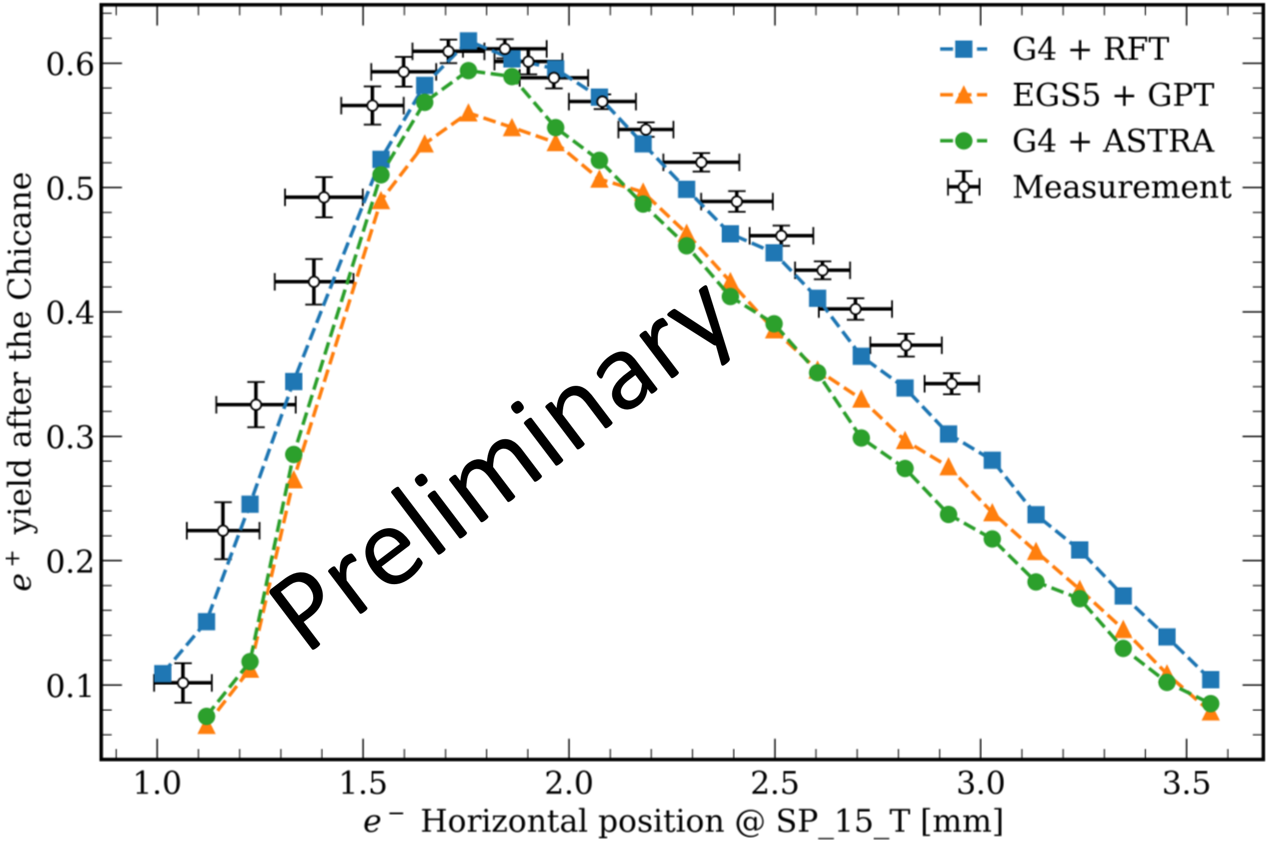
Primary electron beam - position scan on the target

- The upstream magnets are included in the simulation environment to estimate the primary electron beam position in SP_15_T and on the target.
- Primary electron beam imping in the target with angle causing the beam to travel longer in the target => more positron produced.



Primary electron beam - position scan on the target

- Horizontal position scan on the target , an example of the benchmarking study.



- Measurements performed during the benchmarking study:
  - Primary e- position scan on the target (horizontal & vertical)
  - Solenoidal field (around the structures) current/field scan.
  - 1D & 2D RF phase scan of the RF structures in the capture linac.

- Simulation results are in a very good agreement with measurement (**article in preparation**).

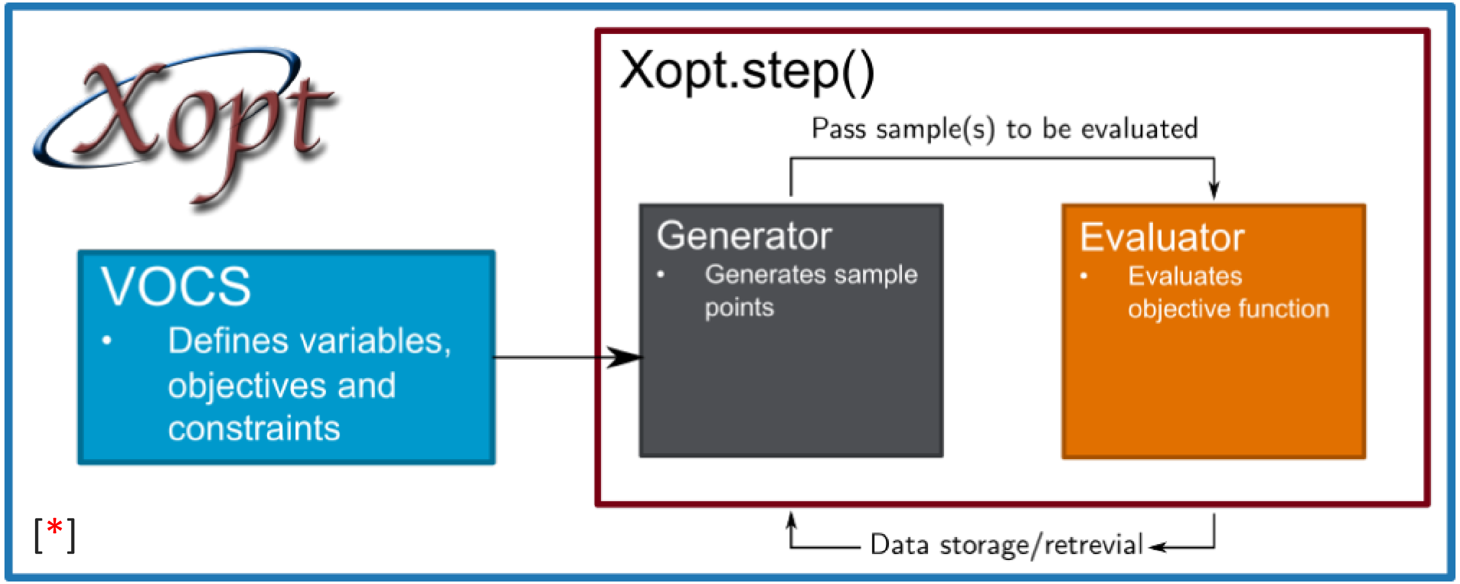
$$Yield = \frac{Qe^+ @(SP\_16\_5)}{Qe^- @(SP\_15\_T)}$$

Machine learning in application to the FCC-ee positron source optimization

Machine learning optimization in application to the FCC-ee positron source

- X-opt is a python package (developed at SLAC) dedicated to provide advanced algorithmic support for arbitrary optimization problems (simulations/control systems) with minimal required coding.

[9]



Examples of the available Optimization algorithms:

- Genetic algorithms
- Bayesian optimization (BO) algorithms

[*] R. Roussel et al., "Xopt: A simplified framework for optimization of accelerator problems using advanced algorithms", in Proc. IPAC'23, Venice, Italy . doi:10.18429/JACoW-IPAC2023-THPL164

X-opt in application to the FCC-ee positron source optimization

- Application to the FCC-ee positron source.
  - RF phases optimization of the accelerating structures in the capture linac (used in the baseline).
  - A-start-to-end optimization of the FCC-ee positron source.

- As a starting point we considered the **positron production** and tracking in **the capture section**.

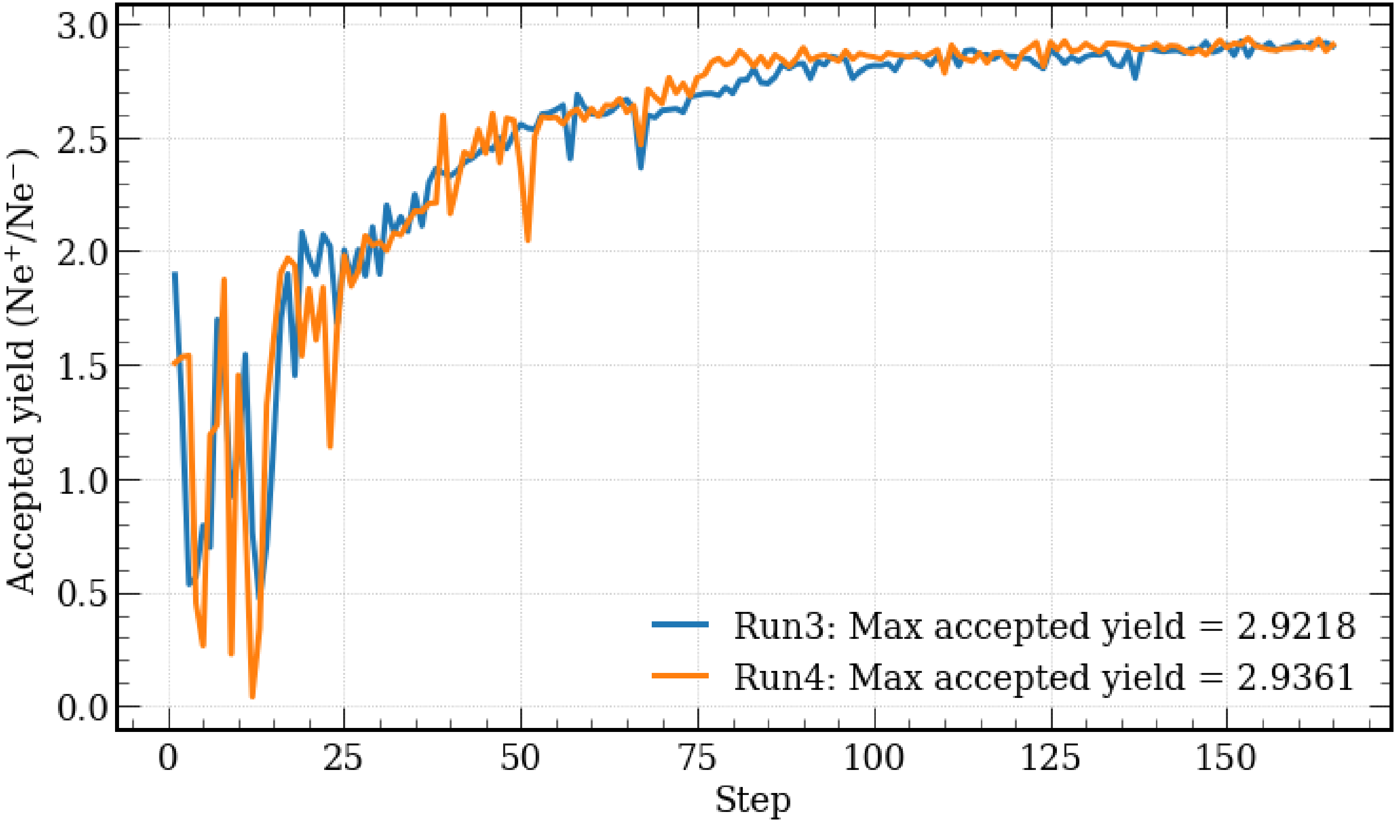
  - 11 variables with constraints.
  - 3 variables related to e+ production.
  - 8 variables related to e+ capture and tracking.

  - Objective: maximize the accepted yield.

```
# Define the VOCS with 11 free parameters: 2 beam sizes,
# target thickness, target position, and 7 RF phases
vocs = VOCS(
    variables={
        "bsizx": [1, 1.5],           # Beam size in X
        "bsizy": [1, 1.5],           # Beam size in Y
        "thk": [13, 17],             # Target thickness
        "target_position": [20, +50],  # Target position
        "phs1": [200, 360],            # RF phase 1
        "phs2": [200, 360],            # RF phase 2
        "phs3": [200, 360],            # RF phase 3
        "phs4": [200, 360],            # RF phase 4
        "phs5": [200, 360],            # RF phase 5
        "phs6": [200, 360],            # RF phase 6
        "phs7": [200, 360],            # RF phase 7
    },
    objectives={"accepted_yield": "MAXIMIZE"},
)
```

X-opt in application to the FCC-ee positron source optimization

- Preliminary results of the start-to-end optimization (with 11 free parameters).
- After 4 runs (each run is 165 steps) the accepted yield converges to **~2.94** (current baseline is **2.97**).



Conclusion

- We have successfully validated the FCC-ee positron source model with multiple measurements conducted at the SuperKEKB positron source, and we are finalizing a detailed paper that will be submitted shortly.

- The ongoing start-to-end optimization of the FCC-ee positron source using X-opt is yielding highly promising results.

- Next step: Integrate the positron linac into the optimization study and conduct a multi-parametric optimization of the entire positron injector.

Thank you for your attention!

Credits

IJCLab	F. Alharthi, I. Chaikovska, R. Chehab, V. Mytrochenko, Y. Wang
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References

[1] https://geant4.web.cern.ch/
[2] https://rcwww.kek.jp/research/egs/egs5.html
[3] https://gambitbsm.org/
[4] http://www.fluka.org/fluka.php?
[5] https://phits.jaea.go.jp/
[6] https://gitlab.cern.ch/rf-track
[7] https://www.desy.de/~mpyflo/
[8] https://www.pulsar.nl/gpt/
[9] https://github.com/xopt-org/Xopt