FCC-ee positron source

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On behalf of the FCC-ee injector study collaboration

Outline

- Positron source performance.
- FCC-ee Injector layout.
- Conventional positron source (Target , Matching device , Capture linac)
- Beam dynamics and tracking.
- Crystal-based positron source (Innovative, alternative to the conventional scheme).
- Summary and conclusion.

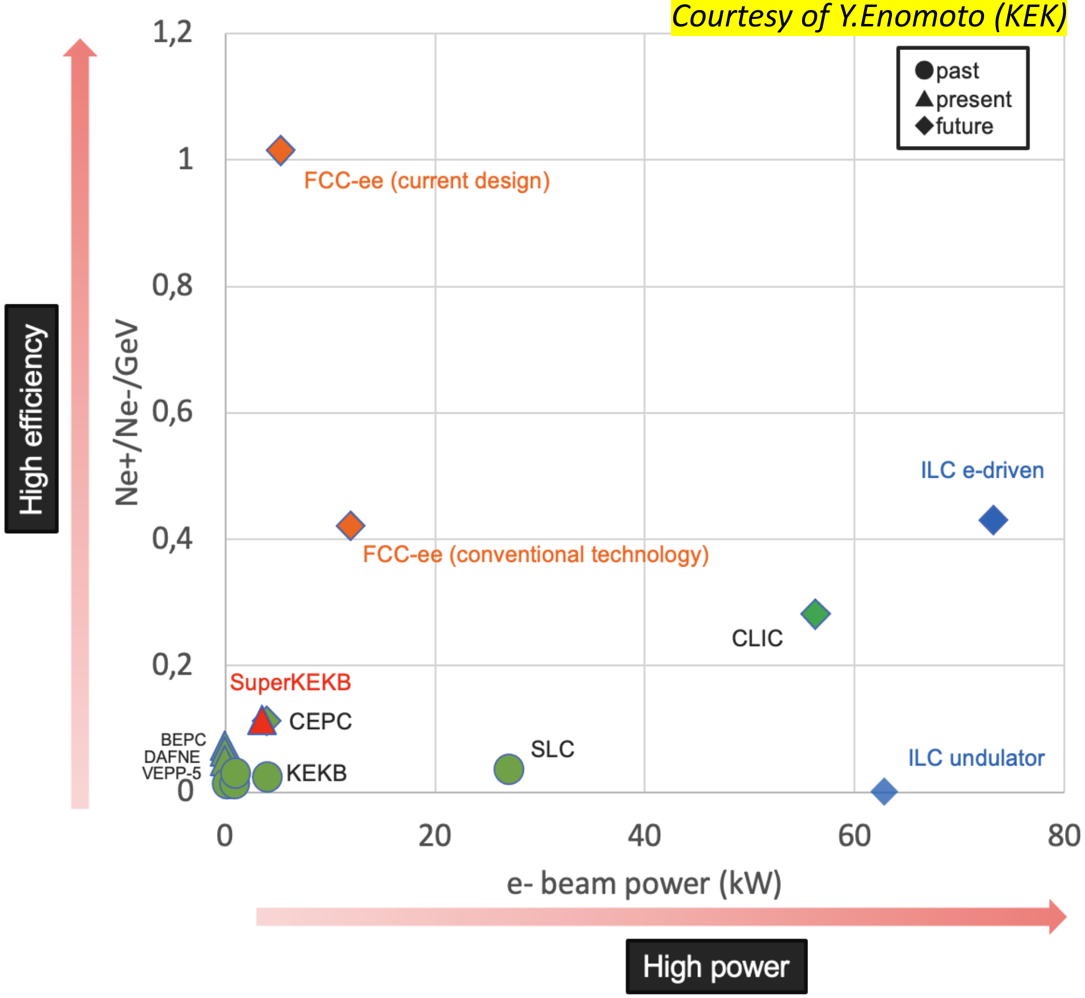
Positron sources performance

- Key factors for high positron yield:
  - Primary e- energy
  - Target design
  - Magnetic strength around the target and capture linac
  - Transverse aperture of the capture linac.

$$\eta^{e^+}_{\text{Accepted}} = \frac{N^{e^+}_{\text{DR accepted}}}{N^{e^-}_{\text{Primary}}}$$

- In the case of FCC-ee positron source, the use of an **HTS solenoid** with a peak field of **~12T** around the target together with **large aperture capture linac** can substantially increase state-of-the-art e+ yield, by one order of magnitude.

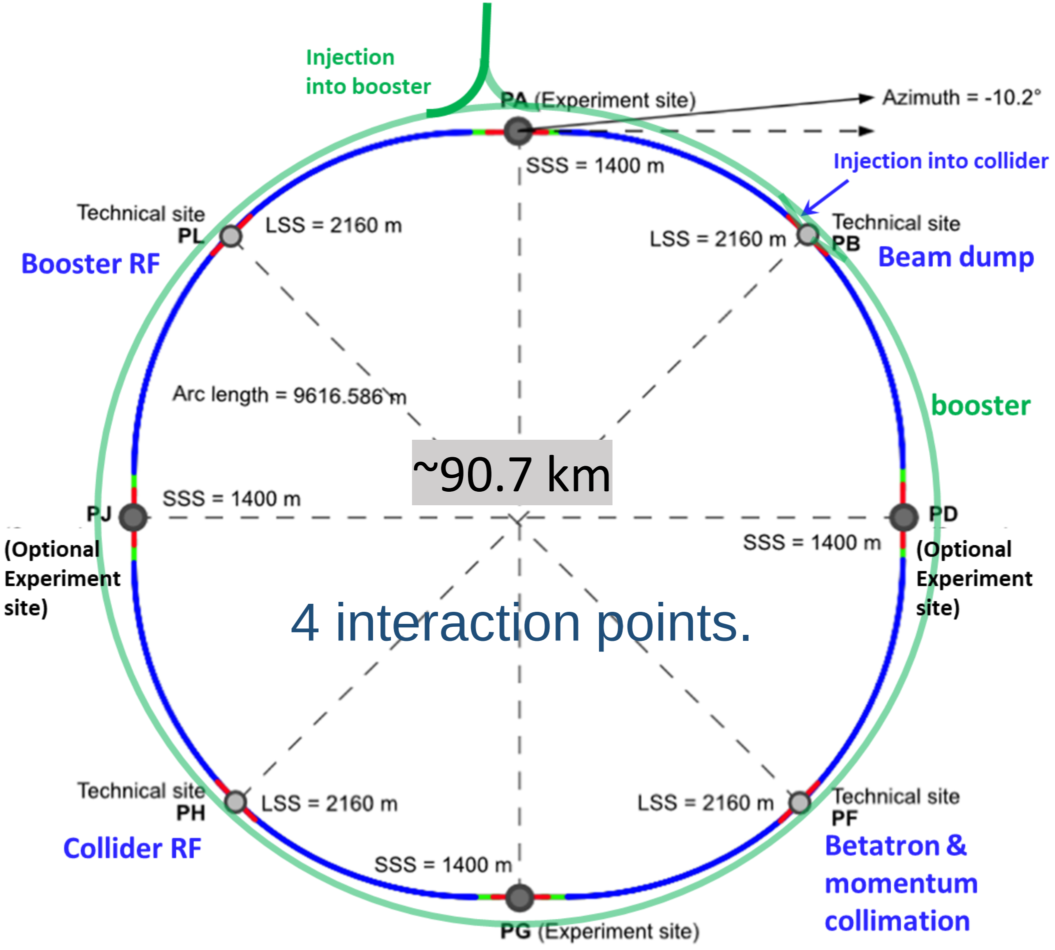
Courtesy of Y.Enomoto (KEK)



- FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities.

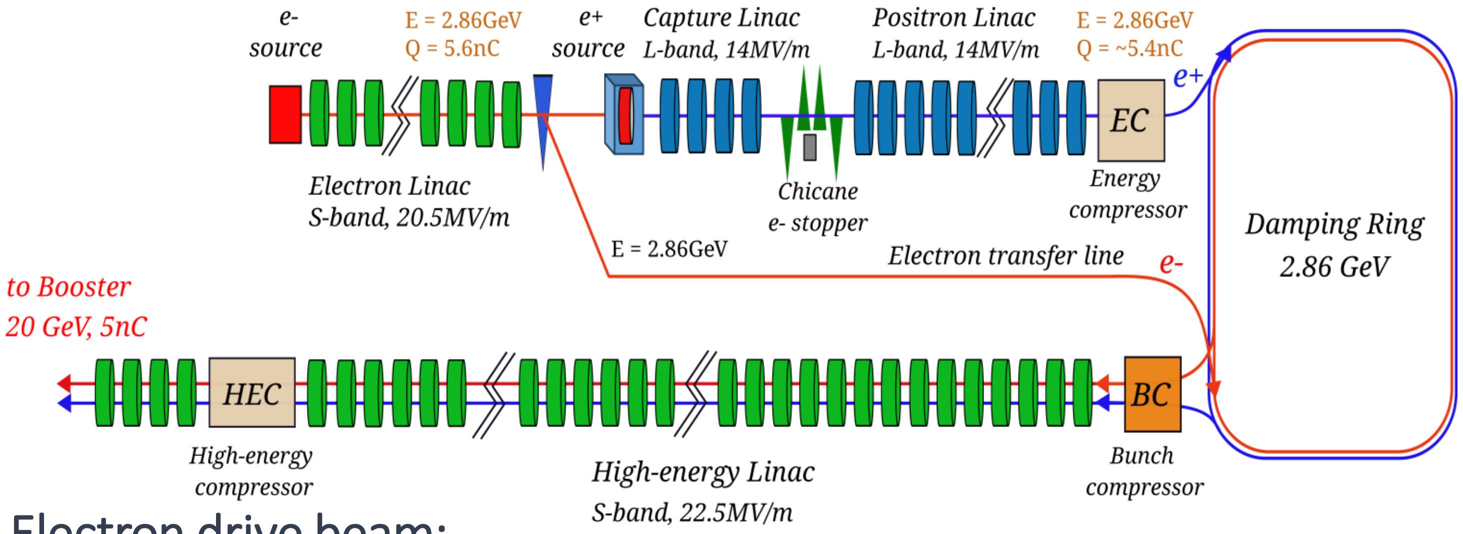
parameters	Z*	WW	H (ZH)	$t\bar{t}$
beam energy [GeV]	45.6	80	120	182.5
synchrotron radiation/beam [MW]	50	50	50	50
beam current [mA]	**1294**	**135**	**26.8**	**5.1**
number bunches / beam	11200	1852	300	64
total RF voltage 400/800 MHz [GV]	0.08 / 0	1.0 / 0	2.09 / 0	2.1 / 9.2
luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	145	20	7.5	1.4
total integrated luminosity / IP / year [ab^{-1} / yr]	17	2.4	0.9	0.17
beam lifetime [min]	21	13	9	10

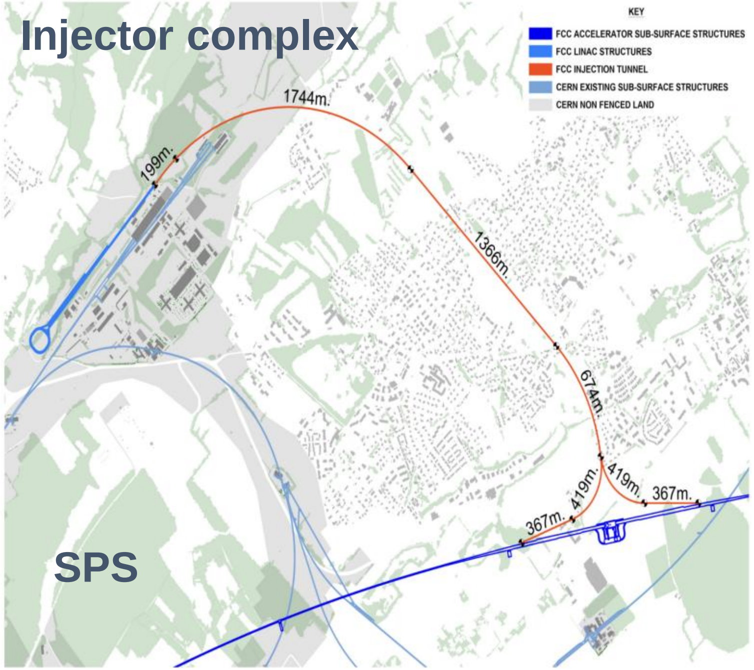
*Most demanding mode for the positron source due to the high beam current requirement.



2045 - 2065

Injector layout (Current baseline)





Electron drive beam:

Beam energy	2.86 GeV
Bunch charge	~5.6 nC (max)
Bunch length	1 mm
Bunch transverse size	≳ 0.5 mm

Nb of bunches per pulse	4
Bunch separation	25 ns
Repetition rate	100 Hz
Beam power	~6.4 kW

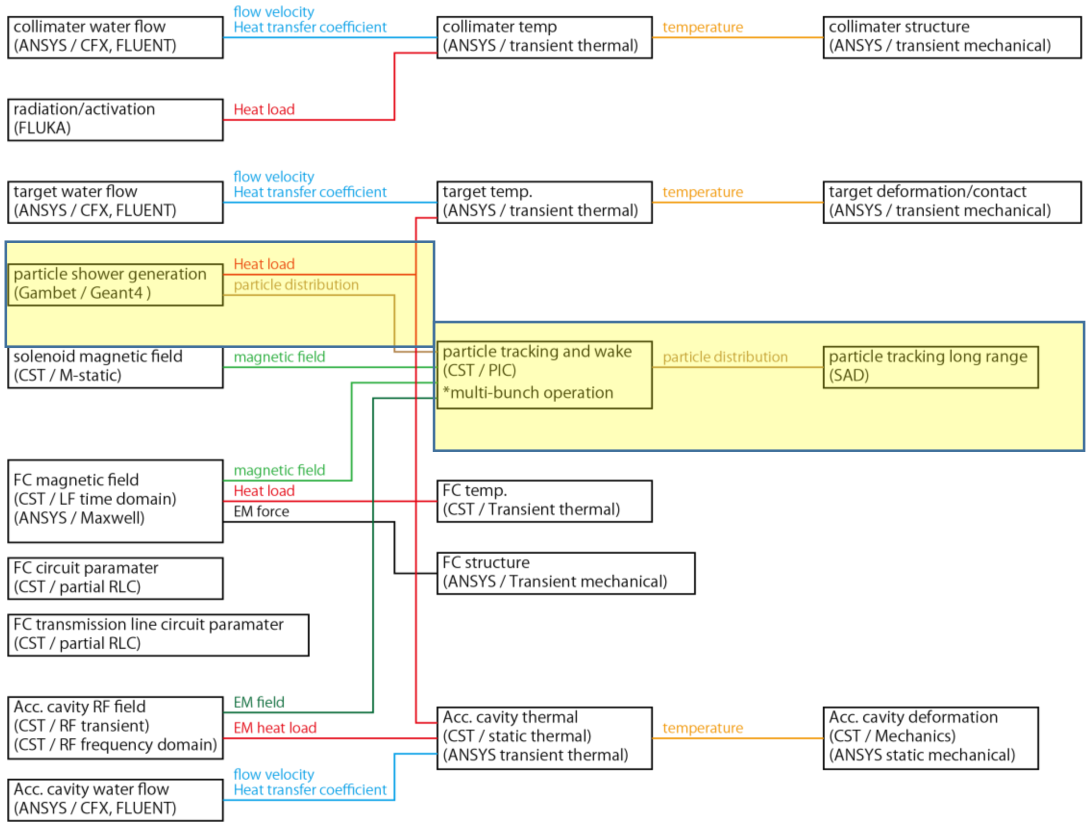
$$\eta^{e^+}_{\text{Accepted}} = \frac{N^{e^+}_{\text{DR accepted}}}{N^{e^-}_{\text{Primary}}}$$

Accepted yield with factor 2.6 safety margin*

**50% losses for injection in the DR +*
20 % losses from target up to the end of the e+ linac

- Injector complex on the Prévessin site with damping ring next to the “Decheterie”

Toward a start-to-end modeling of the positron source.

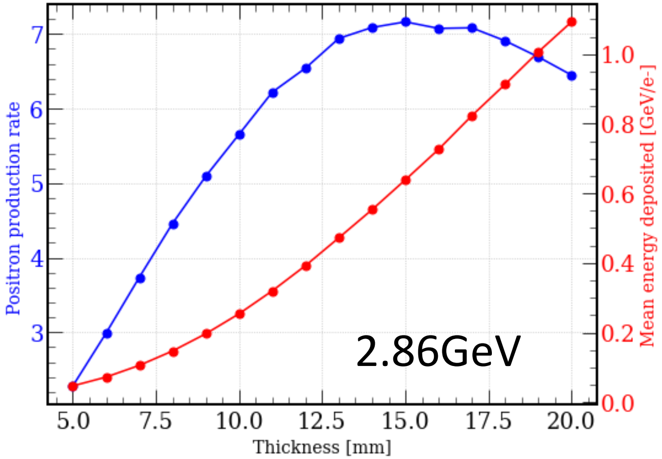


- The simulation chain is complex and interconnected.
- At its core lies the positron production and tracking up to the Damping Ring to estimate the positron yield.
- This yield drives the optimization of all downstream components.
- A flexible experimentally validated, start-to-end simulation framework is essential.

- The start-to-end simulation for the FCC-ee positron source is based on **: Geant4 + RF-Track**.
- The simulation environment has been validated experimentally at the **SuperKEKB** positron source.

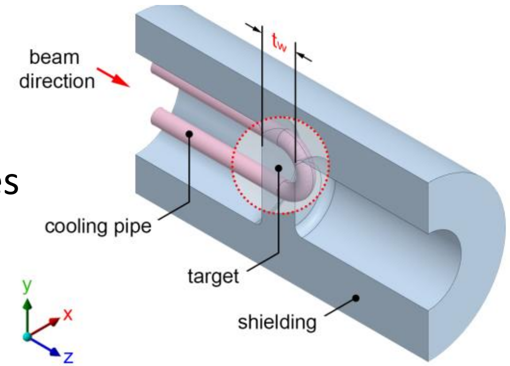
- **Conventional scheme (**Well understood and used in current and previous positron sources**)**

Bremsstrahlung -> *Pair production*



Target mechanical design: [R. Mena Andrade @CERN SY-STI]

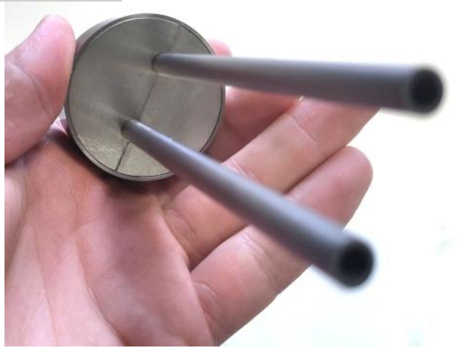
- Fixed tungsten (W) target
- Integrated shielding
- Embedded Tantalum (Ta) cooling pipes
- Symmetry around x axis (1/2 model)
- General dimensions: D70x128.5mm



Considered parameters for Positron source target:

- Positron production (*high Z-material*)
- Energy deposition (*target heating , cooling requirements*)
- Peak Energy deposition density “PEDD” (*Instantaneous, thermomechanical stress due to temperature gradient.*)
- Radiation around the target (*shielding requirements*)
- Huge emittance /angular divergence (*immediate matching*)

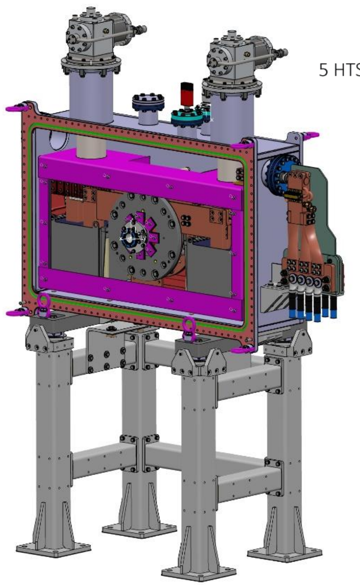
Target prototype (simplified version)

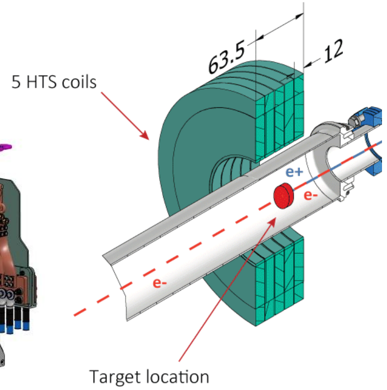


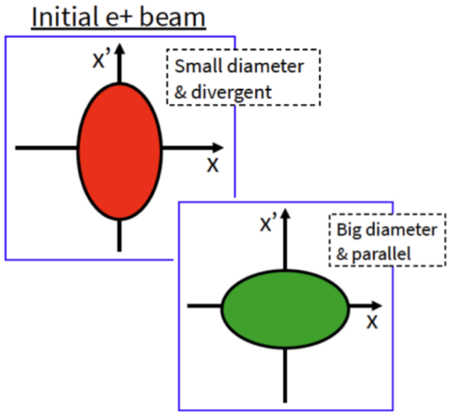
Positron source : Matching Device (Adiabatic matching device)

Matching device => a fast phase space rotation to transform the small size/high divergence in big sizes/low divergence beam

HTS solenoid integrated in the cryostat

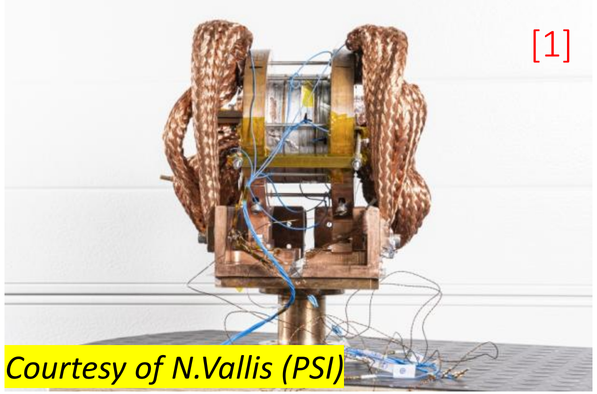


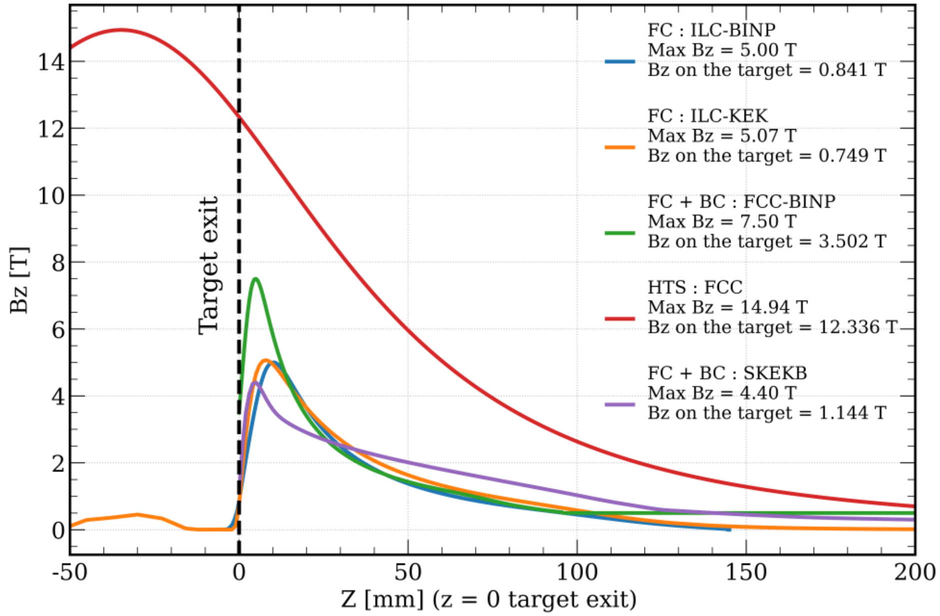




innovative in application for e^+ capture

The same HTS solenoid design and cryostat aperture as for P^3 experiment (72 mm).

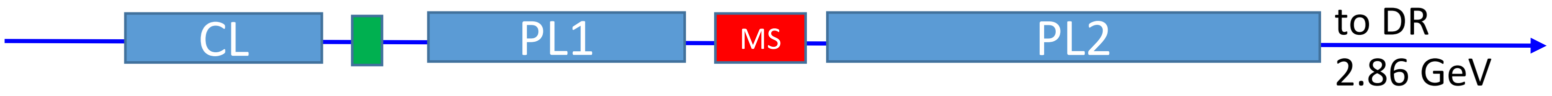


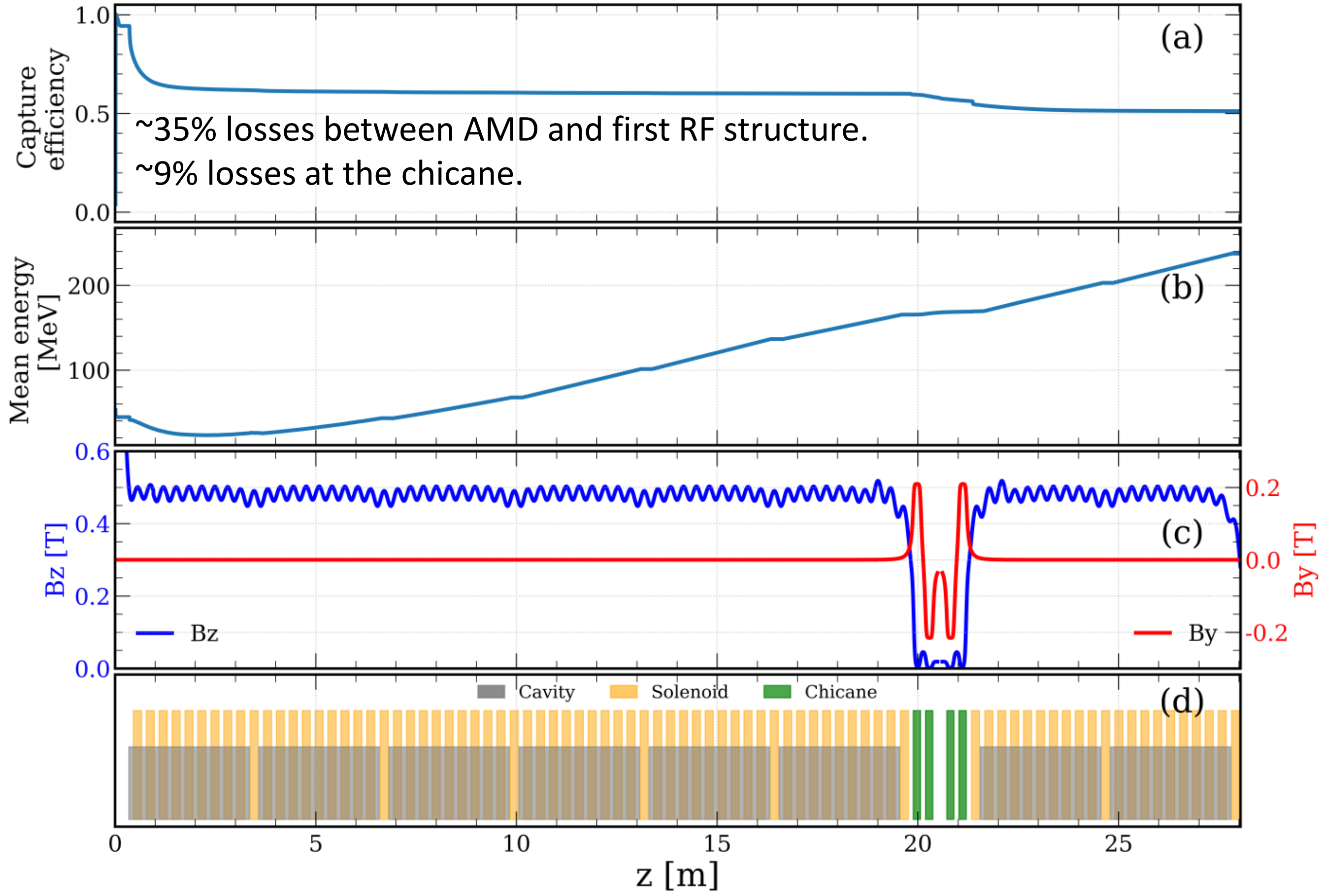


Compared with classical AMD:

- Higher peak field (~15 T, ~12 T @Target)
- Larger aperture (∅ = 30-60 mm)
- Flexible target position and field profile
- Axially symmetric solenoid field
- DC operation

Positron source : Capture LINAC



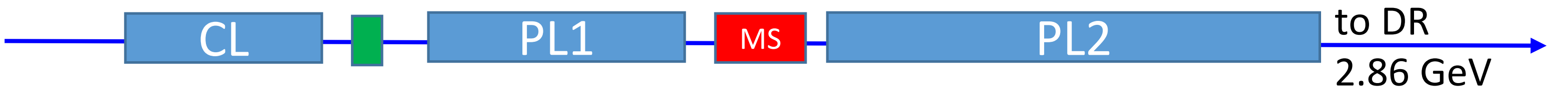


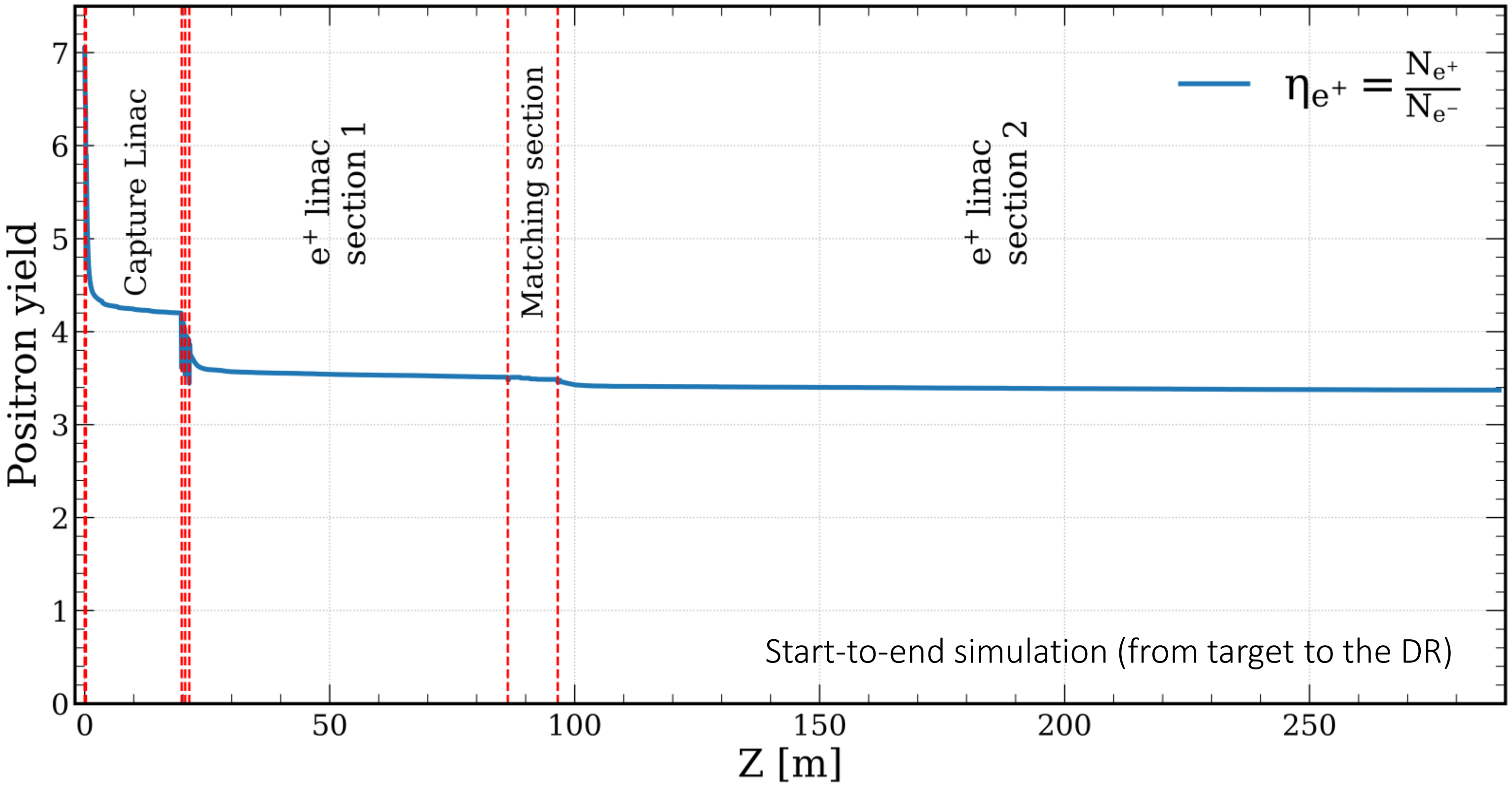
- **RF structures**: 2GHz L-band with aperture (2a) = 60mm , 3m long and 13.1MV/m.

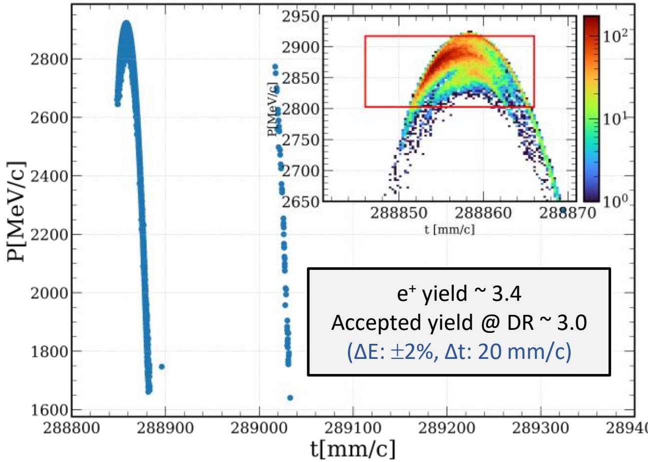
- **Solenoids**: 10 NC short solenoids surrounding each RF structure to create 0.5T magnetic channel.

- **Chicane**: 4 dipoles (0.2T) to separate e- and e+, with electron stopper at the middle (to be updated).

Positron source: Positron LINAC overall efficiency



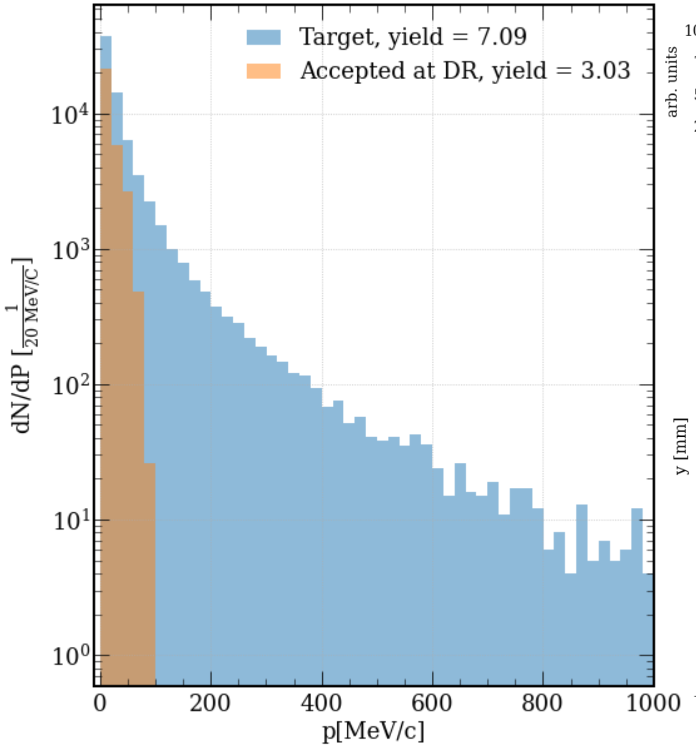


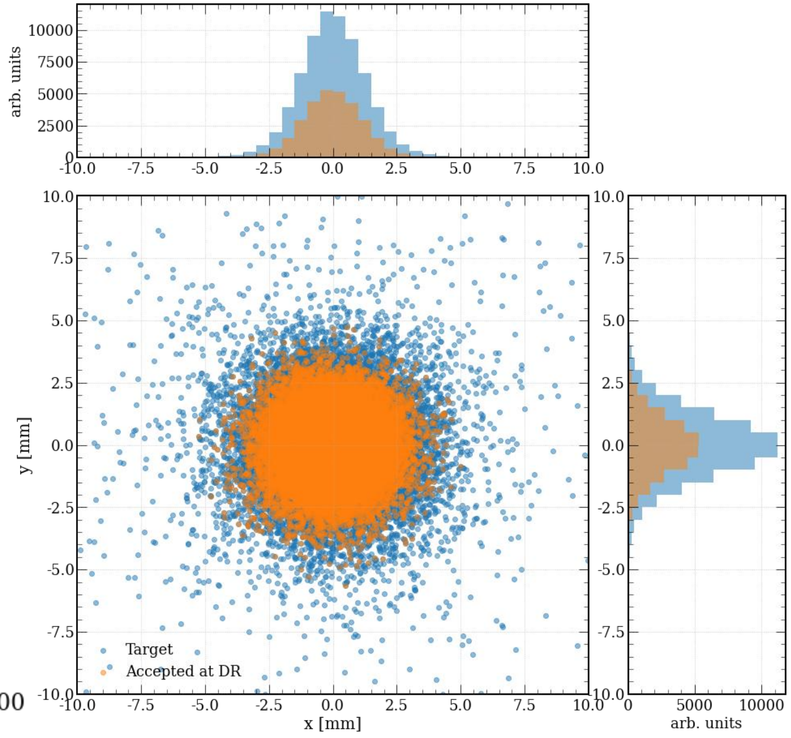


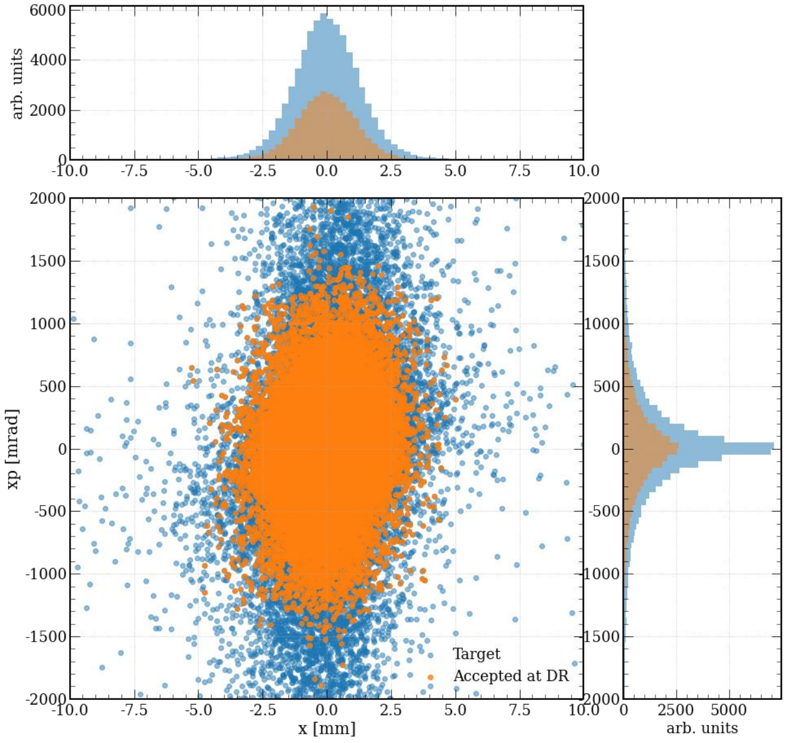
Positron source design ensures reliable e^+ production and meets the requirements set by FCC-ee (Z-pole) with the safety margins.

Which positrons are accepted by the DR ?

- Momentum : accepted positrons ≤ 100 MeV/c
  Primary factor
- Transverse aperture and divergence:
  Secondary factor.



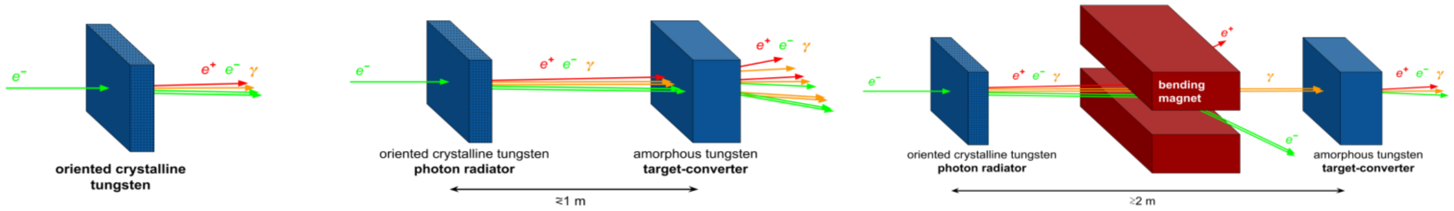


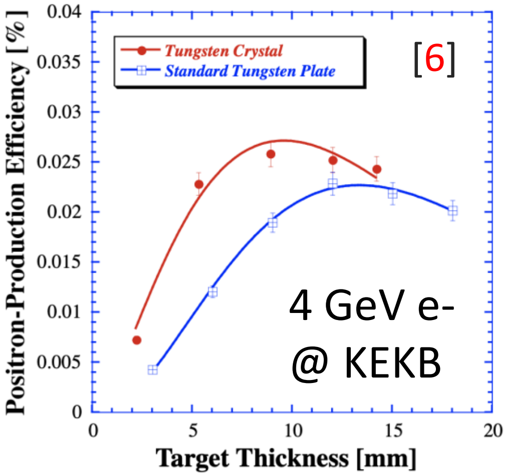


More positrons in the low energy spectrum with lower divergence => increase the accepted yield.

Crystal-based positron source

- Originally proposed by R. Chehab, A. Variola, V. Strakhovenko and X. Artru [2].
- Several experiments performed: (Orsay[3], WA103@CERN[4] and KEK[5]) in the 1 – 10 GeV region.
- Three approaches have been studied experimentally.



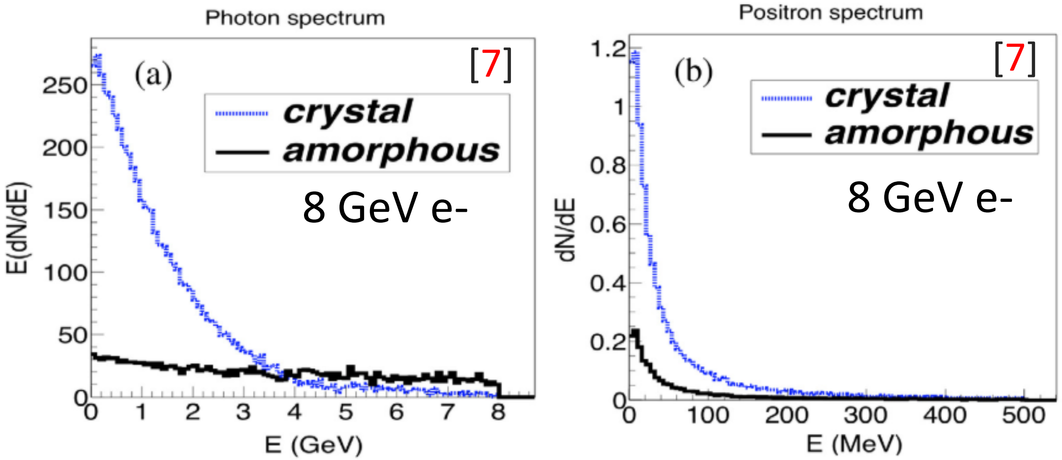


Use of lattice coherent effects in oriented crystals (W) <111> : channeling and over barrier motion

— Enhancement of photon generation in oriented crystals

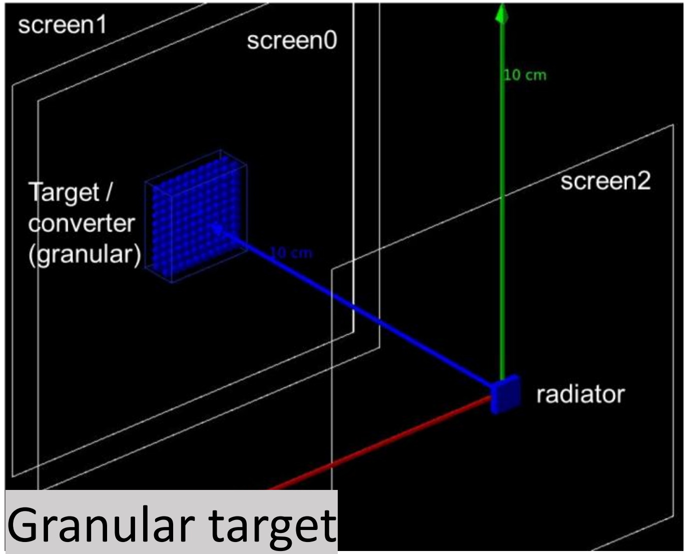
— Soft photons will generate the soft positrons → easier to capture by matching devices.

— Lower energy deposit and PEDD in target → lower heating and thermo-mechanical stress (target reliability)

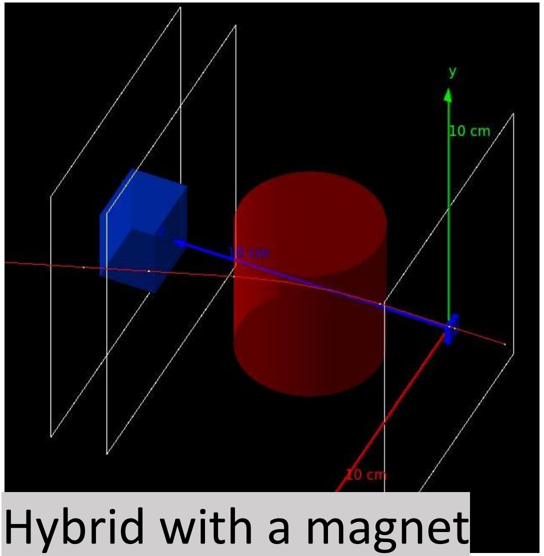


PositronSource Geant4 application

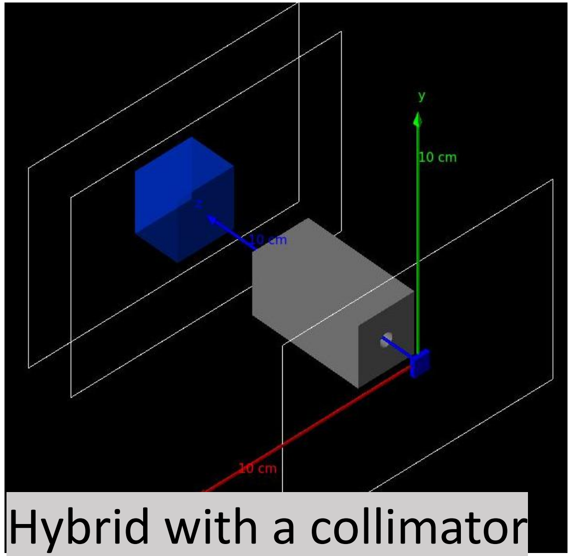
- Channeling simulation in Geant4: novel *G4ChannelingFastSimModel* and *G4BaierKatkov* classes were developed and embedded in Geant4 (since 11.2.0 version). These models are based on CRYSTALRAD [by A. Sytov [8]] ==> The model has been validated experimentally. [9]
- ***PositronSource***: is a Geant4 application developed to simulate different configuration of positron source, [developed in collaboration with INFN Ferrara (G. Paternò)].
- The application is fully compatible with **multi-threading** and everything can be controlled via **macro commands**.
- The application is planned to be included in the Geant4 extended example.



Granular target

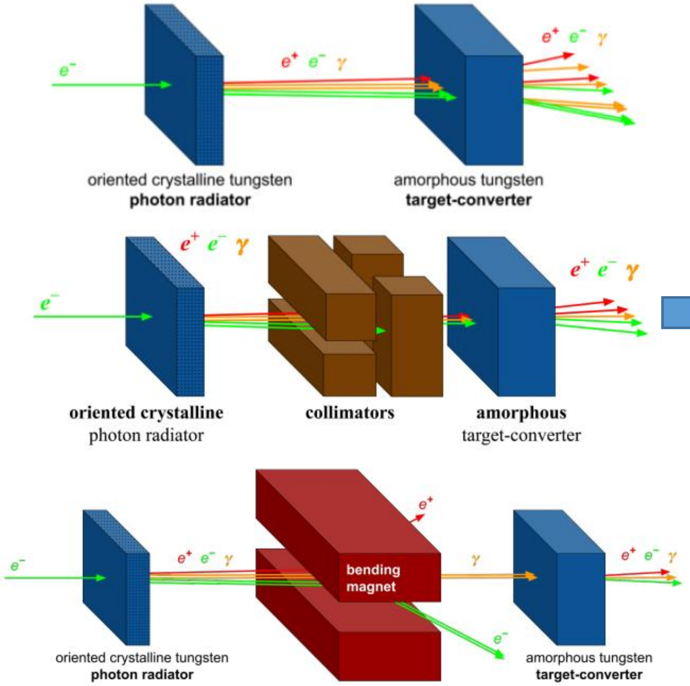


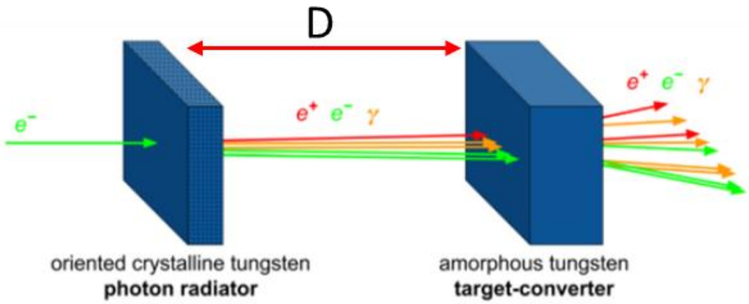
Hybrid with a magnet



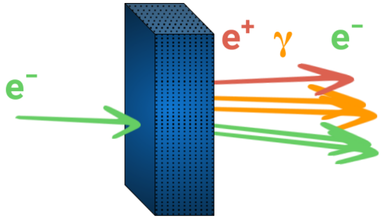
Hybrid with a collimator

- Several setups have been simulated.
- In the case of FCC-ee positron source, the simulation results converged to single thick crystal, acting as a radiator and convertor.





Thin crystal as a radiator + amorphous target as converter with D optimization

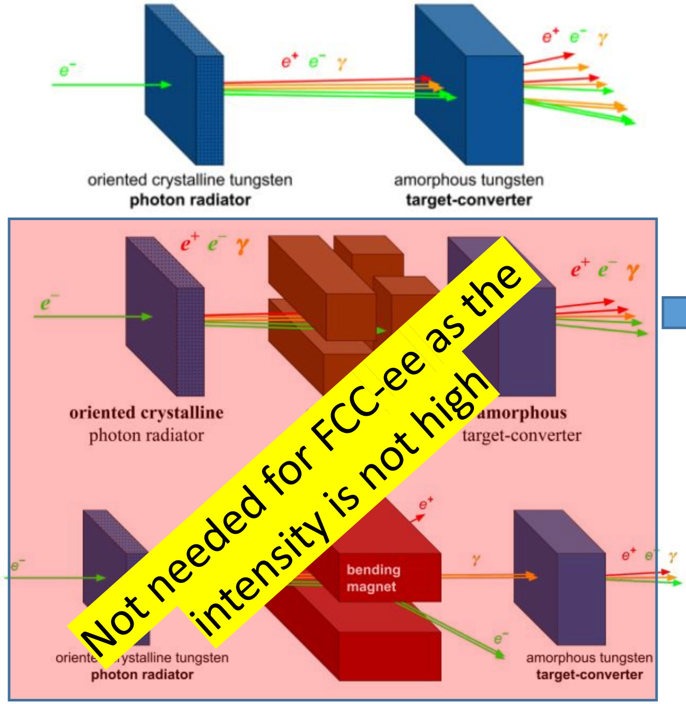


Single thick crystal act as radiator and converter

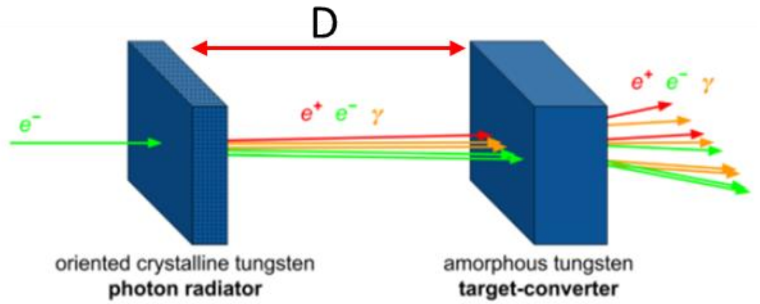
[12]

Crystal-based positron source: simulation

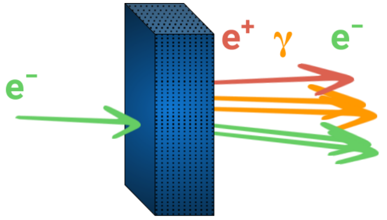
- Several setups have been simulated.
- In the case of FCC-ee positron source, the simulation results converged to single thick crystal, acting as a radiator and convertor.



[10]



Thin crystal as a radiator + amorphous target as converter with D optimization

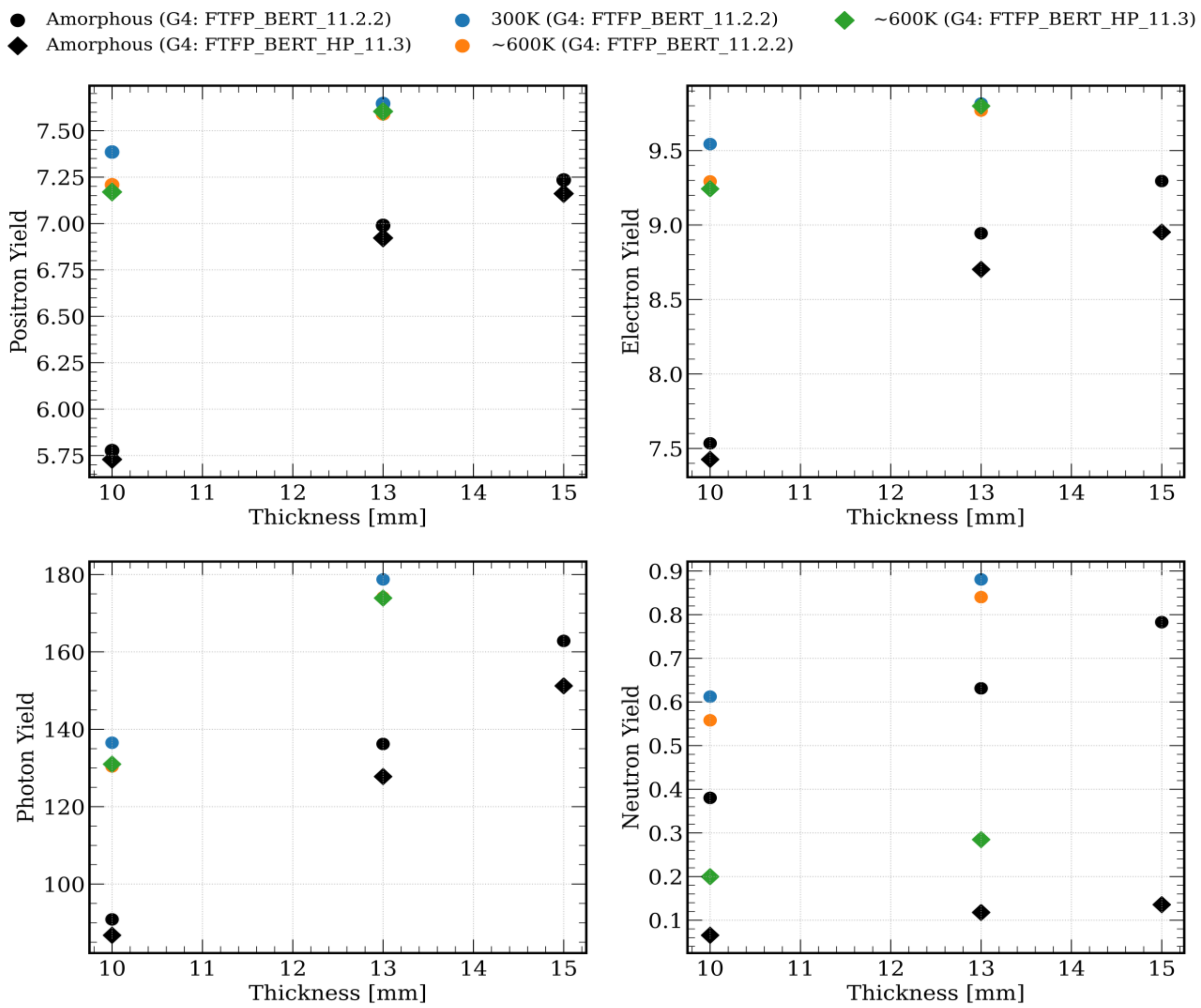


Single thick crystal act as radiator and converter

Single crystal thickness optimization

- Amorphous with **15mm** is used in the conventional scheme.
- Single crystal simulation performed at two temperatures: **300K and 590K.**

- **Insignificant reduction** in the number of all the particles when the temperature is higher.
- When using the **FTFP_BERT** physics list, the neutron yield is 2-3 times higher when compared to FLUKA simulation.
- **FTFP_BERT_HP** provides similar results to FLUKA simulation.

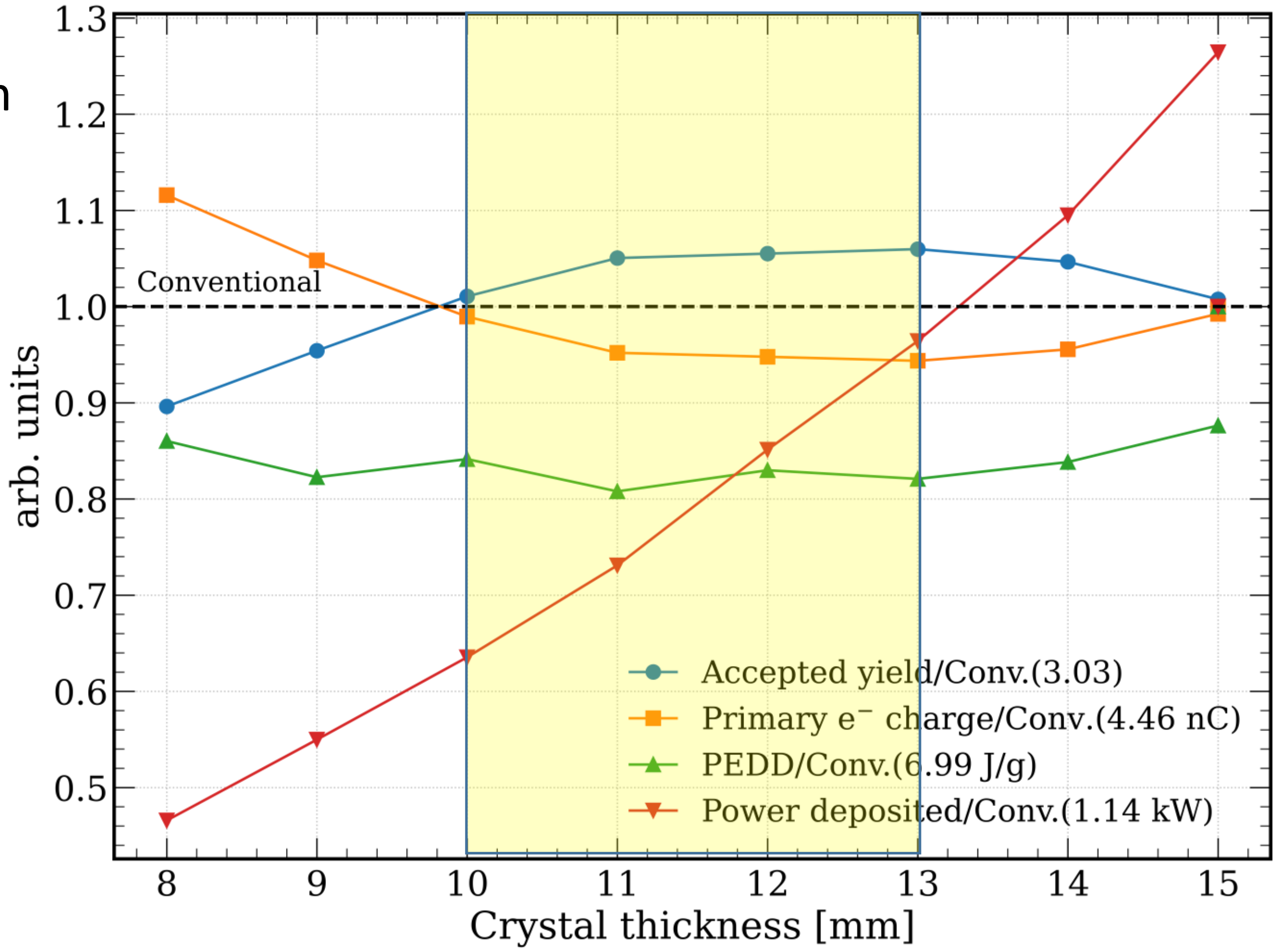


Single crystal thickness optimization

Simulation results converge to 10 – 13mm thick crystal :

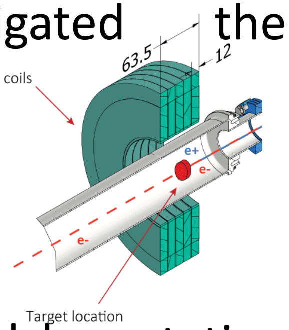
- Target thickness : thinner target => clean radioactive environment.
- Accepted yield: 2%↑– 7%↑ => lower e- bunch charge.
- Power deposited: 35%↓– 3%↓ => lower cooling requirements.
- PEDD: ~ 16% ↓ => increase target reliability.

E = 2.86 GeV, spot size (rms) x/y = 1mm



Single crystal misalignment study.

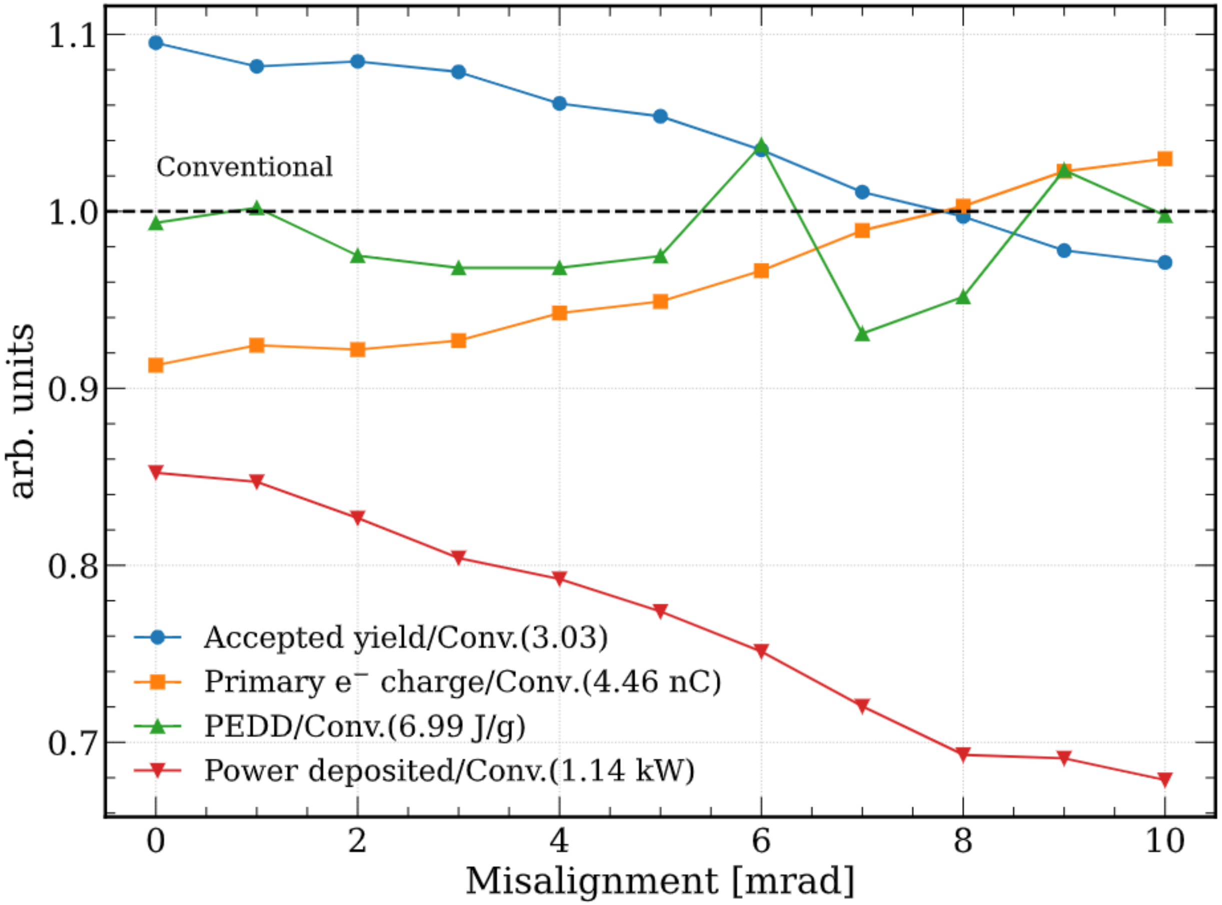
- Since the target is inside the HTS cryostat, we investigated the misalignment tolerance.



- The simulation performed by rotating the crystal away from its axis and, at the same time, avoiding possible skew capture planes.

- The result shows up to **8mrad** the crystal is still above the conventional case.

E = 2.86 GeV, spot size (rms) x/y = 1mm, W<111> 12mm.



Conclusion

- The design of the FCC-ee injector including the positron source is finalized and included in the ***FCC-ee Feasibility Study.***
- Flexible Geant4 application (*PositronSource*) is developed and soon will be included in the extended examples of Geant4.
- Conceptual design of crystal-based positron source: **several options were simulated and the results converges to single thick crystal (*35% lower Energy deposition, 16% lower PEDD*),** with potential of proof of principles experiments @ PSI [P3] (phase 2).

Credits

PSI	B. Auchmann, P. Craievich, M. Duda, J. Kosse, M. Schaer, N. Vallis, R. Zennaro
IJCLab	F. Alharthi, I. Chaikovska, R. Chehab, V. Mytrochenko, Y. Wang
CERN	S. Doebert, A. Grudiev, A. Latina, B. Humann, A. Lechner, R. Mena Andrade, J.L. Grenard, A. Perillo Marcone, P. Sievers, Y. Zhao
INFN/Ferrara	L. Bandiera, D. Boccanfuso (INFN Naple) , N. Canale, O. Iorio (INFN Naple), A. Mazzolari, R. Negrello, G. Paternò, M. Romagnoni, A. Sytov
INFN-Milano	A. Bacci, M. Rossetti Conti
KEK	Y. Enomoto

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