FCC-ee positron source:
HTS-based matching device

Fahad A. Alharthi
Laboratoire de Physique des 2 Infinis Irène Joliot-Curie (IJCLab)
CNRS, Université Paris-Saclay
alharthi@ijclab.in2p3.fr

On behalf of the FCC-ee injector study collaboration

Outline

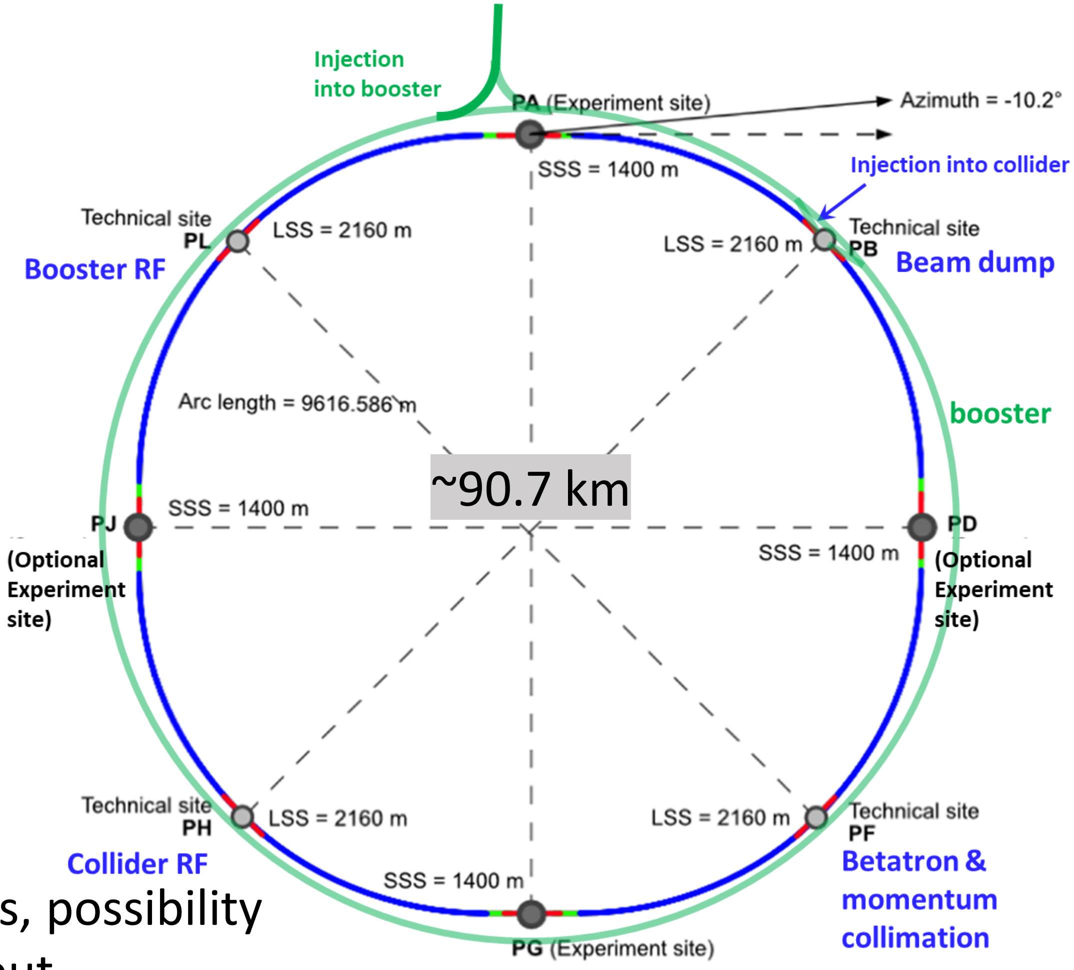
- FCC-ee Injector latest layout.
- Conventional positron source (Target , Matching device , Capture linac)
- Beam dynamics and tracking.
- Crystal-based positron source (Innovative, alternative to the conventional scheme).
- Summary and conclusion.

Future Circular Collider (FCC-ee)

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

Operation Mode	Final Energy [GeV]	Beam Current [mA]
Z *	45	1270
W	80	135
H	120	26.7
ttbar	182.5	5

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

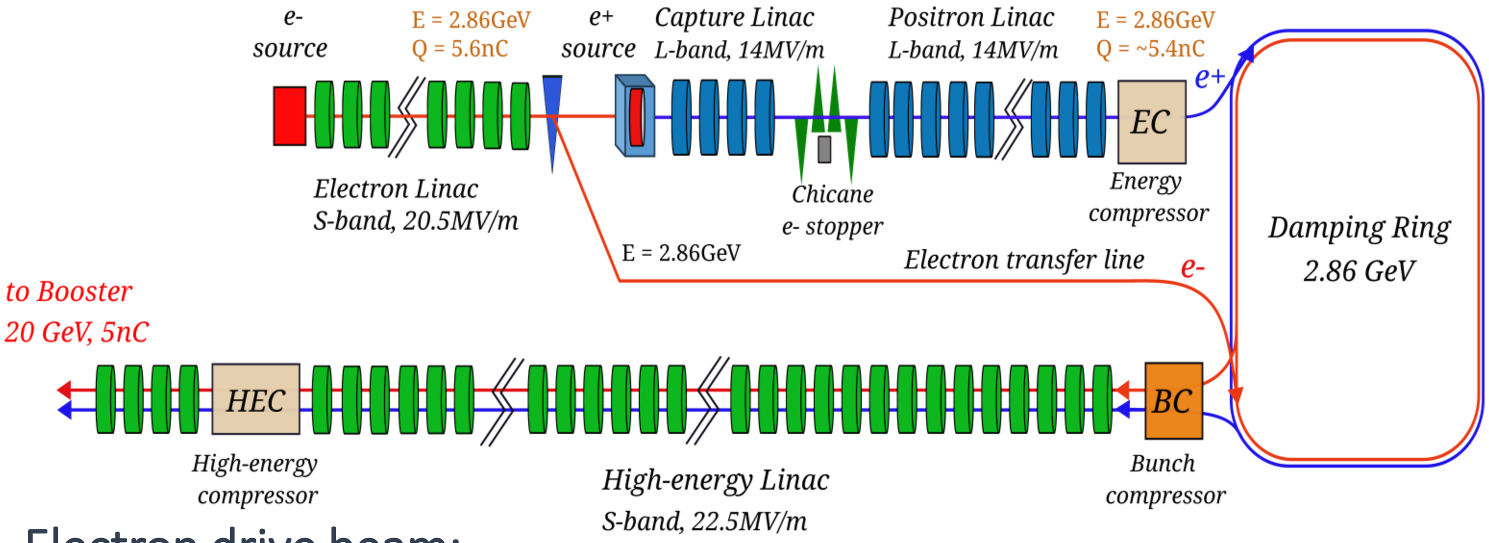


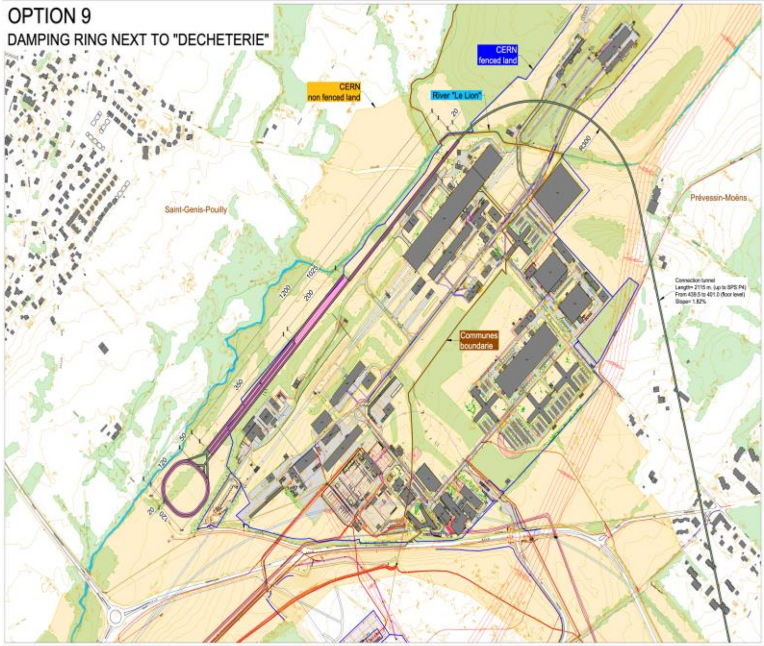
~2048 - 2063

- Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output.

Injector layout (Current baseline)

H. Bartosik, T. Watson, P. Craievich





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 2.5 safety margin*

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

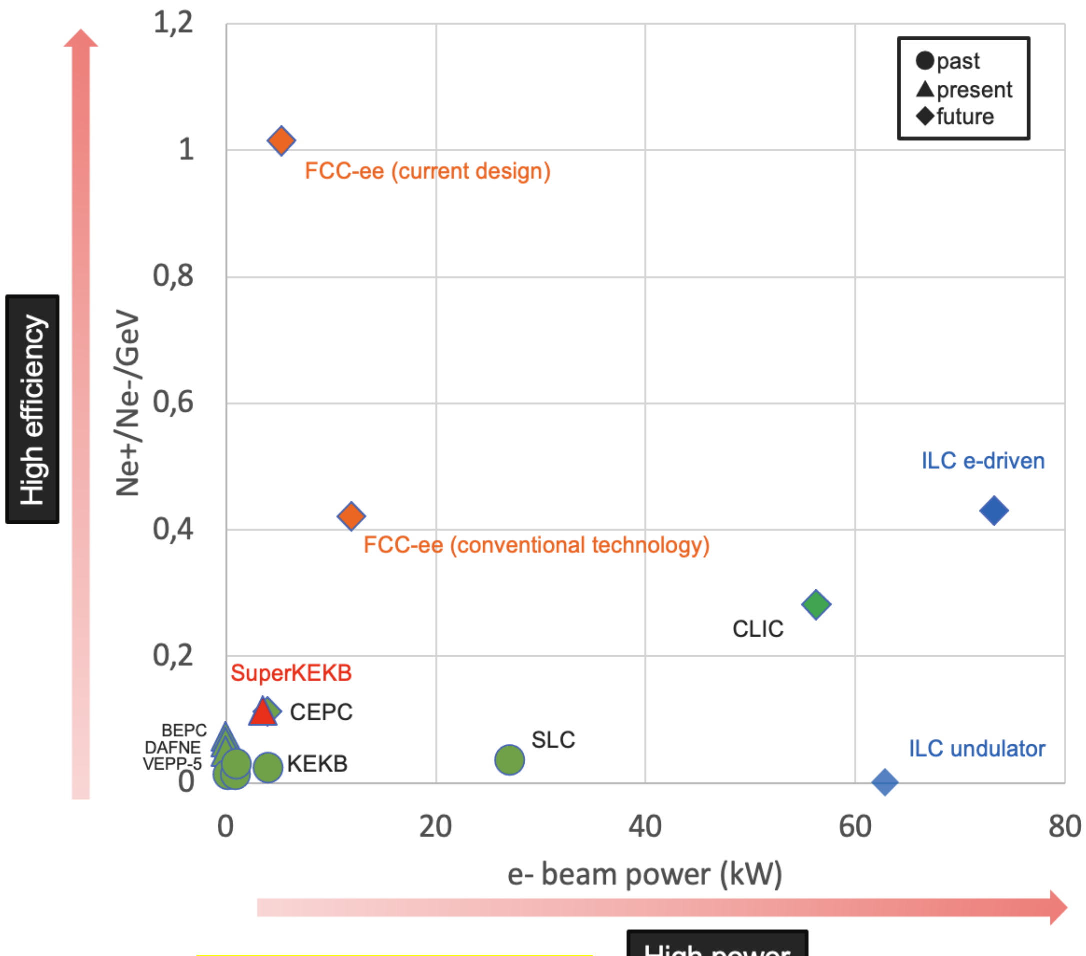
- Latest proposal: injector complex on the Prévessin site with damping ring next to the “Decheterie”
- High energy linac next to North Area and Beam Dump Facility

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.

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

- The use of an **HTS solenoid** with a peak field of **~12T** around the target can substantially increase state-of-the-art e+ yield, by one order of magnitude.

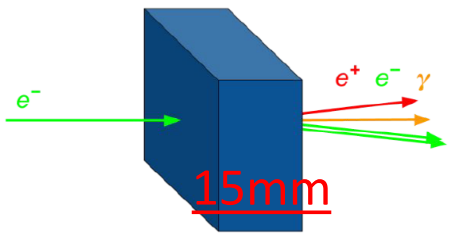


Courtesy of Y.Enomoto (KEK)

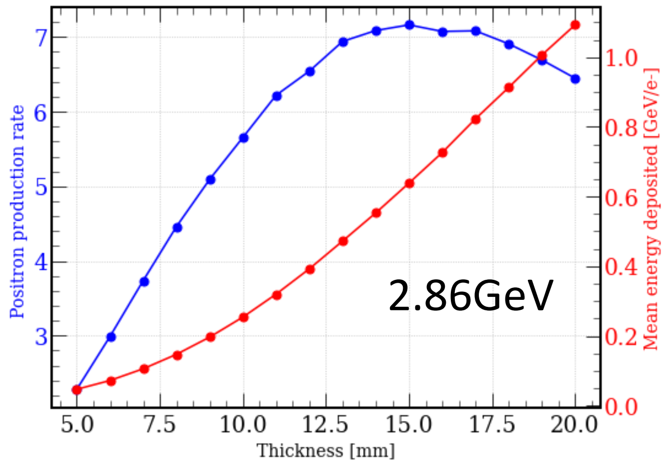
Positron source : Target design

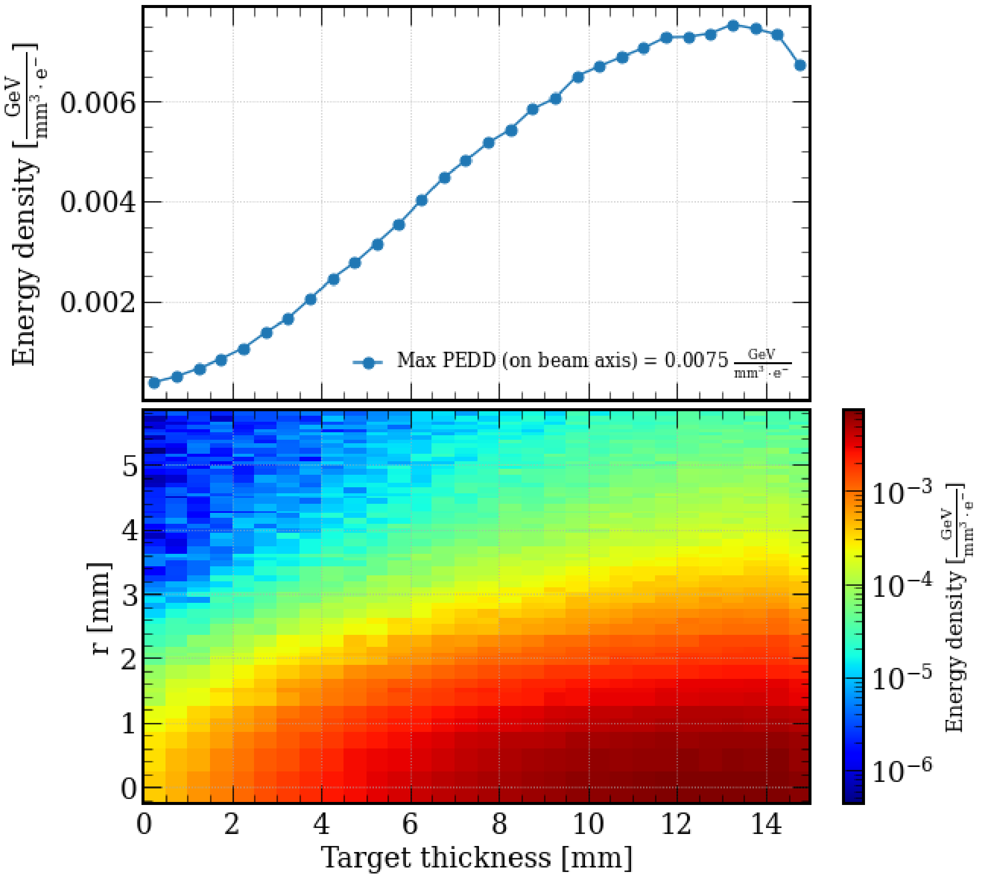
- **Conventional scheme (**Well understood and used in current and previous positron sources**)**

Bremsstrahlung -> *Pair production*



amorphous tungsten



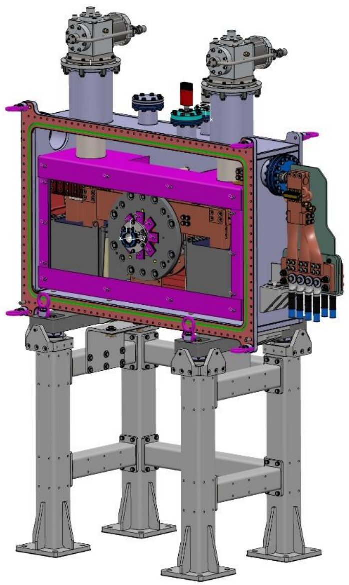


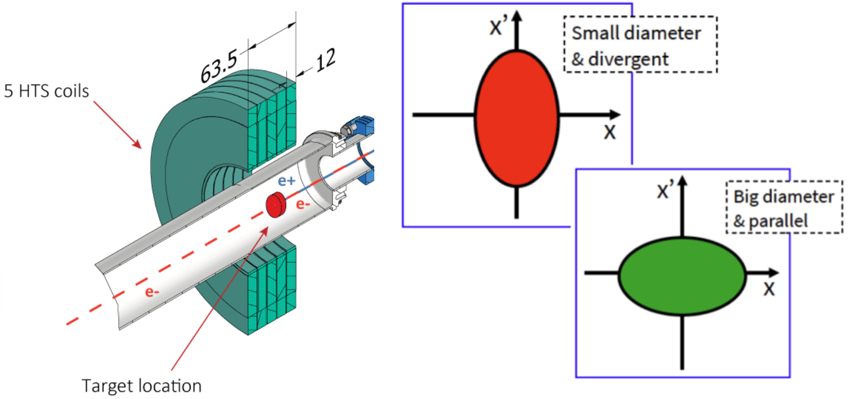
Considered parameters for Positron source target:

- 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*)

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

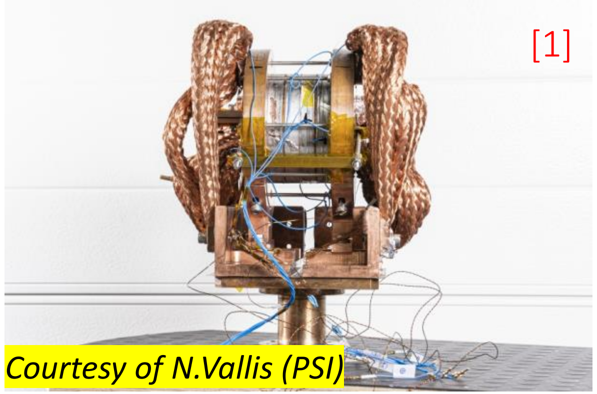
HTS solenoid integrated in the cryostat

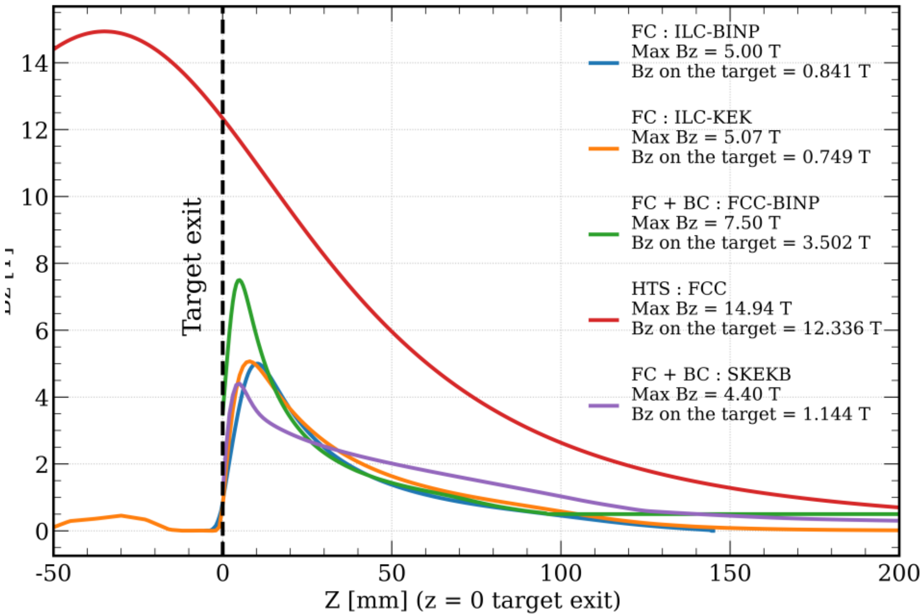




innovative in application for e^+ capture

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





Compared with classical AMD:

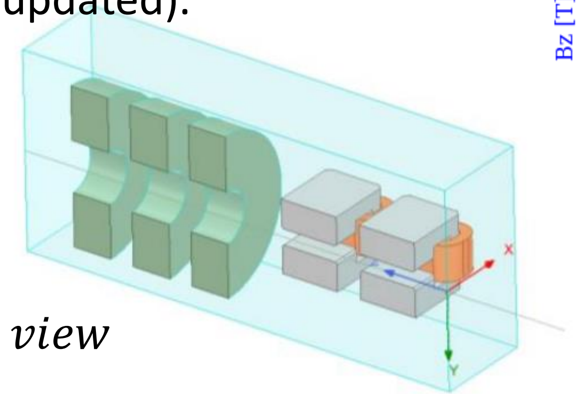
- Higher peak field (~15 T, ~12 T @Target)
- Larger aperture (∅ = 30-60 mm)
- Flexible target position and field profile
- Axially symmetric solenoid field
- DC operation

Positron source: Capture LINAC

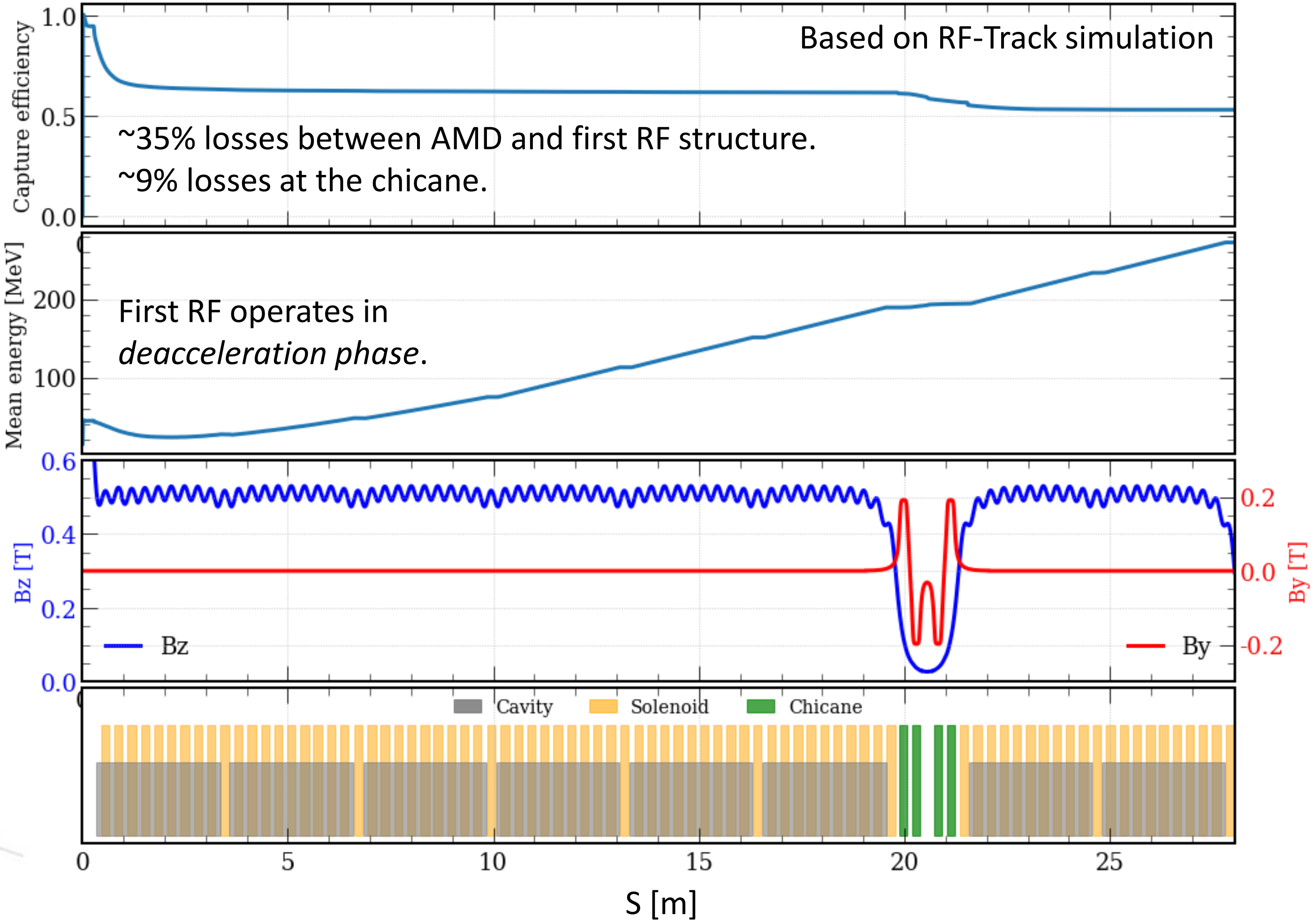
- **RF structures**: 2GHz L-band with aperture (2a) = 60mm , 3m long and 14MV/m.

- **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).



$^1/_4$ *view*



Positron linac + Damping Ring (DR)

Y. Zhao

- Positron linac (PL) under optimization, composed of two sections with one matching sections :

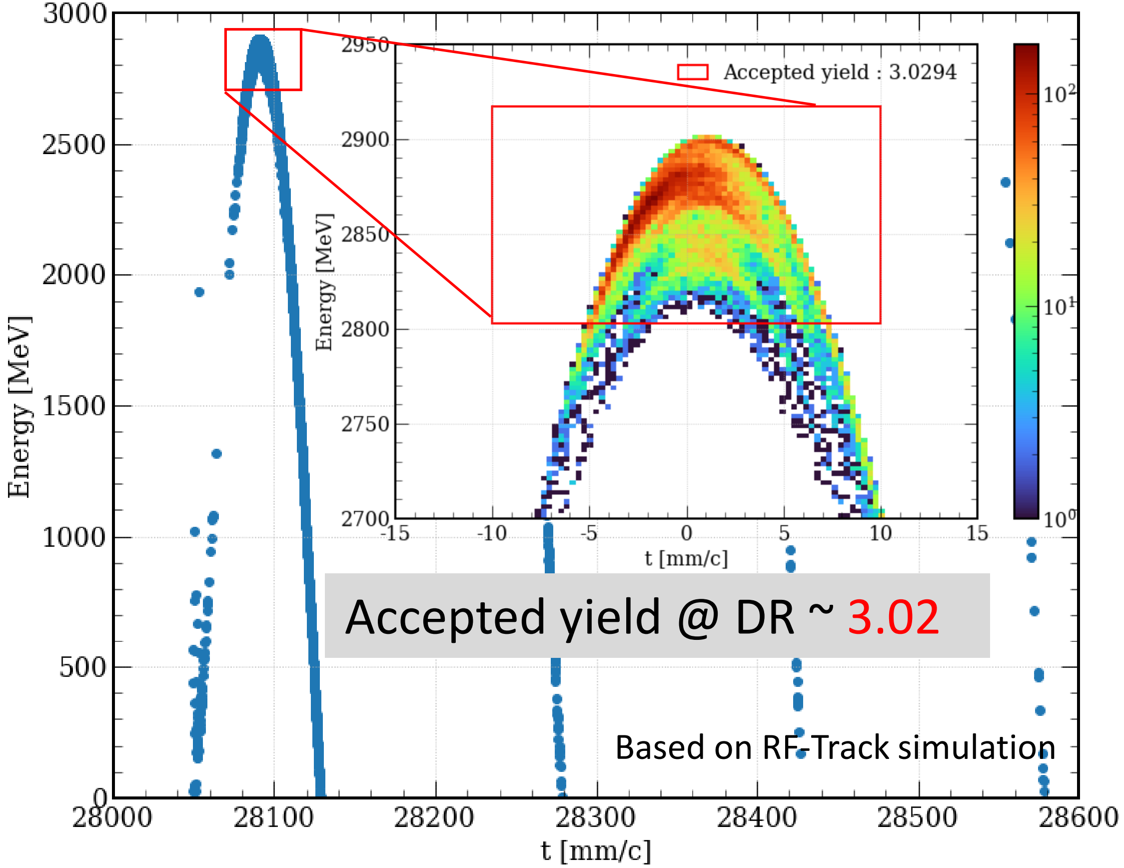
- **<u>PL section 1</u>**: **16** RF structures, with solenoids → **~0.821GeV.**

- **<u>PL section 2</u>**: **52** RF structures, with 2 RF structures per FODO cell → **~2.86 GeV.**

- **New DR is under design and optimization.**
- Energy/time window is used to estimate the accepted yield:

(ΔE: ±2%, Δt: 20 mm/c)

Longitudinal phase space and window acceptance*

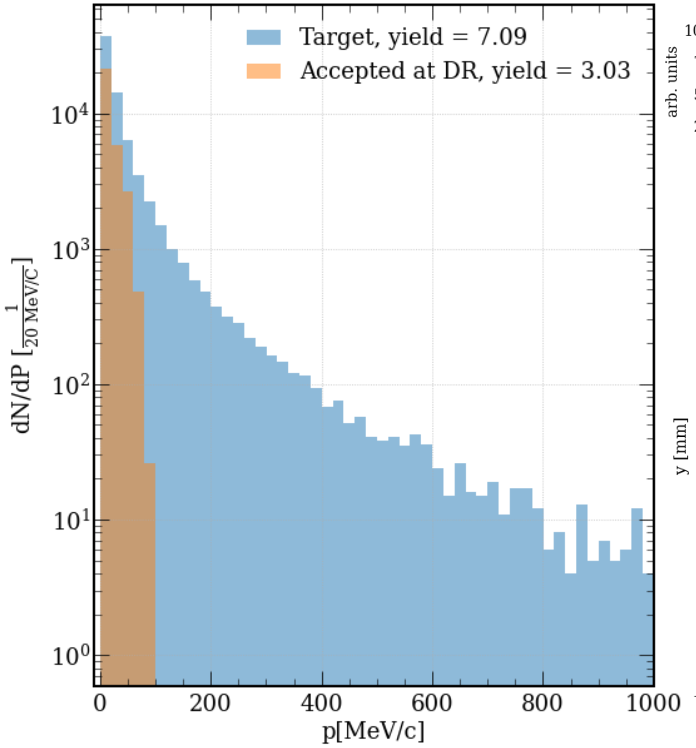


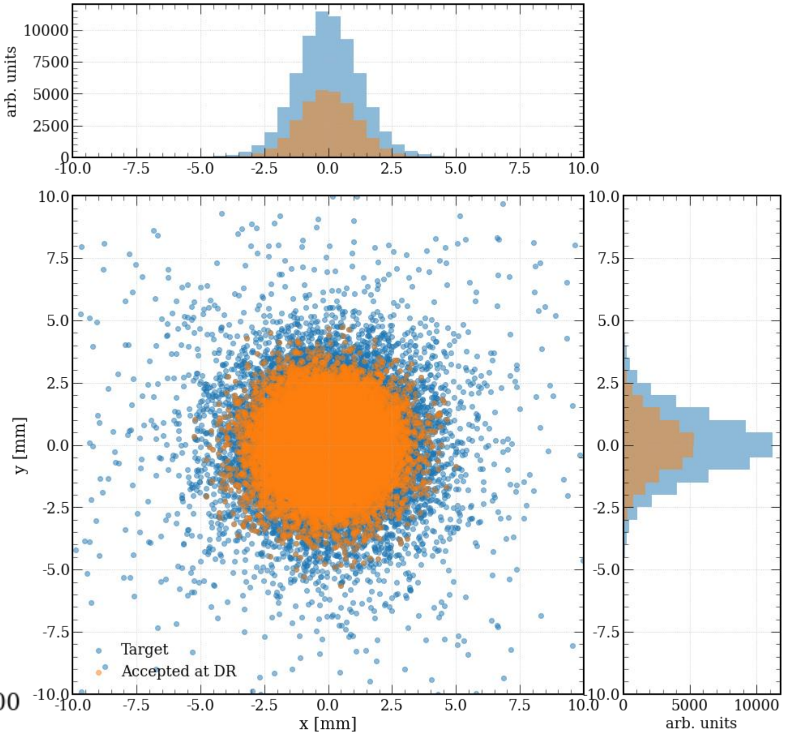
* Simplified longitudinal analytical formula used to track the particles in the positron linac

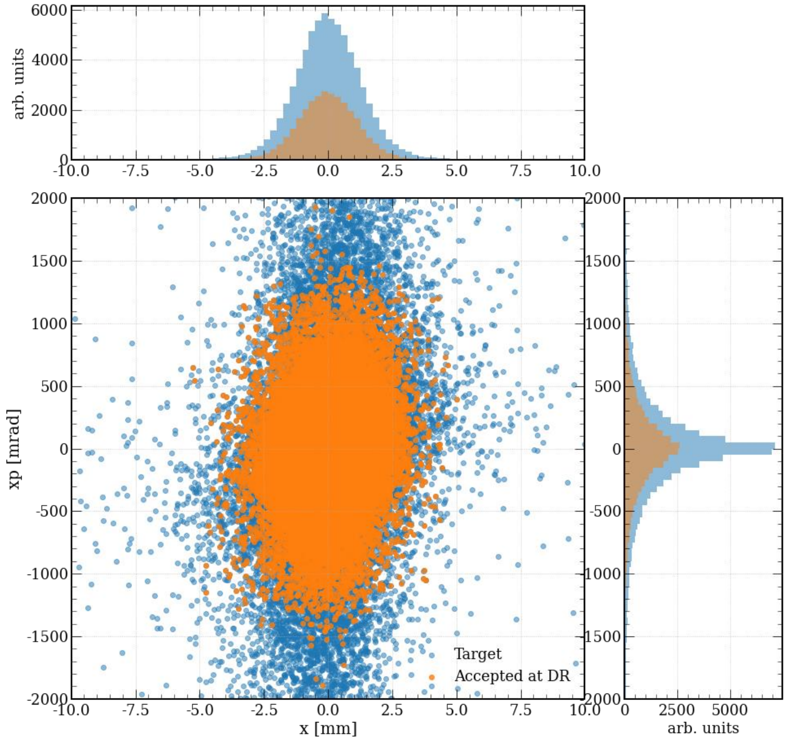
Which positrons are accepted by the DR ?

- Momentum : accepted positrons ≤ 100 MeV/c
  Primary factor

- Transverse aperture and divergence:
  Secondary factor.



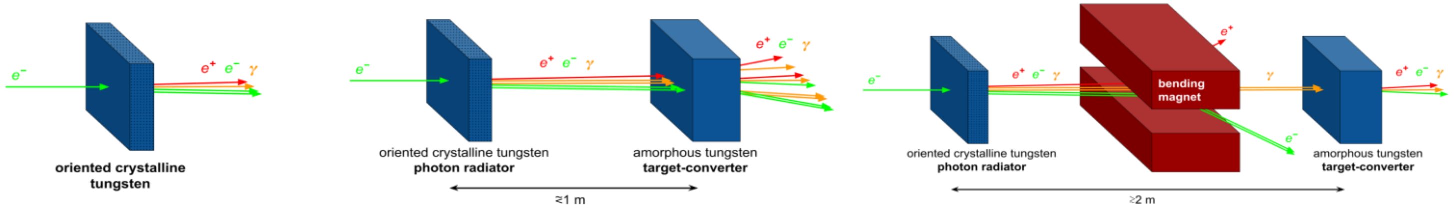


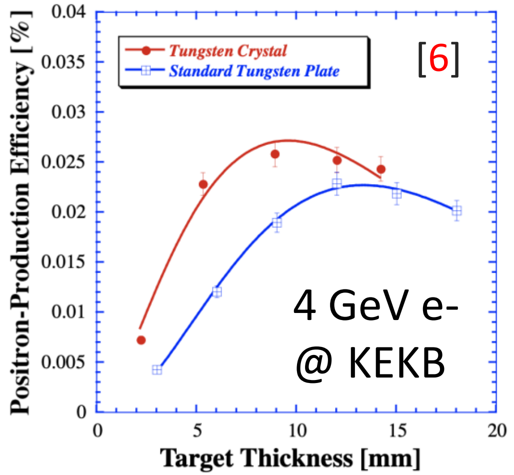


More positrons in the low energy spectrum with lower divergence => increase the accepted yield.

Crystal-based positron source

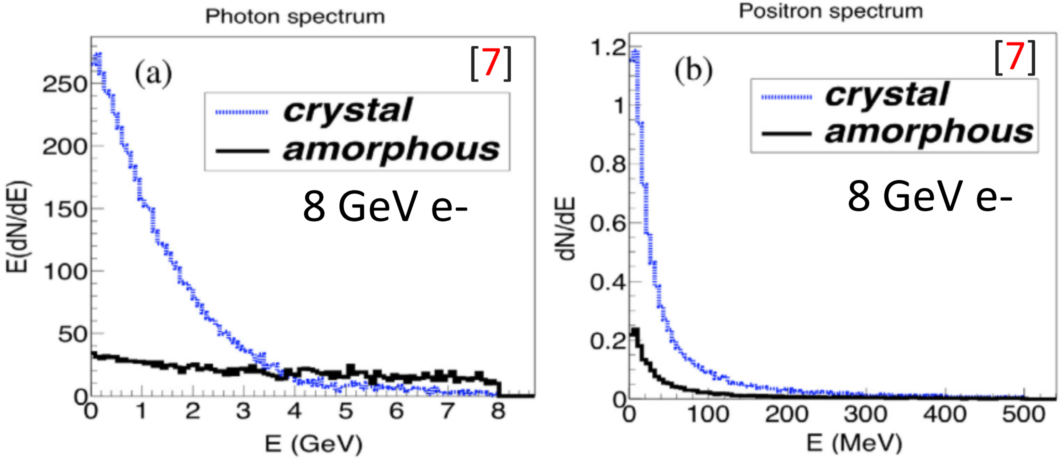
- Originally proposed by R. Chehab, A. Variola, V. Strakhovenko and X. Artru [2].
- Several experiments performed: (Orsay[3], WA103@CERN[4] and KEK[5]) in the 1 – 10 GeV region.
- Three approaches have been studied experimentally.





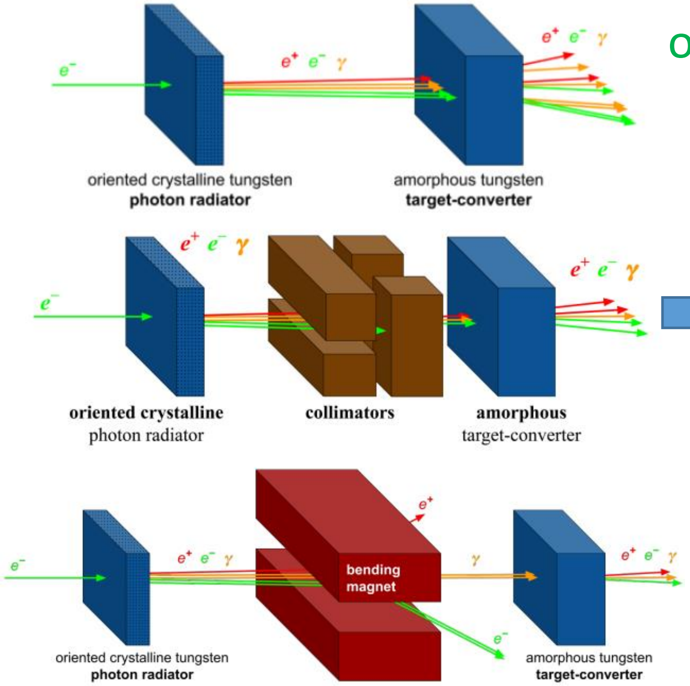
Use of lattice coherent effects in oriented crystals (W) <111> : channeling and over barrier motion

- 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)

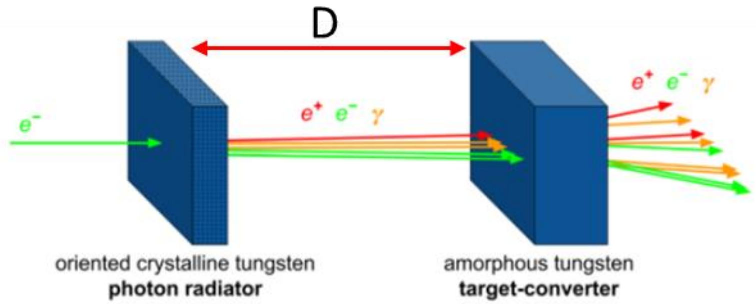


The whole setup was simulated through Geant4 toolkit taking advantage of GeantG4ChannelingFastSimModel [8]

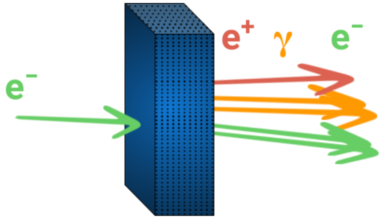
- The simulation environment was benchmarked/validated with experiments at energies of interest for positron sources of future colliders → optimization studies for the FCC-ee [9]



[10]



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



Single thick crystal act as radiator and converter

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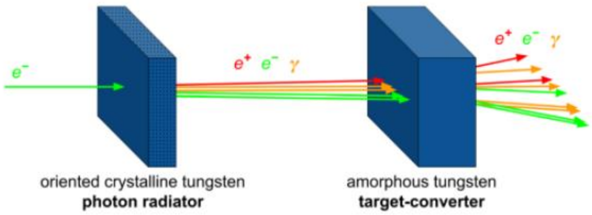
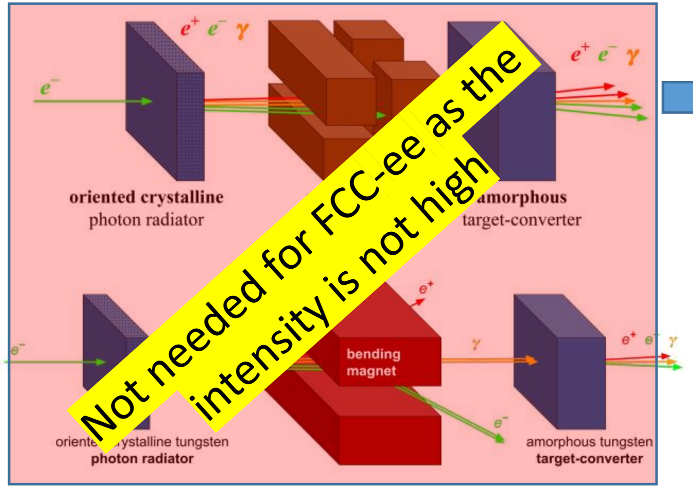
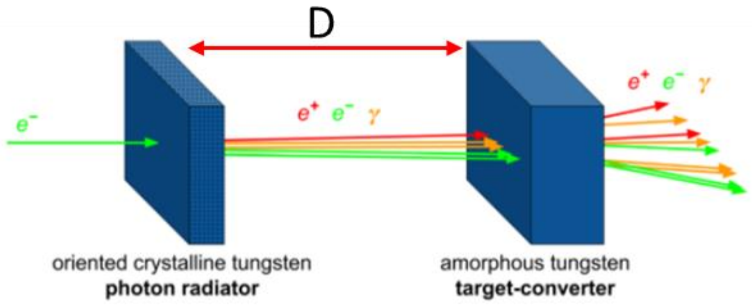
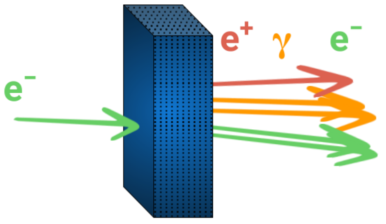




[10]



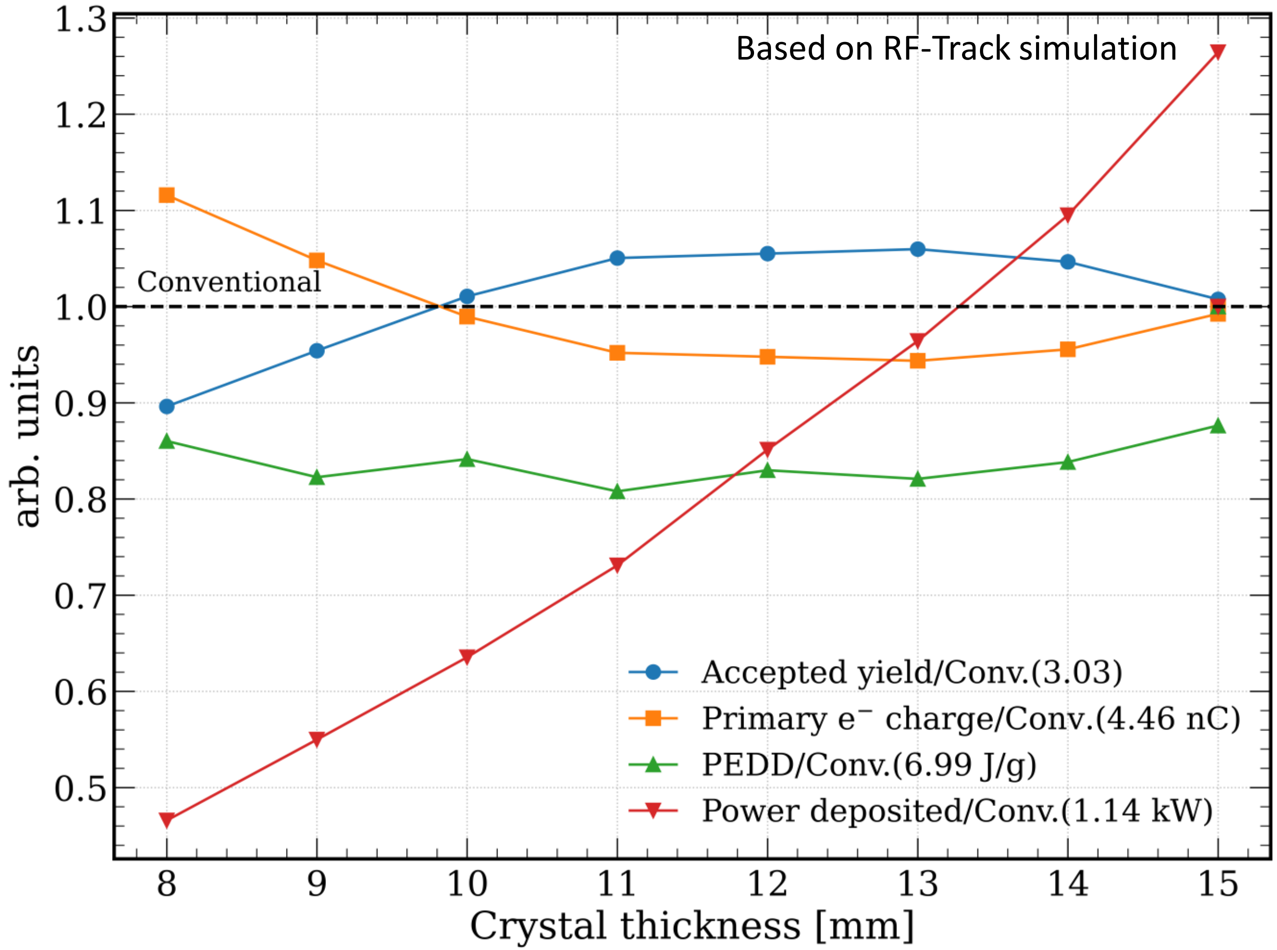
Thin crystal as a radiator + amorphous target as converter with D optimization



Single thick crystal act as radiator and converter

Single crystal thickness optimization

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

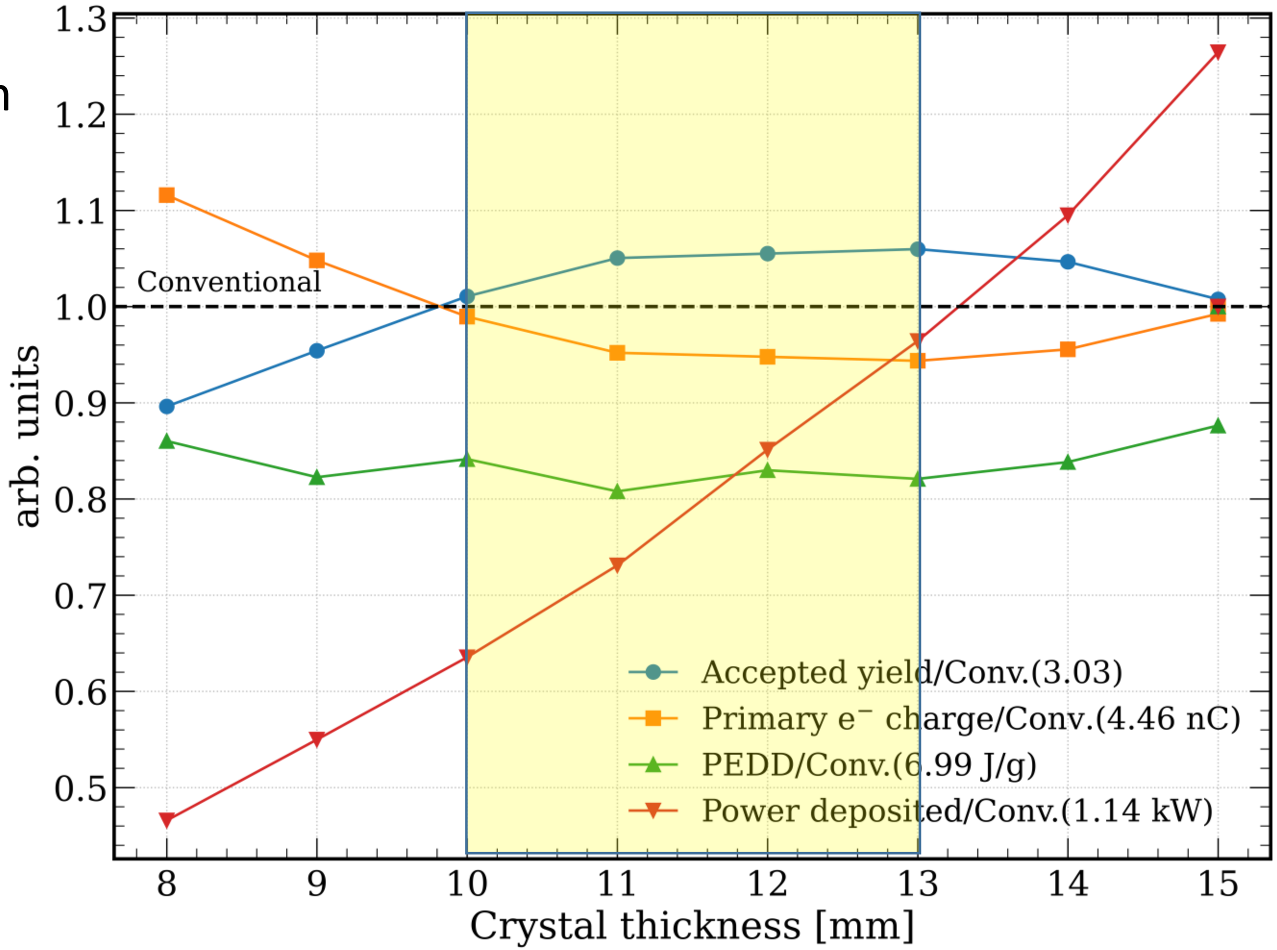


Single crystal thickness optimization

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



Summary table

Parameter	Unit	Conventional	Crystal based
Matching device peak magnetic field (@target)	T	HTS: 14.94 (11.77) T	
Matching device aperture	mm	2r = 30~60	
Target thickness	mm	15	10
Positron yield @ target	N_{e+}/N_{e-}	7.09	7.6
Positron yield @ PL	N_{e+}/N_{e-}	3.7	3.7
Accepted yield @ DR (ΔE: 2%, Δt: 20 mm/c)	N_{e+}/N_{e-}	3.03	3.1
Primary bunch charge	nC	4.46	4.41
Target deposited power	kW	1.14	0.73
PEDD	J/g	6.99	5.9
Emittance x/Emittance y (normalized)	mm.rad	9.6/10.1	9.7/10.2
Energy spread @PL	%	0.8	0.8
Bunch length	mm	2.6	2.6

Work in progress

Conclusion

- The work is in progress to optimize the FCC-ee injector (including the positron source) and maximize the yield (***~3 Ne+/Ne-***)
- New DR is under design and optimization.
- The design of the FCC-ee injector will be finalized by the **end of this year** (***end of FCC-ee feasibility study.***)
- 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
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Thank you for your attention!

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