Study and optimization of a hybrid crystal-based positron source for the FCC-ee

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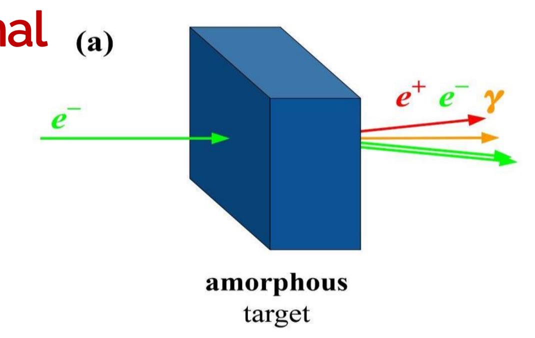
Positron sources are the key elements for the future and current e⁻e⁺ collider projects, introducing challenging critical requirements for high intensity and low emittance beams in order to achieve high luminosity. The conventional way to realize a e+ source consists in using a target with high atomic number Z hit by a high energy primary electron beam. Photons are produced by Bremsstrahlung within the target and are then converted in e⁻e⁺ pairs. A severe heat load and a high density of energy deposited in the target represent a crucial constraint for the intensity achievable with this technology. A possible way to overcome such limitations will be presented, exploiting the intense channeling radiation in oriented crystals to achieve a high rate of e⁻e⁺ pairs, while strongly decreasing the energy deposited and the peak deposition density in the target. An e+ source using channeling is conceived as a compound or hybrid target with two elements: a thin crystal with the function of radiator followed downstream by a thicker amorphous target acting as converter of photons into e⁻e⁺ pairs.
A realistic proposal for a crystal-based intense e⁺ source recently proposed in the e⁺BOOST project will be outlined, together with the prospect's applications at Future Colliders.

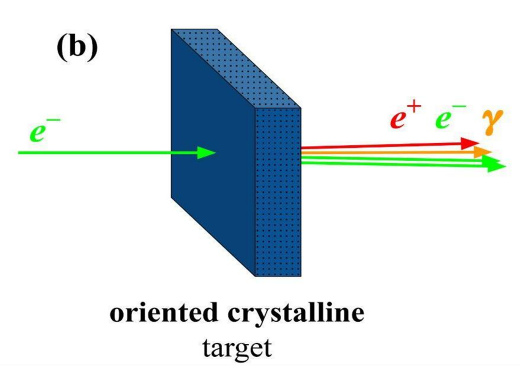
Hybrid crystal based positron source for electron-positron colliders

UNPOLARIZED POSITRON SOURCES

1. Conventional

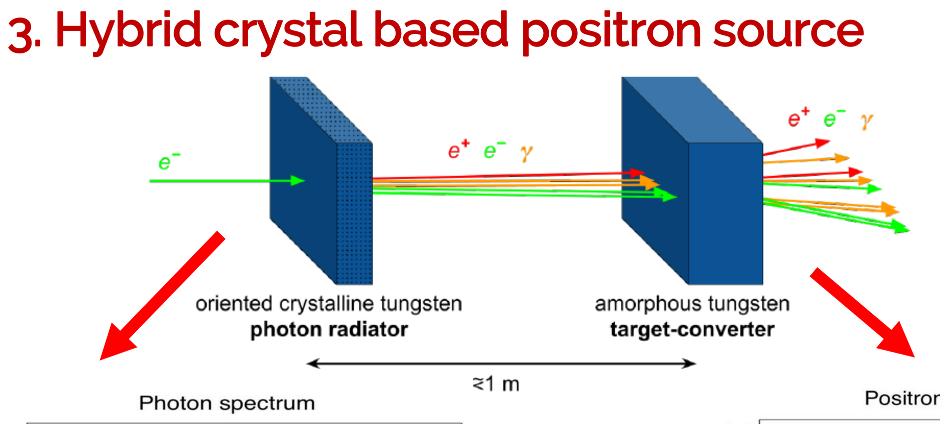


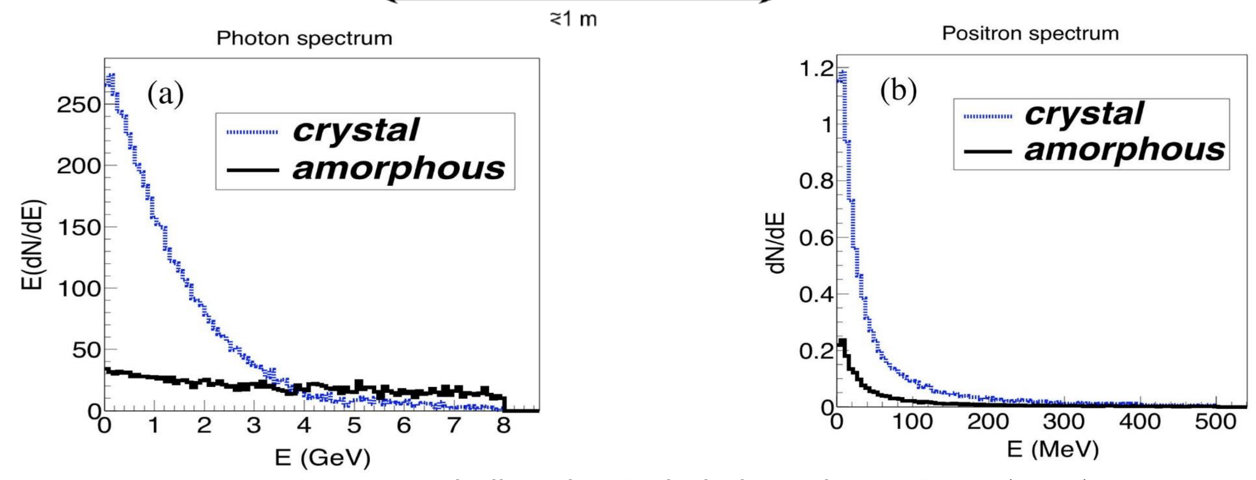
2. e+ from channeling radiation



3. Hybrid crystal based positron source

Idea of R. Chehab, V. Strakhovenko and A. Variola, NIM B 266 (2008) 3868





X. Artru, I. Chaikovska, R.Chehab et al. NIM B 355 (2015) 60

ADVANTAGES of a HYBRID SOURCE

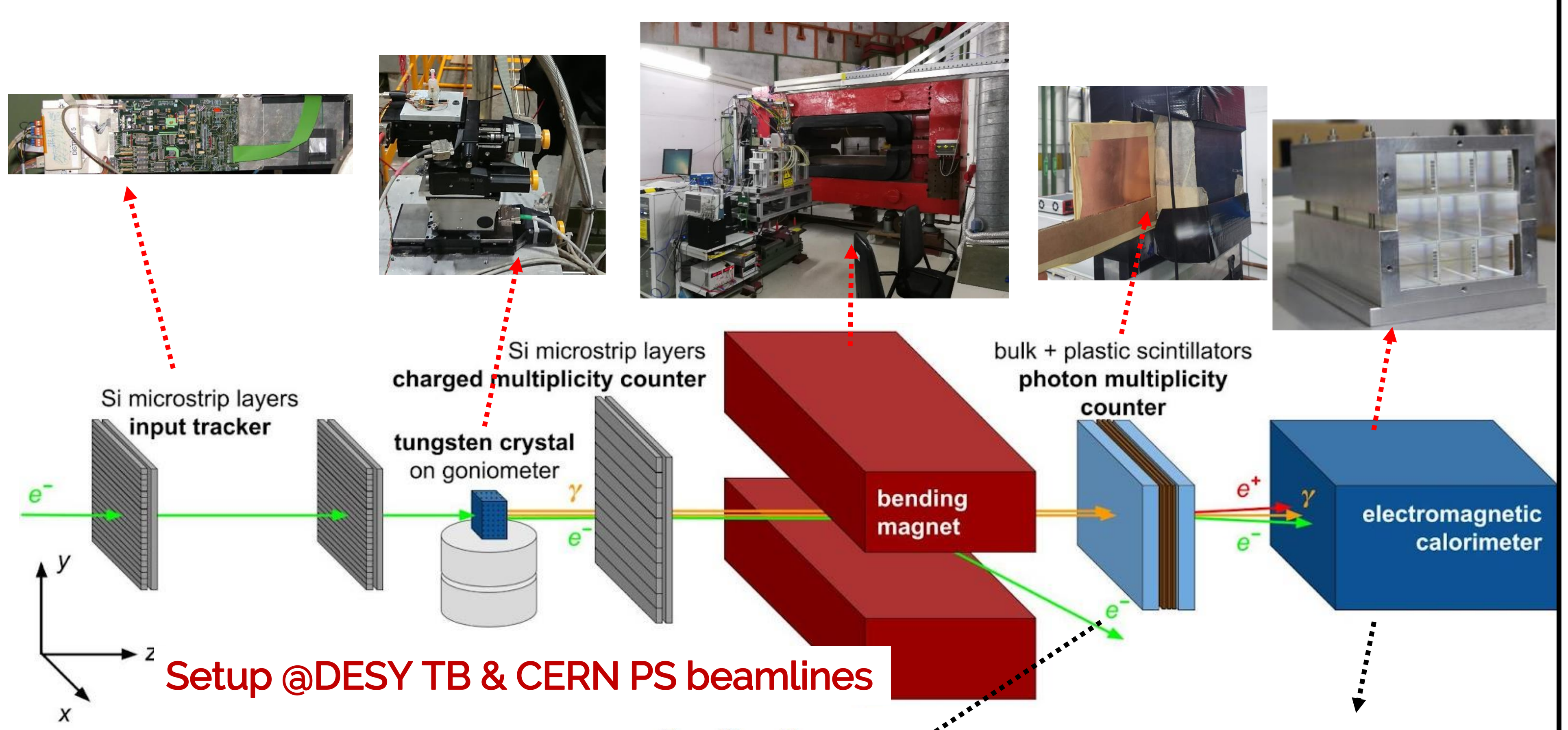
→ Enhancement of photon generation in crystals in channeling conditions ⇒ **enhancement of pair production in the converter target**

→ High rate of soft photons ⇒ **creation of soft e+ easily captured in matching systems**

→ total energy deposit shared between the two stages ⇒ **overall lower energy density**

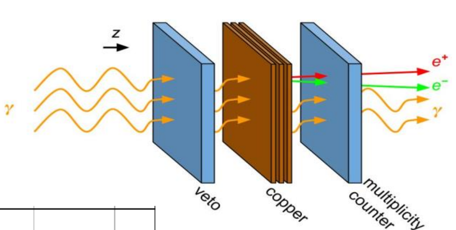
→ **very low energy deposit and PEDD in radiator** ⇒ very low heating and thermo-mechanical stress

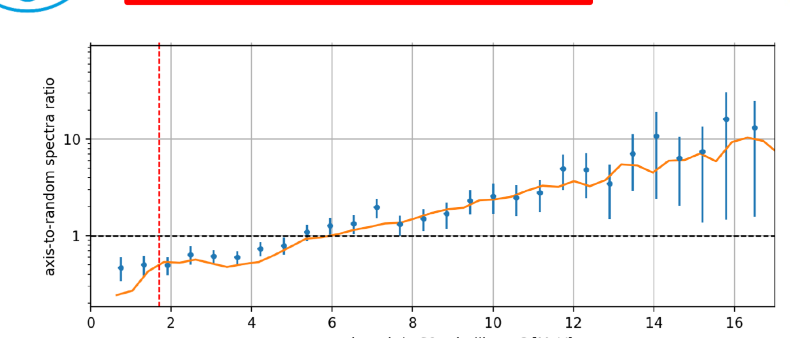
Test of crystal radiator and Monte Carlo validation



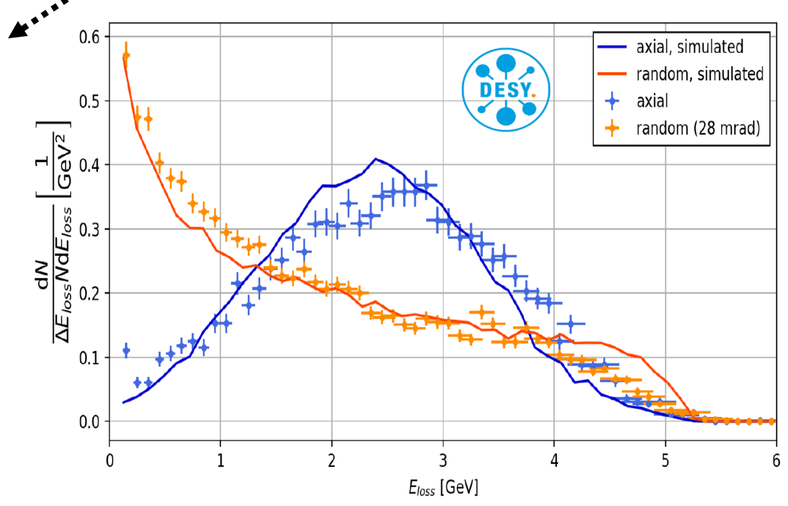
Setup @DESY TB & CERN PS beamlines

Electron beam energy: 5.6 GeV
Crystal: W <100>, 2.24 mm



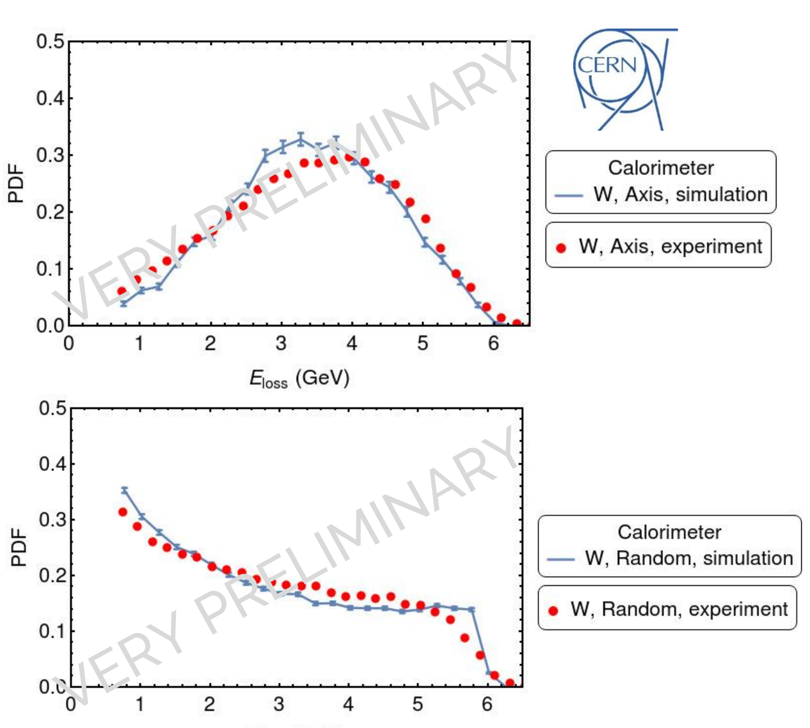


Enhancement of energy deposited in the photon multiplicity counter in case of axial orientation of the crystal related to the random orientation -> increase in the number of emitted photons!



Enhancement of radiative energy loss by the electron collected by the BGO calorimeter in axial (blue) and random (orange) crystal orientation

Electron beam energy: 6 GeV
Crystal: W <111>, 2 mm long

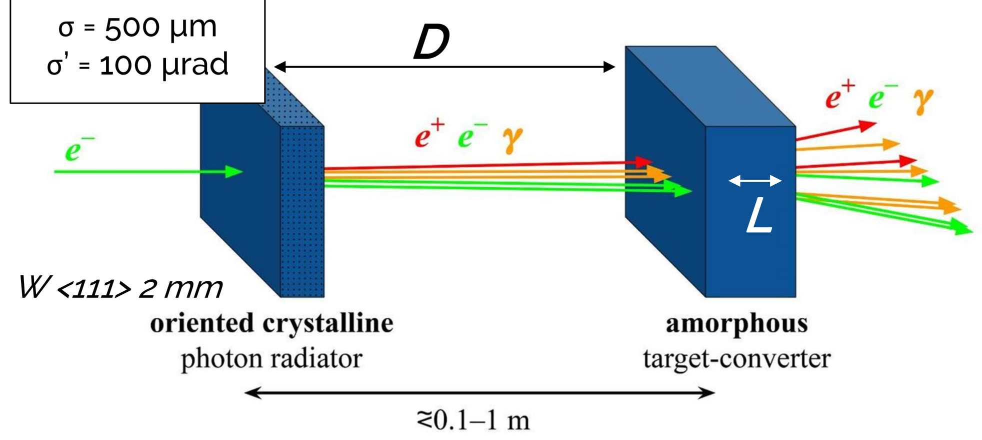


DESY TB and CERN PS beam tests results agree with Monte Carlo simulation:
- Crystal radiator simulated with the CRYSTALRAD code [4];
- Output file including all the secondary γ and e± compatible with the Geant4 toolkit and used to simulate the further interaction with the completeexperimental setup [3]

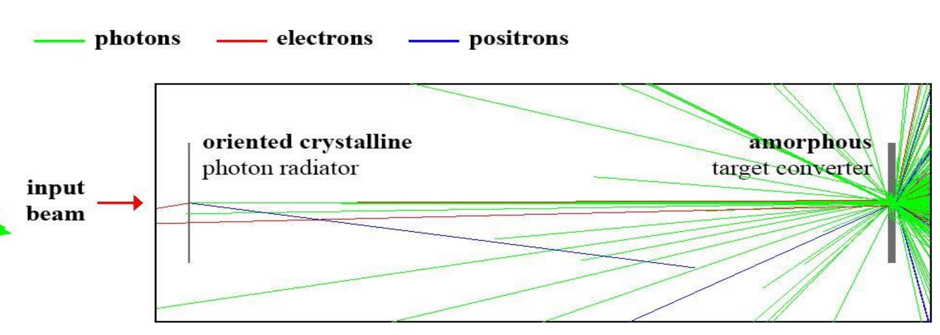
After the validation of the simulation environment with experimental data, we proceeded with the optimization of the FCC-ee hybrid scheme Parameters chosen for the FCC-ee hybrid source optimization via Geant4 !

FCC-ee hybrid source optimization via Geant4

E = 6 GeV
σ = 500 μm
σ' = 100 μrad



energy deposit and PEDD can be reduced by tuning L and D

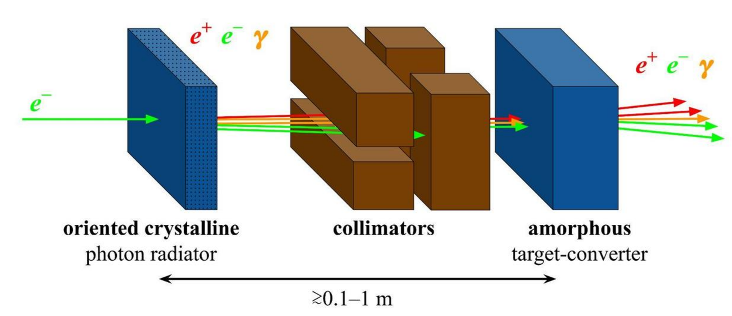


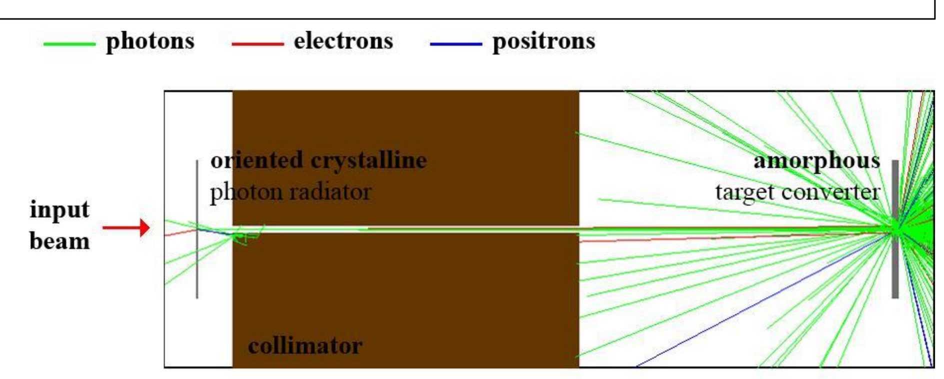
Geant4 simulation of the downstream stage…

(upstream stage –crystal radiator- simulated with [4] → dedicated input files)

improving the hybrid scheme… …with collimator

L = 11.6 D = 600, 1000, 2000 mm

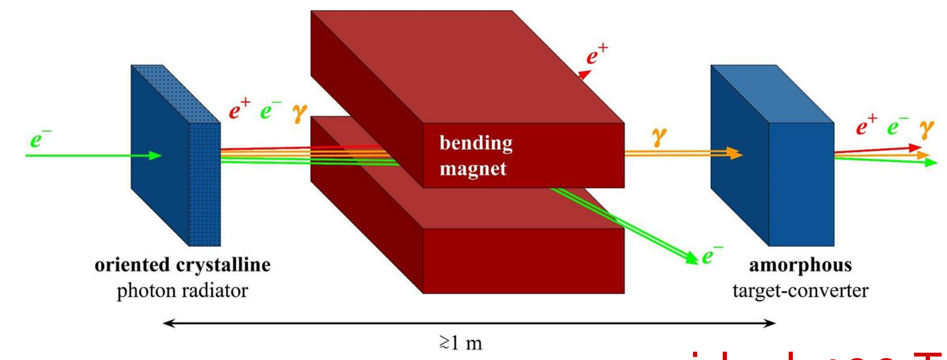


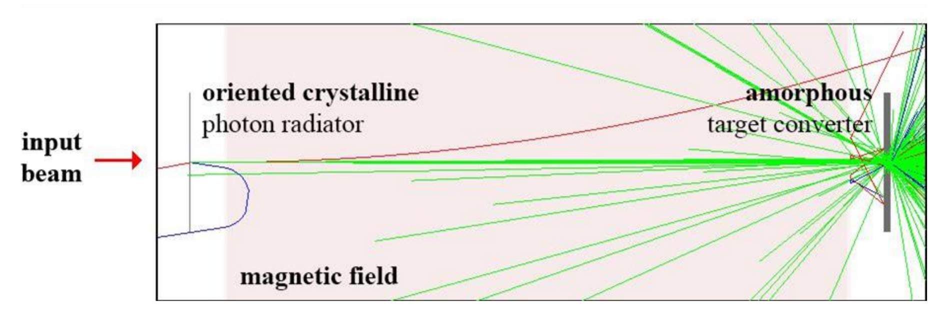


M. Soldani (INFN-Ferrara)

tungsten block of thickness 50 cm with square hole of side *a*

…with magnet





ideal, 100 T field to swipe all charged particles away

All together…

M. Soldani (INFN-Ferrara)

a = 5.5 mm

Scheme	conv.	hybrid						
L_{crys} [mm]	–				2			
D [m]	–	0.6		1			2	
L [mm]	17.6				11.6			
Collimator?	no	no	no	yes	no	no	yes	no
Magnet?	no	no	no	no	yes	no	no	yes
E_{dep} [GeV/e^-]	1.46	1.34	1.32	1.13	1.32	1.27	1.11	1.27
PEDD [MeV/(mm³ · e^-)]	38.3	12.8	8.4	8.2	8.4	4.1	3.8	3.9
Out. e^+/e^-	13.7	15.1	15.1	13.6	15	14.9	13.7	14.9
Out. e^+ beam size [mm]	0.7	1	1.2	1.2	1.2	1.5	1.5	1.5
Out. e^+ beam div. [mrad]	25.9	27.4	26.8	27.7	28.9	29.2	25.6	27.1
Out. e^+ mean energy [MeV]	48.7	46.2	45.6	47.4	45.9	46.1	47.7	46.3
Out. n/e^-	0.37	0.31	0.31	0.27	0.29	0.29	0.26	0.3
Out. γ/e^-	299	310	308	270	307	301	268	301

conventional (amorphous)
collimator
magnet

- PEDD is strongly decreased!
- e+ production a bit higher!
- Similar beamsize (a bit higher) and divergence!

References
[1] I. Chaikovska et al 2022 JINST 17 P05015
[2] X. Artru, I. Chaikovska, R.Chehab et al. NIM B 355 (2015) 60
[3] L. Bandiera et al., Eur. Phys. J. C 82 (2022) 699
[4] A. I. Sytov et al Phys. Rev. Accel. Beams 22 (2019) 064601

Intense positron source Based On Oriented cryStals - e+BOOST
(PI L. Bandiera)
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