target for positron source in FCC-ee

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bremsstrahlung (& Pair Production) **enhancement in oriented metallic crystals**

crystals and positron sources

which kind of positron source?

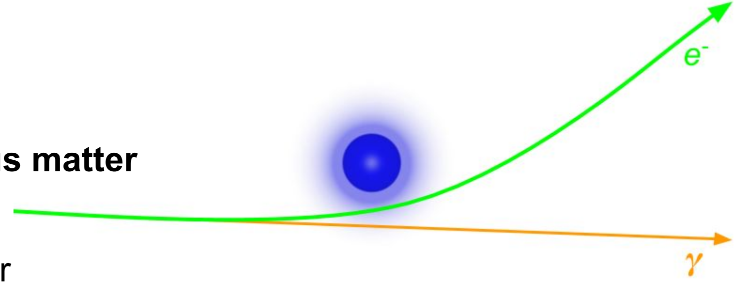
what’s the best configuration?

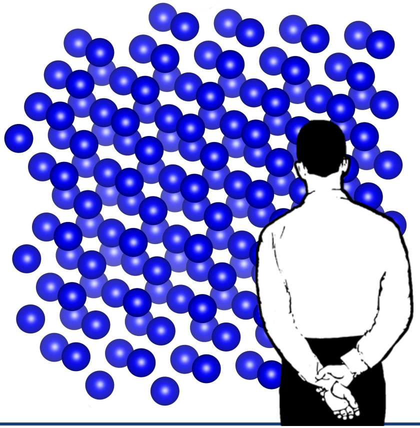
EM in crystals in a nutshell

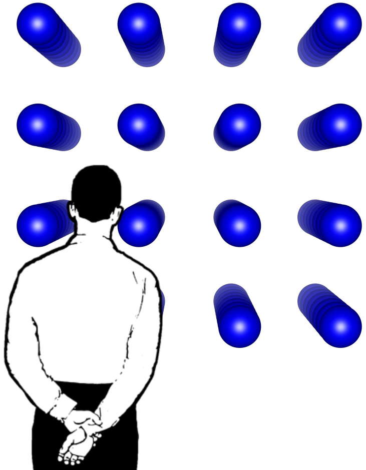
passage of **electrons through amorphous matter**

random interactions with single-nucleus Coulomb fields, <u>independent on each other</u>

→ standard bremsstrahlung radiation emission

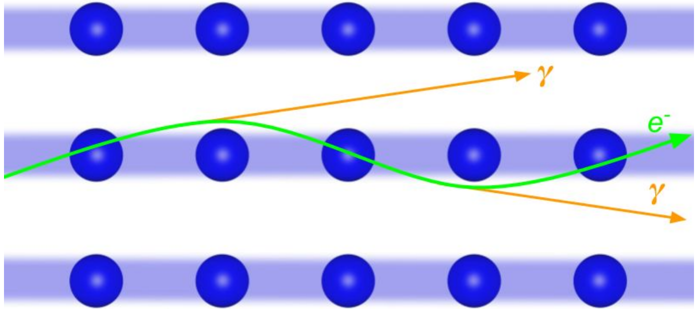






at *small* angle between the particle trajectory and the nuclear strings, **axial condition**:

→ continuous potential along the axes (Lindhard)



→ <u>oscillatory dynamics</u>

→ electromagnetic radiation builds up coherently ⇒ <u>radiation emission enhancement</u>

EM in crystals in a nutshell

***small* particle-to-axis angle** (within few mrad, ≫ Lindhard angle @ GeV scale)

$$< \Theta_0 = \frac{U_0}{mc^2}$$

CB/CPP: less pronounced effects attained within 1°

+

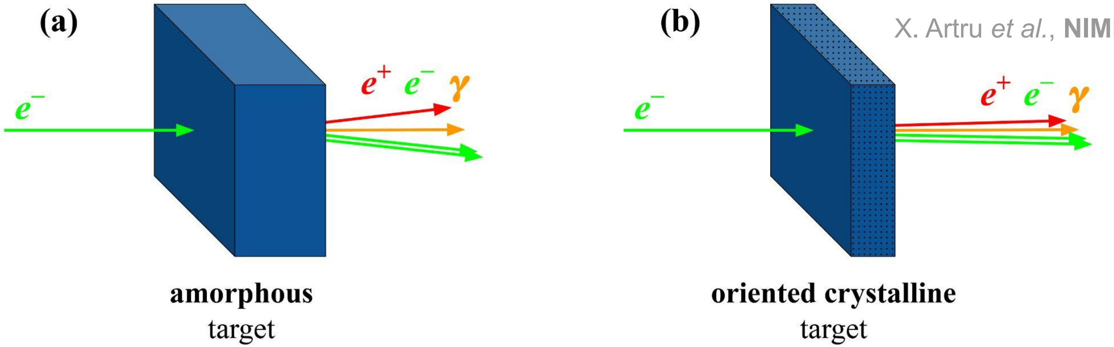
high energy (≳10 GeV) → **Lorentz contraction**

$$\chi = \frac{\gamma E}{E_0} > 1 \qquad E_0 = \frac{m^2c^3}{e\hbar} = 1.32 \cdot 10^{18}\,\frac{\mathrm{V}}{\mathrm{m}}$$

= Strong Field

(U_0 and E being the axis potential and the corresponding field in the lab frame → crystal-dependent)

PS schemes **from conventional…**



X. Artru *et al.*, **NIMB 240**, 762 (2005)

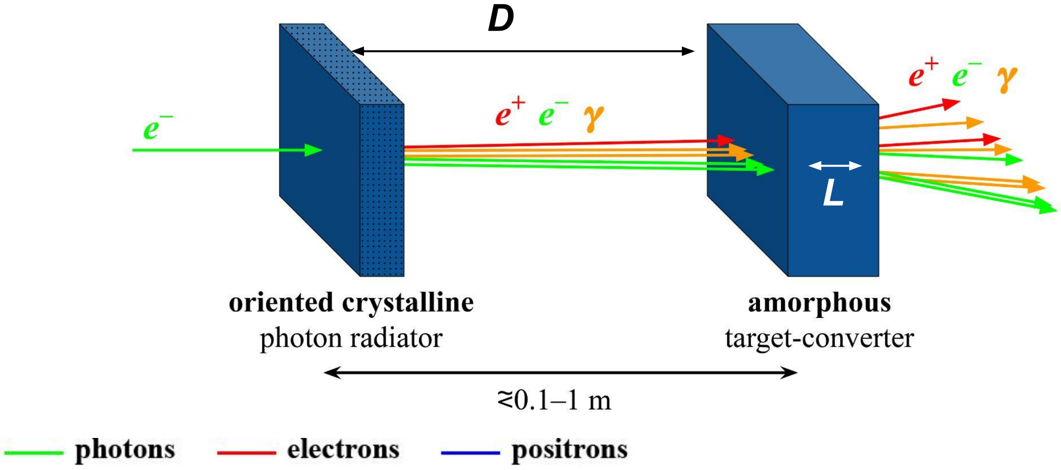
start of an electromagnetic shower in

(a) **amorphous** single target
- → large output emittance (divergence, momentum spread)
- → high energy deposit ⇒ heating, thermo-mechanical stress, activation

(b) **oriented crystalline** single target
- → same positron production rate
- → lower emittance
- → lower energy deposit
- → still unsatisfactory, as stress can degrade the crystalline lattice

PS schemes **…to hybrid**

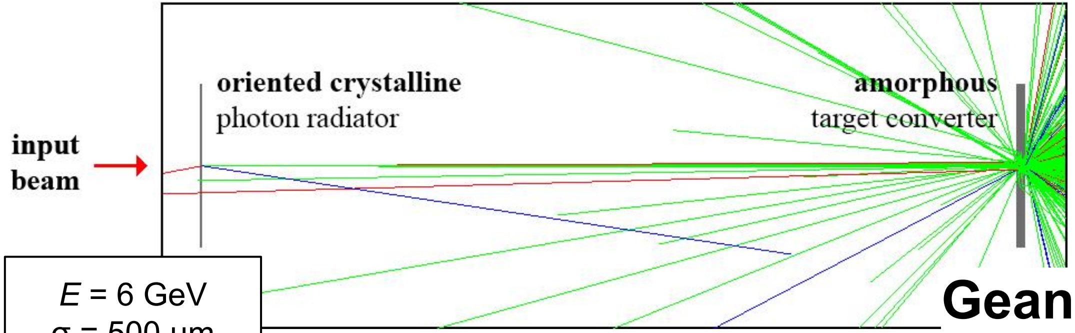
R. Chehab, *et al.*, **NIMB 266,** 3868 (2008)



→ 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

→ energy deposit and PEDD in amorphous converter can be reduced by tuning ***L*** (while keeping the radiator thickness fixed to maximise EM enhancement) and ***D***



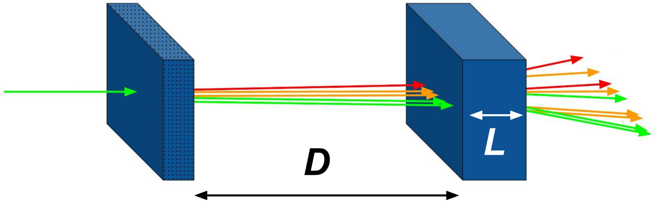
E = 6 GeV
σ = 500 µm
σ’ = 100 µrad

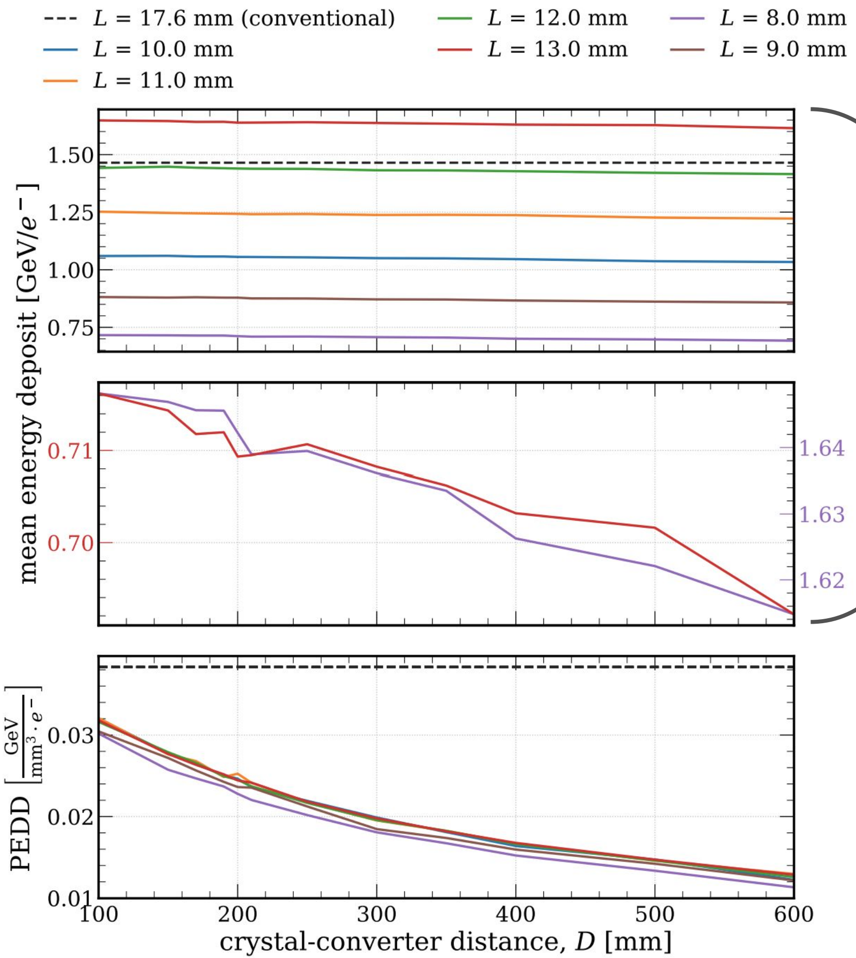
Geant4 simulation of the downstream stage…

(upstream stage already optimised with dedicated code and experimental data→ dedicated input files)

L. Bandiera *et al.*, **EPJC 82**, 699 (2022)

energy deposit & PEDD



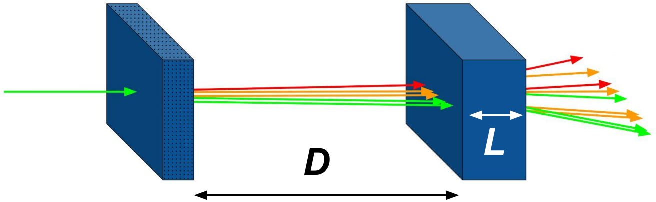


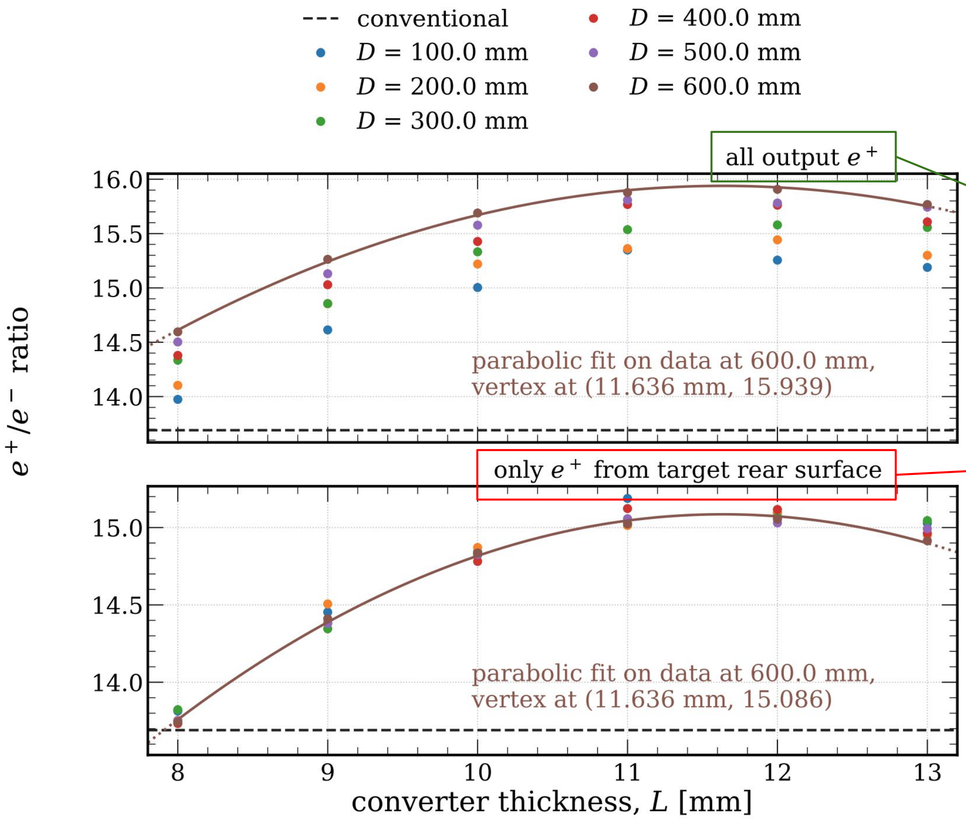
energy deposit <u>heavily depends on *L*</u> and slightly on *D*

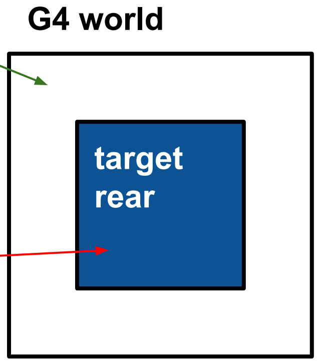
in general, it is <u>better than in the conventional</u> case (but for very thick converter target → inconvenient)

PEDD: essentially independent on *L*, heavily depends on *D* → <u>crystal-target distance has to be as high as possible</u> (bound by output beam aperture requirements)

positron production rate







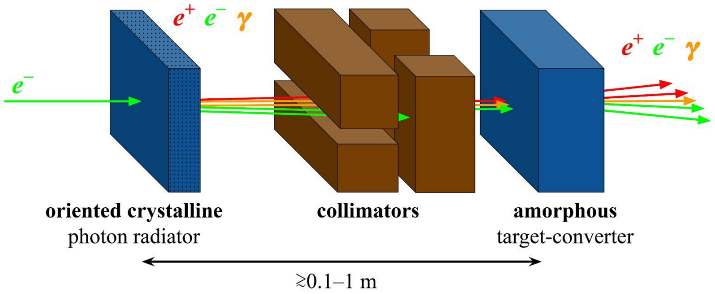
transition curve <u>has a maximum at L ~ 11.6 mm</u>, which corresponds to an integral energy deposit lower than the conventional case

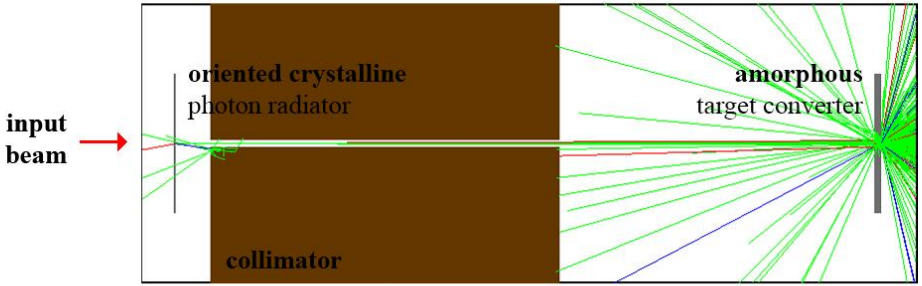
improving the hybrid scheme…

L = 11.6 D = 600, 1000, 2000 mm

— **photons** — **electrons** — **positrons**

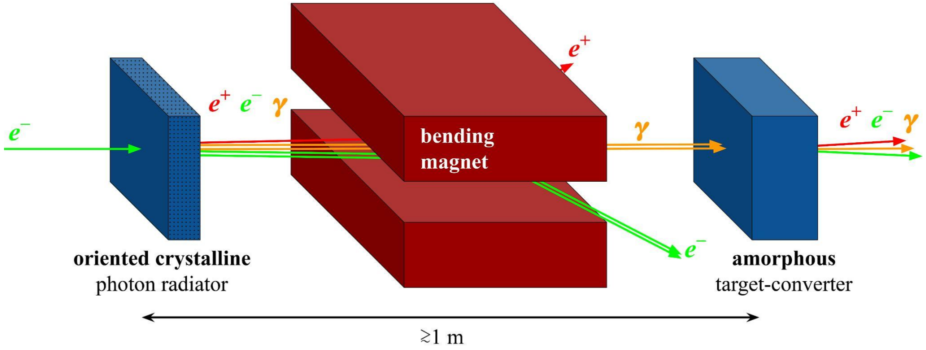
…with **collimator**

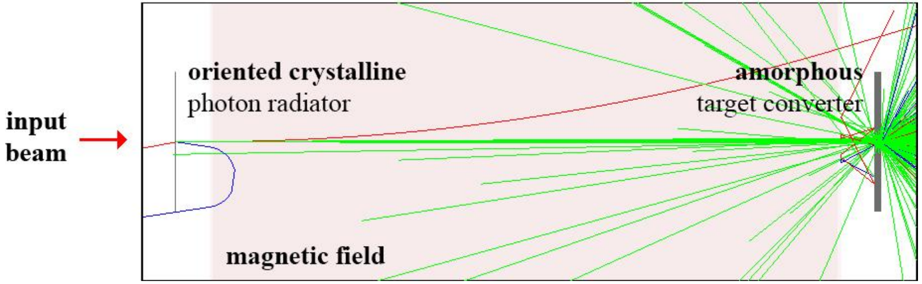




tungsten block of thickness 50 cm with square hole of side ***a***

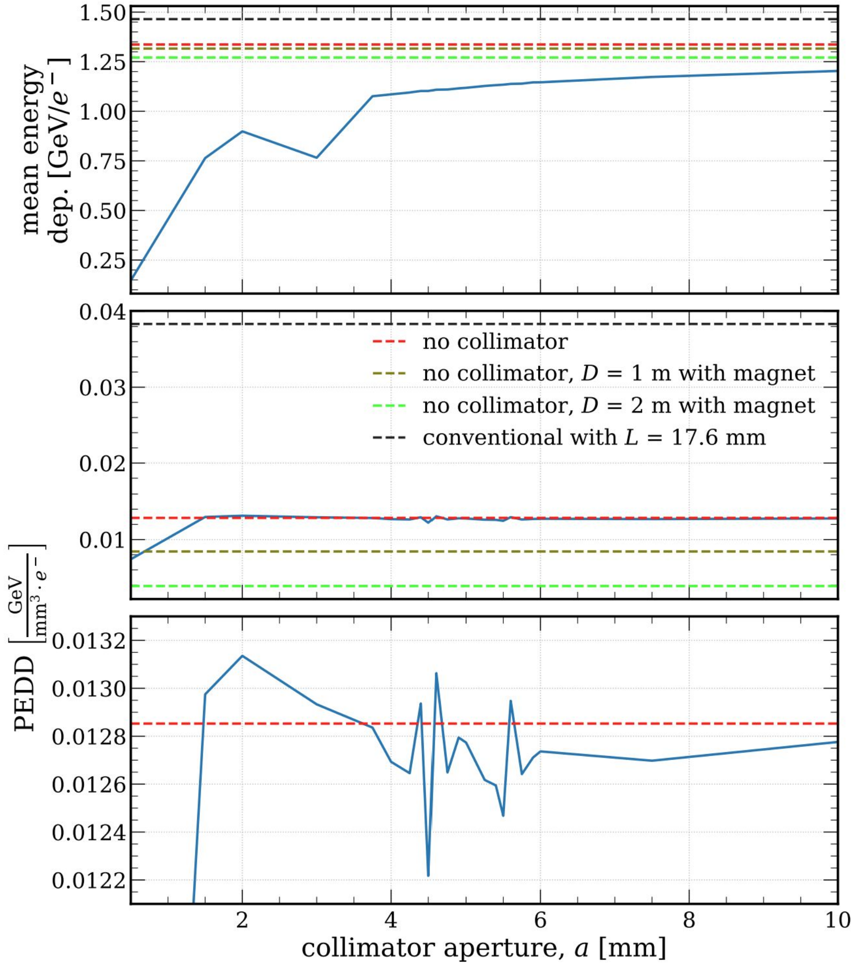
…with **magnet**

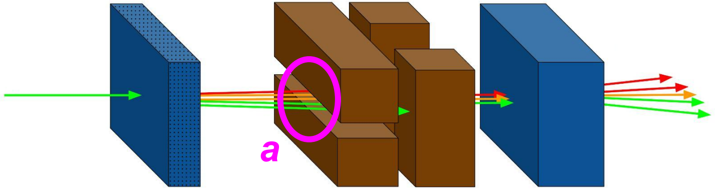




ideal, 100 T field to swipe all charged particles away

energy deposit & PEDD



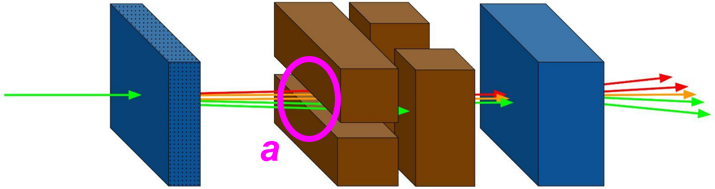


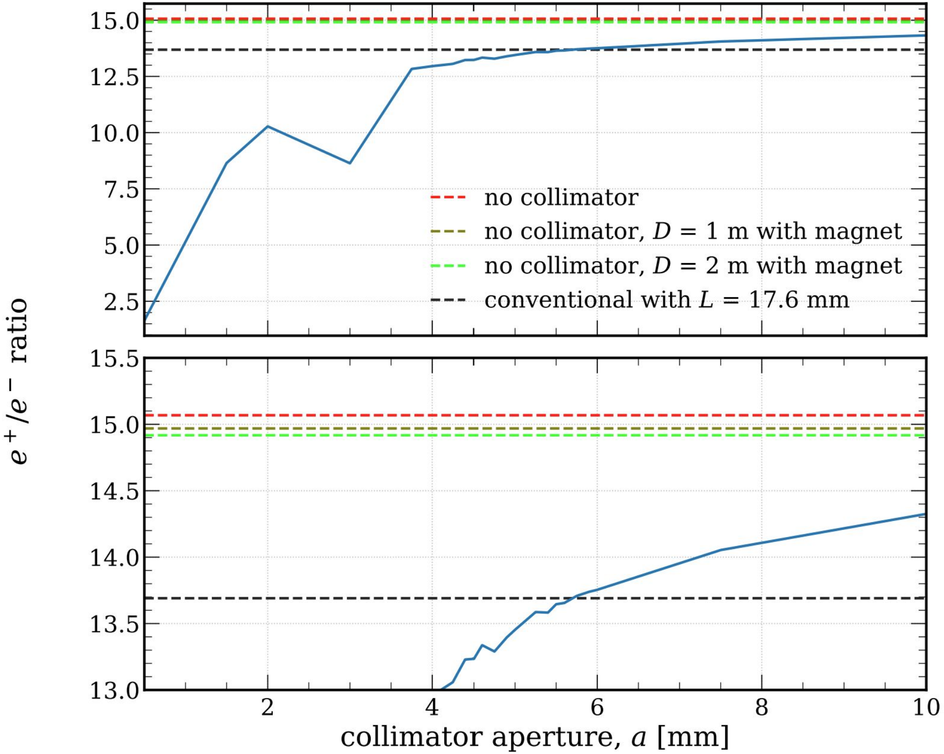
in general, **energy deposit** is lower (much lower) with magnet (collimator) wrt normal hybrid case, and it grows with *a* → better to keep *a* as low as possible

PEDD with collimator is similar to normal hybrid case, only a slight reduction for *a* with minimum around 7 mm is observed

PEDD with magnet (with larger *D*) is lower

positron production rate





output positron rate with collimator improves as *a* increases

⇒ conventional value is obtained at *a* ~ 5.5 mm, hybrid (without and with magnet) value is obtained asymptotically

for final comparison, choosing *a* = 5.5 mm – improvements wrt the no-collimator case:

- → significantly lower energy deposit
- → slightly lower PEDD
- → positron yield equal to conventional case

in conclusion

conventional (amorphous)
collimator
magnet

Scheme	conv.	hybrid						
L_{crys} [mm]	–	2						
D [m]	–	0.6			1			2	
L [mm]	17.6	11.6						
a = 5.5 mm **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/(mm$^3 \cdot e^-$)]	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

outlook

joint effort by INFN Ferrara (Italy) and IJCLab (France)

each of the configurations under study has its own strengths and caveats ⇒ choosing the final configuration will require additional info concerning the downstream stages…

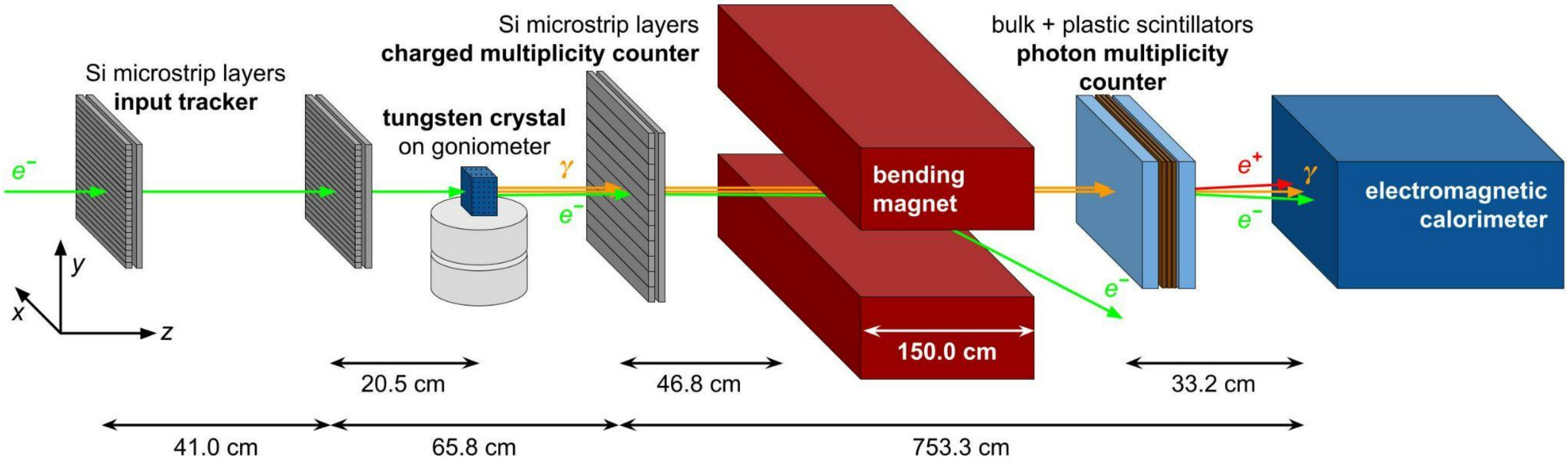
indeed output tracks can be fed to the magnetic capture system simulations ⇒ work in synergy to optimise the whole chain

the simulation environment has now been fully developed and can be used for more sophisticated studies

thank you!

any comments or questions? contact me at *mattia.soldani@unife.it*!

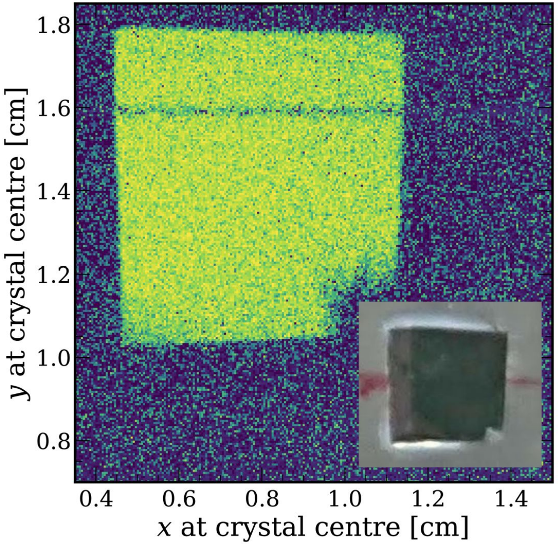
crystal characterisation @ DESY (2019)

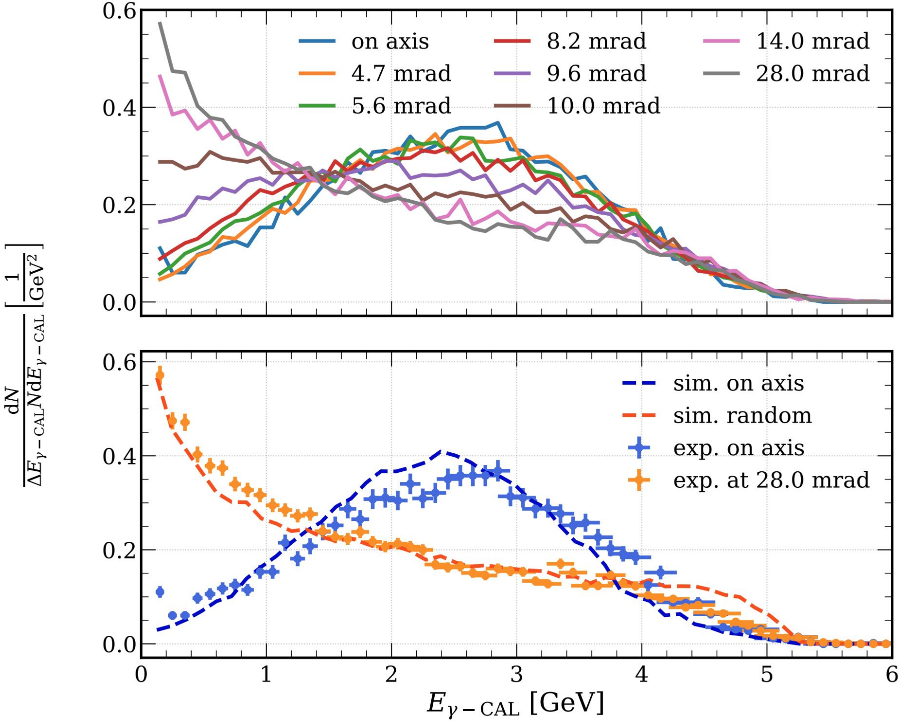


L. Bandiera *et al.*, **EPJC 82**, 699 (2022)

crystal characterisation @ DESY (2019)

W ⟨100⟩
~2.2 mm thick





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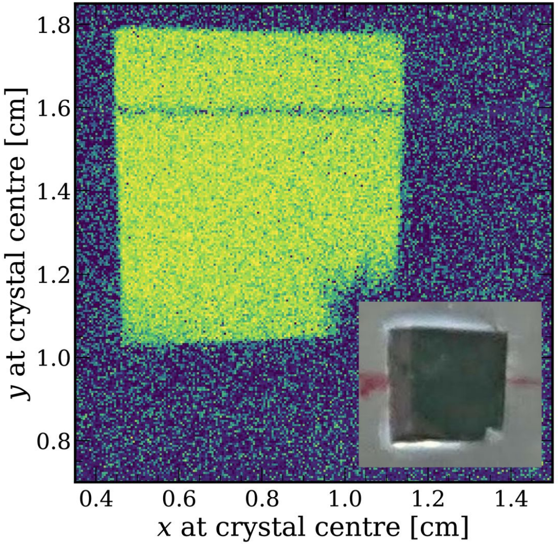

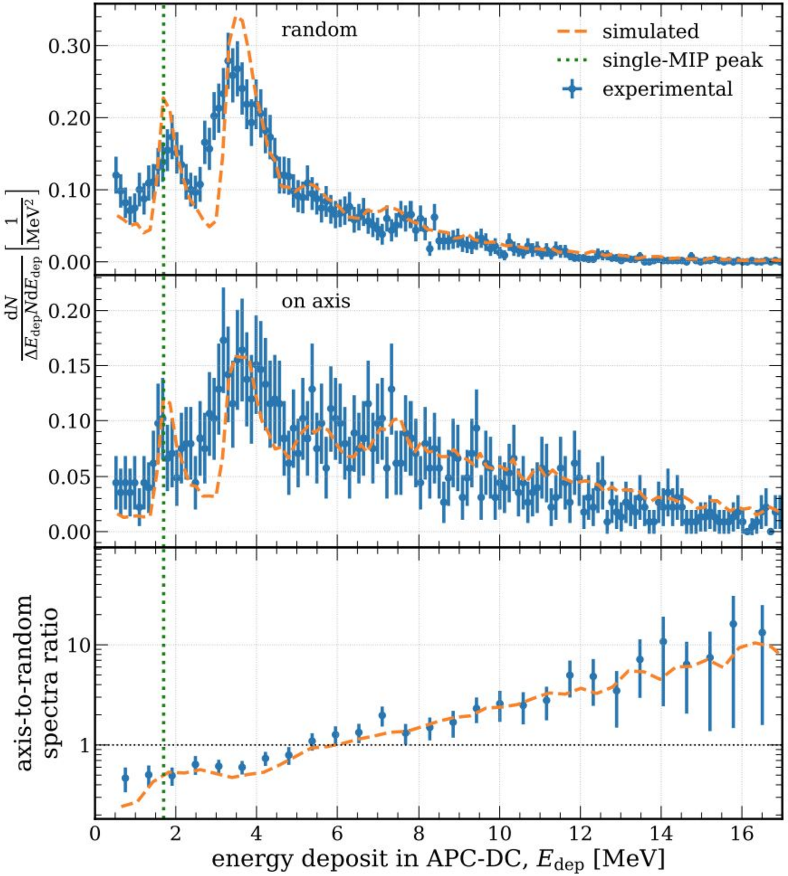

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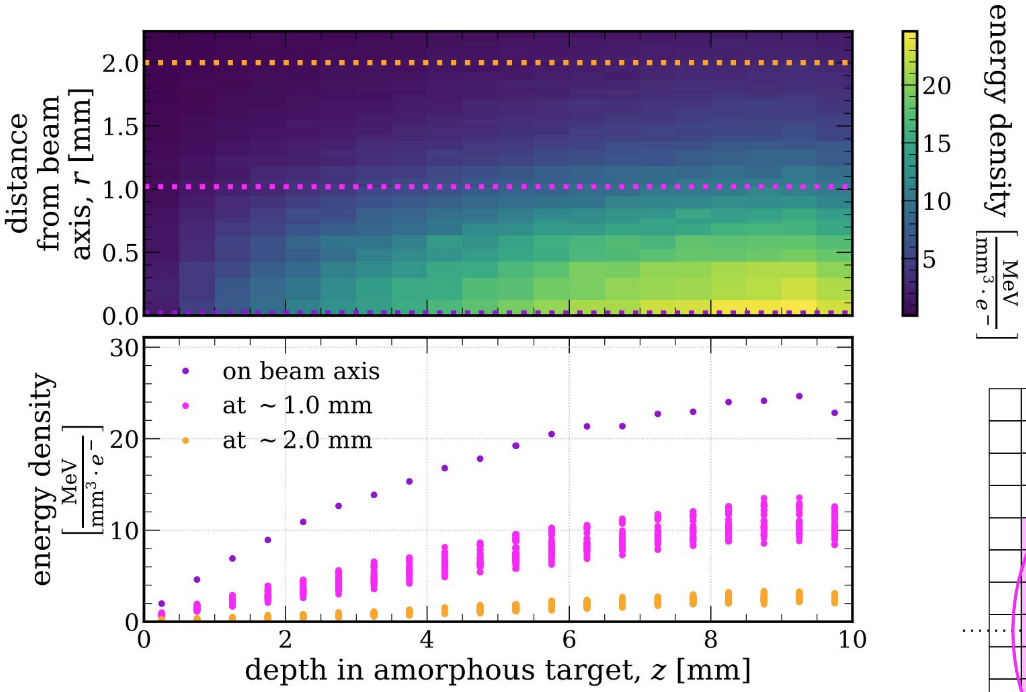
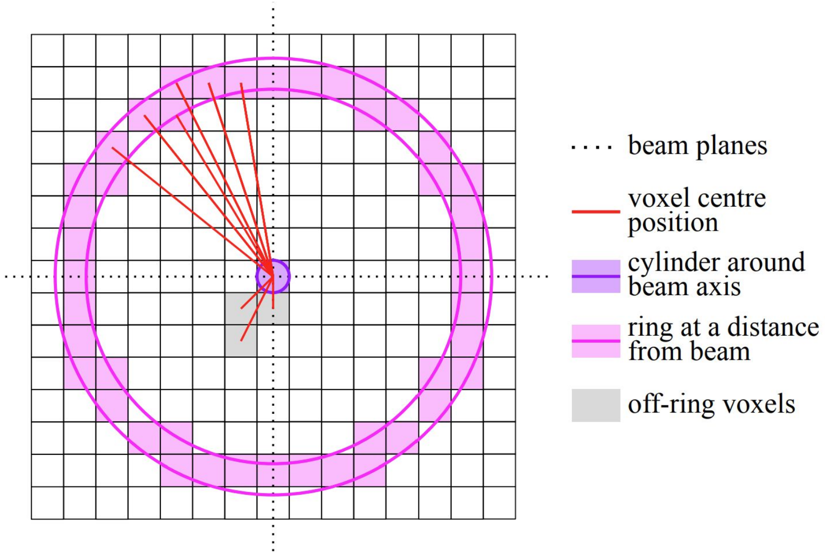
the target **mesh**





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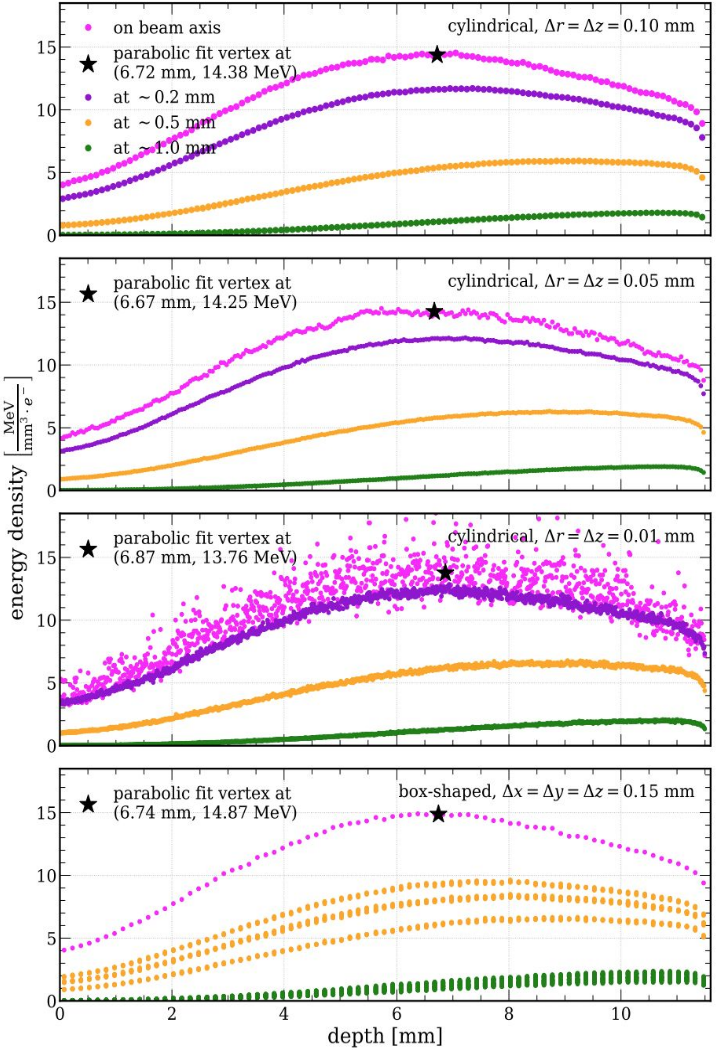

final simulations:

- box-shaped besh
- transverse bin size: 250 μm
- longitudinal bin size: 500 μm

output positron emittance