electromagnetic radiation generated by electrons in **oriented crystalline tungsten**

recent experimental investigation and possible applications

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why a radiator?

what for?

why tungsten?

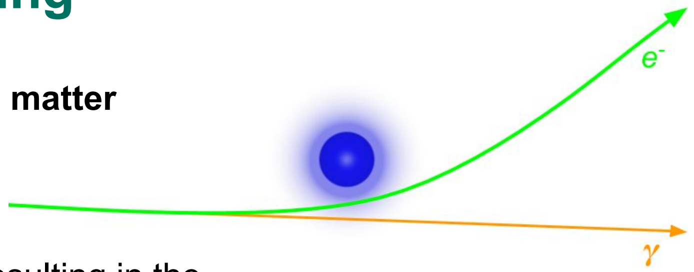
what's new?

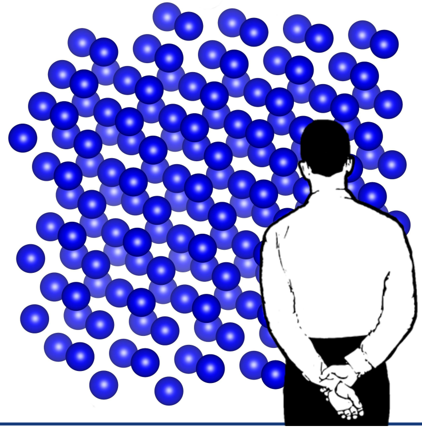
@ small angle **axial channeling**

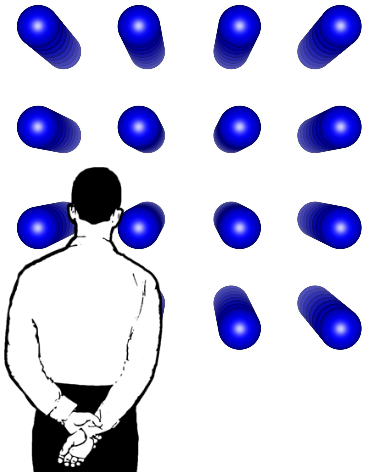
passage of **electrons through amorphous matter**

random interactions with single-nucleus Coulomb fields, independent to each other

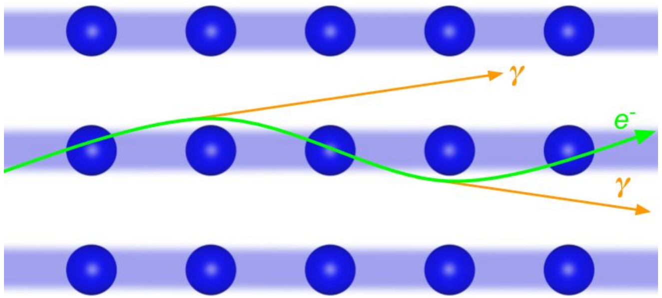
→ Bremsstrahlung radiation emission, resulting in the emission of photons with a Bethe-Heitler spectrum







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 → for ≳GeV particles, <u>high-intensity radiation emission, peaked at high photon energy fraction</u>

J. Lindhard *K. Dan. Vidensk. Selsk. Mat. Fys. Medd.* **34** (1965) 14
M. L. Ter-Mikaelian *Zhur. Eksp. Teor. Fiz.* **25** (1953) 289
F. J. Dyson and H. Überall *Phys. Rev.* **99** (1955) 604

@ small angle **the strong crystalline field**

***small* particle-to-axis angle** (within few mrad)

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

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)

V. N. Baier and V. M. Katkov *J. Exp. Theor. Phys.* **26** (1968) 854
A. I. Akhiezer and N. F. Shul'ga *High energy electrodynamics in matter* (1996)

@ small angle **the strong crystalline field**

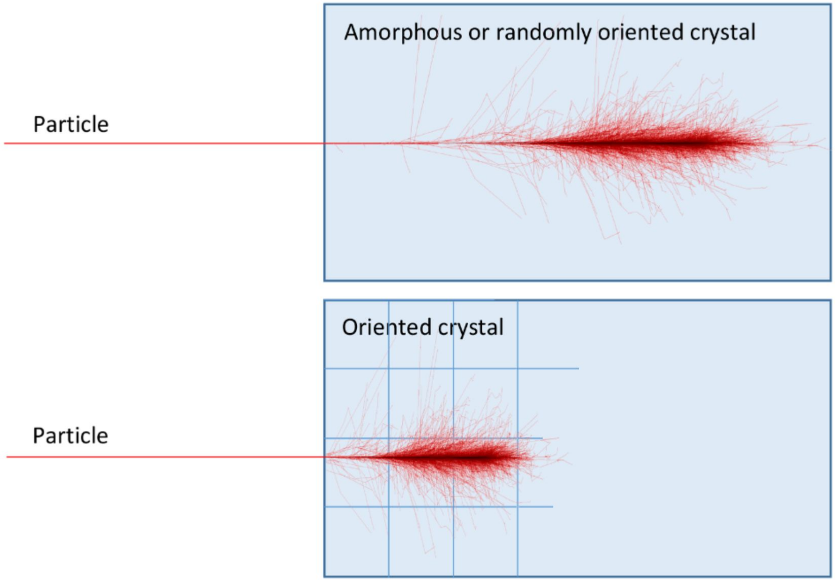
enhanced Bremsstrahlung

process is more likely, and energy loss often accounts for a large fraction of the electron initial energy → even more <u>intense and hard photon emission</u>

+

enhanced Pair Production

coherent interaction dominates over the Bethe-Heitler process
→ overall <u>PP cross section strongly increased</u>



effective radiation length X_0 is much shorter

or equivalently…

electromagnetic shower is way more compact

compact radiators

i.e. same photon yield as an amorphous target can be attained with a much thinner oriented crystal of the same material → lower target heating and radiation damage, lower output emittance

SF radiation energy spectrum can feature a broad hard peak — input energy- and thickness-dependent

hybrid positron sources for future leptonic colliders

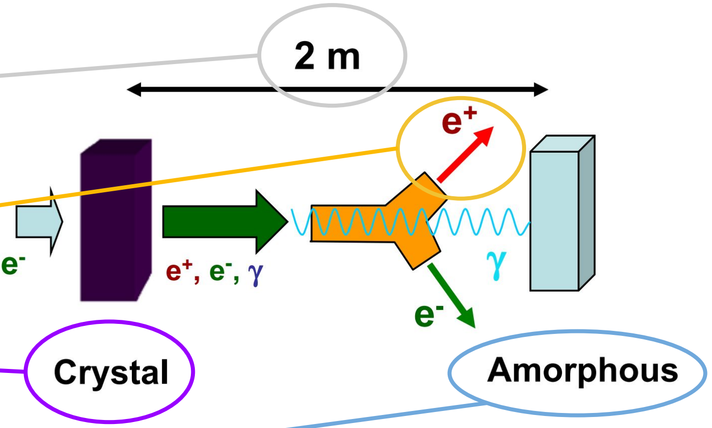
(an idea of R. Chehab and A. Variola)

a few meters distance between radiator and converter ← trade-off between positron yield & energy absorption in converter

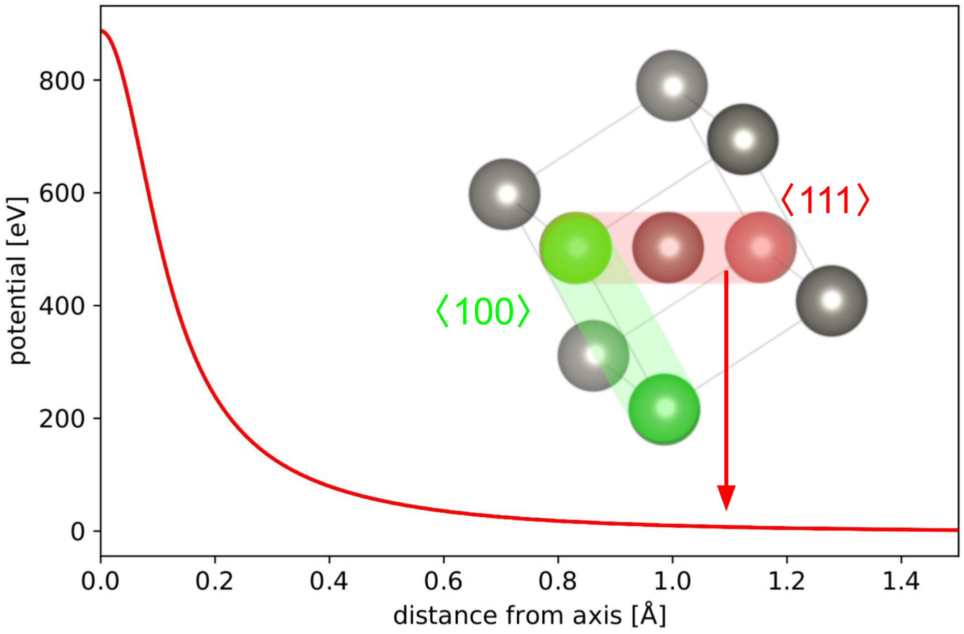
charged pairs from crystal are swiped away

e.g. ~1 mm thick tungsten

thick amorphous target for (electron-)positron production



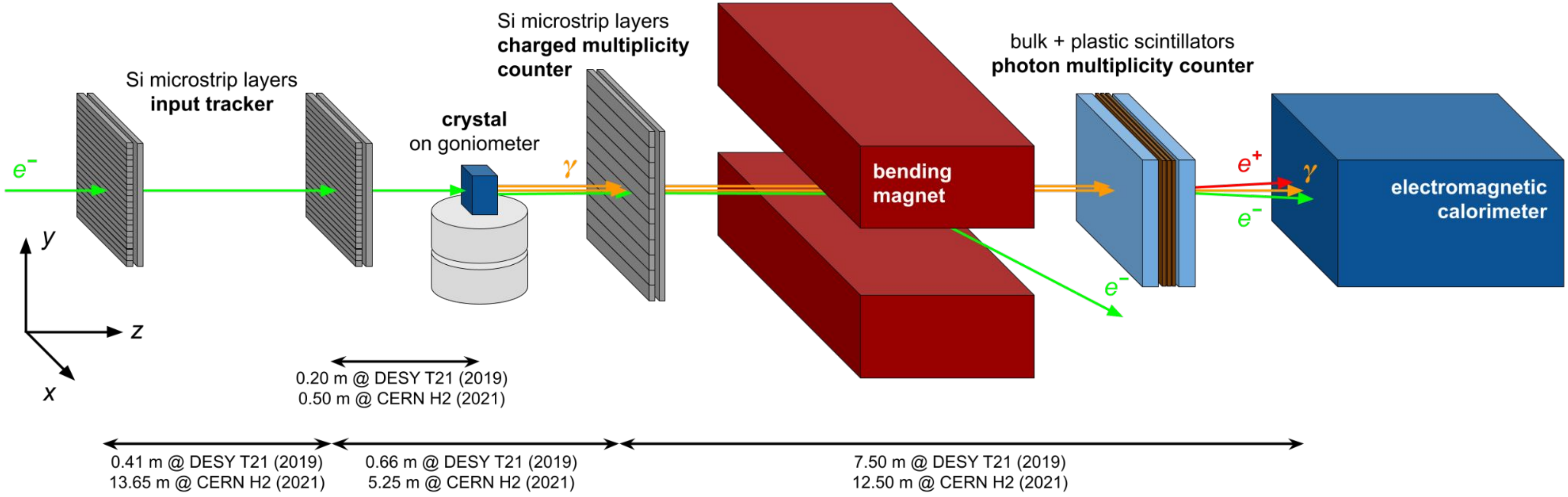
crystalline tungsten



- very high-Z and high-density
- (amorphous) **radiation length**
  X_0 = 0.3504 cm
- Body-Centered Cubic unit cell
- lattice constant
  a = 3.1652 Å
- ⟨111⟩ **axial potential** at room temperature
  U_0 ~ 900 eV
- ⟨111⟩ **critical angle**
  Θ_0 ~ 1.75 mrad
- ⟨111⟩ **SF threshold energy** (χ~1)
  E_{thres} ~ 13.6 GeV
- ⟨100⟩ axis slightly weaker
  (U_0 ~ 800 eV)

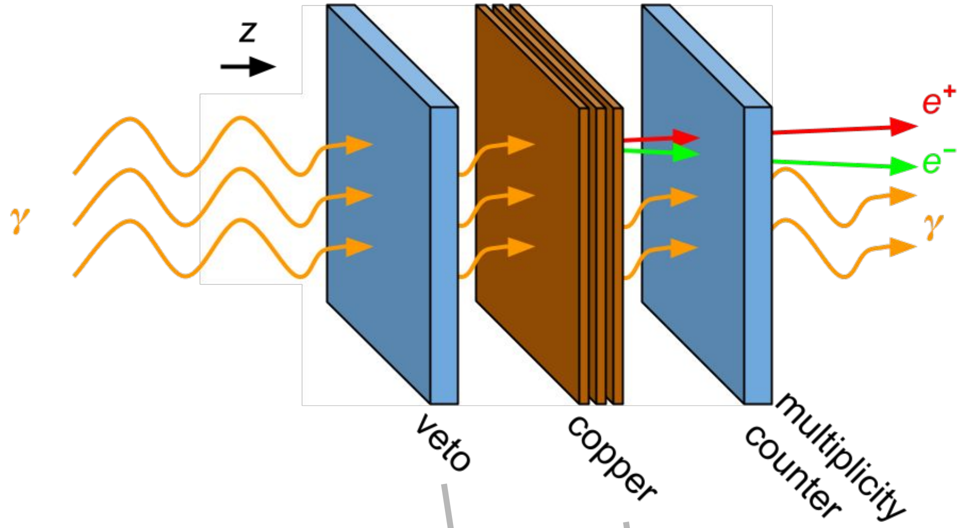
new measurements **setup**

- W⟨100⟩ ~0.31X_0 thick @ CERN H2 at **20 GeV/*c*** ***χ*~1**
- W⟨111⟩ ~0.70X_0 thick @ DESY T21 at **5.6 GeV/*c*** ***χ*~0.2**



both samples are courtesy of LMS @ RAS ISSP

new measurements **active photon converter**



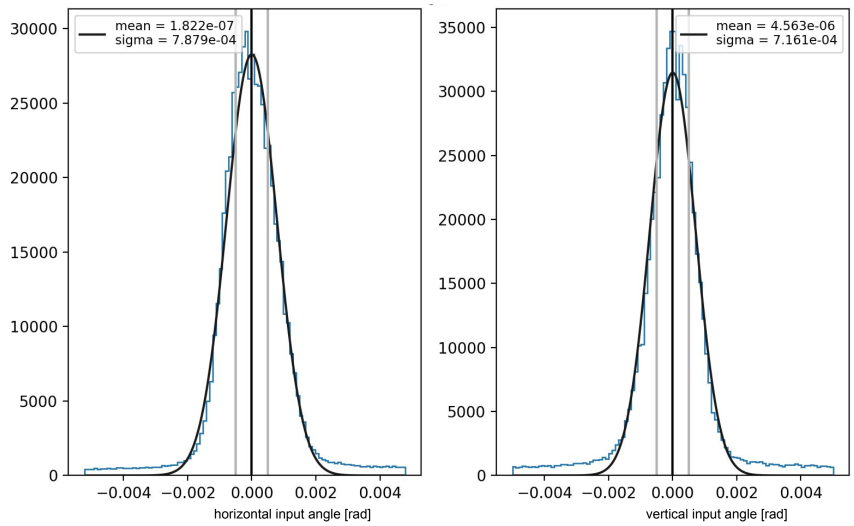
1. charged background in equilibrium with the photon beam is **vetoed** by upstream scintillator
2. some photons undergo **pair production** inside the pure Cu (X_0 = 1.436 cm) layer
3. downstream scintillator counts the **pairs multiplicity**

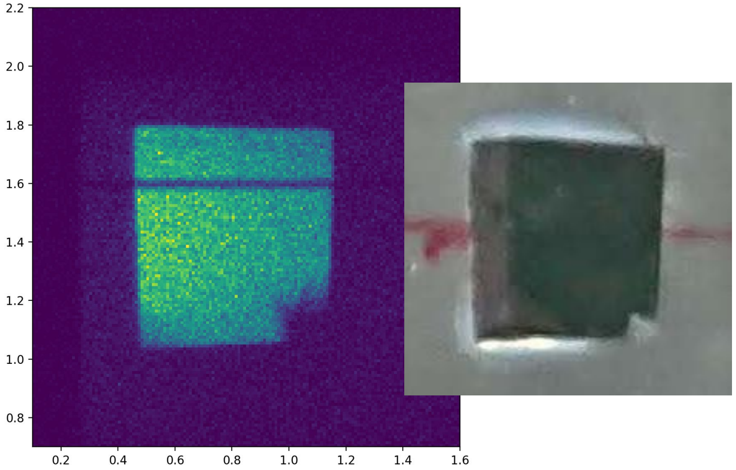
tunable converter thickness with 450 μm resolution → final configuration: 2.7 mm ~ 0.2 X_0

⇒ statistical information on the <u>number of photons per single electron</u> impinging on the crystal

@ 5.6 GeV/*c* **input beam**

incident beam divergence is ~700-800 μrad → way within the SF critical angle



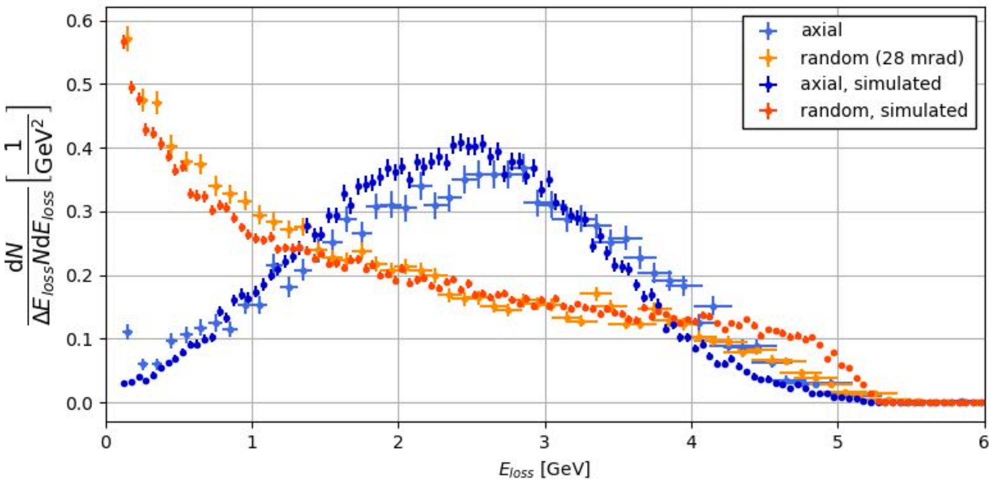


in order to find the crystal transverse profile, selection with the downstream multiplicity counters: only events with high multiplicity of charged particles in output are selected

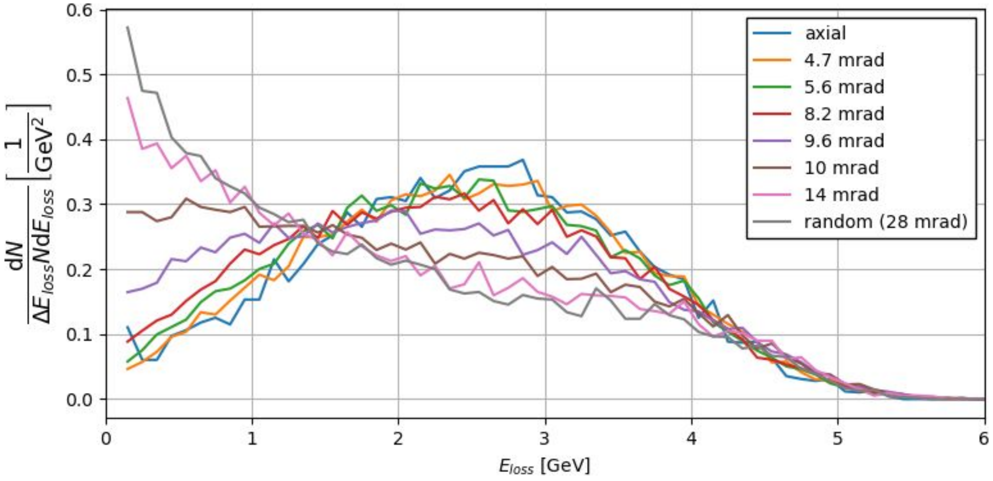
@ 5.6 GeV/*c* radiated energy

spectra of energy loss inside the crystal in random and axial orientation: the random corresponds to standard Bethe-Heitler, whereas the axial <u>is harder, with a broad peak at ~2.5 GeV</u>

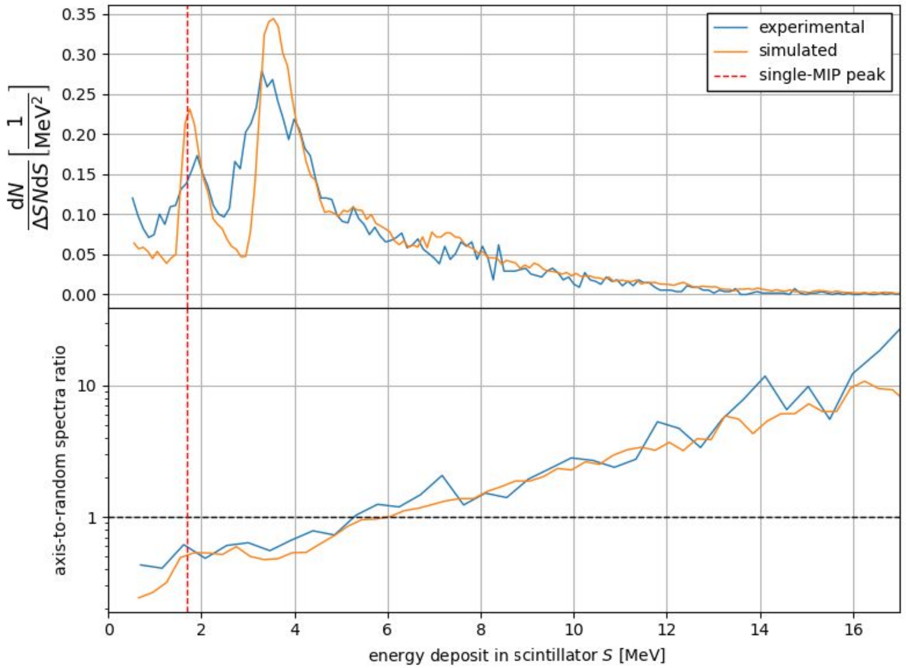
excellent agreement between experimental data and simulations



smooth transition from axis to random-like orientation (@ 28 mrad); <u>hard-peaked structure persists up to ≳8 mrad</u>



@ 5.6 GeV/*c* **photon multiplicity**



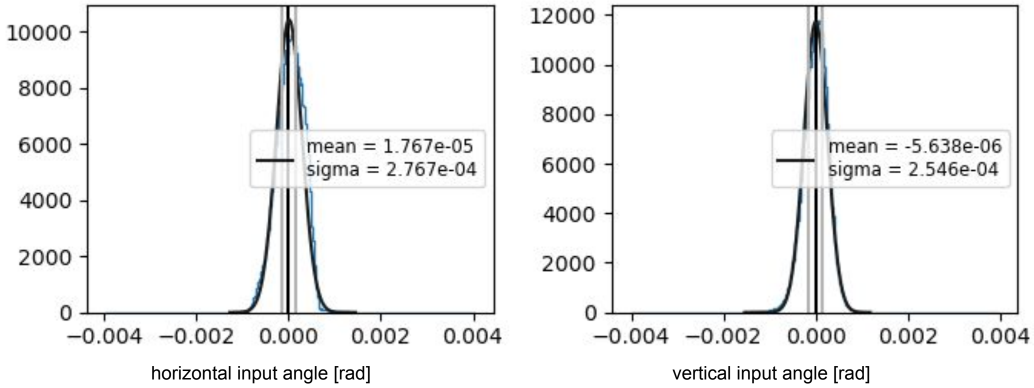
ratio between axial and random spectra of the active converter downstream scintillator:

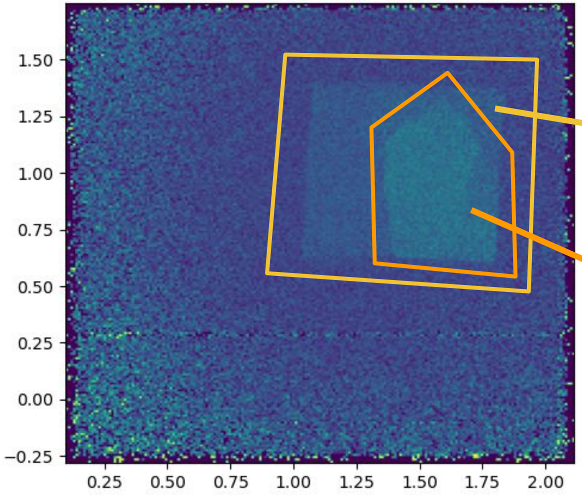
- exponential trend
- when on axis, emission of up to ~2 photons (i.e up to 4 charged pairs, i.e. up to ~5 MeV here) is suppressed, whereas higher photon multiplicities are enhanced

again, excellent agreement between measurements and simulations

@ 20 GeV/c **input beam**

incident beam divergence is ~250-280 μrad → way within the SF critical angle

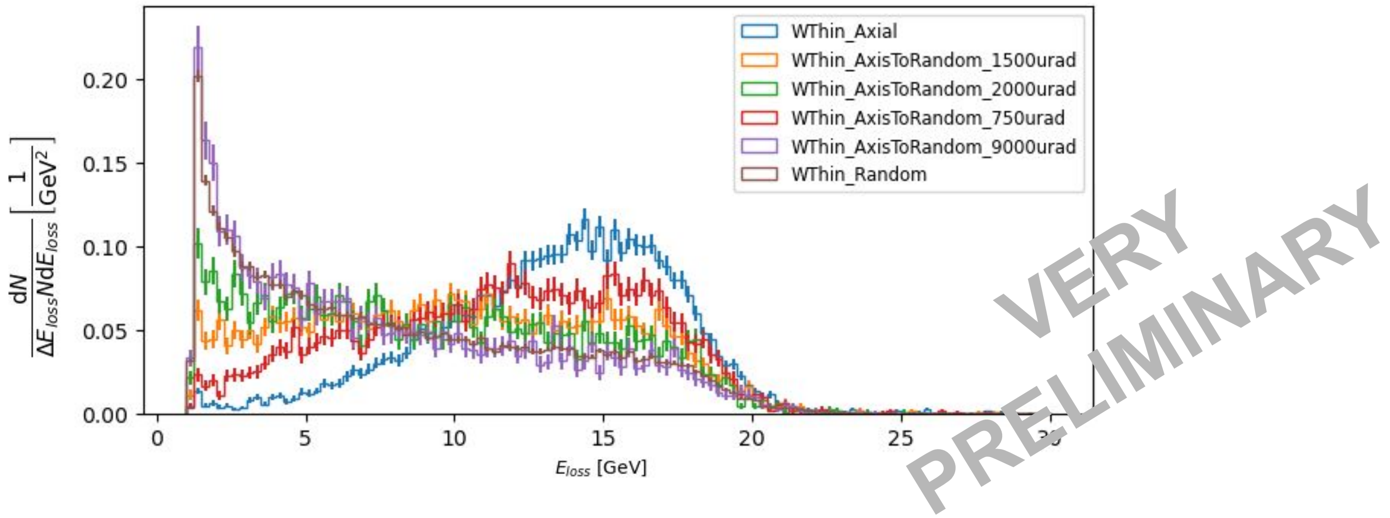




crystal profile obtained via high-multiplicity output state efficiency map

only part of the sample was axially oriented

@ 20 GeV/*c* radiated energy

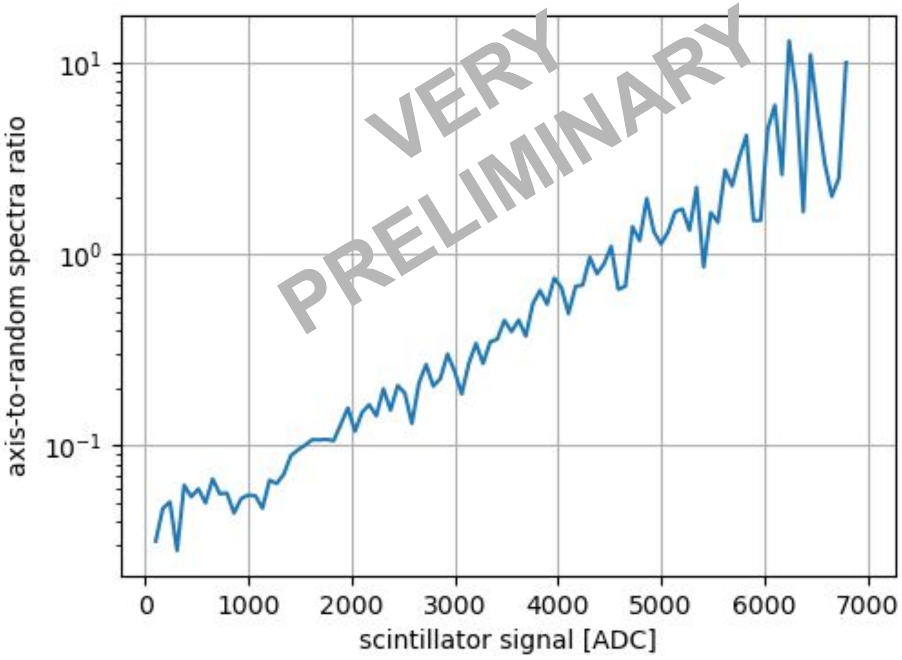


hard-peaked shape of the on-axis spectrum is even more evident at 20 GeV, as is the difference from the random (Bethe-Heitler) one

peak centre at ~15 GeV

very strong enhancement up to ~1.5 mrad off-axis; then transition to amorphous-like behaviour is similar to lower-energy case

@ 5.6 GeV/*c* **photon multiplicity**



ratio between axial and random spectra of the active converter downstream scintillator: analysis is still at an early stage, but the clean exponential trend is very promising…

so what?

- the enhancement of the radiation emitted by electrons across oriented tungsten samples has been proved macroscopically strong, in both energy and intensity, in the sub-SF and SF regimes

- the results obtained at 5.6 GeV already validate the simulation tools of coherent interactions in crystals

- what's next?
  - finalise the analysis of the data collected at 20 GeV
  - perform further radiation tests also at the 100-MeV scale at MAMI
  - new sample irradiation tests at MAMI are also upcoming in collaboration with IJCLab…

thank you!

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