



Istituto Nazionale di Fisica Nucleare



European
Commission



Korea Institute of
Science and Technology Information

TRILLION

New results of the Project TRILLION: Geant4 model of X- and gamma-rays production in oriented crystals

Dr. Alexei Sytov, Dr. Laura Bandiera, Prof. Kihyeon Cho

2023 KPS Spring Meeting

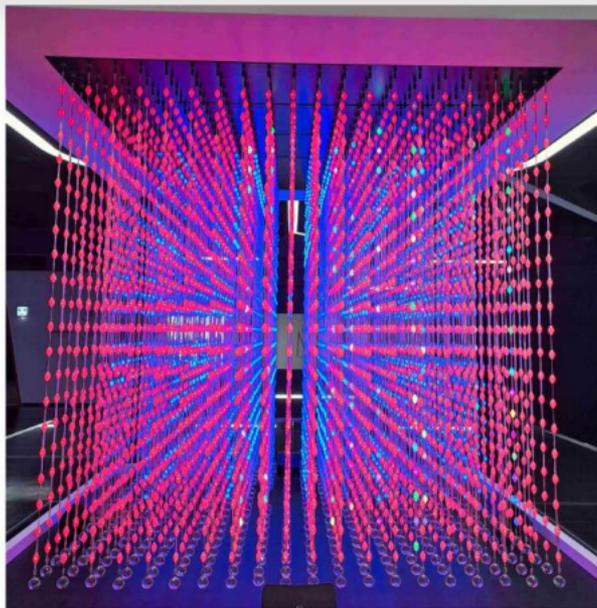
Daejeon, April 19, 2023



European
Commission

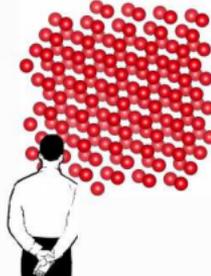
How an oriented crystal looks like

Trillion

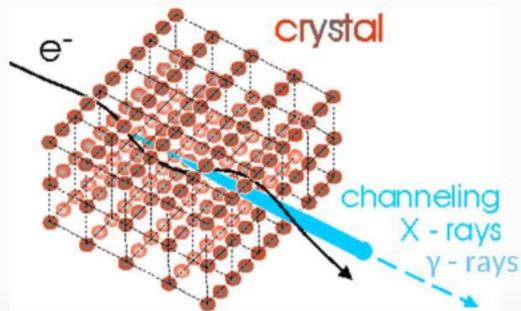
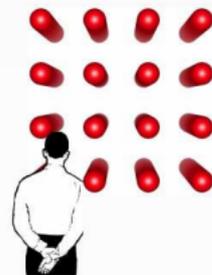


from National Science
Museum, Daejeon, Korea

Non-oriented
crystal

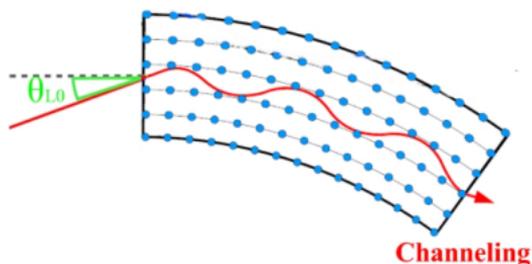


Oriented crystal



Coherent effects in a crystal

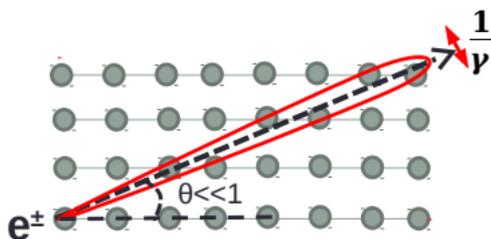
Channeling*



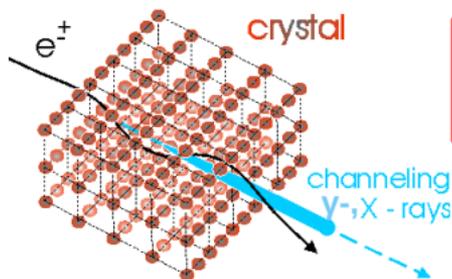
Energies:
MeV - TeV

Equivalent
magnetic
field: more
than 100 T

Coherent bremsstrahlung***

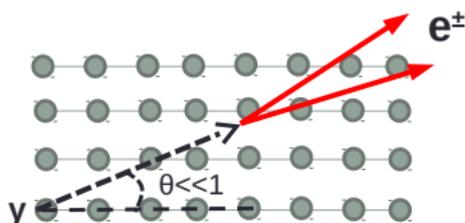


Channeling radiation**



Planar/
Axial field
 $10^9/10^{11}$ V/cm

Coherent pair production****



*J. Stark, Zs. Phys. 13, 973-977 (1912); J. A. Davies, J. Friesen, J. D. McIntyre, Can J. Chem. 38, 1526-1534 (1960)

**M.A. Kumakhov, Phys. Lett. A 57(1), 17-18 (1976)

***B. Ferretti, Nuovo Cimento 7, 118 (1950); M. Ter-Mikaelian, Sov. Phys. JETP 25, 296 (1953).

**** H. Überall, Phys. Rev. 103, 1055 (1956).

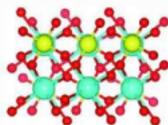
Applications*

Crystal-based collimation or beam extraction from an accelerator

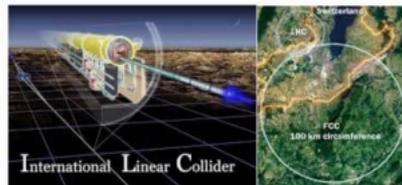
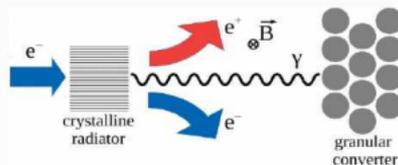


Gamma-ray Space Telescope

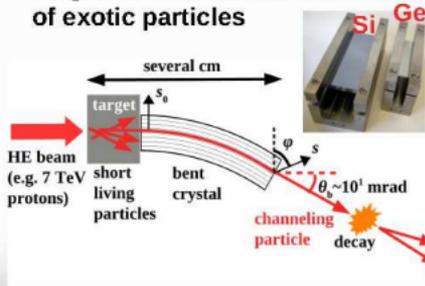
Ultrashort crystalline calorimeter



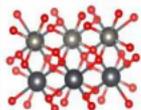
Positron source for future e+/e- and muon colliders



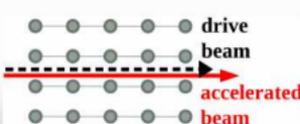
Measurement of dipole magnetic and electric moments of exotic particles



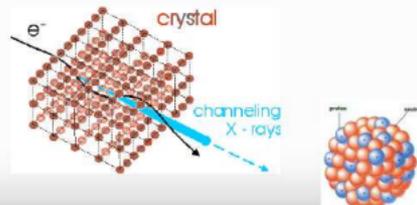
Oriented crystals



Plasma acceleration



X and gamma-ray source for nuclear and medical physics



Marie Skłodowska-Curie Action Global Individual Fellowships by A. Sytov in 2021-2025, Project TRILLION GA n. 101032975

Main goal: The **implementation** of both physics of **electromagnetic processes in oriented crystals** and the design of specific applications of crystalline effects into **Geant4** simulation toolkit as Extended Examples **to bring them to a large scientific and industrial community** and under a free Geant4 license.

Group:

- ◆ **A. Sytov** – project coordinator
- ◆ **L. Bandiera** – INFN supervisor
- ◆ **K. Cho** – KISTI supervisor
- ◆ **G. Kube** – DESY supervisor
- ◆ **I. Chaikovska** – IJCLab Orsay supervisor

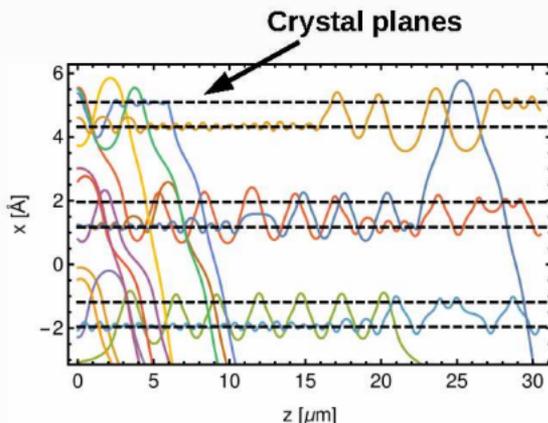


Location:

- ◆ 2 years at **KISTI** (partner organization)
- ◆ 1 year at **INFN Section of Ferrara** (host organization)
- ◆ 1 month of secondment at **DESY** (partner organization)
- ◆ 1 month of secondment at **IJCLab Orsay** (partner organization)

Channeling simulation technique: Geant4 ChannelingFastSimModel

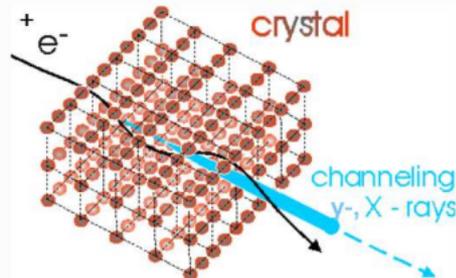
Main conception – simulation of classical trajectories of charged particles in a crystal
Multiple and single **scattering simulation** at every step



Advantages:

- ◆ High calculation speed
- ◆ MPI parallelization for high performance computing

channeling*



Baier-Katkov formula:

integration is made over the classical trajectory

$$\frac{dE}{d^3k} = \omega \frac{dN}{d^3k} \frac{\alpha}{4\pi^2} \iint dt_1 dt_2 \frac{[(E^2 + E'^2)(v_1 v_2 - 1) + \omega^2 / \gamma^2]}{2E'^2} e^{-ik'(x_1 - x_2)}$$

A.I. Sytov, V.V. Tikhomirov. NIM B 355 (2015) 383–386.

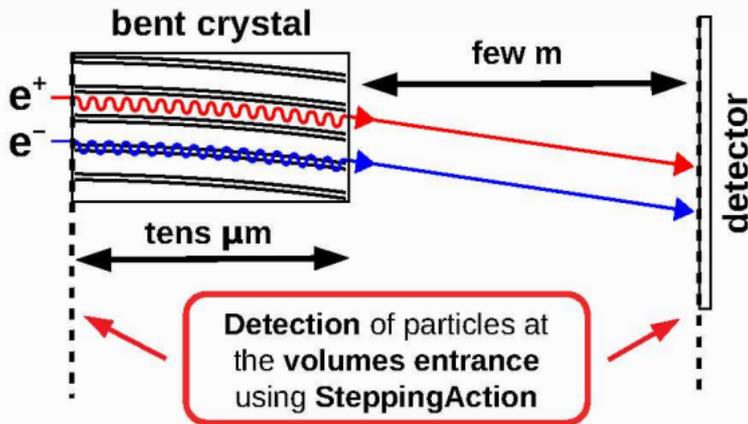
L. Bandiera, et al., Nucl. Instrum. Methods Phys. Res., Sect. B 355, 44 (2015)

*A. Sytov et al. arXiv: 2303.04385, Accepted for publication in JKPS

A. I. Sytov, V. V. Tikhomirov, and L. Bandiera. PRAB 22, 064601 (2019)

First Geant4 channeling example for electrons/positrons

- Inspired by our experiments* of 855 MeV electron beam deflection by an ultrashort bent crystal at Mainz Mikrotron MAMI



Beam setup in run.mac using GPS commands; all the geometry in DetectorConstruction

Multithreading works! Checked at the supercomputer Galileo100@CINECA (Italy) NURION@KISTI (Korea)

Output both in root (only primary particles) and in textfile (all the particles) format



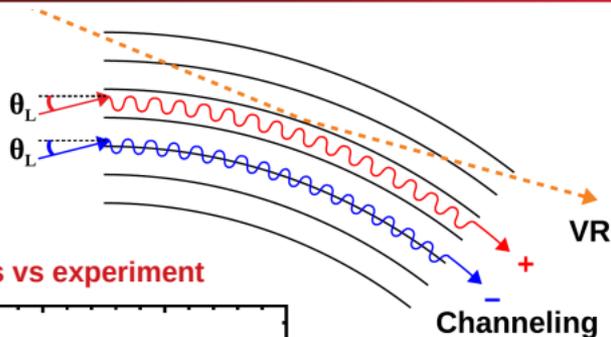
*A. Mazzolari et al. Phys. Rev. Lett. 112, 135503 (2014)

A. Sytov et al. Eur. Phys. J. C 77, 901 (2017)

First simulations with Geant4 channeling model: beam deflection by a bent crystal

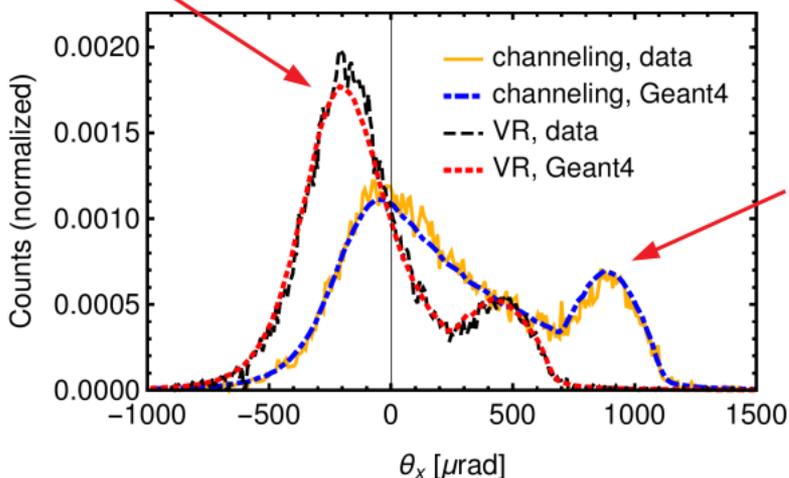
855 MeV
electrons

15 μm thick
bent crystal



volume reflection (VR)

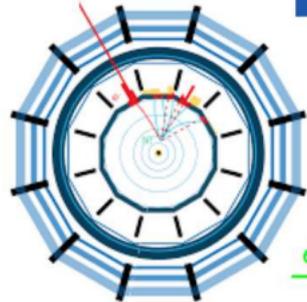
Geant simulations vs experiment



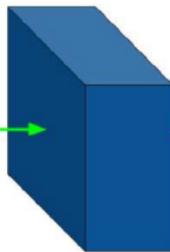
channeling

Positron source for future lepton colliders

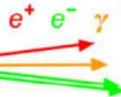
FUTURE
CIRCULAR
COLLIDER



e^-



amorphous
tungsten



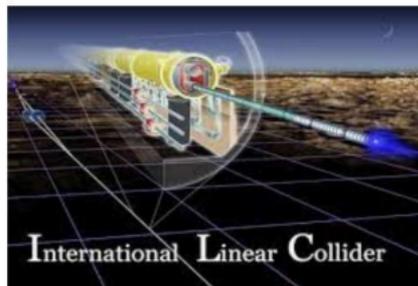
All the future e^+e^- colliders
will need an **intense
positron source**

Potential challenges:
Target overheating/melting



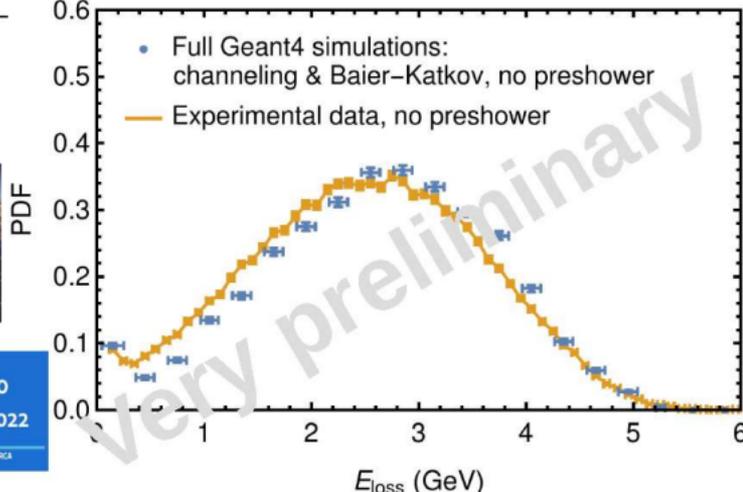
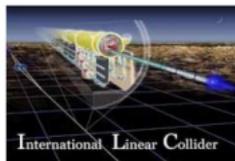
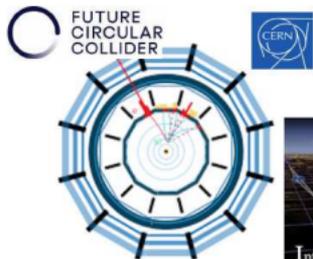
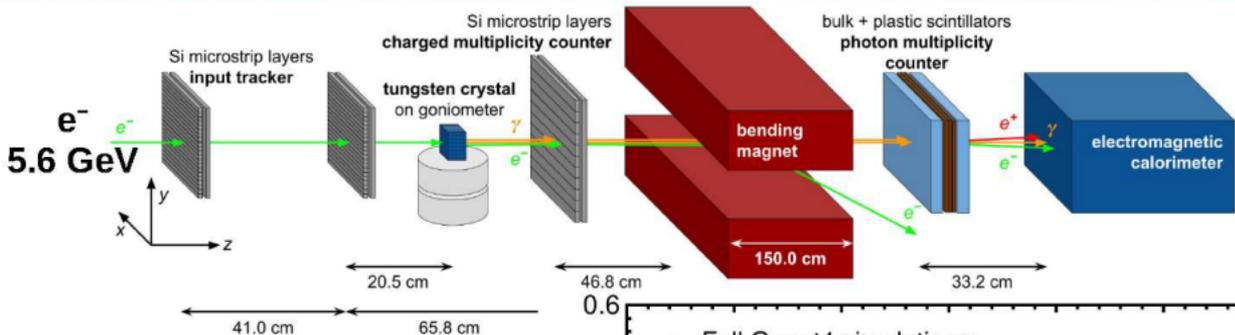
Peak Energy Deposition
Density (**PEDD**) limit:
35 J/g for W^*

The main **challenge:**
to **increase positron yield**
and to **decrease PEDD**



International Linear Collider

Full Geant4 simulations of the DESY experiment* for the FCC-ee positron source project



Intense positron source Based On Oriented crySTals - e+BOOST
(PI L. Bandiera)
PRIN2022-2022Y87K7X
Financed by Italian Ministry of University and Research - PRIN project



Current status

◆ Add to main:

```
Register FastSimulationPhysics
```

Already in Geant4 kernel!

```
G4FastSimulationPhysics* fastSimulationPhysics = new G4FastSimulationPhysics();  
fastSimulationPhysics->ActivateFastSimulation("e-");  
// -- activation of fast simulation models having fast simulation models  
// -- attached in the physics list  
fastSimulationPhysics->ActivateFastSimulation("e-");  
fastSimulationPhysics->AttachFastSimulationPhysicsList();  
// -- Attach the fast simulation physics list to the physics list:  
physicsList->RegisterPhysics(fastSimulationPhysics);
```

Geant4-11.2.0.beta
Please use it!

G4BaierKatkov

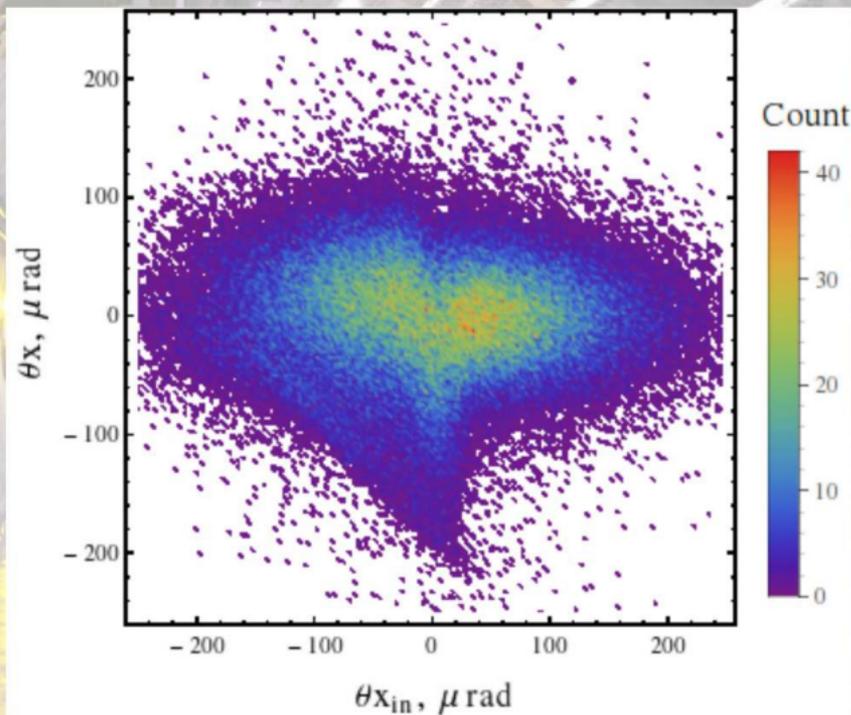
**Don't hesitate to contact me in the case of
any problems/issues/suggestions
sytov@fe.infn.it**

Please cite our papers if you use our model:

1. A. Sytov et al. JKPS 83, 132–139 (2023)
2. A. I. Sytov, V. V. Tikhomirov, and L. Bandiera. PRAB 22, 064601 (2019)

Conclusions

- **Oriented crystals** can be **applied**:
 - at **e-/e+/hadron synchrotrons** (crystal-based beam extraction/collimation)
 - in **nuclear** and **medical physics** (radiation source)
 - at e-/e+ colliders – **ILC**, **FCC-ee** and **muon collider** (positron source)
 - as **ultrashort electromagnetic calorimeters**
 - for **MDM** and **EDM** measurement
 - ultrahigh gradient (more than 1 **TeV/m**) **plasma wakefield acceleration**
- The goal of **TRILLION** is to implement **electromagnetic processes in oriented crystals** into **Geant4** which will bring to a large scientific and industrial community most of possible applications of a crystal.



Thank you for attention!