New Extended Channeling Examples

Marie Curie Global Fellowships, Project TRILLION GA n. 101032975

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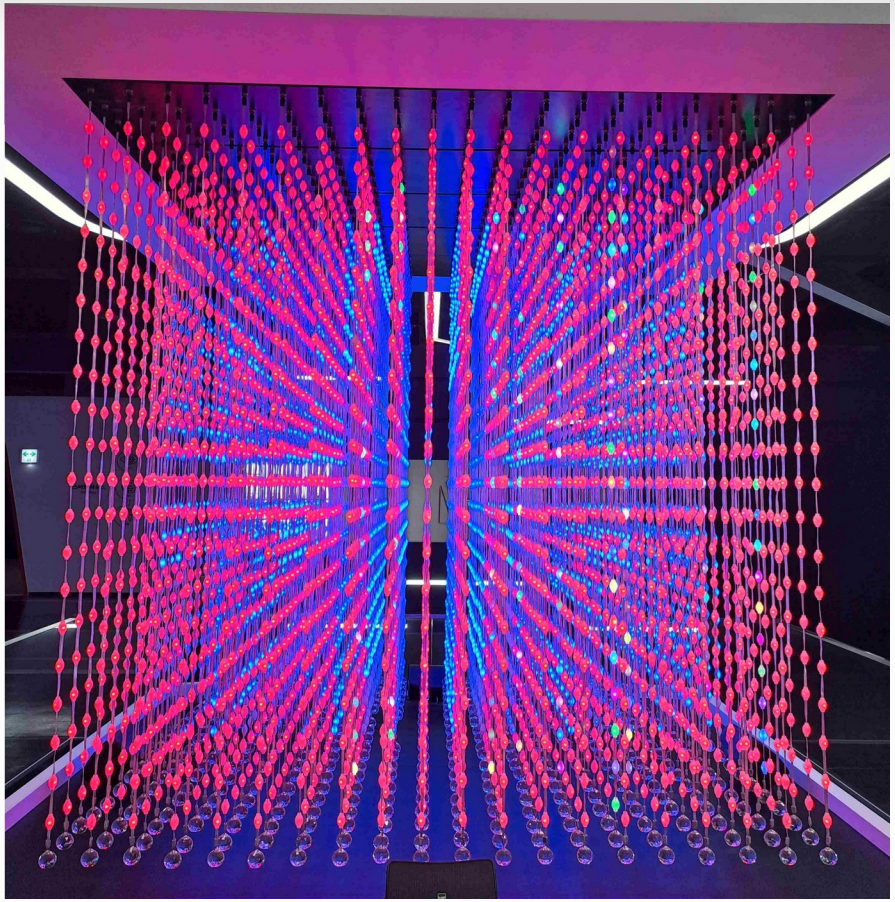
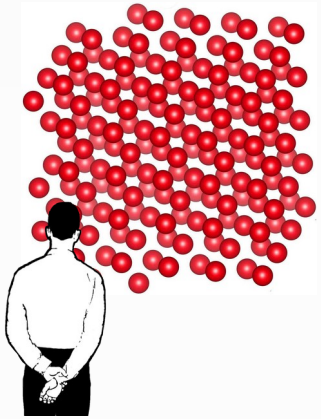
29th Geant4 Collaboration Meeting, 08/10/2024

How an oriented crystal looks like

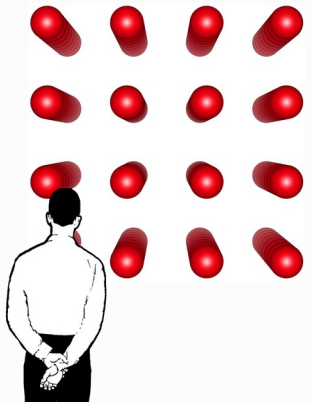


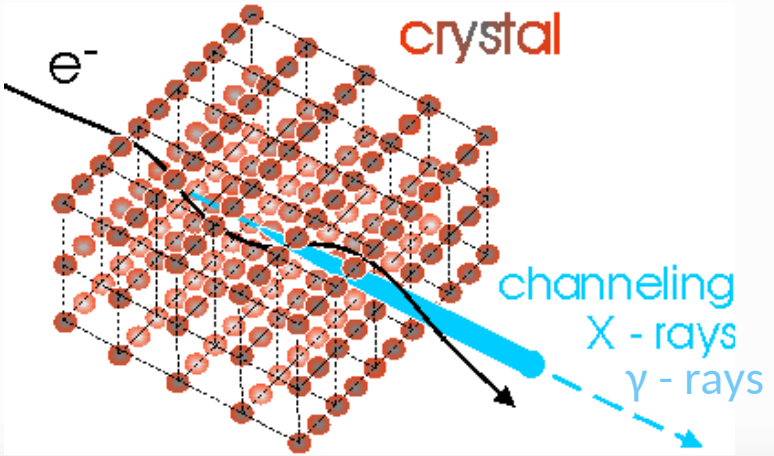
from National Science Museum, Daejeon, Korea

Non-oriented crystal

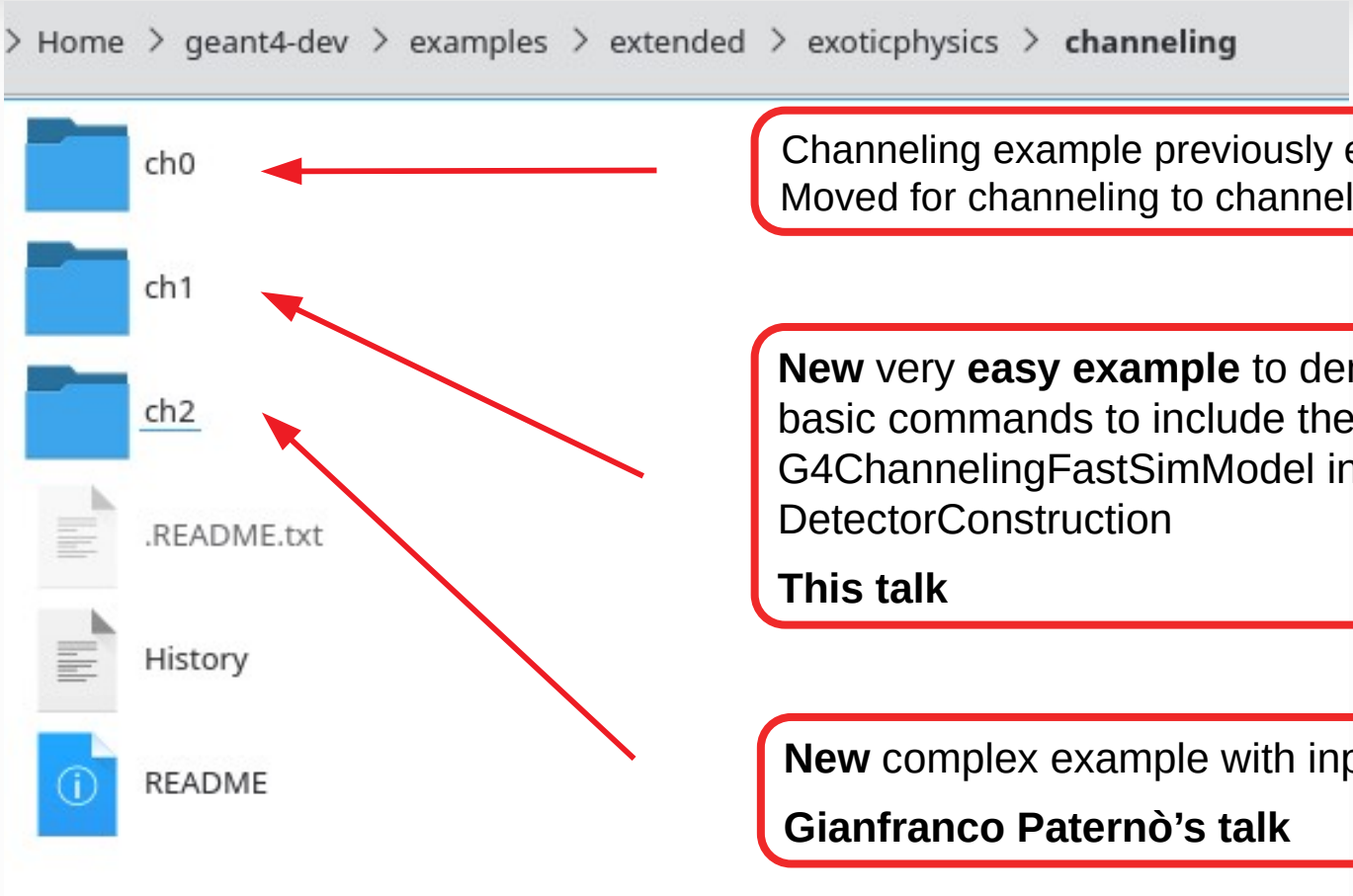


Oriented crystal





List of channeling Geant4 examples successfully merged



Channeling example previously existed.
Moved for channeling to channeling/ch0

New very **easy example** to demonstrate basic commands to include the G4ChannelingFastSimModel in DetectorConstruction

This talk

New complex example with input/output

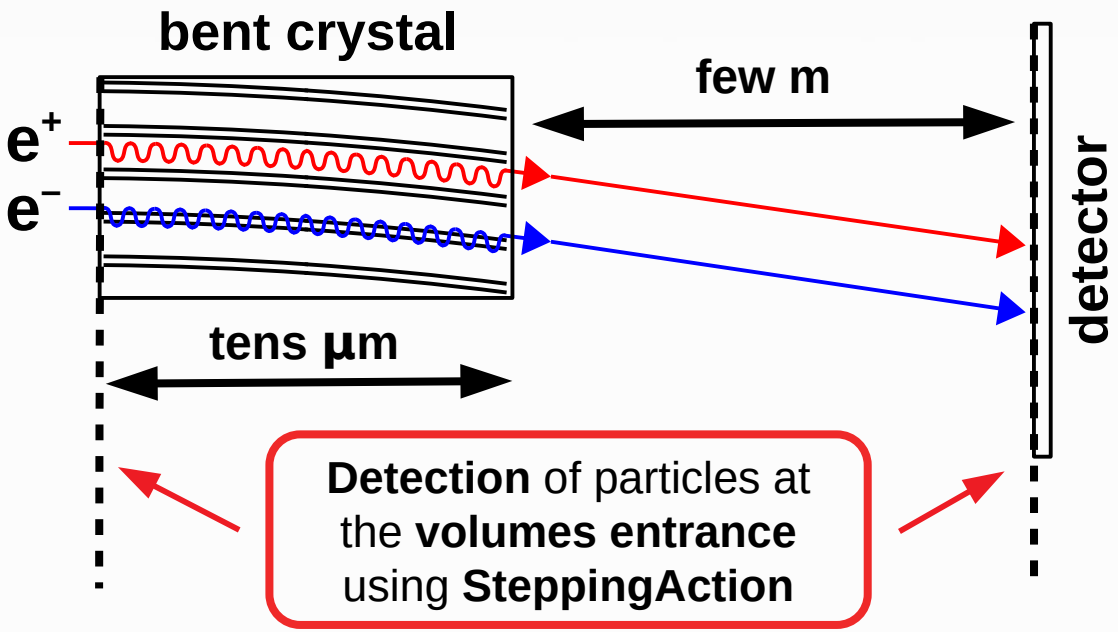
Gianfranco Paternò's talk

New example dedicated to FCC-ee positron source is coming!

Gianfranco Paternò's talk

ch1 – first Geant4 channeling example for e-/e+

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



Detection of particles at the **volumes entrance** using **SteppingAction**

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

Output both in **root** (x-coordinate on the detector and radiation spectrum)

*A. Mazzolari et al. Phys. Rev. Lett. 112, 135503 (2014)
A. Sytov et al. Eur. Phys. J. C 77, 901 (2017)

How to copy/paste channeling from ch1 into your example?

- **Add to DetectorConstruction::Construct()**

```
//crystal volume
G4Box* crystalSolid = new G4Box("Crystal",CrystalSizeX/2,CrystalSizeY/2,CrystalSizeZ/2.);
crystalLogic = new G4LogicalVolume(crystalSolid,crystalMaterial,"Crystal");
            new G4PVPlacement(xRot,posCrystal,crystalLogic,"Crystal",logicWorld,false,0);
//crystal region (necessary for the FastSim model)
fRegion = new G4Region("Crystal");
fRegion->AddRootLogicalVolume(crystalLogic);
```

Volume declaration (completely standard)

G4Region declaration

- **Add to DetectorConstruction::ConstructSDandField()**

```
void DetectorConstruction::ConstructSDandField()
{
    // --------------- fast simulation --------------------------
    //extract the region of the crystal from the store
    G4RegionStore* regionStore = G4RegionStore::GetInstance();
    G4Region* RegionCh = regionStore->GetRegion("Crystal");

    //create the channeling model for this region
    G4ChannelingFastSimModel* ChannelingModel =
        new G4ChannelingFastSimModel("ChannelingModel", RegionCh);
    //activate the channeling model
    ChannelingModel->Input(crystalMaterial, Lattice);
    //setting bending angle of the crystal planes (default is 0)
    ChannelingModel->GetCrystalData()->
            SetBendingAngle(BendingAngle,crystalLogic);

    //activate radiation model
    if (ActivateRadiationModel) ChannelingModel->RadiationModelActivate();
}
```

Get crystal region

Channeling FastSim model declaration

Model activation and input

Optional

Radiation model activation

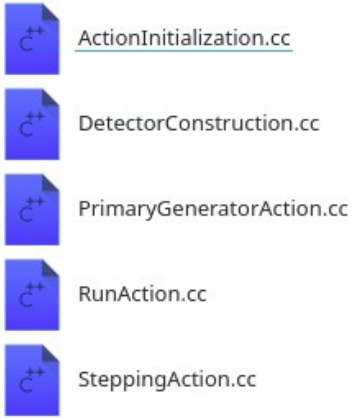
How to copy/paste channeling from ch1 into your example?

- **Add to main:**

Register FastSimulationPhysics

```
G4FastSimulationPhysics* fastSimulationPhysics = new G4FastSimulationPhysics();
fastSimulationPhysics->BeVerbose();
// -- activation of fast simulation for particles having fast simulation models
// -- attached in the mass geometry:
fastSimulationPhysics->ActivateFastSimulation("e-");
fastSimulationPhysics->ActivateFastSimulation("e+");
// -- Attach the fast simulation physics constructor to the physics list:
physicsList->RegisterPhysics( fastSimulationPhysics );
```

Physics list independent

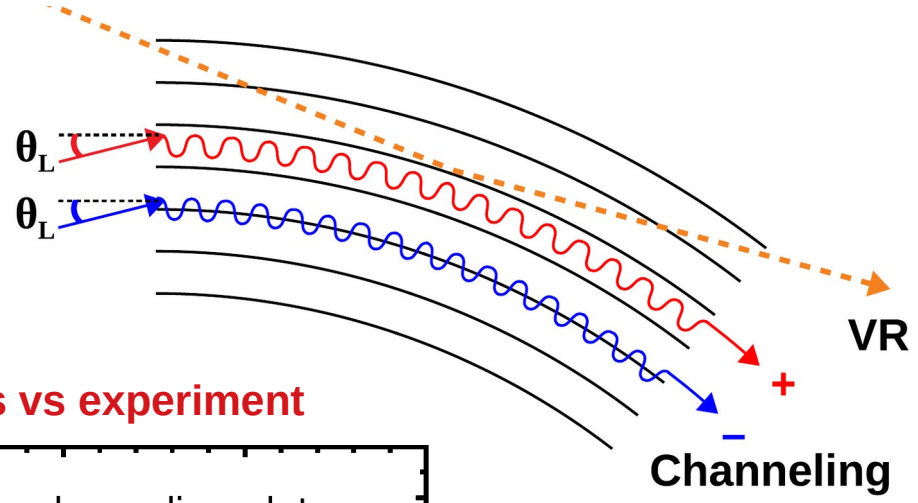


That's it. Enjoy! :)

Geant4 channeling model validation: beam deflection by a bent crystal

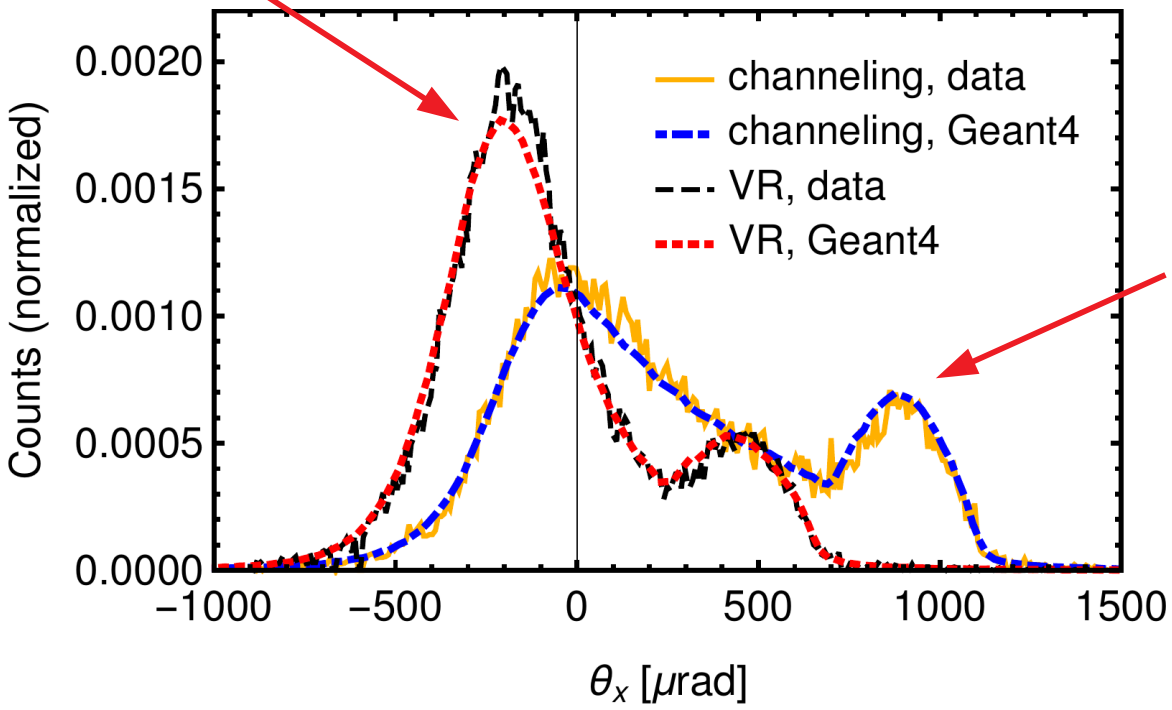
855 MeV electrons

15 µm thick bent crystal



volume reflection (VR)

Geant simulations vs experiment



channeling

Thank you for attention!

Current status

In Geant4 since geant4-11.2.0 !

geant4-v11.2.0/source/parameterisations/channeling/

Please use it!

https://geant4.web.cern.ch/download

Don't hesitate to contact me in the case of any problems/issues/suggestions

sytov@fe.infn.it

Geant4 Physics Reference Manual:

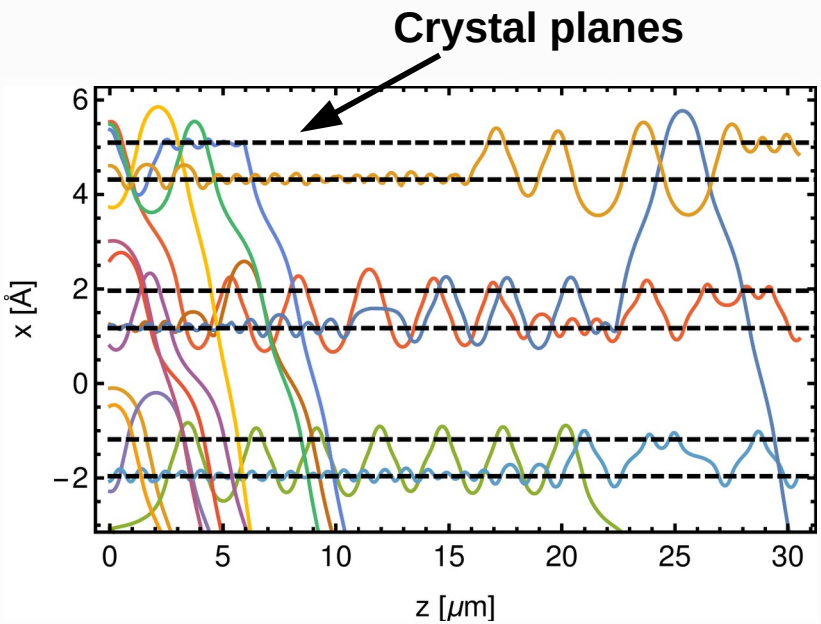
https://geant4-userdoc.web.cern.ch/UsersGuides/PhysicsReferenceManual/html/solidstate/channeling/channeling_fastsim.html

Please cite our papers if you use our model:

1. A. Sytov et al. Journal of the Korean Physical Society 83, 132–139 (2023)
2. A. I. Sytov, V. V. Tikhomirov, and L. Bandiera. PRAB 22, 064601 (2019)

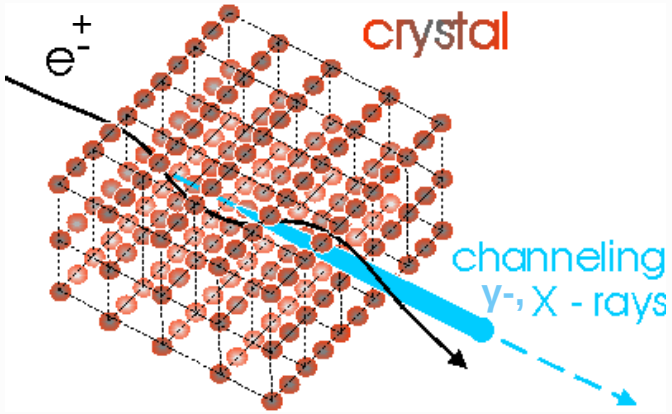
Baseline channeling simulation technique: CRYSTALRAD Monte Carlo simulation code

Main conception – simulation of classical trajectories of charged particles in a crystal in averaged atomic potential of planes or axes. Multiple and single **scattering simulation** at every step



channeling*

New 2024: ionization losses in channeling



Baier-Katkov formula:

integration is made over the classical trajectory

$$\frac{dE}{d^3k} = \omega \frac{dN}{d^3k} \frac{\alpha}{4\pi^2} \iint dt_1 dt_2 \frac{\left[(E^2+E'^2)(v_1v_2-1)+\omega^2/\gamma^2\right]}{2E'^2} e^{-ik'(x_1-x_2)}$$

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. Journal of the Korean Physical Society 83, 132–139 (2023)

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

Old channeling model in Geant4

Currently implemented*
Channeling physics:

- Only trajectories (**no radiation**)
- Only for hadrons
- Changing cross-sections using **Geant4 Biasing**

To do:

- To resolve the **problems** with modification of **continuous discrete processes**
- To add channeling of **e+/e-**
- To add channeling **radiation**
- To add coherent **pair production**

Problem with modification of the **electromagnetic physics list**:
class G4ChannelingOptrChangeCrossSection

```
93
94      switch (type) {
95          case fNotDefined:
96              fProcessToDensity[processName] = fDensityRatioNone;
97              break;
98          case fTransportation:
99              fProcessToDensity[processName] = fDensityRatioNone;
100             break;
101         case fElectromagnetic:
102             if(subType == fCoulombScattering ||
103                subType == fMultipleScattering){
104                fProcessToDensity[processName] = fCancelProcess;
105             }
106             if(subType == fIonisation ||
107                subType == fBremsstrahlung){
108                fProcessToDensity[processName] = fCancelProcess;
109             }
110             if(subType == fPairProdByCharged ||
111                subType == fAnnihilation ||
112                subType == fAnnihilationToMuMu ||
113                subType == fAnnihilationToHadrons){
```

It is not possible to turn off/to modify **continuous discrete processes** (multiple scattering, ionization losses) in this way but only **discrete processes**

Crucial for e+/e- though not so important for high energy protons

*E. Bagli Eur. Phys. J. C 74, 2996 (2014)

Marie Sklodowska-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 **IJCLab Orsay** (partner organization)
- 1 month of secondment at **DESY** (partner organization)