Dr. Alexei Sytov

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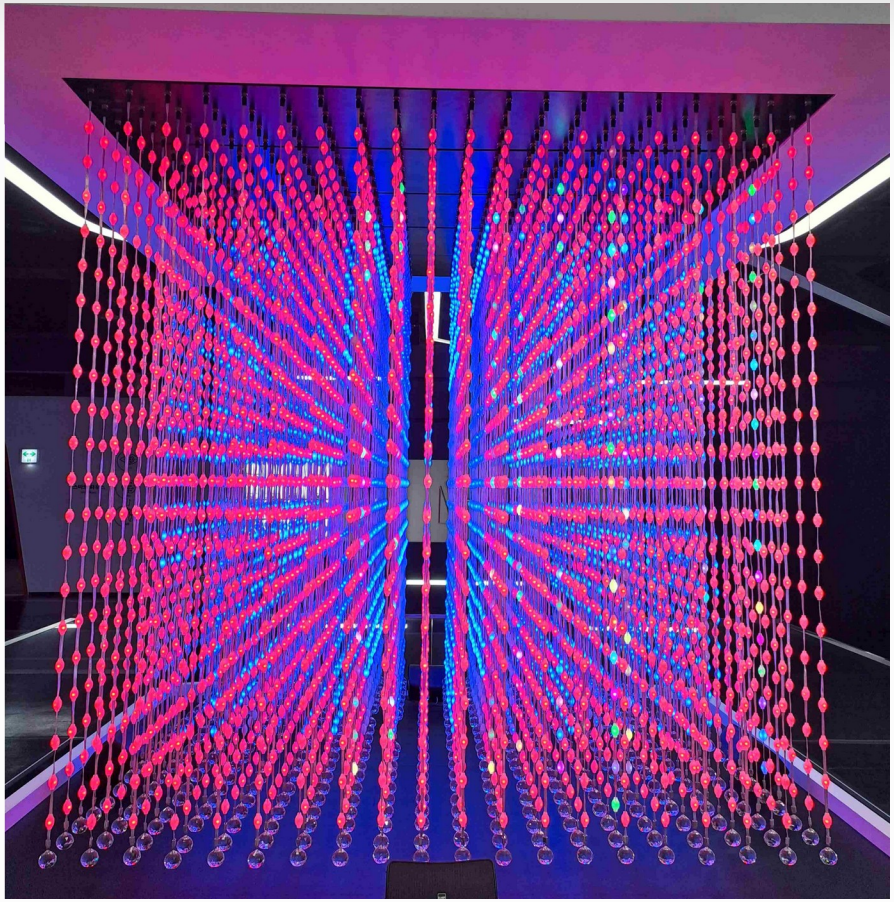
On behalf of the OREO collaboration

New Geant4 model with crystal orientation effect

DRD6 Collaboration Meeting at CERN

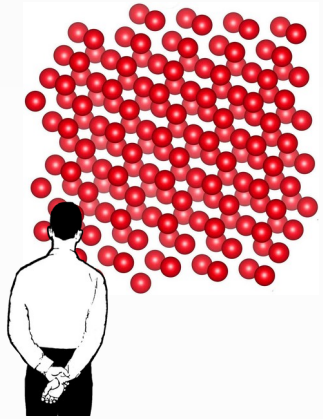
CERN, 01/11/2024

How an oriented crystal looks like

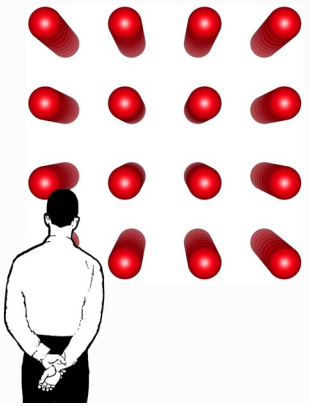


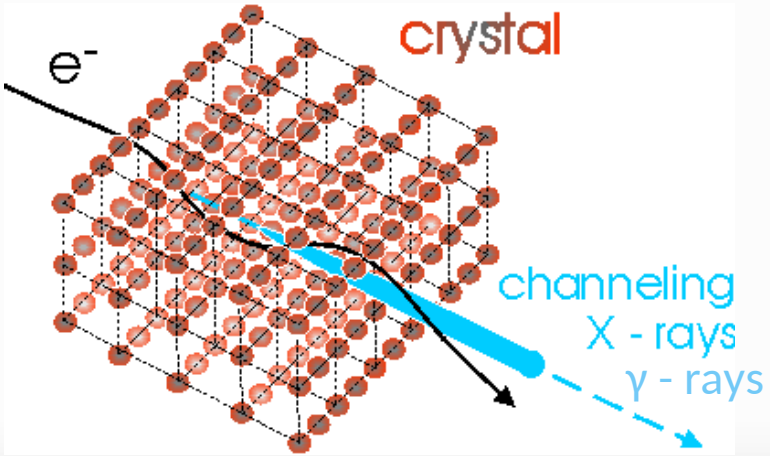
from National Science Museum, Daejeon, Korea

Non-oriented crystal



Oriented crystal

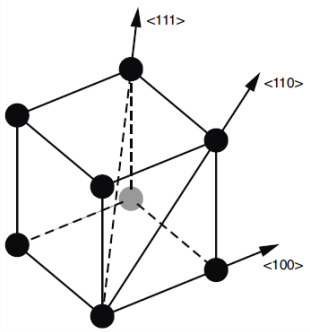


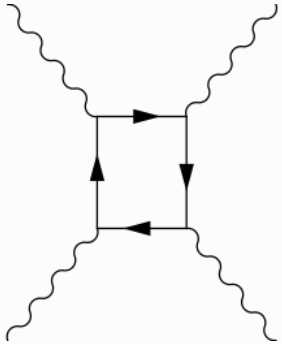


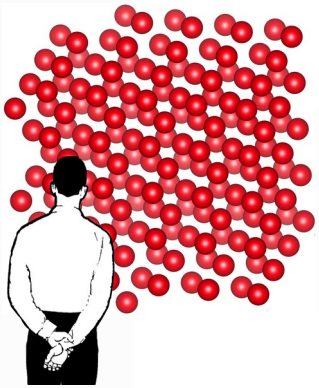
Electromagnetic shower acceleration

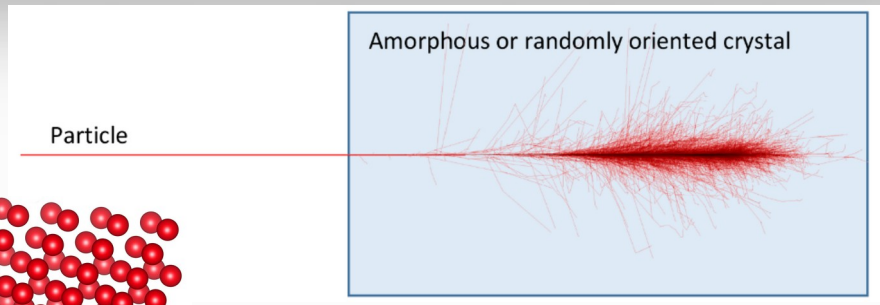
Axial field
10^{11} V/cm

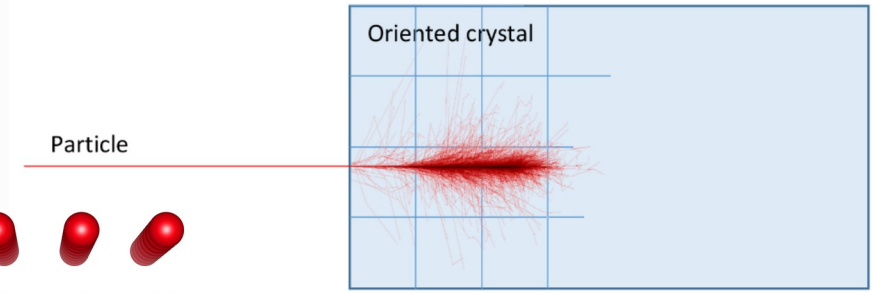
Approaching the **Schwinger limit** starting from few **GeV** for **e+/e-**

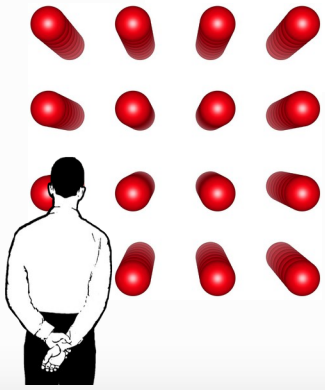










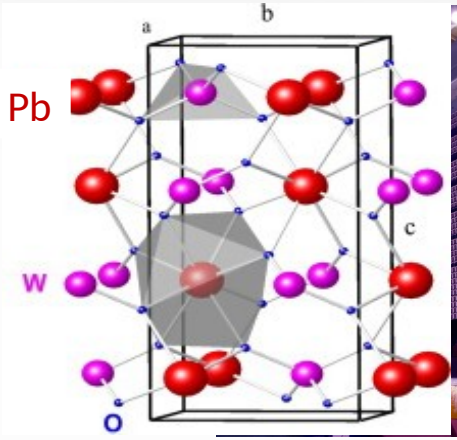


The **radiation** intensity and the **pair production** cross-section **drastically increase** in **oriented crystals!**

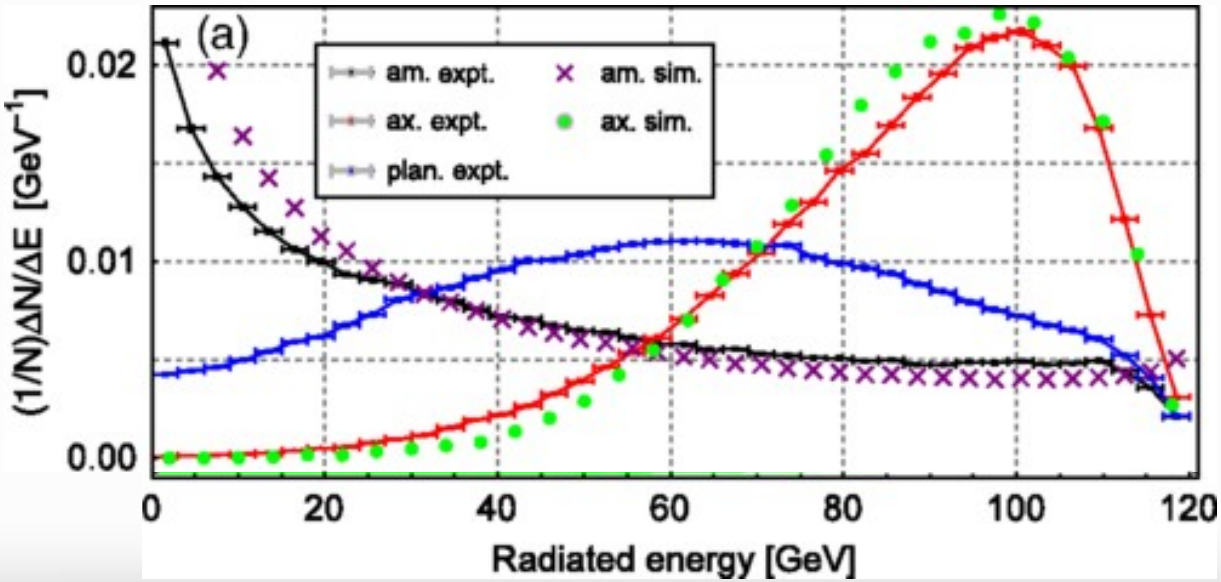
Shower development in the field of axes is **accelerated**. The radiation length is considerably reduced.

Orienting the electromagnetic calorimeter => making it thinner!

Lead tungstate: $PbWO_4$



INFN OREO by L. Bandiera et al.



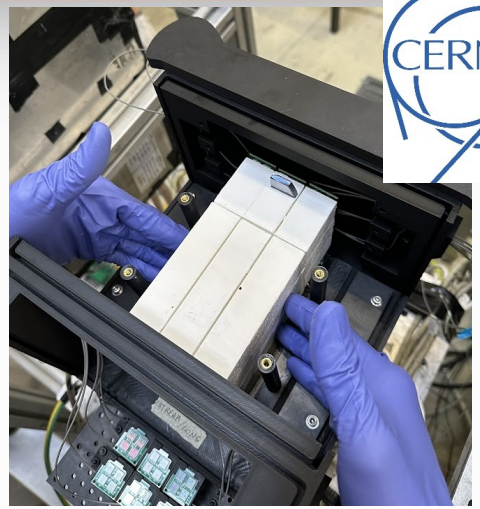
Experimental data in $PbWO_4$ crystal at **CERN SPS***

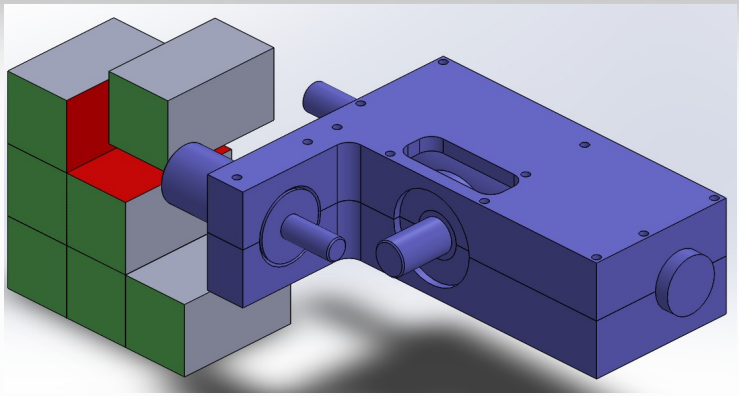
Electromagnetic shower in oriented calorimeter is hugely different

L. Bandiera et al. Frontiers in Physics 11, 1254020 (1-11) (2023)

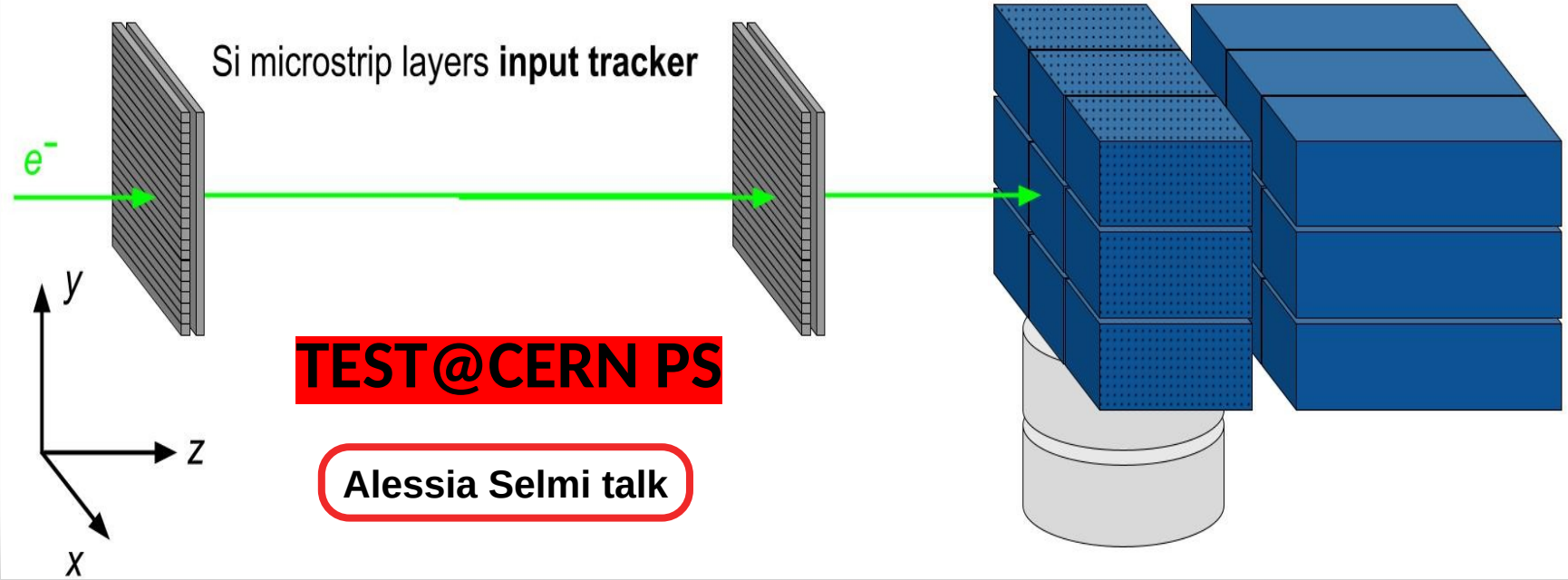
*L. Bandiera et al. Phys. Rev. Lett. 121, 021603 (2018)

Experimental test of the OREO prototype 3x3 matrix

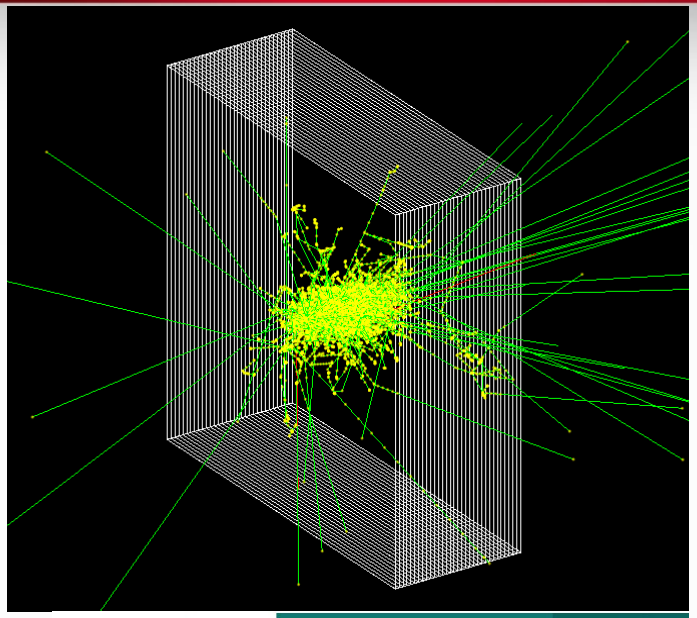


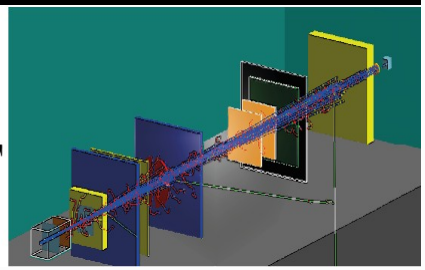


Misalignment < 0.3 mrad (< Θ_{max})

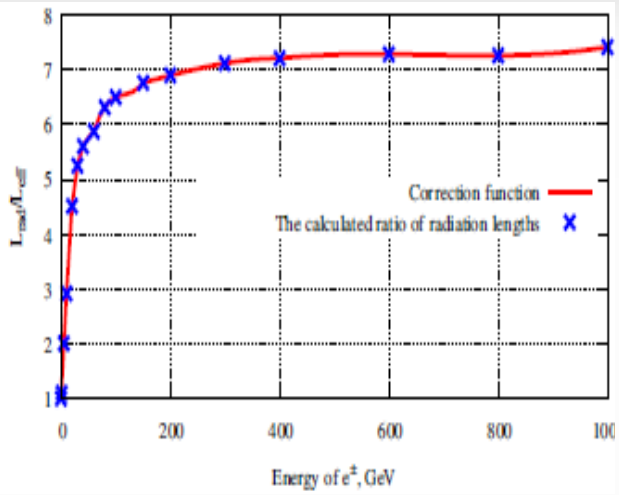


First Gean4 models to simulate electromagnetic calorimeters: modification of cross-sections of standard Geant4 processes

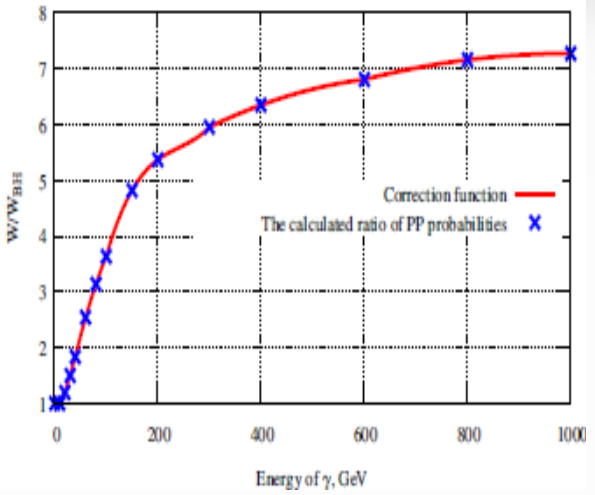




Bremsstrahlung



Pair production



The electromagnetic shower is simulated using the **Geant4** toolkit in which the cross sections for **bremsstrahlung and pair production are rescaled** in agreement with a full Monte Carlo code including the strong field effects in crystals.

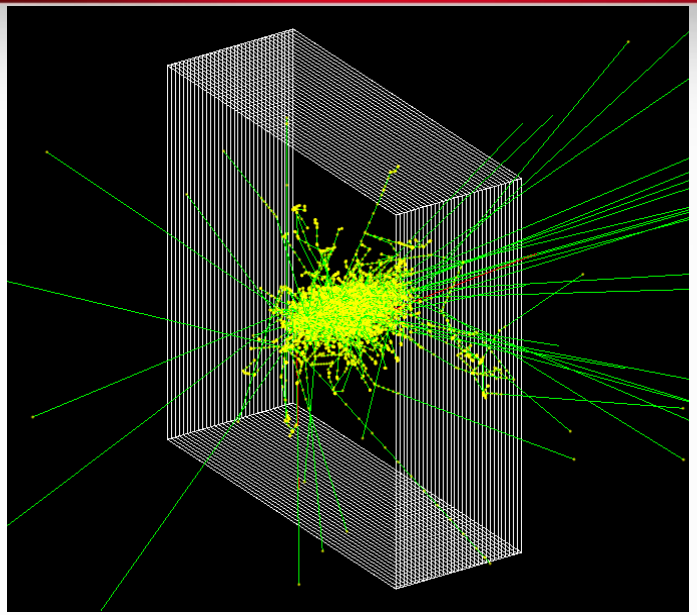
Deputy coord. EM Physics Group Geant4 Collaboration: A. Sytov

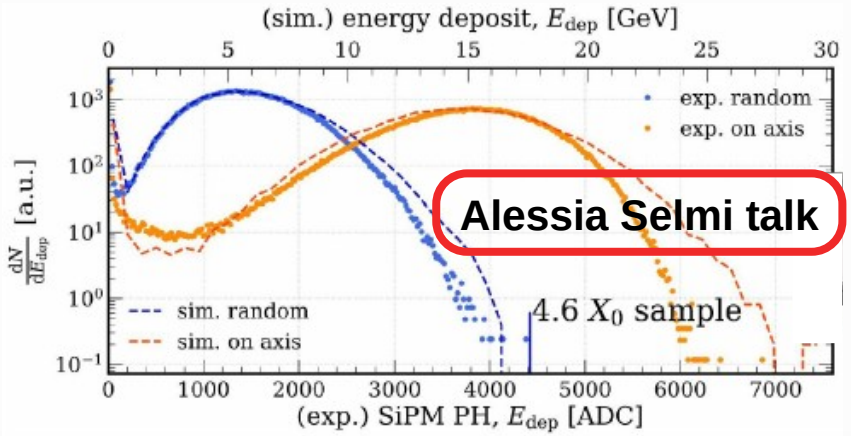
Coord. of Geant4INFN at Ferrara Division: G. Paternò

***V.G. Baryshevsky et al. NIM B 402, 35 (2017)**

L. Bandiera, V.V.Haurylavets, V. Tikhomirov NIM A 936, 124 (2019)

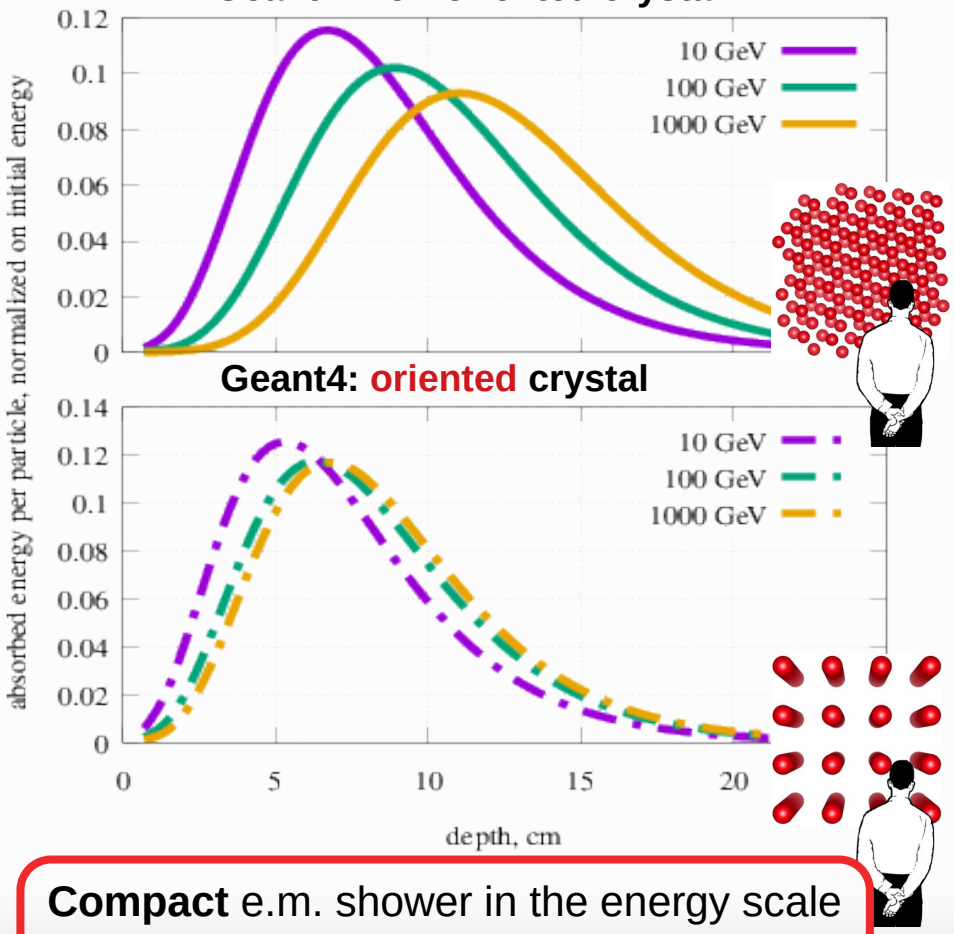
First Gean4 models to simulate electromagnetic calorimeters: modification of cross-sections of standard Geant4 processes





Alessia Selmi talk

Simulation of the e.m. shower of HE electrons in a PWO crystal



Compact e.m. shower in the energy scale from **multi-GeV** up to **multi-TeV**!

*M. Soldani et al. arXiv:2404.12016

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:

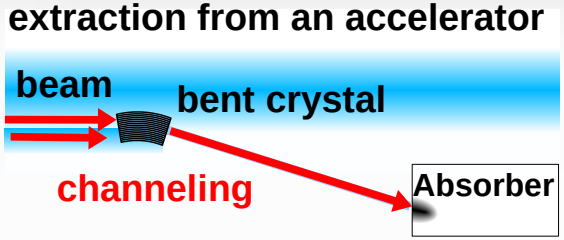
- **A. Sytov** – project coordinator
- **L. Bandiera** – INFN supervisor
- **K. Cho** – KISTI supervisor
- **G. Kube** – DESY supervisor
- **I. Chaikovska** – IJCLab Orsay supervisor

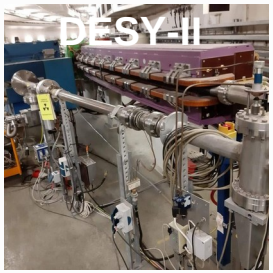
Location:

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

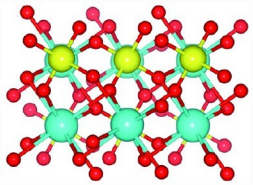
Applications*

Crystal-based collimation or beam extraction from an accelerator



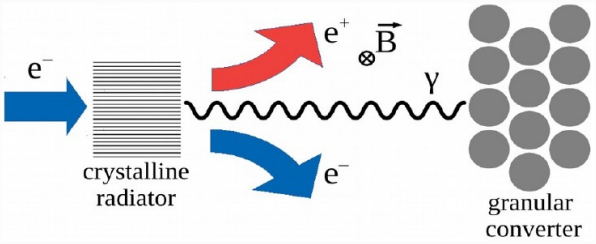


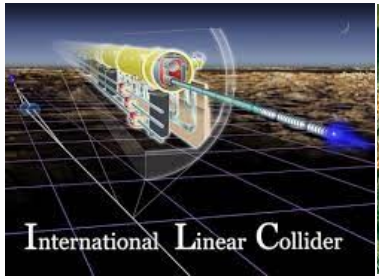
Ultrashort crystalline calorimeter



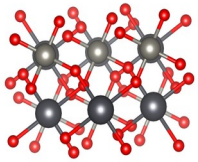
Gamma-ray Space Telescope

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

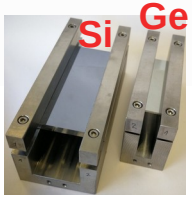




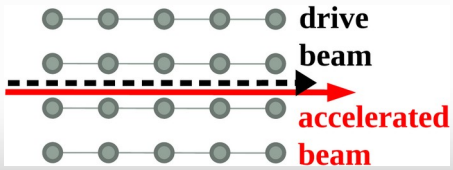
Oriented crystals



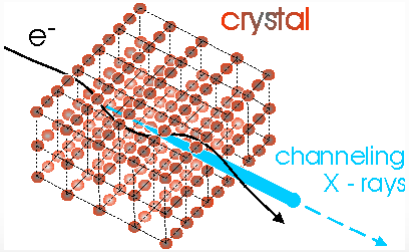
Measurement of dipole magnetic and electric moments of exotic particles

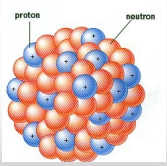


Plasma acceleration



X and γ-ray source for nuclear and medical physics

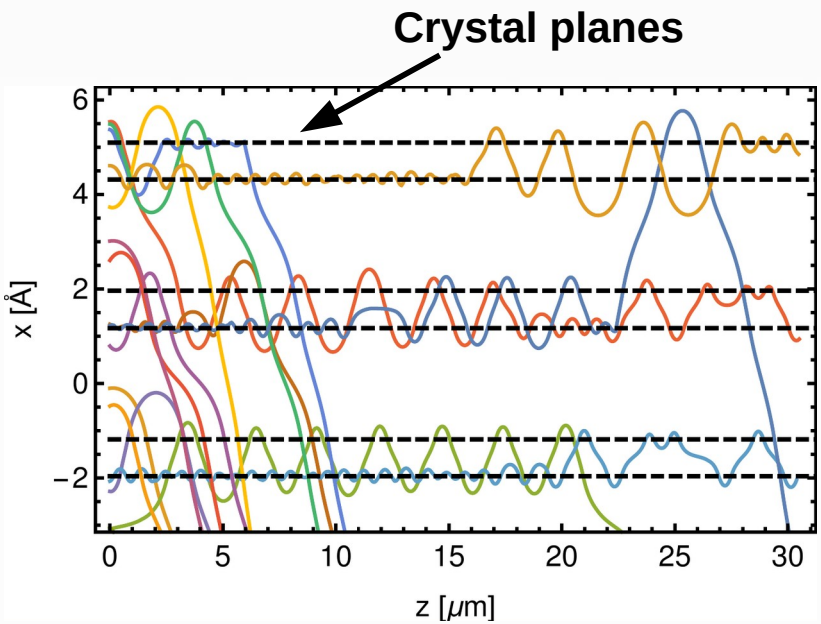




*A. Sytov et al. Journal of the Korean Physical Society 83, 132–139 (2023)

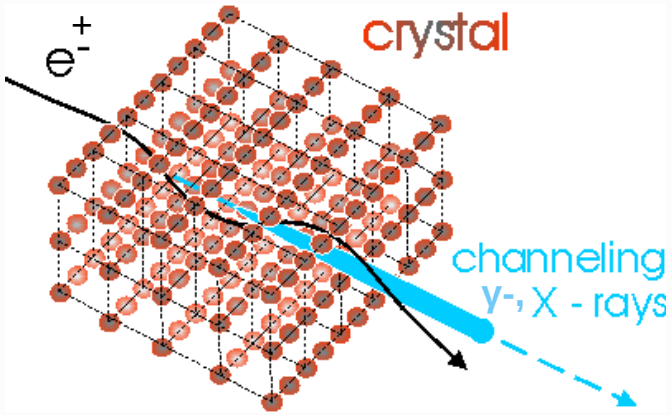
FULL simulation model

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

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

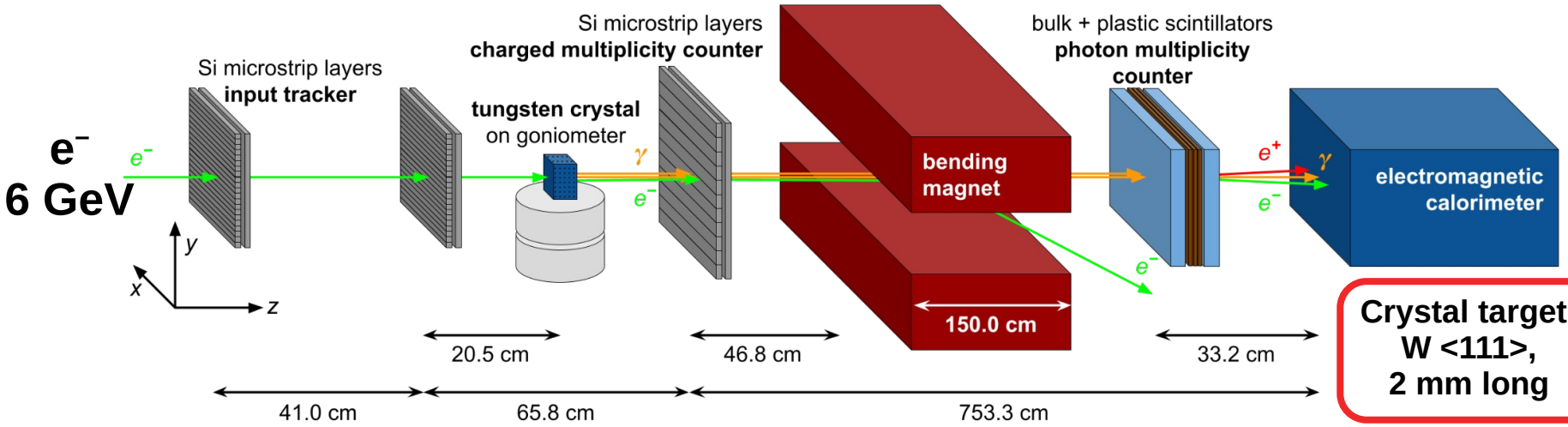
A.I. Sytov, V.V. Tikhomirov. NIM B 355 (2015) 383–386.

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

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

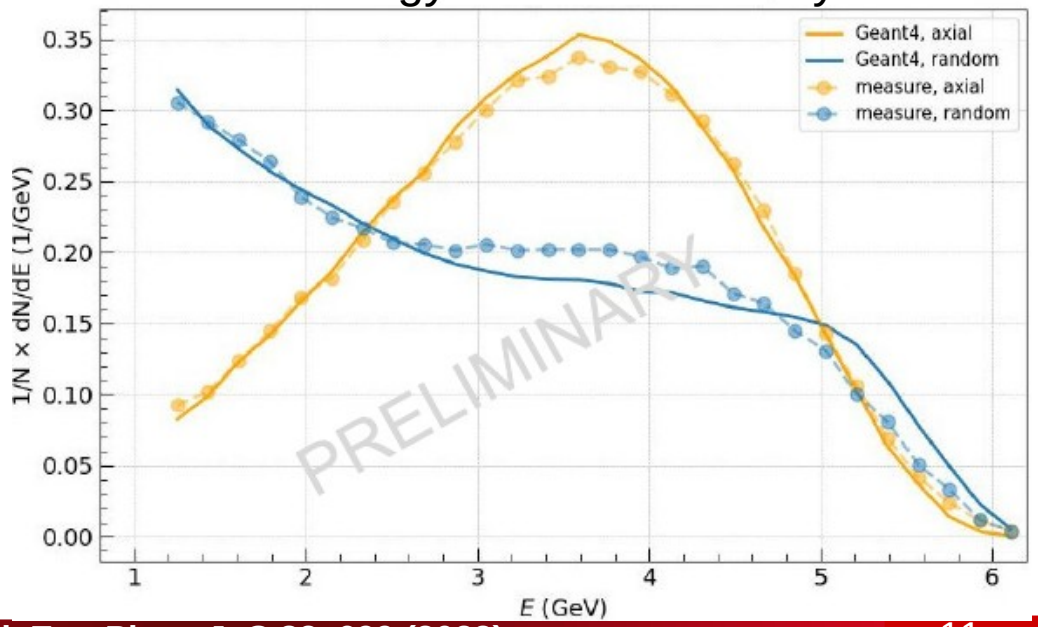
*A. Sytov et al. Journal of the Korean Physical Society 83, 132–139 (2023)

Full Geant4 simulations of experimental studies on crystal radiators @CERN PS T9/DESY TB beamlines*



Crystal target: W <111>, 2 mm long

Radiative energy loss measured by the Ecal



Materials and alignment in G4CHANNELINGDATA

Compatible with PWO, W and much more!

If you need any other crystal, just contact me: sytov@fe.infn.it

*L. Bandiera et al. Eur. Phys. J. C 82, 699 (2022)

How to use the Geant4 channeling model in 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

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)

NEW developments in Geant4

Full Simulation Models:

- **G4ChannelingFastSimModel** – **channeling** model along with crystal structure and geometry classes. — **In Geant4 since 2023**
- **G4BaierKatkov** – model of **radiation** in an oriented crystal based on G4ChannelingFastSimModel — **In Geant4 since 2023**
- **G4CoherentPairProduction** – model of pair production in an oriented crystal — **MERGED* in October 2024**

Examples:

- **ch1** a very **easy example** to demonstrate basic commands to include both **channeling** and **radiation** model in DetectorConstruction (no input/ simple output) — **MERGED* in September 2024**
- **ch2** a **complex example** including both **channeling** and **radiation** model, crystalline undulator, input with macro commands, root output and full spectrum of options — **MERGED* in September 2024**
- **ch3** a very **easy example** to demonstrate basic commands to include **pair production** to simulate **electromagnetic shower** in an oriented crystal. — **Submitted for MERGE***
- **Crystal-based hybrid positron source for FCC-ee example** — **Prepared**

*MERGED = included in the Geant4 main release, the end of 2024: geant4-v11.3.0

DRD6 activities/milestones for OREO

Milestones

- **M2**: Report on MC simulation of the **first prototype in Geant4**
- **M5**: Implementation of the **OREO technology in realistic experimental scenarios** – in synergy with other DRD6 groups

Deliverables

- **D3**: Final MC package in Geant4

We acknowledge the support of UE Commision through AidaInnova (G.A. No 101004761) and TRILLION (G.A. No 101032975).
We acknowledge the Geant4INFN project.

Thank you for attention!