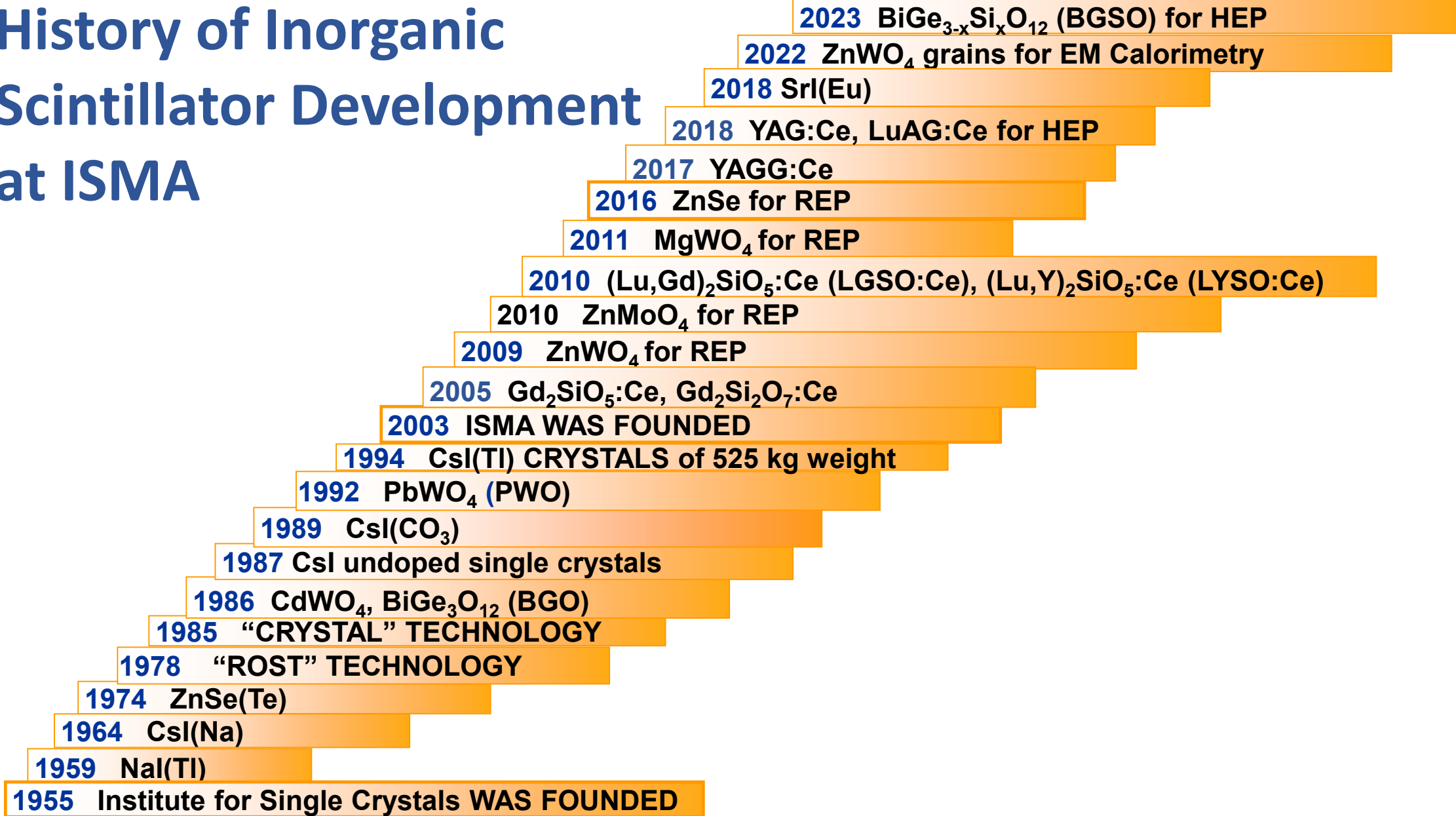


OXIDE SCINTILLATORS FOR CALORIMETRY

Senior Researcher, PhD
High-melting scintillation materials Laboratory
iren.rybalka@gmail.com

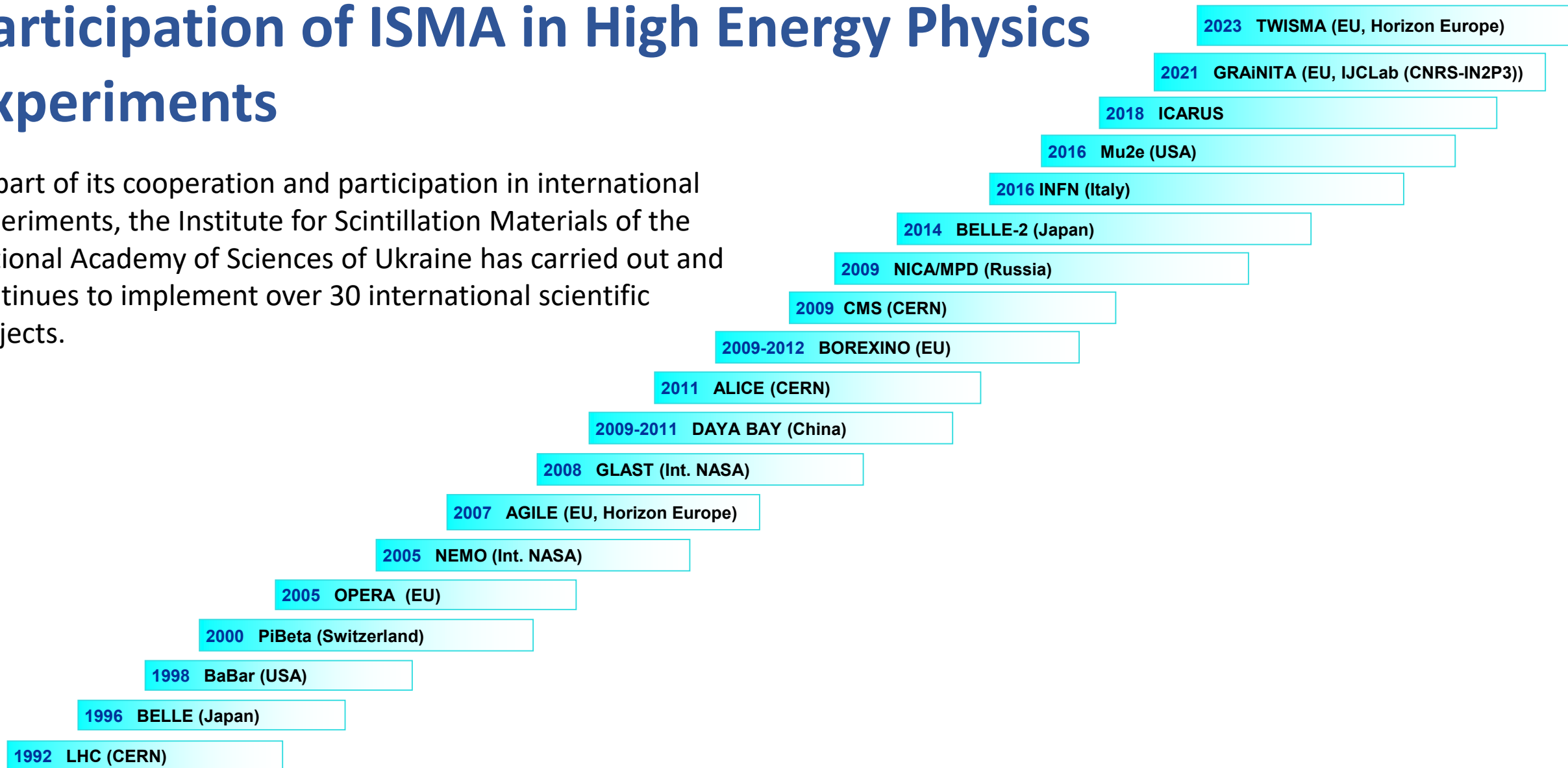
Iryna Rybalka

History of Inorganic Scintillator Development at ISMA



Participation of ISMA in High Energy Physics experiments

As part of its cooperation and participation in international experiments, the Institute for Scintillation Materials of the National Academy of Sciences of Ukraine has carried out and continues to implement over 30 international scientific projects.



REQUIREMENTS TO SCINTILLATORS

for High Energy Physics (HEP) EM calorimetry

- **high radiation hardness**
- **high Z_{eff} , density** (short radiation length)
- **high light yield**
- **short decay time**
- **high optical quality**
- **possibility of tonnage production** (hundreds of tons)
- **low cost**

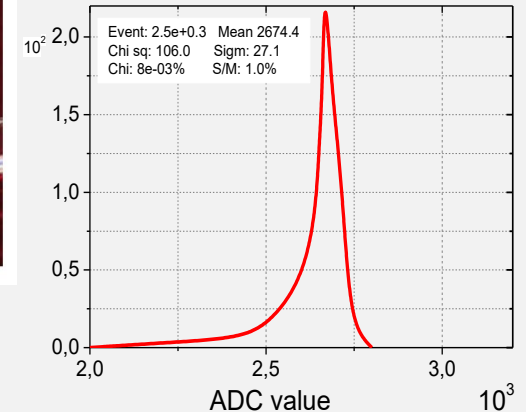
Scintillators used in HEP calorimeters

	NaI(Tl)		BaF ₂		CsI(Tl)		CeF ₃		BGO Bi ₄ Ge ₃ O ₁₂		PWO PbWO ₄	
X ₀ , sm	2,59	☹	2,03	☹	1,86	☹	1,66	☹	1,12	☹	0,92	☹
ρ, g/sm ³	3,67	☹	4,89	☹	4,53	☹	6,16	☹	7,13	☹	8,2	☹
τ, ns	230	☹	0,6 620	☹	1050	☹	30	☹	340	☹	15	☹
λ, nm	415	☹	230 310	☹	550	☹	310 340	☹	480	☹	420	☹
LY, %NaI	100	☹	5 16	☹	85	☹	5	☹	10	☹	0,5	☹
Experi- ment	Crystal Ball		L, GEM, TAPS		Belle, BaBar Bes III		L3P		L3, Belle		LHC	

PbWO₄ for CMS



L. Nagornaya et al., Fast scintillators based on large "heavy" tungstate single crystals, *Proc. "Crystal 2000" Int. Workshop, Chamonix, France, 1992, p. 367–374.*



Spectrogram of the detector based on a 20×20×150 mm³ PWO crystal when excited by electrons with an energy of 26 GeV.

P. Lecoq, et al., *Inorganic Scintillators for Detector Systems*, Springer Cham, 2017, 408 P.
<https://doi.org/10.1007/978-3-319-45522-8>

2012 - the Higgs boson has been found

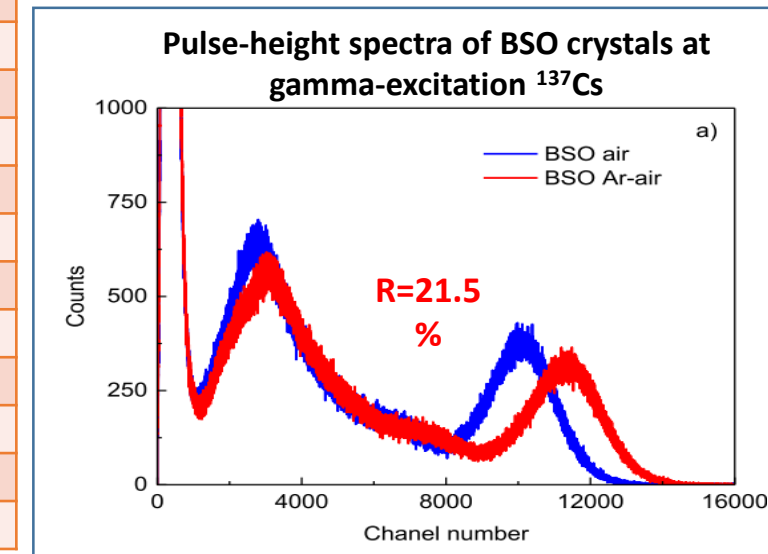
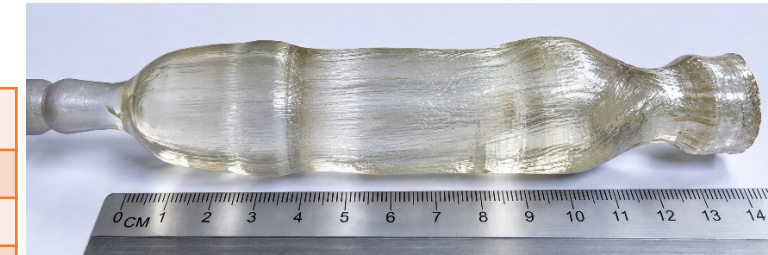
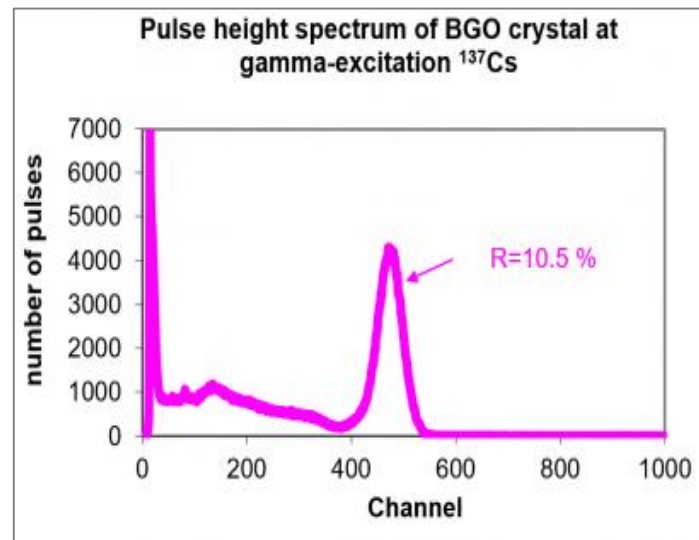
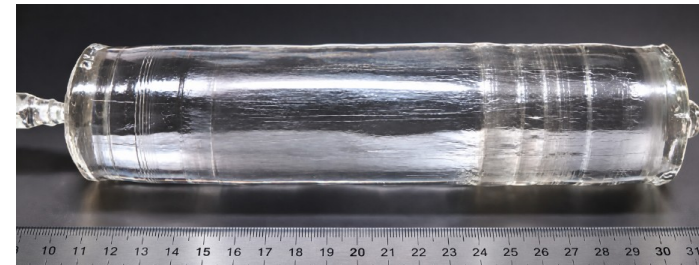
Scientists from the European Center for Nuclear Research (CERN) announced that they have detected a signal of a particle with a mass equal to 125 GeV, that a new subatomic particle corresponding to the parameters of the Higgs boson has been found.

Bi₄Ge₃O₁₂ (BGO) for EM calorimetry

Bi₄Si₃O₁₂ (BSO)

Physical and scintillation properties

	BGO	BSO
Effective atomic number	75.2	75
Density, g/cm ³	7.13	6.80
Melting point, K	1323	1303
Radiation length, cm	1.12	1.15
Refractive index at emission max	2.15	2.06
Wavelength of emission max, nm	480	480
Hygroscopicity	no	no
Decay time, ns	300	100
Light yield, ph/MeV	8,000-10,000	1,900-2,140
Light yield, % (NaI:TI)	15-20	4-5
Cherenkov Yield	moderate	high
Energy resolution (662 keV), %	10.0-12.0	21.5-23
Afterglow, % (after 3 ms)	0.005	-
Radiation hardness	+	+

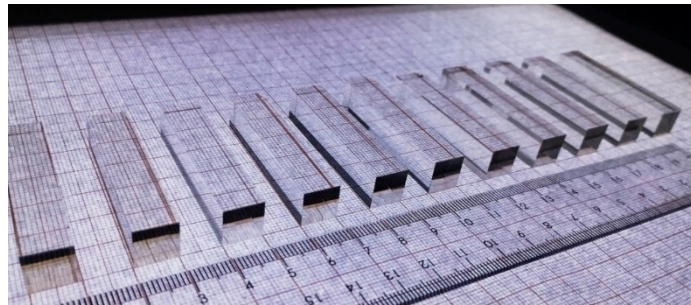


A.V. Kolesnikov, E.P. Galenin, O.Ts. Sidletskiy et al., Optimization of heating conditions during Cz BGO crystal growth, Journal of Crystal Growth, 407 (2014) 42–47. <https://doi.org/10.1016/J.JCRYSGRO.2014.08.030>

S. Tkachenko, I. Gerasymov, D. Kurtsev, et al., Optimized Bi₄Si₃O₁₂ scintillation crystals grown in dynamic atmosphere for future particle physics experiments, Journal of Alloys and Compounds, 1015 (2025) 178895. <https://doi.org/10.1016/j.jallcom.2025.178895>

Project supervisor at ISMA – Professor Oleg Sidletskiy, e-mail: osidletskiy@yahoo.com

Bi₄Ge_{3-x}Si_xO₁₂ (BGSO) mixed crystals for EM calorimetry



Scientific Goal: Develop innovative electromagnetic calorimeters for high-energy physics experiments (such as the Large Hadron Collider) using advanced scintillation materials.



Materials Researched:

- Bismuth germanate-silicate oxide (BGSO) homogeneous crystals.
- Cerium-doped garnet (YAG:Ce,Ca,Mg and GAGG:Ce) bulk and fibre-shaped crystals.

Scintillation elements fabricated in ISMA for tests in CERN

	BGSO
Effective atomic number	75
Density, g/cm ³	6.9
Melting point, K	1303-1323
Radiation length, cm	1.12
Refractive index at emission max	2.1
Wavelength of emission max, nm	480
Hygroscopicity	no
Decay time, ns	174
Light yield, ph/MeV	3,100
Cherenkov Yield	High efficiency
Radiation hardness	+



Pictures from the 2023 testbeam. Left: the light-tight box containing the samples with three DWCs (blue) in front. Right: the samples wrapped and connected to the readout boards.

R. Cala' et al. Characterization of mixed Bi₄(Ge_xSi_{1-x})₃O₁₂ for crystal calorimetry at future colliders, NIMA A, 1032 (2022) 166527.
<https://doi.org/10.1016/j.nima.2022.166527>

R. Cala' et al. Exploring scintillators and Cherenkov radiators for MIP timing detectors, JINST, 20 (2025) P04004.
<https://doi.org/10.1088/1748-0221/20/04/P04004>

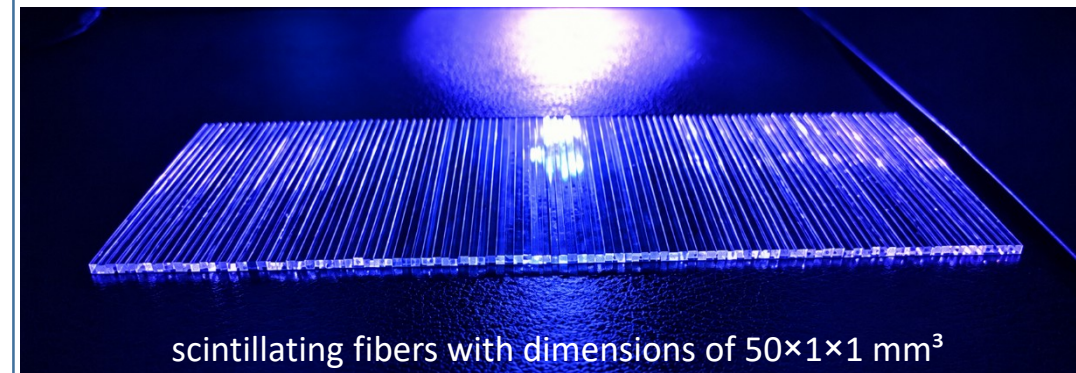
Project supervisor at ISMA – Professor Oleg Sidlets'kiy, e-mail: osidlets'kiy@yahoo.com

RARE-EARTH GARNETS $\text{Y}_3\text{Al}_5\text{O}_{12}:\text{Ce}$, $\text{Lu}_3\text{Al}_5\text{O}_{12}:\text{Ce}$ (YAG:Ce, LuAG:Ce) for HEP



	YAG:Ce	LuAG:Ce
Crystal size available, mm	up to 45 dia. and 150 length	
Crystal structure	cubic	
Cleavage	no	
Hygroscopicity	no	
Density, g/cm ³	4.55	6.7
Refraction index at emission max	~ 1.8	~ 1.8
Hardness (Mohs)	—	8.5
Wavelength of emission max, nm	550	535
Light yield, ph/Mev	30,000	27,000
Primary decay time, ns	50-100	60

YAG:Ce,Ca,Mg for SpaCal



scintillating fibers with dimensions of 50×1×1 mm³

Light yield: 22,400 photons/MeV

Decay time: 27.8 ns

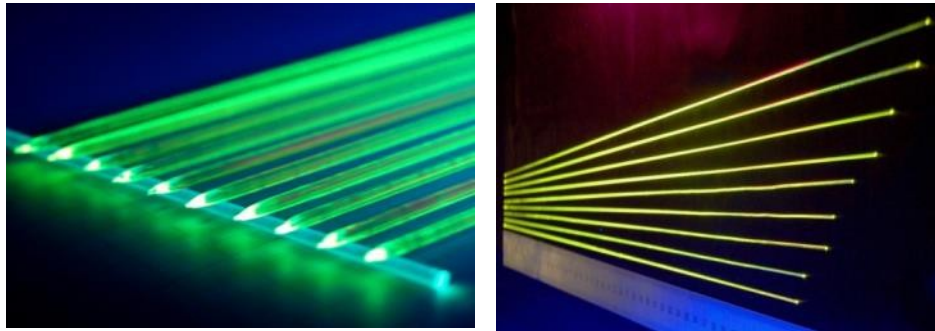
Crystals up to 200 mm in length were grown using the Czochralski method for testing at CERN as part of a spaghetti calorimeter (SpaCal) prototype; from these 101 scintillation fibers measuring 50×1×1 mm³ were fabricated.

O. Sidletskiy, I. Gerasymov, D. Kurtsev, et al., Progress in fast-timing Ce-doped garnet scintillators by complex codoping with divalent cations, Materials Research Bulletin, 184 (2025) 113283. <https://doi.org/10.1016/j.materresbull.2024.113283>

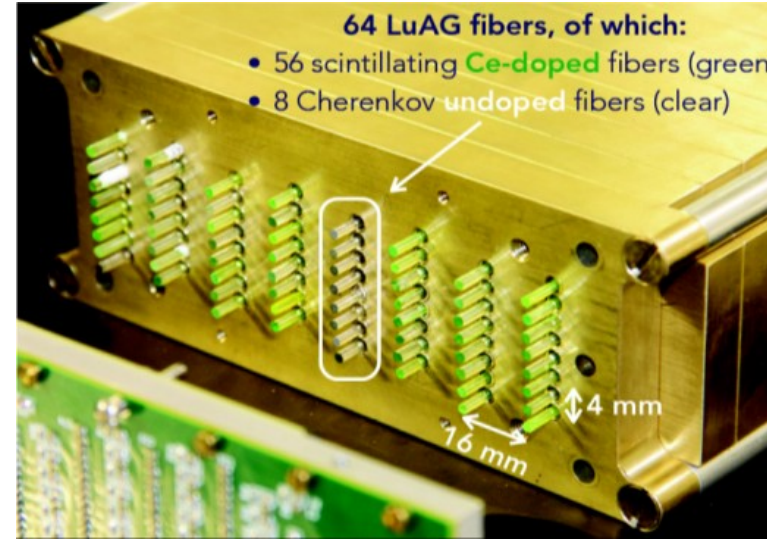
Project supervisor at ISMA – Professor Oleg Sidletskiy, e-mail: osidletskiy@yahoo.com

LuAG and LuAG:Ce single crystal fibers for dual readout calorimetry

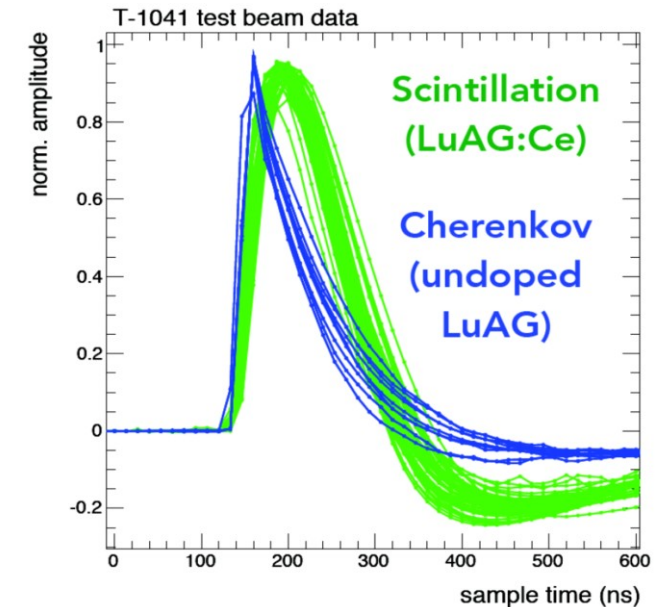
Collaboration with the Institut Lumière Matière (Lyon, France)



LuAG and LuAG:Ce single crystal fibers with the lengths over 22 cm grown by micro-pulling down technique.



Prototype of a detector for the simultaneous registration of Cherenkov and ionizing radiation.



Detection of Cherenkov and ionizing radiation using LuAG and LuAG:Ce fibers.

V. Kononets, E. Auffray, C. Dujardin, et al., Growth of long undoped and Ce-doped LuAG single crystal fibers for dual readout calorimetry, Journal of Crystal Growth, 435 (2016) 31-36. <https://doi.org/10.1016/j.jcrysgro.2015.11.024>

Project supervisor at ISMA – Professor Oleg Sidletskiy, e-mail: osidletskiy@yahoo.com

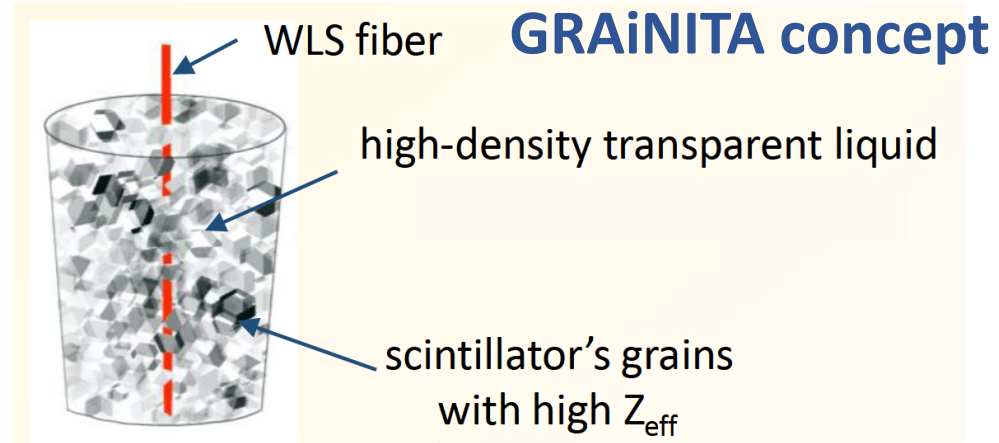
ZnWO₄ (ZWO) scintillation crystal grains for GRAiNITA calorimeter



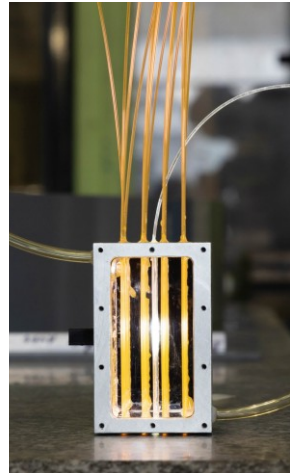
ZnWO₄ crystals for nuclear physics and medical radiography grown by Cz method



ZnWO₄ scintillation crystal grains grown by the flux method



ZnWO ₄	CaWO ₄
LY= 10 000 ph/MeV	LY= 14 000 ph/MeV
• $Z_{\text{eff}}=61$	• $Z_{\text{eff}}=62$
• Density 7.85 g/cm ³	• Density 6.01 g/cm ³
• Index $n=2.1-2.3$	• Index $n= 1.9$
• $\tau = 20 \mu\text{s}$	• $\tau = 12 \mu\text{s}$
• $\lambda_{\text{max}}^{\text{em}} = 490 \text{ nm}$	• $\lambda_{\text{max}}^{\text{em}} = 420 \text{ nm}$



The small-size prototype

S.Barsuk, et al, GRAiNITA – a new generation calorimeter, Réunion GDR DI2I, 10-12 juillet 2023, Subatech, Nantes, France, <https://indico.in2p3.fr/event/29808/contributions/126587/>

Project supervisors at ISMA – PhD Iryna Tupitsyna, e-mail: irina250124@gmail.com; Professor Andrii Boyaryntsev, e-mail: aboyar74@gmail.com

Growth of MeWO_4 scintillation crystal grains

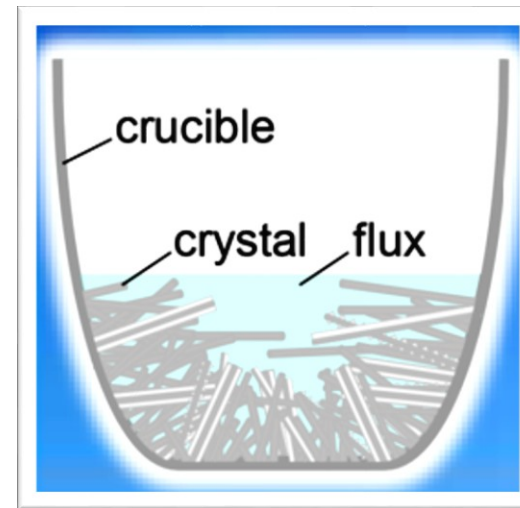
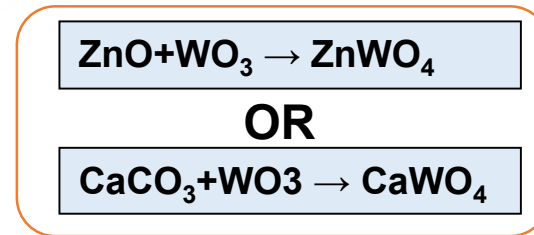


ZnWO_4

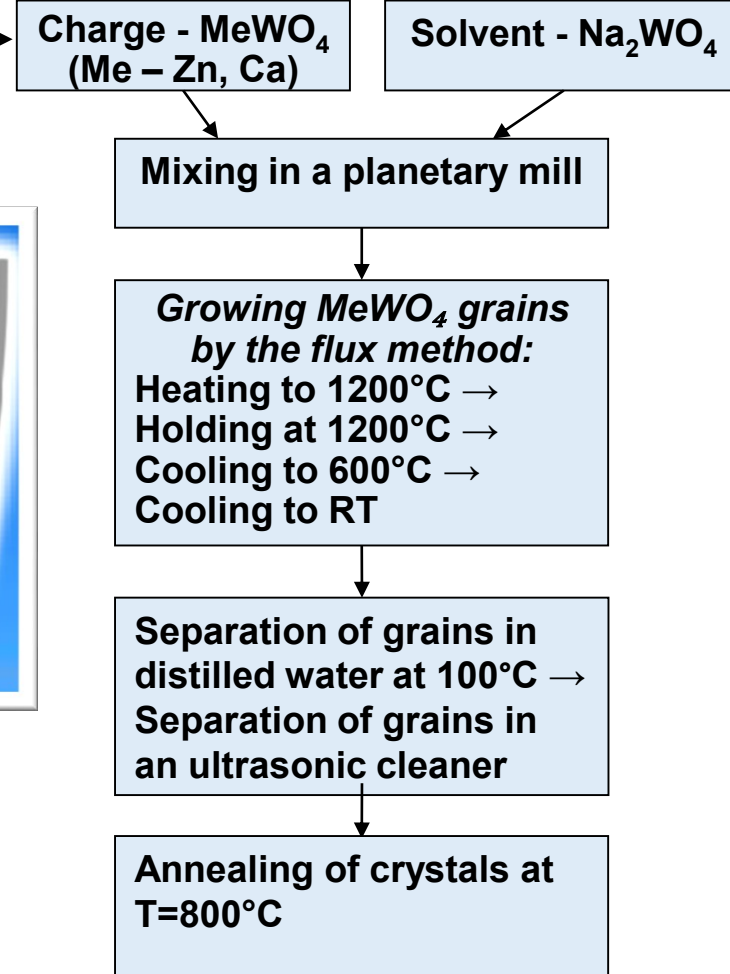


CaWO_4

A technology has been developed for producing tungstates scintillation grains of the required size using the flux method, with a product yield of **85%** of the raw material weight.

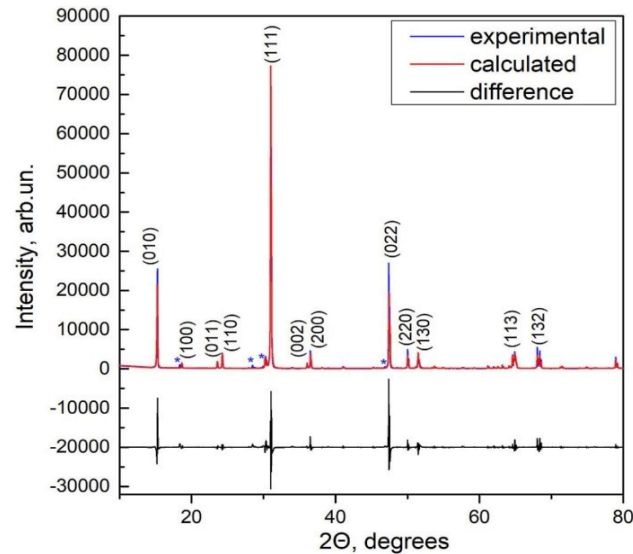


The flux method



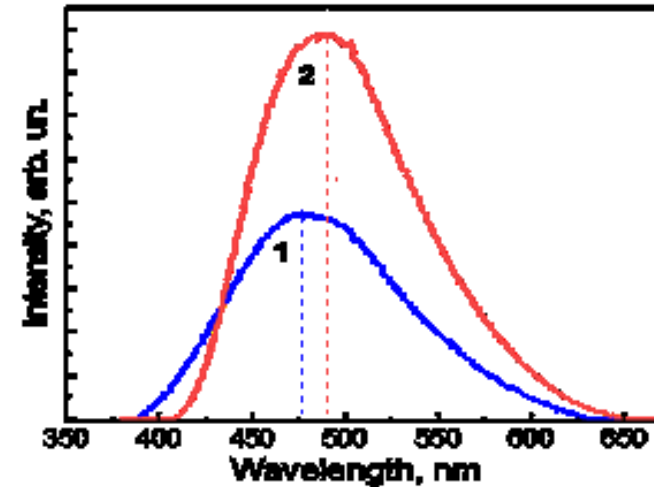
Project supervisors at ISMA – PhD Iryna Tupitsyna, e-mail: irina250124@gmail.com; Professor Andrii Boyaryntsev, e-mail: aboyar74@gmail.com

Characterization of ZnWO₄ grains

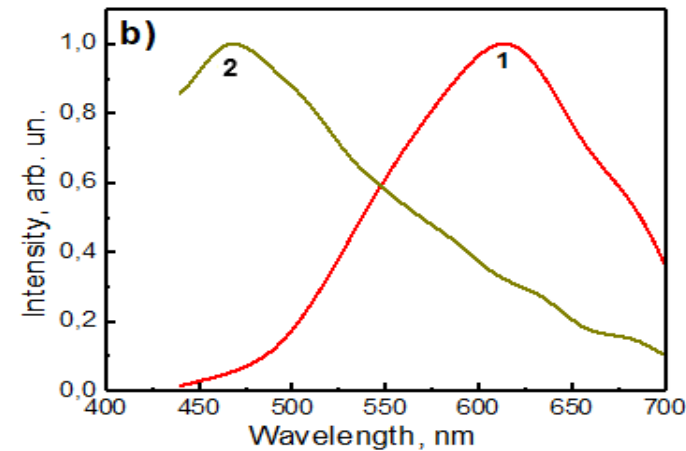
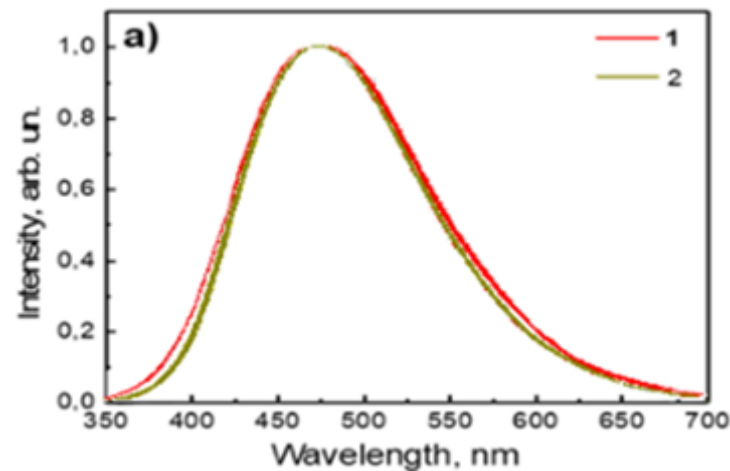


Phase	P2/c (monoclinic)
a, Å	4.6925 (1)
b, Å	5.7180 (1)
c, Å	4.9210 (2)
β, °	90.611 (3)
Cell volume, Å ³	132.03 (1)

According to the results of X-ray powder diffraction analysis, ZnWO₄ grains possess the monoclinic wolframite-phase structure as well as single crystal ZnWO₄.

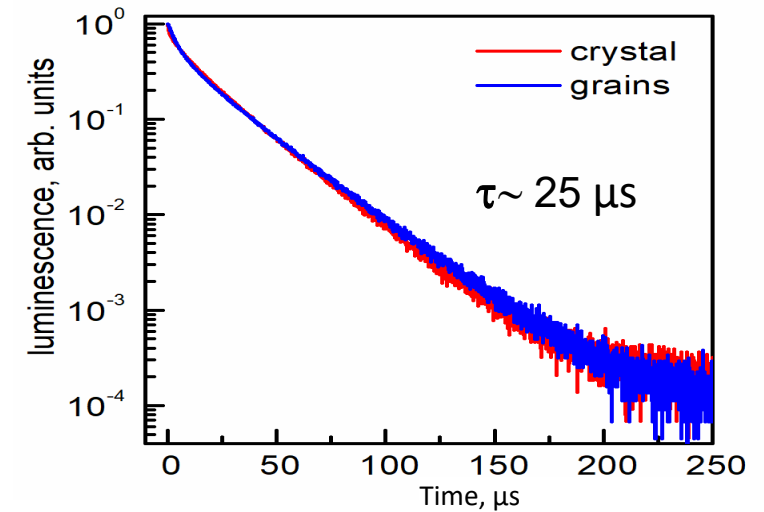


X-ray luminescence spectra of ZnWO₄ crystal (1) and grains (2). Luminescence spectra of ZnWO₄ grains and single crystal are similar. The small shift of the luminescence maximum towards the long-wavelength region in the case of grains is the result of the increased absorption/scattering of light by the grains.



Normalized luminescence spectra (a, $\lambda_{\text{ex}} = 250$ nm (intrinsic luminescence)) and (b, $\lambda_{\text{ex}} = 360$ nm (defect centers)):

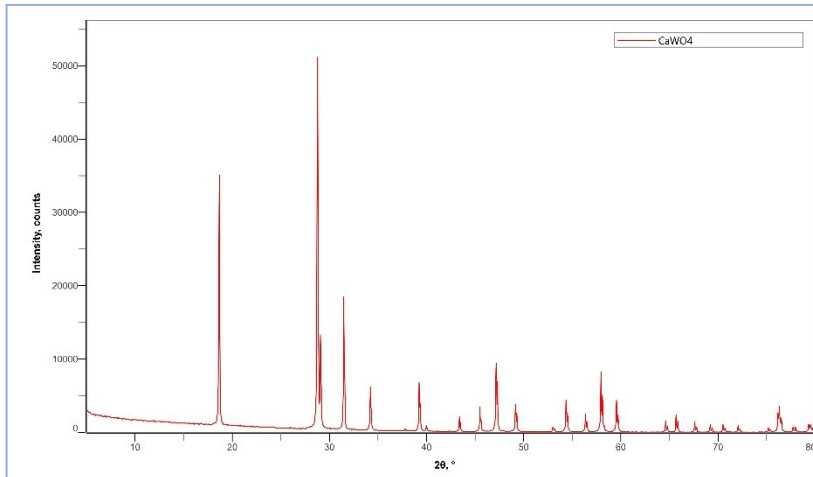
- (1) ZnWO₄ crystal grown by the Czochralski method,
 (2) ZnWO₄ grains grown by the flux method after annealing and additional washing.



Luminescence kinetics of ZnWO₄ grains and crystal ($\lambda_{\text{ex}} = 266$ nm, $\lambda_{\text{em}} = 480$ nm).

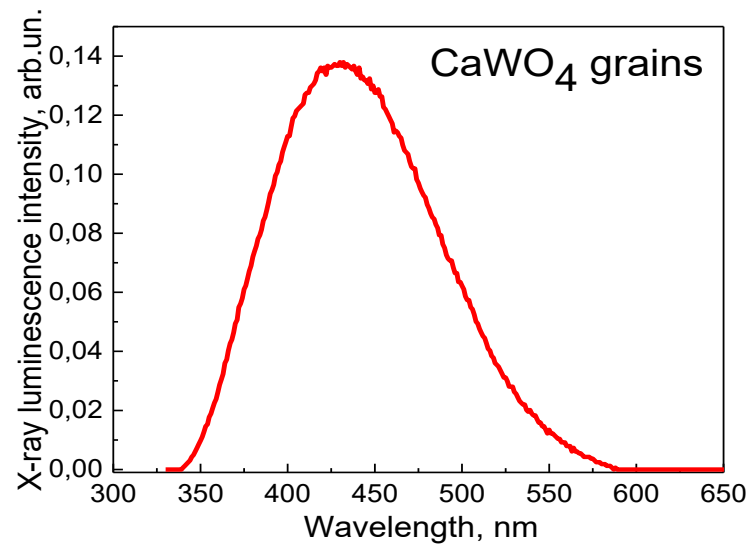
Project supervisors at ISMA – PhD Iryna Tupitsyna, e-mail: irina250124@gmail.com; Professor Andrii Boyaryntsev, e-mail: aboyar74@gmail.com

Characterization of CaWO_4 grains

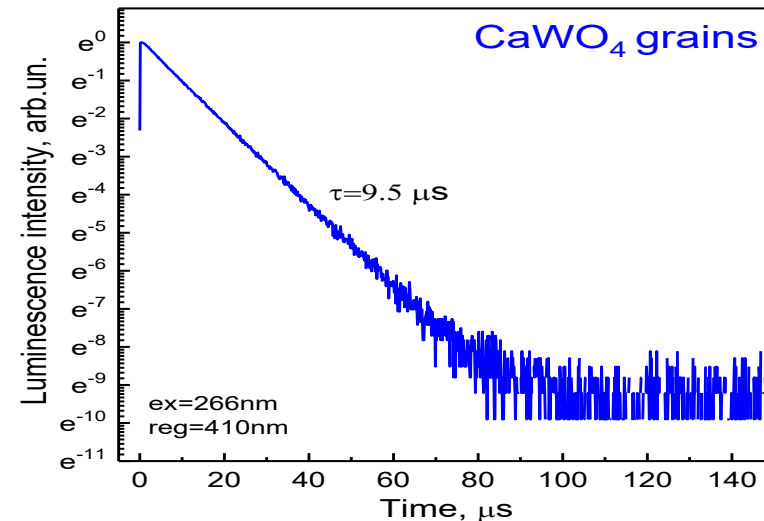


X-ray powder diffraction pattern of CaWO_4 grains.

	CaWO_4 published crystallographic data	CaWO_4 grains crystallographic data
Phase	$I4_1/a$ (tetragonal)	$I4_1/a$ (tetragonal)
a , Å	5.24294	5.24086
c , Å	11.373	11.37239
Cell volume, Å ³	312.63	312.36



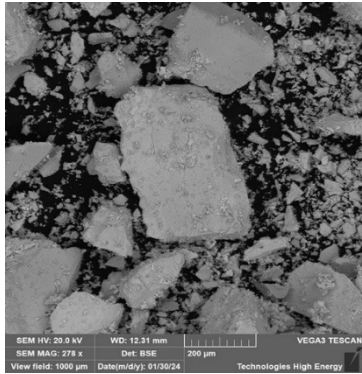
X-ray luminescence of CaWO_4 grains.



Luminescence kinetics of CaWO_4 grains.

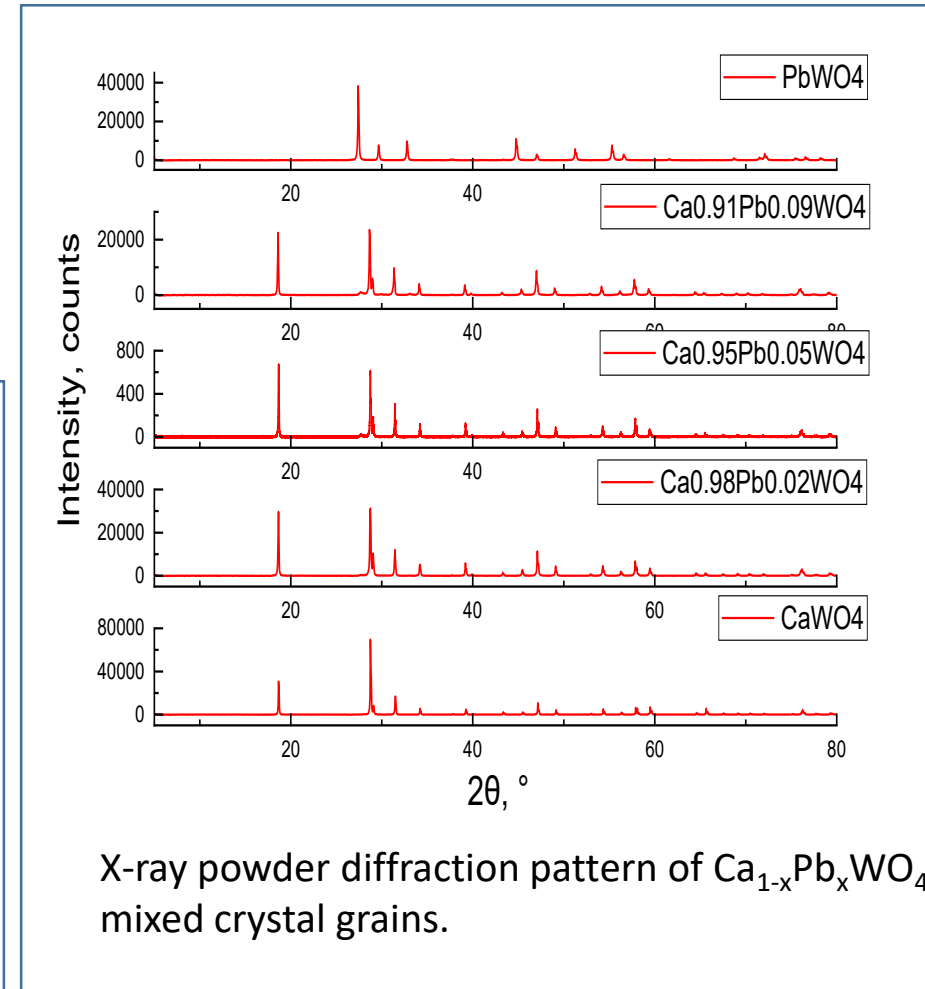
Project supervisors at ISMA – PhD Iryna Tupitsyna, e-mail: irina250124@gmail.com; Professor Andrii Boyaryntsev, e-mail: aboyar74@gmail.com

$\text{Ca}_{1-x}\text{Pb}_x\text{WO}_4$ mixed scintillation crystal grains as a candidate for GRAiNITA

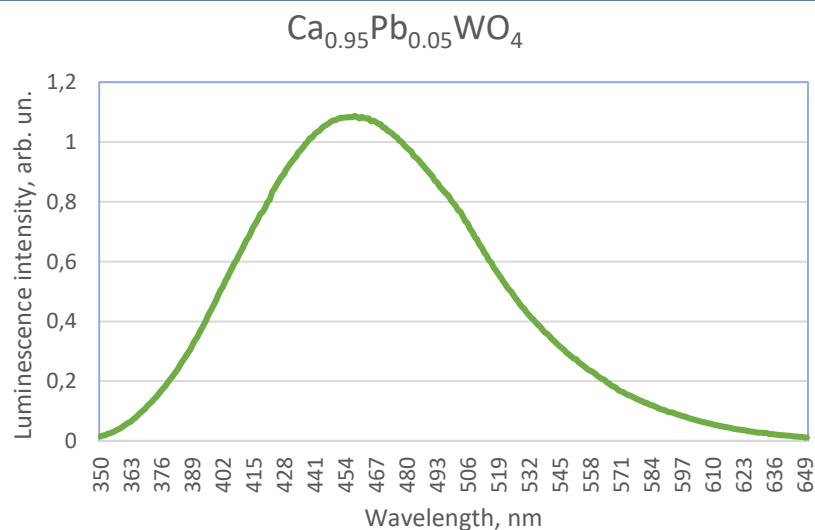


SEM images of CaPbWO_4 grains

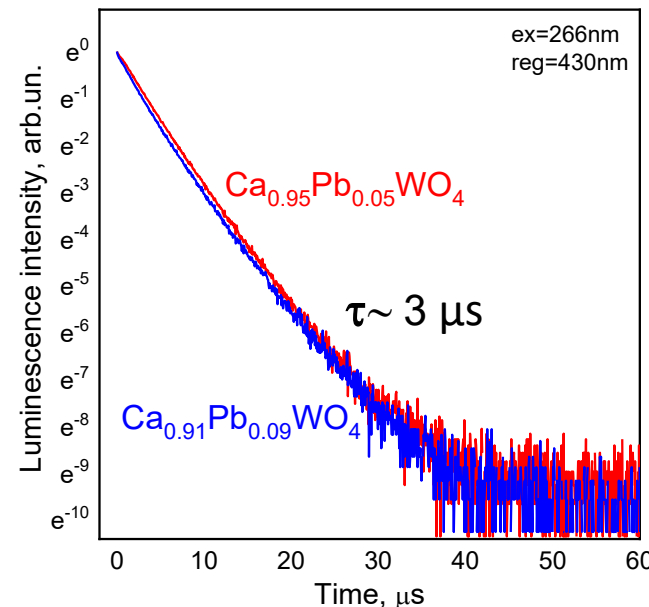
Composition	Crystal structure	a, Å	c, Å	Cell volume, Å ³
$\text{Ca}_{0.98}\text{Pb}_{0.02}\text{WO}_4$	$I4_1/a$ (tetragonal)	5.24724	11.38953	313.594
$\text{Ca}_{0.95}\text{Pb}_{0.05}\text{WO}_4$	$I4_1/a$ (tetragonal)	5.25050	11.39361	314.096
$\text{Ca}_{0.91}\text{Pb}_{0.09}\text{WO}_4$	$I4_1/a$ (tetragonal)	5.25419	11.41361	315.090



X-ray powder diffraction pattern of $\text{Ca}_{1-x}\text{Pb}_x\text{WO}_4$ mixed crystal grains.



X-ray luminescence spectrum of $\text{Ca}_{0.95}\text{Pb}_{0.05}\text{WO}_4$ grains.



Luminescence kinetics of $\text{Ca}_{1-x}\text{Pb}_x\text{WO}_4$ grains.

Project supervisors at ISMA – PhD Iryna Tupitsyna, e-mail: irina250124@gmail.com; Professor Andrii Boyaryntsev, e-mail: aboyar74@gmail.com

Summary

The Institute for Scintillation Materials of the National Academy of Sciences of Ukraine (ISMA), with its powerful scientific potential, many years of experience and significant achievements of highly qualified scientists, as well as a modern scientific, technological and experimental base that provides a full cycle of research — from the synthesis of the initial charge and the growth of single crystals to the comprehensive study of their structural, optical, luminescent and scintillation characteristics — develops the new scintillation materials for a wide range of applications and is open to international scientific cooperation, joint research projects and promising partnerships.

Welcome to the ISMA www.isma.kharkiv.ua

THANK YOU FOR YOUR ATTENTION!