Novel Fast Radiation-Hard Scintillation Detectors for Ion Beam Diagnostics

P. Boutachkov (GSI)

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- SCI detectors at GSI
- ZnO scintillator development
- ZnO for detection of relativistic ions

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GSI FAIR TECHNISCHE UNIVERSITÄT DARMSTADT POLYTECH Shvabe ERA.Net RUS Plus DLR

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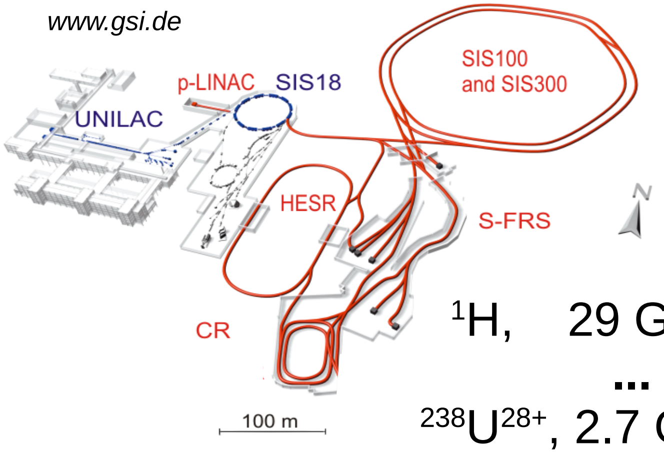
www.gsi.de



^{1}H, 29 GeV

...

$^{238}U^{28+}$, 2.7 GeV/u

Intensity and micro-spill detector

BC400(EJ212)

75x80x1 mm^3

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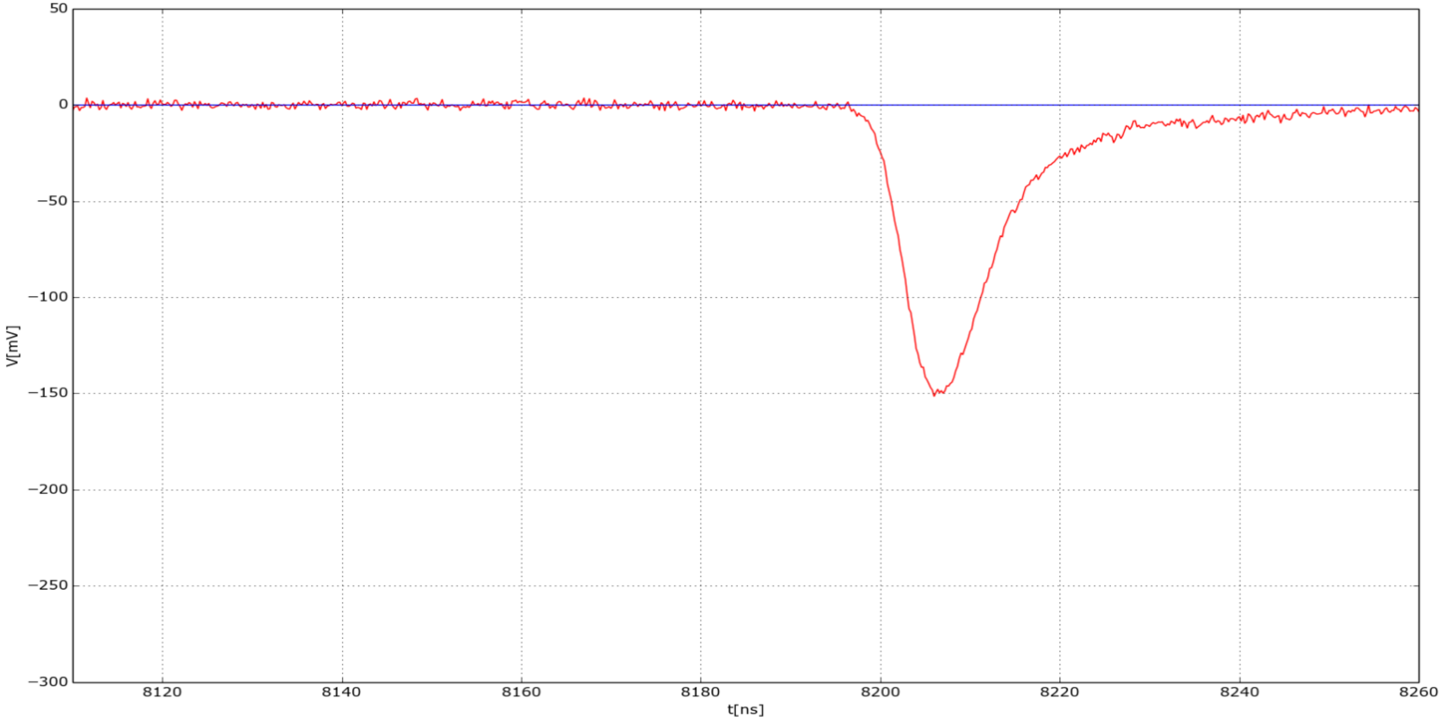
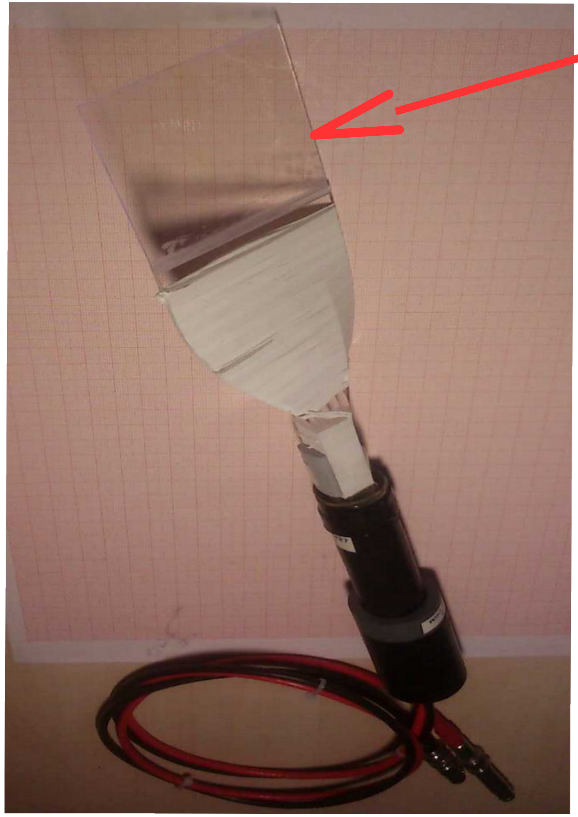
75x80x1 mm³



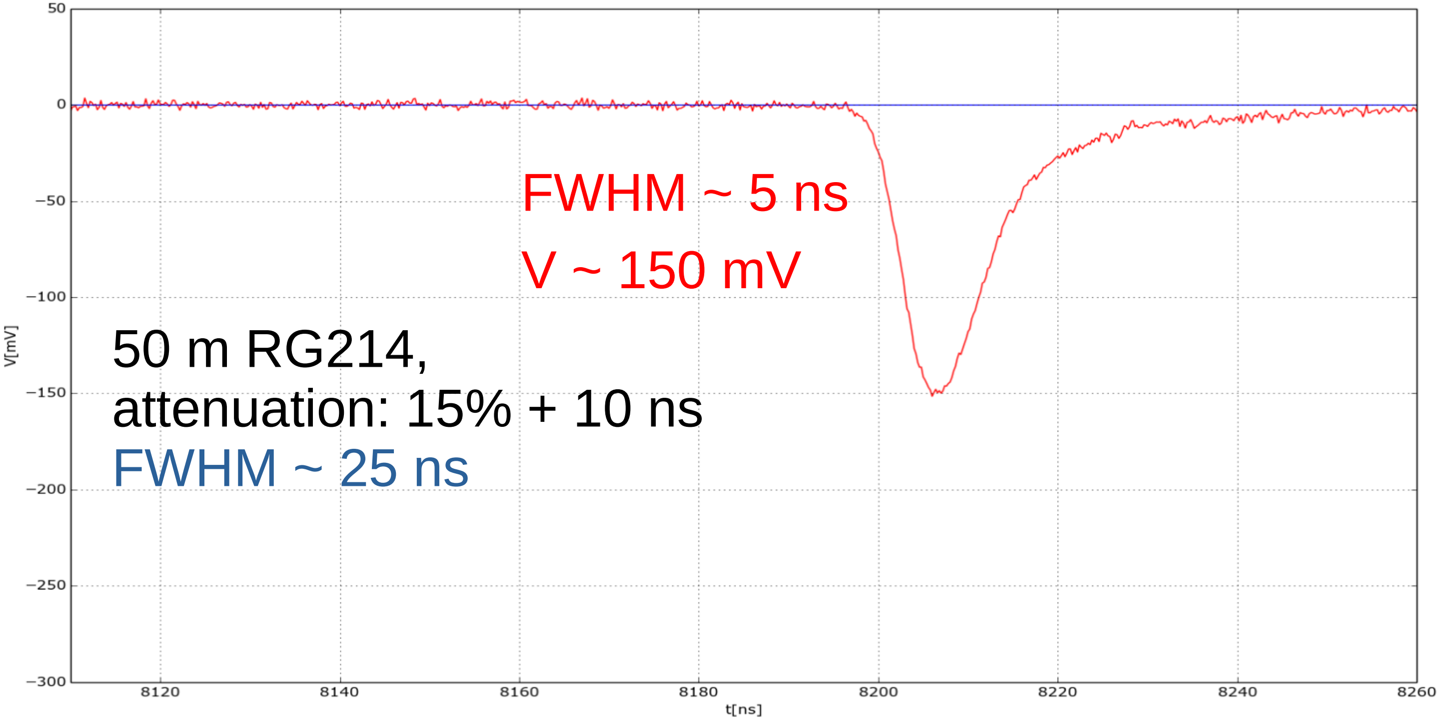
Each particle is counted

Intensity and micro-spill detector



BC400(EJ212)

75x80x1 mm^3



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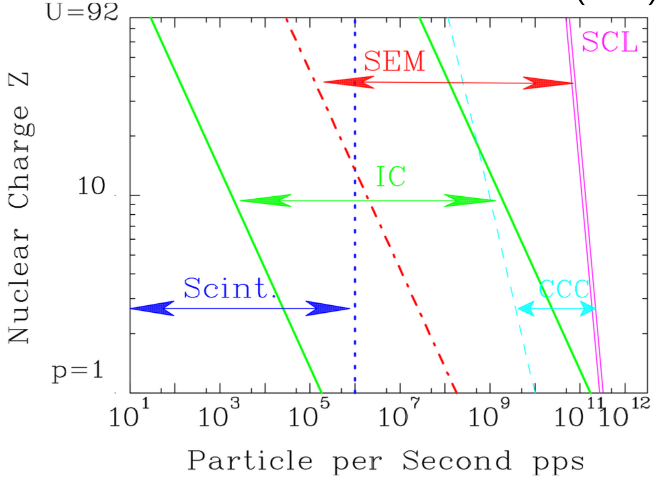
Beam intensity

P. Forck JUAS (2011)



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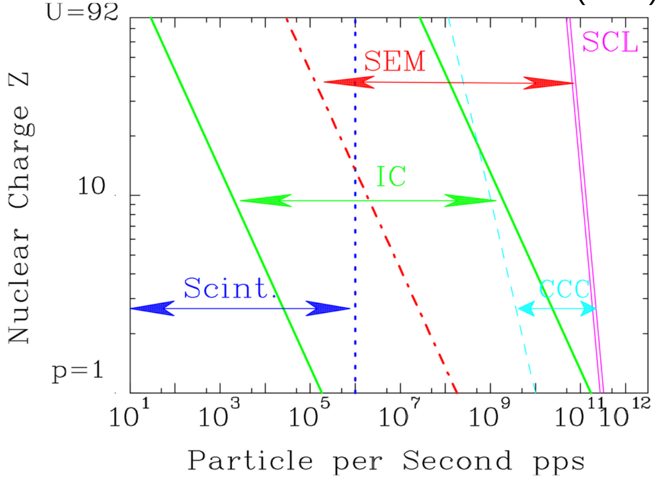

Spill microstructure

For example see: J. Yang et. al. TUP36

- Combine info from SCI and BPM

R. Singh

10^7 pps U^{28+}
→ 50 µV on the BPM plates
→ 0.1 mm resolution

Beam intensity

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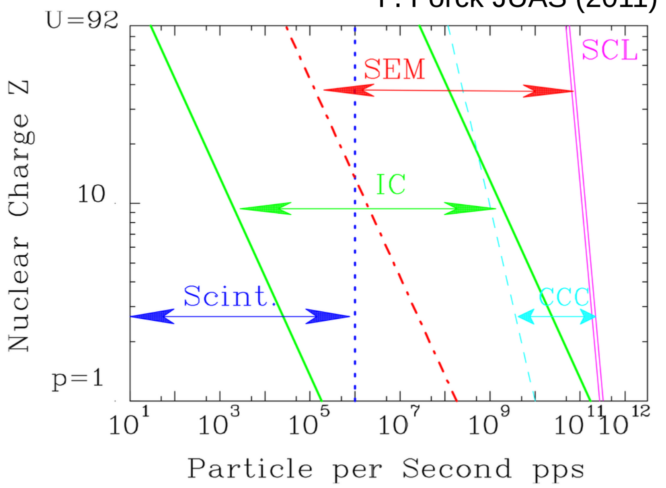

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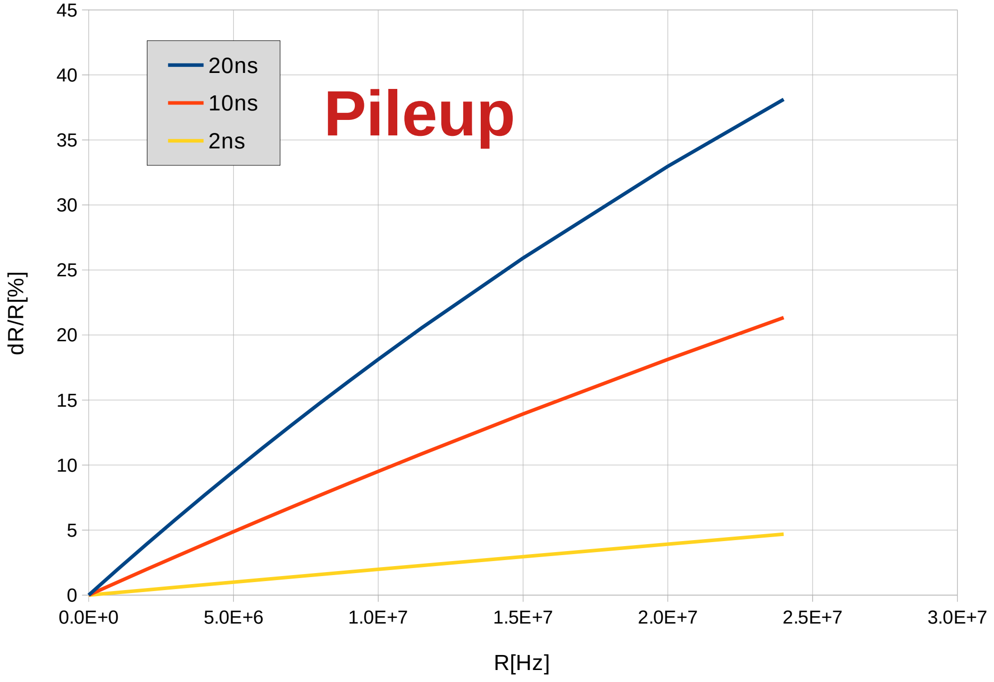
Positive

- No calibration is needed (each particle is counted)
- DC coupled
- Large dynamic range:
  Operation over 5 decades, detects **p** to **U**
- With Active Voltage Divider:
  counting rate of a few x**10**^{7} pps can be reached

To be careful



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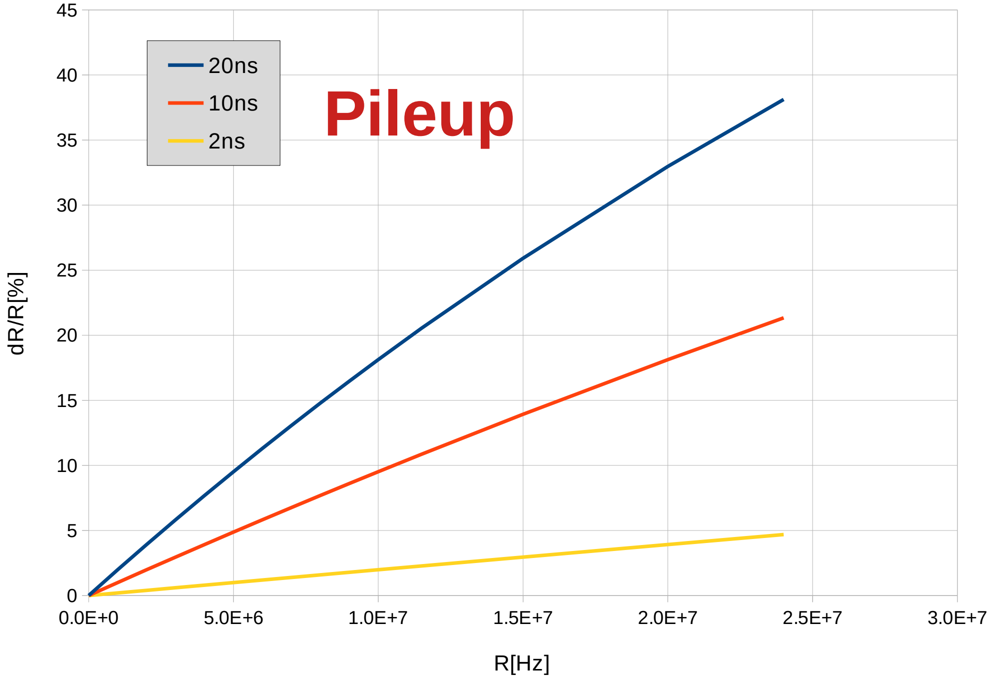
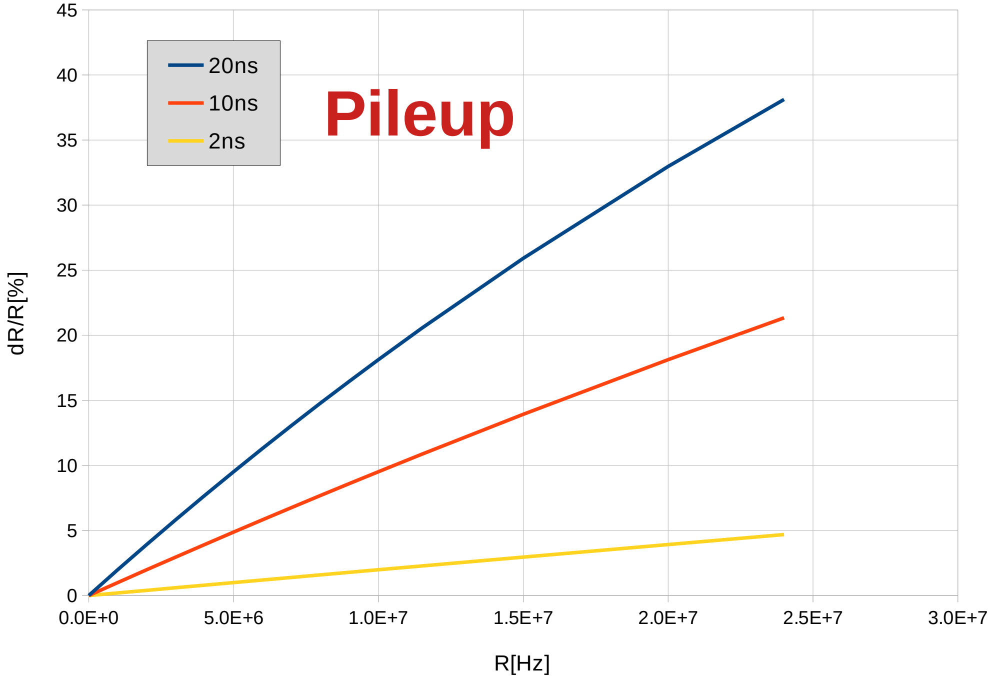


FWHM ~ 5 ns

50 m RG214,
FWHM ~ 25 ns

To be careful



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Many solutions: e.g. S.E. Engel et. al. WEP42
(best options FWHM < 1 ns)

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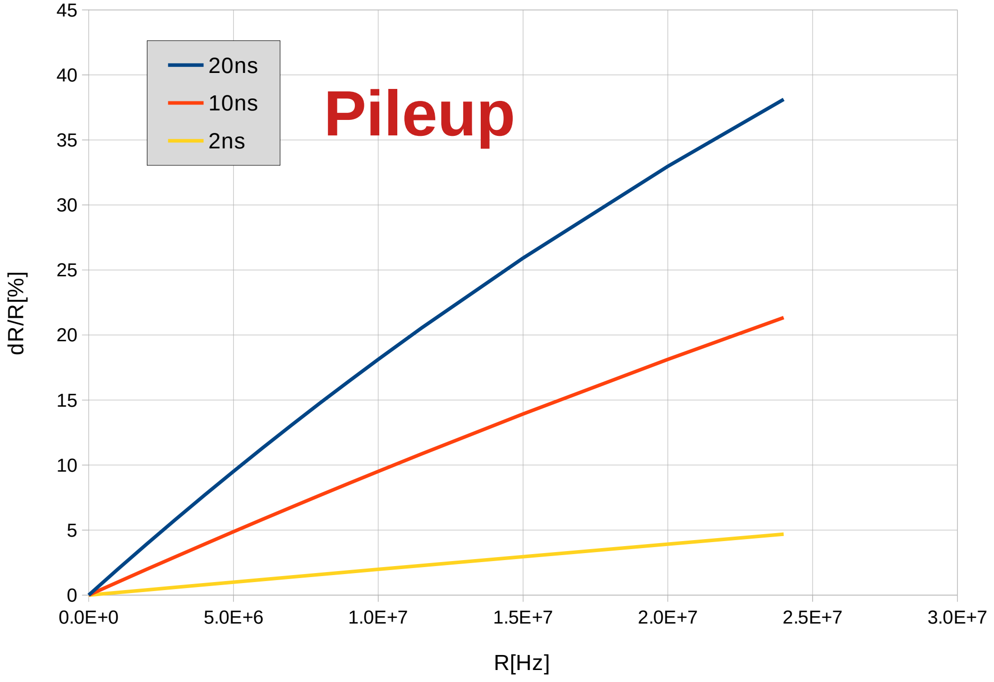

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Problematic

Radiation Damage

The discovery of ZnO SCI

W. Lehmann, “Edge emission of n-type conducting ZnO and CdS,” Solid-State Electronics,1966.

Abstract: Edge emission **luminescence of ZnO** and CdS appears in useful intensity at **room temperature** if the materials are **n-type doped** and prepared under **reducing conditions**. The emission spectra consist each of a **structureless band** near to the **optical absorption edge**. The luminescences are extremely fast, the time constants of their probably exponential decay are **at most 10^{-9} sec**. The emissions are assumed to be due to electron transitions from shallow states below the conduction band.

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From the paper: The phosphors can then be excited by any common means (**e.g. u.v. or cathodo-rays**) to show edge emission (**near-u.v. for ZnO**) while the ordinarily observed longer-wave emissions (**green for ZnO**) are absent.

ZnO Applications

- X-ray detector
- α-detectors
- γ-detectors

- Nano-structures
  - Gas sensors
  - SE detectors

- Transparent electrodes
- LED

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P.A. Rodnyi, et. al. “Novel Scintilation Material ZnO Transparent Ceramics” IEEE 59 (2012) 2152

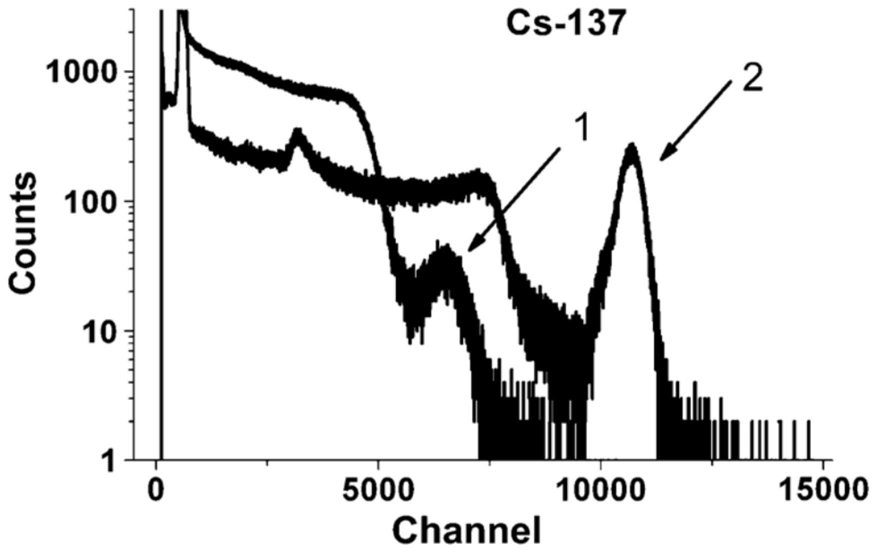
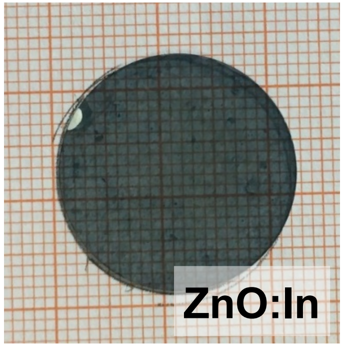


Fig. 6. Pulse height spectra of ^{137}Cs, obtained for (1) ZnO ceramics and (2) CsI:Tl single crystalline scintillators.

ZnO Transparent Ceramics

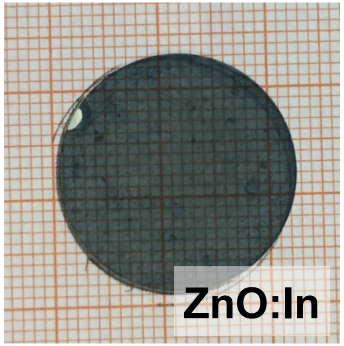


diameter = 2 cm
thickness = 0.4 mm

<u>The receipt</u>

- Mix ZnO nano-powder with In_2O_3
- Use uniaxial hot pressing in high vacuum furnace
- Polish to the desired thickness
- Optionally treat with H_2

ZnO Transparent Ceramics



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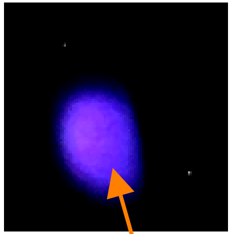
Test at GSI in 2016



Xe@300 MeV/u

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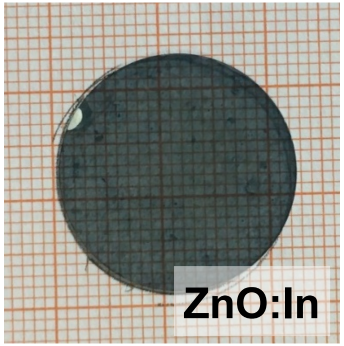

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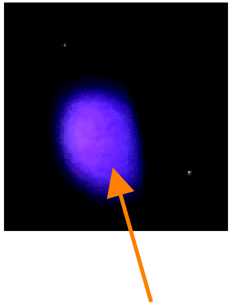

Xe@300 MeV/u

ERA.Net RUS Plus 2018

DLR

E. Gorokhova (State Optical Institute Scientific Production Enterprise, St. Petersburg, Russia)

P.A. Rodnyi (Peter the Great St. Petersburg Polytechnic University)

L. Grigorjeva (Institute of Solid State Physics of University of Latvia)

P. Boutachkov,
M. Saifulin,
B. Walasek-Höhne,
C. Trautmann,
P. Forck
(GSI, Germany)

Experiments at GSI

Ar-U @ **250** – **500** MeV/u
Ca, Au @ **5** MeV/u, **8** MeV/u

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(1) SIS-18 beam line;

(2) Beam collimator;

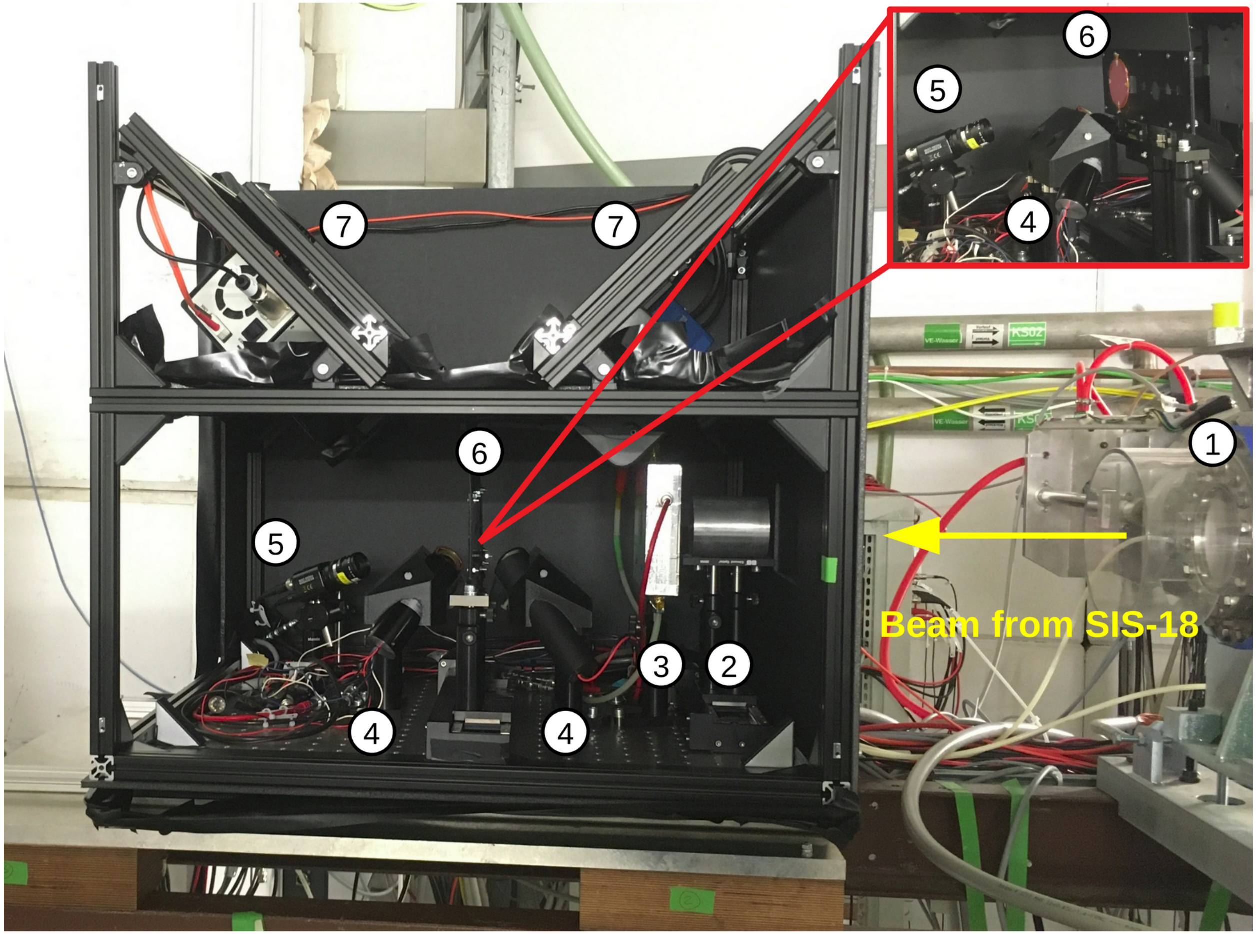
(3) Ionization chamber;

(4) Photomultipliers;

(5) Video camera;

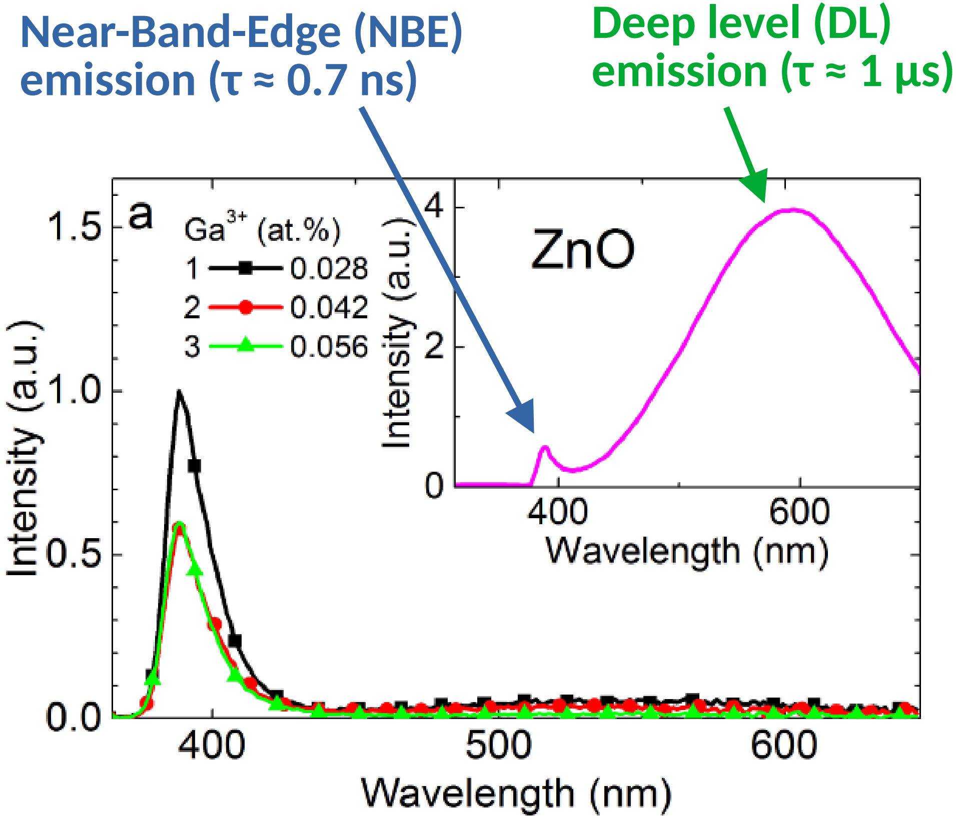
(6) Target holder;

(7) Spectrometers;



M. Saifulin

Luminescence



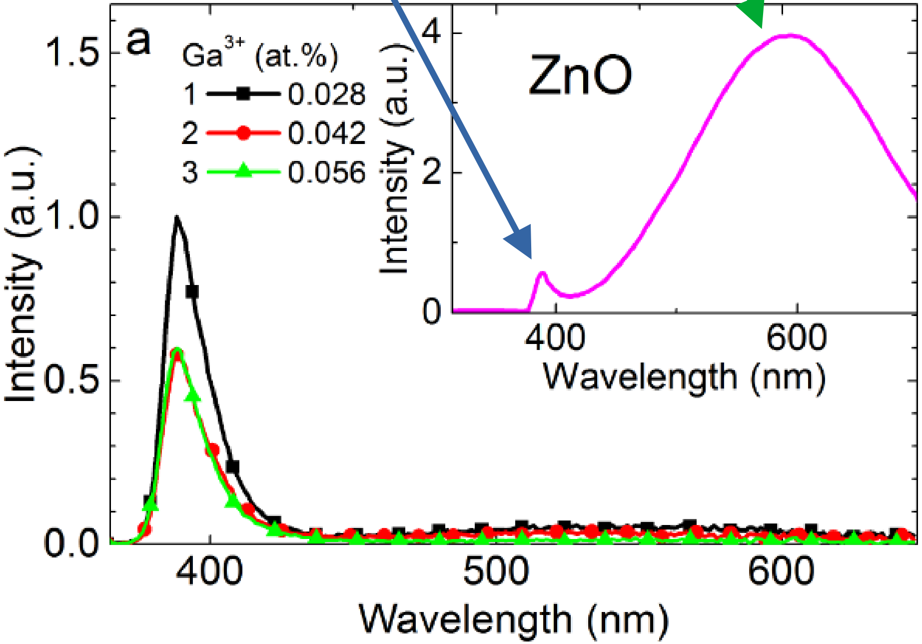
X-ray (40 kV, 10 mA) excitation

K. Chernenko, et. al. IEEE 65 (2018) 2196

Luminescence

Near-Band-Edge (NBE) emission (τ ≈ 0.7 ns)

Deep level (DL) emission (τ ≈ 1 μs)



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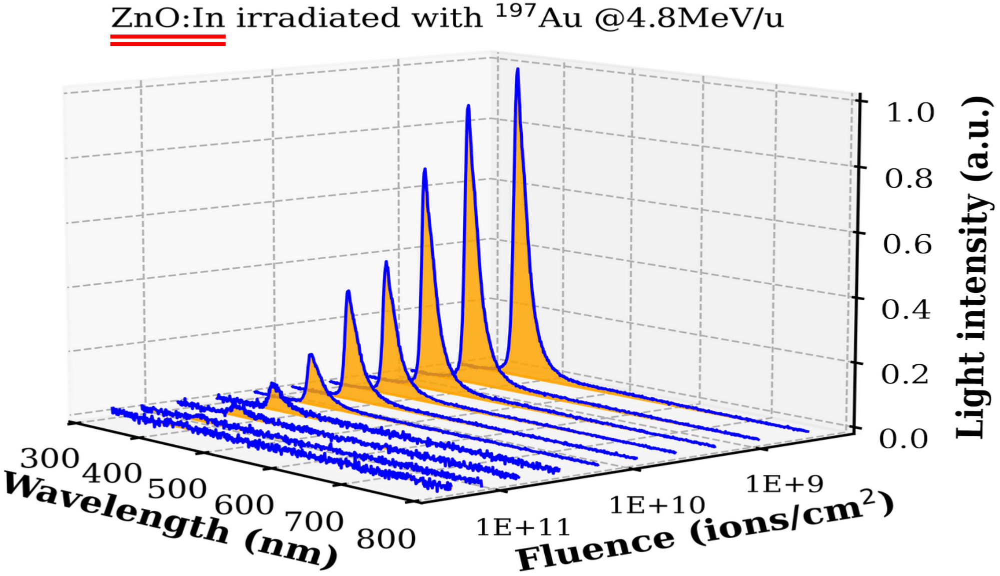
M. Saifulin, et. al., Journal of Applied Physics (see poster TUP29 for more details)



$\lambda_{MAX} = 0.39\ \mu m$

Luminescence

P. Boutachkov, et. al., JACoW IBIC2019

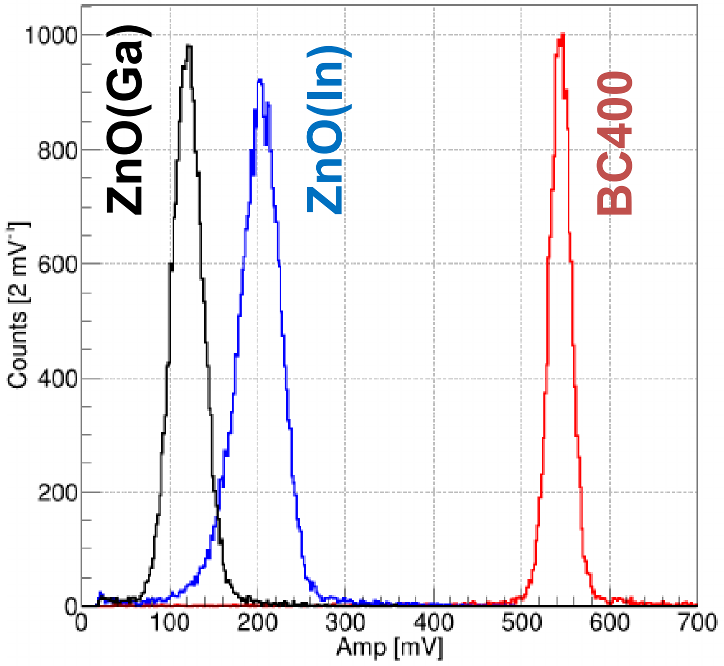


Figure 3: Comparison of the amplitude distribution of the investigated materials. The scintillators are bombarded with 300 MeV/u ^{124}Xe. In red: 1 mm thick BC400, in blue: 0.4 mm thick ZnO:In and in black 0.4 mm thick ZnO:Ga.

FWHM(ZnO) > FWHM(BC400)

Luminescence

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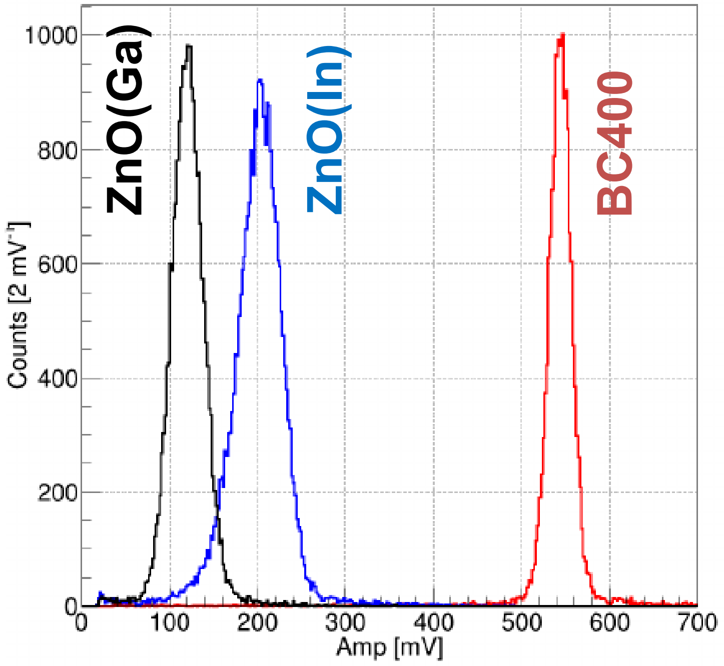

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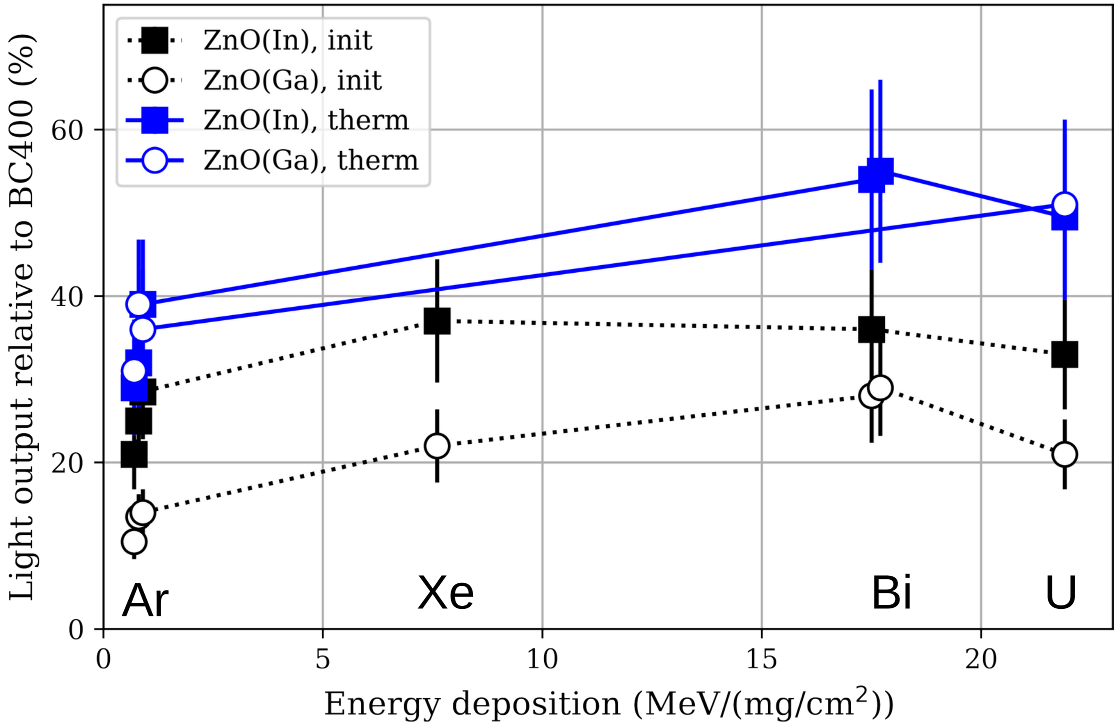
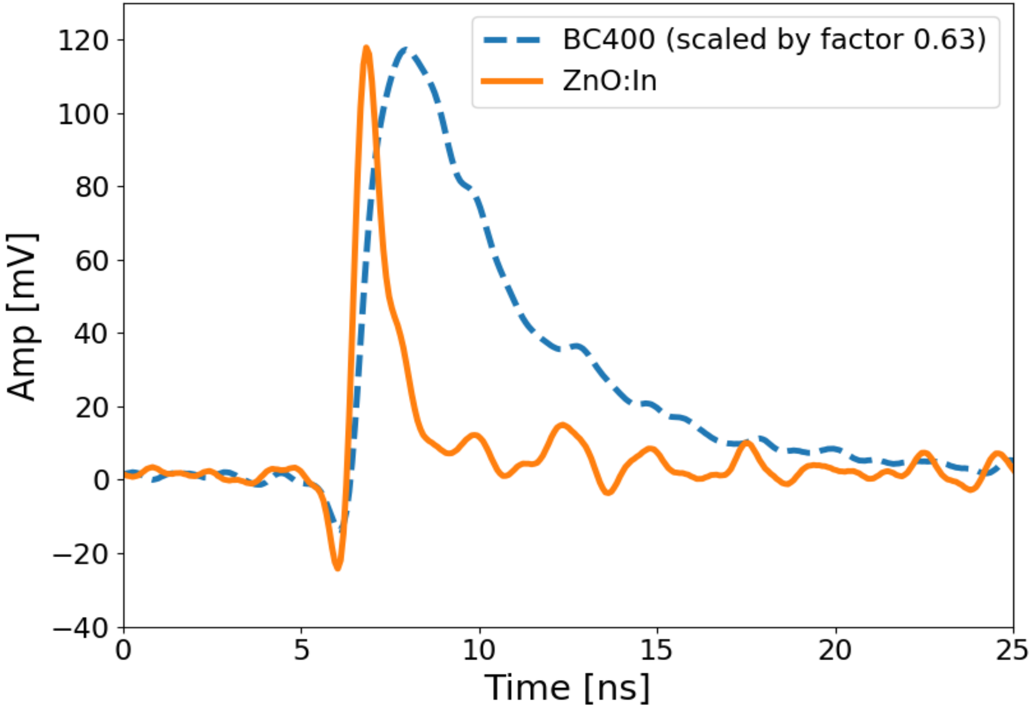


M. Saifulin, et. al., to be published in IEEE

How Fast is ZnO?

^{238}U@300 MeV/u interacting with BC400 and ZnO:In

M. Saifulin, et. al. IBIC2020



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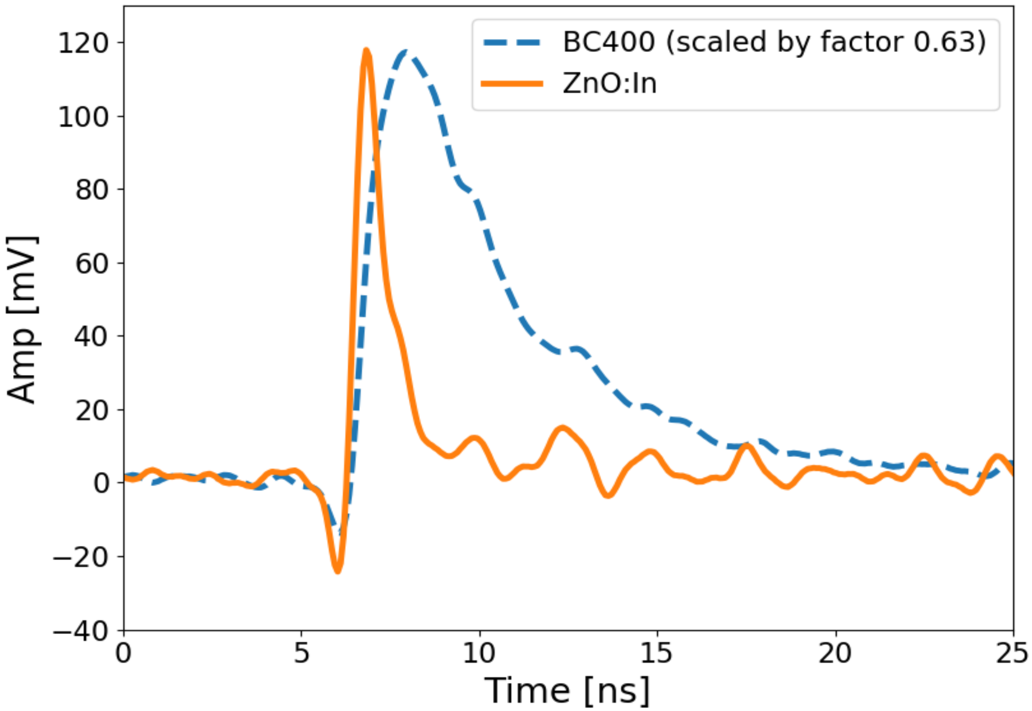

H13661-PMT(PMT rise time ~ 230 ps, PMT FWHM 430 ps) signal captured with 2 GHz scope

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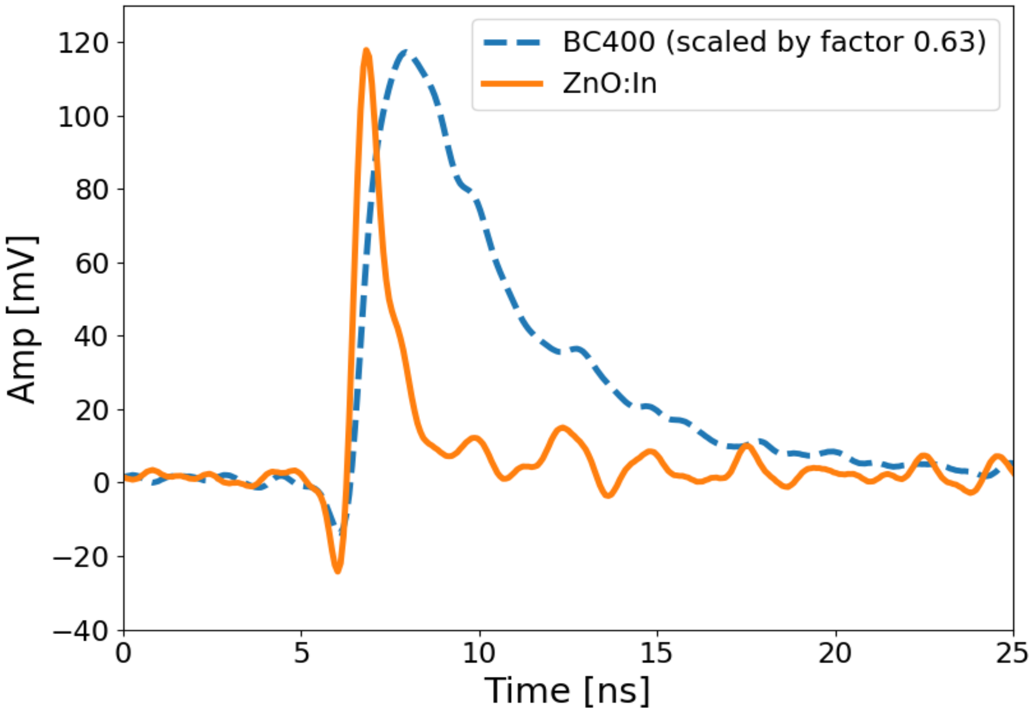

ZnO:In

- FWHM < 1 ns
- Rise time < 5 ps/mV

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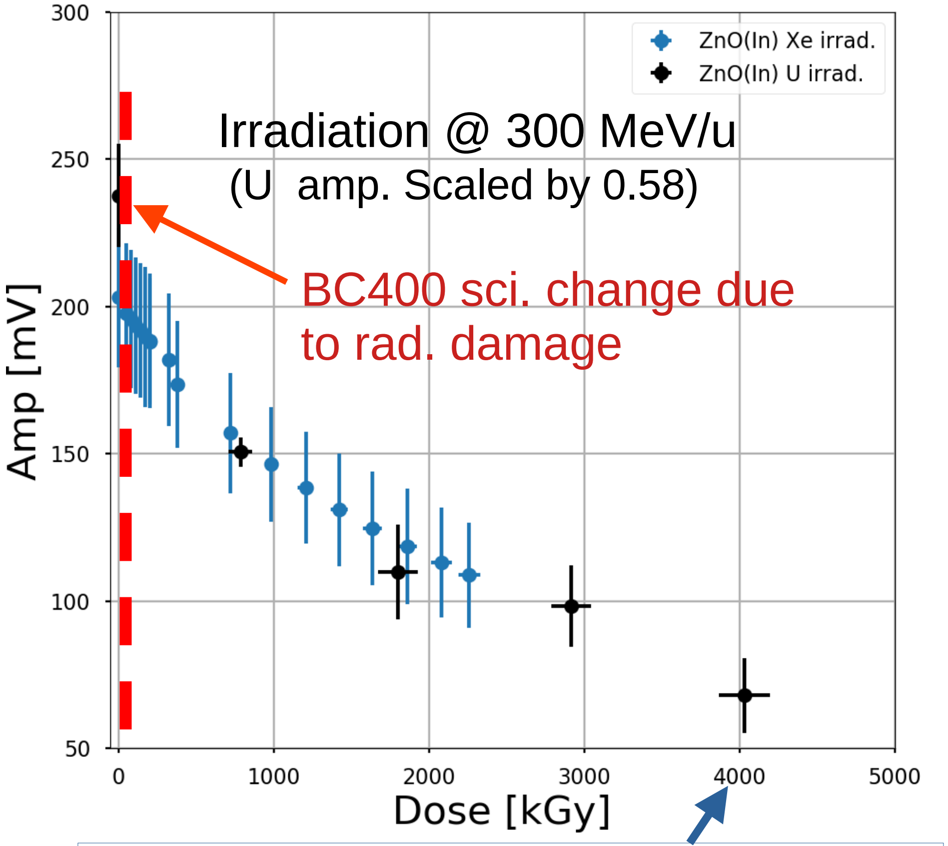
ZnO:In Radiation hardness

P. Boutachkov, et. al., JACoW IBIC2019



^{238}U: 10^{12} 1/cm^2, or ^{124}Xe: 3×10^{12} 1/cm^2

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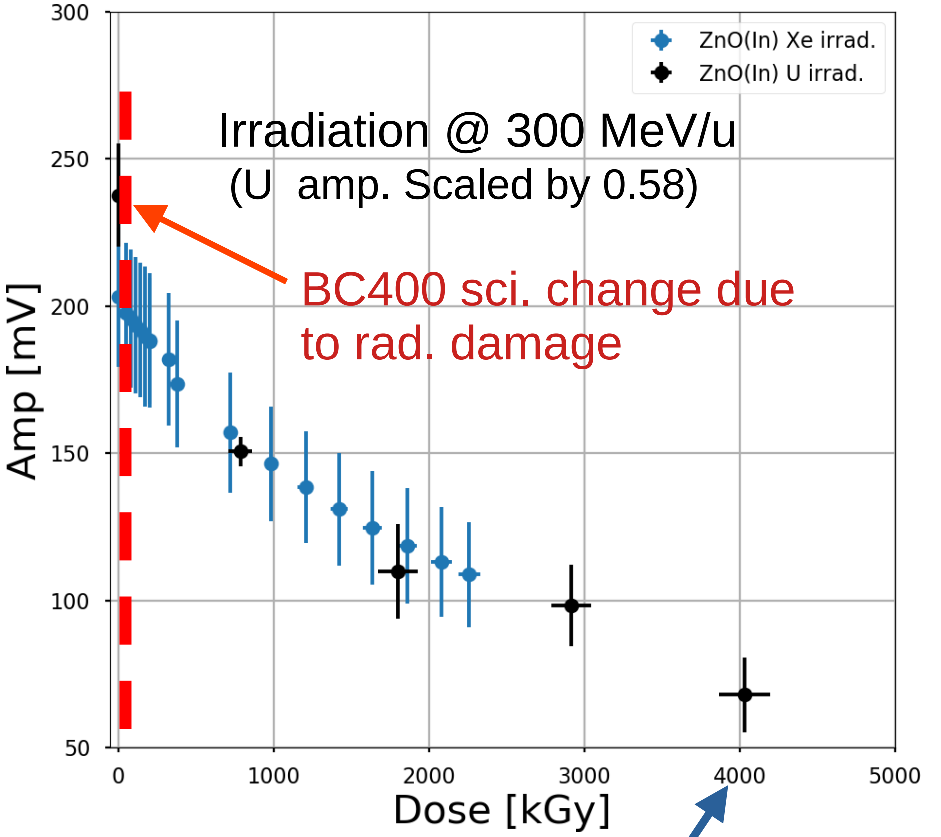

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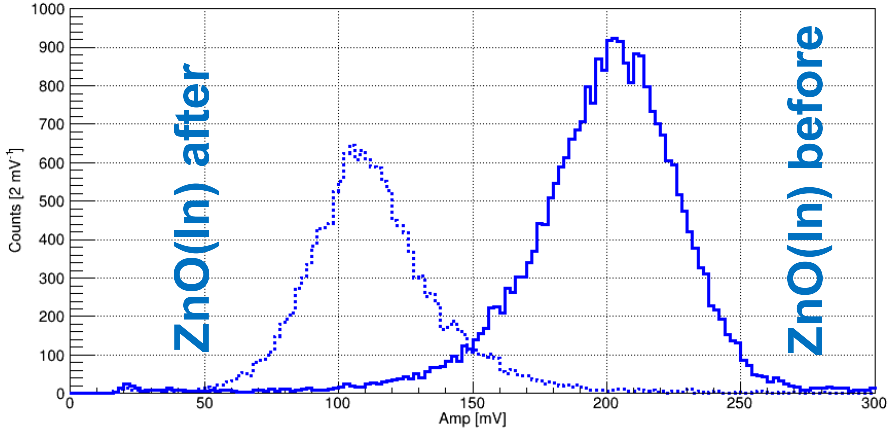
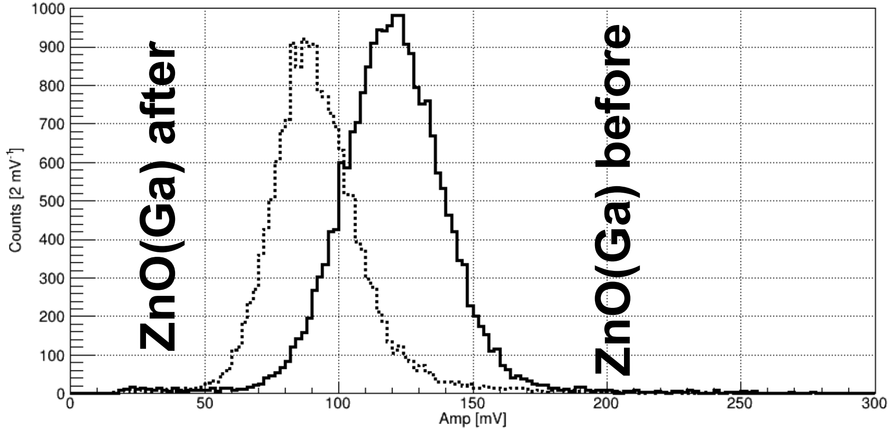
Irradiation with Xe





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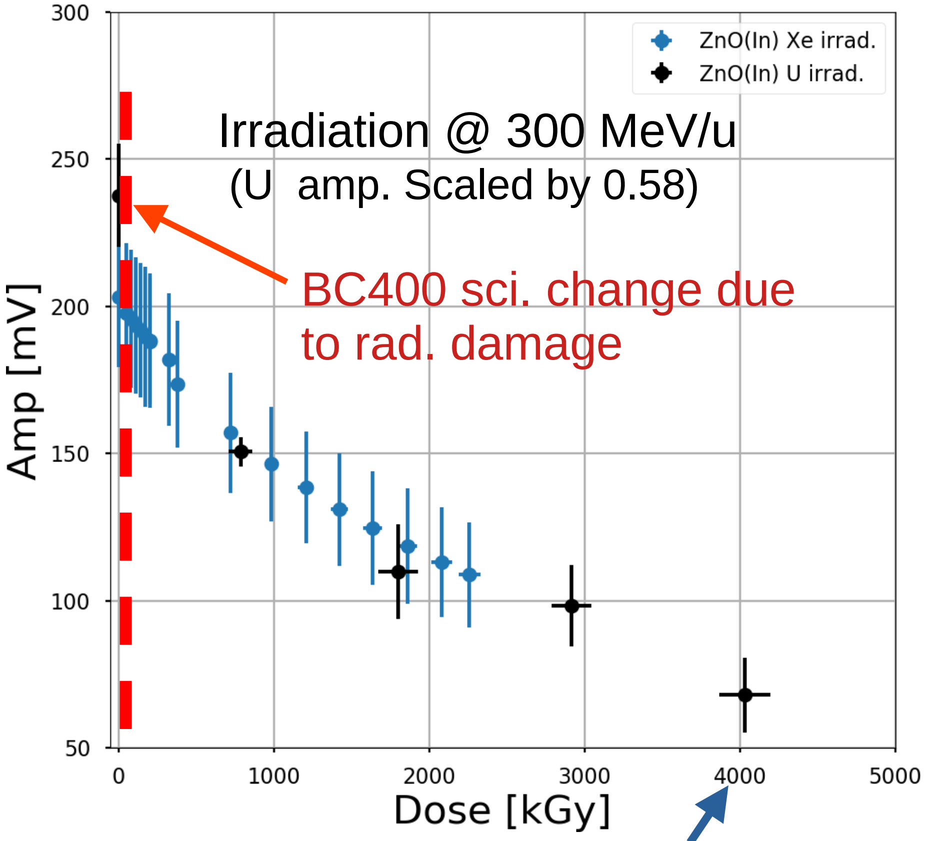
P. Boutachkov, et. al., JACoW IBIC2019



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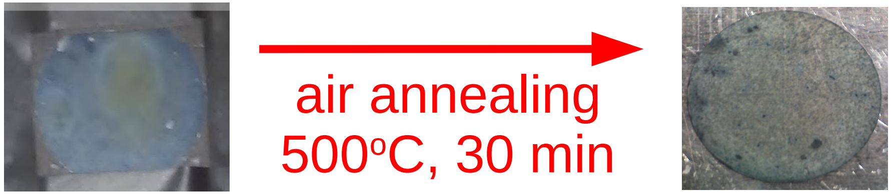
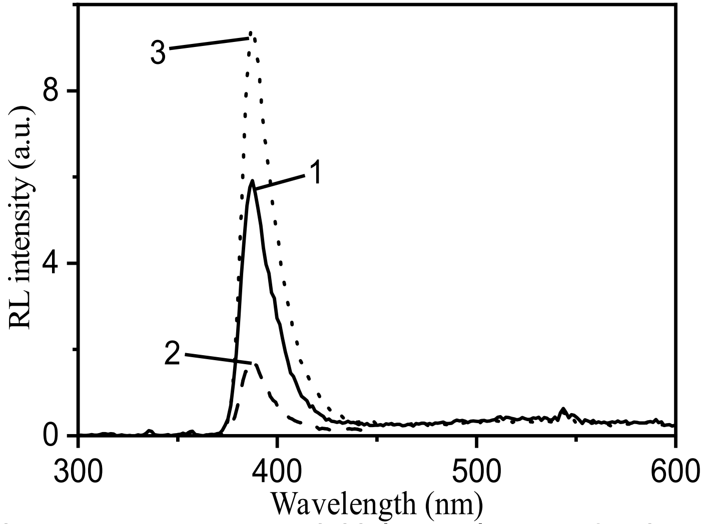
after ^{238}U irradiation

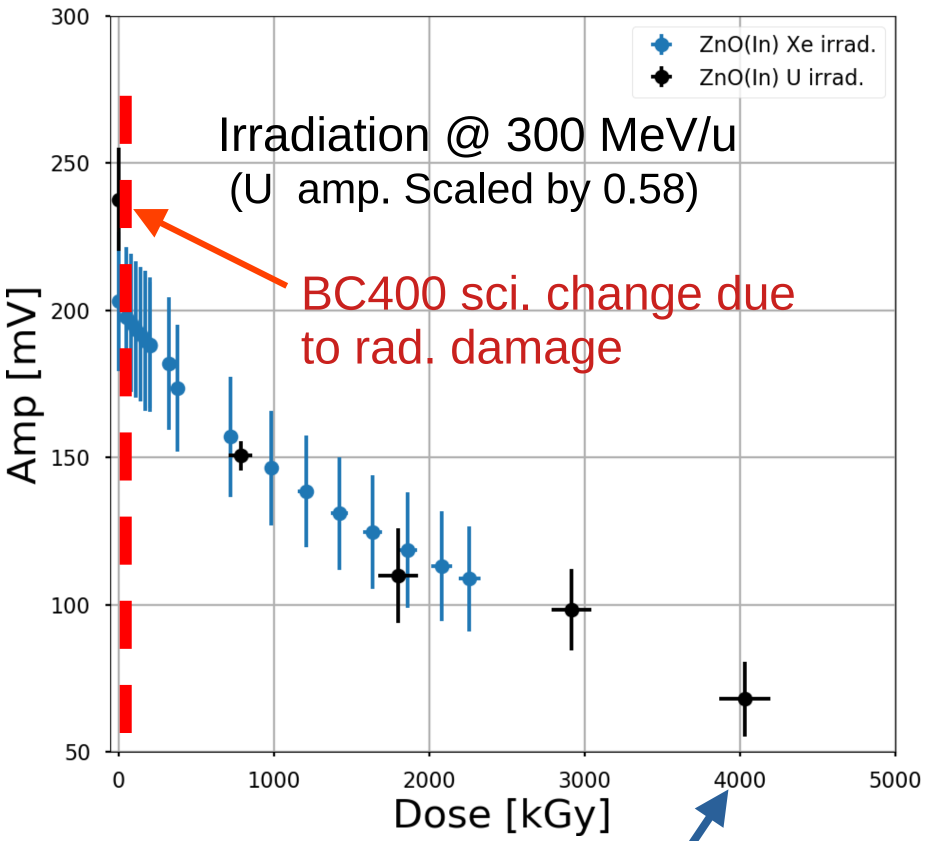




Radioluminecence spectra: 1 – initial sample; 2 – after irradiation with ^{238}U ; 3 – after annealing, Figure from: P.A. Rodnyi *et al.*, IEEE EExPolytech, October 17-18, 2019

ZnO:In Radiation hardness

P. Boutachkov, et. al., JACoW IBIC2019



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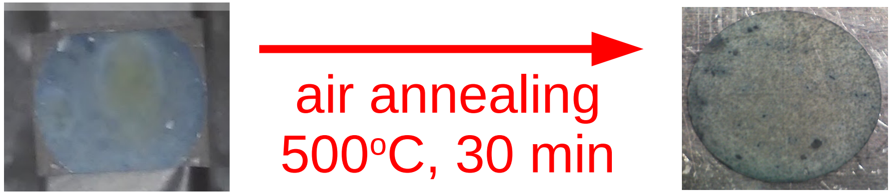

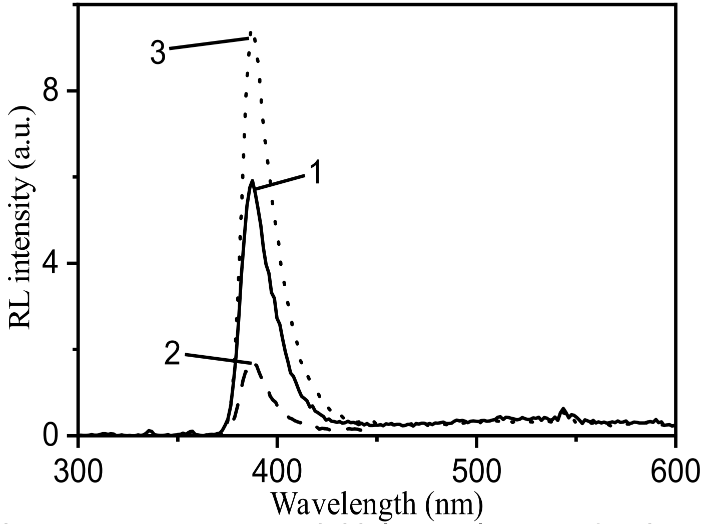

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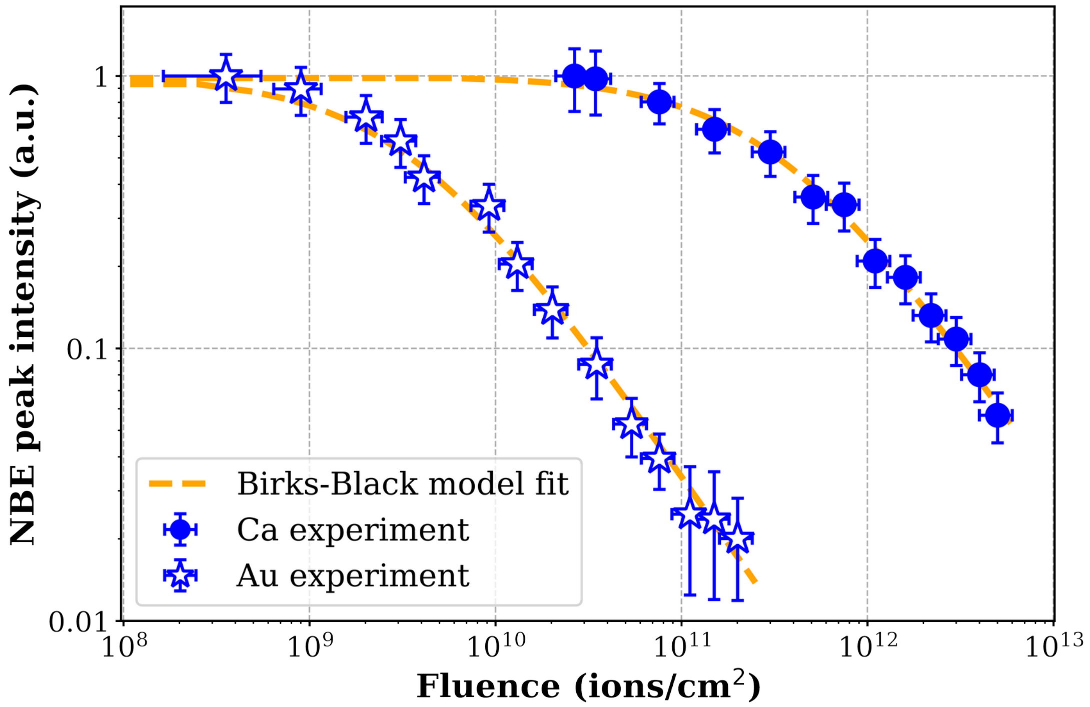
Study with ^{238}U after anneal.: <u>luminescence properties are restored</u>

Birks-Black model and ZnO

M. Saifulin, et. al., Journal of Applied Physics
(see poster TUP29 for more details)

Ca, Au @ 5 MeV/u



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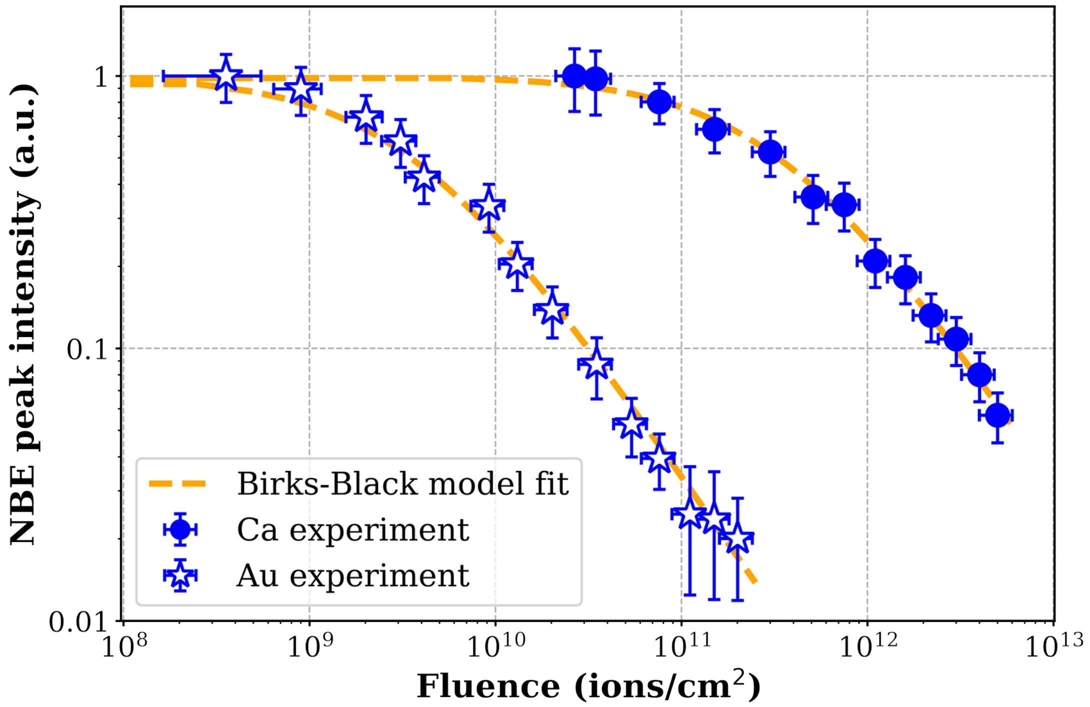

J. B. Birks and F. A. Black 1951
Proc. Phys. Soc. A 64 511

$$I(\phi) = I_0 / (1 + \phi / \phi_{1/2})$$

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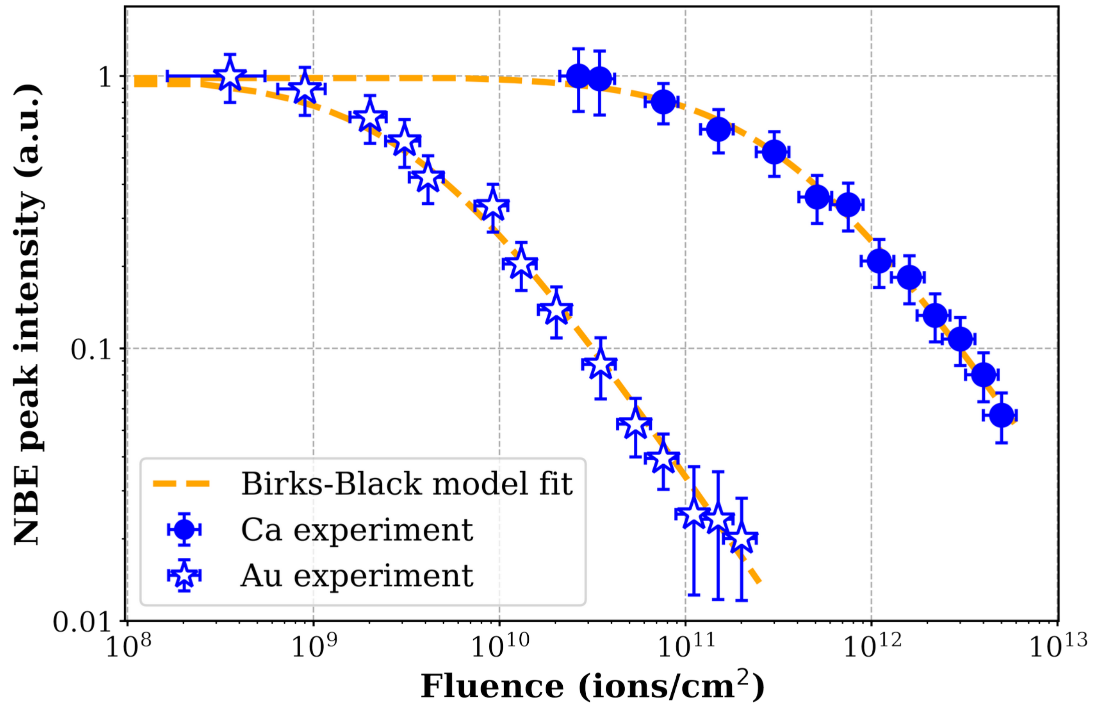

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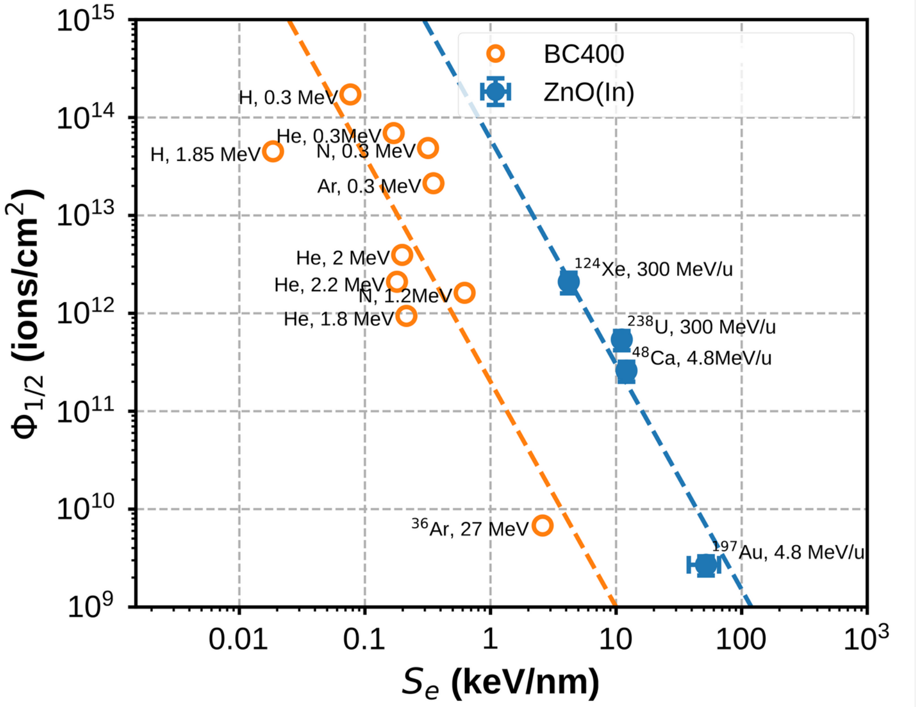
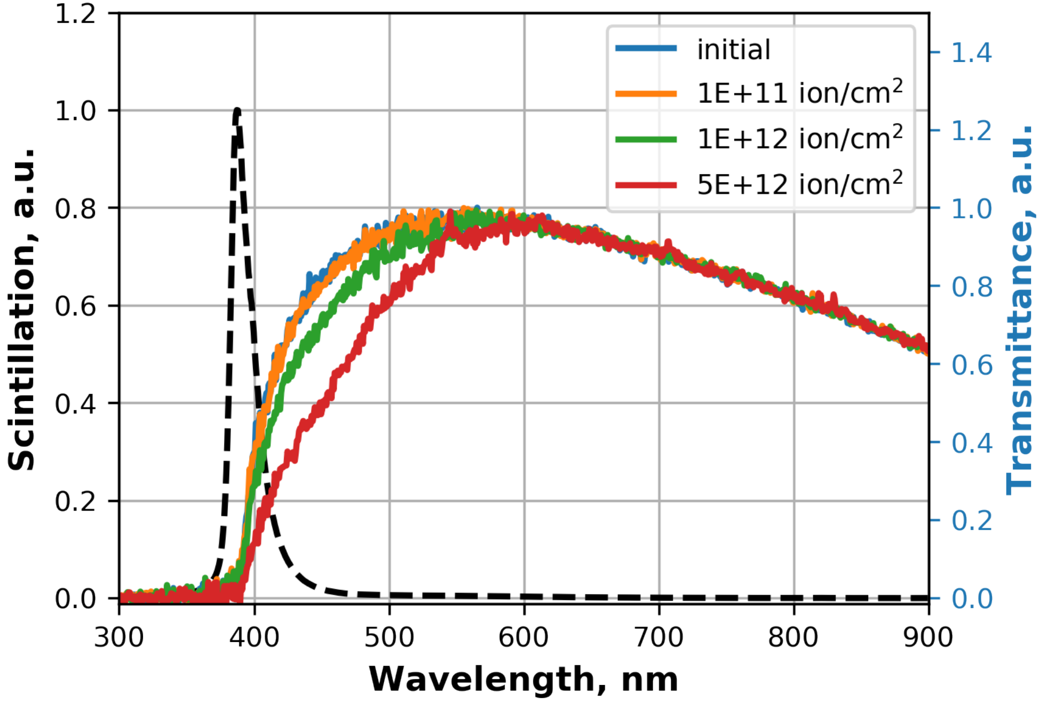


ZnO Transmition

^{48}Ca @4.8MeV/u, ZnO:In luminescence and transmittance



M. Saifulin, et. al., Journal of Applied Physics

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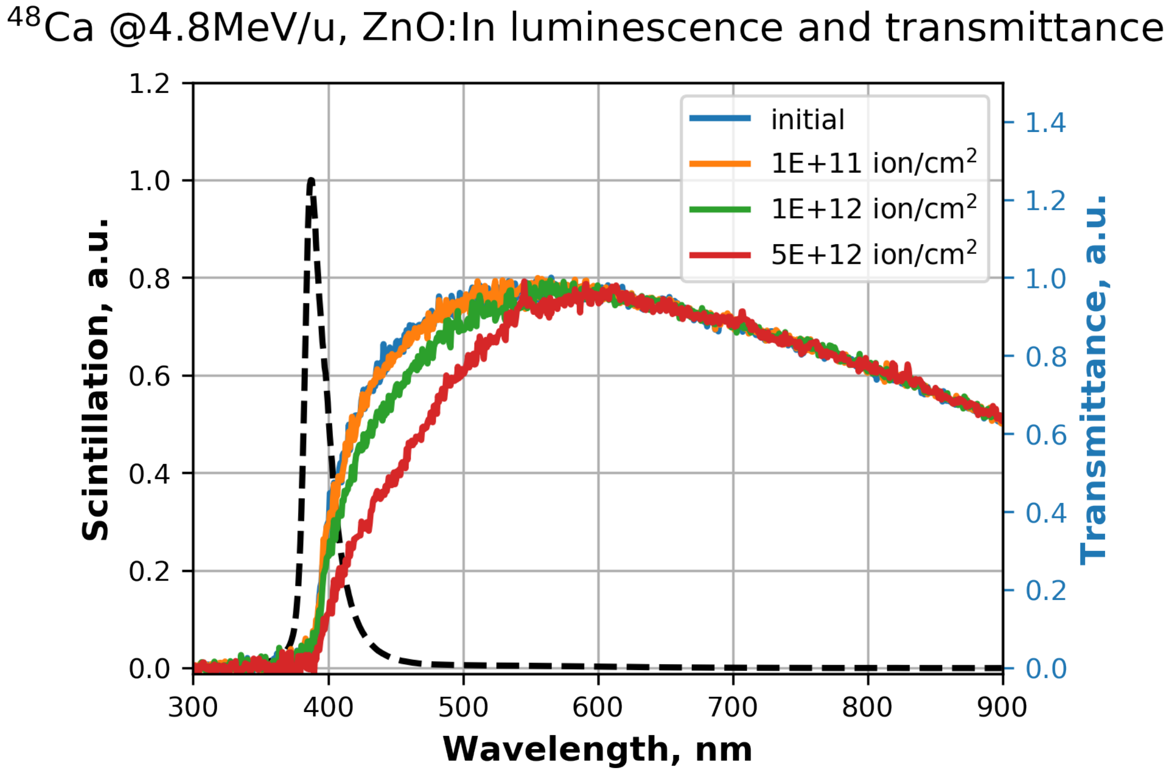

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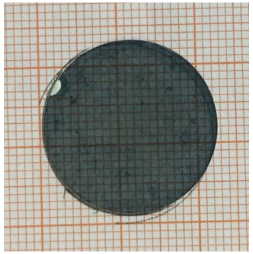
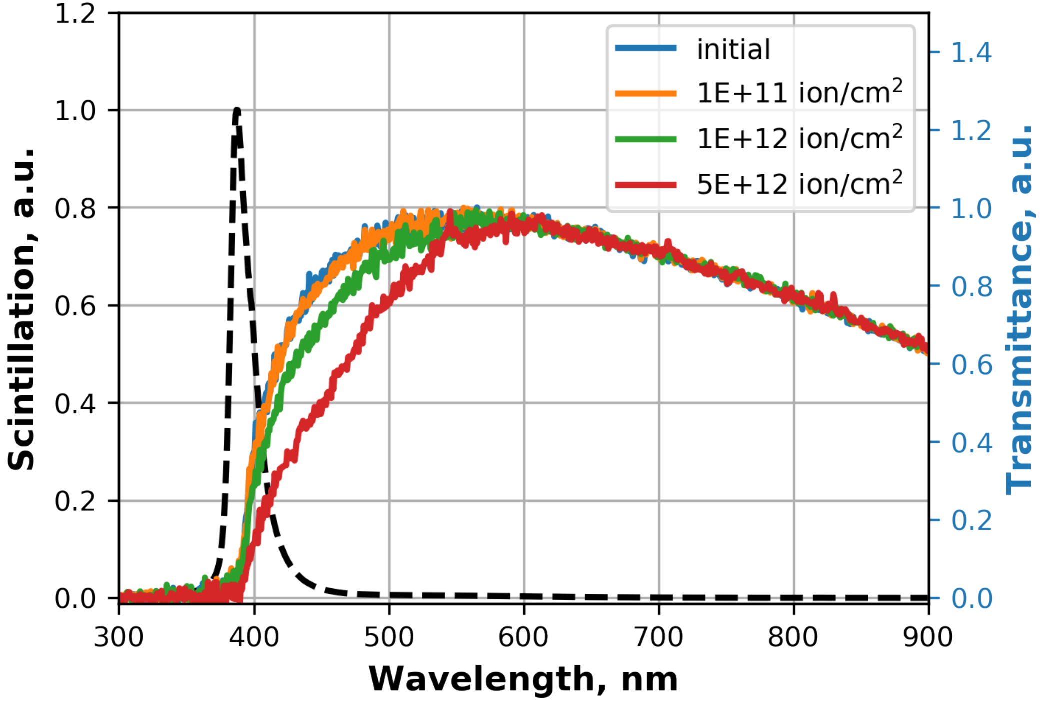
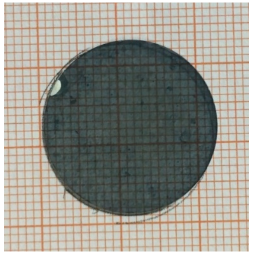


ZnO Transmition

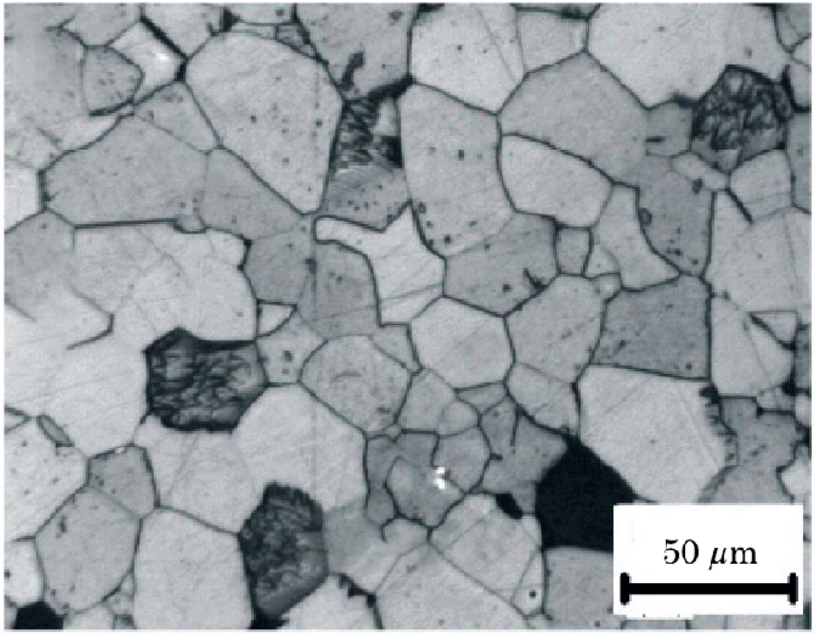
^{48}Ca @4.8MeV/u, ZnO:In luminescence and transmittance



M. Saifulin, et. al., Journal of Applied Physics



Elecron Micrograph of ZnO sample



E. I. Gorokhova et. al. Journal of Optical Technology, 85 (2018) p. 729

Building a tile detector

<u>ZnO:In</u>

- 15x15 mm^2 tiles, 0.4 mm thick
- Active area 45mm x 45mm

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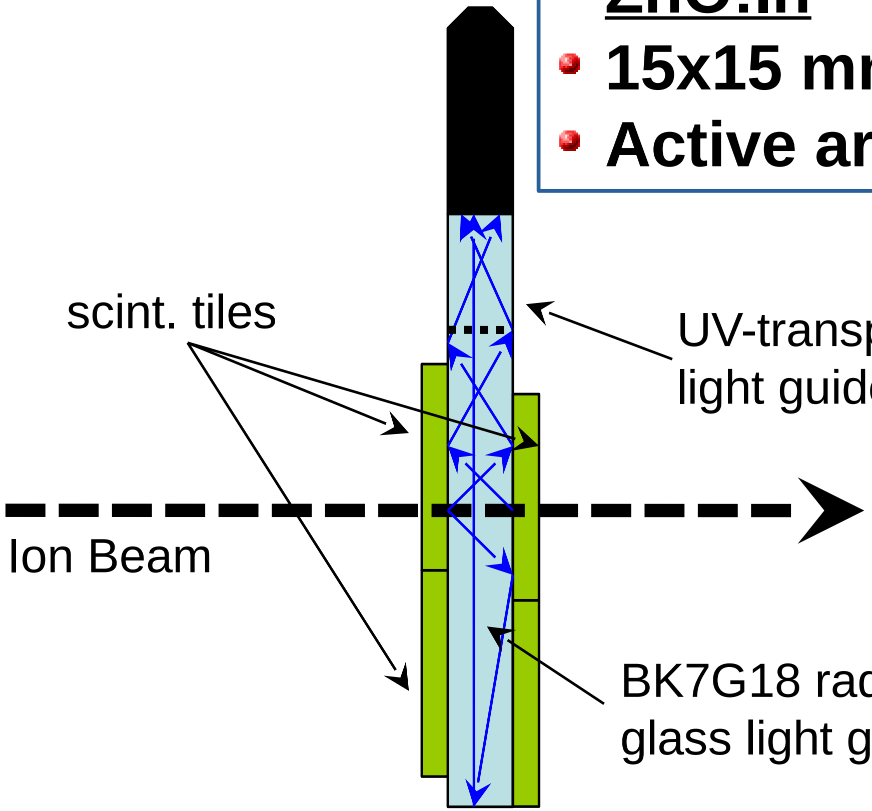

M. Saifulin, et. al., SCINT 2022, M. Saifulin, TU Darmstadt Thesis

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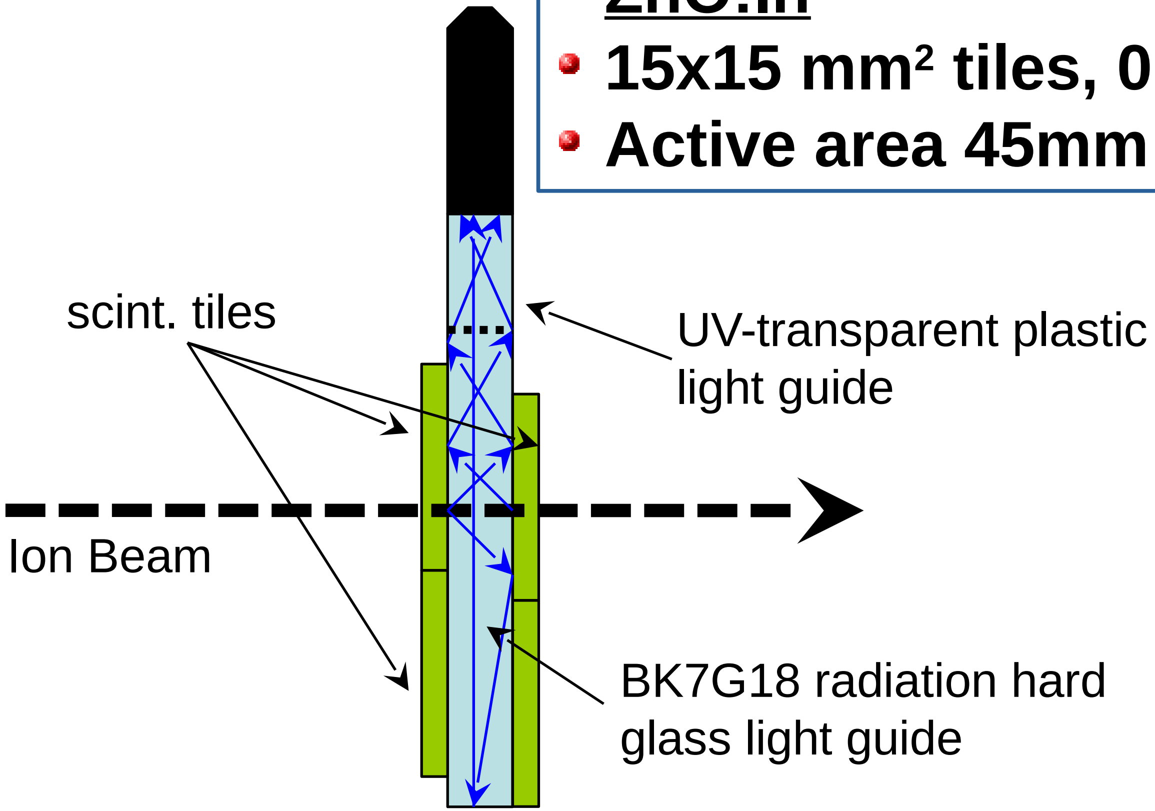
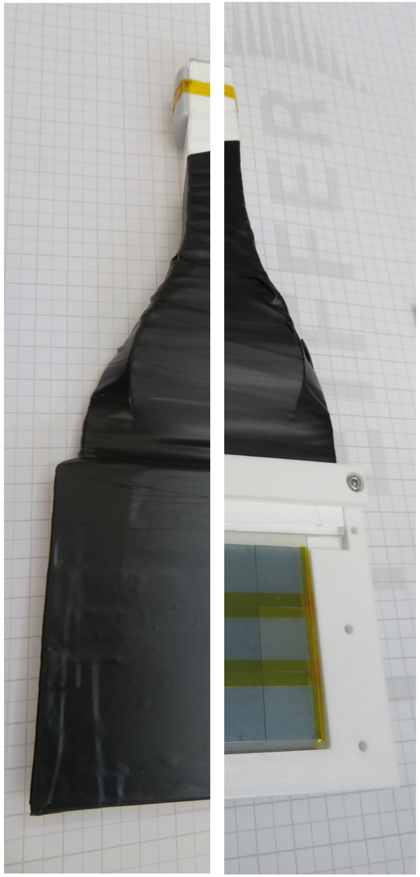
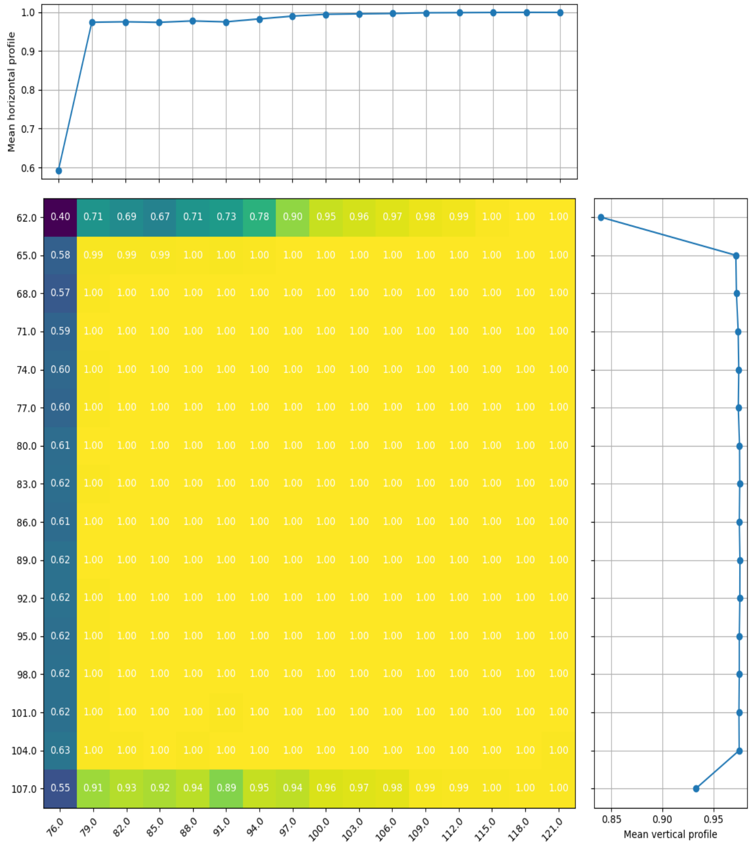




M. Saifulin, et. al., SCINT 2022, M. Saifulin, TU Darmstadt Thesis

Prototype counting efficiency map



Characterized with 300 MeV/u: Ar, Au, Pb, U

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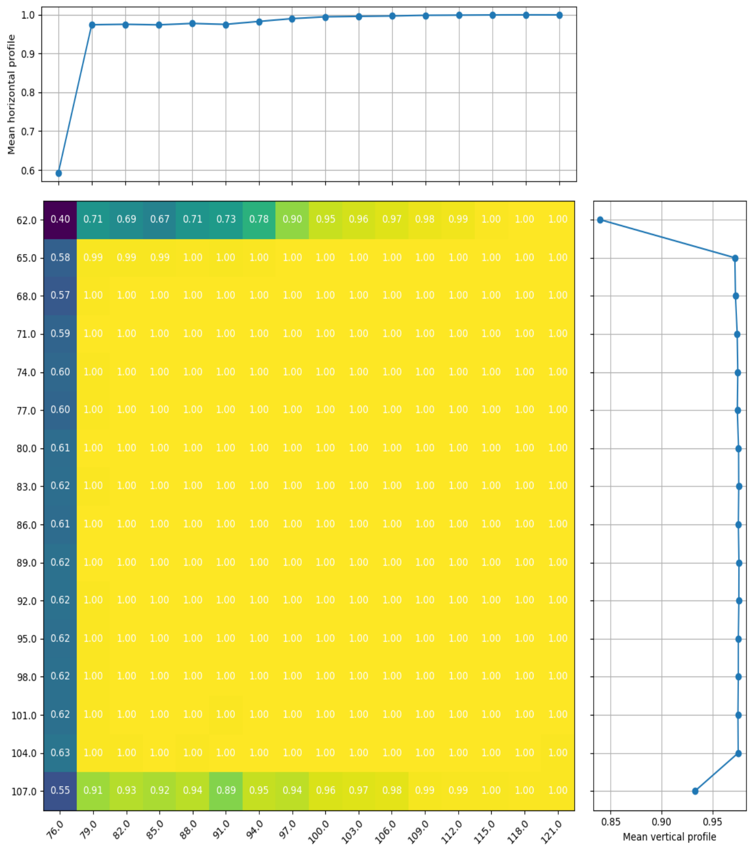

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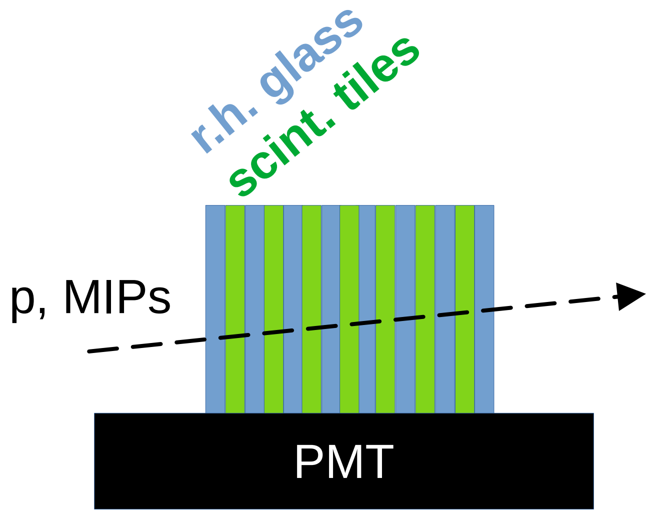
Summary

- ZnO:In ceramics
  - Fast
  - Radiation hard
  - Annealing → restore of lumin.
- Material response to relativistic heavy ions was determined
- Development of 45x45 mm^2 ZnO:In“compact detector”

Outlook

R.H MIPs detector



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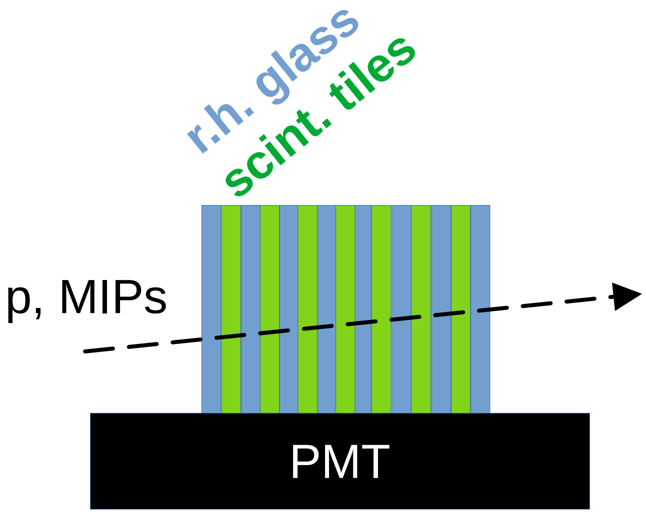

Longitudinal profile Measurements

Screen saturation

Based on XFEL results: G. Kube et. al. FEL2019

One expects Al_2O_3:Cr effects at $6x10^9$ particles of U-ions, 10 mm beam spot.

extraction time at SIS >> ZnO:In decay time

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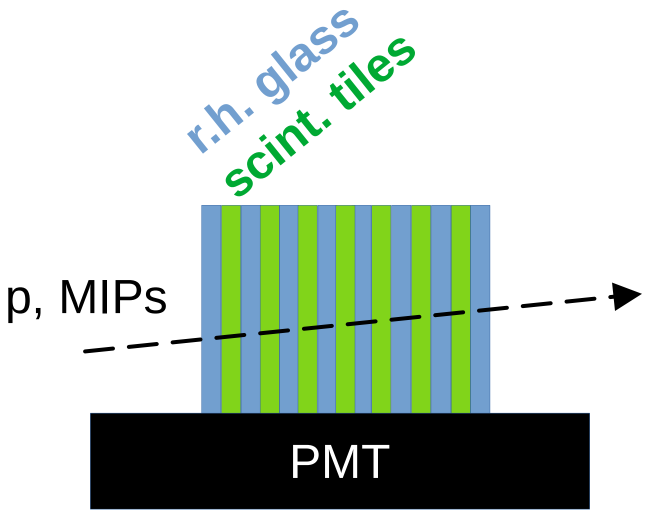

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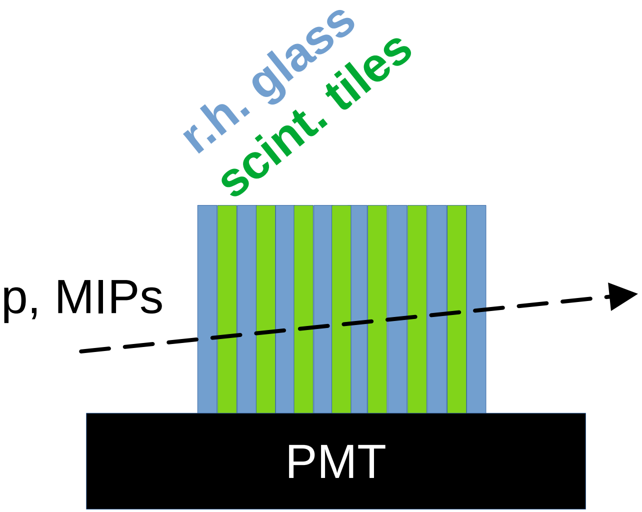

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C. Trautmann [1,2], and B. Walasek-Höhne [2]

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[3] “Research and Production Corporation S.I. Vavilova”, St. Petersburg, Russia
[4] Peter the Great Polytechnic University, St. Petersburg, Russia