

New radiation hard fast scintillator for heavy ion detection

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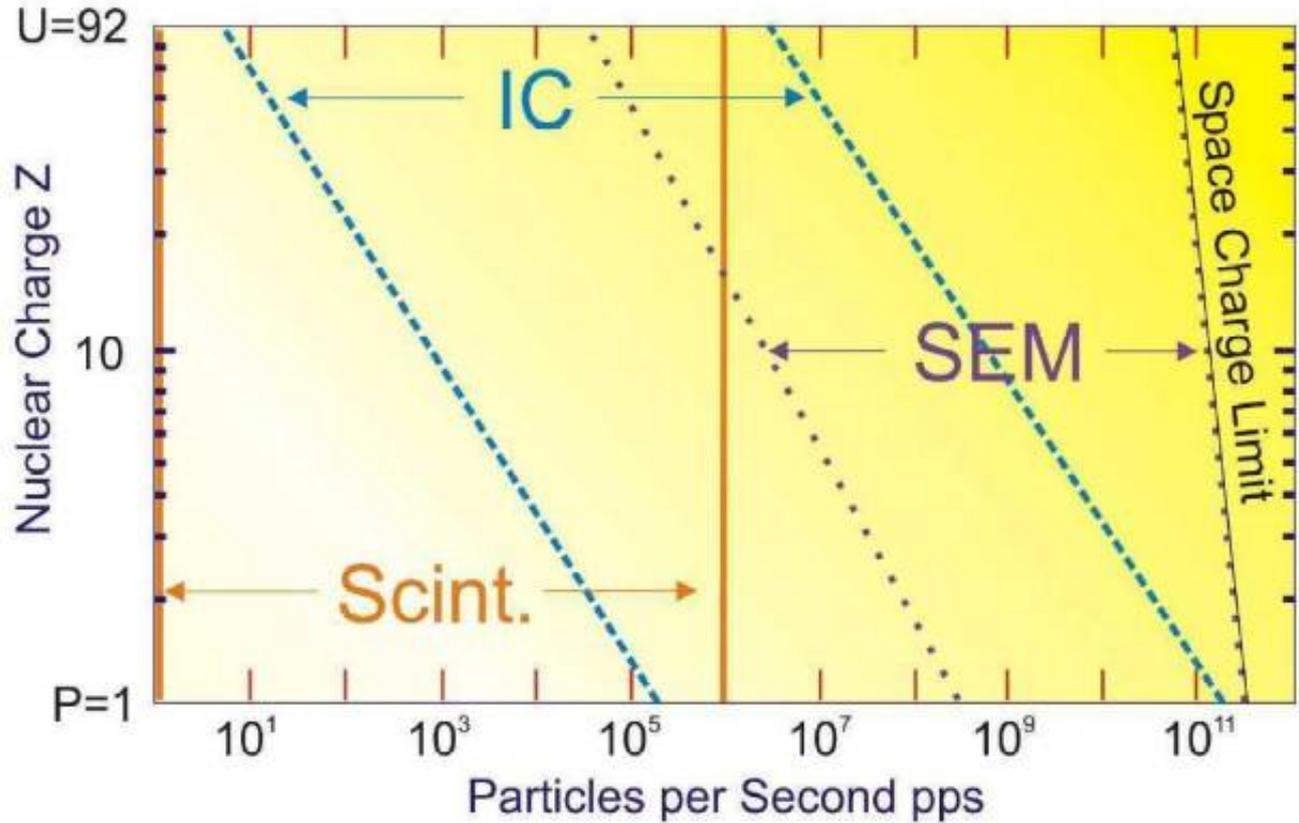


Outline

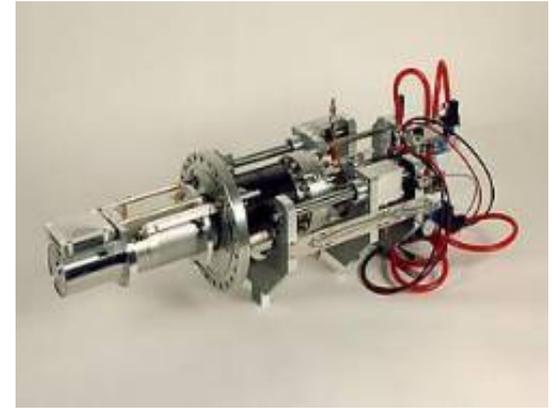
- PDC for beam intensity and spill structure measurements
- ZnO scintillation ceramic overview
- Investigation of ZnO scintillation ceramics at GSI



Particle Detector Combination (PDC)



- Measure beam intensity
- Measure spill structure

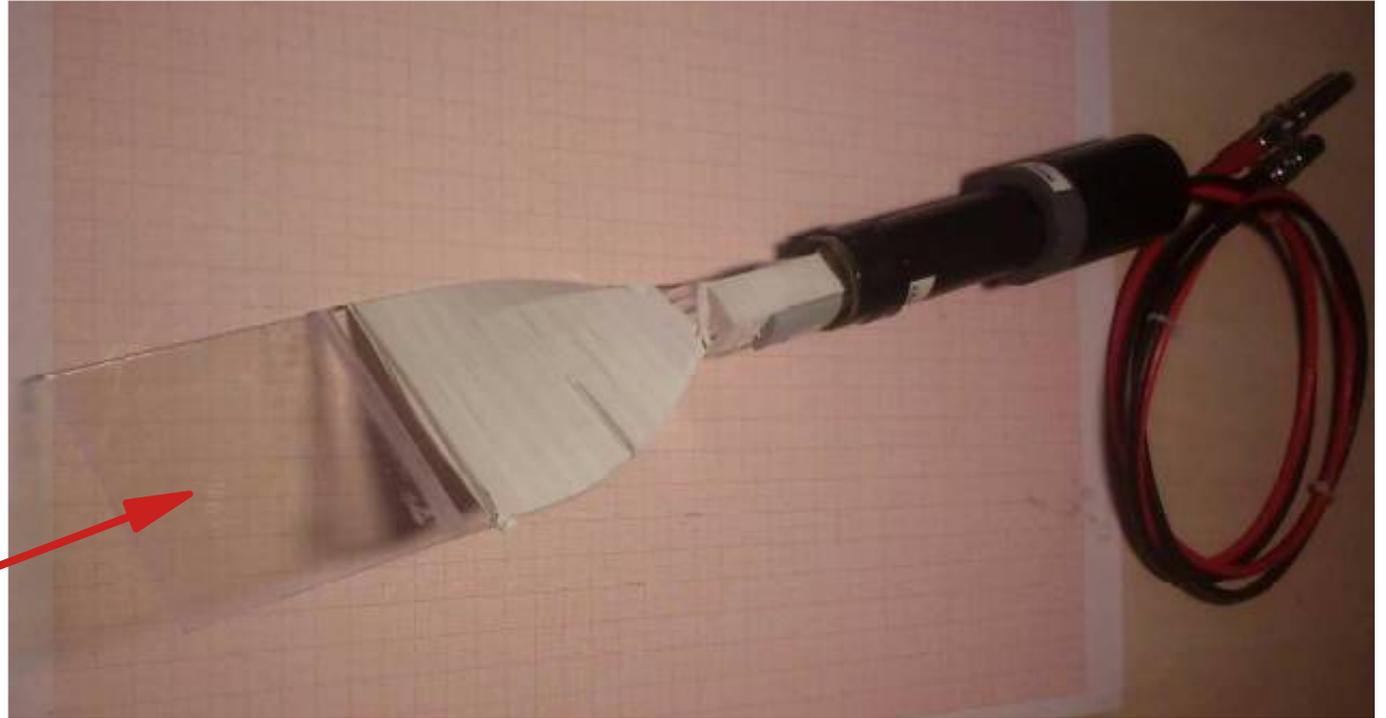


BC400 scintillation detector

$$\tau_{\text{DEC}} = 2.4 \text{ ns}$$

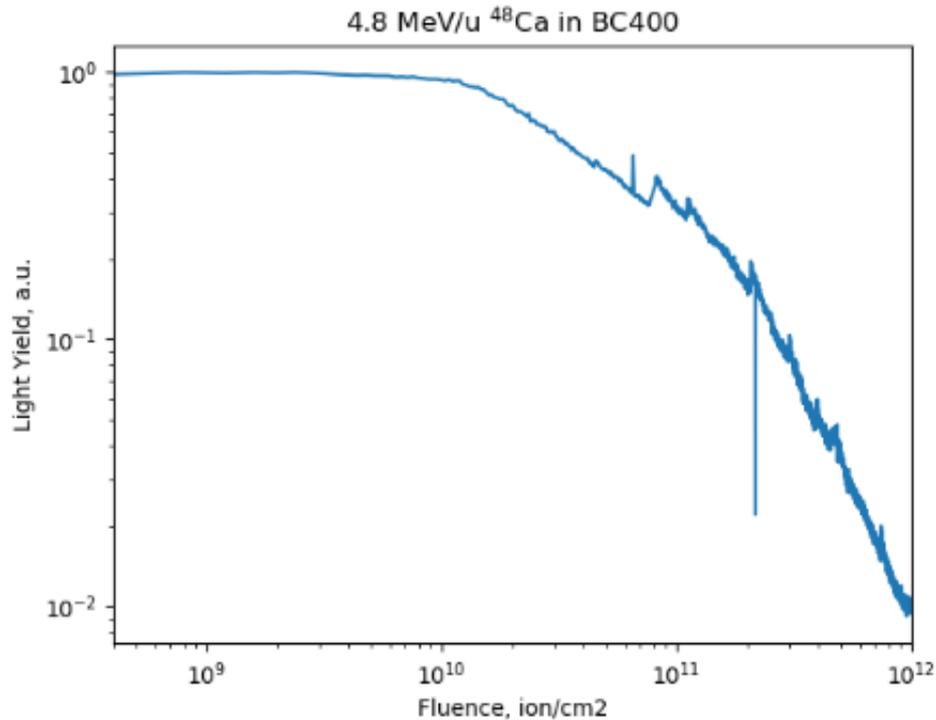
$$l_{\text{ATN}} = 250 \text{ cm}$$

$$\lambda_{\text{MAX}} = 423 \text{ nm}$$



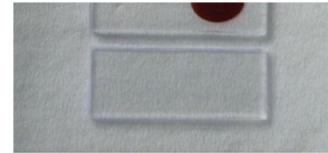
BC400 plastic scintillator

BC400 radiation damage

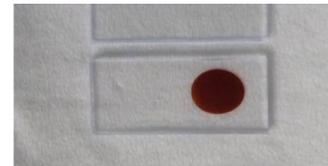


$^{48}\text{Ca}@4.8\text{ MeV/u}$, $dE/dx = 23\text{ MeV}/(\text{mg cm}^2)$

$^{238}\text{U}@300\text{MeV/u}$, $dE/dx = 29.7\text{ MeV}/(\text{mg cm}^2)$



Before irradiation
(pristine BC400)



After irradiation
($^{48}\text{Ca}@4.8\text{ MeV/u}$,
 $1\text{E}+12\text{ ion/cm}^2$)

Scintillation detector requirements for FAIR

- Rise and fall time better than 10 ns
- Radiation hardness better than BC400
- PMT readout
- Amplitude variation $dA/A < 20\%$
- Active area $100 \times 100 \text{ mm}^2$



ZnO scintillator history

E. Mollwo, Das ultraviolette Absorptionsspektrum der Sulfide und Oxyde von Zink und Kadmium. Reichsber. Physik 1, 1 (1944)

~ 76 years of ZnO research

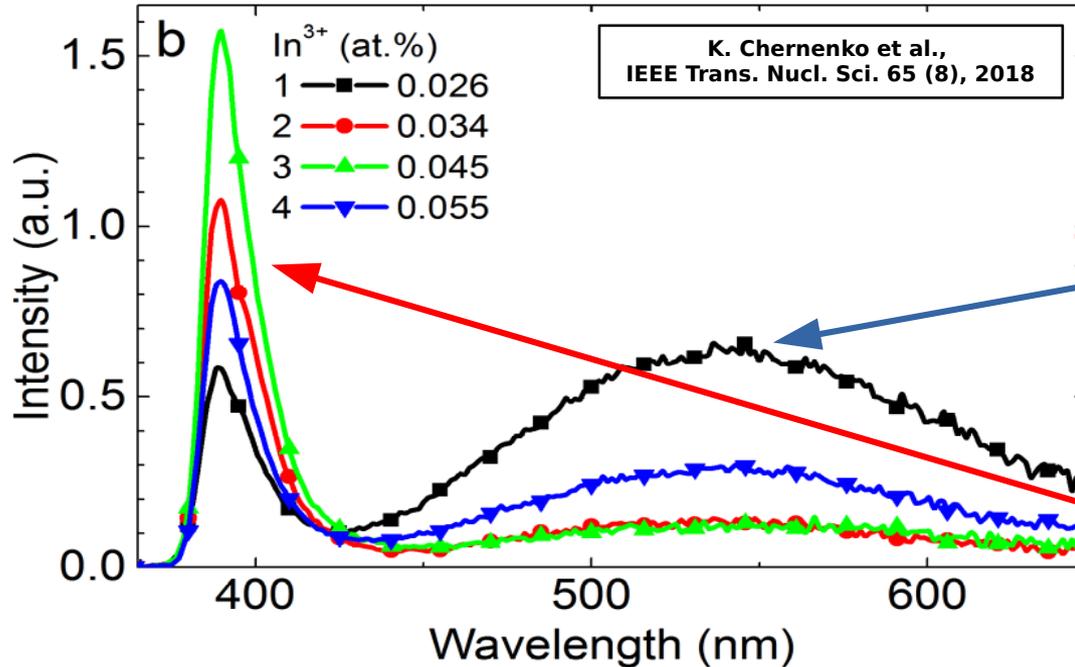
- Alpha-particles detector
- Light Emitting Diodes and Laser Diodes
- Spintronix and quantum computing application
- Gas sensors
- Field Emitters
- Solar Cells, etc.

Direct band gap = 3.37 eV

Exciton binding energy = 60 meV



ZnO scintillating ceramic



Deep Level (DL) emission:

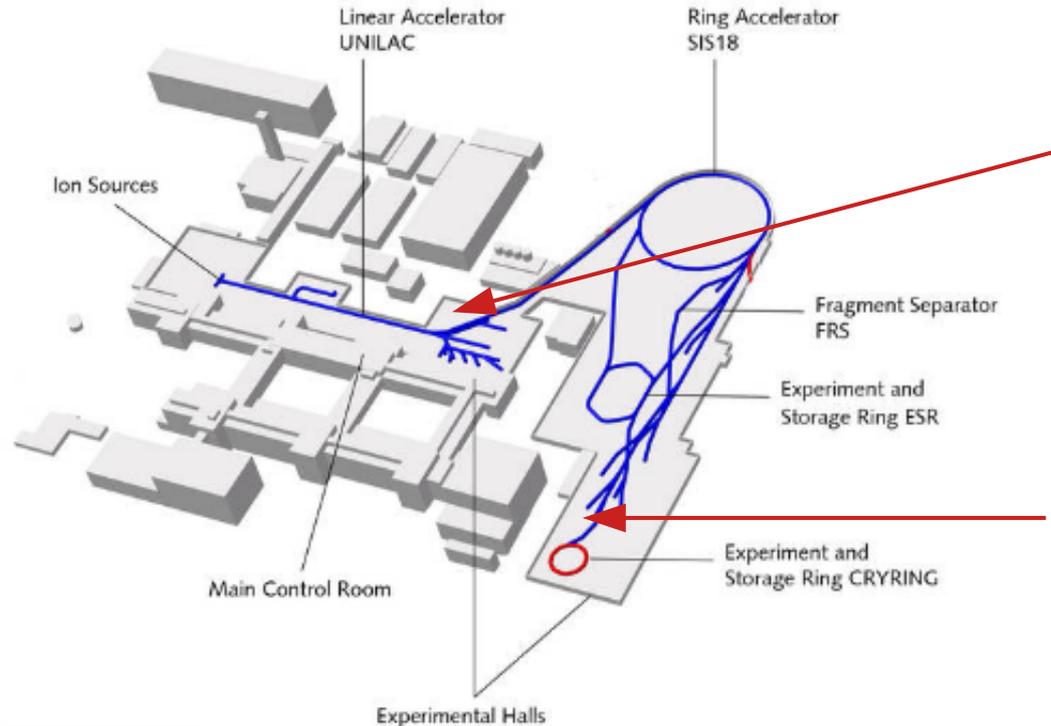
- $\tau_{\text{DEC}} \approx 1 \mu\text{s}$
- $\lambda_{\text{MAX}} \approx 500 - 550 \text{ nm}$

Near Band Edge (NBE) emission:

- $\tau_{\text{DEC}} \approx 0.7 \text{ ns}$
- $\lambda_{\text{MAX}} \approx 390 \text{ nm}$

ZnO scintillators investigation at GSI

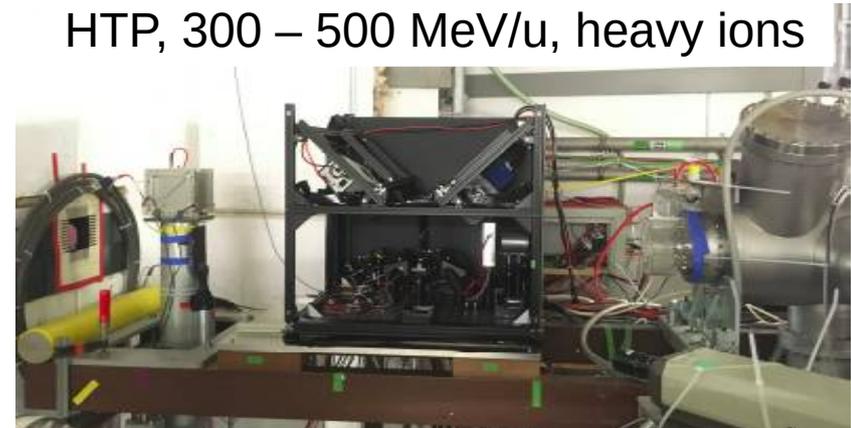
M3, 4.8 MeV/u, heavy ions



100 meters

March 3, 2020

NUSTAR week, GSI



HTP, 300 – 500 MeV/u, heavy ions

ZnO scintillators investigation at GSI



- Beam goes in air through \varnothing 5mm collimator and Ionization Chamber
- Beam hits the target which induces scintillation
- Scintillation is detected with spectrometers on top of the setup
- Scintillation is detected with PMTs at the bottom of the setup

ZnO scintillators investigation at GSI

Spectrometer



- Horiba CP 140-202
- PCO.SensiCam
- PCO.1600

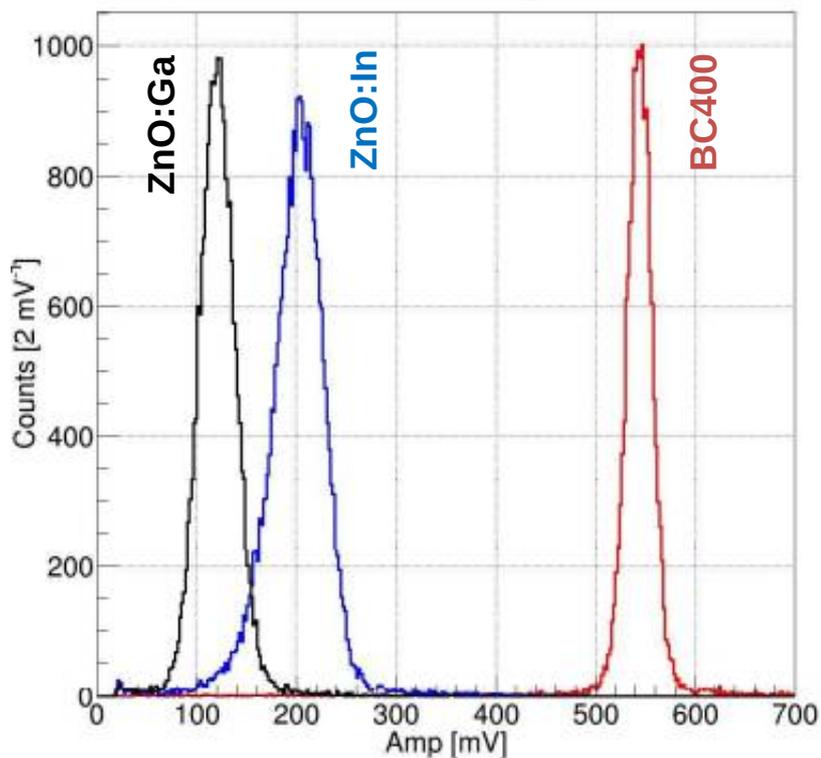
Wave length: 200 – 800 nm

PMT

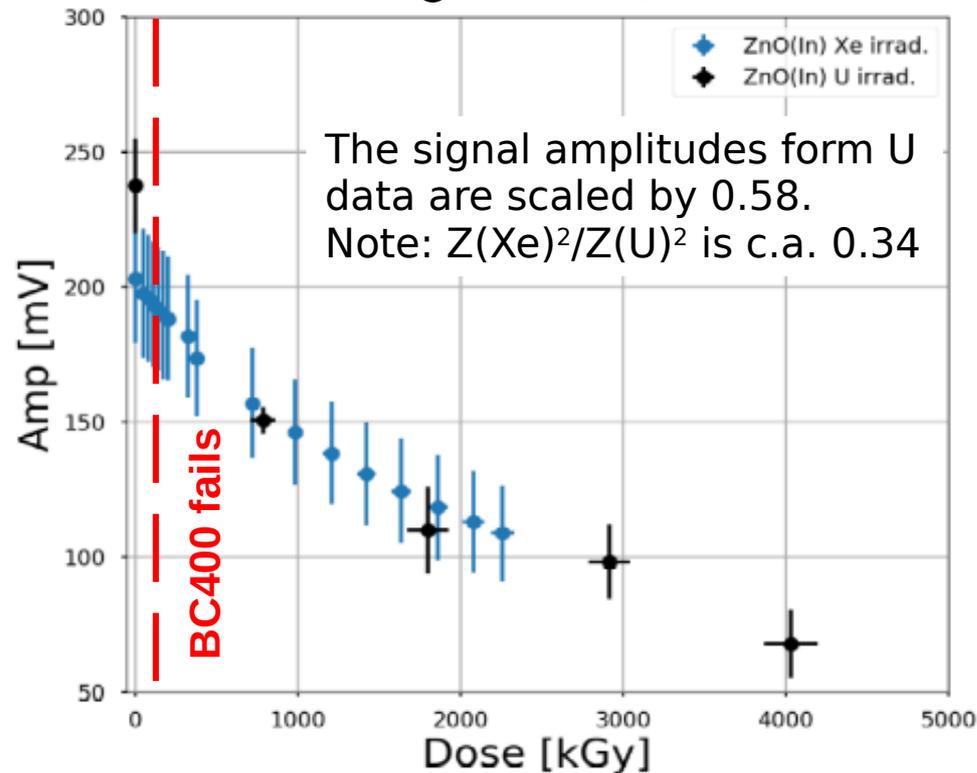
- Hamamatsu **H7415**:
 - Active area: 25 mm
 - Peak wave length: 420 nm
 - Gain: $\sim 5 \times 10^5$
 - Rise time: 1.7 ns
- Hamamatsu **H13661**:
 - Active area: 25 mm
 - Peak wave length: 420 nm
 - Gain: $\sim 3 \times 10^4$
 - Rise time: 230 ps
 - FWHM: 430 ps

Scintillation detected by PMT

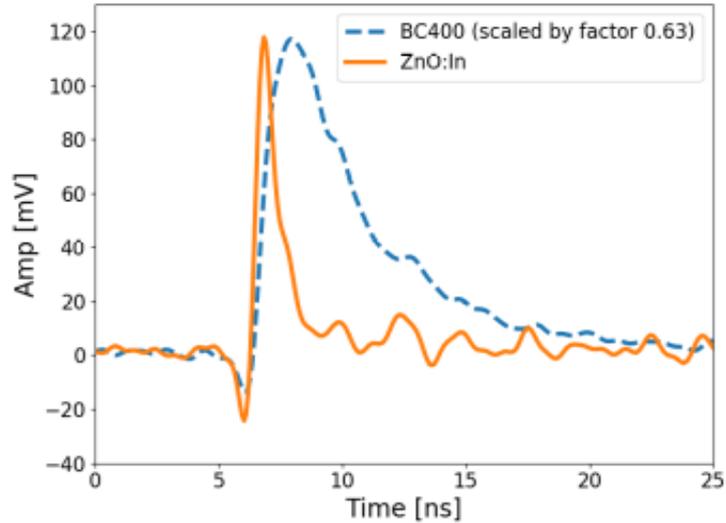
Response to Xe ions @ 300 MeV/u



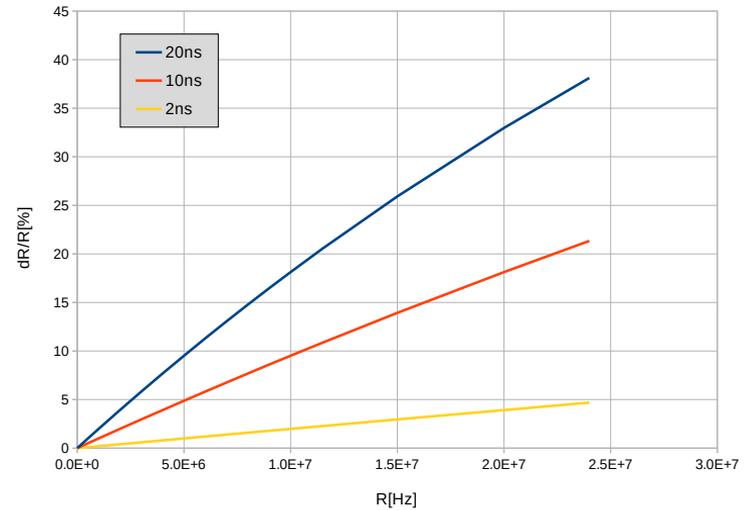
Xe and U @ 300 MeV/u in ZnO:In



Fast PMT signal



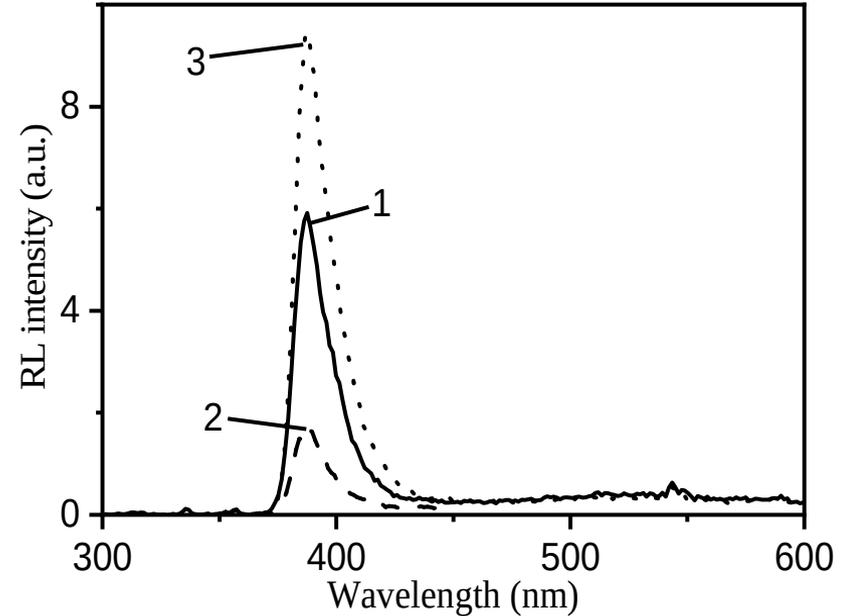
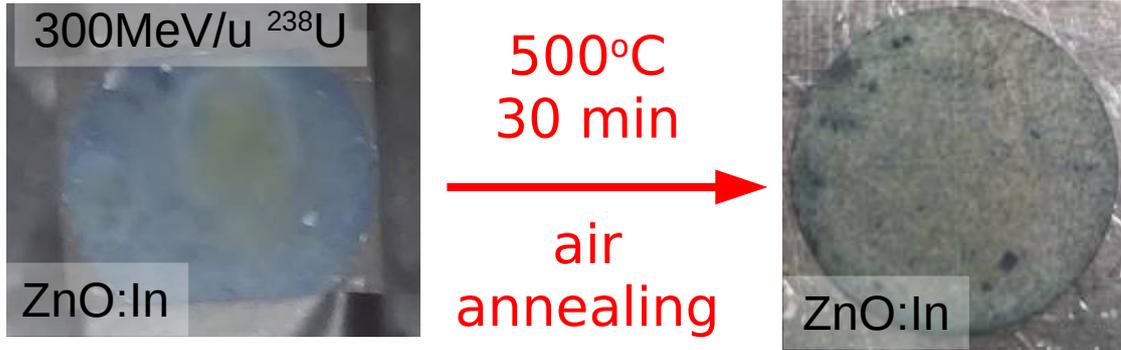
H13661-PMT(PMT rise time ~ 230 ps, PMT FWHM 430 ps) signal,
 ^{238}U @300 MeV/u interacting with BC400 and ZnO:In



Pileup for different signal widths.
(beam: Poisson distribution)

ZnO:In signal $1/(\text{rise time}) \sim 3.9$ ps/mV
FWHM ~ 800 ps

Recovery by annealing



Radioluminescence spectra under continuous excitation by an x-rays: 1 – initial sample; 2 – after irradiation with ^{238}U ; 3 – after annealing, Figure from P.A. Rodnyi *et al.*, IEEE EExPolytech, Saint Petersburg, Russia, October 17-18, 2019

Future plans and prospective

- Radiation damage recovery after annealing
- Light yield and Transparency of ceramic vs. dose
- Light yield vs. energy deposition
- Luminescence spectra changes vs. dose
- Scint. Detector prototype for fast counting applications (by March 2022)





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Thank you for attention



March 3, 2020

NUSTAR week, GSI

