NATIONAL
RESEARCH CENTER
"KURCHATOV INSTITUTE"

Institute of Chemical Reagents
and High Purity Chemical
Substances, "IREA"

Polycrystalline Scintillators for Large Area Detectors in HEP Experiments

G. Dosovitskiy[1], A. Fedorov[2], P. Karpyuk[1], D. Kuznetsova[1], A.Mikhlin[1], D.Kozlov[2], A. Dosovitskiy[3], M. Korjik[2]

[1] Institute of Chemical Reagents and High Purity Chemical Substances IREA NRC "Kurchatov Institute", Moscow, Russia
[2] Research Institute for Nuclear Problems, Minsk, Belarus
[3] NeoChem JSC, Moscow, Russia

INSTR 2017
Novosibirsk
01 March

Work is supported by Russian Ministry of Science and Education,
Subsidy agreement № 14.625.21.0033 dated 27.10.2015,
project identifier RFMEFI62515X0033

Motivation:

Use of plastic scintillators in electromagnetic and hadronic calorimeters at experiments at hadron colliders with high luminosity becomes problematic.

Requirements for scintillation materials for large area detectors:

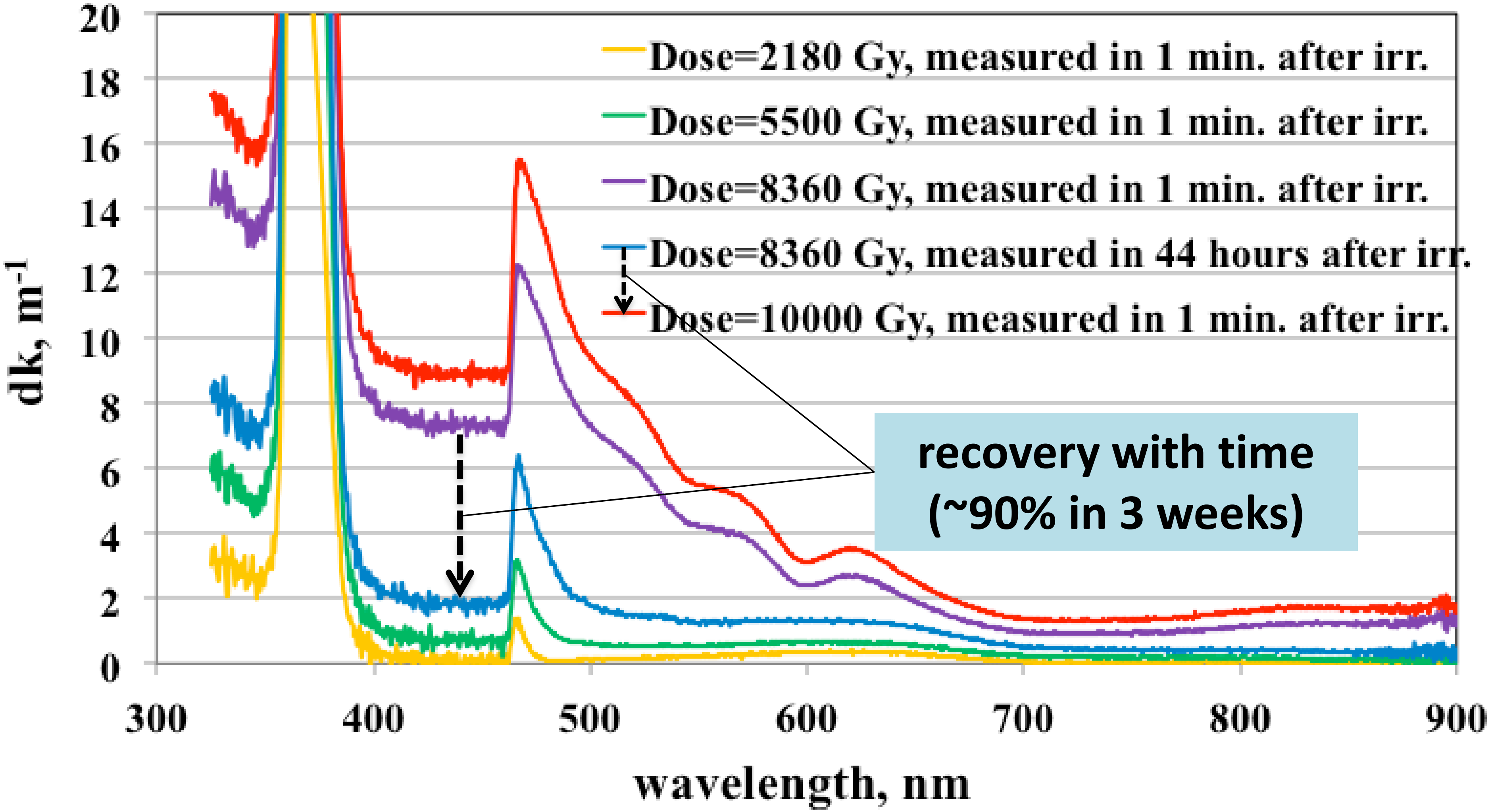
– Radiation hard
– Sufficient signal
– Not too expensive

Candidates:

Composite materials
Ceramic materials

Induced absorption in the well known EJ260 green plastic scintillator under ^{60}Co irradiation (ϒ 1.17 MeV + ϒ 1.33 MeV)

Rather high, but recovers with time

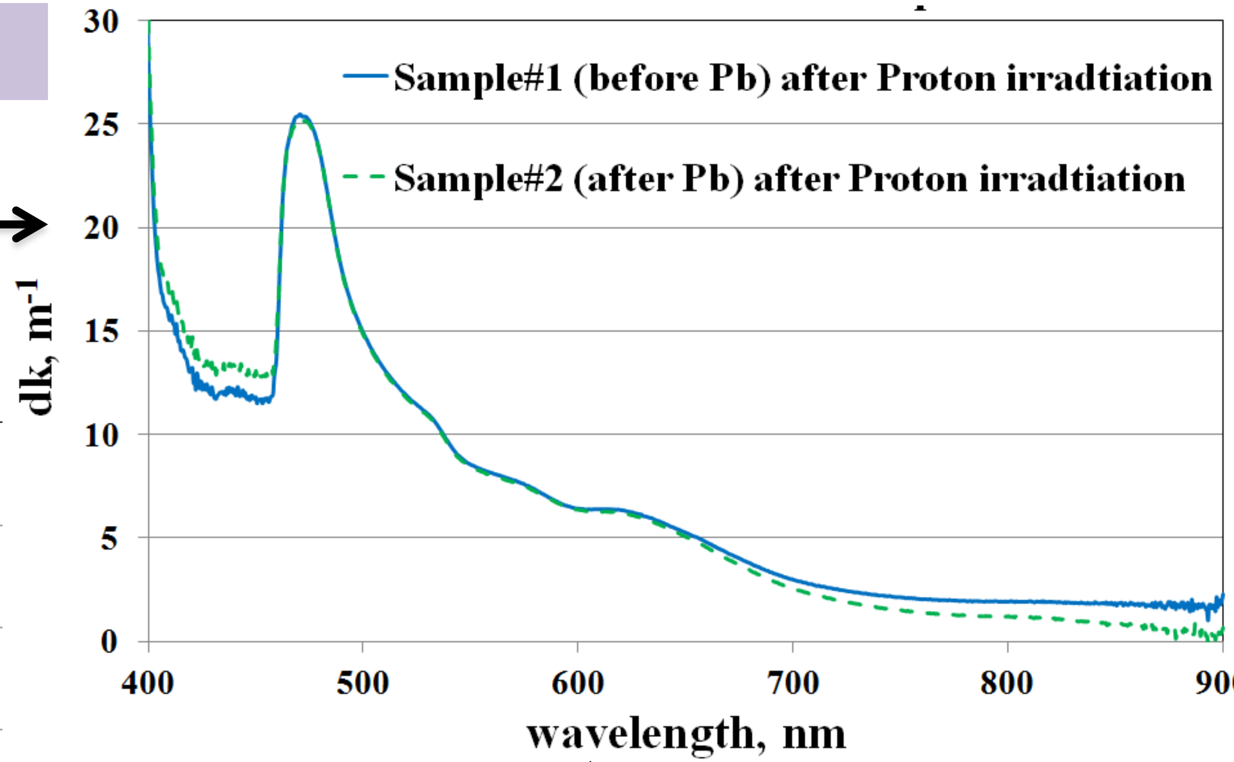


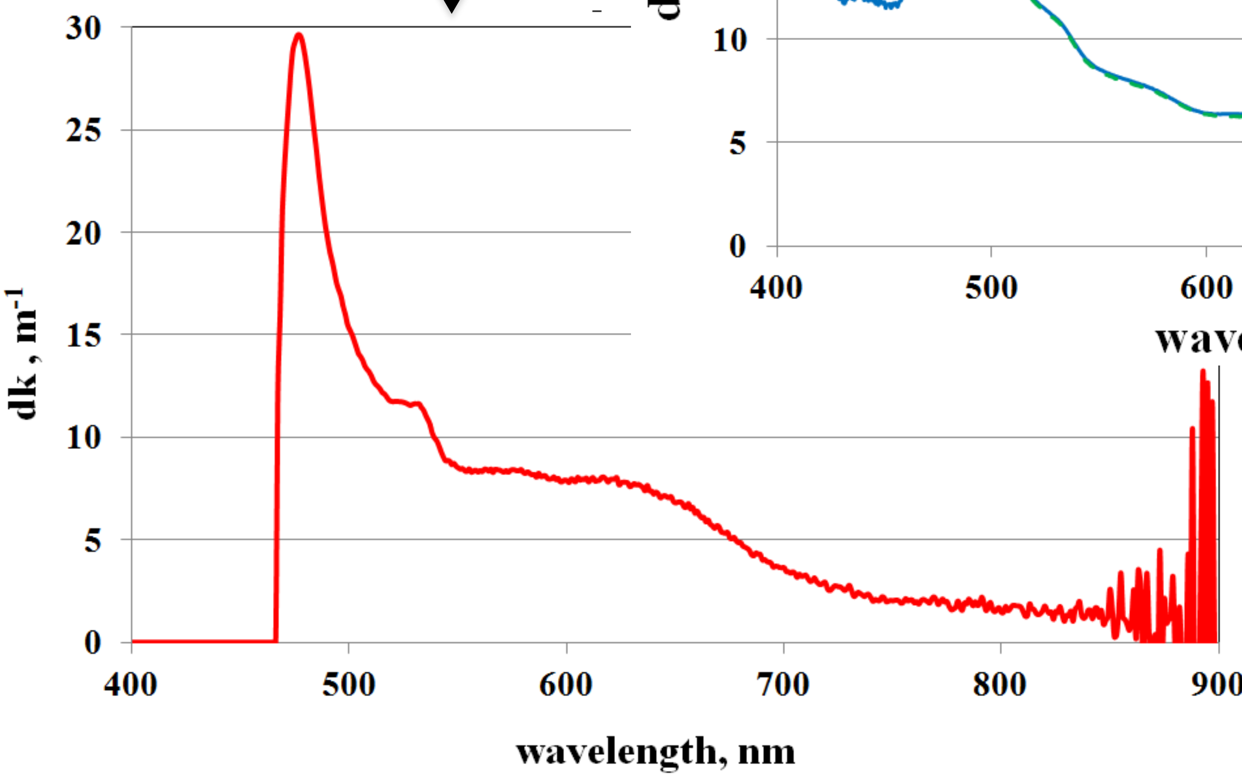
Induced absorption, 1 month after irradiation with protons

Fluence ~5×10^{13} p/cm^2

150 MeV →

24 GeV ↓

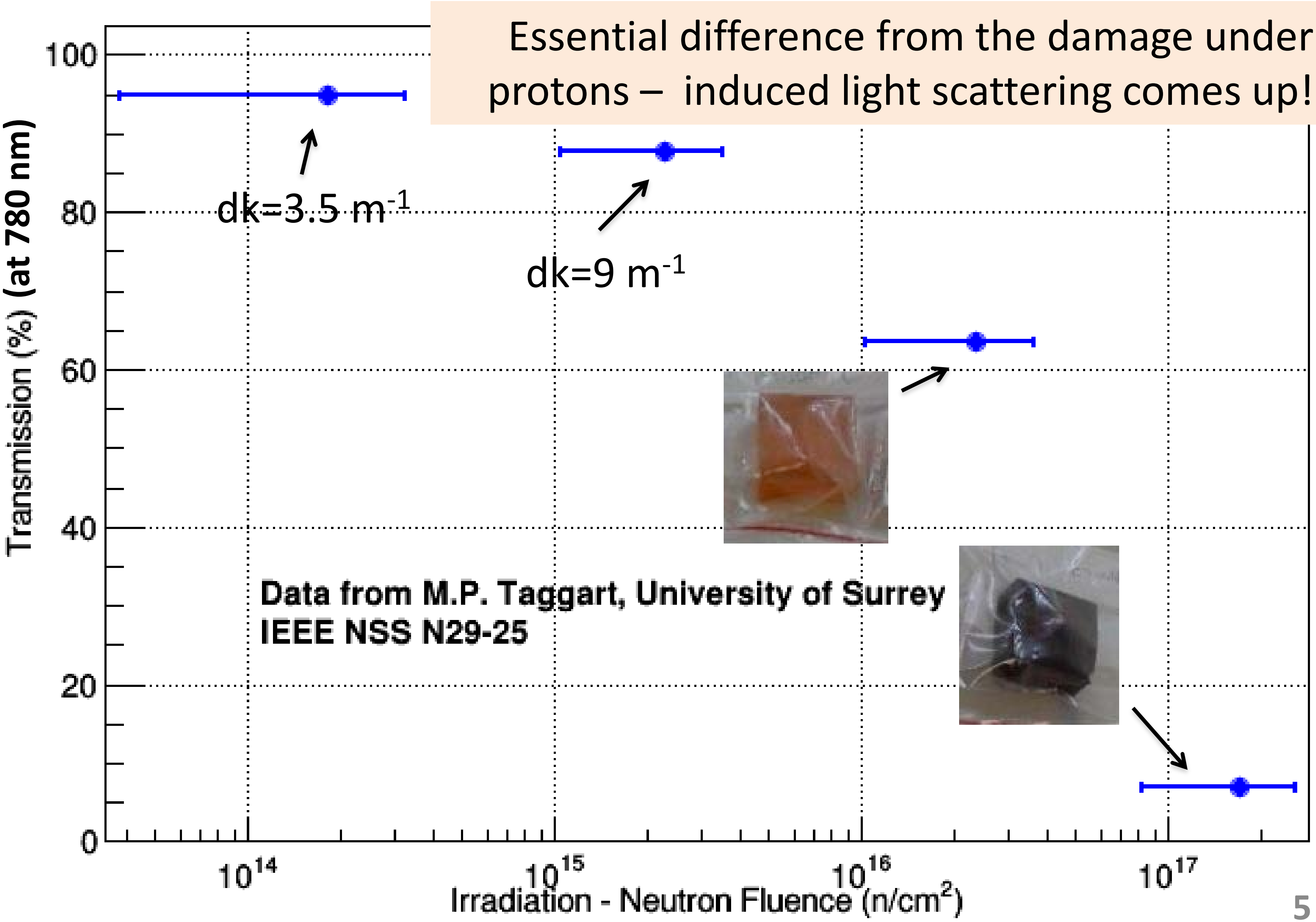




After gamma-irradiation 90% of induced absorption is recovered in 3 weeks.
After irradiation with protons – no spontaneous recovery is observed.

Shapes of **dk** curves in the range 480-900 nm are close after gamma and proton irradiation.

EJ-200 plastic scintillator irradiation with fast neutrons



Alternative solution –

Single crystalline middle heavy scintillators on a base of Ce doped materials

Advantages :

Radiation hard and bright

More details:

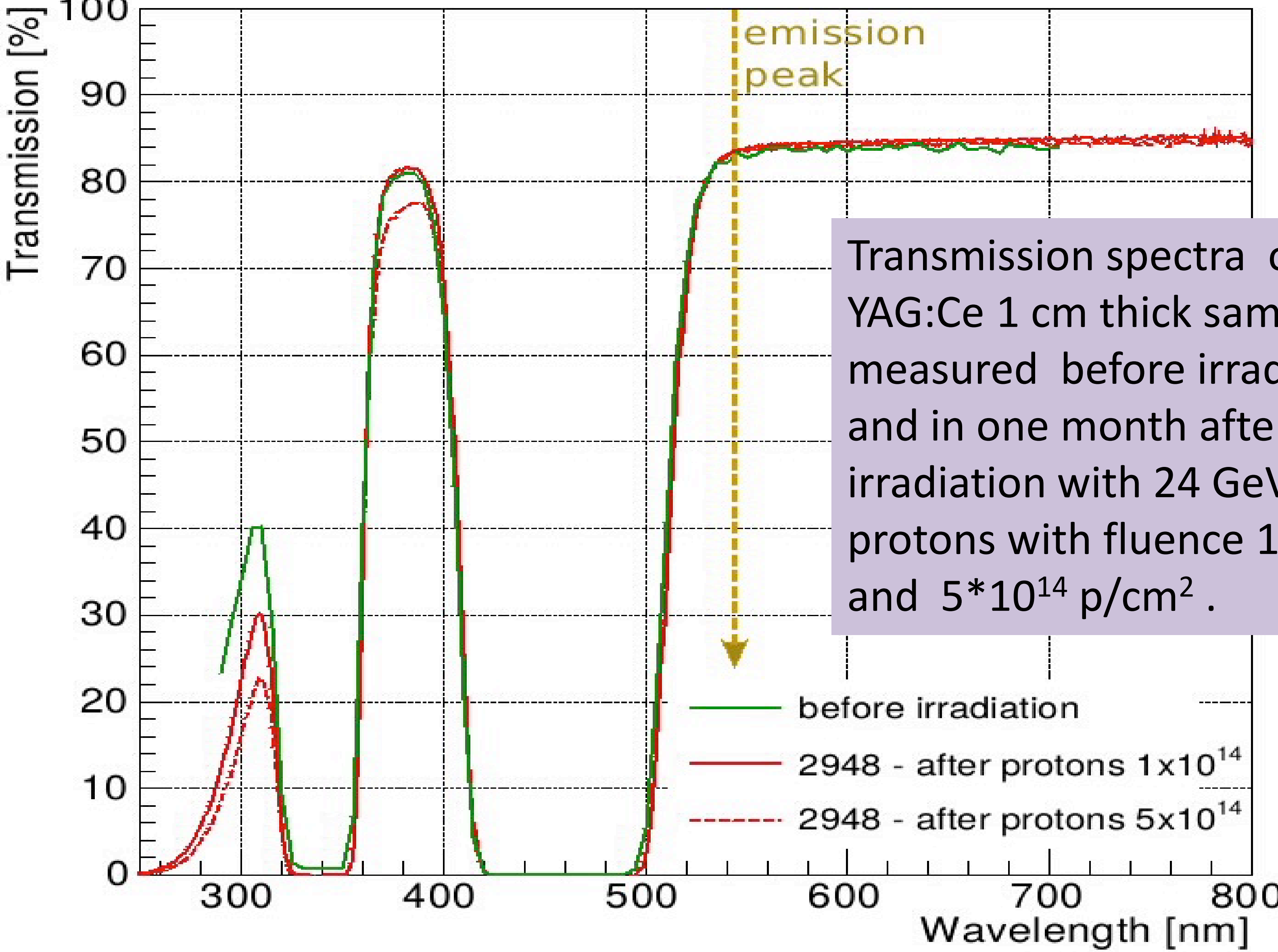
- Were in previous report by Dr. Mikhail Korjik
- See P.Lecoq, M.Korzhik, A.Gektin, Inorganic Scintillators for Detecting Systems, 2017, Springer, P.408

Concerns:

Not optimal price performance for a large area detectors, 10 times more expensive than plastic, but comparable with 200 µm thick silicon wafers

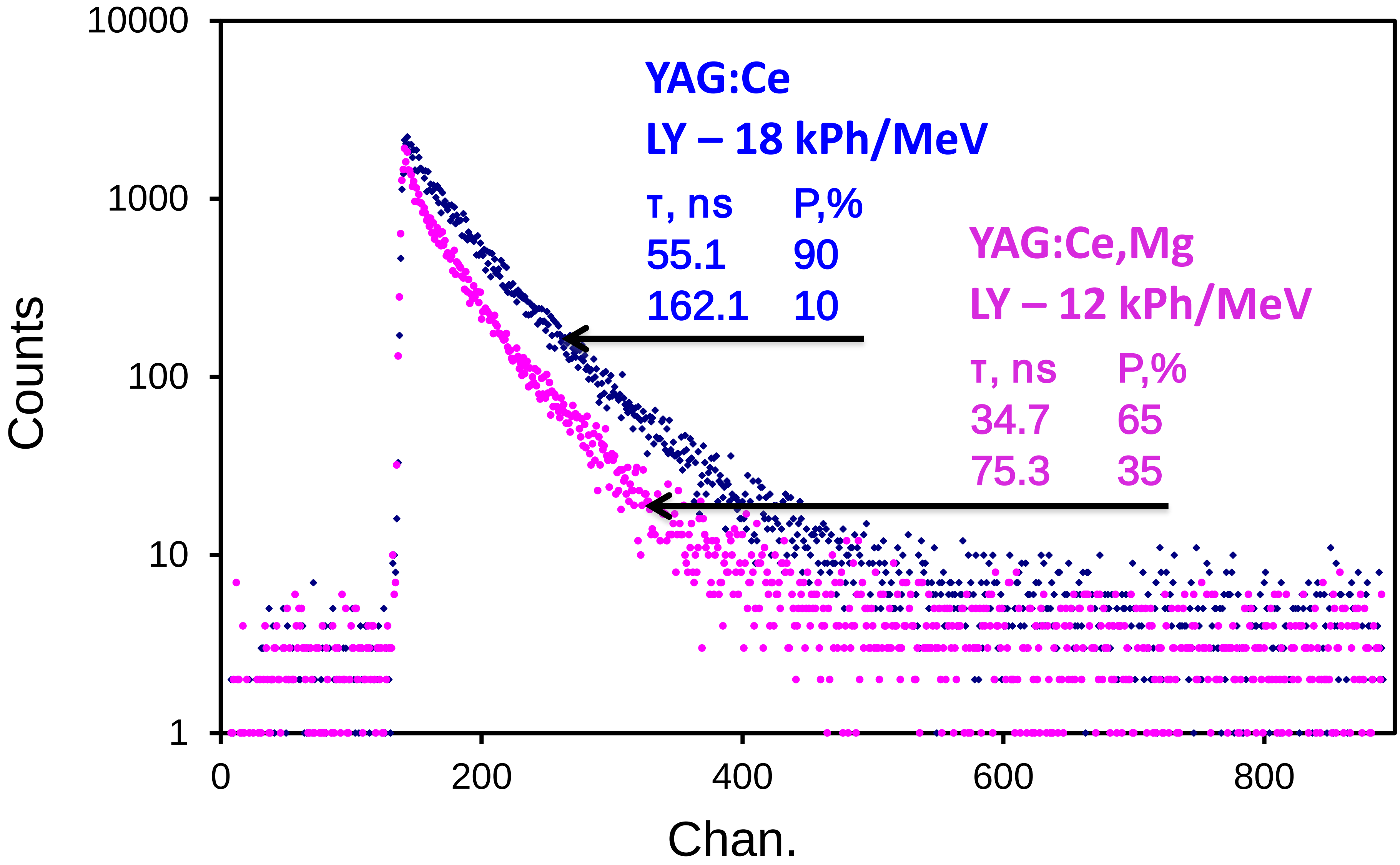
YAG:Ce was discovered to be the most radiation hard material of this kind

No visible change of transmission



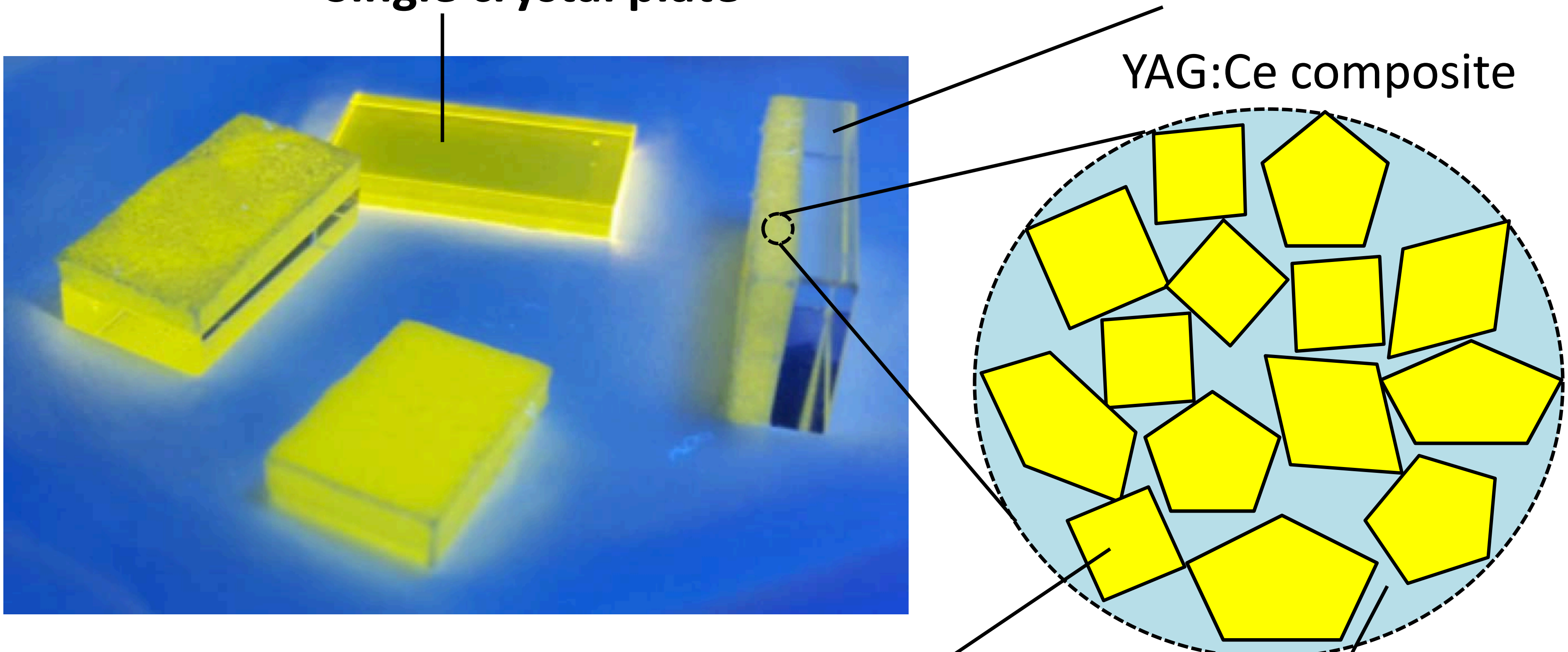
Transmission spectra of YAG:Ce 1 cm thick sample measured before irradiation and in one month after irradiation with 24 GeV protons with fluence $1*10^{14}$ and $5*10^{14}$ p/cm^2 .

Kinetics of YAG:Ce could be adjusted keeping sufficient LY

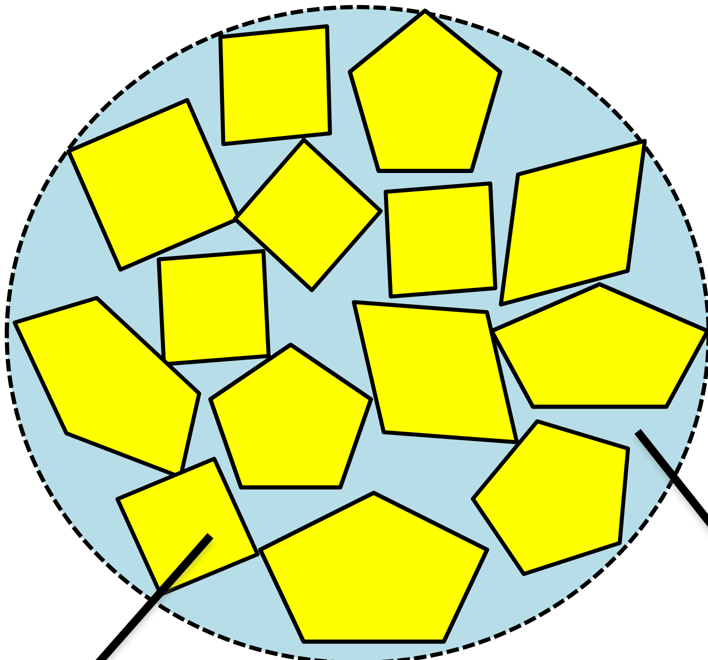


Composite of glued grains of YAG:Ce

Key points – Proper choice of the dimensions of the grains;
Proper packing and gluing of particles.



Improve composite?

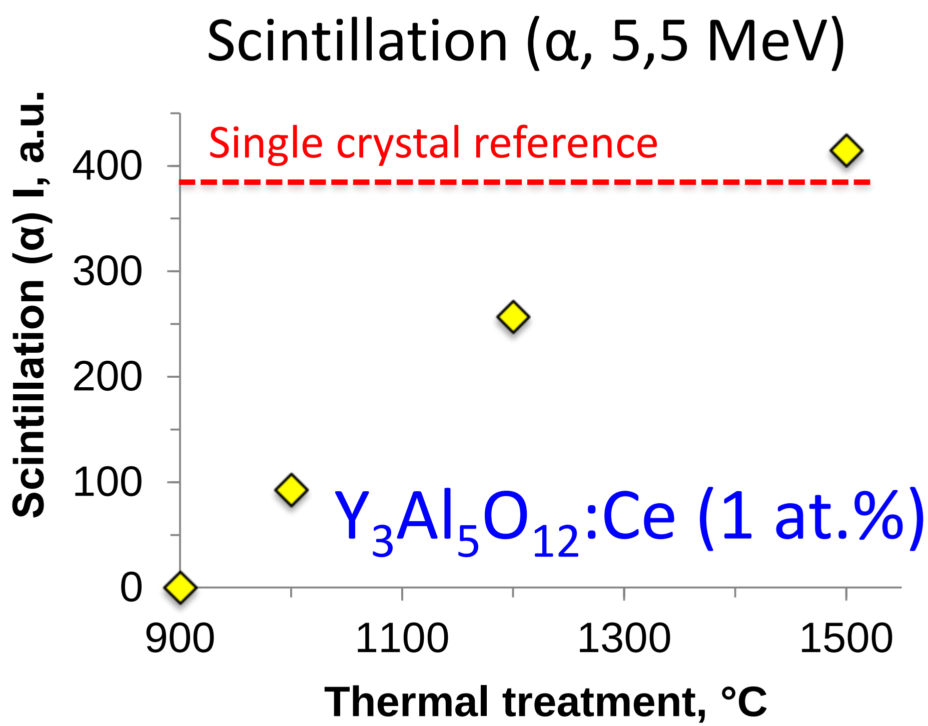


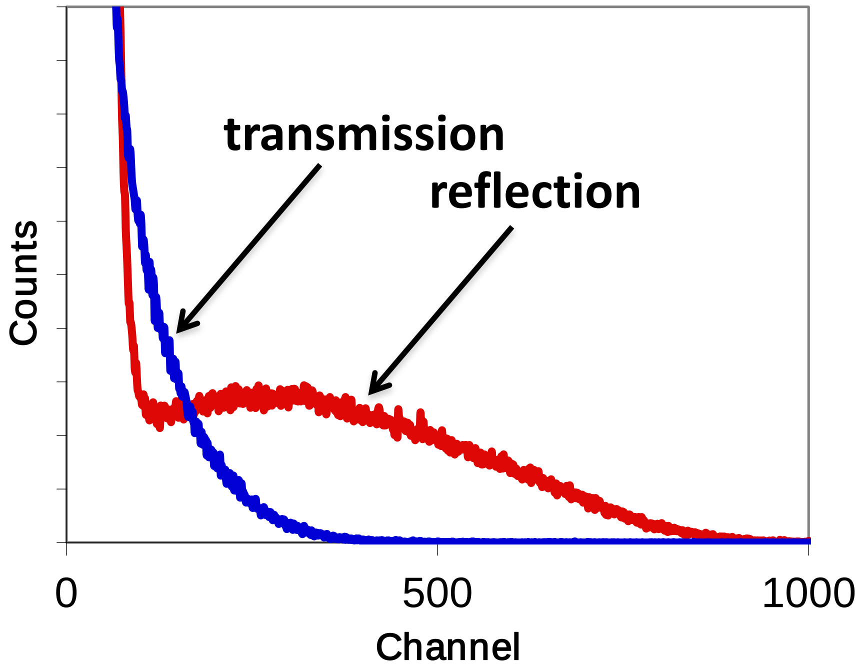
Glue is organic compound, consisting of C and H. So, it is damaged under irradiation

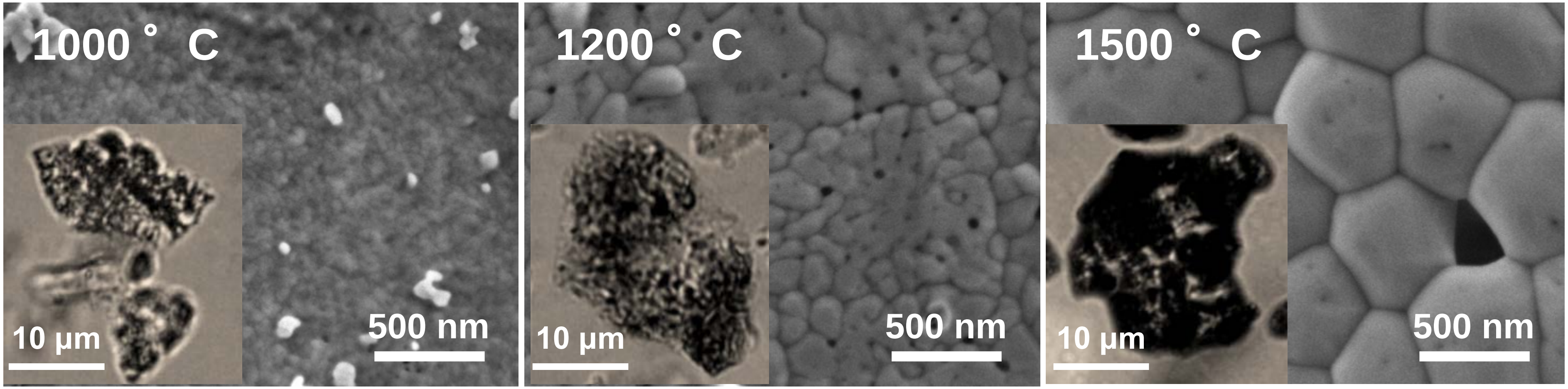
1. Make cheaper
Replace grinded single crystal with synthesized powders

2. Improve radiation hardness
Remove organic binder

Polycrystalline powders scatter light strongly







Ceramics formation – cost depends on choice of techniques

Powder preparation

Precipitation, Commercial powders, Sol-gel, Spray pyrolysis

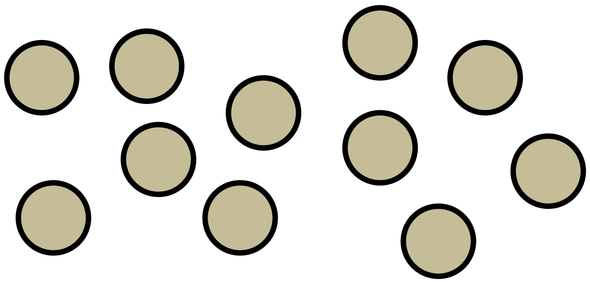
Compacting

Pressing, Isostatic pressing, Slip casting, Tape casting

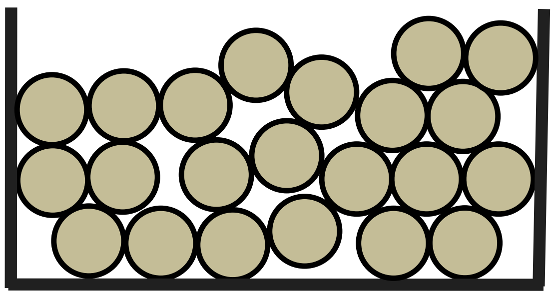
Sintering

Vacuum sintering,
Hot pressing,
Spark plasma sintering

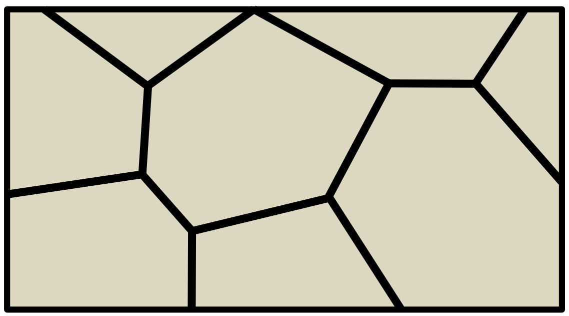
Small size powders (~100 nm)



Dense packing (≥ 50% of $\rho_{teor.}$)

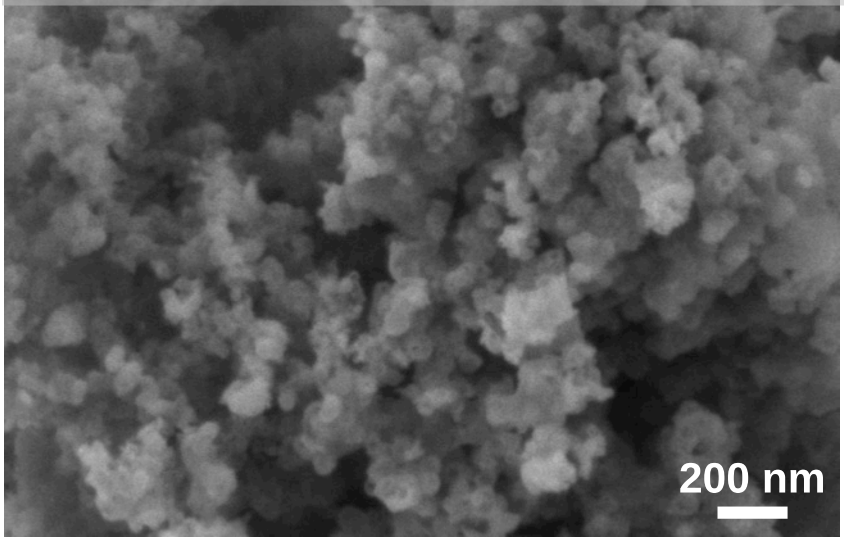


Sintering (up to 99,99% of $\rho_{teor.}$)

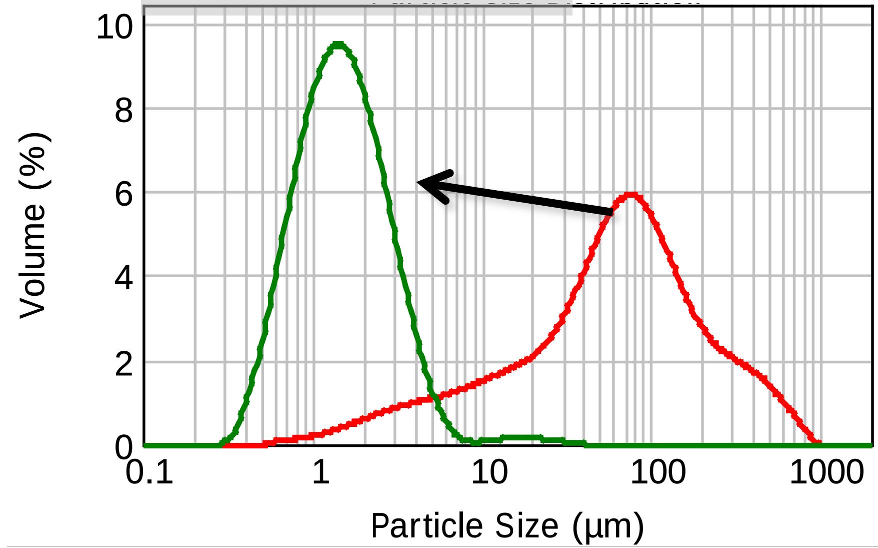


YAG:Ce translucent ceramics

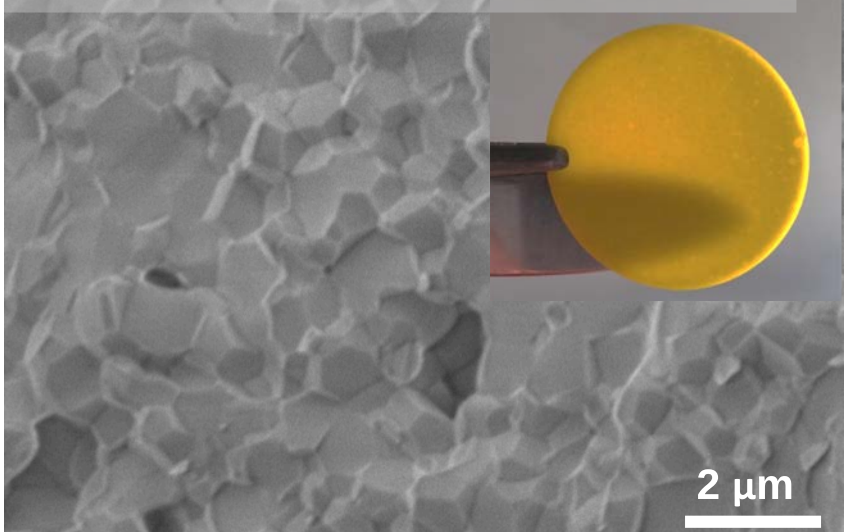
Nanopowder by coprecopitation



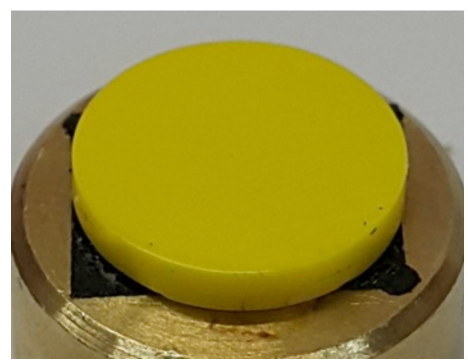
Powder milling

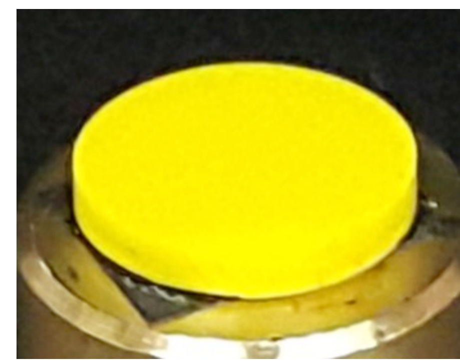


Compacting and air sintering



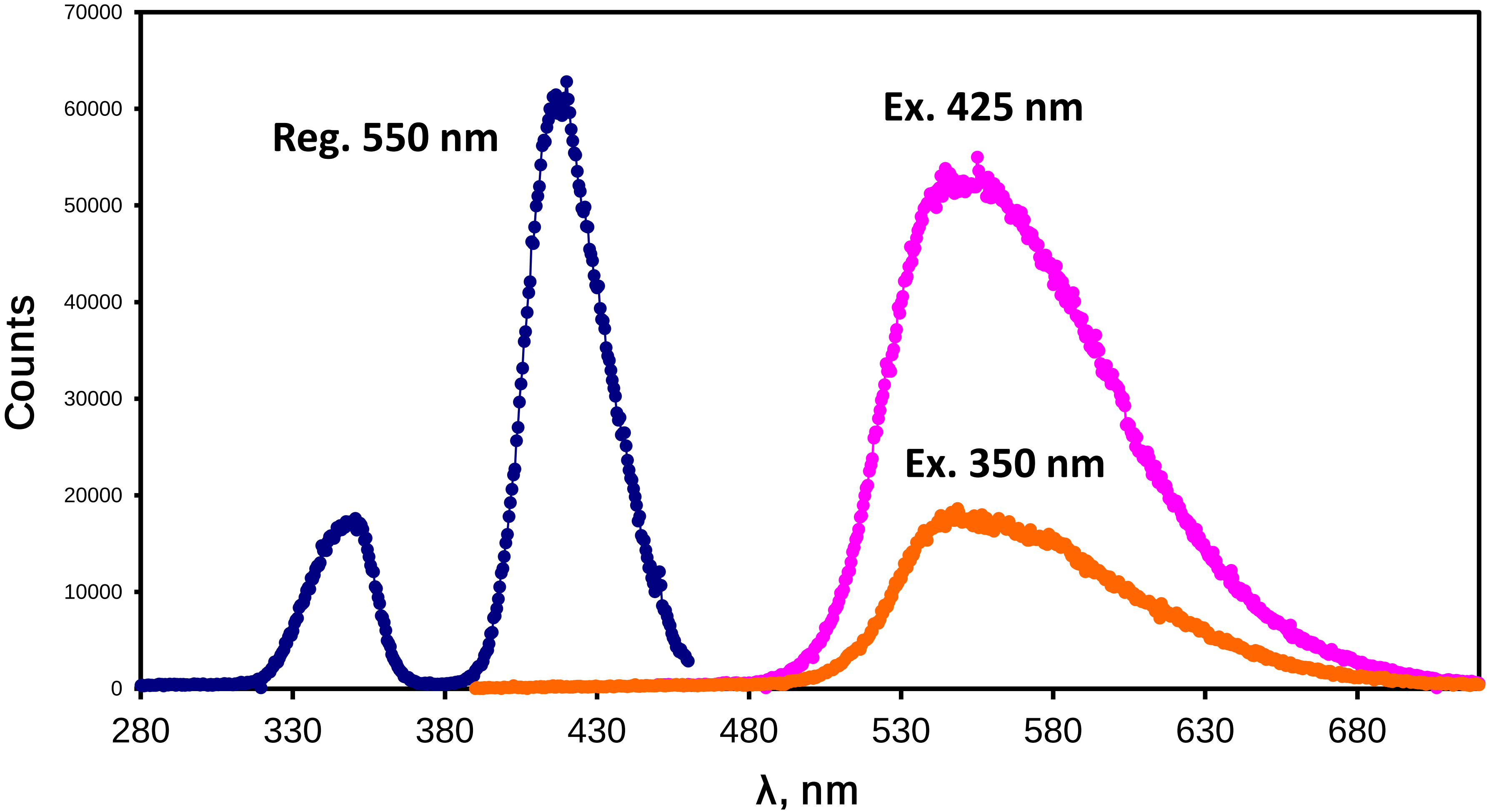
Under UV 365 nm





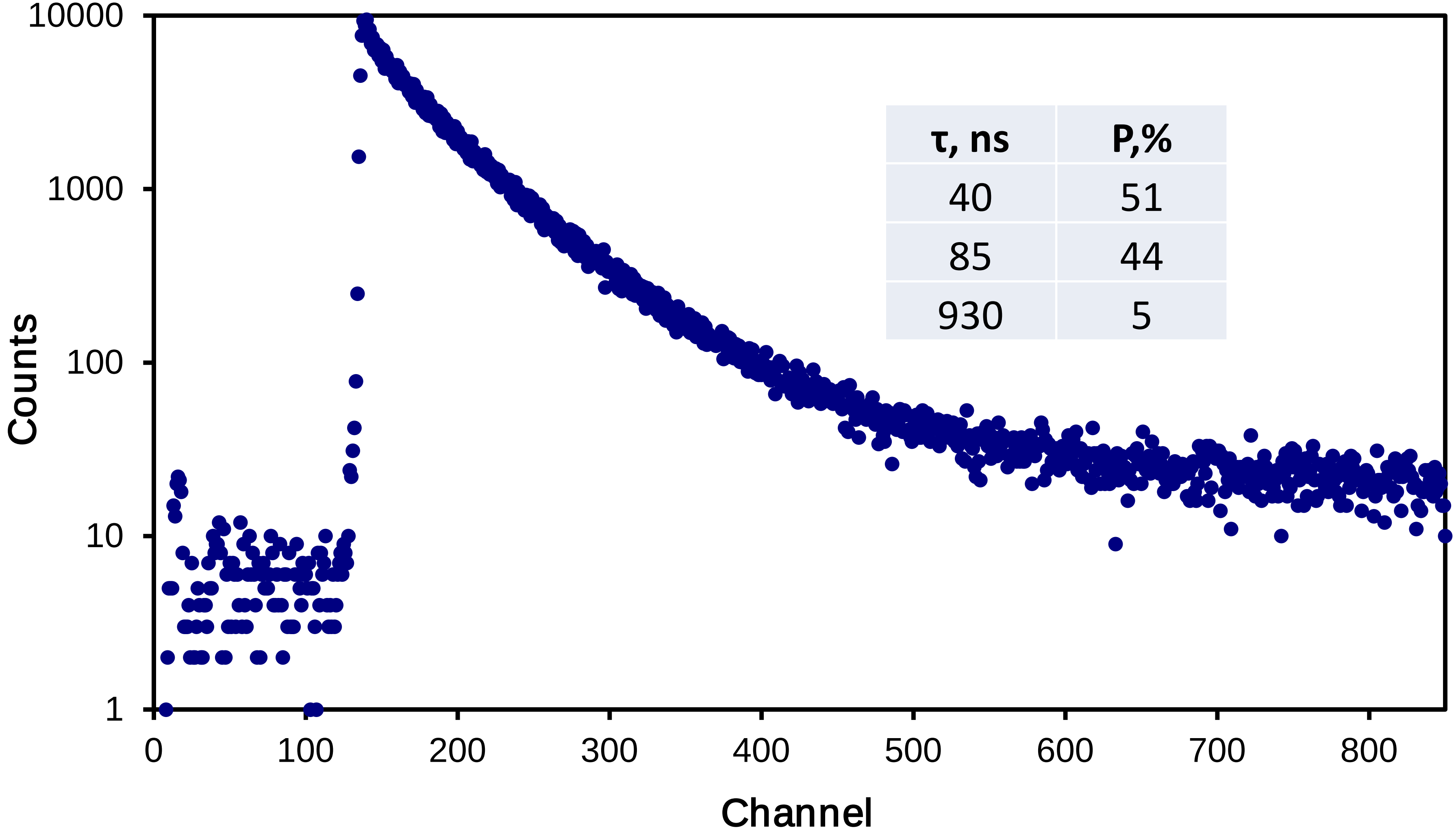
ρ ~ 98%

Excitation and luminescence spectra of YAG:Ce ceramics at room temperature



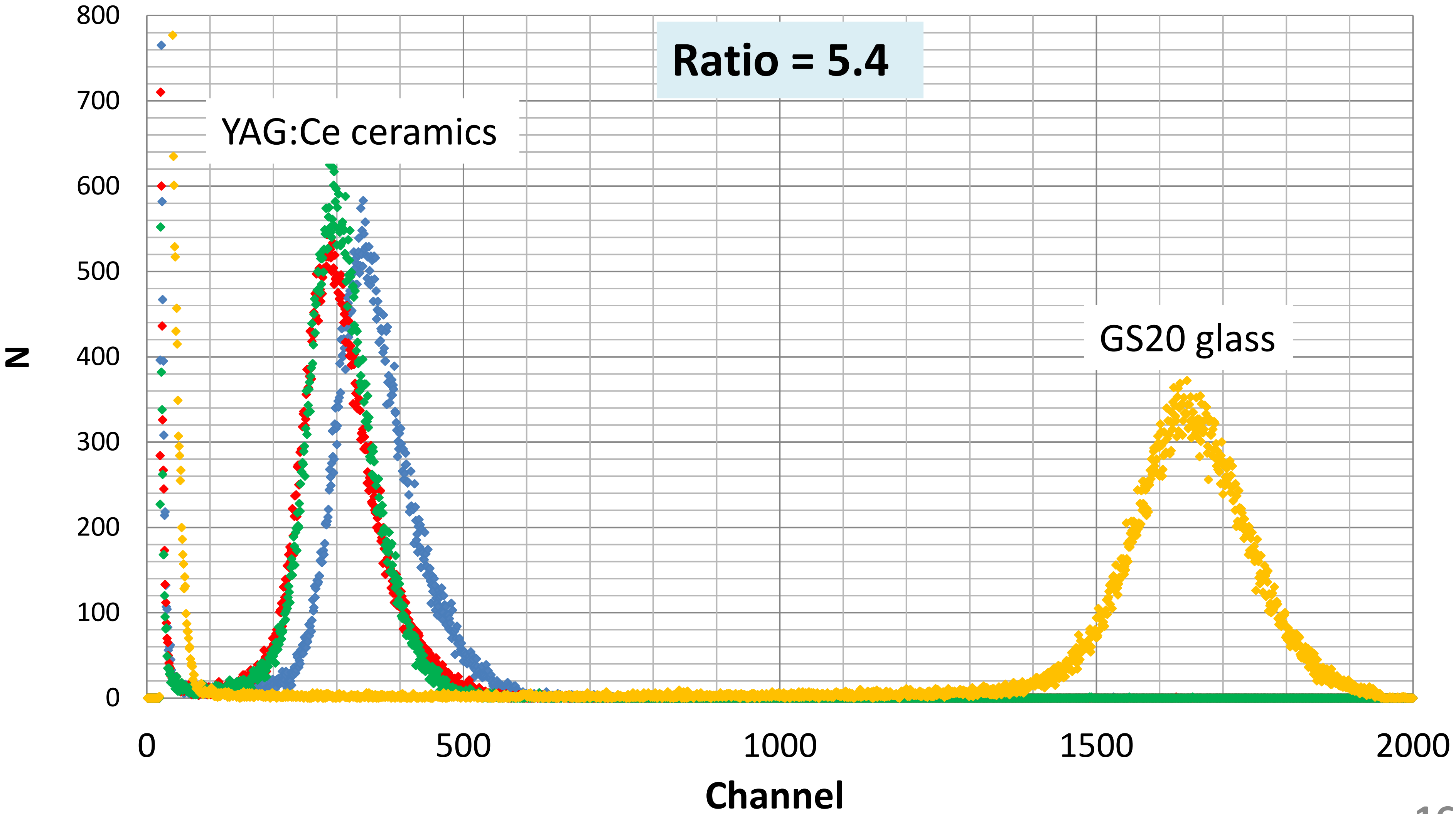
Scintillation kinetics of YAG:Ce ceramics (room T)

Quenching is achieved by Ce concentration

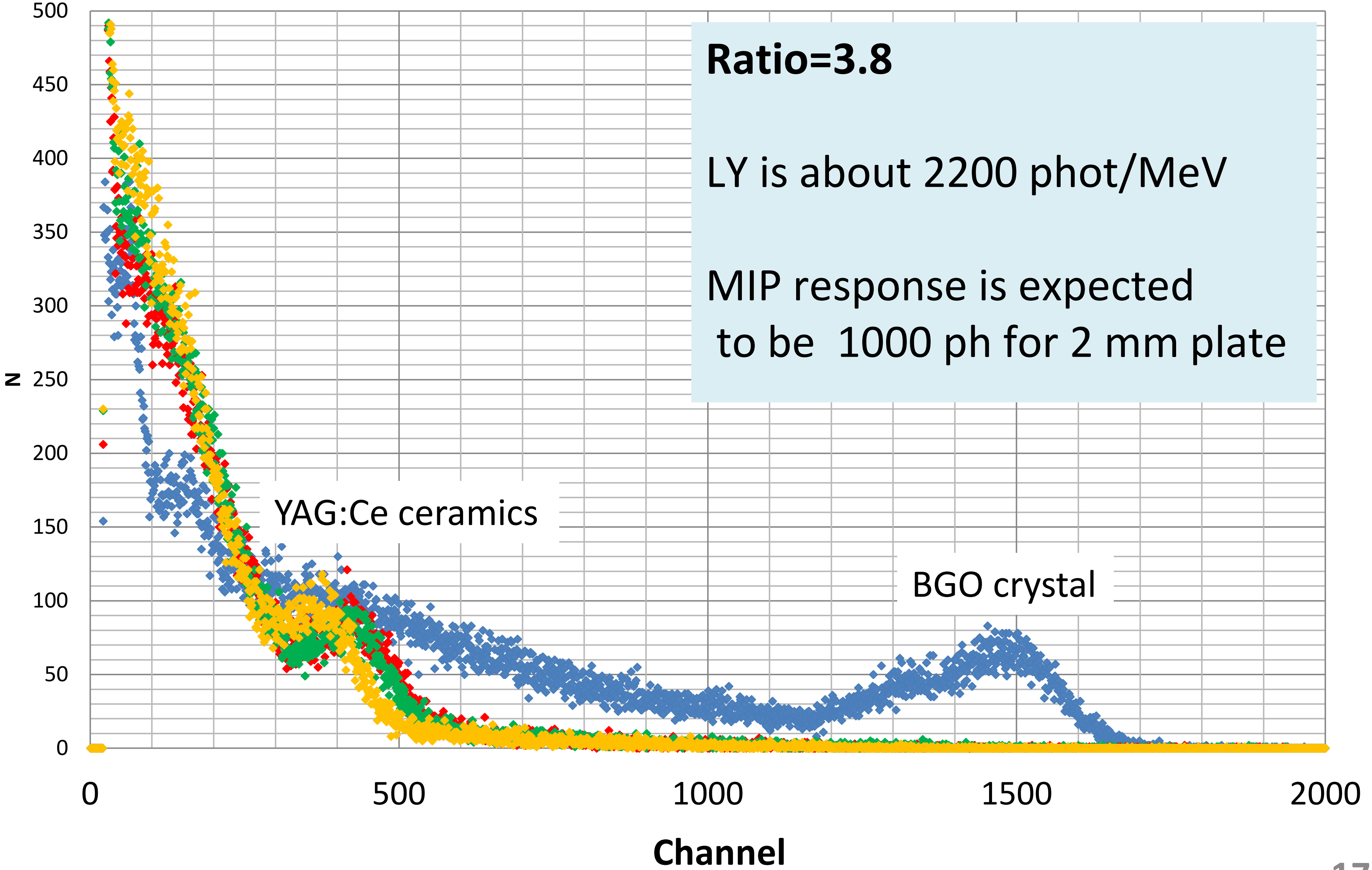


τ, ns	P,%
40	51
85	44
930	5

5,5 MeV alpha-particle amplitude spectra of 2 mm thick YAG:Ce ceramics compared to GS20 scintillation glass
(surface excitation, strong light loss due to scattering)



662 keV gamma-quanta amplitude spectra of 2 mm thick YAG:Ce ceramics compared to 2 mm thick BGO

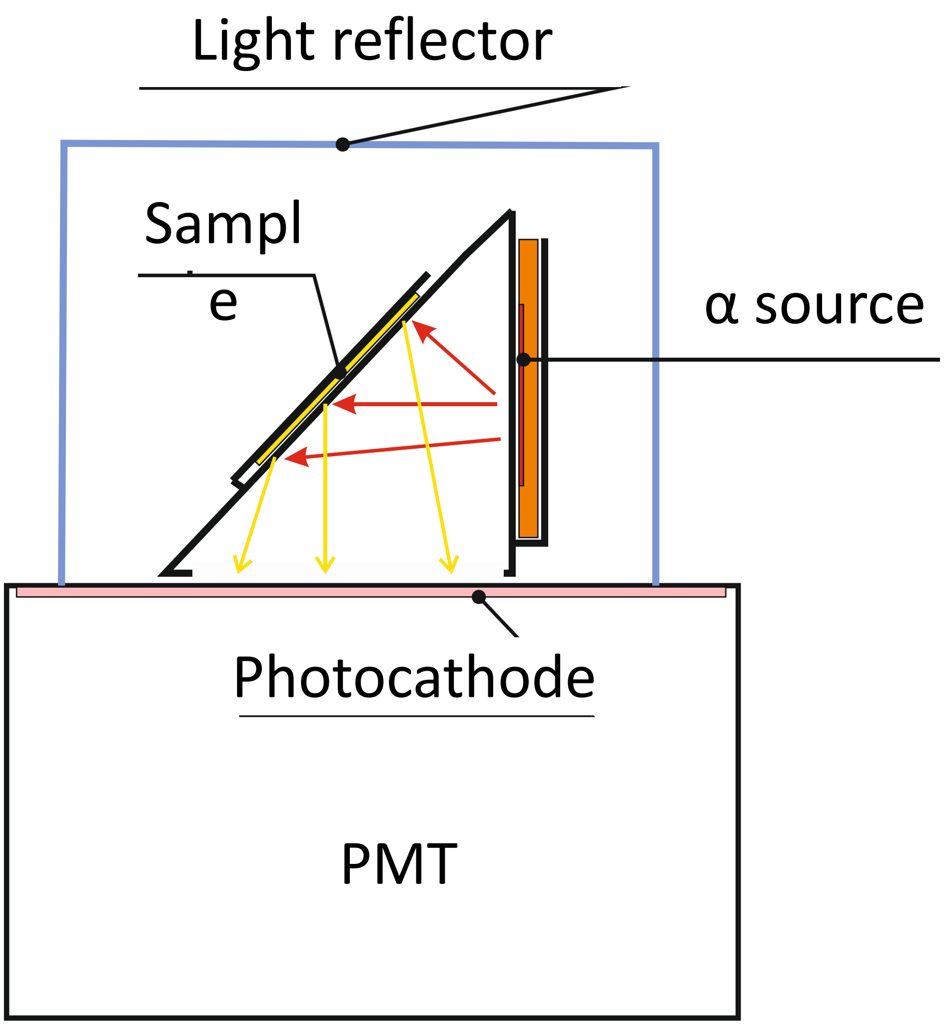


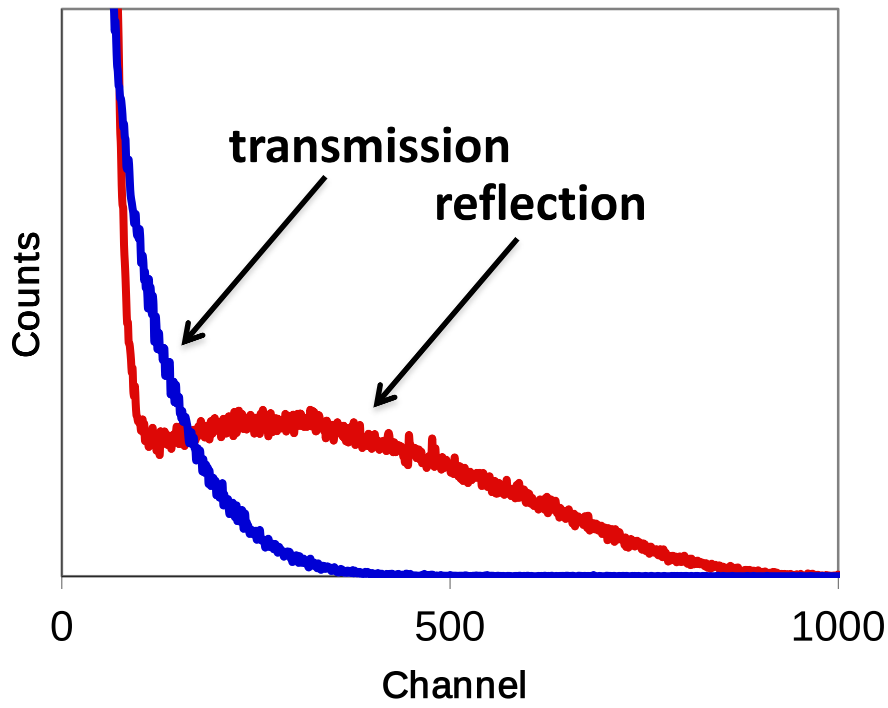
Ratio=3.8

LY is about 2200 phot/MeV

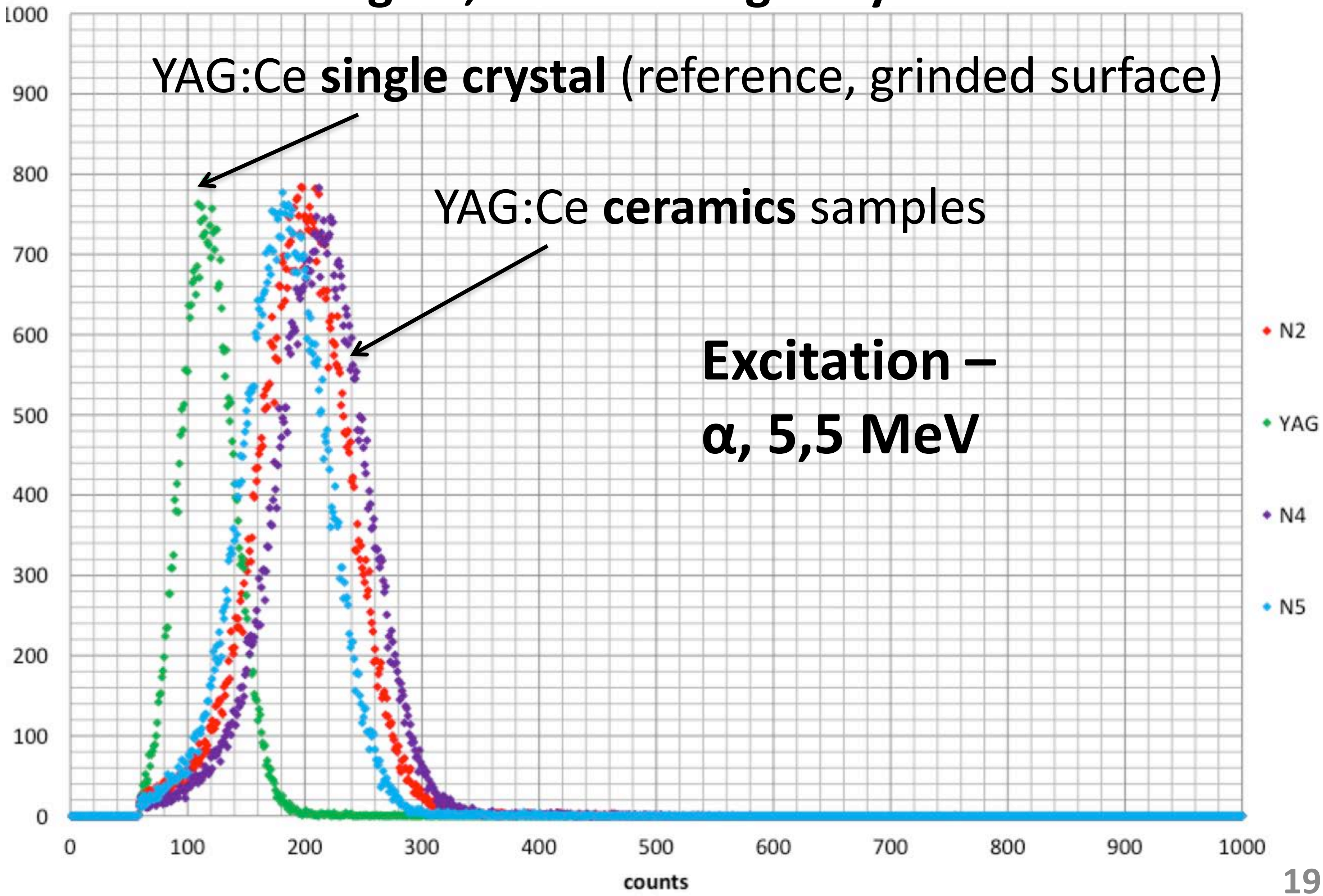
MIP response is expected to be 1000 ph for 2 mm plate

Scintillation measurements for highly light scattering samples – signal collection from samples surface





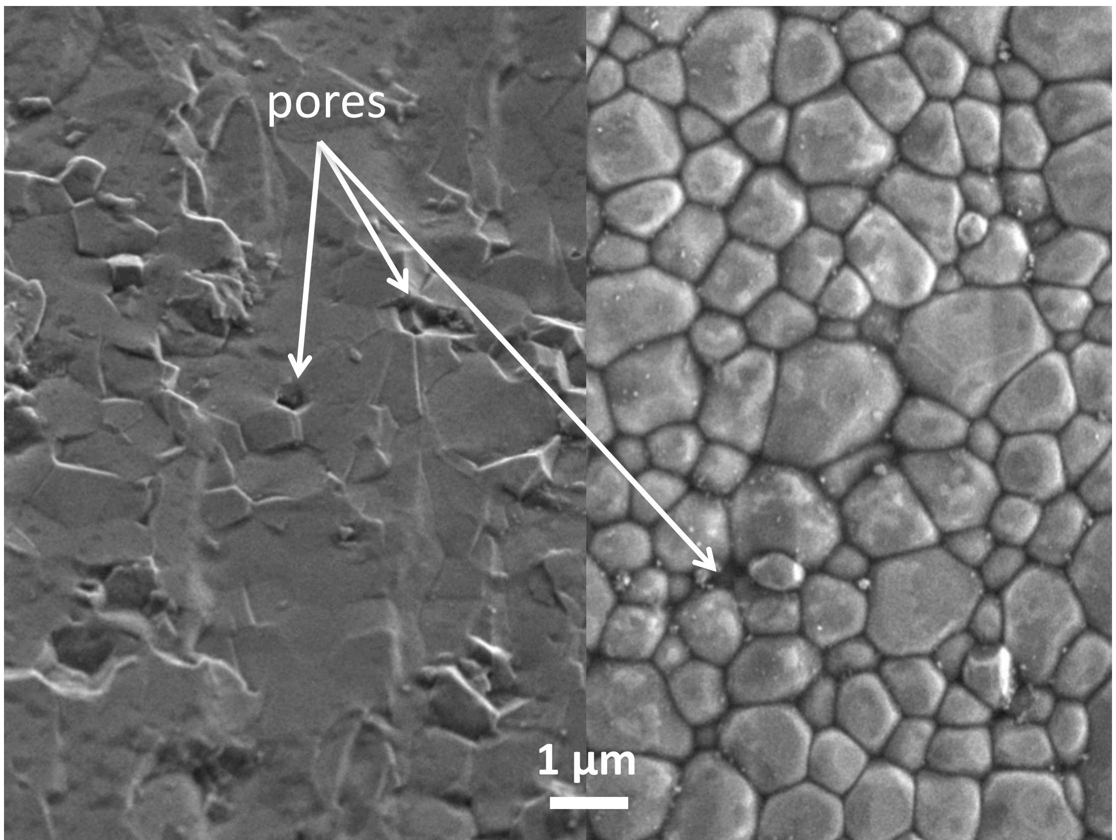
Scintillation measured from surface – higher, than for single crystal



Room to improve

Air sintering ↓ Vacuum sintering ⇨ ρ 98% ↓ ρ 99,5% ⇨ Better light collection

split | surface



h = 3 mm,
LED 460 nm illumination

Potential of scale-up to a production technology

Raw materials preparation
See poster № 41

↓

Powder co-precipitation
Classic solution chemistry

↓

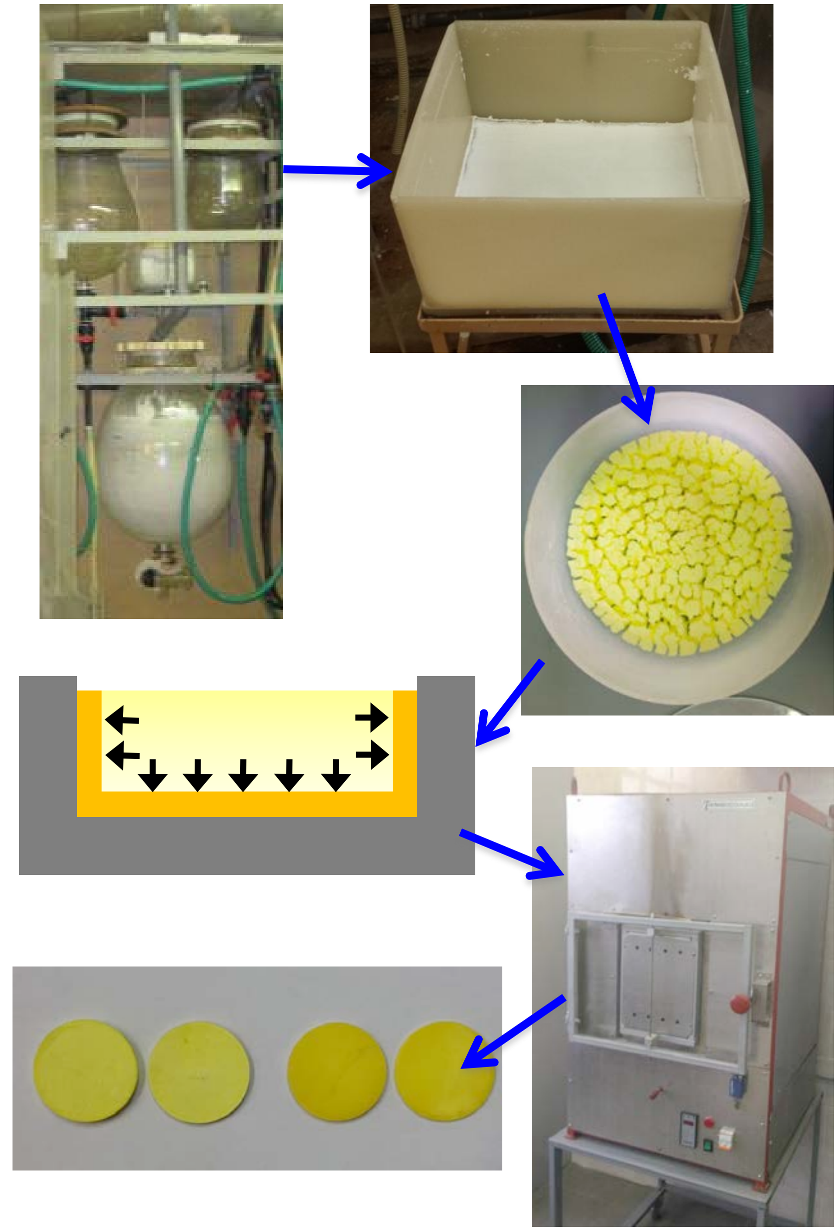
Drying-heating-milling
Classic powder technology

↓

Slip casting
Classic ceramic technology

↓

Vacuum / air sintering
Used for advanced ceramics



Conclusions and outlook

YAG:Ce crystals have suitable properties for strongly irradiated detectors, but are too expensive

YAG:Ce ceramics is a fully inorganic crystalline material, and it can be made cheaper, compared to single crystals

Even weakly translucent samples demonstrate promising scintillation characteristics

Performance could be further improved

Thank you for your attention!!!

Acknowledgements:

Dr. Vladimir N. Schlegel (Institute of Inorganic Chemistry, Novosibirsk) – for reference BGO crystal
Dr. Etiennette Auffray, Dr. Marco Lucchini (CERN),
Dr. Valeriy Dormenev (KVI, Groningen) – for data on irradiated plastic scintillators

Work is supported by Russian Ministry of Science and Education, subsidy agreement № 14.625.21.0033 dated 27.10.2015,
project identifier RFMEFI62515X0033

Contacts: Georgy Dosovitskiy

+7-916-117-32-20
george.dos@gmail.com