News on $PbWO_4$ Crystals

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and for the PANDA collaboration

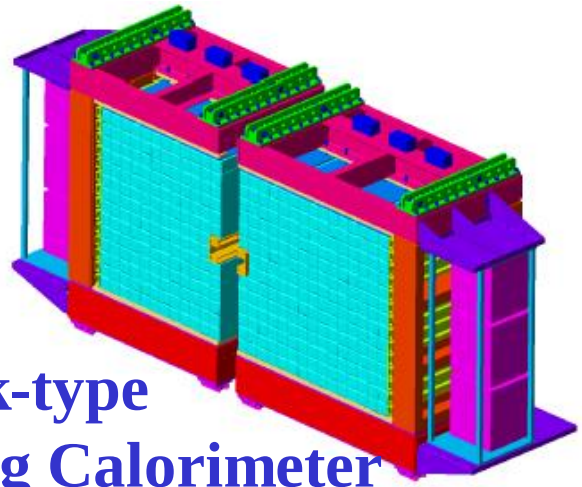
- **The PANDA requirements**
- **Some comments on radiation hardness**
- **Available manufacturer**
  - **SICCAS**
  - **CRYTUR**
- **Status**

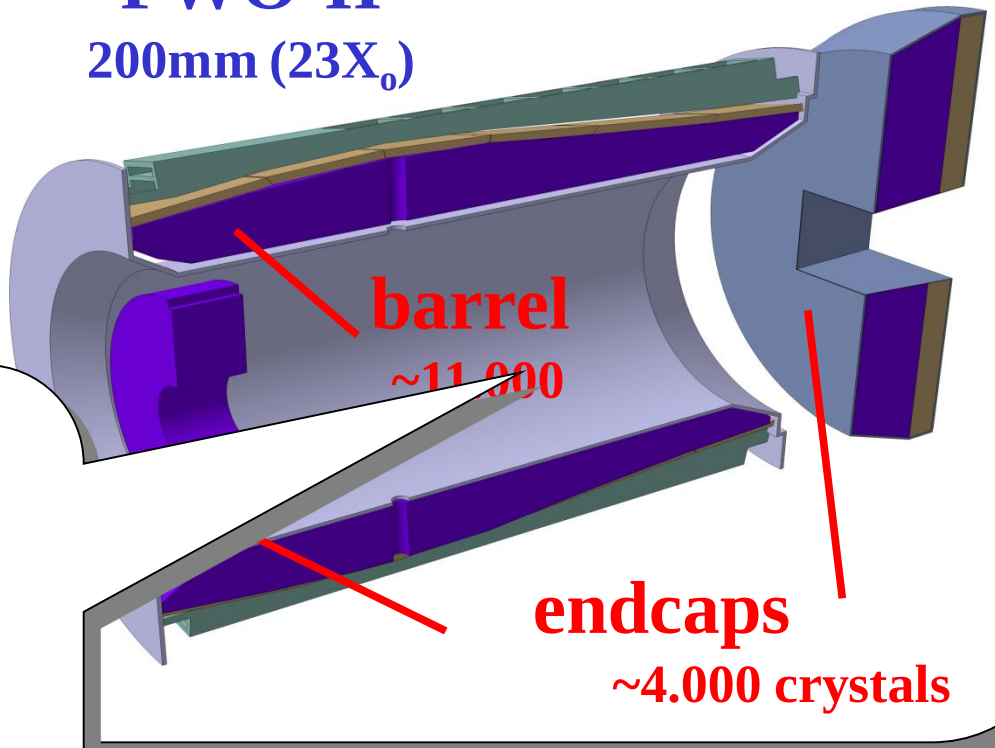
• the PANDA detector at FAIR

• photon detection with

over

10MeV < E





4π detector for spectroscopy and reaction dynamics with antiprotons

the Target Spectrometer:
based on high-quality PWO-II

- physical goals of PANDA require further development

	PWO-I (CMS)	PWO-II (PANDA)
luminescence maximum, nm	420	420
La, Y concentration level, ppm	100	40
expected energy range of EMC	150MeV - 1TeV	10MeV - 10GeV
light yield, phe/MeV at room temperature	8-12	17-22
EMC operating temperature, °C	+18	-25
energy resolution of EMC at 1GeV, %	3,4	2,0

Similarity and difference of the colour centres created under ϒ-quanta and protons

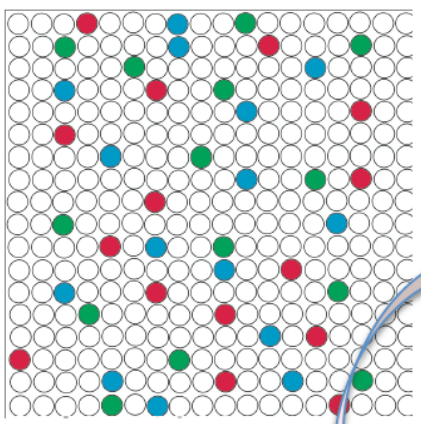
Point defects due to crystal growth

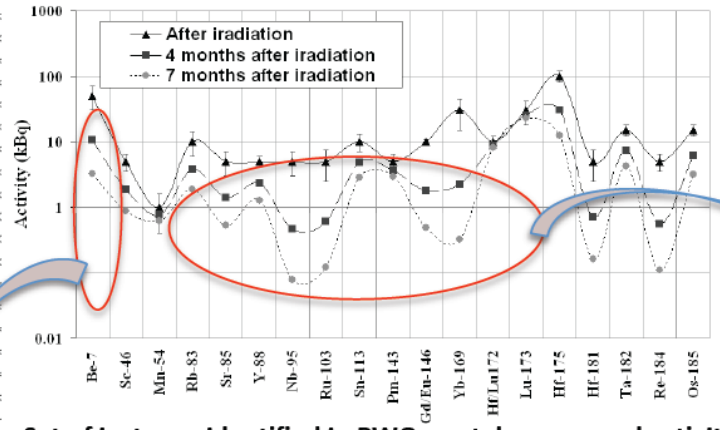
Stars created by fission products

-V_A

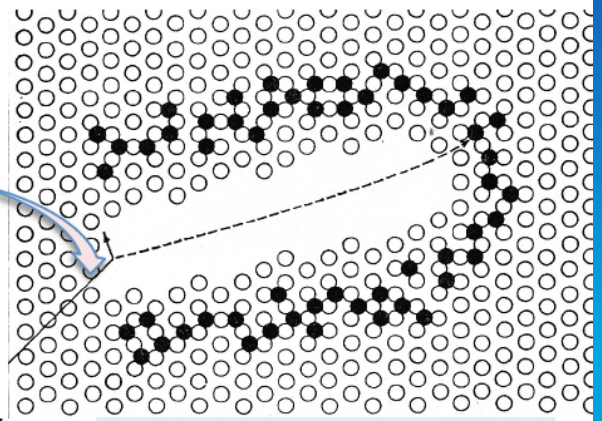
-V_C

-In.Si.





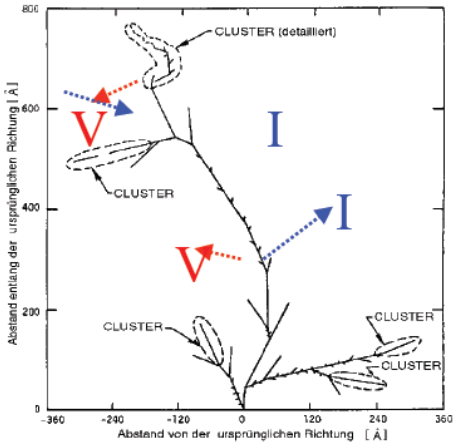
Set of isotopes identified in PWO crystal : measured activity 4 months after irradiation and the extrapolated values at 24 h and 7 months after the end of irradiation.

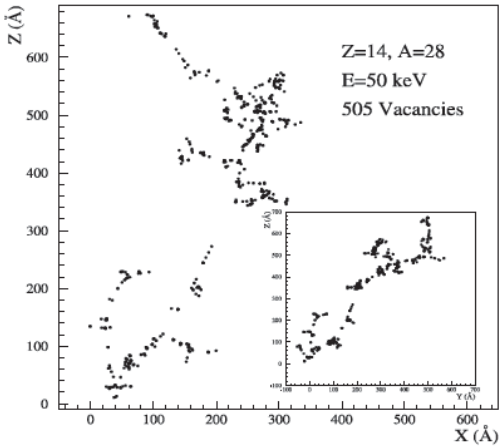


L.T.Chadding, 1965

Point defects and their clusters which are created by knocked ions

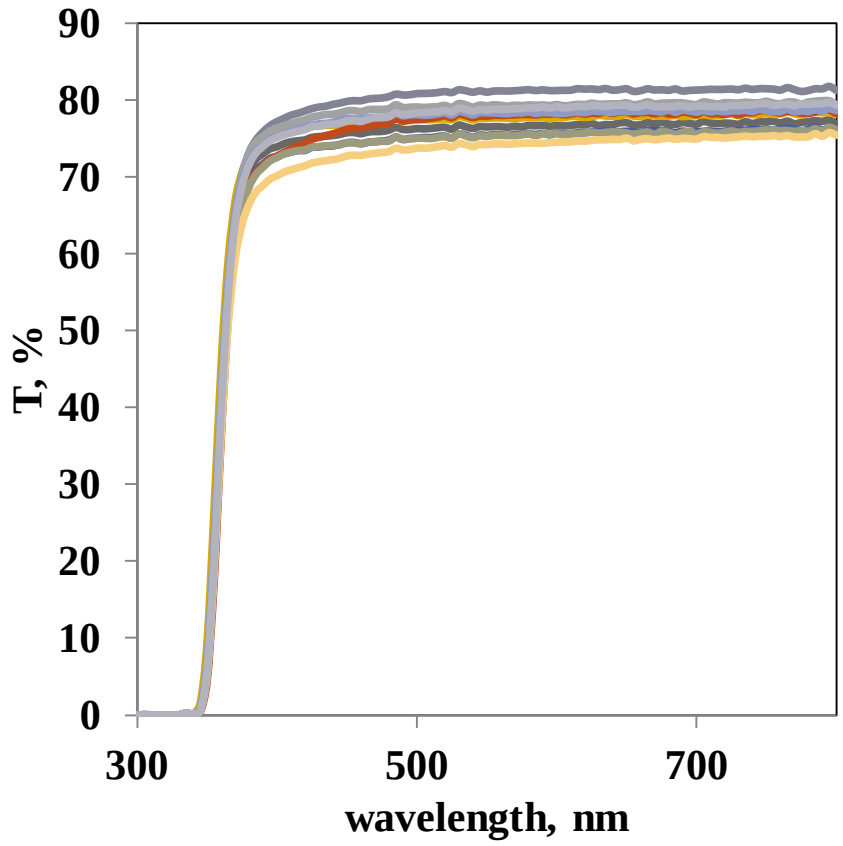
Van Lint 1980

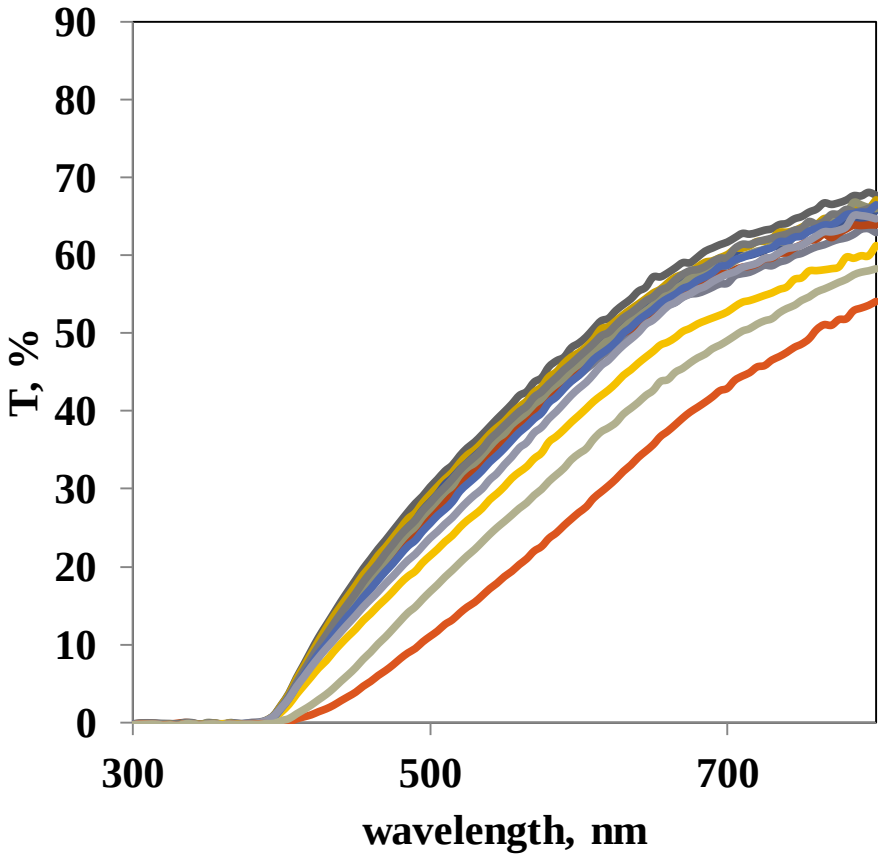




M.Huhtienen 2001

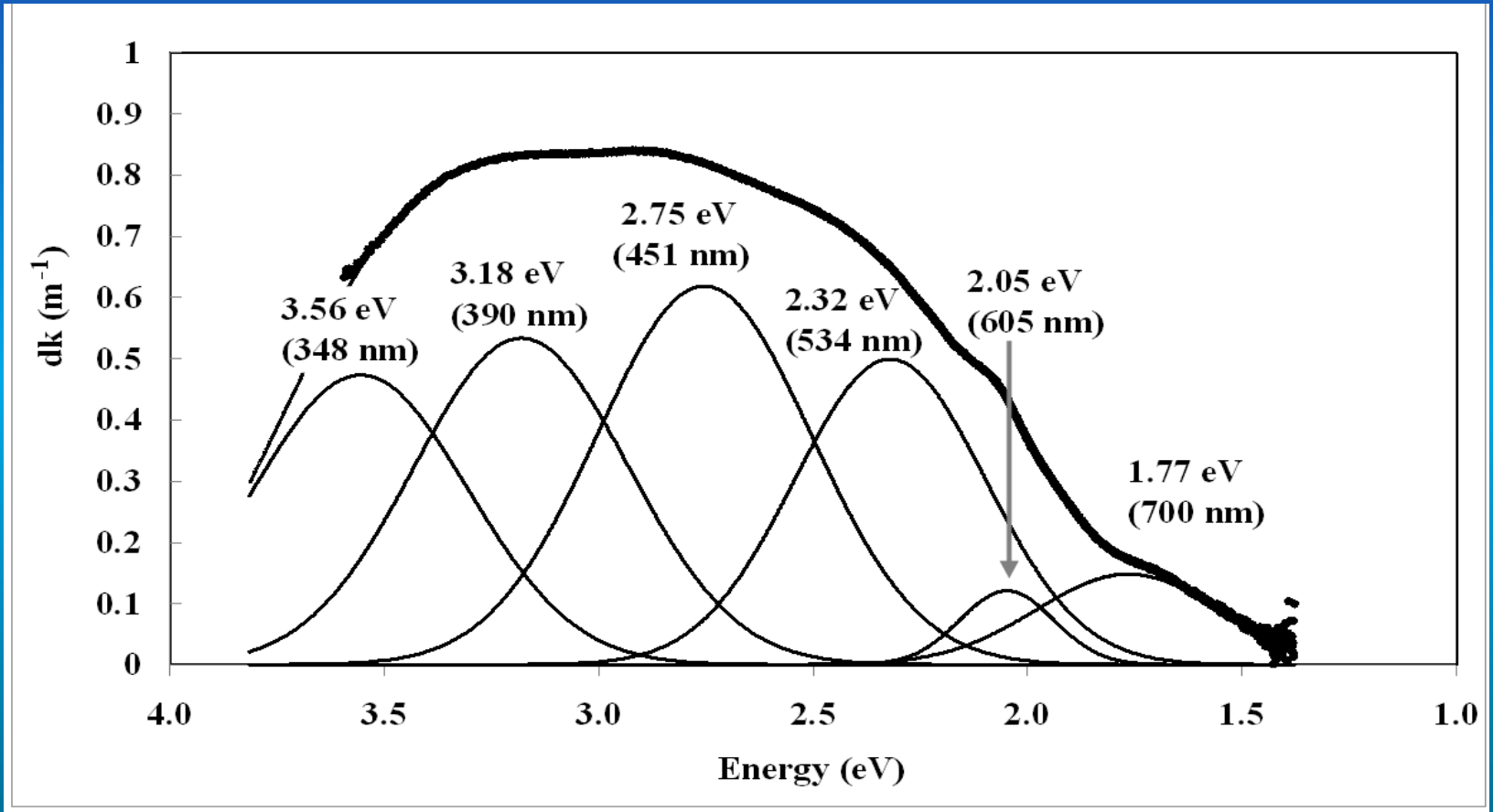
Change of the transmission under hadron irradiation





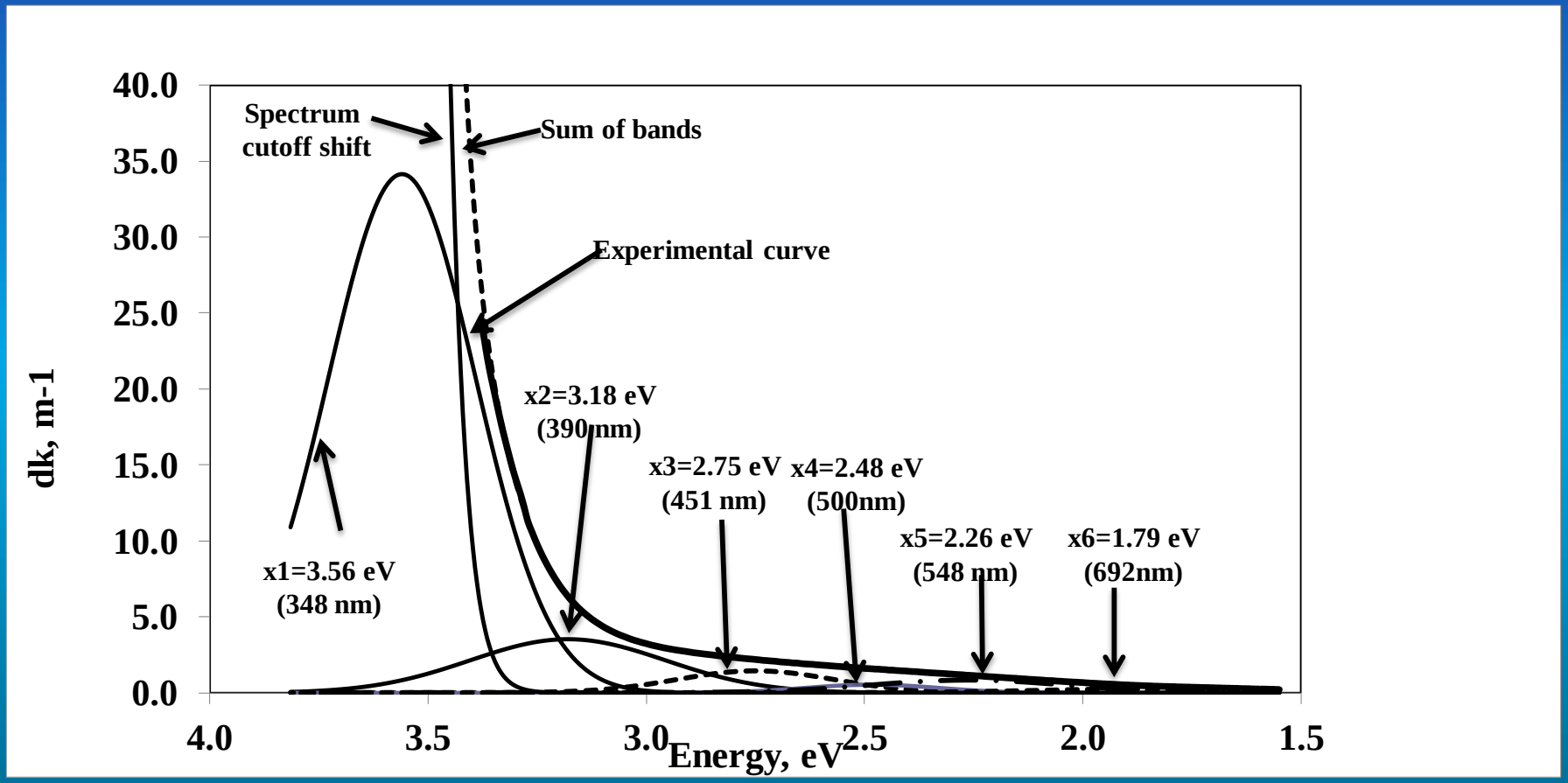
Change of the longitudinal transmission of 22 cm long PWO crystals after irradiation with ϒ-quanta (60Co, 1000Gy) and 24GeV protons with fluence 3,6 · 10^{13} p/cm^2.

PWO: Short term intense irradiation by γ-quanta ^{60}Co (1.2MeV, 1 MGy)



Radiation induced absorption spectrum and its approximation with set of Gaussians

PWO: intense irradiation with 24GeV protons ($3.6x10^{13}$(p/cm^2))

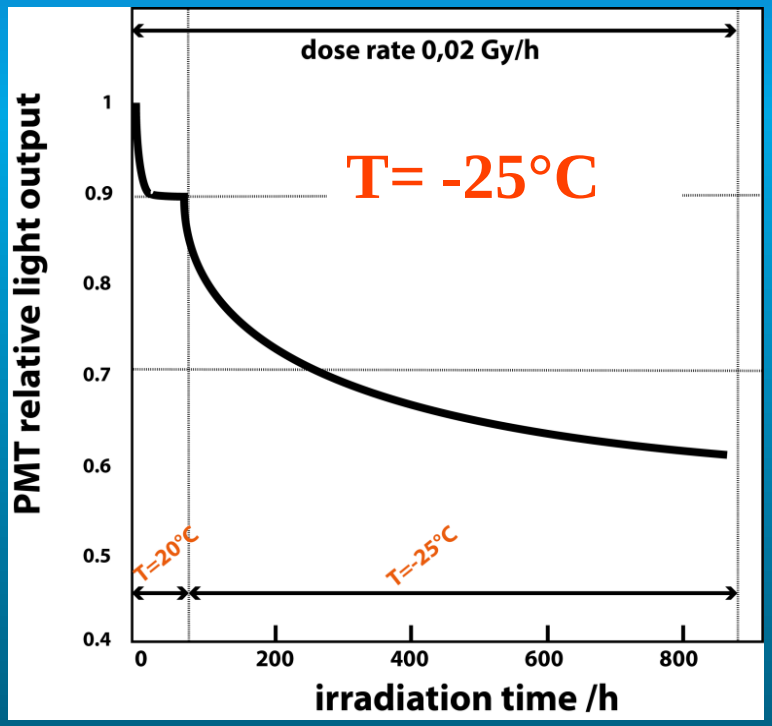


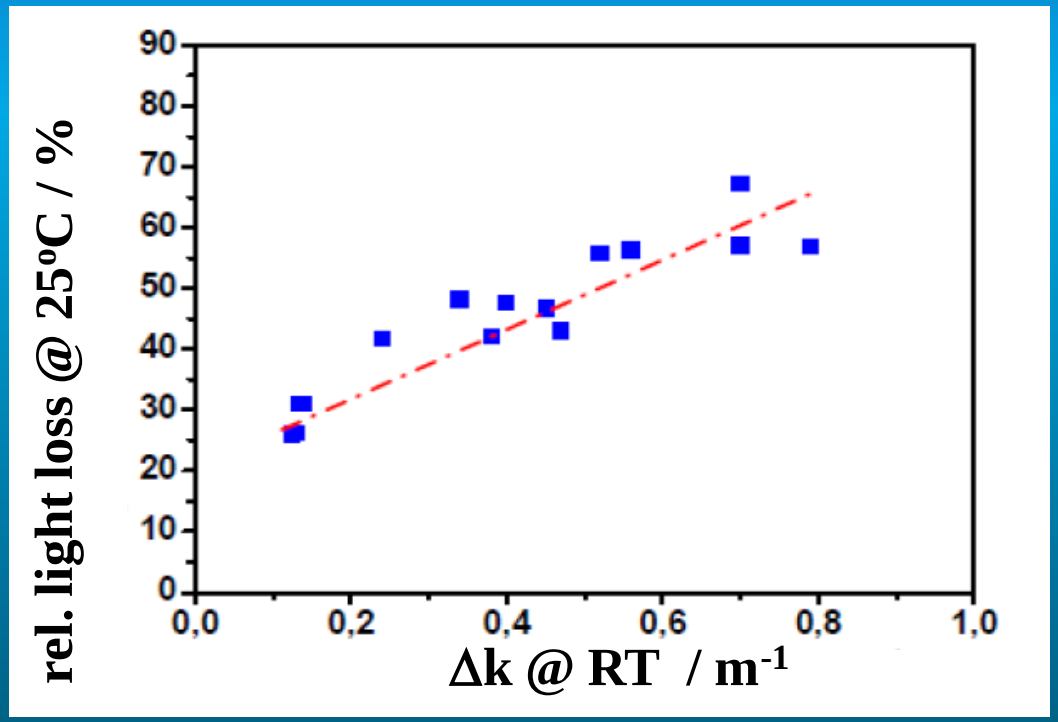
Radiation induced absorption spectrum and its approximation with set of Gaussians

• consequences of cooling

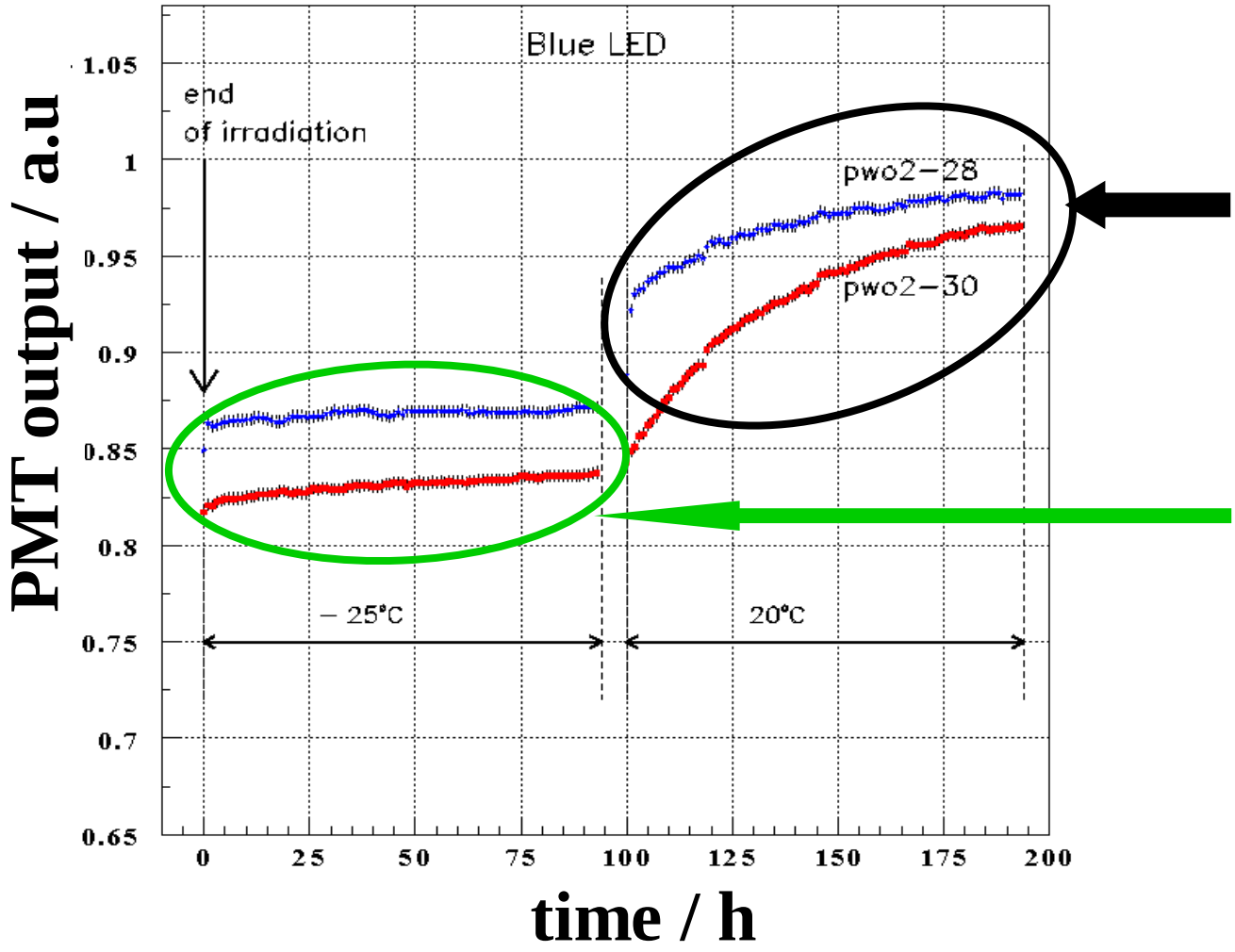
- fast decay kinetics even at T=-25°C: LY(100ns)/LY(1µs) > 0.9
- constant temperature gradient: LY(-25°C)/LY(+18°C) ~ 3.9

- „no“ statistical recovery of radiation damage at T=-25°C
  asymptotic light loss correlated with Δk (@RT)





• radiation hardness: limitations at T=-25°C

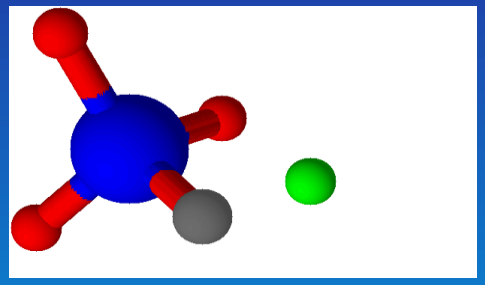


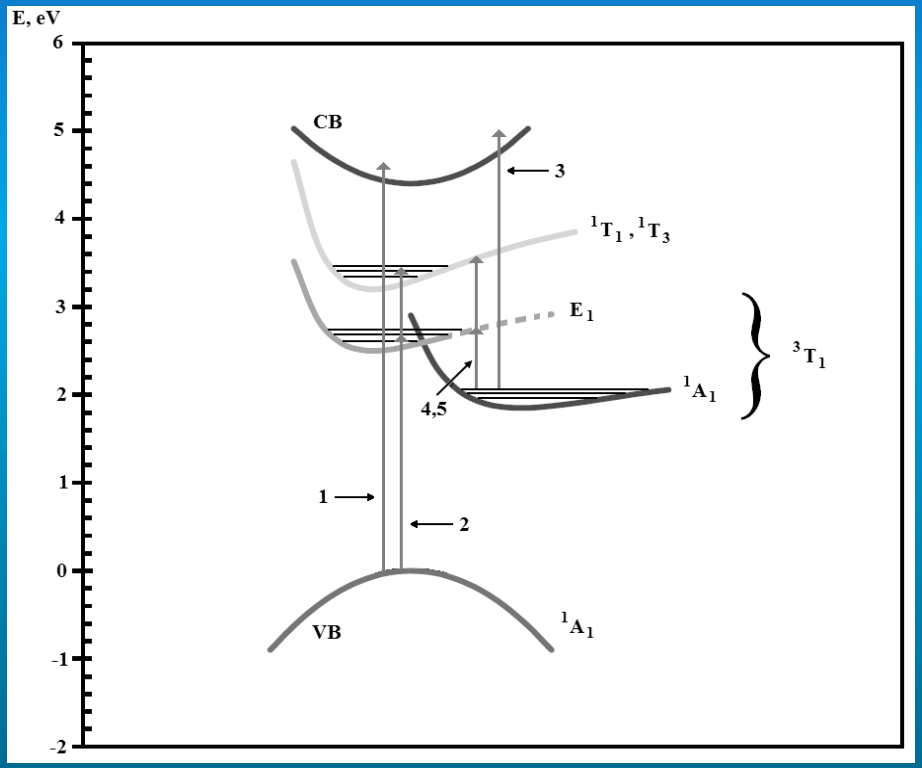
recovery at +20°C

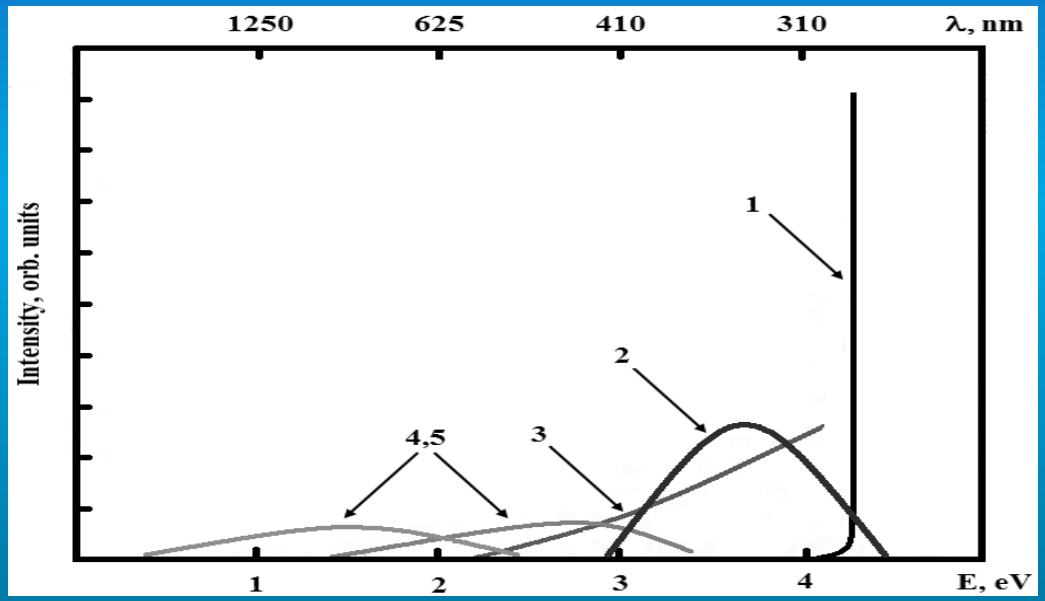
recovery at –25°C

Optical transmission: stimulated recovery in PWO

WO_3 + O is an oxygen vacancy and oxygen ion in a close intersite position (FTD)

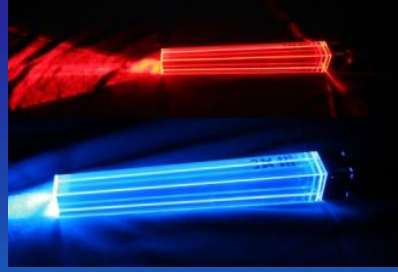


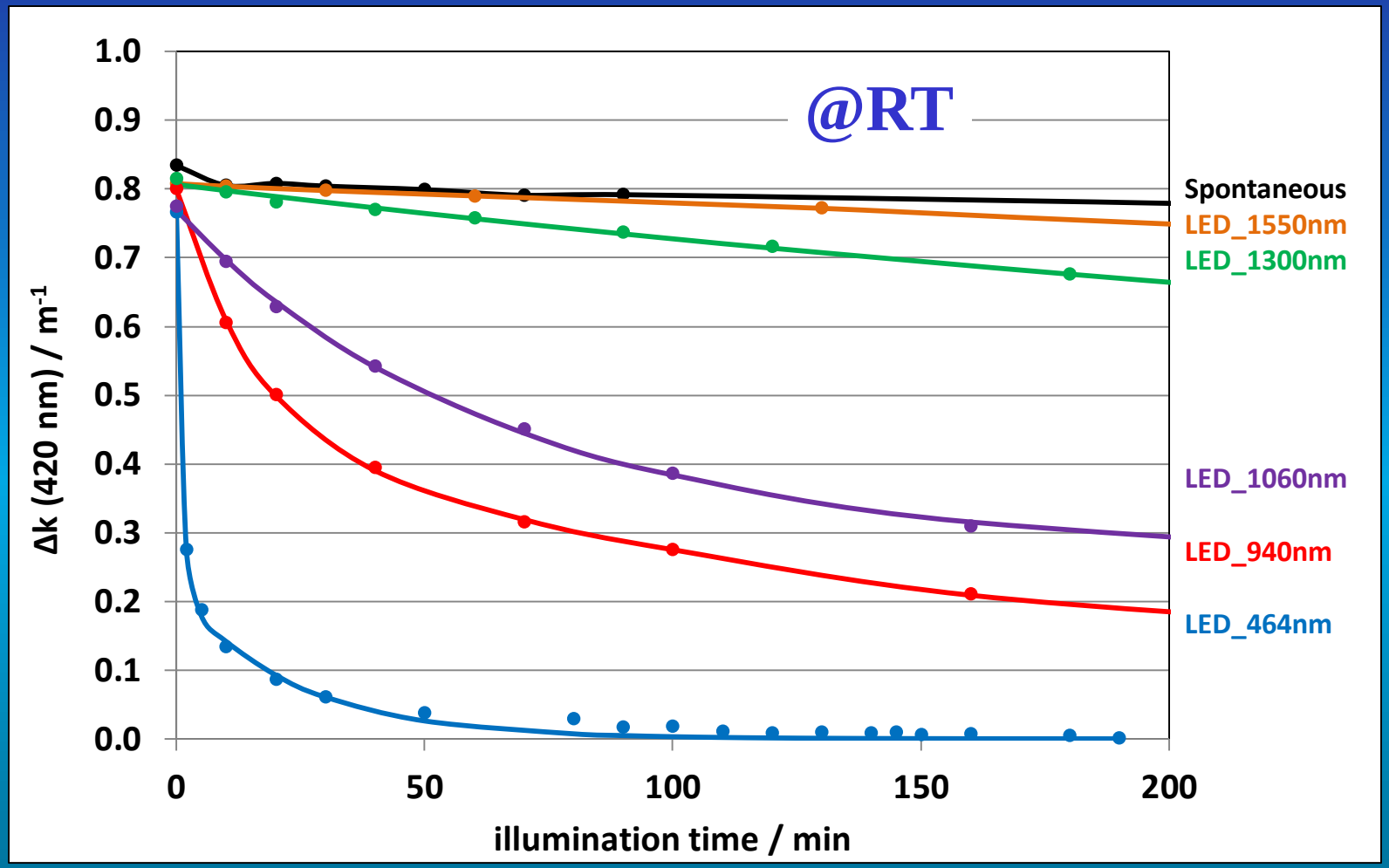




Electronic transitions in PWO containing FTD and dedicated absorption bands

- ***stimulated recovery* of radiation damage**

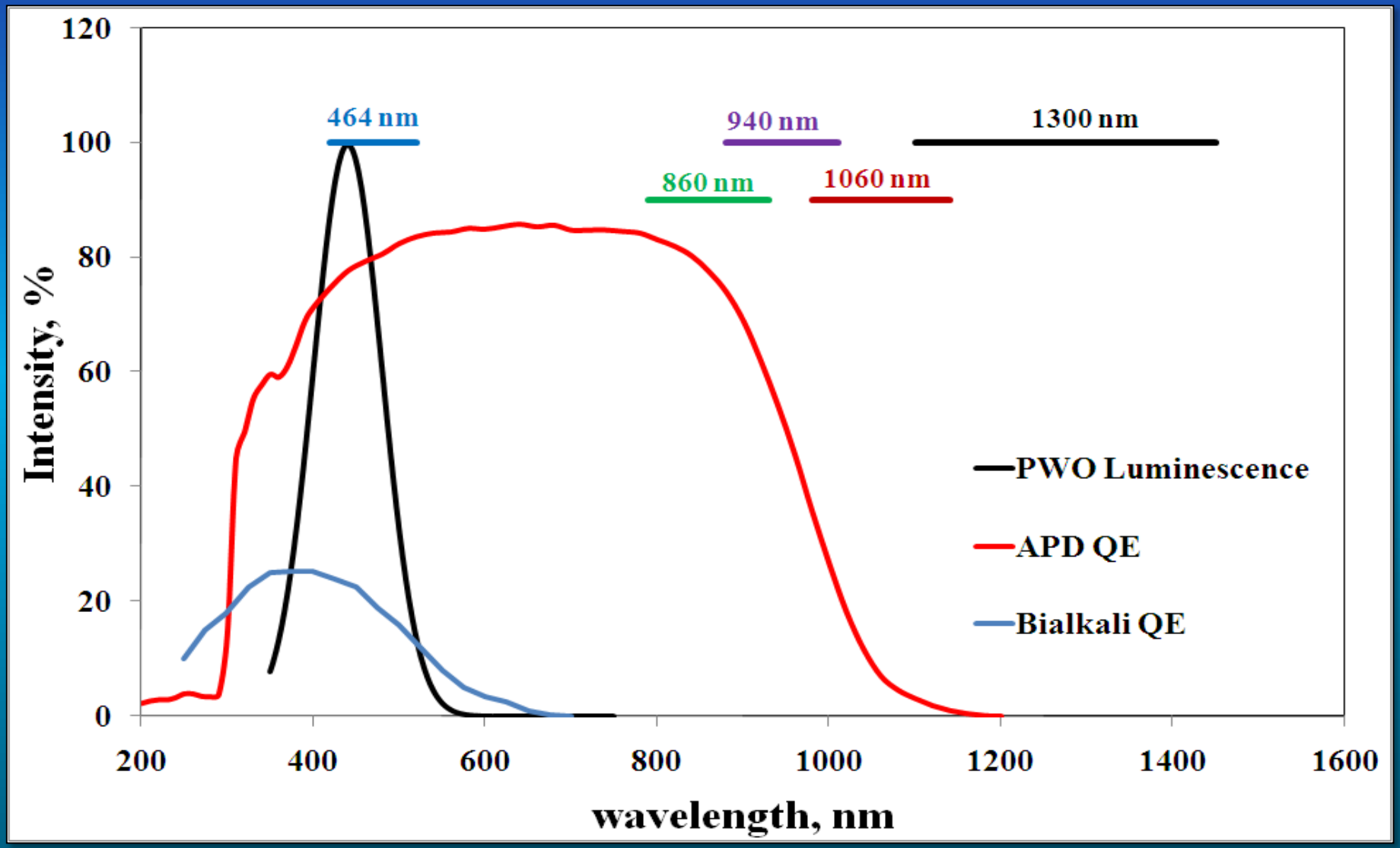




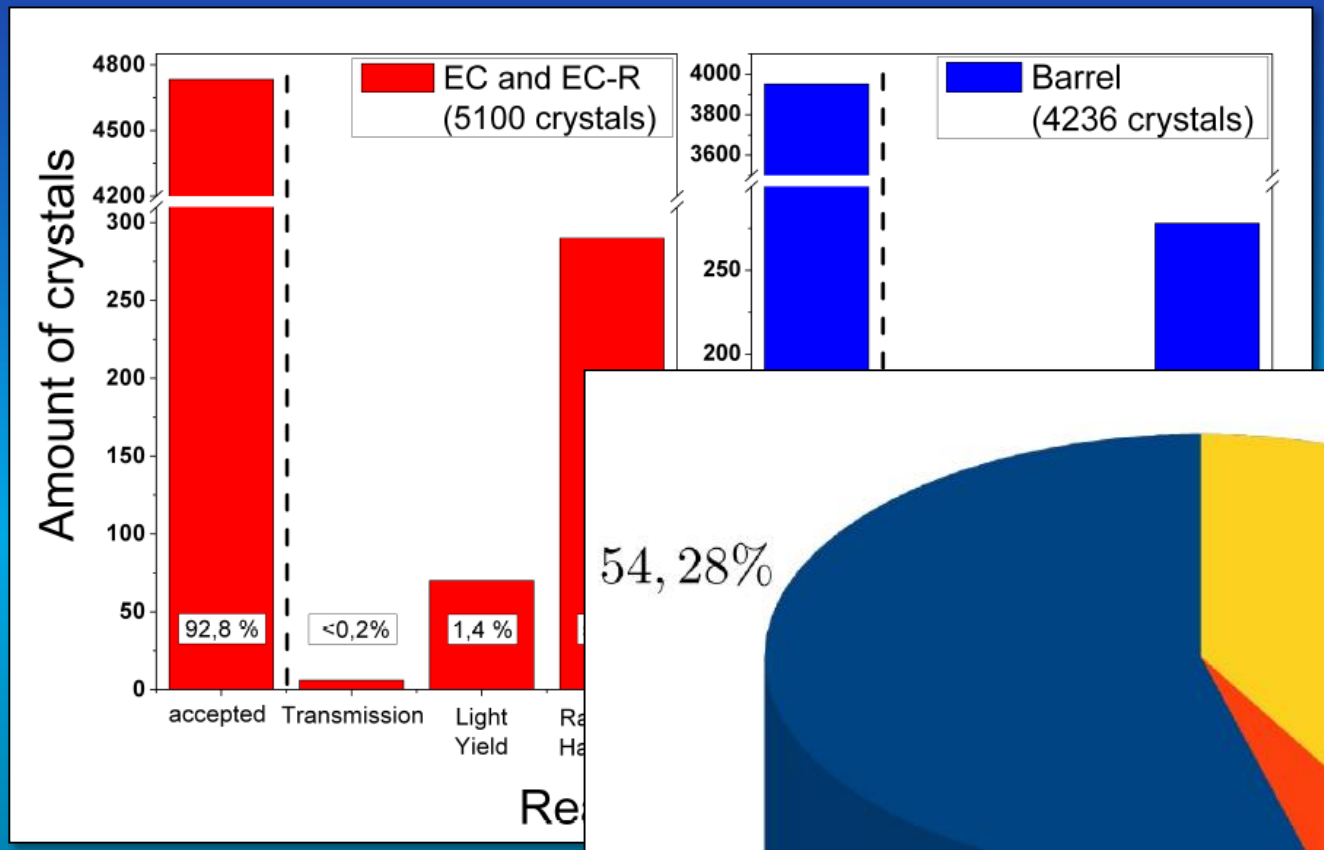
applied integral dose of ^{60}Co: D = 30Gy

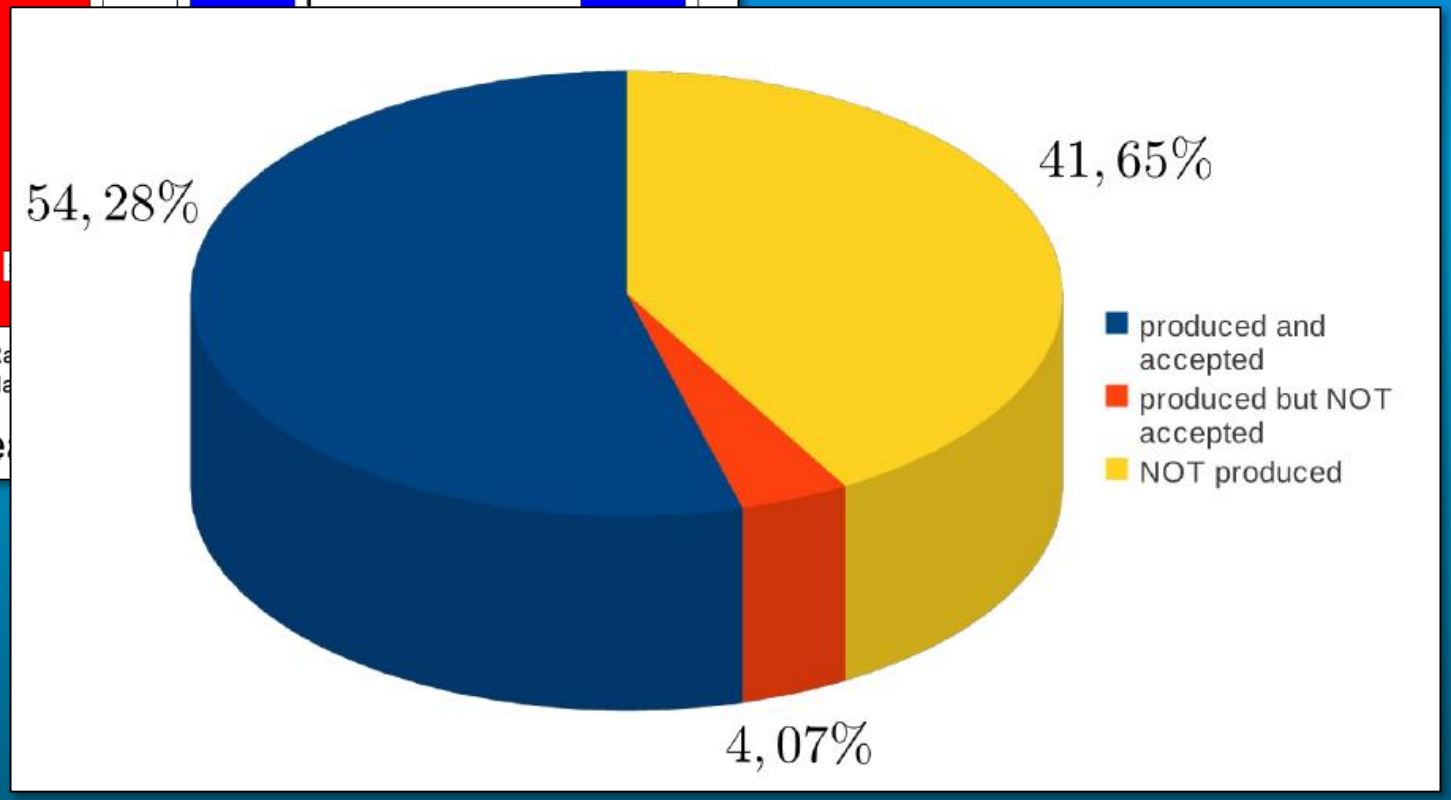
V. Dormenev et al., NIM A623 (2010) 1082 - patented

- **implications for EMC operation**



• overall quality of the available BTCP crystals





• remaining PWO manufacturer

SICCAS – Shanghai, China

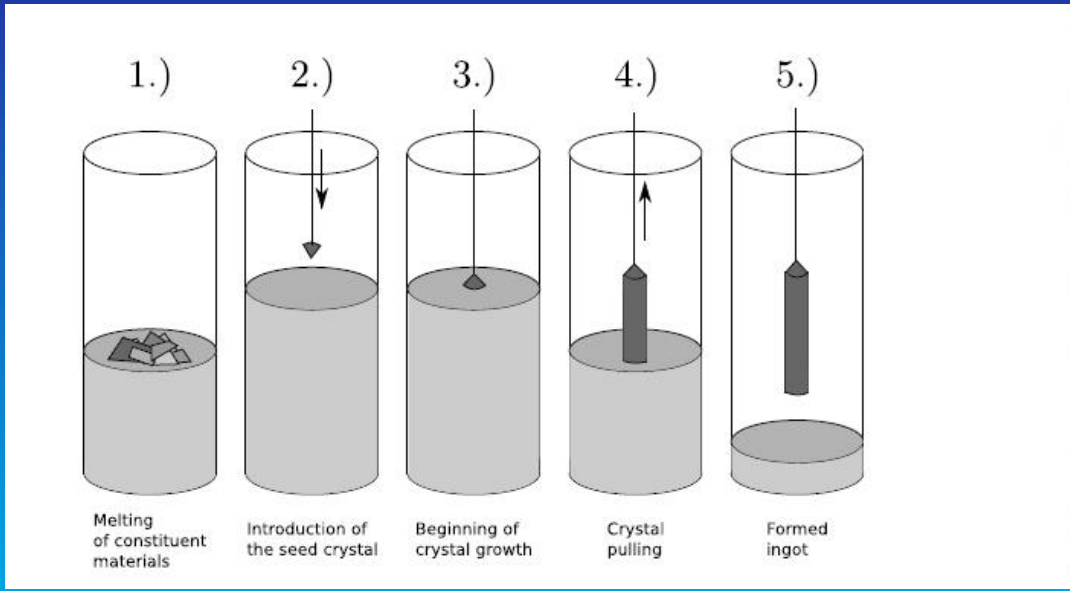
- R&D continued in parallel
- Bridgeman technology (not comparable to BTCP)
- fully acceptable crystals delivered in the past
- presently search for appropriate raw material
  and optimization of technology

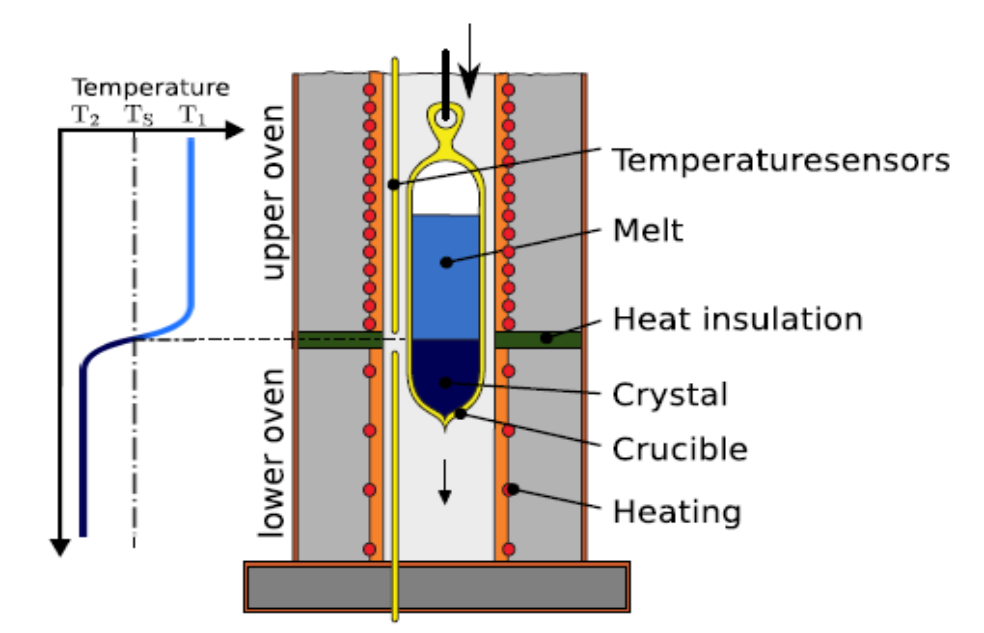
CRYTUR – Turnov, Czech Republic

- R&D phase just started (June 2014)
- Czochralsky technology (identical to BTCP)
- know-how and raw material still available

- **how to produce crystals**

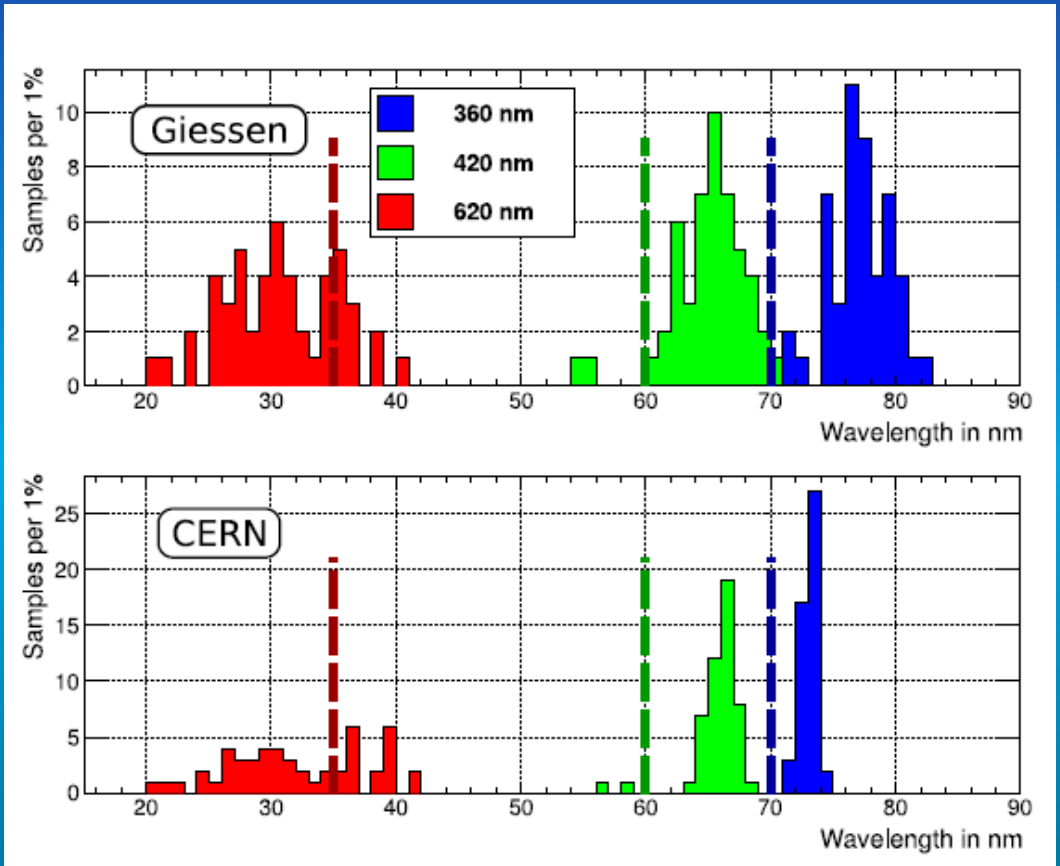
Czochralsky-method

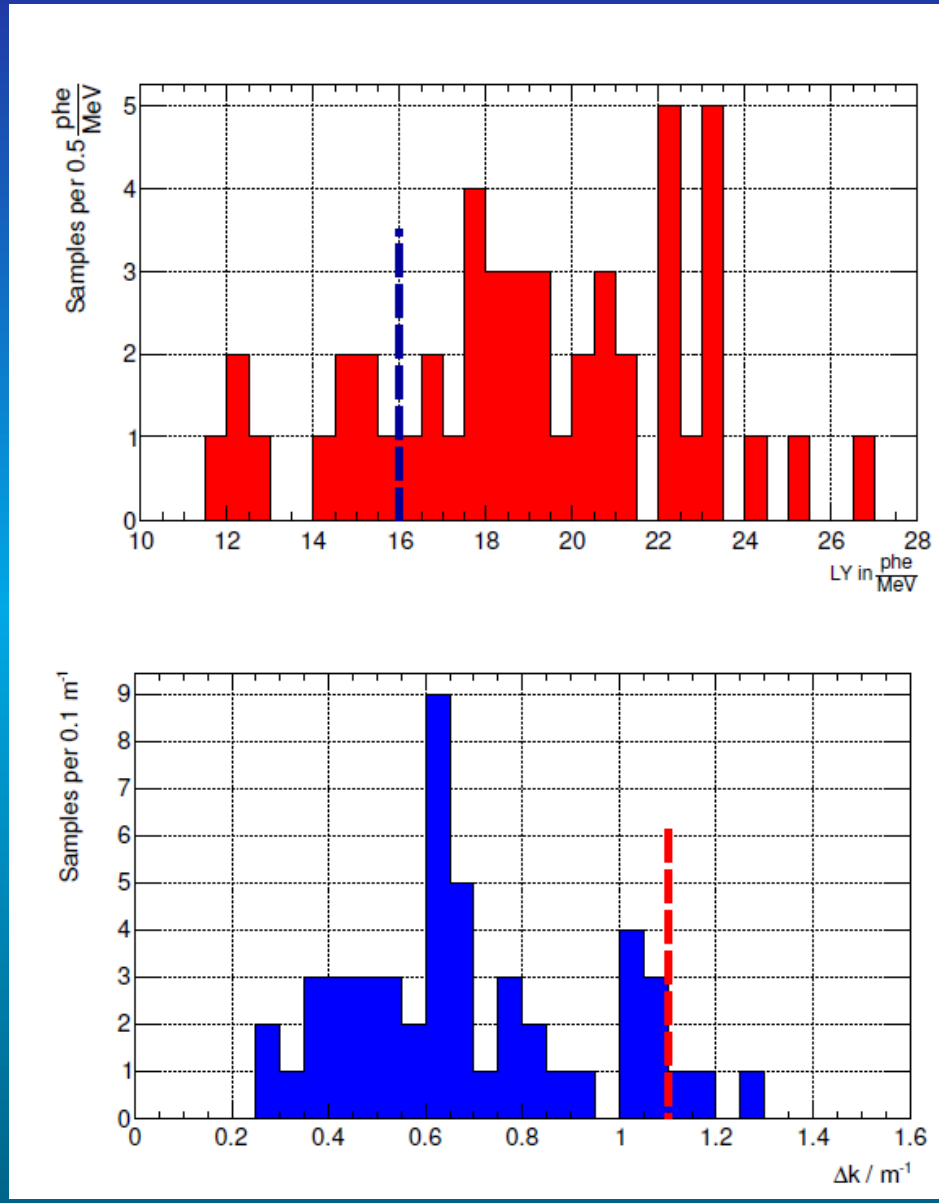




Bridgeman-technology

- **former production @ SICCAS**

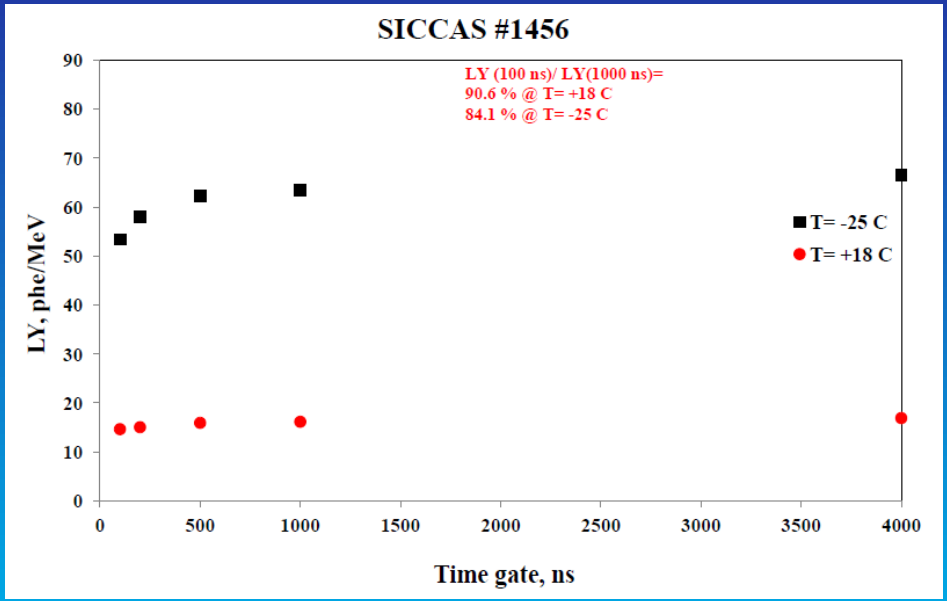


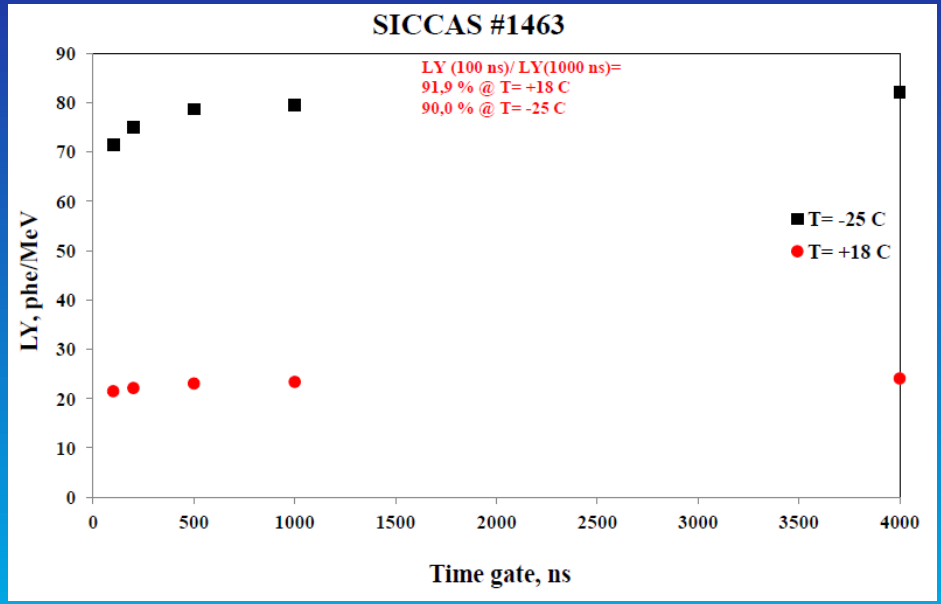


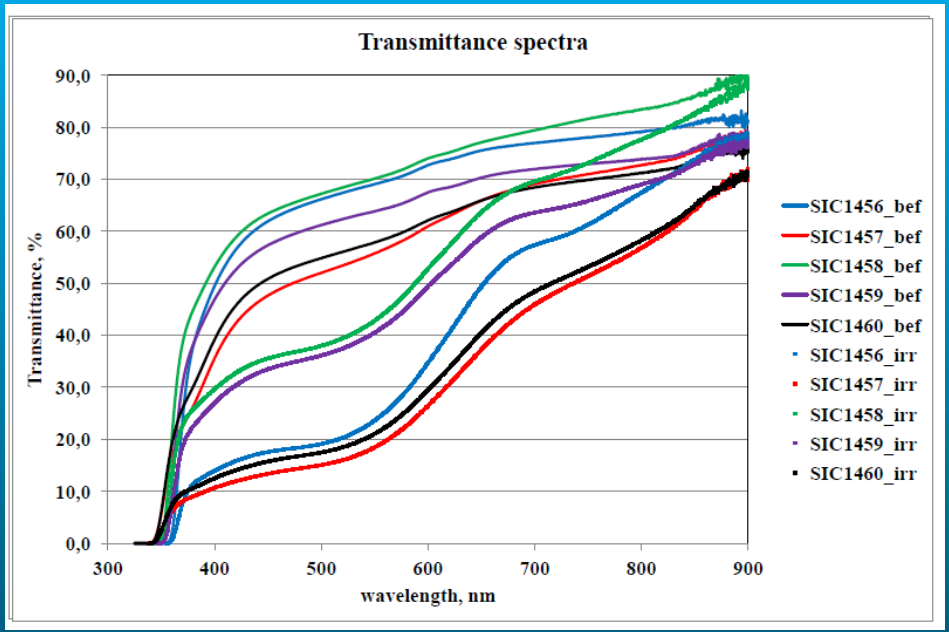
• recent delivery from SICCAS (2014 - 2015)

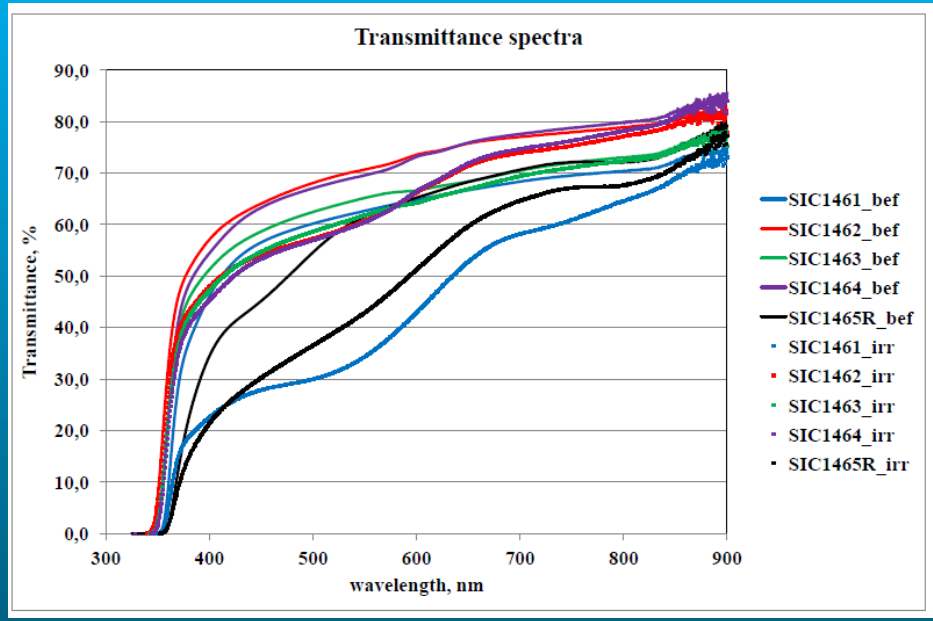
SICCAS ID	T(360	T(420	T(620	LY(T= +18 C, t=100	LY(100	dk(420 nm)
	%	%	%	phe/MeV	at T=18C, %	m^{-1}
limits	≥ 35	≥ 60	≥ 70	≥ 16	> 90	< 1.1
1451	19,0	58,8	73,8	22,3	94,1	1,92
1452	25,2	62,9	74,2	22,3	94,1	0,72
1453	23,2	57,8	75,3	11,1	90,4	3,94
1454	35,0	67,2	77,8	26,9	93,7	0,69
1455 rus	10,1	52,5	73,5	15,4	93,9	2,68
1456	2,0	56,5	73,8	15,6	90,6	6,36
1457	16,4	42,3	62,9	13,1 at -25 C	87,8	6,32
1458	20,4	58,8	75,2	17,8	91,3	2,93
1459	11,3	52,6	68,5	19,2	92,1	2,74
1460	19,1	45,7	63,6	?	?	5,89
1461	8,8	52,0	65,6	19,7	91,7	3,59
1462	32,5	60,7	74,3	21,9	91,5	0,85
1463	22,9	55,1	67,3	21,5	91,9	0,38
1464	22,7	59,0	74,1	20,5	91,6	0,89
1465 rus	1,8	40,3	66,5	12,9	90,8	2,26
1466	31,2	56,9	72,0	23,4	90,1	0,86
1467	20,6	55,8	71,1	21,4	90,4	0,71
1468	21,5	56,5	69,7	19,9	89,9	0,65
1469	26,9	56,9	69,0	21,2	90,7	0,44
1470	25,5	56,2	70,3	22,8	90,0	1,33
1471	24,7	57,8	70,8	20,6	90,5	0,80
1472	33,6	59,1	72,1	20,7	90,1	0,16
1473	22,2	60,3	72,2	20,8	90,7	0,71
1474	23,2	60,5	72,2	20,3	89,9	0,59
1475	35,0	65,2	78,0	22,0	91,4	0,84

• recent delivery from SICCAS (1)

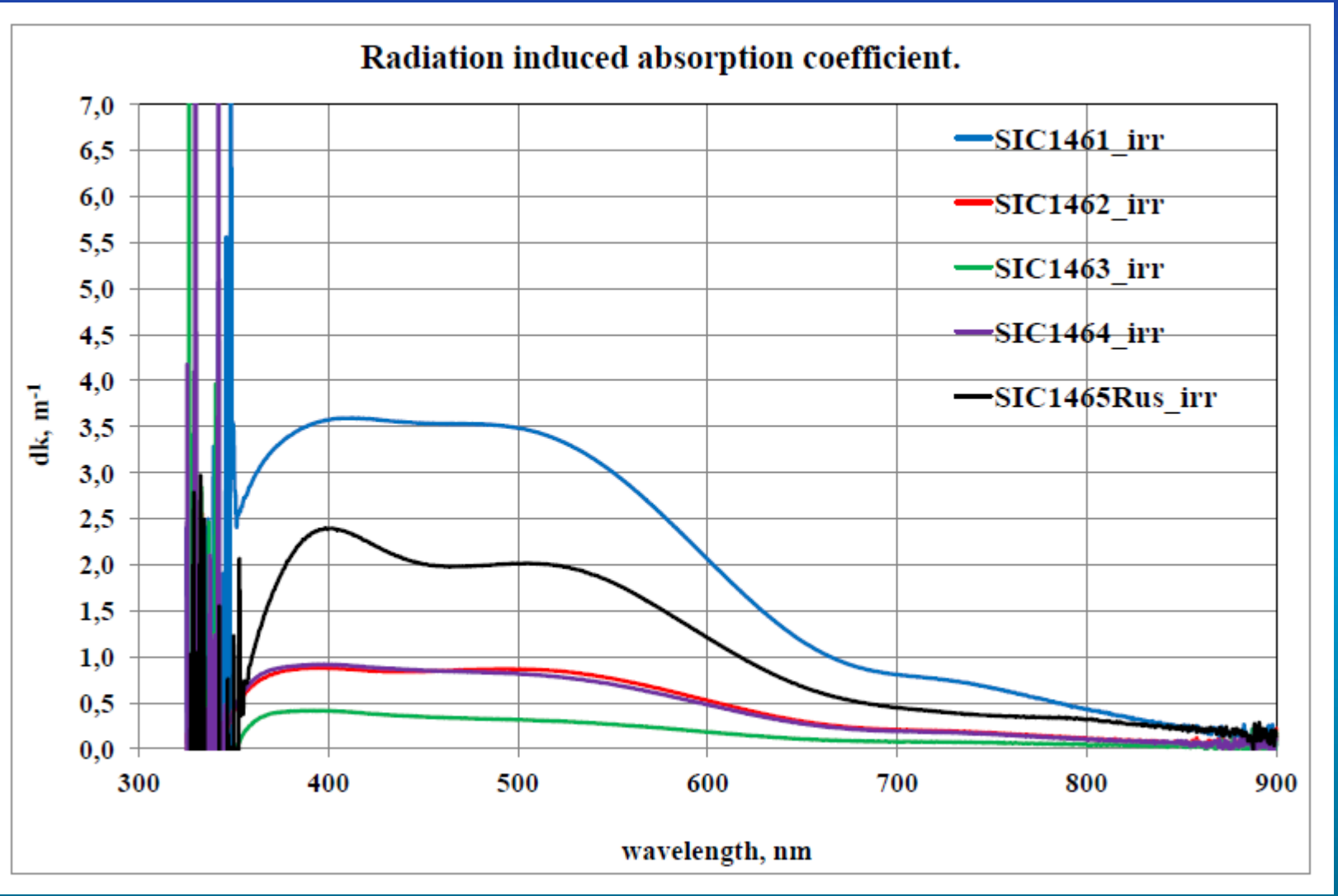








- **recent delivery from SICCAS (1)**



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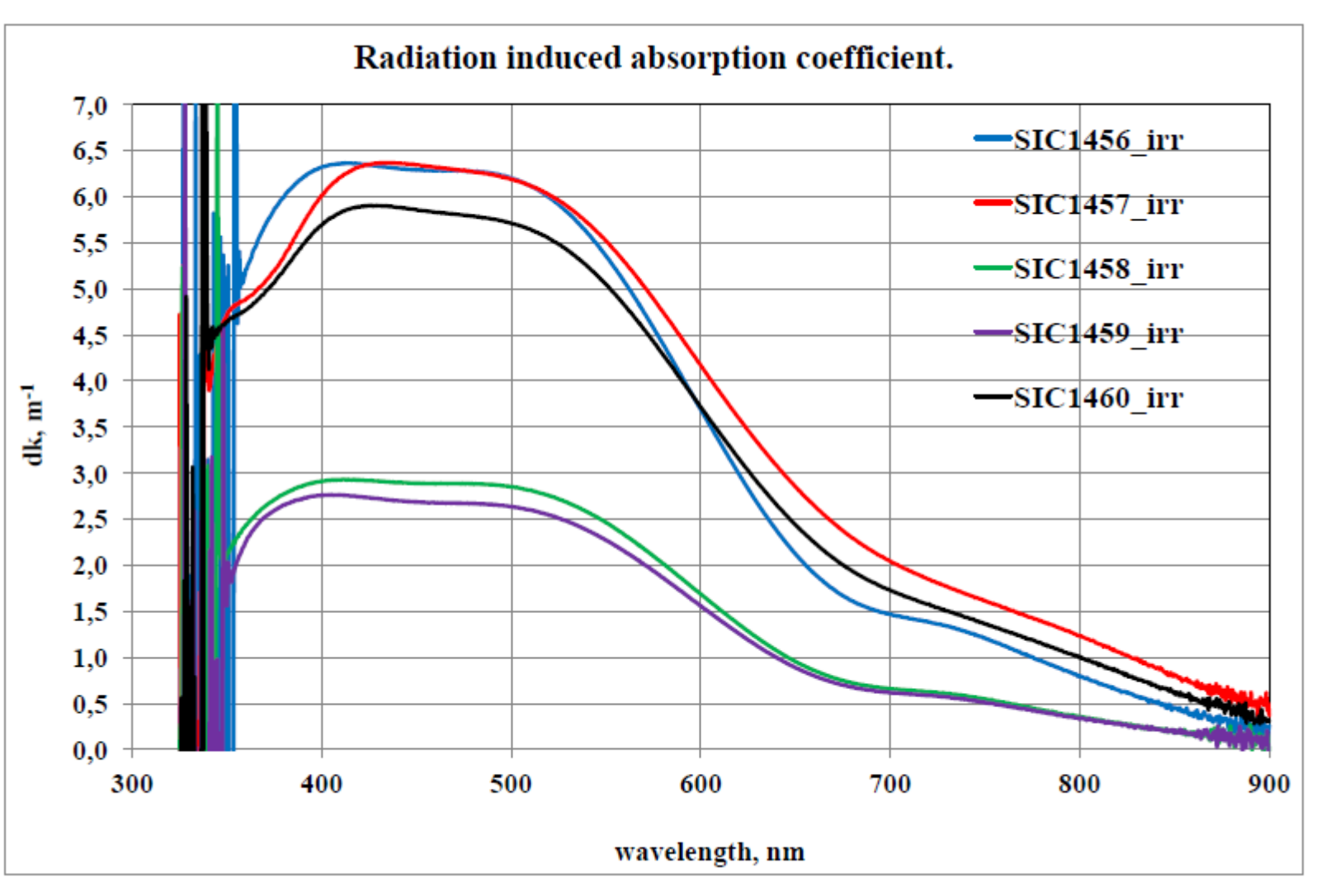

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1469	26,9	56,9	69,0	21,2	90,7	0,44
1470	25,5	56,2	70,3	22,8	90,0	1,33
1471	24,7	57,8	70,8	20,6	90,5	0,80
1472	33,6	59,1	72,1	20,7	90,1	0,16
1473	22,2	60,3	72,2	20,8	90,7	0,71
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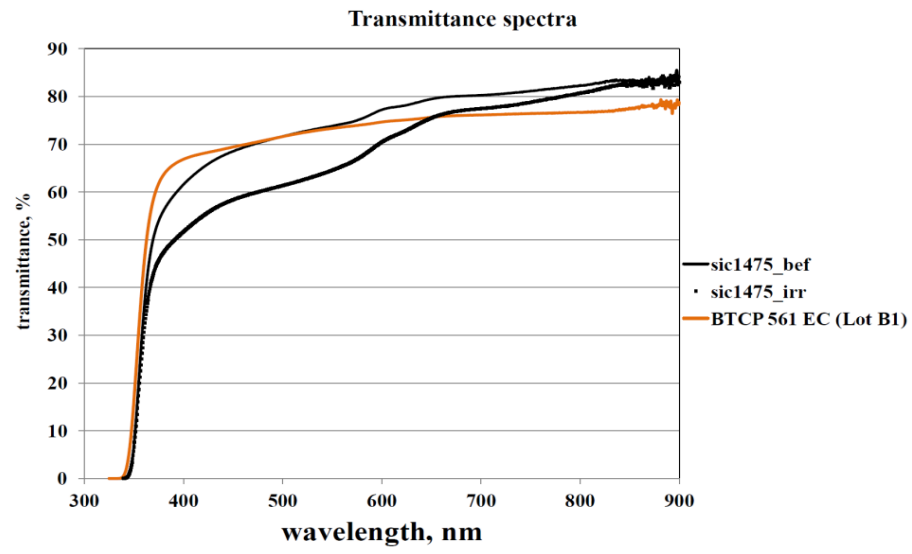
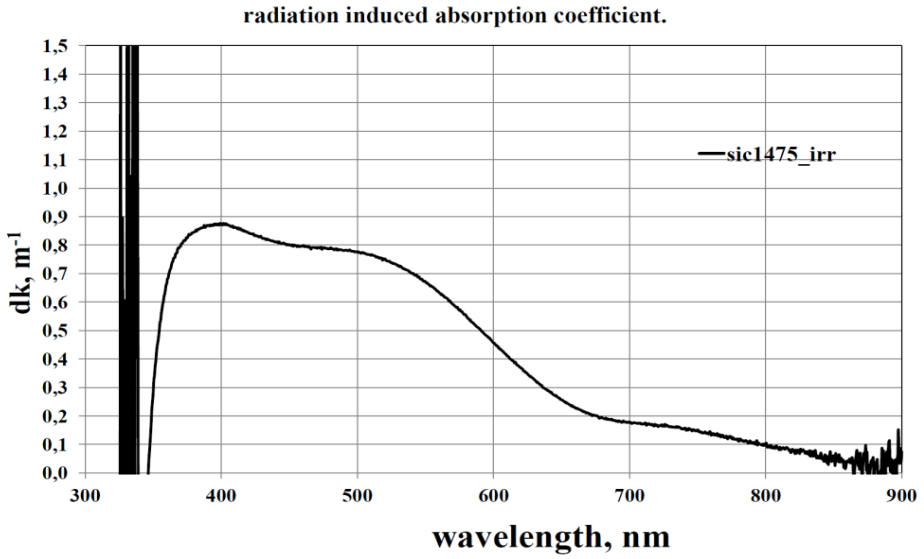
- **recent delivery from SICCAS May 2015**

SICCAS 1475





• additional new PWO manufacturer

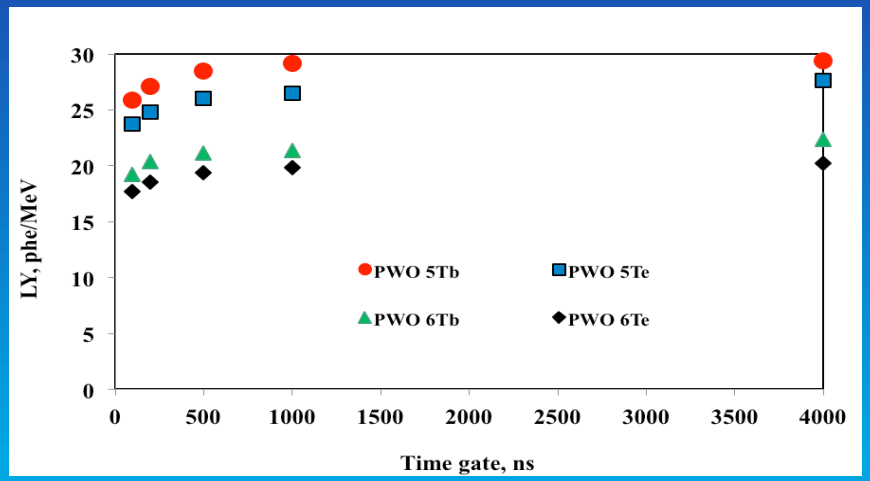
CRYTUR – Turnov, Czech Republic

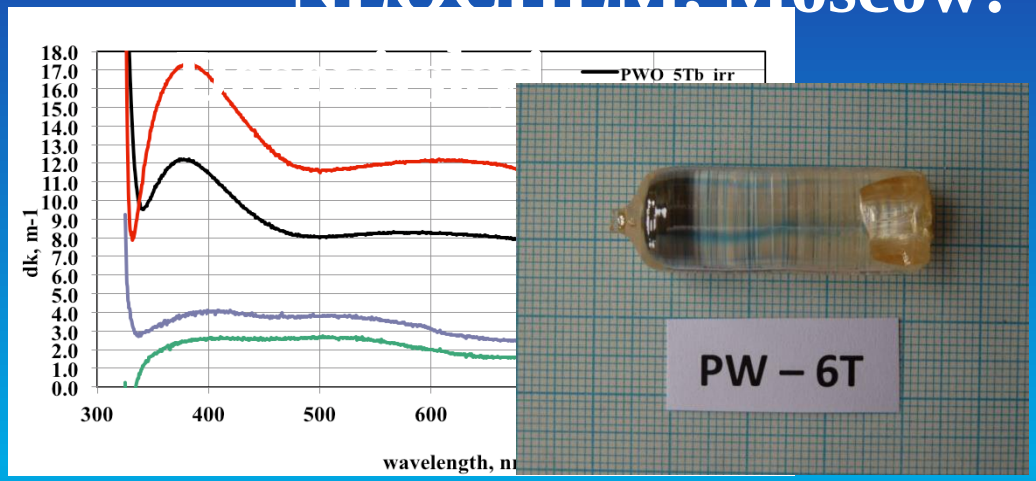
- R&D phase just started (June 2014)
- Czochralsky technology (identical to BTCP)
- know-how and raw material still available

• start results @ CRYTUR (1)

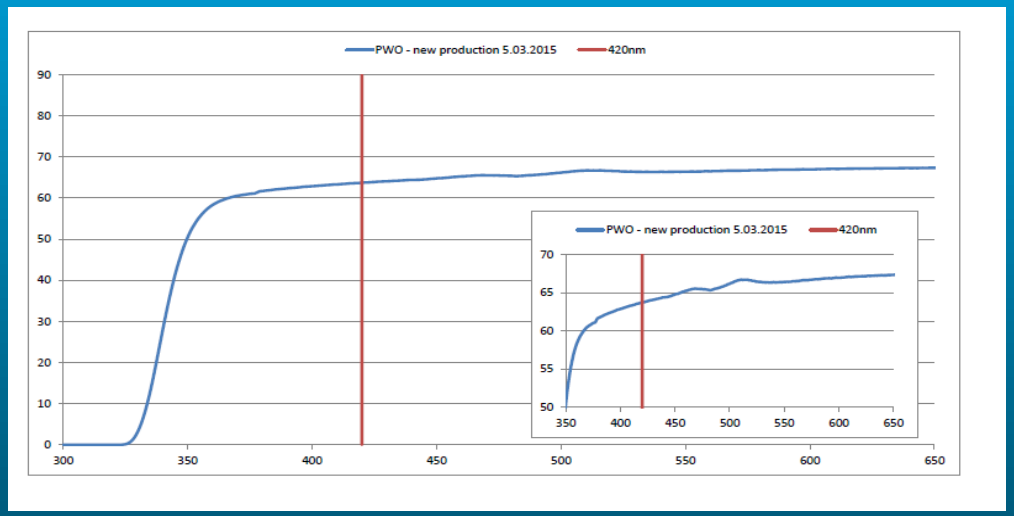
supported by: RINP Minsk: M. Korjik NEOCHEM, Moscow:

• first experiences under different conditions: small test samples



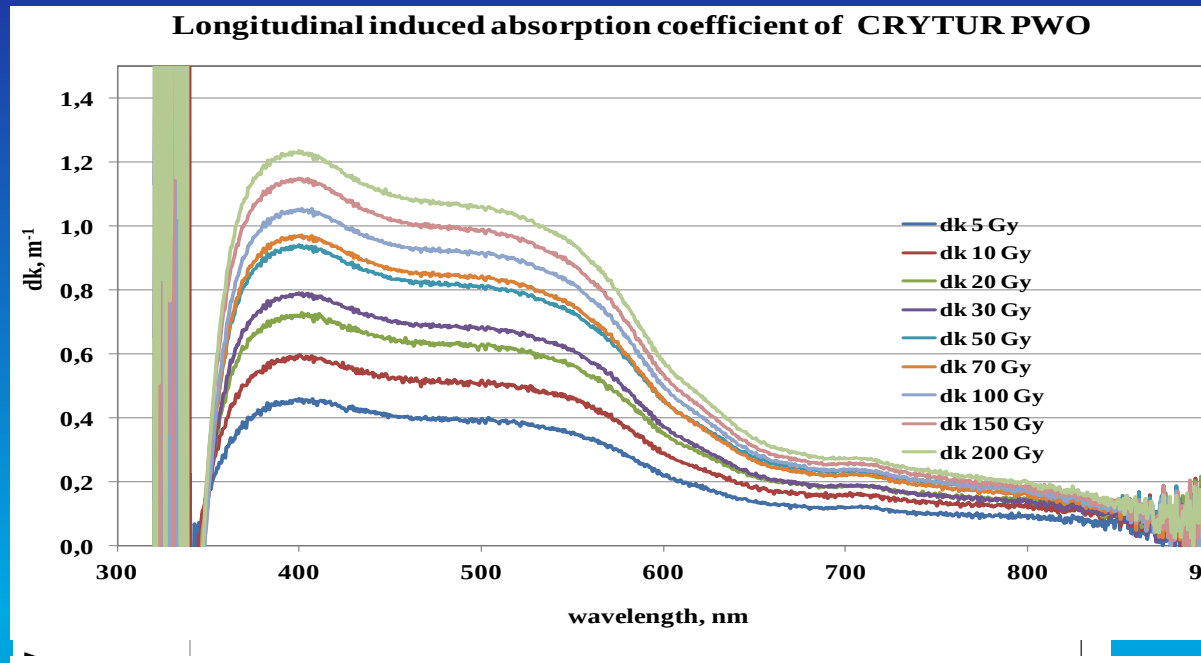


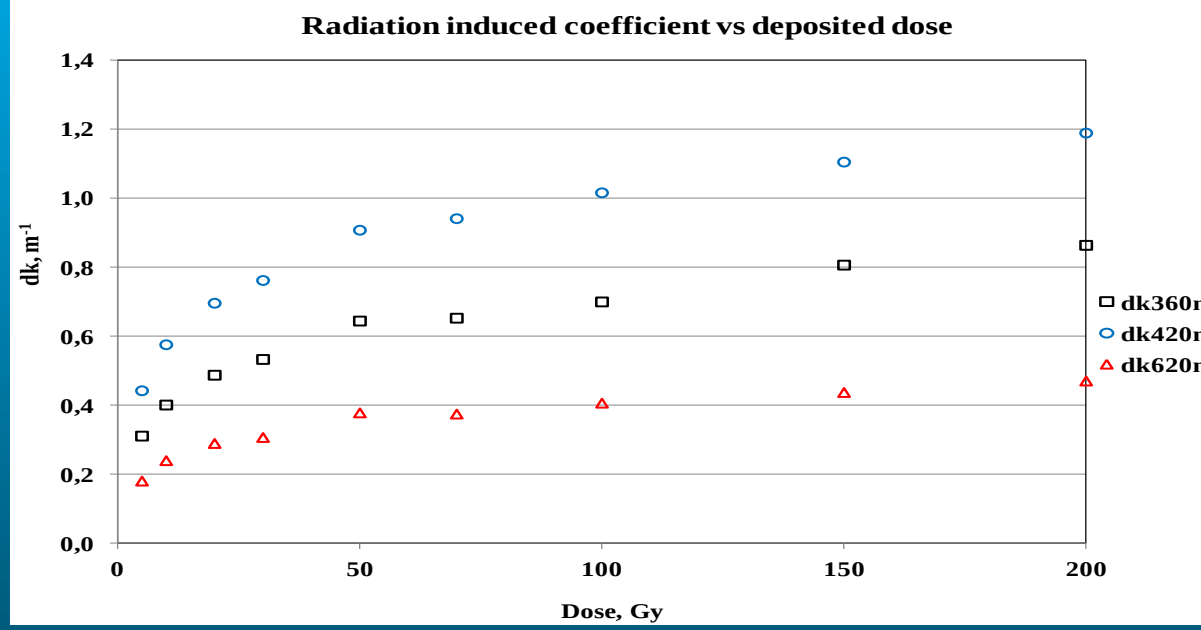
• first and second full size ingot (~ 23cm long)



• start results @ CRYTUR (2)

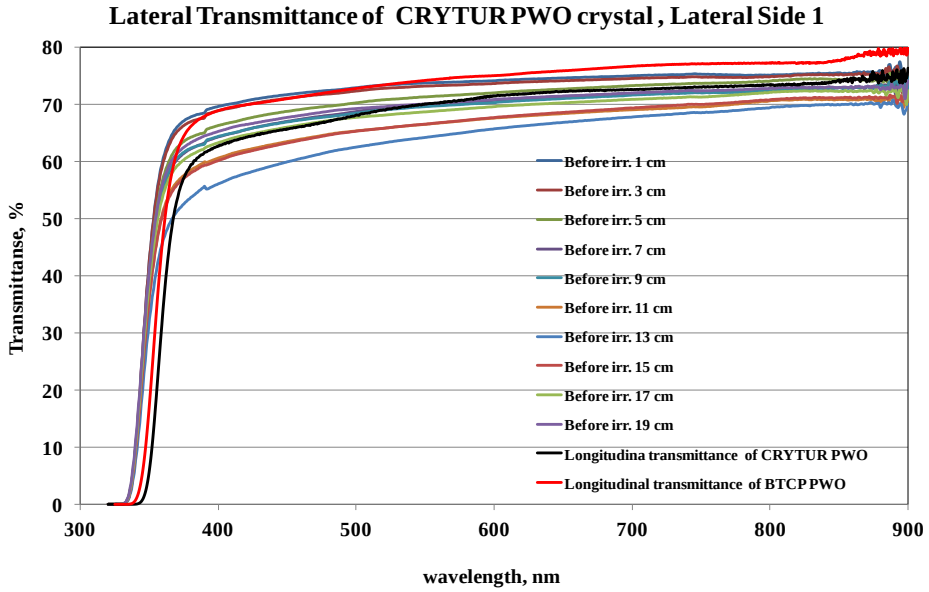
test crystal:
20 x 20 x 200 mm^3

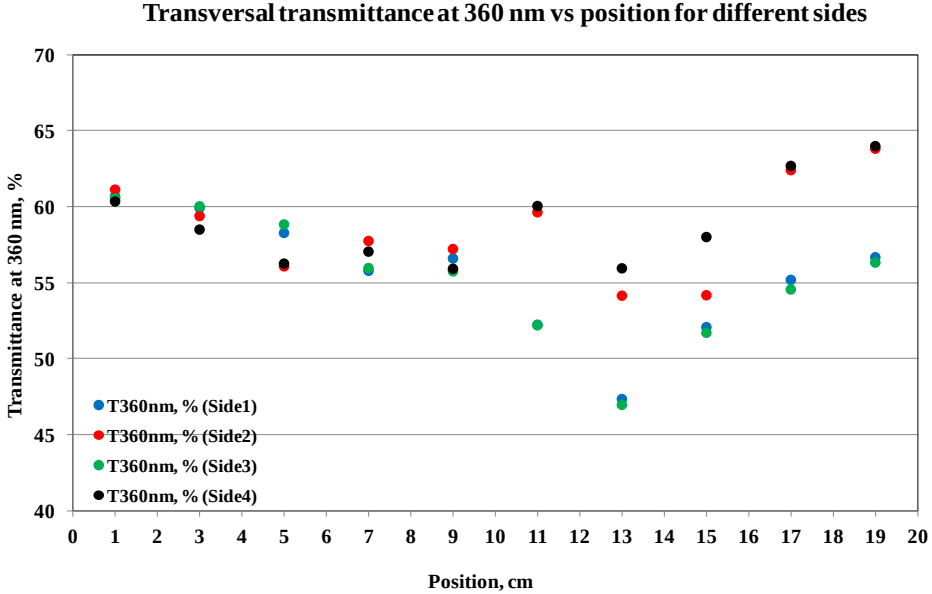


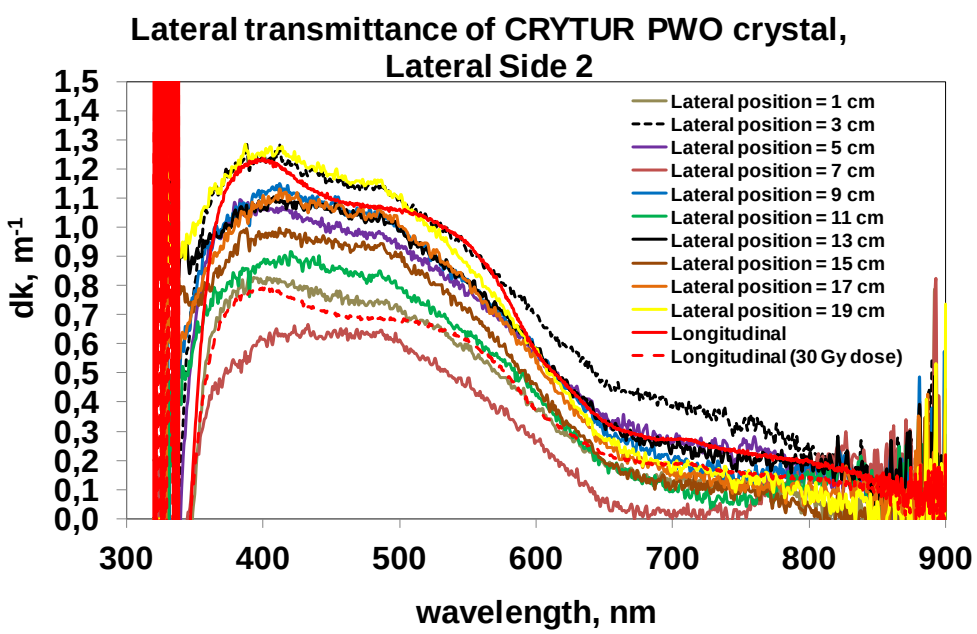


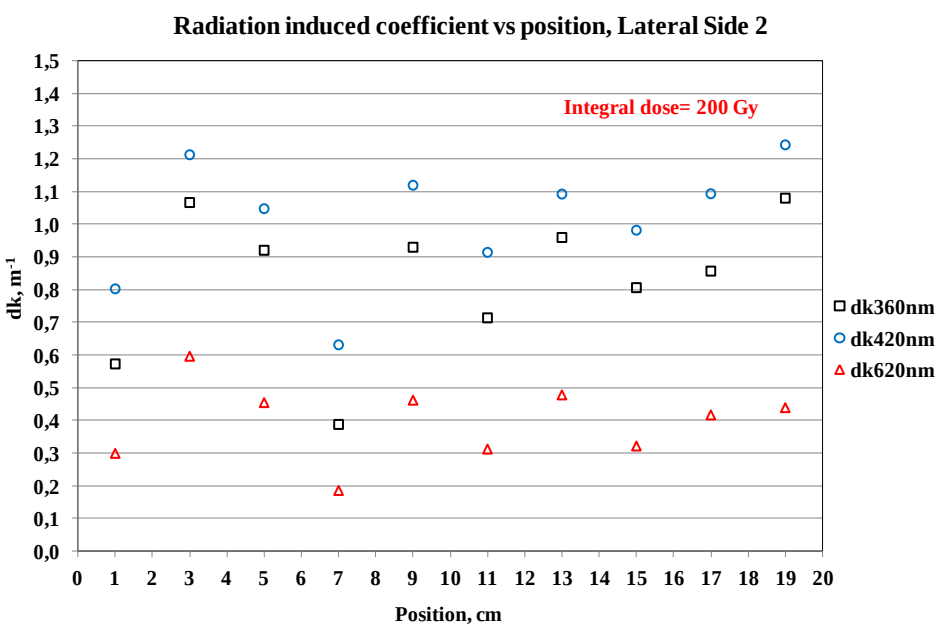
- **longitudinal inhomogeneity scattering centers**
- **sufficient light yield**
- **radiation hard**

test crystal: 20 x 20 x 200 mm^3

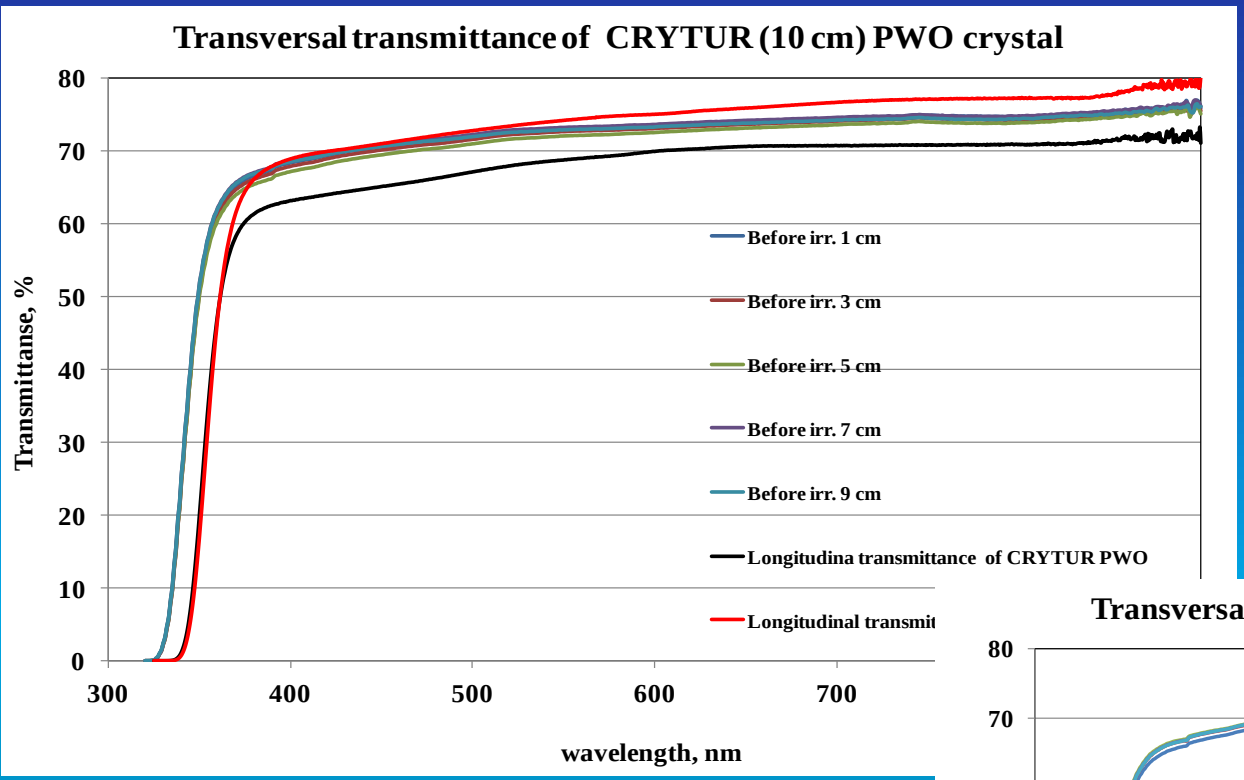


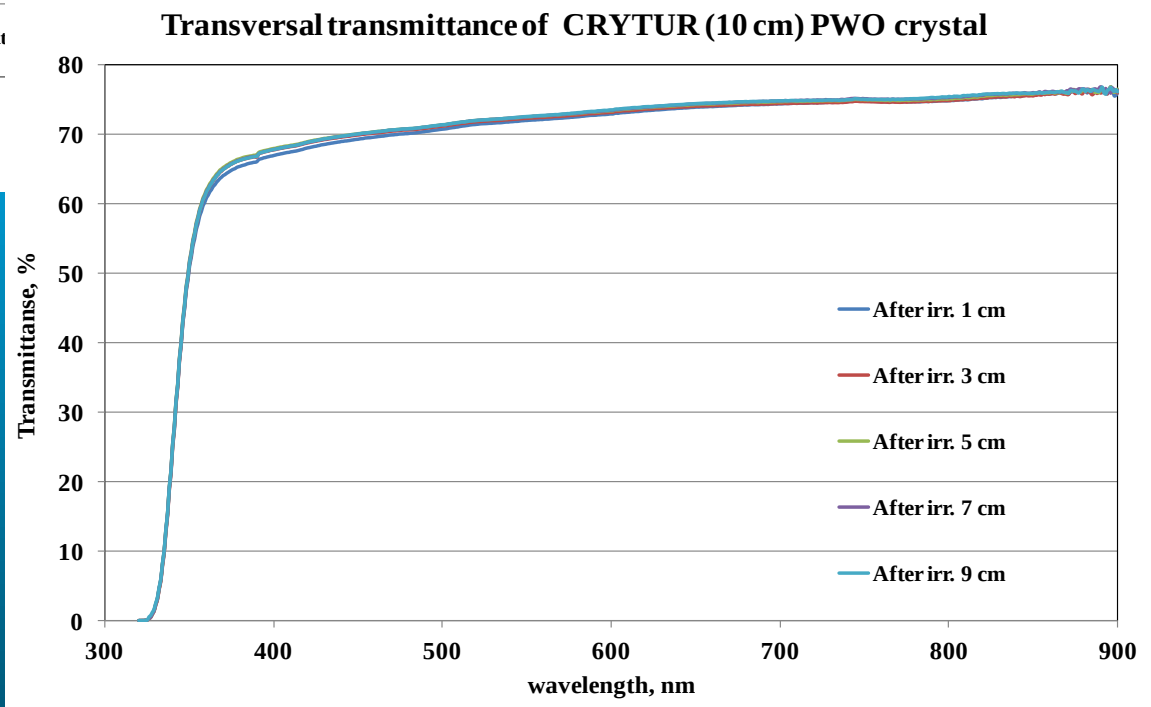




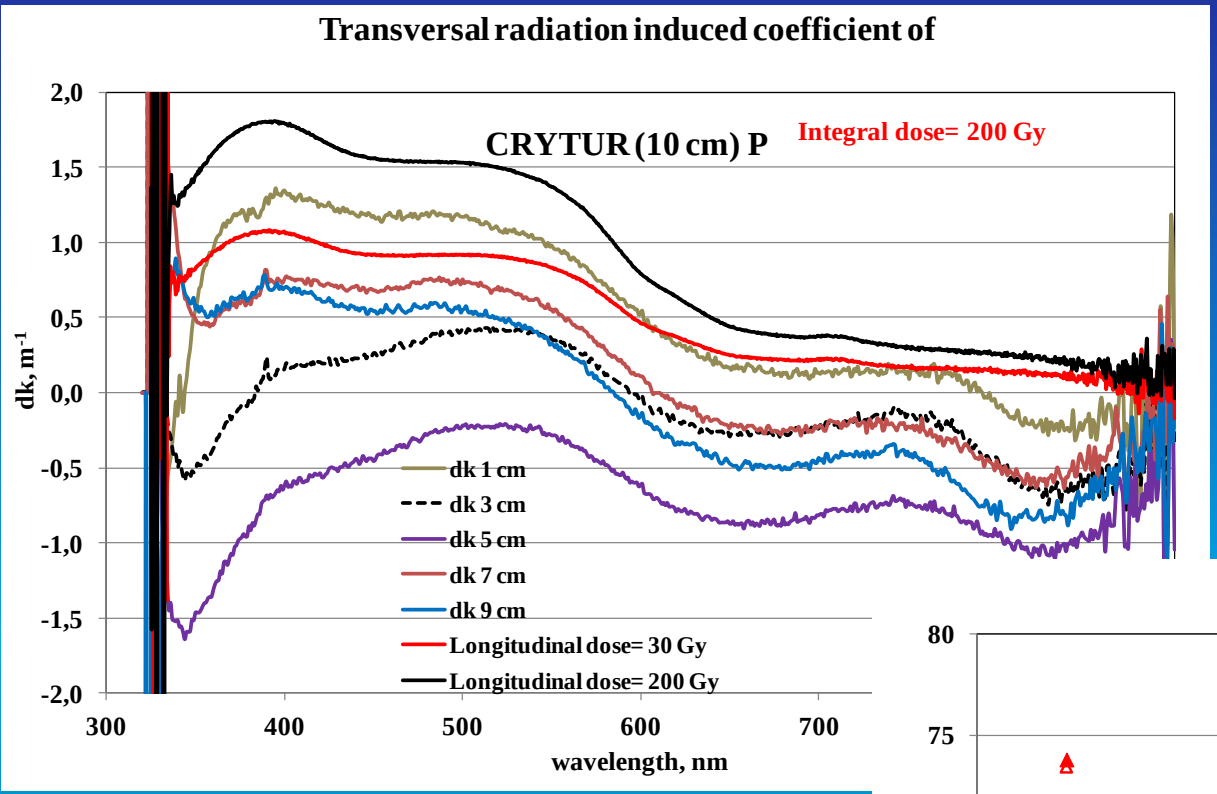


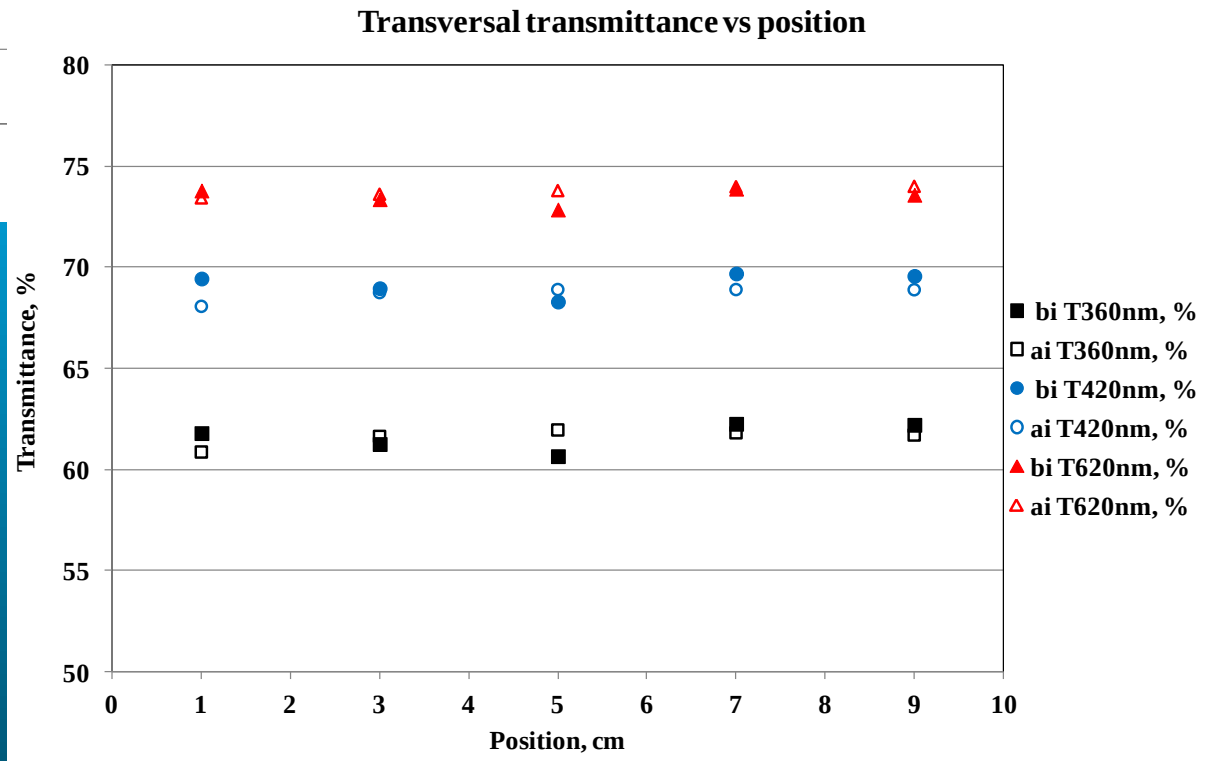
test crystal: 20 x 20 x 100 mm^3

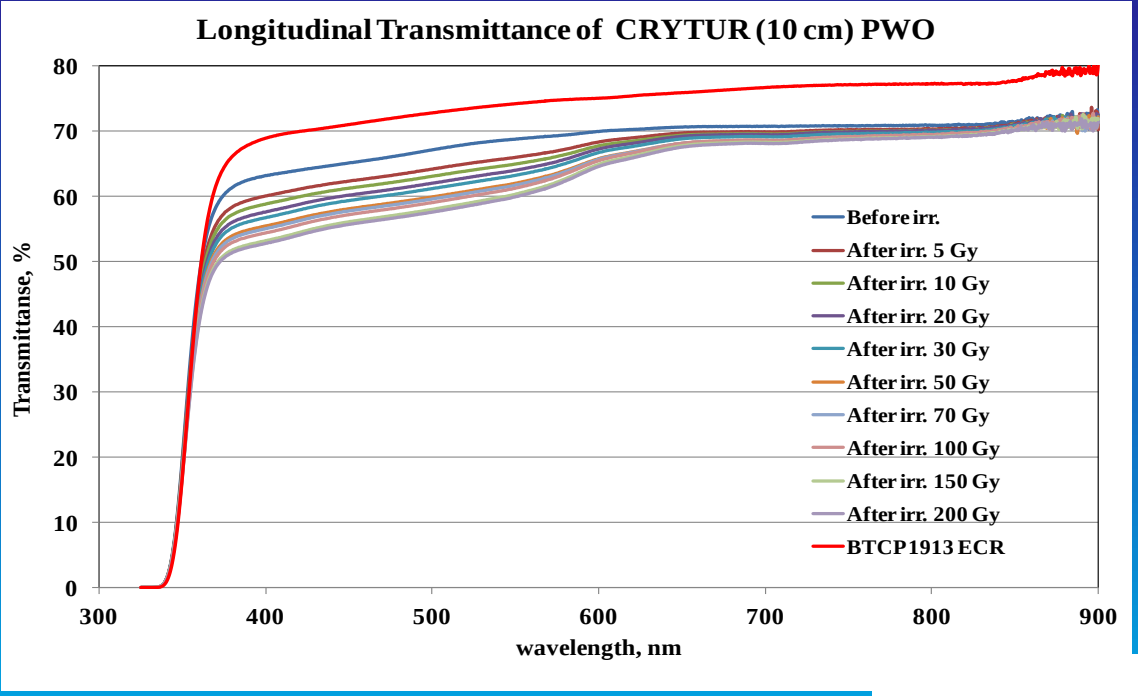




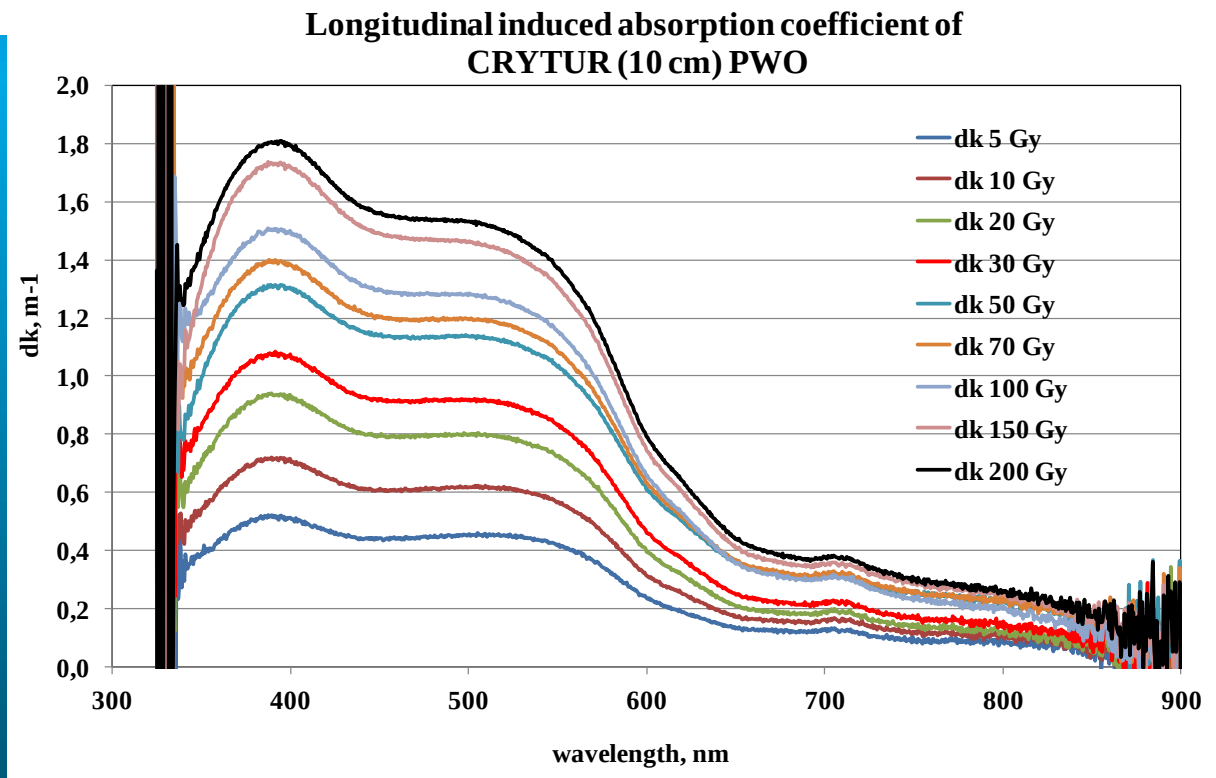
test crystal: 20 x 20 x 100 mm^3



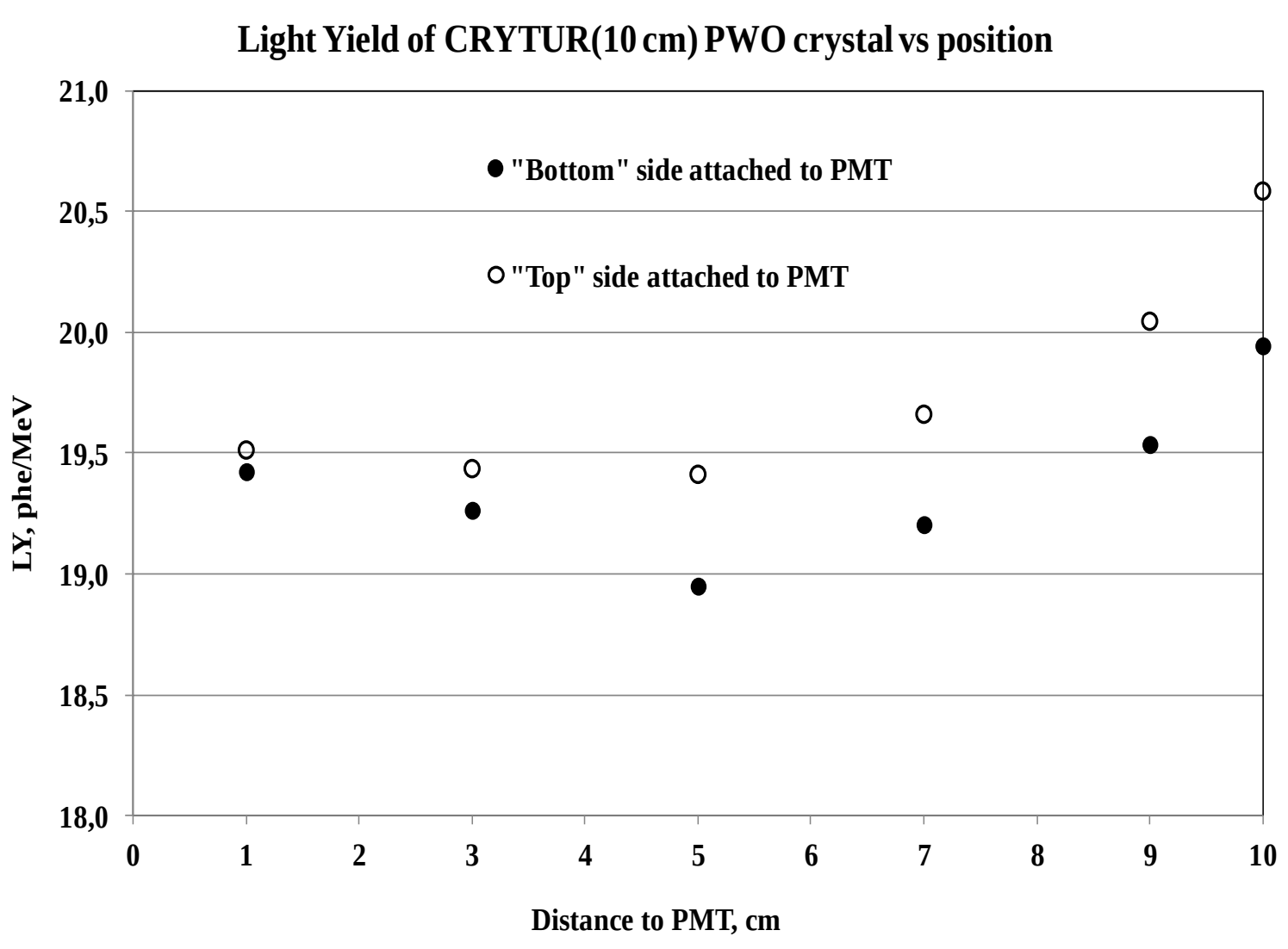




test crystal: 20 x 20 x 100 mm^3



test crystal: 20 x 20 x 100 mm^3



Status @ CRYTUR

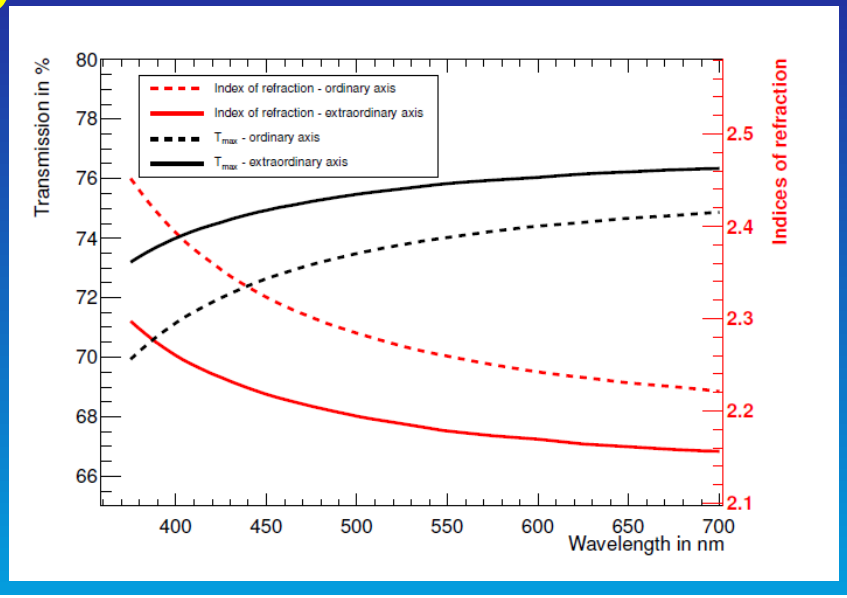
- **status July 15:** **installation of 4 ovens**
  polishing and cutting
- **order of R&D crystals**
  Giessen
  Uppsala
- **next meeting @Turnov: middle of July**
- **production start in August**

- **the quality requirements**

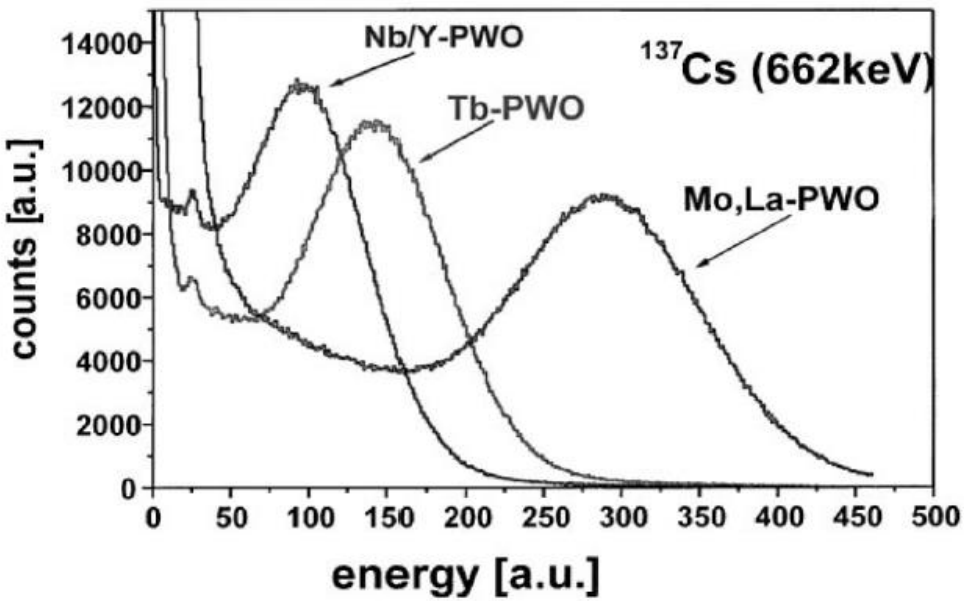
Property	Unit	Limit
longitudinal transmission at 360 nm	%	≥ 35
longitudinal transmission at 420 nm	%	≥ 60
longitudinal transmission at 620 nm	%	≥ 70
non-uniformity of transversal transmission at T= 50%	nm	≤ 3
LY at T= 18 °C	phe/MeV	≥ 16.0
LY(100 ns)/LY(1 μs)		≥ 0.9
induced absorption coefficient Δk at room temperature, integral dose 30 Gy	m^{-1}	≤ 1.1
mean value of Δk distribution for each lot of delivery	m^{-1}	≤ 0.75

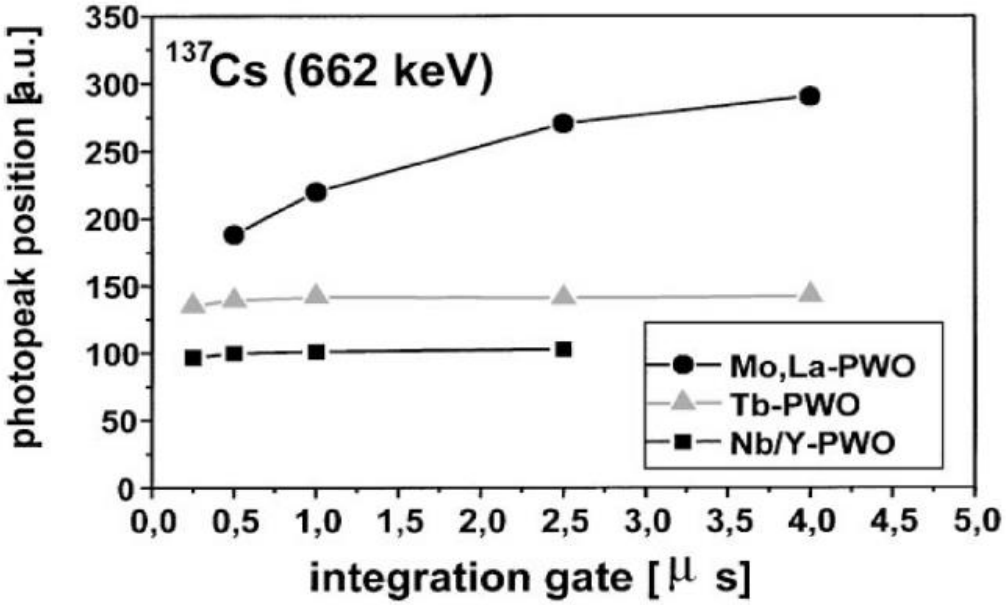
• some general remarks on PWO

index of refraction



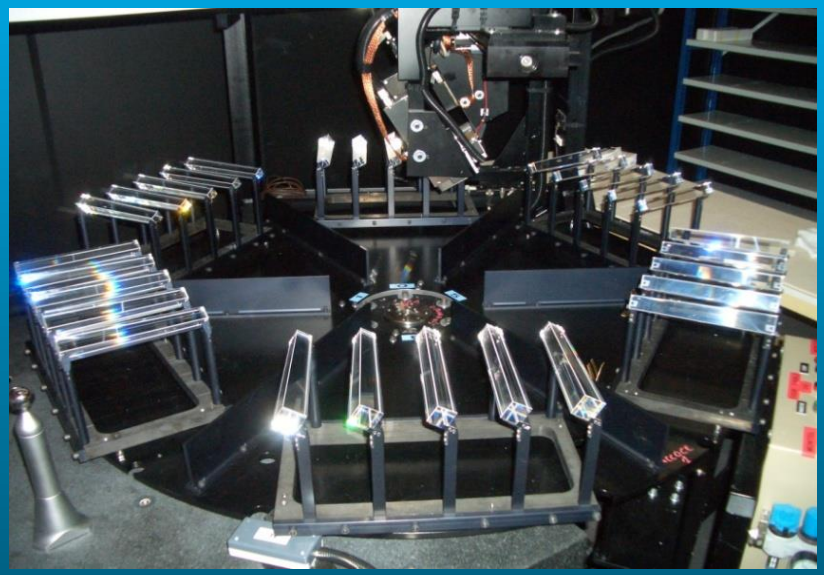
increased light yield due to doping



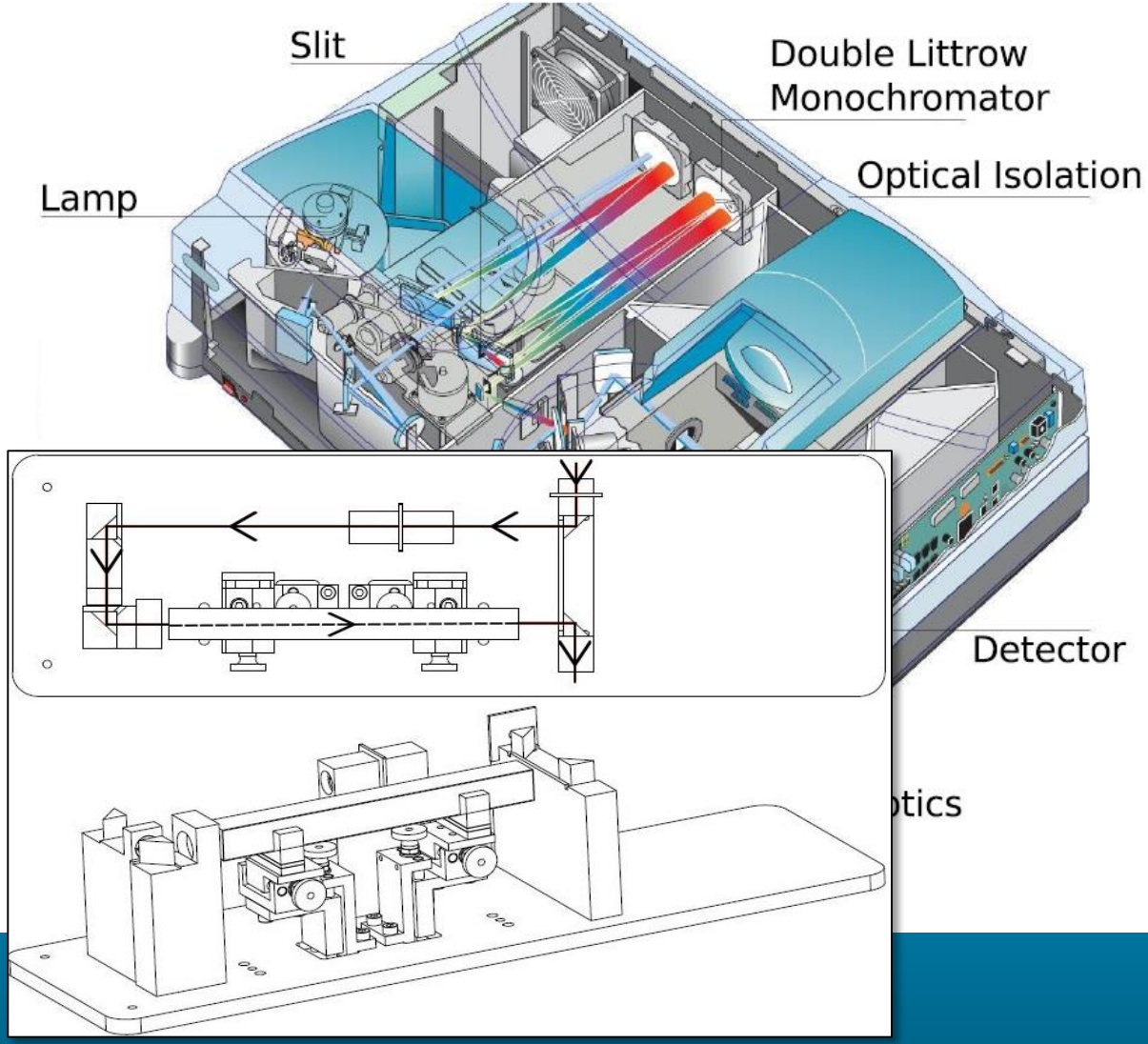


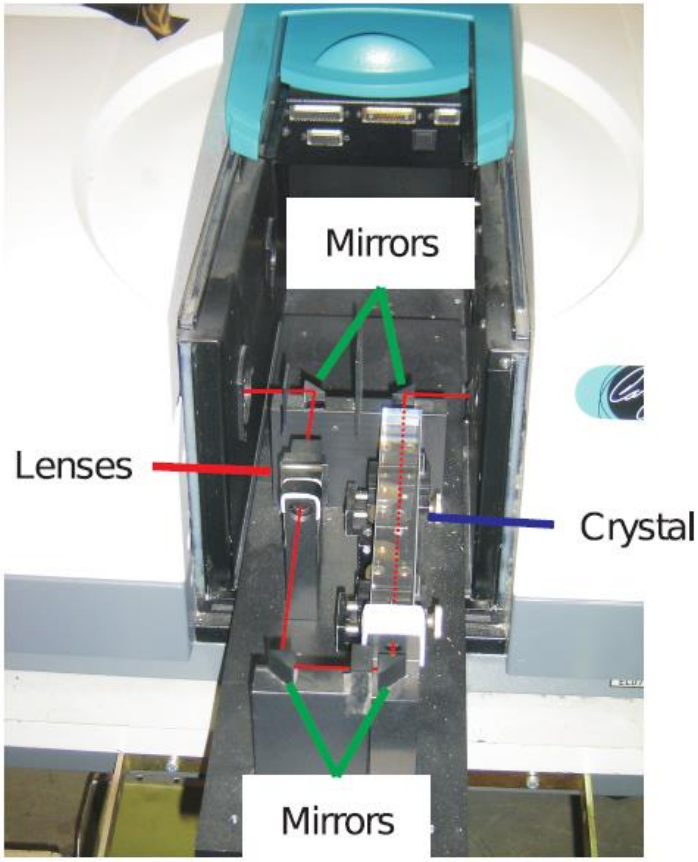
- **production at BTCP**

- **quality control and performance**



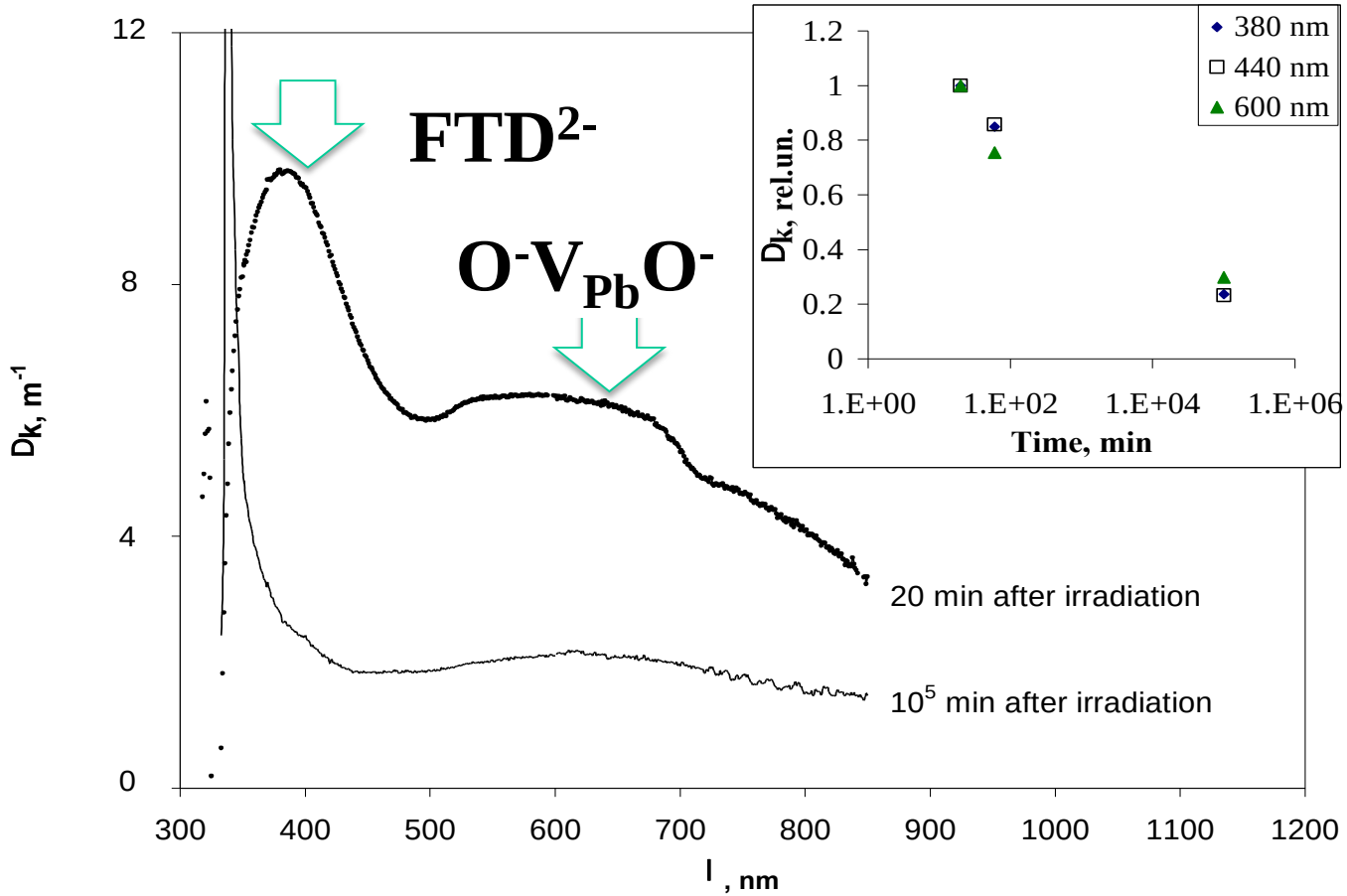
• the optical transmission





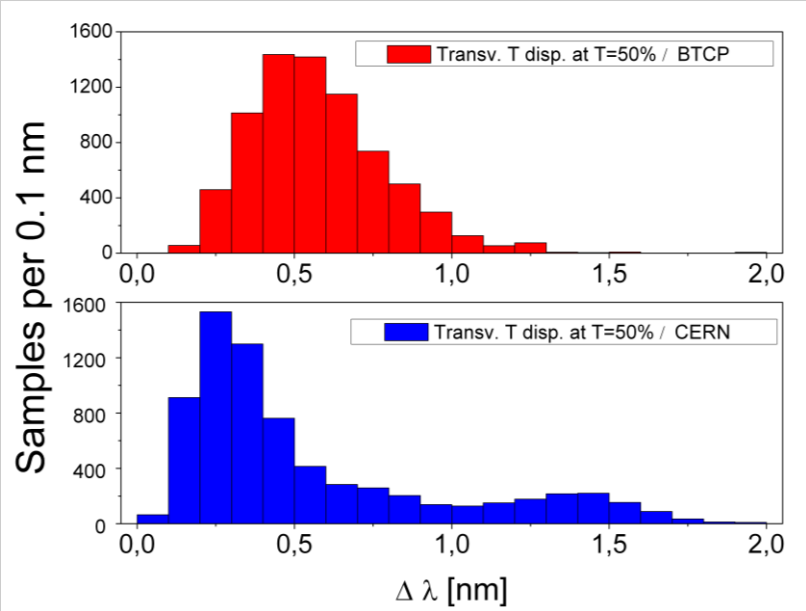
(b) Additional optics by [29].

• radiation hardness



Typical induced absorption spectra of PWO undoped and uncompensated crystal grown in early days

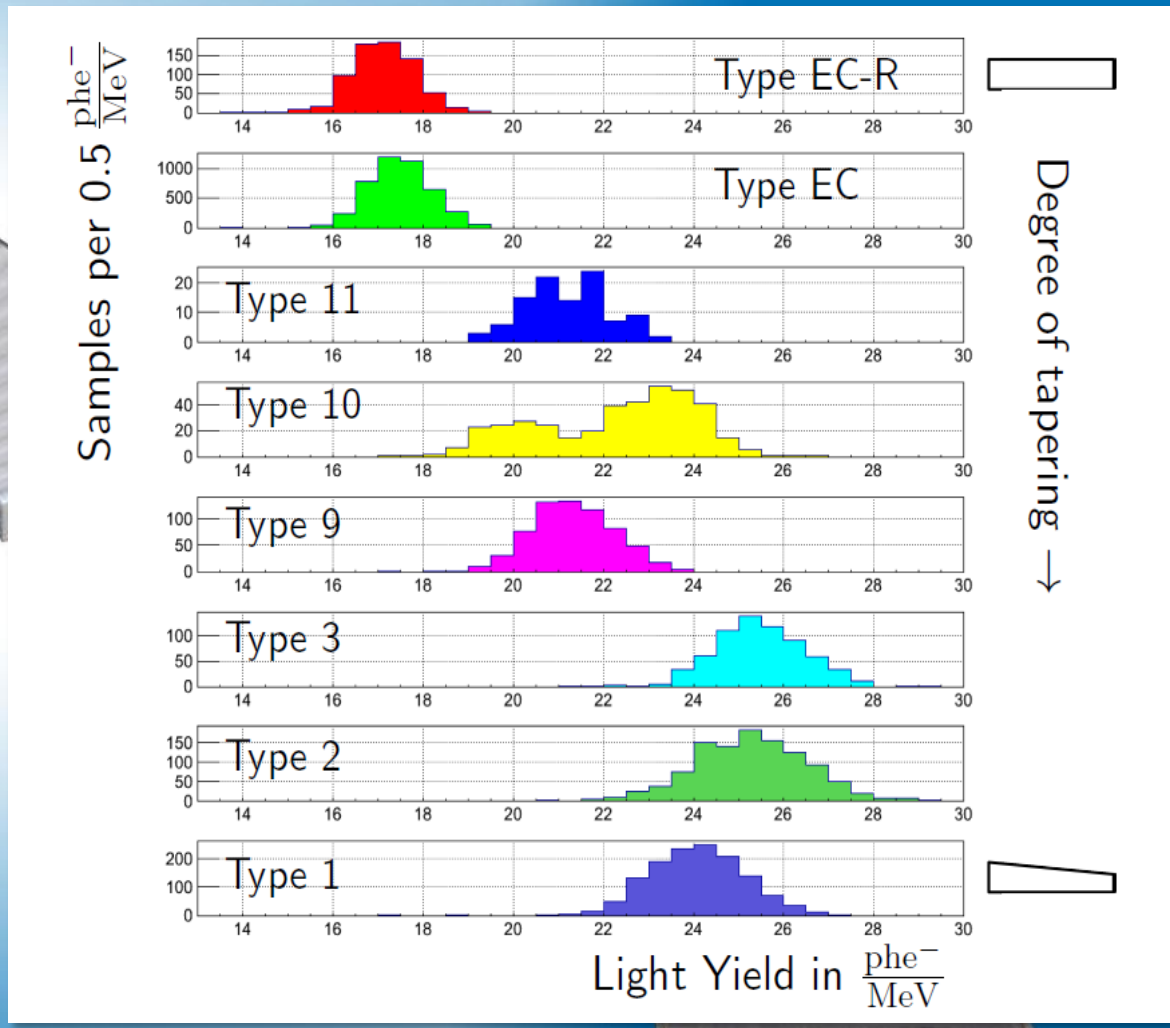
• optical longitudinal transmission



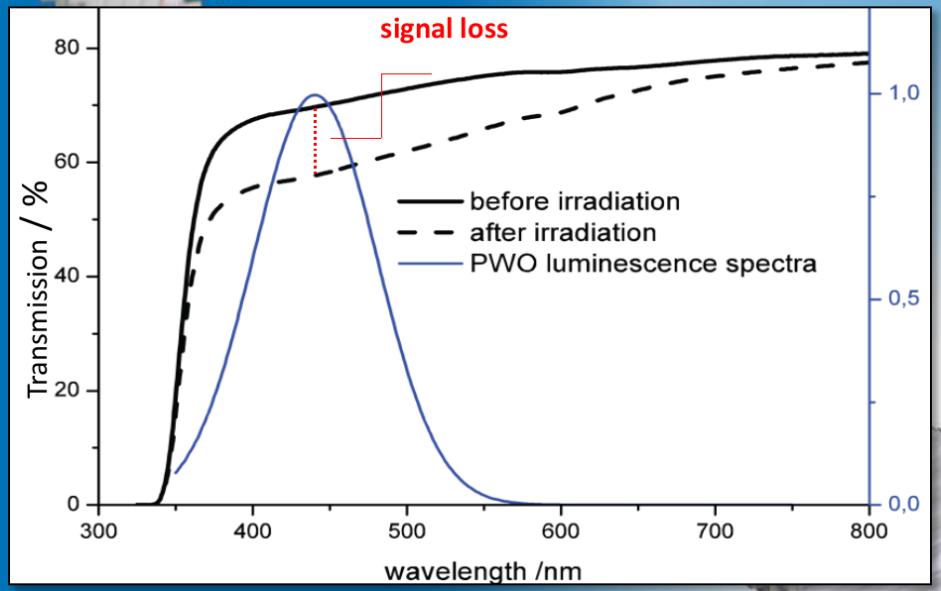
longitudinal homogeneity

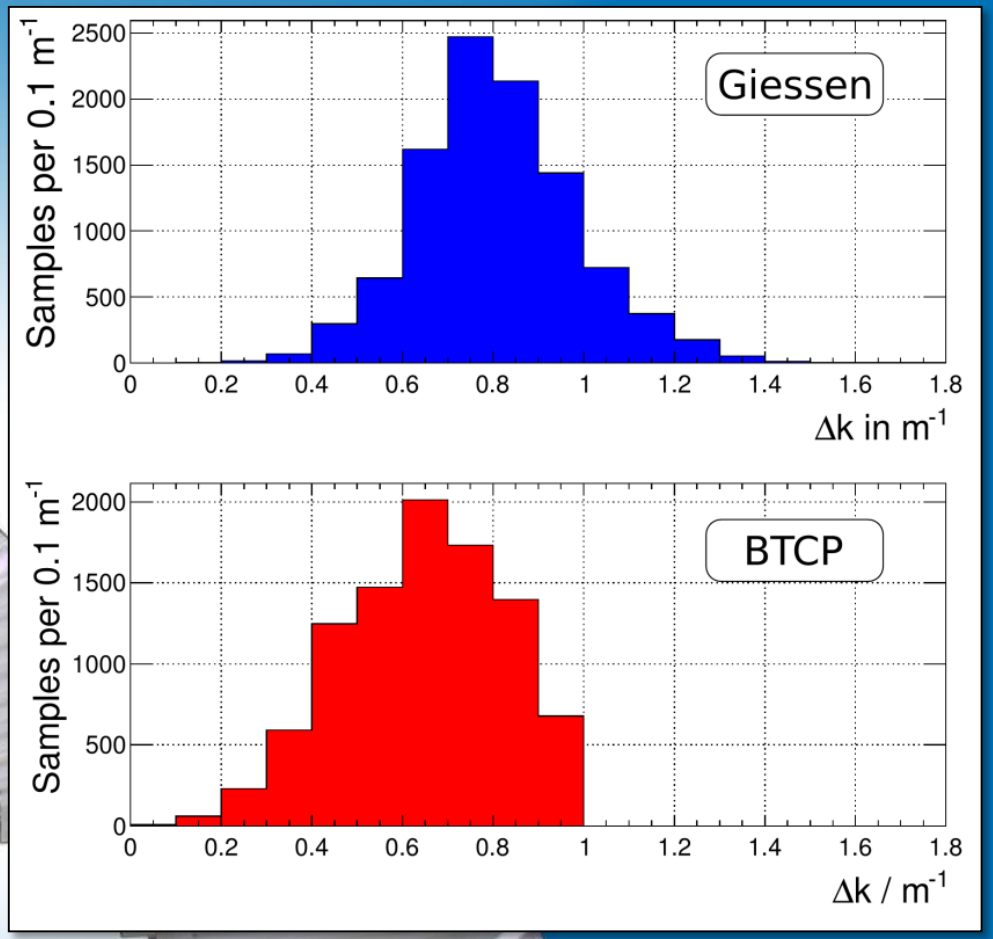
property	condition	specification
longitudinal transmission	at 360nm	$\geq 35\%$
	at 420nm	$\geq 60\%$
	at 620nm	$\geq 70\%$
uniformity of transv. transmission	wavelength at $T = 50\%$	$\Delta\lambda \leq 3$nm

• light yield @ 18ºC



• radiation hardness





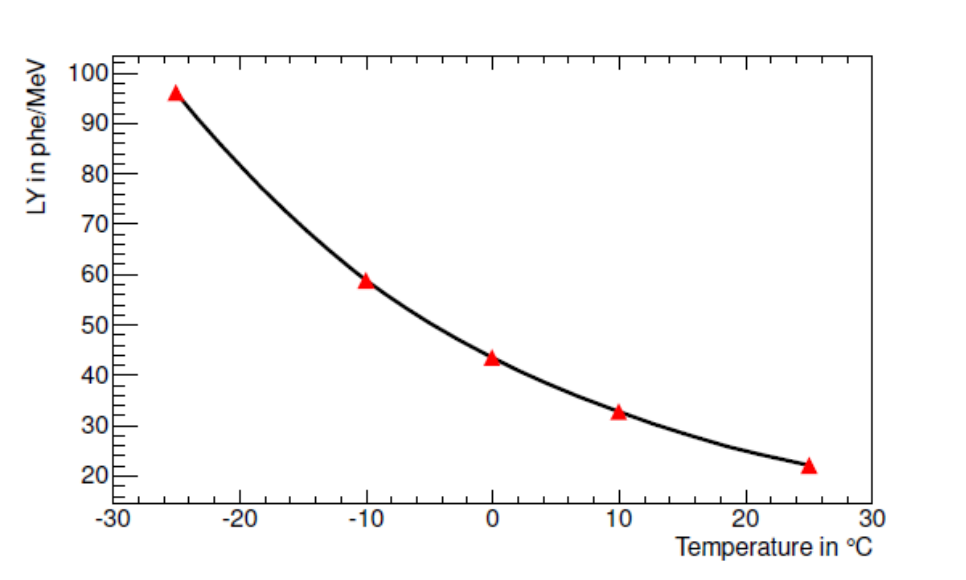
tested using γ-rays: ~ 1.2 MeV
^{60}Co
integral dose: 30Gy

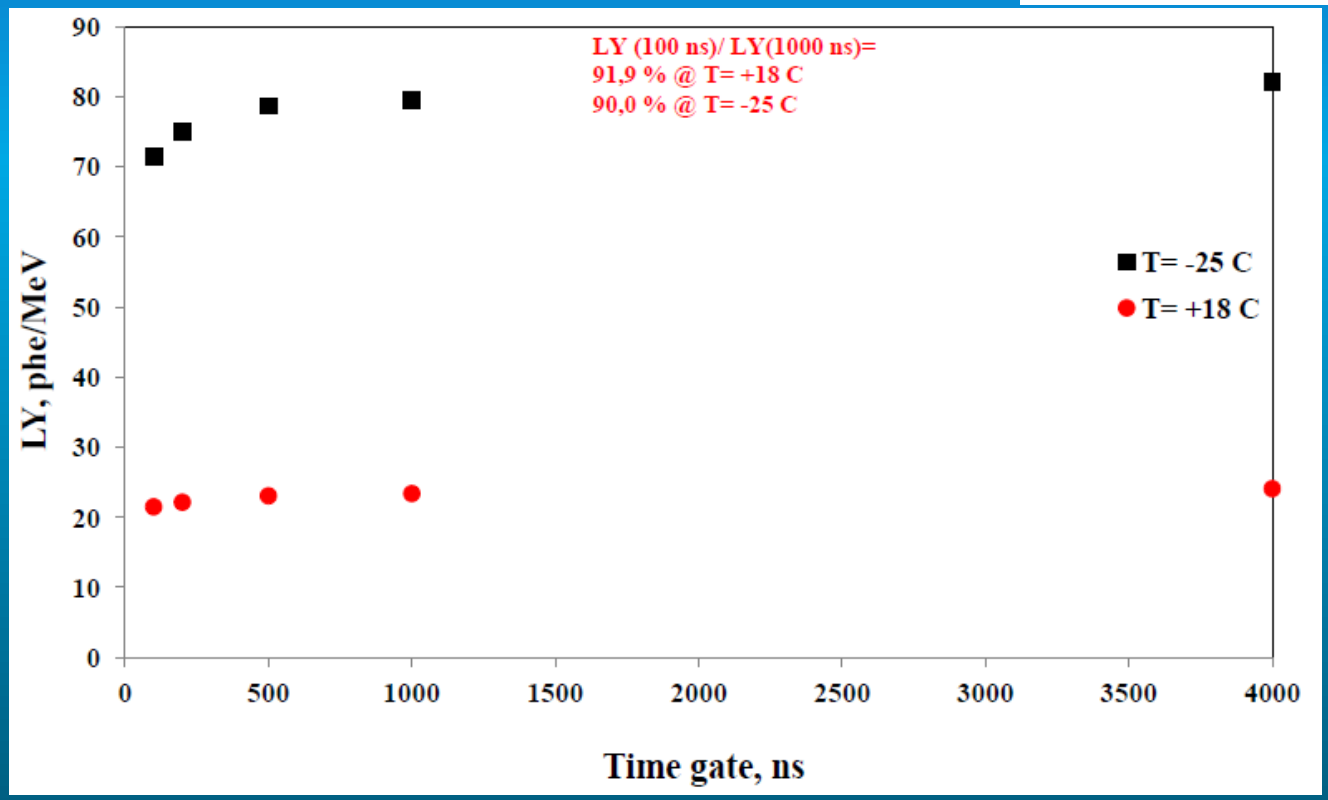
$$\Delta k = \ln\left(\frac{T_{bef}}{T_{after}}\right)\cdot\frac{1}{d}$$

acceptance limit: $\Delta k < 1.1\ m^{-1}$

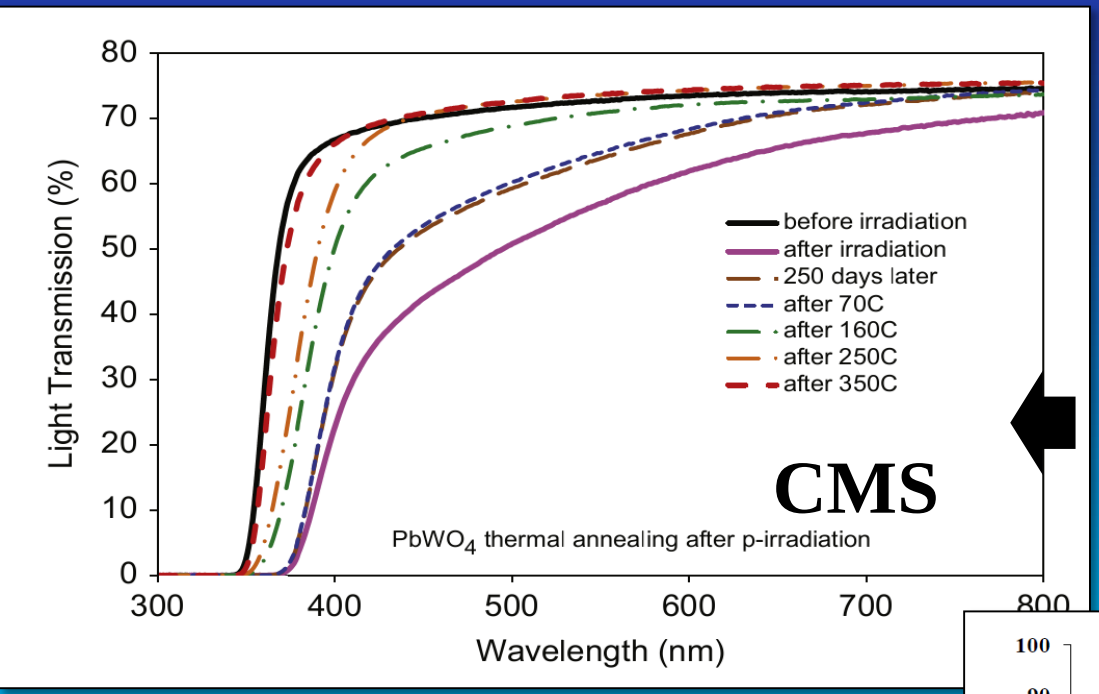
• light yield measurement

temperature dependence of luminescence





• observation of severe radiation damage due to hadrons



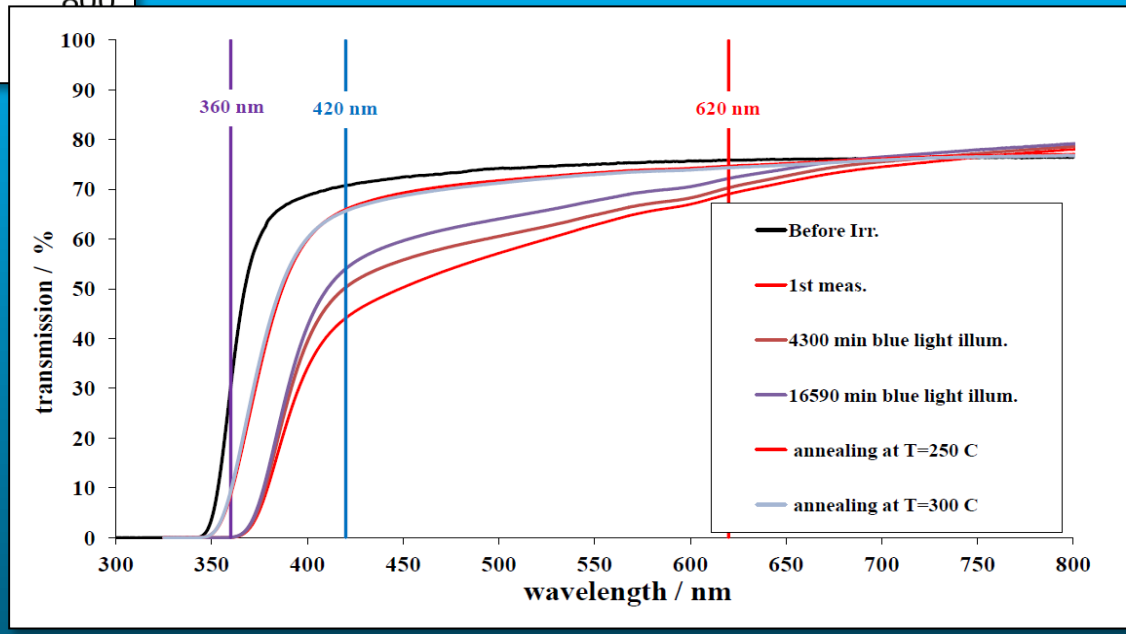
G. Dissertori et al., NIM A684 (2012)57

24 GeV/c protons

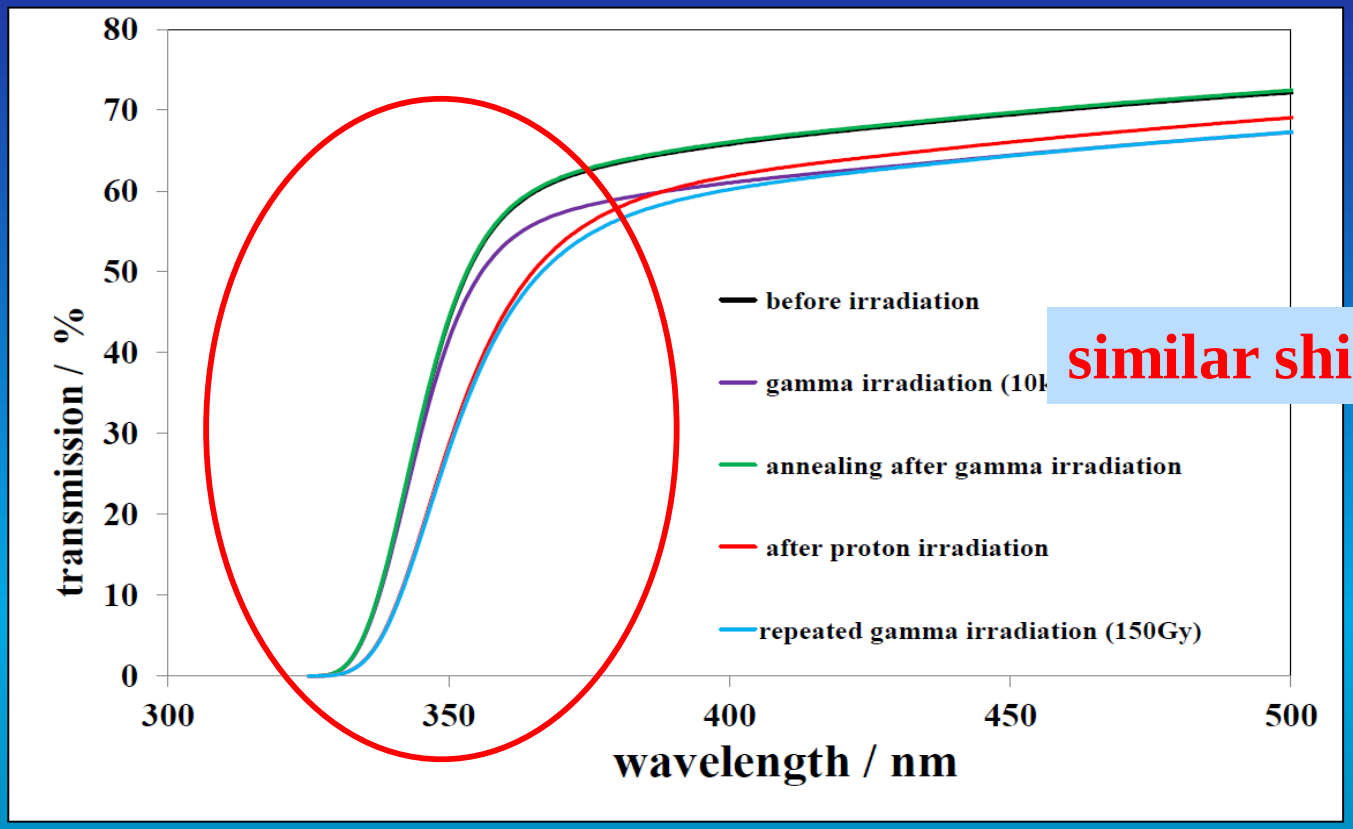
fluence: $(1.32 \pm 0.11)10^{13}cm^{-2}$

thermal treatment up to T=350°C

measurements and treatments @ GI
started several months after irradiation:
stimulated recovery + heating



- **similar observation for 150MeV protons**



fluence: 1.8 x 10^{13}p/cm^2

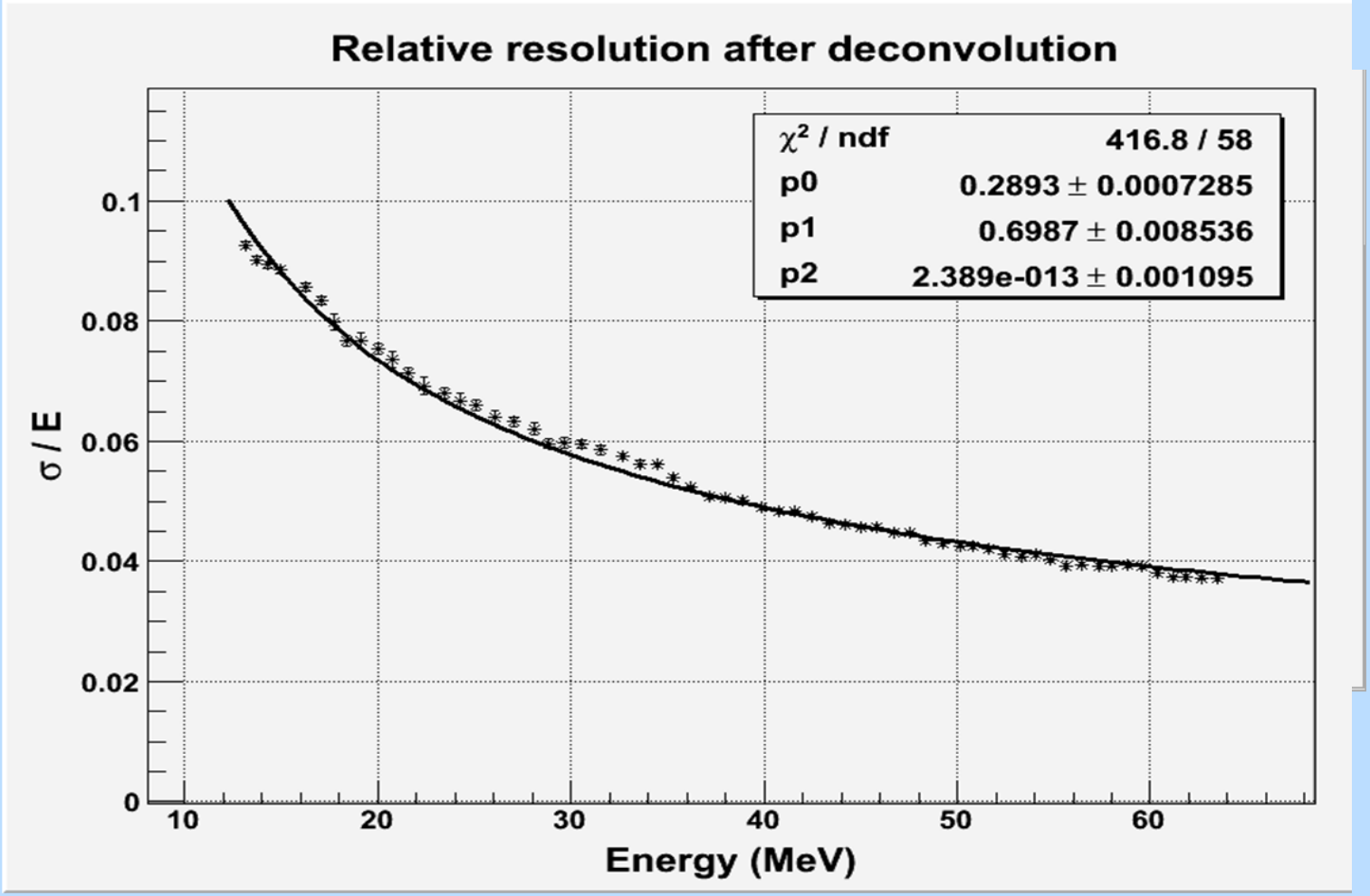
similar shift like at 24GeV/c

- **strong radiation damage due to protons at high fluence**
  severe damage due to highly ionizing secondaries
  clusters of color centers due to ion displacements
- **damage due to γ-rays: stimulated recovery**
  proton damage: annealing by heating

prototype performance

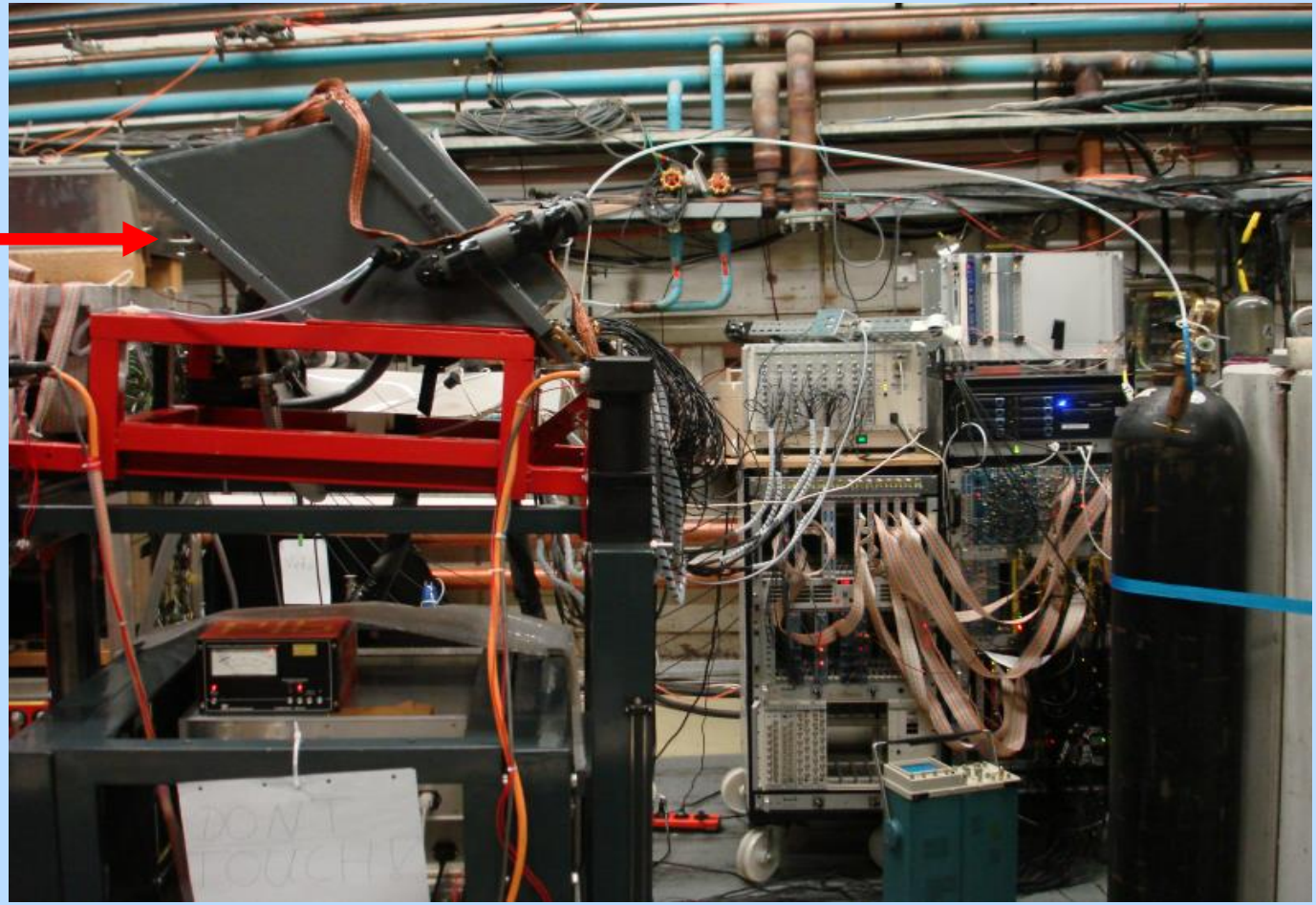
- optimized light output: PWO-II
- cooling: operation at T=-25°C

extension to energies < 50MeV @ MaxLab

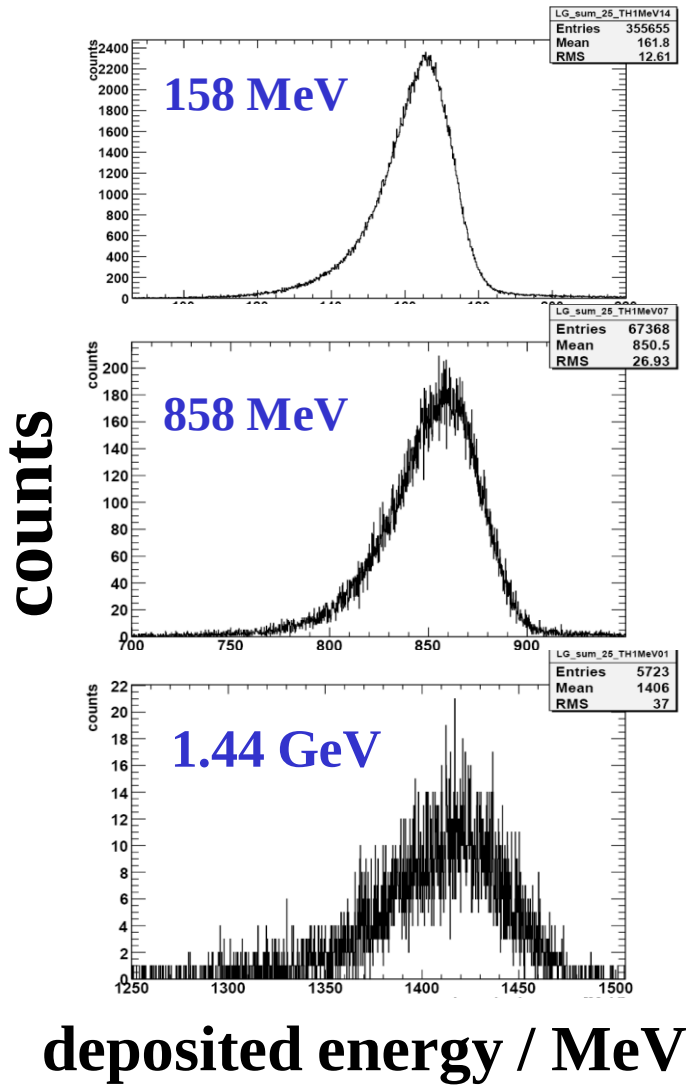


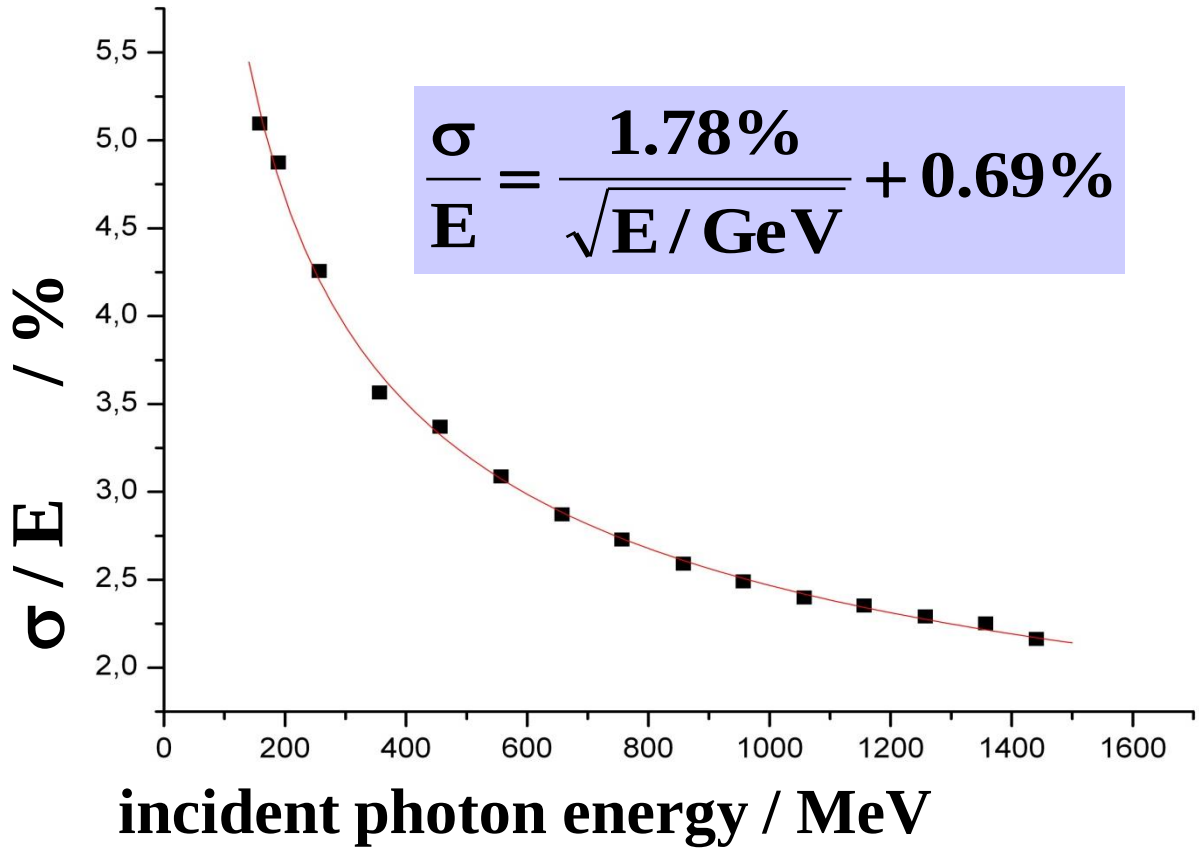
prototype performance PROTO 60

photon beam



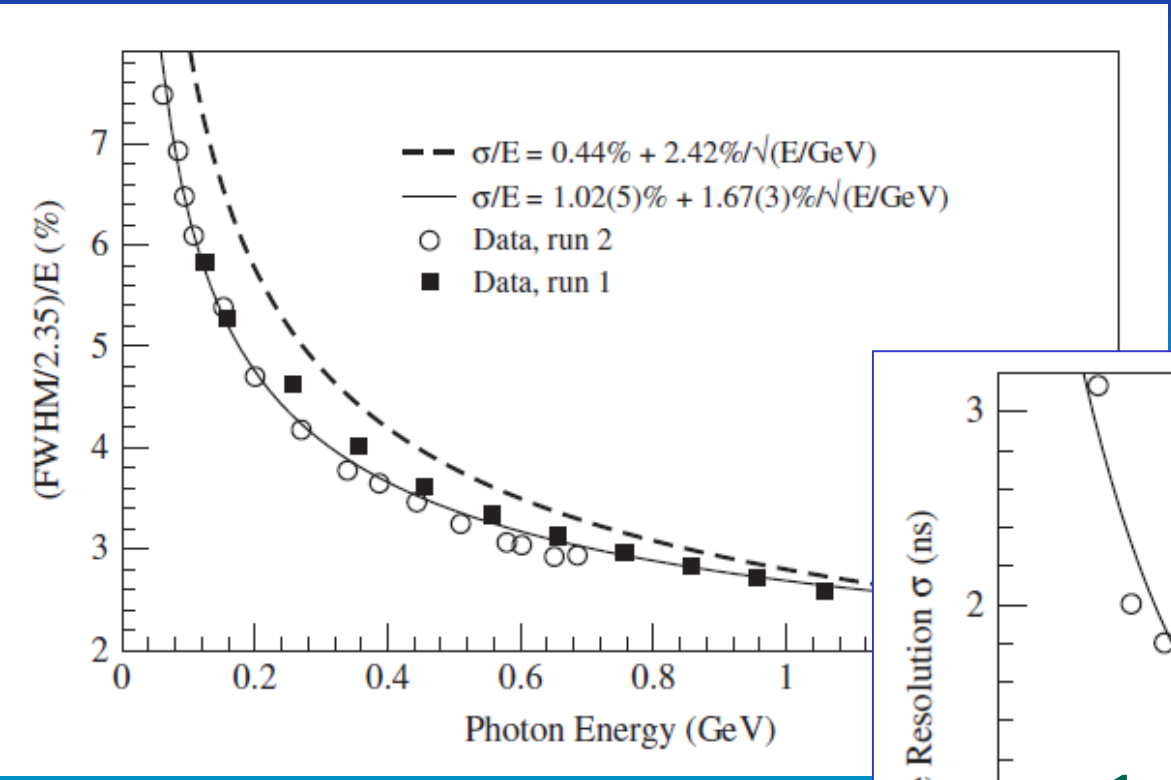
prototype performance PROTO 60



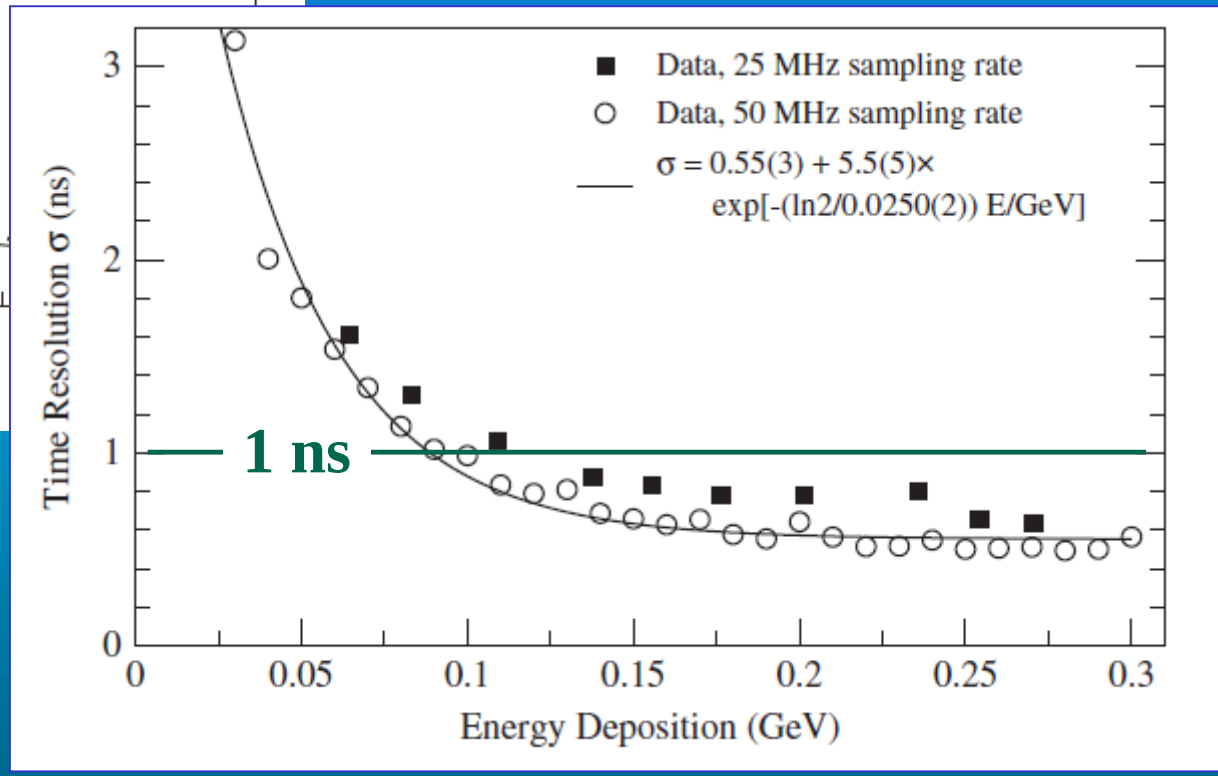


- **digitization:**
  shaping /peak-sensing ADC

readout via SADC: → further improvement

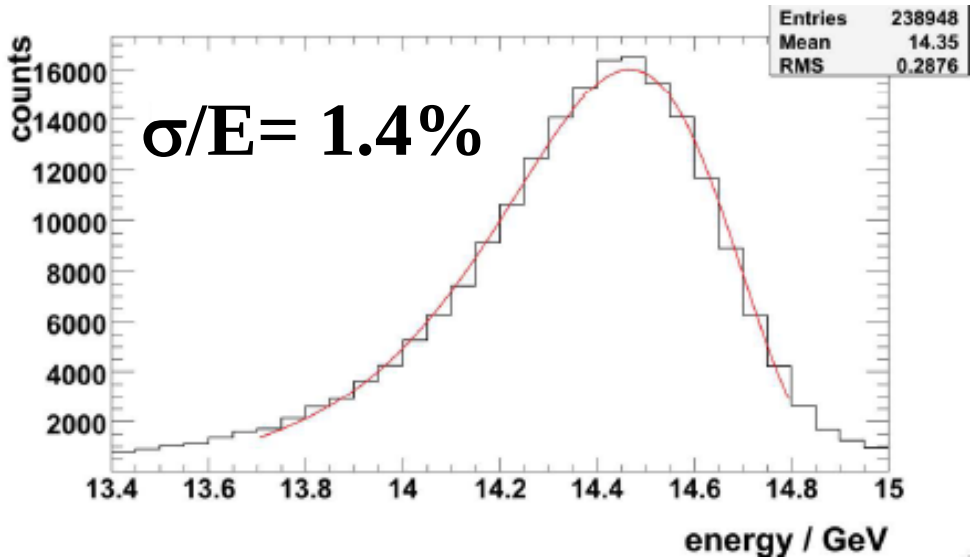


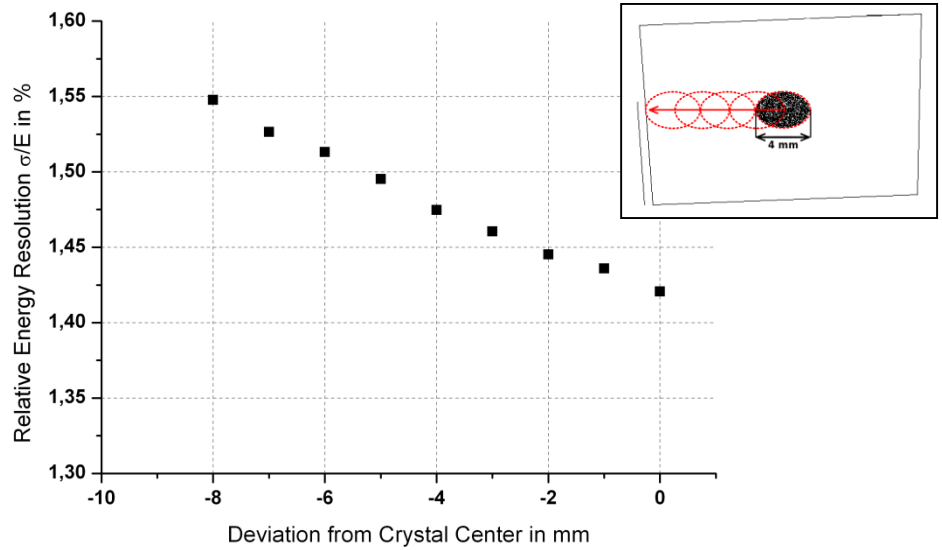
energy-resolution (3x3 matrix)

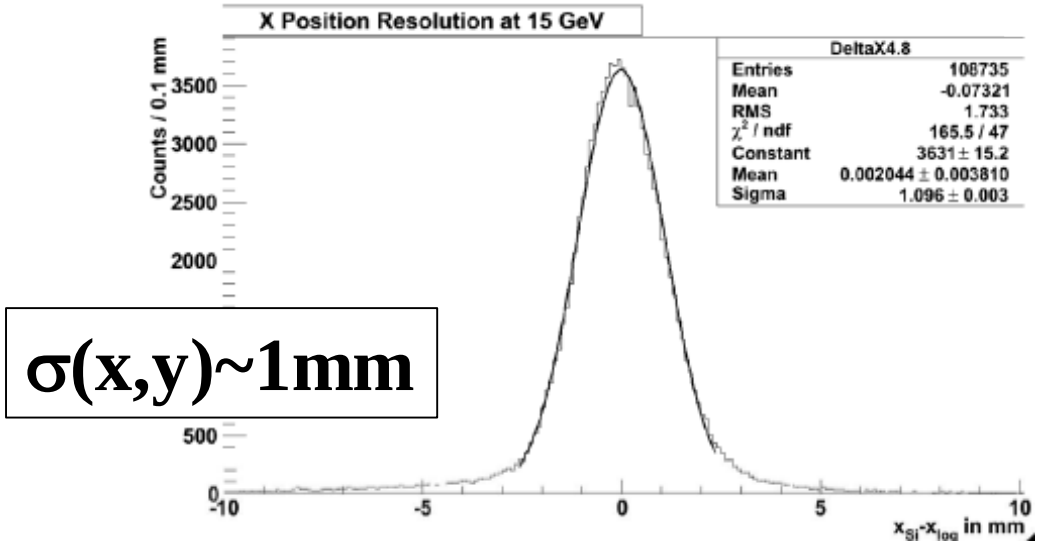


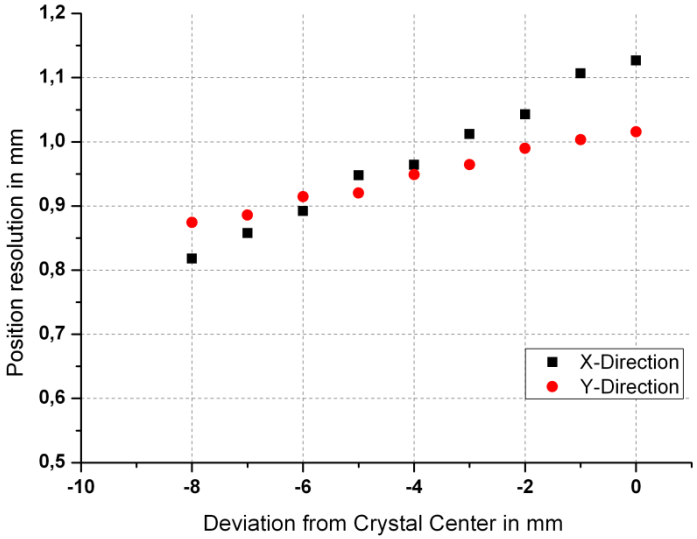
time resolution

prototype performance PROTO 60 15 GeV positrons









- **alternatives ?**