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## **X-rays, Protons and Electrons Radiation Effects on Fiber Bragg Gratings**

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# *X-rays, Proton and Electron Radiation Effects on Fiber Bragg Gratings*

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RADECS 2017  
CERN, Geneva

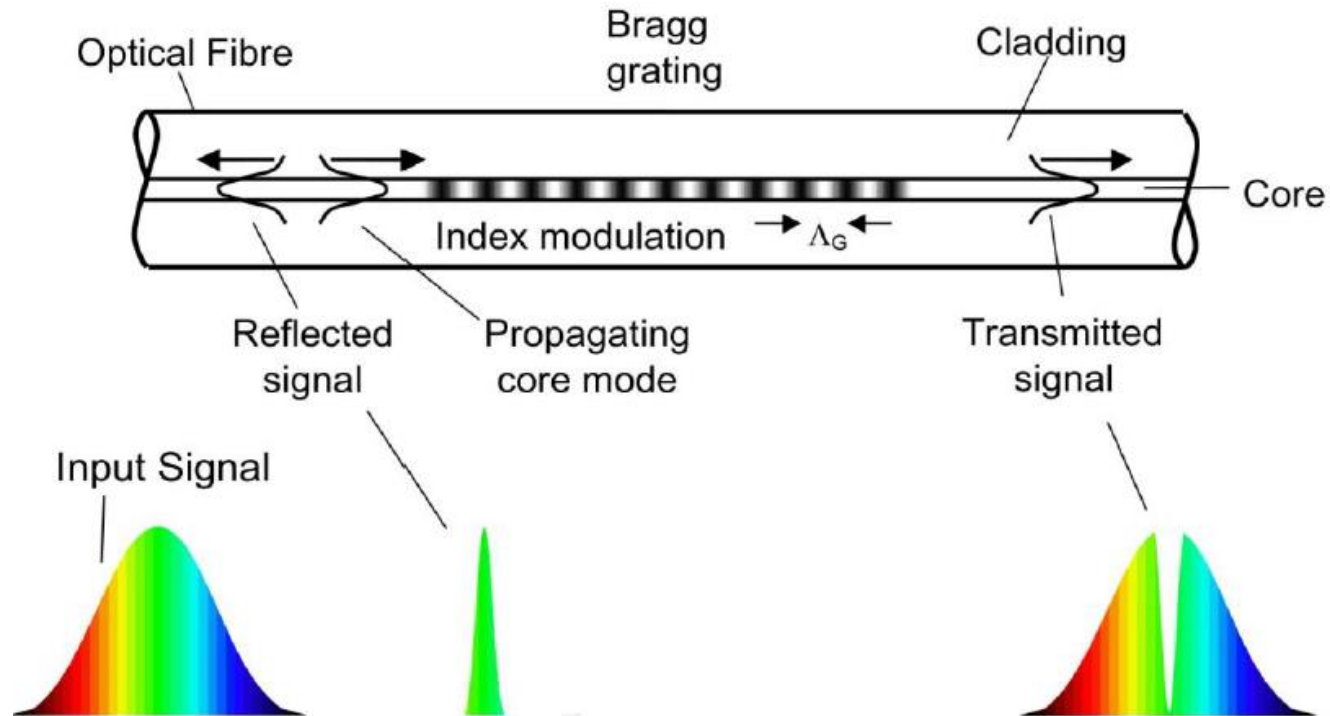


# Optical Fibers

- **Use in:**
  - Telecommunication
  - Sensors
  - Lasers
  - Lighting
  - Medicine
- **Sensors:**
  - Space Environment (1kGy/year)
  - Nuclear Power Plants:
    - Inside the core < MGy/year



# Fiber Bragg Grating based sensors for temperature and strain measurements in harsh environments



**Bragg wavelength :  $\lambda = 2 n_{eff} \Lambda$**

- $n_{eff}$  : effective index
- $\Lambda$  : grating period

[1] Mihailov et al. Sensors, No. 12, 2012

# Fiber Bragg Gratings based Optical Fiber Sensors for distributed measurements under radiation

- **The Radiation Induced**

- Attenuation (RIA):

- Ionization and/or Knock on process
    - degradation of the fiber transmission properties
    - decrease of the signal-to-noise ratio

- **Radiation Induced Bragg Wavelength Shift (RI-BWS):**

- error on the sensing parameter measurements

# Type I UV-FBGs are the more classical ones

## 1. Pre-inscription hydrogenation

## 2. Inscription :

- cw Laser at 244 nm (Argon)
- Interferometric method : Lloyd's mirror

## 3. Post-Inscription annealing 8 h 120°C

Fiber	Compositions		H <sub>2</sub>
	Core	Cladding	
Germanium (High Content)	Ge >15 wt%	Pure silica	yes
Germanium (Low Content)	Ge ~5 wt%	Pure silica	yes
Boron/ Germanium	Ge ~10 wt% B ~5 wt%	Pure silica	no
Phosphorus/ Cerium	P ~8 wt% Ce (below EDX detection limit)	Pure silica	yes

# How the different types of radiation influence the FBG responses?

## • TRIUMF Facility (Vancouver – CANADA) :

- 63 MeV proton Irradiations
- Irradiations: equivalent dose rate of 0,75 Gy/s up to a least 7 kGy



## • CEA GRAMAT (France) :

- 6 MeV electron irradiations
- Irradiation: 120 Gy/s up to 500 kGy



TO COMPARE THE EFFECTS

## • X –rays Chamber MOPERIX LabHC:

- 40 – 45 keV X-rays irradiations
- Irradiations:
  - 0.75 Gy/s (SiO<sub>2</sub>) up to 10 kGy
  - 60 Gy/s to 500 kGy

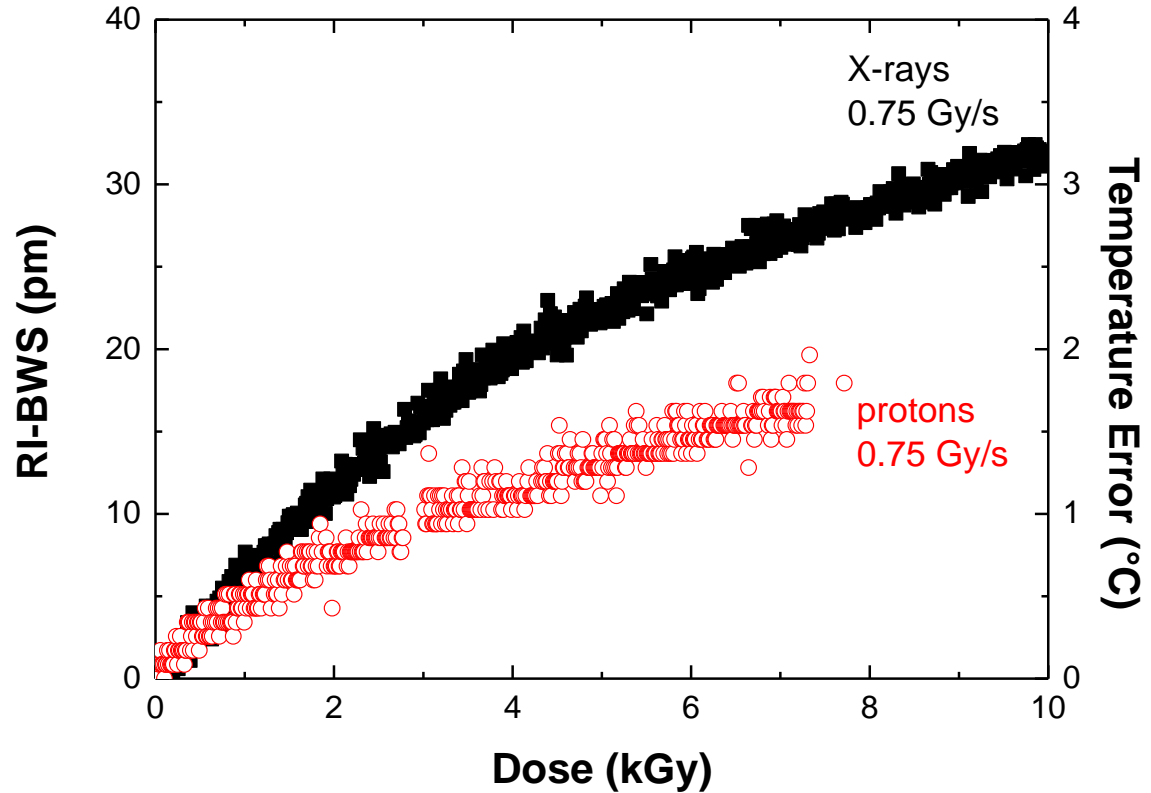


# Comparison Protons/X-rays



# No significant difference between proton and X-rays effects at low dose for Ge-doped fiber

RI-BWS more important under X-rays than under protons?

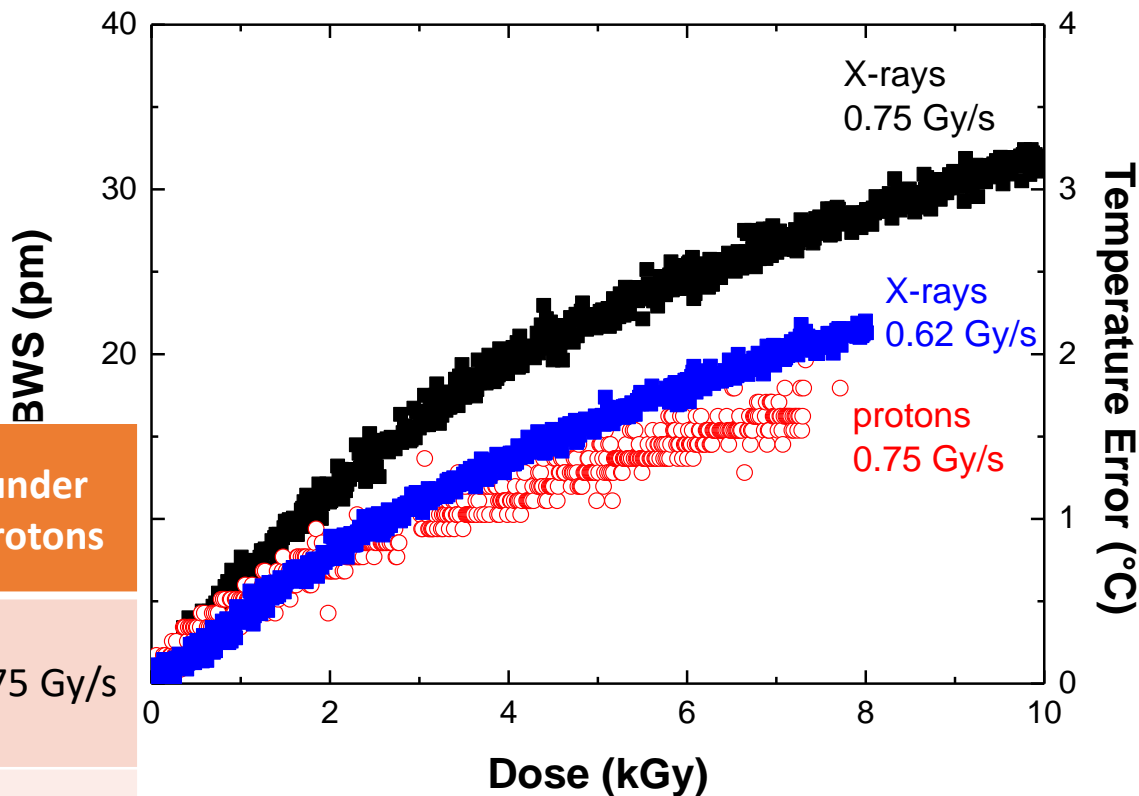


# No difference between proton and X-rays effects at low dose for Ge-doped fiber

RI-BWS more important under X-rays than under protons?

Error on the dose-rate 15%

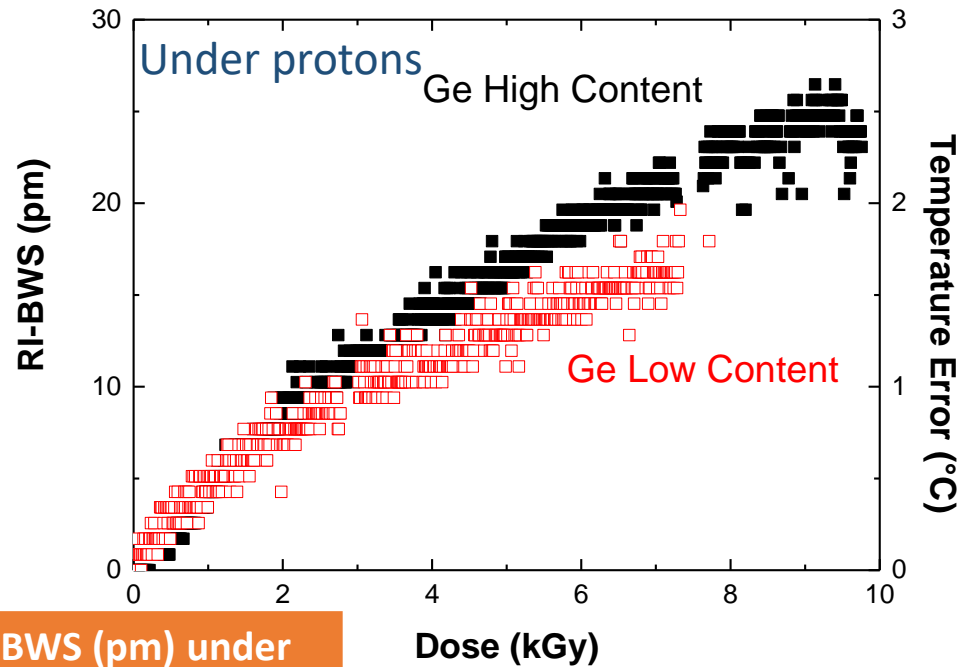
	under X-rays		under Protons
Dose rate	0,75 Gy/s	0,62 Gy/s	0,75 Gy/s
RI-BWS At 7kGy (pm)	27 ± 2	20 ± 2	17 ± 2



# The higher the Ge concentration, the larger the shift induced under X-rays and protons

Already demonstrated under X-rays

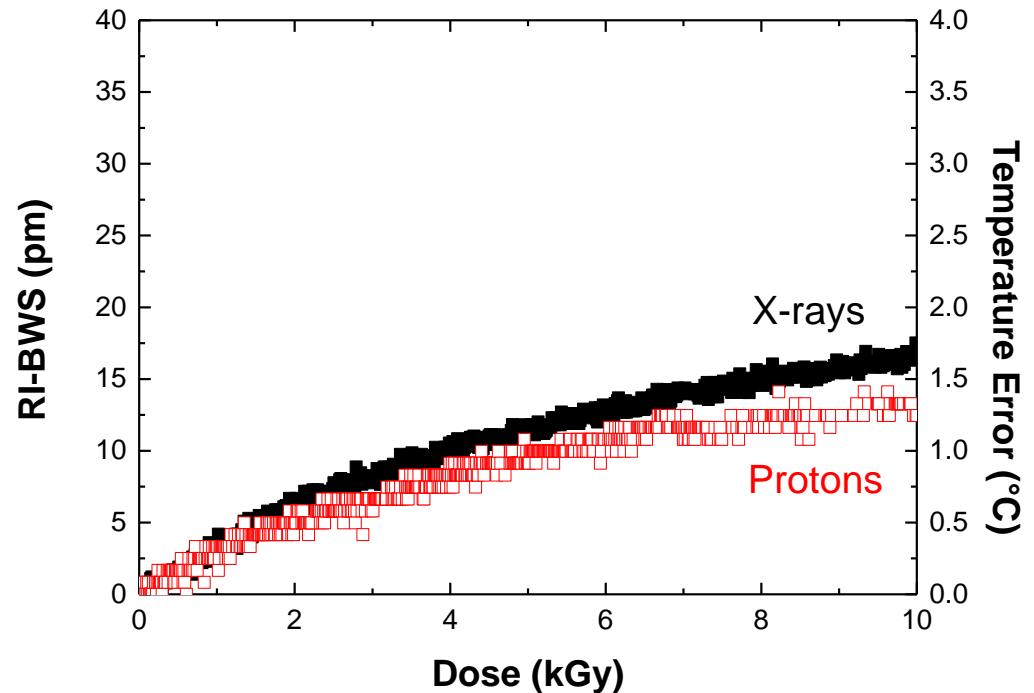
[2] Lin et al. *IEEE TNS*, vol. 58, No. 4, 2011



FBGs	RI-BWS (pm) under X-rays at 7 kGy	RI-BWS (pm) under Protons at 7 kGy
Ge Low Content- 5 wt%	$27 \pm 2$	$17 \pm 2$
Ge High Content >15 wt%	$30 \pm 2$	$22 \pm 2$

# No difference between proton and X-rays effects at low dose for B/Ge co-doped fiber

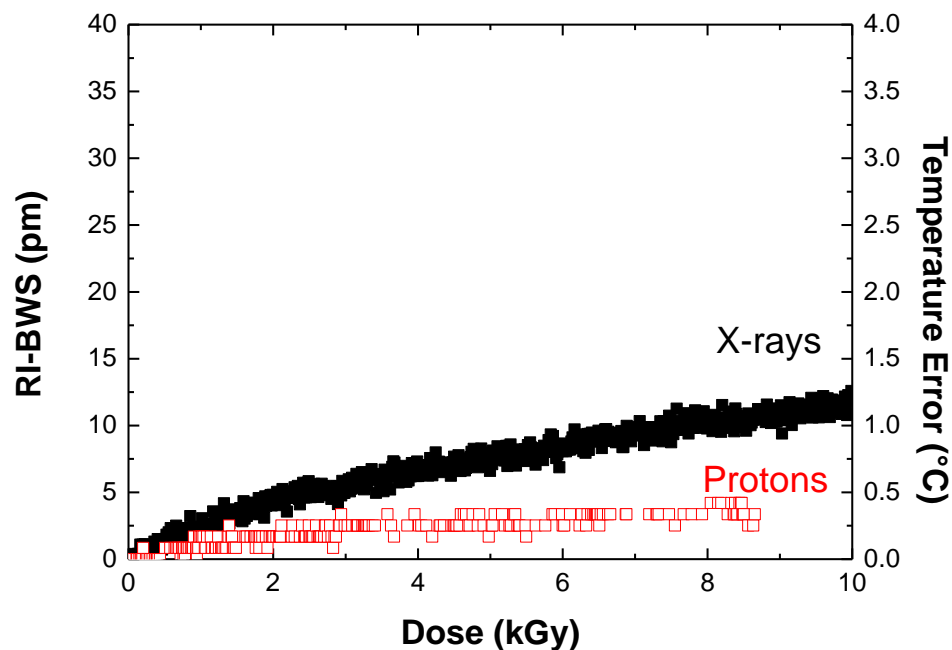
The RI-BWS for the B/Ge doped fiber is lower than in the Ge-doped one



FBGs	RI-BWS (pm) under X-rays at 7 kGy	RI-BWS (pm) under Protons at 7 kGy
B/Ge	$14 \pm 2$	$13 \pm 2$

# No proton effect on the FBG in P/Ce co-doped fiber

RI-BWS more important under X-rays than under protons.

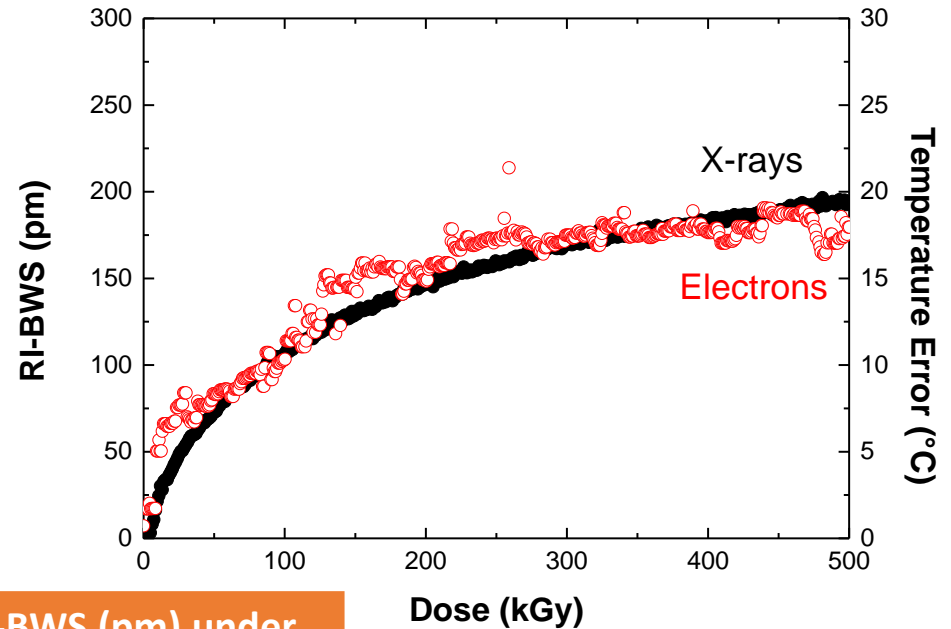


FBGs	RI-BWS (pm) under X-rays at 7 kGy	RI-BWS (pm) under Protons at 7 kGy
P/Ce	$7 \pm 2$	$4 \pm 1$

# Comparison Electrons/X-rays

# No difference between electron and X-rays effects at 500 kGy dose for Ge-doped fiber

## Saturation of the BWS under electrons

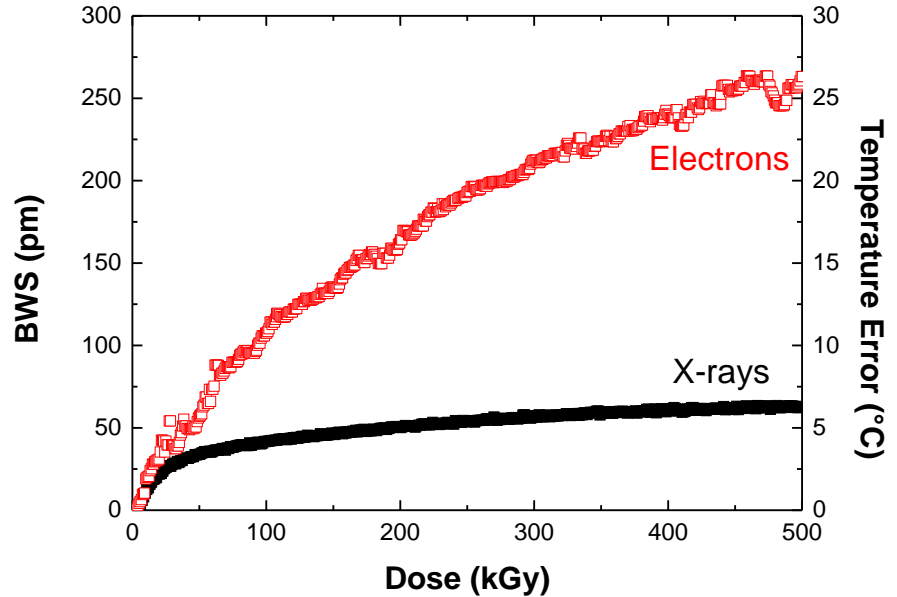


More Ge-doped the fiber is, more the shift is important

FBGs	RI-BWS (pm) under X-rays at 500 kGy	RI-BWS (pm) under Electrons at 500 kGy
Ge Low Content 5 wt%	$190 \pm 2$	$170 \pm 10$
Ge High Content > 15 wt%	$230 \pm 2$	$170 \pm 10$

# The FBG in B/Ge co-doped fiber is more sensitive to electron beam than to X-rays

RI-BWS more important under electrons than X-rays :  
no stabilisation under electrons



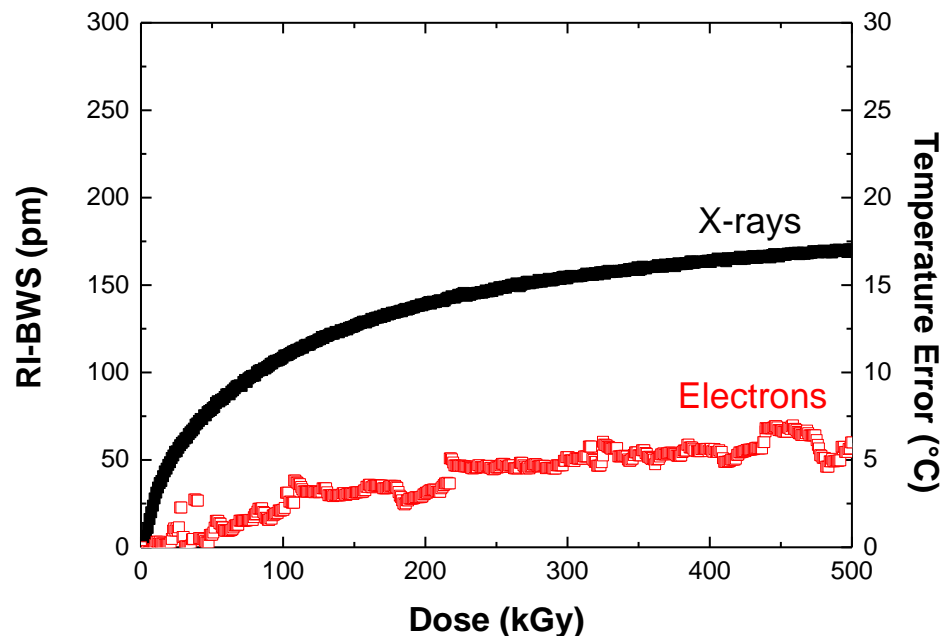
FBG	RI-BWS (pm) under X-rays (pm) at 500 kGy	RI-BWS under Electrons (pm) at 500 kGy
B/Ge	$60 \pm 2$	$260 \pm 10$



# The FBG in P/Ce doped fiber is less sensitive to electron beam

RI-BWS more important under X-rays than under electrons.

Completely different behavior



FBG	RI-BWS (pm) under X-rays at 500 kGy	RI-BWS (pm) under Electrons at 500 kGy
P/Ce	$170 \pm 2$	$55 \pm 10$

# Conclusions

- **Ge-doped fibers:**

- Influence of the dopant concentration: the larger the Ge content, the larger the RI-BWS

- **Comparison X-rays and protons:**

- Proton and X-rays induce similar effects on the grating response (with an error of less than 15% on the dose-rate), maybe with a slightly larger effect of X-rays

- **Comparison X-rays and electrons:**

- For the Ge doped fibers : FBGs seems less sensitive to electrons than X-rays + saturation of the BWS under electrons
- For the B/Ge co-doped fibers : BWS more important under electrons with no saturation effects
- For P/Ce co-doped fibers : BWS less important under electrons



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MOPERE GROUP



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**Thank you for your  
attention**



**TRIUMF**



**UNIVERSITÉ  
JEAN MONNET**  
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FROM RESEARCH TO INDUSTRY

