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

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RADECS 2017
CERN, Geneva

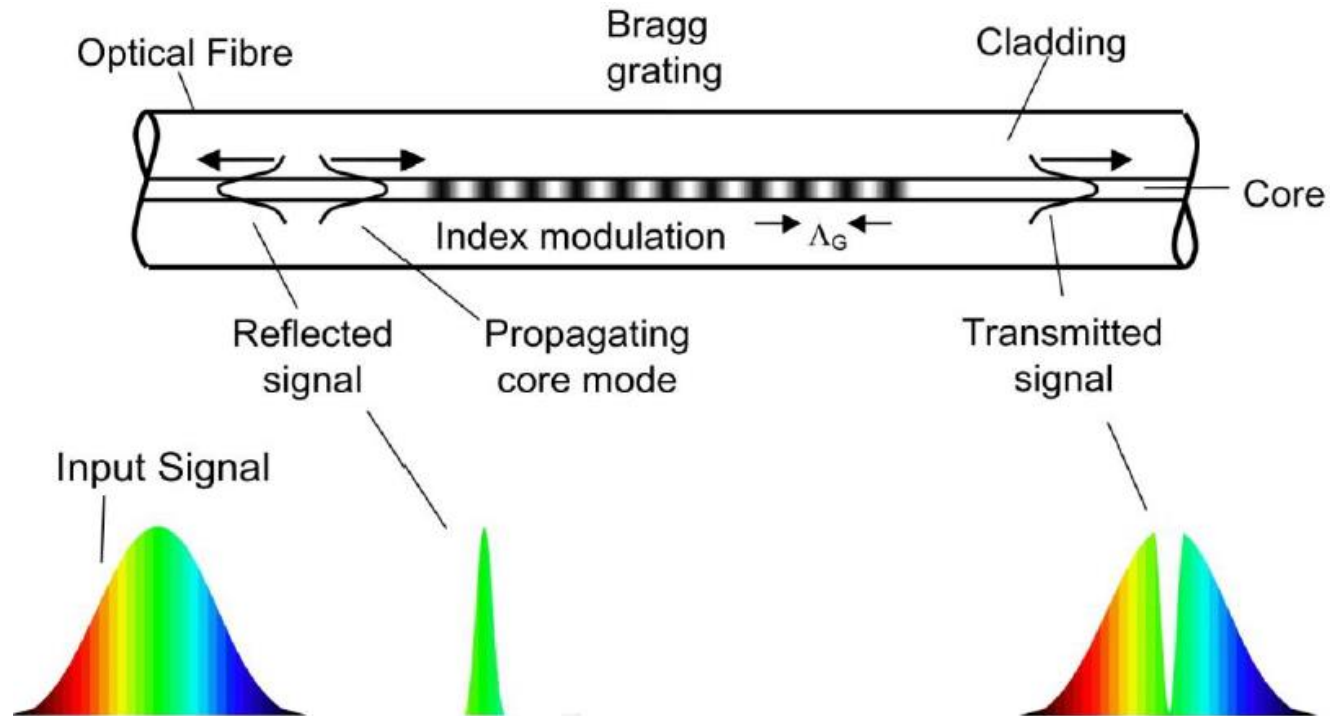


Optical Fibers

- **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
- Λ : 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 ₂
	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:

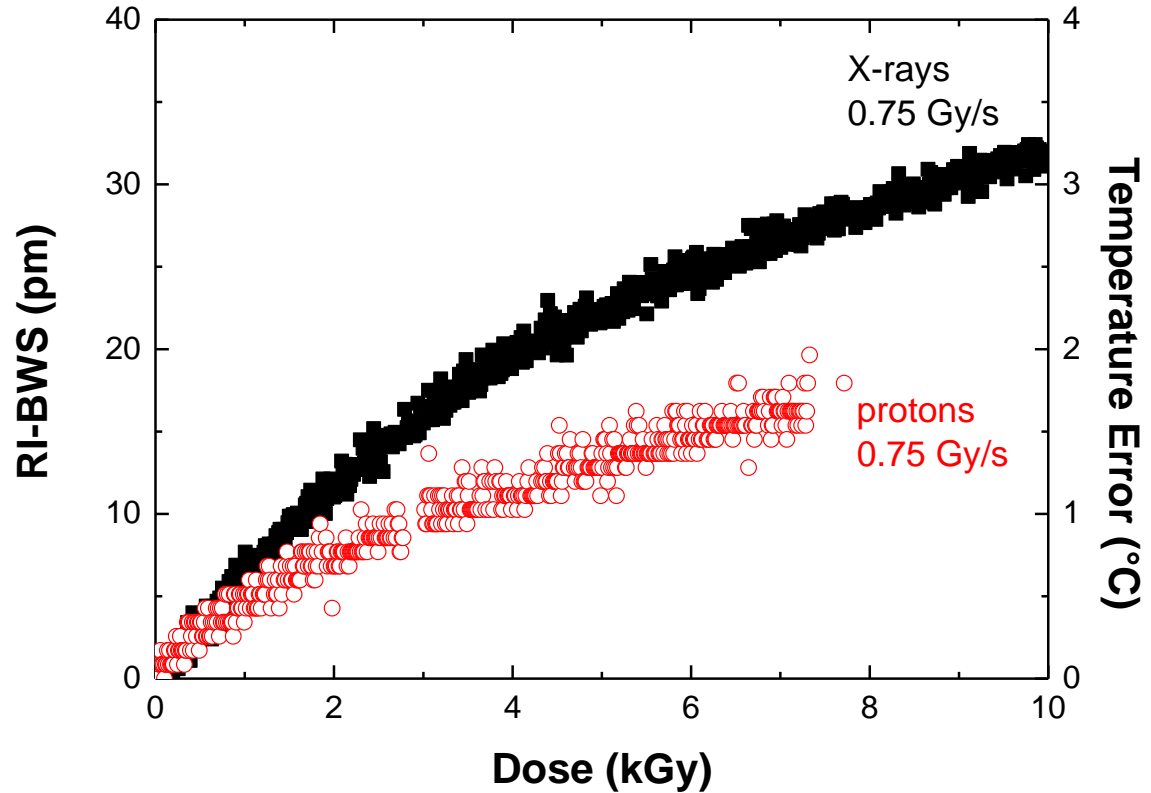
- 40 – 45 keV X-rays irradiations
- Irradiations:
 - 0.75 Gy/s (SiO₂) up to 10 kGy
 - 60 Gy/s to 500 kGy



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?

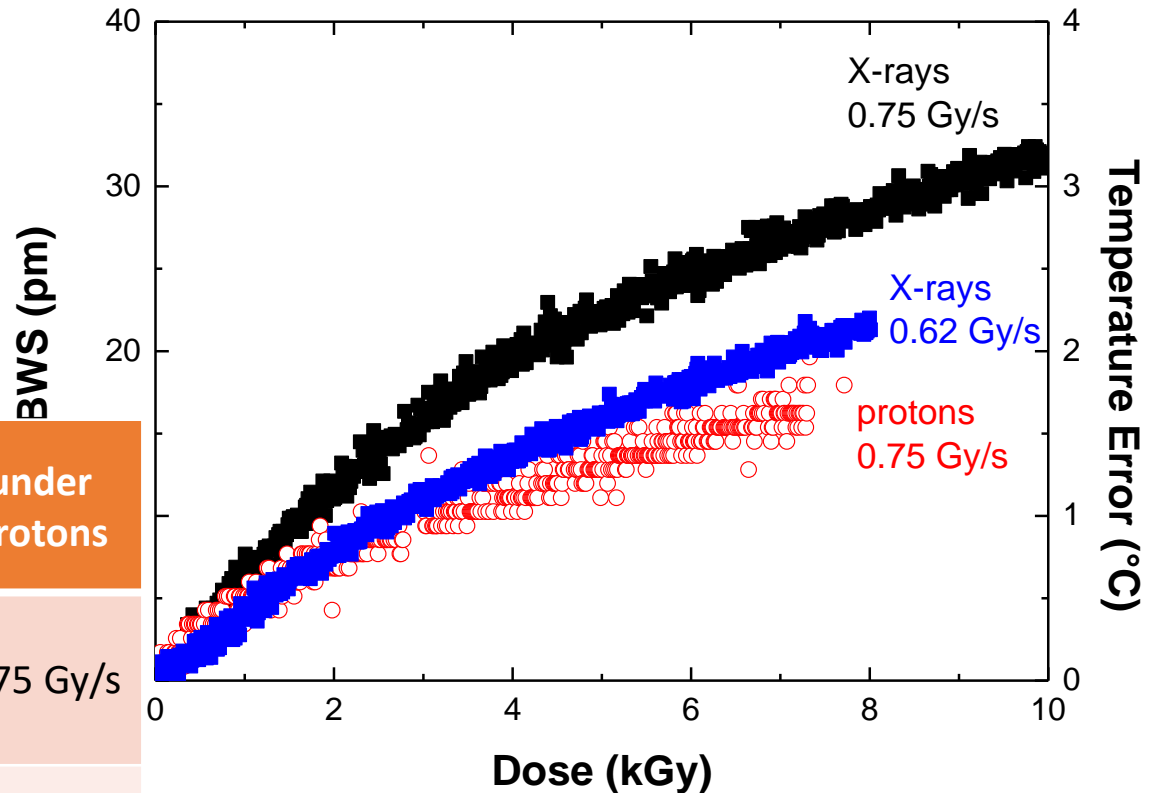


No difference between proton and X-rays effects at low dose for Ge-doped fiber

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

Error on the dose-rate 15%

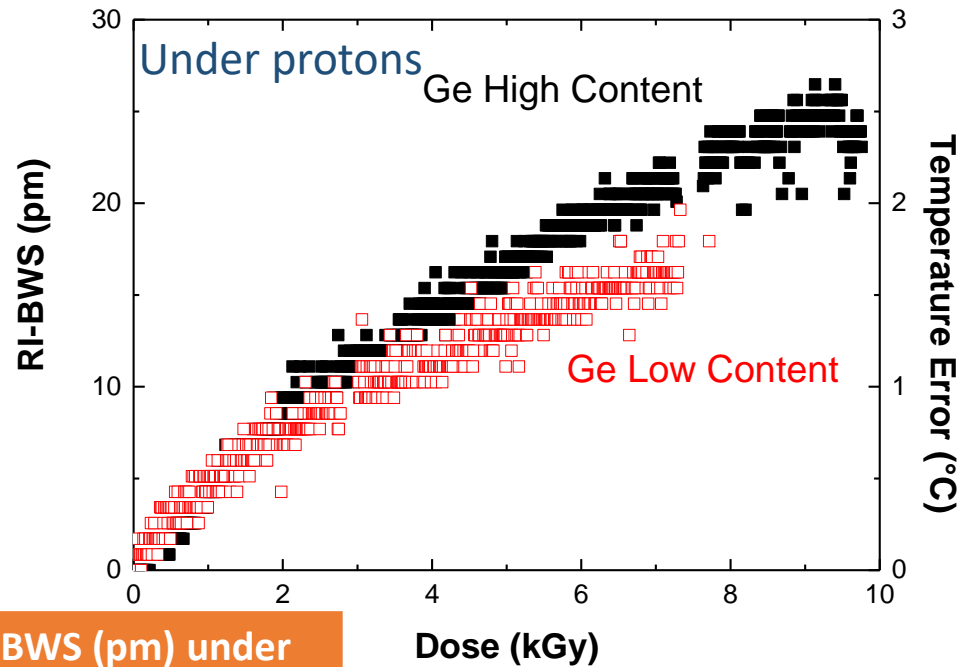
	under X-rays		under Protons
Dose rate	0,75 Gy/s	0,62 Gy/s	0,75 Gy/s
RI-BWS At 7kGy (pm)	27 ± 2	20 ± 2	17 ± 2



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

Already demonstrated under X-rays

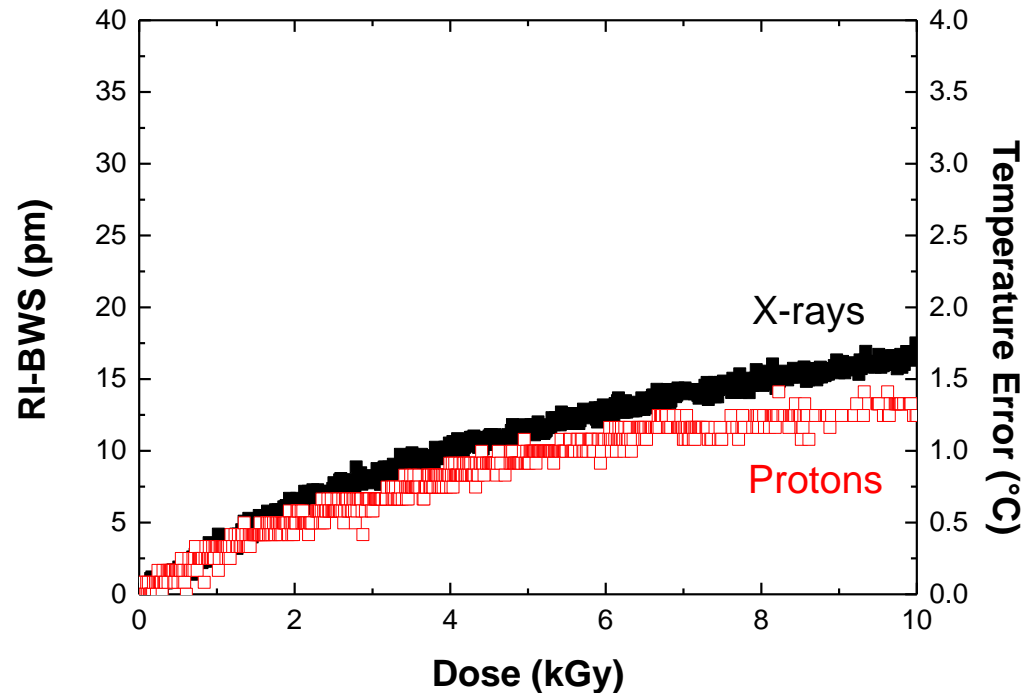
[2] Lin et al. *IEEE TNS*, vol. 58, No. 4, 2011



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

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

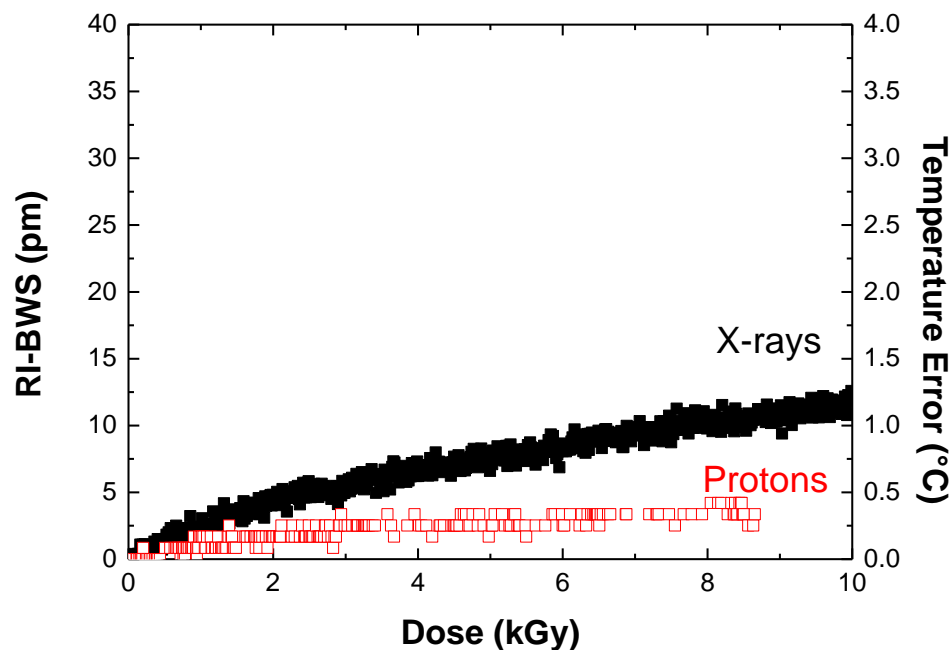
The RI-BWS for the B/Ge doped fiber is lower than in the Ge-doped one



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

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

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

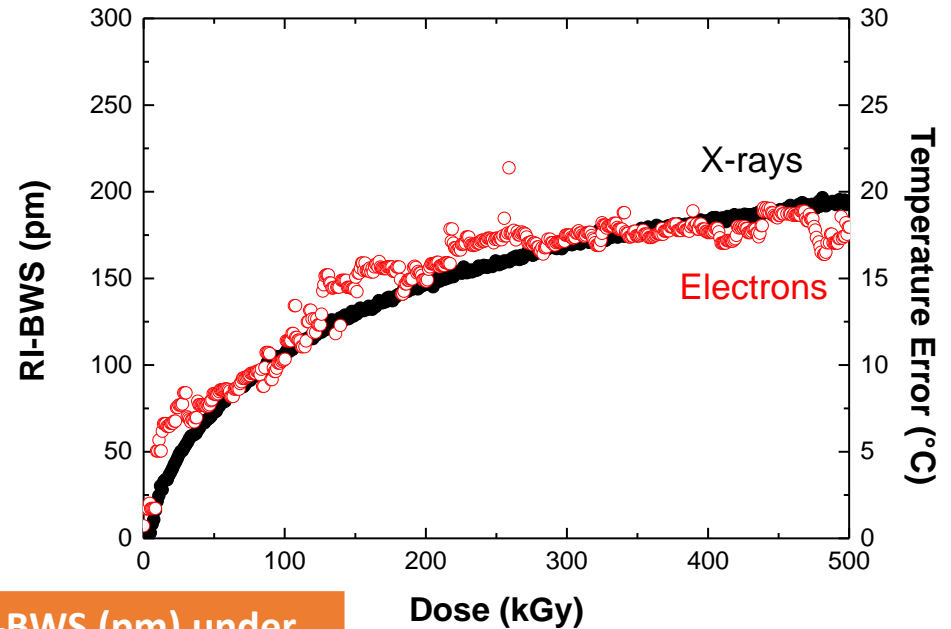


FBGs	RI-BWS (pm) under X-rays at 7 kGy	RI-BWS (pm) under Protons at 7 kGy
P/Ce	7 ± 2	4 ± 1

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

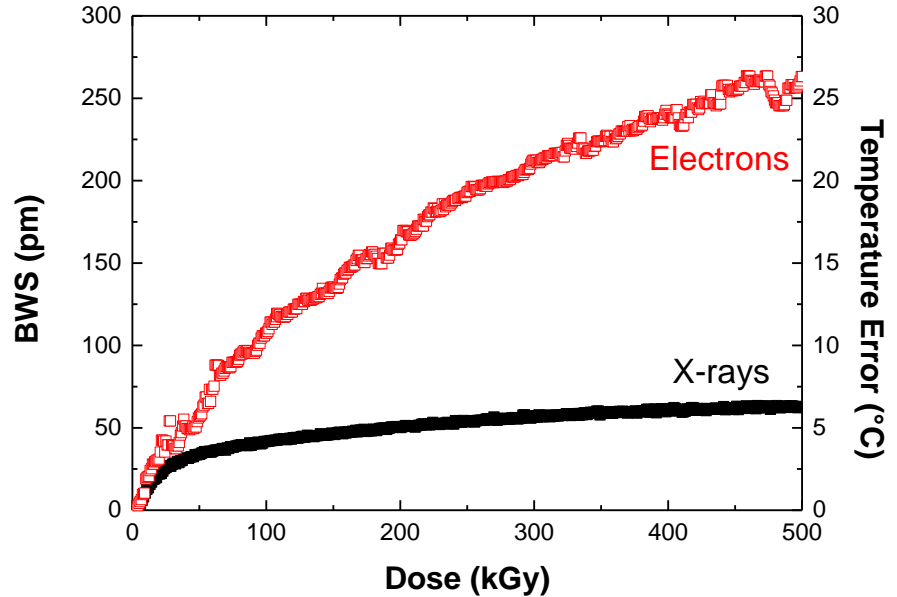


More Ge-doped the fiber is, more the shift is important

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

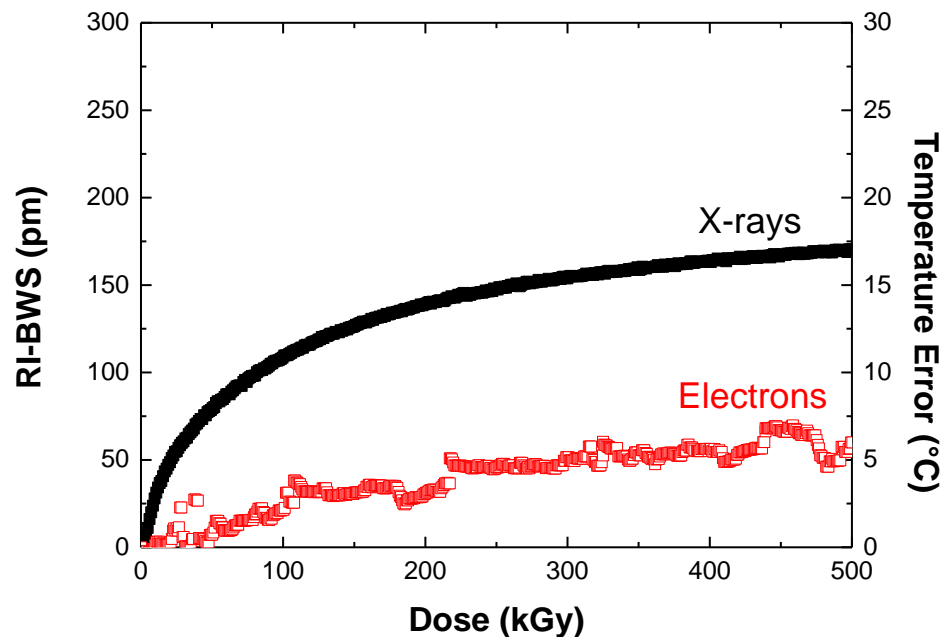


FBG	RI-BWS (pm) under X-rays (pm) at 500 kGy	RI-BWS under Electrons (pm) at 500 kGy
B/Ge	60 ± 2	260 ± 10

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 ± 2	55 ± 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



RADECS 2017
CERN, Geneva

**Thank you for your
attention**



TRIUMF



**UNIVERSITÉ
JEAN MONNET**
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FROM RESEARCH TO INDUSTRY

