Fraunhofer Institut Naturwissenschaftlich-Technische Trendanalysen

Radiation Tolerant Optical Fibres for LHC Beam Instrumentation

Radiation Effects

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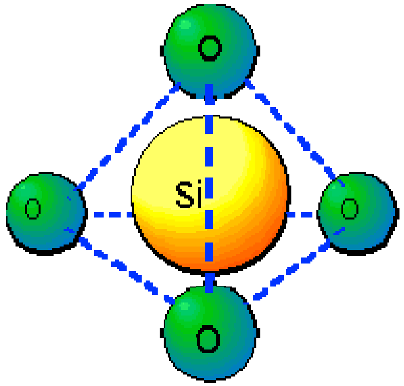
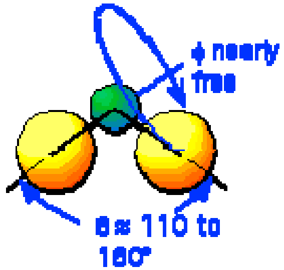
Silica

- Silica (SiO_2) exists in
  - crystalline form
  - amorphous form (*a-SiO_2*)

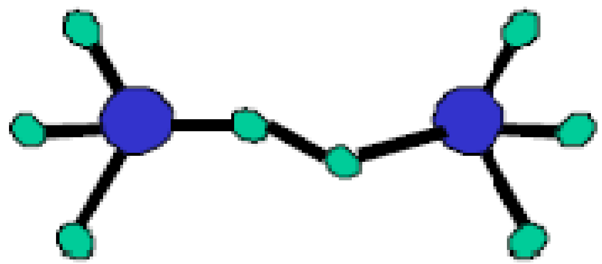
  (amorphous : no long range order)
- *a-SiO_2* is easily formed :
  - bond angle can vary by ~70°
  - rotation of bond is nearly free





Silica Optical Fibers

- Fibres are long ‘drawn’ strands of silica
- Fibre drawing generates additional disorder via
  - irregular arrangements of Si and O in the lattice
  - impurity atoms (such as OH)
- Random structure leads to
  - light scattering
  - light absorption
- Dopants
  - to modify refractive index
  - to modify attenuation spectrum

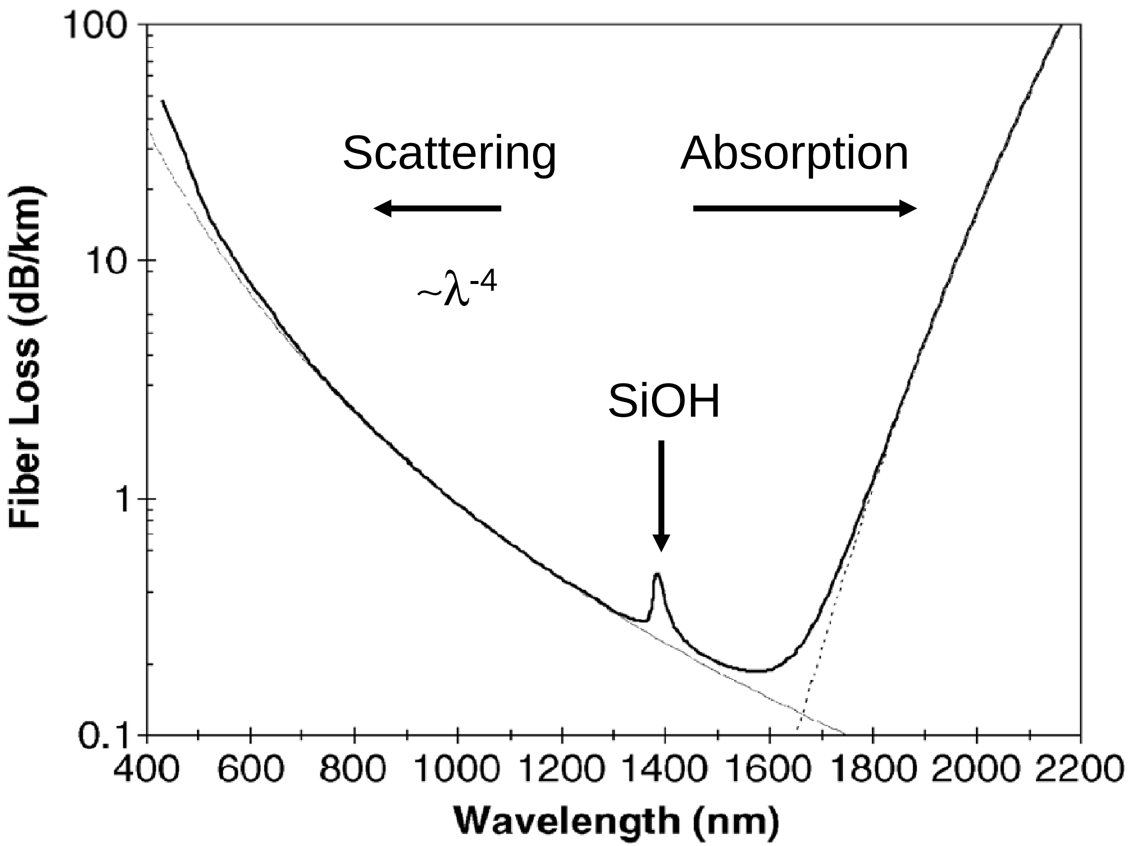


O≡Si-O-O-Si≡O

Color defects

- Color defects lead to optical absorption bands
  - Silanonol absorbs at 1380 nm (“water peak”)
    (SiOH group from *hydrogen pollution*)
- Radiation creates additional color defects via
  - radiolysis mechanism (ionisation)
  - knock on mechanism (displacement)

Optical fiber loss components

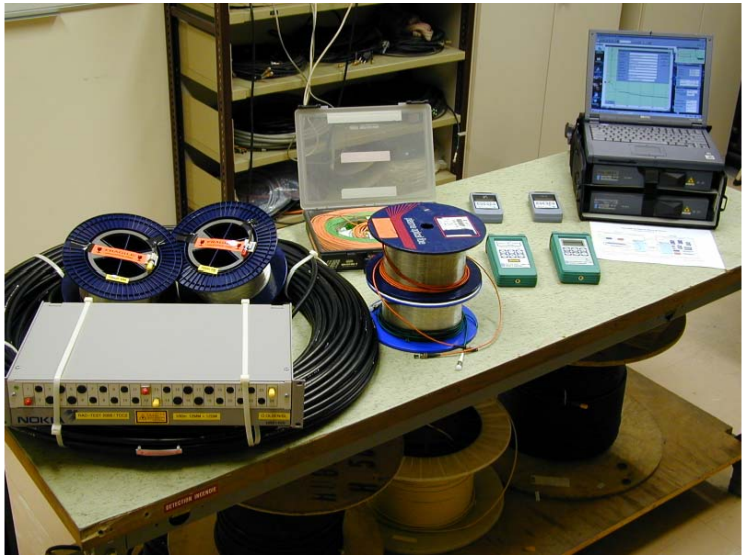


Experimental techniques

Study radiation induced defects via :

- Photoluminescence
- Electron Spin Resonance
- Optical attenuation measurements
  - at fixed wavelengths (here 1310 and 1550 nm)
  - for complete spectrum (here only at beginning/end)

Radiation tests in 1999-2000

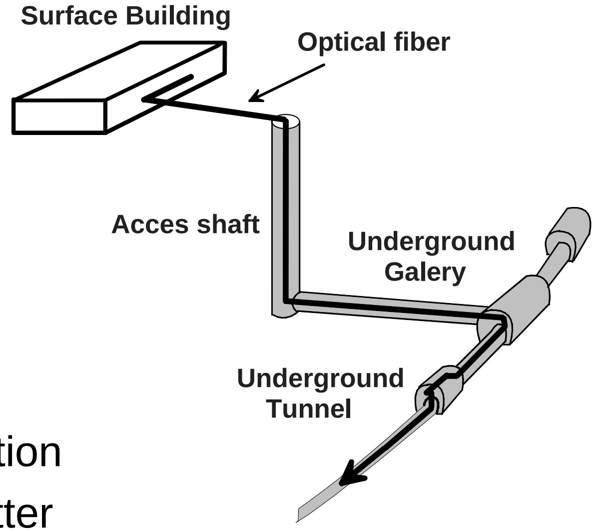


Radiation Induced Attenuation (RIA) :

- SM fibre 1330 nm 0.1 dB/km per Gy
- LHC Tunnel (ARCs) : 10 Gy per year

Collimation areas LHC

- Monte Carlo simulations (2005)
  - Fibres exposed to ~10 kGy/year
- Requirement :
  - RIA cannot exceed 6 dB total for BPM analog signals
  - ~500 m fibre length exposed



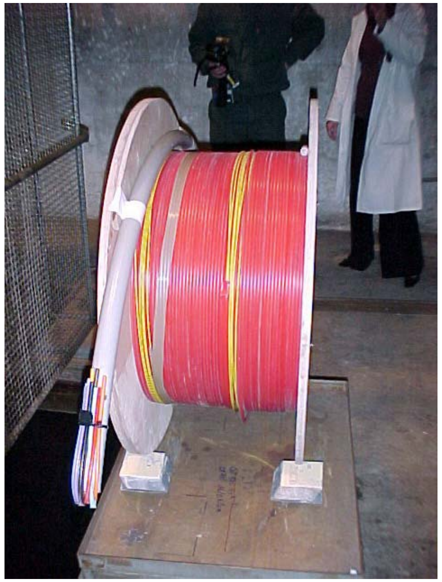
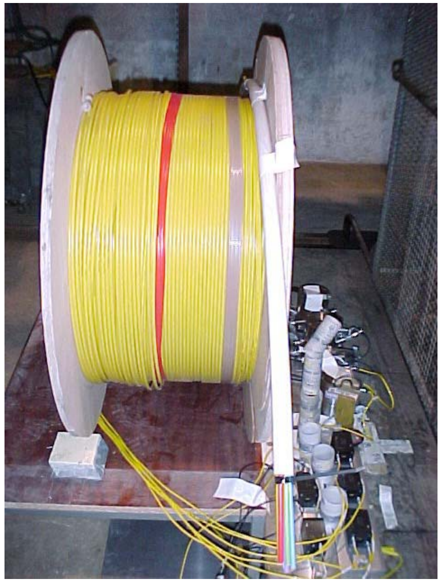
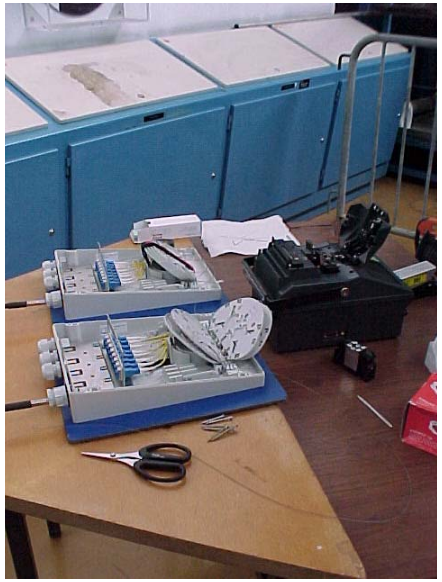
→ This was a reason for concern :

- 6 dB would be reached in 2.4 days LHC operation
- For 10 yrs LHC we would need factor 1000 better
- How about the ducts and blowing with oil ?

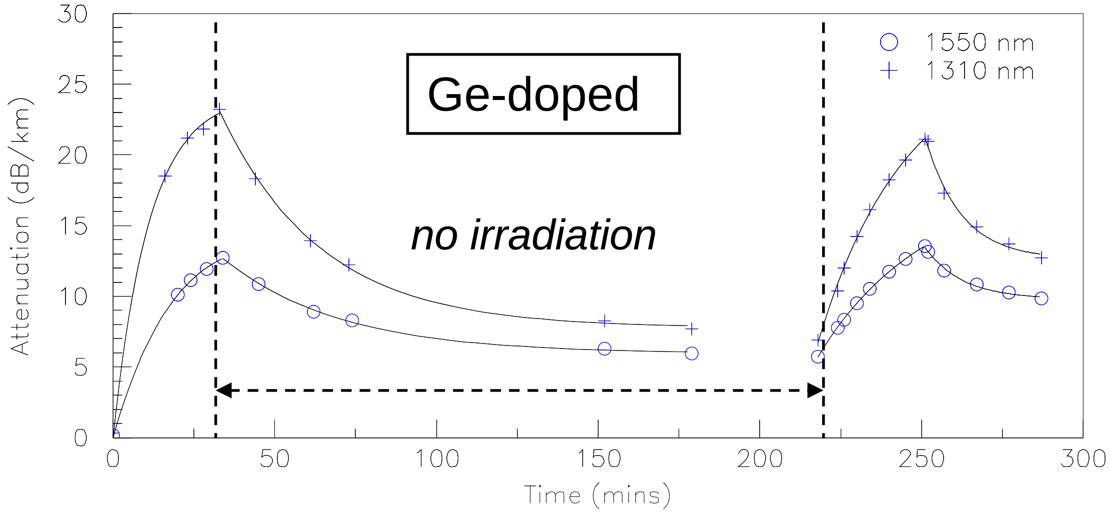
Acknowledgement : R. Schmidt

^{60}Co irradiation test standard SM LHC fibres

- Material testing for duct blowing technique
- Attenuation at 1310 nm in fibres for tunnel in :
  - Ge-P doped MCVD (Draka NK Cables Ltd)
  - Ge-doped PCVD (Draka Fibre Technology BV)

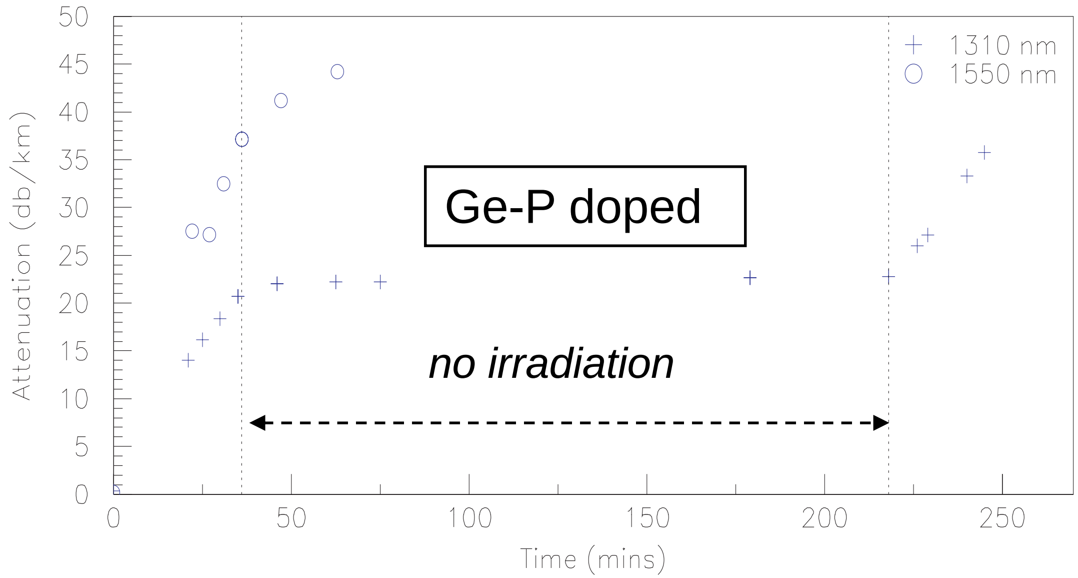




Optical absorption in standard LHC SM fibres



Co-60

1 kGy/hr



Co-60

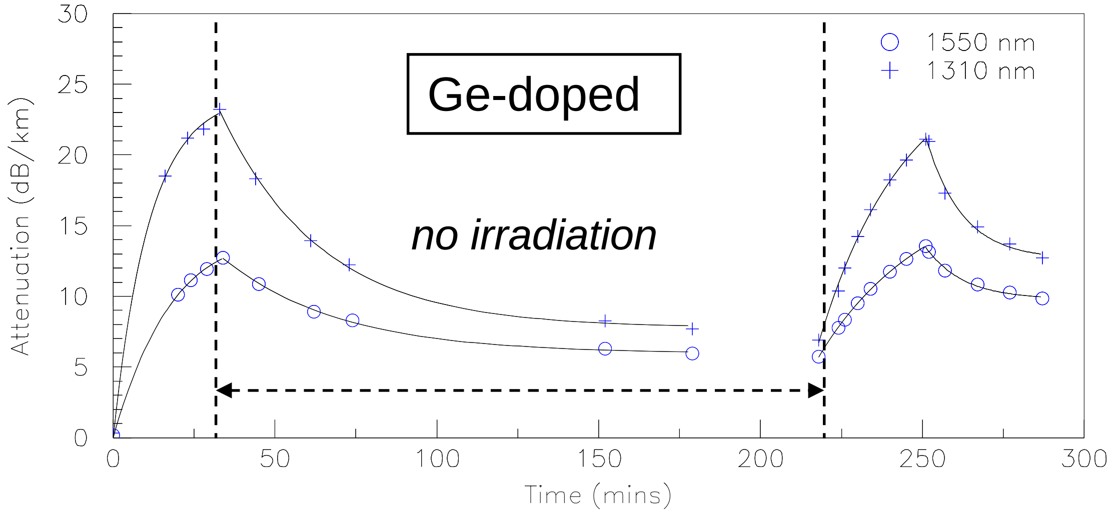
500 Gy/hr

RIA in Ge-doped SM fibres

- In GeO_2 fibres :
  - Ge(0), …, Ge(3) defects
    (0,..,3 electrons trapped at O vacancies of Ge-ions)
  - Ge(0) and Ge(3) much lower in concentration compared to Ge(1) and Ge(2)
  - <u>100-450 nm absorption bands</u>
- Annealing
  - detrapping of the electrons
  - Ge(3) trap is deeper than G(2) and so on
  - Ge(3) gives residual attenuation

E.J. Friebele et al, J. Appl. Phys. Vol. 45 No.8 July 1974

Optical absorption in standard LHC SM fibres



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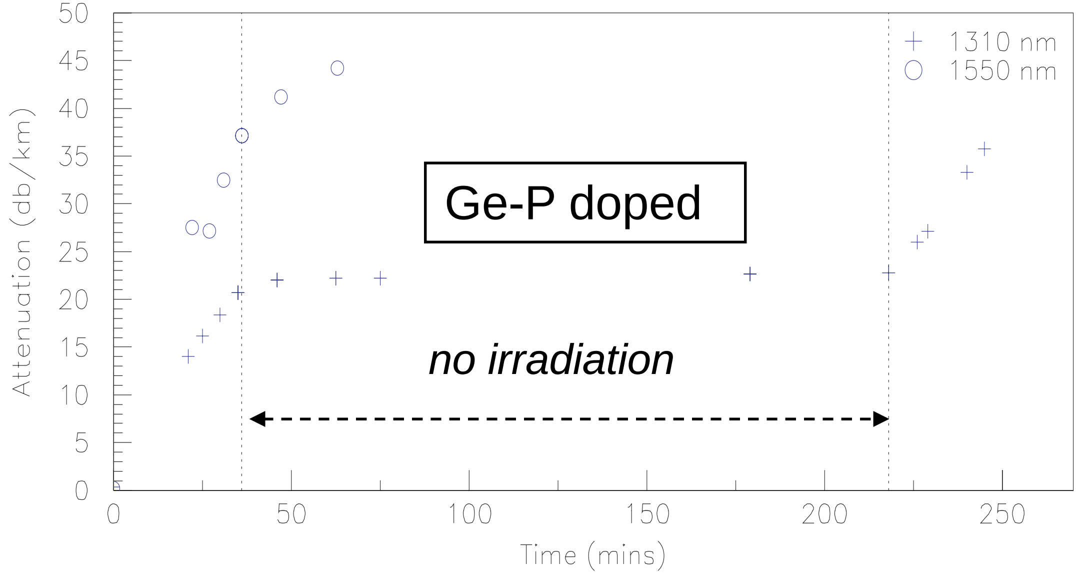
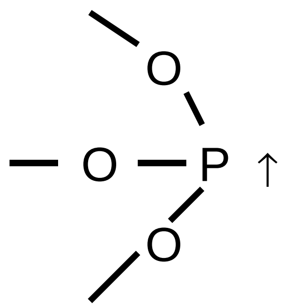


Co-60

500 Gy/hr

RIA in Ge-P doped SM fibres

- In pure SiO_2 - P_2O_5 fibres :
  - P1, P2, P3, P4, POHC and S defects observed
  - Absorption via P1 effect dominates <u>at 1450 nm</u> :
    - PO_3^{2-} molecular ions



  - Annealing :
    - POHC *decrease* and PO_3^{2-} *increase*
    - all others constant

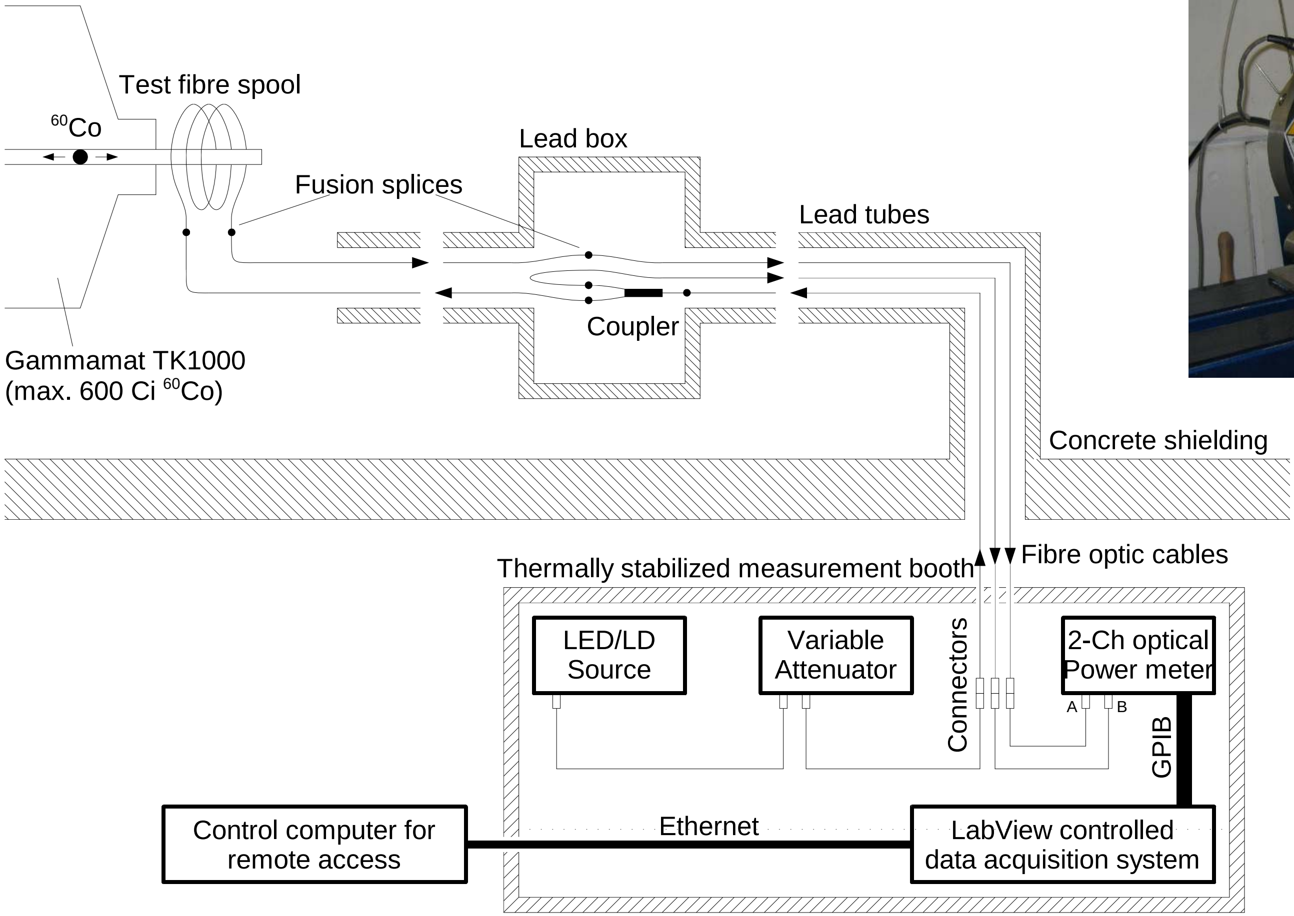
Griscom *et al*, J. Appl. Phys. Vol. 54 No.7 July 1983

Optical Fibre irradiation tests – Fraunhofer INT

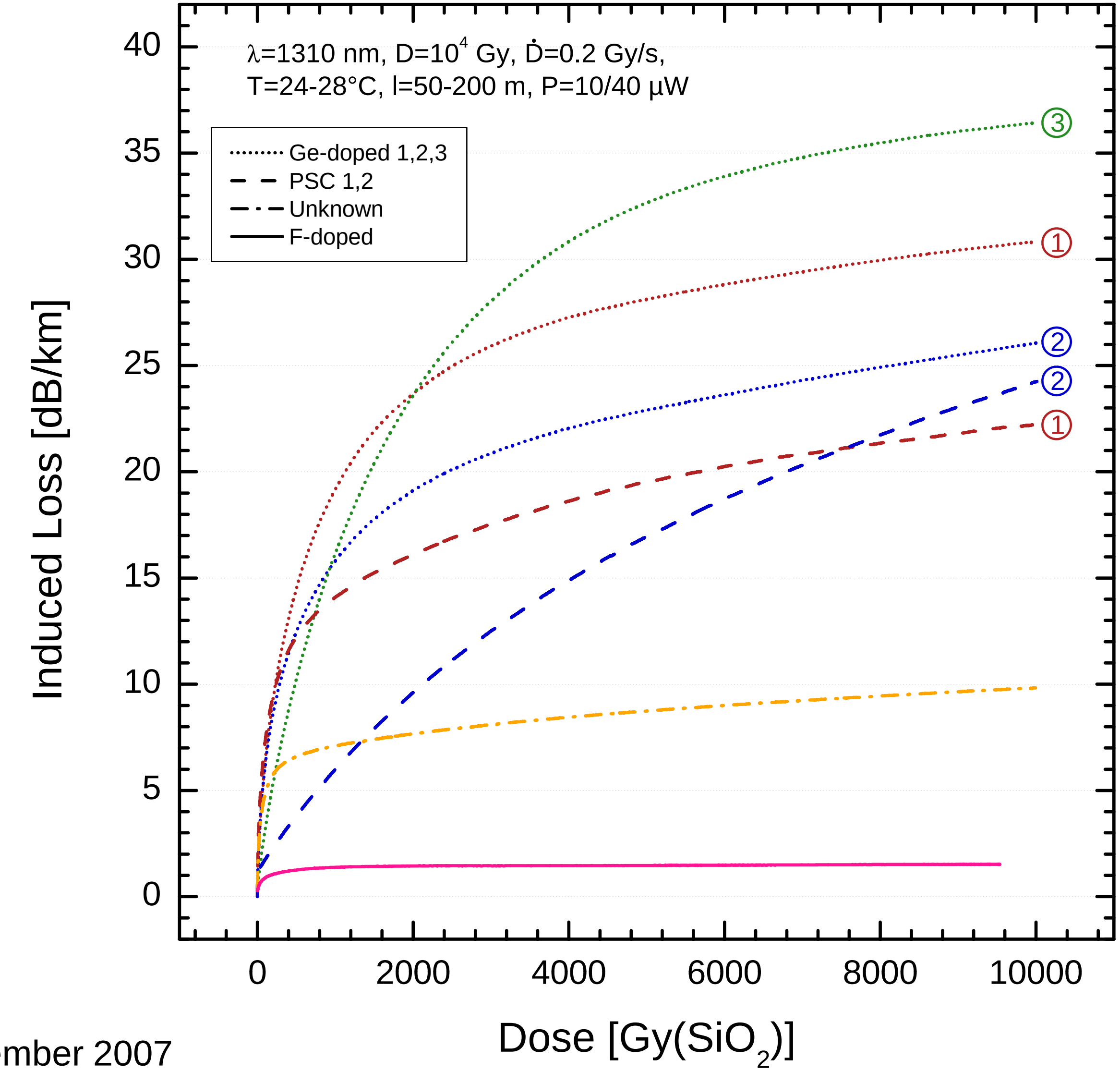
Sample preparation (video)

Fibre Splicing

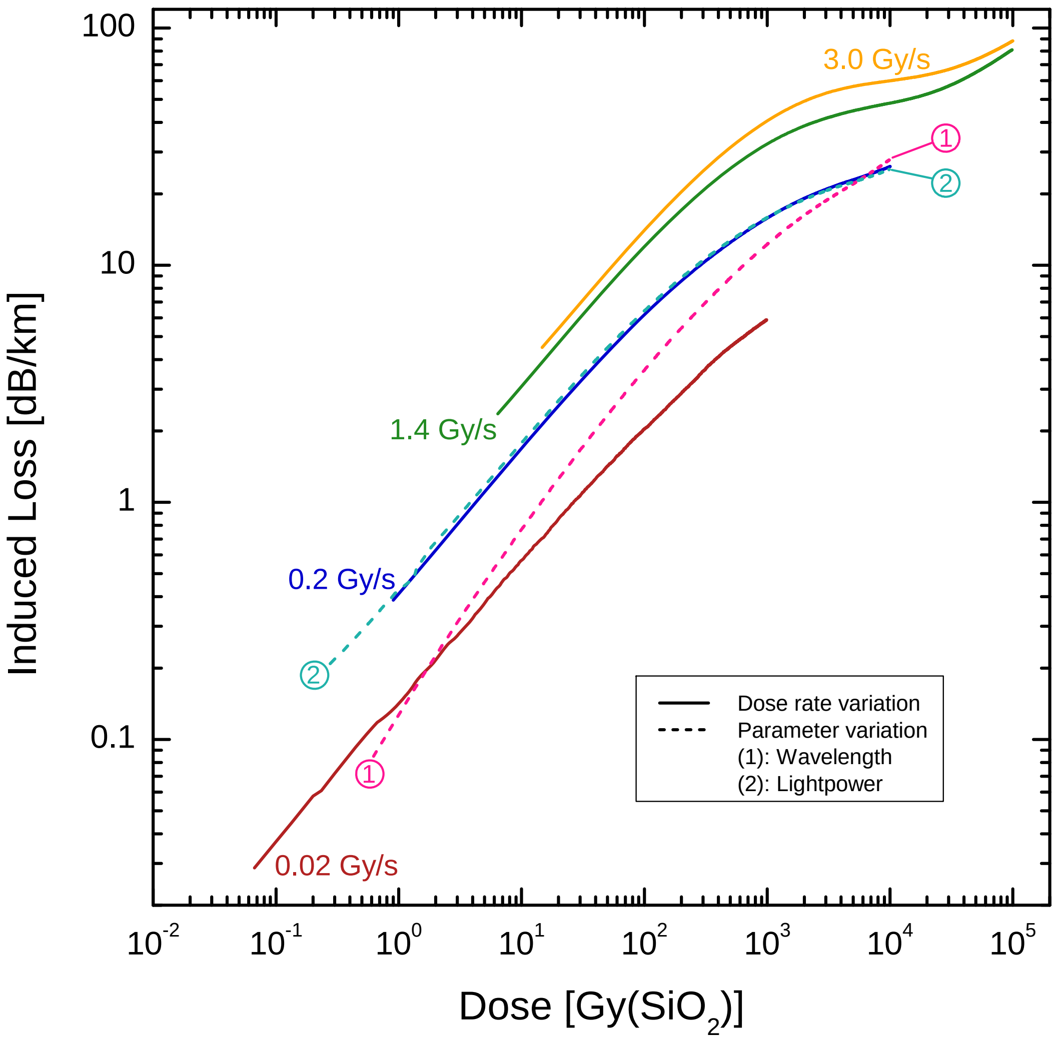
Screening test at Fraunhofer INT



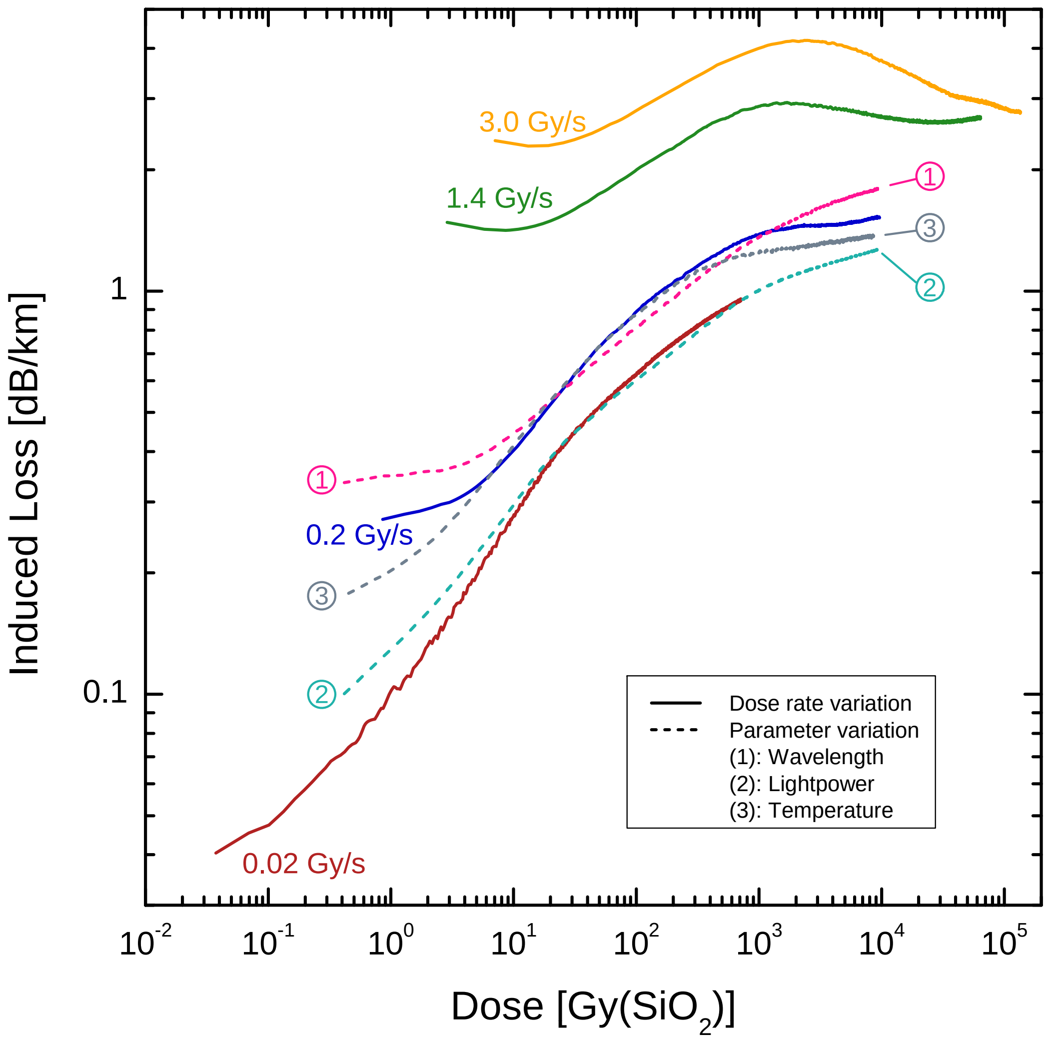
Radiation Induced attenuation



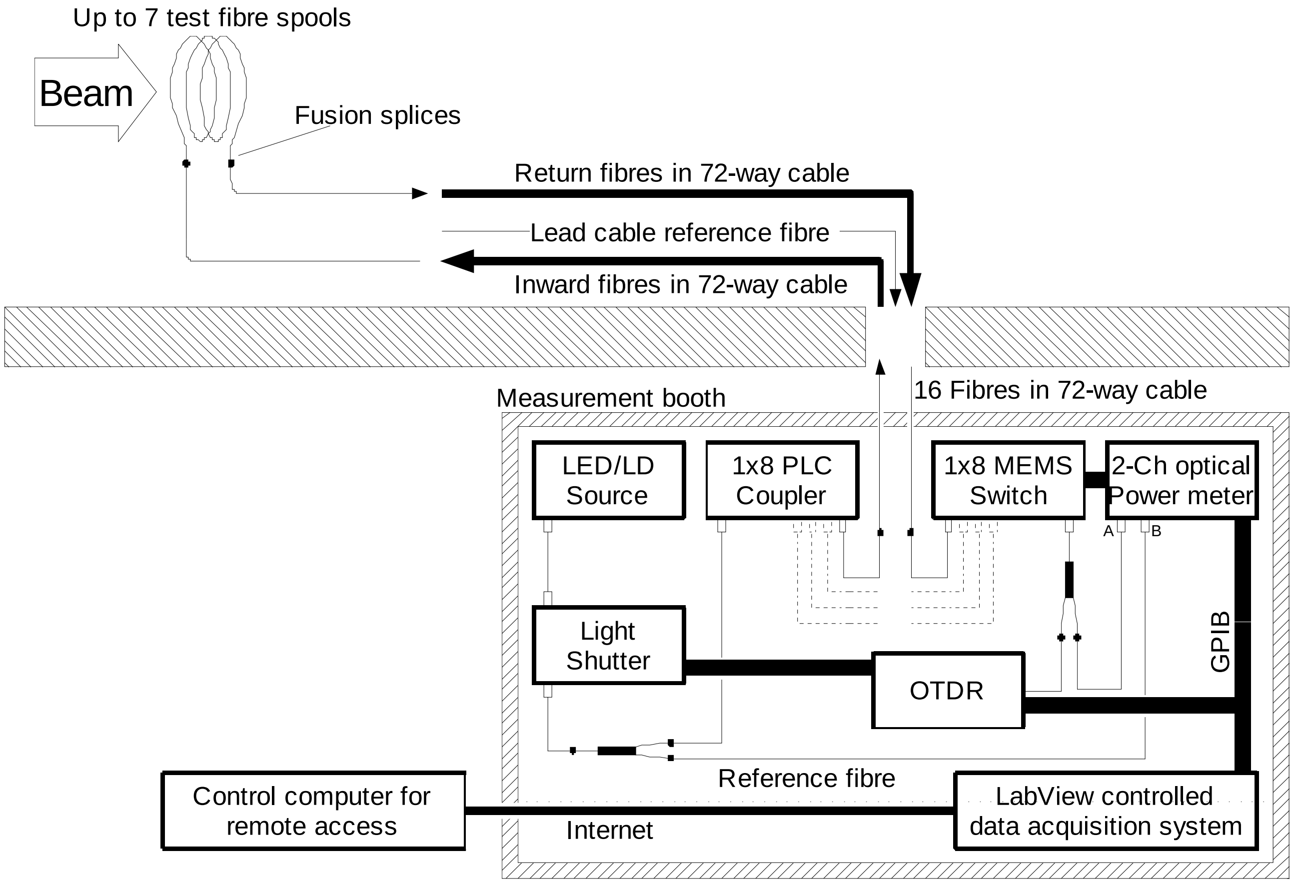
Standard Ge-doped SM fiber



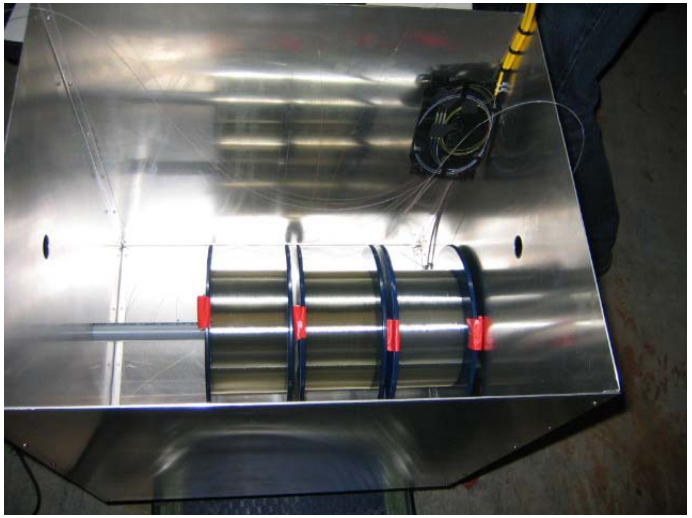
Radiation hardened F-doped fiber

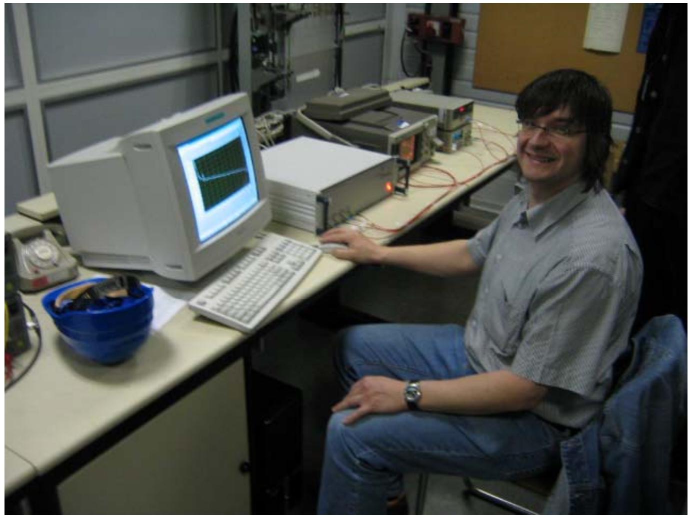


High Energy Physics irradiation test at CERN

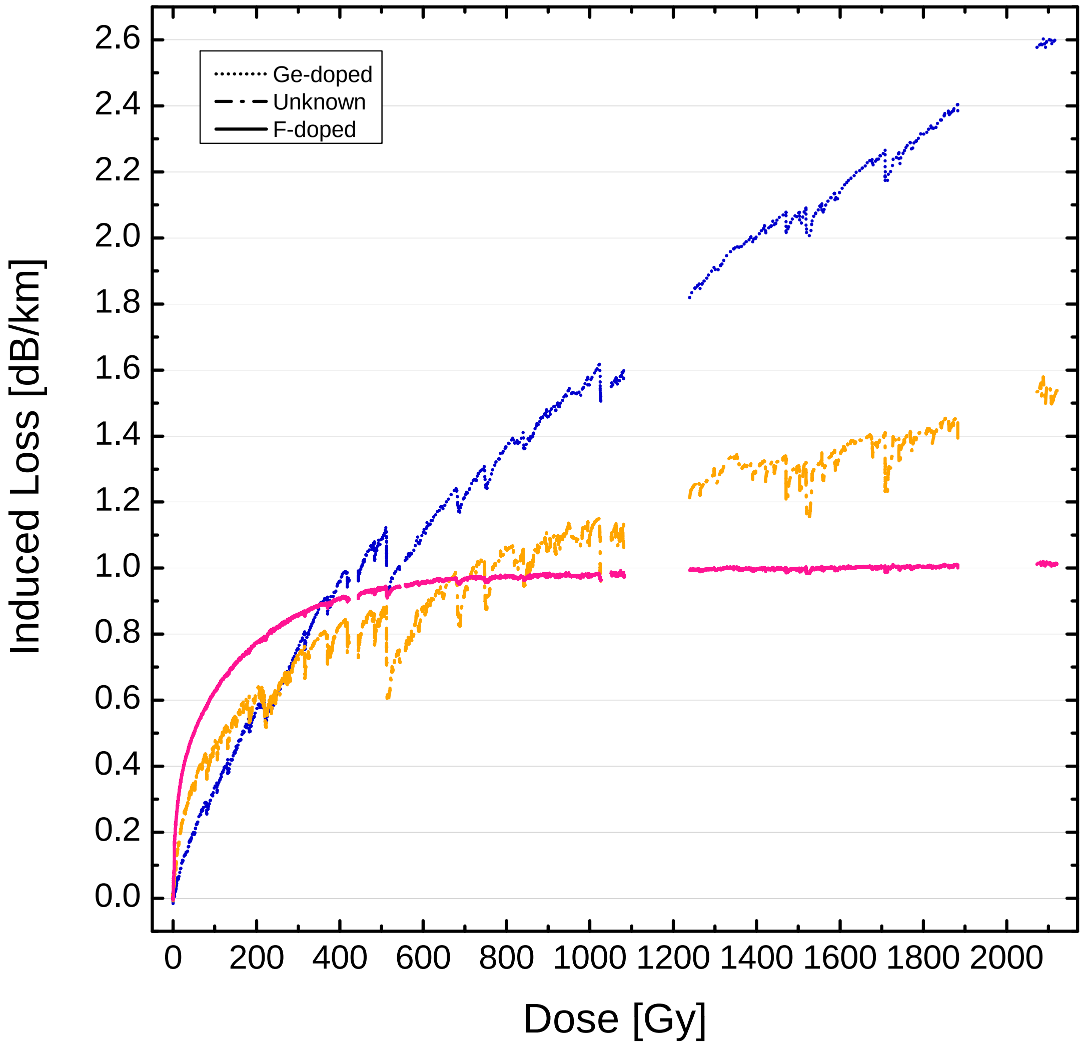


LHC Radiation Test Facility (TCC2)

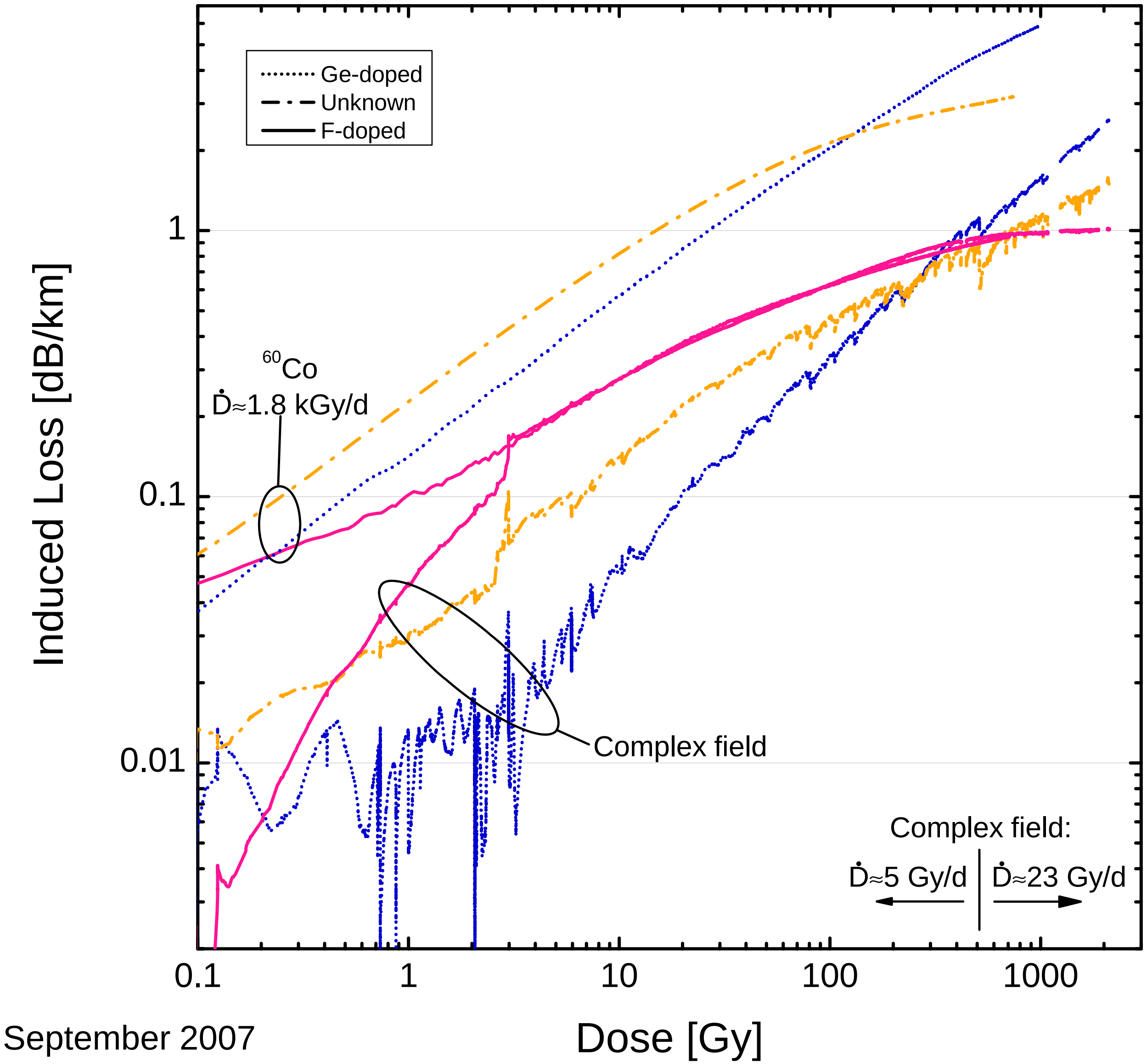




High Energy Physics Radiation field



High Energy Physics radiation field vs ^{60}Co



SM fibres Fujikura Ltd Japan

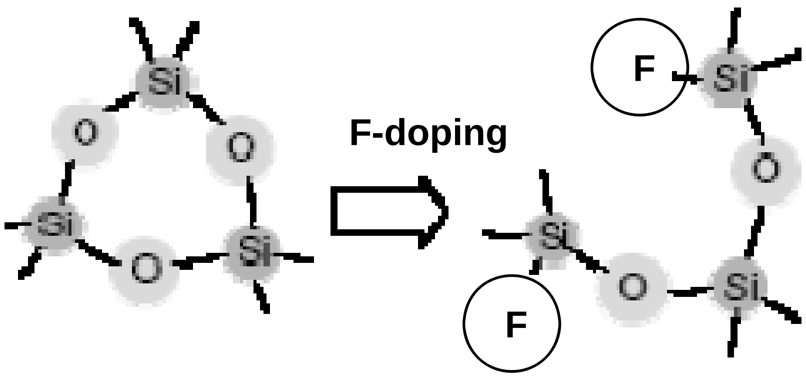
- Radiation hardening via :
  - F-doping
  - Special manufacturing process
  - H-loading ?

F-doping

What are the positive effects of Fluorine doping ?

- Quenches defects absorbing in the short wavelength region
- Breaking of strained bonds (reduction of disorder)
- Increase of band gap energy
- Reduction of glass viscosity

K. Sanada et al , Journal of Non-Cryst. Solids 179 (1994) 339-344

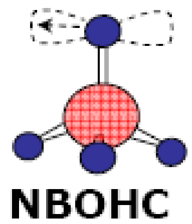


Fluorine contents has an optimum !

Reducing the SiOH impurity

- Silanol (SiOH) absorbs light between 1300-1500 nm
- SiOH is produced via :
  - NBOHC Defect + Hydrogen

$\equiv$Si - O• + •H^{o} $\rightarrow$ $\equiv$Si – OH



$\equiv$Si - O•

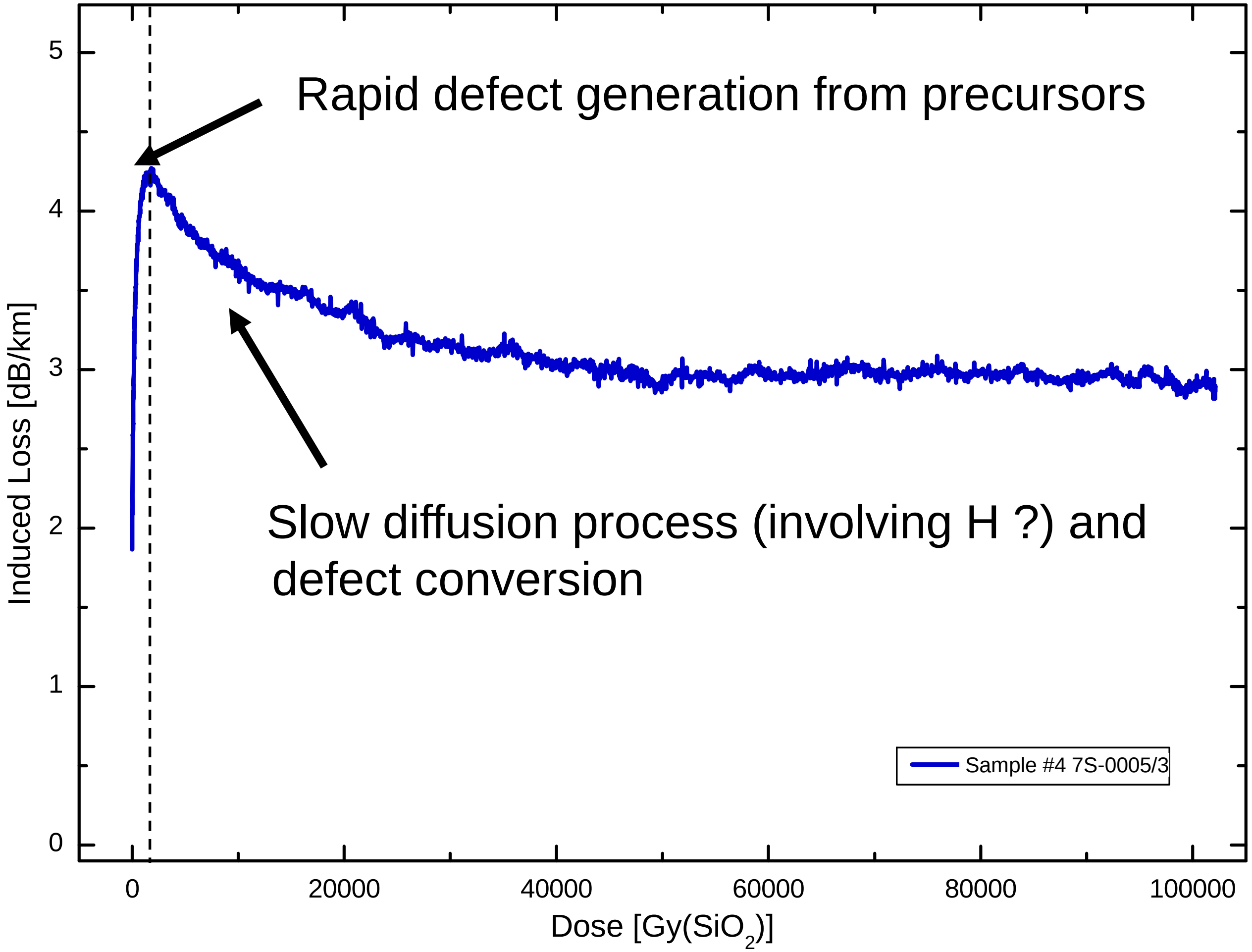
D.L. Griscom, J. of the Ceramic Soc. Japan, Int Edition Vol.99-903

H – loading technique

- From literature :
  - H_2 doping reduces losses of F-doped silica
  - Large reduction in absorption peak at early stage of irradiation
  - Two staged process :
    - H_2 diffusion into the fibre core
    - Reaction of H_2 with existing defects

K. Sanada et al , Journal of Non-Cryst. Solids 179 (1994) 339-344

Series sample testing (^{60}Co) 1310 nm



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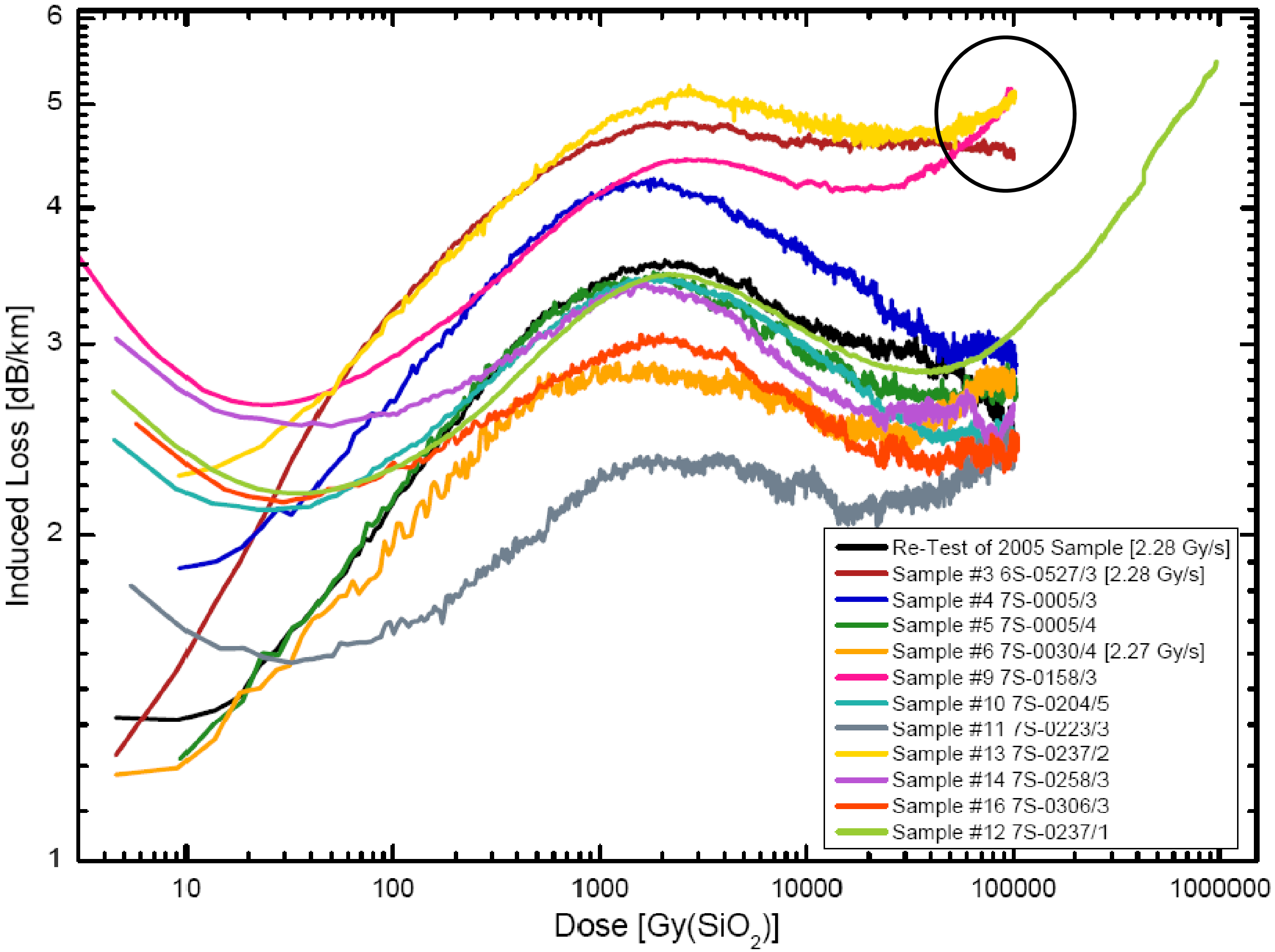

Conclusions

- Radiation Effects in OF are complex
- RIA in Co-60 and HEP radiation fields comparable
  - radiolysis
  - knock on process
  - particle type
  - particle energy
- F-doped SM fibre Fujikura Ltd shows excellent performance
- QA production lot acceptable
- RIA < 5 dB/km at 1310 nm and 1550 nm (< 1 MGy)

  unprecedented result – meets LHC BLM specifications !!!
- Further studies are ongoing :
  - What is the role of H ?
  - What is the annealing behavior ?
  - Spectral shifts ?
- Fibre monitoring in LHC IR3/IR7 is recommended