Rad-tolerant optical components for the CMS Tracker

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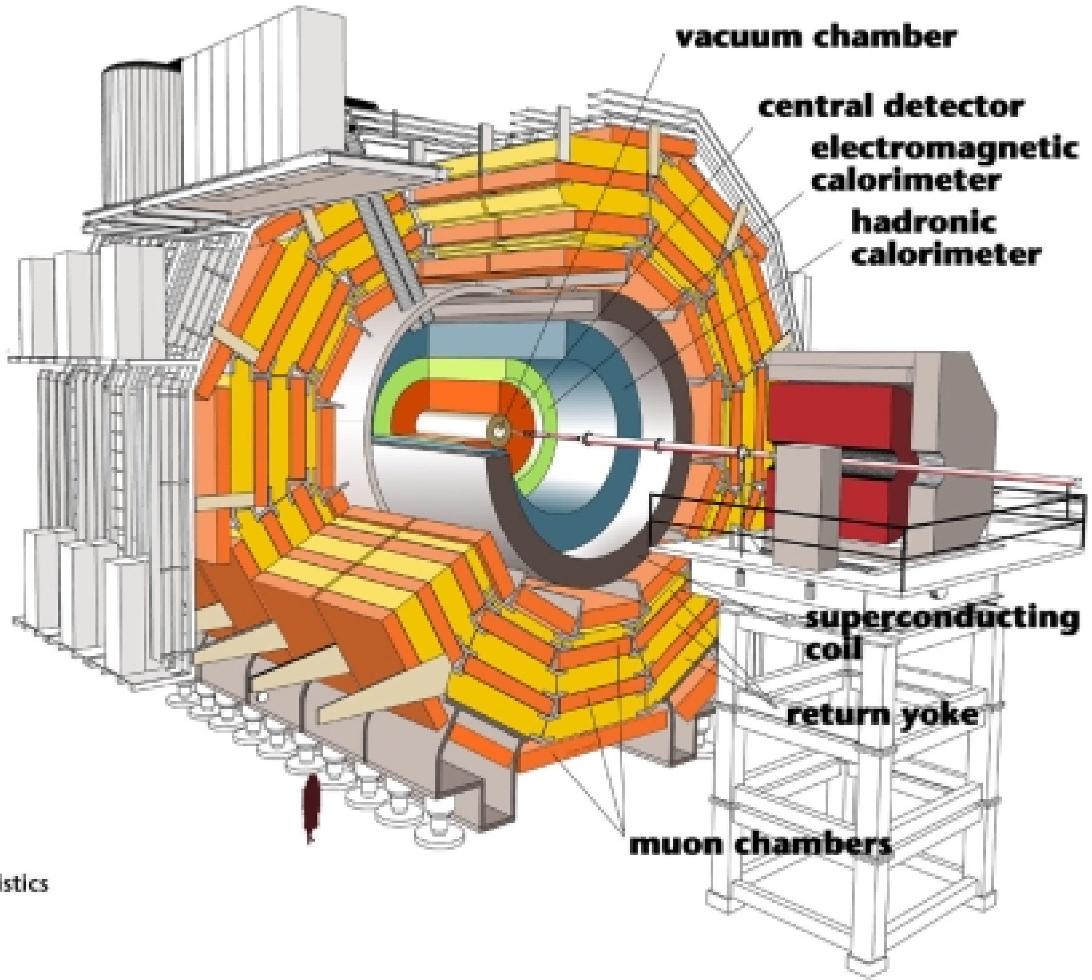
6th RD49 meeting 23-3-01

Outline

- **1. Brief Overview**
  - **CMS Tracker Optical Links**
  - **Environment**
- **2: Radiation damage testing at CERN**
  - **Lasers**
  - **fibres**
  - **connectors**
  - **photodiodes**
  - **System considerations**
- **3: Summary**

CMS at CERN/LHC

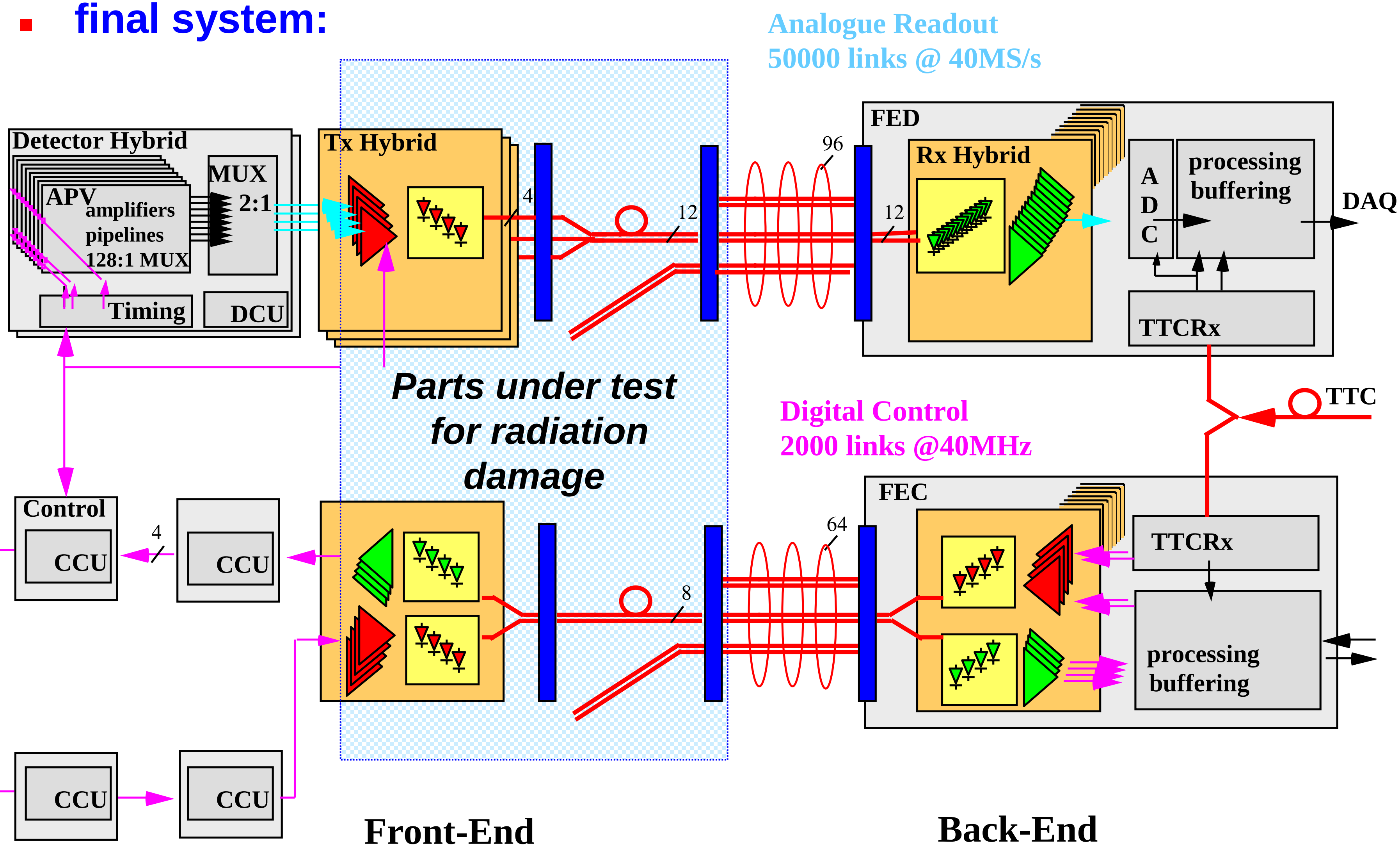


Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t

CMS Tracker readout and control links

- **final system:**



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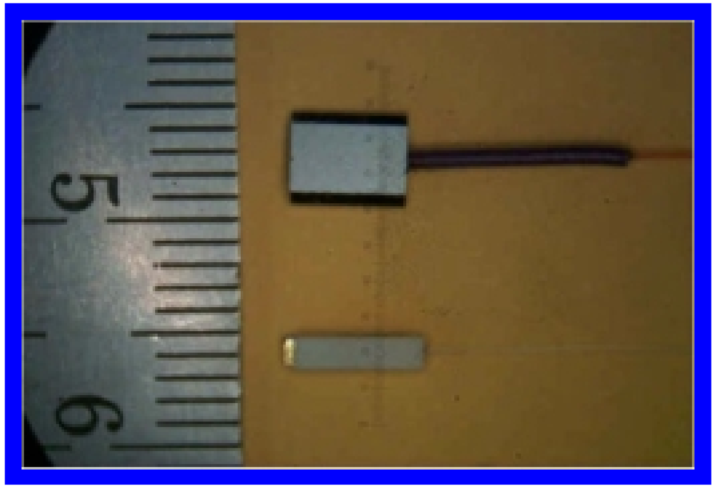
CMS Tracker optical link components

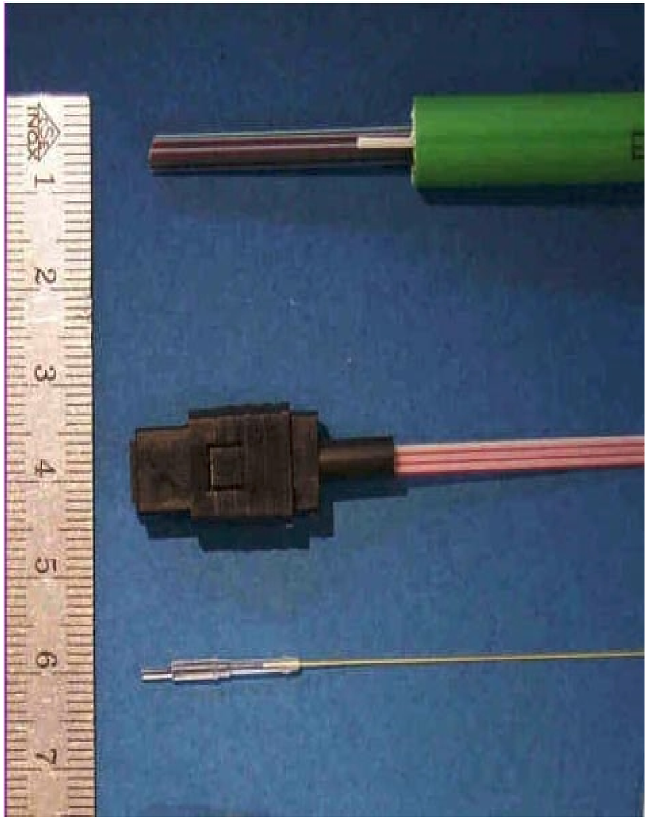
- **Inside the Tracker and at patch panels inside CMS**
  - **Transmitter (analogue and digital links)**
    - **edge-emitting 1310nm InGaAsP/InP multi-quantum well laser (single channel die)**
  - **Fibres (analogue and digital links)**
    - **Ge-doped single mode standard telecom fibre**
      - **1-way fibre pigtails, 12-way fibre ribbon cables, 8x12-way cables**
  - **Connectors (analogue and digital links)**
    - **1-way (MU-type)**
    - **12-way**
  - **Receivers (digital links)**
    - **InGaAs/InP pin photodiodes (single channel)**
- **These components exposed to radiation**

COTS components for CMS Tracker links

- **Some examples of prototypes:**

1-way InGaAsP edge-emitting lasers on Si-submount with ceramic lid





96-way cable

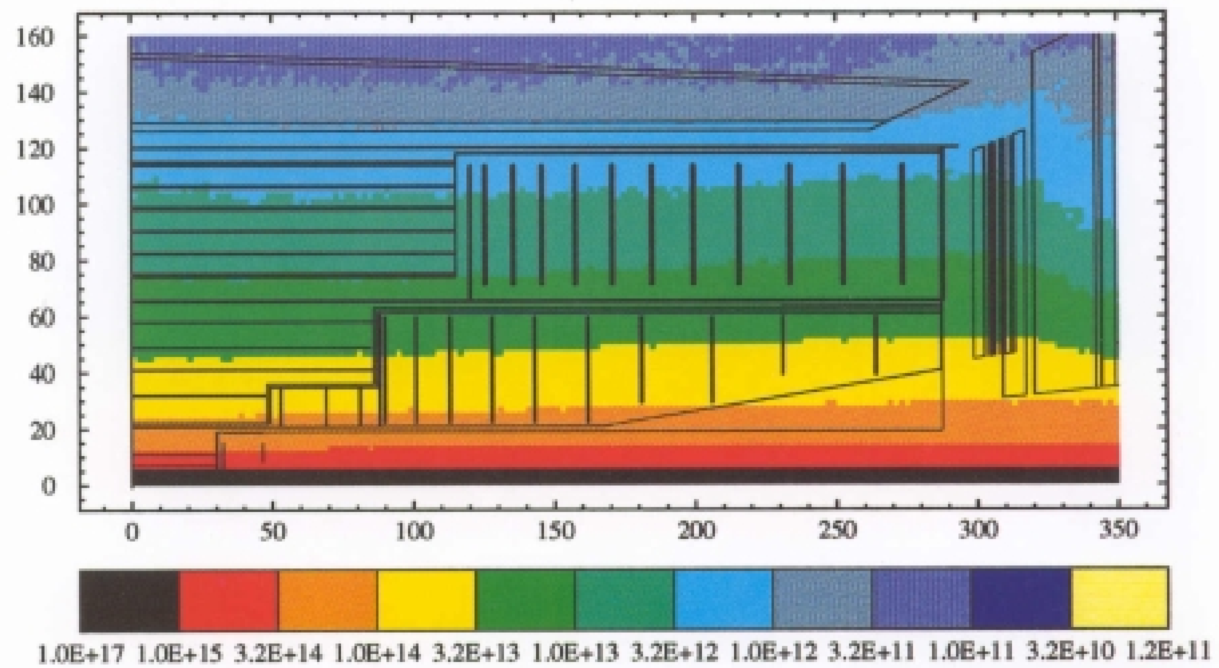
12-way optical ribbon and MT-connector

single fibre and MU connector

COTS issues

- **Extensive use of commercial off-the-shelf components (COTS) in CMS optical links**
  - **Benefit from latest industrial developments**
    - **cheaper**
    - **“reliable” tested devices**
  - **However COTS not made for CMS environment**
    - **no guarantees of long-life inside CMS**
- **<u>validation testing of COTS mandatory before integration into CMS</u>**

Tracker radiation environment



Charged hadron fluence (/cm² over ~10yrs)

high collision rate
high energy
large number of tracks
radiation damage

lifetime >10 years
temperature -10C

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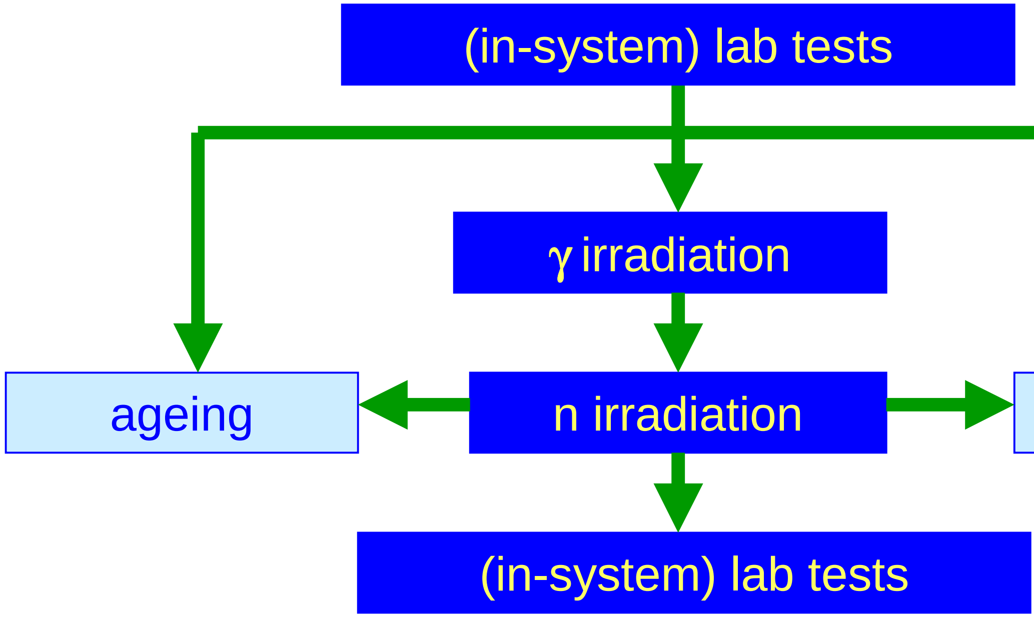
Validation procedures for rad-resistance

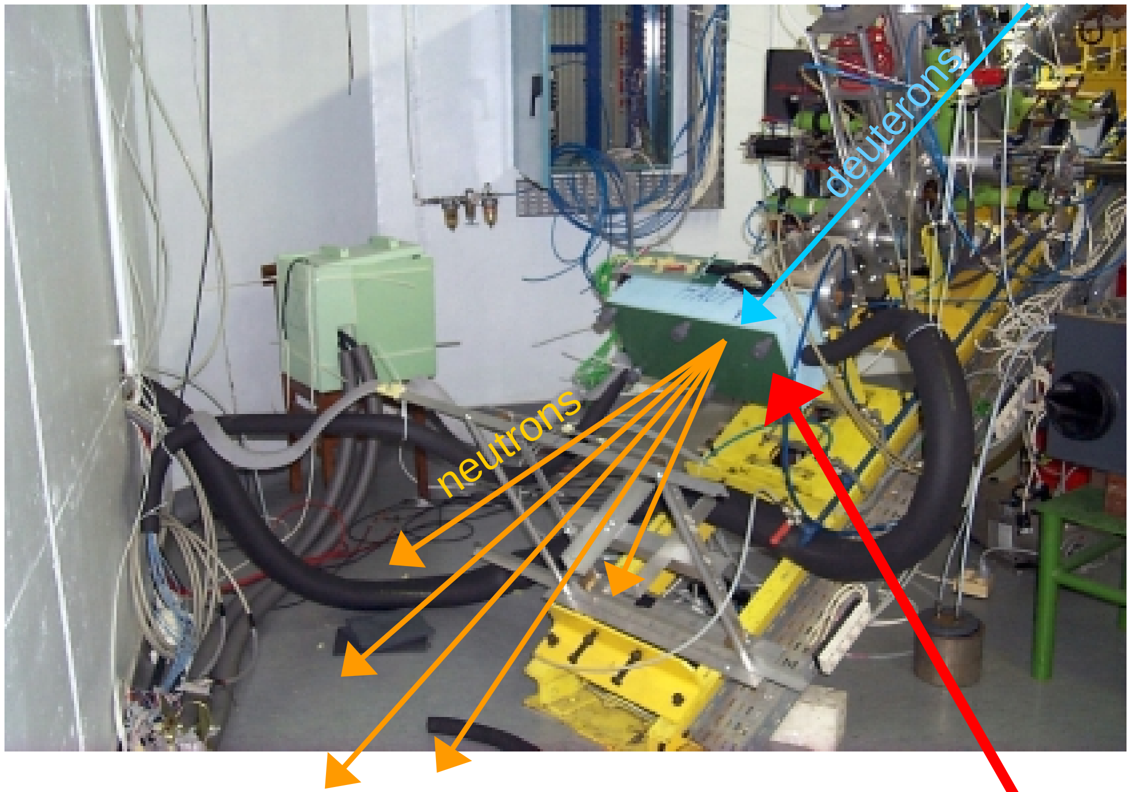
- **E.g. lasers and photodiodes**

Highlighted:
1999 Market survey validation tests



- **Feedback test results into system specifications**
  - **radiation damage effects can then be mitigated**

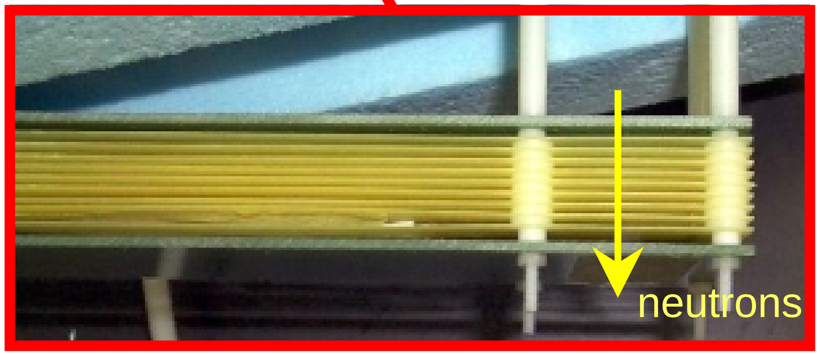
Neutron tests at UC Louvain-La-Neuve



Recent validation tests of laser diodes

~20MeV neutrons
flux ~ $5x10^{10}$n/cm^2/s
fluence ~ $5x10^{14}$n/cm^2

(Similar to CMS Tracker 10 year exposure)



Samples stacked inside cold box (-10C)

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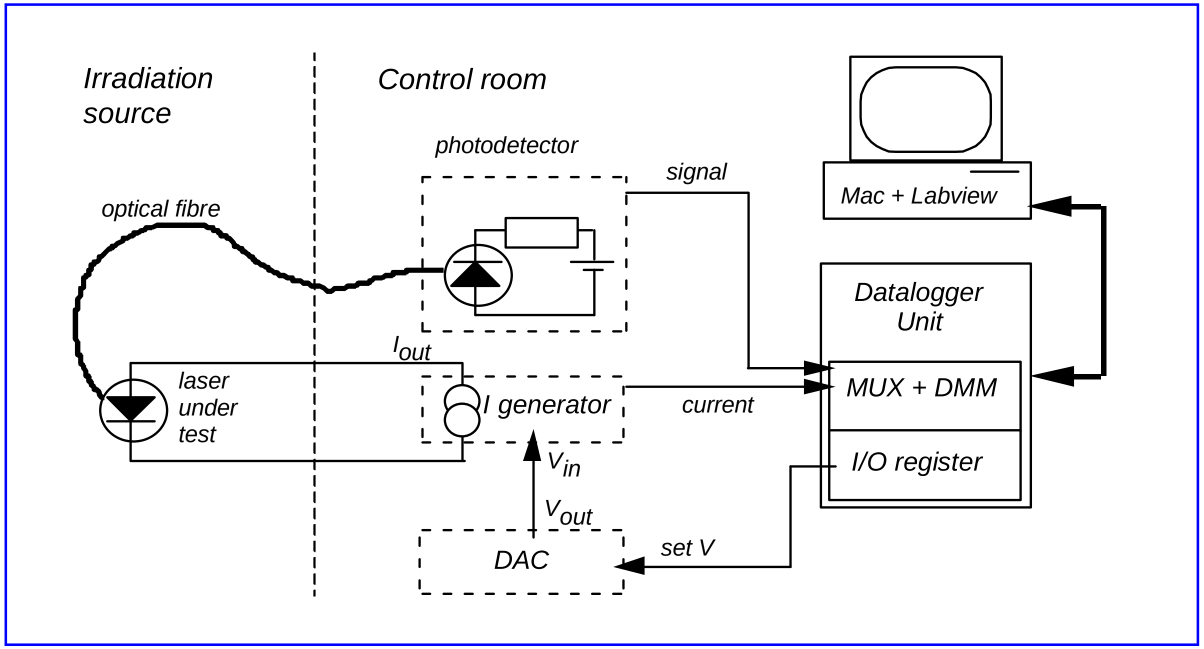
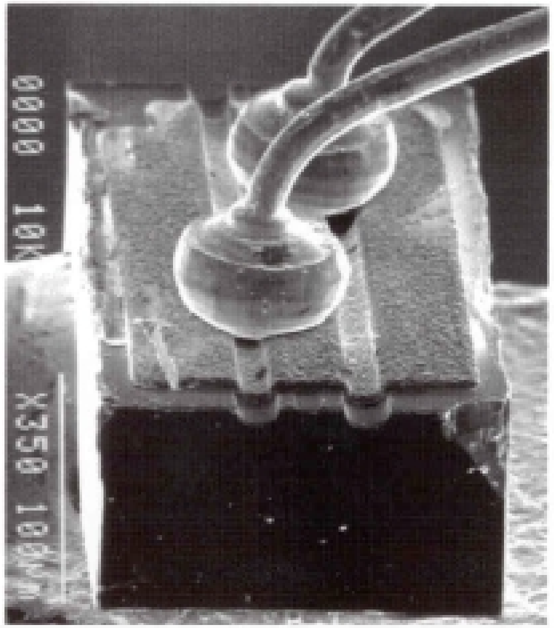
Radiation test system

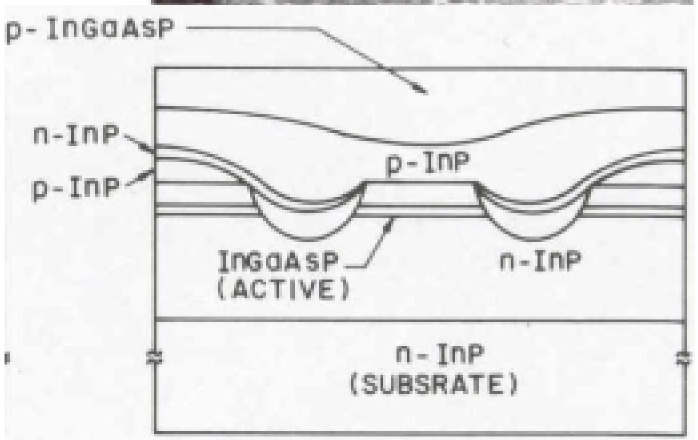
- **Test setup for in-situ measurements**



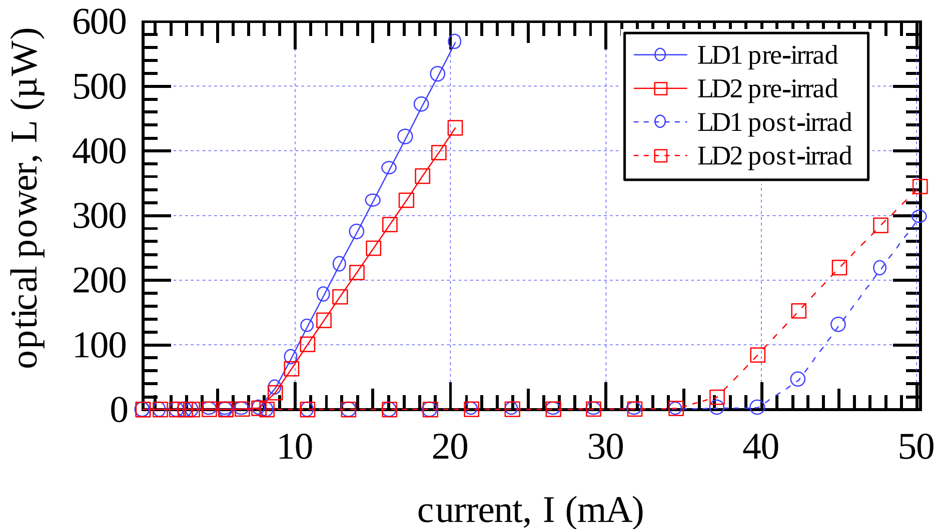
- **In-situ measurements give powerful capability to extrapolate damage effects to other radiation environments**
  - **e.g. CMS Tracker, if damage factors of different particles known**
- **Similar test setup for p-i-n and fibre studies**

neutron damage - Italtel/NEC lasers





Light output vs current characteristics
before and after neutron irradiation



Fluence = 5x10^{14}n/cm^{2}
temperature =23C

Damage effects consistent with build-up of non-radiative recombination centres in/around active laser volume, causing a decrease in injected charge carrier lifetimes

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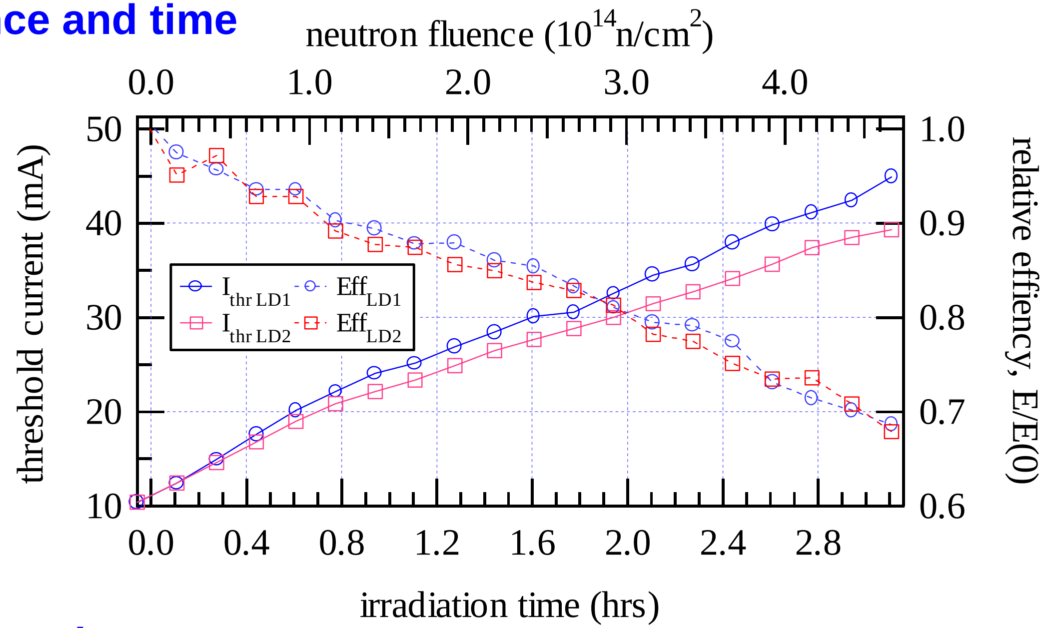
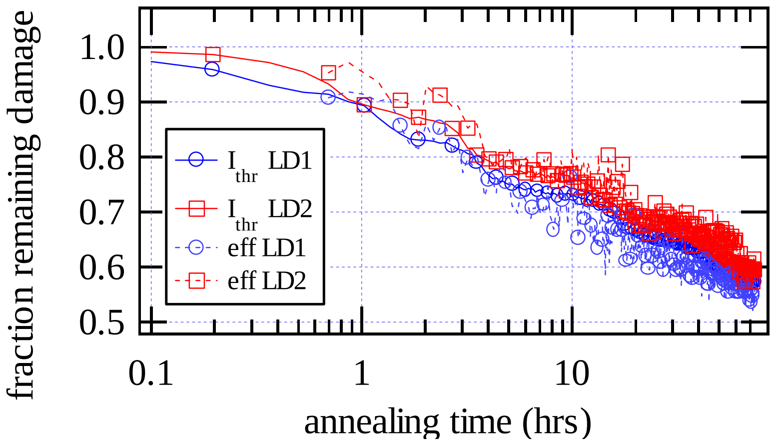
neutron damage - Italtel/NEC LD

Damage vs fluence and time



Roughly linear increase in damage with fluence

annealing vs time



Same annealing dynamics for threshold and efficiency therefore indicate same underlying physical damage mechanism

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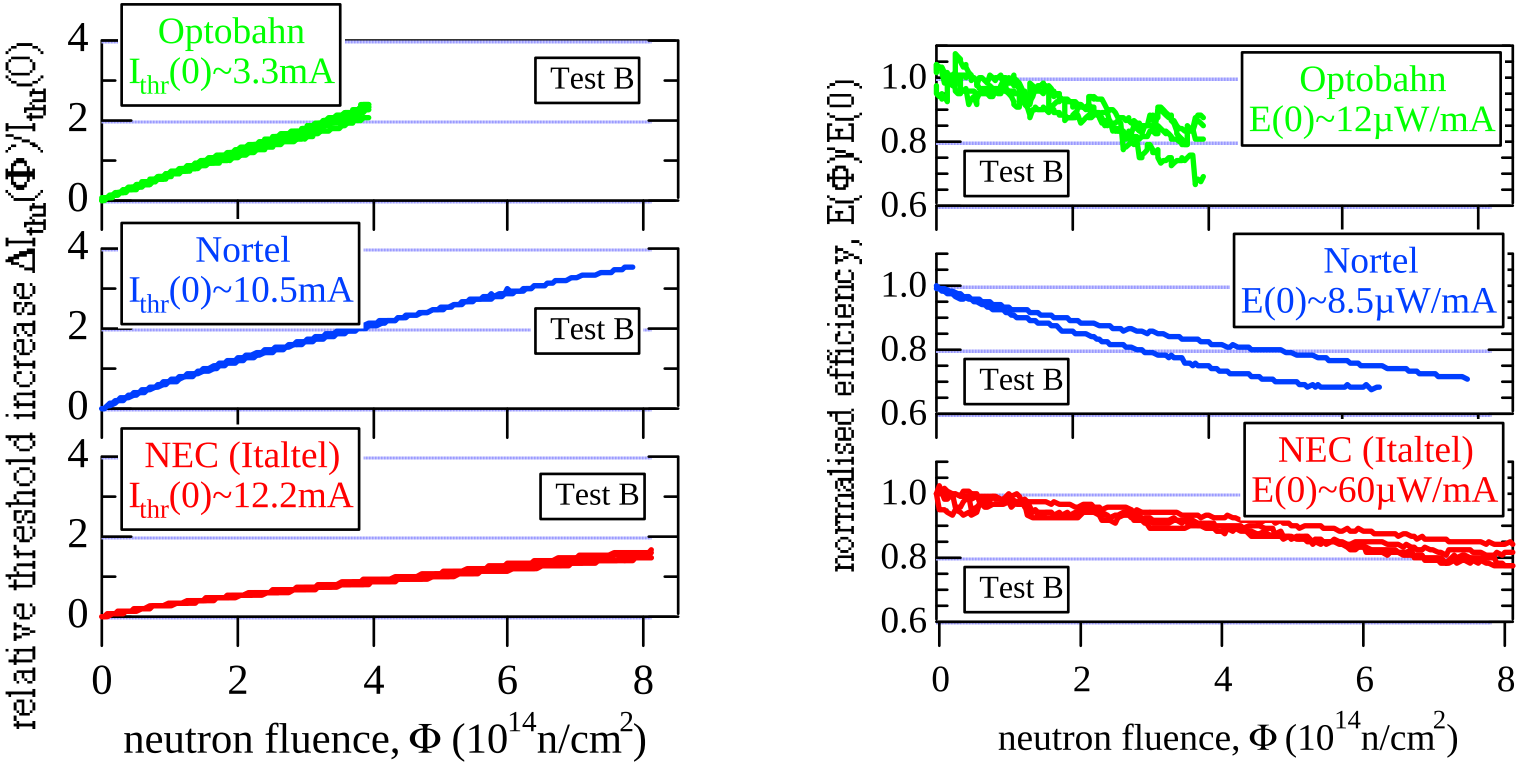
Different vendors compared

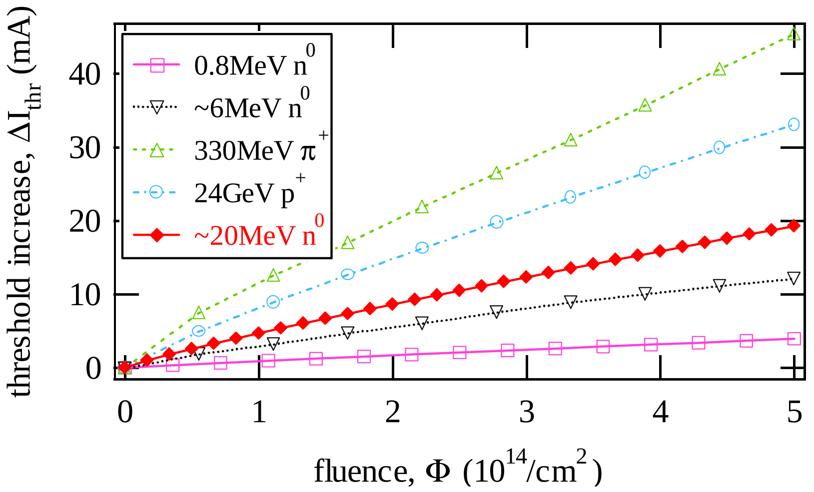
- I_{thr} and Eff changes vs neutron fluence



- similar effects in all 1310nm InGaAsP lasers

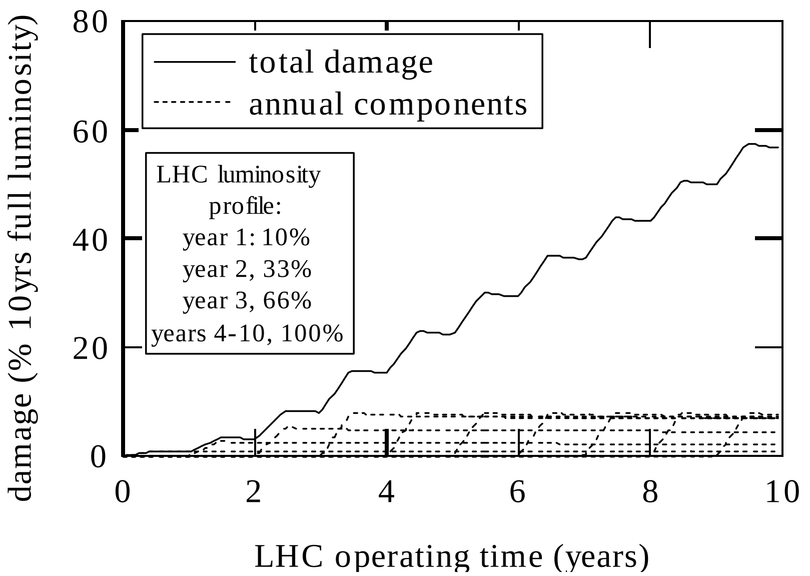
Radiation source comparison - Italtel/NEC laser

For comparison with other sources:
Normalize to fluence = $5x10^{14}\pi/cm^2$
in 96 hours irradiation



Damage factor ratios:
0.8MeV n = 1
~6MeV n = 3.1
~20MeV n = 4.9
330MeV pi = 11.5
24GeV p = 9.4

Extend to 10 years, taking into account LHC luminosity profile



possible to estimate damage to laser threshold in CMS Tracker:

in worst case, at low radii ΔI_{thr} = 14mA for Italtel/NEC lasers

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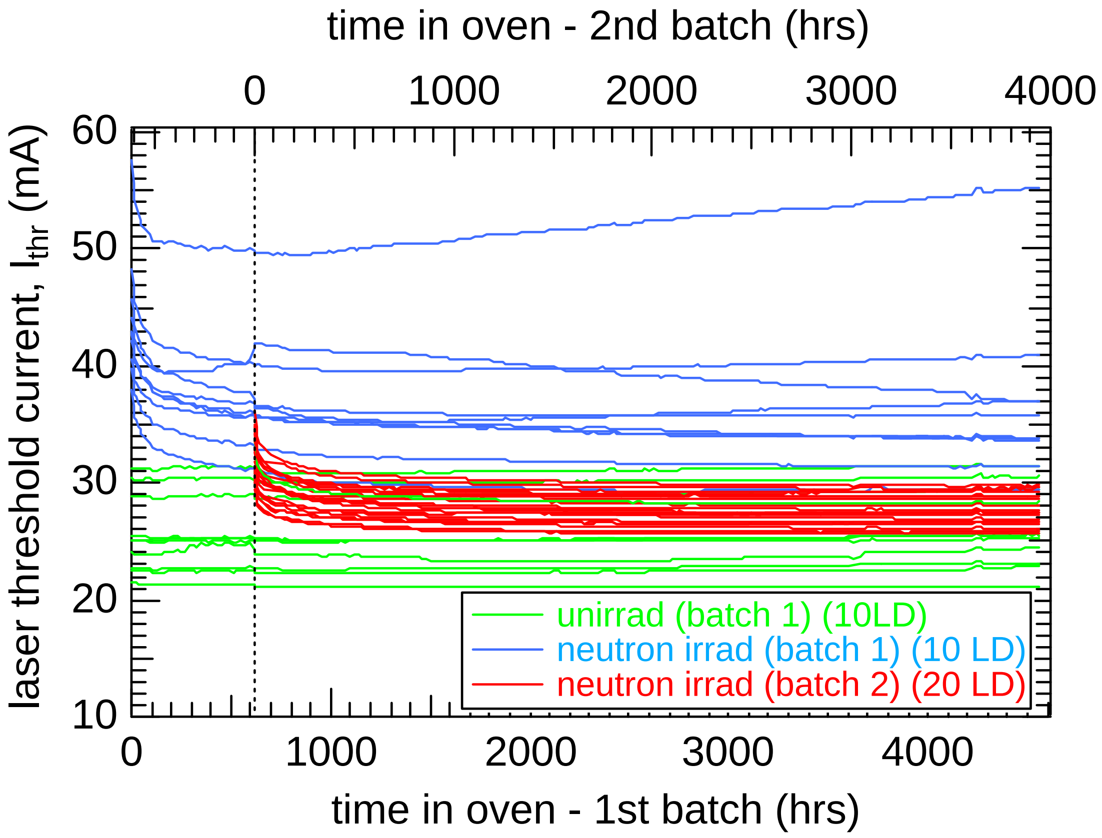
Reliability of irradiated lasers

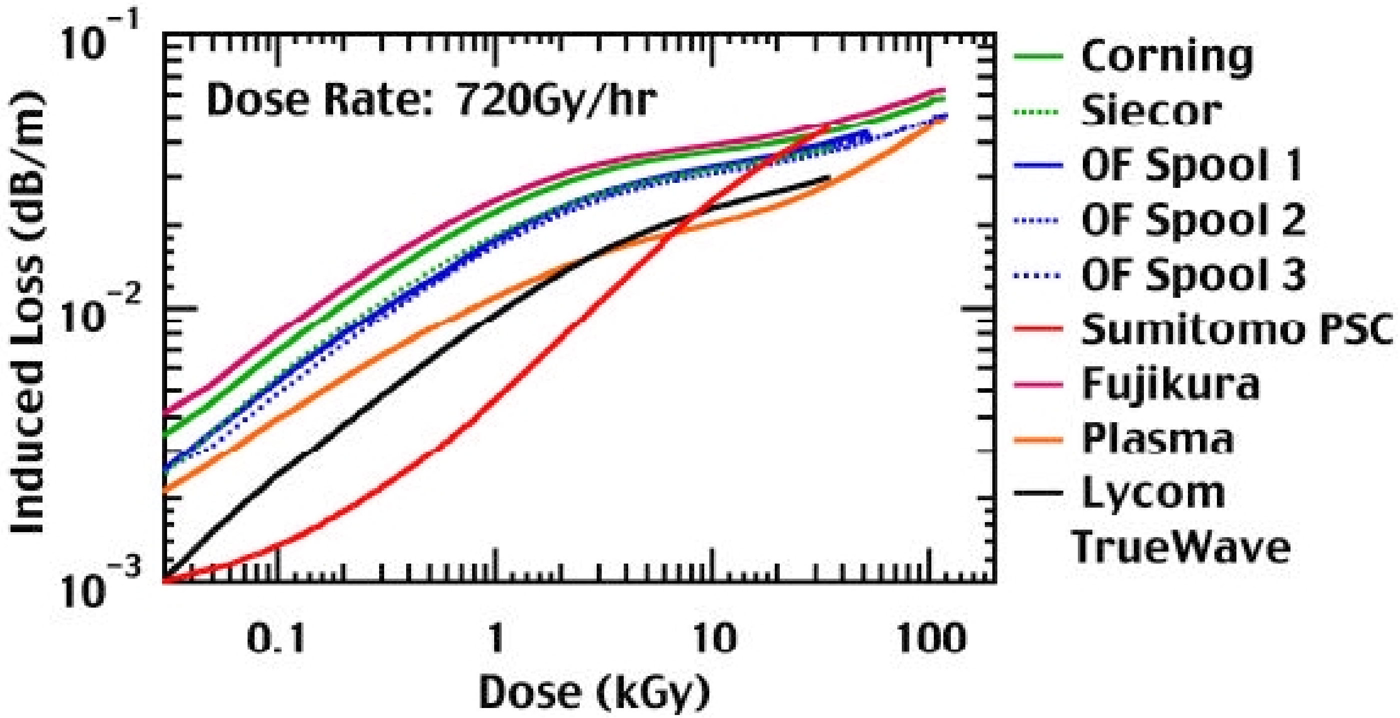
- **irradiated device lifetime > 10 years??**
- **Ageing test at 80C**



- **No additional degradation in irradiated lasers**
- **acc. Factor ~400 relative to -10C operation**
- **lifetime >>10years**

Tests of fibre attenuation

- **Gamma damage (CMS-TK COTS single-mode fibres) at 1310nm**



- Loss below 0.1dB/m
- PSC fibre advantageous only below ~ 10-20kGy

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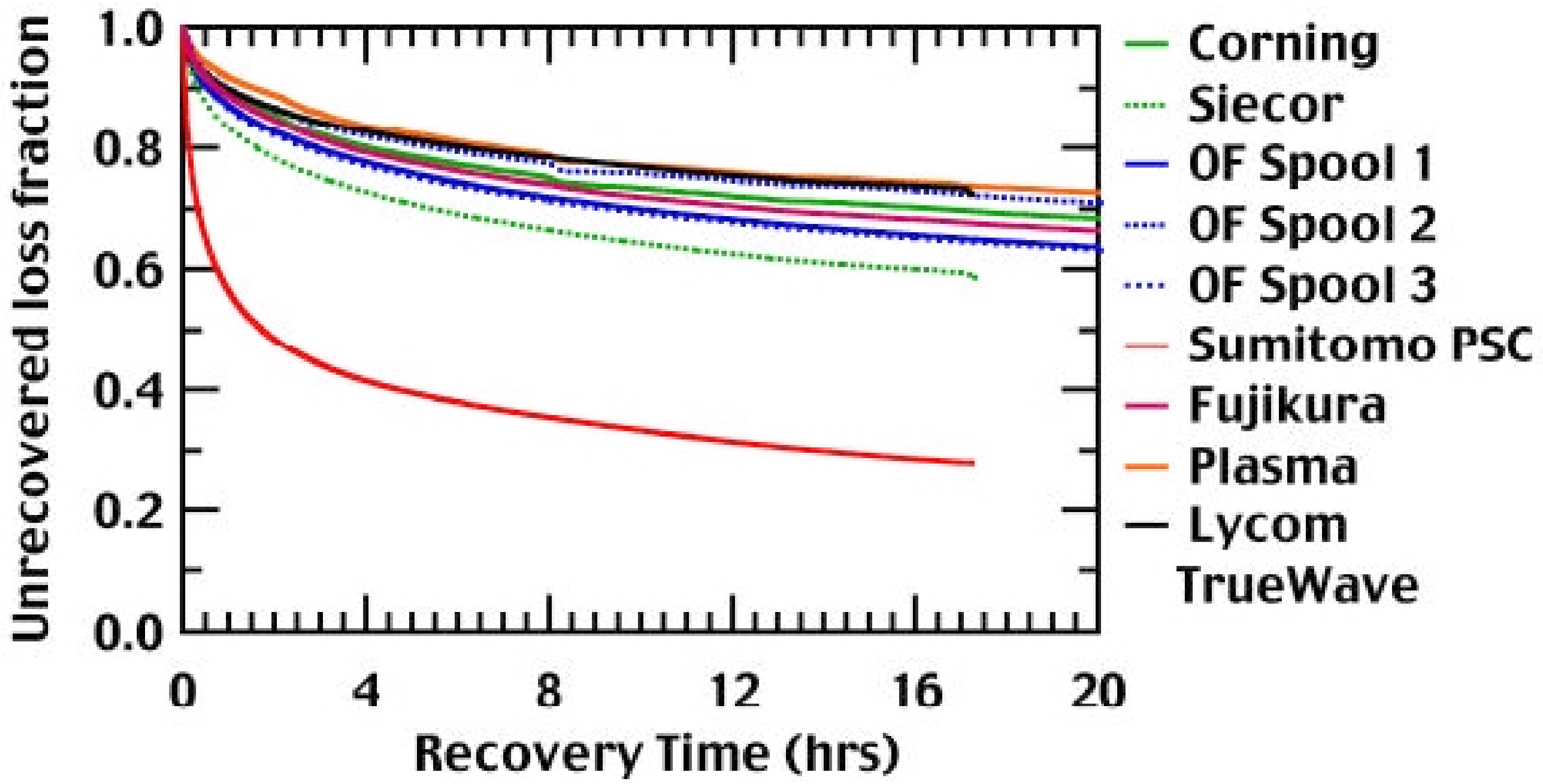
Fibre annealing

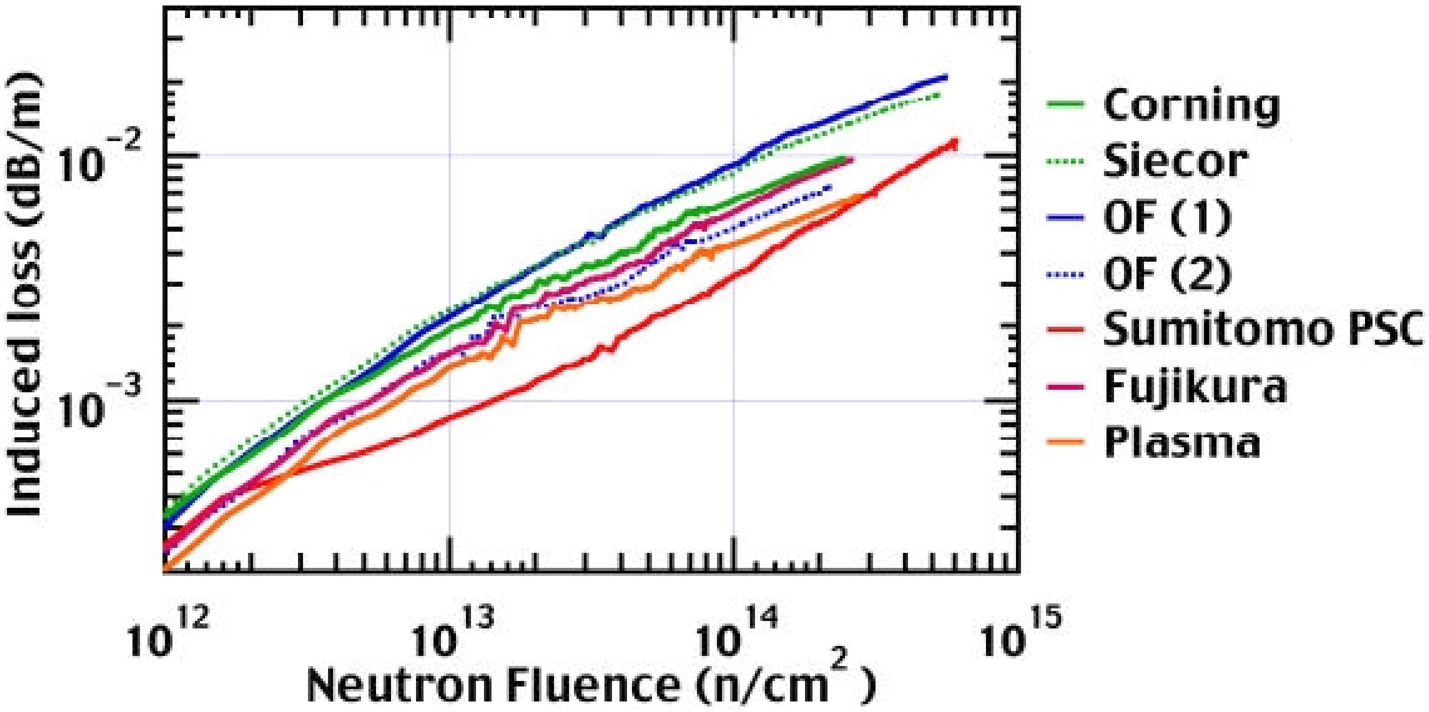
- **damage recovers after irradiation (e.g. gamma)**



- **Damage therefore has *dose-rate* dependence**

Fibre attenuation vs fluence

- **‘Neutron’ damage (CMS TK)**



- **damage actually most likely due to gamma background**

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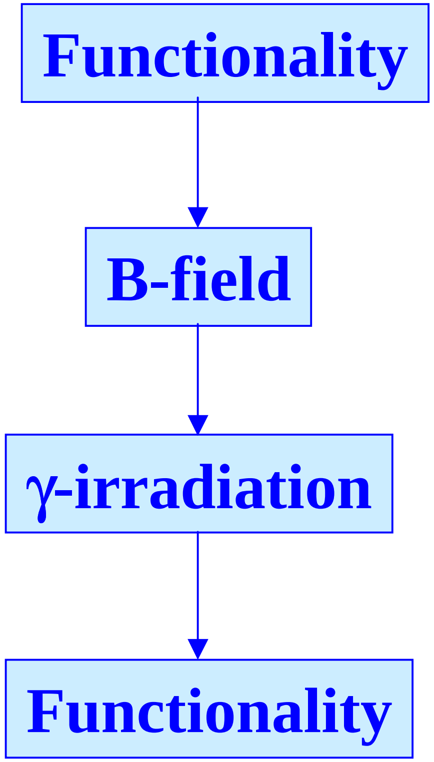
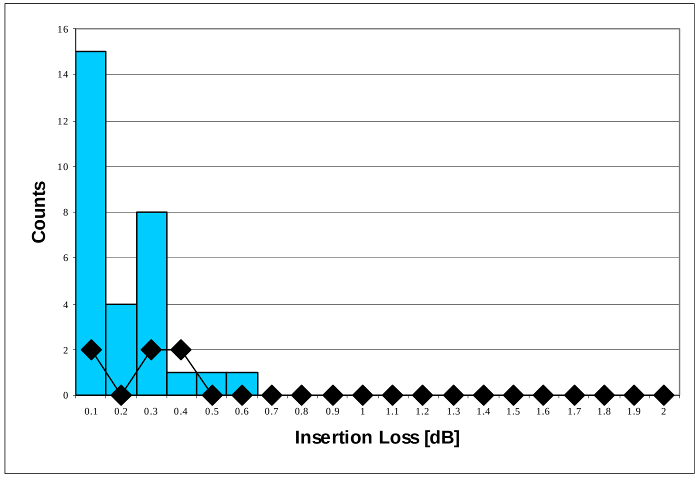
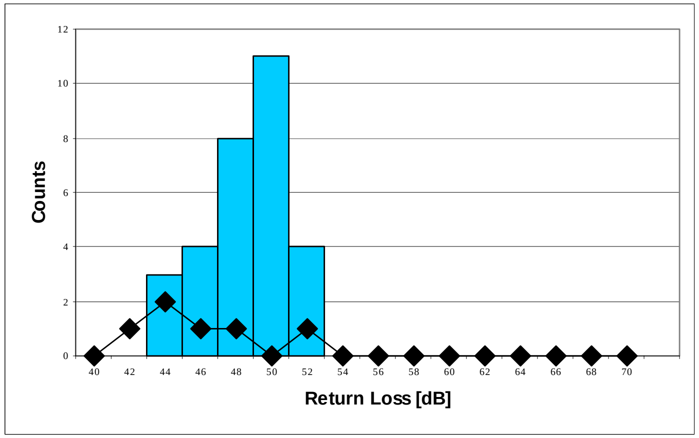
Connector validation







- **E.g. MU connector results**

	TOT min		TOT avg		TOT max	
	IL	**RL**	**IL**	**RL**	**IL**	**RL**
Before irr:	0	45	0.15	49	0.58	53
After irr:	0.02	43	0.23	47	0.4	52

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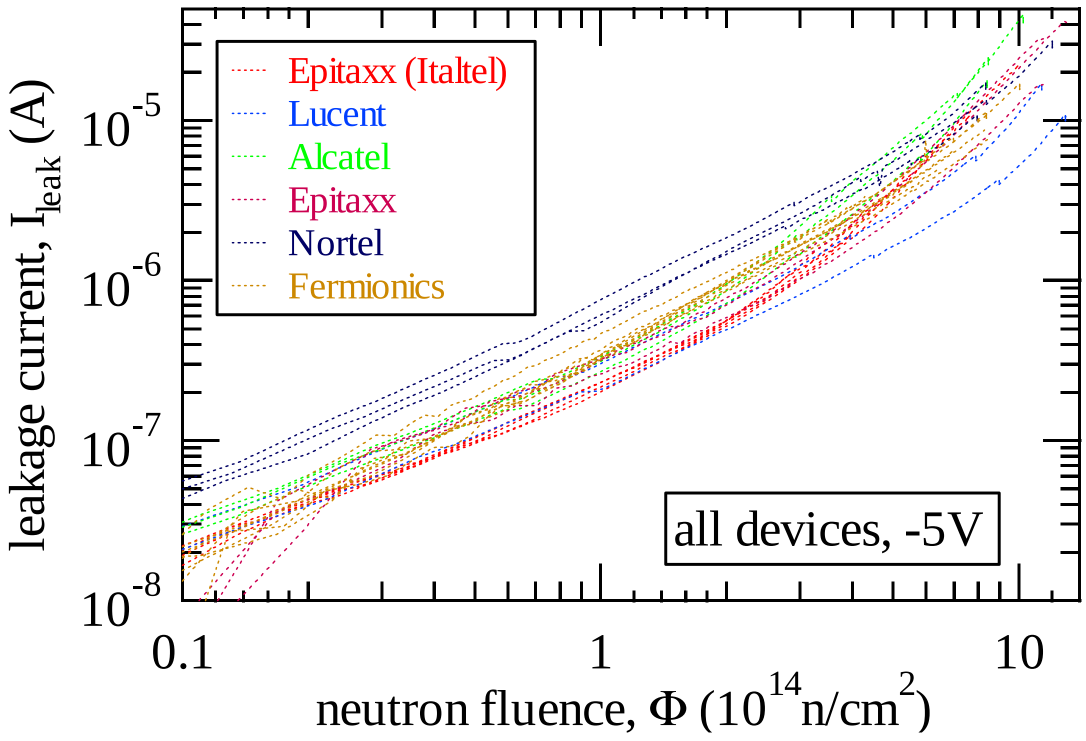
Tests of photodiodes - leakage

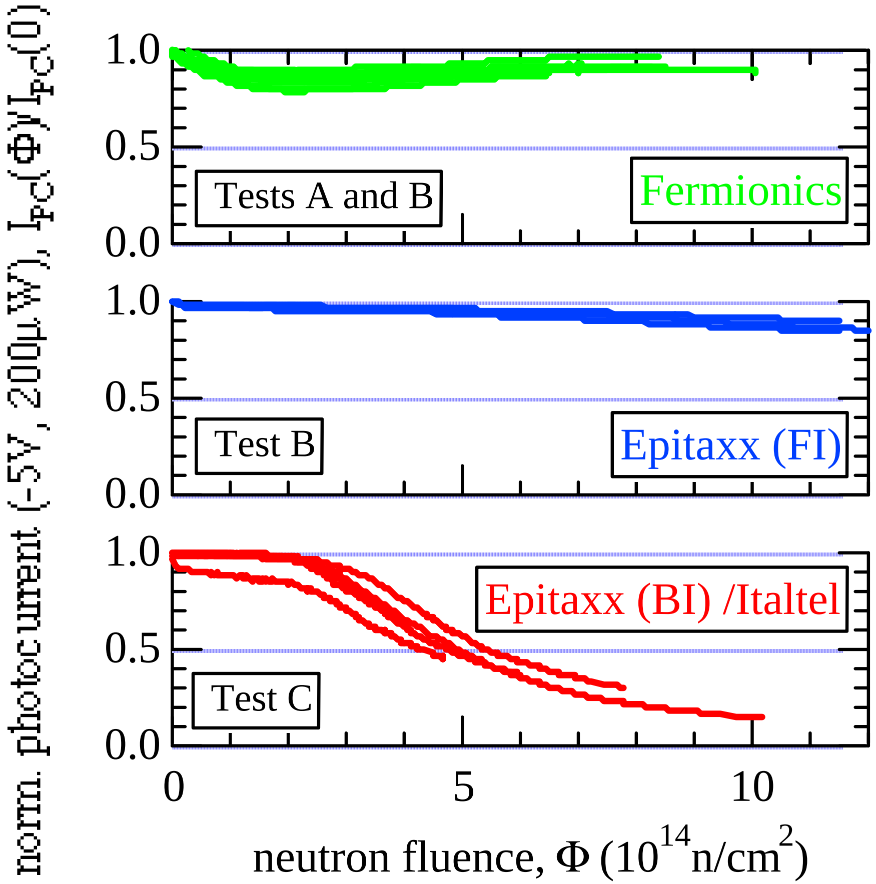
- **leakage current (InGaAs, 6MeV neutrons)**



- **similar damage over many (similar) devices**

Photodiodes - response

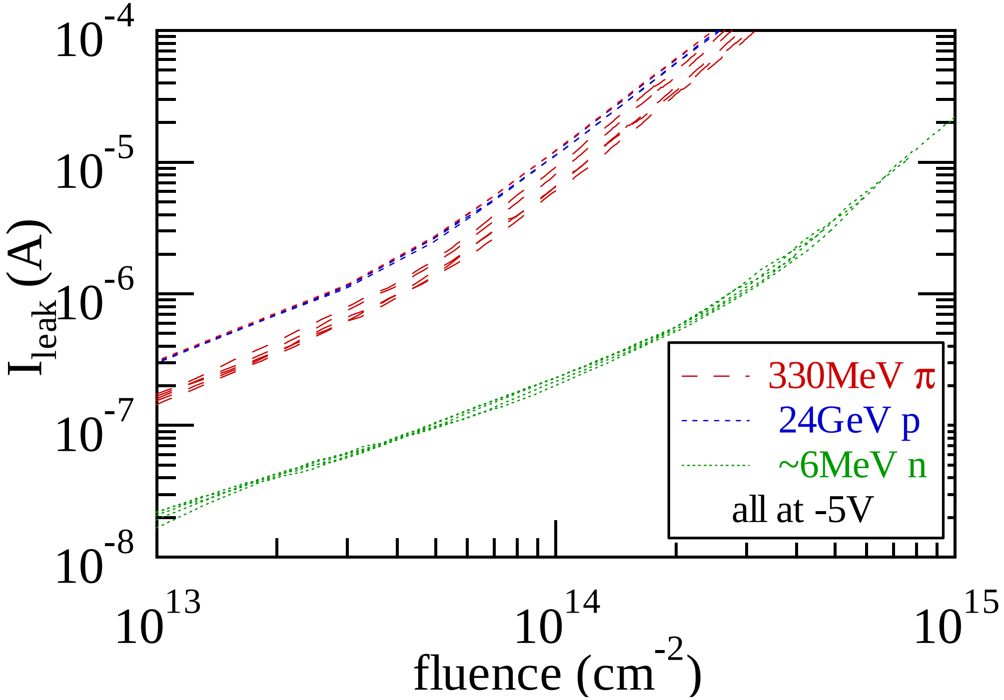
- **Photocurrent (InGaAs, 6MeV neutrons)**



- **Significant differences in damage**
- **depends mainly if front or back-illuminated**
  - **front-illuminated better**

Different particles (leakage)

- leakage current (InGaAs, different particles, 20C)



- higher energy π, p more damaging than n

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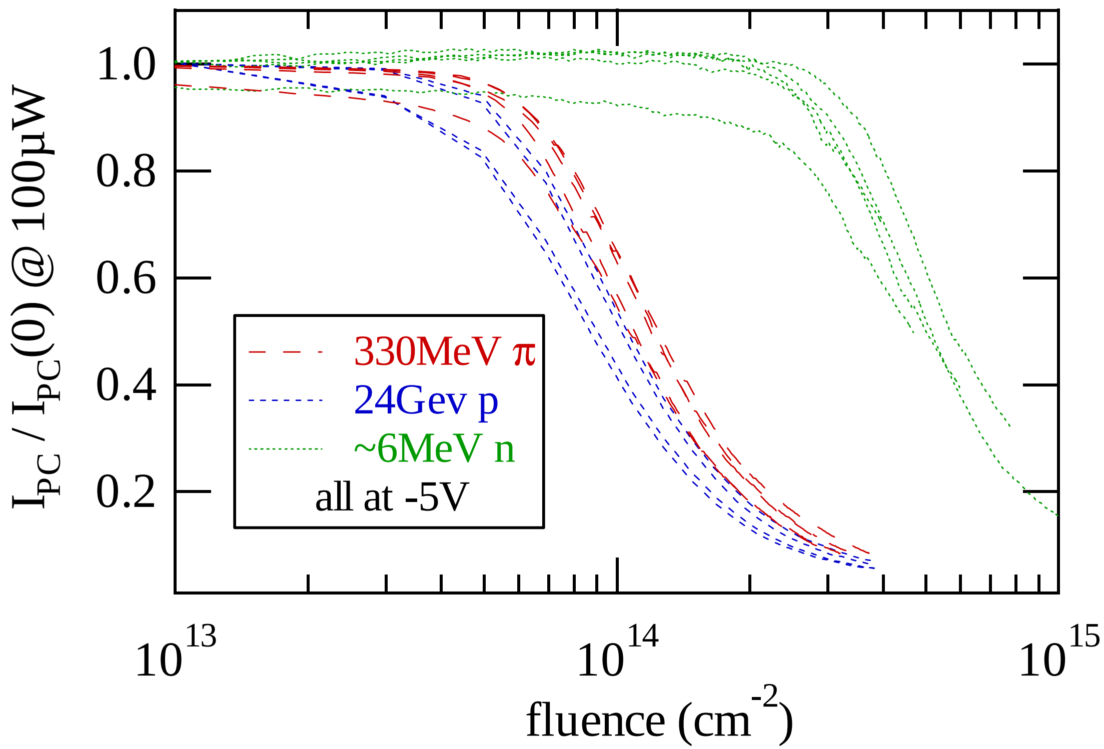
Different particles (response)

- **different particles:**



- **higher energy π, p more damaging than n**

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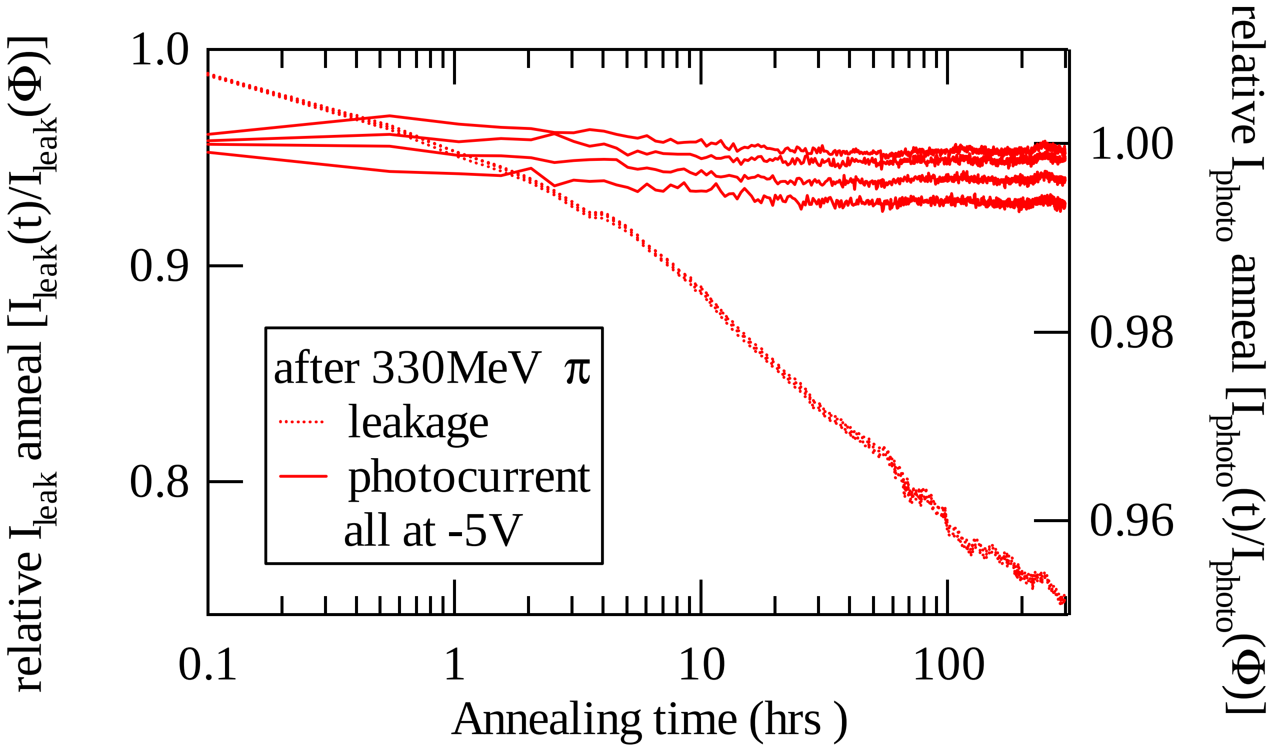
InGaAs p-i-n annealing

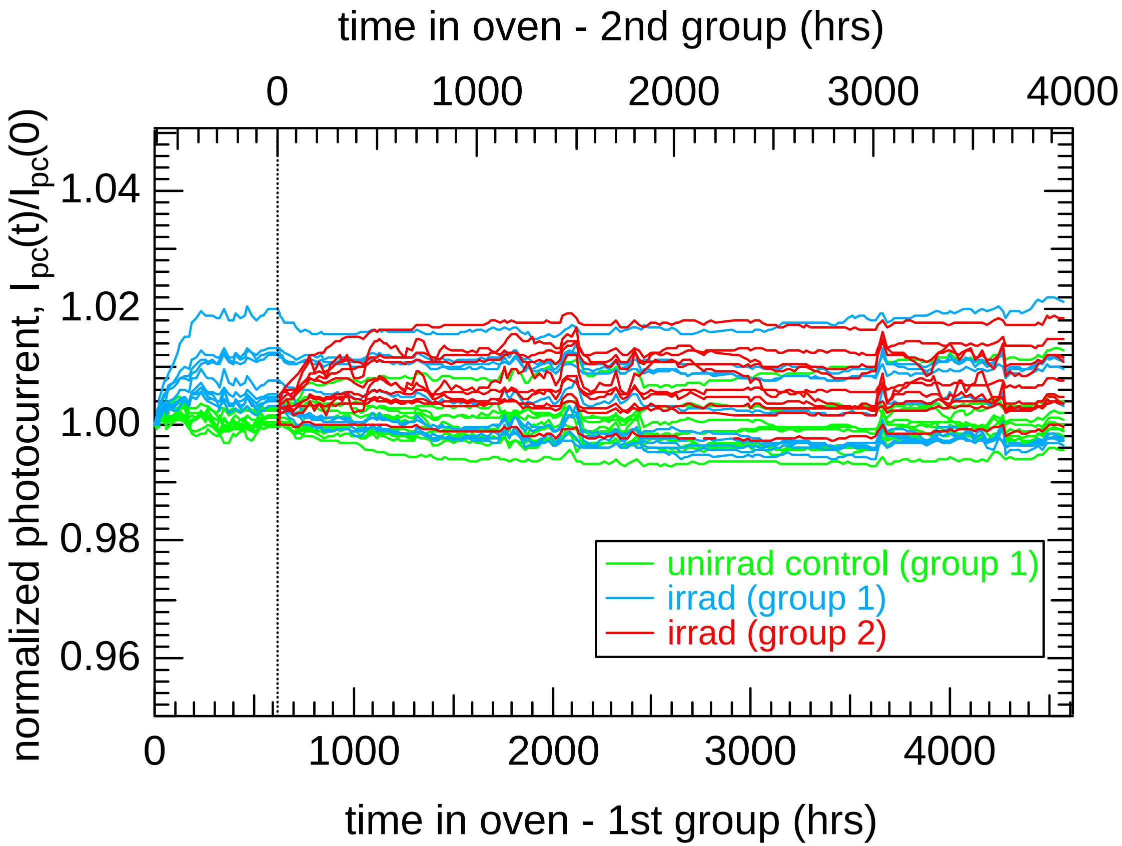
- **After pion irradiation (room T, -5V)**



- **Leakage anneals a little**
- **No annealing of response**

InGaAs p-i-n reliability

- **irradiated device lifetime > 10 years??**
- **Ageing test at 80C**



- **No additional degradation in irradiated p-i-n's**
- **lifetime >>10years**

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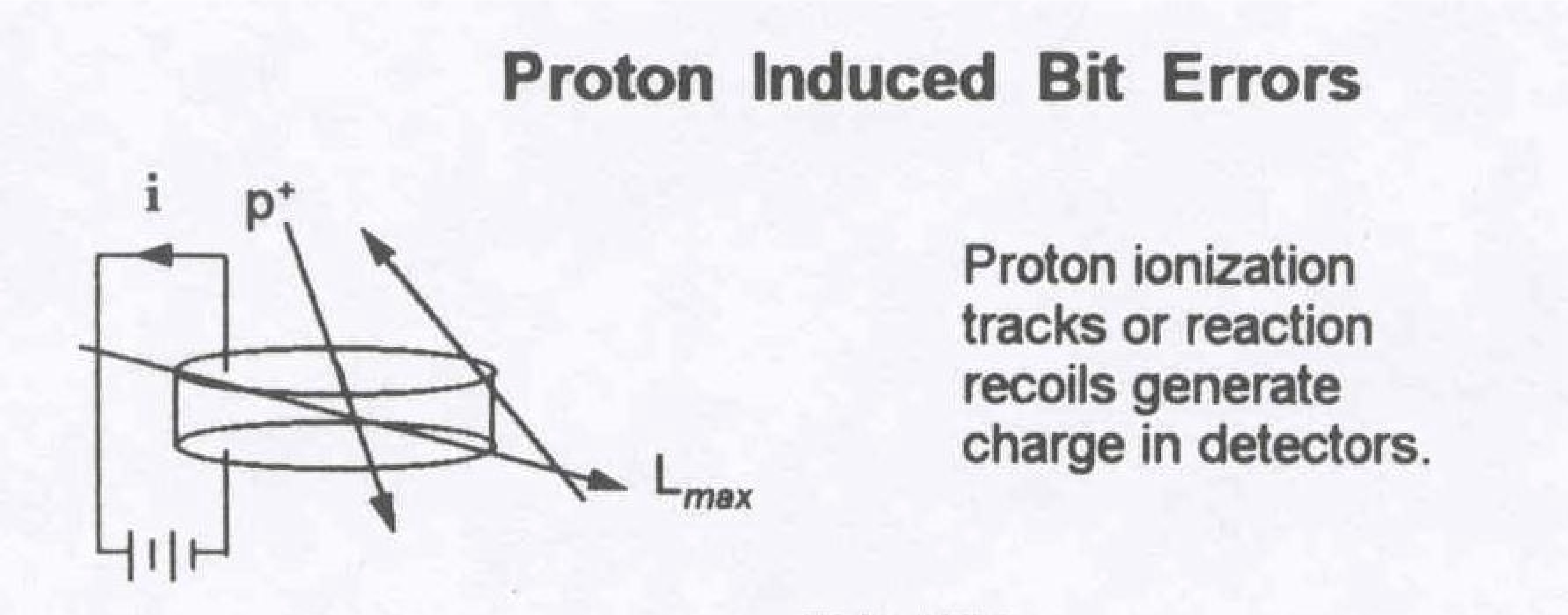
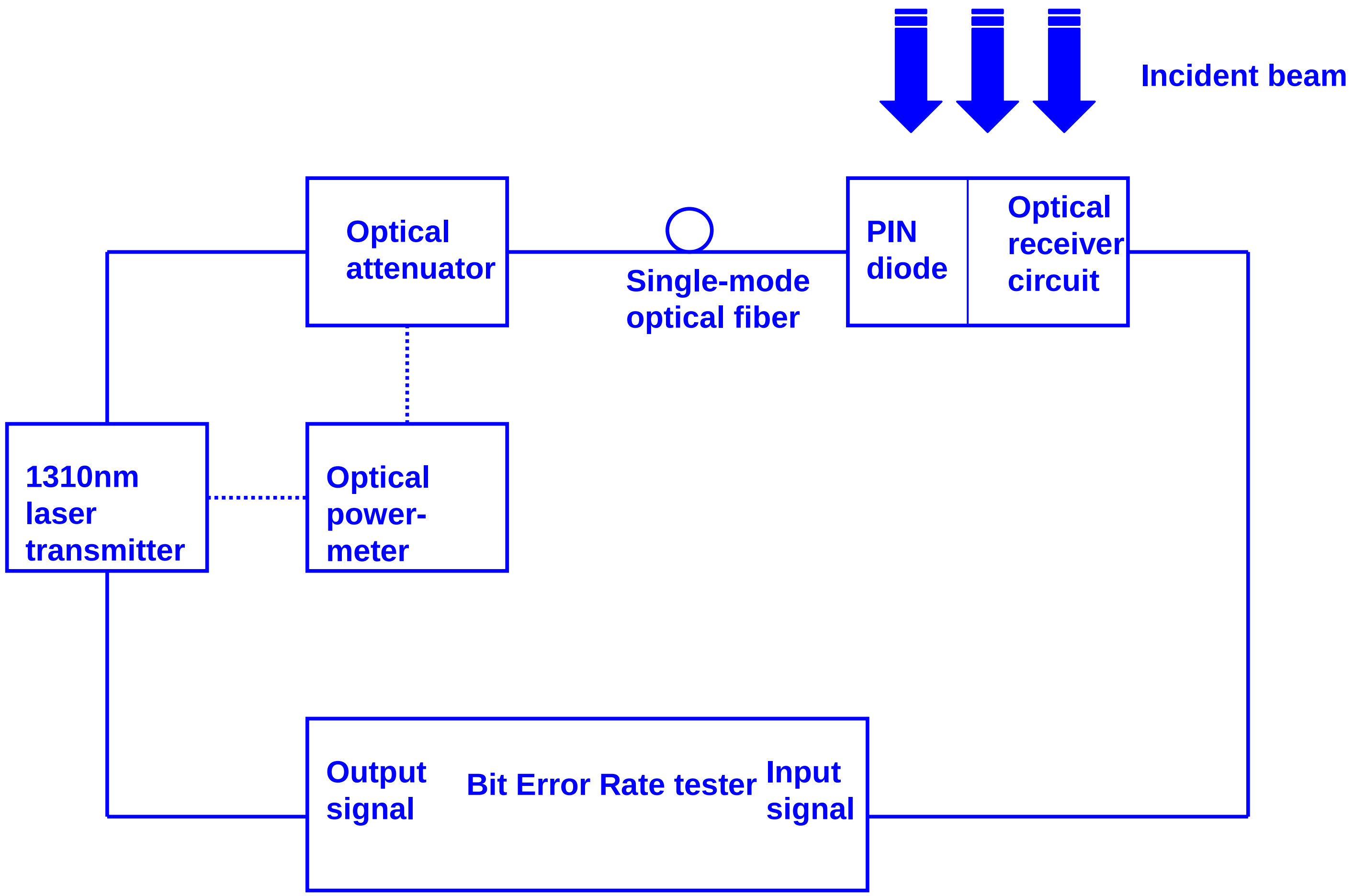
PD SEU

- **photodiodes sensitive to SEU**



- **strong dependence upon particle type and angle**

Experimental setup for particle-induced BER



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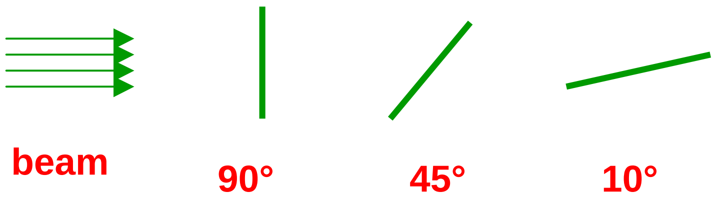
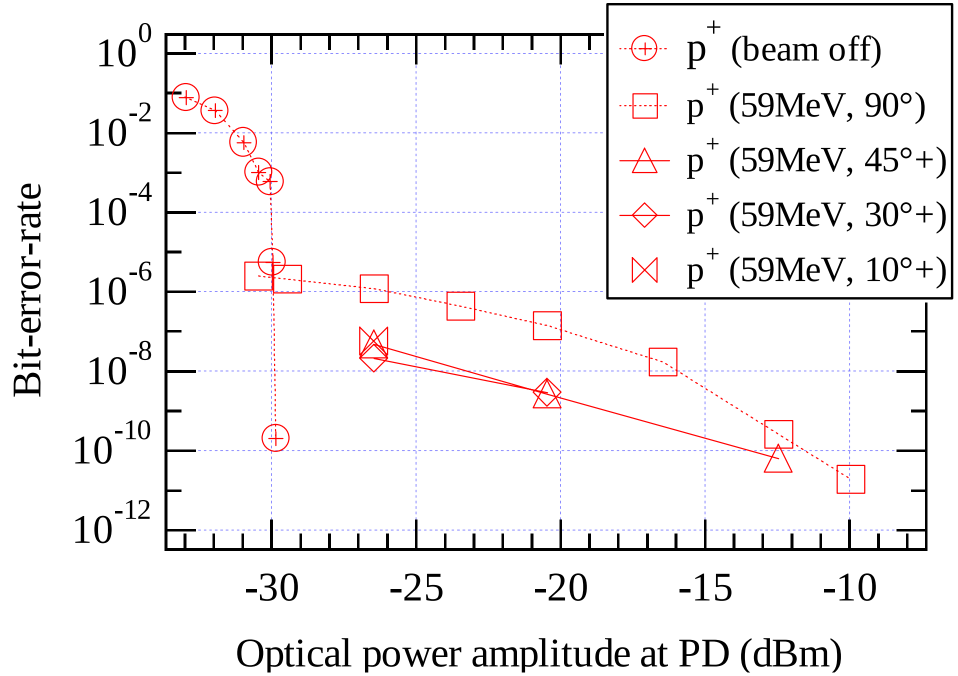
Photodiode Single-event-upset

- **Bit-error-rate for 80Mbit/s transmission with 59MeV protons in InGaAs p-i-n (D=80µm)**
- **10-90° angle, 1-100µW optical power**
- **flux ~10^6/cm^2/s *(similar to that inside CMS Tracker)***



- **Ionization dominates for angles close to 90°**
- **nuclear recoil dominates for smaller angles**
- **BER inside CMS Tracker similar to rate due to nuclear recoils**
- **should operate at ~100µW opt. power**



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System considerations

- **Build in radiation damage compensation into optical link system**
  - **Lasers**
    - **provide adjustable d.c. bias to track threshold increase**
    - **provide variable gain to compensate for efficiency loss (and other gain factors)**
  - **Fibres and connectors**
    - **No significant damage**
  - **Photodiodes**
    - **provide leakage current sink**
    - **provide adjustable gain**
    - **use sufficient optical power (~100μW) to avoid significant SEU effects**

Summary

- **CMS Tracker Optical links project**
  - **50000 analogue + 1000 digital links**
  - **harsh radiation environment, 10 years at -10C**
  - **COTS components**

- **Extensive validation testing of radiation hardness necessary**
  - **ionization damage (total dose)**
  - **displacement damage (total fluence) and annealing**
  - **reliability**
  - **SEU**

- **Accumulated knowledge of radiation damage effects**
  - **compensation built into optical link system**
  - **confidence of capacity to operate for 10 years inside CMS Tracker**