Environmental Resistance and Reliability

Outline

- Introduction
  - Environment and reliability
  - Components
- Component radiation damage and reliability testing
  - lasers
  - fibres
  - connectors
- Conclusions

Reliability

- Probability of components surviving for the required lifetime in the given operating environment

- For our ‘unusual’ environment separate reliability issues
  - effects and tests specific to CMS Tracker environment
  - usual known degradation mechanisms and reliability tests
    - but check for influence of irradiation

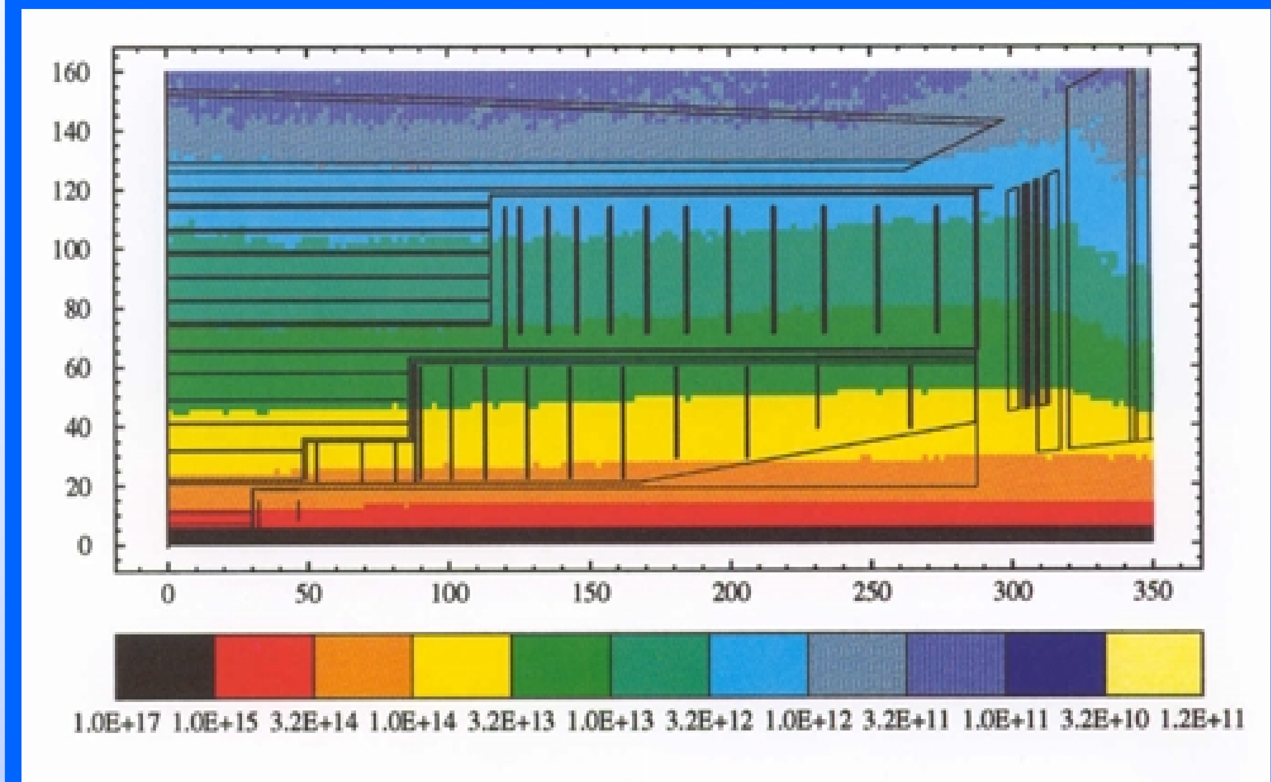
Tracker environment

- 10 years minimum operational lifetime at
  - T ~ -10°C
  - B = 4T
  - exposed to high radiation field
- radiation damage the most important issue
  - can exclude magnetic components
  - -10°C within typical telecoms operating specs

Tracker radiation environment

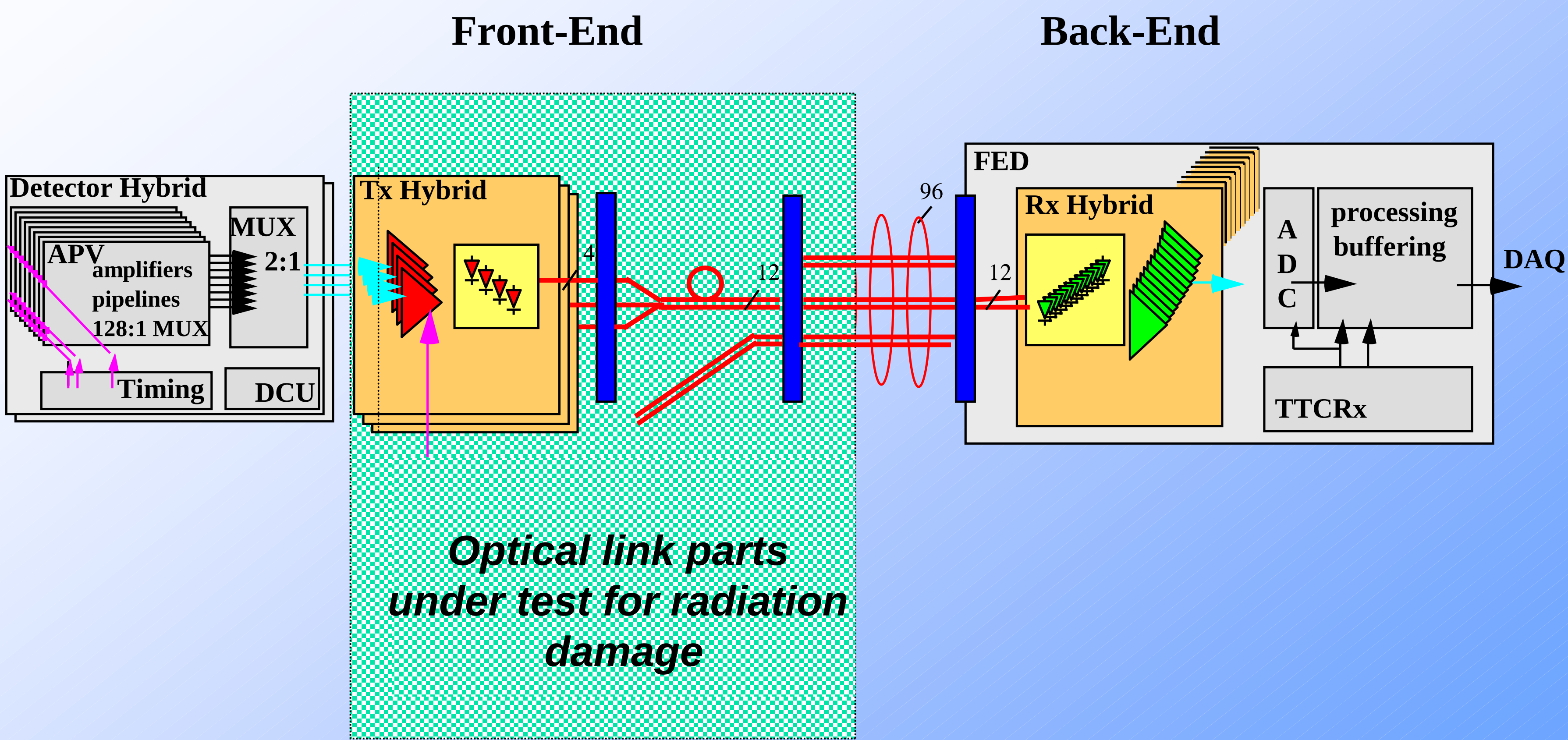
high collision rate
high energy
large number of tracks

cause of radiation damage



Charged hadron fluence (/cm^2 over ~10yrs)

CMS Tracker optical links



Components under review

- Transmitter
  - edge-emitting 1310nm InGaAsP/InP MQW lasers
    - most sensitive component...
- Fibres
  - SM standard telecom fibre
  - 1-way fibre pigtails, 12-way fibre ribbon cables, 8x12-way cables
- Connectors
  - 1-way (e.g. MU), multi-way (e.g. MT)

- All either COTS or based on COTS components

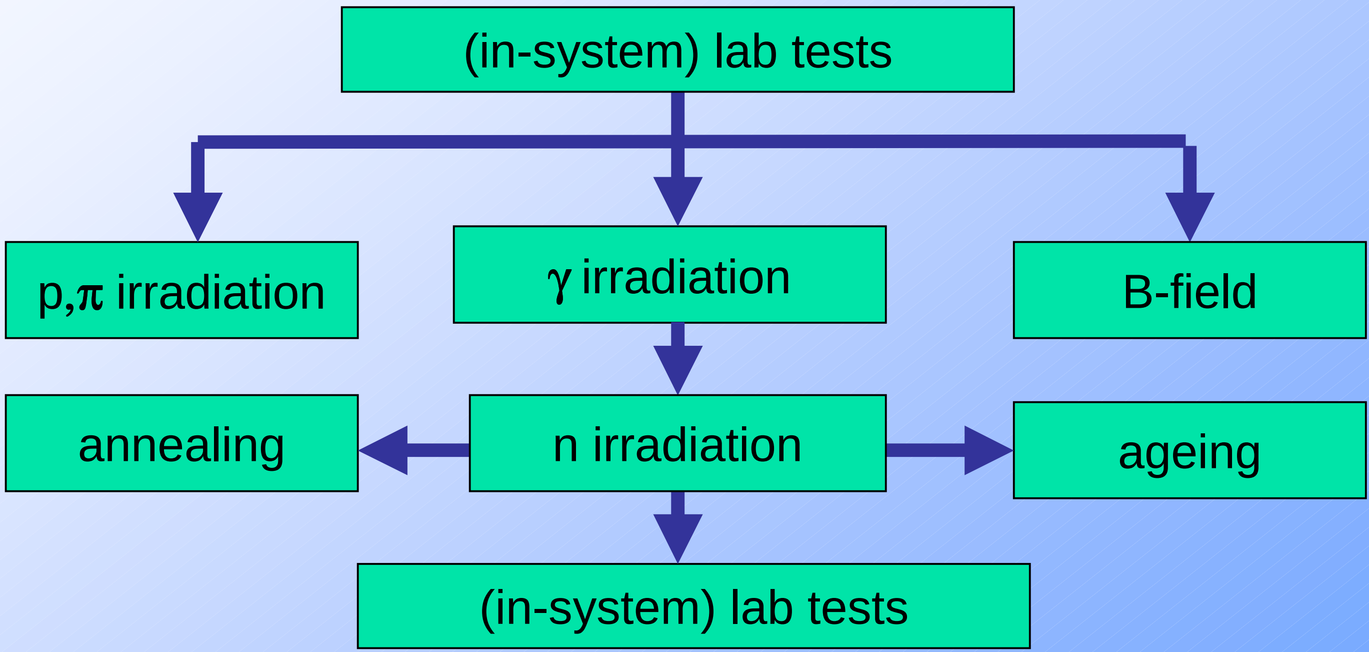
Testing during development phase

- Environmental tests
  - Irradiation (all components)
  - B-field (lasers and connectors)
  - also Temperature (lasers)

- Reliability (irrad+un-irrad)
  - Thermally accelerated ageing (lasers)
  - Strength (fibres, cables)
  - Mating cycles (connectors)

Sample test overview

- e.g. lasers



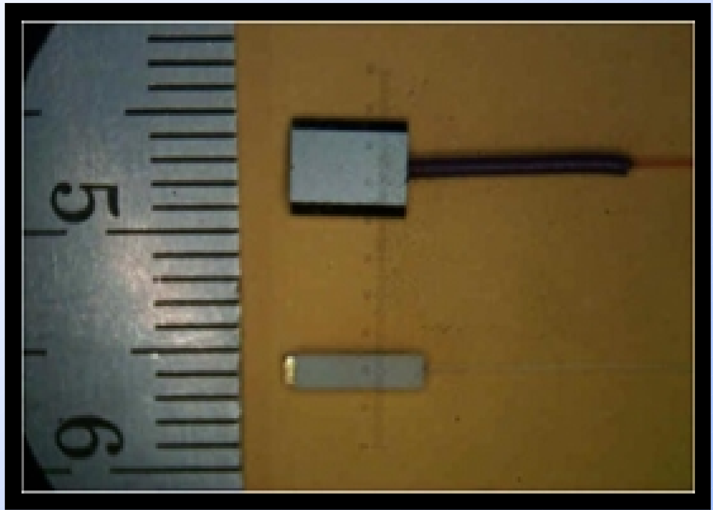
Testing aims

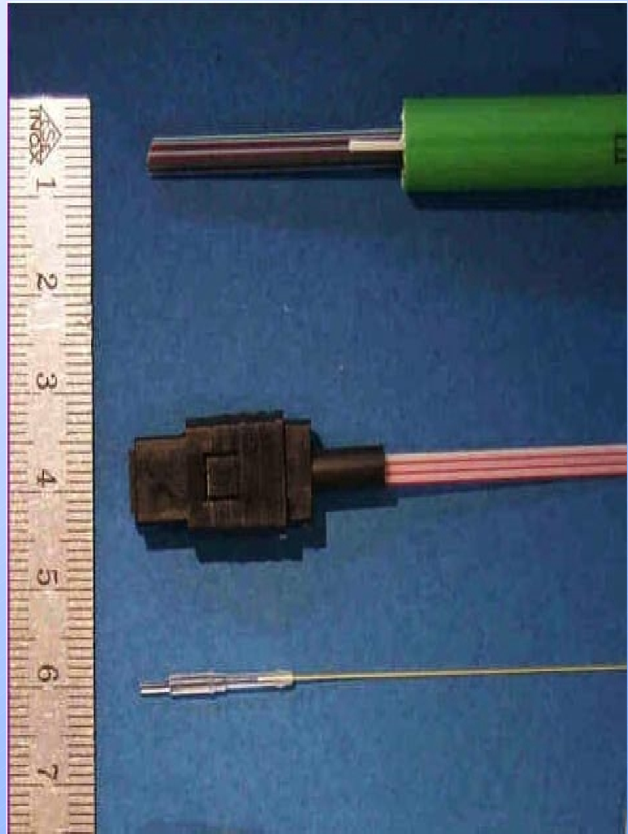
- Validate candidate components
  - suitability for use in Tracker
- Detailed investigation of radiation effects
  - Measure effects for Tracker doses/fluences
  - Understand the damage mechanisms
  - Extrapolate to full experiment lifetime
- Feedback effects into definition of specs

Examples of components

- tested for rad-hardness

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





96-way cable

12-way optical ribbon and MT-connector

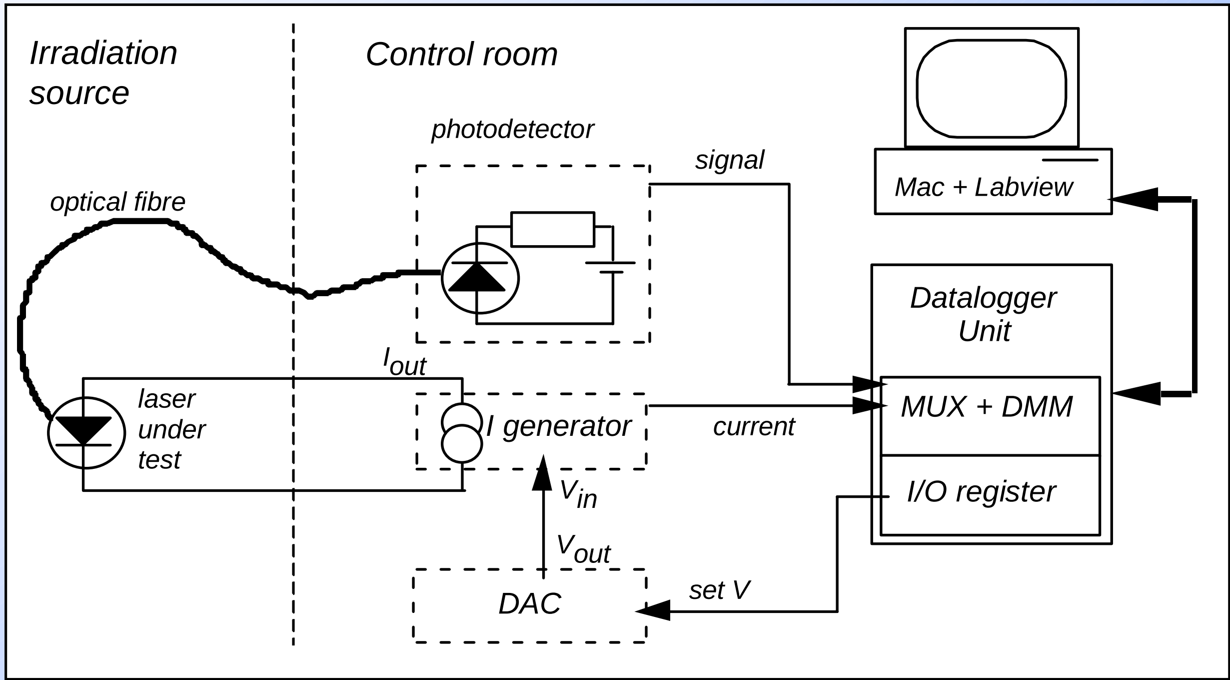
single fibre and 1.25mm connector ferrule

Laser testing

- Radiation damage
  - ionization
  - displacement
  - annealing
- Accelerated ageing
- B-field

Irradiation test system

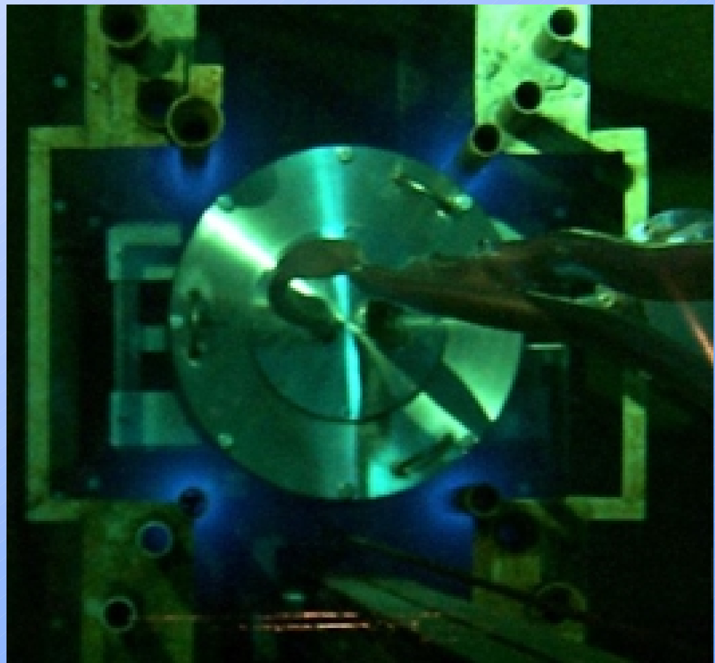
- in-situ measurement setup (lasers)



- in-situ data better for extrapolation

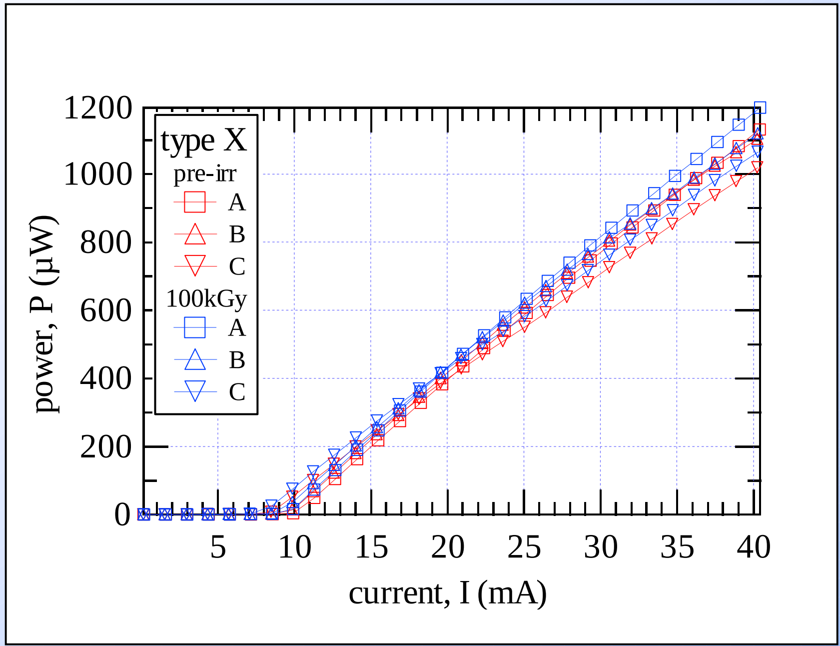
Gamma irradiation at SCK-CEN

1999 Market Survey
underwater source
Co-60 gammas
dose rate 2kGy/hr



Gamma irradiation

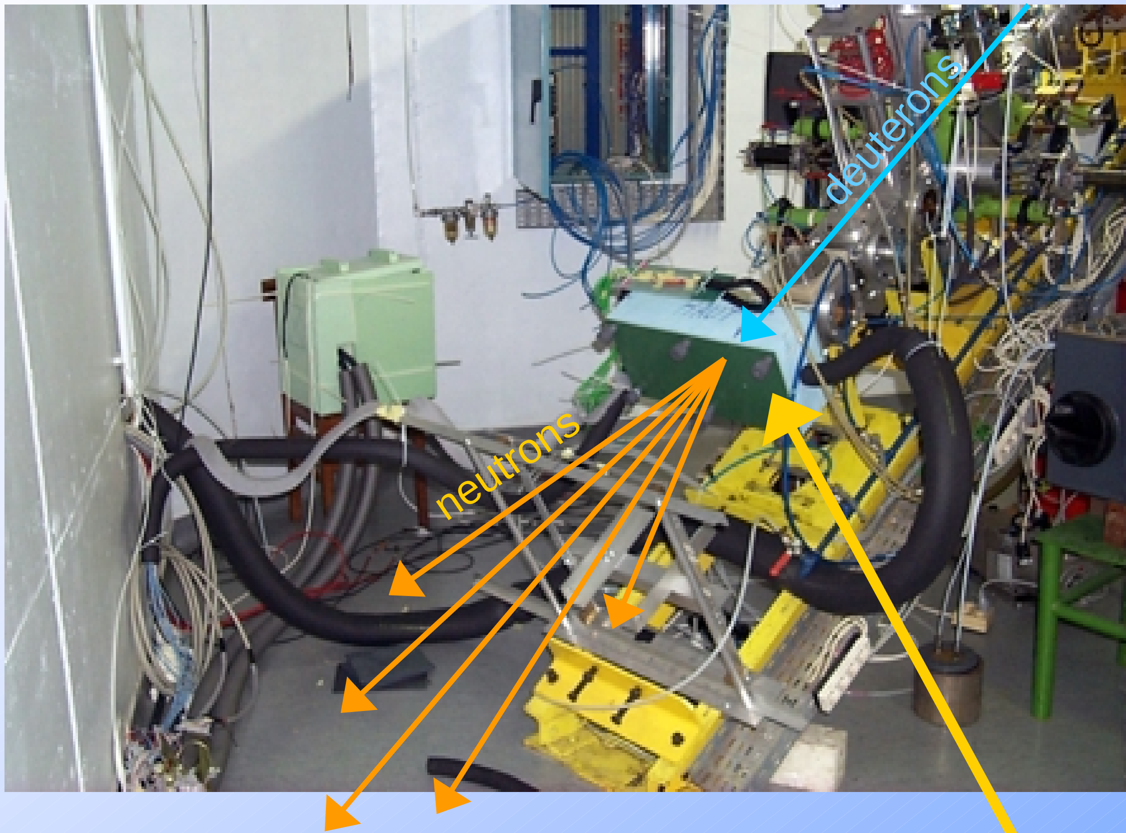
- Laser L-I characteristics



- Before/after 100kGy

- No significant effects for ionization damage
- Same conclusion for <u>all</u> laser diodes tested

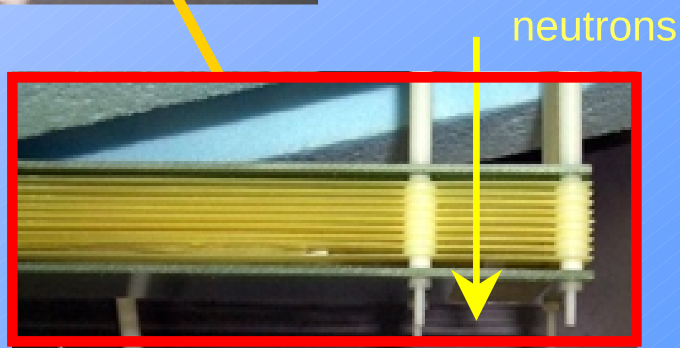
Neutron irradiation at UCL



Recent validation tests of laser diodes

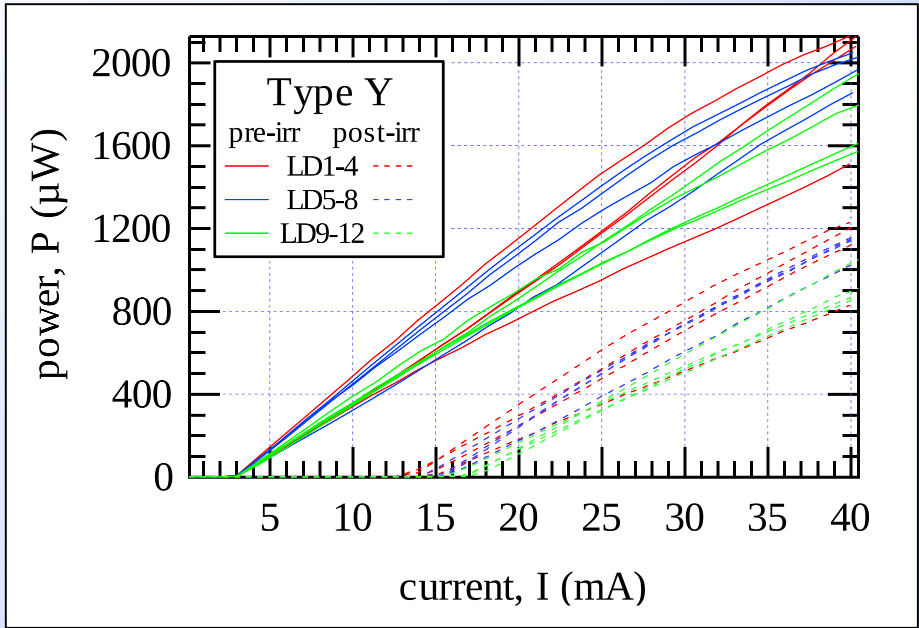
~20MeV neutrons
flux ~ $5x10^{10}n/cm^2/s$
fluence ~ $5x10^{14}n/cm^2$

Samples stacked inside cold box (-10°C)



Neutron irradiation

- Laser L-I before/after 3x1014n/cm2

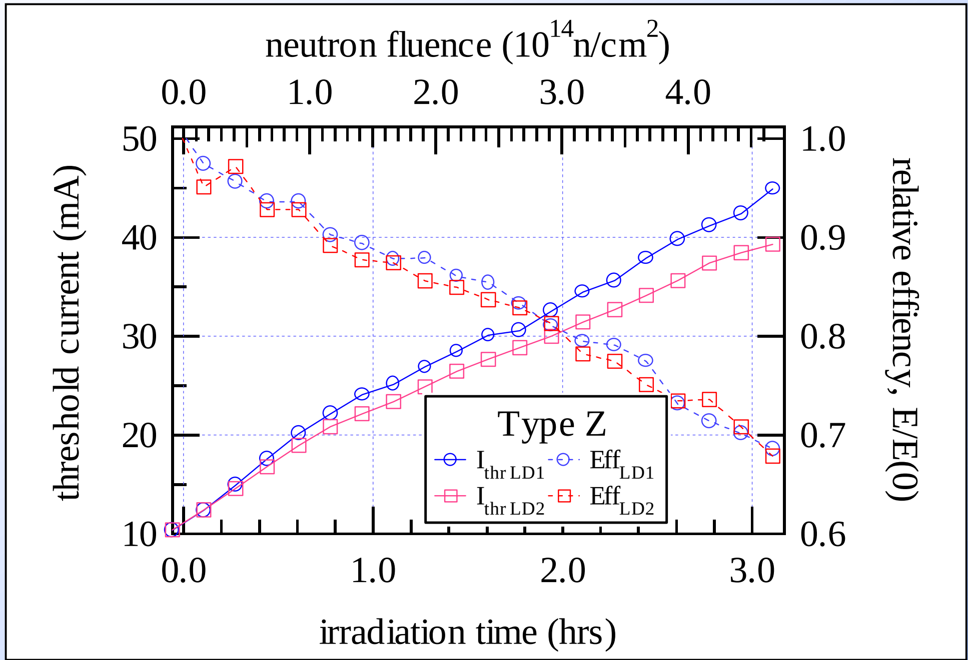


- ~20MeV neutrons (UCL)
- Temp -10°C

- Laser threshold I_{thr} ↑, efficiency E ↓
- effects similar (to factor ≤2) in <u>all devices</u>

Damage vs fluence

- Laser threshold I_{thr} and efficiency E

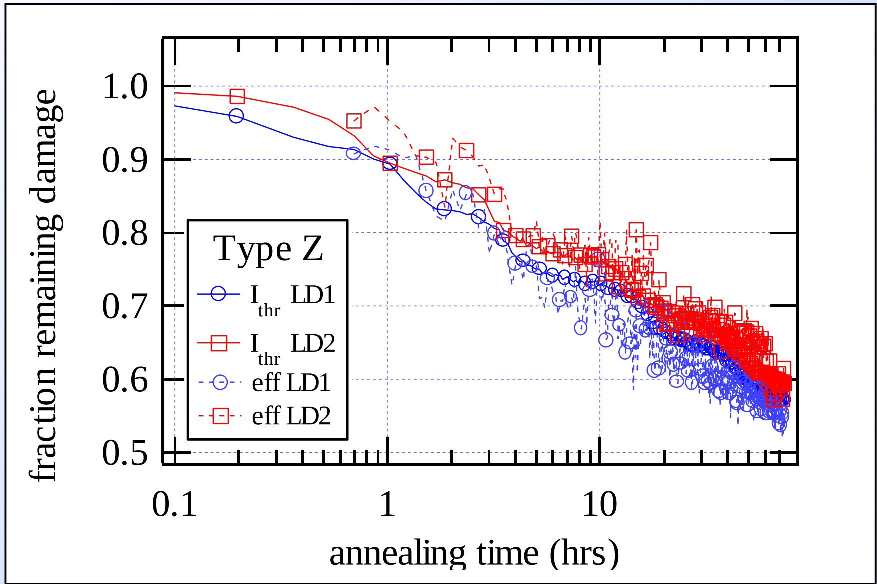


- ~20MeV neutrons (UCL)
- Temp 20°C

- Damage <u>always</u> ~linear with fluence
  - NIEL dependence..?

Annealing

- Laser threshold I_{thr} and efficiency E

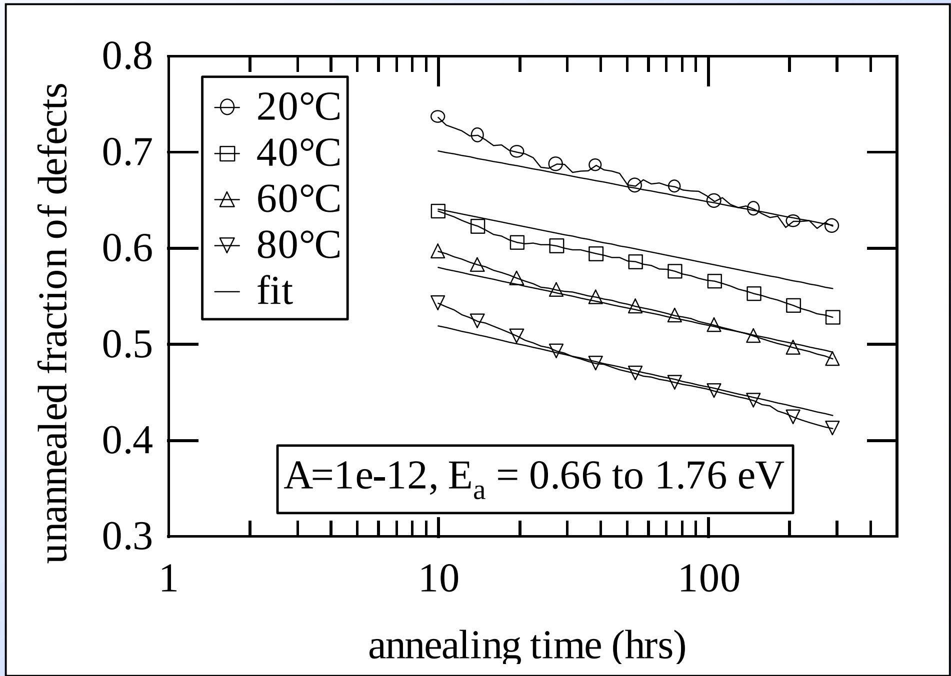


- after $4.7 \times 10^{14} n/cm^2$
- ~20MeV neutrons (UCL)
- Temp 20°C

- Beneficial annealing only
  - recovery of damage during/after irradiation
- Same basic mechanism for I_{thr} and E

Annealing vs Temperature

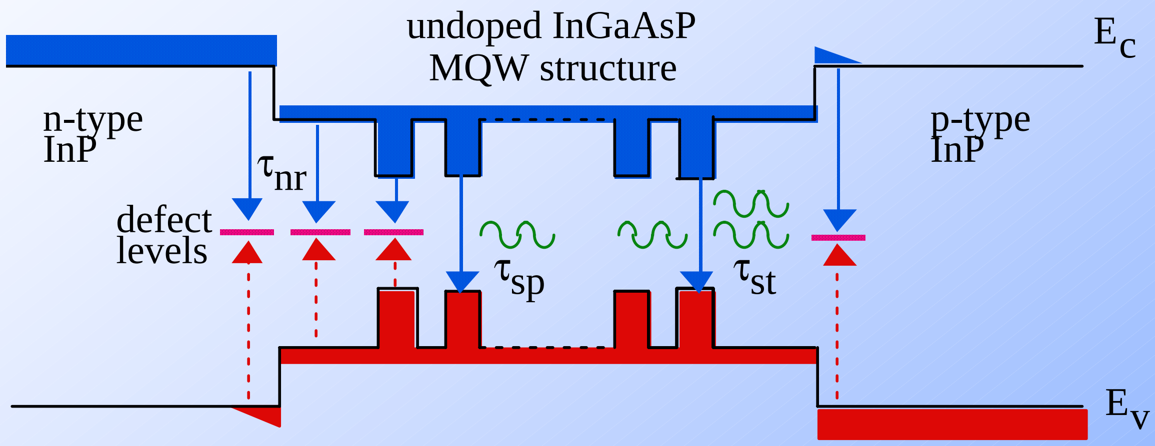
- Measure at different T



- Type Z
- 10^{15}n/cm^2 ~0.75MeV n
- Annealed at 20,40,60,80°C

- Fit data with activation energy spectrum
  - uniform range 0.66<E_a<1.76 eV works well

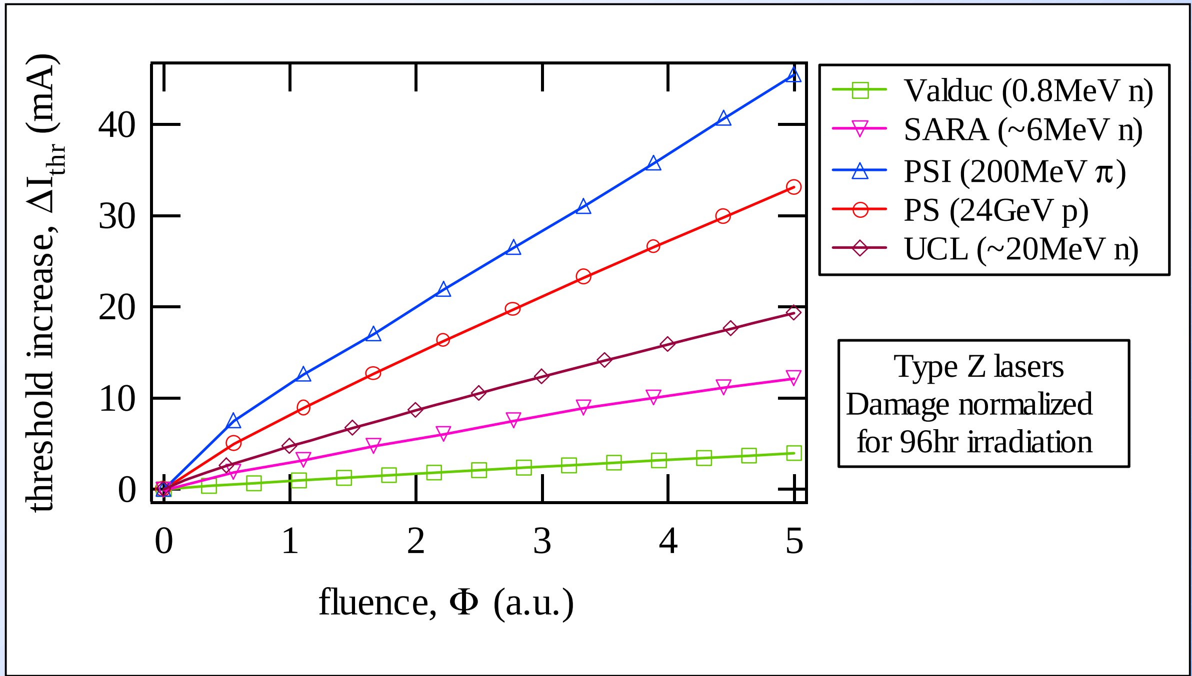
Damage model



- non-radiative recombination
  - defects in and around active volume reduce carrier lifetime
    - (ref: SPIE 2000)
  - competes with radiative recombination

Damage comparison

- Laser threshold I_{thr} with different sources

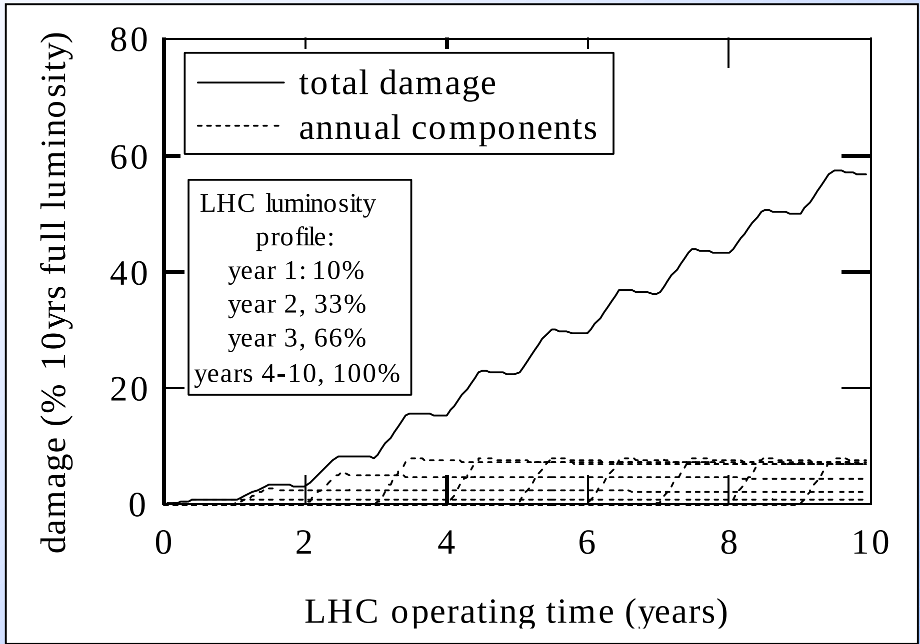


- Relative damage factors
  - 0.75MeV n (=1)
  - ~6MeV n (=3.1)
  - ~20MeV n (=4.9)
  - 200MeV π (=11.5)
  - 24GeV p (=9.4)
  - 1MeV γ (~0)

- Coverage of CMS particle energy spectrum
- <u>Similar factors</u> for different InGaAsP/InP lasers

Damage prediction

- Knowing damage factors and Ea spectrum
  - Predict damage evolution in 10yr CMS lifetime

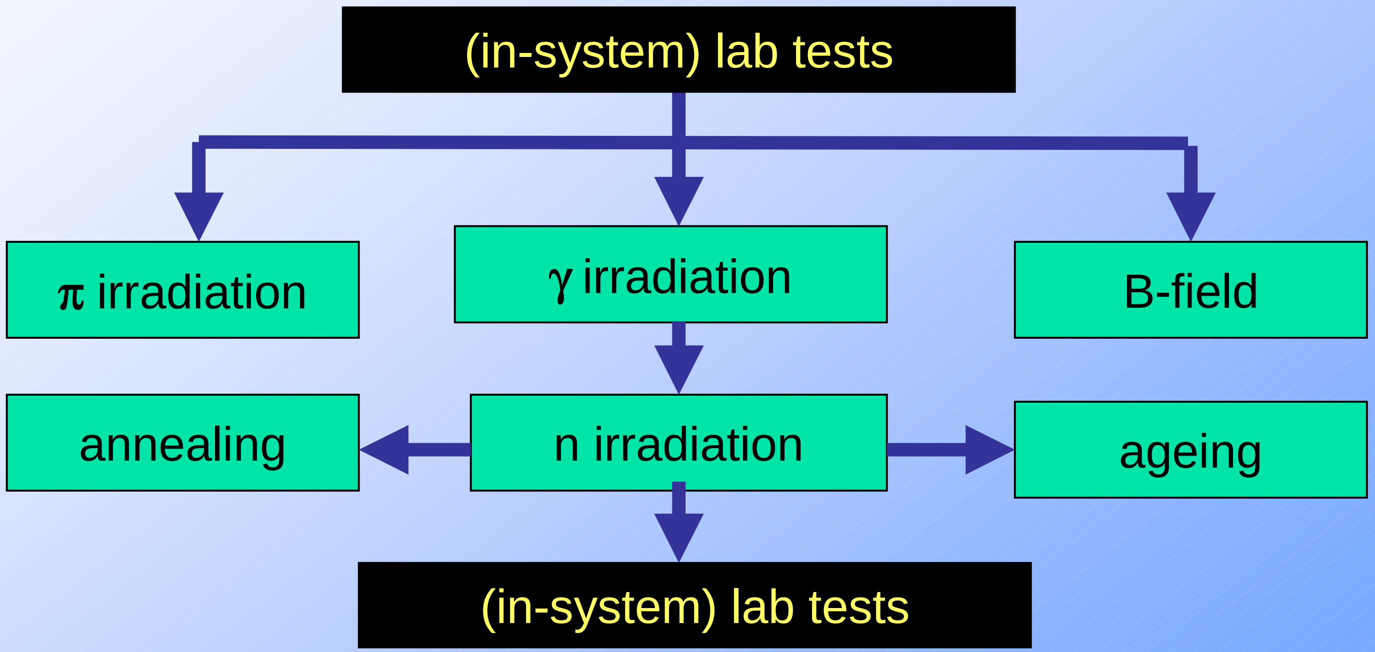


- Important damage dominated by pions
- Type Z lasers
  - ΔI_{thr}~14mA
  - first 10yrs at radius=22cm

ref: Proc. SPIE 2000

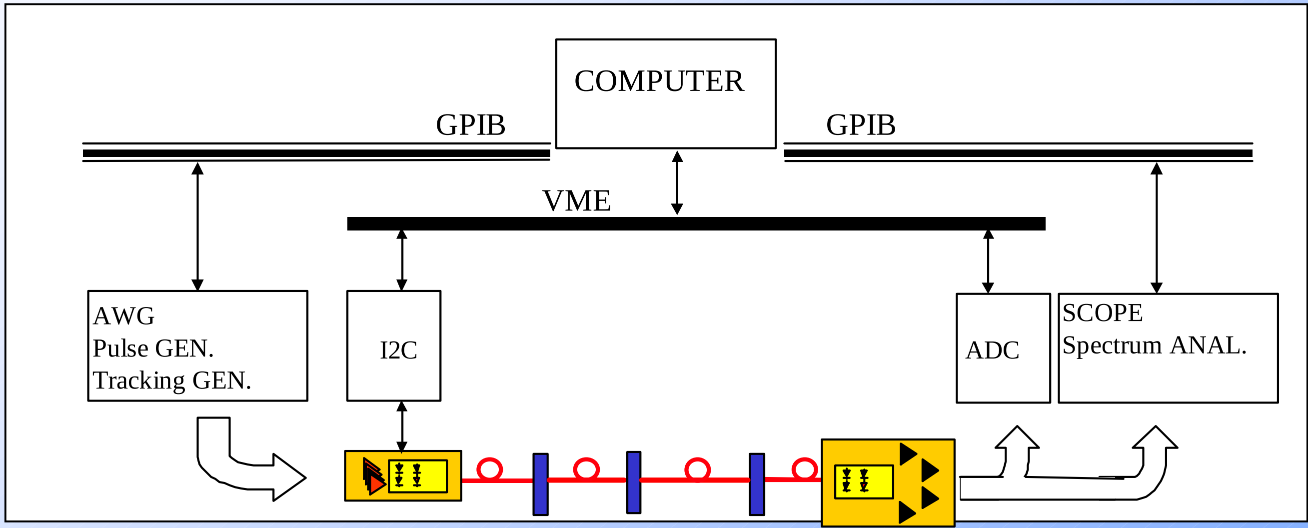
Laser test procedures (revisited)

- Focus now on in-system lab tests



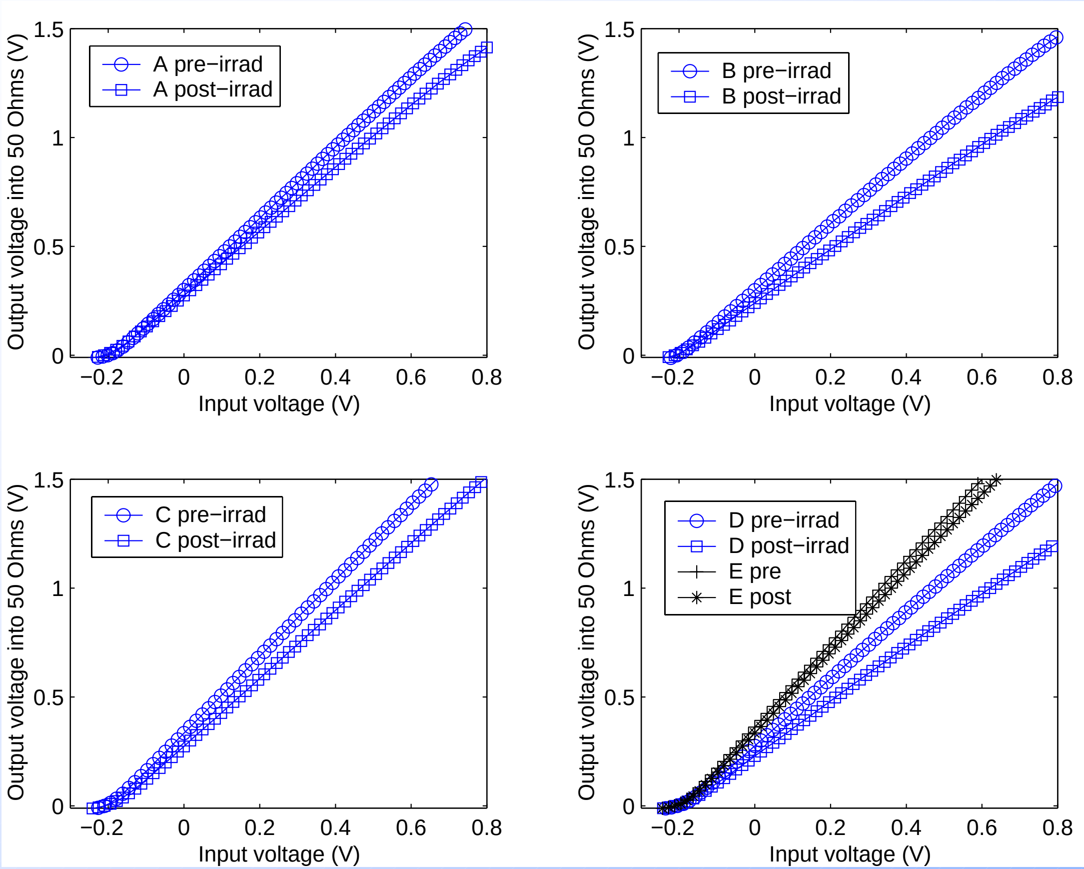
Lab testing pre/post irrad

- In-system test-bed



- Static tests
  - measure threshold, gain, noise, linearity,
- Dynamic tests
  - rise-time (bandwidth)

Transfer characteristics

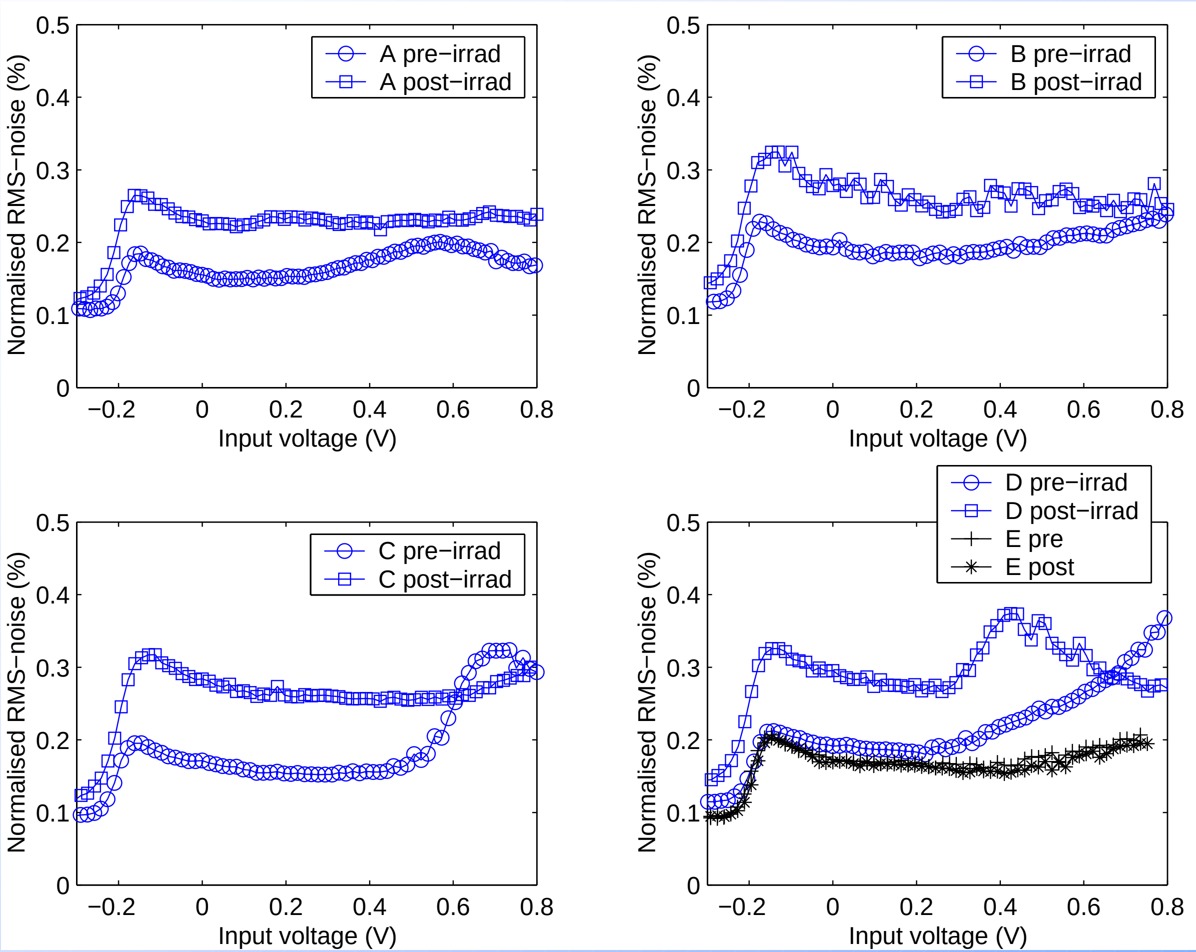


- Transfer characteristics before and after irradiation
  - Need to increase in d.c. bias-point
    - due to threshold increase
  - gain decrease
    - due to efficiency loss

Table 2: I2C pre-bias settings for laser A-E

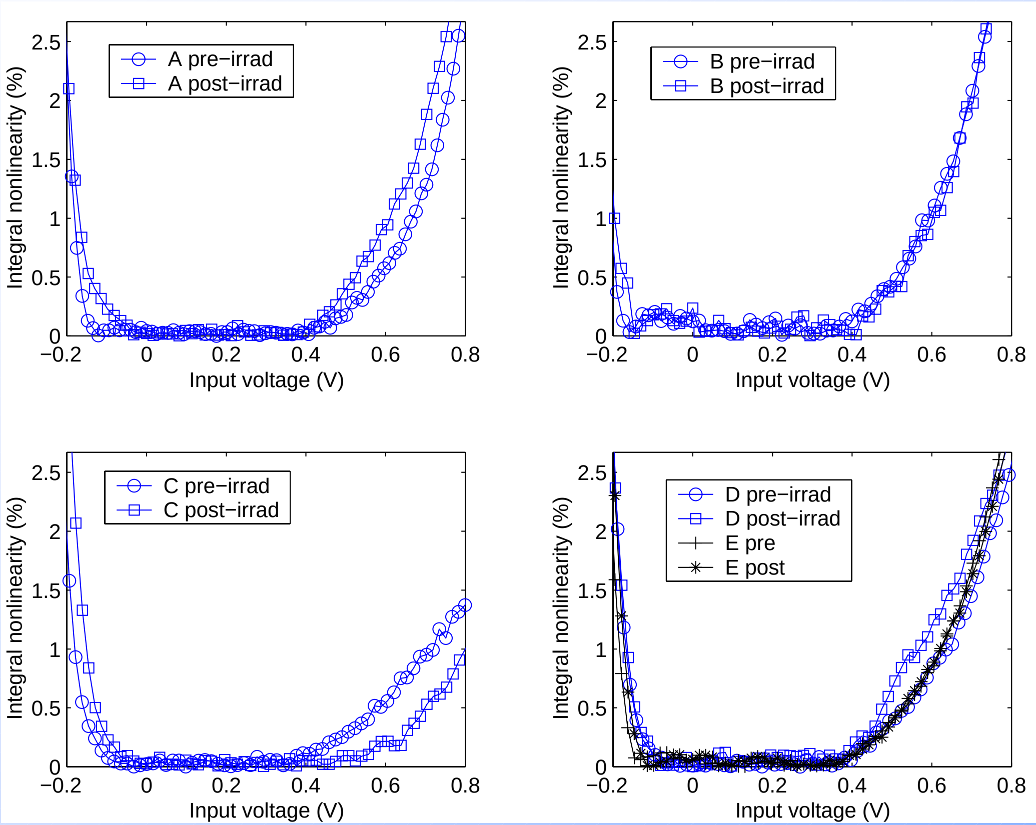
	Laser				
	A	B	C	D	E
I2C-bias setting before irradiation	8	8	9	9	8
I2C-bias setting after irradiation	14	15	1A	19	8 (not irrad)

Noise



- Noise normalized to peak-signal before and after irradiation
- Decrease in signal/noise
  - gain loss
  - more noise at higher currents
  - Laser driver related

Linearity



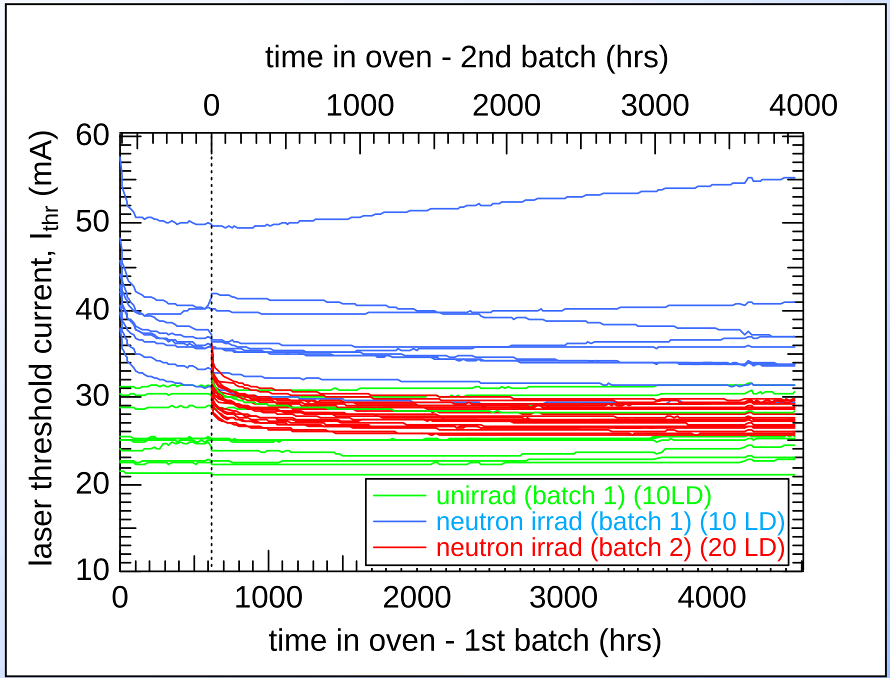
- Linearity before and after irradiation
- no significant change

Other studies on lasers

- Accelerated ageing
- B-field

Laser reliability

- Ageing test at 80°C



ref: Proc. RADECS 1999

- 40 devices (Type Z)
- 30 devices irradiated to $>10^{14}$n/cm^2
- 4000 hrs ageing
- No additional degradation in irradiated lasers
- acc. Factor ~400 relative to -10°C operation, for E_a=0.4eV
- **<u>lifetime >>10years</u>**

B-field: functionality

- Spectral and static characterization
  - in-system functionality test
  - up to 2.4T
  - various angles

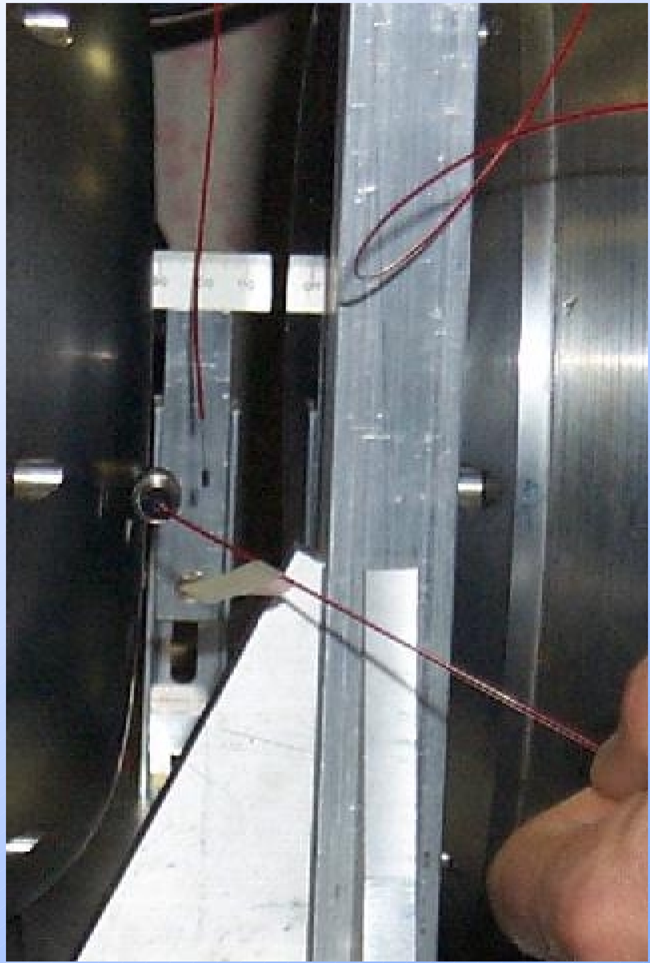
  - No effect on spectrum
  - No effect on L-I, noise, linearity

    - ref: CMS Note 2000/40

  - recent Vienna data (now up to ~10T)

B-field: packaging

- Exclude magnetic materials in laser package



Laser summary

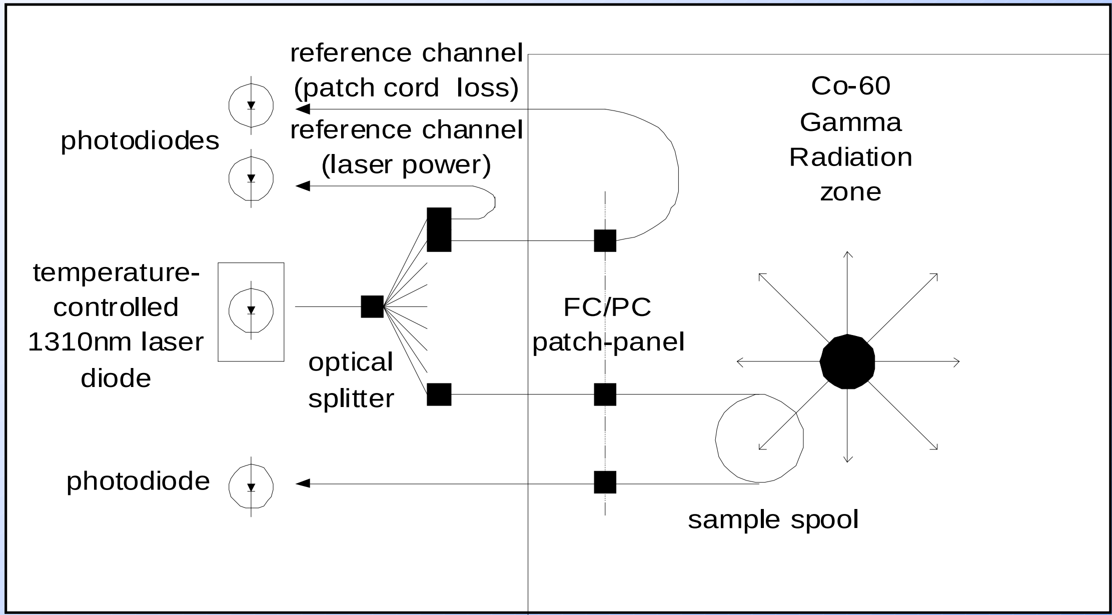
- Radiation damage and annealing
  - threshold increase, efficiency decrease, beneficial annealing
    - add compensation into laser driver specs
- Ageing
  - lifetime >>10yrs
  - no additional degradation in irradiated lasers
- B-field
  - no effect up to 10T
  - non-magnetic package

Fibre radiation damage testing

- 1-way fibre
  - attenuation
  - strip force
- 12-way cable
  - insertion loss
  - bending loss
- 96-way cable
  - strength tests

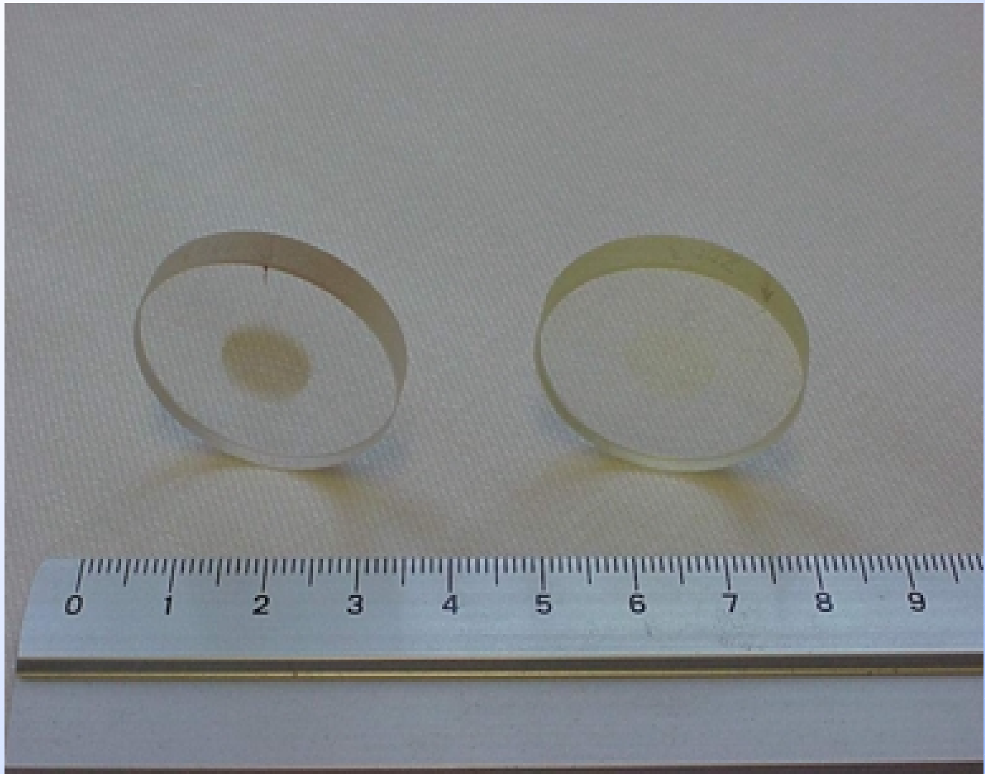
Radiation test system - fibre att'n

- in-situ measurement of fibre attenuation



Ref: Market Survey, 2000 (SCK-CEN Co-60 source)

‘Colour centres’

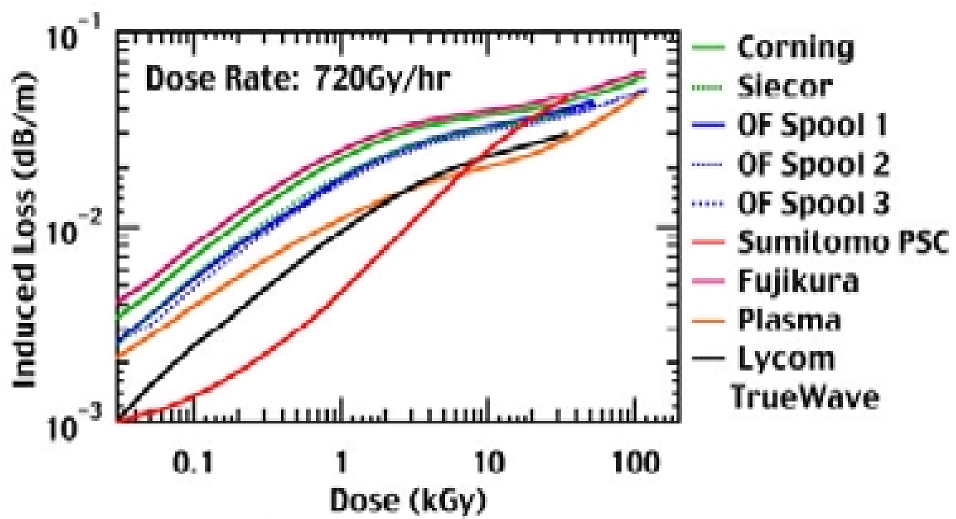


courtesy A.Gusarov (SCK-CEN)

- Attenuation in irradiated glass due to radiation induced “colour centres”
- e.g. lenses irradiated in collimated beam
- impurities affect degree of damage

Gamma damage

- Fibre attenuation up to 100kGy



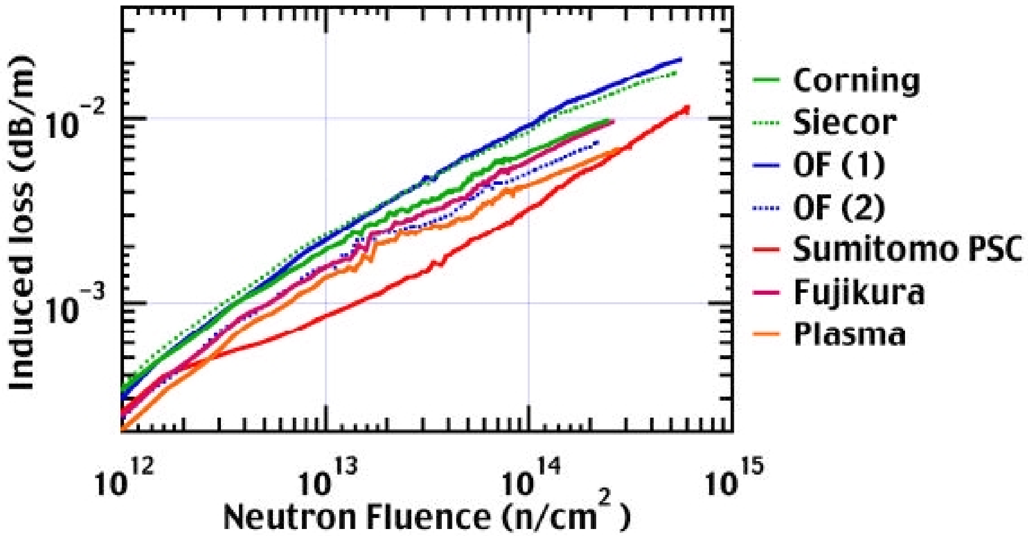
- Loss below 0.1dB/m
- PSC fibre advantageous only below ~ 10-20kGy

- COTS single-mode fibres
  - 1310nm
- for ~10m length inside CMS Tracker expect no more than ~0.6dB (not including annealing)

ref: Proc. SPIE 1998

Neutron damage

- ~6MeV neutrons to ~$5x10^{14}n/cm^2$



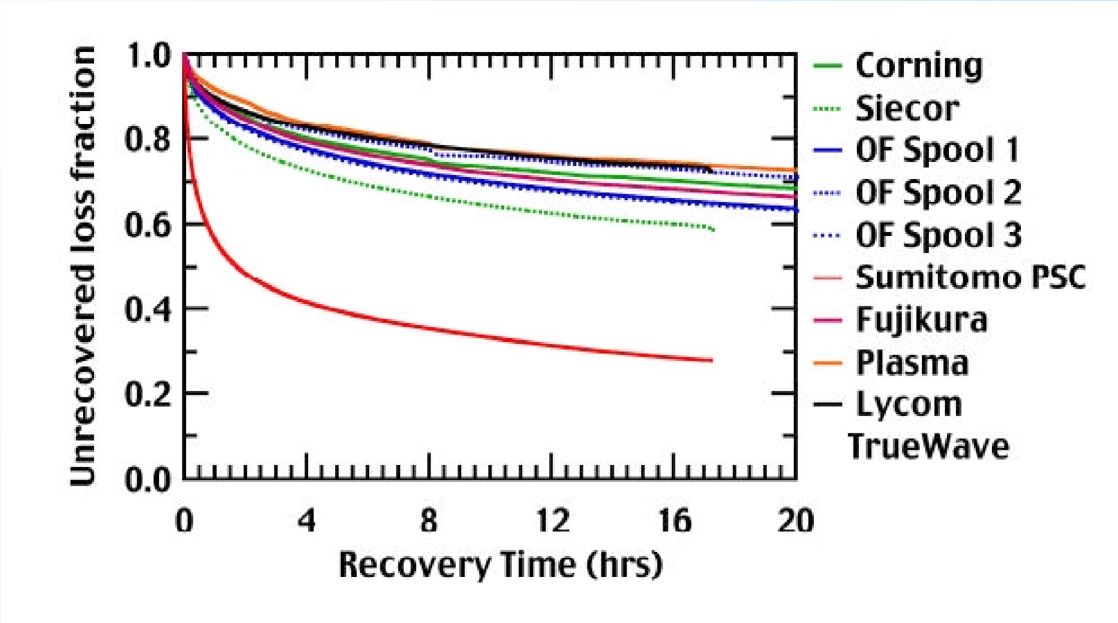
- Loss below 0.1dB/m

Rates are different for different fibres

- Damage most likely due to γ background

Fibre annealing

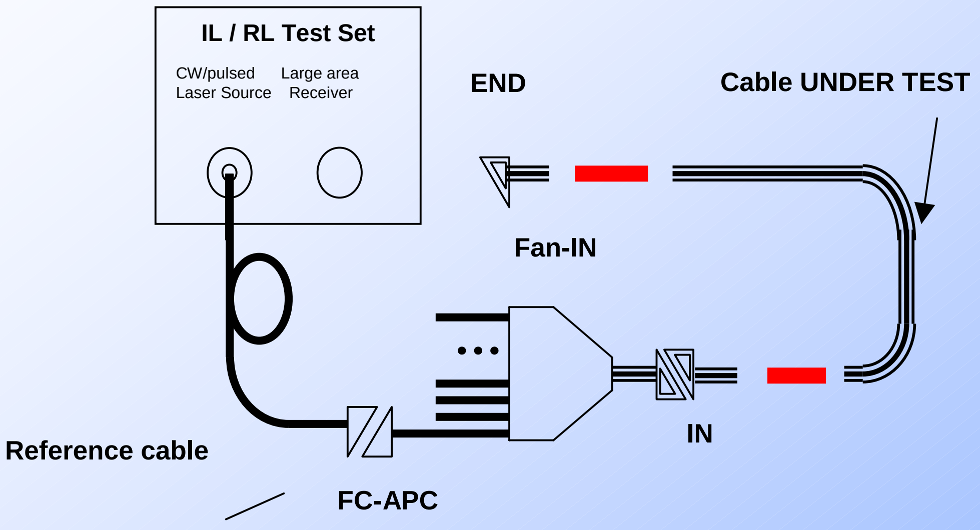
- damage recovers after irradiation (e.g. γ data)

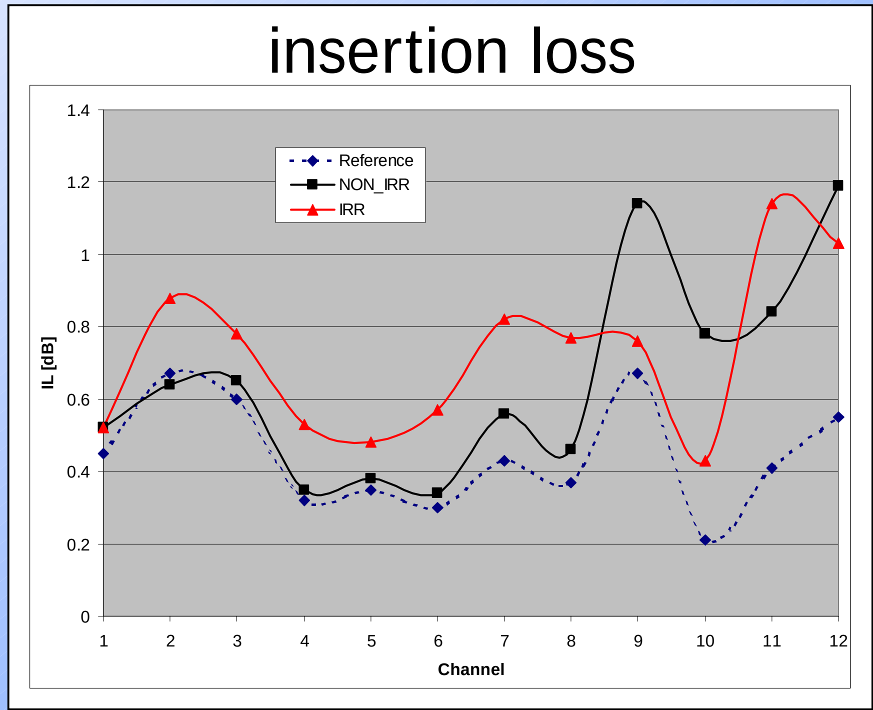


- Significant annealing after irradiation
- Damage therefore *dose-rate* dependent
  - expect more annealing over CMS Tracker lifetime
  - i.e. less damage than measured here

12-way ribbon cable test

- 12-way ribbon cable bef/after 100kGy





- No significant degradation after irradiation
- No bending loss seen down to 1.5cm bend-radius (spec=3cm)

Cable strength

- 4x10m 96-way cable samples
  - 1x 100kGy gamma
  - 1x 10^{14}n/cm^2 0.75MeV neutrons
  - 1x 100kGy gamma + 10^{14}n/cm^2 0.75MeV neutrons
  - 1x unirradiated

- Tested by Ericsson Cables
  - Impact
  - Repeated bending
  - Tensile load

  - no significant degradation due to radiation damage

Fibre summary

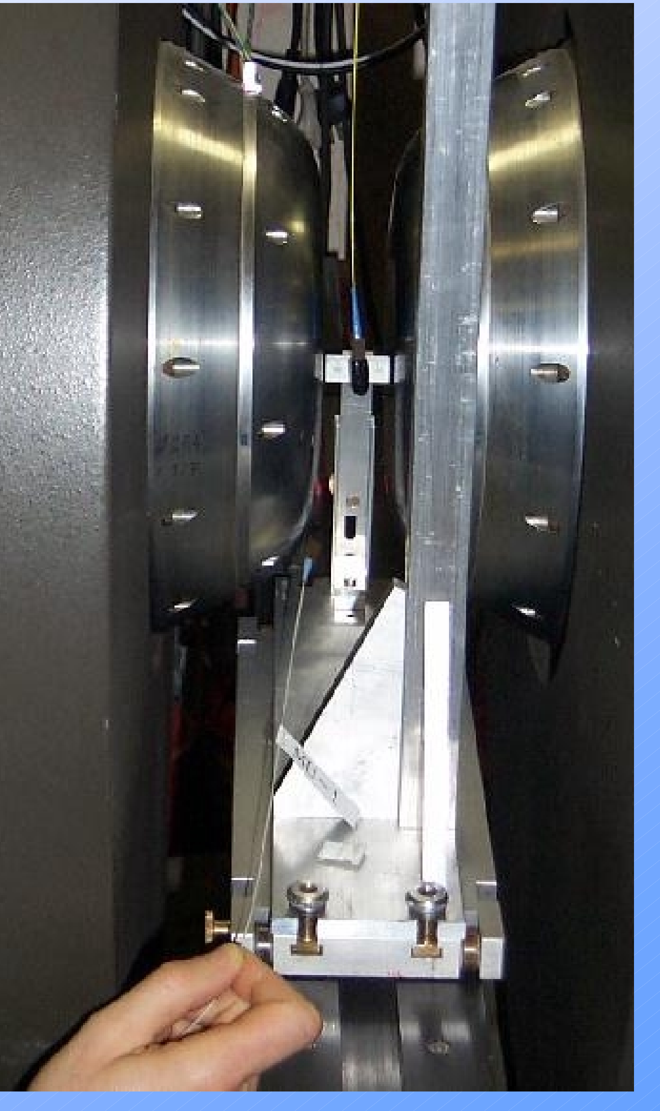
- Radiation damage (to attenuation)
  - losses <<1dB expected in Tracker
- cable insertion and bending losses
  - no difference before/after irradiation
- strength tests
  - no difference before/after irradiation

Connector testing

- B-field
  - exclude magnetic components
- Radiation damage
  - irradiate non-magnetic components
  - insertion-loss and return-loss bef/after 100kGy
    - single-way
    - multi-way

B-field

- e.g. MU connector test



B-field + functionality summary

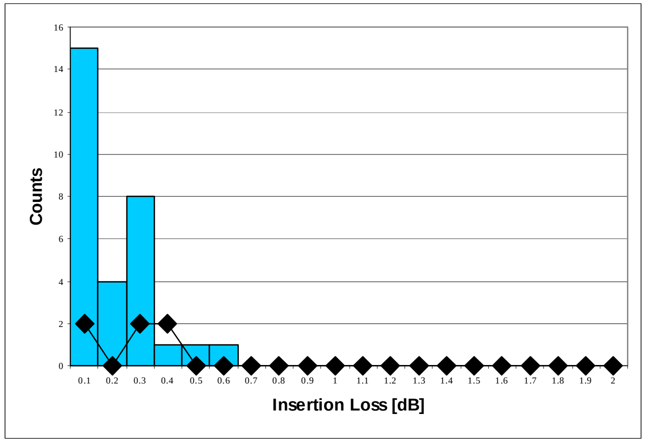
Company	SC-APC <-> FC-APC	SC2 <-> FC-APC	LC <-> FC-APC	MU <-> FC-APC	sMU <-> FC-APC	Reglette <-> MPO	12FC-APC <-> FC-APC	Redel-D <-> FC-APC	2MT-RJ <-> FC-APC	12MT <-> MPO	4MT <-> MPO	12MPO <-> FC-APC	12MPO <-> MPO	4MPO <-> MPO	4miniMPO <-> MPO	12MFS A/B <-> MPO	4MFS A/B <-> MPO	12SMC <-> MPO	MD <-> MD
Amphenol	– – o –		■ ■ ■ –																
Compel				– – X –															
Computer Crafts									■ 13 o –			– – X –							
Diamond										■ ■ ■ –	– – ■ –					4 6 o ■	– – ■ –		
FITEL (Furukawa)				■ ■ o ■									■ 2 ■ –	– – ■ –	– – ■ –				
Fujikura				– – X –						■ 24 ■ X	– – ■ –		– – X –	■ ■ X –					
LEMO								■ – X ■											
NTT				■ ■ o ■	■ ■ o ■								■ ■ ■ ■	– – ■ ■					
Radiall						■ ■ ■ –	– – ■ –												– – X –
Infineon (Siemens)		■ ■ o –	■ ■ ■ ■															■ ■ ■ ■	
Sumitomo			■ ■ o ■	■ ■ ■ ■						43 2 ■ ■			11 11 o ■						

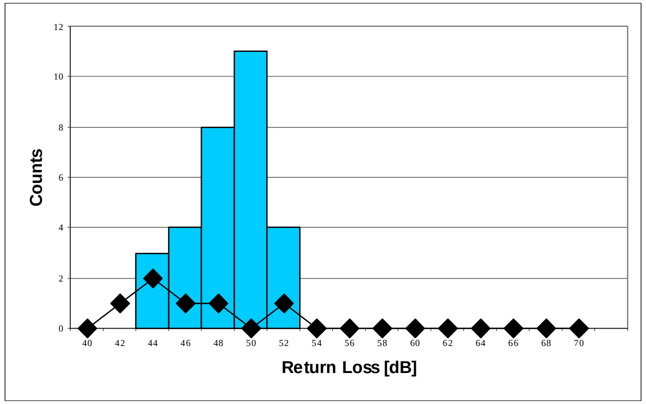
Sub-columns of each connector column: Insertion loss, return loss, B-field connector, B-field adaptor

■	=	test passed
n	=	# of connectors that failed
X	=	B-field test failed
o	=	B-field test passed (weak effect)

MU-connector irradiation

- After 100kGy
  - no damage effects

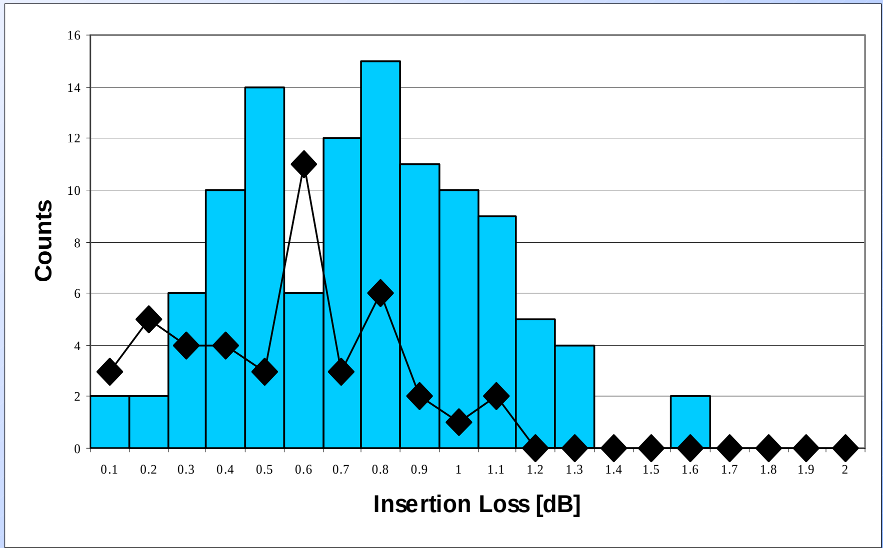


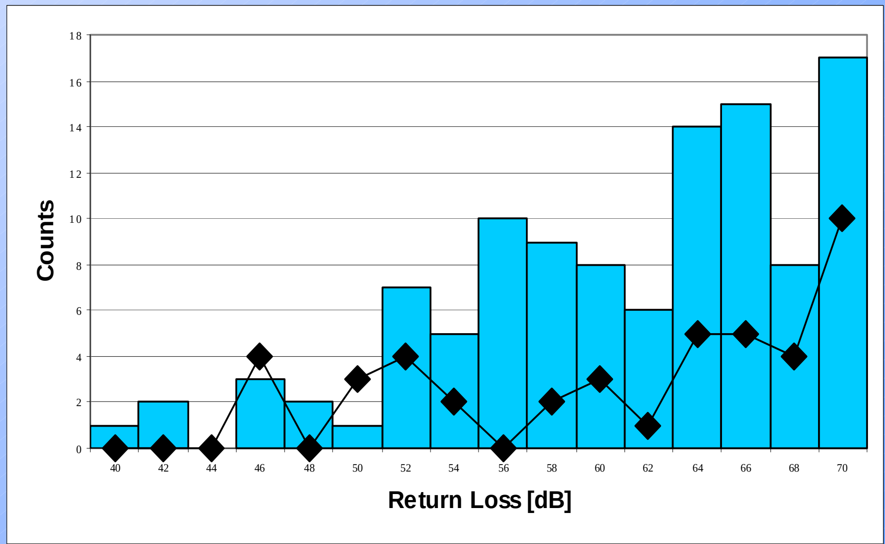


	TOT min		TOT avg		TOT max	
	IL	RL	IL	RL	IL	RL
Before irr:	0	45	0.15	49	0.58	53
After irr:	0.02	43	0.23	47	0.4	52

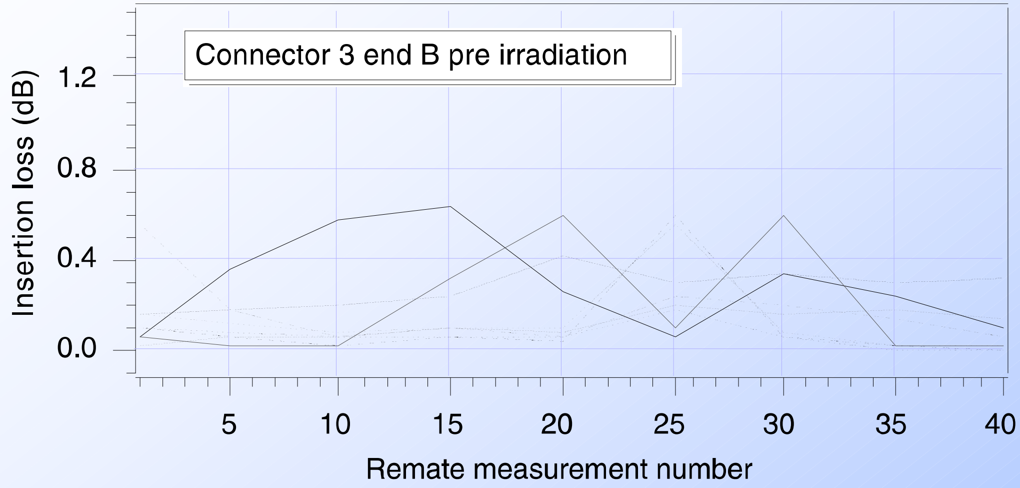
MT-connector irradiation

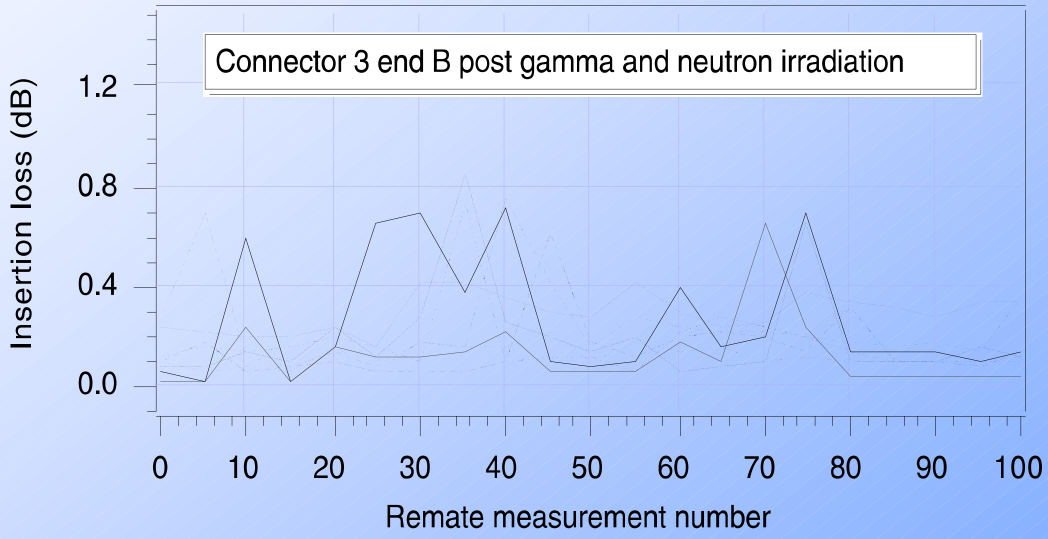
- After 100kGy
  - no damage effects





MT-connector reliability





- Repetitive connection cycles
  - 40 before irradiation
  - 100 after irradiation
    - 200kGy and 10^{14}n/cm^2
- No radiation damage effects
  - Ref: RADECS 1997 Data Workshop

Connector summary

- magnetic components excluded
- insertion loss, return loss and reliability (repetitive cycles) unaffected by radiation damage

Conclusions

- Extensive series of environmental and reliability tests
  - significant number of devices tested over 5 years
- Enabled selection of components suitable for use in CMS Tracker
- Feedback of test results into system spec’s
  - compensation of important radiation damage effects built in system
  - final failure rate unlikely to be dominated by radiation damage