CERN/CMS optical links radiation damage

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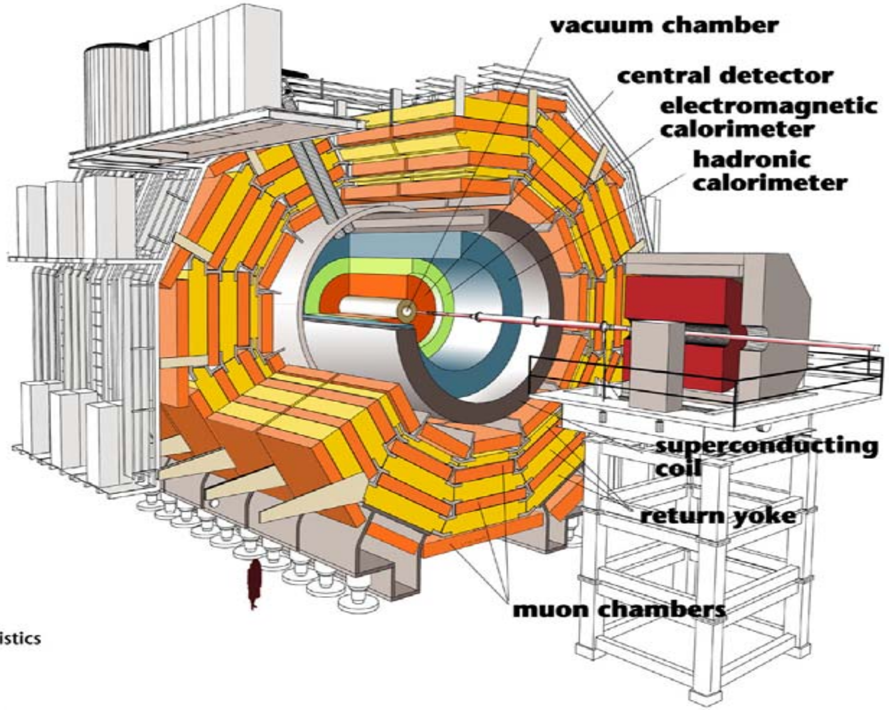
Outline

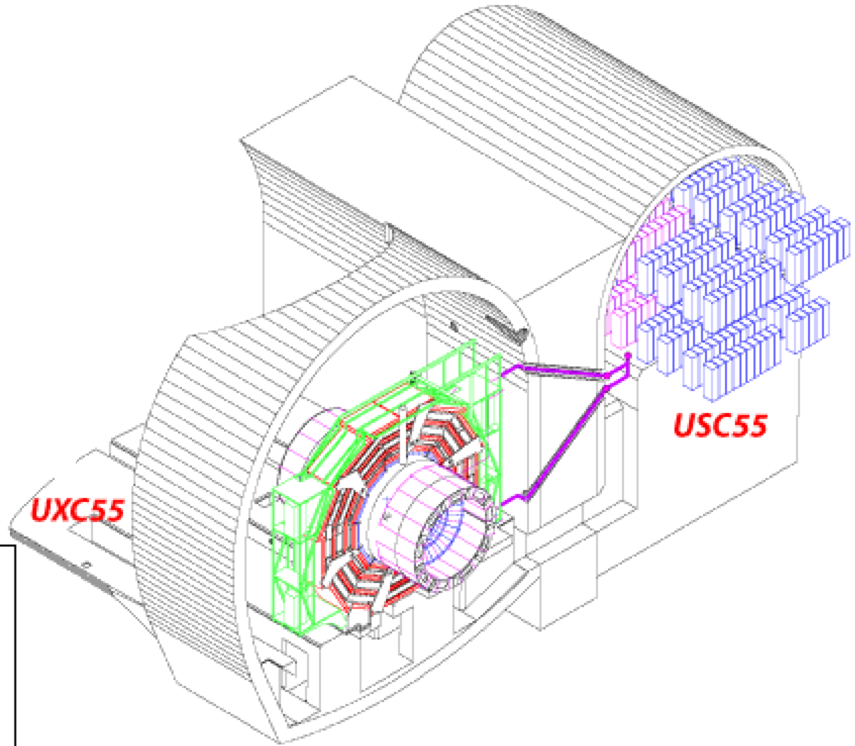
- Optical links
- QA programme
- Selection of test results

Optical link for CMS Tracker readout/control



Detector characteristics

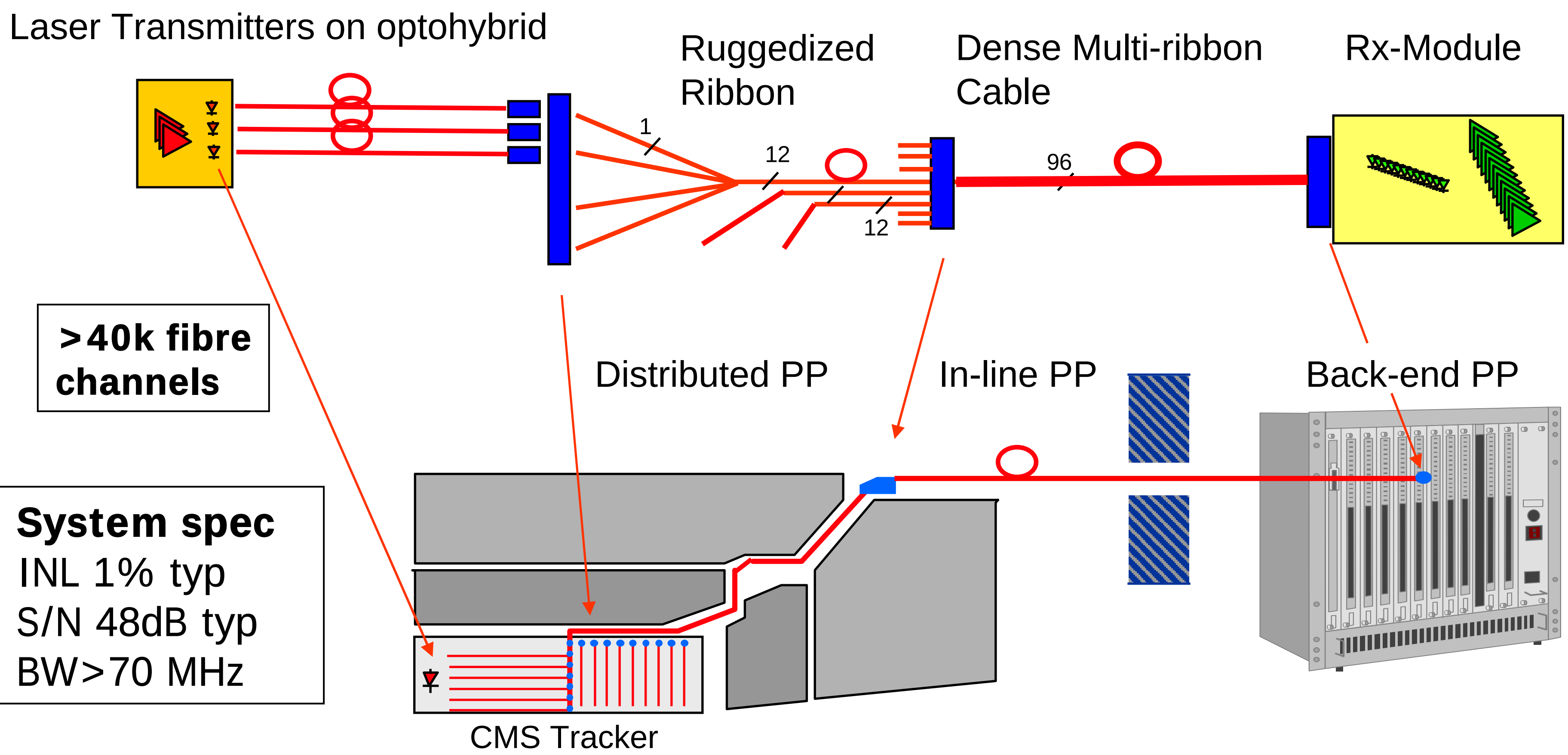
Width: 22m
Diameter: 15m
Weight: 14'500t



40k fibres (40Msamples/s analogue 8 bit)
7k fibres (80Mbit/s digital)
9k fibres (1Gbit/s digital)

Links ~70m long, multiple breakpoints

Analogue link architecture (1996)



>40k fibre channels

System spec
INL 1% typ
S/N 48dB typ
BW>70 MHz

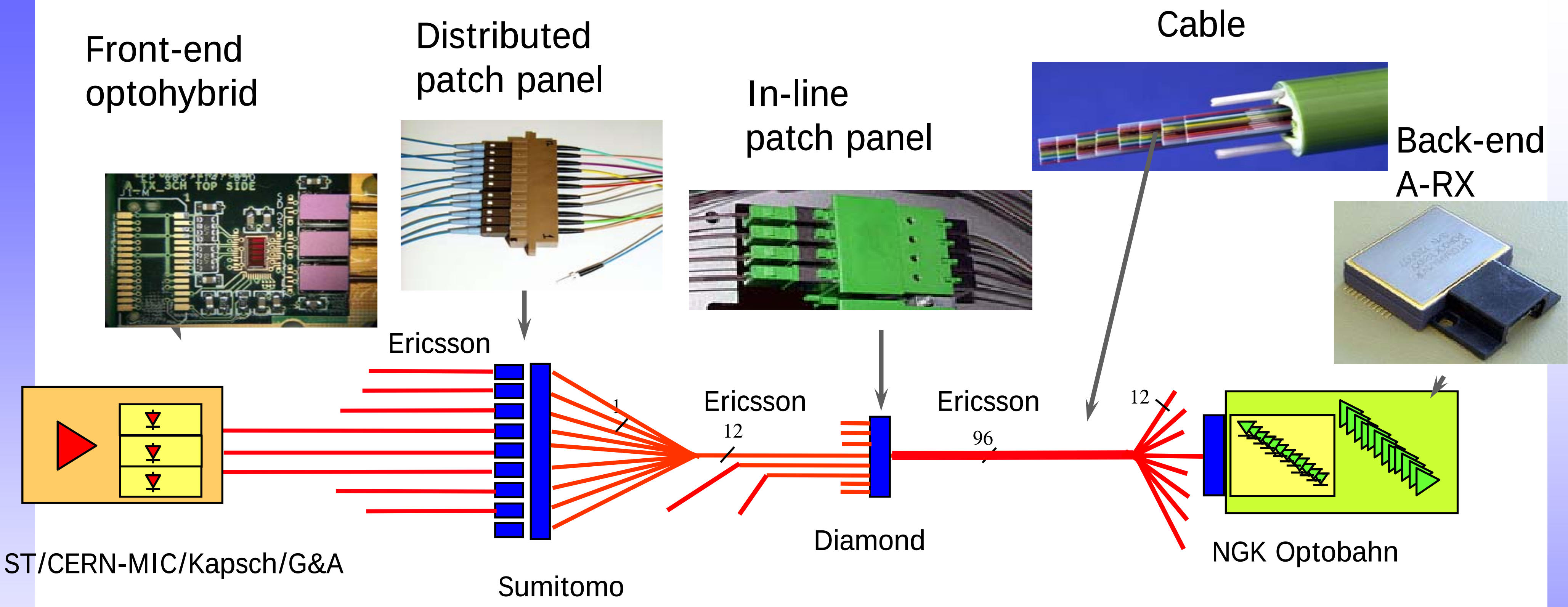
Implementation: Technology choice (1996)

- Developed analogue link system first (most links + most difficult)

Requirement	Technology choice
Linearity	Edge emitting Laser
Dynamic Range	Single mode system, 1310nm wavelength
Settling Time	Fast electronics (CMOS-Subμ)
Gain	10bit ADC with equalization
Magnetic Field	Non-magnetic connectors and packages
Radiation	Extensive qualification of COTS-based components
Density Low mass	Semi-customized laser package Fibre ribbon & array connectors Customized multi-ribbon cable Semi-customized Rx-module

- Control link and ECAL readout link developed later using many of same parts

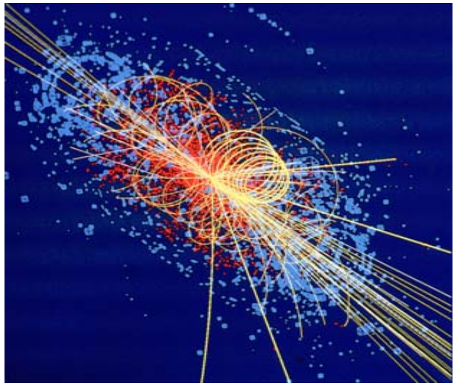
Implementation: Components (2000-02)

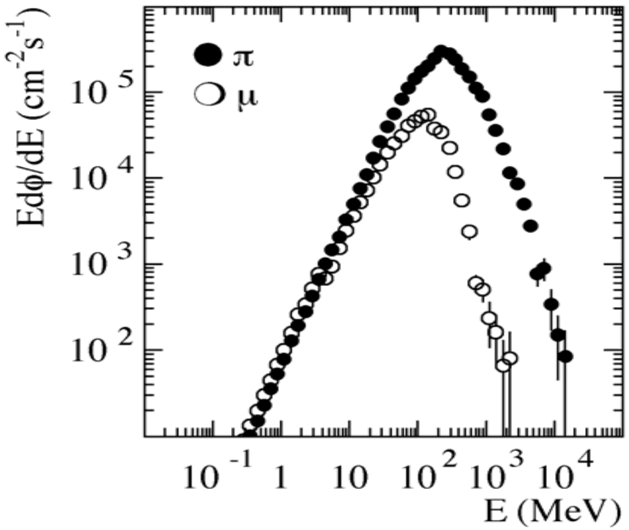


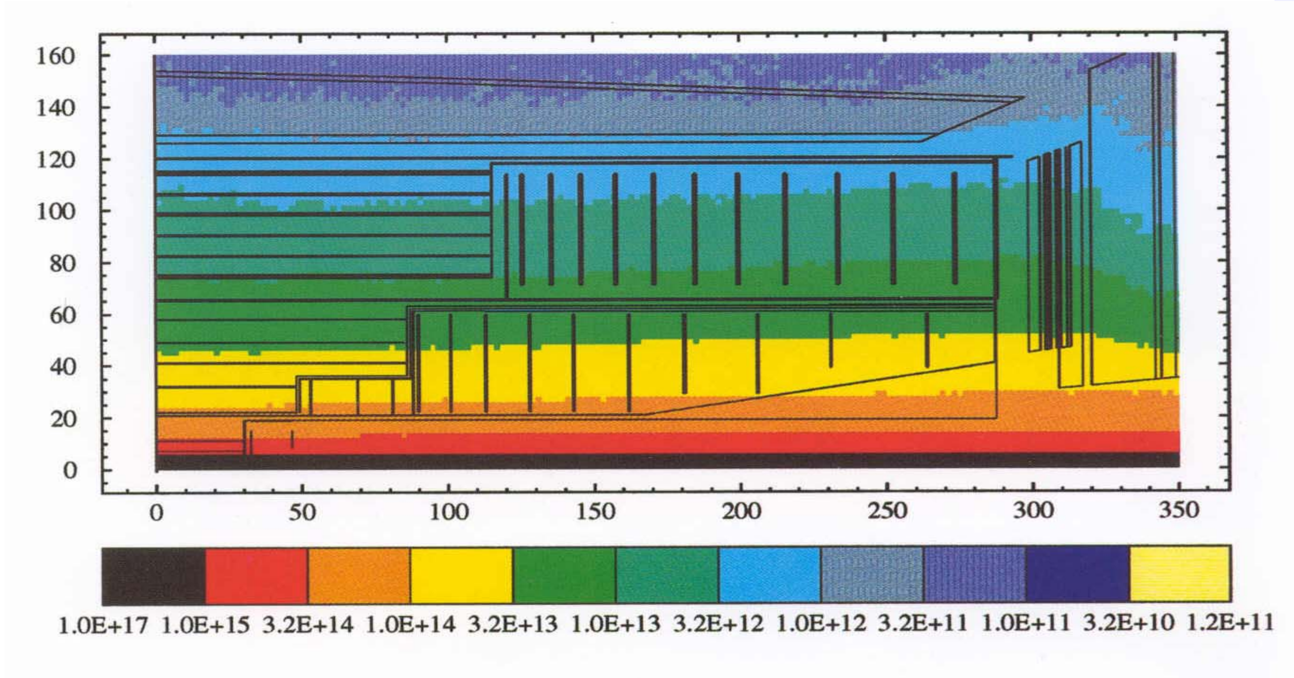
- Many COTS/COTS-based parts
- Each component also has CERN and supplier specification
- Long procurement and qualification process, complicated logistics
- Current status - production complete or very nearly complete for all parts
- Collaboration including Perugia, Vienna, Minnesota university groups

Requirements: radiation environment

- High Energy 7+7TeV
- High rate
  - Large radiation field
    - mainly pions (few hundred MeV) in Tracker



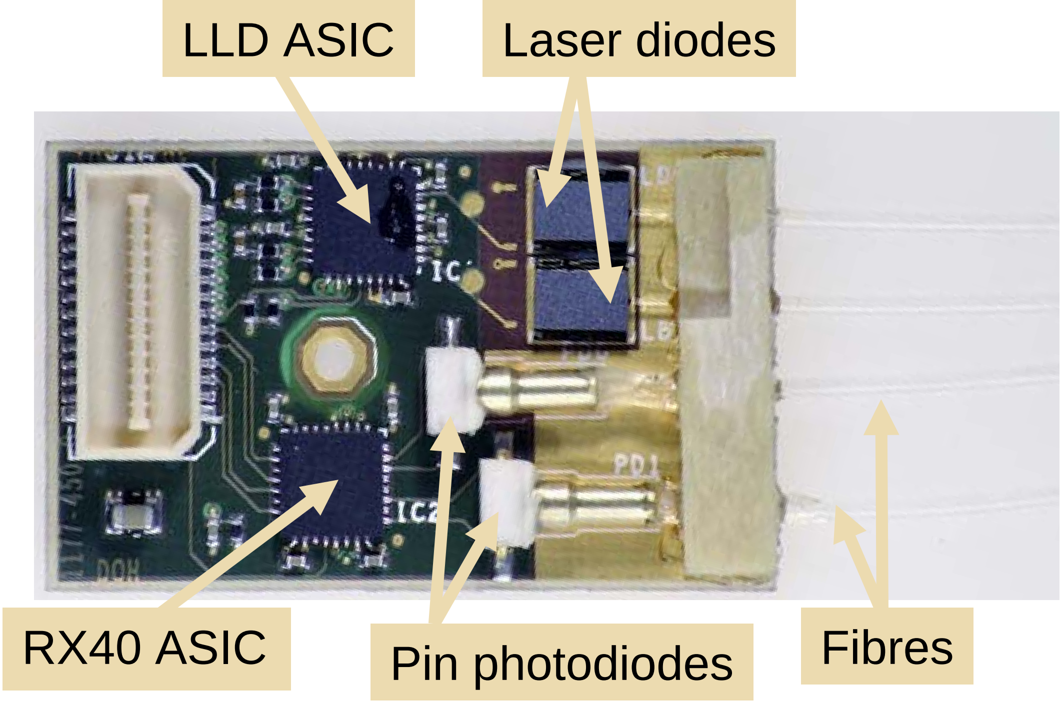




Charged hadron fluence (/cm^2 over ~10yrs)
(M. Huhtinen)

COTS issues

- Extensive use of commercial off-the-shelf components (COTS) in CMS optical links
  - Benefit from latest industrial developments
    - cheaper
    - reliable qualified 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>



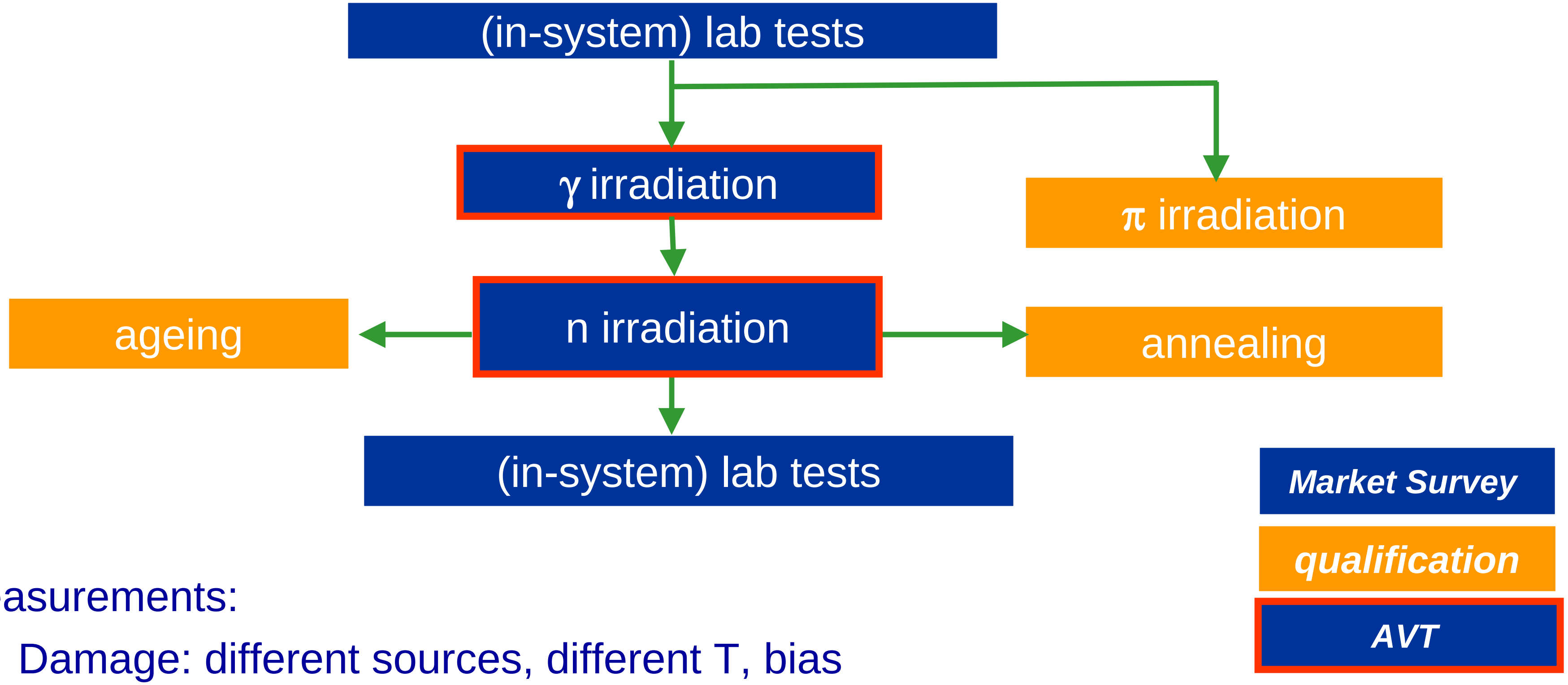
e.g. control links digital opto-hybrid

Quality Assurance programme

Period	Stage	Tests
1995-2000	Prototype sample validation	Functionality Radiation hardness
2000-2002	Pre-production Qualification	Functionality Radiation hardness Reliability
2003-2004	Pre-production Advance validation test (AVT)	Radiation hardness Reliability
2003-2005	Lot acceptance	Functionality
2005-2006	Integration	Functionality

Radiation testing

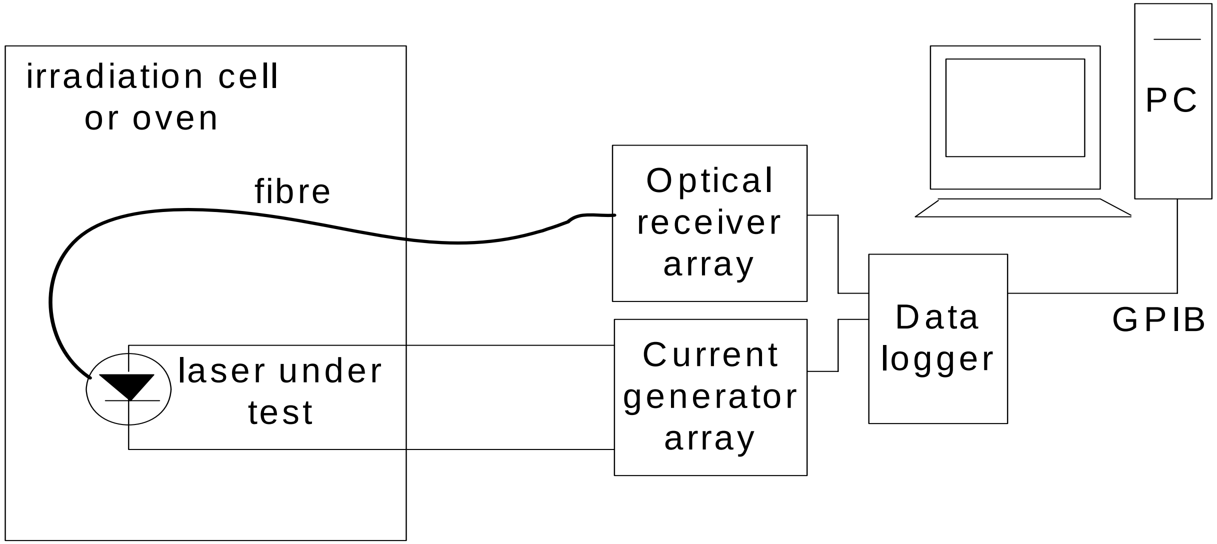
- e.g. validation tests on lasers



- Measurements:
  - Damage: different sources, different T, bias
  - Annealing rates, acceleration factors
  - Wearout
- >500 laser samples tested in total

Irradiation test system

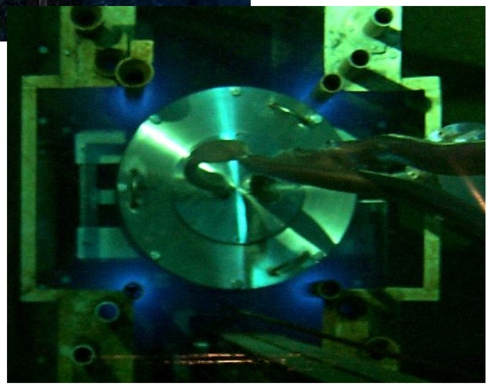
- Measurement setup (lasers)



- In-situ measurements allows confident extrapolation/comparison of accelerated tests
  - Avoid before/after tests unless damage kinetics understood
  - Few changes to test-procedure since 1997 for consistency

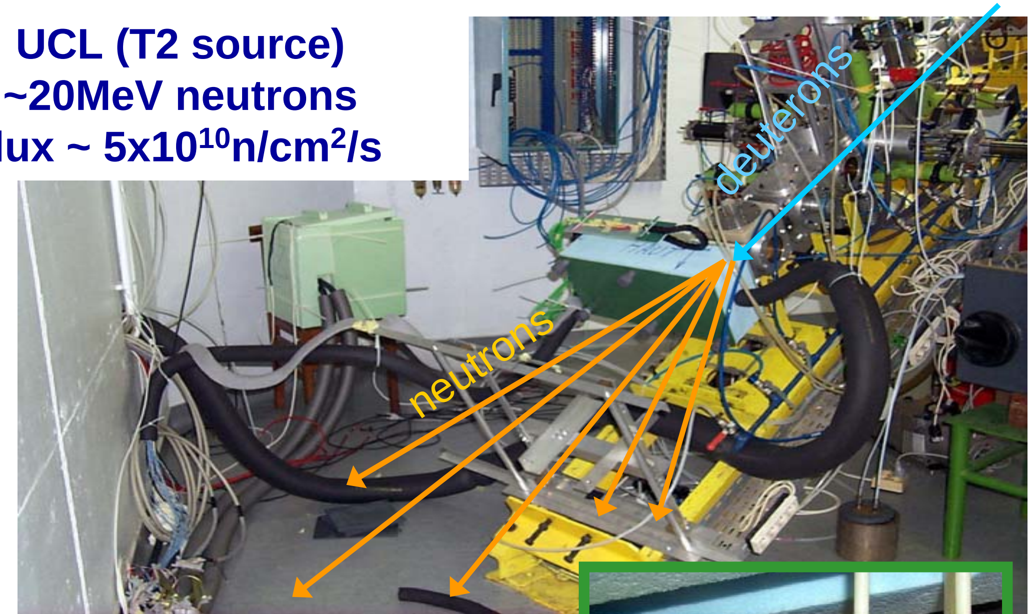
- Very similar system used for fibre and photodiodes

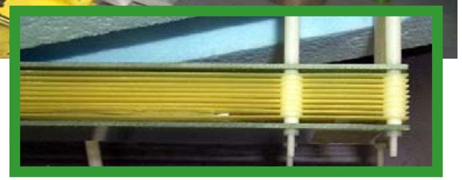
Irradiation at SCK-CEN and UCL



SCK-CEN Co-60
γ 2kGy/hr
underwater

UCL (T2 source)
~20MeV neutrons
flux ~ 5×10^{10} n/cm^2/s



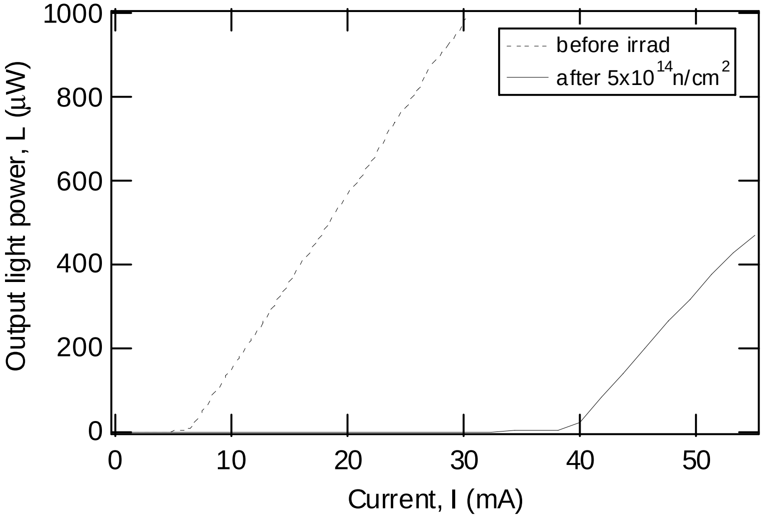


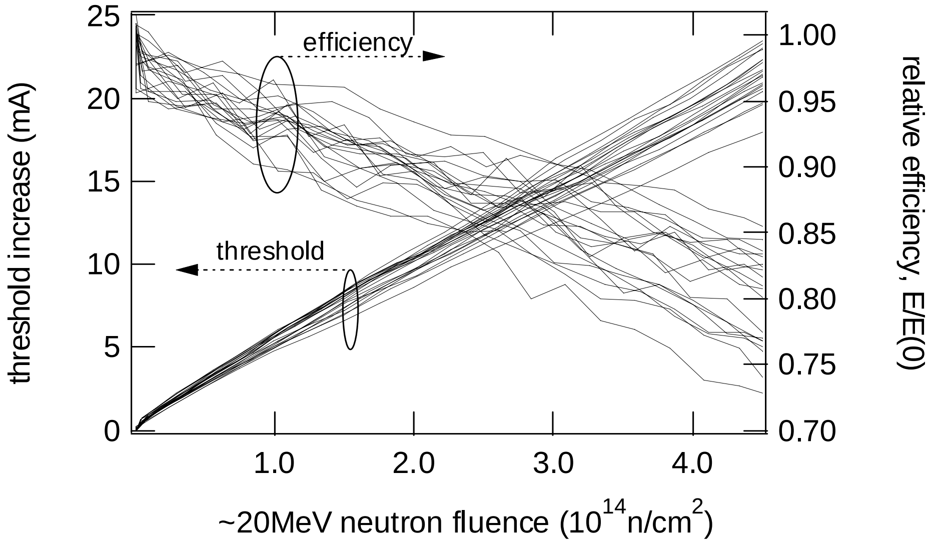
Samples stacked
inside cold box (-10°C)

Interested to use these sources?
please contact me...

Radiation Damage in lasers – 20MeV neutrons

Typical L-I characteristics before and after $5x10^{14}n/cm^2$



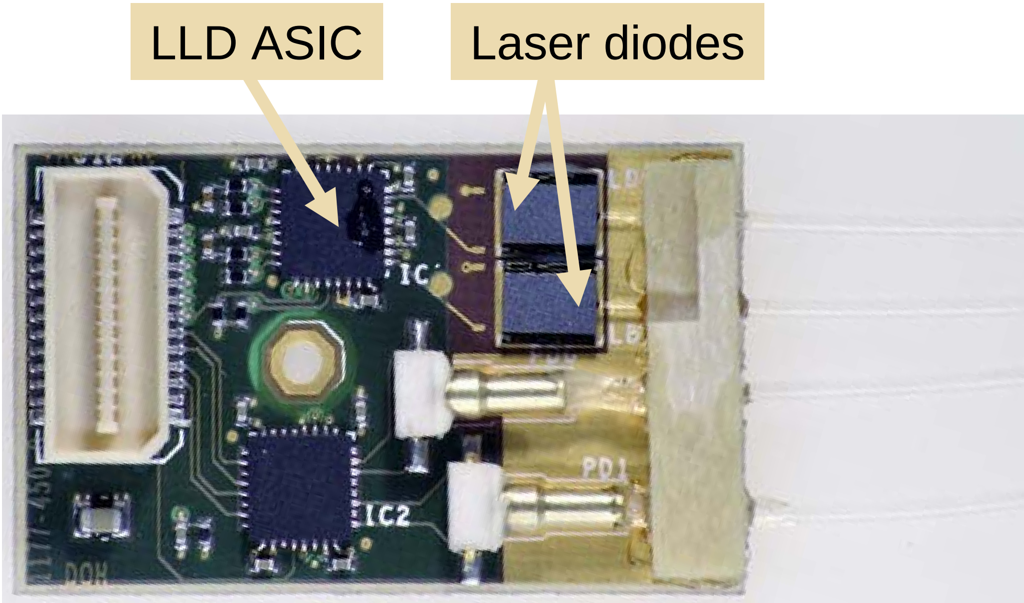


- A lot of damage from neutrons
  - Increase in laser threshold current
  - Decrease of laser efficiency
- Damage proportional to fluence
  - Degradation of carrier lifetime
- After $4.5x10^{14}n/cm^2$
  - Threshold increase ~20mA
  - Efficiency loss ~20%
- All wafers tested with this source in advance of final production (2002-2004)
  - 300 lasers in total

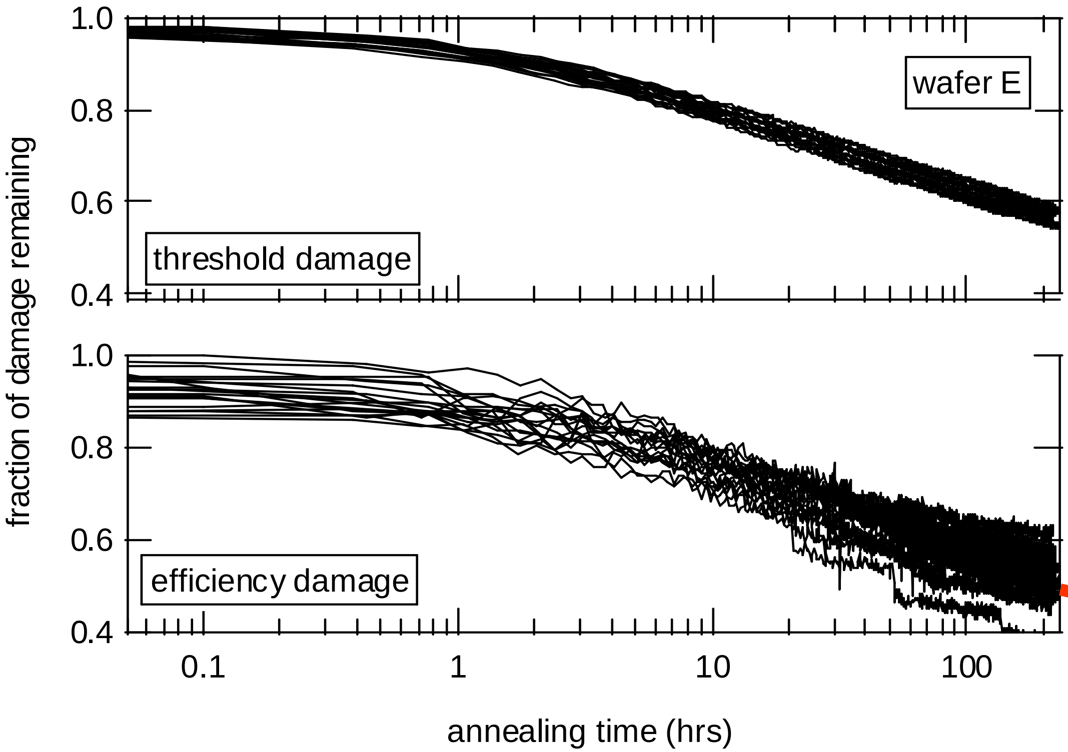
Laser damage mitigation

- LLD specified to compensate for laser damage
  - for threshold up to 45mA

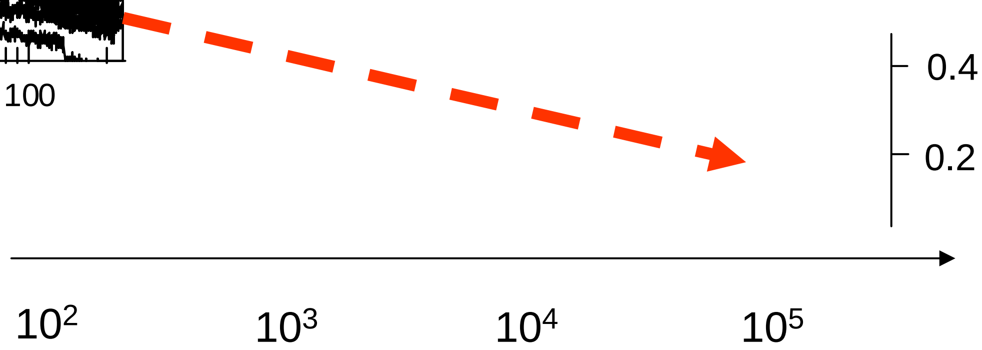
– Recall worst-case CMS-Tracker ΔI_{thr}~5.3mA after 10 years
  - Large safety margin (almost 10x)



Annealing in lasers



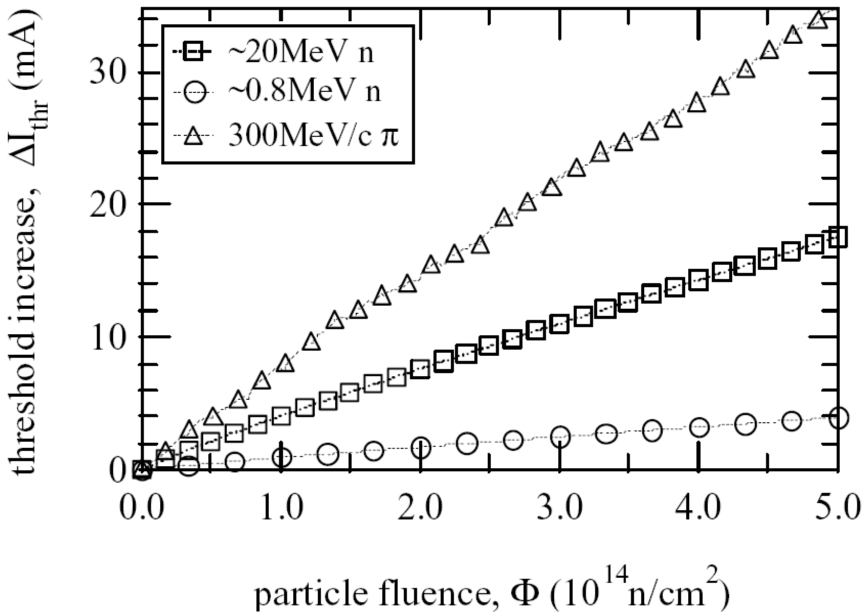
- Significant amount of annealing
  - Proportional to log(t_{anneal})
    - distribution of activation energies for annealing
- Similar rate for efficiency
  - damage mechanism same as ΔI_{thr}



- Expect at least 70% annealing after 10 years

Damage different sources

- Laser threshold I_{thr} with different sources (averaged and normalized) (1998-2000)



Relative damage factors

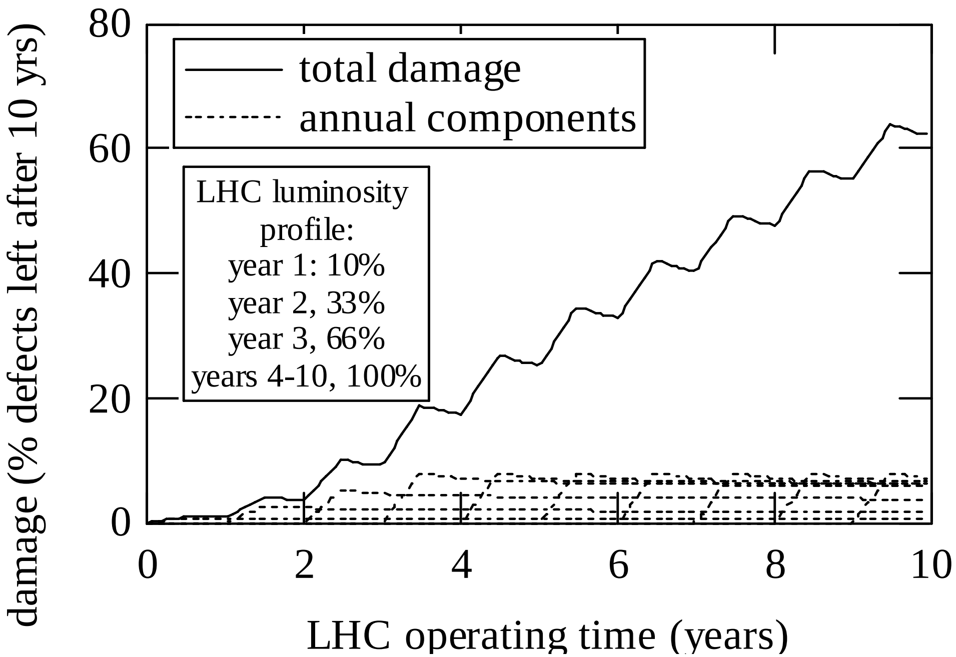
Valduc 0.75MeV n	(=1)
UCL 20MeV n	(=4.5)
PSI 200MeV π	(=8.4)
^{60}Co γ	(~0)

- Coverage of various parts of CMS particle energy spectrum
  - Pions most important

- Similar factors for other 1310nm InGaAsP/InP lasers

Laser damage prediction in CMS Tracker

- Even without thorough understanding, can predict damage evolution over a 10-year lifetime inside Tracker



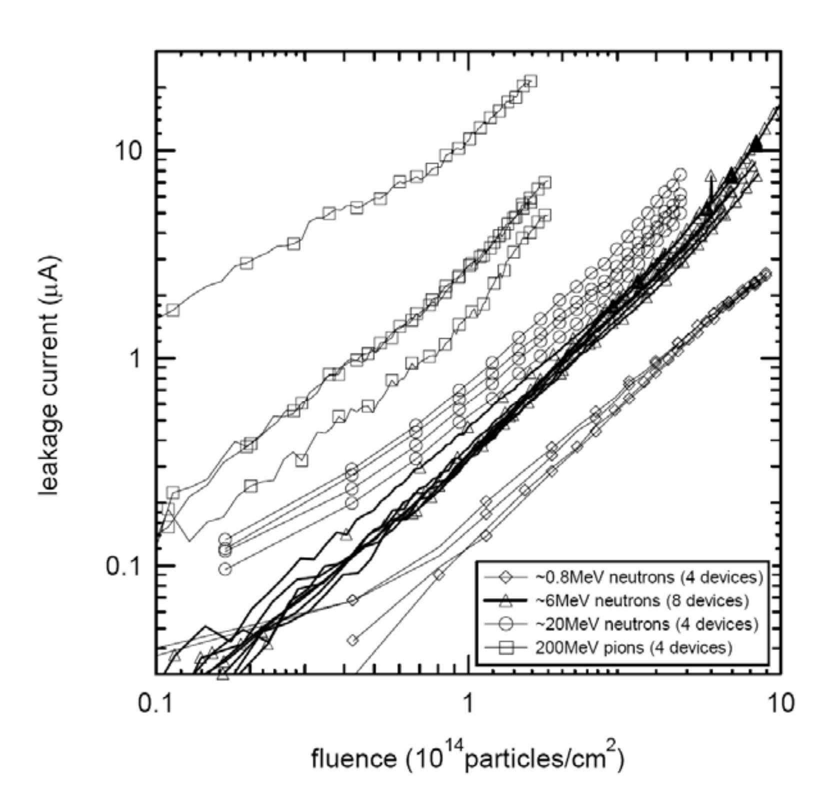
- Based on damage factors and annealing rate at close to -10°C
- Take worst-case
  - radius=22cm in Tracker
  - pion damage dominates

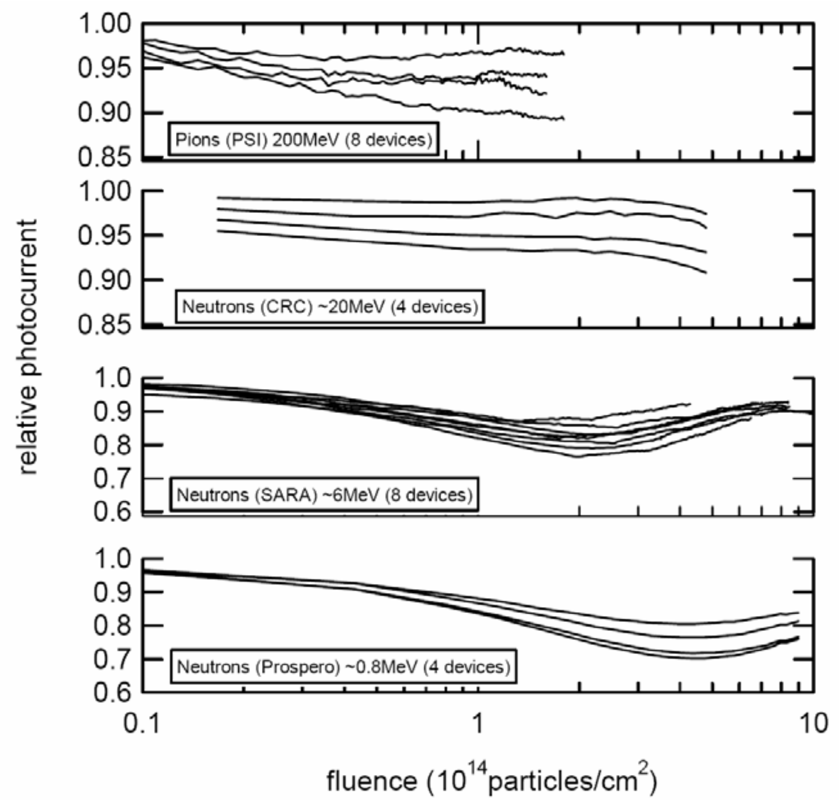
ΔI_{thr} = 6mA in 10 years
ΔE = 6% in 10 years

- Damage decreases rapidly with distance from beam interaction point
  - ~50% at r=32cm

Photodiode leakage and response

- leakage current and responsivity Fermionics InGaAs 80um diameter (1996-2000)

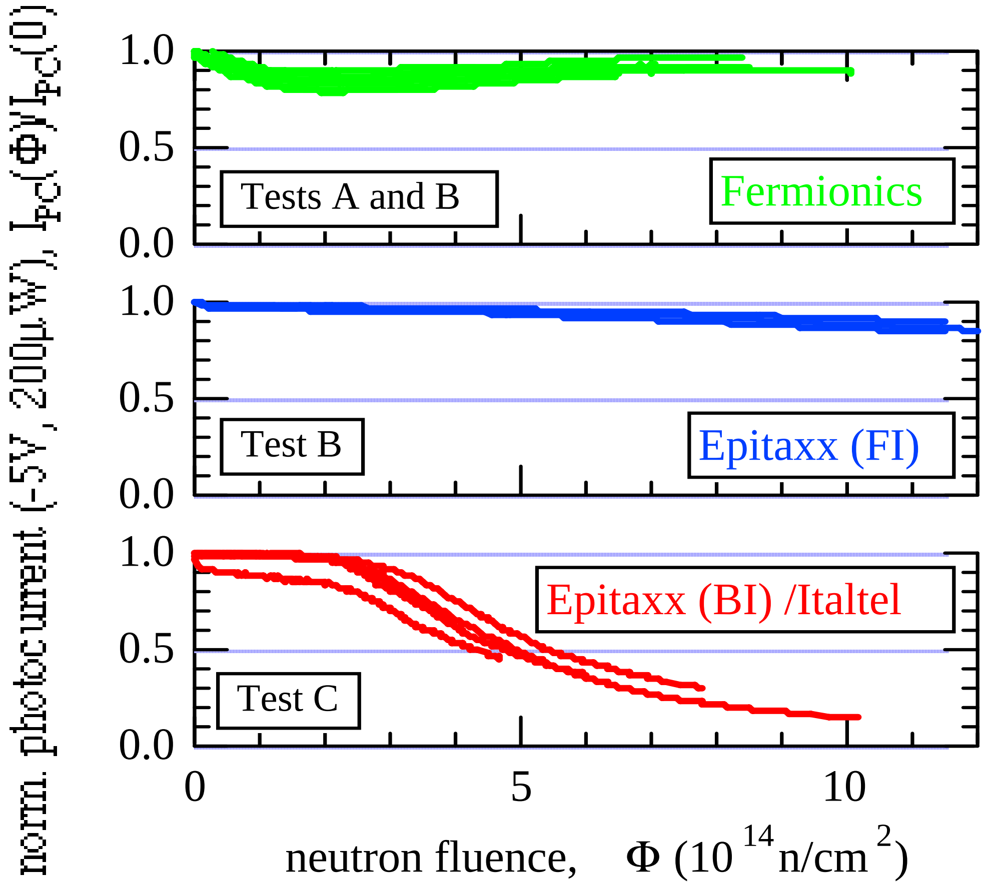




- RX40 ASIC designed to compensate for damage
  - dc current offset up to 500uA
  - automatic gain control (signals of 10-500uA)

Photodiodes - response

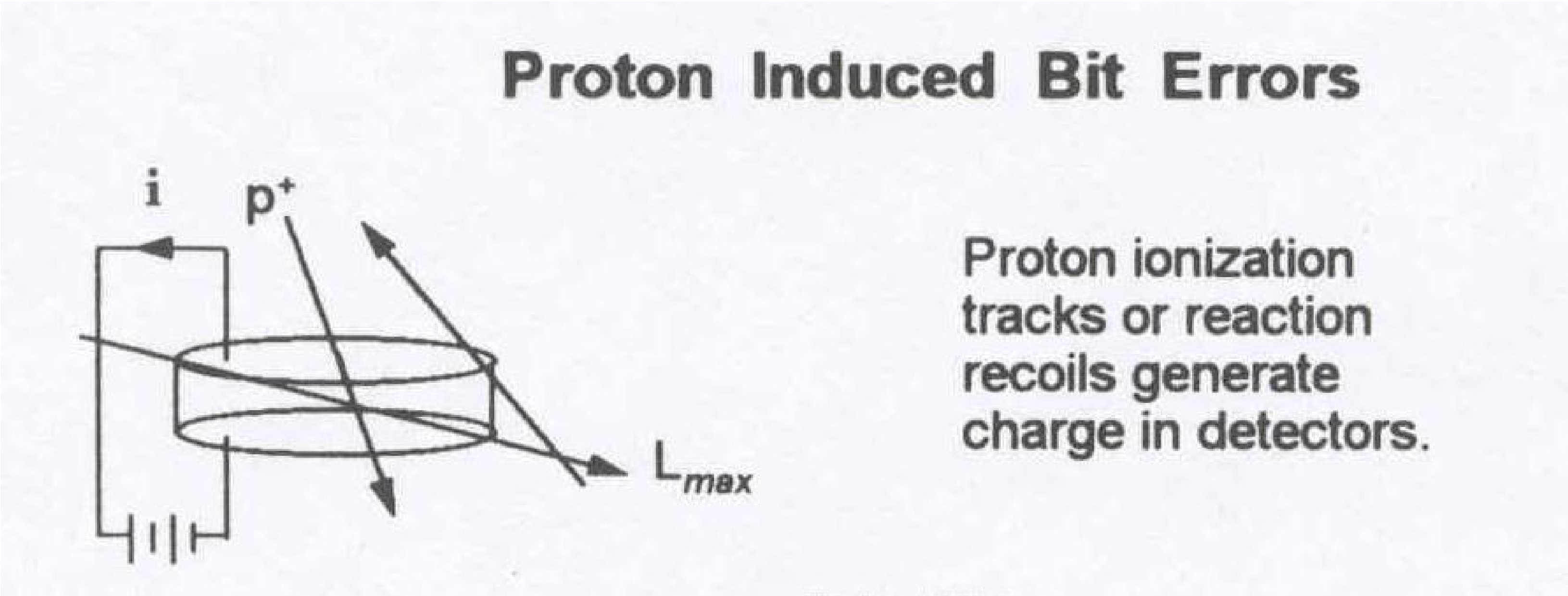
- Photocurrent (InGaAs, 6MeV neutrons, 1998)



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

PD SEU

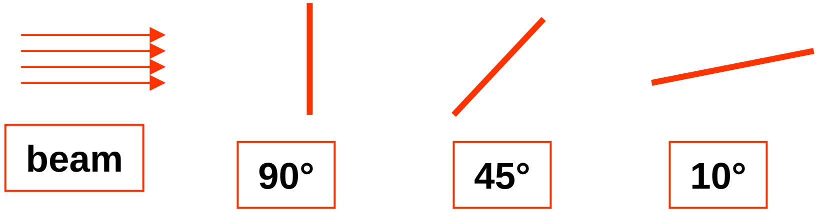
- photodiodes in control links sensitive to SEU
  - Bit-errors in control commands, clock and trigger signals

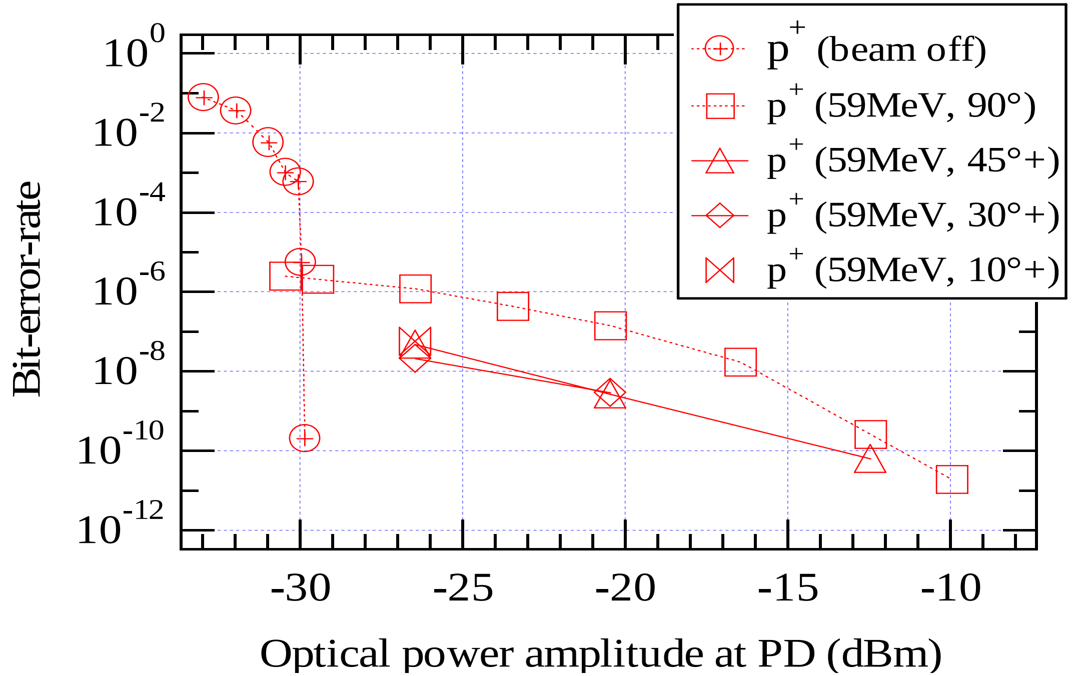


- strong dependence upon particle type and angle

Photodiode Single-event-upset

- Bit-error-rate for 80Mbit/s transmission with 59MeV protons in InGaAs p-i-n (D=80μm)
- (UC Louvain la Neuve, 2000)
- 10-90° angle, 1-100μW optical power
- flux ~10^6/cm^2/s *(similar to that inside CMS Tracker)*

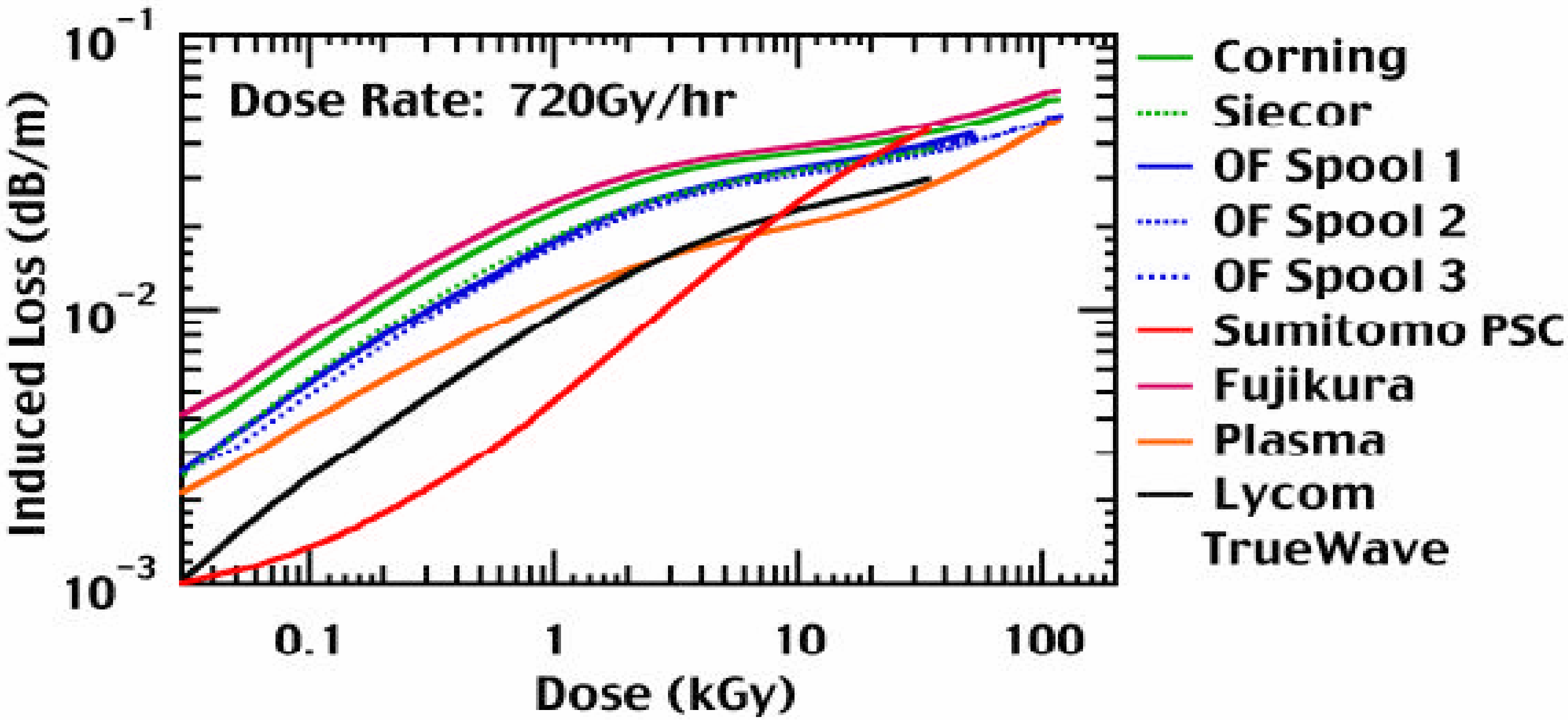




- Ionization dominates for angles close to 90°
- nuclear recoil dominates for smaller angles
  - Confirmed with neutron tests
- BER inside CMS Tracker similar to rate due to nuclear recoils
- should operate at ~100μW opt. power

Tests of fibre attenuation

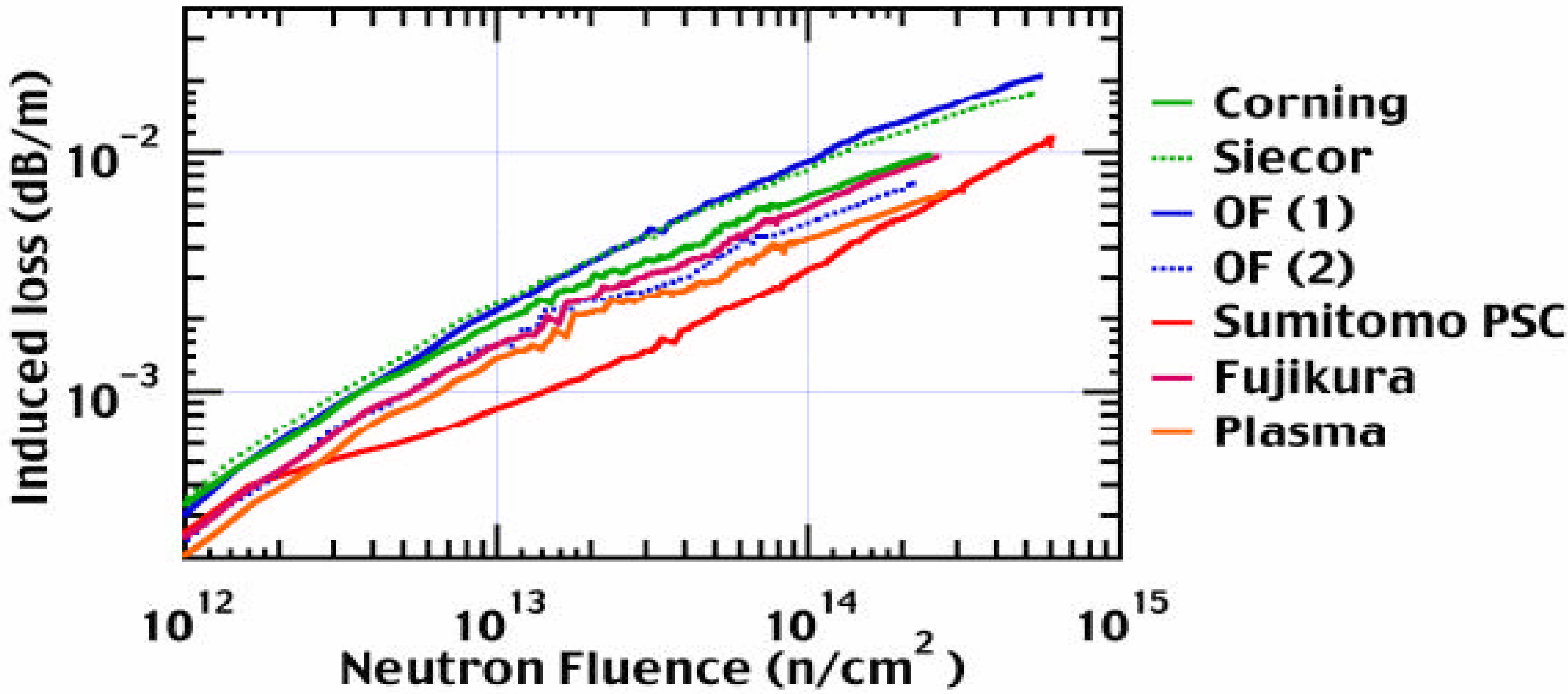
- Gamma damage in various COTS single-mode fibres at 1310nm (1997-8)



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

Fibre attenuation vs fluence

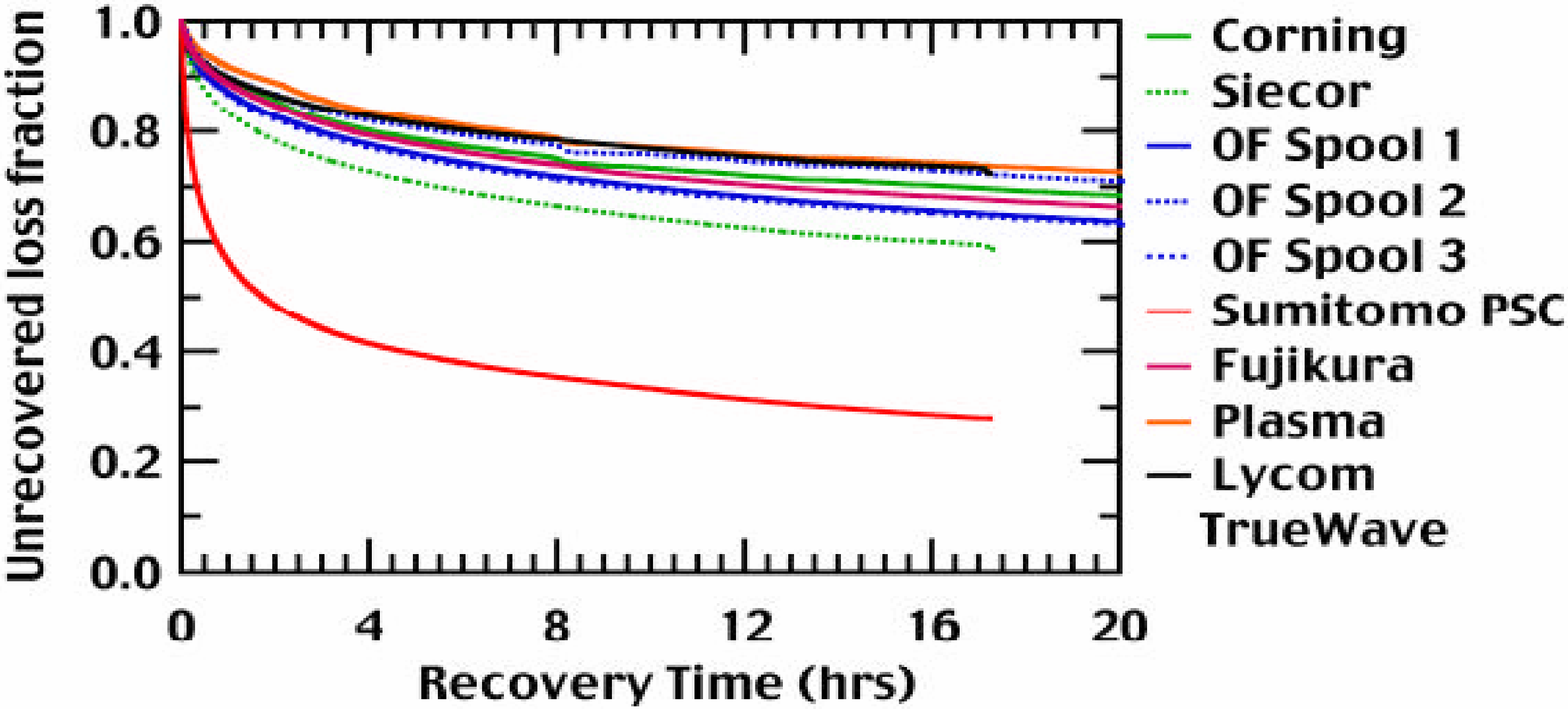
- 'Neutron' damage (1997)



- damage actually most likely due to γ background

Fibre annealing

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



- Damage therefore has *dose-rate* dependence

Conclusions

- We are building large systems of COTS (tele/datacoms) based optical links for CMS
- Challenges include
    - Radiation damage and reliability
    - Large number of parts and density of links
    - Low mass, non magnetic packages
    - Also long project timescale, procurement, logistics, manpower….
- Our approach
    - Extensive quality and reliability assurance program
        - CMS radiation effects
        - Reliability (Bellcore standard GR 468)
    - Build good relationships with suppliers and partners
    - Validation of sensitive parts (lasers, photodiodes, fibres) before production
        - Prototypes, pre-production qualification, advance validation in production
    - Compensation for damage effects built into system
- Production phase essentially complete
    - good confidence of reliability, large safety margins