Reliability of Components and Project QA

Outline

- Component Reliability
  - Environment and lifetime
  - Components
  - Tests
    - Recent tests on final components
- Project QA
  - QA Manual
  - Specs
  - Testing
  - Traceability
  - Laser Safety

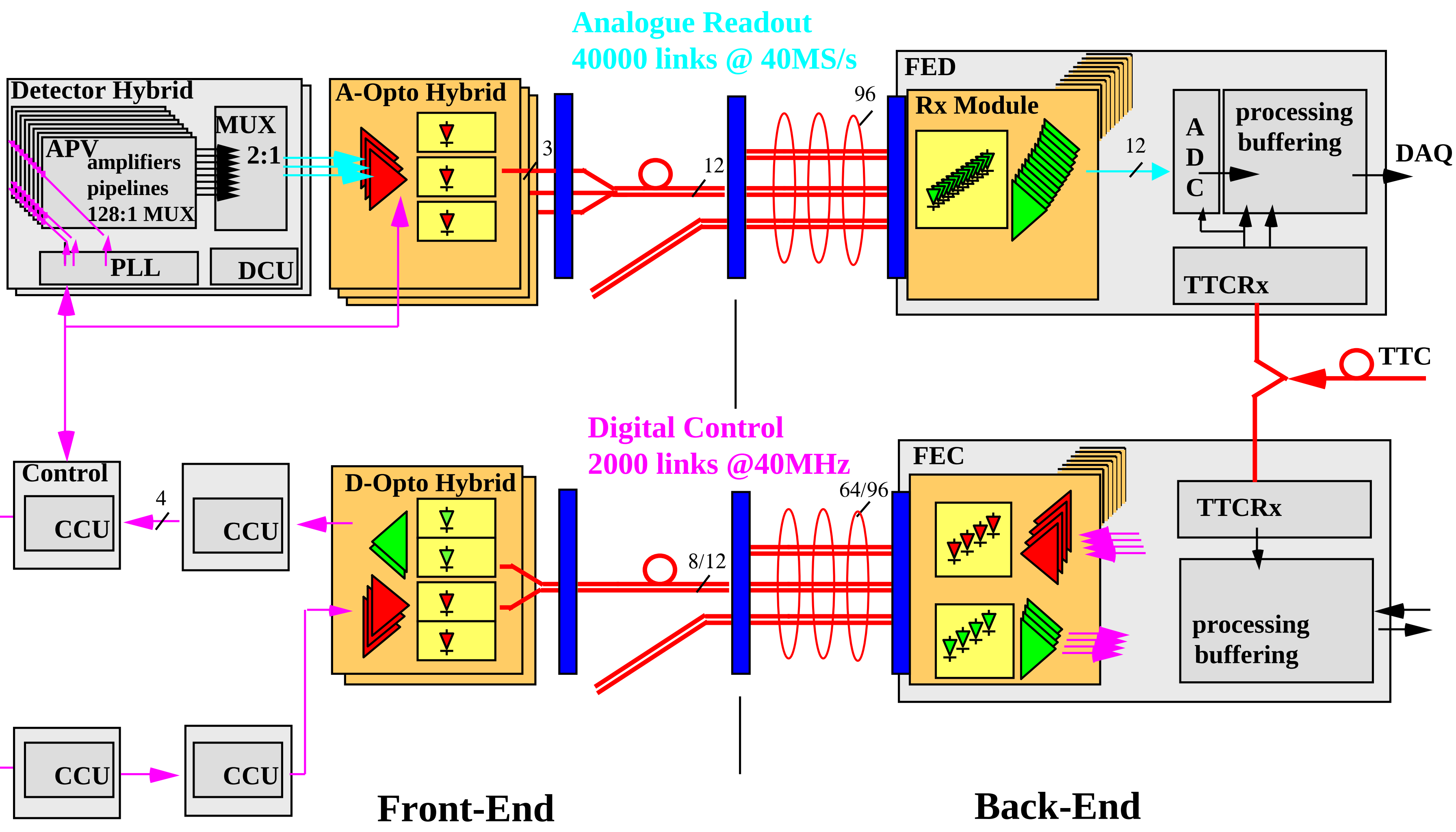
Tracker environment and lifetime spec

- Harsh operating environment
  - high radiation field
  - T ~ -10°C
  - B = 4T

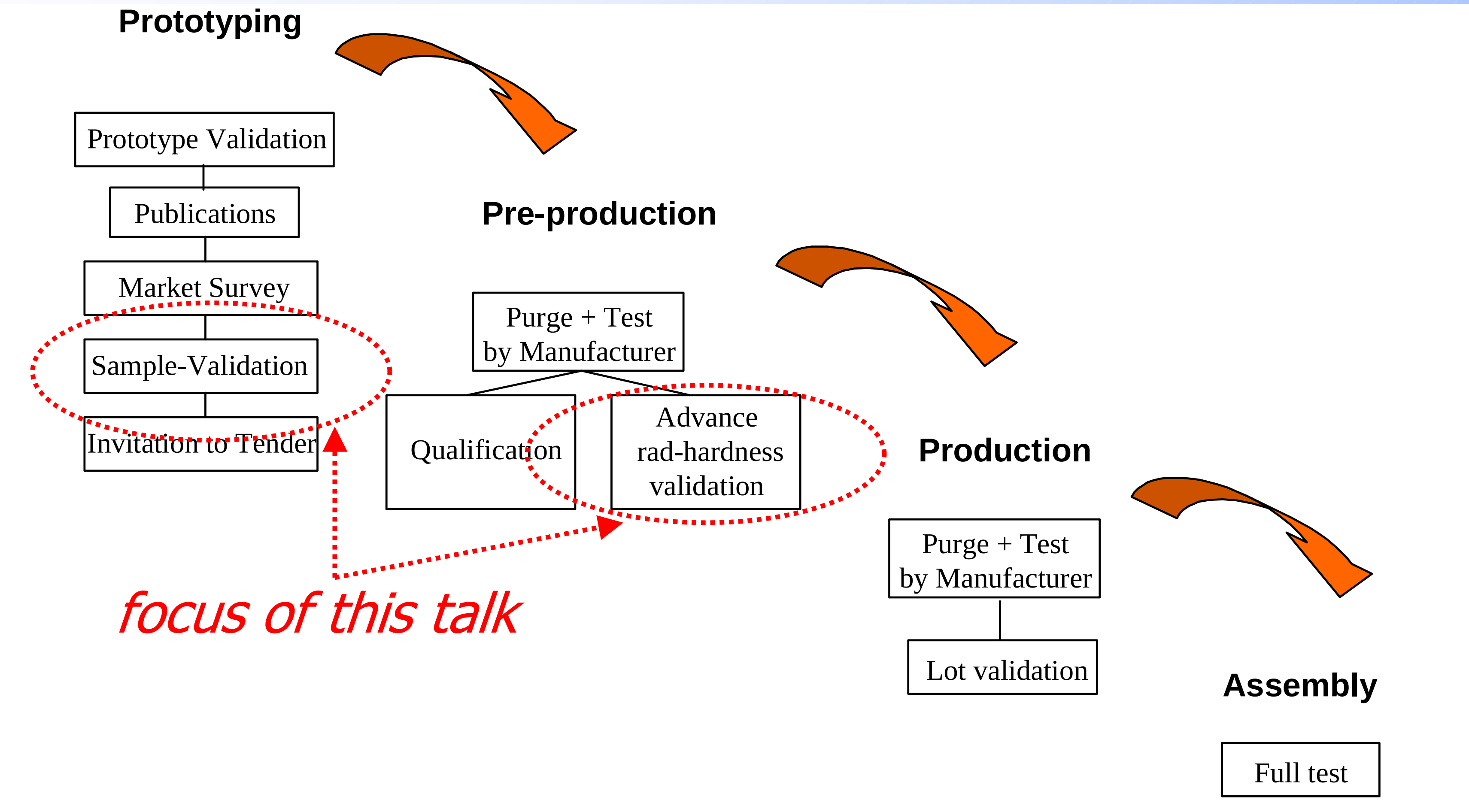
  - radiation damage the most important issue
    - can exclude magnetic components
    - -10°C within typical telecoms operating specs

- 10 years minimum operational lifetime

CMS Tracker optical links



Evolution of QA procedures



Testing during development phase

- Extensive series of tests since work started within RD23

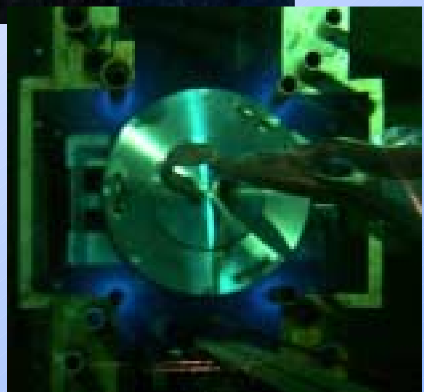
- Suitability for Tracker environment
  - Irradiation (all components)
  - B-field (lasers and connectors)
  - also Temperature (lasers)

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

Accelerated test philosophy

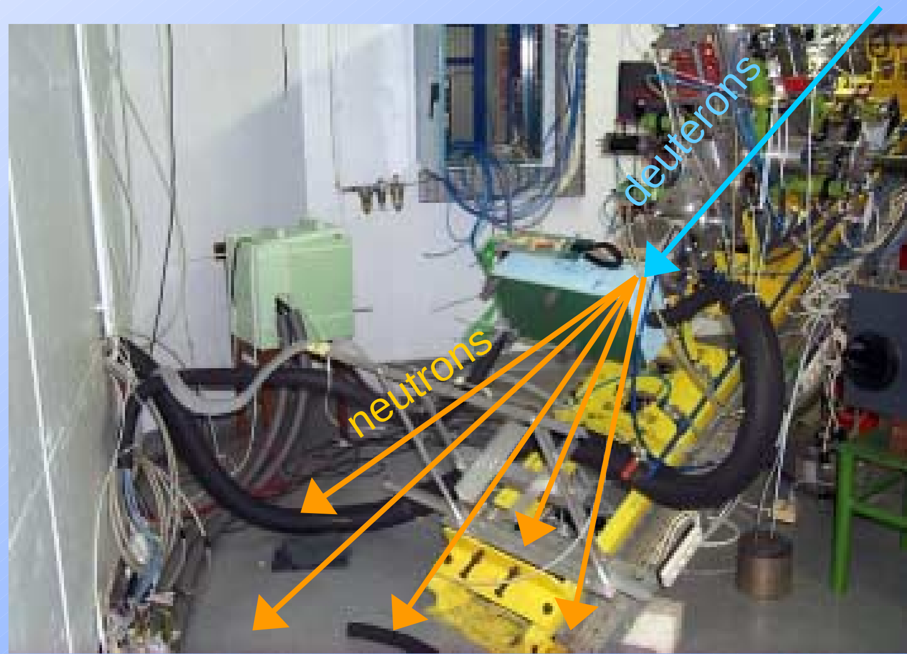
- Forced to make accelerated tests due to limited time available
  - try to test **'worst-case'** of total exposure equivalent to 10yrs in Si Tracker
    - higher dose rates or fluxes
    - also can include other factors
      - e.g. increased temperature, bias
        - enhance annealing
        - accelerate wearout
- Make the accelerated tests then extrapolate to CMS Tracker conditions
- With accumulated understanding of effects can use only few radiation sources in future
    - gamma - ionisation damage
    - neutron - displacement damage
    - proton, neutron - single event effects

Irradiation at SCK-CEN and UCL



SCK-CEN Co-60 γ
dose rate 2kGy/hr
underwater
source

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



Samples stacked inside cold box (-10°C)

Radiation damage results

- Full set of publications 1995-2000 on links web-page
  - http://cms-tk-opto.web.cern.ch

- Review only most recent tests and data:

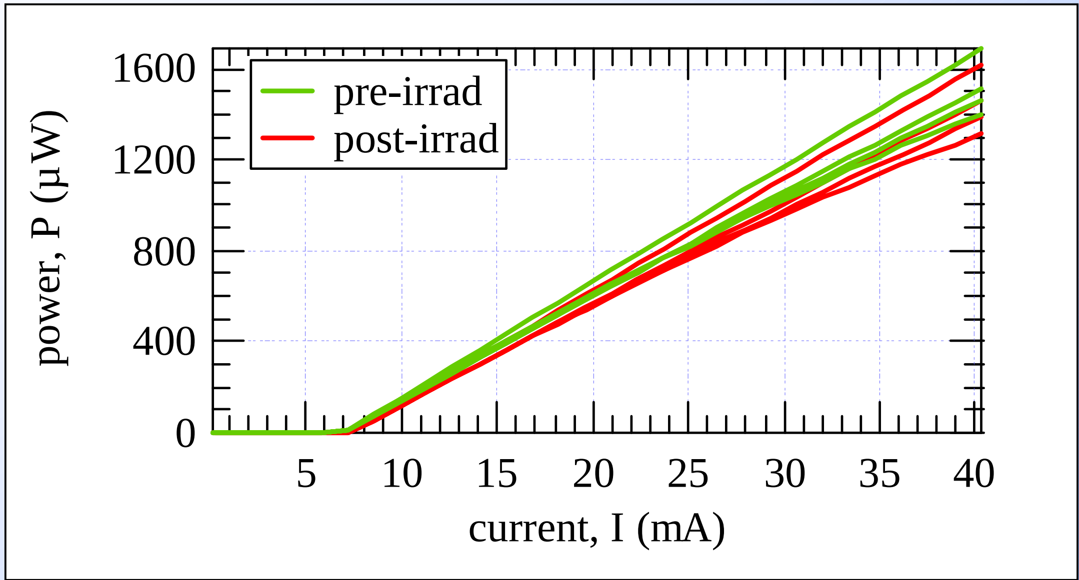
  - Results from ***final laser type***
    - Mitsubishi 1310nm edge-emitter
    - Radiation damage, Annealing, Long-term degradation

  - SEU tests of digital Rx

  - Advance validation test ***of final fibre*** for the laser pigtails
    - Ericsson
    - Test of the actual raw fibre to be used

Ionization damage

- Laser L-I characteristics

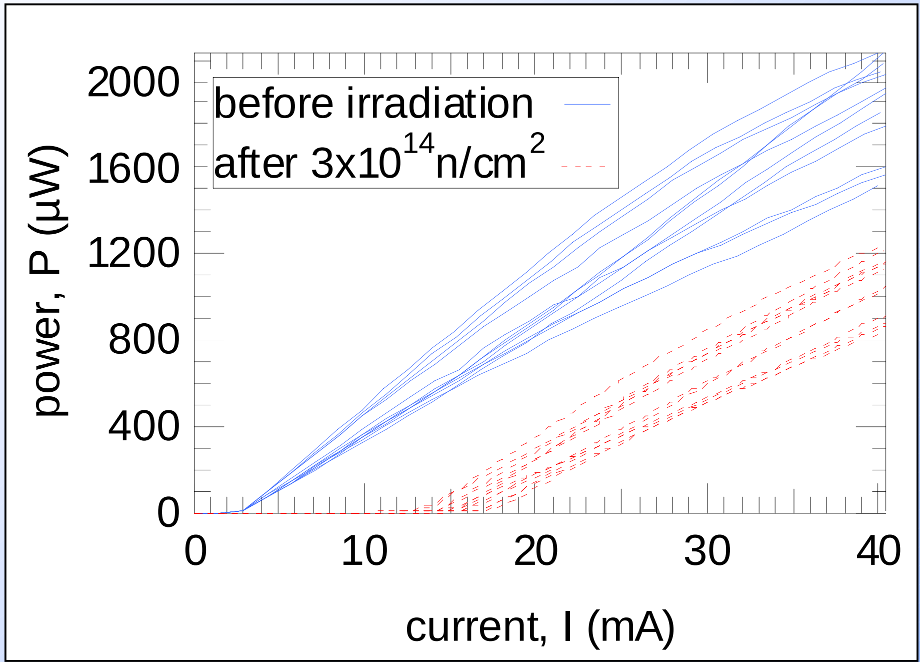


- Before/after 100kGy

- No significant effects with ionization damage
- Same conclusion for all laser diodes tested

Displacement damage

- Laser L-I before/after $3x10^{14}$n/cm^2

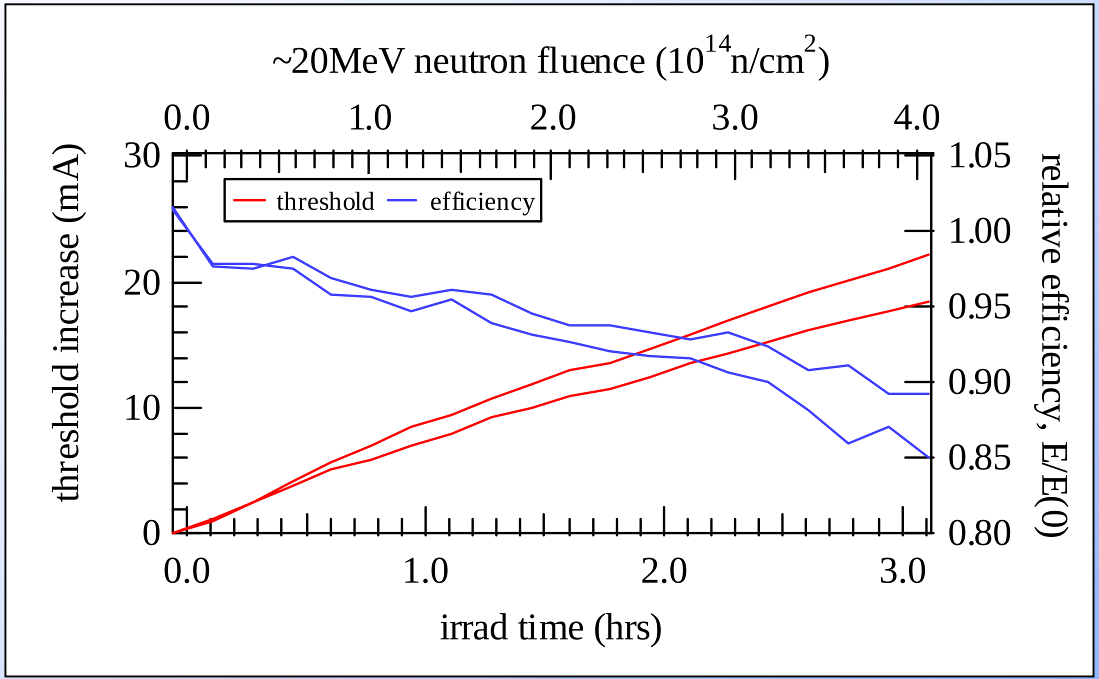


- ~20MeV neutrons (UCL)
- Temp -10°C

- Laser threshold I_{thr} ↑, efficiency E ↓
- Damage effects similar (to within factor ~2) in ***all lasers***
  - ref: Gill, LEB 1998

Damage vs fluence

- Laser threshold I_{thr} and efficiency E

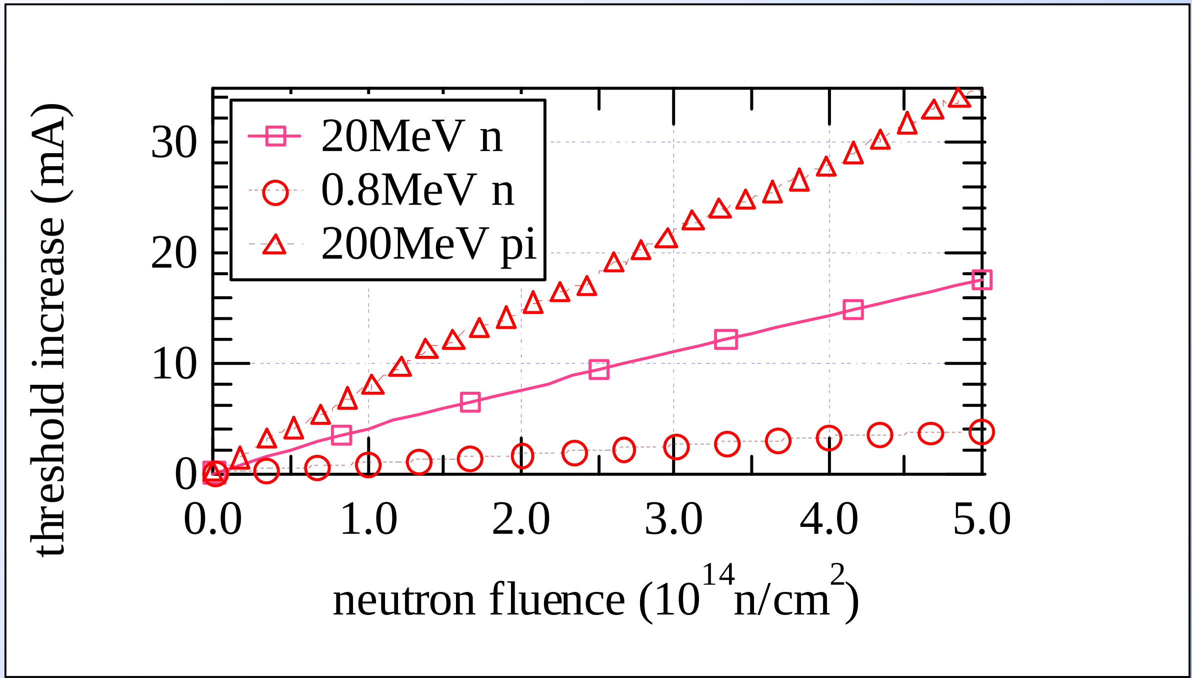


- ~20MeV neutrons (UCL)
- Temp 20°C

- Damage ***always ~linear*** with fluence
  - NIEL dependence..?

Damage comparison

- Laser threshold I_{thr} with different sources

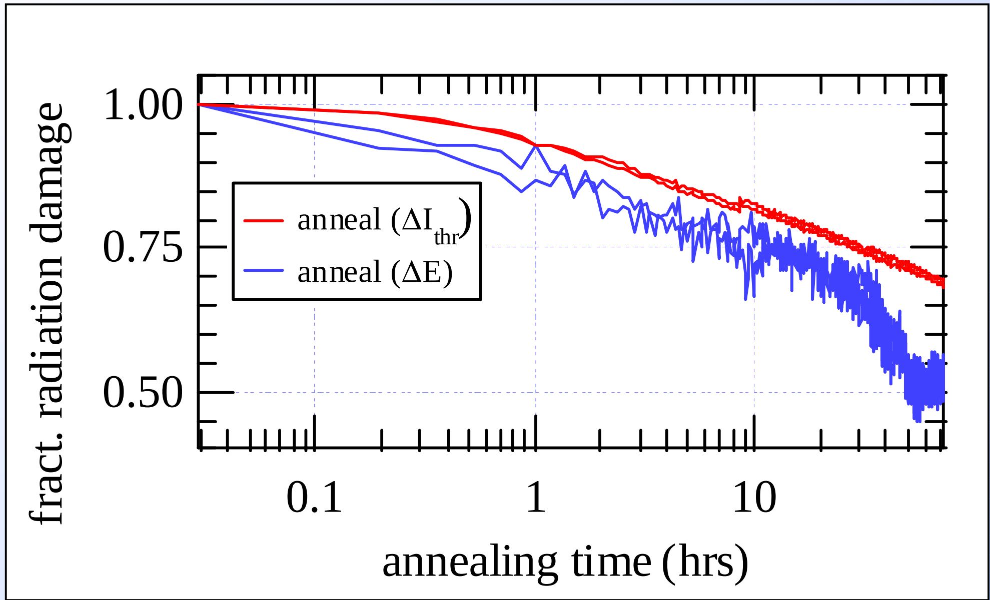


- Relative damage factors
  - 0.75MeV n (=1)
  - ~20MeV n (=4.5)
  - 200MeV π (=8.4)
  - 1MeV γ (~0)

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

Annealing

- Laser threshold I_{thr} and efficiency E

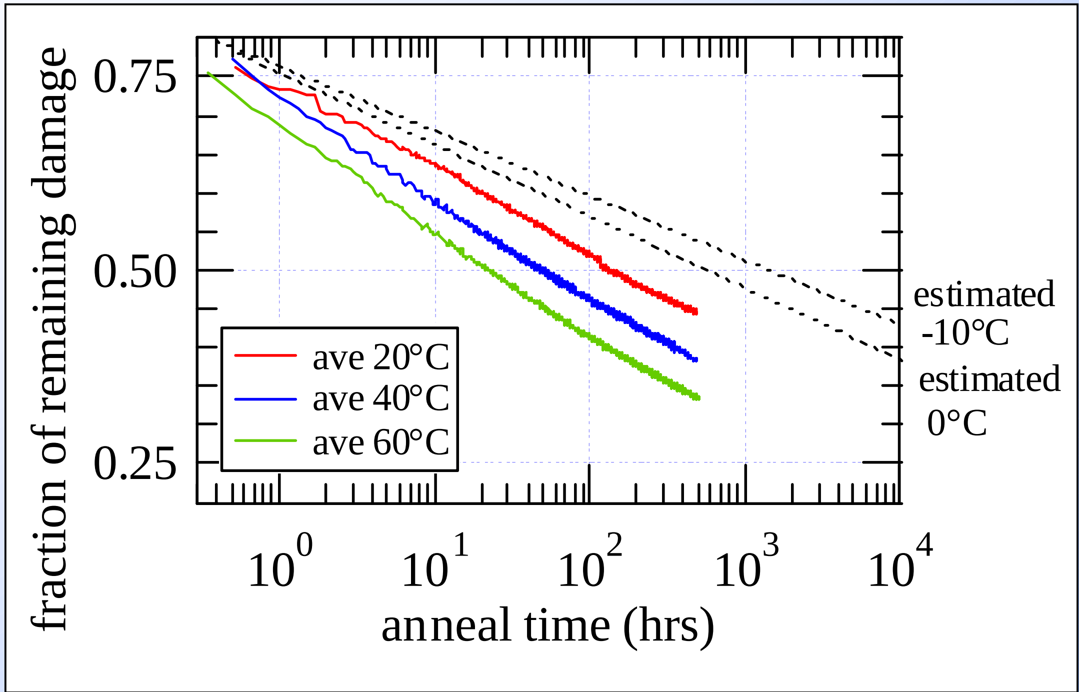


- after $4x10^{14}n/cm^2$
- ~20MeV neutrons (UCL)
- Temp 20°C

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

Annealing vs Temperature

- Measure at different T

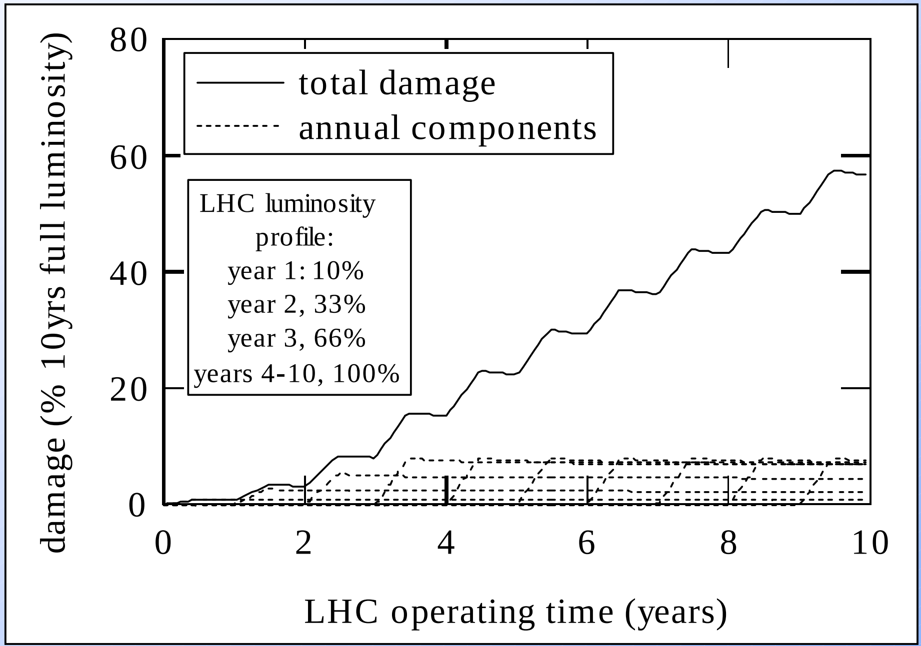


- after $3 \times 10^{14} n/cm^2$
- ~20MeV neutrons (UCL)
- Temp(irrad) -10°C

- Uniform annealing activation energy spectrum very likely

Damage prediction

- Knowing damage factors and annealing rate
  - Can predict damage evolution over whole 10yr CMS lifetime
    - ref: Proc. SPIE 2000



- Important damage dominated by pions
- Mitsubishi lasers (v. preliminary!)
  - ***ΔI_{thr}~1mA/year***
  - ***ΔE~1%/year***

B-field

- Exclude magnetic packaging materials
- Spectral and static characterization
  - in-system functionality test
  - up to 2.4T
  - various angles

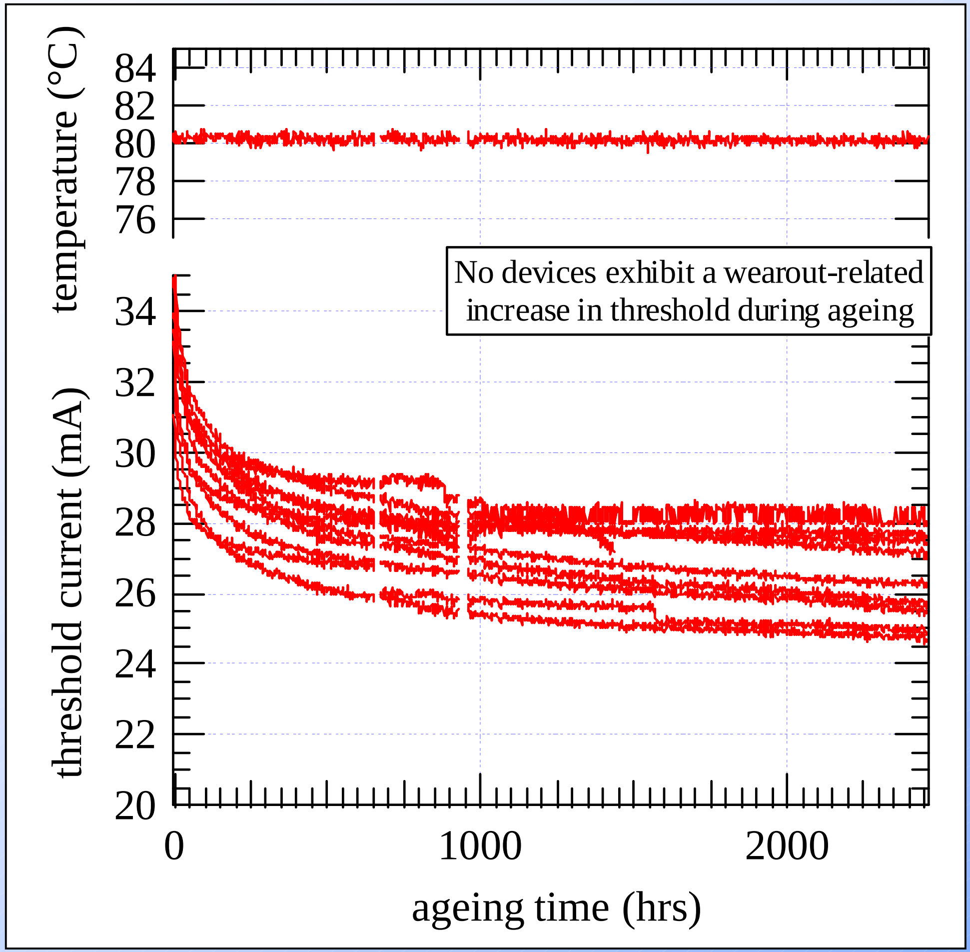
  - No effect on spectrum
  - No effect on L-I, noise, linearity

    - ref: CMS Note 2000/40

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

Laser reliability

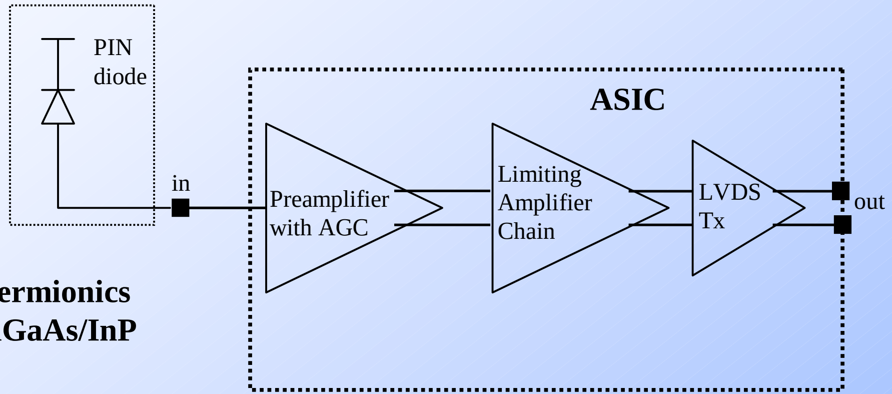
- Ageing test at 80°C   Also ref: Proc. RADECS 1999



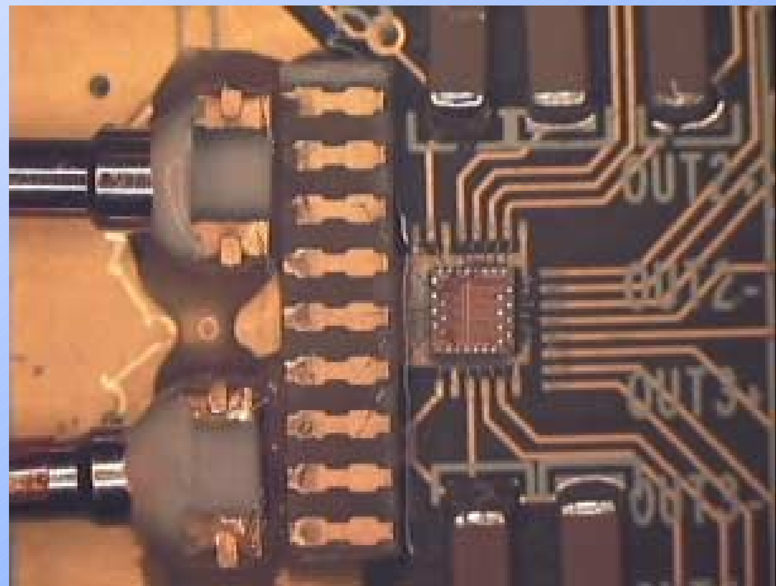
- 12 devices irradiated to >10^{14}n/cm^2 (UCL)
- 2500 hrs ageing
- No additional degradation in irradiated lasers
- acc. Factor ~400 relative to -10°C operation, for E_a=0.4eV
  - ***10^6hrs at -10°C !!***
- ***lifetime >>10years***

Optical receiver SEU testing

- SEU tests made with neutrons and protons (UCL)
  - Ref: LEB 2000.



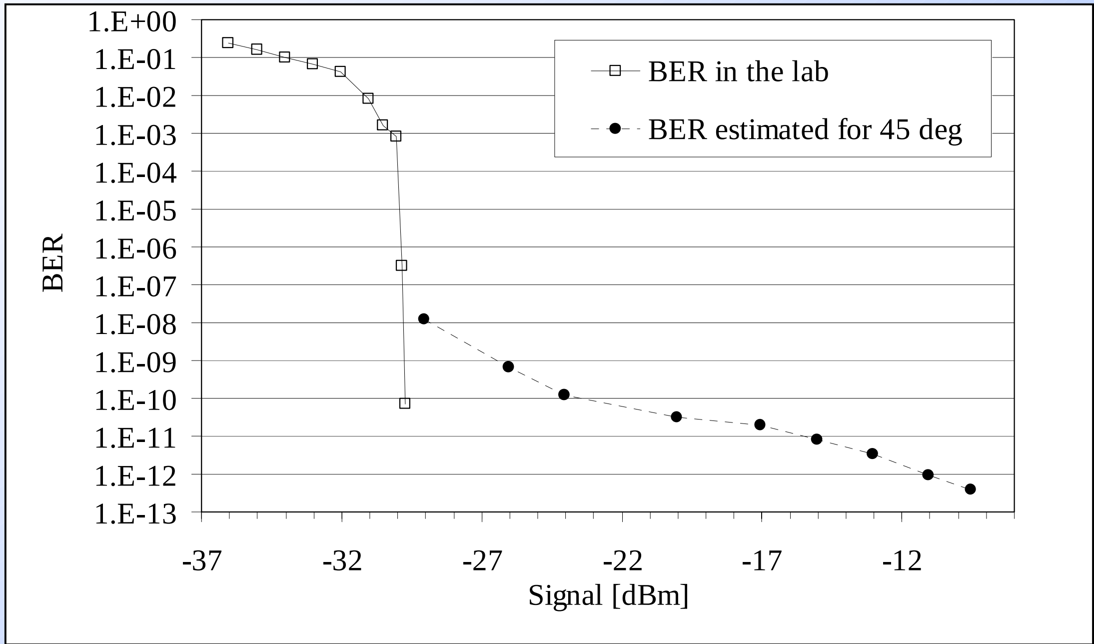
Fermionics InGaAs/InP



ASIC mounted with 2 photodiodes

System implications

- Based on a charged particle flux of $10^6/cm^2/s$
  - typical of tracker levels



Should maintain optical power > ~100µW

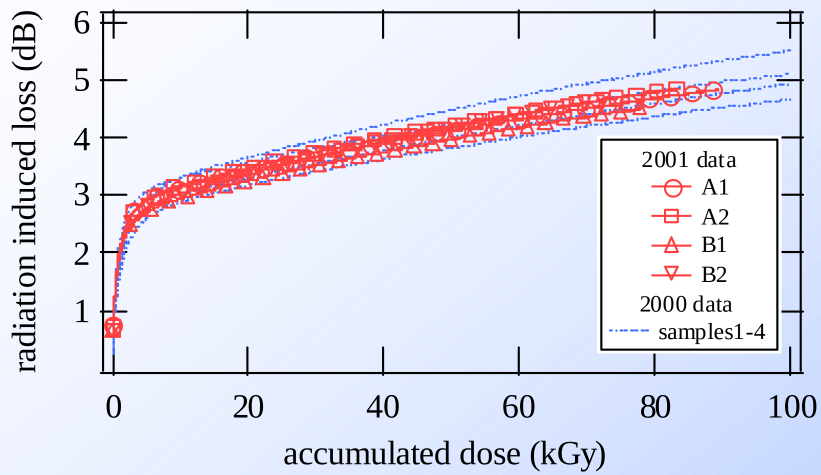
Fibre radiation damage testing

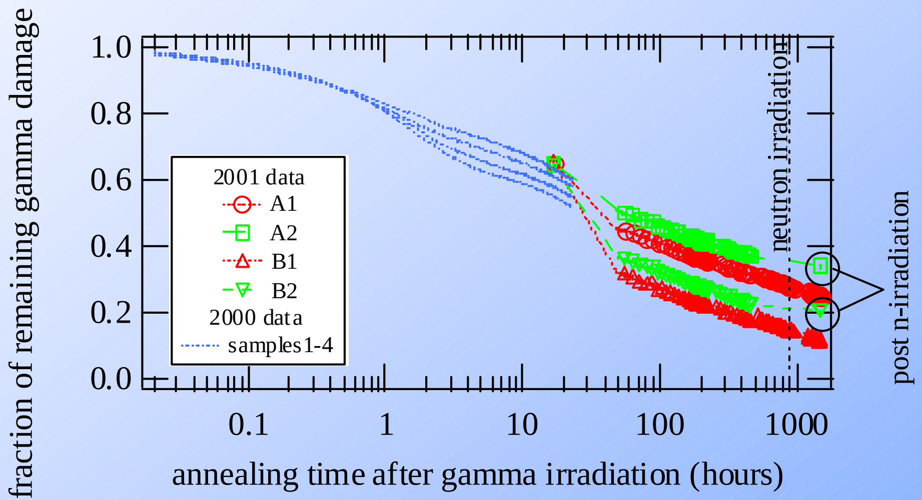
- Tests before and after irradiation:

1-way fibre	Attenuation Fibre strip force
12-way ribbon cable	Insertion loss Bending loss
96-way multi-ribbon cable	Strength tests

- ***Focus here on recent Advance Validation Test of final fibre***

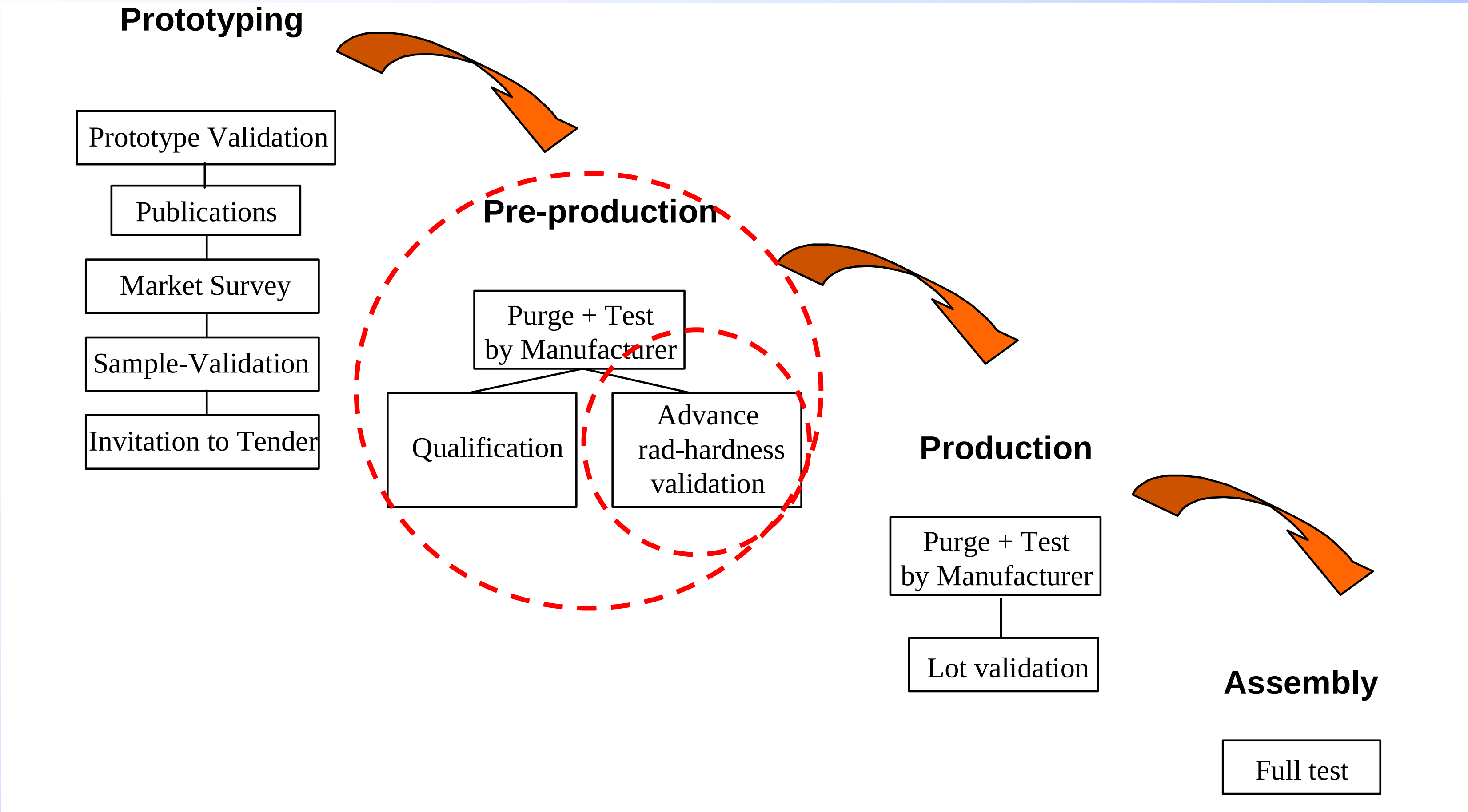
Radiation damage in final fibre





- Ericsson standard single-mode fibre
  - Advance validation test of final naked fibre spools
    - Before plastic buffer added.
- 100m long samples from 2 glass preforms irradiated with
  - ~80kGy Co-60 gamma
  - $1.1 \times 10^{14} n/cm^2$ (~20MeV)
- Final loss at 1310nm in final system with 150kGy max dose limited to ~0.01dB/m
- ***Accept fibre for final production***

(Pre)Production QA

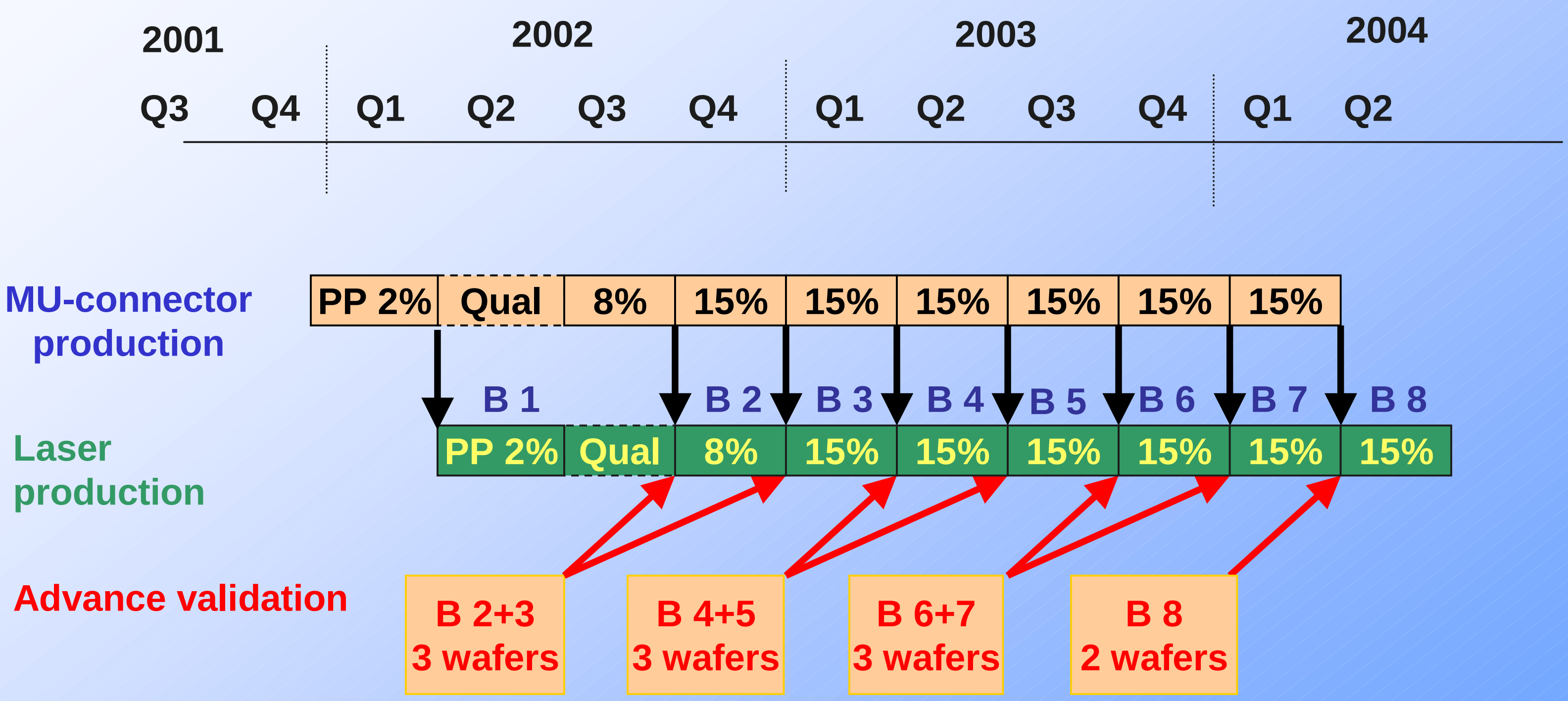


Advance rad-hardness validation

- All COTS components manufacturer-qualified as market ready
  - However, still unfortunately ***not guaranteed rad-resistant***
- Must avoid rejection of delivered production batches due to non-compliance
  - very difficult to remedy quickly
- Proposed **advance validation test (AVT)** of rad-resistance
  - laser die
  - photodiode die
  - naked fibre – ***results from first test just described***
- Validated raw sub-components
  - purchased and stored, then used later for production
- Non-compliant components kept by manufacturer for ‘usual applications’

Laser AVT planning

- Preliminary scheduling of laser AVT's
  - Complex procedure – involves lots of interaction with manufacturers

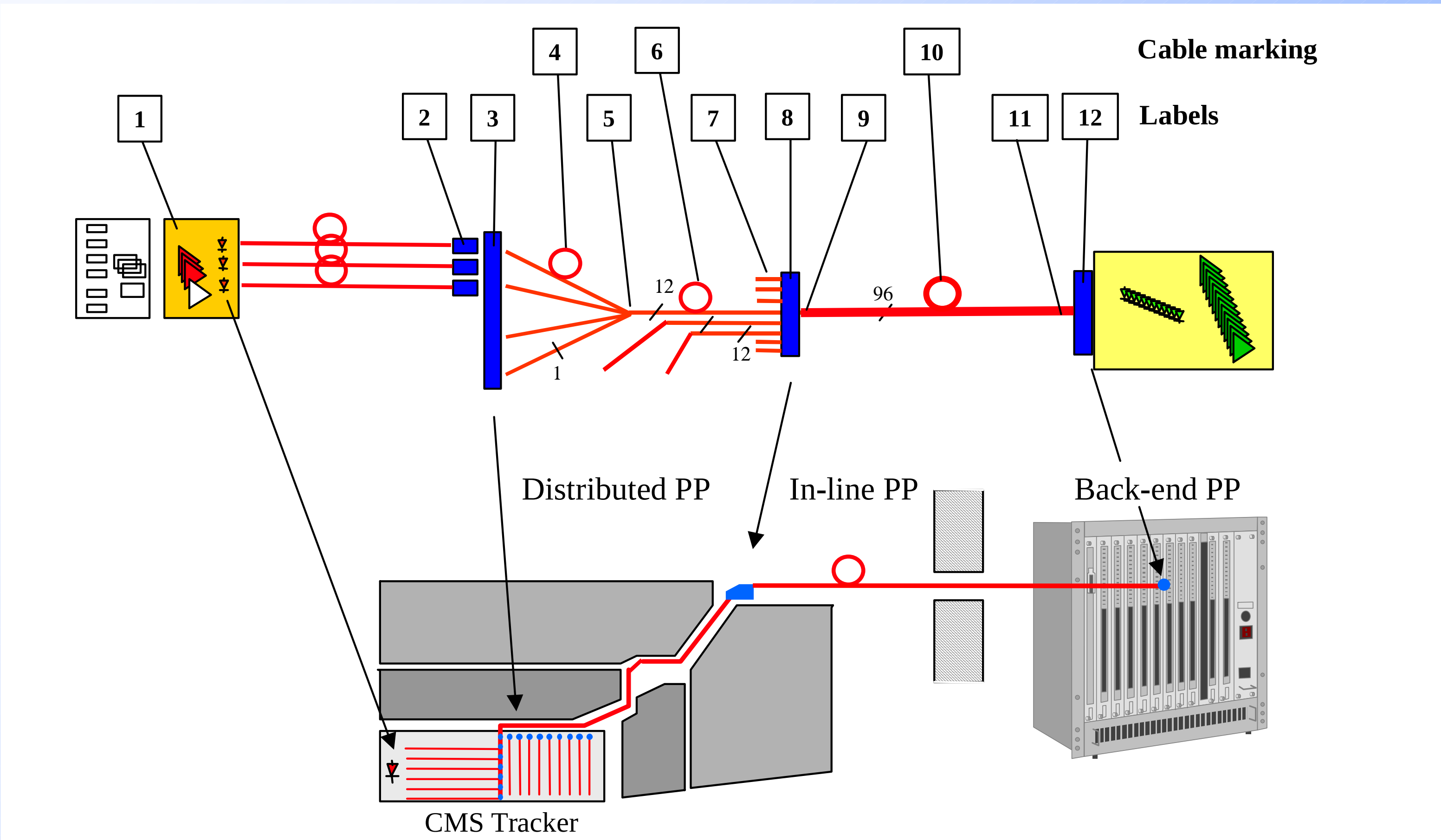


Project QA

- Some other issues not yet presented for Project QA:
  - Traceability
  - Safety
    - particularly laser safety

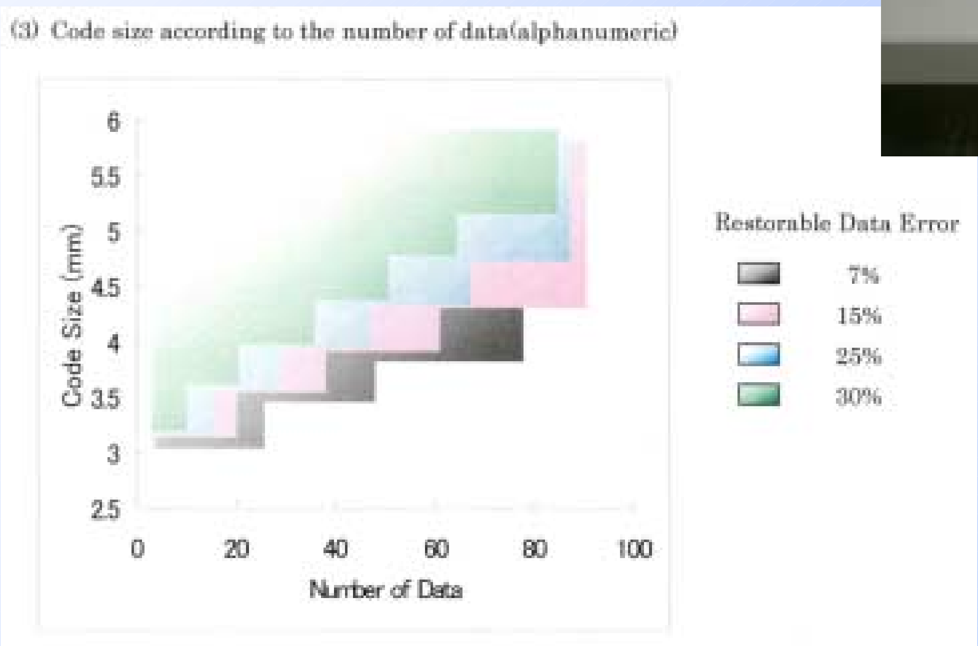
Traceability

- All components labeled
  - unambiguous identification during testing, installation, maintenance



2-D barcode scheme

- Proposed solution
  - 2-D bar-code
  - 10’s of characters
  - Small area



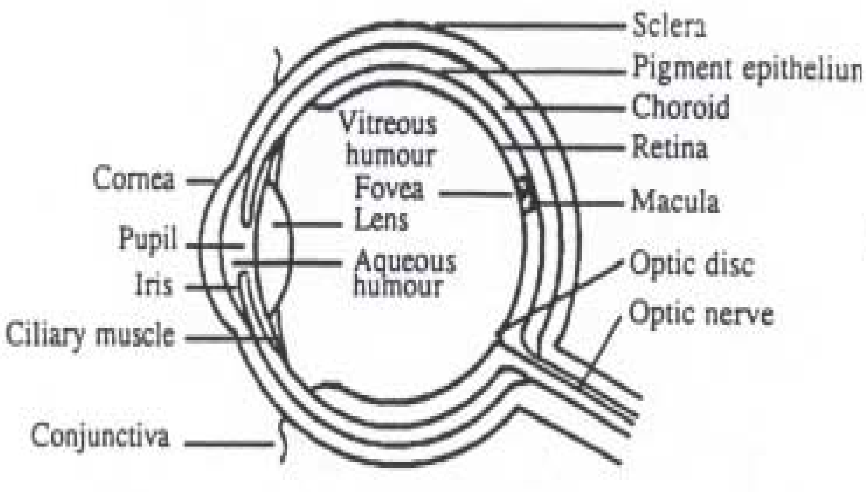
Laser safety

- Aim to ensure safety of all people in optical links project
  - development lab at CERN
  - users/workers in CMS

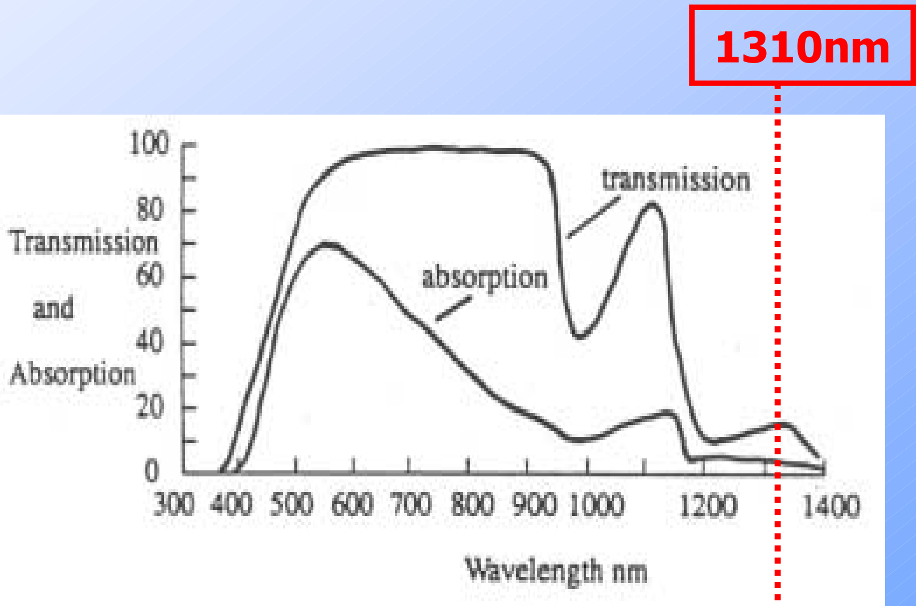
- Hazard classification made
  - Specific requirements and working practices
    - based on 'current' IEC standards
      - 60825-1 (1998-01) Safety of laser products
      - 60825-2 (2000-05) Safety of fibre optic communication systems

Eye damage at 1310nm

- at 1310nm, ***thermal damage to retina dominant***



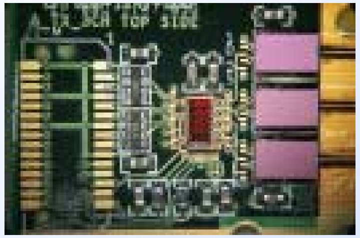
Schematic diagram of the anatomy of the human eye

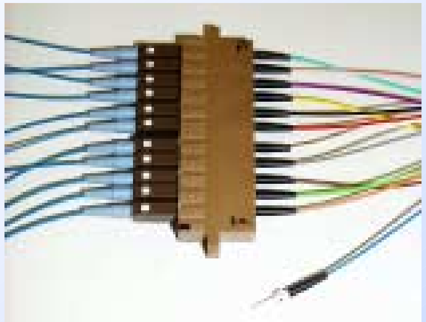


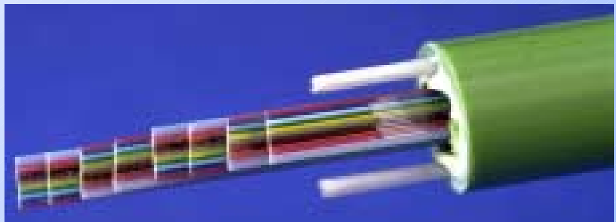
Transmission through the eye to the retina and absorption in the retina and choroid as a function of wavelength

- 1310nm a relatively safe wavelength

CMS TK opto-links Hazard Classification

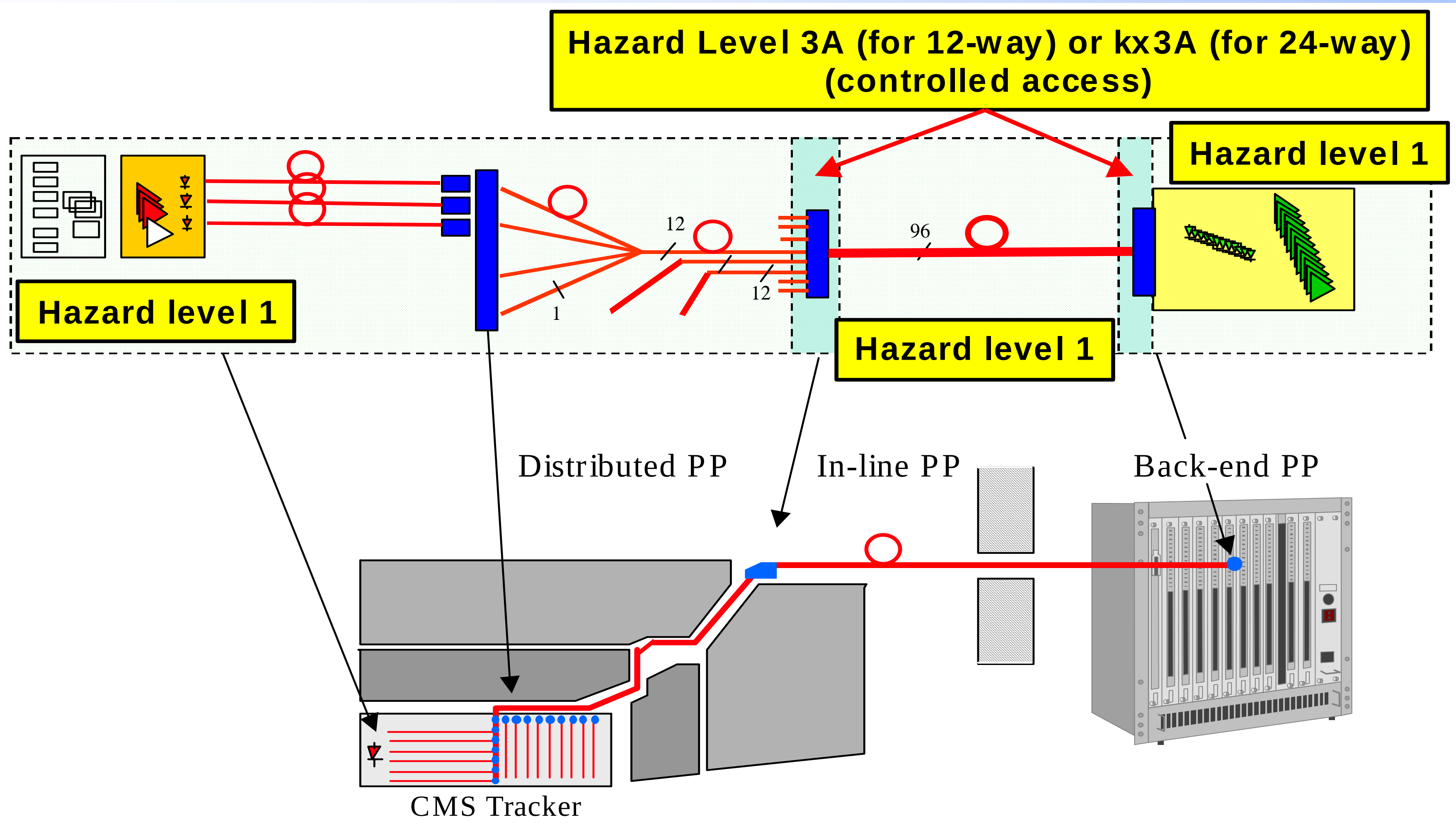






- (a) Lasers, transmitter hybrids and distibuted patch-panel
  - calculate AEL's for 1310nm light from 1-way single-mode fibre pigtails out of MU connector
- (b) In-line and back-end patch panels
  - calculate AEL's for 1310nm light from 12- or 24-way polished single-mode fibre ends in MT-termination
- (c) Optical fibre and cables
  - calculate AEL's for light in fibre pigtails and cables in cases of cleaving (splicing) and breakage

Hazard classification (valid until ~2003)



OFS control requirements

- administrative and engineering controls in IEC 60825-2 (2000)

Summary of engineering requirements at locations in optical fibre communication system

Hazard level	Location type		
	Unrestricted	Restricted	Controlled
1	No requirements	No requirements	No requirements
2	1) Labelling, and 2) Class 1* from connector, or connector requires tool	Labelling	Labelling
3A	1) Labelling, and 2) Class 1* from connector or connector requires tool	Labelling	Labelling
$k \times$ 3A	Not permitted **	1) Labelling, and 2) Protected cables, and 3) Class 3A* from connector, or connector requires tool	Labelling
3B	Not permitted **	Not permitted**	1) Labelling, and 2) Protected cables, and 3) $k \times$ 3A* from connector or connector requires tool
4	Not permitted **	Not permitted **	Not permitted**

* To be achieved by mechanical design of connector, automatic power reduction or other suitable means.

** See 4.4.3. Where systems employ power levels of class 3A or more, protection systems such as APR may be used to obtain the acceptable hazard level for the particular location type.

Summary

- Environmental QA and reliability
  - Extensive sample test on all (sub-)component types
    - selection of suitable components for use inside Tracker
    - feedback of effects into system specifications

- Development of formal QA procedures
  - Market Surveys
  - Advance validation tests
  - Pre-production qualification

- Other QA issues also addressed within project
  - QA manual available on cms-tk-opto.web.cern.ch