Laser Safety training to work with CMS Tracker Optical Links

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Outline

- Aim to ensure safety of all people involved in Tracker optical links project
  - in development lab at CERN
  - users/workers in CMS Tracker and CMS as a whole

- Scope
  - Brief recap of general laser safety issues for 1310nm systems
  - CMS Tracker Optical link system and component overview
  - Hazard classification
  - 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
  - Effects of latest amendments to 60825-1 and future amendments to 60825-2

Brief recap from general course

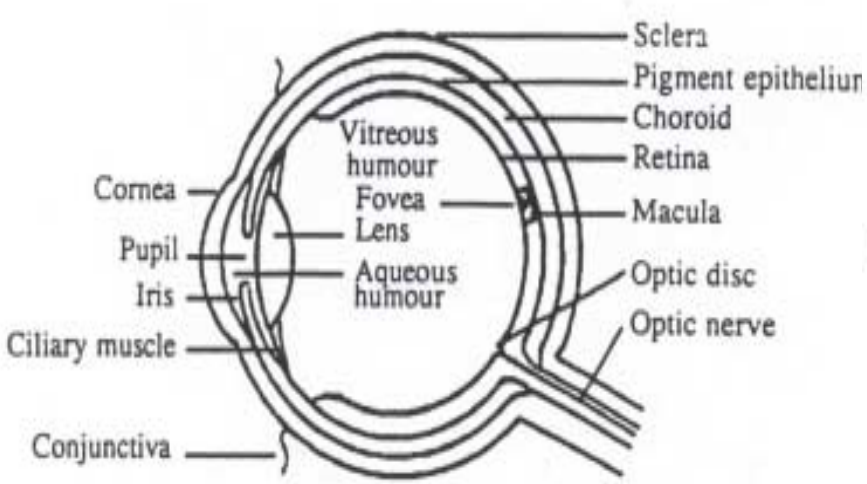
eye damage at 1310nm

nature of sources

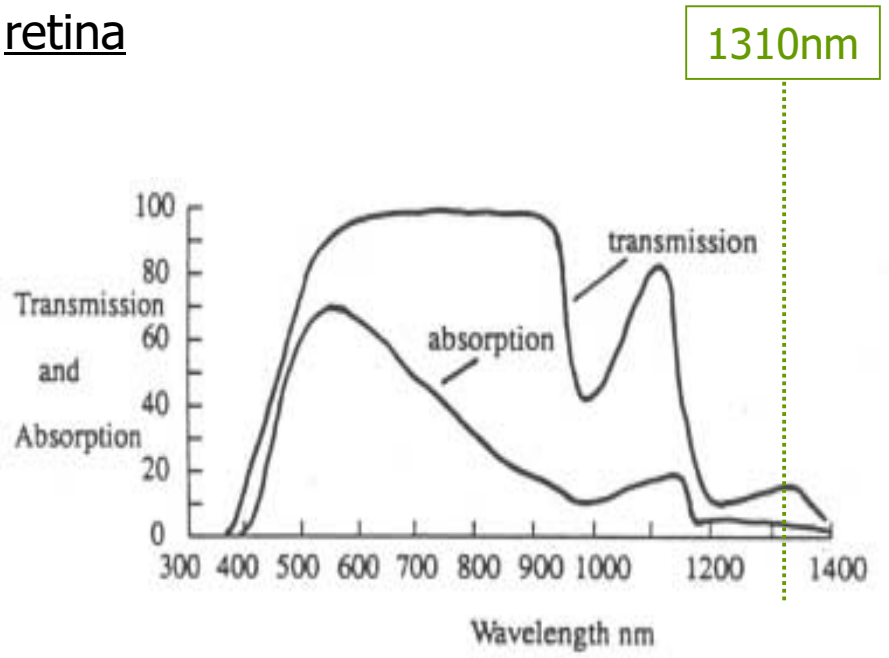
MPE and AEL

Eye damage at 1310nm

- recall from general tutorial…
  - at 1310nm, thermal damage to retina



Schematic diagram of the anatomy of the human eye

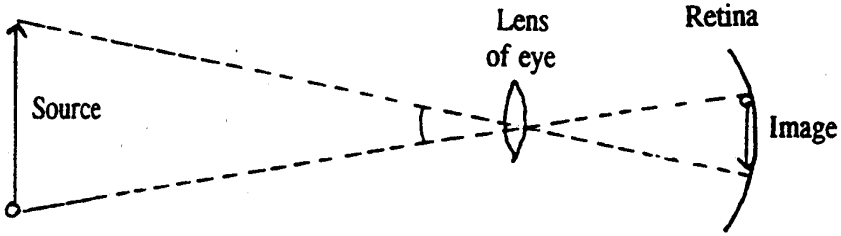


Transmission through the eye to the retina and absorption in the retina and choroid as a function of wavelength

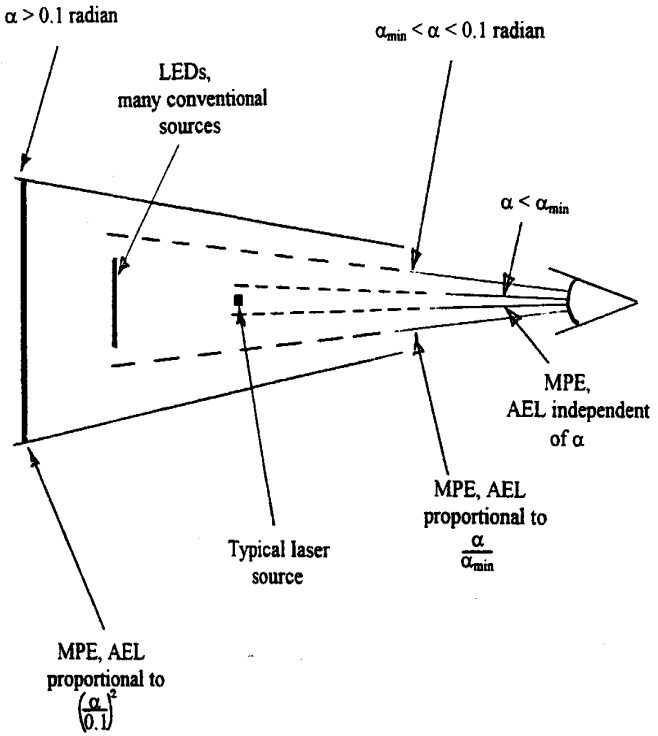
- Thermal damage effects dominant
- MPE at 1310nm can much different to other ('telecom') wavelengths

Effect of source size

- Size of image depends upon angle subtended at the eye
  - size must be compared with effects of thermal diffusion and eye movements



The size of the image of a source depends on the angle the source subtends at the eye. If it is small compared with the effects of thermal diffusion, scattering and eye movements, then the damage threshold will be independent of source size.



- Implications for ribbonized fibre (and laser arrays)

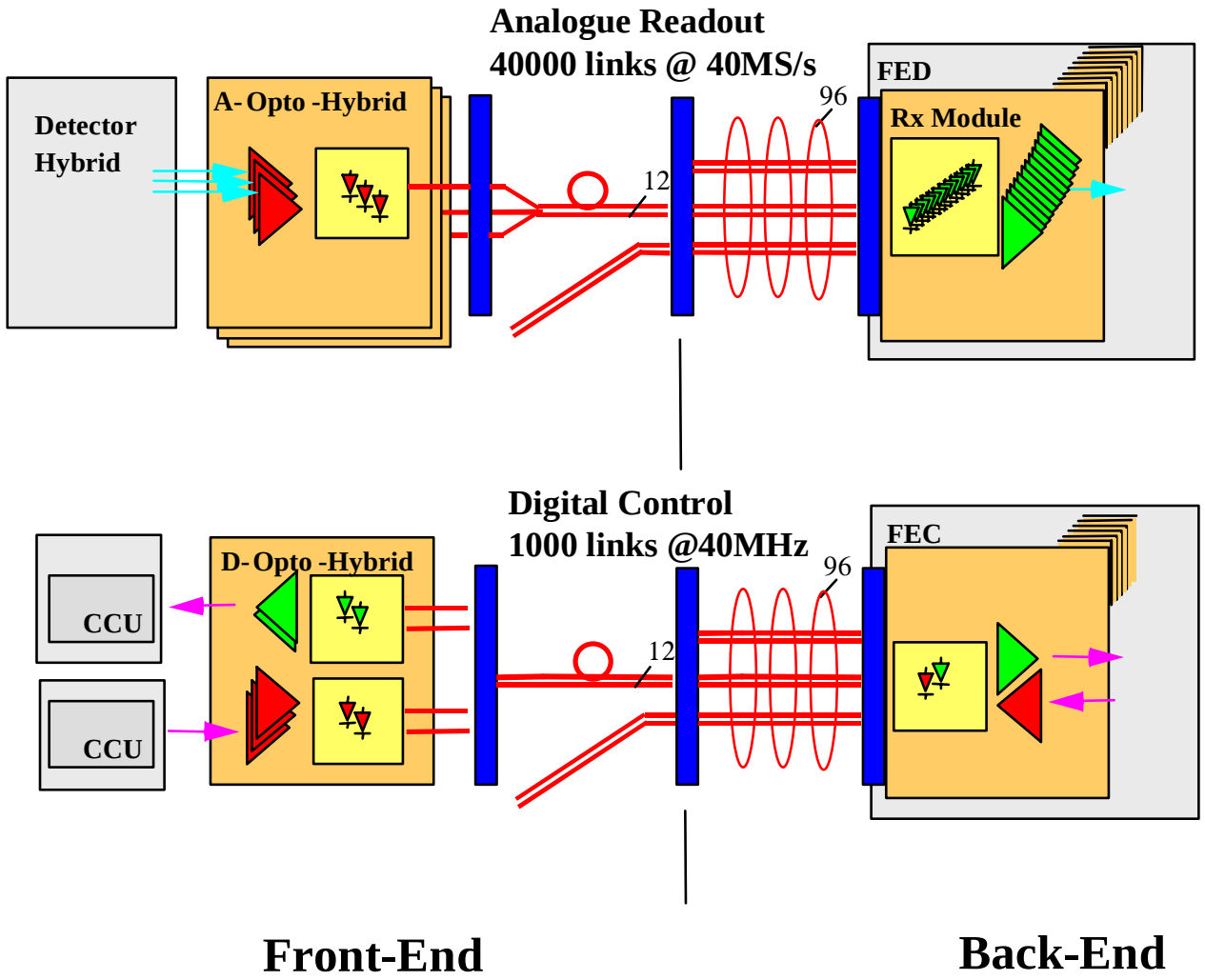
MPE and AEL

- Recall from general tutorial
  - Maximum Permissible Exposure (MPE) is level to which persons may be exposed without suffering injury
    - MPE calculated for risk assessment of using a given source, many factors
      - wavelength
      - exposure time
      - nature of tissue exposed
      - nature/size of source
  - Accessible Exposure Limit (AEL) is the limit of exposure from a particular source to fall within a given hazard Class
    - AEL has to be calculated for classification of a given source
  - will show some calculations for CMS Tracker links classification

Tracker Optical Link Systems

analogue readout and digital timing, trigger and control
basic laser safety requirements from IEC 60825-2
link components

CMS Tracker optical-link systems



CMS TK optolinks - basic laser safety requirements

4.3 Provision of information

Manufacturers of ready-for-use optical fibre communication systems and manufacturers of ready-for-use subassemblies shall provide the operating organization with the following information, where applicable:

a) an adequate description of the engineering design features incorporated into the product to prevent access to hazardous levels of optical radiation;

b) adequate instructions for proper assembly, maintenance and safe use, including clear warnings concerning the precautions to be taken in order to avoid possible exposure to hazardous radiation;

c) a statement, in SI units, of the power propagating in the fibre at all locations in the system, together with the pulse duration and pulse repetition frequency, or the maximum modulation frequency. The cumulative measurement uncertainty and any expected variation in the measured quantities at any time after manufacture shall also be provided;

d) a statement of the range of operating wavelength(s) within the optical fibre communication system at the time of manufacture and under specified conditions as well as the range of emission wavelengths expected during normal operation at any time after manufacture;

e) the reaction time of any automatic power reduction system;

f) legible reproductions (in appropriate colours or in black and white) of all the labels and hazard warnings to be displayed at locations within an optical fibre communication system or subassembly, as appropriate;

g) a clear indication of all locations of apertures and fibre connectors;

h) a listing of controls, adjustments and procedures for operation and maintenance, including a warning, where appropriate;

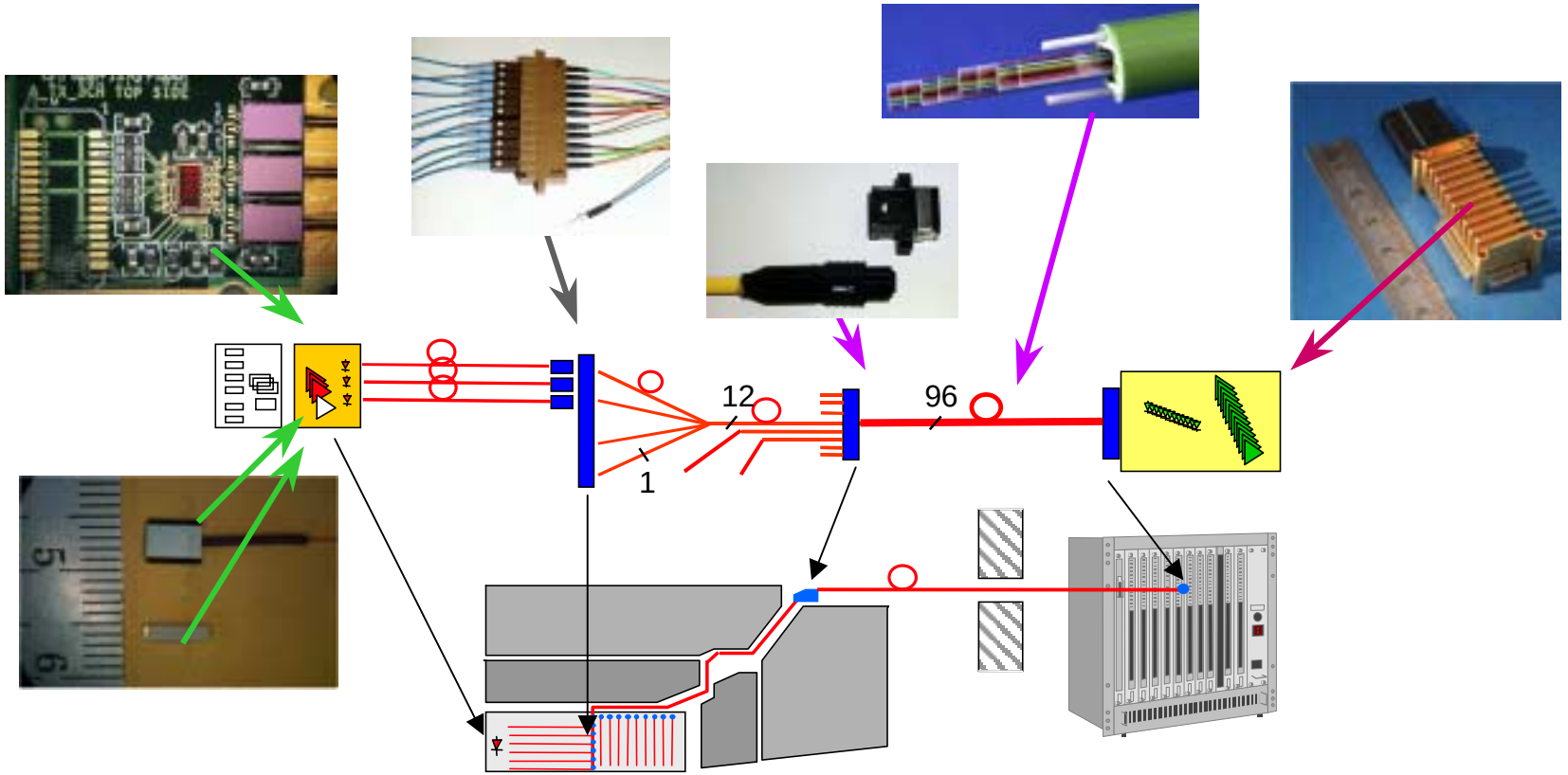
i) advice on safe operating procedures, and warnings concerning known malpractices, malfunctions and hazardous failure modes. Where maintenance procedures are detailed, they shall, wherever possible, include explicit instructions on the safe procedures to be followed;

j) where installation or servicing requires that an automatic power reduction system is overridden, information to enable the operating organization to specify a safe system of work at such times, and a safe procedure for the reinstating and safe testing of the automatic power reduction system;

k) any other information relevant to the safe use of the optical fibre communication system or subassembly, as appropriate.

Will cover in this presentation

Component overview



- Analogue readout links shown
- Digital links use similar devices, but with light also transmitted into the Tracker.

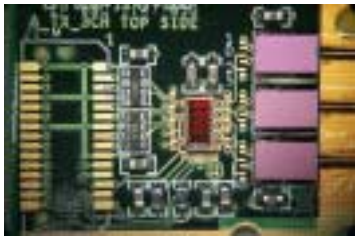
Tracker Optical Link Systems
Hazard Classification

lasers, optohybrids

fibres, fibre cables

fibre ribbon connectors

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 Classes - Lasers

- IEC 60825-1 (1997) Lasers
  - Class 1
    - safe (under reasonably foreseeable circumstances)
  - Class 2
    - safe provided blink and aversion reflexes operate - *visible radiation*
  - Class 3A
    - safe provided optical instruments are not used
  - Class 3B
    - can cause injury
  - Class 4
    - exposure can be dangerous, can cause fire.

- IEC 60825-1 Ammendment 2 released in 2001
    - significant changes - see later

Hazard levels: Fibre-optic systems

- According to IEC 60825-1 (1997) fibre-optic systems are inherently Class 1
  - since all light contained
  - 60825-1 does not address fully issues in fibre-optic systems
    - e.g. radiation accessible in remote location from source

- Another Standard, IEC 60825-2 (2000) written for Optical Fibre Systems
  - relevant to CMS TK links
  - define hazard levels corresponding to laser classes
  - additional new hazard level kx3A
    - hazard in excess of level 1 and level 3A under reasonably foreseeable circumstances
    - applies only to trained workers in restricted or controlled environments
    - recognizes that risk is significantly lower for level 3B

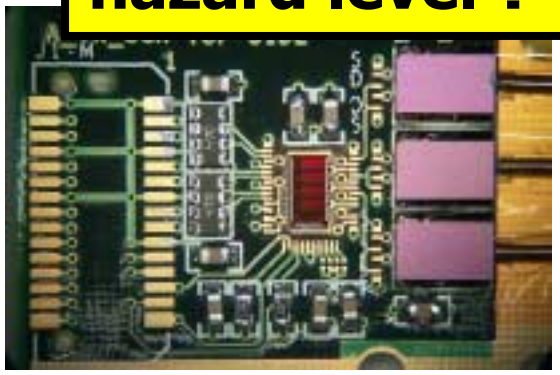
- IEC 60825-2 (2000) valid until 2003

Classification of CMS/TK lasers - 1

- For lasers with single-mode fibre pigtails
  - bare die can possibly emit significant amount of power e.g. 10mW at ~200mA
    - with a strong enough current source
      - OUTSIDE SCOPE OF PROJECT
      - (Class 3A for information)
  - on optohybrid drive current limited to ~65mA
    - laser power output limited to 3.25mW

Bare die
Class 3A

On hybrid
hazard level ?



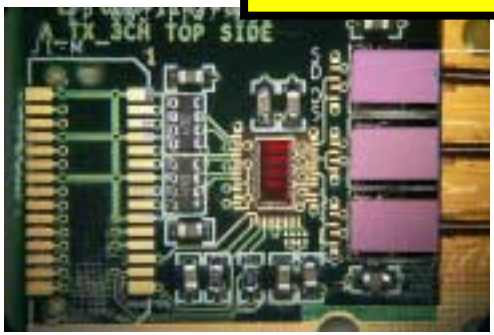
Classification of CMS/TK lasers - 2

- Calculate AEL for Class 1 [using definitions in 60825-1 (1997)]
  - from Table 1, total power condition
    - exposure time t=100s
    - correction factors C_6=1, C_7=8

$$P_{AEL} = 3.5x10^{-3} t^{-0.25} C_6 C_7$$

  - $\underline{P_{AEL} = 9mW}$
- Consider all power from fibre coupled into 50mm aperture at 100mm
  - i.e. safe to view with 'optical instruments'
  - Class 1 limit is 9mW
- All lasers in links system have P<3.2mW
- therefore **Class 1/hazard level 1**.

Class 1



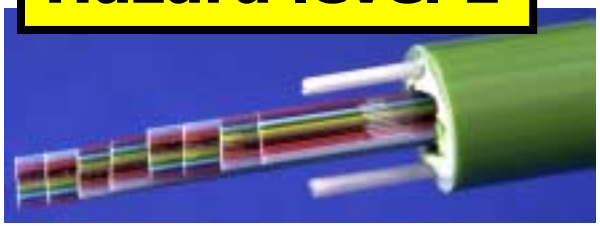
Classification of fibres, fibre cable

- Lasers, optohybrids **Class 1**
  - Single fibres in system therefore **hazard level 1**
  - MU-connectors at distributed patch-panels **hazard level 1**

Hazard level 1

- Broken fibre, ribbon, cable
  - According to IEC 60825-2
    - considered equal to risk of single fibre
      - **hazard level 1**

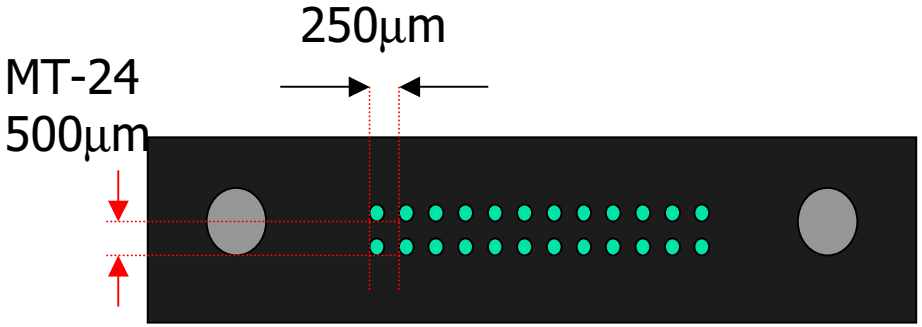
Hazard level 1



- *Cleaved ribbon* and MT-12, MT-24 connectors?
  - … next calculation

Classification of MT-type connectors - 1

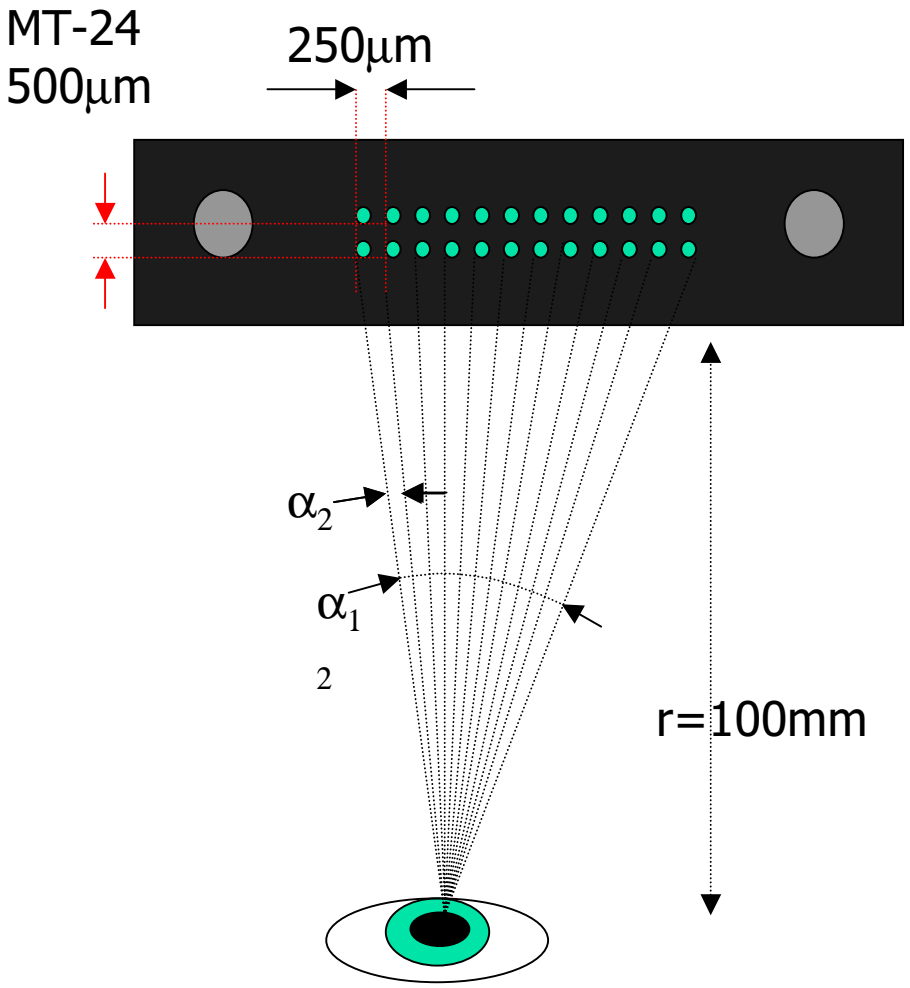
- Consider both 12-way and 24-way connectors



- Total power could be as much as
  - 12-way 12x3.2 = 39mW
  - 24-way 24x3.2 = 78mW
- But fibres at 250μm pitch in ribbon
  - need to take into account the angular subtense at 100mm distance

MT-12 same size but
just a single row of 12 fibres

Classification of MT-type connectors - 2



- Need to take into account groups of fibres from 2-12, subtending angles α_2 to α_{12}
- angles α_i limited to $\alpha_{min} < \alpha_i < \alpha_{max}$
  - Note, the angle α_i is actually mean subtense in x and y directions
    - In 60825-1
      - α_{min} =11mrad (for exposure>10s)
      - α_{max} =100mrad
- at distance r=100mm
  - $\alpha_{i<5}$ =11mrad (= single small source)
  - $\alpha_{i>=6}$ =11.7 + (i-6)*1.3 mrad
    - relaxation factor $C_6 = \alpha_i / \alpha_{min}$

Classification of MT-type connectors - 3

- Hazard level 1 AEL of P<9mW coupled into d=50mm aperture at r=100mm exceeded
- Calculate hazard level 3A AEL's [use Class 3A definitions in 60825-1 (1997)]
  - two AEL conditions
    - (a) total power (W)

$$AEL_{3A(a)} = 1.8x10^{-2}\, t^{-0.25} C_6 C_7$$

      - for $\alpha_{min} < \alpha < \alpha_{max}$ into aperture of 7mm distance r from source

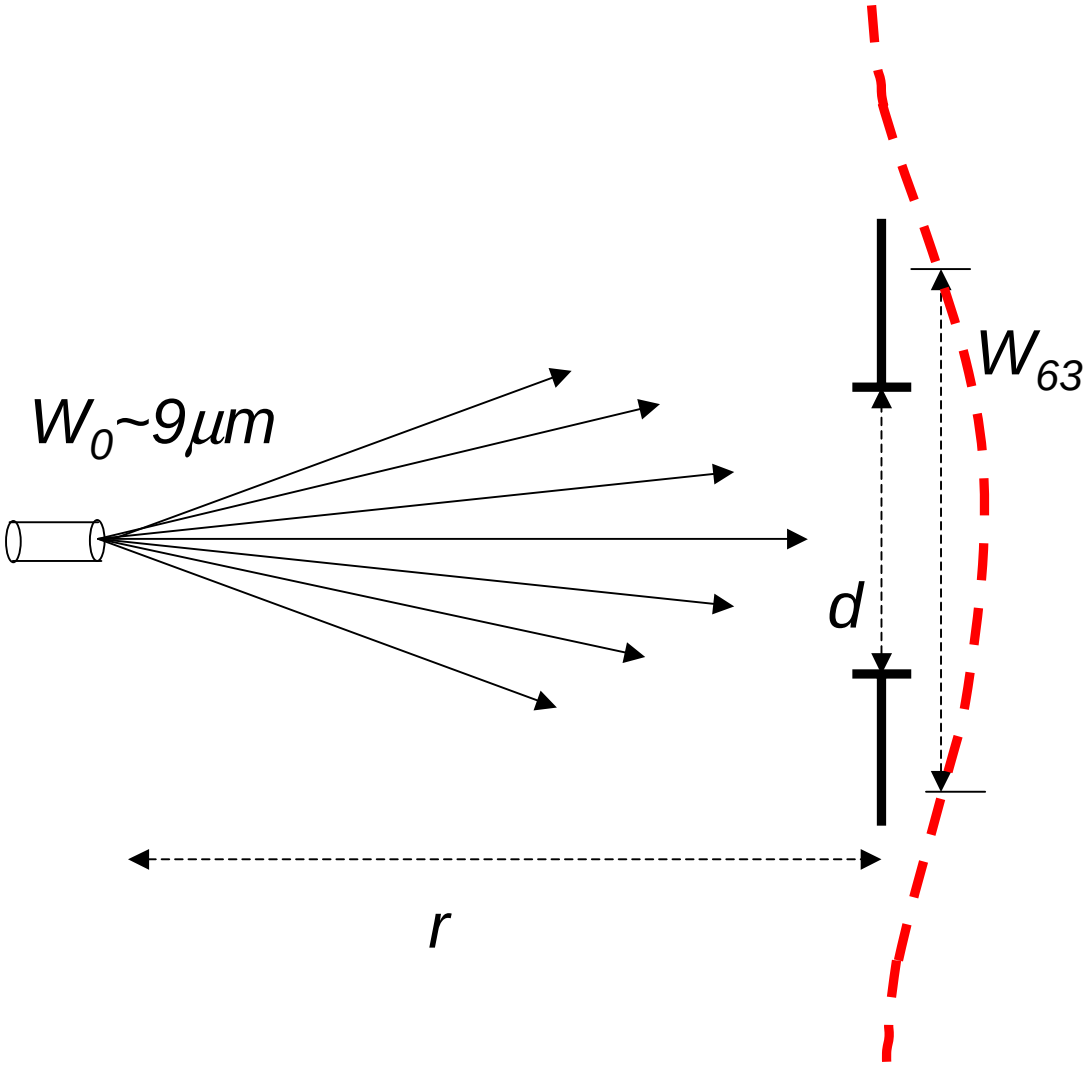
$$r = (100mm)\sqrt{\left(\frac{\alpha + 0.46mrad}{\alpha_{max}}\right)}$$

    - (b) irradiance (W/m^2)

$$AEL_{3A(b)} = 90\, t^{-0.25} C_6 C_7$$

      - integrated over aperture of 7mm at 100mm from source

Classification of MT-type connectors - 4



- Light from each fibre is divergent - only fraction of light coupled into eye pupil
  - the 7mm aperture in hazard level 3A calculation
- fraction of light passing through an aperture of diameter *d* at a distance *r* from fibre tip

$$f = 1 - \exp\left(-\frac{d}{w_{63}}\right)$$

$$w_{63} = \frac{2\sqrt{2}r\lambda}{\pi w_0}$$

Classification of MT-type connectors - 5

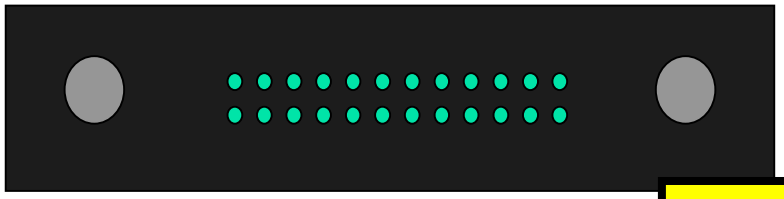
- (a) Hazard level 3A AEL for total power condition
  - Worst case is of group of 12 fibres (MT-12) or 24-fibres (MT-24)
    - AEL_{power} = 8.6mW/fibre MT-12
    - AEL_{power} = 4.3mW/fibre MT-24
- (b) Hazard level 3A AEL for irradiance condition
  - Worst case is again group of 12 fibres (MT-12) or 24-fibres (MT-24)
    - AEL_{power} = 5.0mW/fibre MT-12
    - AEL_{power} = 2.5mW/fibre MT-24
- Irradiance condition (b) is most stringent requirement for 3A classification

Classification of MT-type connectors - 6

MT-12

Hazard level 3A

MT-24



Hazard level ??

- max power of 3.2mW/fibre
- in-line patch panel
  - if 12-way MT used
    - **<u>hazard level 3A</u>**
  - but if 24-way MT used
    - **<u>exceeds level 3A</u>**
- back-end (FED) patch panel
  - 12-way MT
    - **<u>hazard level 3A</u>**

Classification of MT-24 connectors

- Check AEL for hazard level kx3A from IEC 60825-2 (fibre optic systems)
  - same calculation as for level 3A but aperture at 250mm and t=10s
  - takes into account a 'trained worker' - tough Class 3B controls not required
    - 1-way single-mode fibre limit of 83mW
  - at 250mm, angular subtense α(24-fibres)<11mrad
    - all 24 fibres appear as a single small source
      - recall max. power = 78mW (i.e. <83mW)
      - hazard level kx3A appropriate

MT-24

Note- k is not a calculable constant

Tracker Optical Link Systems
Laser Safety Requirements

administrative controls

engineering controls

training

OFS control requirements

- The following administrative and engineering controls are specified for optical fibre systems in IEC 60825-2 (2000)

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 × 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* × 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.

Requirements - administrative controls

- 60825-2 (2000)
  - Only administrative controls are required for Tracker
    - but require a controlled environment for kx3A
- Class 1 and hazard level 1 - No special requirements
- hazard level k x 3A
  - **'Controlled Access'**
    - authorized, trained personnel only
    - nominated responsible personnel
  - **appropriate labeling**
    - entry-ways
      - warning nature of hazard
      - warning of nature of kx3A components

CONTROLLED ACCESS
HAZARD LEVEL kx3A
FIBRE OPTIC SYSTEM

LIMITED TO
AUTHORIZED PERSONNEL

responsible: A.N. Other
tel: 99999

Labeling of connectors and patch-panels

- Question - labeling of patch-panels vs labeling of individual fibres?

4.2 Labelling

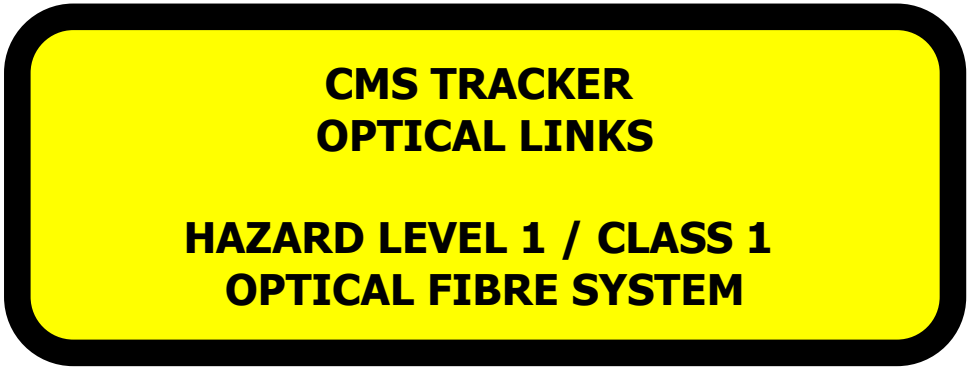
4.2.1 Optical fibre cables should carry appropriate markings to distinguish them from cables containing other services, e.g. electricity.

4.2.2 Sleeving, a tag or a tape shall be associated with each optical connector if the hazard level at the location is in excess of hazard level 1. The sleeving, tag or tape shall be coloured yellow, with the warning label according to figure 14 of IEC 60825-1 and the hazard level number incorporated in the explanatory label according to figure 15 of IEC 60825-1; both labels appropriately reduced in size.

4.2.3 Groups of connectors such as patch panels may be labelled as a group, with just a single clearly visible location hazard label rather than having each connector individually labelled. If a group of connectors is enclosed within a box, a label shall be clearly visible both before and after the access panel is opened, which may require the use of more than one label.

Labels: Class 1

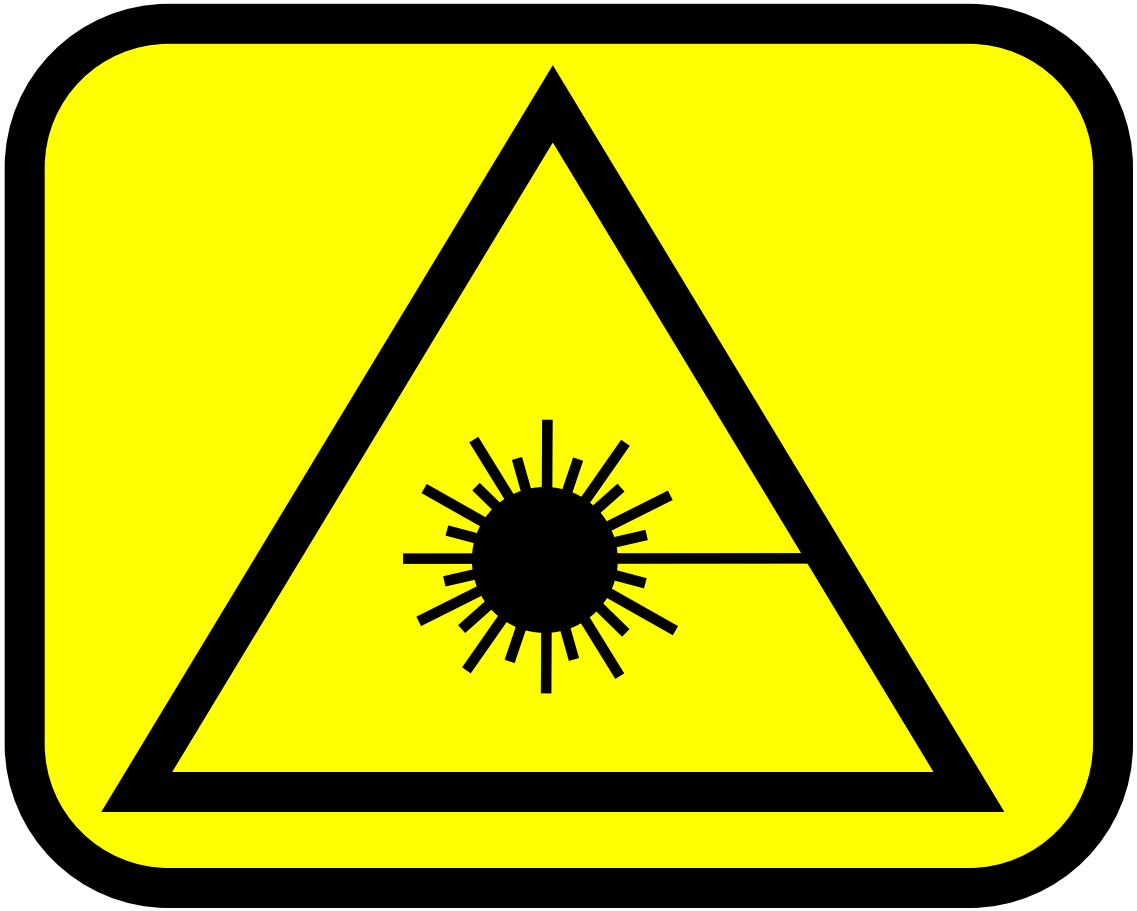
- IEC label for Class 1
- Although labels not required, they are a good idea
  - attach labels to distributed patch-panels in Tracker
  - attach labels to test-benches using Class 1 components



- Proposed label for cable ducts in CMS
- Recall, do not need to label individual fibres and/or lasers/hybrids !

Labels: hazards > 1

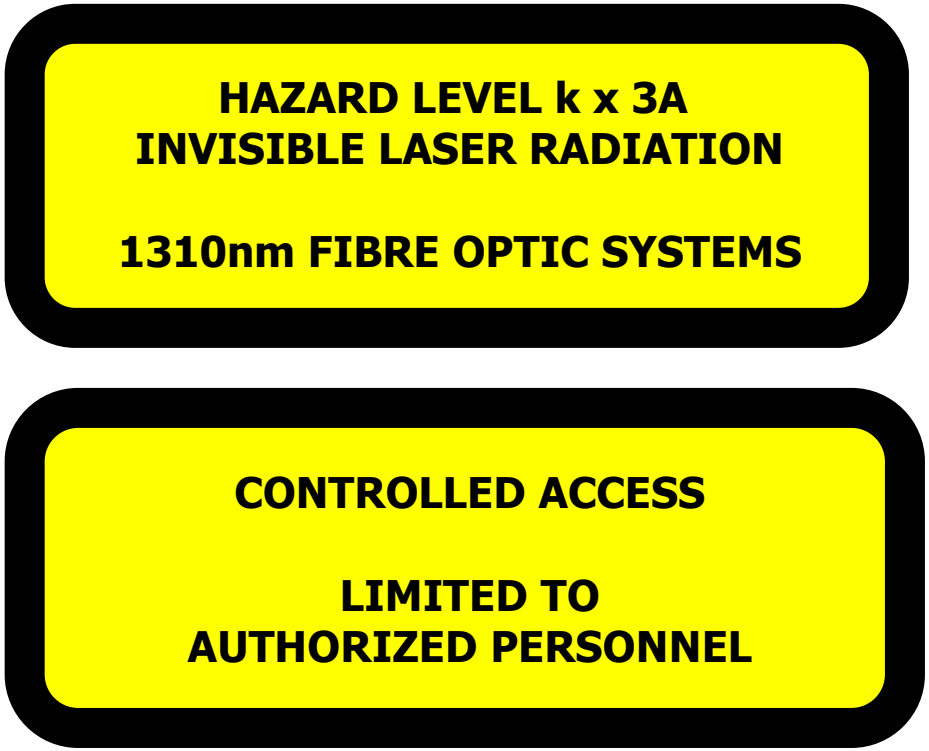
- For all hazards levels > 1



IEC Laser Hazard Symbol

Labels: Hazard level k x 3A

- hazard level k x 3A (similar for parts with level 3A)



- In addition to laser hazard symbol
- Label MT-based patch panels
  - in-line patch-panel
  - FEDs
  - must also be visible when panels open
- Label laboratory entries
  - plus name of responsible
- Label test-benches using components fanned into fibre-ribbons

Training

- Standards contain only guidelines for legal requirements and best working practices
- Training must be sufficient to cover eventual risks
  - up to hazard level k x 3A level for this system
  - proof required to obtain authorization to access controlled parts of system
- Establish a list of authorized personnel for final system

Safe practices

- Based on IEC 60825-2
  - Training must be sufficient
    - proof required to obtain authorization to access controlled parts of system
  - take reasonable precautions when working with system
    - check beams not dangerous (eye level, pointing at other workers)
    - power-off when opening fibre connectors
      - check with operator in remote systems
    - **do not look at open energized connector/fibre ends**
    - **use optical aids** to observe connector output
      - power meter, camera, attenuators
    - check safety measures adequate
    - report problems or failed equipment
  - and more……..

Requirements - engineering controls

- Further engineering controls not strictly required in CMS Tracker system, according to IEC 60825-2
  - e.g. interlocks, shutters, APR...
    - Only **Class/Hazard level 3B and above**
  - re-emphasize this is a low-risk system
    - low power levels
    - 1310nm wavelength
    - current limited at lasers to 65mA max.
    - power confined to fibres under normal operating conditions
    - classification calculations very conservative
- appropriate eye protection should be available
  - although not mandatory for power levels in this system

Effects of new amendments to IEC60825-1 and plans for 60825-2

New laser hazard classes

future of kx3A

New (2001) Hazard Classes

- IEC 60825-1 (1997) Lasers, updated in 2001 (in Amendment 2)
  - Class 1 (now with new limits)
  - Class 1M (partly replaces 3A)
    - as for Class 1, provided optical instruments not used
  - Class 2
  - Class 2M
    - as for Class 2, but provided optical instruments are not used
  - Class 3R (partly replaces 3A)
    - low risk lasers with <5x AEL of Class 1
  - Class 3B
  - Class 4
- IEC 60825-2 (future, i.e. after 2003) Hazard Level k x 3A will be suppressed

no more kx3A

TC 76 /IEC 60825-2
(Second edition – 2000)
IS 01

Safety of laser products

Part 2: Safety of optical fibre communication systems

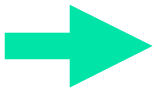
INTERPRETATION SHEET

General instruction for all normative clauses, including Annex B:

Replace "Hazard Level 2 " *with* "Hazard level 2 or Hazard level 2M, as appropriate".

Replace "Hazard Level 3A" *with* "Hazard Level 1M or Hazard Level 3R, as appropriate".

In Annex B, 3B Hazard Level, controlled location column, replace "Hazard Level kx3A" with "Hazard Level 1M or 2M."



Delete all remaining references to "Hazard Level kx3A".

All classification and hazard level evaluations shall be made in accordance with IEC 60825-1, Amendment 2.

Class 1 - New limits

- Suppression of kx3A may not be a problem
  - Class 1 (or Hazard Level 1) AEL relaxed at 1310nm

- For 1-way 11micron core single-mode fibre at 1310nm wavelength

  - Class 1 (old) power limit = 9mW,
  - Class 1 (new) power limit = 15mW

  - Class 3A (old) power limit = 22mW
  - Class 1M (new) power limit = 50mW

  - why?
    - Exposure time of 100s relaxed to ~10s
      - depending upon size of source

Angular subtense limits

- Over-conservative approach recognized in old standard!
  - α_{min} now 1.5mrad, not 11mrad
    - for wavelengths where thermal damage dominates
      - e.g. 1310nm
    - photochemical retinal limits for angular subtense vary similarly to old values
- This makes a big difference in fibre ribbon calculations…

Revised hazard calculations

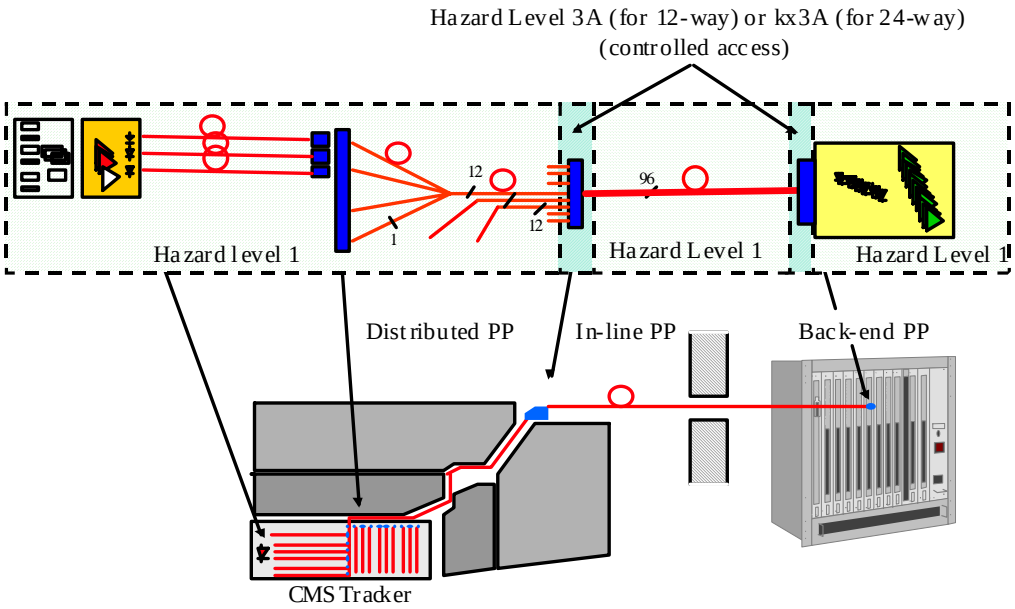
- cleaved fibre ribbon, MT-12 or MT-24 connectors in the Tracker optical links systems

		# fibres in group	$\bar{\alpha}$ (mrad)	AEL (Class 1) (mW/fibre)	AEL (Class 1M) (mW/fibre)
MT-24	MT-12	1	1.5	15.6	62
		2	2.0	10.5	42
		3	3.3	11.4	45
		4	4.5	11.6	46
		…	…..	…..	….
		12	14.5	11.7	47
		…	…..	…..	….
		24	16.3	6.6	26

- since we have <3.2mW/fibre, all of system according to **<u>new 60825-1</u>** is **<u>Hazard level 1</u>**
  - bigger margins since angular subtense effect is greater and time is shorter

Summary (valid until ~2003)

- System hazard classes defined using IEC 60825-1 [1997], 60825-2 [2000]
  - **Class 1**
    - lasers
  - **Hazard level 1**
    - fibres, cables
    - MU-based patch panels
  - **Hazard Level 3A**
    - 12-way MT patch-panels
  - **Hazard level k x 3A**
    - 24-way MT patch-panels



- Current requirements
  - Labeling
  - Restricted environment for hazard level 3A, Controlled environment for kx3A
  - Training

- When new IEC 60825-1 fully released (~2002-3?), all system will be **Class 1**

Conclusions

- CMS Tracker optical links present low risk
  - Hazard level 1, or kx3A
    - safe under foreseeable circumstances
      - trained workers
      - following safe working practice
      - controlled environment
      - (future Class 1 throughout!)

- Do not assume the same level of safety for other optical/optoelectronic equipment
  - e.g. other systems in CMS or LHC

- All systems should ideally have a nominated laser responsible person
  - e.g. CMS TK optical links (K. Gill)

- If in doubt, or for other equipment, do not hesitate to contact TIS Laser Safety Officer, Guy Roubaud.