WG3 – RD4

Cherenkov-light based detectors, and in particular RICH detectors, are occupying a place more and more essential in high-energy experiments, in which non-destructive, positive particle identification is required.

However, as energy and luminosity (and radiation) step up, so the RICH detector needs a strong R&D to demonstrate its effectiveness in future applications.

Strategy

The case for the RICH seems simple enough to be spelled on a single slide:

1. Keep peak Occupancies (in time and space) < 30%
2. Improve Single Photon Cherenkov Angle precision to < 0.5 mrad
3. Control radiation aspects
4. Get a wonderful tracking system to work with

Achieving these conditions is unfortunately not so simple … ☺

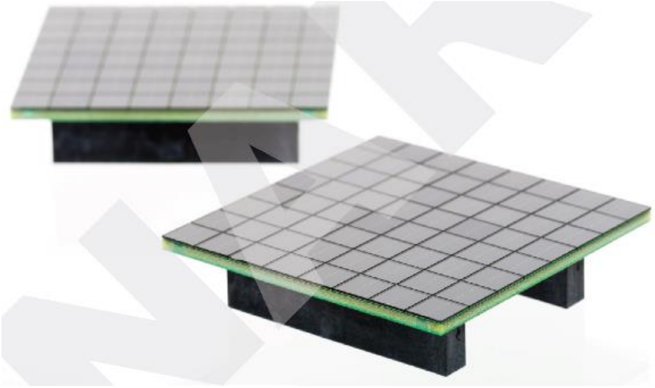
1. Keep peak Occupancies (in time and space) < 30%

High granularity photodetector arrays

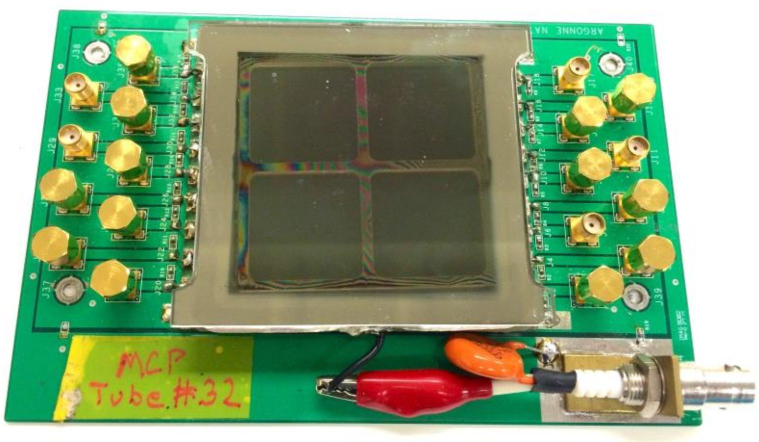
2 or more bits front-end electronics

Time resolved 2-D images (3-D with time included)

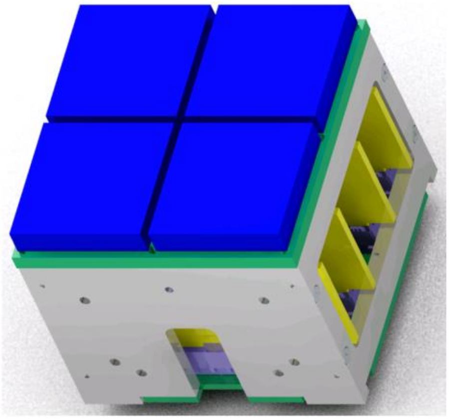
Low noise gated photonic images



SiPMs Arrays

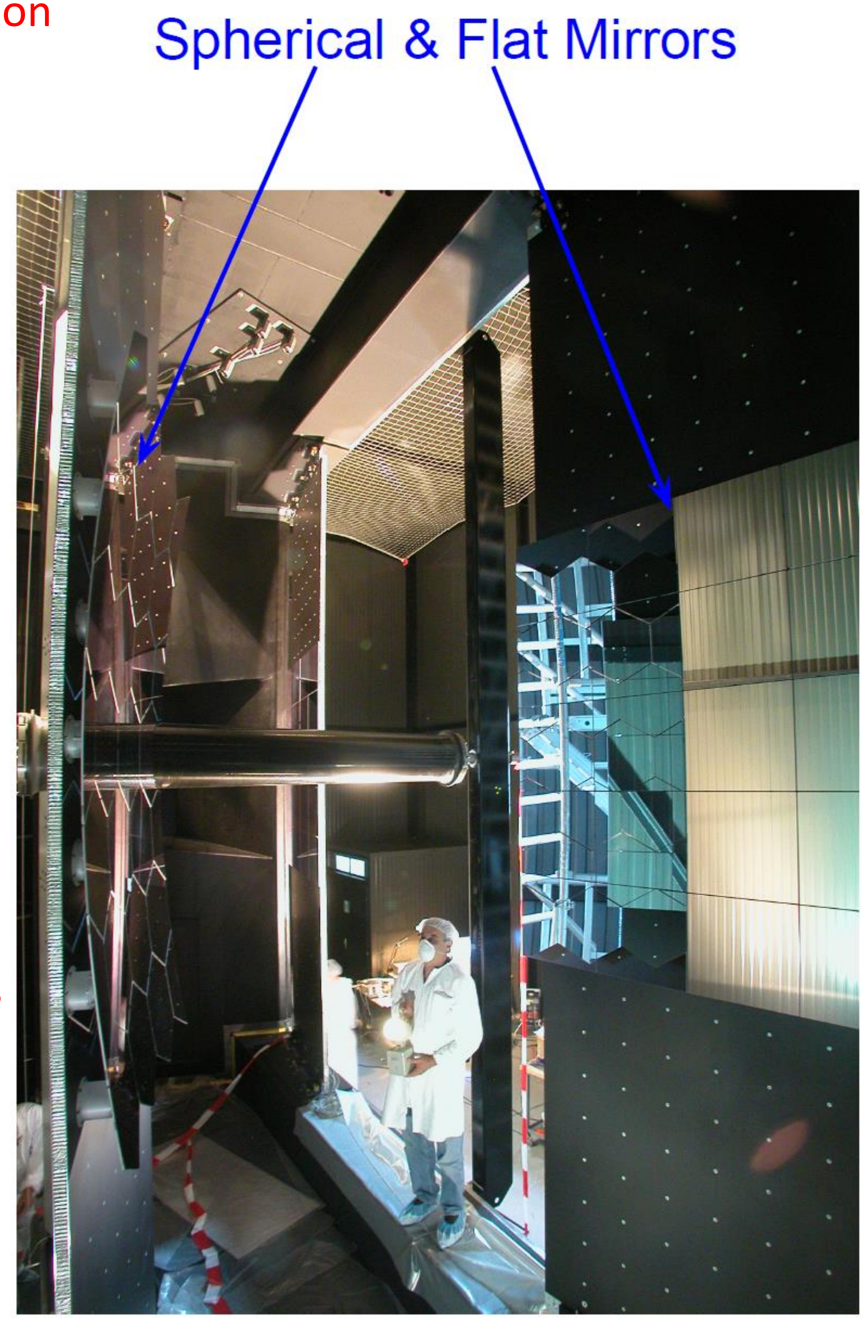


MCP-PMT ANL prototype



CLARO++ based system

2. Improve Single Photon Cherenkov Angle precision to < 0.5 mrad



Pixel size over focal length

Aberration-free optical system*

Low chromatic dispersion**

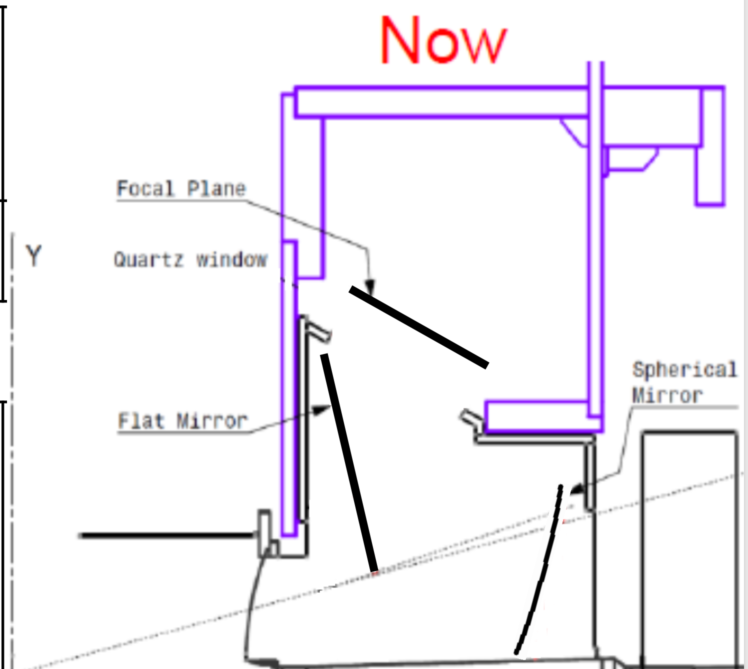
*Need to place optics inside the experiment acceptance, therefore develop light-weight mirrors (see slide 9)

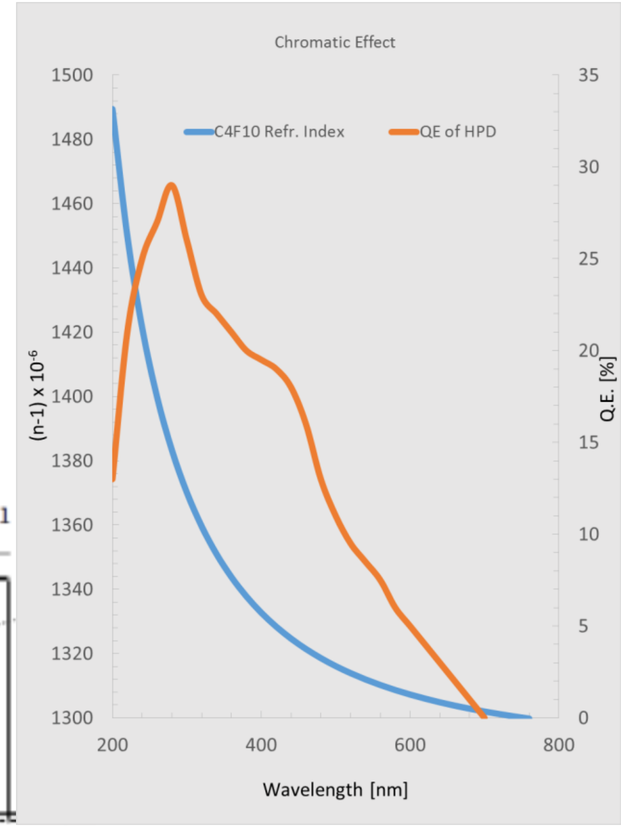
**Need photodetectors with high QE towards the green wavelength region, like SiPMs (see slide 10)

Optical Performance and Photon Yields (example LHCb RICH1)

Lumi = 2 x 10^{32} cm^{-2} s^{-1} ; Occupancy < 30%

Detector Version	RICH-1 Current (HPD)
Avr. Phel. Yield	30
Single Photon precision [mrad]	
Chromatic	0.84
Pixel	0.9
Emission Point	0.8
Track resolution	0.4
Overall	1.52





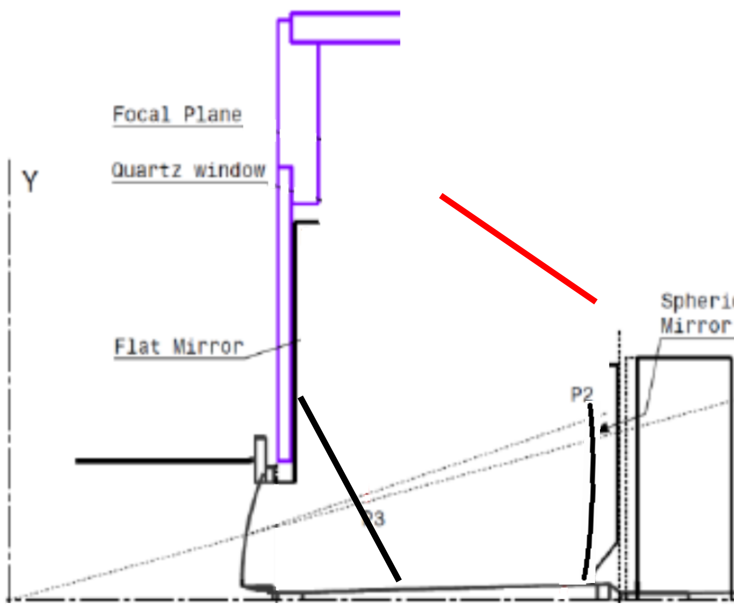
Chromatic depends on the overlap between dispersion and photodet. QE

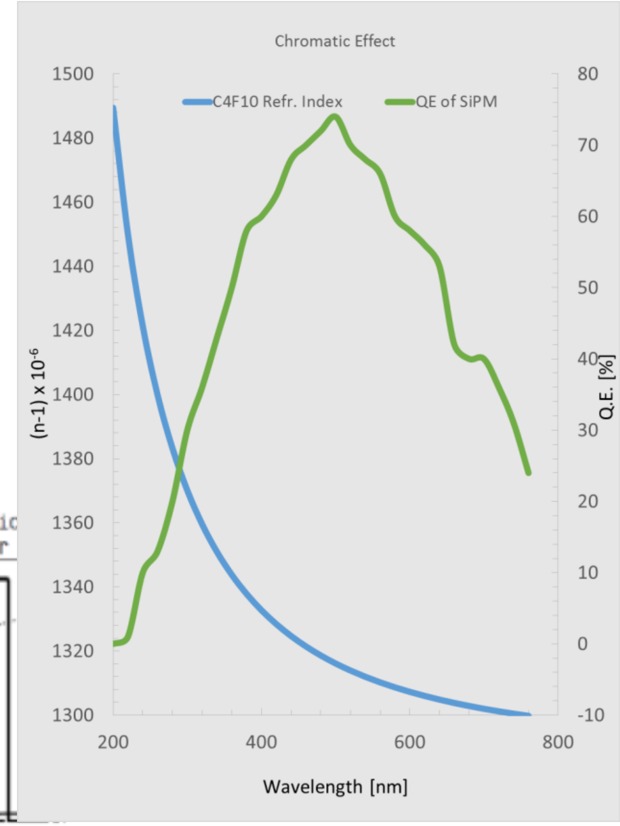
Optical Performance and Photon Yields (example LHCb RICH1)

Lumi = 10^{34} cm^{-2} s^{-1} ; Occupancy < 30%

Detector Version	RICH-1 Upg2
Avr. Phel. Yield	60 - 40
Single Photon precision [mrad]	
Chromatic	0.24
Pixel	0.15
Emission Point	0.1
Track resolution	?
Overall	0.3

Upg2



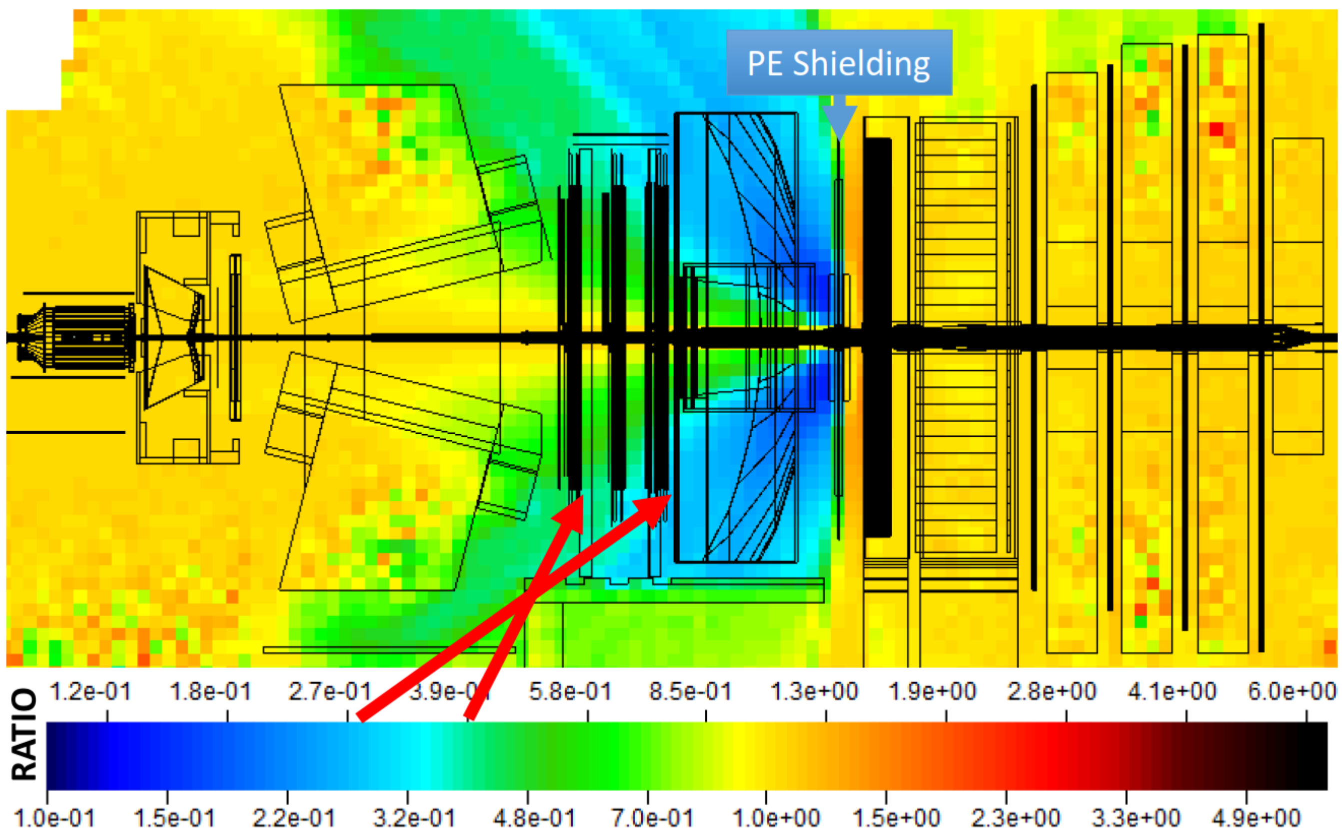


Chromatic depends on the overlap between dispersion and photodet. QE

3. Control radiation aspects

The main constituent sensitive to radiation is the optoelectronic chain. Mitigate through:

- Neutron Shield (plastic based, envelops the cryostat, provides further thermal insulation)
- Rad. Hard electronics
- Cryogenic temperatures if SiPMs are used



1 MeV n. equ. fl.: RATIO between final 30 cm Shielding VS No Shielding

M. Karakson et al.

4. Get a wonderful tracking system to work with

The RICH Detectors will not work without a consequent tracking system.

At high angular resolutions (0.1 – 0.2 mrad) from the RICHes:

- Angular resolution required from the tracker   < 0.2 mrad
- Multiple scattering from particles in the RICHes (can we roughly measure p?);
- Particle trajectory bent by stray and not stray magnetic fields;

Therefore, it seems fit to propose continuing to pursue a strong R&D activity on RICH detectors, specifically:

- New photodetectors, single-photon sensitive, with high blue-green QE spectrum, picoseconds capable, to be carried out with the relevant industry: Main candidates are SiPMs and vacuum technology photodetectors;
- New radiator materials, spanning from gases to aerogel, to metamaterials and photonic crystals (which exhibit a so-called quantum Cherenkov effect);
- New optical materials for (light-weight) mirrors and optical coatings and elements;
- New mechanical techniques, cryogenic optical boxes (containing SiPMs) and carbon-fibres based structures;
- New front-end electronics with tens of picoseconds time resolutions and high-rate capabilities.

This activity is starting inside the framework of the LHCb RICH Upgrade II Project.

CERN would specifically retain the responsibility to develop two critical items inside the framework of the "R&D programme on experimental technologies":

- New optical materials for (light-weight) mirrors and optical coatings and elements;
- New mechanical techniques, cryogenic optical boxes (containing SiPMs) and carbon-fibres based structures;

Light-weight flat mirrors and supports :
CF spherical mirrors and supports already in RICH1;
First CF flat mirror prototype for RICH1 produced;
Good resistance to radiation.
(from CMA, Austin, Texas)

The goal of this R&D would be to achieve
further in-house developments and improvements,
by making use of know-how and expertise at CERN

~ 1 %Xo

New mechanical techniques, cryogenic optical boxes (containing SiPMs) and carbon-fibres based structures

There is no chance at present and in the near future to operate SiPMs fruitfully in a radiation environment without cooling them down. The LHCb SciFi tracker keeps them at -40 ^{o}C.

In future, down to -100 ^{o}C may be necessary to safely operate SiPM arrays*
and therefore the need of an "optical" cryostat.

The goal would be a cryostat with sizes

1.2 m x 0.7 m x 0.2 m

Thermally insulated, but optically coupled to the Cherenkov medium;
Containing all the very low consumption front-end electronics;
Made of light material and wrapped in plastic to decrease neutron flux.

A first prototype of 0.3 m x 0.2 m x 0.2 m is foreseen.

*Perhaps bump bonded arrays in hybrid detectors….?

All references of concepts, figures and photographs can be found in the previous presentation (public), both from the 1st Workshop and the WG3 dedicated session

https://indico.cern.ch/event/696066/
https://indico.cern.ch/event/704508/
Also
https://indico.cern.ch/event/393078/contributions/2195232/attachments/1331928/2002037/C
armelo_RICH2016_f.pdf

WG3 – RD5

A special place in light-based detectors is taken by the plastic scintillating fibres technique, in the fact that the fibre can be used for tracking and calorimetry purposes.

In the past ~30 years, trackers have been proposed with fibre radii ranging from 30 μm to 2 mm, while mostly 0.5 to 2 mm radii fibres are used for calorimetry.

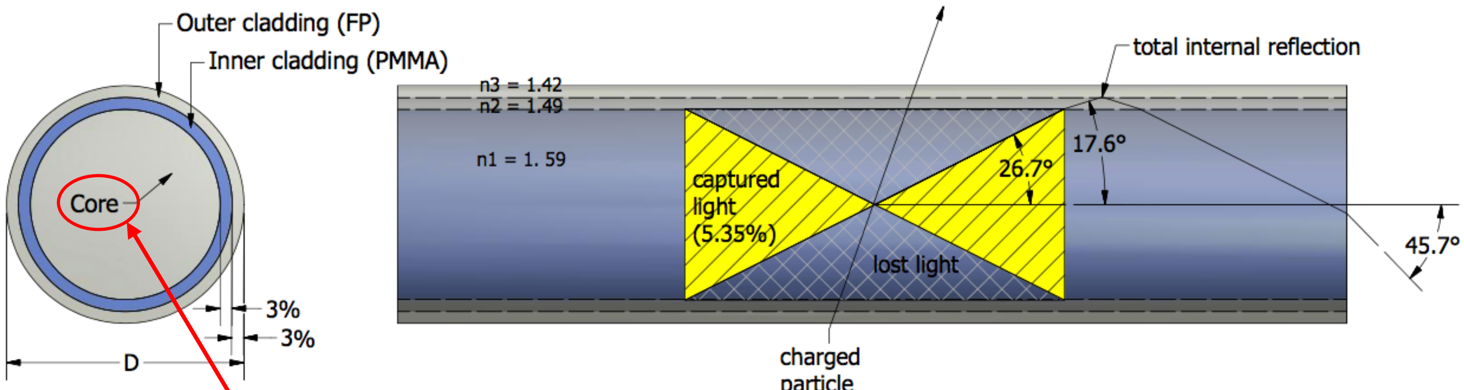
While at present plastic scintillating fibres are widely used for calorimeters, only one complete tracking system is expected to come to fruition in the LHCb experiment, after some old experiences with UA2, D0, CHARM2 and the “mythic ALFIE” proposal (an all fibres experiment) at SSC…

It is perhaps time to re-start a complete R&D project on a collaborative effort.

Plastic scintillating fibres

Plastic (organic) scintillators are aromatic molecules (hydrocarbon compounds)

Properties: 10000 photons per MeV, low Z, low density (1 g/cm^3), fast (ns decay times),



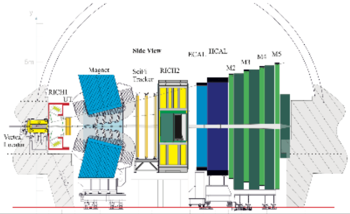
D ~ 1 mm typ.

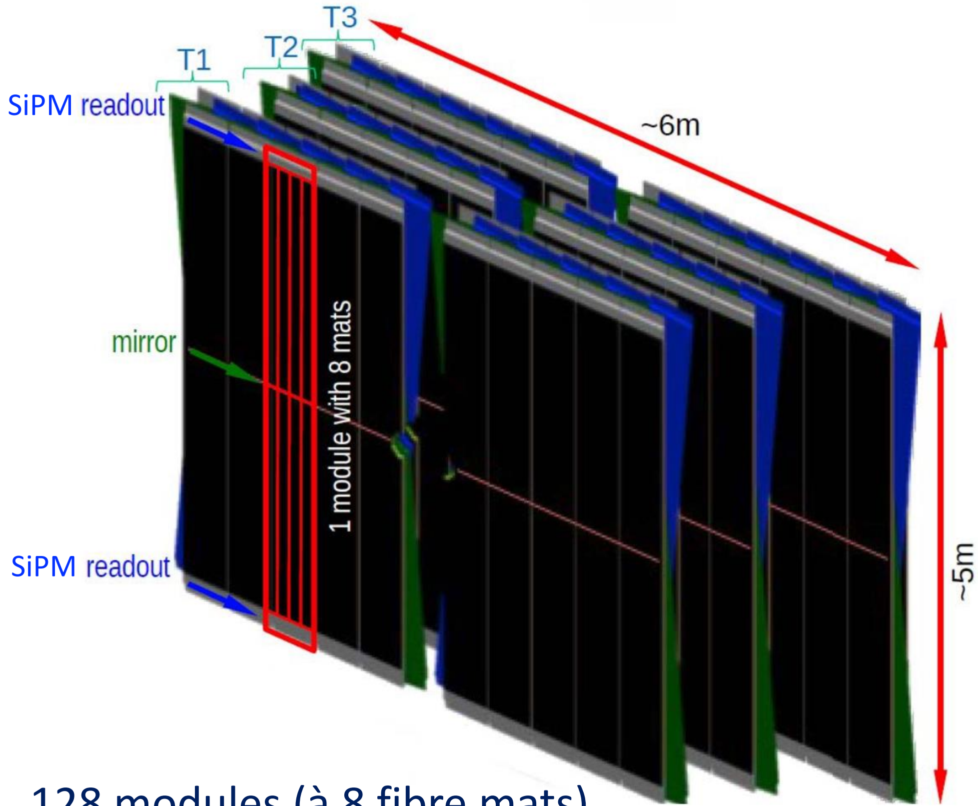
Active material:
- Solvent (e.g. Polystyrene)
- Activator (e.g. p-Terphenyl) 1-2%
- Wavelength shifter (WLS) < 0.1%

Applications in particle physics: tracking (fibre tracker), calorimetry, active targets (trigger, vertexing) – in combination with modern photodetectors (e.g. SiPMs)

But: only mildly radiation tolerant O(10) kGy, labour intense production, quality control, processing. Very little evolution in last 25 years.

A modern example :LHCb SciFi tracker



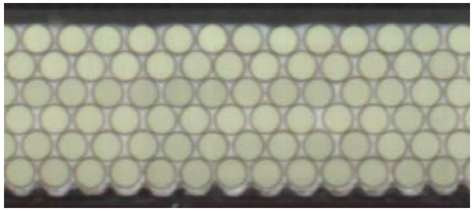


- → 340 m^2 total area
- → 3 stations with 4 layers (XUVX)
- → 11,000 km of scintillating fibre (Kuraray SCSF-78, ⌀ = 250 µm)
- → 4096 custom-made SiPM arrays
- → 524k readout channels

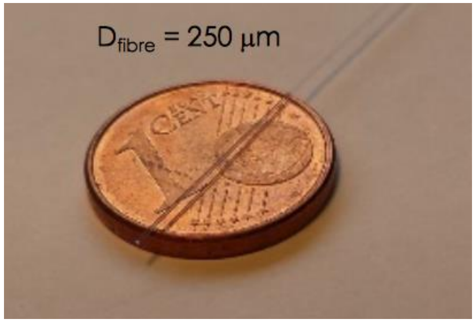
Requirements:

- Hit efficiency ~ 99%
- Spatial resolution < 100 µm
- X/X0 ≤ 1% per detection layer
- 35 kGy close to the beam pipe

128 modules (à 8 fibre mats)



6 fibre layers per mat



Strategy

Three areas surely deserve attention and may be capable of delivering advances for future high-energy experiments, if a strong R&D was stimulated upon:

1. Studies of high precision compact fibre tracker concepts for the next generation of high-energy experiments, namely future colliders, but not exclusively; these studies would be essential to address specific requirements and designs for the rather different collider types;

2. Single photon sensitive detectors with high sensitivity and granularity and improved radiation hardness;

3. Fibre development; scintillation mechanisms, light yield and transport, new cost-effective fabrication techniques, new activation and wavelength shifting mechanism (dopants) and, last but not least, radiation resistance.

Of these three points, nr. 3 seems the most adapted to be proposed for this R&D programme on experimental technologies. Nr. 2 is the principal object of several worldwide R&D projects and nr.1 can be implemented by the collaboration without substantial resources.

Plastic scintillating fibres

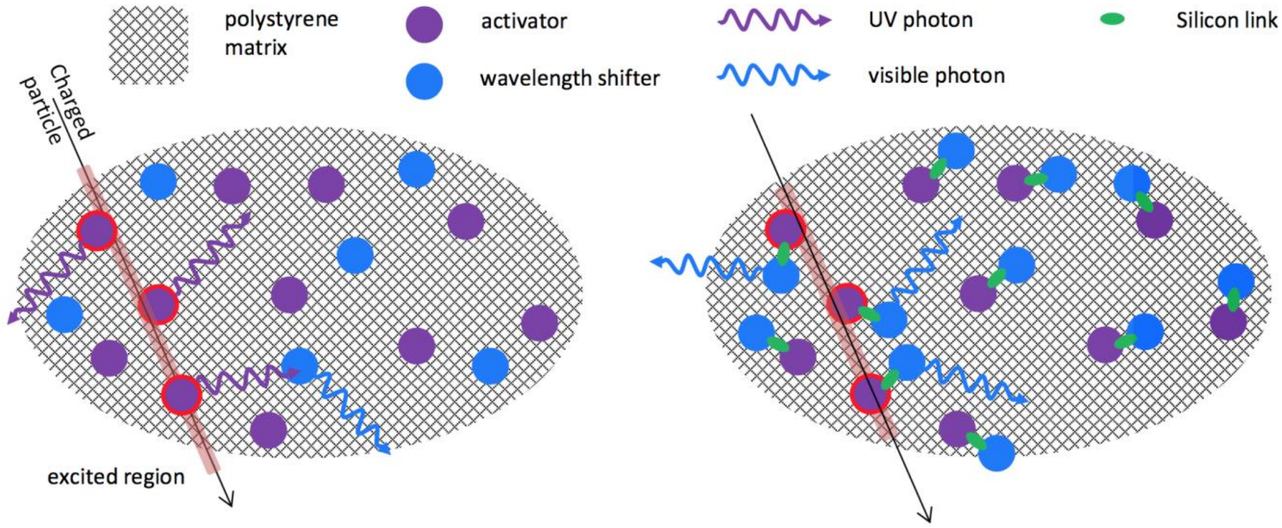
EP R&D

Two main lines of R&D

1. Fast scintillating (or WLS) fibres with higher intrinsic light yield, emission at longer WL → lower attenuation length, better efficiency, higher radiation tolerance

NOL: Nanostructured Organo-silicon Luminophores

S.A. Ponomarenko et al., Nature Sci. Rep. 4 (2014) 6549



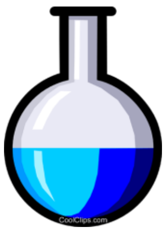
Various samples produced in a CERN/Kuraray/Russia team *O. Borshchev et al., 2017 JINST 12 P05013*
Achieved world fastest scintillators (~1 ns) and WLS (~1 ns), but no significant progress for light yield yet.

C. Joram

Plastic scintillating fibres

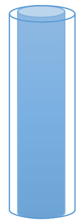
EP R&D

2. Cost effective production of fibre detectors by 3D printing

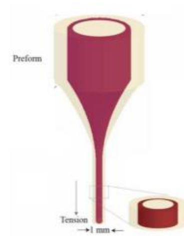


Mix solvent
+ additives

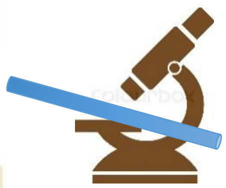
polymerize



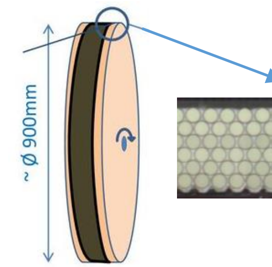
add cladding(s)



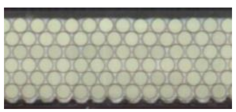
fibre drawing



QA



fibre winding

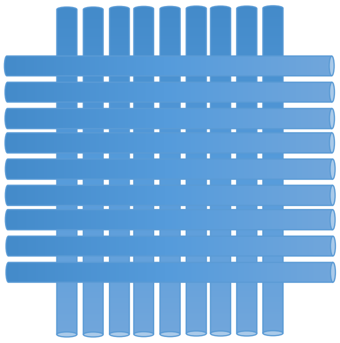


fibre mat

traditional

What could be replaced by 3D printing ?

A possible demonstrator:
2D beam telescope, 10 x 10 cm, Ø1-2 mm fibres.



Foreseeable issues:

- Short attenuation length
- Cladding
- Uniformity

C. Joram

All references of concepts, figures and photographs can be found in the previous presentation (public), both from the 1st Workshop and the WG3 dedicated session

https://indico.cern.ch/event/696066/
https://indico.cern.ch/event/704508/

Summary – Light-based detectors

- **Received diverse input on existing and proposed R&D projects (link)**
- **Converged on two R&D projects that were accepted by the EP R&D steering group:**
  - R&D on RICH detectors for future high energy experiments
  - R&D on plastic scintillating fibres trackers
- **For the two areas there is already strong activity at CERN in the framework of LHCb**
- **Workplans including concrete R&D lines, milestones, deliverables, resource estimates have been developed and agreed by the steering group**
- **Workplans have been included in the EP R&D Report**