# Evolution of the LHCb RICH System for Phase II

Carmelo D'Ambrosio*

Drive for upgrades in LHC: more physics and physics reach.
How? By increasing Luminosity … and detectors must follow.
Drag: Resources, Space (the sub-det envelopes are defined).

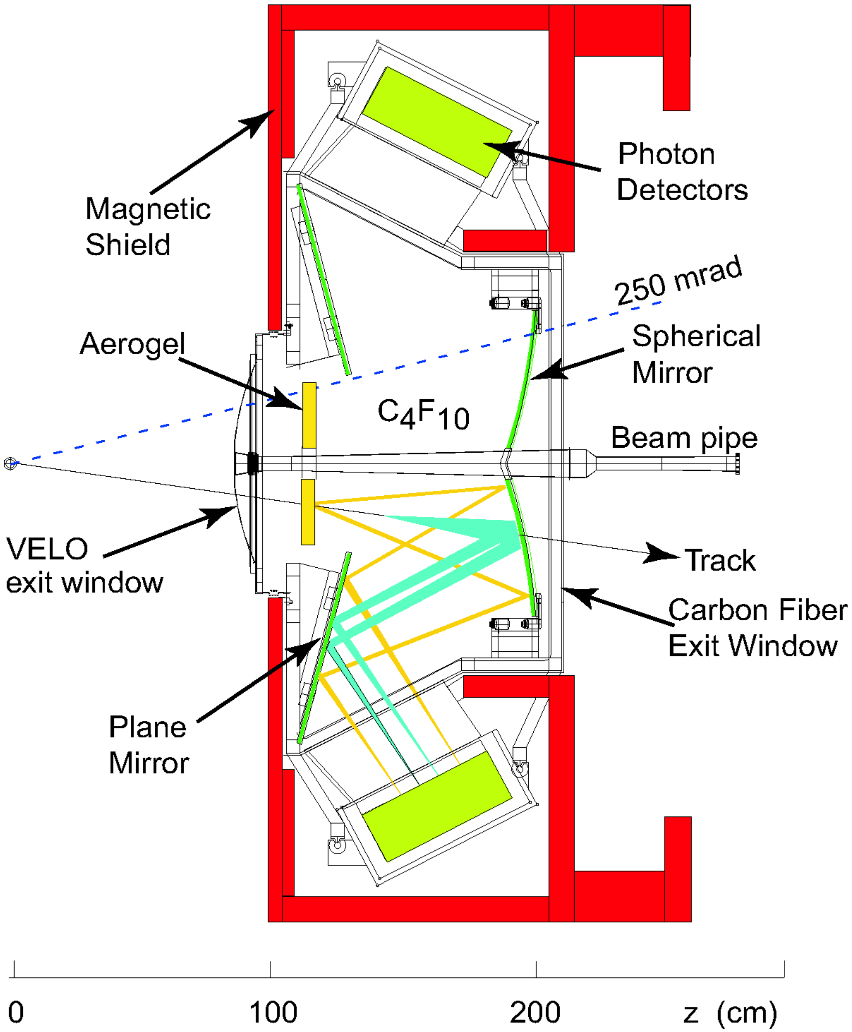
In the LHCb roadmap … :

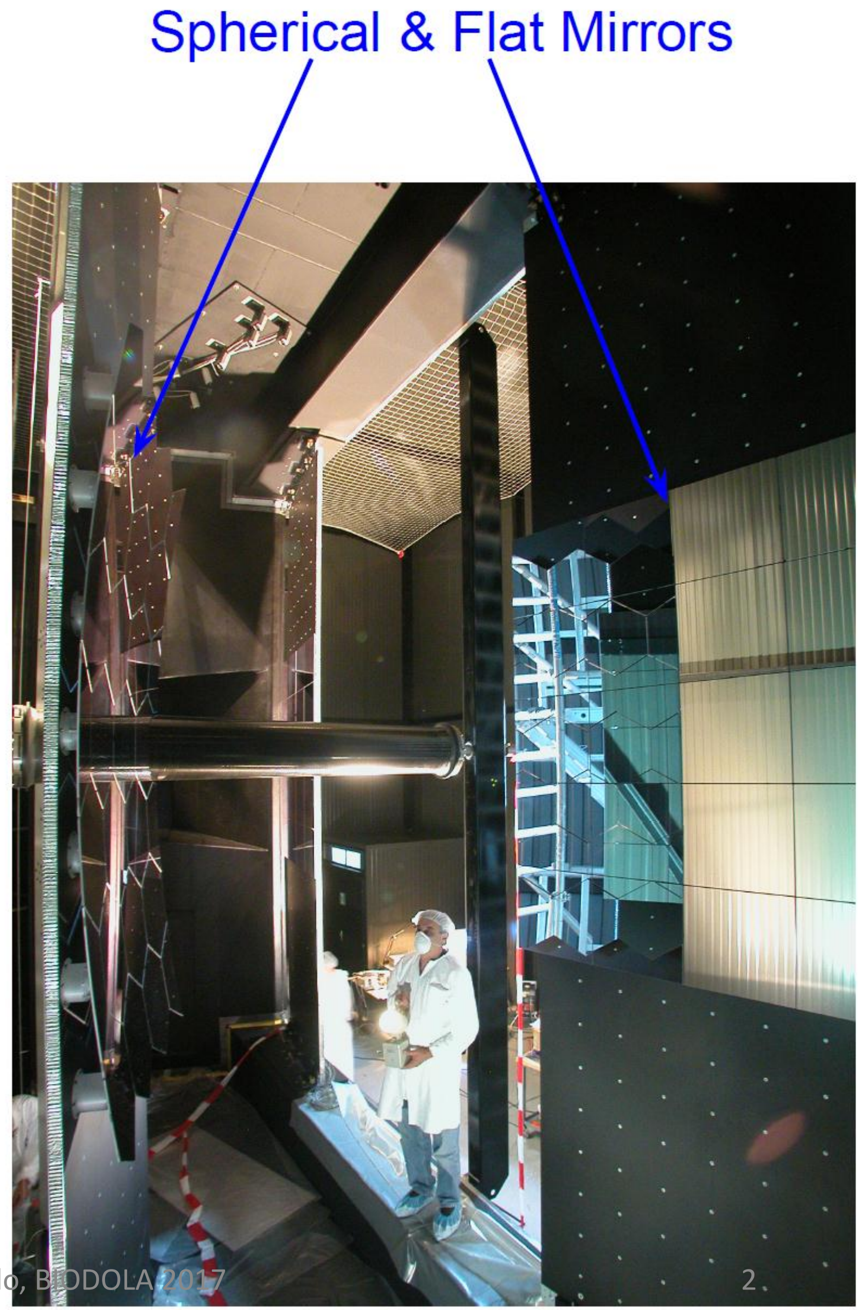
Upg1 2021 will see the first upgrade of the RICHes and LHCb (x10 present Lumi);

Upg2a 2025 may see a small upgrade in preparation for
Upg2b 203x, a major possible upgrade (HL-LHC, x50 present Lumi).

- on behalf of several LHCb RICH collaborators

# RICH1 and RICH2



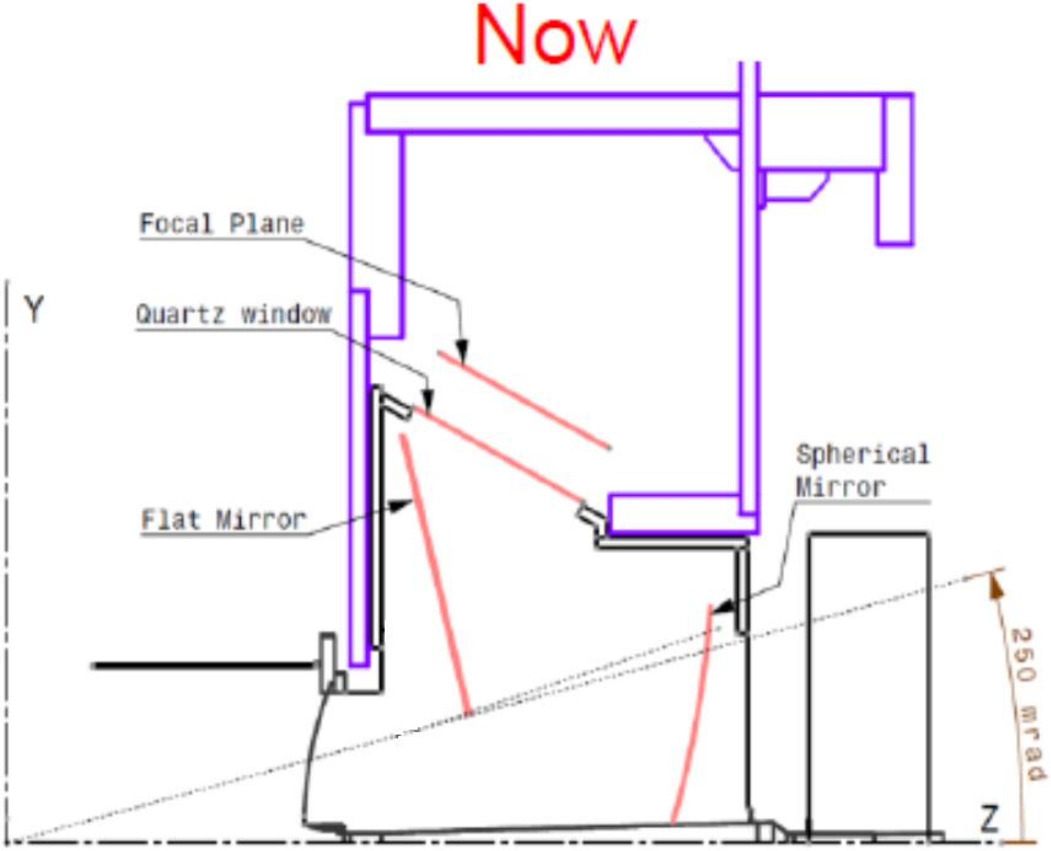



# Present, Run II, 25 ns, ~2 x $10^{32}$ $cm^{-2}$ $s^{-1}$

RICH 1
Wide acceptance (300 mrad), tight space
Low-medium mom. range (~10 to ~ 60 GeV/c)
High photon yields
and medium resolutions (1.60 mrad per hit).

RICH 2
Small acceptance (120 mrad), wide space
Medium-high mom. range (~50 to ~100 GeV/c)
Lower photon yields
and high resolutions (0.67 mrad per hit).

Improved PID and online cal. and mon.;
RICH system fully included in HLT.



# Contents

- Strategy
- The case for RICH 1
- Critical issues and associated R&D
- The shopping list
- Photodetectors still own the game!
- Conclusions

A lot of information will be available from Gianluigi and Sajan presentations (RICH Upg) and from Christian (SciFi), Rok (BELLEII) and Neville (TORCH) on related topics

# Strategy

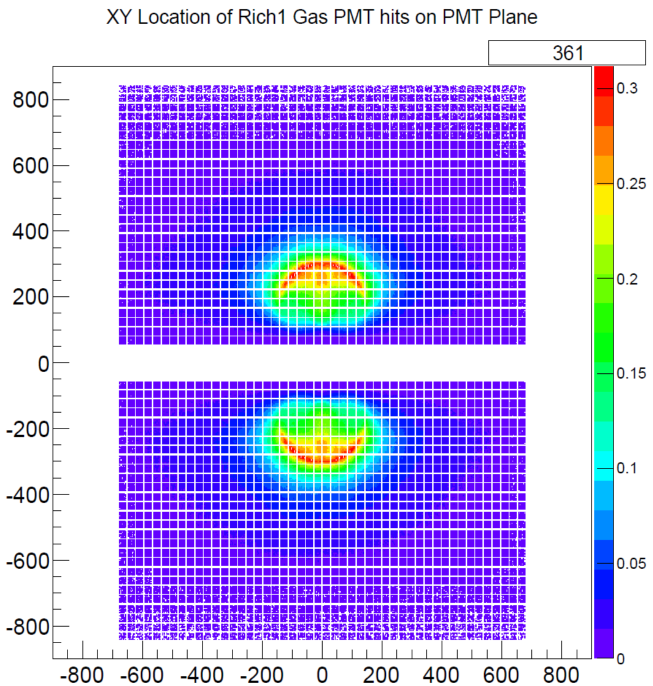
- Keep peak Occupancies (time and space) < 30%
- Improve Single Photon Cherenkov Angle precision to < 0.5 mrad

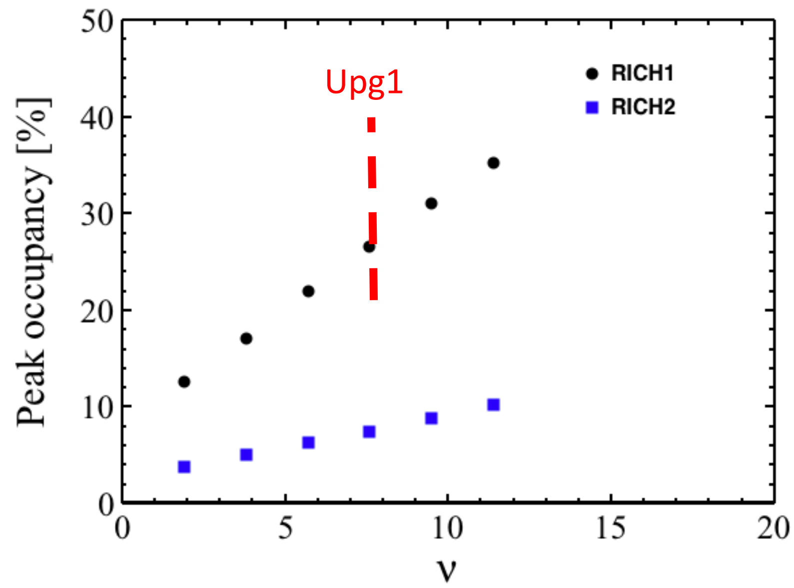
In short, we want a digital camera with:

| | |
|---|---|
| • Lots of quality pixels | Photodetectors and assoc. electronics |
| • An excellent lens | Optical and gas systems |
| • A fast and precise shutter | Gating and time resolution |

# Going to L = $10^{34}$cm$^{-2}$s$^{-1}$ increases occupancies on both RICH 1 and 2

At a $\nu$ = 38*, peak occupancies are in excess of 100% in RICH 1. However the region of extreme occupancies is limited.




From experience, we try to keep Occupancies always below ~30%

| | | |
|---|---|---|
| Present | 30% | $A_p$=6.3mm$^2$, f=1.35 m |
| Upg1 | ½ 2 x 30% | $A_p$=6.8 mm$^2$, f=1.9 m |
| Upg2 | $^1/_{7.5}$ 10 x 30% | $A_p$=1 mm$^2$, f=2 m |

* $\nu = 38$ is the number of primary vertices per collision at $10^{34}$cm$^{-2}$s$^{-1}$ (upg2).

# With Luminosities increasing

Pattern recognition a challenge:

Granularity is a necessary but not sufficient condition to ensure pattern recognition: improve the single photon Cherenkov angle resolution.

$$(\sigma_\vartheta \cdot f) \lesssim \sqrt{A_p}$$

Essentially keep this smaller than the pixel size!!

For Upg2*, $\boldsymbol{\sigma_\vartheta \lesssim 0.5 mrad}$ (present 1.6 mrad)

$\sigma_\vartheta$ is the Cherenkov angle resolution
$f \sim 2m$ is the mirror focal length
$A_p$ is the pixel area

*and for RICH1 regions with high occupancies

# Improve Cherenkov angle resolution…

$\sigma_\vartheta$ depends on a sum (in quadrature) of uncertainties:

Pixel size, $\sim\sqrt{\frac{A_p}{12}}$;

Emission Point, optical system aberrations

Chromatic dispersion, $\cos\vartheta_c(\lambda) = \frac{c}{n(\lambda)\cdot v}$

of course ultimately we want $\frac{\sigma_\vartheta}{\sqrt{N}}$

$\vartheta_c$ is the Cherenkov angle
$\sigma_\vartheta$ is the Cherenkov angle resolution
$N$ is the number of detected photons
$A_p$ is the pixel area

# Simulated Optical Performance and Photon Yields

For Upg2, $\boldsymbol{\sigma_{\vartheta} \lesssim 0.5mrad}$ (present 1.6 mrad)

| Radiator | $C_4F_{10}$ | | | $CF_4$ | |
|---|---|---|---|---|---|
| Detector Version | RICH-1 Current (HPD) | RICH-1 Upg1 | RICH-1 Upg2 | RICH-2 Upg1 | RICH-2 Upg2 |
| Avr. Ph.Electron Yield | 25 (30)* | 40 (rms=8) | 40 - 30 | 22 (rms=5) | 30 - 20 |
| Single Photon Errors [mrad] | | | | | |
| Chromatic | 0.84 | 0.58 | 0.24 – 0.18 | 0.31 | ~0.1 |
| Pixel | 0.9 | 0.44 | 0.15 | 0.20 | 0.07 |
| Emission Point | 0.8 | 0.37 | 0.1 | 0.27 | 0.05 |
| Track resolution | 0.4 | ?0.4? | ?0.4? | ?0.4? | ?0.4? |
| Overall | 1.52 | 0.9 | 0.5 (0.3 – 0.2) | 0.60 | 0.42 (0.13) |

*Value from data (expected)

# With Luminosities increasing

Time resolution (time granularity) will also help disentangle busy events, while delivering more information:

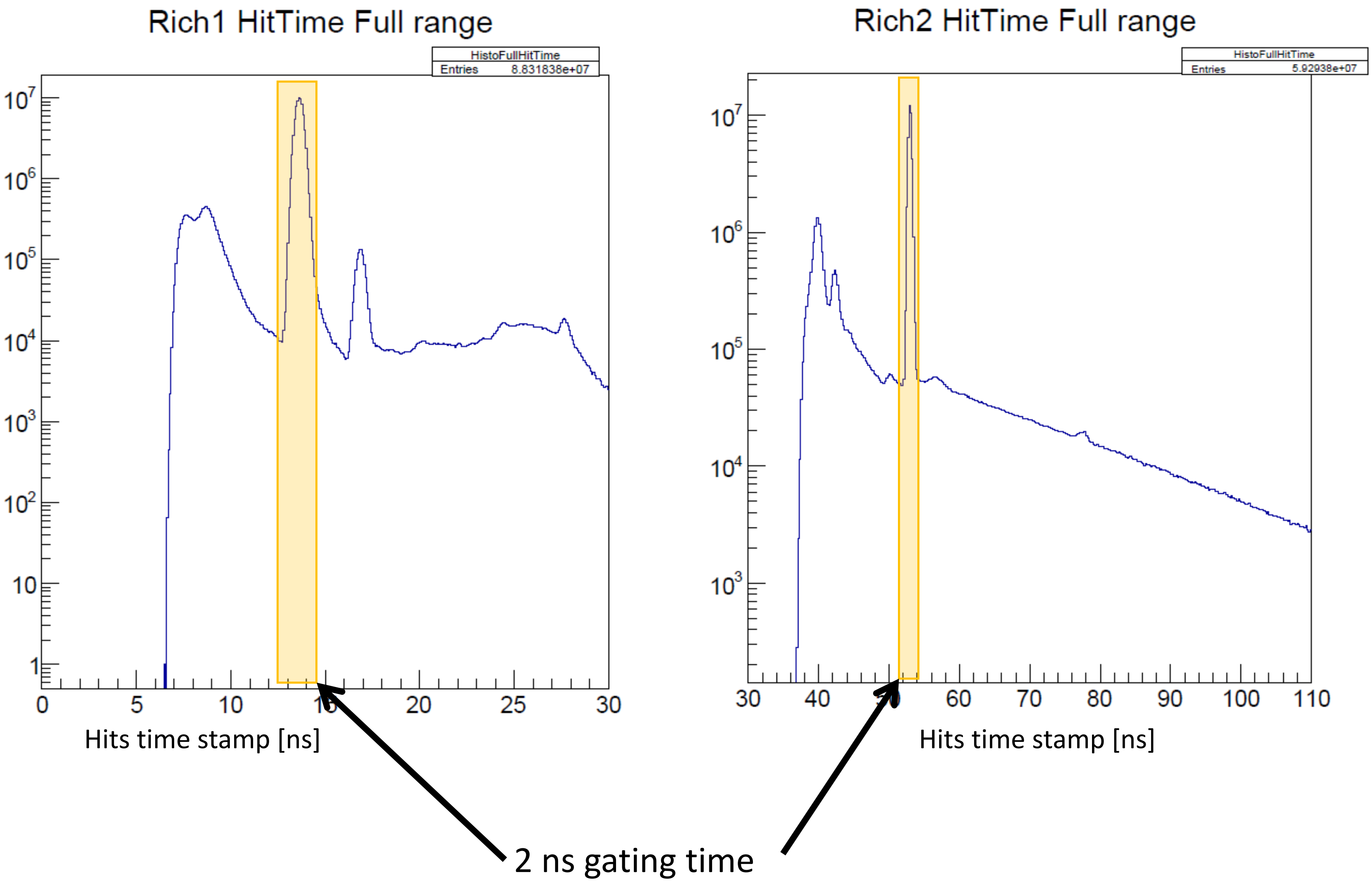
Provide the system with time resolution

~0.2 to 1 ns (time resolution on single photon)

and ~50 to 150 ps (time resolution with ~40 detected photons).

Provide an absolute time stamp.

# Hits Arrival Time Distributions (physics events)



# A word of caution

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

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

- Maximum angular resolution required from the tracker < 0.2 mrad
- Multiple scattering from particles in the RICHes* ;
- Particle trajectory bent by stray and not stray magnetic fields;

* $\sigma_{ms} \approx p^{-1}$ [mrad] in RICH1 $C_4F_{10}$ , p [GeV/c]

# Upg2, Run XX, 25 ns, up to $10^{34}$ $cm^{-2}$ $s^{-1}$, 202x onwards

## The recipe ☺

Increase granularity, or/and provide a 2-bits/double-discri readout electronics

Improve optical error,
- by moving light-weight flat mirrors into the acceptance,
- by further reducing mirror tilts

Further reduce chromatic error
- by tuning the gas
- by further moving the photodetector sensitive region towards the green
- by increasing photodetector QE

Provide the system with time resolution

Work on new and specific pattern recognition algorithms

Perhaps get rid of the magnetic shielding by using B-insensitive photodetectors

# Upg2, Run XX, 25 ns, up to $10^{34}$ $cm^{-2}$ $s^{-1}$, 202x onwards

## The shopping list

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.

**< 1.5 % of Xo only**

# Upg2, Run XX, 25 ns, up to $10^{34}$ $cm^{-2}$ $s^{-1}$, 202x onwards

## The shopping list

Photodetectors :

| | |
|---|---|
| Gas chambers with CsI | VUV photons |
| Vacuum Devices | UV – Blue photons |
| Solid-state devices | VIS photons |

Vacuum devices: MaPMTs, HPDs and MCP-PMTs with green-enhanced QE response;
Solid State: <40°C cooled SiPMs (see LHCb SciFi detector);

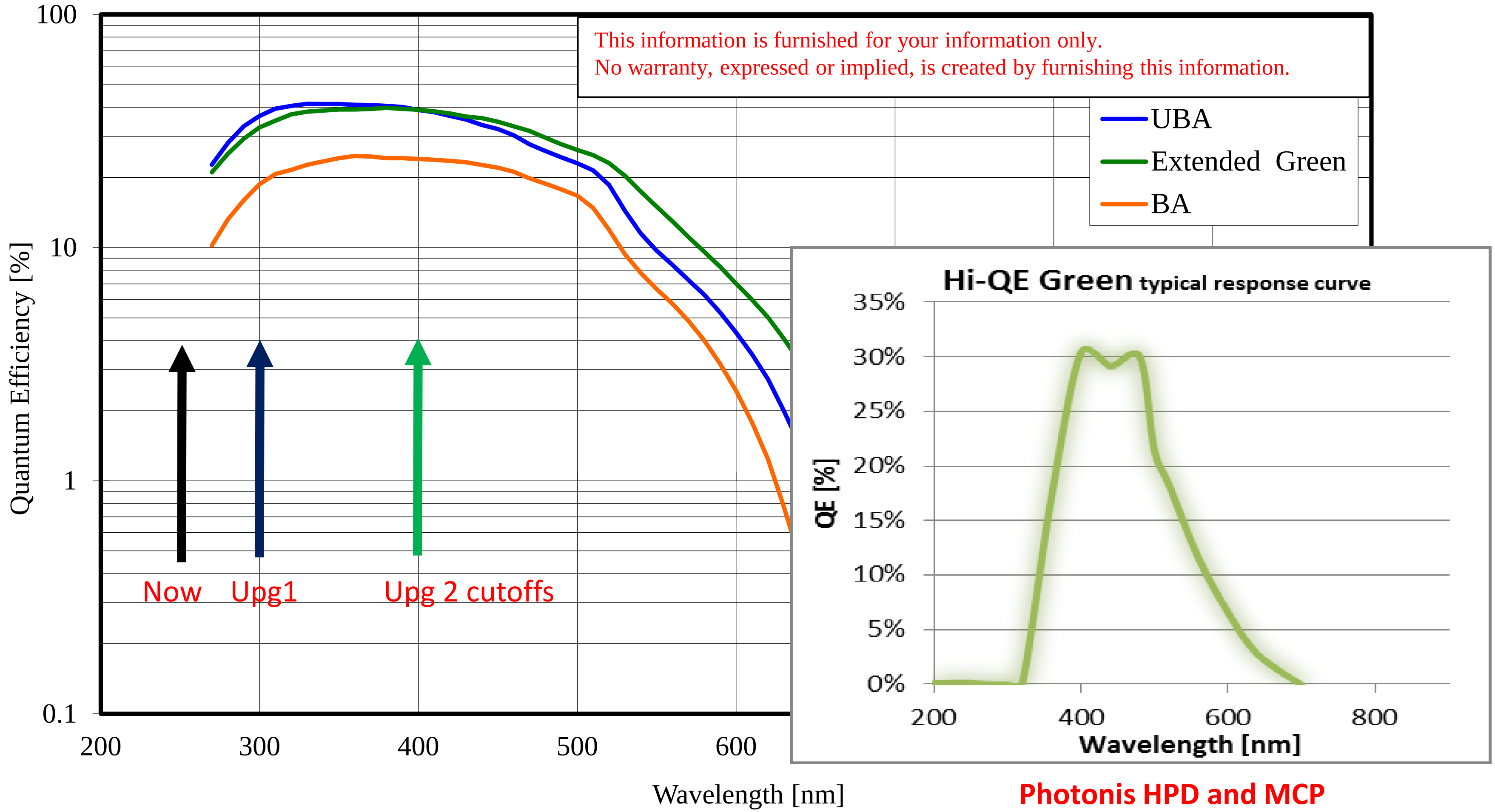
New SiPM from SensL
8x8 pixels, 3x3 mm

If this scares you, remember that the Central Fibre Tracker of D0 had VLPC photodetectors operating at 9 °K!!

It looks as if it could already nicely fit in an Elem. Cell !!

All marked in red needs R&D!!

# R7600-M64 Spectral Response Characteristics




**Photonis HPD and MCP**
**Green-enhanced**

HAMAMATSU
HAMAMATSU PHOTONICS K.K. Electron Tube Division

Already efforts from vacuum devices producers are visible

# Upg2, Run XX, 25 ns, up to $10^{34}$ $cm^{-2}$ $s^{-1}$, 202x onwards

## The shopping list

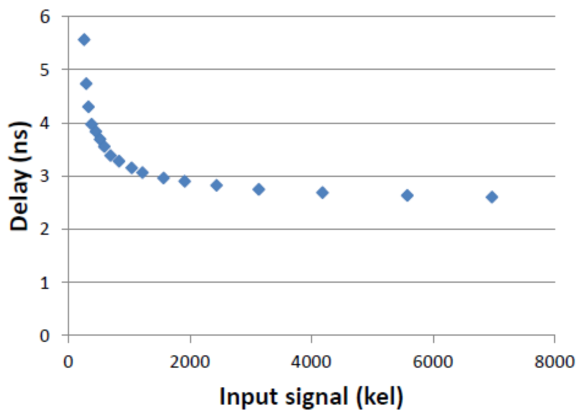
On-detector electronics with space and time resolution:

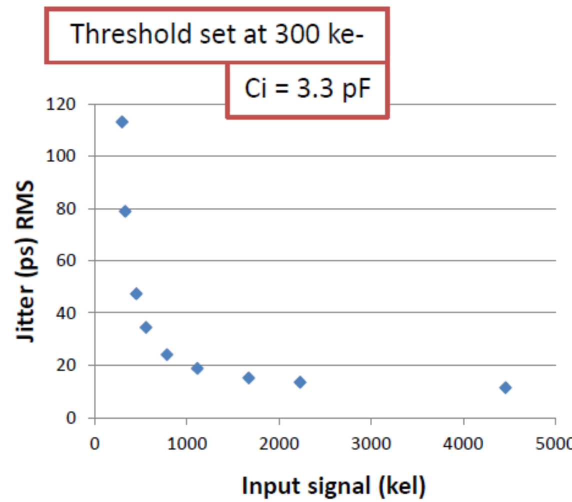
CLARO8 already features some of the needed functionalities;

### Timing performance

Excellent timing performance at 0.7 mW/channel:

- Time walk < 3 ns
- Leading edge jitter from 110 ps RMS (just above threshold) to 11 ps RMS (large signals)




Even better berformance could be achieved by doubling the power to 1.5 mW/channel.

C. Gotti - TIPP 2014

The PDM Digital Board can be developed accordingly.

DAQ is a challenge; compress/reduce data on detector.
Work on new and specific pattern recognition algorithms.

All marked in red needs R&D!!

# Wishful Thinking?

Seen the enthusiastic response of present and future collaborators,
we could propose well before LS3 to:

- install a few Elementary Cells instrumented with SiPM in a low-radiation, uninstrumented region of Upg1 RICH 2 (already foreseen).
- provide moderate cooling (parasite SciFi…? Oops, nothing said!);

- provide a ns time resolution;
- study the long-term behavior and characteristics of the system.

# Conclusions

Through further improvements and staying in the present envelope, the LHCb RICHes could continue to perform PID efficiently at luminosities up to $10^{34}$ $cm^{-2}$ $s^{-1}$.

The single-photon cherenkov angle resolution could be squeezed from 1.6/0.7 mrad (present system) to 0.2/0.1 mrad for RICH 1 and 2 respectively.

A critical point will be the development of green-enhanced photodetectors with high space and good time resolution (cooled SiPMs, PMTs, HPDs and MCPs).

The tracking system has to follow in term of resolution.

We see the future of LHCb RICHes as high-precision, green-enhanced, compact machines.

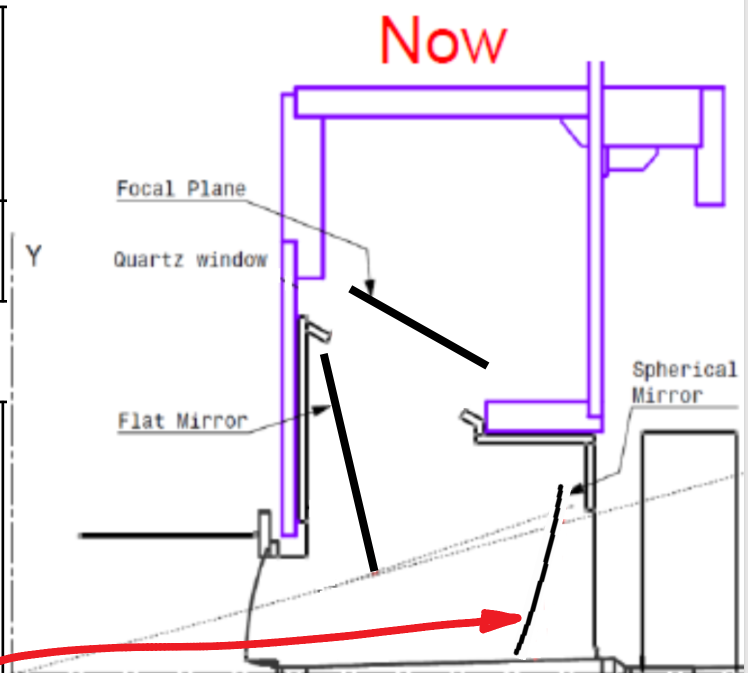
A few slides to show a possible way to improve the LHCb RICH System*

*For the sake of simplicity, let us suppose to be able to use SiPM detectors. Also, quite simple calculations here, no detailed simulations

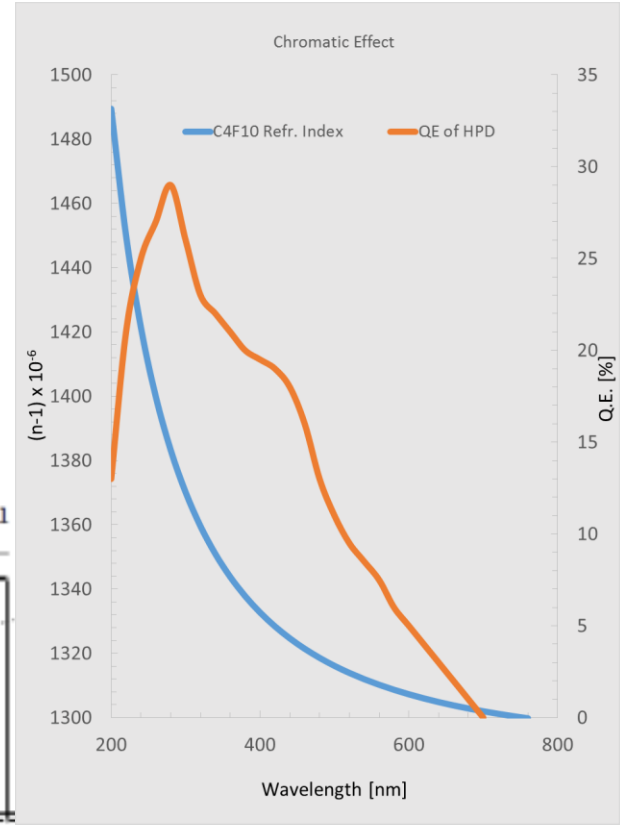
# Optical Performance and Photon Yields

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

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




depends on spherical mirror
tilt and focal length

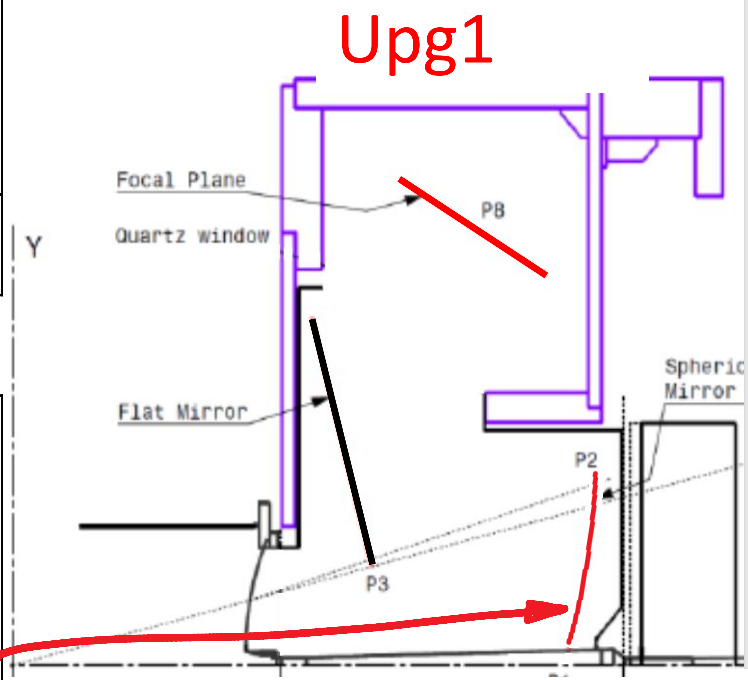



Chromatic depends on the overlap between dispersion and photodet. QE

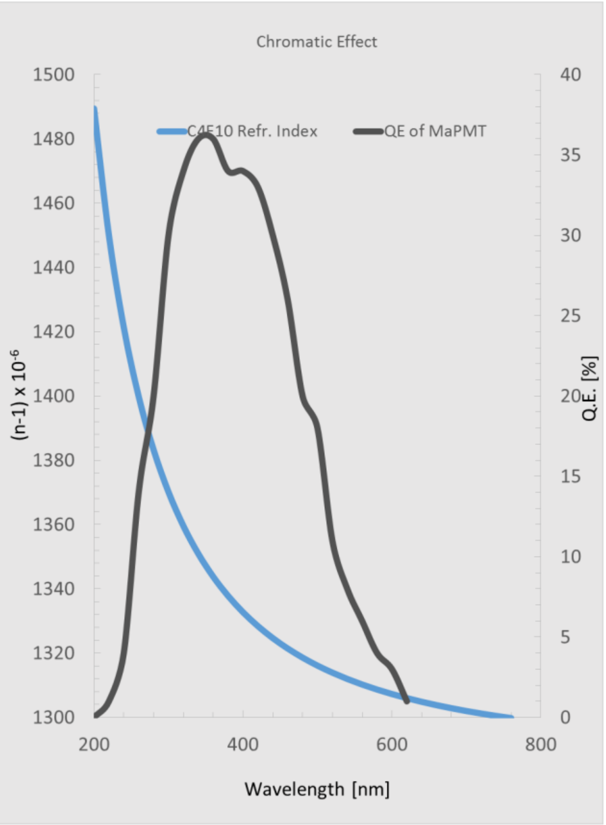
# Optical Performance and Photon Yields

Lumi ≤ 2 x $10^{33}$ $cm^{-2}$ $s^{-1}$ ; Occupancy < 30%

| Detector Version | RICH-1 Upg1 |
|---|---|
| Avr. Phel. Yield | 40 |
| Single Photon Errors [mrad] | |
| Chromatic | 0.58 |
| Pixel | 0.44 |
| Emission Point | 0.37 |
| Track resolution | 0.4 |
| Overall | 0.9 |




depends on spherical mirror tilt and focal length



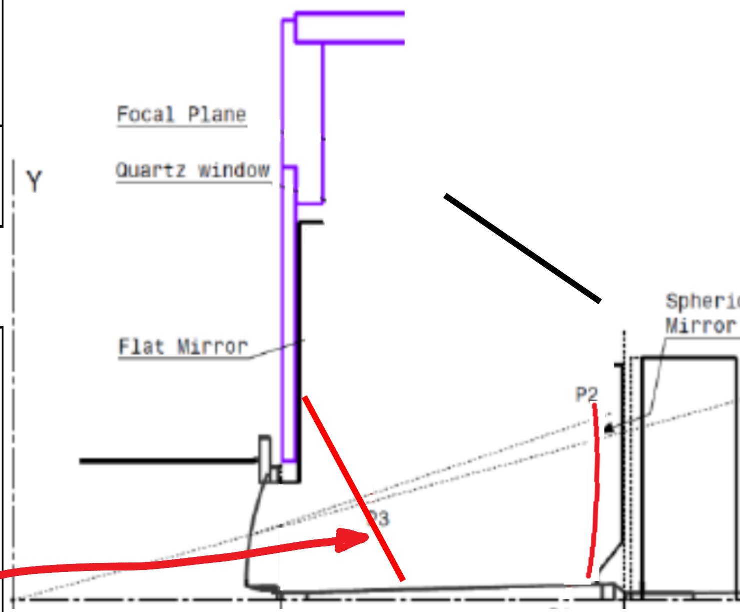

Chromatic depends on the overlap between dispersion and photodet. QE

# Optical Performance and Photon Yields

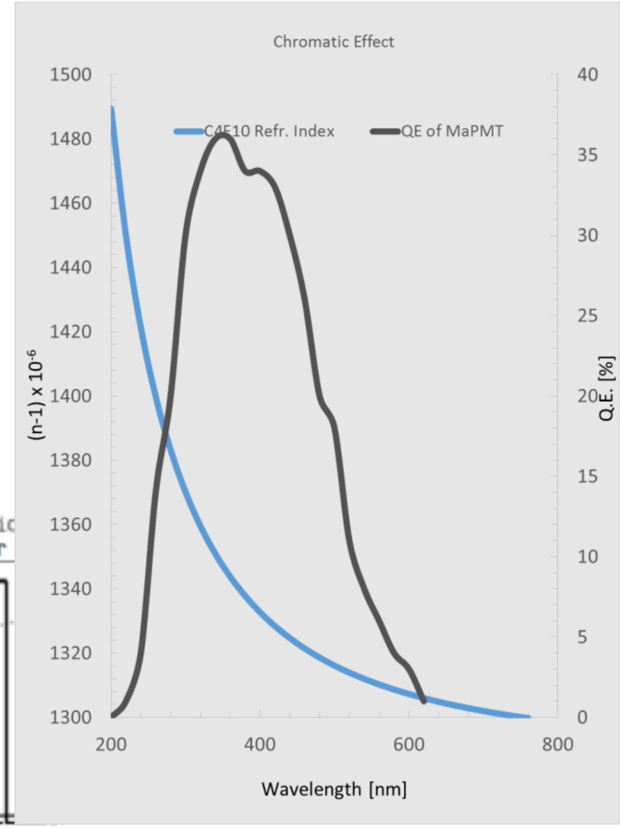
Lumi = $10^{34}$ $cm^{-2}$ $s^{-1}$ ; Occupancy > 100%

| Detector Version | RICH-1 Upg2 |
|---|---|
| Avr. Phel. Yield | |
| Single Photon Errors [mrad] | |
| Chromatic | 0.58 |
| Pixel | 0.44 |
| Emission Point | 0.1 |
| Track resolution | ? |
| Overall | 0.7 |

Upg2




Use lightweight flat mirror in the acceptance (reduce aberrations)



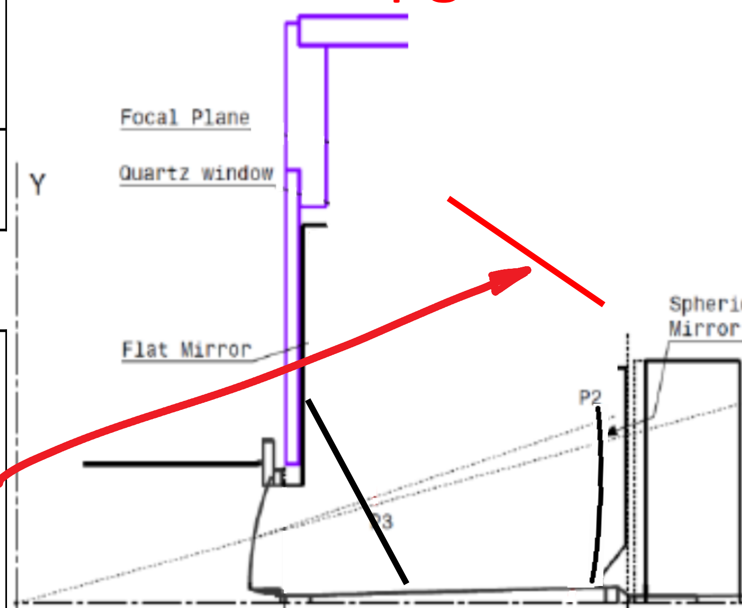

Chromatic depends on the overlap between dispersion and photodet. QE

# Optical Performance and Photon Yields

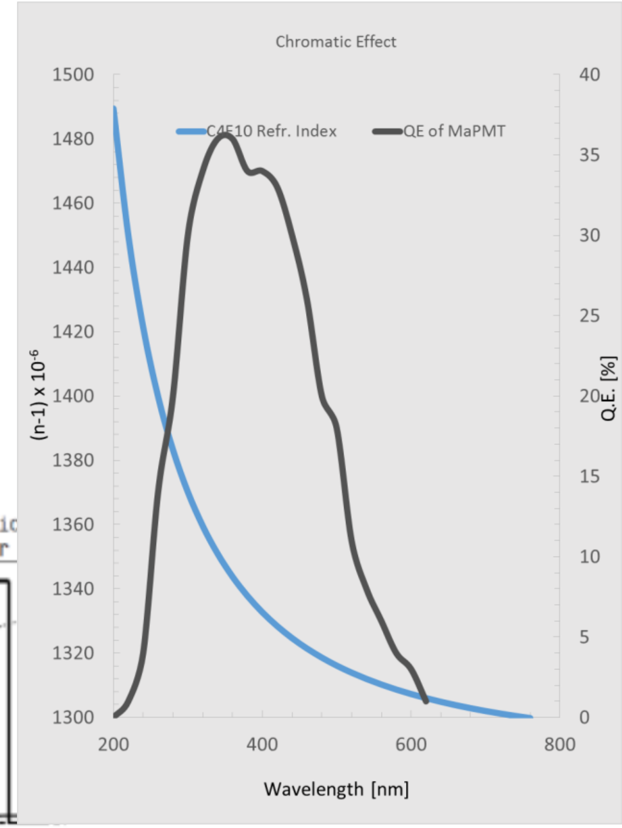
Lumi = $10^{34}$ $cm^{-2}$ $s^{-1}$ ; Occupancy < 30%

| | |
|---|---|
| Detector Version | RICH-1 Upg2 |
| Avr. Phel. Yield | |
| Single Photon Errors [mrad] | |
| Chromatic | 0.58 |
| Pixel | 0.15 |
| Emission Point | 0.1 |
| Track resolution | ? |
| Overall | 0.6 |

Upg2




Reduce pixel size to ~1mm

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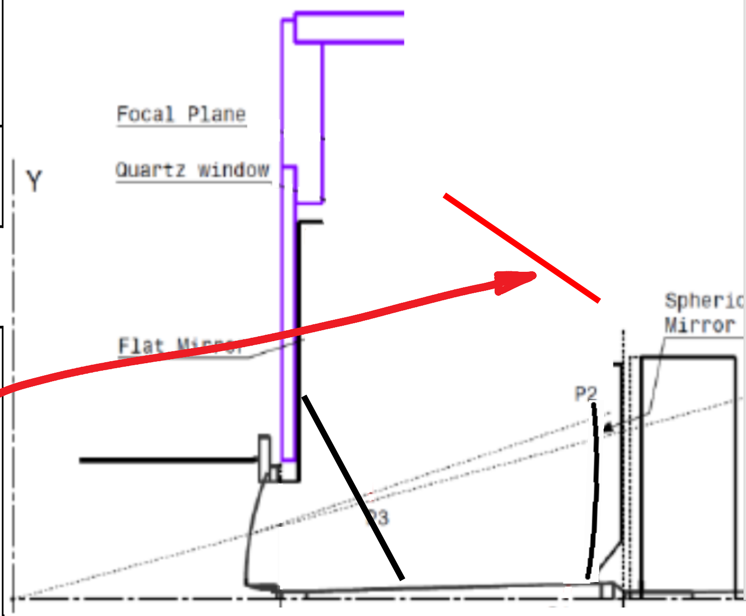
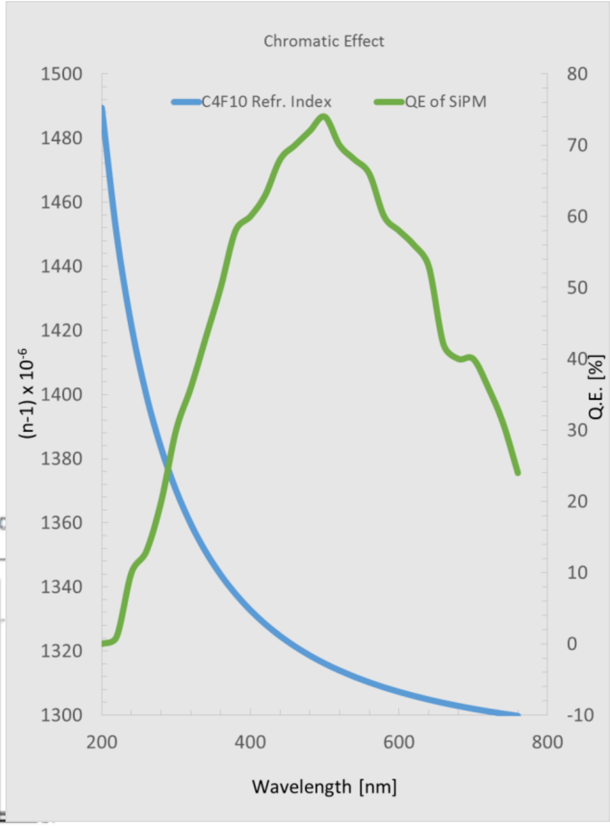
# Optical Performance and Photon Yields

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

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

Upg2




Reduce chromatic by choosing a photodetector with a "green-shifted" QE curve (and filter the shorter wavelengths)

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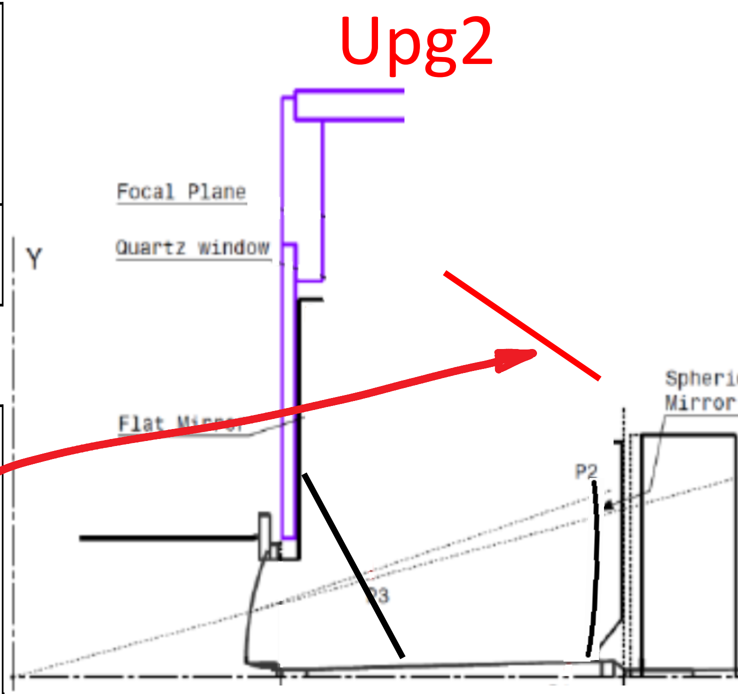


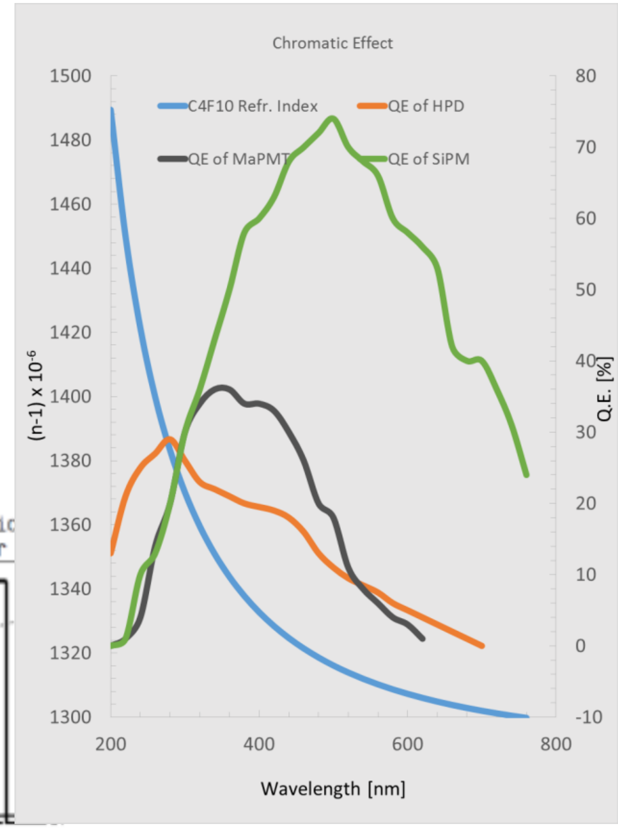


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# Simulated Optical Performance and Photon Yields

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| Pixel | 0.9 | 0.44 | 0.15 | 0.20 | 0.07 |
| Emission Point | 0.8 | 0.37 | 0.1 | 0.27 | 0.05 |
| Track resolution | 0.4 | ?0.4? | ?0.4? | ?0.4? | ?0.4? |
| Overall | 1.52 | 0.9 | 0.5 (0.3 – 0.2) | 0.60 | 0.42 (0.13) |

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