LHCb RICH, past, present, future and future^2 (Carmelo*)

The LHCb-RICH was born in the 20th century, what will it be in 2035?? ☹

Disclaimer: in the spirit of the "T'es Fou (TTFU)" meetings, I am allowed to keep to general principles** … and mainly on RICH 1

* Together with Alessandro, Antonis, Jibo, Olav, Roberta, Sajan and many more, who contribute to everyday discussions.
** The following presentation from Sajan will show preliminary detailed simulations.

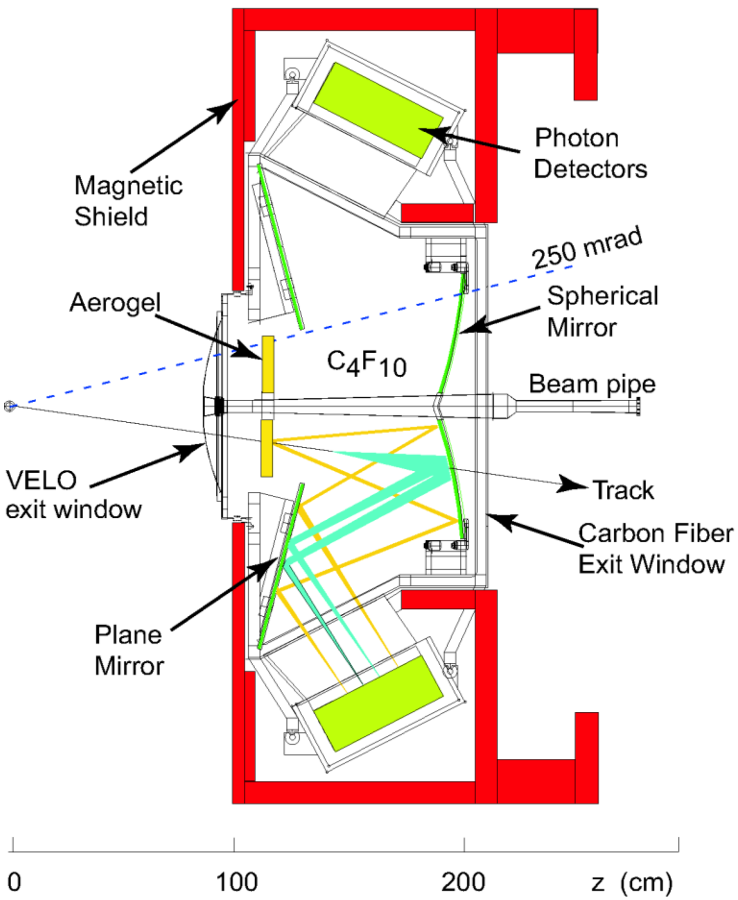
In fact, the RICH system has already been evolving.

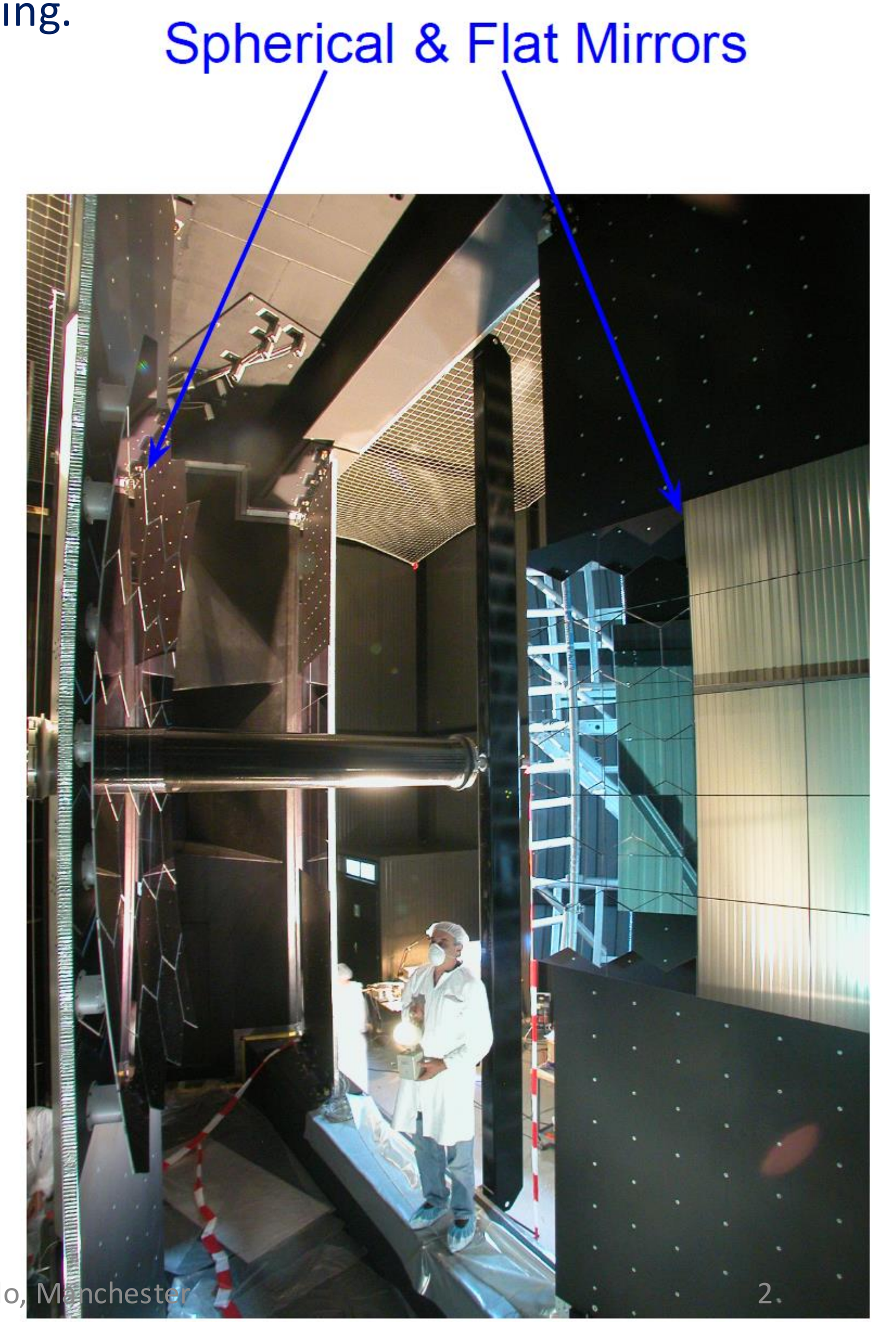
Mainly due to:

Better understanding of components and detection processes;

Pressure to increase luminosities

and ultimately to extend physics reach.





Past, Run I, 50 ns, 2 to 4 x 10^{32} cm^{-2} s^{-1}

RICH 1 and RICH 2

Improvements in DAQ, overall system stability,
suppression of scintillation from CF_4 and of BILE onset, etc.

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

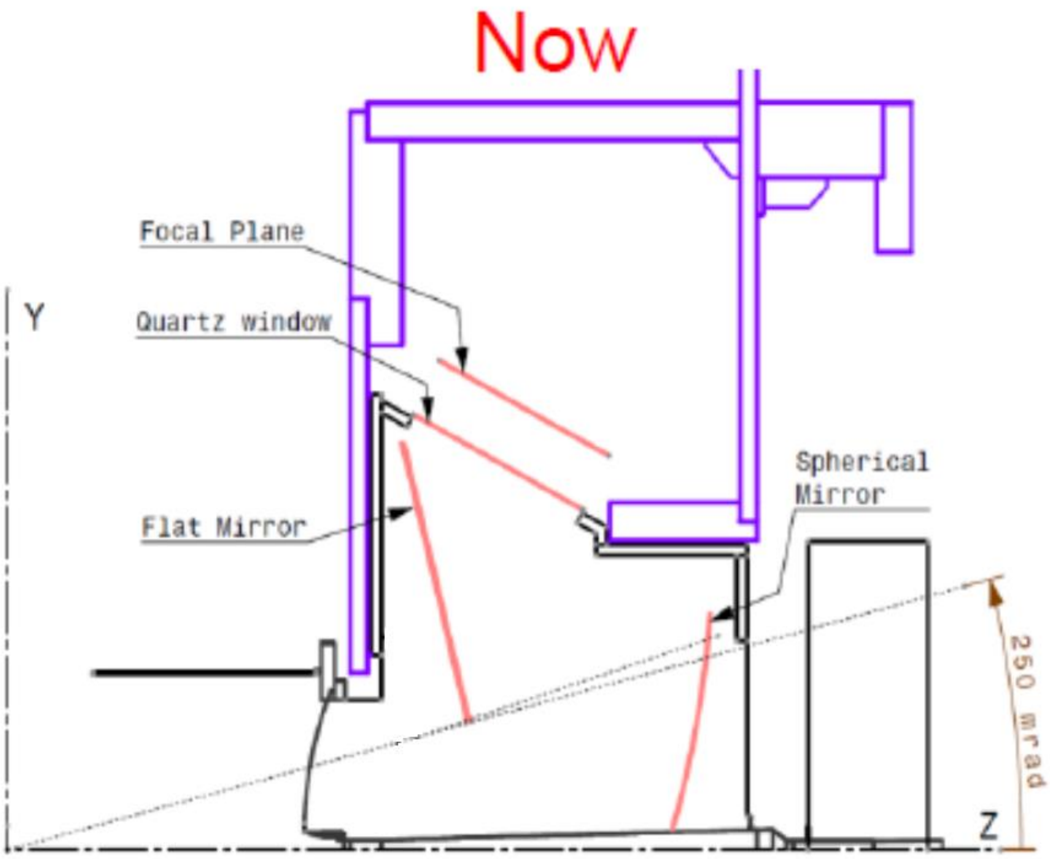
RICH 1

Wide acceptance (300 mrad), tight space
Low-medium mom. range (~10 to ~ 60 GeV/c)
High photon yields
and medium resolutions (1.55 mrad per hit).

RICH 2

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

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



The upgraded RICH for RUN III (2021)

Rather than a new system, the upgraded RICH is more of an evolved detector:
It had to be so, due to time, resources, costs and ultimately space.

The goal is to realize a system with equal PID performance compared to the present, however @ 10 times today's luminosities and keeping in the same envelope.

The upgraded^2 RICH for RUN .... (202x)

Cannot expect more resources while our flagships will have become blackholes …
Keep again in the same envelope and show that it can be done!

The goal is again to realize a system with equal PID performance compared to the present, however @ 50 times today's luminosities!!

With Luminosities increasing and Physics Reach extending

1. Occupancies jump up: improve granularity;
2. Pattern recognition a challenge: improve cherenkov angle resolution.

With Luminosities increasing and Physics Reach extending

1. Occupancies jump up: improve granularity;

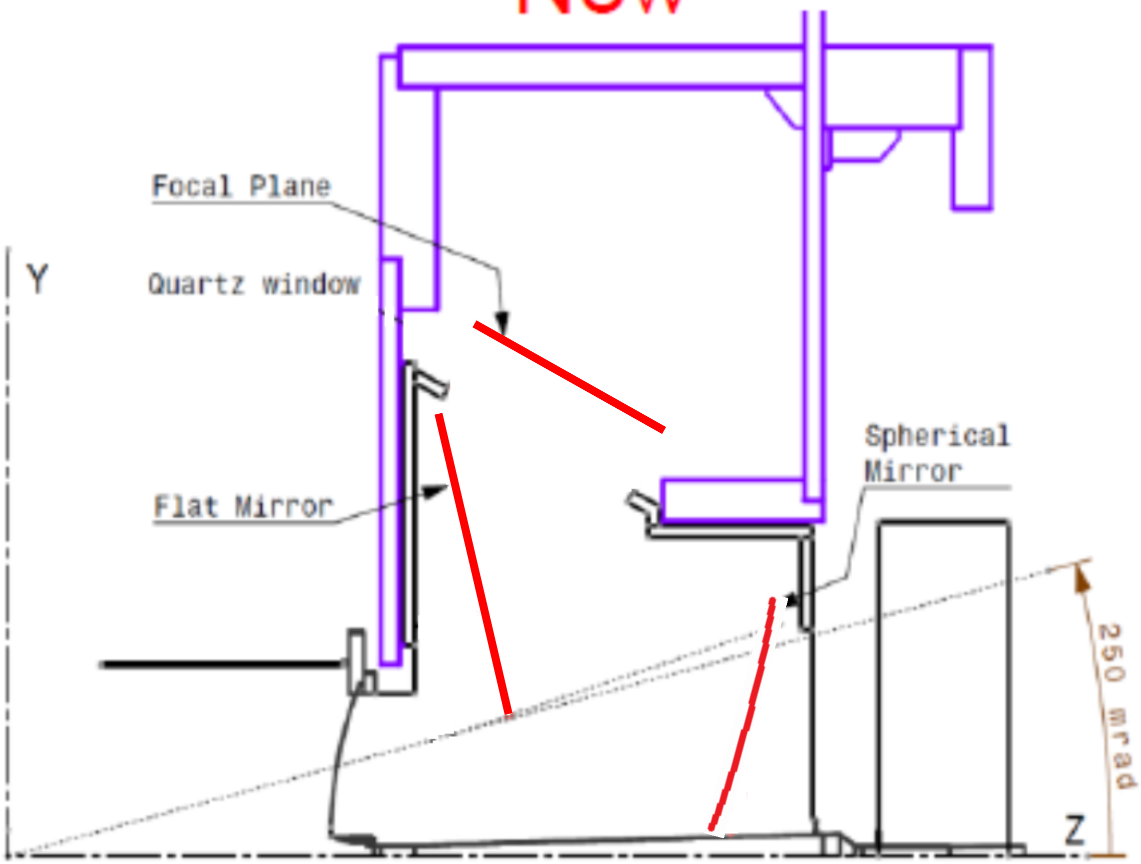
$$\frac{A_p}{A_i} \propto \frac{A_p}{f^2}$$

A_p is the pixel area
A_i is the image area
f is the mirror focal length

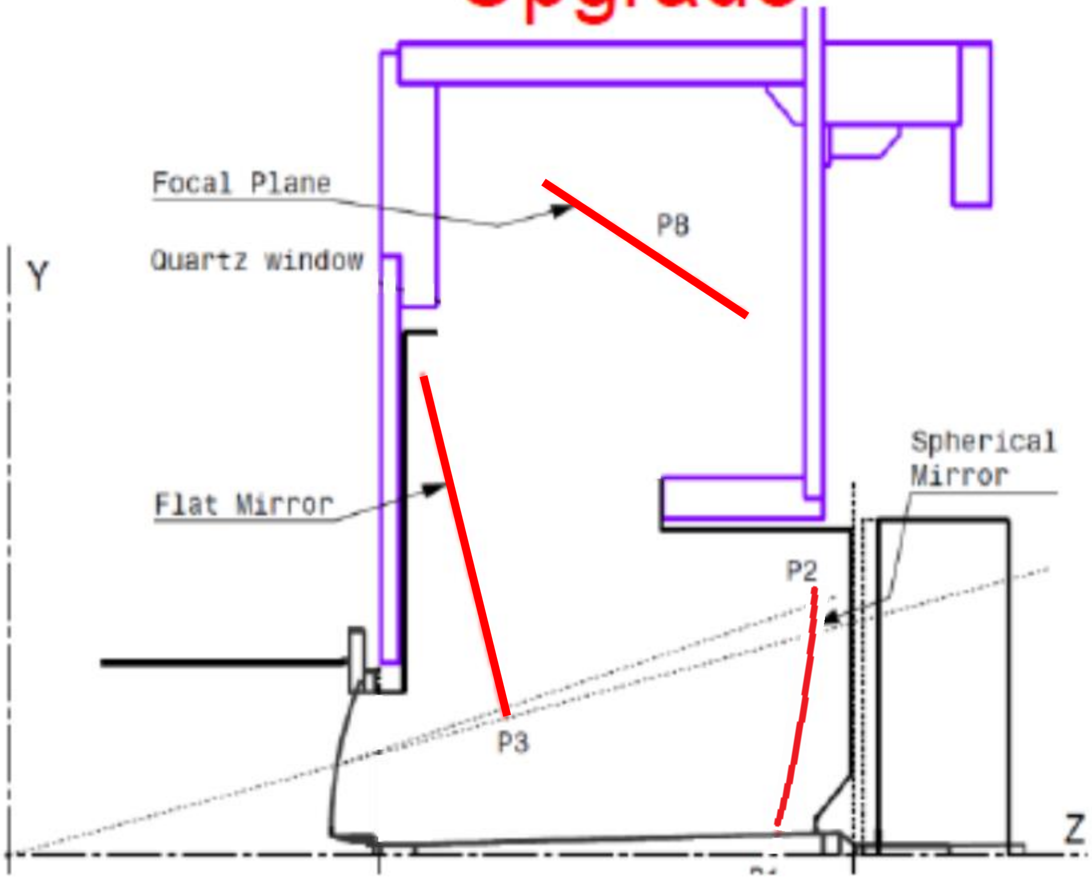
Example:

In the Upg RICH1, we are increasing the mirror focal length (x 2 Occupancy decrease).

Now


Focal Plane
Y
Quartz window
Flat Mirror
Spherical
Mirror
250 mrad
Z

Upgrade



Focal Plane
Quartz window
Flat Mirror
Spherical Mirror
PB
P2
P3
Y
Z

With Luminosities increasing and Physics Reach extending

1. Occupancies jump up: improve granularity;

$$\frac{A_p}{A_i} \propto \frac{A_p}{f^2}$$

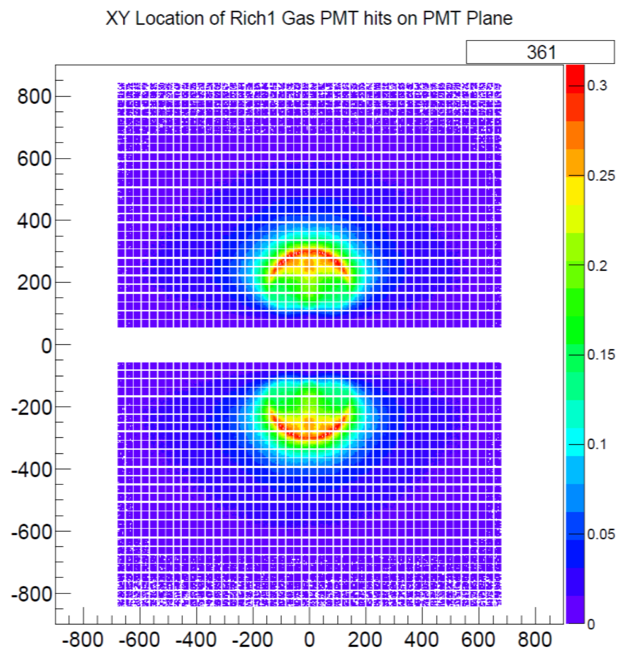
A_p is the pixel area
A_i is the image area
f is the mirror focal length

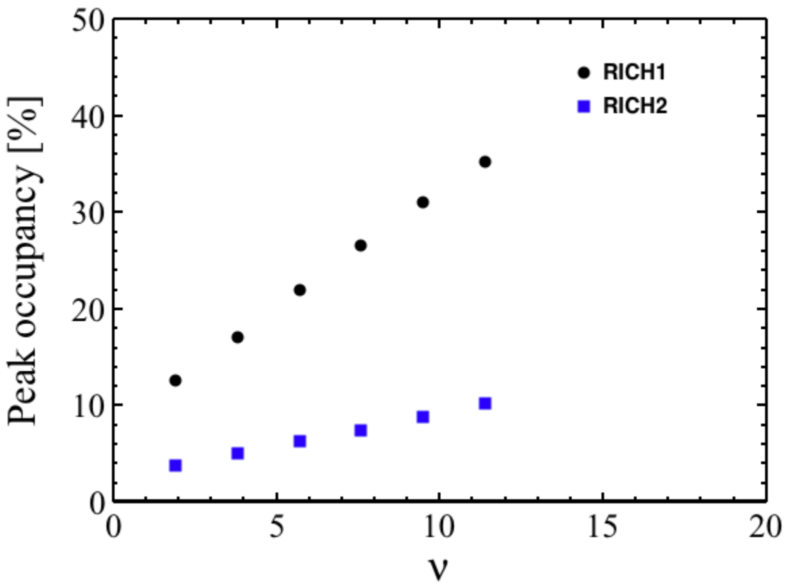
In the Upg^2 RICH1, we will decrease the pixel area (from ~7mm^2 to 1mm^2) and have a 2-bits electronics.

Time resolution (time granularity) will also help disentangle busy events ...

Going to 10^{34} increases occupancies on both RICH 1 and 2

At a ν = 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=6.3mm², f=1.35 m
Upg.	½ 2 x 30%	A_p=6.8 mm², f=1.9 m
Upg.²	$^1/_{7.5}$ 10 x 30%	A_p=1 mm², f=2 m

With Luminosities increasing and Physics Reach extending

2. Pattern recognition a challenge:

Granularity is a necessary but not sufficient condition to ensure pattern recognition: improve the single photon Cherenkov angle resolution. After lengthy calculations (☺)*,

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

Essentially keep this smaller than the pixel size!!

For Upg[2], $\sigma_\vartheta \lesssim \frac{1}{2}\,mrad$

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

*and for regions with high Occupancies

Improve Cherenkov angle resolution…

σ_ϑ depends on a sum 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 $\frac{\sigma_\vartheta}{\sqrt{N}}$

ϑ_c is the Cherenkov angle
σ_ϑ is the Cherenkov angle resolution
N is the number of detected photons
A_p is the pixel area

And now a few slides to show:

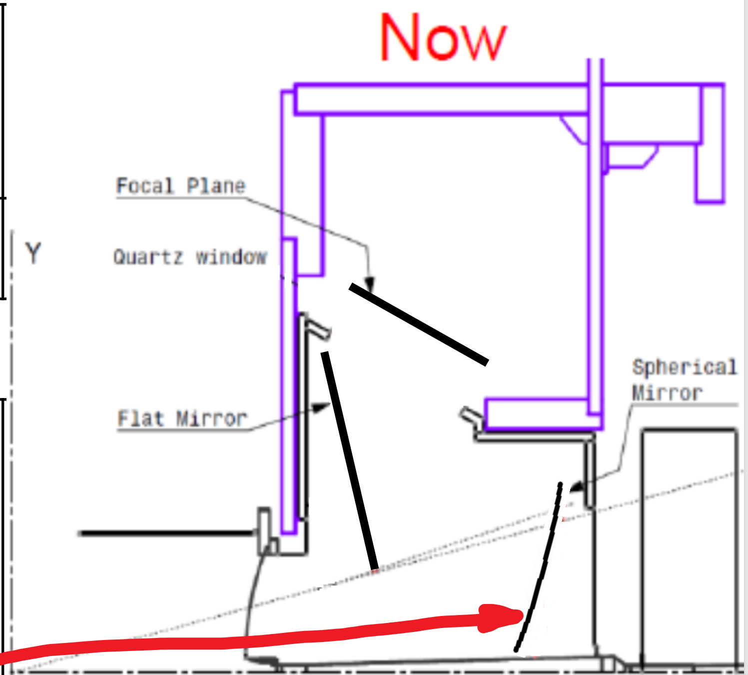
How to offer your RICH a tune-up

☺

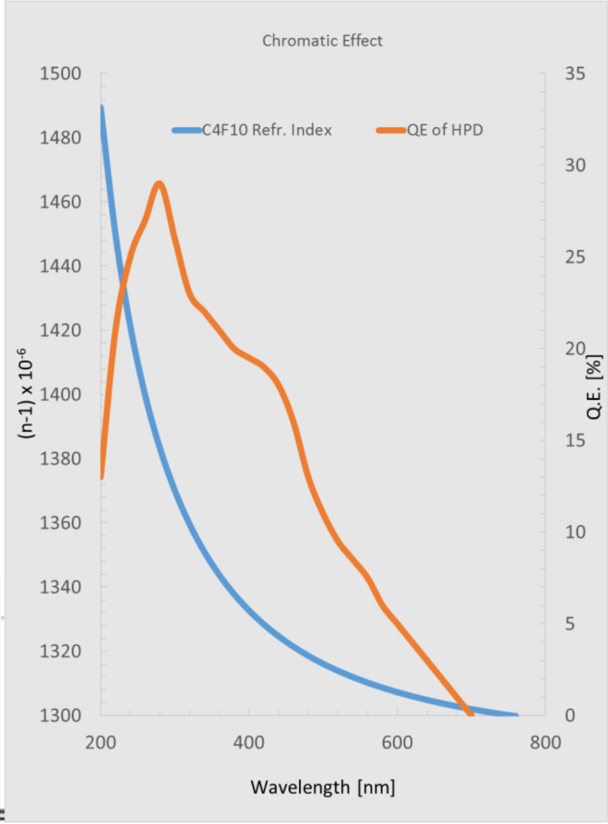
Optical Performance and Photon Yields

Lumi = 2×10^{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

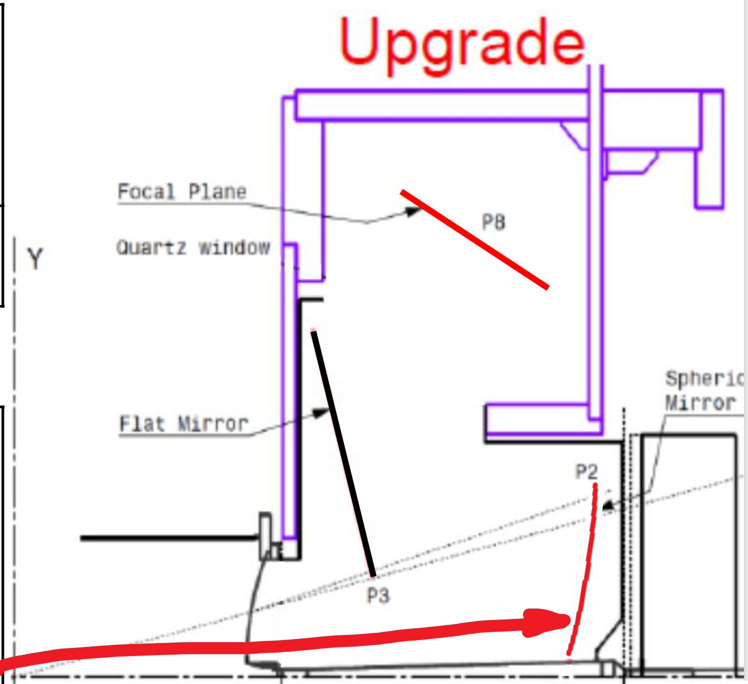


Chromatic depends on the overlap between dispersion and photodet. QE

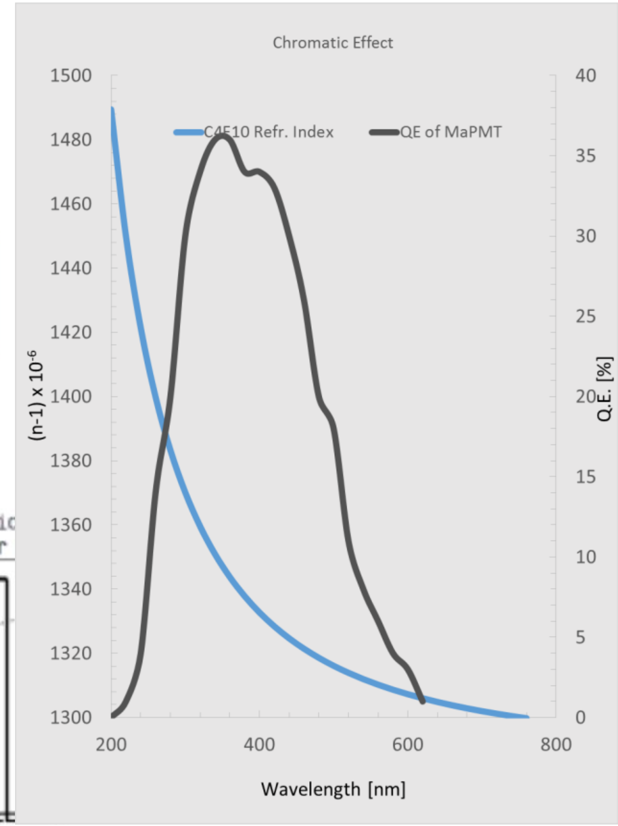
Optical Performance and Photon Yields

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

Detector Version	RICH-1 Upg
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



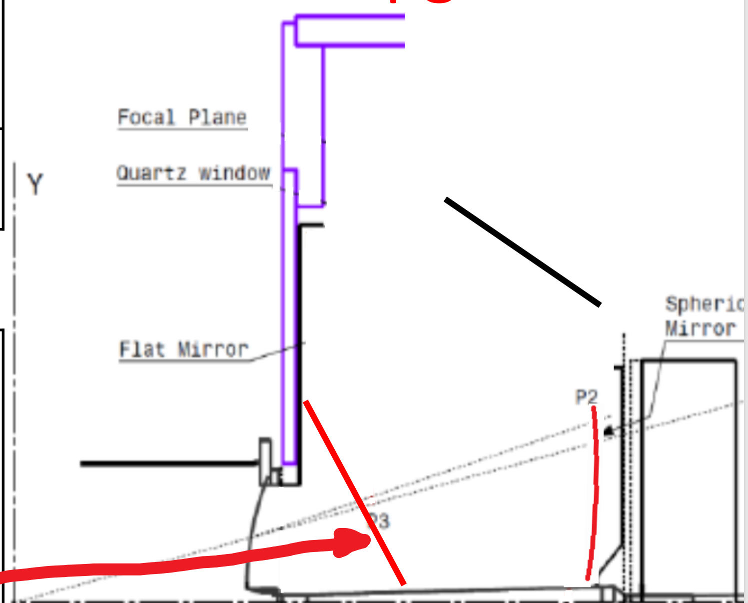
Chromatic depends on the overlap between dispersion and photodet. QE

Optical Performance and Photon Yields

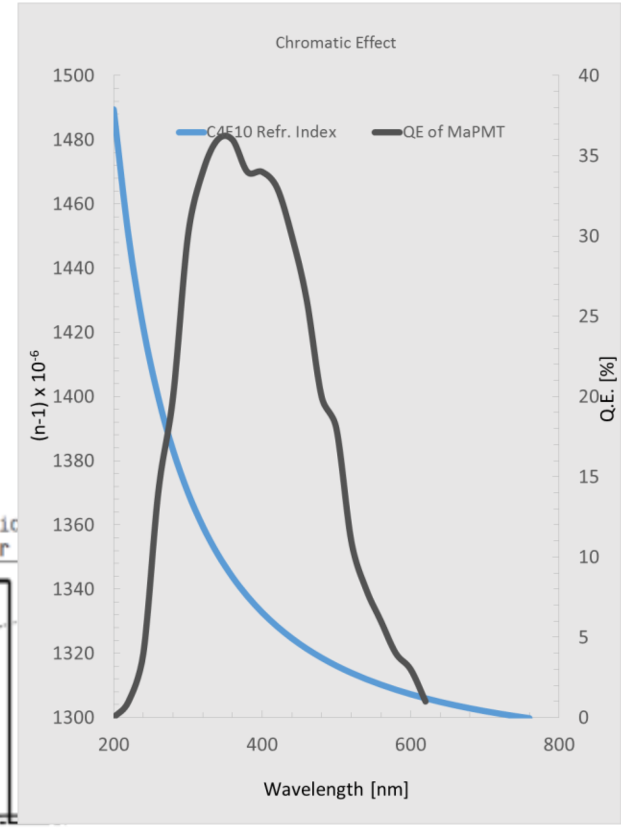
Lumi = 10^{34} cm^{-2} s^{-1} ; Occupancy > 100%

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

Upgrade²



Use lightweight flat mirror in the acceptance (reduce aberrations)



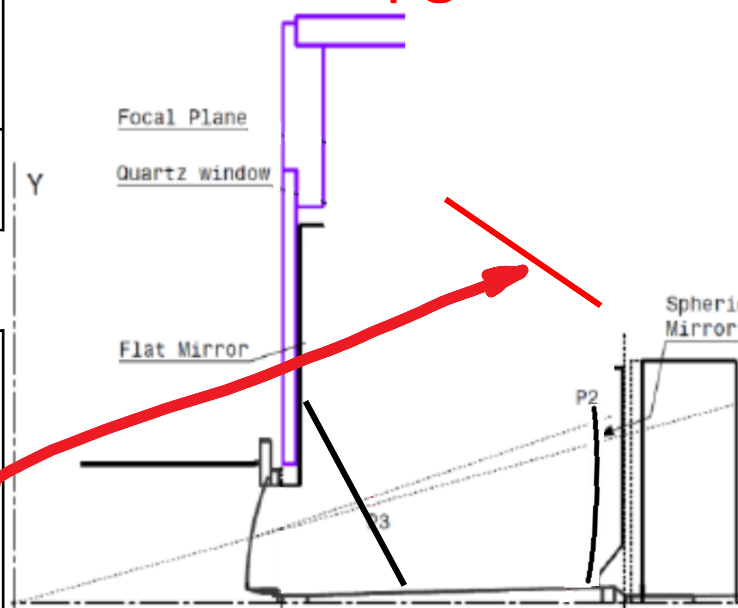
Chromatic depends on the overlap between dispersion and photodet. QE

Optical Performance and Photon Yields

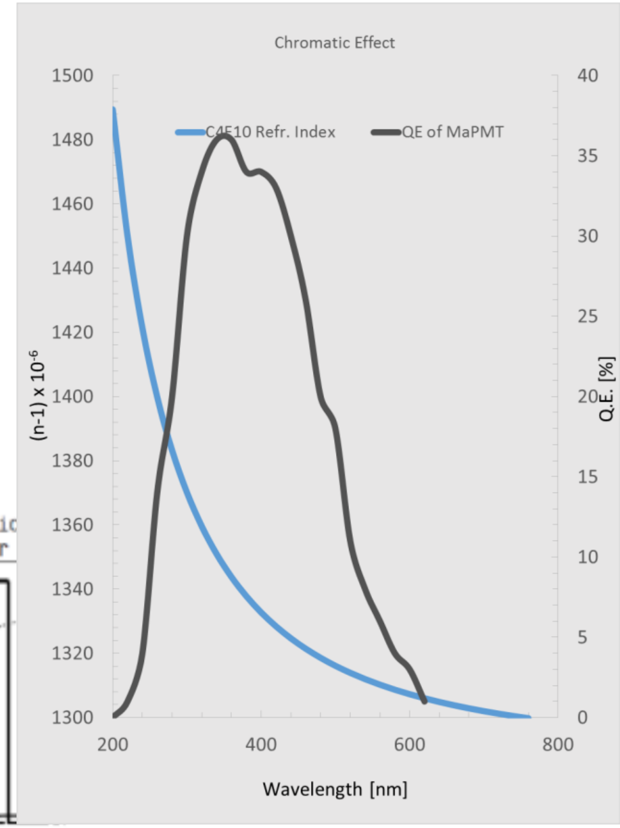
Lumi = 10^{34} cm^{-2} s^{-1} ; Occupancy < 30%

Detector Version	RICH-1 Upg^2
Avr. Phel. Yield	
Single Photon Errors [mrad]	
Chromatic	0.58
Pixel	0.15
Emission Point	0.1
Track resolution	?
Overall	0.6

Upgrade^2



Reduce pixel size to ~1mm



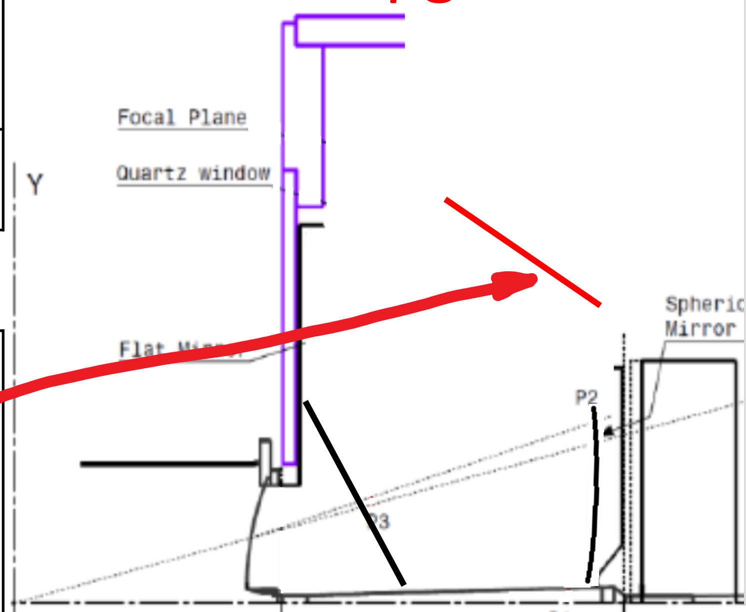
Chromatic depends on the overlap between dispersion and photodet. QE

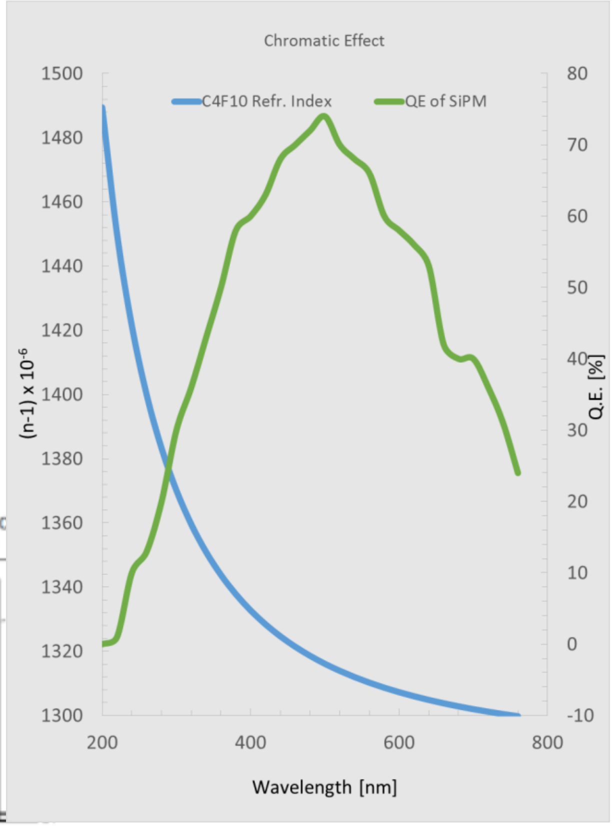
Optical Performance and Photon Yields

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

Detector Version	RICH-1 Upg^2
Avr. Phel. Yield	60 - 40
Single Photon Errors [mrad]	
Chromatic	0.24
Pixel	0.15
Emission Point	0.1
Track resolution	?
Overall	0.3

Upgrade^2





Reduce chromatic by choosing a photodetector with a "red-shifted" QE curve (and eventually filter the short wavelengths)

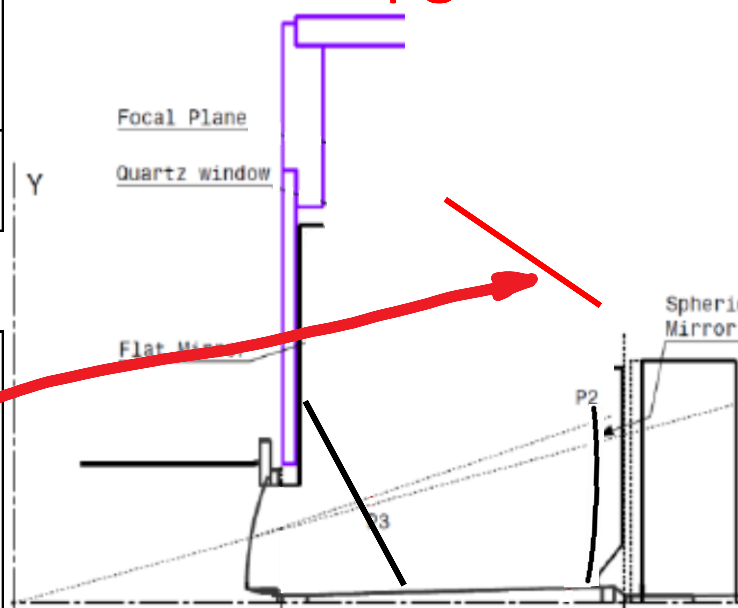
Chromatic depends on the overlap between dispersion and photodet. QE

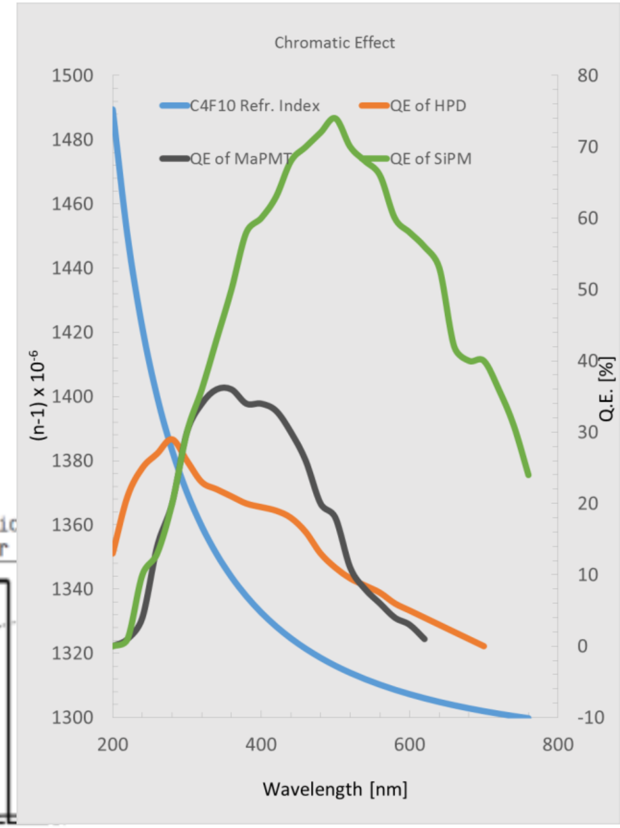
Optical Performance and Photon Yields

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

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

Upgrade²





Reduce chromatic by choosing a photodetector with a “red-shifted” QE curve (and eventually filter the short wavelengths)

Chromatic depends on the overlap between dispersion and photodet. QE

Optical Performance and Photon Yields (very preliminary)

Radiator	C_4F_{10}			CF_4	
Detector Version	RICH-1 Current (HPD)	RICH-1 Upgraded	RICH-1 Upg[2]	RICH-2 Upgraded	RICH-2 Upg[2]
Avr. Ph.Electron Yield	25 (30)*	40 (rms=8)	60 - 40	22 (rms=5)	30
Single Photon Errors [mrad]					
Chromatic	0.84	0.58	0.24 – 0.12	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) [2]

With Luminosities increasing and Physics Reach extending

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

Provide the system with intrinsic time resolution and synchronism

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

and ~50 to 150 ps (time resolution with ~40 detected photons, synchronism)*

*with low optical aberrations all Cherenkov photons get on the focal plane at the same time

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

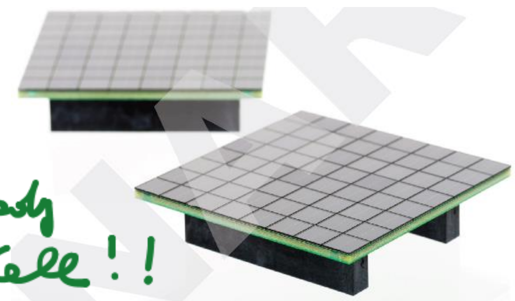
Get rid of the magnetic shieldings by using B insensitive photodetectors
for example: SiPM or MCP tubes
Increase granularity from ~3mm (present) to 1mm and optical focal length
factor ~10 decrease in occupancies
Improve optical error,
by moving light-weight flat mirrors into the acceptance,
by further reducing mirror tilts
Further reduce chromatic error
by tuning the gas
by further moving the photon sensitive region towards the red
by increasing photodetector QE
for example: SiPM
Provide the system with 2-bits readout electronics

Provide the system with intrinsic time resolution and synchronism

Work on specific pattern recognition algorithms

To start a serious activity on this, we plan:

New SiPM from Sensl
8x8 pixels, 3x3 mm



To start a specific R&D on cooled single-photon-capable SiPM
(we would profit a lot from present SciFi activities);

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

Continue the R&D on light-weight mirrors

Collaborators from institutes are willing to explore specific 2-bits and high time resolution readouts for SiPM (the CLARO chip was devised at the beginning for this application).

CERN, RAL and Genova have started simple simulations.

A DAQ and specific space-time pattern recognition activity should also start….

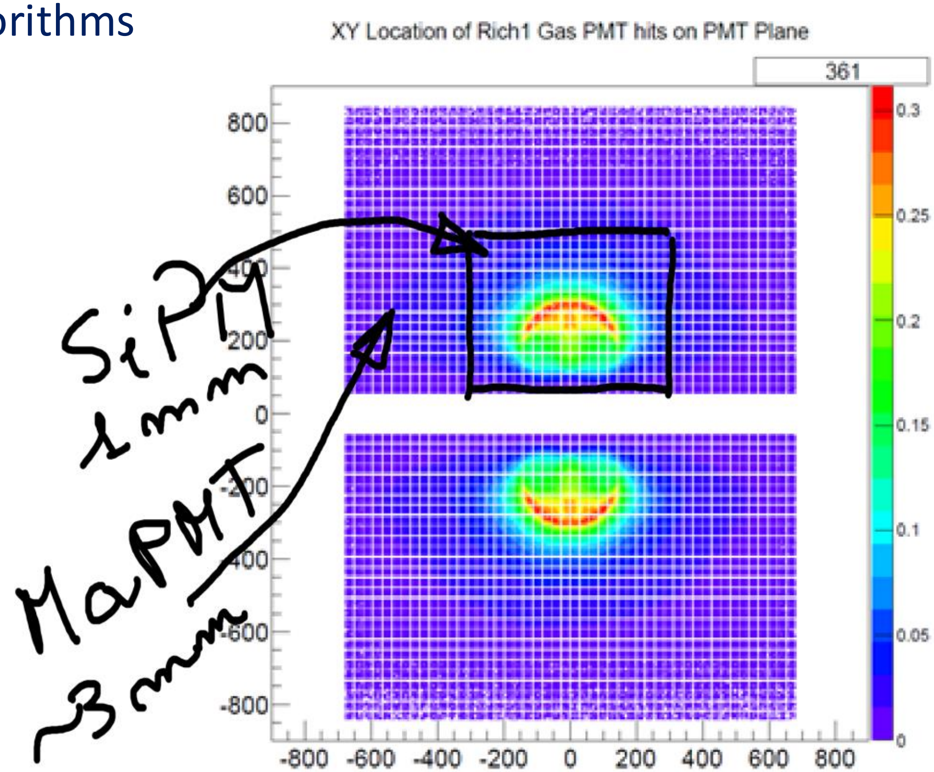
…. If we want to be ready for LS3!!

… If we want to be ready for LS3!! …

Only in the central regions of RICH 1*:

- Increase granularity from ~3mm (present) to 1mm
- Reduce chromatic error and increase QE by using SiPMs
- Provide the system with 2-bits readout electronics
- Provide the system with intrinsic time resolution and synchronism
- Work on specific pattern recognition algorithms

- Keep same geometry and mechanics, evolve electronics, cool the SiPM plane



All marked in red needs R&D!!

* I would not exclude the whole array …

Conclusions

“The politics of small steps may nicely reward the patient one”, (from an old chinese saying)

… especially if there is no other choice!