LHCb RICH Proposal for Upgrade Ib and II

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Link to the UPG2 RICH meeting: https://indico.cern.ch/event/881465/

Introduction

The RICH System in Upgrade II

Strategy towards Upgrade II

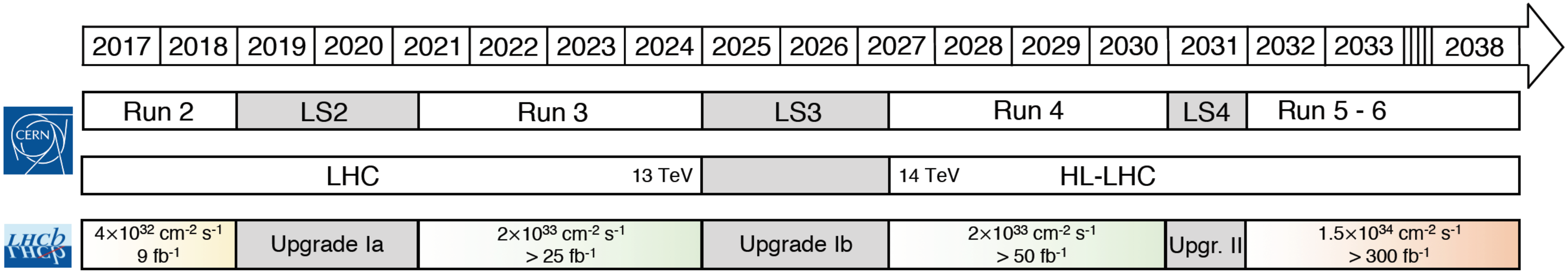
Upgrade Ib

Conclusion

Spares

* On behalf of many collaborators from the LHCb RICH Team

Evolution of the LHCb RICH System for Phase II



In the LHCb roadmap … :

Upg Ia 2021 sees the first upgrade of the RICHes and LHCb (x10 10^{32} Lumi);

Upg Ib (LS3, between 2025 – 2027* included) 2028 sees a consolidation;

Upg II (LS4, 2031) 2032, a major possible upgrade (HL-LHC, x100 10^{32} Lumi).

The main question to answer is still: what do we do in Upg Ib and what in Upg II?

* This corresponds in time to ATLAS and CMS Phase II upgrade

Proposal for Upgrade II

Run 5, 25 ns, up to 1.5 x 10^{34} cm^{-2} s^{-1}, 2032 onwards

Strategy

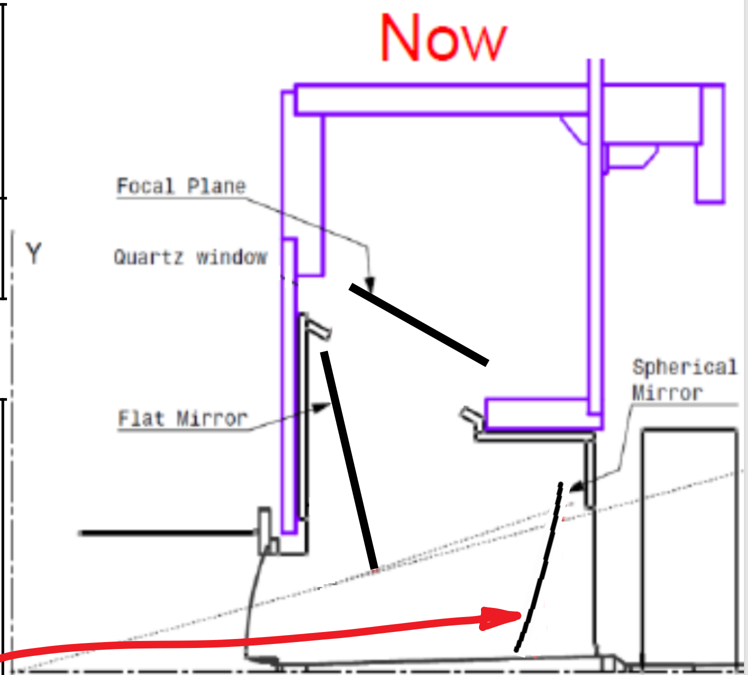
- Keep peak Occupancies (time and space) < 30%
- Improve Single Photon Cherenkov Angle precision to < 0.5 mrad
- Provide the system with timing capabilities (event gating and photon ToD*)
- Provide the frontend electronics with a 2-bits-like logic
- Profit as much as possible from the unique property of our RICHes, that is the common arrival time of photons
- Provide RICH1 and RICH2 with green gases** (or a leak-less system…)

*ToD = Time of Detection
** This is becoming an extremely important issue. New options open up if we are sensitive in the green ….

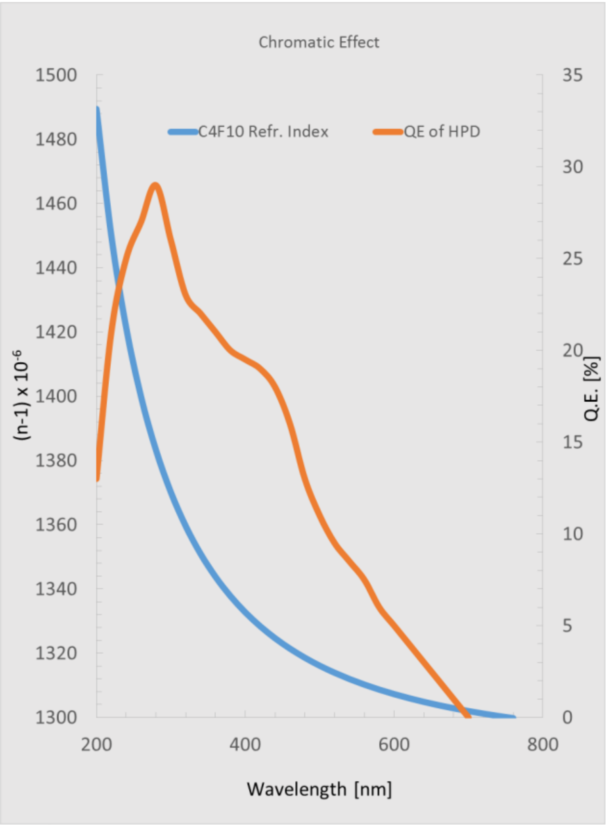
Optical Performance and Photon Yields

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

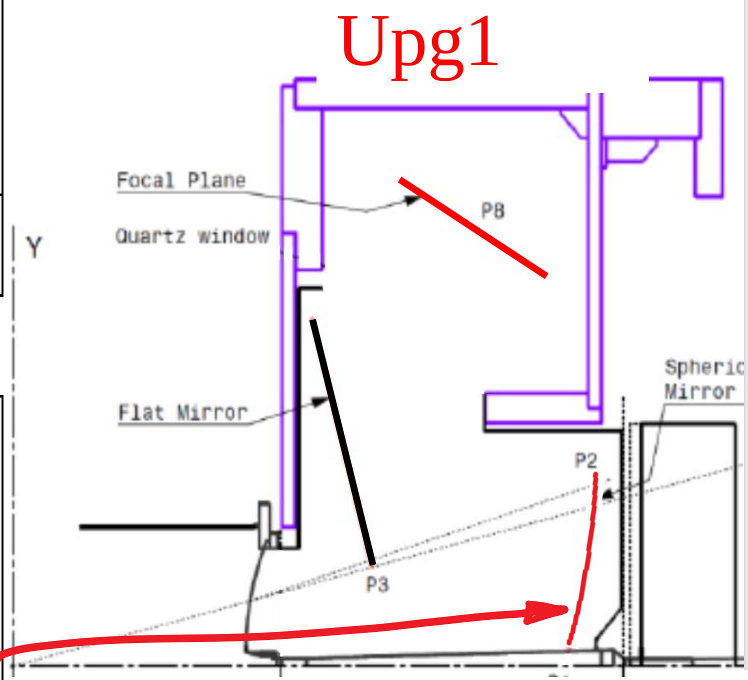


Chromatic depends on the overlap between dispersion and photodetector QE

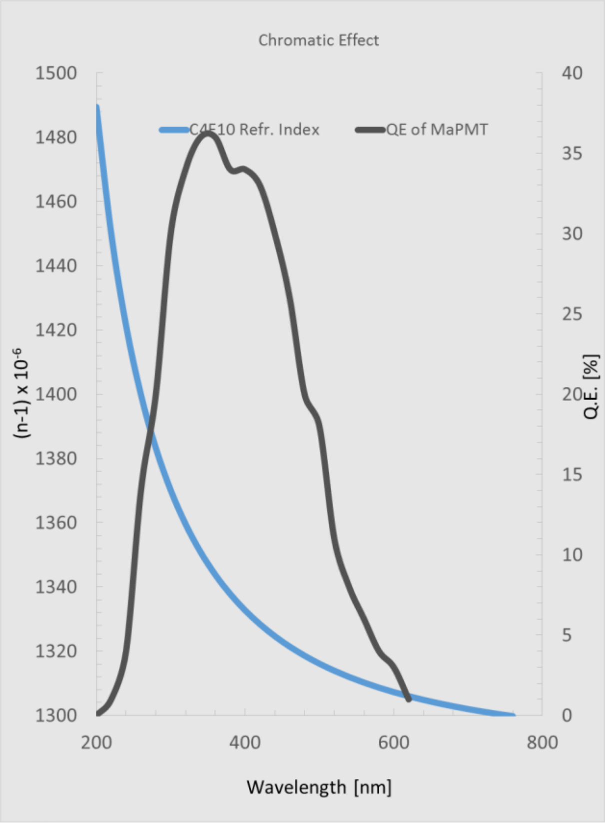
Optical Performance and Photon Yields

Lumi $\leq 2 \times 10^{33}$ 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



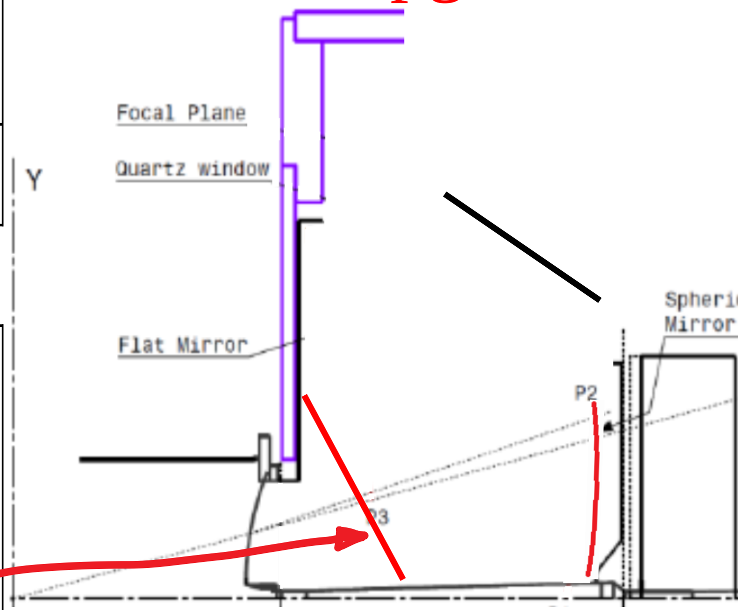
Chromatic depends on the overlap between dispersion and photodet. QE

Optical Performance and Photon Yields

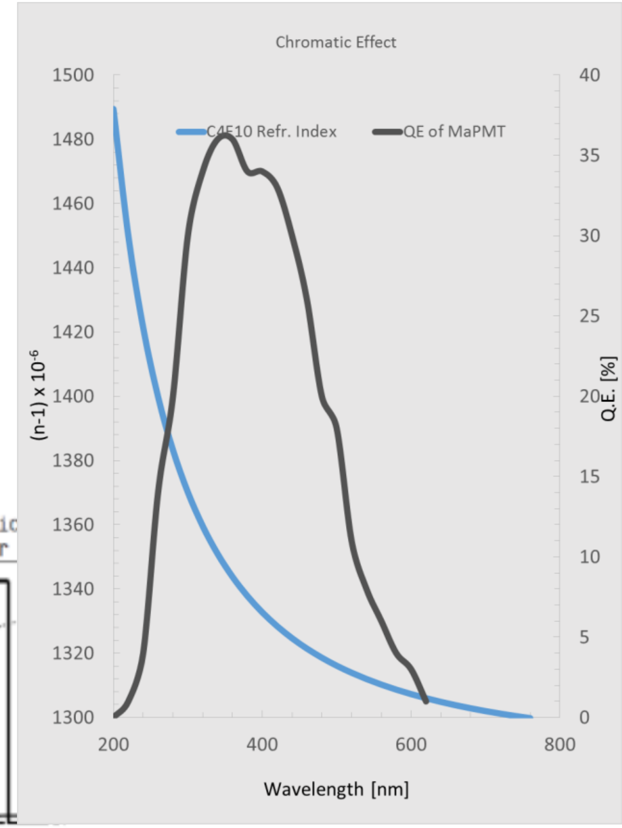
Lumi = 10^{34} cm^{-2} s^{-1} ; Occupancy > 100%

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)

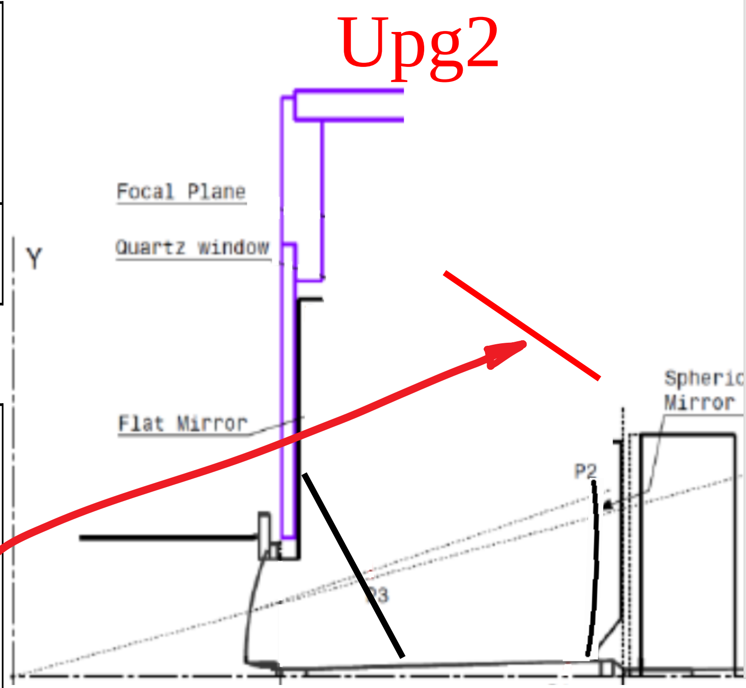


Chromatic depends on the overlap between dispersion and photodet. QE

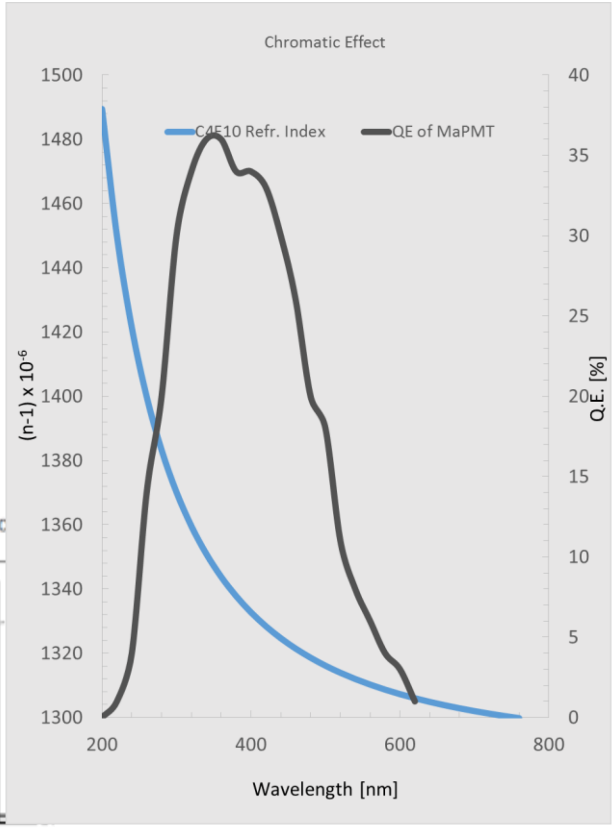
Optical Performance and Photon Yields

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



Reduce pixel size to ~1mm



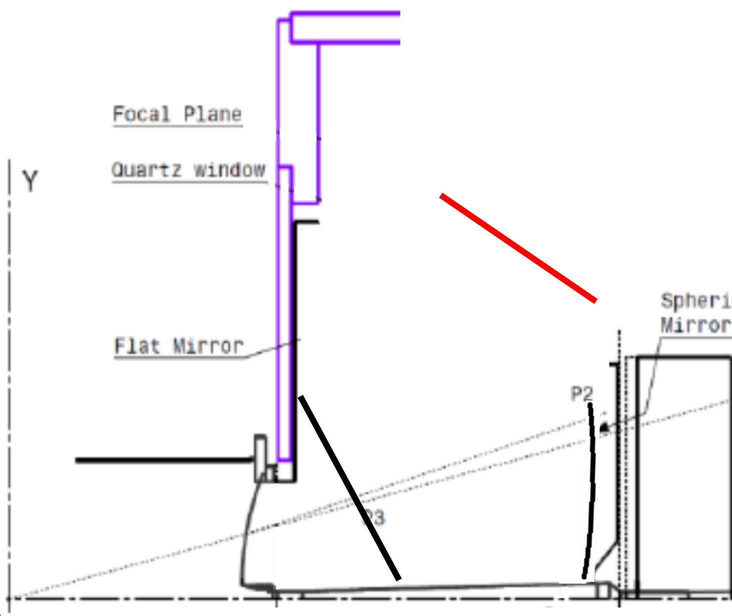
Chromatic depends on the overlap between dispersion and photodet. QE

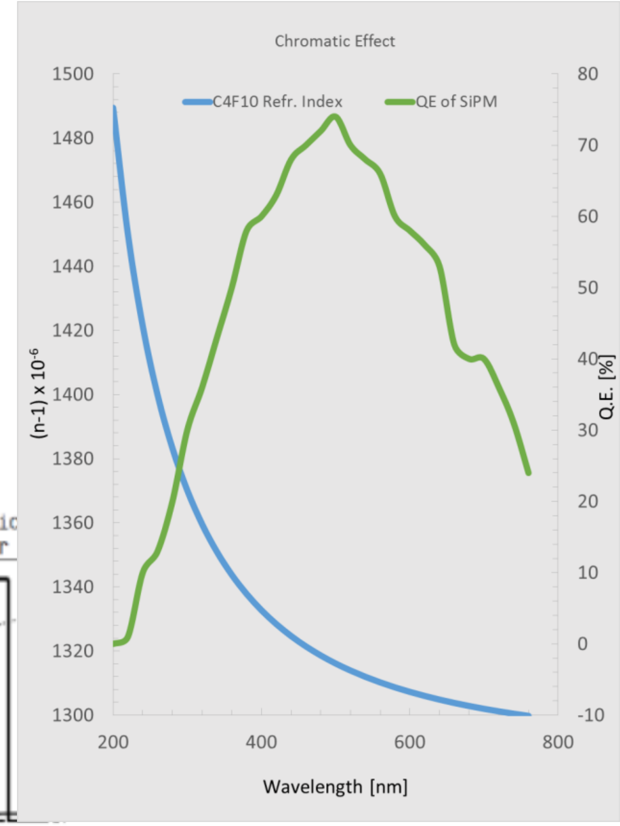
Optical Performance and Photon Yields

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

Detector Version	RICH-1 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)

Chromatic depends on the overlap between dispersion and photodet. QE (this example of a SiPM QE is rather from literature than realistic, QE between 50% and 60% would be closer to reality)

Simulated Optical Performance and Photon Yields

For Upg2, $\sigma_\vartheta \lesssim 0.5mrad$ (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)

Back-on-the –envelope performance improvement @ high momenta

	OLD	UPGRADE Ia	UPGRADE Ia	UPGRADE II	UPGRADE II
p_{max} [GeV/c]	HPD, N_{phel}=17, CF_4, σ=0.67	MaPMT, N_{phel}=25, CF_4, σ=0.50	MaPMT, N_{phel}=22, CO_2, σ=0.50	SiPM, N_{phel}=25, CO_2, σ=0.2	SiPM, N_{phel}=25, CO_2, σ=0.13
$n_{3\sigma k\pi}$	85	109	108	177	235
$n_{3\sigma kp}$	144	183	182	297	396
$n_{3\sigma\pi p}$	167	213	212	346	460

The recipe ☺

Improve space and time resolutions

- Increase granularity and/or provide a 2-bits-/double-discri-like readout electronics
- Provide the system with a ToT frontend ASIC followed by a TDC

Improve optical uncertainty,

- by moving light-weight flat mirrors into the acceptance
- by further reducing mirror tilts

Further reduce chromatic uncertainty

- by tuning the gas
- by further moving the photodetector sensitive region towards the green
- by increasing photodetector QE

Work on new and specific pattern recognition algorithms

Get rid of the magnetic shielding by using B-insensitive photodetectors

We propose to get to Upg2 in two main Stages:

- -U1b:
  - Change of the complete electronics chain from the front-end to the digital board: the same electronics (or a close evolution of it) would be used in Upg2;
  - Leave untouched optics and mechanics systems, LV, HV systems, modularity and services;
  - Gas systems could also be improved (new green gases and/or leak-less systems).
- -U2:
  - Change everything else (see previous slides).

-U1b:

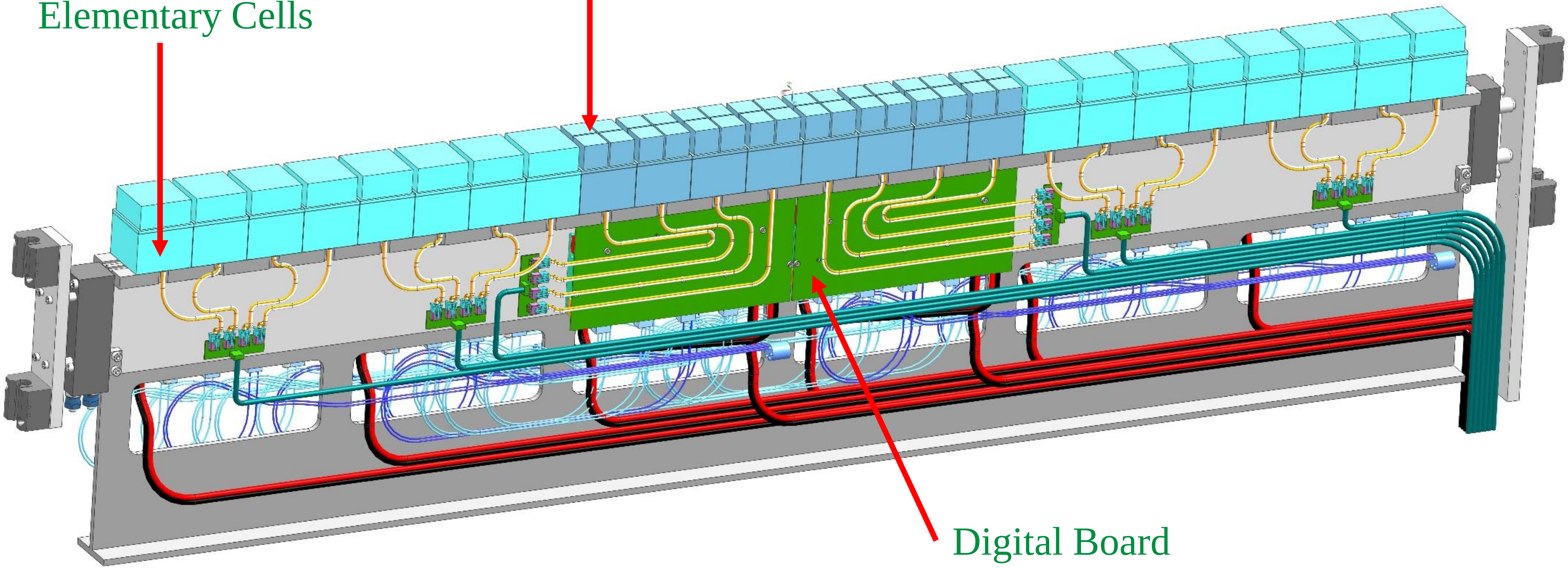
- Change of the complete electronics chain from the front-end to the digital board: the same electronics (or a close evolution of it) would be used in Upg2;
- This new electronic chain would provide:
  - ns gating, 2-bits(?);
  - O10 ps time resolution;

  by applying a ToT readout ASIC, a TDC and a new Digital Board and Optical Links;

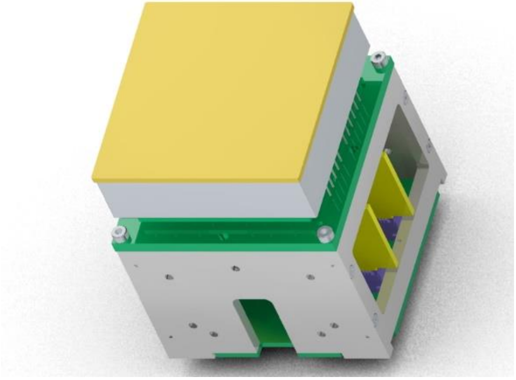
- Leave untouched optics and mechanics systems, LV, HV systems, modularity and services;
- Gas systems could also be improved (new green gases and/or leak-less systems).

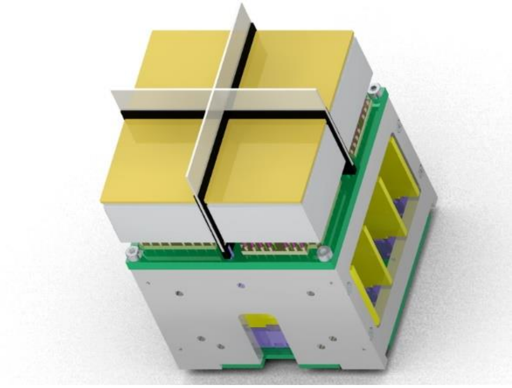
Example

A column with all components
and services is shown here



Elementary Cells (H- and R- Type)
contain all the components needed to deliver our photonic images:
from the MaPMTs,
to the analogue-to-binary front-end electronics.

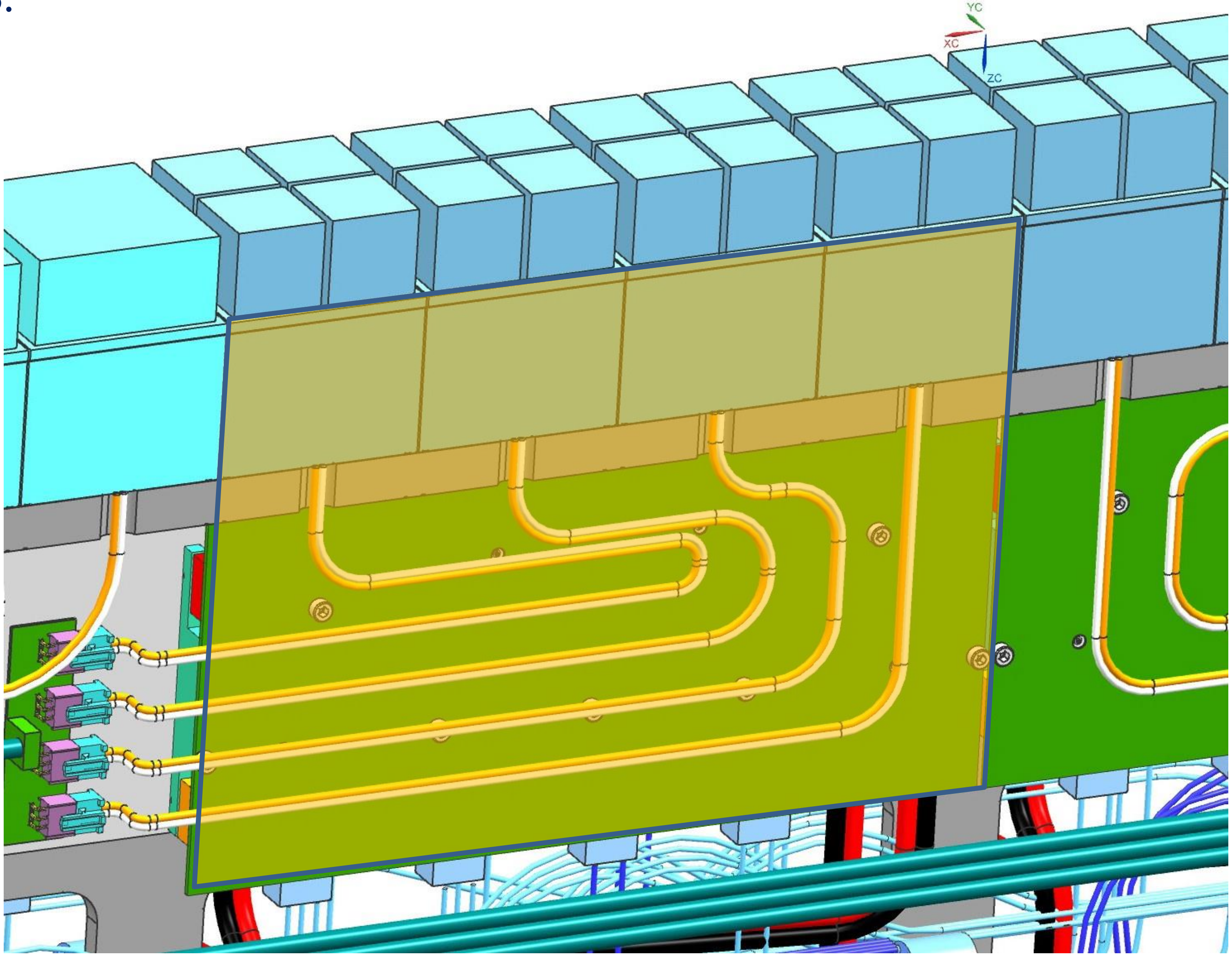




Mechanically stable, cooled and easy to maintain.
In total 1052 ECs for both RICHes (122880 channels only in RICH1).

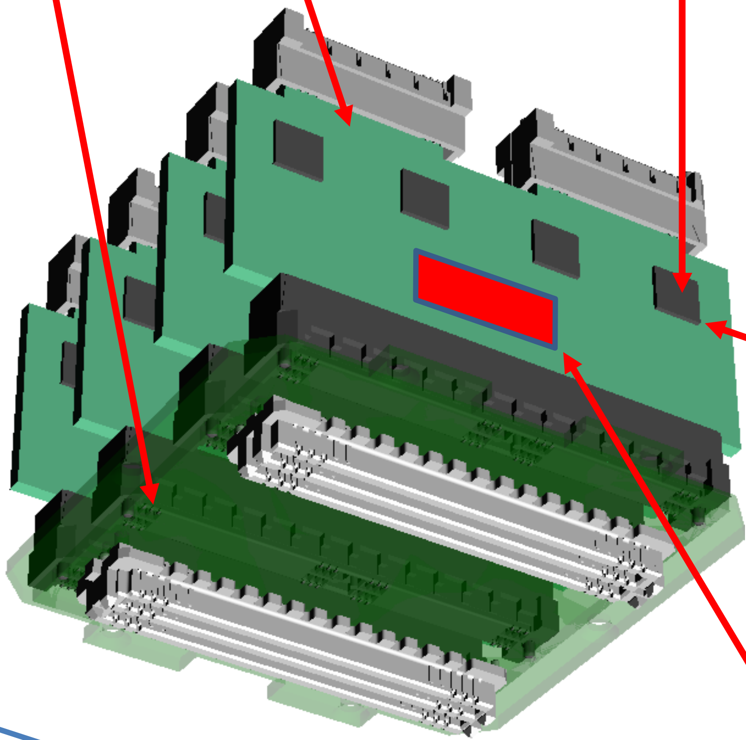
A Section of a RICH Column, showing a
Photon Detector Module (PDM) and services

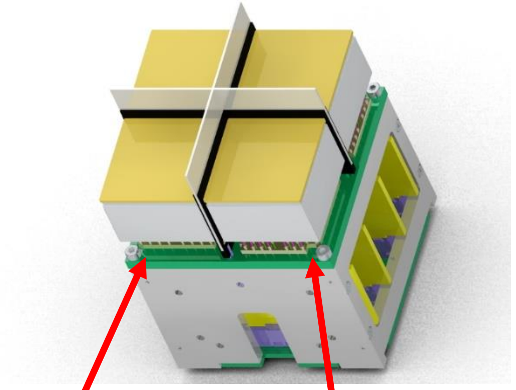
Change the whole electronics components of the Photon Detector Module (PDM), from the CLARO to the PDMDB.



Same geometry based on FEBs, each hosting a TDC with 64 channels.

Front-End Boards with mounted new ASICs and Backboard





Baseboard

Note the ASICs are placed as close as possible to the single-photon signal generation (only a few millimeters from the MaPMTs anodes)

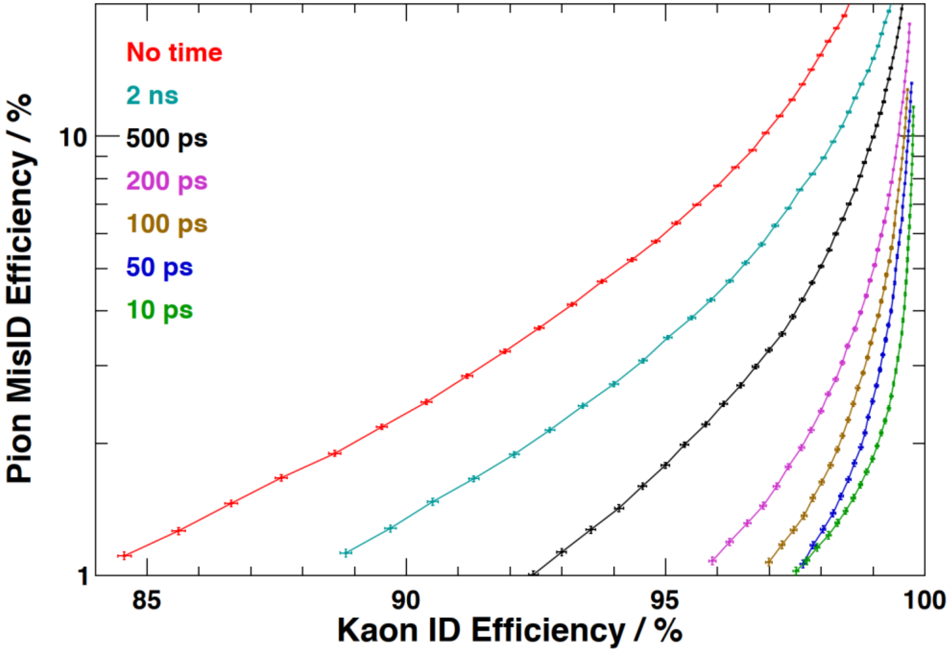
Lateral EC Size = 55 mm

Add a 64-channels TDC, possibly on the FEB

Advantages of this approach

- Improve PID performance and physics throughput during Run IV;

Particle ID performance simulation for the Run 4 / Upgrade Ib detector



The absolute numbers are preliminary, but the trend is clear: the application of a time gate during Run 4 can improve the particle ID efficiency.

However, these particle ID curves assume knowledge of the Primary Vertex time.

03/02/2020 Floris Keizer 5

Advantages of this approach

- Improve PID performance and physics throughput during Run IV;
- Get the electronics components ready in advance for Upg2;
- The improvements versus the costs (est.: between 1 and 2 MCHF) are very favorable;
- The timing electronics scheme is "classic" but new prototype components are already available for testing (fast-IC and pico-TDC)*;
- First ever time-resolved (gaseous) RICH detector and a very interesting project;
- Possibility to develop new software techniques and simulations with present improved tools (remember the luminosity in Run IV remains the same as in Run III);
- Independently, tests of new green gases as equivalent Cherenkov radiators and leak-less system (applied for example to RICH1 gas system, RICH2 would be using CO_2 instead) can also take place;
- It will be ready in 5 years, nice project for young (and less young) people

* Barcelona (David Gascon) and CERN

In parallel …

…preparation for Upg2 would continue with:

Full simulations with new optical schemes (and without the shielding…);

Photodetector development, tests and choice;

New optoelectronic chain geometry (compatible with cooling);

New mechanics (and cooling) systems;

New light-weight optics for both RICHes;

Development of micro-lenses array;

New green extended photocathodes;

Neutron shields;

DAQ aspects (compression, bandwidth, format, etc);

PID aspects (global algorithm, others?);

Study the long-term behavior and characteristics of the system;

Possible first prototype to be inserted in the RICH system already during LS3 …

…..

Conclusions

Our RICH community has been having meetings for 4 years now, the main focus being Upgrade II (LS4).

What could we already prepare for LS3?

- We propose to integrate a new electronic chain to the present system!

(Fast-IC* and pico-TDC, are available and could be a good starting point)

- Cost is limited with many advantages expected;
- Synergies with CALO and TORCH on the electronic chain;
- Nice 5-years project.

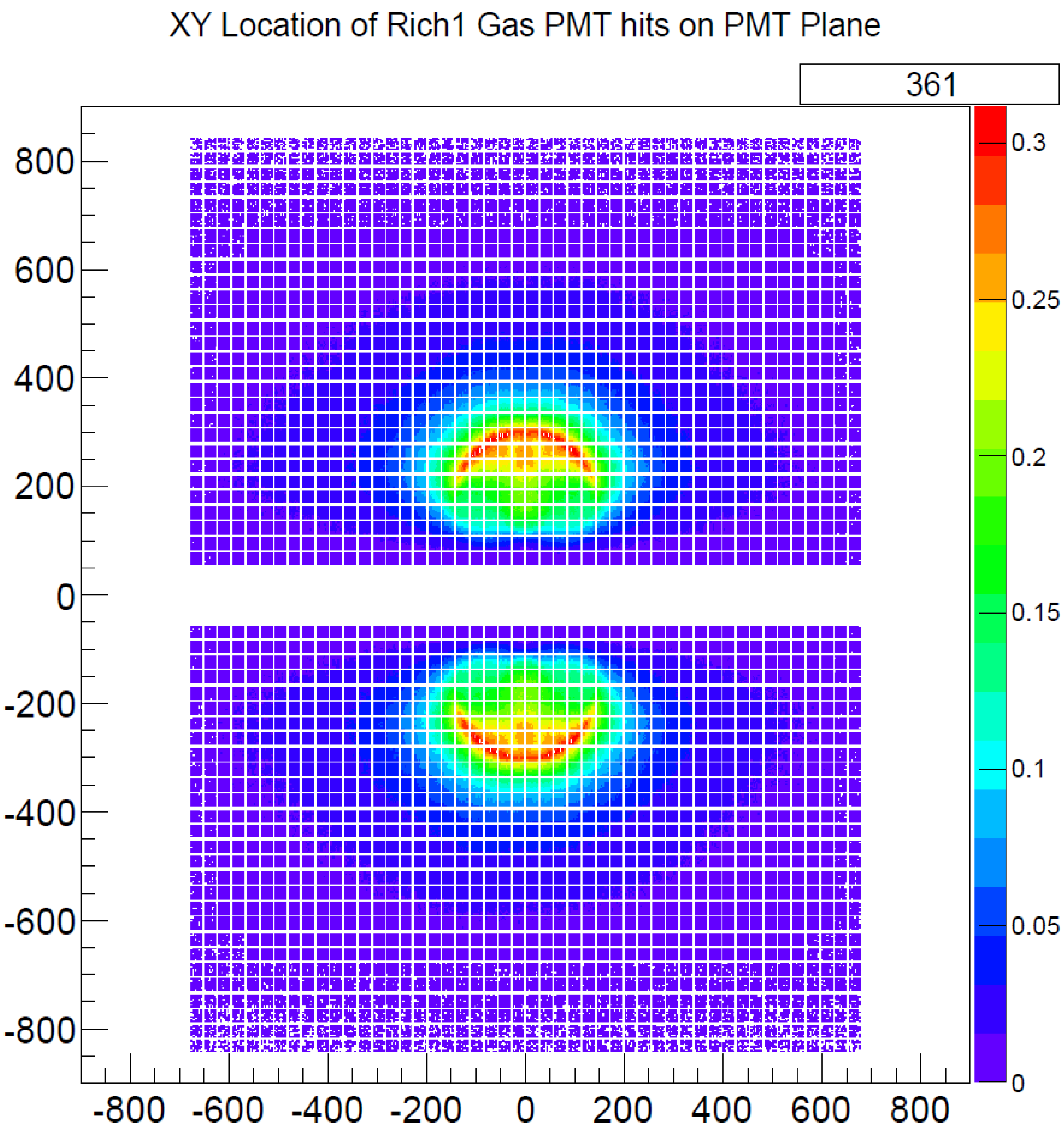
However, remember, we have no choice, we need a new RICH System for LS4:
a lot of sw and hw R&D to produce and a prototype to readying for LS3.
CERN and UK have already put a bid (for R&D).

Time frame for Documentation:
For LS4, a framework TDR is expected for the beginning of 2021; for LS3 specifically, full TDRs are expected towards the end of 2021.

Together with the rest of this PID session, to complement my and Floris Keizer presentations, please look at:
Kazu Akiba (VELO Sensors) and Guido Haefeli (SciFi Sensors) excellent talks and my spare slides

*https://indico.cern.ch/event/881465/contributions/3713929/attachments/1982352/3301734/20200205_FastIC_Ballabriga_LHCb_final.pdf

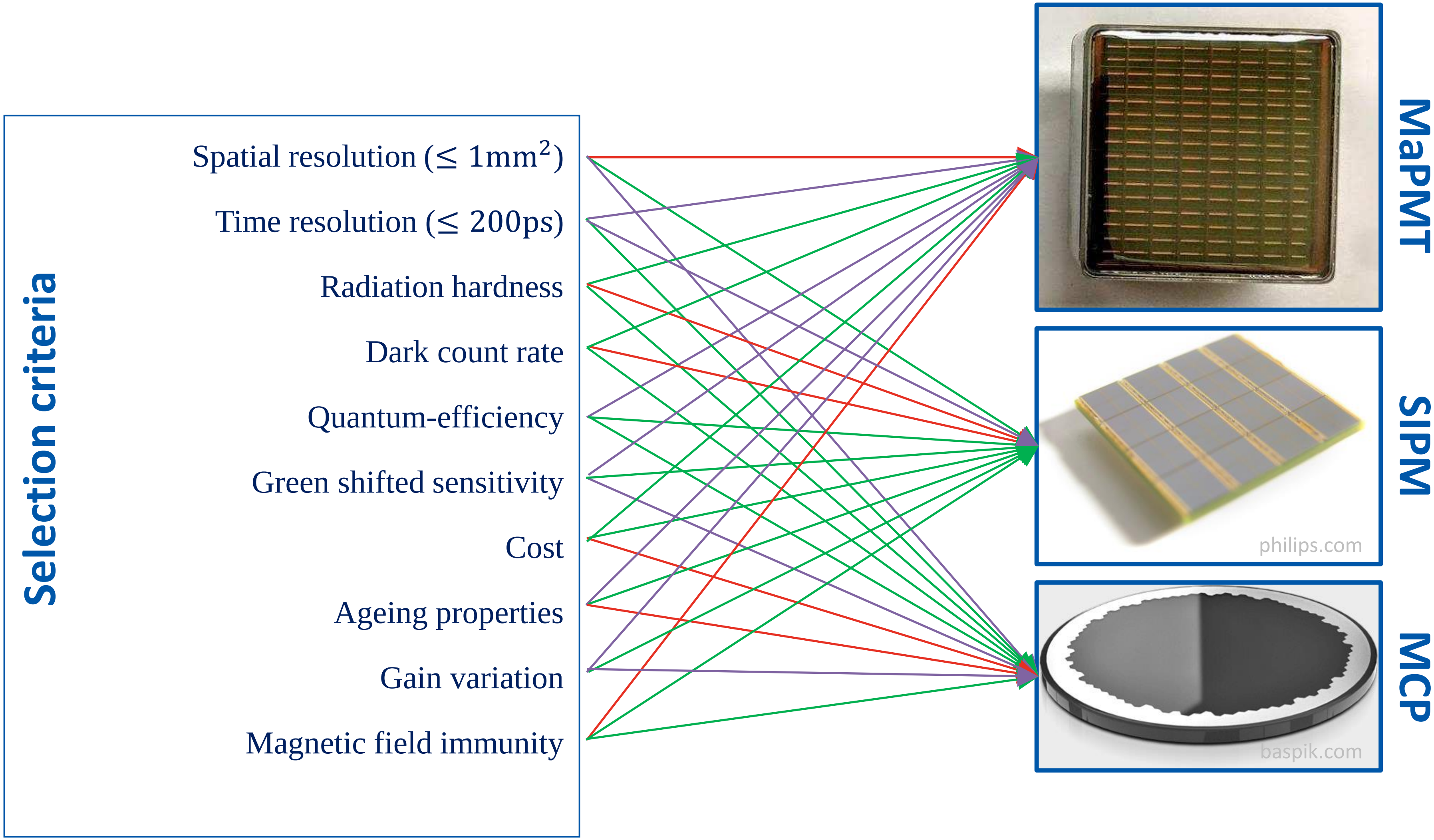
SPARES



RICH occupancy distribution is extremely non-uniform: the region with O>10% is ~10% of the whole det. plane

10%

Possible photodetectors (from Michele Blago)



Work is starting At Edinburgh University for MCPs and LAPPDs

Future R&D plans

- **Edinburgh photon detector lab**
  - Existing setup to measure time resolution
  - Measurements made with
    - LAPPD – ANL prototype tiles
    - Photek MCP-PMT
    - SiPMs - time resolution consistent with expectation
- **Next steps**
  - Ordered new picosecond laser diode < 60 ps pulse width
  - acquire 8"x8" LAPPD for Watchman with Sheffield University
- **Planned measurements with LAPPD**
  - Time resolution
  - Position resolution
  - B – field dependence
  - ...

Work carried out by undergraduate students

Work is starting At Edinburgh University for MCPs and LAPPDs

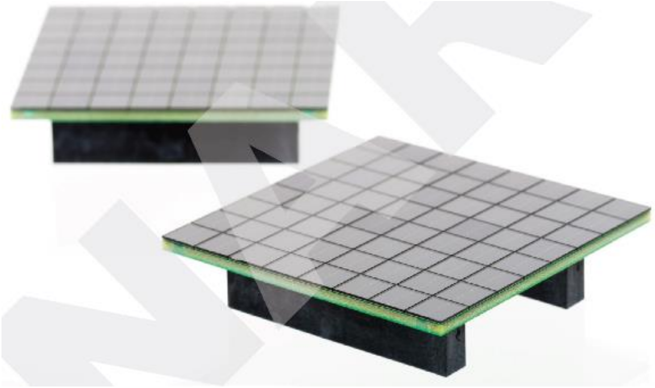
Future R&D plans

- **Pixellated Cathode**
  - Fabricate prototype
  - optimise pixels size with simulation
- **Electronics readout**
  - PSEC card use by ANNIE
  - Digital board – Cambridge
  - superNino and PicoTDC @ CERN / align with TORCH plans
- **Simulations of physics gain for phase 1b upgrade**
  - Higher occupancy -> overlapping rings
  - Efficiency vs misidentification rate
  - Physics channels, e.g. Bs -> $Ds^{(*)}$ $D^{(*)}$
  - Tagging power

A word about SiPMs

+ High QE in the green, good single photon sensitivity, becoming cheap and easy to produce arrays with punchthrough technologies, insensitive to magn. field, etc

– Very sensitive to neutrons and ionizing particles;
– High dark count rates (DCR), depend on:
    - Temperature, a factor ~2 every 10 ^{o}C,
    - Surface, ~linear,
    - Structure,
    - Operational electric conditions.



1. Cool down (develop cooling and vacuum systems to host the array);
2. Use microlenses to decrease diode surface: optimize diode shape, increase array active surface and improve time resolution;
3. Gate inside the 25 ns LHC clock (1 ns or less);
4. Implement neutron plastic shields: **RICH1 will be "wrapped" in plastic, instead of iron!**

Use microlenses/light guides to decrease diode surface: optimize diode shape, increase array active surface and improve time resolution;

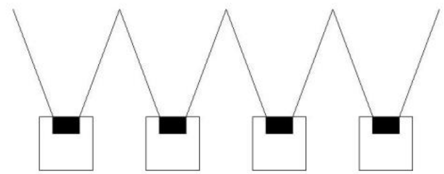
~ x8 lower noise rate

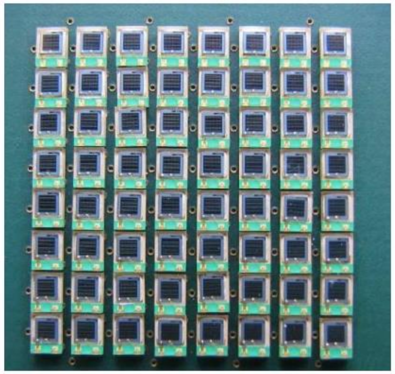
~ x2 higher yield

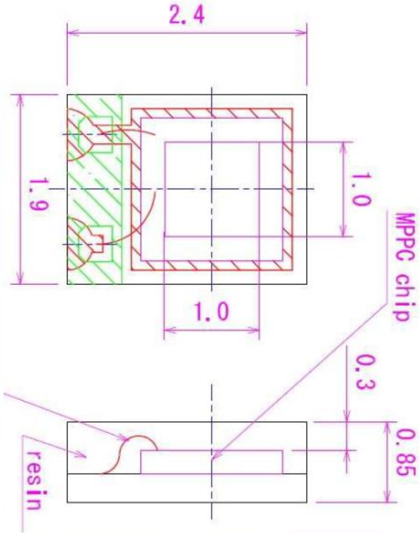
~ x2.5 better time res.

8x8 array of SMD-MPPCs

- Detector module with 8x8 array of SMD MPPCs at 2.54 mm pitch

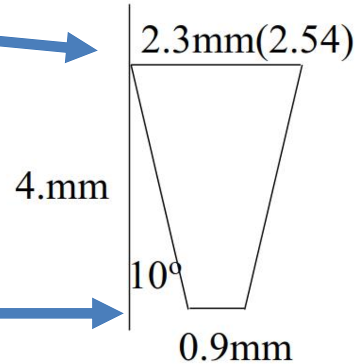


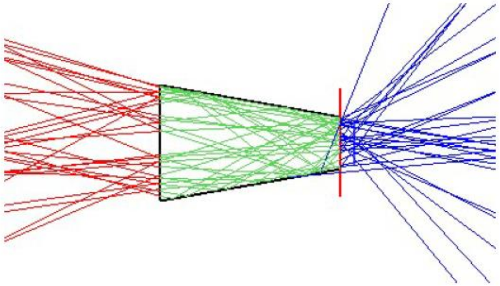




Optical pixel size

Electronic pixel size





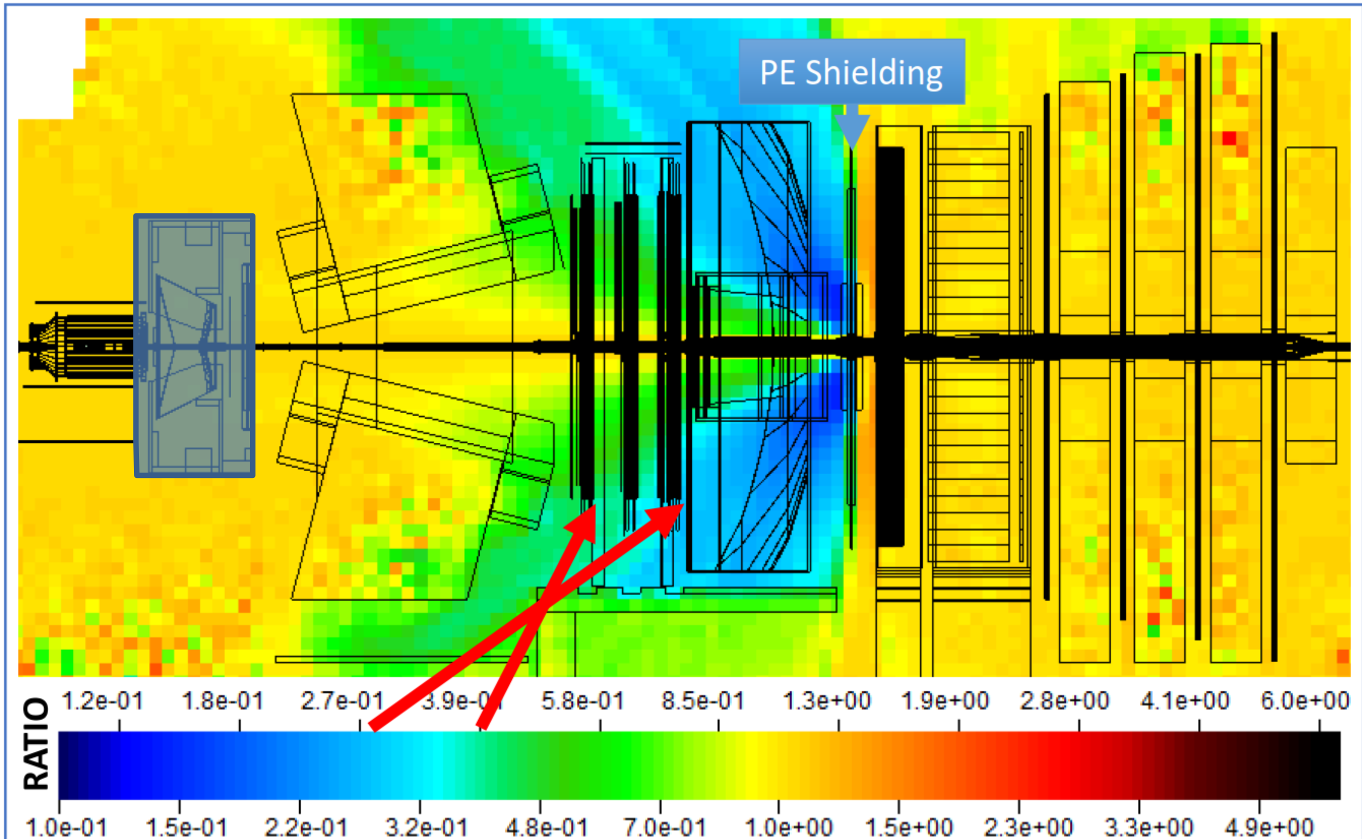
Light guides were machined from plastic (HERA-B lens material).

NIMA 2009

Implement neutron plastic shields:

RICH1 will be "wrapped" in plastic, instead of iron!

Factor 2 to 4, 20/30 cm thick Polyethylene



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

M. Karakson et al.

Rough rough estimations:

For every x10 n_{eq} cm^{-2} over the 10^{10} n_{eq} cm^{-2} (which is considered ok for SiPMs), DCR increases x10, so for 10^{13} n_{eq} cm^{-2}, we need at least a 10^{-3} improvement in DCR.

Starting with a DCR of 1 MHz for a 3x3 mm^2 pixel (standard SiPM specs),

Surface	1/8	(reduce size of SiPM to 1 mm^2)
Cooling	10^{-2}	(by cooling down to ~-50 °C, more would be even better ...)
Gating	1/25	(1 ns gating)
Plastic wrapping	1/4	(wrap the RICHes with plastic to reduce neutron flux)
Total	~ 10^{-5}	

We would start (at 10^{10} n_{eq} cm^{-2}) with a DCR ~10 Hz to end (at 10^{13} n_{eq} cm^{-2}) with 10 kHz on a 1 mm^2 SiPM