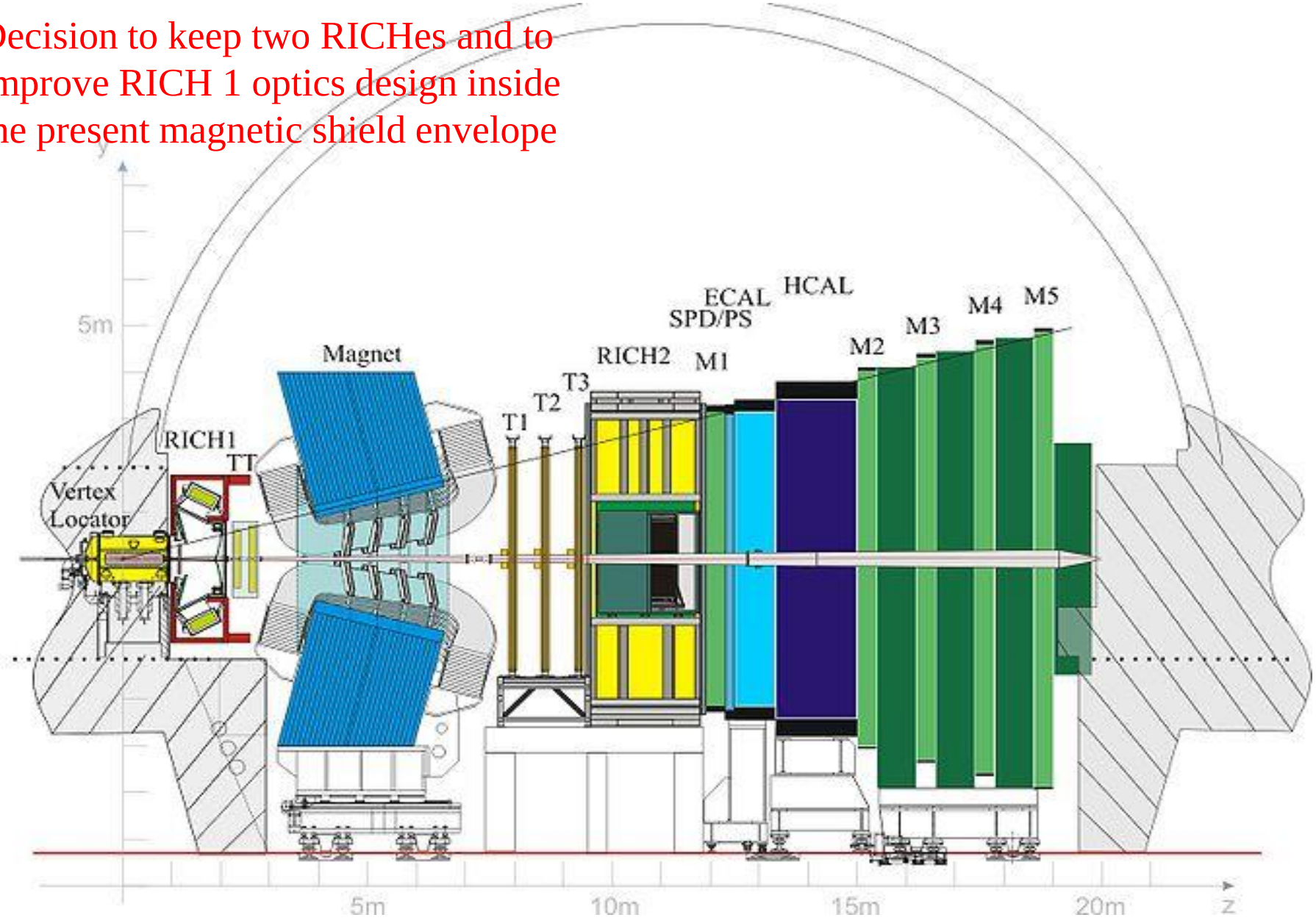
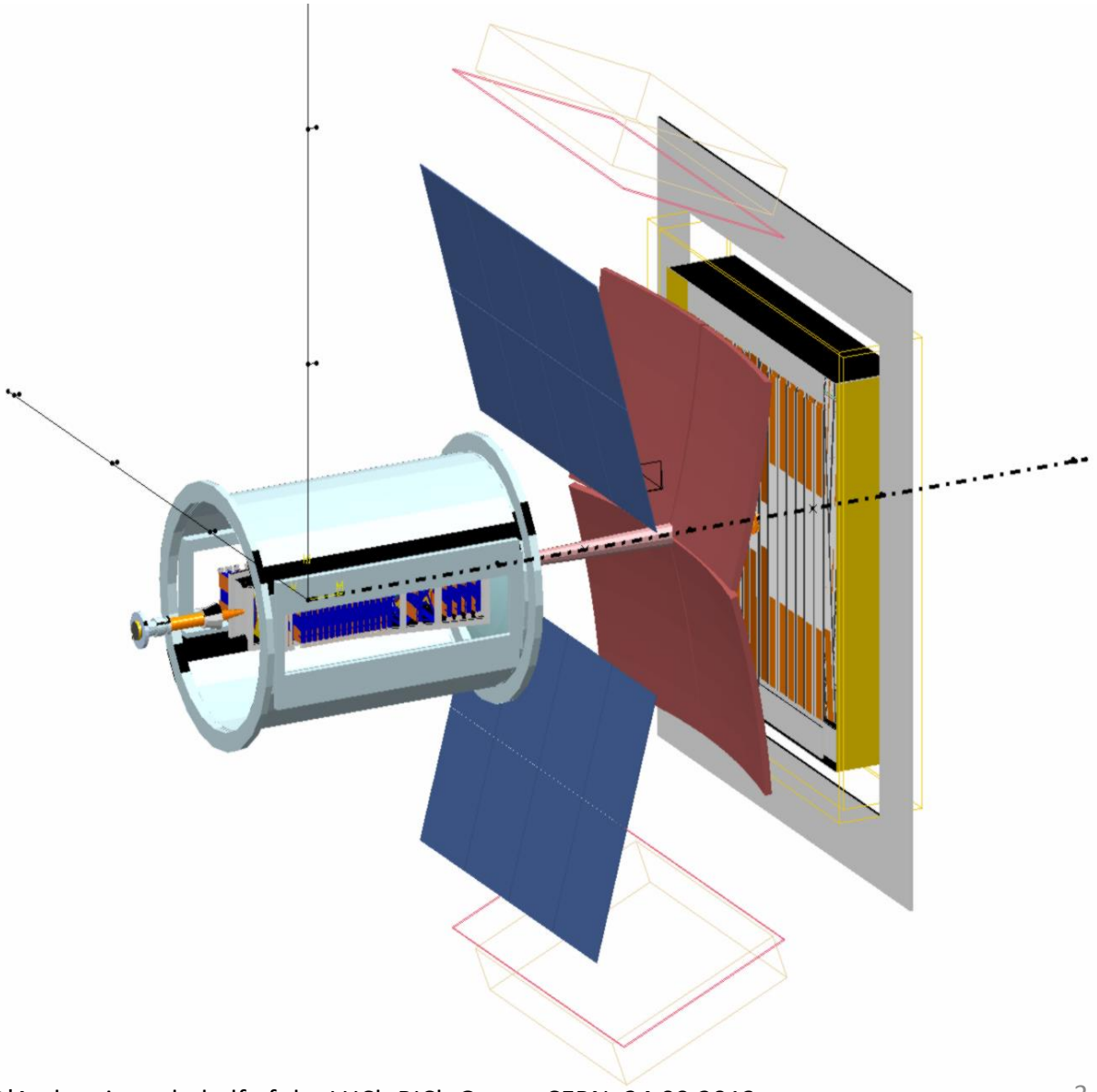
The Enhanced RICH System for the LHCb Upgrade

On behalf of the LHCb RICH Group

Decision to keep two RICHes and to improve RICH 1 optics design inside the present magnetic shield envelope



RICH 1 Optical System



An Enhanced RICH System for the LHCb Upgrade

Introduction

Important decision for the coming 10 Years for RICH and LHCb:

- Deliver excellent PID performance.
- Conceive, develop and build during operation years (2015 – 2017).
- Install during LS2 (2018, 18 months, perhaps).
- Cost inside the FW-TDR (or less?).

An Enhanced RICH System for the LHCb Upgrade

Our FW-TDR asks for a detector capable of

40 MHz readout rate @ 2×10^{33} cm^{-2} s^{-1}

Change the opto-electronic chain

Photon Detector

Front-end

DAQ

RICHes optics and mechanics

Modify RICH 1 optics

Reduce optical aberrations

Optimize available space

With Radiation Hardness issues being tackled in order to keep system alive until 2030

Opto-Electronics and DAQ Status

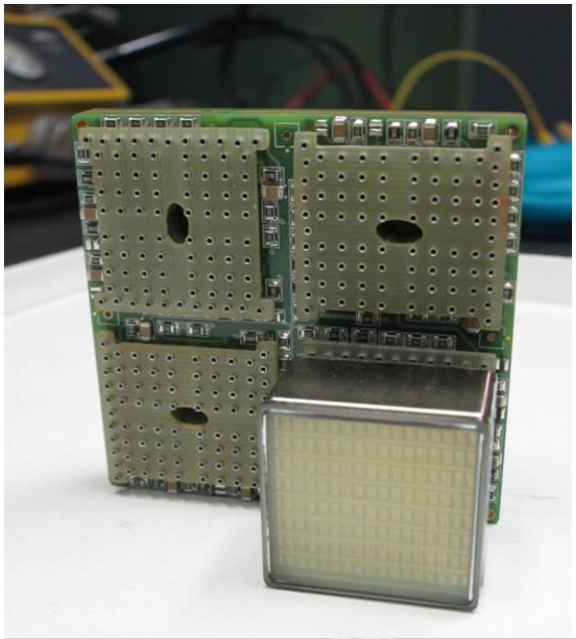
Major Specs for the Photon Detector Plane:

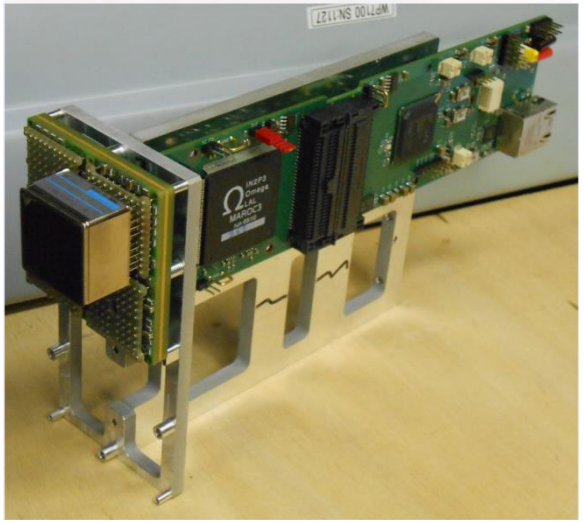
High single photon sens.,

<3 mm pixel size,

operation in magn. field,

no spillover (<25 ns)





Baseline option: 64 pixels MAPMT

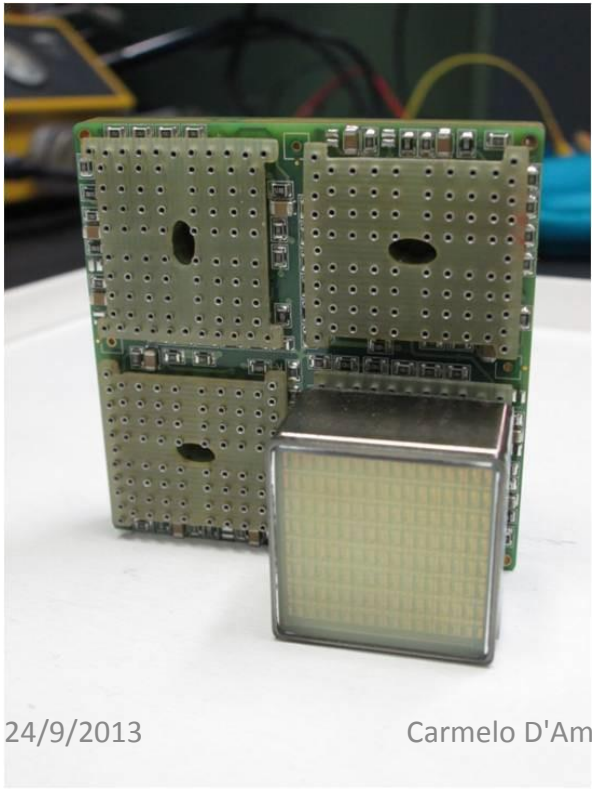
+ custom FE chip

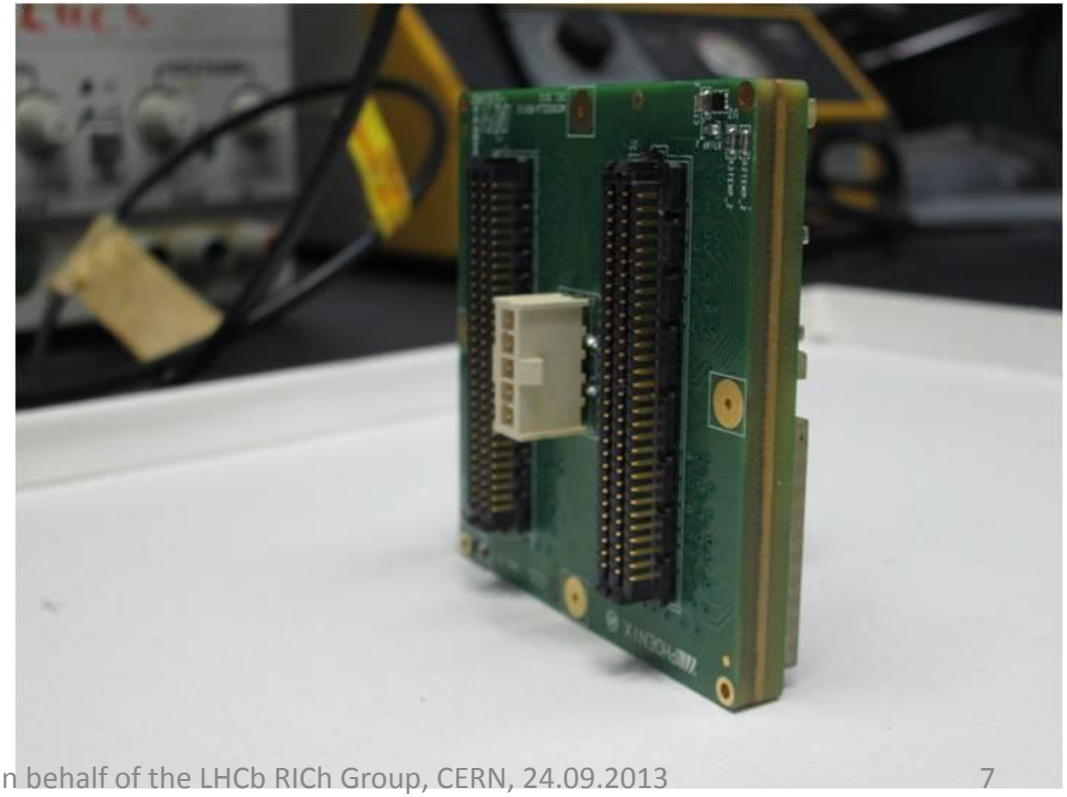
+ motherboard + GBTs

Backup option: HPD with external electronics

Prototype of the Base-Board of the EC (Elementary Cell)

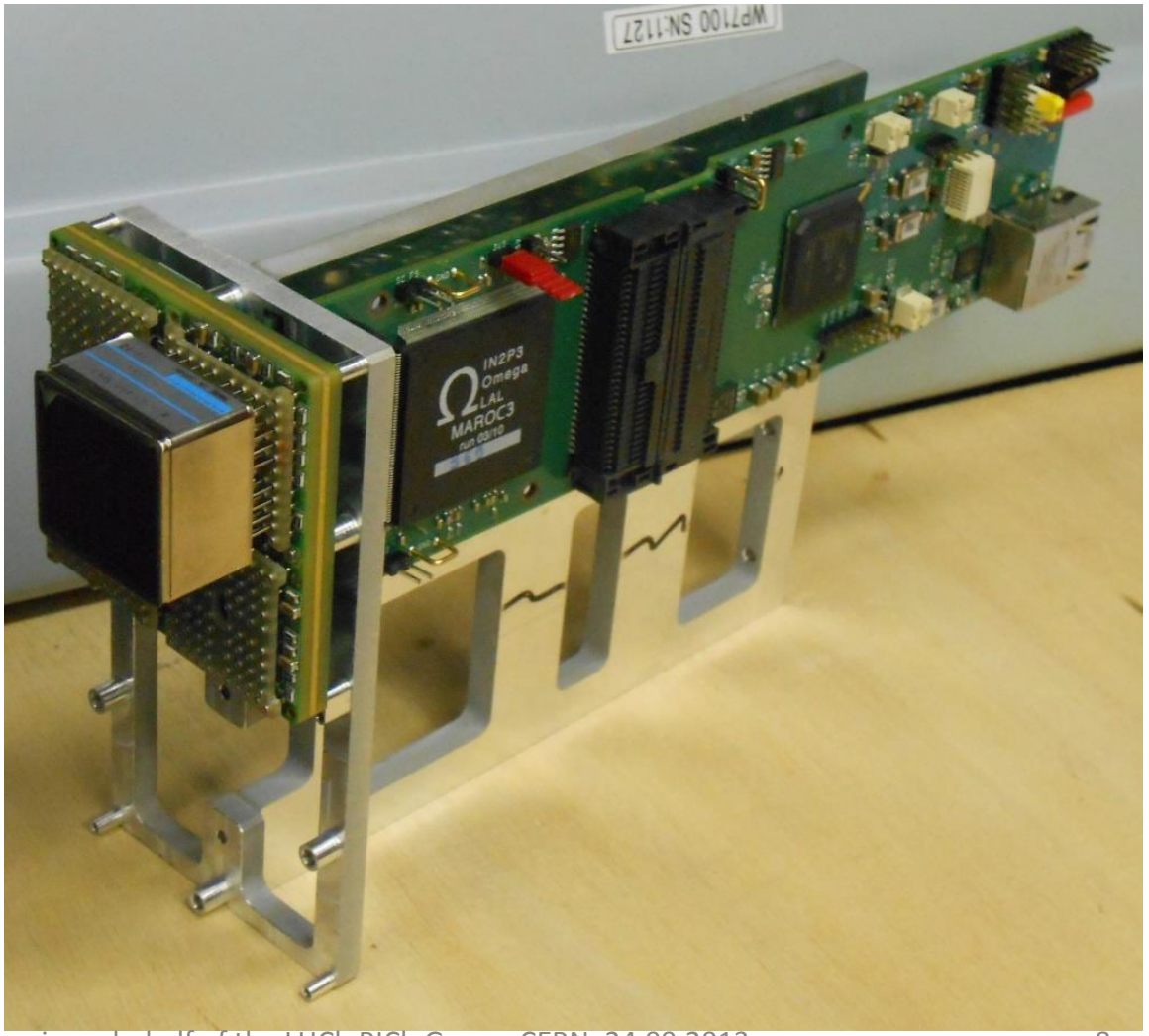
Current prototype for laboratory tests, for readout via the prototype MAROC readout board





Prototype of a PDM (Photon Detector Module)

Current prototype for laboratory tests, for readout via the prototype MAROC readout board*

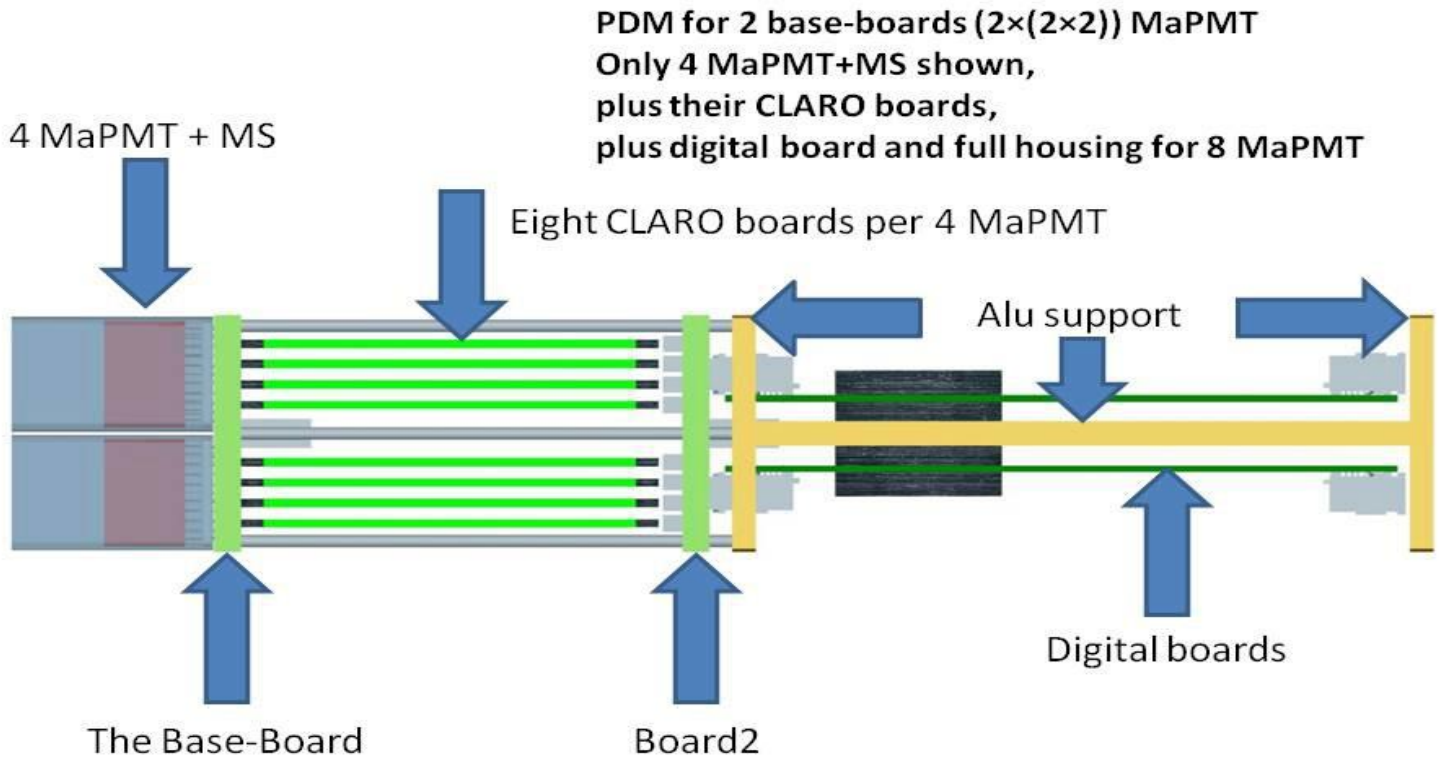


*Plans to integrate a few in RICH 2 during LS1

CLARO baseline

Design of PDM made of two EC, that is: 2 × (2 × 2) = 8 MaPMT

NOT to SCALE

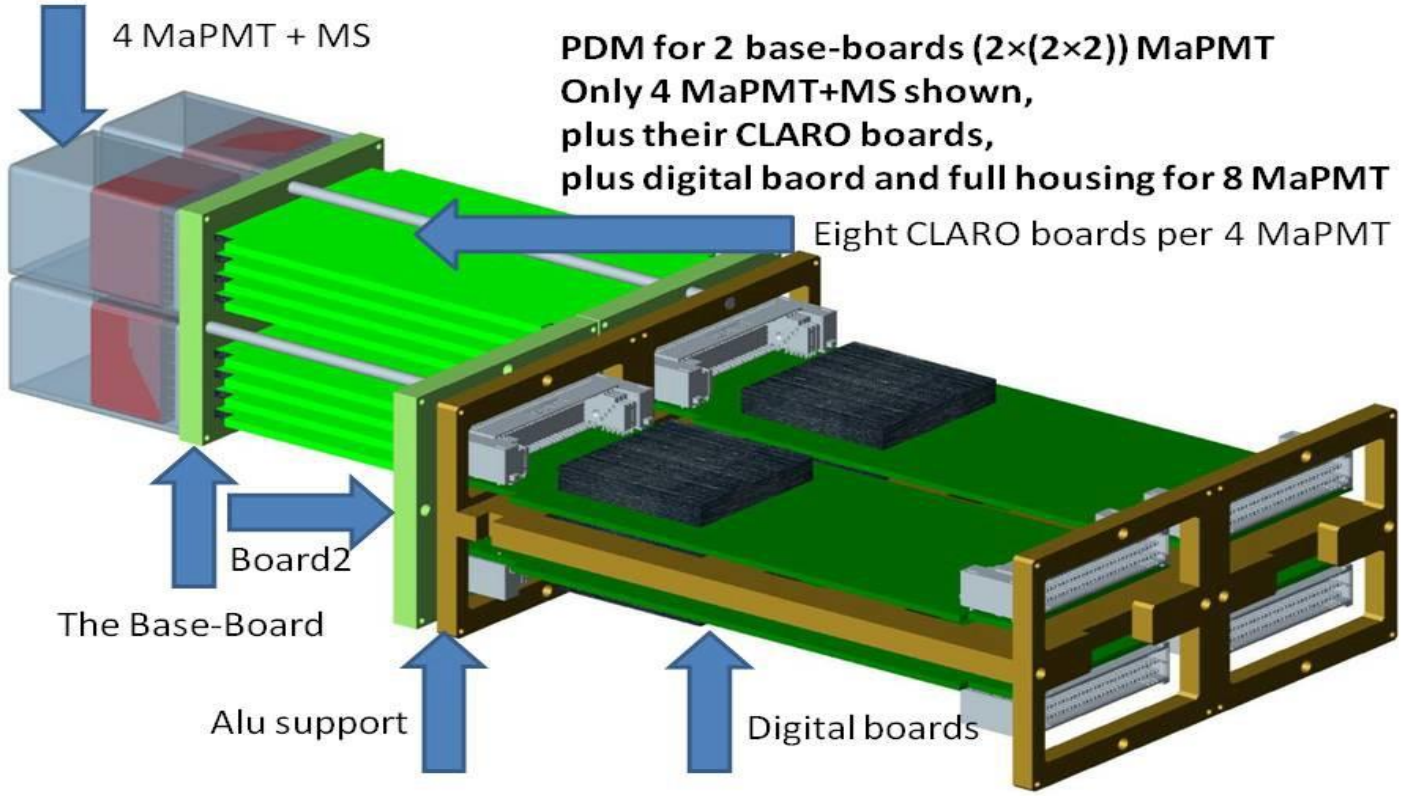


Total length goal ~30 cm

- To be updated: four EC, that is: 4 × (2 × 2) = 16 MaPMT, (doubled with respect to figure).
- To be updated: four CLARO boards on the back of every EC, (instead of the eight in the figure).

Design of PDM made of two EC, that is: $2 \times (2 \times 2) = 8$ MaPMT

NOT to SCALE



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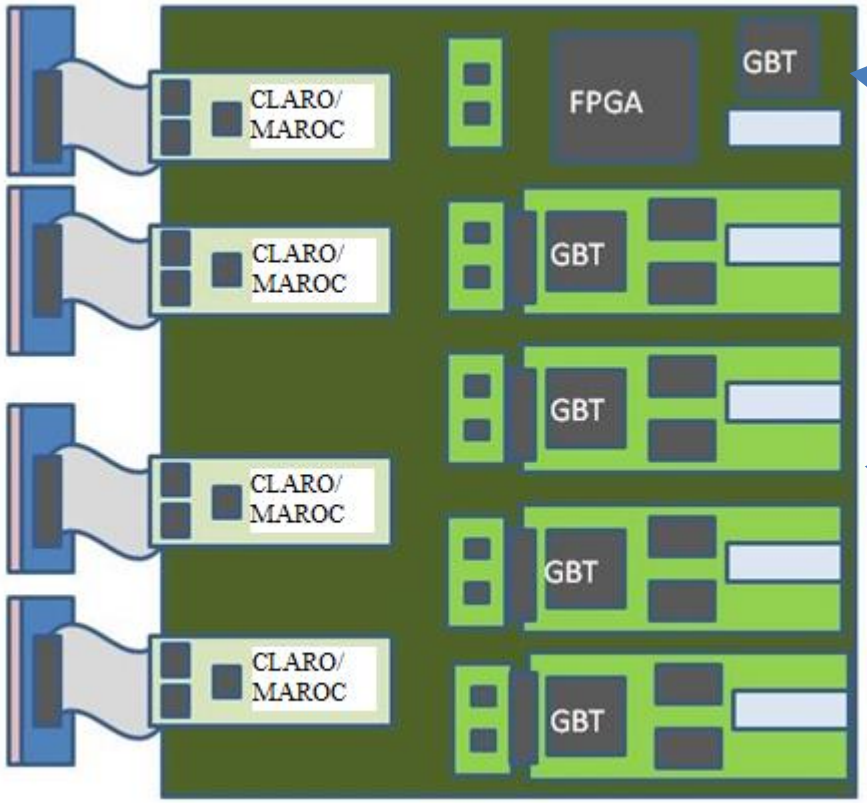
- To be updated: four CLARO boards on the back of every EC, (instead of the eight in the figure).

Schematic of a front-end / DAQ Board



One Master Link

No of Datalinks
Depends
on MaPMT occupancy

(1, 2, 3, 4 MaPMTs/Link)

PD-assembly: a tentative proposal towards the TDR

Current assumptions, might be possibly improved during the executive design:

– pitch between MaPMT: 29 mm;

– clearance between two EC and/or two PDM: 1 mm;

– use a magnetic shield;

– be ready to use a lens system* if needed.

Working hypothesis: one PDM made of four EC, that is: $4 \times (2 \times 2) = 16$ MaPMT.

– RICH1: assume PD-assembly size $\approx 1380 \times 630$ mm^2;

Approximate to: 5 columns made of (1×12) PDM (gives: 1440×600 mm2, 1920 MaPMT).

– RICH2: assume PD-assembly size $\approx 1477 \times 698$ mm^2;

Approximate to: 6 columns made of (1×12) PDM (gives: 1440×720 mm2, 2304 MaPMT).

Doubling the pixel size in RICH2 is being studied, by using the newly developed Hamamatsu R12700: it would replace four R11265s. Implementation: re-design the base-board and adapt the rest (easier, 1/4 pixels....).

*Lenses could be placed in front of PMTs to de-magnify the photonic images and therefore saving on the overall number of PMTs

RICH 1 Mechanics in the present envelopes of LHCb

Reduce occupancies and improve optical errors by optimizing the optical design:

Longer radius of curvature (RoC) and smaller angular tilts for mirrors

Optimizations:

Tune the optics

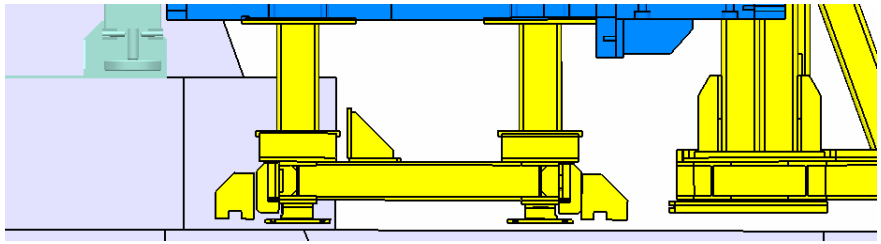
Better define the PD plane

Smarter use of existing space

Further improve physics performance

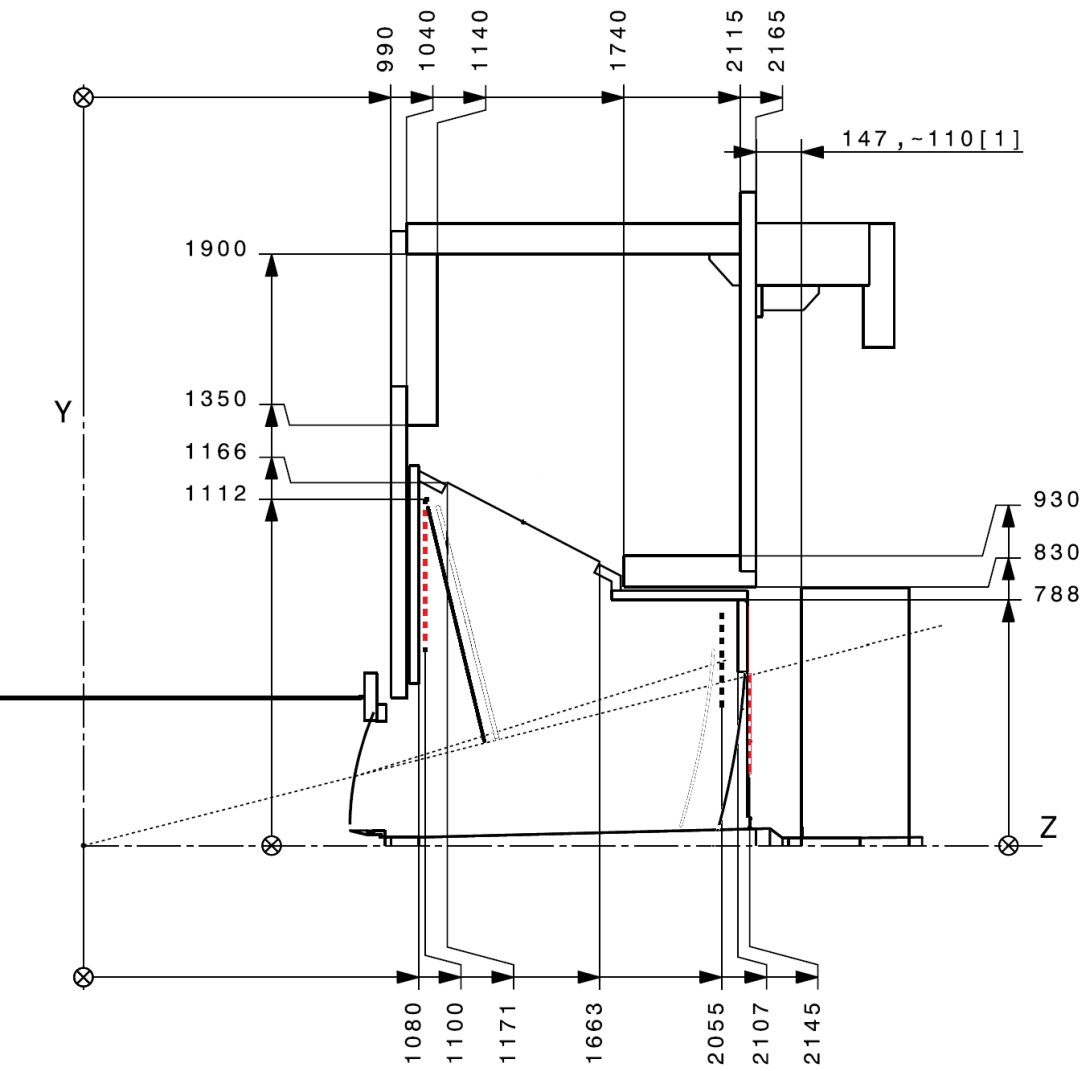
Lenses?

Reduce costs



Old RICH1 mechanical envelope (not a technical drawing)

First Optimization without modification of Magn. Shield



Optimizations:

Place mirrors further apart, enlarge gas vessel, improve design of optical mounts and adjustments,

use new concepts and materials;

start looking into boxes, improve available space, first evaluation of opto-electronic chain impact, smart designs, etc..

Can we make it?

Complete the simulation for physics performance and finalize the optics layout;
Main dimensions and envelope defined;
Conceptual design of the detectors.

11/2013 Technical Design Review

In 2014: it follows the mechanical design of the different systems (including finite element analysis, verification and tests for new components, etc.).
List of main systems (WPs):
Gas enclosure
Optical Elements
Photon detector assemblies
...

Middle 2015 Engineering Design Review

At this stage, all the final design will be frozen, manufacturing drawings prepared, the different production processes established, including final cost and delivery time of the components listed above.

Middle 2016 Production Design Review

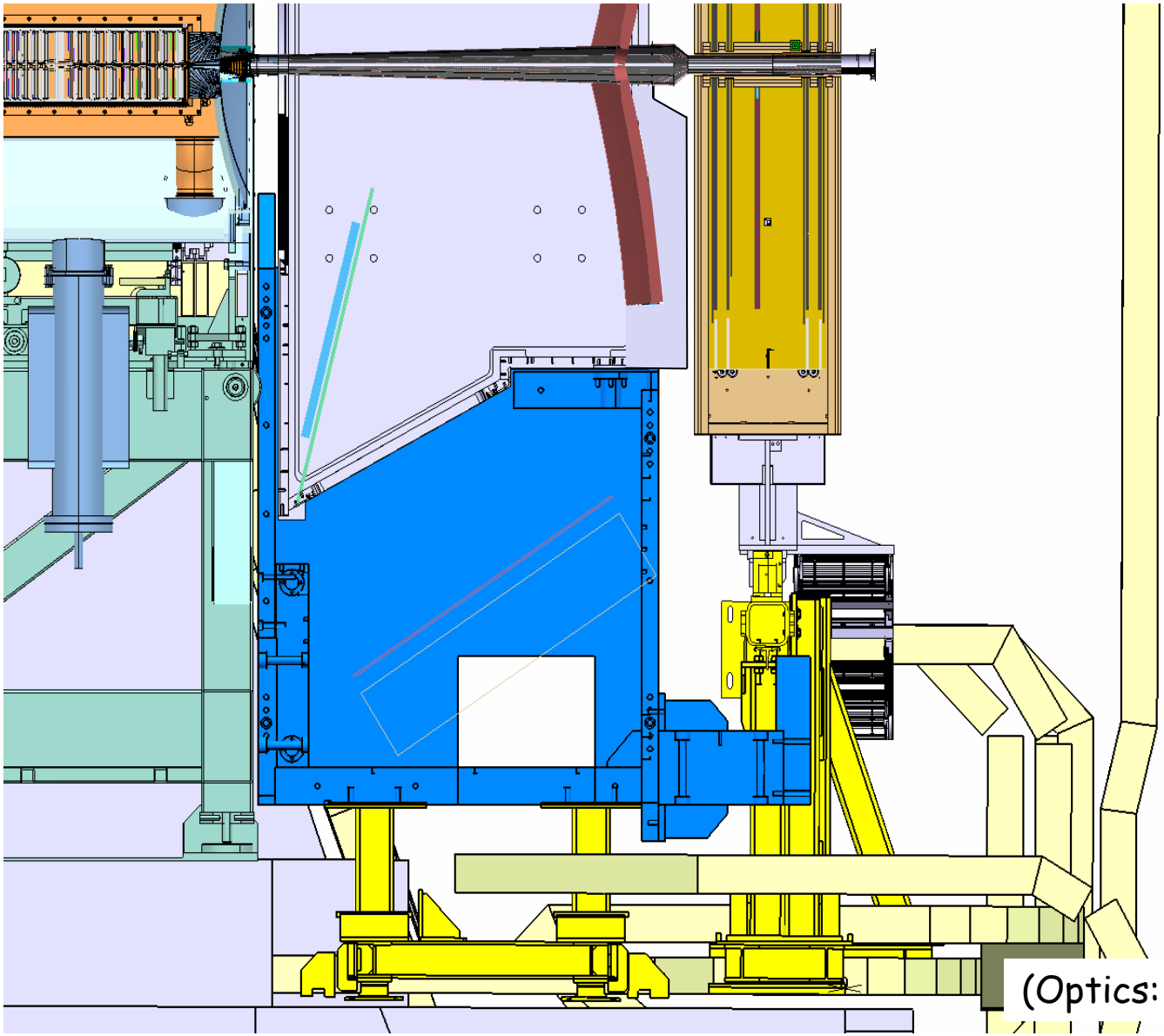
Can we install it into LHCb?

Collaborate with Tech. Coord. to establish main technical and resources issues.

RICH integration in LHCb must be achieved during LS2:

Estimated <40 days to remove old RICH 1 gas enclosure and install new one.

Not a technical drawing !!



(Optics: SE-v7F)

Detector Studies and Performance

Detector Parameters

	RICH-1	RICH-1	RICH-2
	current	2019	current/2019
RoC [m]	2.7	~3.8	8.6
Acceptance [mrad]	25-300	25-300	15-120
% X_0	4.7	4.7	15
Sph. Mirr. Surf. [m^2]	2.1	1.6	8.2
Flat. Mirr Surf. [m^2]	2.1	2.5	6.2
Ph. Det. Surf. [m^2]	1.5	1.6	2.1
Cherenkov Gas	C_4F_{10}	C_4F_{10}	CF_4
Ch. Sig. Gas Vol. [m^3]	2.5	2.5	10
Avr. Ph.Electron Yield	25 (30)*	40	23

*Value from data (expected)

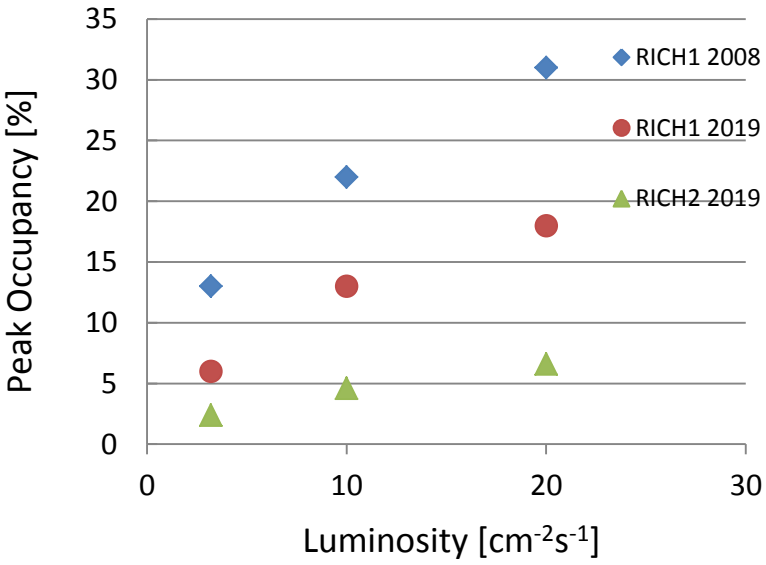
Optical Performance and Photon Yields

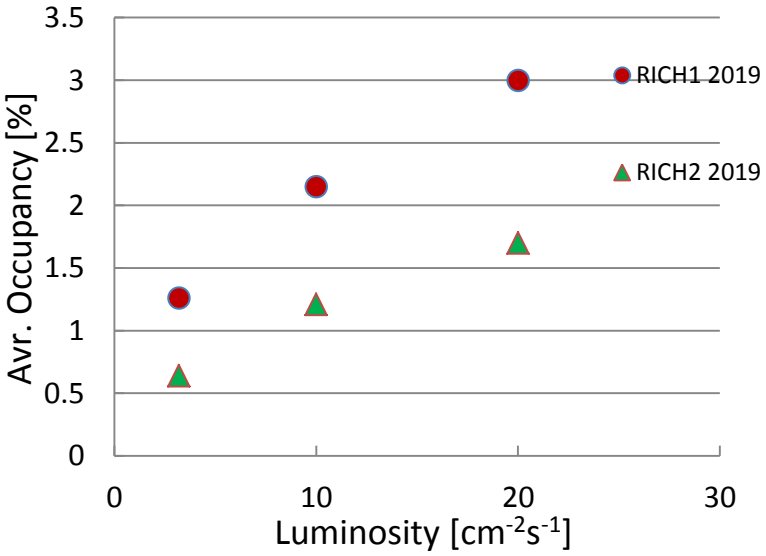
Radiator	C_4F_{10}		CF_4	
Detector Version	RICH-1 Current (HPD)	RICH-1 2019	RICH-2 Current (HPD)	RICH-2 2019
Avr. Ph.-el. Yield	25 (30)*	40 (rms=8)		23 (rms=5)
Optical Errors [mrad]				
Chromatic	0.84	0.58	0.5	0.32
Pixel	0.6	0.44	0.2	0.19
Emission Point	0.8	0.37	0.2	0.25
Track resolution	0.4	0.4	0.4	0.4
Overall	1.50	0.88	0.7	0.60
$p_{3\sigma}$(K-π) [GeV/c]	51	72	92	99

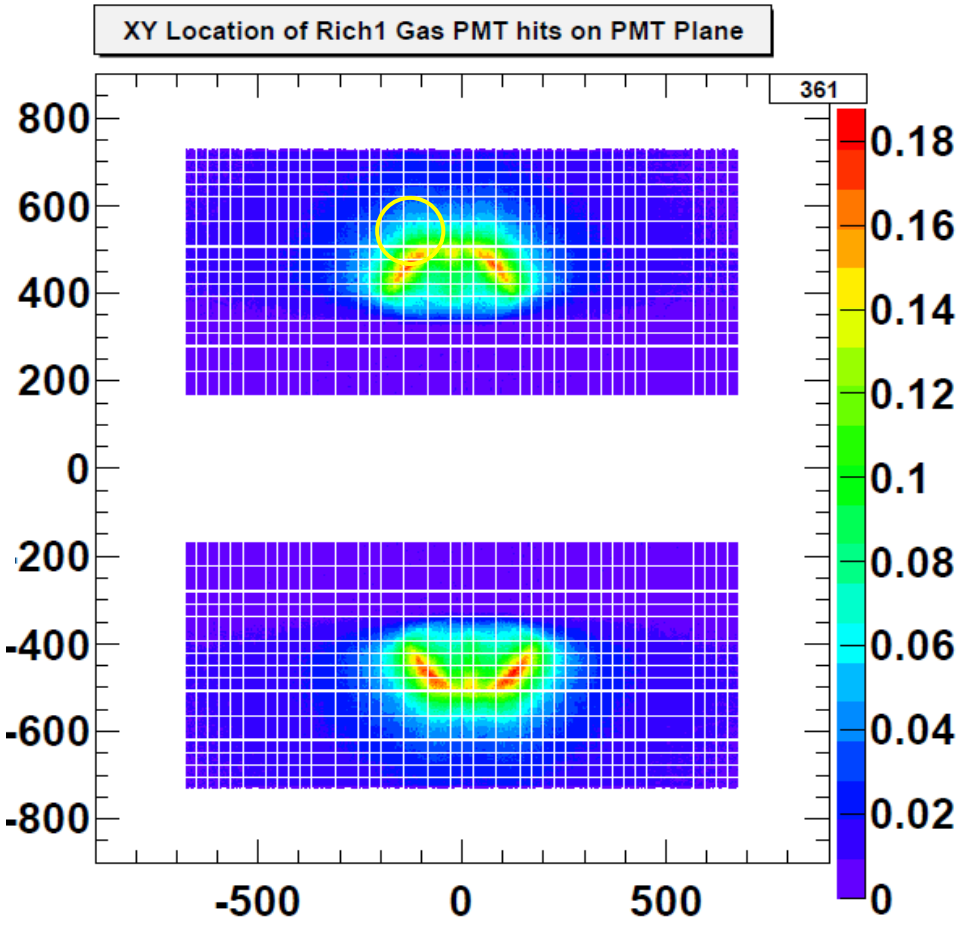
*Value from data (expected)

Focus is on RICH1, due to its high peak occupancies at 2 x 10^{33} $cm^{-2}s^{-1}$

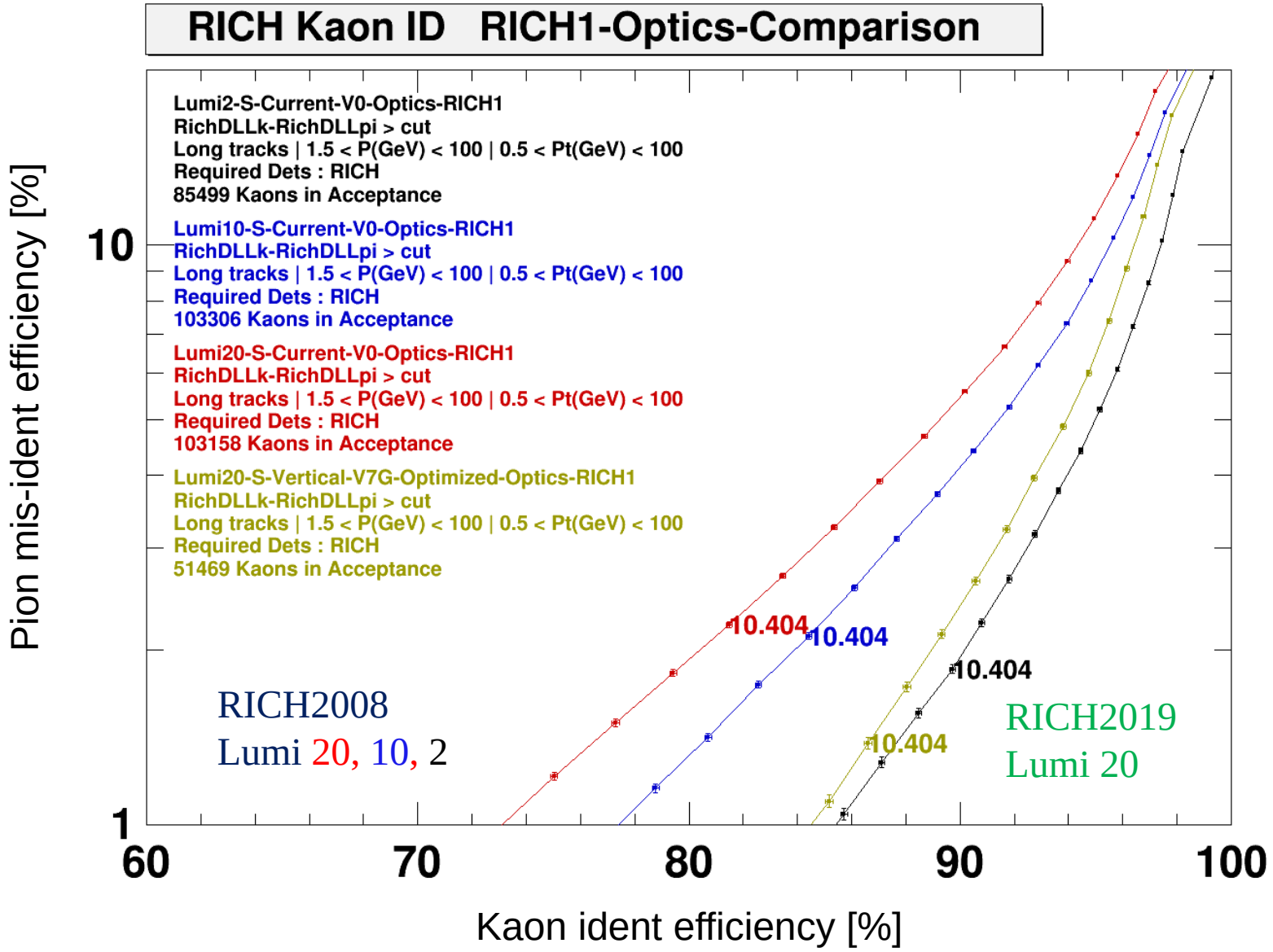
Occupancies and Pattern recognition



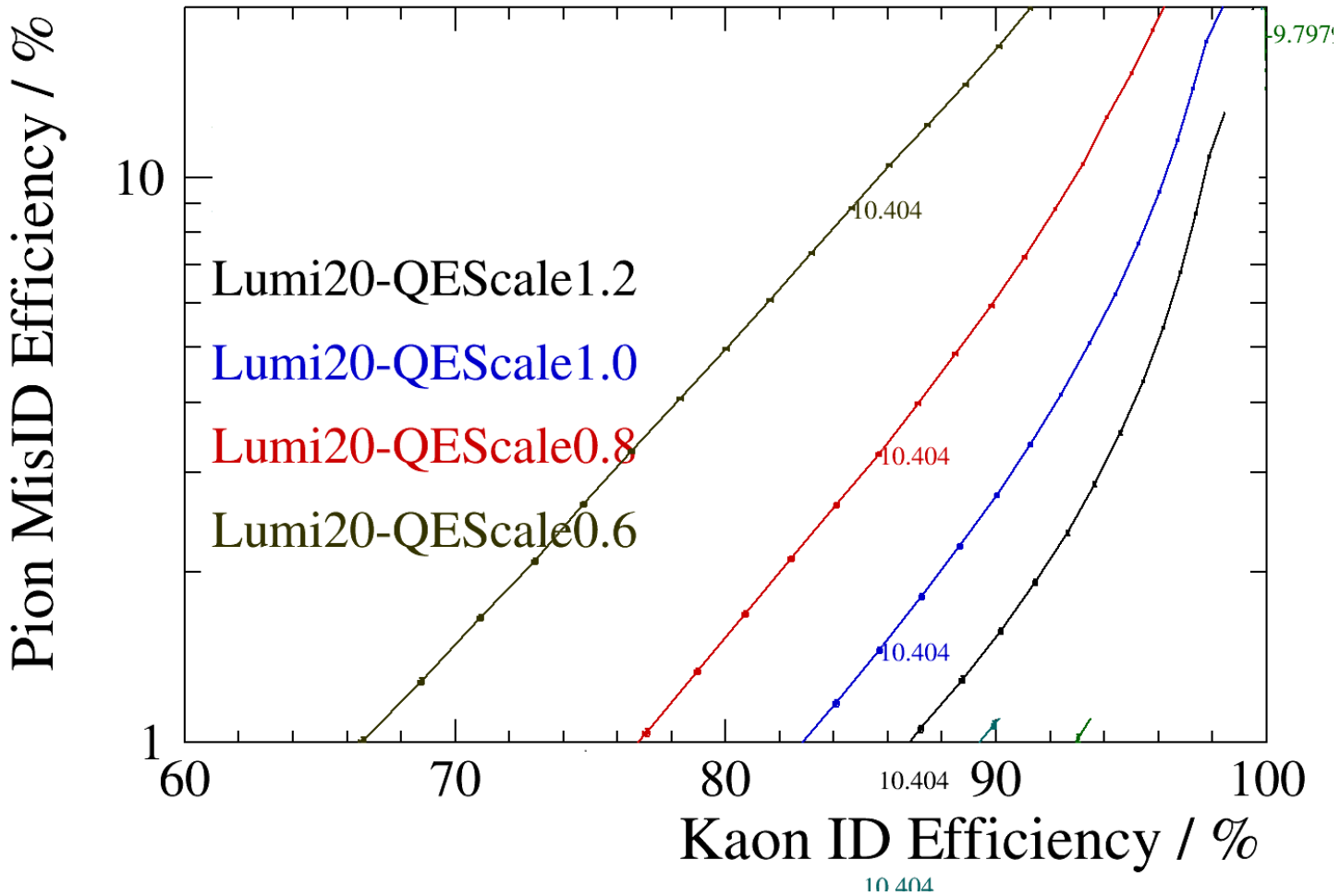




PID performance



PID performance optimization: different QEs

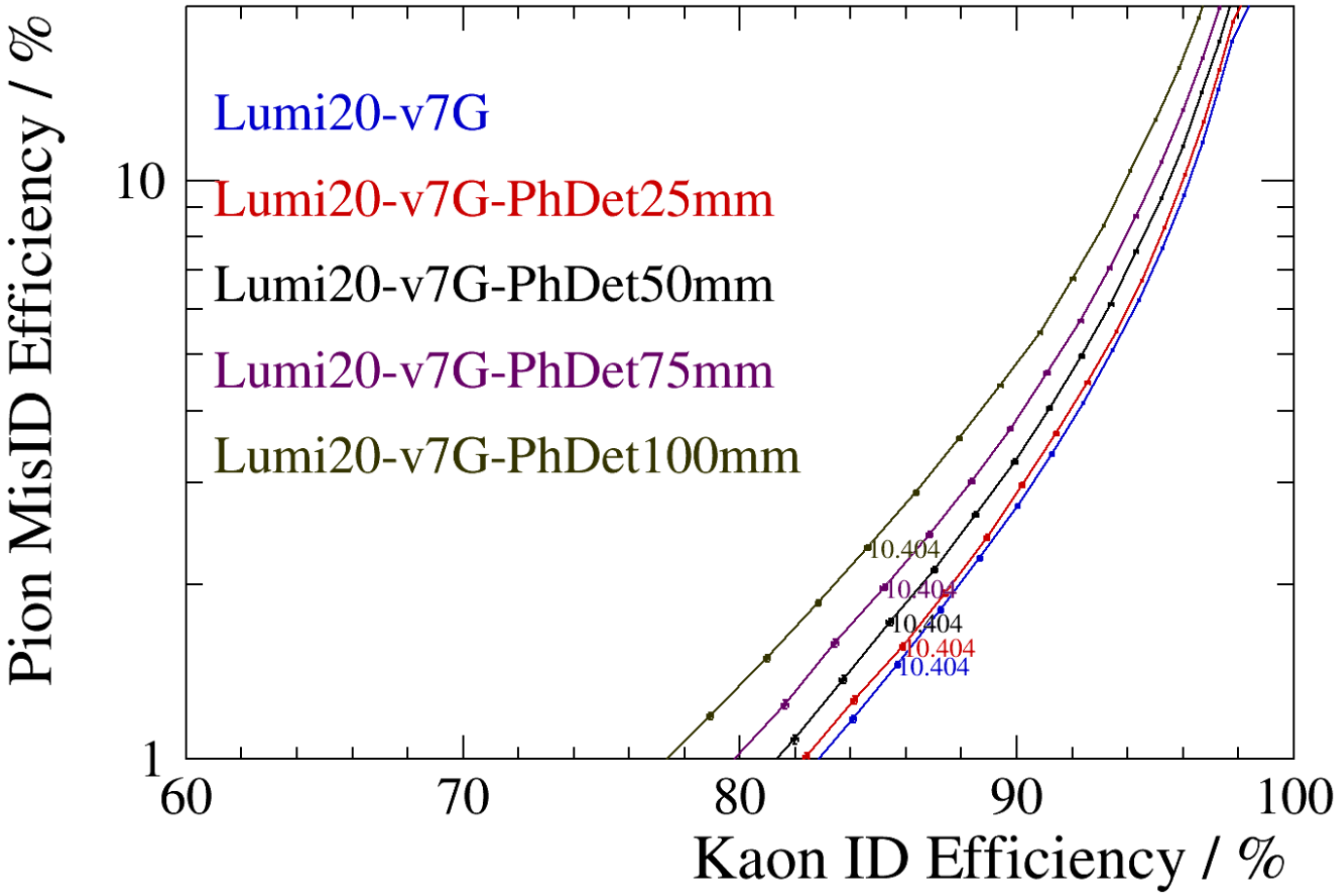


Blue: Standard QE

All plots with v7G optics and NEW Lumi20-S.

Higher QE → more signal hits (occupancy) per track → better PID

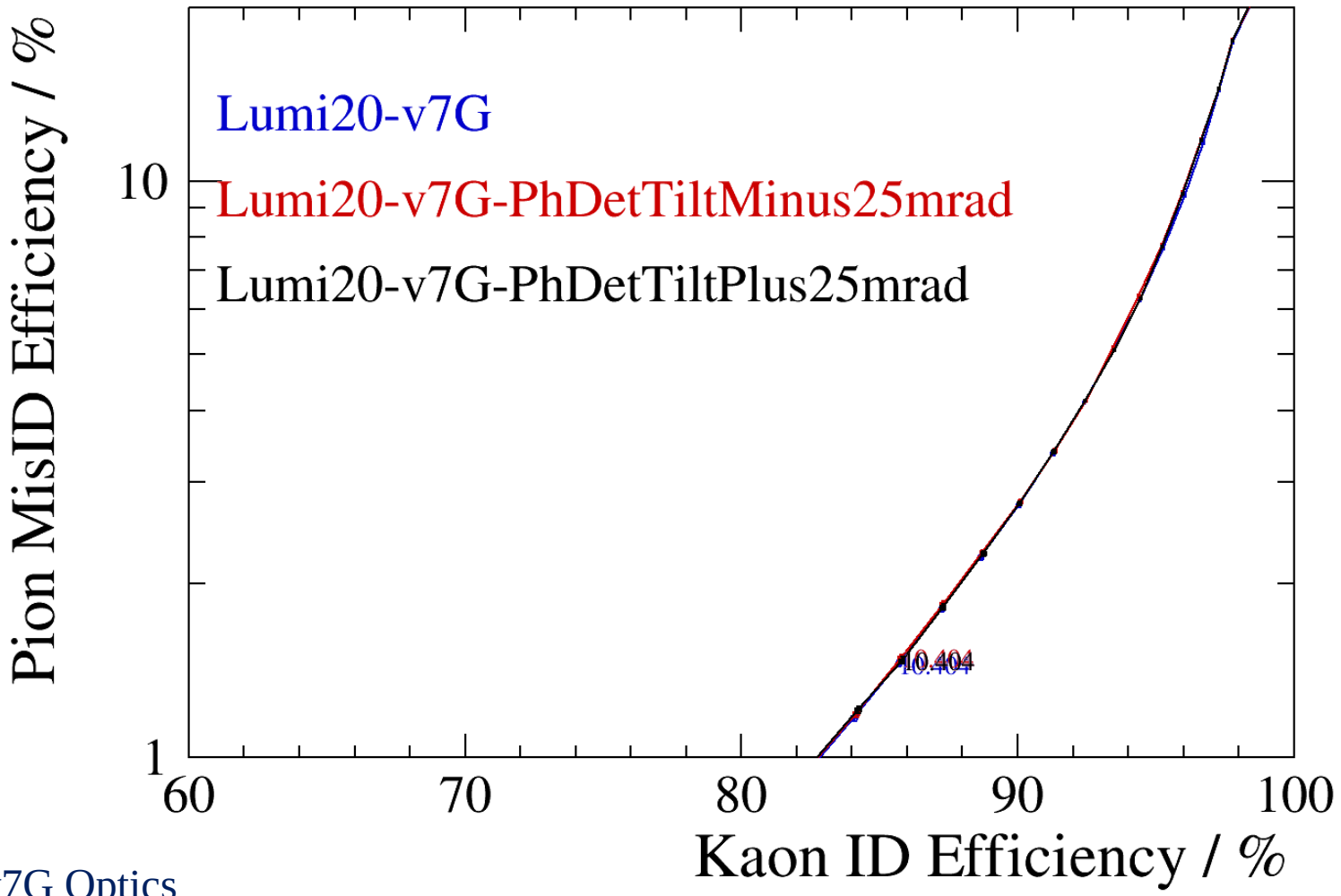
PID performance optimization: Photon Detector Plane Position



Blue plot: Standard v7G Optics
Other plots from right to left: 25 mm, 50 mm, 75 mm, 100 mm shift

Detector plane shift from 'best focal plane' →increase emission point error → worsen PID

PID performance optimization: Photon Detector Plane Tilt



Blue: Standard v7G Optics
Red:-25 mrad tilt , black: + 25 mrad tilt

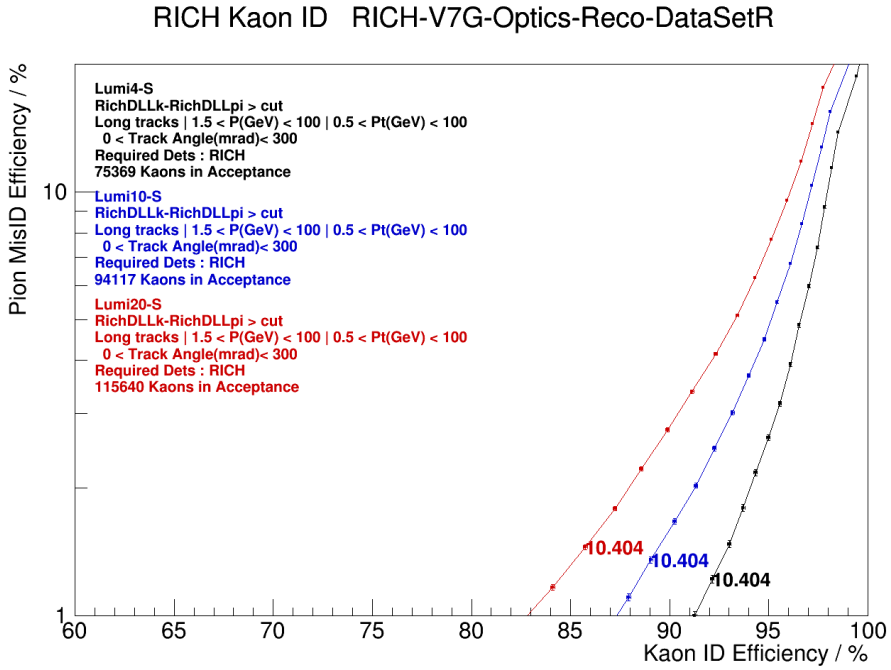
PID performance unchanged, as expected.

Further optimization studies

1. Tune the RICH reconstruction for PID with PMTs
2. Optimize the number of PMTs in RICH1 and RICH2
3. Use new PMT QE curves from new specifications
4. Use more realistic module sizes and PMT pitches
5. Further re-optimization of RICH1 optics
6. Simulation tuning for real data

These studies are expected to continue post-TDR

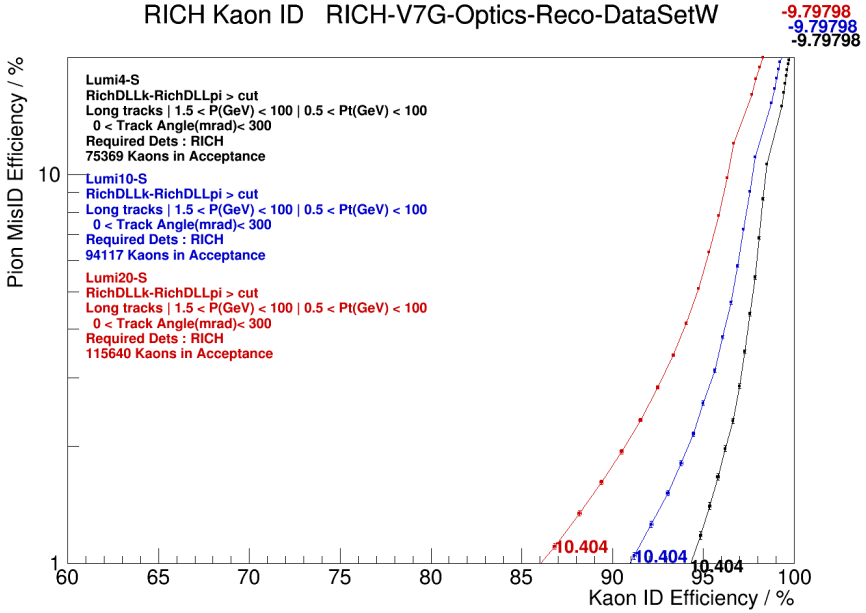
PID Performance: Reconstruction tuning



Current standard reconstruction

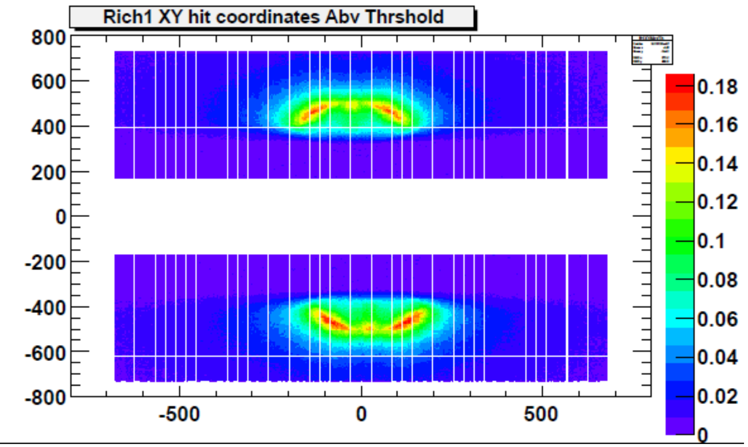
Improved reconstruction

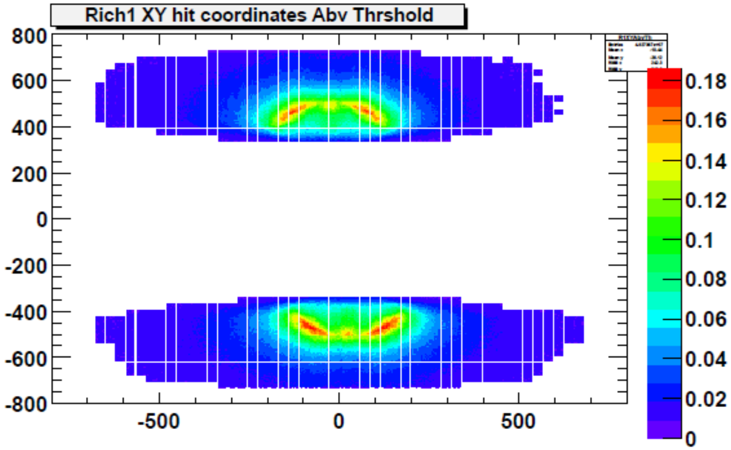
- Minor tuning of PID algorithm in Brunel.
- Using this as the 'new standard' for the rest of this presentation.

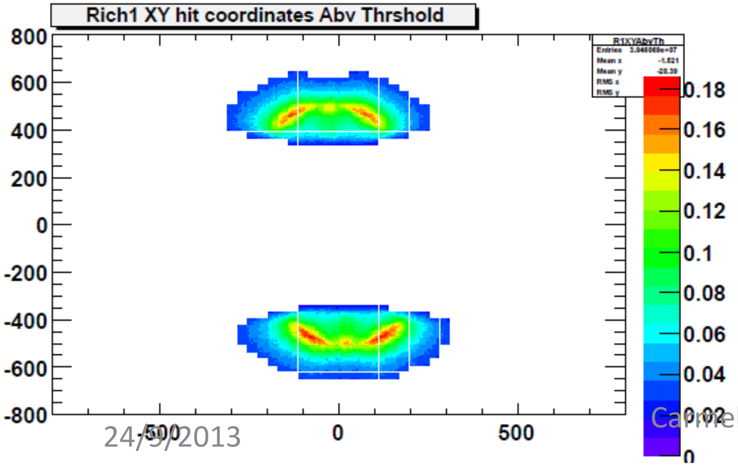


RICH1 v2019 2D Image [mm]

Lumi20, R=3.8 m, 1920 MAPMTs







Occup. cut [%]	Number of MAPMTs	Surface fraction [%]
0	1920	100
0.5	1904	99
1.0	1116	58
1.5	711	37
2.0	547	28
2.5	431	22
3.0	354	18
10.0	73	4
14.0	18	0.9

TDR milestones

- 5 Oct: Deadline for individual sections
- 12 Oct: 1st draft circulated
- 23 Oct: Comments back from 1st draft.
- 30 Oct: 2nd draft circulated
- 5 Nov: Comments back from 2nd draft. Incorportated into the full PID with muons and CAL
- 12 Nov: TB (and sending to CB) with Cal/Muon (final draft)
- 26 Nov: Submit PID Upgrade TDR to LHCC

Overall editorship: Neville Harnew, Carmelo D'Ambrosio

RICH Upgrade Electronics Review

- CERN Tuesday 1st October
- Organized by Steve Wotton
- 2 external referees : Walter Snoeys, Gianluca Aglieri Rinella; Internal referee Federico Alessio (+ Ken Wyllie)
- Documentation being prepared
- Aim to confirm the electronics technologies including the front-end chip baseline

LHCC milestones

2.5 RICH

Sub-subsystem	Milestone	Schedule	Achieved	Comment
Simulation & geometry	Review of RICH geometrical layout and cost	May-13	May-13	
Simulation & geometry	Final decision on RICH layout	Jul-13	June-13	RICH2019
Photon detector	Confirm technology	Jul-13		
Electronics	Decision on front-end electronics technology	Sep-13	1 Oct 13	
Electronics	Design review of full electronics readout chain	Oct-13	1 Oct 13	
Mechanics	Photon detector module design and modularity review	Oct-13		
Mechanics	Conceptual design review of mechanical layout	Oct-13		
RICH	TDR	Jan-14	Nov13	

Conclusions

RICH1 v2008 will surely suffer in the upgrade and should not be maintained as it is.

We have opted for a two RICH option:

It can be made for LS2 (supposing to start in 2018).

It can be integrated and readied for 2019 at the start of the LHCb upgrade data-taking.

The Design and Tests of the new Opto-electronics and DAQ systems are progressing well;

The Optical System and Mechanics are well defined for both RICHes.

Conclusions

The Enhanced RICH System performs well from full simulation studies.

Optimization will further improve physics performance and technical issues.

Optimization will also reduce price!

Schedules are very tight: we plan to present our TDR (together with Calo and Muon) to the LHCC already in November.

Thank you for your attention

Spare Slides

Simulation configurations

- Old Simulation Conditions

S: *PMT with Super-Bialkali*

	Luminosity cm^{-2} s^{-1}	# bunches	L_B cm^{-2} s^{-1}	Beam Energy (TeV)	ν
Lumi2-S	3.2 x 10^{32}	1300	0.247×10^{30}	3.5	2
Lumi10-S	10.4 X 10^{32}	2400	0.433×10^{30}	7	3.9
Lumi20-S	20 x 10^{32}	2670	0.749×10^{30}	7	6.8

Lumi2-S ~ 2011 conditions.

L_B = Luminosity per bunch crossing
= Luminosity * 11.245 kHz /Crossing rate

- New Simulation Conditions : For all upgrade studies

	Luminosity cm^{-2} s^{-1}	# bunches	L_B cm^{-2} s^{-1}	Beam Energy (TeV)	ν
Lumi4-S	3.9 X 10^{32}	1300	0.302×10^{30}	4	2.5
Lumi10-S	10 X 10^{32}	2400	0.417 X 10^{30}	7	3.8
Lumi20-S	20 X 10^{32}	2400	0.834 X 10^{30}	7	7.6

Lumi4-S ~ 2012 running conditions. Lumi20-S : upg harsher conditions.

History from FW-TDR to Present to TDR

- In 2009, we started discussions on the RICH system for the LHCb upgrade ...
- FW-TDR, Apr. 2012 (CERN-LHCC-2012-007)
  - Possibility of modifying RICH 1 optics.
- In Sept. 2012, proposal for a single RICH system: TRIDENT.

- 8th May – Progress meeting.
- 22nd May – Documentation produced for the remaining options and circulated to the RICH group and the referees.
- 3rd June (LHCb week) - Final Review Meeting at CERN with referees.
- Referees report, 10th June. Circulated to RICH group.
- 17th June – Final RICH meeting to give last opinions.
- 18th June – Team leader's meeting. Recommendation ratified unanimously.
- 20th June – Technical Board unanimously endorsed the RICH group decision to build RICH 2019

RICH Technical Design Report : Nov-2013

Decision between RICH2019 and TRIDENT

After ~9 months of studies on both approaches:

- The optical performances were comparable;
- The performance in LHCb seemed equivalent;
- The PID performance of RICH 2019@Lumi20 demonstrated to be similar to RICH2008@Lumi2.

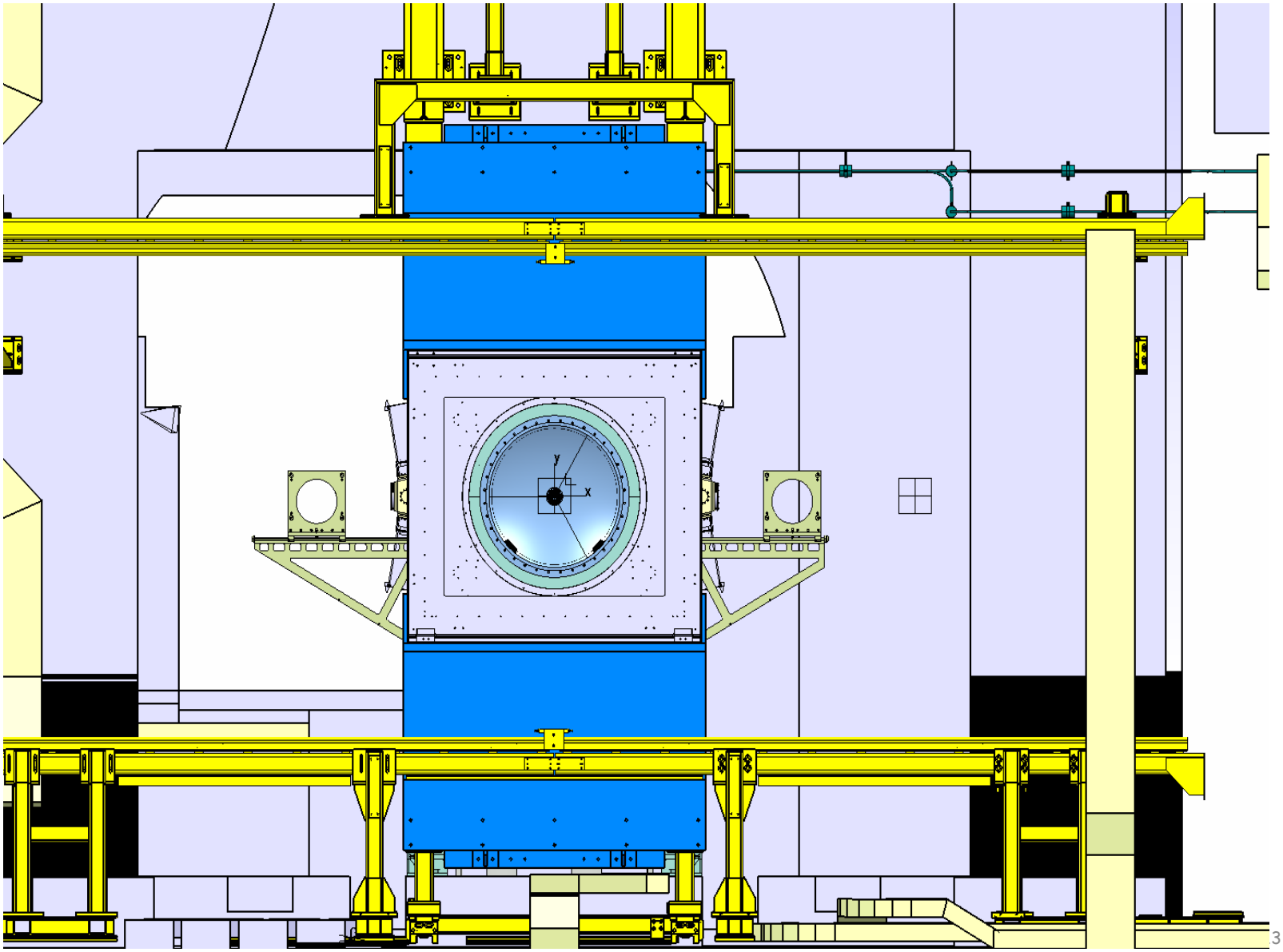
Need to be ready for LS2. Therefore, trade off between

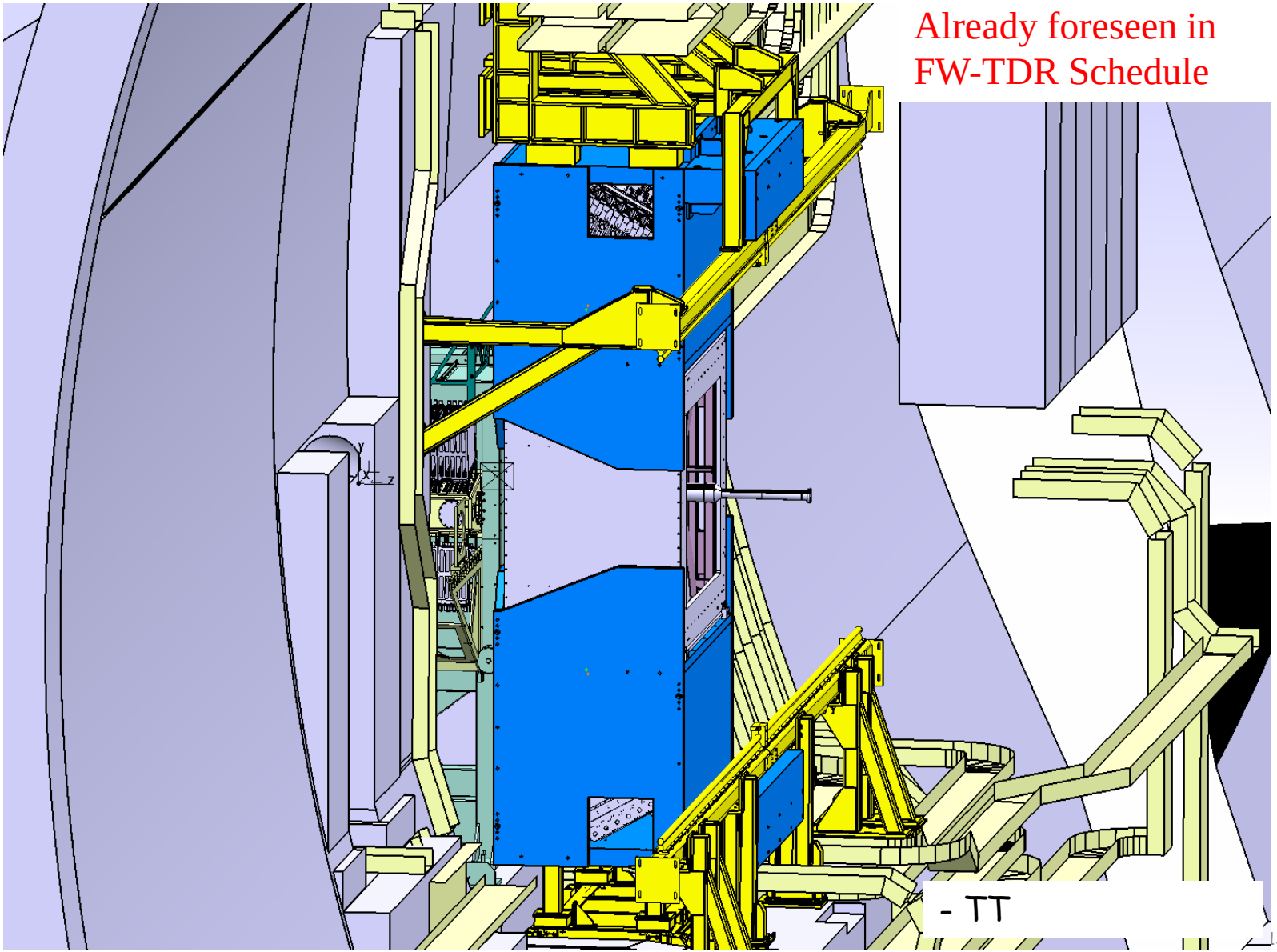
Associated risk;

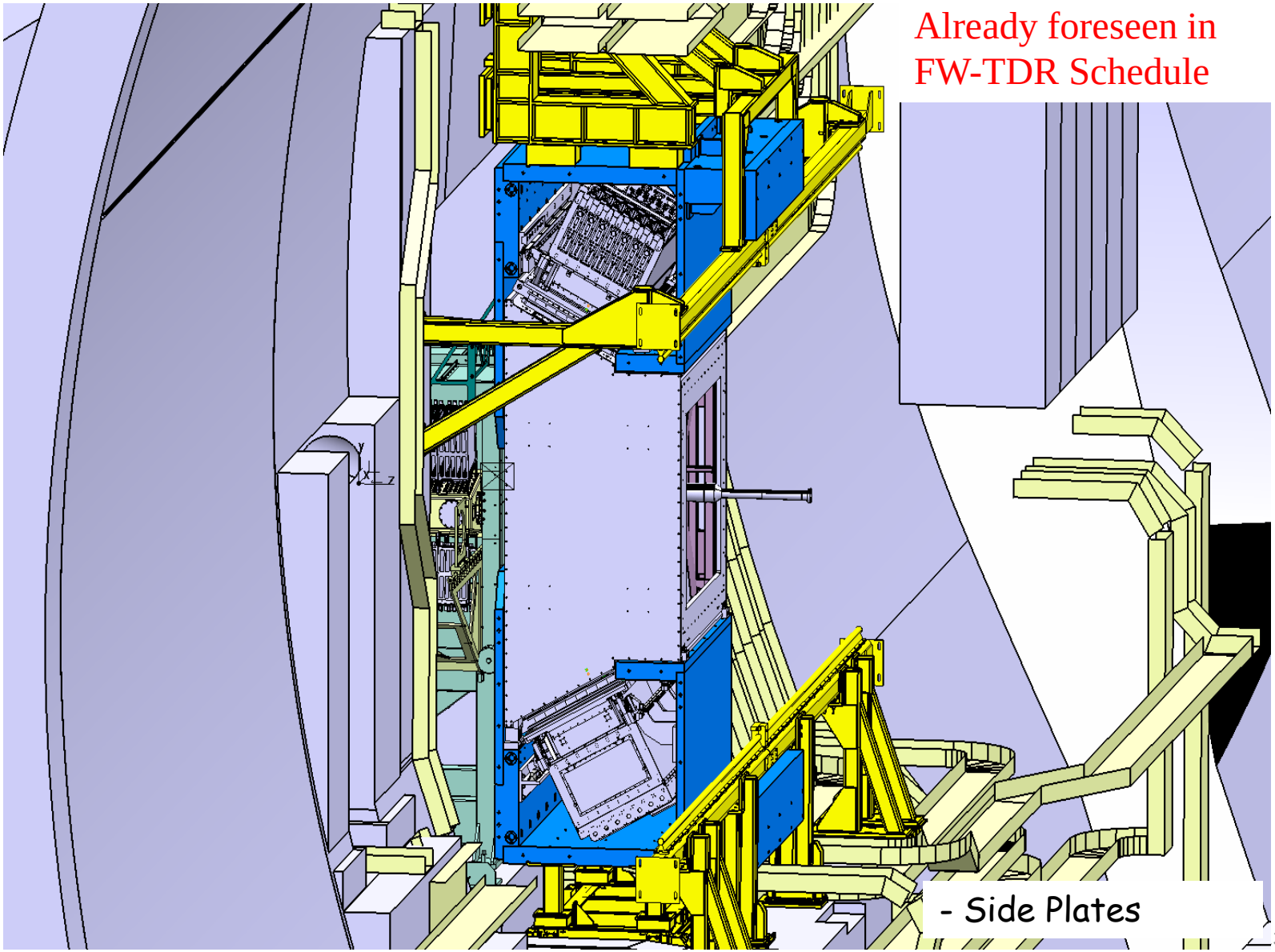
Time to build and install;

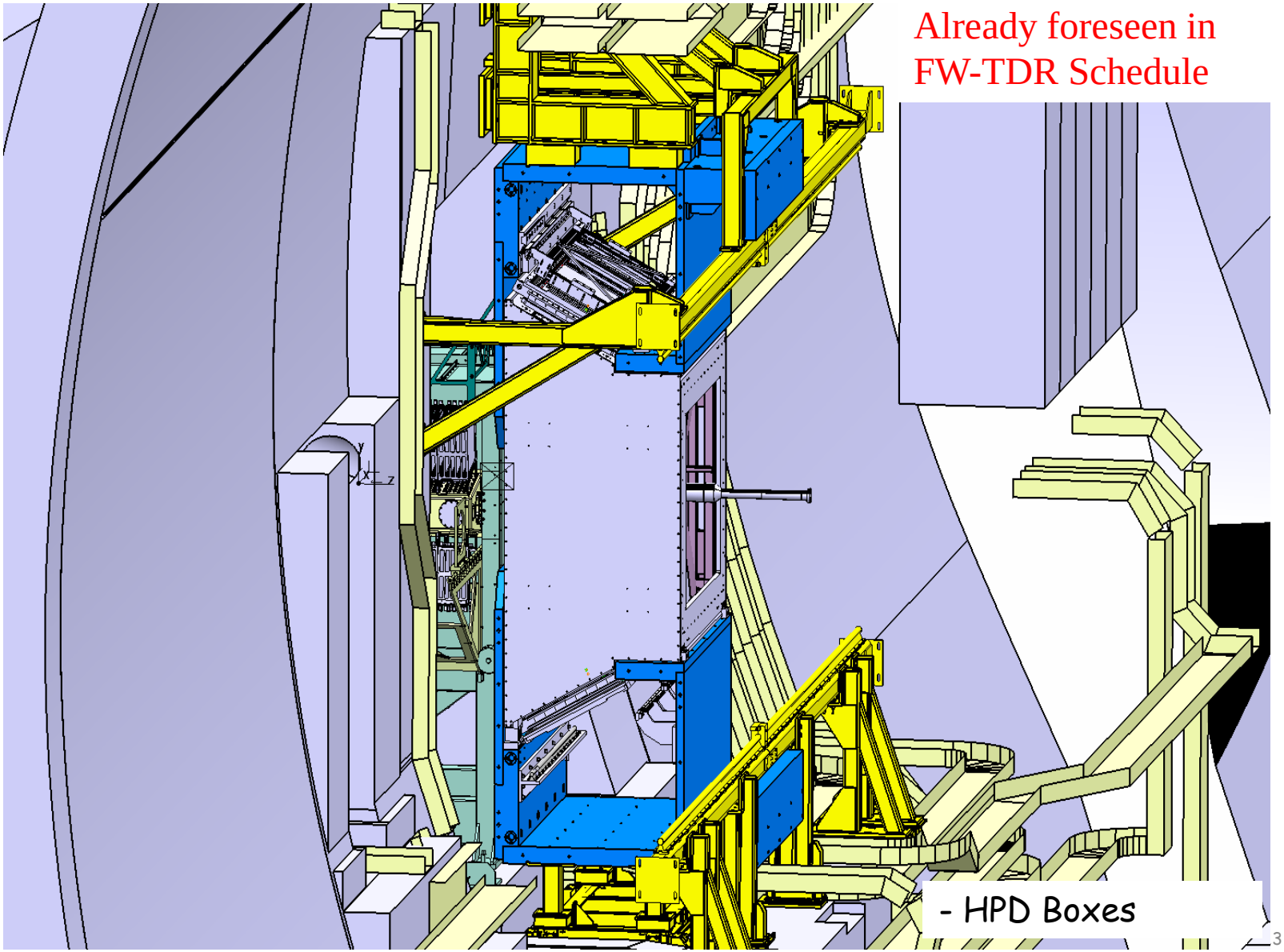
Cost.

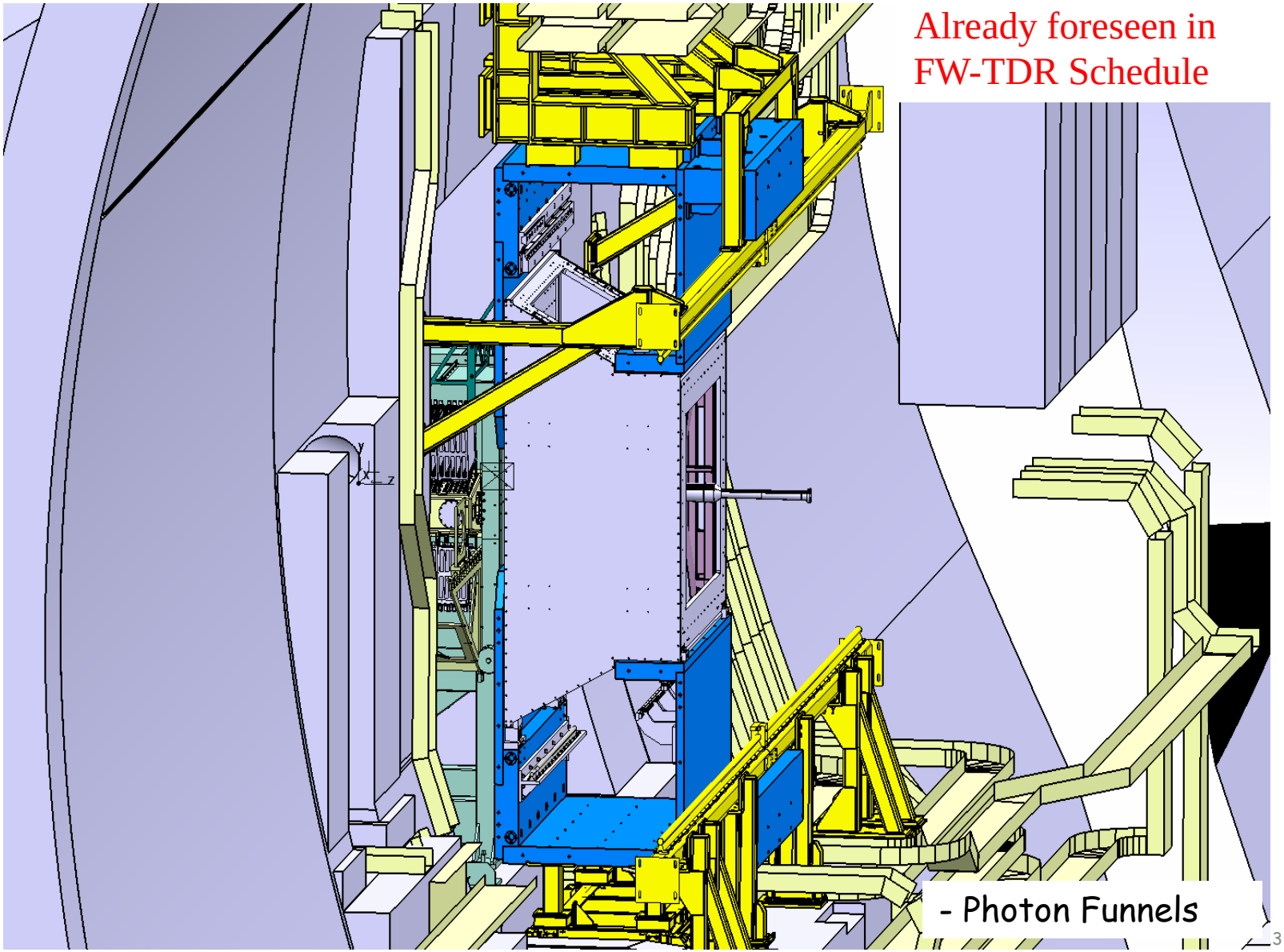
RICH1 – Removing Issue

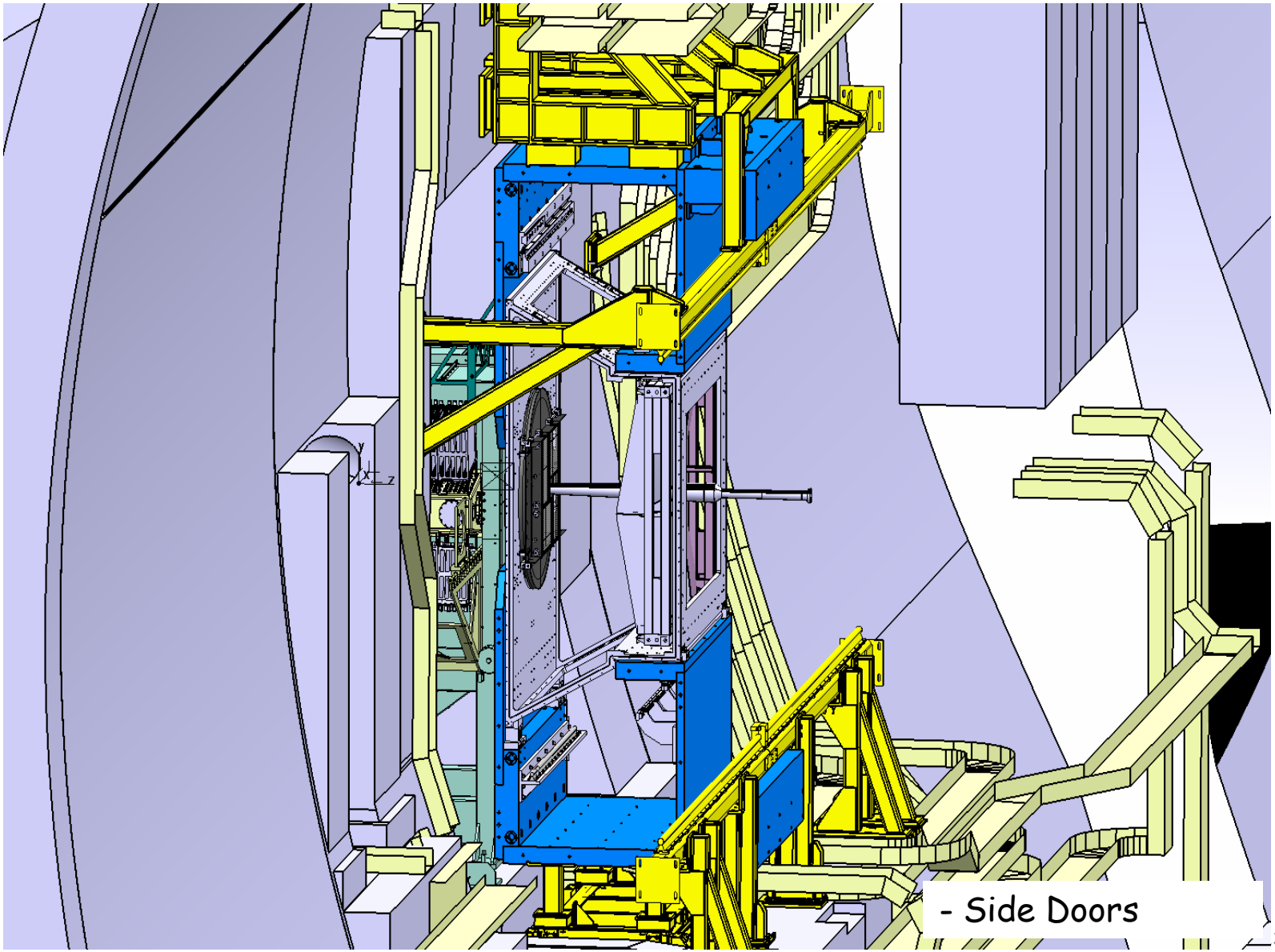


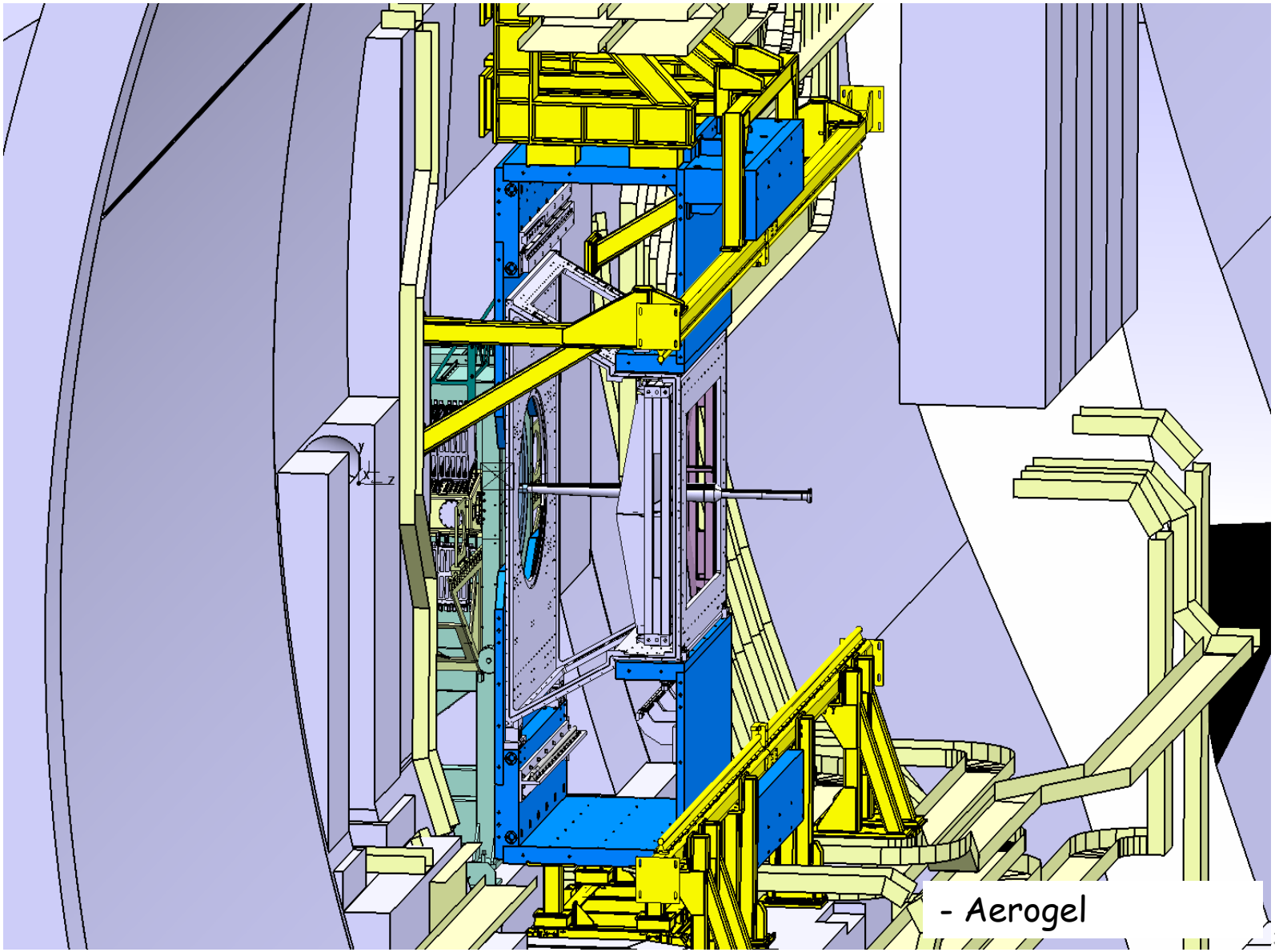

Already foreseen in
FW-TDR Schedule
- TT


Already foreseen in
FW-TDR Schedule
- Side Plates

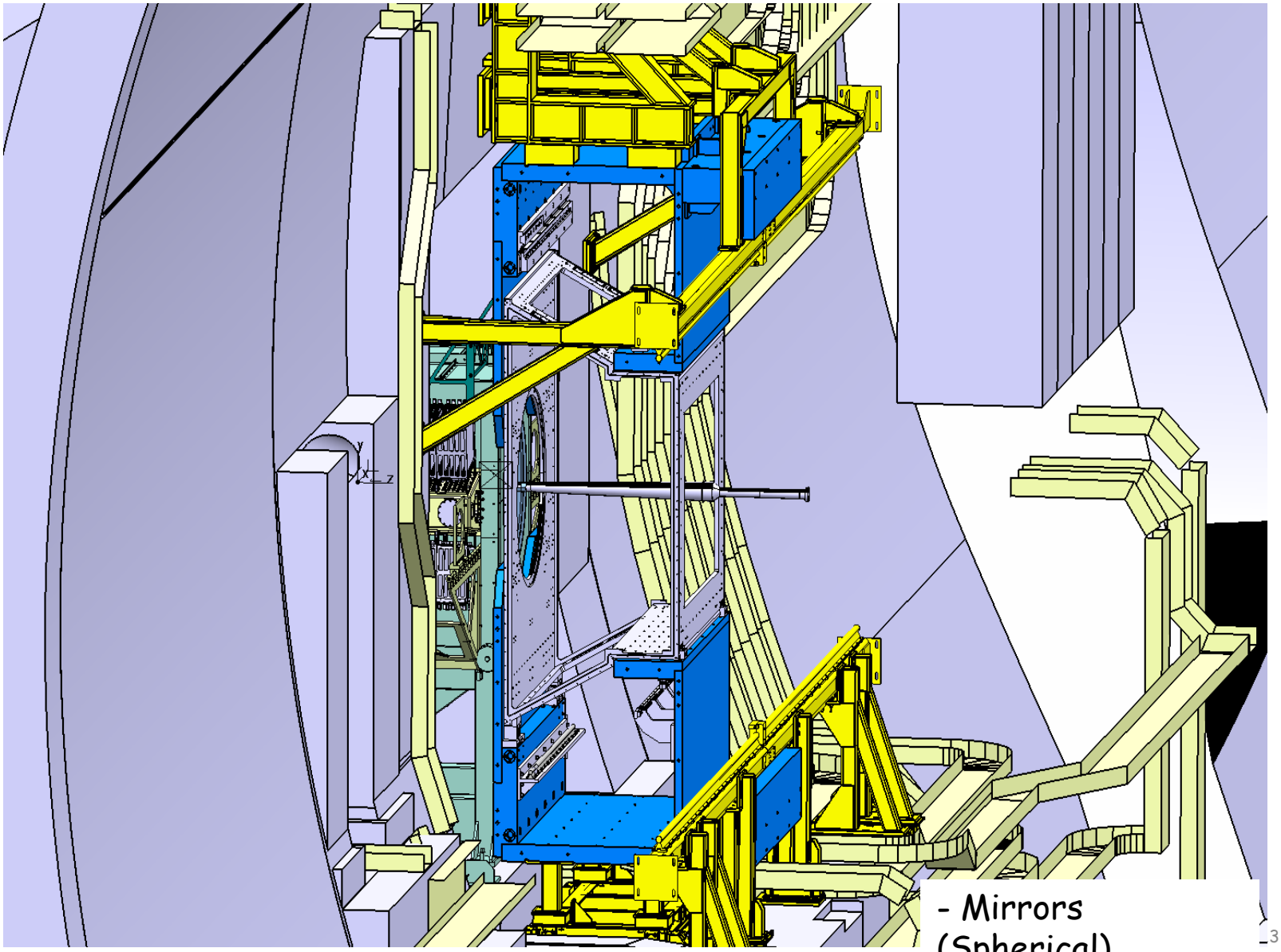

Already foreseen in
FW-TDR Schedule
- HPD Boxes


Already foreseen in
FW-TDR Schedule
- Photon Funnels

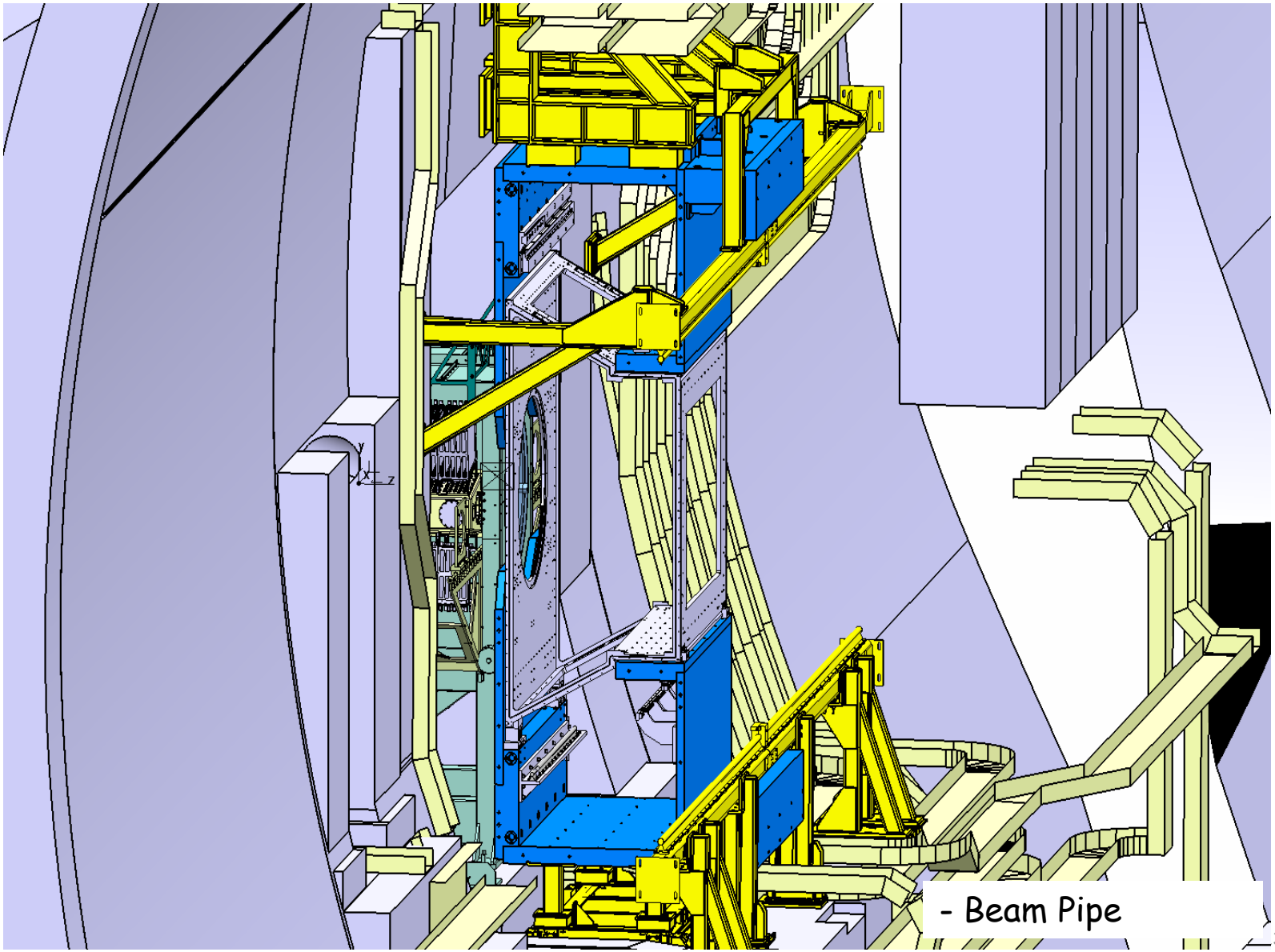

- Side Doors

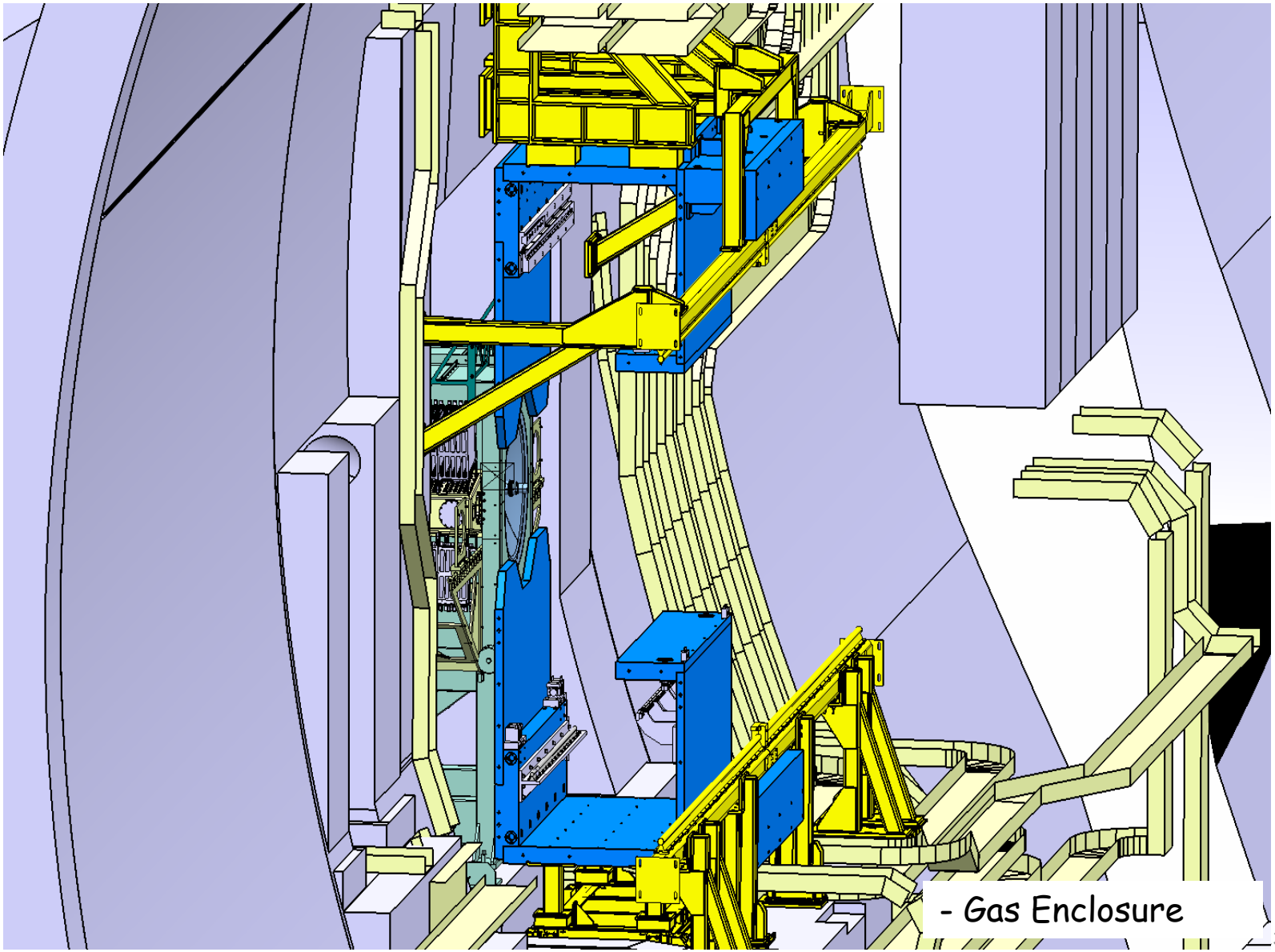


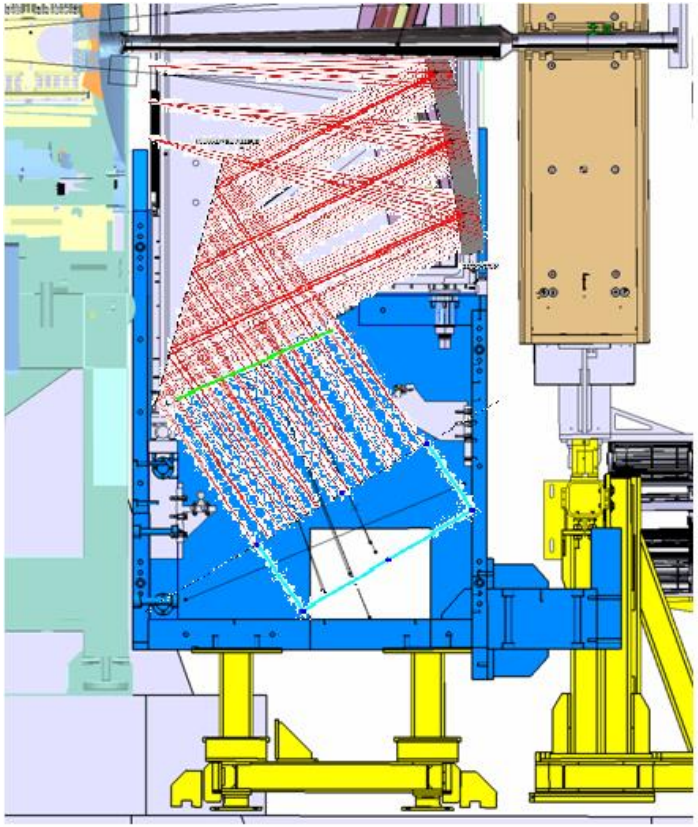
- Aerogel

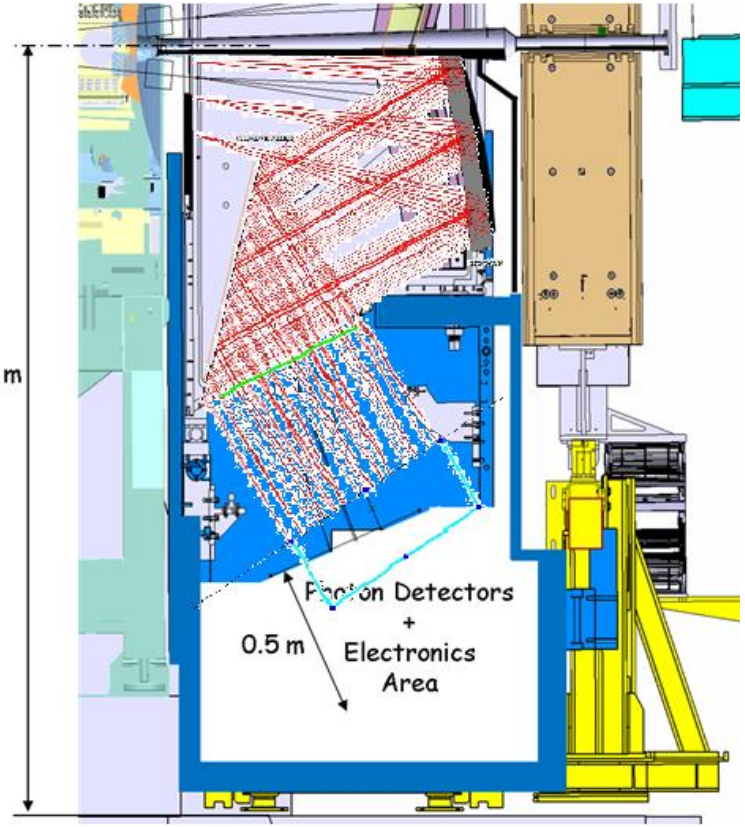


- Mirrors (Spherical)


- Beam Pipe


- Gas Enclosure





Without modif of the Magn Shield*

Can we make it? ☑

Can we install it? ☑

*Exactly what we wrote in the FW-TDR

With modif of the Magn Shield

Can we make it? ☑

Can we install it? ☒

**Not a technical drawing