



MT: A “Lower” Scenario

B. Leverington, on behalf of the Mighty-Tracker collaboration

Introduction

- I will focus here on cost cutting scenarios for the MightyPixel and MightySciFi
 - Ongoing R&D work on the detectors, test-beams, and simulation but I am unable to talk about it here today.
[MT General Meeting September 5](#)
- I hope to get across that with **money saved in each scenario**, there is a similar cost in **performance, time, labour, and/or risk**.
- Costing numbers and performance are quite preliminary

You get what you pay for.

Scoping Document

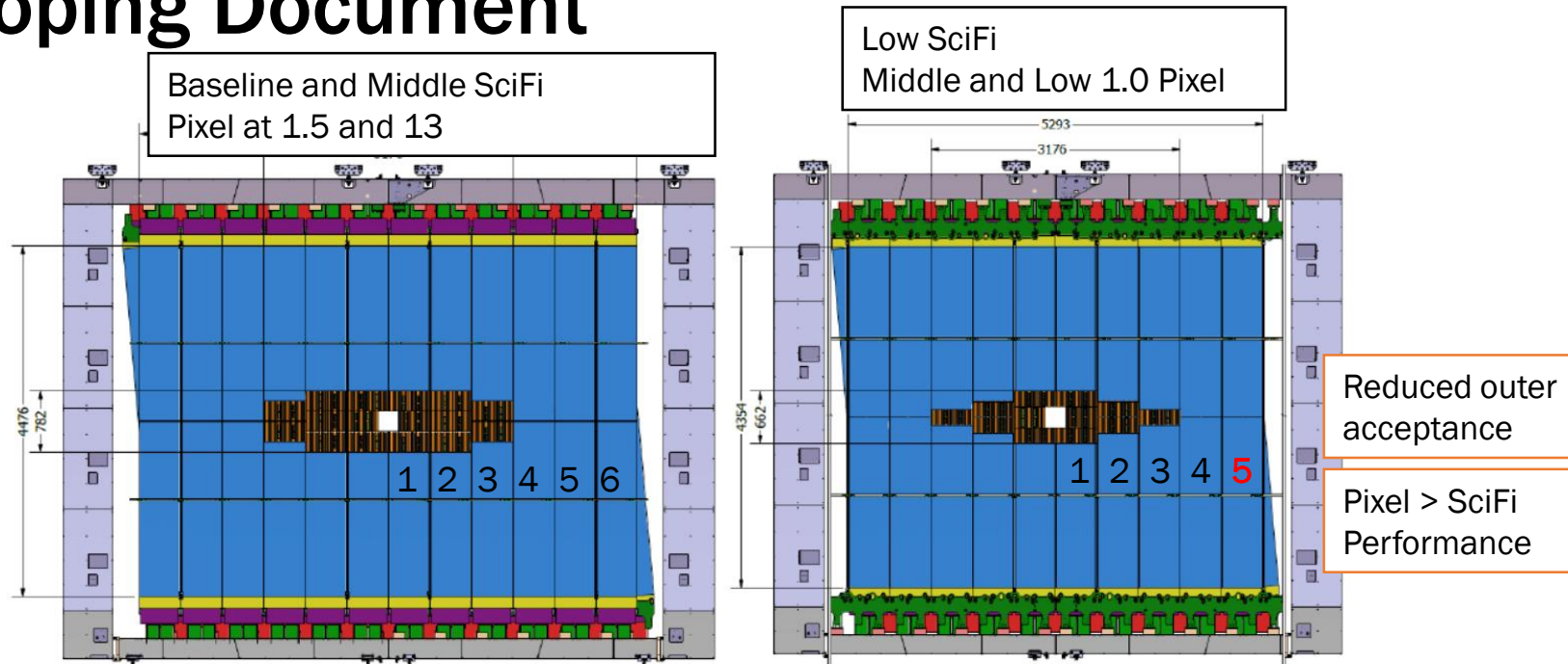


Figure 12: (Left) Front view of the Mighty-Tracker detector modules and frames in the Baseline scenario. (Right) Front view of the detector in the Low scenario, with smaller area covered by pixels and the outer Mighty-SciFi modules removed.

The Pixel area was the same in Middle and Low 1.0 scenarios

Scoping Document

Table 26: Cost estimate for the Mighty-Tracker in Baseline, Middle, and Low scenarios.

	Baseline (kCHF)	Middle (kCHF)	Low (kCHF)
Outer region: Mighty-SciFi			
Scintillating fibres, mats, modules	5811	5317	3555
Coldboxes, SiPMs	4592	4592	3828
Electronics	6414	6414	5055
Infrastructure, services	4950	4950	4950
Total Mighty-SciFi	21767	21273	17388
Central region: Mighty-Pixel			
MightyPix sensors	6384	3789	3449
Electronics	3789	2707	2707
Infrastructure, services	5821	5145	4905
Total Mighty-Pixel	15994	11641	11061
Total Mighty-Tracker	37761	32914	28449

Low = 81% new instrumentation costs

New C-Frames, Cryo-infrastructure, transfer line, cables, etc.

Middle to Low = cheaper, but heavier materials in the Pixel staves and flexes

Scoping Document

Mighty-Pixel

6 planes pixel $\times 2.1 \text{ m}^2$ 6 planes pixel $\times 1.3 \text{ m}^2$ 6 planes pixel $\times 1.3 \text{ m}^2$

Mighty-SciFi

12 planes fibres 12 planes fibres 12 planes fibres
 25.9 m^2/plane shorter, 23.7 m^2/plane narrower, 18.9 m^2/plane

Table 9: Acceptance reduction in the Middle and Low scenarios, with respect to the Baseline scenario, for representative physics channels, accounting for modifications of the VELO and MT detectors. All final-state particles are reconstructed as long tracks and required to have $2.0 < \eta < 4.8$. The results were obtained with the full simulation and include the VELO reconstruction efficiency.

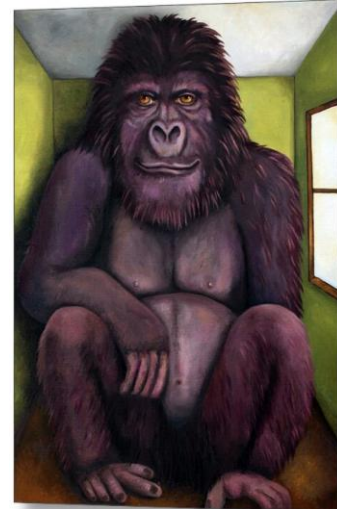
Channel	Relative acceptance %	
	Middle	Low
$B_s^0 \rightarrow \mu^+ \mu^-$	99.3 ± 0.1	95.3 ± 0.1
$B_s^0 \rightarrow \phi(\rightarrow K^+ K^-) \phi(\rightarrow K^+ K^-)$	99.4 ± 0.1	90.6 ± 0.2
$D^0 \rightarrow K_S^0(\rightarrow \pi^+ \pi^-) \pi^+ \pi^-$	99.7 ± 0.1	84.8 ± 0.8

Mighty-Tracker BR⁽²⁾, CH^(50,51), CL⁽⁹⁵⁾, CR⁽⁹⁾, DE^(17,18,19,20,22,76,86), ES^(46,48), LT⁽⁹⁴⁾,
 PL^(40,41,42,96), SE⁽⁸²⁾, UK^(56,58,59,60,61,62,63)

Since then...

- No UK investment funding for the MT-Pixel in the current picture
 - The Op8e34 luminosity reduction proposal
- MT-SciFi is still well short of the 17 MCHF Low Scoping Budget
 - Stronger Polish interest in the MT-SciFi, Fibre Module production in addition to the PACIFIC++ ASIC;
 - Re-use significant parts of the Run3/4 SciFi detector where feasible
 - An air-based chiller investigated by EN-CV for Run4 (-60°C) could reach -110°C (165K) for Run 5
- MT-Pixel with 5 Layers instead of 6
 - loss of redundancy in case of module failure

800lb Gorilla



by Leah Saulnier



MANCHESTER
1824

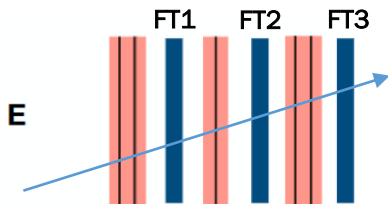
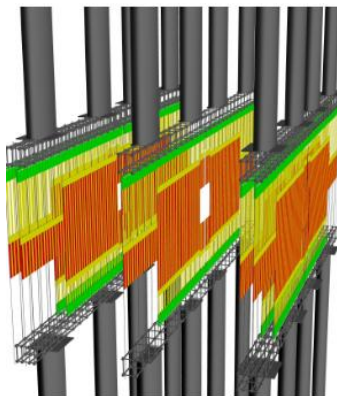
The University of Manchester

Slide from Stefano De Capua
and Oscar Francisco

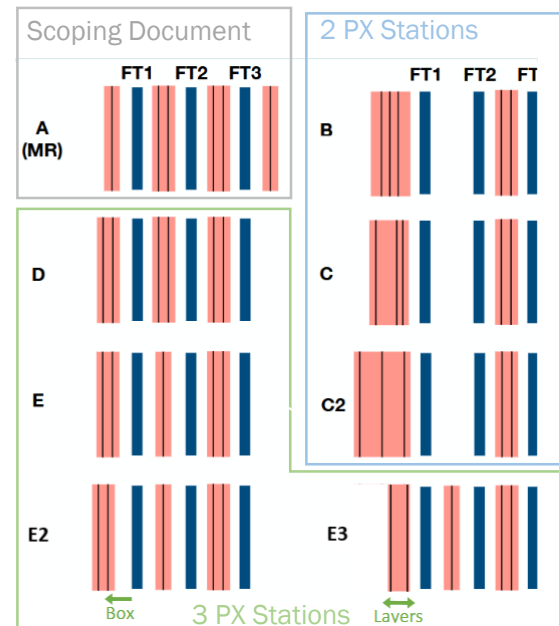
Pixel with 5-layers

Goal: Reduce costs and materials, optimize performance

Layout E



- Alternative geometries for the MP provided by [Donata] with full 1p0e34 simulation
- Reduced material wrt. current nominal (A) from fewer enclosure boxes (BCDE) and fewer active layers (BCE)
- Adapted MP tracker algorithm and added 3-hit tracking with χ^2 -cut
- ϵ for long tracks reconstructed as T-tracks very similar between options
- Slightly higher (but acceptable) ghost rate



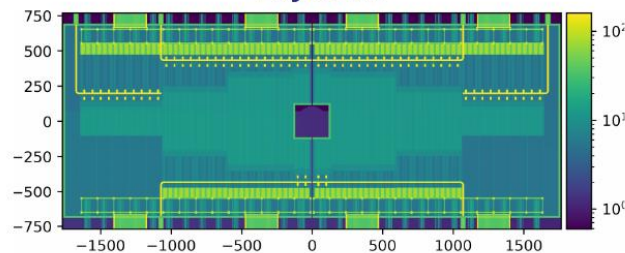
Efficiency	Layout A	Layout B	Layout C	Layout D	Layout E	Layout E2	Layout E3
Long	97.66 %	98.18 %	97.90 %	97.29 %	97.08 %	97.19 %	96.99 %
Long, $P > 5$ GeV	98.74 %	98.97 %	98.99 %	98.88 %	98.63 %	98.77 %	98.48 %
Ghost	0.78 %	2.85 %	3.85 %	1.14 %	2.40 %	2.63 %	2.32 %

(MP-only) T-track reconstruction efficiency for long tracks

[C. Schudy]

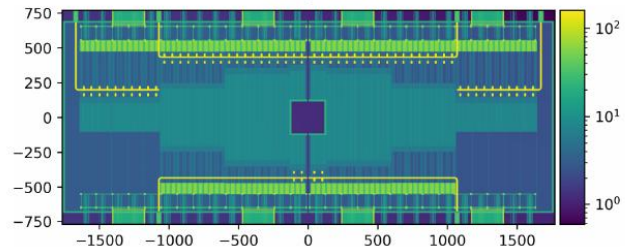
Material and Momentum Resolution

Layout A



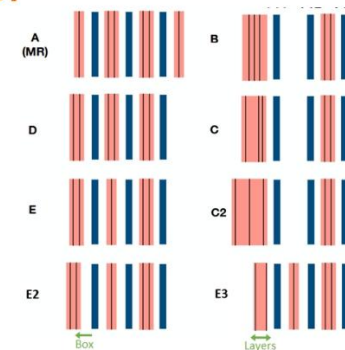
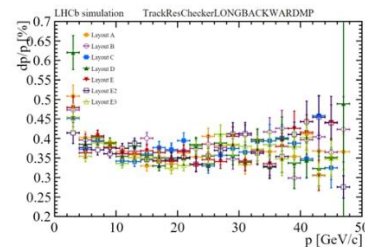
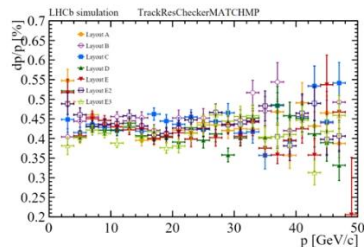
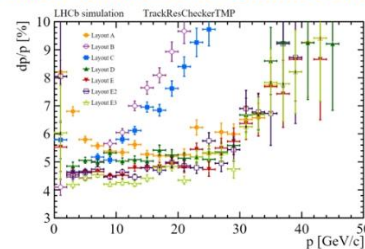
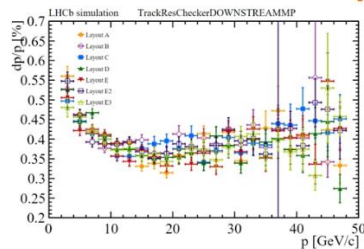
Mean MB = 20.48 X_%
Median = 8.80 X_%

Layout C



Mean MB = 14.61 X_%
Median = 6.07 X_%

[Donata Osthuies and Claudia Schudy]



- Results for 100 events $\cong \mathcal{O}(10^4)$ tracks, 3 hit χ^2 fit

- Momentum resolutions for T-tracks best for the “E” scenarios = 2+1+2
- Next iteration of central production will be done with scenario E¹

¹Modulo some minor shifts to eliminate overlaps.

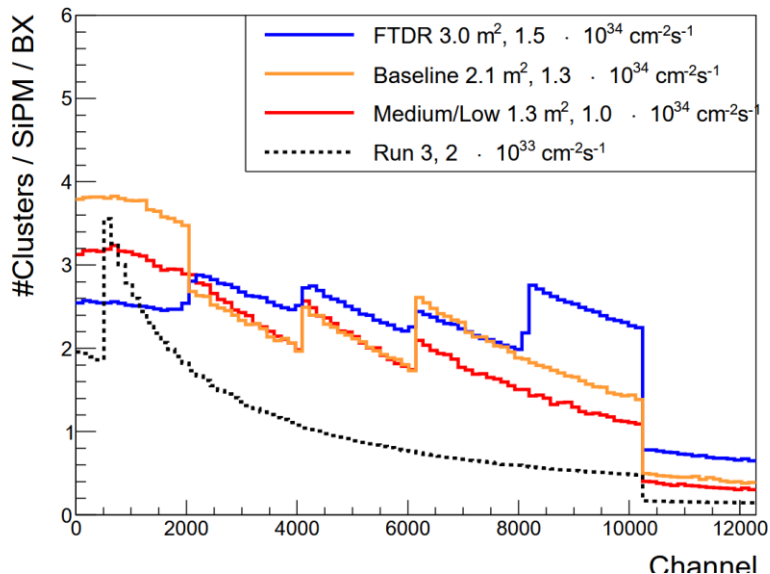
LHCb C. Langenbruch (Heidelberg) 10.09.2026

MT_U2_optimisation

0p8e34 & OCCUPANCY

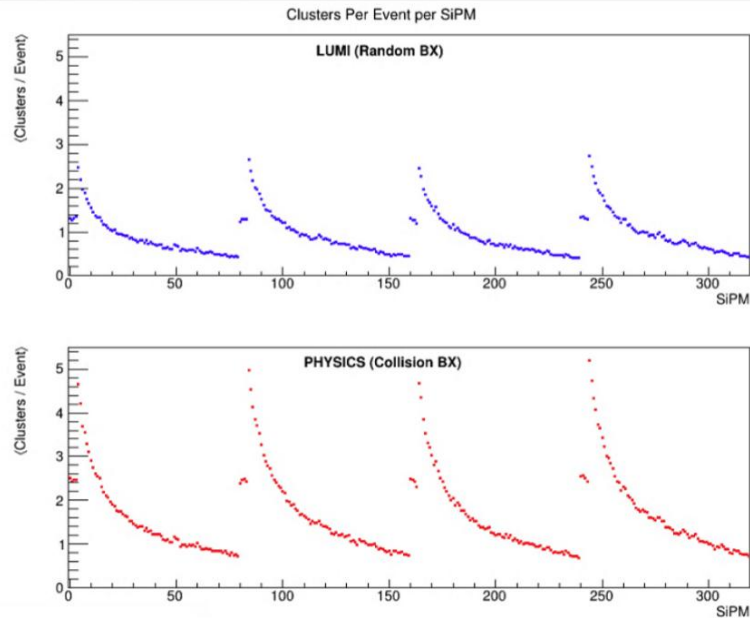
From Scoping Document epoch, C. Langenbruch

Fibre Occupancy



Here, SiPM = 128 channels

Likely missing late particle signal spillover



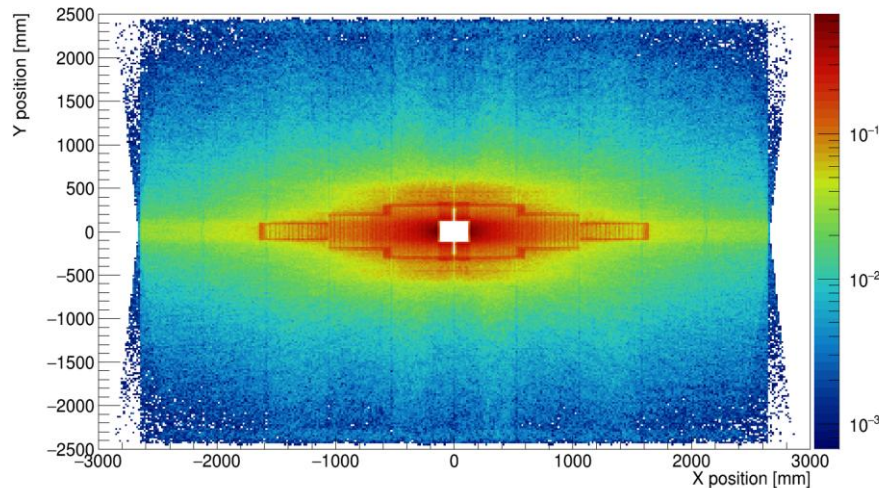
Run 3 data, from monitoring. Peaks around 5, not as flat.

Use 5/3.6 = 1.4 Data/MC factor, roughly

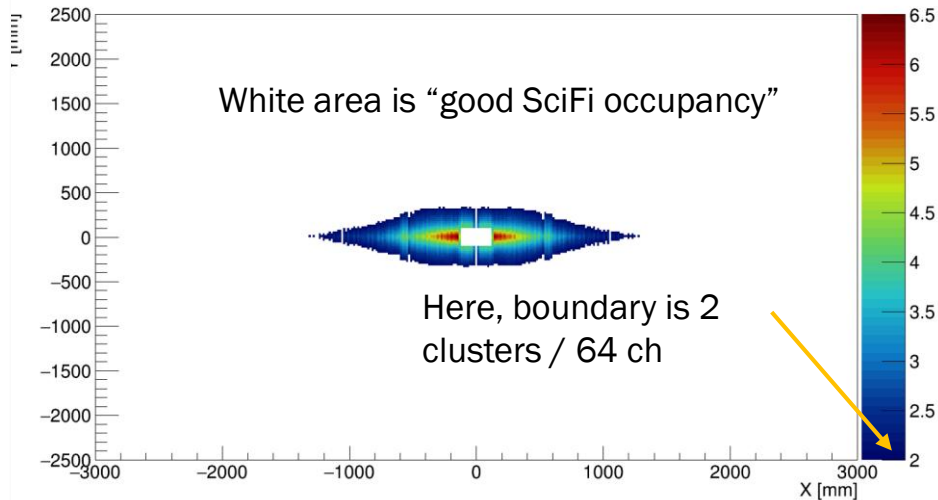
0p8e34 & OCCUPANCY

A study: What is the occupancy boundary for SciFi?

Merged Single Layer Raw Hitmap



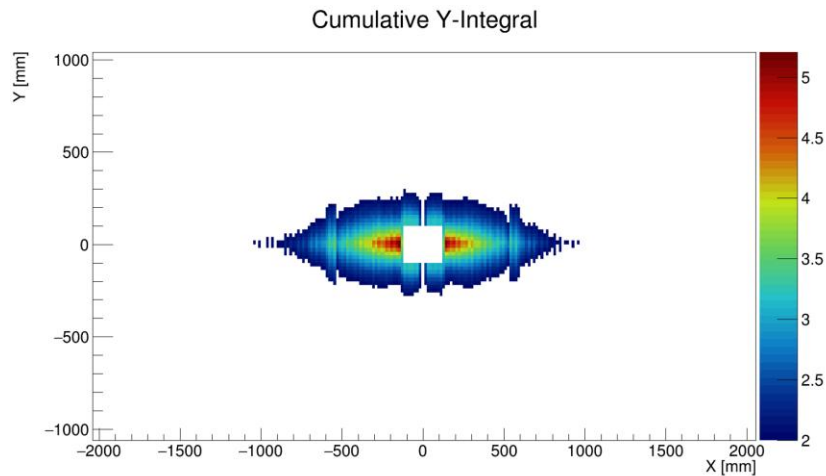
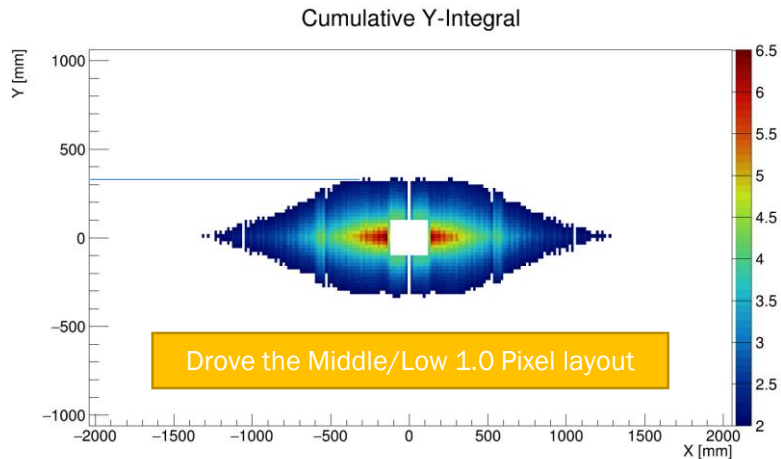
Strip occupancy vs Y-boundary



Hits taken from **1p3e34** July 2026 sim by Renato

1.3E34 as safety margin on 1.0E34

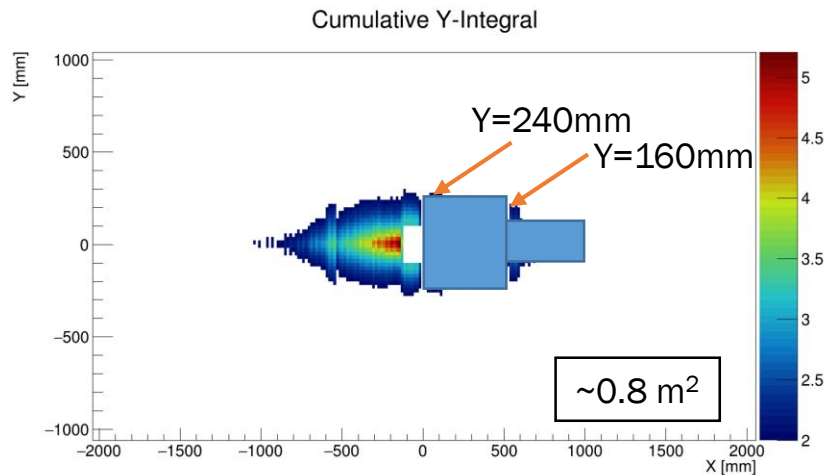
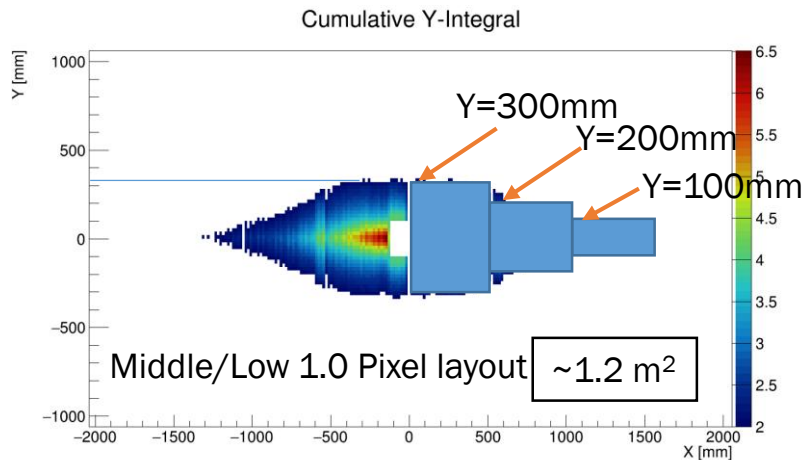
Scaled by 0.8



2 clusters per 64ch boundaries
(White area = SciFi OK)

1.3E34 as safety margin on 1.0E34

Scaled by 0.8

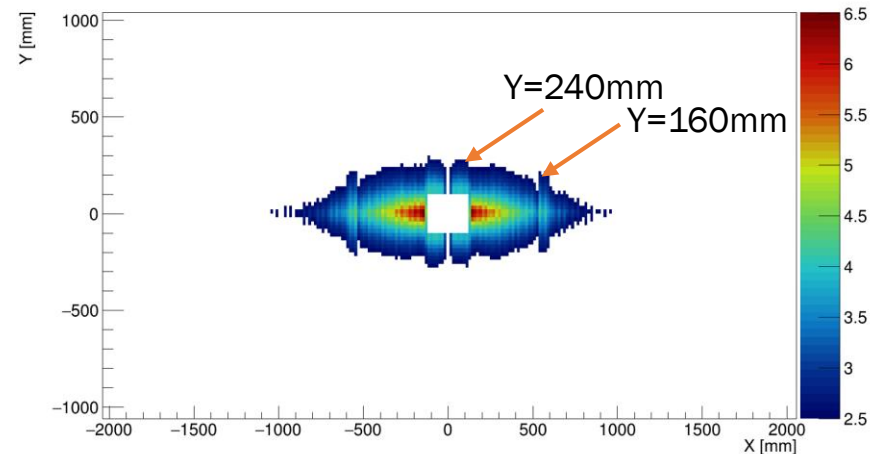


2 clusters per 64ch boundaries
(White area = SciFi OK)

What if we allow +25% more occupancy into SciFi?
(relatively)

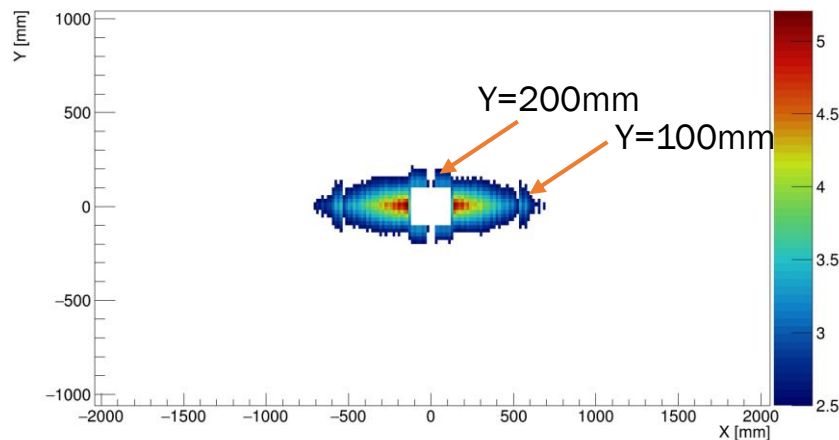
1.3E34

Cumulative Y-Integral



Scaled by 0.8

Cumulative Y-Integral



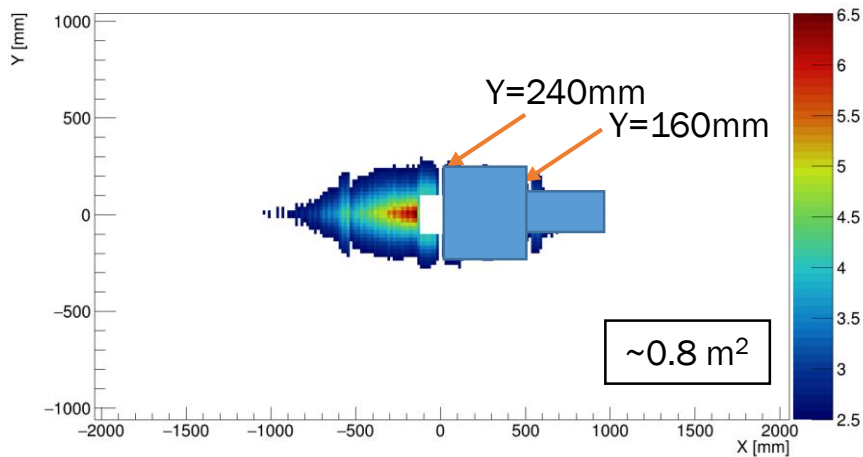
2.5 clusters per 64ch boundaries
(White area = SciFi OK)

Should also be ok. 2.0 was the Safe value. Everyone loves more pixel.

What if we allow +25% more occupancy into SciFi?
(relatively)

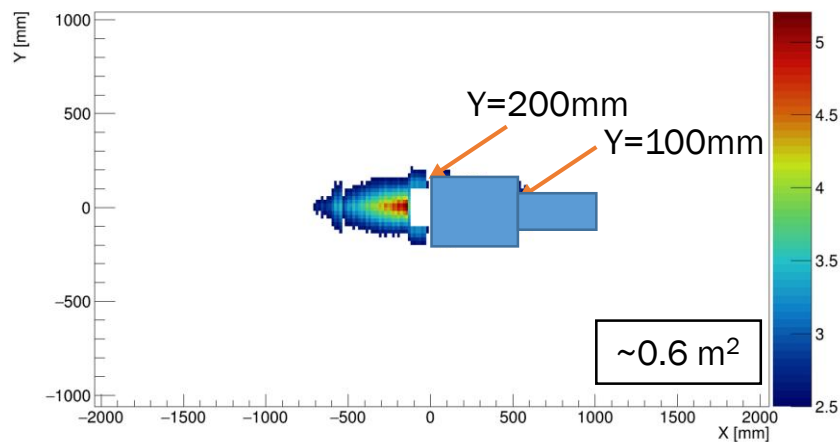
1.3E34

Cumulative Y-Integral



Scaled by 0.8

Cumulative Y-Integral



2.5 clusters per 64ch boundaries
(White area = SciFi OK)

From our [MT General meeting](#) last week

For fast iteration using modified Run 3 min. bias simulation with 1.3 m², 0.8 m², and 0.6 m²

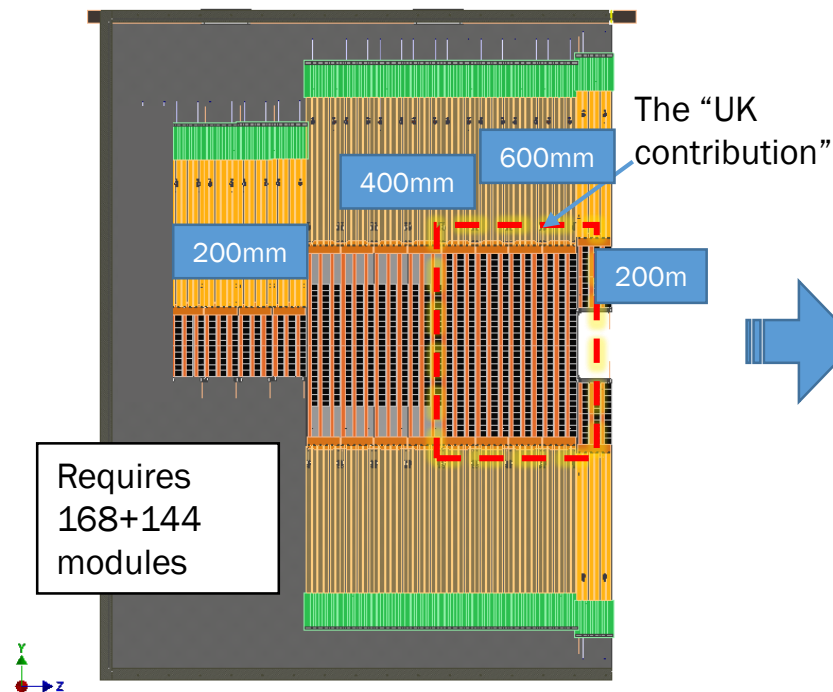
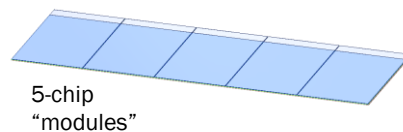
Using Run 3 modules with the following cutouts:

area	configuration
1.3 m ²	2 × 52.8 × (60.0 + 40.0 + 20.0) cm ²
0.8 m ²	2 × 52.8 × (48.0 + 32.0) cm ²
0.6 m ²	2 × 52.8 × (40.0 + 20.0) cm ²

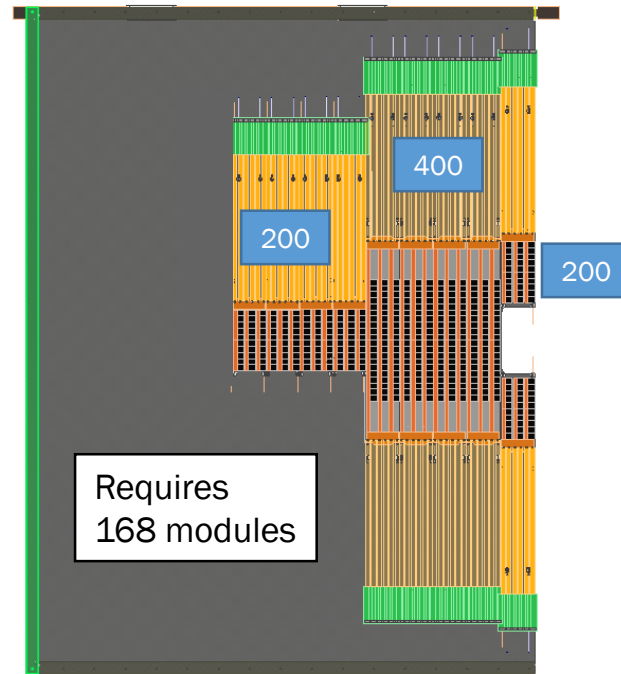
Luminosity $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$				
MP area	1.3 m ²	0.8 m ²	0.6 m ²	0 m ²
ε [%]	92.9	93.0	93.2	92.8
ε(p > 5 GeV) [%]	97.9	97.4	97.4	96.5
ghost rate [%]	0.9	1.2	1.9	21.0
fraction tracks FT/all [%]	56	64	71	100
Luminosity $0.8 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$				
MP area	1.3 m ²	0.8 m ²	0.6 m ²	0 m ²
ε [%]	89.6	89.5	88.9	80.87
ε(p > 5 GeV) [%]	96.5	95.9	94.9	83.95
ghost rate [%]	8.3	13.7	21.6	79.5
fraction tracks FT/all [%]	56	65	71	100
Luminosity $1.0 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$				
MP area	1.3 m ²	0.8 m ²	0.6 m ²	0 m ²
ε [%]	87.9	87.3	86.2	75.3
ε(p > 5 GeV) [%]	95.7	94.8	93.5	78.2
ghost rate [%]	12.3	20.3	30.8	85.6
fraction tracks FT/all [%]	56	64	71	100

- Efficiency/ghost rate for T-tracks in the FT reconstructible as long tracks
- Lower eff (−1% and −2%) and higher ghost rate (+8% and +18%)

Staged Assembly



(Low Scenario 1p0e34;
x1.00 occupancy in SciFi)



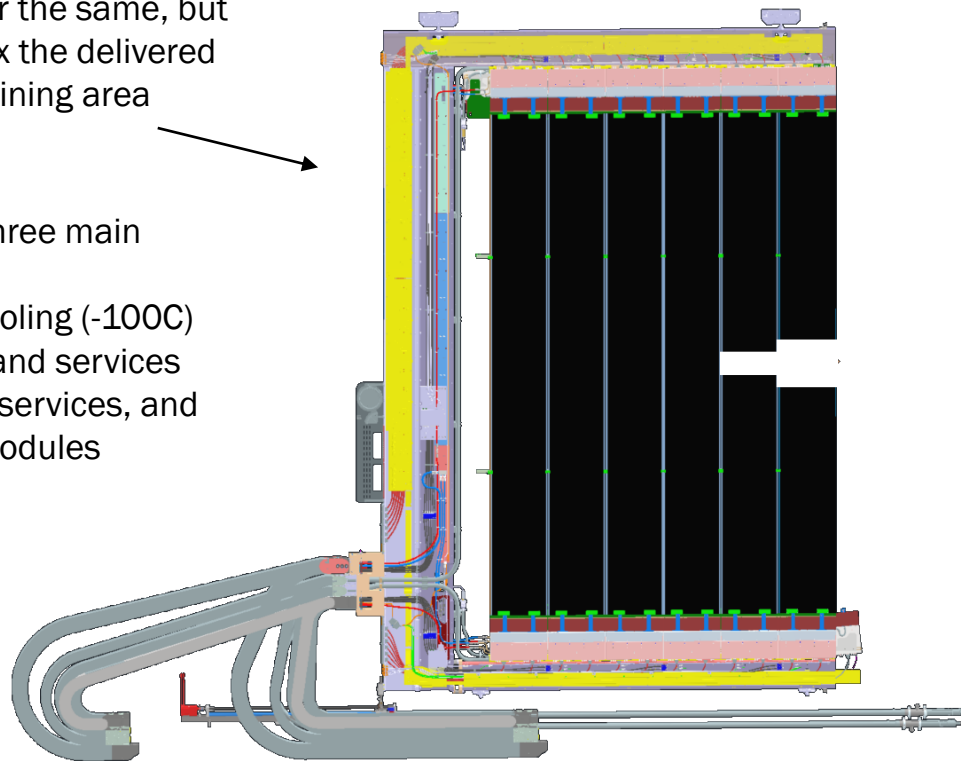
(55% of the size for Op8e34;
x1.25 occupancy in SciFi)

“Lower” cost SciFi scenarios.

The SciFi might appear the same, but it needs to handle 4-5x the delivered luminosity in the remaining area

We are investigating three main Scenarios:

- A) Re-using Run4 cooling (-100C)
- B) Re-using frames and services
- C) Re-using frames, services, and up to 80 Run-3 modules



A) Re-use Run 4 Chiller

New M0-M4 “short” modules. M5 removed on T3, removed M4 on T1/T2.

New Cryo- Cold-boxes

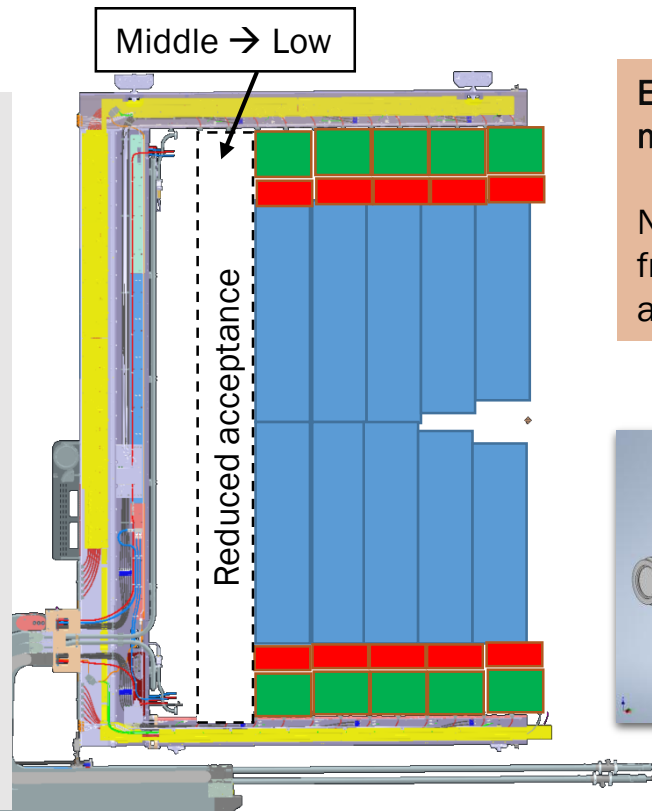
New electronics + SiPMs (PDE boost) + new backend

New data & control fibres.

Mechanics follows proposed Upgrade 2 geometries (508mm pitch), overlapping mats

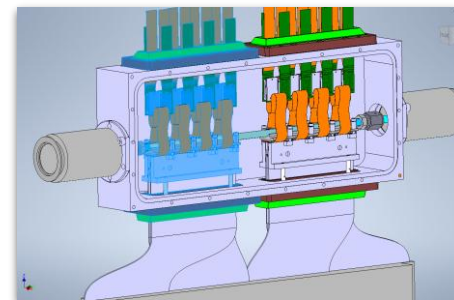
New C-Frames and Services

Could build and test everything before LS4.



EPFL's cold-box and module design.

New everything aside from some cables and cable chains.



Florian Bernard

EPFL

A) Re-use Run 4 Chiller

Need at least 30 degrees more cooling
(to -90C or better -110C) for dark noise.

Foresee to run possible new chiller for
Run 4 colder for Run 5

- Still under investigation for Run 4

A cryo-plant is likely factors more
expensive for LHCb with transfer lines
down to the cavern. Need to start this in
2027...

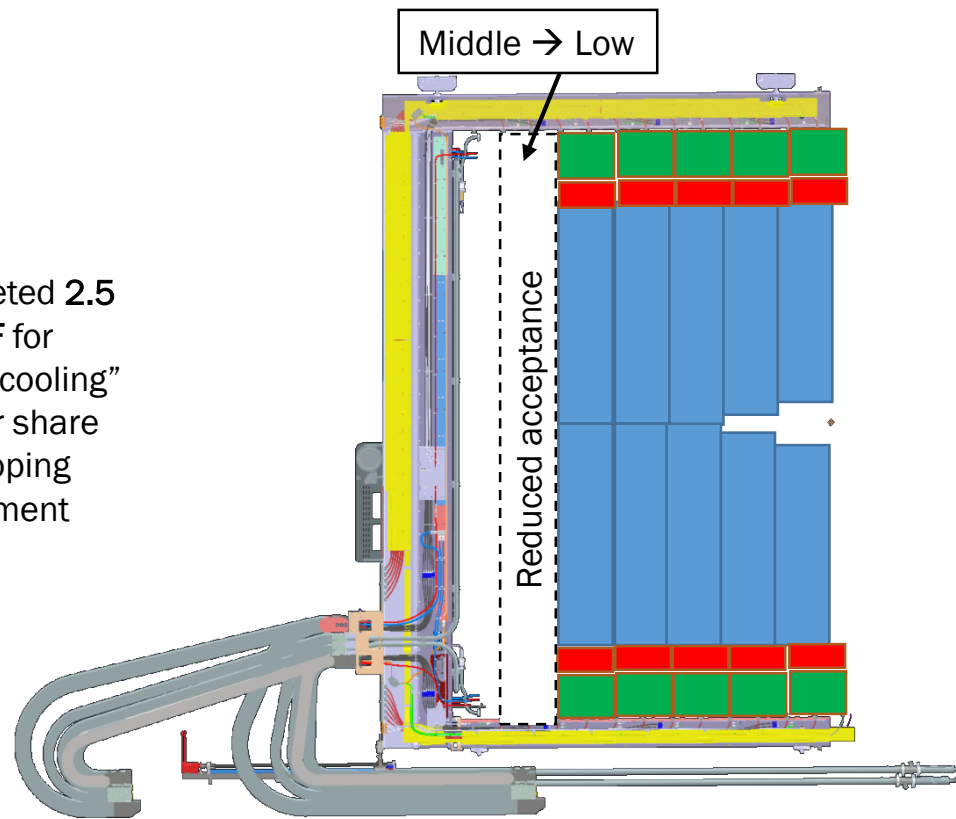
- RICH1, please talk to Guido H. and
SciFi about synergies

Need more light detection from new
generation SiPMs

Shorter modules have to be built to
remove material at the pixel.



SciFi
budgeted 2.5
MCHF for
“cryo-cooling”
chiller share
in Scoping
Document



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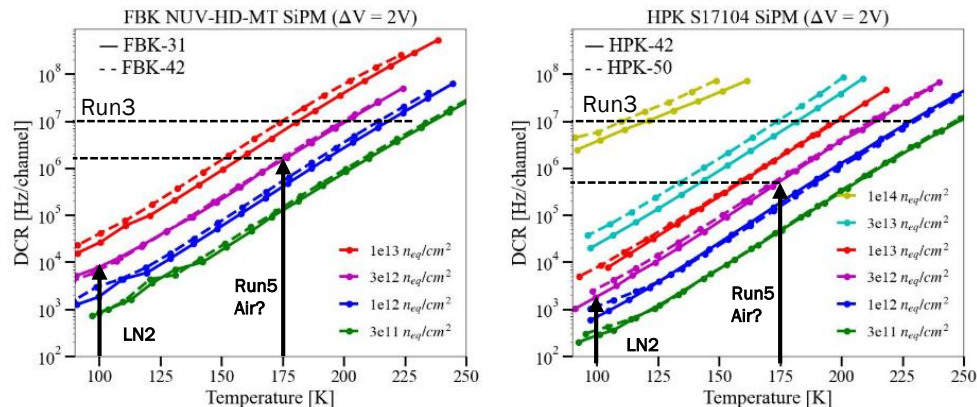


Figure 5.22: Left: FBK device at $\Delta V = 2V$, the correlated noise component makes its appearance at the highest irradiation fluence ($1 \times 10^{13} n_{eq}/cm^2$). A small increase for the $42\mu m$ pixel device is seen. Right: In comparison the Hamamatsu (HPK) device at $\Delta V = 2V$. At $1 \times 10^{14} n_{eq}/cm^2$ a dramatic increase in DCR is seen. Note the strong reduction in PDE for the low ΔV operation. Peak PDE is only 30%.

Requires higher clustering thresholds;
impact on timing resolution

Novec 7100 at -100C?

Typical Physical Properties

Properties	3M™ Novec™ 7100 Engineered Fluid
Formula	C ₄ F ₉ OCH ₃
Molecular Weight	250
Boiling Point (°C)	61
Freeze Point (°C)	-135
Liquid Density (g/ml)	1.52
Surface Tension (dynes/cm)	13.6
Solubility of Solvent in Water (ppmw)	12
Solubility of Water in Solvent (ppmw)	95
Vapor Pressure (mmHg)	202

Data compiled from published information.

Not for specification purposes. All values @ 25°C unless otherwise specified.

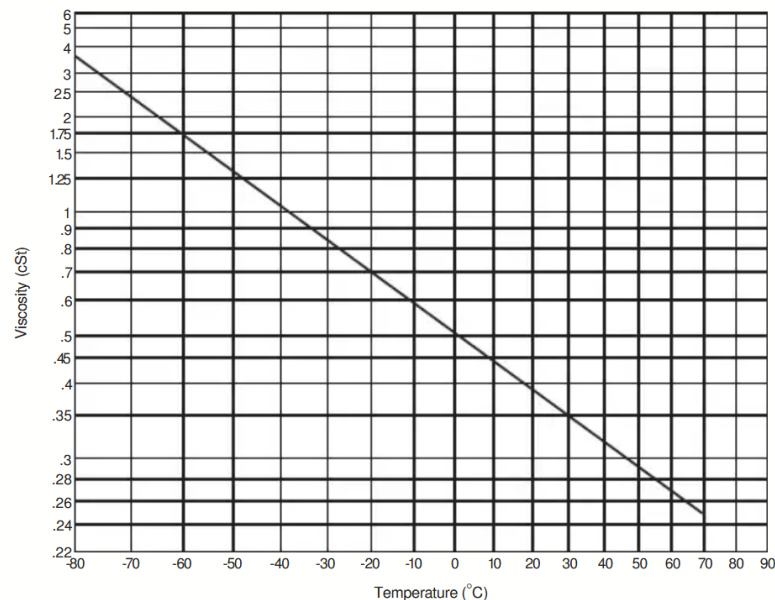
Environmental and Safety Properties

Properties	3M™ Novec™ 7100 Engineered Fluid
Ozone Depletion Potential–ODP ¹	0.00
Global Warming Potential ²	320
Atmospheric Lifetime (years)	4.1
Flash Point	None
Flammability Range in Air	None
Exposure Guidelines (8 hr. time-weighted average)	750
Exposure Ceiling (ppm)	None
Acute Toxicity (4 hr. LC ₅₀ [Rat])	>100,000

Diesel fuel (~3–5 cSt)

Ethylene glycol (~16–18 cSt)

HFE-7100 Kinematic Viscosity



EU: PFAS bans

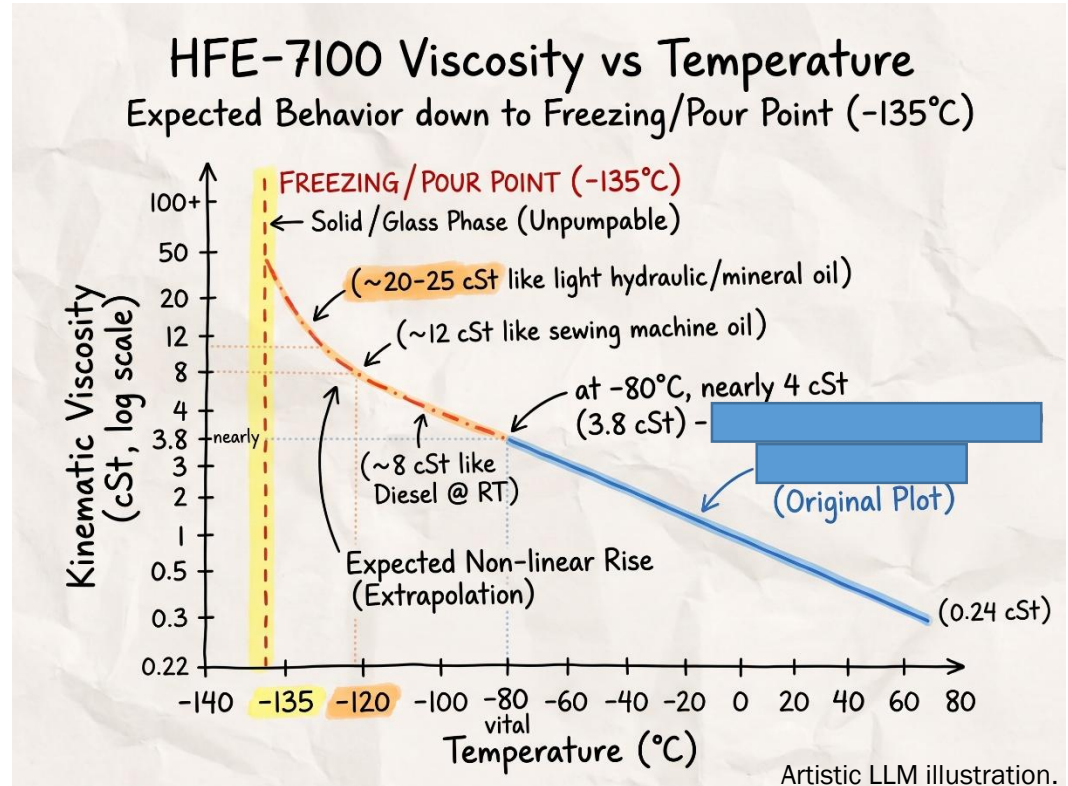
3M stopped production of Novec™ Engineered Fluids in December 2025

Entry into Force (EIF): Expected in late 2027 or 2028 after final adoption by the European Commission.

General Transition Period: 18 months post-EIF for non-derogated uses (putting the earliest strict bans around mid-2029 to late 2030).

Derogation Periods: Time-limited derogations (often structured as 5 or 12 years plus the initial 18-month transition) may apply to specific critical industrial uses where substitutes are not yet ready.

Most alternatives seem to be quite flammable.



B) Reuse frames and services only

New M0-M4 “short” modules. M5 removed on T3, removed M4 on T1/T2.

New Cryo- Cold-boxes

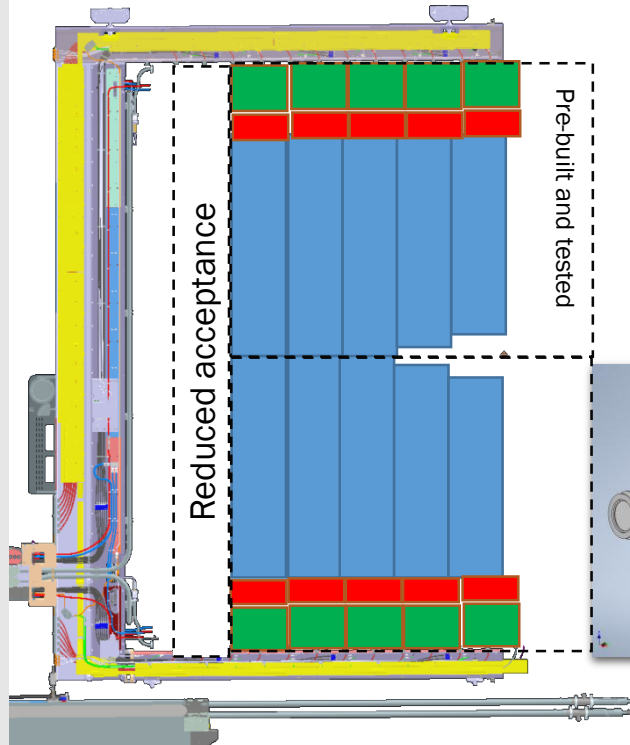
New electronics + SiPMs (PDE boost) + new backend

New data & control fibres.

Mechanics follows proposed Upgrade 2 geometries (508mm pitch), overlapping mats

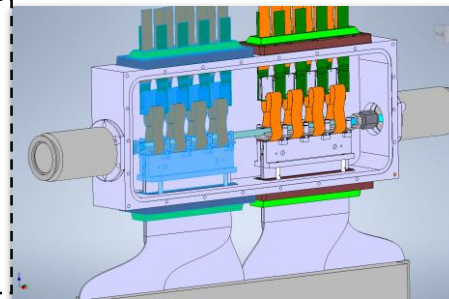
New system needs to use old service lines (cooling, power).

Could pre-build and test top and lower halves before LS4. Needs time in LS4. Re-commissioning after reconnecting in the frame.



Compatible with EPFL's cold-box and module design.

Needs new module mounting, water cooling blocks, SiPM cooling distribution.



Florian Bernard

EPFL

C) Reusing modules, frames, and services

96 new M0-M1 “short” modules 
 80 “old 5m” modules at ~75fb-1 of 235fb-1
 already built 

New Cryo Cold-boxes. No cold-spots 

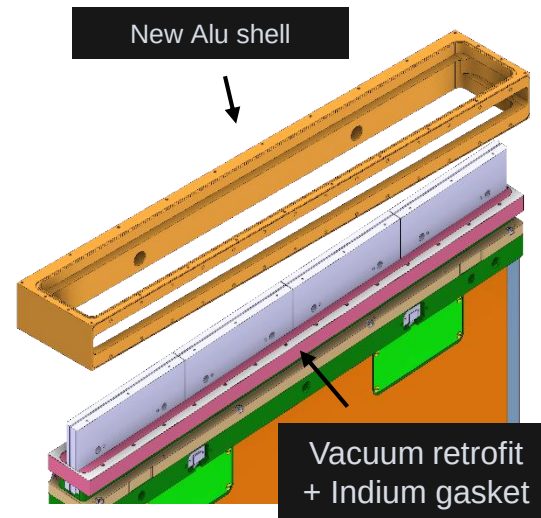
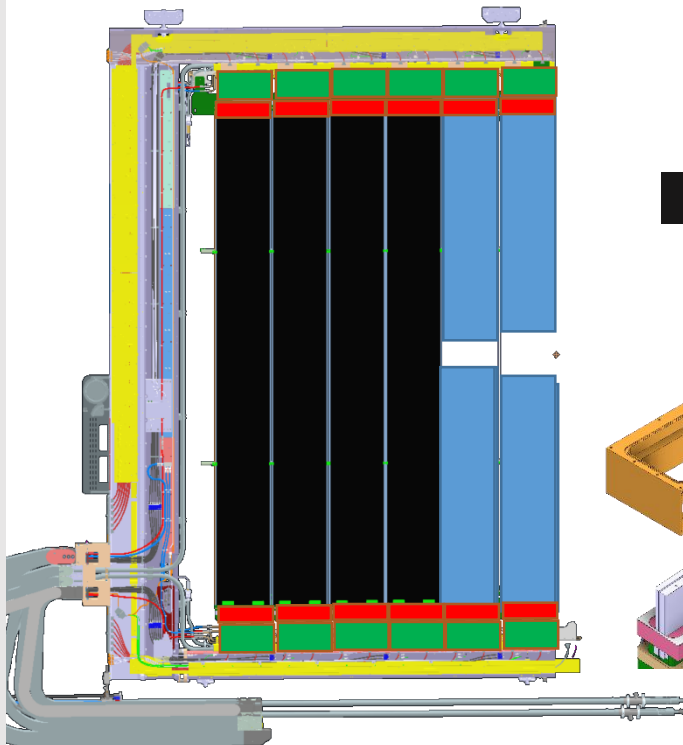
New electronics + SiPMs (PDE boost) + new
 backend 

New data & control fibres. 

Mechanics follows Upgrade 1 geometries
 (530mm pitch)

New system needs to use old service lines
 (cooling, power) and C-Frames.

Need time (1-2 years) to rework the
 modules to be compatible with cryo-like-
 boxes. Not compatible with LS4 alone.



D.Fehr, M.Wlochal

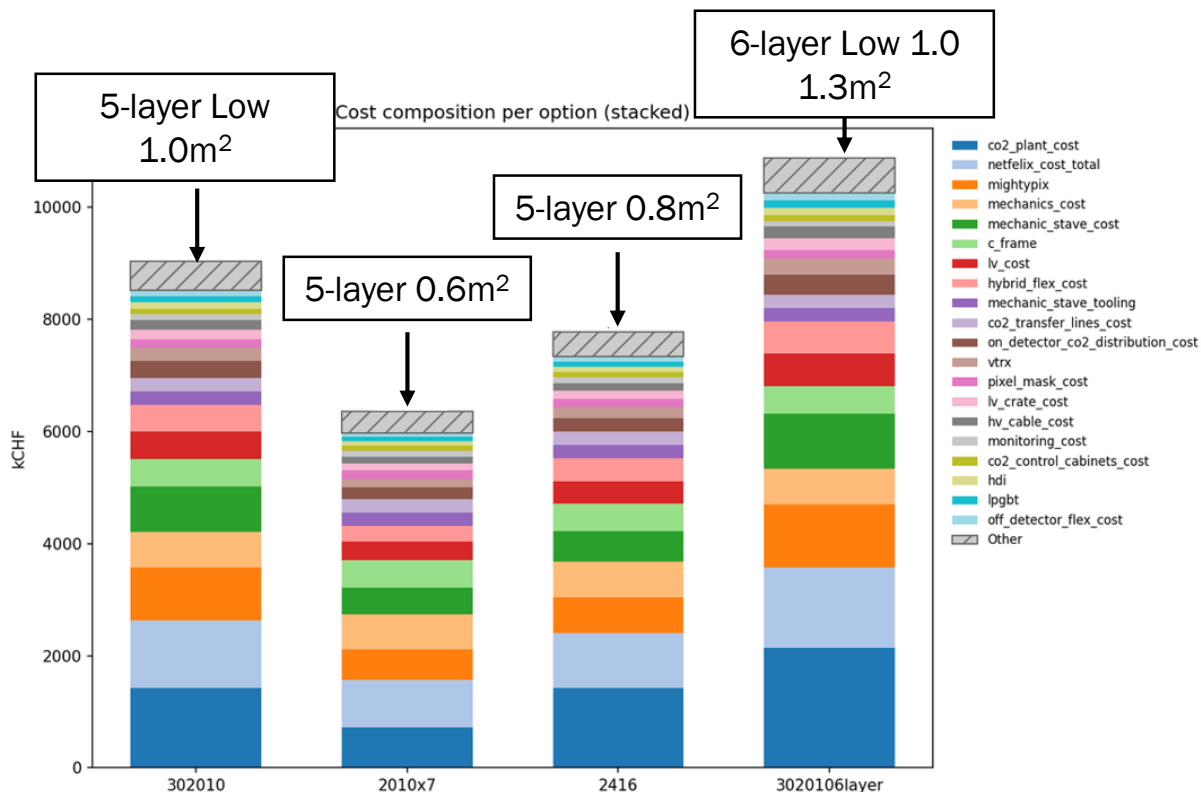
Do we still have timing?

- Budget still assumes electronics and backend for timing
- We haven't seen if 0.5 photoelectron thresholds are compatible with our detector spillover.
 - 0.5 or 1.5 p.e. thresholds for cluster timing probably ok. ($\sigma_t < 1\text{ns}$)
 - Performance at -100C needs further study
- Timing will not allow for a further increased occupancy in scifi, only a decrease of occupancy in the backend
 - Finite strip (channel) size and cluster widths
 - Real hits will begin to merge too often, not separable with per-channel time resolution from a few (couple) photoelectrons
 - Bandwidth (cluster) limits match this channel occupancy.

SciFi Scenario Costs

Component	Scenario C		Scenario B	
Scintillating Fibres & Mats	81	96 half-length modules (M0,M1)	08	6 layers
Tooling	0	same mat tools as U1	0	Institution lab costs
Modules	99	96 short modules (M0,M1)	64	208 short modules
Tooling	50	short modules	50	Lab Costs for remainder
SiPM + Flex	50	replace all SiPMs with Hamamatsu (o	50	replace all SiPMs with Hamamatsu (only 15% s
SiPM Bias Supply	0	ALDO chip	0	ALDO chip
Coldboxes + on detector lines	24	250+30 new coldboxes and colbars, b	51	208+22 new coldboxes
Tooling, Leak Tester, QA	0	Institution R&D costs	0	Institution R&D costs
Heating/CPS system	50	foils instead of wires?	50	reuse+adapt+spares
Cryo (off detector)	00	Run 4 plant adaptation?	00	Run 4 plant adaptation?
C-Frames + Prototype	0	also reuse	00	"half" mounts
Cable Chains	0	also reuse	0	also reuse
Bridge	30	modified bridge	30	modified bridge
FE Boards + ASIC(s)	50	New master boards and LS	72	
FE Common Components	37		37	
Cables (Bunker TO C-Frame)	25	power boards or adapter to old cable	25	power boards or adapter to old cables.
FE Power supplies (12V LV)	0	already bought in LS3	0	already bought in LS3
PCIE400	48		52	
MiniDAQ	0	R&D costs	0	R&D costs
Fibres (FE to PP) (no trunk)	65		53	
FE Water Cooling Block	0	reuse	60	new
Water Cooling Piping/Manifol	0	also reuse	0	also reuse
Total	9708	Run 3 acceptance	11500	6-layer version
	-1030	"remove outer modules save another	-1069	4L and 6L difference
	8678	low refurbished version	10431	4-layer version

Pixel Scenario Costs



Scenario Costs

Mighty Pixel Scenario	Estimated Cost (MCHF)	Fraction
Scoping Document Low 1.0	11.0	
Low 1p0e34 6-Layer (302010) 1.3m2	11	1
Low 1p034 5-Layer (302010) 1.3m2	9	0.83
Lower 0p8/1p0e34 5-Layer (2416) 0.8m2	8	0.72
Lowest 0p8 5-Layer (2010) 0.6m2	6.5	0.59
Mighty SciFi Scenario	Estimated Cost (MCHF)	Fraction
Scoping Document Low 1.0 LN2 Cryo – 4-layer mats	17.4 (*16.8)	1* (*use 96 netFELIX @ est. 12kCHF)
Scenario A + new modules with new frames+srcv	~14.0	0.83
Scenario B (all Run 5 modules) - 6-layer mats	~11.5	0.68
Scenario B (all Run 5 modules) - 4-layer mats	~10.5	0.62
Scenario C (reuse 80 Run 3 modules) Middle	~10	0.58
Scenario C (reuse 56 Run 3 modules) Low	~9	0.52

Preliminary being discussed internally

Summary

- You get what you pay for. All cost savings comes with a loss of performance. Some also with a schedule risk.
 - The pixel tracker always performs better in the higher occupancy region around the beampipe
 - The number people required to achieve some of these things might actually increase, e.g. SciFi refurbishment, if the work can't be spread in time.

- Reduction of the pixel size requires the MightySciFi still performing well with higher occupancies and ionizing radiation
 - MightyPixel: up to 30-40% savings possible at 0.8×10^{34} lumi by reducing the area and going from 6 to 5 layers.
 - MightySciFi: up to 30-40% savings by reusing Run4 cooling and reusing C-Frames and Services. Anything further requires more time than LS4 allows to upgrade the modules to vacuum tightness.

- Backup slides

- Reduction of SciFi costs

- netFelix boards est 12k (~0.5 MCHF)
- Some costs like tooling and QA moved to R&D and Lab costs (~1MCHF)
- Can reuse the C-Frame mechanics and Cables (~1MCHF)
- Majority of Savings depends on running a Run4 chiller at -100C
 - Whatever the share of LN2 installation with transfer lines would cost (**SciFi share est. 2.5 MCHF**)
 - And confirm the current SciFi Novec lines would support this, and transition costs (500k?)
- Can then reuse C-Frame Services (Novec transfer lines in cavern) (~ 1MCHF)
- Reduce the number of Layers of fibres per Mat from 6 to 4 (~1MCHF) in Scenario A
 - LN2 would have easily allowed this. Need to check with -90C to -110C.
- Re-use modules but can't touch them before Run 4 data taking is stopped. (~2MCHF in Scenario B)
- Reduce the outer acceptance (less modules, sipm, elec, backend, etc.) (~ 1MCHF in Scenario B)

Ionising Radiation

	L=1.0 x 10 ³⁴ LHC Delivered Luminosity projection January 2026 (Round Beams)	Updated LHCb recorded luminosity assuming maximum instantaneous luminosity of 0.8			L=0.8 x 10 ³⁴ LHCb Updated recorded estimate (eff=0.94) Round Beams	L=0.8 x 10 ³⁴ LHCb Updated Recorded Estimate (eff=0.94) Flat Beams
Run 1-3	41.4				37.0	37.0
2030	3.4				3.2	3.2
2031	8.8				8.3	8.3
2032	9.7				9.1	9.1
2033	9.5				8.9	8.9
Run 1-4	72.8				66.5	66.5
2036	29.7				13.0	14.5
2037	38.9	45.0	36.6	42.3	32.0	35.6
2038	39.6	45.9	37.2	43.1	32.6	36.3
2039	39.6	45.9	37.2	43.1	32.6	36.3
2040	28.8	33.4	27.1	31.3	23.7	26.4
2041	40.2	46.6	37.8	43.8	33.1	36.8
Run 5	216.8	251.1	190.7	220.9	166.9	185.7
Total Run 1-5	289.6	323.8	257.2	287.3	233.4	252.2

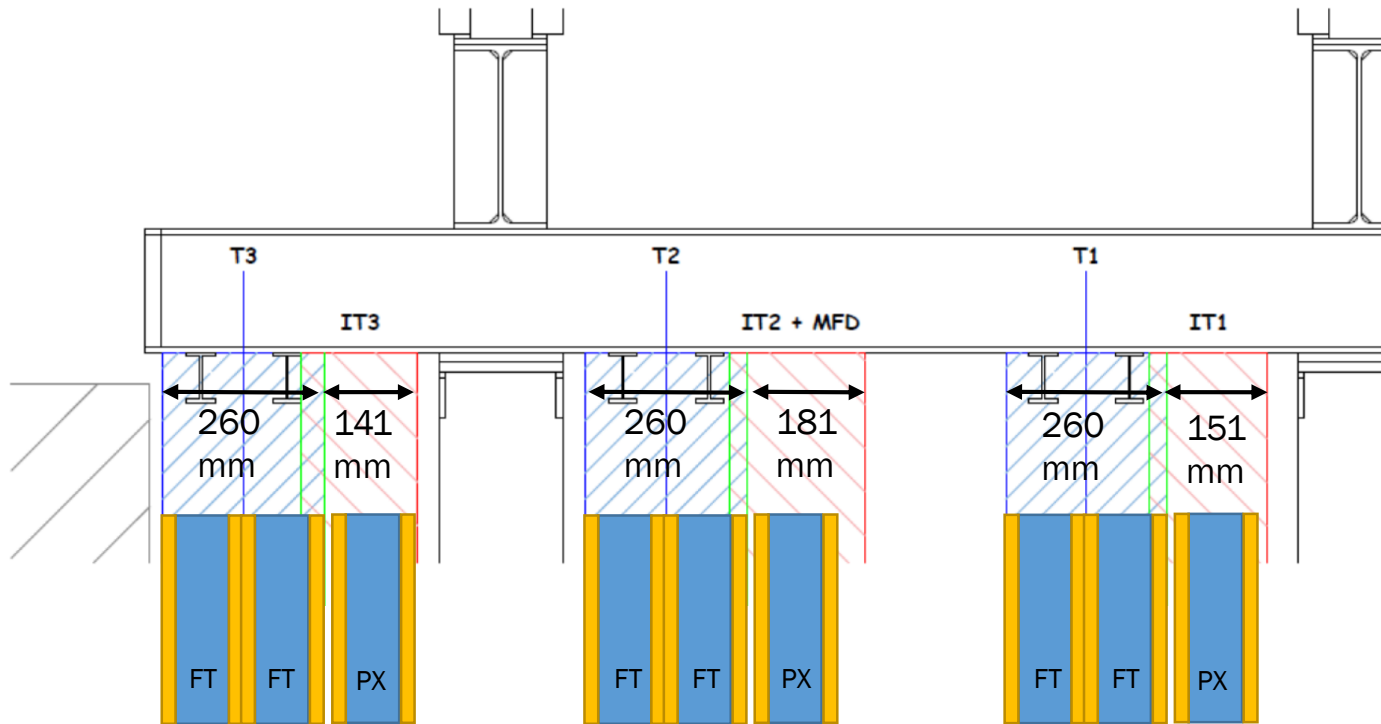
Slides shared by Paula in U2PG

https://indico.cern.ch/event/1717258/contributions/7230211/attachments/3329177/5963207/u2pg_aug_19.pdf

200 fb-1 delivered for Op8e34
235 fb-1 delivered for 1p0e34

*assumption of LHCb efficiency 0.5 for 2036 in all scenarios, new assumption of 94% otherwise

No bridge modifications?



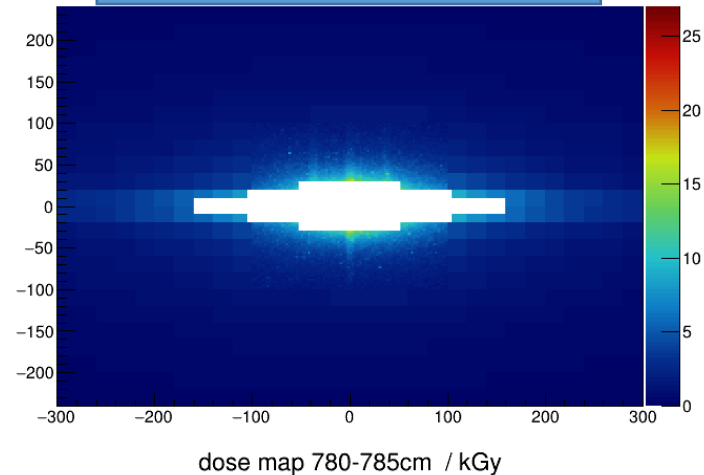
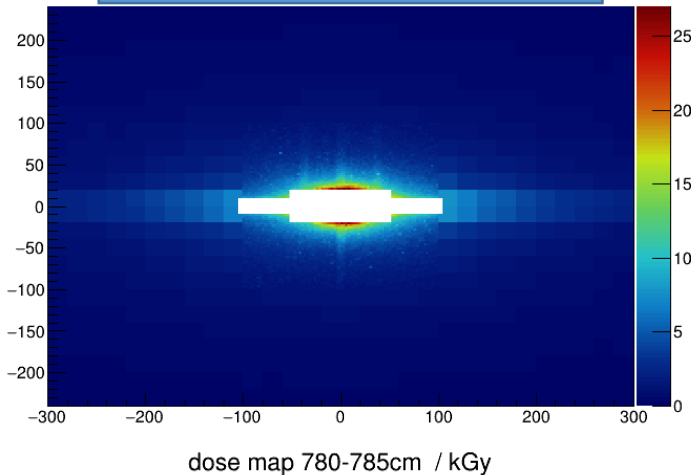
Run3 C-Frames need 130mm $\rightarrow$ 110mm width + 2*10mm clearance

NB: Cryo-SciFi with cold-boxes have **150mm** width, hence the pillar removal studies (not shown here)

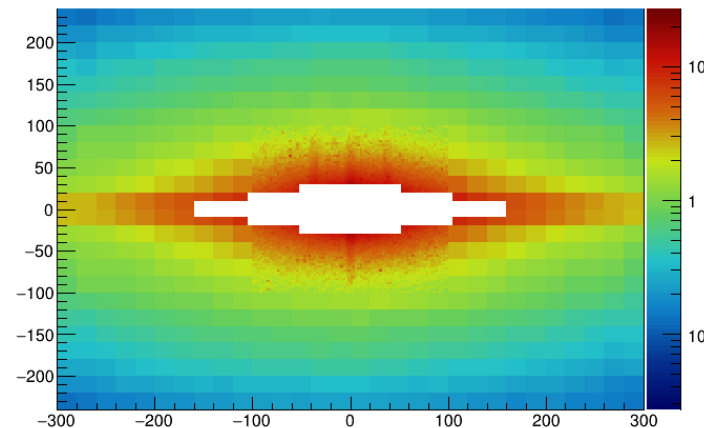
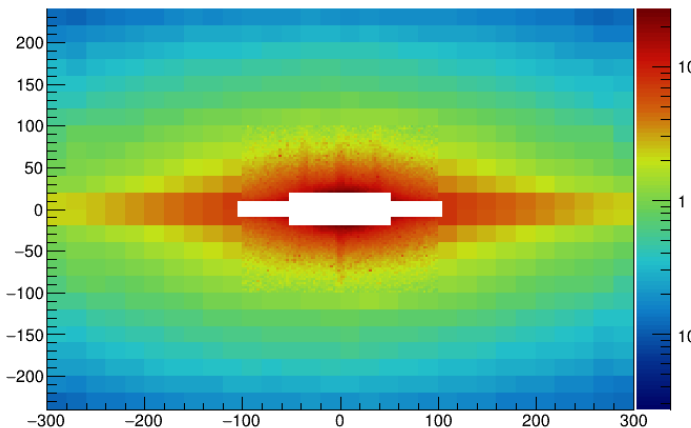
200 fb-1 delivered for Op8e34

235 fb-1 delivered for 1p0e34

Linear
scale

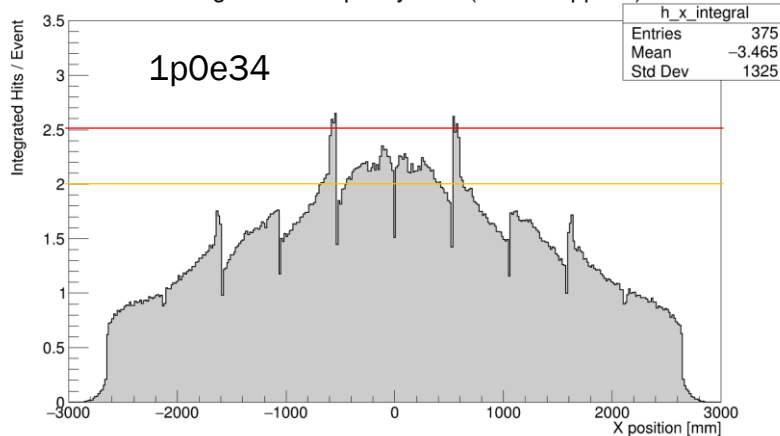


Log
scale

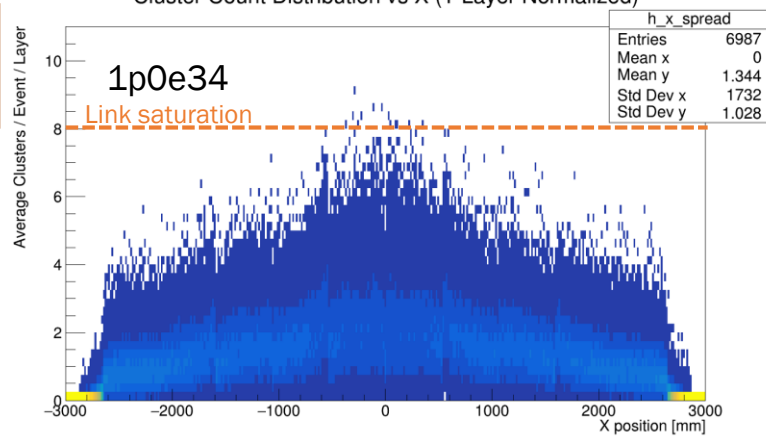


1.2 m²

Y-Integrated Occupancy vs X (Cutout Applied)



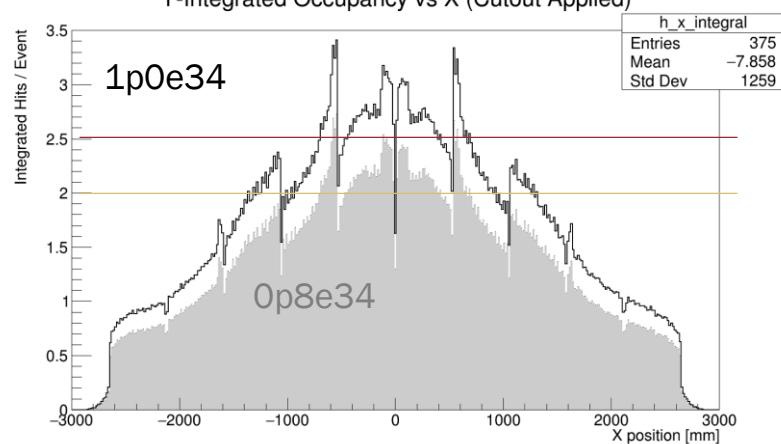
Cluster Count Distribution vs X (1-Layer Normalized)



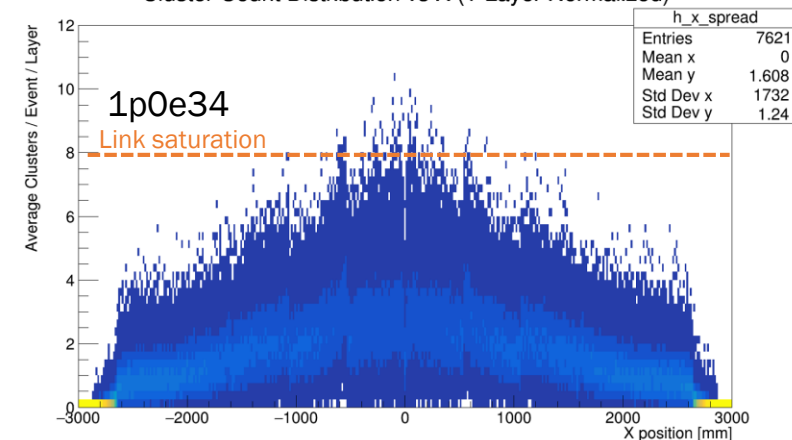
NB: MCHits
within
dX<0.5mm
“merged”

0.6 m²

Y-Integrated Occupancy vs X (Cutout Applied)



Cluster Count Distribution vs X (1-Layer Normalized)



mirai-intex.com/products/mirai-cold-40-t/p37

800 lb gorilla

VPN

MIRAI INTEX

ABOUT PRODUCTS REFERENCES TECHNOLOGY SERVICE NEWS CONTACTS

EN PARTNERS ZONE

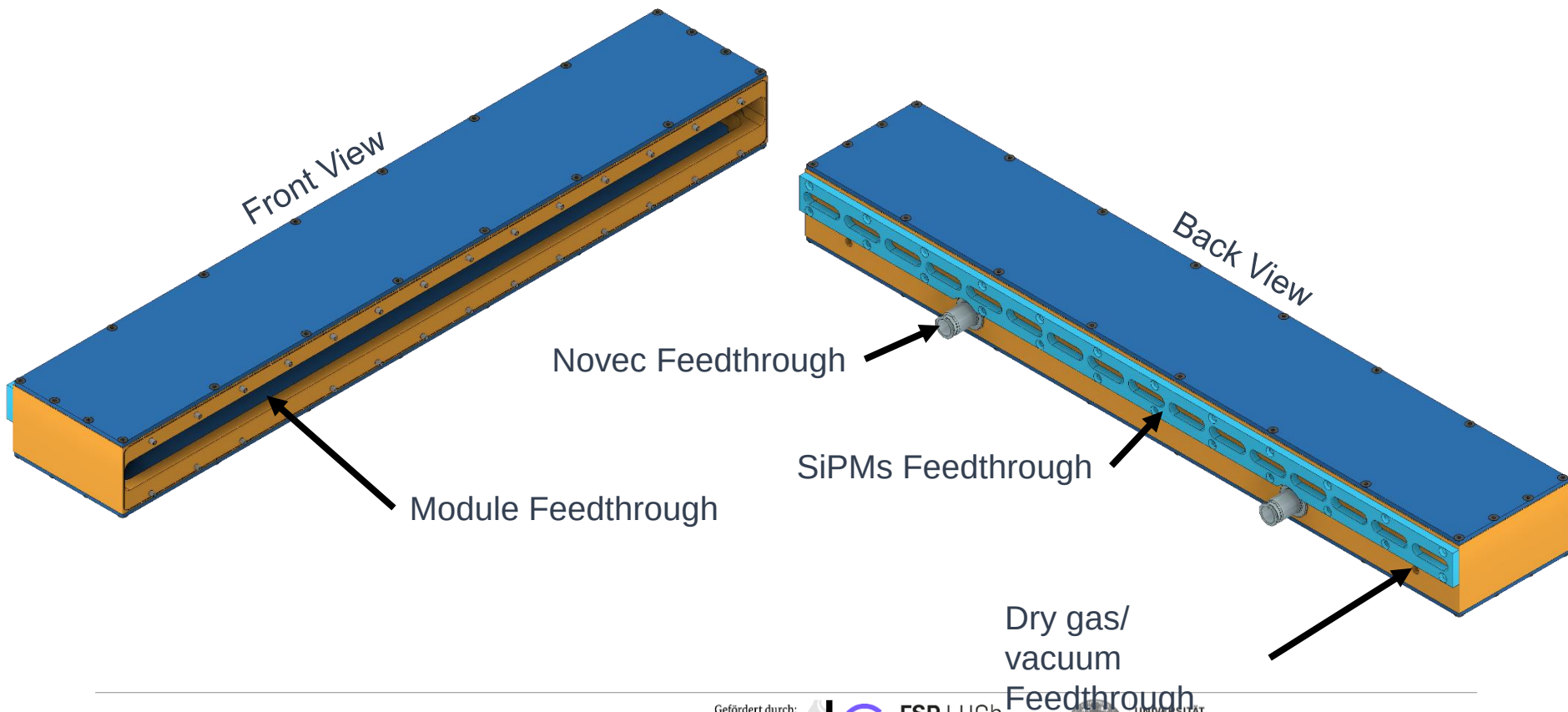
Technical Data

Refrigerant Natural Air	Dimensions (WxDxH) 80 × 177 × 197 cm
Rated Motor Power 40 kW	Weight 1875 kg
Noise Level up to 68 dB	System Cooling Water Water-cooled
Temperature Range from -40 °C to -160 °C	

↑

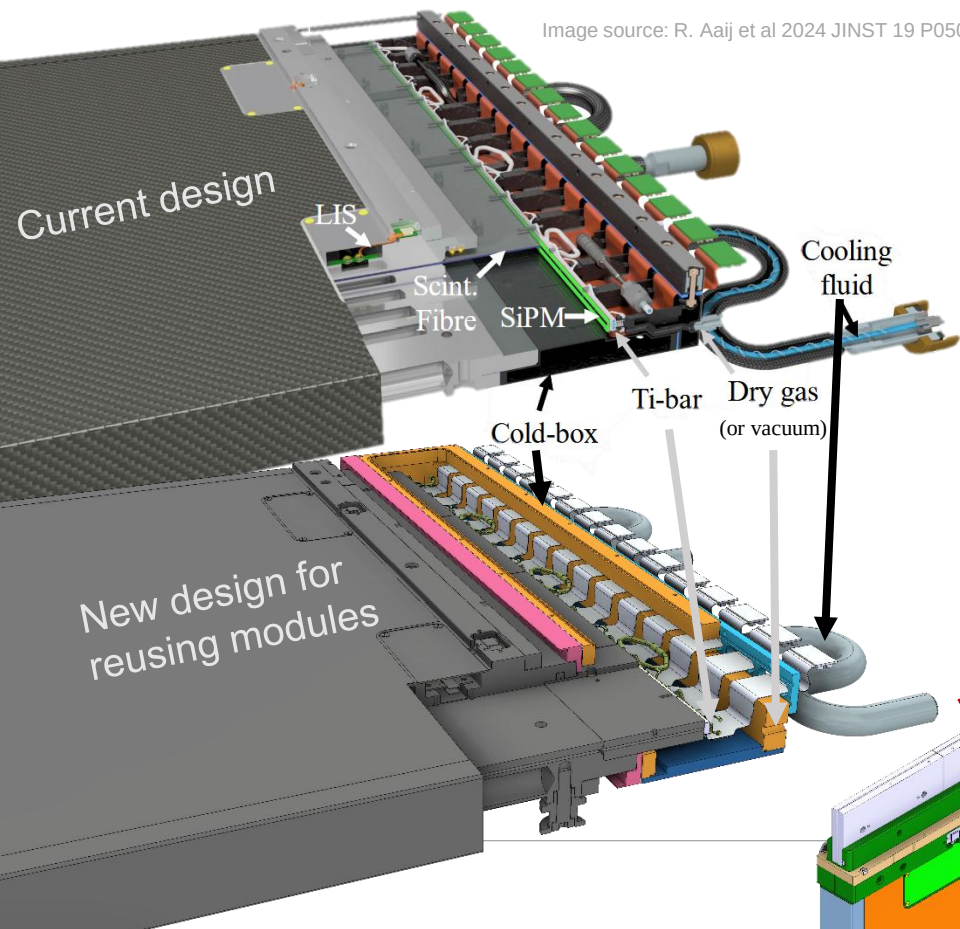
CONTACT US

Vacuum Insulated Coldbox



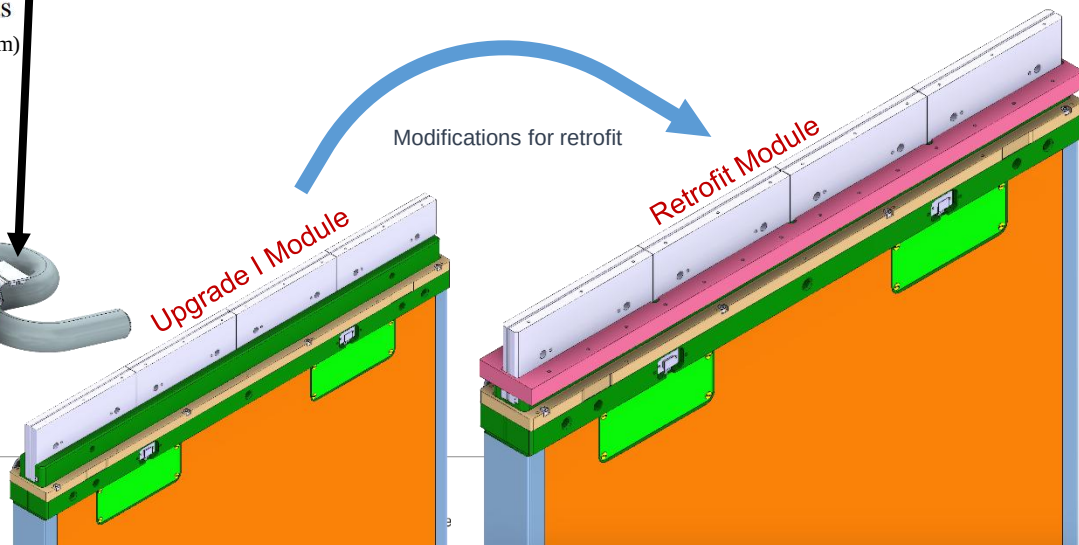
Vacuum Insulated Coldbox

Image source: R. Aaij et al 2024 JINST 19 P05065 (modified)

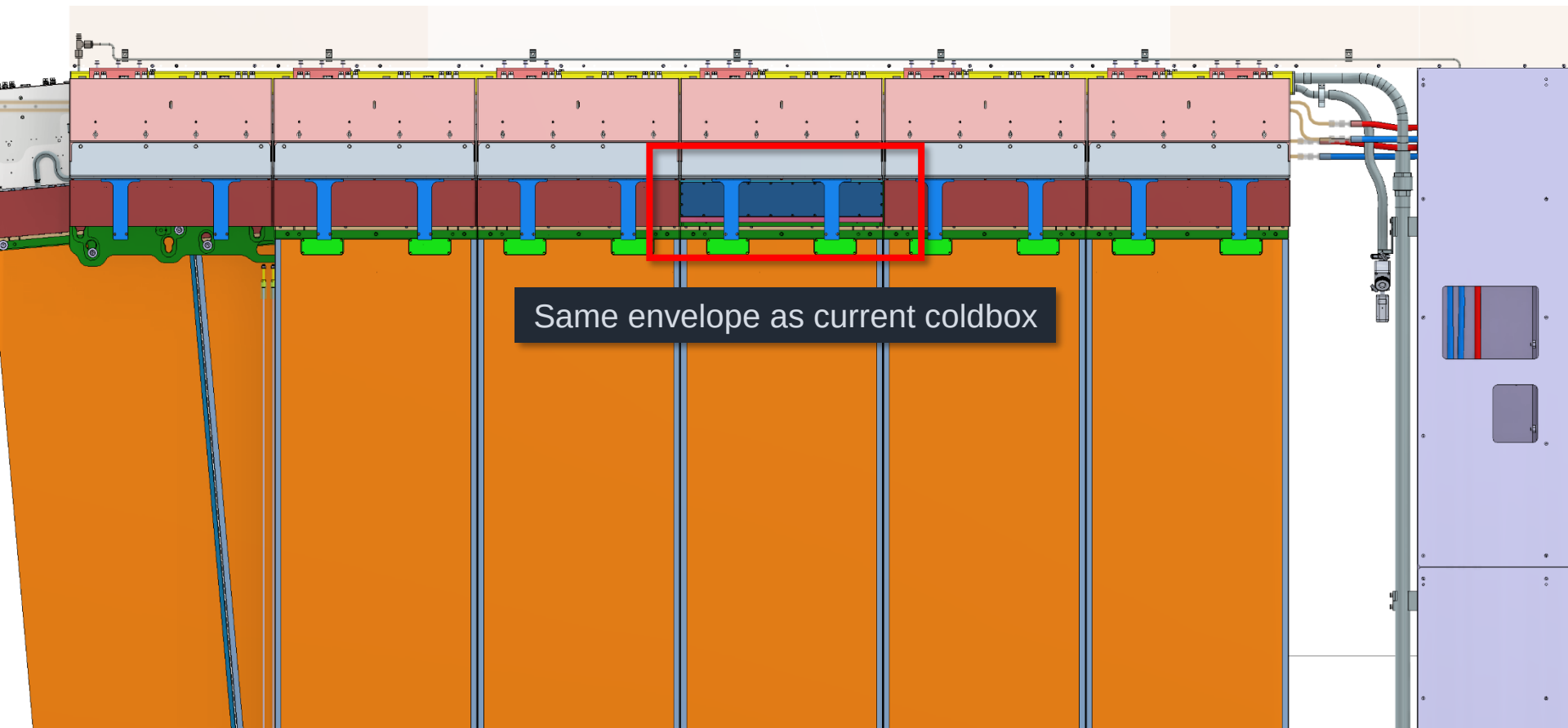


Main differences between Upgrade I and vacuum retrofit:

1. Aluminium flange on Upgrade I module
2. Aluminium coldbox
3. Vacuum feedthrough for SiPMs and Module

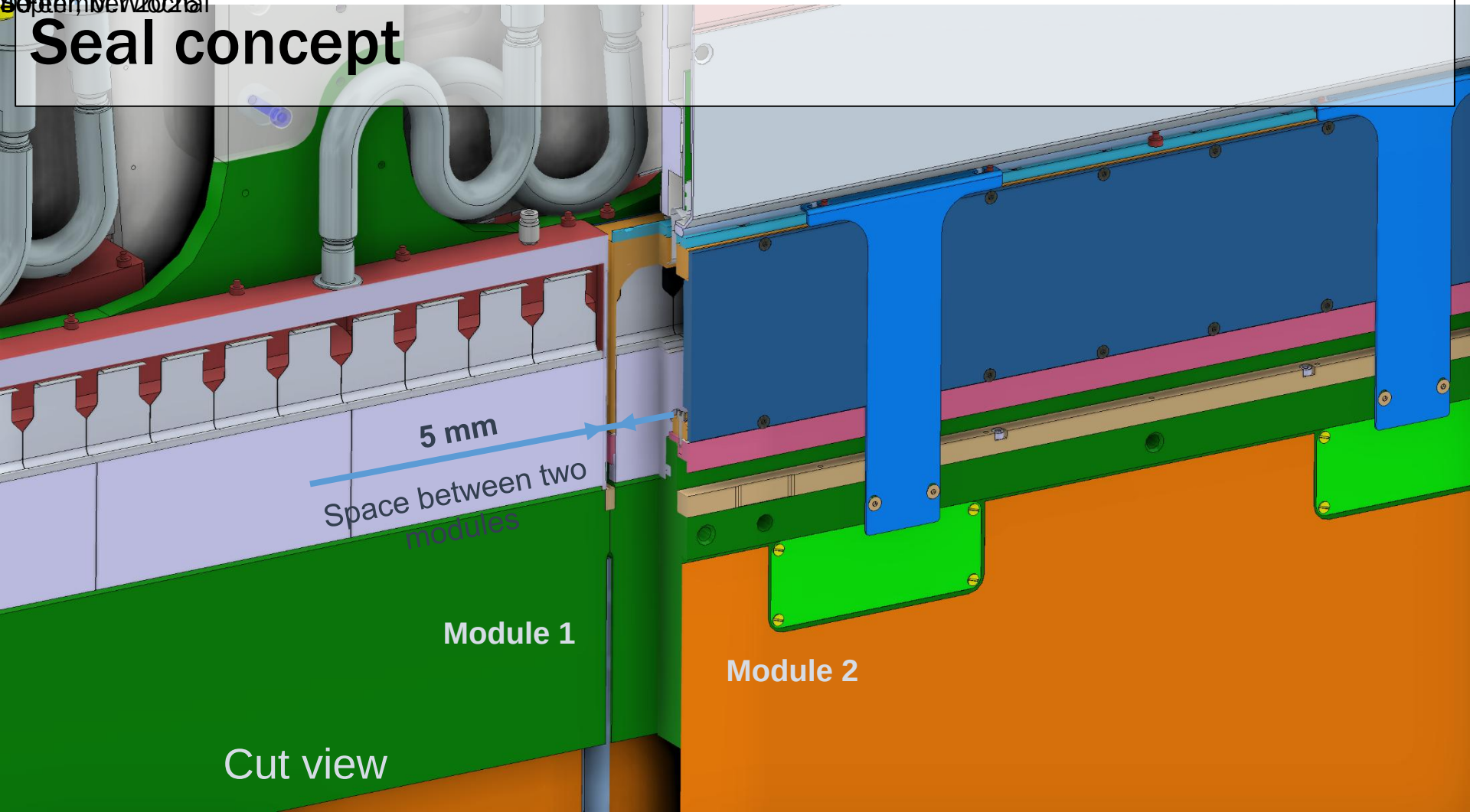


Vacuum Insulated Coldbox



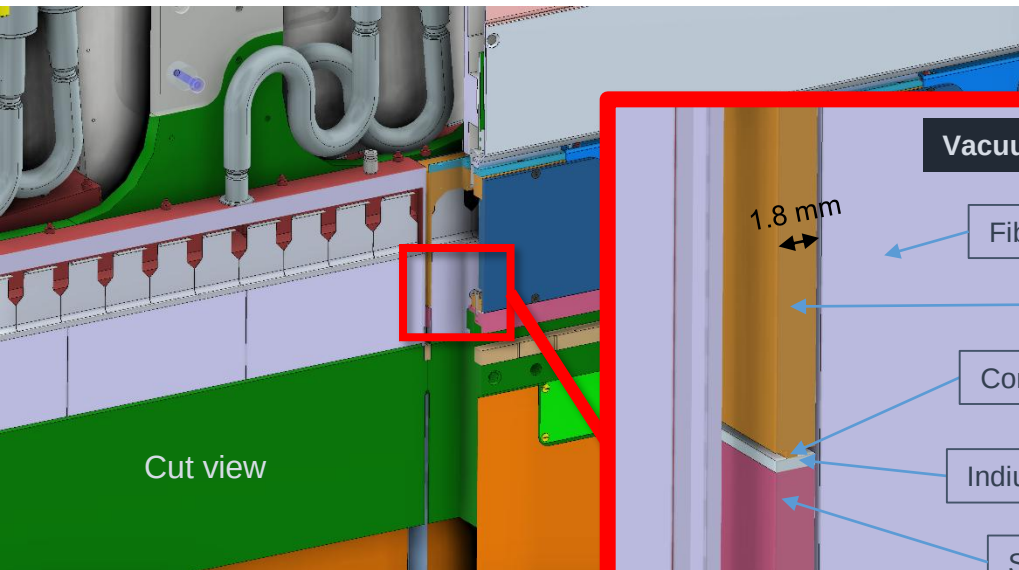
Same envelope as current coldbox

Seal concept

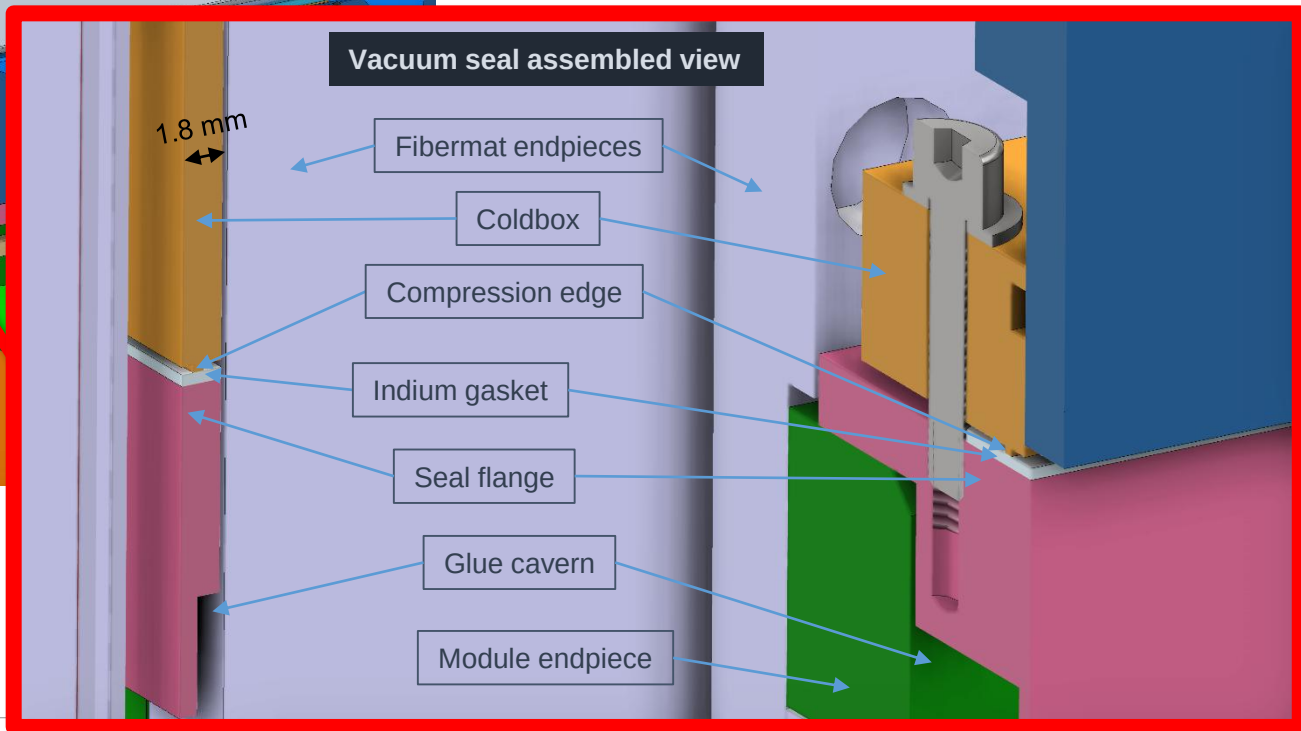


Cut view

Seal concept



Cut view



Gefördert durch:



FSP LHCb
Erforschung von
Universum und Materie



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