A VERTEX DETECTOR FOR UPGRADE II (OVERVIEW)

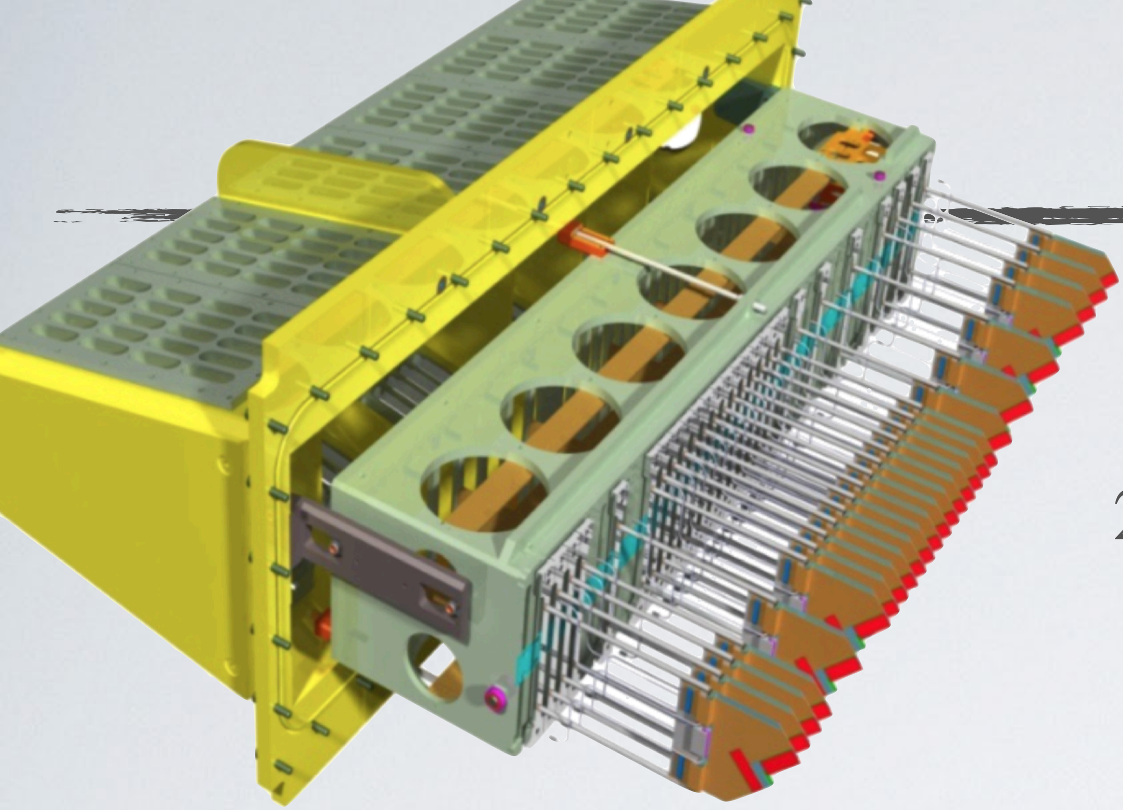
Malcolm John, for the future VELO project

9 April 2019

UNIVERSITY OF OXFORD

v2

Motivation for fast timing



Luminosity scenarios taken from: `LHCb-PUB-2019-001`

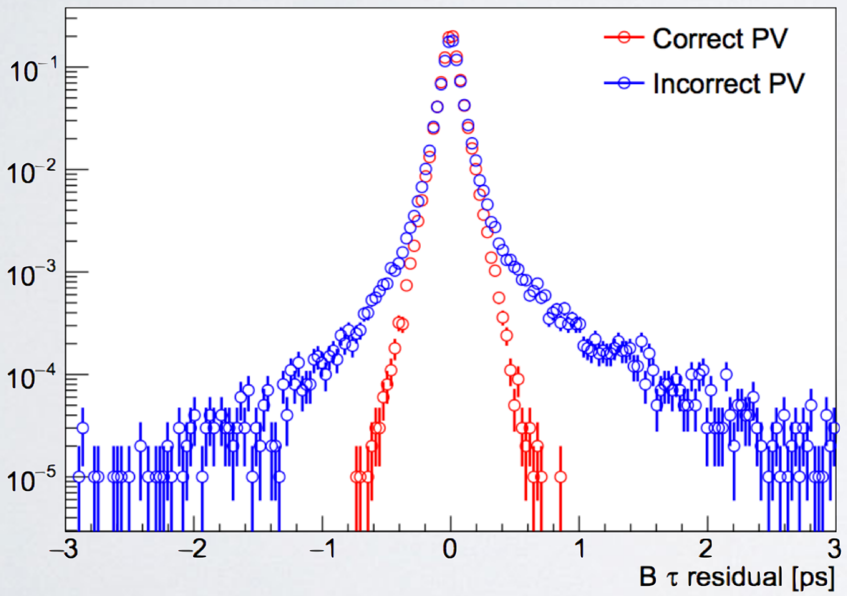
Upgrade I	Upgrade 2
$2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	$1.5 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
Pile-up = 5	Pile-up = 42

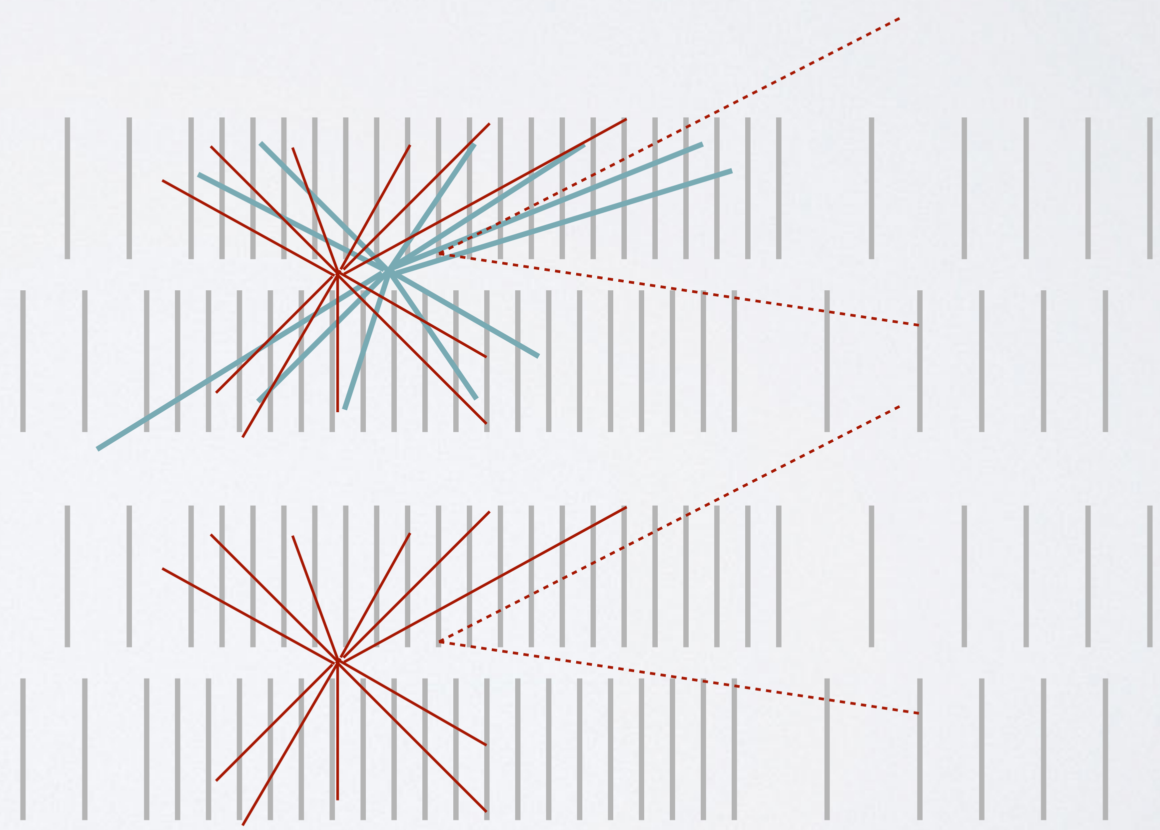
$\sigma_z(\text{lumi region}) \approx 45\,\mathrm{mm}$

$\sigma_t(\text{lumi region}) \approx 190\,\mathrm{ps}$

Typical B meson flight time ~15ps

Direct degradation to proper times resolution from mis-associated primary vertices.





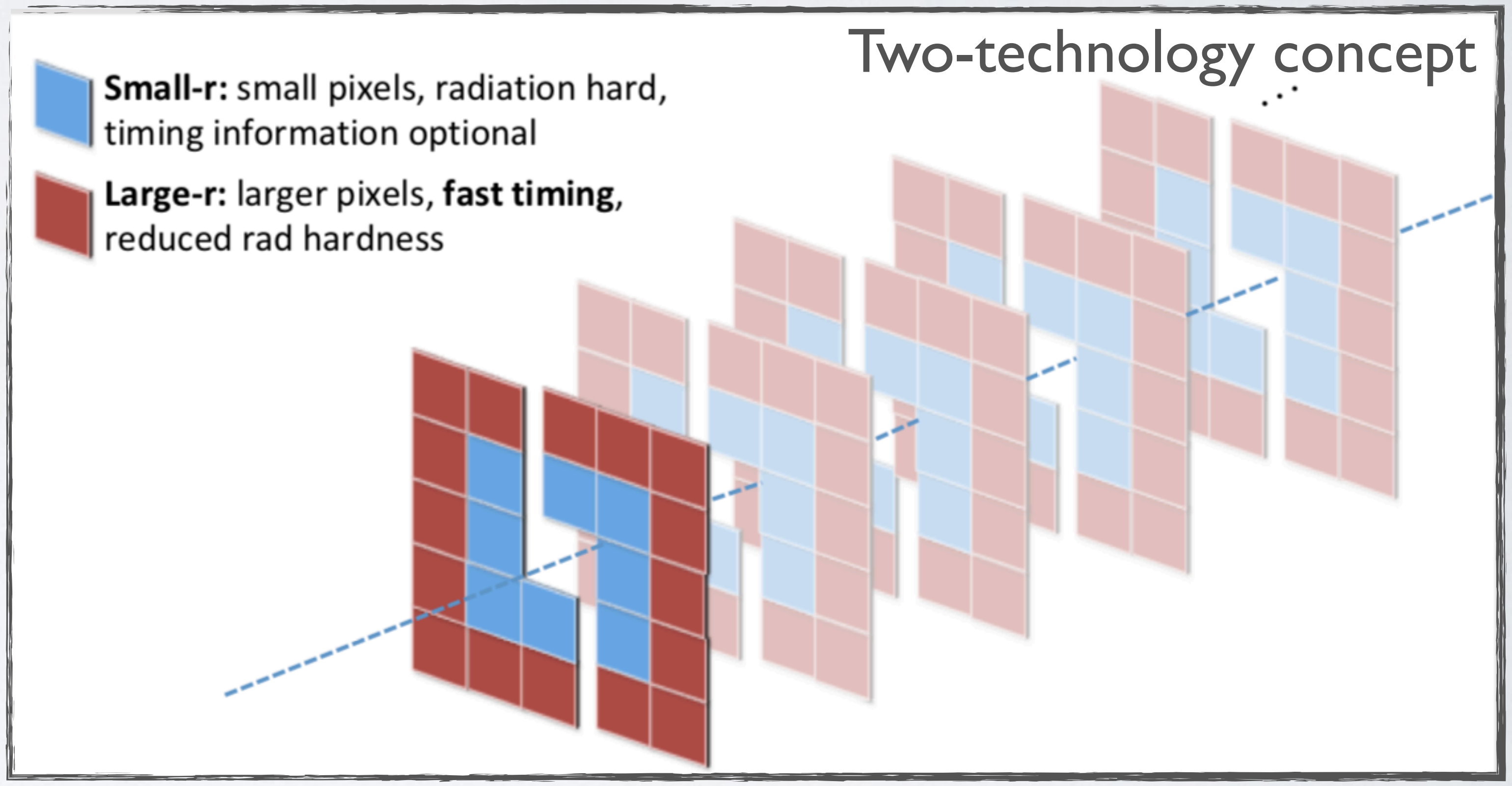
Recovered with O(100ps) timing measurements of pixel hits.

Conceptual designs

Like Upgrade I, probably technology: hybrid ASICs + thin sensor
see Martin van Beuzekom's talk

Basic questions on pixel geometry:

- **What timing precision is necessary?**
- **Are smaller pixels needed?**
- Is a "regularly-spaced modules with square array" design ideal?
- Could the active element move closer to the beam?

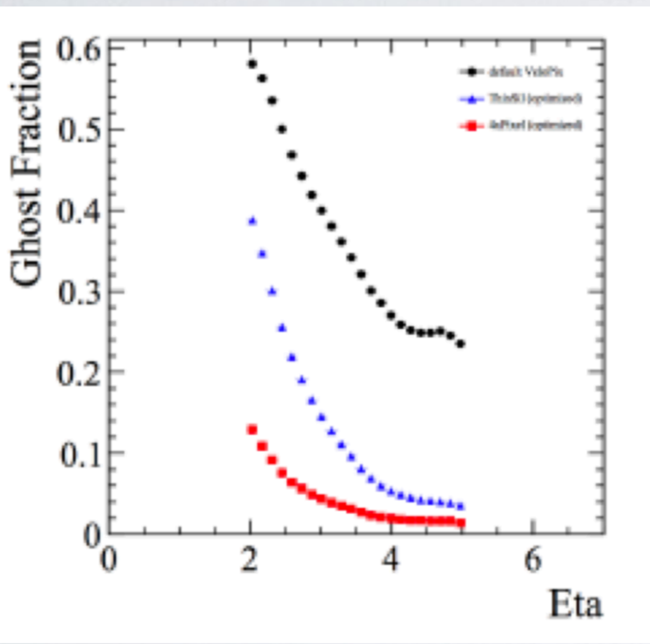


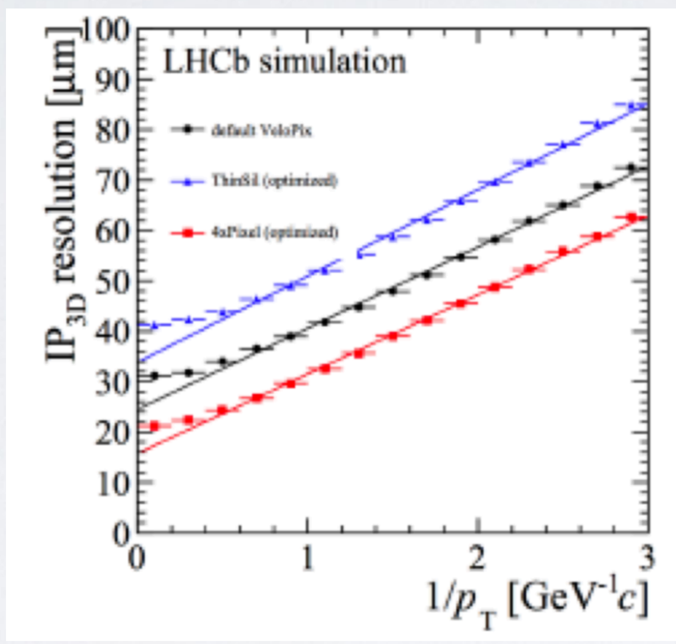
No question: pixels will be in two halves:

- Will still sit within vacuum.
- Must retract for injection.

Pixel size

$$\sigma_{\mathrm{IP}}^2 \approx r_1^2 \left(\frac{13.6\,\mathrm{MeV}}{c\,p_{\mathrm{T}}} \right) \frac{x}{X_0} + \frac{r_2^2 \sigma_1^2 + r_1^2 \sigma_2^2}{(z_2 - z_1)^2 \tan^2\theta}$$



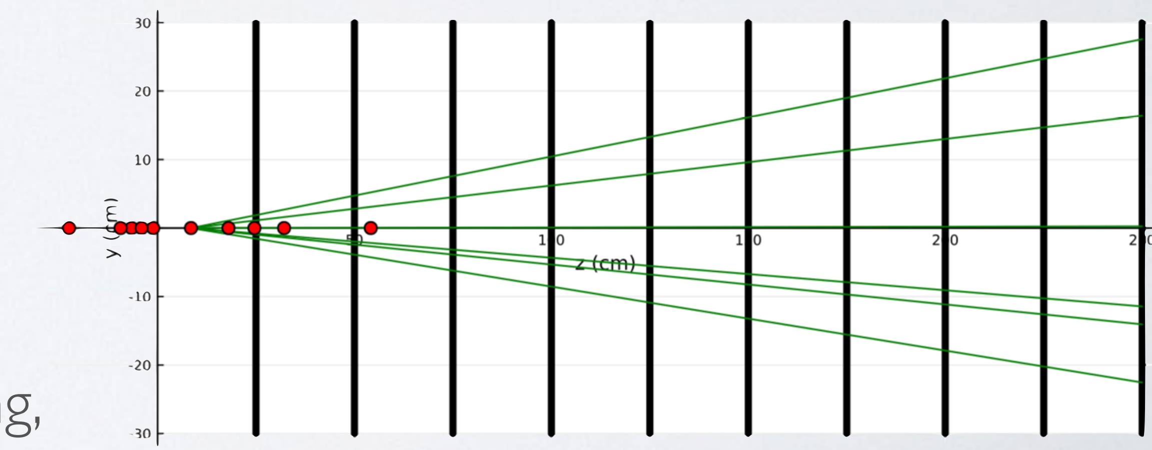


Reduced pixel size always desirable

- Good for ghost rate
- Good for IP resolution
  - *(assuming good PV matching)*
  - Particularly attractive if foil is removed.

Perform simplified pattern recognition

- nPV~40 PV spread=190ps
- 10 homogeneous planes, 25mm spacing
- Adjust pixel size, and timing resolution
- Metric: number of operations, interpolating, checking, calculating. Proxy for trigger processing.



(Mikhail Mikhasenko)

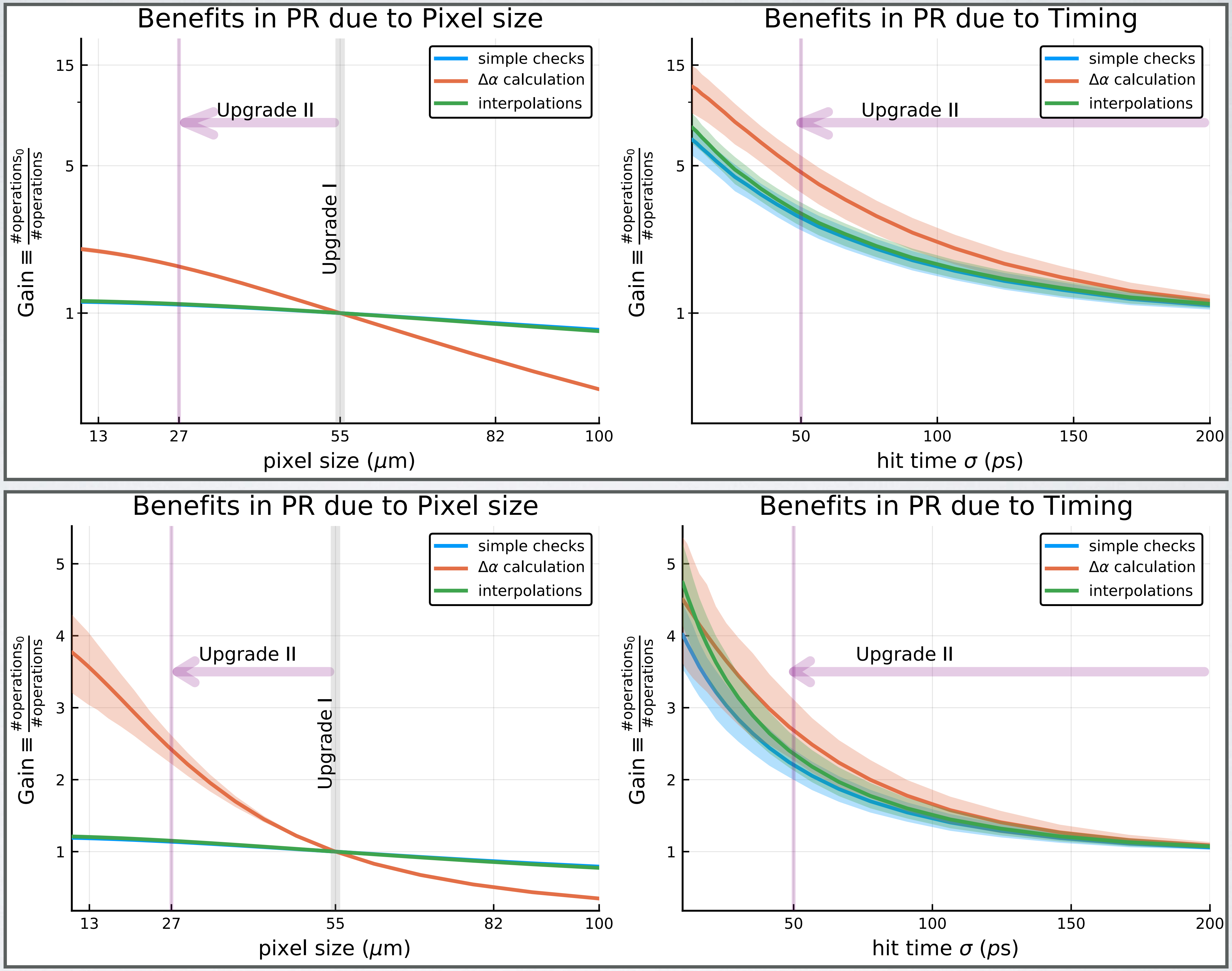
Pattern recognition studies (Mikhail Mikhasenko)

Scenario 1:

nPV=36 PV
nTrk/PV=80

Scenario 2.
nPV=42 PV
nTrk/PV=30

Adjusted search window.

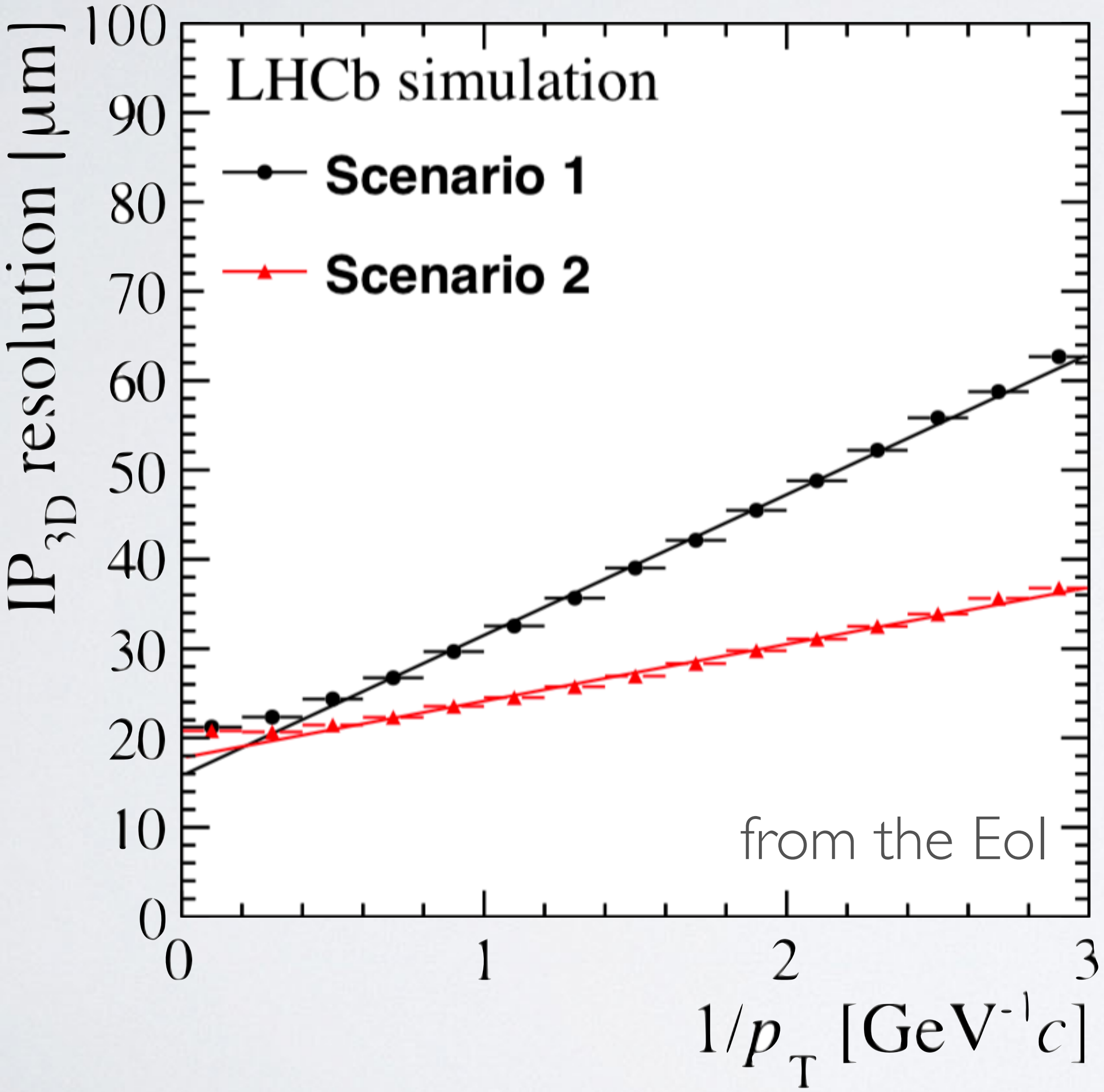


50ps hit time resolution desirable for pattern recognition

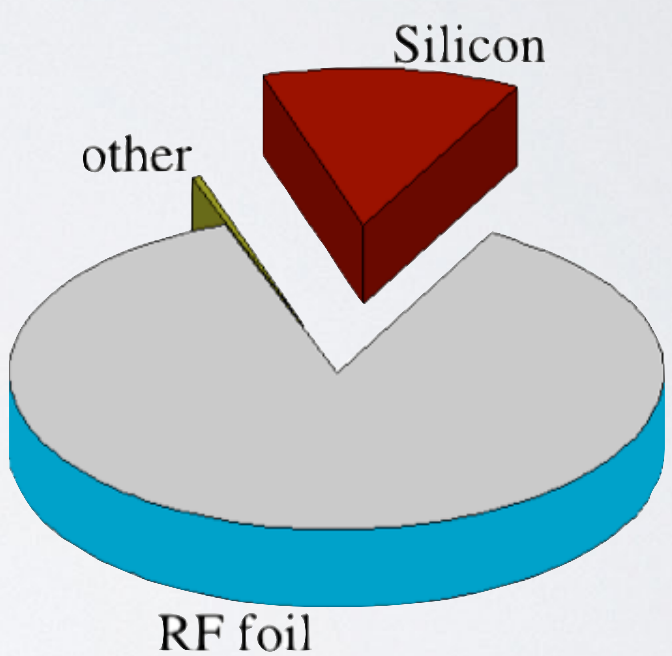
- timing helps reduce initial combinations and number of hits in the extrapolation

RF foil removal

$$\sigma_{\mathrm{IP}}^2 \approx r_1^2 \left(\frac{13.6\,\mathrm{MeV}}{c\,p_{\mathrm{T}}} \right) \frac{x}{X_0} + \frac{r_2^2\sigma_1^2 + r_1^2\sigma_2^2}{(z_2 - z_1)^2\, \tan^2\theta}$$



Foil removal

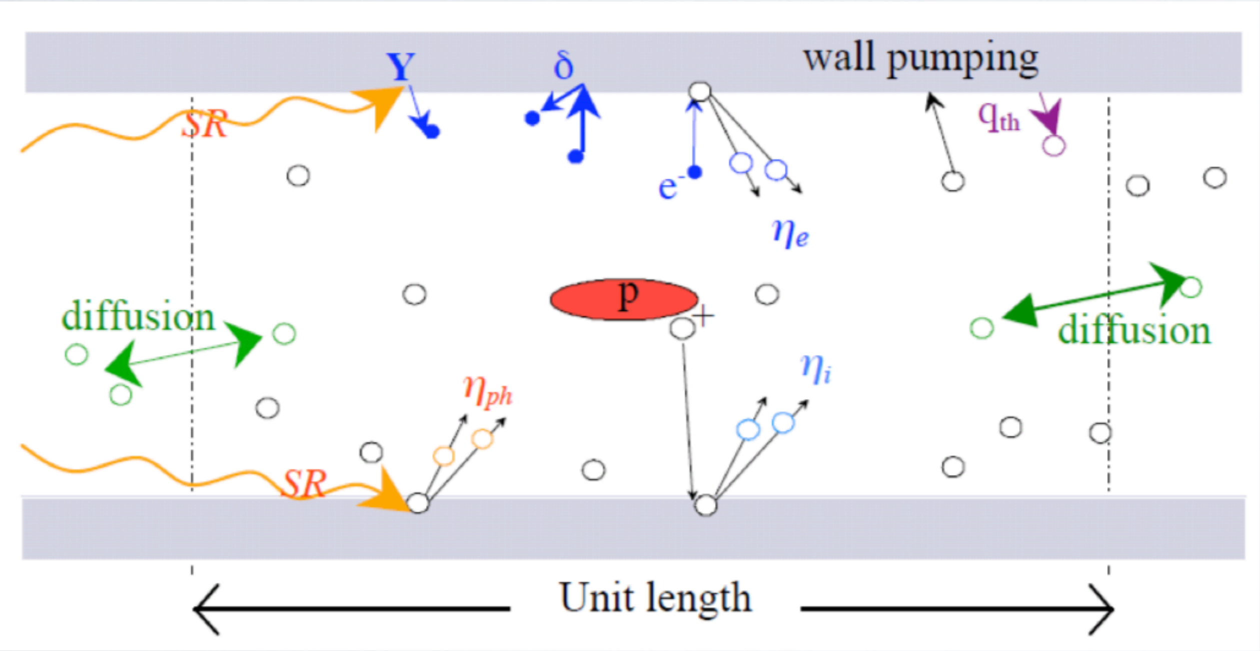


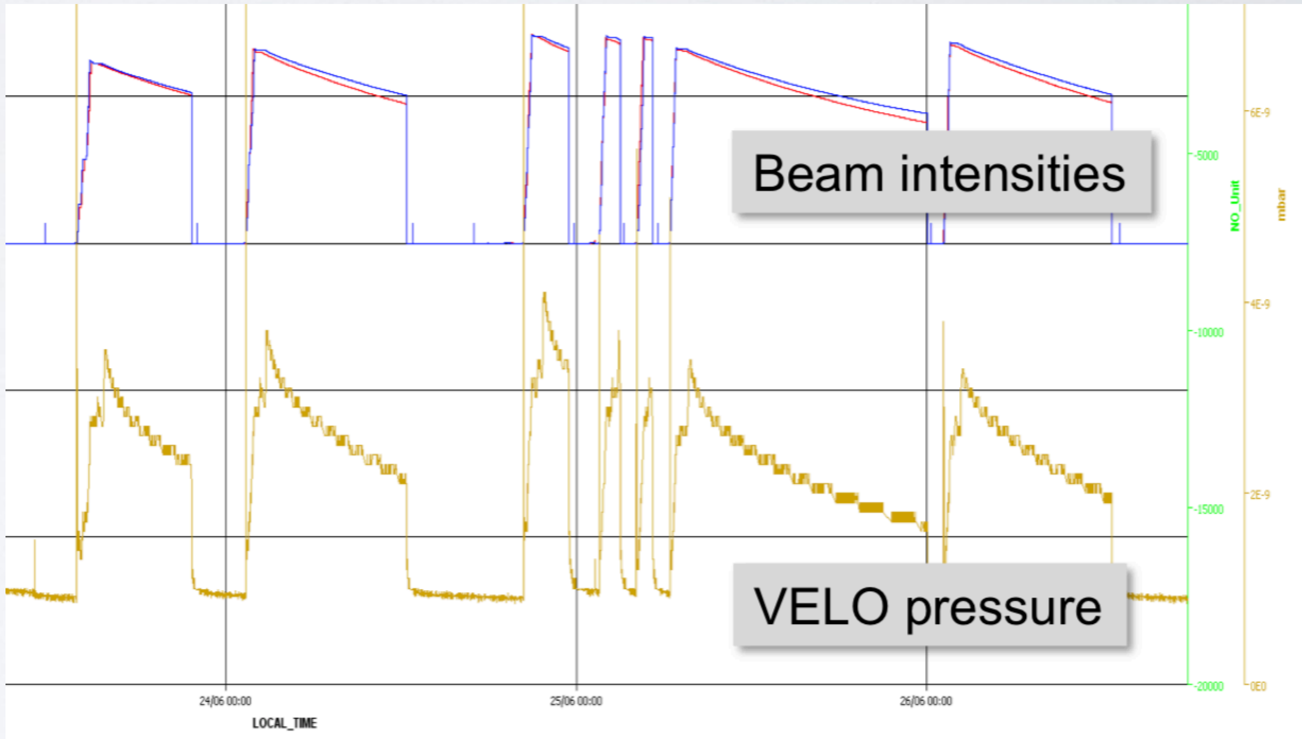
Total material before second measured point : 3.8 % X_0

RF foil removal

Purpose of the foil:

- static vacuum barrier (least concerning)
- guide for the wake field (low impedance conductor vital)
- **controls dynamic vacuum effects**
- protect VELO from beam-induced noise





Material directly exposed to the beam must have low *secondary electron yield* and low *ion absorption yield*

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  (low impedance conductor vital)
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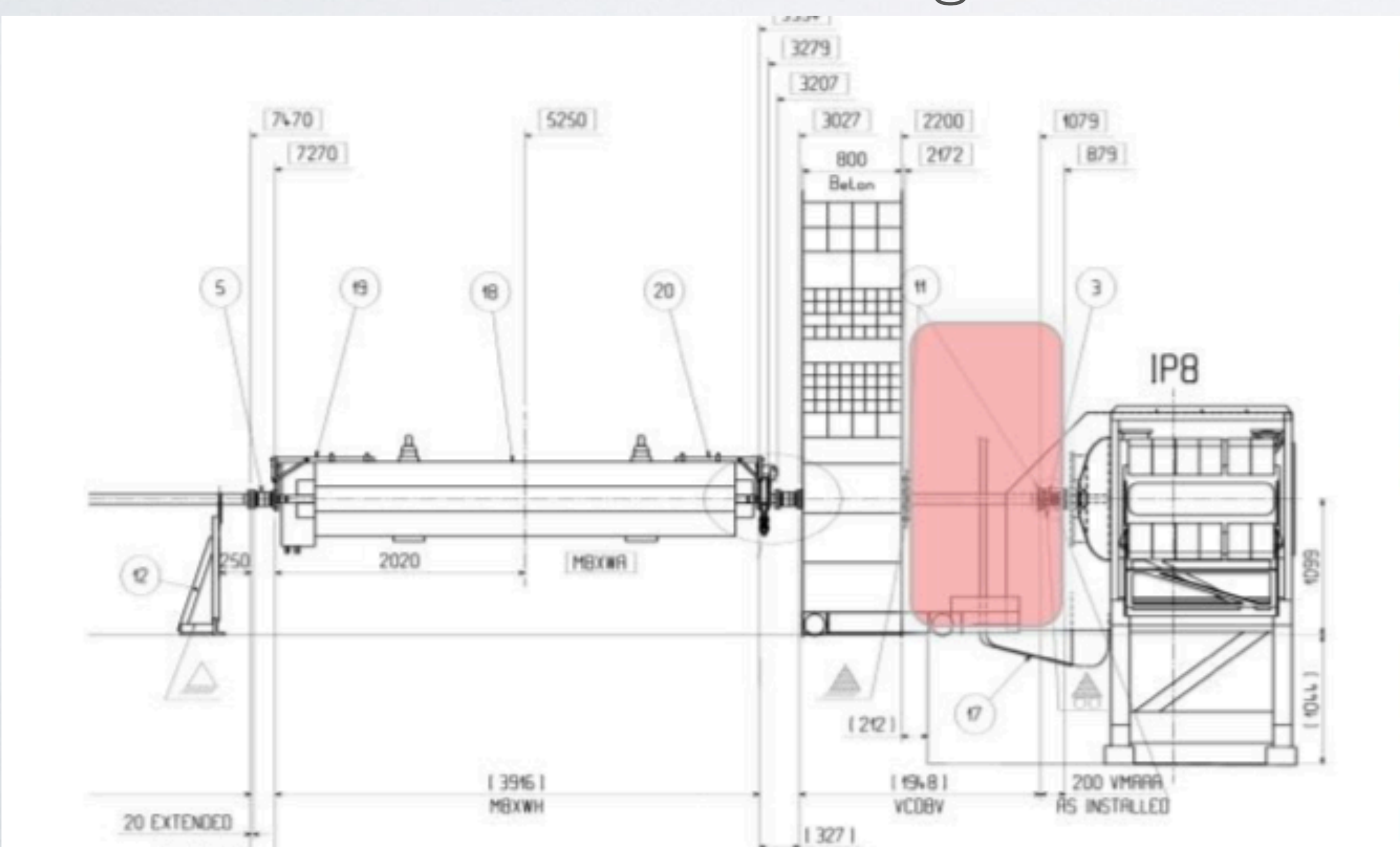
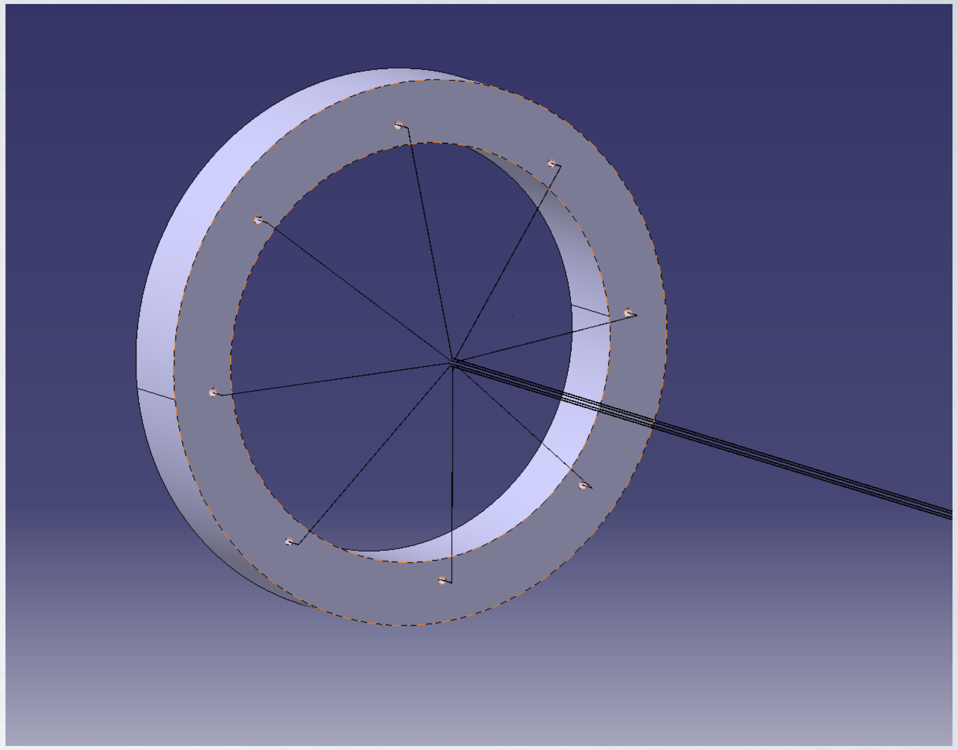
Prototype can be tested during Run 3 using a special slot valve allows installation without breaking the LHC/VELO vacuum.

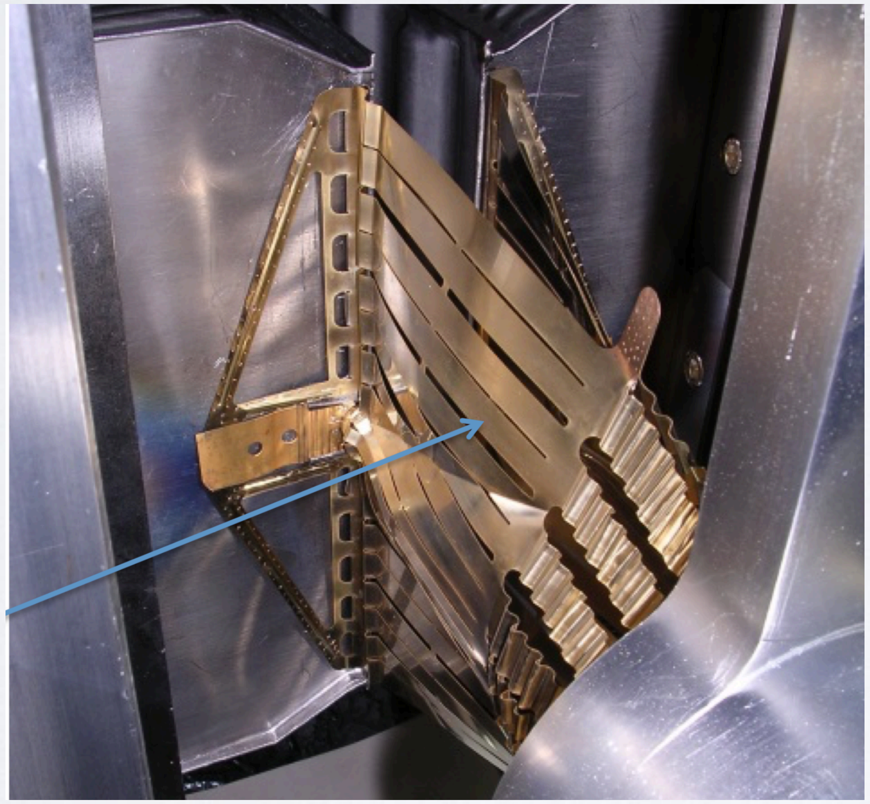


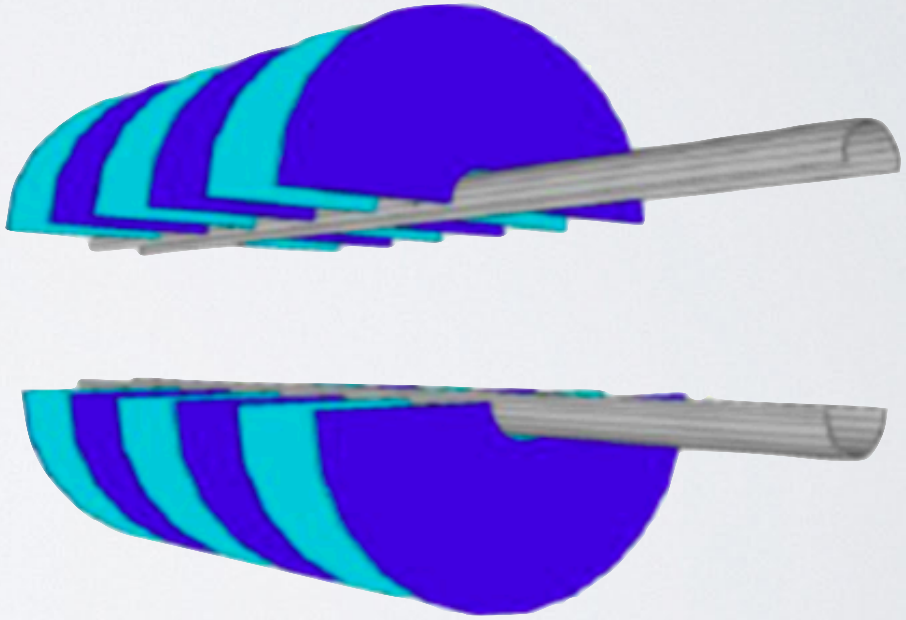
RF foil removal

Solution? wire mesh, partial light foil…

- How many wires, what thickness?
- What temperature would they rise to?
- How would either concept interface with the wake-field suppressor?
- How do they deal with opening for beam injection?





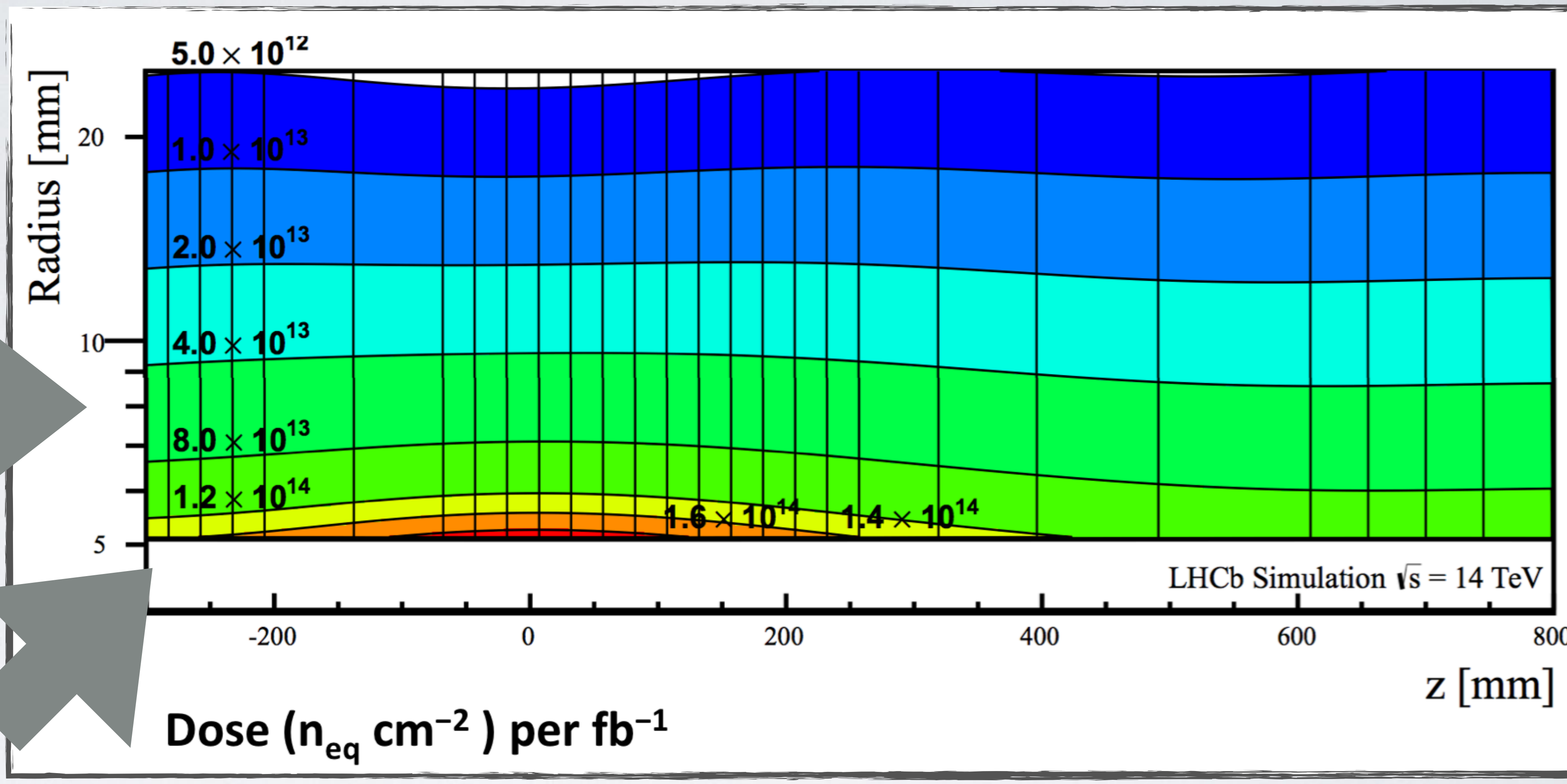


Not easy or obvious

Urgent issue: affects all other design considerations

Radiation damage

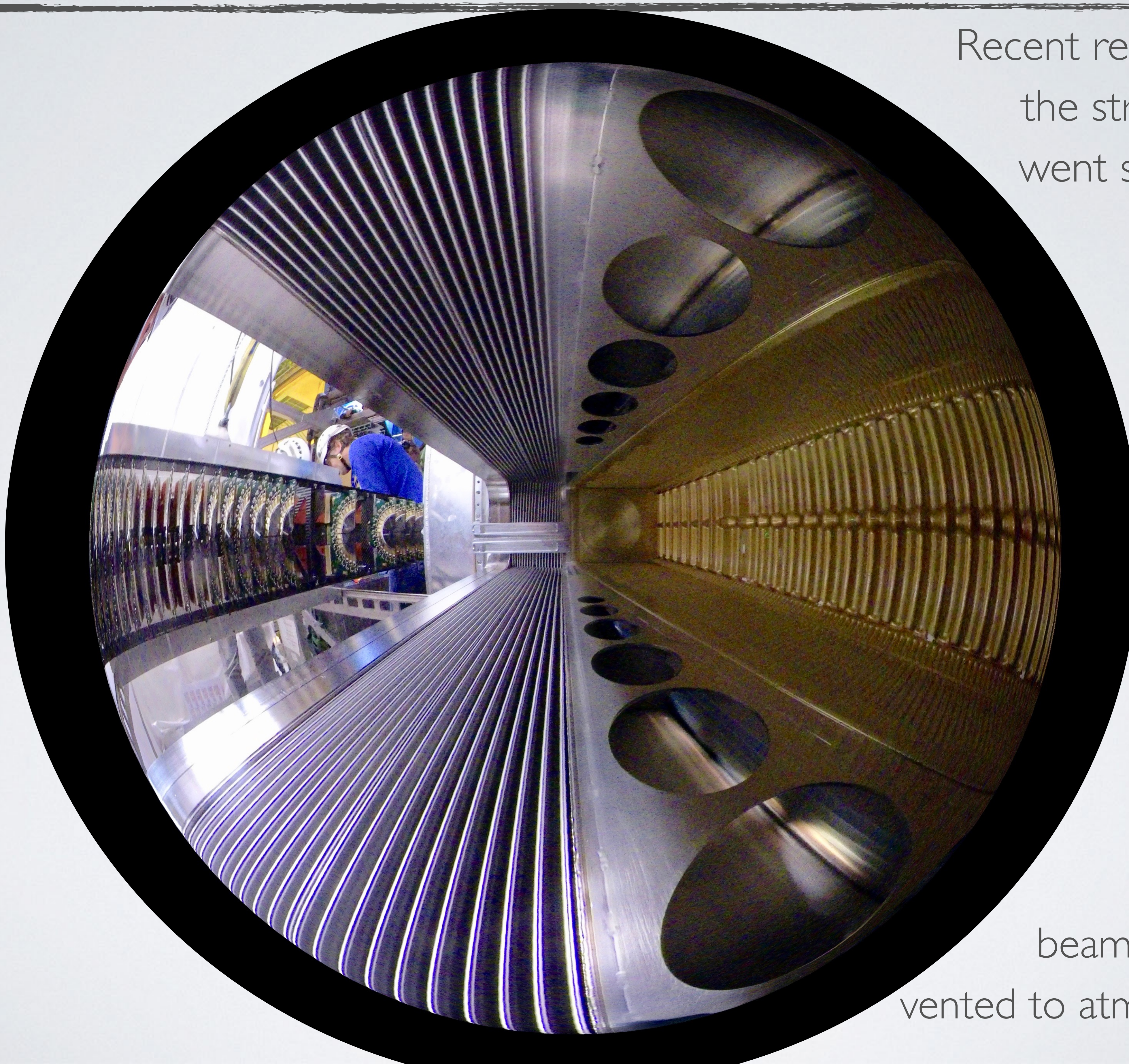
Strip VELO @8mm
total: 7×10^{14}



LHCb Upgrade	**5 mm**	**50 fb^{-1}**	**8×10^{15}**
LHCb Upgrade II	**5 mm (??)**	**300 fb^{-1}**	**5×10^{16}**

<u>Very high fluence.</u>
Probably mandates replacement the VELO halves every 1-2 years
- Implication on mechanics

Module replacement with a foil, neon in the primary vacuum

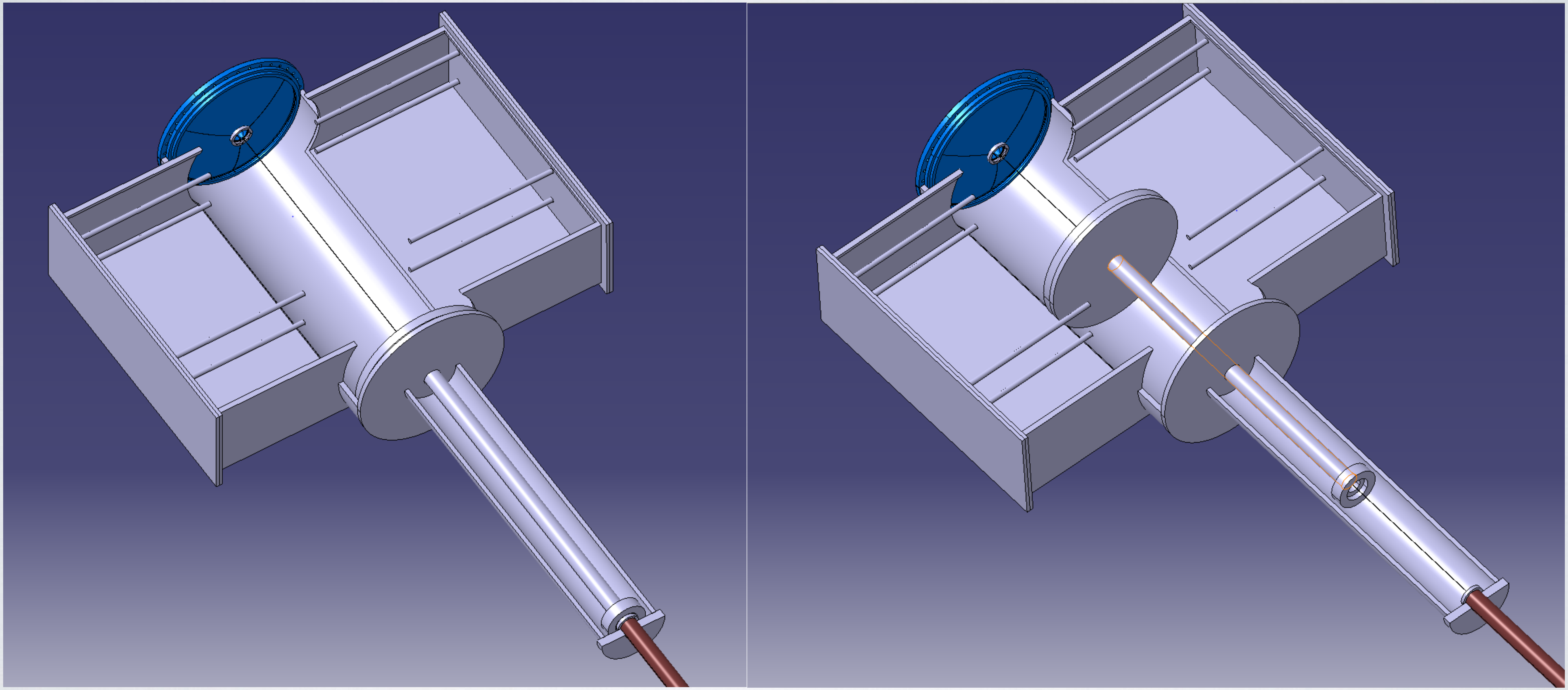


Recent removal of the strip VELO went smoothly

Though beampipe was vented to atmosphere

Module replacement without a foil

Radiation tolerance challenges strongly point to needing annual replacement of the front-end detectors: big mechanical challenge

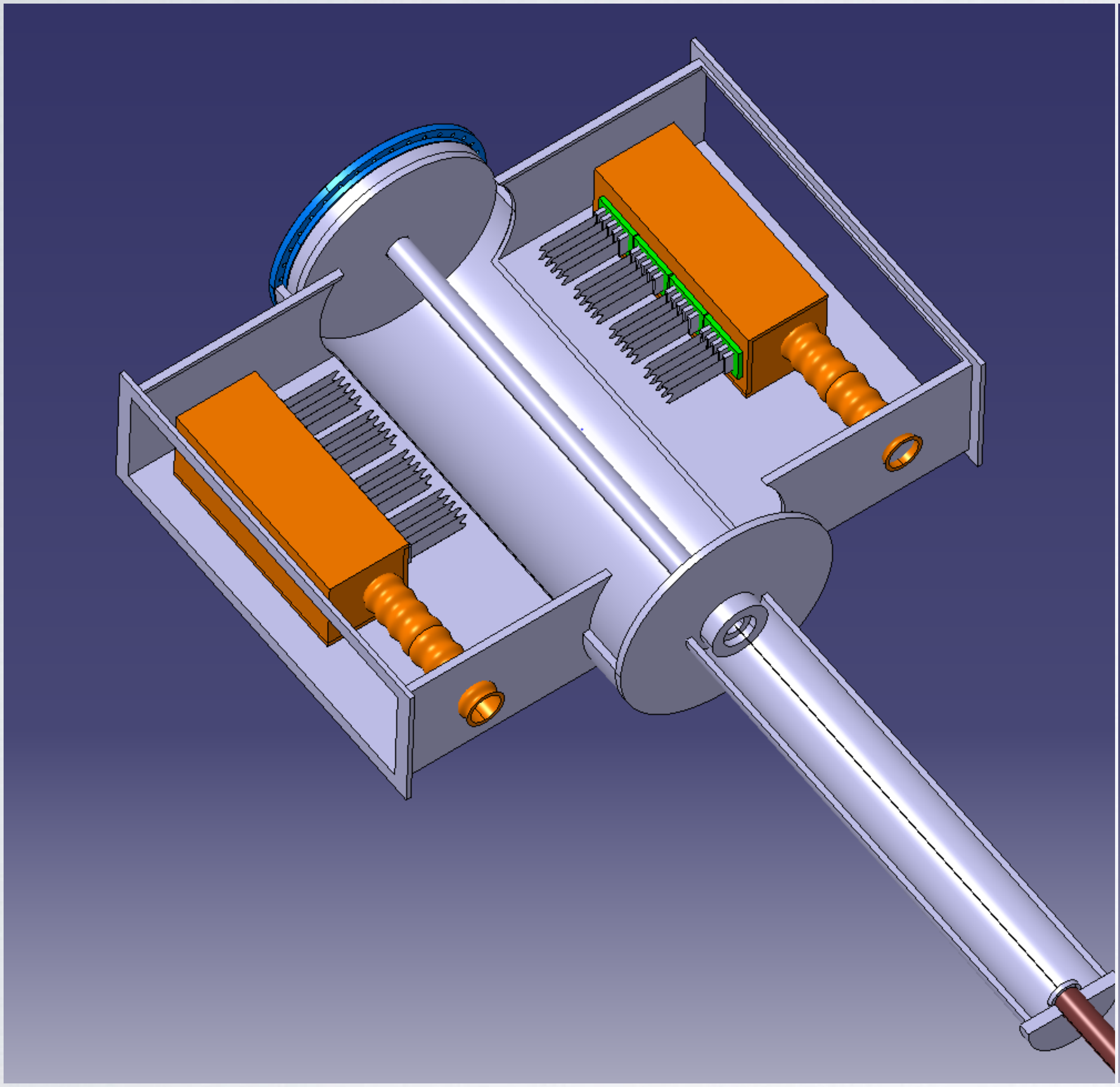


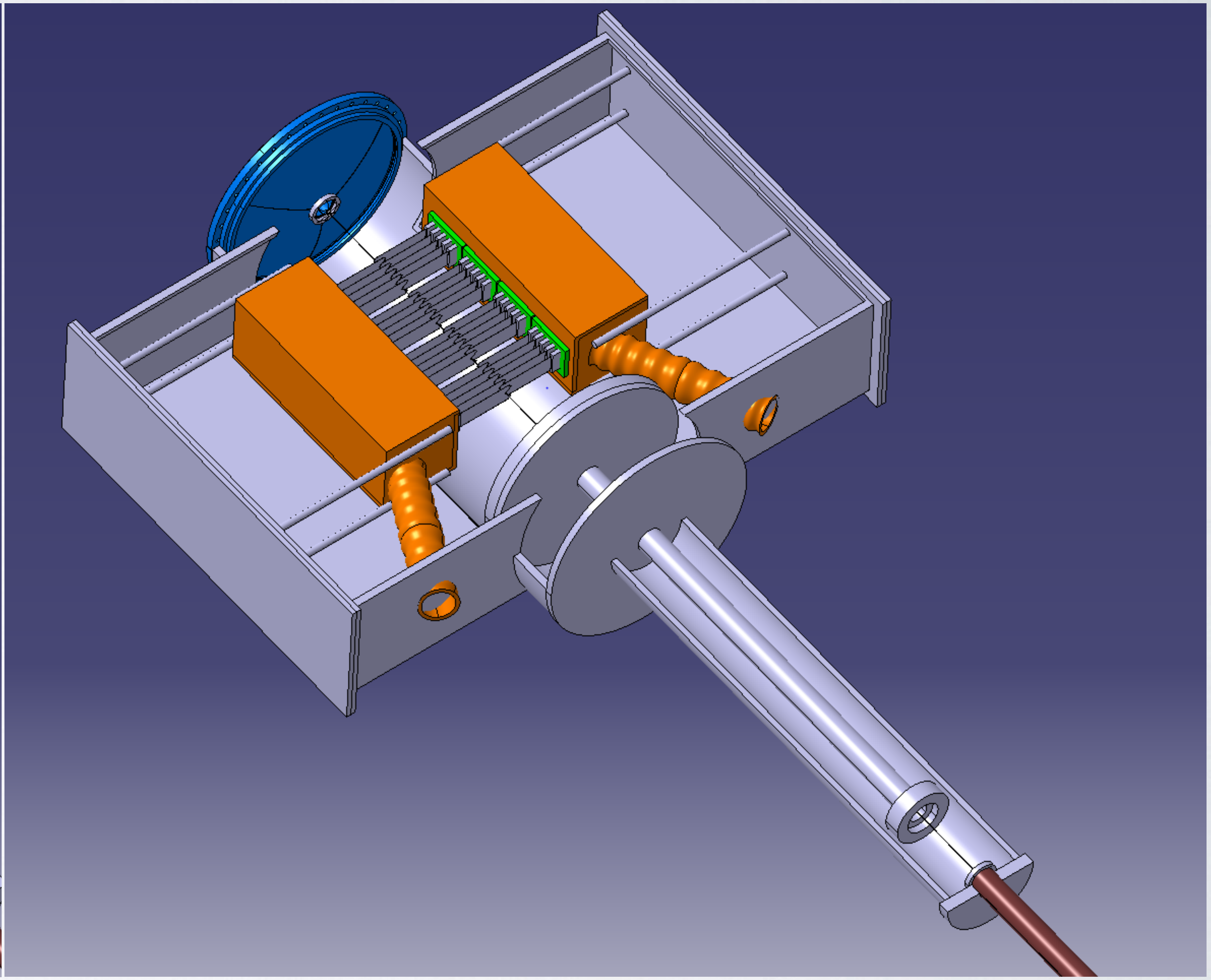
Consider partial robotic replacement to reduce radiation exposure of personnel.

(R.Dumps)

Macro mechanics

Radiation tolerance challenges strongly point to needing annual replacement of the front-end detectors: big mechanical challenge

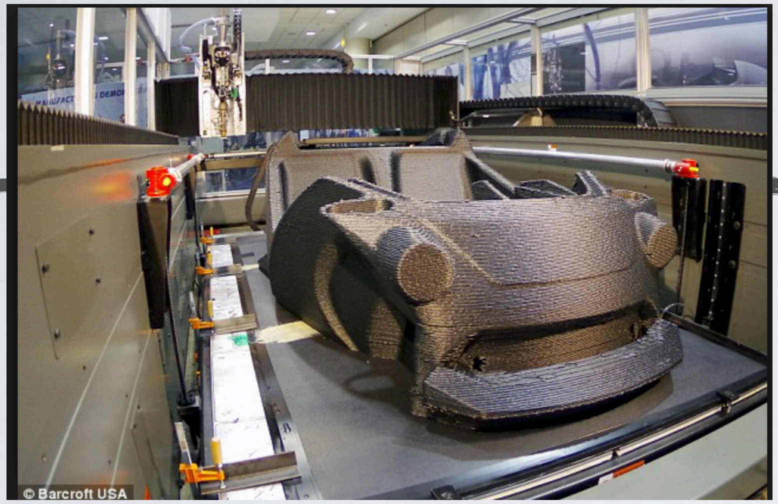




Consider partial robotic replacement to reduce radiation exposure of personnel.

(R.Dumps)

In-vacuo mechanics



3D printed car

Replacement paradigm requires cost-efficient VELO halves.

3D printing used widely and applied to LHCb in the SciFi.
Use for all the replaceable mechanics to be investigated.

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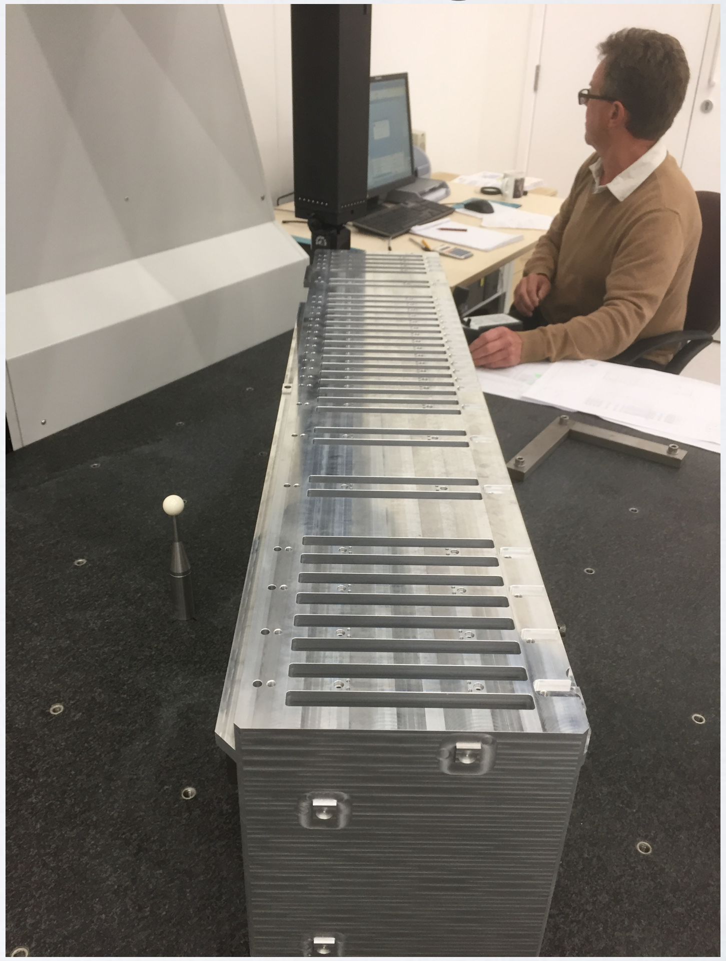
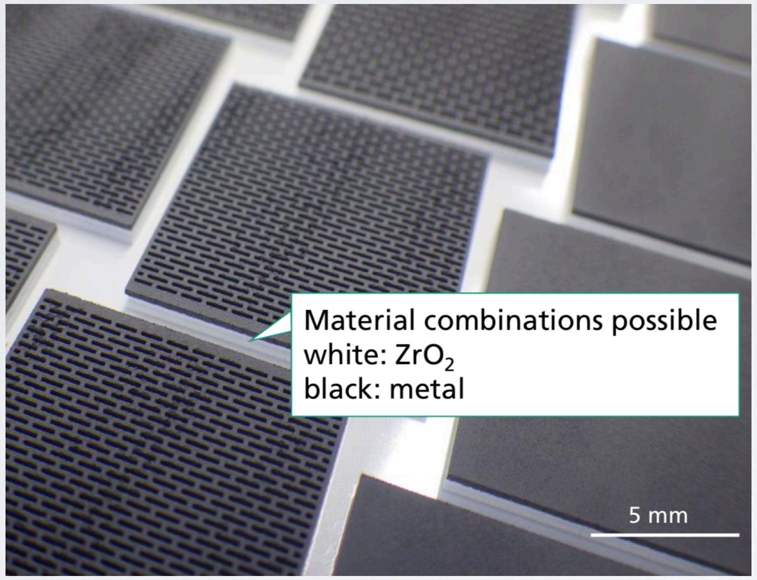
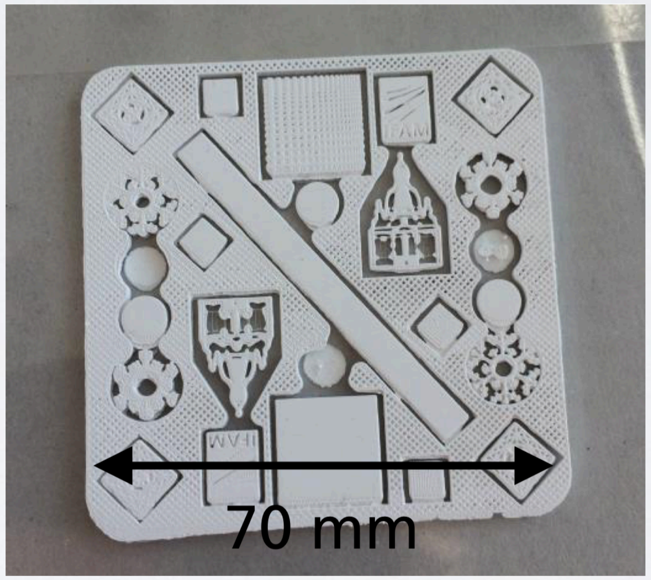


Related technology is 3D screen printing

- Limits complexity of design to 2D
- Mixed material printing (ceramic + metal) possible
- Large area devices (20x20 cm^2) is commercially available





Al_2O_3

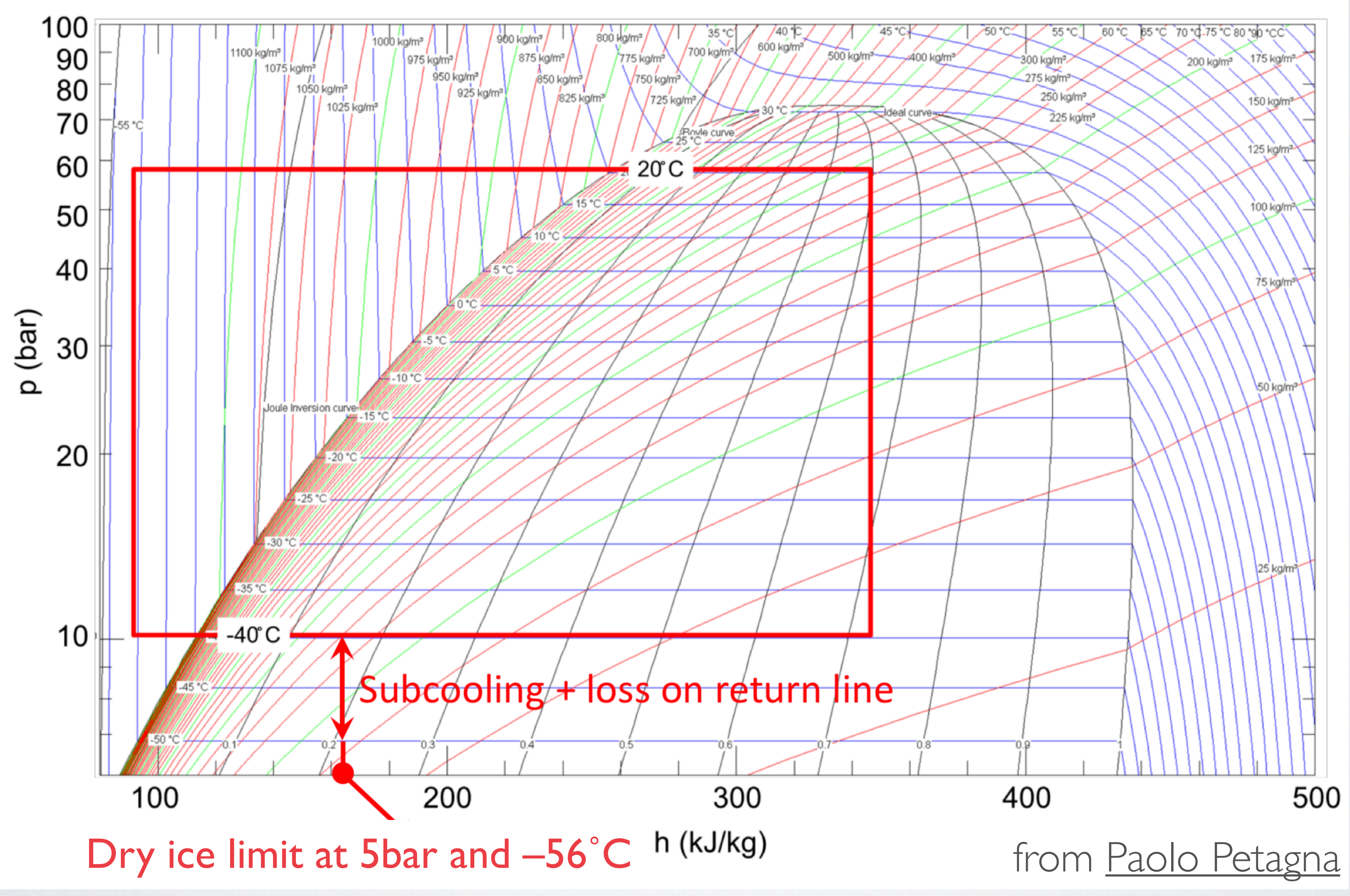
fraunhofer.de

Could power routing be integrated into the structure?

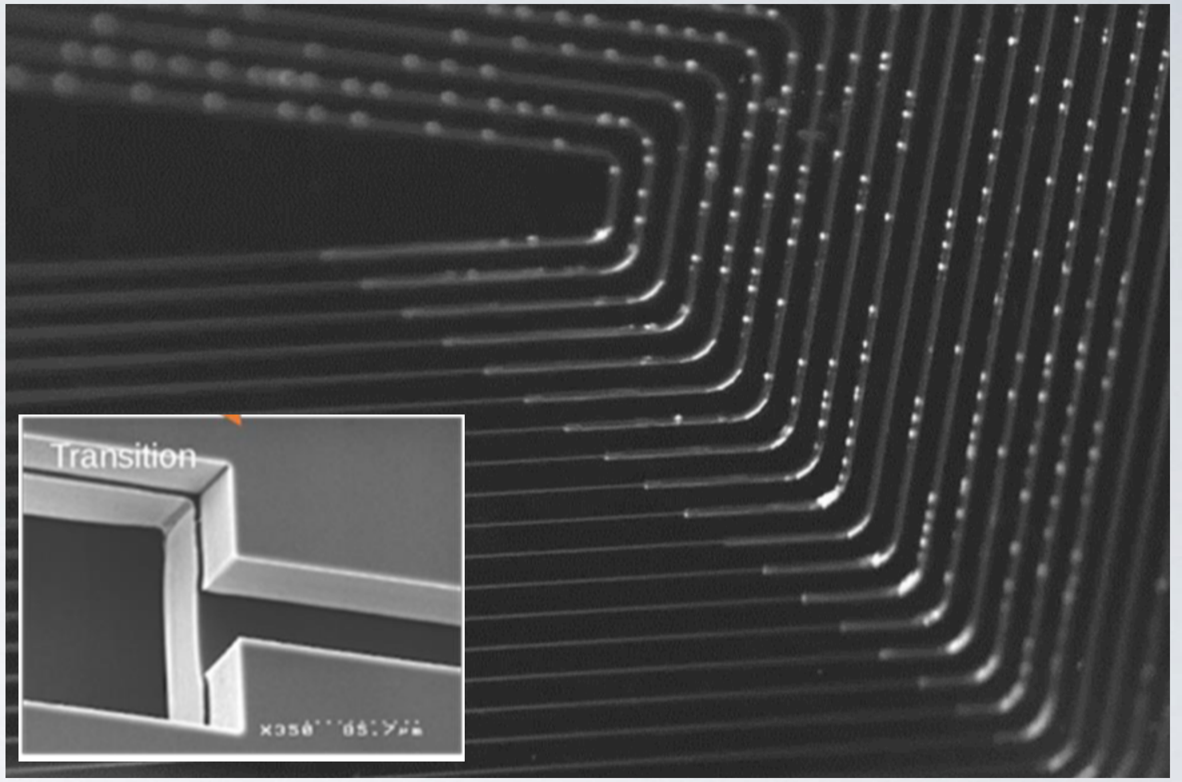
- Reduces copper wiring in acceptance, reduces outgassing sources

Conductive cooling in vacuum vital to remove heat (ASICs) and optimise sensor (fastest response, lowest leakage current)

- Upgrade I solution (CO_2, microchannels) sinks <80W/module and maintain all below –25˚C.
- To go colder must look beyond CO_2



from Paolo Petagna



Silicon microchannels are elegant, and provide the smallest ΔT between coolant and silicon.

- But complex manufacturing and associated expense does not match well with a replacement paradigm

Avenues of investigation:

- Alternative refrigerant (Krypton, Xenon, N_20) in –90~–70°C
- Integrate cooling in 3D support structure (à la *plan Z*)
- Remote heat sink relying on conductivity of the support structure – though large ΔT. liquid Nitrogen cooling?)

Project timeline

In just 130 months, we shall assemble the UpgradeII VELO at P8.

- *Are we ready?*

LS2		Run3			LS3			Run4			LS4	Run5		
2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Ideas	Research, Development, Demonstration				Production-ready prototyping			Construction, Production, Installation				Rolling Production.…		

U^{2}PG review — TDR — PRRs — Commissioning

The future VELO project is big: everything could being changed with technical challenges everywhere. New groups are **very** welcome!