Performance of Tilted Inner Barrel

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1 April 1st 2014

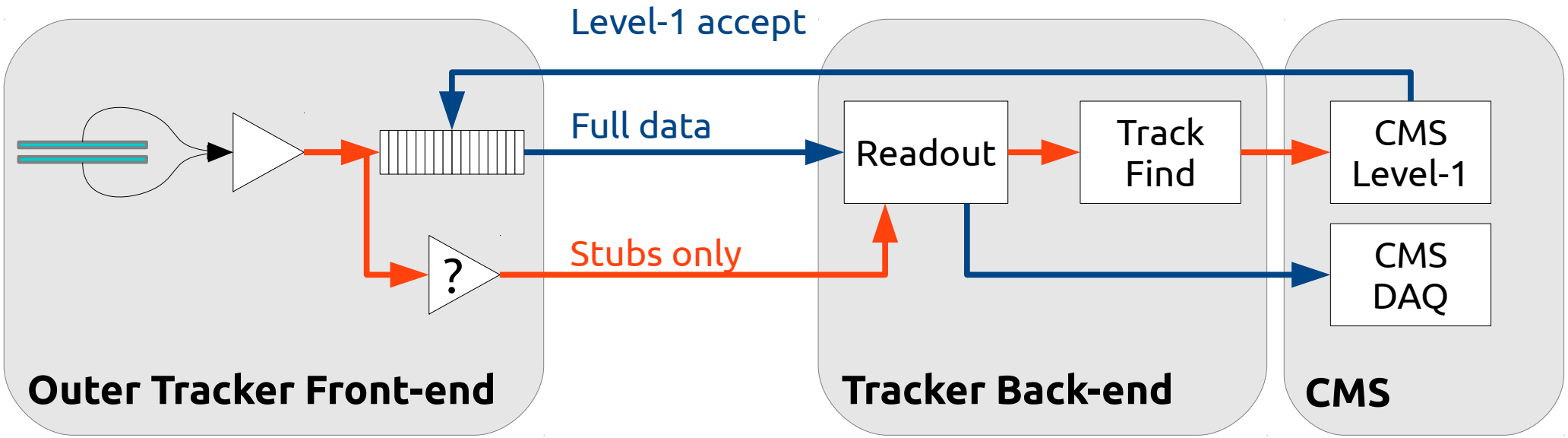
CMS Upgrade Workshop

Providing tracks for trigger

Readout architecture

Level-1 “stubs” are processed in the back-end

Form Level-1 tracks, pT above ~ 2 GeV, contributing to CMS Level-1 trigger

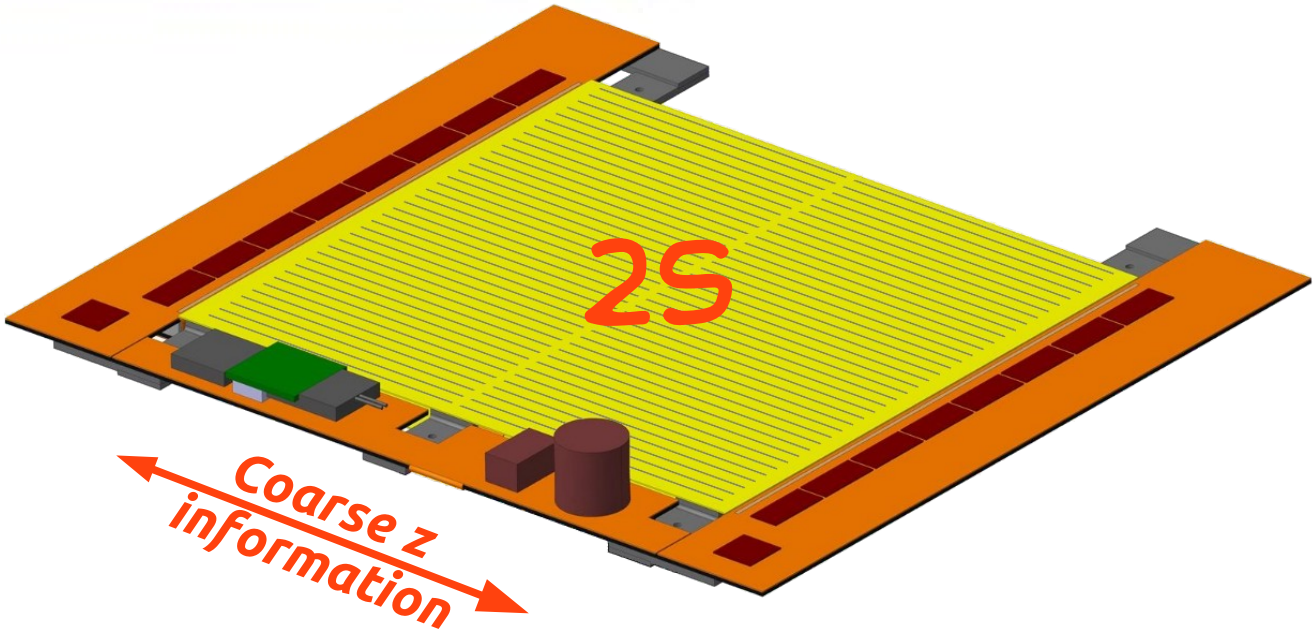


@ 40 MHz – Bunch crossing
@ > 500 kHz – CMS Level-1 trigger

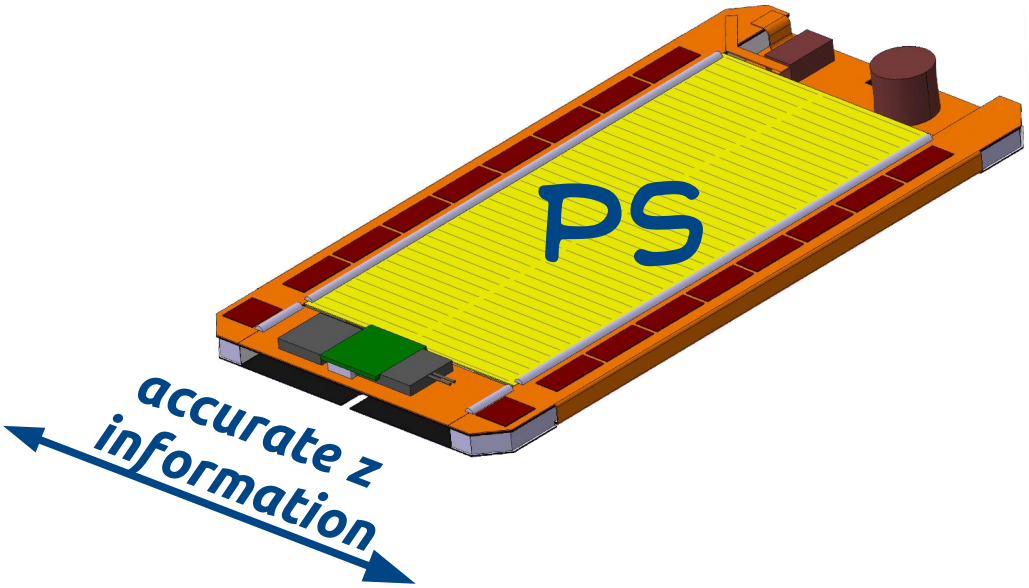
Module design

Only two module types

2 Strip sensors
Strips: 5 cm × 90 µm
Strips: 5 cm × 90 µm
P = 2.7 W
~ 92 cm² active area
For r > 40 cm

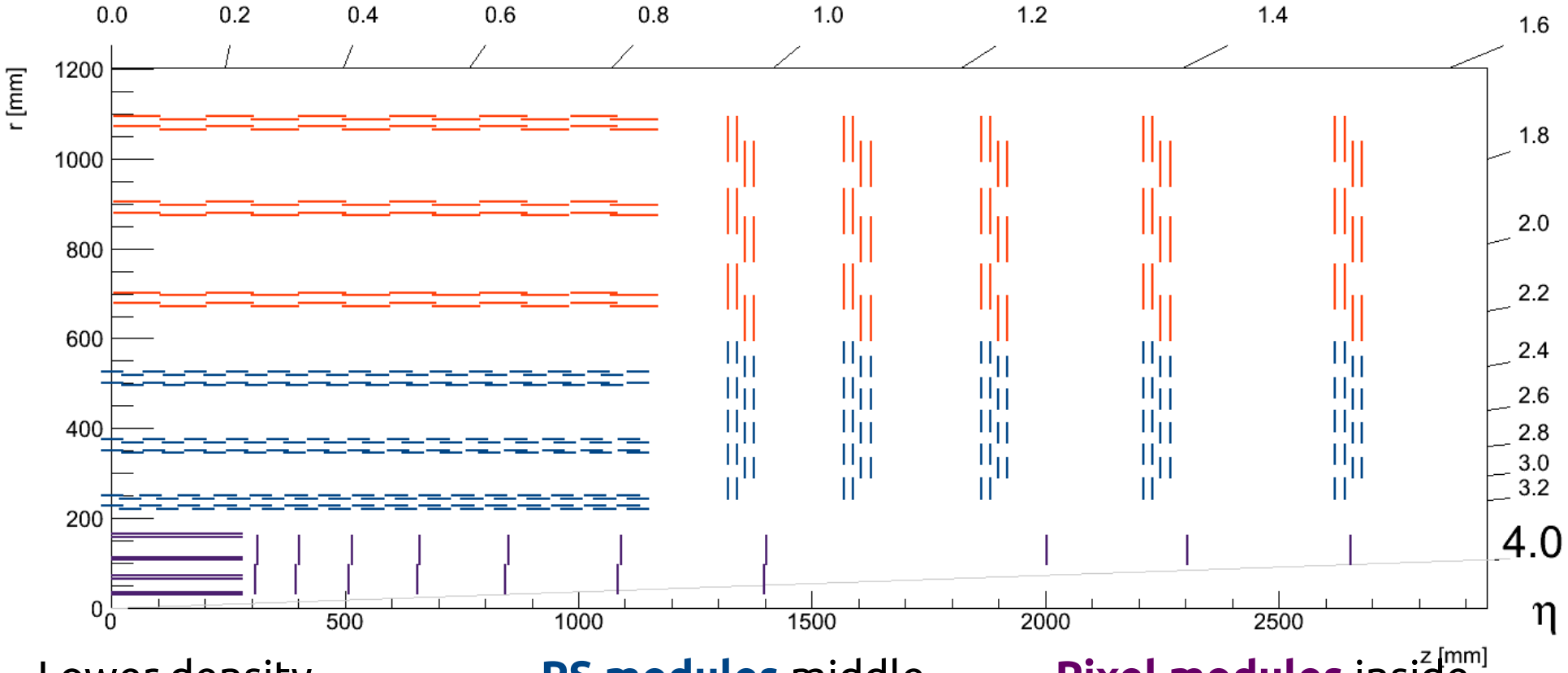


Pixel + **S**trip sensors
Strips: 2.5 cm × 100 µm
Pixels: 1.5 mm × 100 µm
P = 5.0 W
~ 44 cm² active area
For r > 20 cm



About the same weight

Tracker Layout



Lower density
2S modules outside
(~8'424 modules)

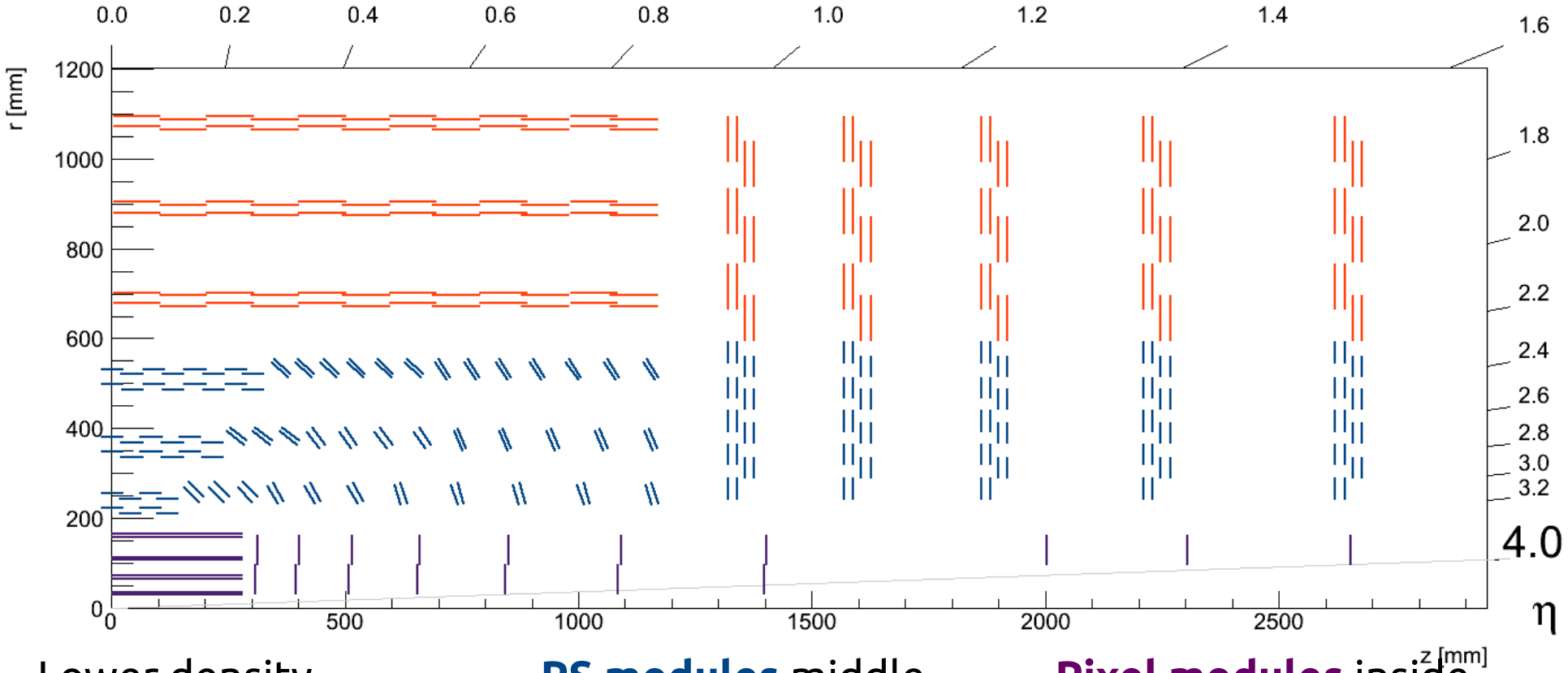
PS modules middle
z info in trigger
θ info in trigger
(~6'930 modules)

Pixel modules inside
accurate impact parameter resolution & forward coverage

More detailed model
15'354 total modules

No detailed model: using Phase-I detector layout w/ more disks in the forward

Tracker Layout



Lower density
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PS modules middle
z info in trigger
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(~5'708 modules)

Pixel modules inside
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More detailed model
14'132 total modules

No detailed model: using Phase-I detector layout w/ more disks in the forward

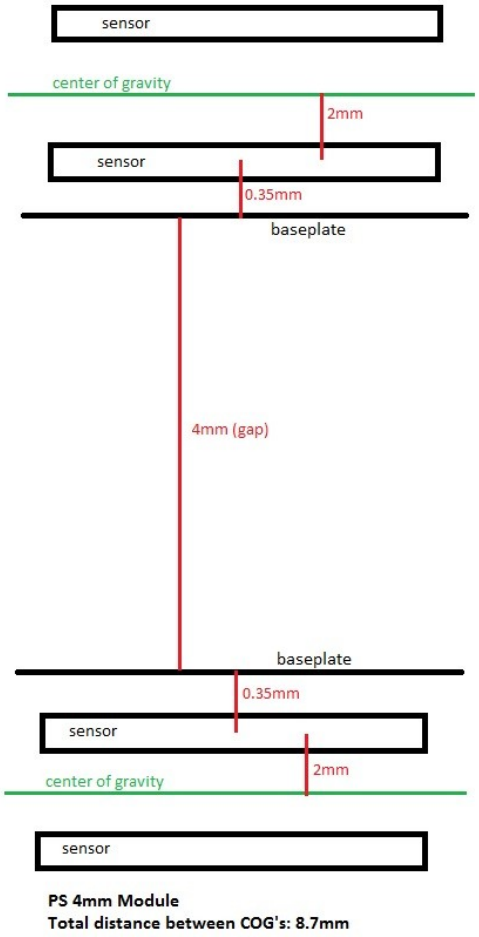
Upgrade overview

	Current	Upg flat	Upg tilted
Silicon [m^2]	~200	216	206
Strips [M]	9.3	47.6	45.2
MacroPixels [M]	0	212.9	175.3
Modules	15'148	15'354	14'132

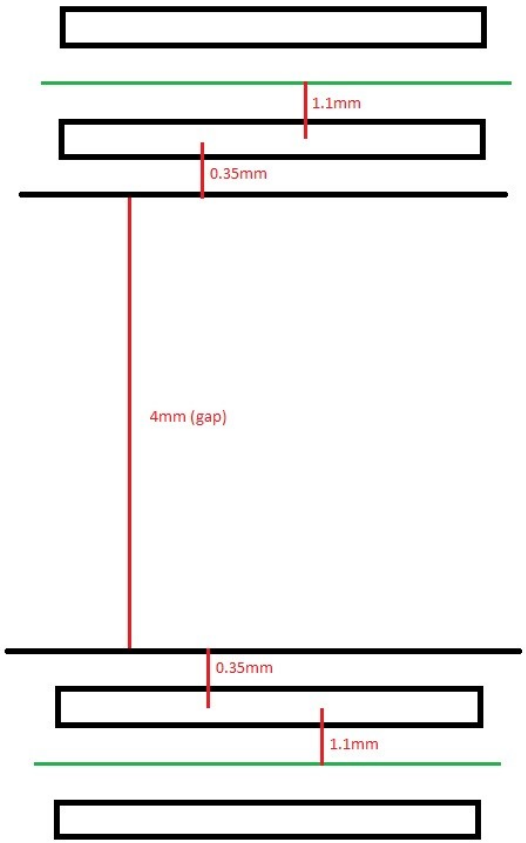
Mechanics Constraints

Modules relative placement studied in some detail

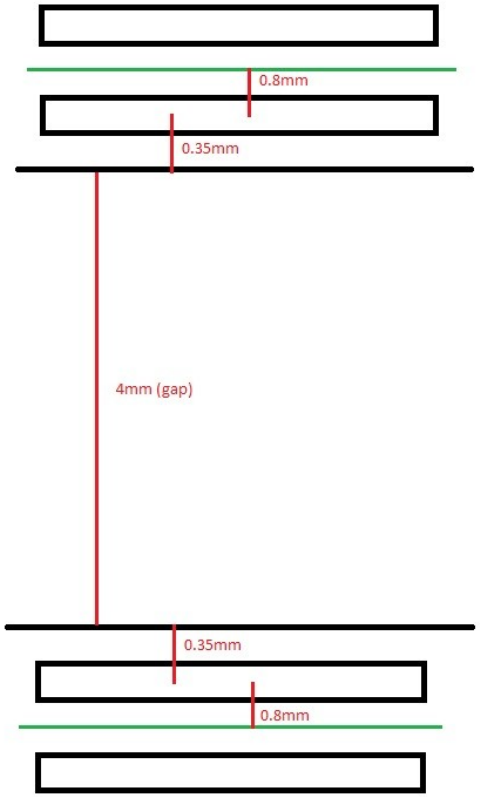
Clashes avoided in radial and z directions



PS 4mm Module
Total distance between COG's: 8.7mm

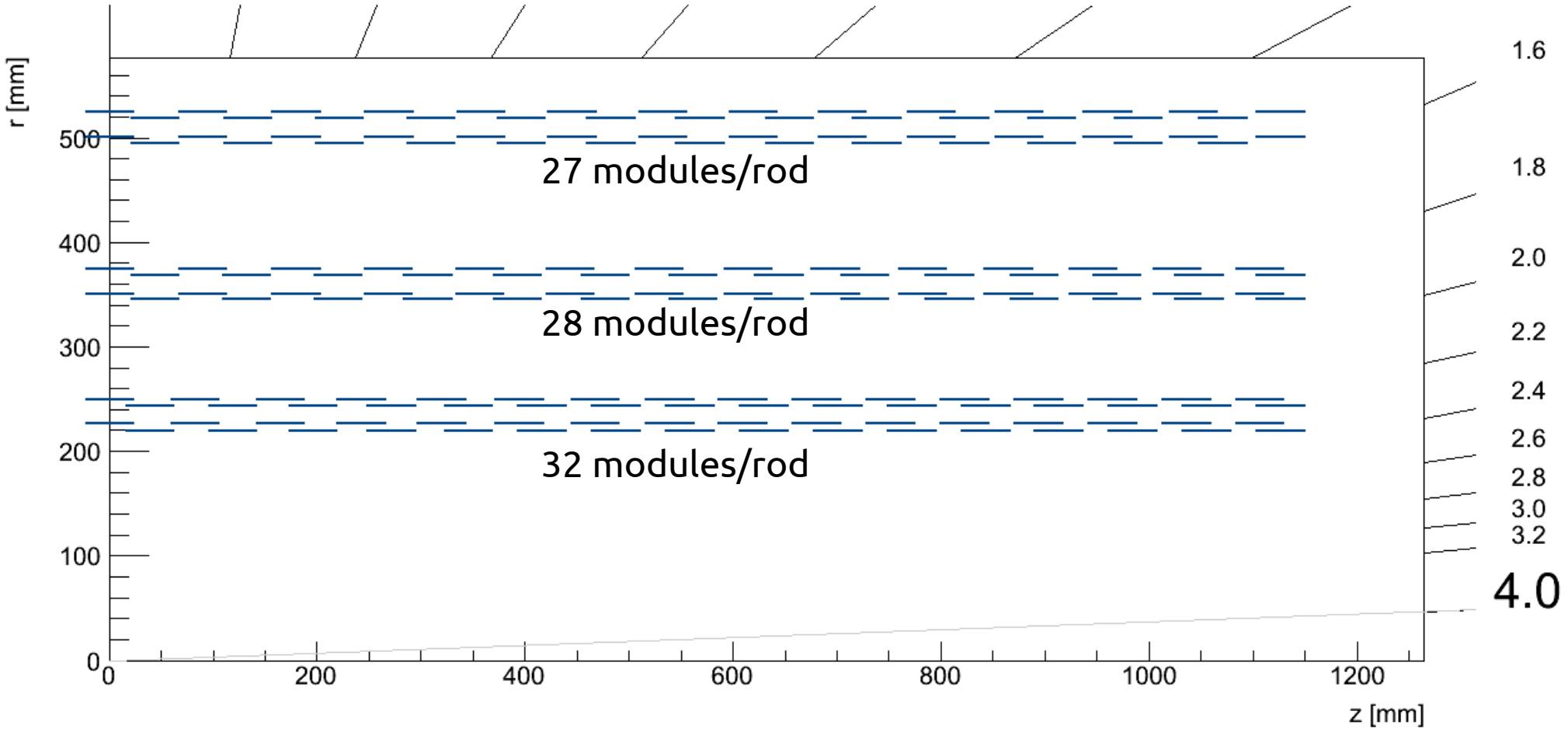


PS 2.2mm Module
Total distance between COG's: 6.9mm

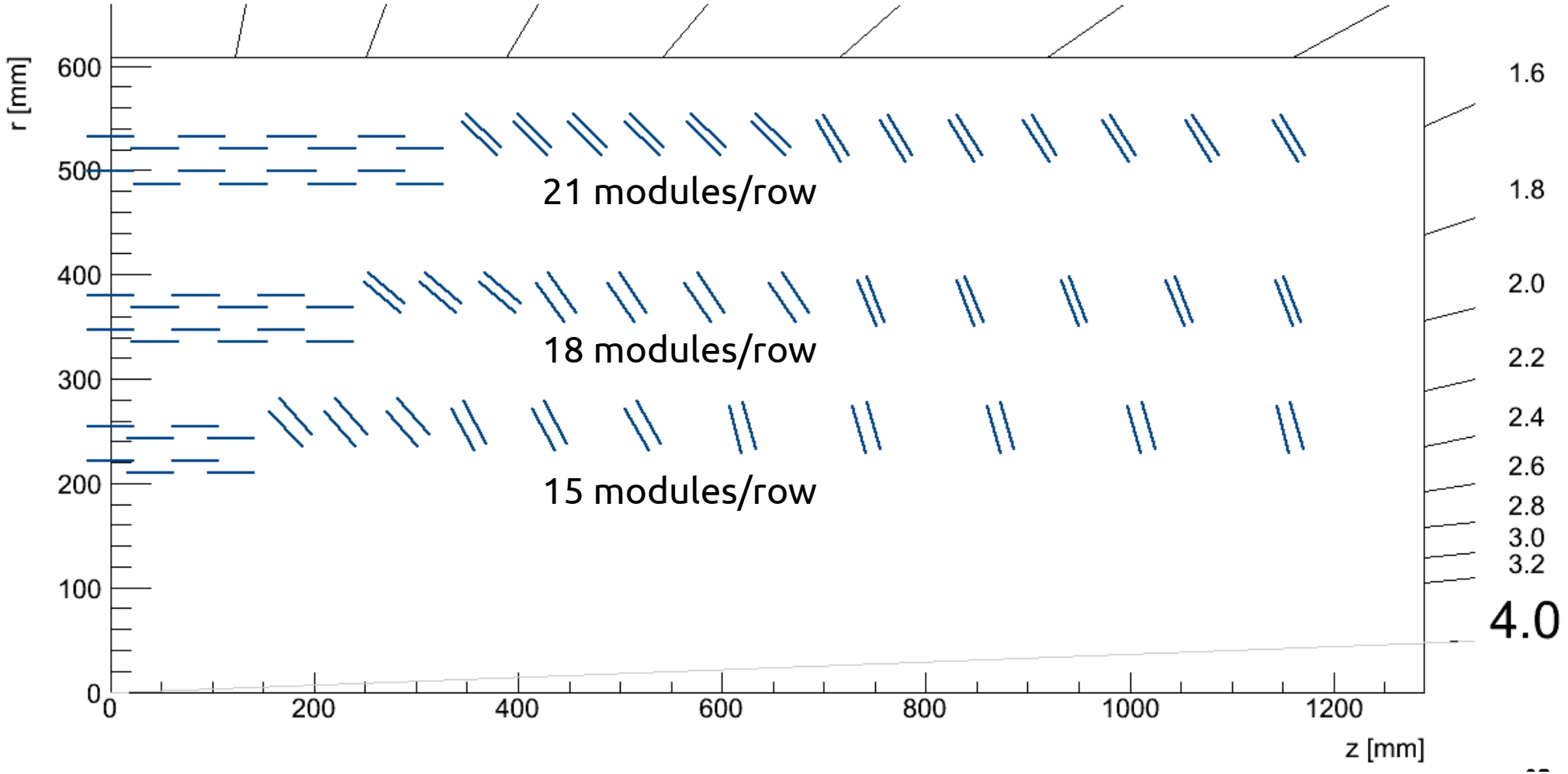


PS 1.6mm Module
Total distance between COG's: 6.3mm

Flat inner barrel geometry

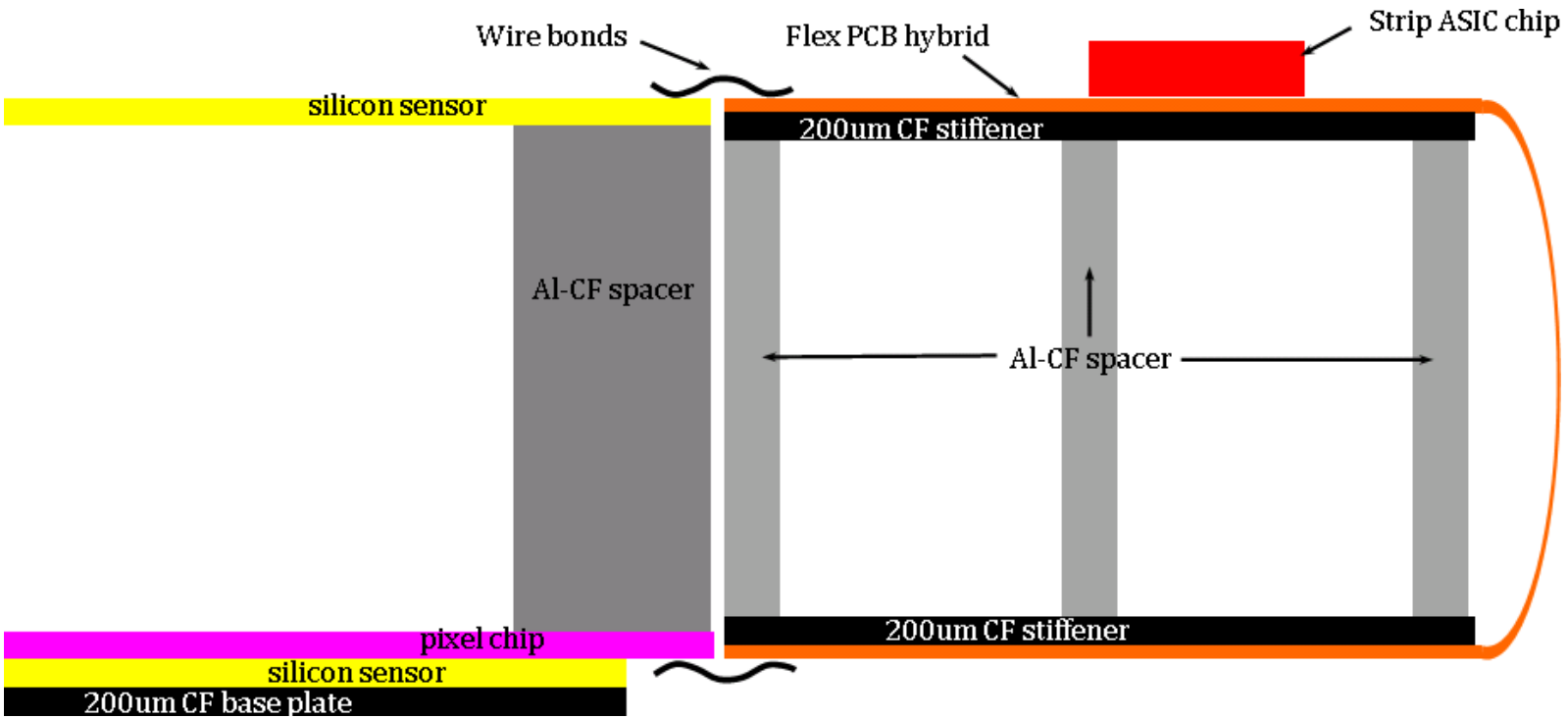


Tilted inner barrel geometry



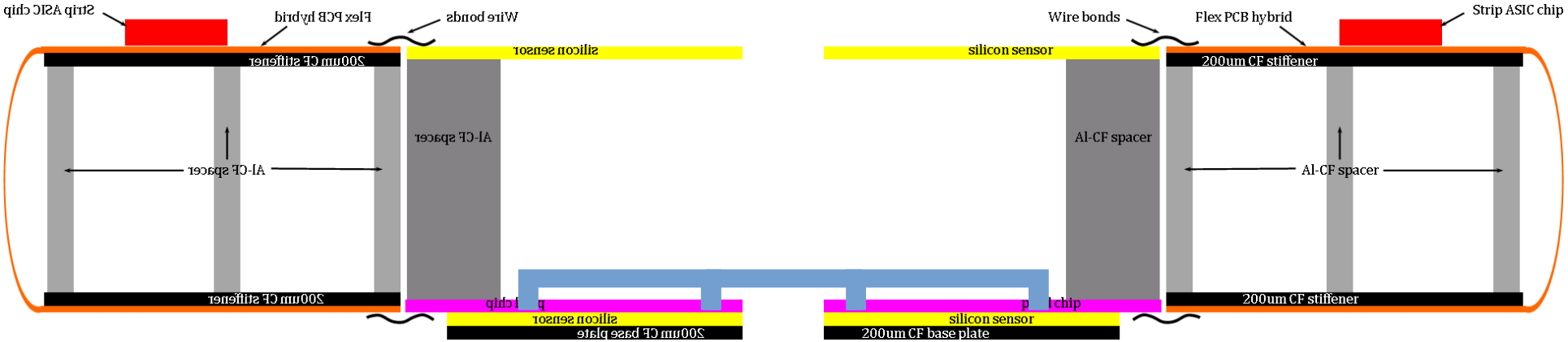
PS modules

Face-to-face connection



PS modules

Side-to-side connection?

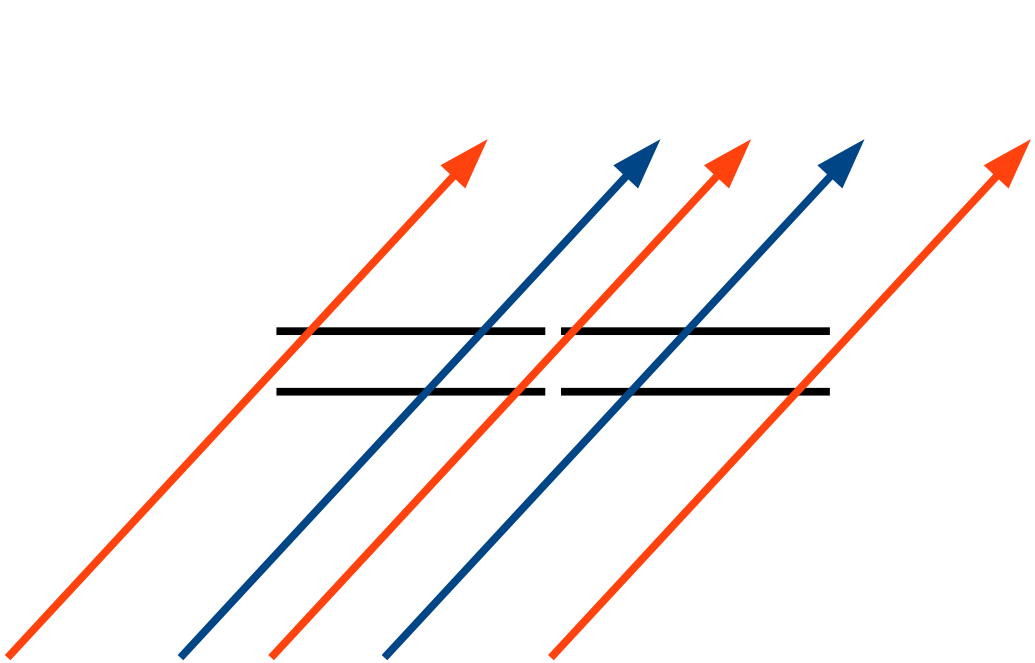


Through-silicon VIAs would be needed
to allow for cross-side communication

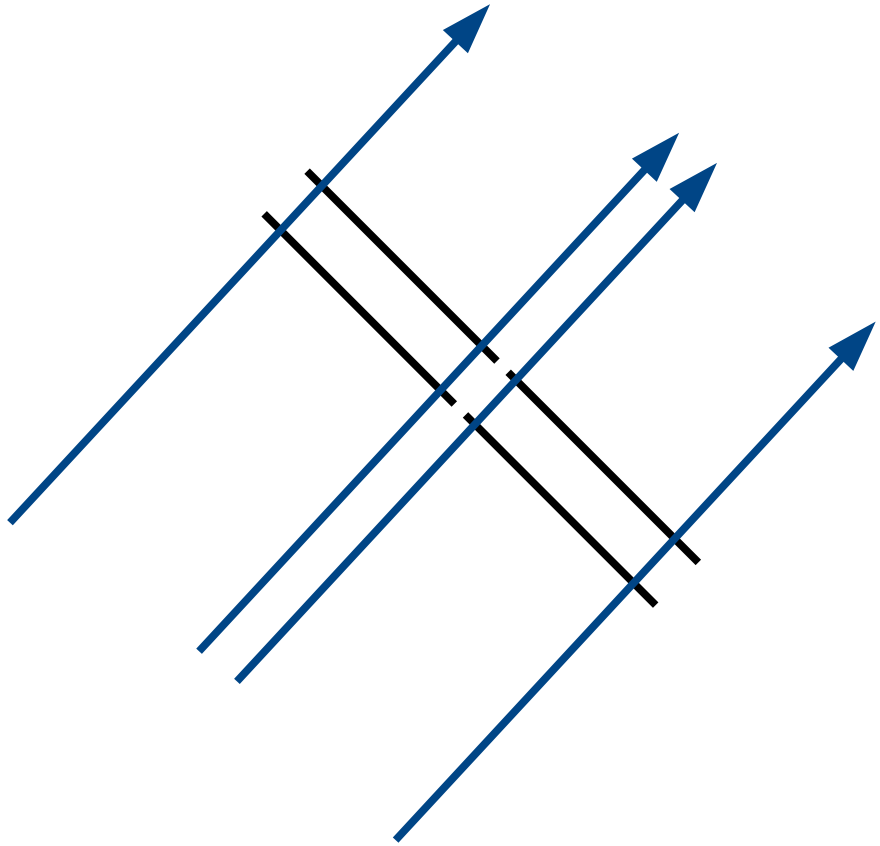
Stub coverage

On a module with no TSV

Without an interconnect technology between the two sides of the module, tracks crossing the middle will not be identified as stubs



Flat

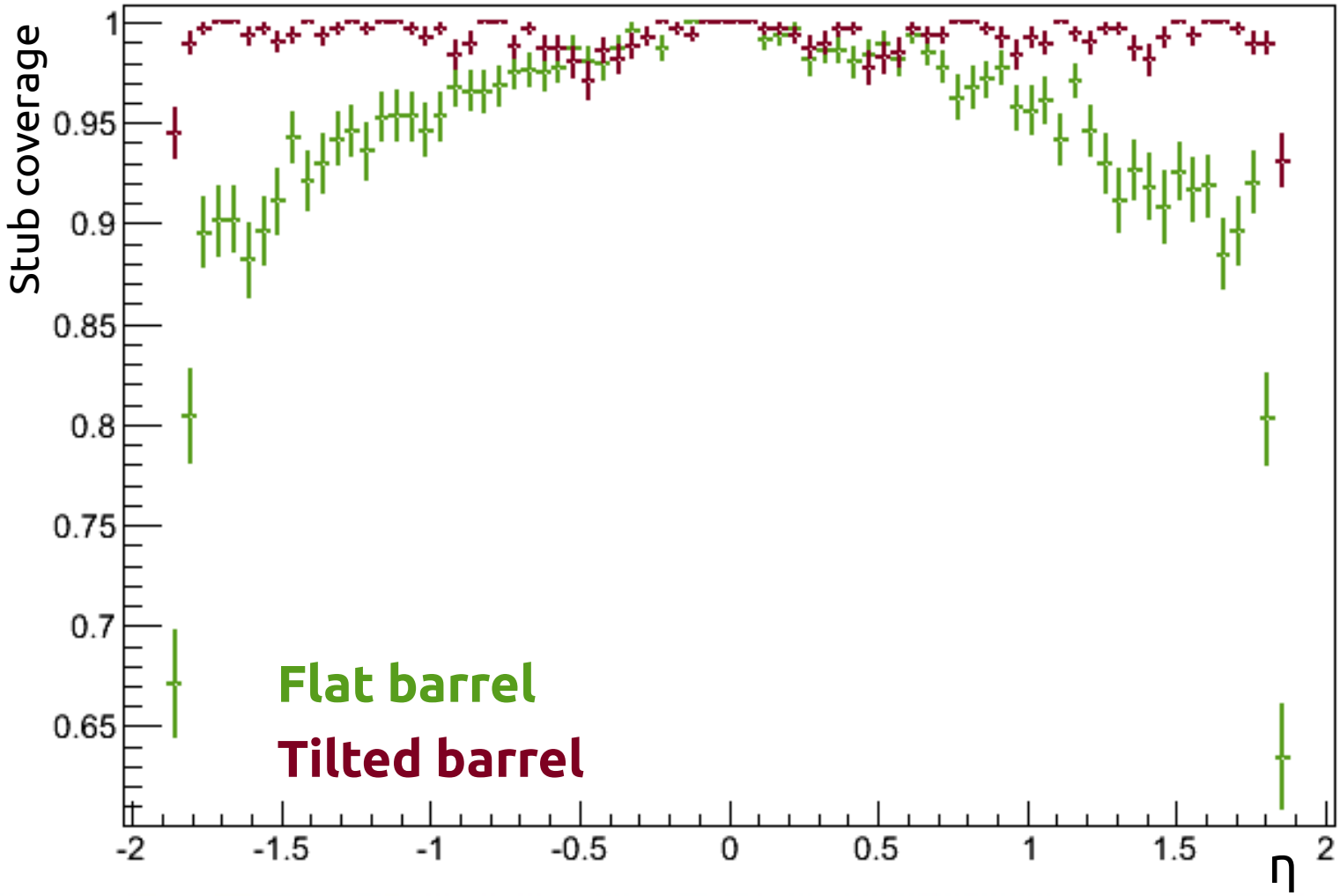


Tilted

Stub coverage

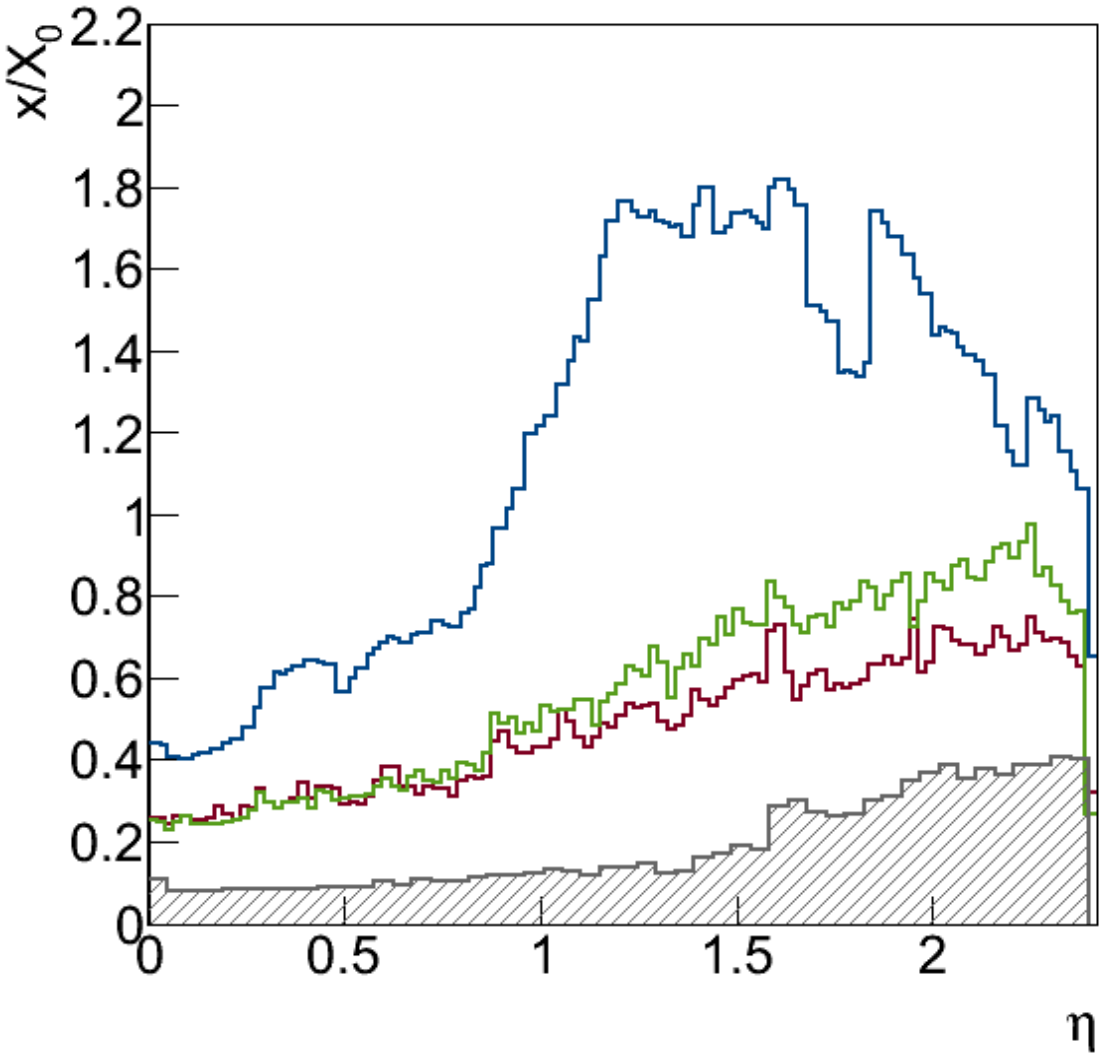
Layer 1 as example

Probability of catching ≥ 1 stub from high-pT track in Layer 1 assuming no through-silicon VIAs



Material in Tracker

Material Budget in radiation length

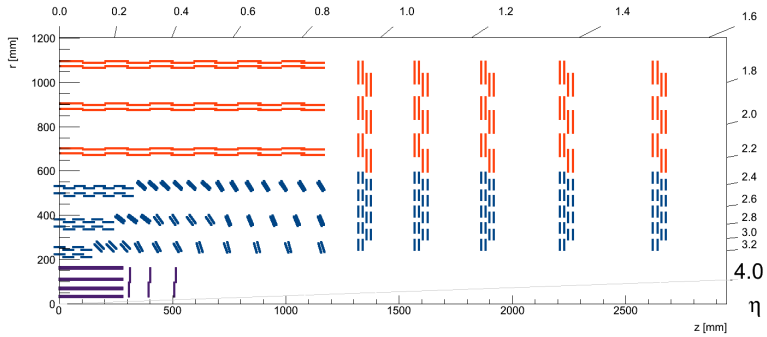


CMS Phase-1

CMS Phase-2 Flat
estimate, if keeping
~ phase-1 pixels material

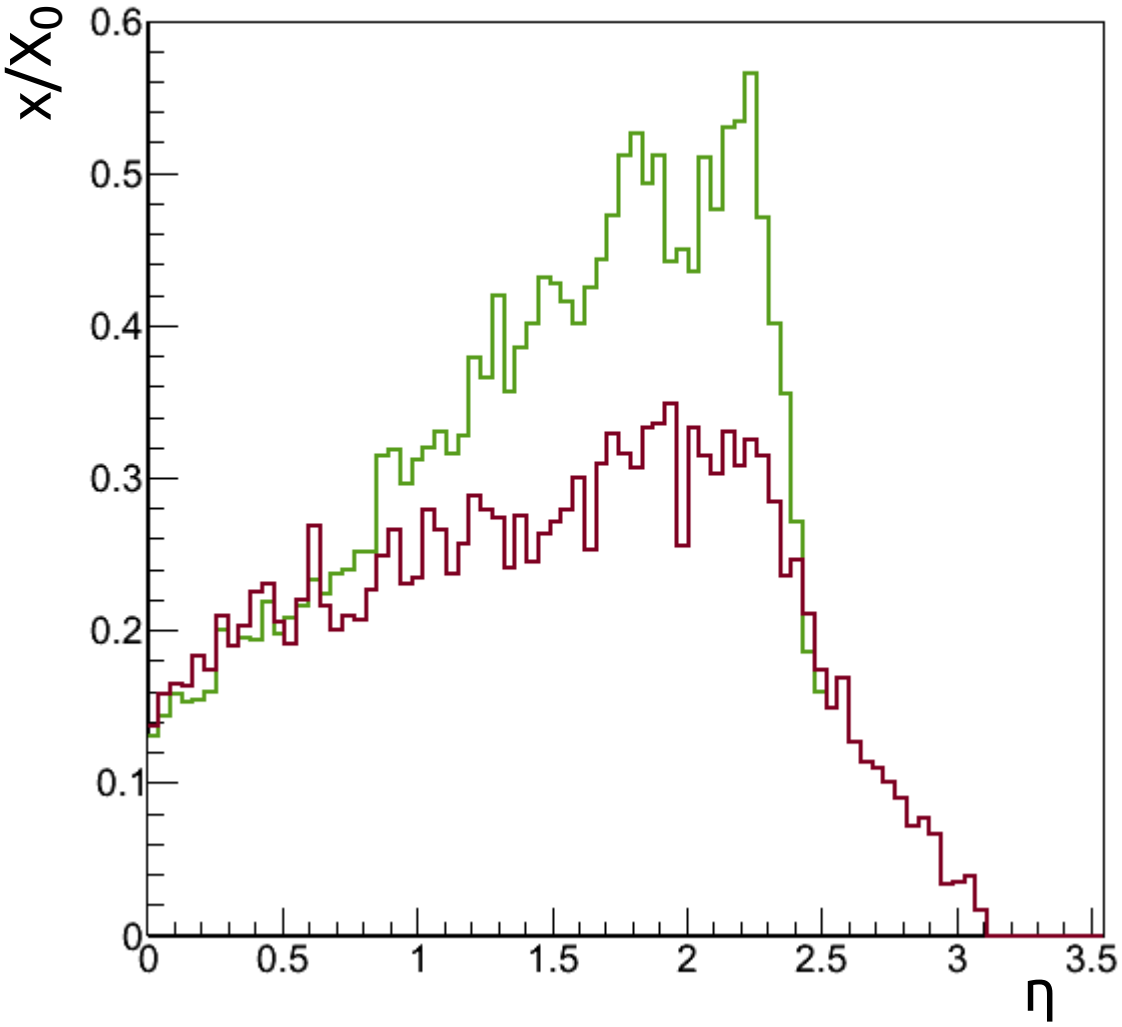
CMS Phase-2 Tilted
estimate, if keeping
~ phase-1 pixels material

Phase-1 Pixel



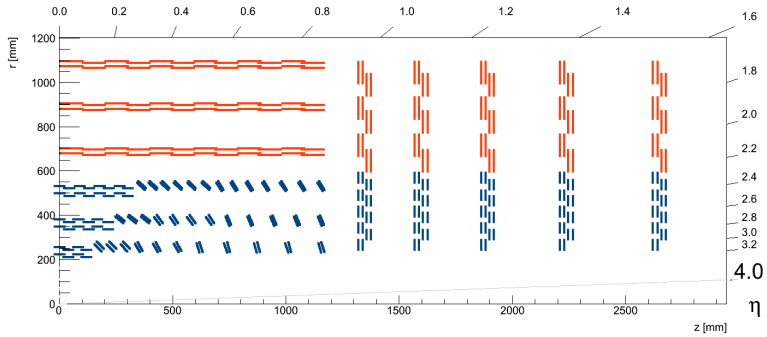
Material in Outer Tracker

Material Budget in radiation length

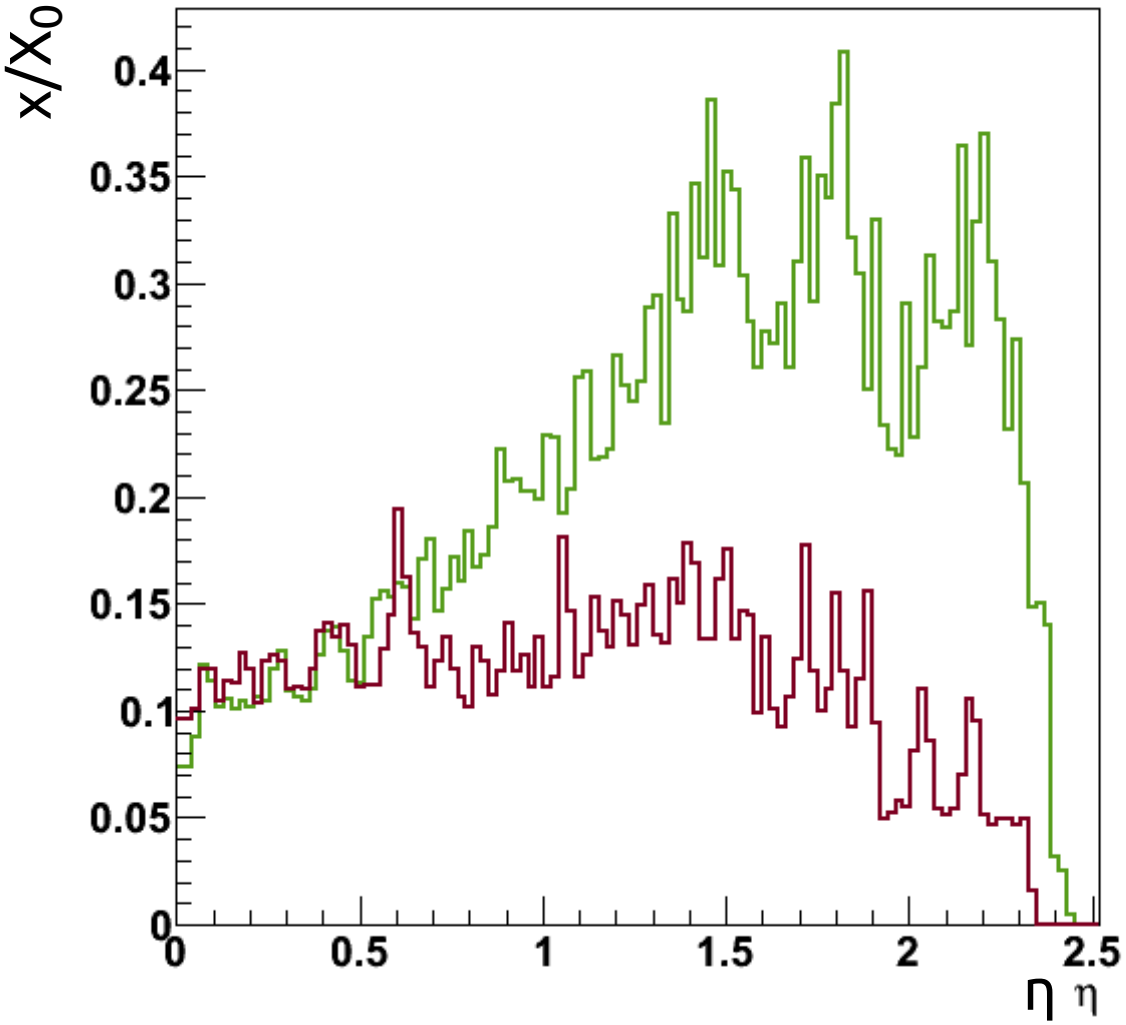


CMS Phase-2 Flat

CMS Phase-2 Tilted

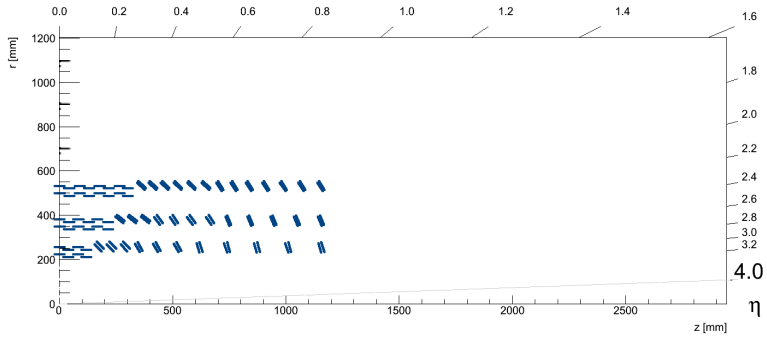


Material in Inner Barrel

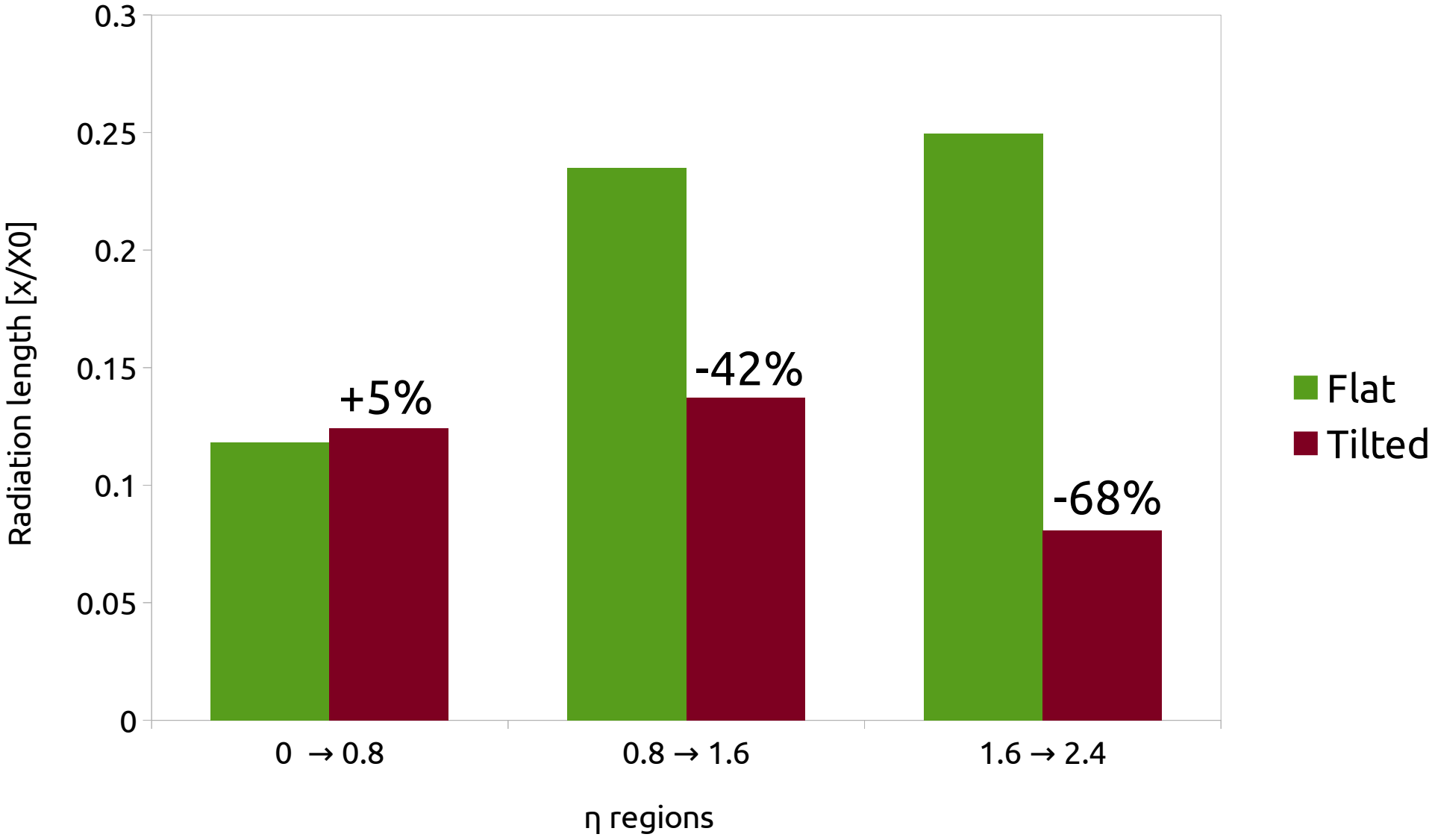


CMS Phase-2
Flat Inner Barrel

CMS Phase-2
Tilted Inner Barrel



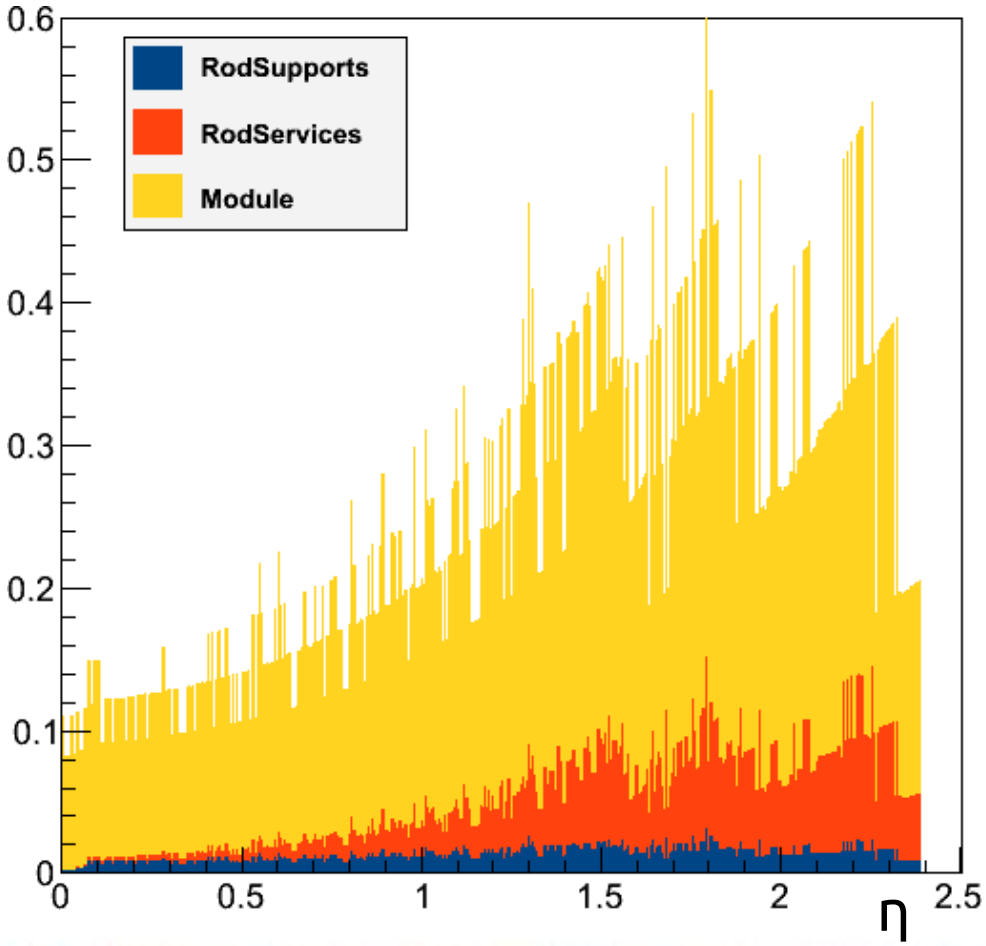
Material in Inner Barrel



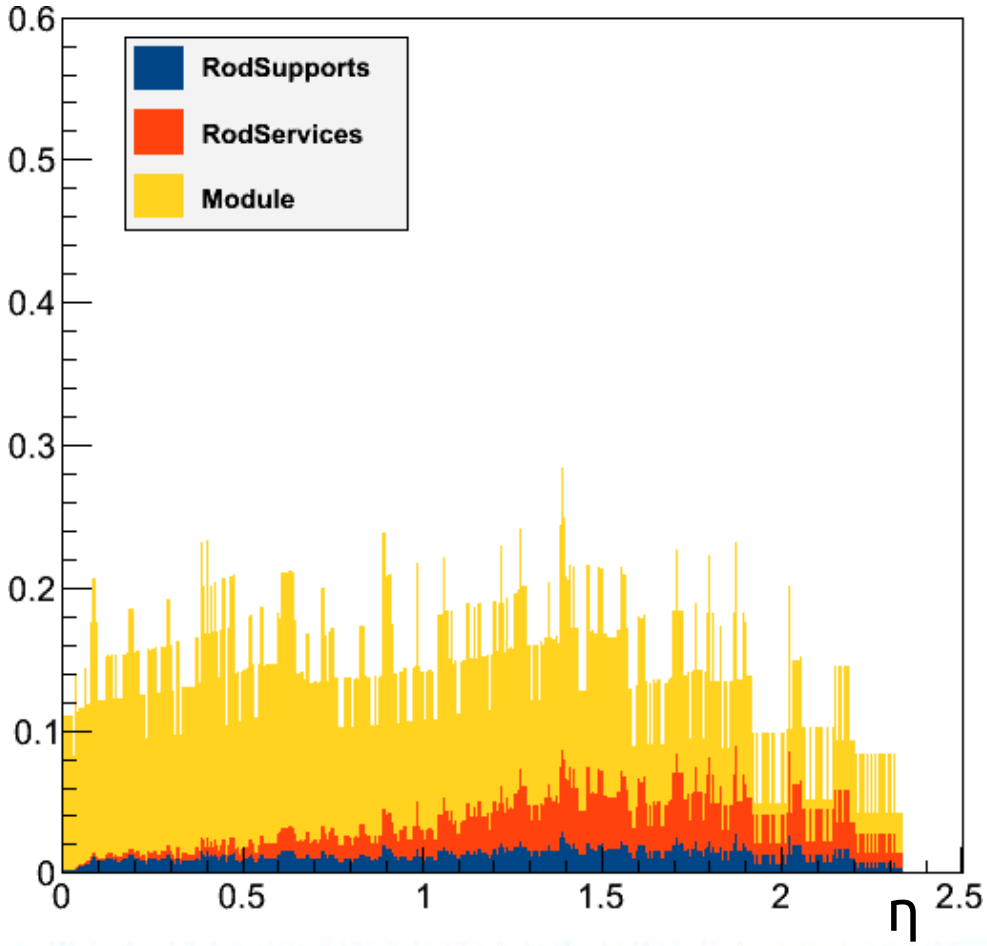
Material in Inner Barrel

Tilted barrel has less material because seen by tracks of the number of modules and their optimal orientation

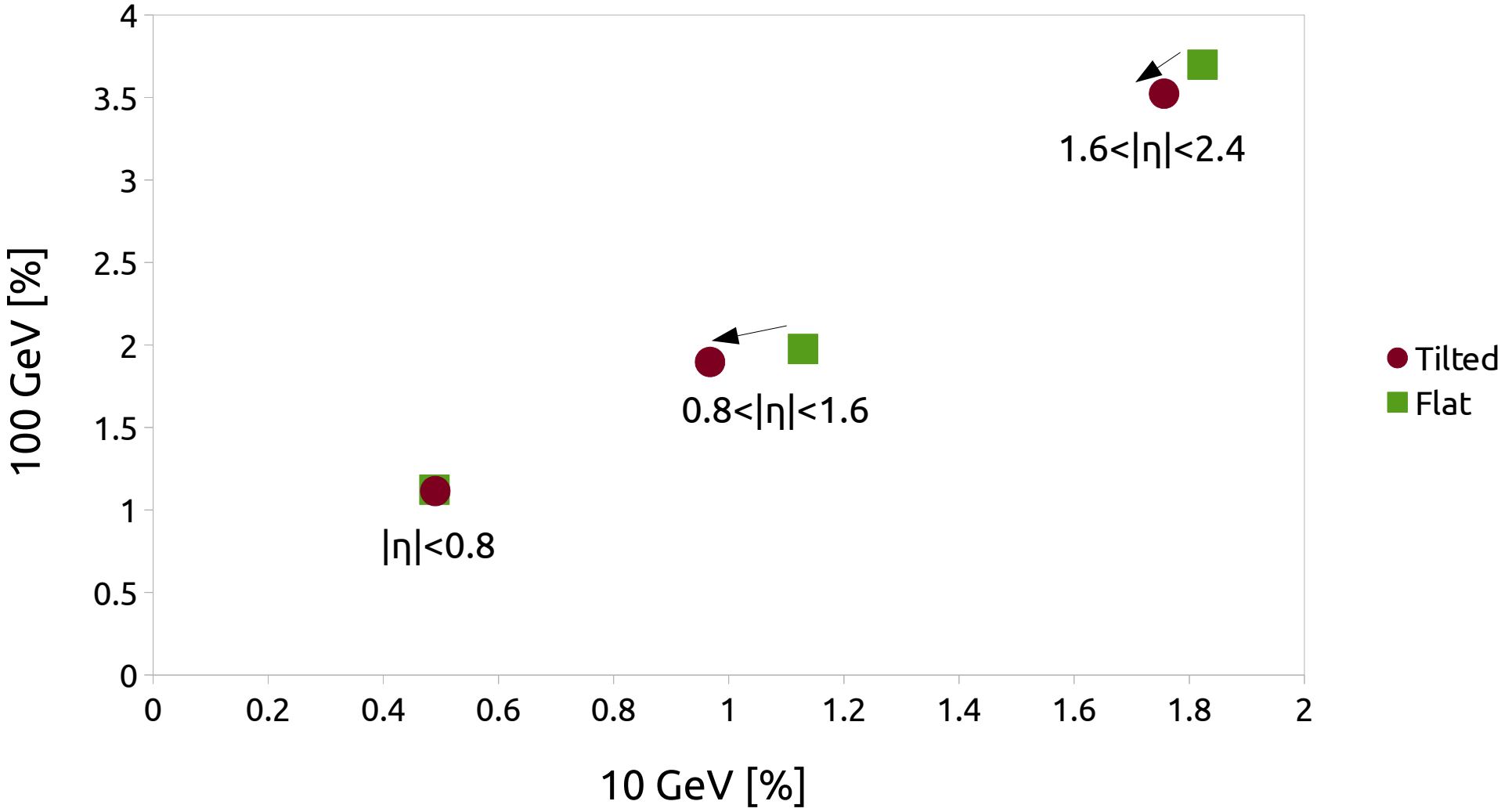
Flat inner barrel



Tilted inner barrel

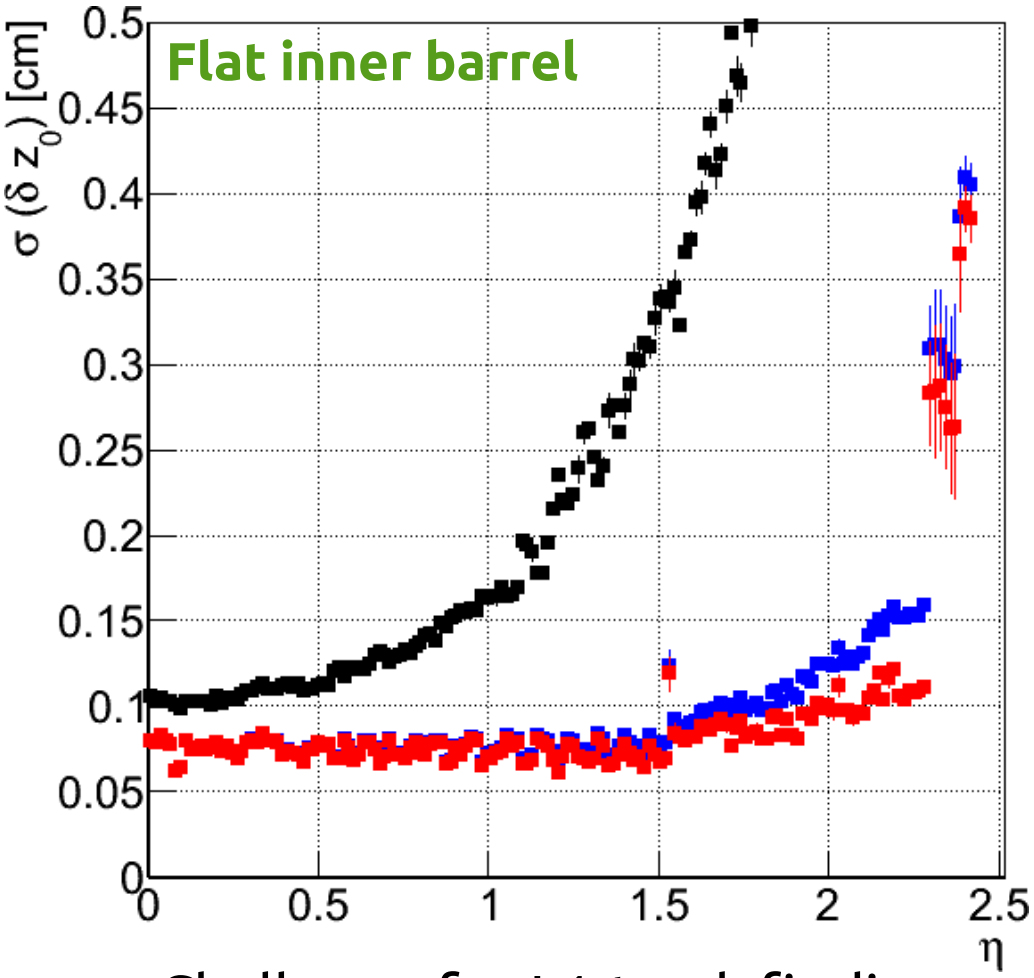


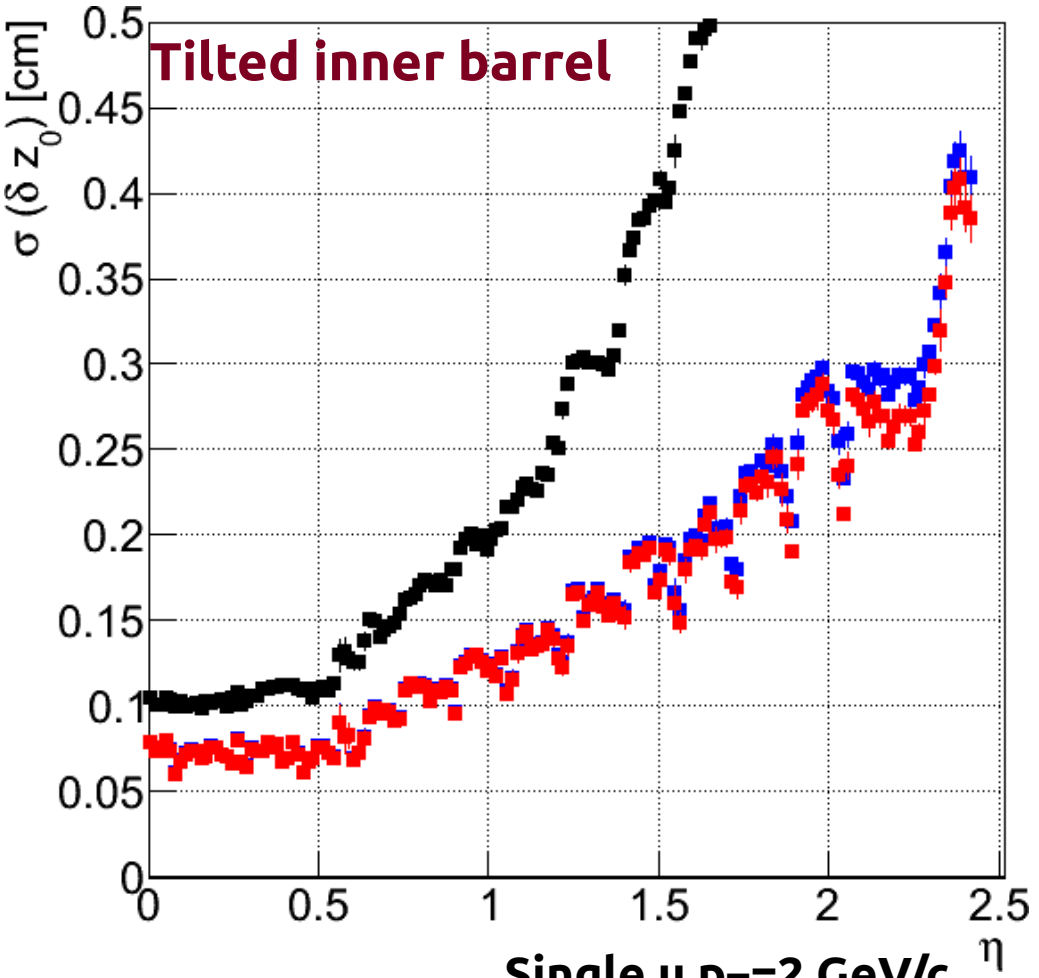
pT resolution



Track-trigger resolution

Potential z_0 resolution using all stub info





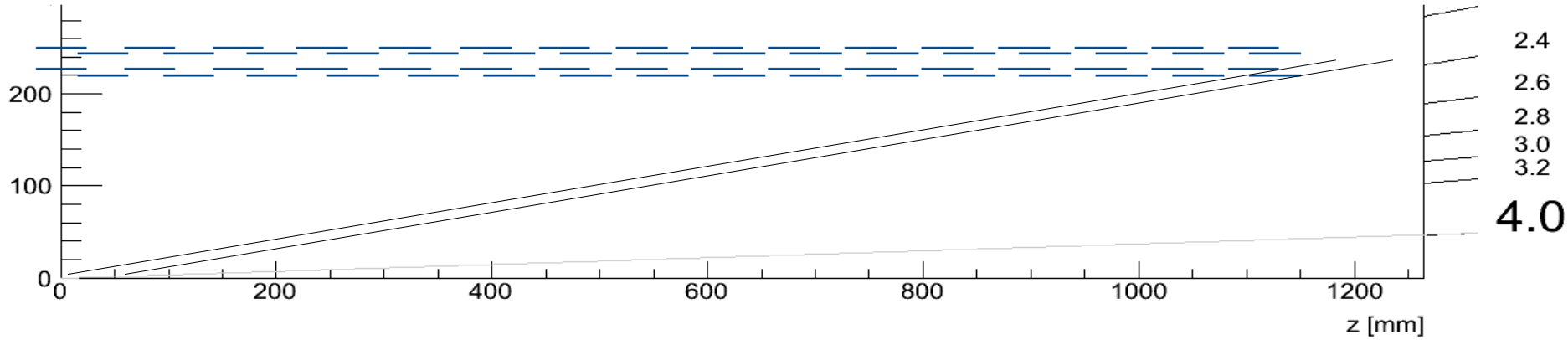
Challenge for L1-track finding:
finding precise tracking information

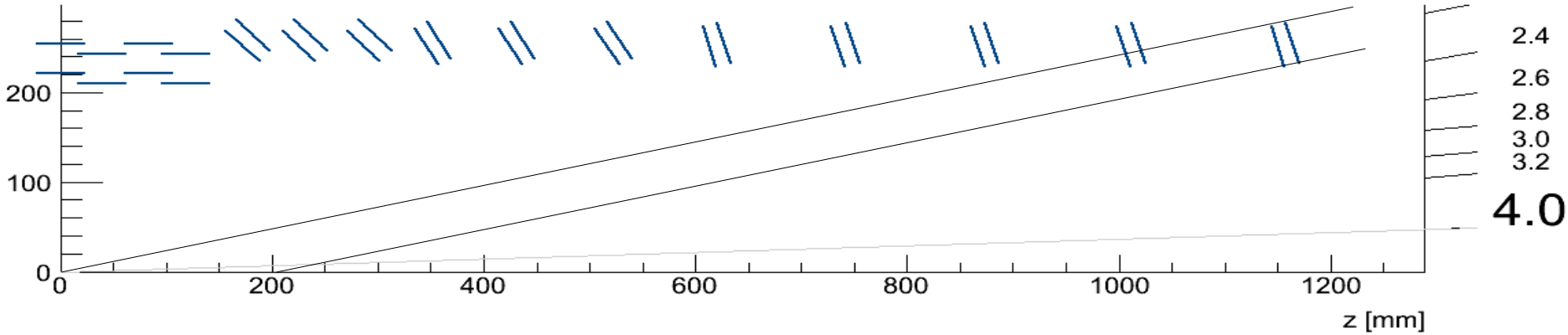
Single μ p_T=2 GeV/c
Single μ p_T=10 GeV/c
Single μ p_T=100 GeV/c

Track-trigger resolution

A small digression

The difference in z0 resolution derives from the sensitive element orientation leading to a tighter constraint on the track direction

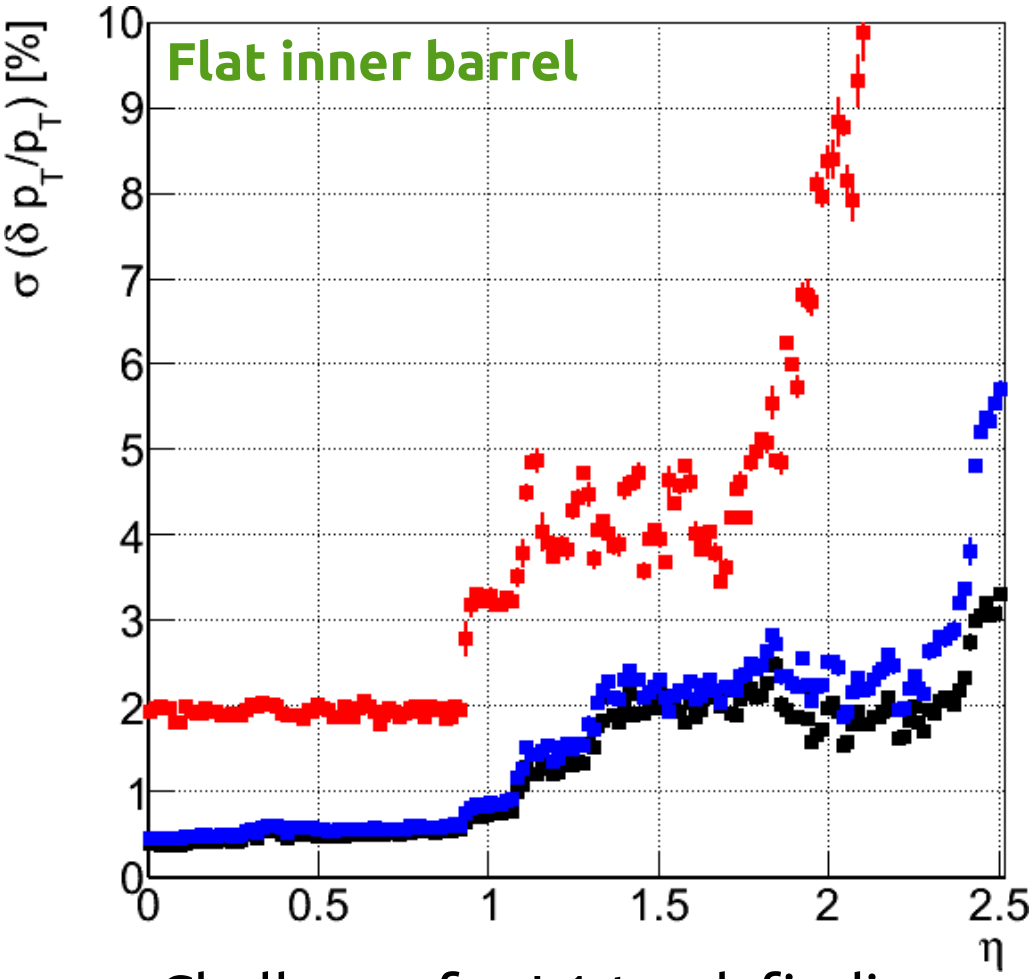


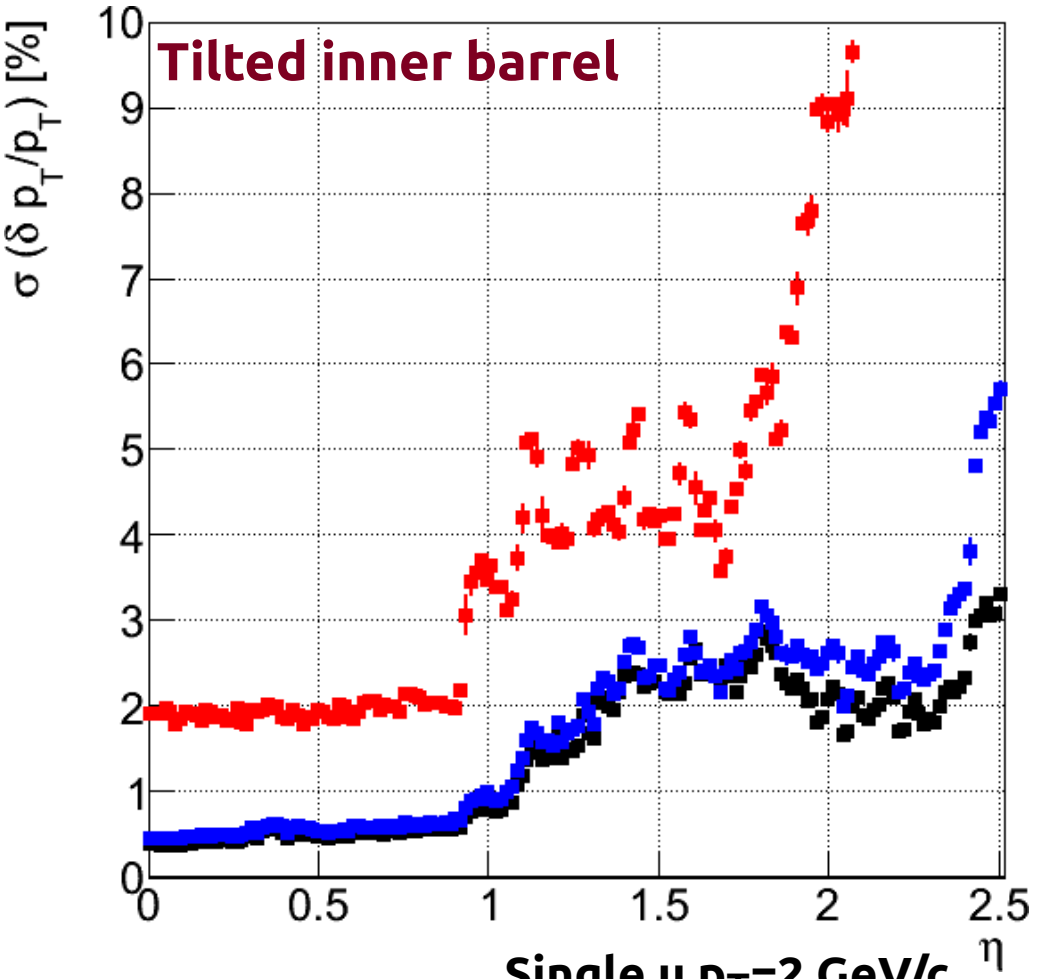


Track-trigger resolution

Potential p_T resolution using all stub info

Almost identical resolutions





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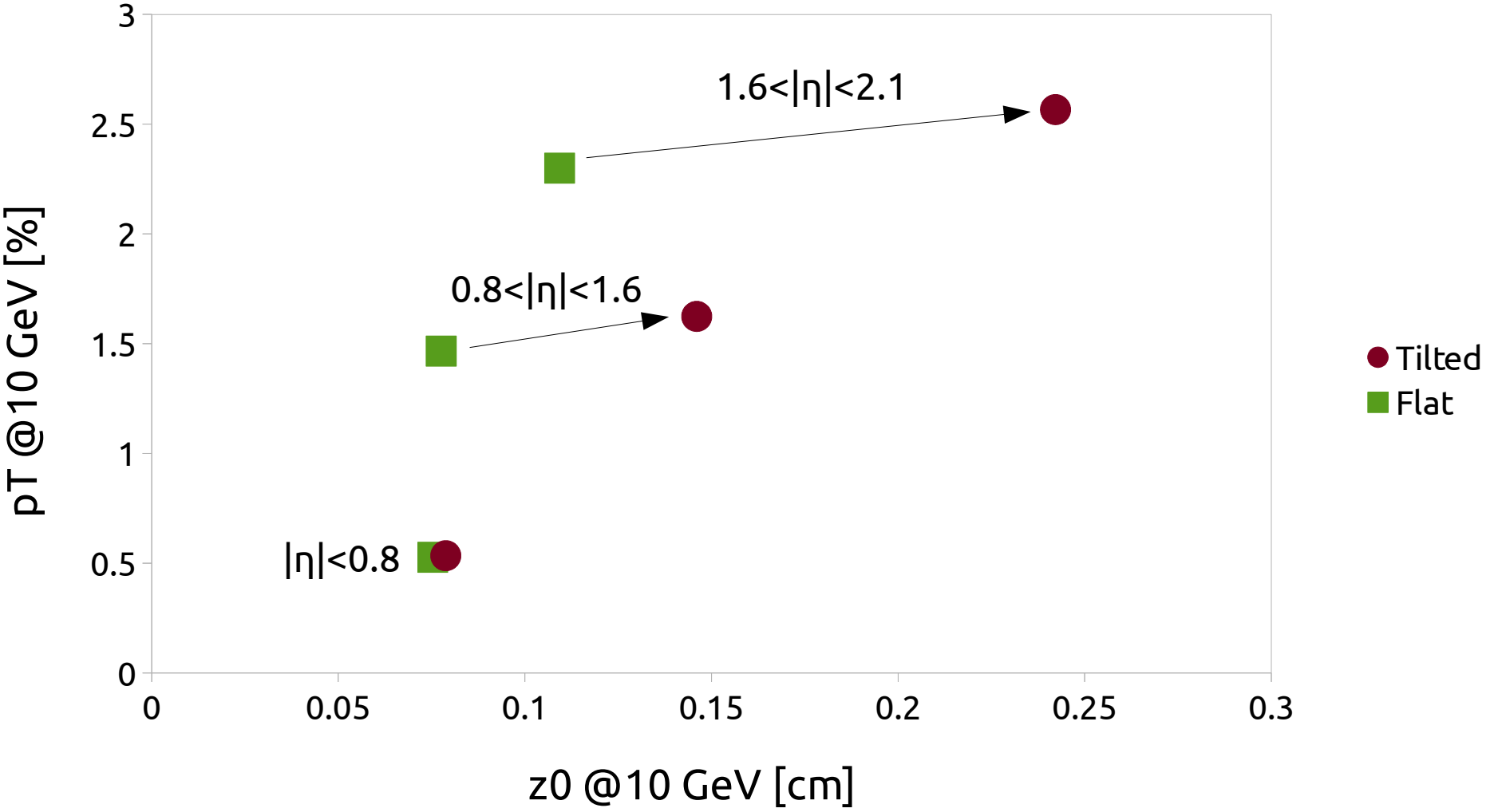


Conclusions on tilted barrel

Cons:

- Has a lower potential for z0 resolution in L1 tracking
  - pT ~10 GeV/c: (0.7→2.4)mm vs (0.7→1)mm

Pros:

- Stub finding coverage
  - More flexible
  - No need of through silicon VIAs
- Has a potential for a large material reduction in the inner barrel
  - -40% to -70% radiation lengths in intermediate and forward η regions
  - Consequently less particle interactions in inner barrel
- Cost saving (3 to 5 MCHF)
- Achieves ~20% better resolution at low pT in the intermediate $0.8<|\eta|<1.6$ region

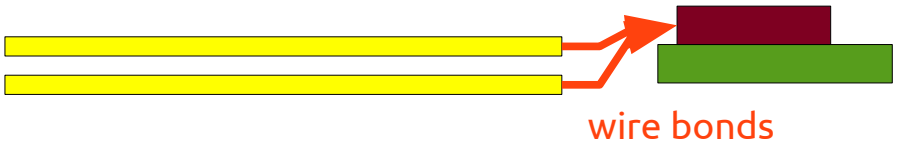

Thank you!

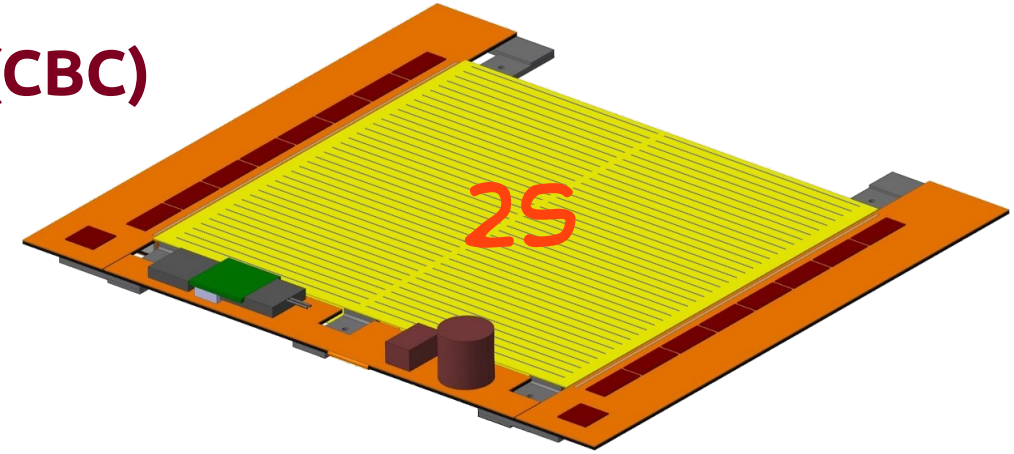
Module design

Only two module types

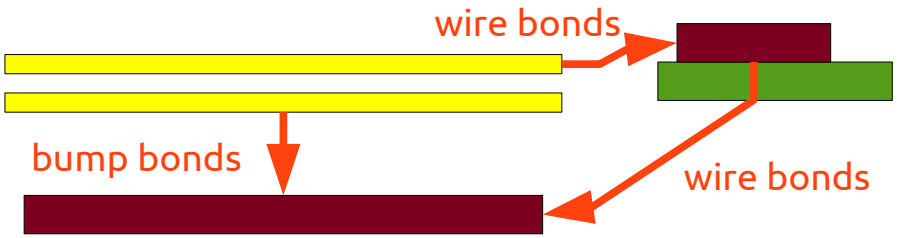
Hit correlation in different chips

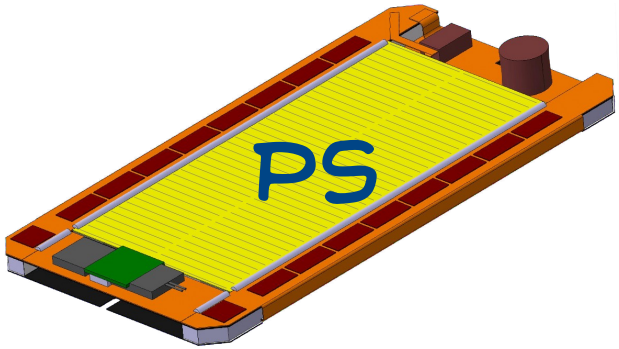
Cms Binary Chip (CBC)
strip readout
+ correlation





Readout only

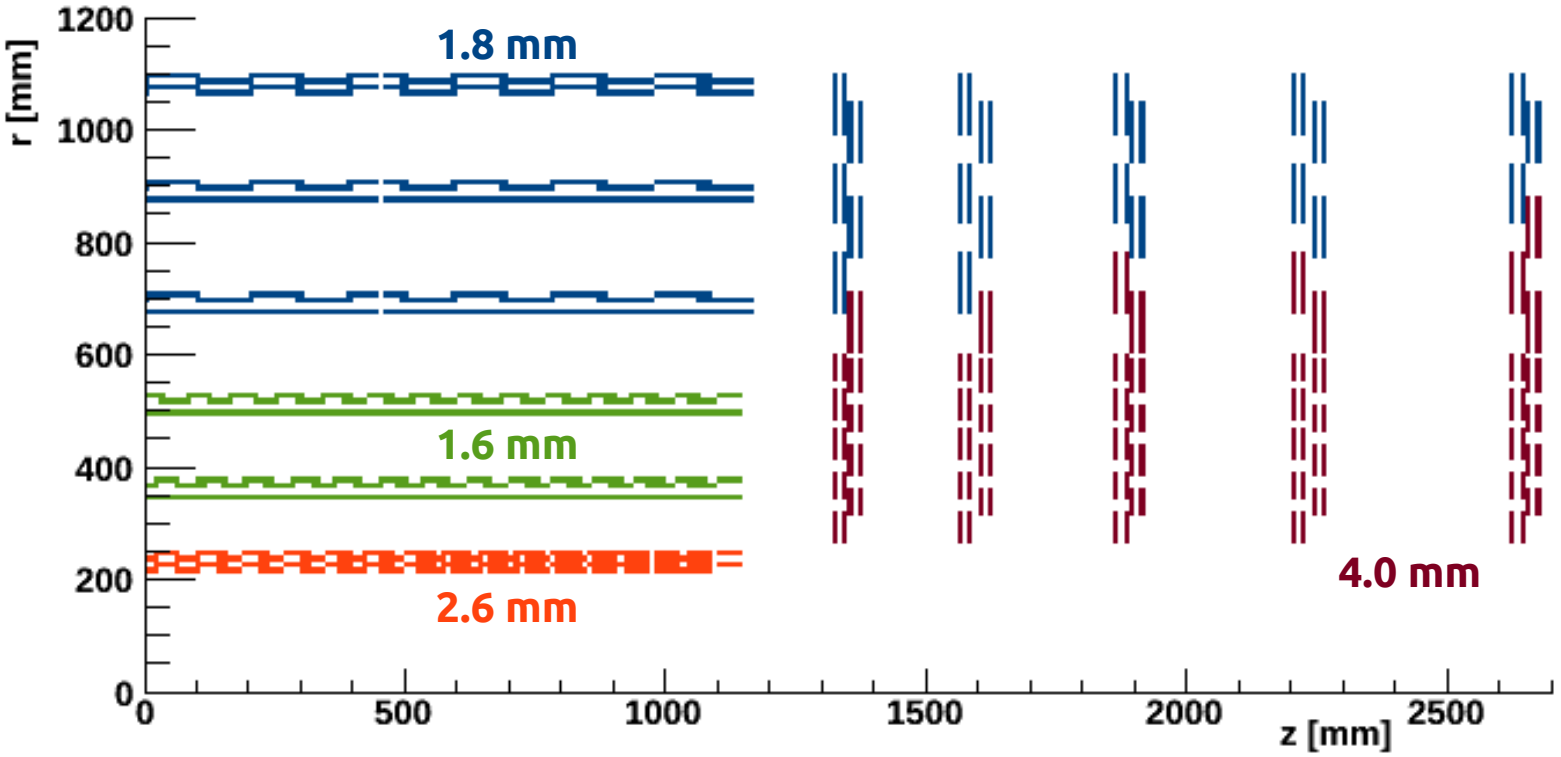




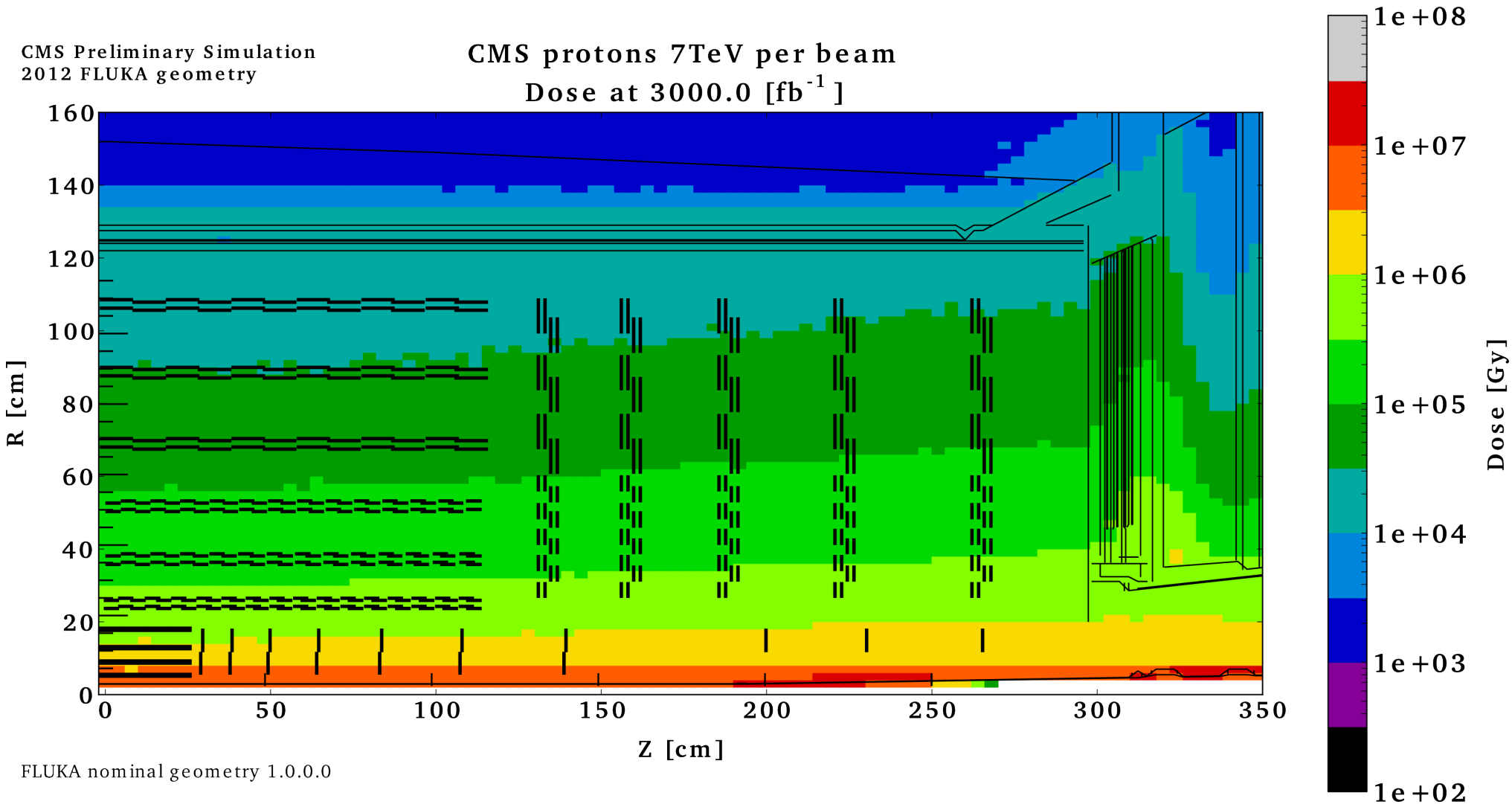
MacroPixel ASIC (MPA):
pixel readout
+ correlation

sensor spacing

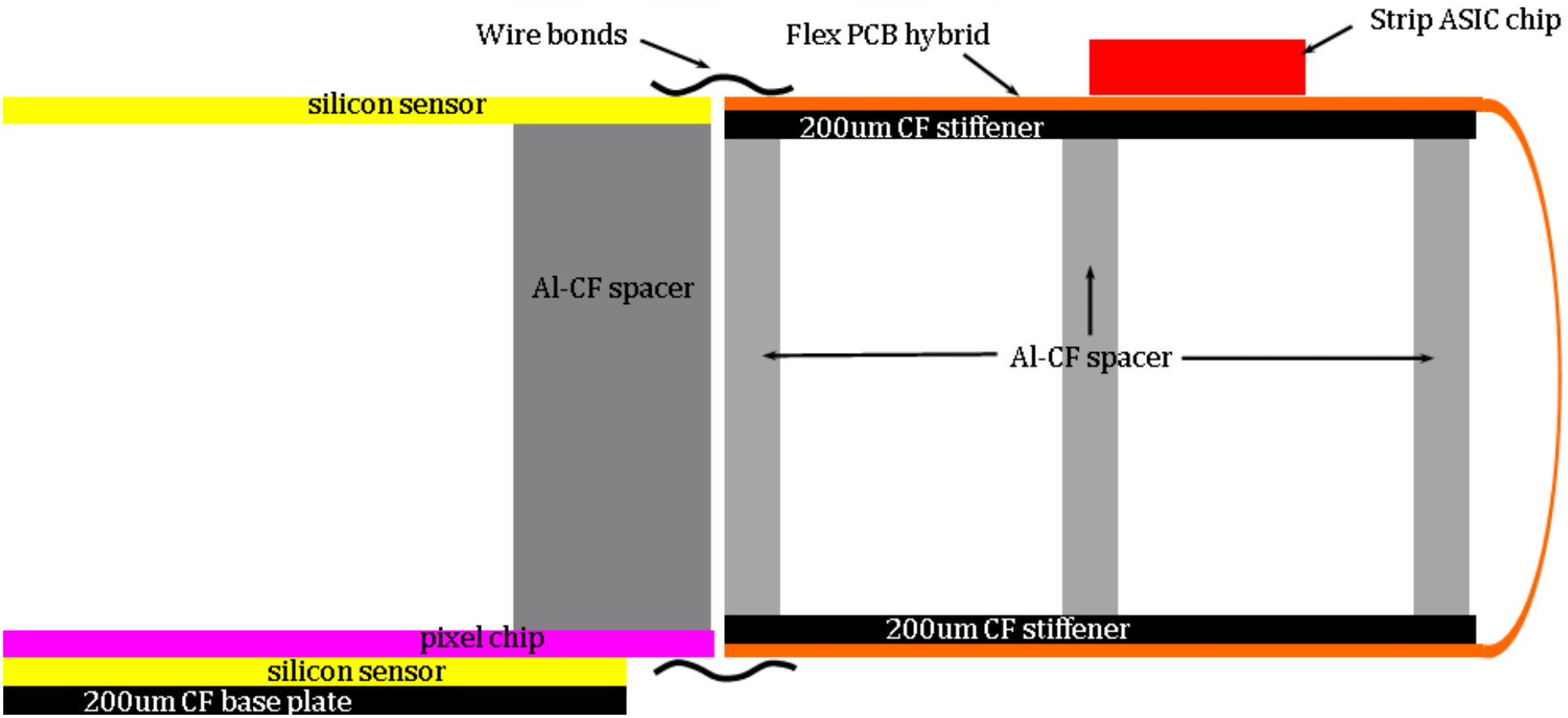
must be tuned along with search windows



Radiation map



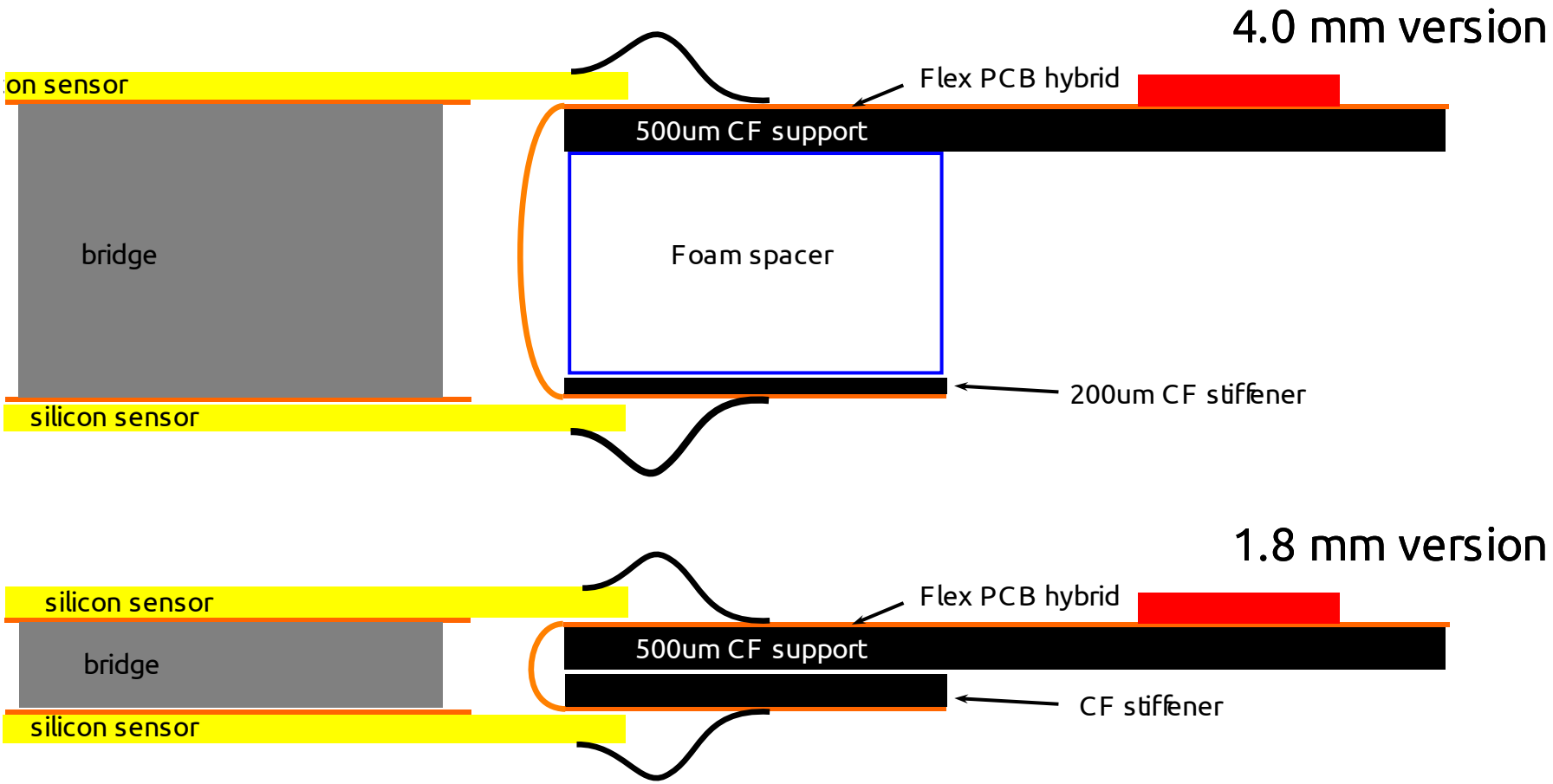
PS modules



Flex hybrid:

- Technology leap
- Key element for 2-sensor design

2S modules



Flex hybrid:

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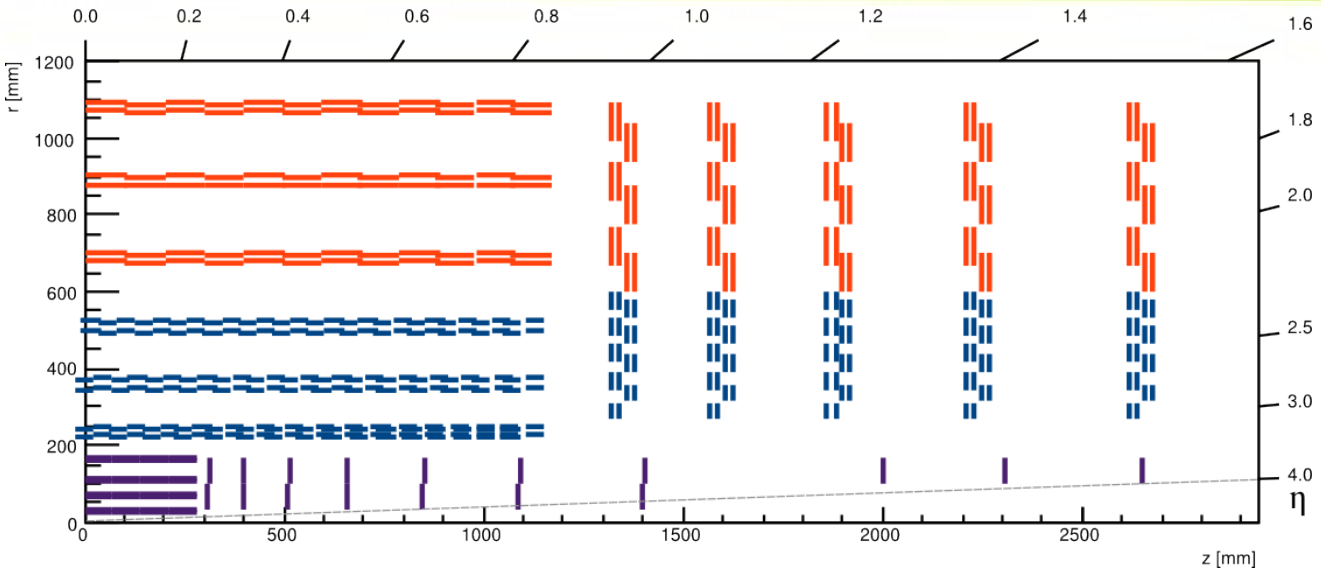
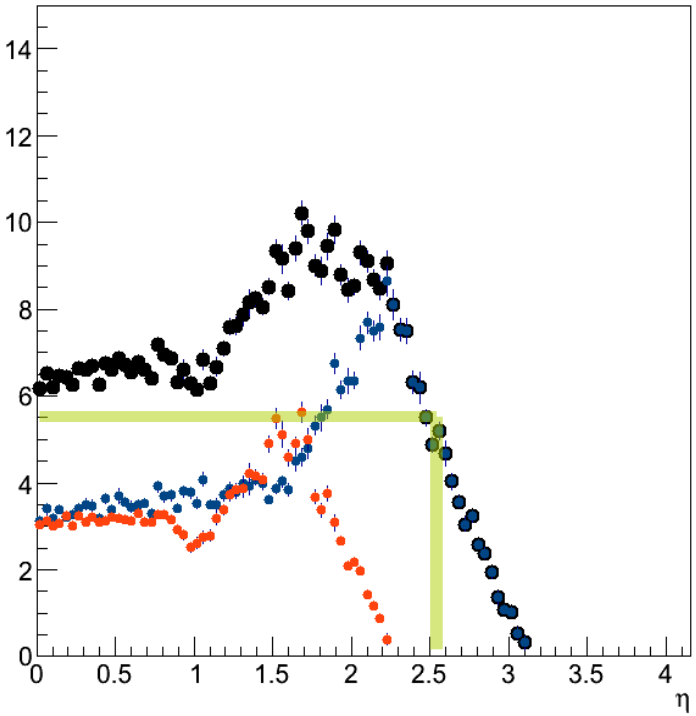
Layout
Current baseline

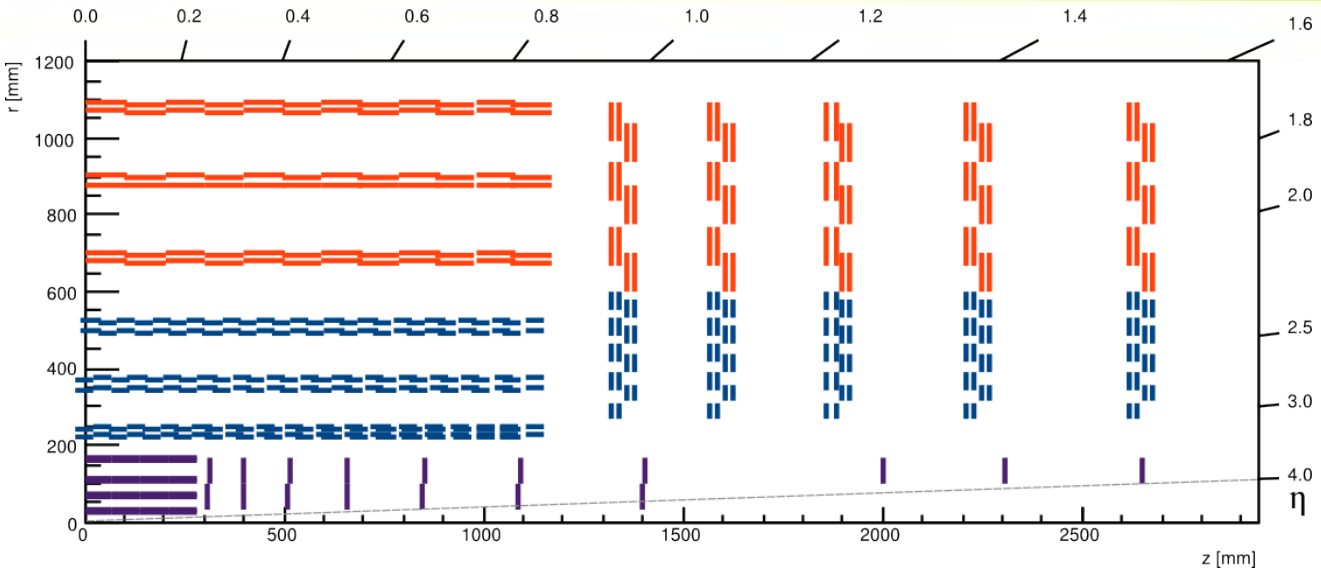


10 trigger hits → η=2.5

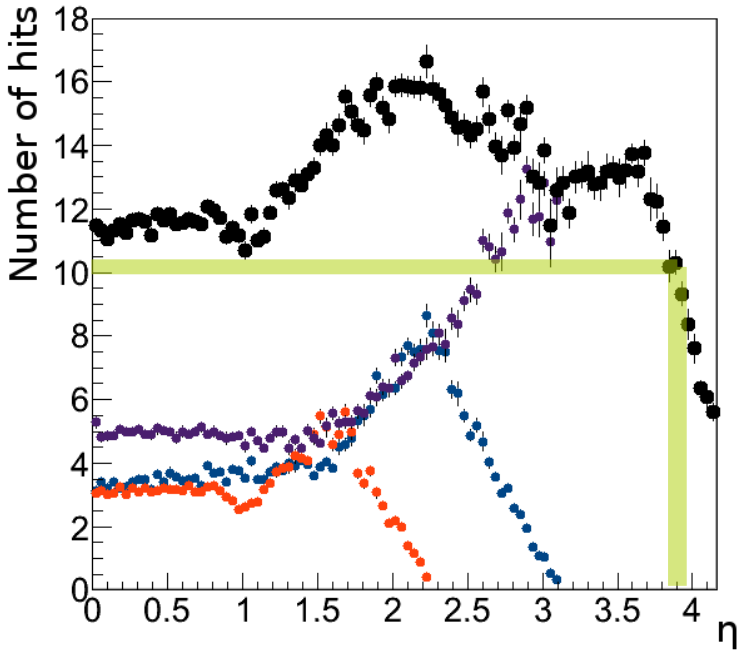


- **×4 granularity** in strip sensors
- +3 layers of MacroPixel sensors
  - Unambiguous **3D coordinates** helps track finding in high pile-up
- Up to **10 points** available for track-trigger up to η=2.5
  - Comparable to current tracker's coverage, **but at L1**

Layout
Current baseline



Hit coverage → η≈4



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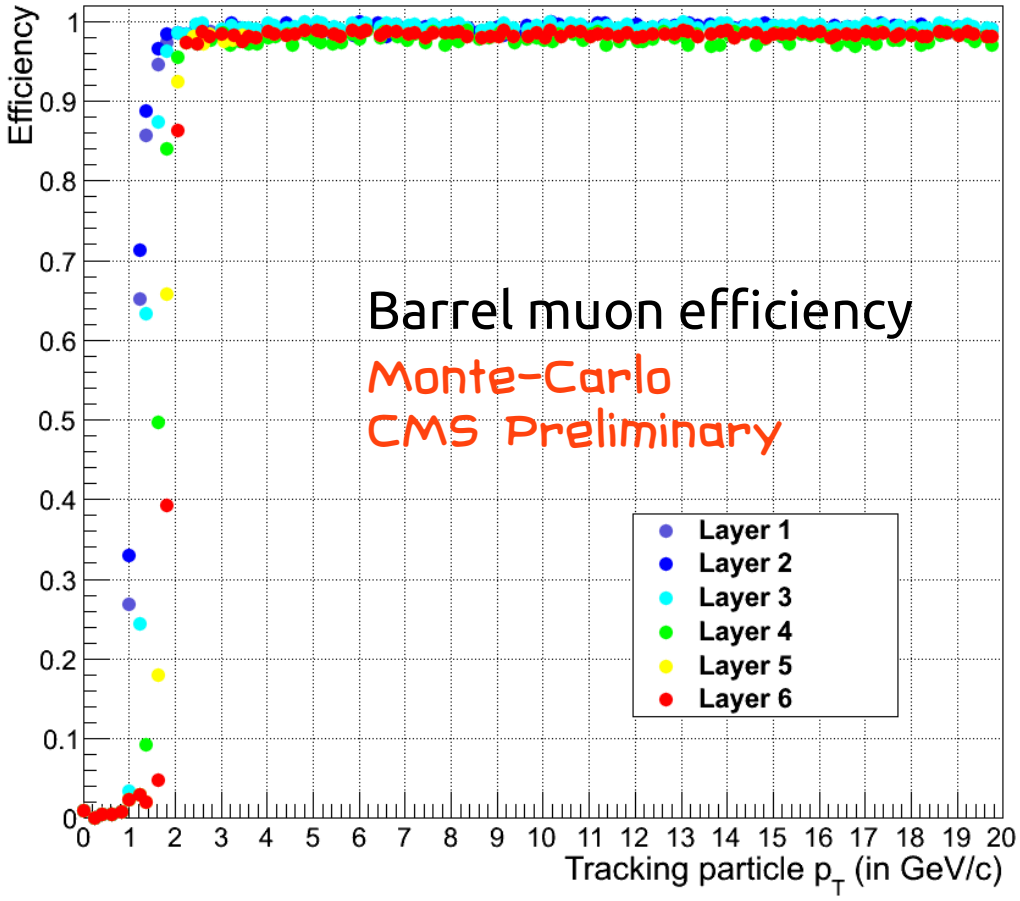
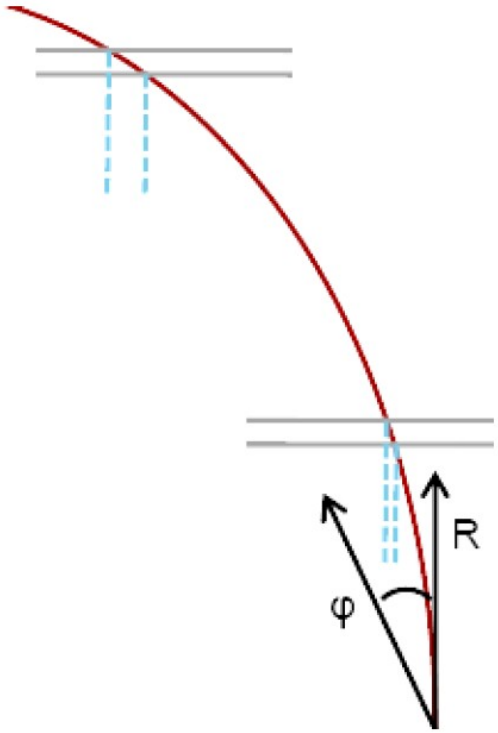
- Up to **10 points** available for track-trigger up to η=2.5
  - Comparable to current tracker's coverage, **but at L1**
- Hit coverage up to **η≈4** at L1A

Uniform cut

Possible, with tuning





(@construction) (@front-ends)

Need to tune **sensor spacings** and **hit matching windows** are required to maintain uniform p_T cut

pT modules

Providing "stubs" for tracking trigger

Need to ship hits off detector

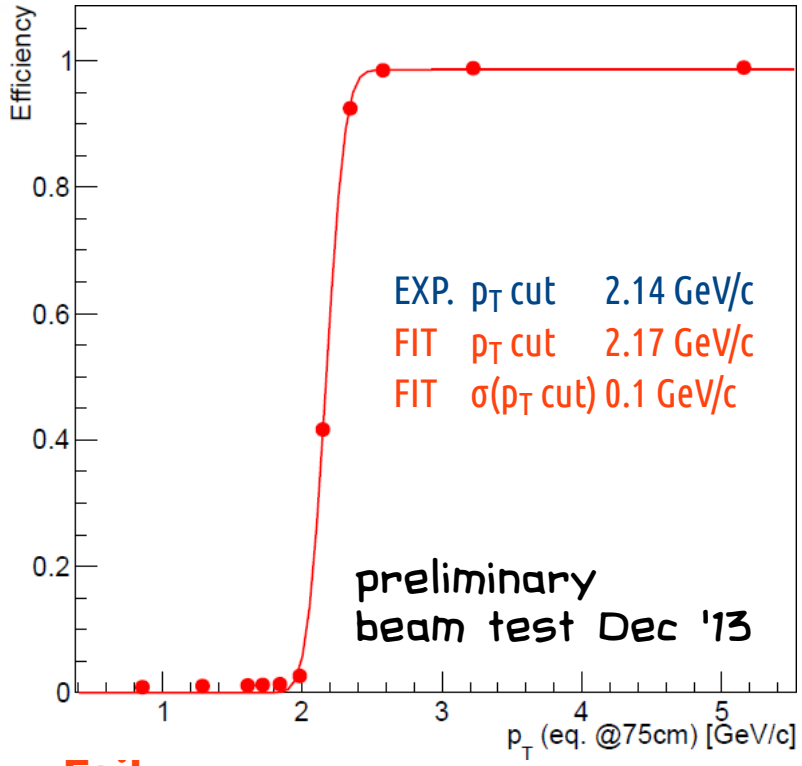
Ship all hits @ 40 MHz? No

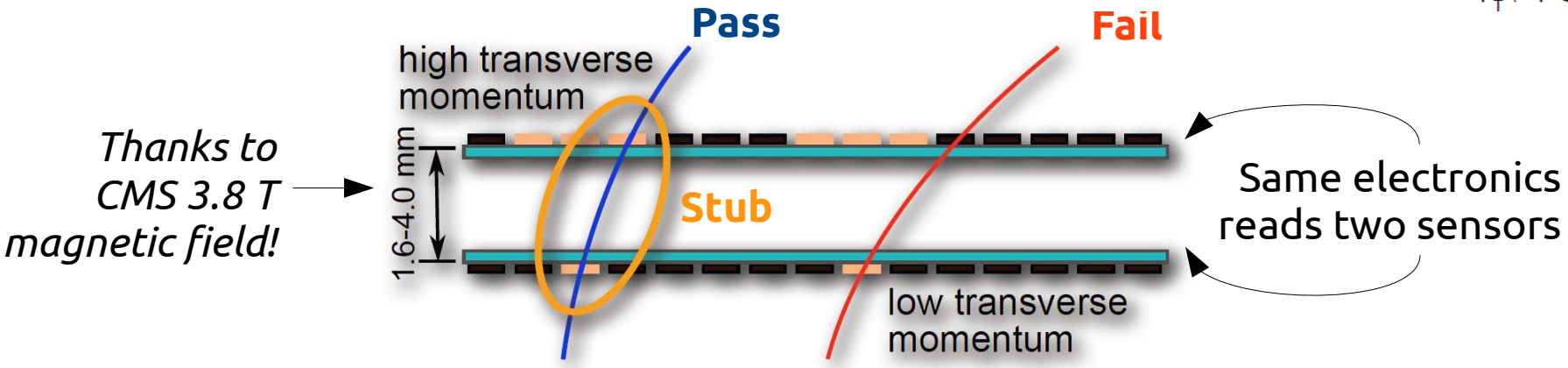
- Bandwidth needed: off by 1 order of magnitude (order of 10 Gbps per module)
- Track reconstruction ~ impossible

Solution: ship only high-pT hits (stubs)

- Threshold of ~ 2 GeV
- Data reduction of one order of magnitude or more

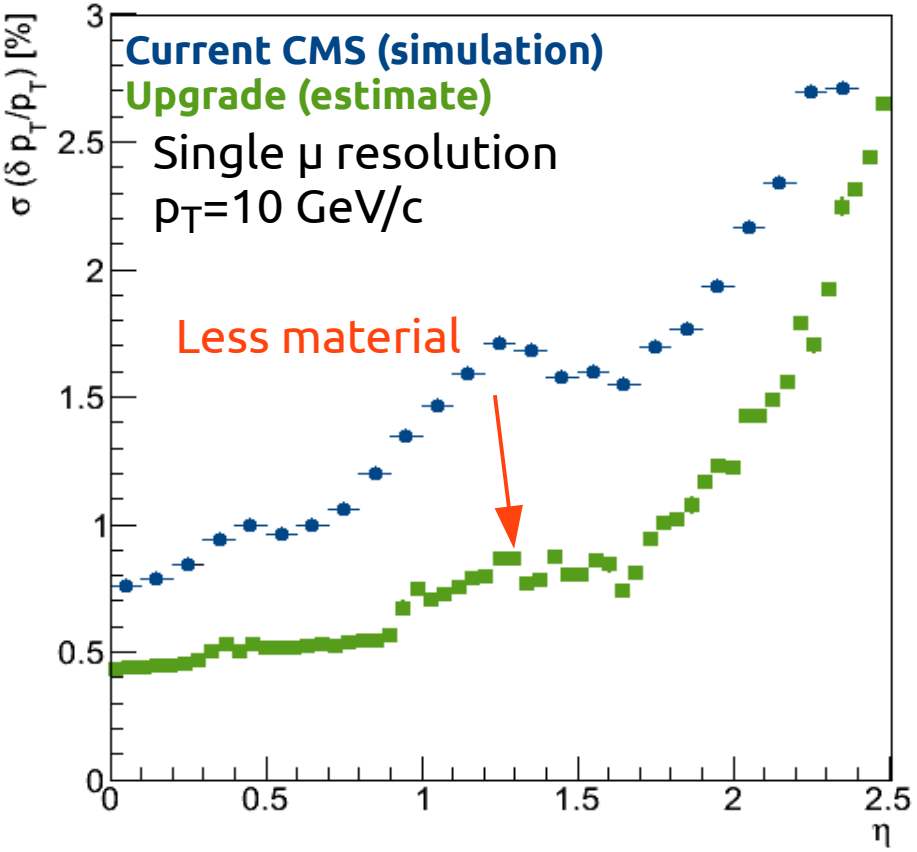
Modules with pT discrimination ("pT modules")

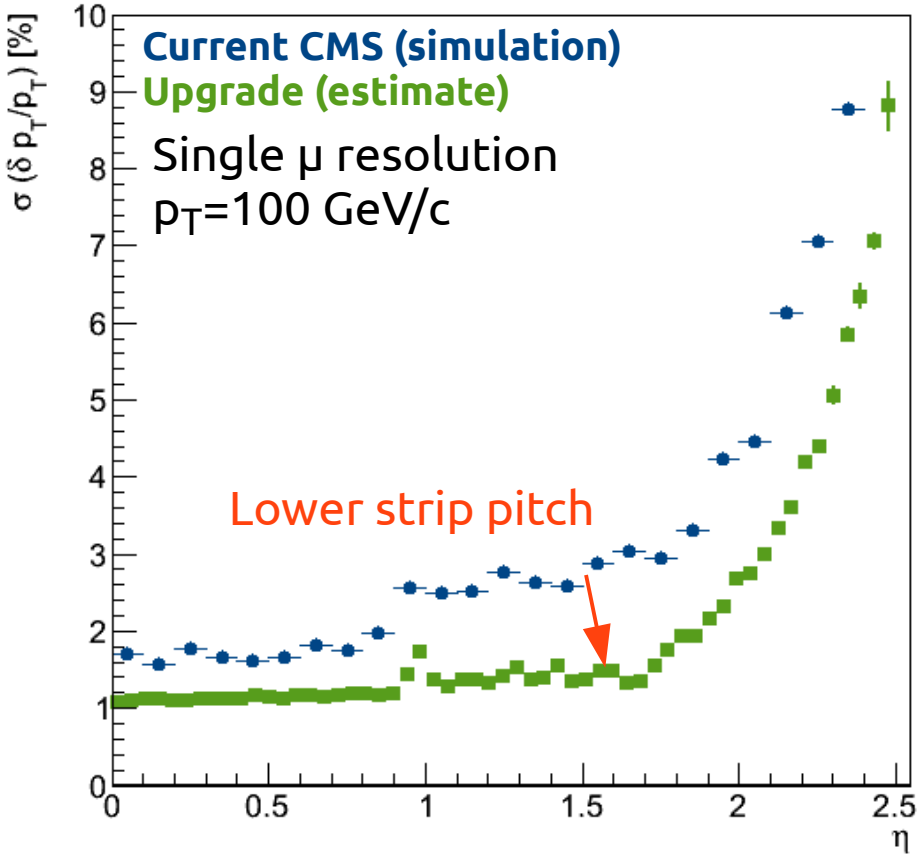




Tracking resolution

pT resolution of single muons





Clear improvement expected in the whole pT range

Track-trigger resolution

A small digression

The difference in z0 resolution derives from the sensitive element orientation leading to a tighter constraint on the track direction