

TKLAYOUT, A TOOL FOR CMS TRACKER DESIGN

Coffee seminar

Stefano MARTINA

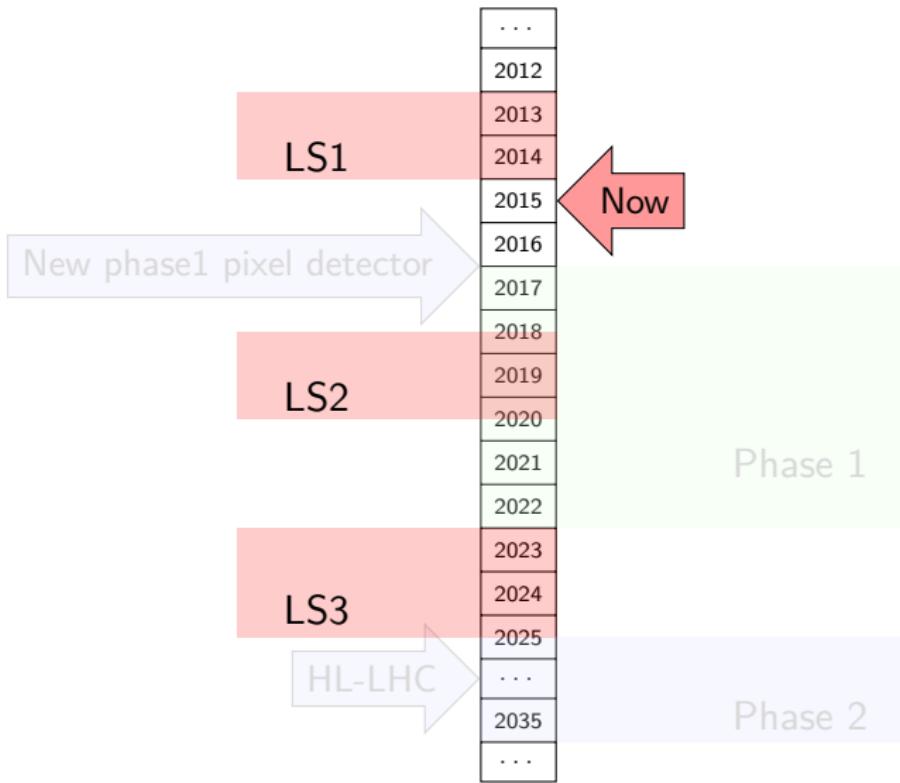
stefano.martina@cern.ch

European Organization for Nuclear Research

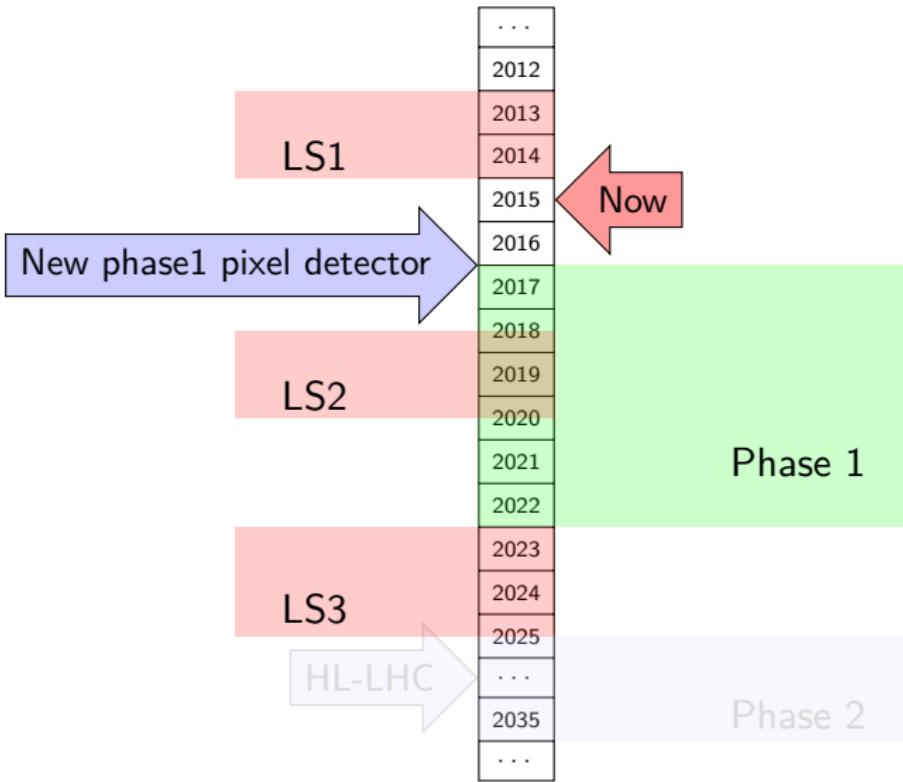


March 27, 2015

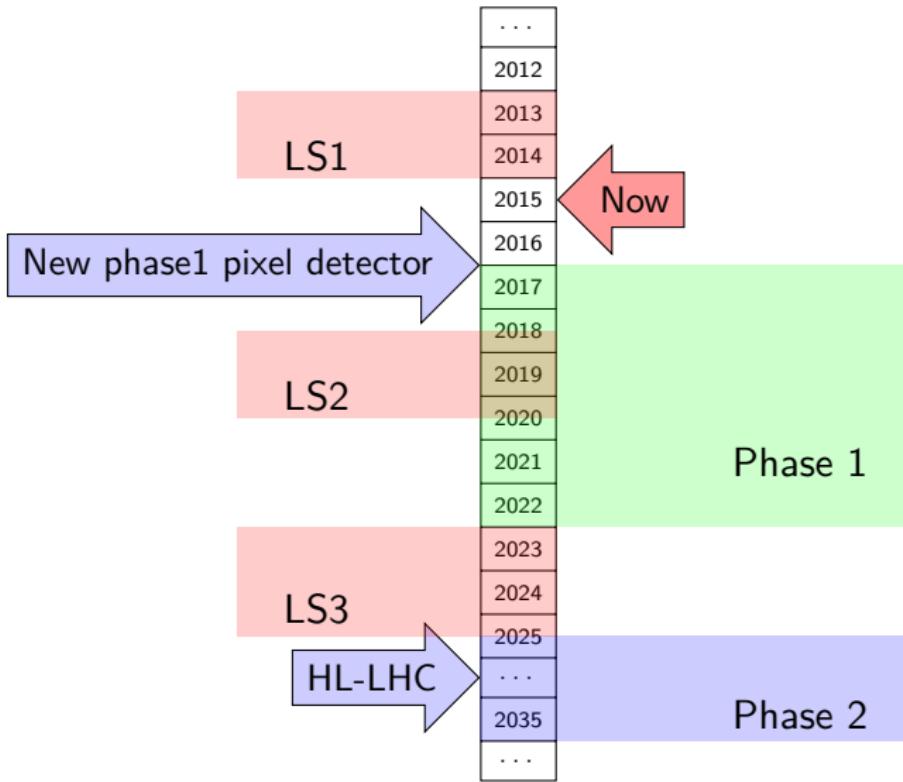
Timeline



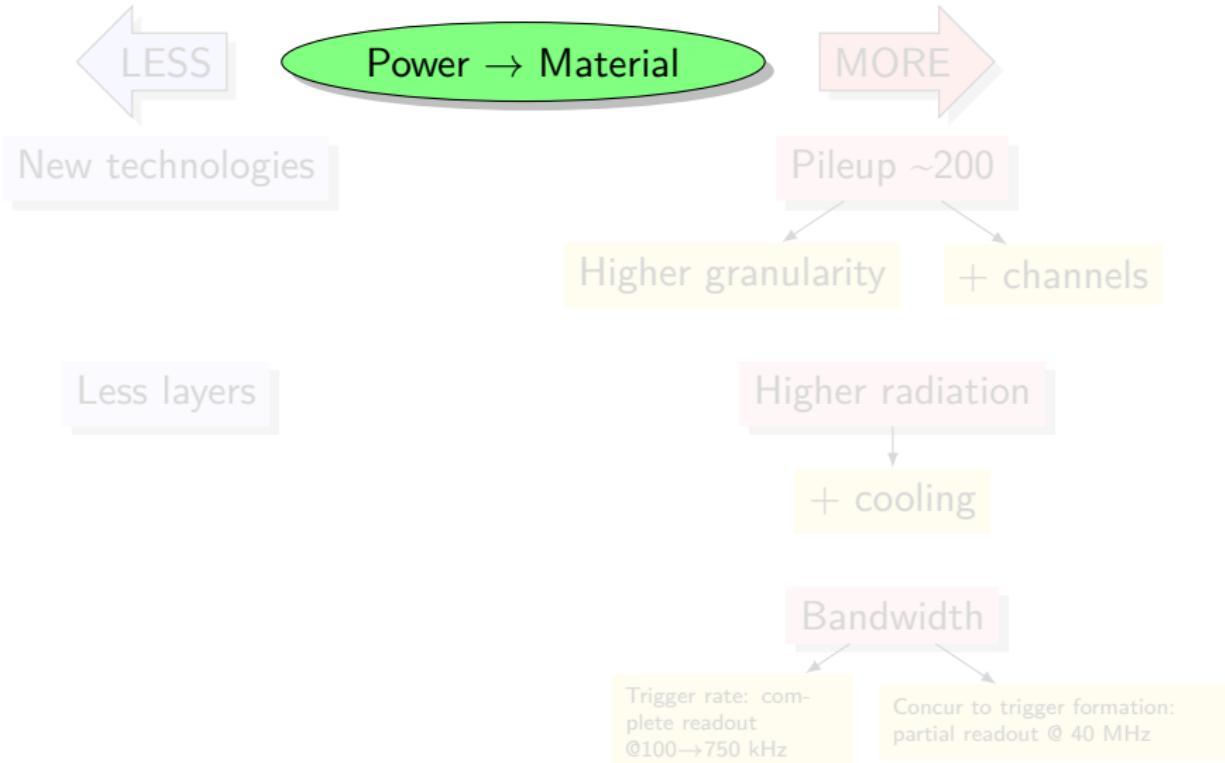
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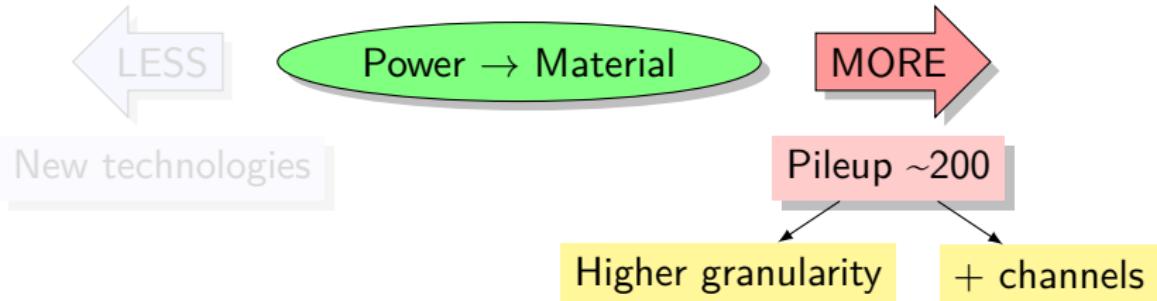
Timeline



Tracker design: material budget



Tracker design: material budget



Less layers

Higher radiation

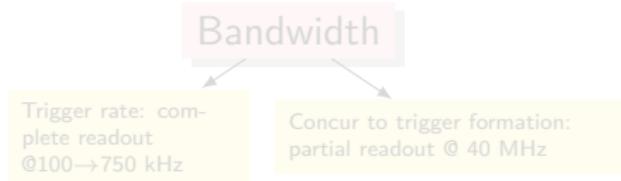
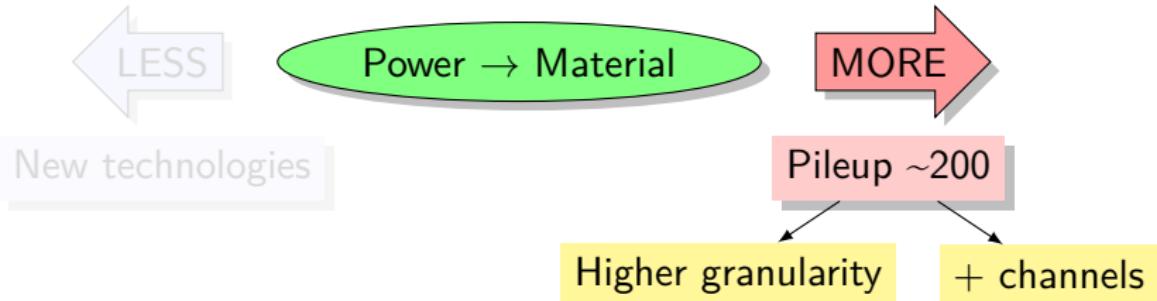
+ cooling

Bandwidth

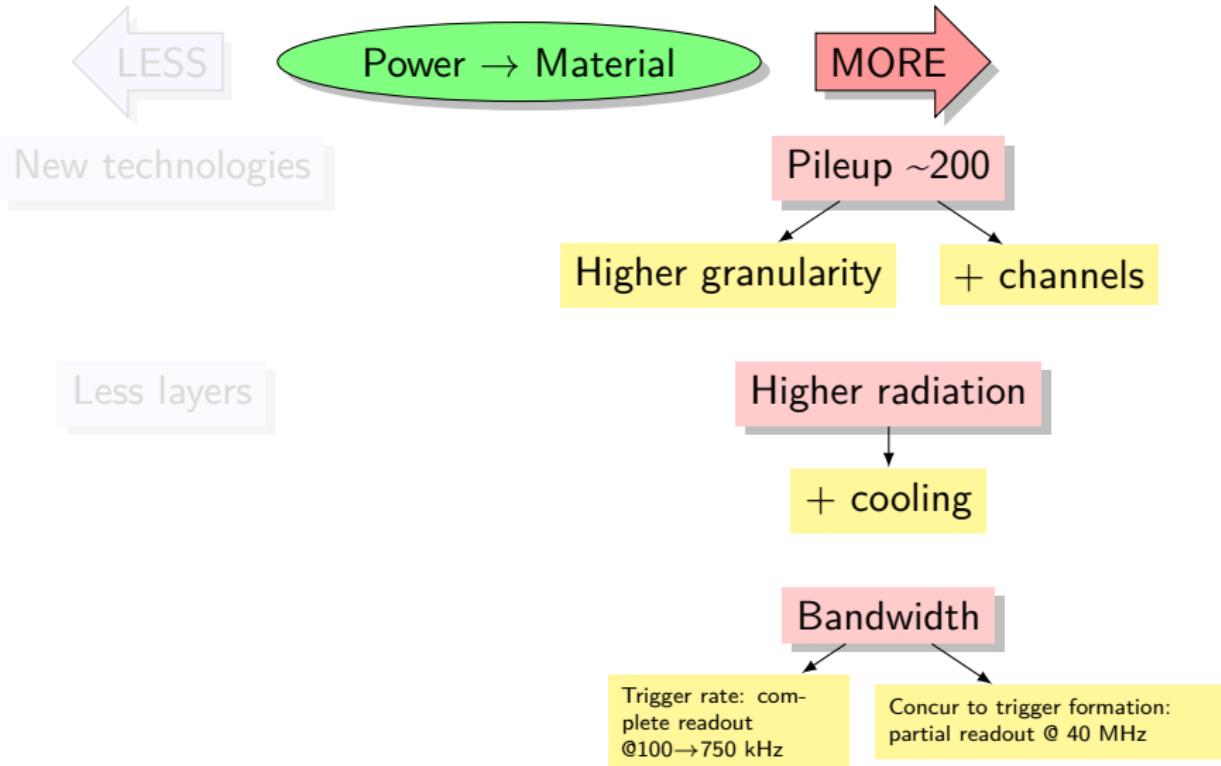
Trigger rate: complete readout @100→750 kHz

Concur to trigger formation: partial readout @ 40 MHz

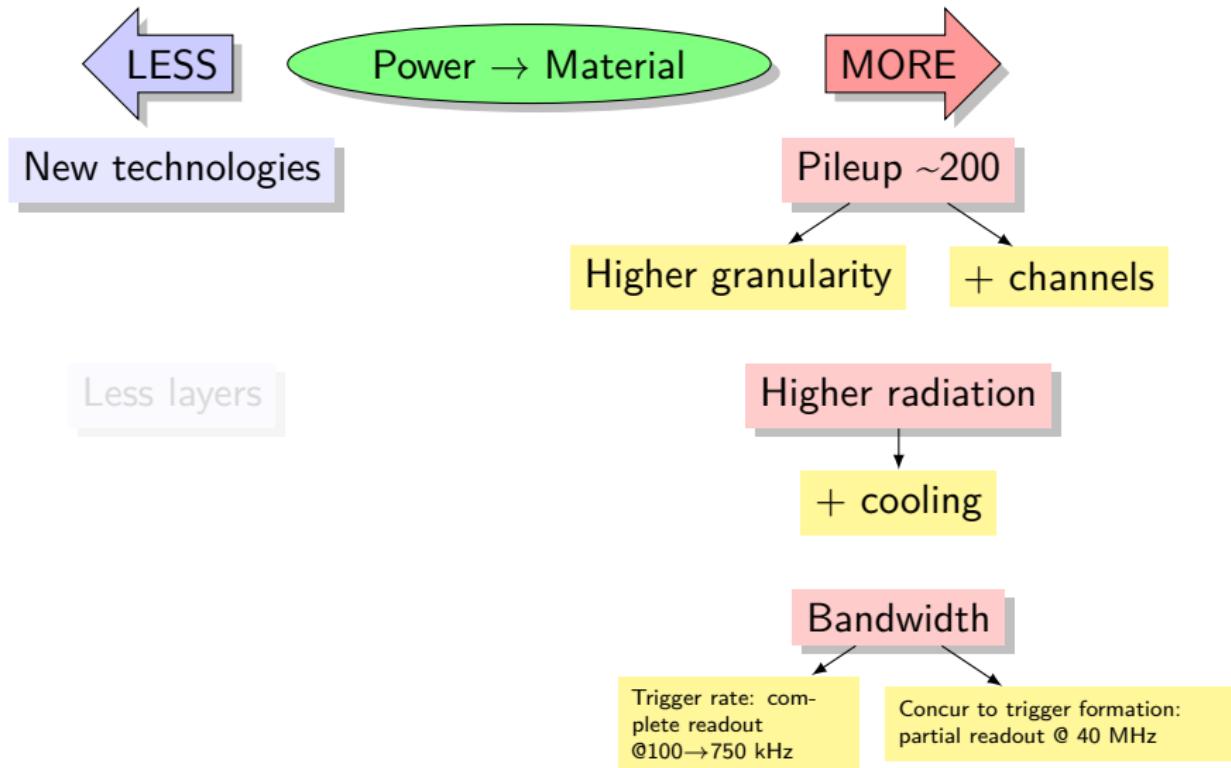
Tracker design: material budget



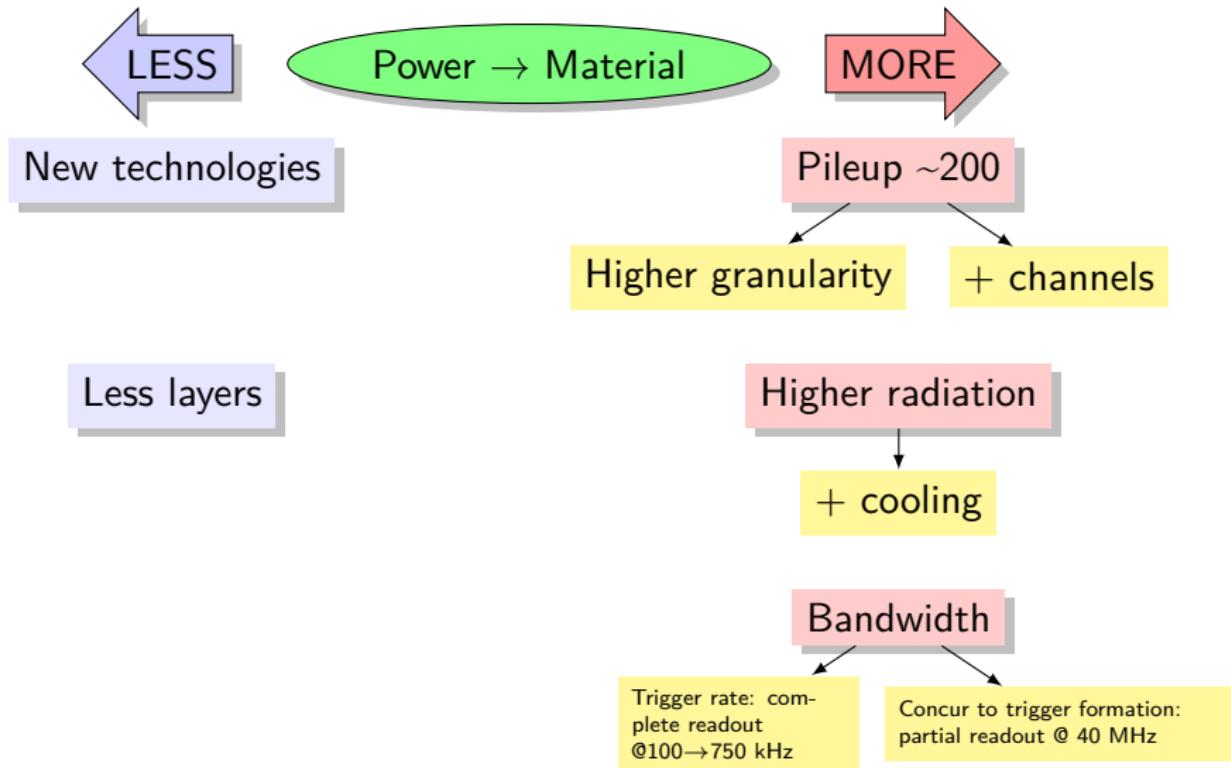
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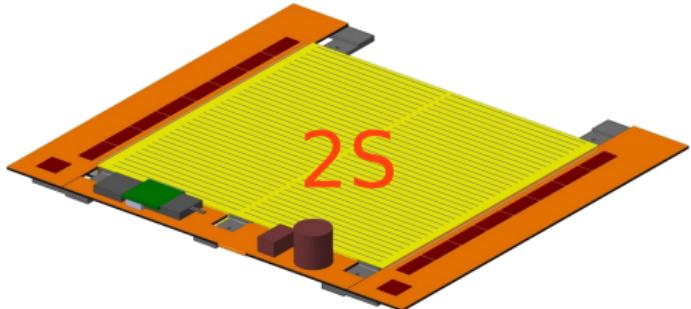
Modules

Outer Tracker

2 Strip sensors

Strips: $5\text{ cm} \times 90\text{ }\mu\text{m}$

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Outer Tracker

Pixel + Strip sensors

Strips: $2.5\text{ cm} \times 100\text{ }\mu\text{m}$

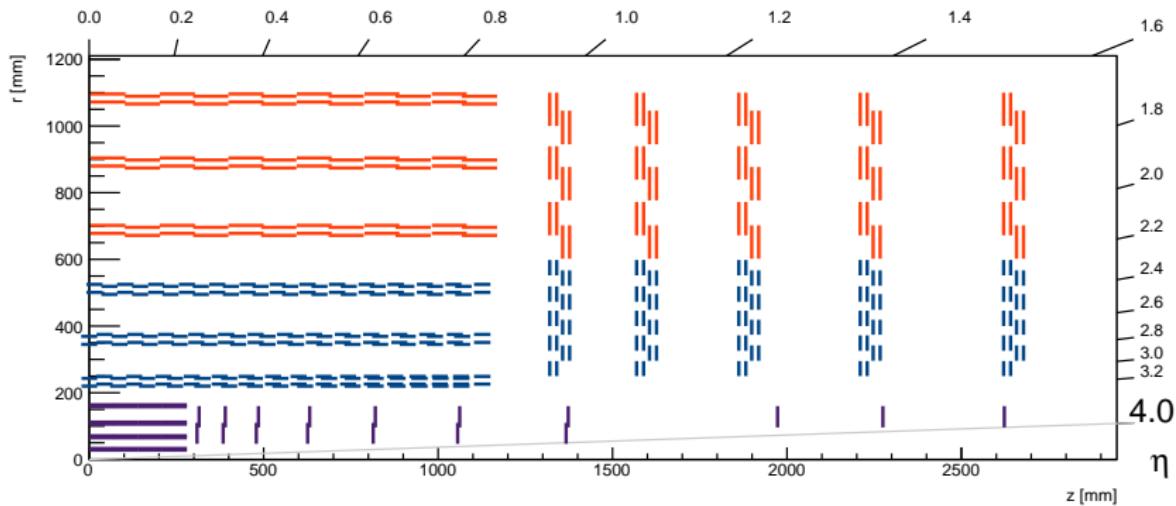
MacroPixels: $1.5\text{ mm} \times 100\text{ }\mu\text{m}$



Pixel

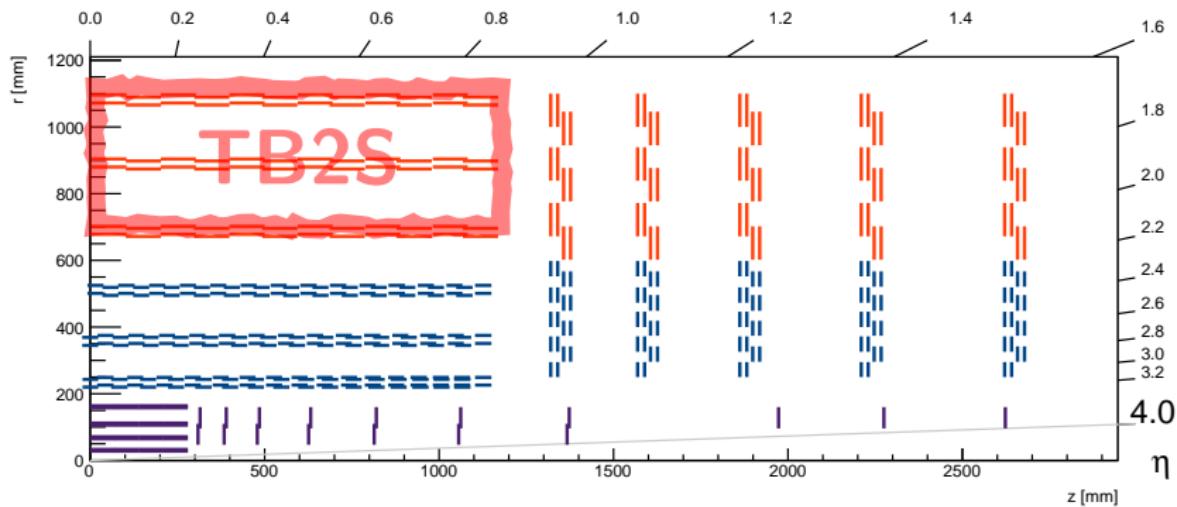


Tracker layout



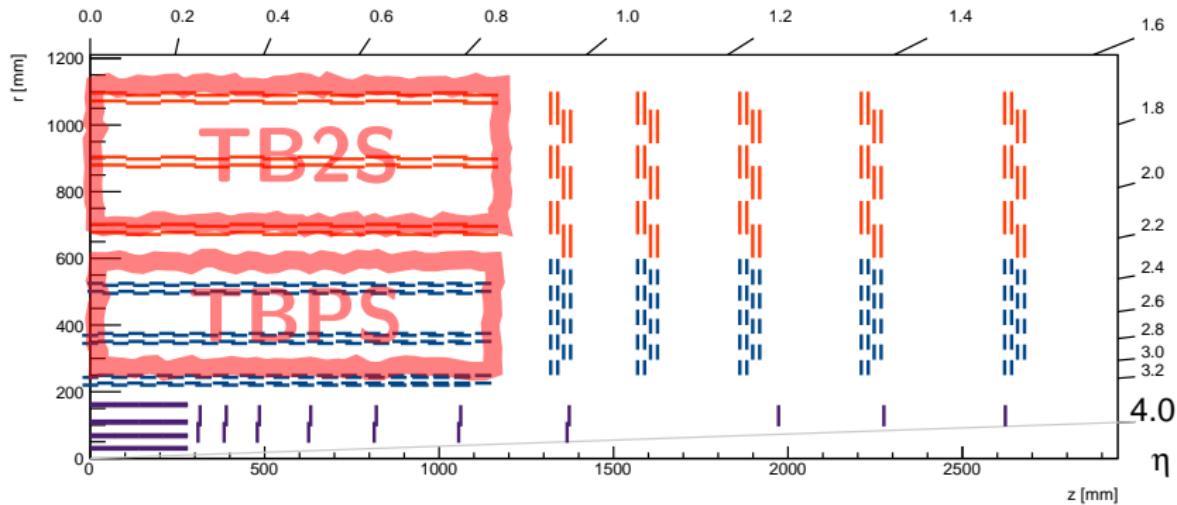
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- ✓ Tracker Barrel PS
- ✓ Tracker Endcap Double Disk
- ✓ Pixel barrel and endcap $\eta \rightarrow 4$

Tracker layout



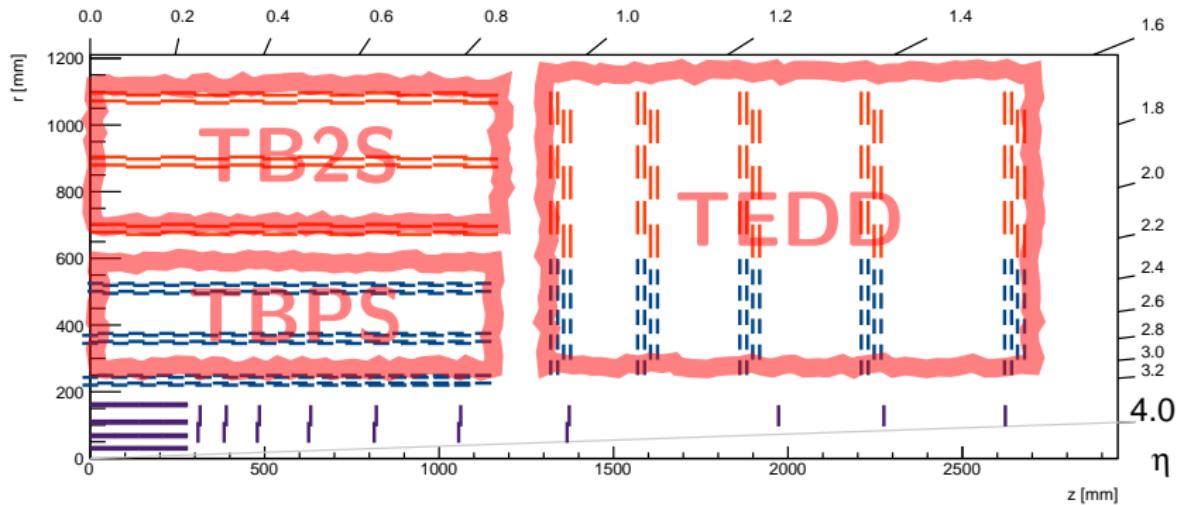
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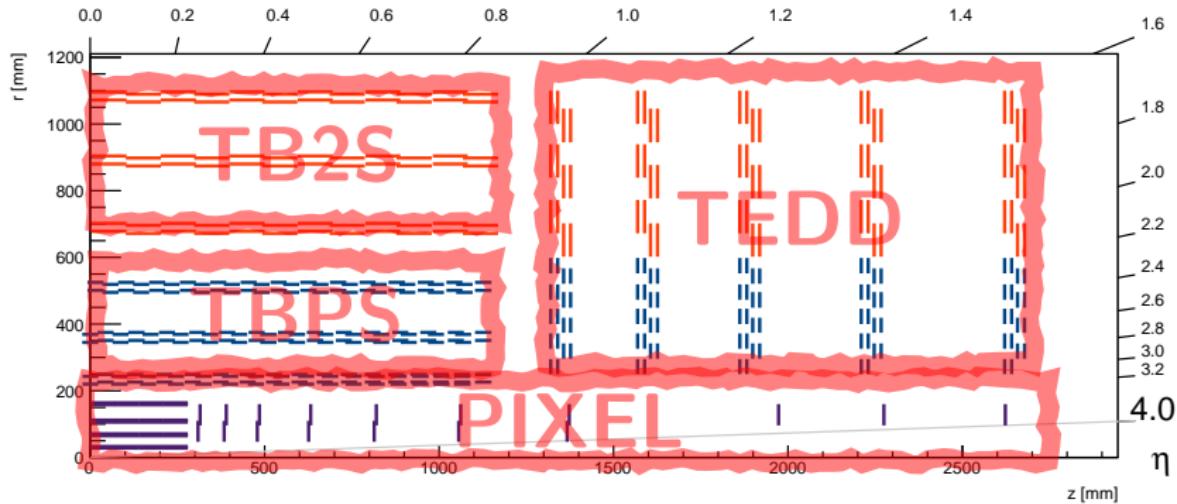
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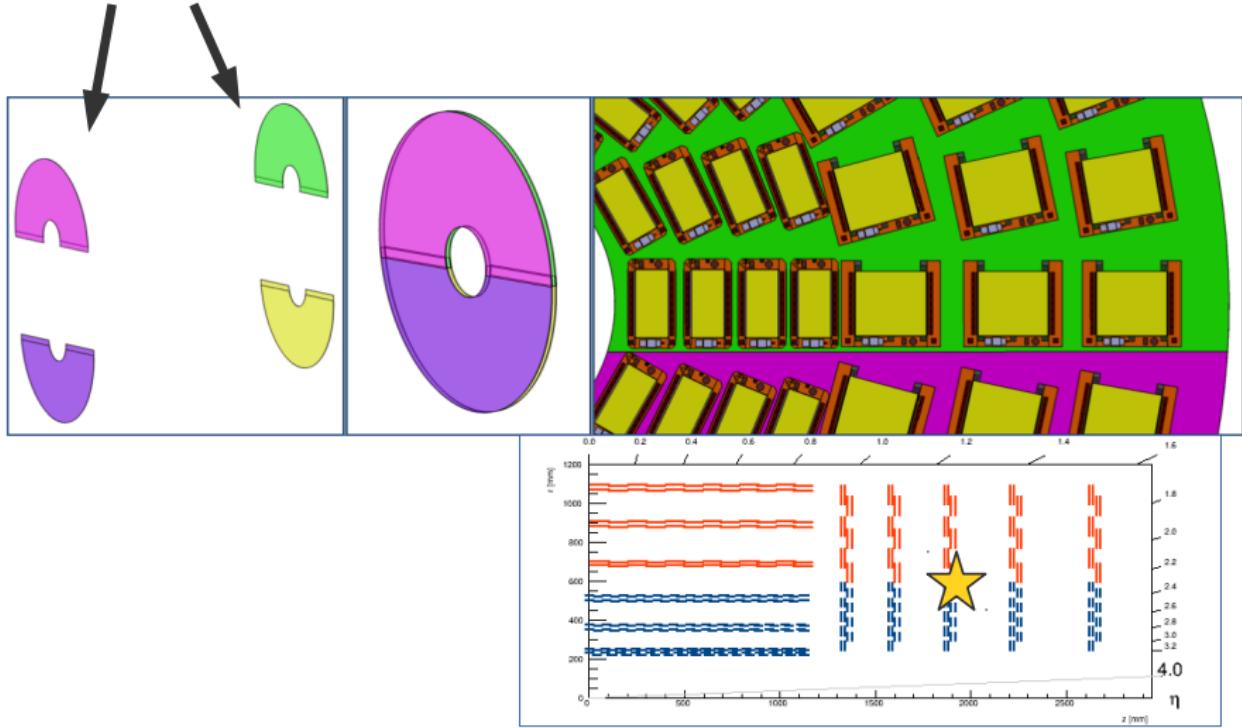
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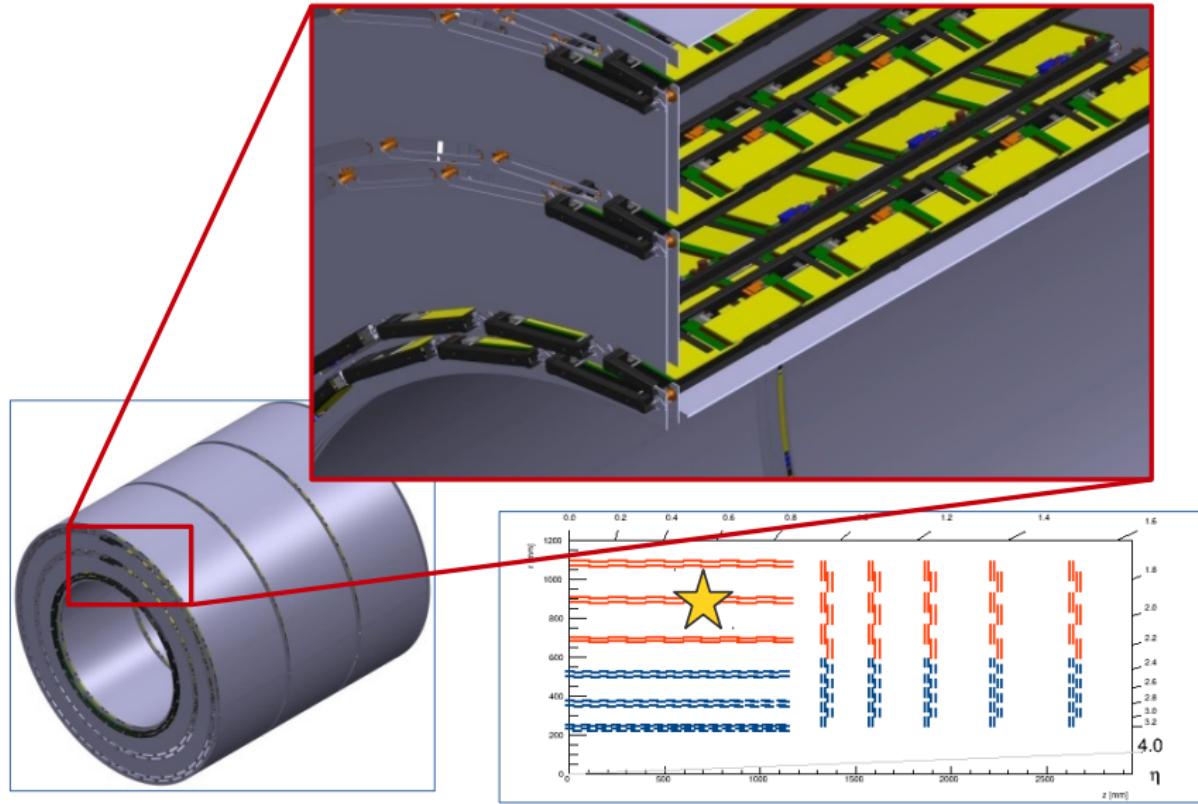
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TEDD mechanics (2S & PS)

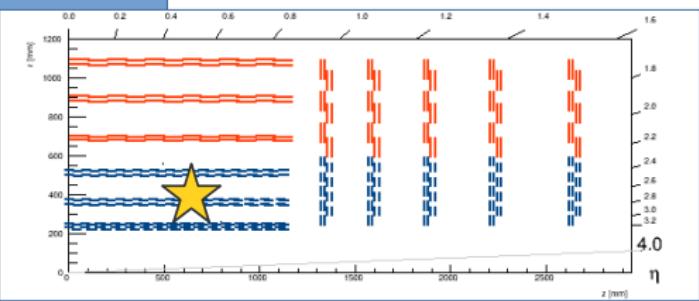
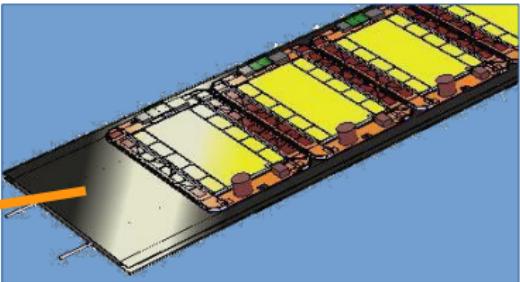
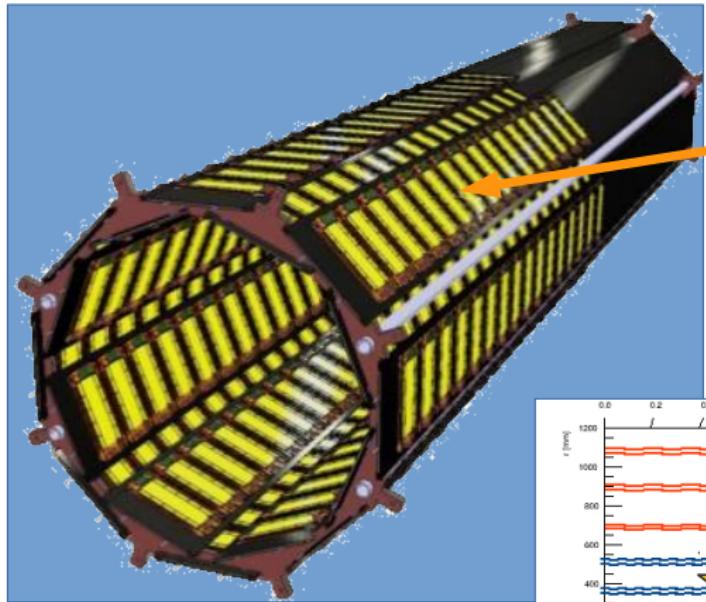
Double disks



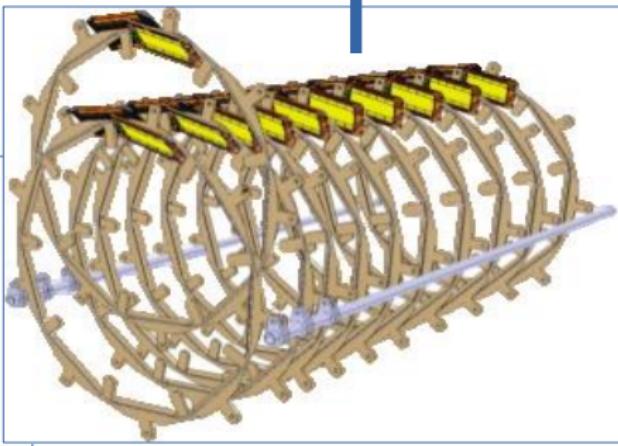
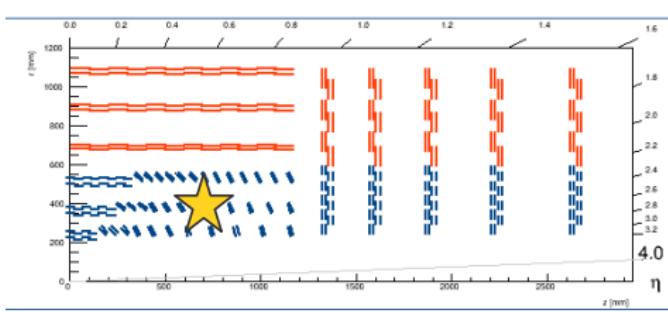
TB2S mechanics (2S)



TBPS mechanics (PS)



TBPS mechanics alternative



Target

- ✓ Evaluate material amount (aim to a lighter tracker with respect to the current one)
- ✓ Evaluate tracking performance

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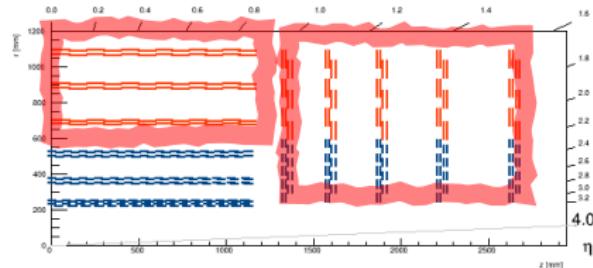
- ✓ We know how to build **modules** for outer
- ✓ not yet for pixel
- ✓ we have a fairly **stable** design for the **TB2S** and **TEDD**
- ✓ we have two **competing** concepts for the **TBPS**
- ✓ the **pixel** detector design is much less detailed

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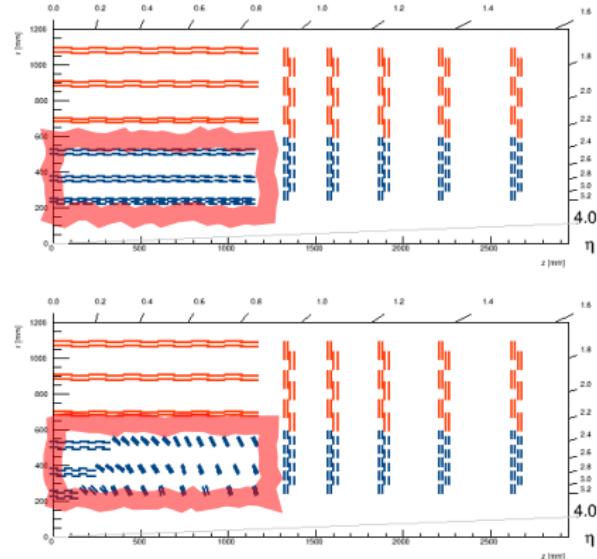
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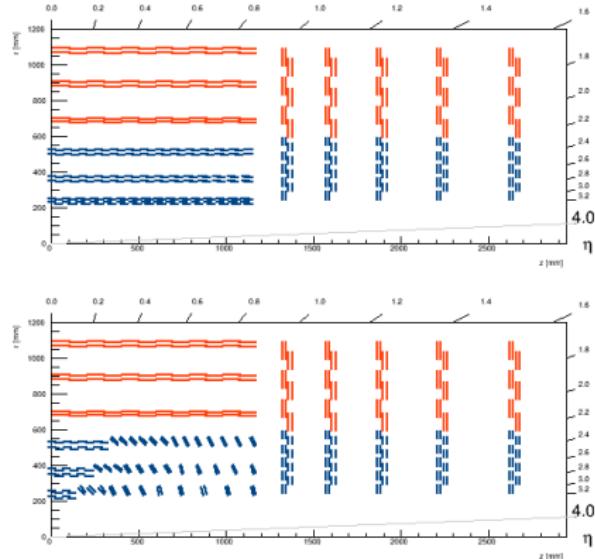
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1. in order to **study** the **pixel** detector a more **detailed** radiation **map** of the inner region was needed, along with a coarser, but wider radiation map for the outer tracker
2. the **tilted** barrel option offers an attractive **reduction** of number of **modules** needed (less material and lower cost), at the potential expense of **z0 resolution** in the trigger readout (comparative study needed)
3. **material** from **pixel** detector **effect** on tracking resolution is to be quantified

Solution

- 1 → more **flexible** input of **FLUKA** radiation maps into **tkLayout**
- 2,3 → completely **rework** the model of **material** (see later)

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TkLayout main features

- ✓ generate detailed **geometry**
- ✓ predict **material** distribution and effects
- ✓ predict **resolution**
- ✓ generate **CMSSW** input files for simulation (XML with geometry)

Using

- ✓ error **propagation**
- ✓ **not** use simulations
 - **fast** analysis

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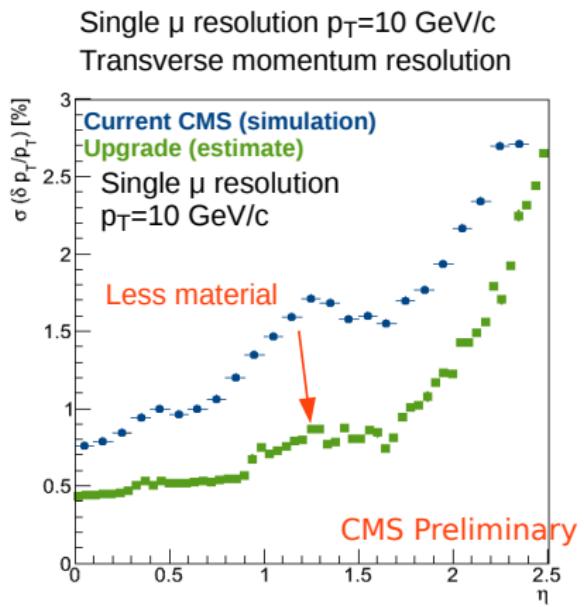
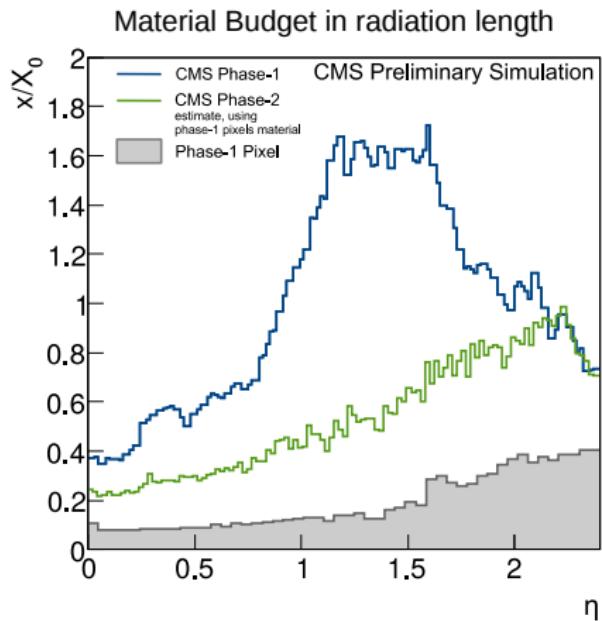
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Importance of material

- ✓ material is important for determine the **resolution** of phase2 tracker



.../geometries/Baseline2015

```
Tracker Outer {
    @include Baseline2015_SupportsTracker.cfg

    // Layout construction parameters
    zError 70
    bigDelta 12
    zOverlap 1
    phiOverlap 1
    etaCut 10
    barrelRotation 1.57079632679
    smallParity 1

    trackingTags trigger,tracker

    Barrel TBPS {
        @include Baseline2015_SupportsBarrelTBPS.cfg
        Layer 1 { smallDelta 3.65 }
        Layer 2,3 { smallDelta 3.15 }
        numLayers 3
        maxZ 1150
        startZMode modulecenter
        innerRadius 230
        outerRadius 508 // 509 or 540
        width 96
        length 46.26
        physicalLength 71
        phiSegments 2
    }
    ...
}
```

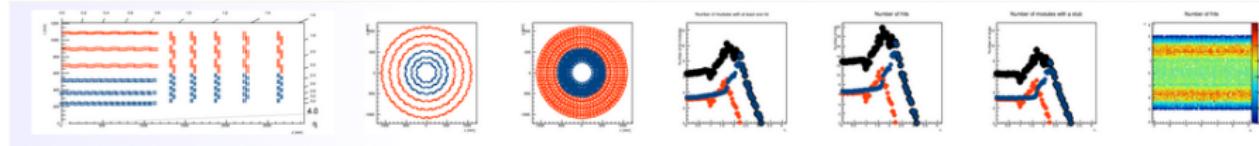
Geometry

layers and disks

| Layer | 1 | 2 | 3 | 1 | 2 | 3 | Total | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|---------|---------|---------|---------|---------|---------|---------|----------|----------|
| r | 686.000 | 887.901 | 1080.000 | 230.000 | 357.368 | 508.000 | | | | | | | | | |
| z_max | 1169.445 | 1169.445 | 1169.445 | 1150.000 | 1150.000 | 1150.000 | | | | | | | | | |
| # mod | 1152 | 1488 | 1824 | 1008 | 1320 | 1836 | 8628 | | | | | | | | |
| # rods | 48 | 62 | 76 | 16 | 24 | 34 | | | | | | | | | |
| Disk | 1 | 2 | 3 | 4 | 5 | Total | | | | | | | | | |
| z | 1349.445 | 1597.452 | 1891.039 | 2238.583 | 2650.000 | | | | | | | | | | |
| # mod | 680 | 680 | 680 | 680 | 680 | 6800 | | | | | | | | | |
| Ring | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| r_min | 245.559 | 292.723 | 323.197 | 370.867 | 397.703 | 447.368 | 470.641 | 519.273 | 550.565 | 600.567 | 670.515 | 775.849 | 838.158 | 944.543 | 999.500 |
| r_max | 291.819 | 338.983 | 369.457 | 417.127 | 443.963 | 493.628 | 516.901 | 565.533 | 596.825 | 701.067 | 771.015 | 876.349 | 938.658 | 1045.043 | 1100.000 |

modules

plots

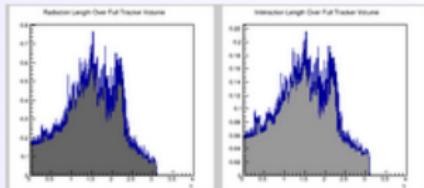


Material distribution 1D

1d overview

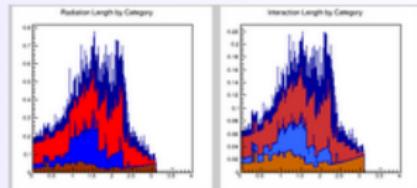
Average radiation length in full volume (eta = [0, 4.0]) 0.24597

Average interaction length in full volume (eta = [0, 4.0]) 0.07726



detailed

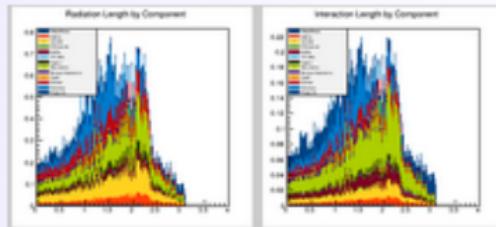
| | Average (eta = [0, 4.0]) Radiation length | Interaction length |
|----------|---|--------------------|
| modules | 0.16252 | 0.04678 |
| services | 0.05477 | 0.01454 |
| supports | 0.02868 | 0.01594 |



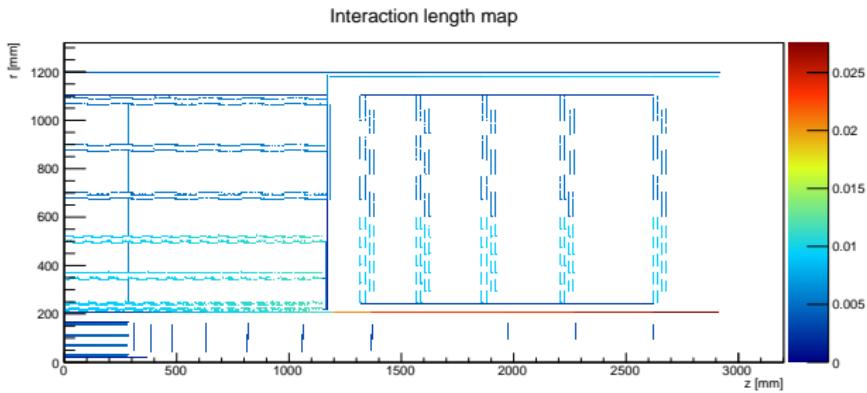
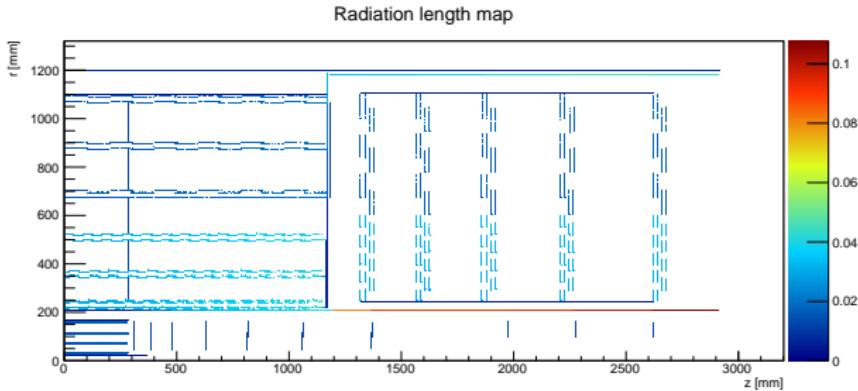
module components detail

Average ($\eta = [0, 4.0]$) Radiation length Interaction length

| | | |
|------------------|---------|---------|
| 2NaI SPairs | 0.00060 | 0.00013 |
| ASICs | 0.01356 | 0.00273 |
| DC/DC | 0.03593 | 0.00531 |
| FEHybrids | 0.00264 | 0.00056 |
| GBTs | 0.01014 | 0.00556 |
| HV tails | 0.00057 | 0.00027 |
| Hybrid | 0.01119 | 0.00238 |
| Mechanics | 0.04599 | 0.01959 |
| Module Mechanics | 0.00836 | 0.00343 |
| NaI S | 0.00293 | 0.00065 |
| Sensor | 0.03061 | 0.00616 |
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Material distribution 2D



My contribution to the project

✓ radiation maps

- import of FLUKA maps
- multiple maps possible
- more detail
- developed for pixel study

✓ new material model

- configuration files definition
- internal representation
- routing algorithm
- developed for tilted barrel and pixel study

✓ small bug-fix and improvements

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Irradiation maps

- ✓ Features in irradiation maps
 - Presence of an header with map properties
 - Presence of multiple maps with different resolutions and size
- ✓ Values are read and interpreted directly from the header
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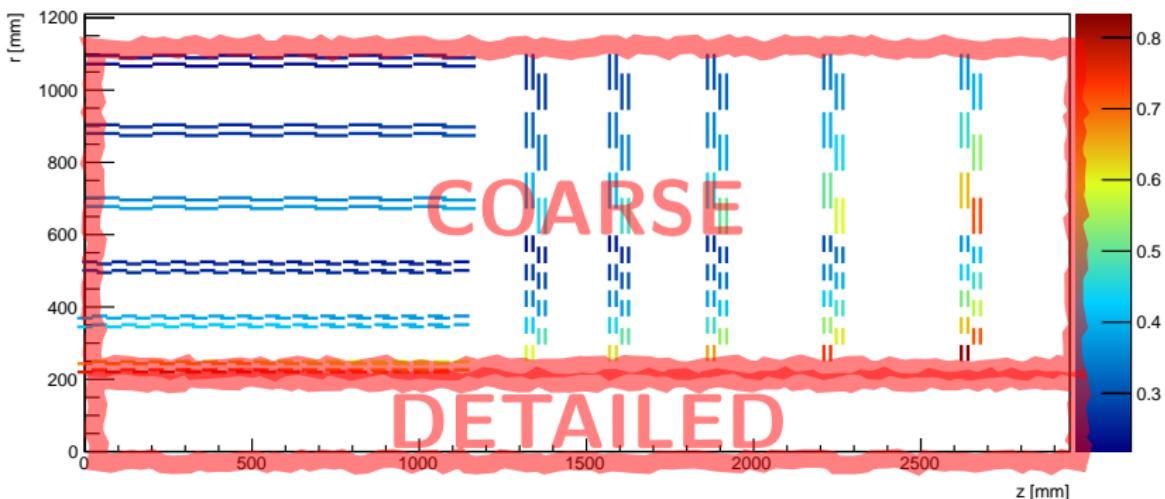
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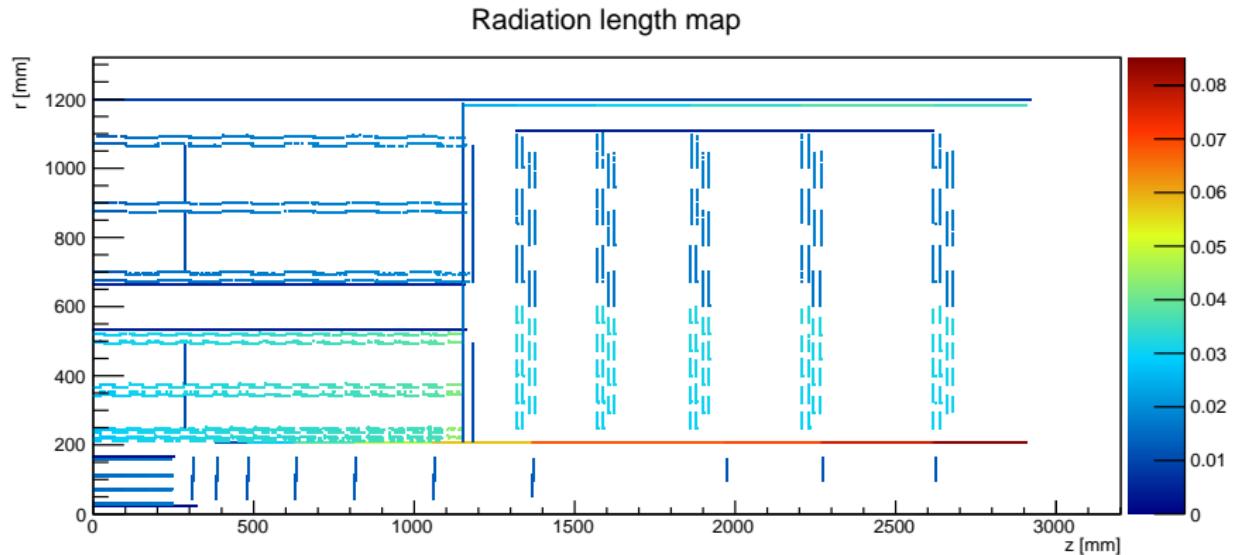
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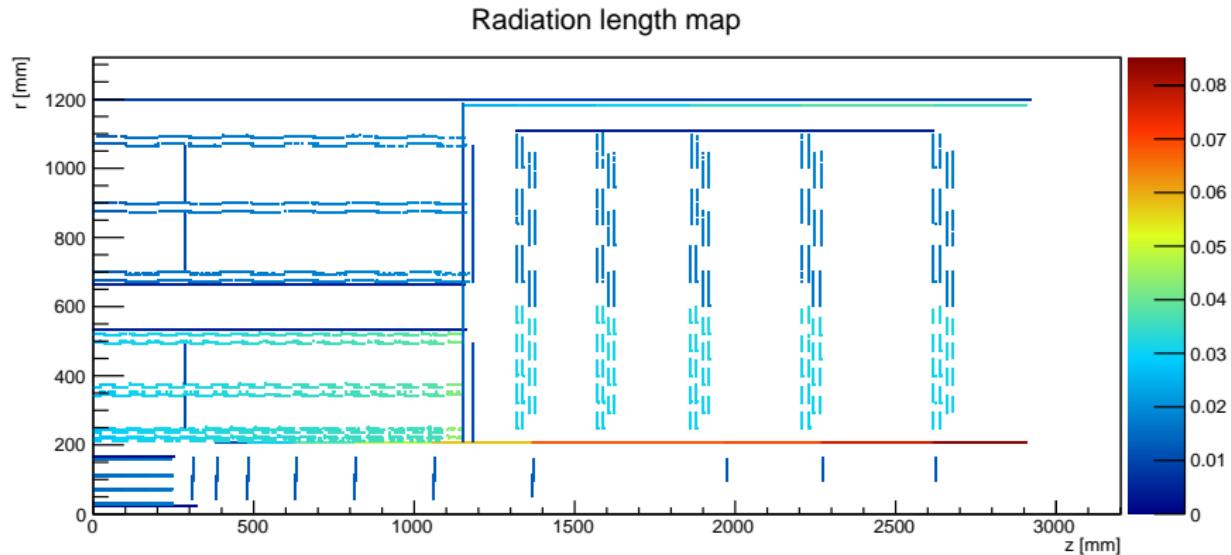


Old material model



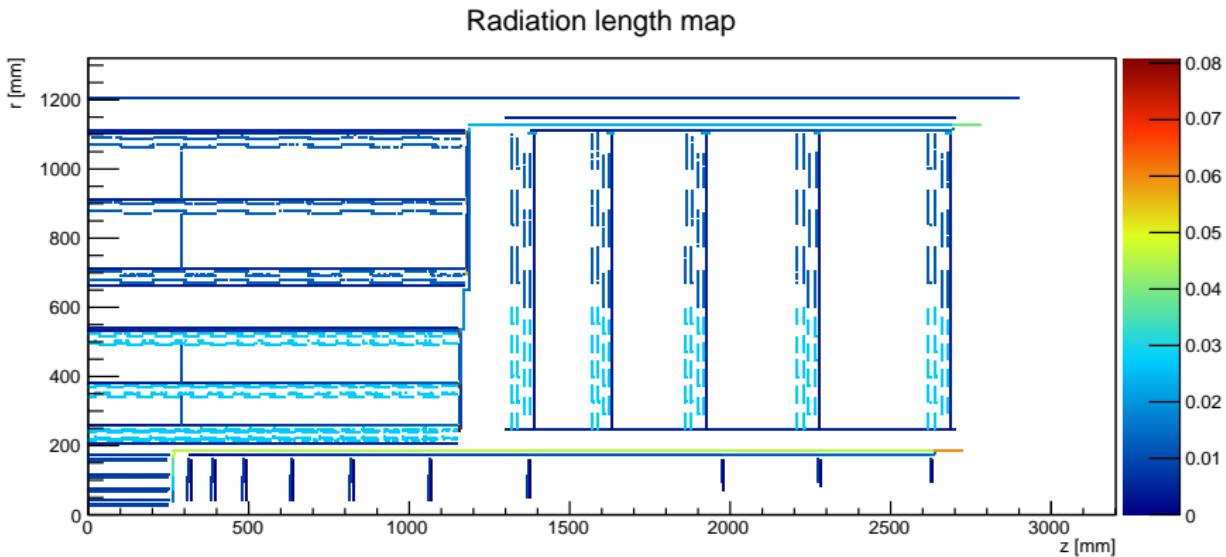
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- ✓ Possible to model **cooling pipe** along rods, **manifold** in the flange and bigger cooling pipe out of the barrel

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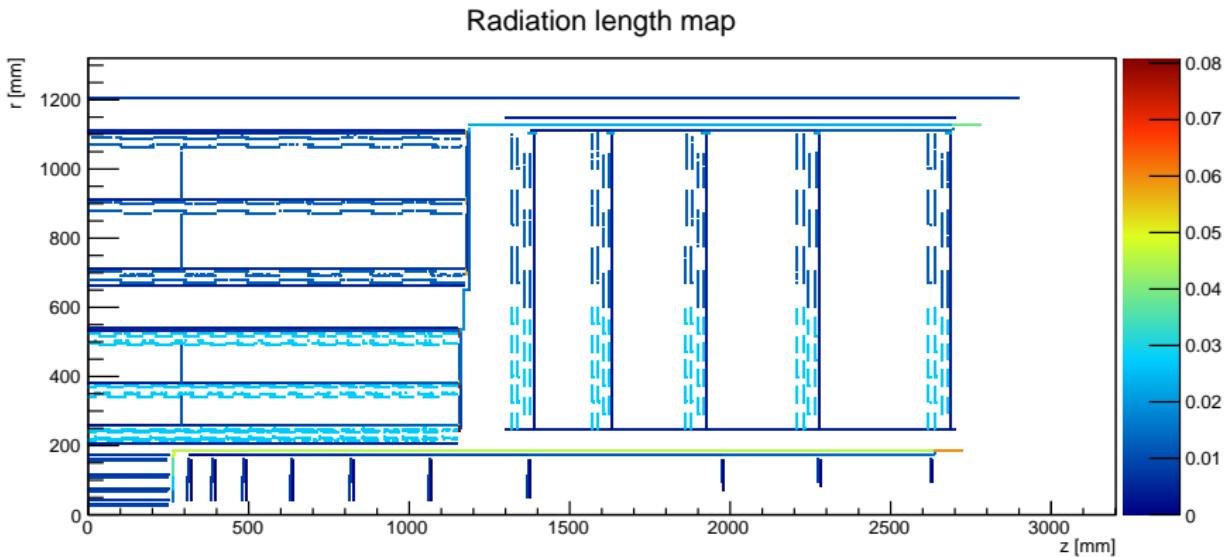
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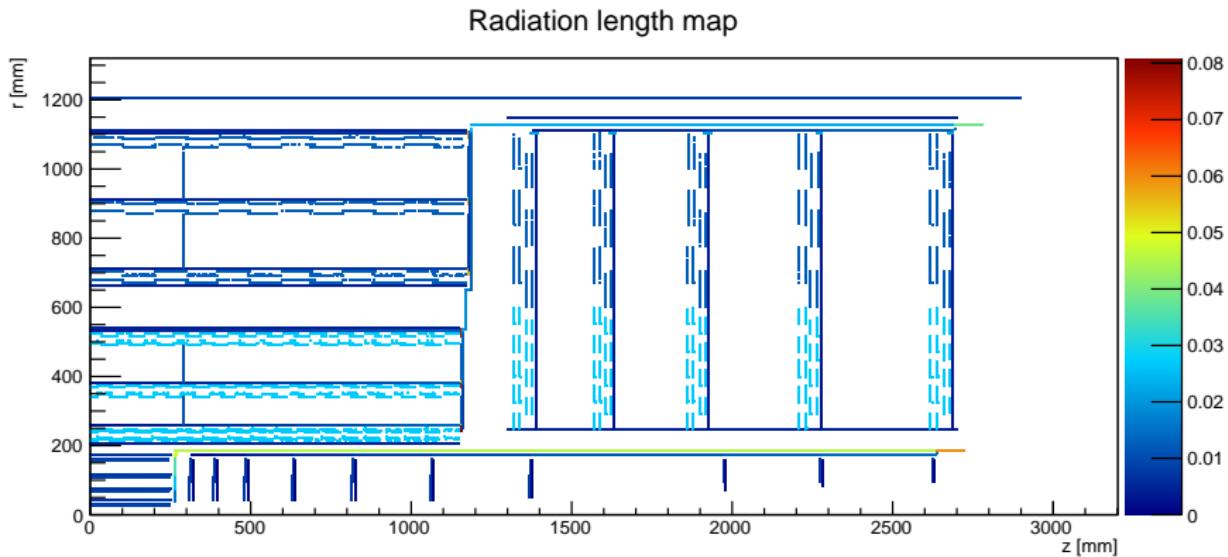
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- ✓ More detailed
- ✓ Better routing algorithm
 - automatically decide where cables go
 - avoid collisions
- ✓ More functionality

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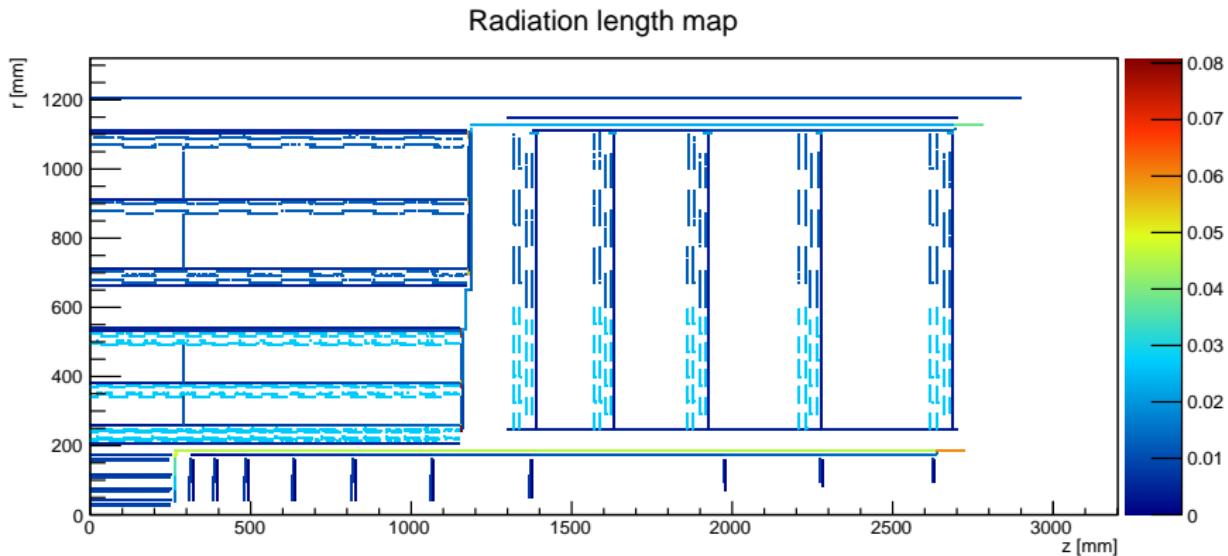
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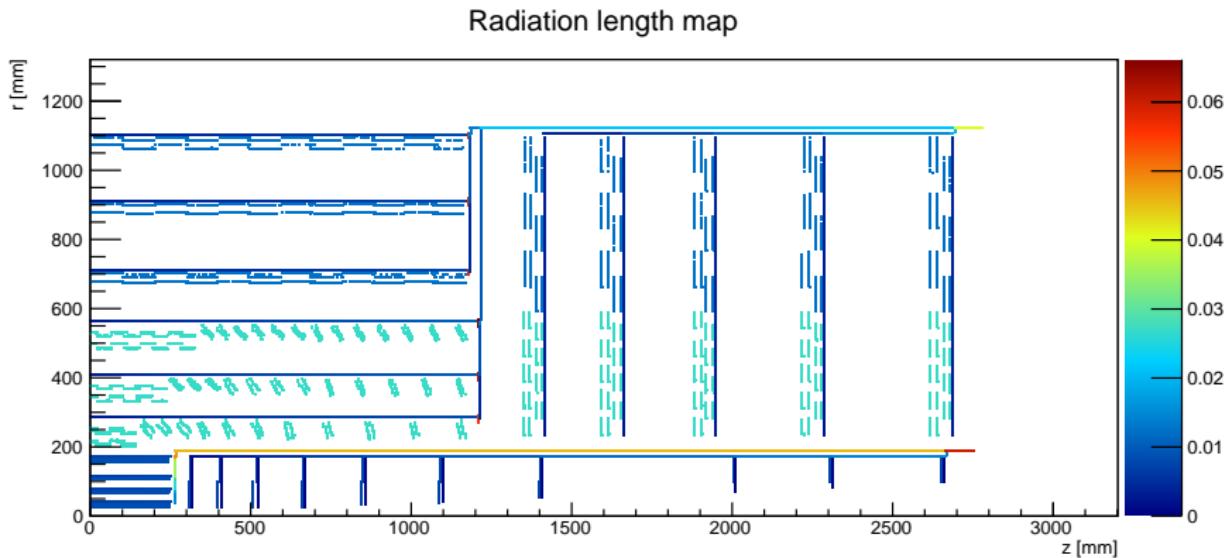


- ✓ Cables material in **dedicated** volumes
- ✓ More **detailed**
- ✓ Better routing **algorithm**
 - automatically decide where cables go
 - avoid **collisions**
- ✓ More **functionality**

Advantages

Correct description for a barrel with **tilted** modules

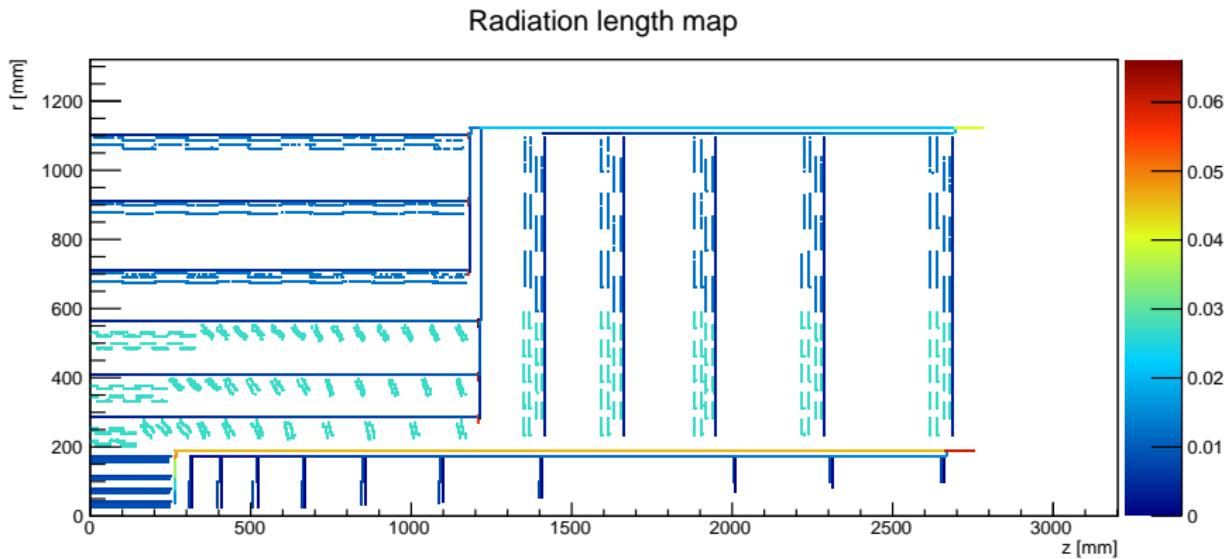
- ✓ In old model the cables were distributed **inside** the modules
 - **wrong** result in case of tilted modules
- ✓ Now is **possible** to model this design



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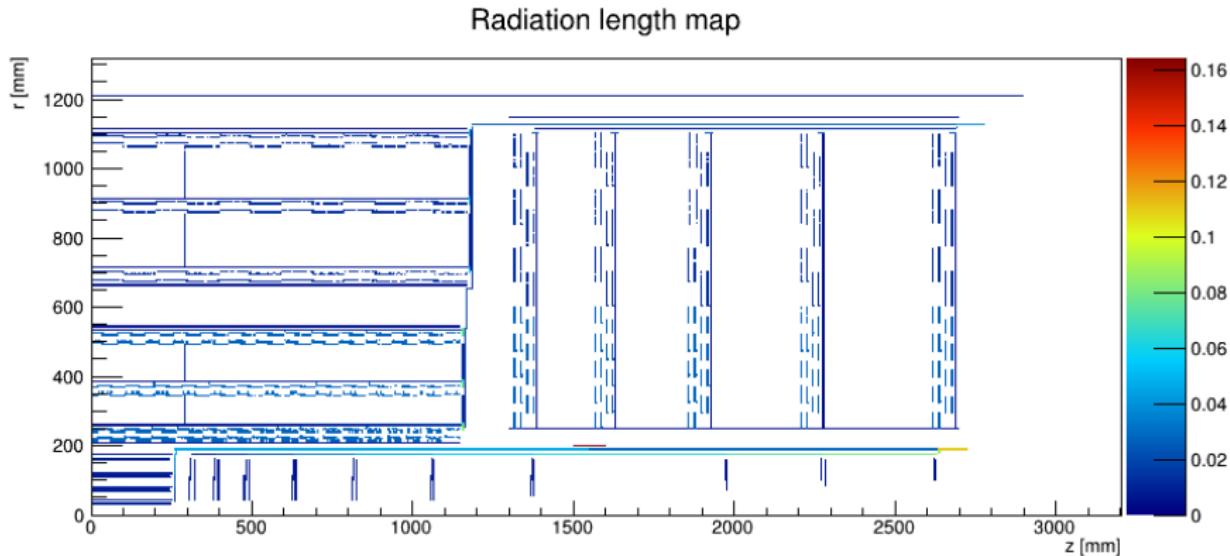
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New feature

Model for pixel-like materials

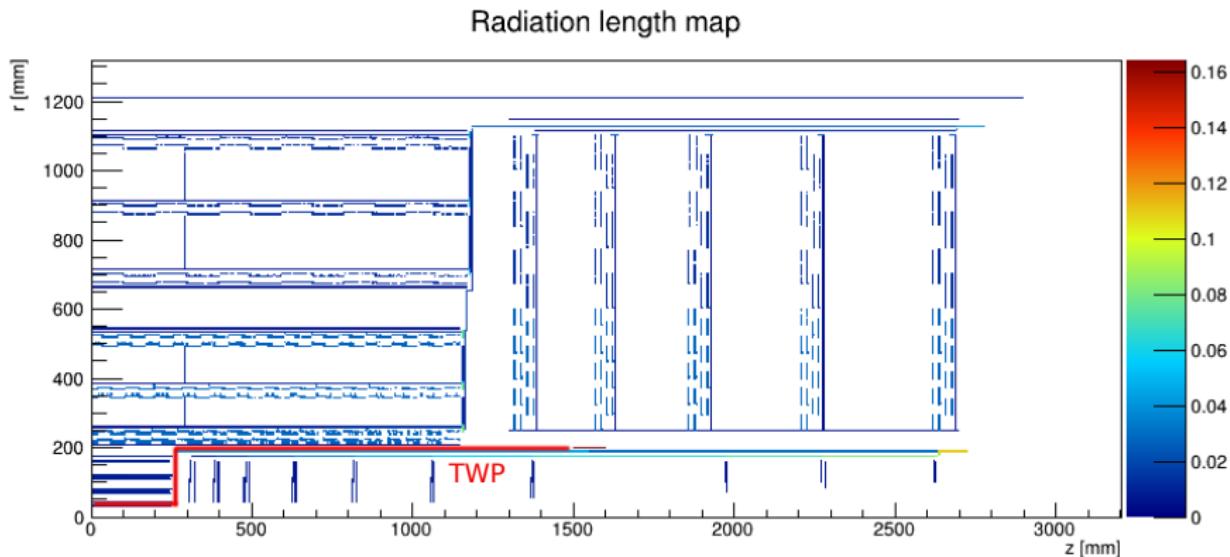
- ✓ All the situations where material conversion are far from the modules
- ✓ For instance twisted pair from modules, electrical optical transducer, and optic fibres after it



New feature

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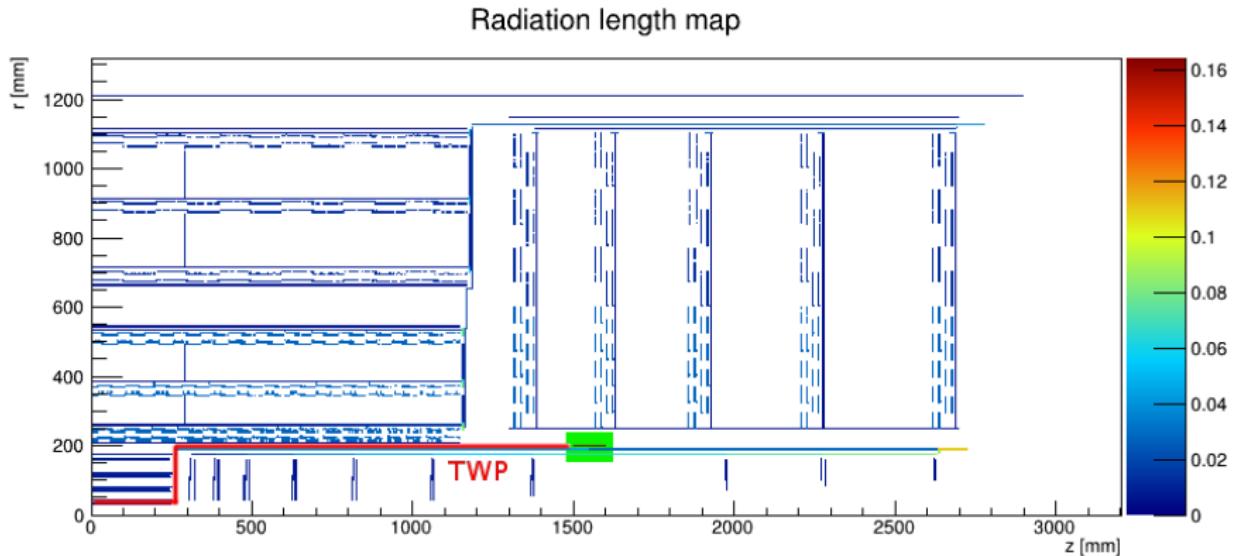
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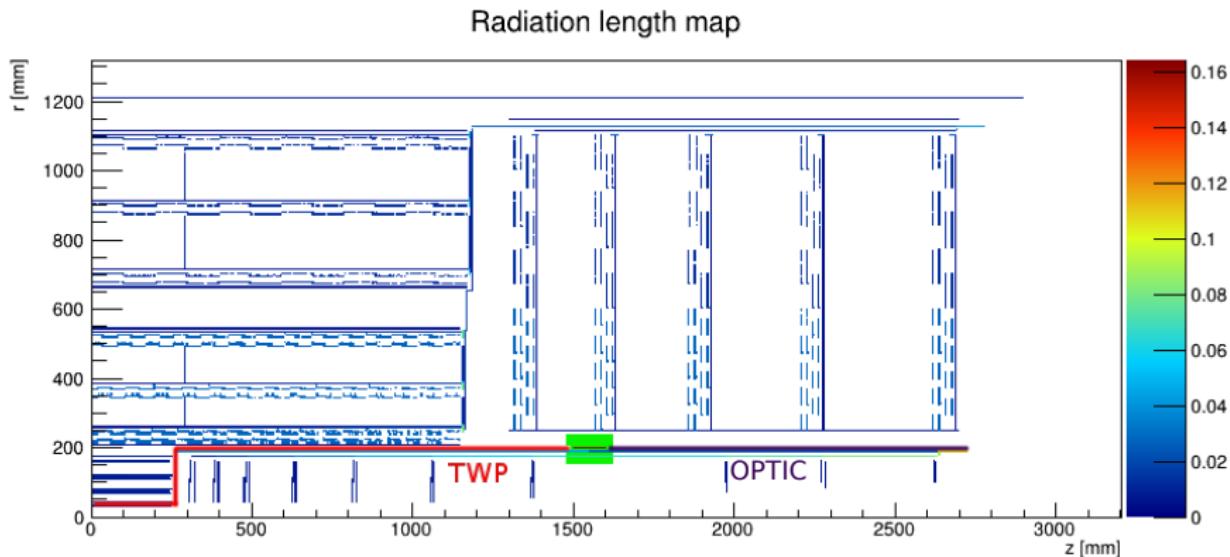
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Advantages

- ✓ The new algorithm use the **same** underlying c++ objects of the old
- ✓ This means that the **export** to **CMSSW** is working as usual
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1. Comparison between old and new models on a simplified tracker model
2. Accurate **tests** new model only with controlled amount of material and exact computation of material amount

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Comparison

- ✓ discrepancy between old/new model is small
- ✓ mainly due to limitations of old model (new model more precise)

| [g] | Refactoring | Trunk | Difference |
|----------------|---------------|---------------|---------------|
| L1 | 39914 | 39665 | 249 |
| L2 | 53176 | 52780 | 397 |
| L3 | 73771 | 73643 | 127 |
| L4 | 50871 | 49828 | 1043 |
| L5 | 65635 | 64361 | 1274 |
| L6 | 80275 | 78894 | 1382 |
| 2xD1 | 52183 | 55666 | -3482 |
| 2xD2 | 52183 | 55666 | -3482 |
| 2xD3 | 52183 | 55666 | -3482 |
| 2xD4 | 52183 | 55666 | -3482 |
| 2xD5 | 52183 | 55666 | -3482 |
| 2xVB | 29807 | 29294 | 513 |
| 2xHG (Endcap*) | 26952 | 85630 | -58678 |
| 2xHH (Barrel*) | 72601 | 79087 | -6485 |
| Total | 753918 | 831509 | -77590 |

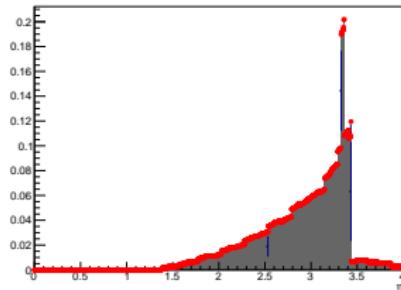
*Trunk: HH = only-Barrel tracker; HG = only-Endcap tracker 6

Test15 → tested in all possible inputs

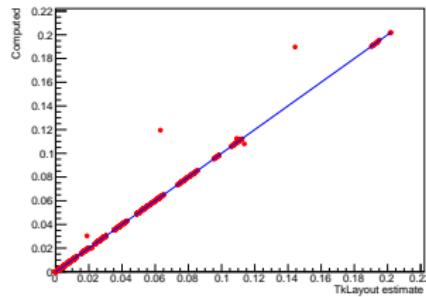
100g/m of Cu in the disk of endcap

✓ service true

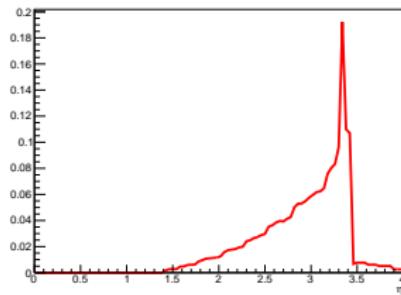
TkLayout estimate vs computed



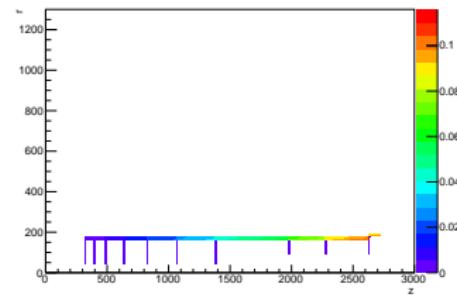
Correlation



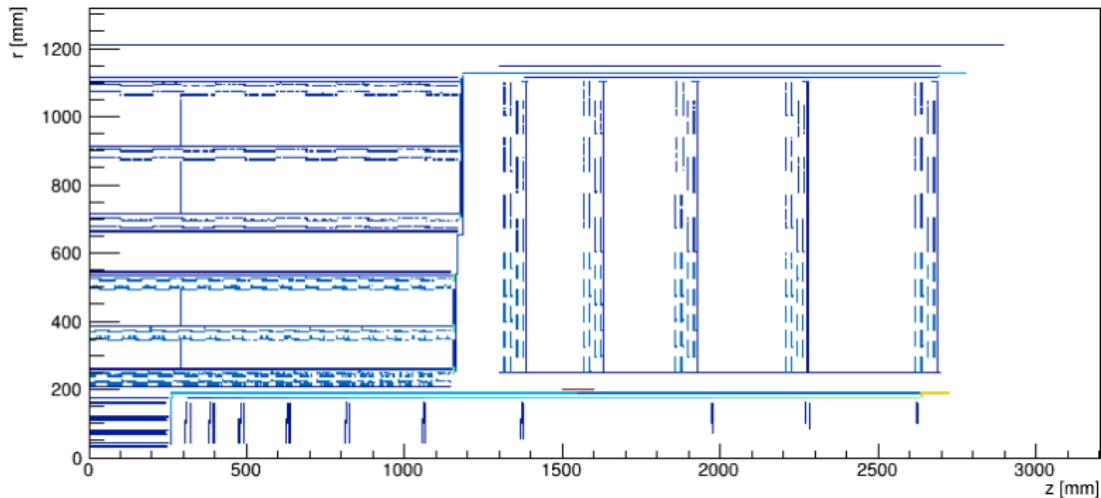
Computed function



Computed map



Material destination, with different unit (g, g/m, mm)



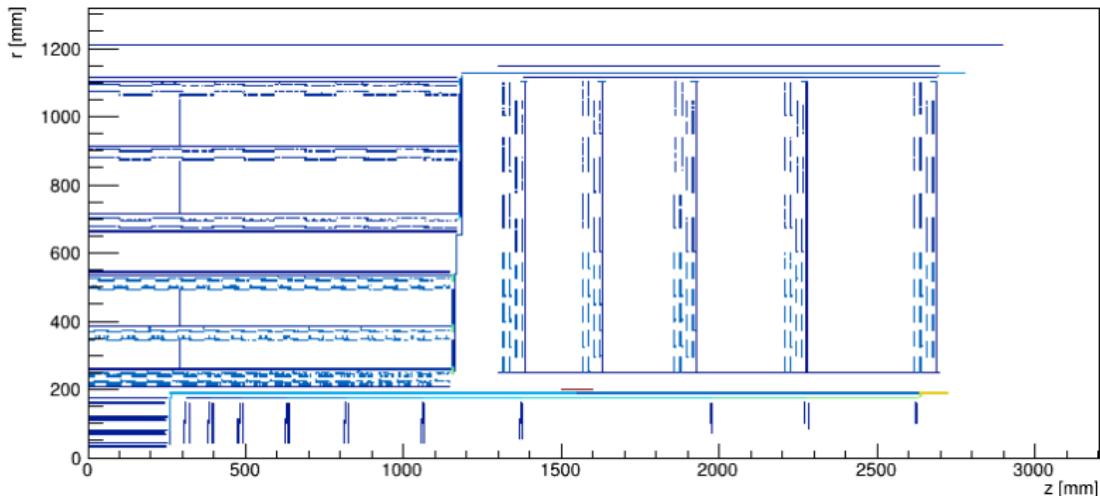
Destination

- ✓ In module
- ✓ In rods, a series of modules of barrel with same ϕ
- ✓ In layers/disks

Behavior

- ✓ Locally (also volumes inside module)
- ✓ as a service
 - can be converted in flange or custom position

Material destination, with different unit (g, g/m, mm)



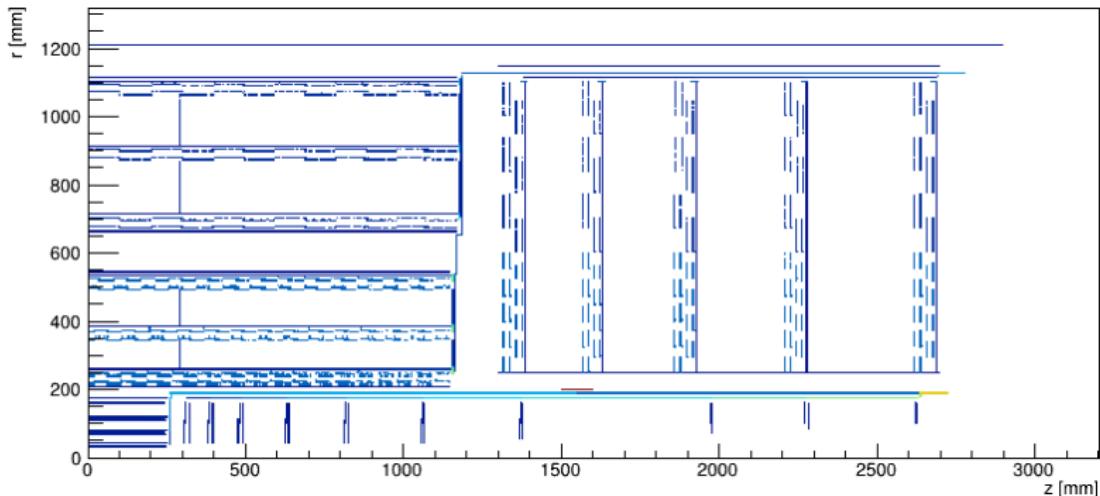
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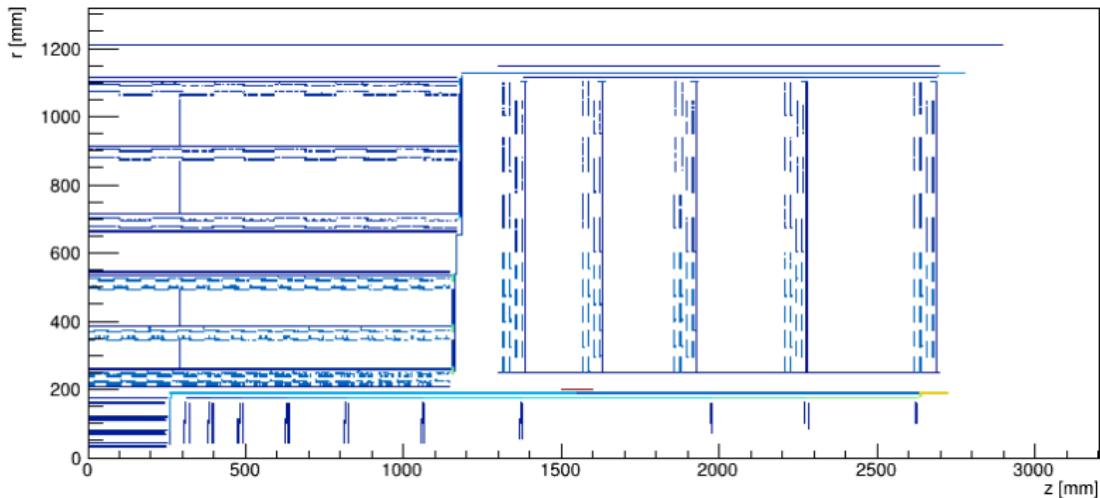
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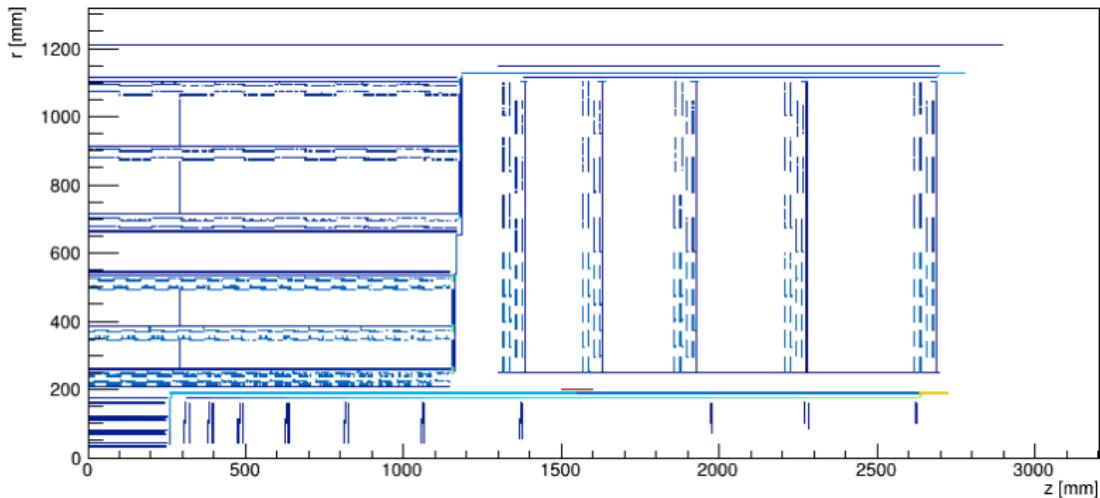
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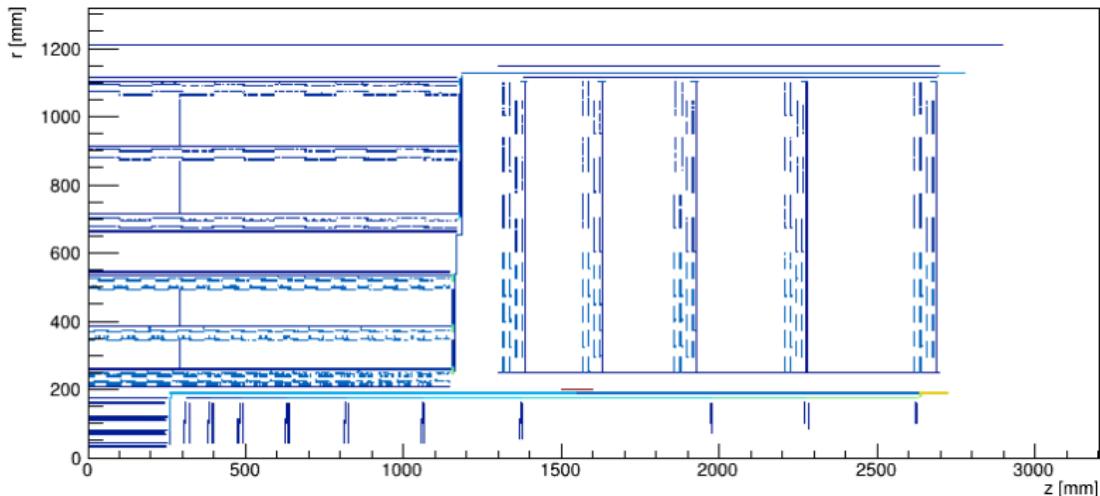
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| | Unit= g/m | Unit= mm | Unit= g |
|---|--|---|---|
| Module Service=false | Module $\times moduleLength$ No accumulation No conversion Scaling possible | Module $\times moduleSurface \times \rho$ (sensor surface) No accumulation No conversion Scaling possible | Module $\times 1$ No accumulation No conversion Scaling possible |
| Module ring R of N Service=true | Following supports $S_{R+1} \dots S_i \dots S_N$ $\times numModules_R \times supportLength_i$ Accumulation Conversion(1:1 by default, with warning) Scaling possible | Following supports $S_{R+1} \dots S_i \dots S_N$ $\times numModules_R \times supportSurface_i \times \rho$ Accumulation Conversion(1:1 by default, with warning) Scaling possible Deprecated warning | Error |
| Rod(barrel) Service=false | All supports $S_1 \dots S_i \dots S_N$ $\times numModules_1 \times supportLength_i$ No accumulation No conversion Scaling not possible | All supports $S_1 \dots S_i \dots S_N$ $\times supportSurface_i \times \rho$ No accumulation No conversion Scaling not possible | All supports $S_1 \dots S_i \dots S_N$ $\times numModules_1 \times \frac{supportLength_i}{\sum_{j=1}^N supportLength_j}$ No accumulation No conversion Scaling not possible |
| Rod(barrel) Service=true | All supports $S_1 \dots S_i \dots S_N$ $\times numModules_1 \times supportLength_i$ No accumulation Conversion Scaling not possible | All supports $S_1 \dots S_i \dots S_N$ $\times supportSurface_i \times \rho$ No accumulation Conversion Scaling not possible Deprecated warning | Error |
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Example configuration

.../Materials/ptPS

```
Materials module-ptPS {  
    type module  
  
    // Default sensor:  
    ReferenceSensor 1 {  
        numStripsAcross 960  
        numSegments 32  
    }  
    ReferenceSensor 2 {  
        numStripsAcross 960  
        numSegments 2  
    }  
  
    // Sensor  
    Component {  
        componentName Sensor  
        service false  
        scaleOnSensor 0  
        targetVolume 1  
        Element {  
            elementName SenSi  
            quantity 0.2  
            unit mm  
        }  
    }  
  
    ...
```

.../Materials/rodPtPS

```
Materials rodPtPS {  
    type rod  
  
    Component {  
        componentName Cooling  
        service true  
        scaleOnSensor 0  
        Element {  
            elementName Steel  
            quantity 7.860696517  
            unit g/m  
        }  
        Element {  
            elementName CO2  
            quantity 1.791044776  
            unit g/m  
        }  
    }  
  
    ...
```

Example configuration

.../Conversions/flange

```
Station {  
    stationName flange  
    type flange  
    ...  
    Conversion {  
        Input {  
            Element {  
                elementName Cu_MV  
                quantity 10  
                unit g/m  
            }  
        }  
        Output {  
            Element {  
                elementName Cu  
                quantity 10  
                unit g/m  
                service true  
            }  
            Element {  
                elementName Cu  
                quantity 0.423  
                unit g  
                service false  
            }  
        }  
    }  
    ...
```

.../Conversions/endcap1

```
Station {  
    stationName endcap1  
    type second  
    minZ 1500  
    maxZ 1600  
    ...  
    Conversion {  
        ...
```

Conclusions

- ✓ new material model **finished**
- ✓ model validated
- ✓ detailed **radiation maps**

Next steps

- ✓ use new features for study the pixel tracker and inspect possibilities
- ✓ tracking & track-trigger performance with tilted barrel (within tkLayout)
- ✓ study of pixel (vertex resolution & impact of material on tracking in general)
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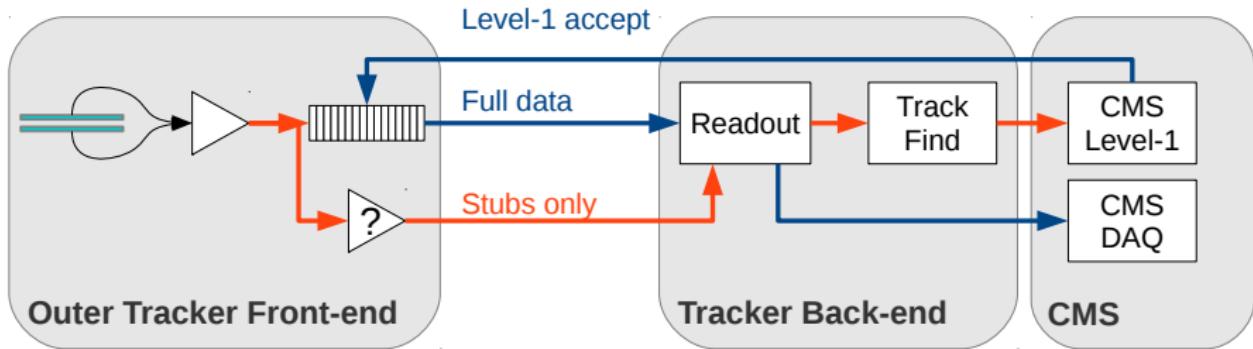
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SO LONG,

AND THANKS FOR ALL THE FISH.

Outer tracker Bandwidth



Modules

2 Strip sensors

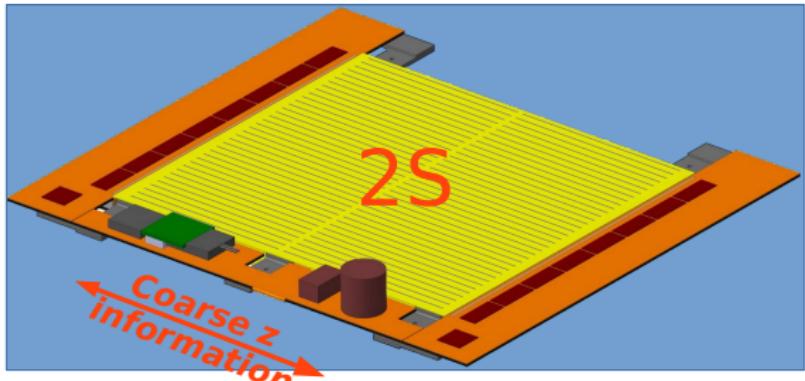
Strips: $5 \text{ cm} \times 90 \mu\text{m}$

Strips: $5 \text{ cm} \times 90 \mu\text{m}$

$P = 2.7 \text{ W}$

$\sim 92 \text{ cm}^2$ active area

For $r > 40 \text{ cm}$



Pixel + Strip sensors

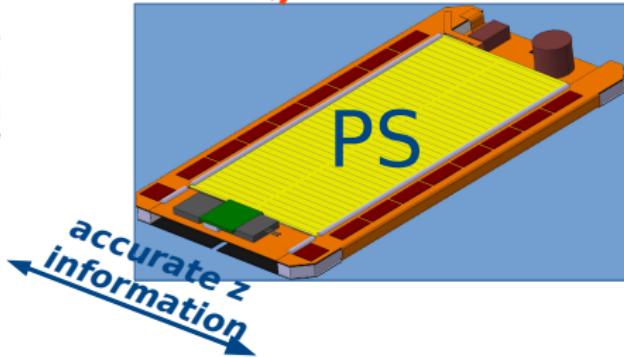
Strips: $2.5 \text{ cm} \times 100 \mu\text{m}$

Pixels: $1.5 \text{ mm} \times 100 \mu\text{m}$

$P = 5.0 \text{ W}$

$\sim 44 \text{ cm}^2$ active area

For $r > 20 \text{ cm}$



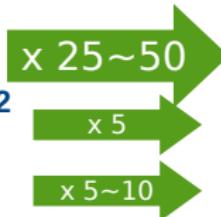
Pixel Bandwidth

Bandwidth

Phase-1

Rate → **400 MHz/cm²**

L1 rate **100 kHz**



HL-LHC

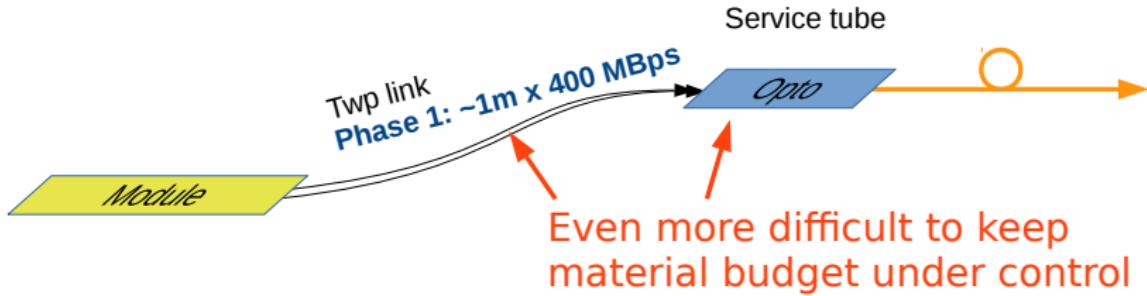
Rate → **2 GHz/cm²**

L1 rate **750 kHz**

Optical on-board readout not possible:

- Rad-hardness
- Material/space

=> **Electrical links to opto links**



Pixel Powering

Target: $O(0.5)$ W/cm²

Traditional inductor-based on-board DC/DC not possible:

Possible options:

Serial powering

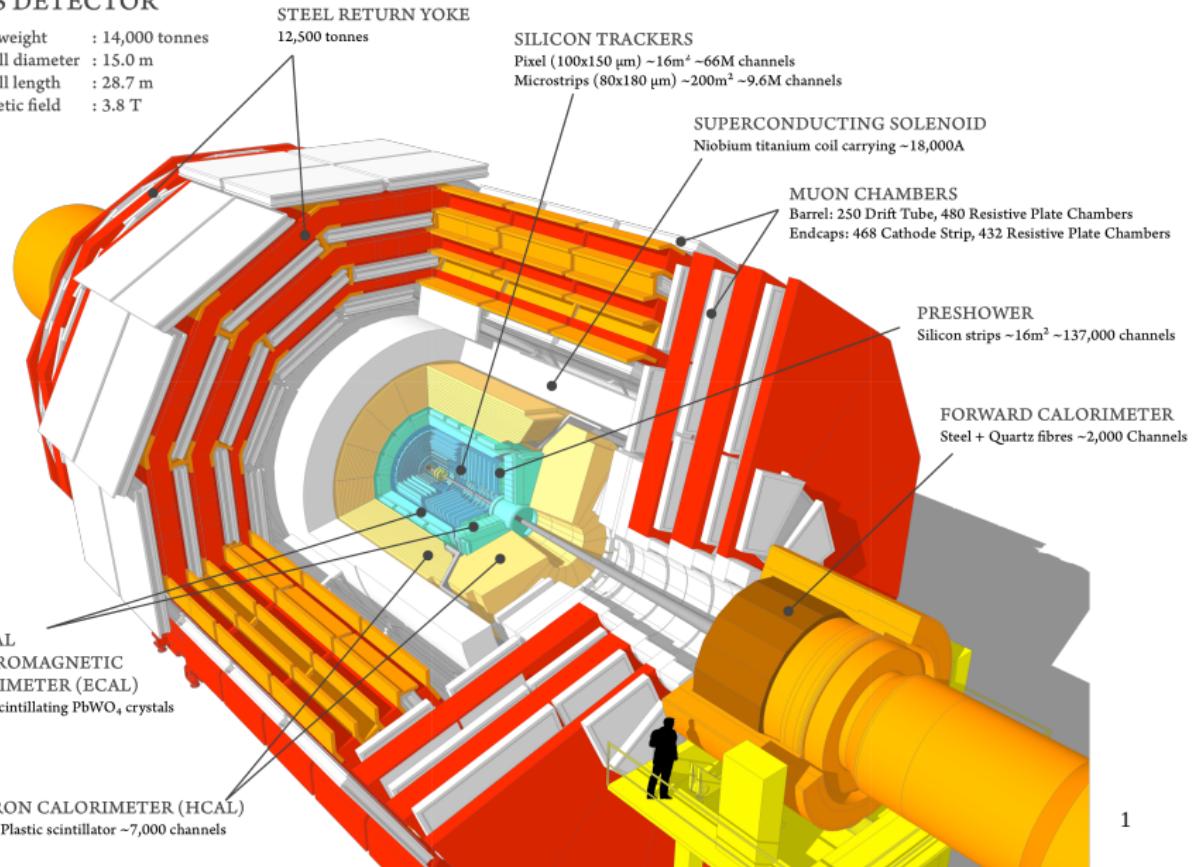


More complex schemes



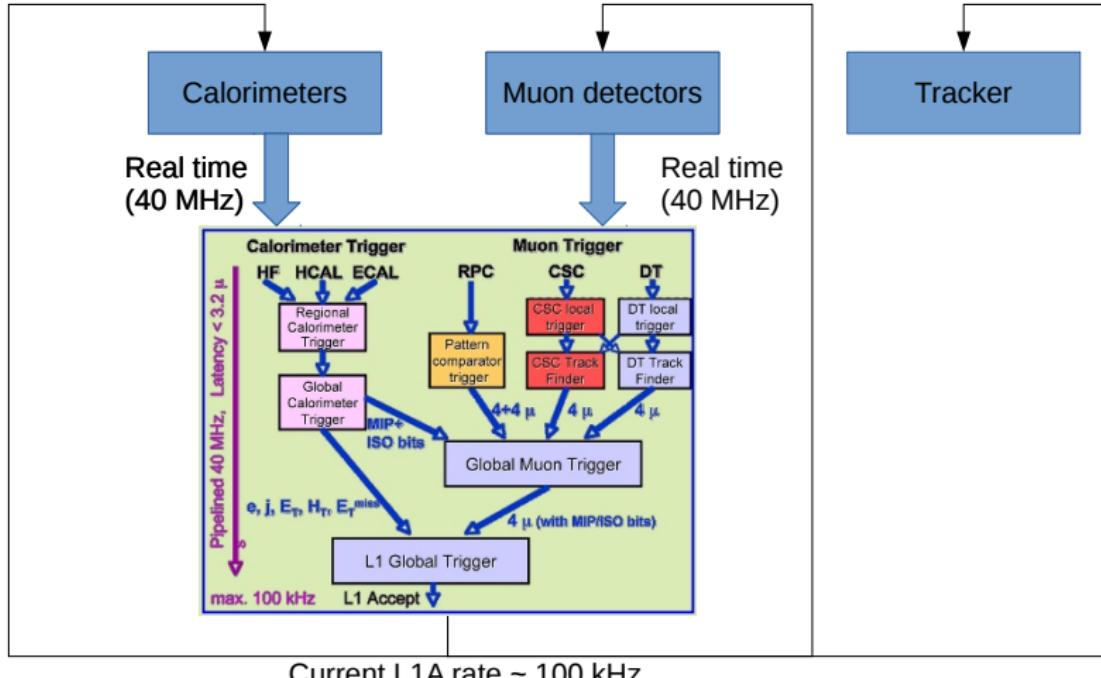
CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T



1

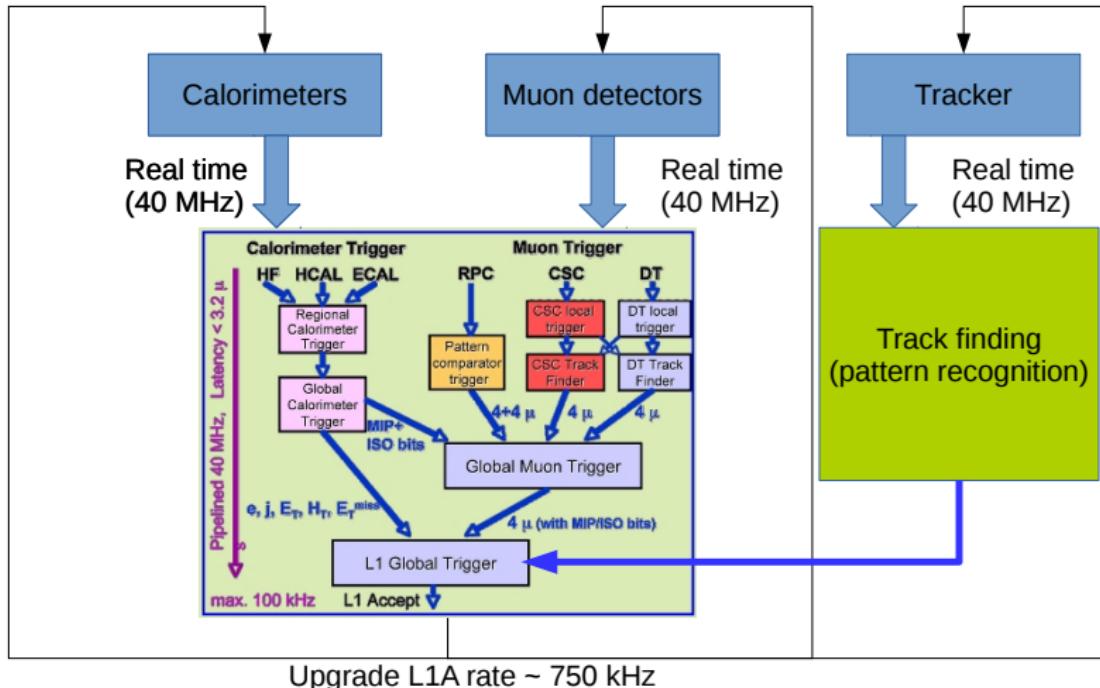
Current Readout Architecture



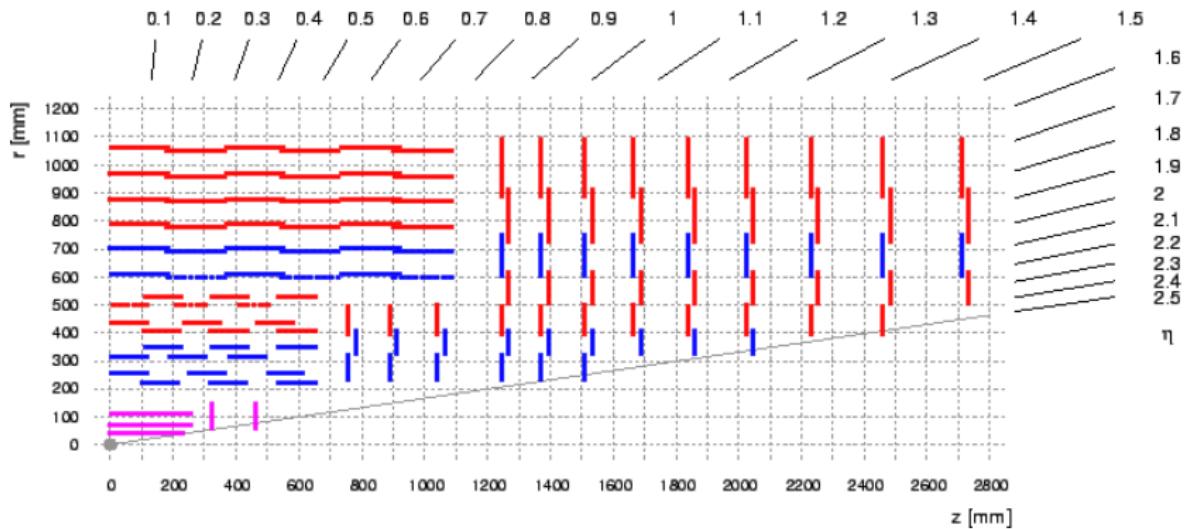
Trigger (a.k.a. Level-1 Trigger, a.k.a. Level-1 Accept, a.k.a. L1A)

2

Upgrade Readout Architecture



Current CMS Tracker



Outer tracker front-ends

Need to ship hits off detector

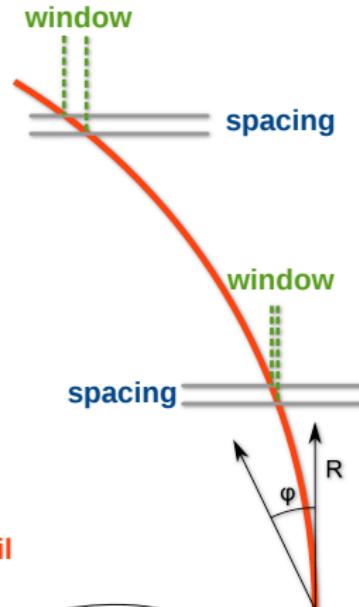
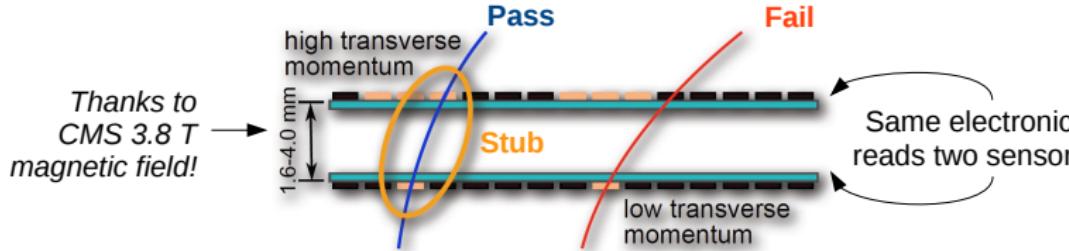
Ship all hits @ 40 MHz? No

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

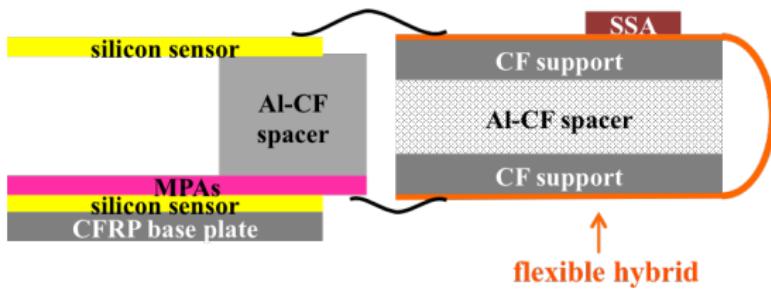
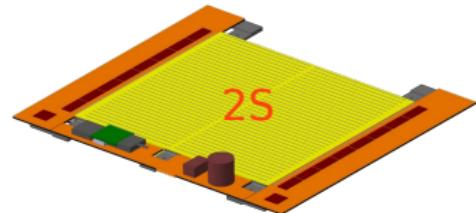
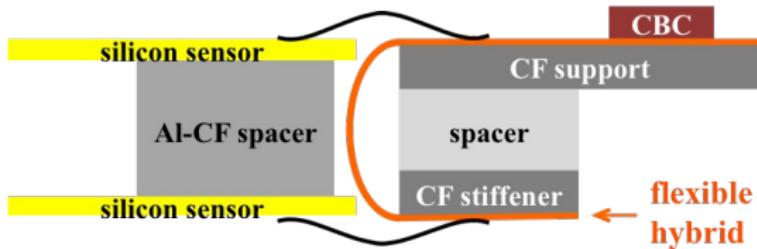
Solution: ship only high-pT hits (stubs)

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

Modules with pT discrimination ("pT modules")



Front-end interconnection



Flex hybrid:

- Technology leap
- Key element for 2-sensor design