Layout studies

Tools and results – general overview

Outline

Description of tkGeometry tools

- tkLayout (operational)
- tkMaterial (operational)
  - validation
- tk2CMSSW (under development)
- Outlook

Overview of (some) studies done so far

- Endcap with rectangular detectors
- Modelling of different options
- Outlook

tkGeometry tools

- tkLayout: generation of detector geometry
  - Starting from (relatively) small n of input parameters and assumptions
  - Basic geometrical validation (n of hits)
  - Calculation of overall basic parameters (surface, channels, power…)
- tkMaterial: modelling of detector material
  - Simplified modelling with small n of input parameters
  - Creation of (additional) inactive volumes
  - Produce radpidity profile of radiation and interaction lengths
- tkCMSSW: Creation of geometry files for CMSSW
  - Should be readable by IGUANA
    - Tracking is another story…

tkLayout

Two configuration files

- Geometry.cfg
  - Defines the geometry of active surfaces

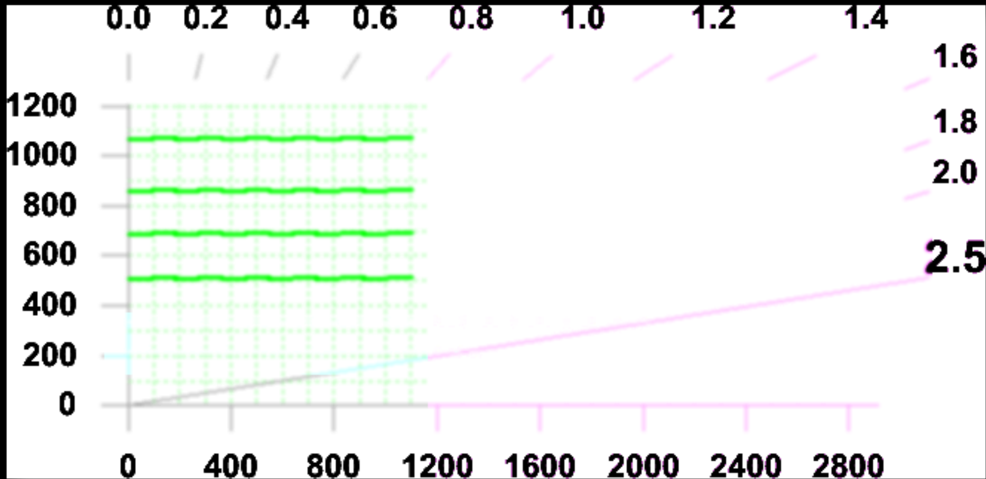
- Module_type.cfg
  - Defines which type of module populates each surface (layer/ring/disk)

Some (non exhaustive) examples in the following slides

Definition of Tracker Volumes

```
Tracker aRandomName {
  // ...
}


Barrel ABARREL {
  // ...
}
```

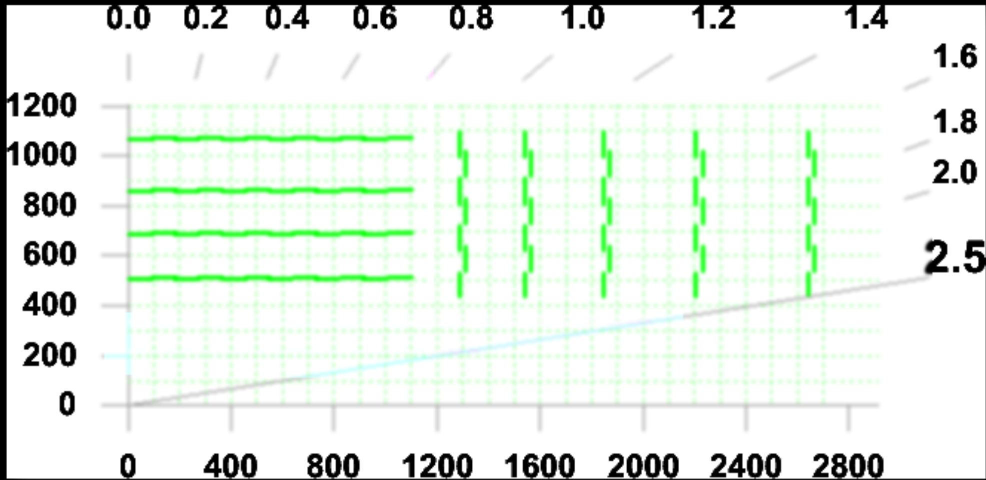
Generic structure of the geometry configuration file



Definition of Tracker Volumes

```
Tracker aRandomName {
  // ...
}


Barrel ABARREL {
  // ...
}


Endcap SOMEDISKS {
  // ...
}
```

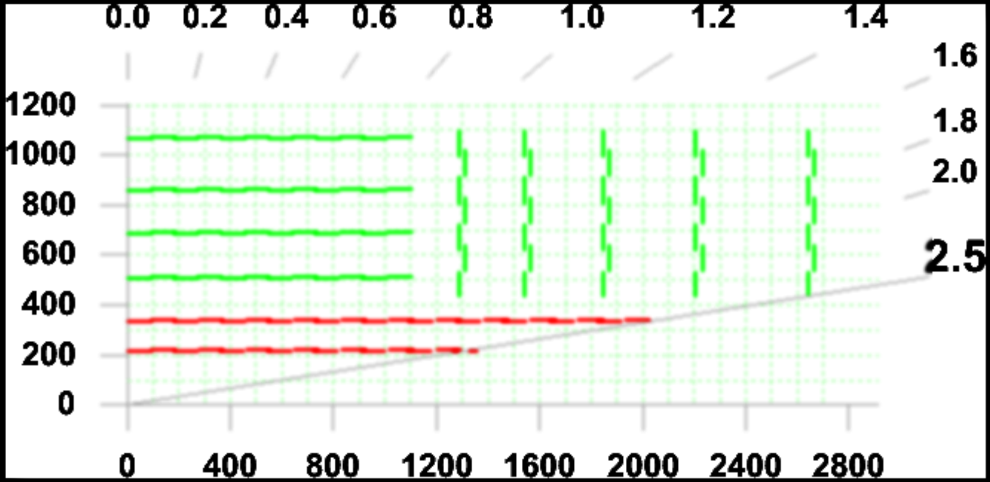
Generic structure of the geometry configuration file



Definition of Tracker Volumes

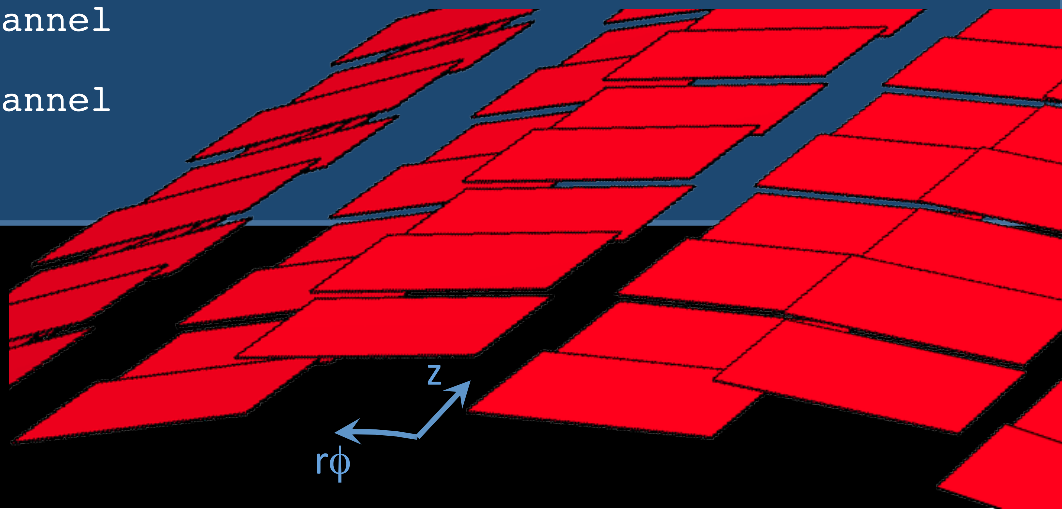
```
Tracker aRandomName {
  // ...
}


Barrel ABARREL {
  // ...
}


Endcap SOMEDISKS {
  // ...
}


Barrel ANOTHERBARREL {
  // ...
}
```

Generic structure of the geometry configuration file



Main TK parameters

```
Tracker 2pt_ecsq {
zError = 70;         // spread in IP z position, mm
overlap = 1;         // required overlap as seen from IP, mm
smallDelta = 2;      // radial distance consecutive sensors along z (rphi)
bigDelta = 12;       // radial distance consecutive sensors along rphi (z)
etaCut = 2.55;       // remove detectors above cut
ptCost = 200;         // CHF / cm^2
stripCost = 40;       // CHF / cm^2
ptPower = 0.1;        // mW / channel
stripPower = 0.5;     // mW / channel
}
```



Modules

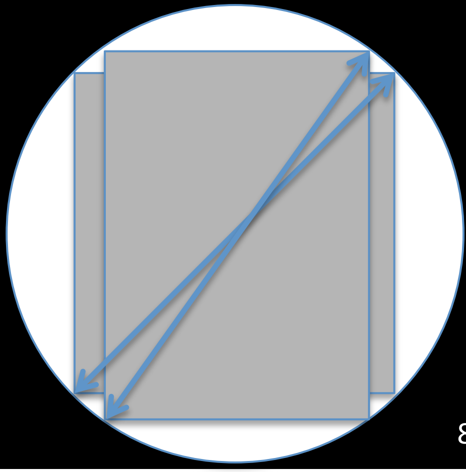
Sensors optimally cut out of 6” wafers

- Usable radius to be specified
- Square sensors default

`aspectRatio`

- Parameter to generate rectangular sensors

Option to generate smaller sensors not yet implemented



tkLayout

Barrel geometry

Space in r-z defined by

- `nModules`
- `innerRadius`
- `outerRadius`

N of layers

- `nLayers`

Multiplicity in ϕ

- `phiSegments`

Radii of layers

- Automatically approximated to equidistant
- Can be manually adjusted through several options

Overall length

- Layers re-adjusted to same length, within each barrel

tkLayout

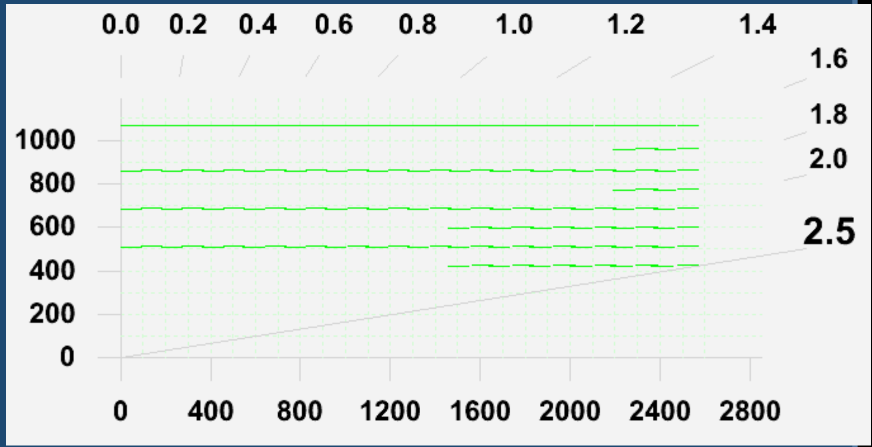
Barrel special options

Double-Stack layers

- Inner stack is a shrunk clone of the outer stack
- `Option stacked 3/-40;`
- Creates a clone of layer 3, 40 mm inside

Mezzanine barrels

- Specify starting z position
- `minimumZ = 2110;`



N.B. Module arrangement always without Lorentz angle compensation

- Feature to be added, if needed

EndCap geometry

Space in r

- `innerRadius` or `innerEta`
- `outerRadius`

N of disks

- `nDisks`

Z of first and last disk given by

- `minimumZ` or `barrelGap`
- `maximumZ`

Multiplicity in ϕ

- `phiSegments` as in barrel

Z of intermediate disks

- Automatically placed following geometrical progression
- $z_i/z_{i-1} = z_{i+1}/z_i$

tkLayout

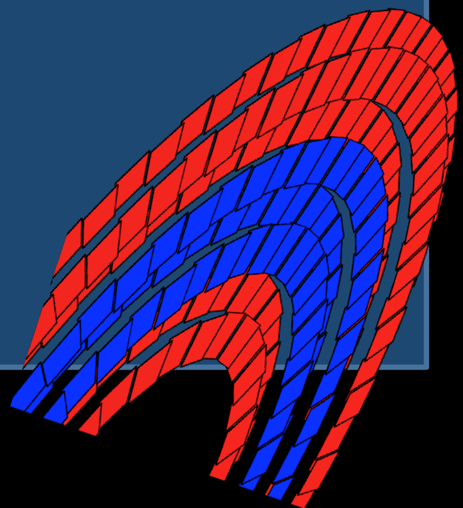
Procedure to define rings

Wedge-shaped modules (default)

- Shape automatically optimized (ring-by-ring) to maximize silicon sensor surface
- Can be retuned (manually) in some rings, to match overall radial range

Rectangular modules

- `Shape=rectangular; // default wedge`
- `aspectRatio=1.1; // default 1.0`
- No optimization possible
- Aspect ratio tuned "by hand"
  - possibly for both barrel and end-caps
- Overlap calculated at the tip of the module



tkLayout

Definition of module types

- For each volume, define module types as follows:

```
BarrelType Barrel{
nStripsAcross[1] = 768;        //  768 strips along rφ, ≈ 110÷120 μm pitch
nSides[1] = 1;                 //  SS module (one sensor)
nSegments[1] = 4;              //  4-fold z segmentation (≈ 2.5 cm strip length)
type[1] = rphi;                // rphi, stereo, pt  - name used in summaries
…
}
```

- In the EndCaps, modules can be specified by rings

```
nStripsAcross[nring] = xxx;
```

- Or by ring and disk

```
nStripsAcross[nring,ndisk] = xxx;
```

tkLayout

One non-trivial output: occupancy estimate

- Occupancy parametrized from present Tracker
  - From full simulation
  - Separately for Barrel and EndCap
  - Observed values reproduced to batter than 10%
- Re-scaled according to channel length
  - Accurate for pitch ≈ 100 μm
  - Pessimistic (overestimated) for significantly smaller pitch
- Used to evaluate needed strip length
  - Assuming a target occupancy within a few %
- Also used to evaluate needed bandwidth
  - Too pessimistic: to be improved

N.B. All numbers shown in the following correspond to 400 mb/BX!!

Conclusions and outlook

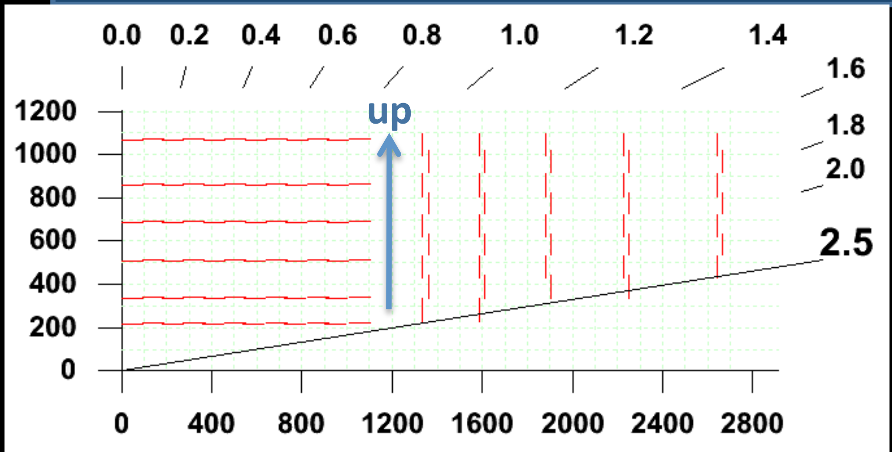
- Tool easy and fast to use
  - Avoids clumsy powerpoint/excel exercises
    - (… and/or relying too much on intuition)
  - Output can be easily extended to include other quantities
    - Multiplicities of services, electronics components etc… once input defined
- Code modular, can be evolved as needed
  - Add new options if requested, e.g.
    - Module arrangement with Lorentz angle compensation
    - Parametrization of "cluster occupancy", instead of channel occupancy
    - User-defined module size
    - …

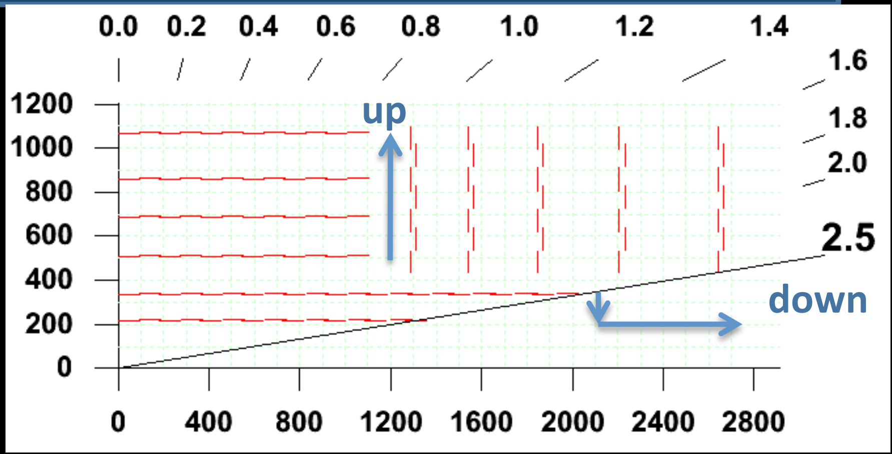
tkMaterial

- Creation of volumes
  - Starting from a geometry generated with tkLayout
- Modelling of materials
  - Strategy chosen to limit complexity and maximize flexibility
- Configuration file
  - Some examples

Volumes

- Volumes are created around the active surfaces
  - **Will receive materials related to**
    - Modules
    - Services (power, cooling, readout..)
    - Support structures
- Other volumes dedicated to services
  - **Created automatically after analysis of tkLayout geometry**
    - Cfr "up" and "down" configurations below
- Additional volumes for support structures
  - **Some automatic, some user-defined**





tkMaterial

Volumes: Barrel modules

P = position of the module; n = n of channels

For *each module type:*

- $M = A \times n(p-1) + B \times n + C \times (p-1) + D$
  - D: constant amount
    - Examples: sensors, cooling pipes, module frame…
  - C: scaled with module position
    - Example: HV wires (accumulate from z=0 towards higher z)
  - B: scaled with n of channels
    - Example: hybrids in readout modules and their cooling contacts
  - A: scaled with n of channels and module position
    - Example: LV wires, twp for signals….
- Flag assigned to each contribution
  - "L" = Local; "E" = exiting
    - Contribution with "E" flag are taken as input for module services

tkMaterial

Modules: examples

```
// Sensor – does not scale
M Si 0 0 0 0.2 mm L ;


// Hybrid – scales with n of channels
M G10 0 2.26 g 0 0 L ;
M Cu 0 0.83 g 0 0 L ;


// All services below calculated over 100 mm length = 1 module


// 4 TWP/hybrid – scales with n of channels and module position
M Cu_twp 0.132 g 0 0 0 E ;
M PE_twp 0.08 g 0 0 0 E ;
```

"M" indicates a Module volume

tkMaterial

Volumes: EndCap modules

Same concept as for barrel, but

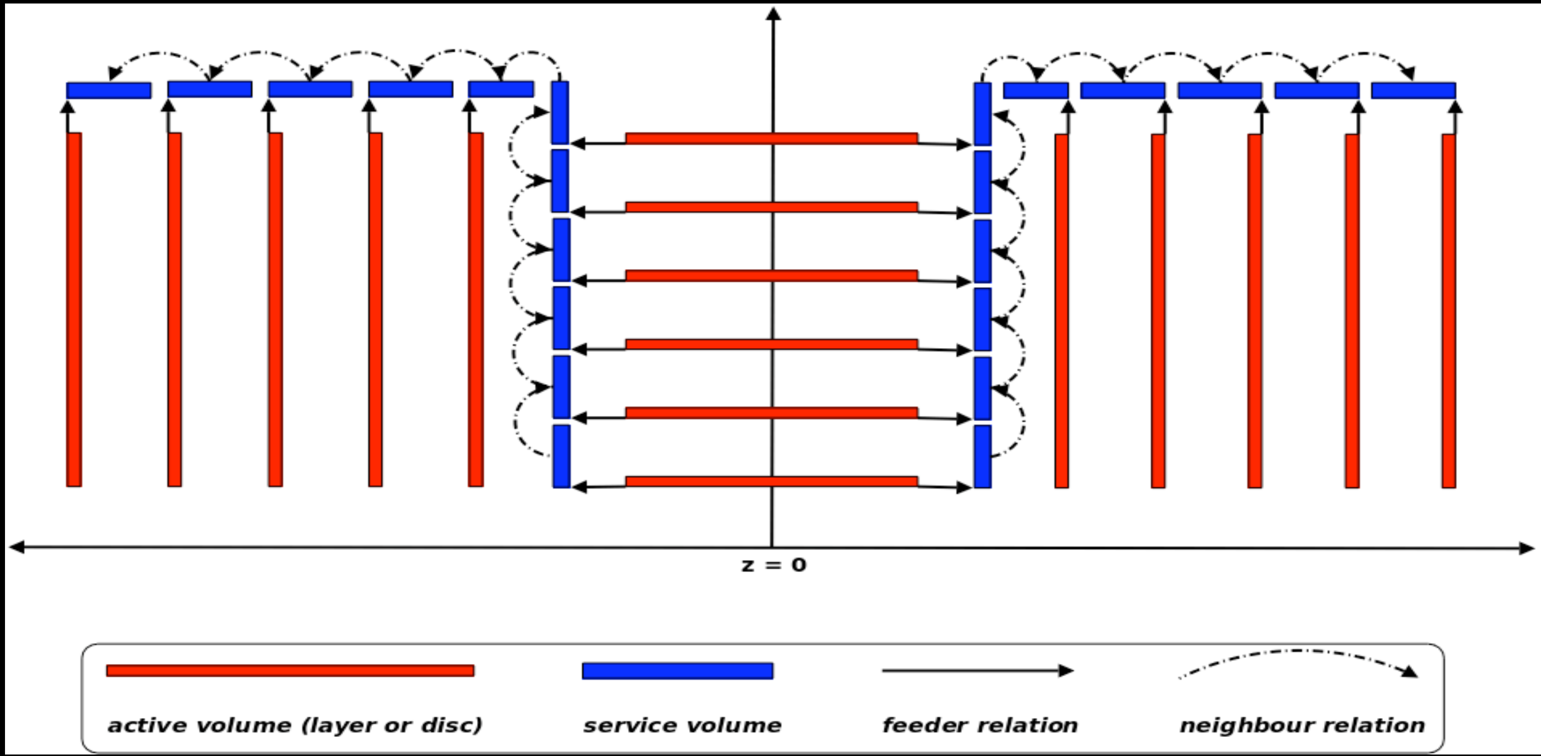
- Different rings in a disk may have different module flavours
  - While modules are all identical along a Barrel rod/string
- Services from inner rings decrease in density while running outwards on a disk
  - Simple scaling with ring # does not work

Solution

- Explicit calculation of material from inner rings
  - Taking into account module types and density scaling

tkMaterial

Volumes: Service Volumes



- Service volumes receive material:
  - **from module volumes**
    - With user-defined scaling laws from module materials with “E” flags
  - **from neighbour service volumes**
    - Materials with “E” flag: everything that goes in goes out
      - With appropriate geometrical scaling
      - Done automatically by the software

Service Volumes: Examples

```
//Manifolds
D 0.79 g Steel 4.2 g Steel L;
D 0.18 g CO2 1.4 g CO2 L;

//Radial pipes
D 0.79 g Steel 17.2 g/m Steel E;
D 0.18 g CO2 3.7 g/m CO2 E;

//Service holding mechanics
D 0.79 g Steel 7.4 g Al L;
```

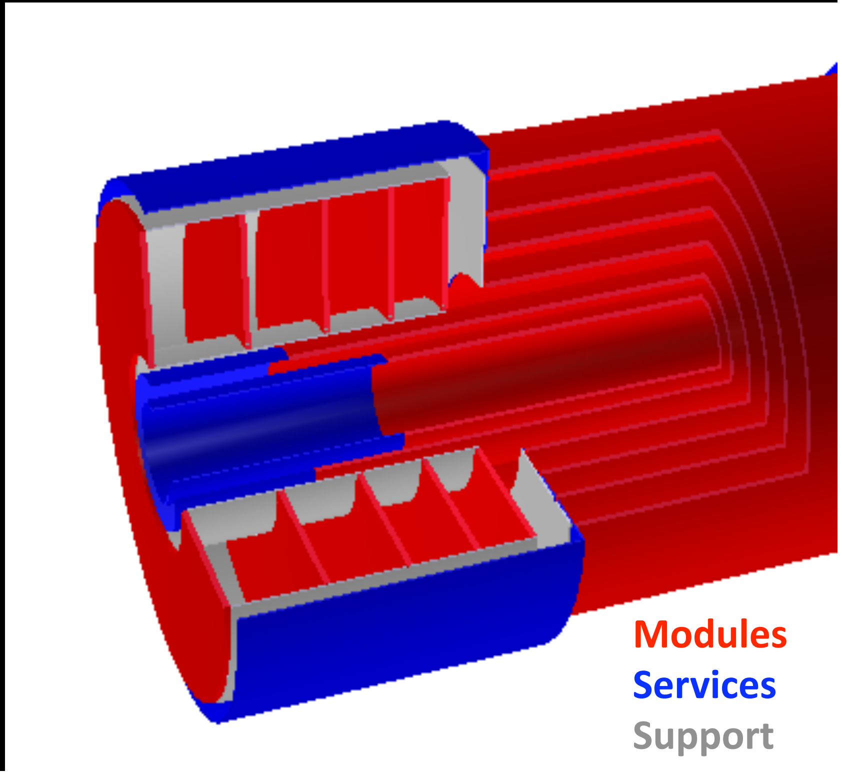
- "D" indicates the service volume
- Only "E"xiting materials from the module volumes are taken into account
- Materials flagged with "E" are then propagated across service volumes

tkMaterial

Volumes for mechanical supports

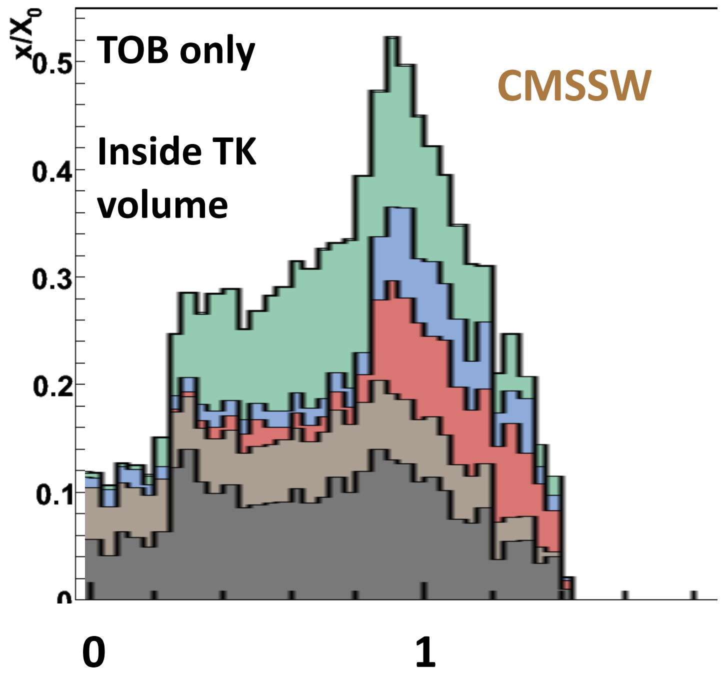
- Some created automatically
  - **e.g. inner support tube for barrel and endcap**
- Some user defined
  - **e.g. support disks in Outer Barrel**

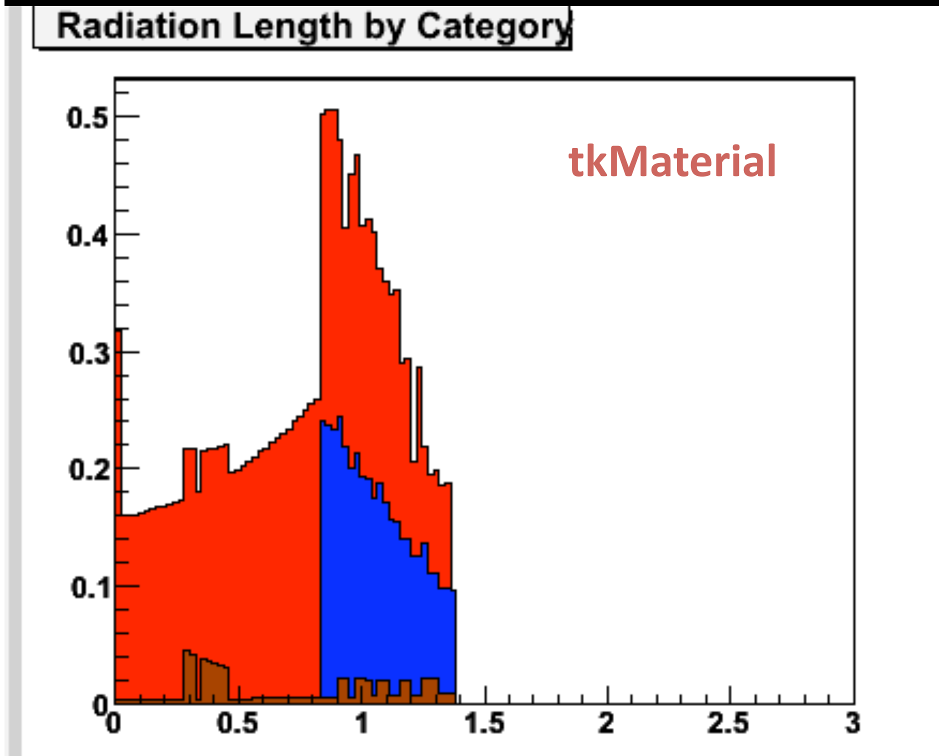
N.B. All studies focused only on material inside the Tracking Volume (so far)

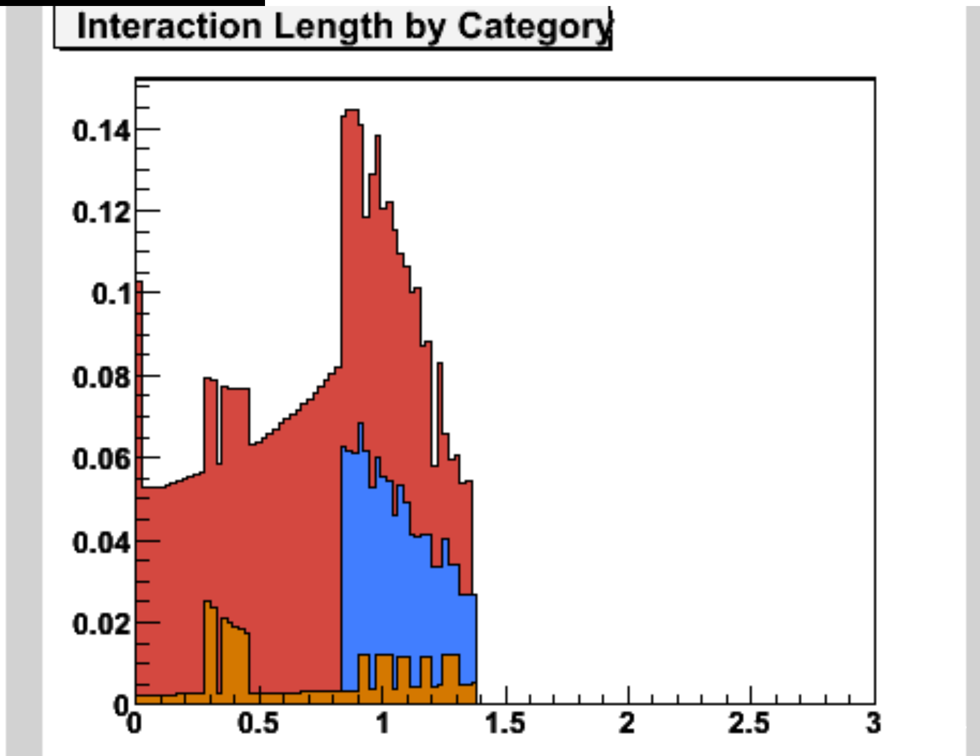


Validation with TOB

- Spike at z=0: correct
  - Tiny overlap in z=0, seen or not depending on binning
- Modelling of IC Bus imperfect - by choice
  - Causing local increase for $\eta<0.4$, decrease for $0.4<\eta<0.8$
  - Not necessarily so relevant for modelling next TK
- Electronics at the end of the rod (CCUM, optical connectors, wiring…) moved just outside
  - Makes rising edge of the $\eta\approx1$ peak sharper







tkMaterial

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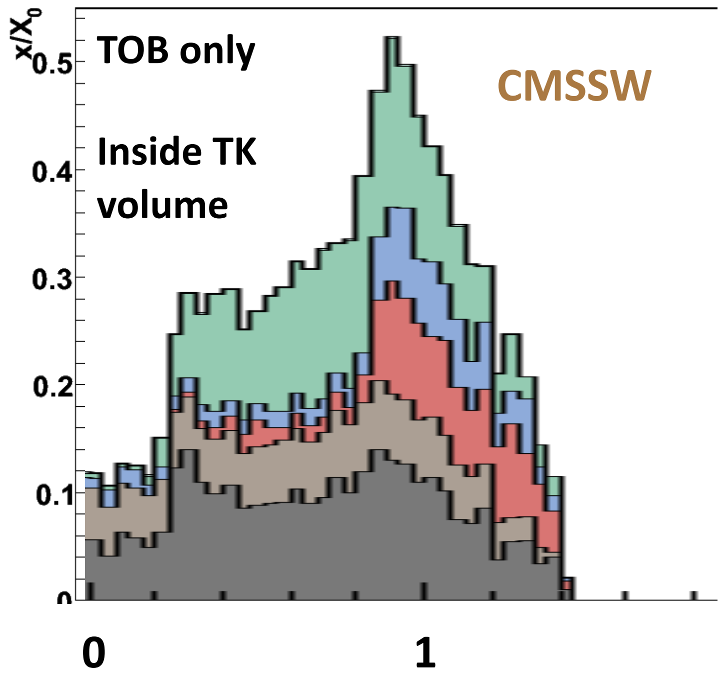
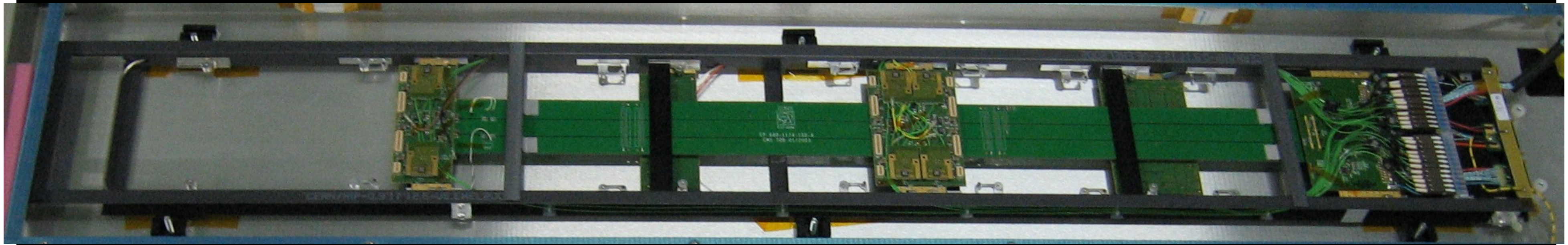




tkMaterial

Conclusions and outlook

- Accuracy and flexibility fully adequate for present needs
  - Cannot model heavy objects localized in some regions of the sensor volumes (hopefully not needed!)
  - Very accurate (≈ %) otherwise
  - Could in fact be accurate enough for many years
- Can be used to follow the evolution of the material estimate during the Tracker design
  - Can help to compare different options
    - And therefore help and support detector engineering
- Only material inside the Tracking volume has been studied so far
  - There may be still problems to fix in the volumes at the TK boundaries

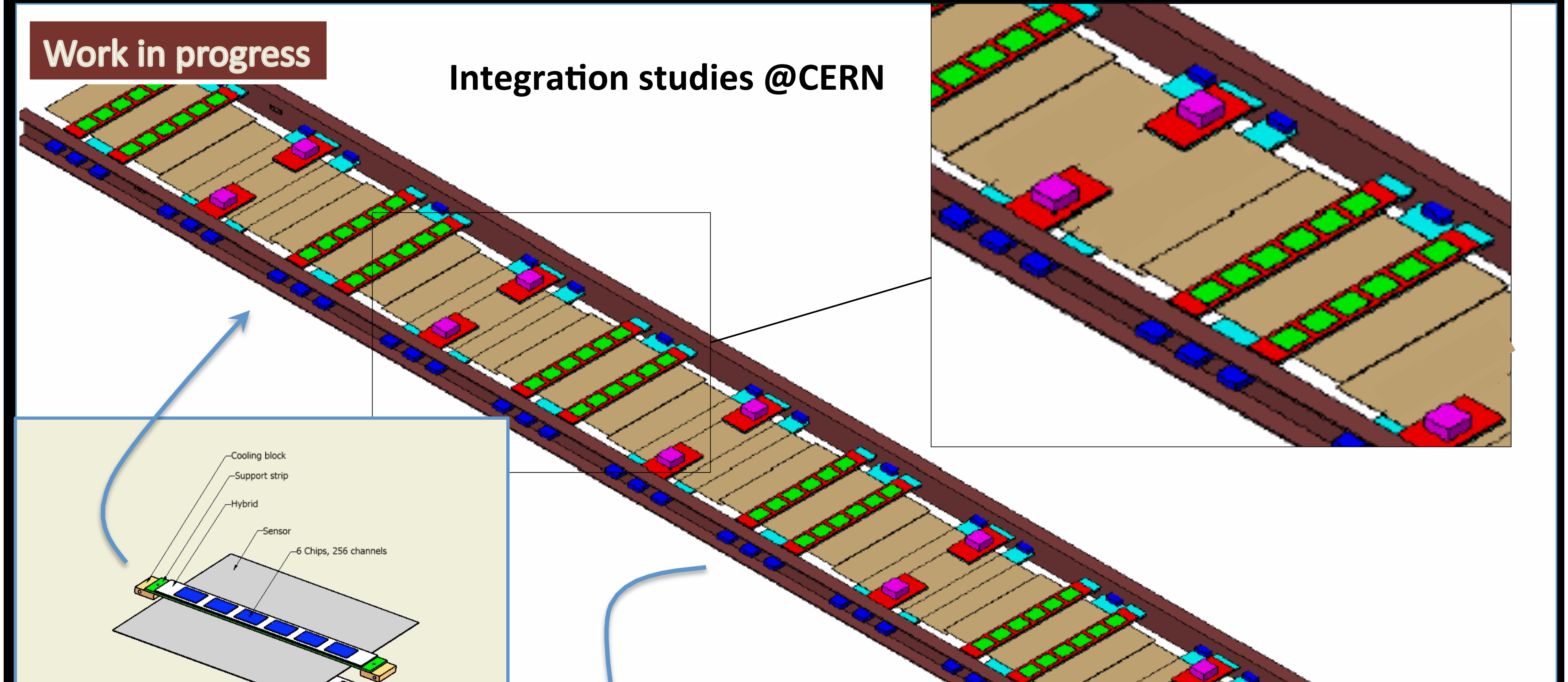
Next steps

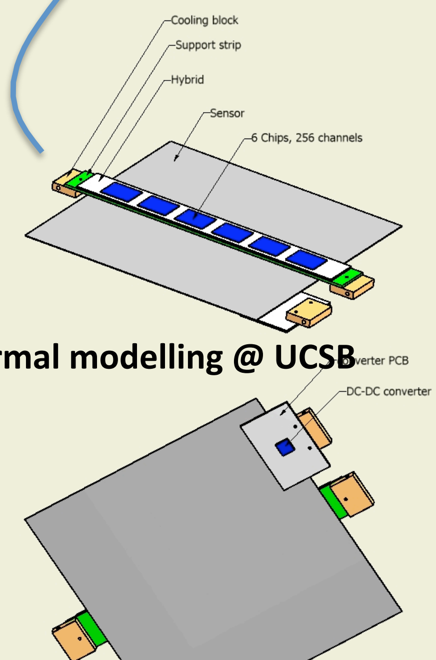
- tkLayout
  - Implement additional features, as needed
    - Notably “small” modules
- tkCMSSW
  - Translation of geometry to xml files for CMSSW ongoing
    - Barrels already visibile in IGUANA; EndCaps will take longer
    - Discussing about validation steps
    - In parallel investigating reconstruction/tracking code (N. Giraud)
- tkMaterial
  - Debug and validate volumes on boundaries
    - Low priority; can be relevant if translation to CMSSW is successful
- All packages
  - Write documentation and user instructions
    - One brave “external” user so far, perhaps some more soon

Modelling of Outer Layers (readout only)

Work in progress

Integration studies @CERN

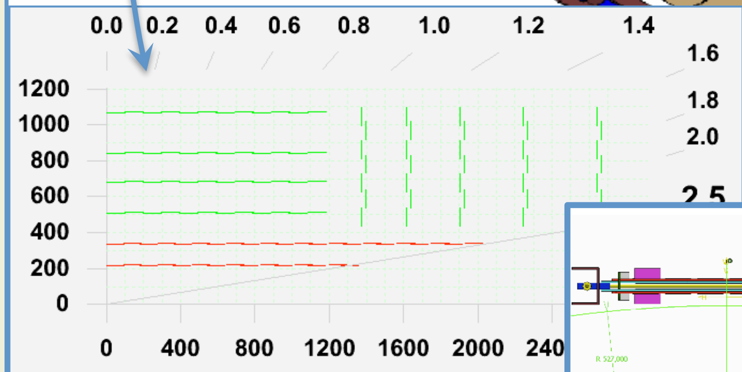


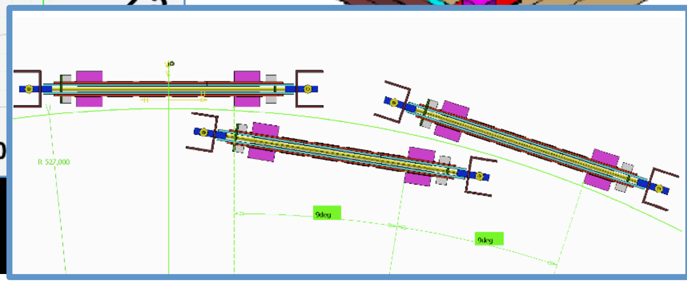


Thermal modelling @ UCSB

Susanne Kyre, Dean White

First results very encouraging





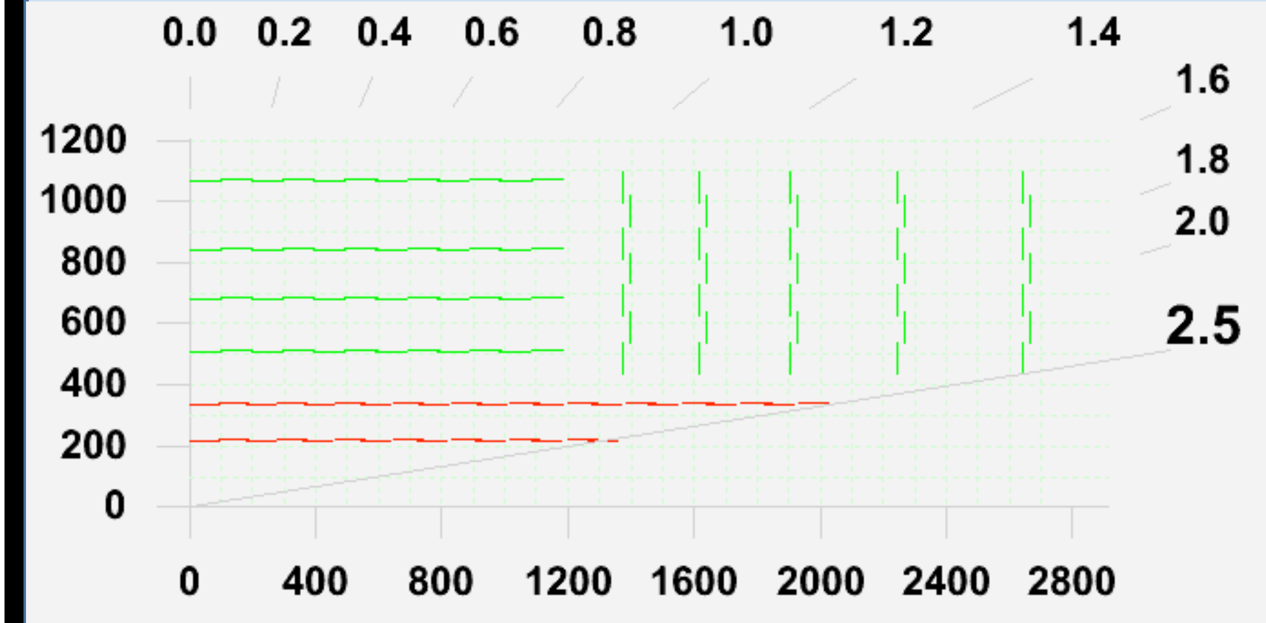
General concepts

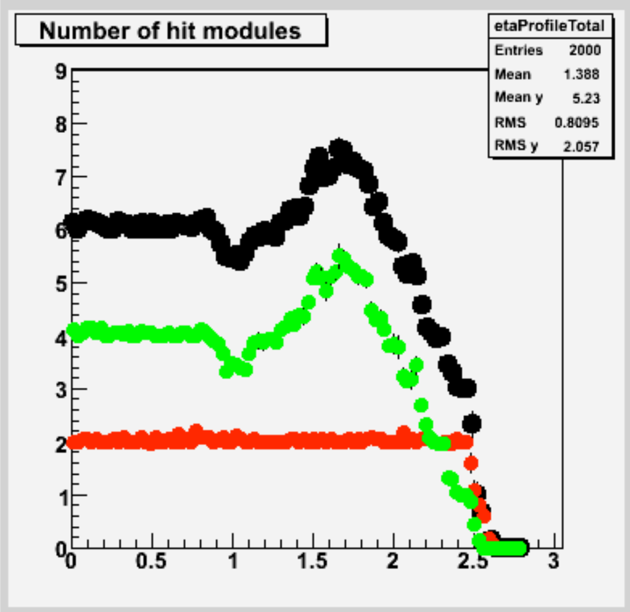
(details given in previous presentations)

- Strip length reduced to ≈ 5 or 2.5 cm to cope with particle density
- Hybrids mounted on sensors. One hybrid serving two rows of strips
- Pitch adapter integrated on hybrid (or on sensor)
- Power through wires, data through twps, no large PCBs
- Optical links (GBT) integrated at the end of the rods (periphery of disks)
  - **GBTs receive twps from modules**
  - **Assume TOB twps, for the time being**
- Power converters integrated on small separate PCBs, one per hybrid
- Mechanics and cooling contacts adapted from present TOB
  - **Assume CO_2 cooling**
- For material modelling take wires, connectors and all other elements from TOB
  - **A priori pessimistic**
  - **Should ensure that nothing relevant is forgotten**

Some studies on outer part

Layout taken as reference:





Outer Part:

- 4 single-sided layers in the radial range 50-110 cm (barrel)
- A 12-module long Barrel requires a 5 disks forward to complete rapidity coverage

In the example above:

- Same rectangular modules in Barrel and End-Cap
- Two versions used: 110 µm × 2.5 cm and 110 µm × 5 cm

Show results about this option, then make one step back and compare with other options

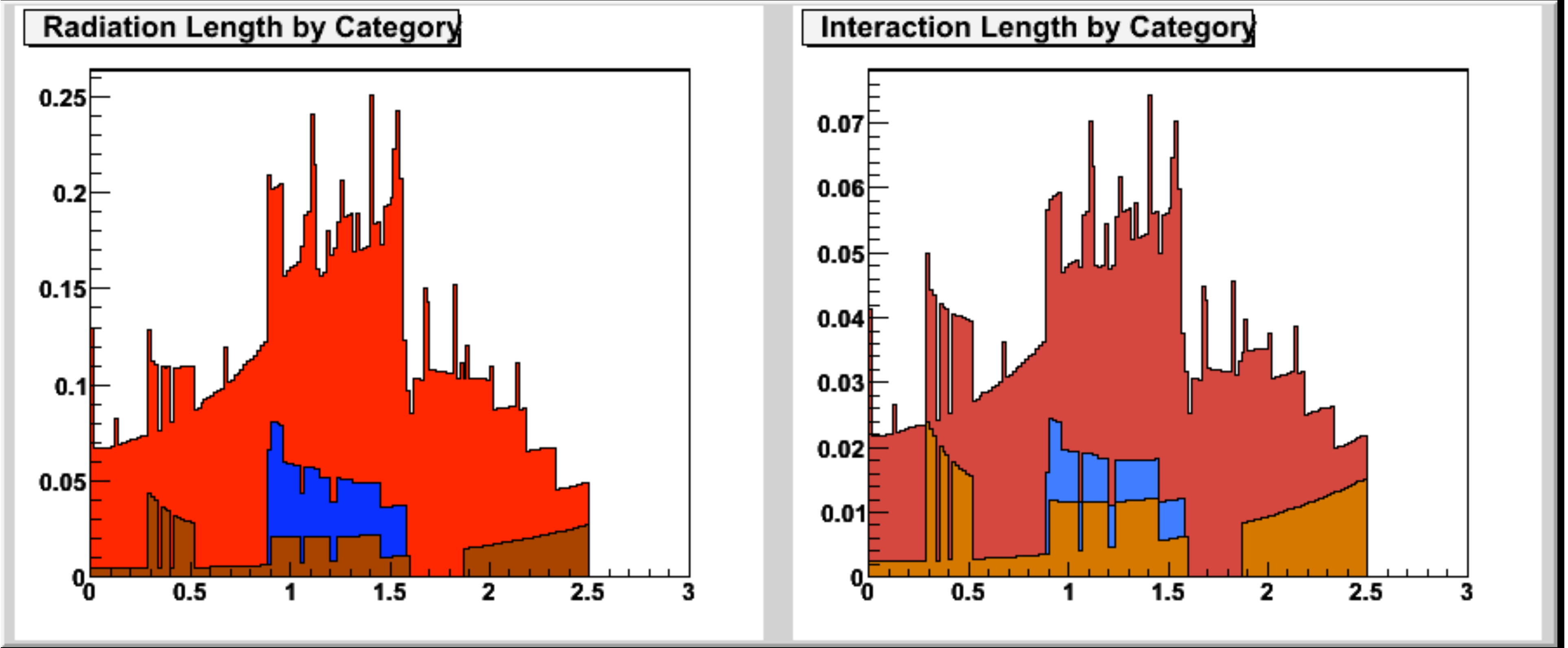
Statistics

Tag	OB_L1	OB_L2	OB_L3	OB_L4	EC_R1	EC_R2	EC_R3	EC_R4	EC_R5	EC_R6	EC_R7	
Type	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	--
Area (mm^2)	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	85.1(m^2)
Occup (max/av)	2.7/2.6	3.2/3.0	1.9/1.8	0.8/0.8	3.9/3.5	2.8/2.5	2.2/2.0	3.3/3.0	2.6/2.4	2.0/1.8	1.7/1.5	--
Pitch (min/max)	110	110	110	110	110	110	110	110	110	110	110	--
Segments x Chips	4x6	2x6	2x6	2x6	4x6	4x6	4x6	2x6	2x6	2x6	2x6	--
Strip length	24.9	49.8	49.8	49.8	24.9	24.9	24.9	49.8	49.8	49.8	49.8	--
Chan/Sensor	3072	1536	1536	1536	3072	3072	3072	1536	1536	1536	1536	--
N. mod	960	1248	1536	2016	400	480	560	600	680	760	800	10040
Channels (M)	2.95	1.92	2.36	3.1	1.23	1.47	1.72	0.92	1.04	1.17	1.23	19.11
Power (kW)	1.5	1	1.2	1.5	0.6	0.7	0.9	0.5	0.5	0.6	0.6	9.6
N of GBTs	160	104	128	168	80	80	120	60	60	80	80	1120
GBT power (kW)	0.3	0.2	0.3	0.3	0.2	0.2	0.2	0.1	0.1	0.2	0.2	2.2

Assumptions for power

- Readout: 0.5 mW / channel
- 2 W / GBT optical channel

Material inside tracking volume



	Rad length	Int length	
AVG in η=[0,2.4]	0.12	0.038	
Peak	0.2	0.06	in η=[0.9,1.6]
Services on flange	0.03	0.006	in η=[0.9,1.6]

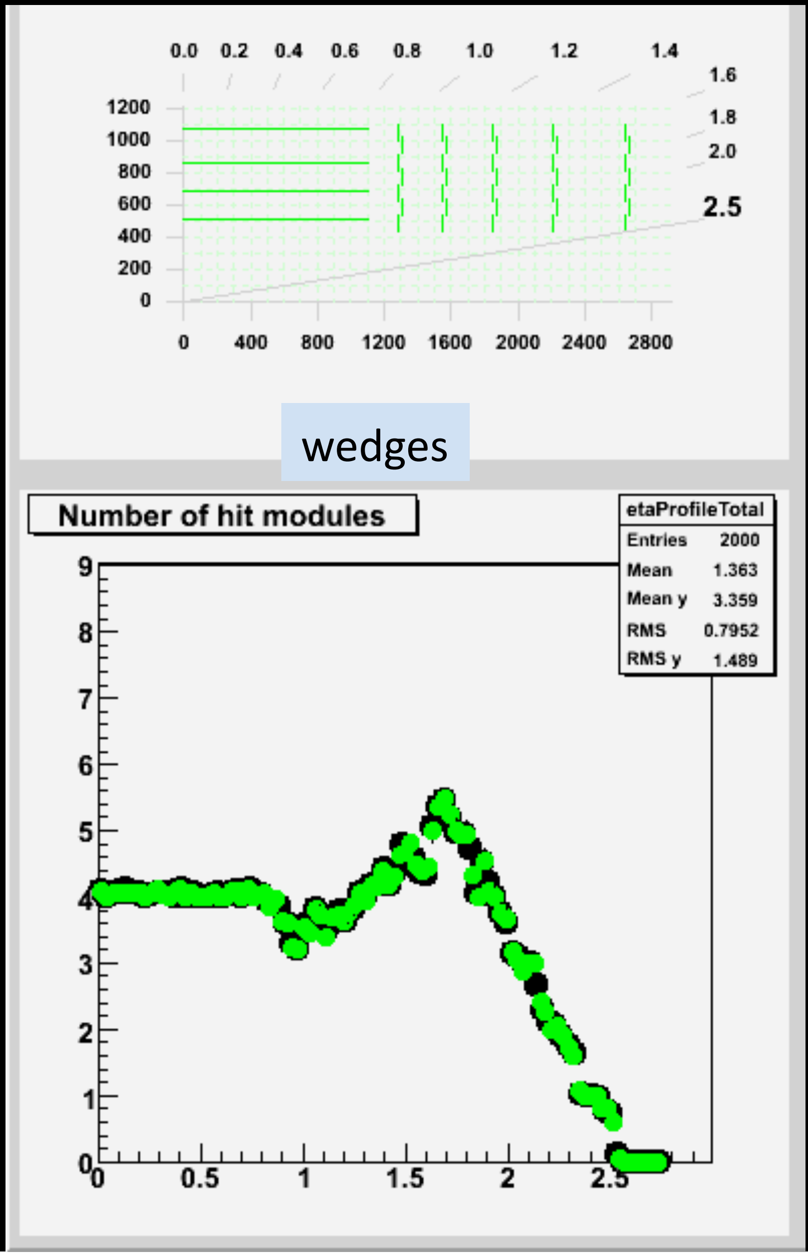
One step back: EndCap with wedges

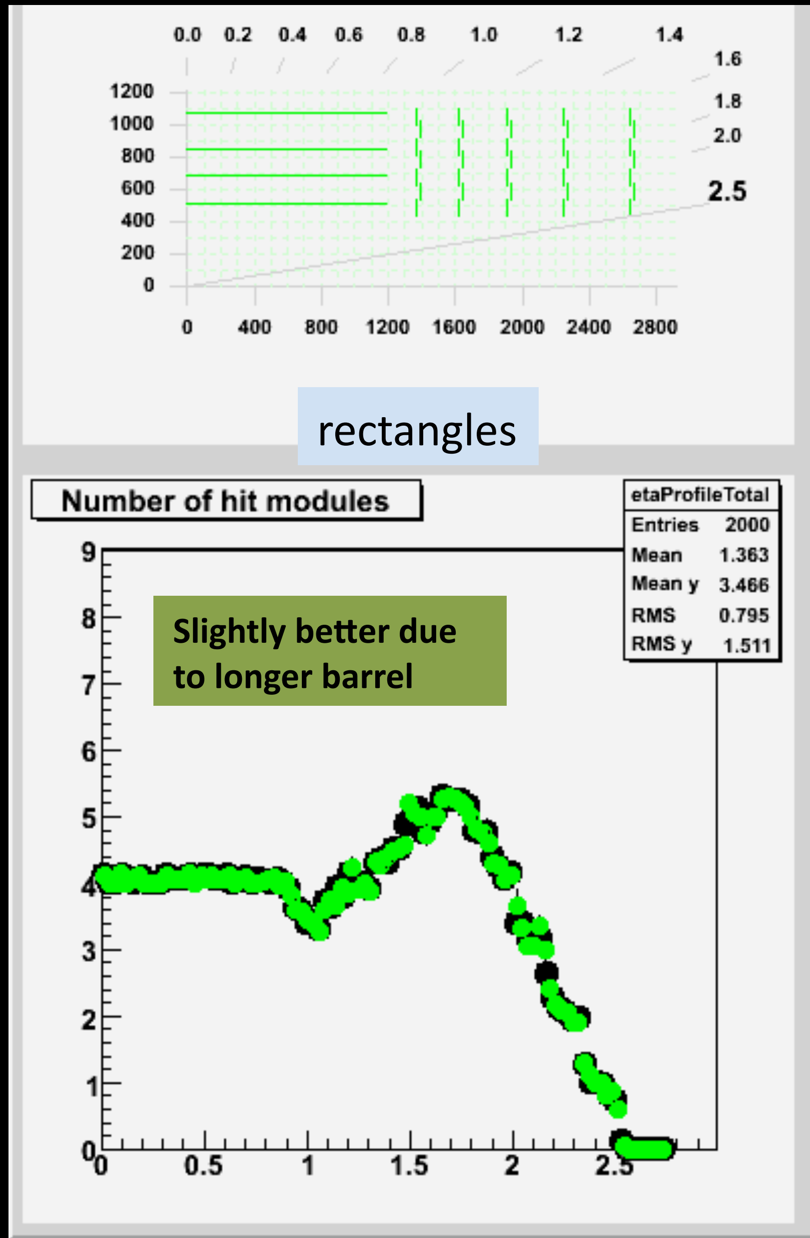
This was the starting point

Comparison of optimization procedures

- EndCap with wedges
  - Build barrel with square modules (optimal use of of silicon), with a chosen number of modules along z
  - Position disks after barrel, optimize overall use of silicon in all rings (e.g. in the specific case "stretch" the shape compared to individual optimization)
- EndCap with same modules as barrel
  - Modify aspect ratio to cover radial range with integer number of rings
  - Recalculate barrel
  - Iterate to account for second order effects
    - Barrel modules are not square anymore
    - EndCap modules have excess of overlap because of non-optimal shape
    - Expect penalty in n of modules, n of channels, power, material

Comparisons: coverage

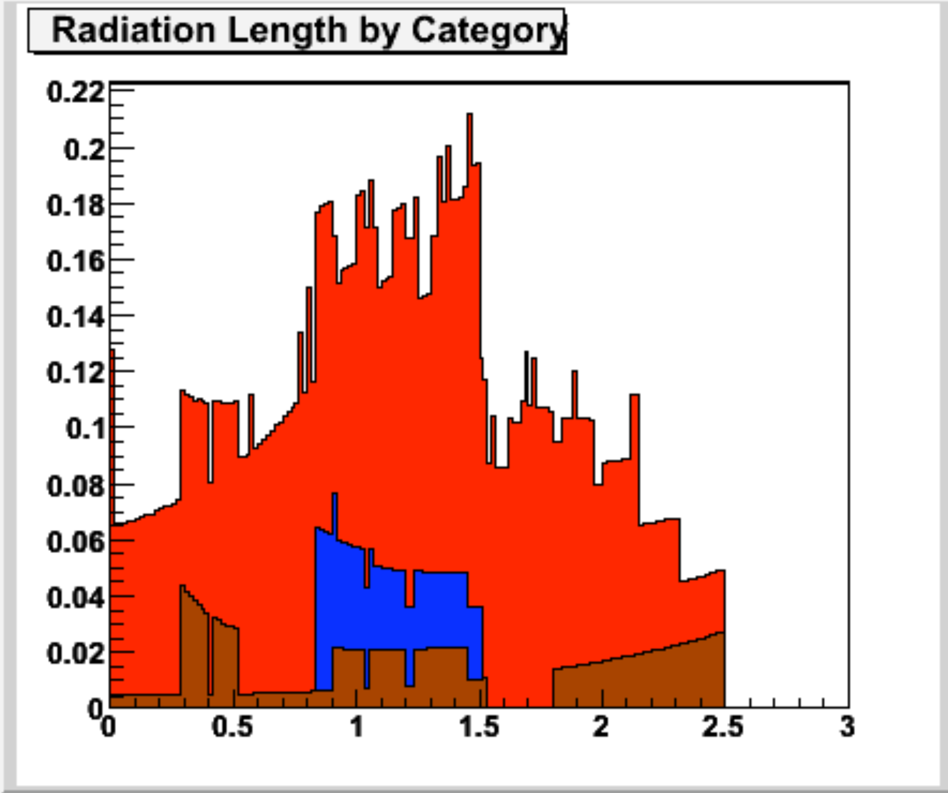


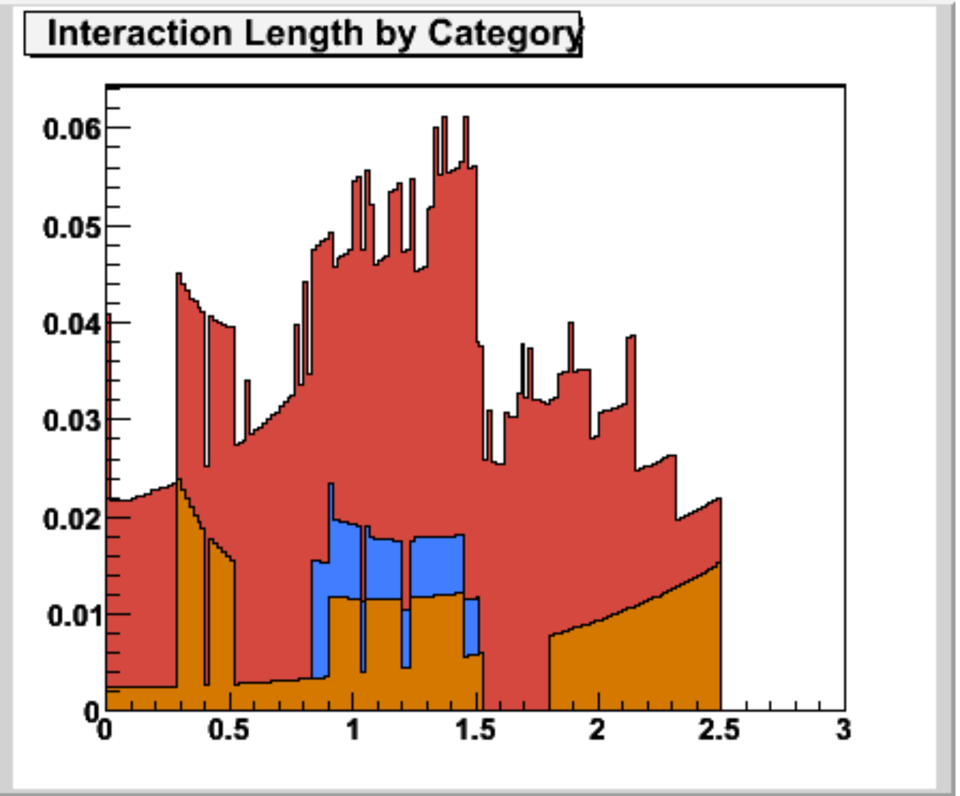


Wedges: statistics

Tag	OB_L1	OB_L2	OB_L3	OB_L4	EC_R1	EC_R2	EC_R3	EC_R4	EC_R5	EC_R6	EC_R7	
Type	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	--
Area (mm^2)	8580.5	8580.5	8580.5	8580.5	8439.9	8438.5	8371.2	8521.3	8304.2	8334.4	8167.5	80.5(m^2)
Occup (max/av)	2.7/2.6	3.2/3.0	1.8/1.8	0.9/0.8	3.5/3.1	2.6/2.3	2.0/1.8	3.1/2.8	2.5/2.2	1.9/1.7	1.6/1.4	--
Pitch (min/max)	120	120	120	120	100/123	101/120	99/115	108/122	98/111	100/111	103/113	--
Segments x Chips	4x6	2x6	2x6	2x6	4x6	4x6	4x6	2x6	2x6	2x6	2x6	--
Strip length	23.2	46.3	46.3	46.3	24.5	24.8	25.3	48.2	51.6	51.3	49.1	--
Chan/Sensor	3072	1536	1536	1536	3072	3072	3072	1536	1536	1536	1536	--
N. mod	960	1152	1440	1824	360	440	520	560	680	760	800	9496
Channels (M)	2.95	1.77	2.21	2.8	1.11	1.35	1.6	0.86	1.04	1.17	1.23	18.1
Power (kW)	1.5	0.9	1.1	1.4	0.6	0.7	0.8	0.4	0.5	0.6	0.6	9.0
N of GBTs	160	96	120	152	80	80	120	60	60	80	80	1088
GBT power (kW)	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.1	0.2	0.2	2.2

Wedges: material





	Rad length	Int length	
AVG in η=[0,2.4]	0.114	0.036	
Peak	0.18	0.055	in η=[0.9,1.6]
Services on flange	0.03	0.006	in η=[0.9,1.6]

Comparison: numbers

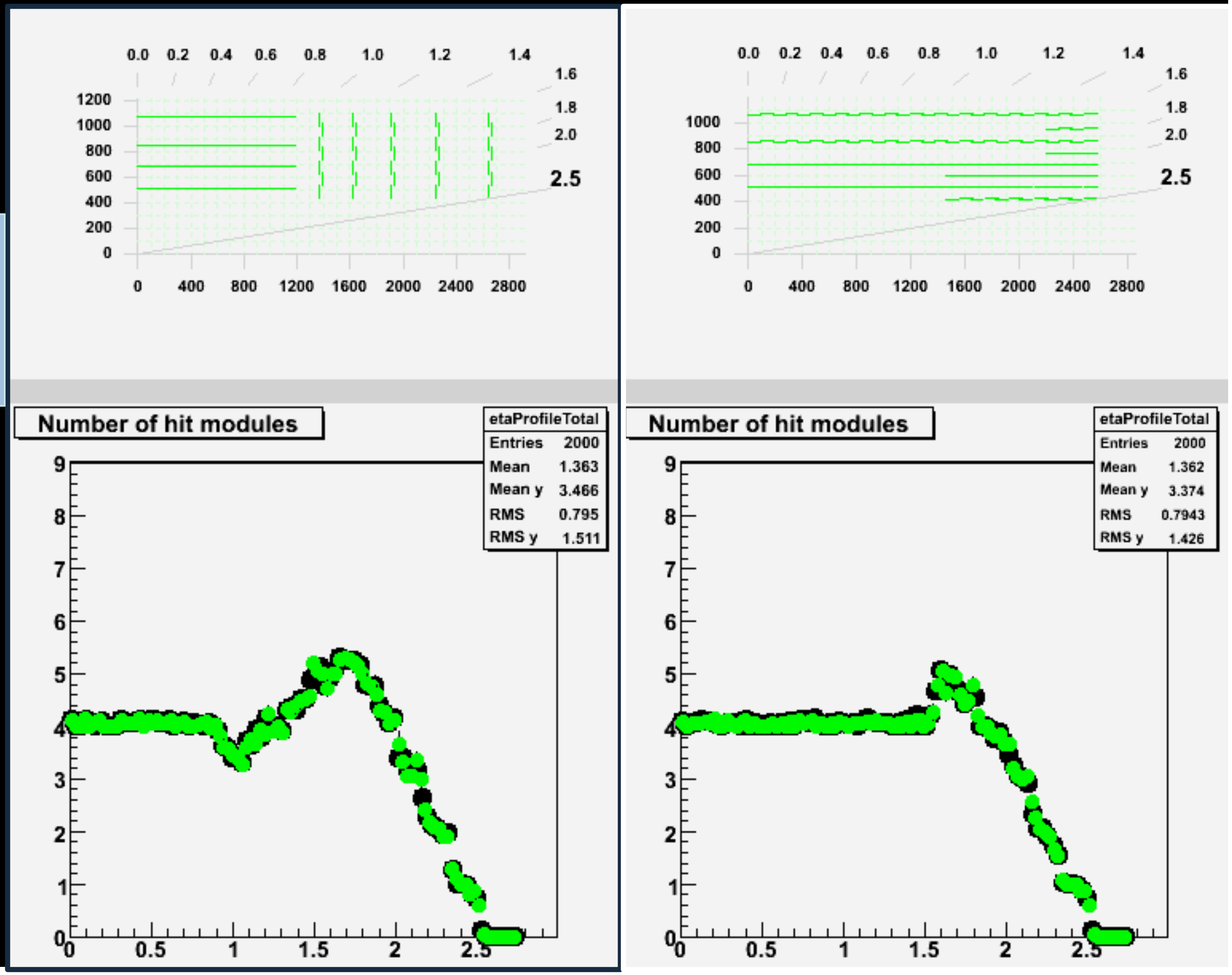
	Wedges	Rectangles	Increase
Sensor area barrel	8580.5	8475.8	
Sensor area forward	8368.1	8475.8	
Pitch barrel	120	110	
Pitch endcap	100/120	110	
Strip length barrel	23/46	25/50	
Strip length forward	25/50	25/50	
N of modules	9496	10040	5.7%
N of channels (M)	18.1	19.1	5.6%
FE power (kW)	9.0	9.6	6.7%
N of links	1088	1120	2.9%
Overall power (kW)	11.2	11.8	5.9%
$\langle X/X_0 \rangle$	0.114	0.120	5.6%
$\langle \lambda/\lambda_0 \rangle$	0.036	0.038	4.7%

- Penalty in n of modules, power, material ≈ 5%
- Comes also with some positive features
  - Slightly longer barrel / slightly better coverage
  - Smaller pitch in barrel
- Seems to be a good option!

Another study: barrel-only geometry for outer part

- First step: build two geometries with similar coverage

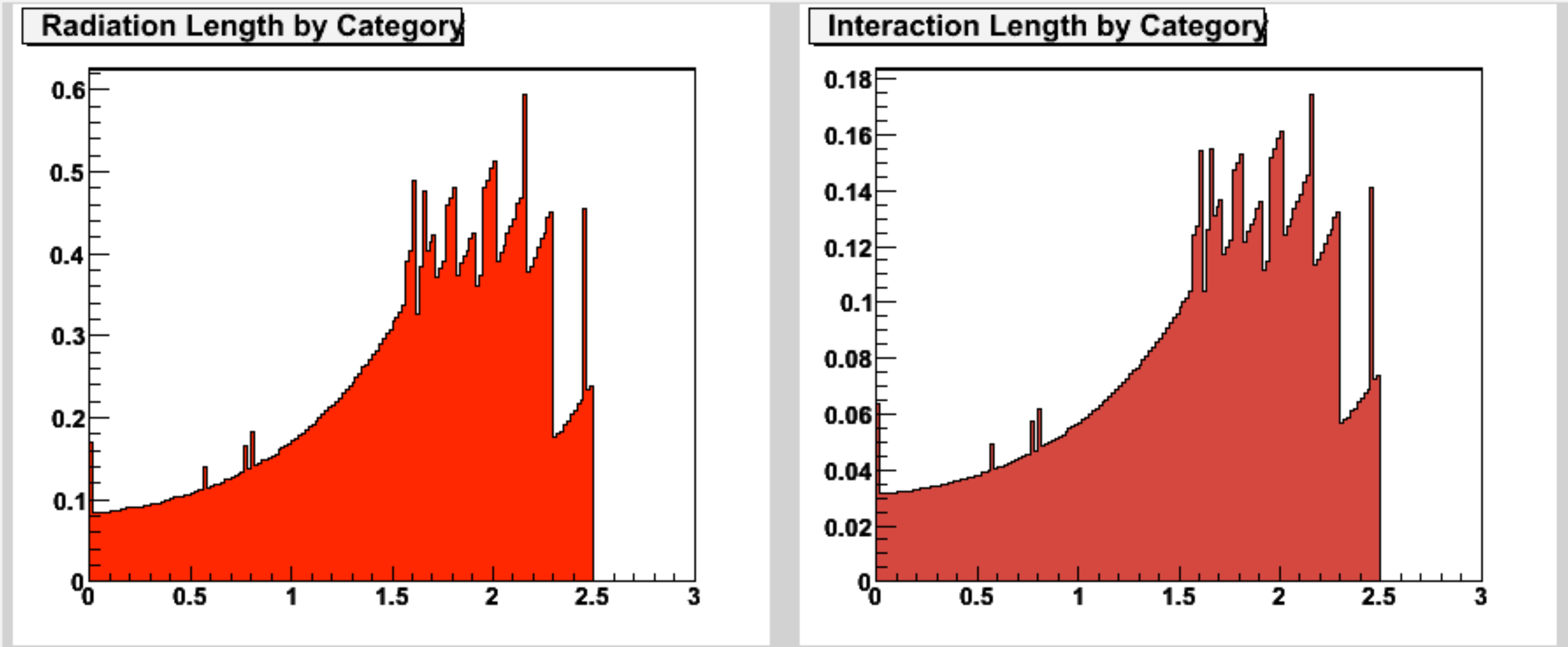
The barrel-only geometry can use square detectors



Barrel only: statistics

Outer - Barrel only									
Tag	SH_1_L1	SH_1_L2	SH_2_L1	SH_2_L2	OB_L1	OB_L2	OB_L3	OB_L4	Total
Type	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	--
Area (mm^2)	8580.5	8580.5	8580.5	8580.5	8580.5	8580.5	8580.5	8580.5	131.8(m^2)
Occup (max/av)	3.6/3.5	4.1/4.0	2.4/2.3	1.3/1.3	2.7/2.6	3.2/3.0	1.8/1.8	0.9/0.8	--
Pitch (min/max)	120	120	120	120	120	120	120	120	--
Segments x Chips	4x6	2x6	2x6	2x6	4x6	2x6	2x6	2x6	--
Strip length	23.2	46.3	46.3	46.3	23.2	46.3	46.3	46.3	--
Chan/Sensor	3072	1536	1536	1536	3072	1536	1536	1536	--
N. mod	768	1056	448	544	2240	2688	3360	4256	15360
Channels (M)	2.36	1.62	0.69	0.84	6.88	4.13	5.16	6.54	28.21
Power (kW)	1.2	0.8	0.3	0.4	3.4	2.1	2.6	3.3	14.1
GBTs	128	88	112	136	480	288	360	456	2048
Power (kW)									4.096

Barrel only: material



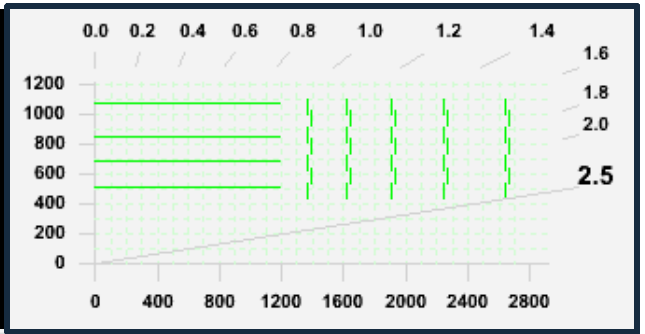
	Rad length	Int length	
AVG in η=[0,2.4]	0.244	0.079	
Peak	0.45	0.14	in η=[1.6,2.3]

Comparison: numbers

	EndCap	Barrel	Increase
Sensor area barrel	8475.8	8580.5	
Sensor area forward	8475.8	-	
Pitch barrel	110	120	
Pitch endcap	110	-	
Strip length barrel	25/50	23/46	
Strip length forward	25/50	-	
N of modules	10040	15360	53%
N of channels (M)	19.1	28.2	48%
FE power (kW)	9.6	14.1	47%
N of links	1120	2048	83%
Overall power (kW)	11.8	18.2	54%
$\langle X/X_0 \rangle$	0.120	0.244	103%
$\langle \lambda/\lambda_0 \rangle$	0.038	0.079	108%

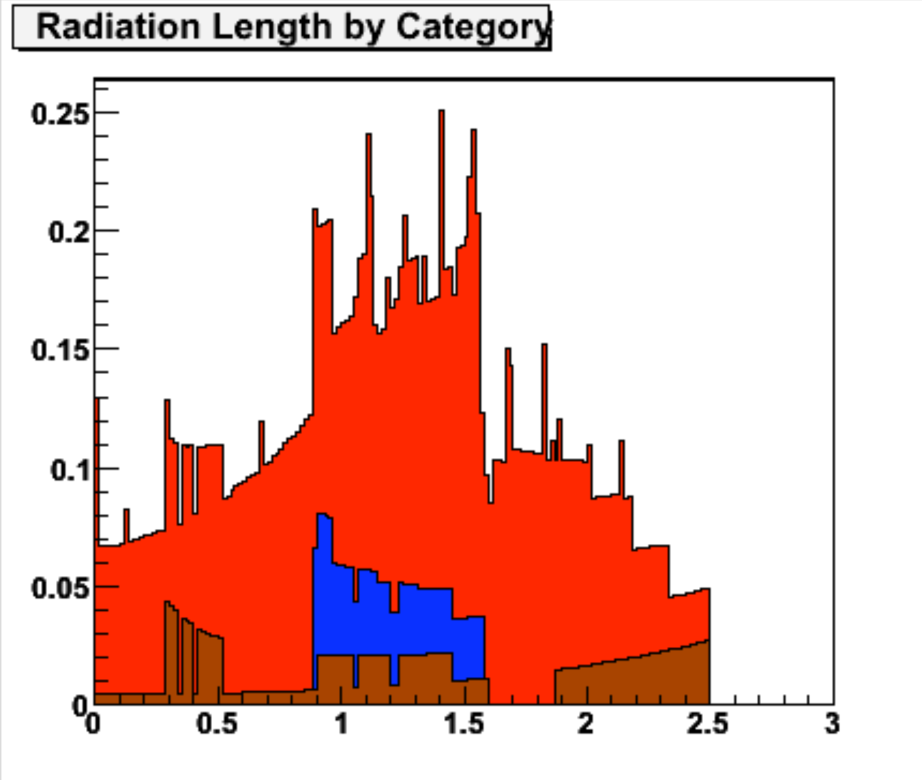
- Despite the use of square sensors, the Barrel-only has a large penalty
  - Particularly bad at low radii
- Barrel + Endcap is clearly preferable

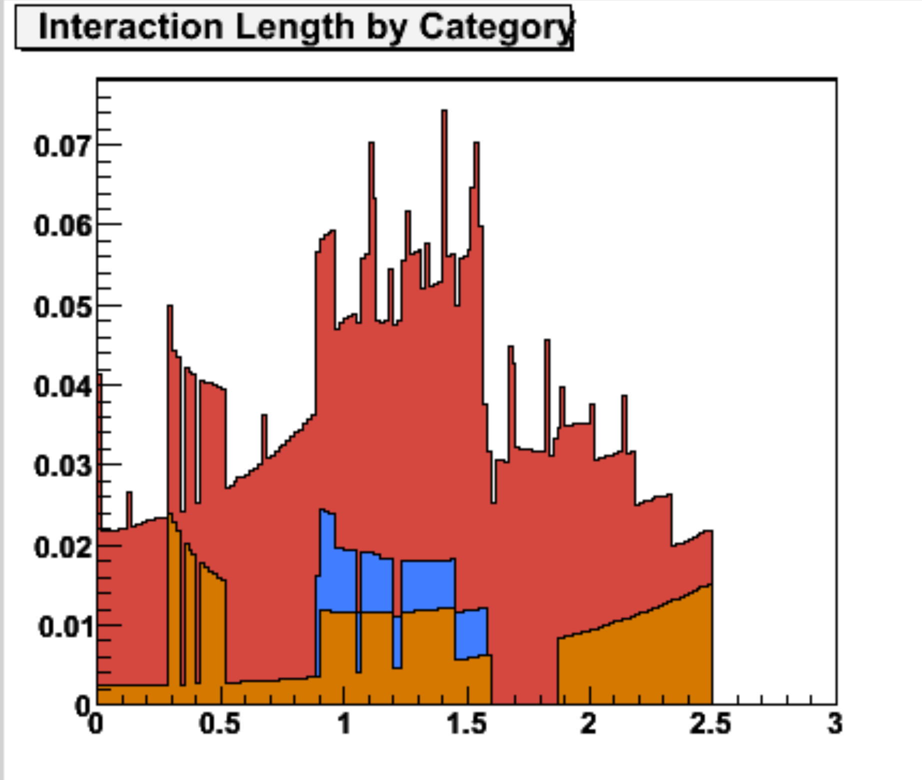
Another small study: location of GBTs



GBTs at the end of the barrel

(option shown before)

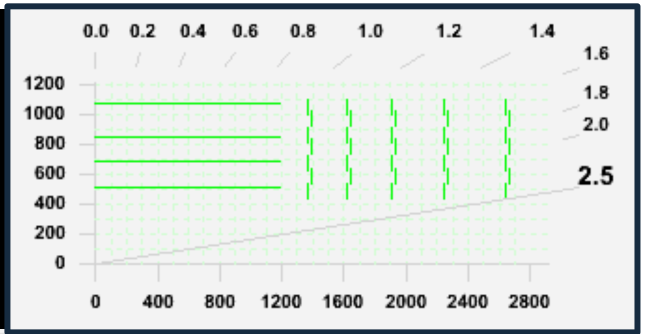


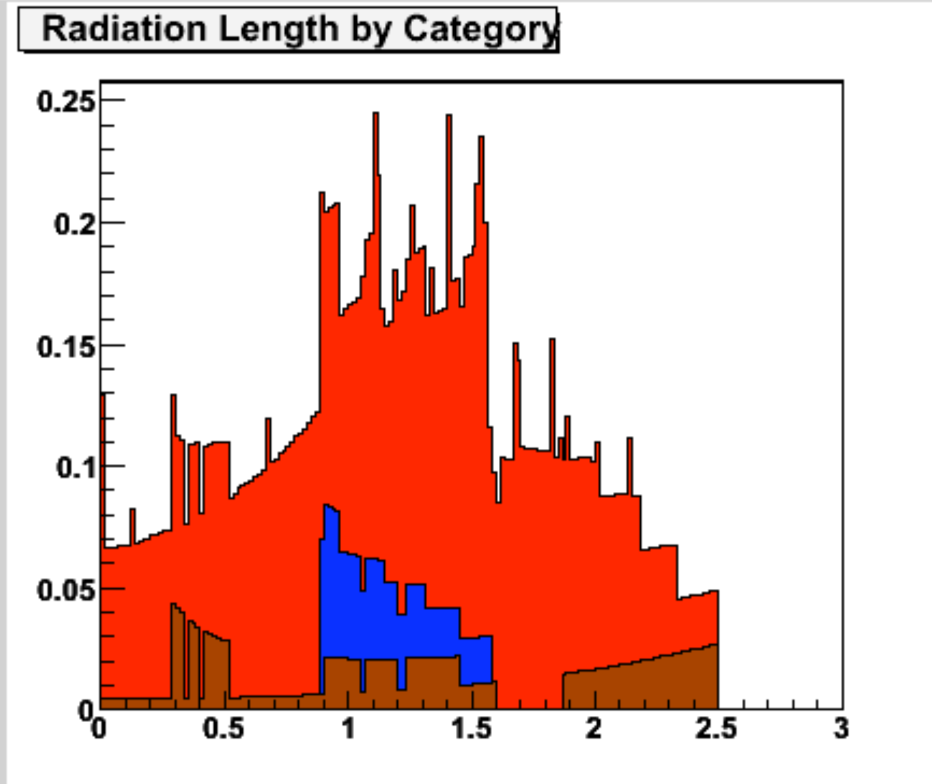


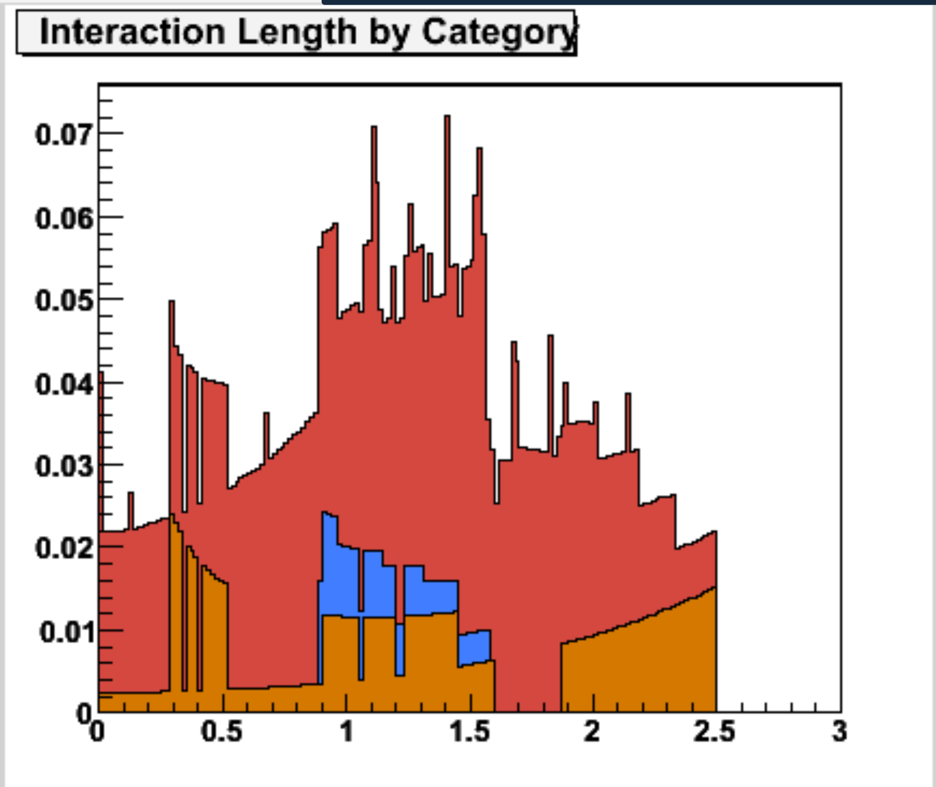
Another small study: location of GBTs

GBTs outside the Tracking volume

(e.g. over the EndCap or on bulkhead)





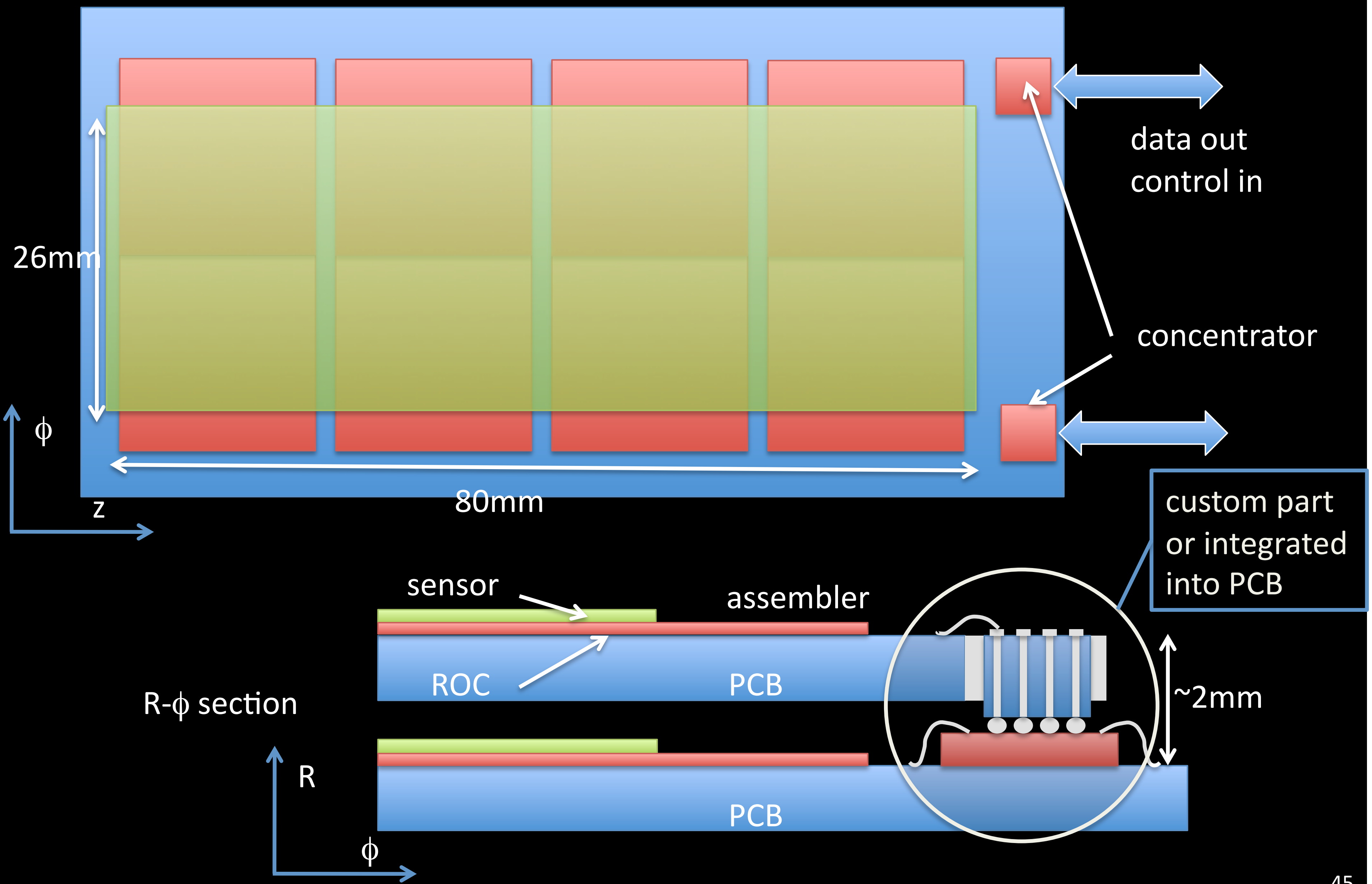


- Basically no change
  - With present assumptions material of twps ≈ material of GBTs + power wires
  - To be re-evaluated in future

Next step: modelling of P_T layers

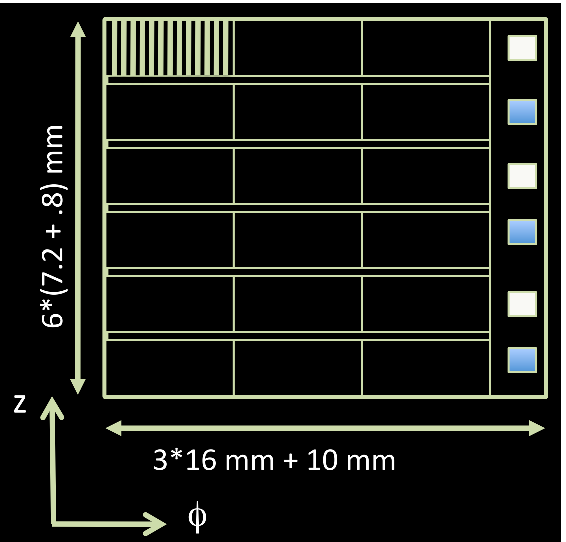
- Understanding of integration aspects much more limited than for readout layers
  - Dedicated discussion in TUPO last week
  - Expect more progress in the coming weeks/months
- Used as baseline the two geometries presented in the R&D proposal from Geoff/Anders
  - Surface similar, module material similar, power estimates compatible, data rate the same (given by functionality)
    - No need to distinguish between the two at this stage
- Part list should be reasonably OK
  - Although it is not yet understood how they may come together
  - Some provision of material for cooling (and mechanics)
  - Basic assumptions recalled in the following slides

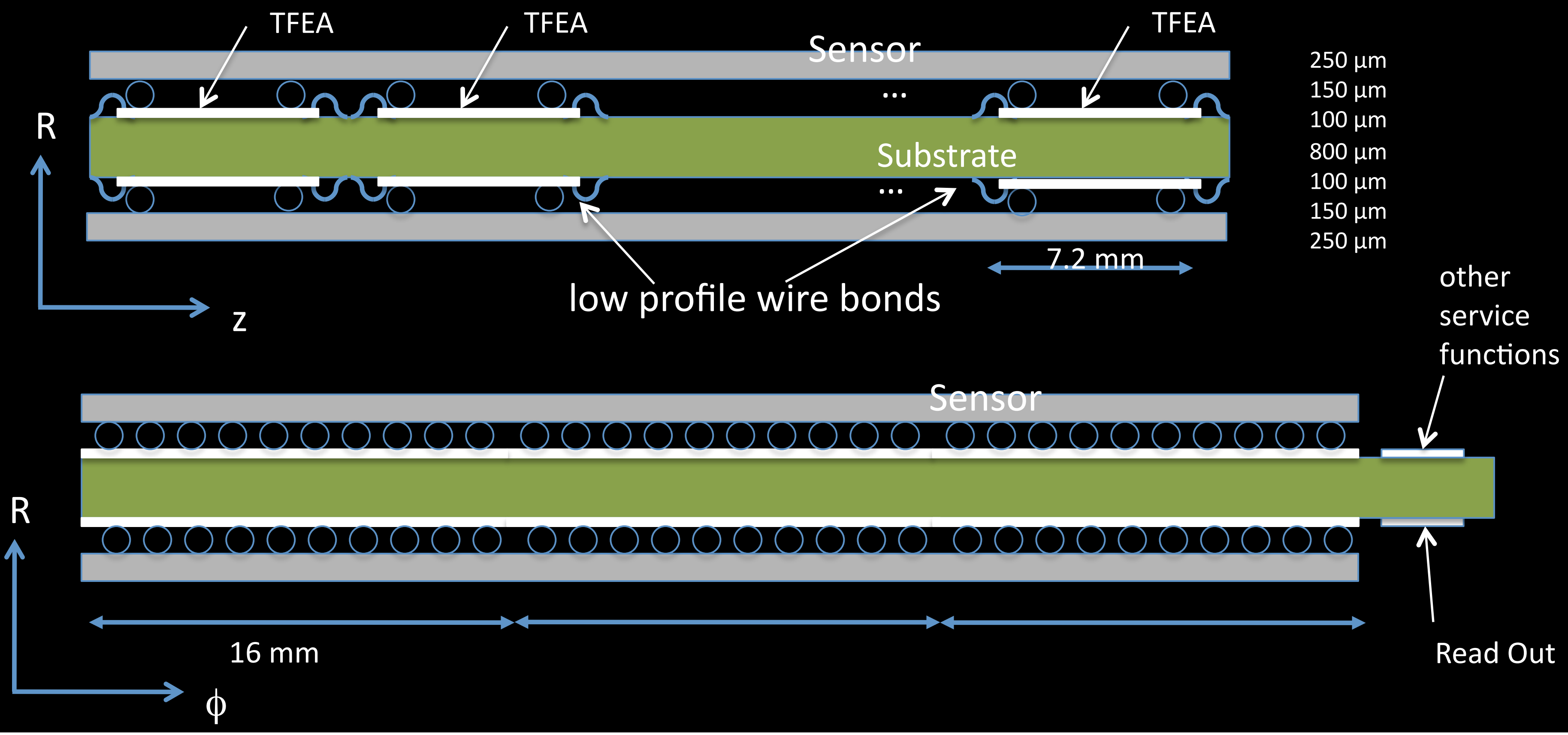
P_T module with horizontal link



P_T module with vertical link

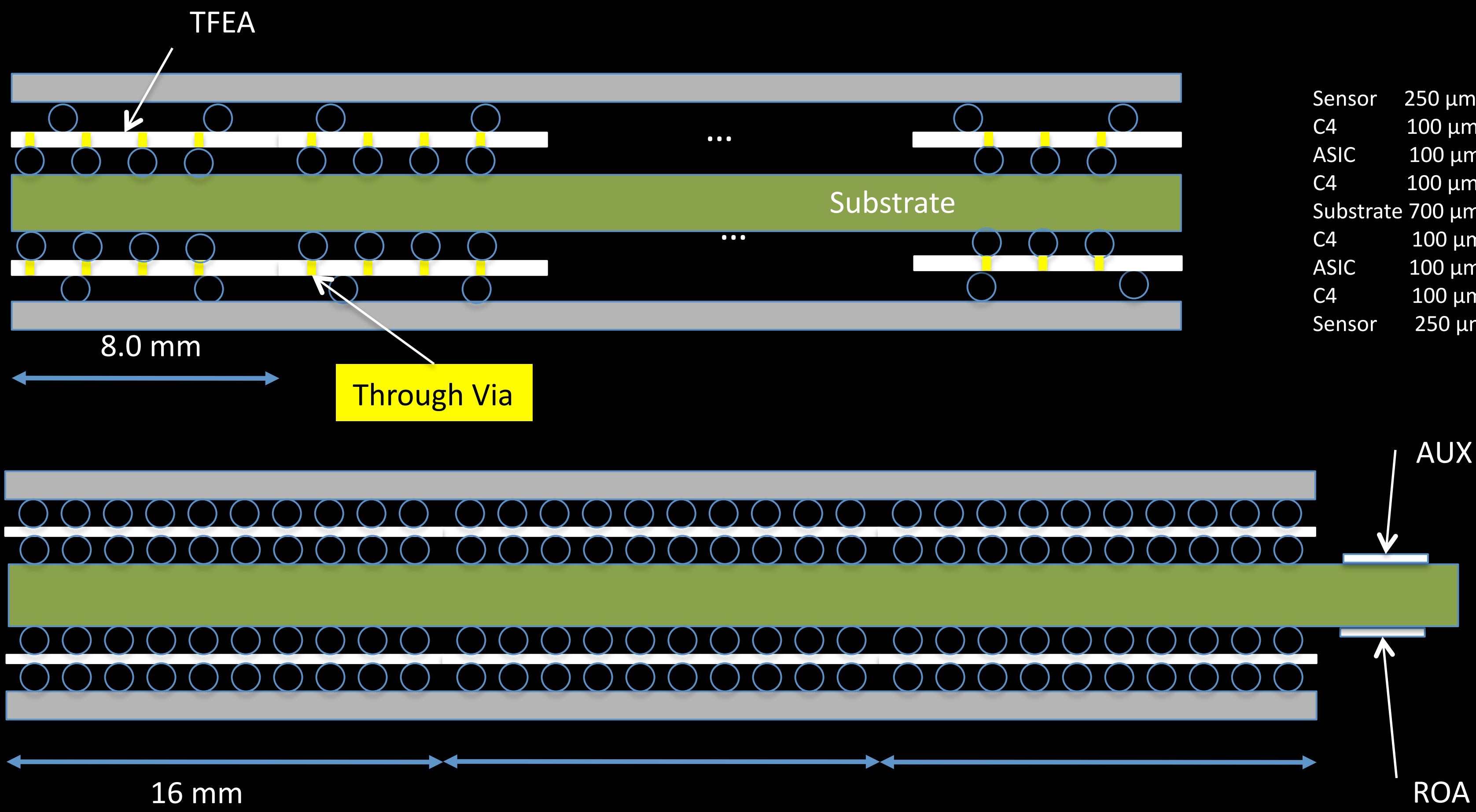
- “Vertical” data transmission through substrate
- Correlation logic implemented at pixel level
- Dimension limited by substrate technology





P_T module with vertical link – a variant

- Same as before with different interconnection technology
- Double bump assembly with through vias in the chip

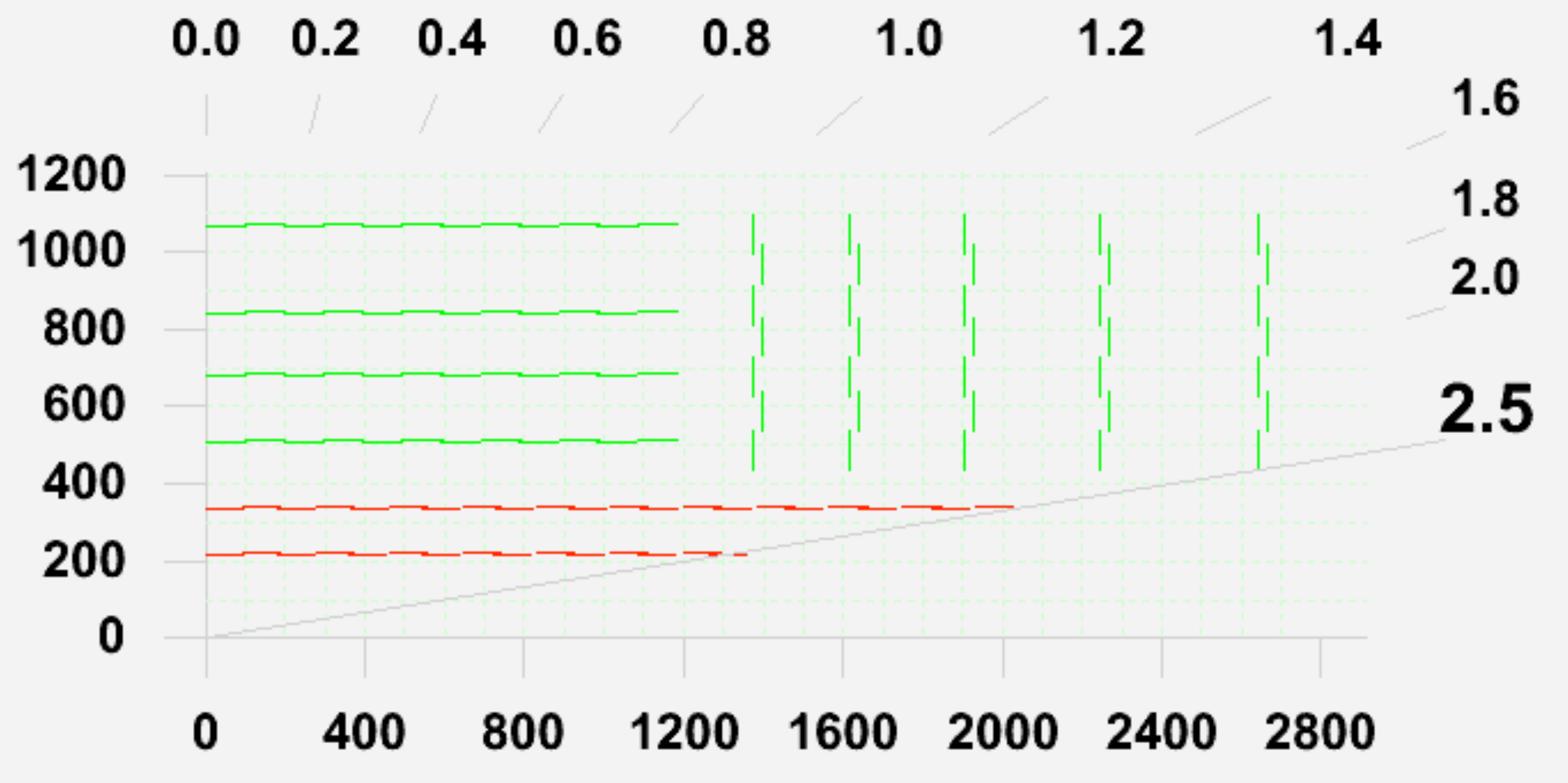


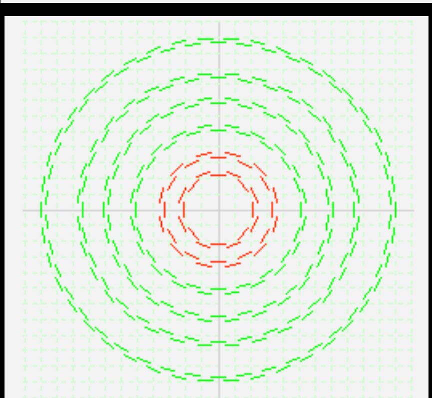
Sensor	250 µm
C4	100 µm
ASIC	100 µm
C4	100 µm
Substrate	700 µm
C4	100 µm
ASIC	100 µm
C4	100 µm
Sensor	250 µm

Part list and assumptions

- Module
  - 2×200 μm sensor thickness
  - 800 μm substrate with ≈70 μm Cu
- GBTs
  - One link / module for trigger
  - One link / 12 modules for readout (4 twps / module)
- Power converters
  - 3 converters / (module + trigger GBT)
  - 2 converters / readout GBT
- Cooling
  - 2 straight pipes per row of modules
  - Provision of some TPG and Alu for cooling contacts
- Mechanics
  - Some CF…
- Wires, connectors etc…
  - As in readout layers

Two P_T layers





- Layers still modelled with ≈ 10×10 cm^2 sensors
  - **Multiplicities given earlier rescaled accordingly**
- Along rϕ, module multiplicity in ratio 2:3 in the two layers
  - **Convenient to define sectors**

Statistics

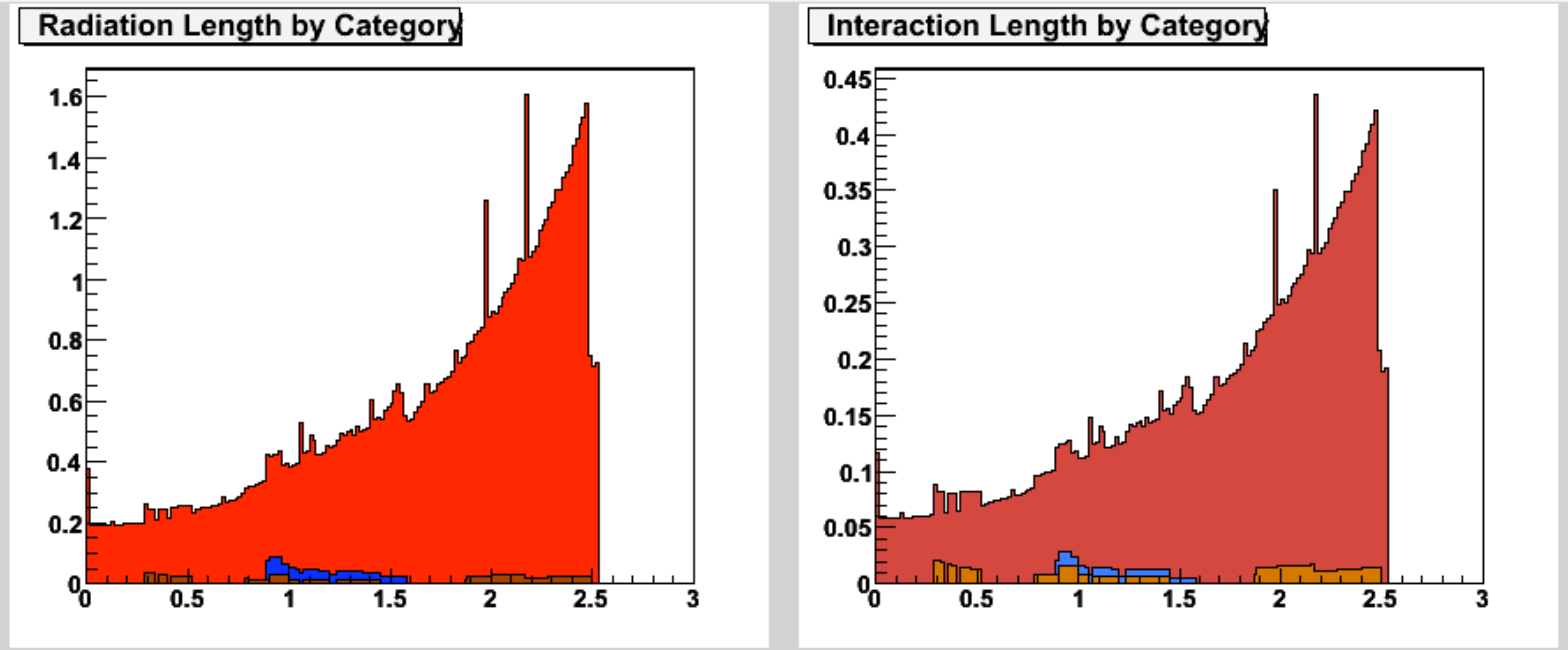
Two Pt layers + Outer tracker														
Tag	PT_L1	PT_L2	OB_L1	OB_L2	OB_L3	OB_L4	EC_R1	EC_R2	EC_R3	EC_R4	EC_R5	EC_R6	EC_R7	Total
Type	pt	pt	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	rphi	--
Area (mm2)	8580.5	8580.5	--	--	--	--	--	--	--	--	--	--	--	26.9(m2)
Area (mm2)	--	--	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	8475.8	85.1(m2)
Occup (max/av)	1.0/0.9	0.6/0.5	2.7/2.6	3.2/3.0	1.9/1.8	0.8/0.8	3.9/3.5	2.8/2.5	2.2/2.0	3.3/3.0	2.6/2.4	2.0/1.8	1.7/1.5	--
Pitch (min/max)	90	90	110	110	110	110	110	110	110	110	110	110	110	--
Segments x Chips	36x8	36x8	4x6	2x6	2x6	2x6	4x6	4x6	4x6	2x6	2x6	2x6	2x6	--
Strip length	2.6	2.6	24.9	49.8	49.8	49.8	24.9	24.9	24.9	49.8	49.8	49.8	49.8	--
Chan/Sensor	36864	36864	3072	1536	1536	1536	3072	3072	3072	1536	1536	1536	1536	--
N. mod	512	1056	960	1248	1536	2016	400	480	560	600	680	760	800	11608
N. sens	1024	2112	960	1248	1536	2016	400	480	560	600	680	760	800	13176
Channels (M)	--	--	2.95	1.92	2.36	3.1	1.23	1.47	1.72	0.92	1.04	1.17	1.23	19.11
Channels (M)	37.75	77.86	--	--	--	--	--	--	--	--	--	--	--	115.61
Power (kW)	3.8	7.8	1.5	1	1.2	1.5	0.6	0.7	0.9	0.5	0.5	0.6	0.6	21.1
GBTs (readout)	192	384	160	104	128	168	80	80	120	60	60	80	80	1696
Power (kW)														3.4
GBTs (trigger)	2048	4224												6272
Power (kW)														12.5
Total Power (kW)														37.0

Assumptions for power

- Readout: 0.5 mW / channel
- P_T: 0.1 mW / channel
- 2 W / GBT

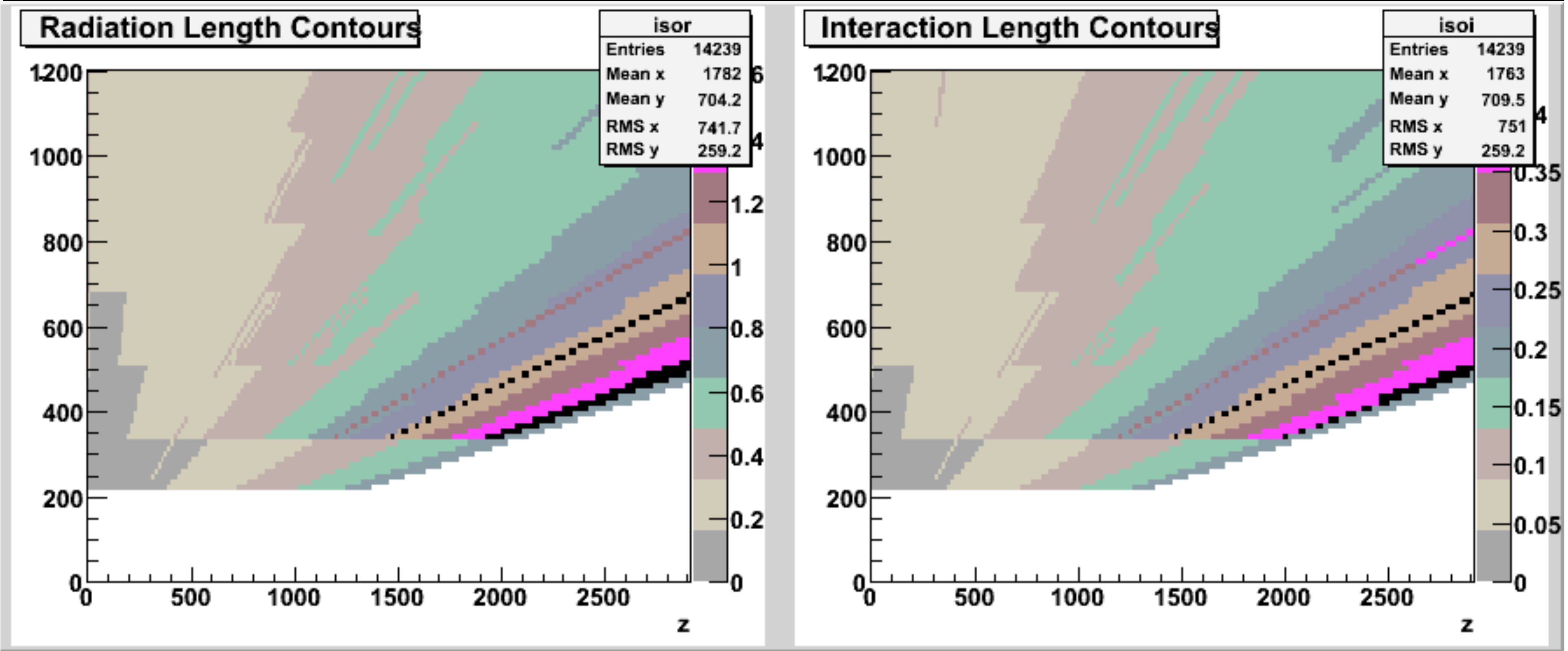
- N.B. P_T module count in the table corresponds to ≈ 10×10 cm^2 sensors

Material



- Average radiation length in tracking volume [0, 2.4]: 55%
  - Max of ≈155%
- Average interaction length in tracking volume [0, 2.4]: 16%
  - Max of ≈42%
- Material entirely dominated by the two P_T layers

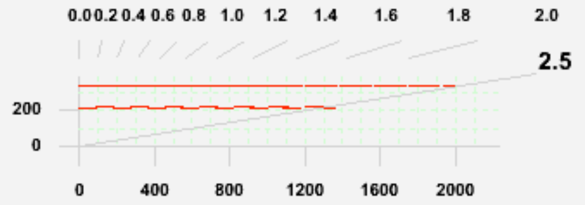
Material

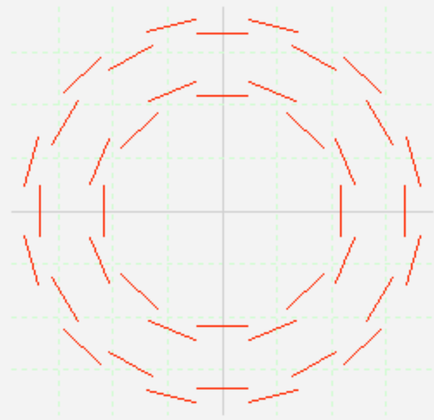


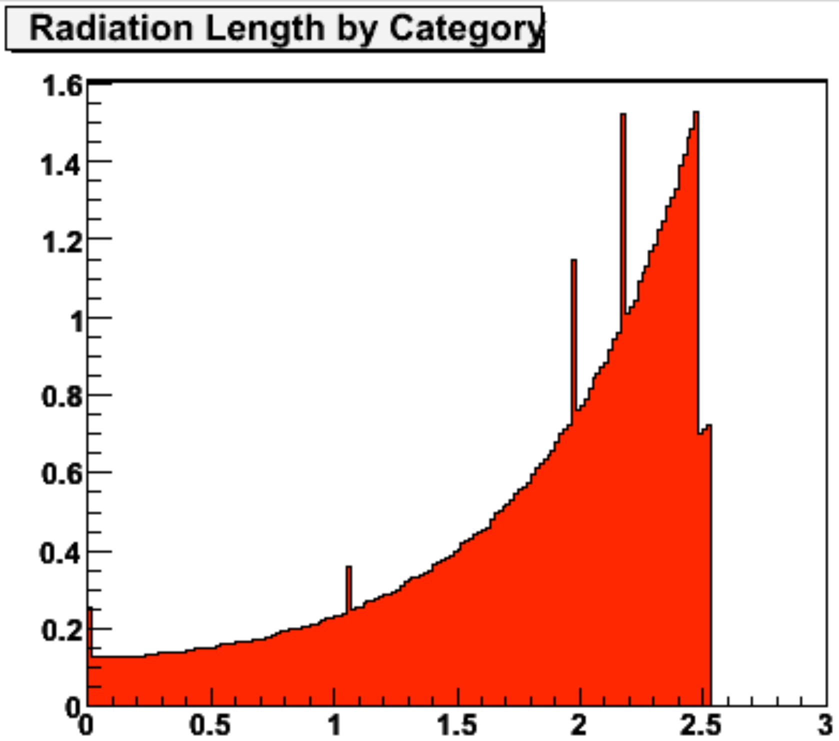
- Average radiation length in tracking volume [0, 2.4]: 55%
  - Max of ≈155%
- Average interaction length in tracking volume [0, 2.4]: 16%
  - Max of ≈42%
- Material entirely dominated by the two P_T layers

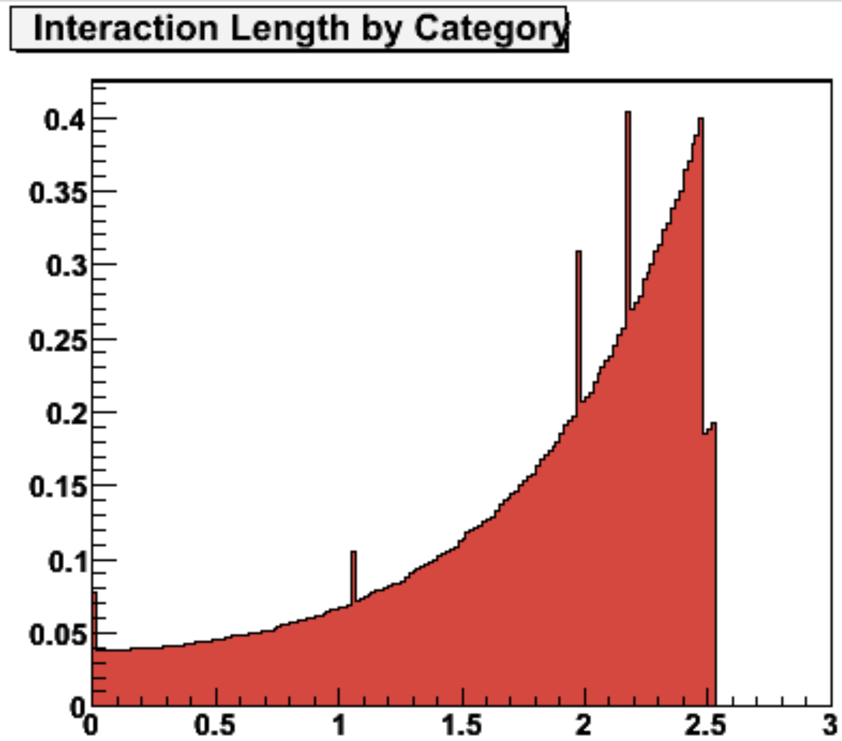
More on P_T layers

- Two PT layers only
- No complication from geometry

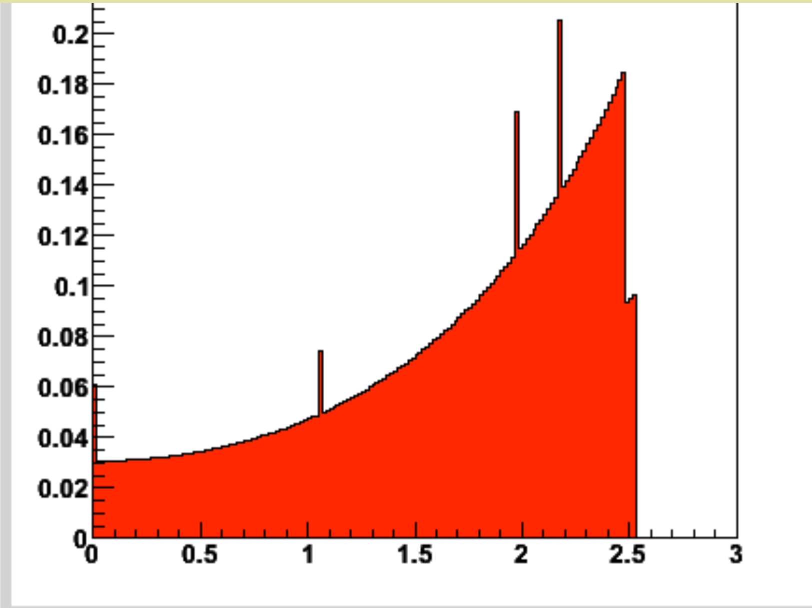




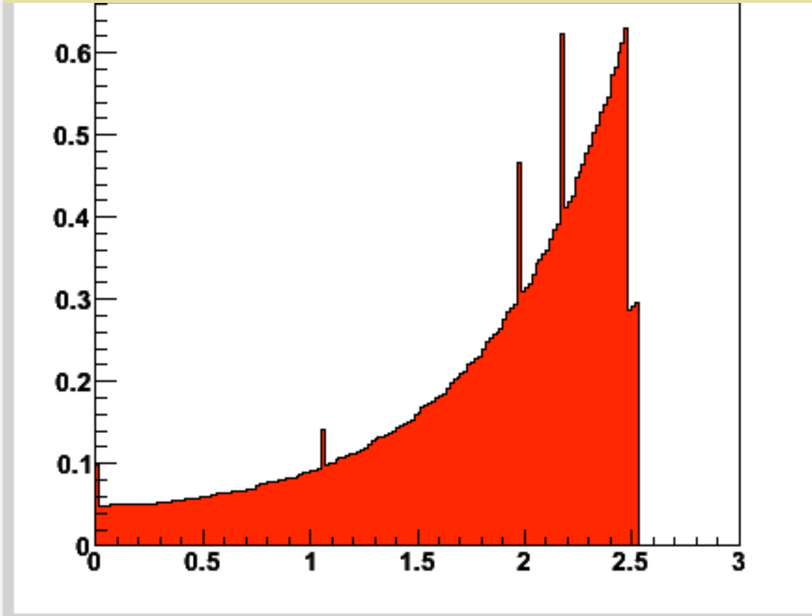




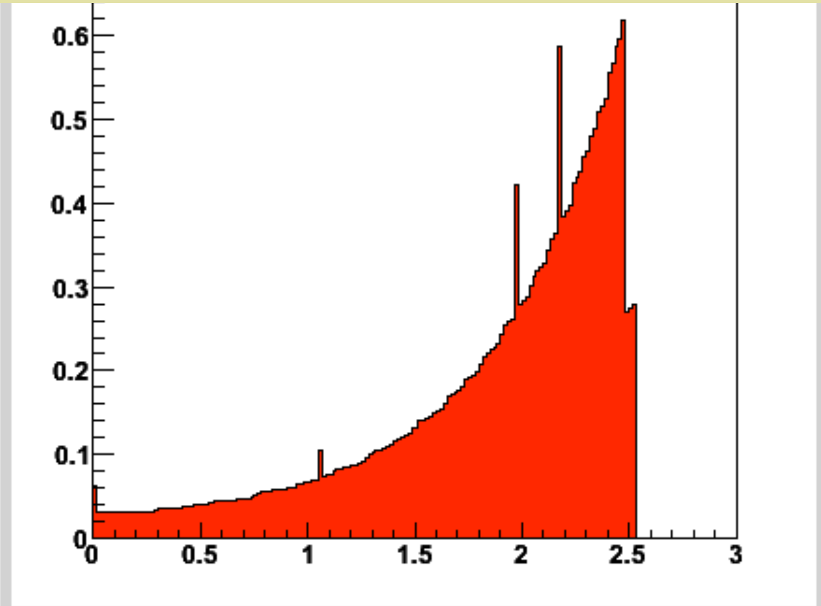
Sensors and substrate



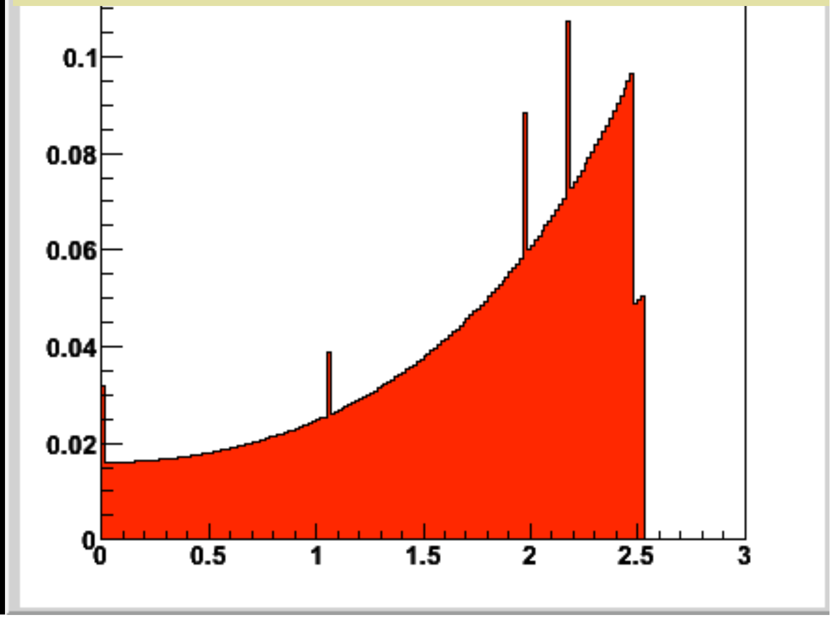
FE power and cooling



GBTs + their power and cooling



Rest

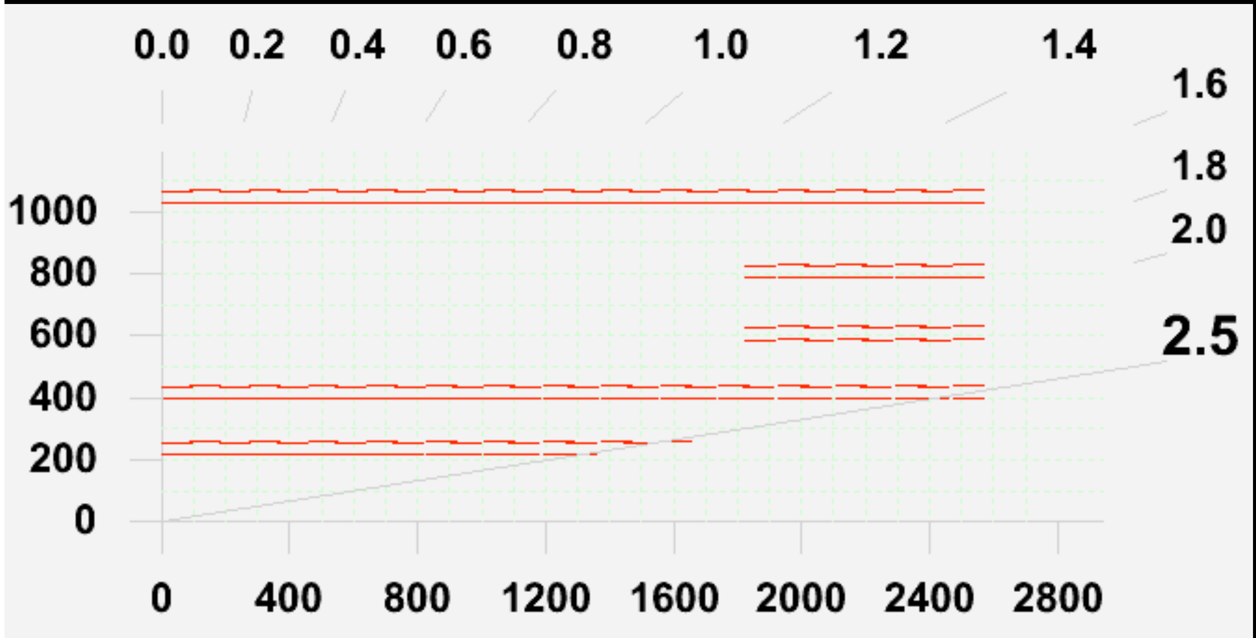


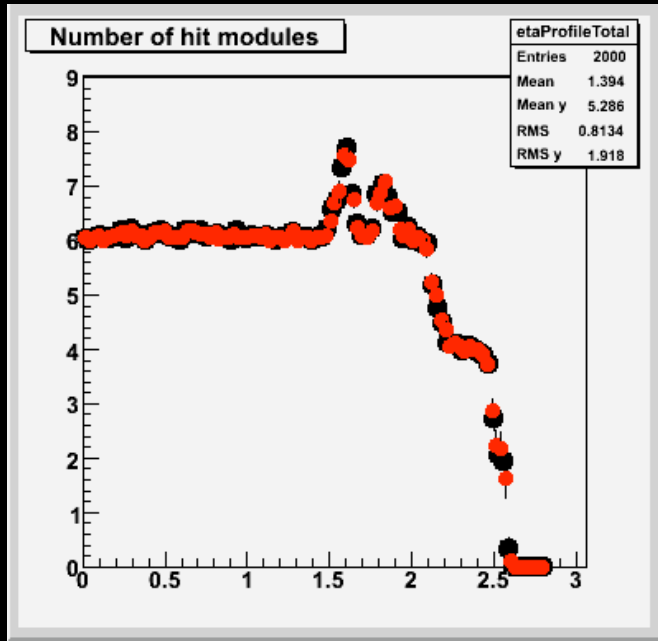
Comparison in numbers

	Average X/X_0	
Two P_T layers	0.435	
Sensors + substrate	0.072	17%
FE power and cooling	0.175	40%
GBTs + power and cooling	0.150	35%
Rest	0.038	9%

Modules are not very light
But services dominate

Double-stack all-trigger layout



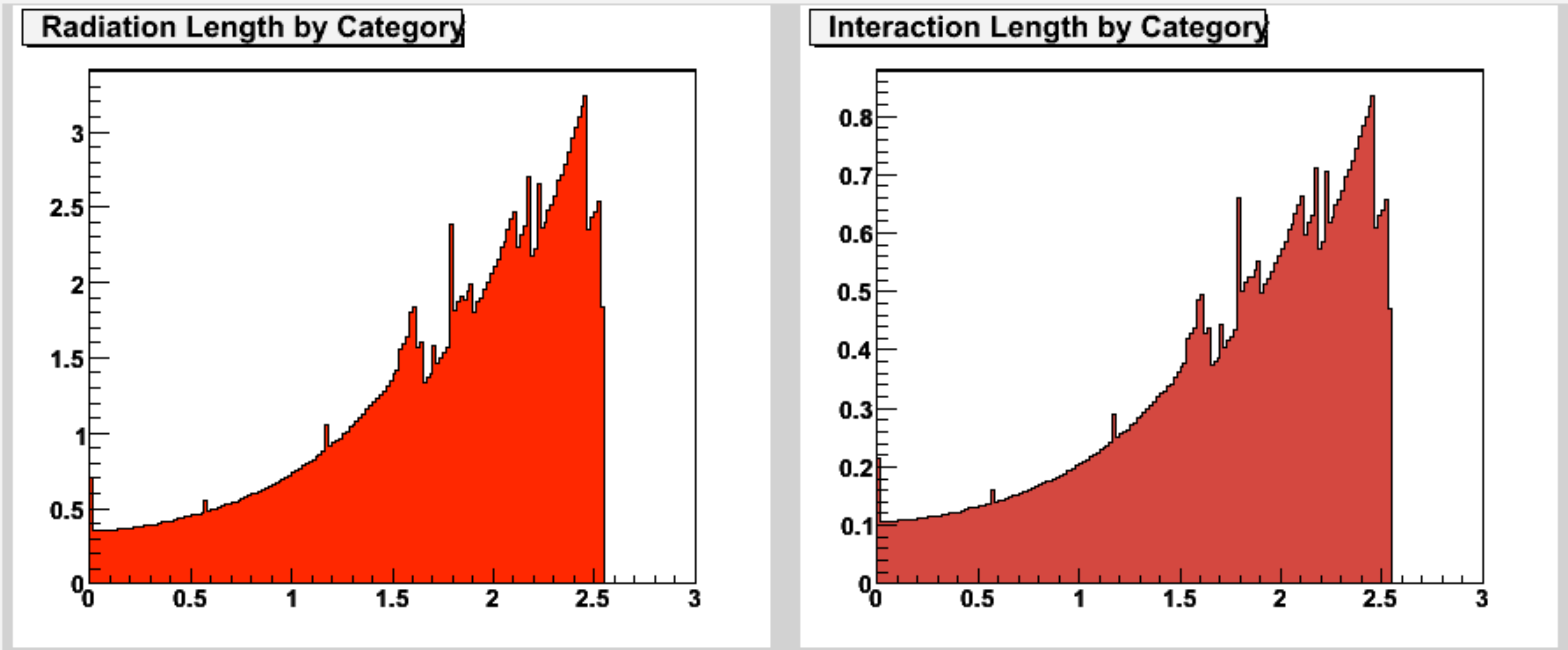


- Same assumptions as before for first two P_T layers (double-stack)
- First rough guess for outer layers
  - One GBT every six layers
  - 50% of power consumption in front-end (optimistic?)
    - To account for lower particle rate

Statistics

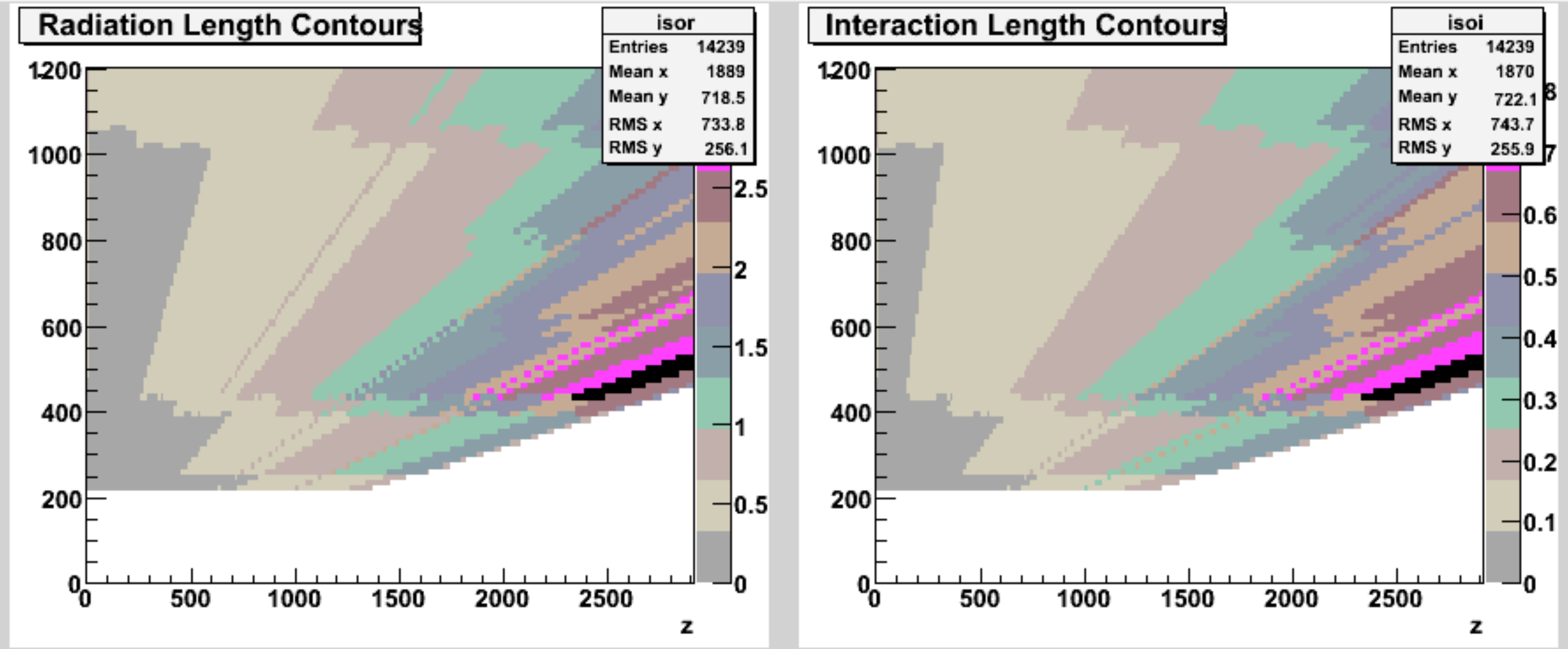
All-pt Tracker						
Tag	B_1	B_2	B_3	SH_1	SH_2	Total
Type	P_T	P_T	P_T	P_T	P_T	--
Area (mm2)	8580.5	8580.5	8580.5	8580.5	8580.5	288.7(m2)
Occup (max/av)	1.0/0.8	0.4/0.4	0.1/0.0	0.2/0.2	0.1/0.1	--
Pitch (min/max)	90	90	90	90	90	--
Segments x Chips	36x8	36x8	36x8	36x8	36x8	--
Strip length	2.6	2.6	2.6	2.6	2.6	--
Chan/Sensor	36864	36864	36864	36864	36864	--
N. mod	1400	3584	8512	1408	1920	16824
N. sens	2800	7168	17024	2816	3840	33648
Channels (M)	103.22	264.24	627.57	103.81	141.56	1240.4
Power (kW)	10.3	26.4	31.4	5.2	7.1	80.4
Readout GBTs	480	1280	3040	528	720	6048
Power (kW)						12.1
Trigger GBTs	5600	14336	5675	939	1280	27830
Power (kW)						55.7
Total power (kW)						148.2

Material



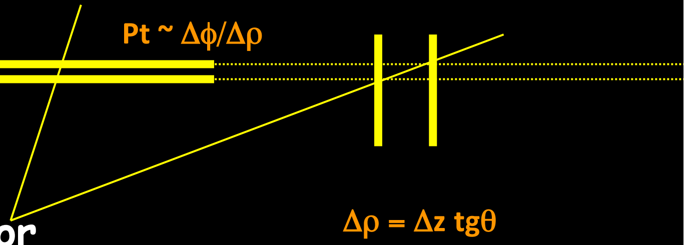
- Average radiation length in tracking volume [0, 2.4]: 119%
  - Max of ≈300%
- Average interaction length in tracking volume [0, 2.4]: 33%
  - Max of ≈80%

Material



- Average radiation length in tracking volume [0, 2.4]: 119%
  - Max of ≈300%
- Average interaction length in tracking volume [0, 2.4]: 33%
  - Max of ≈80%

Trigger from cluster width



Basic concepts and ideas

Data reduction in barrel

- Discriminate on the basis of cluster size within one sensor
- Works down to R ≈ 40÷50 cm using small pitches (≈ 60 μm)

Need End-Cap to extend rapidity coverage
Cluster width not effective in End-Cap orientation

- Use "2-in-1" modules to provide trigger in forward
- Strip length has to be 5cm at least
- Forced to accept somewhat high occupancy (≈ 6÷7 %) in the innermost part

Can use "simple" readout modules in the radial region 20 < R < 40 cm

- But need to further reduce strip length to ≈ 1.1 cm (x8 z segmentation)

Need to introduce stereo modules (since no pixellated layers)

- Can add tilted sensor behind a "trigger" sensor in the barrel
- Need dedicated double modules in the forward

In principle End-Cap can be made of rectangular detectors

- But P_T acceptance varies within a module. To be evaluated.

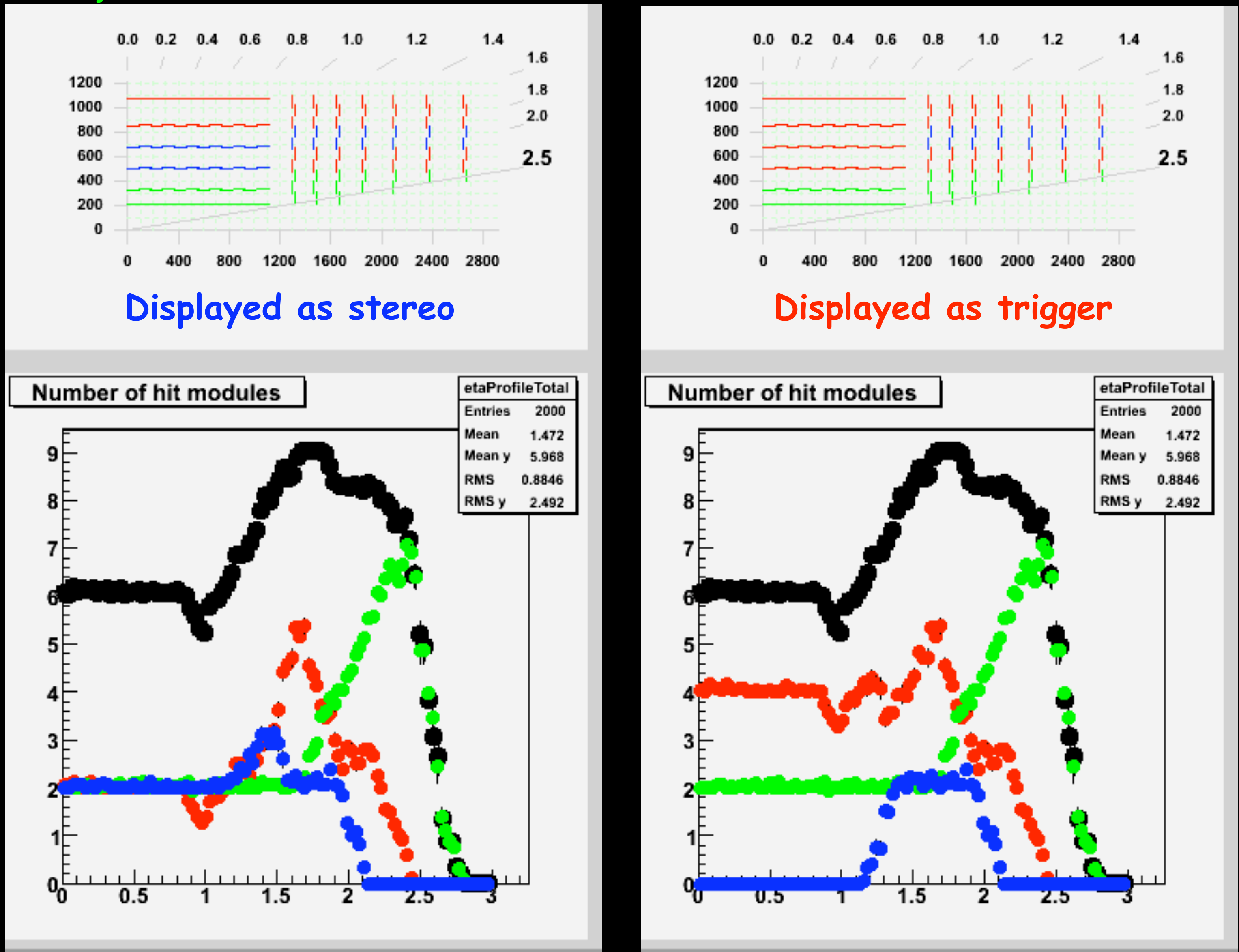
N.B. The following study is made with 10x10 cm^2 detectors

- Most likely would need half-modules at least at the top of the End-Cap

Layout for cluster width

Barrel layers 3 and 4 are both trigger layers and stereo layers

— R-ϕ (single-sided)
— Stereo
— Trigger



Very reasonable rapidity coverage achieved

Statistics

	B_L1	B_L2	B_L3	B_L4	B_L5	B_L6
Type	rphi	rphi	pt/st	pt/st	pt	pt
Area (mm2)	8578.8	8578.8	8578.8	8578.8	8578.8	8578.8
Occup (max/av)	4.3/4.0	2.5/2.4	2.8/2.6	1.6/1.6	1.9/1.8	0.8/0.8
Pitch (min/max)	59	59	59	59	119	119
Segments x Chips	8x12	8x12	4x12	4x12	2x6	2x6
Strip length	11.7	11.7	23.4	23.4	46.8	46.8
Chan/Sensor	12288	12288	6144	6144	1536	1536
N. mod	480	576	864	1152	1440	1824
N. sens	480	576	1728	2304	1440	1824
Channels (M)	5.9	7.08	10.62	14.16	2.21	2.8
Power (kW)	3.5	4.2	6.4	8.5	1.3	1.7
Modules/GBT	2	2	2	2	6	6
Readout GBTs	240	288	432	576	240	304
GBTs/module			4	4	1	1
Trigger GBTs			3456	4608	1440	1824

Power estimate:
Front-end only
Use 0.6 mW/channel (instead of 0.5) to account for additional logic and electrical links

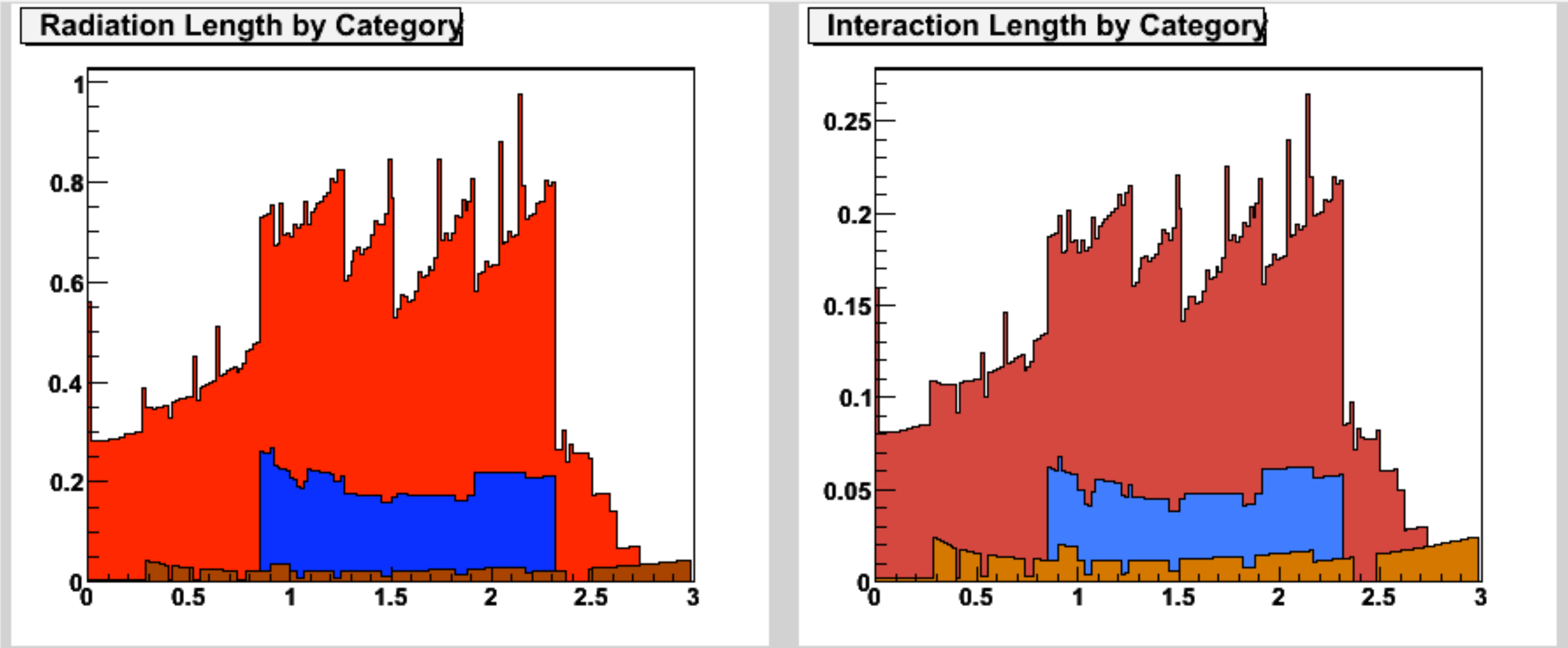
N.B. Occupancy should be somewhat overestimated for layers with 60 μm pitch

	EC_R1	EC_R2	EC_R3	EC_R4	EC_R5	EC_R6	EC_R7	EC_R8	EC_R9	EC_R10
Type	rphi	rphi	rphi	pt	pt	stereo	stereo	pt	pt	pt
Area (mm2)	8578.8	8578.8	8578.8	8578.8	8578.8	8578.8	8578.8	8578.8	8578.8	8578.8
Occup (max/av)	4.6/4.4	3.1/2.9	2.3/2.0	6.8/6.0	5.0/4.5	4.0/3.6	3.1/2.8	2.6/2.3	2.0/1.8	1.7/1.5
Pitch (min/max)	59	59	59	59	59	119	119	119	119	119
Segments x Chips	8x12	8x12	8x12	2x12	2x12	2x6	2x6	2x6	2x6	2x6
Strip length	11.7	11.7	11.7	46.8	46.8	46.8	46.8	46.8	46.8	46.8
Chan/Sensor	12288	12288	12288	3072	3072	1536	1536	1536	1536	1536
N. mod	120	280	504	560	672	728	840	896	1008	1064
N. sens	120	280	504	1120	1344	1456	1680	1792	2016	2128
Channels (M)	1.47	3.44	6.19	3.44	4.13	2.24	2.58	2.75	3.1	3.27
Power (kW)	0.9	2.1	3.7	2.1	2.5	1.3	1.5	1.7	1.9	2
Modules/GBT	2	2	2	2	2	6	8	8	8	8
Readout GBTs	60	140	252	280	336	126	112	112	126	140
GBTs/module				4	4			1	1	1
Trigger GBTs				2240	2688			896	1008	1064

Summary

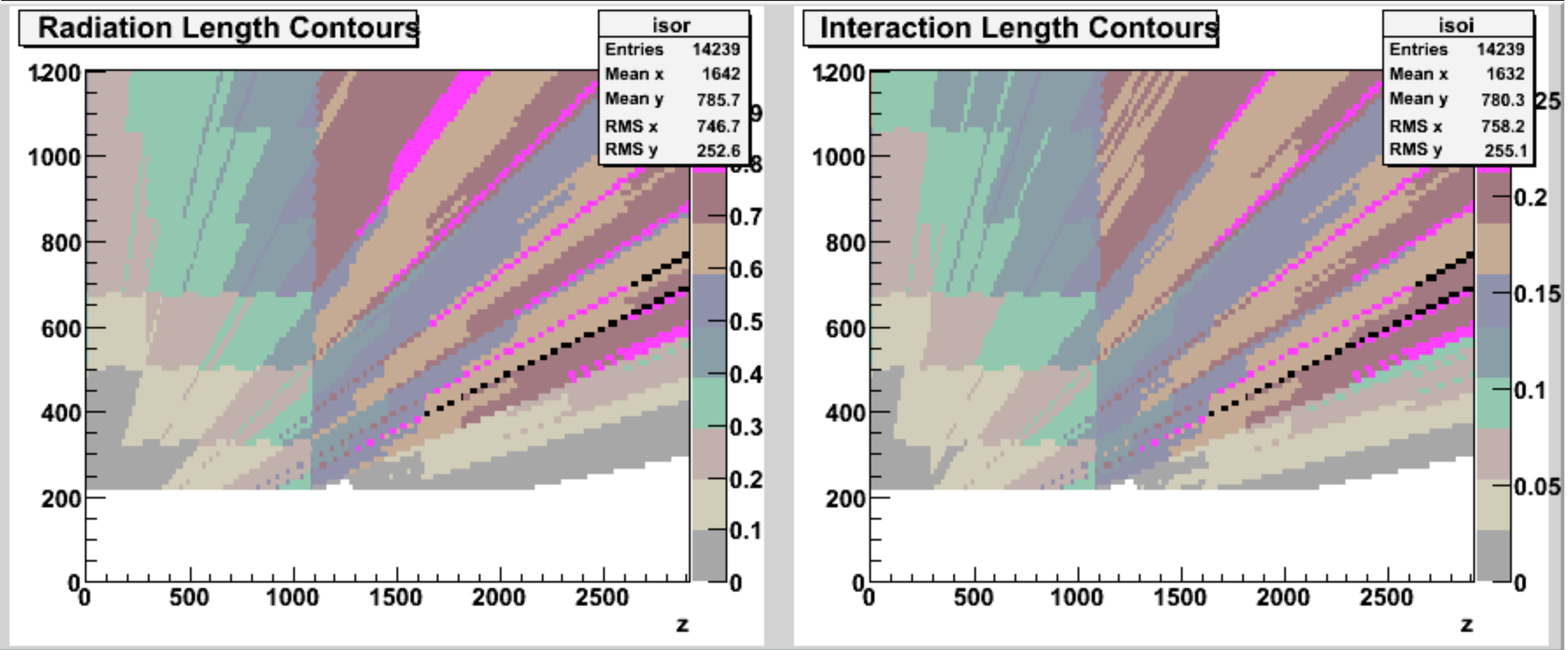
Active surface (m^2)	178.4
N of channels (M)	75.4
Power Front-End (kW)	45.2
Readout GBTs	3764
Trigger GBTs	19224
Power in GBTs (kW)	46.0
Total power (kW)	91.2

Material – "Cluster width"



- Average radiation length in tracking volume [0, 2.4]: 57%
  - Max of ~80%
- Average interaction length in tracking volume [0, 2.4]: 16%
  - Max of ~20%

Material – “Cluster width”



Summary table

	Pixellated Pt		All pixel/trigger		CW - strips only	
Surface (m^2)	Pt (pixels)	27	Pt (pixels)	289		
	Readout (strips)	85			Strips	179
Channels (M)	Pt (pixels)	116	Pt (pixels)	1240		
	Readout (strips)	19			Strips	75
Power (kW)	Pt (pixels)	11.6		80.4		
	Readout (strips)	9.5			Strips	45.2
	Trigger GBTs	12.5		55.7	Trigger GBTs	38.4
	Readout GBTs	3.4		12.1	Readout GBTs	7.5
	Total	37		148.2		91.2
Material	Average X/X_0	55%	Average X/X_0	119%	Average X/X_0	57%
	Max X/X_0	155%	Max X/X_0	300%	Max X/X_0	80%
	Average λ/λ_0	16%	Average λ/λ_0	33%	Average λ/λ_0	16%
	Max λ/λ_0	42%	Max λ/λ_0	80%	Max λ/λ_0	20%
Points	2 trigger points inside		6 trigger points inside		4 trigger points outside	
	4 readout points outside				2 readout points inside	
z info in tracking	Two pixellated layers with ~ 2 mm length. No stereo layers.		Six pixellated layers with ~ 2 mm length. No stereo layers.		Two stereo layers	
z info in trigger	Same as tracking.		Same as tracking.		Info only from strip length	

Outlook – tools & studies

- Still quite some work to do on tools
  - Add useful features to tkLayout
    - "Small" modules
    - Parameterization of particle occupancy
    - …
  - Continue "commissioning" of tkMaterial
    - Notably check volumes at the boundaries
  - Pursue translation to CMSSW
  - Prepare documentation and "user manuals"
- Further studies
  - Depend essentially on availability of better input
  - Will evolve according to progress in development of components and integration studies

Assumptions used in material estimates

- Assumptions used in these first studies are based on expectations from planned developments + existing objects
- They are on purpose not exceedingly optimistic, based on elements we have today in hand (or at least in mind), and that we believe should be usable
- Such exercises should help to
  - Identify the aspects where we need to invest more effort
  - Keep the estimates "live" as we proceed with the developments
    - E.g. to avoid discovering the weight of the Tracker only after it is built…
  - Choose a detector baseline that provides a good common ground for the needed developments
  - Evaluate different options and support engineering design

Comments on layouts studied: cluster width

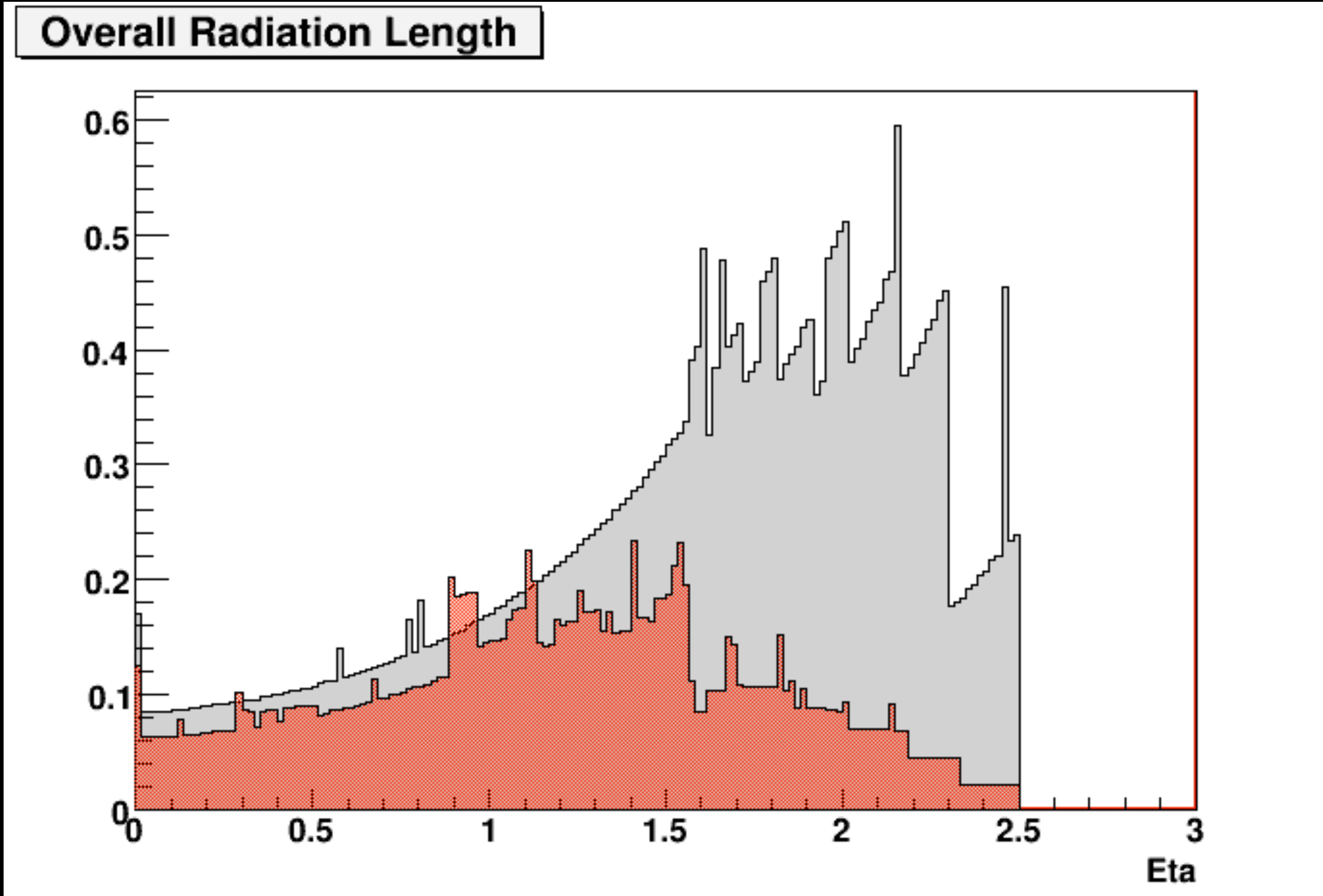
- The layout (in this version) contains several module flavours
  - Single, readout, 60 µm × 12 mm
  - Double, CW + stereo, 60 µm × 24 mm
  - Single, CW, 120 µm × 47 mm
  - 2-in-1 for trigger, 60 µm × 47 mm
  - Double, rϕ + stereo, 120 µm × 47 mm
  - 2-in-1 for trigger, 120 µm × 47 mm
- A lot of work would be needed to improve the modelling
- Provides more information in different aspects
  - More tracking information in the z view (two stereo coordinates)
  - Trigger information from 4 layers
    - Really useful?
  - Narrower pitch ≈ everywhere
- No (or very poor) z information on primary vertex for trigger

Comments on layouts studied: pixellated P_T

- It is clear that at the present stage we cannot drop the development of readout modules / layers
  - And that will remain the case certainly for quite a while
- The n of P_T layers that we can afford, and the overall quality of the tracker, will depend crucially on what will be achieved with the development of P_T modules
  - In terms of minimizing the mass of the module and its power consumption
- Packaging of optical links and interconnectivity of module, links and power converters are crucial as well
  - Finally, we need to evaluate "layers", not just modules

Backup

Outer: Long barrel vs “TOB+TEC”



Outer: Long barrel vs "TOB+TEC"