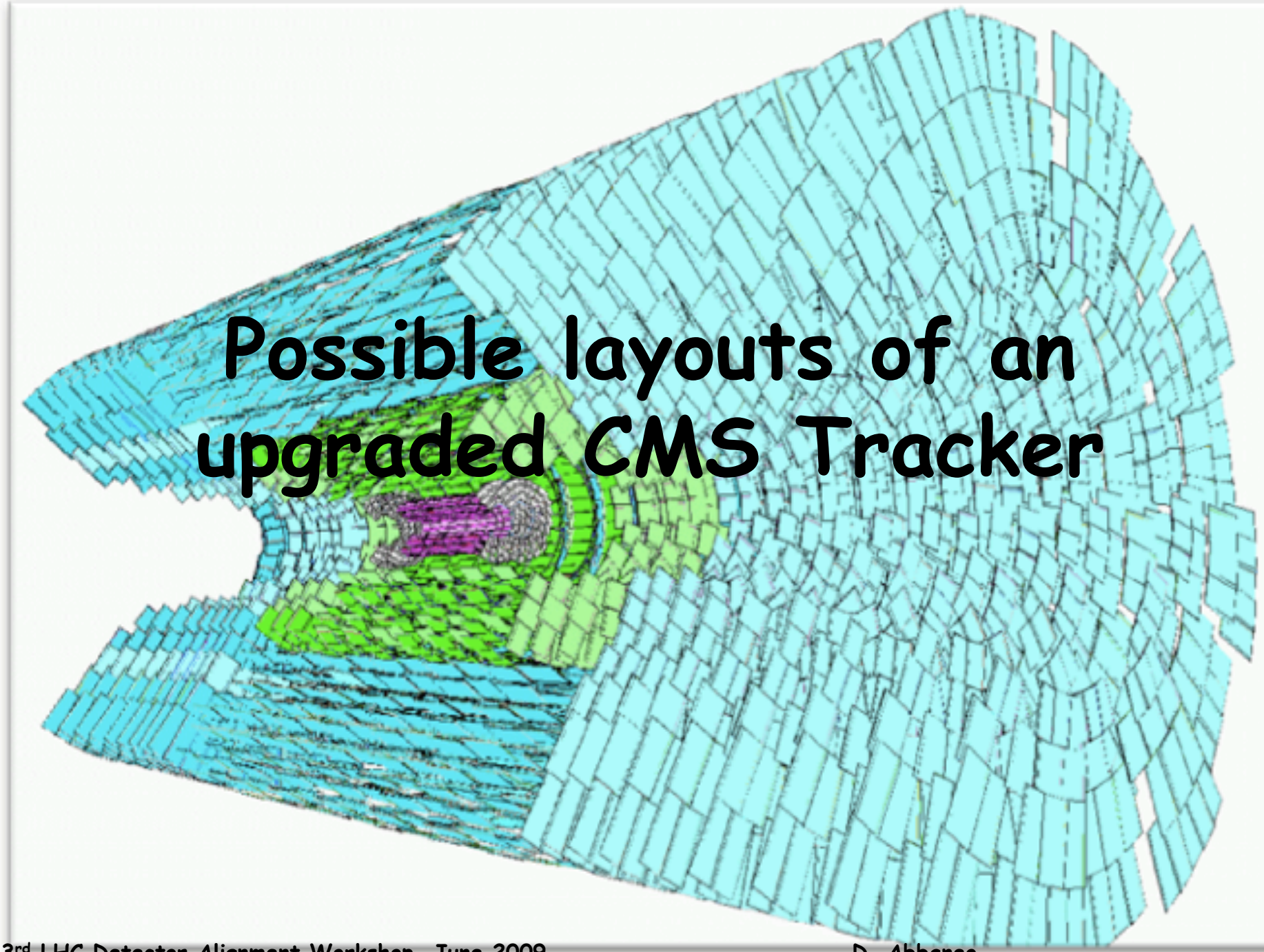
Possible layouts of an upgraded CMS Tracker



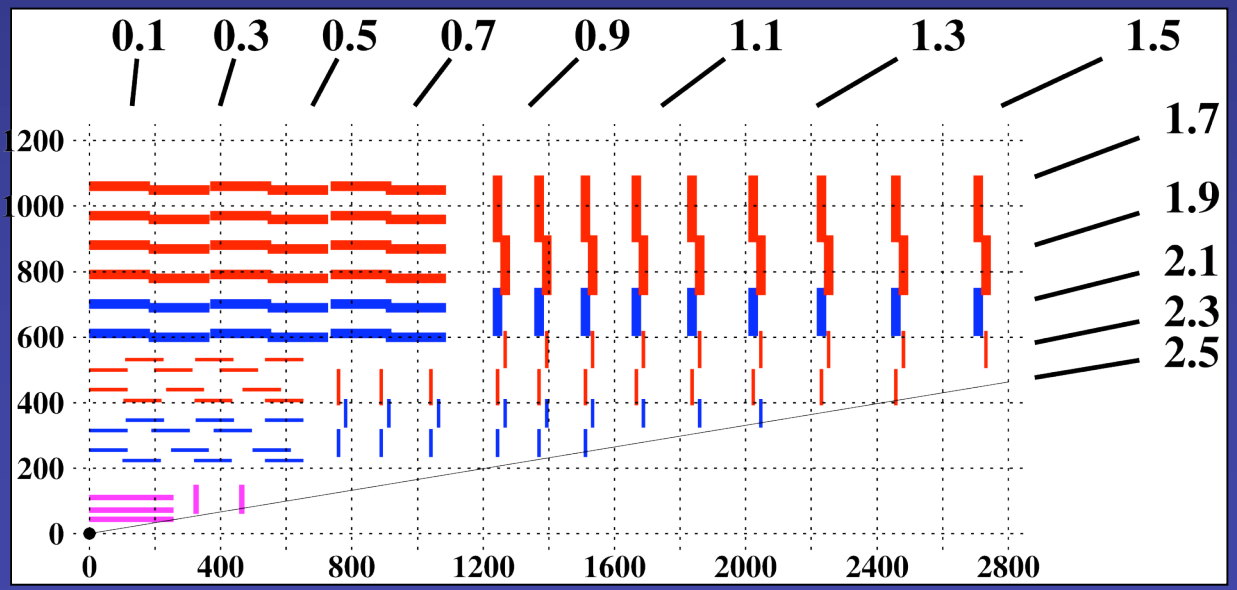
Outline

- Brief overview of present Tracker
- Requirements for upgrade
- Example of a possible layout
  - Assumptions, open issues
  - Main differences wrt present Tracker
  - Possible implications for alignment
- Alternative options and ideas
- Conclusions

The CMS Tracker

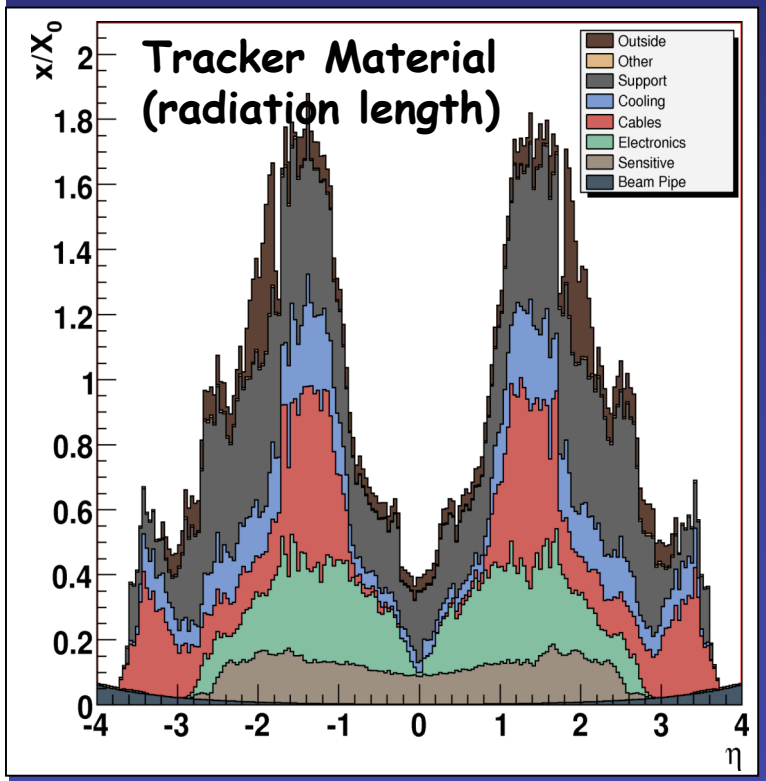
- 3 Silicon pixel layers
  - Easily removable for beam pipe bakeout or detector replacement
- 10 Silicon micro-strip layers
  - 4 double-sided with stereo angle
  - 6 single-sided
- End-caps to complete η=2.5 coverage

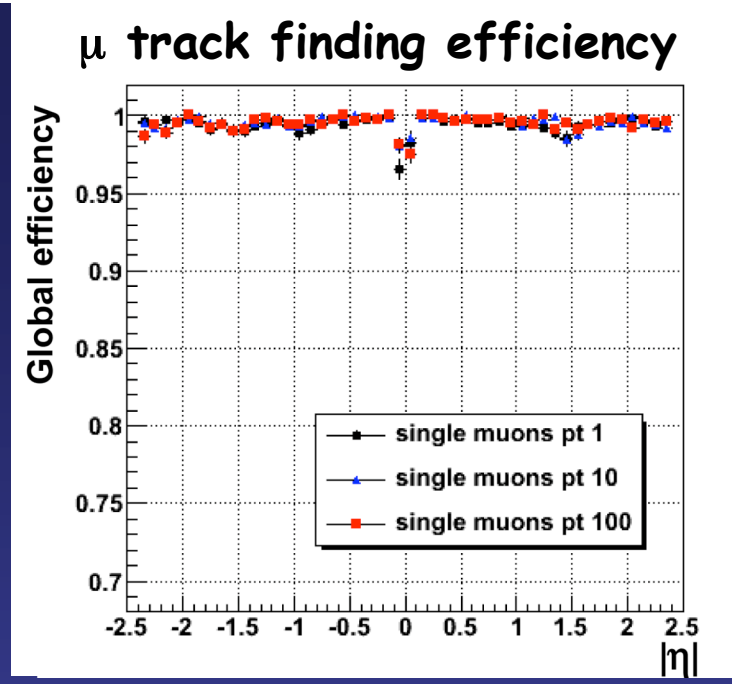
Pixel detector	Strip detector
~1 m2 of silicon	~210 m2 of silicon
66M channels	9.3M channels
16k ROCs	73k APV25s
3.6 kW	33 kW
Size ~100μm x100μm	Pitch 80-180μm
1440 detectors	15k detectors

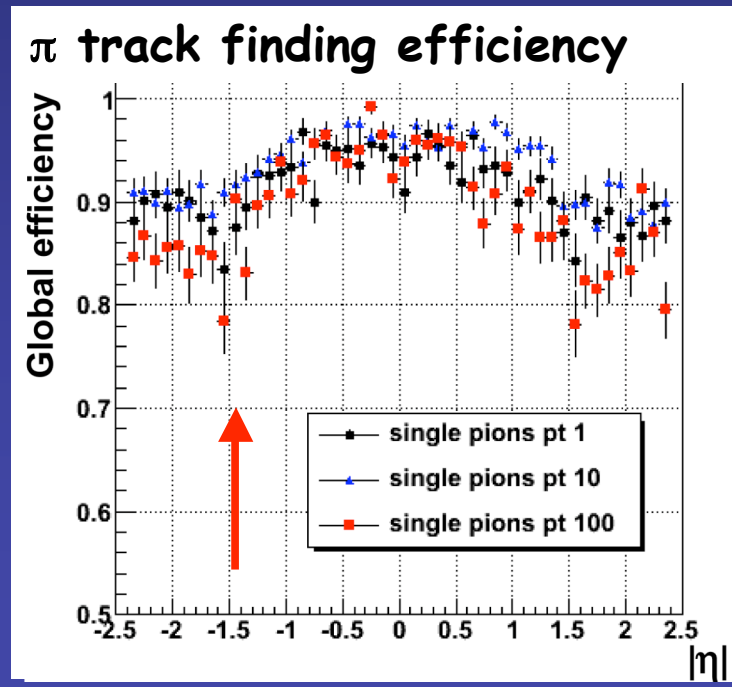


The Tracker performance

- Low occupancy
  - Pixels ~10^{-4}
  - Inner strips ~3×10^{-2}
  - Outer strips ~10^{-2}
- Excellent performance and robustness
- Partially degraded by material in the Tracking volume
  - Substantial contribution linked to power dissipation in the FE electronics





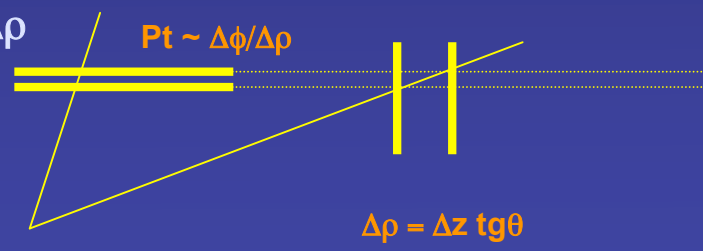


Requirements for the "phase II" upgrade

- Maintain tracking performance in higher density environment (up to 20x)
  - Increase granularity of strip tracker
    - → No reason to decrease pitch significantly
    - → Rather decrease strip length
  - The goal is to keep the occupancy below a few %
  - Outer strips ~10^{-2}
- Cope with higher radiation dose
  - Mostly an issues for sensors
- Re-use services running across CMS
  - Interleaved with other subdetectors, too long/difficult/risky to replace
- Reduce amount of material
  - Requirement dictated from present performance
    - → Minimize (or moderate) power consumption
    - → Optimize (presumably reduce) total n of layers
- Keep L1 total rate within 100 kHz
  - Need information at L1 from the Tracker!!

Implications of the trigger requirement

- Sending out all data @ 40 MHz would require enormous bandwidth (… and power!)
  - Develop strategies to reduce data volume at FE level
    - → Reject signals from low-Pt Tracks
- The principle: measure $\Delta\phi/\Delta\rho$
  - Barrel: need higher $\Delta\rho$ at lower radii
    - → correlate hits between two closely-spaced sensors
      - » Good option at low radii
    - → discriminate on the basis of cluster size within one sensor
      - » Works at large radii
  - End-cap:
    - → in wedge-shaped detectors strips measure $\phi/\Delta\rho$
    - → in a pair $\Delta\rho$ translates to Δz
      - » But with a fairly large scaling factor (~5)

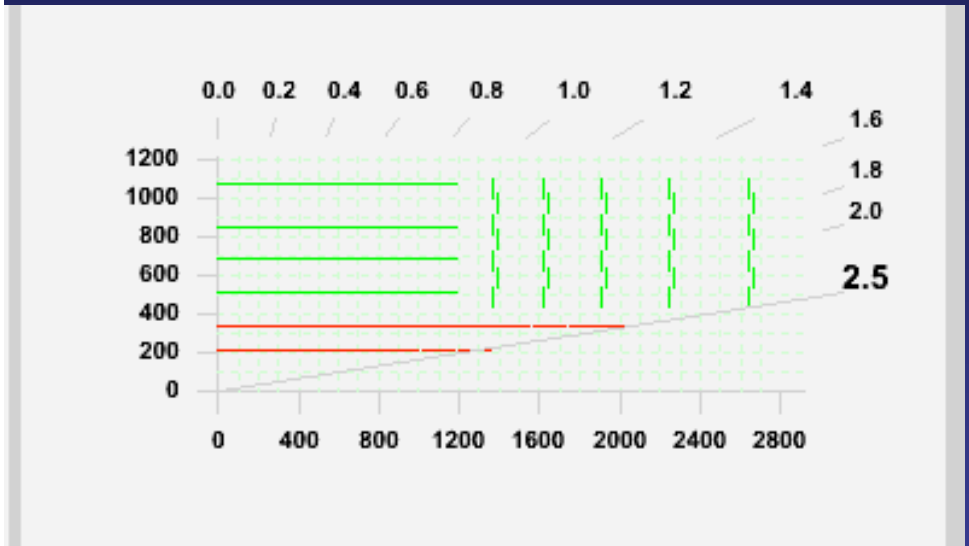


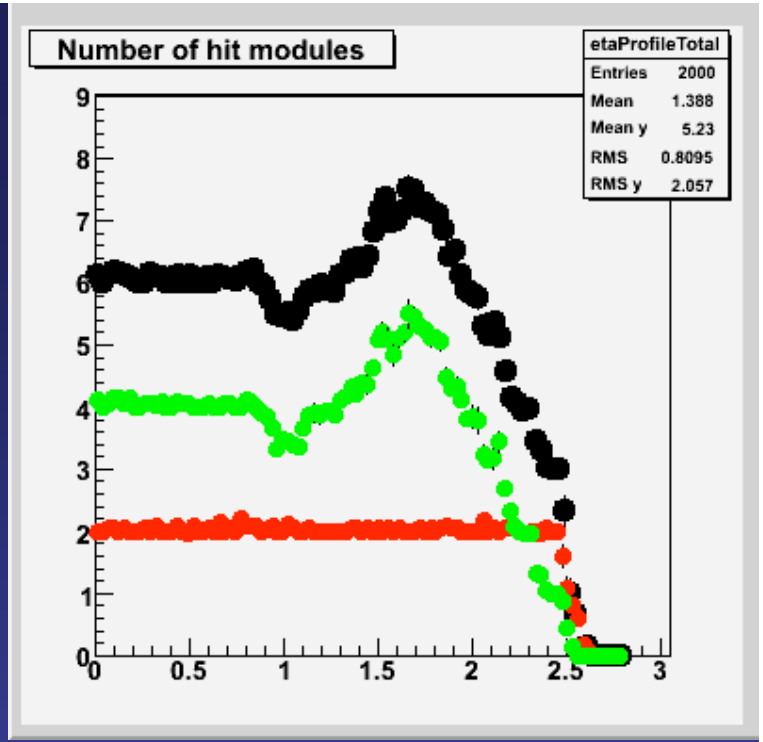
- In addition: some PV discrimination
  - Ideally it would be desirable to distinguish individual p-p collisions
    - → most likely unfeasible
    - → interaction position can be constrained by using pixellated detectors

The upgrade of the pixel detector

- The pixel detector is not expected to survive the whole LHC lifetime (by design)
  - Expected to be replaced in ~5 years: "phase I"
    - → In principle possible during a standard shutdown
  - Current plan: significantly enhanced detector!
    - → Four barrel layers + three end-cap disks
      - » Fits in the same envelope
    - → Substantially reduced material in the η acceptance
  - Improve physics performance
    - → Robustness of Track seeding in high-density environment
    - → Track reconstruction efficiency
  - N of modules 1440 → 1888 (quite moderate increase)
- The ultimate pixel upgrade
  - Not yet defined
    - → Important input is seeding performance at highest luminosity
      - » One more layer (wrt phase I upgrade, so 5 total) would require to move the boundary with strips outwards by ~ 8 cm

Layout with two pixellated "trigger" layers





	B1	B2	B3	B4	B5	B6	E1	E2	E3	E4	E5	E6	E7	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 (mm)	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**

Assumptions: 0.5 mW/channel for readout layers; 0.1 mW/channel for Pt layers
Link power not included

Features and caveats (I)

- Same boundary with pixel detector
  - May need to be revised
    - → Studies of track seeding performance ongoing
- Two "trigger" layers
  - Not known whether they are sufficient
    - → Trigger simulation studies ongoing
- Six layers in total (+ 4 pixel)
  - Not sure whether they provide sufficient robustness
    - → Needs to be studies with tracking simulation
- No stereo layers
  - But one more pixel layer + two pixellated trigger layers
  - Precision in the z view has to be evaluated

Features and caveats (II)

- Rectangular detectors in the End-cap
  - Strips are not pointing
  - Presumably some adjustments needed in the tracking code
- For trigger modules, not clear whether to align "modules" or "detectors"
  - Likely high precision assembly of the two sensors in a module
- Possibly trigger modules will be smaller for technical reasons
  - Exercise shown assumes that all modules are ~10x10 cm^2
    - → 11.6 k "modules", 13.1 k "detectors" (currently 15k detectors)
  - Trigger modules could be rather ~5x5 cm^2, and therefore 4x more numerous
    - → 16.3 k "modules", 22.6 k "detectors"

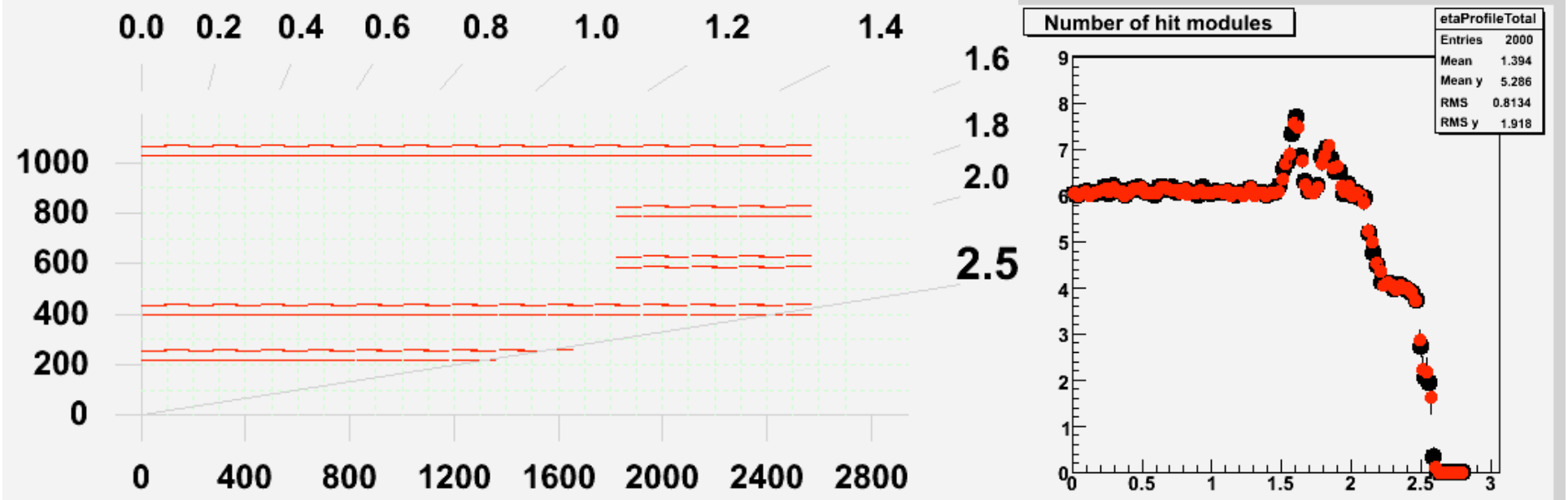
Other issues

- Binary readout
  - In all cases, present analogue readout will be dropped
    - → In principle no implications for alignment
- Mechanical precision and stability, survey data
  - ~100 μm precision can be achieved with light mechanics
    - → Will set it as goal
  - Availability of survey data depends on assembly process
  - In the coming time will learn about stability of present Tracker
- Hardware alignment system
  - Adds non-trivial constraints in the detector design
  - Adds material in the tracking volume
    - → Much more knowledge today than 8 years ago
    - → Can it be simplified or dropped?
- Alignment constants and trigger
  - Requirement on coordinate precision for L1 likely to be rather modest
    - → Module-level alignment constants may or may not be needed in L1 reconstruction
    - → Probably more a trigger issue than an alignment issue…

Summary for the example given

- Segmentation in the precise coordinate comparable to present Tracker
- N of modules to align also comparable to the present Tracker
- Whole detector would be reoptimized if the pixel/outer TK boundary is moved
  - But no dramatic changes
- Mechanical precision: aim for the best achieved in present tracker
- Availability of survey data not easy to predict
  - If the mechanics has ~100 μm precision, are they really useful?
- Hardware alignment system: good to avoid or minimize
  - What do we really need?

Alternative concepts (I): all trigger tracker



- ~ 290 m² of pixellated detectors, 1.4 G channels
- ~ 140 kW in FE
- Additional (large) amount in readout links
- Several doubts on feasibility, as well as performance

	B1	B2	B3	B4	B5	Total
Type	pt	pt	pt	pt	pt	--
Area (mm2)	8580.5	8580.5	8580.5	8580.5	8580.5	288.7(m2)
Occup (max/av)	0.9/0.7	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	40x8	40x8	40x8	40x8	40x8	--
Strip length (mm)	2.3	2.3	2.3	2.3	2.3	--
Chan/Sensor	40960	40960	40960	40960	40960	--
N. mod	1400	3584	8512	1408	1920	16824
N. sens	2800	7168	17024	2816	3840	33648
Channels (M)	114.69	293.6	697.3	115.34	157.29	1378.22
Power (kW)	11.5	29.4	69.7	11.5	15.7	137.8

- However, several R&Ds are ongoing; perspectives may change with time
- Possibility of a full-pixel Tracker not to be excluded a priori
  - Although perhaps "full-trigger" is not a good option, unless mandatory

Alternative concepts (II): cluster width method

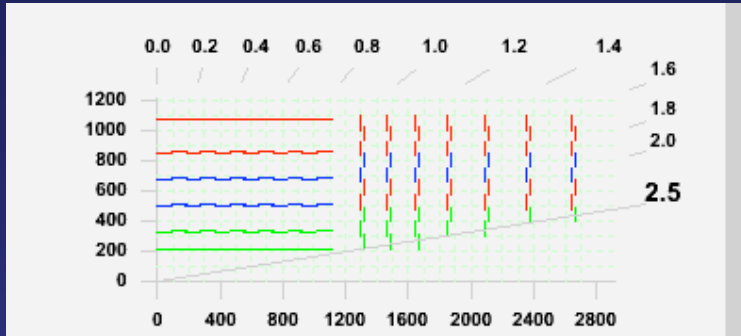
- Provide trigger info from outer part
  - In barrel reduce data in single sensors discriminating on cluster width
  - In forward use pairs of strip sensors bonded to the same readout hybrid
- Put "simple" readout modules (short strips) in the inner layers
- Add stereo detectors for z coordinate measurements
  - Since there are no pixellated layers in the Outer Tracker
- Need to use smaller pitches (down to ~60 μm) for a good Pt discrimination
- Also consider to use rectangular detectors in forward
- Previous considerations on total n of layers apply

- No discrimination on PV position in trigger information
- Not clear if this is acceptable

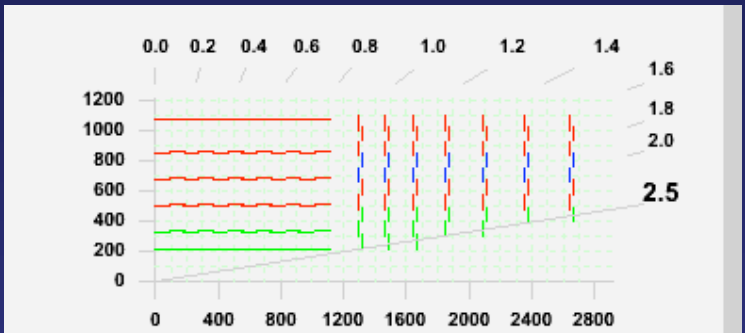
"Cluster width" layout

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

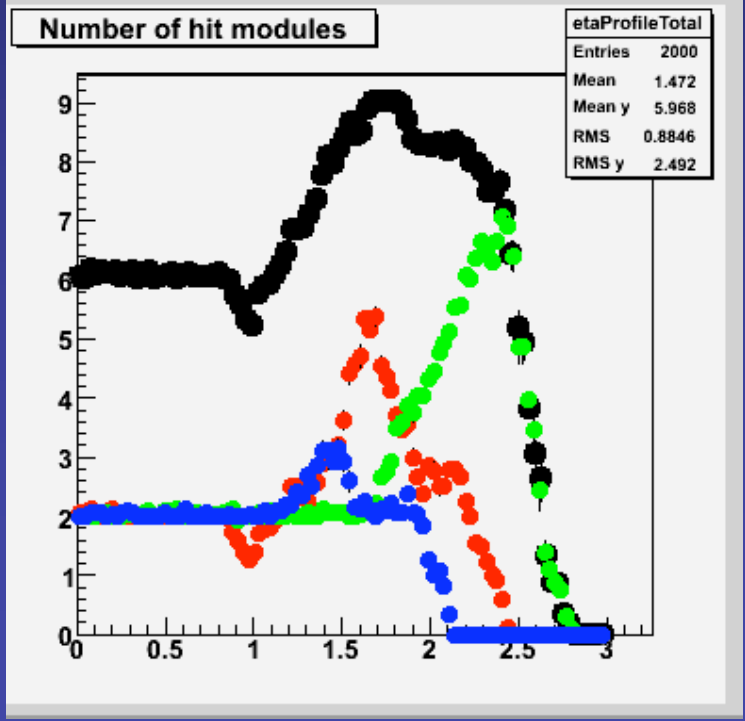
- R-ϕ (single-sided)
- Stereo
- Trigger

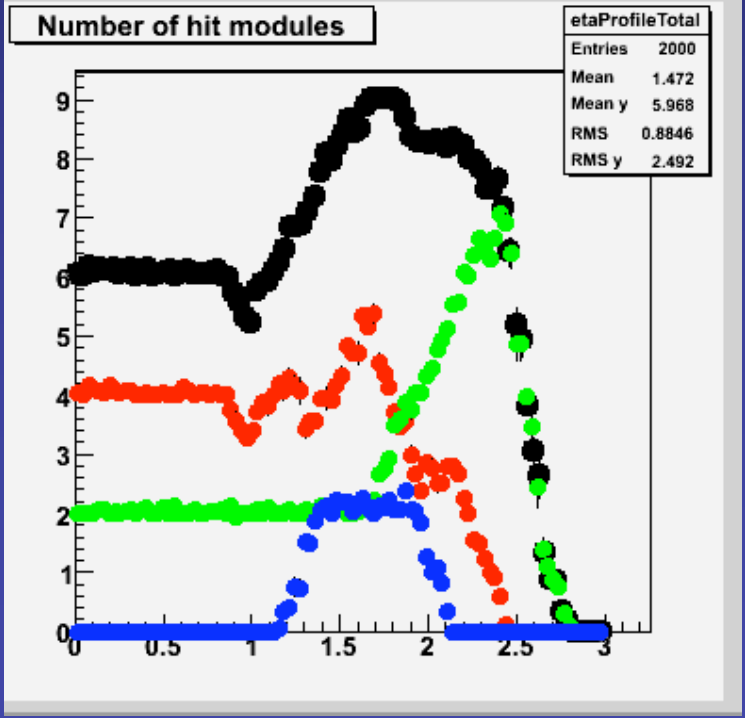


Layers 3-4 displayed as stereo



Layers 3-4 displayed as trigger





Statistics for "cluster width" layout

Tag	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

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

Tag	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

Total active surface	178.4 m^2
Total n of channels	75.4 M
Total power (front-end)	45.2 kW
N of "modules"	13.0 k
N of "detectors"	20.8 k

Conclusions

- We do not have yet a baseline detector concept and layout for the upgrade of the CMS Tracker
- Current most plausible options suggest that the task of aligning the upgraded Tracker should be not too different from the current one
  - Precision is comparable. N of degrees of freedom is comparable.
  - But there are also more exotic ideas being pursued…
- We can to profit from the experience with the current tracker to optimize the approach for the next one
  - Notably with respect to the hardware alignment system
- These are just first thoughts…
  - … so stay tuned for second thoughts!