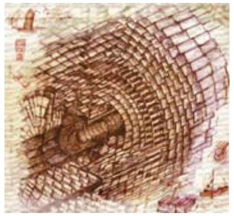
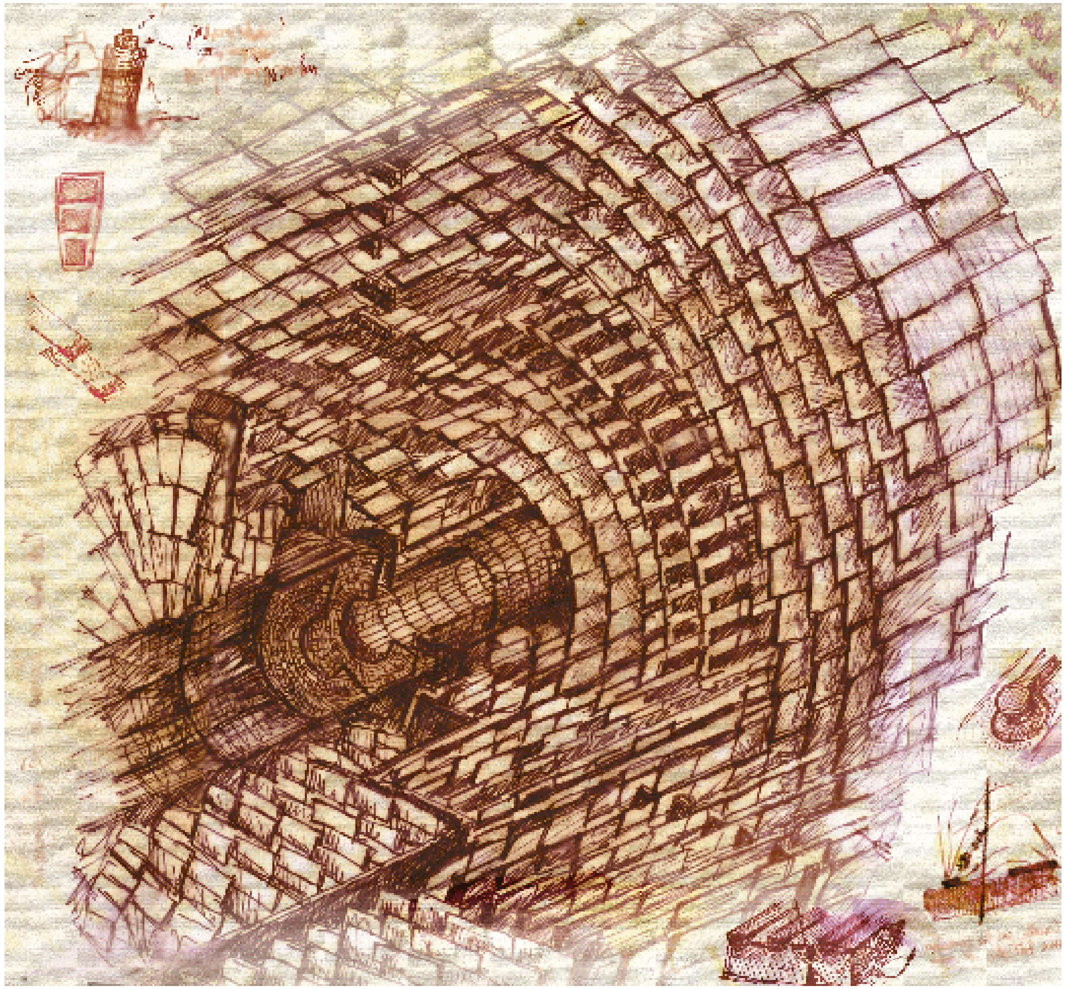
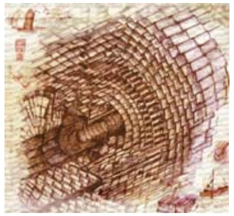


Stacked Tracker Trigger
Straw Man

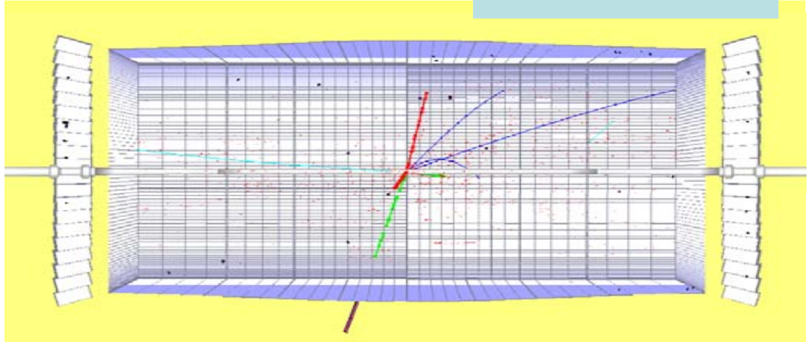


Marcello Mannelli FNAL
CMS SLHC Work-Shop

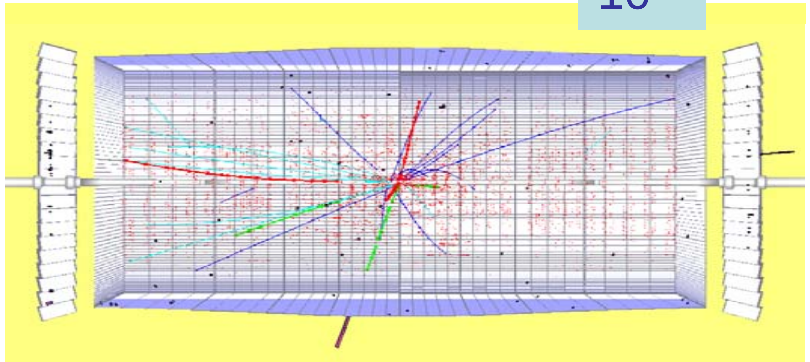


CMS from LHC to SLHC

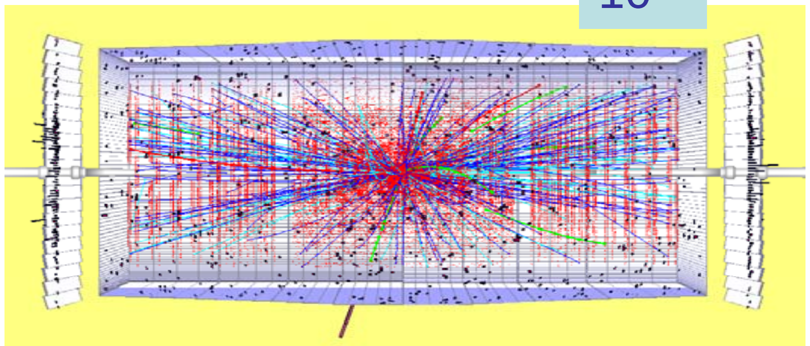
10^{32} cm^{-2} s^{-1}



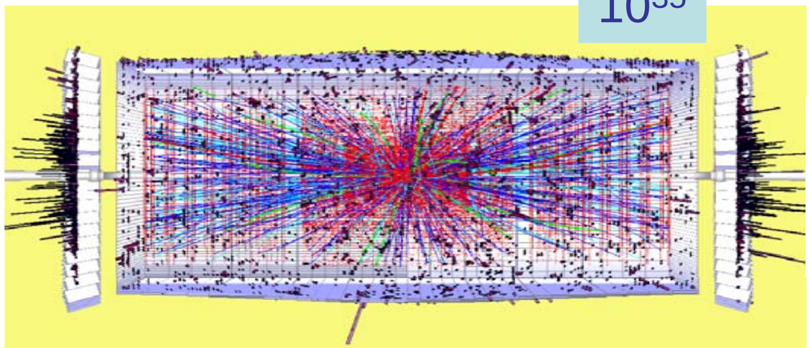
10^{33}



10^{34}

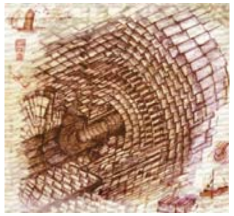


10^{35}



I. Osborne

The tracker is the key detector which will require upgrading for SLHC



Scope of this Discussion: Outer Tracker

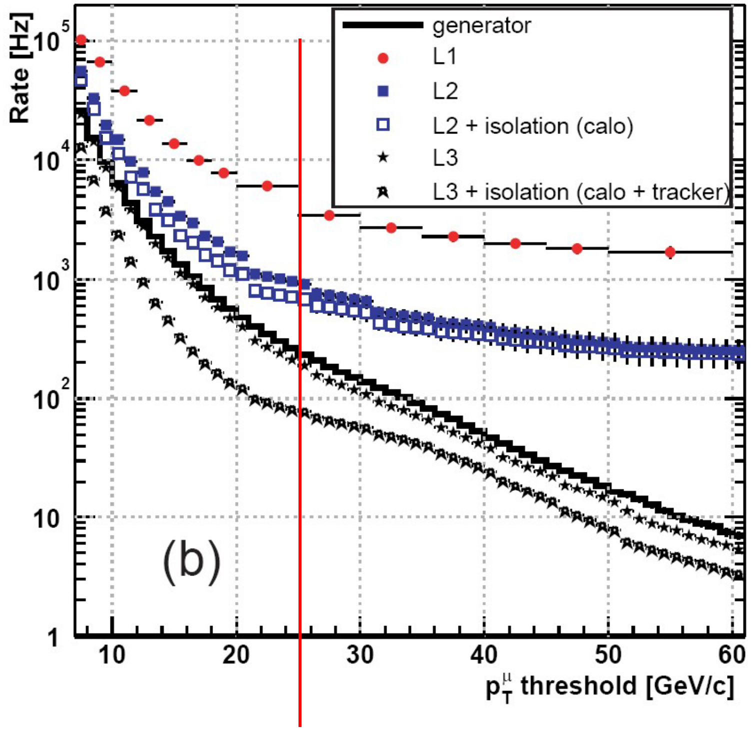
- **The region of the inner-most Pixel Layers is fundamentally challenging at the SLHC, especially for the Sensor Technology**
  - One may speculate as to the most promising way forward
  - B-tagging, e/γ discrimination remain Very Important

- **Assume 4 Layers of Fine-Pitch Pixels**
  - To be better defined

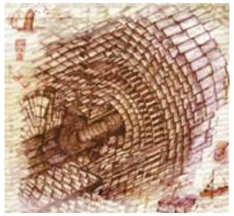
- **Here focus on Outer Tracker**
  - Assume boundary between inner-most Pixel Layers and Outer Tracker is somewhere between 20 ~ 40cm
  - In any future baseline layout, Outer Tracker and inner-most Pixel Layers will have to make a coherent Tracking System

Required Functionality
L1 Trigger

- **Confirmation of Isolated High-pt μ Candidates**
  - **Fast, Efficient & Clean Tracking**
  - **Excellent Pt resolution**
  - **Isolation**
- **Increased Rejection of fake e/γ Candidates**
  - **Match with Track (nb conversions…)**
  - **Isolation**
- **Tau Jet trigger**
  - **Low Multiplicity, Isolation**
- **MET ?**
  - **Clean up High Pile-up environment**
- **Rejection of Uncorrelated Combinations, from different primary vertex ?**
  - **Match with Tracks at Vertex ?**



Factor ~ 100 reduction
For same Pt threshold



Required Functionality
L1 Trigger

- **Confirmation of High Pt Track Candidates**
  - Tracks with Pt above ~ 20 GeV
  - Excellent Efficiency
  - Good Pt resolution

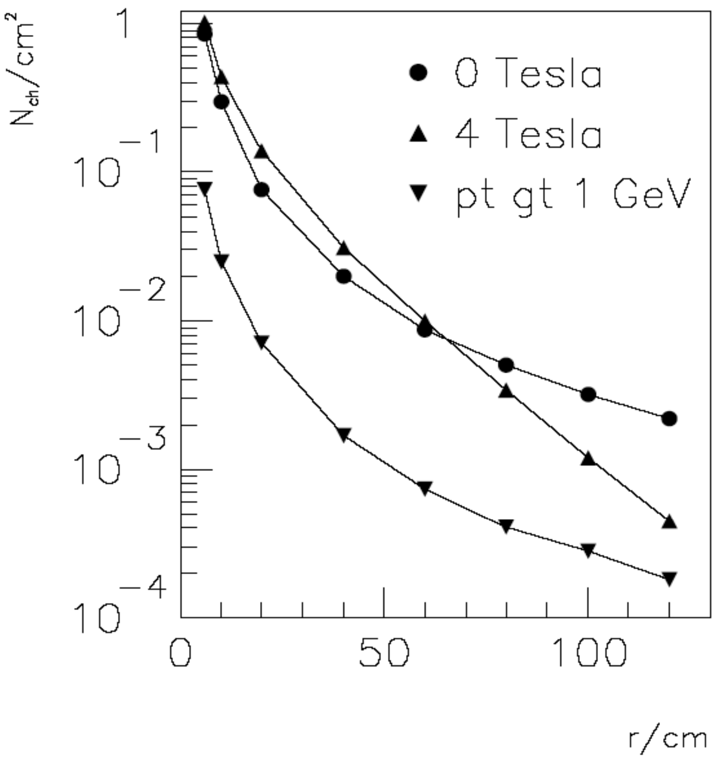
- **Isolation**
  - Tracks with Pt above 2 ~ 4 GeV
  - Good Efficiency

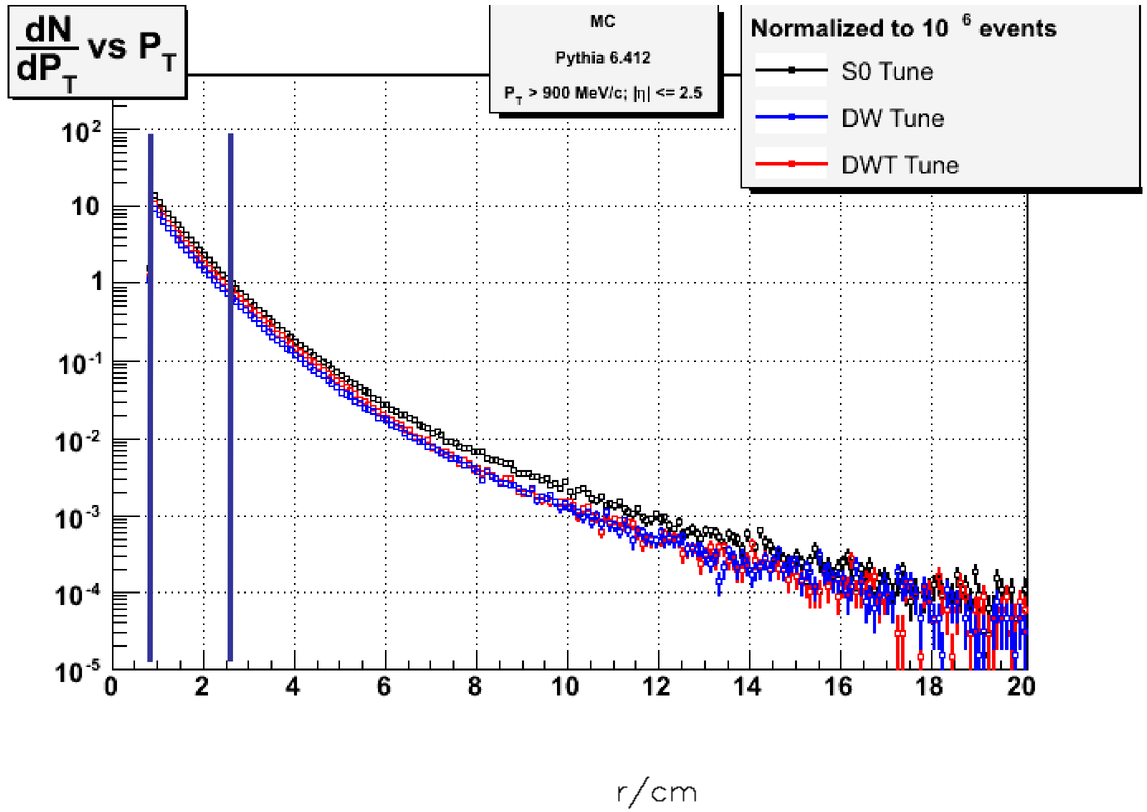
- **Longitudinal Vertex association**
  - Tracks with Pt above 2 ~ 4 GeV
  - Good Z Vertex resolution

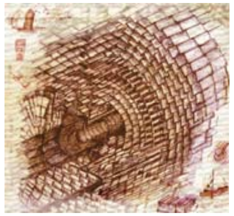
Local Occupancy Reduction

Tracks with Pt > 1 GeV
< 10% of Tracks in acceptance

Tracks with Pt > 2.5 GeV
< 10% of the remaining Tracks





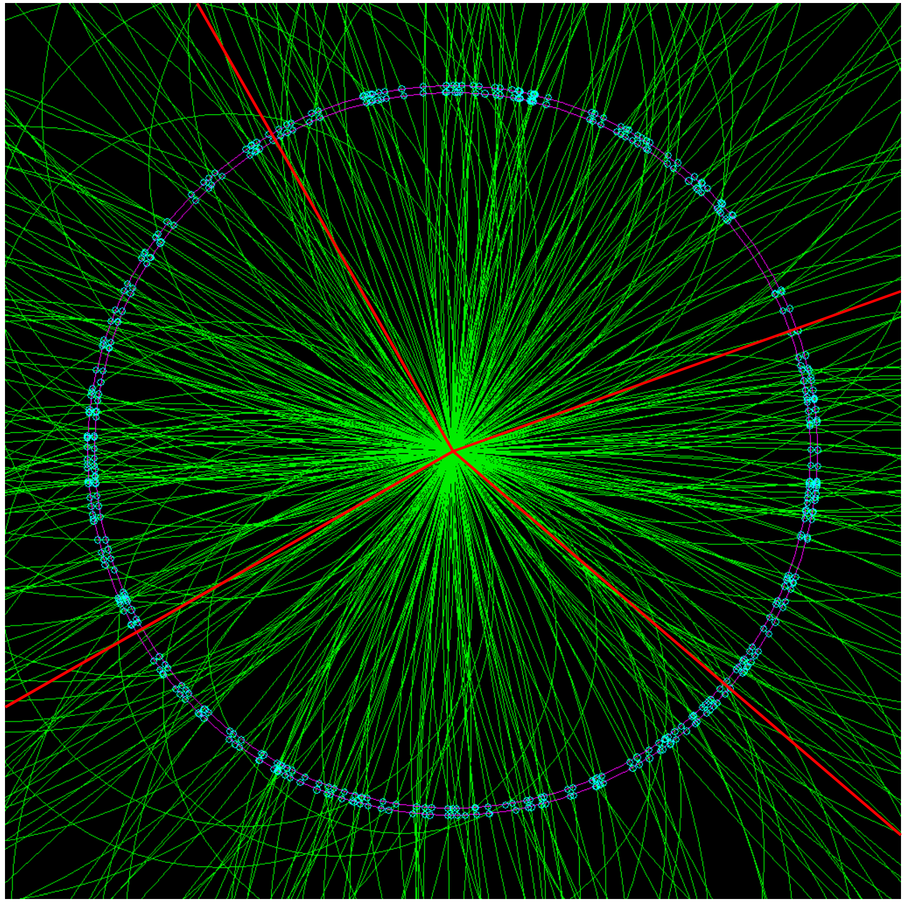


Local Occupancy Reduction

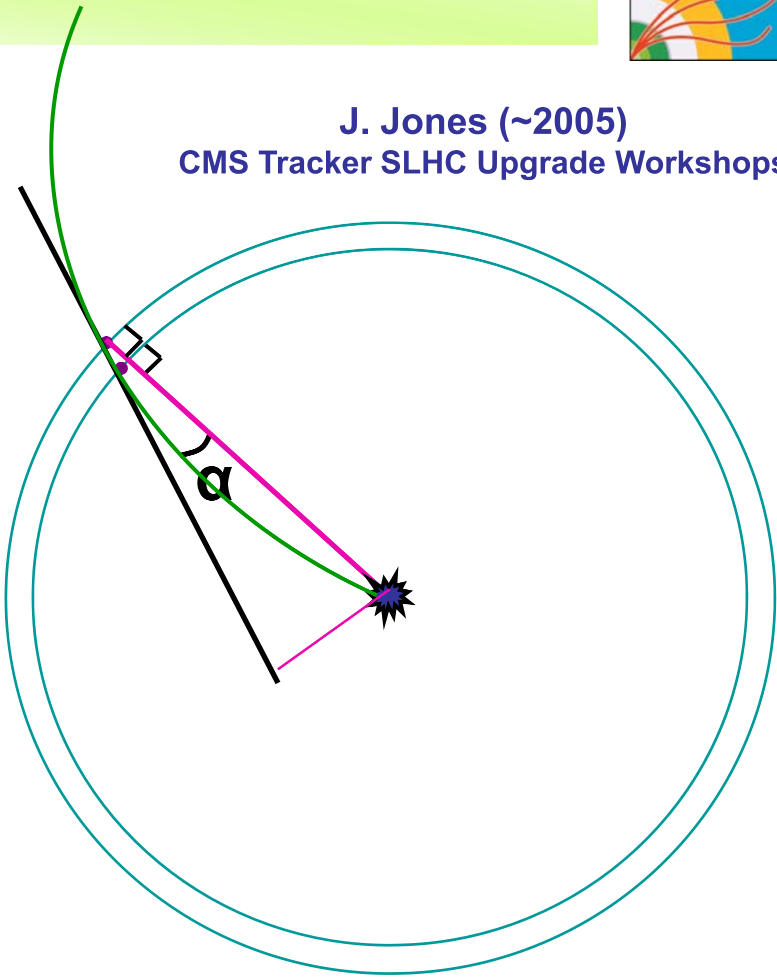
- **Cannot possibly transfer all Tracker data at 40MHz !**
- **Target reduction factor between 100 ~ 1'000 (more later)**
  - **Tracks with Pt > 2.5GeV are less than 1% of Tracks inside acceptance**
- **For L1 Trigger propose to transfer only hits from tracks with**

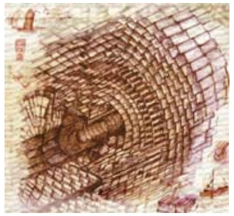
  Pt > 2 ~ 4 GeV
  - **The aim is to provide useful Isolation information**
- **In addition, must provide means of rapidly identifying high (isolated) tracks (Pt > 15 ~ 25 GeV)**

Local Occupancy Reduction



J. Jones (~2005)
CMS Tracker SLHC Upgrade Workshops





Local Occupancy Reduction

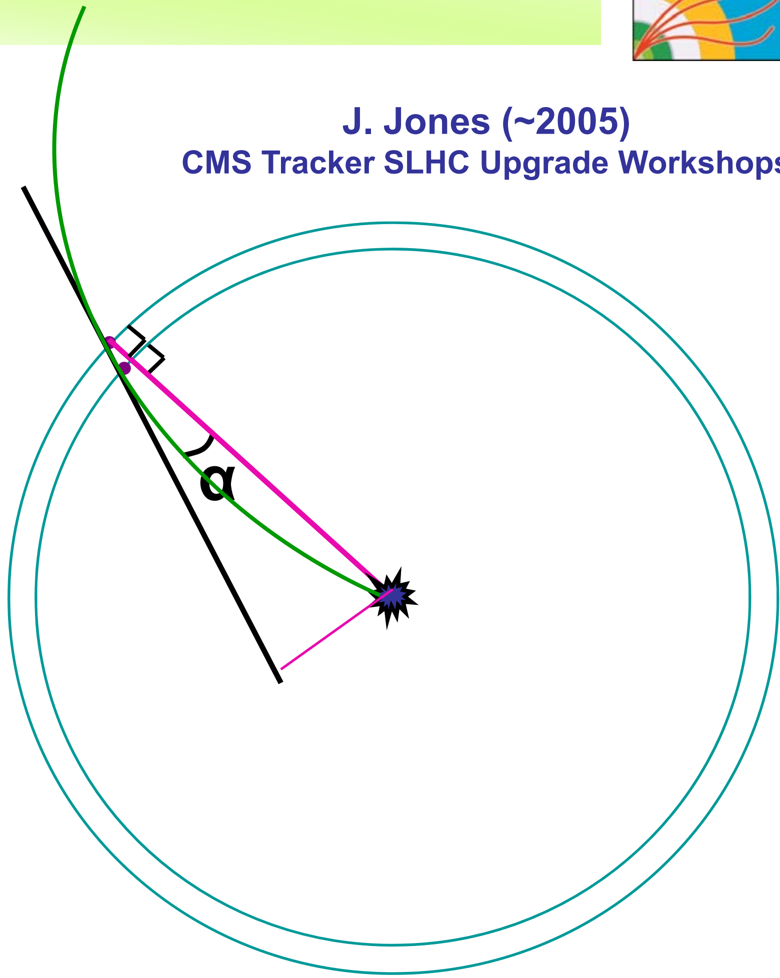
- **Doublets of Sensor Planes, for local Pt measurement**

- **High Pt tracks point towards the origin, low Pt tracks point away from the origin**

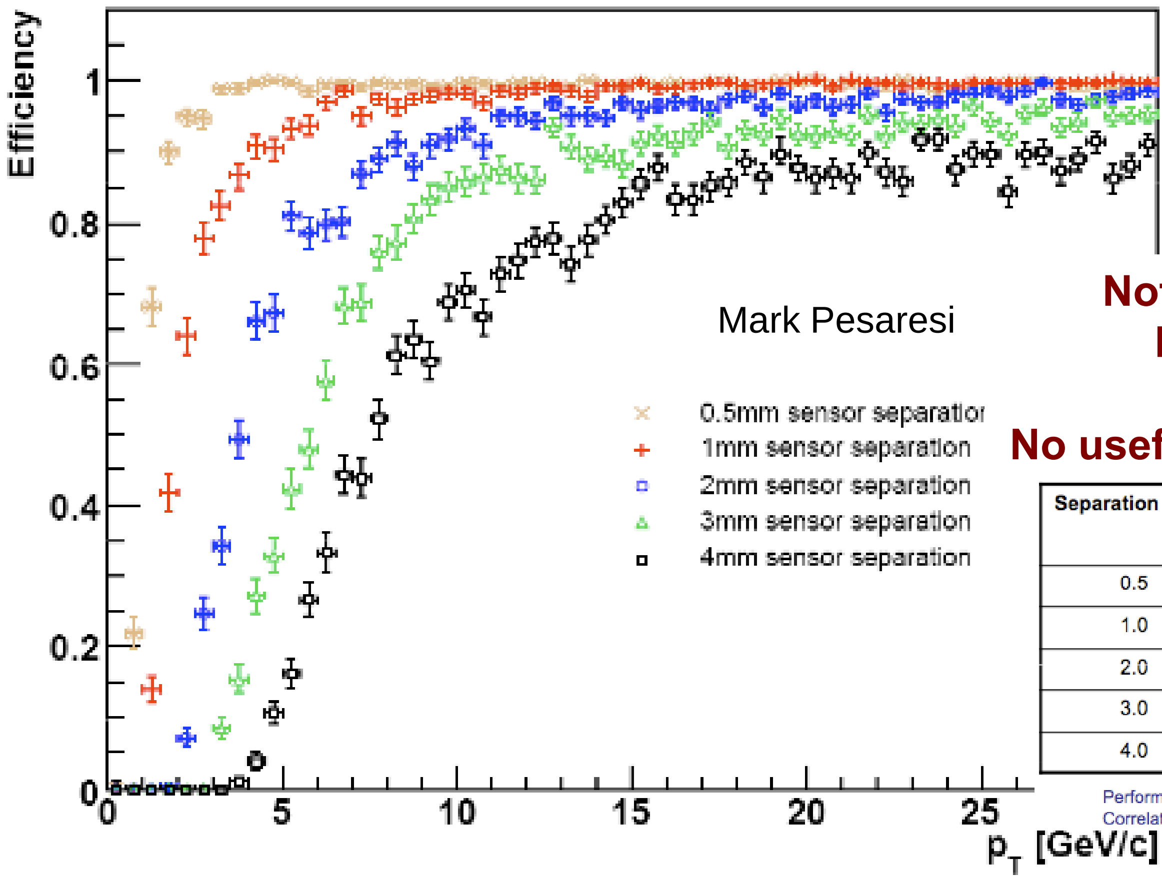
- **Use a Pair of Sensor Planes, at ~ mm distance**
  - **Pairs of Hits provide Vector, that measure angle of track with respect to the origin**
  - **Note: angle proportional to hit pair radius**

- **Keep only Vectors corresponding to high Pt Tracks**

J. Jones (~2005)
CMS Tracker SLHC Upgrade Workshops



Recent results for a doublet of closely spaced sensors: pitch ~ 100um*2.4mm (M. Pesaresi)



p_T discriminating performance of a stacked layer at r=25cm for various sensor separations using 10,000 di-muon events with smearing

Note much Sharper Threshold For Low Threshold Value

No useful discrimination at Pt ~ 20 GeV

Separation [mm]	Max Efficiency [%]	Fake [%] (or average number/event)	Reduction Factor
0.5	99.05	0.73 (12.22)	8.04
1.0	99.35	4.14 (25.58)	22.26
2.0	97.745	17.83 (18.74)	95.99
3.0	96.00	39.08 (23.76)	210.28
4.0	92.95	47.27 (32.39)	254.35

Performance of a detector stack at r=25cm for sensors with pitch 100μmx2.37mm.
Correlation cuts optimised for high efficiency

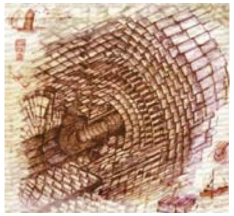
Local Occupancy Reduction
a Hierarchical scheme with Stacked Doublets

Local Information Gathering, and Processing Hierarchy

- **Within a Doublet-Sensor Module**
  - Collect Hits from each Sensor
  - Match into Hit Pairs & Reject Hit Pairs from Very low Pt Tracks: Pt < 1~2GeV
  - Nb one datum / Hit Pair

- **Within a Stacked Doublet**
  - Collect Hit Pairs from each Sensor Doublet Module
  - Match into Track Vectors & Reject Track Vectors with Pt < 2~4GeV

- **Transmit to USC for High Pt & Isolation L1 Track Trigger Primitives**



Stacked Tracking Trigger Straw Man

- **This Simple Concept drives all aspects of the System, and Defines Requirements and Challenges throughout the System**

- **Module**
  - **Sensors; Alignment; On Module Connectivity, Data Transmission & Reduction; Module I/O and Interface to ROD; Power & Cooling**

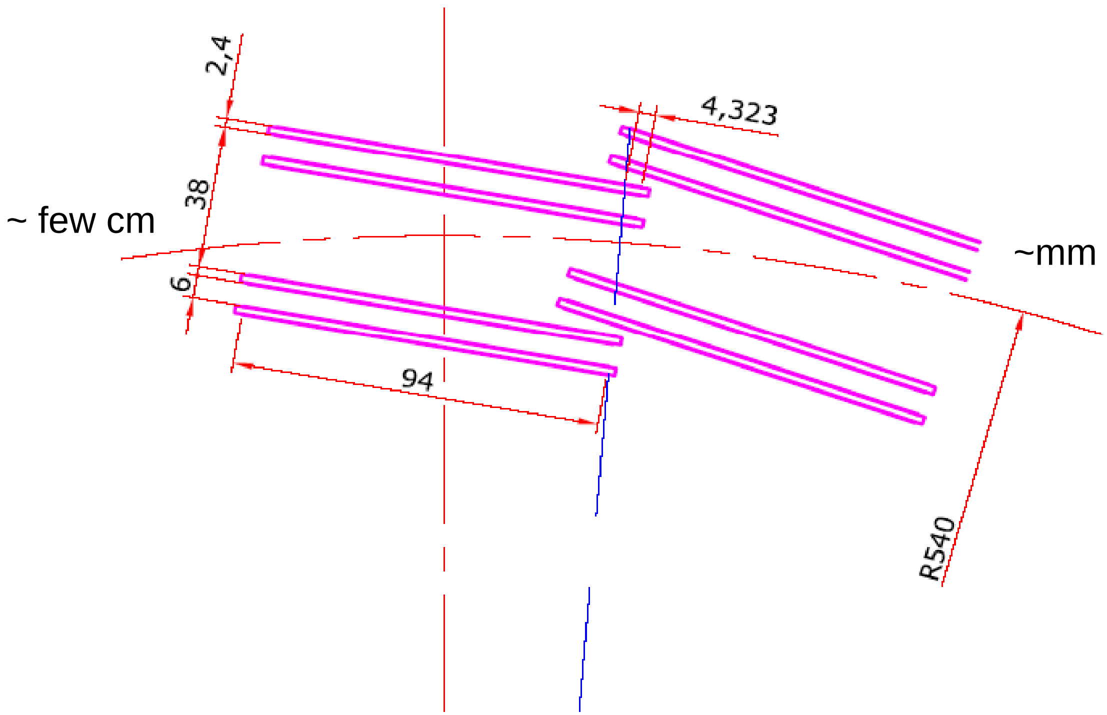
- **ROD**
  - **Module Alignment; On ROD Data Transmission & Reduction; Power Distribution; Mechanics & Cooling**

- **Off-Detector**
  - **ROD to USC Data Transmission; Tracking Trigger Primitives; Event Read-Out; CTRL System; Power System; Cooling System**

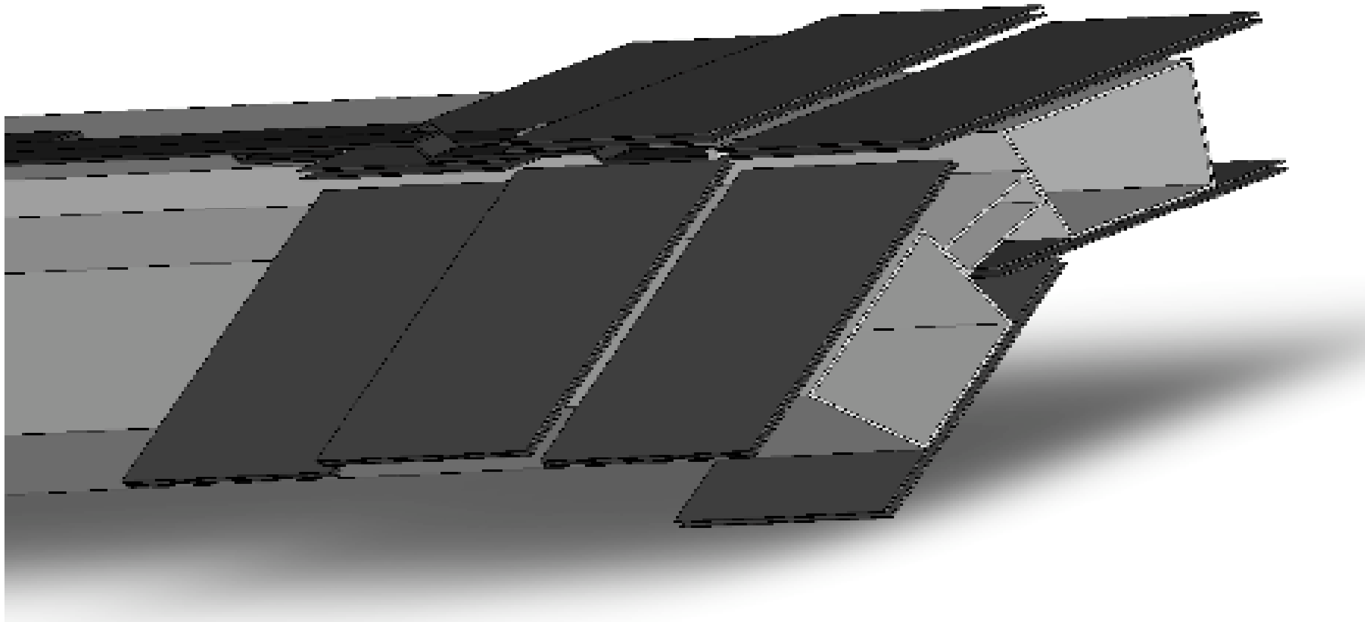
CMS SLHC Tracker
Straw Man Layout Illustrations

r-phi Hermiticity: get all 4 hits in one ROD or in the neighbor

No communication across r-phi stacks

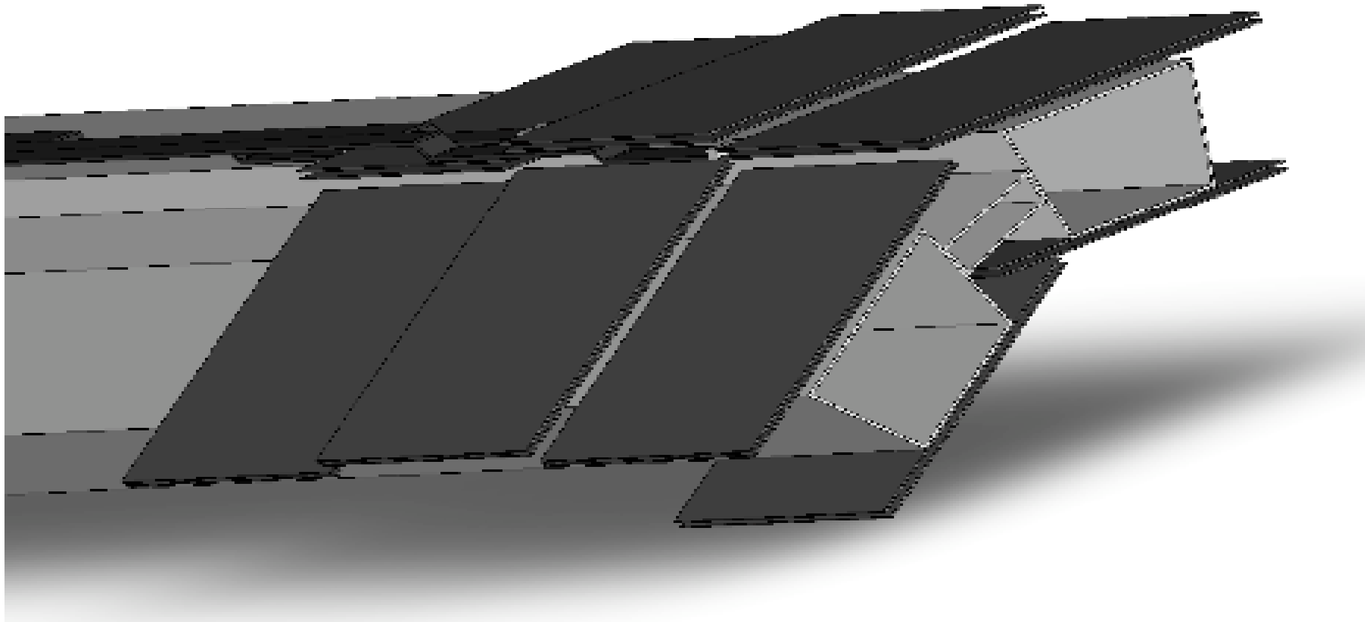


Substantial Space for Mechanics & Services inside ROD:
Mechanical Supports; Cooling
L1 Trigger, Read-Out & CTRL Data Reduction & Transmission
Power Distribution (eg DC-DC)



CMS SLHC Tracker
Straw Man Layout Illustrations

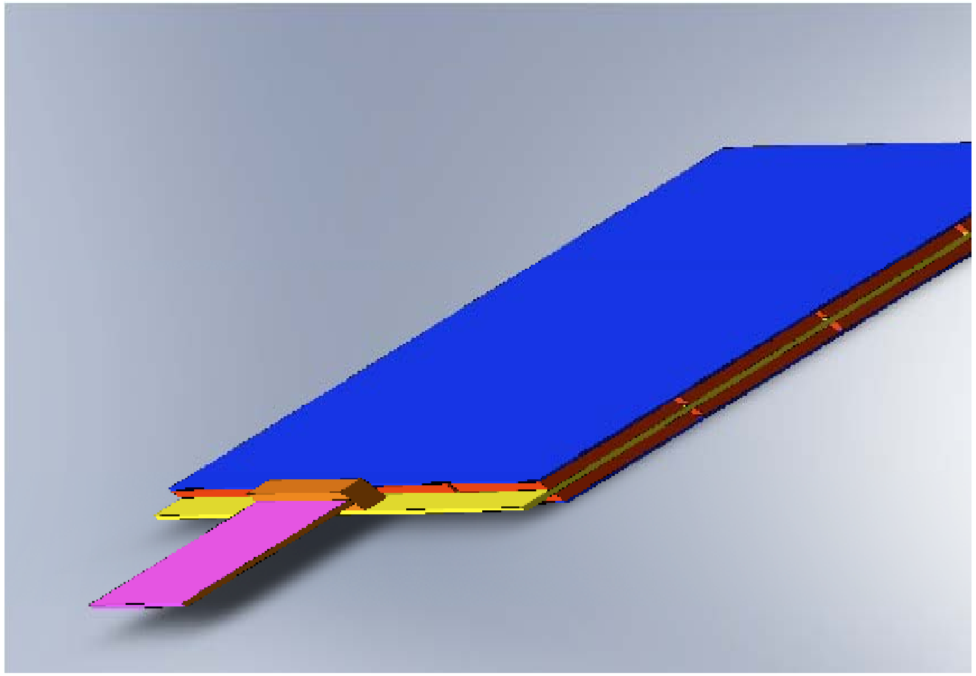
Reduce Output Rates from Module
Low Power Electrical Data Transmission to Bulk-Head / PP1
Reduce Output Rates from ROD @ Bulk-Head / PP1
Simplest, but large number of Electrical Links: see later
Optical Data Transmission from Bulk-Head / PP1 to USC

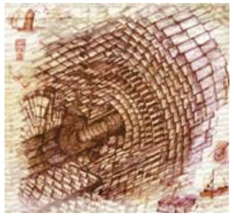


Marcello Mannelli FNAL
CMS SLHC Work-Shop

Straw Man Sensor Doublet Module: Vertically Integrated Hybrid Module

- **Example of Vertically Integrated Hybrid Module:**
  - Chips are bump bonded to sensor
  - And connected to central (Si) pcb through vias to back-side of Chip
  - Direct Vertical Chip-to-Chip transmission: minimizes Power
  - Requires through-via technology

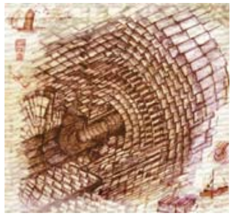




Some Numbers

- **Basic Input: Occupancy at 10^{35} at R ~ 35cm (TIB L2 Radius)**
  - Typical ~ 2 hits / cm^2 / 25ns   Maximum < 10 * 2 = 20 hits / cm^2 / 25ns
    - Strip Occupancy ~ 120MHz / cm^2 at R = 25cm
    - Strip Occupancy ~ 80MHz / cm^2 at R = 34cm
    - Strip Occupancy ~ 40MHz / cm^2 at R = 50cm   1/2
    - Strip Occupancy ~ 20MHz / cm^2 at R = 60cm   1/2

    (Geoff Hall, compilation of full simulation results from Ian Tomalin)
  - Nb these occupancy are for 320um~500um thick sensors
  - Do not account for reduction expected from use of thinner sensors
    - Expected Reduction factor 1.5 ~ 2, to be verified
- **Crossing Frequency / Event Read-Out ~ 40MHz / 100kHz ~ 1 / 400**
  - L1 Data reduction by a factor of 100 ~ 1'000 is a reasonable target

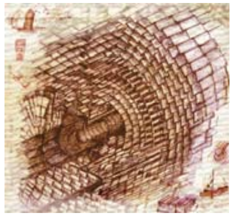


Some Numbers

- **Material Budget ~ Material / cm^2**
  - Consider rates and power / cm^2
  - Nb normalize to cm^2 of Silicon
  - 1 module = 2 sensitive layers = 2 * x*y cm^2 (eg 2 * $100cm^2$)

- **Present CMS Tracker Event Read-Out ~ 4 channels / cm^2 @ 100KHz**
  - Data Rate ~ 4MHz / cm^2 (analogue info ~ 10bits equivalent)

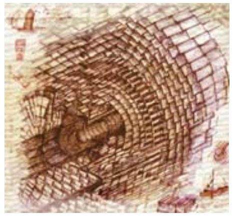
- **Present CMS Tracker Power Inside Volume ~ 33kW over ~ $210m^2$**
  - Power Density ~ 16mW /cm^2 inside Tracking volume
  - 6 Single-Sided + 4 Double-Sided = 14 Sensitive Layers



Data Transmission, Reduction, Power Density

In the following Assume

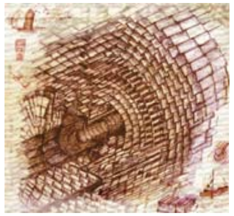
- **Zero Suppressed Read-Out**
  - Data rates ~ driven by Occupancy, NOT by Channel Count
- **De-randomized Read-Out from Module to USC**
  - Available Bandwidth ~ Average Bandwidth, with * 2 safety margin
  - Non De-randomized within Module: Available Bandwidth ~ 10 * Average
- **Reduce Output Data Rates from Module by 2 * 10**
  - 2 hits = 1 datum per Hit Pair Output from Module
  - Accept 1 / 10 Hit Pairs: Pt Threshold 1 ~ 2 GeV
- **Reduce Output Data Rates from ROD by 10**
  - 2 hit pairs = 2 data per Track Vector Output from ROD
  - Accept 1 / 10 Track Vectors: Pt Threshold 2 ~ 4 GeV



Data Transmission, Reduction, Power Density

In the following Assume

- Pixel Dimension ~ 100um * 1mm
  - 1'000 Pixels /cm^2
  - (more on this later)
- ~ 18 bits / L1 hit Address & Time Stamp info within Module
  - Assume no analogue information for L1
- ~ 24 bits / L1 hit Address & Time Stamp info from Module
- 32 bits / Read-Out hit info inside Tracker
  - Assume ~ 8 bits analogue information for Read-Out
  - Nb if "Short Strips" ~ 32mm address field is reduced by ~ 5bits
    - ~ 20% reduction in Address Information for ~ 32 fewer channels / cm^2

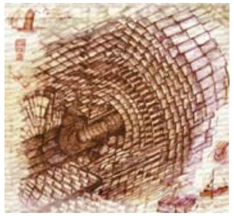


Data Transmission, Reduction, Power Density

- **Within a Doublet-Sensor Module:** — **Un-terminated Lines**
    - Only transmit from one sensor plane to the other…
  - Transmission distance ~ few mm
  - Input * Output Data reduction ~ 1 * 20
  - Power driven by by Actual Usage — Available ~ 10 * Average
  - Energy/bit of Link over ~ few mm < 2pJ/bit — (1pJJ/bit possible?)
  - Transmission rate ~ 320Mb/s — (1Gb/s possible?)

Data Rates / cm^2	Average Bandwidth	Available Bandwidth
– L1	~ 800Mb/s	< 8Gb/s
– Read-Out	~ 6Mb/s	< 60Mb/s

Power / cm^2	Average Bandwidth	Available Bandwidth
– L1	~ 1.6mW	< 16mW
– Read-Out		



Data Transmission, Reduction, Power Density

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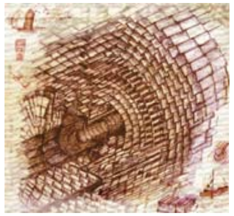
  - Power driven by by Actual Usage — Available ~ 10 * Average
  - Energy/bit of Link over ~ few mm < 2pJ/bit — (1pJJ/bit possible?)
  - Transmission rate ~ 320Mb/s — (1Gb/s possible?)

Data Rates / cm^2	Average Bandwidth	Available Bandwidth
L1	~ 1.6Gb/s	< 16Gb/s
Read-Out	~ 6Mb/s	< 60Mb/s

Links / Chip ~ $6cm^2$	Average Bandwidth	Available Bandwidth
L1	~ 14	~ 140
Read-Out		

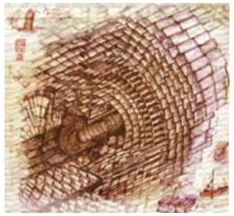


Data Transmission, Reduction, Power Density

- **To the End of a ROD ~ PP1:** — **Transmission Line**
  - Transmission distance 3 ~ 10m
  - Input * Output Data reduction ~ 20 * 10 ~ 200
  - Power driven by Available Bandwidth — (~ 2 * Average)
  - Energy/bit for Link over ~ 10m < 20pJ/bit — (10pJ/bit over ~ 1m)
  - Transmission Rate ~ 320Mb/s — (1Gb/s possible?)
    - Includes Clock & Error Recovery

Data Rates / cm^2	Average Bandwidth	Available Bandwidth
L1	~ 100Mb/s	~ 200Mb/s
Read-Out	~ 6Mb/s	~ 10Mb/s

Power / cm^2	Average Bandwidth	Available Bandwidth
L1	~ 2mW	~ 4mW
Read-Out	~ 0.1W	~ 0.2mW



Data Transmission, Reduction, Power Density

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  - Transmission distance 3 ~ 10m
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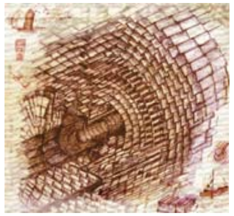
  - Power driven by Available Bandwidth — (~ 2 * Average)
  - Energy/bit for Link over ~ 10m < 20pJ/bit — (10pJ/bit over ~ 1m)
  - Transmission Rate ~ 320Mb/s — (1Gb/s possible?)
    - Includes Clock & Error Recovery

Data Rates / cm^2	Average Bandwidth	Available Bandwidth
L1	~ 100Mb/s	~ 200Mb/s
Read-Out	~ 6Mb/s	~ 10Mb/s

Links / Module	Average Bandwidth	Available Bandwidth
L1	~ 60	~ 120 !
Read-Out	~ 4	~ 8

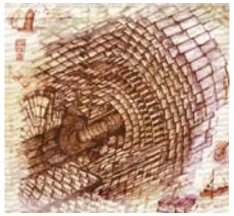


Data Transmission, Reduction, Power Density

- **To USC:** **Optical Link**
  - Transmission distance ~ 100m
  - Input Data Reduction ~ 200
  - Power driven by Available Bandwidth (~ 2 * Average)
  - Energy/bit for Link over < 200pJ/bit (100pJ/bit possible?)
  - Transmission Rate = 10Gb/s
    - Includes Clock & Error Recovery

Data Rates / cm^2	Average Bandwidth	Available Bandwidth
– L1	~ 10Mb/s	~ 20Mb/s
– Read-Out	~ 6Mb/s	~ 12Mb/s

Power / cm^2	Average Bandwidth	Available Bandwidth
– L1	~ 2mW	~ 4mW
– Read-Out	~ 1.5mW	~ 3mW

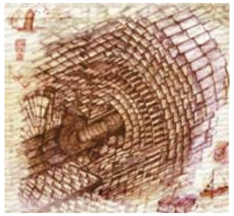


Data Transmission, Reduction, Power Density

- **To USC:** **Optical Link**
  - Transmission distance ~ 100m
  - Input Data Reduction ~ 200
  - Power driven by Available Bandwidth (~ 2 * Average)
  - Energy/bit for Link over < 200pJ/bit (100pJ/bit possible?)
  - Transmission Rate = 10Gb/s
    - Includes Clock & Error Recovery

Data Rates / cm^2	Average Bandwidth	Available Bandwidth
L1	~ 10Mb/s	~ 20Mb/s
Read-Out	~ 6Mb/s	~ 12Mb/s

Links / Module	Average Bandwidth	Available Bandwidth
L1	~ 1/4	~ 1/2
Read-Out	~ 1/8	~ 1/4

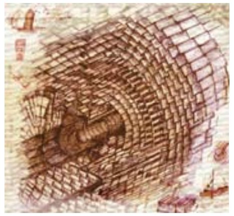


Data Transmission, Reduction, Power Density

At R ~ 35cm

Based on 1/2*10 off Module * 1/10 off ROD data rate reduction

- **Power for Data Transmission within Module**
  - L1@ 40MHz ~ 3mW/cm^2 — Read-Out @ 100kHz < 0.1mW/cm^2
- **Power for Data Transmission To the End of a ROD**
  - L1 @ 40MHz ~ 4mW/cm^2 — Read-Out @ 100kHz ~ 0.2mW/cm^2
- **Power for L1 Trigger Info Transmission To USC (at Bulk head)**
  - L1 @ 40MHz ~ 4mW/cm^2 — Read-Out @ 100kHz ~ 3mW/cm^2
- **Total Power Budget L1 & Read-Out Data Transmission @ R ~ 35cm**
  - Inside Tracking Volume: ~ 7mW/cm^2
  - At Bulkhead: ~ 7mW/cm^2



Data Transmission, Reduction, Power Density

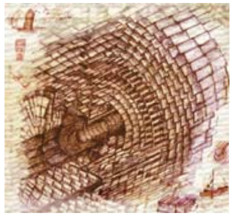
At R ~ 35cm

Based on 1/2*10 off Module * 1/10 off ROD data rate reduction

- **Total Power Budget L1 & Read-Out Data Transmission @ R ~ 35cm**
  - Inside Tracking Volume: ~ 7 mW/cm^2
  - At Bulkhead: ~ 7 mW/cm^2

- **A L1 Track Trigger based on the scheme presented here is NOT ruled out by the Power requirements for the L1 Data Transfer**

- **Challenges for Data Transmission & Reduction include:**
  - Module interconnect technology
  - High rate (1Gb/s) Low Mass Low Power Electrical Link several meters long
  - De-randomized L1 data transfer protocol
  - Hit Doublet & Track Vector Logic (distributed along ROD?)
  - …



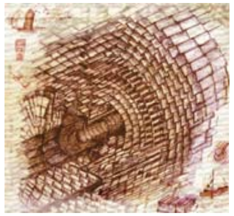
Granularity: Short Strips vs Long Pixels

- **The CMS Silicon Strip Tracker is extremely effective because:**
  - **Excellent Quality of Pixel Seeds**
  - **Fine strip pitch, from 80um to 200um**
    - each hit has high resolution and track parameters are rapidly constrained
  - **Strip length, from 10cm to 20cm results in cell size ~ $0.5mm^2$**
    - occupancy ~ 2% or less at 10^{34}
  - **Pattern recognition converges ~ unambiguously with first few hits => fast**

- **At SLHC occupancy 10~20 times higher**

- **Short Strips**
  - **Strip length in range 1 ~ 2cm to maintain low occupancy**

- **Long Pixels**
  - **Pixel length in range 1 ~ 2mm => reduce occupancy to ~ Inner Pixel like**
  - **3D info => 3D Tracking without Stereo Layers**
  - **Sufficient Z resolution at L1 to sort Trigger Primitives by Interaction Vertex**



Granularity: Short Strips vs Long Pixels

- **Comparative Performance Studies are Important Guidance**
  - Rejection of tracks from different interaction vertices at L1?

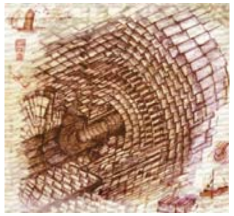
- **Cost and Manufacturability are a Key Input**

- **Implications on System, Read-Out Architecture etc.**

- **Reliable projections of Power Dissipation/cm^2 are a Fundamental Input**

- **Short Strips vs Long Pixels**
  - Extrapolate from Strip Tracker APV25 to reduced capacitance short strips
  - Extrapolate from Pixel ROC to larger capacitance long pixel
  - Compare: Power, Material, Cost, Feasibility, Performance

- **Pursue both approaches until these points are sufficiently well understood to draw some conclusions**



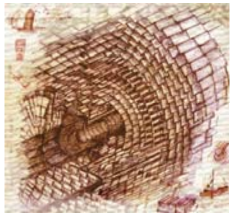
Front-End Power for “Long Pixel” Tracker

- **Power of present CMS Pixel ROC ~ 30uW / channel**
  - 100um * 150um Pixel, Power Density ~ 200mW / cm^2
    - Pixel Power Density ~ 16 * Strips, Pixel Channel Density ~ 1’500 * Strips !

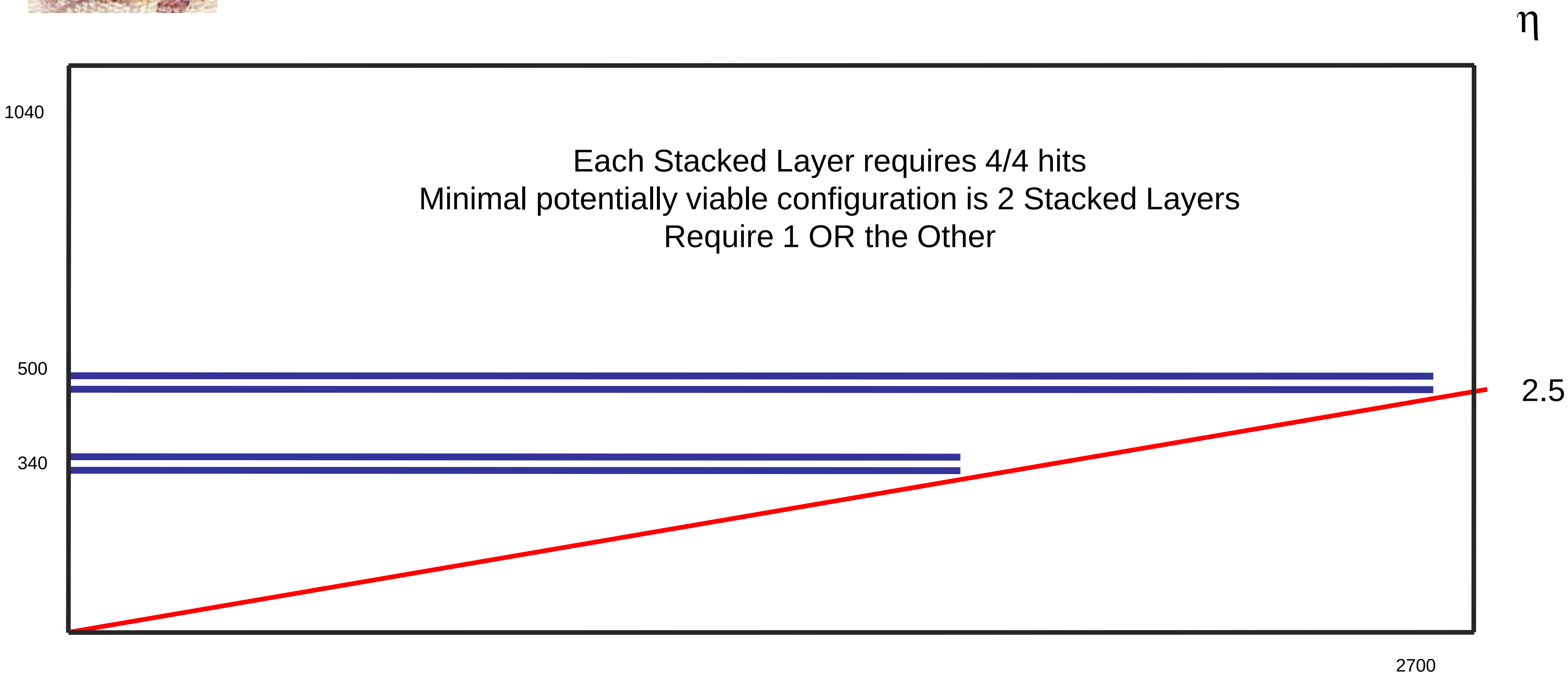
- **Assume 20 ~ 30uW / channel for 100um * 1 ~ 2mm Long Pixels**
  - Private communication from Roland

- **Results in ~ 15mW / cm^2**
  - Compares with ~ 12mW /cm^2 of present Strip Tracker APV25 FE Chip
  - Compares with ~ 7mW/cm^2 for Data Transmission inside TK Volume
  - Long Pixel Channel Density 100 ~ 200 * Strips

- **Long Pixels not ruled out by Front-End Power requirements**
  - Worth pursuing further

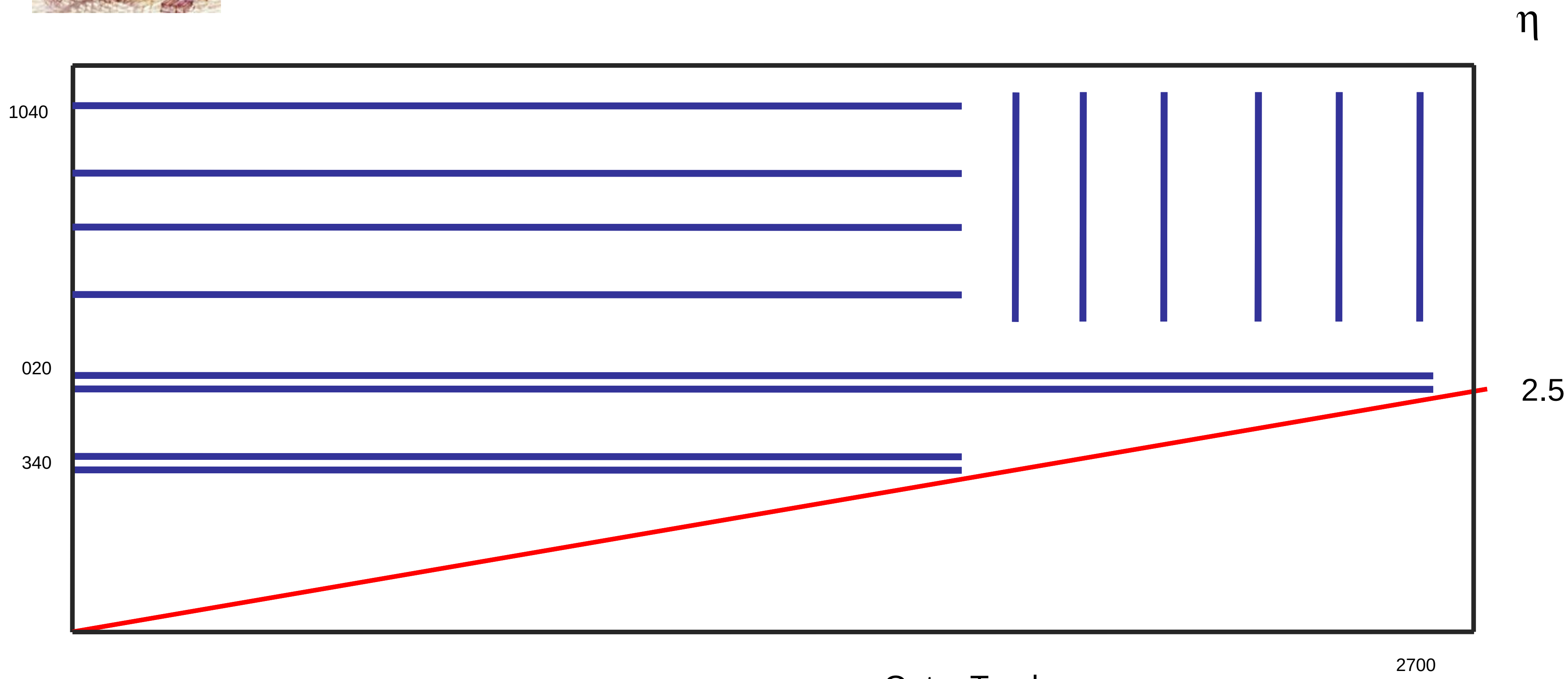


Straw Man Layout: Stacked Doublet Layers



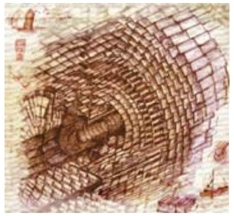
2 Stacked Doublet L1 & Tracking Layers,
with full acceptance up to η ~ 2.5:
Each Layer provides 2 * 2 = 4 hits
2 Layers = 8 hits

Straw Man Layout:
2 Stacked Doublet Layers + Outer Tracker



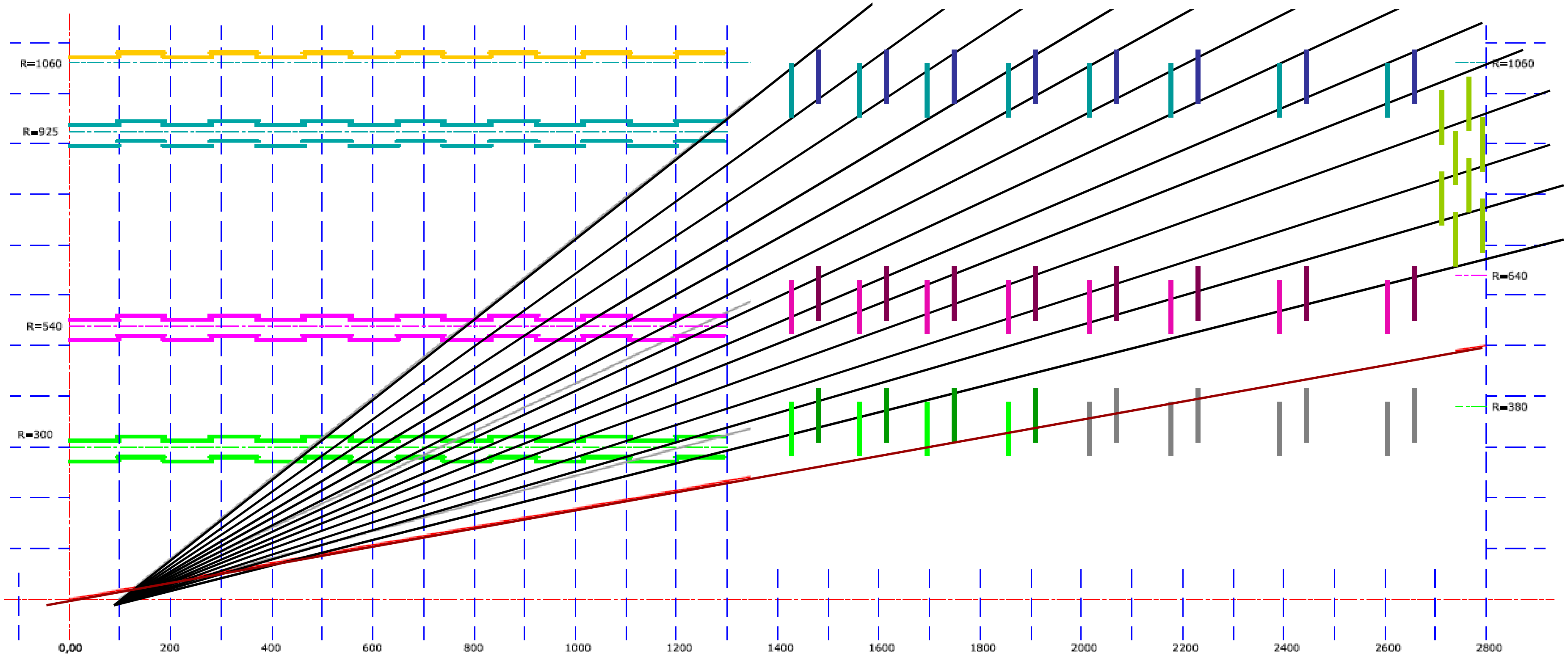
2 Stacked Doublet L1 & Tracking Layers,
with full acceptance up to η ~ 2.5:
Each Layer provides 2 * 2 = 4 hits
2 Layers = 8 hits

Outer Tracker:
Optimized for Tracking
No L1 functionality
Introduces 3'rd System, in two "flavors"



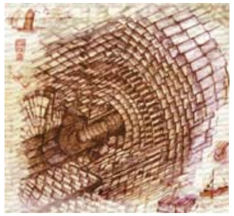
End-Cap Rings

Additional Sensors = 4’368 | Additional Sensors ~ 1’000

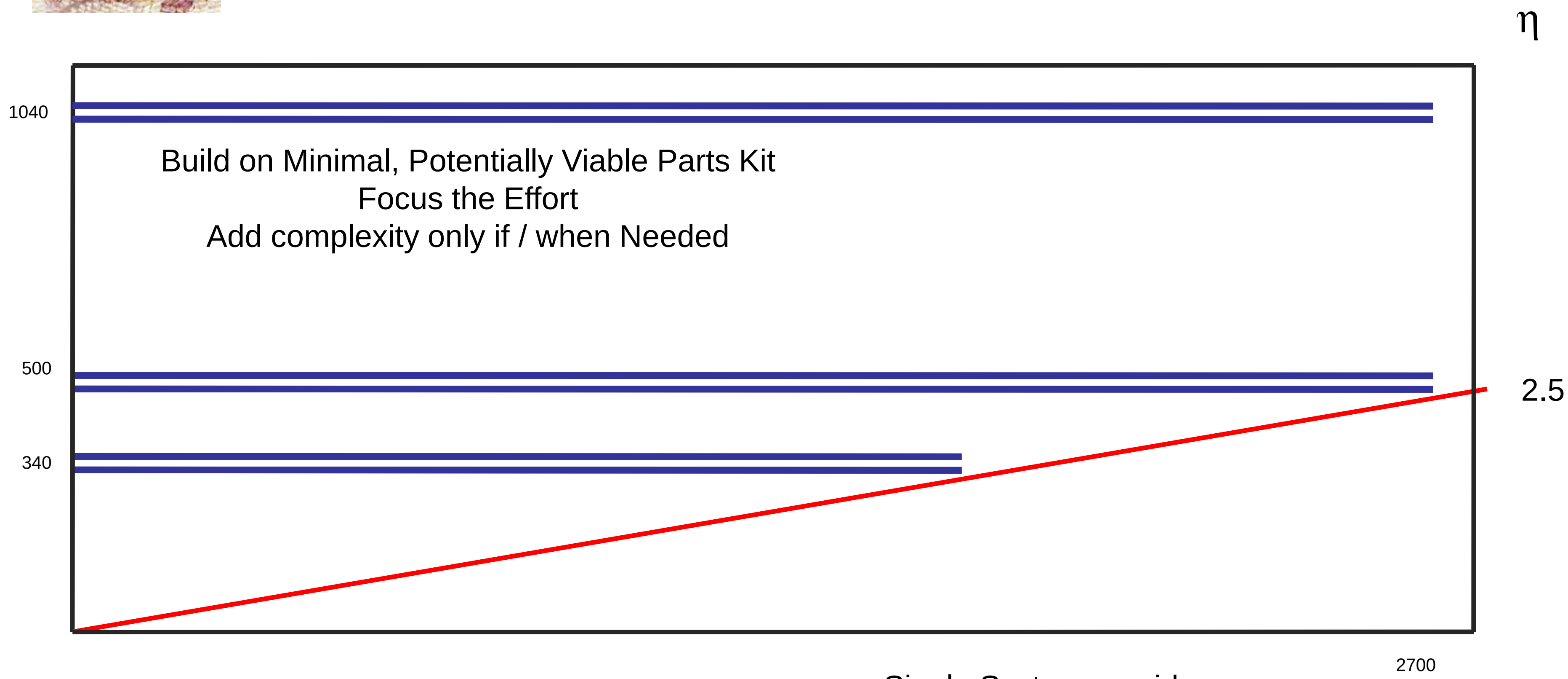


Total Barrel
Double Sensor Modules = 9’464
Sensors = 18’928
Present Barrel Sensors ~ 14’000

Total End-Caps
Double Sensor Modules ~ 4’500
Sensors ~ 10’000
Present End-Caps Sensors ~ 10’500



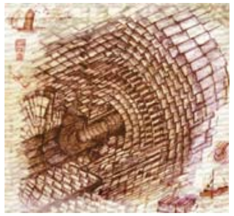
Straw Man Layout: 3 Stacked Doublet Layers



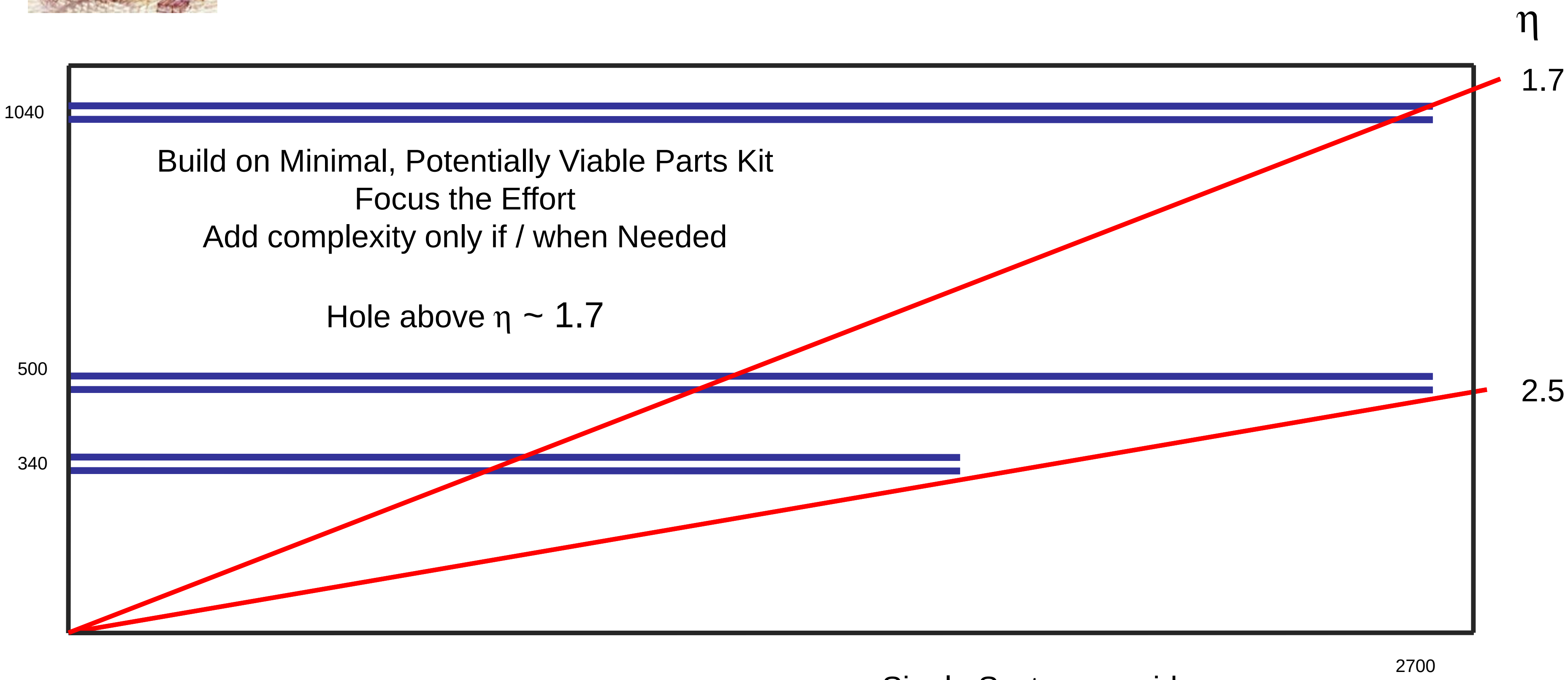
3 Stacked Doublet L1 & Tracking Layers,

Each Layer provides 2 * 2 = 4 hits
3 Layers = 12 hits

Single System provides
Full L1 & Tracking functionality

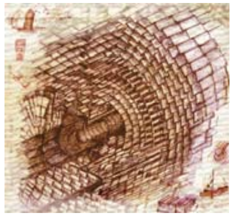


Straw Man Layout: 2 Stacked Doublet Layers + More of the Same



3 Stacked Doublet L1 & Tracking Layers,
with full acceptance up to $\eta \sim 1.7$:
Each Layer provides 2 * 2 = 4 hits
3 Layers = 12 hits

Single System provides
Full L1 & Tracking functionality



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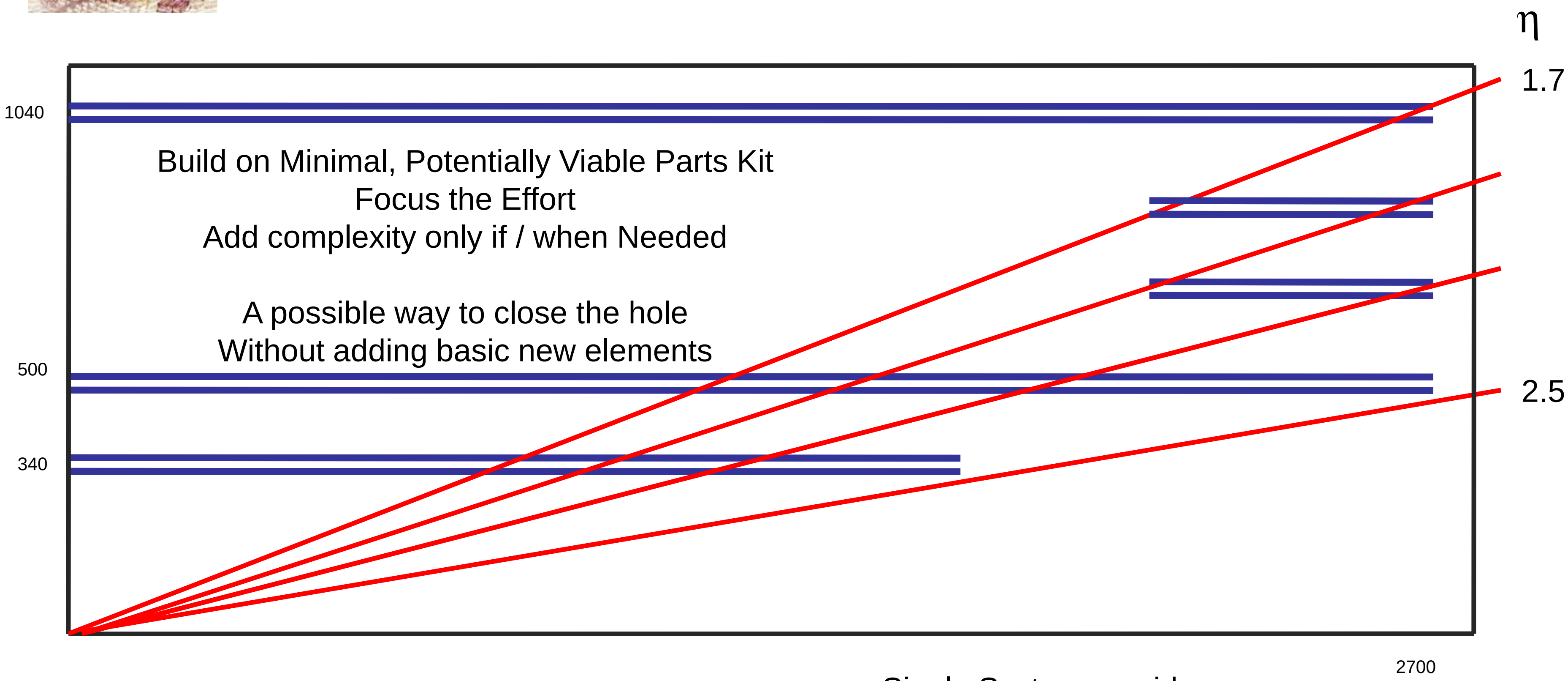
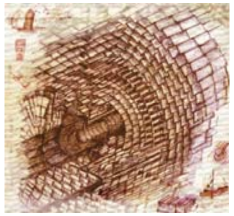


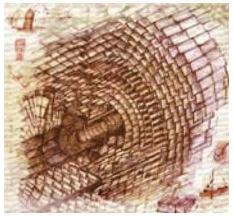
3 Stacked Doublet L1 & Tracking Layers,
with full acceptance up to η ~ 2.1:
Each Layer provides 2 * 2 = 4 hits
3 Layers = 12 hits

Single System provides
Full L1 & Tracking functionality
Short FWD Cylinders close acceptance
Total Silicon Surface ~ 275m^2
Present Tracker ~ 210m^2



Conclusions

- **The Function of the Straw Man is to Illustrate the Underlying Ideas, for a CMS SLHC Tracker with L1 Trigger capability**
- **It is intended to highlight the Pros and Cons of these Ideas, to allow informed decisions down the line**
- **And to Provide a Framework to help Direct and Focus different Lines of Activity**
  - **Performance Studies**
  - **Sensors / Front-End Read-Out / Interconnects**
  - **(Unique) Module Functionality & Design**
  - **Mechanics / Cooling and Services Integration**
  - **Data Reduction and Data Transmission**
  - **Improved Power Distribution Scheme, Local Voltage Regulation etc**
  - **Material Budget Reduction and Optimization**
  - **Etc….**
- **On the way to a Base-Line Layout**

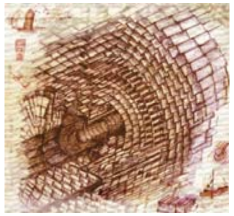


Conclusions

- The Function of the Straw Man is to Illustrate the Underlying Ideas, for a CMS SLHC Tracker with L1 Trigger capability
- It is intended to highlight the Pros and Cons of these Ideas, to allow informed decisions down the line
- And to Provide a Framework to help Direct and Focus different Lines of Activity
- An Effective L1 Track Trigger is a Major Challenge:

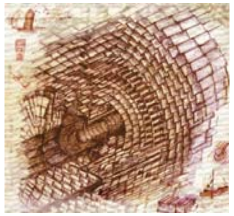
A Straw-Man is Required in order to make Effective Progress

- On the way to a Base-Line Layout



Full Stacked Trigger Tracker
Straw Man Layout

- **Basic L1 Tracker Trigger concept:**
  - Local Data Reduction based on Track Vectors
- **An r-phi hermetic Stacked Doublet arrangement of RODs is proposed**
  - Rapid L1 High Pt Track identification (10~25 GeV), in hermetic r-phi sectors
  - Isolation criteria with lowest possible Pt threshold (2 ~ 4 GeV)
- **The Stacked Doublet layers will also provide Tracking**
  - Track Reconstruction for the HLT & Off-line should be very fast
  - Track Parameters should be of high quality (to be verified in detail)
- **The use of ~mm long Pixels provides opportunity for primary vertex association of Track Trigger Primitives**
- **The RODs provide opportunities for Material Budget Reduction**



Full Stacked Trigger Tracker
Straw Man Layout

- **Propose that a Full Stacked Trigger Tracker Straw Man be studied**
  - As a Potentially Viable Concept
  - As a means of providing a focus for the System Design & defining sets of work-packages for each subsystem in the Upgraded Tracker
  - As a Benchmark for alternative Stacked Trigger + Outer Tracker Layouts

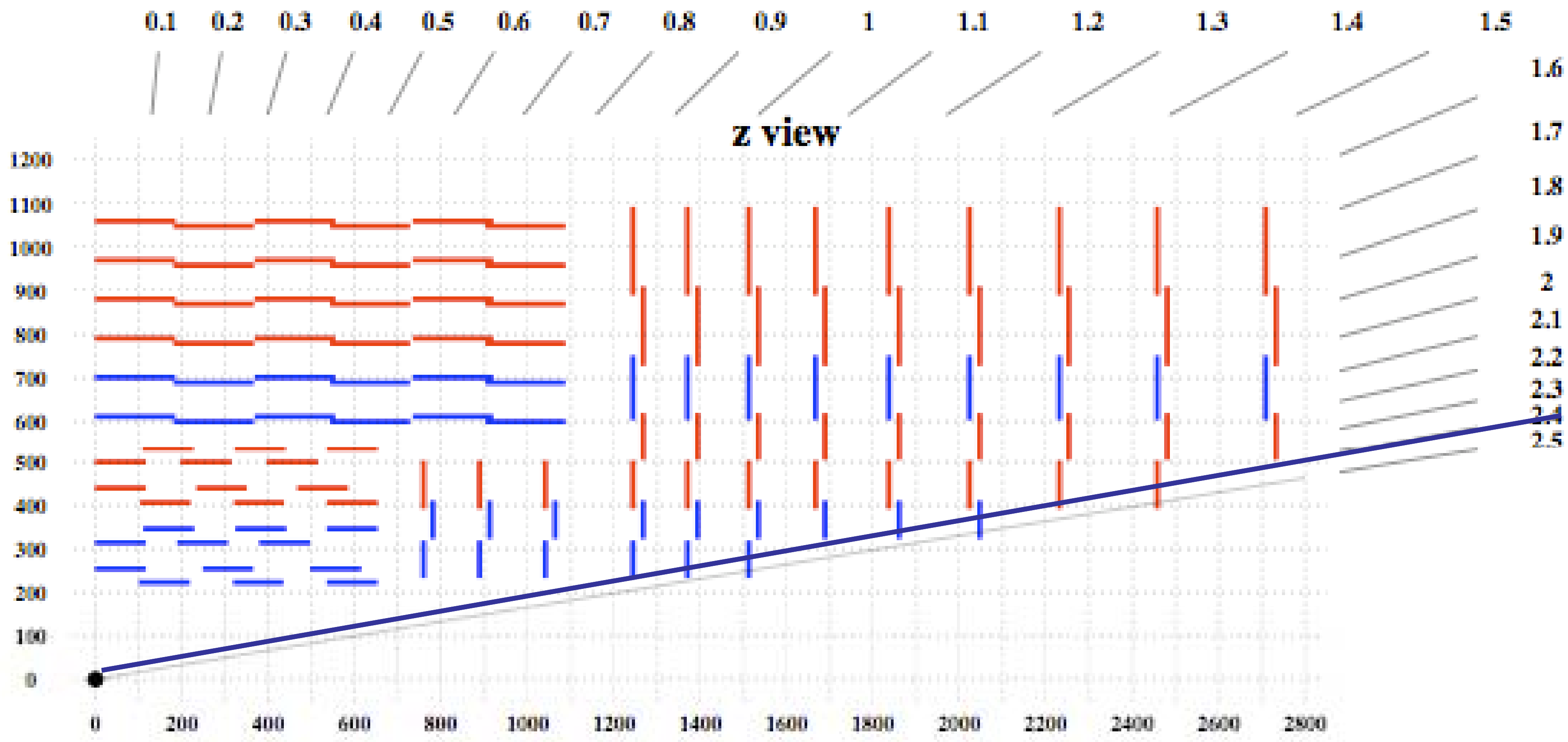
- **There are Many Challenges**

BUT

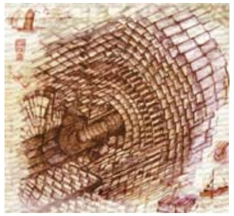
- **CMS needs a viable Trigger for SLHC**
  - Robust L1 Track Trigger primitives are a Must

- **An all Pixel Stacked Trigger Tracker will be "Game Changing" detector**
  - Just as the present CMS Tracker is a Game Changing detector

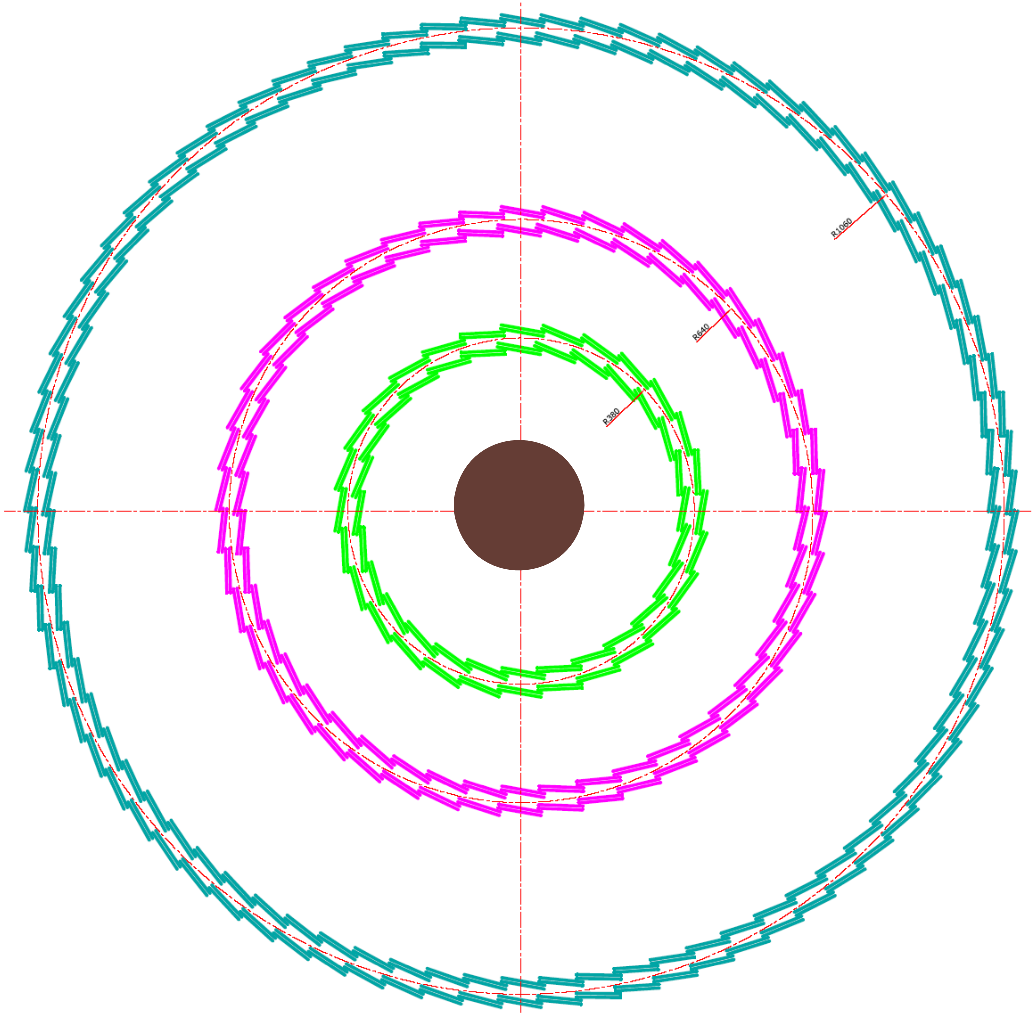
Back-Up Slides



z view
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3 2.4 2.5
1200 1100 1000 900 800 700 600 500 400 300 200 100 0
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800



Full Stacked Trigger Tracker
Straw Man Layout

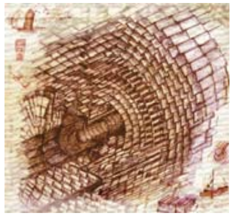


12 Measurement Layers

Organized in 3 Super-Layers

Each Super-Layer consists of a Stack of Doublet Sensor Modules
(4 measurement layers / Super-Layer)

- **Inner Super-Layer ~ 30cm (Geometry of Inner Vtx layers?)**
- **Middle Super-Layer ~ 50cm**
- **Outer Super-Layer ~ 100cm**



Full Stacked Trigger Tracker
Straw Man Layout

12 Measurement Layers

Organized in 3 Super-Layers

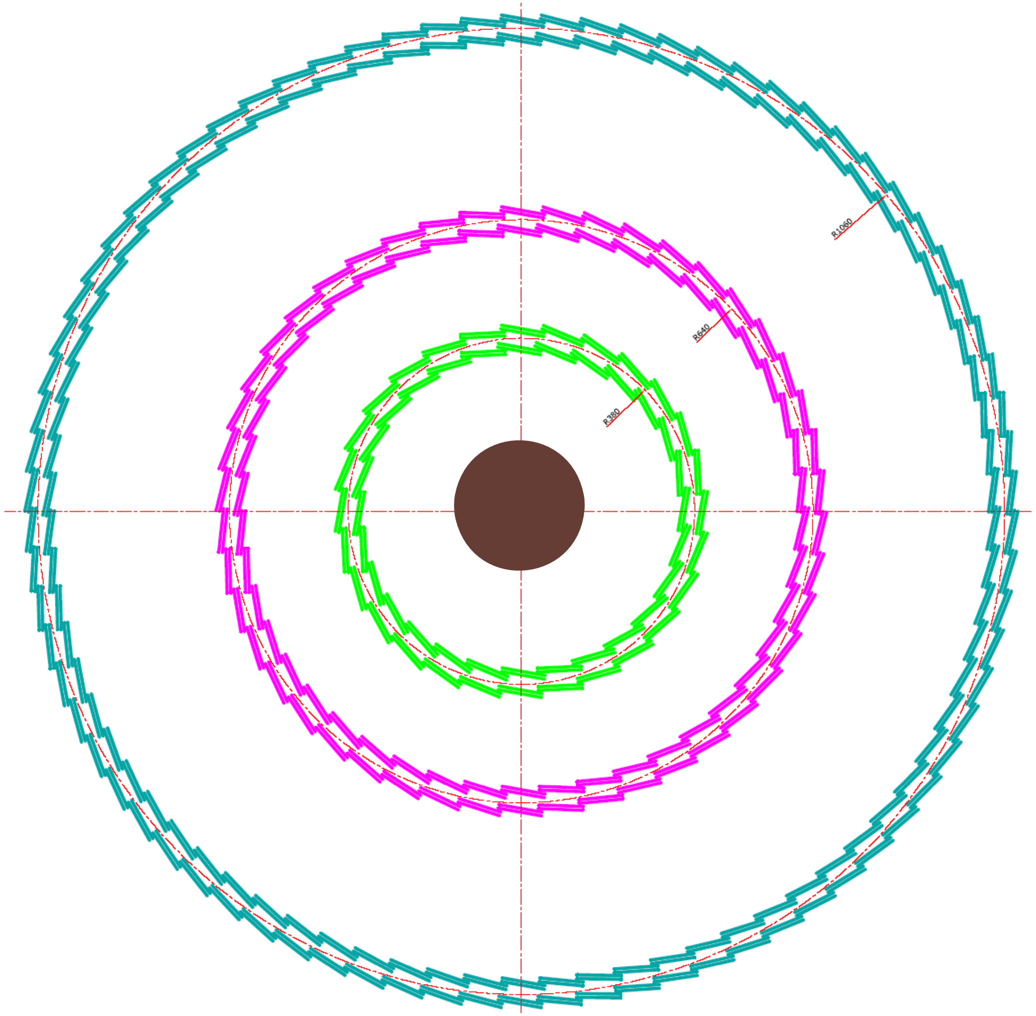
Each Super-Layer consists of a Stack of Doublet Sensor Modules
(4 measurement layers / Super-Layer)

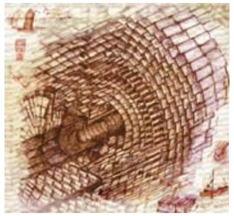
Can search for high Pt Track Stubs Independently in each Super-Layer

Can Combine Super-Layers to ensure High Efficiency & Low Fake rate

Can use for L1 Trigger

And for Prompt Tracking at HLT





Full Stacked Trigger Tracker
Straw Man Layout

Material Budget Reduction

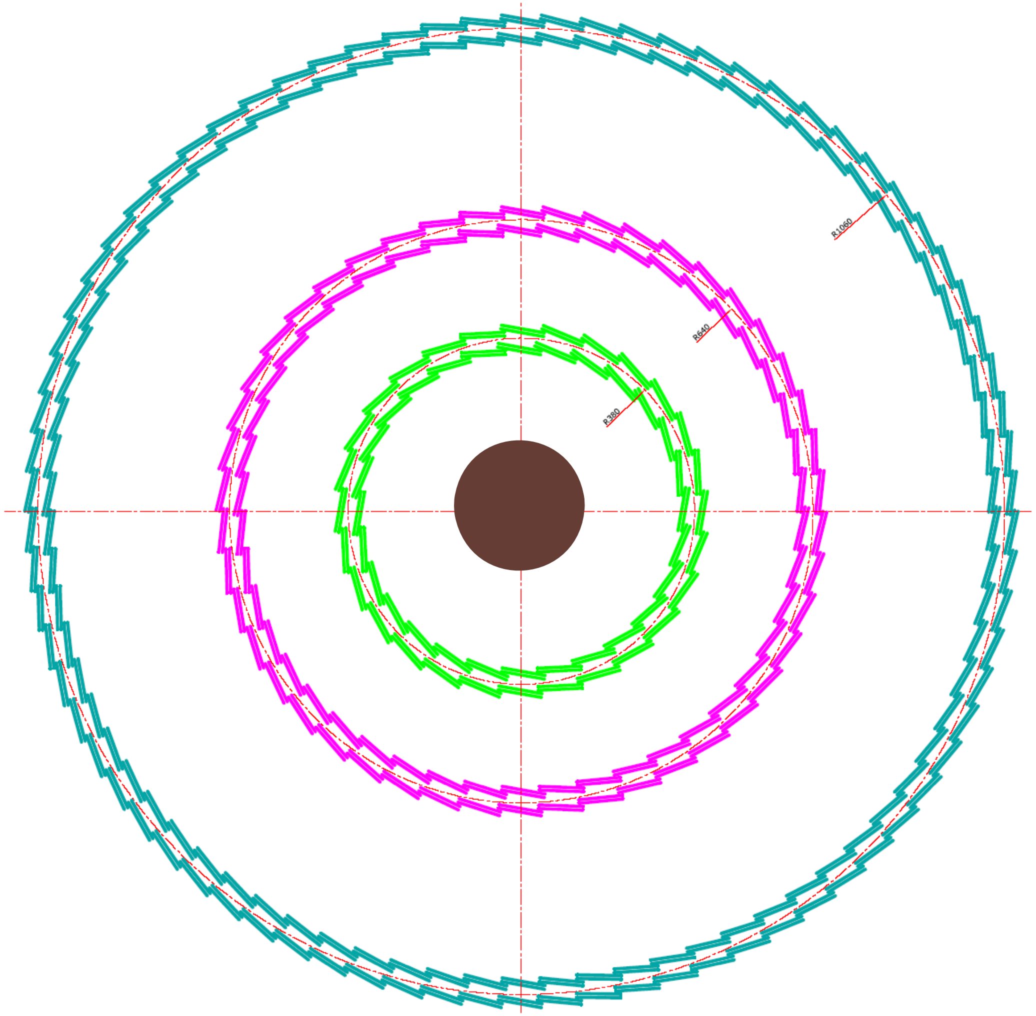
Stack of Sensor Pairs provide opportunity for shared mechanics and services

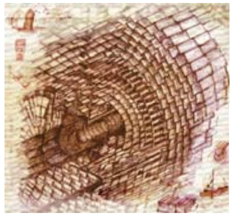
A Double-Sided ROD = 2 hits
For 1.5 * X0 of Single-Sided ROD

6 Layers of Double Modules = 12 hits
For 9 * X0 of Single Module layer

Current Tracker = 14 hits
For 12 * X0 of Single Module layer
(If all “TOB - Like”)

Stacking Doublets onto Beams could allow to further reduce X0 with respect to RODs?

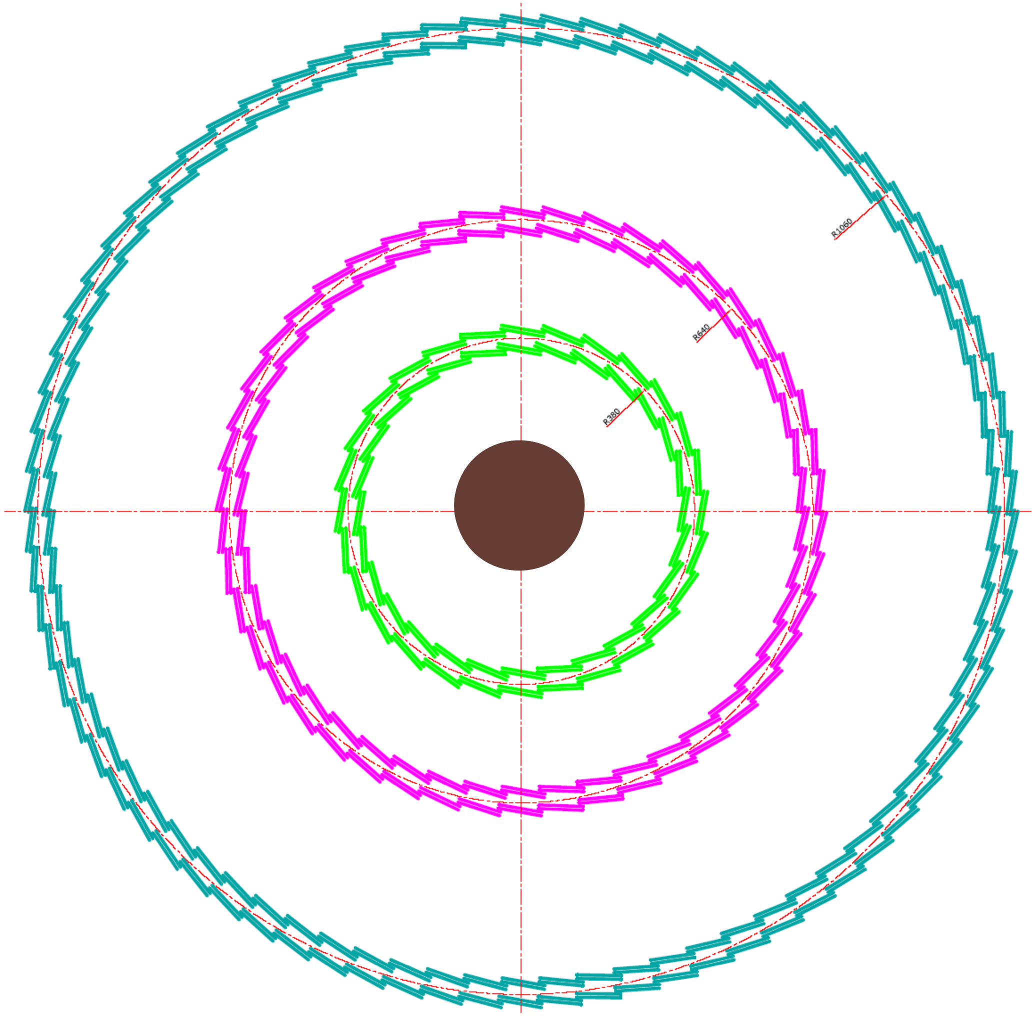




Simulation and Performance Issues

Basic Things to Check

- Hit Pair
  - Pt Resolution & Discrimination
  - Rate vs threshold
- Track Stub
  - Pt Resolution & Discrimination
  - Rate vs threshold
- Track Quality
- Combinatorial Complexity & Calculational Efficiency: L1 & HLT
- Fake Rate & Efficiency if require
  - Single Hit Efficiency: 95%~99.5%
  - 4/4 hits in sensor pair
  - 1/2 vs 2/3 Track Stubs
- All the above varying the design parameters over the Plausible Range



Imperial College London

SLHC strip readout

LHC strip readout based on 0.25 μm APV25

long strips, analog pipeline, analog O/P and analog transmission off-detector

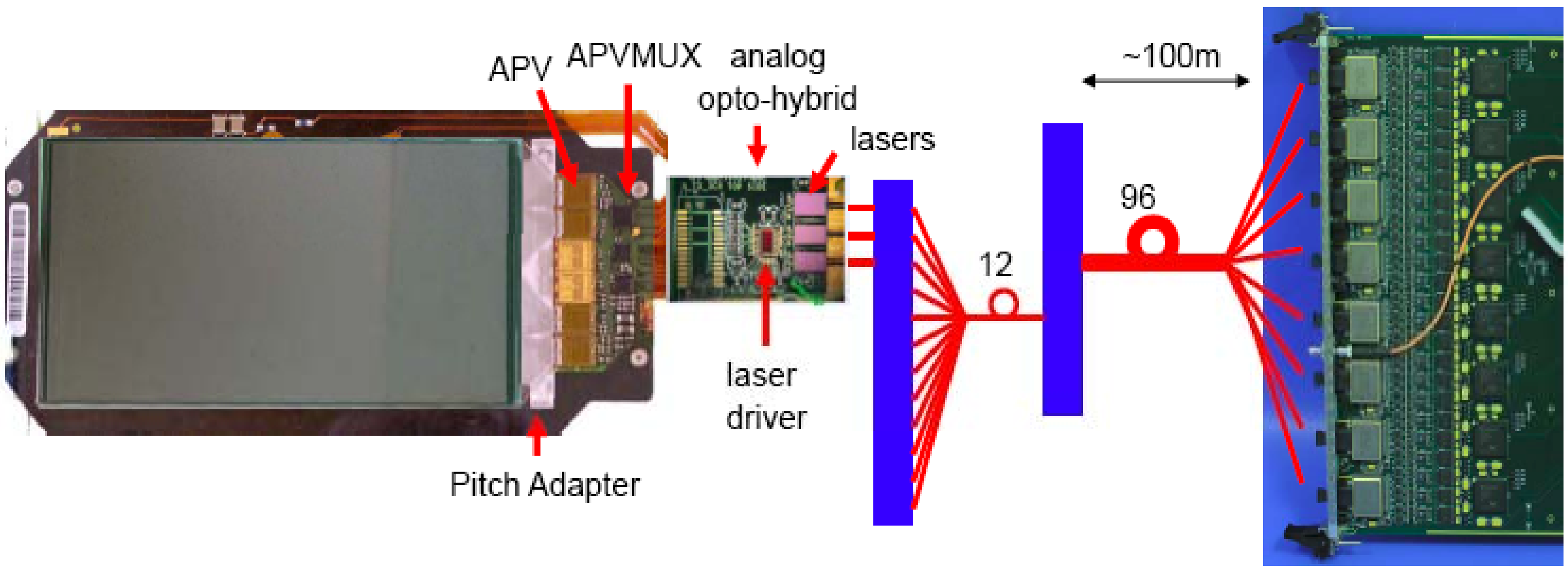
SLHC will be very different

higher granularity, more FE chips, digital transmission

power is the big issue: consumption and provision

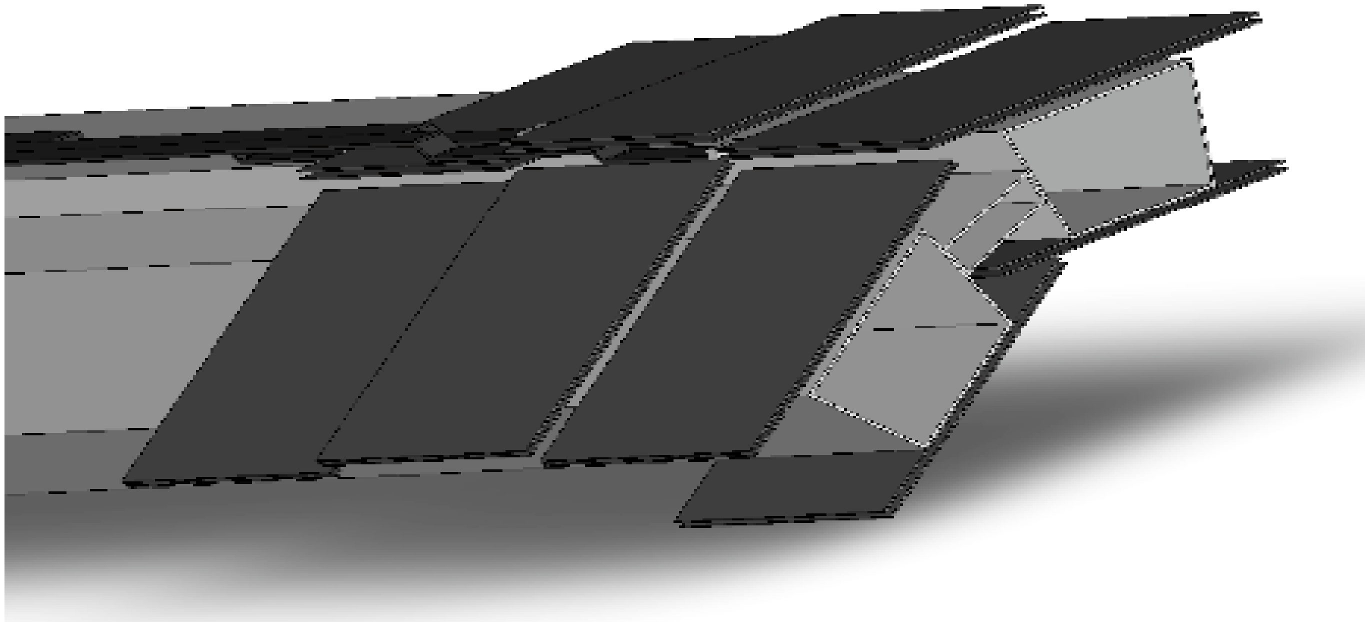
Mark Raymond
m.raymond@imperial.ac.uk

will concentrate here mainly on front end chip power consumption issues

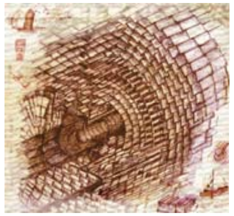


CMS SLHC Tracker
Straw Man Layout Illustrations

Reduce Output Rates from Module
Low Power Electrical Data Transmission ~ Locally in ROD
Reduce Output Rates from ROD ~ Locally along ROD ?
~ 10 * less Electrical Links, but Complicated Geometry…
Low Power Electrical Transmission of Reduced ROD Data to PP1
Optical Data Transmission to USC



- **Granularity vs Power Consumption**



Granularity vs Power Consumption
Power Consumption of Present CMS Strip Tracker

- **Power Dissipation of Strip FE chip (APV25) ~ 350mW (128 channels)**
- **Total Number of APV25 chips in CMS LHC Strip Tracker ~ 73’000**
- **Total FE Chip Power Dissipation of CMS LHC Strip Tracker ~ 26kW**
  - **This is Nominal FE Chip Power dissipation**
  - **Total Power dissipation inside the Tracker volume is estimated at 33kW**
- **Note:**
  - **210m^2 / 73’000 chips ~ 28cm^2 / chip** (4.6 strips / cm^2)
  - **350mW / 28cm^2 ~ 125W/m^2**

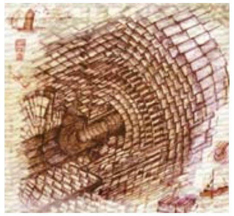
Overall channel power estimate

FE pipeline chip – 128 channels	μW	
preamp/shaper	120 – 180	simulation (C_{DET} 5 -10 pF)
pipe readout	50	APV25/4
ADC	50	ITRS estimate, 1 ADC/chip
digital	120	APV25/10 x 3
160 Mb/s serial driver	~ 230	large uncertainty (30 mW / 128)
FE chip total	~ 550 – 630 μW / channel	

I expect some of the numbers on this page will turn out to be wrong

intention is to stimulate thought – not to mislead

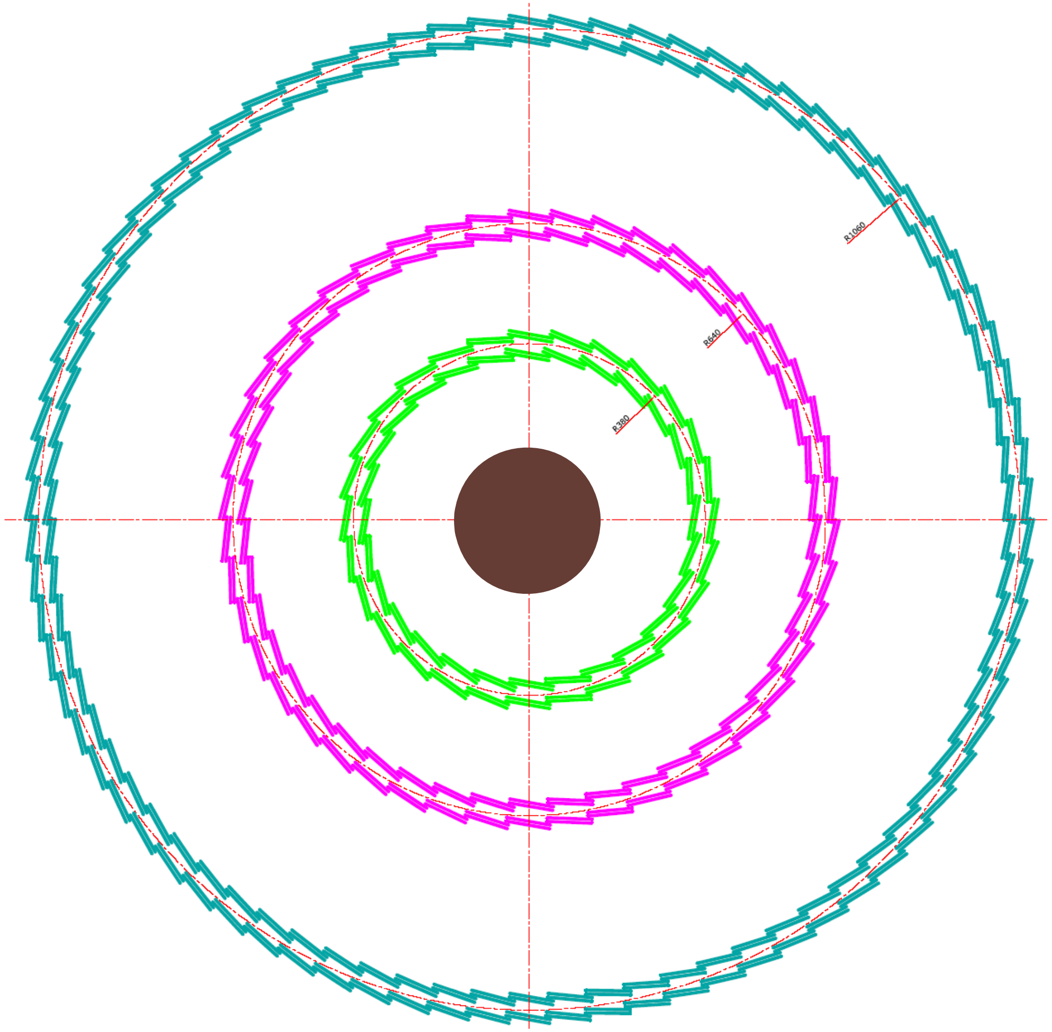
- **This is about 5 ~ 6 times less power than APV25**
- **Could have strips in the range of 120um * ~ 4cm length for 125W/m^2 Front-End Power dissipation**

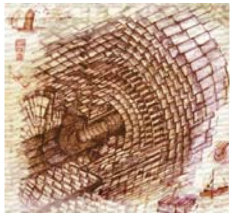


Granularity vs Power Consumption
Power Consumption for Long Pixel Tracker

- **Power Dissipation of Present CMS Pixel FE Chip ~ 30uW/channel**
  - **30uW / 15'000um^2 ~ 2kW/m^2 for current LHC Pixel**
  - **Compare to ~ 125W/m^2 for present LHC Strip Tracker ~ 16 * Power Density**
  - **Nb 6'666 pixel / cm^2 vs 4.5 strip / cm^2 => 1'500 higher channel density**
- **Assume SLHC Pixel size ~ 120um * 2.0mm ~ 0.24mm^2**
  - **This implies ~ 4M Channels / m^2**
- **Assume Power / Pixel of SLHC chip = LHC Pixel chip**
  - **This results in ~ 125W/m^2 ~ present Strip Tracker Power Density**
    - **~ 12.5mW/cm^2**
- **Assume Total Sensitive Area is ~ 250m^2**
  - **Implies ~ 1'000M Channels… "Giga Tracker"**

CMS SLHC Tracker
Straw Man Layout Illustrations





Optimization and Performance Issues

Basic Things to Vary

•Cell Geometry:

Pitch 80~120~160um
Length 1~2~4mm/1~2~4cm
Sensor Thickness 60~100~200um

•Sensor Pair Geometry

D ~ 1~2~4mm,
Align Transverse 20~200um,
Align Longitudinal 50~200um

•Stack of Sensor Pairs:

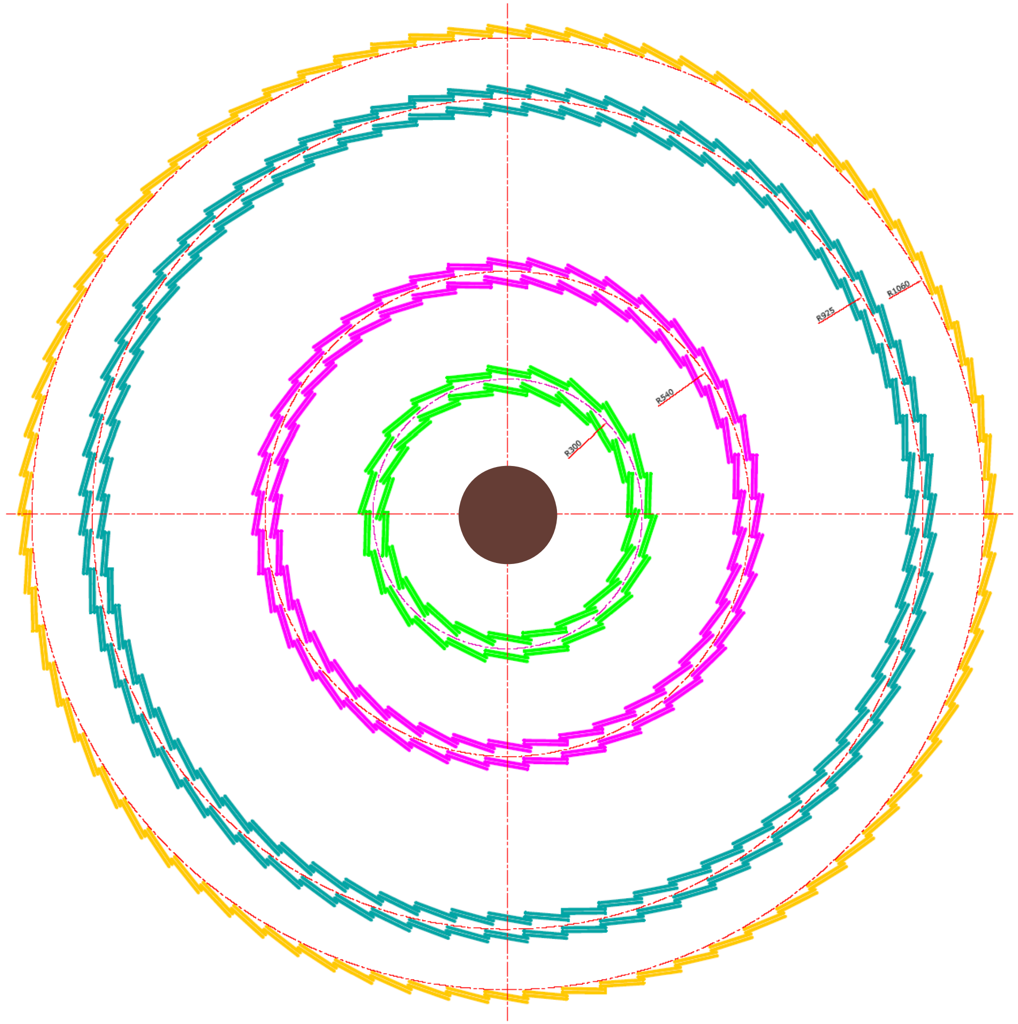
D ~ 20~40~80mm, (160mm ?)
Align Transverse 100~400um,
Align Longitudinal 100~1000um

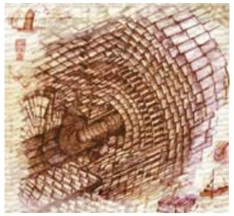
•Radial Positions

30~35~40cm, 50~60~70cm, ~100cm

•End-Cap Barrels vs Rings

•(Extended Barrel and End-Cap Coverage)





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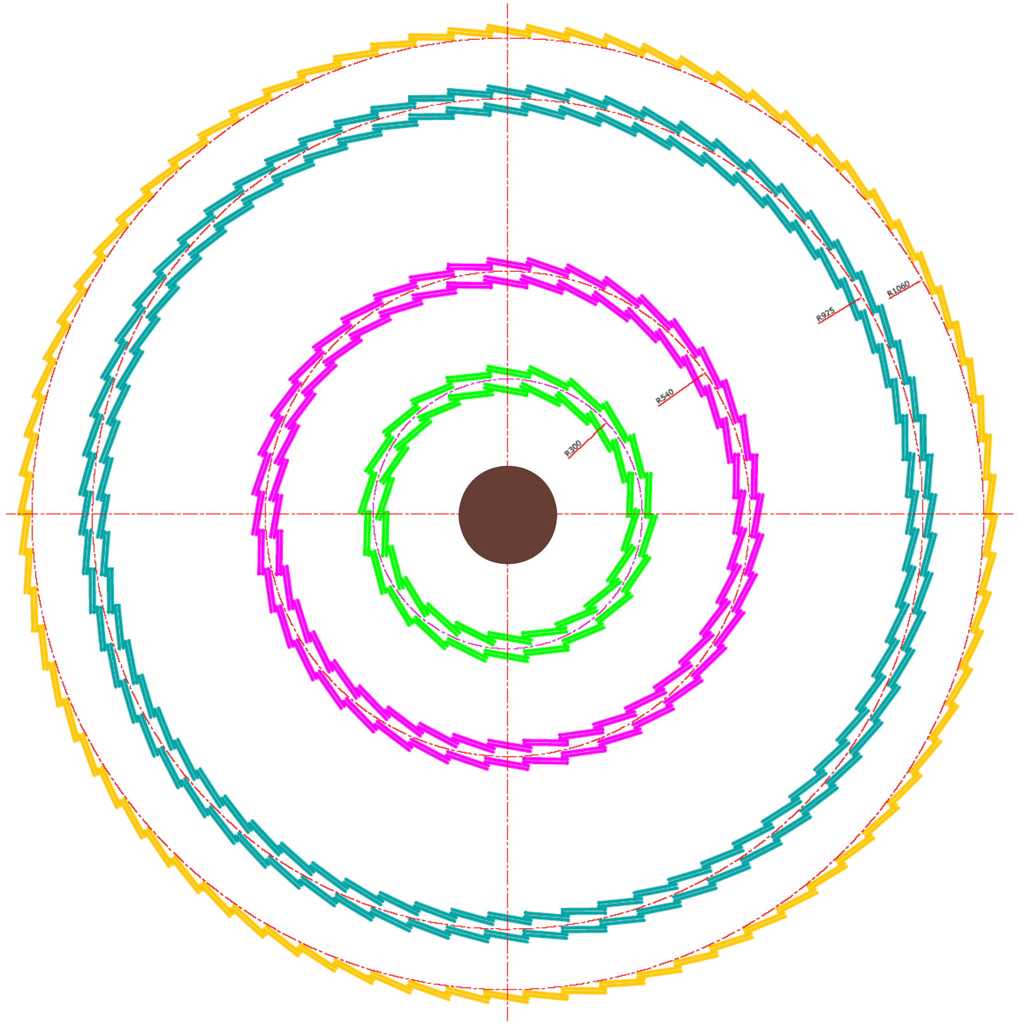
- Impact of End-Cap Barrels vs Rings
- Impact of Extended Barrel & End-Cap Coverage



Optimization and Performance Issues

Material Budget vs Layout

We Do Not Know Material for

- Cables vs Watts (DC-DC)
- Cooling vs Watts
- Mechanics
- Electronics

Major Design & Engineering Goal:
Minimize / Optimize Material Budget

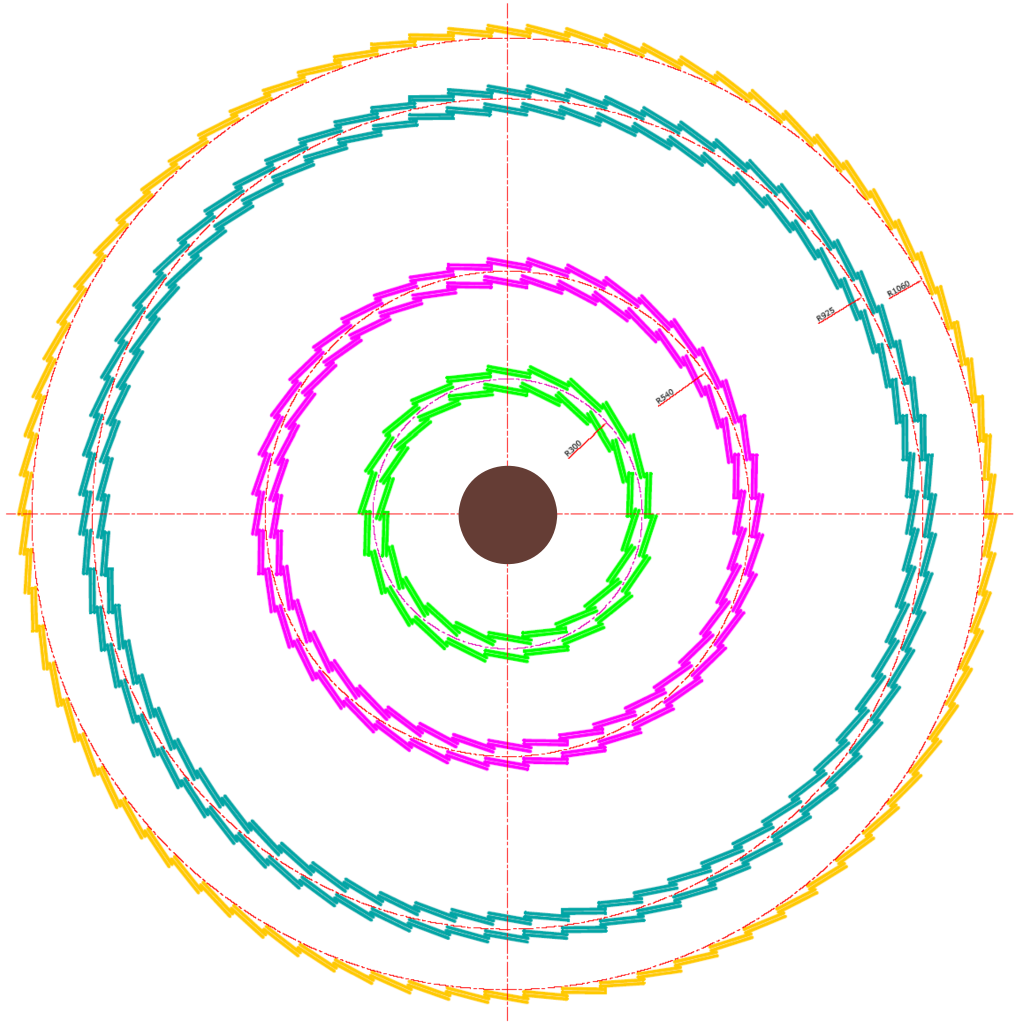
Proposal for Simulation:

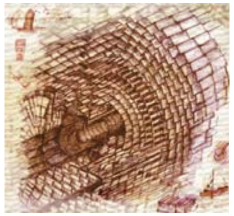
Implement Material Layers for
Modules, Rods, Barrels

- **Quantify Effect varying the X0 for each Material Layer over an Agreed Range**

- **Impact of End-Cap Barrels vs Rings (?)**

- **Impact of Extended Barrel & End-Cap Coverage**





L1 Stacked Trigger
Data Transmission, Reduction, Power Density

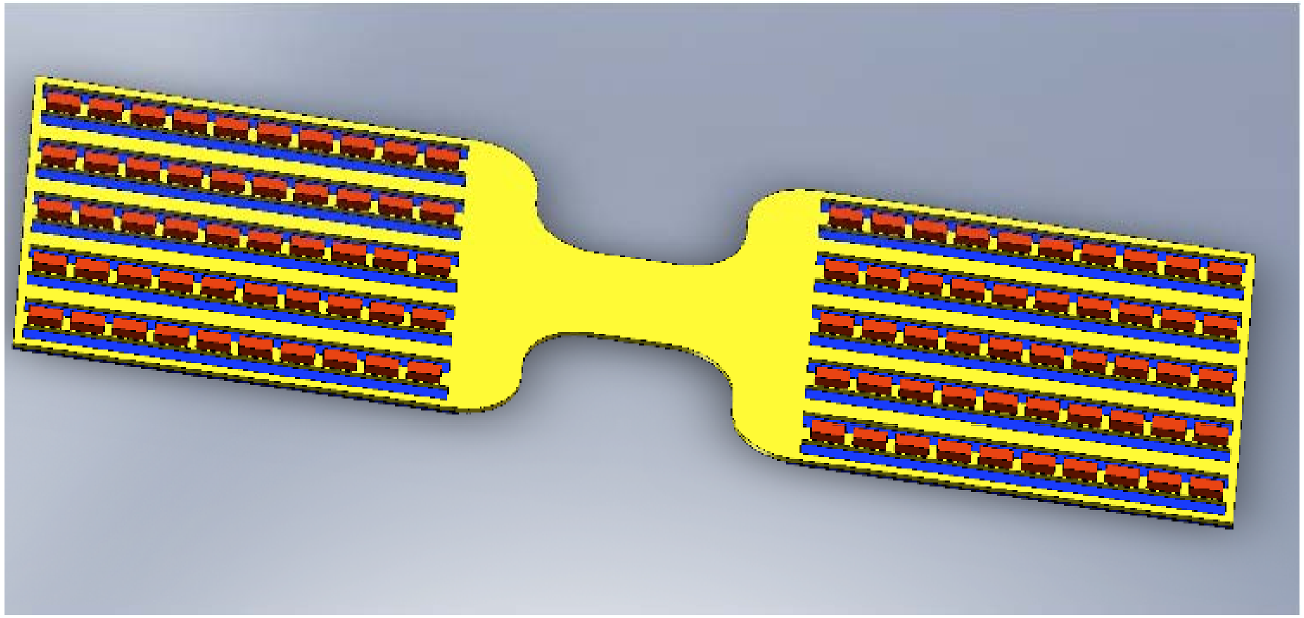
- **Power for L1 Trigger Information Transmission inside the Tracker volume, and within the Module in particular, is likely to be very high**

- **Puts a premium on improved**
  - **Power distribution**
  - **Cooling**
  - **Etc**

- **The present Pixel detector has ~ 16 * Power /cm^2 than the Strip Tracker, but ~ same material budget / layer…**

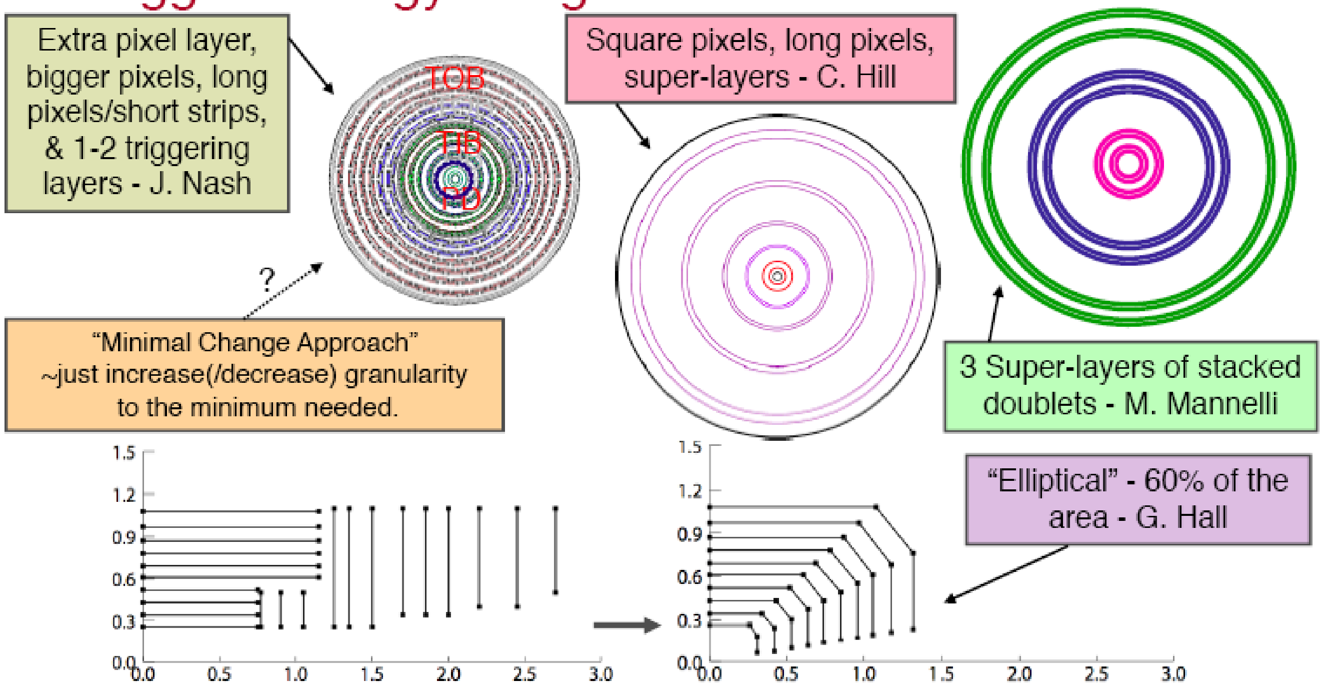
Straw Man Module:
Folded Module

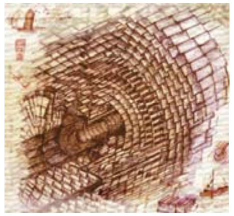
- **Folded Module:**
  - Chips are wire bonded to sensor
  - And wire bonded to flex pcb which is then folded
  - Horizontal transmission: requires Very High Power
    - Vertical Transmission possible? Seems to be required



CMS SLHC Tracker Straw Man Proposal

- **Broad ranging discussion**
  - **First, Explore alternative ideas and approaches**
  - **Then, Focus on most promising ones**
    - No single strawman tracking system or tracking trigger strategy/design

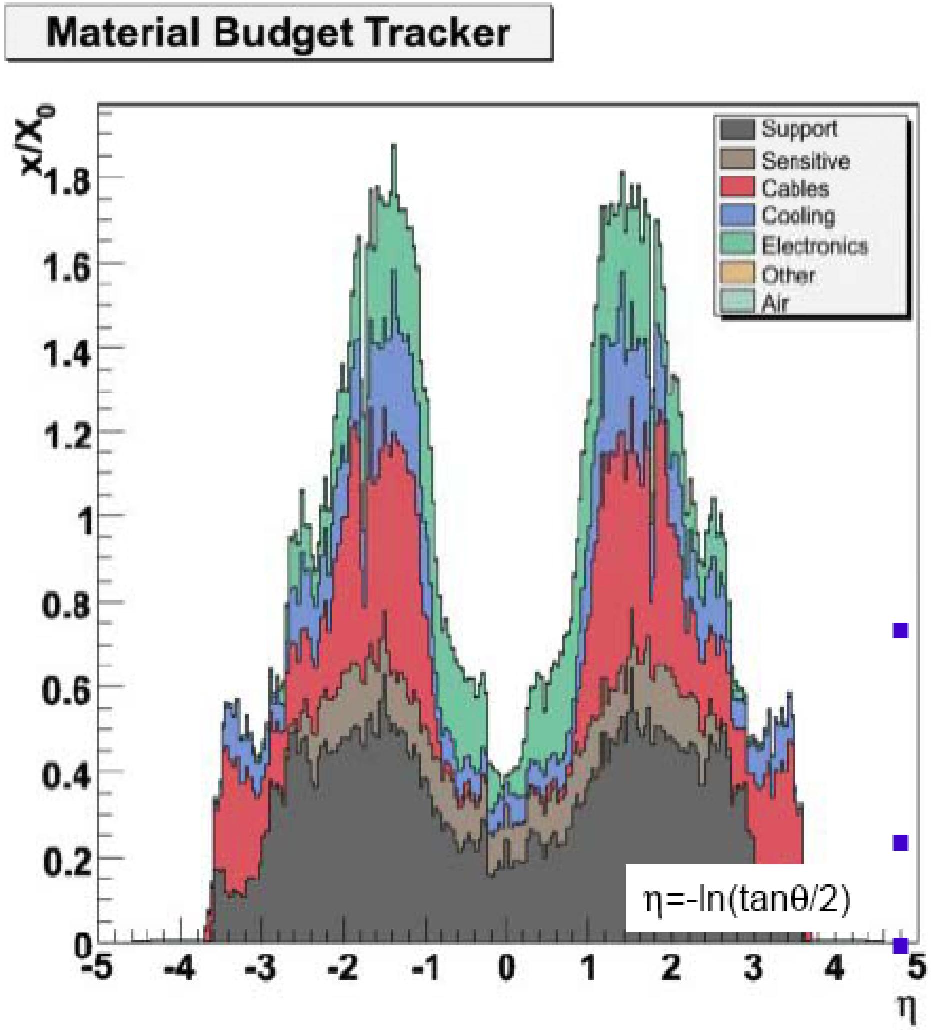




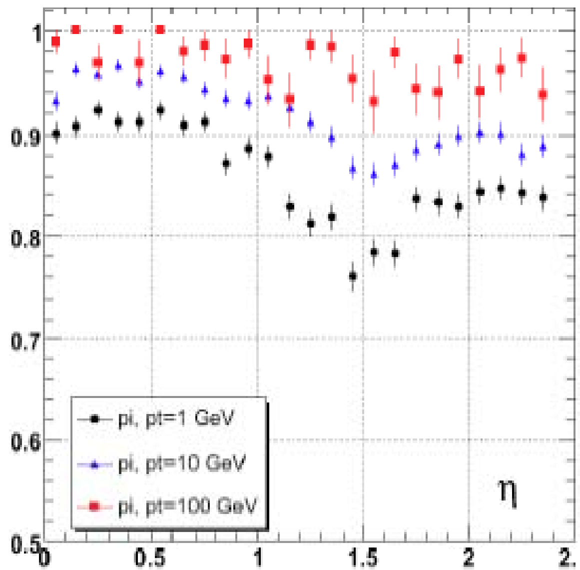
Material Budget Reduction

- <u>**Material Budget Reduction**</u>

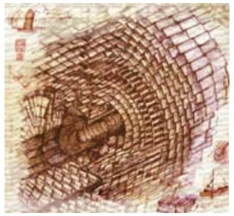
Material and its consequences



Pion track finding efficiency vs η



- Present power requirements
  - inner microstrips: ~400 $W.m^{-2}$
  - Pixels: ~2700 $W.m^{-2}$ (pre-rad)
    ~3700 $W.m^{-2}$ (post-rad)
- Modern ASIC technologies use less FE power but currents scale
- Power reduction and delivery are huge challenges



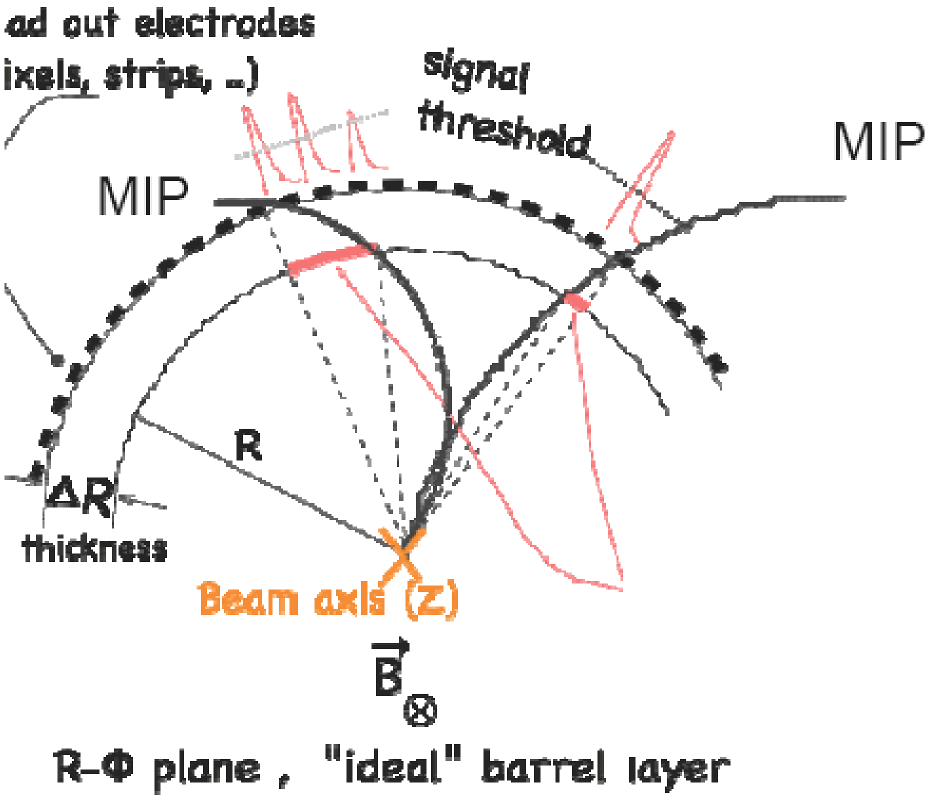
Material Budget Reduction

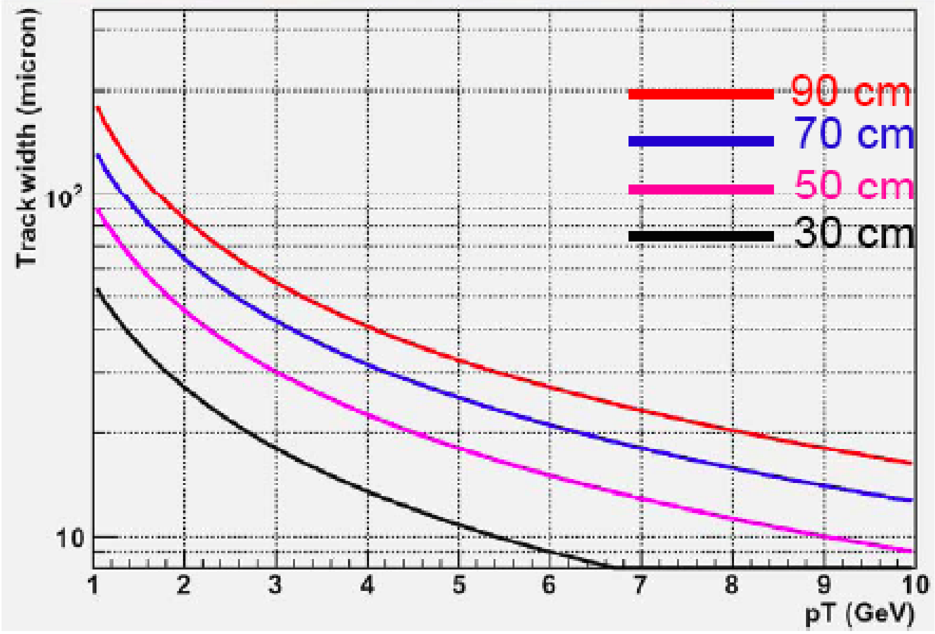
- The present CMS Silicon Strip Tracker will provide Superb Performance with the LHC
- The performance limiting factor is NOT intrinsic precision, and most likely will NOT be our ability to align etc.
- The performance limiting factor is the Material Budget of the Tracker
- This also limits the performance of the CMS ECAL
- There is much to gained if we can lower the material budget
- AS WELL AS achieving the performance requirements just mentioned

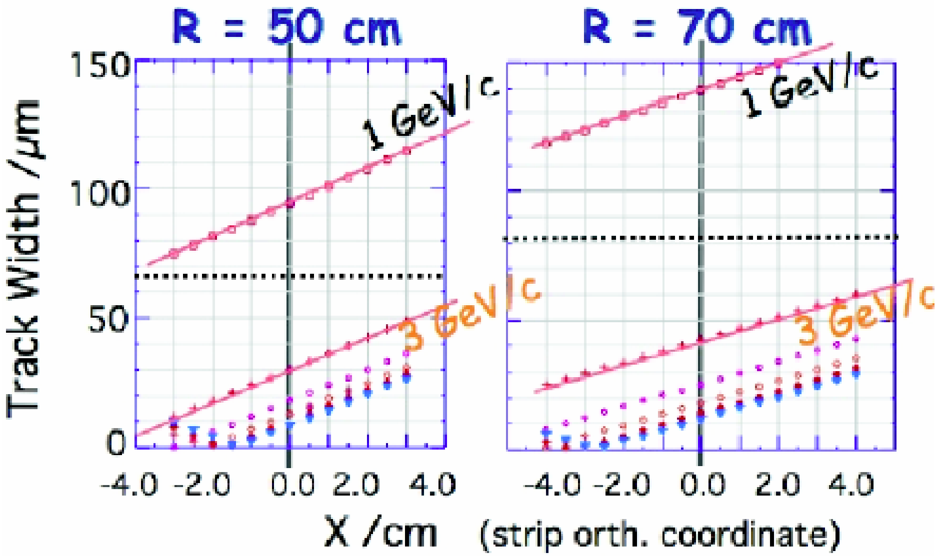
<u>Material Budget Reduction</u>

- **Local Occupancy Reduction**

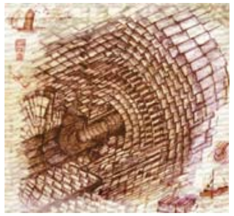
Cluster width discrimination



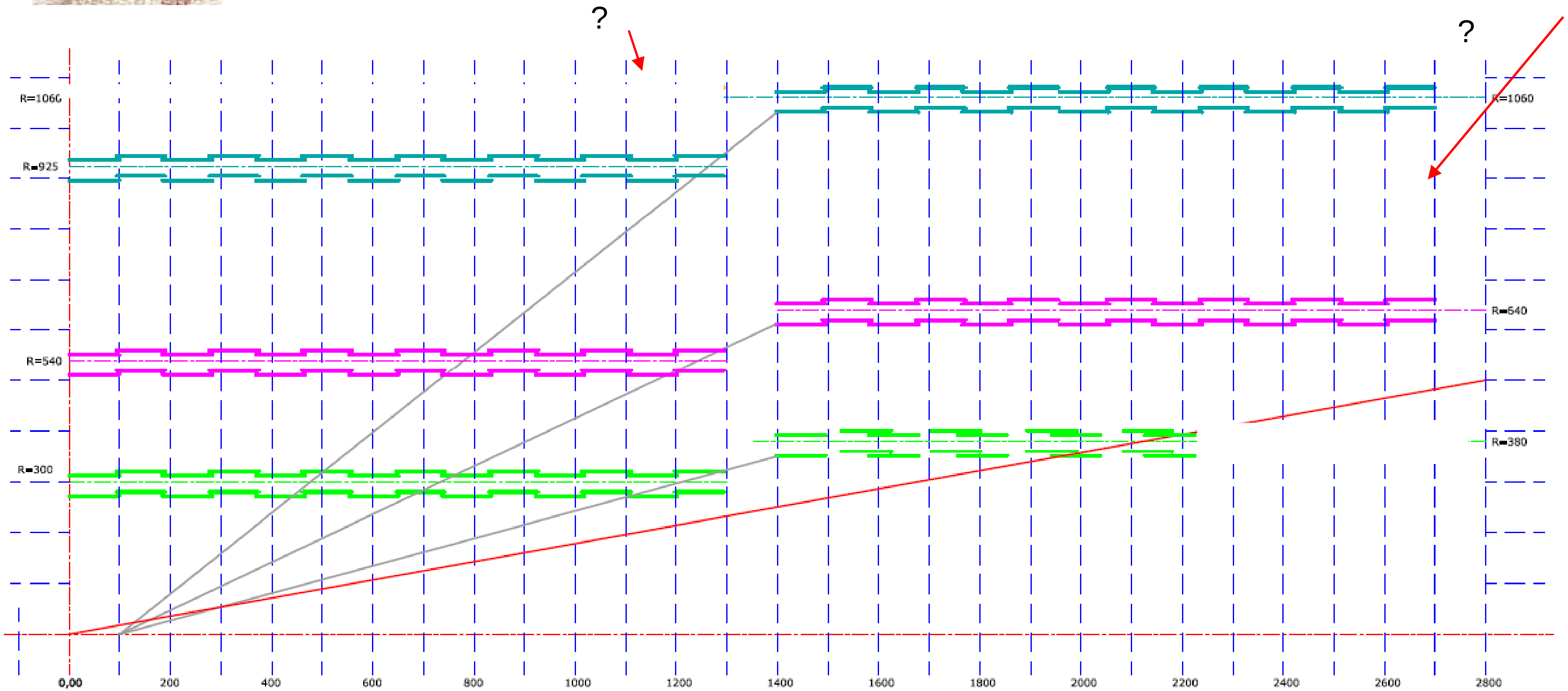




iscrimination of low p_T tracks made directly on ne strip detector by choosing suitable pitch alues in the usual range for strip sensors.

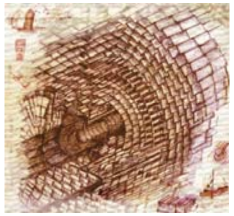


End-Cap Barrels



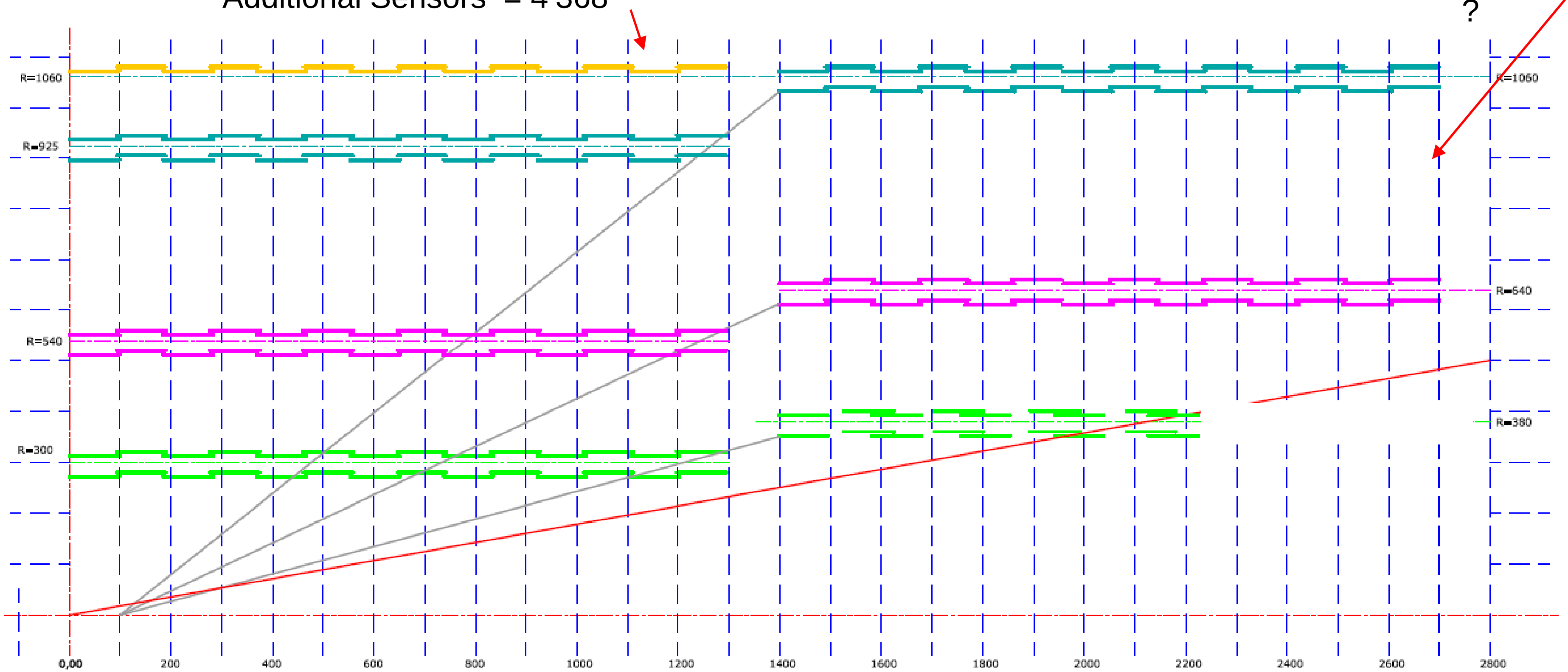
Total Barrel
Double Sensor Modules = 7’280
Sensors = 14’560
Present Barrel Sensors ~ 14’000

Total End-Caps
Double Sensor Modules = 7’952
Sensors = 15’904
Present End-Caps Sensors ~ 10’500



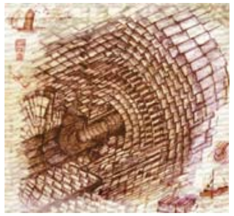
End-Cap Barrels
or Very Long Barrel (s)

Additional Sensors = 4’368



Total Barrel
Double Sensor Modules = 9’464
Sensors = 18’928
Present Barrel Sensors ~ 14’000

Total End-Caps
Double Sensor Modules = 7’952
Sensors = 15’904
Present End-Caps Sensors ~ 10’500



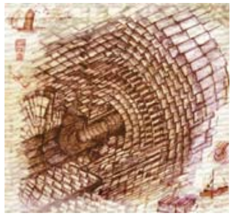
End-Cap Barrels

Pros:

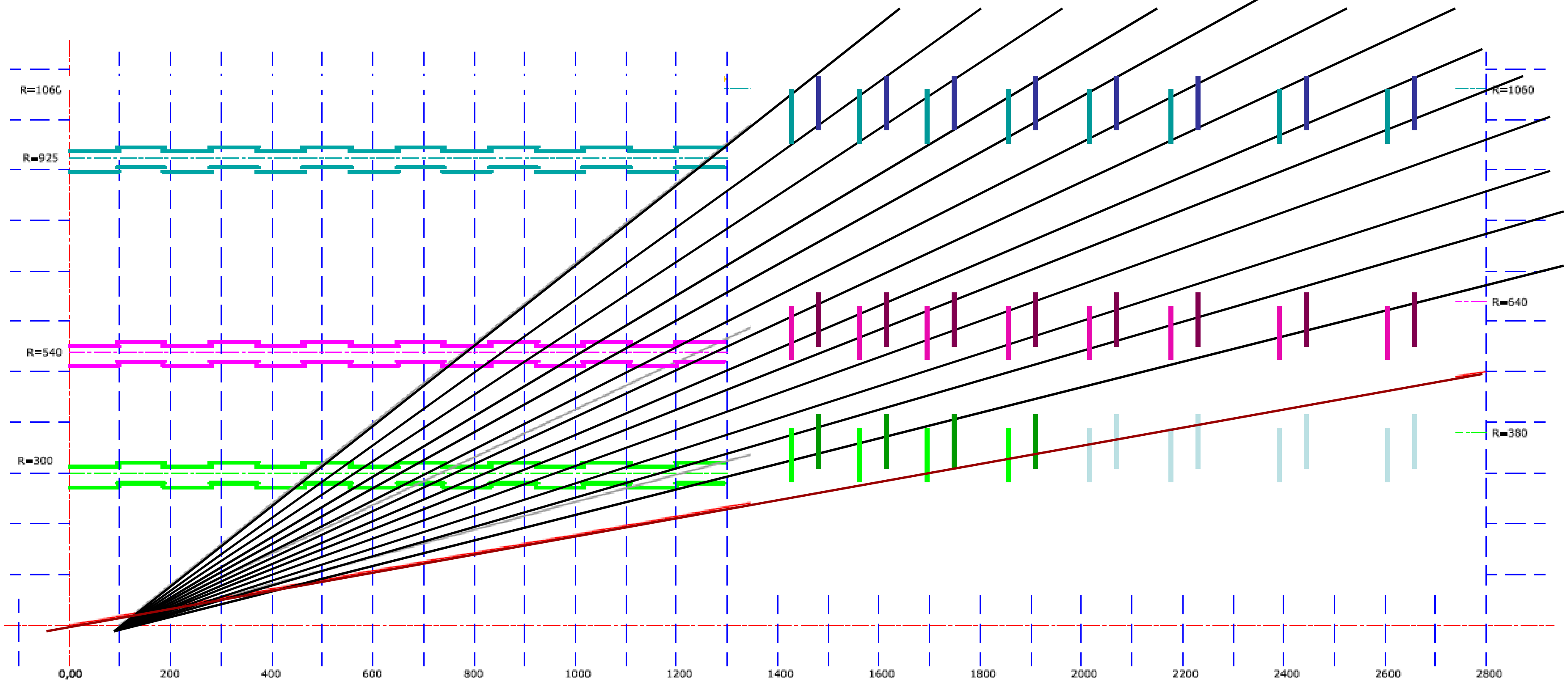
- Barrel and End-Caps ~ Similar
- Homogenous up to η ~ 1.6, in the r-phi projection
  - Constant Number, Radius and Information content of hits
    - Local Pt discrimination, Pattern recognition, Track Parameters
- Unique Module Type for entire Tracker

Cons:

- Full use of Radial Lever Arm in Barrel requires Additional Layer
  - 4’368 Sensors
- Inefficient use of sensor active area at large η
  - About 50% more End-Cap sensors wrt Present Tracker
  - Unfavorable evolution of Material Budget with η
- Abrupt transition from 3 (2) to 2 (1) Super Layers at η ~ 1.6 (2.0)

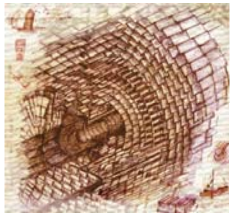


End-Cap Rings



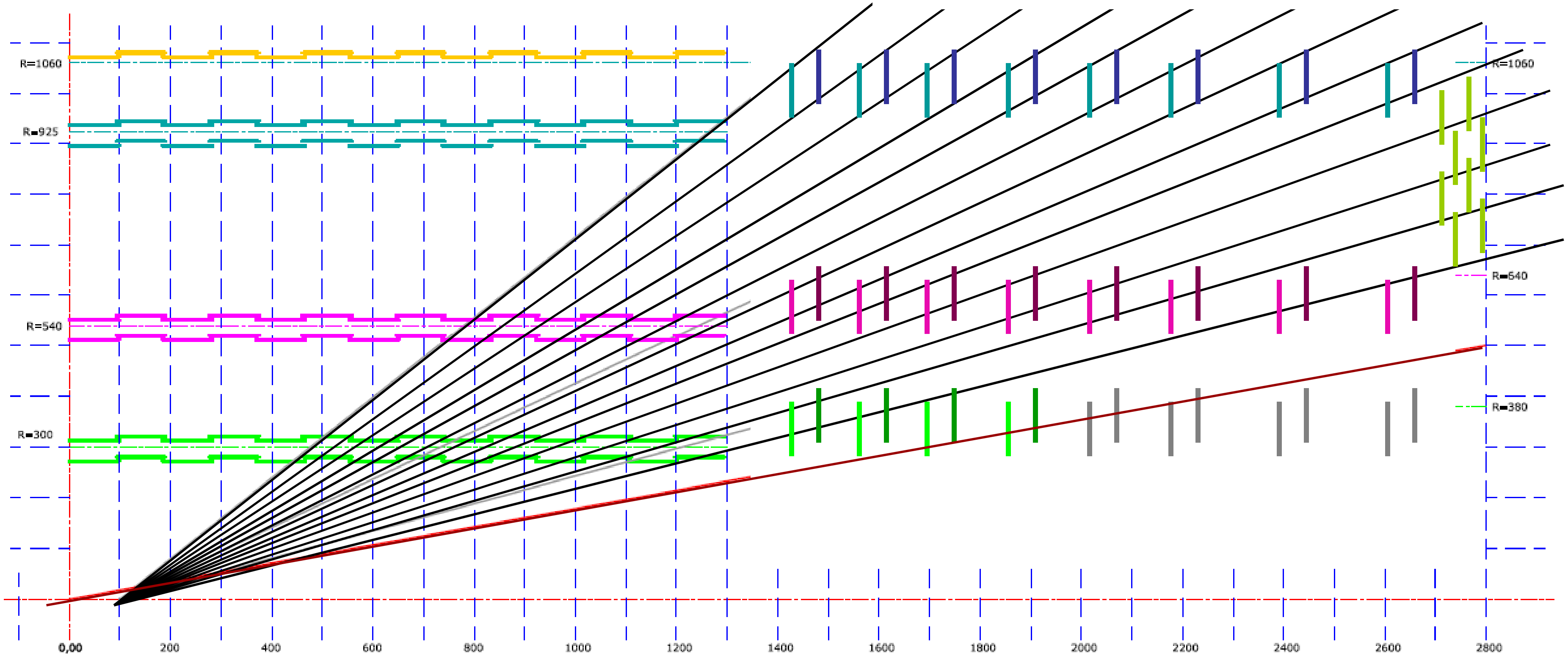
Total Barrel
Double Sensor Modules = 7’280
Sensors = 14’560
Present Barrel Sensors ~ 14’000

Total End-Caps
Double Sensor Modules ~ 4’500
Sensors ~ 9’000
Present End-Caps Sensors ~ 10’500



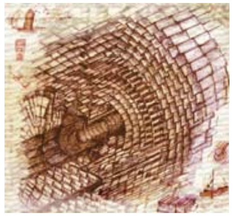
End-Cap Rings

Additional Sensors = 4’368 Additional Sensors ~ 1’000



Total Barrel
Double Sensor Modules = 9’464
Sensors = 18’928
Present Barrel Sensors ~ 14’000

Total End-Caps
Double Sensor Modules ~ 4’500
Sensors ~ 10’000
Present End-Caps Sensors ~ 10’500



End-Cap Rings

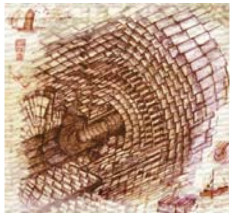
Pros:

- Efficient use of sensor active area at large η
  - Comparable number of End-Cap Sensors wrt Present Tracker
- Favorable Material Budget evolution at large η
- Can recover Hit Coverage and Trigger capability at large η
  - ~ 1’000 sensors

Cons:

- Central Barrel and End-Cap will be quite different
  - But can at least maintain unique module type
- Somewhat Less Homogenous hits, in the r-phi projection

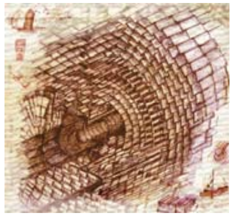
  ΔR between hit pairs no longer constant in η



Extension of Straw-man Layout in the End-Caps?

Proposal:

- **Develop Barrel geometry as baseline for Full Tracker**
  - **Optimize homogeneity & Minimize number of variants**
- **Maintain End-Cap Rings (or other variants) as Fall-Back**
  - **In case of Problem with Barrel and/or demonstrable overriding advantages of Fall-Back**



Conclusions

- **The present CMS Tracker will be a powerful tool for LHC Physics**

- **For SLHC Upgrade: Build on and Extend the basic approach of the Present CMS Tracker**
  - Tracking with “few” high quality hits, in High Occupancy environment

- **Technology Highlights of Present CMS Tracker:**
  - Move from Strips to Pixels for Vertex + Seeding (very radiation hard)
  - Extend use of Strips from Vertex to Tracker (radiation hard)
  - Low Power High Band-Width (analogue) Optical Links

- **Possible Technology Highlights of SLHC CMS Tracker**
  - Develop Extremely Radiation Hard Pixels for Vertex
  - Extend use of (long) Pixels from Vertex to Tracker (very radiation hard)
  - Integrate Local Data Reduction to Provide L1 Trigger capability
  - Very Low Power Very High Band-Width (digital) Electro-Optical Links
  - Material Budget Reduction