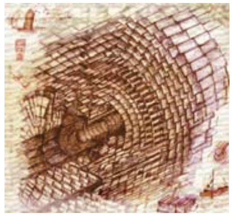
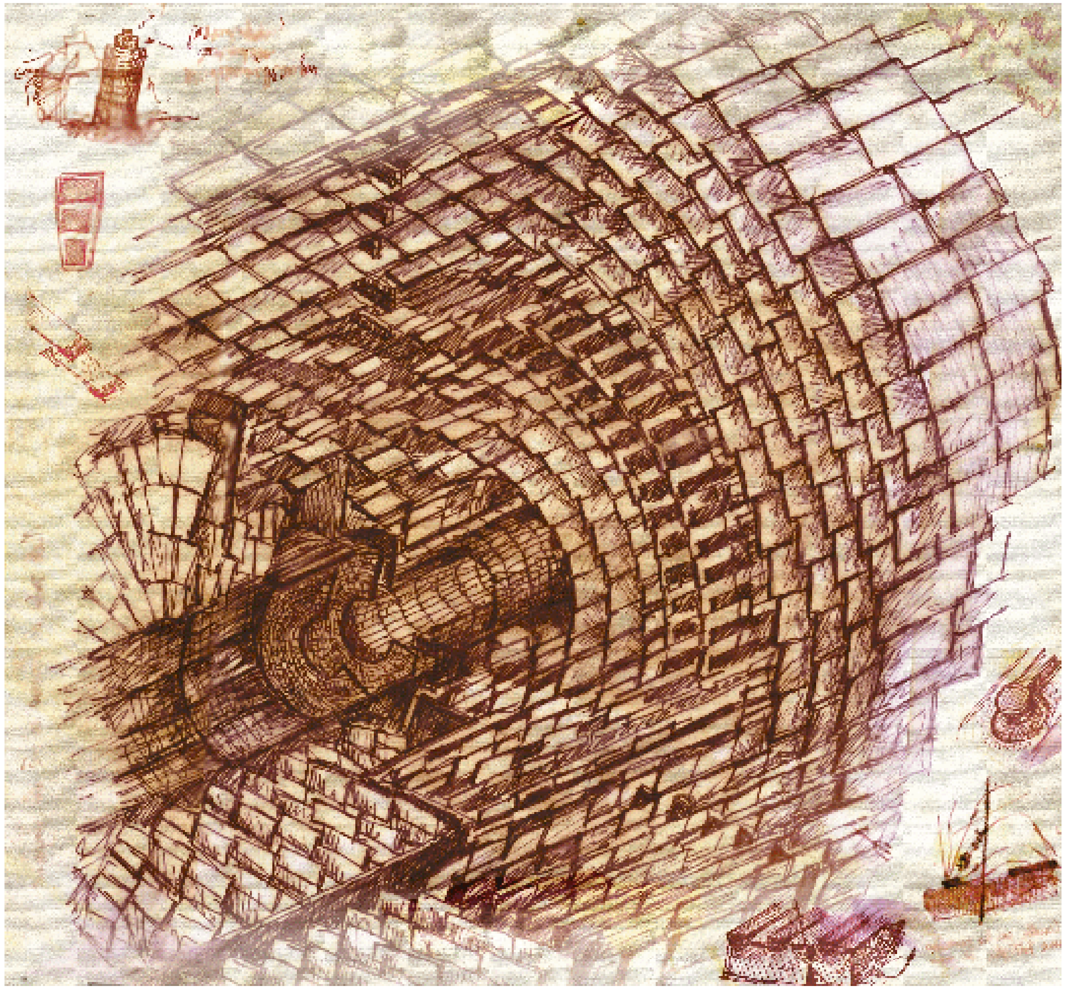
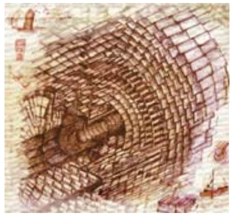


CMS SLHC Tracker Upgrade
Thoughts, Challenges & Strategies

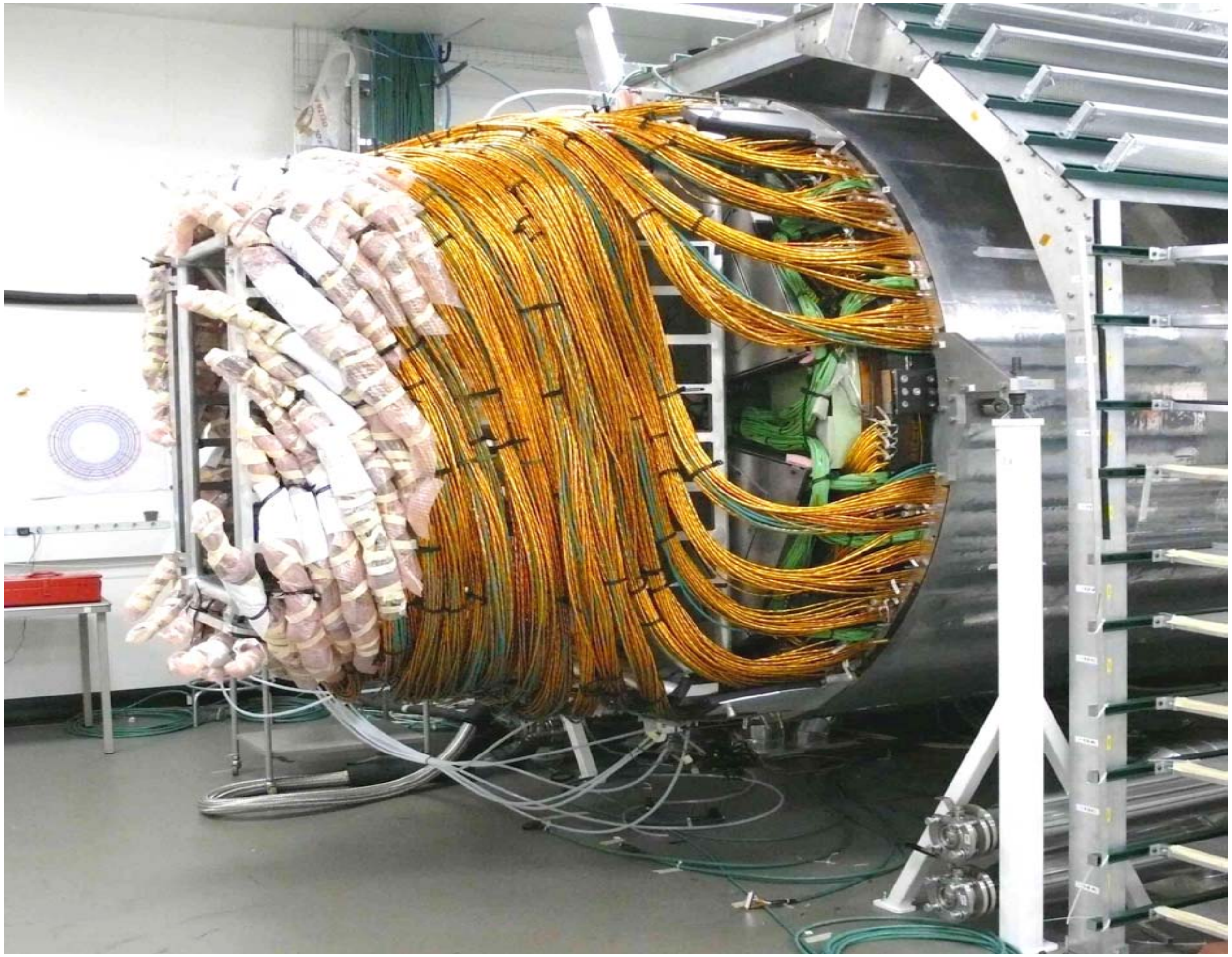


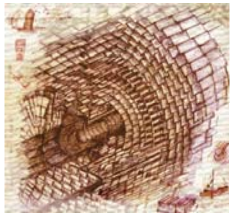
September 2007 Marcello Mannelli Vertex 2007

CMS SLHC Tracker Upgrade Prospects



CMS SLHC Tracker Upgrade
Thoughts, Challenges & Strategies



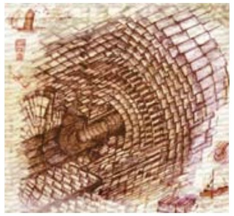


CMS SLHC Tracker Upgrade
Thoughts, Challenges & Strategies

- **Broad ranging discussion**
  - **First, Explore alternative ideas and approaches**
  - **Then, Focus on most promising ones**

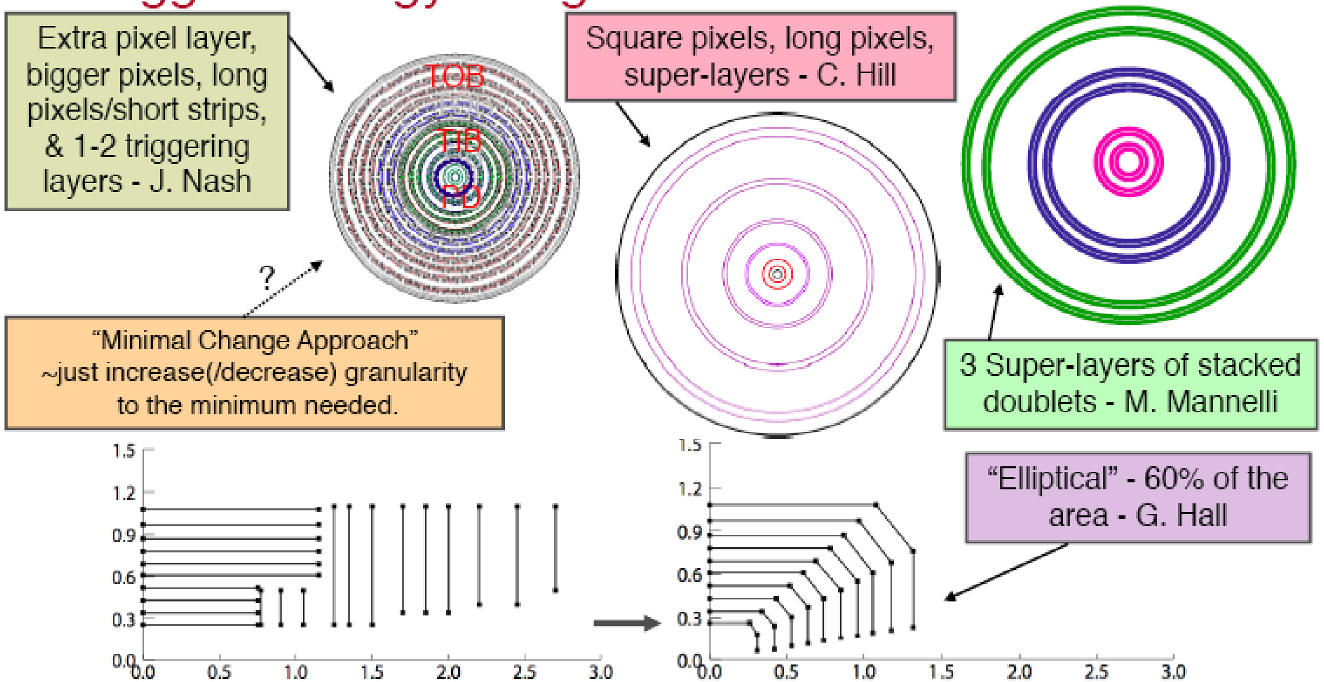
▪ 19 July	Tracker-Trigger Joint meeting
▪ 2 Aug	Sensor WG meeting
▪ 11 Sep	Simulations WG
▪ 12 Sep	Readout WG
▪ 13 Sep	Material, cooling, engineering WG (1/2 day)
▪ 13 Sep	Steering Group

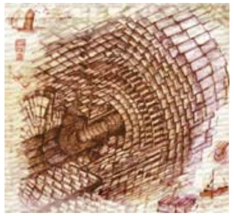
- Expect follow ups in monthly Tracker meetings (Thursday)
- 8 Nov   Readout WG (tbc)
- 6 Dec   Simulations   Sensors (tbc)
  - + Simulations video meeting every two weeks



CMS SLHC Tracker Upgrade Thoughts, Challenges & Strategies

- **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





CMS SLHC Tracker Upgrade
Thoughts, Challenges & Strategies

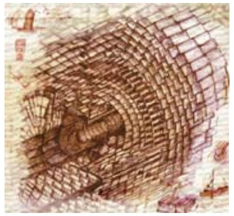
- **Broad ranging discussion**
  - **First, Explore alternative ideas and approaches**
  - **Then, Focus on most promising ones**

- **This presentation will NOT be and Over-view**

- **Highlight Two sets of Thoughts concerning:**

<u>Local Occupancy Reduction / Hit Discrimination</u>

<u>Granularity vs Power Consumption</u>



SLHC CMS Tracker Upgrade
Required Functionality

- **Fast, Robust, Efficient, High Resolution Tracking**

- **HLT Capability:**
  - The present CMS Tracker will be used in the HLT, immediately after the hardware Level-1 Trigger, to select Physics Objects and Event Topology with much better Resolution, Efficiency & Background Rejection
    - High Pt muons, electrons, b-jets, tau-jets, Missing ET, etc.

- **Level 1 Trigger Capability:**
  - Must keep ~ same L1 Trigger rate, despite 10 time higher event rate, 10 ~ 20 times higher occupancy, without sacrificing Efficiency and Background Rejection
  - Just raising thresholds will not work AND is NOT desirable: scale is set by Physics

At SLHC need to transfer use of the Tracker from HLT to Level-1 Trigger

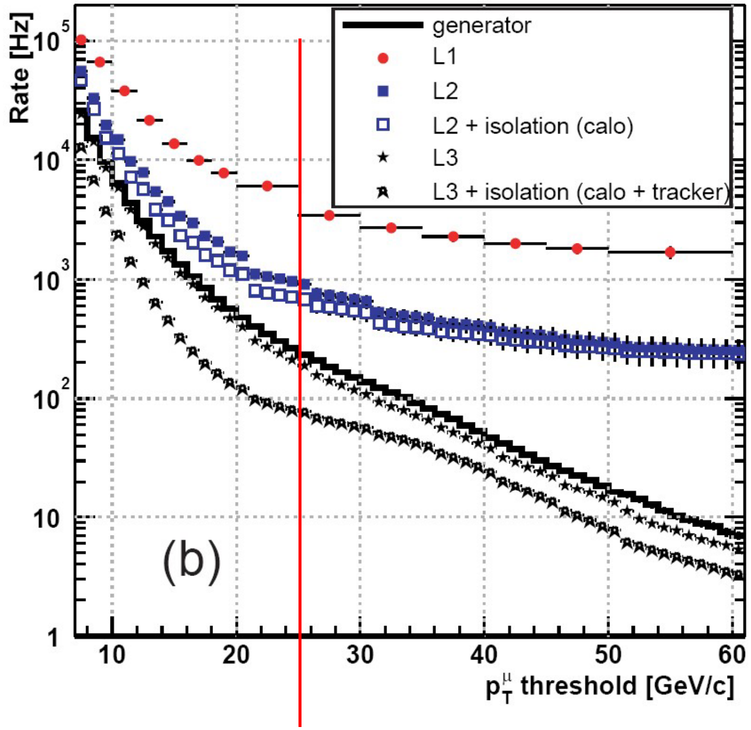
Tracker: From HLT to L1

- **Confirmation of Isolated High-pt μ Candidates**
  - **Fast, Efficient & Clean Tracking**
  - **Excellent Pt resolution**

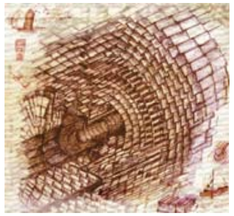
- **Increased Rejection of fake e/γ Candidates**
  - **Match with Track at Vertex**

- **Rejection of Uncorrelated Combinations, from different primary vertex**
  - **Match with Tracks at Vertex**

- …



Factor ~ 100 reduction
For same Pt threshold



Tracker: From HLT to L1

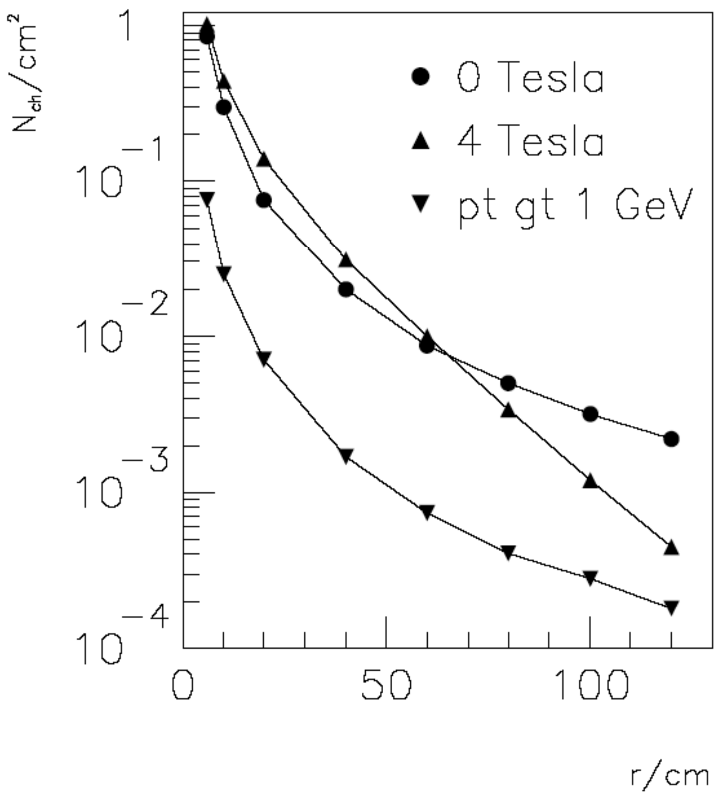
- **The CMS Tracker produces vast amounts of information for each L1 Triggered event**
  - For the Strip Tracker, the Analogue Information for each Strip is read-out at ~ 100kHz
  - For the Pixel Detector, the Analogue Information for each Cluster is read-out at ~ 100kHz
    - Local Zero Suppression
  - All hits in a given Region of Interest are taken into consideration in the HLT

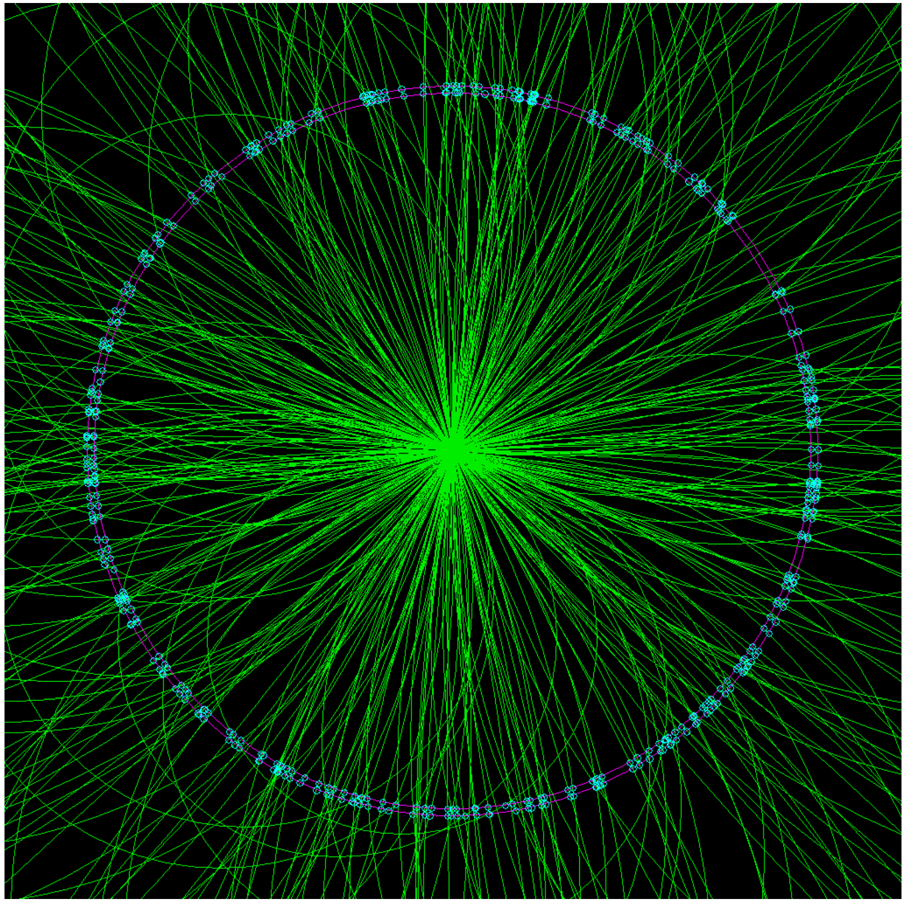
- **It is implausible to access this information at 10^{35} Luminosity & 20(40)MHz crossing rate, as input to the L1 Trigger Decision**

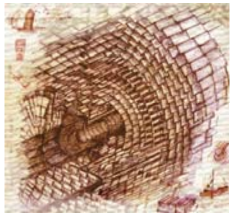
- **Local Zero-Suppression will be required for the full Tracker.**
  In addition consider

Local Occupancy Reduction / Hit Discrimination

SLHC CMS Tracker Upgrade
Local Occupancy Reduction







SLHC CMS Tracker Upgrade
Possible Local Occupancy Reduction Scheme

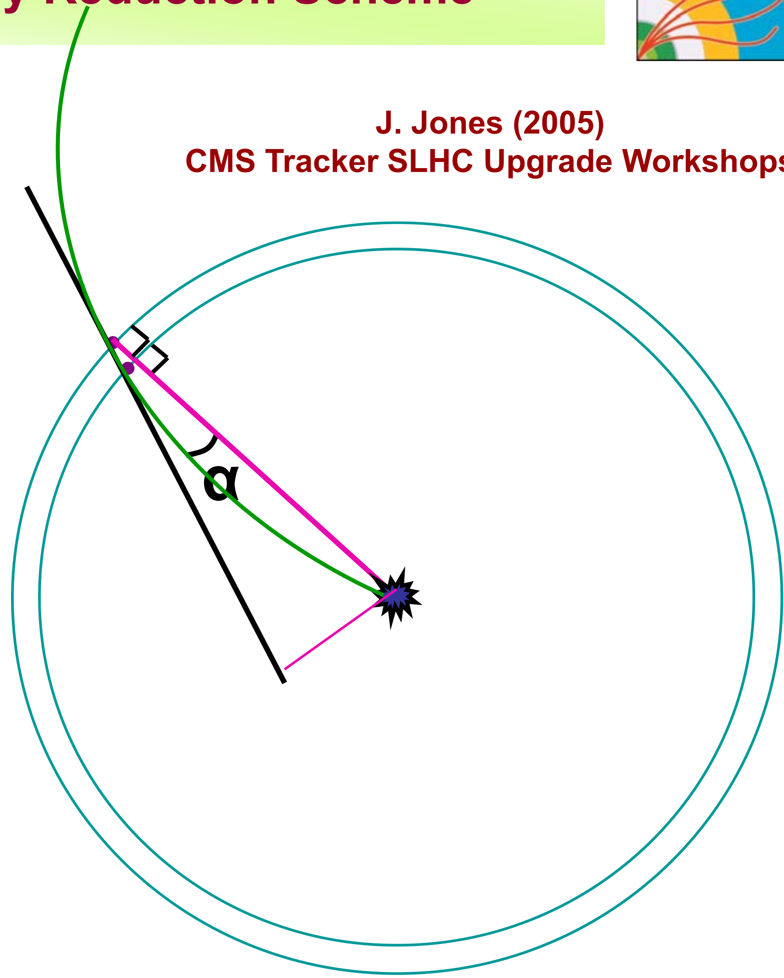
Possible Strategy: Local Pt Discrimination

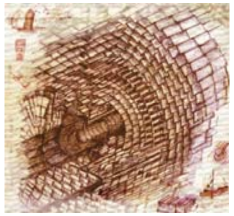
- **Only read-out hits from tracks above a certain Pt threshold**
  - 1 GeV Pt threshold would reduce read-out hits by ~ factor 10
  - Tracks below 1 GeV Pt are usually not very interesting, especially in the early phases of event selection
- **For Level 1 Triggering purposes, need also to identity (muon) tracks above 10 ~ 20 GeV**
- **Consider a hierarchical scheme for Local Pt Discrimination**

SLHC CMS Tracker Upgrade
Possible Local Occupancy Reduction Scheme

- **Pairs 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**

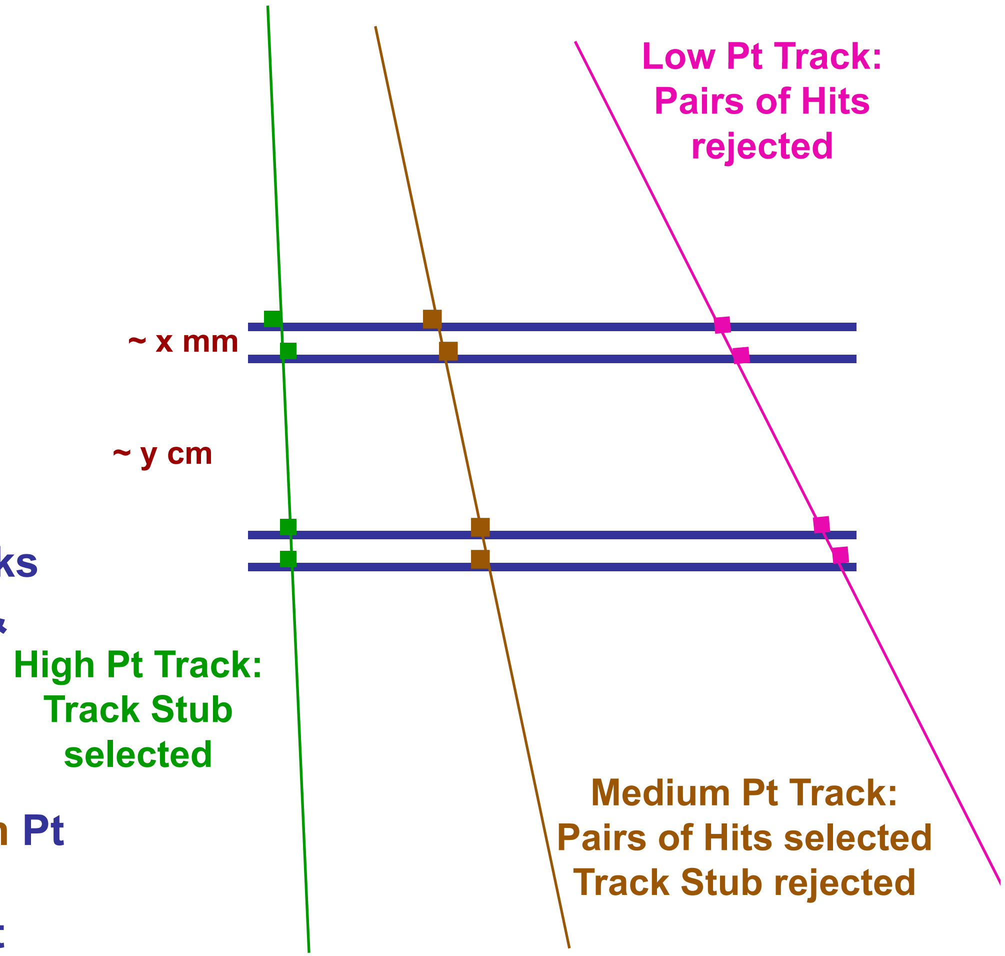
J. Jones (2005)
CMS Tracker SLHC Upgrade Workshops

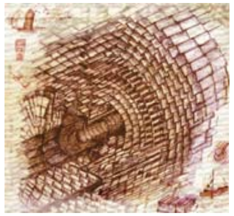




SLHC CMS Tracker Upgrade
Possible Local High Pt Discrimination Scheme

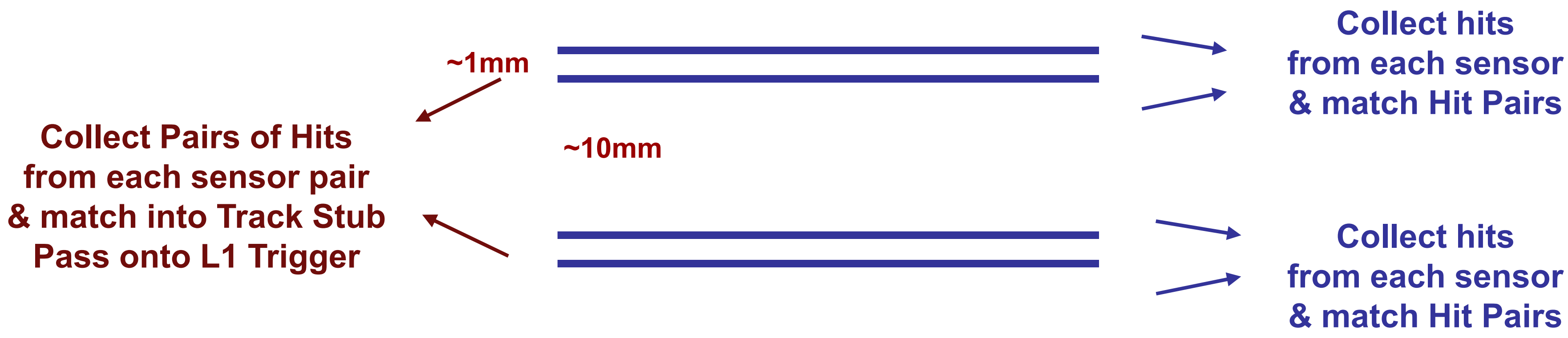
- **Stacks of 2 Sensor Pairs, at ~ cm distance**
  - Redundancy
  - Track Stub provides higher resolution local Pt measurement
- **Two level data reduction**
- **Each Sensor Pair**
  - Rejects Hit Pairs from low Pt tracks
  - Accepts Hit Pairs from medium & high Pt track
- **The Stack of Sensor Pairs**
  - Rejects Track Stubs from medium Pt tracks
  - Accepts Track Stubs from high Pt tracks





SLHC CMS Tracker Upgrade
Possible Local High Pt Discrimination Scheme

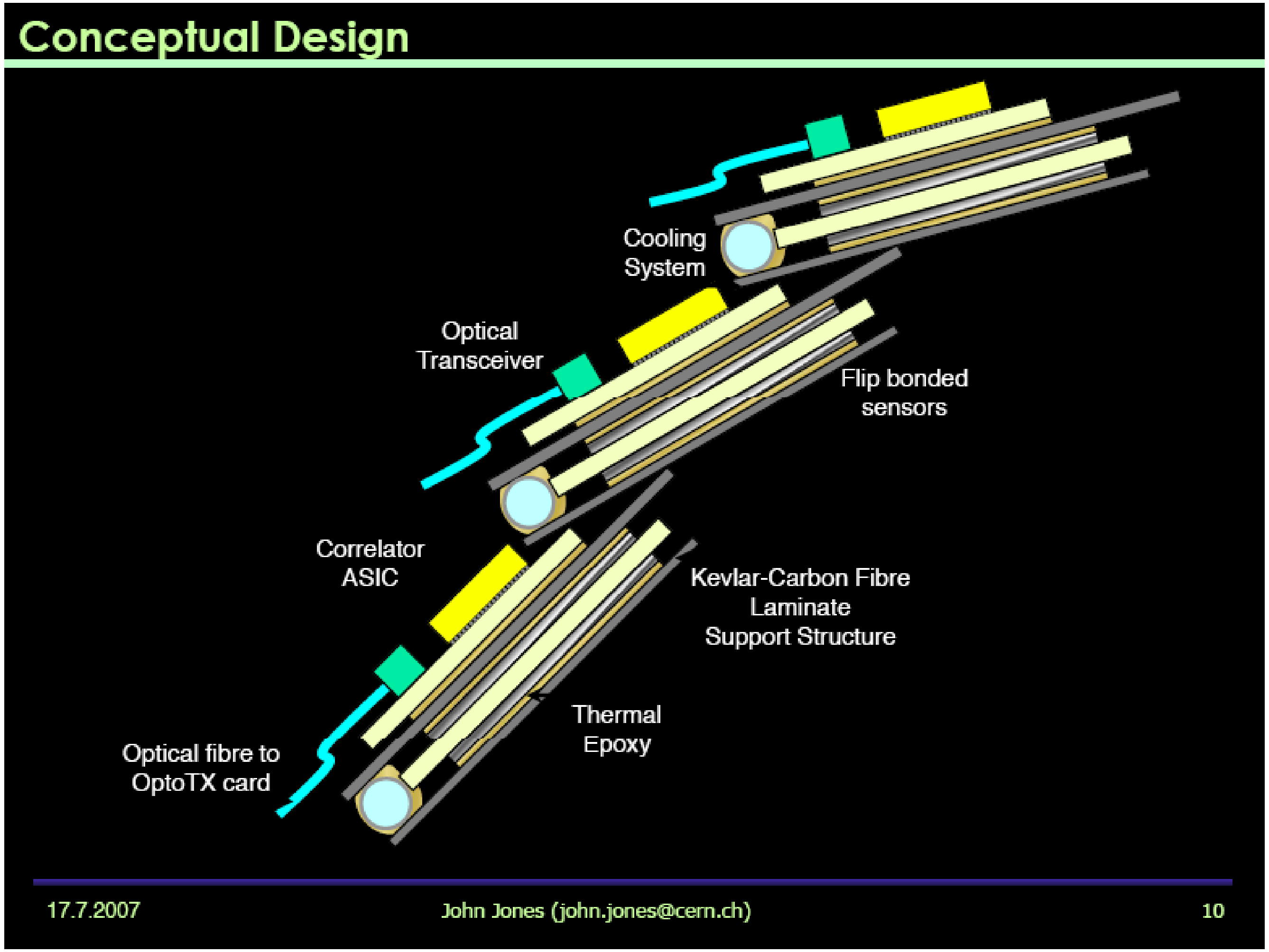
Local Information Gathering, and Processing Hierarchy



- Collect hits from each Sensor in a Pair
  - Match into Hit Pairs
  - Retain Hit Pairs from medium & high Pt Tracks

- Collect Hit Pairs from each Sensor Pair in a Stack
  - Match into Track Stubs
  - Retain Track Stubs from high Pt Tracks
  - Pass onto L2 Trigger

SLHC CMS Tracker Upgrade
Possible Local High Pt Discrimination Scheme



SLHC CMS Tracker Upgrade
Straw-man Layout to examine scheme

Straw-man Layout Example

12 Measurement Layers

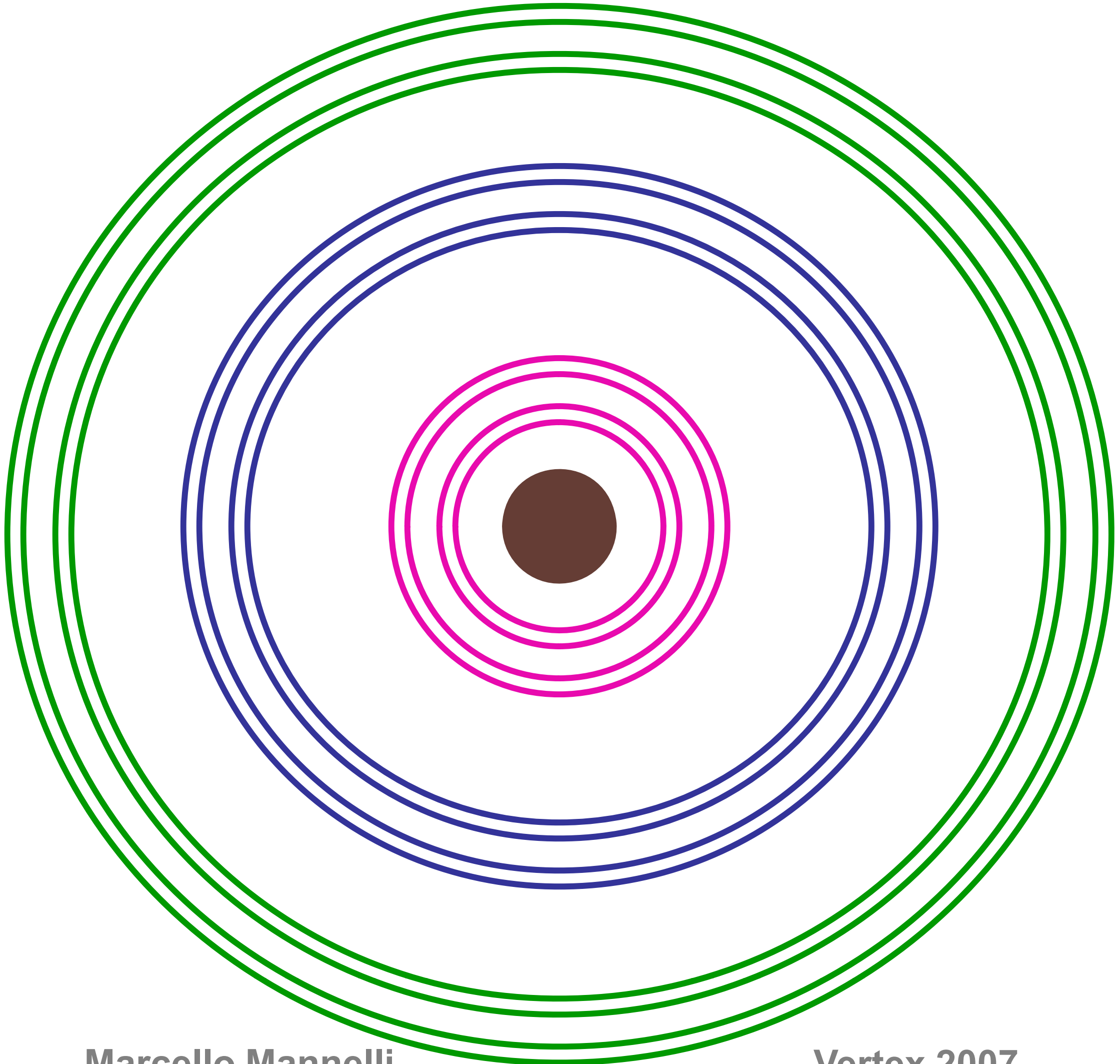
Organized in 3 Super-Layers

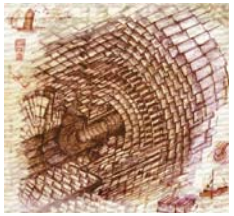
Each Super-Layer consists of a Stack of 2 Sensor Pairs
(4 measurement layers / Super-Layer)

- Inner Super-Layer ~ 20~40cm
(Geometry of Inner Vtx layers?)

- Middle Super-Layer ~ 60cm

- Outer Super-Layer ~ 100cm



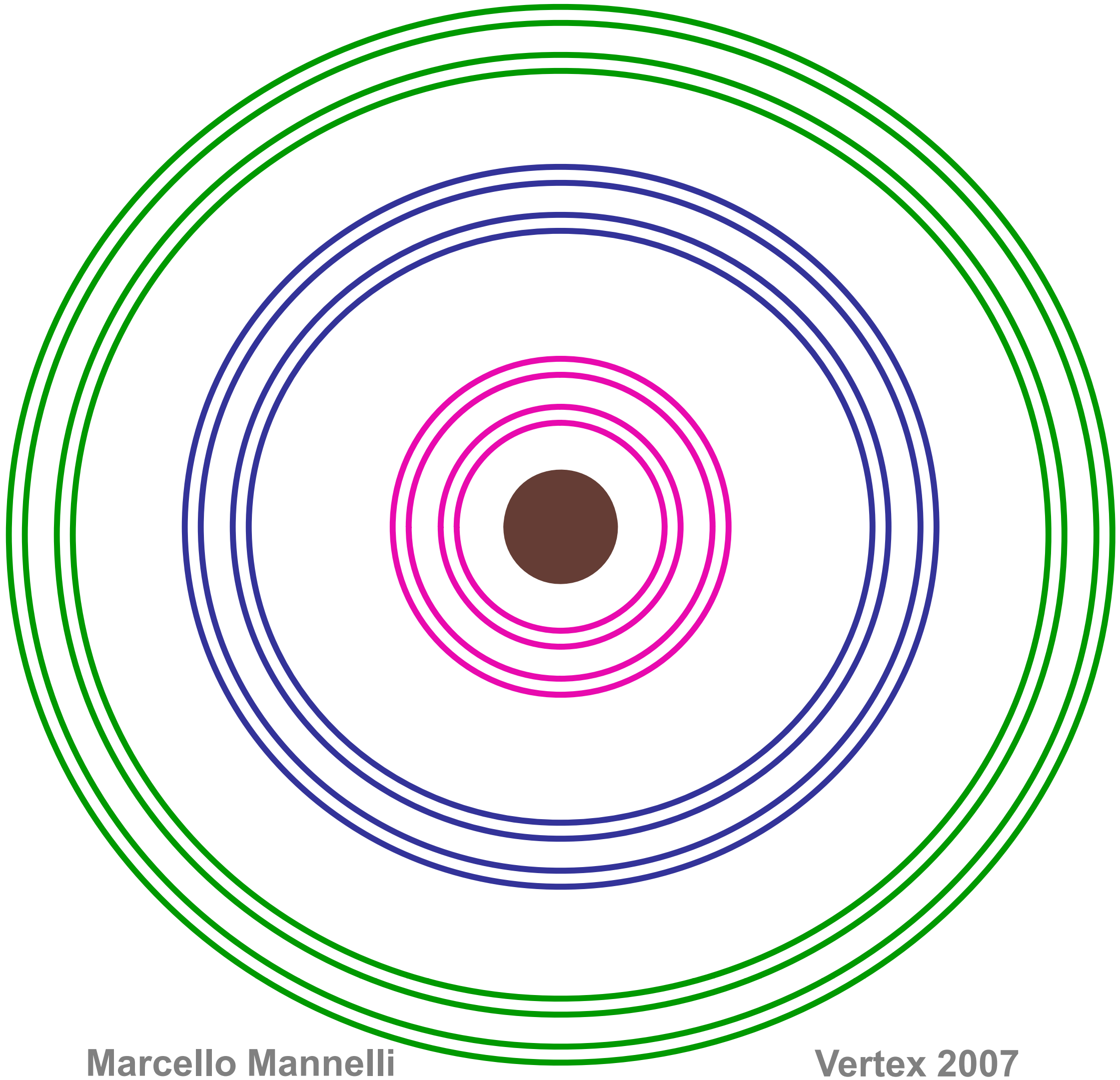


SLHC CMS Tracker Upgrade
Straw-man Layout to examine scheme

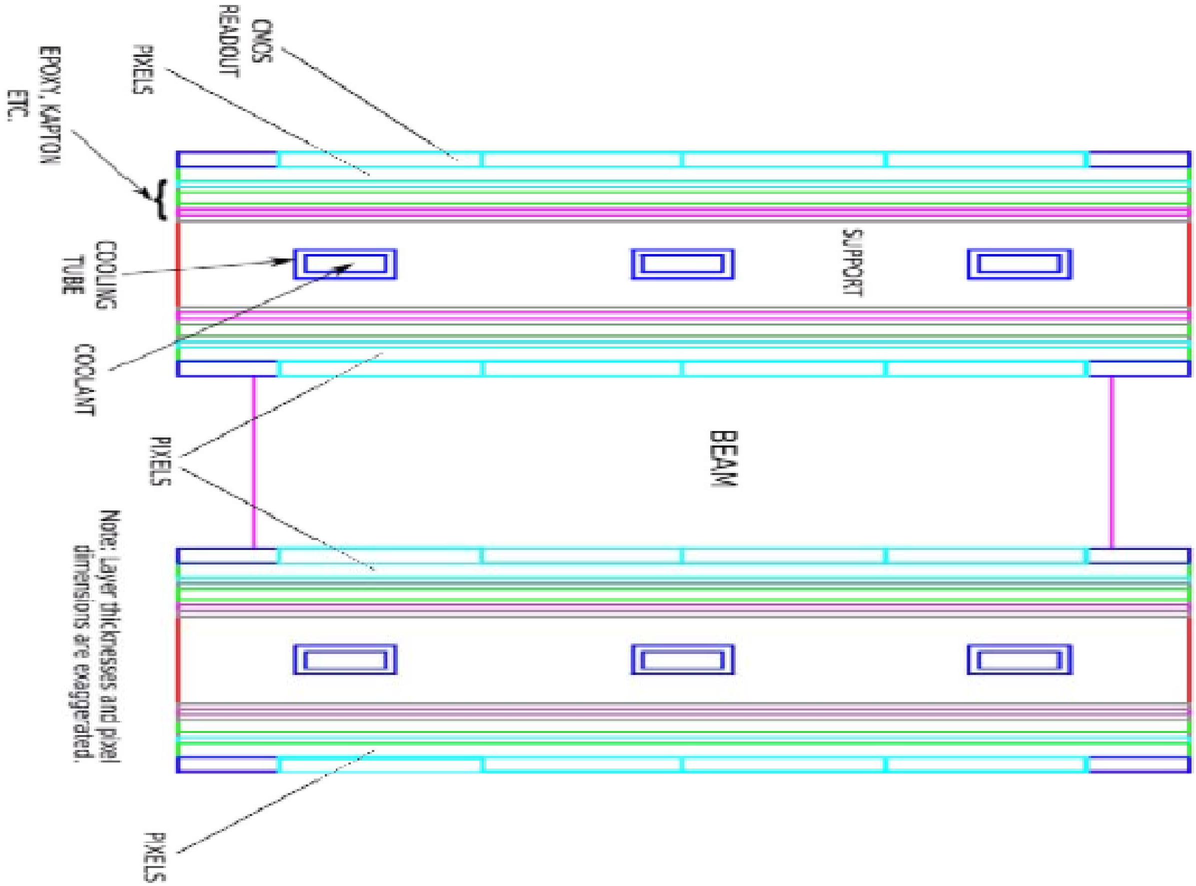
Comments:

Stack of Sensor Pairs provide opportunity for shared mechanics and services

=> May be useful approach for reducing Material Budget, independent of Local Occupancy Reduction scheme



SLHC CMS Tracker Upgrade
Possible Local High Pt Discrimination Scheme



Roberto Rossin
SWG 11 Sep 2007

Aspect ratio
NOT to scale

SLHC CMS Tracker Upgrade
Straw-man Layout to examine scheme

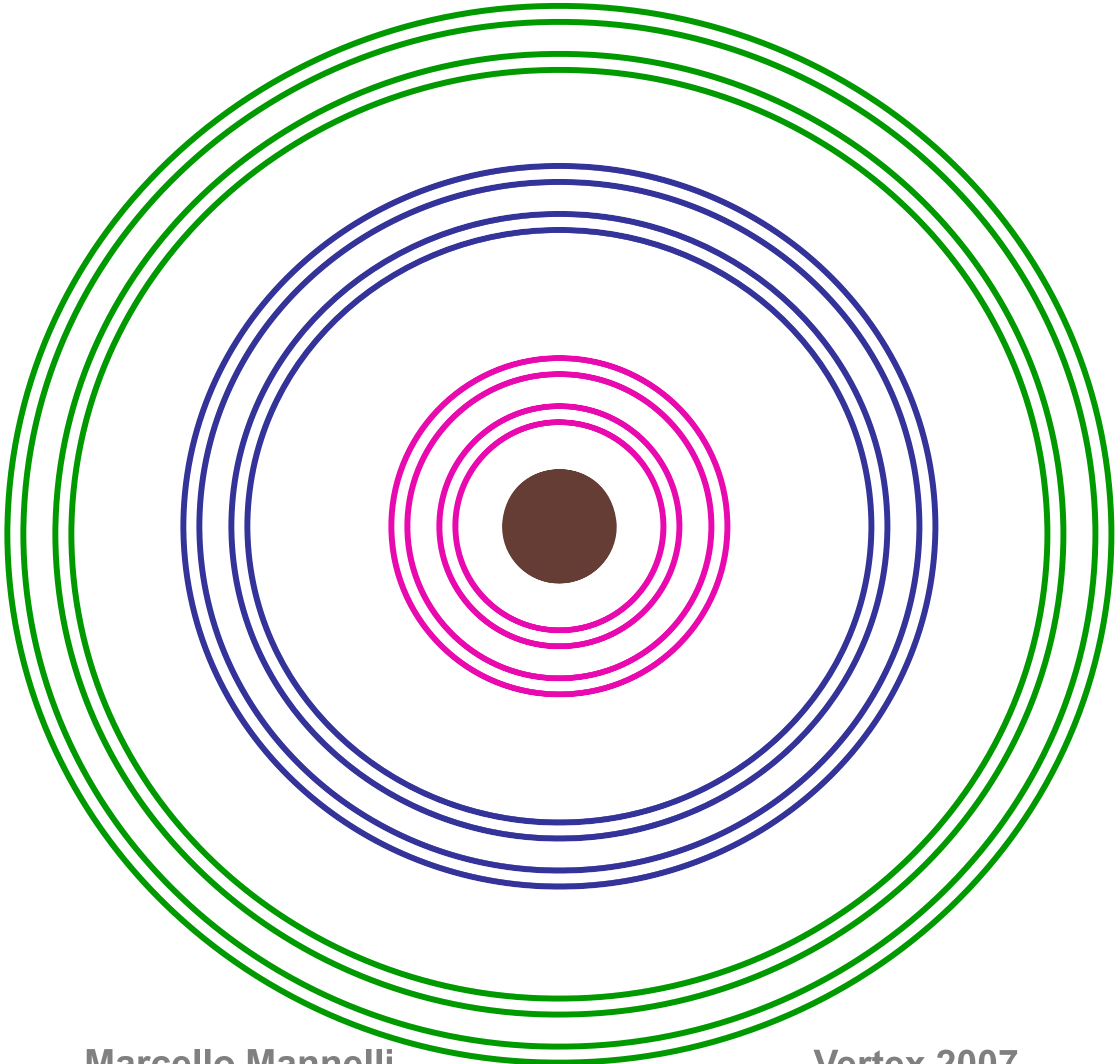
Comments:

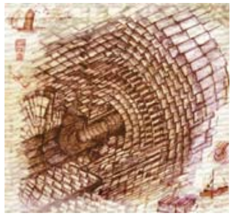
Stack of Sensor Pairs provide opportunity for shared mechanics and services

=> May be useful approach for reducing Material Budget, independent of Local Occupancy Reduction scheme

Drawbacks if used throughout?

Optimal arrangement & Layout?





SLHC CMS Tracker Upgrade
Straw-man Layout to examine scheme

Basic Parameters to Vary

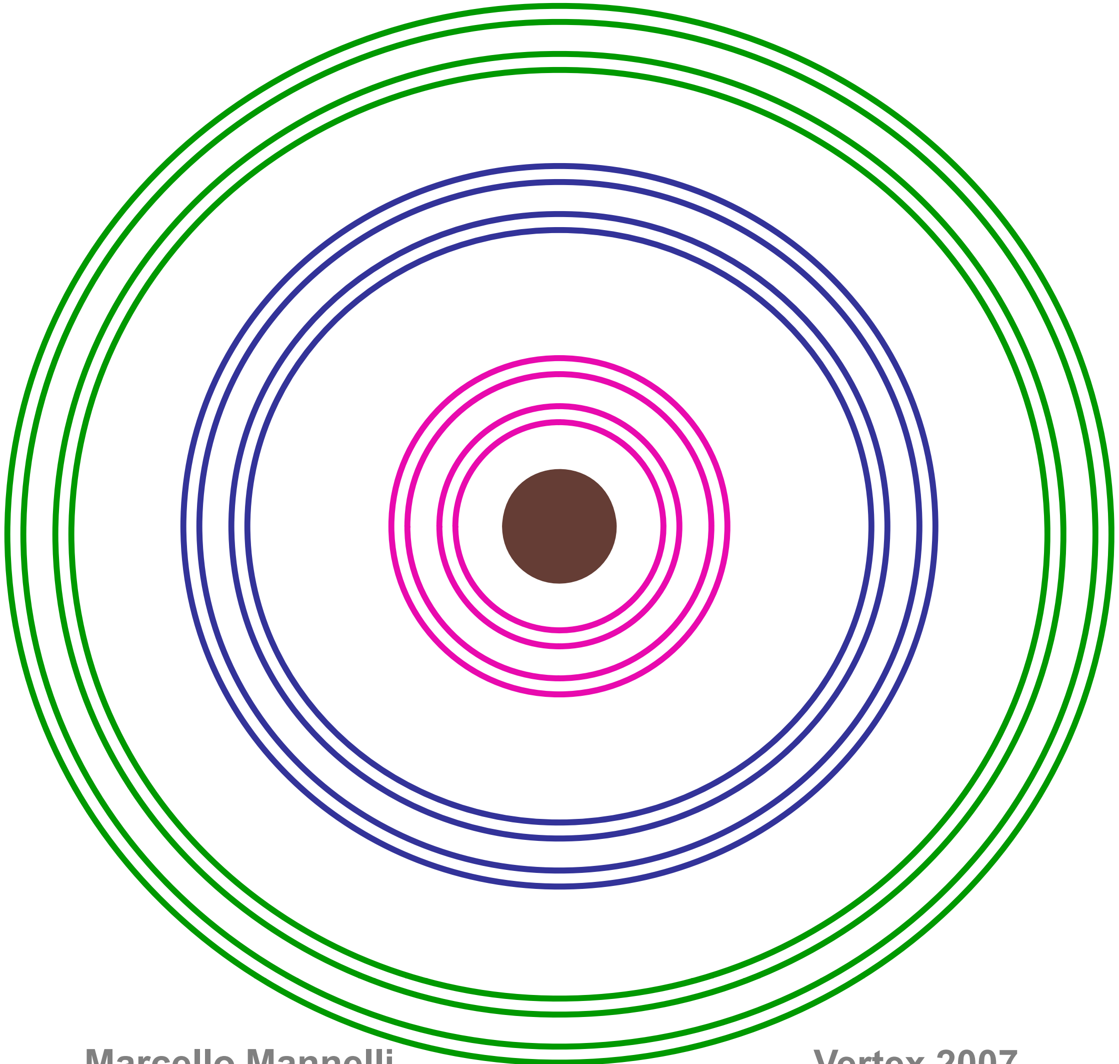
•Cell Geometry:
Pitch 60~120um, Length 1~2mm/2~4cm
Sensor Thickness 60~200um

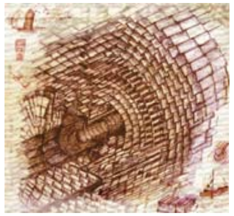
•Single Hit Efficiency:
95%~99.5%

•Sensor Pair Geometry
D ~ 1~4mm,
Align Transverse 20~200um,
Align Radial 50~200um

•Stack of Sensor Pairs:
D ~ 10~100mm,
Align Transverse 100~400um,
Align Radial 100~1000um

•Radial Positions
(10?) 20~40cm, 60~80cm, ~100cm

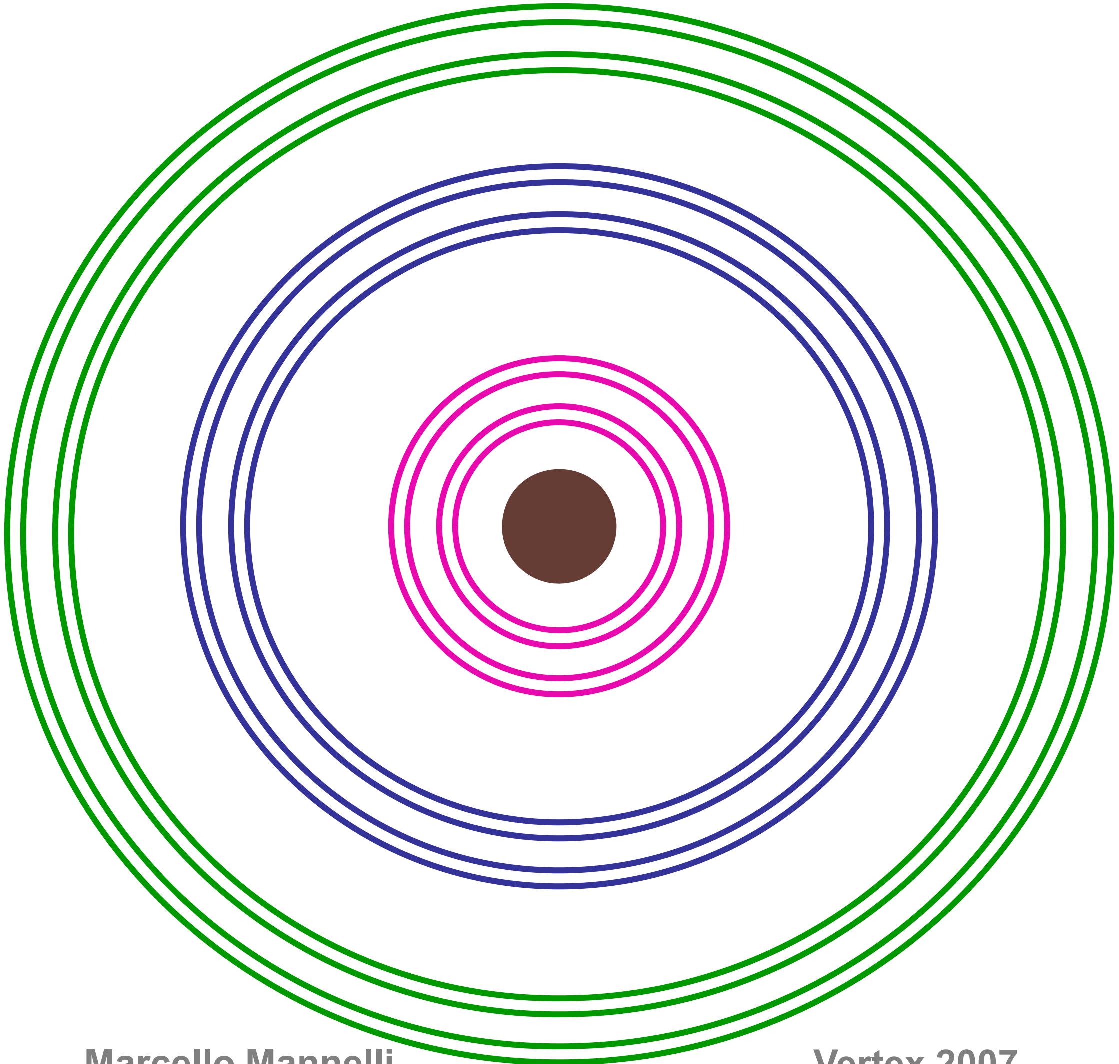


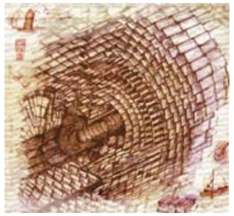


SLHC CMS Tracker Upgrade
Straw-man Layout to examine scheme

Basic Things to Check

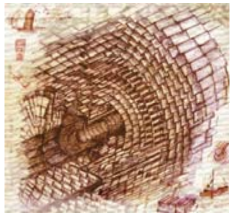
- Track Quality
- Hit Pair Pt Resolution, Data Volume & Efficiency vs Pt cut
- Track Stub Pt Resolution, Fake Rate & Efficiency vs Pt cut
- Min radius at which scheme works effectively
- Fake Rate & Efficiency if require
    - 3/4 vs 4/4 hits in a Track Stub
    - 1/3 vs 2/3 Track Stubs
- All the above varying the design parameters over the plausible range
    - Eg. Effect of cell geometry on occupancy and resulting effect on fake rate & efficiency





SLHC CMS Tracker Upgrade
Granularity vs Power Consumption (Mass)

- **The CMS Silicon Strip Tracker is extremely effective because:**
  - 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**
  - Strip length in range 1 ~ 2cm to maintain low occupancy
    - **Short Strips**
  - Pixel length in range 1~2mm => reduce occupancy, 3D info
    - **Long Pixels**

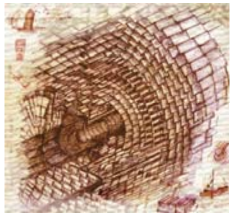


SLHC CMS Tracker Upgrade
Granularity vs Power Consumption (Mass)

The present CMS Silicon Strip Tracker is extremely effective

- **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**

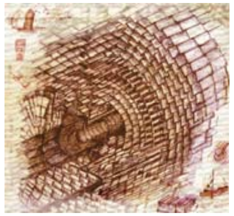
Low(wer) Mass!



SLHC CMS Tracker Upgrade
Granularity vs Power Consumption (Mass)

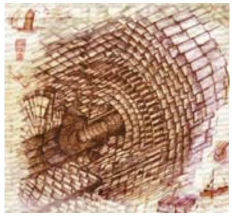
- **The Tracker Material Budget is strongly driven by**
  - **Large Power Dissipation, and need for Efficient Cooling (~33kA)**
  - **Large Current requirements (~20kA)**

<u>Lower Power Dissipation and Current Consumption</u>



Granularity: Short Strips vs Long Pixels

- **Cost and Manufacturability are a Key Input**
- **Implications on System, Read-Out Architecture etc.**
- **Comparative Performance Studies are Important Guidance**
- **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**



Power Consumption of CMS Strip Tracker

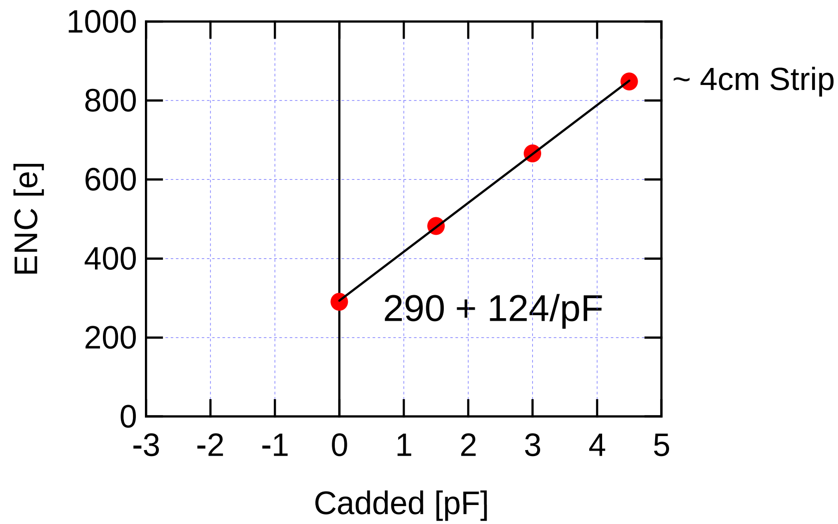
- **Power Dissipation of Strip FE chip (APV25) ~ 350mW (128 channels)**
- **Total Number of APV25 chips in CMS LHC Strip Tracker ~ 73’000**
- **Total Power Dissipation of CMS LHC Strip Tracker ~ 26kW**
  - **This is Nominal FE Chip Power dissipation**
  - **Actual Power dissipation is estimated at 33KW**
- **Note:**
  - **$210m^2$ / 73’000 chips ~ $28cm^2$ / chip**
  - **350mW / $28cm^2$ ~ $12mW/cm^2$ ($120W/m^2$)**

Power Consumption for Short Strip Tracker

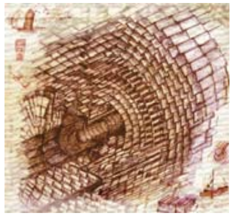
- **Analogue Current Consumption of APV25 driven Strip Capacitance**
  - C_{strip} ~ 1.2pF/cm; Strip Length 10 ~ 20cm => C_{strip} 12 ~ 24pF

- **For Short Strips can accept higher Noise vs C slope => reduce power**

- **For example:**
  - "APV" tuned to Short Strips 1 ~ 4cm (M. Raymond IC)



- **Preamp/Shaper Power/Channel for "APV13", tuned to short strips implemented in 0.13um, may be reduced from 1mW to 0.12mW ~ 1/8**

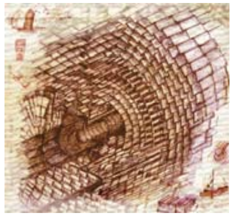


Power Consumption for Short Strip Tracker

- **Assume Preamp/Shaper Power/Channel can reduced by a factor ~ 1/10**
  - **Is it realistic to expect overall FE chip Power Dissipation to decrease by such a factor?**

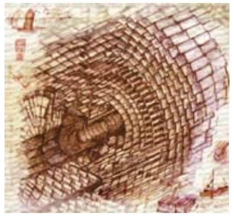
- **Within this architecture, likely Lower Limit for Short Strip length 1 ~ 4cm to maintain current Power Dissipation/cm^2**

- **Are there different approaches to a Short Strip FE Chip which would allow to go to ~1cm strip length AND significantly reduce Power Dissipation/cm^2 ?**



Power Consumption for Long Pixel Tracker

- **Power Dissipation of Present CMS Pixel FE Chip ~ 30uW/channel**
  - 30uW / 15’000um^2 ~ 200mW/cm^2 for current LHC Pixel
  - Compare to ~ 12mW/cm^2 for present LHC Strip Tracker (factor ~ 16)
- **Assume SLHC Pixel size ~ 120um * 2.0mm ~ 0.24mm^2**
  - This implies ~ 4M Channels / m^2
- **Which results in ~ 12.5mW/cm^2 (125W/m^2) ~ present Strip Tracker**
- **Assume Total Sensitive Area is ~ 210m^2**
- **This results in Total FE Chip Power Dissipation ~ 26kW vs 26kW now**
  - And 850M Channels…

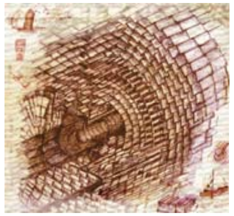


Power Consumption for Long Pixel Tracker

- **Plausible SLHC 0.13um Long Pixel FE Chip Power Dissipation ~ 20uW/channel**
  - Private communication Roland Horisberger

- **IF True, this would:**
  - result in Total FE Chip Power Dissipation ~ 17kW (vs 26kW)
  - leave head room for additional power dissipation (L1 Trigger, etc)
  - open possibility for reduction of overall Power Budget

- **The Power consumption extrapolations shown here are speculative**
  - But Interesting, and worth pursuing until reliable conclusions can be drawn



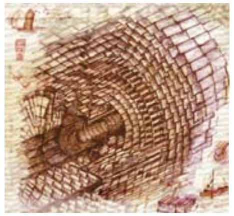
Conclusions

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

- **“Novel” approach:**
  - **Tracking with “few” high quality hits, in high occupancy environment**

- **Technology extrapolation, at “large” radii:**
  - **Very Large Scale Deployment of Radiation Hard Strip Sensors, with Low Power Density, Low Mass, and Low Cost**
    - when proposed, the Strip Tracker represented ~ 2 Order of magnitude extrapolation from existing devices

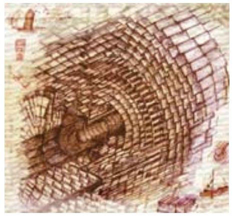
- **Technology extrapolation, at “small” radii:**
  - **Large Scale Deployment of Very Radiation Hard Pixels, with Low Power, and acceptable cost**



Conclusions

- **The CMS SLHC Tracker will be based on the present experience**
  - but is required to provide Tracking and L1 Trigger capability in 10~20 times higher occupancy & radiation environment, and should be lighter
- **"Novel" approach:**
  - Explore schemes for local Occupancy Reduction & Pt Discrimination
- **Technology extrapolation, at "large" radii:**
  - Explore possibility of Very Large Scale deployment of Very Radiation Hard Long Pixels (Short Strips), with Lower Power Density, Lower Mass, and Low Cost
- **Technology extrapolation, at "small" radii:**
  - Large Scale Deployment of Extremely Radiation Hard Pixels, with Lower Power Density, and acceptable cost

Back-up Material



SLHC CMS Tracker Upgrade
Straw-man Layout to examine scheme

Straw-man Layout Example

•**Sensor Pair:**
D ~ 1mm,   Cut ~ 200um

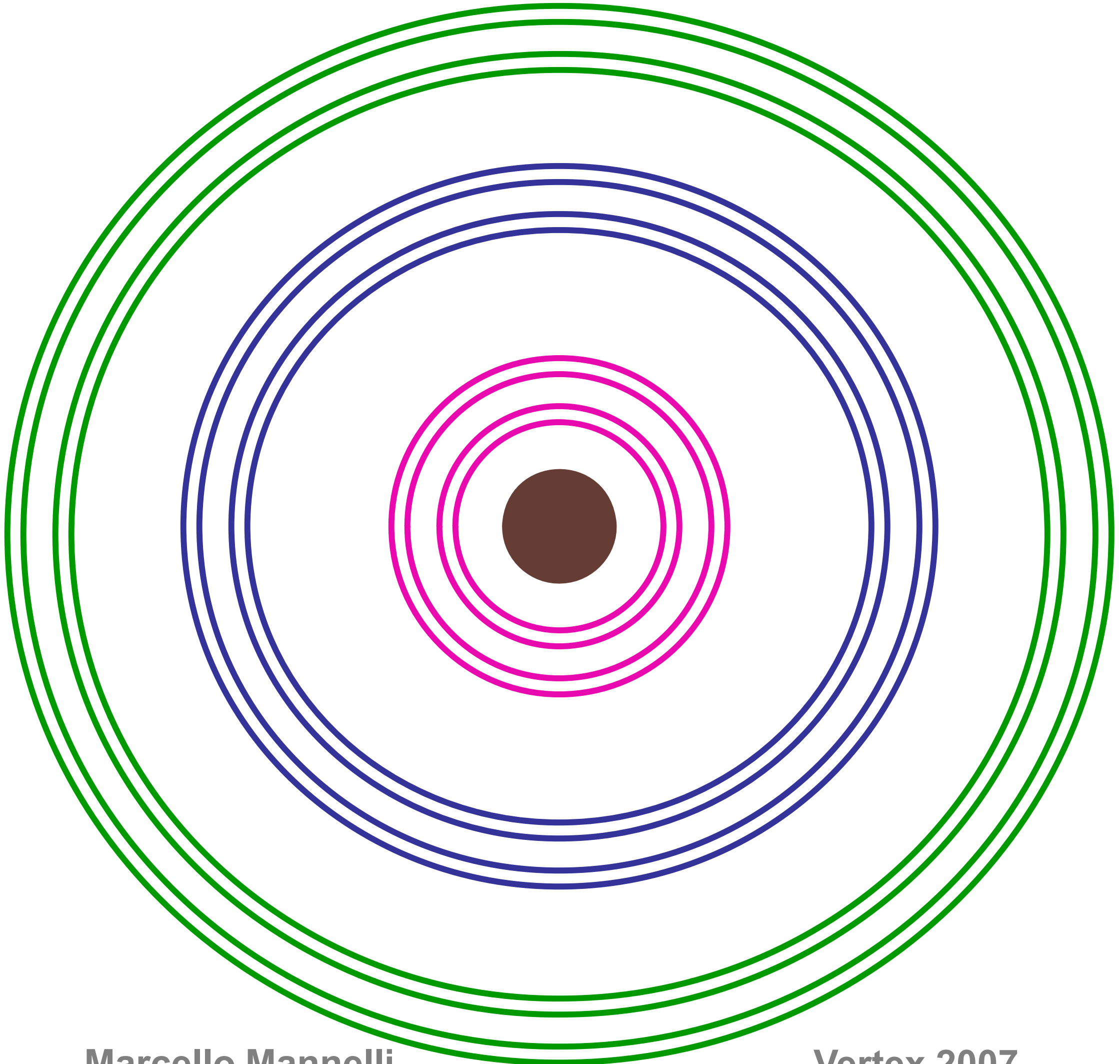
•**Stack of Sensor Pairs:**
D ~ 10mm, Cut ~ 400um

Pt Thresholds (back-of-envelope)

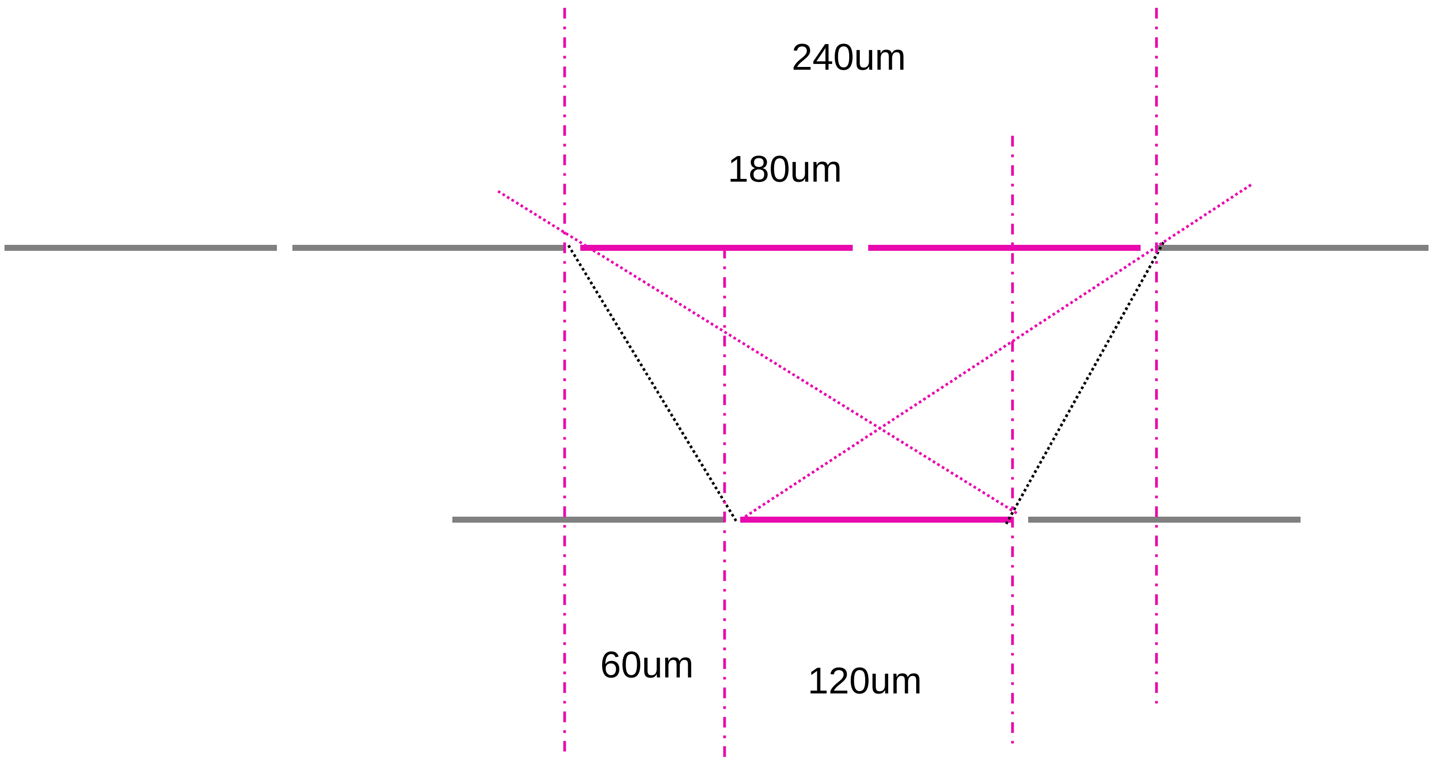
•**Inner Super-Layer ~ 20(40)cm**
Pair ~ 1(3)GeV, Stack ~ 7(13)GeV

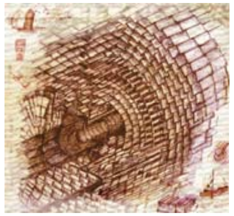
•**Middle Super-Layer ~ 60cm**
Pair ~ 4GeV, Stack ~ 20GeV

•**Outer Super-Layer ~ 100cm**
Pair ~ 7GeV, Stack ~ 30GeV



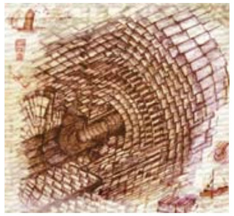
SLHC CMS Tracker Upgrade
Straw-man Layout to examine scheme





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

- **Extend Local Pt discrimination & Triggering Capability to End-Caps**
- **Provide homogeneous response, until loss of lever arm due to Tracker Acceptance**
- **Keep it “Simple”: Minimize number of variants**

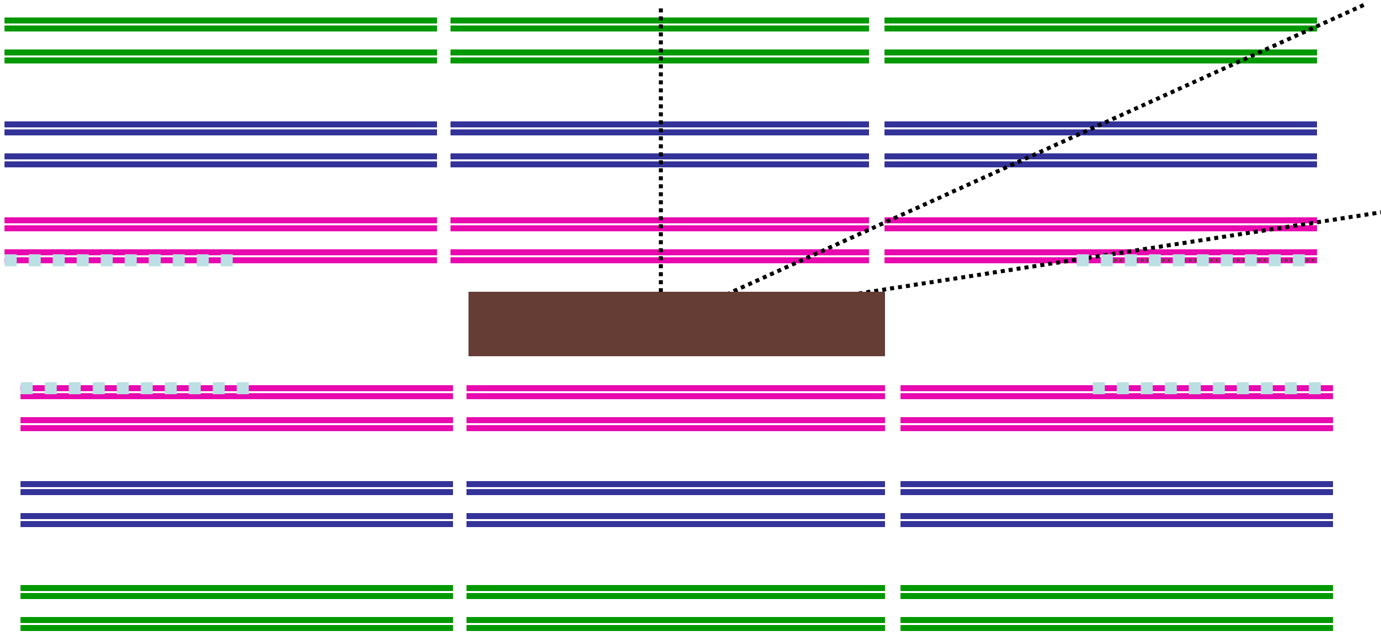


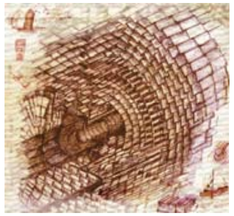
Extension of Straw-man Layout in the End-Caps ?

- **Consider a Central Barrel of 3 Stacks of Sensor Pairs ~ 170cm long**

- **Equip Forward and Backward End-Caps with identical Barrels**
  - **3 ~ identical Barrels, ~ 170cm long, covering the full acceptance**

- **Back of envelope calculation: ~ 240m^2**





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

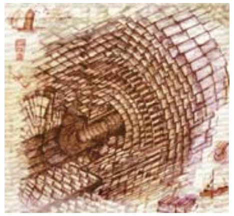
Pros:

- "Simple" (!)
- ~ Homogenous Performance 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

Cons:

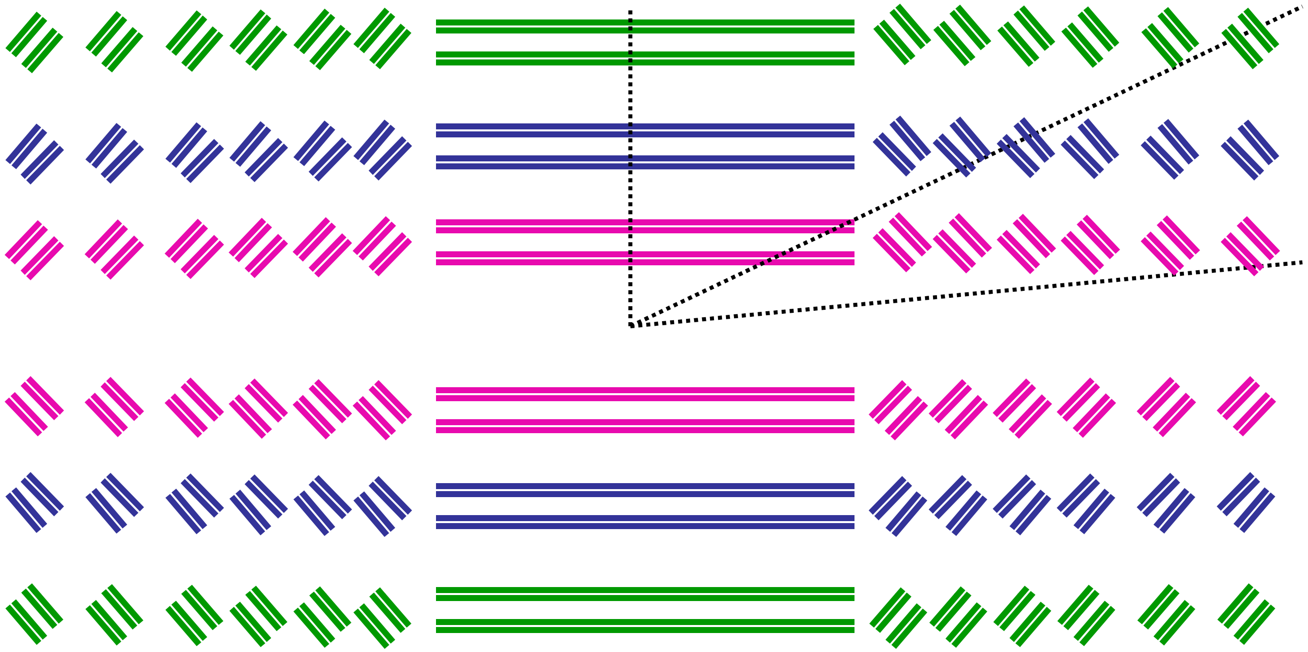
- Abrupt transition from 3 (2) to 2 (1) Super Layers at η ~ 1.6 (2.0)
- ~ Inefficient use of sensor active area at large η
  - Material & Costs
  - Large Cluster length variation with η
    - From ~ few um at low η -> ~ 1mm at high η (if ~ 100um thick sensors)

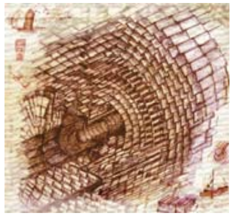
Is there scope for mitigating the Cons, while retaining the Pros?



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

- **Consider a Central Barrel of 3 Stacks of Sensor Pairs ~ 170cm long**
- **Equip Forward and Backward End-Caps Barrels with Inclined Modules**
  - **3 "similar"Barrels, ~170cm long, covering the full acceptance**
- **Back of envelope calculation: 160 ~ 190m^2**





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

Pros:

- **Efficient use of sensor active area at large eta**
  - Significant reduction in active surface
  - Reduced Cluster length variation with eta
- **May also mitigate abrupt hit coverage transitions at large eta**

Cons:

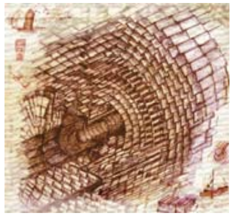
- **Much less “Simple”!**
- **Less Homogenous Performance**

To be Understood

Straw-man Layout
a Word of Caution

- **The Straw-man Layout shown here is Deliberately Extreme**

- **It is intended to highlight the Performance Potential AND the Pitfalls of new ideas, to allow informed decisions down the line**



Power Consumption for Long Pixel Tracker

- Current LHC Pixel FE Chip Power Dissipation ~ 30uW/channel

- SLHC Pixel Analogue current consumption ~ same as LHC Pixel Chip
  - * 2 due to higher pixel capacitance (0.3 ~ 0.4pf vs 0.1pf current pixel)
  - * 0.5 if go from 25ns to 50ns peaking time
  - Independent of technology

- SLHC Pixel Digital current consumption ~ same as LHC Pixel Chip
  - Driven by data rates
  - SLHC data rates at 20cm ~ 1/2 of LHC High Lumi data rates at 4cm

- Analogue & Digital current consumption for SLHC Pixel ~ LHC Pixel

- Expected effect of moving from 0.25um to 0.13um
  - Overall Current Budget ~ same as present Pixel chip
  - Overall Power Budget reduced by a factor ~ 1.5
    - Mainly affecting the Digital part of the chip

- Plausible SLHC Pixel FE Chip Power Dissipation ~ 20uW/channel