Run 2b Silicon

- Some problems
- Some solutions
- Some details
- Some time-critical issues

Joe Incandela for the Run 2b Working Group

CDF Collaboration Meeting

September 21, 2000

Run 2b Silicon Study Group

16 Institutions (so far)

Carnegie Mellon, Davis, Duke, FNAL, Hiroshima, INFN-Padova, JINR-Pittsburgh, LBNL, New Mexico, Okayama, Pittsburgh, Purdue, Rutgers, Texas Tech, Toronto, Tsukuba

Run 2b

- FNAL Supports extended running: ~15 fb^{-1} per experiment by 2007
- Laboratory proposed the following boundary conditions for the Run 2b upgrade projects.
  - The budget for the replacement of silicon vertex detectors should be 2.5M$ per experiment, with contingency
  - The new detectors must be designed with the confidence that they will operate effectively throughout Run 2b, with an anticipated luminosity of at least 15 fb^{-1}
  - The installation of all detector upgrades must occur during a single shutdown of no more than six months duration, with roll-out and roll-in tentatively scheduled between October 2003 and March 2004.

PAC Request

- What are the relative merits and implications of the following strategies?
  - Replace only Layer 00
  - Replace Layer 00 and only the inner 1 or 2 layers of SVXII
  - Complete rebuild of Layer 00 and SVXII

- Response needed for PAC Meeting in November
  - Directorate wants a preview in mid-October
  - CDF Run 2b committee will get our report a bit earlier (we hope)
    - Should release CDF Note 5425 within next two weeks.

Draft Schedule

Year	Integrated Luminosity [fb^{-1}]
2001	0.50
2002	1.05
2003	0.75
Shutdown October 2003 – March 2004	
2004	1.75
2005	2.80
2006	3.60
2007	4.5
Total	14.95

PAC Aspen June

- John Marriner's Presentation:

Integrated Luminosity for CDF and D0 2001-2007

Scenario	Integrated Luminosity (fb^{-1})
Collider (CDF and D0)	14.95
Collider + NuMI	12.67
Collider + NuMI + BTeV	9.41
Collider + NuMI+BTeV+ Kaon	8.10

Assumes NuMI starts 2003

Assumes BTeV starts simultaneous operation with B0 and D0 IN 2005

Assumes Kaon starts in 2005

Run 2b Working Group

- Run 2a silicon
  - Designed to survive 2 fb^{-1} with high degree of confidence.
  - The most appropriate rad-hard technology available at the time

- Run 2b Working Group: Address the following questions
  - Given the new luminosity goal how long will the silicon survive ?
  - If necessary: What are the simplest and most effective strategies for replacements ?
    - Incorporate all of our experience over the past decade
    - Use newer technologies to our benefit

Working Group Achievements

- Identified lifetime of present system
  - The issue is depletion voltage and noise
  - Important caveat: There exist a limited number of direct measurements in actual Tevatron environment. These have some inconsistencies.
    - Ionizing component (surface damage at 3 cm)
      - Run 1a data ⇒ 300 rad/pb^{-1}
      - Run 1b data ⇒ 600 rad/pb^{-1}
    - Leakage currents (damage to nuclear lattice)
      - Run 1a data ⇒ 0.8 nA/strip/pb^{-1}
      - Run 1b data ⇒ 0.6 nA/strip/pb^{-1}
    - Average radial dependence R^{-a} where a = 1.5 to 1.7
      - Extrapolations to very small radii (L00) have large uncertainty
  - Beyond these measurements, we rely upon published radiation damage studies which do not mimic actual operating conditions⇒ interpretations, uncertainties
    - Dose rate is much higher
    - Specific particle types and energies are used
  - What engineering safety margin is appropriate ?
    - LHC is using factors of 1.5 to 2.0

Achievements (2)

- If a replacement is required, WG concluded:
  1. Chip → 0.25 micron of SVX3 architecture
  2. DAQ → New mini-Portcard scheme
  3. Sensors → Single-sided back-to-back rad-hard strips
  4. Modules → Apply L00, CMS concepts and materials
  5. Mechanics → Apply L00, CMS simple ass'ly/support concepts
  6. Material → Studied material budget & its effects: ideas for less
- Analysis of Run 2a experience: How can we streamline ?
  - Single-sided silicon
  - Many fewer and more universal components
  - Simple assembly methods
  - Fine pitch signal cables
- Pixels
  - Formed a subgroup to study feasibility, cost, schedule for CDF use
  - FPIX chip + ATLAS sensor/module/support concepts
  - More detailed work still required – no show stoppers

Outline of this talk

- What are the problems ?
  - Longevity is not something we have in abundance
  - Time is not something we can afford to waste
- What are the solutions ?
  - The bad news: There are no easy solutions
  - The good news: What appears to be a reasonable solution is also very beneficial
- What has to be done now, what can be done later ?

Lifetime calculations

- Run 2a detector design:
  - *guaranteed* to last 2 fb^{-1}, should last longer. But how long ?
- Evaluate two characteristics of each layer on the basis of known operation and available data on radiation damage:
  - Signal-to-Noise Ratio (SNR)
  - Bias voltage required for full depletion (V_D).
- Rad-damage mainly nuclear reactions in bulk
  - Leads to both higher leakage current (I_L) and change in dopant concentration which affects the depletion voltage
    - We can begin to understand I_L with relatively modest doses.
    - To determine V_D in CDF we need larger doses - i.e. Run 2a data.
  - Run 1 data: direct normalization of I_L vs integrated luminosity L.

    $I_L = 1.13\ mA \times V_s \times R^{-1.7} \times L^{-1}$ V_s =*Strip Volume* (units are cm and fb^{-1})

Fluence

- Run 1 I_L data also used to normalized neutron-equivalent fluence Φ_n versus integrated luminosity L.

  $I_L = I_o + \alpha \Phi_n V_s$

  - A range of values for α can be found in literature.
    - We use $(3 \pm 1) \times 10^{-17}$ A /cm to cover commonly used values for our Run 1 operating temperature

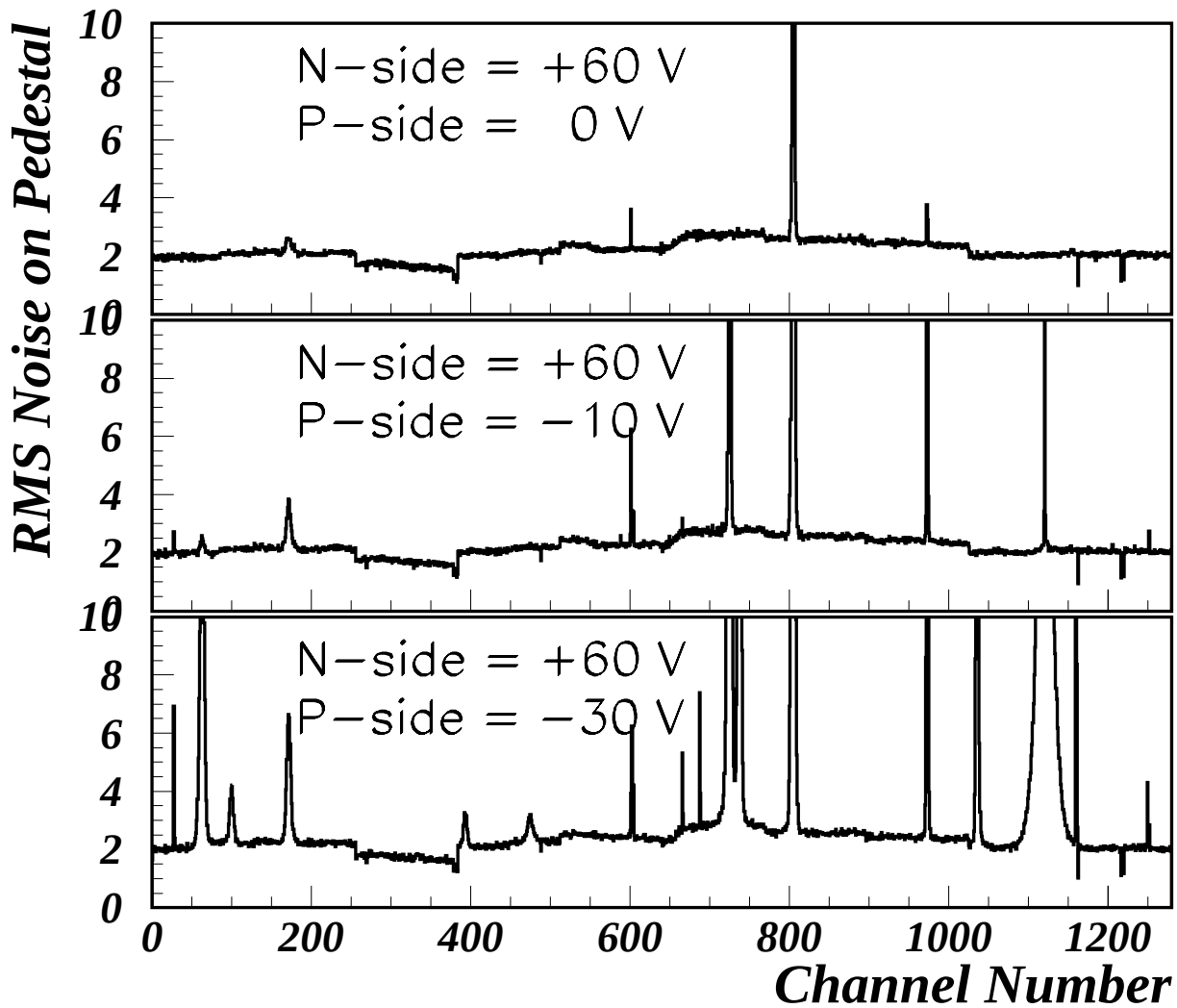
Longevity by layer

Layer	R_{min} [cm]	Lifetime limits [fb^{-1}]		no p-side bias		Cause of Death
		"1σ"	Central	"1σ"	Central	
L00 (10%)	1.35/3	4.5	5.5			SNR
L00 (10%)	1.35/5	6.5	9.0			SNR
L00 (80%)	1.62/7	8.0	11.0			SNR & V_D
L0 ϕ or z	2.54	5.2	7.9			V_D
L1 ϕ–side	4.12	12.0	18			V_D
L1 z–side	4.12	12.0	17			V_D
L2	6.52	10	16	3.8	6.0	V_D
L3 ϕ–side	8.22	38??	76??			V_D
L3 z–side	8.22					
L4	10.1	21 ??	34 ??	8.0??	13??	V_D
L6	20.0	>>30	>>30			V_D
L7	28.0	>>30	>>30	>>30	>>30	V_D
DØ 90°	2.70	?	?	?	?	

Longevity

It appears that we can't bias Micron silicon from the p-side.

When this silicon inverts, it may be useless. Even if it is still usable, it will not be depletable for nearly as long as we had planned.



Implications

- The Good News:
  - All silicon will survive Run 2a and probably longer.
  - The ISL will not need to be replaced

- The bad news:
  - L00, L0, L1, L2 (L4 ?) cannot be assumed to survive to 15 fb^{-1}

- What's the best way to replace dead ladders ?
- Can we replace them and leave everything else alone ?
  - This has got to be the easiest thing to do – right ?

Simple Replacement ?

- Exact replacement of SVXII layers
  - Requires double-sided (DS) silicon.
    - Micron and less experienced companies are the sole vendors available.
      - HPK has said they will not make DS silicon anymore
    - DS silicon is not radiation hard. We would not gain much.
  - What about using single-sided (SS) silicon ?
    - 2 sensors for each 1 used before OR we drop stereo info
    - requires direct cooling to ~ 0° C for small radius layers and high bias voltages
  - It would be a very significant challenge to design a double-thick silicon ladder with integrated cooling that fits into our existing SVXII bulkheads.
  - Even if we were to succeed, such a ladder would be more complicated than anything we had to deal with for Run 2a.

Time

- If we were to reuse any part of the existing SVXII we would need a substantial shutdown
  - Even if all we do is transfer one or two layers worth of ladders and pre-build all other layers on new supports before the shutdown, we estimate that we would be off the air for one year
  - If we re-use the existing bulkheads the shutdown required would be longer still.

  - In all cases, The shutdown period would be entirely time-critical:
    - Any problems that lead to delays in the rebuilding of the SVXII and final assembly would add to the time we are off the air.
    - There is NO contingency
    - There are significant risks.

Shutdown sequence

- Replacement of only those layers which are damaged
  - Technical Challenges: How much disassembly & re-assembly ? Time ?
  - Required shutdown could be long and may involve risks
    - Handling, disassembling, and rebuilding SVXII barrels carries schedule risks: requires reconstruction and testing time <u>during</u> the shutdown period.
      - Extract ISL and transport to SiDet
      - Remove SVXII spacetube and split it open: fair amount of fixture setup and use
      - Uncable and remove L00/beampipe: more fixture setup and use
      - Remove all 3 Barrels and transfer to barrel assembly fixtures
      - Remove ladders
        - Could possibly remove only those ladders which are damaged
        - If bulkhead alignments are affected or questionable, or if we want to survey locations of newly installed ladders then complete disassembly and re-alignment of bulkheads is required.
      - Install new ladders, survey & test
      - Reinstallation and barrel to barrel alignment in spacetube
      - Reinstallation of Layer 00 and beampipe into SVXII, surveyed and aligned, beampipe mounts installed
      - Reinstallation of SVXII into ISL, and ISL into COT, surveyed, aligned, retested
- Time estimate: 1.5 months out + 8 months + 2.5 months in

So where do we stand ?

- Rebuilding an SVXII means
  - A risky repeat with DS silicon and limited longevity,

or

  - A more rad-hard design with even more complicated, internally-cooled ladders and a possible loss of stereo

And

  - All new bulkheads, space tube, and barrel supports with re-use of some ladders (1 year shutdown) or make all new ladders

or

  - We do a full disassembly and rebuild which means more than 1 year off the air with all kinds of schedule risks

No easy way …

The rest is not so bad

- There may be a way to completely replace SVXII at reasonable cost and on schedule
  - The issues
    - The readout chip
    - Short time scale for development of mechanical structures
- We can easily build a Layer 00 replacement.
  - It would cost ~170k$ for all components
    - We should make some components like support shells now (while we are setup to do this), and put them aside.
    - Hybrids and silicon can be done later without much trouble.
    - Fine pitch cables were made by CERN and we now have a second source.
  - Construction time is ~ 3 months
- And don't forget the ISL may not need any work at all
  - We should probably prepare a few replacement ladders for each layer just in case some chips die or whatever… but nothing major

Our Priorities

- Maximum integrated luminosity
  - Get to high luminosity running as quickly as possible
    - Should be done asap if the physics justifies it.
    - Should not wait just for the sake of optimizing component lifetimes
  - Minimize shutdown periods
    - CDF has an overhead of 4 months for moving out and back into the Hall
    - Any changes that must occur should be designed to add minimally to this
  - Be prepared to run longer than anticipated
    - While 15 fb^{-1} is all that is foreseen given the current LHC schedule, it may be wise to have a detector capable of more running than this.
      - We need some safety margin in our detector design
      - The AD may deliver more luminosity than currently indicated.
- Powerful and robust detector
  - For Run 2b, the Run 2a performance should be retained or improved
    - Do we need to make changes to improve the pattern recognition ?
    - Do the ambiguities of SVXII 90o layers compromise 3D vertexing ? If this is important, we should improve this.

Intermission

- Are there any questions ?

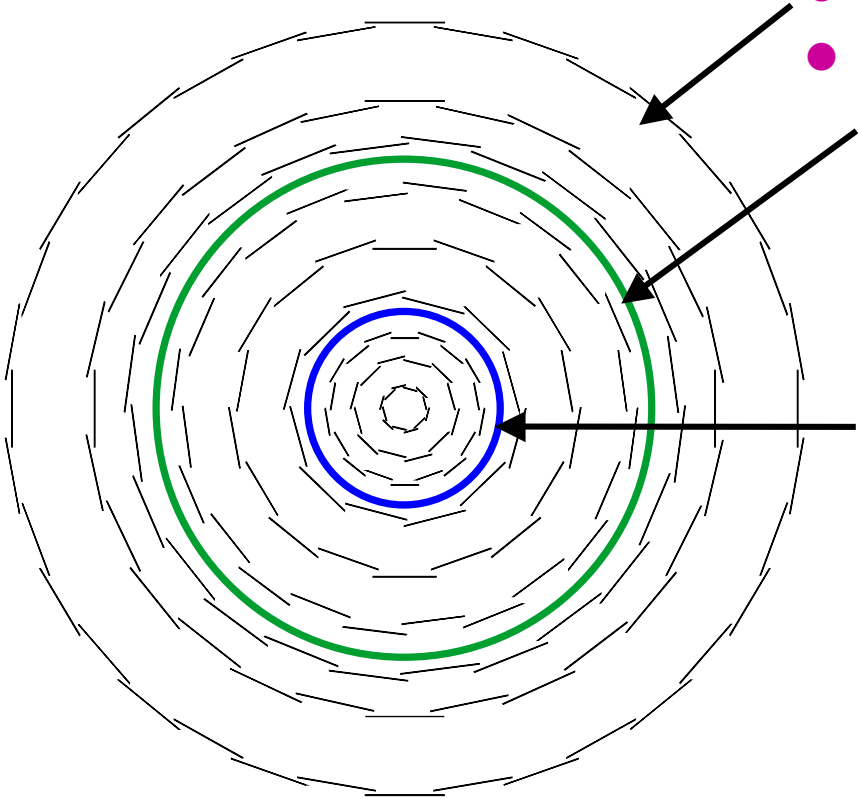
Complete Replacement Scenario

- Build a complete SVXII replacement
  - This isn't a small project but it appears to be the most reasonable choice
- There are advantages
  - When the new system is ready we do a complete swap.
    - The shutdown could be 6 months, maybe less.
    - All the most critical construction steps could be done before the shutdown
  - The new system could be better as a matter of course
    - More rad-hard, providing some insurance
    - Less material
    - A new layout that could integrate some of what we learn in Run 2a
- What's required
  1. **We must get started on the chips !!!**
  2. Benefit from our analysis of the Run 2a projects
  3. Cost must be moderate and risks must be minimal – this follows from 2.

An Example

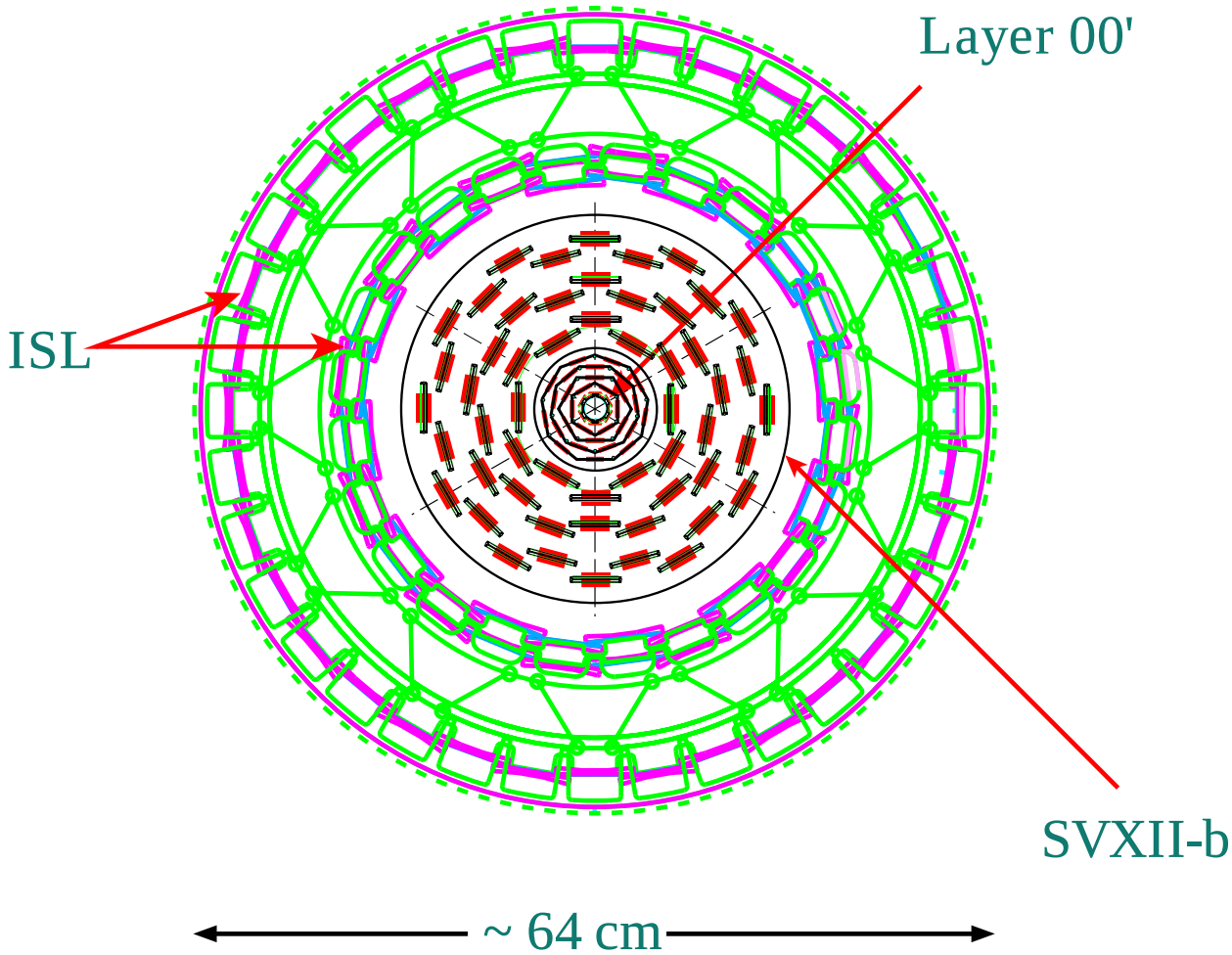
- The Working Group developed an example of a complete replacement of SVXII and Layer 00
  - This is not a proposal for a specific layout. We will have time to study specifics and to make decisions on
    - Number of layers
    - Radii of these layers
    - Strip pitches
    - Stereo angles
    - Pixels
  - The example does however identify
    - The approximate scale for a complete replacement
    - A methodology for streamlined, low cost production
    - Components that need to be addressed very soon as a result of long development or production lead times.
      - We have in fact already started development of some – reported below

Basic Concept

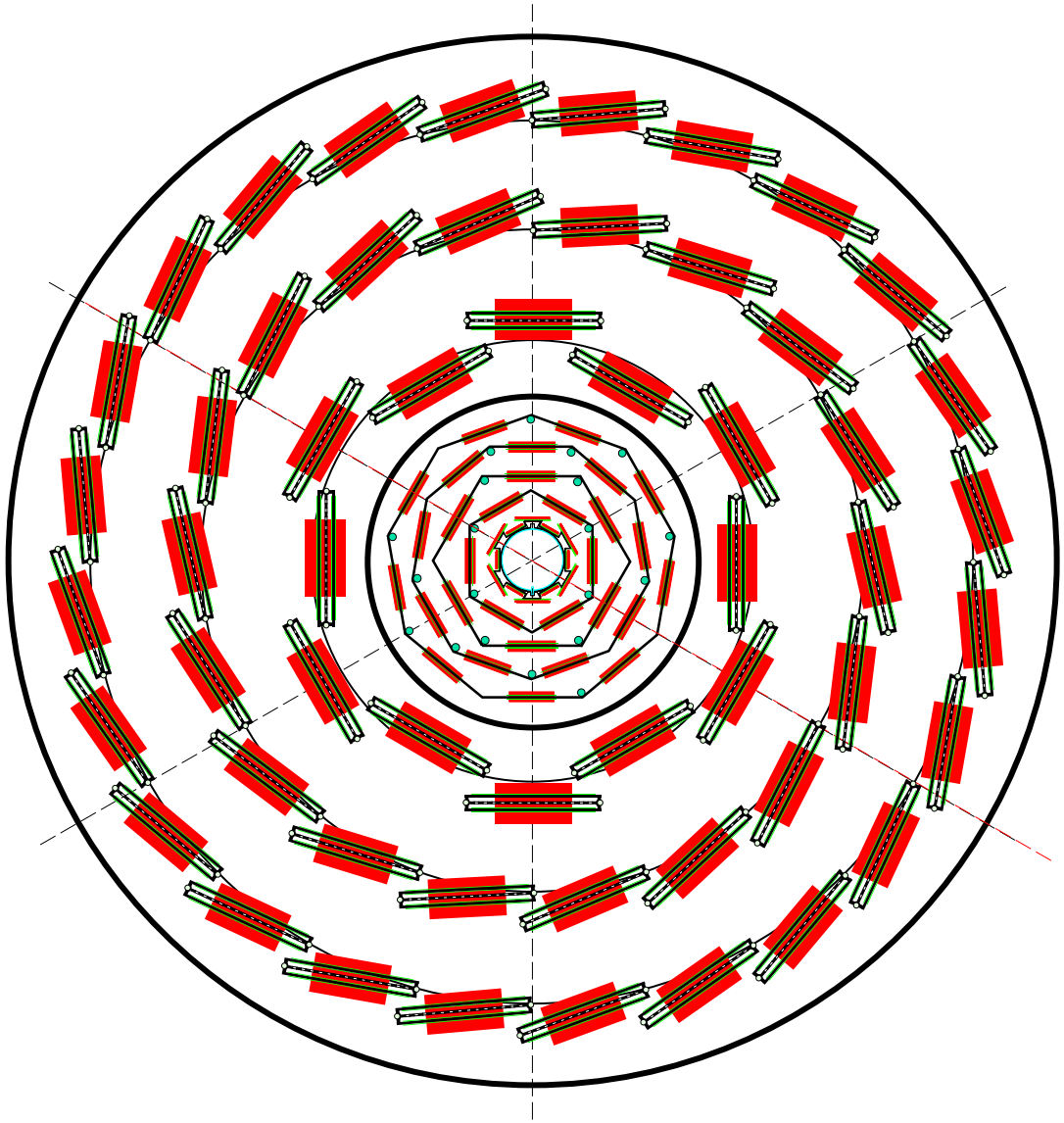


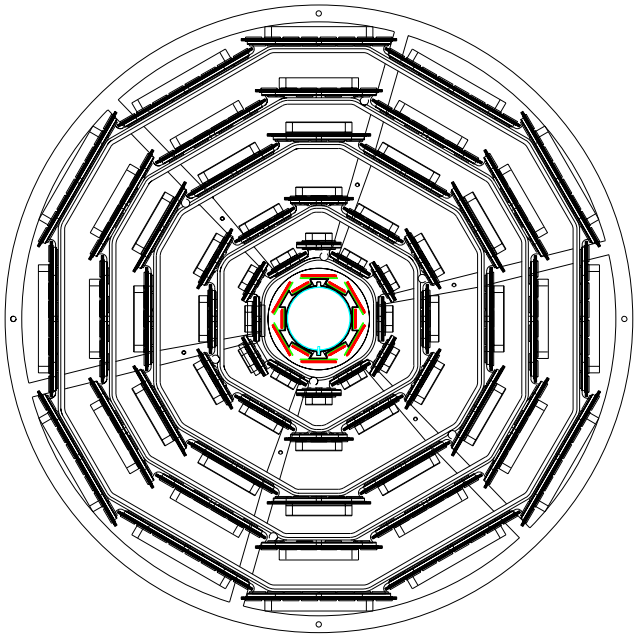
- Goal: Keep or improve functionality
- Retain ISL (~8 krad/fb^{-1})
- 2 New Radial Groups
  - Outer
    - Design to last a long time
    - Simple:
      - two single-sided sensor designs
      - one double-sided hybrid design
      - carbon fiber supports with cooling
  - Inner (within blue circle)
    - Design to last minimum of 15 fb^{-1}
    - Integrated cooling at lower temp.
    - Two outermost layers w/simple design:
      - 2 single sided sensor designs
      - L00 style hybrid design
    - Innermost layer: L00 replacement
      - Exact replacement
      - Could use pixels if ready and sufficiently lightweight.

The example



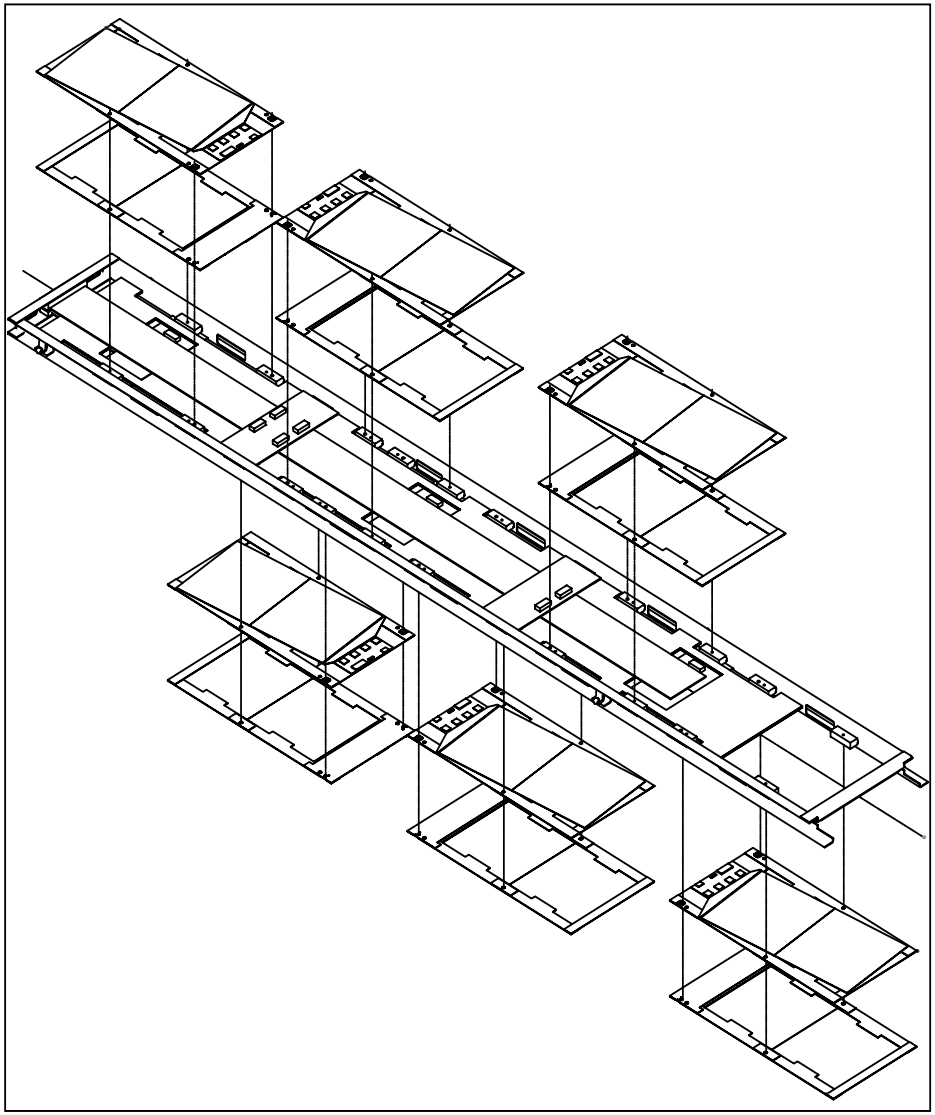
Comparison



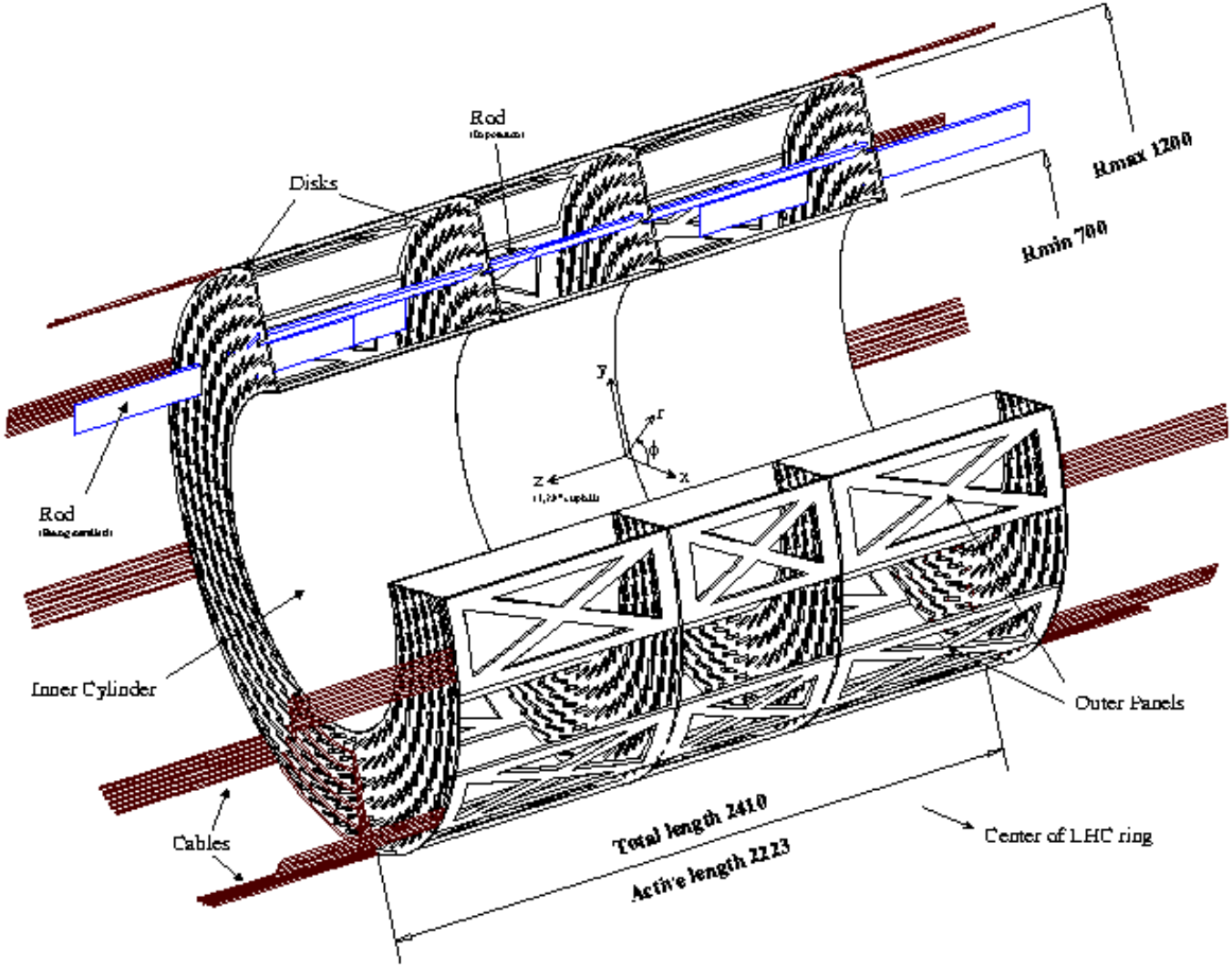


CMS Rod concept

- Outer Section uses simple single-sided modules and CMS rod concept
  - Axial strip modules
  - Shallow stereo modules
- Rod
  - Integrates cooling and cables
  - Dual views obtained by stacking single sided modules
- Rods install into simple wheel supports

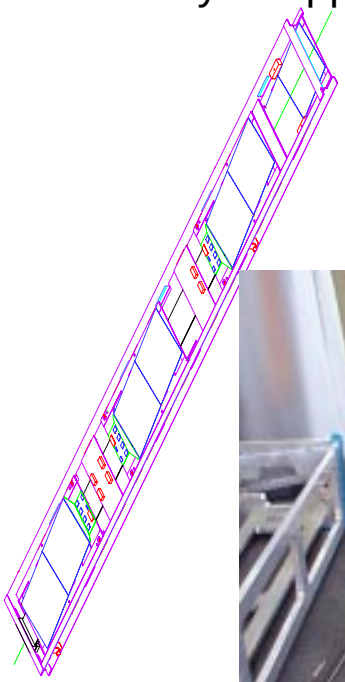


CMS Wheel Support

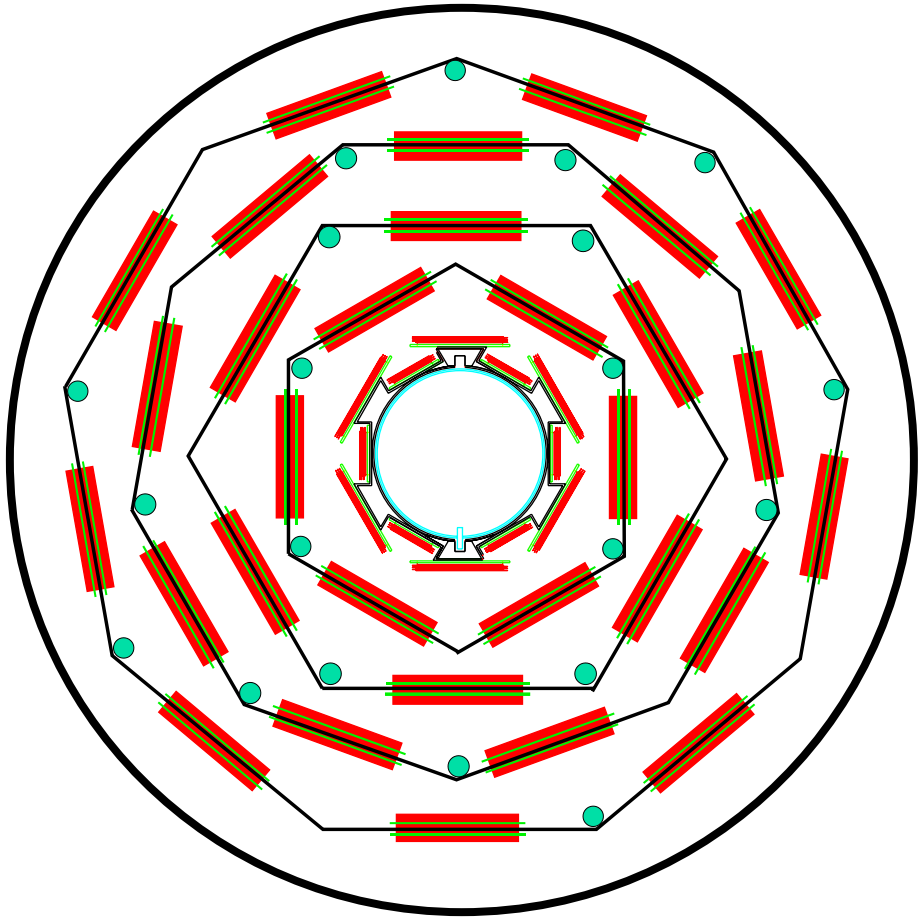


CMS Rod Support Concept

Uses only stereo modules made up of two single-sided modules. These are installed back to back with small overlap in z in boxlike “rod”. Rods install in C-fiber endplate system like COT field sheets. CMS achieves very high precision alignments from one rod to next. They are also easily swapped in and out.

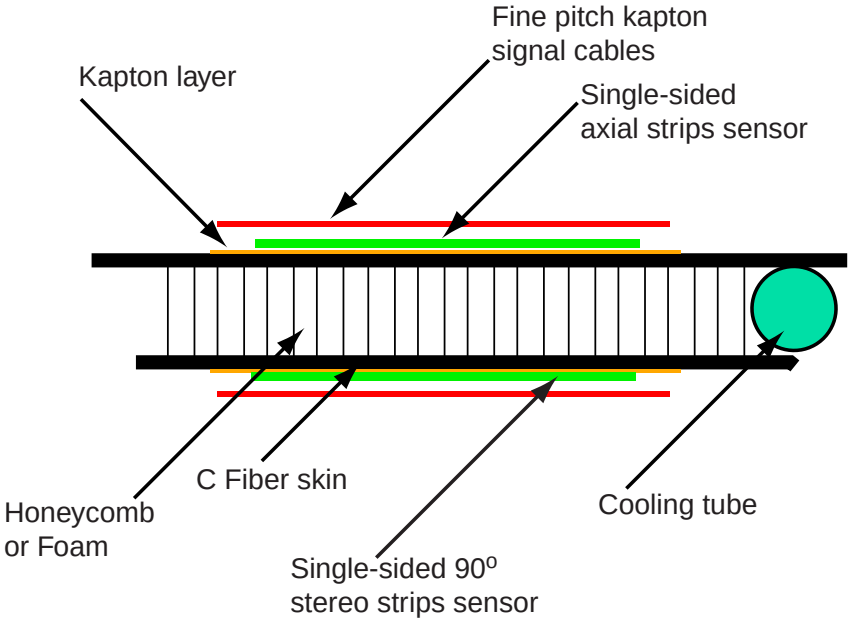


Inner Section



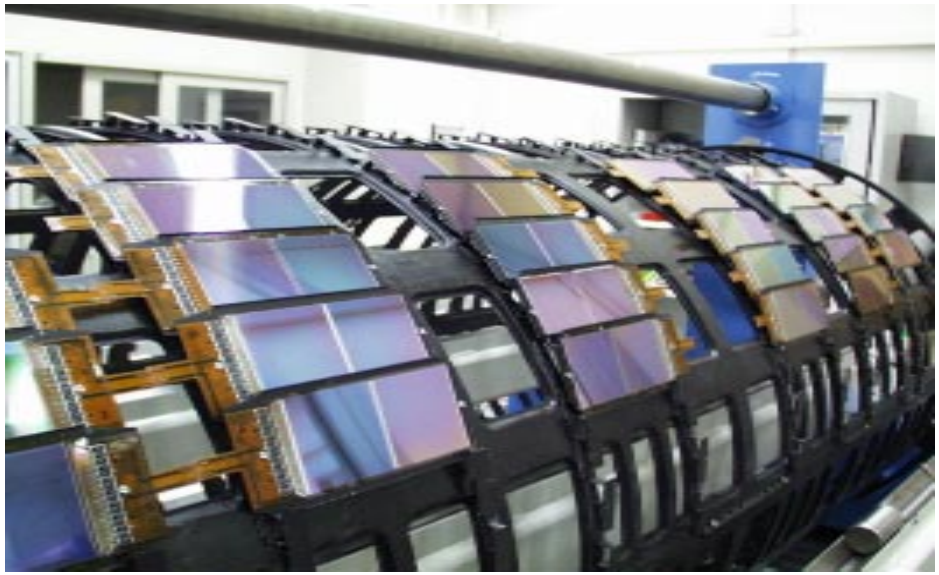
- Innermost layer on beam pipe could be the same as Layer 00 or it could be pixels.
- The other two layers can be like Layer 00 with electronics outside the tracking volume:
    - Low mass inner layers
    - Could remove z ambiguities

The 2 layers beyond L00



- Build C-fiber support cylinders with polygonal cross-section
- Install single sided silicon using long kapton readout cables
  - This is similar to Layer 00
  - Traces can have larger pitch and less capacitance
- Cooling can be integrated into them directly
- Silicon can be mounted inside and outside to obtain stereo views
- Stereo can be shallow or 90°
  - We don't need to decide now

Shell Support Concepts



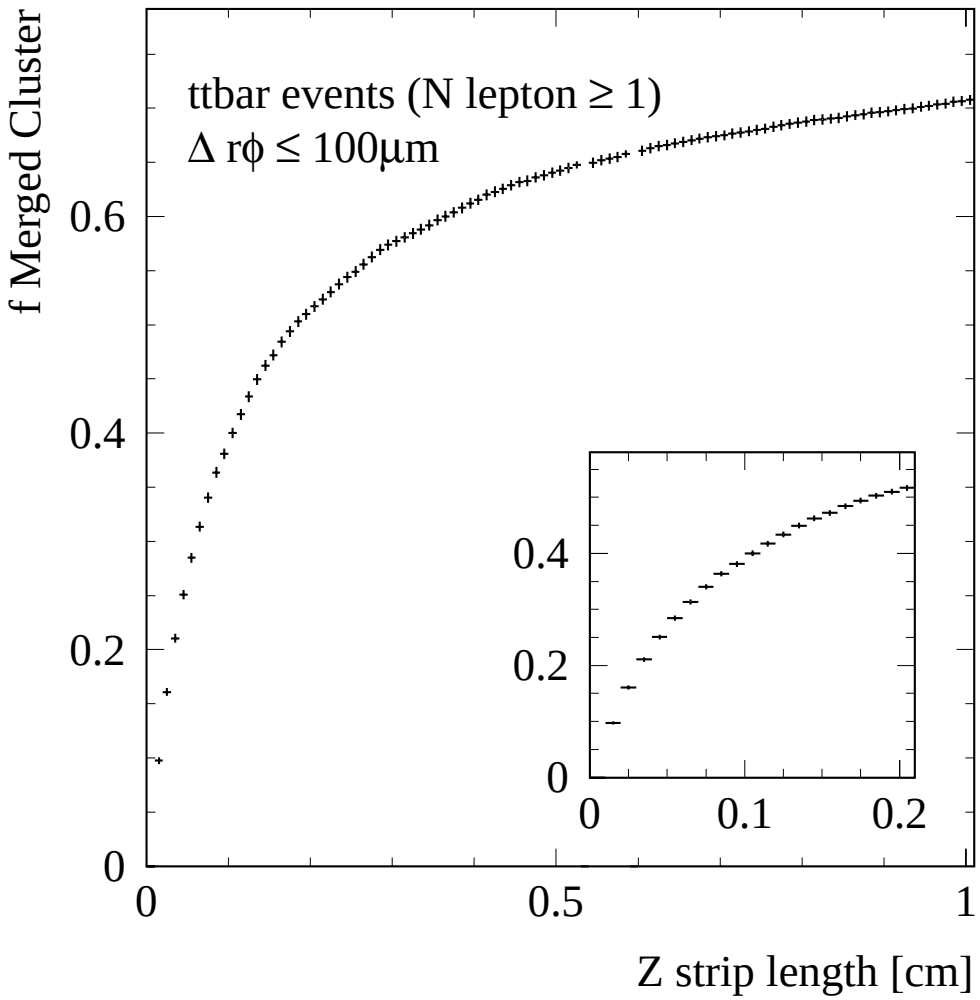
- At small radii, Carbon Fiber shells can be used to support modules
  - CMS is using molded cylinders with integrated cables and cooling
    - Modules are installed on both the exterior and interior in order to maintain z overlap
  - In Layer 00 we use molded shells with cooling tubes running under ledges
    - Silicon is installed on the flat sections and all electronics are outside the tracking region

Detailed Example

Layer	R [cm]	Nphi	chips	pitch	hybrid pitch	width	total chips	cumulative	phi coverage
L0A-1	1.35	6	1	0.0025	0.005	0.84	36	36	59%
L0A-2	1.65	6	2	0.0025	0.005	1.48	72	108	86%
L1A	3.5	12	2	0.0035	0.007	1.992	144	252	109%
L1S	3.5	12	2	?	0.007	1.992	144	396	109%
L2A	5.25	18	2	0.0035	0.007	1.992	216	612	109%
L2S	5.25	18	2	?	0.007	1.992	216	828	109%
L3A	8	12	4	0.0028	0.0084	4.5008	288	1116	107%
L3S	8	12	3	?	0.0112	4.5008	216	1332	107%
L4A	12	18	4	0.0028	0.0084	4.5008	432	1764	107%
L4S	12	18	3	?	0.0112	4.5008	324	2088	107%
L5A	16	24	4	0.0028	0.0084	4.5008	576	2664	107%
L5S	16	24	3	?	0.0112	4.5008	432	3096	107%

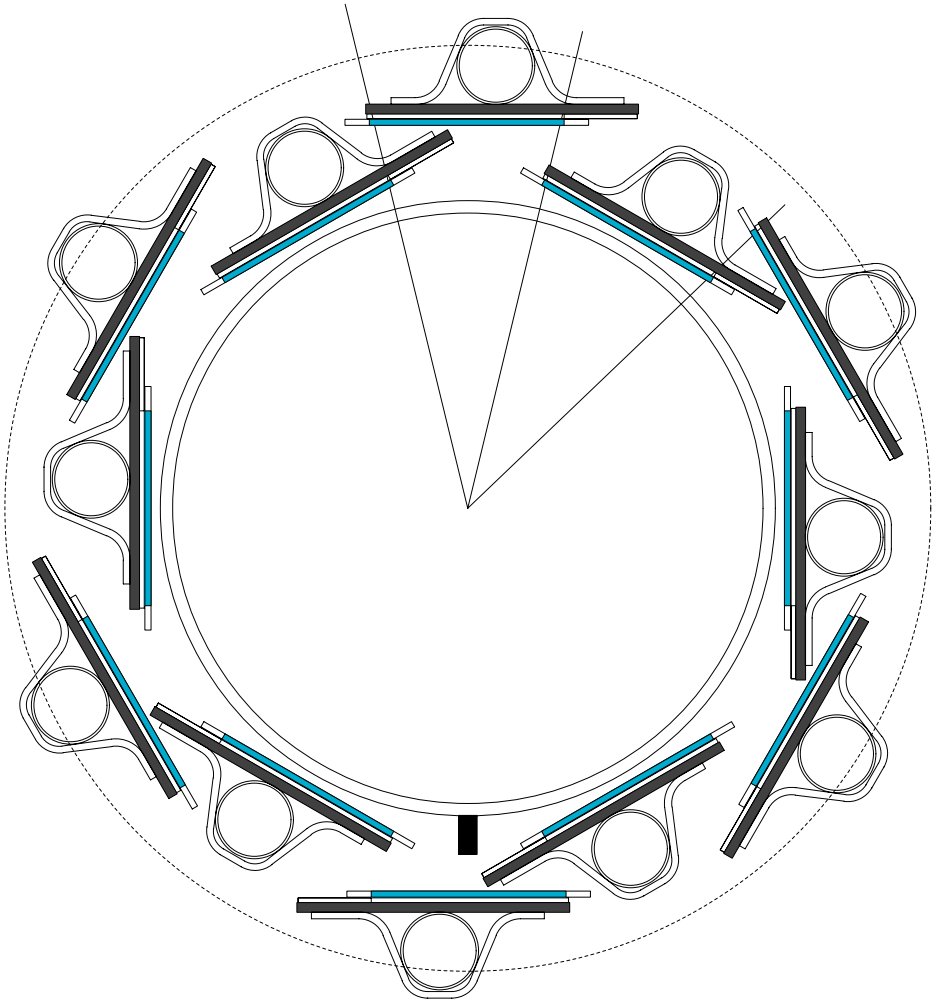
- Total installed chip count of SVXII + L00 = 3168+108 = 3276
- This example has 3096 installed chips.

Pixels

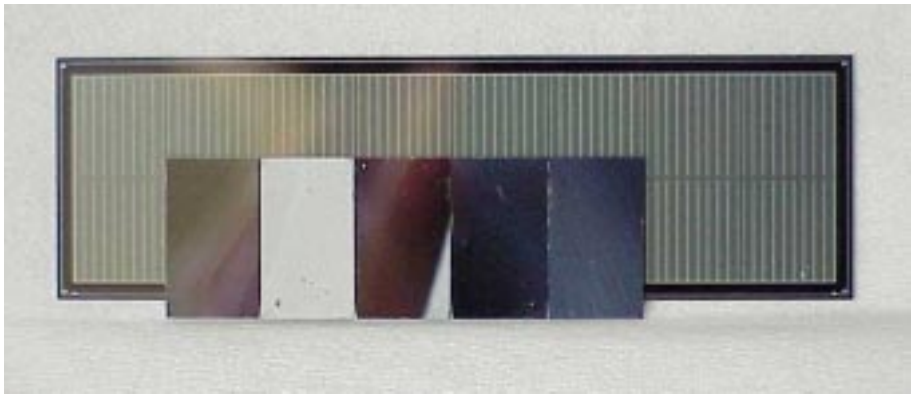


- Could be beneficial to physics
  - Improved pattern recognition
  - Separation of hits which would will be overlapped in Layer 00
    - In high energy b jets up to 30% of hits are shared in Layer 00
  - Good r-ϕ impact parameter resolution and moderately good z resolution
- Important Issues
  - Material
  - Cost
  - Schedule

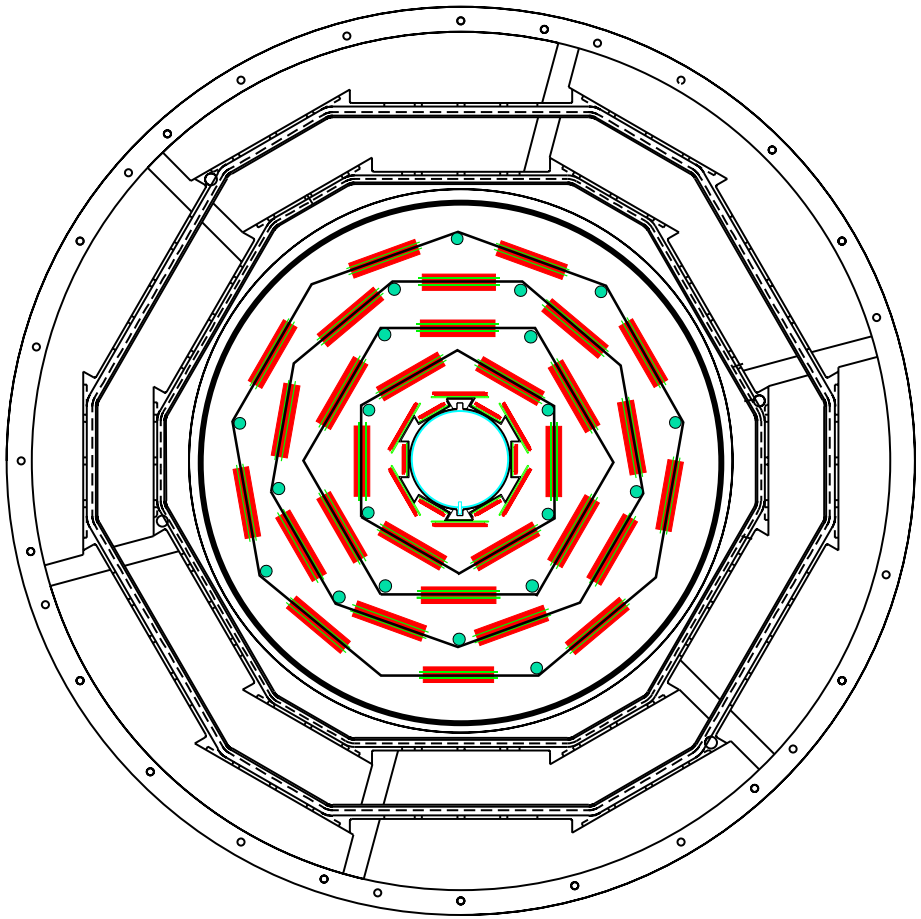
Pixels (2)



- Piggy back lots of previous development
  - Use ATLAS sensors and stave support concept
  - FPIX readout chip
- Basic module has already been prototyped



Partial replacement studied



- Pre-build as much as possible – e.g. the inner section
  - Layer 00 with Single-sided hybrids should be built no matter what
  - Pixels could be installed if ready
  - L0, L1, with simple single-sided hybrids and long readout cables
    - Single sided sensors back-to-back w/ 90 degree stereo
- Outer section
  - Make new annular bulkheads to support SVXII ladders
  - Would seek to reuse SVXII layers 3,4
    - Spares needed (~15% ?) means we need to make more double-sided silicon
  - Pre-assemble as much as possible then transfer ladders from SVXII

Chips

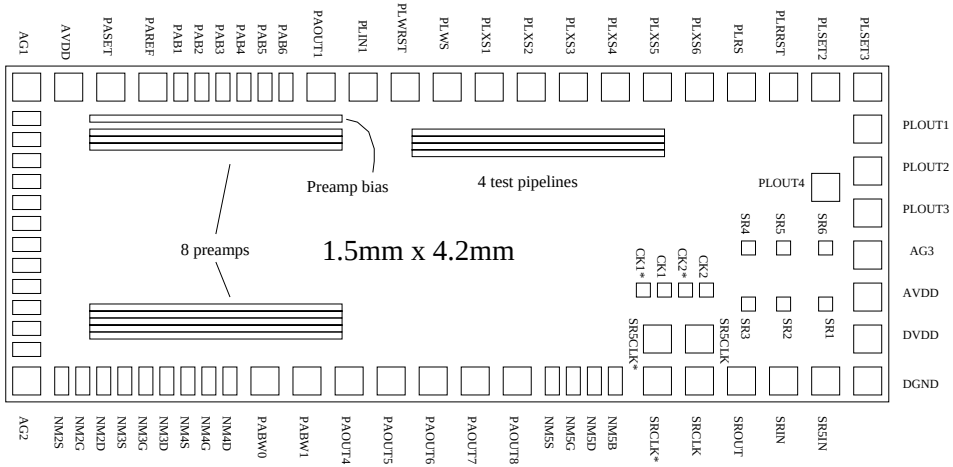
- SVX Chips – presently Honeywell SVX3D
  - There are too few remaining for ANY level of rebuild
  - Honeywell Issues
    - Honeywell history has not been good for CDF
      - Low and inconsistent yields
      - High failure rate after dicing and on hybrids
      - Long lead times
    - Honeywell has boosted price significantly to ~20k$ per wafer !
    - Other experiments have had equal or worse experience recently
  - Options
    1. Order more Honeywell at high cost – must act very soon.
    2. Use an existing LHC chip (e.g. CMS APV25)
       - This requires significant changes to DAQ and cable infrastructure
    3. Develop a new version with a different vendor

Chips (2)

- Option 3 recommended:
  - Technology has evolved: commercially available 0.25 μm process has been studied and applied for HEP (e.g. CMS APV, FNAL FPIX)
    - Better performance (lower noise)
    - Intrinsically rad hard with special design rules
    - Low cost and short lead times
  - Two approaches for CDF

    1. Complete redesign using appropriate models and design rules
       - Long lead time, chips available 2003
    2. Transformation of existing circuit, redo only those elements that must be redone
       - Exploratory study underway (LBL/Padova)
       - Possible submission this month (MOSIS – TSMC)
         - New pre-amp with expected lower noise included
         - Verify models and process
       - 1 FTE year estimated for complete transformation but there is some technical risk

0.25 µm Conversion Progress

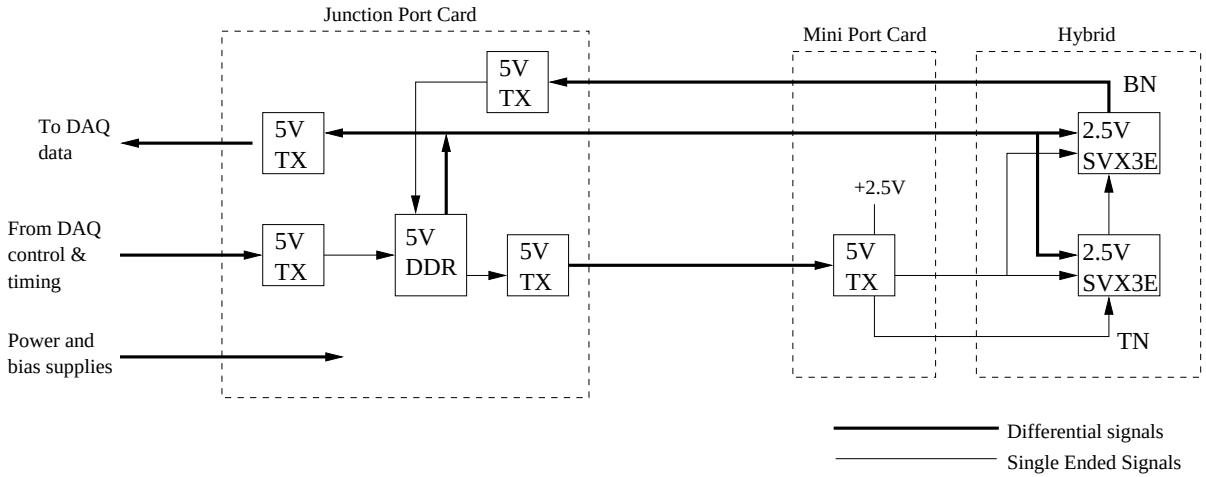


- Preamp layout done, pipeline and shift register layout in progress
- New manpower from Padova
- Interface scheme worked out
- Analog test chip (shown above) to MOSIS 9/25/00
  - 8 preamps with transistor variations
  - 4 pipelins
  - Encosed transistor test structures
  - 6 cell shift register

Portcards/DAQ

- Issues for current PC
  - Compatibility with a new chip (2.5 V levels needed)
  - PC Material in track volume
  - Voltage regulators may not survive dose
  - DOIMs may not survive dose and have to be replaced with Cu DOIMs or VCSELs
- New Mini-PC (mPC) and Junction PC (JPC) Scheme
  - ➢ XMIT/RECV scheme like ISL where PC is far from ladders
  - ➢ JPC outside tracking volume and mPC near or on the hybrid
    - Low mass cable between mPC and JPC
  - ➢ JPC uses existing Honeywell XCVR and DDR chips
    - Have enough XCVR, need DDRs
  - ➢ mPC would use existing XCVR (believed compatible with 2.5 V)

Interface to 2.5 V chip



- Mini-PC scheme works for both SVX3D or new 0.25 μm chip
  1. Honeywell XCVR chip differential outputs can be configured as complementary CMOS outputs
  2. Diff'l outputs have dedicated power pin that can be connected to 2.5V
  3. There is no step 3. 1 and 2 give 2.5 V CMOS complementary outputs

Practical Considerations

- SVX4 :
  - Redesign: 2 FTE 2yrs ~ 1.1 M$
  - Translation ~ 500k$
- Honeywell
  - 1-2 M$ and schedule risks
- Power Supplies, Portcards, Cables
  - Of order 1M $
- New beampipe
  - Of order 250 k$
- Single-sided silicon
  - Budgetary quote ~ 1 M$
    - 99.9% good strips
    - $V_{BD} \geq 700V$
- Module production labor 750 k$
  - 1152 single sided equiv. (SS) modules
  - Production requirements are modest.
  - Based on ISL experience:
    - **2 technicians could fabricate, and 1-2 technicians could inspect, wirebond and repair 6 SS modules per day on one CMM (includes contingency)**
    - **6 technicians could complete all modules in 26 weeks**
- Hybrids 600 k$
    - Off silicon, and use adequate real-estate to make robust, simple, easy to manufacture
- Mechanical Supports (1 M$?)
  - Model after CMS/L00:
    - nested cylinders at small radius
    - rods at intermediate radii

Schedule Issues

- We need final chips one year before the date we install a completed system inside ISL.
  - If we have chips by end of 2002 or early 2003 we can make a shutdown somewhere in the period from late 2003 to mid 2004.
- We should begin an engineering and prototyping effort for
  - Module and support mechanics and cooling
  - Fine pitch Cables (qualify new vendors)
  - Mini-PC scheme
  - Hybrids (use existing SVX3D chips)
- Silicon can be ordered later – 2002.
- Should finalize layout by early 2002.

Response to PAC

- Our answers to the PAC:
  - L00-only replacement could be adequate IF
    - Fluences turn out to be at the low end of expectations
    - We can live without SVX L0
    - SVX L2 can be biased or we can live without it as well
  - Any partial replacement of SVXII Layers entails
    - Complicated construction issues
    - A lengthy shutdown
  - A full replacement of SVXII and Layer 00
    - While it involves more new channels, the Run 2b working group judges this to be an easier and less risky option.
    - Involves a much smaller loss of running time than any partial SVXII replacement scheme.
    - Could be achieved at reasonable cost and in a reasonable time IF
      - We streamline the design with simple mechanics and a minimum number of different parts
      - Use single-sided silicon
      - We have adequate chips

Summary and Conclusions

- Estimates of silicon life expectancies fall in wide range
- We can't guarantee we won't need a large replacement.
- With data (by say early to mid- 2002), we could know precisely how extensive the replacements will have to be.
- The prudent course is to start preparations now in case a large scale replacement is required
  - Push ahead quickly with a new chip in order to have production chips available in early 2003.
  - Develop and prototype portcard, hybrids, mechanics and cooling.
- The Run2b Working group recommends that CDF request funding for such a program of R&D in FY01.
  - This program can be detailed prior to the Fall PAC meeting.